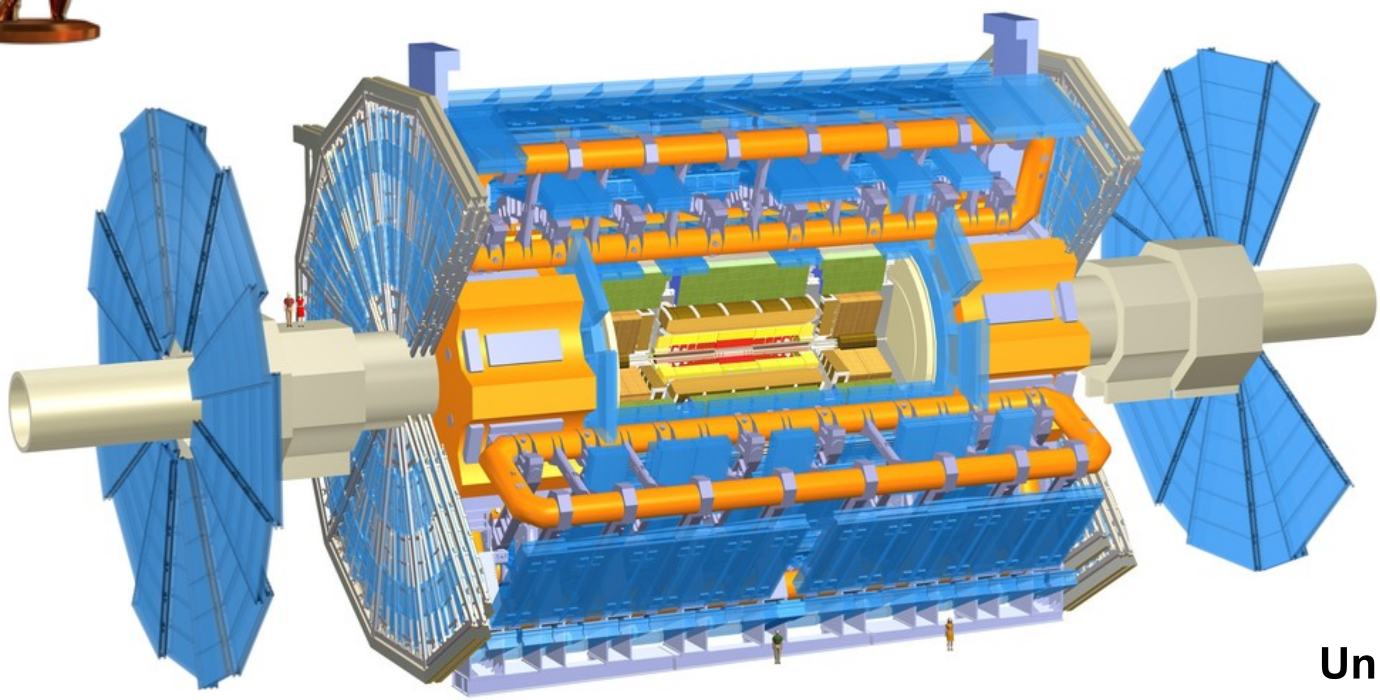
ATLAS Exotics Searches

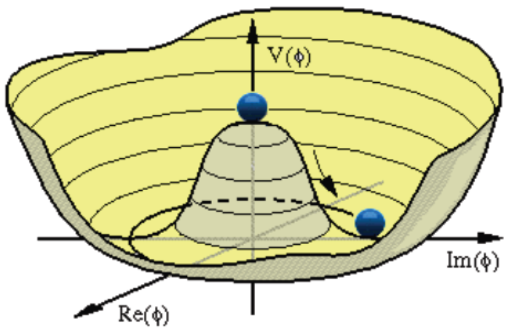


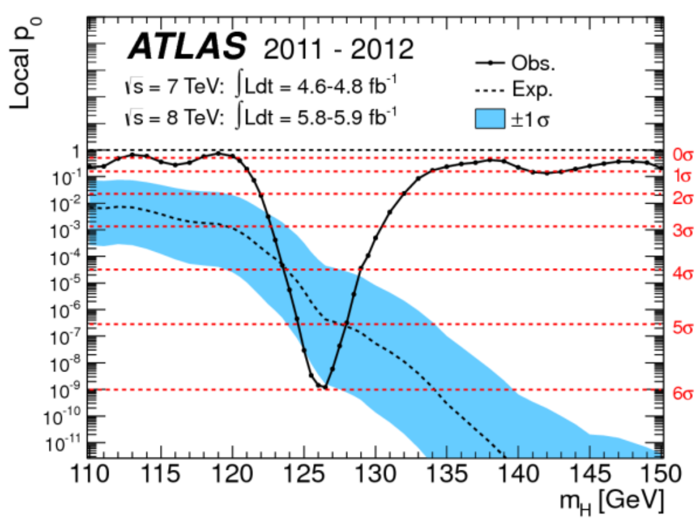
Cigdem Issever
University of Oxford
On behalf of the ATLAS Collaboration

SUSY 2013
ICTP Trieste, Italy
26.08-31.08.2013

What Characterizes Exotics Searches?

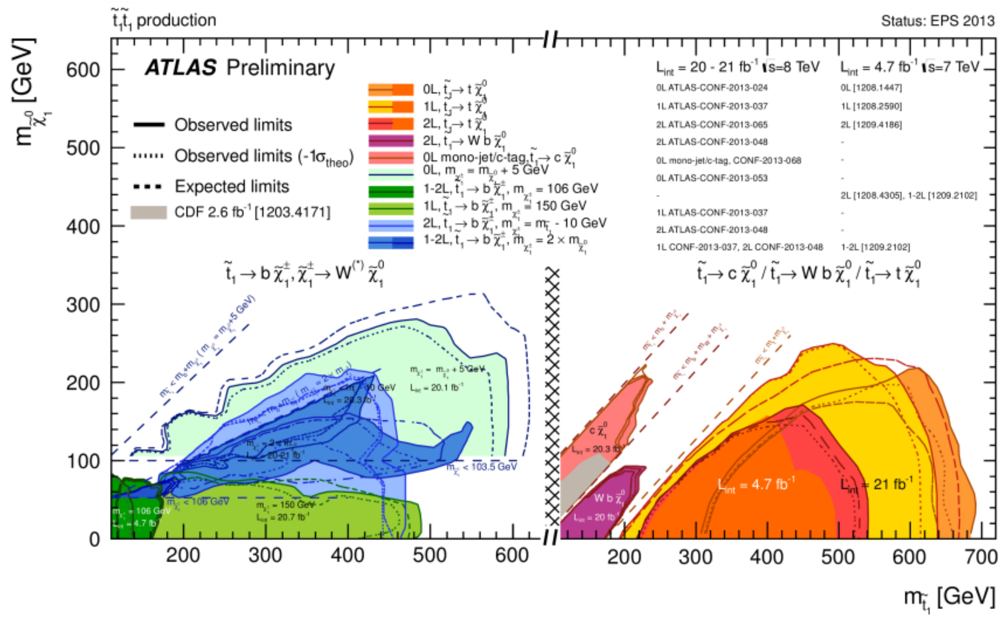
- No precise model to guide us.



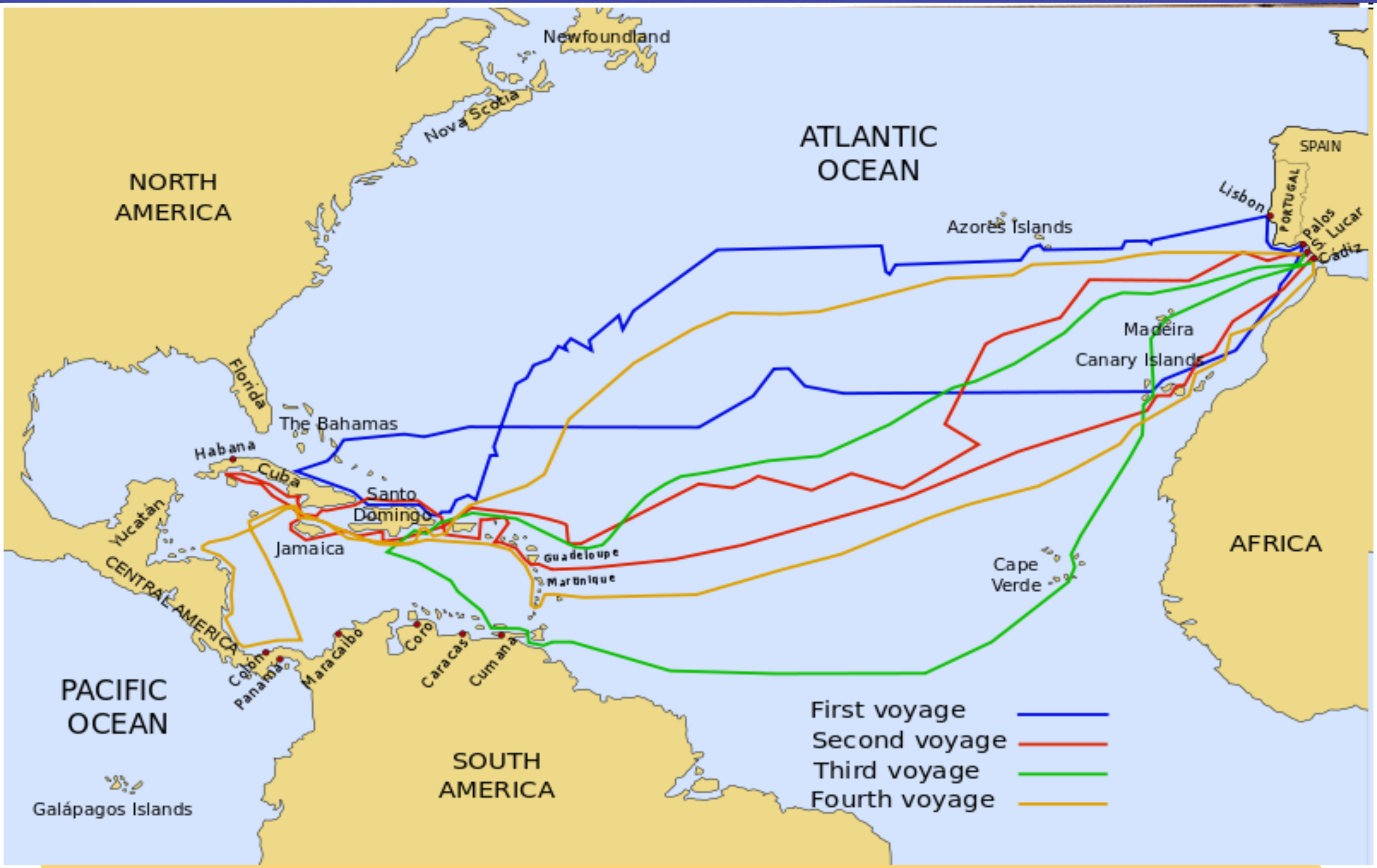


[Phys. Lett. B 716 (2012) 1-29]()

- No unified parameter phase space to map results



The Role of Models in "most" Exotics Searches



Columbus' Voyages
Ocean, which directly influenced Columbus's plans

Exotics Search Strategy

- Cover wide range of final states
- Largely model independent
  - Look for resonances
  - Look for any disagreement from expectations
- Cover interesting new BSM models

Comment to Result Selection in this Talk

Show some typical Exotics search examples

“What is the impact of the newly discovered boson on Exotics searches at the LHC?”

8 TeV Results

All ATLAS Public Exotics Results are HERE

Overview of Results

Dark Matter

Boosted mono-W/Z new

ATLAS-CONF-2013-073

BSM Higgs/VLQ

$T \rightarrow tH$	ATLAS-CONF-2013-018 new
$H^{++/--}$	1210.5070 ; 1207.2666

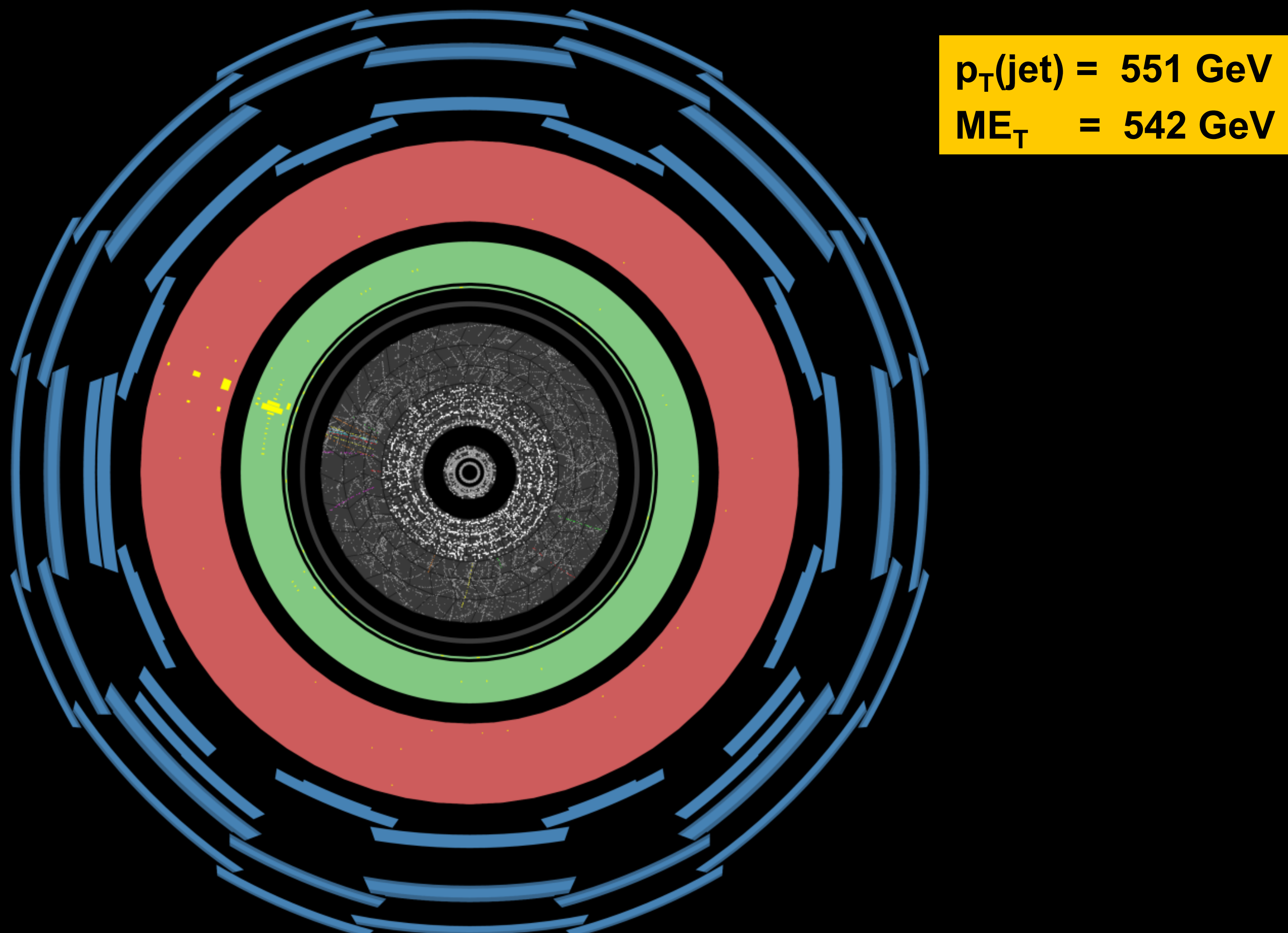
Resonances

ee/μμ		ATLAS-CONF-2013-017
$\tau\tau$	new	ATLAS-CONF-2013-066
dijets		ATLAS-CONF-2012-148
dijets + W/Z	new	ATLAS-CONF-2013-074
boosted tops		ATLAS-CONF-2013-052

Generic Searches

Same-sign dilepton	1210.4538
Tri-leptons	ATLAS-CONF-2013-070 new

Dark Matter Searches at ATLAS



JHEP 1304 (2013) 075

Dark Matter (DM) Production at LHC $pp \to \chi\chi + X$

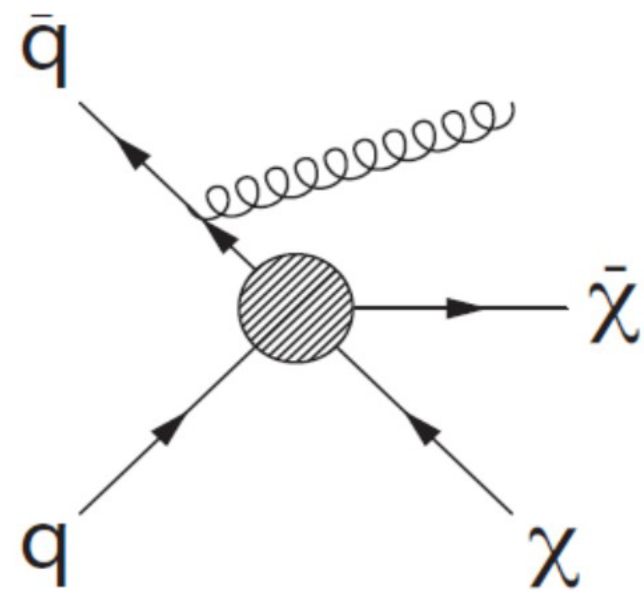
- Effective theory with only 2 parameters (arXiv:1008.1783)
  - M^* : characterize **interaction strength** of the interactions with SM particles
  - m_χ : mass of dark matter candidate

EFT valid for $Q_{TR} < 4\pi M_*$

Effective interactions coupling DM to SM quarks or gluons

1210.4491v2

Name	Initial state	Type	Operator
D1	qq	scalar	$\frac{m_q}{M_\star^3}\bar{\chi}\chi\bar{q}q$
D5	qq	vector	$\frac{1}{M_\star^2}\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$
D8	qq	axial-vector	$\frac{1}{M_\star^2}\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$
D9	qq	tensor	$\frac{1}{M_\star^2}\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$
D11	gg	scalar	$\frac{1}{4M_\star^3}\bar{\chi}\chi\alpha_s(G^a_{\mu\nu})^2$



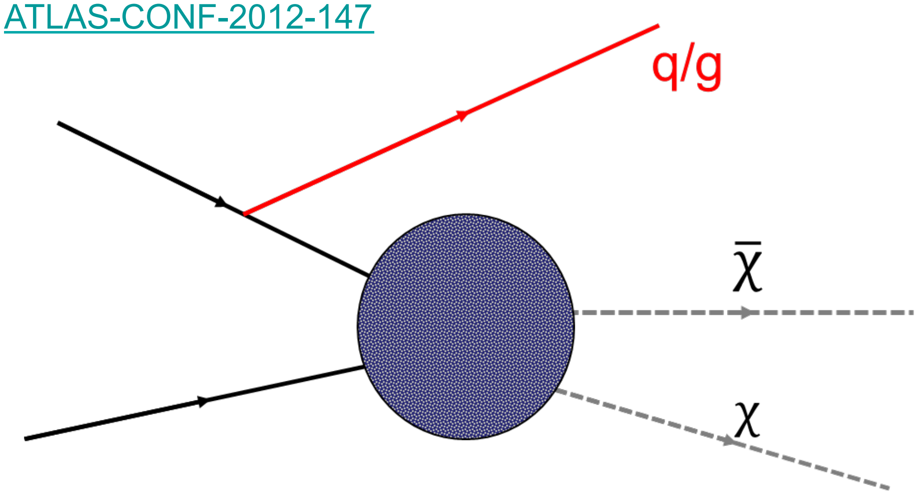
- Pair production of DM:
  - Events with ME_T, recoiling against additional hadronic radiation

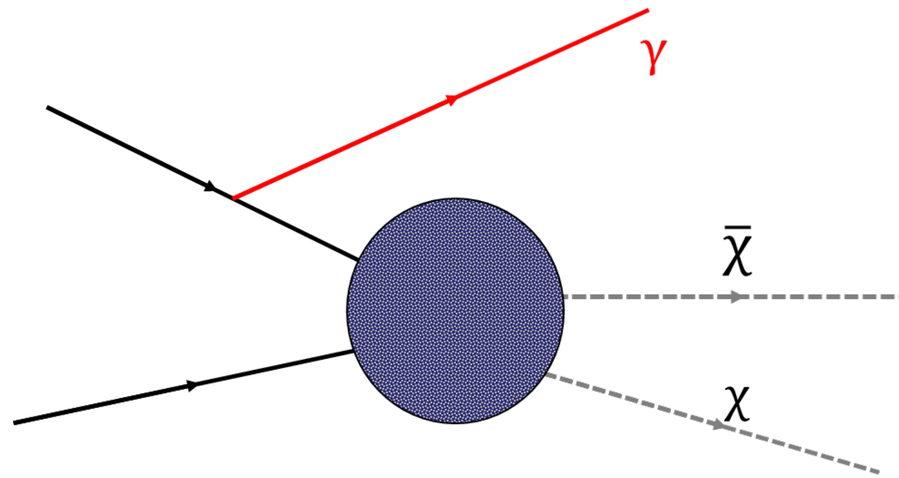
Mono Jet and Mono Photon Searches

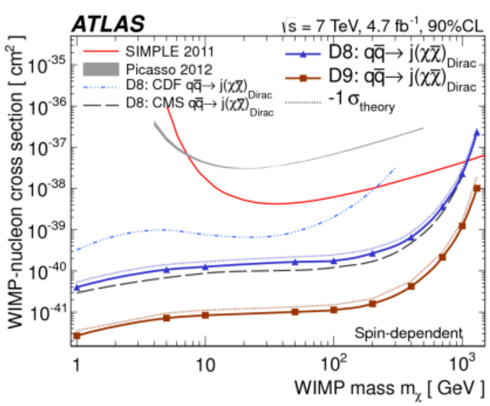
JHEP 1304 (2013) 075

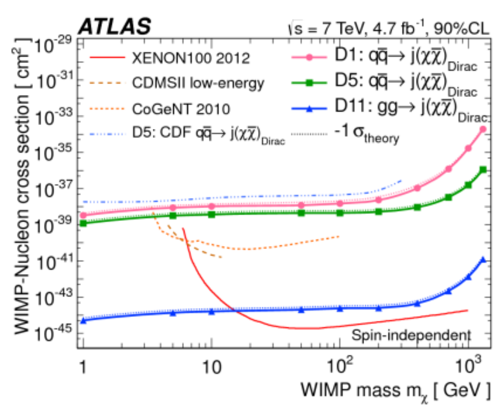
ATLAS-CONF-2012-147

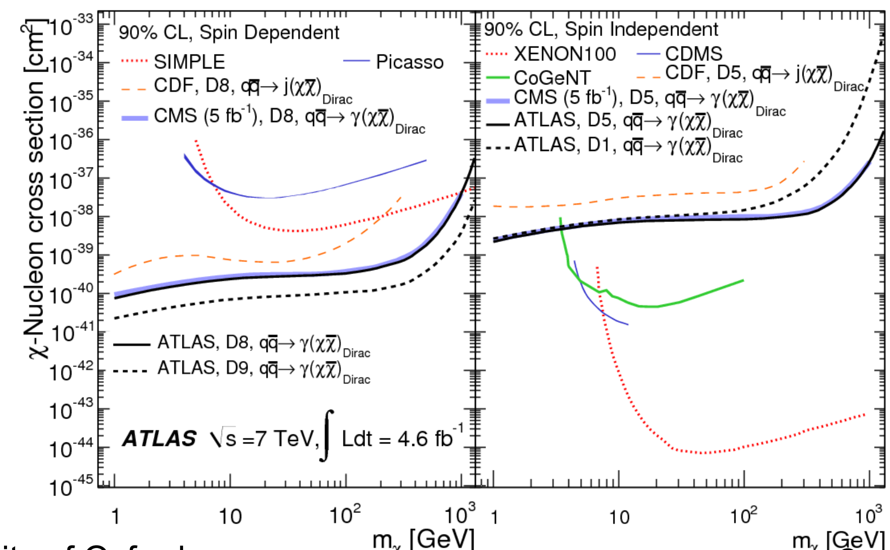
Phys. Rev. Lett 110, 011802 (2013)







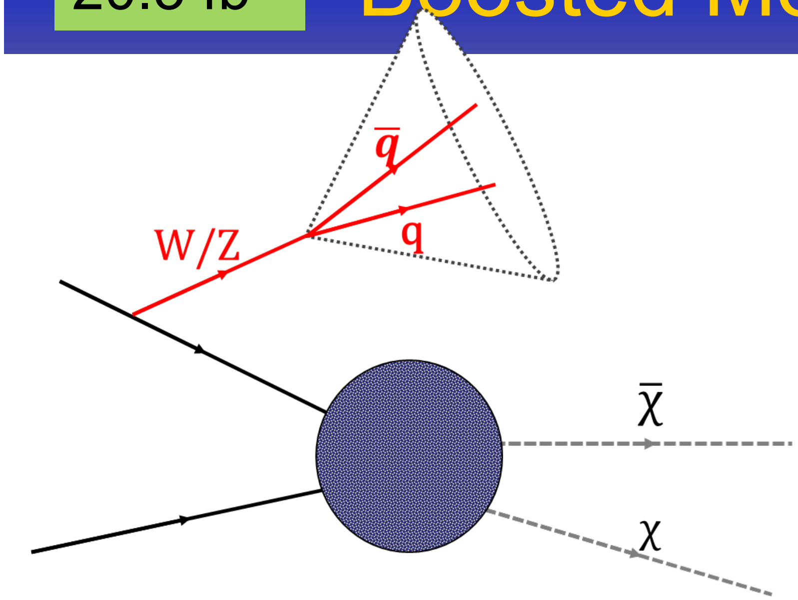




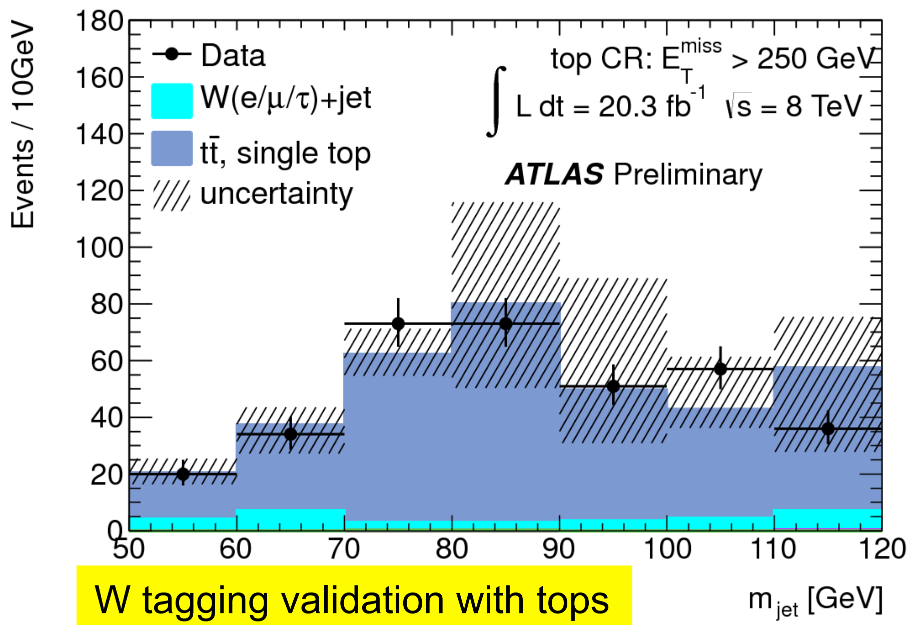
20.3 fb^{-1}

Boosted Mono W/Z Production

ATLAS-CONF-2013-073

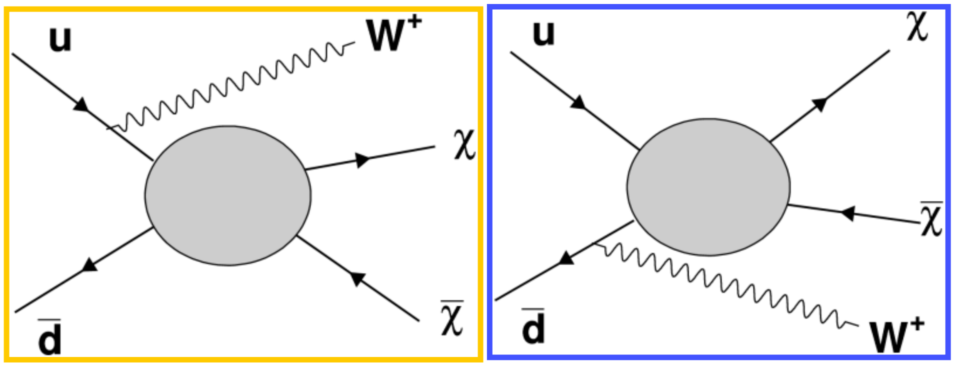


- 1st time:
- Hadronically decaying W/Z's
- Jet Substructure techniques
  - Cambridge-Aachen 1.2 jets
  - Probe momentum balance
    - $\sqrt{y} = \min(p_{T1}, p_{T2})\,\Delta R / m_{jet}$
- Backgrounds
  - $Z \to \nu\nu$ + jet and $W/Z \to l\nu/ll$ + jet
    - Use data control regions
  - Diboson, ttbar, single top
    - Use simulation
  - Multijet negligible



W tagging validation with tops

Signal Samples



Name	Operator	Coefficient
D9	$\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$	$1/M_*^2$
D5	$\bar{\chi}\gamma^{\mu}\chi\bar{q}\gamma_{\mu}q$	$1/M_*^2$
D1	$\bar{\chi}\chi\bar{q}q$	m_q/M_*^3
C1	$\chi^{\dagger}\chi\bar{q}q$	m_q/M_*^2

Interference btw diagrams

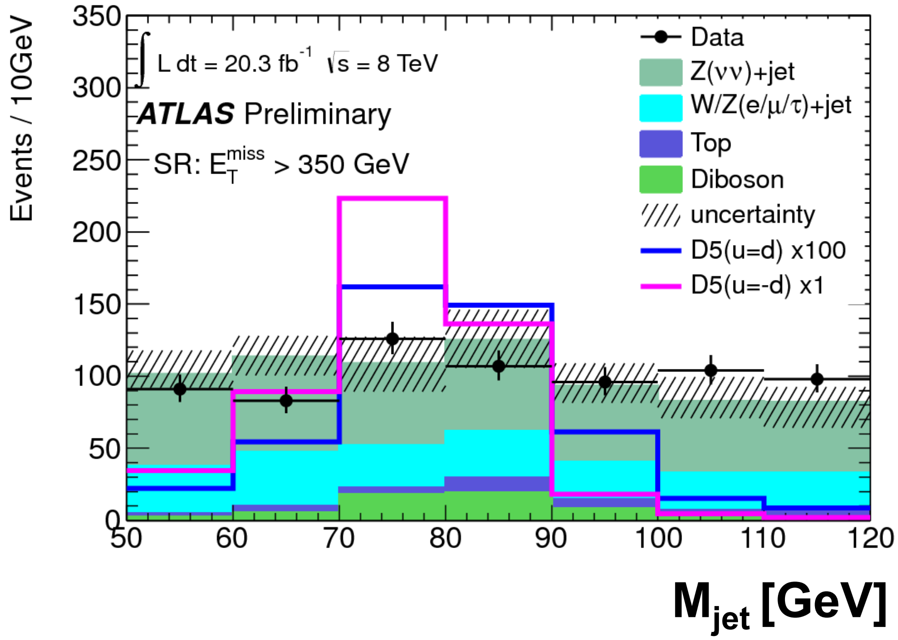
- C(uχ)=C(dχ), C=coupling
  - destructive
  - W's p_T low
- C(uχ) = -C(dχ)
  - Constructive
  - W's p_T high
- D5 signal generated
  - C(uχ)=C(dχ)
  - C(uχ)=-C(dχ)

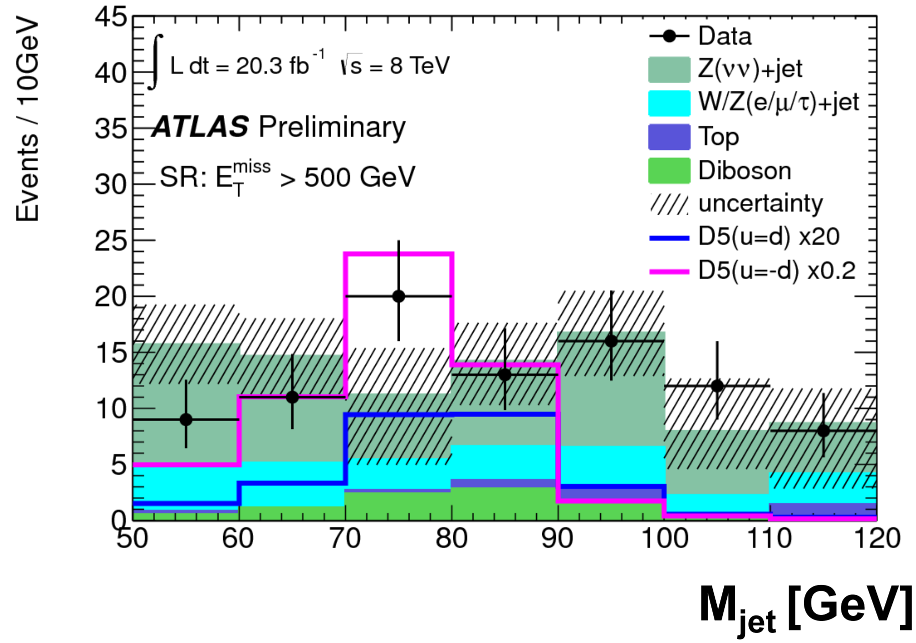
new

Boosted Mono W/Z Production

new

2 Signal Regions: **ME_T > 350 GeV** **ME_T > 500 GeV**

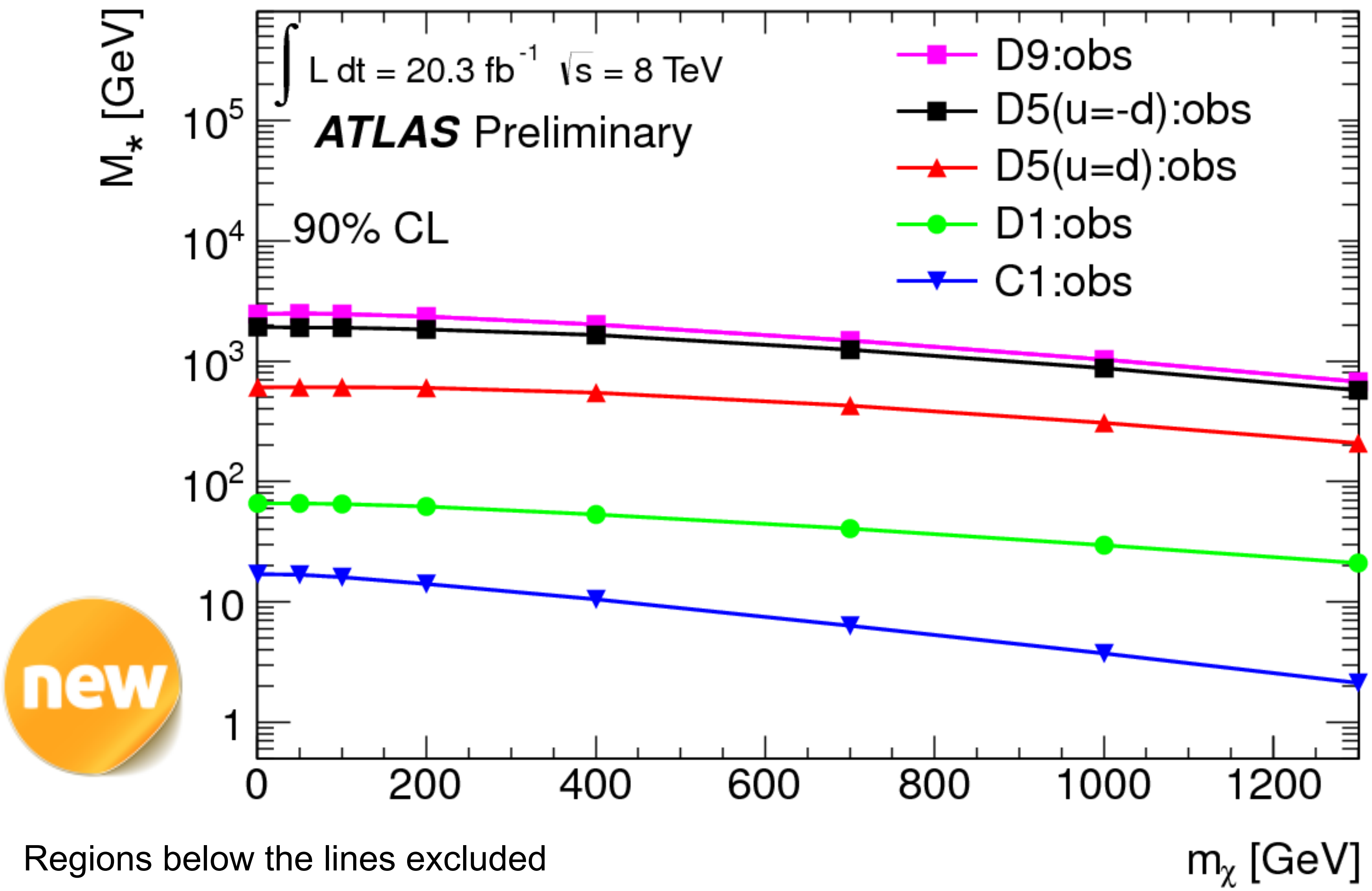




- Good agreement
- Exclusion limits at 90% CL using shape of m_{jet}

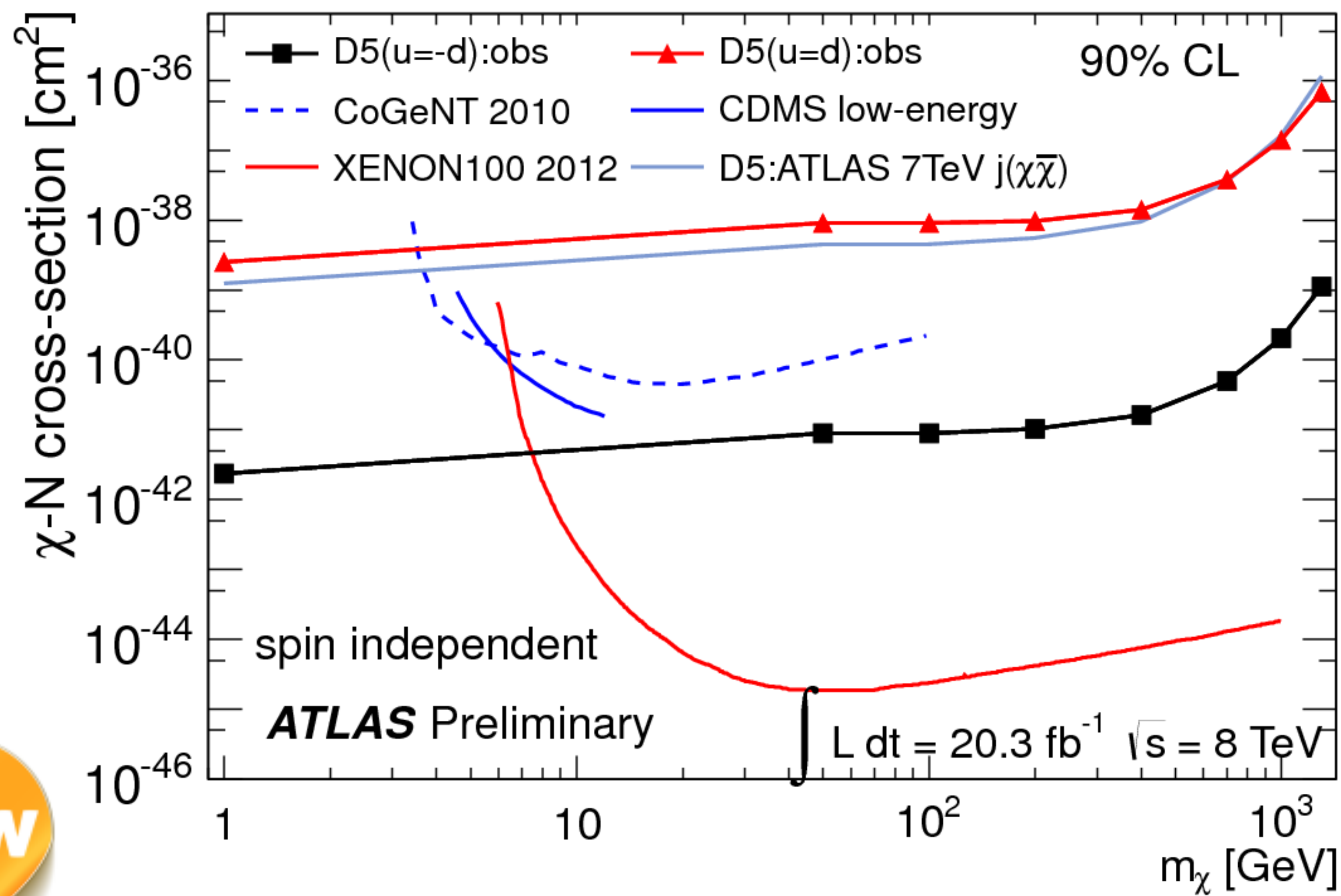
Process	$E_T^{miss} > 350$ GeV	$E_T^{miss} > 500$ GeV
$Z \to \nu\bar{\nu}$	400^{+39}_{-34}	54^{+8}_{-10}
$W \to \ell^{\pm}\nu, Z \to \ell^{\pm}\ell^{\mp}$	210^{+20}_{-18}	22^{+4}_{-5}
WW, WZ, ZZ	57^{+11}_{-8}	$9.1^{+1.3}_{-1.1}$
$t\bar{t}$, single t	39^{+10}_{-4}	$3.7^{+1.7}_{-1.3}$
Total	710^{+48}_{-38}	89^{+9}_{-12}
Data	705	89

Limits on Parameters of effective DM Model



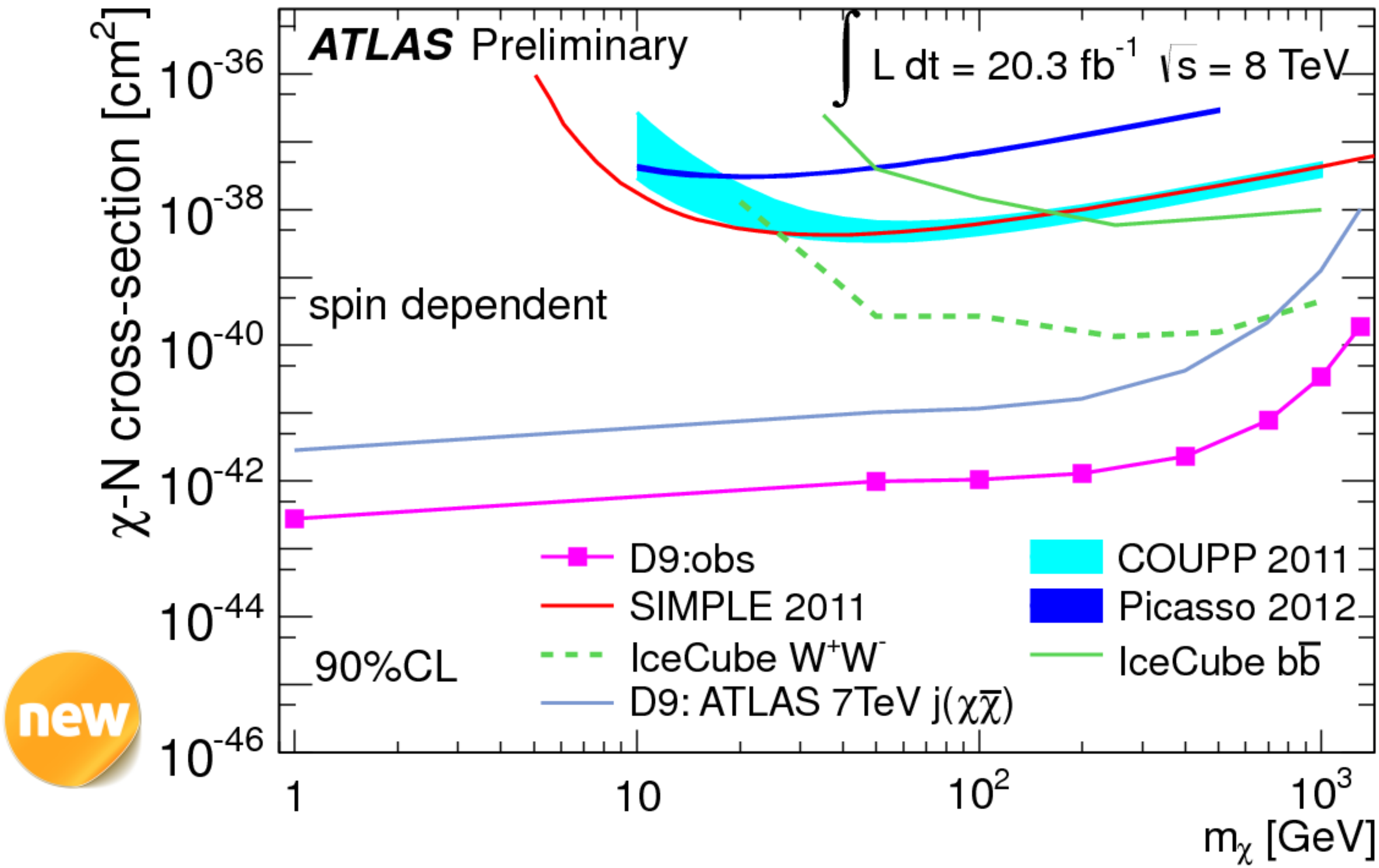
Regions below the lines excluded

Limits on Nucleon-χ Cross Section



new

Limits on Nucleon-χ Cross Section



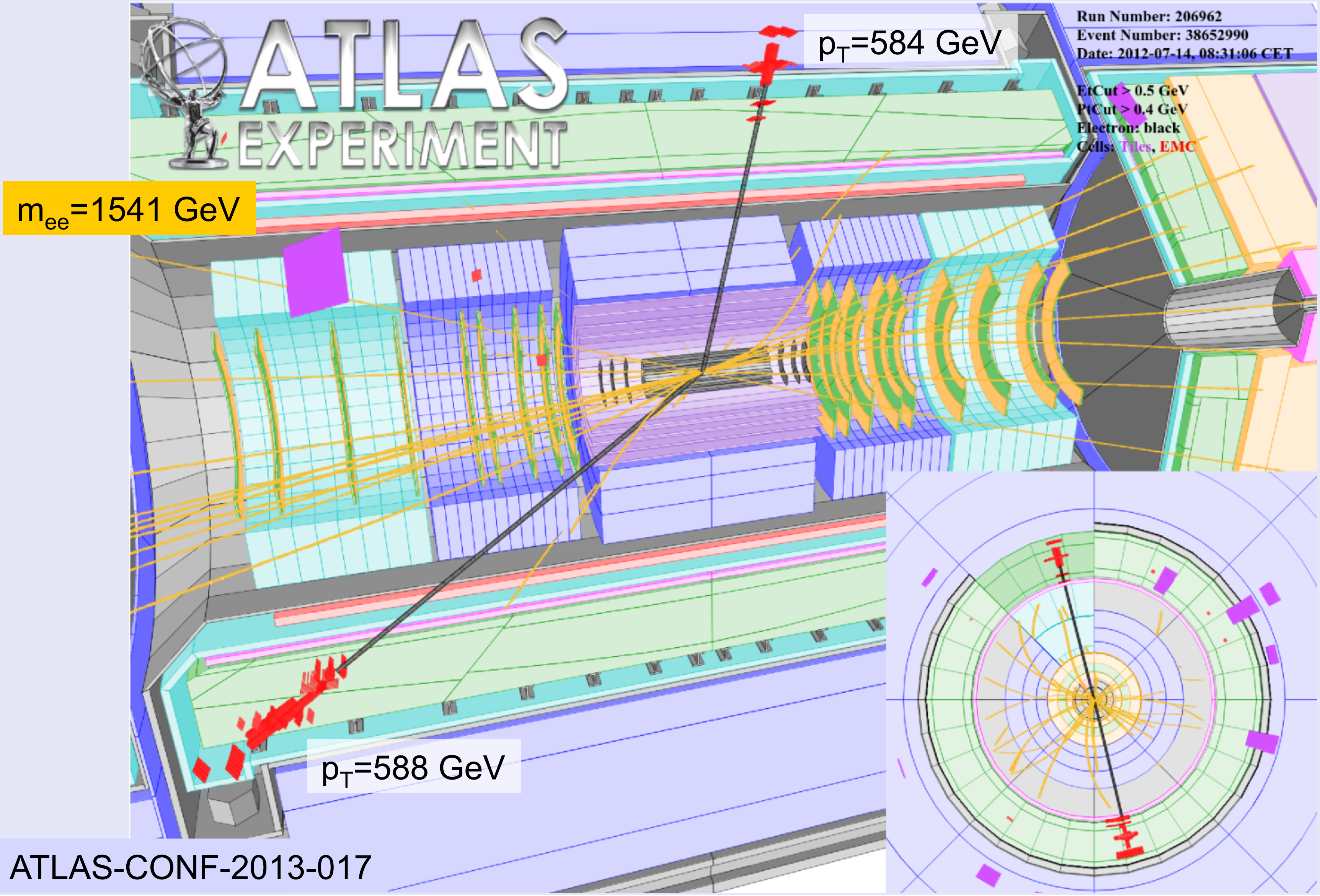
Intensive Discussion about how to interpret Mono-X analyses

