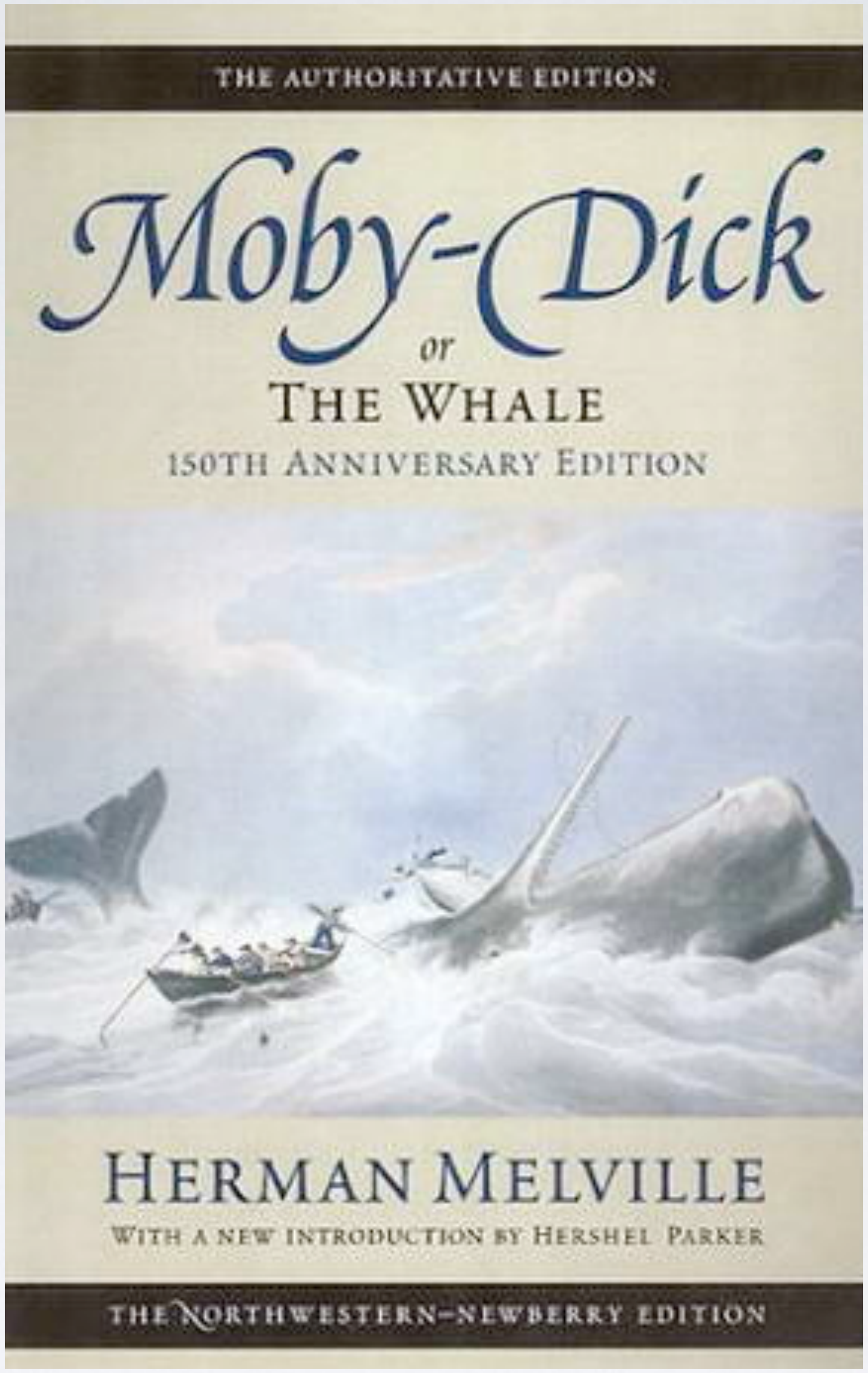
MODELING SOFT GLUONS AND FIDUCIAL CROSS SECTIONS: NEW PHYSICS OR OLD QCD?

Patrick Meade
Yang Institute for Theoretical Physics
Stony Brook University

Based on:

D. Curtin, P. Jaiswal, PM 1206.6888
D. Curtin, P. Jaiswal, PM, P. Tien 1304.7011
D. Curtin, PM, P. Tien 1406.xxxx (wednesday night EDT)
PM, H. Ramani, M. Zeng 1406.xxxx

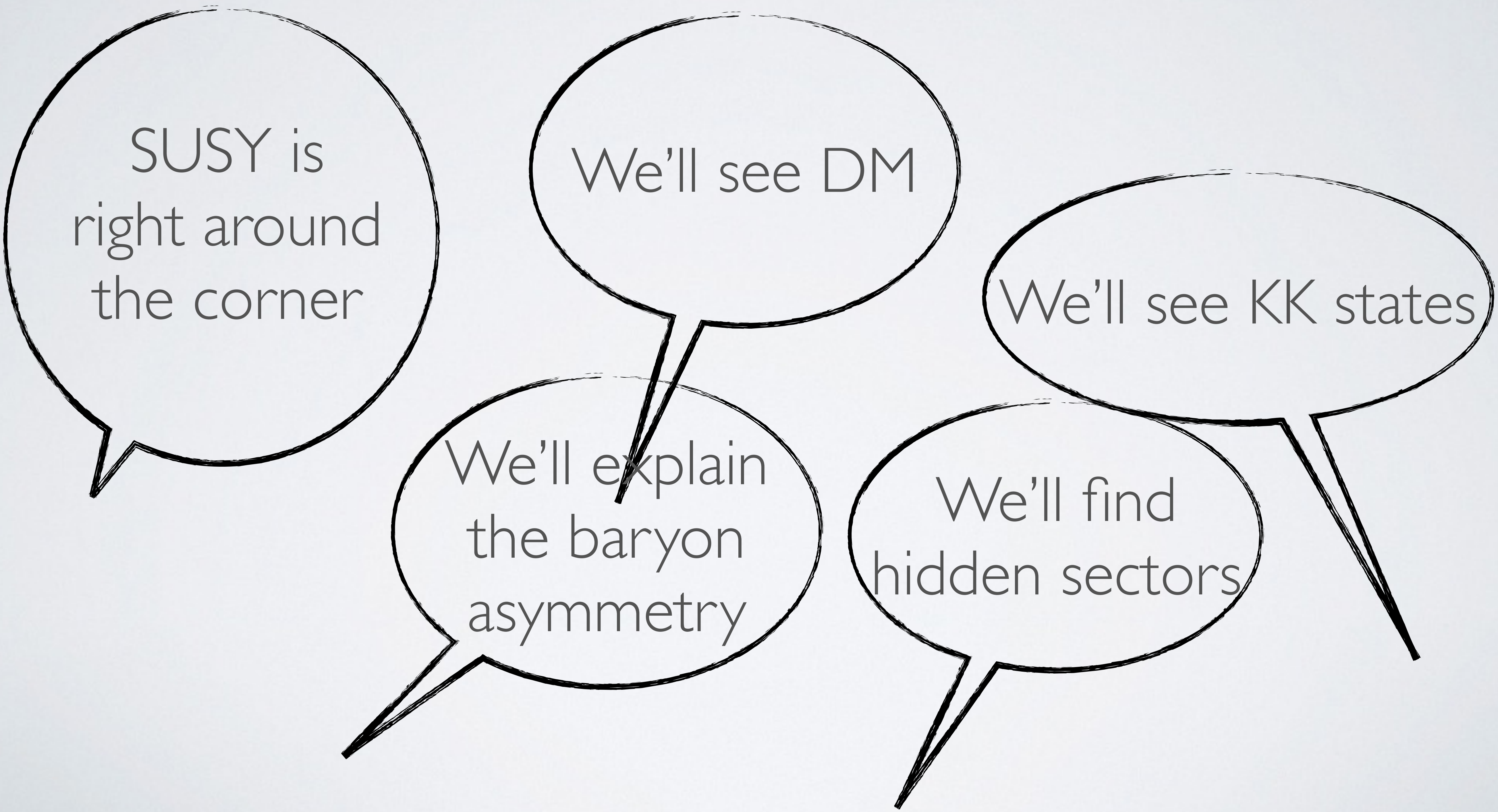
A LONG AND WINDING TALE…



Is new physics the theorists white whale?

A LONG AND WINDING TALE…

WHAT THEORISTS WERE SAYING PRE LHC



A LONG AND WINDING TALE…

POST 7 AND 8 TEV RUNS

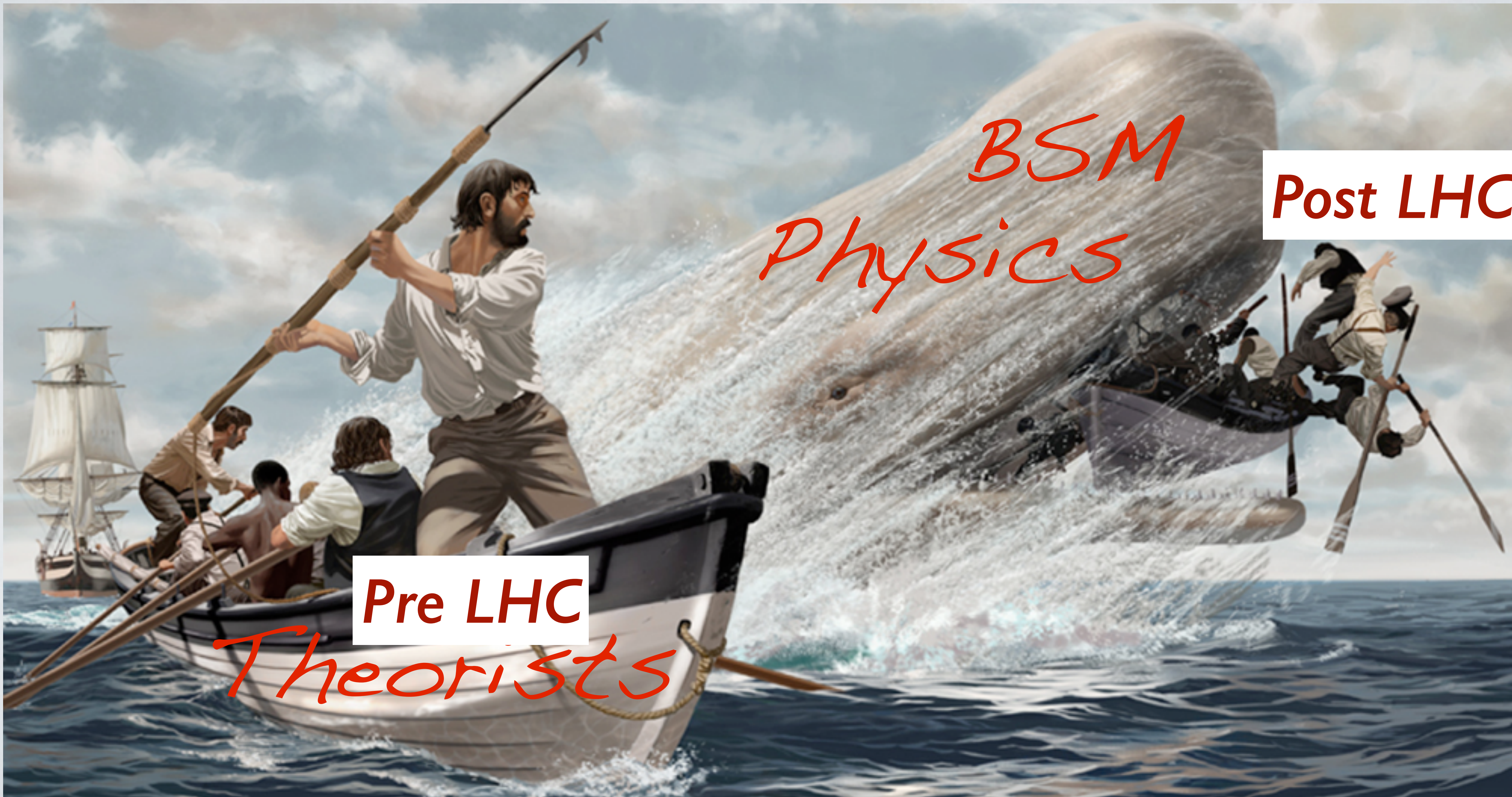
Maybe SUSY is at 100 TeV

Maybe it's just the Higgs

Have we reached the end of particle physics?

Maybe DM is an axion

A LONG AND WINDING TALE...



THERE'S OF COURSE A REASON FOR THIS…

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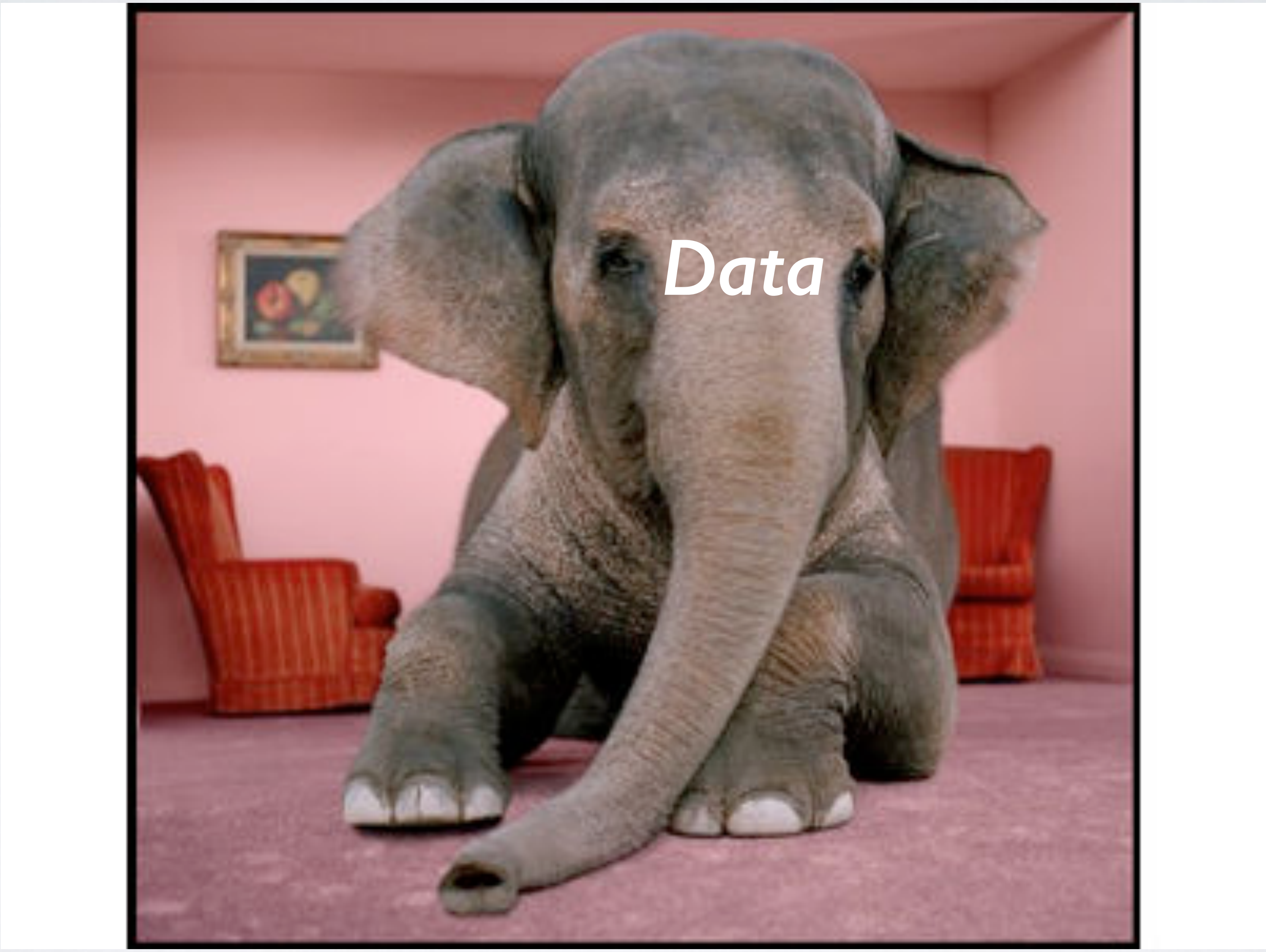

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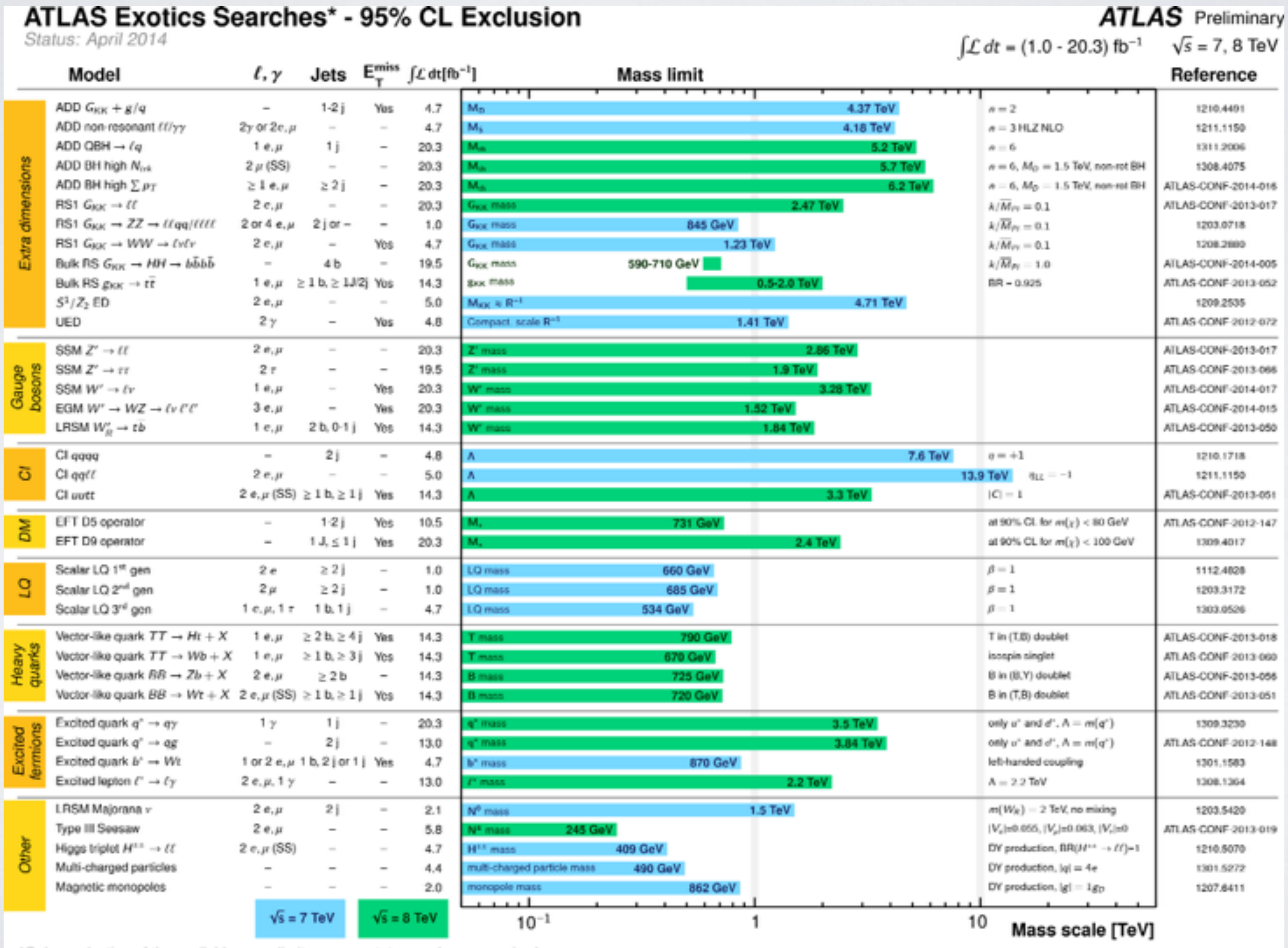

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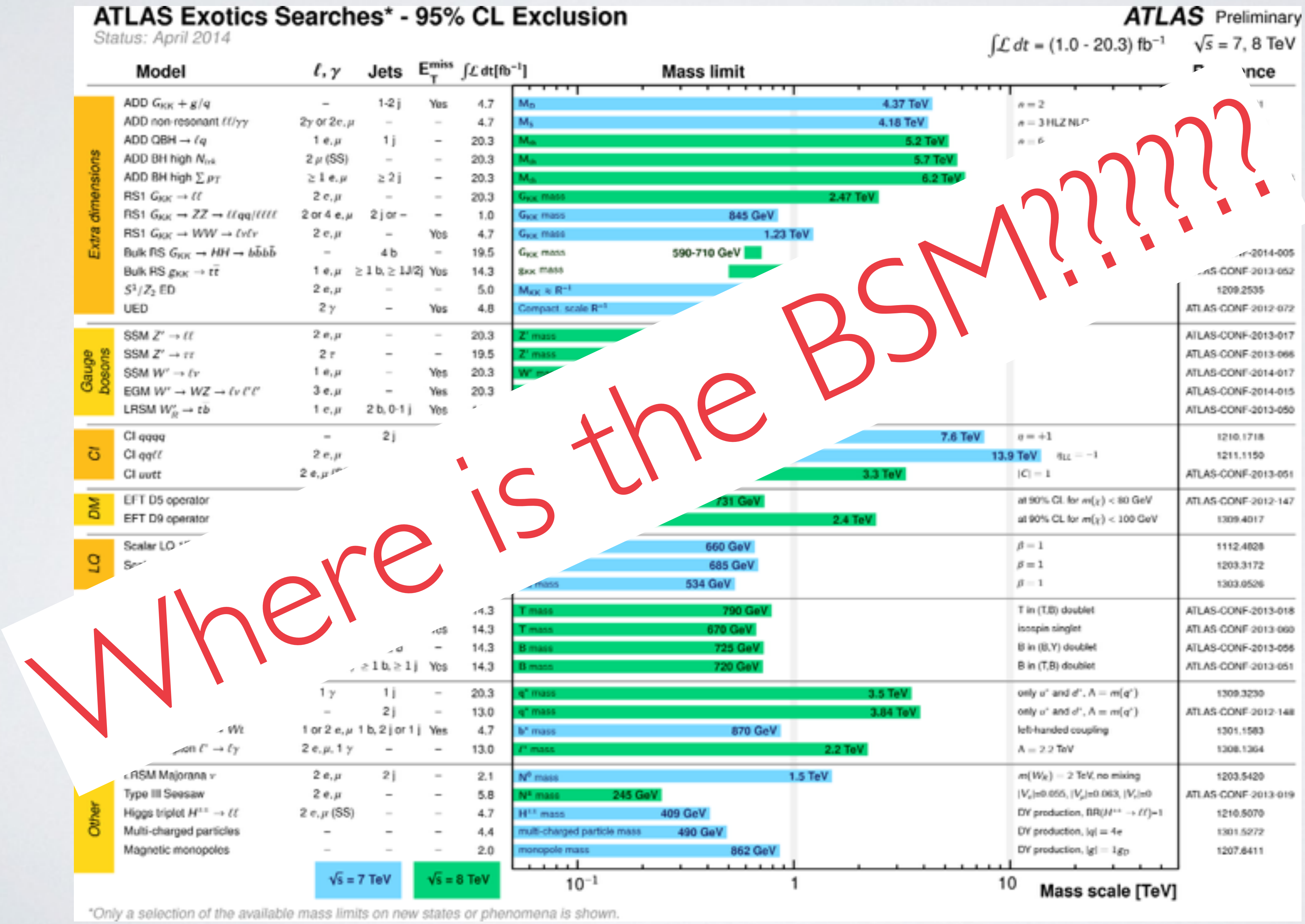

THERE'S OF COURSE A REASON FOR THIS…

It must be at higher mass scales!!!

