Angular correlations in top quark pair & single top events with ATLAS

BERKELEY LAB

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Lawrence Berkeley National Laboratory

Top Quark Physics at the Precision Frontier

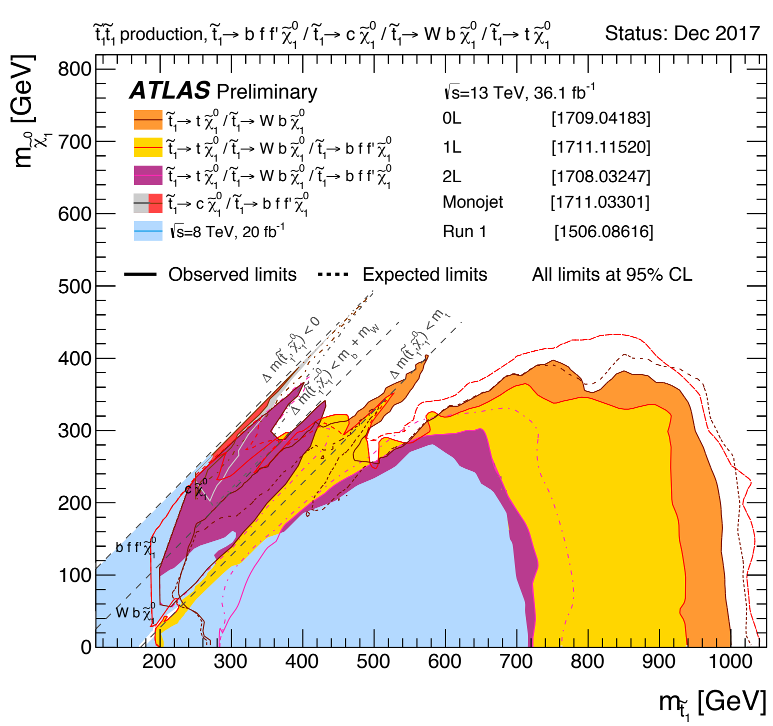
ATLAS EXPERIMENT

Overview

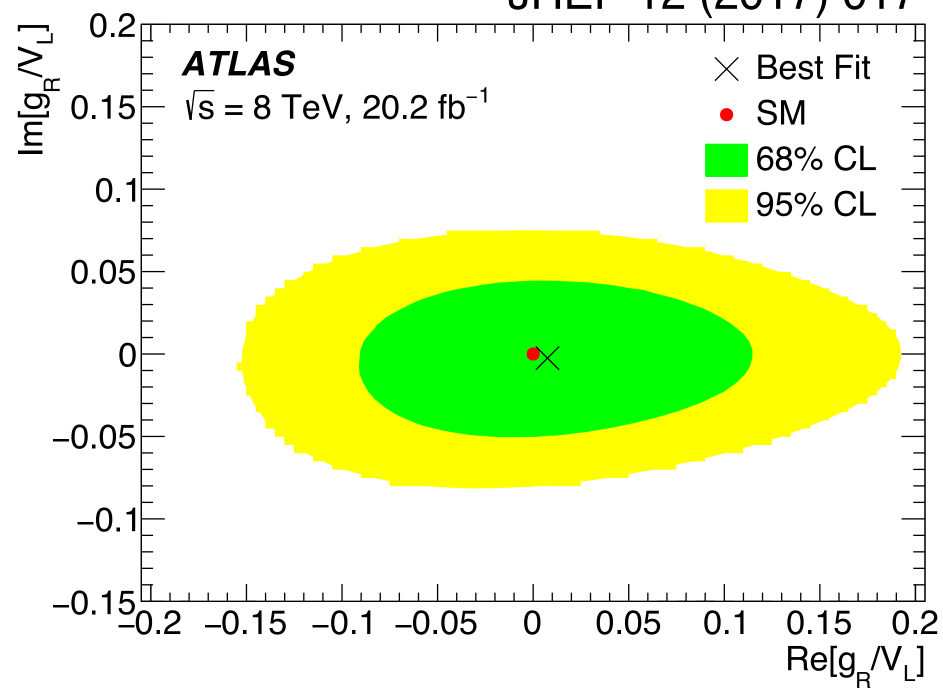
Angular correlations in top events are an interesting probe for **(in)direct BSM** as well as for **over-constraining the SM**.

Unlike cross-section or mass measurements, they are less sensitive to the jet energy scale and PDFs.

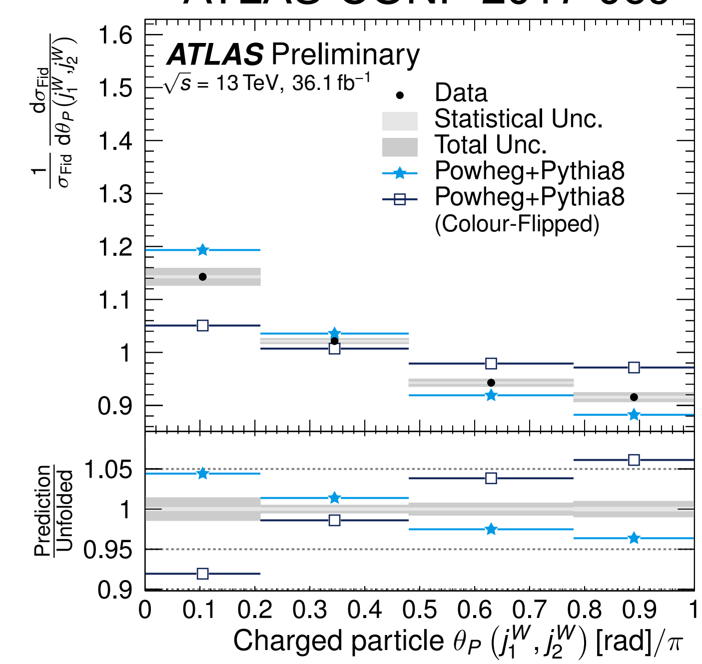
ATLAS has performed many such measurements; in this talk, I'll focus on three important results.



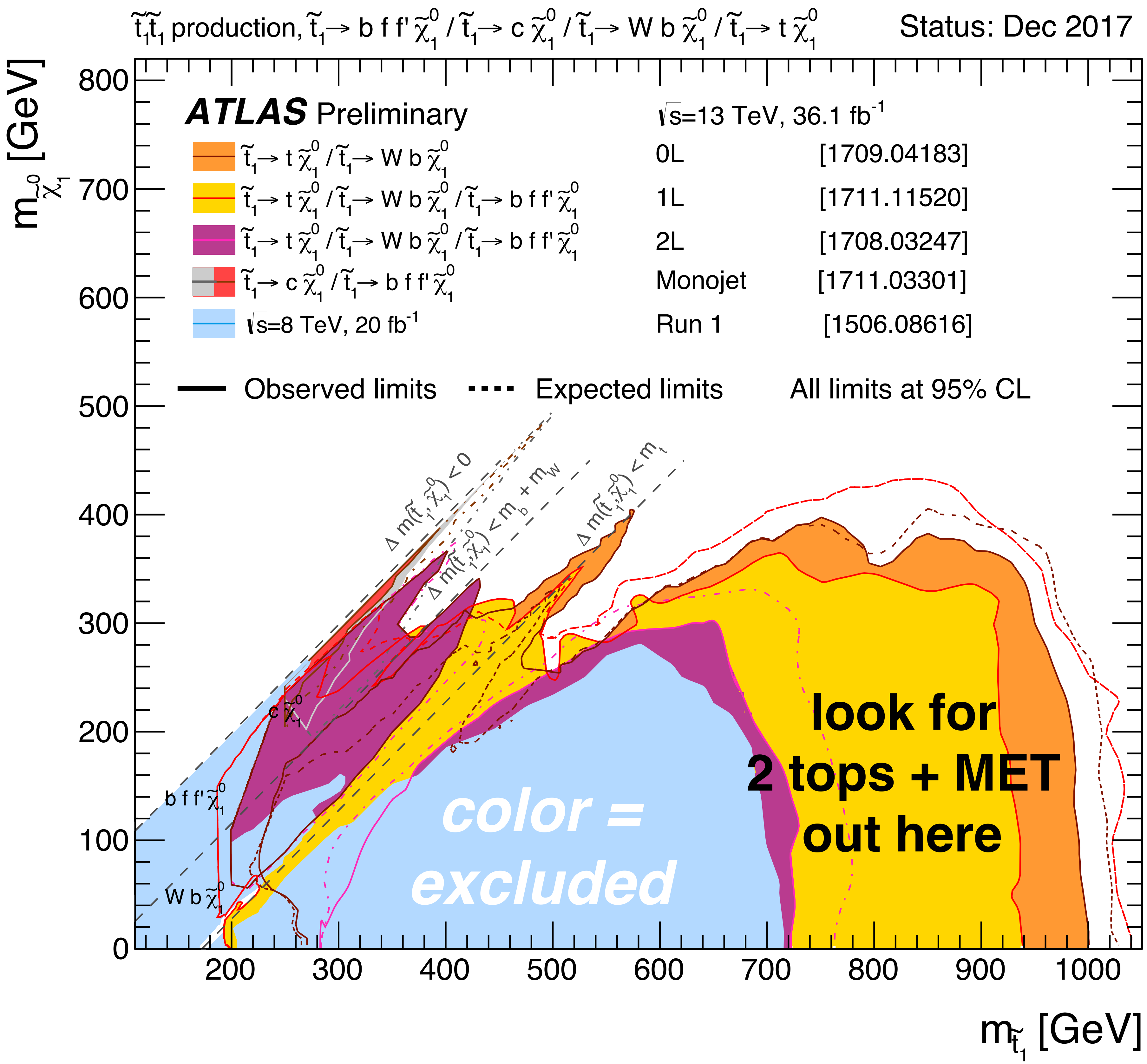
JHEP 12 (2017) 017



ATLAS-CONF-2017-069

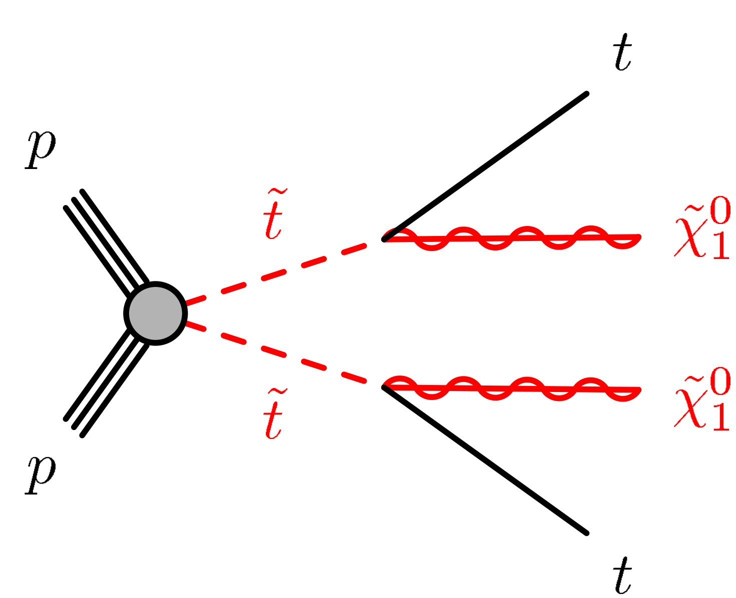


Part I: Direct BSM

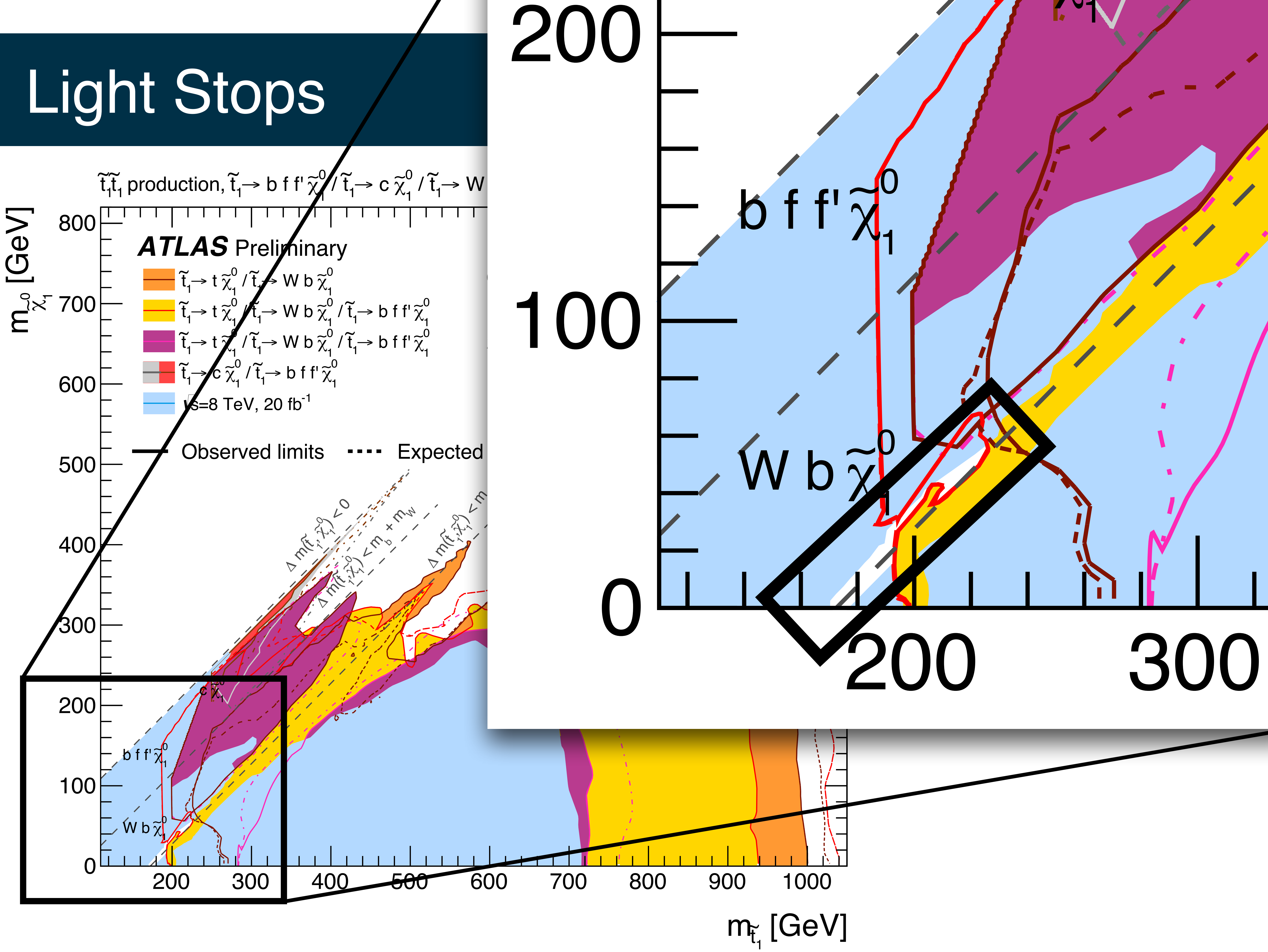


Top-like BSM particles modify measured cross-section but we can also probe with angles if their spin is different.