- G. Busonia, A. De Simonea, E. Morgantec, A. Riotto
  - “On the Validity of the Effective Field Theory for Dark Matter Searches at the LHC”, arXiv:1307.2253v1
  - Derive stronger bounds than currently used by LHC experiments

- New models:
  - A. DiFranzo, K. I. Nagao, A. Rajaraman, T.M.P. Tait,
    - “Simplified Models for Dark Matter Interacting with Quarks”, arXiv:1308.2679v1
  - S. Chang, R. Edezhath, J. Hutchinson, and M. Luty,
    - “Effective WIMPs”, arXiv:1307.8120v1
  - Yang Bai and Joshua Berger,
    - “Fermion Portal Dark Matter”, arXiv:1308.0612v2

For more details refer to Marie-Helene Genest’s talk yesterday

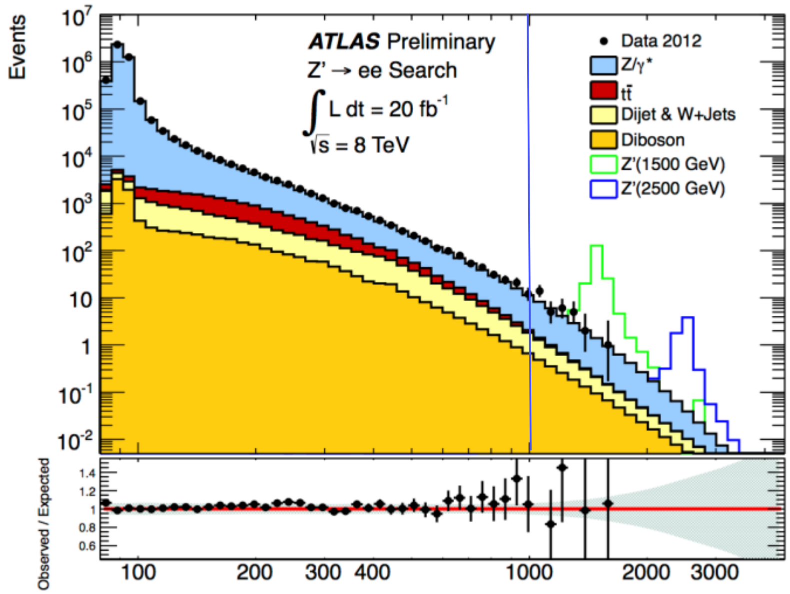
Dielectron Event Display



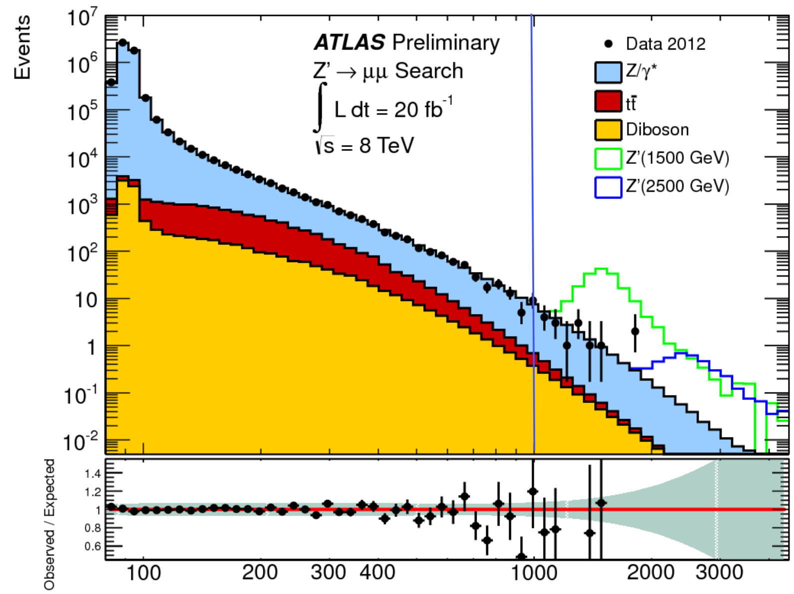
ATLAS-CONF-2013-017

20 fb^{-1} Dilepton Searches: invariant mass

- Experimental Challenge:
  - lepton pT resolution and efficiency up to **1 TeV**!



m_{ee} [GeV]



$m_{\mu\mu}$ [GeV]

- Good agreement btw data and prediction

Dilepton Searches: Systematic Uncertainties

Source	Dielectrons		Dimuons	
	Signal	Background	Signal	Background
Normalization	5%	NA	5%	NA
PDF variation	NA	15%	NA	15%
PDF choice	NA	17%	NA	17%
Scale	NA	-	NA	-
α_s	NA	4%	NA	4%
Electroweak corrections	NA	3%	NA	3%
Photon-induced corrections	NA	4%	NA	4%
Efficiency	-	-	6%	6%
Resolution	-	-	-	3% (7%)
W + jet and multi-jet background	NA	9%	NA	-
Diboson and ttbar extrapolation	NA	5%	NA	4%
Total	5%	26%	8%	25% (26%)

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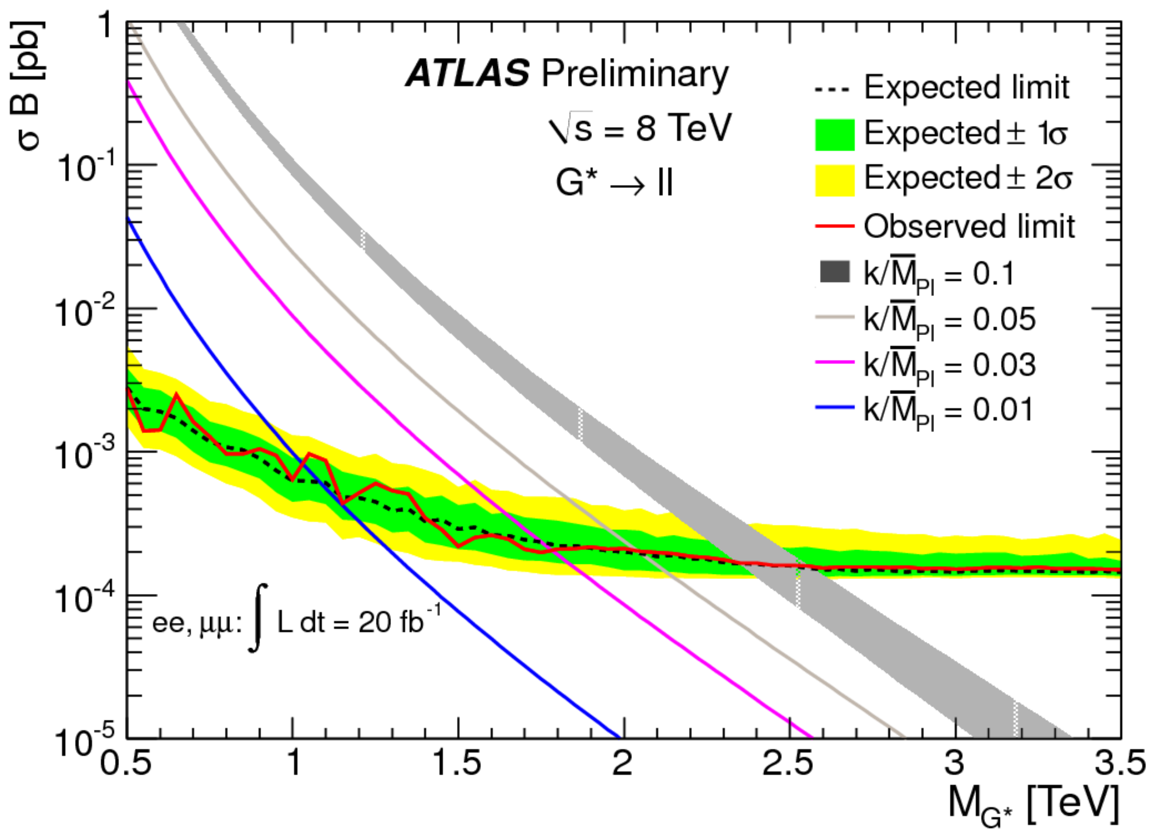
Dilepton Credibility Limits



Model	Obs. Limit
SSM Z’	2.86 TeV
E6 Z'_{ψ}	2.38 TeV
RS-G* (k/M_{Pl}=0.1)	2.47 TeV

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More interpretations with 7 TeV:

Z^*, LSTC ρ_T , MWT M_A , Z_{KK} /γ_{KK} , TS

http://dx.doi.org/10.1007/JHEP11(2012)138

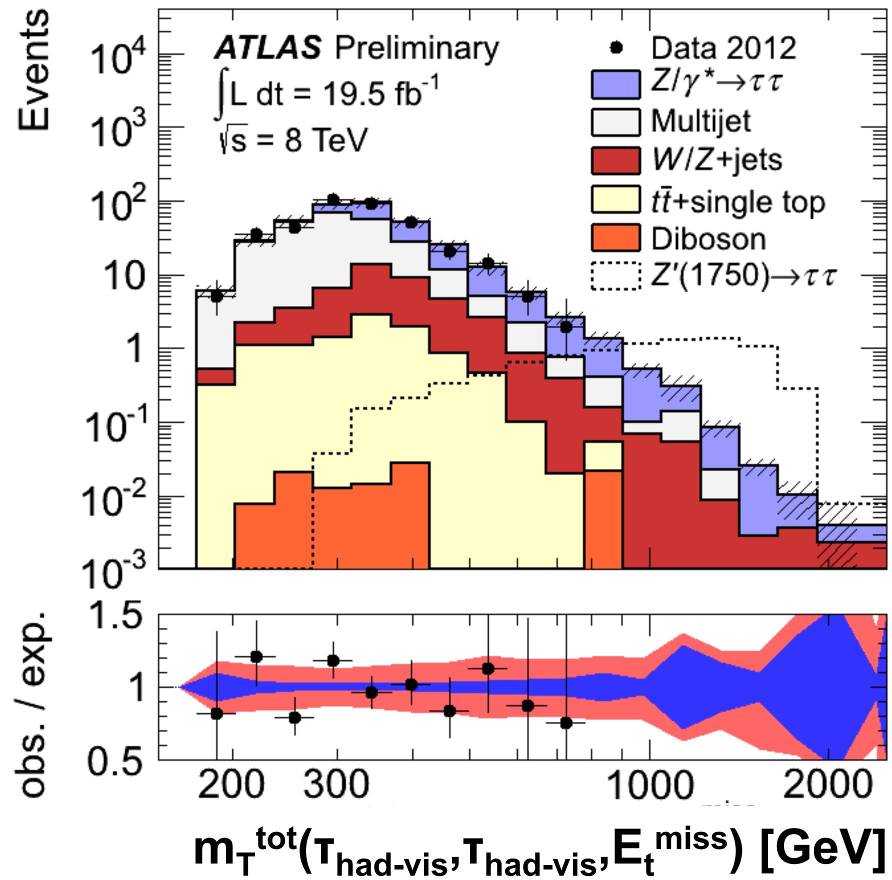
Ditaus (fully hadronic)

- Lepton universality not necessary for these new gauge bosons

→ Essential to search in ALL decay modes

19.5 fb^{-1}

Selections	
≥2 τ candidates	
$p_T(\tau_1) > 150$ GeV	
Trigger matched	
Opposite charge	
$\Delta\varphi(\tau_1,\tau_2)>2.7$	
Loose BDT ID (60%)	
mass resolution is 30–50% single tau trigger	Axε(mZ'>750) ~ 7-9 % Axε(mZ'=500) ~ 3 %



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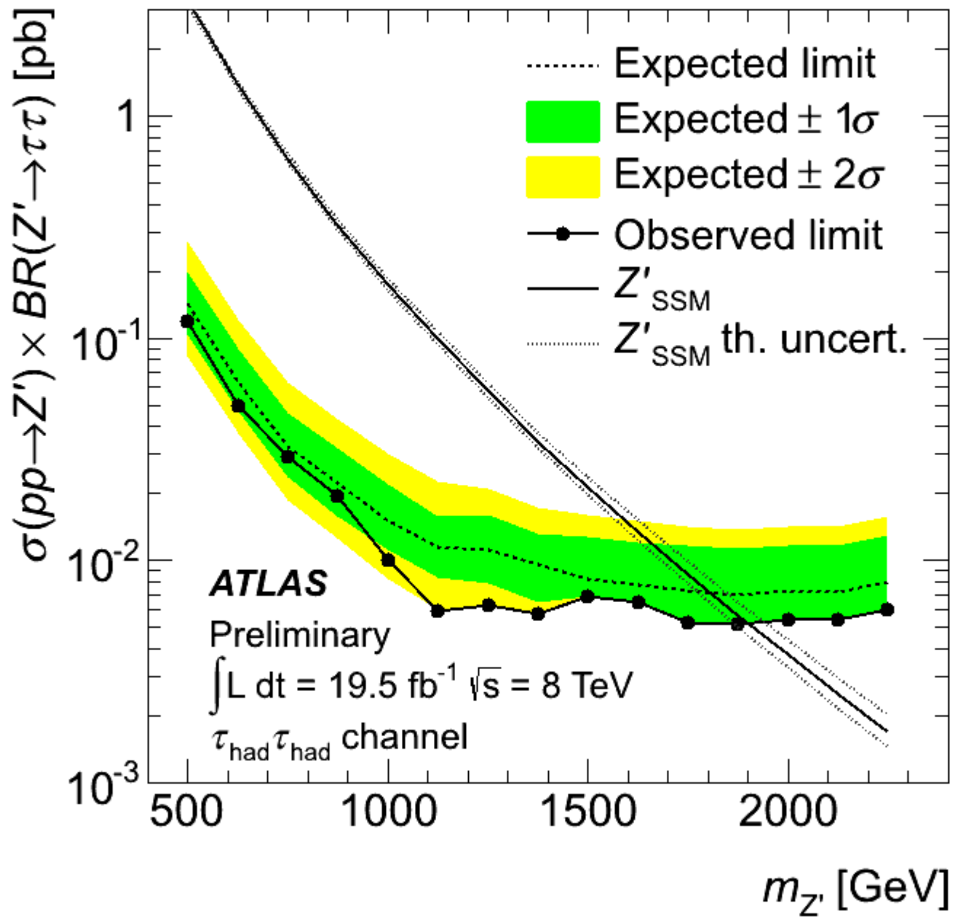
Ditau 95% Credibility Limits

new

ATLAS-CONF-2013-066



Model	Obs. Limit
SSM Z'	1.9TeV

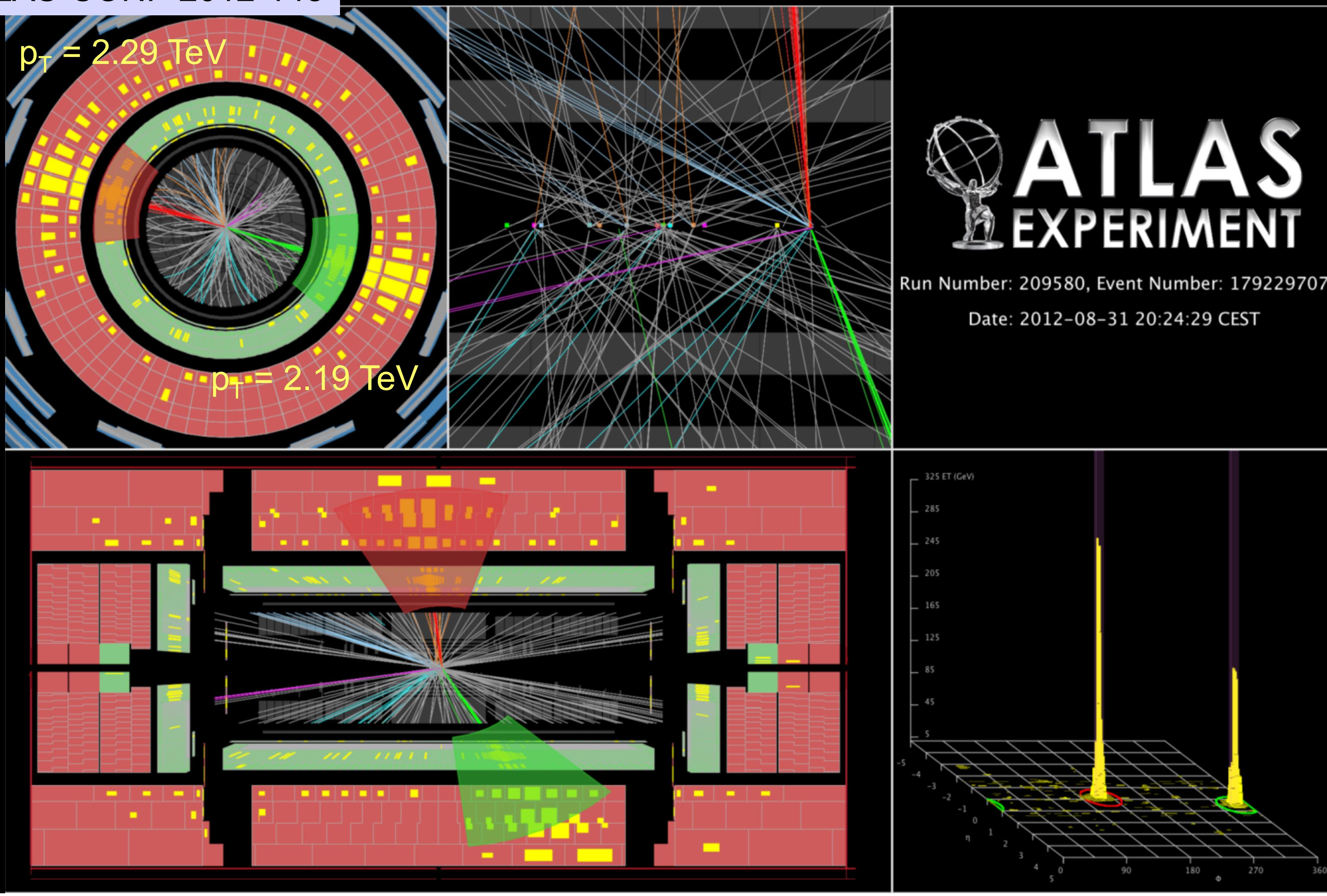
Important Systematics @ 1.5 TeV

- Jet-to-τ fake rate: 9% on bkg
- Tau energy scale: 9%
- Tau ID : 10%
- Tau trigger: 7 %

Mass Point [GeV]	500	625	750	875	1000	1125	1250–1375	≥1500
m_T^{tot} [GeV]	>400	>450	>500	>550	>600	>700	>750	>850

Dijet Event Display with m_{inv} = 4.69 TeV

ATLAS-CONF-2012-148



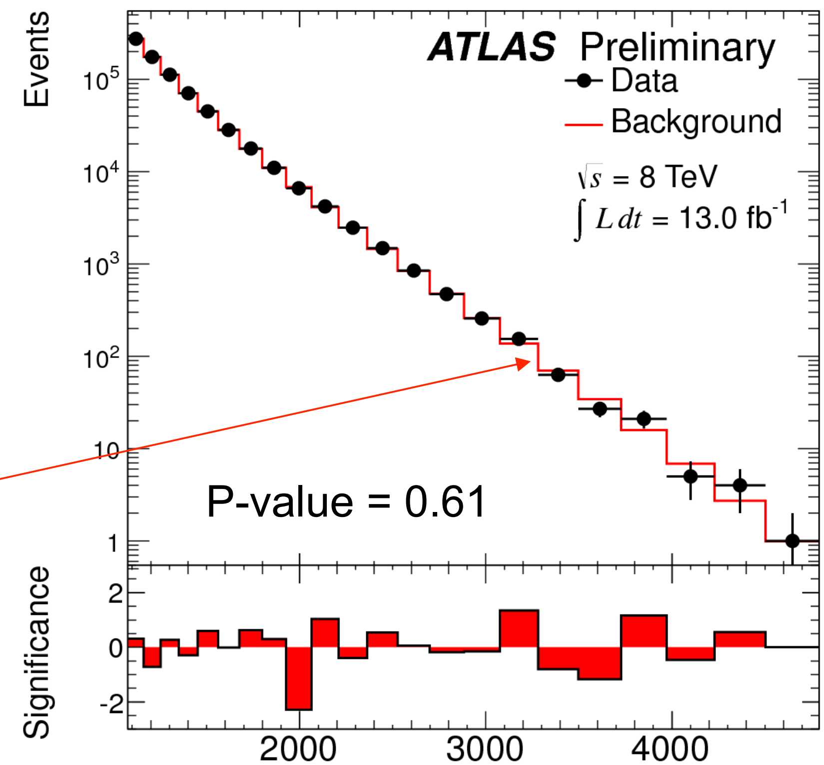
Heavy Resonance Search: 8 TeV Dijets

- Strong gravity, excited quarks
- Selections
  - Two anti-kt 0.6 jets
  - p^j_T>150 GeV && m_{jj}>1 TeV
  - |y|<2.8 && dijet CM rapidity |y*| < 0.6, $y^*=\pm0.5*(y_1-y_2)$
- Look for resonance above phenomenological fit of data

Probing quark structure ~ 5 TeV

$$f(x) = p_1(1-x)^{p_2}x^{p_3+p_4\ln x}$$

$$x \equiv m_{jj}/\sqrt{s}$$



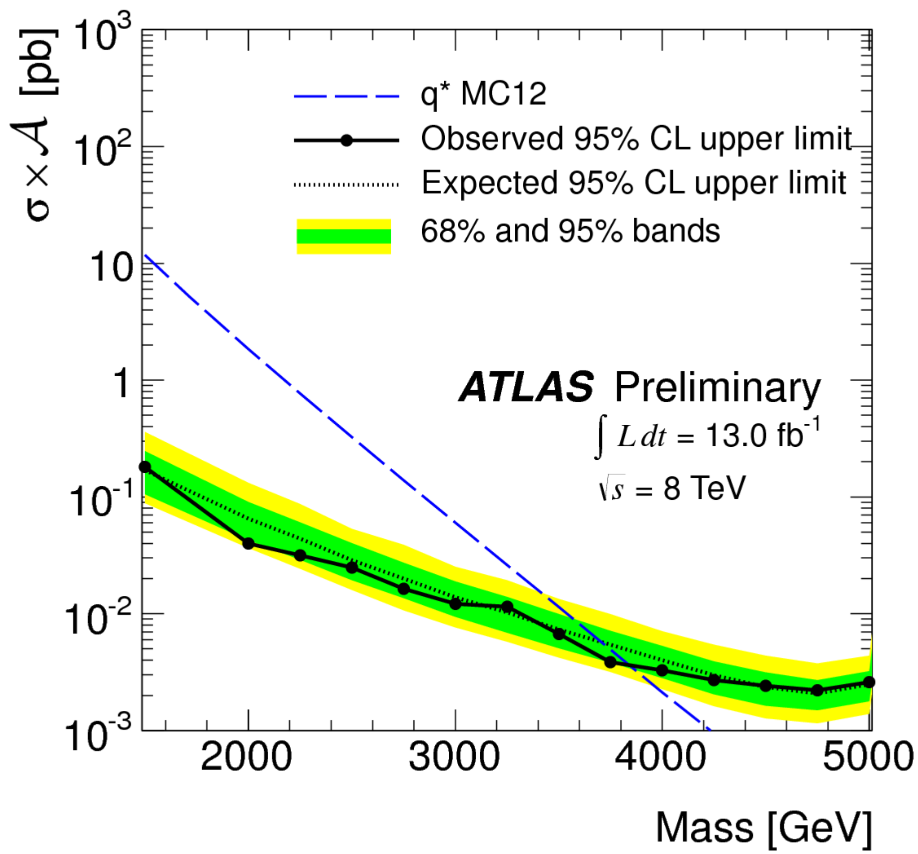
m_{jj} [GeV]

ATLAS-CONF-2012-148

Heavy Resonance Search: 8 TeV Dijets

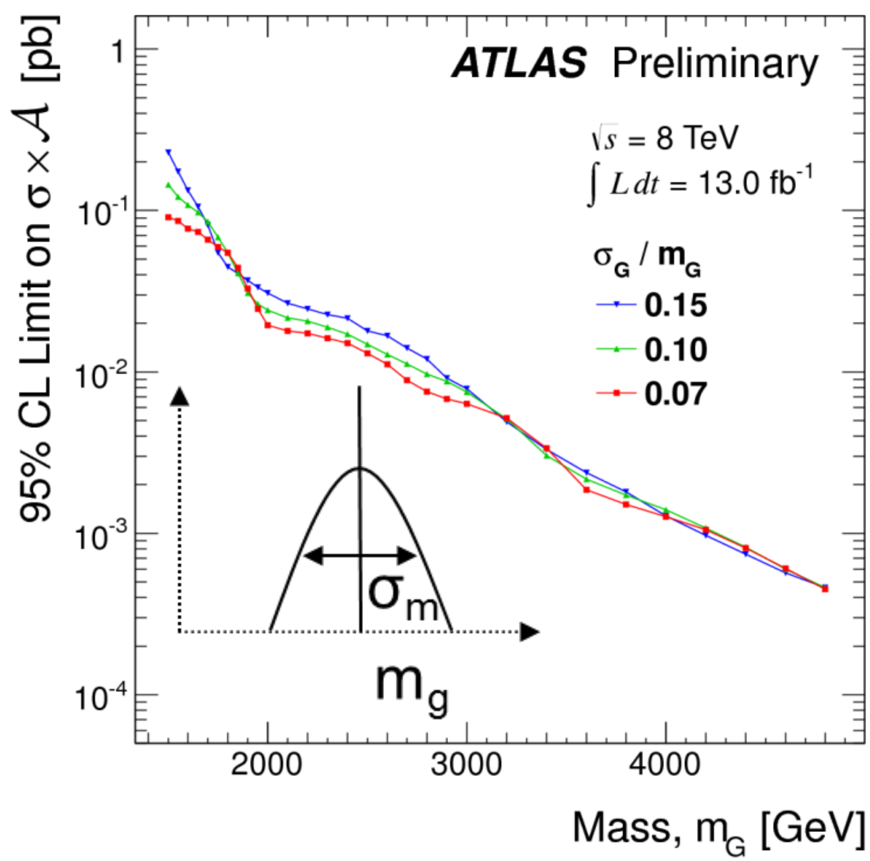
Excited quark limit:

m > 3.84 TeV at 95% CL



Gaussian resonance limits:

mean mass, $m_{G,}$ and 3 σ_G



20.3 fb^{-1} Dijet resonance + $W/Z \rightarrow l\nu/ll$

ATLAS-CONF-2013-074

- Very interesting final state
  - Sensitive to VH
  - Extradimension
  - Technicolor, little Higgs

Selections
$p_T^{l\nu/ll} > 50$ GeV
≥2 jets with $p_T > 30$ GeV
$\lvert\Delta\eta_{jj}\rvert < 1.75$, $\lvert\Delta\varphi_{jj}\rvert > 1.6$

Backgrounds

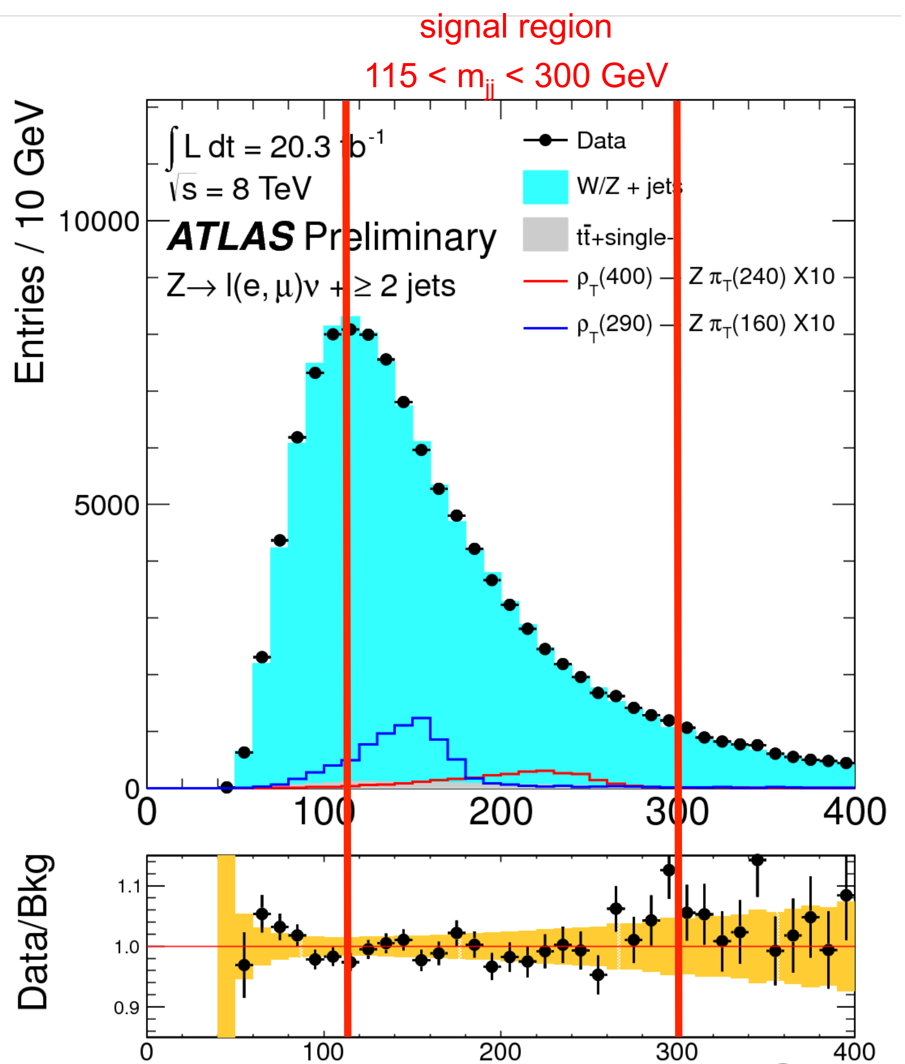
- Estimated with MC
  - **W/Z+jets dominant**
  - ttbar
  - single-top
  - Diboson
- Multijet – estimate w data

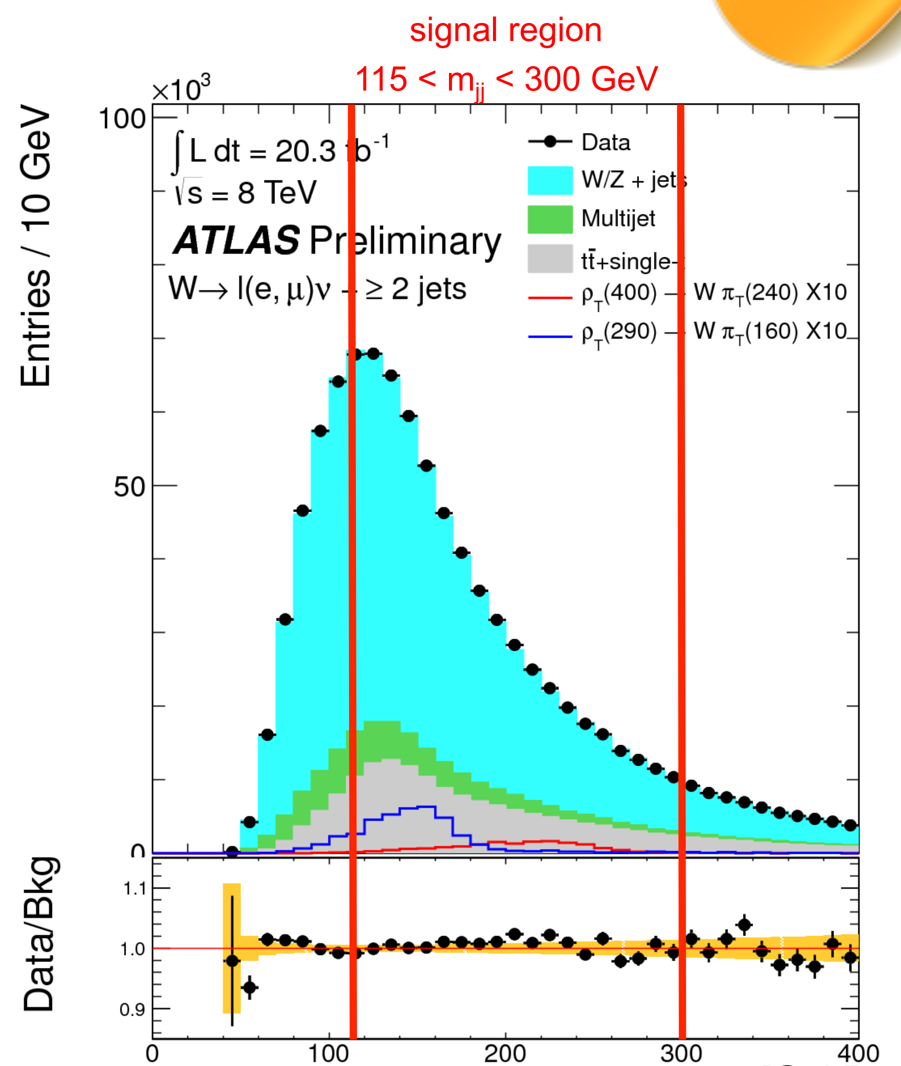
Systematic Uncertainties

Source	$\Delta\sigma/\sigma$% for Wjj	$\Delta\sigma/\sigma$% for Zjj
W/Z+jets normalization	±5	±16
W/Z jets shape variation	±2	±4
Multijet shape and normalization	±5	N/A
Top normalization	±4	±7
Top Modeling	±3	±4
Jet energy scale (all samples)	±10	±11
Jet energy resolution (all samples)	±2	±3
Lepton reconstruction (all samples)	±1	±3
PDF (signal)	±5	±6
PDF (top)	±6	±3

$m(\pi_T) = 180$ GeV

m_{jj} distributions for Z/W+2 jets





Good agreement

m_{jj} [GeV]

versity of Ox

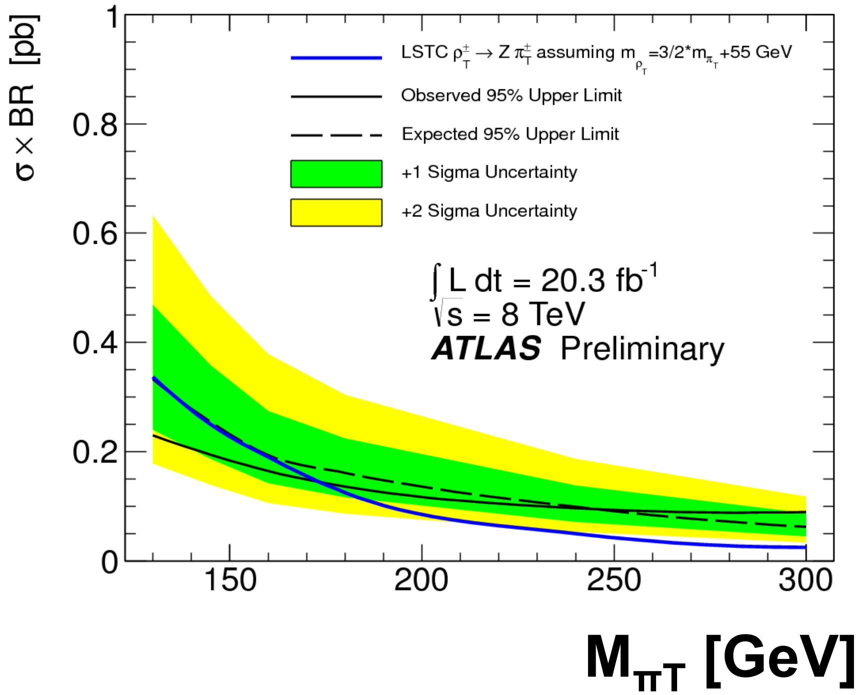
Good agreement

m_{jj} [GeV]

95% CL upper σXBR on LSTC Technipion + Z/W production

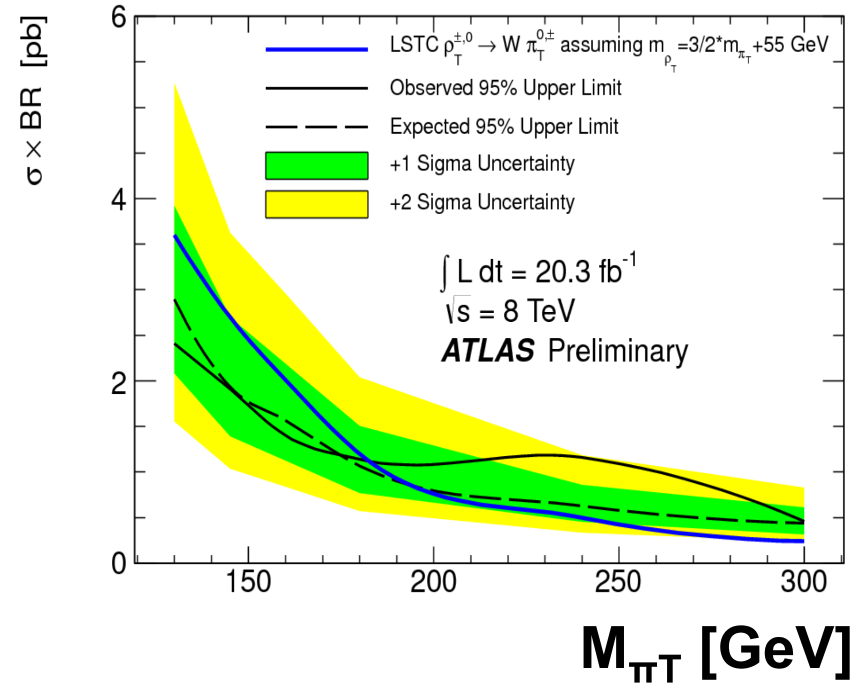
LSTC = Low Scale TechniColor

LSTC $\rho_T{}^{\pm} \rightarrow Z\pi_T{}^{\pm}$



$m_{\pi T} > 170$ GeV

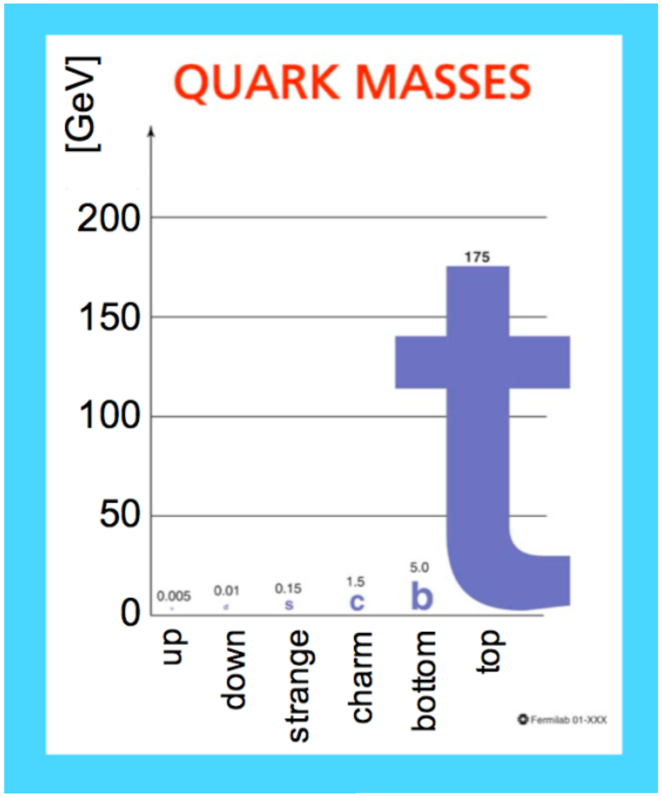
LSTC $\rho_T{}^{\pm,0} \rightarrow W\pi_T{}^{0,\pm}$



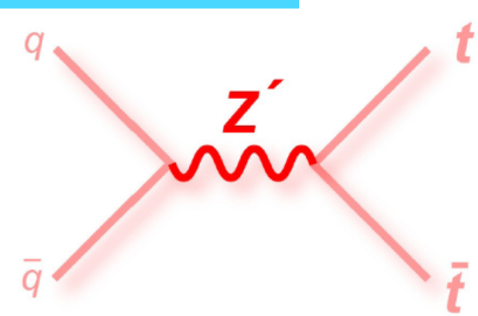
$m_{\pi T} > 180$ GeV

$$m_\rho = \frac{3}{2} * m_\pi + 55\ GeV$$

New Physics Searches with high-pt top quarks



- Highly coupled to EWK symmetry breaking
- LHC is a top factory
- Huge mass of top
  - Bizarre
  - New physics
- Heavy new particles
  - Couple strongly to top
  - Produce boosted tops
- New techniques for top ID

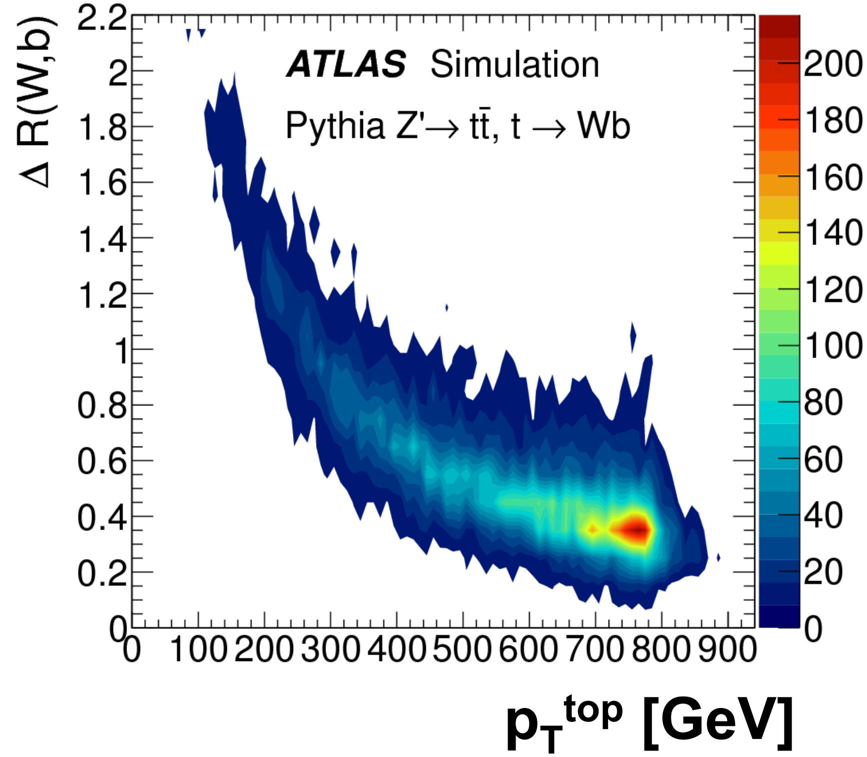


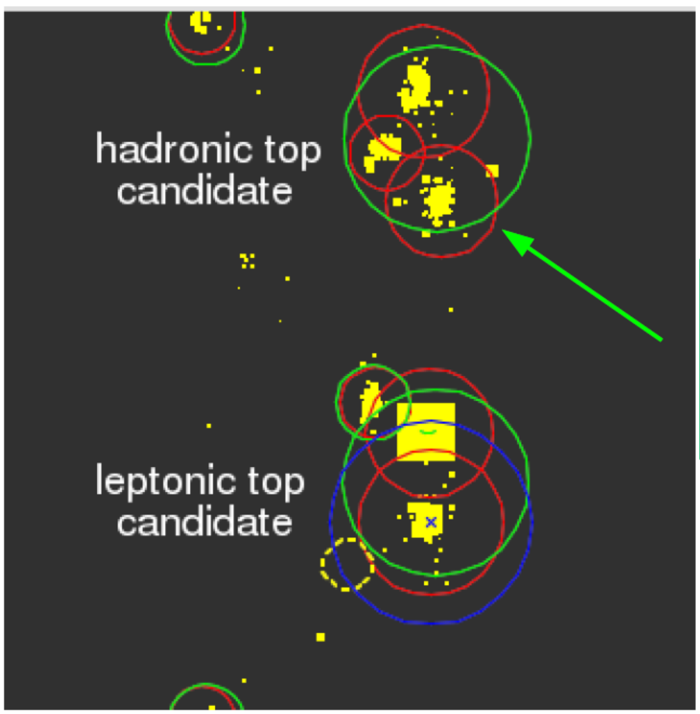
Boosted Regime

- Rule of thumb: $\boxed{dR \sim \frac{2m}{p_T}}$

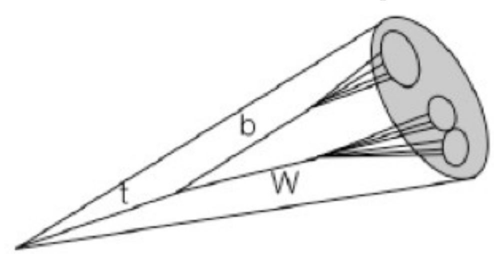
- top with p_T > 350 GeV
  decay products within R~1