LET'S MAKE SURE NOT TO LEAVE ANY SCALE BEHIND!

LET'S MAKE SURE NOT TO LEAVE ANY SCALE BEHIND!

Not just a commentary on the USA being left behind on the Energy Frontier

THE ONLY NEW PHYSICS WE'VE FOUND SO FAR IS THE HIGGS

Is there anything else lurking at the EW scale?
(remember the CDF Wjj saga…)

It's difficult to go after this scale… It runs contrary to deep ingrained desire of BSM experimentalists ***not*** to trust theorists and do everything in a "data-driven" manner

DATA-DRIVEN SEARCHES…

DATA-DRIVEN SEARCHES…

- Based on being able to separate signal and control regions
  - What if there isn't a good place where the signal isn't?
  - Assumes shapes extrapolate almost perfectly, don't trust MCs for normalizations…
  - If there are exceptions, this doesn't just have dire consequences for searches, but for the Higgs as well in principle!

ARE THERE ANY POTENTIAL DISCREPANCIES IN THE DATA?

S. Mrenna Talk

- some discrepancies:[2]
  - p_T of the individual top quarks in $t\bar{t}$
  - p_T of the leptons in W^+W^-
- difficult to describe both minimum bias (MB) and underlying event (UE) data with the same tune
- `http://mcplots.cern.ch`
  - a good overview of the distributions and comparisons (for many event generators and tunes)

[2] There are some disagreements between ATLAS and CMS on which ones.

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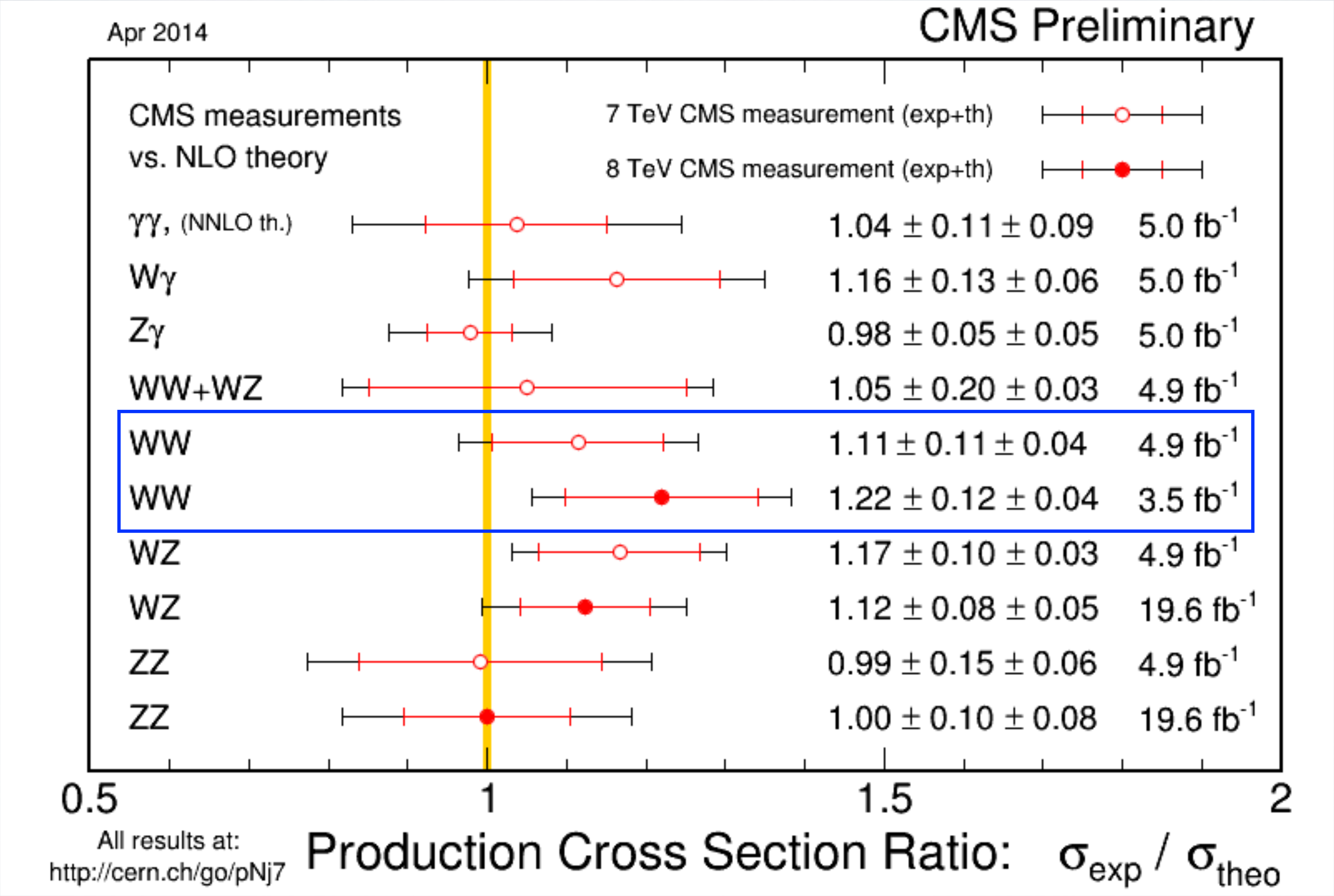
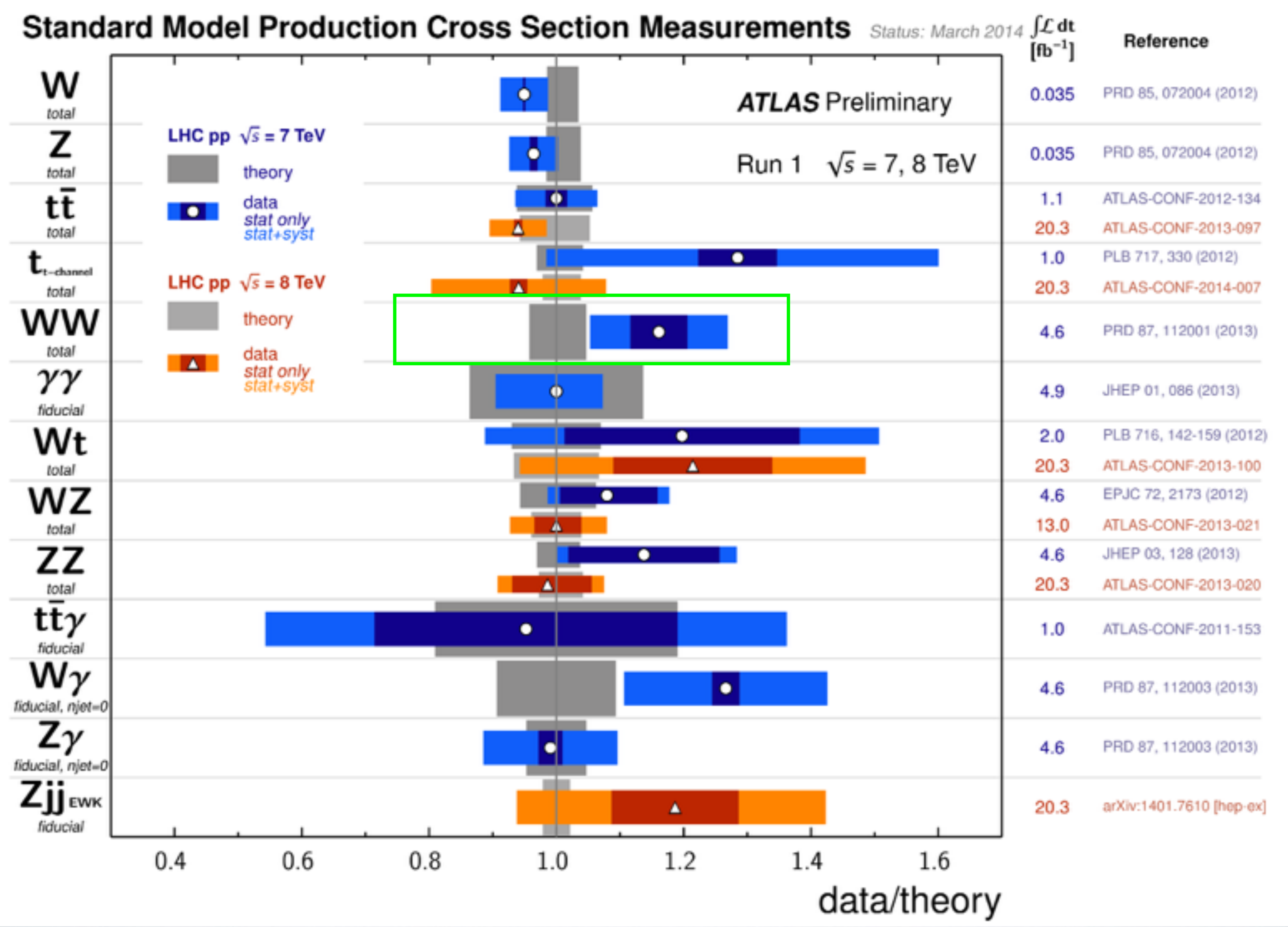
*I didn't pay him to put this on his slide…

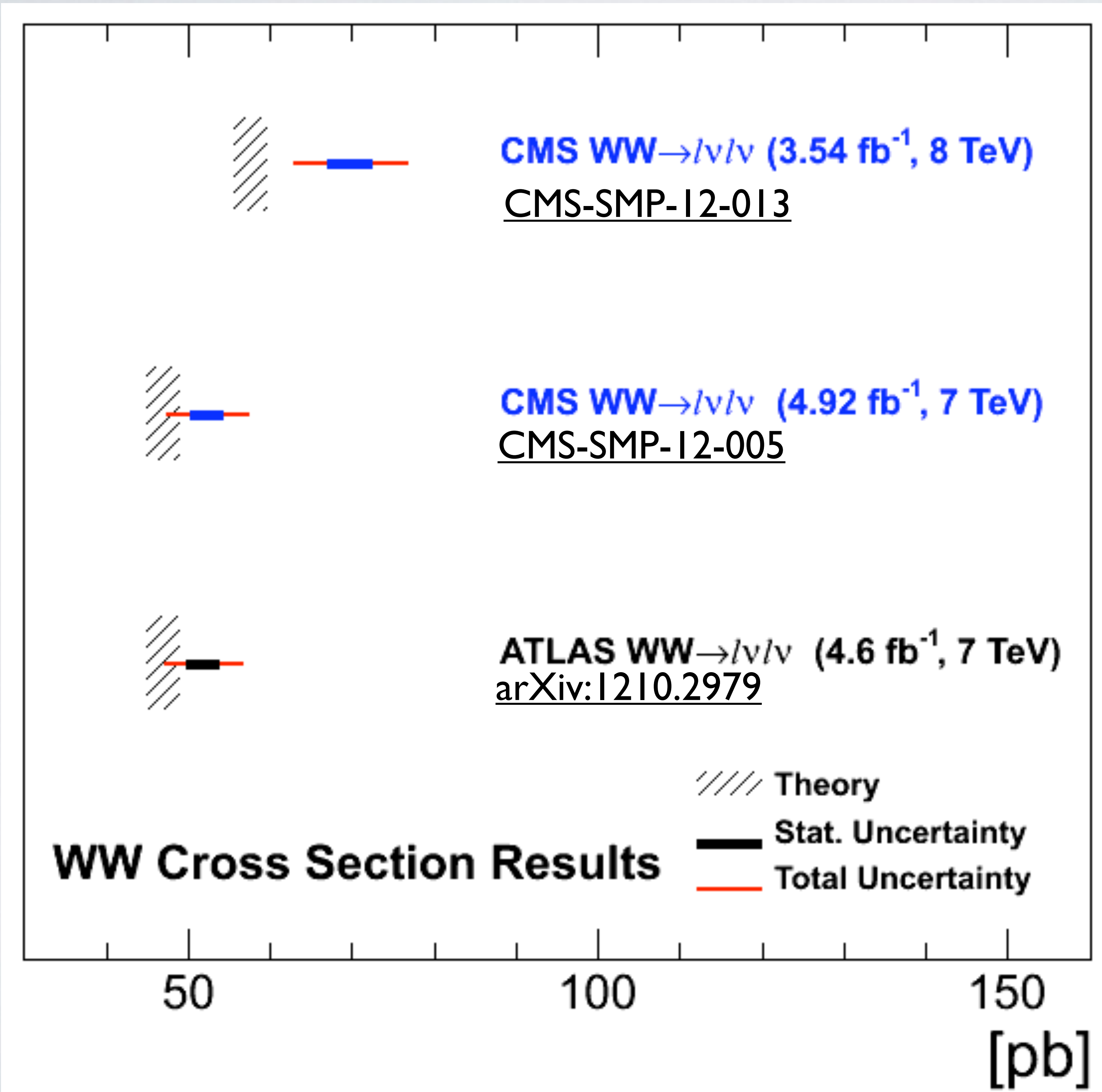
[2] There are some disagreements between ATLAS and CMS on which ones.

THERE'S MORE TO IT!




Standard Model Production Cross Section Measurements
Status: March 2014
∫ℒ dt [fb⁻¹]
Reference
ATLAS Preliminary
Run 1 √s = 7, 8 TeV
LHC pp √s = 7 TeV
theory
data
stat only
stat+syst
LHC pp √s = 8 TeV
theory
data
stat only
stat+syst
W total
Z total
tt̄ total
t t-channel total
WW total
γγ fiducial
Wt total
WZ total
ZZ total
tt̄γ fiducial
Wγ fiducial, njet=0
Zγ fiducial, njet=0
Zjj EWK fiducial
0.035 PRD 85, 072004 (2012)
0.035 PRD 85, 072004 (2012)
1.1 ATLAS-CONF-2012-134
20.3 ATLAS-CONF-2013-097
1.0 PLB 717, 330 (2012)
20.3 ATLAS-CONF-2014-007
4.6 PRD 87, 112001 (2013)
4.9 JHEP 01, 086 (2013)
2.0 PLB 716, 142-159 (2012)
20.3 ATLAS-CONF-2013-100
4.6 EPJC 72, 2173 (2012)
13.0 ATLAS-CONF-2013-021
4.6 JHEP 03, 128 (2013)
20.3 ATLAS-CONF-2013-020
1.0 ATLAS-CONF-2011-153
4.6 PRD 87, 112003 (2013)
4.6 PRD 87, 112003 (2013)
20.3 arXiv:1401.7610 [hep-ex]
0.4
0.6
0.8
1.0
1.2
1.4
1.6
data/theory

VISUAL "EVIDENCE"



>3 sigma by naive combination…

Theory:

NLO $q\bar{q} \to W^+W^-$

$+ \quad gg \to W^+W^-$

Generators:

MC@NLO, POWHEG, MG, MCFM, The Kitchen Sink

WW CROSS SECTION

- In principle the LHC makes 8 measurements highly sensitive to the WW cross section
  - SM WW at CMS7, ATLAS7, CMS8, ATLAS8
  - h → WW at CMS7, ATLAS7, CMS8, ATLAS8
- What's the status?

Every reported* measurement is higher than the SM

NOT JUST THE SM GROUPS

Control Region estimates at 8TeV-ATLAS

Estimate	N_{obs}	N_{bkg}	N_{sig}	N_{WW}	N_{VV}	$N_{t\bar{t}}$	N_t	N_{Z/γ^*}	$N_{W+\text{jets}}$
WW									
$N_{\text{jet}} = 0$	2224	1970 ± 17	31 ± 0.7	1383 ± 9.3	100 ± 6.8	152 ± 4.4	107 ± 4.3	68 ± 10	160 ± 3.6
$N_{\text{jet}} = 1$	1897	1893 ± 17	1.9 ± 0.3	752 ± 6.8	88 ± 5.5	717 ± 9.5	243 ± 6.7	37 ± 7.5	56 ± 2.5

Full luminosity @ 8 TeV!

Discrepancy ***must*** exist with
full lumi when SM groups publish

NOT J… UPS

Control R… TLAS

Estimate	N_{obs}	N_{b}…	… γ^*	$N_{W+\text{jets}}$
WW				
$N_{jet} = 0$	2224	1970	± 10	160 ± 3.6
$N_{jet} = 1$	1897	1893	± 7.5	56 ± 2.5

Full l… eV!

