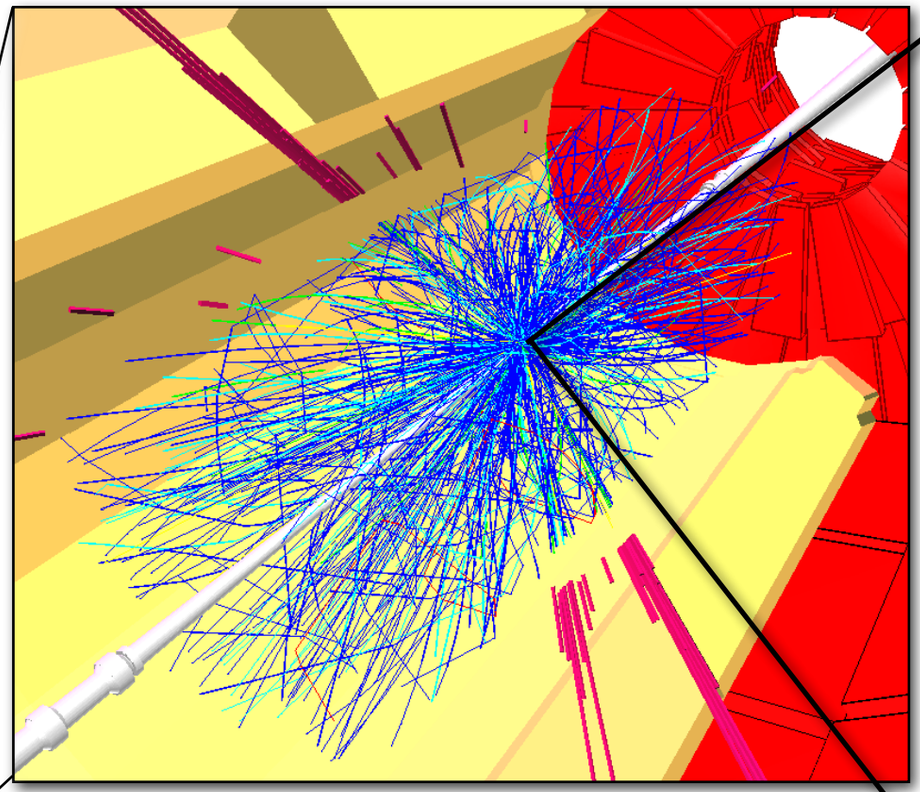
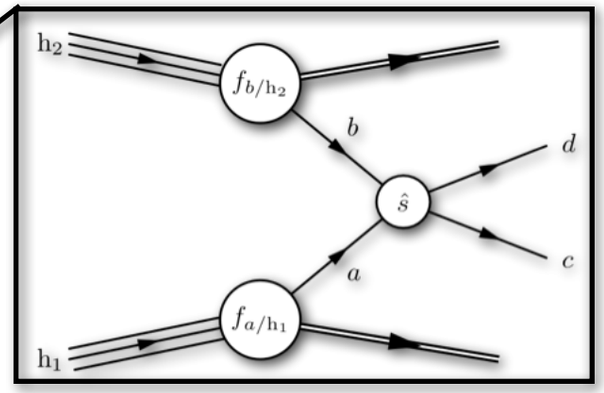
CMS Run 2 Results

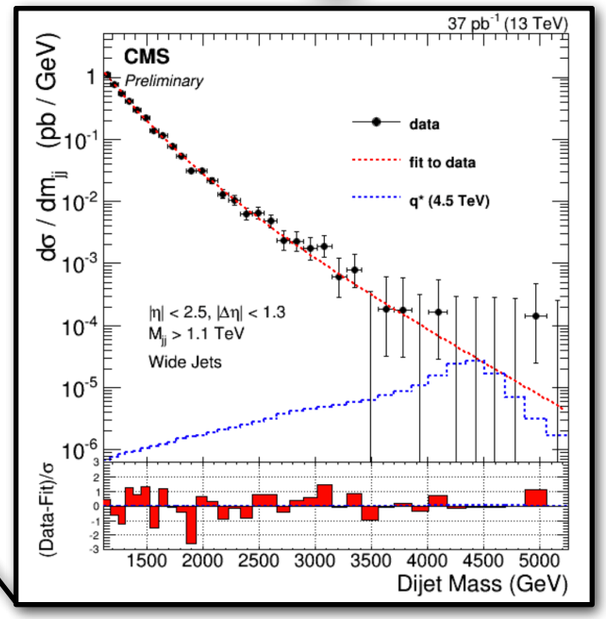
Günther Dissertori

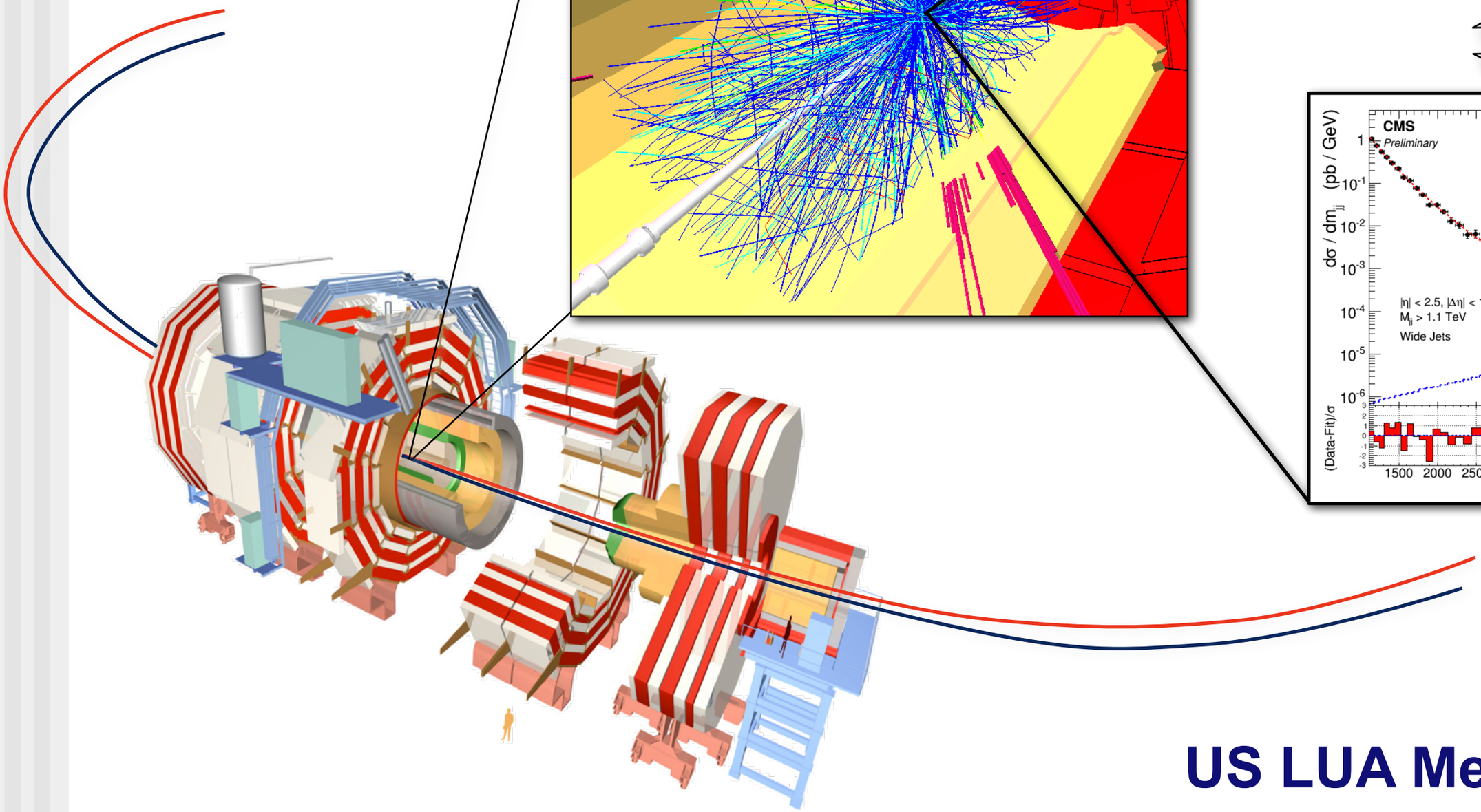
ETH Zürich

ETH Institute for Particle Physics









US LUA Meeting

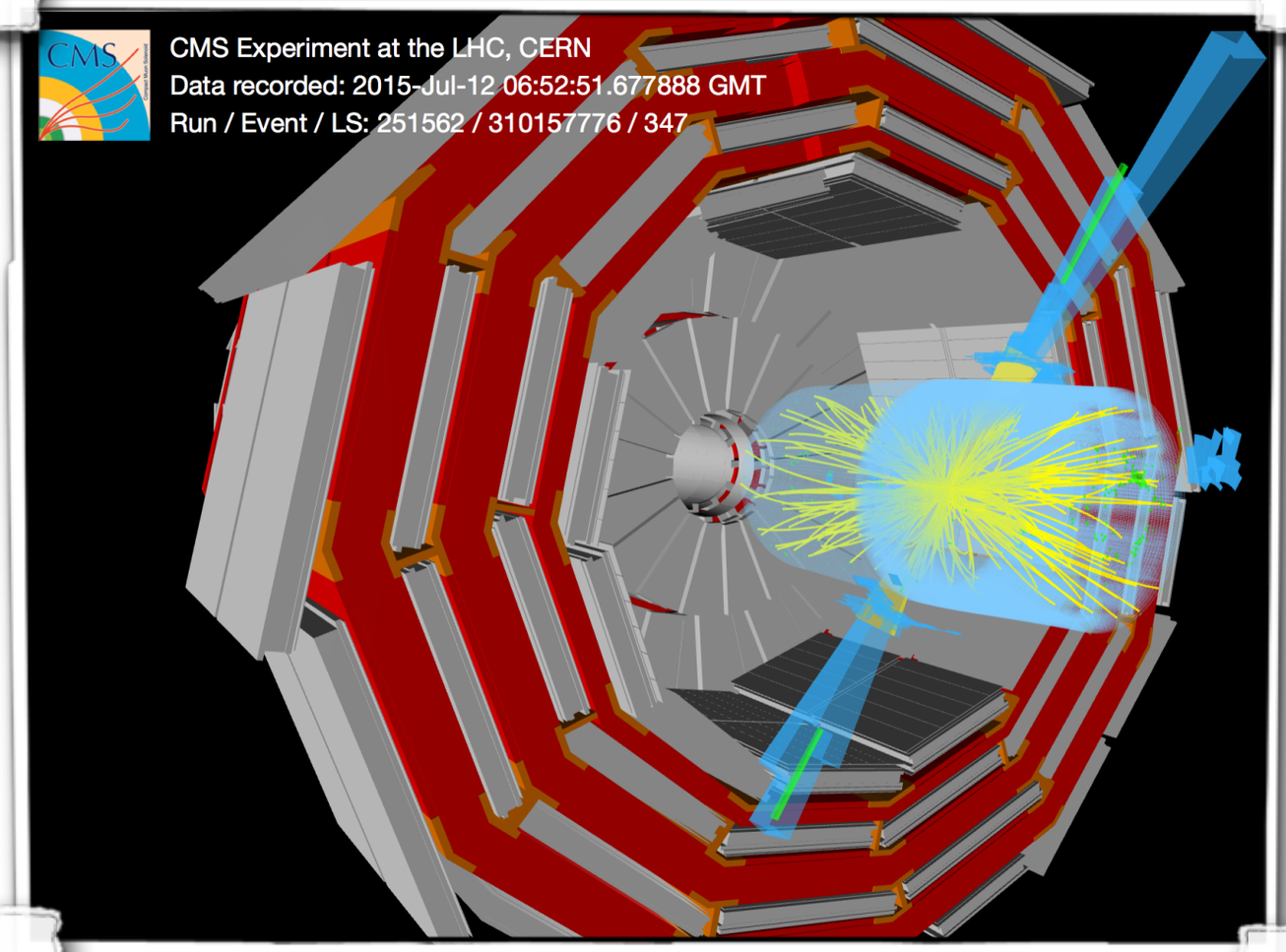
Fermilab

Outline

ETH Institute for Particle Physics

"soft" QCD

the top



W,Z prod.

searches

Remarks:

- *more details on the general status of CMS and performance studies: see talk by J. d'Hondt*
- *just a glimpse, for details see http://cms-results.web.cern.ch/cms-results/public-results/publications/*

Run 1: as things appeared with time....

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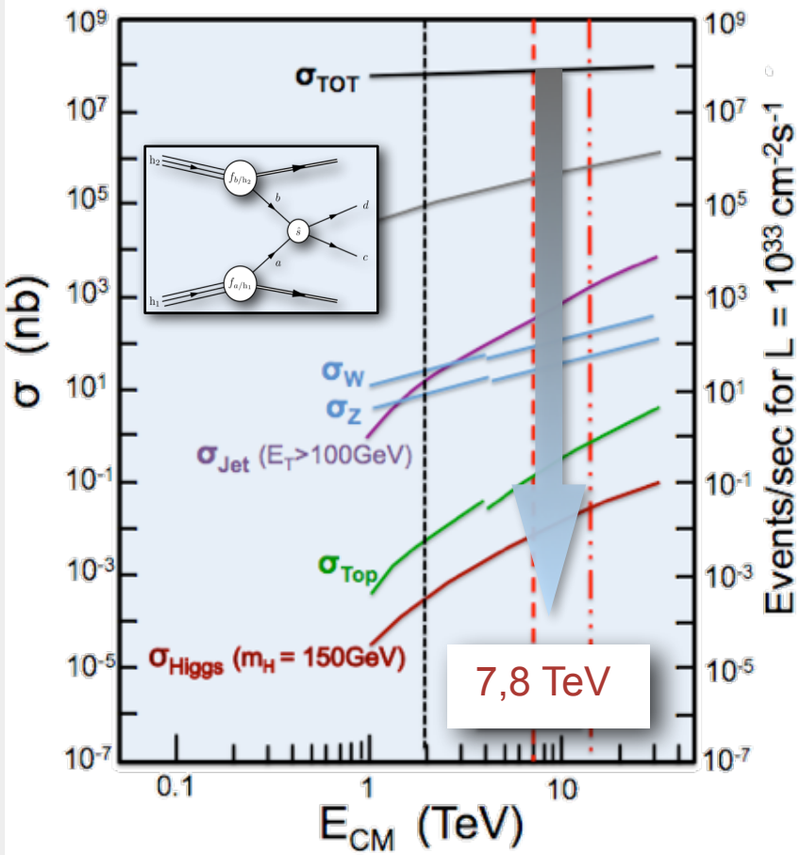

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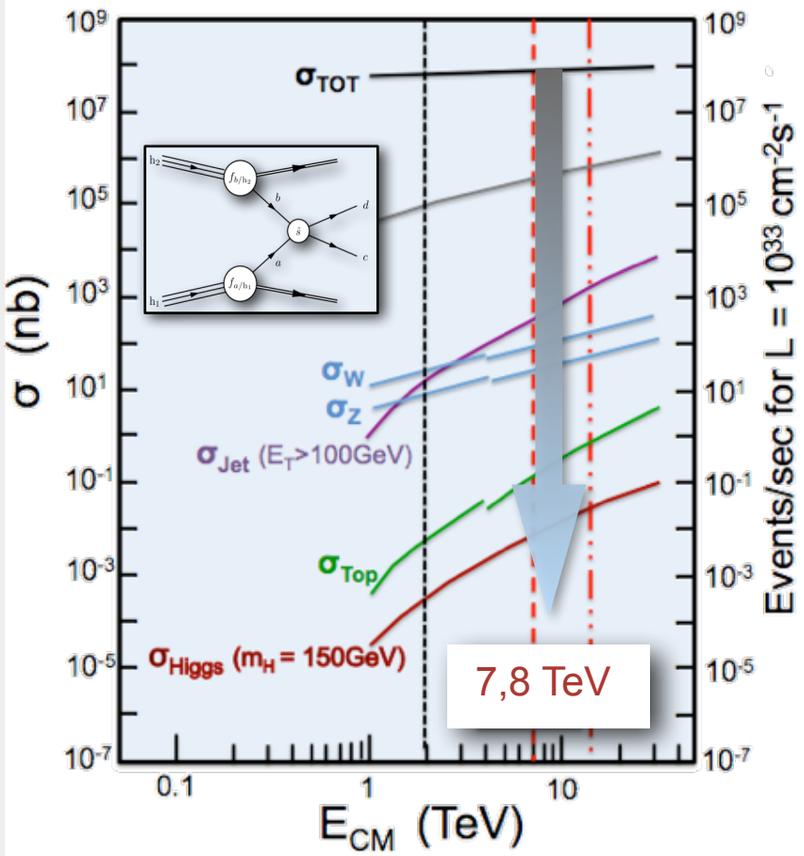

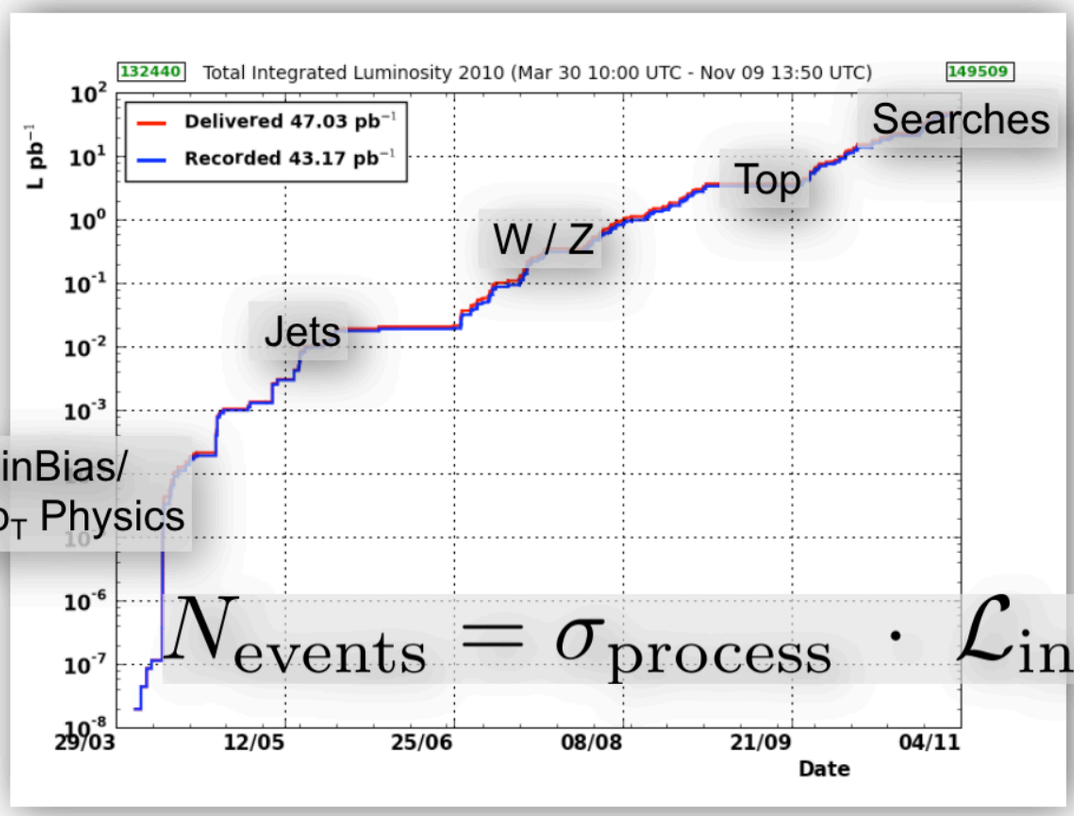

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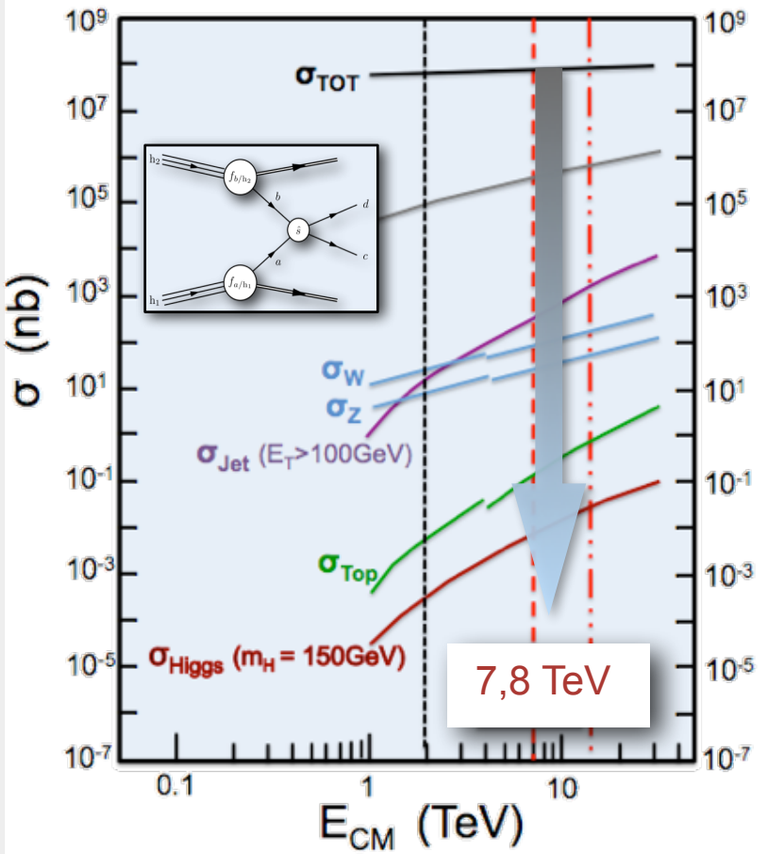

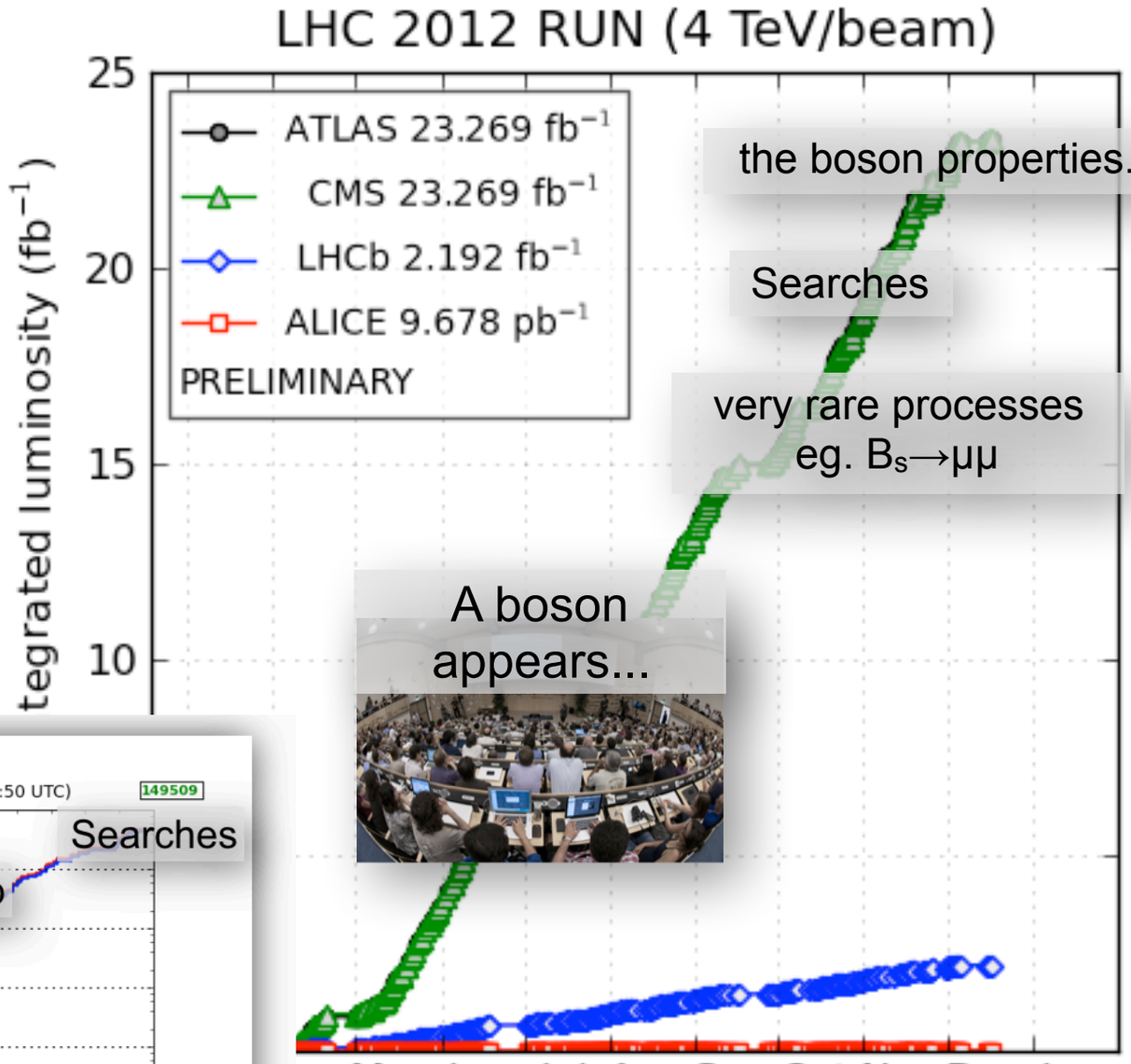

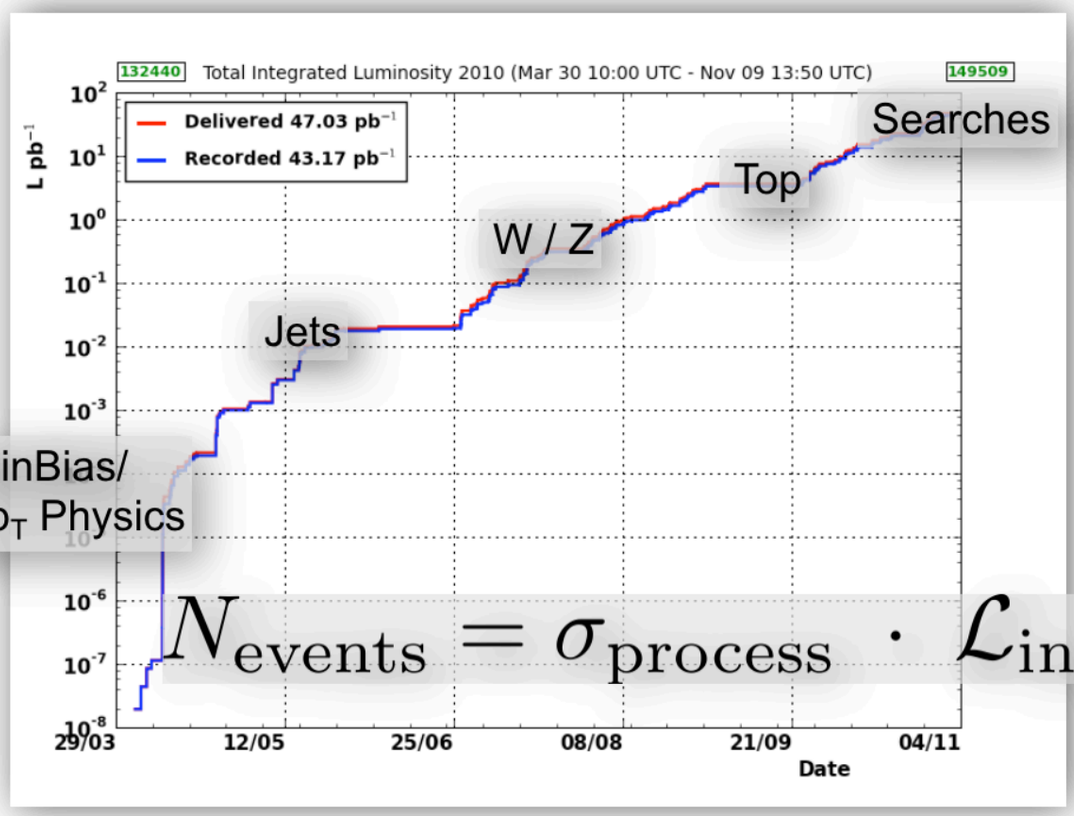

$$N_{\text{events}} = \sigma_{\text{process}} \cdot \mathcal{L}_{\text{int}}$$

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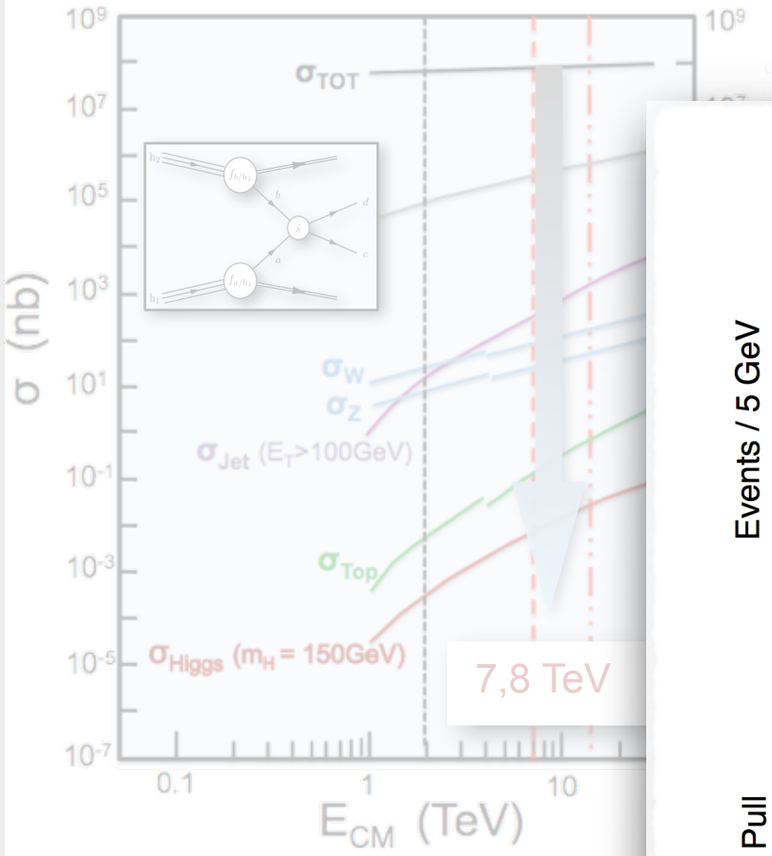
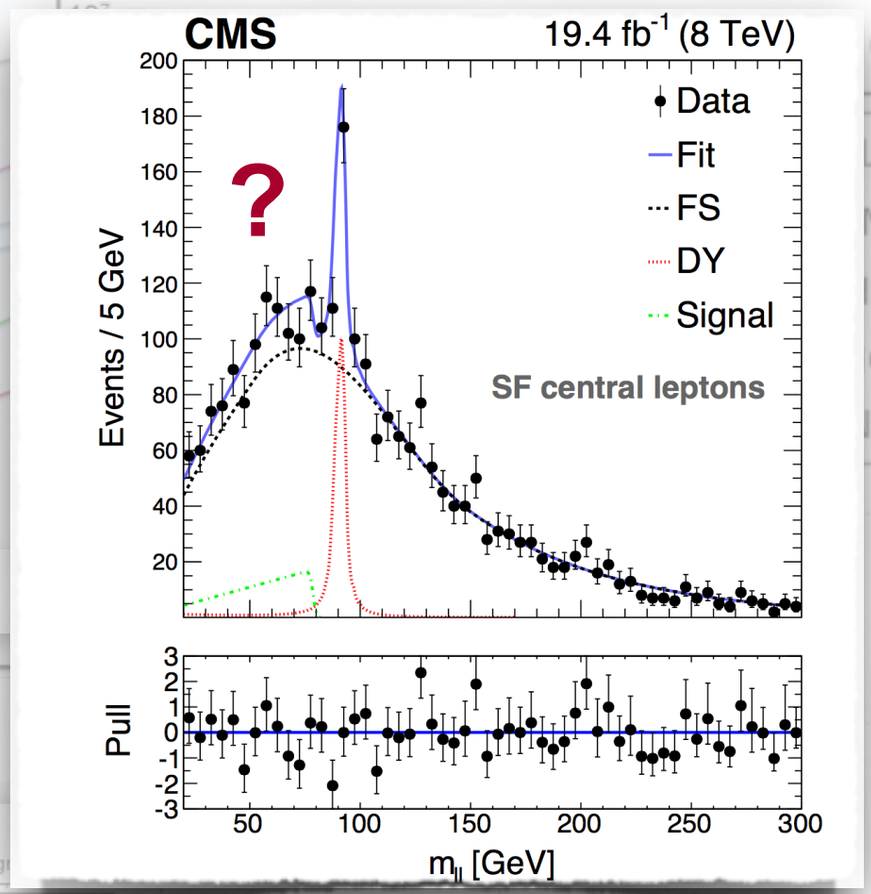
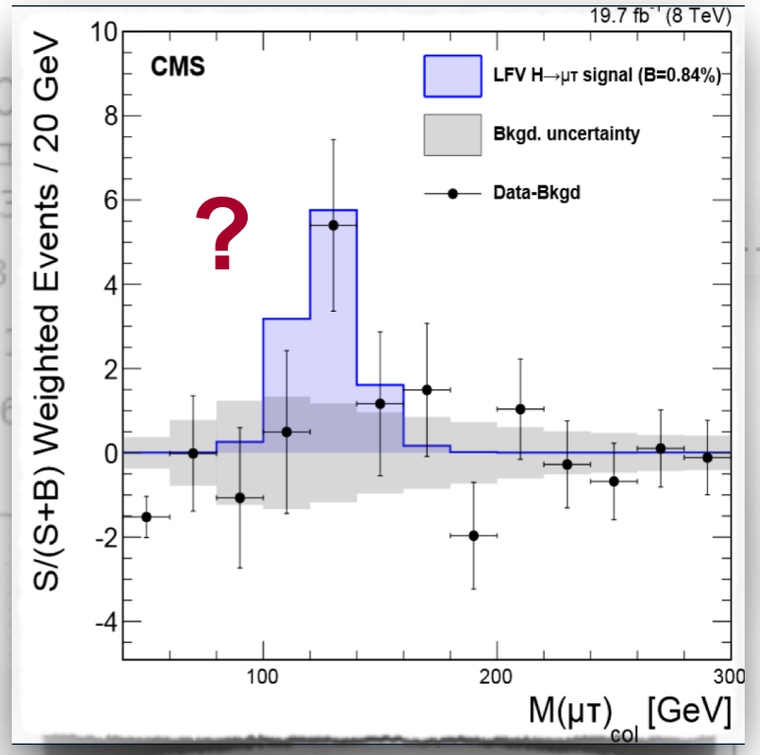
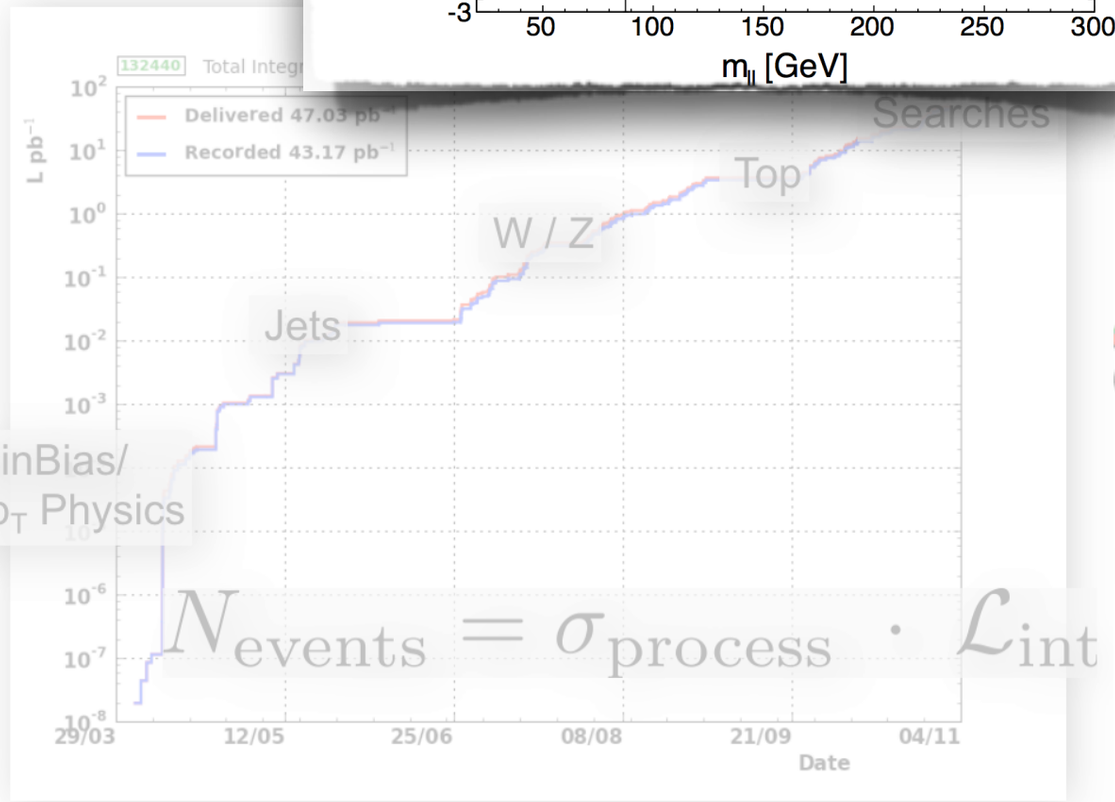


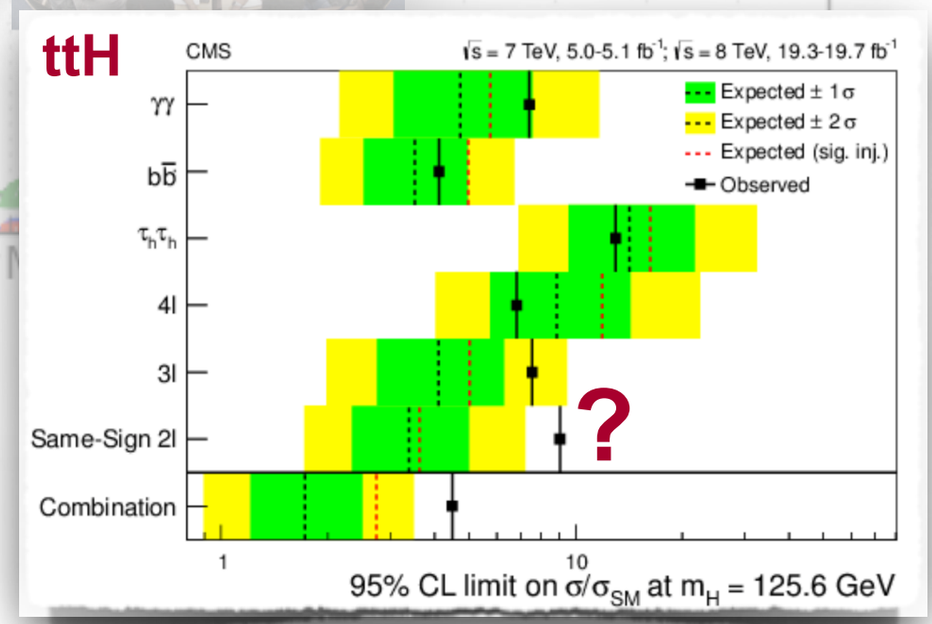




appears...



$$N_{events} = \sigma_{process} \cdot \mathcal{L}_{int}$$



So, “just” repeat it….