CERN-PH-EP-2013-069, arXiv:1306.4945





R = 1
m_j=197 GeV
P_T=356 GeV



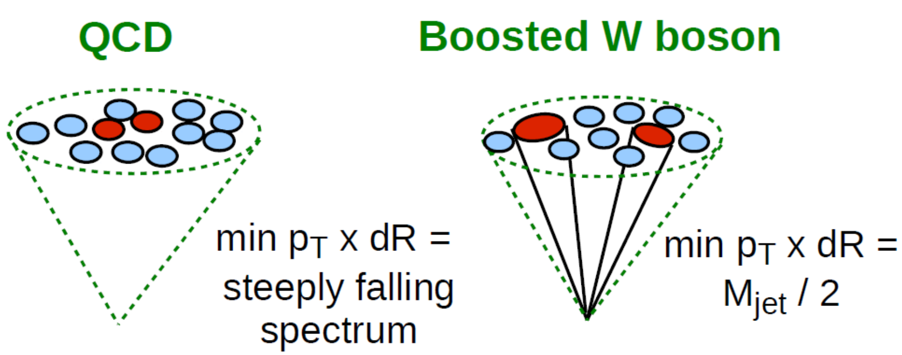
Jet Substructure: Splitting Scales

- e.g k_T-splitting scales

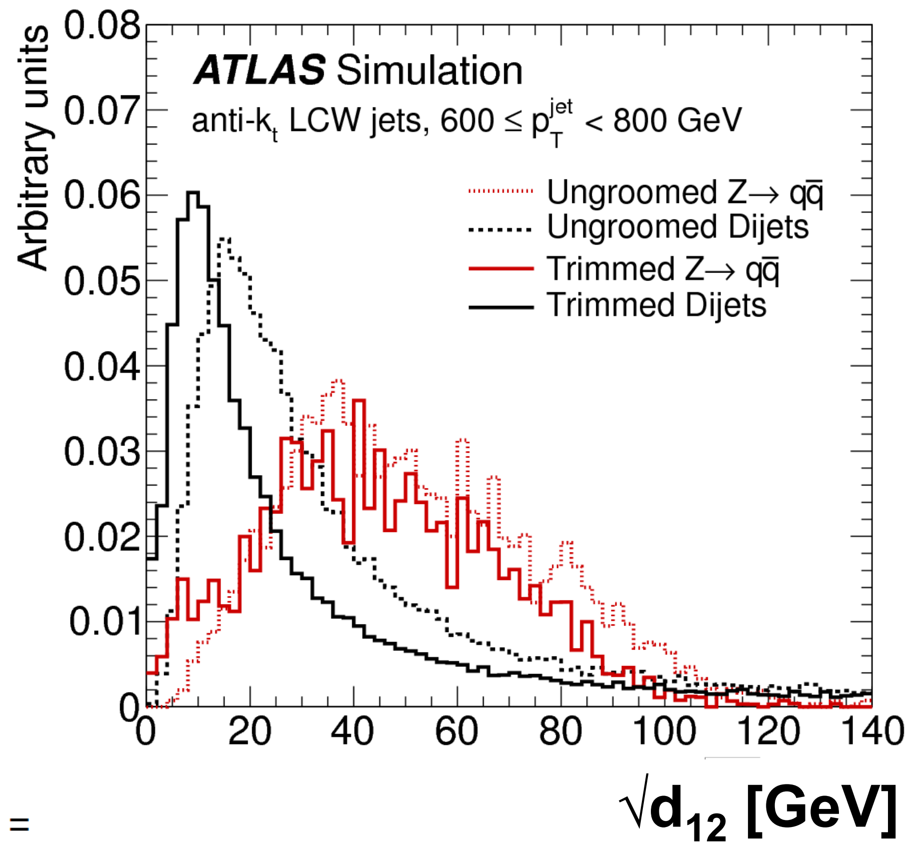
$$d_{ij} = \min({p^2}_{Ti}, {p^2}_{Tj}) \times {\Delta R^2}_{ij}/R^2$$

  - i, j constituents of current jet clustering step
  - re-cluster constituents using kt

    → highest p_T constituents clustered last



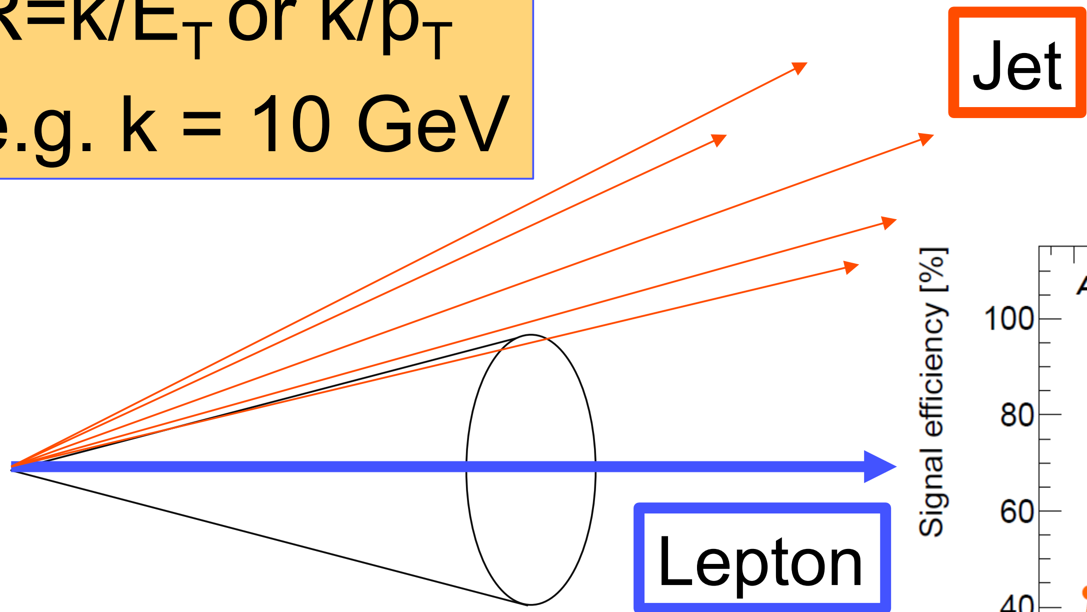
CERN-PH-EP-2013-069, arXiv:1306.4945



Variable Isolation Cone

$R = k/E_T$ or k/p_T

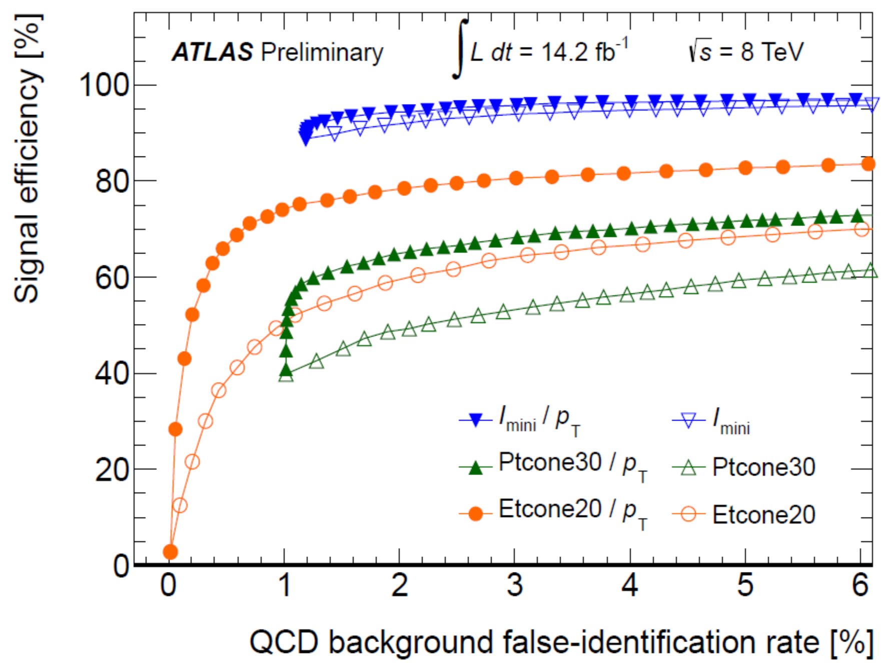
e.g. k = 10 GeV



"Variable" Isolation Cone

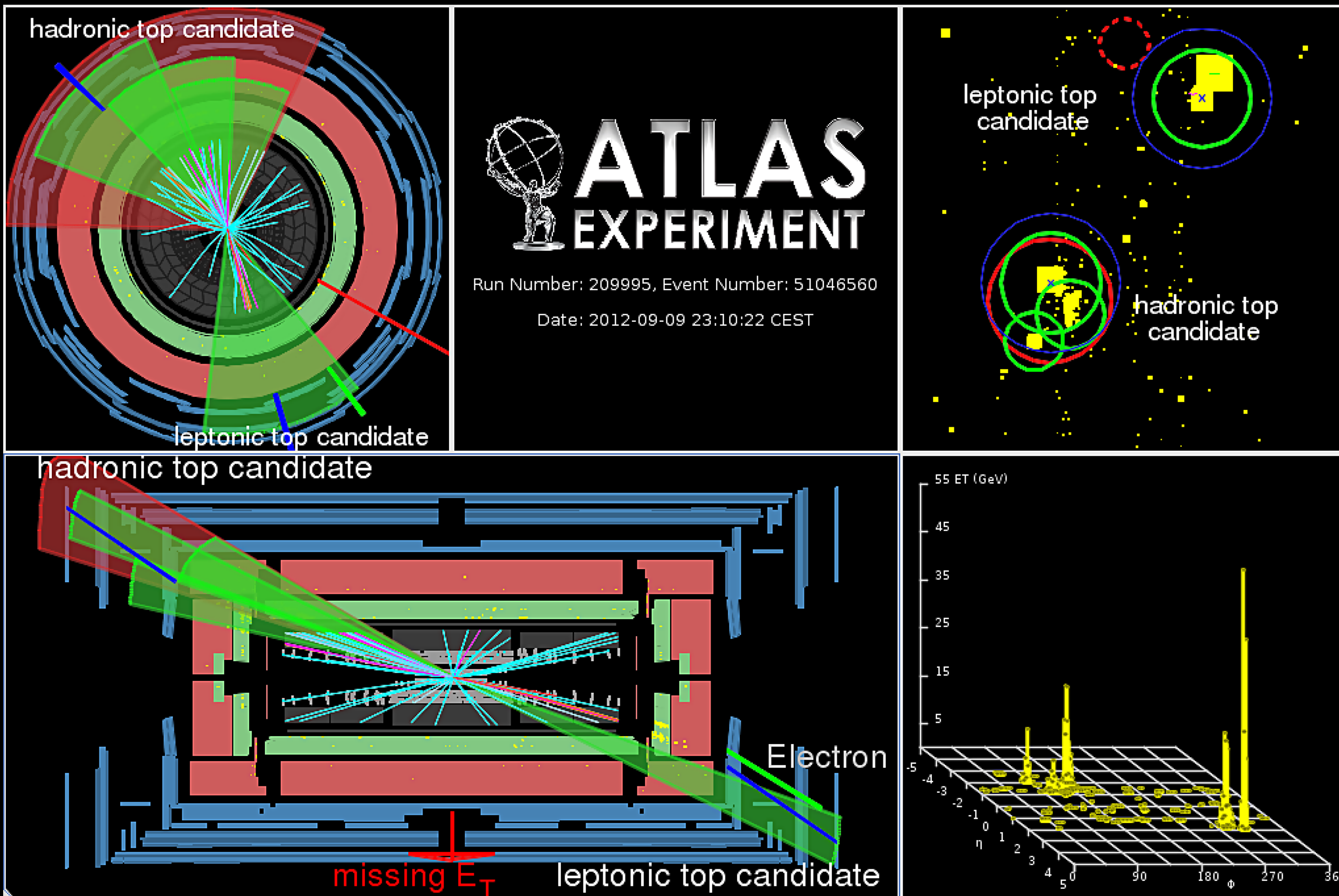
$I < 0.05 * E_T$ (for electrons)

$I < 0.05 * p_T$ (for muons)

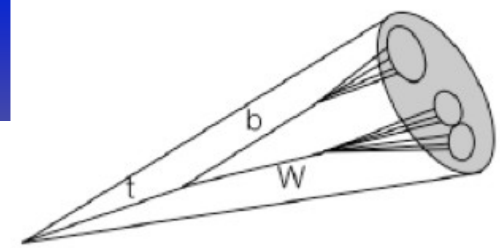


(d) 2.0 TeV Z'

Boosted Top Event Candidate with m_{ttbar}=2.6 TeV



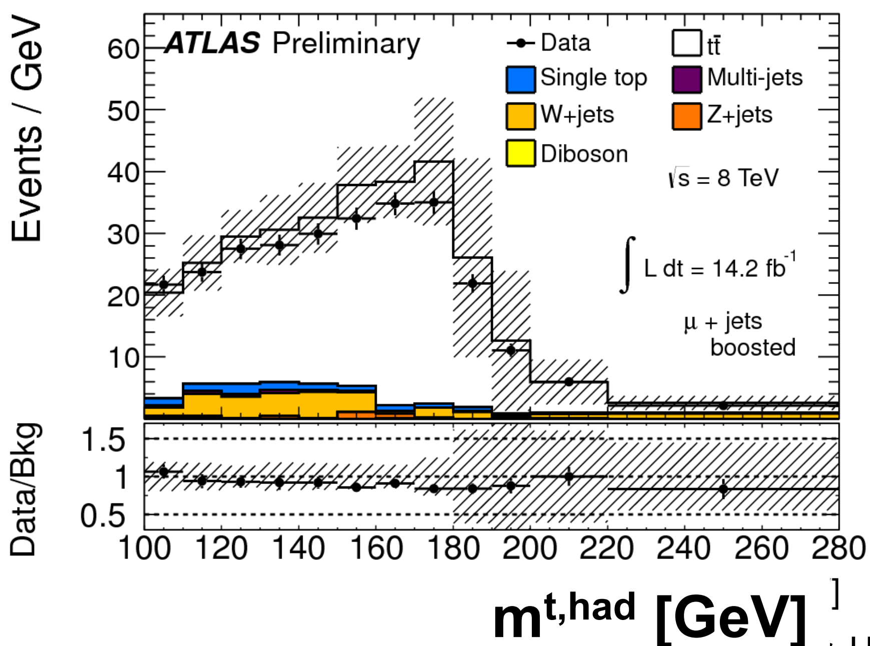
Heavy Resonances Search: ttbar

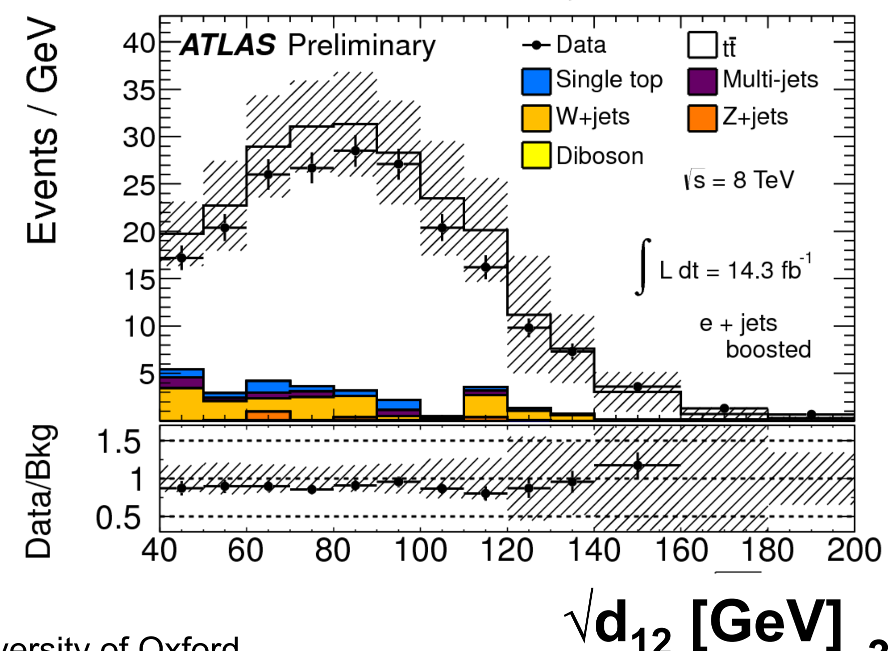


ATLAS-CONF-2013-052

- Lepton+jets channel
- Models: e.g. bulk-RS (esp. KK gluons) and Leptophobic Z'
  - Large Branching Ratio to top-antitop
- Combining **resolved** and **boosted** reconstructions
- Taking full advantage of boosted techniques

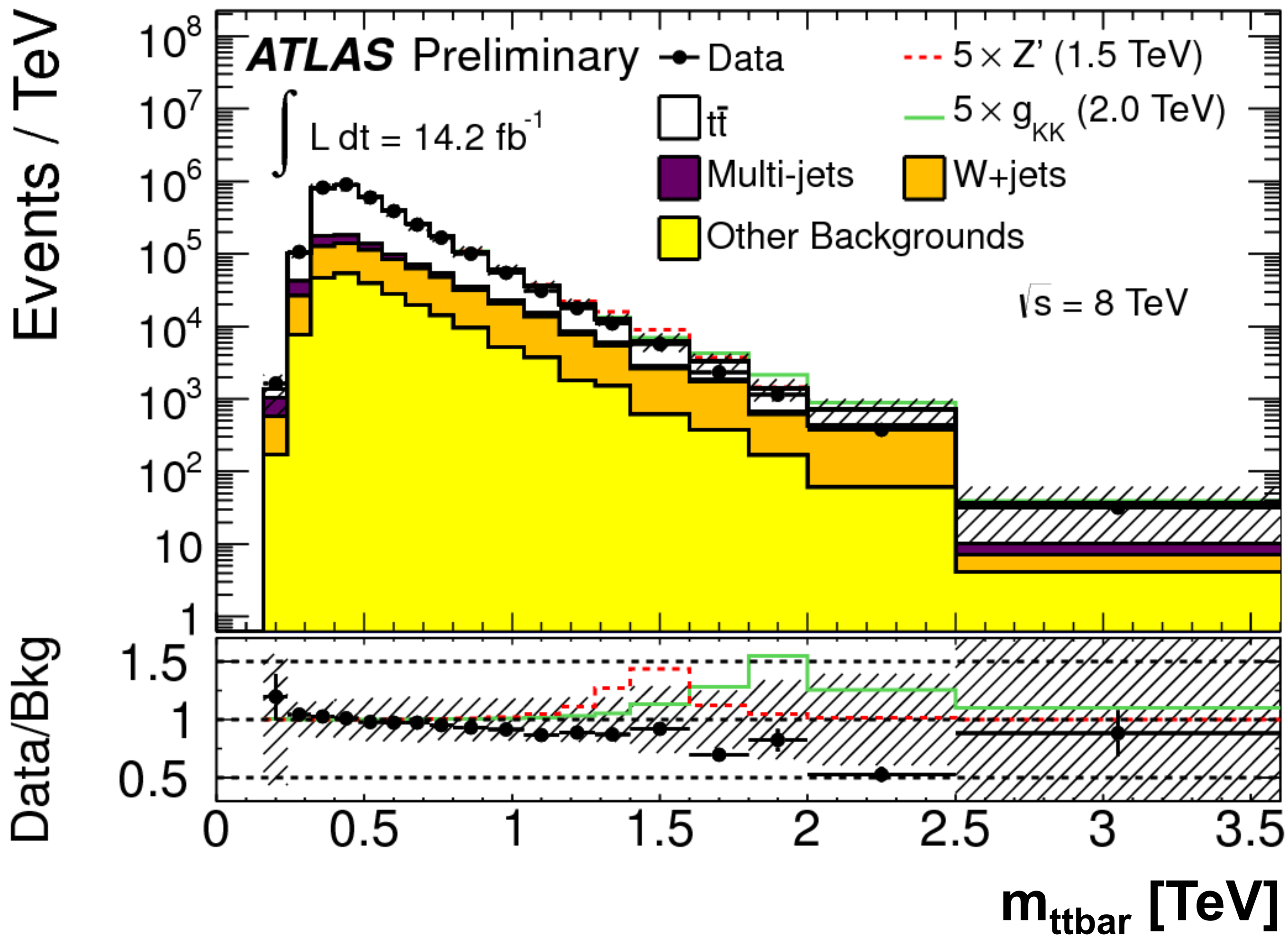
$$d_{ij} = \min(p^2{}_{Ti}, p^2{}_{Tj}) \times \Delta R^2{}_{ij}/R^2$$



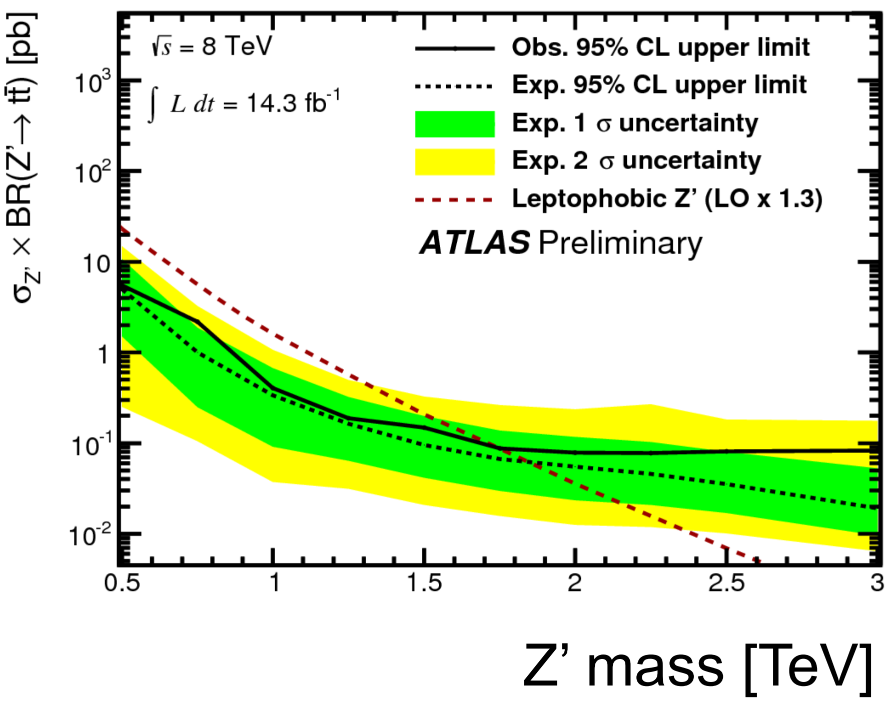


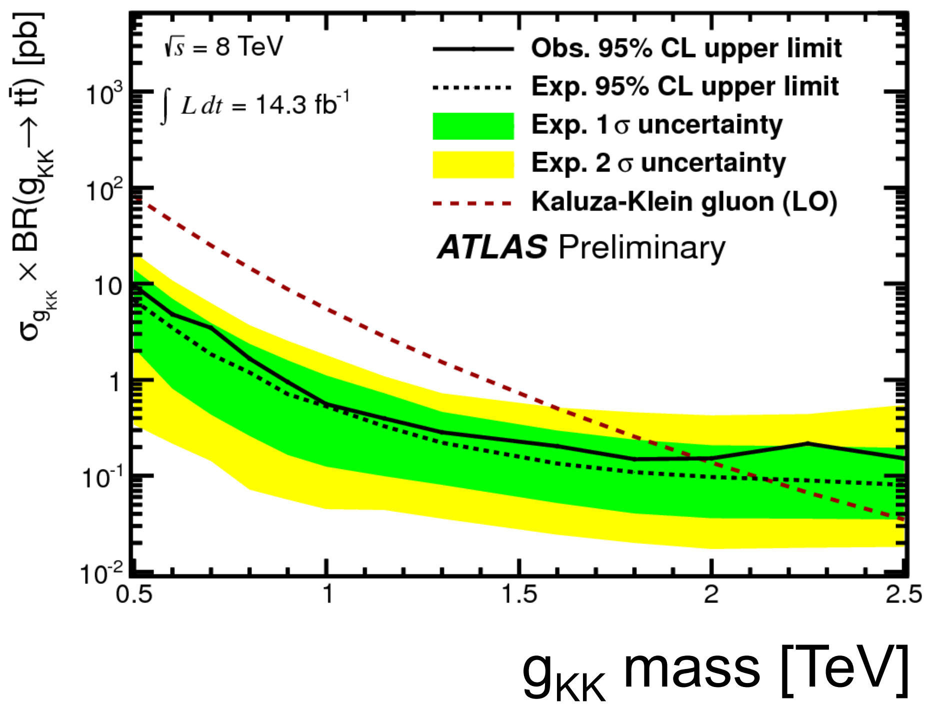
Discriminant distribution m_{ttbar}

- $m_{t\bar{t}}$ resolved + boosted in *e*+jets and *μ*+jets



Heavy Resonances Search: ttbar





m(Z') > 1.8 TeV @95% CL

Γ/m(Z') = 1.2%

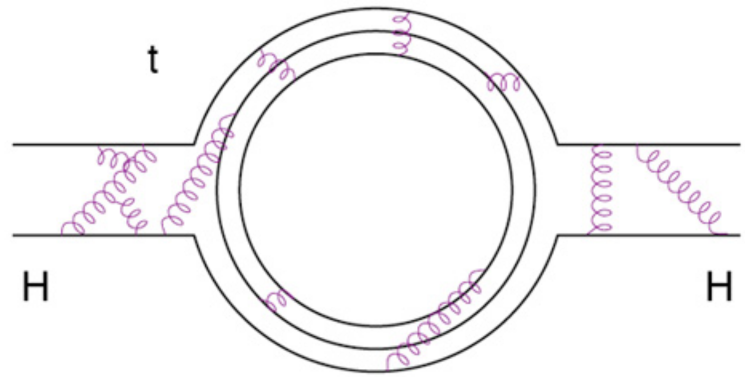
m(g_{KK}) > 2.0 TeV @95% CL

Γ/m(g_{KK}) = 15%

More details by Oana E.Vickey Boeriu this afternoon

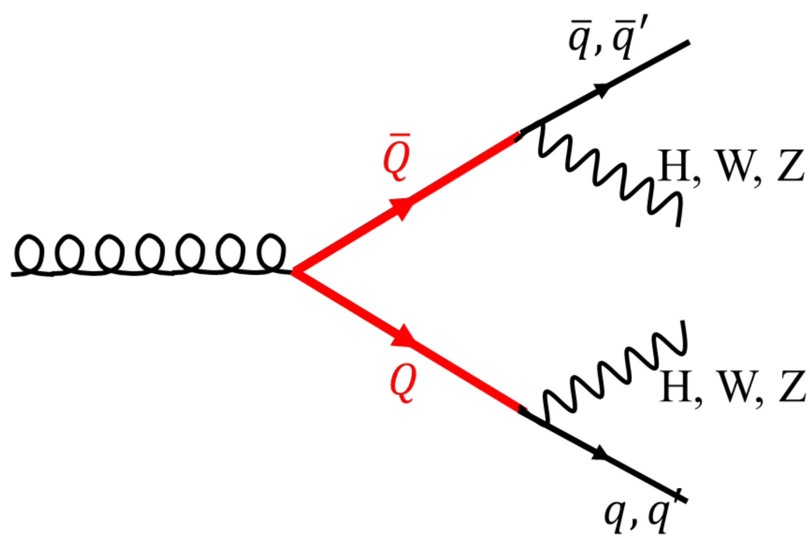
Searches for Vector-like Quarks (T, B)

- Composite Higgs
- Little Higgs models
- Warped extra dimension
- 2HDM models



- Not excluded by Higgs mass constraints/branching ratios

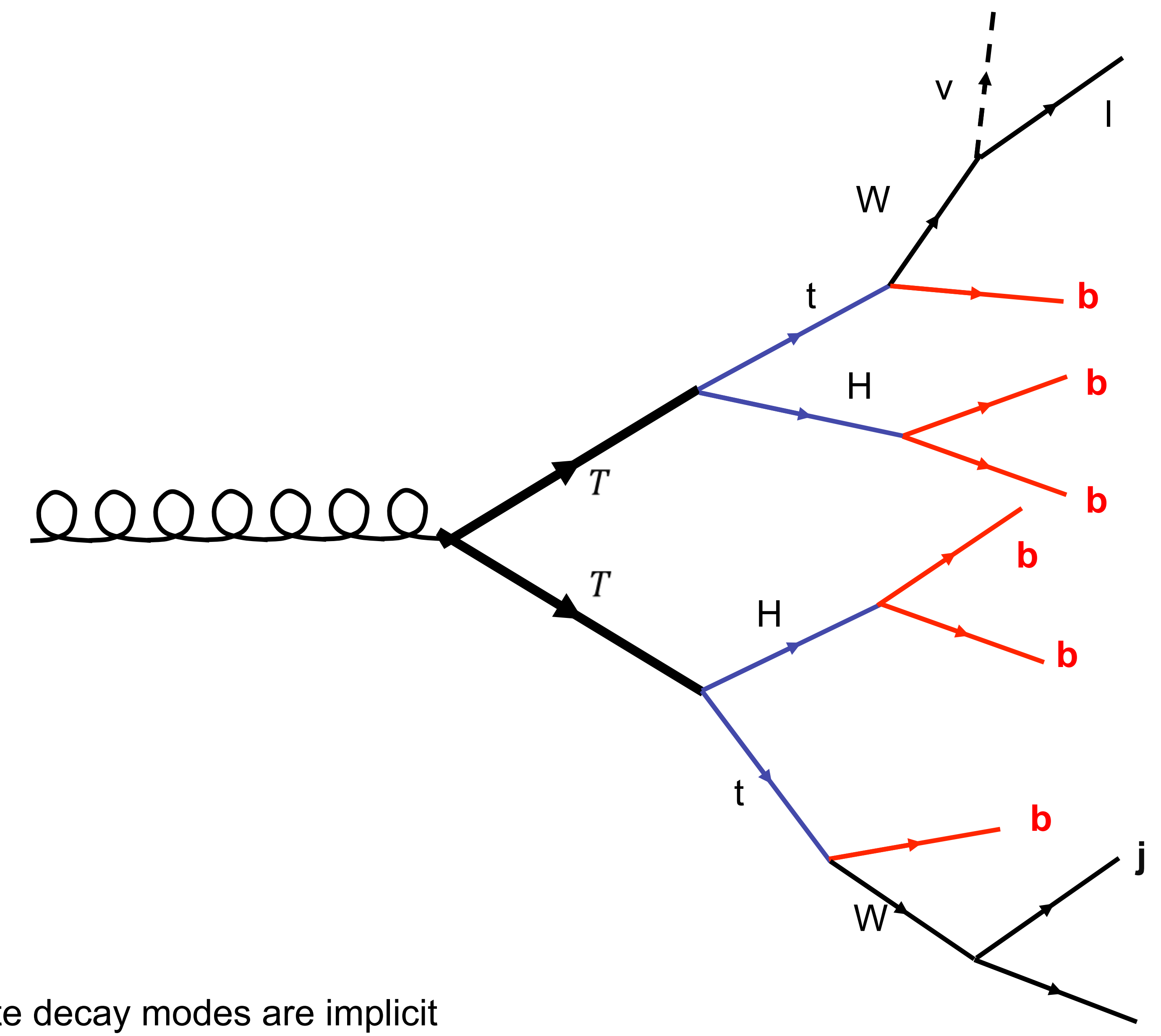
- Very rich phenomenology
  - Final states with multiple
    - W/Z/H's, b and top quarks
  - T: Decays to Wb, Zt, Ht
  - B: Decays to Wt, Zb, Hb



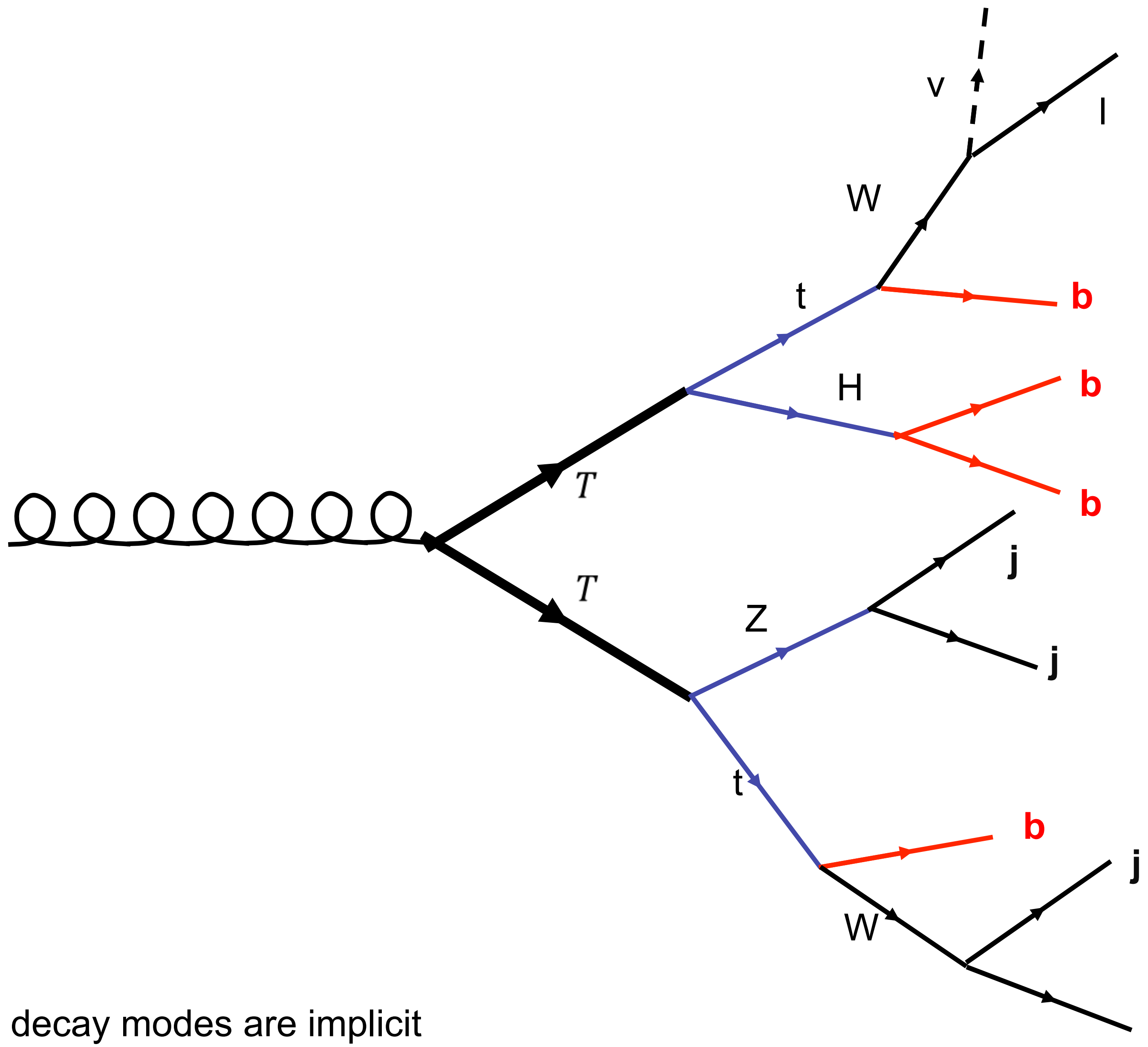
- Loose constraints on CKM4 → decays to light quarks possible!

$T \rightarrow \mathbf{H}\ t$

ATLAS-CONF-2013-018

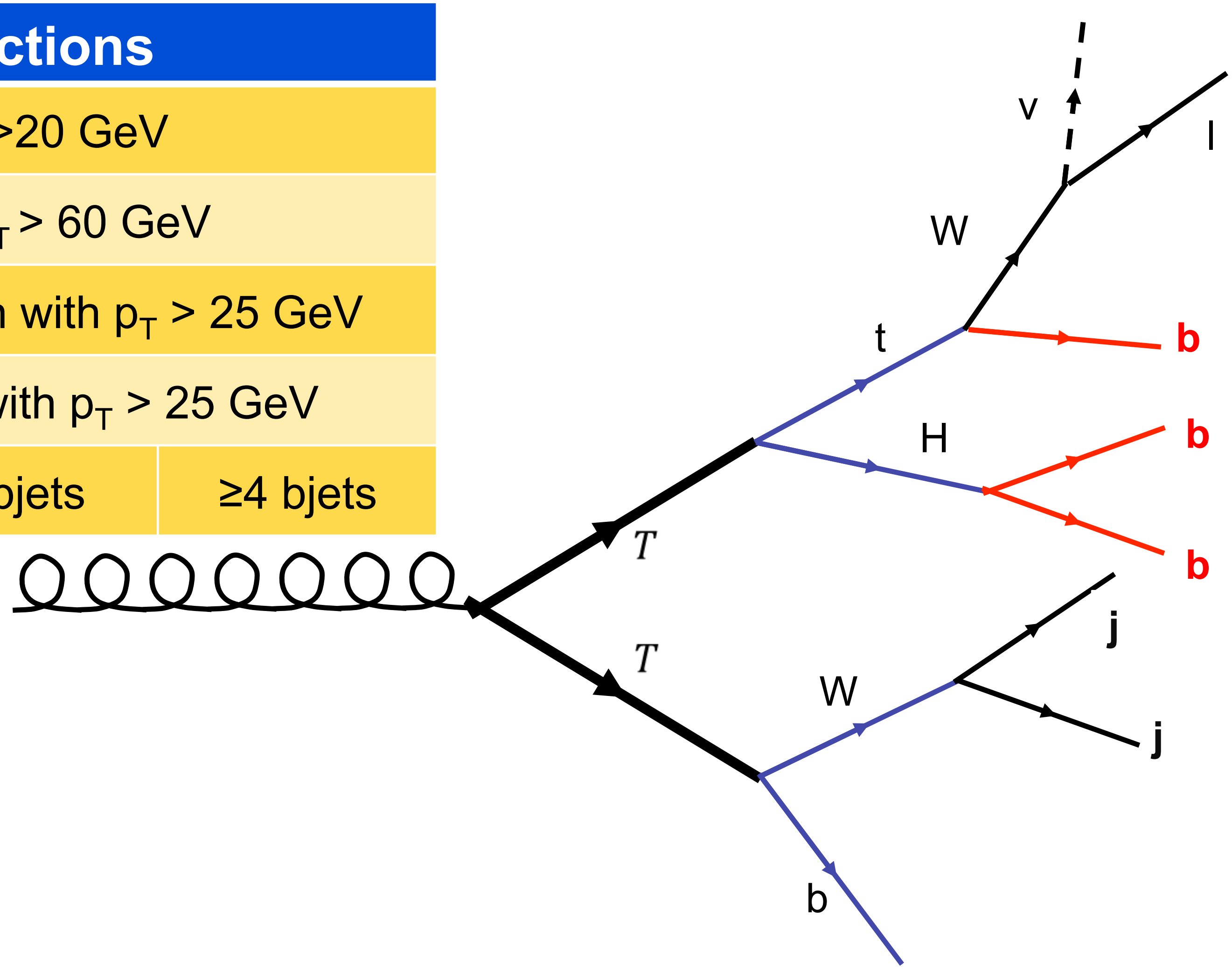


Complex-conjugate decay modes are implicit



Complex-conjugate decay modes are implicit

Selections		
E_T^{miss} >20 GeV		
$E_t^{miss}+m_T$ > 60 GeV		
1 Isolated lepton with p_T > 25 GeV		
≥ 6 akt4 jets with p_T > 25 GeV		
2 bjets	3 bjets	≥4 bjets