This includes scalars (stops, LQs) or vectors (LQs)



Light Stops



$\tilde{t}_1\tilde{t}_1$ production, $\tilde{t}_1 \to b f f' \tilde{\chi}_1^0$ / $\tilde{t}_1 \to c \tilde{\chi}_1^0$ / $\tilde{t}_1 \to W$
ATLAS Preliminary
$\tilde{t}_1 \to t \tilde{\chi}_1^0$ / $\tilde{t}_1 \to W b \tilde{\chi}_1^0$
$\tilde{t}_1 \to t \tilde{\chi}_1^0$ / $\tilde{t}_1 \to W b \tilde{\chi}_1^0$ / $\tilde{t}_1 \to b f f' \tilde{\chi}_1^0$
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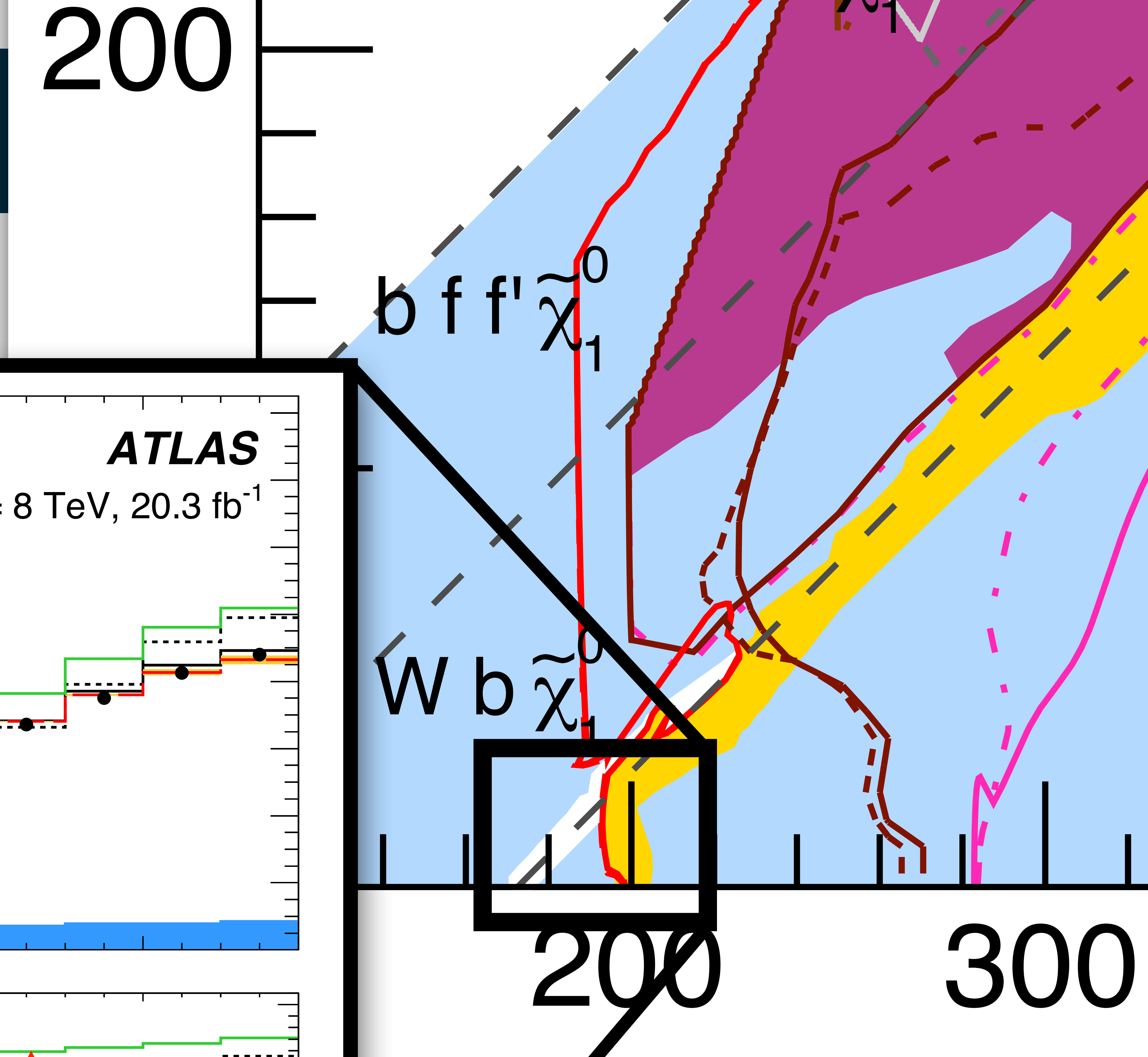
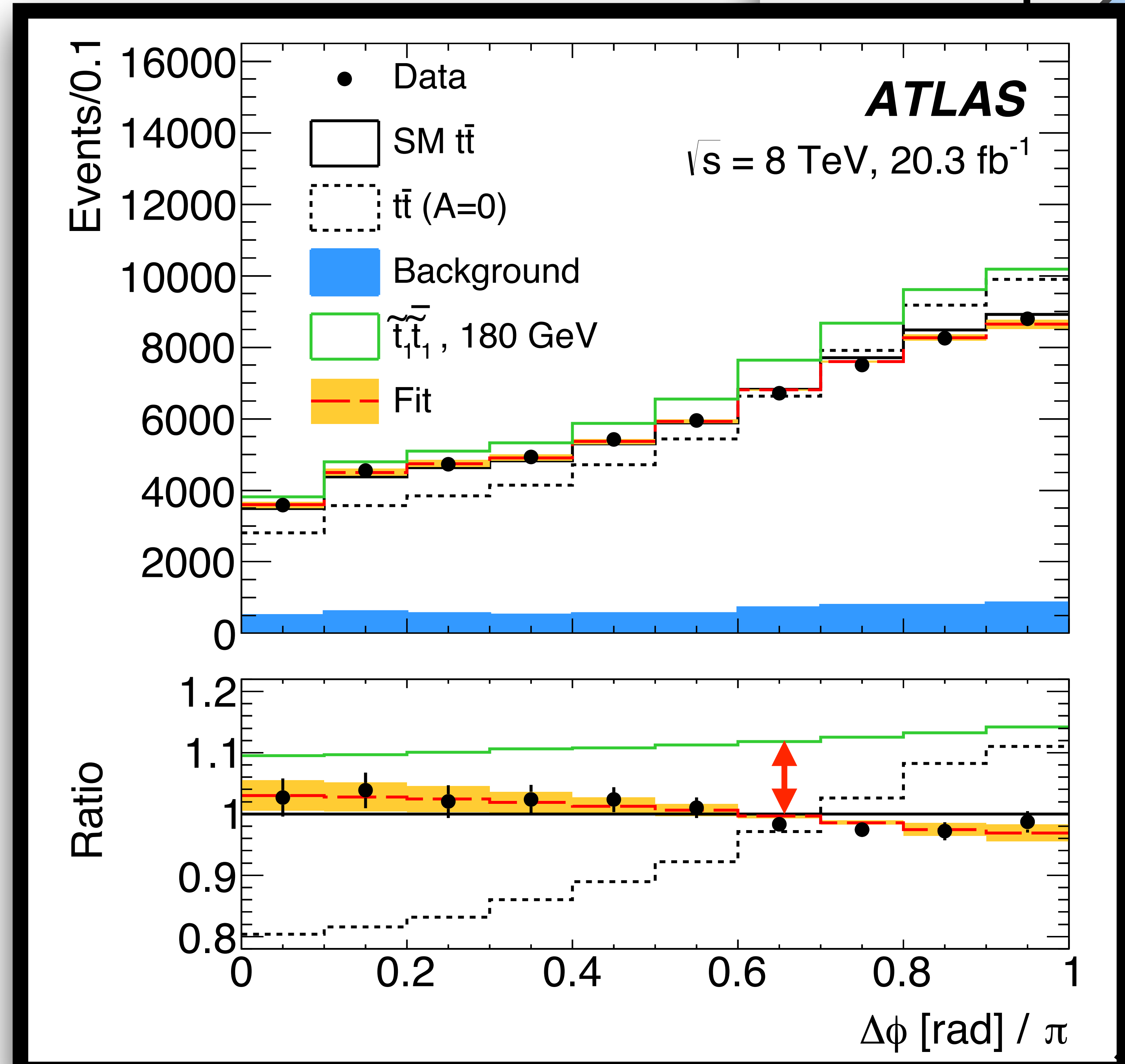
$\tilde{t}_1 \to c \tilde{\chi}_1^0$ / $\tilde{t}_1 \to b f f' \tilde{\chi}_1^0$
$\sqrt{s}$=8 TeV, 20 fb^{-1}
Observed limits
Expected
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{t}_1}$ [GeV]
$\Delta m(\tilde{t}_1, \tilde{\chi}_1^0) < 0$
$\Delta m(\tilde{t}_1, \tilde{\chi}_1^0) < m_b + m_W$
$c \tilde{\chi}_1^0$
$b f f' \tilde{\chi}_1^0$
$W b \tilde{\chi}_1^0$

Light Stops



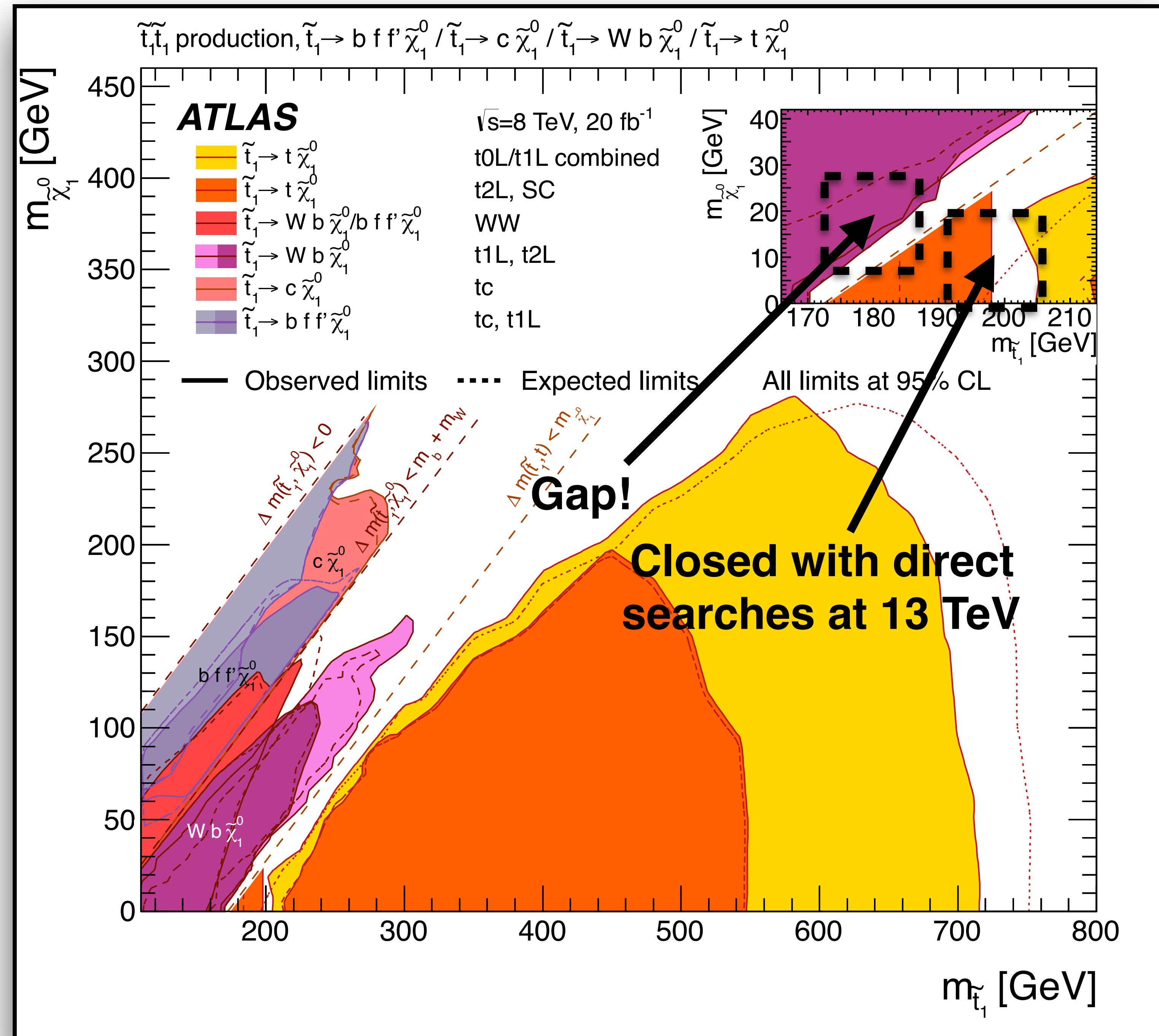


From **xs alone**: up to 180 GeV

Using **shape**: up to 185 GeV

(expected limits)

Light Stops



Can we close the gap?

-already systematics limited

- get a small gain from sqrt(s)

- get a small gain from improved xs precision

-signal modeling is challenging

N.B. right-handed + bino LSP - not conservative!