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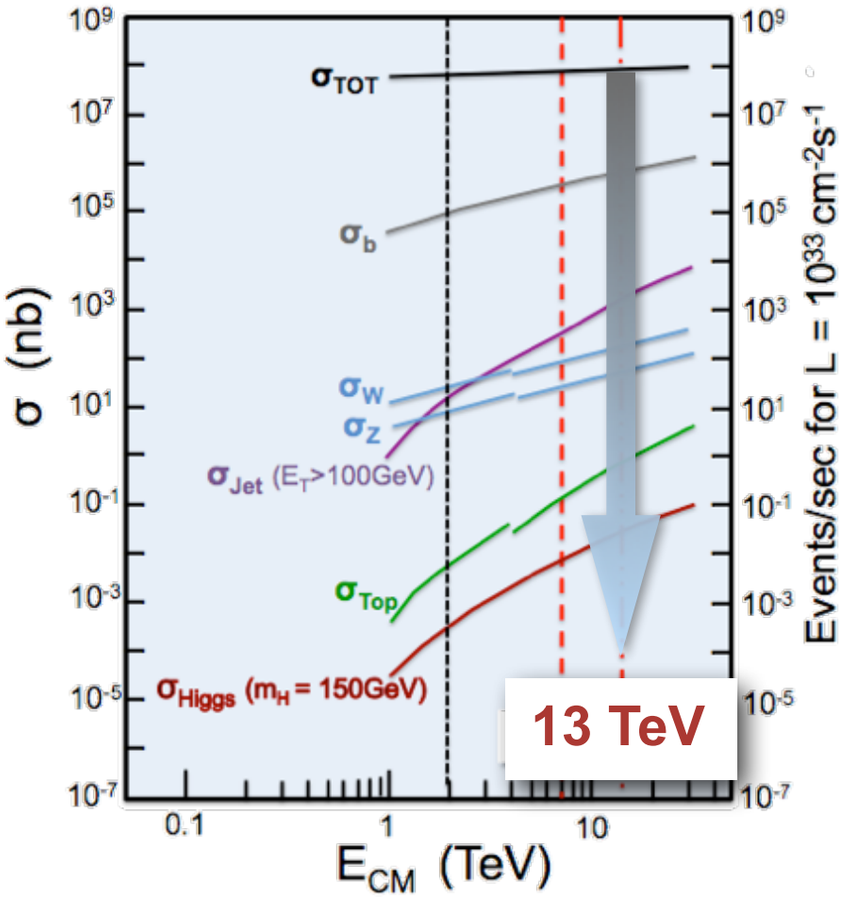

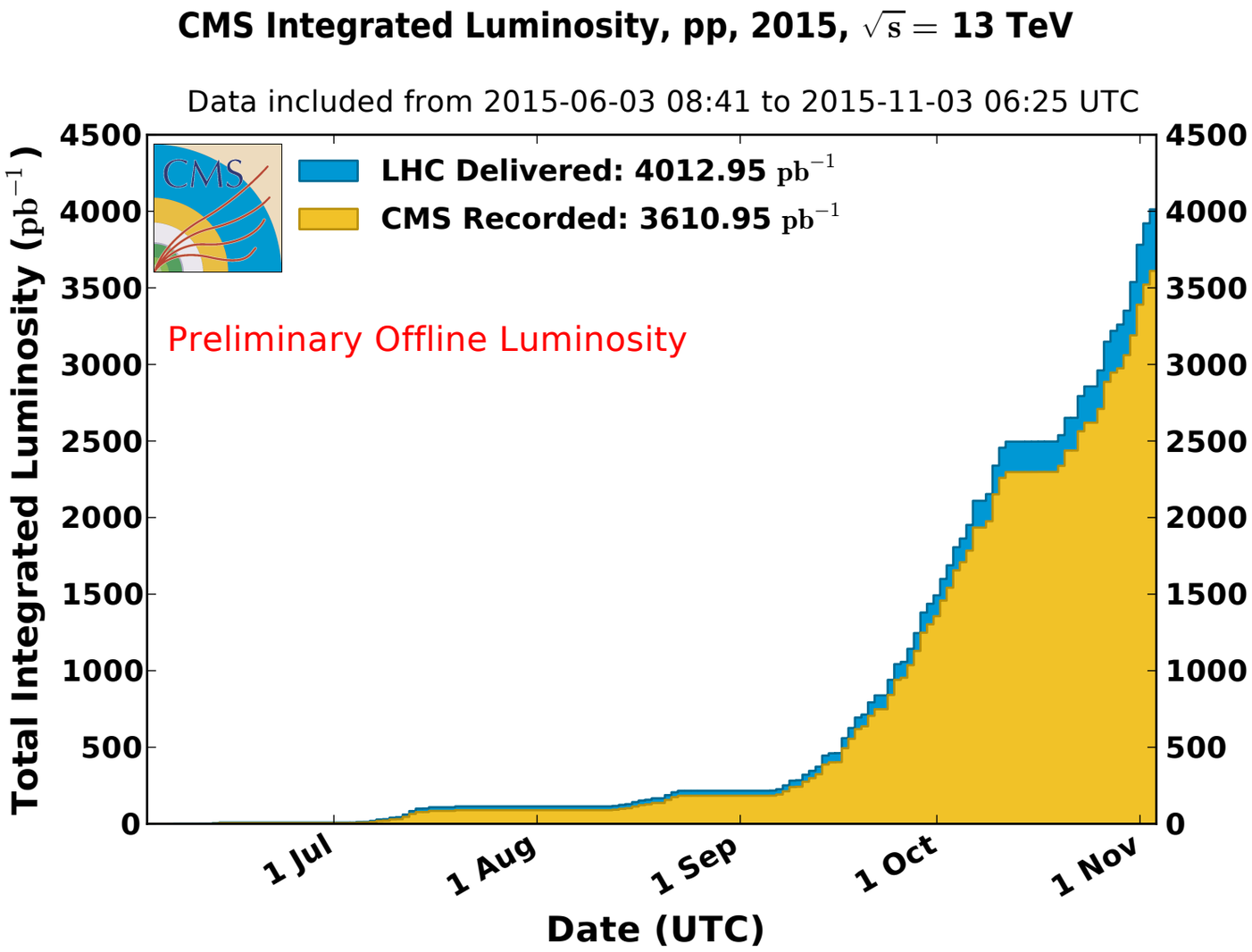

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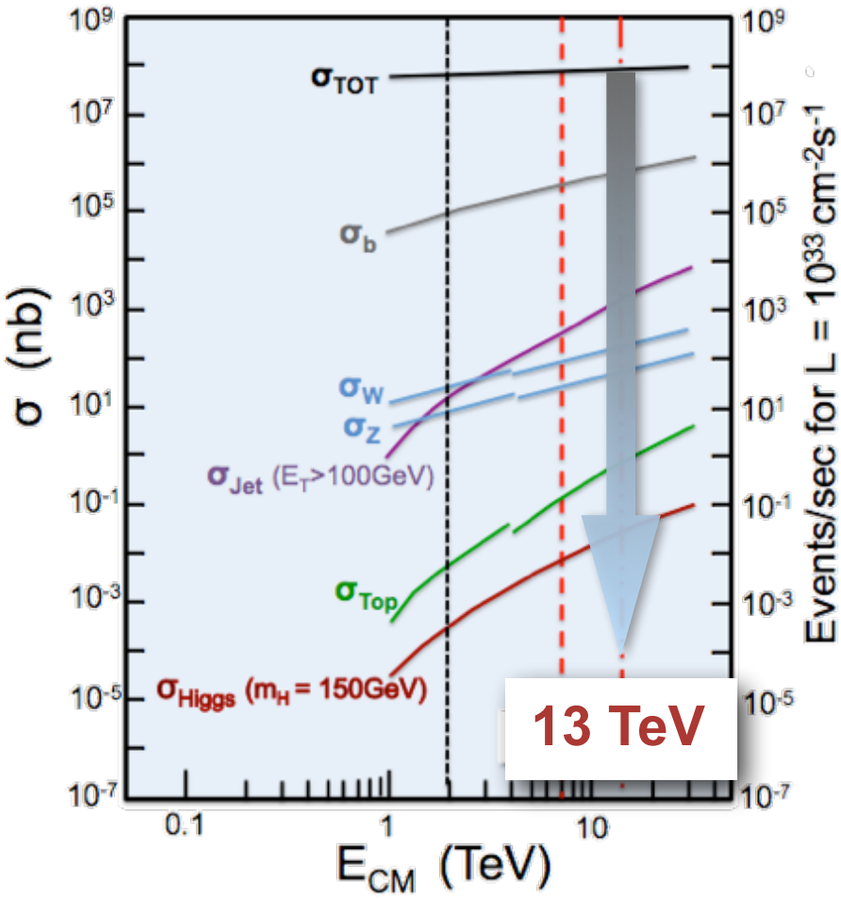
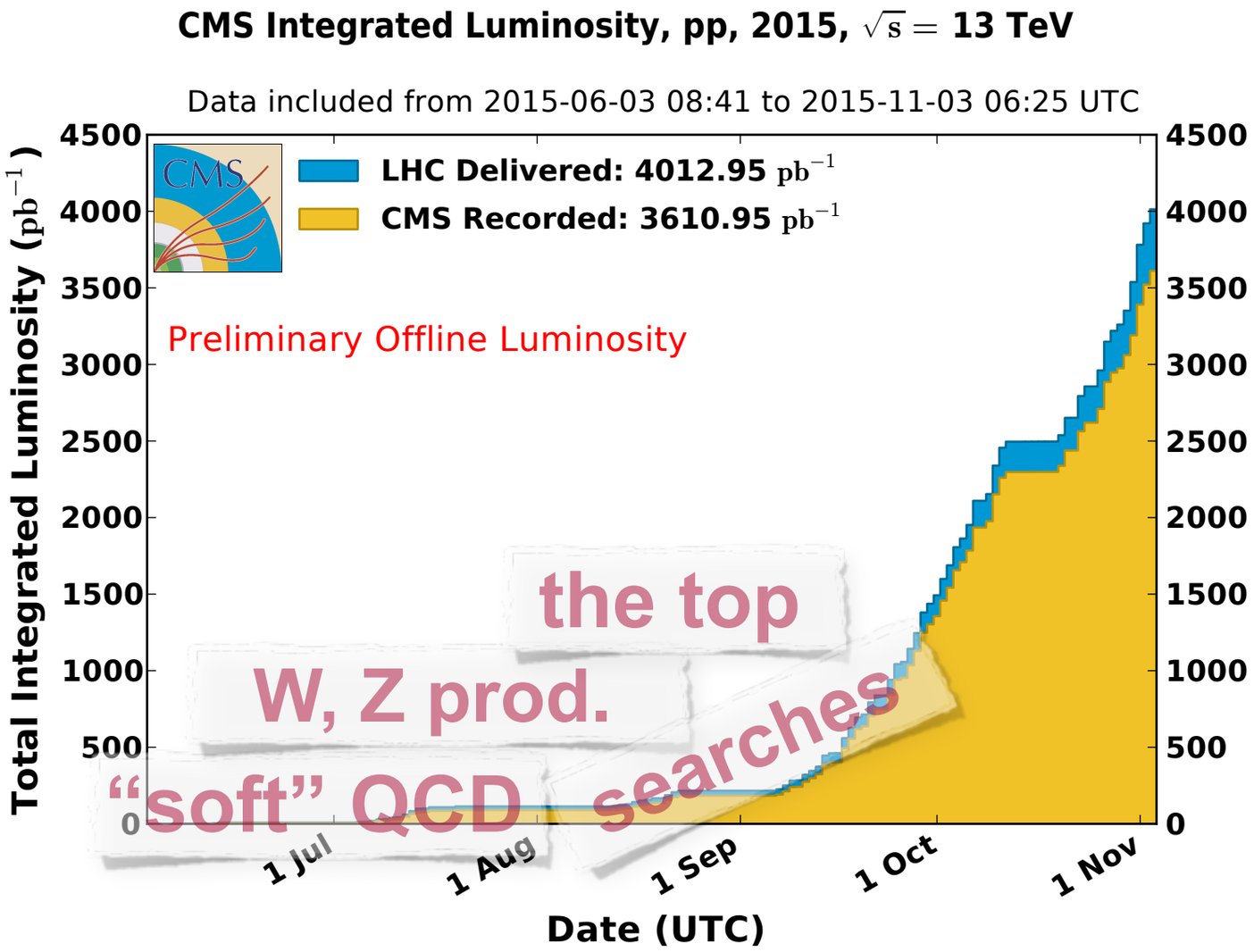
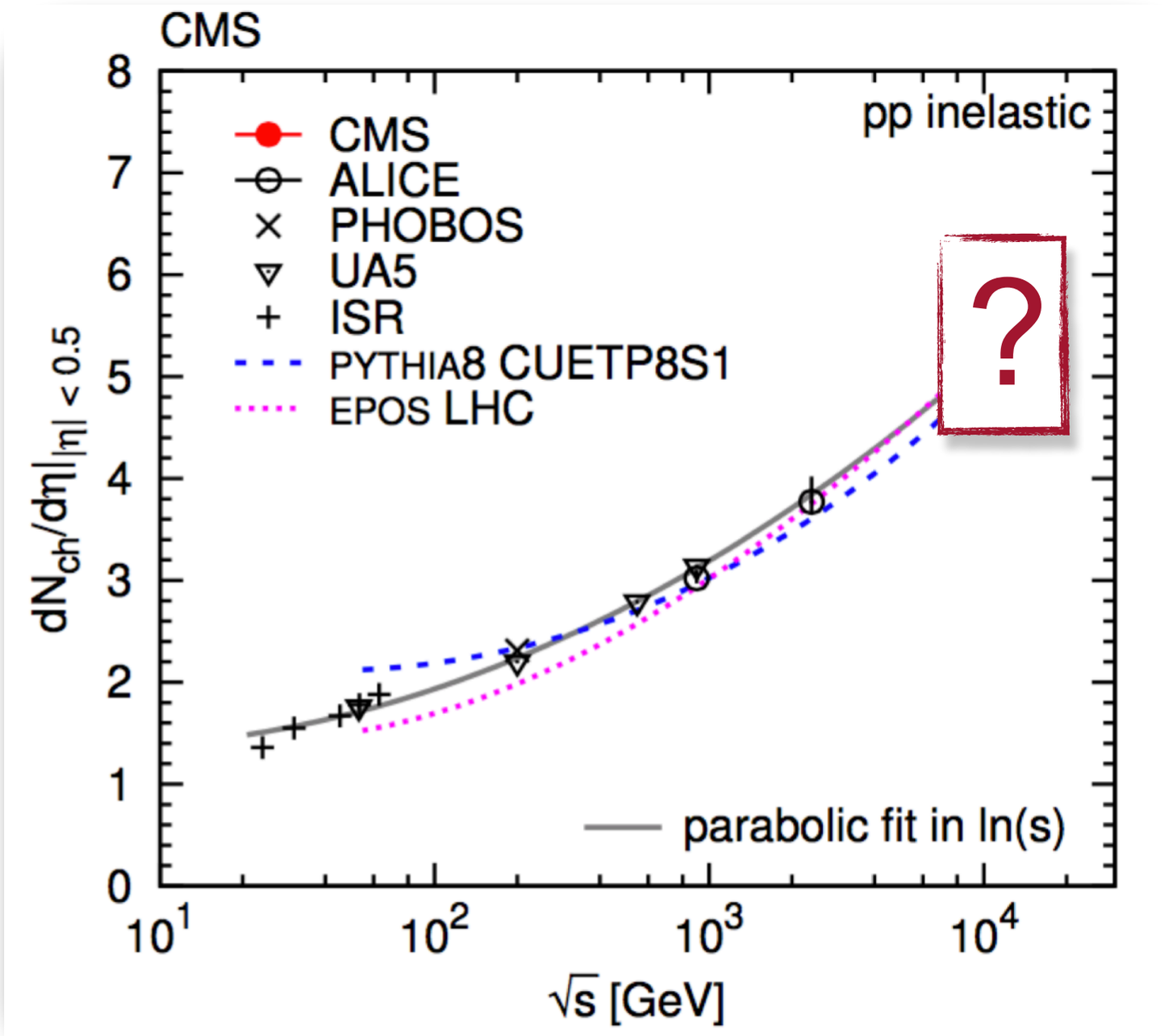




However, beware of **higher E_{CM}** : early discoveries? see later…

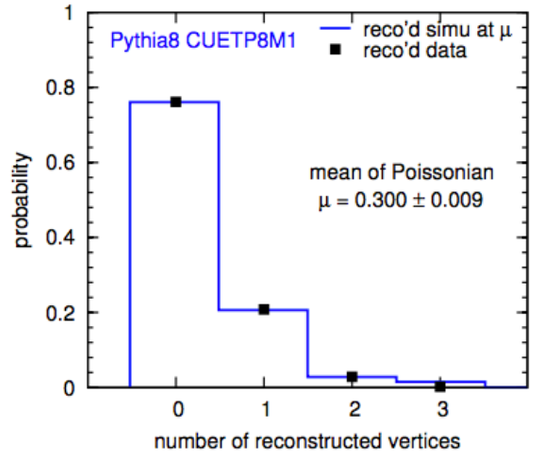
“soft” QCD


CMS
pp inelastic
CMS
ALICE
PHOBOS
UA5
ISR
PYTHIA8 CUETP8S1
EPOS LHC
?
parabolic fit in ln(s)
$dN_{ch}/d\eta|_{|\eta|<0.5}$
$\sqrt{s}$ [GeV]
0
1
2
3
4
5
6
7
8
10^1
10^2
10^3
10^4

Special circumstances

ETH Institute for Particle Physics

- no magnetic field (straight tracks)
- **trigger** on incoming proton bunches from the LHC;
  offline: at least one reconstructed interaction vertex is required;
  corrected to correspond to **inelastic pp sample**
- special low-intensity beam configuration with 0.2–5% proton-proton interaction probability per bunch crossing.



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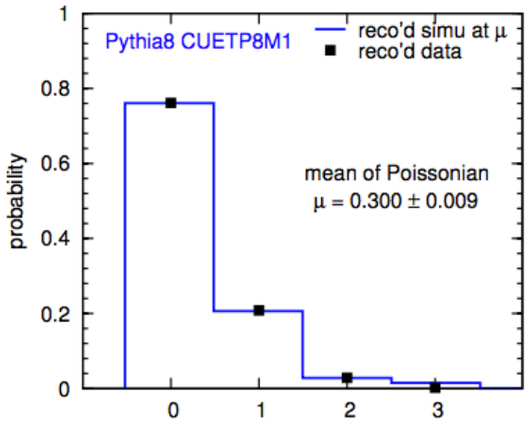
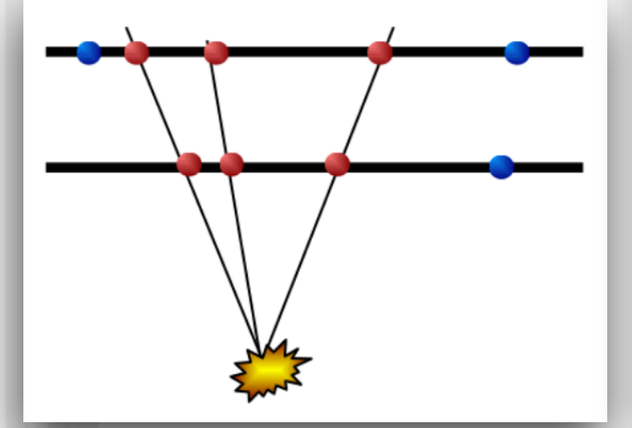
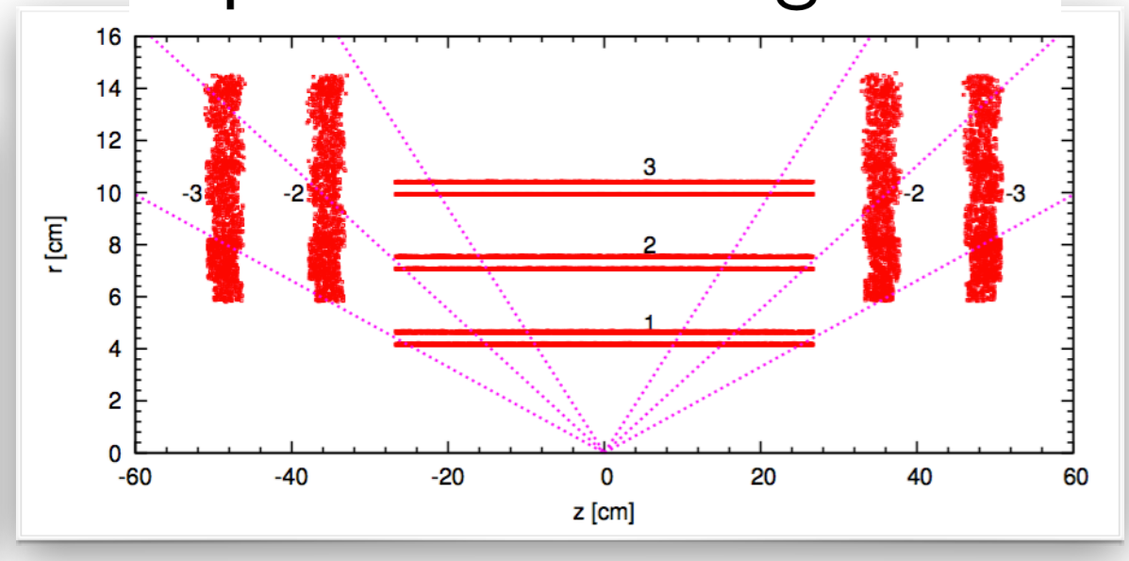


triplets on a straight line

$(\Delta\eta, \Delta\phi)$ correlation





main result using Pixel detector:
Tracklets (2 hits) and pixel hits triplets

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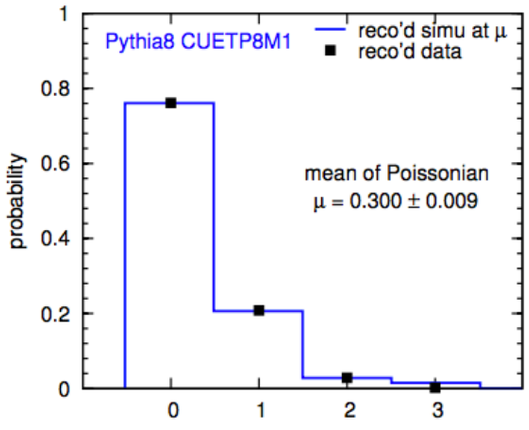

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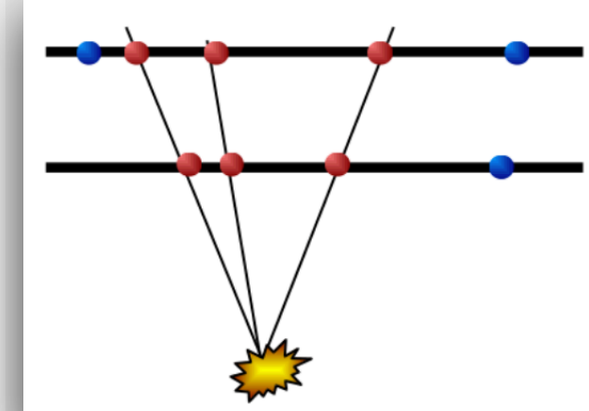
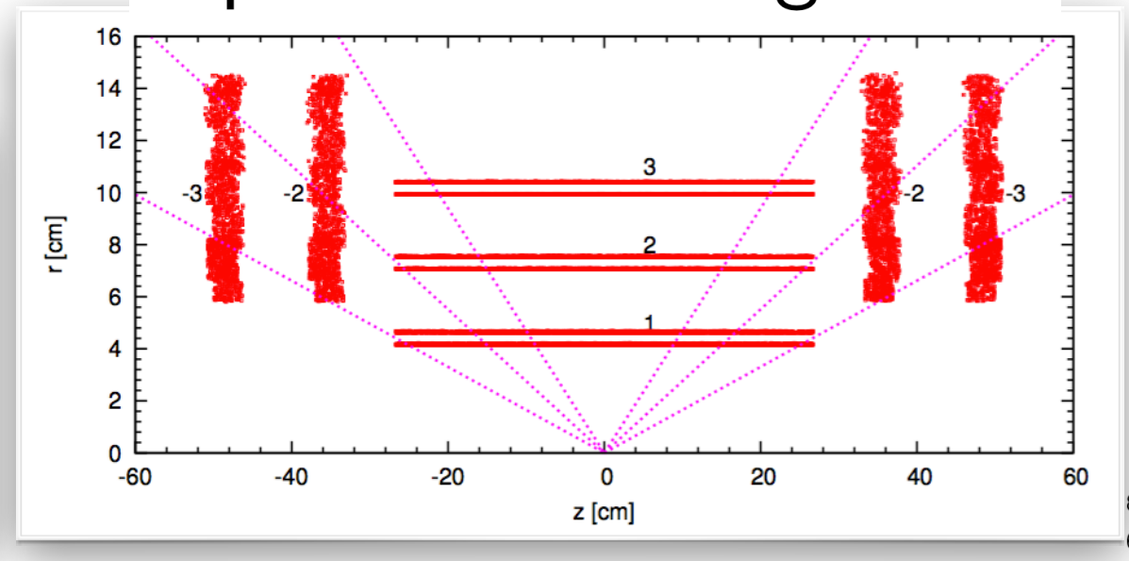
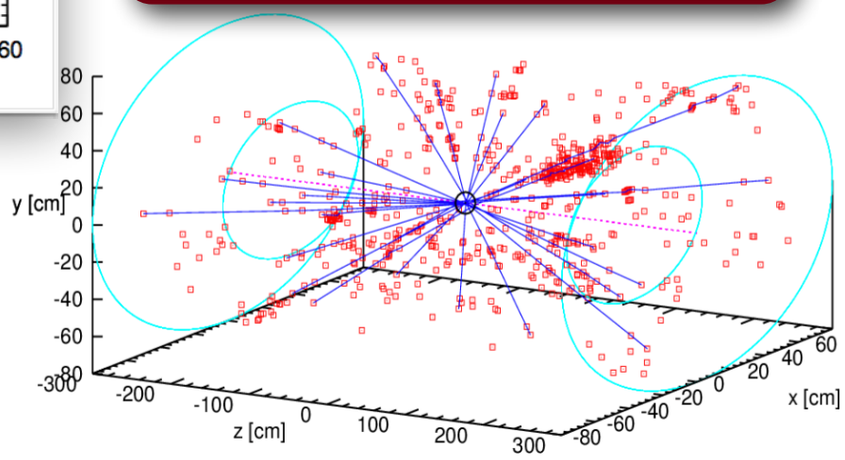




cross check:
3D hits in silicon tracker



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Charged Particles - dN/dη

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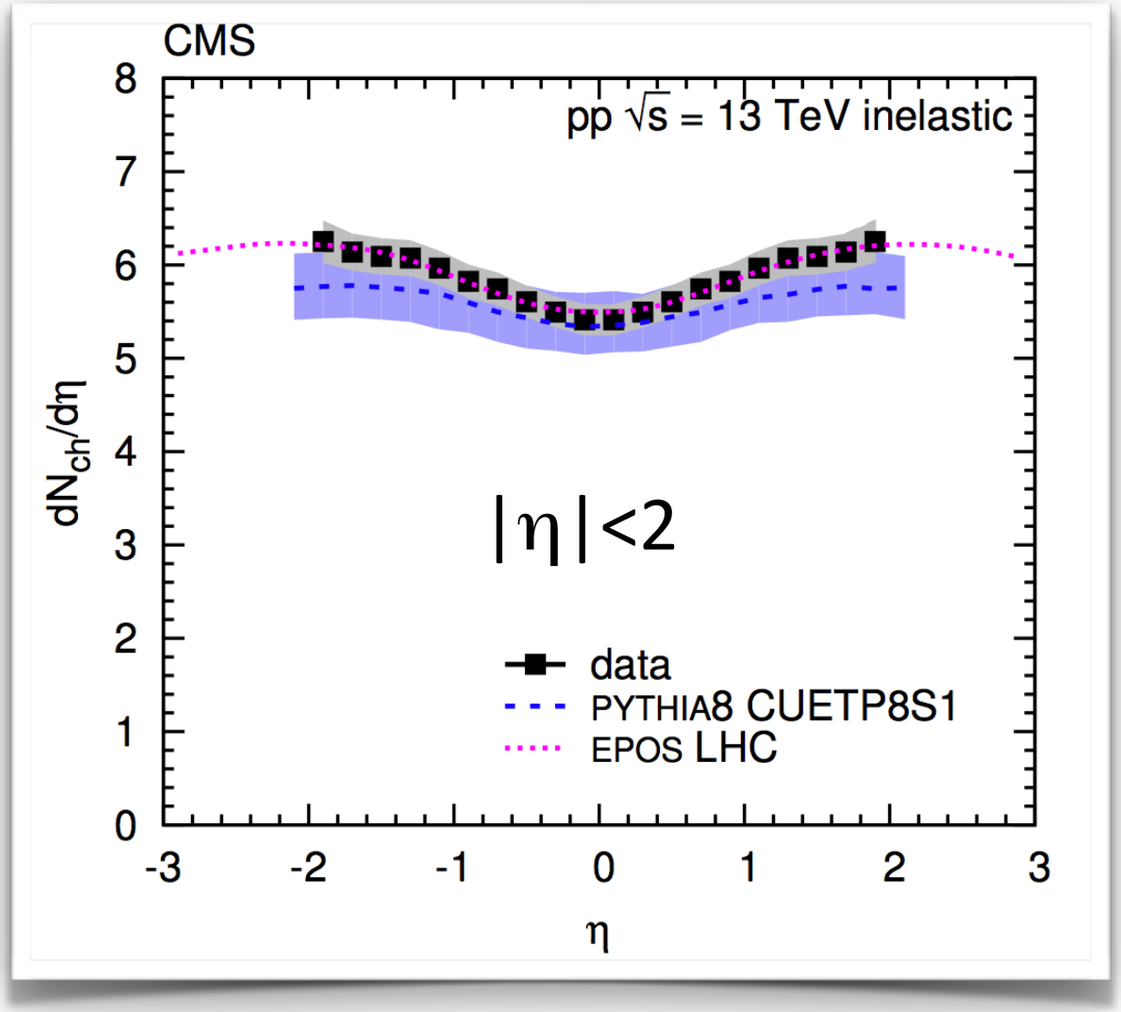
Phys. Lett. B 751 (2015) 143



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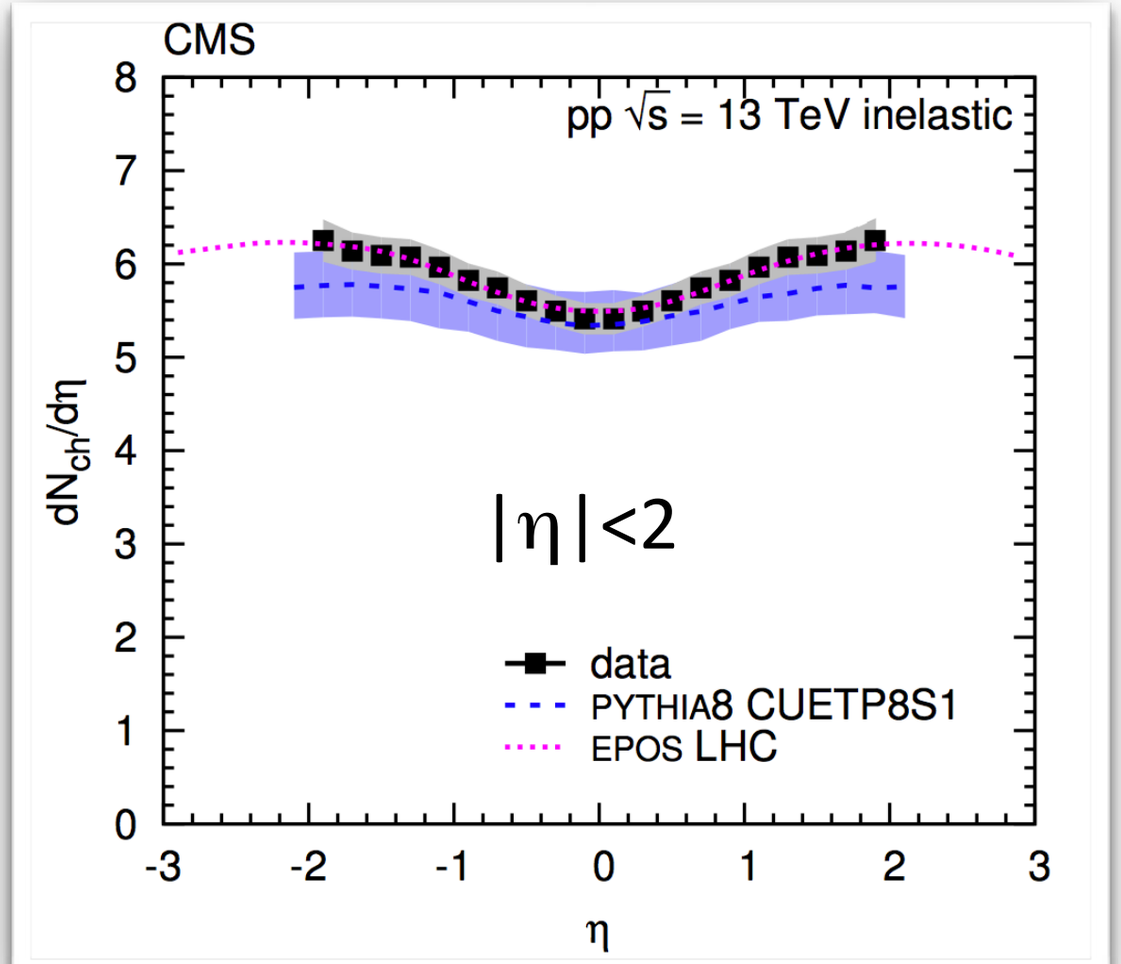

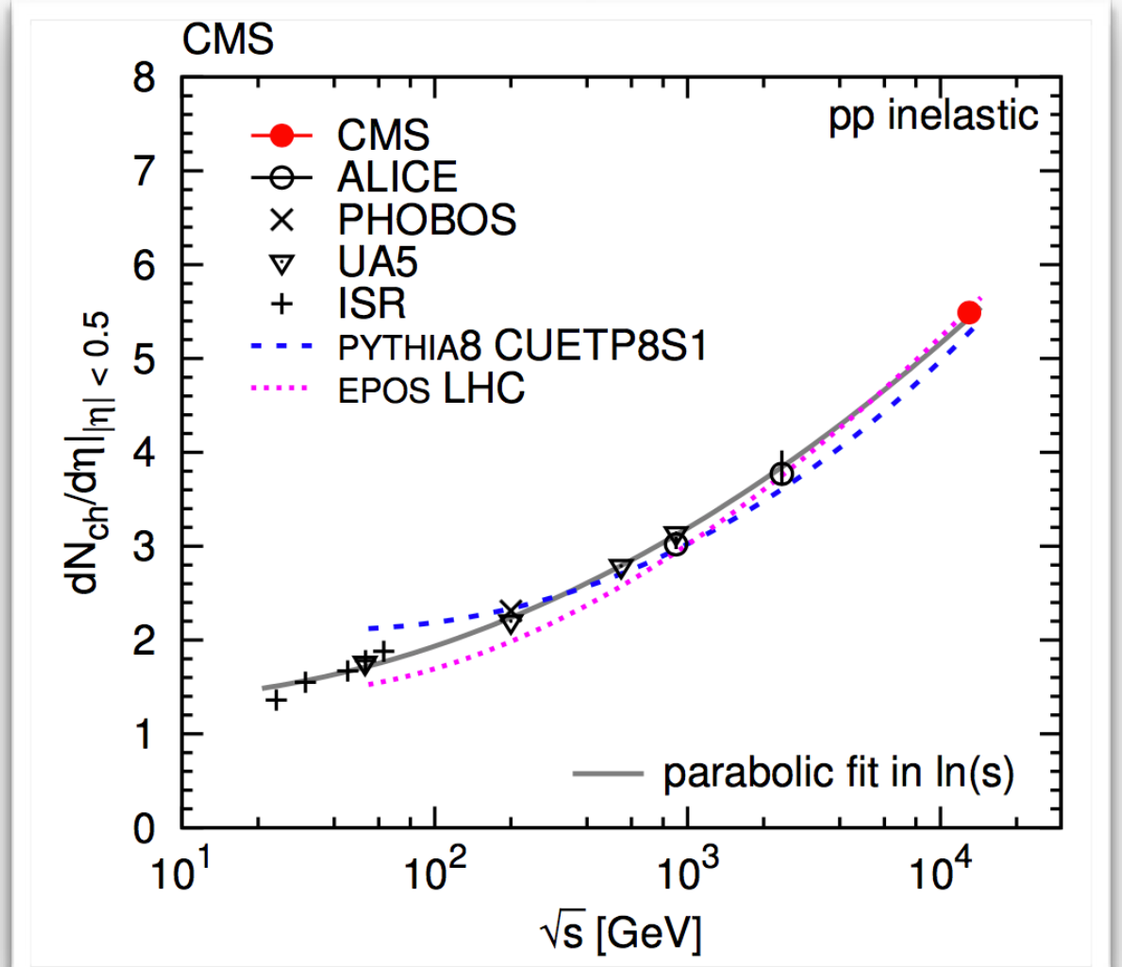

$$\text{Inelastic pp: } dN/d\eta|_{|\eta|<0.5} = 5.49 \pm 0.01(\text{stat}) \pm 0.17(\text{syst})$$

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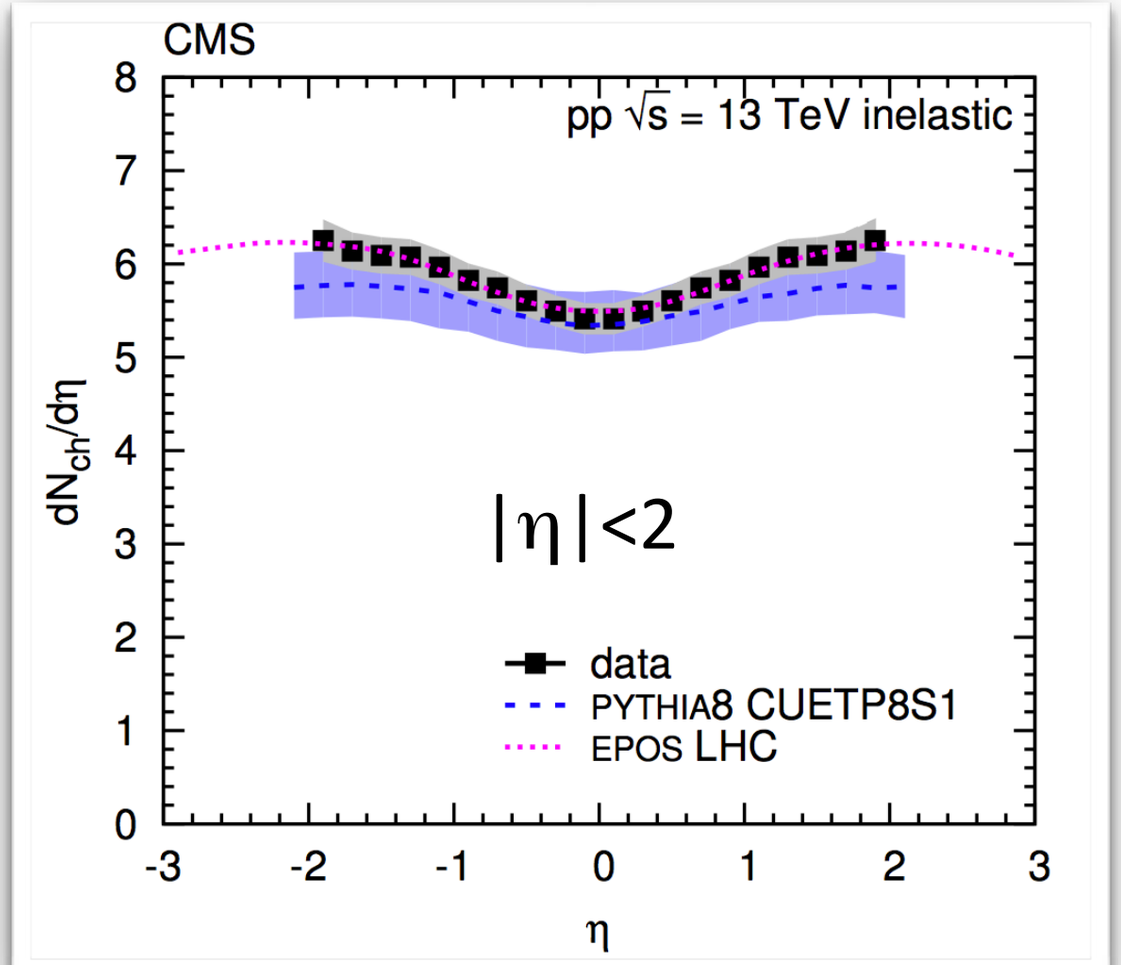
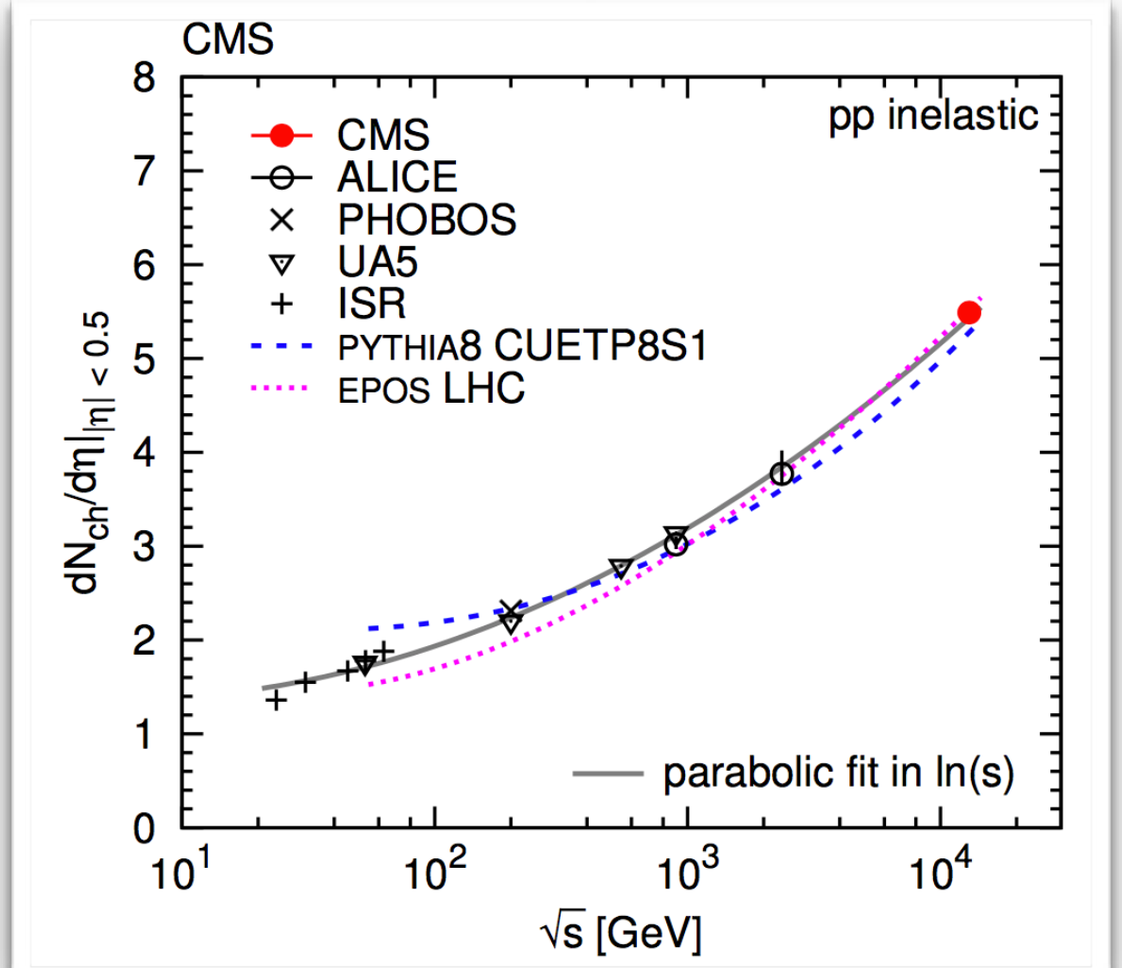