The Nobel Prize in Physics 2013

Photo: A. Mahmoud

François Englert

Prize share: 1/2

Photo: A. Mahmoud

Peter W. Higgs

Prize share: 1/2

The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"*

Discrepancy ***must*** exist with full lumi when SM groups publish

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NOT Bicep2 high… only a few sigma

WW CROSS SECTION

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  - SM WW at CMS7, ATLAS7, CMS8, ATLAS8
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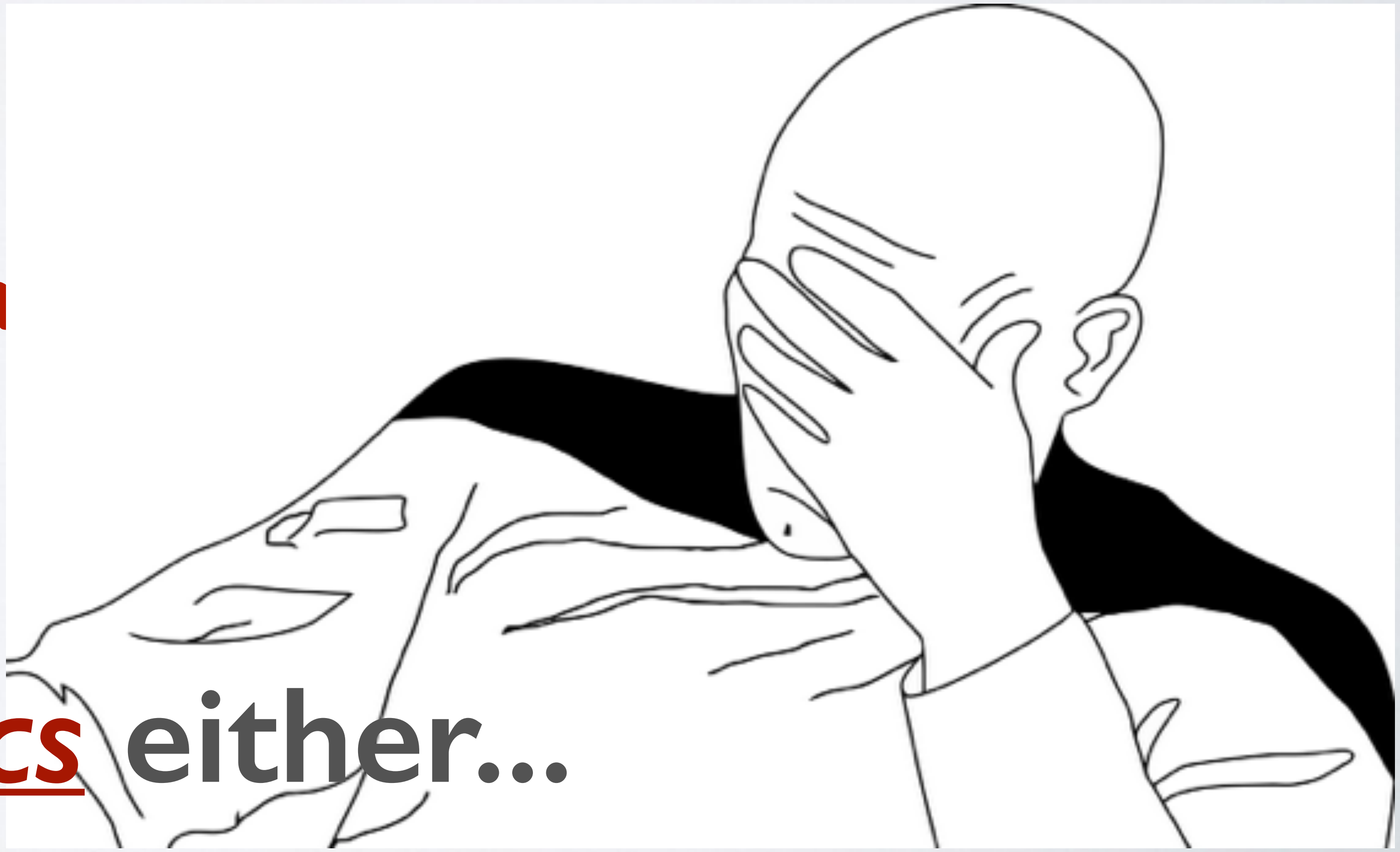
- What's the status?

Every reported*

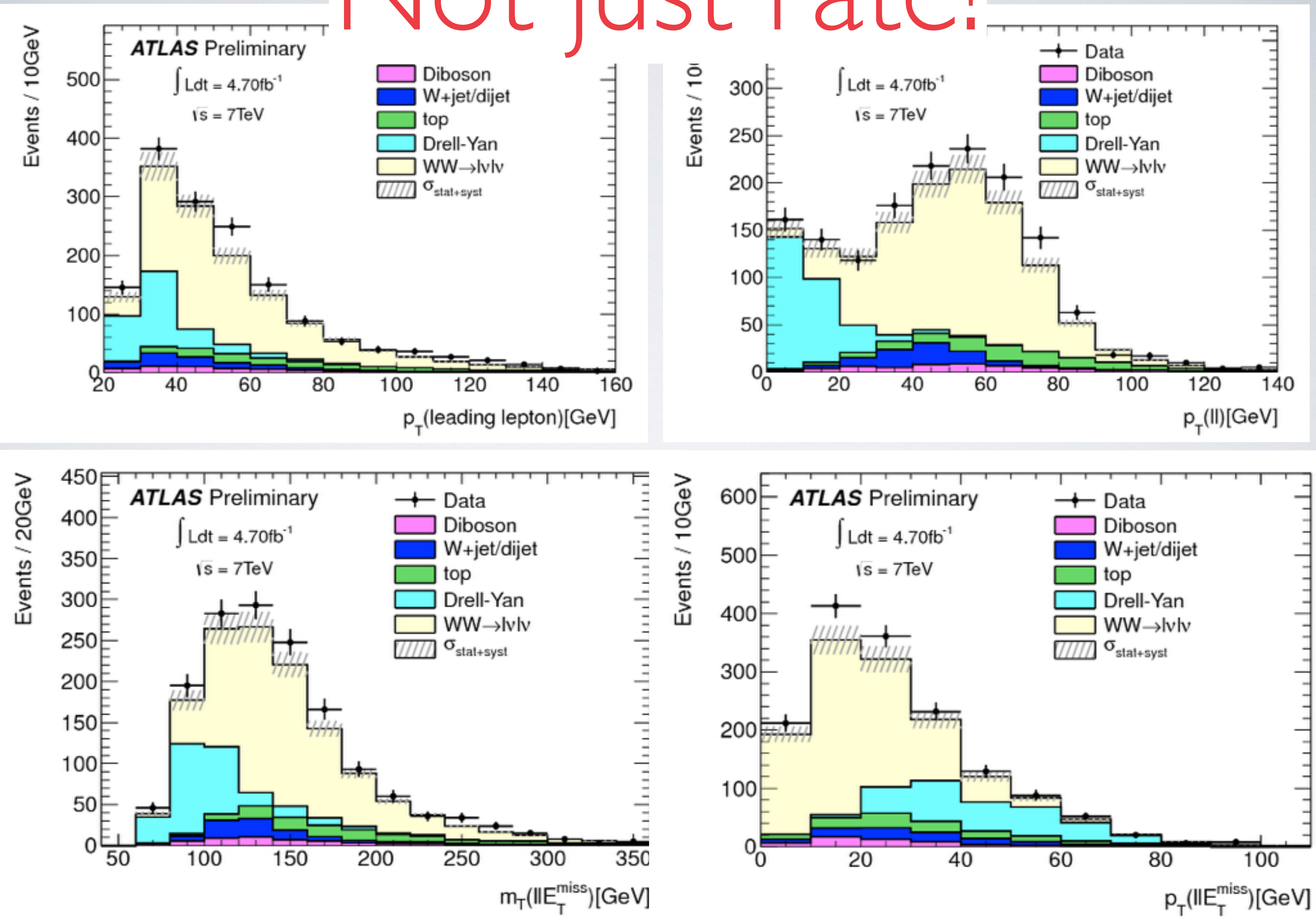
tha

NOT Bicep2 high...

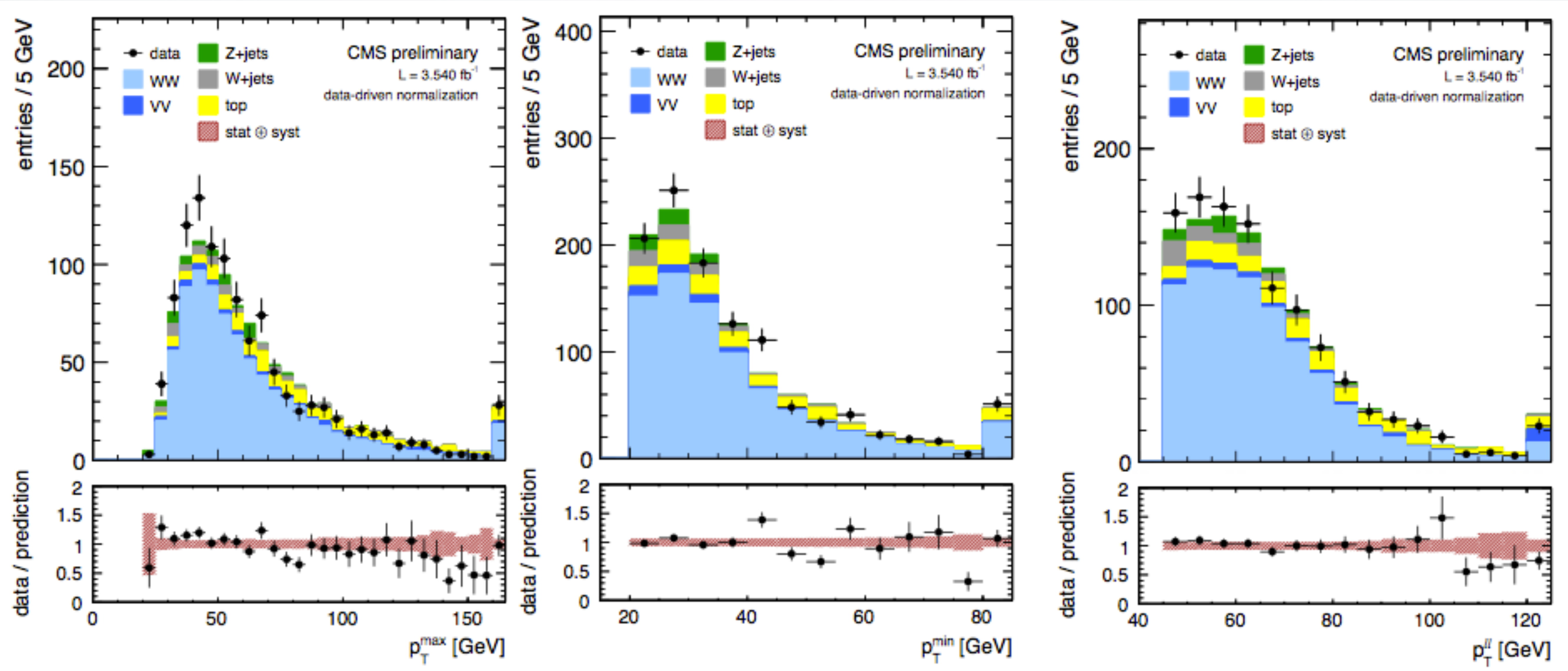


Not *astrophysics* either...

Not just rate!

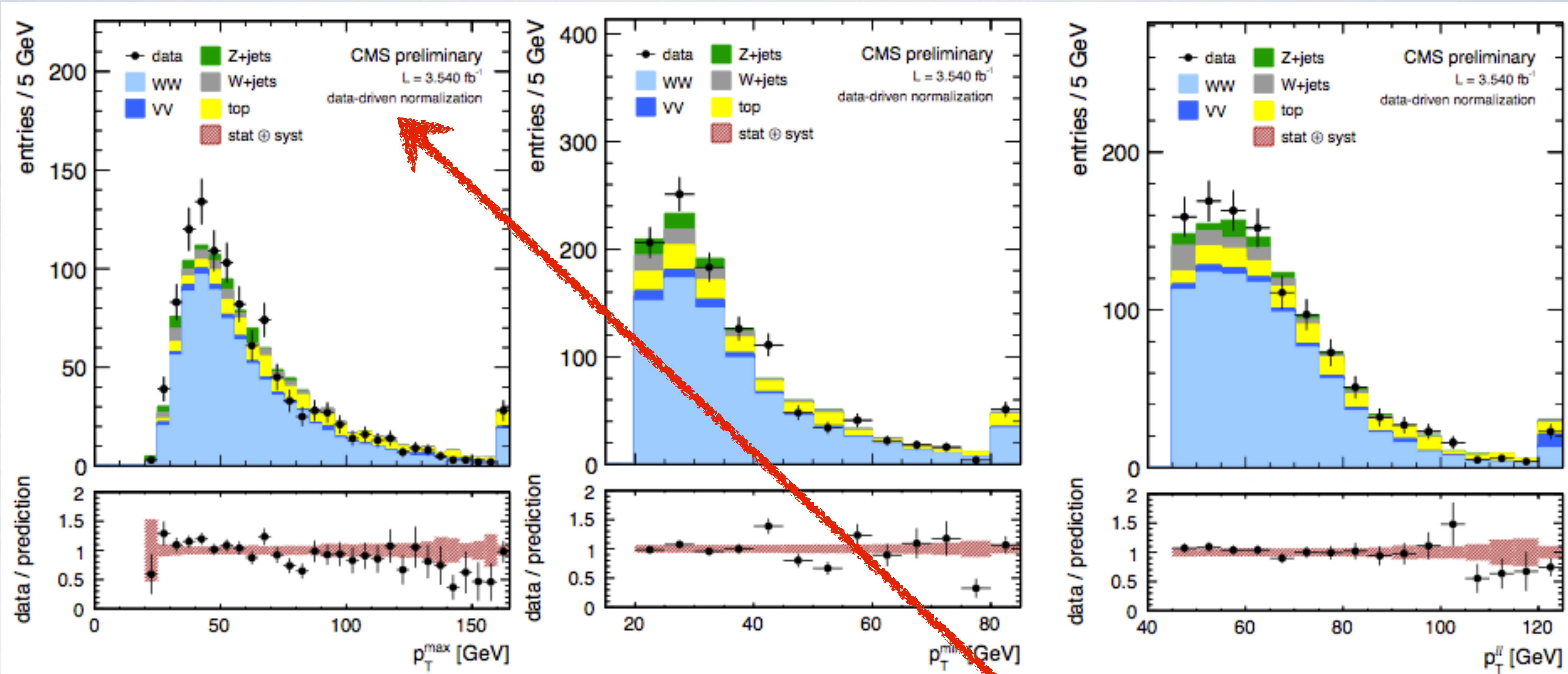


CMS8



Looks pretty good...

CMS8



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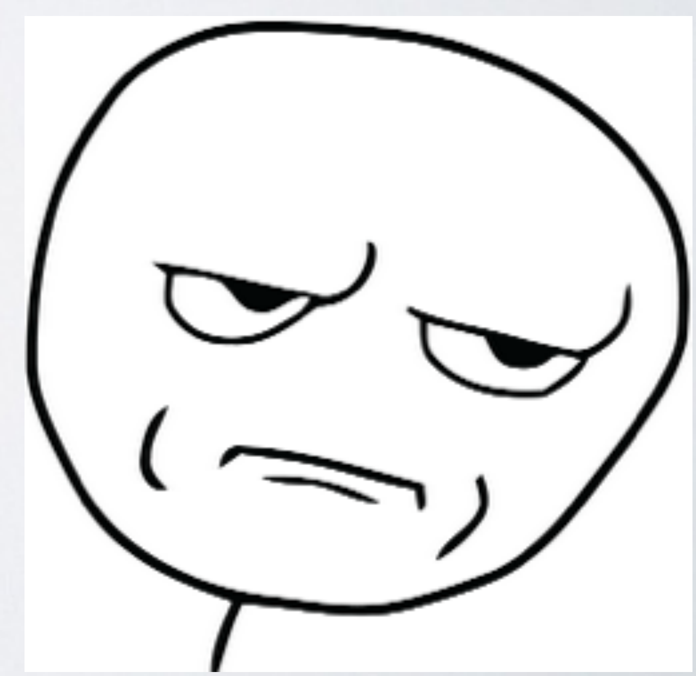
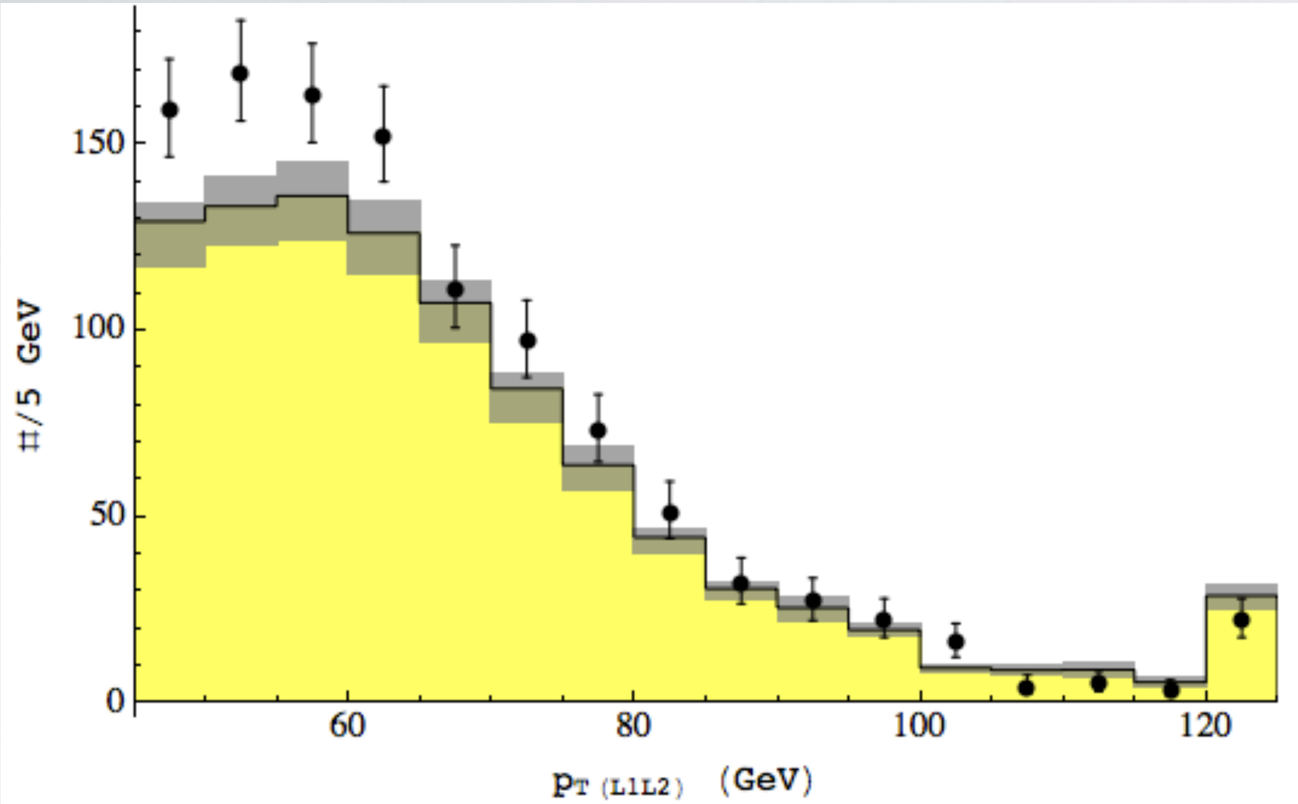
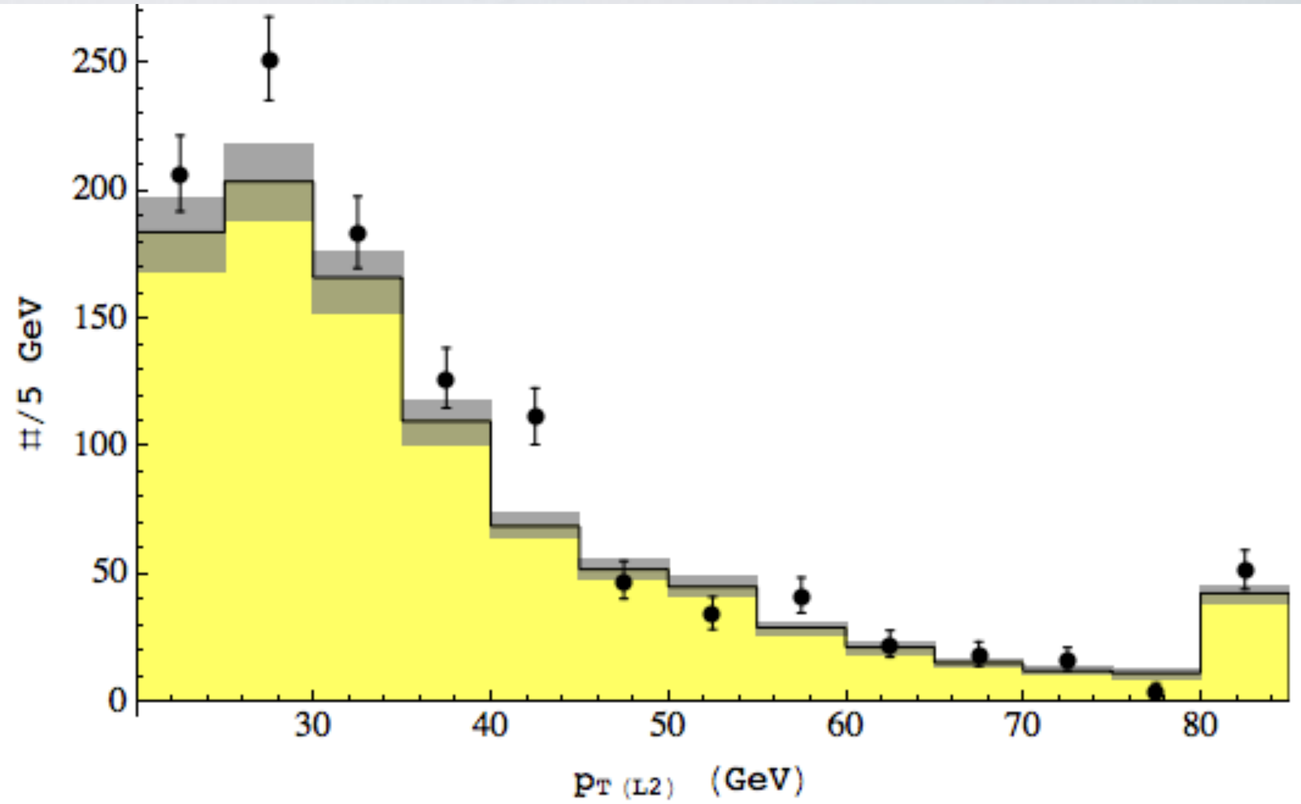
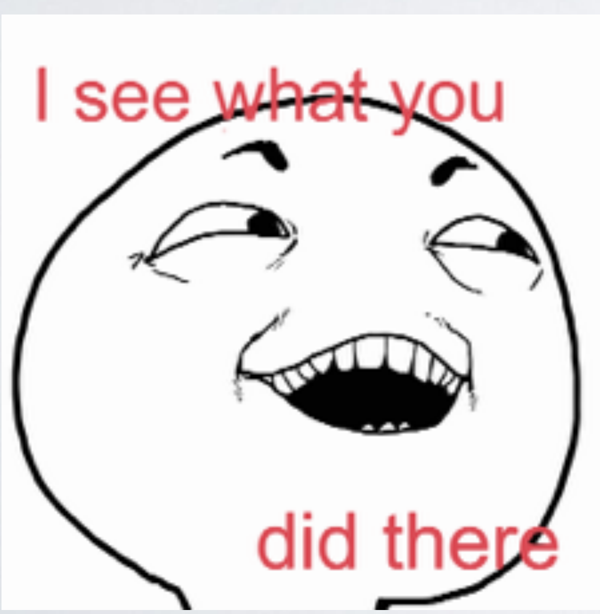
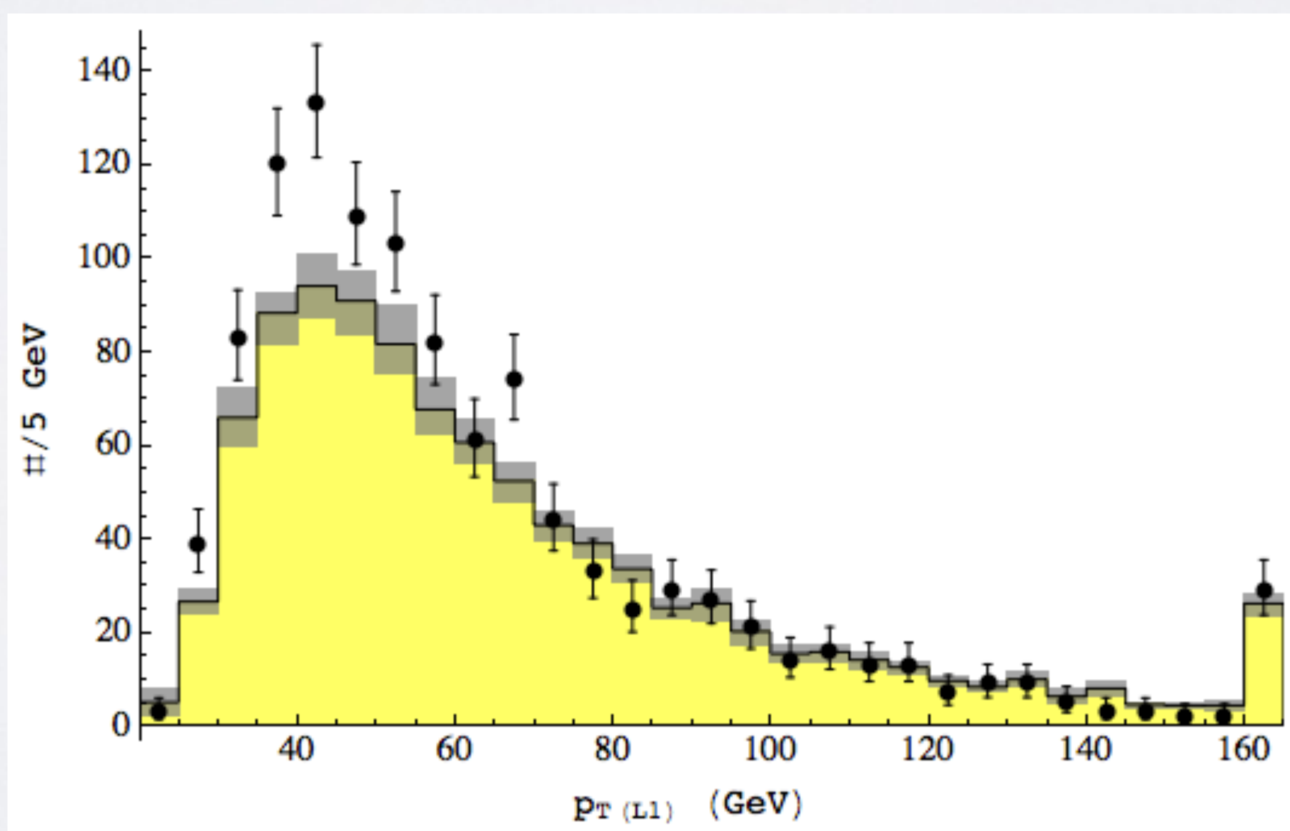