Light Stops

Source of uncertainty	Δf_{SM}
Detector modeling	
Lepton reconstruction	± 0.01
Jet energy scale	± 0.02
Jet reconstruction	± 0.01
$E_{\mathrm{T}}^{\mathrm{miss}}$	< 0.01
Fake leptons	< 0.01
b-tagging	< 0.01
Signal and background modeling	
Renormalization/factorization scale	± 0.05
MC generator	± 0.03
Parton shower and fragmentation	± 0.06
ISR/FSR	± 0.06
Underlying event	± 0.04
Color reconnection	± 0.01
PDF uncertainty	± 0.05
Background	± 0.01
MC statistics	± 0.04
→ Total systematic uncertainty	± 0.13
→ Data statistics	± 0.05

does not include top cross section uncertainties

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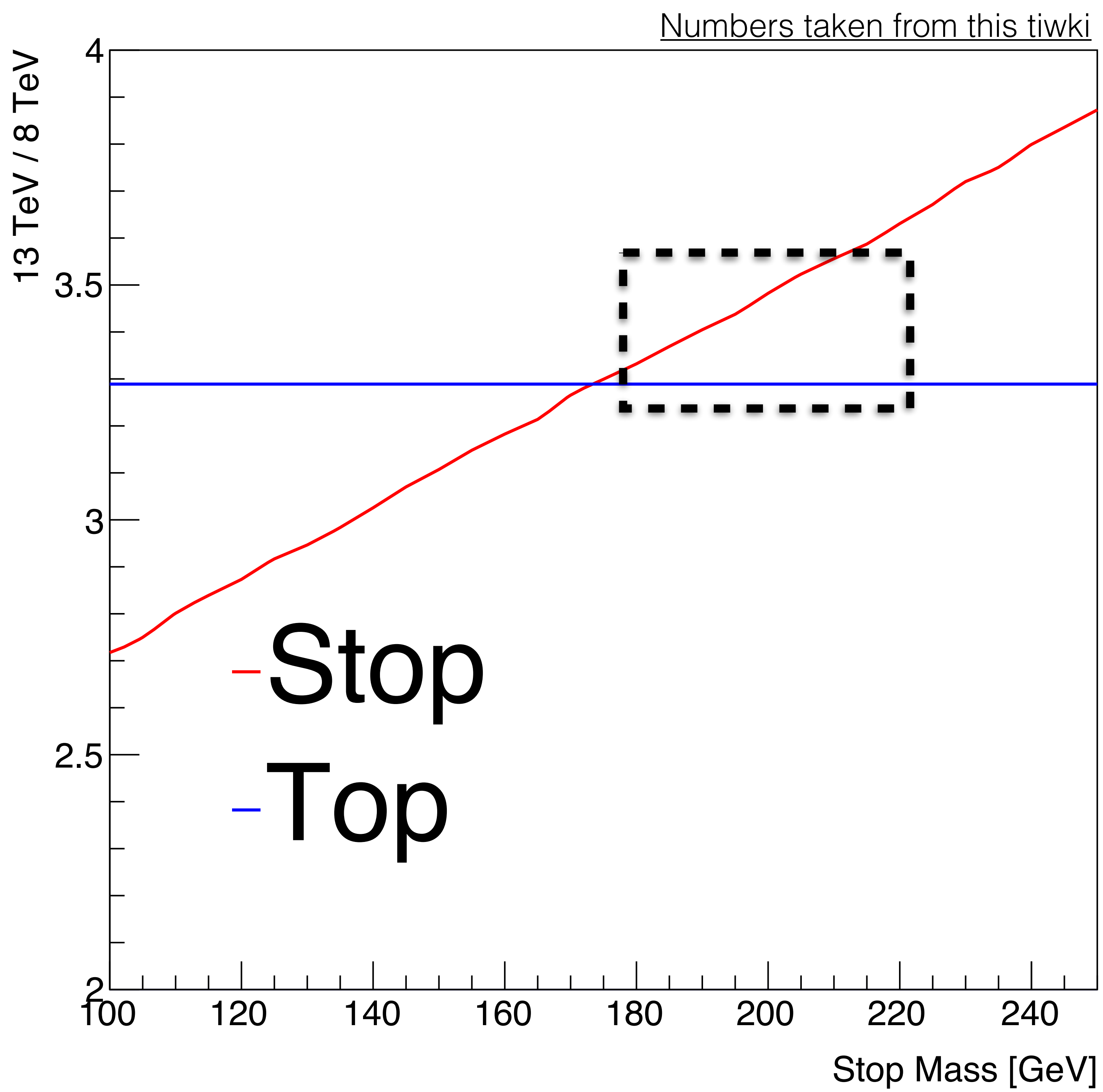

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Phys. Rev. Accel. Beams 20 (2017) 081003

Nominal momentum (GeV/c)	Actual momentum (GeV/c)	Relative uncertainty (%)
450	450.31	0.024
1380	1380	0.1
2510	2510	0.1
3500	3500	0.1
4000	4000	0.1
6370	6370	0.1
6500	6500	0.1

(was 0.7% for the paper; at least for the xs measurement, this was same size as exp. uncertainty)

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Light Stops

(1) Need high precision MC, also for uncertainties, on signal

(2) Off-shell tops require careful treatment for spin correlations

(3) Interplay with the top mass

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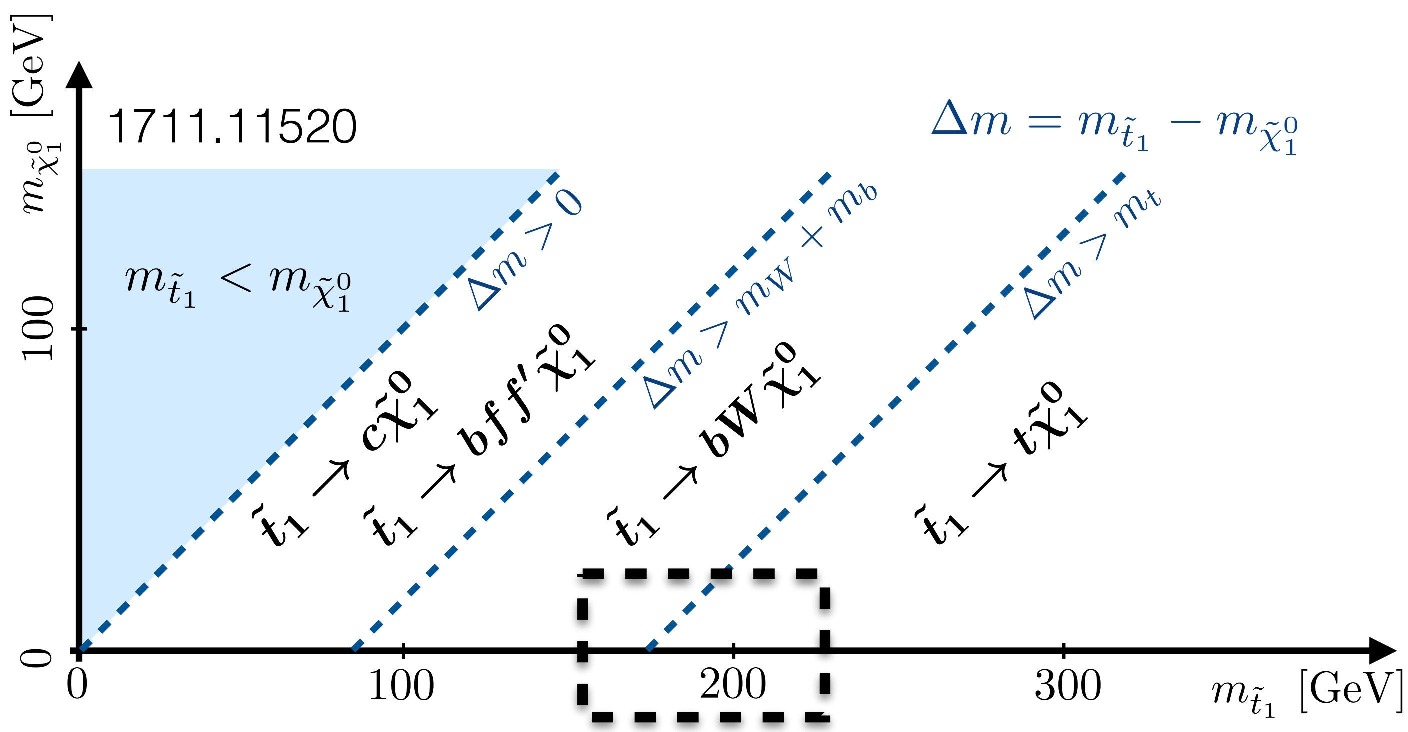

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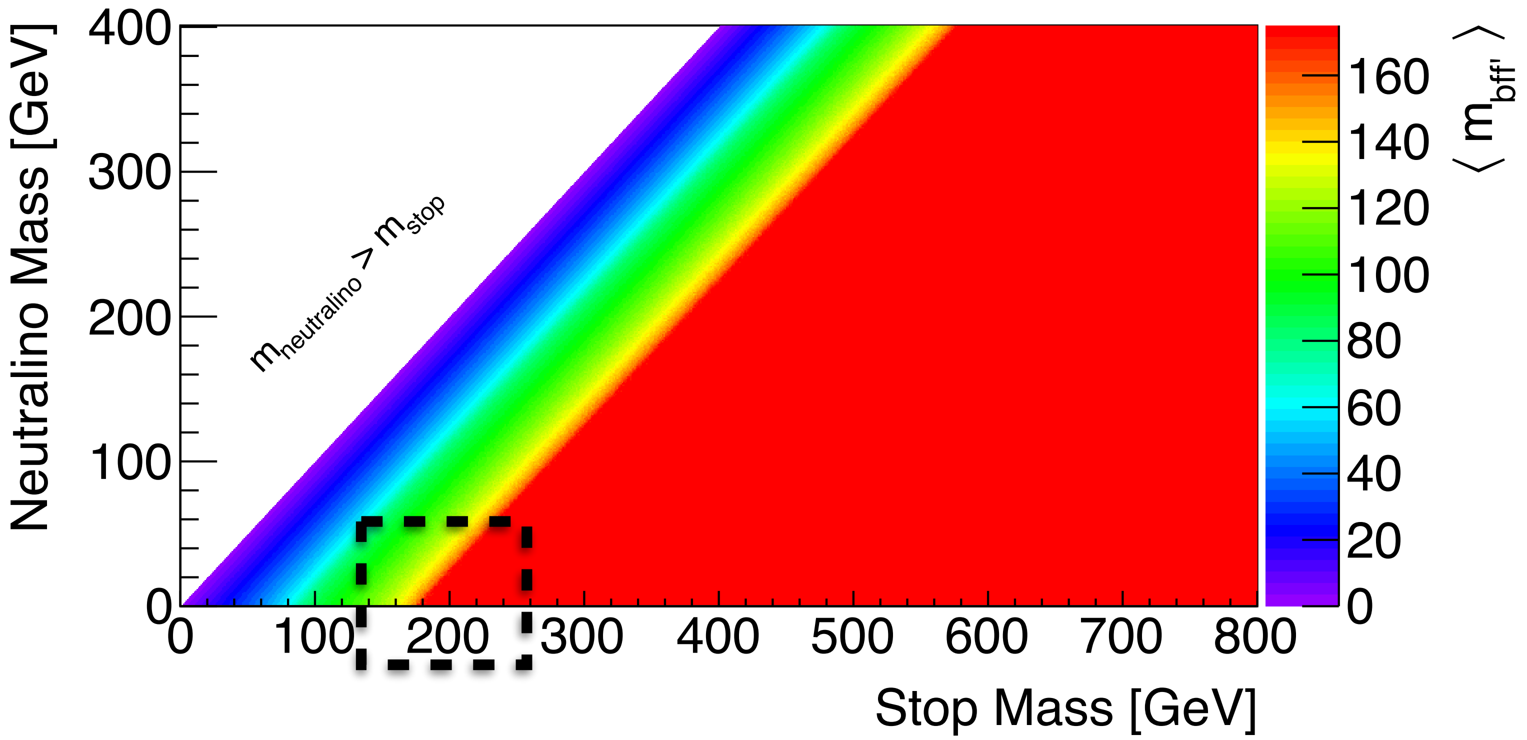

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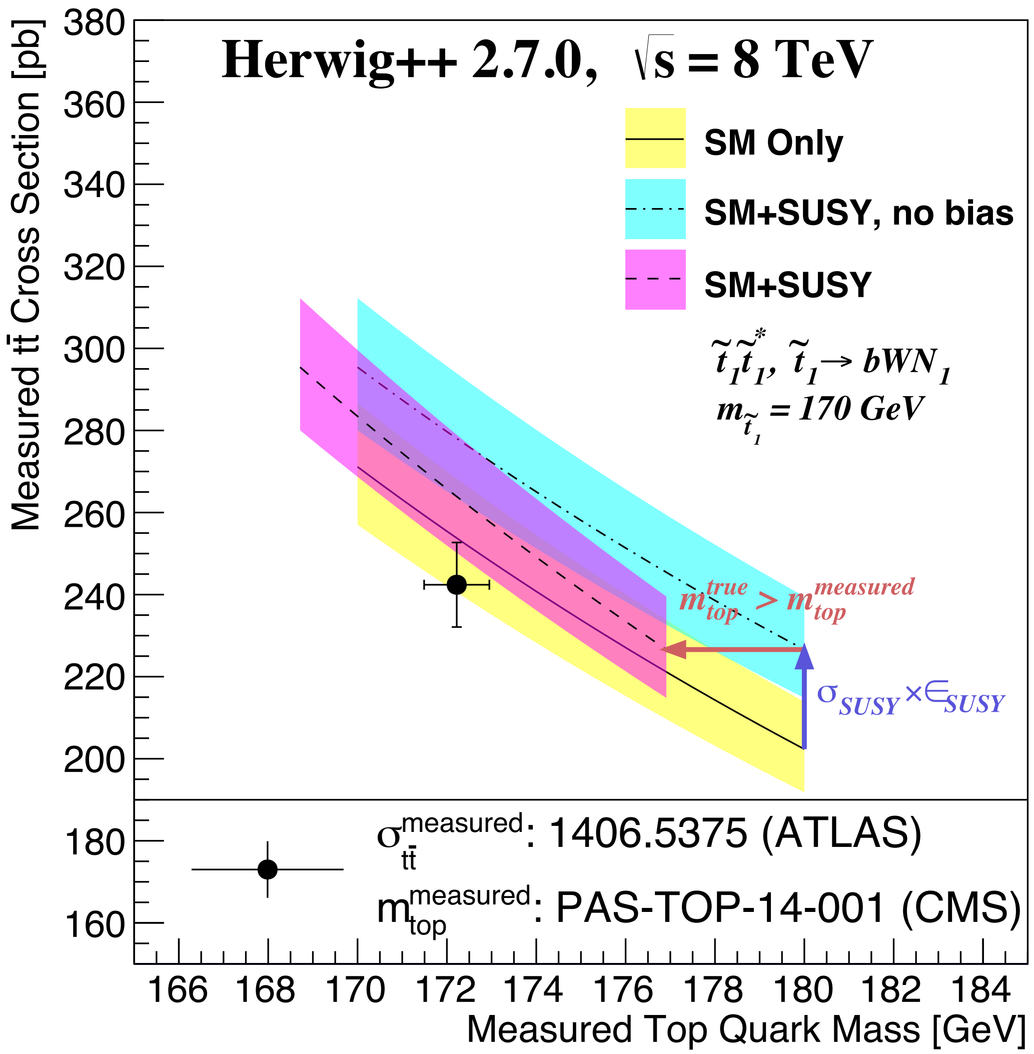