Inelastic pp: $dN/d\eta|_{|\eta|<0.5} = 5.49 \pm 0.01(\text{stat}) \pm 0.17(\text{syst})$

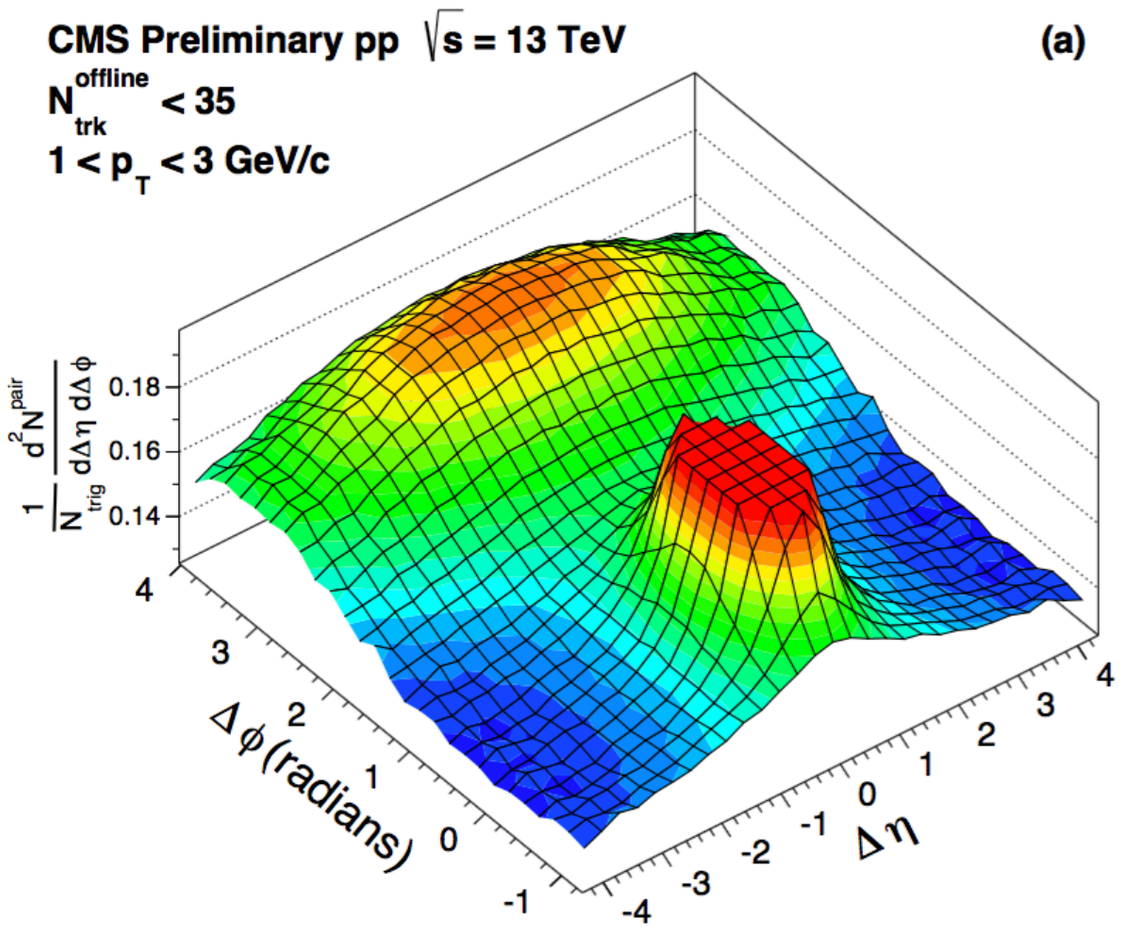
First LHC Run 2 publication:
3-4 % systematic uncertainty,
consistent with PYTHIA8 tune,
better agreement with EPOS LHC MC

Two-Particle Correlations

ETH Institute for Particle Physics

- **“the ridge”** : one of the biggest surprises in Run 1
- long-range rapidity correlations, for chg. particles close-by in azimuth, in very-high multiplicity pp collisions; not simulated by “standard MCs”, but also seen in HI and pPb collisions
- Now: what is the **energy dependence**?

low multi



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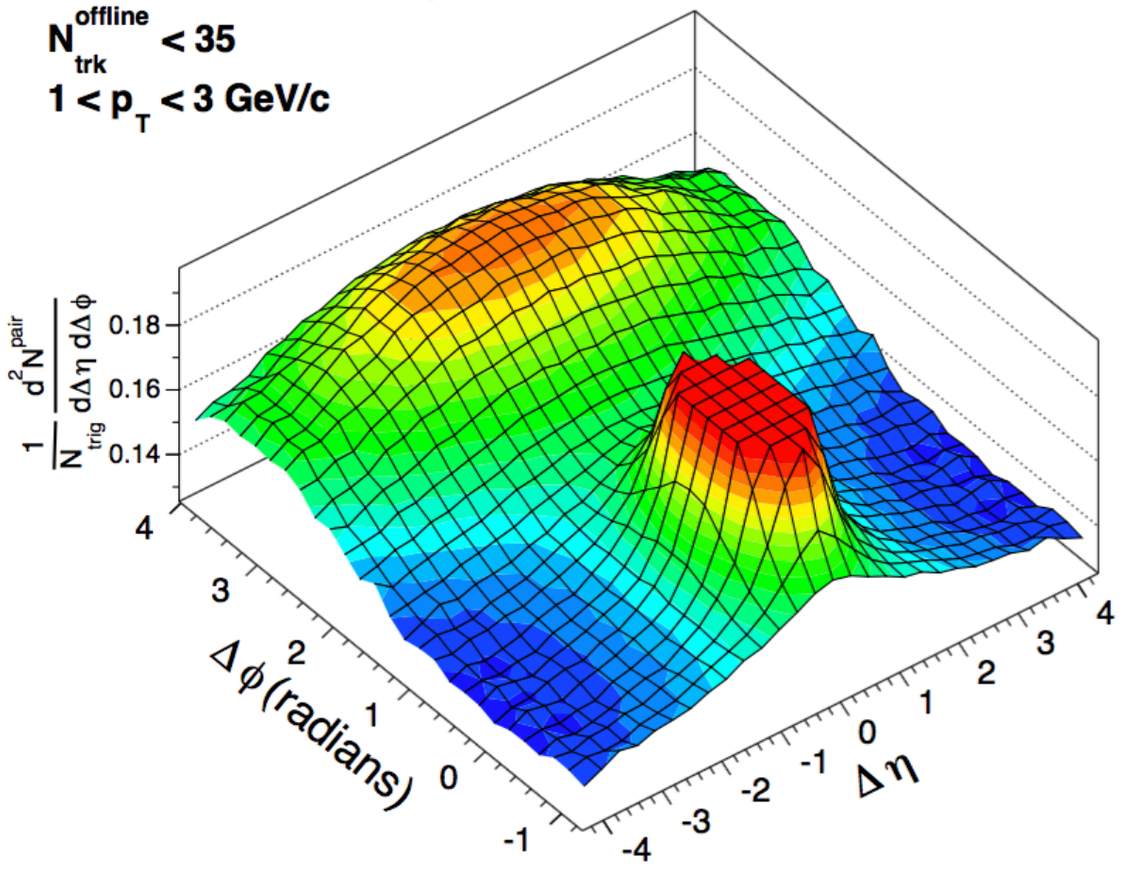
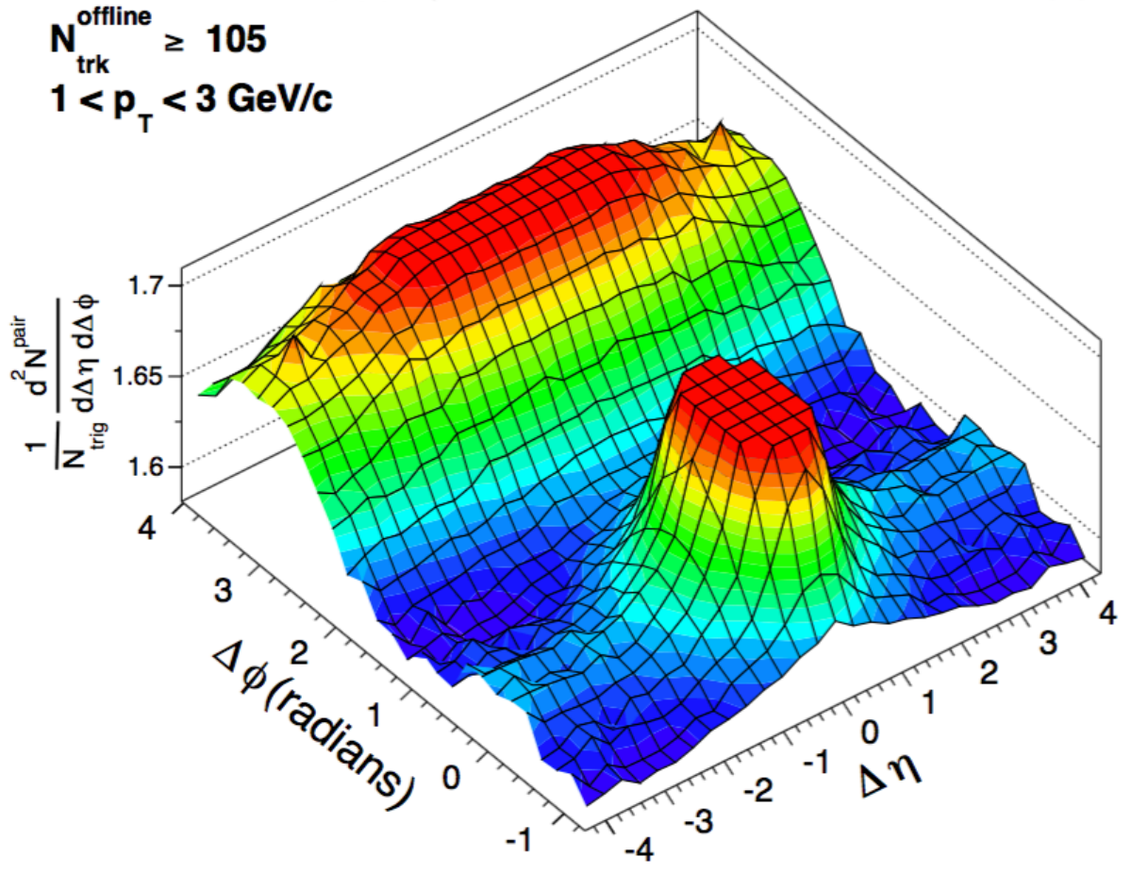


high multi



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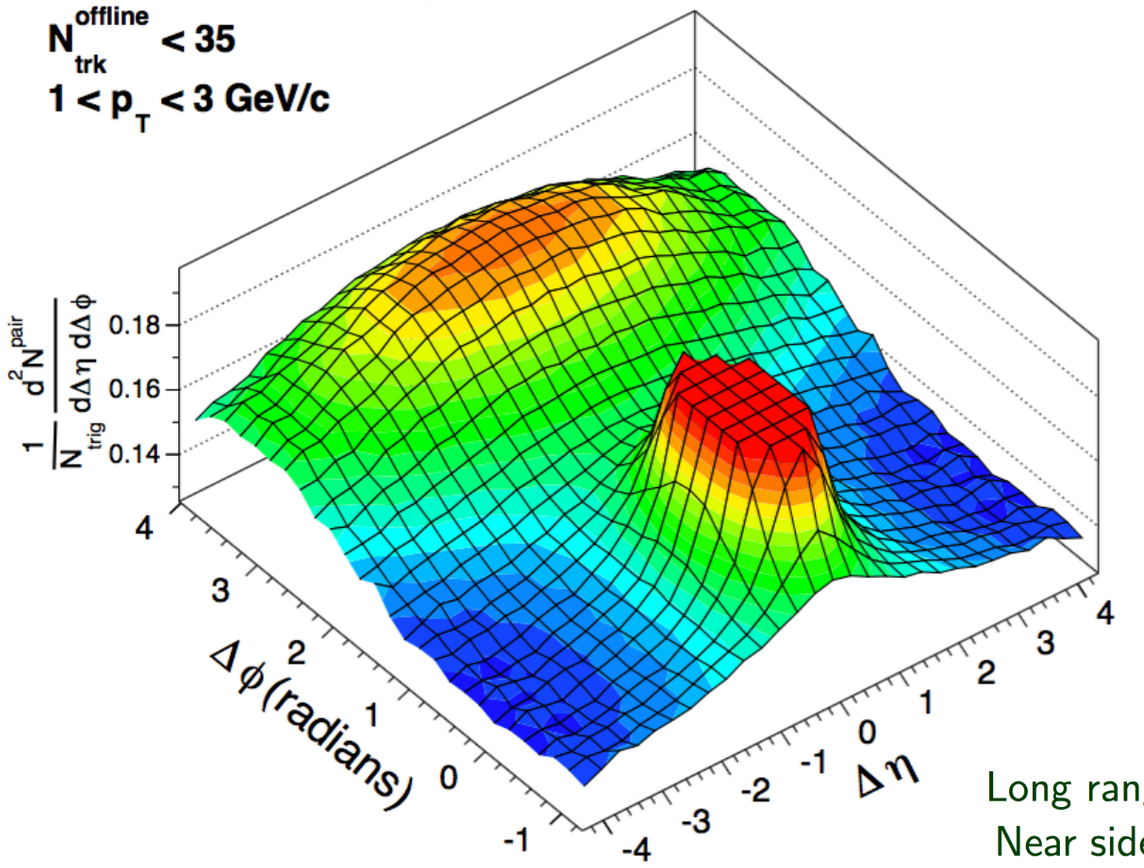

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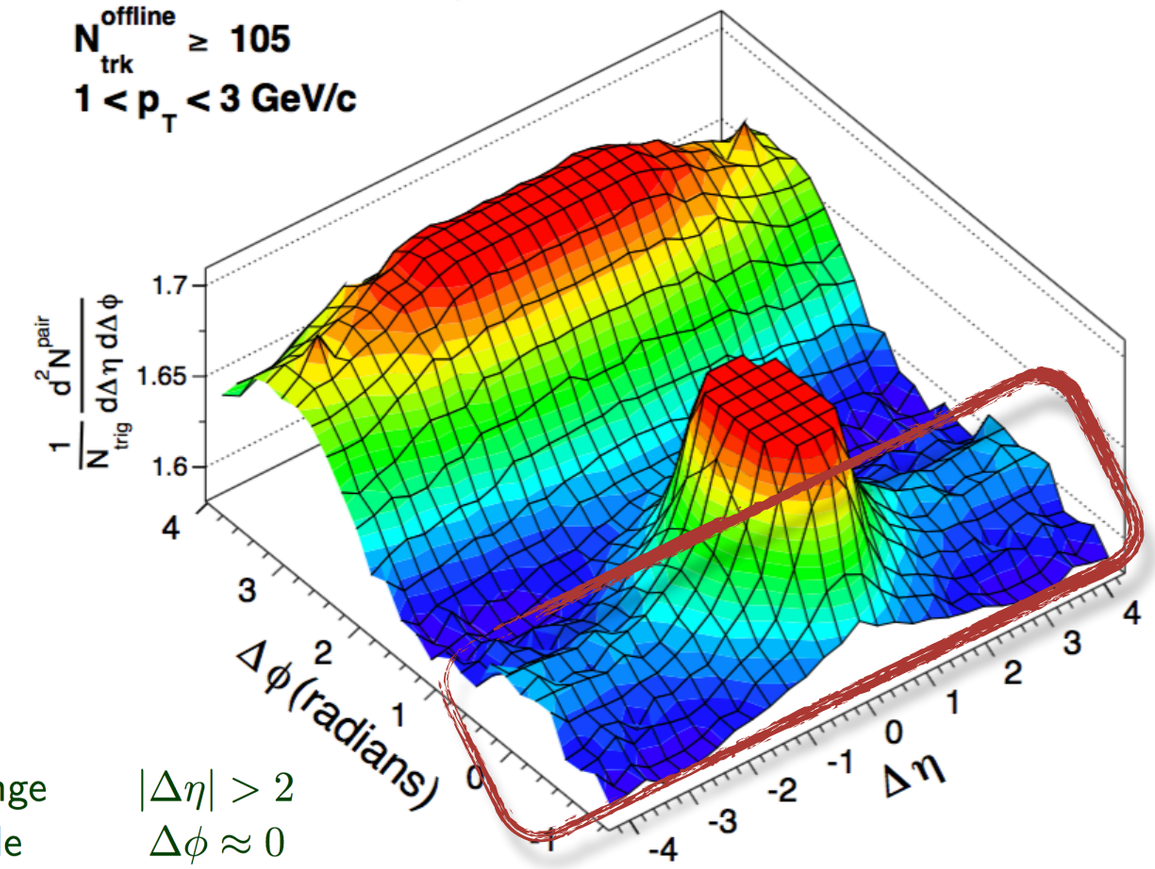

Long range $|\Delta\eta| > 2$

Near side $\Delta\phi \approx 0$

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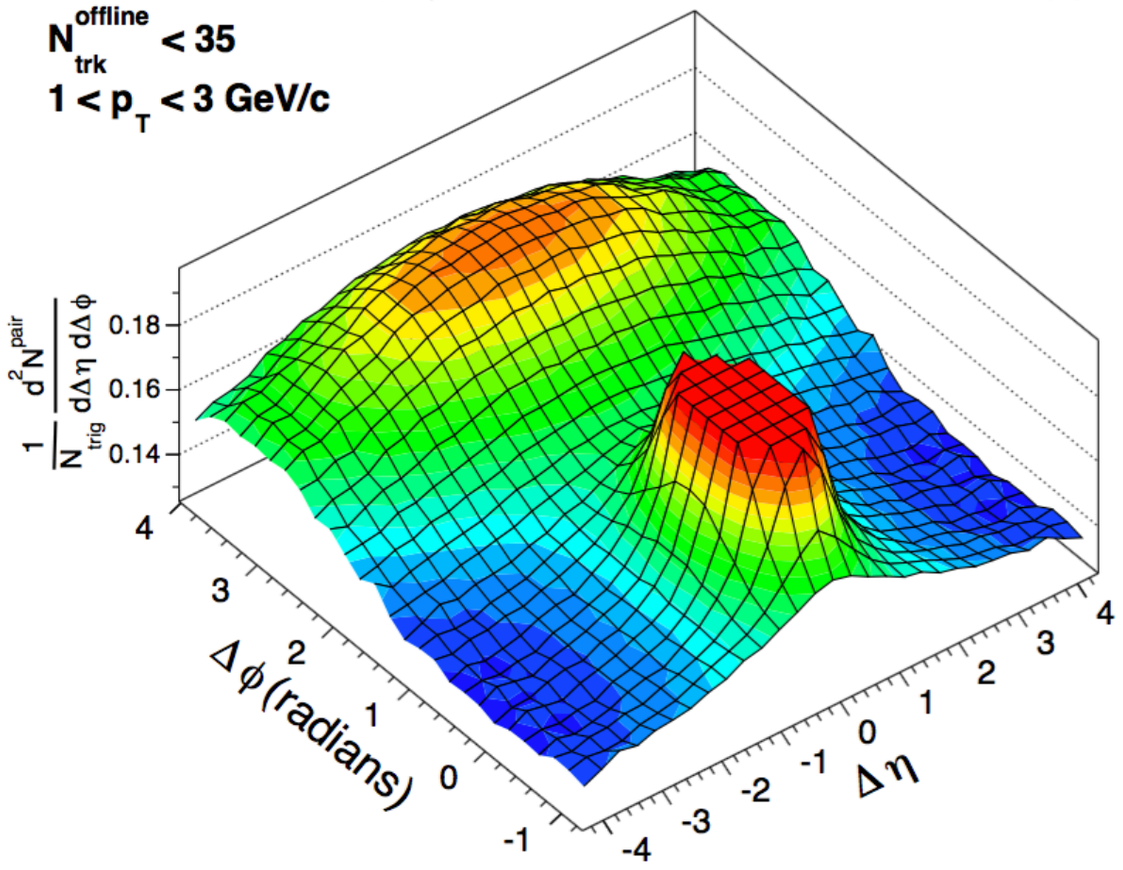

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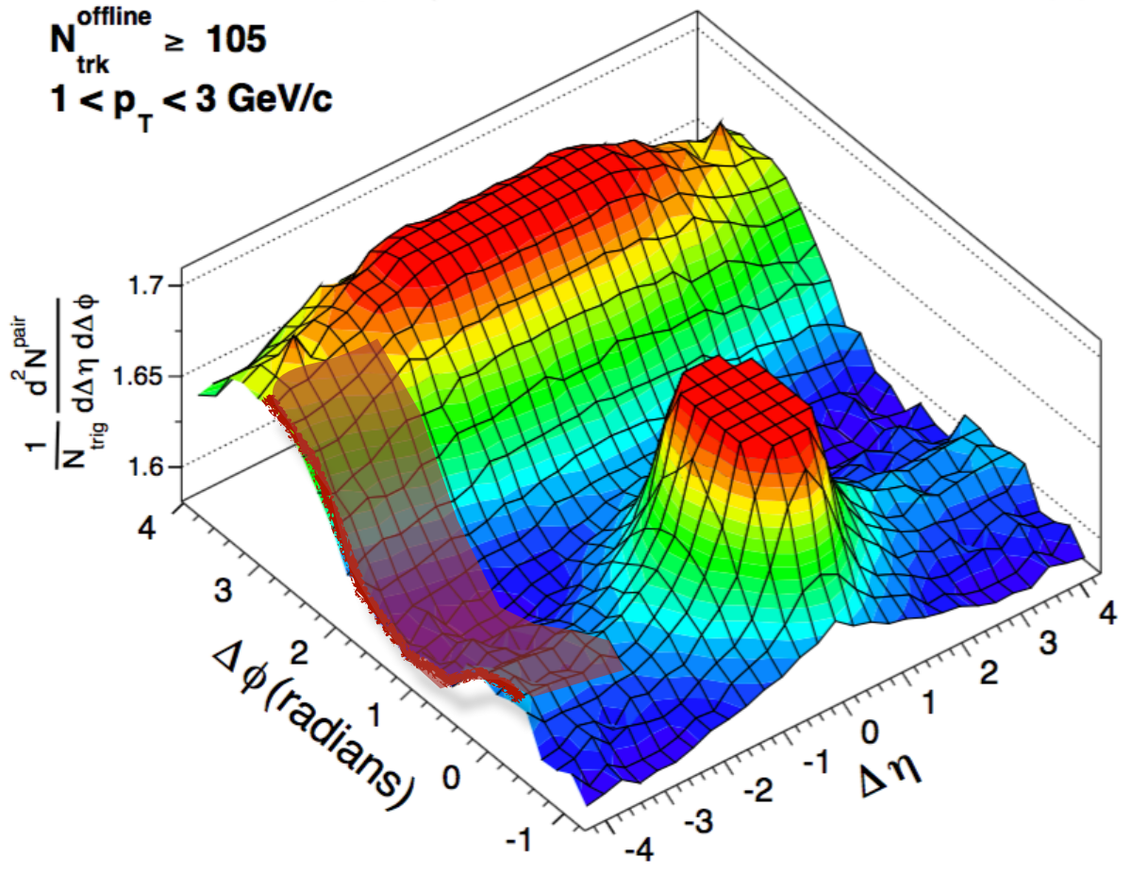

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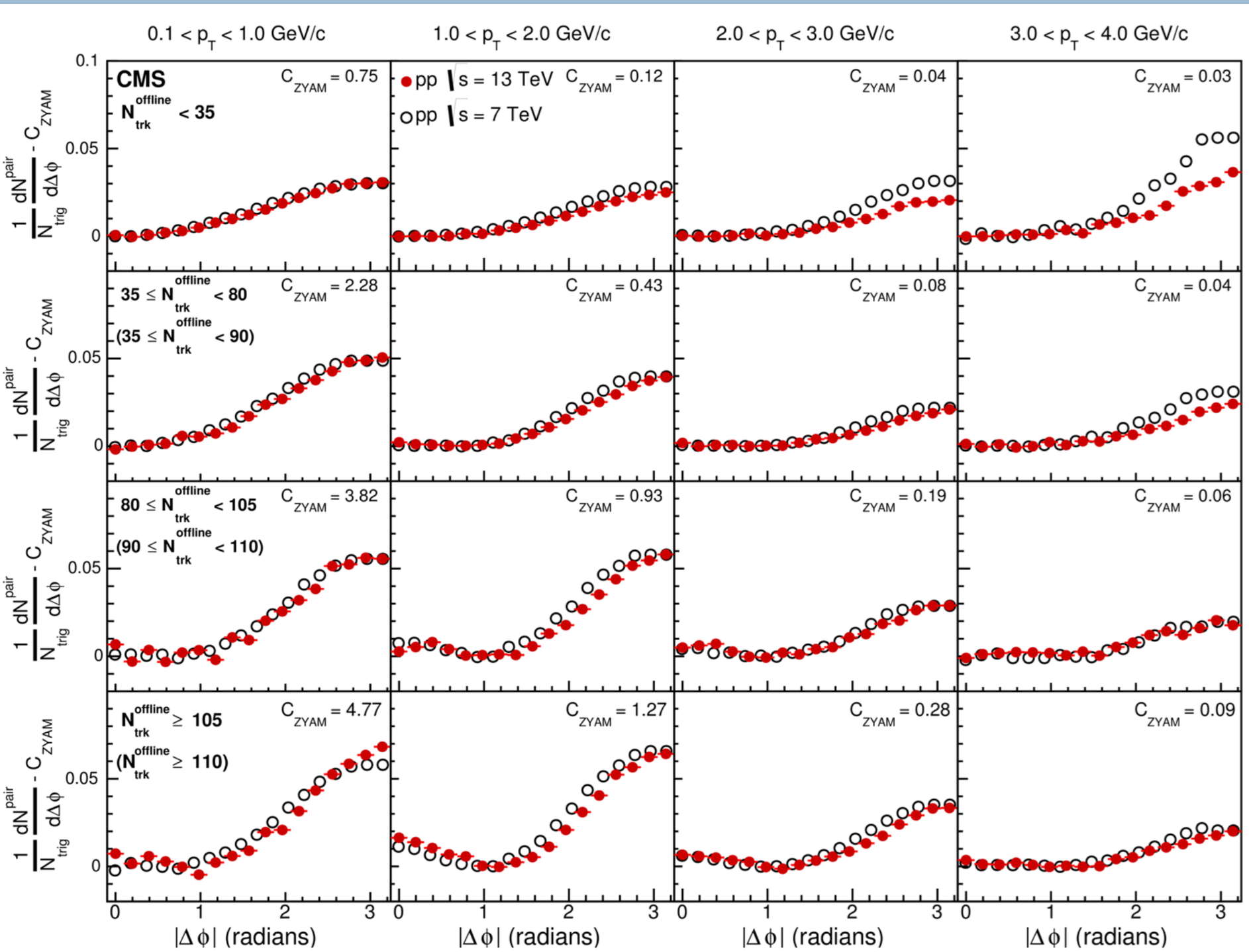

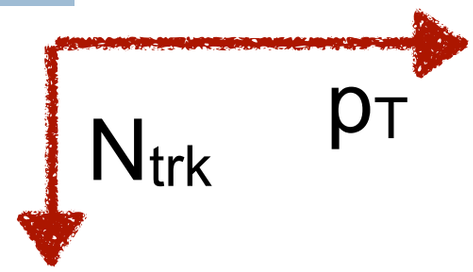

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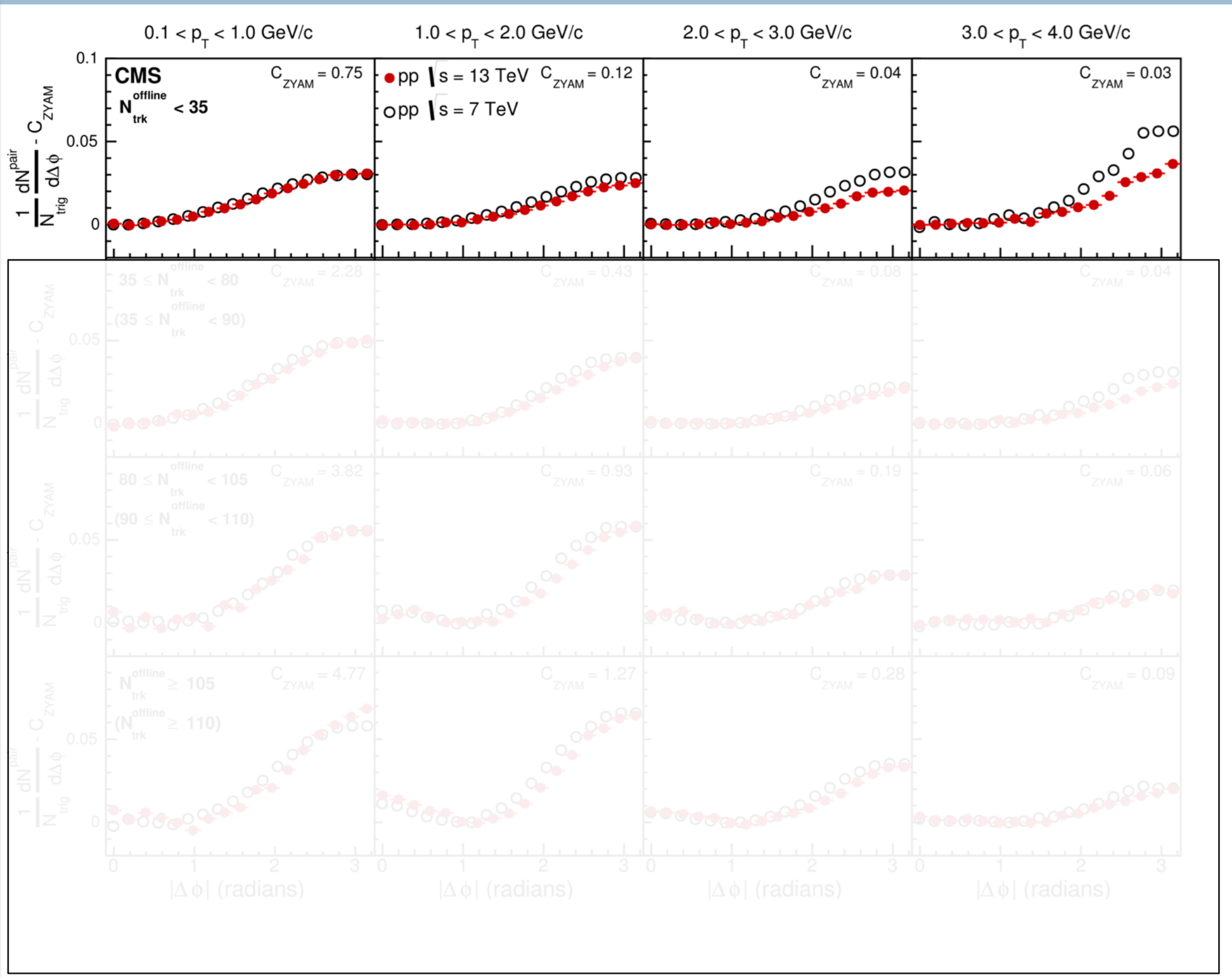
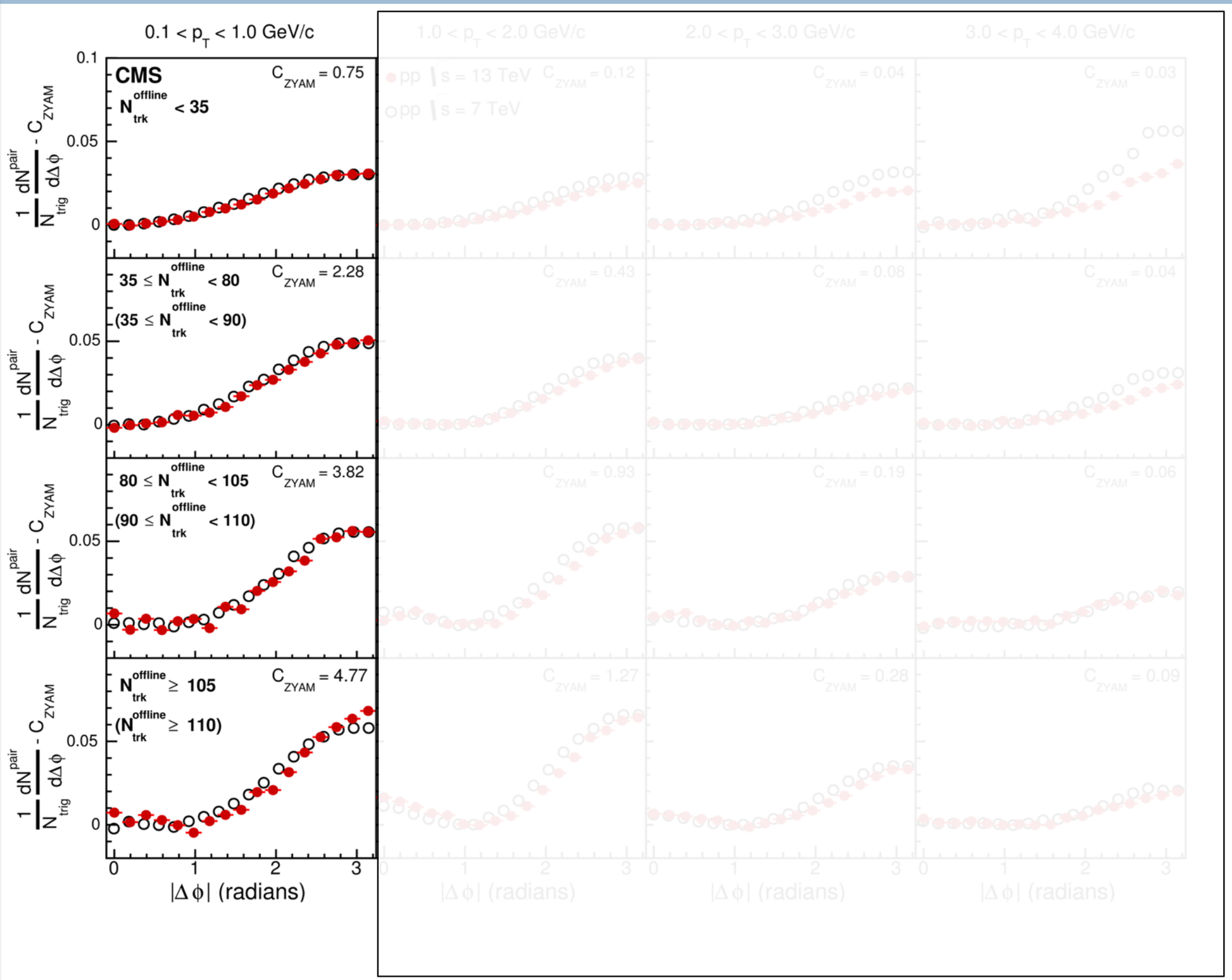