NO EXTRA NORMALIZATION...









CMS 8 TEV 3.5/FB

WW→2ℓ2ν at 8 TeV: systematics & results

σ = 69.9 ± 2.8 (stat) ± 5.6 (sys) ± 3.1 (lum) pb

NLO prediction (MCFM): 57.25 ($^{+2.35}_{-1.60}$) pb

- **Already 4% statistical precision**
- **About 1.8σ higher than the NLO prediction**

It grows at 8 TeV even faster!

$$\left.\frac{\sigma(8)}{\sigma(7)}\right|_{\mathrm{th}} = 1.21 \qquad \left.\frac{\sigma(8)}{\sigma(7)}\right|_{\mathrm{exp}} = 1.33$$

Upward fluctuations in ***all*** measurements ***or*** a trend**?**

If a trend… ***then*** what explains it**??**

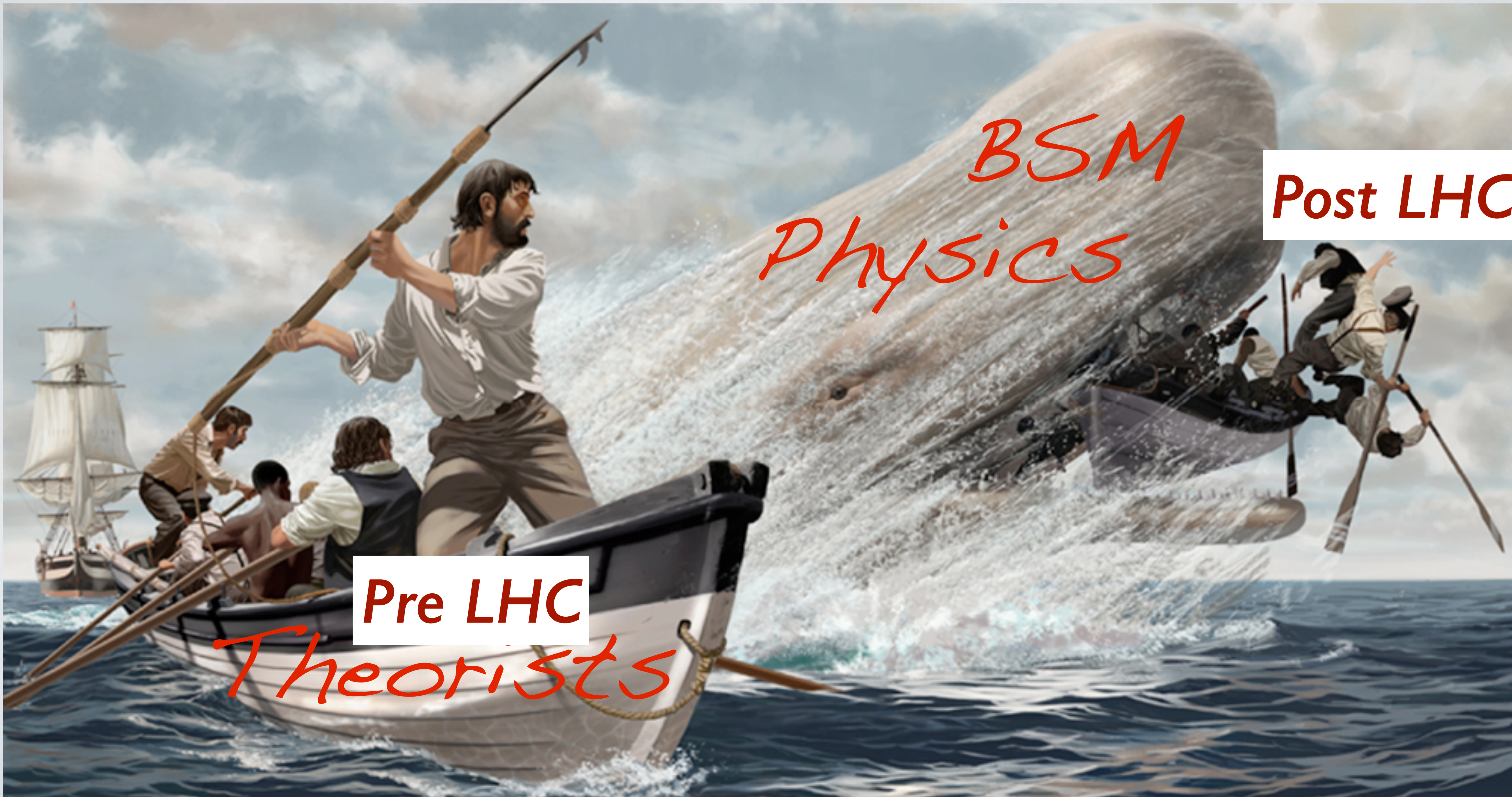
SM calculation wrong

New Physics

"Old QCD?"

Need around a 20% effect on WW!!!

A LONG AND WINDING TALE…

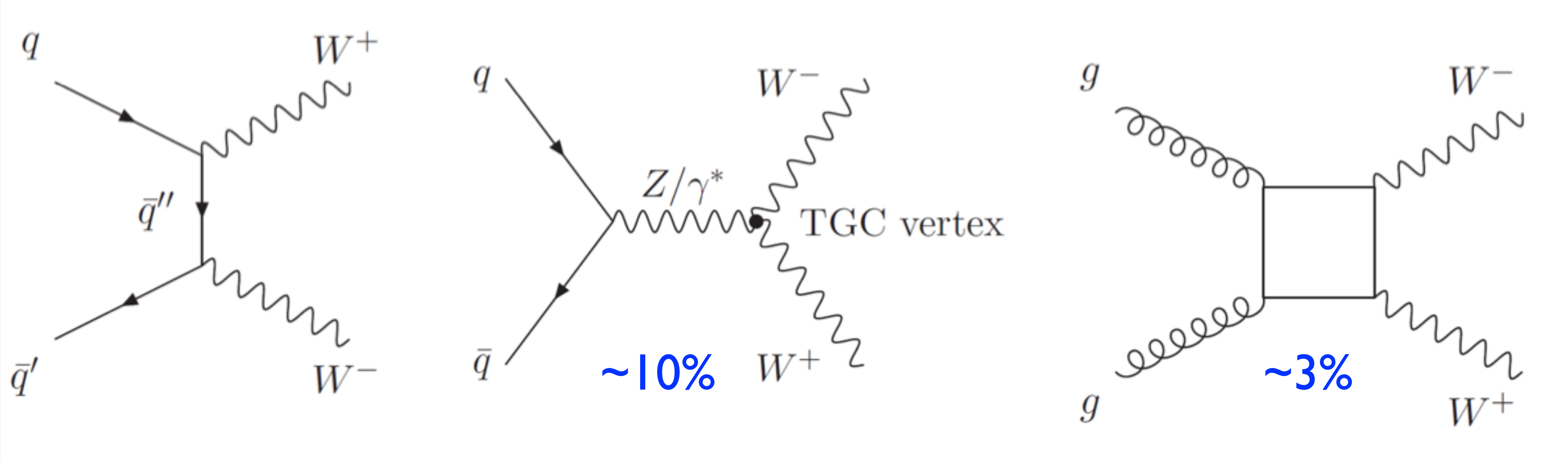


INGREDIENTS FOR AN EXPLANATION

- Need to first understand what it MEANS to measure the WW cross section!

Total cross section

$$\sigma_{WW} = \frac{N_{\mathrm{data}} - N_{\mathrm{bkg}}}{C_{WW} \times A_{WW} \times \mathrm{BR} \times \mathcal{L}}$$

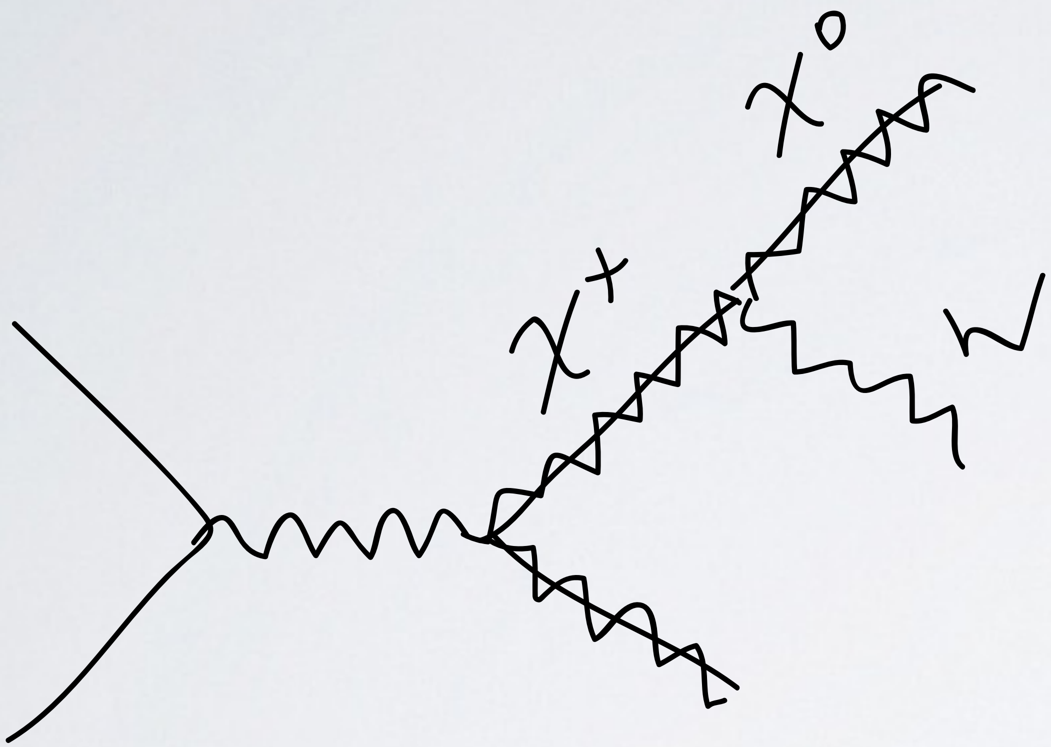


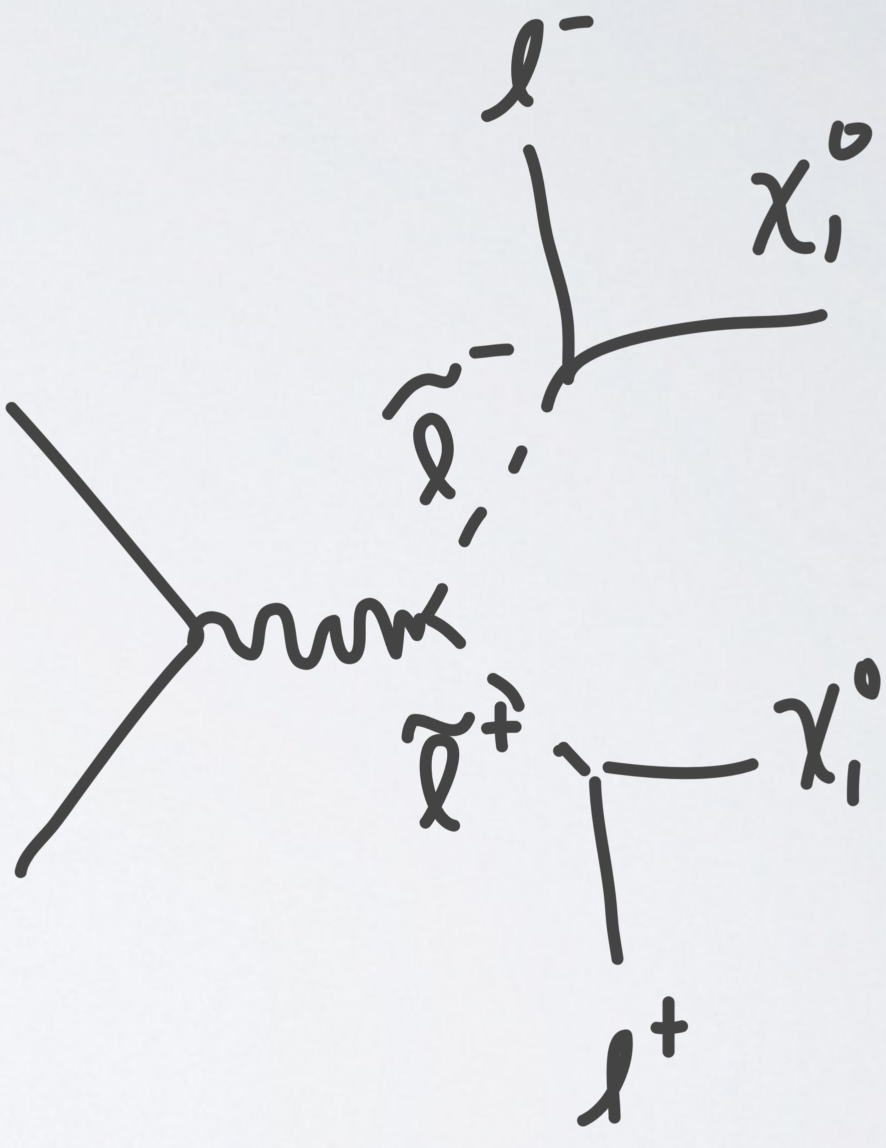
Count opposite sign dileptons + MET in a fiducial region with ***a jet veto*** and a few other requirements

INGREDIENTS FOR BSM EXPLANATION

- ATLAS and CMS both measure OS dileptons + MET **with** a jet VETO
- Final state needs to be OS leptons+MET with *nothing* else essentially
- Does ***NOT*** imply there have to be ***REAL W's***
- Need a cross section of a few pb!