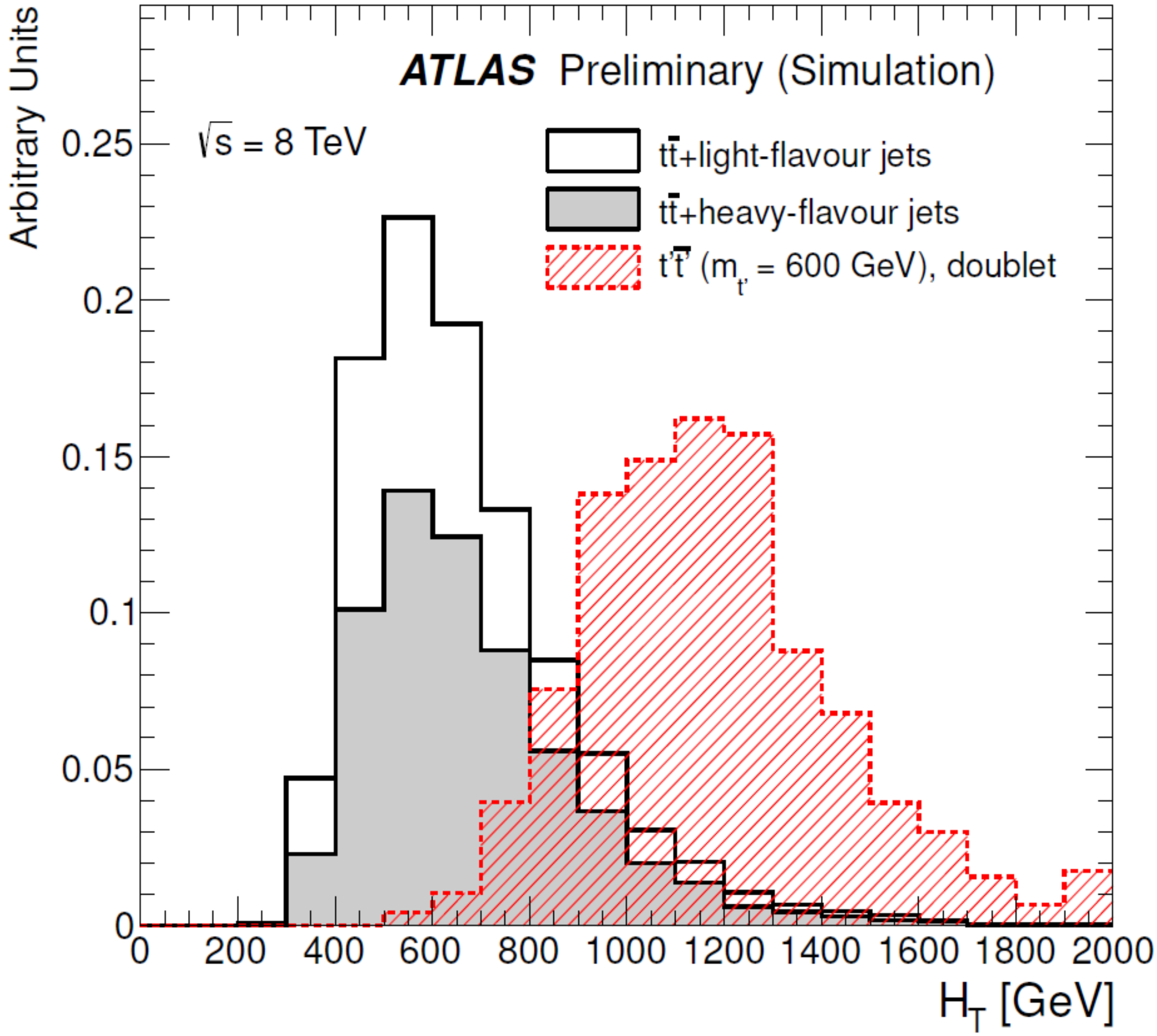


Complex-conjugate decay modes are implicit

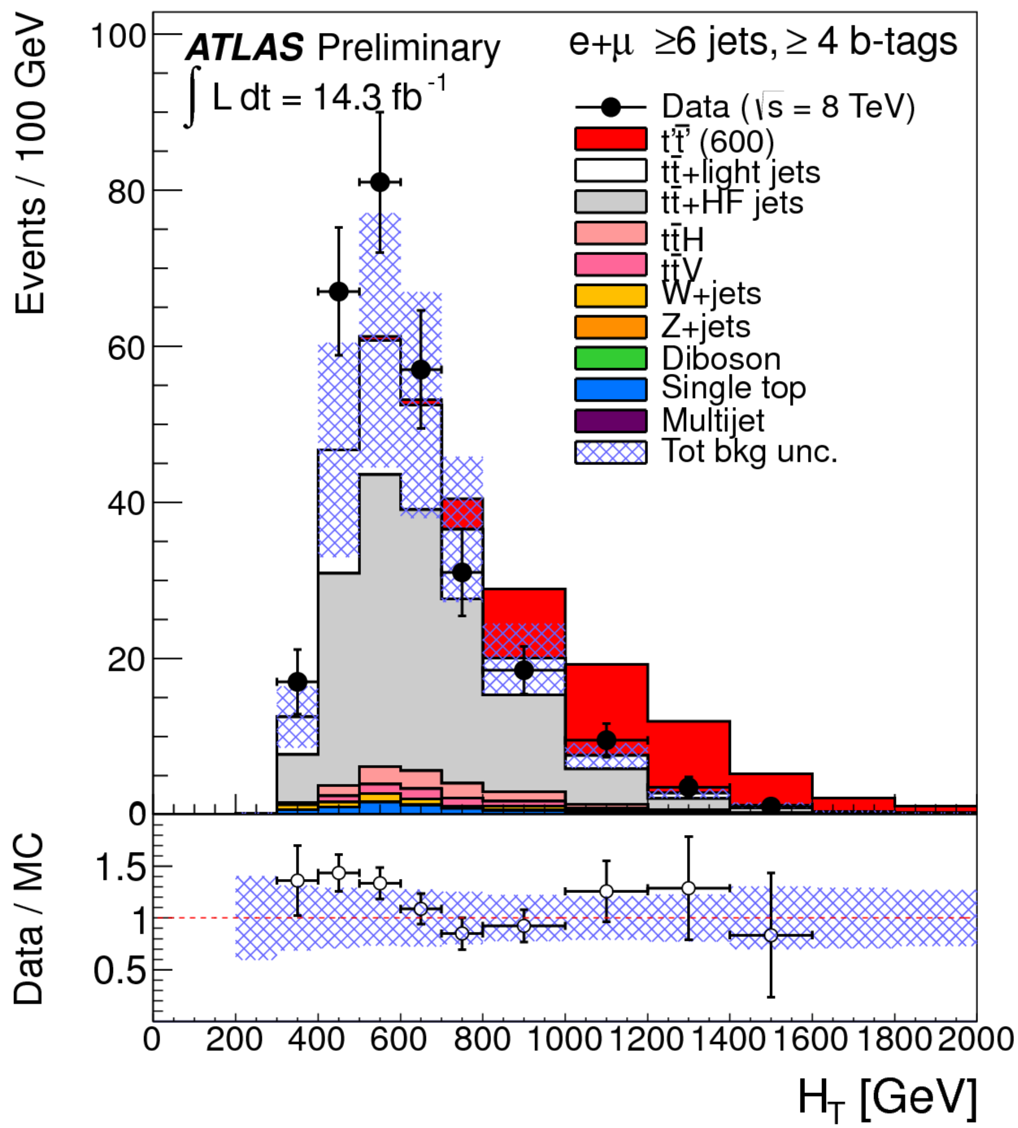
Discriminant Variable H_T

$$H_T = \sum_{Scalar\ Sum} P_{T,lepton} + E_{T,miss} + P_{T,jets}$$

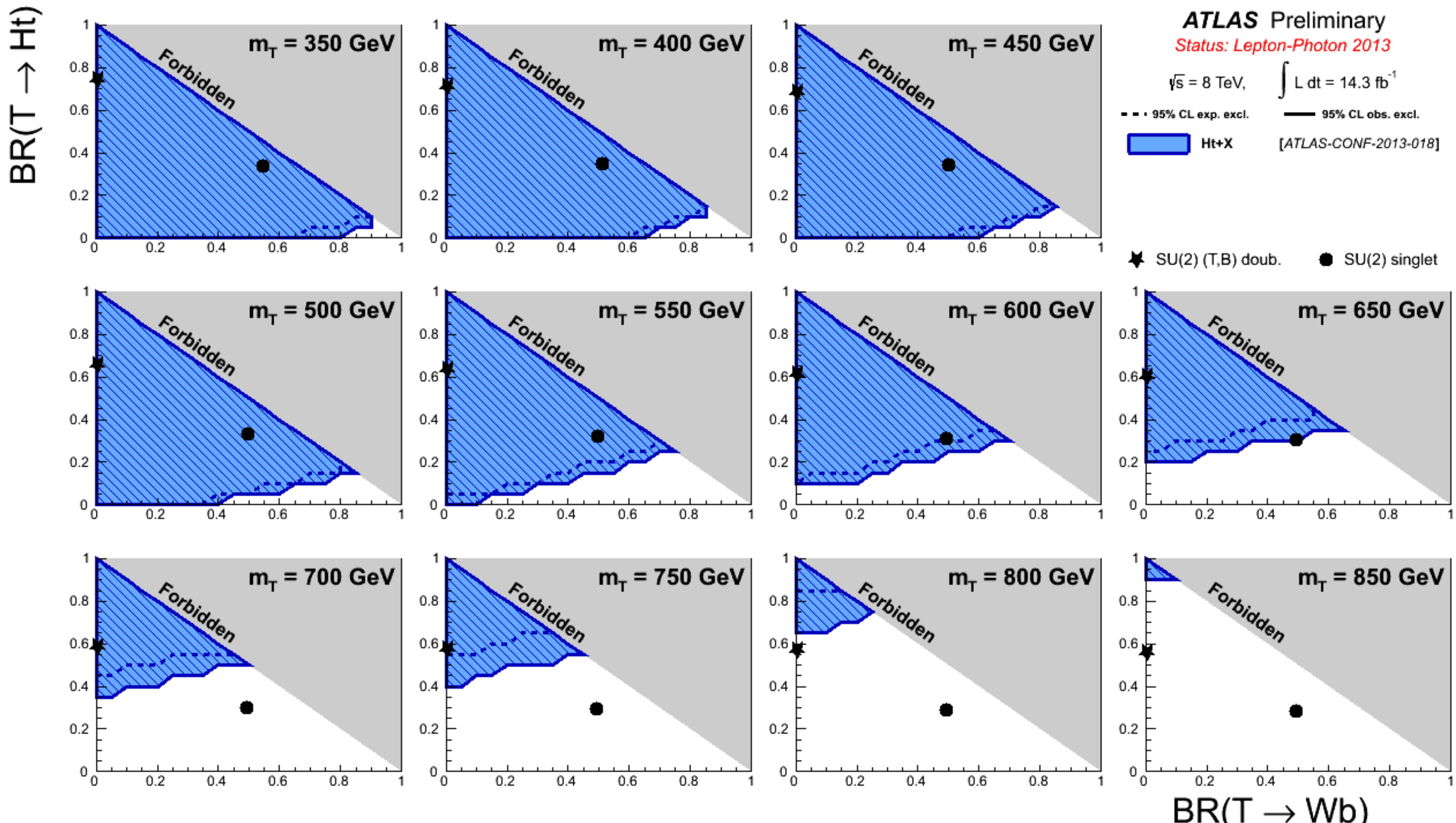
Discriminant Variable H_T



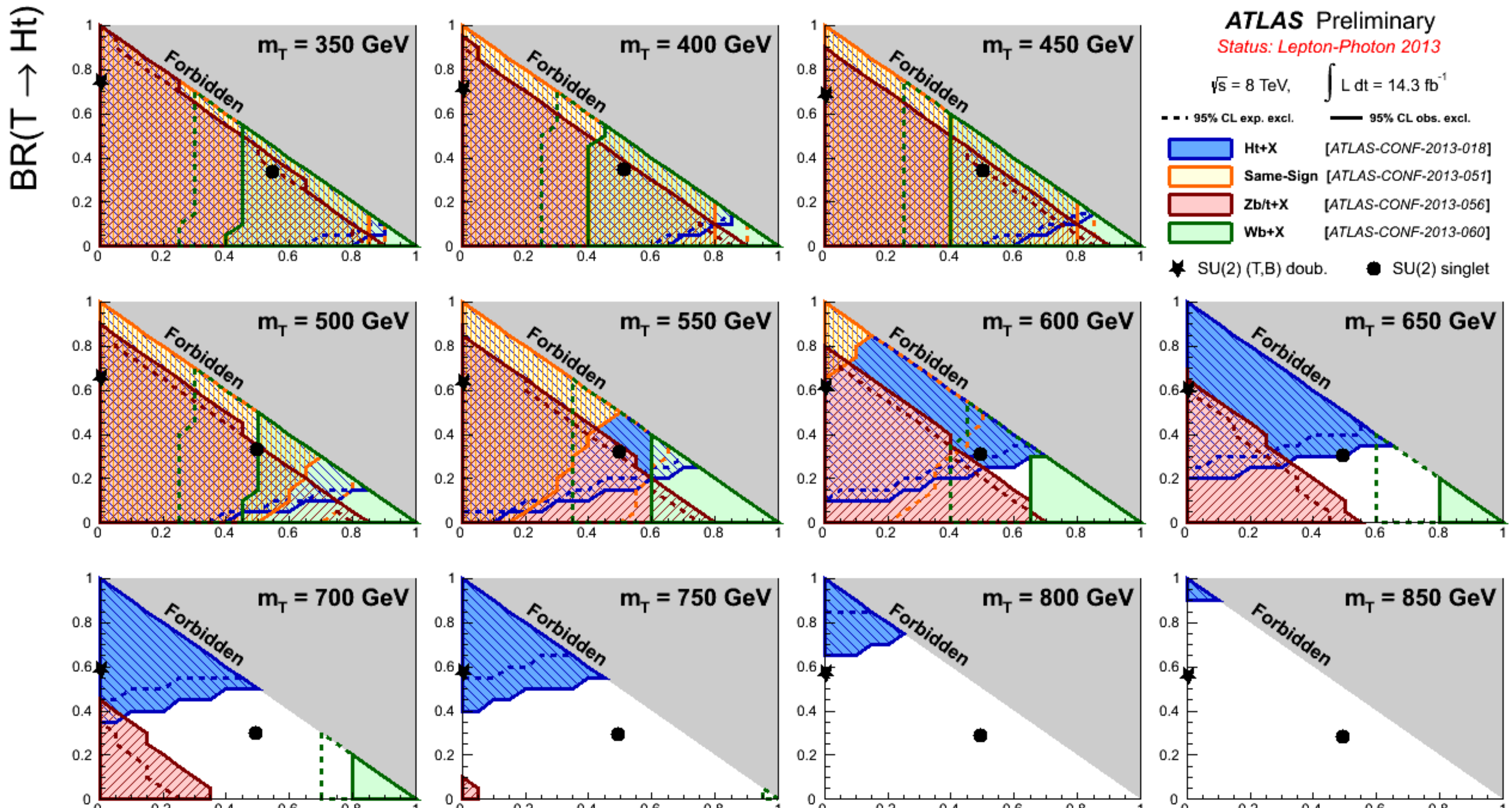
Discriminant Variable H_T



Exlusion Limits for Vector Like T Quark

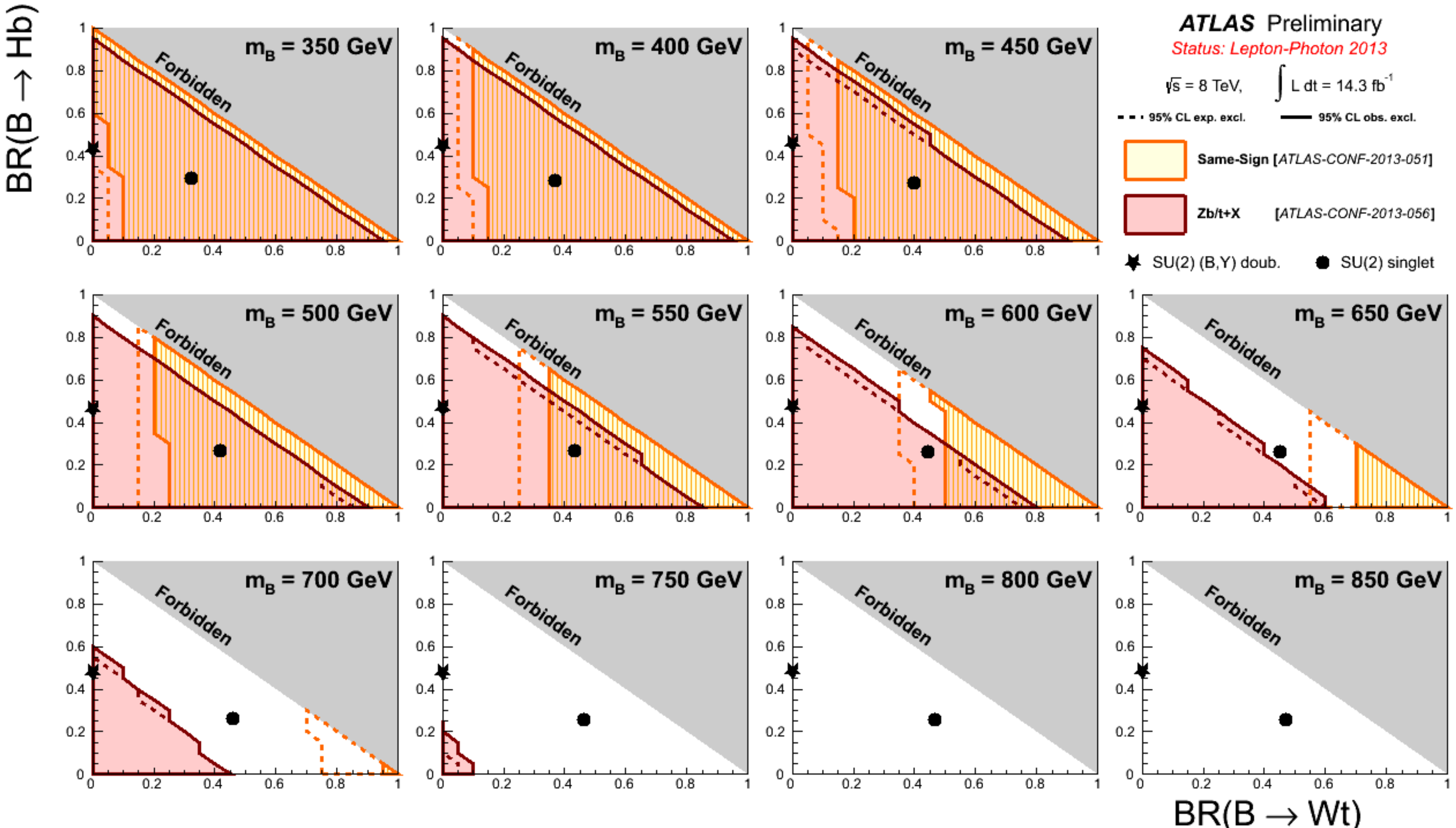


Exlusion Limits for Vector-Like T Quark



More details on Wb+X by Oana E.Vickey Boeriu this afternoon

Exlusion Limits for Vector Like B Quark



Inclusive Same-Sign Dilepton Search

1210.4538

- Model independent approach
  - Limit presented in terms of fiducial cross-section limit

$$\sigma_{95}^{\text{fid}} = \frac{N_{95}}{\varepsilon_{\text{fid}} \times \int \mathcal{L} dt}$$

95% CL upper limit on yield (given N_{obs} and N_{bkg})

Reconstruction and Selection efficiency
Within acceptance

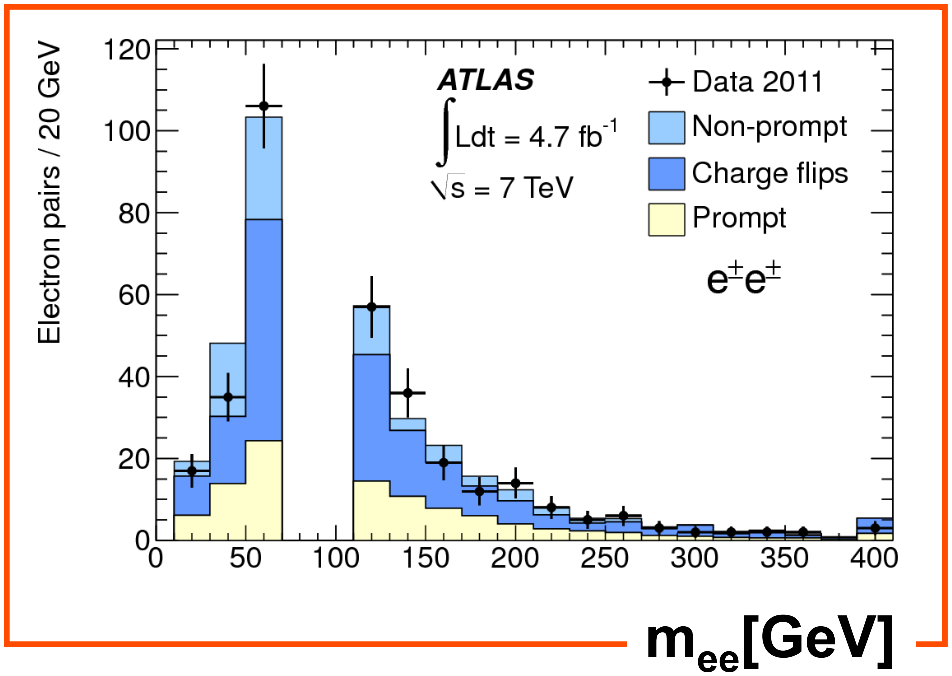
  - σ^{fid} is (almost) model-independent
  - Can turn σ^{fid} into σ^{total} with generator-level information only
  - Caveat: not exactly model-independent → must be conservative

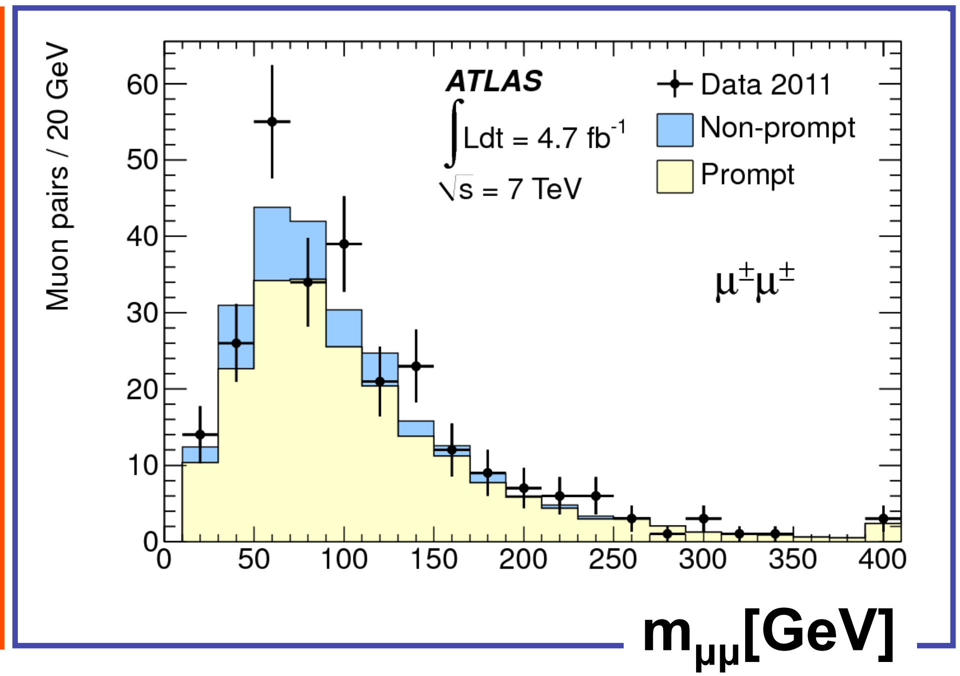
Particle-level definition of acceptance

	Electron requirement	Muon requirement
Leading lepton p_T	$p_T > 25$ GeV	$p_T > 20$ GeV
Sub-leading lepton p_T	$p_T > 20$ GeV	$p_T > 20$ GeV
Lepton η	$\lvert\eta\rvert < 1.37$ or $1.52 < \lvert\eta\rvert < 2.47$	$\lvert\eta\rvert < 2.5$
Isolation	$p_T^{\text{cone}0.3}/p_T < 0.1$	$p_T^{\text{cone}0.4}/p_T < 0.06$ and $p_T^{\text{cone}0.4} < 4\text{ GeV} + 0.02 \times p_T$

Inclusive Same-Sign Dilepton Search

1210.4538





Inclusive Same-Sign Dilepton Search

1210.4538

- 95% upper limits
  - 1.7 fb and 64 fb

Fiducial cross section upper limits

Mass	ee		eμ		μμ	
	exp	obs	exp	obs	exp	obs

Mass range	95% C.L. upper limit [fb] expected	observed	expected	observed	expected	observed
	$e^\pm e^\pm$		$e^\pm \mu^\pm$		$\mu^\pm \mu^\pm$	
$m > 15$ GeV	46^{+15}_{-12}	42	56^{+23}_{-15}	64	$24.0^{+8.9}_{-6.0}$	29.8
$m > 100$ GeV	$24.1^{+8.9}_{-6.2}$	23.4	$23.0^{+9.1}_{-6.7}$	31.2	$12.2^{+4.5}_{-3.0}$	15.0
$m > 200$ GeV	$8.8^{+3.4}_{-2.1}$	7.5	$8.4^{+3.4}_{-1.7}$	9.8	$4.3^{+1.8}_{-1.1}$	6.7
$m > 300$ GeV	$4.5^{+1.8}_{-1.3}$	3.9	$4.1^{+1.8}_{-0.9}$	4.6	$2.4^{+0.9}_{-0.7}$	2.6
$m > 400$ GeV	$2.9^{+1.1}_{-0.8}$	2.4	$3.0^{+1.0}_{-0.8}$	3.1	$1.7^{+0.6}_{-0.5}$	1.7
	$e^+ e^+$		$e^+ \mu^+$		$\mu^+ \mu^+$	
$m > 15$ GeV	$29.1^{+10.2}_{-8.6}$	22.8	$34.9^{+12.2}_{-8.6}$	34.1	$15.0^{+6.1}_{-3.3}$	15.2
$m > 100$ GeV	$16.1^{+5.9}_{-4.3}$	12.0	$15.4^{+5.9}_{-4.1}$	18.0	$8.4^{+3.2}_{-2.4}$	7.9
$m > 200$ GeV	$7.0^{+2.9}_{-2.2}$	6.1	$6.6^{+3.5}_{-1.8}$	8.8	$3.5^{+1.6}_{-0.7}$	4.3
$m > 300$ GeV	$3.7^{+1.4}_{-1.0}$	2.9	$3.2^{+1.2}_{-0.9}$	3.2	$2.0^{+0.8}_{-0.5}$	2.1
$m > 400$ GeV	$2.3^{+1.1}_{-0.6}$	1.7	$2.4^{+0.9}_{-0.6}$	2.5	$1.5^{+0.6}_{-0.3}$	1.8
	$e^- e^-$		$e^- \mu^-$		$\mu^- \mu^-$	
$m > 15$ GeV	$23.2^{+8.6}_{-5.8}$	25.7	$26.2^{+10.6}_{-7.6}$	34.4	$12.1^{+4.5}_{-3.5}$	18.5
$m > 100$ GeV	$12.0^{+5.3}_{-2.8}$	18.7	$11.5^{+4.2}_{-3.5}$	16.9	$6.0^{+2.3}_{-1.9}$	10.1
$m > 200$ GeV	$4.9^{+1.9}_{-1.2}$	4.0	$4.6^{+2.1}_{-1.2}$	4.5	$2.7^{+1.1}_{-0.7}$	4.4
$m > 300$ GeV	$2.9^{+1.0}_{-0.6}$	2.7	$2.7^{+1.1}_{-0.6}$	3.5	$1.5^{+0.8}_{-0.3}$	1.7
$m > 400$ GeV	$1.8^{+0.8}_{-0.4}$	2.3	$2.3^{+0.8}_{-0.5}$	2.5	$1.2^{+0.4}_{-0.0}$	1.2

	$e^- e^-$	
$m > 15$ GeV	$23.2^{+8.6}_{-5.8}$	25.7
$m > 100$ GeV	$12.0^{+5.3}_{-2.8}$	18.7
$m > 200$ GeV	$4.9^{+1.9}_{-1.2}$	4.0
$m > 300$ GeV	$2.9^{+1.0}_{-0.6}$	2.7
$m > 400$ GeV	$1.8^{+0.8}_{-0.4}$	2.3

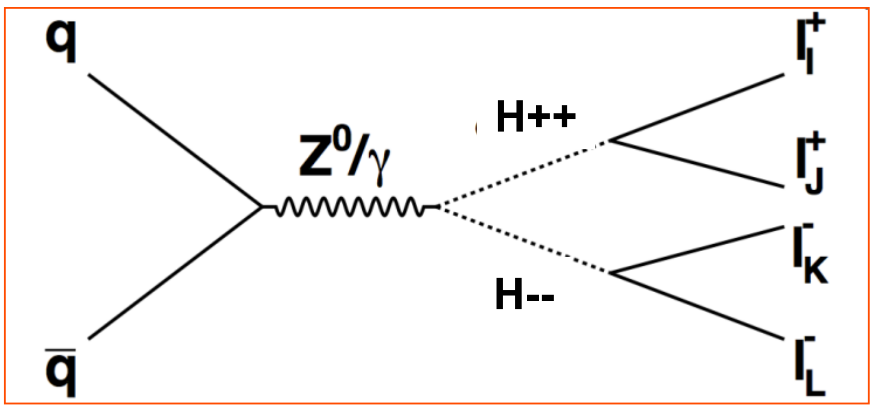
Possible Models

- left-right symmetric models
- Higgs triplet models
- little Higgs model
- fourth-family quarks
- supersymmetry
- universal extra dimensions
- …

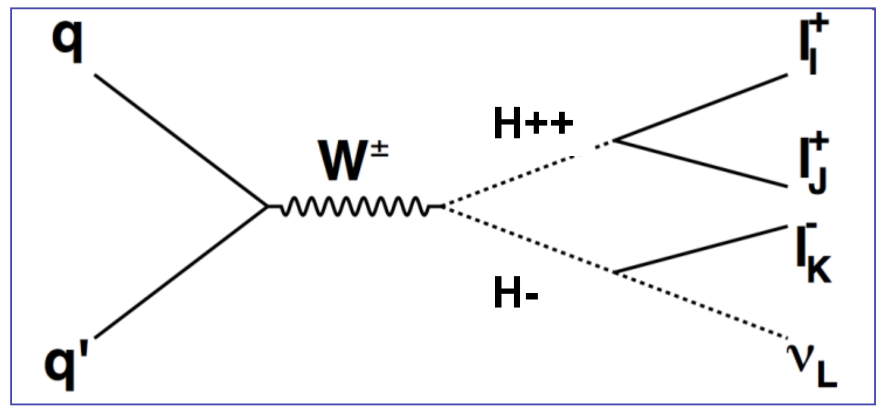
Acceptances: 43% - 65 %

Inclusive Same-Sign Dilepton Search: $H^{++/--}$ Limits

- Models explaining non-zero neutrino masses predict $H^{++/--}$
  - e.g. minimal type II seesaw model
    - additional scalar field
    - triplet (under $SU(2)_L$ with Y=2): $H^{++/--}$, $H^{+/-}$, H^0



pair production



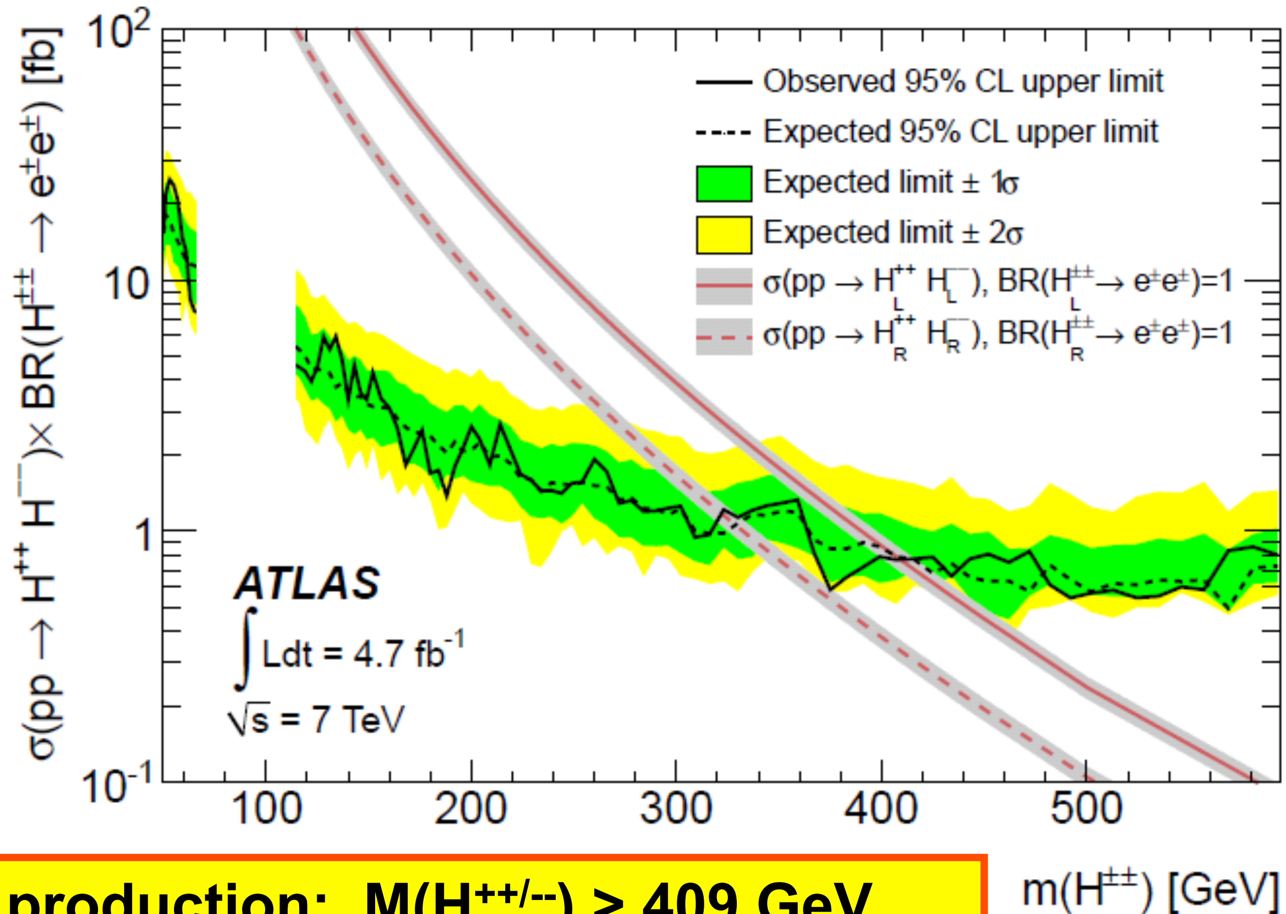
associate production

Signature: same-sign leptons

Doubly Charged Higgs Limits

arXiv:1210.5070

- Used e.g. limits on doubly charged Higgs



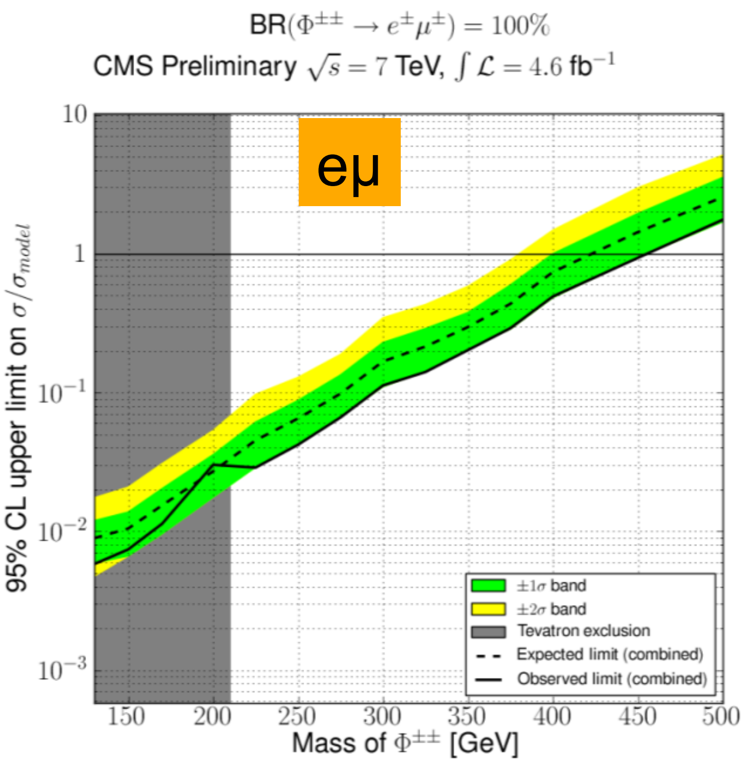
Pair production: $M(H^{++/--}) > 409$ GeV

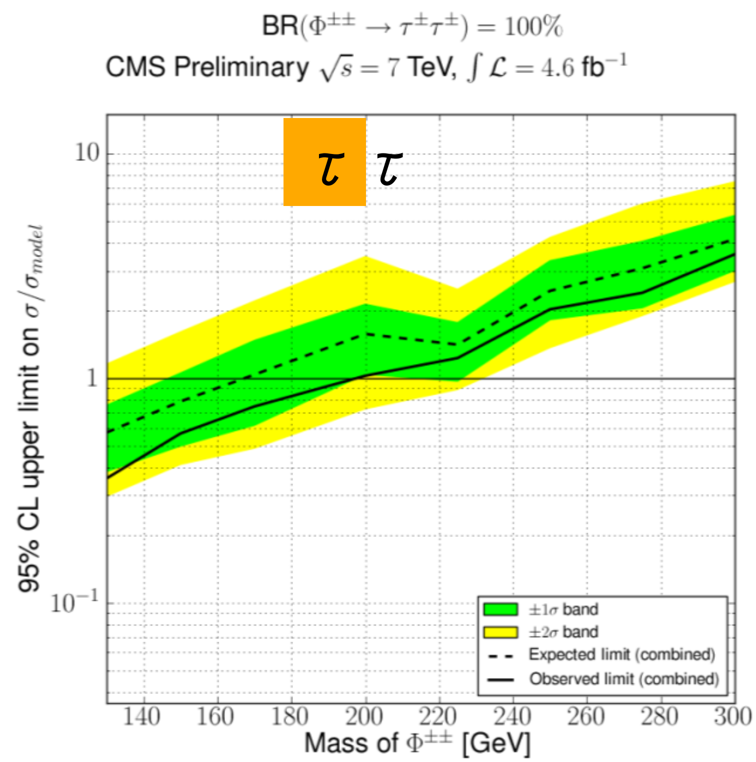
Doubly Charged Higgs Limits

- Example of more optimized search

arXiv:1207.2666

- Includes also τ -channel and associate production.





Combined eμ: M($H^{++/--}$) > 455 GeV

Combined $\tau\ \tau$: M($H^{++/--}$) > 198 GeV

General 3 Charged Lepton (e/μ/ τ) Search

ATLAS-CONF-2013-070

new

20.3 fb^{-1}

- complements previous searches – **model independent**
- 4 inclusive signal regions

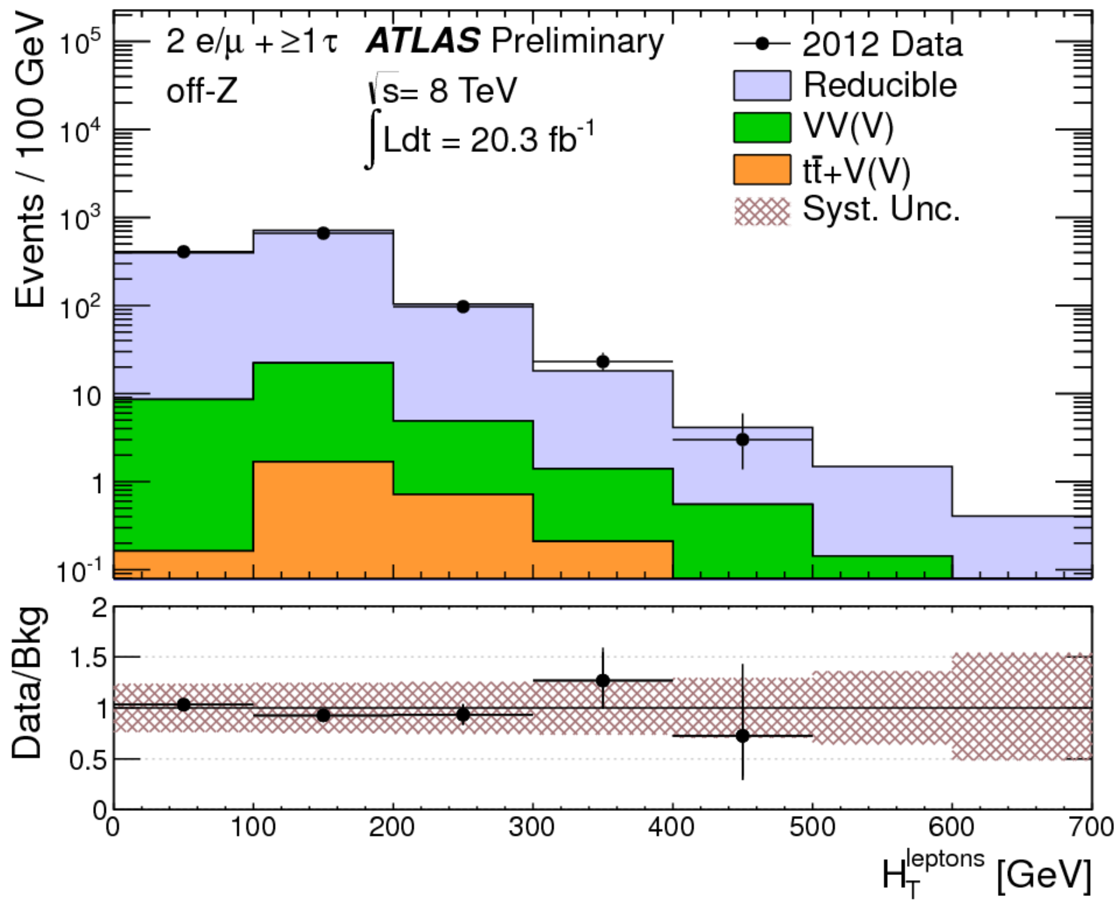
Flavor Chan.	Z Chan.	Expected	Observed
$\geq 3e/\mu$	off-Z	260 ± 10 ± 40	280
$2e/\mu + \geq 1\tau_{\text{had}}$	off-Z	1200 ± 10 ± 290	1193
$\geq 3e/\mu$	on-Z	3100 ± 40 ± 500	3199
$2e/\mu + \geq 1\tau_{\text{had}}$	on-Z	17000 ± 40 ± 4000	14733

- 100 exclusive signal regions
  - $H_T^{leptons}$, H_T^{jets}
  - Min p_T^l
  - $m_{eff}=|H_t^{jets}| +|E_t^{miss}| + |p_T^l|$
  - for on-Z: m_T^W
  - number of b-jets

Selections
2 isolated electrons or muons, p_{T1} > 26 GeV, p_{T2}>15 GeV
3rd lepton: e or μ or τ_{had} p_T(e,μ)>15 GeV, $p_T^{vis}(\tau_{had})$>20 GeV
akt4 jets with p_T > 30 GeV

General 3 Charged Lepton (e/μ/ τ) Search

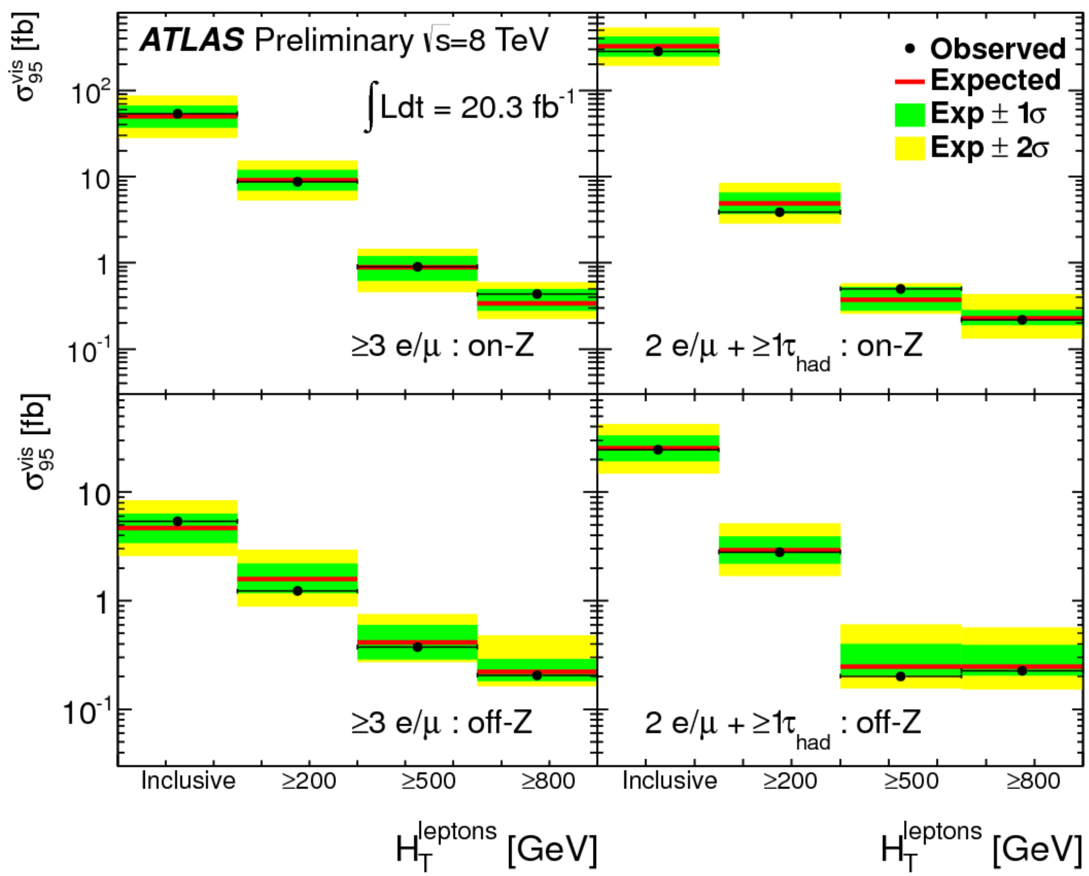
ATLAS-CONF-2013-070



General 3 Charged Lepton (e/μ/ τ) Search

ATLAS-CONF-2013-070

95% Confidence Level Limits (using CL_s)



Model Testing with published fiducial lepton efficiencies

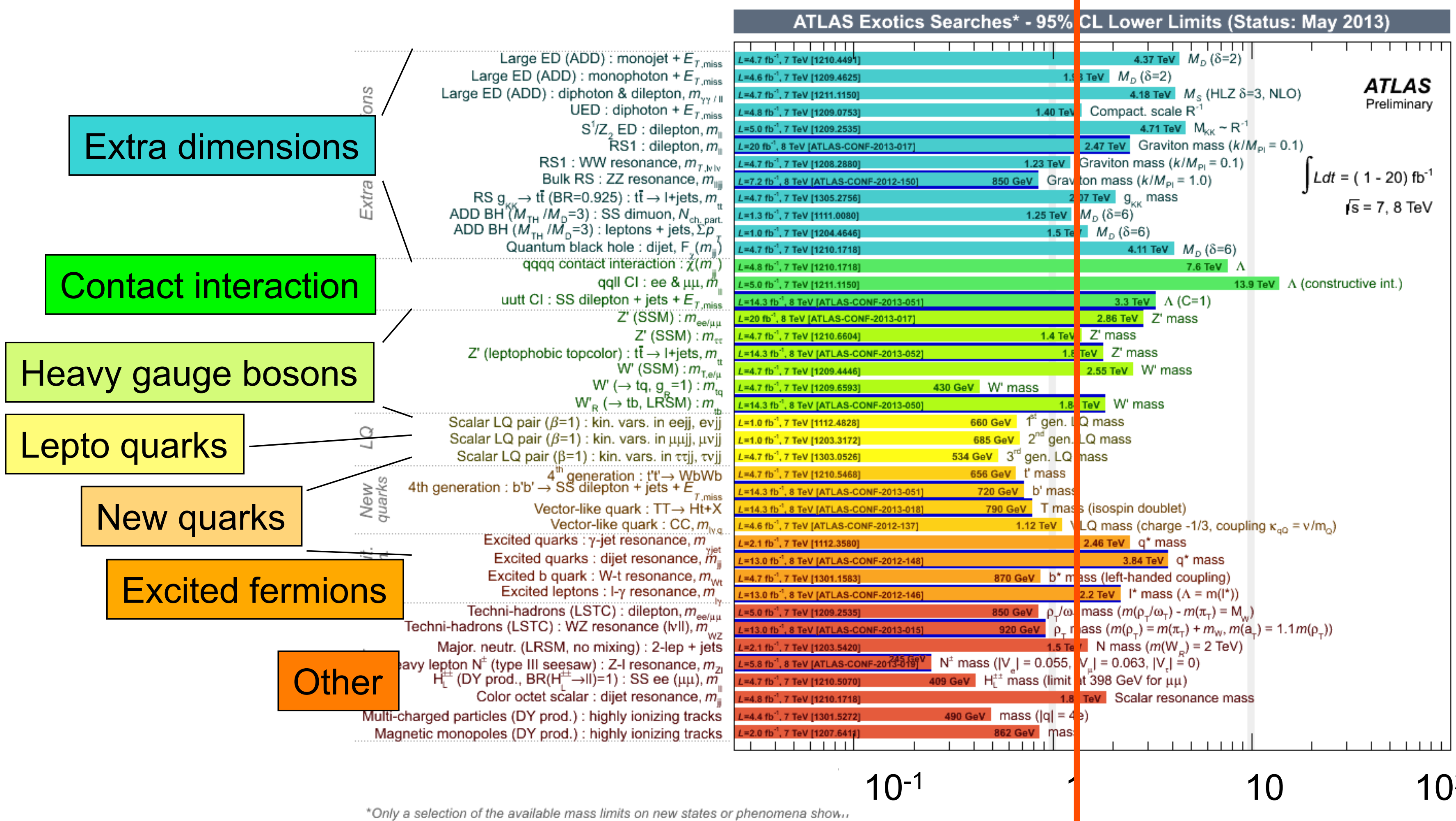
p_T [GeV]	Prompt μ $\lvert\eta\rvert > 0.1$	Prompt μ $\lvert\eta\rvert < 0.1$
10–15	0.021±0.001	0.003±0.002
15–20	0.704±0.003	0.37±0.01
20–25	0.808±0.002	0.42±0.01
25–30	0.855±0.002	0.45±0.01
30–40	0.896±0.001	0.498±0.008

...