Ntrk

pT

Two-Particle Correlations



Ntrk

pT

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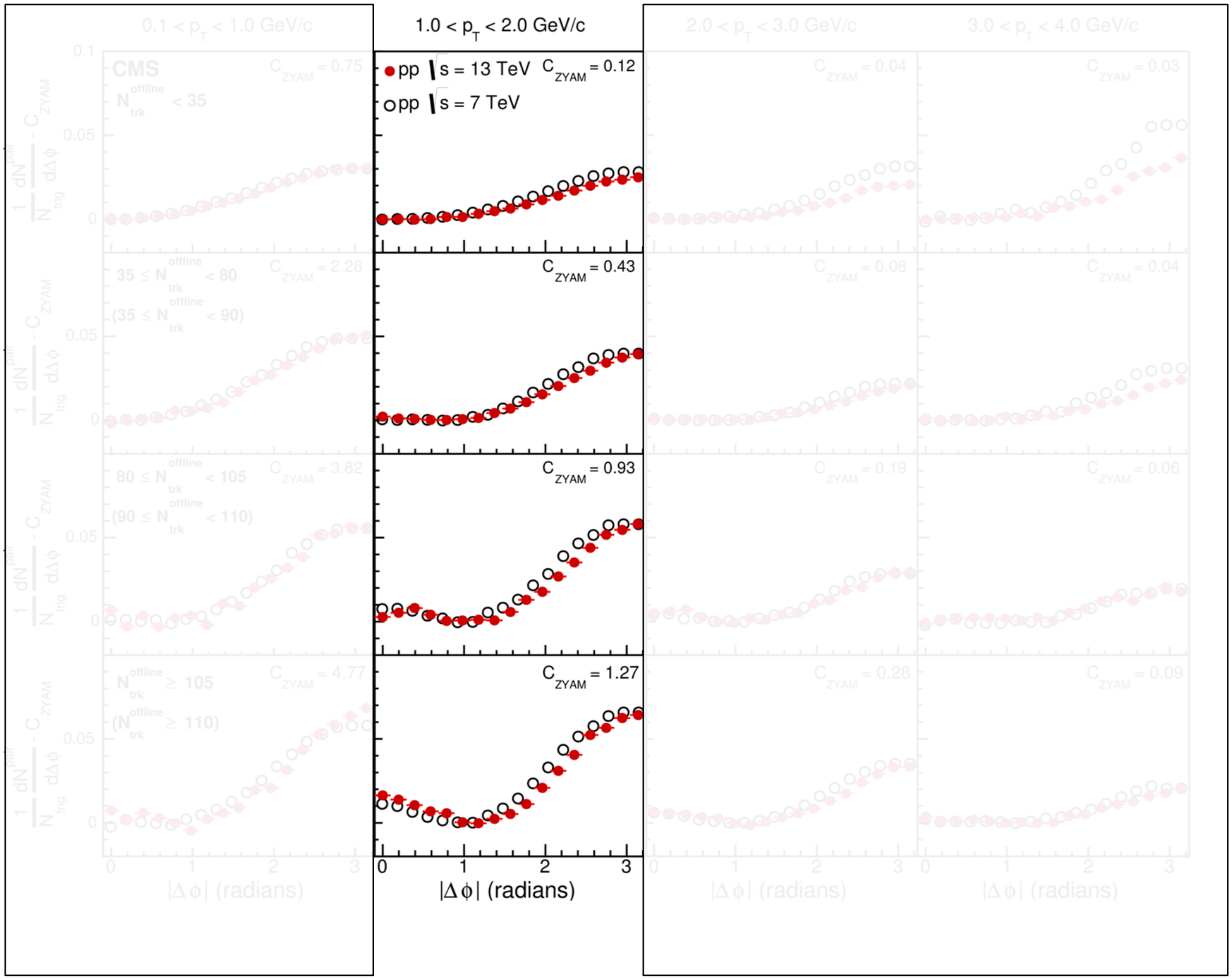
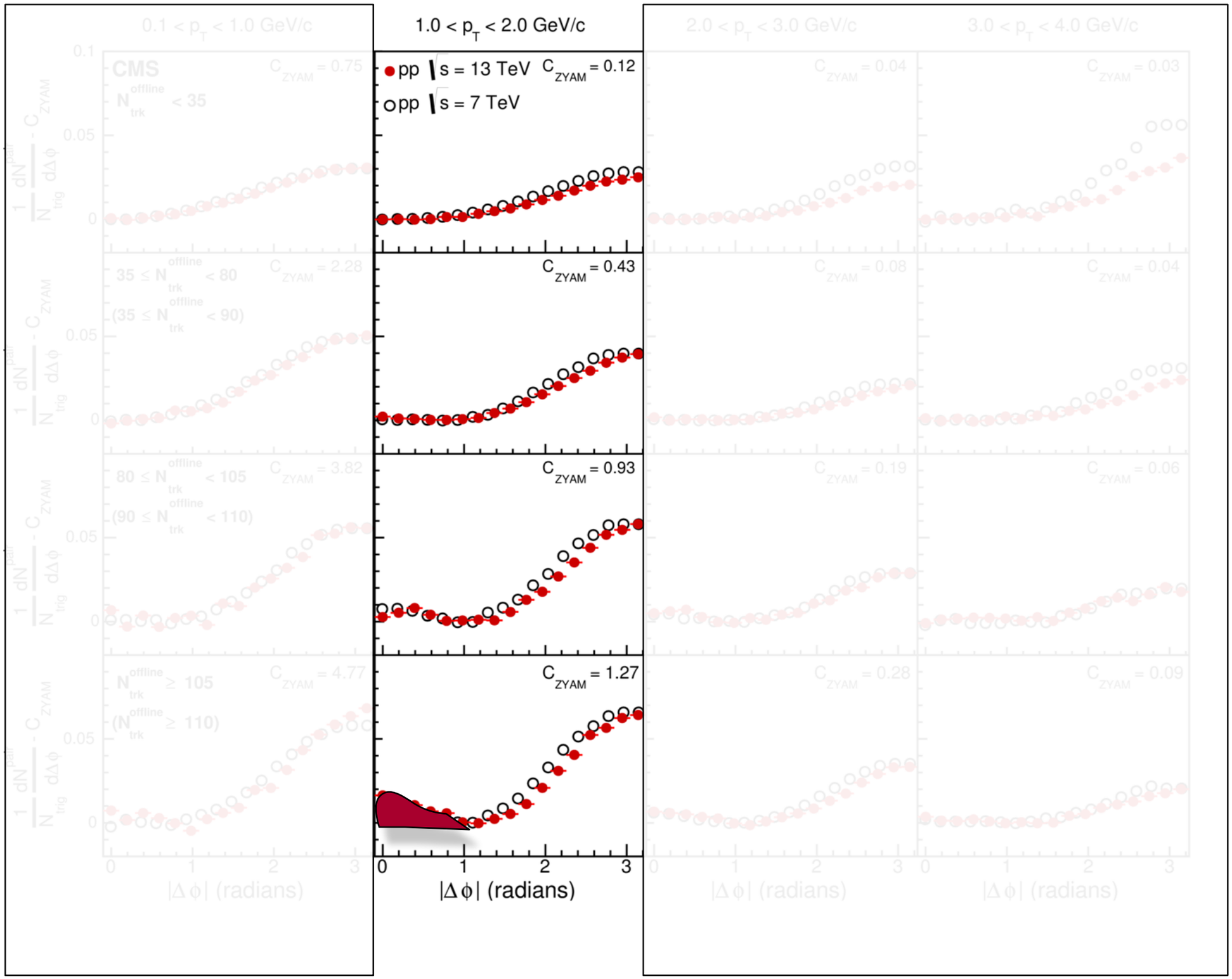
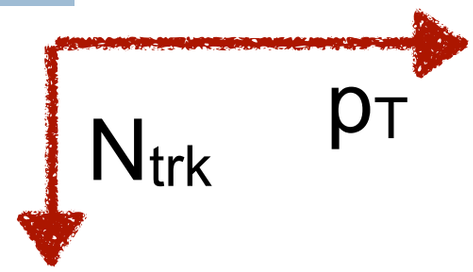


N_{trk}

p_T

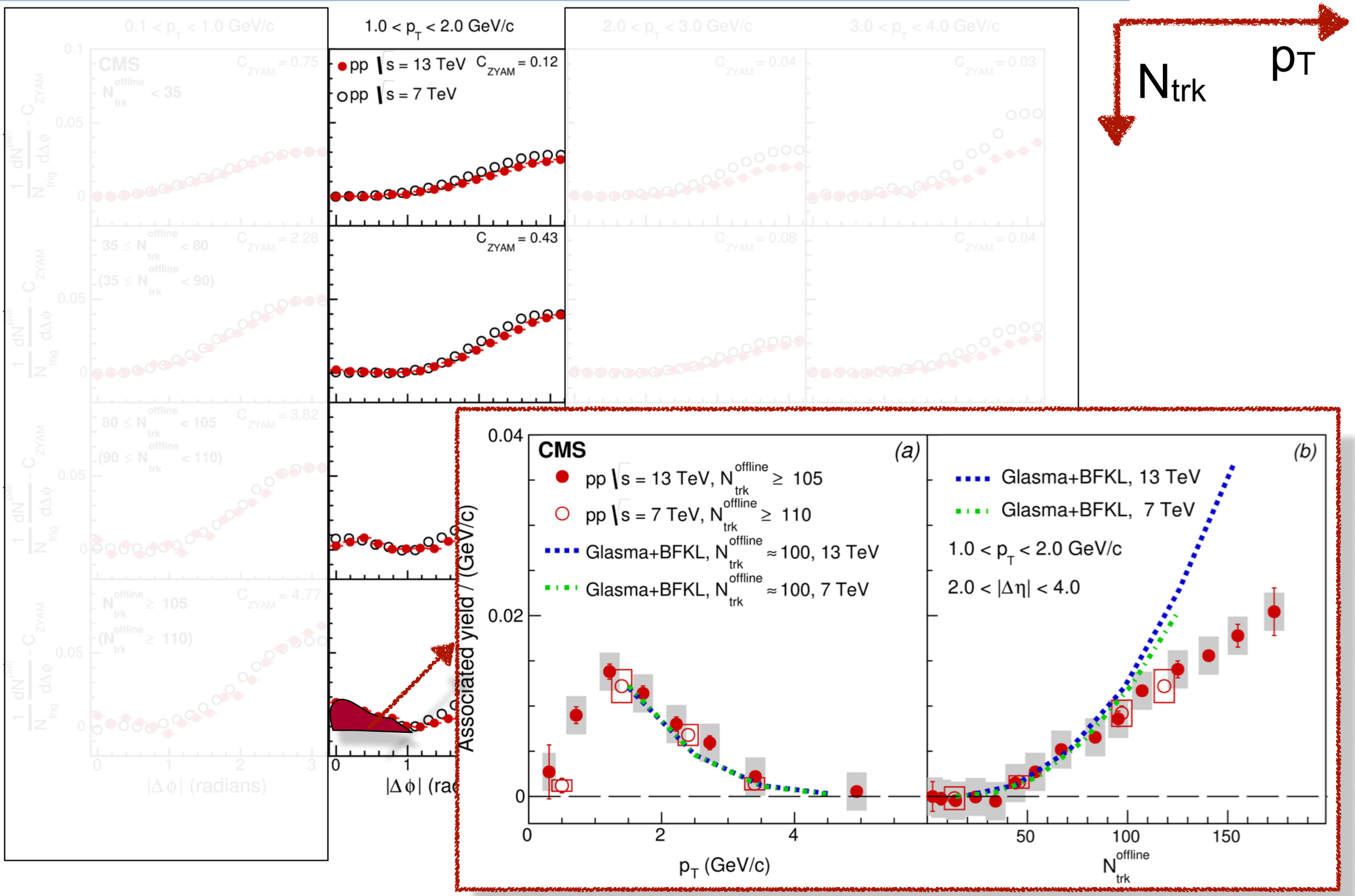
Two-Particle Correlations





Two-Particle Correlations

ETH Institute for Particle Physics



N_{trk}

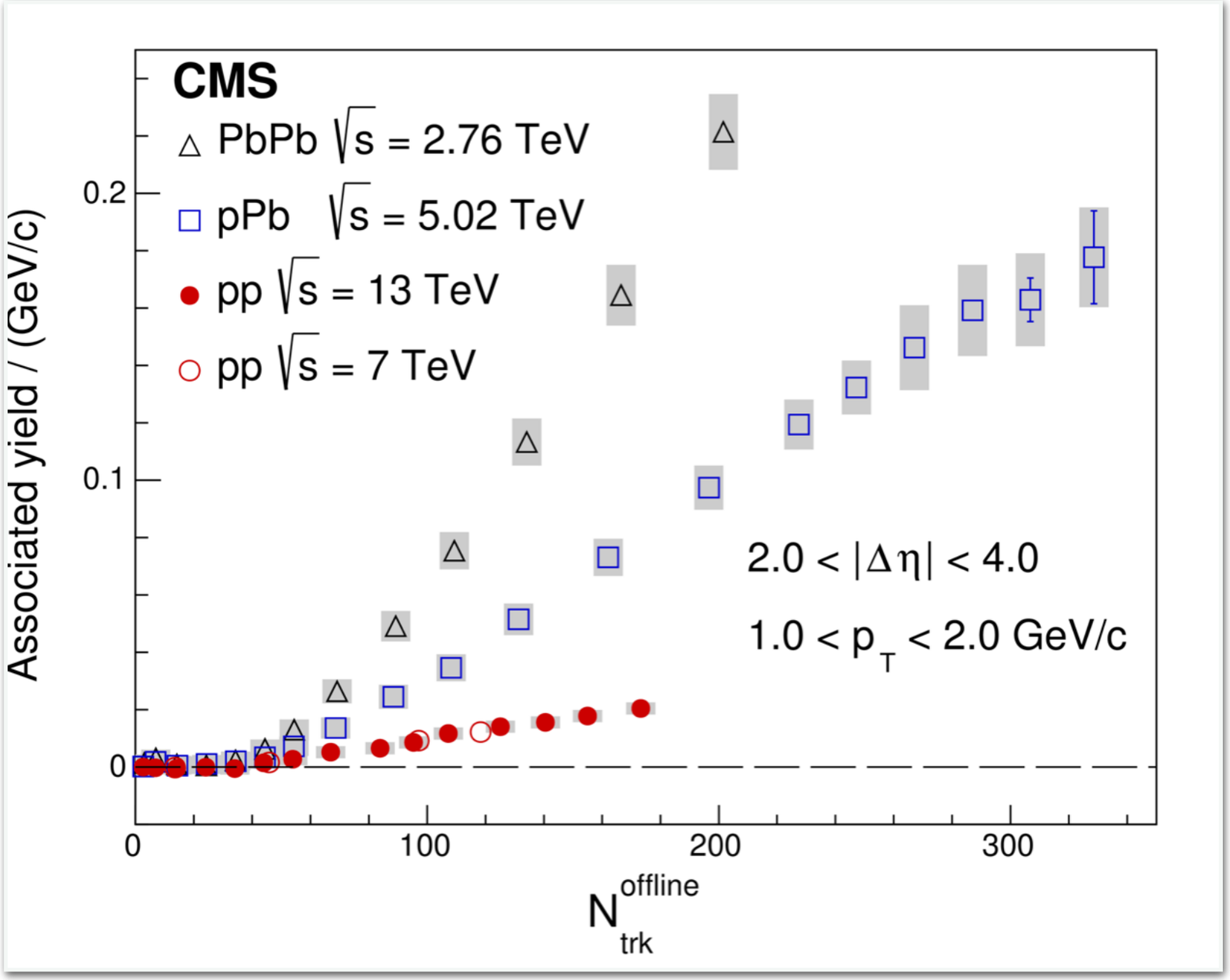
p_T

Two-Particle Correlations

ETH Institute for Particle Physics

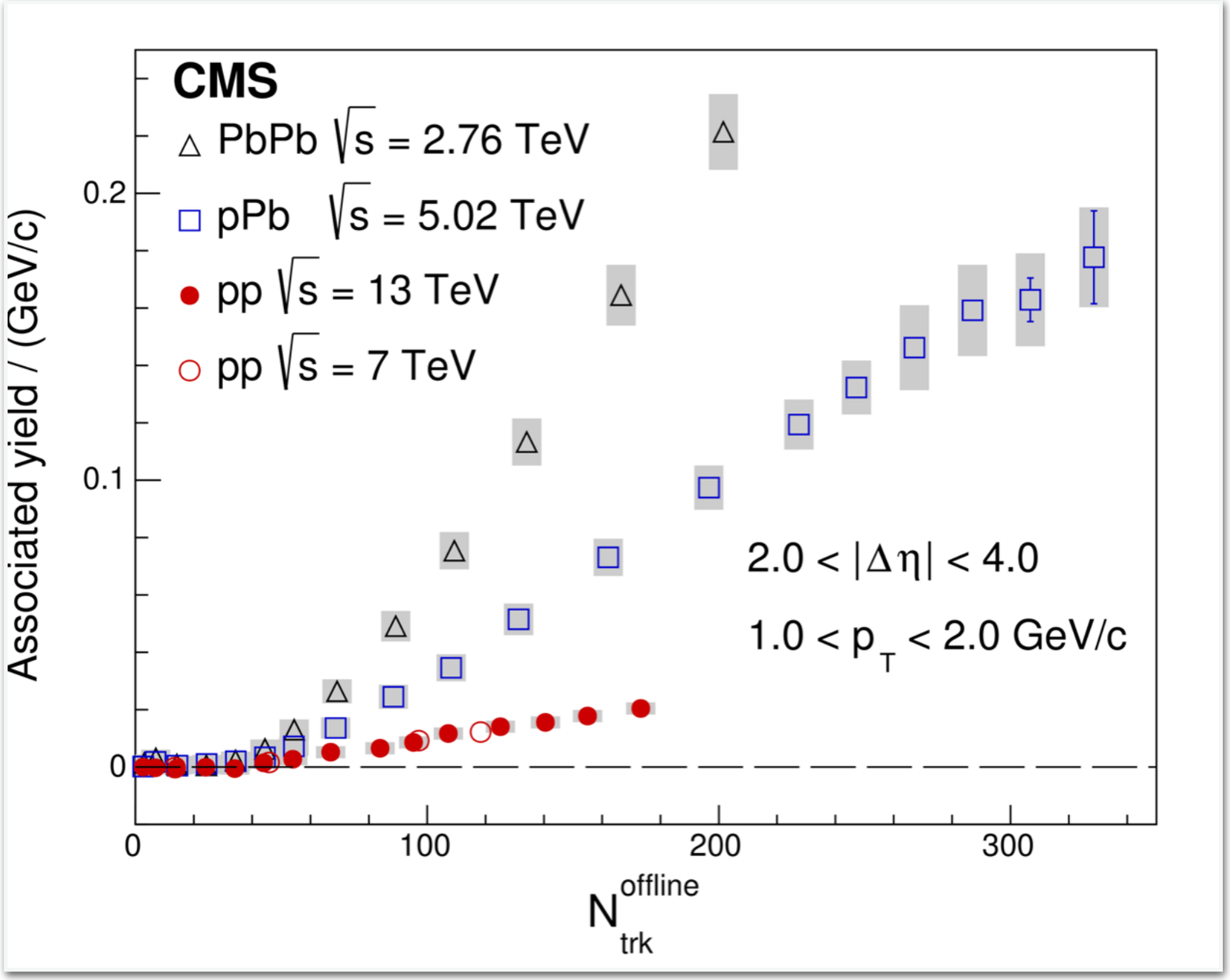
http://arxiv.org/abs/1510.03068

submitted to PRL



Two-Particle Correlations

ETH Institute for Particle Physics



http://arxiv.org/abs/1510.03068

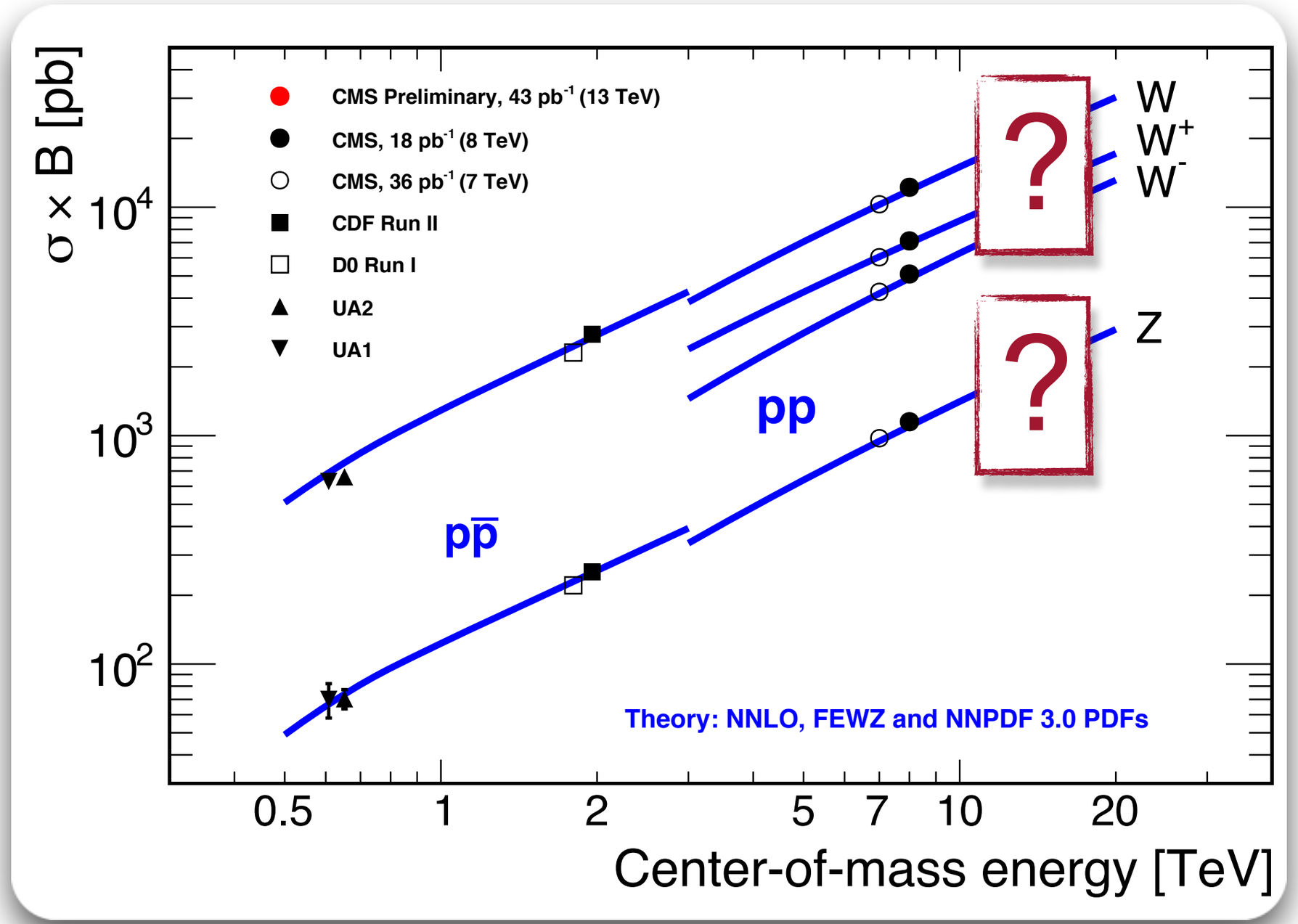
submitted to PRL

Physics origin still not really understood

no E_{CM} dependence in pp collisions

but dependence on colliding system size

W and Z prod.


σ × B [pb]
CMS Preliminary, 43 pb-1 (13 TeV)
CMS, 18 pb-1 (8 TeV)
CMS, 36 pb-1 (7 TeV)
CDF Run II
D0 Run I
UA2
UA1
?
W
W+
W-
?
Z
pp
pp̄
Theory: NNLO, FEWZ and NNPDF 3.0 PDFs
10^4
10^3
10^2
0.5
1
2
5
7
10
20
Center-of-mass energy [TeV]

Analysis method

ETH Institute for Particle Physics

CMS-PAS-SMP-15-004

- single and double lepton samples (electrons and muons)
- W yield from fit to E_{Tmiss} distribution (no cut)
- Z yield from counting over dilepton inv. mass : 60 - 120 GeV

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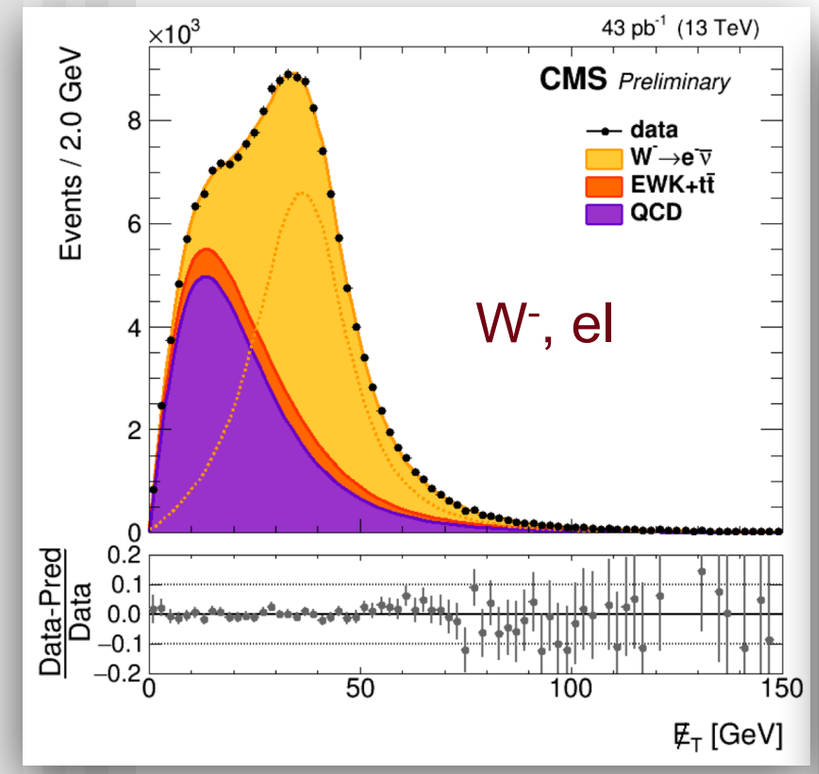

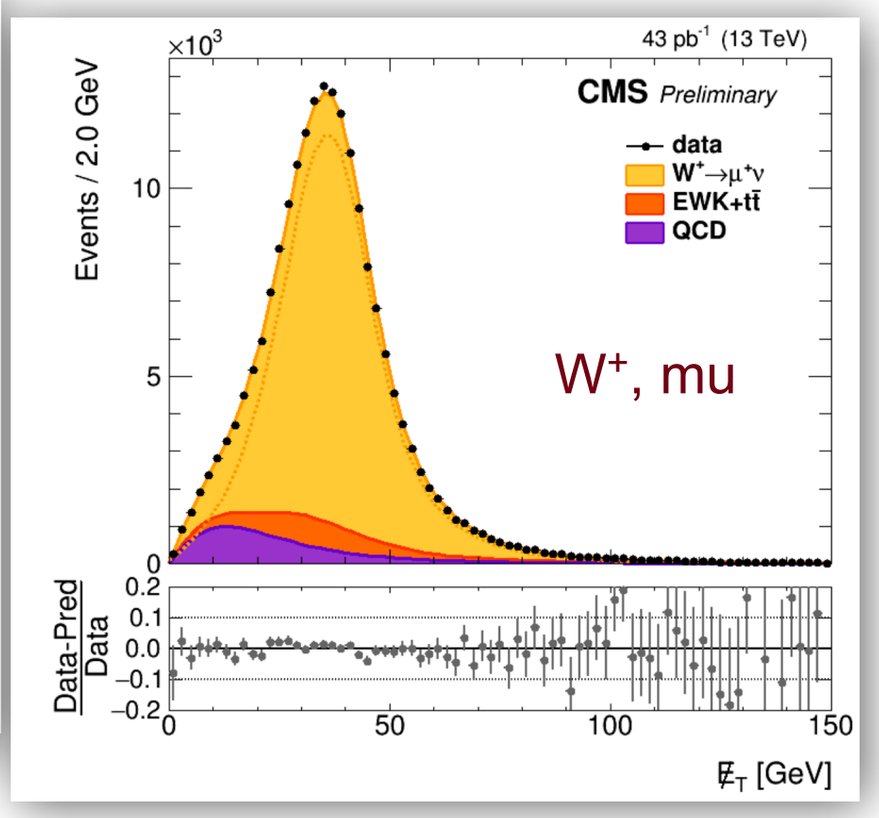

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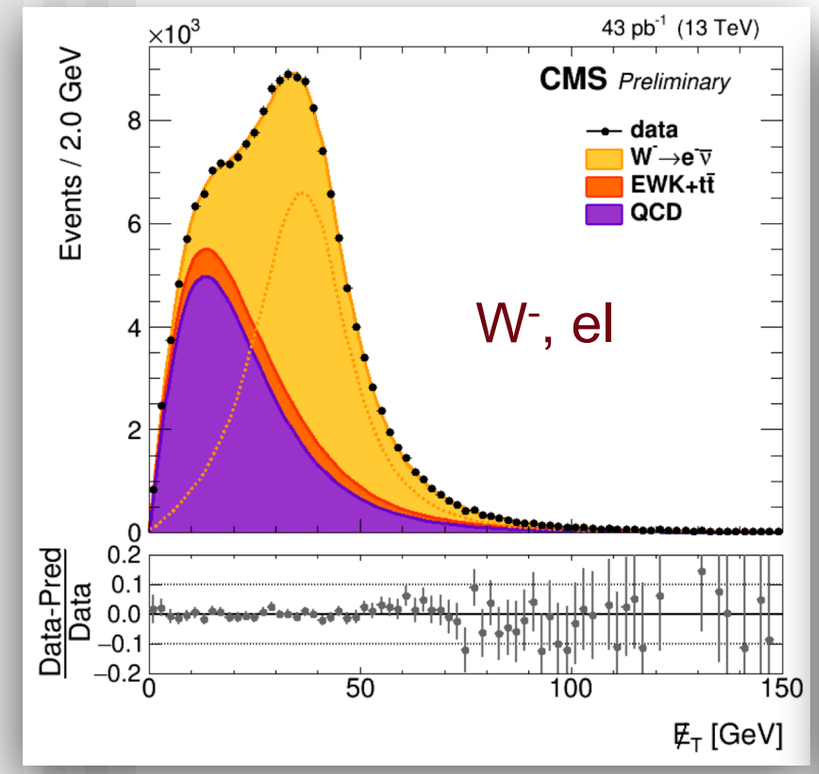

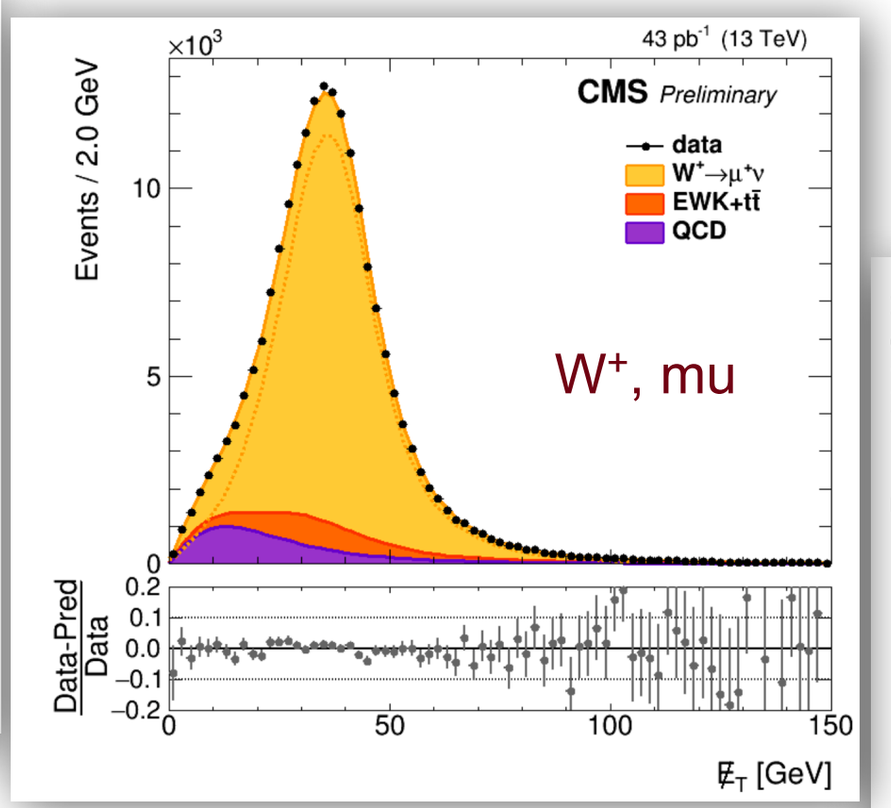

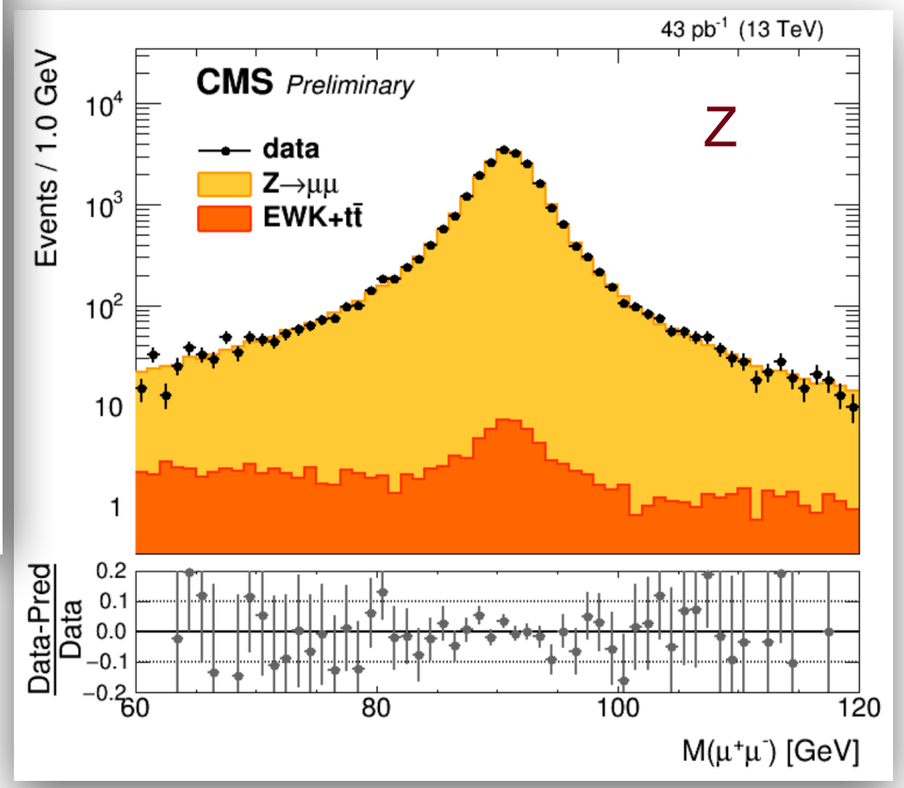

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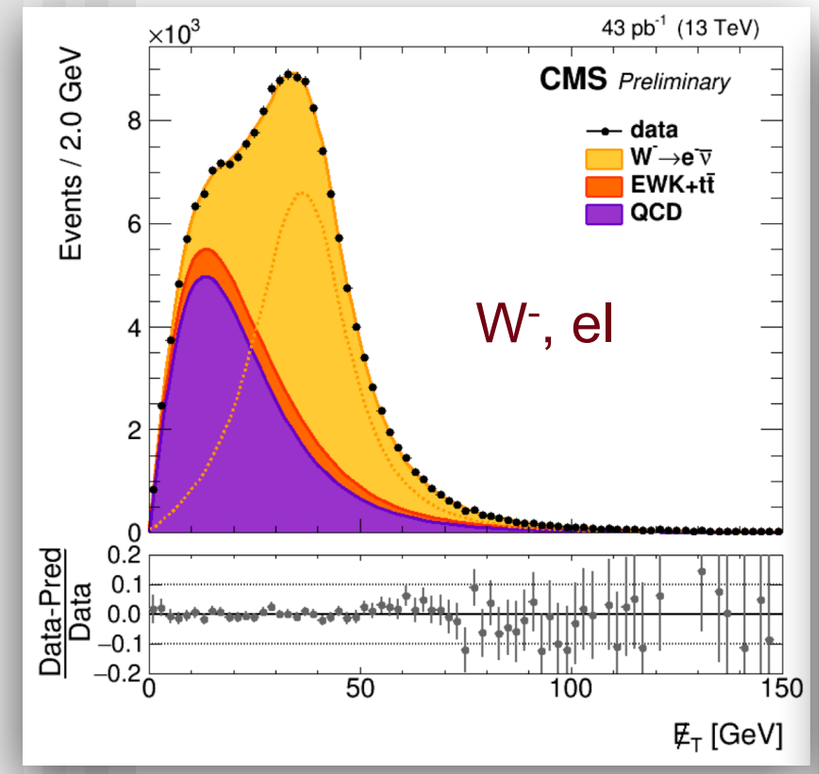
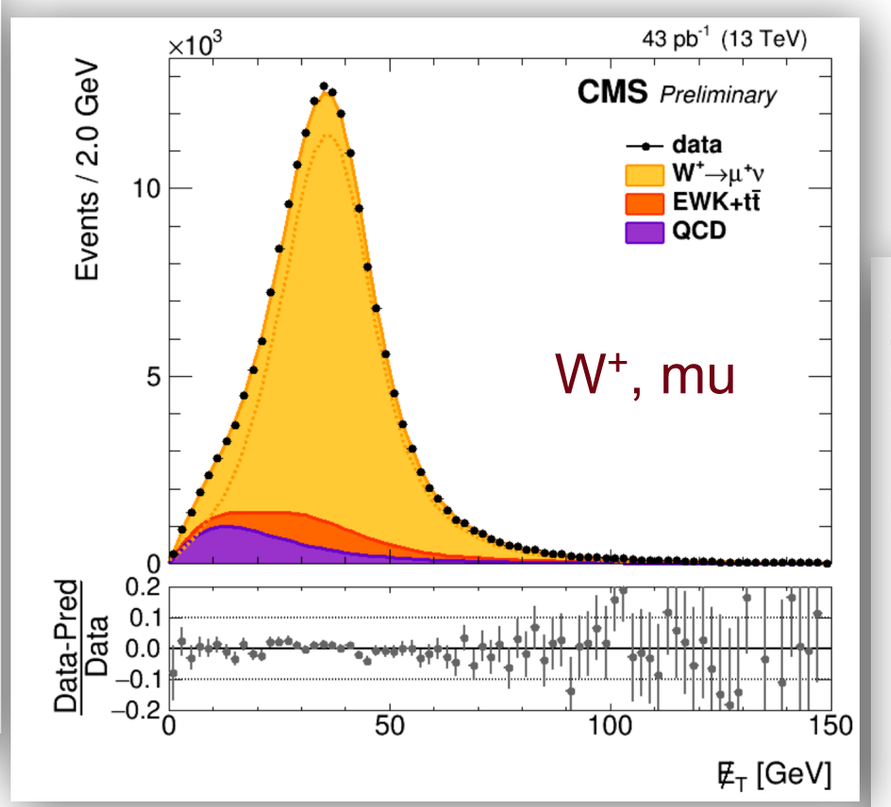
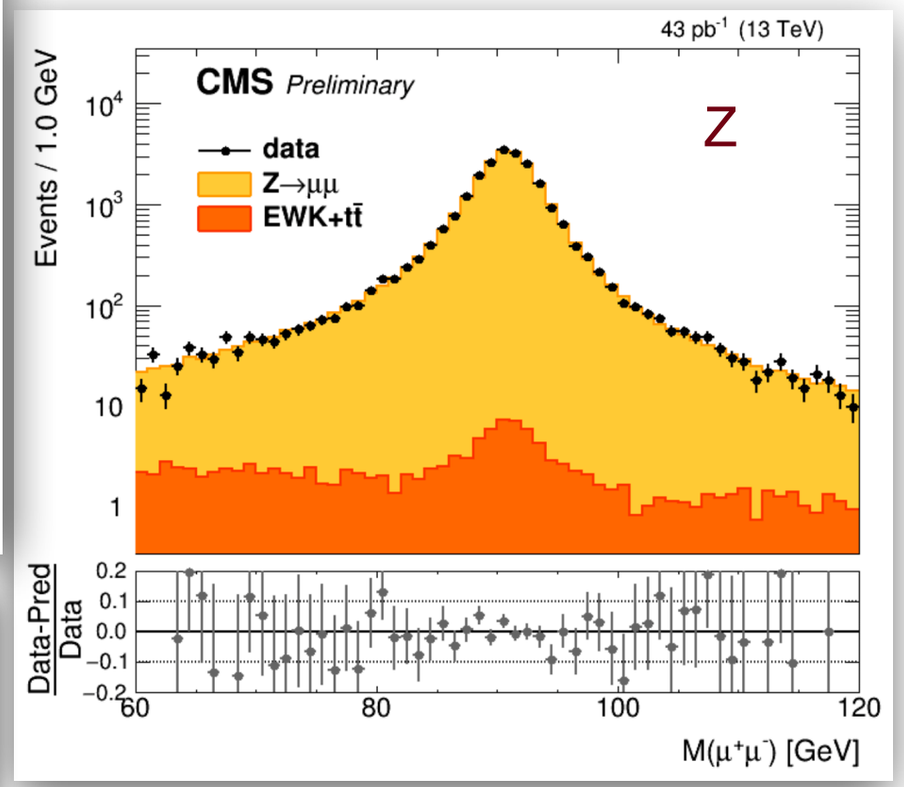






PUPPI*:

- first time usage of a new method for pile-up (PU) subtraction, at the **single particle level** (PFlow particles)
- compute a likelihood per particle to come from PU or not
- assign a weight to each particle accordingly, and discard small-weight or small-E_T particles
- calculate E_{Tmiss} from the remaining ones