PLB 743 (2015) 218

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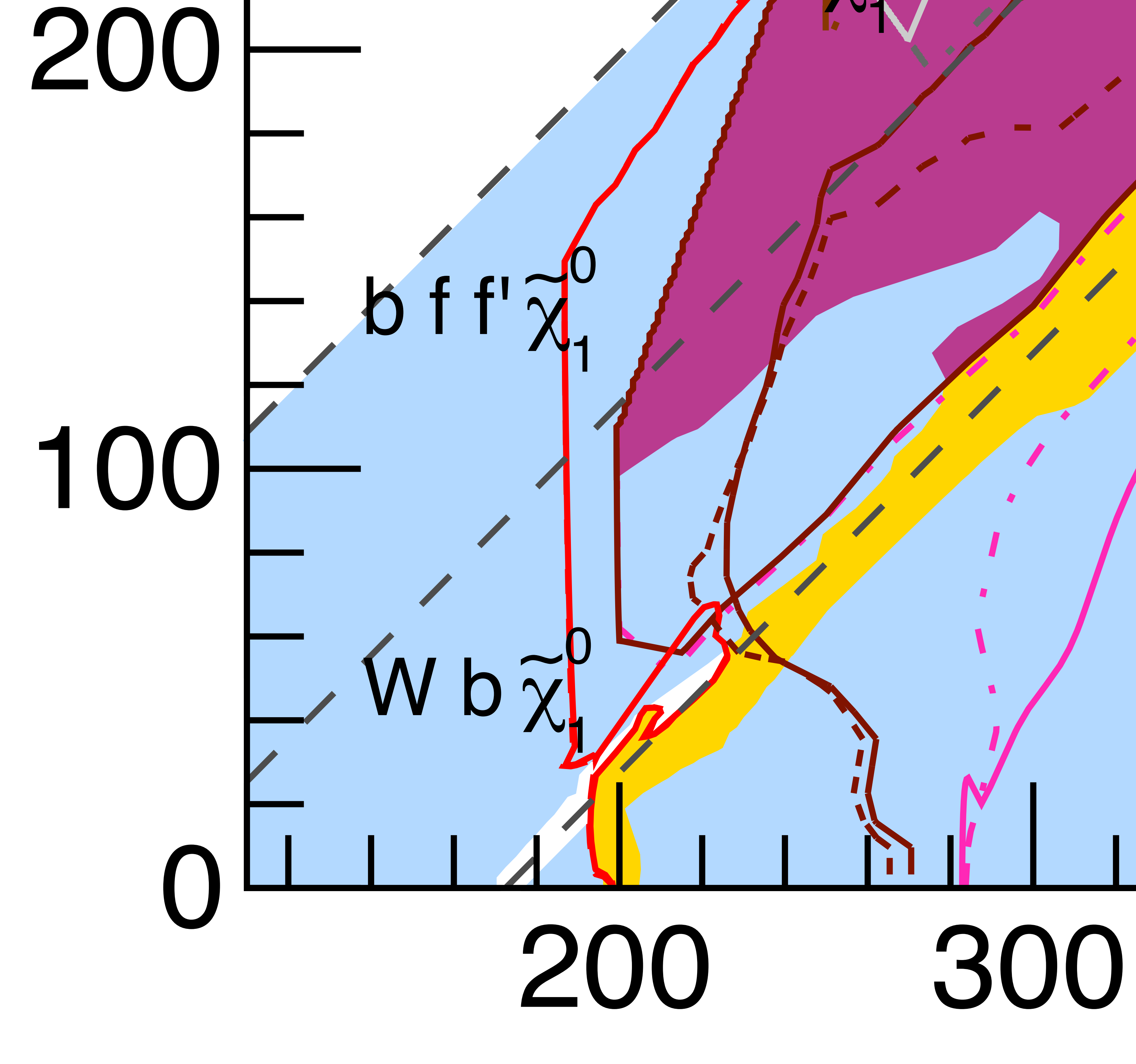
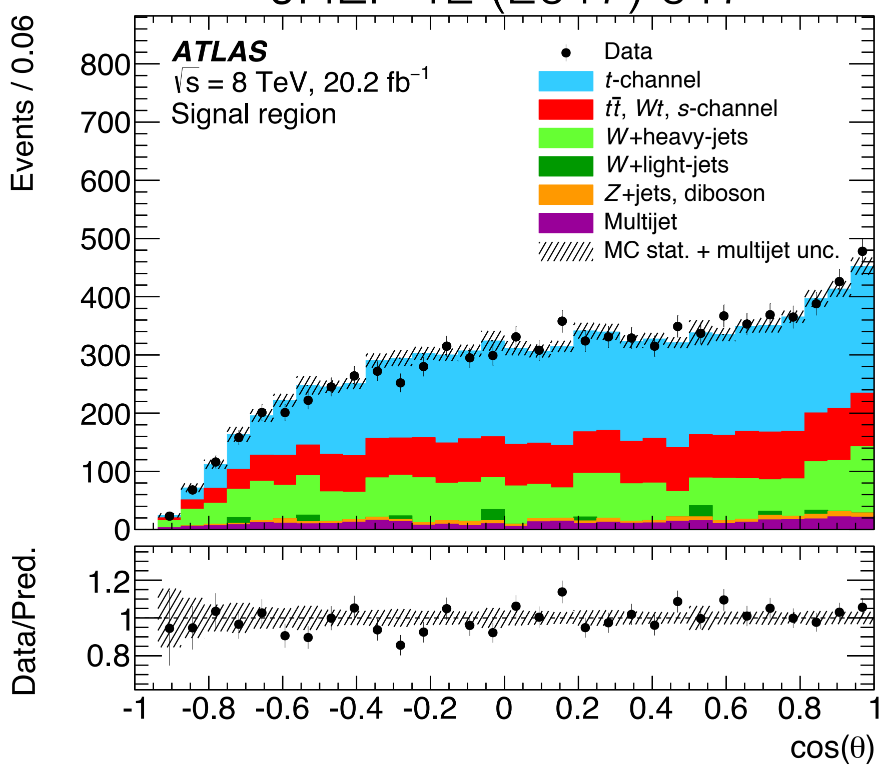


Upshot: **It won't come for free**, but if we work hard, then it should be possible to **close** the sneaky light stop **gap** still during Run 2.

N.B. this applies also for scalar leptoquarks.

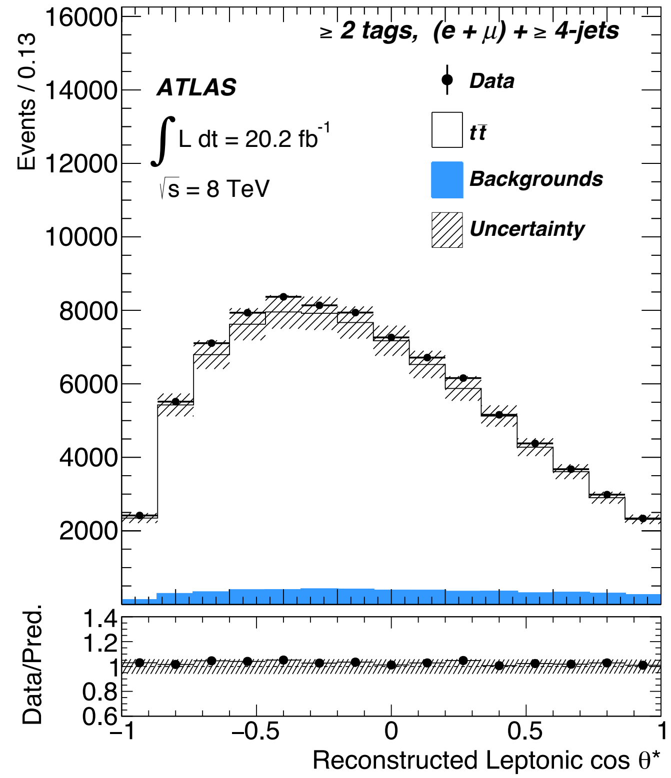
Part II: Indirect BSM (all from 2017!)