Just one example from note

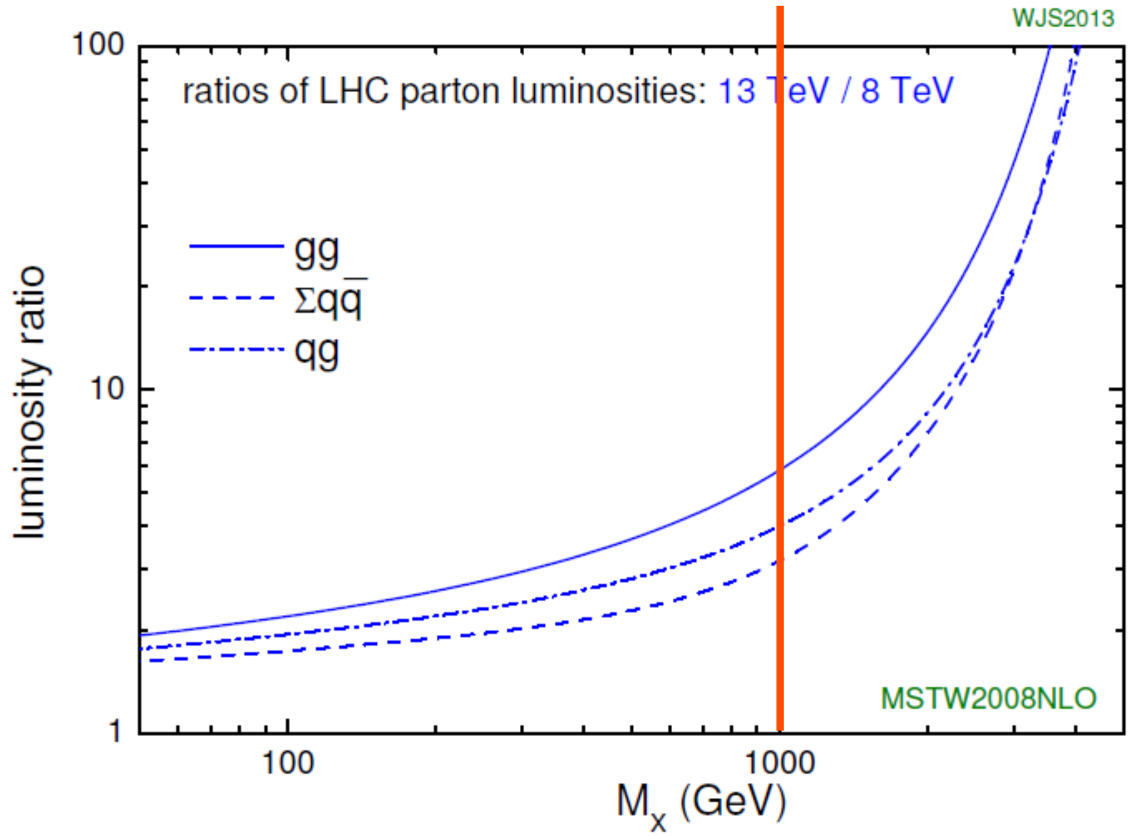
ATLAS Exotics Summary

Limits pushed into 1 TeV regime



https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults

We are at the beginning….



Up to now, small parton luminosity at high masses

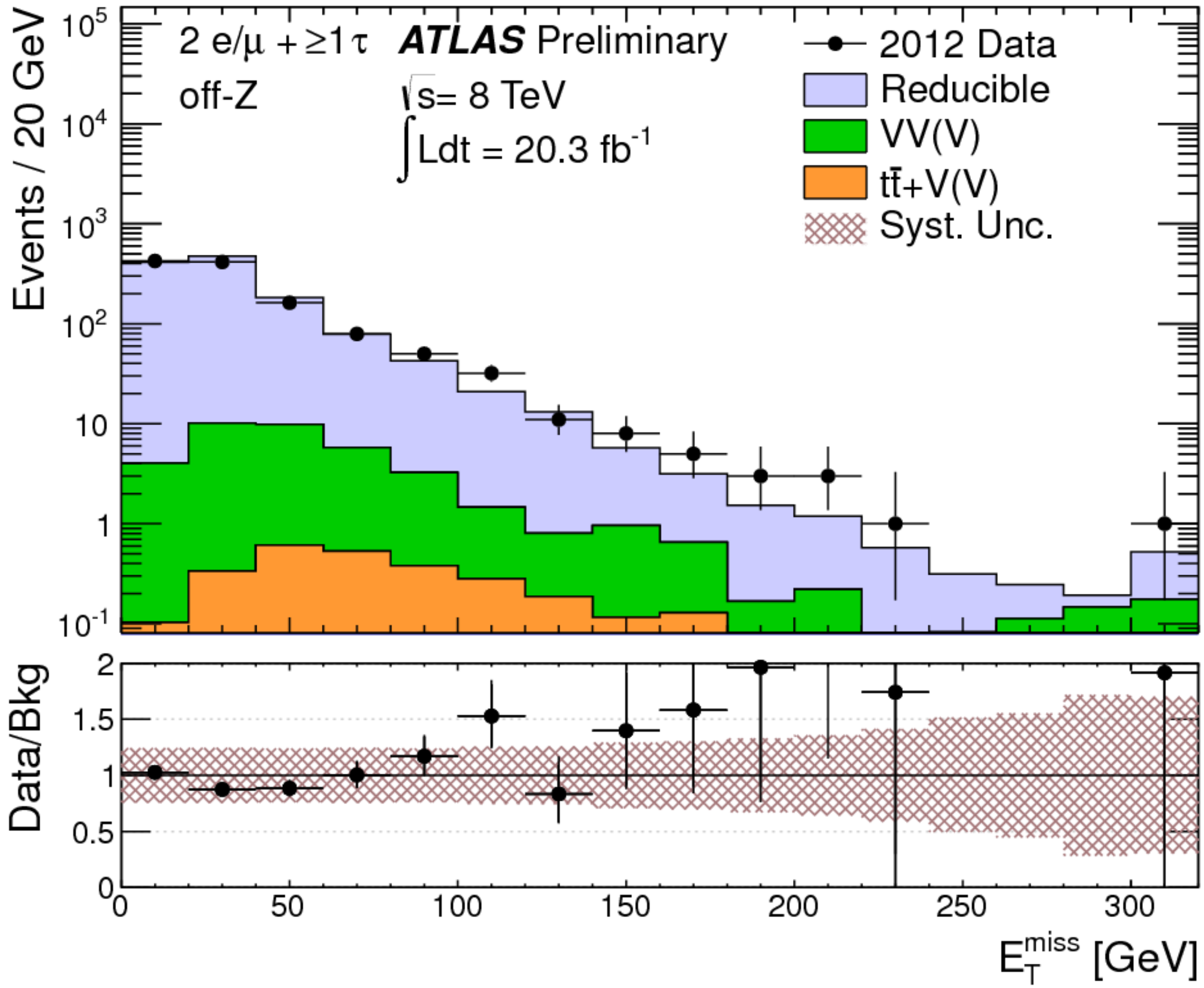
Large discovery potential: 13 TeV

Conclusion

- Role of models in Exotics
  - Models are used map our search reach
  - They give us some guidance where to look
  - But, Exotics searches are mainly model-independent.
- Exotics searches coverage
  - Vast range of final states
  - Vast range of models
  - Searches with H boson in final state added
- Searches will continue
  - Continue exploration **beyond TeV regimes**
  - Push σ-limits at **low invariant masses** down.

Backup Slides

Generic 3 Lepton Search



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No H_T Cut

Generic 3 Lepton Search

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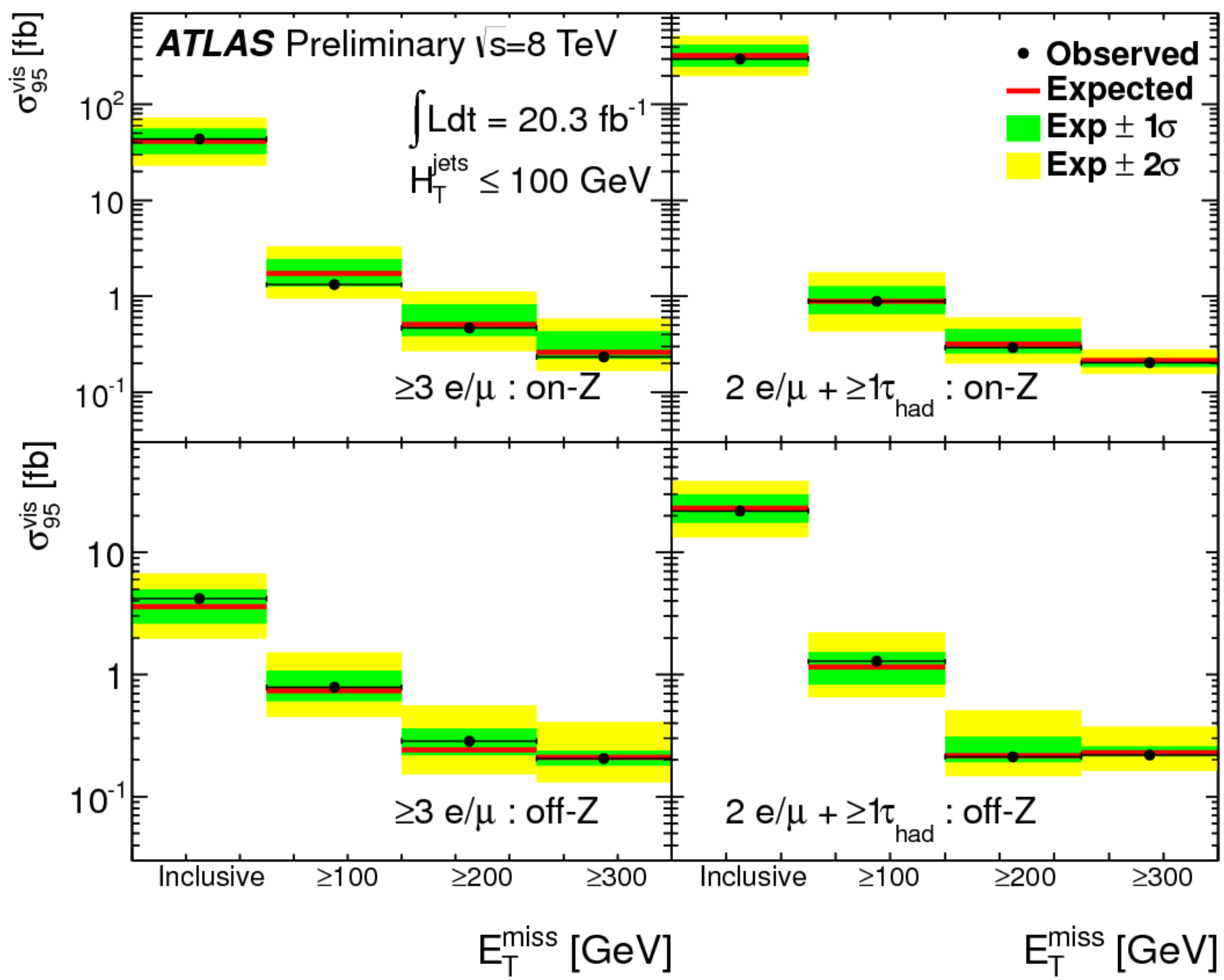

Generic 3 Lepton Search

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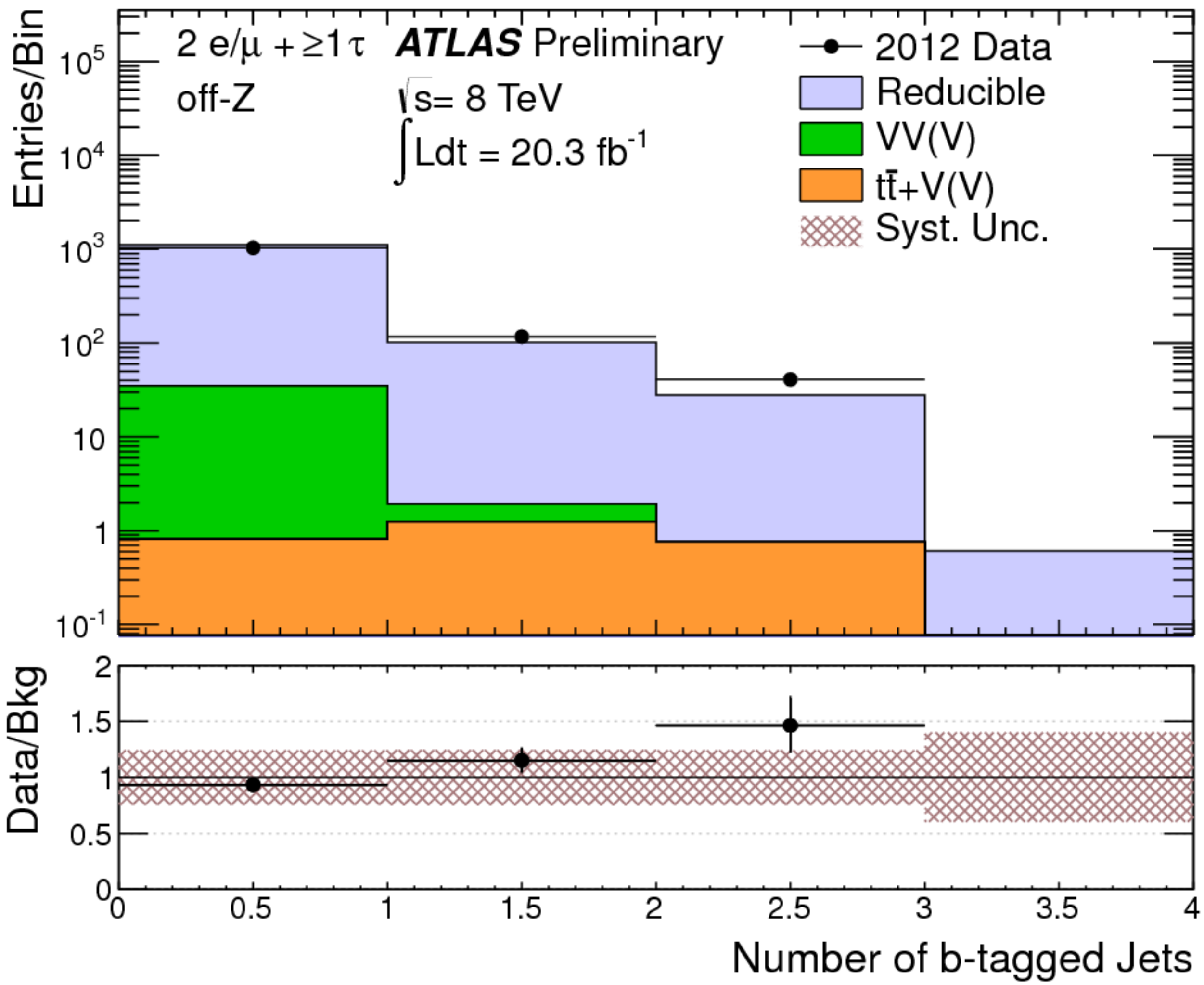

Generic 3 Lepton Search

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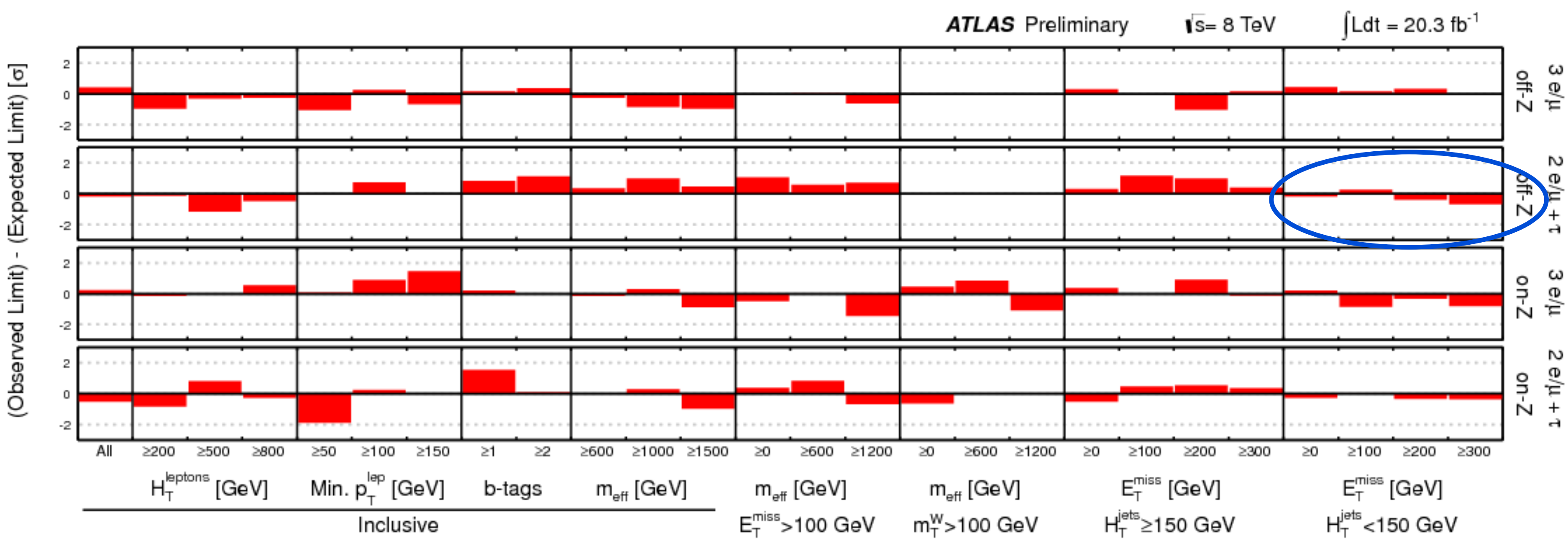


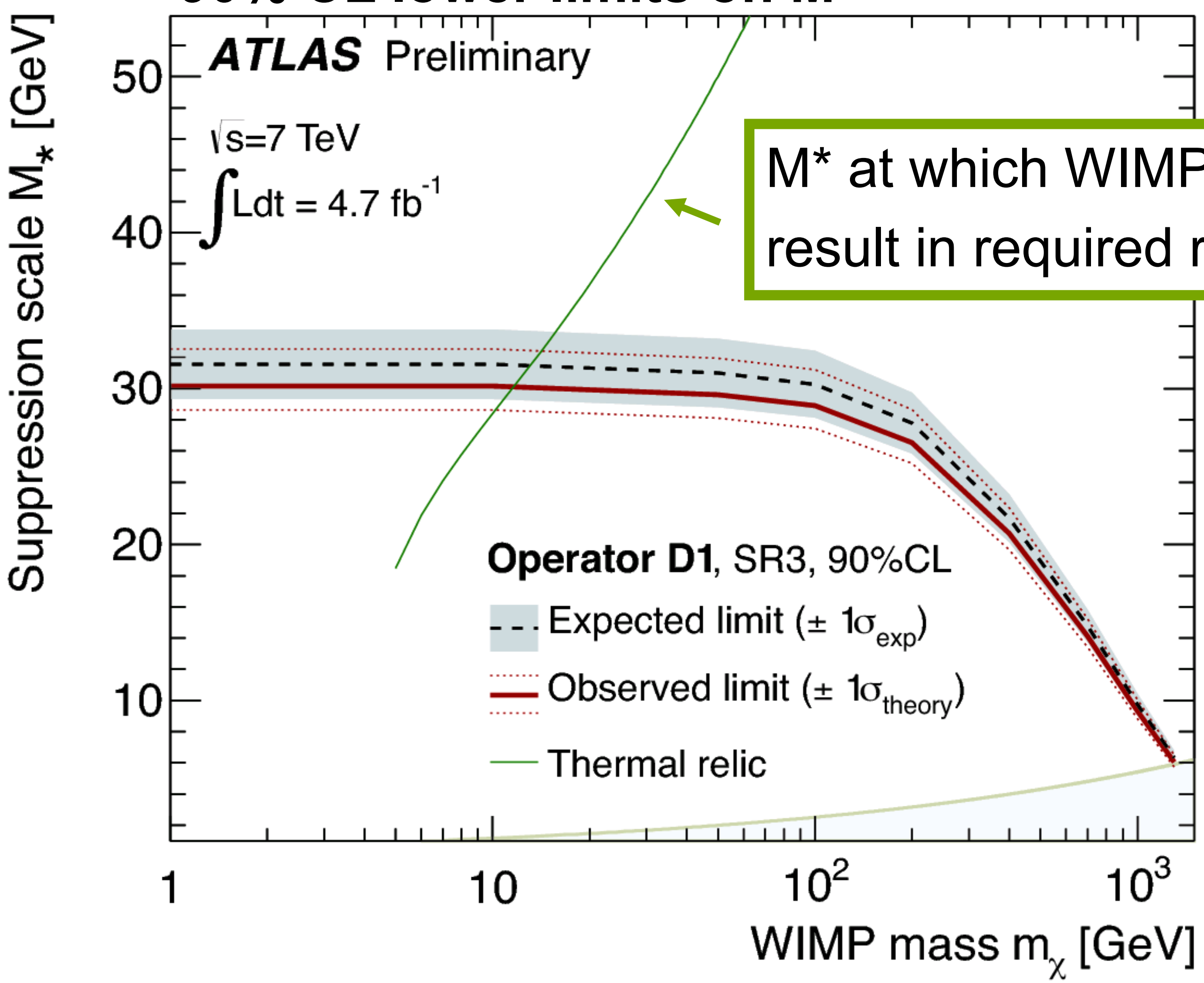
Mono Jet Signal Region Definitions

Signal regions	SR1	SR2	SR3	SR4
Common requirements	Data quality + trigger + vertex + jet quality + $\|\eta^{\text{jet1}}\| < 2.0$ + $\|\Delta\phi(\mathrm{p}_{\mathrm{T}}^{\text{miss}}, \mathrm{p}_{\mathrm{T}}^{\text{jet2}})\| > 0.5$ + $N_{\text{jets}} \leq 2$ + lepton veto			
$E_{\mathrm{T}}^{\text{miss}}$, $p_{\mathrm{T}}^{\text{jet1}}$ >	120 GeV	220 GeV	350 GeV	500 GeV

"Although the results of this analysis are interpreted in terms of the ADD model and WIMP pair production, the event selection criteria have not been tuned to maximize the sensitivity to any particular BSM scenario. To maintain sensitivity to a wide range of BSM models, four sets of overlapping kinematic selection criteria, designated as SR1 to SR4, are defined (table 2)."

Limits on Dark Matter – Mono Jet

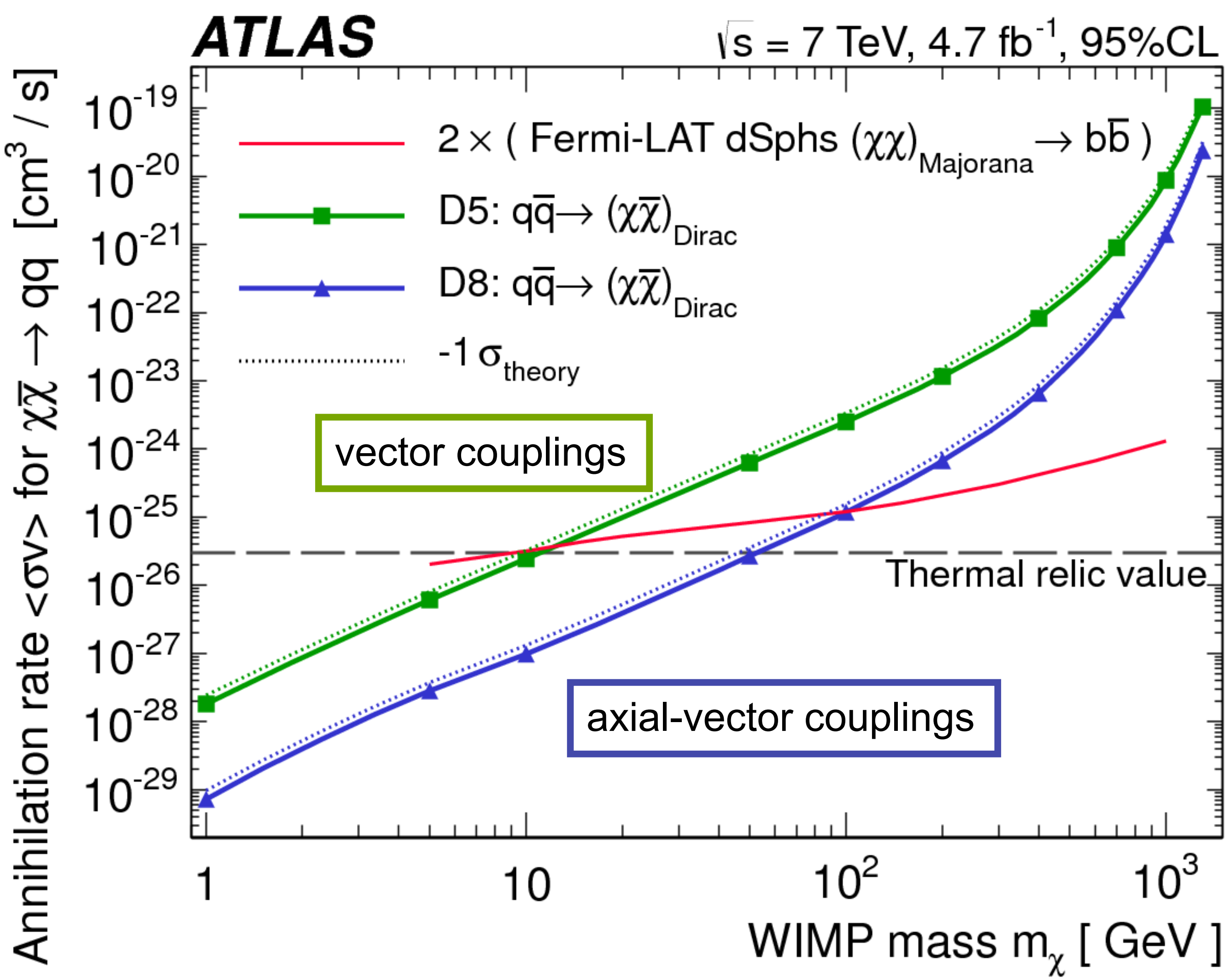
90% CL lower limits on M*



M* at which WIMPs of a given mass result in required relic abundance

convert

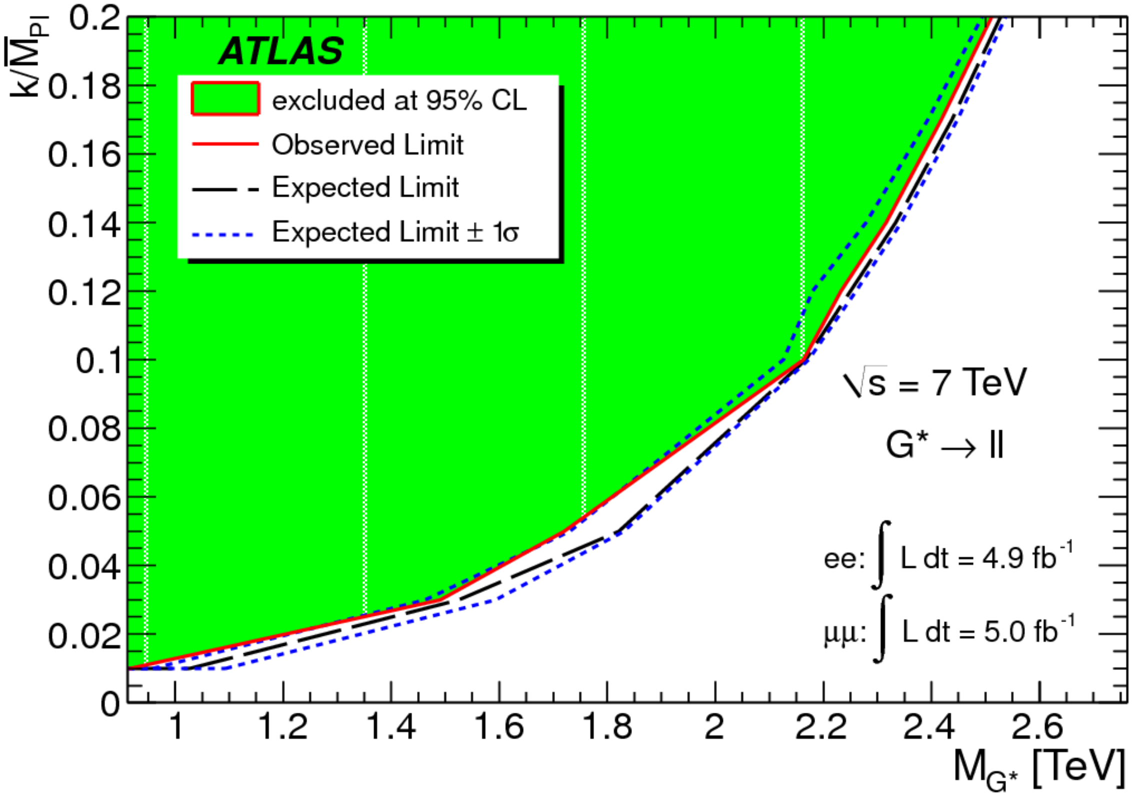
Limits on the annihilation rate of WIMPs



Search for Heavy Resonance: dilepton channel

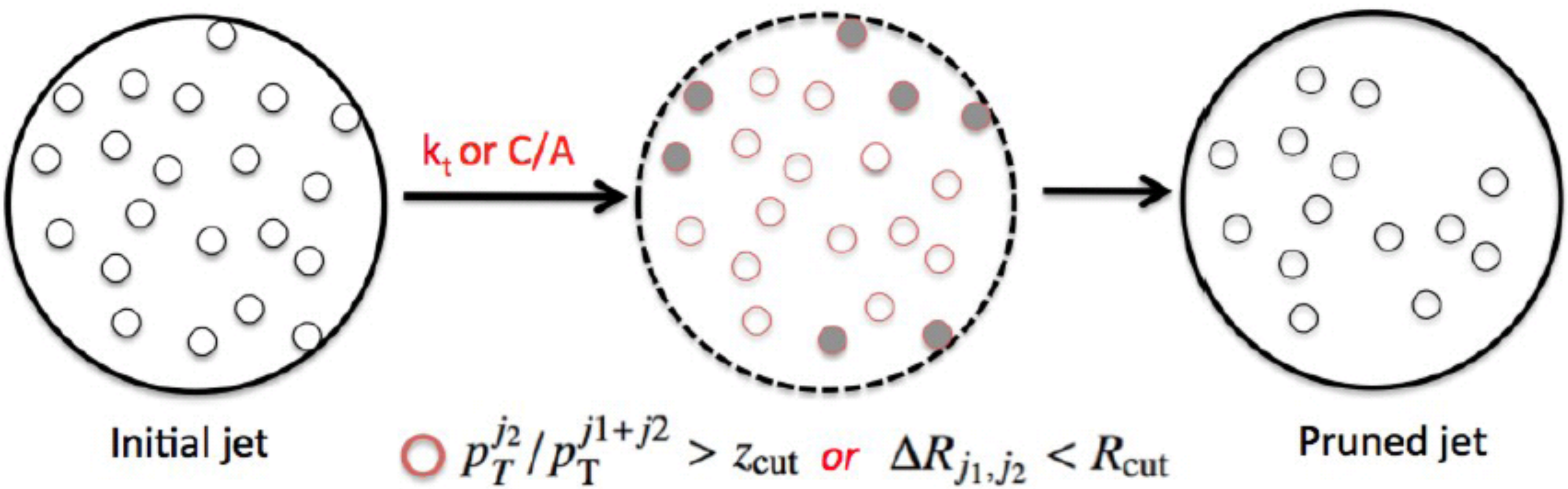
- Limits as a function of RS graviton mass and coupling

  m(RS graviton, k/MPl = 0.1) > 2.16 TeV at 95% CL

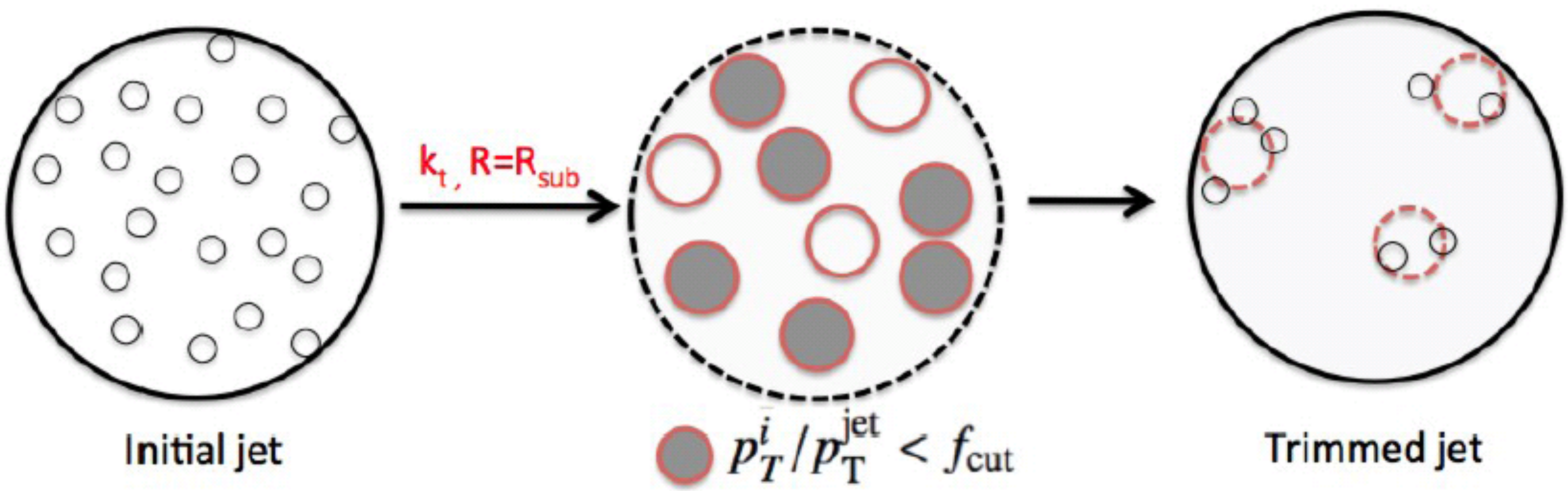


Jet Grooming

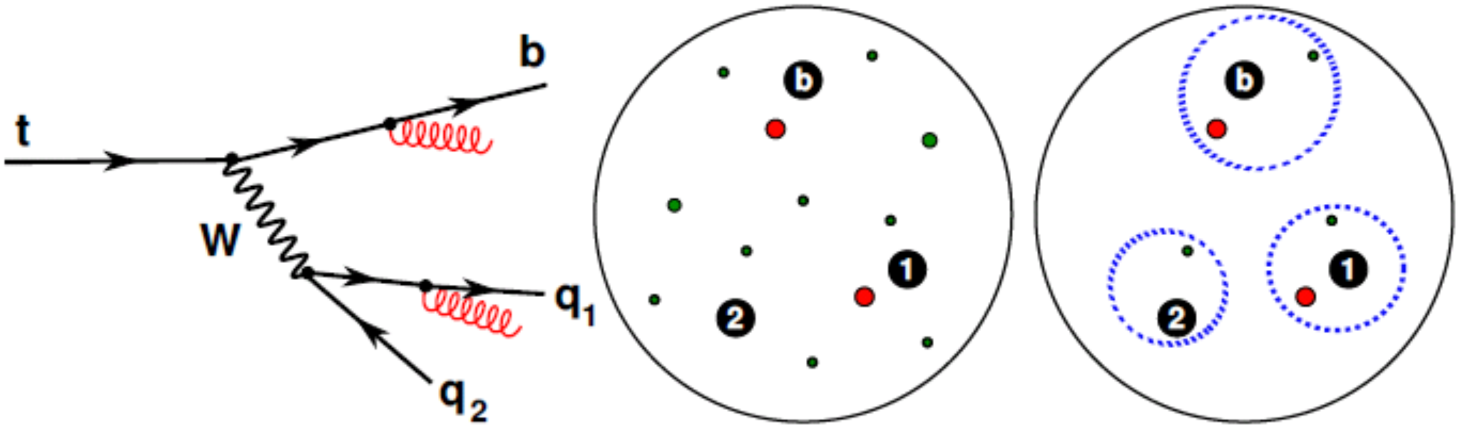
- "Pruning":
- Start with a fat jet (R ~ 1 or more)
- Run k_t or C/A algorithm on clusters within the fat jet
- At each step, if merging of two clusters fails, remove cluster with smallest pT



- "Trimming":
- Start with a fat jet (R ~ 1 or more)
- Run k_t algorithm on clusters within the fat jet
- Keep only jets with pT > pT(fat jet) . f_{cut}



HEPTopTagger (Filtering)



1. Decompose until $m_{j_i} < 30\,\mathrm{GeV}$ with mass drop requirement $m_{j_i} < \mu\, m_{\text{large jet}}$
2. Investigate 3 subjets and their constituents
3. Re-cluster using C/A with parameter $R = \min(0.3, \min_{ij} \Delta R(j_i, j_j)/2)$
4. Use only 5 hardest subjets of last step
5. Built exactly 3 subjets from the selected constituents

S. Fleischmann

Standard Model Lagrangian

$$\mathcal{L}_{SM} = -\frac{1}{4g'^2}B_{\mu\nu}B^{\mu\nu} - \frac{1}{2g^2}\mathrm{Tr}(W_{\mu\nu}W^{\mu\nu}) - \frac{1}{2g_s^2}\mathrm{Tr}(G_{\mu\nu}G^{\mu\nu})$$
$$+\bar{Q}_i i\not{D} Q_i + \bar{L}_i i\not{D} L_i + \bar{u}_i i\not{D} u_i + \bar{d}_i i\not{D} d_i + \bar{e}_i i\not{D} e_i$$

Above: Describes gauge fields and interactions

$\not{D}$ determined by **gauge quantum numbers**

strange

Gravity is not included!!

	$SU(3)$	$SU(2)$	$U(1)$	chirality
Q	3	2	$+1/6$	left
U	3	1	$+2/3$	right
D	3	1	$-1/3$	right
L	1	2	$-1/2$	left
E	1	1	-1	right

Standard Model Lagrangian

$$\mathcal{L}_{SM} = -\frac{1}{4g'^2}B_{\mu\nu}B^{\mu\nu} - \frac{1}{2g^2}\mathrm{Tr}(W_{\mu\nu}W^{\mu\nu}) - \frac{1}{2g_s^2}\mathrm{Tr}(G_{\mu\nu}G^{\mu\nu})$$
$$+\bar{Q}_i i \not{D} Q_i + \bar{L}_i i \not{D} L_i + \bar{u}_i i \not{D} u_i + \bar{d}_i i \not{D} d_i + \bar{e}_i i \not{D} e_i$$
$$+(Y_u^{ij}\bar{Q}_i u_j \tilde{H} + Y_d^{ij}\bar{Q}_i d_j H + Y_l^{ij}\bar{L}_i e_j H + \text{h.c.})$$

- Responsible for mass and mixing of quark masses
- Responsible for charged lepton masses
- Generation index: i, j = 1,2,3
- Why 3 families?
- No neutrino masses or mixing included

Standard Model Lagrangian

$$\mathcal{L}_{SM} = -\frac{1}{4g'^2}B_{\mu\nu}B^{\mu\nu} - \frac{1}{2g^2}\mathrm{Tr}(W_{\mu\nu}W^{\mu\nu}) - \frac{1}{2g_s^2}\mathrm{Tr}(G_{\mu\nu}G^{\mu\nu})$$
$$+\bar{Q}_i i\not{D} Q_i + \bar{L}_i i\not{D} L_i + \bar{u}_i i\not{D} u_i + \bar{d}_i i\not{D} d_i + \bar{e}_i i\not{D} e_i$$
$$+(Y_u^{ij}\bar{Q}_i u_j \tilde{H} + Y_d^{ij}\bar{Q}_i d_j H + Y_l^{ij}\bar{L}_i e_j H + \mathrm{h.c.})$$
$$+(D_\mu H)^\dagger (D^\mu H) - \lambda(H^\dagger H)^2 - m^2 H^\dagger H + \frac{\theta}{32\pi^2}\epsilon^{\mu\nu\rho\sigma}\mathrm{Tr}(G_{\mu\nu}G_{\rho\sigma}).$$

Strong CP Problem in SM

- Why is θ < 1.2 x 10^{-10} ???
- Natural value ~ 1

θ term in QCD

Periodic: 0 - 2π

Violates T and CP

Ditau Discriminant

Transverse mass of visible decay products of tau's and E_T^{miss}

$$m_{\mathrm{T}}^{\mathrm{tot}} = \sqrt{2 p_{\mathrm{T}1} p_{\mathrm{T}2} C + 2|E_{\mathrm{T}}^{\mathrm{miss}}| p_{\mathrm{T}1} C_1 + 2|E_{\mathrm{T}}^{\mathrm{miss}}| p_{\mathrm{T}2} C_2}$$

$$C = 1 - cos\Delta\varphi(\tau 1, \tau 2)$$
$$C_1 = 1 - cos\Delta\varphi\left(\tau_1, E_T{}^{miss}\right)$$
$$C_2 = 1 - cos\Delta\varphi\left(\tau_2, E_T{}^{miss}\right)$$

Backup Slide

Ditau Search

	$Z/\gamma^* \to \tau\tau$	Multijet	W/Z+jets	Top	Diboson	SM total	Data	$Z'_{\mathrm{SSM}}(1750)$
Preselection	270 ± 50	630 ± 100	80 ± 50	27 ± 15	1.1 ± 0.6	1000 ± 140	1016	9.4 ± 1.5
$\Delta\phi(\tau_1, \tau_2)$	120 ± 20	420 ± 70	48 ± 30	13 ± 6	0.1 ± 0.1	600 ± 80	577	9.2 ± 1.5
OS	113 ± 18	210 ± 40	34 ± 22	10 ± 4	0.1 ± 0.1	370 ± 50	372	8.7 ± 1.4
$m_{\mathrm{T}}^{\mathrm{tot}} > 300$ GeV	102 ± 17	96 ± 17	28 ± 19	7 ± 3	0.1 ± 0.1	230 ± 40	235	8.7 ± 1.4
$m_{\mathrm{T}}^{\mathrm{tot}} > 350$ GeV	63 ± 11	40 ± 9	18 ± 12	5.0 ± 1.9	0.1 ± 0.0	126 ± 21	123	8.6 ± 1.4
$m_{\mathrm{T}}^{\mathrm{tot}} > 400$ GeV	37 ± 7	18 ± 4	10 ± 7	2.0 ± 1.1	< 0.1	66 ± 12	59	8.4 ± 1.4
$m_{\mathrm{T}}^{\mathrm{tot}} > 450$ GeV	22 ± 4	9 ± 3	6 ± 4	1.2 ± 0.6		38 ± 7	31	8.3 ± 1.4
$m_{\mathrm{T}}^{\mathrm{tot}} > 500$ GeV	14 ± 3	4.4 ± 1.6	4 ± 3	0.6 ± 0.3		23 ± 5	20	8.0 ± 1.3
$m_{\mathrm{T}}^{\mathrm{tot}} > 550$ GeV	8.9 ± 1.8	2.7 ± 1.1	1.8 ± 1.3	0.4 ± 0.3		14 ± 3	12	7.7 ± 1.3
$m_{\mathrm{T}}^{\mathrm{tot}} > 600$ GeV	5.9 ± 1.2	1.8 ± 0.8	1.1 ± 0.8	0.1 ± 0.1		9.0 ± 1.8	5	7.4 ± 1.3
$m_{\mathrm{T}}^{\mathrm{tot}} > 650$ GeV	4.1 ± 0.8	1.0 ± 0.5	0.7 ± 0.5	0.1 ± 0.1		5.9 ± 1.2	3	7.1 ± 1.2
$m_{\mathrm{T}}^{\mathrm{tot}} > 700$ GeV	2.8 ± 0.6	0.6 ± 0.3	0.5 ± 0.3	< 0.1		3.9 ± 0.8	0	6.7 ± 1.1
$m_{\mathrm{T}}^{\mathrm{tot}} > 750$ GeV	1.9 ± 0.4	0.5 ± 0.3	0.3 ± 0.2			2.8 ± 0.6	0	6.3 ± 1.1
$m_{\mathrm{T}}^{\mathrm{tot}} > 800$ GeV	1.4 ± 0.3	0.3 ± 0.2	0.2 ± 0.2			2.0 ± 0.4	0	6.0 ± 1.0
$m_{\mathrm{T}}^{\mathrm{tot}} > 850$ GeV	1.0 ± 0.2	0.2 ± 0.1	0.2 ± 0.1			1.4 ± 0.3	0	5.6 ± 1.0
$m_{\mathrm{T}}^{\mathrm{tot}} > 900$ GeV	0.7 ± 0.2	0.1 ± 0.1	0.1 ± 0.1			1.0 ± 0.2	0	5.2 ± 0.9

Dilepton Resonance Search: Trigger Strategy

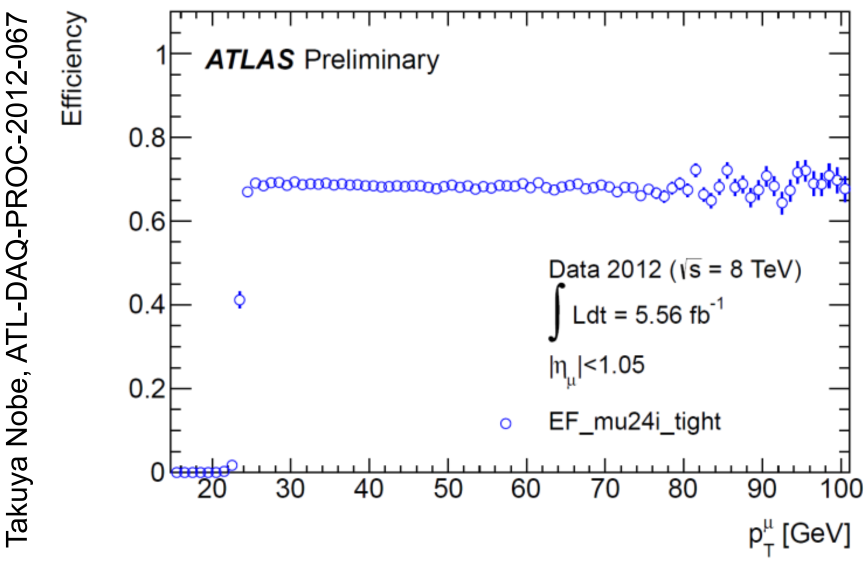
ATLAS

ee channel

- Diphoton trigger
- $E_T > 35$ GeV and $E_T > 25$ GeV

μμ channel

- Single muon triggers
- $E_T > 24$ GeV or $E_T > 36$ GeV



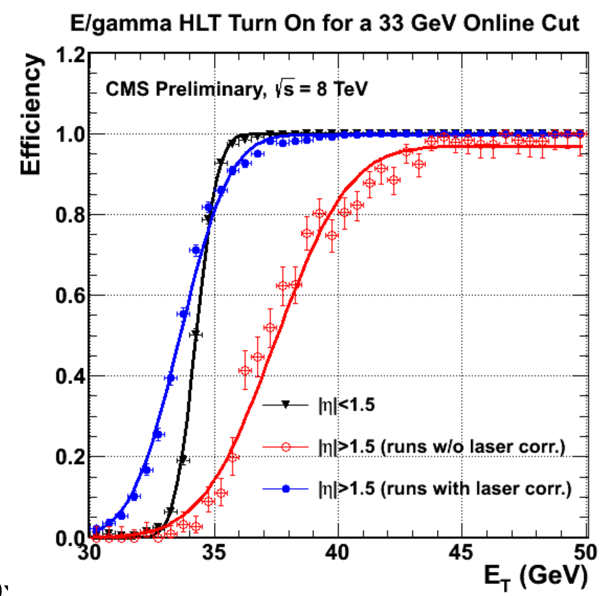
CMS

ee channel

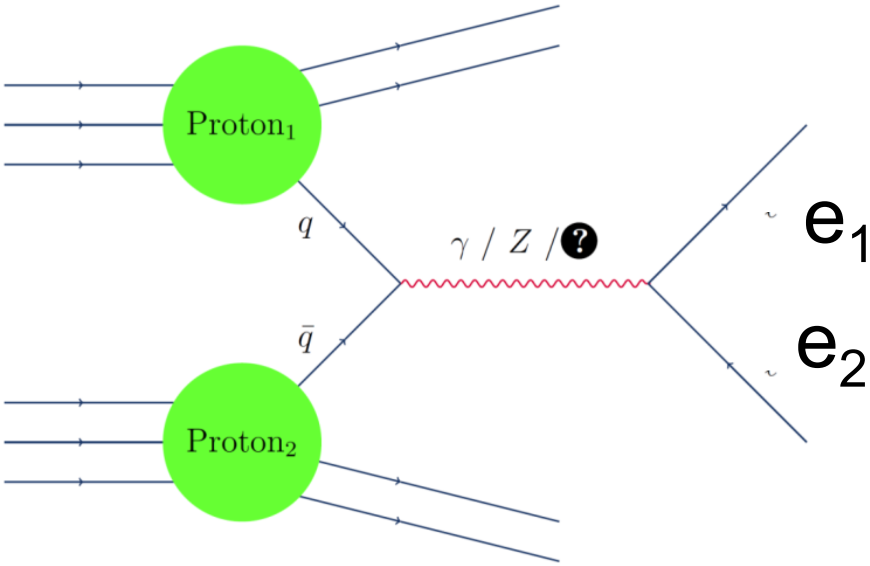
- Dielectron trigger
- Both clusters w $E_T > 33$ GeV