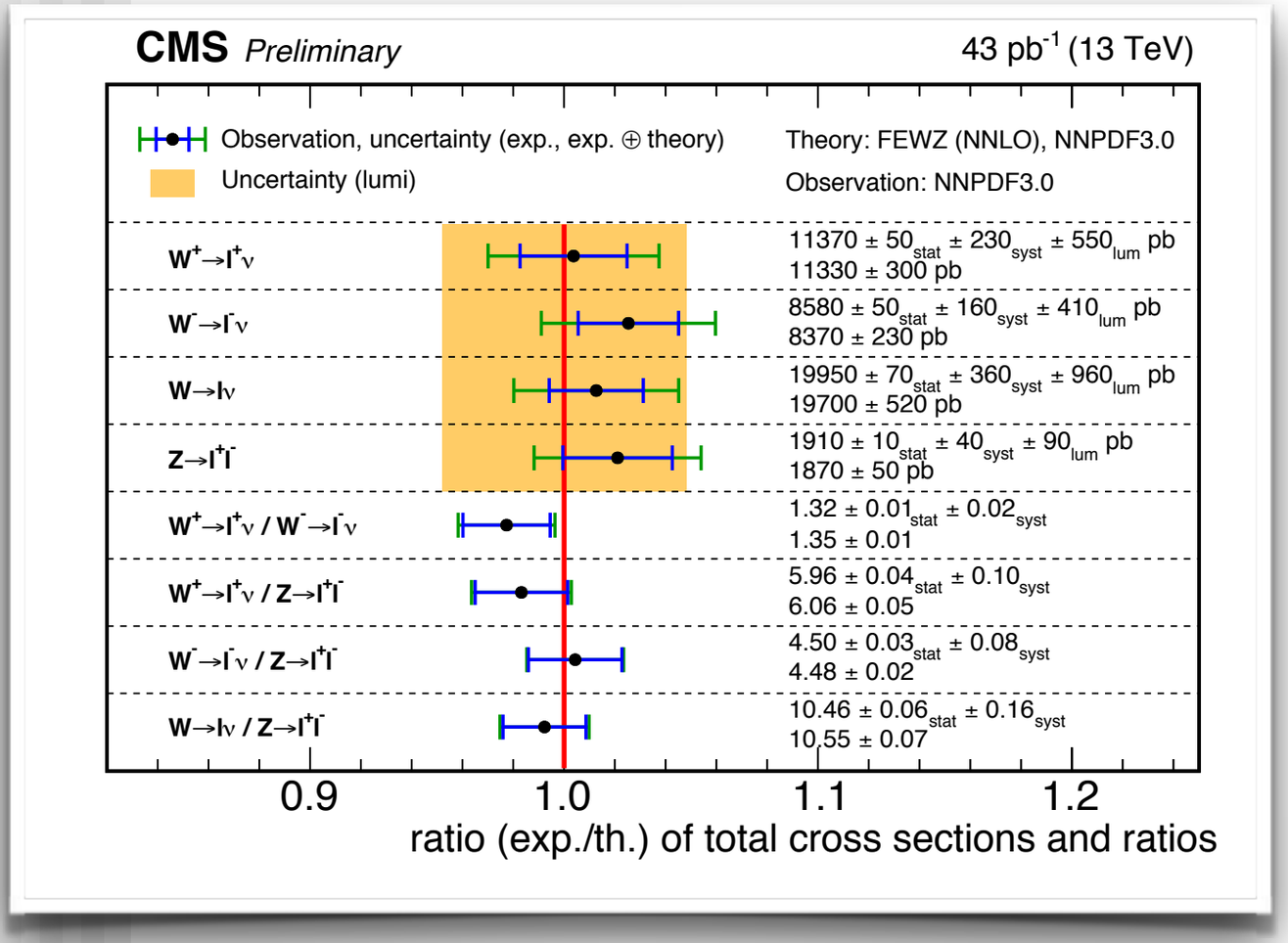
* JHEP10(2014)059, arXiv:1407.6013

Results

ETH Institute for Particle Physics

CMS-PAS-SMP-15-004

inclusive and fiducial cross sections



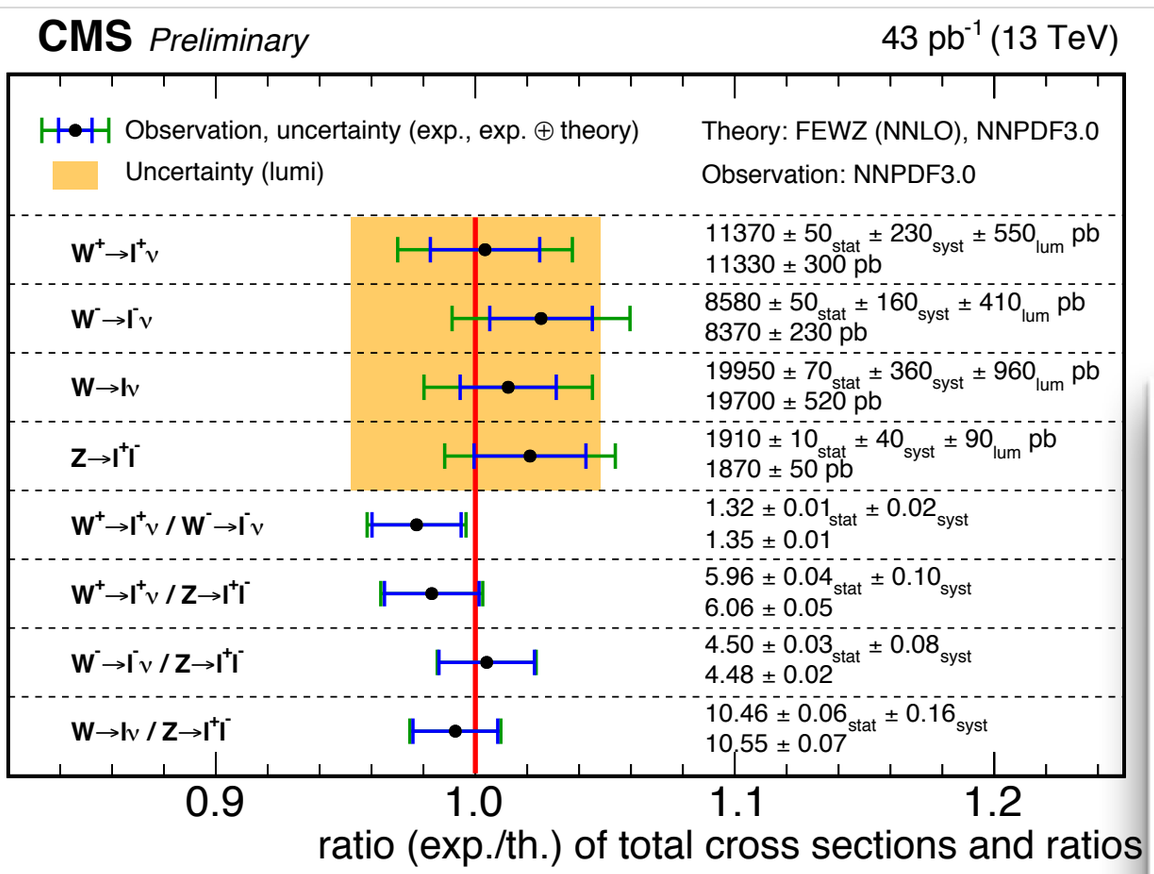
exp,	exp + theo,	lumi	uncert.
~2%	~ 2 + 2-3%	4.8%	
reduced to ~1%		0 %	in ratios

Results

ETH Institute for Particle Physics

CMS-PAS-SMP-15-004

inclusive and fiducial cross sections



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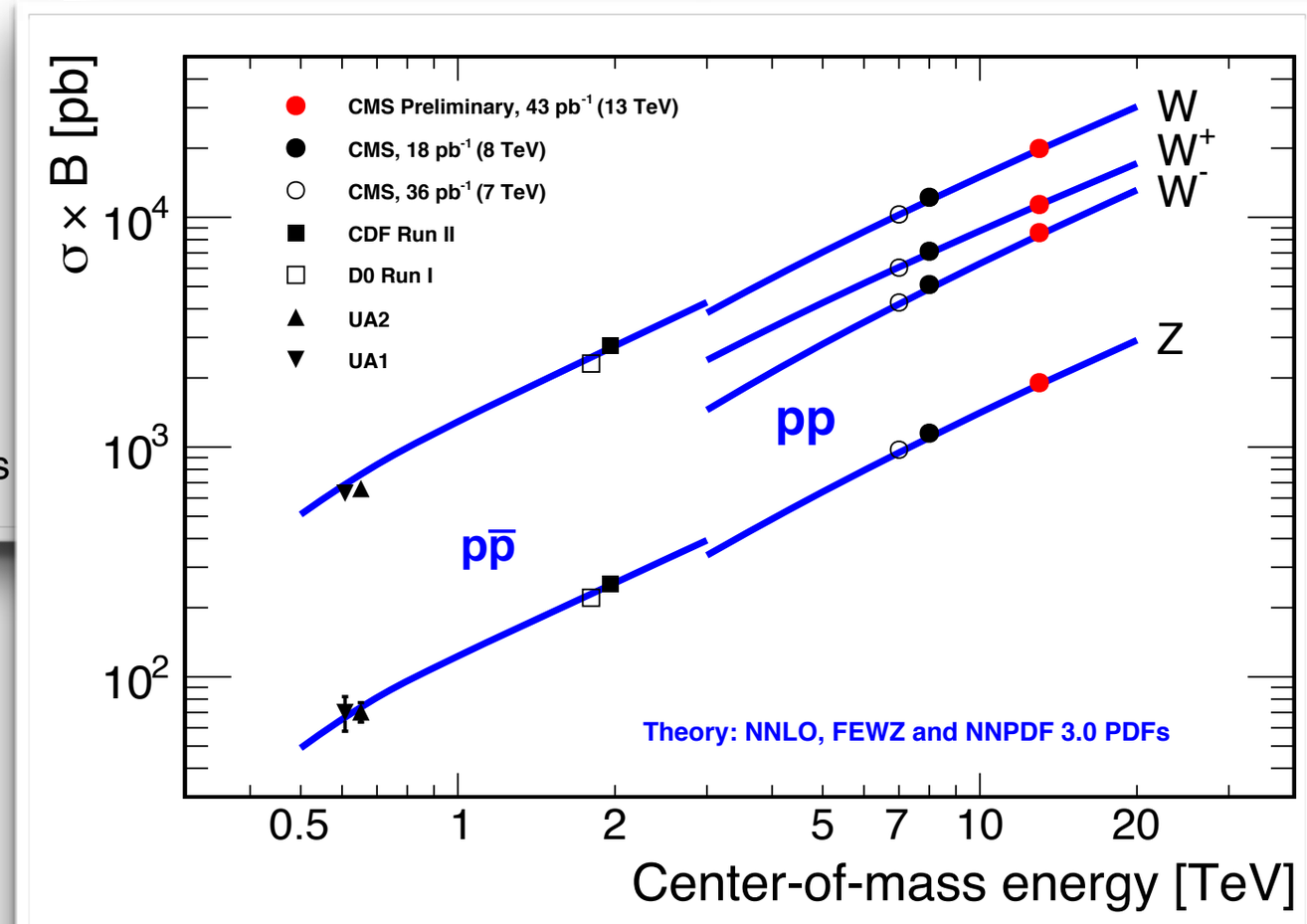
0 %

in ratios



Excellent accuracy achieved already!

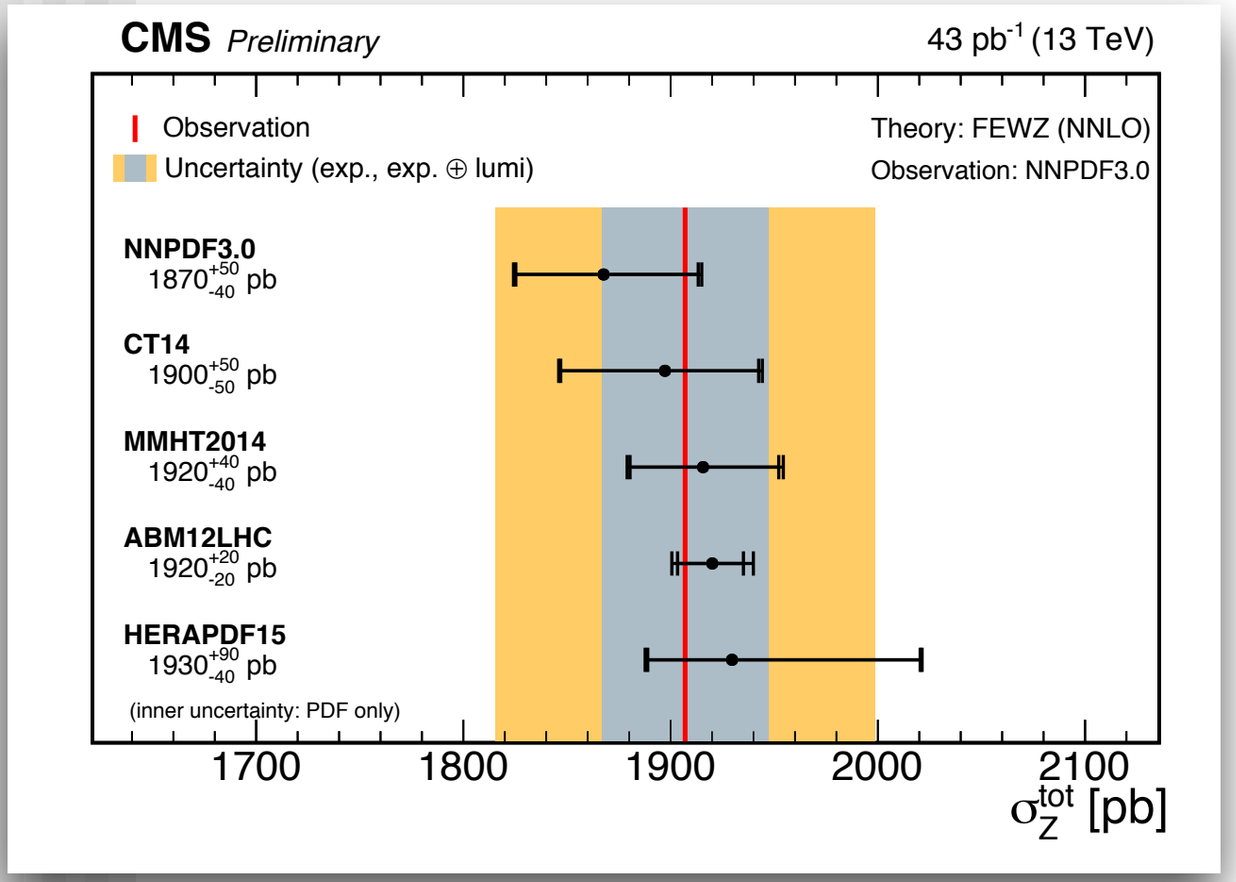
very good agreement with NNLO SM pred.

Results

ETH Institute for Particle Physics

CMS-PAS-SMP-15-004

- exp. uncertainties of similar size compared to theory uncertainties
- handle to constrain PDFs



total incl. Z cross section

Results

CMS-PAS-SMP-15-004

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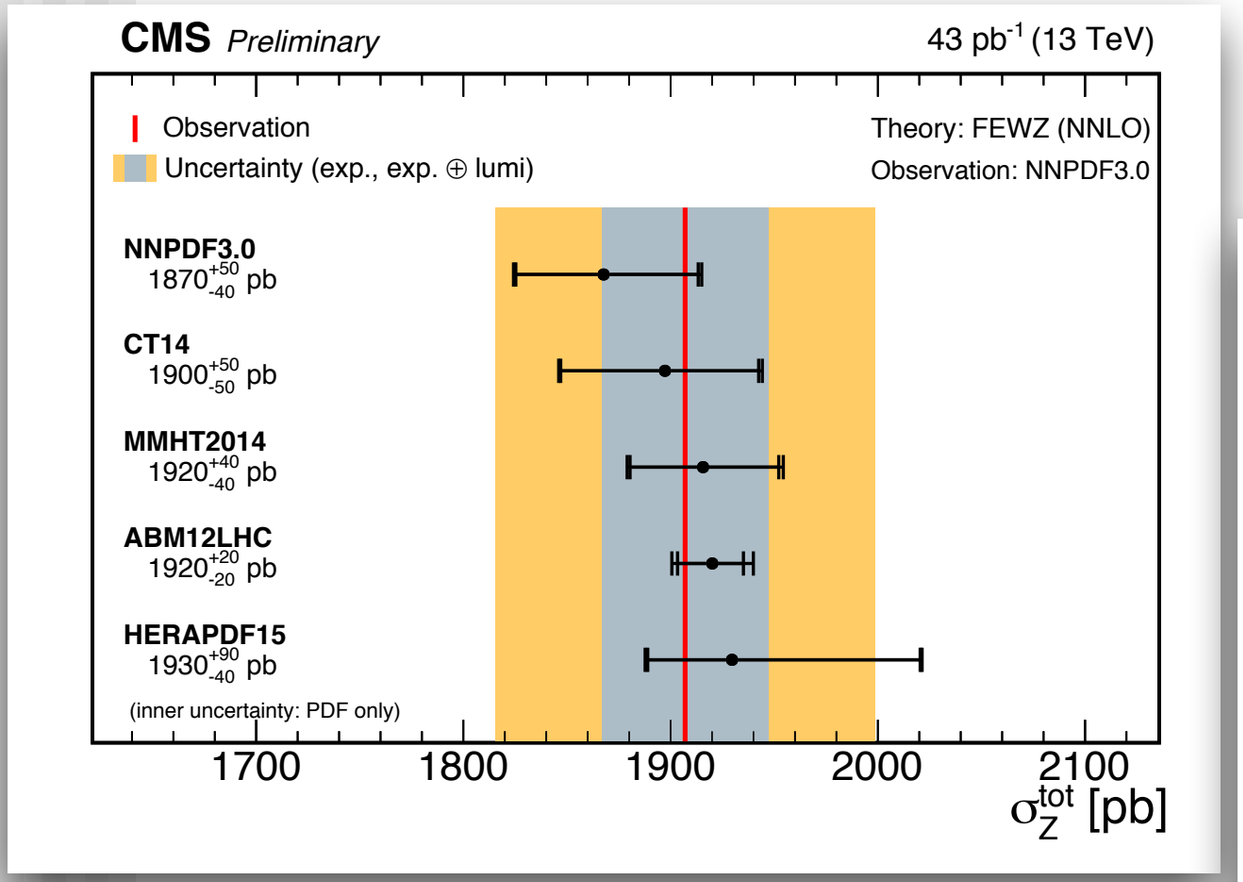
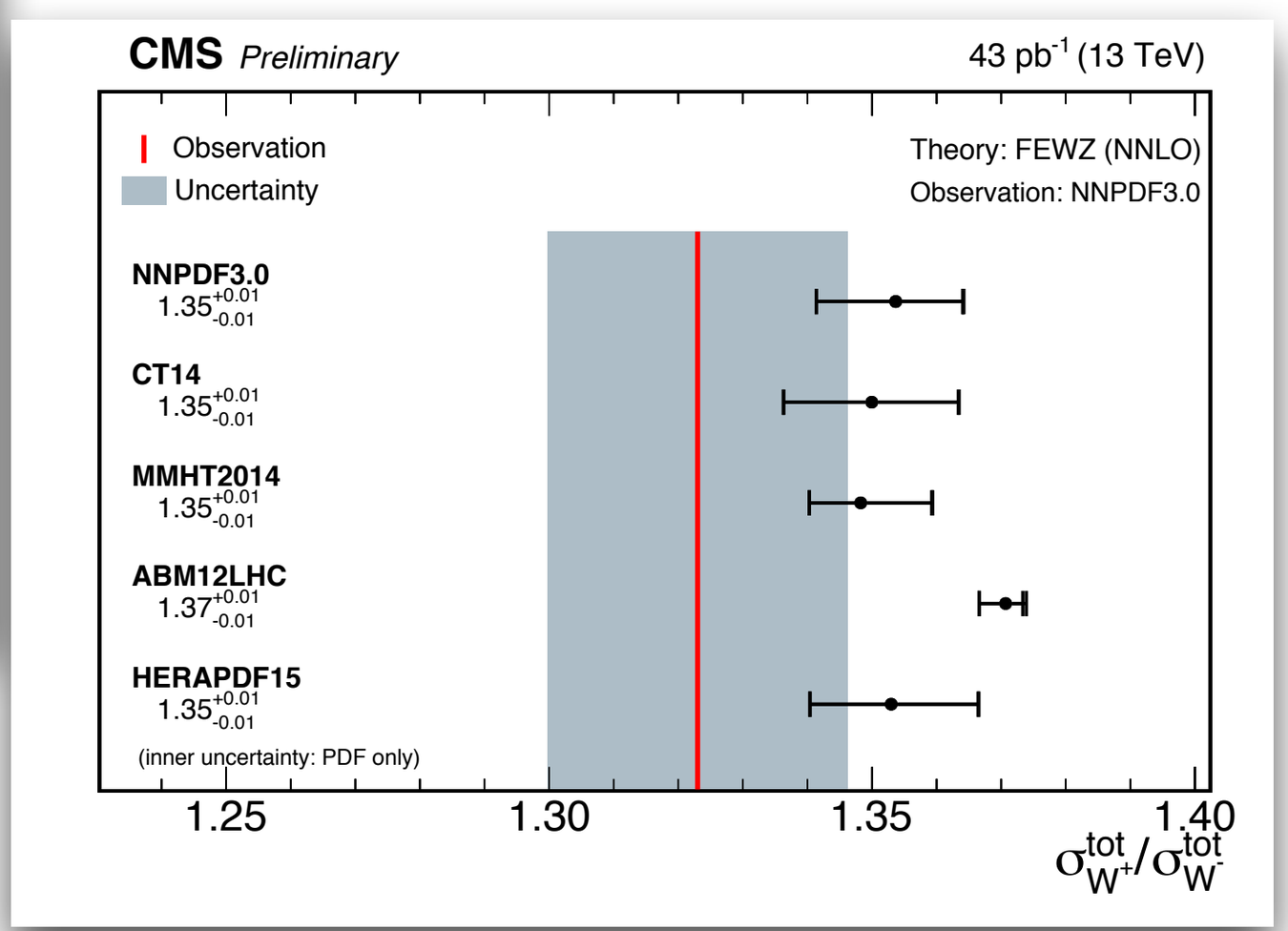
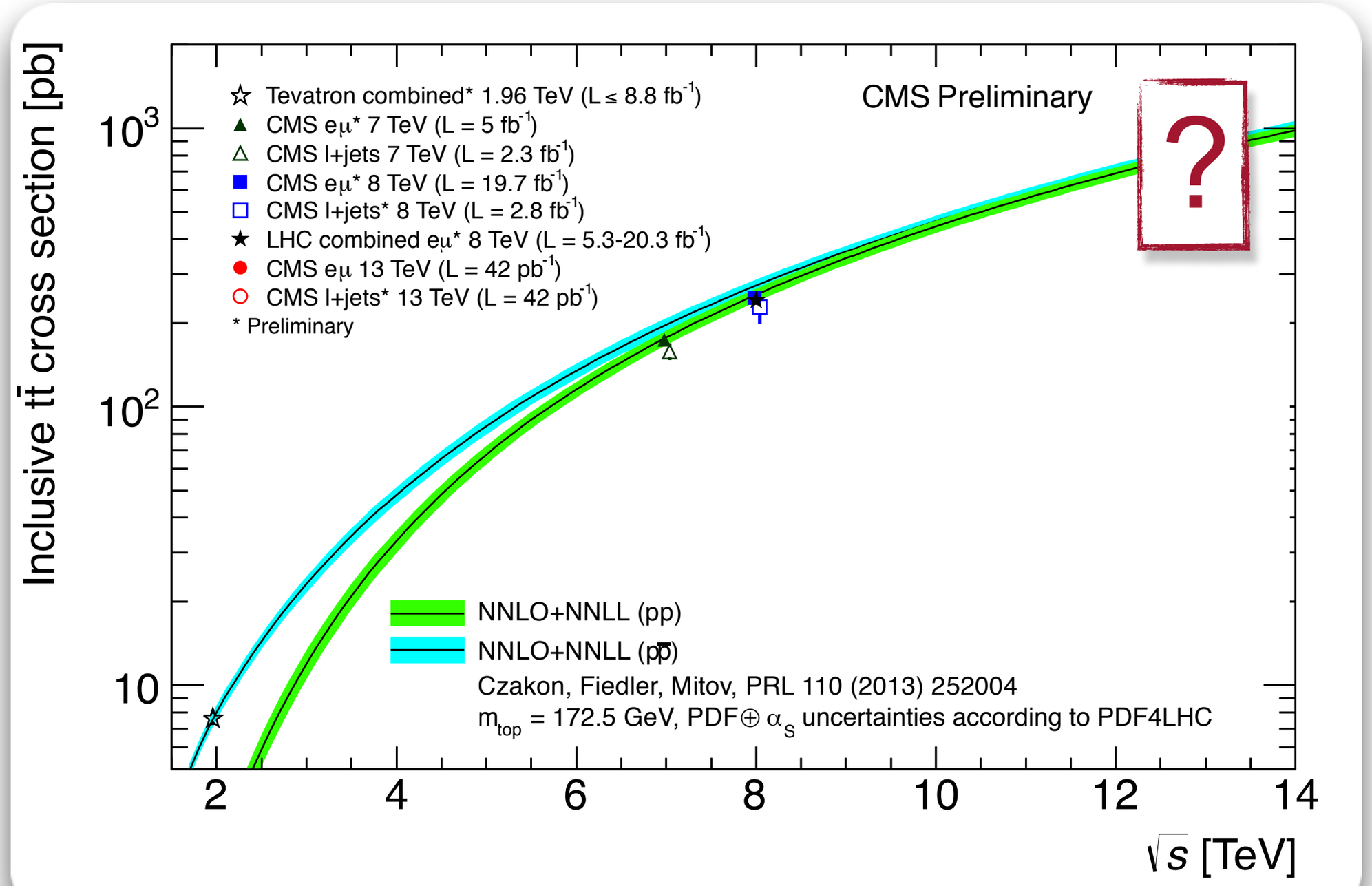


total incl. Z cross section

ratio of incl. W^+ and W^- cross sections



Top Quark


CMS Preliminary
?
Tevatron combined* 1.96 TeV (L ≤ 8.8 fb-1)
CMS eμ* 7 TeV (L = 5 fb-1)
CMS l+jets 7 TeV (L = 2.3 fb-1)
CMS eμ* 8 TeV (L = 19.7 fb-1)
CMS l+jets* 8 TeV (L = 2.8 fb-1)
LHC combined eμ* 8 TeV (L = 5.3-20.3 fb-1)
CMS eμ 13 TeV (L = 42 pb-1)
CMS l+jets* 13 TeV (L = 42 pb-1)
* Preliminary
NNLO+NNLL (pp)
NNLO+NNLL (pp̄)
Czakon, Fiedler, Mitov, PRL 110 (2013) 252004
mtop = 172.5 GeV, PDF⊕αS uncertainties according to PDF4LHC
Inclusive tt̄ cross section [pb]
10³
10²
10
2
4
6
8
10
12
14
√s [TeV]

Top-Pair production, inclusive

- “easiest” channel: **di-lepton**, electron+muon
- at least 2 jets, no MET req., no b-tagging

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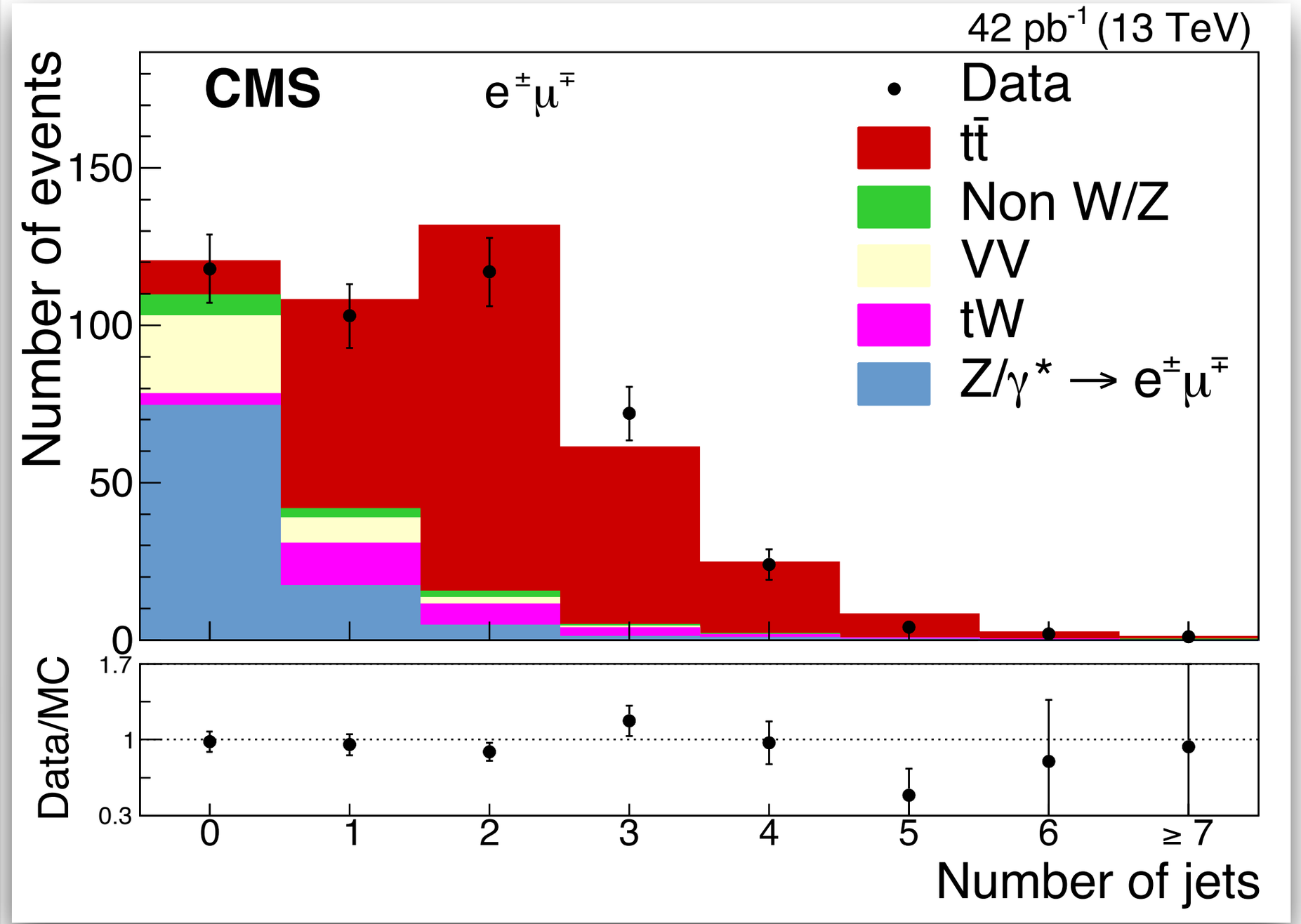

http://arxiv.org/abs/1510.05302

submitted to PRL

Top-Pair production, inclusive

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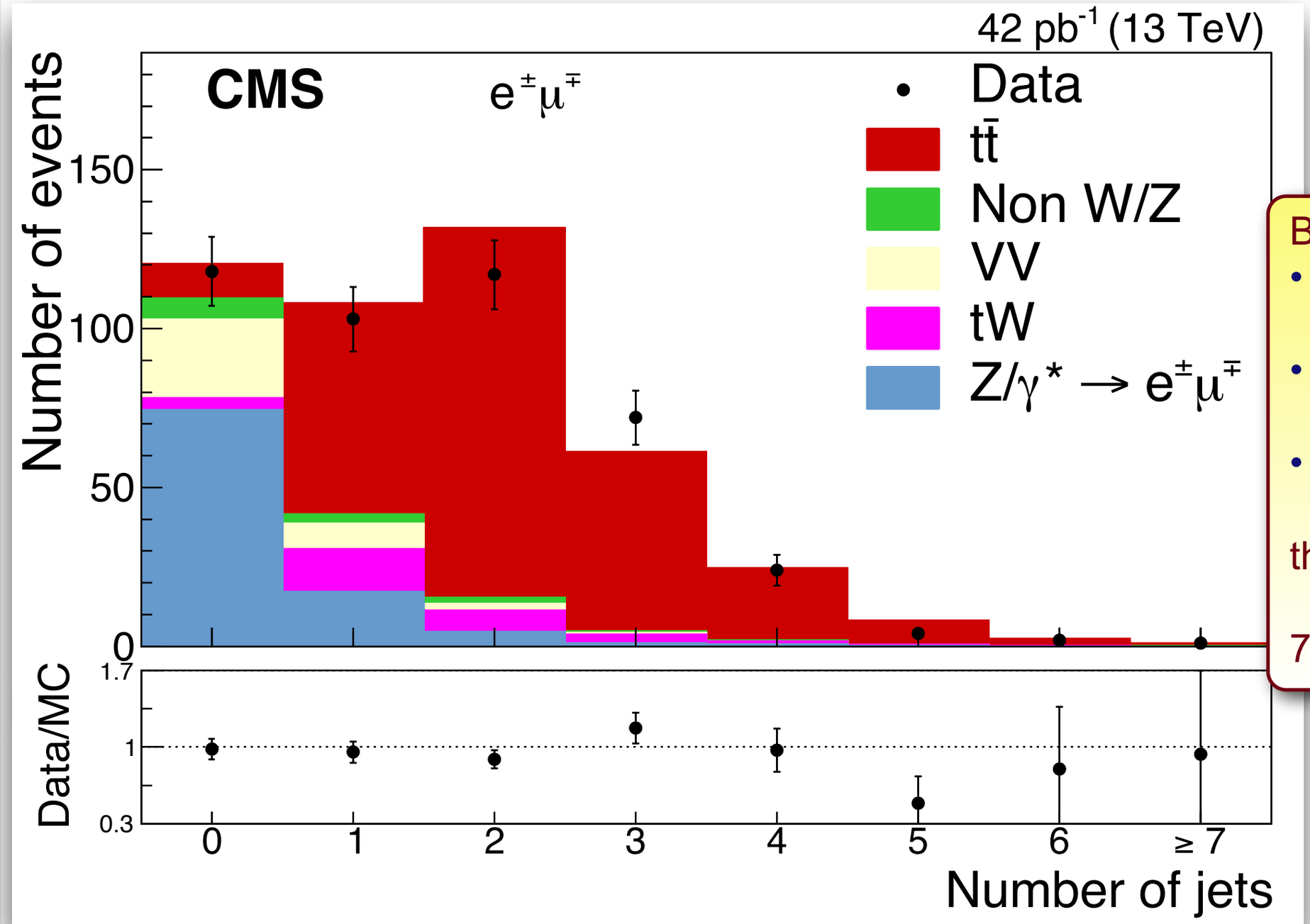

Backgrounds:
- DY from MC, calibrated on Z peak
- non-W/Z from same-sign CR
- others from MC

then cut and count…

7% exp. syst. achieved

http://arxiv.org/abs/1510.05302

submitted to PRL

Top-Pair production, inclusive

ETH Institute for Particle Physics

CMS-PAS-TOP-15-005

- **lepton+jets channel**: electron+muon
- 1 isolated lepton, at least 4 jets, at least 1 b-tagged

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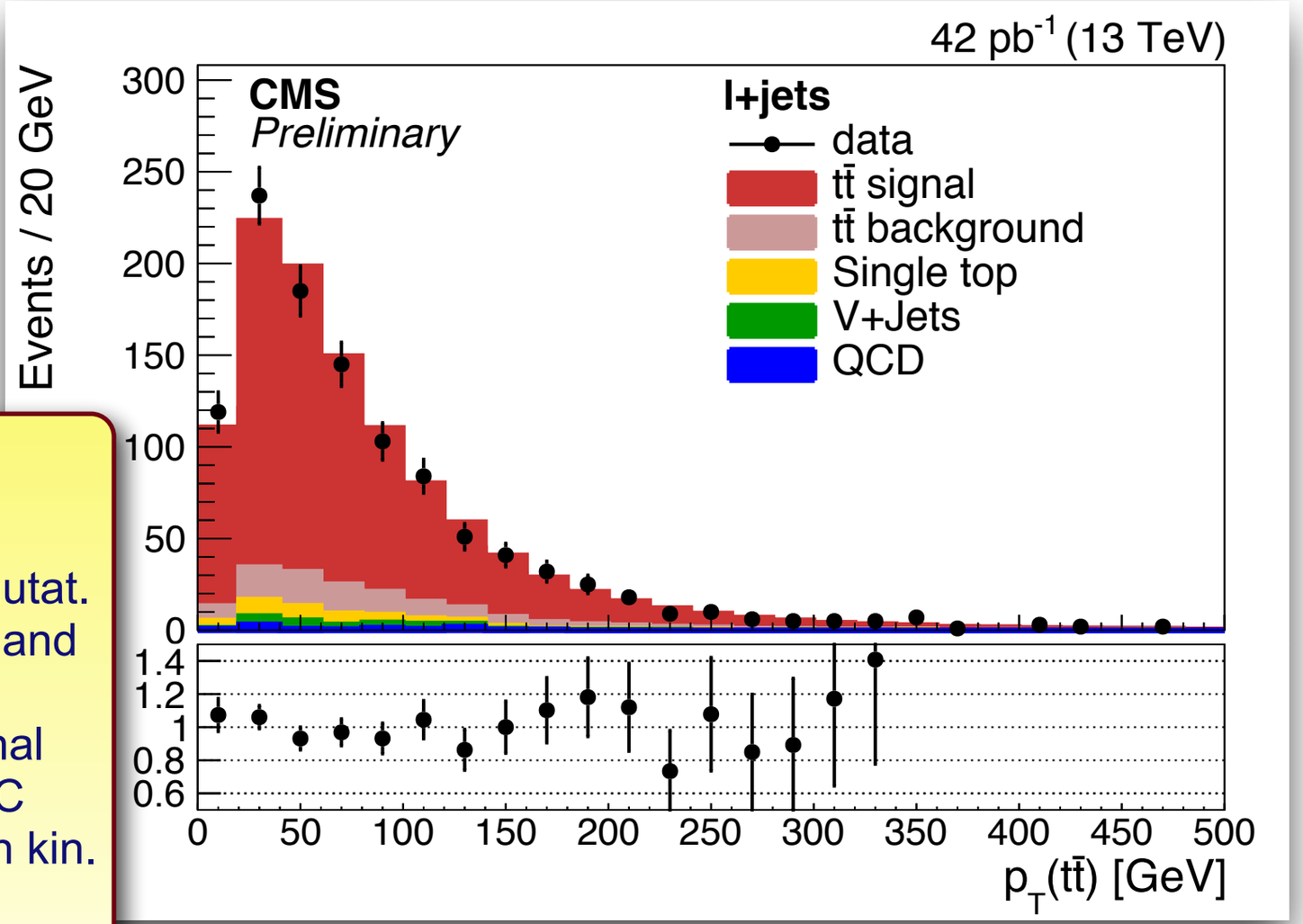


Method:
- kinematic reconstr. to find best jet permutat.
- construct likelihood and cut on it
- 1100 evts, 83% signal
- Bckg subtracted, MC
- analysis done diff. in kin. variables

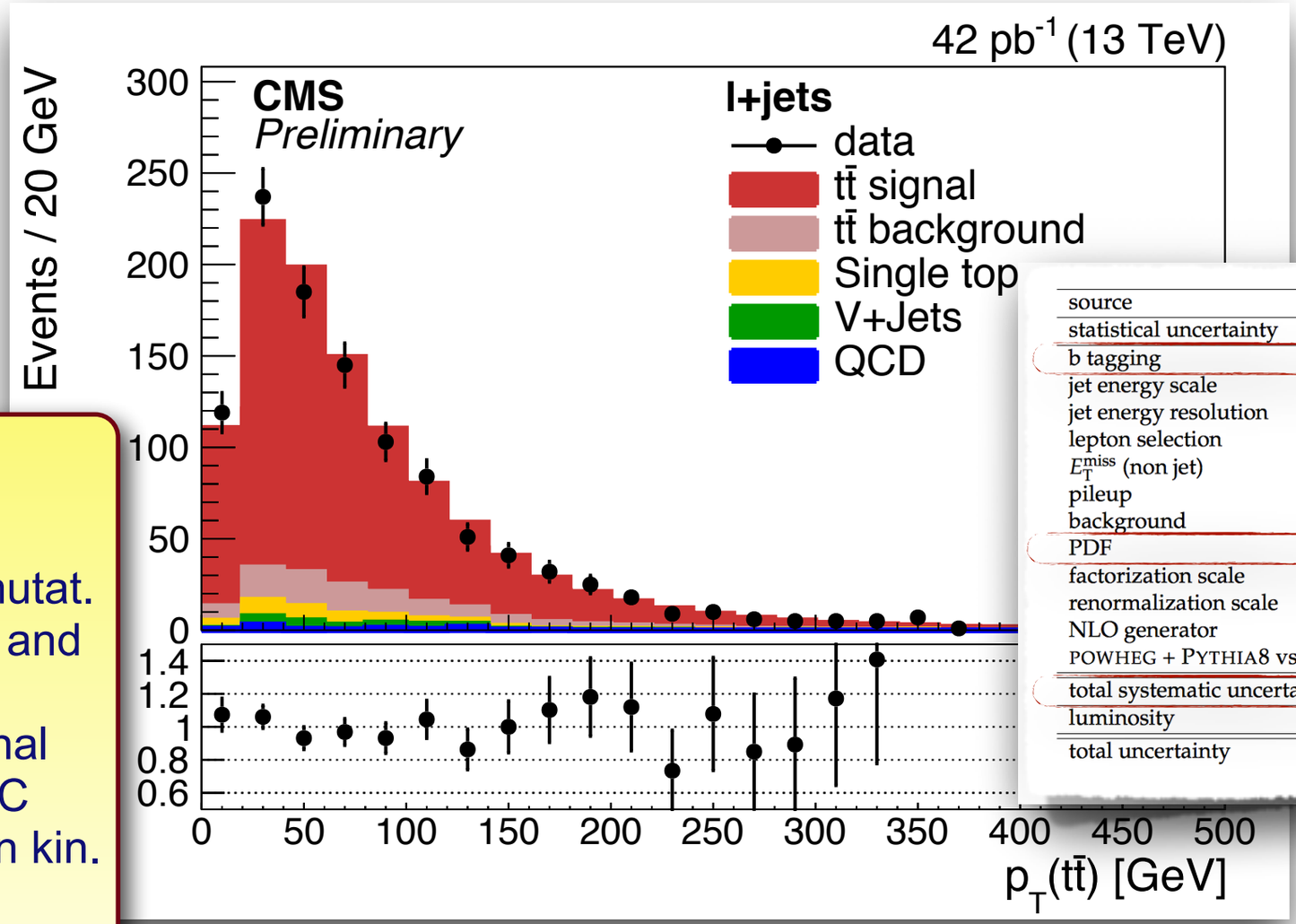
Inclusive cross section from diff. analysis in 1 bin