EXAMPLE SUSY TOPOLOGIES FOR "WW"+MET





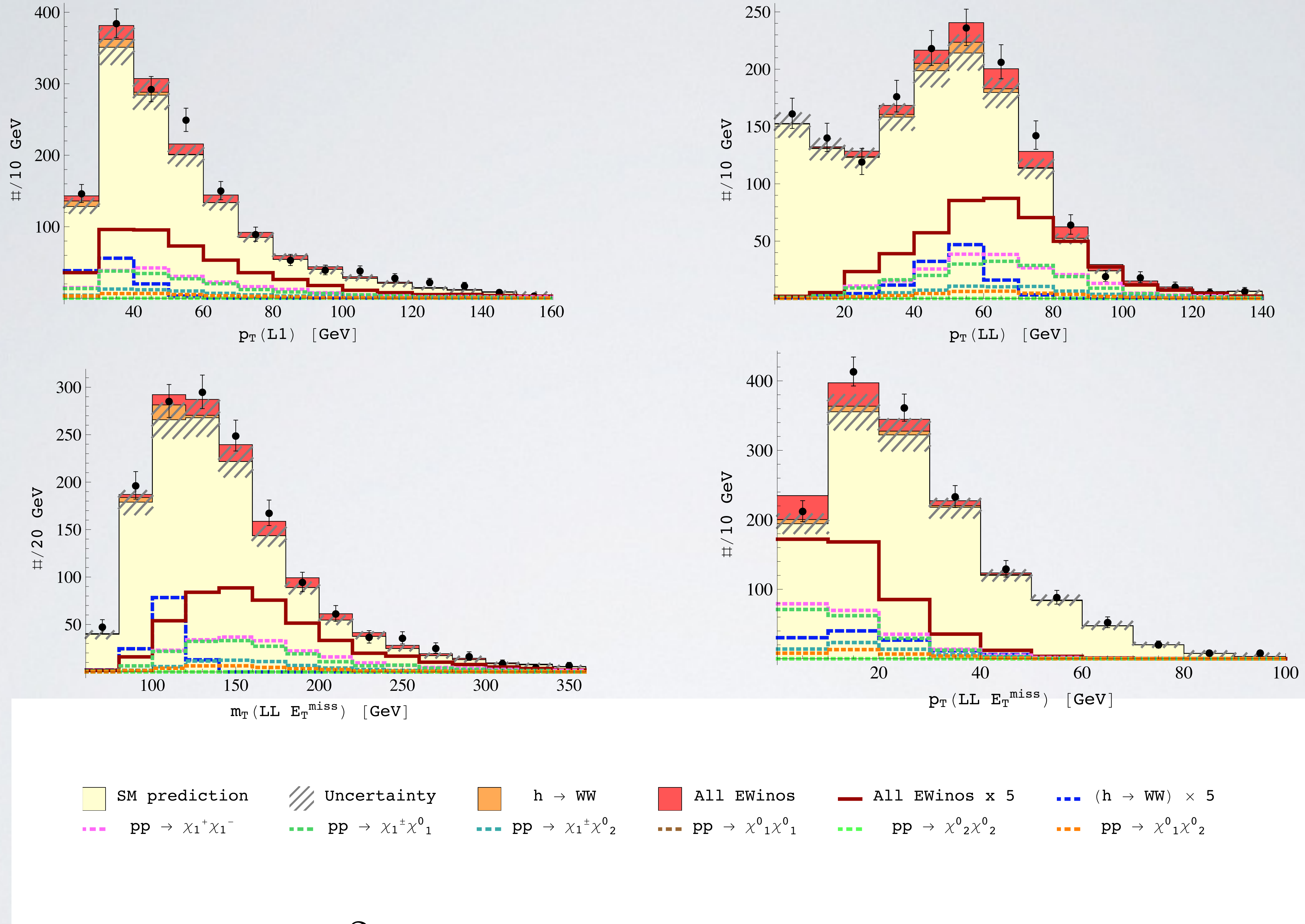
A few pb implies O(100) GeV ***surely*** this is ruled out???

EXAMPLE SUSY TOPOLOGIES FOR "WW"+MET

A few pb implies O(100) GeV ***surely*** this is ruled out???

ATLAS 7 - CHARGINOS

1206.6888



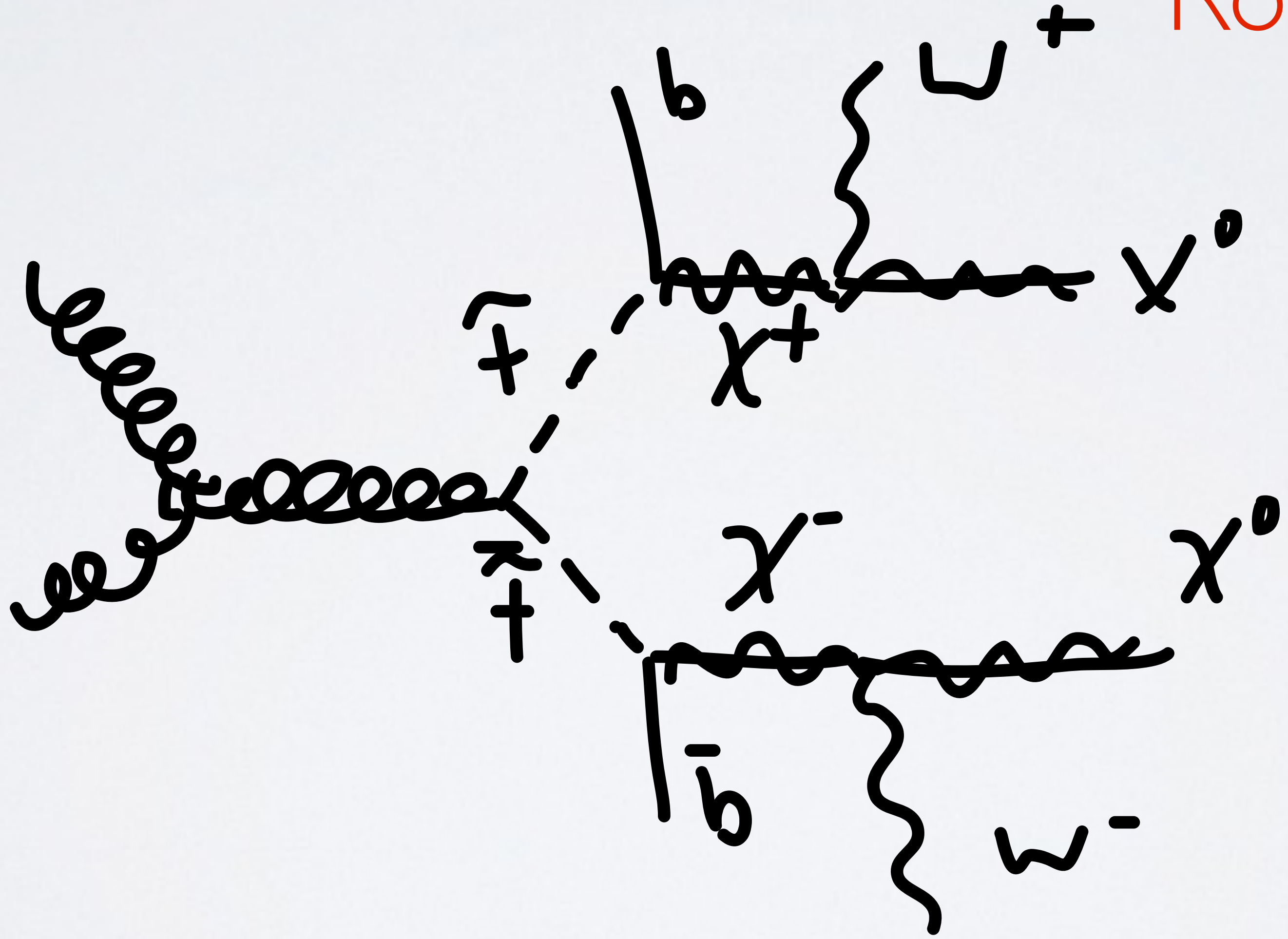
χ^2 cut in **half** compared to SM

BETTER THAN OKAY!

CHARGINOS FROM STRONG PRODUCTION?

$$\tilde{t}_1 \to \tilde{\chi}_1^{\pm}\, b \to \tilde{\chi}_1^0\, W^{(*)}\, b \to \tilde{\chi}_1^0\, \ell\, \nu\, b$$

Rolbiecki and Sakurai
1303.5696

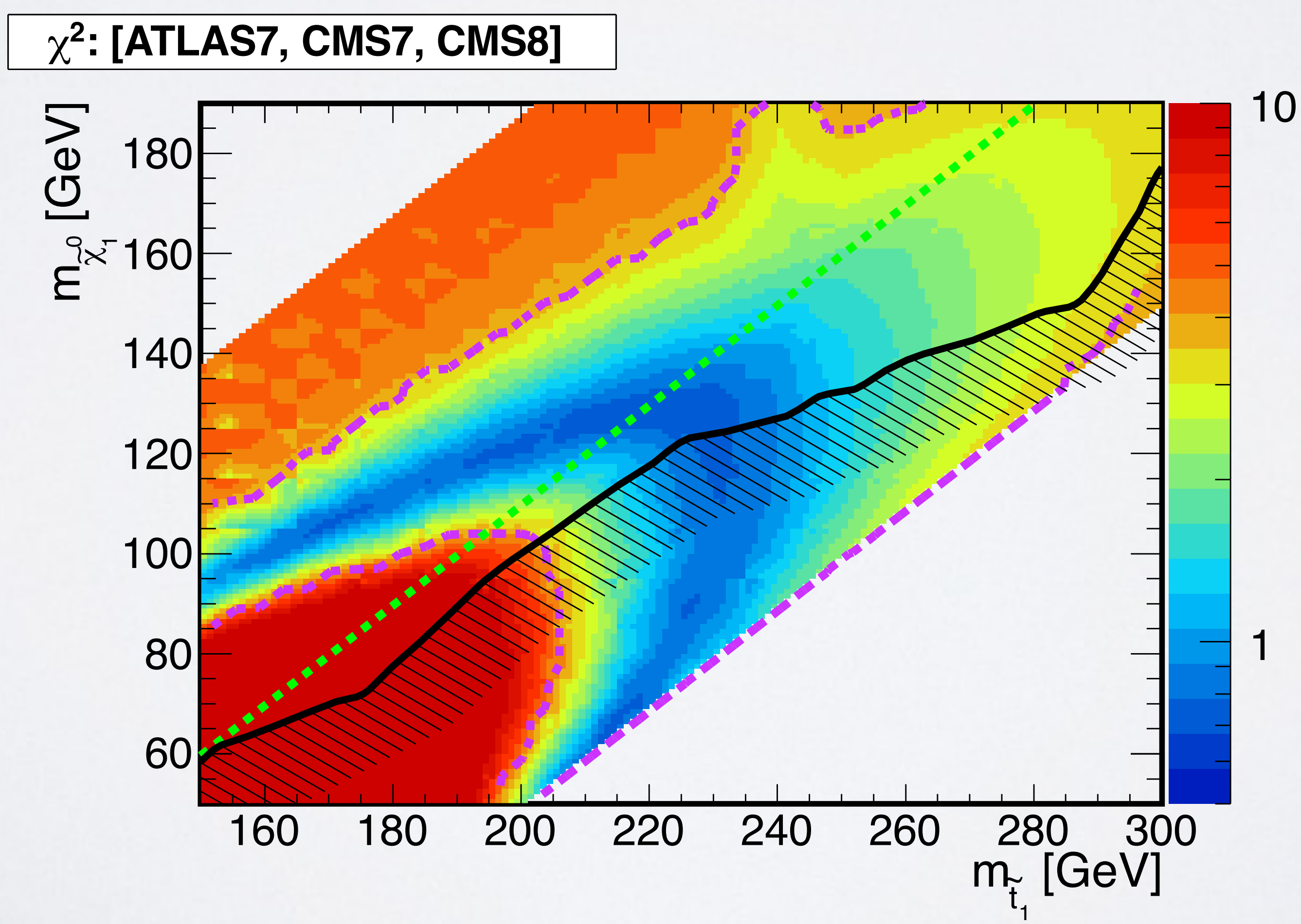


CHARGINOS FROM STRONG PRODUCTION?

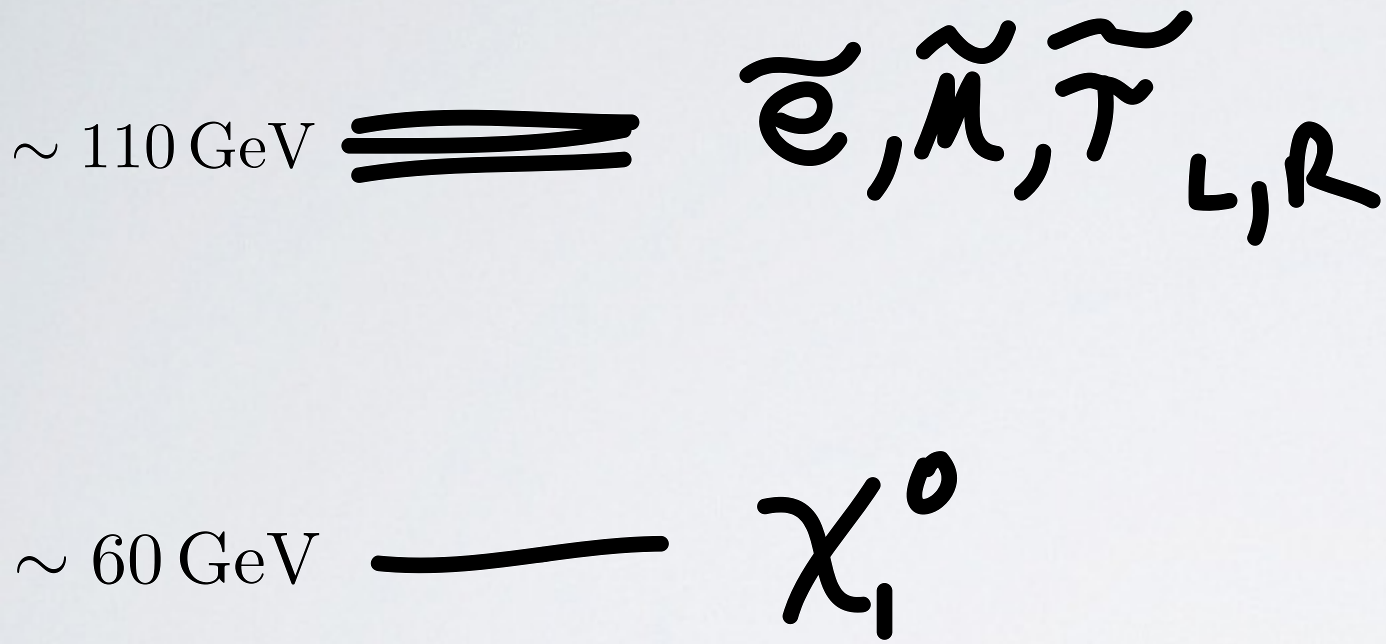
$$\tilde{t}_1 \to \tilde{\chi}_1^{\pm}\, b \to \tilde{\chi}_1^0\, W^{(*)}\, b \to \tilde{\chi}_1^0\, \ell\, \nu\, b$$

Squeeze the b's and you get WW production

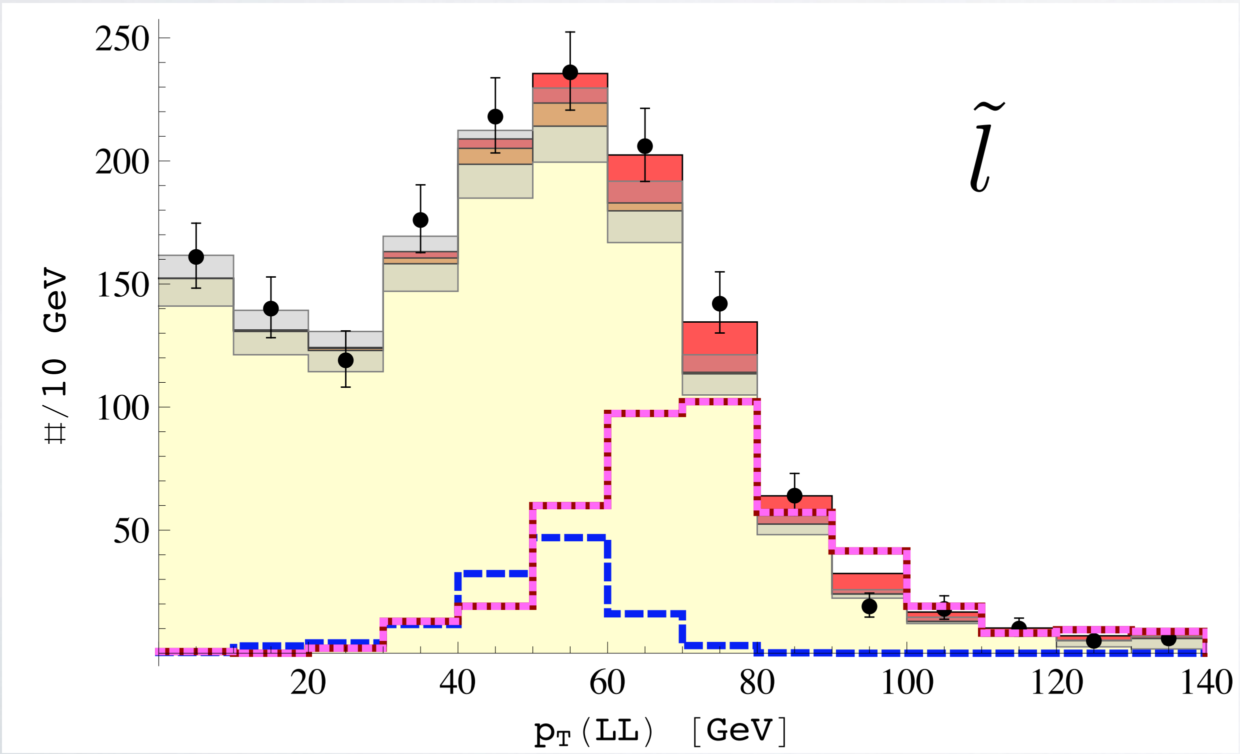
Rolbiecki and Sakurai 1303.5696

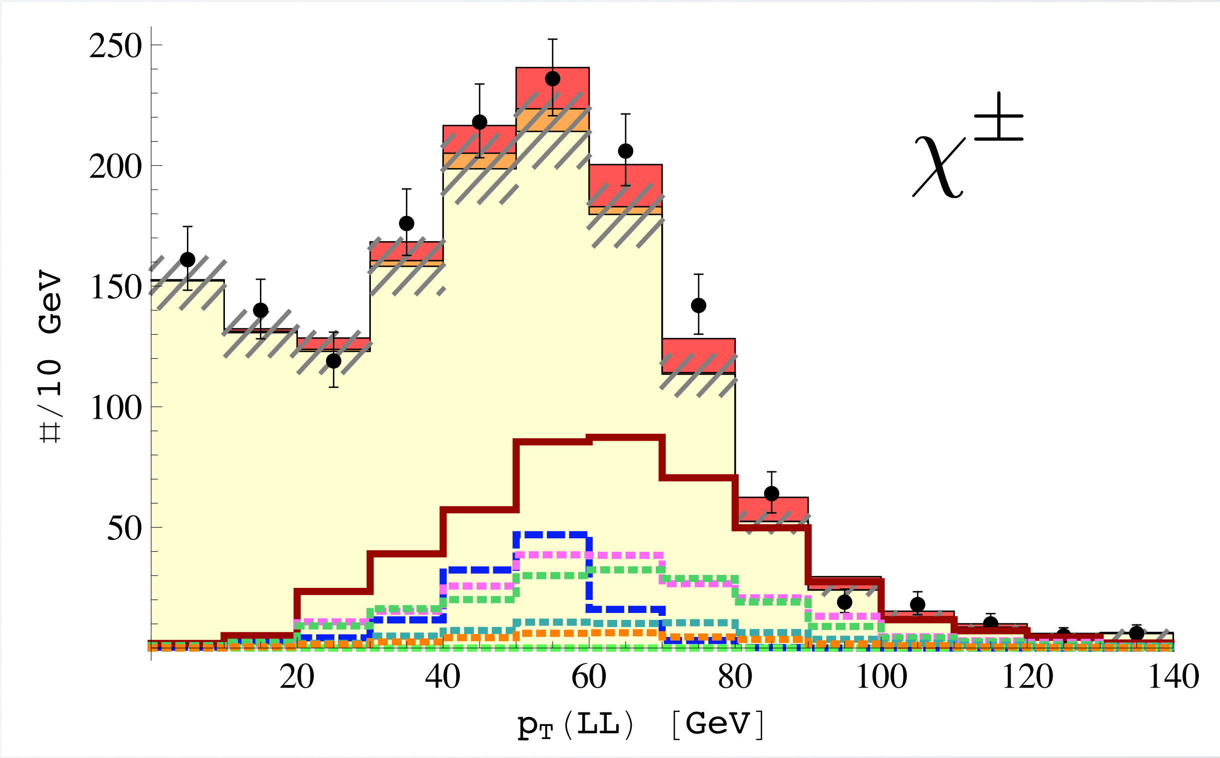


TURNS OUT SLEPTONS FIT JUST AS WELL...