μμ channel

- single muon trigger
- $E_T > 40$ GeV



Selection for Di-Electron Channel

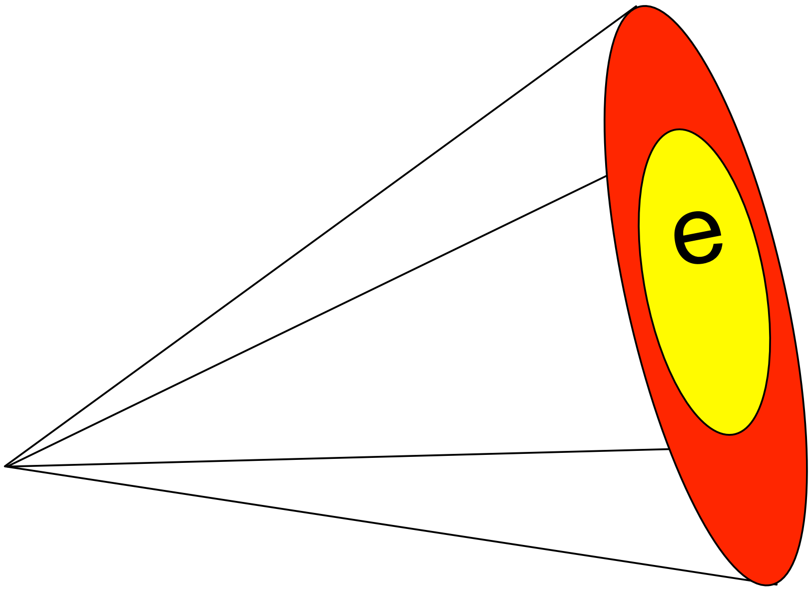


ATLAS	CMS
E_T^1>40GeV	E_T^1>35GeV
E_T^2>30GeV	E_T^2>35GeV

Problem: jets fake electrons

Use isolation to reduce fakes

Electron Isolation $I_{conesize}$



Energy/momentum around lepton

	ATLAS	CMS	
leading	$I^{calo}_{0.2} < 0.7\% \cdot E_T + 5$ GeV	$I^{tracker}_{0.3} < 5$ GeV	$I^{Calo}_{0.3} < 3\% \cdot E_T$
subleading	$I^{calo}_{0.2} < 2.2\% \cdot E_T + 6$ GeV		

Acceptance x Efficiency after all Selections

ATLAS

$A \times \varepsilon(m = 2\ \text{TeV}) = \mathbf{73\%}$

CMS

$A \times \varepsilon(m = 2.5\ \text{TeV}) = \mathbf{67\%}$

Similar

Dilepton Resonance Search:: μμ selections

ATLAS

- Single muon triggers
- $p_T > 25$ GeV
- $|\eta|<2.4$
- Suppress cosmic rays
  - $|d_0| < 0.2$ mm
  - $|z_0-z(\text{vertex})|<1$ mm
- Suppress jets faking μ's
  - $\sum p_T(\Delta R<0.3) < 5\%\cdot p_T$
- Require opposite charge

CMS

- Single muon trigger
- $p_T > 45$ GeV
- $|\eta|<2.4$
- Suppress cosmic rays

  $|d_0| < 0.2$ mm

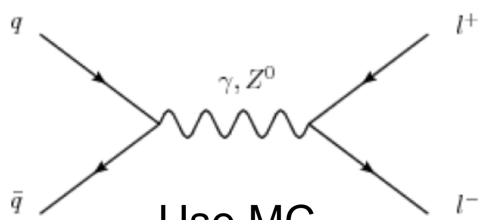
  $|z_0-z(\text{vertex})|<24$ cm
- Suppress jets faking μ's
  - $\sum p_T(\Delta R<0.3) < 10\%\cdot p_T$
  - $|z_0-z(\text{vertex})|< 0.2$mm
- Require opposite charge

Very different

$A\times\varepsilon(m = 2\text{ TeV}) = 46\%$ $A\times\varepsilon(m = 2.5\text{ TeV}) = 80\%$

Dilepton Resonance Search: Backgrounds ee

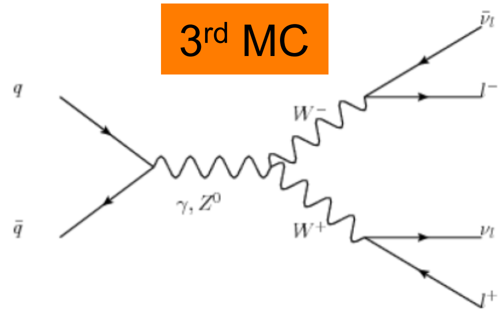
dominant & irreducible



Use MC

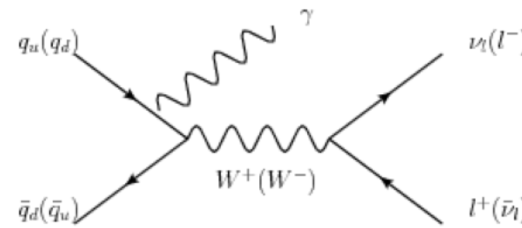
(a) Drell-Yan

3rd MC



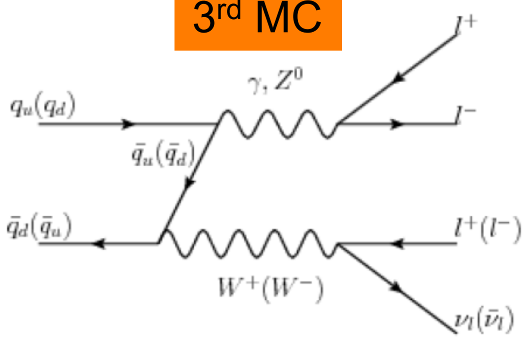
(b) WW

3rd MC



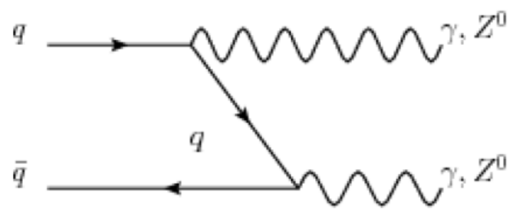
(c) Wγ

3rd MC



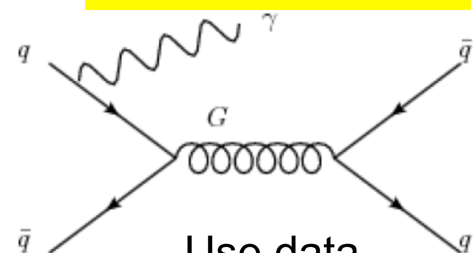
(d) WZ, Wγ

3rd MC



(e) ZZ,Zγ,$\gamma\gamma$

2nd for ee channel

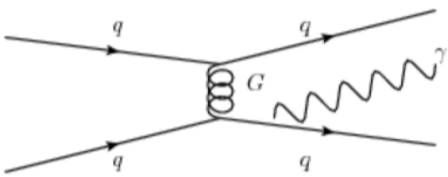


Use data

(f) Dijets (without the exter-
nal photon line),γ+jets

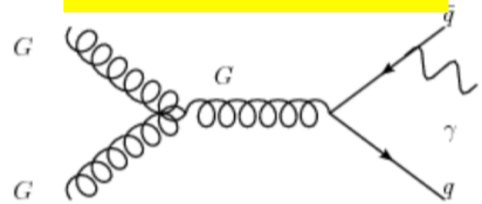
Dilepton Resonance Search: Backgrounds ee

2nd for ee channel data



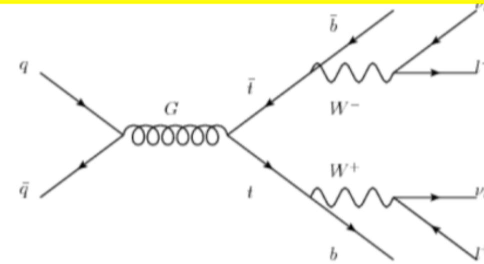
(g) Dijets (without the external photon line), γ+jets

2nd for ee channel data



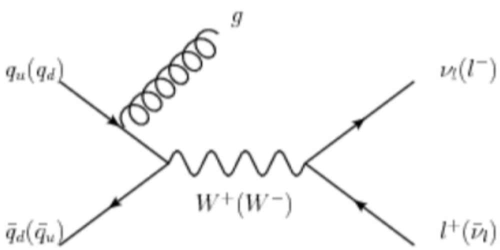
(h) Dijets (without the external photon line), γ+jets

2nd for ee channel semi-leptonic

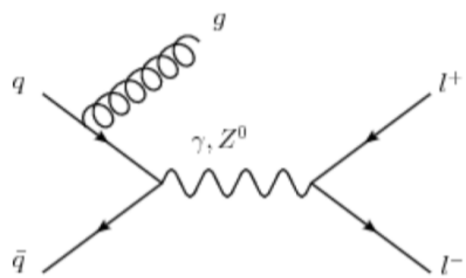


(i) $t\bar{t}$

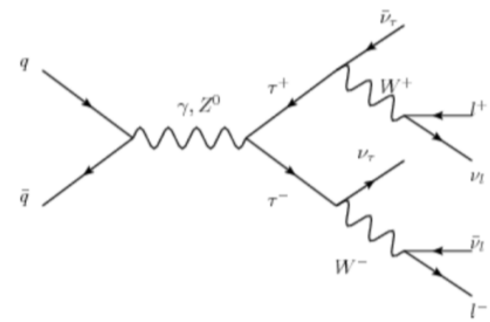
2nd for ee channel data



(j) W+jets



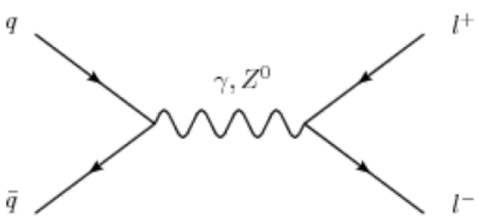
(k) Z+jets



(l) DY to tauons to leptons

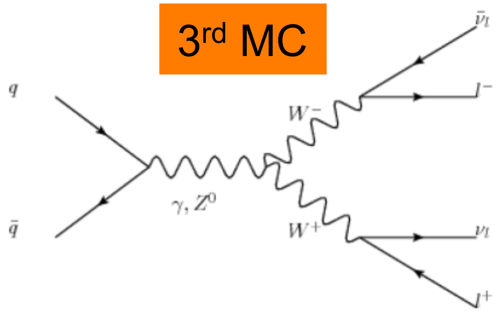
Dilepton Resonance Search: Backgrounds μμ

dominant & irreducible mc



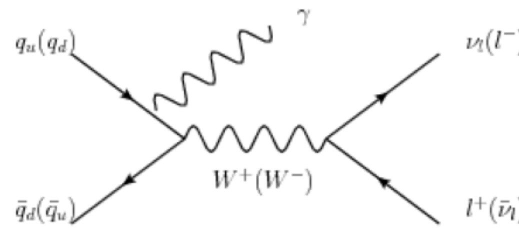
(a) Drell-Yan

3rd MC



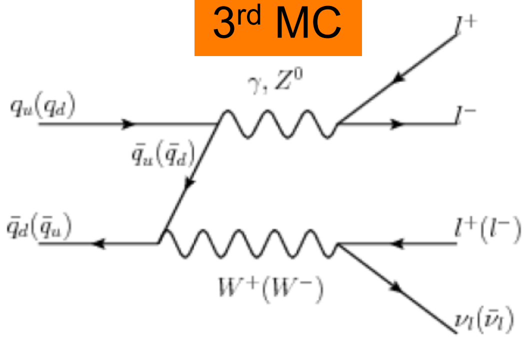
(b) WW

3rd MC



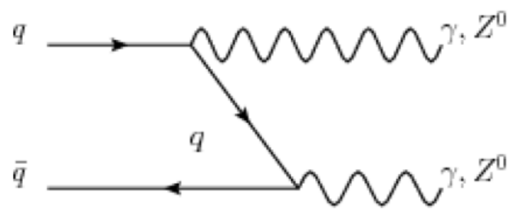
(c) Wγ

3rd MC

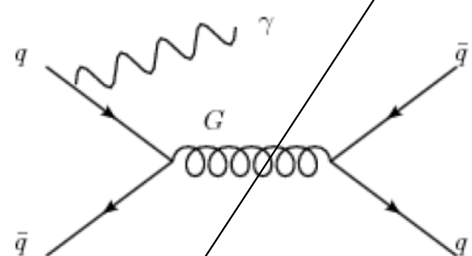


(d) WZ, Wγ

3rd MC



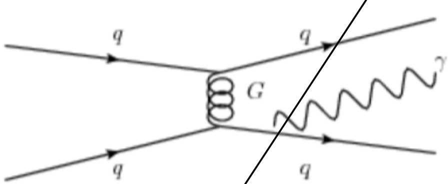
(e) ZZ,Zγ,$\gamma\gamma$



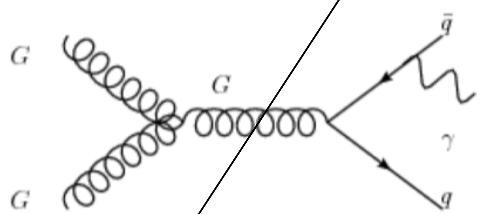
(f) Dijets (without the external photon line),γ+jets

Dilepton Resonance Search: Backgrounds μμ

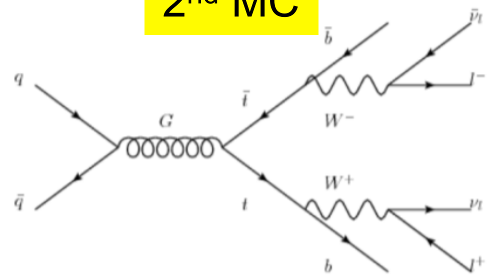
2nd MC



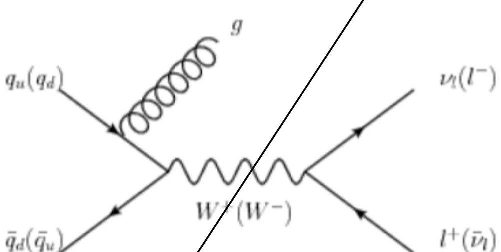
(g) Dijets (without the external photon line), γ+jets



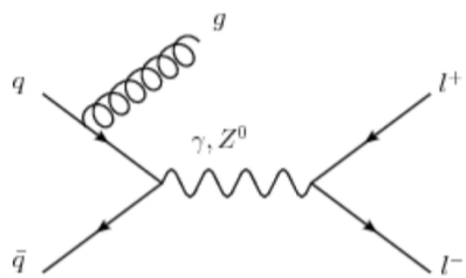
(h) Dijets (without the external photon line), γ+jets



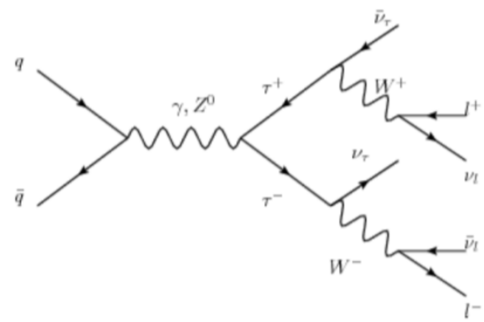
(i) $t\bar{t}$



(j) W+jets



(k) Z+jets



(l) DY to tauons to leptons

Heavy Resonances Search: 8 TeV Dileptons
Backgrounds

- SM Drell-Yan: $\gamma^*/Z \to l^+l^-$
  - shape taken from Monte Carlo
  - normalisation taken from Z peak in data
- t-tbar:
  - where tt goes to e+e-, mu+mu-
  - est. from MC, cross-checked in data
  - also includes Z->ττ, WW, WZ

ee and μμ

- Jet Background:
  - di-jet, W+jet events where the jets are misidentified as electrons/muons

ee

- Cosmic Ray Background:
  - muons from cosmic rays
  - estimated <0.1 event after vertex and angular difference requirements

μμ

Heavy Resonances Search: 8 TeV Dileptons

ATLAS-CONF-2013-017

m_{ee} [GeV]	110 - 200	200 - 400	400 - 800	800 - 1200	1200 - 3000	3000 - 4500
Z/γ^*	119000 ± 8000	13700 ± 900	1290 ± 80	68 ± 4	9.8 ± 1.1	0.008 ± 0.005
$t\bar{t}$	7000 ± 800	2400 ± 400	160 ± 60	2.5 ± 0.6	0.11 ± 0.04	< 0.001
Diboson	1830 ± 210	660 ± 160	93 ± 33	4.8 ± 0.8	0.79 ± 0.26	0.005 ± 0.004
Dijet, W + jet	3900 ± 800	1260 ± 310	230 ± 110	8.6 ± 2.4	0.9 ± 0.6	0.004 ± 0.006
Total	131000 ± 8000	18000 ± 1100	1780 ± 150	84 ± 5	11.6 ± 1.3	0.017 ± 0.009
Data	133131	18570	1827	98	10	0

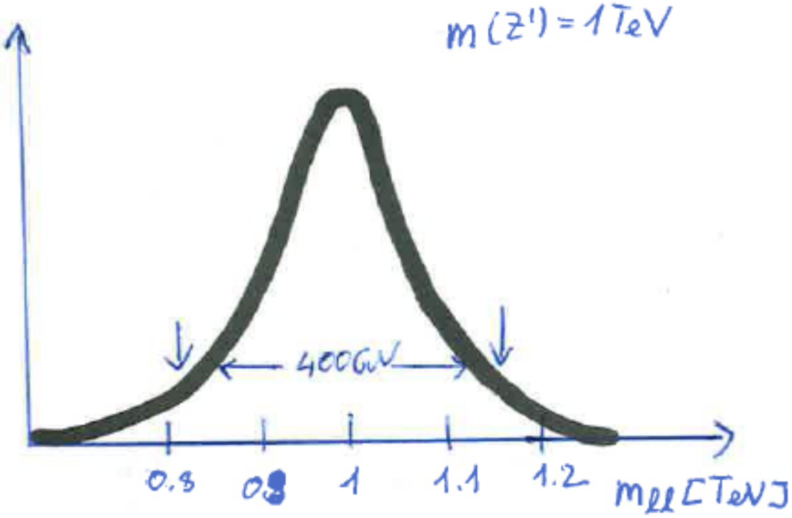
Analysis: P(ee) = 18%

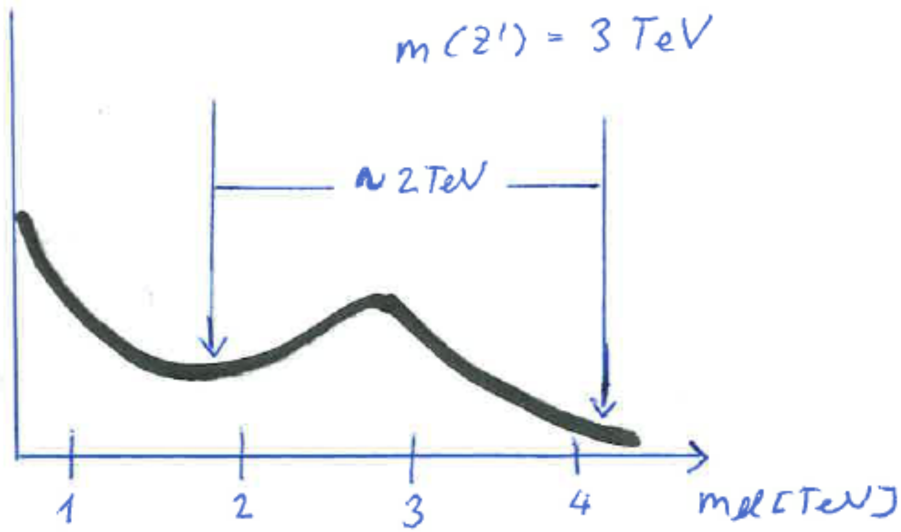
Analysis: P(μμ) = 98%

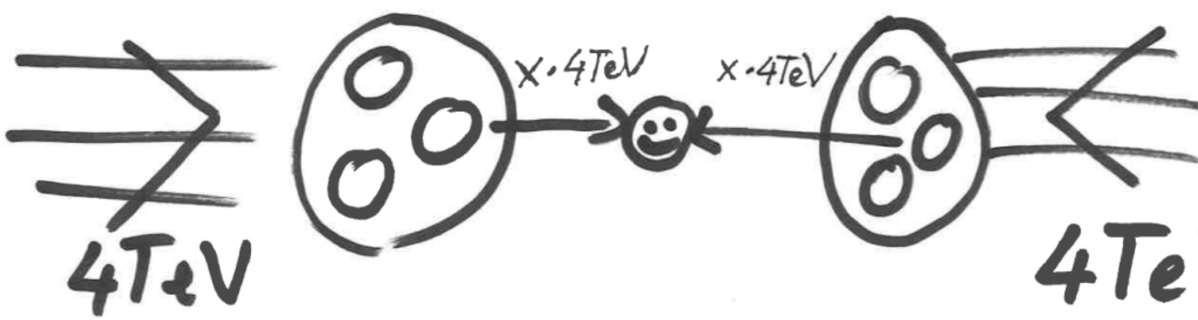
$m_{\mu\mu}$[GeV]	110 - 200	200 - 400	400 - 800	800 - 1200	1200 - 3000	3000 - 4500
Z/γ^*	111000 ± 8000	11000 ± 1000	1000 ± 100	49 ± 5	7.3 ± 1.3	0.033 ± 0.029
$t\bar{t}$	5900 ± 900	1900 ± 400	140 ± 60	2.7 ± 0.7	0.16 ± 0.08	< 0.001
Diboson	1520 ± 190	520 ± 140	62 ± 26	2.8 ± 1.0	0.38 ± 0.28	0.002 ± 0.003
Total	118000 ± 8000	13300 ± 1100	1160 ± 120	55 ± 5	7.8 ± 1.3	0.035 ± 0.029
Data	118701	13349	1109	48	8	0

No deviation from expectation found.

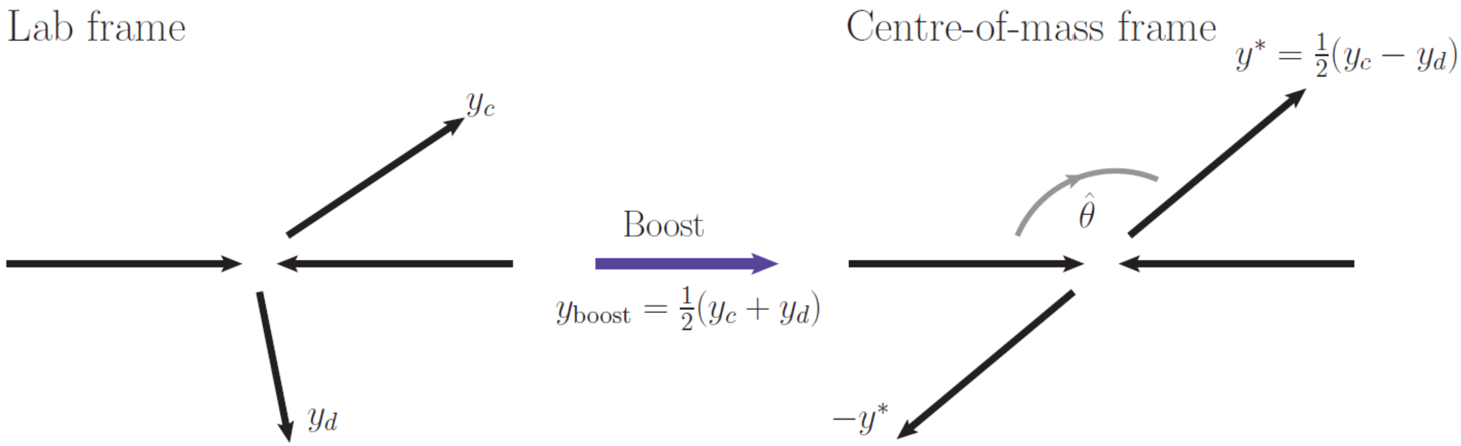
Signal Shapes and Parton Luminosities







Search for Heavy Resonance: Dijet Angular



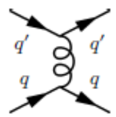
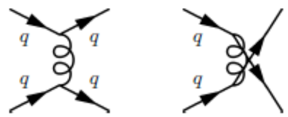
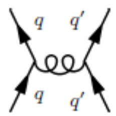
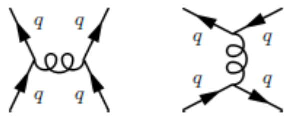
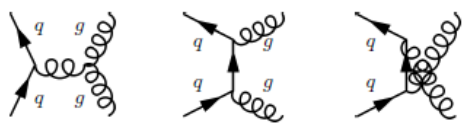
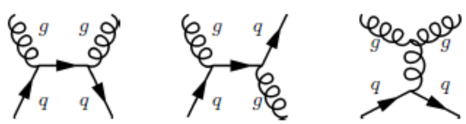
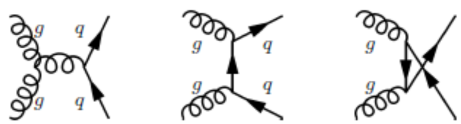
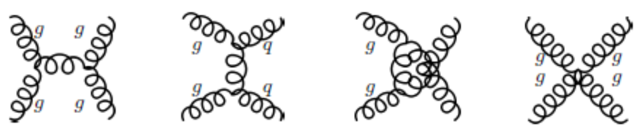
$d\hat{\sigma}/d(\cos\hat{\theta}) \propto \sin^{-4}(\hat{\theta}/2)$ t-channel Spin-1 exchange

$$\chi = \frac{1 + |\cos\hat{\theta}|}{1 - |\cos\hat{\theta}|} \sim \frac{1}{1 - |\cos\hat{\theta}|} \propto \frac{\hat{s}}{\hat{t}}$$

$$\frac{d\hat{\sigma}}{d\chi} \propto \frac{\alpha_s^2}{\hat{s}} \quad (\hat{s}\ \text{fixed}) \quad \hat{s} = m_{jj}$$

Constant in χ for fixed m_{jj}

Search for Heavy Resonance: Dijet Angular

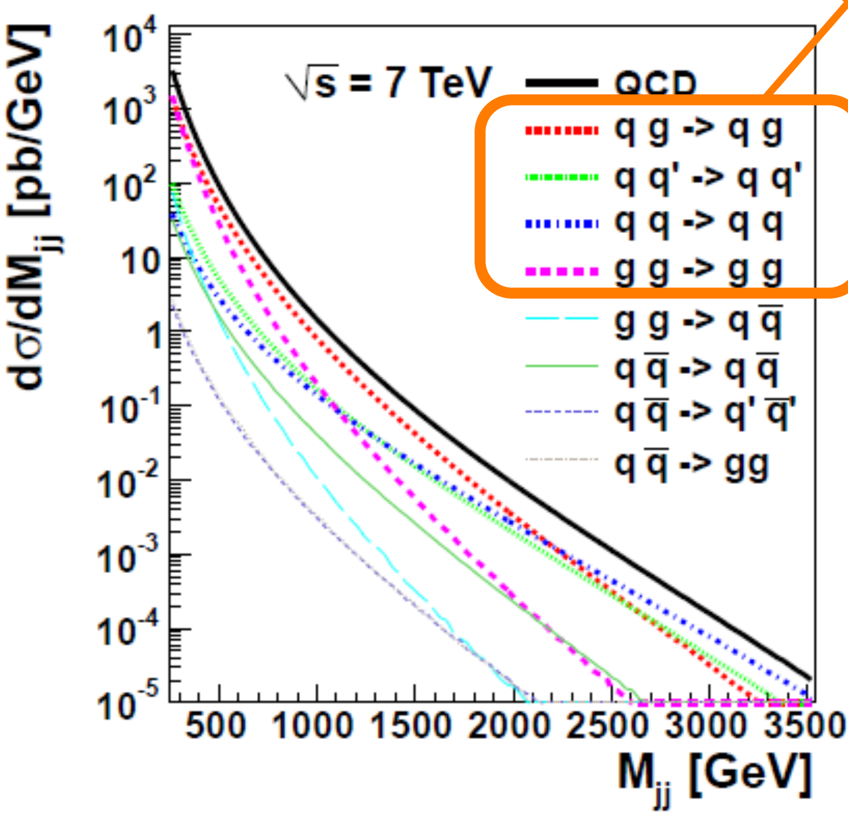
Process	Cross section	Diagrams
$qq' \to qq' = q\bar{q}' \to q\bar{q}'$	$\frac{64}{9}\alpha_s^2\left(\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2}\right)$	
$qq \to qq$	$\frac{64}{9}\alpha_s^2\left(\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2}+\frac{\hat{s}^2+\hat{t}^2}{\hat{u}^2}-\frac{2}{3}\frac{\hat{s}}{\hat{u}\hat{t}}\right)$	
$q\bar{q} \to q'\bar{q}'$	$\frac{64}{9}\alpha_s^2\left(\frac{\hat{t}^2+\hat{u}^2}{\hat{s}^2}\right)$	
$q\bar{q} \to q\bar{q}$	$\frac{64}{9}\alpha_s^2\left(\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2}+\frac{\hat{t}^2+\hat{u}^2}{\hat{s}^2}-\frac{2}{3}\frac{\hat{u}^2}{\hat{s}\hat{t}}\right)$	
$q\bar{q} \to gg$	$\frac{128}{3}\alpha_s^2\left(\frac{4}{9}\frac{\hat{t}^2+\hat{u}^2}{\hat{t}\hat{u}}-\frac{\hat{u}^2+\hat{t}^2}{\hat{s}^2}\right)$	
$qg \to qg$	$16\alpha_s^2\left(\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2}-\frac{4}{9}\frac{\hat{s}^2+\hat{u}^2}{\hat{s}\hat{u}}\right)$	
$gg \to q\bar{q}$	$\frac{8}{3}\alpha_s^2\left(\frac{1}{3}\frac{\hat{t}^2+\hat{u}^2}{\hat{t}\hat{u}}-\frac{3}{4}\frac{\hat{t}^2+\hat{u}^2}{\hat{s}^2}\right)$	
$gg \to gg$	$72\alpha_s^2\left(3+\frac{\hat{t}^2+\hat{u}^2}{\hat{s}^2}+\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2}+\frac{\hat{s}^2+\hat{t}^2}{\hat{u}^2}\right)$	

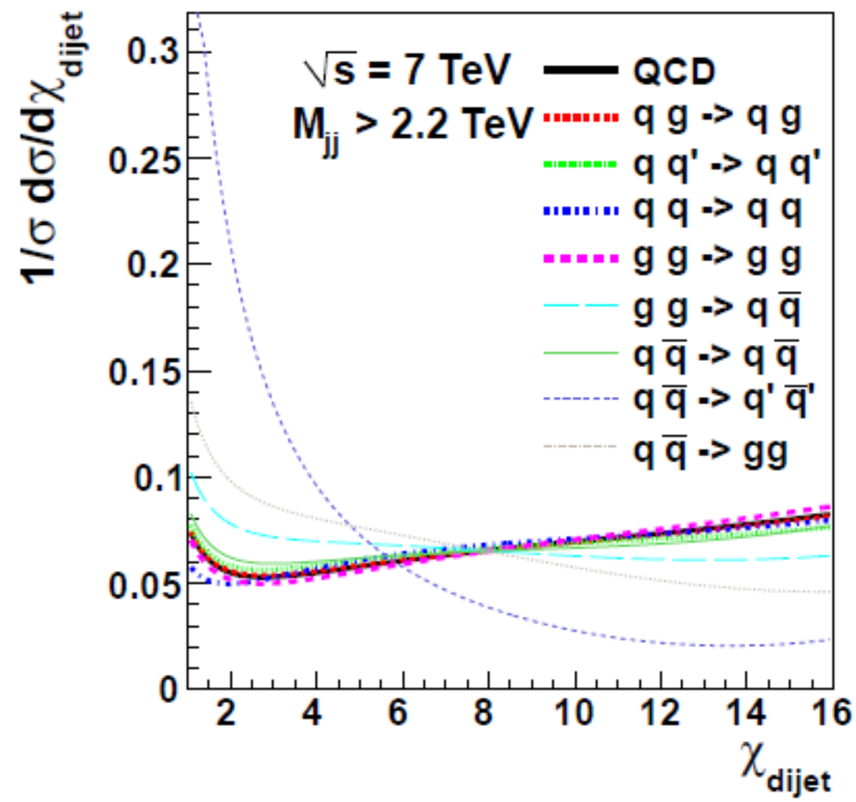
QCD is a bit more complicated…..

Andreas Dominik Hinzmann

Search for Heavy Resonance: Dijet Angular

main processes





low M_{jj} gg and qg dominate

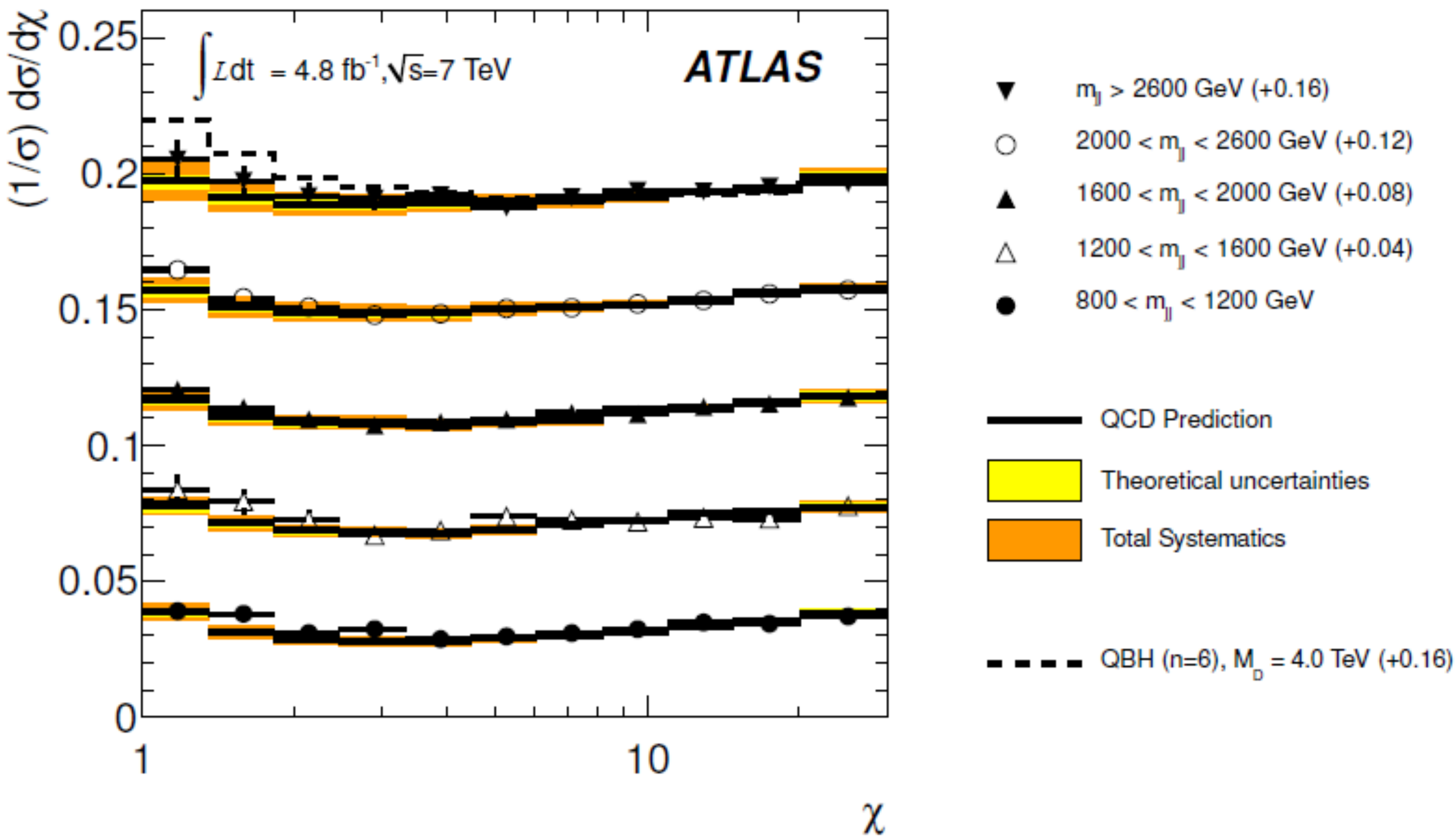
high M_{jj} qq dominate

QCD ~ flat in χ

Andreas Dominik Hinzmann

Search for Heavy Resonance: Dijet Angular

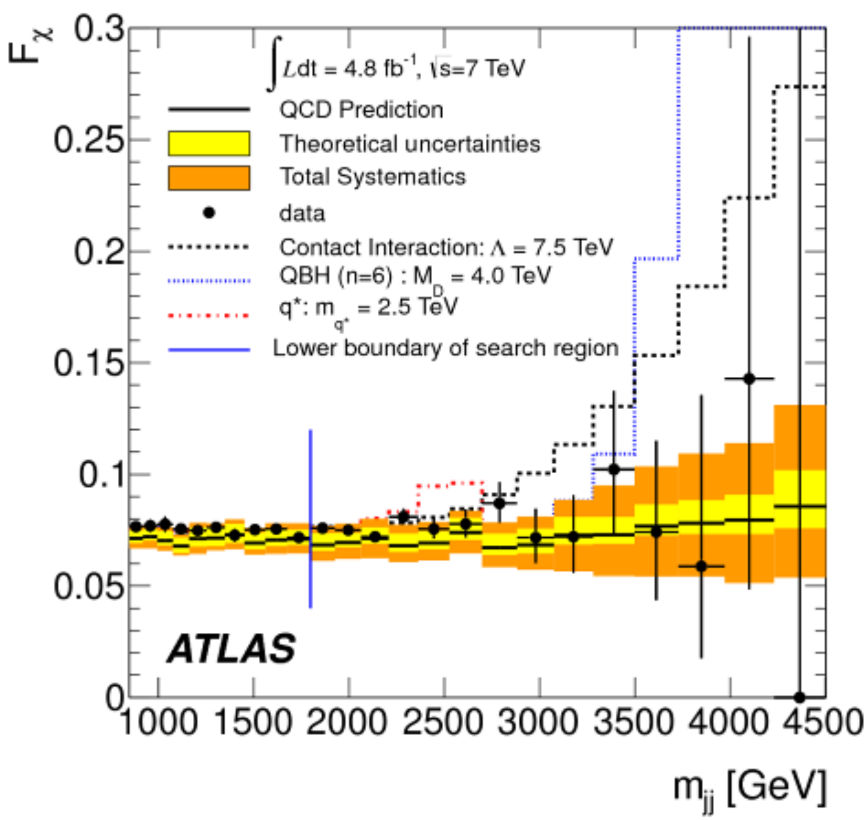
arXiv:1210.1718

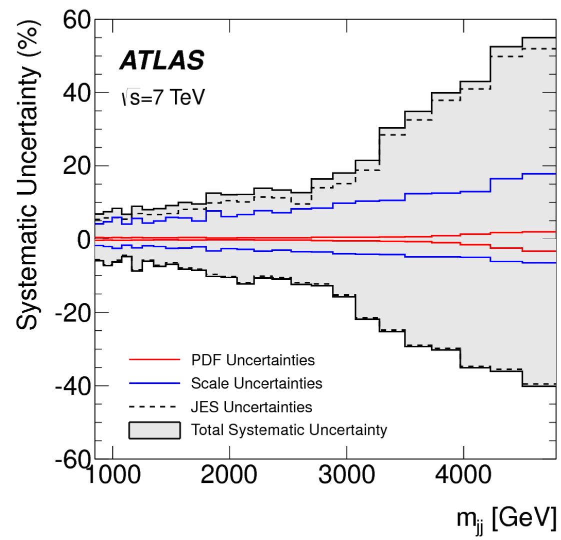


Search for Heavy Resonance: Dijet Angular

arXiv:1210.1718

$$F_\chi(m_{jj}) \equiv \frac{\mathrm{d}N_{\mathrm{central}}/\mathrm{d}m_{jj}}{\mathrm{d}N_{\mathrm{total}}/\mathrm{d}m_{jj}},$$

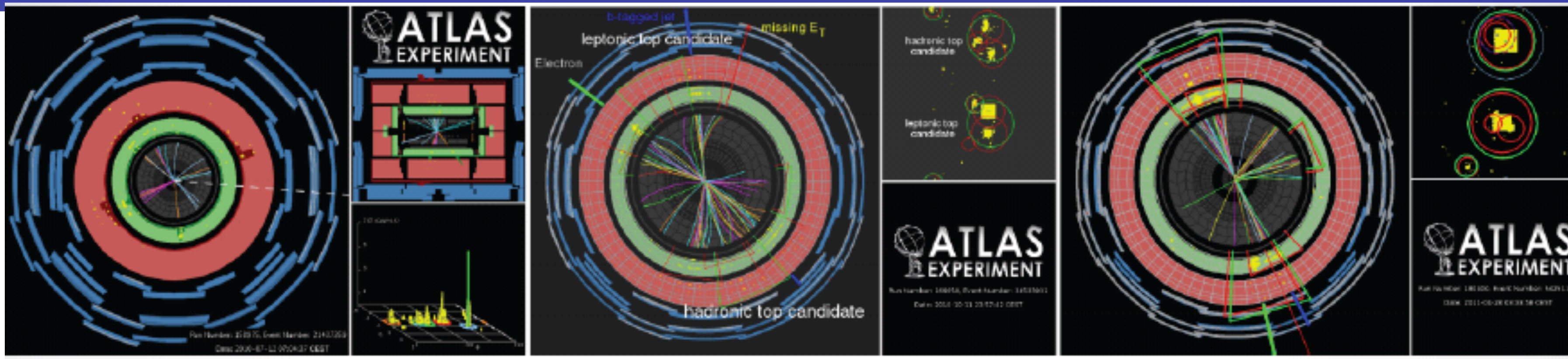




Models and Limits:

- Quark contact interaction (quark compositeness)
  - **Λ>7.6 TeV (7.7 TeV)**
- Quantum Black holes
  - M_D>4.1 TeV (4.2 TeV) n=6