Top-Pair production, inclusive

ETH Institute for Particle Physics

CMS-PAS-TOP-15-005

- **lepton+jets channel**: electron+muon
- 1 isolated lepton, at least 4 jets, at least 1 b-tagged



source	inclusive cross section [%]
statistical uncertainty	3.2
b tagging	5.1
jet energy scale	3.5
jet energy resolution	3.4
lepton selection	3.0
E_T^{miss} (non jet)	< 0.1
pileup	1.2
background	1.6
PDF	4.7
factorization scale	< 0.1
renormalization scale	< 0.1
NLO generator	2.0
POWHEG + PYTHIA8 vs. HERWIG++	3.4
total systematic uncertainty (no luminosity)	10.0
luminosity	12
total uncertainty	15.6

Method:
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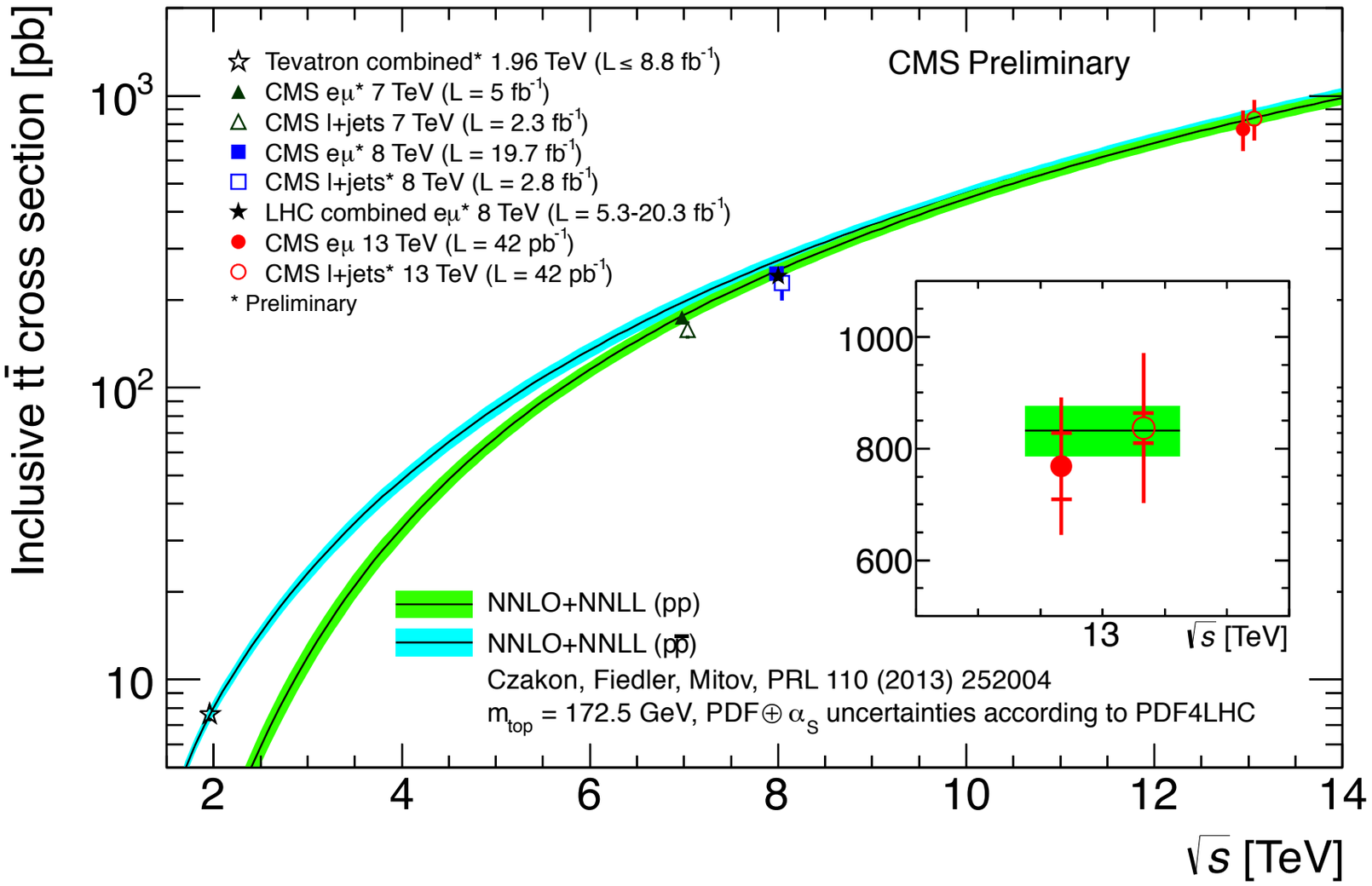
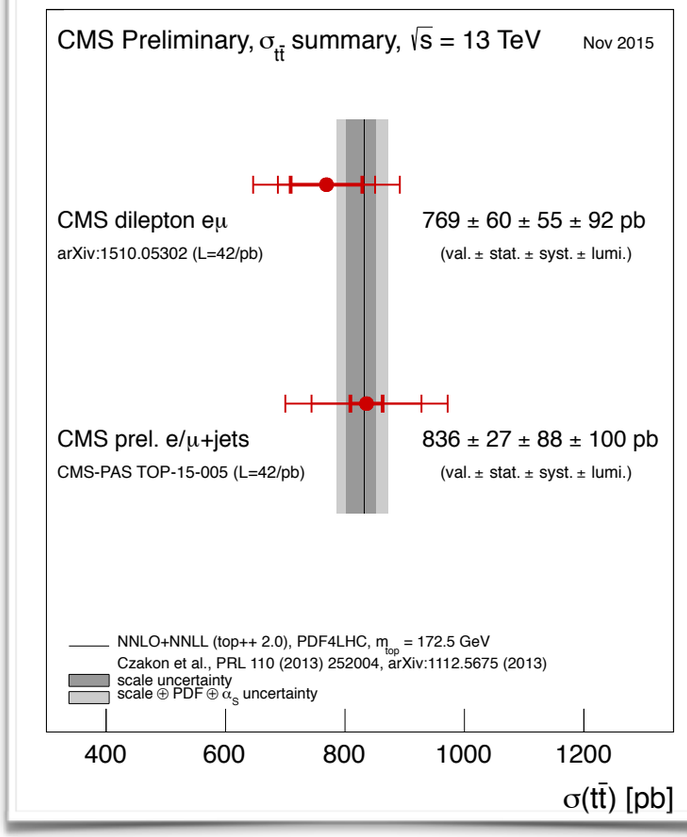
Inclusive cross section from diff. analysis in 1 bin

Top-pair production, inclusive

ETH Institute for Particle Physics

$$\sigma_{t\bar{t}}^{NNLO+NNLL} = 832 \pm 46 \text{ pb}$$





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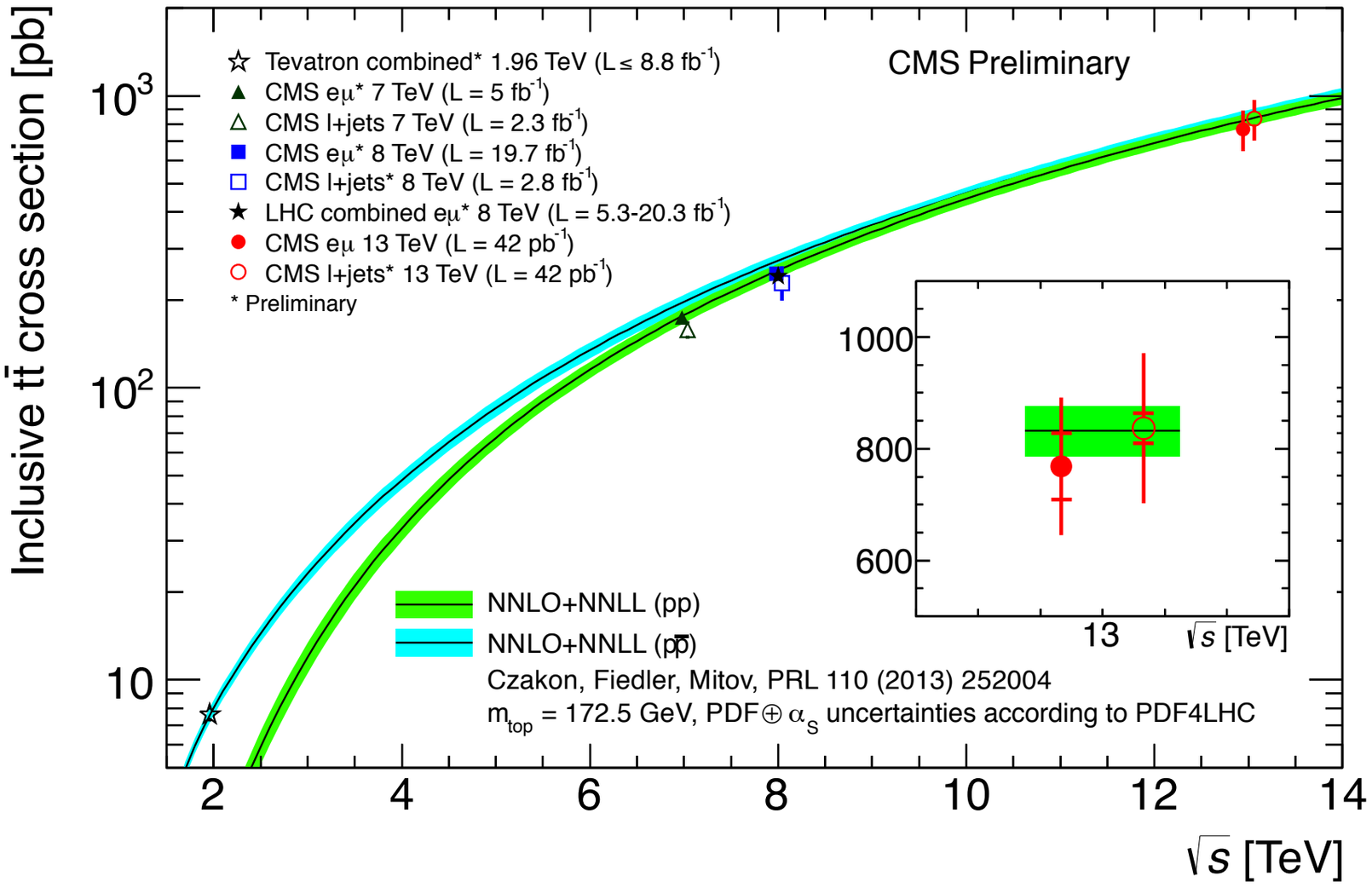

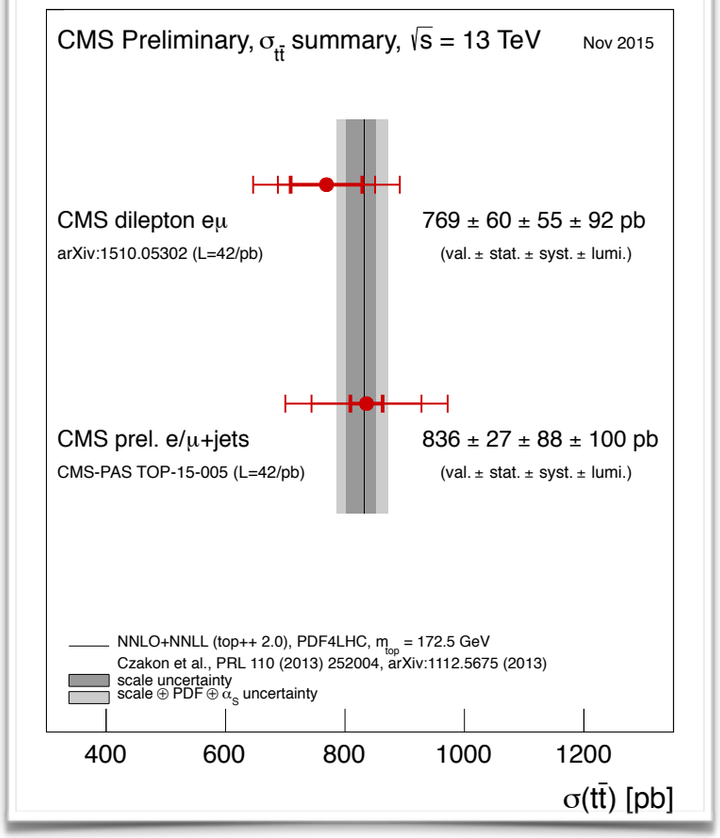

dilepton ch: **7% systematic uncertainty**, 16% total uncertainty;

compare to ~4% precision of Run 1 legacy measurements;

first LHC Run 2 publication on top physics

preliminary result also available for the **l+jets channel**

perfect agreement with SM prediction

Top-pair production, differential

- prelim. results available both for the di-lepton and lepton+jets channel
- normalized to incl. cross section for reduced systematics
- unfolded to parton level and acceptance corrected

CMS-PAS-TOP-15-010

CMS-PAS-TOP-15-005

CMS-PAS-TOP-15-013

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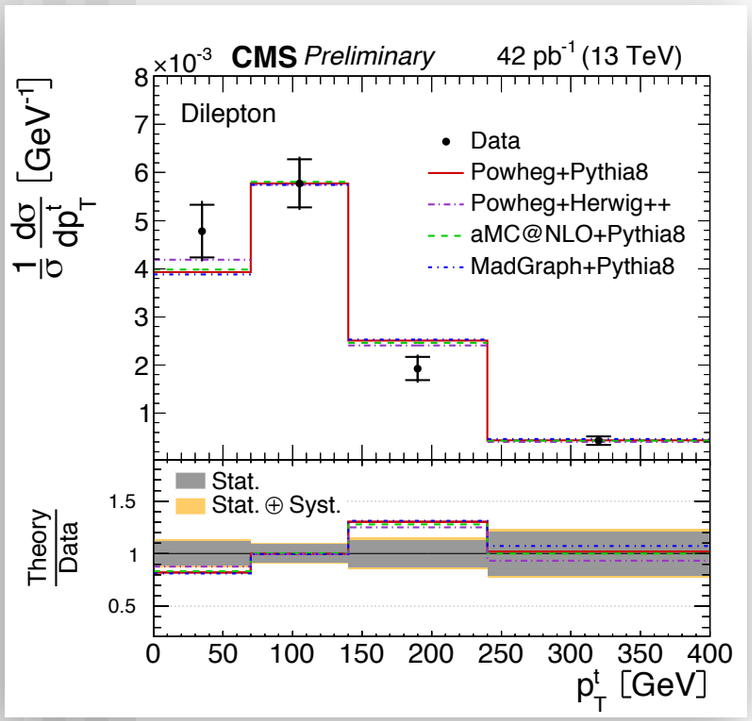

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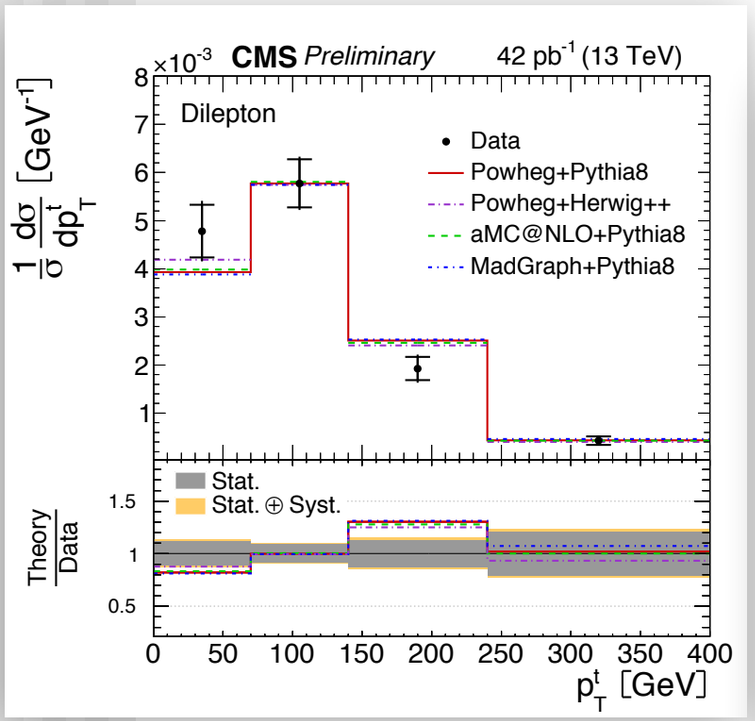

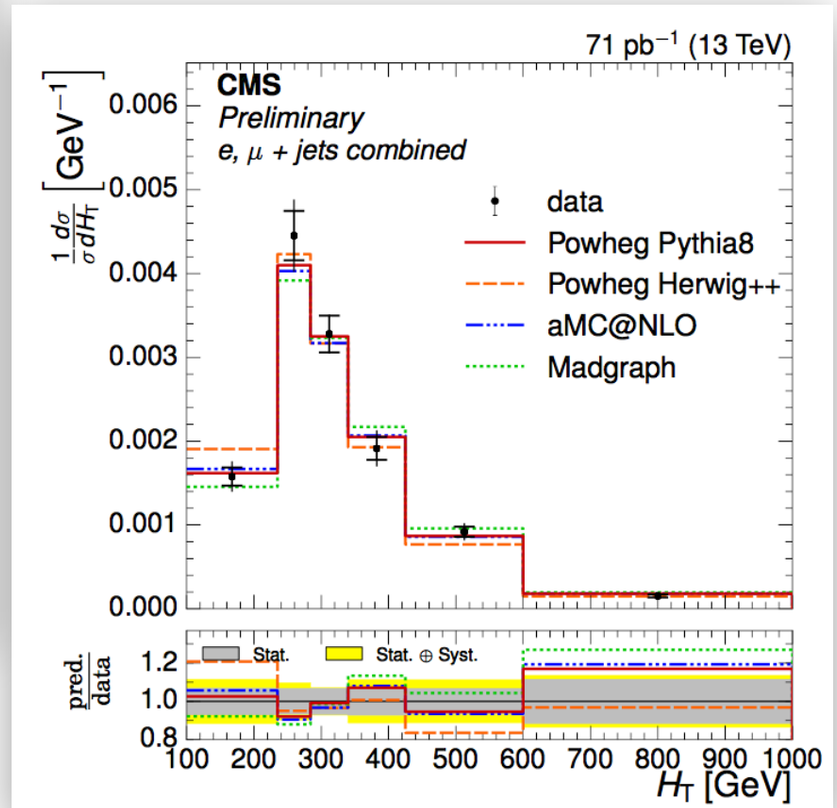

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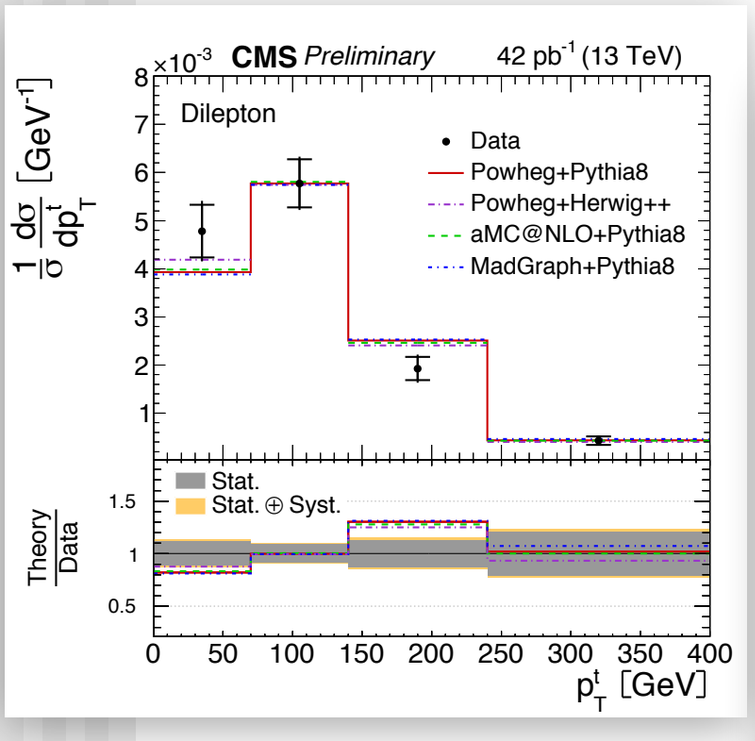
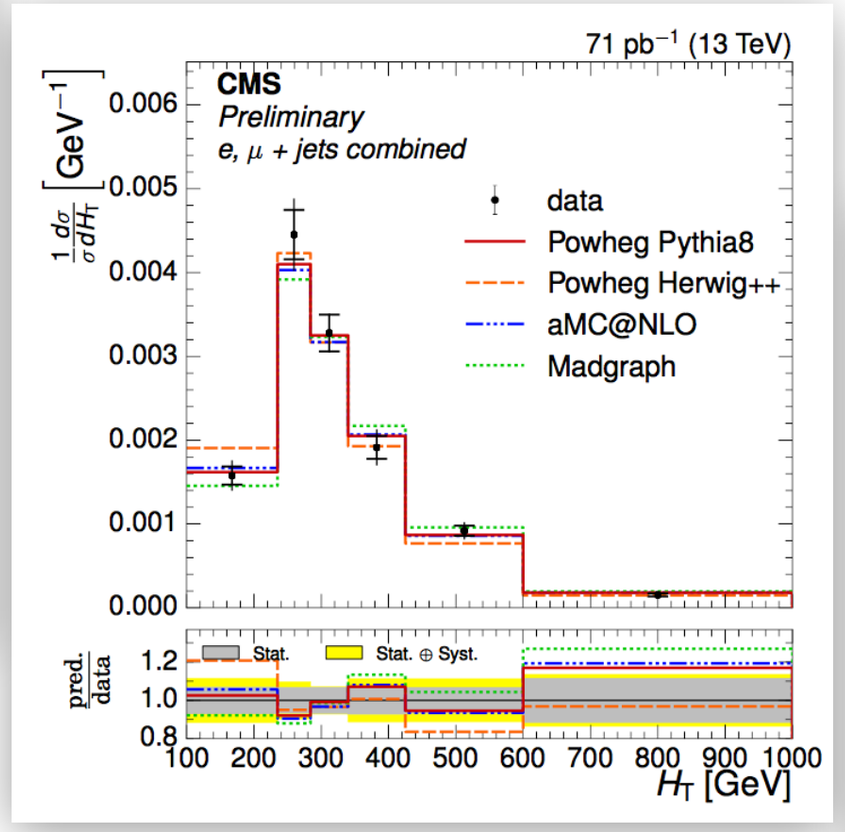
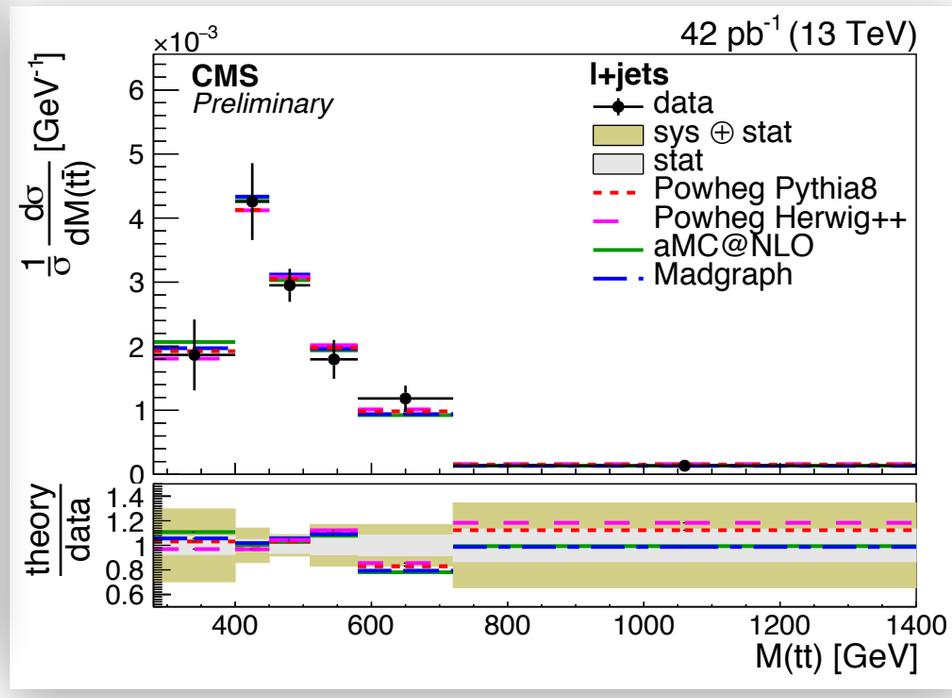






several kinematic observables studied

comparison to LO+PS and NLO+PS MCs

precision mostly limited by statistics so far

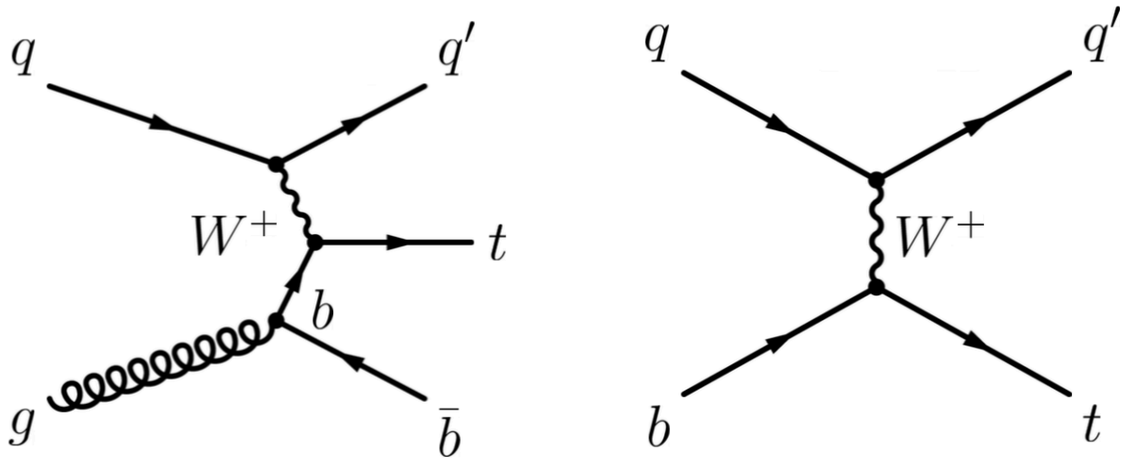
within uncertainties, reasonable agreement with MC pred.

Single-Top production (t-ch.)

ETH Institute for Particle Physics

CMS-PAS-TOP-15-004

- first look at single-top production (80% via t-channel)
- signature: a muon and a b-jet (from top decay), recoiling against a light-quark jet
- analysis closely follows Run 1 methodology



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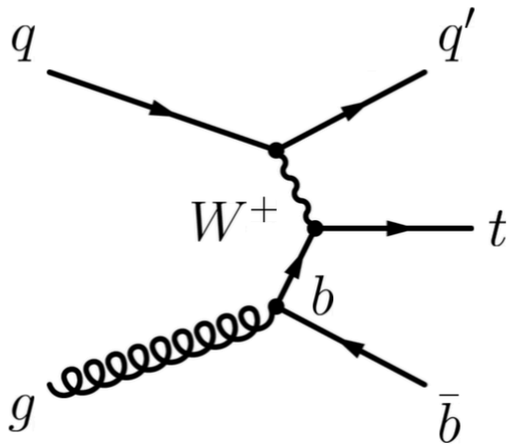
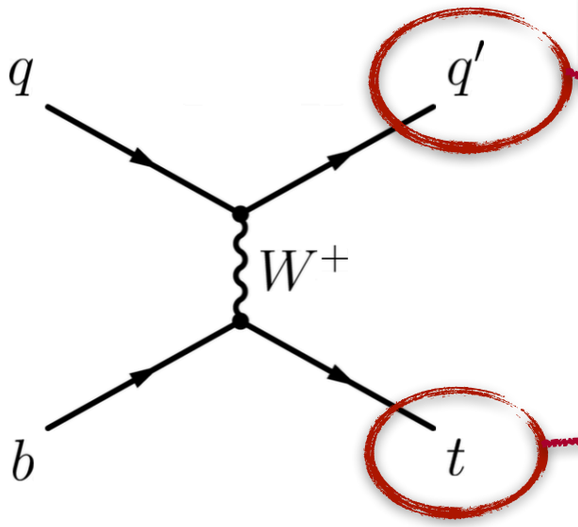
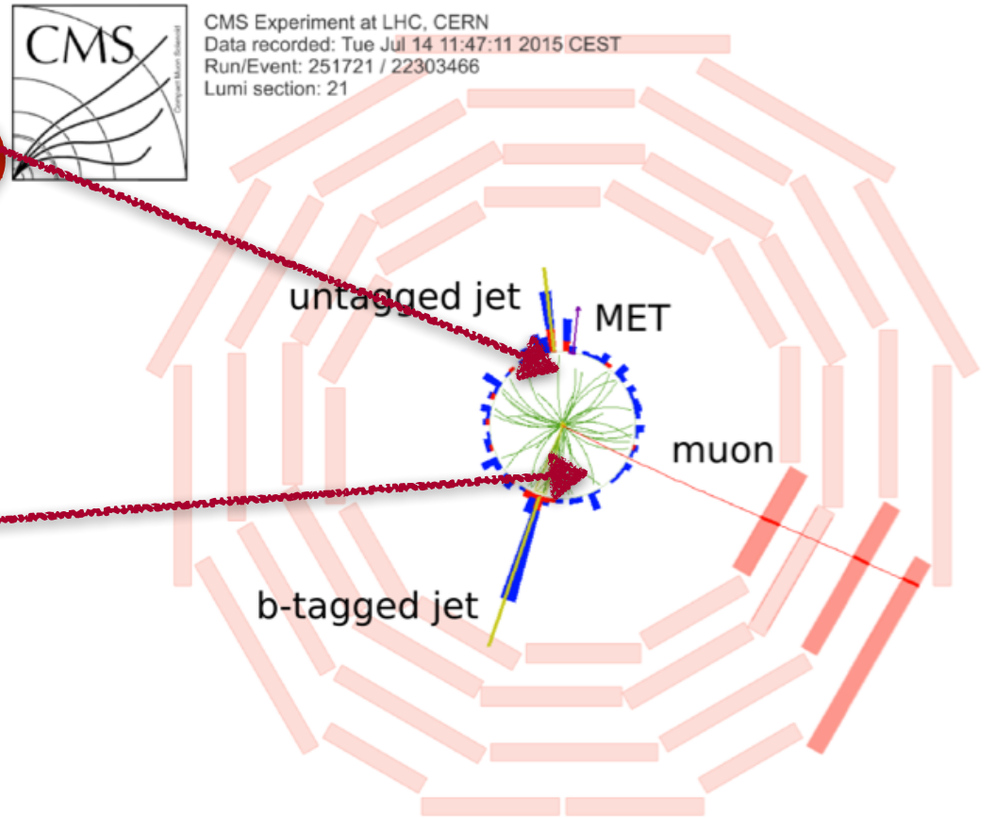




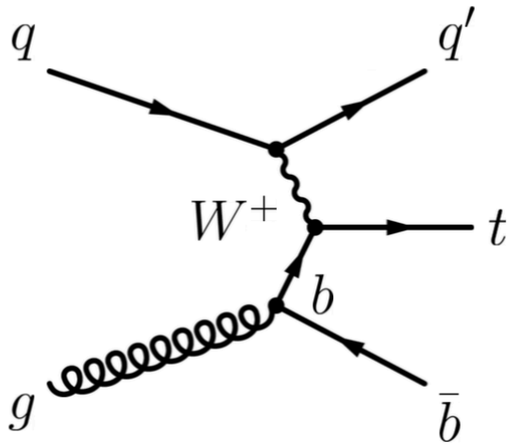


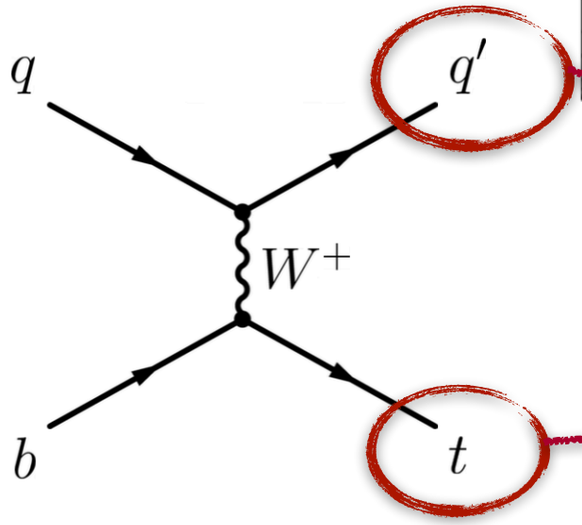
Single-Top production (t-ch.)

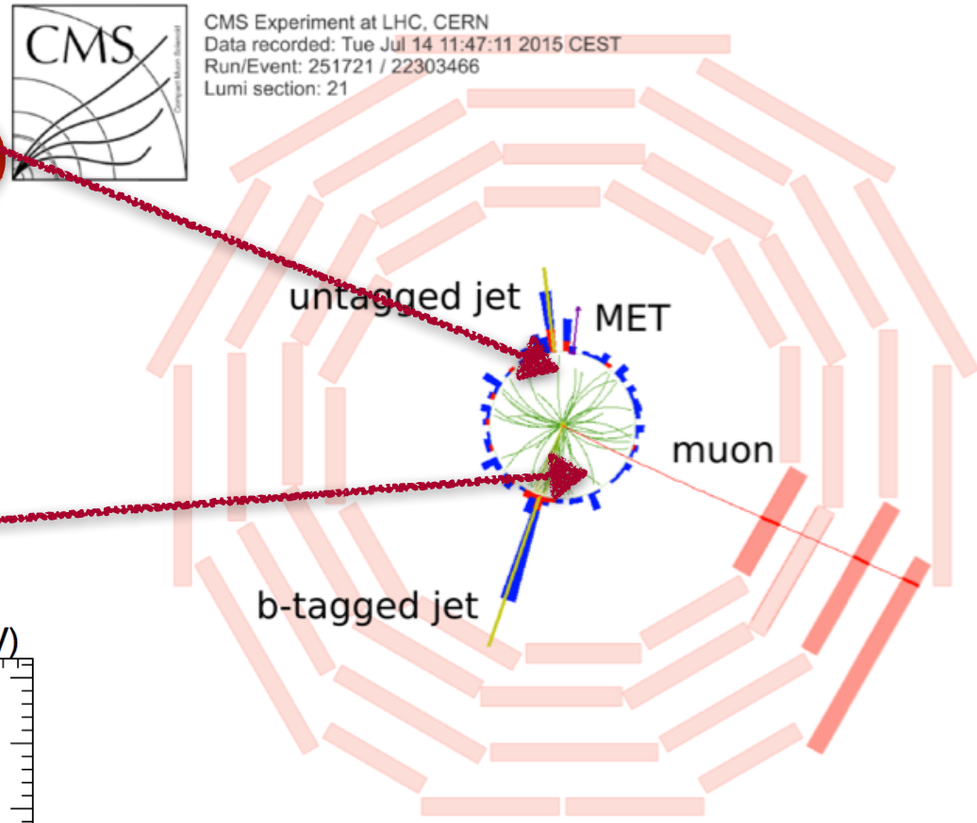
ETH Institute for Particle Physics

CMS-PAS-TOP-15-004

- first look at single-top production (80% via t-channel)
- signature: a muon and a b-jet (from top decay), recoiling against a light-quark jet
- analysis closely follows Run 1 methodology







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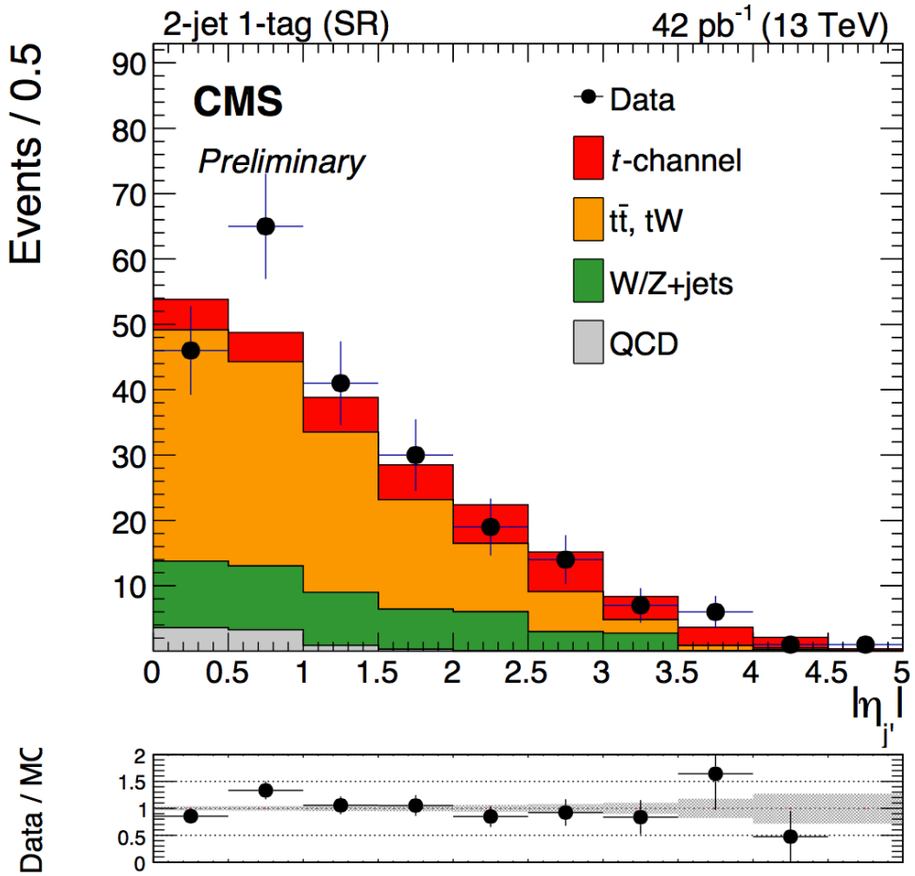

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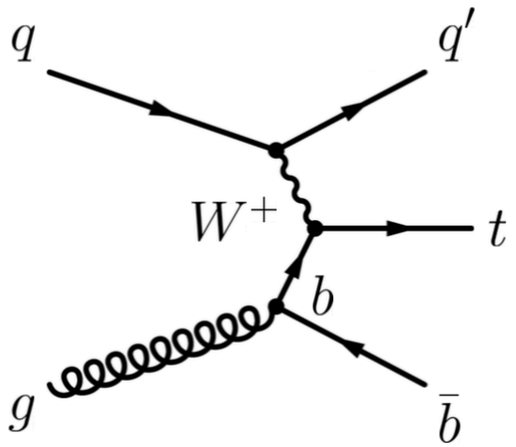