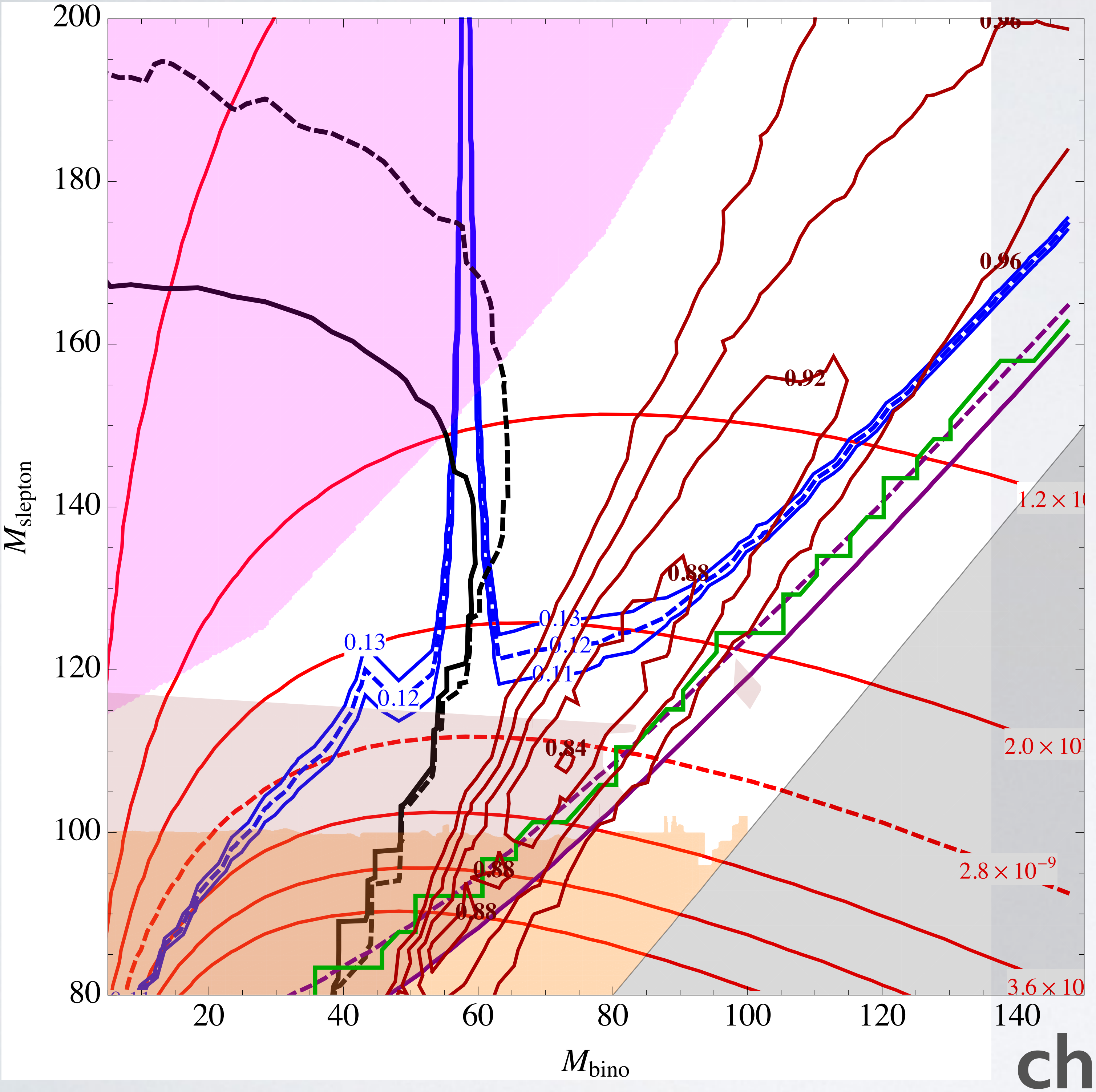


1304.7011





SLEPTONS DO A LOT MORE!



(b) $\tan\beta = 4, \mu = 600\,\text{GeV}$

Bino DM works with light sleptons - BLUE

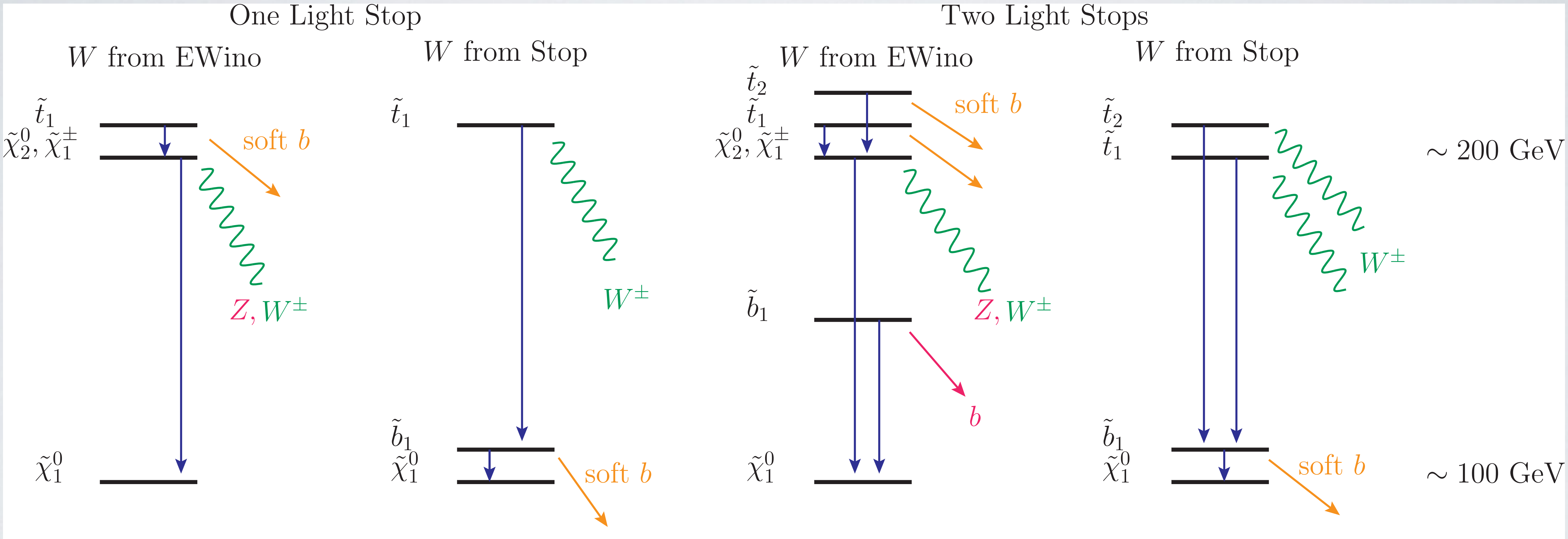
g-2 anomaly - RED Dashed

WW improvement - RED contours

This model ALSO changes the interpretation of the Higgs!!

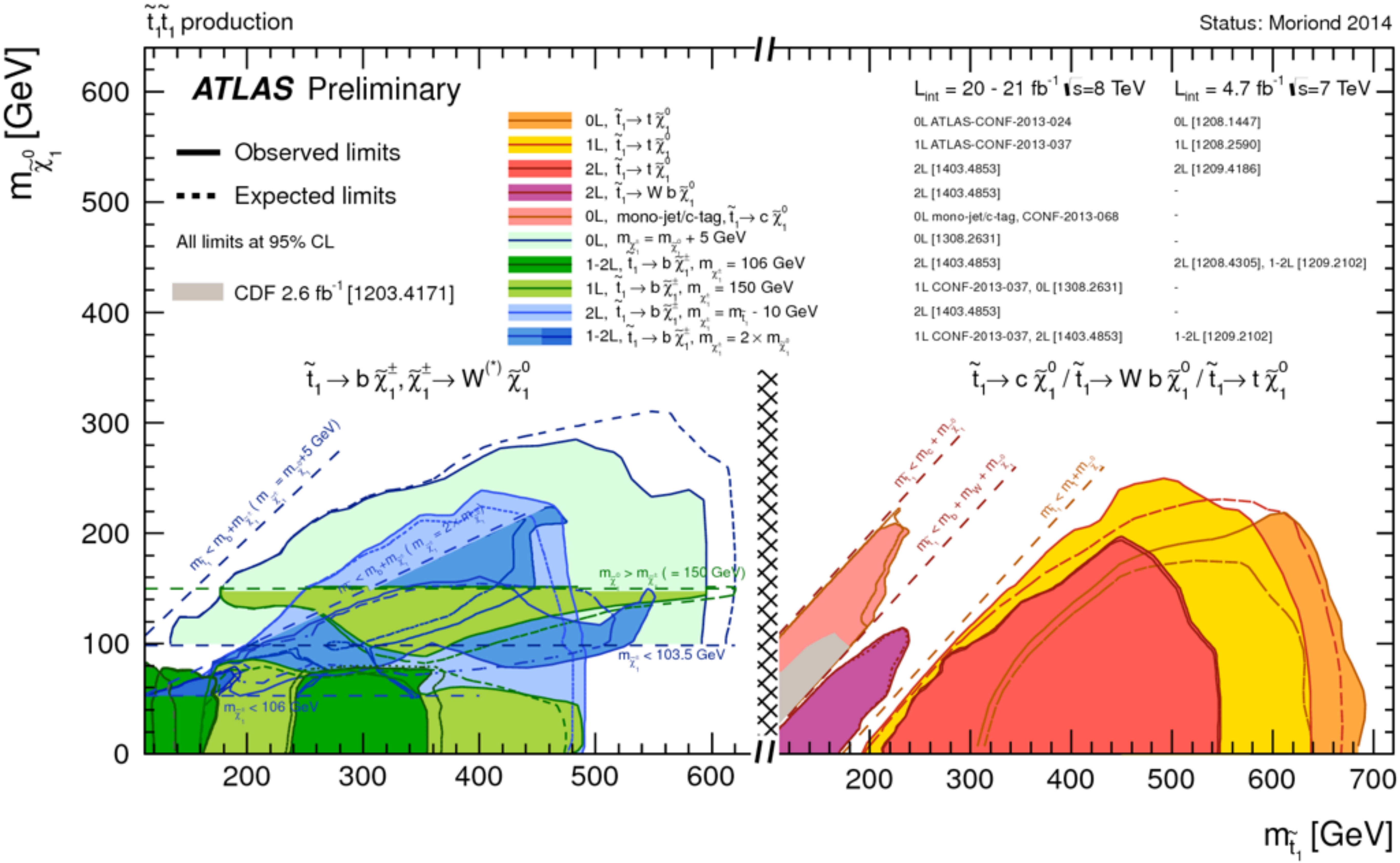
MANY MORE POSSIBILITIES

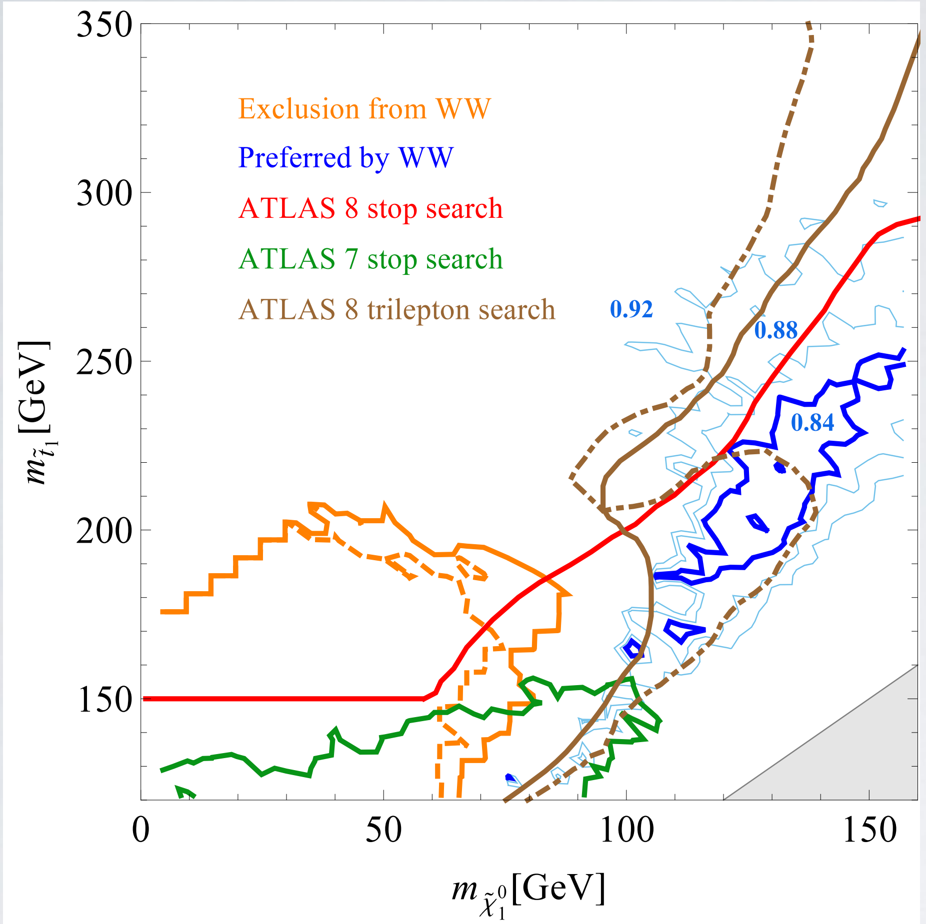
D. Curtin, PM, P. Tien (1406.xxxx tomorrow morning)



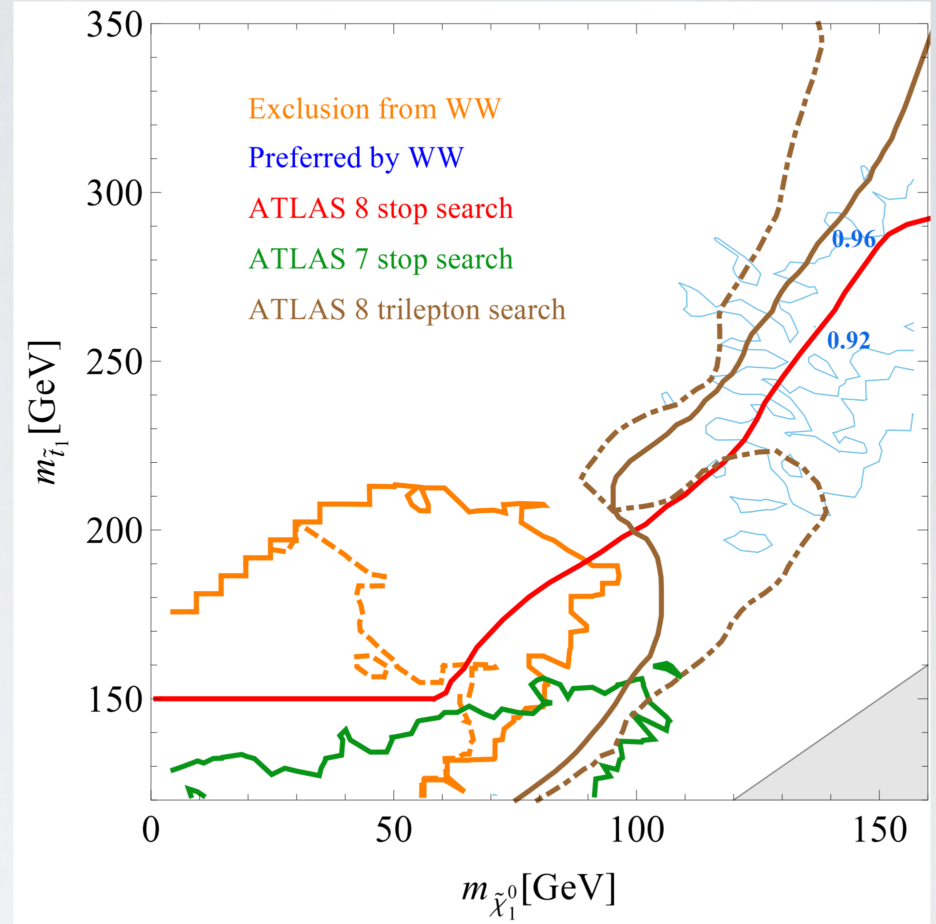
YOU CAN HAVE NATURAL SUSY AS ENVISIONED

SURELY YOU JEST??

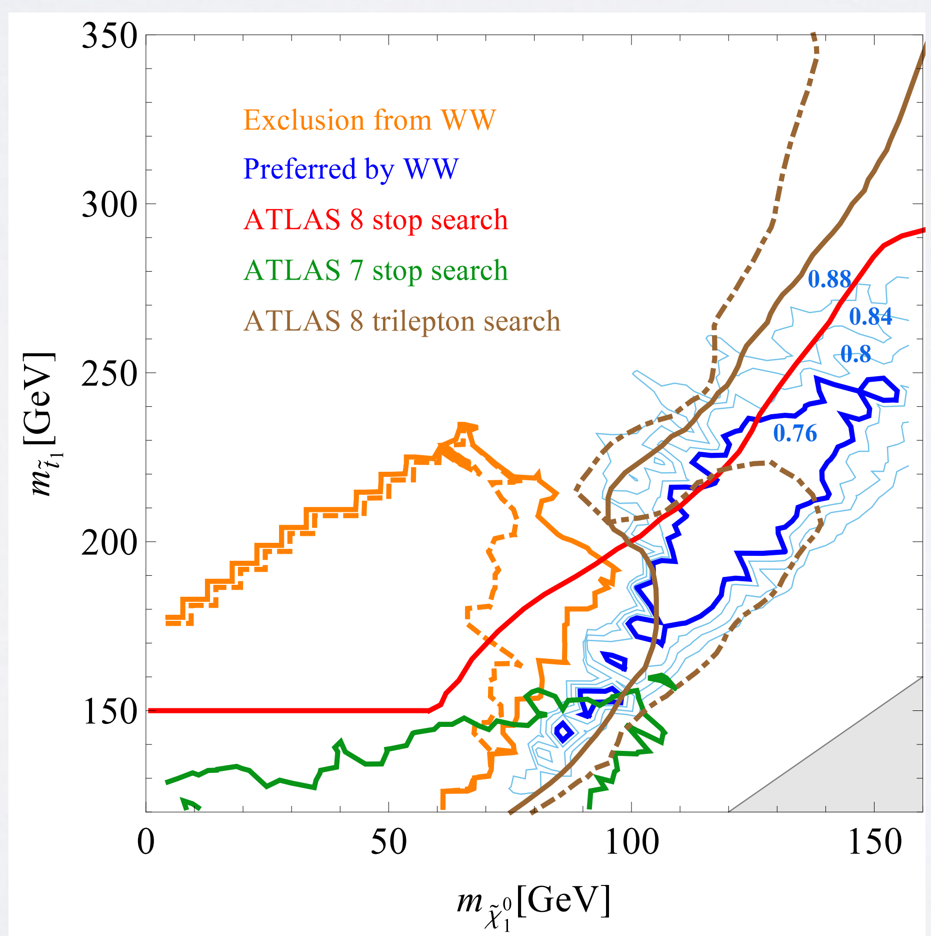




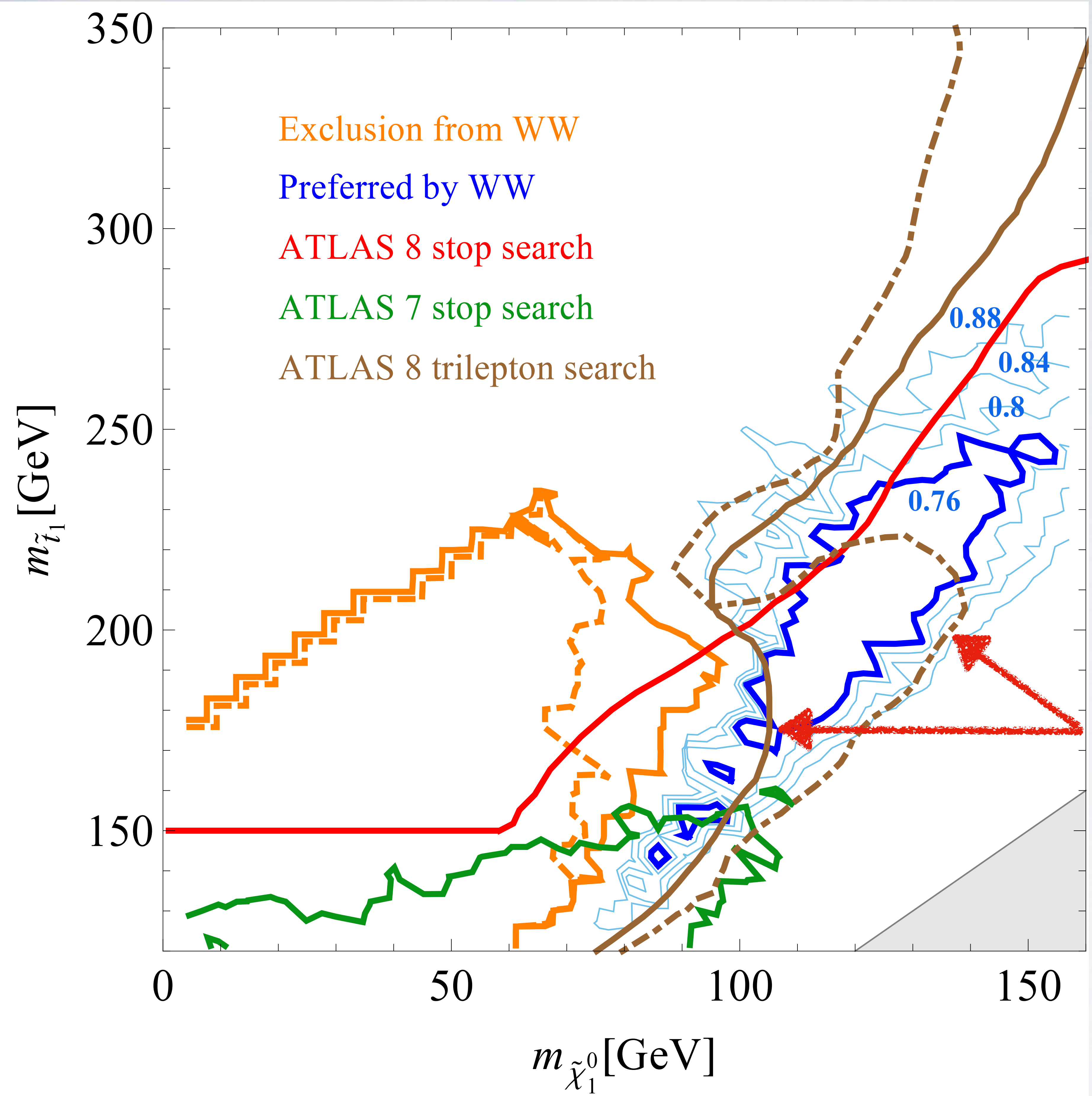
(a) ATLAS 7 TeV 5 fb^{-1} [18]