JHEP 12 (2017) 017



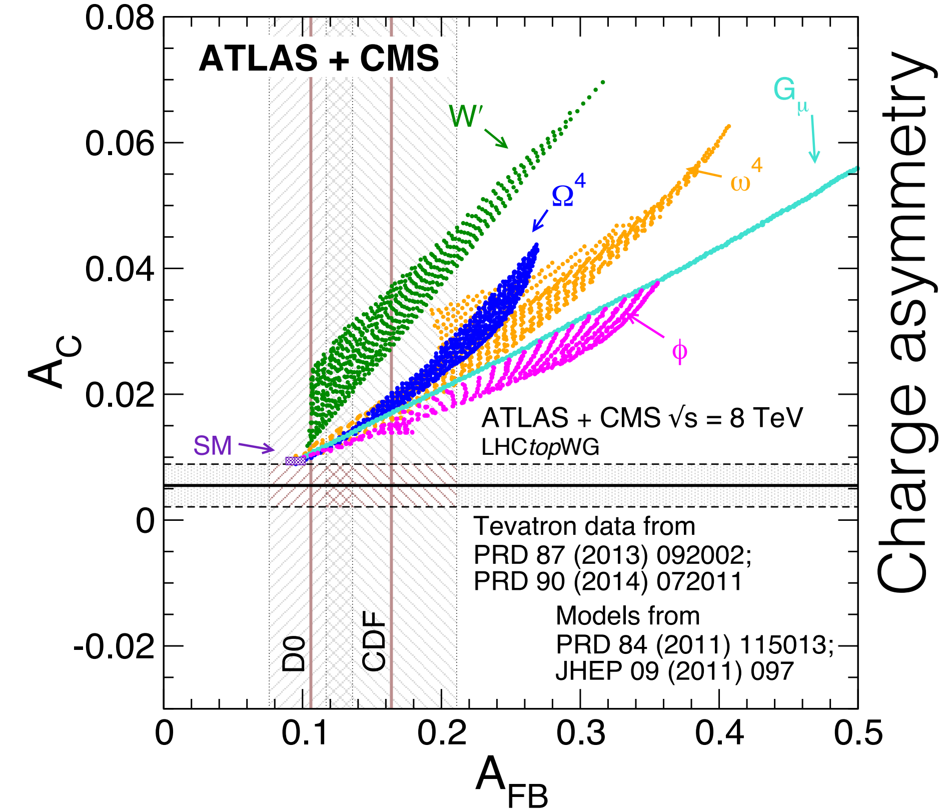
angles in single-lepton t-channel

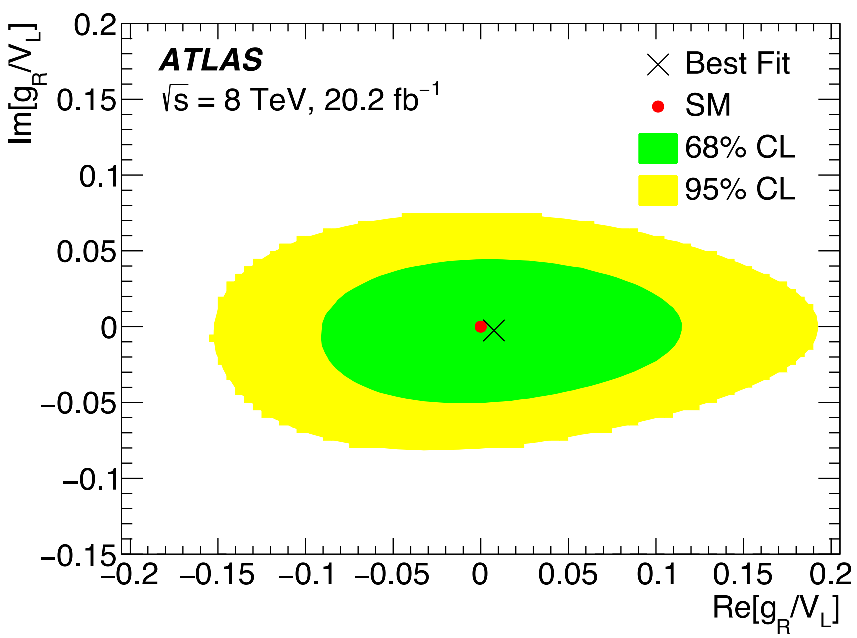
Eur. Phys. J. C 77 (2017) 264



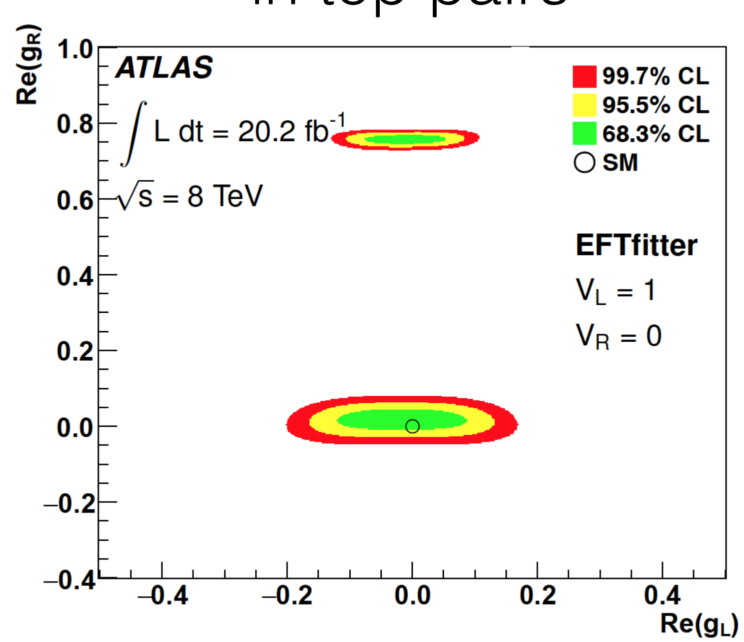
single-lepton in top pairs

1709.05327





see also JHEP04 (2017) 124

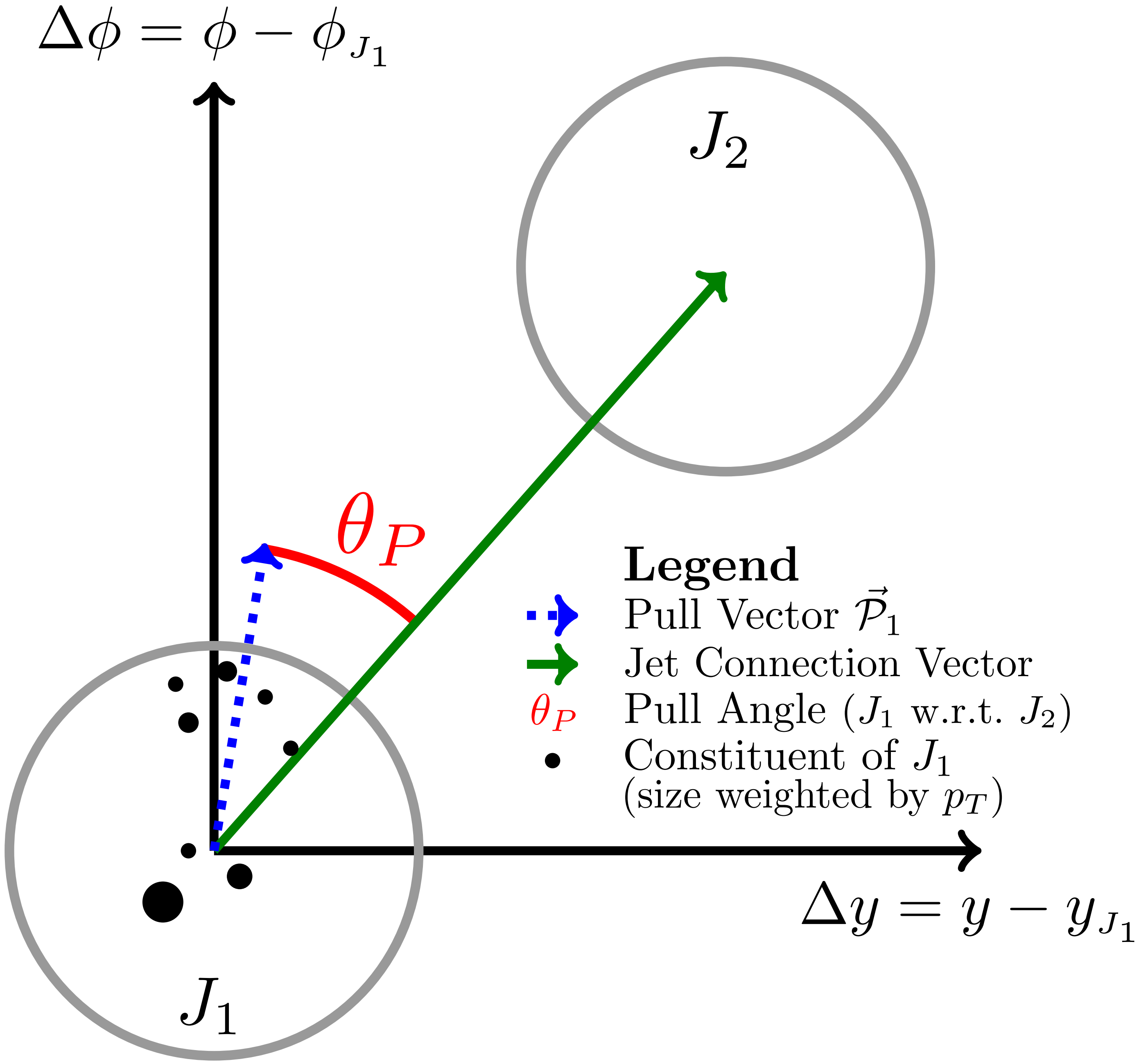


High-scale BSM could manifest as non-resonant modifications to the SM

Precise angular measurements ideal for constraining!

➔ See Jim Mueller's talk

The only way to get a clean sample of jet originating from a singlet decay (since LEP)



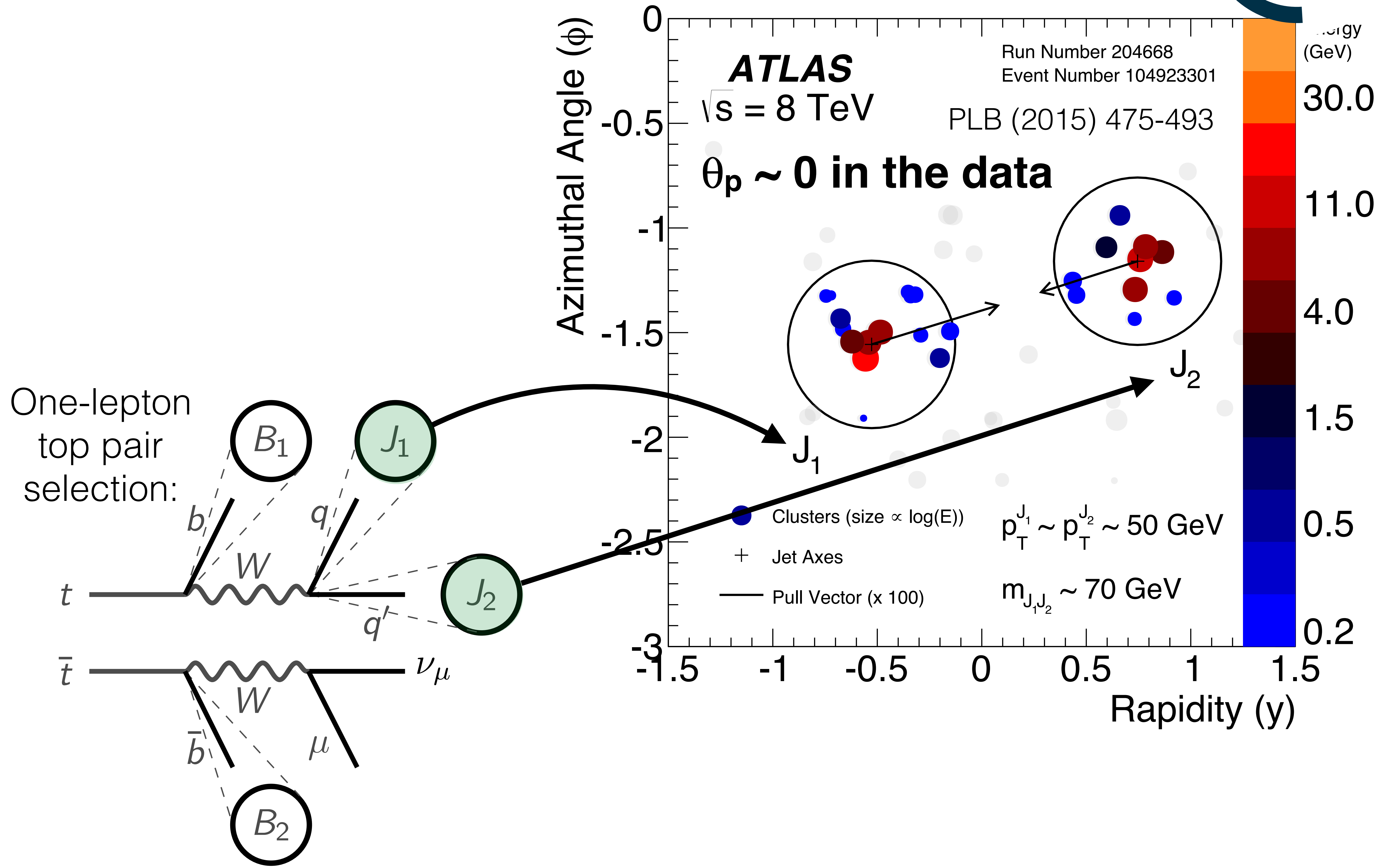
Step 1: How singlet-like is it?

Tool: Jet superstructure - the interplay between jet substructure and global radiation / kinematics.

$$\vec{\mathcal{P}}(J) = \sum_{i \in J} \frac{\left|\vec{\Delta r}_i\right| \cdot p_{\mathrm{T}}^i}{p_{\mathrm{T}}^J} \vec{\Delta r}_i$$

Question: how much does the radiation from one jet lean towards the other?

Hadronic Correlations: Jet Superstructure



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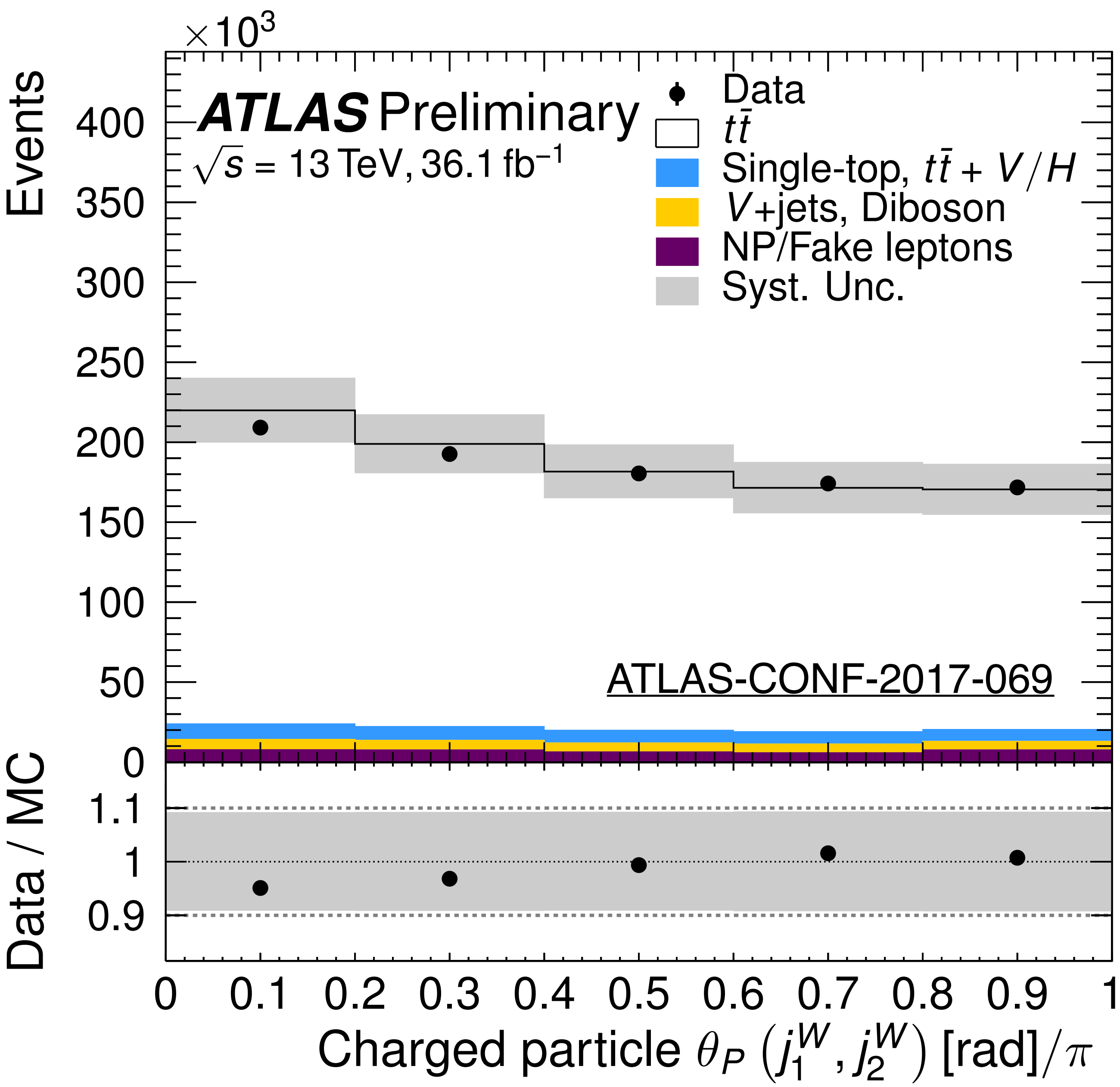
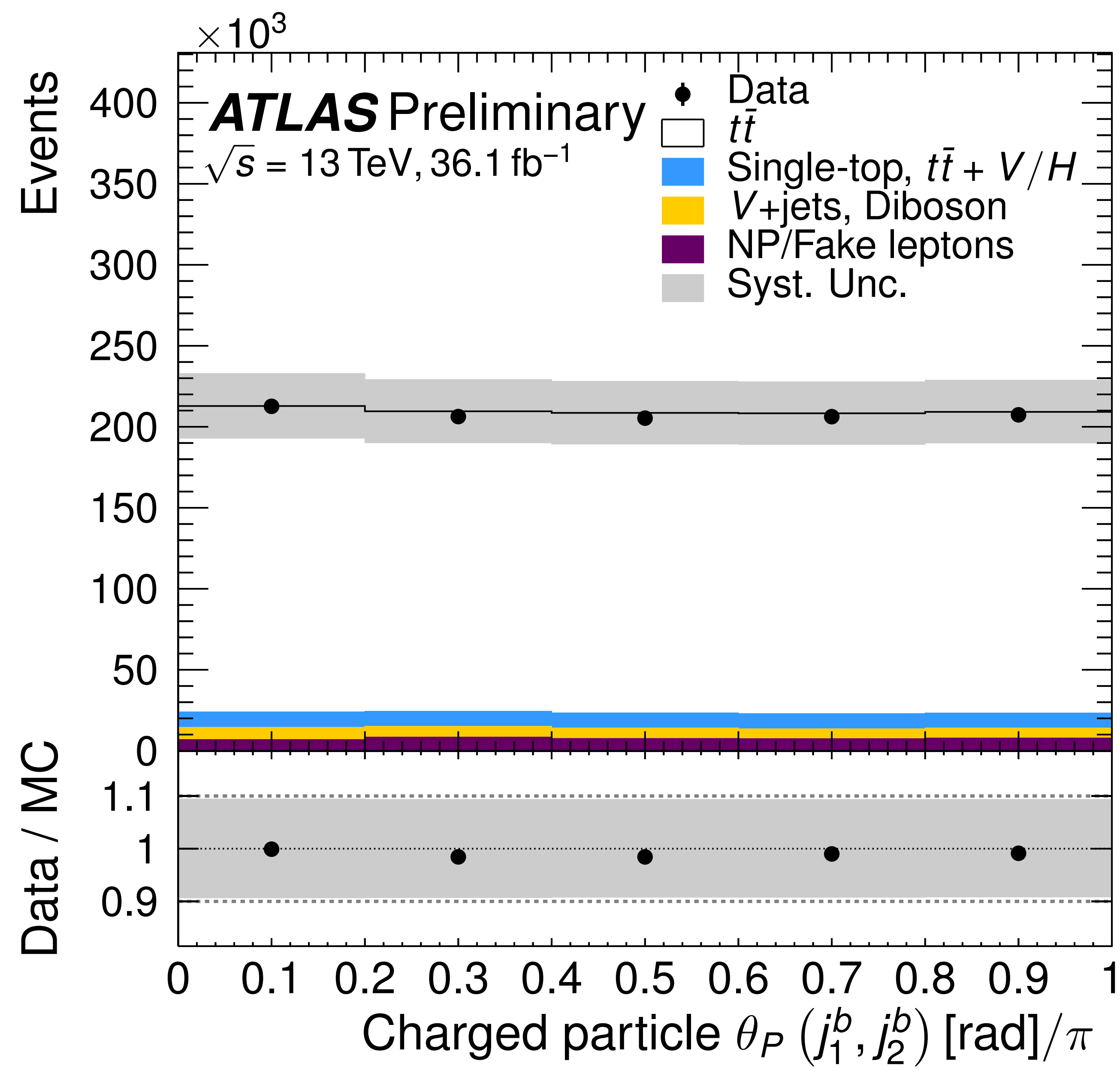


