



Experimental Summary

Klaus Rabbertz





Start with blank Sheet ...



coming from there to ...

Great Ocean Road





here. So despite beautiful Weather ...

Zürich





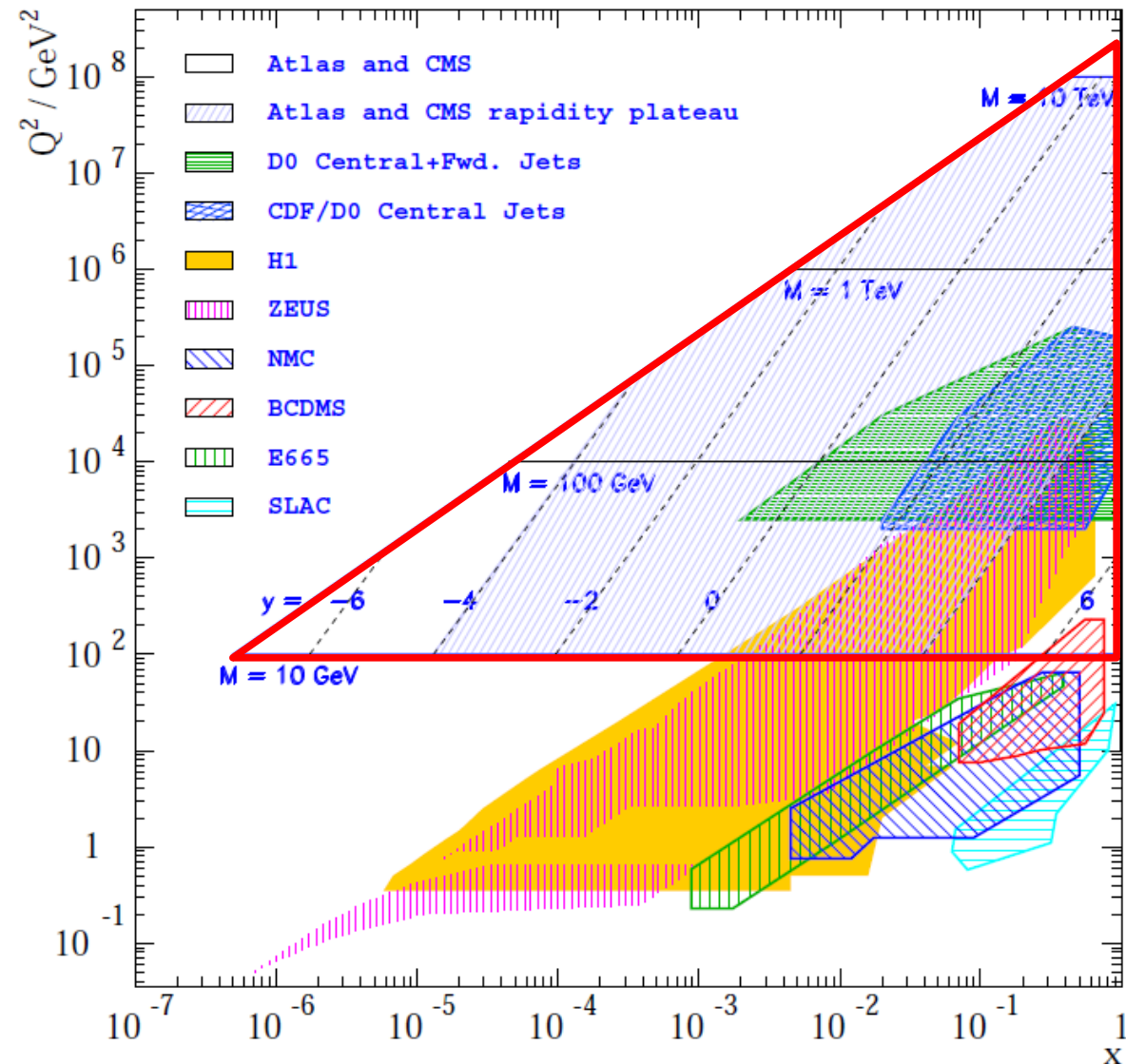
QCD at the LHC

My QCD advertisement slide

- Fascinating – comprises a huge variety of phenomena
- Unavoidable – hadrons are “made of QCD”
- Indispensable – linking piece between many processes
- Demanding – enormous background to searches for new physics
- Uncharted – dominating uncertainty for Higgs cross sections