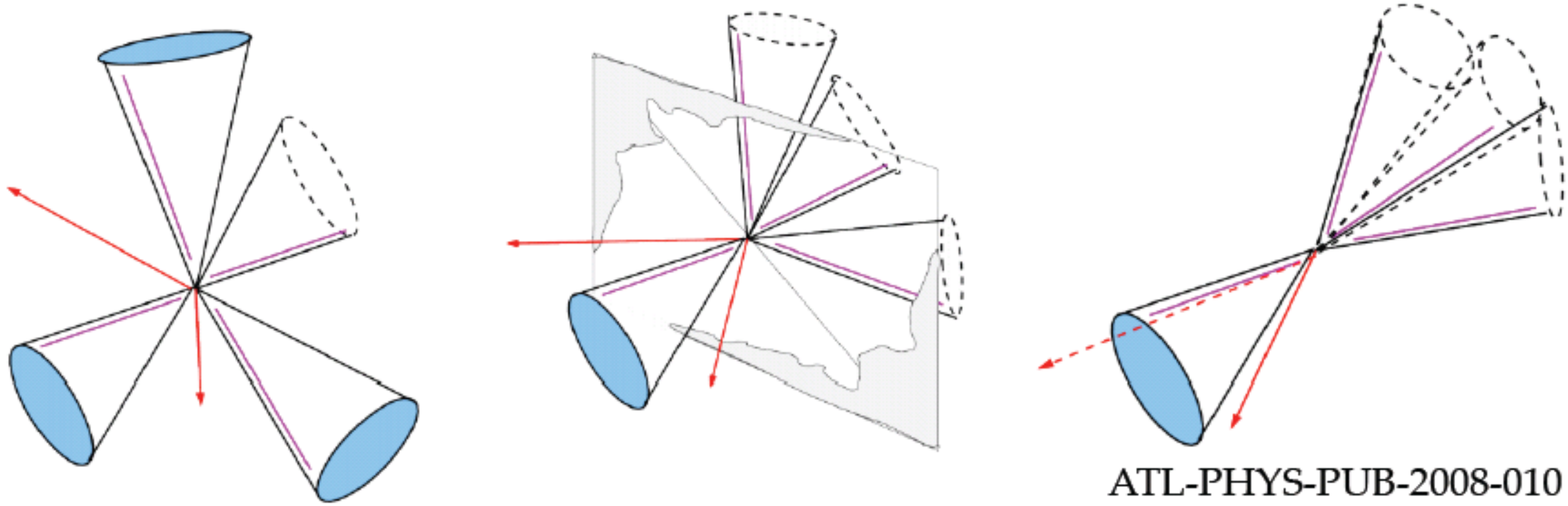
Top Reconstruction @ LHC: 3 Regimes



At rest: Mtt<500 GeV

Transition region:
500GeV<Mtt<700GeV

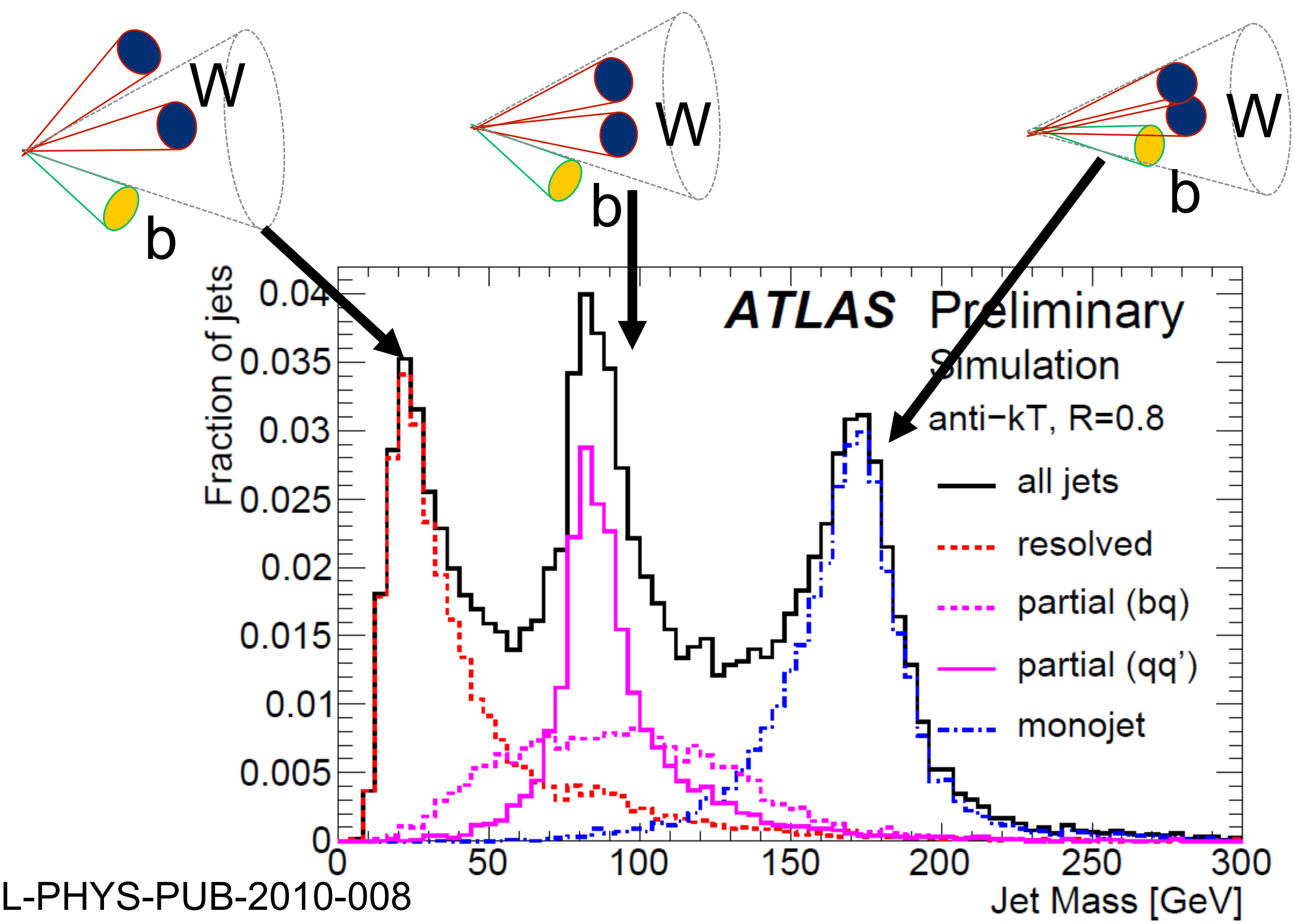
Mono-jet: Mtt>700GeV



ATL-PHYS-PUB-2008-010

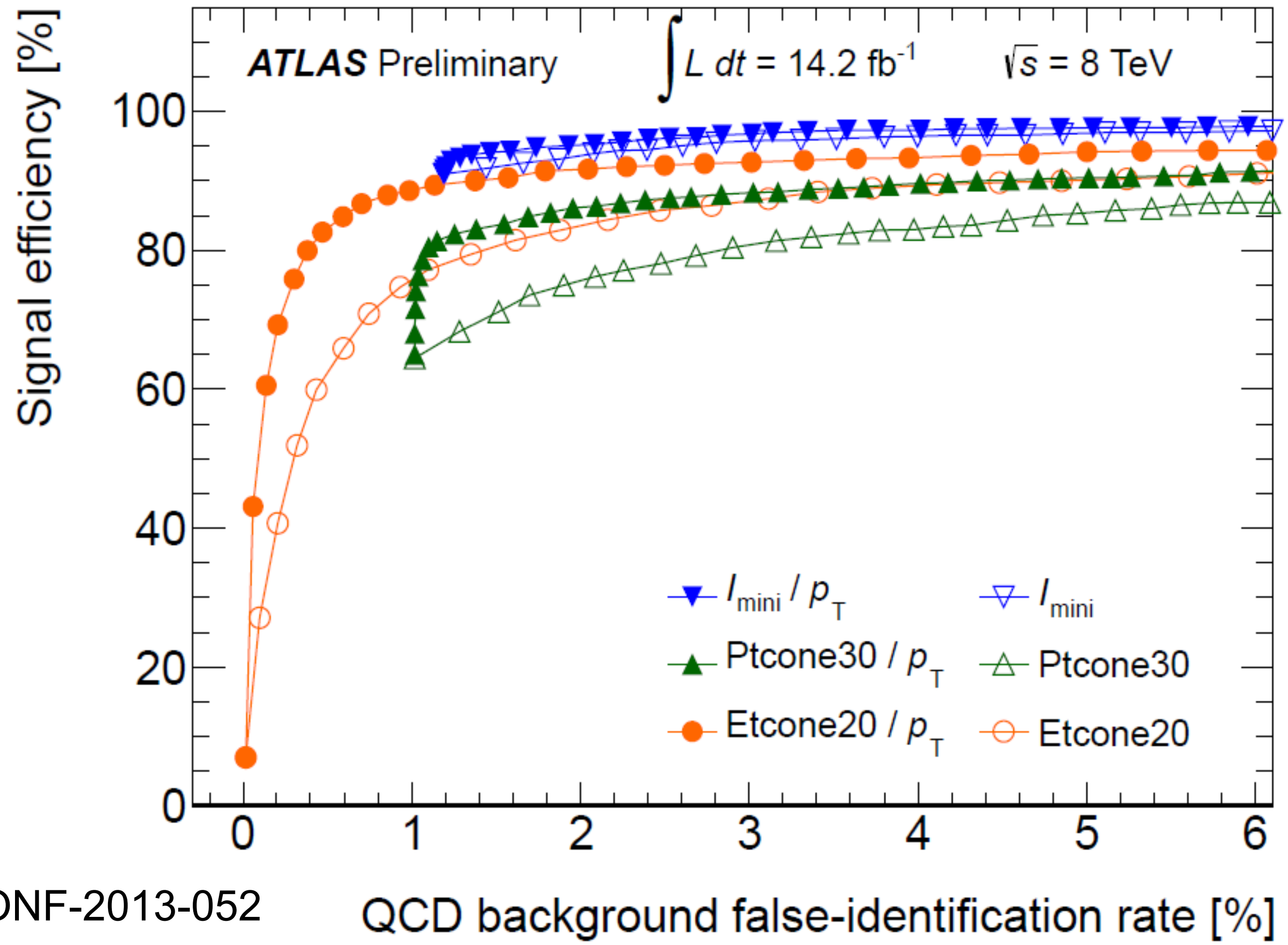
Jet Substructure: jet mass

- Use jet substructure to "tag" boosted tops



ATL-PHYS-PUB-2010-008

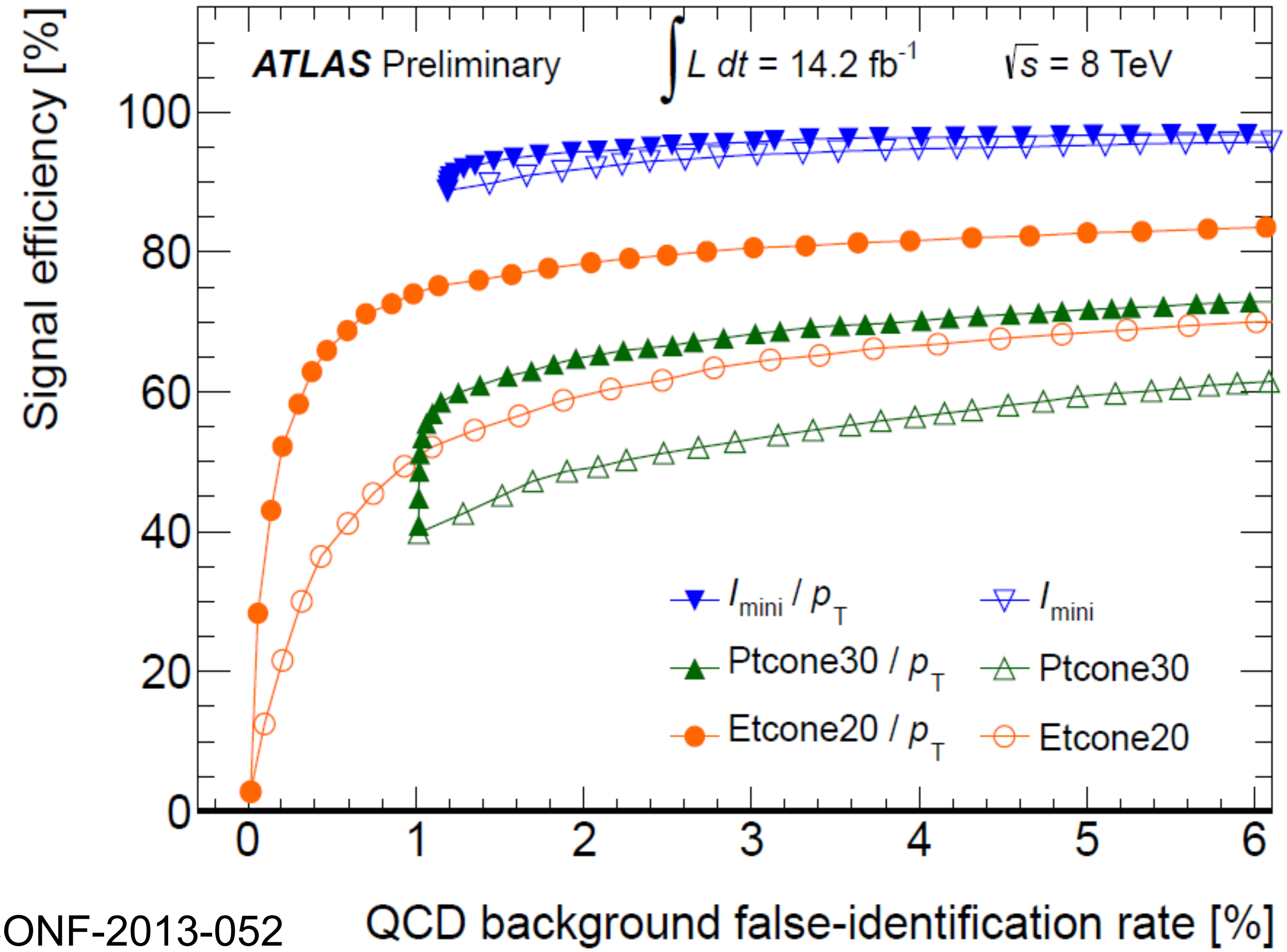
Efficiency Comparisons



ATLAS-CONF-2013-052

(b) 1.0 TeV Z'

Efficiency Comparisons

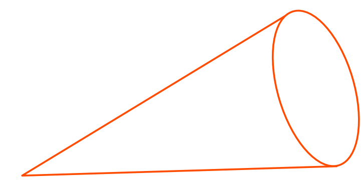


ATLAS-CONF-2013-052

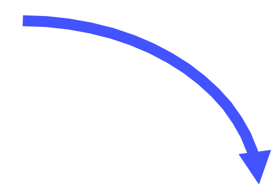
(d) 2.0 TeV Z'

Ttbar search: Object Selection

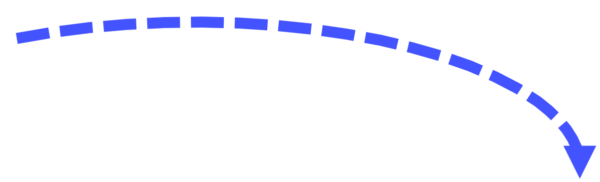
- Jets
  - Small jets: pT > 25 GeV && |η|<2.5
  - Large jets: pT > 300 GeV && |η| < 2.0
  - Require that at least one of the small jets is b-tagged



- Electrons
  - pT > 25 GeV && |η|<1.37, 1.52<|η|<2.47
  - Mini Isolation: $I_{mini} < 0.05\ E_T$
  - z-impact parameter within 2mm of PV



- Muons
  - pT > 25 GeV && |η|<2.5
  - $I_{mini} < 0.05$ pT
  - z-impact parameter within 2mm of PV

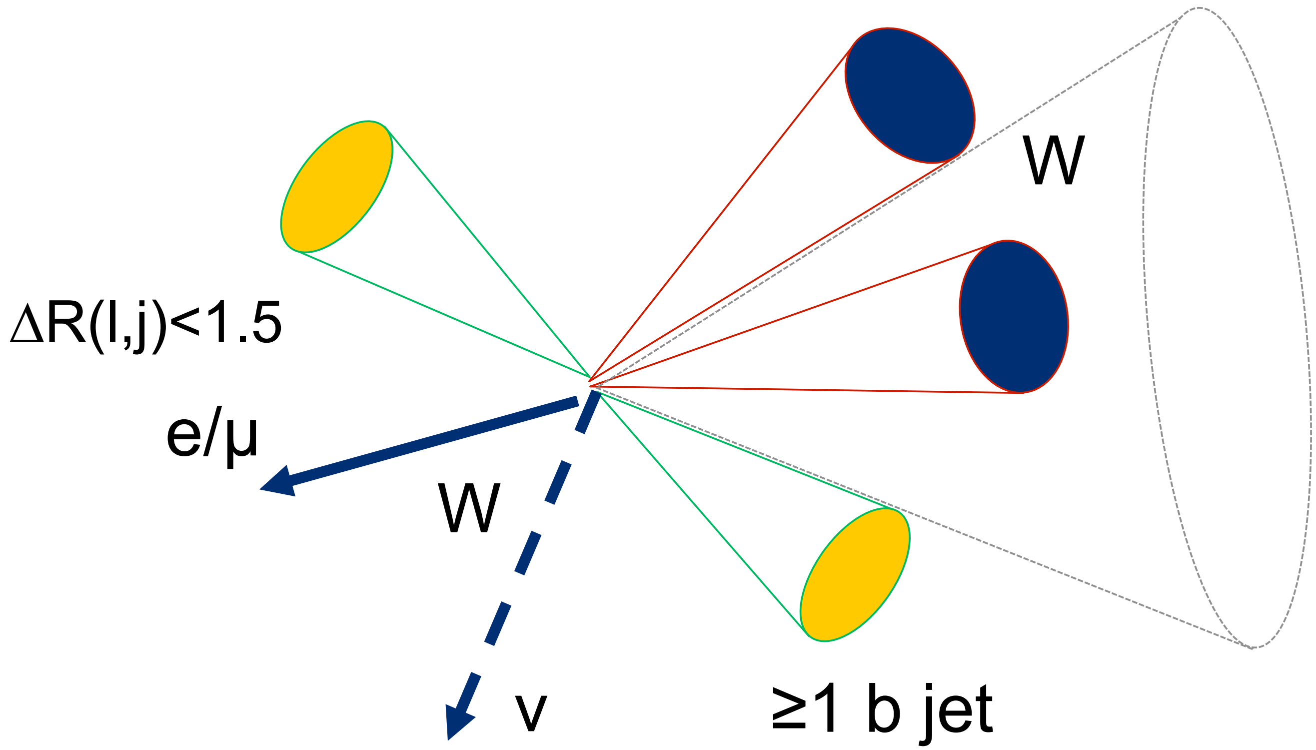


Ttbar Selections Continued

- Optimized for high-pt tops && reduce ttbar bkg
- High-pt single electron or muon trigger
- >1 primary vertex with ≥ 5 tracks of p_T > 0.4 GeV
- Electron channel
  - ME_T > 30 GeV && $m_T = \sqrt{2p_T ME_T(1 - cos\Delta\varphi)}$>30 GeV
- Muon channel
  - ME_T > 20 GeV && ME_T+m_T > 60 GeV

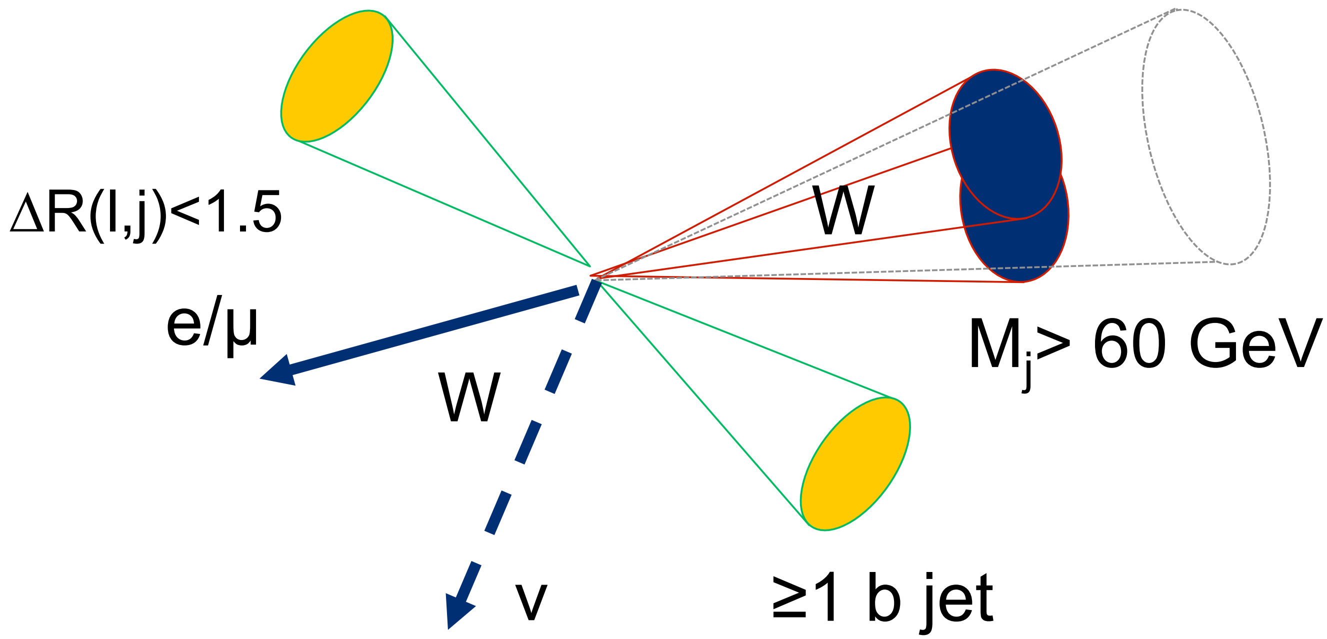
Resolved Selection

≥ 4 small jets, j, with p_T> 25 GeV, |η|<2.5



Merged Selection

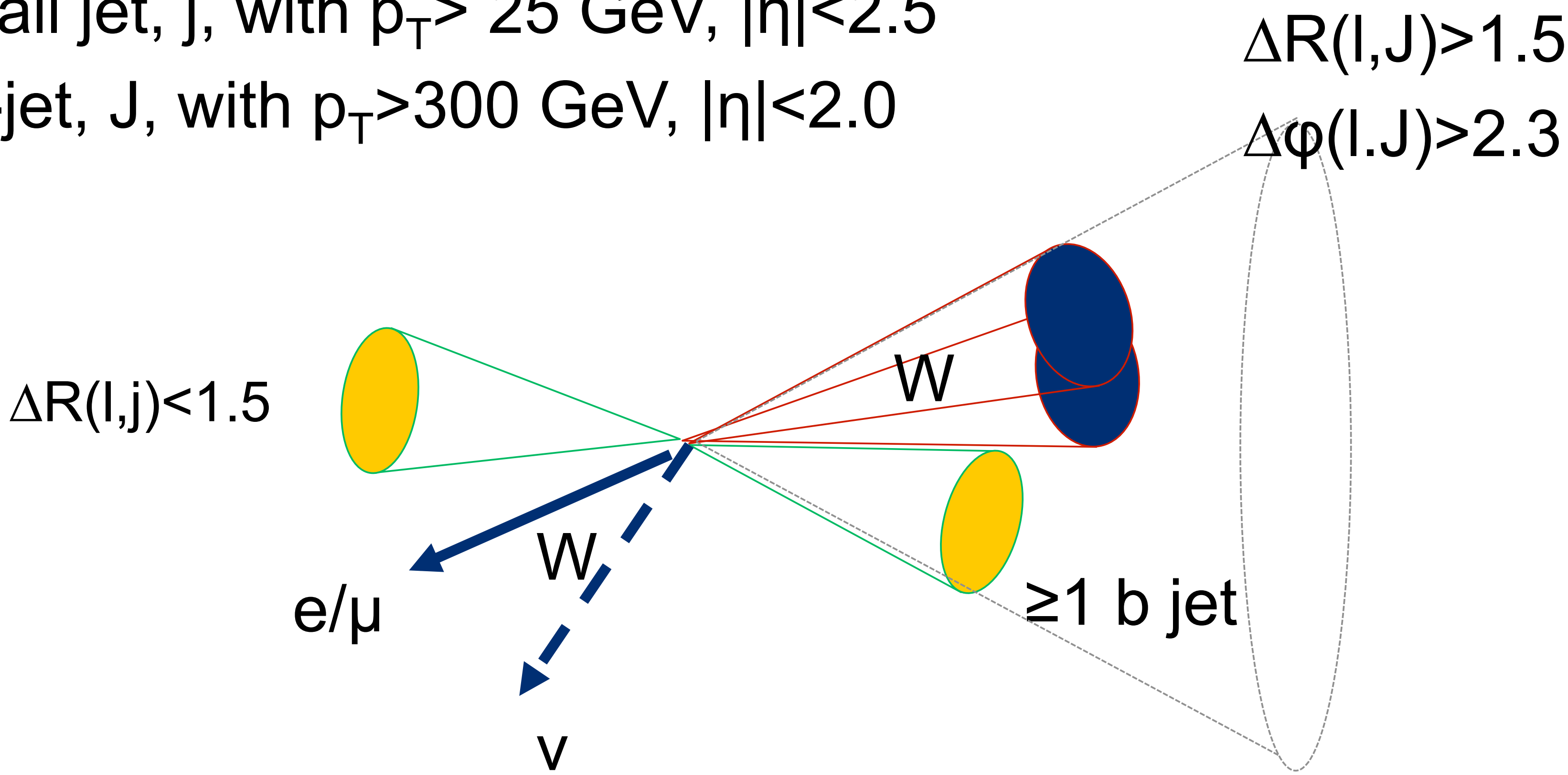
3 small jets, j, with p_T> 25 GeV, $|\eta|$<2.5



Boosted Selection

≥1 small jet, j, with p_T> 25 GeV, $|\eta|$<2.5

≥1 fat-jet, J, with p_T>300 GeV, $|\eta|$<2.0

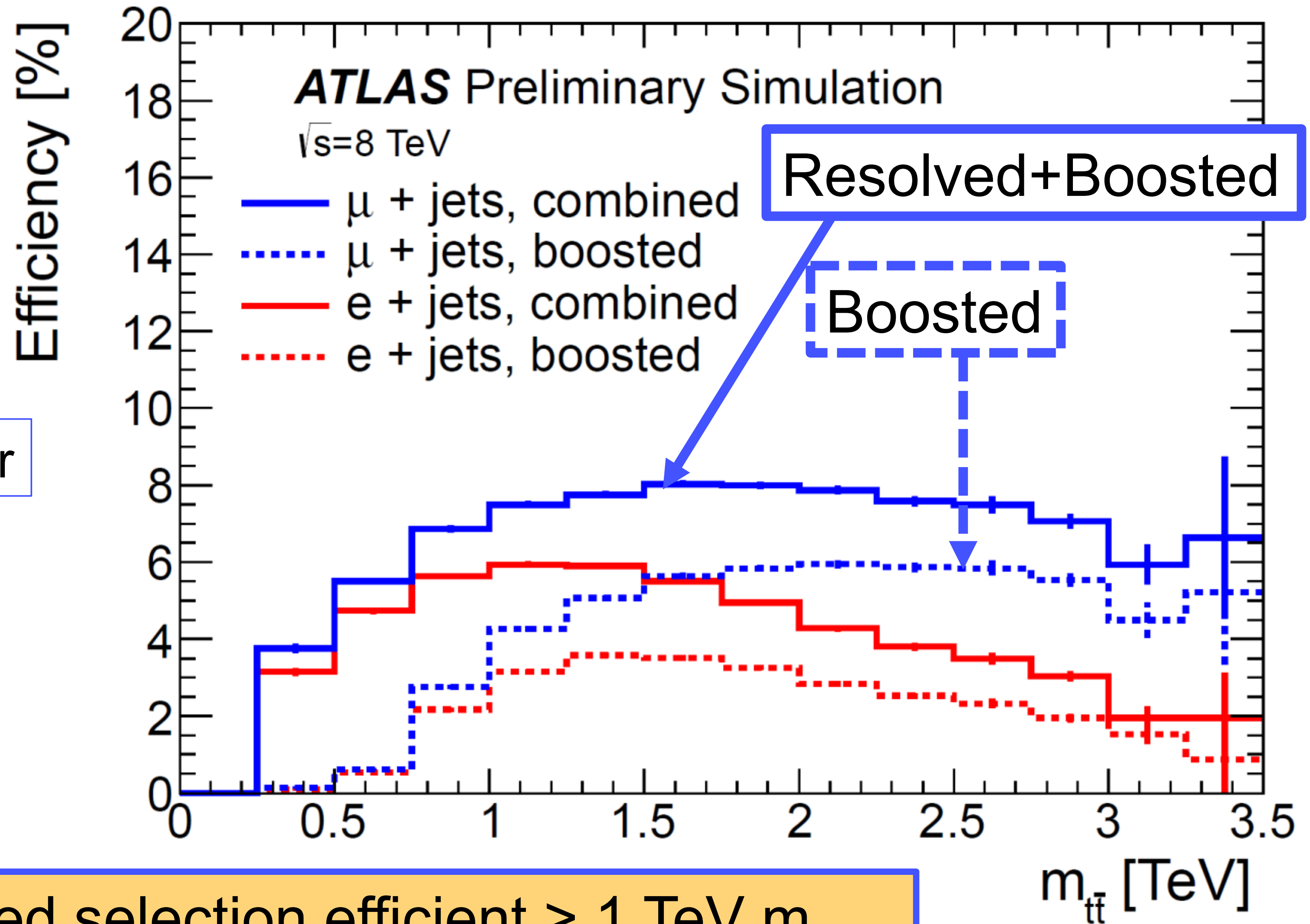


M_J> 100 GeV

$\sqrt{d_{12}} > 40$ GeV

Geometrical Acceptance + Selection Efficiencies

Z'→ttbar

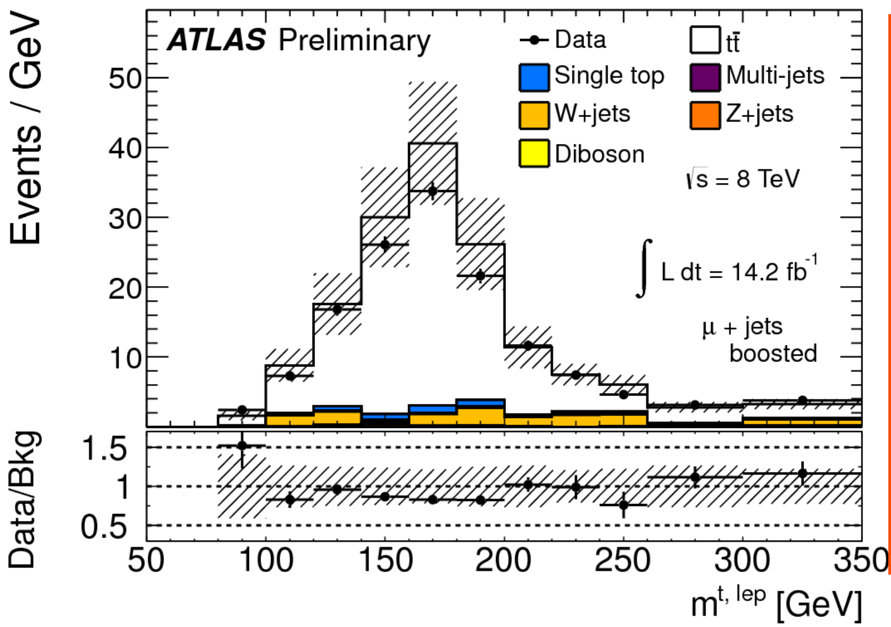


Boosted selection efficient > 1 TeV m_{ttbar}

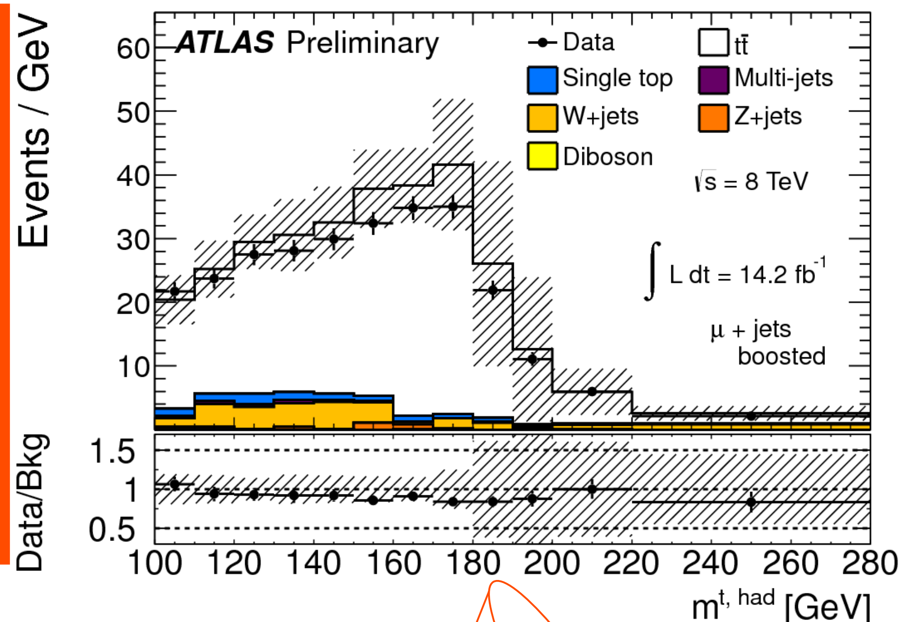
Reconstructed top mass distributions

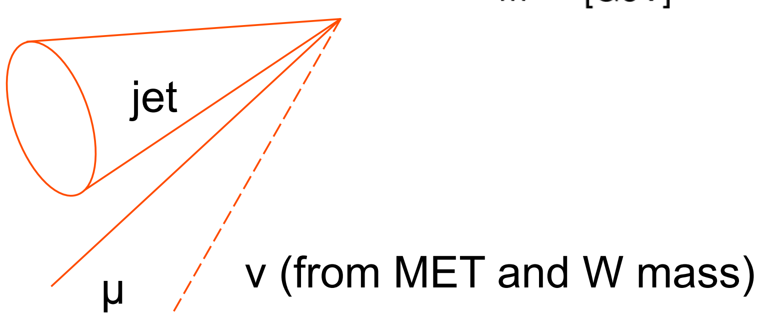
Semi-Leptonically decaying top

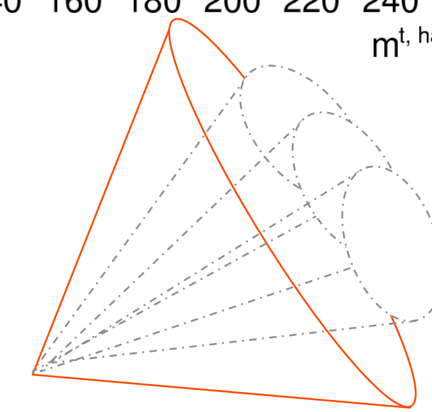
Hadronically decaying top



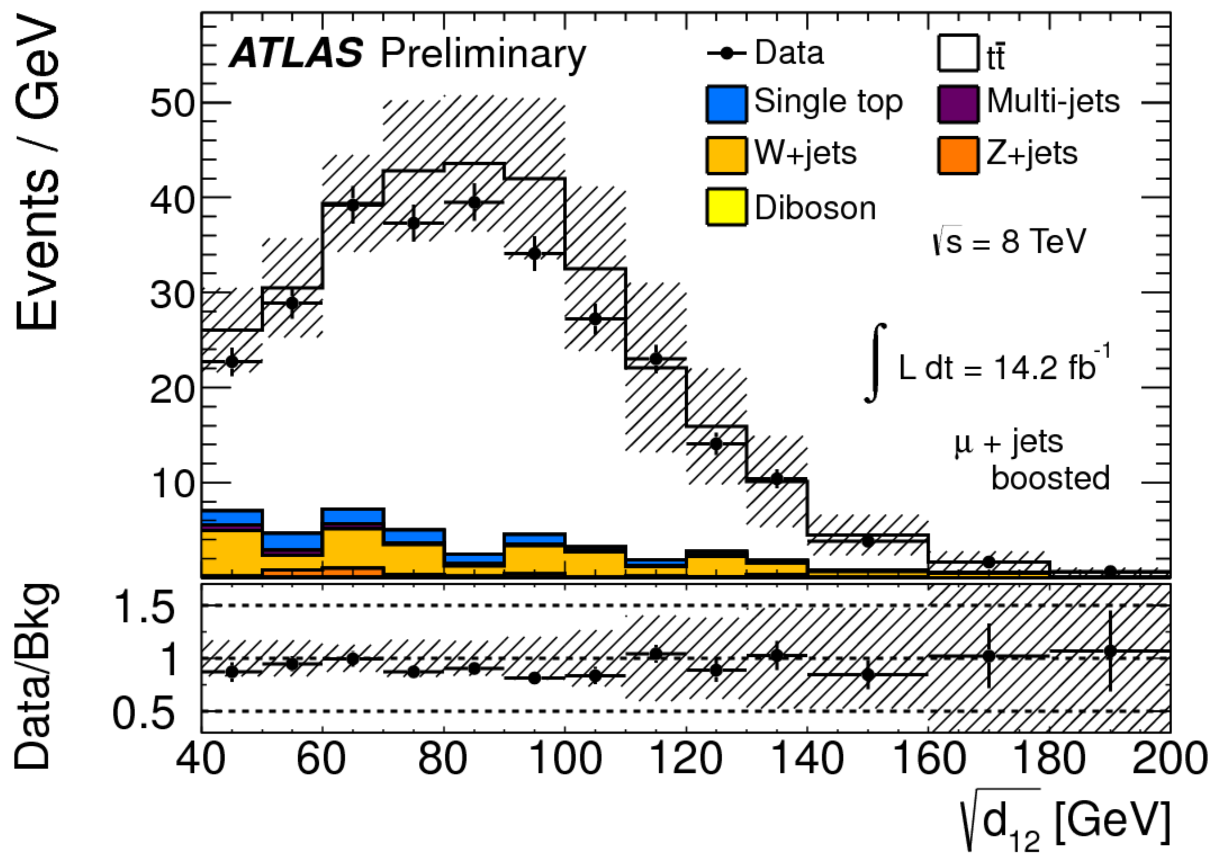
Boosted selection







Reconstructed splitting scale

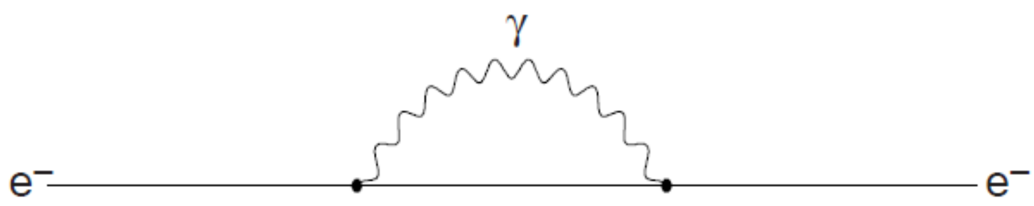


$$\sqrt{d_{ij} = \min(p_{Ti}, p_{Tj}) \times \Delta R_{ij}}$$

Fine-Tuning Problem in Electromagnetism

$$(m_e c^2)_{\text{observed}} = (m_e c^2)_{\text{bare}} + \Delta E_{\text{Coulomb}}$$

Coulomb self-energy



$$\Delta E_{\text{Coulomb}} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r_e},$$

$$r_e \lesssim 10^{-17}\ \text{cm} \quad \Longrightarrow \quad \Delta E \gtrsim 10\ \text{GeV}$$

$$0.511 = -9999.489 + 10000.000\ \text{MeV}$$

Fine tuning!

Murayama hep-ph/9410285

Fine-Tuning Problem in Electromagnetism

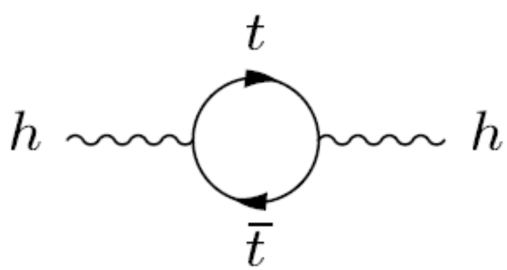
- Picture not complete:
  - Positron cancels $1/r_e$ term
  - New symmetry:
    - particle/anti-particle

$$(m_e c^2)_{\text{observed}} = (m_e c^2)_{\text{bare}} \left[1 + \frac{3\alpha}{4\pi} \log \frac{\hbar}{m_e c r_e} \right]$$

    - Correction to bare mass becomes small

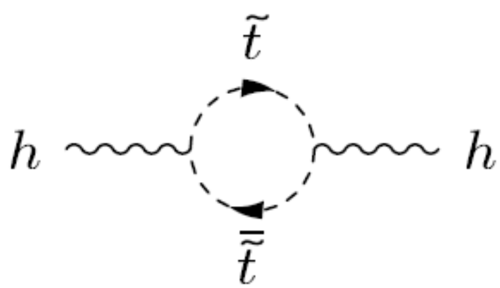
Supersymmetry

- Same problem with Higgs



$$\Delta\mu^2_{\text{top}} = -6\frac{h_t^2}{4\pi^2}\frac{1}{r_H^2}$$ ~ (100 GeV)^2

125 GeV = (huge number)-(huge number) even more fine tuned!

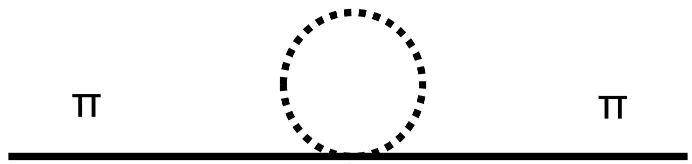


Add new particles (spin symmetry): SUSY

$$\Delta\mu^2_{\text{stop}} + \Delta\mu^2_{\text{top}} = -6\frac{h_t^2}{4\pi^2}(m_{\tilde{t}}^2 - m_t^2)\log\frac{1}{r_H^2 m_{\tilde{t}}^2}$$

Composite Higgs

- But there is another way….look at QCD

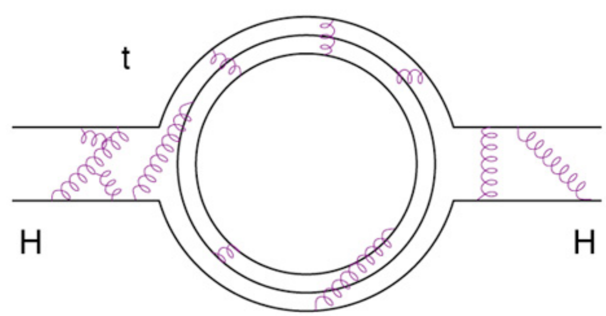


Pion mass is not divergent.

Why?

It is a composite particle!

- **Assume Higgs is a composite particle**
  - Changes couplings
  - Introduces new partners to top quarks
  - Vector-like quarks…
    - (both chiralities same under SU(2)xU(1)
  - Solves fine-tuning problem….