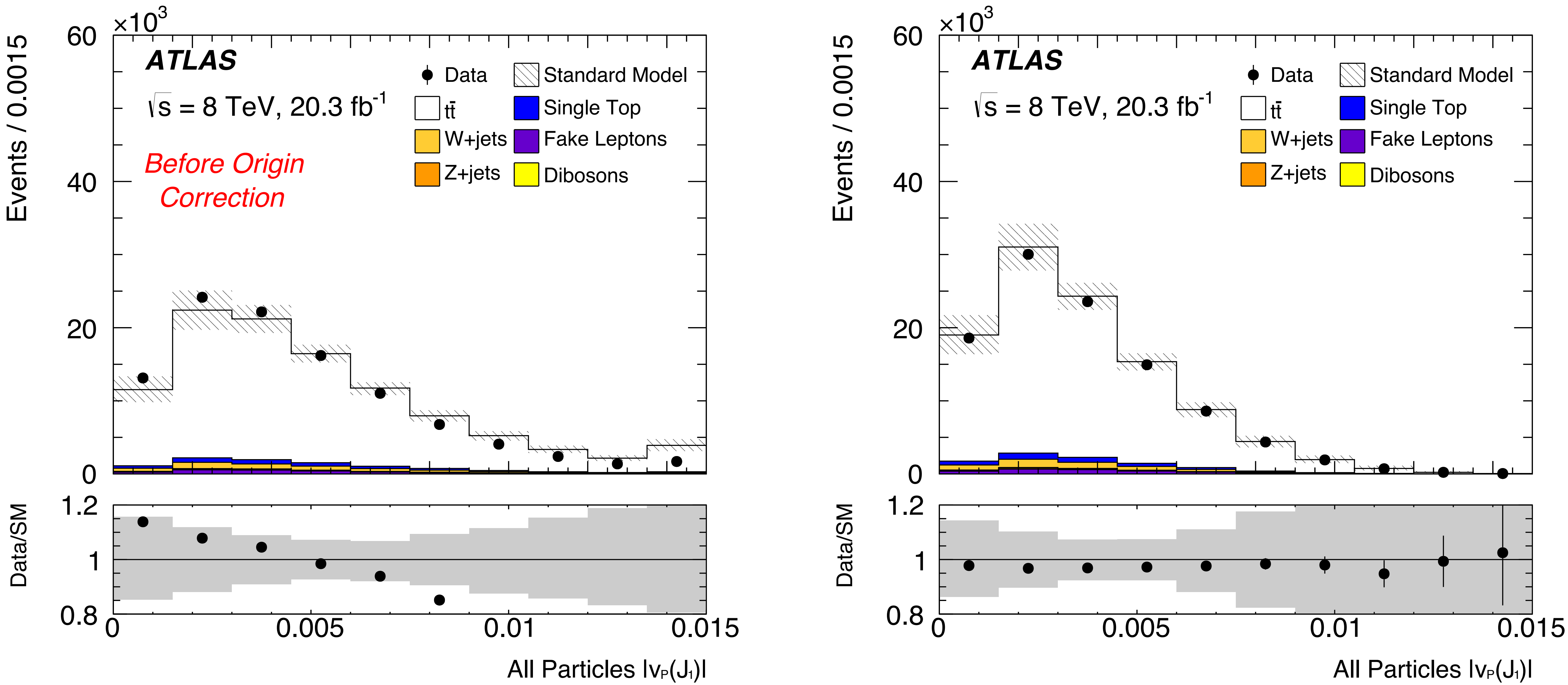


peak at 0 - W daughters are “connected”

no peak - b’s are not connected

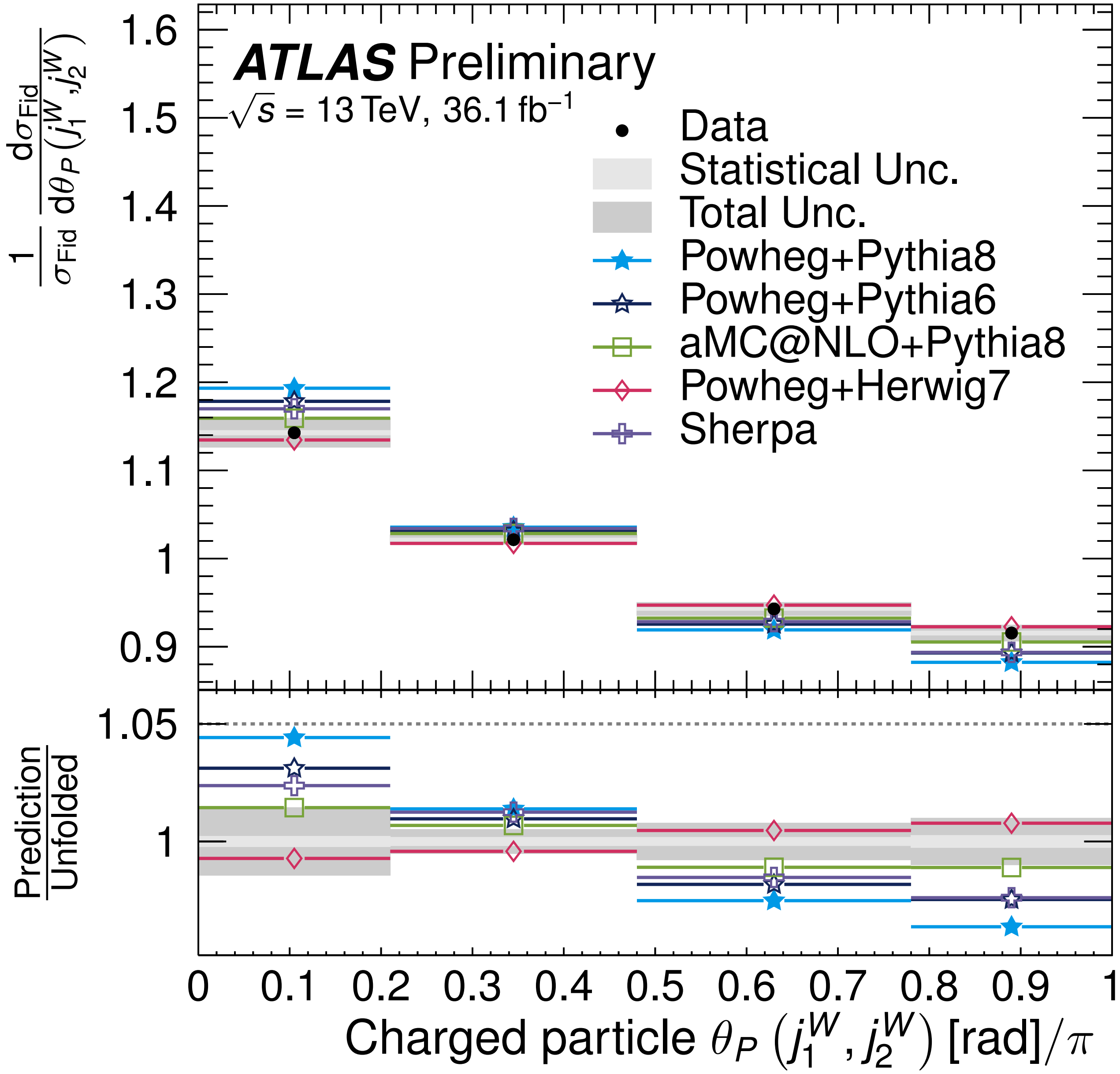
Jet Pull: Experimental Challenges

Measuring hadronic correlations is
much harder than leptonic ones.



For example: origin corrections are crucial!
(axis is the magnitude of the pull vector)

Jet Pull for MC Tuning

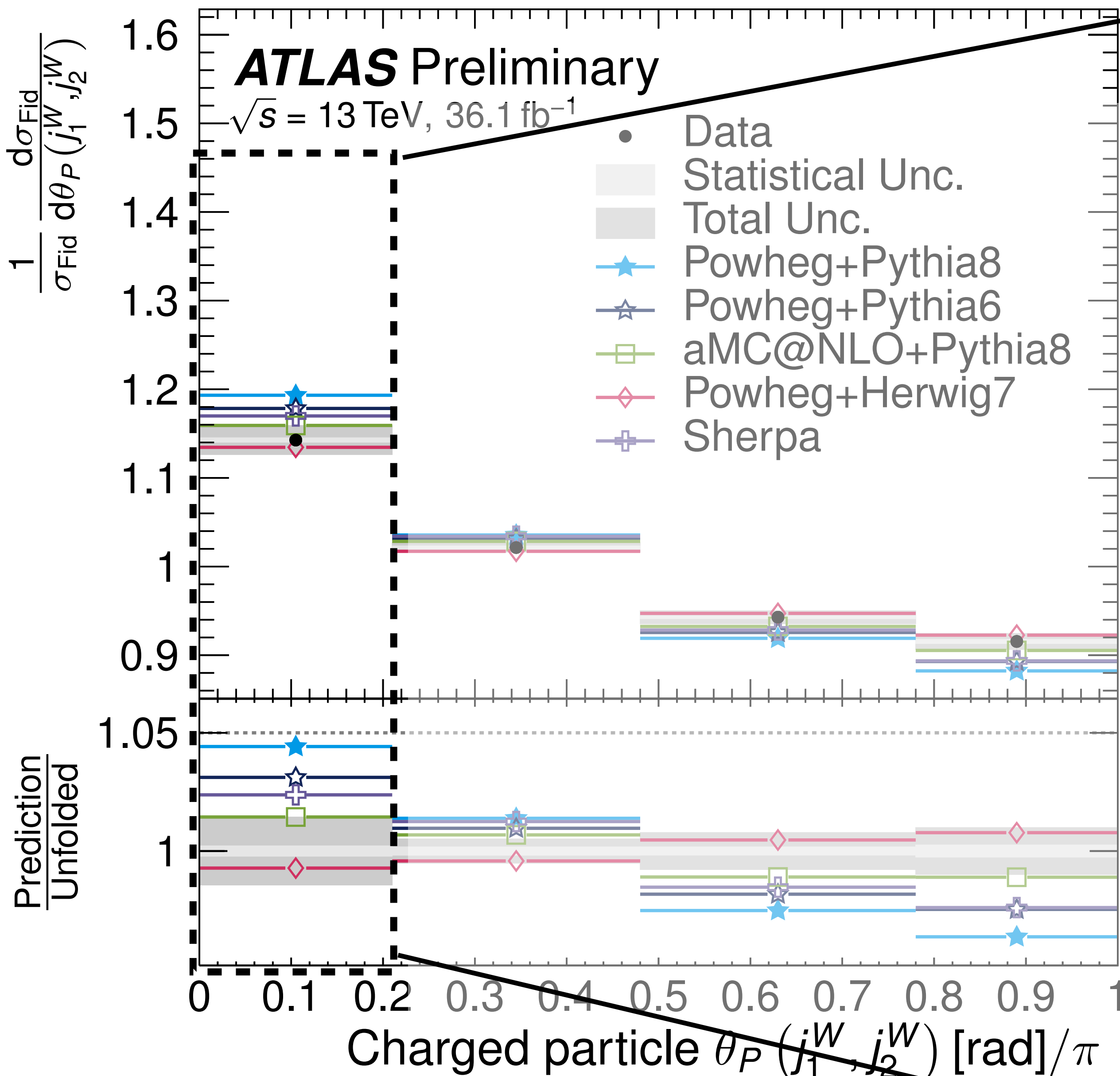


Despite the challenges, we can measure the angle to the 1%-level

Interestingly, there is a rather large spread in the MC predictions.

(useful for tuning!)