➔ **Many analyses :-)**

Huge accessible phase space



S. Glazov, Braz.J.Ph. 37 (2007) 793.



Selection Mandatory

• Disclaimer:

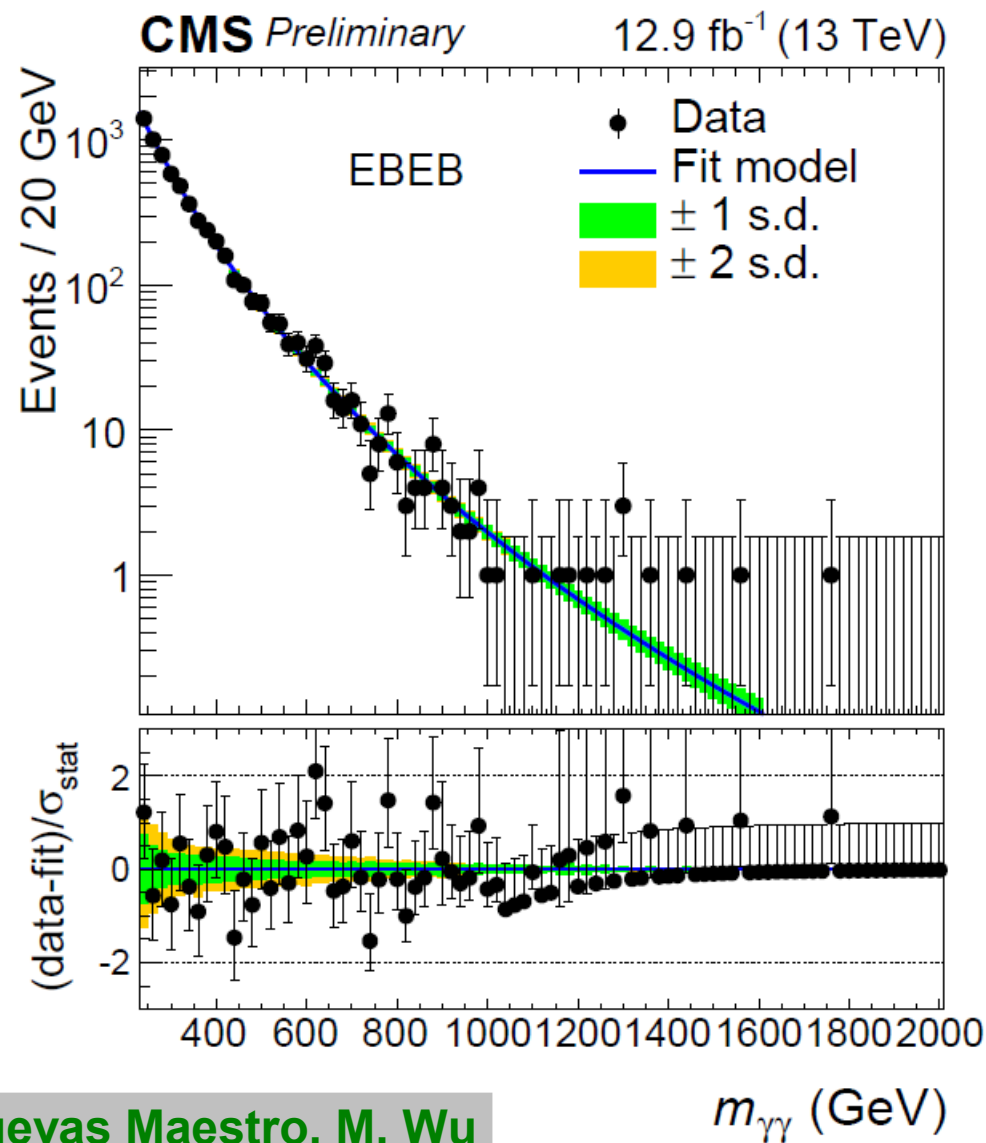
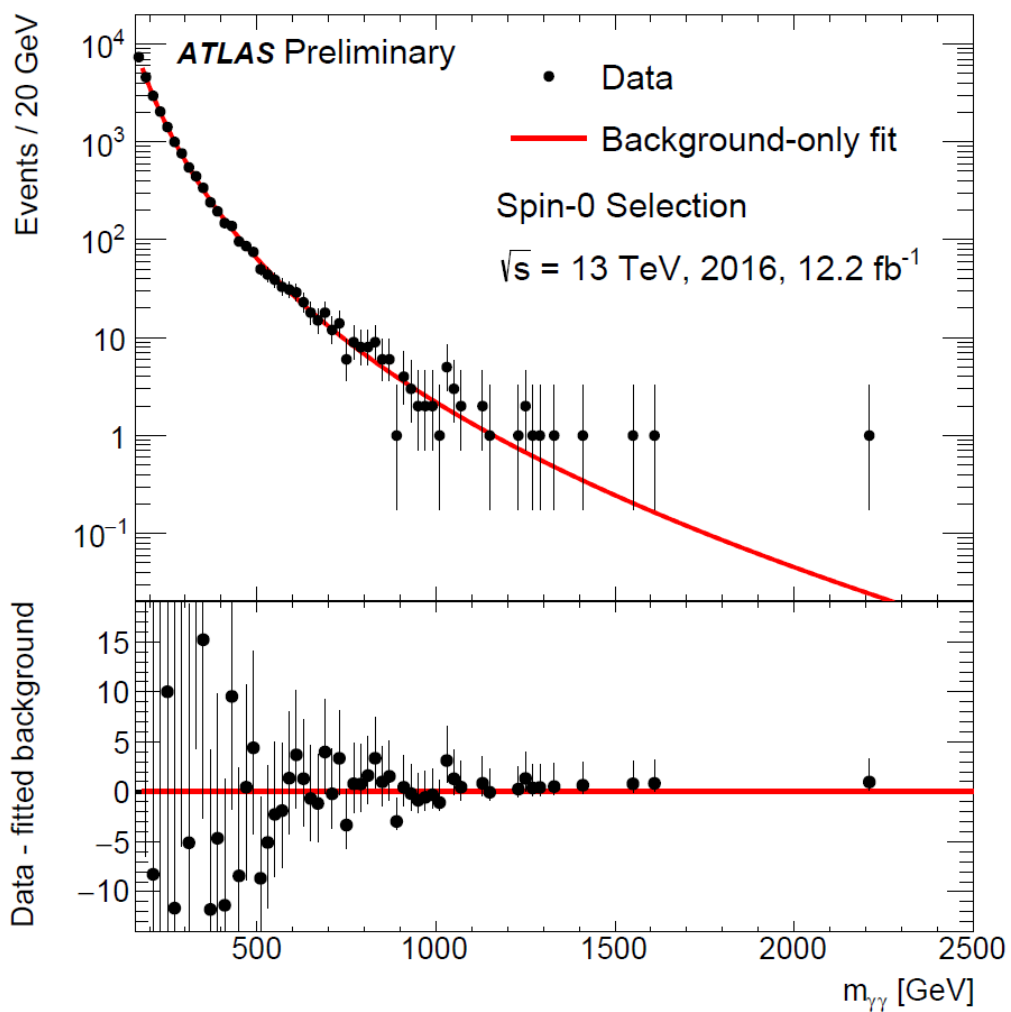
- + Impossible to cover all the nice measurements**
- + Personal and biased selection from roughly 45 experimental Talks in the five subgroups**
- + Some results appear multiple times, e.g. when used for PDFs and in the summary plenaries**
- + Prioritized newer/13 TeV results**
- + Apologies for omissions :-)**