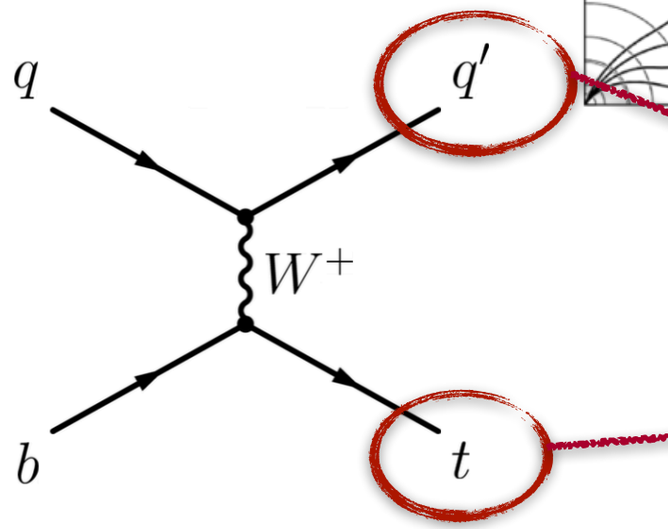

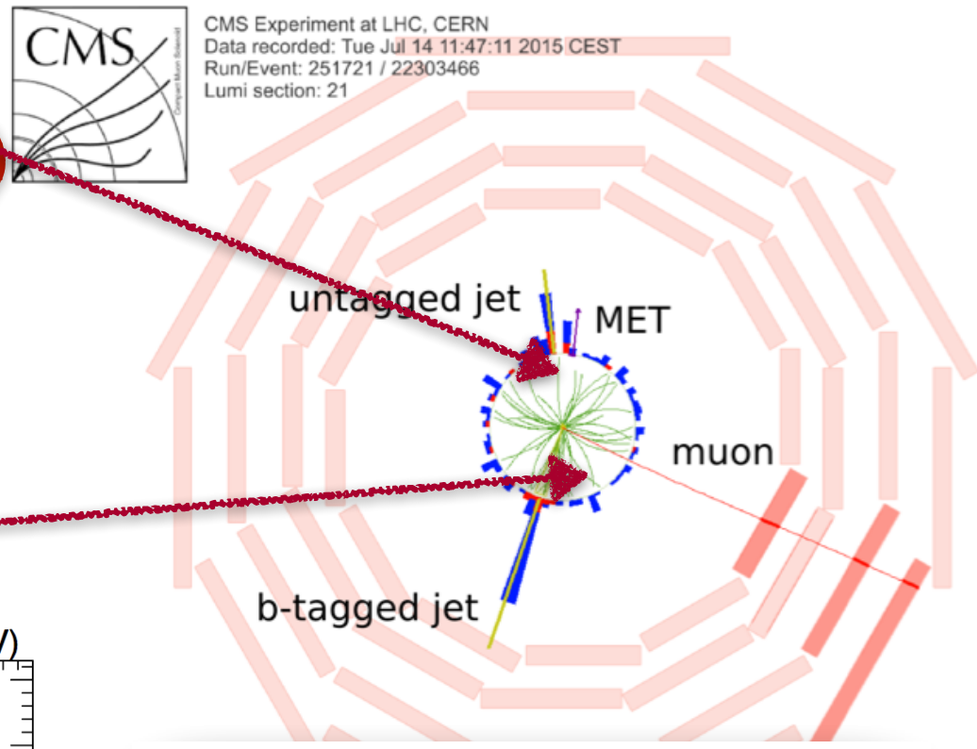

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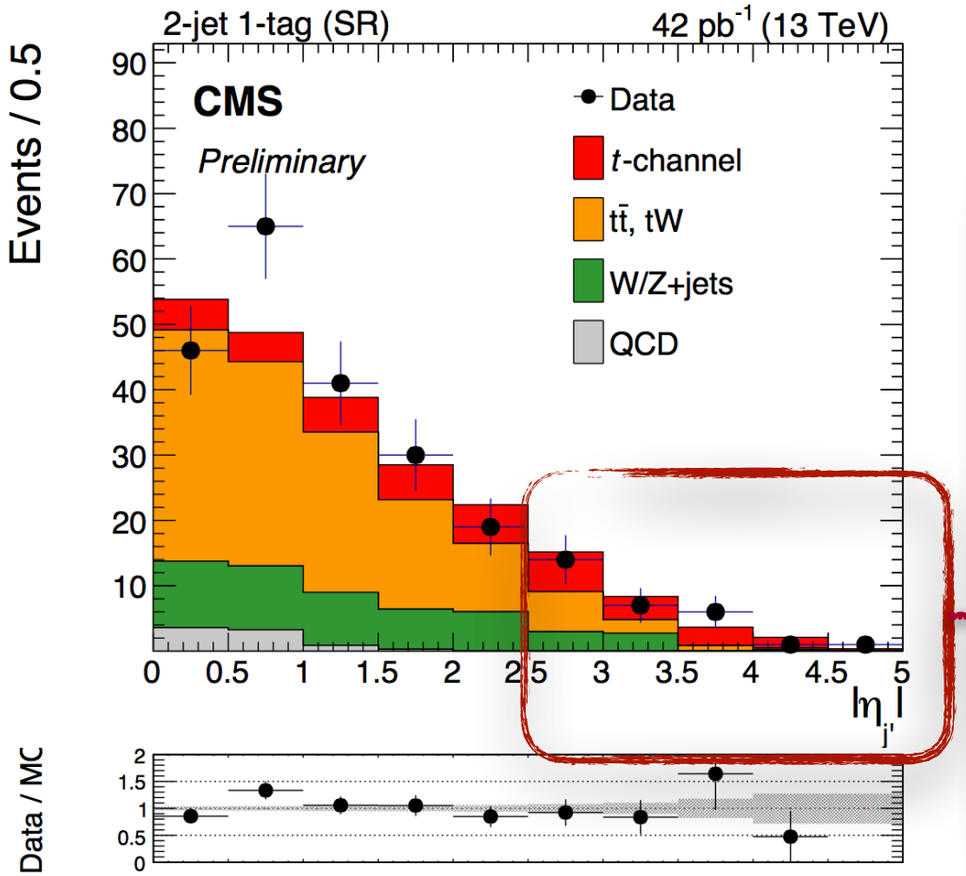

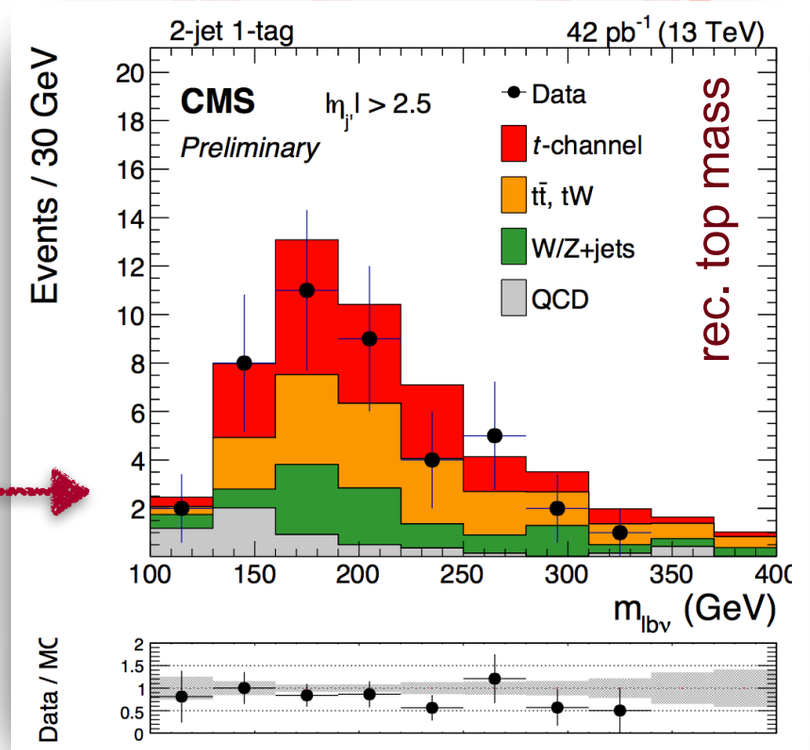

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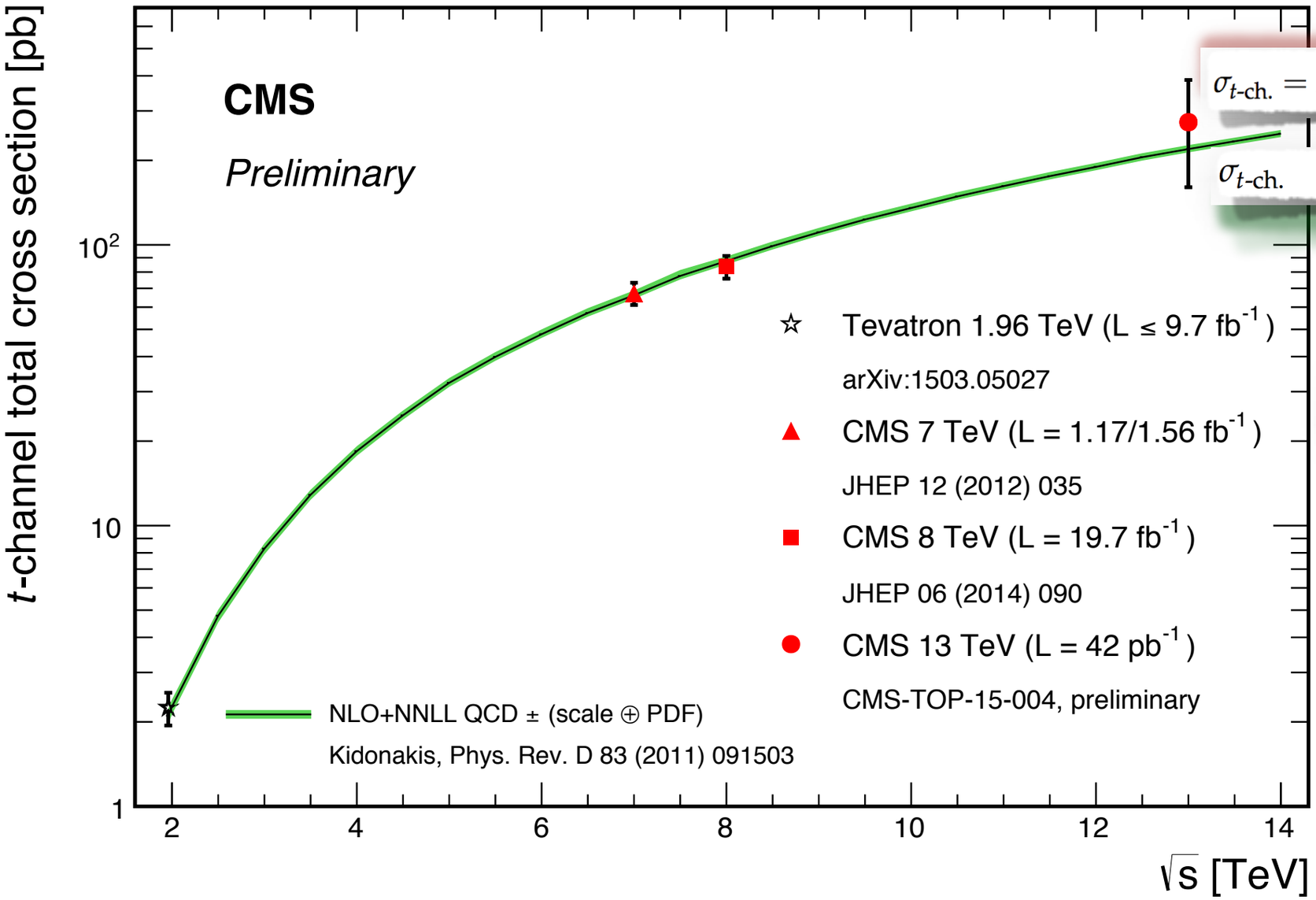

$\sigma_{t\text{-ch.}} = 274 \pm 98\,(\text{stat.}) \pm 52\,(\text{syst.}) \pm 33\,(\text{lumi.})\,\text{pb}$

$\sigma_{t\text{-ch.}} = 216.99^{+6.62}_{-4.64}\,(\text{scale}) \pm 6.16\,(\text{PDF})\text{pb}$

NLO (Hathor v2.1)

$|V_{tb}| = 1.12 \pm 0.24\,(\text{exp.}) \pm 0.02\,(\text{theo.})$

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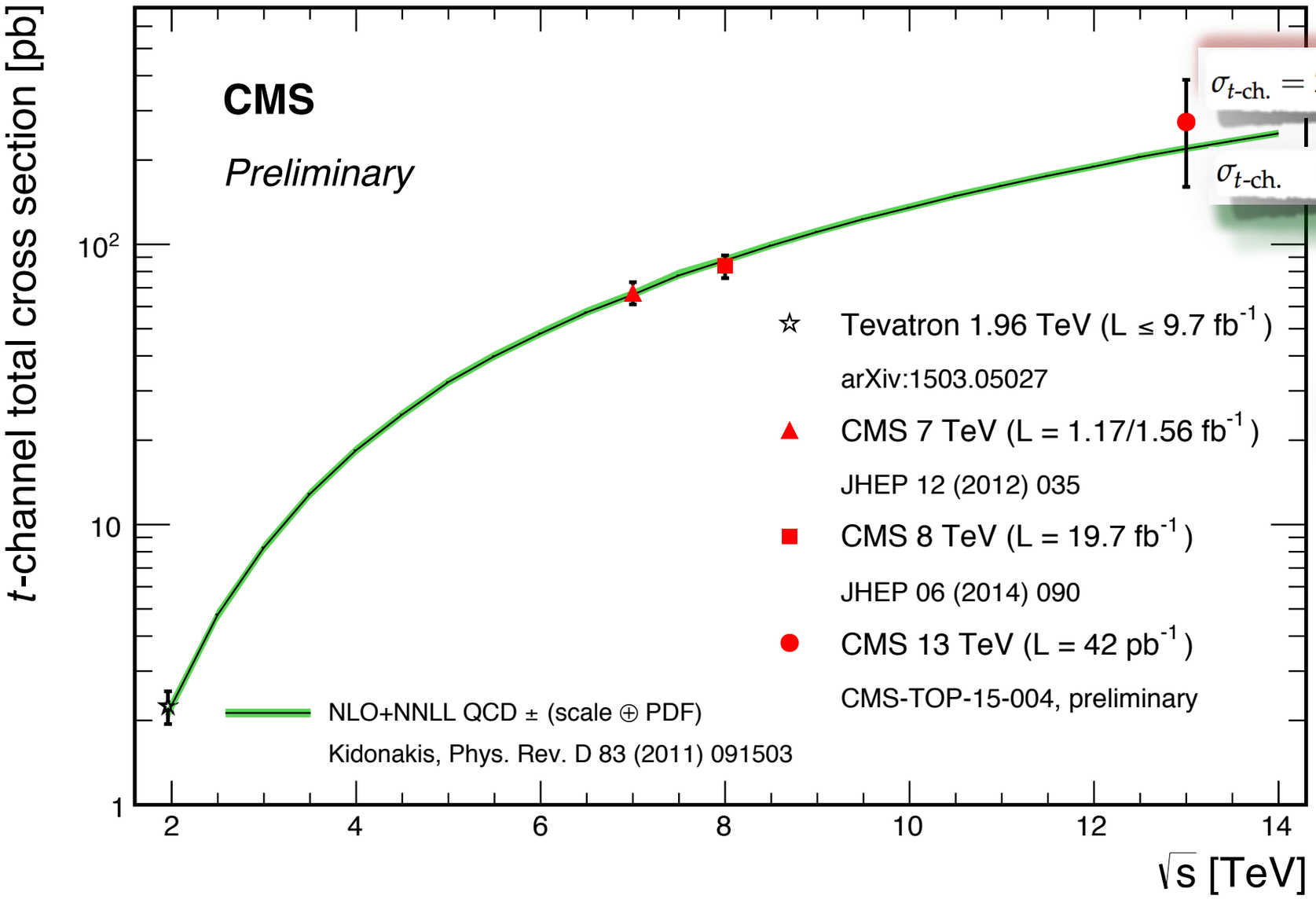

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$|V_{tb}| = 1.12 \pm 0.24\,(\text{exp.}) \pm 0.02\,(\text{theo.})$

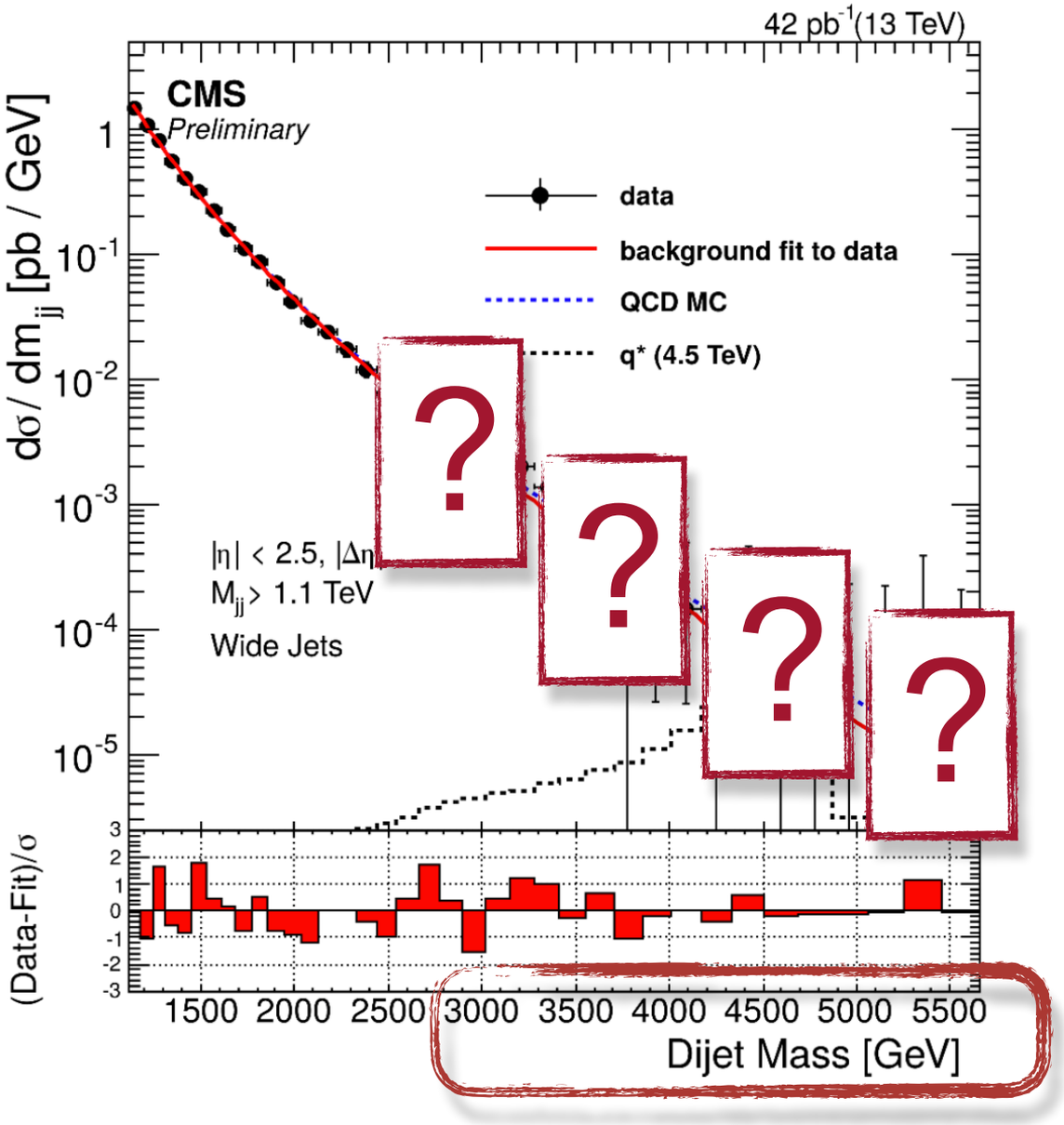
~40% precision on cross section, completely stat. dominated;

observed (expected) significance: **3.5 σ (2.7 σ)**

also used to extract V_{tb}

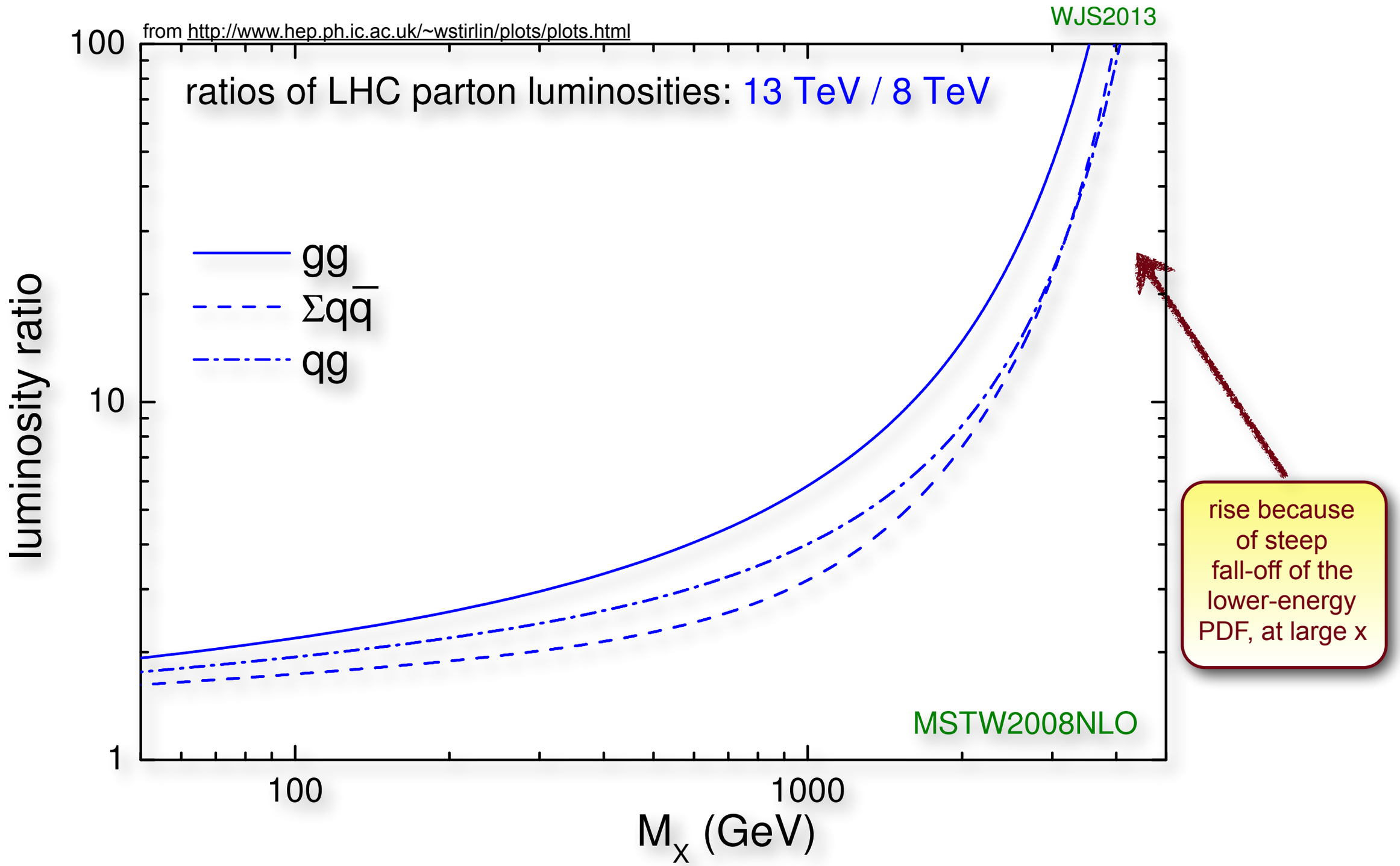
within large uncertainty: consistent with SM prediction

Searches



Is there anybody (new) out there?

Parton luminosities



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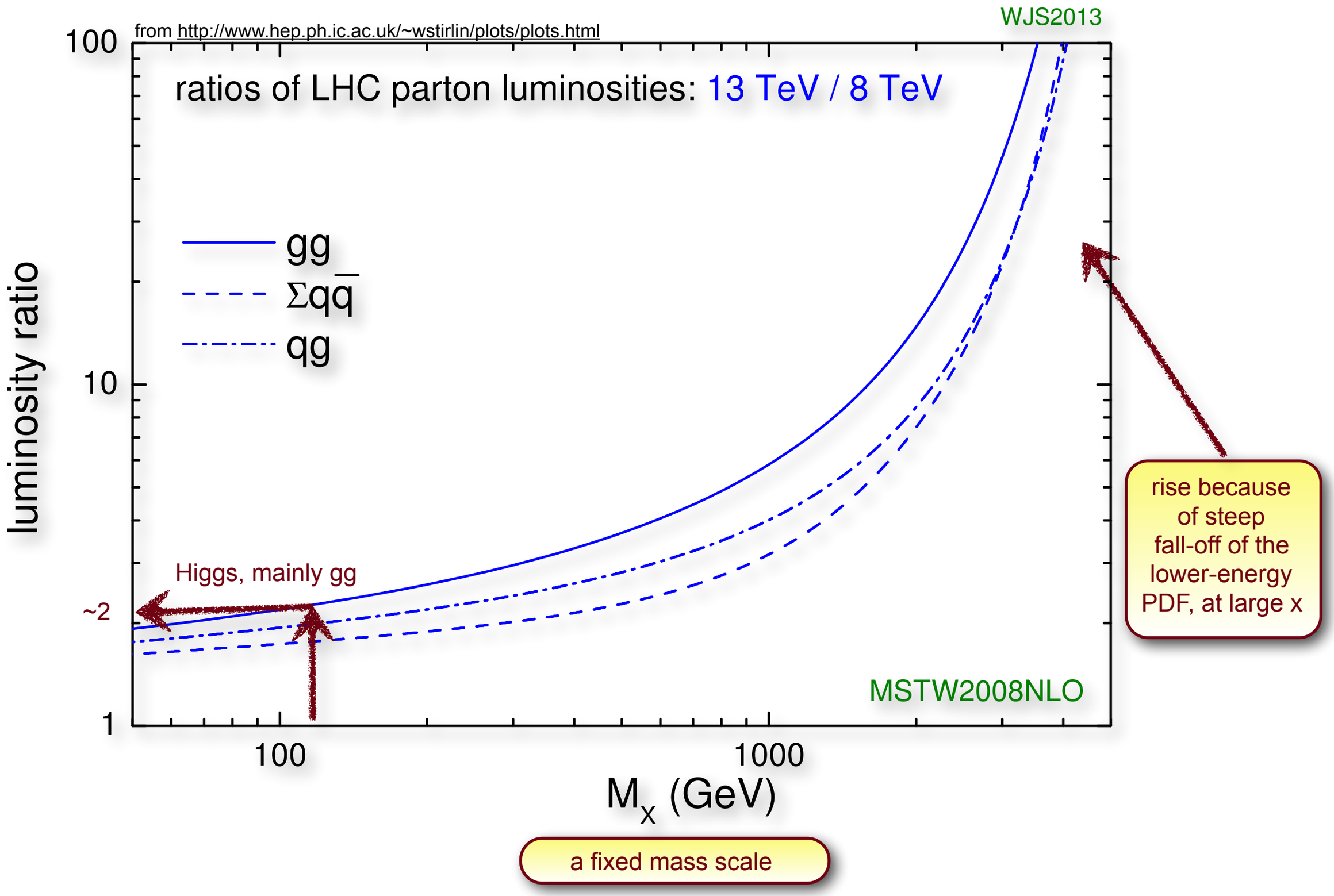

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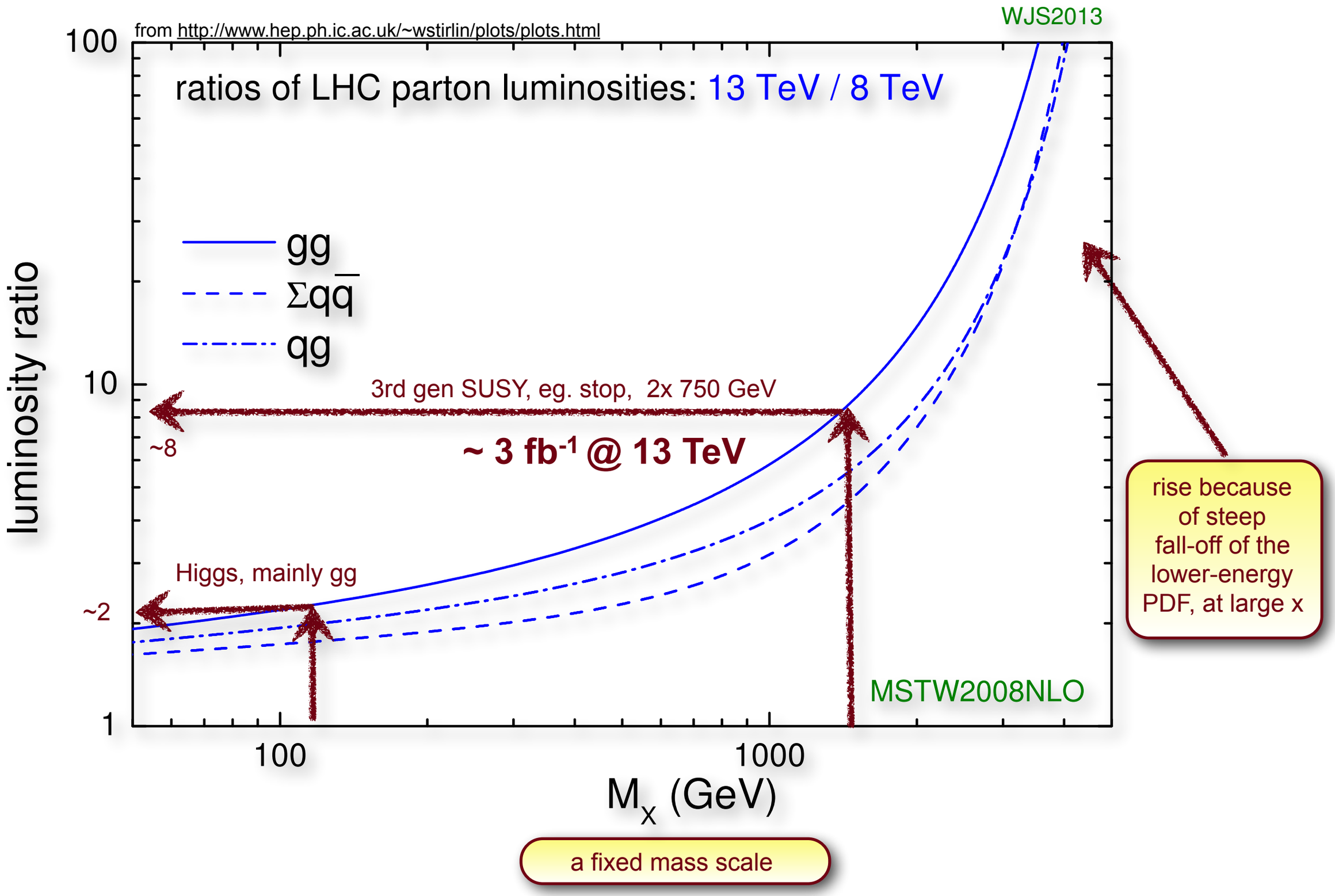

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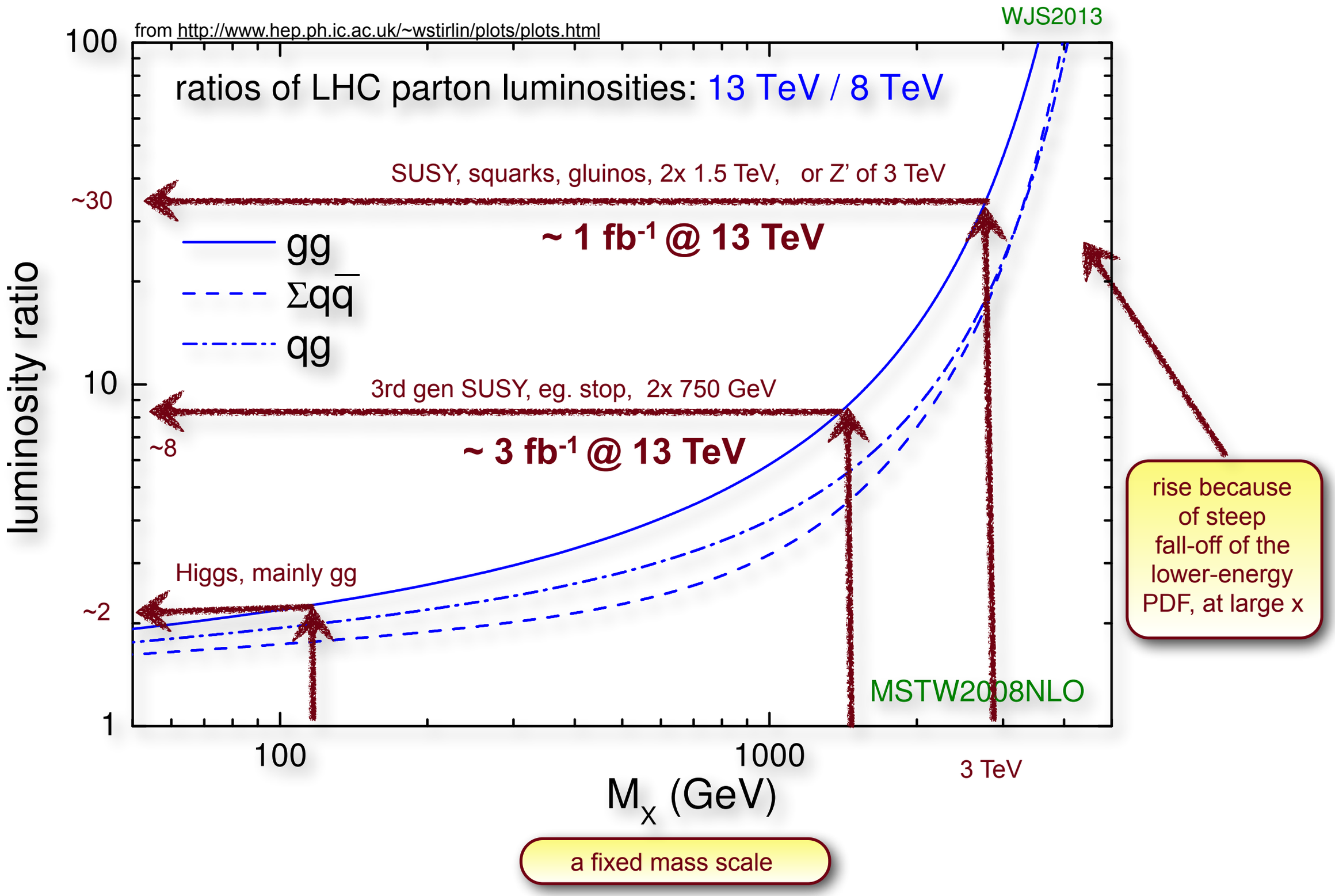

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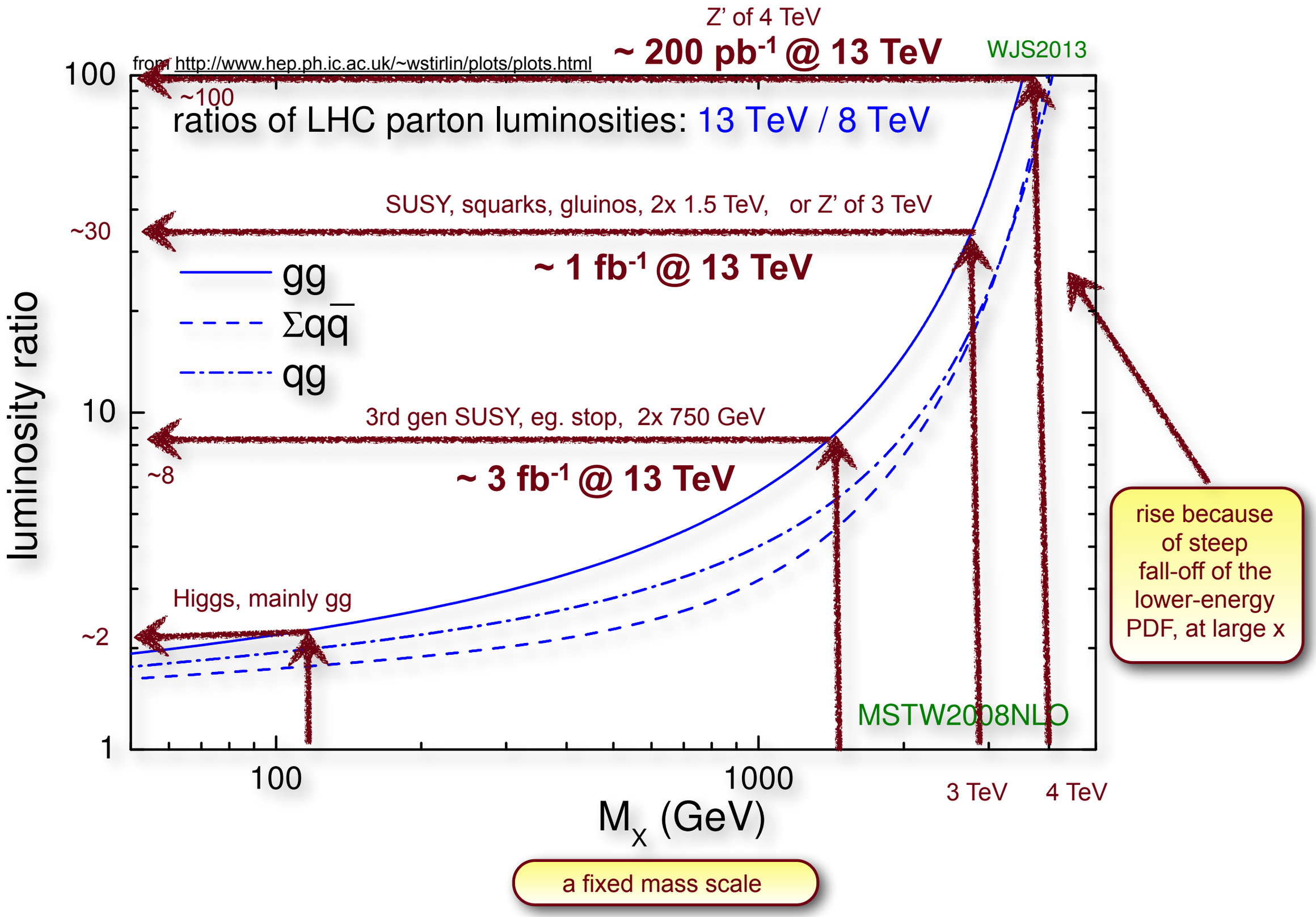
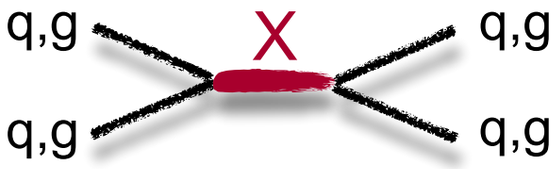


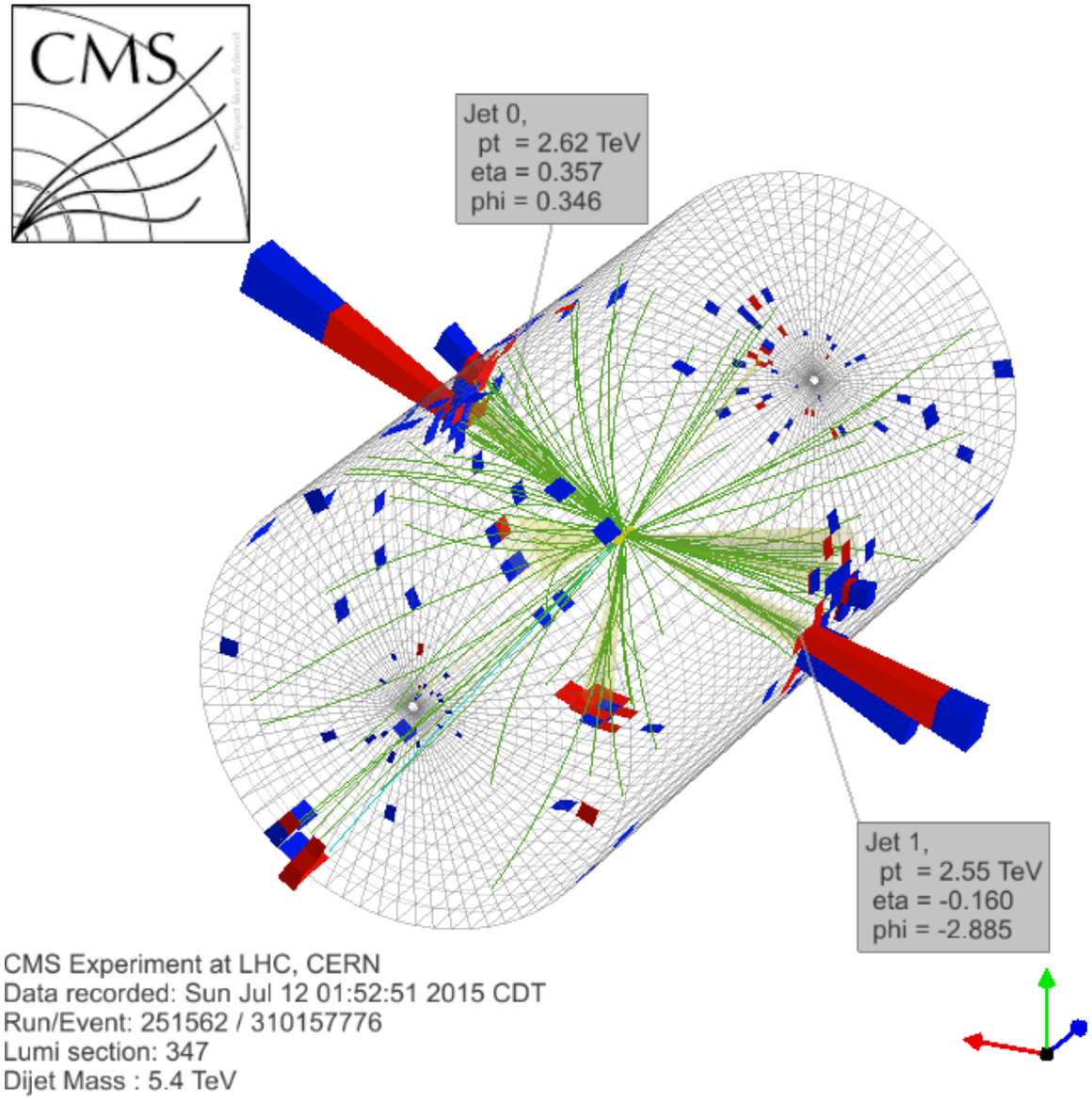
Di-Jet resonances



ETH Institute for Particle Physics

CMS-PAS-EXO-15-001

- First searches at 13 TeV: narrow dijet resonances (s-channel)
- reduce t-channel prod. by requiring jets close-by in rapidity
- build 2 “wide jets” around the two leading anti-k_T 0.4 jets