Jet Pull: Systematic Uncertainties

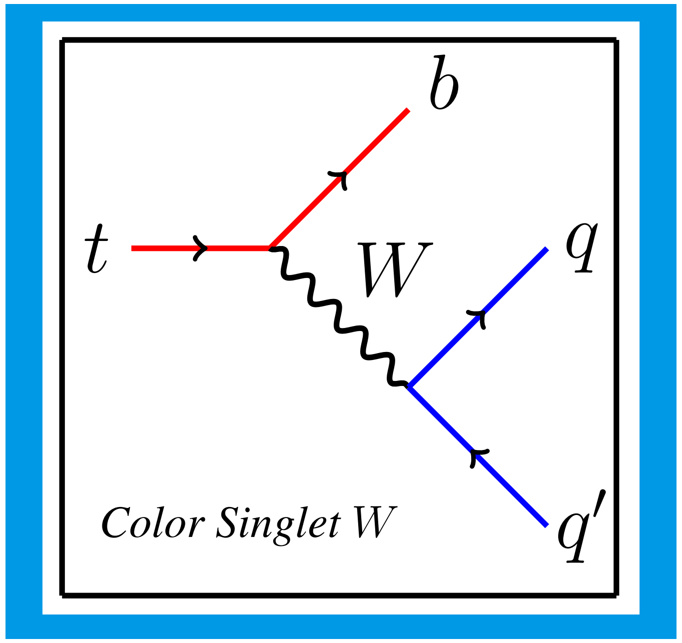


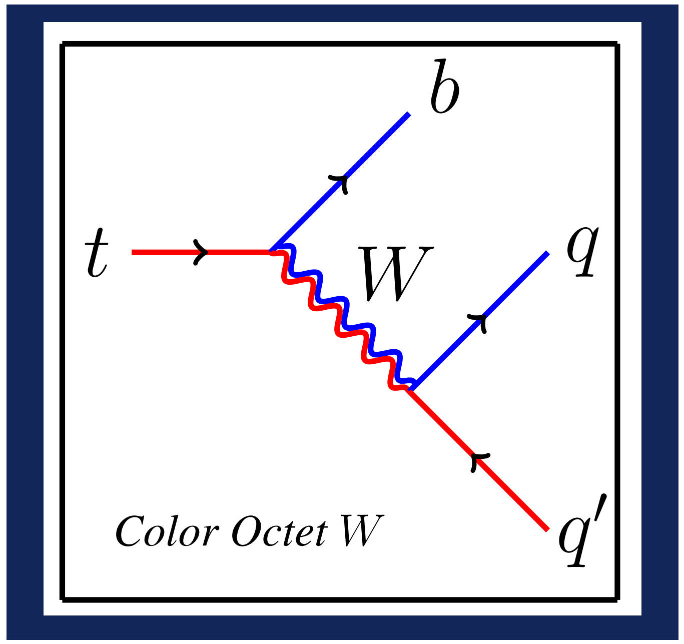
$\Delta\theta_P\left(j_1^W, j_2^W\right)$ [%]	0.0 – 0.21
→ Hadronisation	0.63
Generator	0.37
Colour Reconnection	0.11
b-Tagging	0.35
Non-Closure	0.25
ISR / FSR	0.32
Other	0.25
JER	0.12
JES	0.13
Tracks	0.09
Syst.	0.97
→ Stat.	0.22
Total	0.99

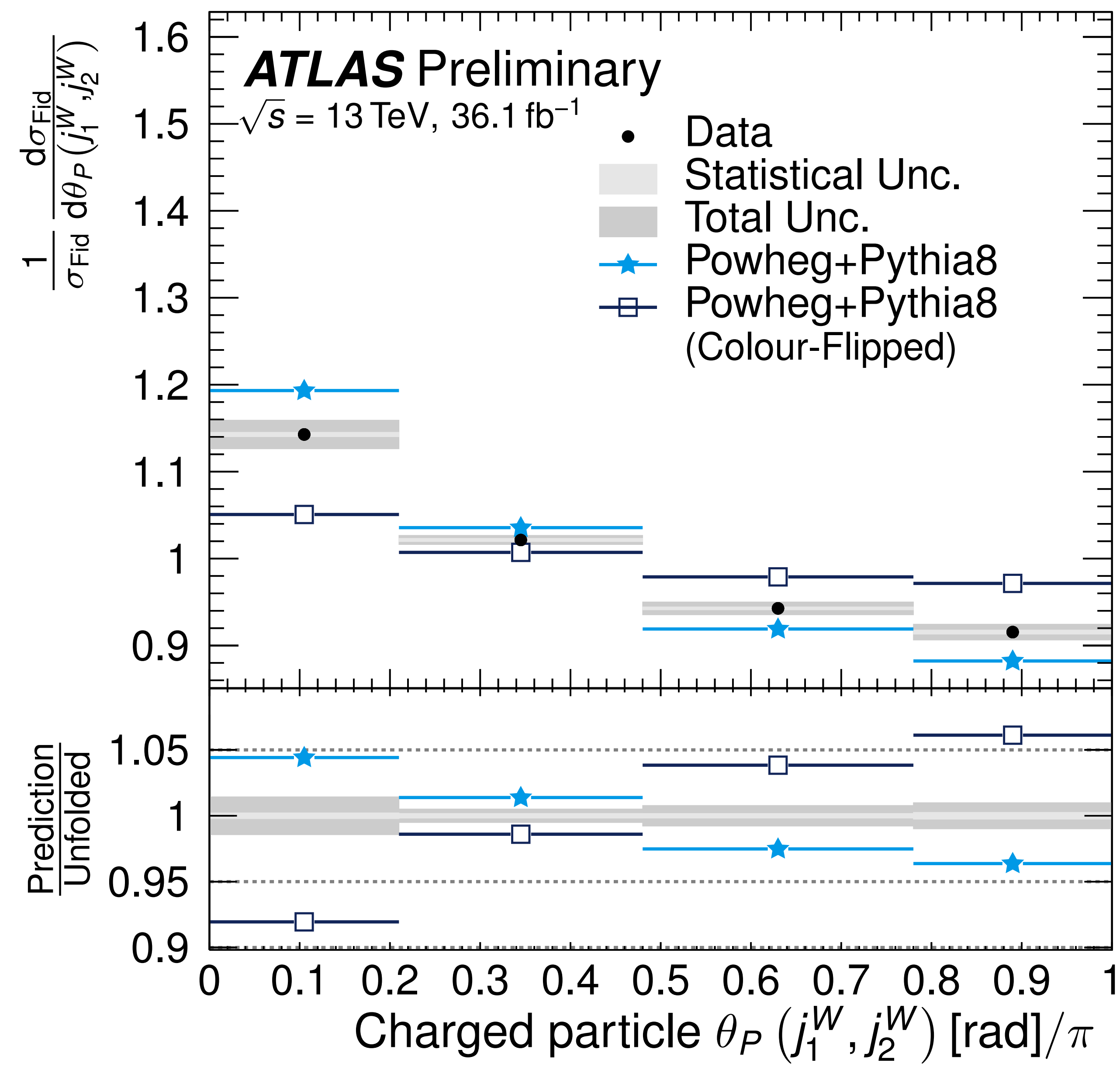
Resolution already much better with charged particles only;

Currently syst-limited

Jet Pull: More on tuning





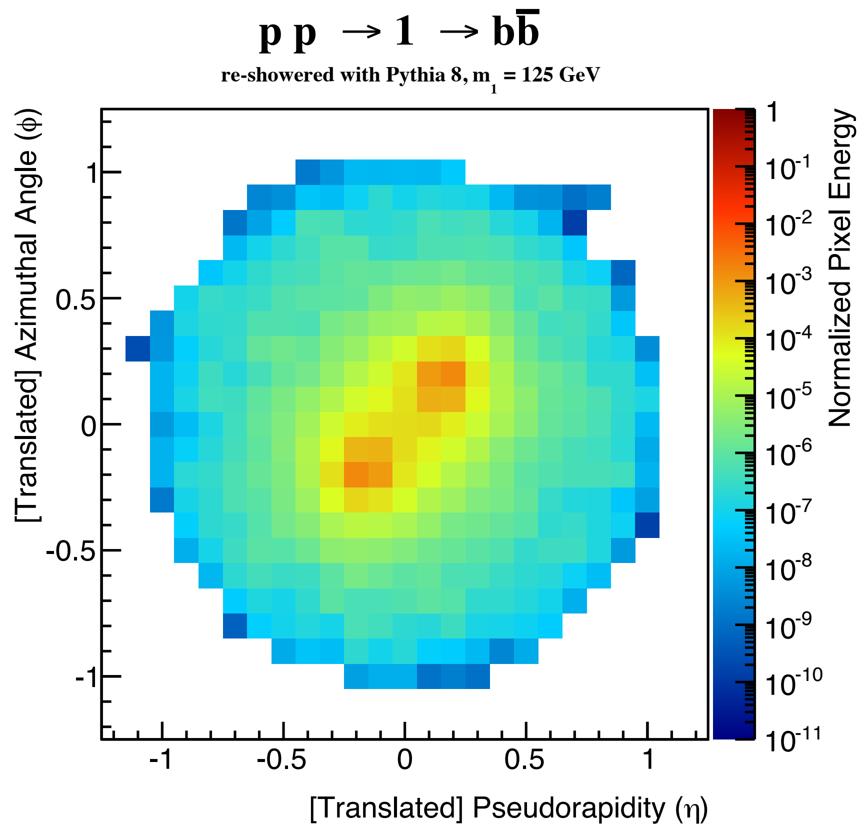


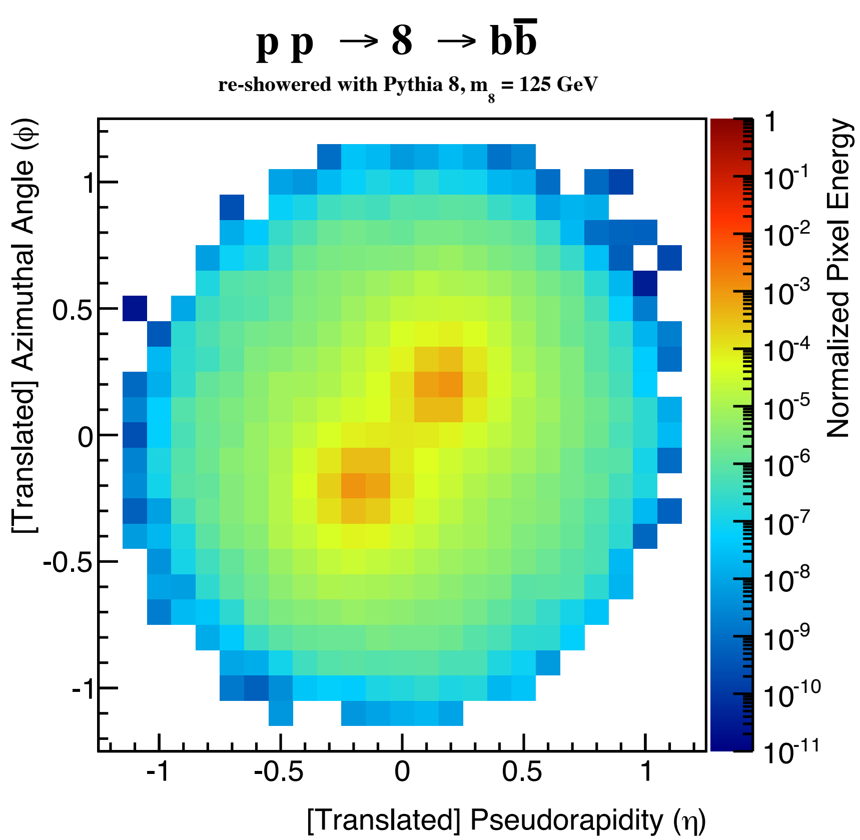
An important message: if we artificially make W's in Pythia octet-like, then we only marginally prefer the singlet.

clearly there is something we can learn for tuning here!

(it is not as dramatic for Pythia 6 and the default tune - maybe that is a hint)

Hadronic Correlations: Future Directions

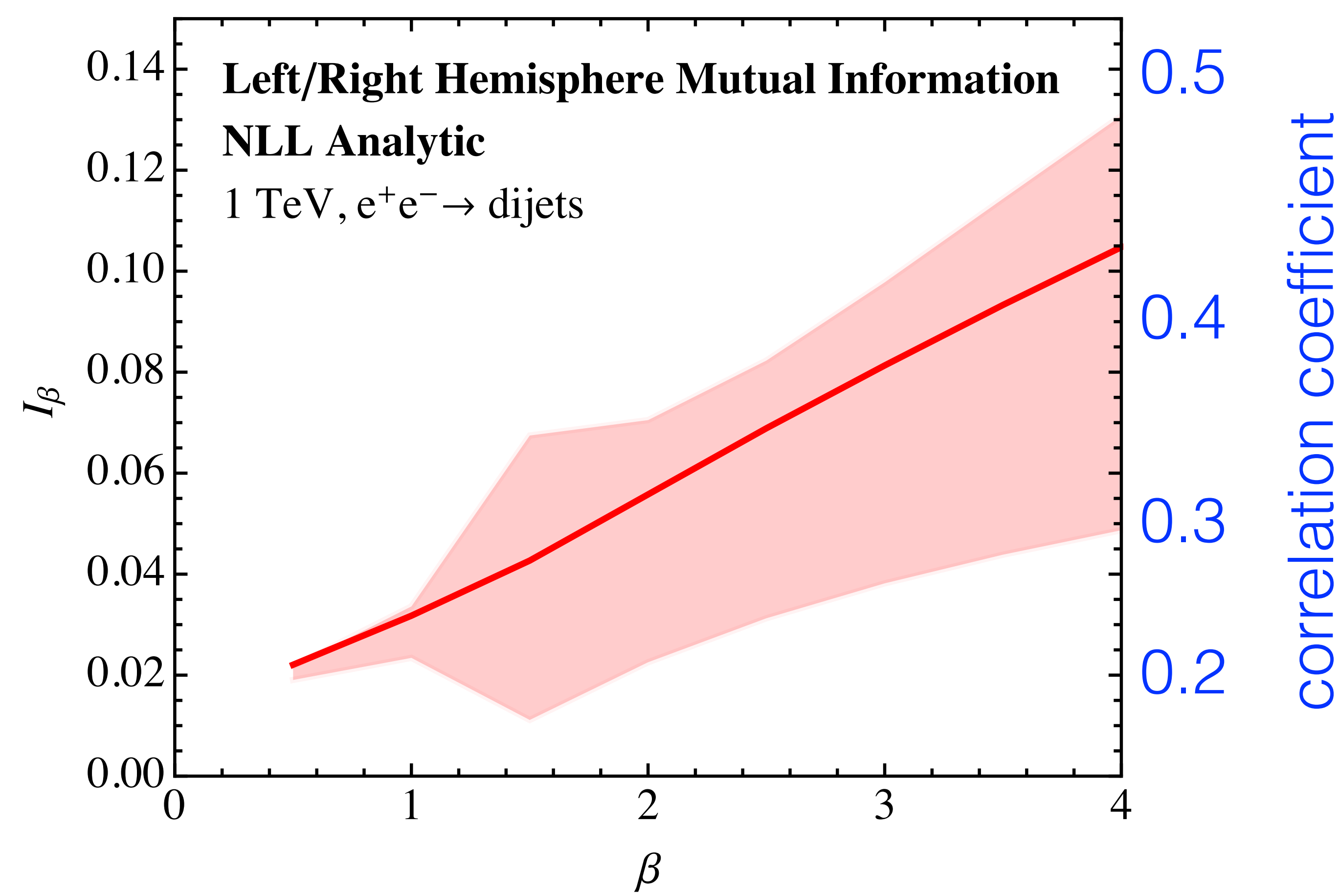




Colorflow more pronounced when boosted;
-> differential measurement (+tagging?)