(b) CMS 7 TeV 5 fb^{-1} [19]



(c) CMS 8 TeV 3.5 fb^{-1} [20]



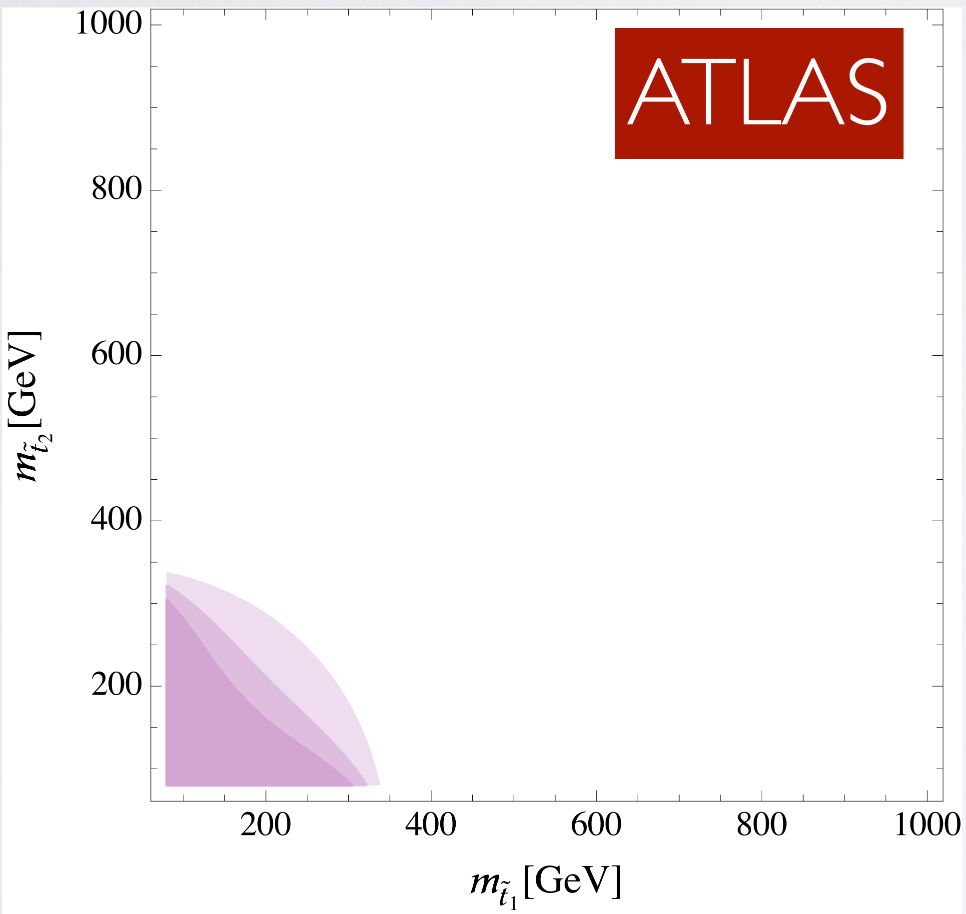
(c) CMS 8 TeV 3.5 fb^{-1} [20]

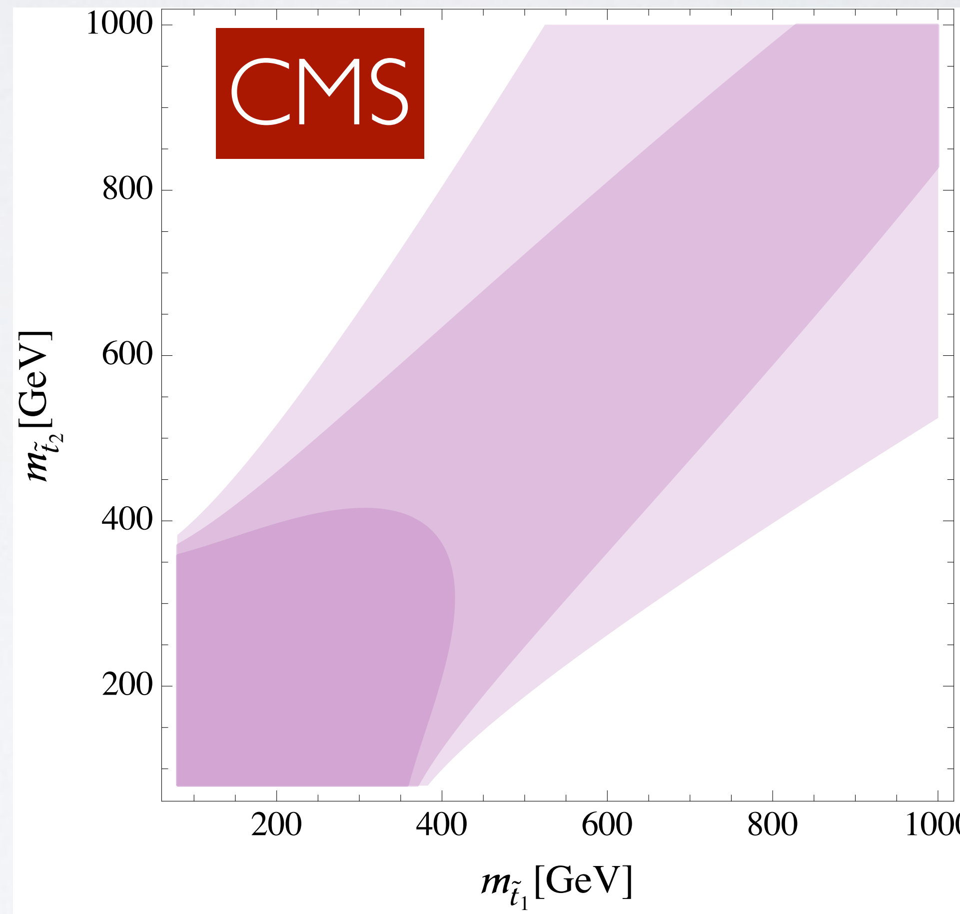
Anomaly was based on OS ***dileptons***

Somehow ***trileptons*** **love** light stops…?

CAVEATS OF COURSE

- Doesn't account for Higgs Mass, but go to D-terms/NMSSM/ model build
- light stops will affect higgs couplings via loops! Status is still uncertain…





J. Fan, M. Reece
1401.7671
+
Private Comm.

MANY POSSIBILITIES…

D. Curtin, P. Jaiswal, PM 1206.6888
Rolbiecki and Sakurai 1303.5696
D. Curtin, P. Jaiswal, PM, P. Tien 1304.7011
D. Curtin, PM, P. Tien 1406.xxxx (wednesday night EDT)
Kim, Rolbiecki, Sakurai, Tattersall 1406.xxxx (wednesday night EDT)

- Charginos at O(100) GeV
- Sleptons at O(100) GeV
- Stops at O(200) GeV
- All can improve the measurement of the WW cross section compared to the SM!!!!!!
  - Consistent with other LHC Data
  - Can explain DM/g-2
  - Can give a natural SUSY spectra

It just seems easier to do than many other "excesses"

top A_{FB} ,multi-muons, CDF Wjj,
CDF inclusive signal charged particle

TESTABLE CONSEQUENCES OF NEW PHYSICS

- Charginos lead to SS dileptons
- Sleptons lead to a flavor diagonal excess
- Stops eventually lead to higgs shifts/trileptons/soft b searches
- Important to note that all of these are NP signatures that IMPROVE on the SM as we know it…
  - Other new physics can/is being hidden normally within error bars, even if the parameter space is cut it will be important to look at these possibilities that live in the "space beyond errors…"

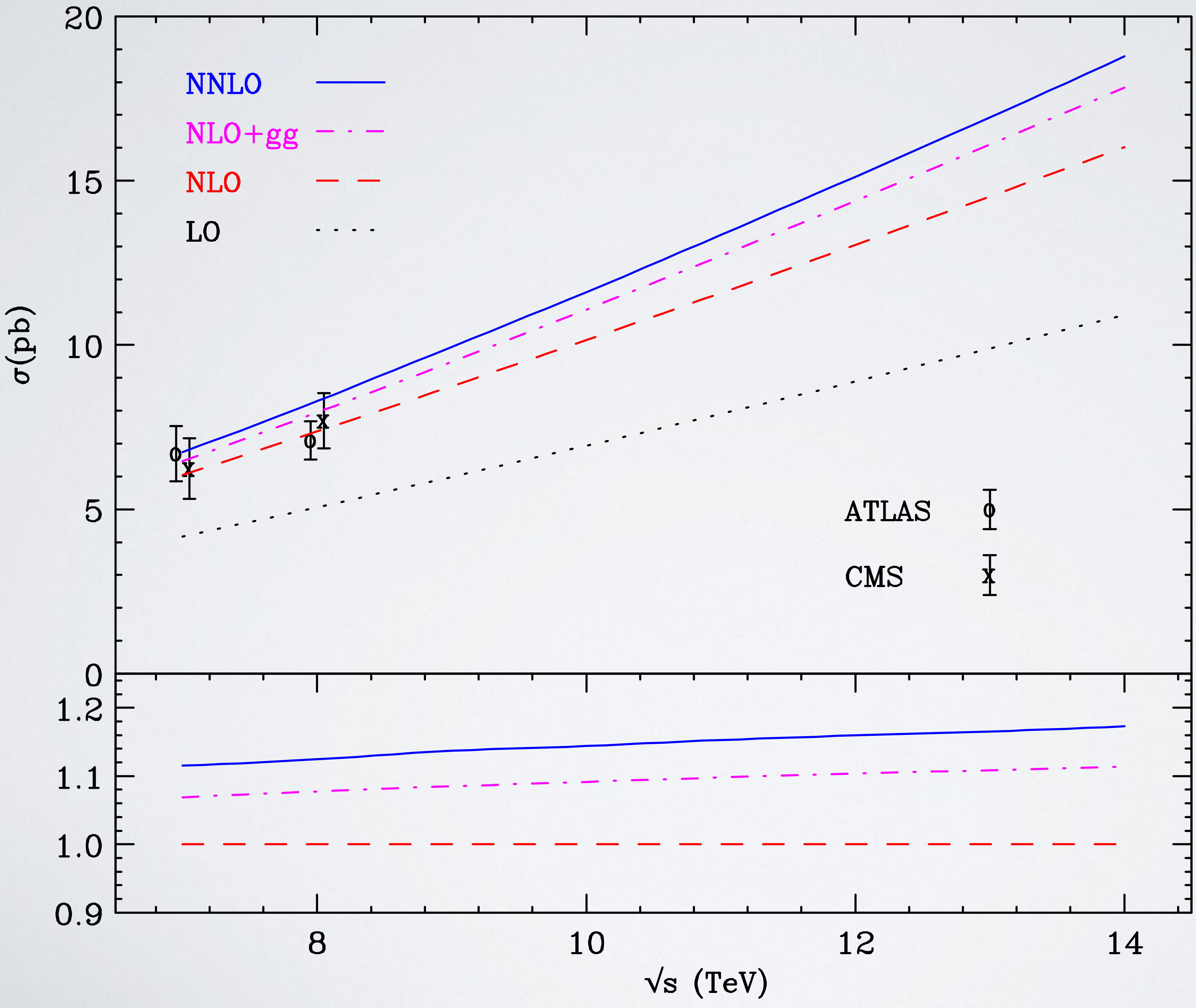
SM/EXPERIMENTAL POSSIBILITIES???

- Backgrounds Wrong - Negligible effect?
- WW cross section wrong (k-factors 1.6ish need a 20% NNLO effect, not demonstrated in ZZ very recently)
  - higgs interferes destructively
  - EW NLO reduces as well
- Systematics

WHY DOES $\sigma(pp \to ZZ)$ AGREE?

1405.2219 ZZ production at hadron colliders in NNLO QCD

F. Cascioli[a], T. Gehrmann[a], M. Grazzini[a]*, S. Kallweit[a], P. Maierhöfer[a], A. von Manteuffel[b], S. Pozzorini[a], D. Rathlev[a], L. Tancredi[a] and E. Weihs[a]



<2% effect…

HOW DO WE IMPROVE QCD PREDICTION?

- NNLO
- Resummation for WW
  - threshold (S.Dawson et al 1307.3249)
  - pT resummation (Grazzini 0510337, Wang et al, 1307.7520, PM, H. Ramani, M.Zeng to appear)
  - jet veto

A. Larkoski

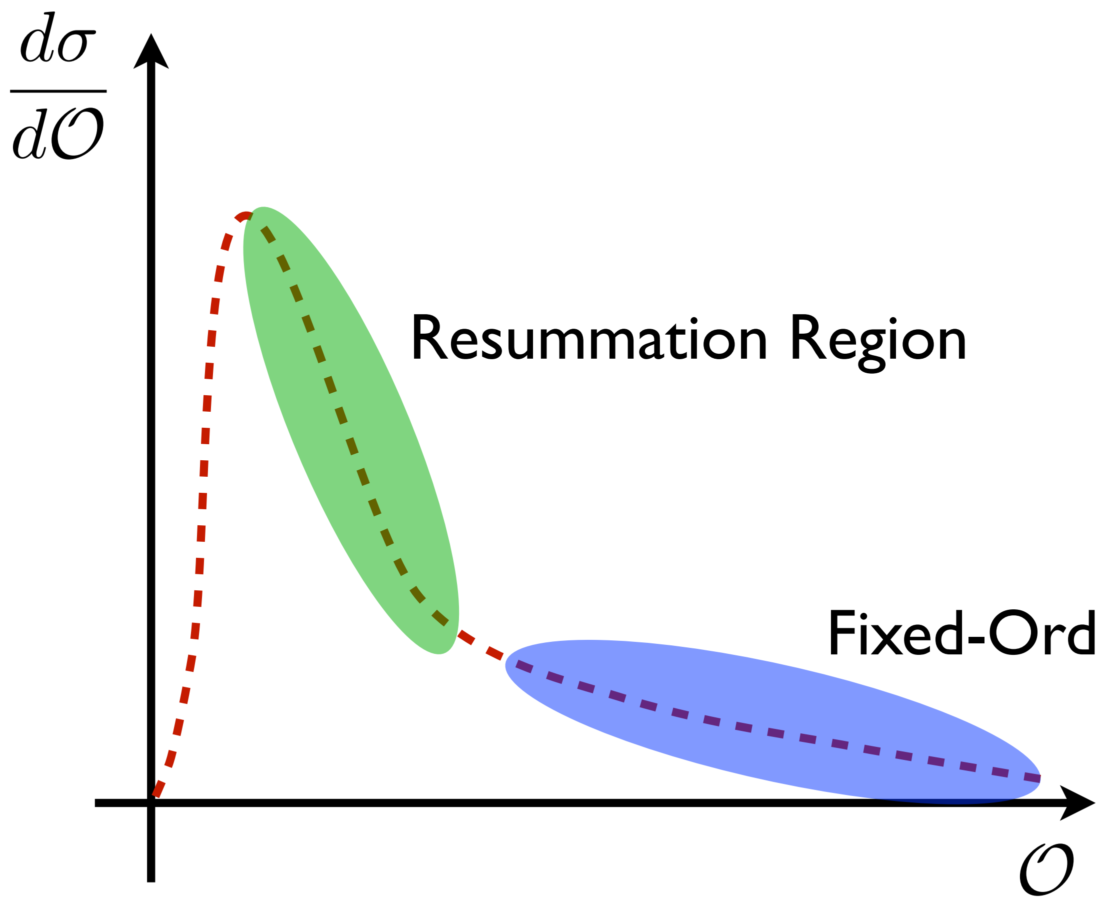
Age-old procedure

Resum large logarithms:

Leading Logarithms

Next-to-Leading Logarithms

$$\frac{d\sigma}{d\mathcal{O}} = (\alpha_s + \cdots)\exp\left[\sum_n \left(\alpha_s^n \log^{n+1}\mathcal{O} + \alpha_s^n \log^n \mathcal{O} + \cdots\right)\right]$$



Methods of resummation

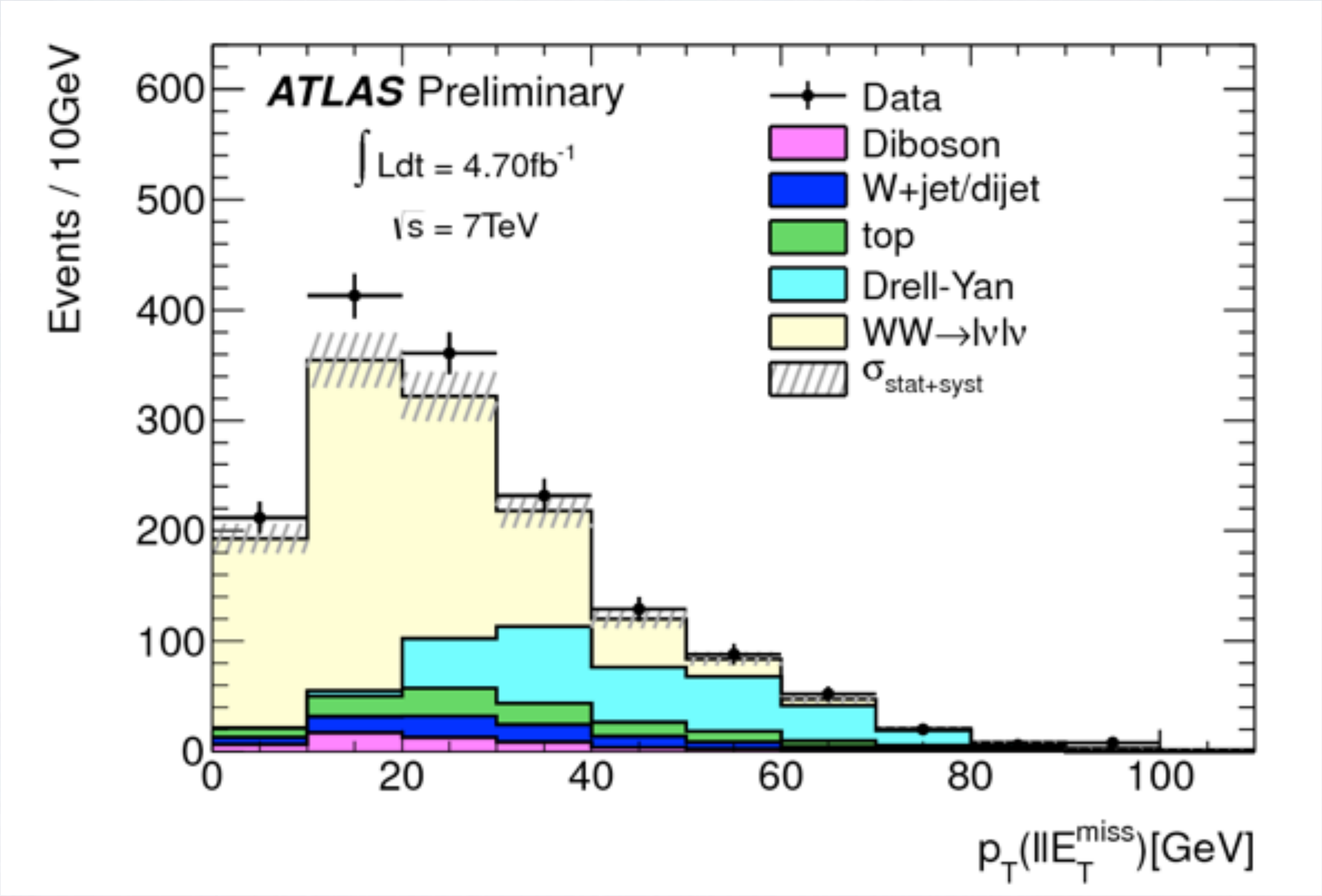
Analytical Effective Theory Methods:
Resummaton by renormalization

Monte Carlo Parton Shower:
Numerical approximation to
all-orders matrix element

Whenever there's factorization, there's evolution, and whenever there's evolution there's resummation

G.Sterman

TRANSVERSE MOMENTUM RESUMMATION



Given the jet veto, this ***all*** is dependent on soft QCD

Need this to get things right like W mass measurements (D0 used Collins, Soper, Sterman formalism to attain precision)