4th Generation and Heavy Quarks

- 4th ge
  enhar
  - (alr
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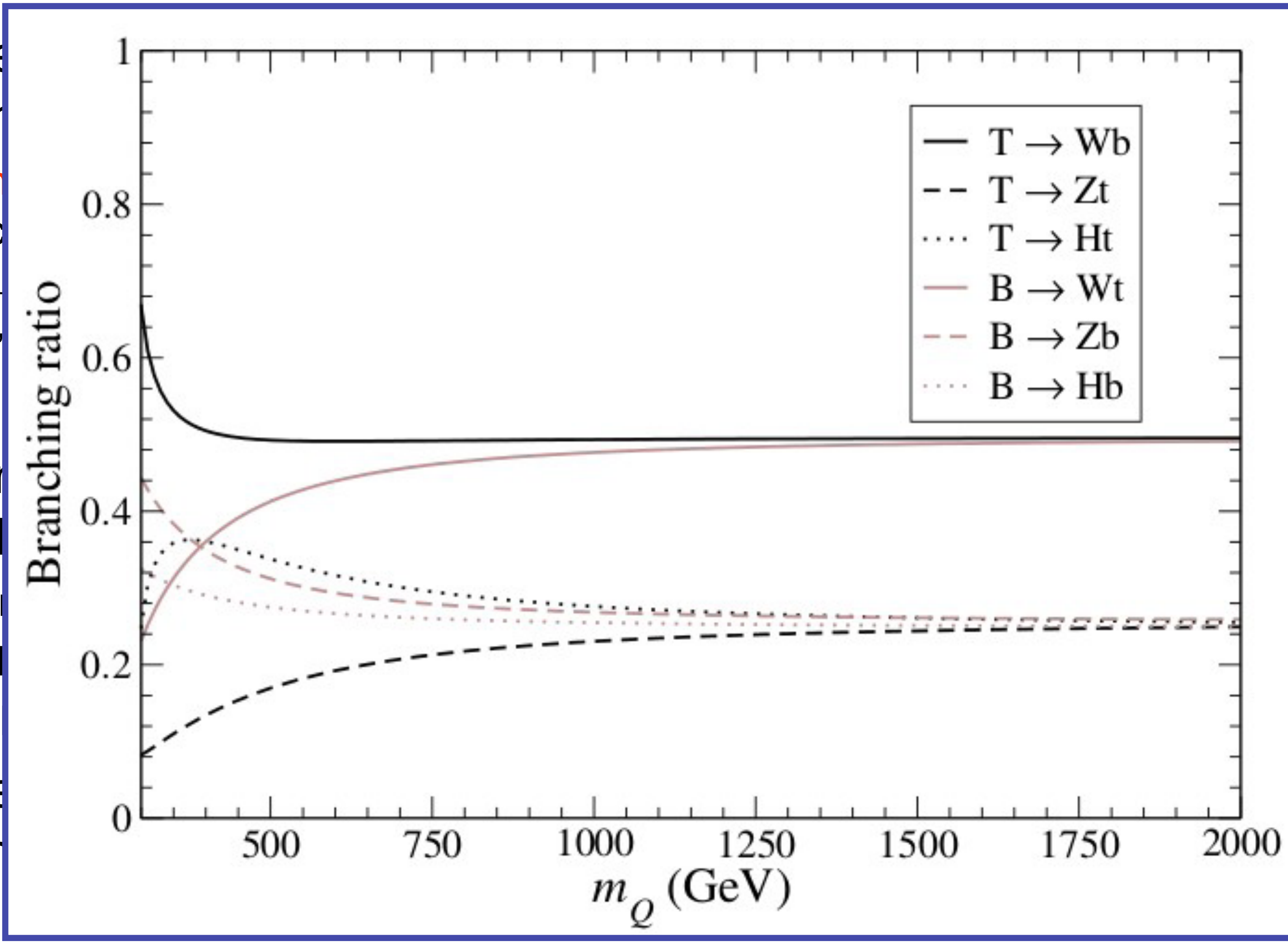
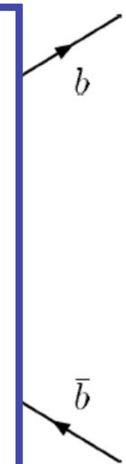
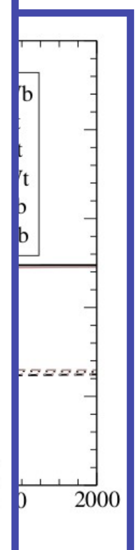
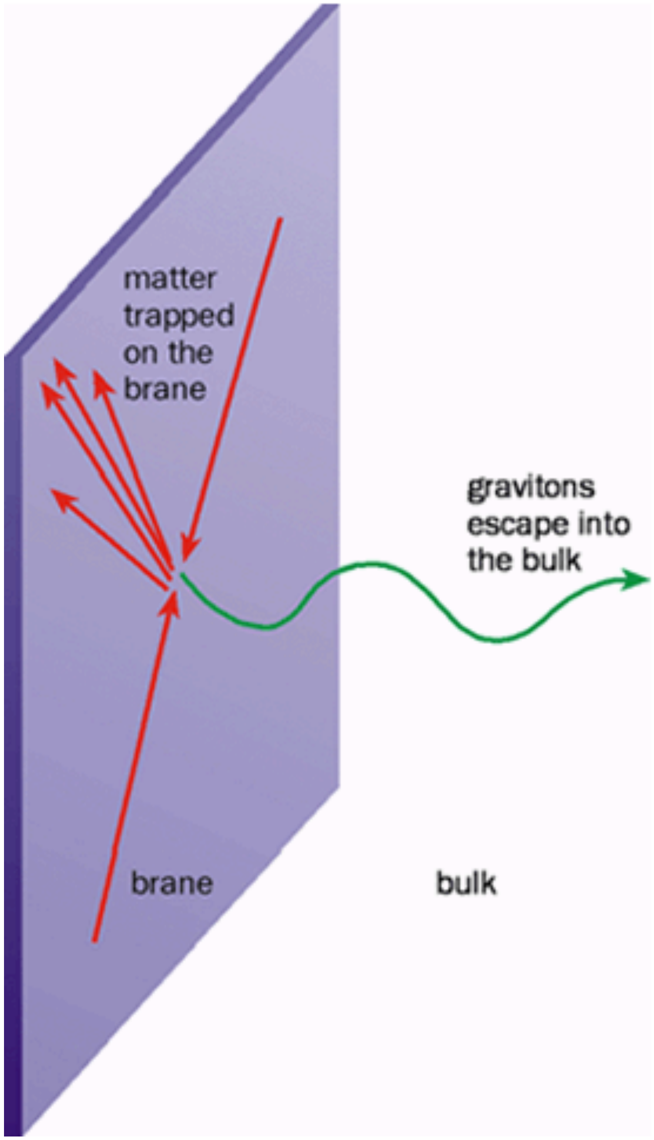
  - b'b'
- Beyor
  Quarl
  - Mo
  - T': I
  - B':
- Loose
  to ligh

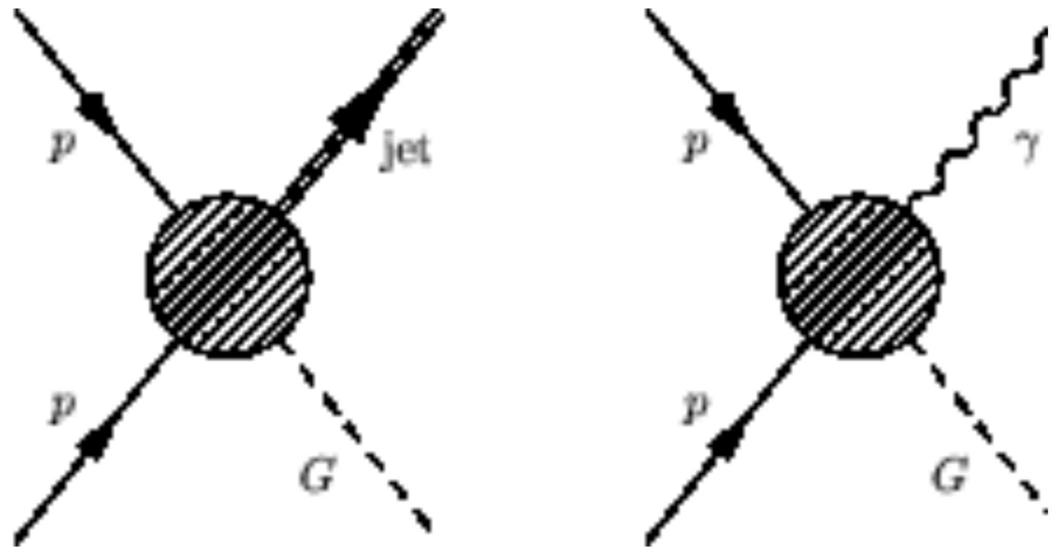






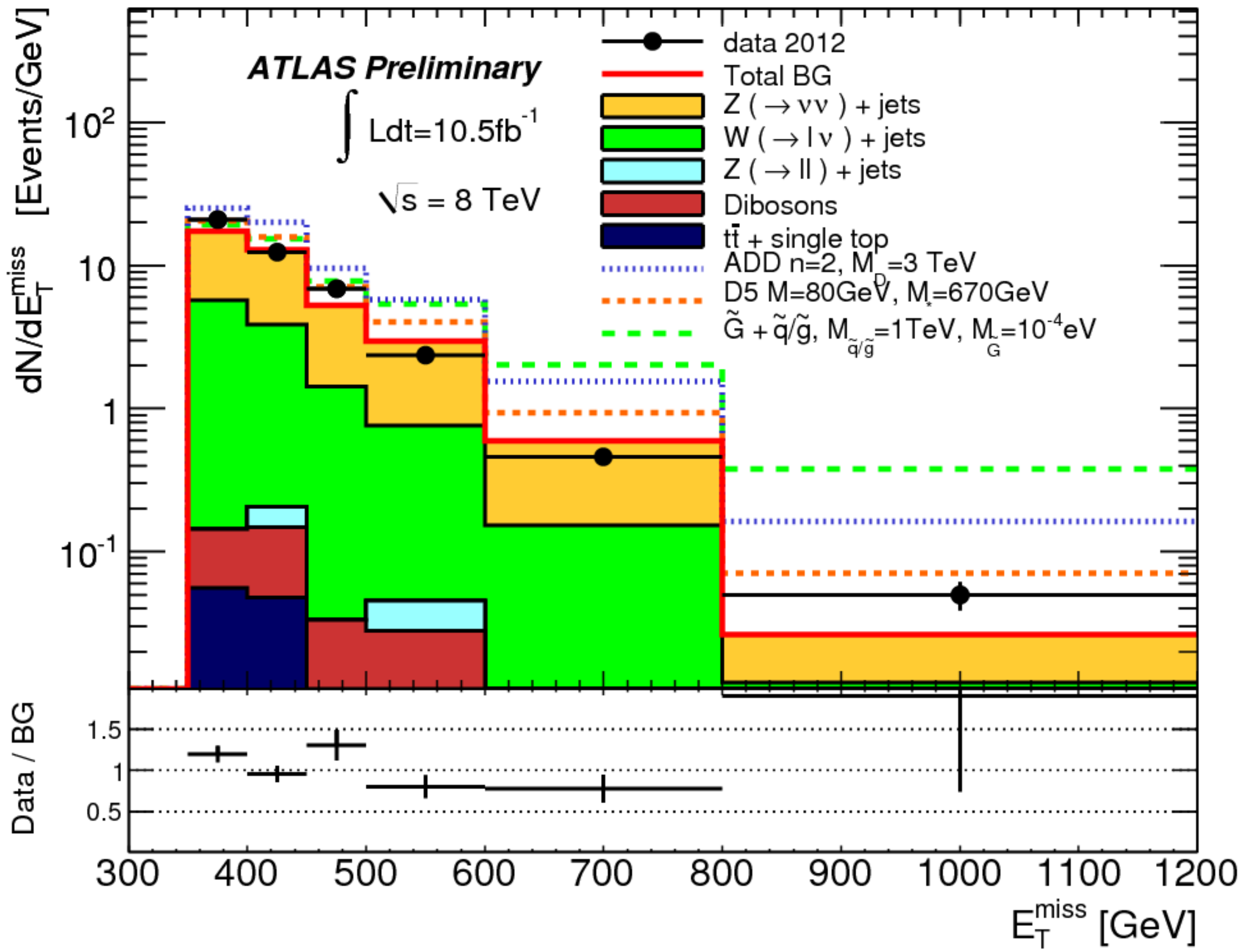
Graviton Production in Extra Dimensions



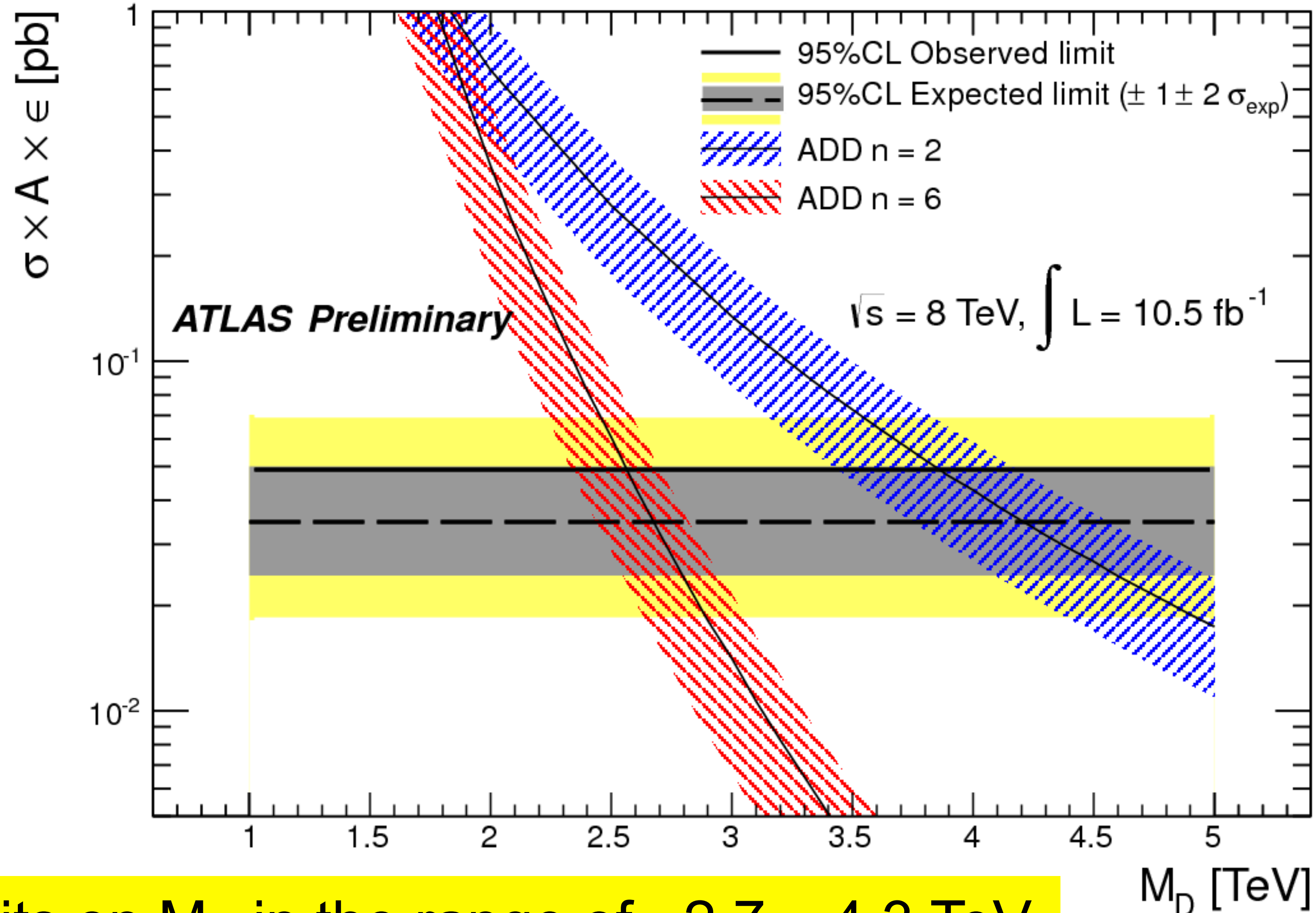


ME_T Distribution of Mono Jet Analysis

ATLAS-CONF-2012-147



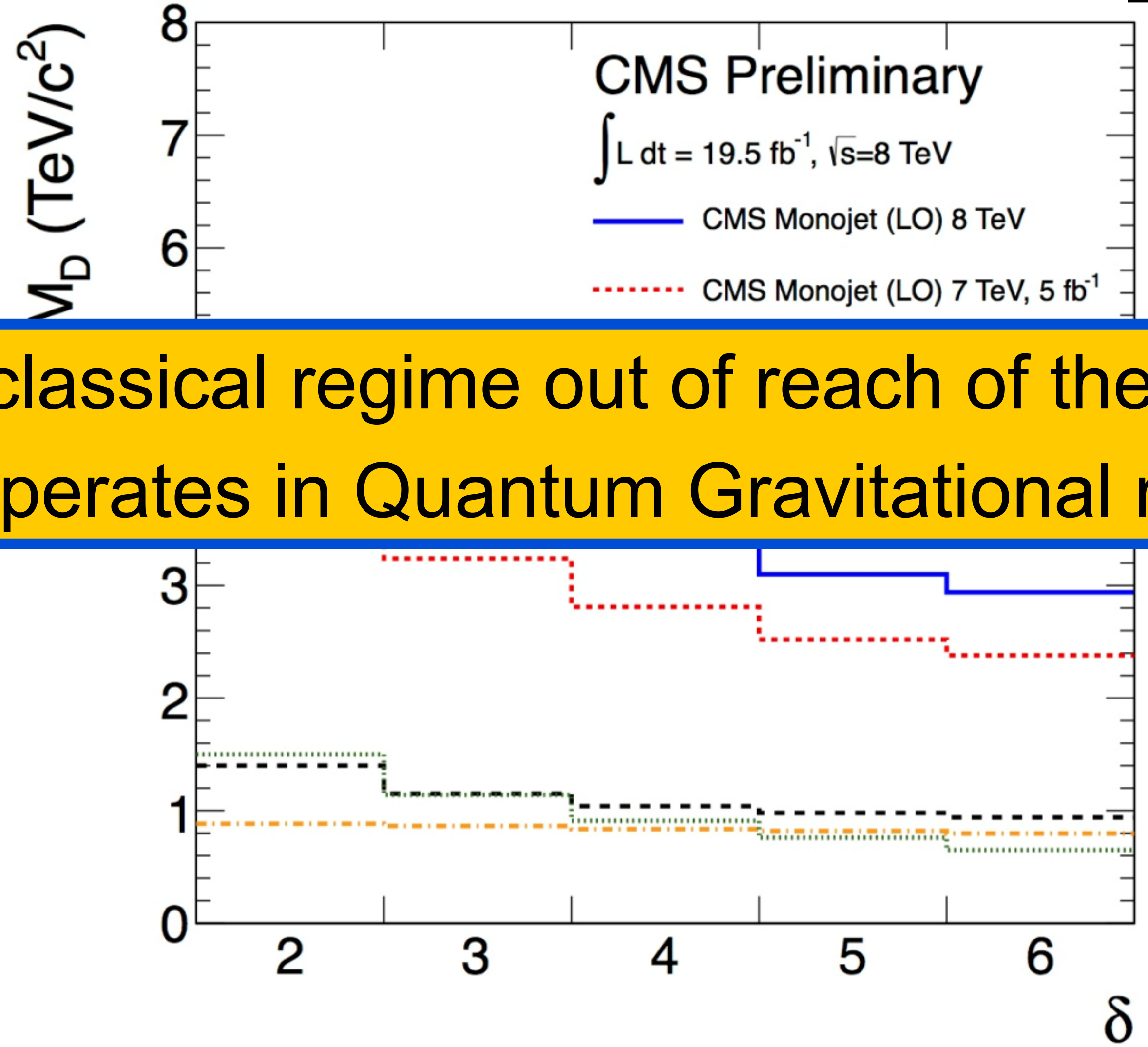
Exclusion Limits



Limits on M_D in the range of ~2.7 – 4.3 TeV

Exclusion Limits on M_D from CMS

EXO-12-048 PAS



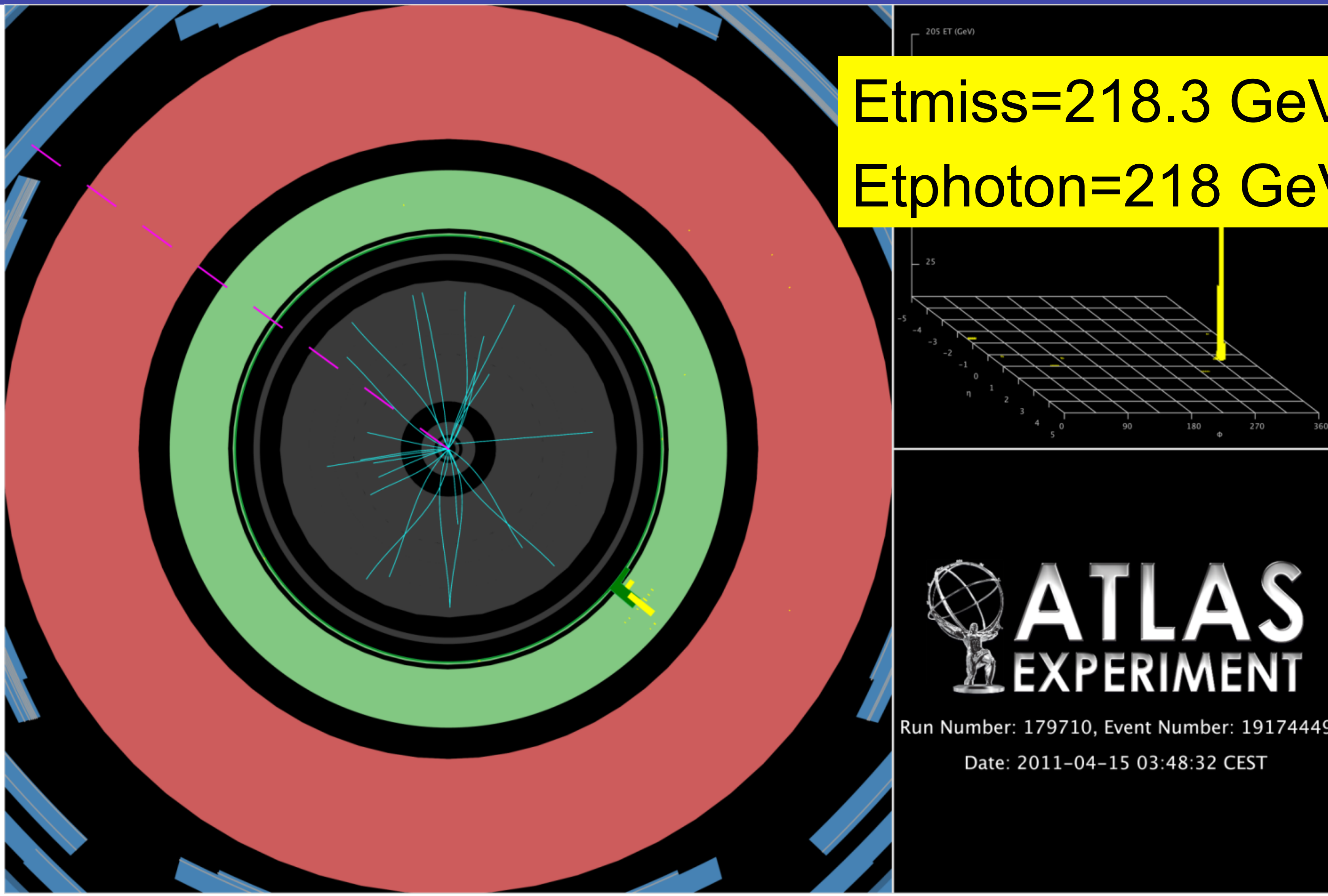
Semi-classical regime out of reach of the LHC

LHC operates in Quantum Gravitational regime

Mono Photon Searches for Extra Dimensions

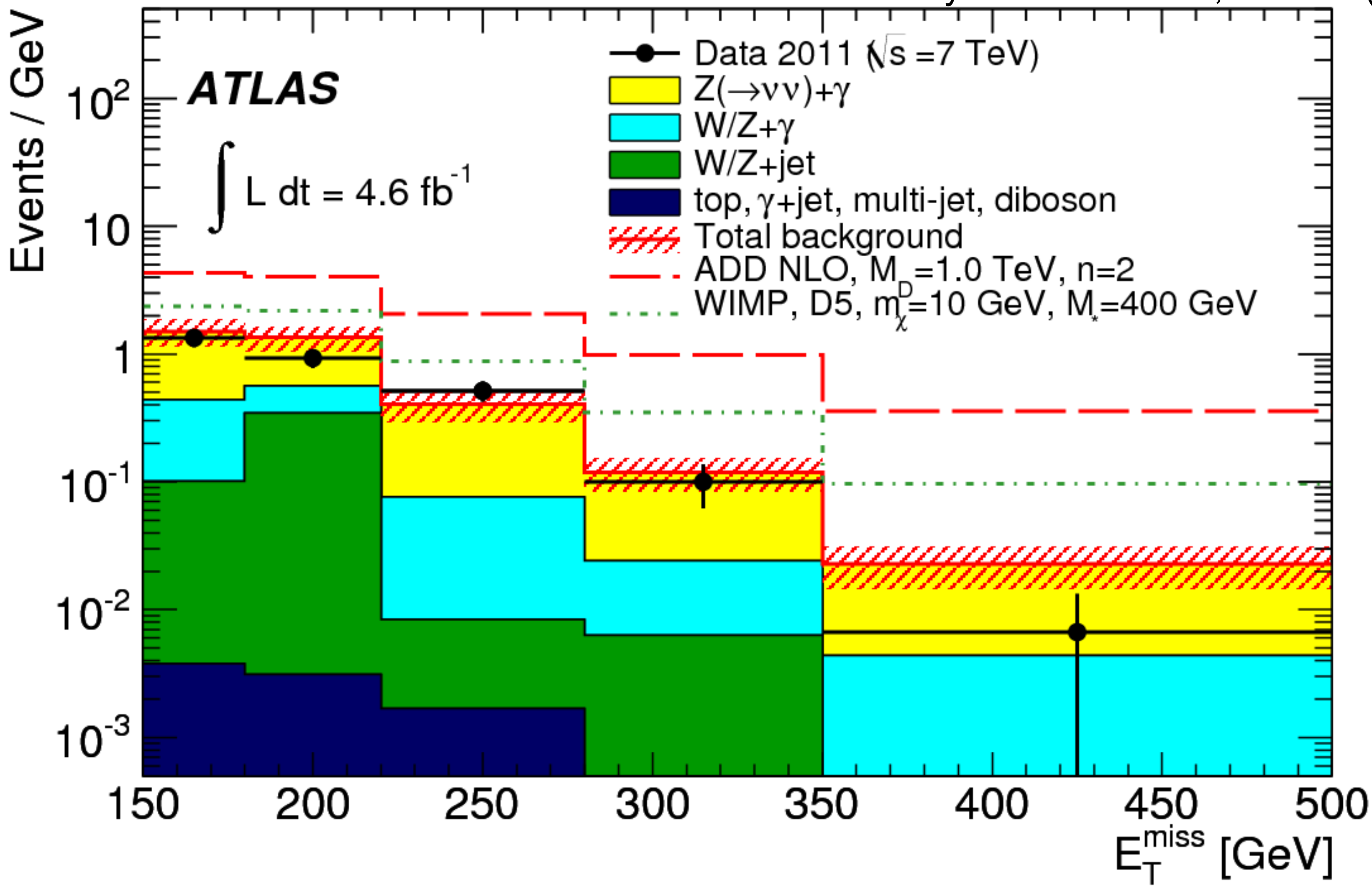
Etmiss=218.3 GeV

Etphoton=218 GeV

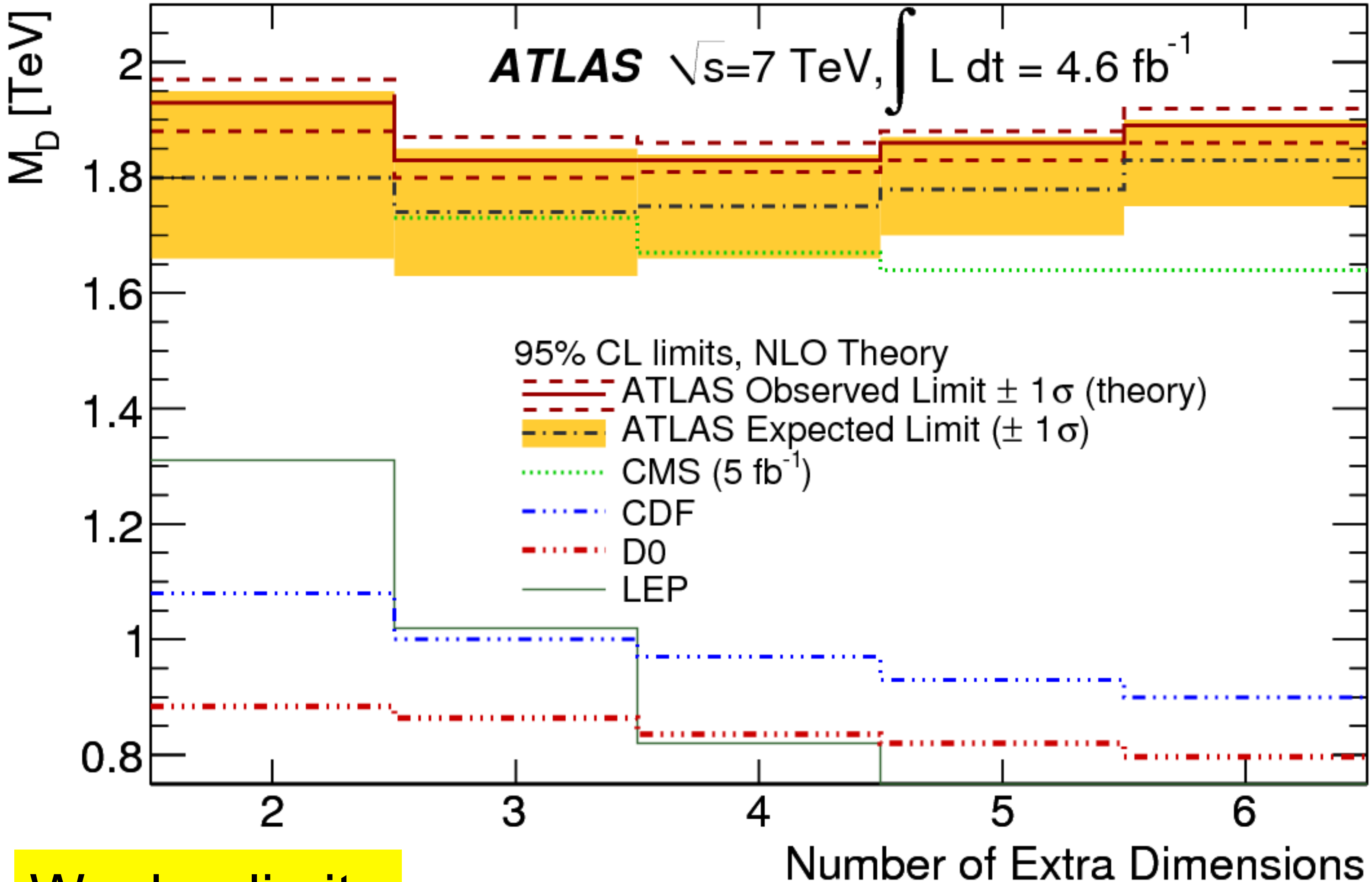


The Discriminant

Phys. Rev. Lett 110, 011802 (2013)



Limits on M_D in Mono Photon Search

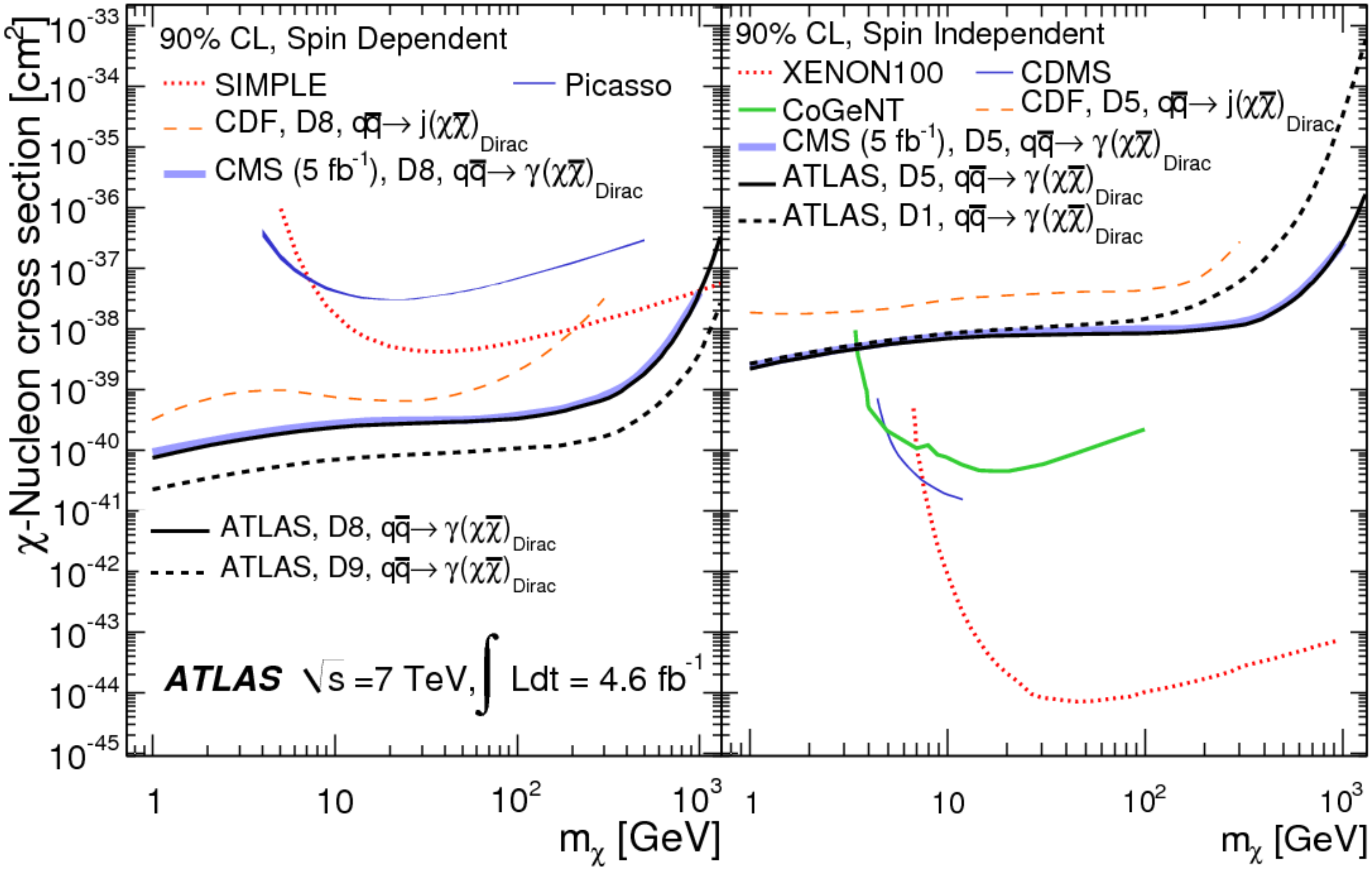


Weaker limits

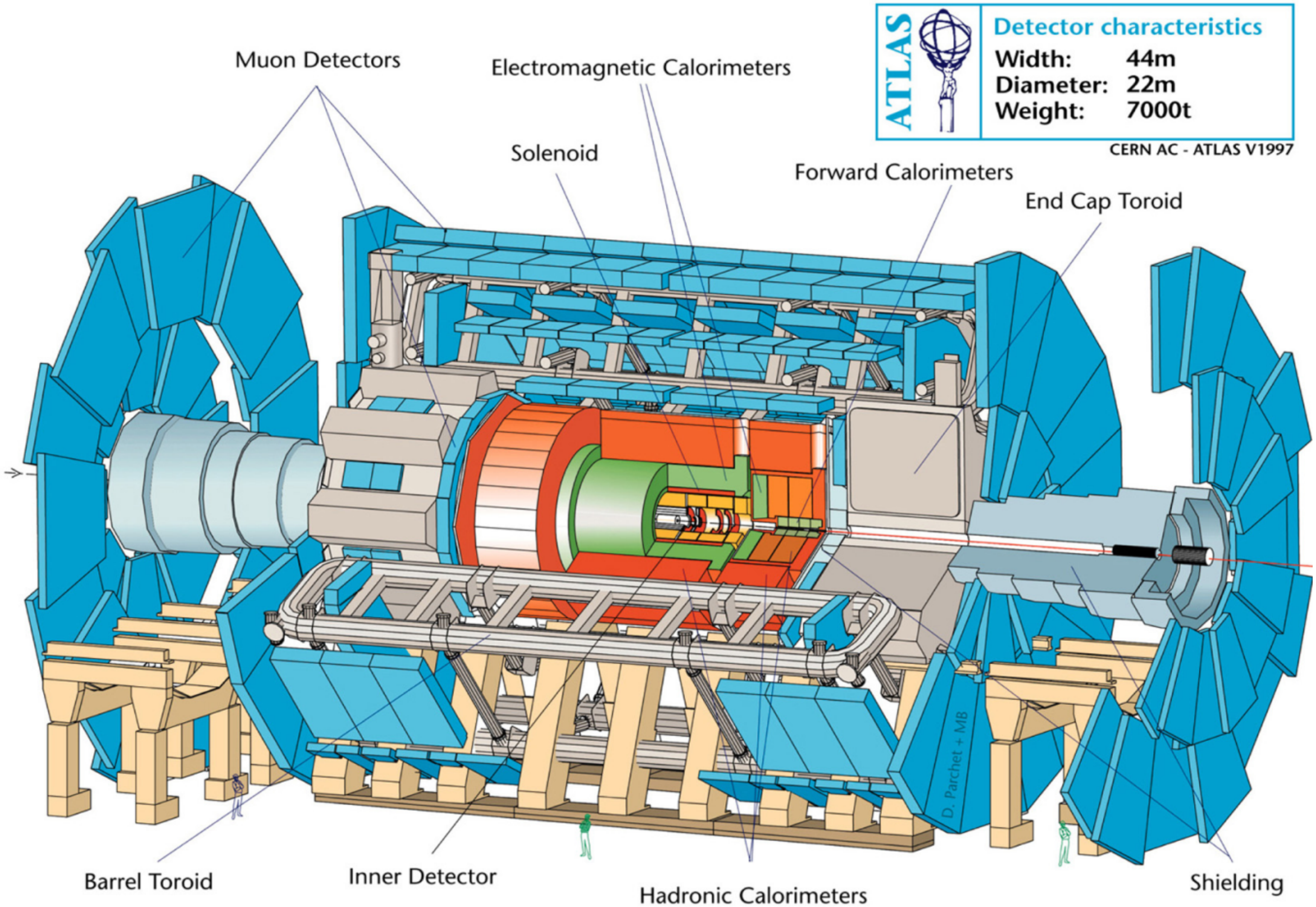
DM-nucleon scattering cross sections

arXiv:1209.4625

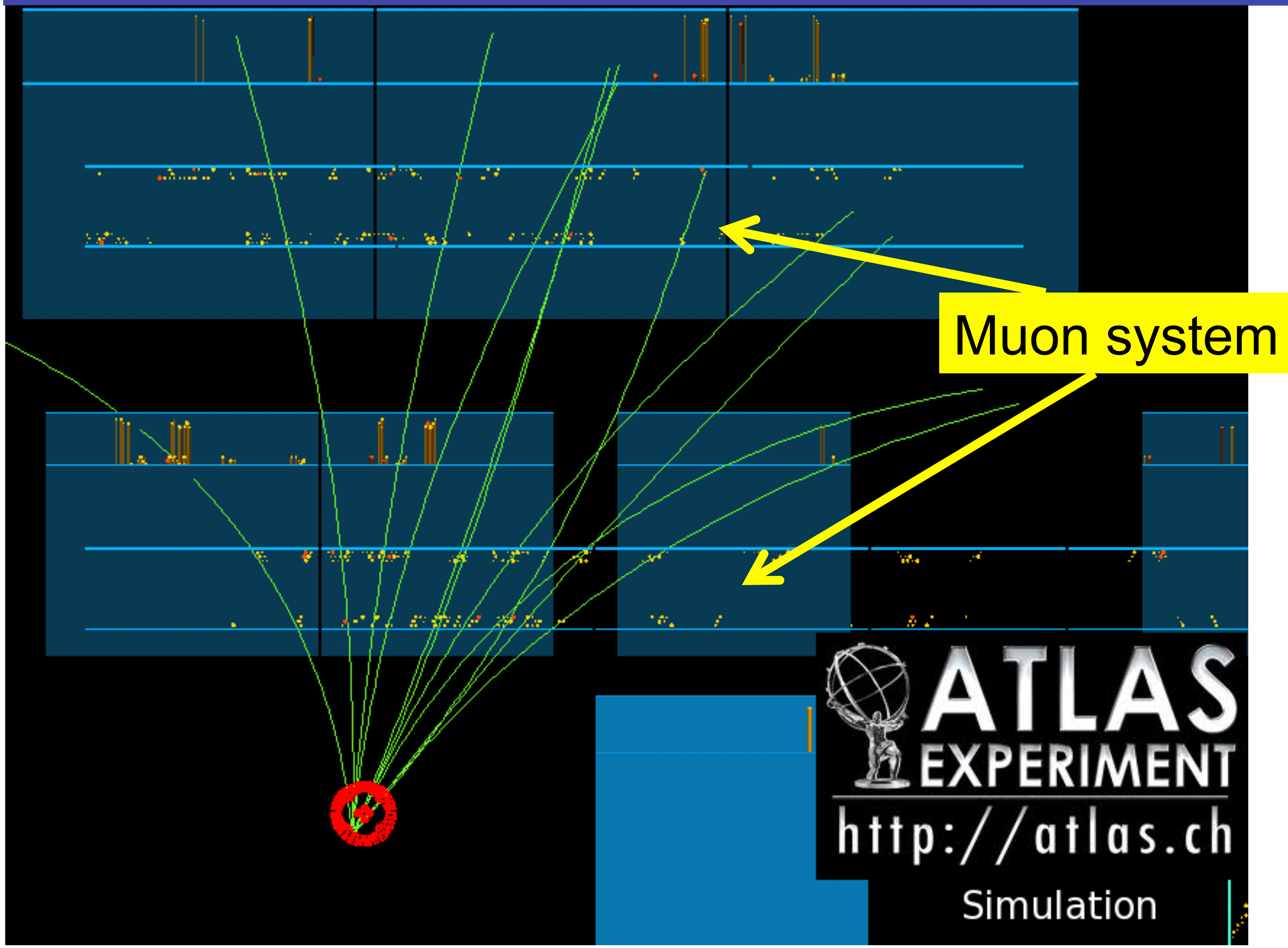
Mono photon analysis



Long lived particles in ATLAS

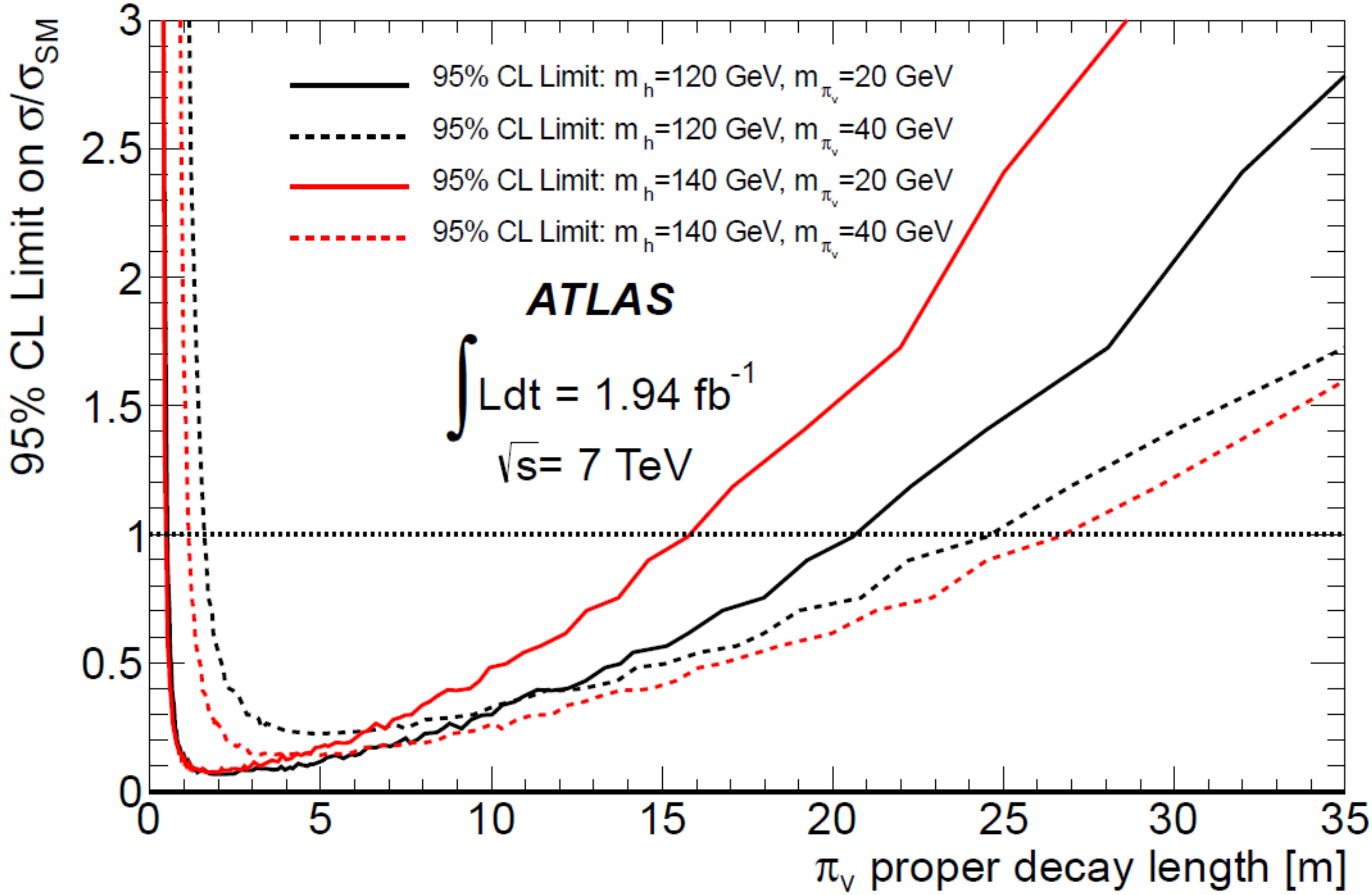


Long Lived weakly interacting particle decaying



Phys.Rev.Lett. 108 (2012) 251801

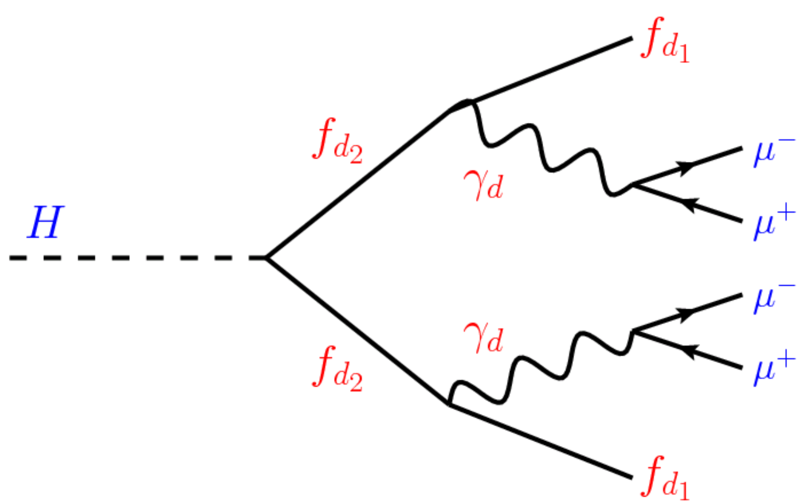
Limits $h \rightarrow \pi_v\ \pi_v$



Displaced Muonic Lepton Jets from Light Higgs

- Search for long-lived neutral particles
- Limits on
  - H → hidden-sector neutral long-lived particles
  - Focus on 100 GeV to 140 GeV mass range
    - Derive constraints on additional Higgs-like bosons
    - placing bounds on BR of discovered 126 GeV resonance into a hidden sector
- Relevant for other distinct models
  - heavier Higgs boson doublets,
  - singlet scalars
  - Z' that decay to a hidden sector

arXiv:1210.0435

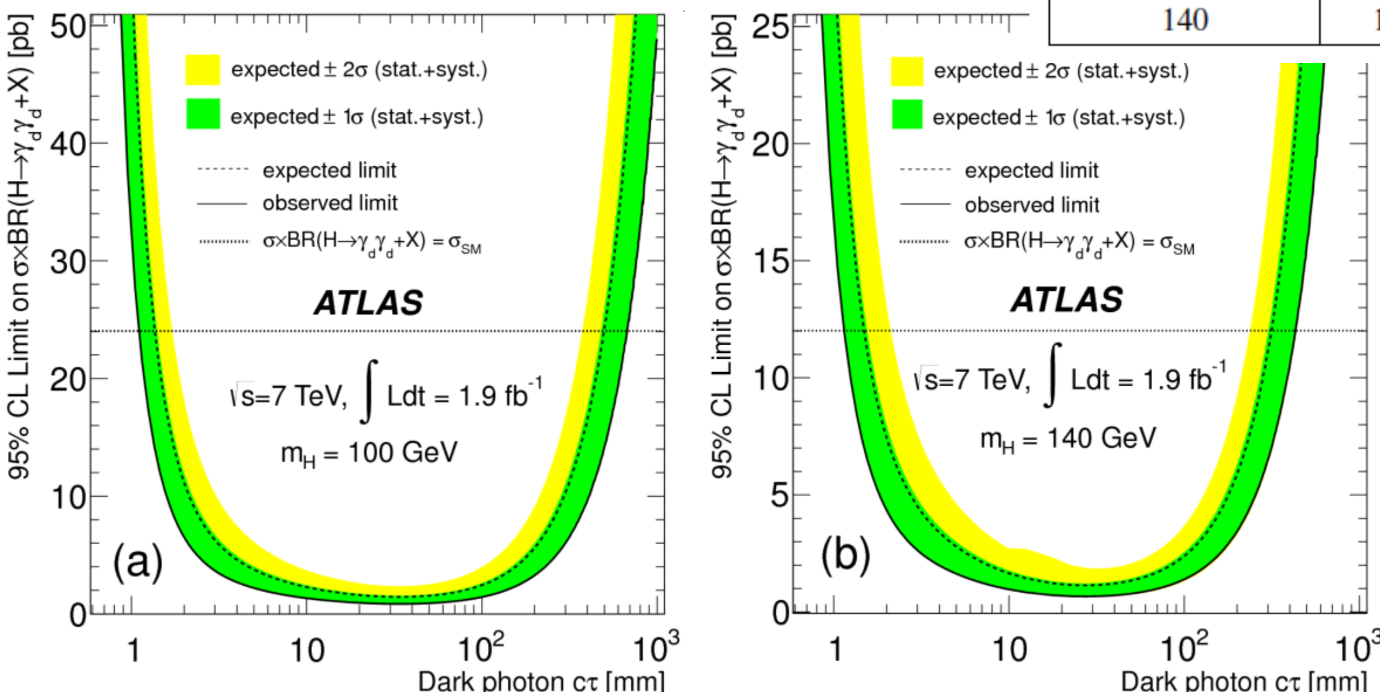


Displaced Muonic Lepton Jets from Light Higgs

- Neutral particles
  - with large decay lengths
  - with collimated final states
  - challenge for the trigger and for the reconstruction

arXiv:1210.0435

Higgs boson mass [GeV]	excluded $c\tau$ [mm] BR(100%)	excluded $c\tau$ [mm] BR(10%)
100	$1 \leq c\tau \leq 670$	$5 \leq c\tau \leq 159$
140	$1 \leq c\tau \leq 430$	$7 \leq c\tau \leq 82$



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