Other observables: jet substructure correlations probe non-global effects in a clean way

A. Larkoski, I. Moult, PRD 93, 014012 (2016)

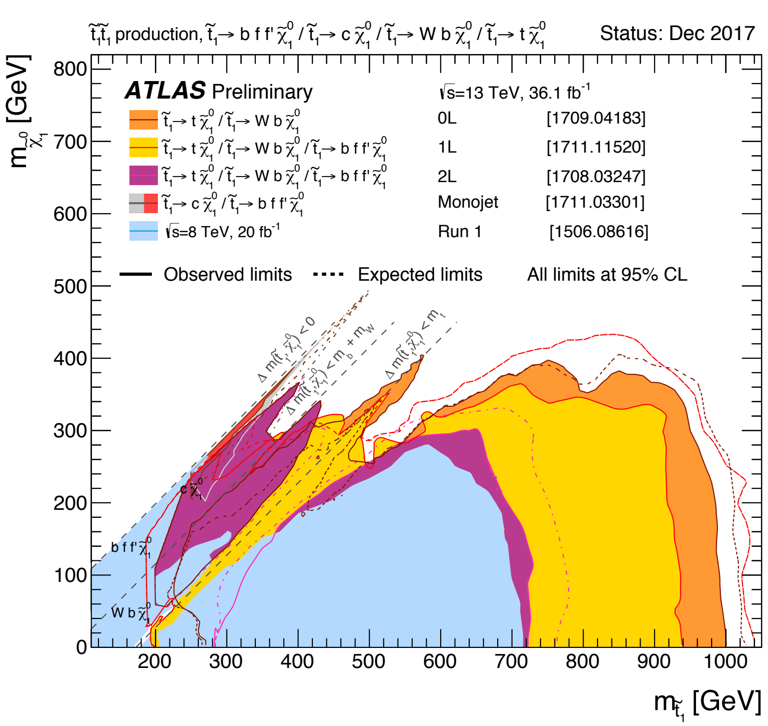


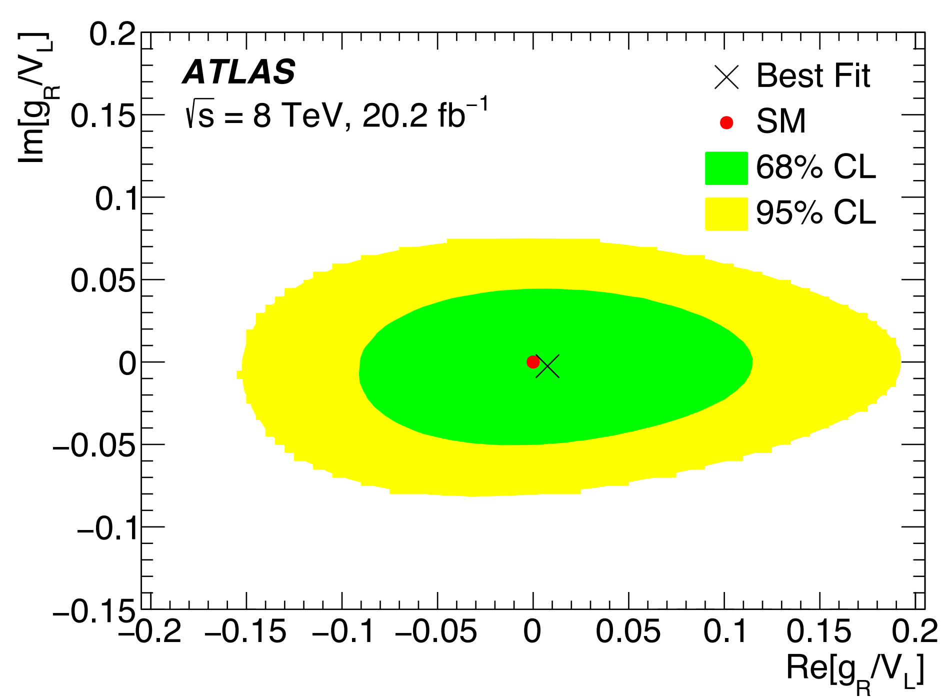
← more jet grooming

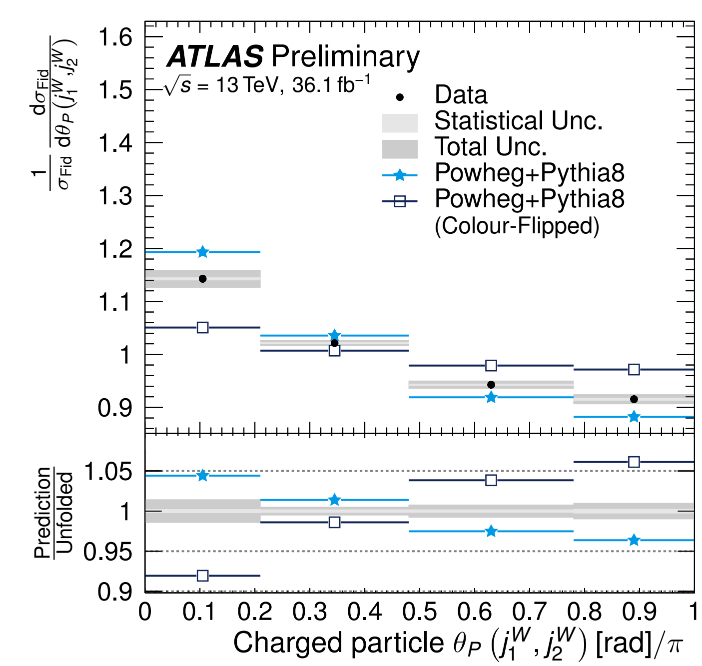
Conclusions and Outlook

During runs 2+3, we will be able to exploit angular correlations in top events to make strong claims about the mass scale of BSM and probe the SM in new and interesting ways!

In many areas, we are already limited by uncertainties - largely in the realm of theory modeling.



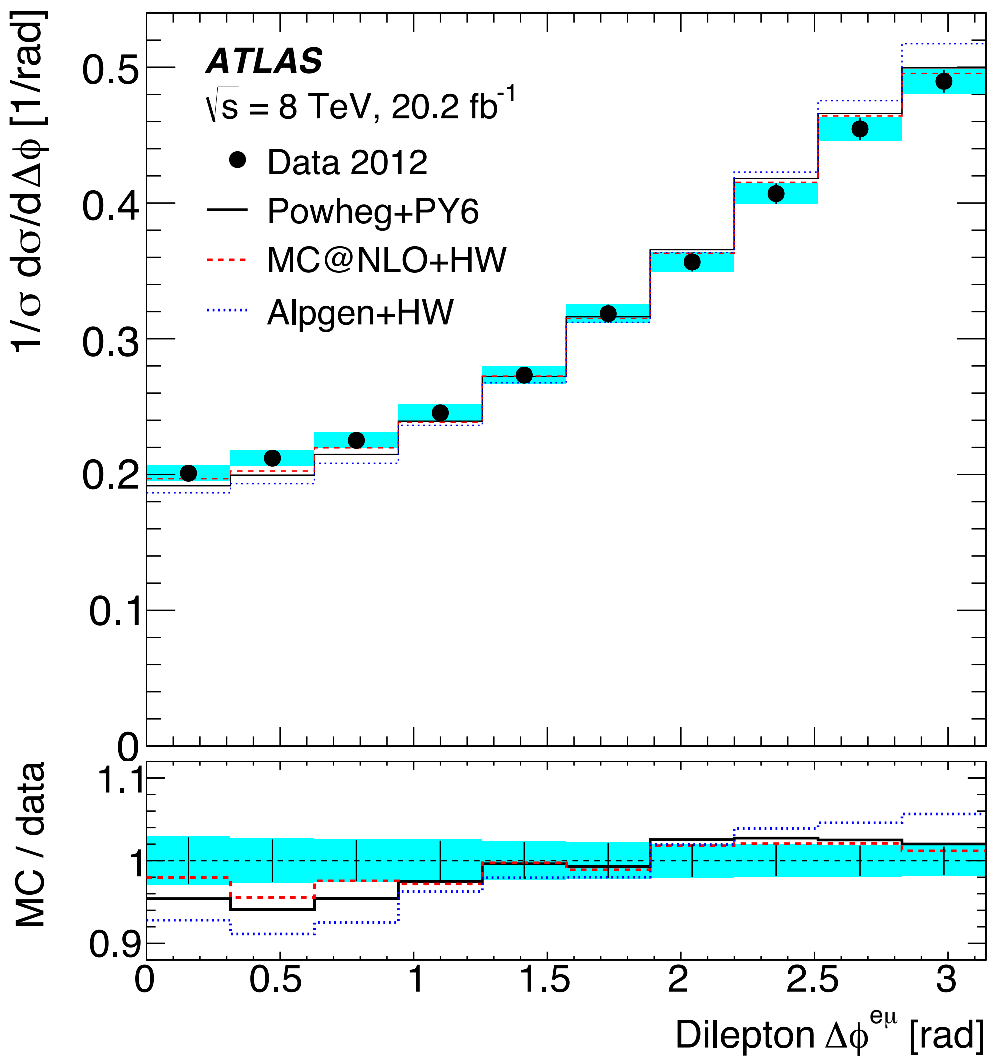


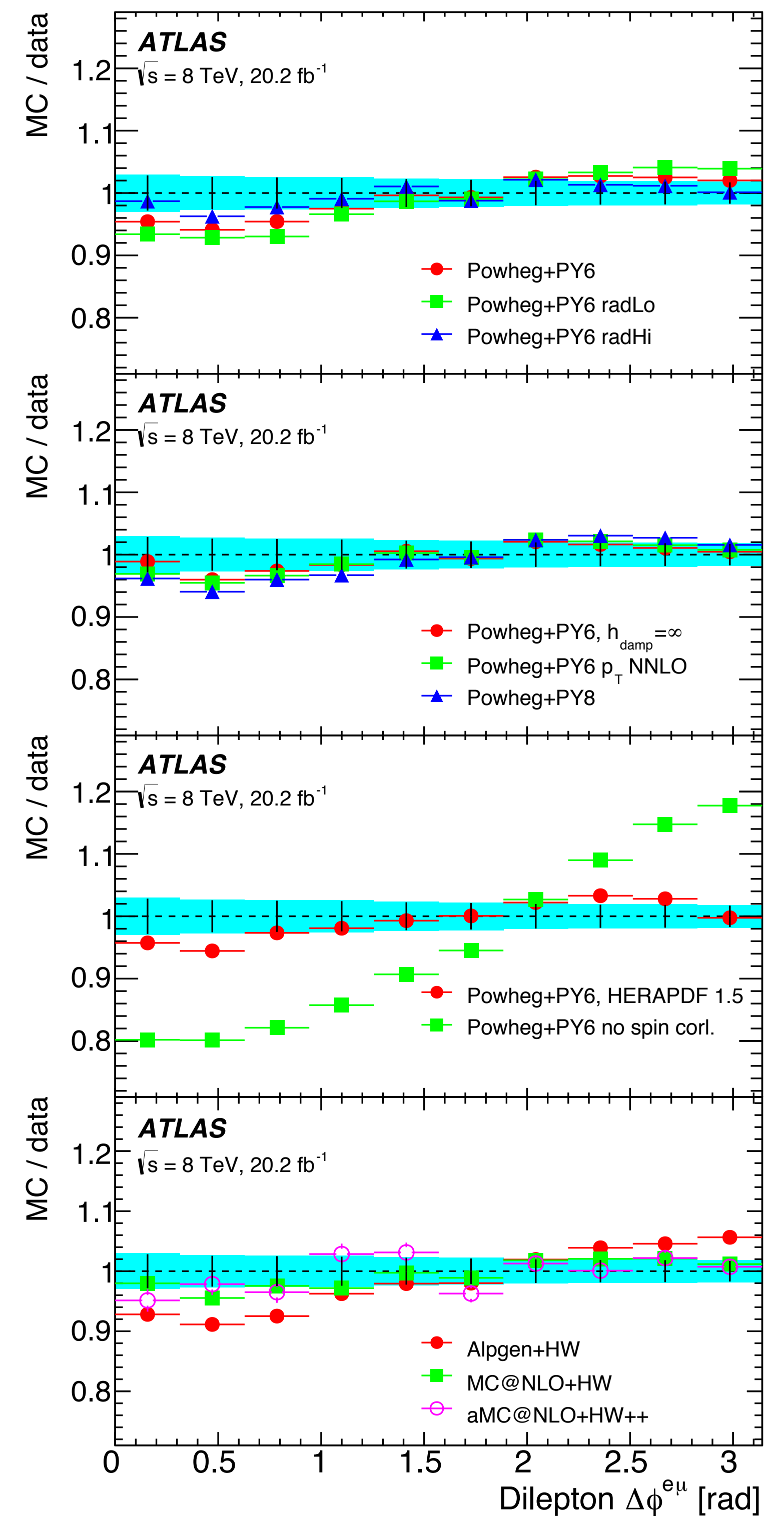


Questions?

Backup

Other correlation measurements





Other correlation measurements

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/TOPQ-2016-16/

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https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/TOPQ-2015-13/

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