DIFFERENCES W/ PARTON SHOWER

ResBos WEBSITE

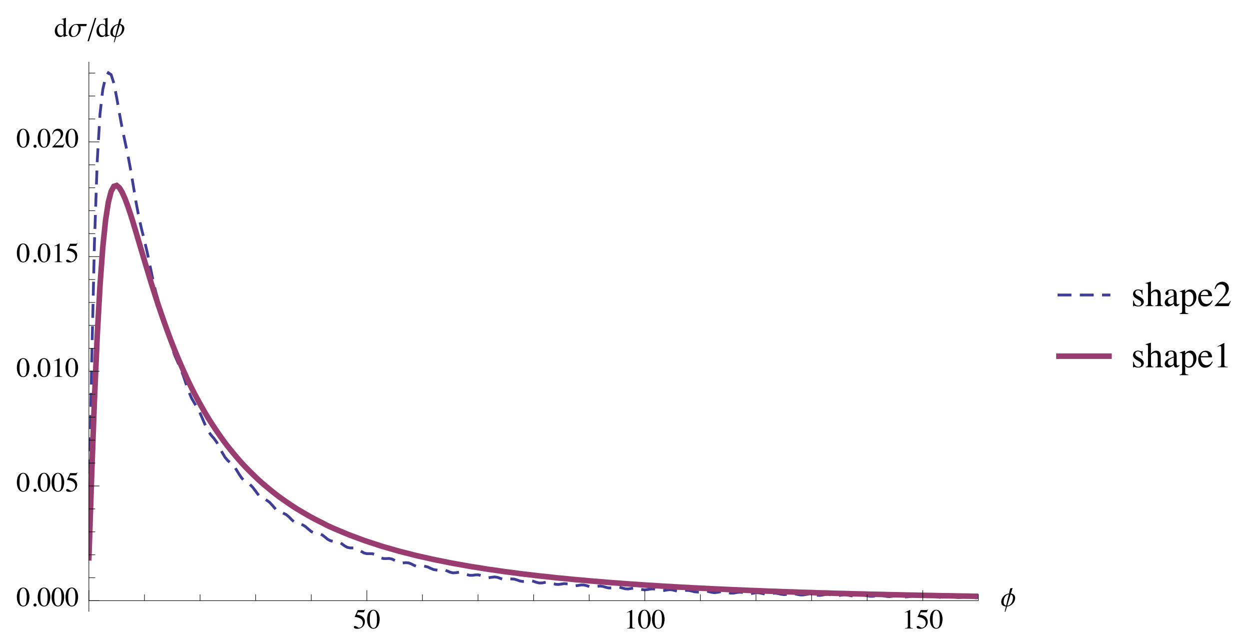
Analytical Q_T resummation	Parton showering programs (Pythia, MC@NLO, Sherpa...)
• evaluate(s) effects of multiple parton radiation in hadronic scattering	
• applies to a restricted class of processes and observables (e.g., lepton distributions in Drell-Yan-like processes); inclusive with respect to hadronic radiation	• apply to a wide range of observables; exclusive with respect to hadronic radiation
• is proved to all orders in the QCD coupling by special factorization theorems devised for each qualified observable	• no factorization proofs for individual observables
• streamlined computation of higher-order corrections and high-p_T contributions	• beyond the leading order, radiative contributions and high-p_T tails may be difficult to implement
• NLO Q_T resummation formulated in 1979-1997; modern Q_T resummation approaches NNLO accuracy	• modern showering programs approach NLO accuracy
• resummation of all logarithms $\ln Q_T^2/Q^2$	• resummation of leading logarithms $\ln Q_T^2/Q^2$
• nonperturbative contributions are constrained by invoking their universality in the considered class of processes	• nonperturbative scattering is evaluated in one of several available models
• more strict and precise; relies on first principles of perturbative QCD	• more flexible; more parameters to tune to describe various hadronic scattering effects

Transverse momentum resummation changes ***shape*** not ***cross section***!

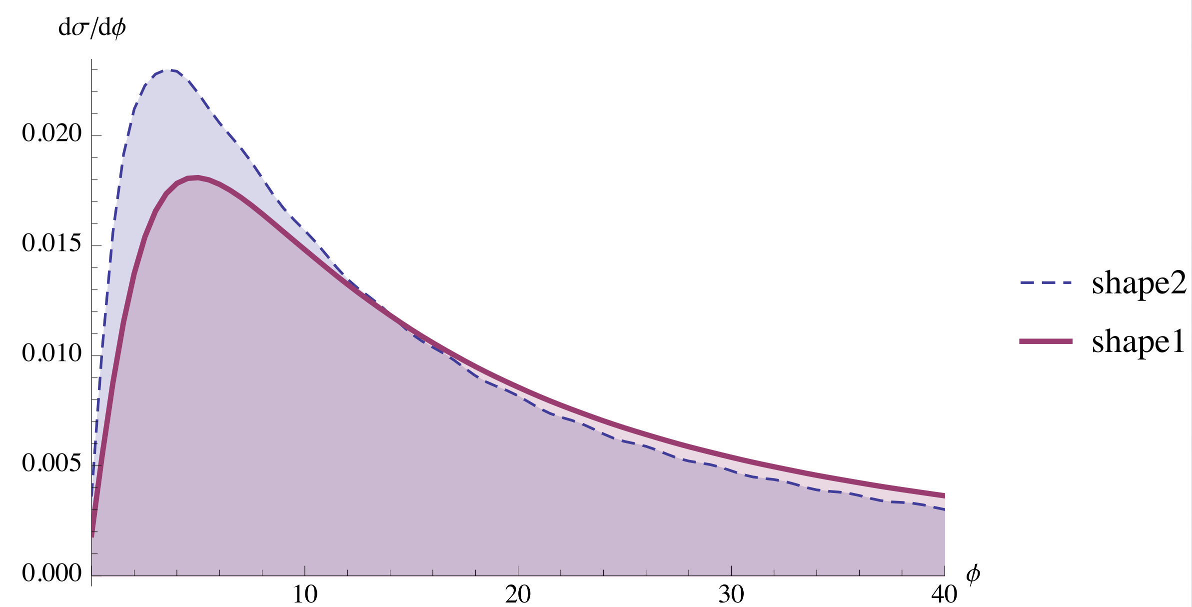
CAN'T DO THIS SOLELY ANALYTICALLY - FIDUCIAL CROSS SECTION

$$\sigma_{fid} = \sigma_{total}\epsilon.A.Br$$

However if resummation causes a shape difference…



Full Phase-space.
Both curves Normalized to unity.



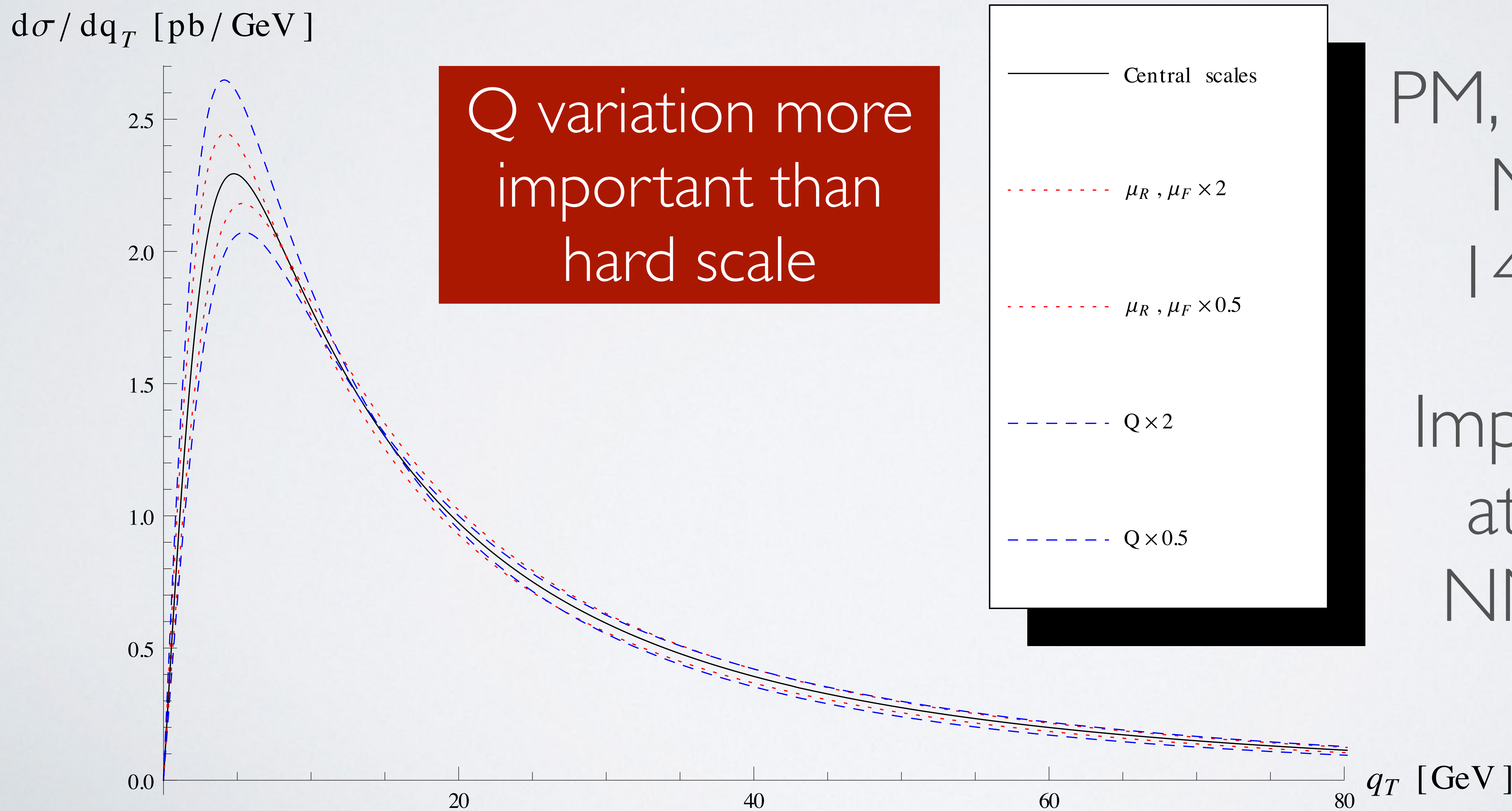
Shape effect translates to different Fiducial cross-section

CAN GET LARGE SHAPE DIFFERENCES FROM MATCHING IN RESUMMATION

- There are various different ways to do transverse momentum resummation, typically you don't work in qT you work in "b" space - problem is how to deal with small qT
  - Work in qT space directly in some approx (Dokshitzer and others)
  - CSS formalism - cut off b space softly (ResBos uses this)
  - CDG formalism - play with contour integral in b space
  - others as well

CAN GET LARGE SHAPE DIFFERENCES FROM MATCHING IN RESUMMATION

- We use CDG formalism, in this there is a matching/ resummation scale Q between fixed order and resummation



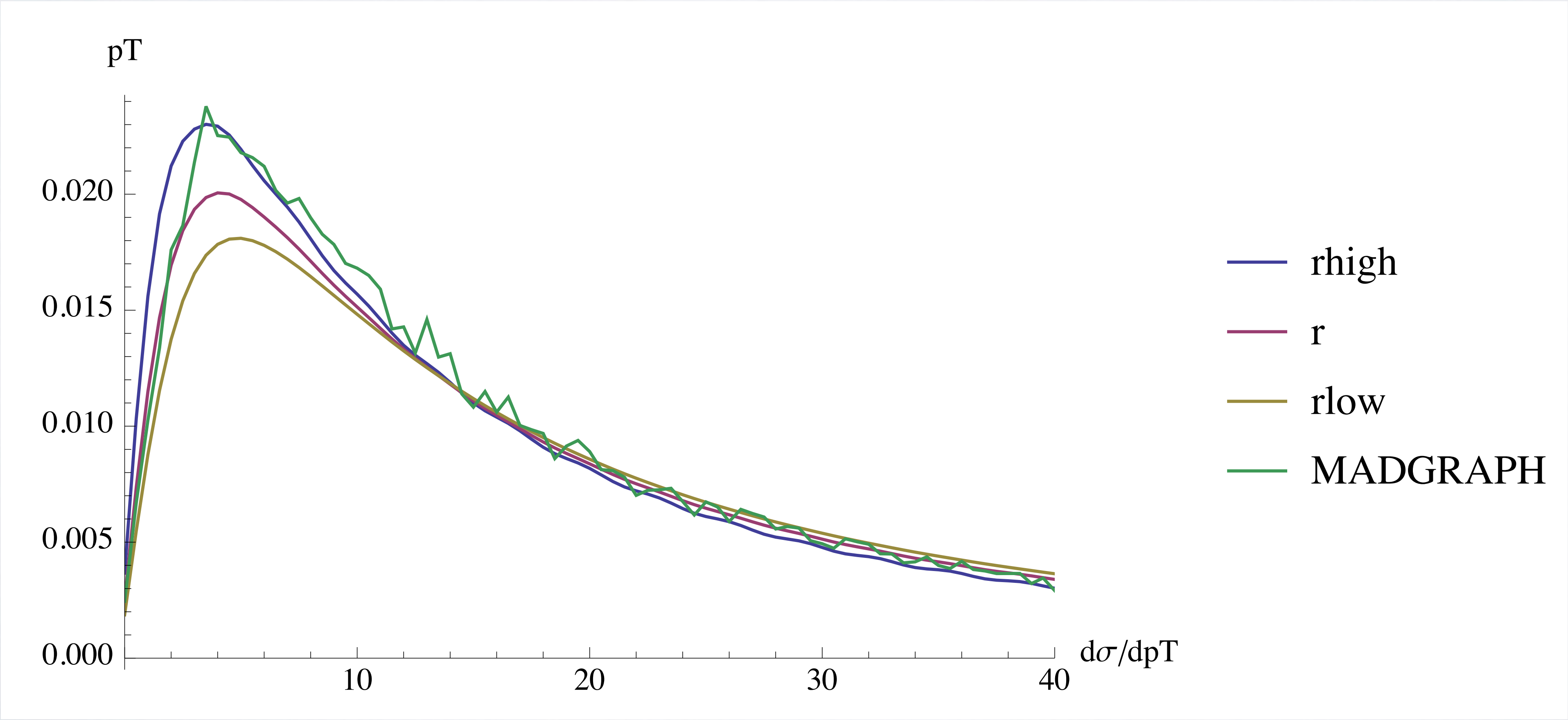
Q variation more important than hard scale

PM, H. Ramani, M. Zeng 1406.xxxx

Implemented at approx NNLL+LO

THE PROBLEM WITH TRANVSERSE MOMENTUM RESUMMATION AND COLLIDERS

- We don't have events, we've summed over all our gluons!
- There isn't an "unfolded" WW pt from experiments
- Have to come up with a proxy to get to fiducial cross section… come up with proxy, reweight MC events a la the Higgs group to see if underlying differences persist!



FIDUCIAL CROSS SECTION EFFECTS EXAMPLE

Cut-flow vs reweighted events

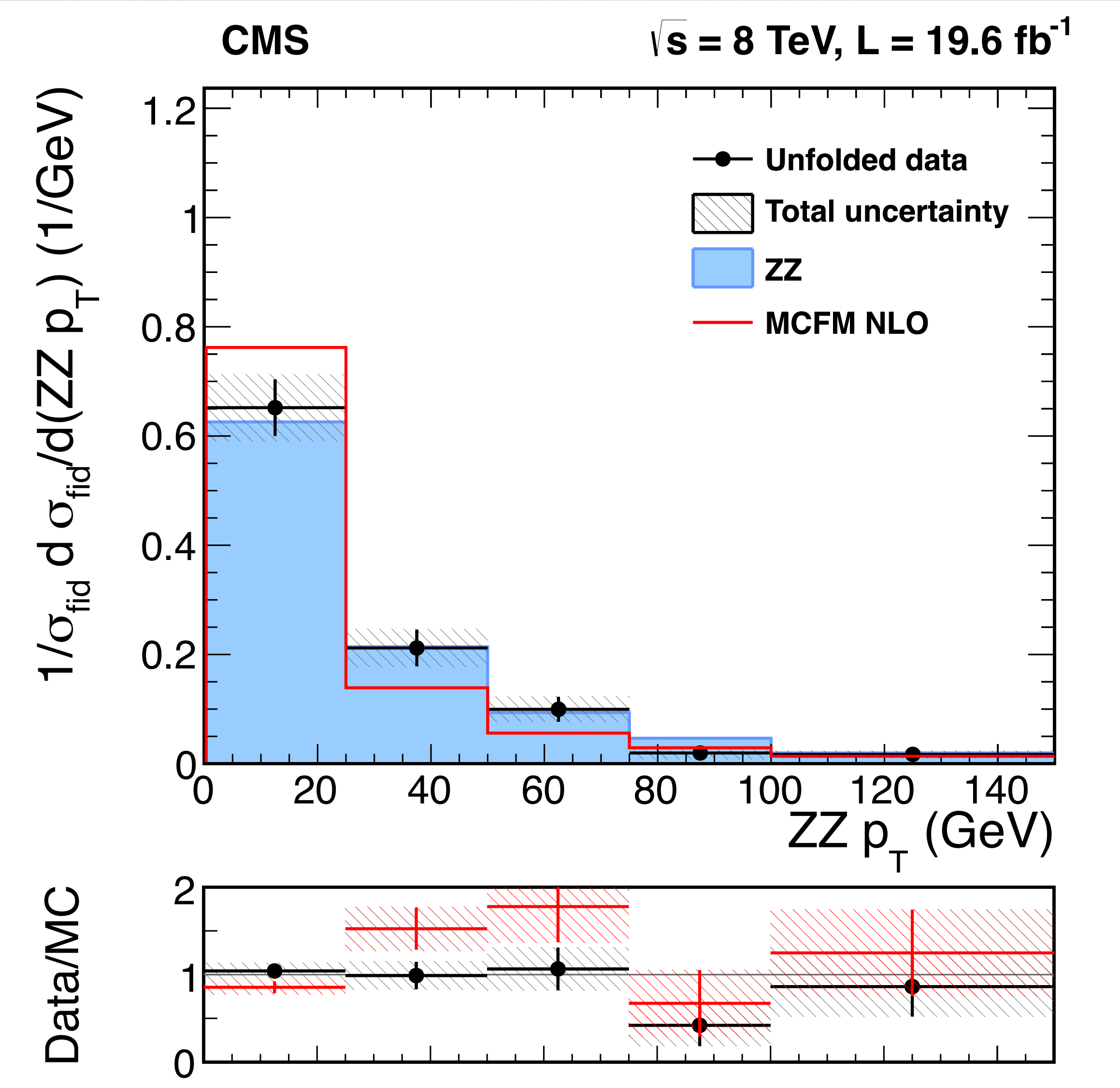
Cut	%
exactly 1 pair of oppositely charged leptons +MET	0
p_t and η cuts on leptons	0.06%
mll cuts	-0.32%
$E_{TMiss,rel}$	1.16%
Jet Veto	8.37%
p_{Tll}	8.50%

PRELIMINARY 8 TEV RESULTS

MC	Percentage Increase Q=mW/2	Percentage Increase Q=mW	Percentage Increase Q=2mW
Powheg+Pythia	4.05	0.16	-5.35%
aMC@NLO +Herwig	8.50	2.98	-0.82
Madgraph +Pythia	-1.13	-5.94	-8.88

Transverse Momentum Resummation can have an effect, but it should be UNIVERSAL…

ZZ RESULTS JUST OUT



The agreement between PowHEG and ZZ is very good

Correlation then with PowHEG
and resummation in WW is crucial

EXPLORING JET VETO EFFECTS DIRECTLY?

- Jet veto scale ~25-30 GeV introduces a new scale in the problem, and hence logs

- A number of groups have investigated this for Higgs/Drell-Yan

  Banfi, Salam, Zanderighi/Stewart, Tackmann, Walsh, Zuberi and others

- This should be studied directly for SM WW
  - Similar to Banfi et al 1203.5773 comparison between HqT and jet vetoes

CONCLUSIONS…

- There could be BSM right around the corner: understand WW!!!!
    - Charginos, Sleptons, Stops all can fit better than the SM, or certainly exist at low energies!!!!!!!!!!!
    - Can ***also*** set new bounds better than experimentalists using SM cross sections! 1304.7011
- Important to get QCD predictions/MC as accurate as possible to push back on experimentalists
    - Transverse momentum resummation can have an effect on WW, but it can go both wa and we have to understand the best scale choice
    - jet veto resummation or joint pt/eta resummation would be useful to investigate
    - Experimentalists need to care just as much about background shapes as signal
- Crucially important to get EW scale correct before pushing higher, as it can have serious implications for Higgs physics! Experimentalists also tend not to revisit things…