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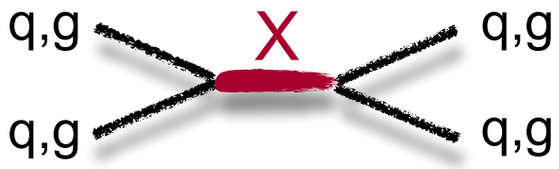

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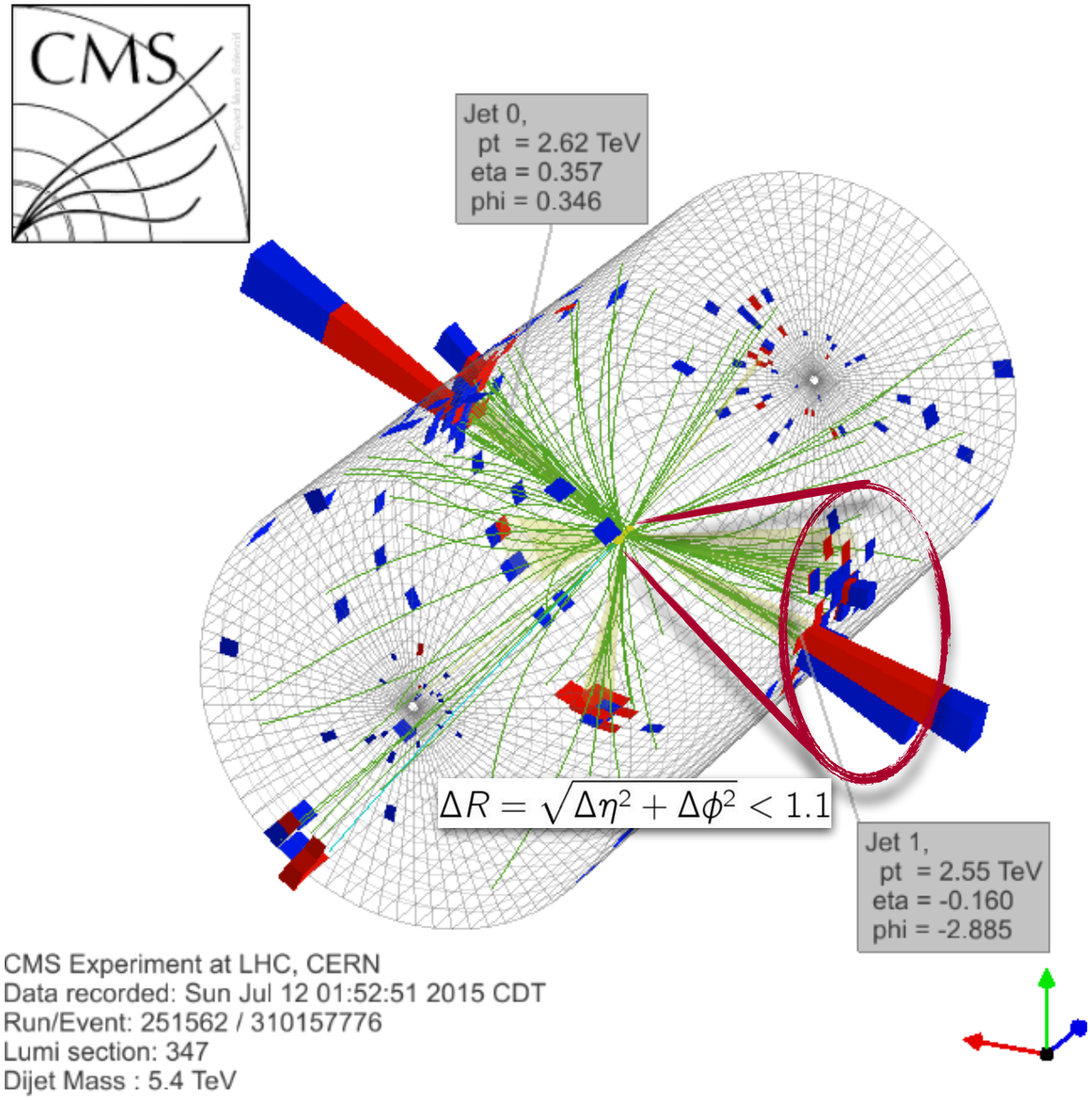

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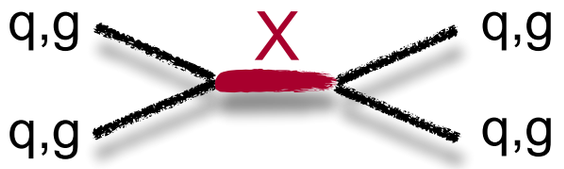

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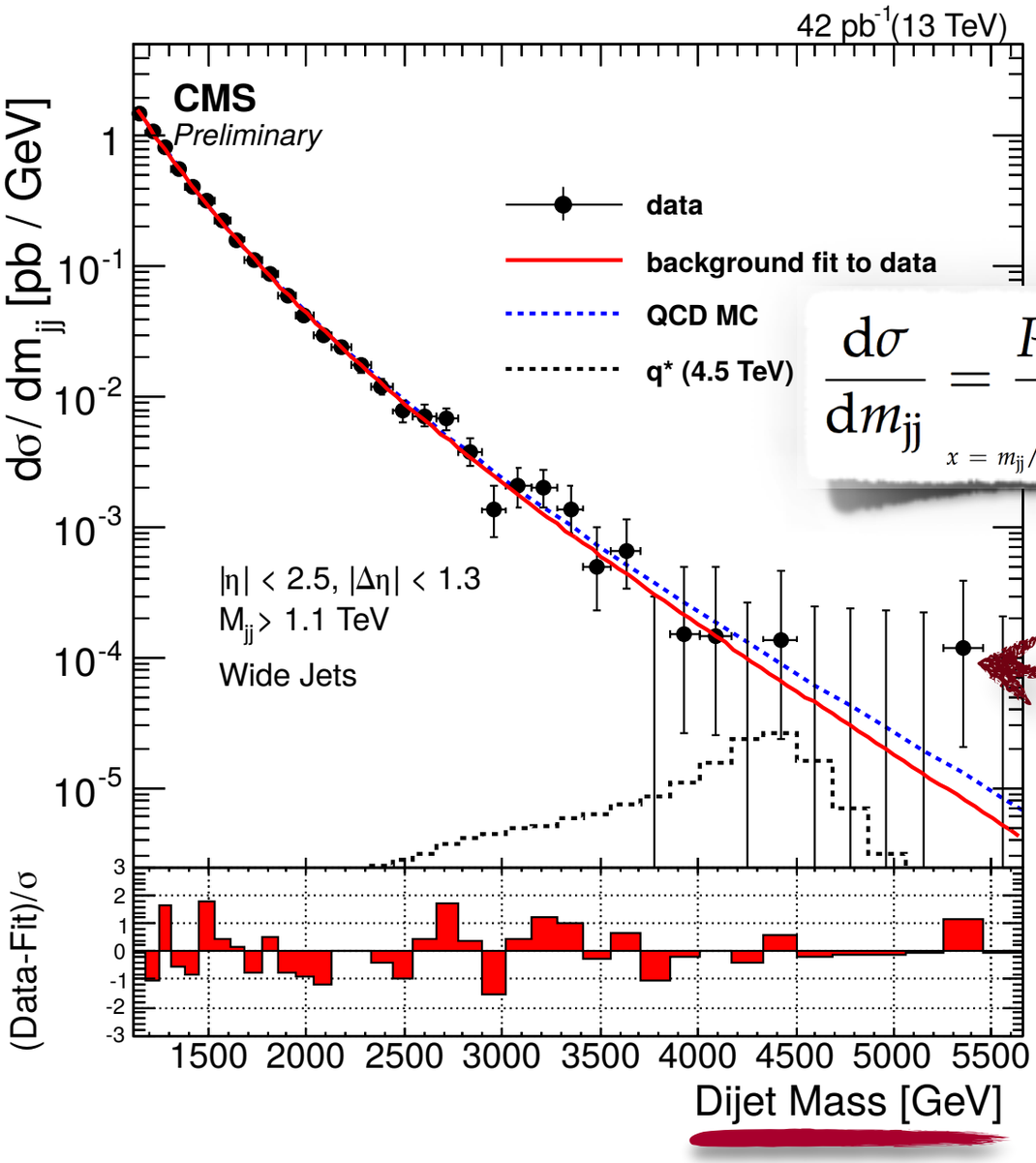
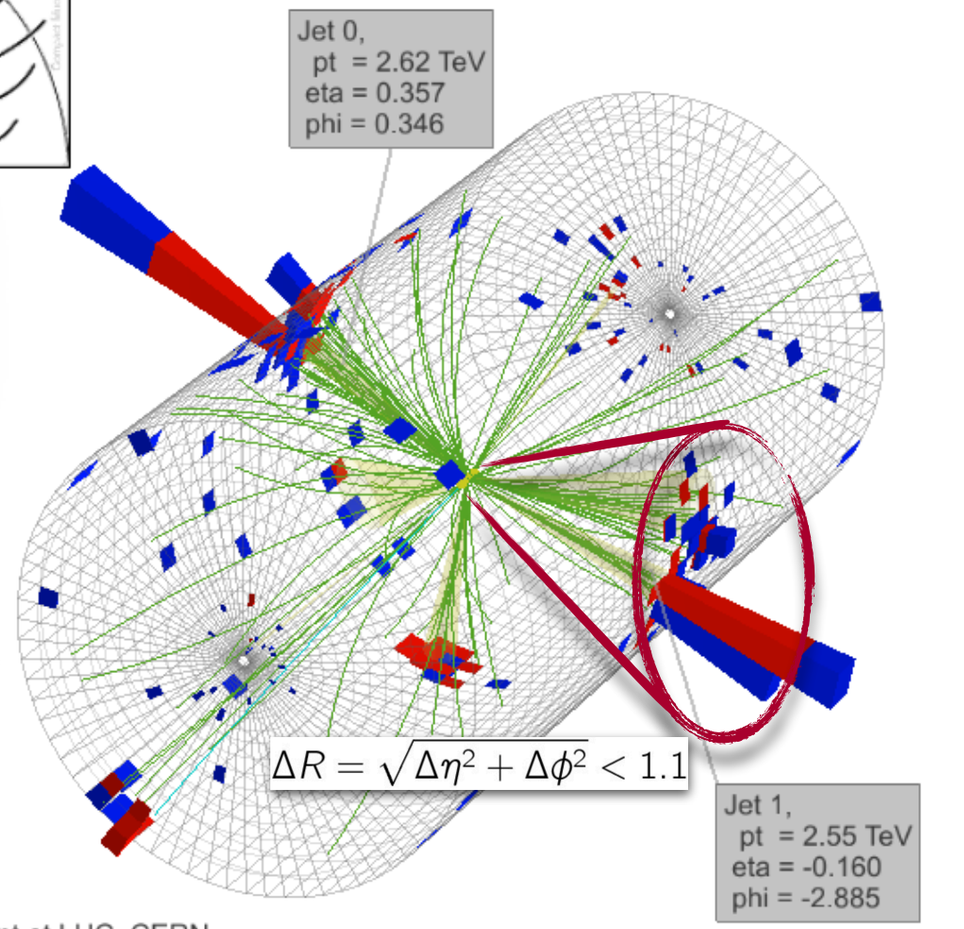
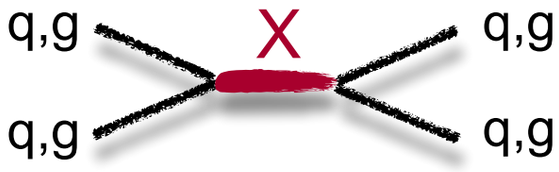


$$\frac{d\sigma}{dm_{jj}} = \frac{P_0(1-x)^{P_1}}{x^{P_2}} \qquad x = m_{jj}/\sqrt{s}$$



CMS Experiment at LHC, CERN
Data recorded: Sun Jul 12 01:52:51 2015 CDT
Run/Event: 251562 / 310157776
Lumi section: 347
Dijet Mass : 5.4 TeV

Di-Jet resonances



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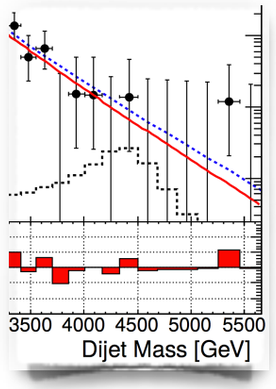
- eg. above 3.5 TeV: 4 evts. observed, ~4.6 expected



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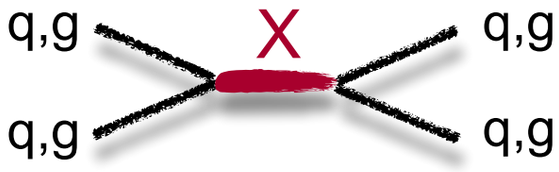

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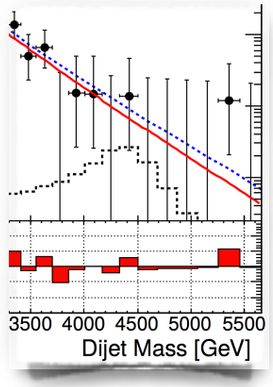

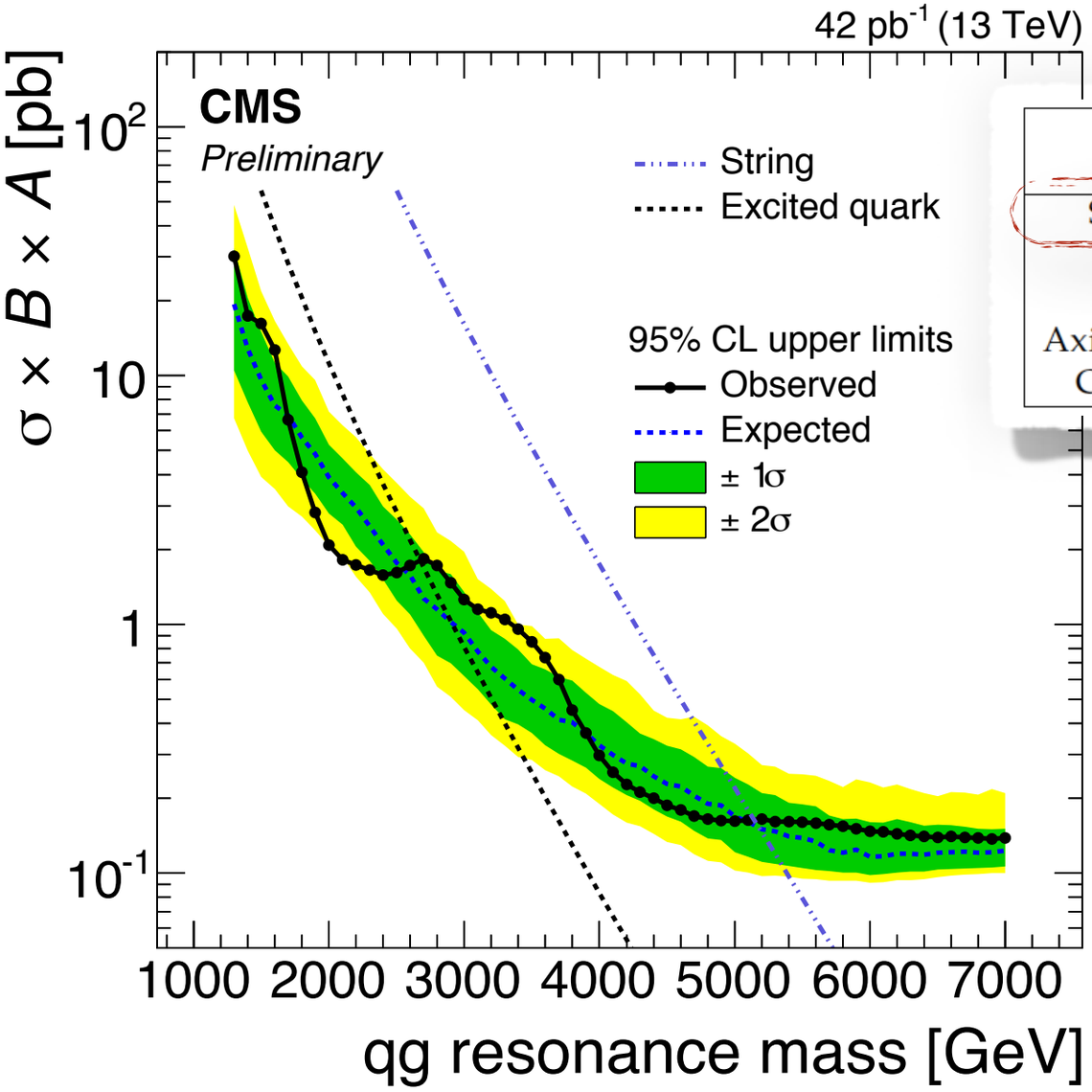

Model	Final State	Obs. Mass Limit [TeV]	Exp. Mass Limit [TeV]
String Resonance (S)	qg	5.1	5.2
Excited Quark (q^*)	qg	2.7	2.9
Scalar Diquark (D)	qq	2.7	3.3
Axigluon (A)/Coloron (C)	$q\bar{q}$	2.7	2.9
Color Octet Scalar (s8)	gg	2.3	2.0

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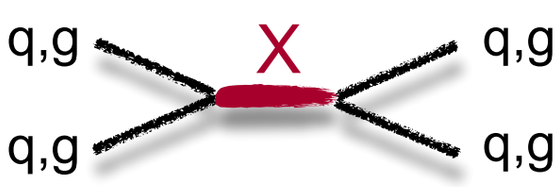

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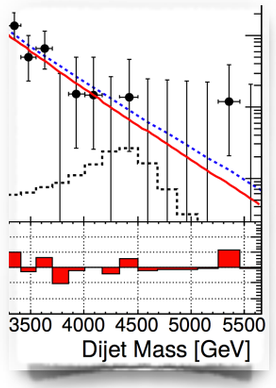

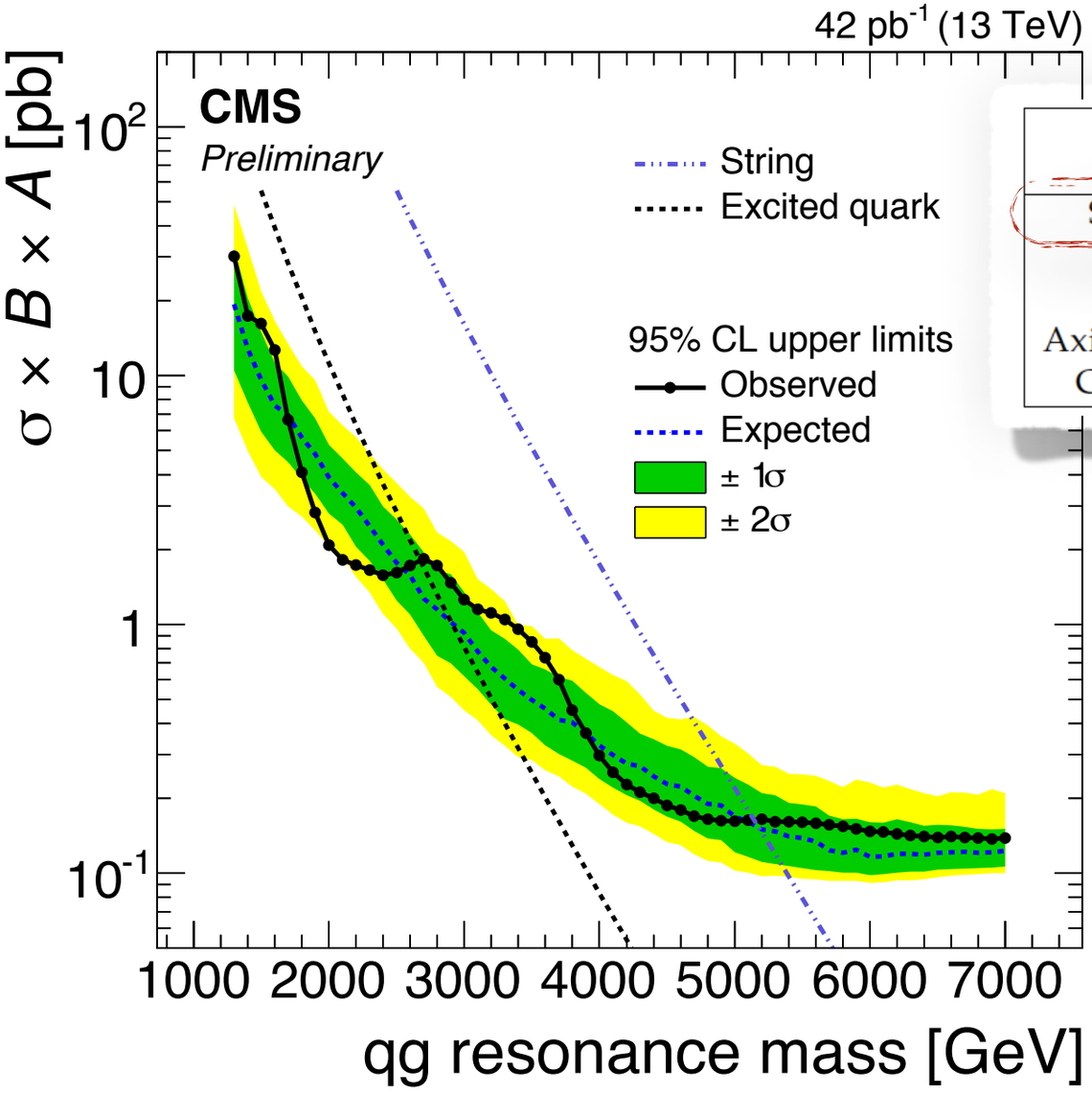

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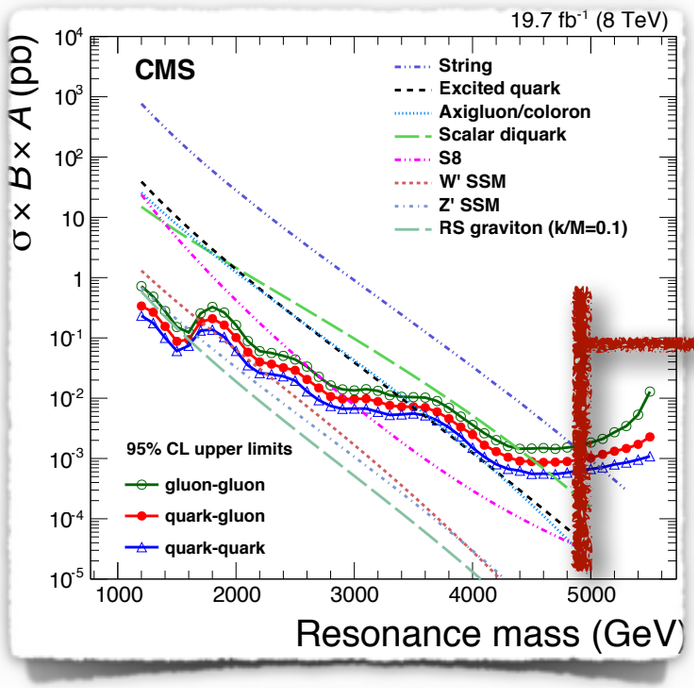
An example of a very early search

for resonances of ~ 5 TeV, a sample of ~40 pb^{-1} at 13 TeV can surpass the 8 TeV limits !

Going beyond the current limits

ETH Institute for Particle Physics

Dijets < 100 pb^{-1}



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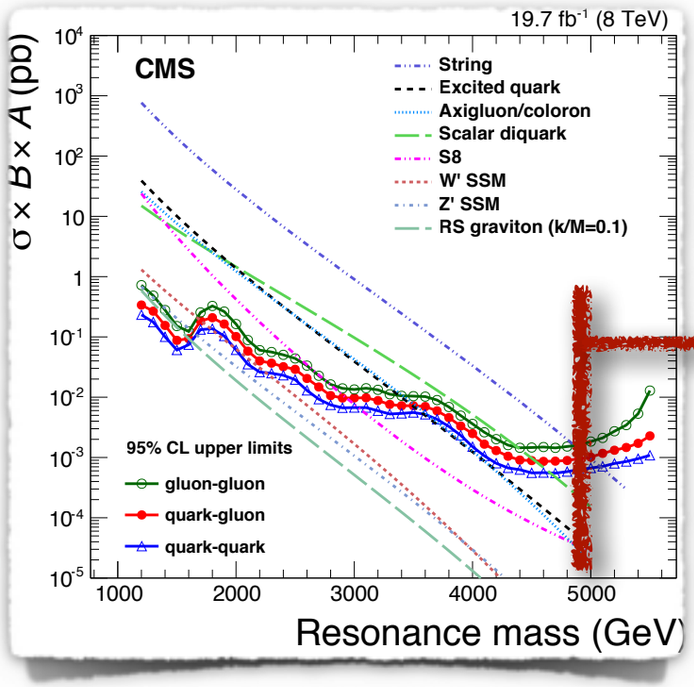
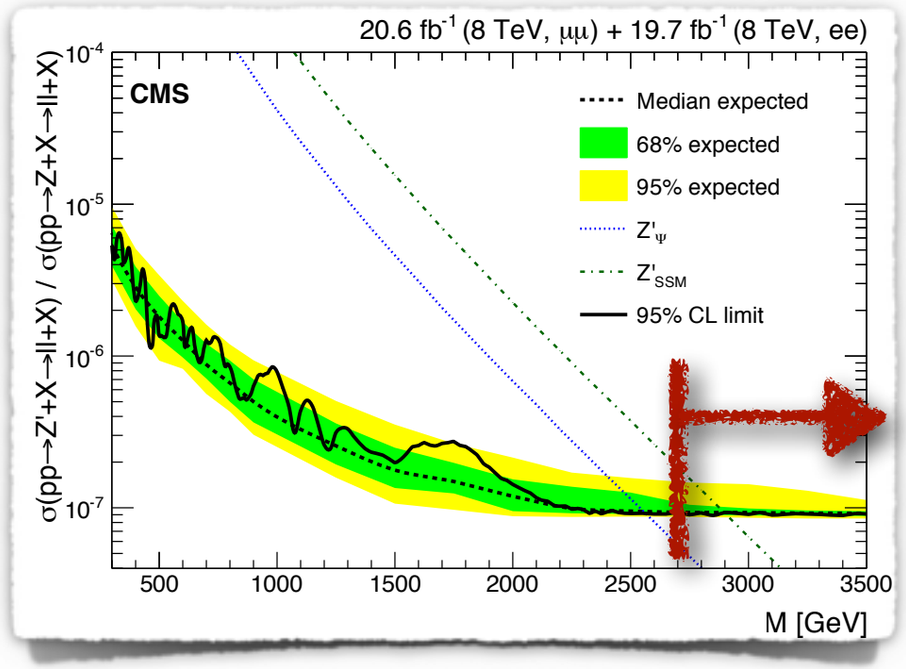


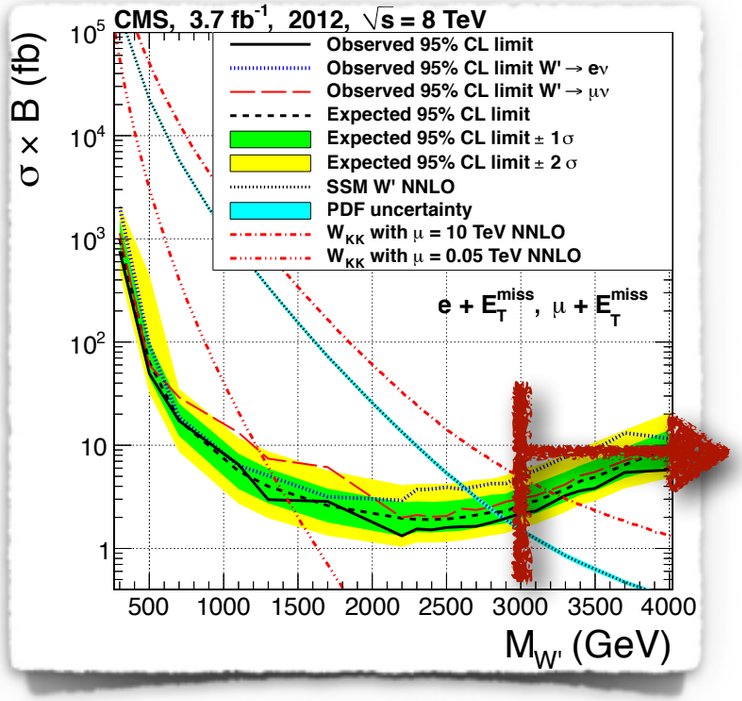


Z’

1 fb^{-1}

W’

1 fb^{-1}



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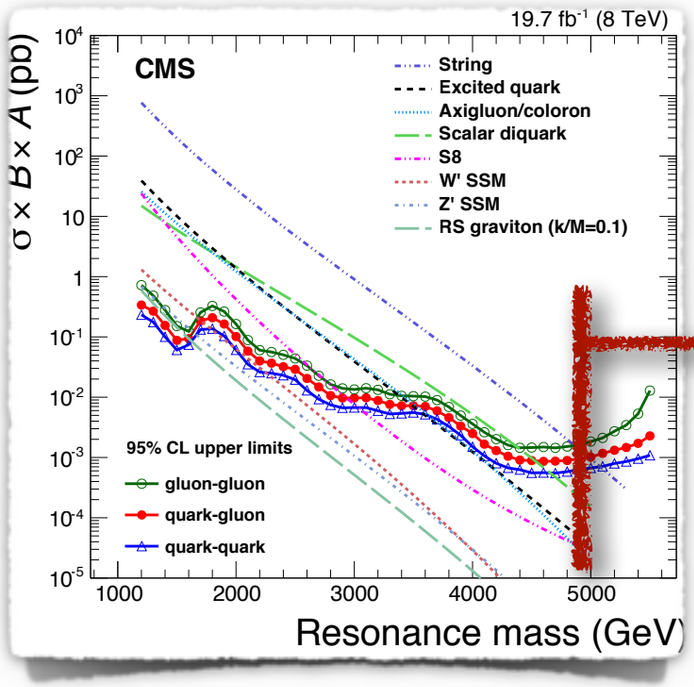

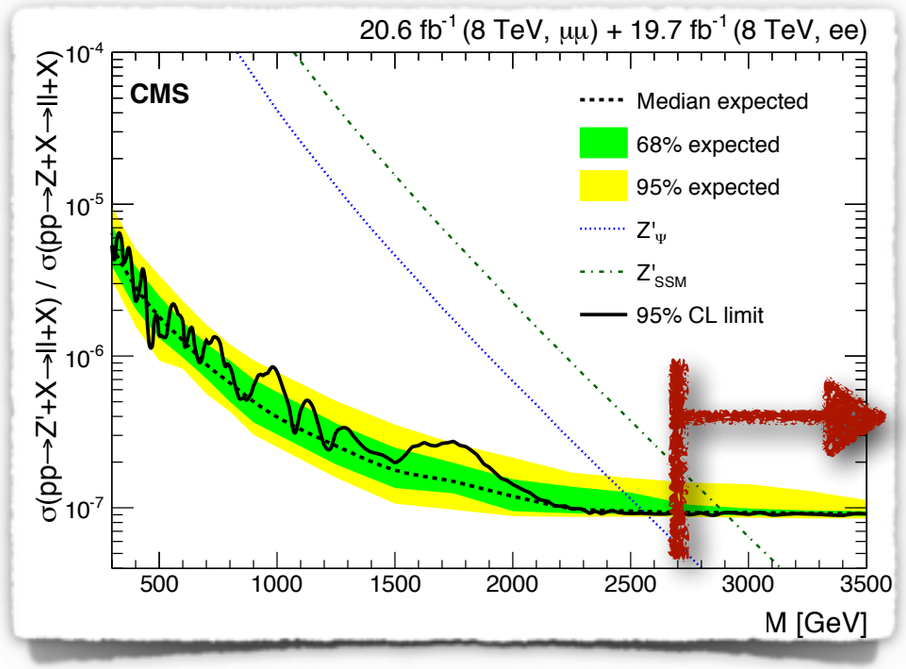

Z'

1 fb^{-1}

W'

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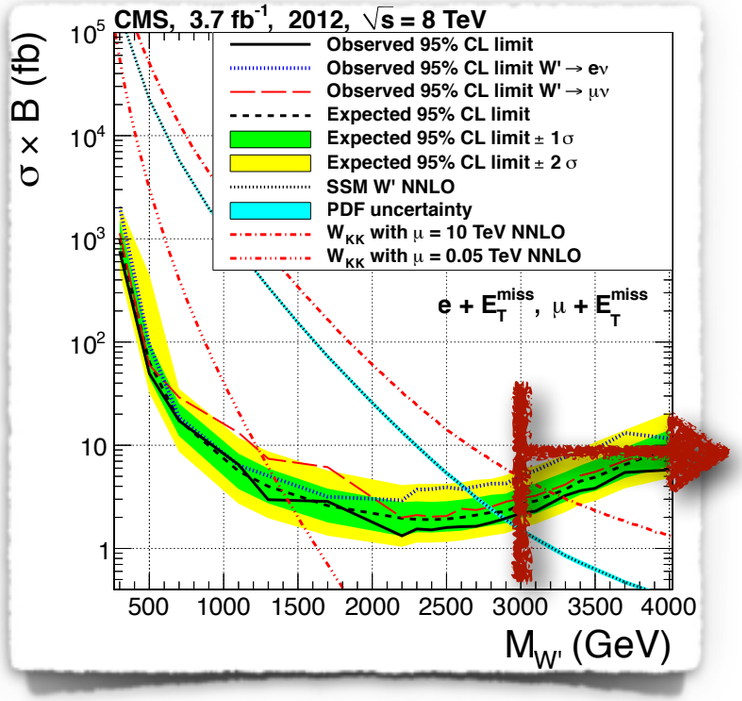

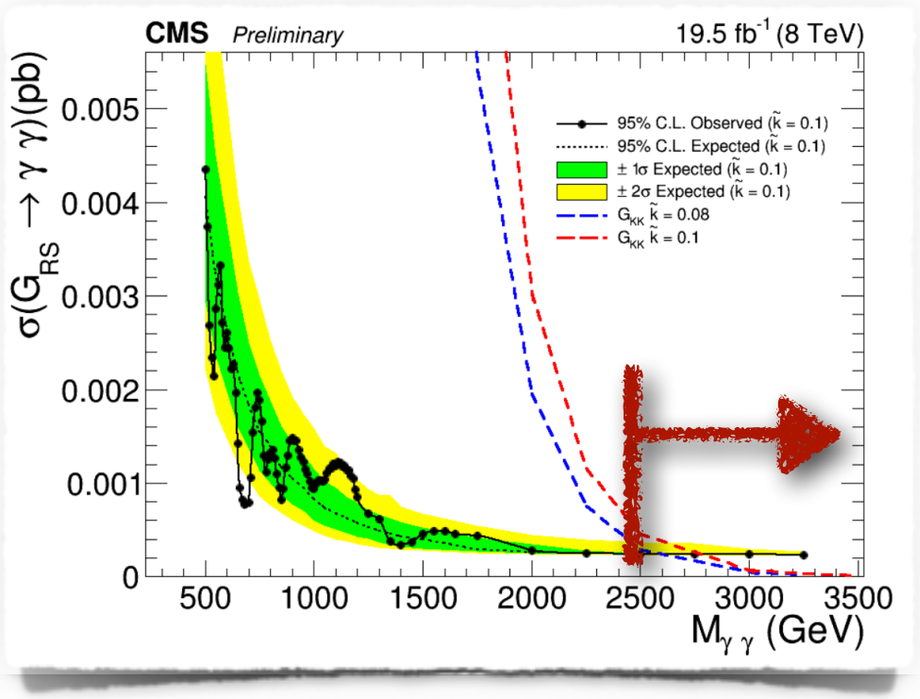

3 fb^{-1}

Diphotons

watch out for a large set of results, in preparation for the CERN Jamboree in Dec 2015 !

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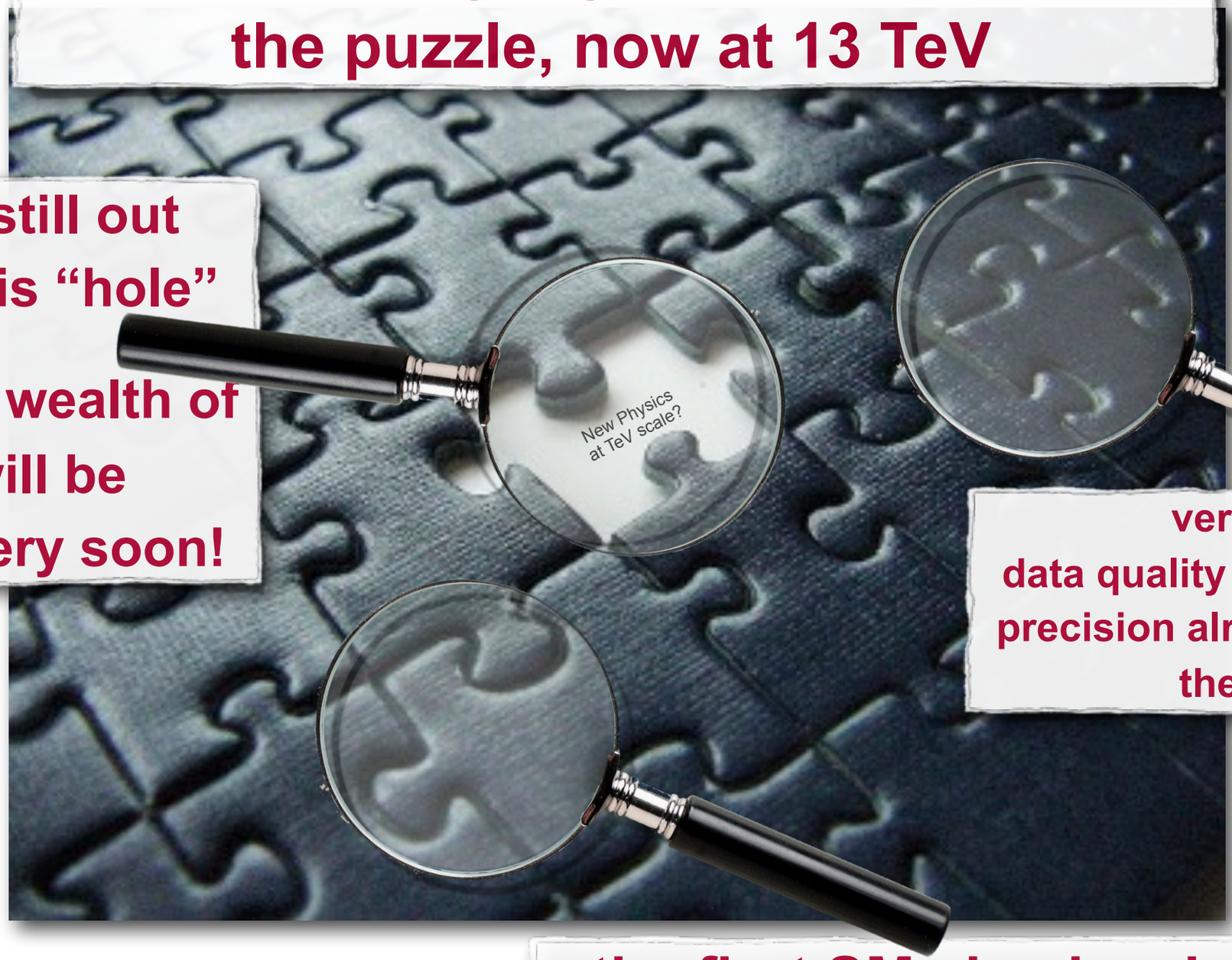

the jury is still out regarding this “hole”

stay tuned, a wealth of results will be unleashed very soon!

very good data quality allows for good precision already early on in the game

the first SM checks show: pieces are fitting well