750 GeV Excess “flatlined”

Diphoton mass spectrum re-measured in 2016

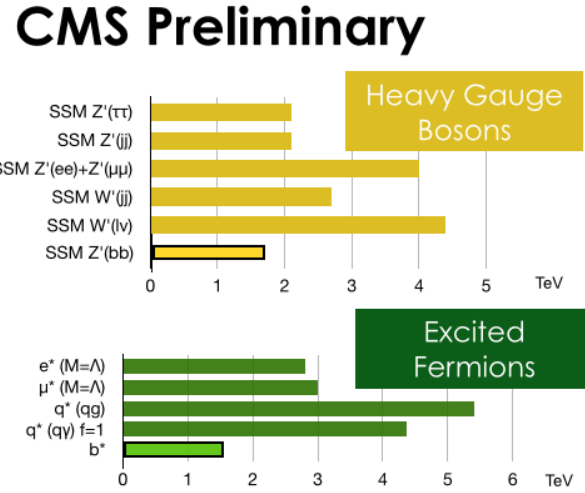
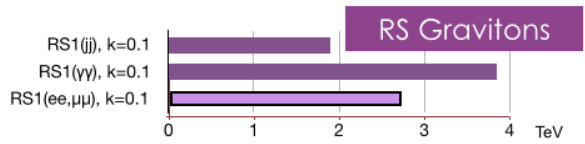
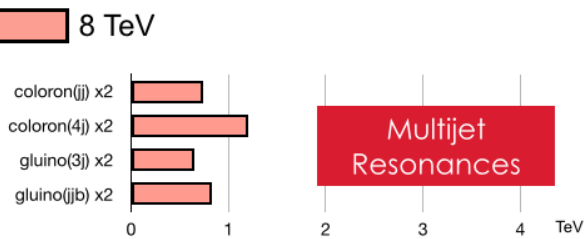
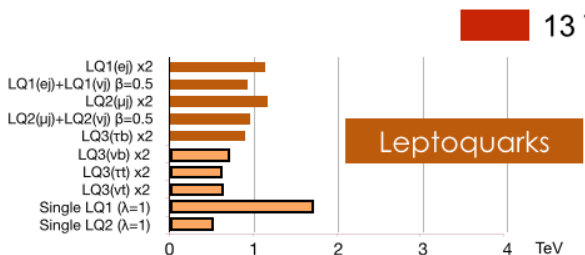
Much discussed anomaly not confirmed with 4 times more data than in 2015



J. Cuevas Maestro, M. Wu

Updated Exclusion Limits

Exotica Searches from ATLAS & CMS Similar for SUSY



- ADD (gamma+MET), nED=4
- ADD (jj), nED=4
- QBH, nED=6, MD=
- NR BH, nED=6, MD=
- String Sci
- QBH (jj), nED=4, MD=
- ADD (gamma+MET), nED=4
- ADD (ee, mu mu), nED=4
- ADD (gamma gamma), nED=4
- Jet Extinction:
- dijets, Lambda+ LL
- dijets, Lambda- LL
- dimuons, Lambda+ L
- dimuons, Lambda- L
- dileptons, Lambda+ L
- dileptons, Lambda- L
- single e, Lambda Hn
- single mu, Lambda Hn
- inclusive jets
- inclusive jets

ATLAS Exotica Searches* - 95% CL Exclusion

Status: August 2016

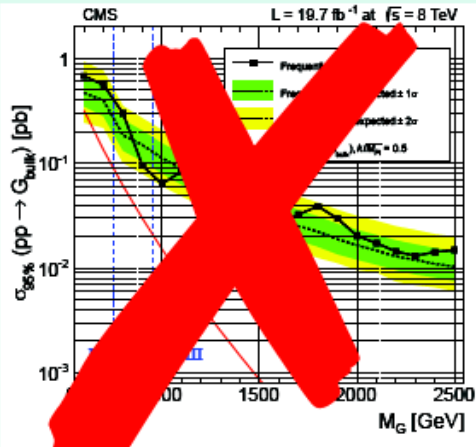
ATLAS Preliminary
 $\int \mathcal{L} dt = (3.2 - 20.3) \text{ fb}^{-1}$
 $\sqrt{s} = 8, 13 \text{ TeV}$

Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Limit	Reference
Extra dimensions	ADD $G_{KK} + g/q$	$\geq 1j$	Yes	3.2	M_D 6.58 TeV	$n=2$ 1604.07773
	ADD non-resonant $\ell\ell$	$2 e, \mu$	-	20.3	M_{KK} 4.7 TeV	$n=3 \text{ HLZ}$ 1407.2410
	ADD QBH $\rightarrow \ell q$	$1 e, \mu$	$1j$	20.3	M_{KK} 5.2 TeV	$n=6$ 1311.2006
	ADD QBH	$2j$	-	15.7	M_{KK} 8.7 TeV	$n=6$ ATLAS-CONF-2016-069
	ADD BH high $\sum p_T$	$\geq 1 e, \mu$	$\geq 2j$	-	M_{KK} 8.2 TeV	$n=6, M_D = 3 \text{ TeV, rot BH}$ 1606.02285
	ADD BH multijet	-	$\geq 3j$	-	M_{KK} 9.55 TeV	$n=6, M_D = 3 \text{ TeV, rot BH}$ 1512.02586
	RS1 $G_{KK} \rightarrow \ell\ell$	$2 e, \mu$	-	20.3	G_{KK} mass 2.68 TeV	$k/\overline{M}_{Pl} = 0.1$ 1405.4123
	RS1 $G_{KK} \rightarrow \gamma\gamma$	2γ	-	3.2	G_{KK} mass 3.2 TeV	$k/\overline{M}_{Pl} = 0.1$ 1606.03833
	Bulk RS $G_{KK} \rightarrow WW \rightarrow qq\ell\nu$	$1 e, \mu$	$1j$	Yes	1.24 TeV	$n=6, M_D = 3 \text{ TeV, rot BH}$ ATLAS-CONF-2016-062
	Bulk RS $G_{KK} \rightarrow HH \rightarrow bbbb$	-	$4b$	-	360-860 GeV	$k/\overline{M}_{Pl} = 1.0$ ATLAS-CONF-2016-049
	Bulk RS $G_{KK} \rightarrow tt$	$1 e, \mu$	$\geq 1b, \geq 1J/2$	Yes	2.2 TeV	$BR = 0.925$ 1505.07018
	2UED / RPP	$1 e, \mu$	$\geq 2b, \geq 4j$	Yes	3.2	Tier (1,1), $BR(A^{(1-1)} \rightarrow \tau\tau) = 1$ ATLAS-CONF-2016-013
Gauge bosons	SSM $Z' \rightarrow \ell\ell$	$2 e, \mu$	-	-	Z' mass 4.05 TeV	ATLAS-CONF-2016-045
	SSM $Z' \rightarrow \tau\tau$	2τ	-	-	Z' mass 2.02 TeV	1502.07177
	Leptophobic $Z' \rightarrow bb$	-	$2b$	-	Z' mass 1.5 TeV	1603.08791
	SSM $W' \rightarrow \ell\nu$	$1 e, \mu$	-	Yes	W' mass 4.74 TeV	ATLAS-CONF-2016-061
	HVT $W' \rightarrow WZ \rightarrow qq\nu\nu$ model A	$0 e, \mu$	$1j$	Yes	W' mass 2.4 TeV	$g_V = 1$ ATLAS-CONF-2016-082
	HVT $W' \rightarrow WZ \rightarrow qqqq$ model B	$0 e, \mu$	$2j$	-	W' mass 3.0 TeV	$g_V = 3$ ATLAS-CONF-2016-055
	HVT $V' \rightarrow WH/ZH$ model B	multi-channel	-	-	V' mass 2.31 TeV	$g_V = 3$ 1607.05621
	LRSM $W'_R \rightarrow tb$	$1 e, \mu$	$2b, 0-1j$	Yes	W'_R mass 1.92 TeV	1410.4103
	LRSM $W'_R \rightarrow tb$	$0 e, \mu$	$\geq 1b, 1j$	-	W'_R mass 1.76 TeV	1408.0886
CI	CI $qqqq$	-	$2j$	-	Λ 19.9 TeV $\eta_{LL} = -1$	ATLAS-CONF-2016-069
	CI $\ell\ell qq$	$2 e, \mu$	-	-	Λ 25.2 TeV $\eta_{LL} = -1$	1607.03689
	CI $uutt$	$2(SS) \geq 3 e, \mu \geq 1b, \geq 1j$	Yes	20.3	Λ 4.9 TeV $ C_{RR} = 1$	1504.04605
DM	Axial-vector mediator (Dirac DM)	$0 e, \mu$	$\geq 1j$	Yes	m_A 1.0 TeV	$g_{\tau} = 0.25, g_{\mu} = -1.0, m(\chi) < 250 \text{ GeV}$ 1604.07773
	Axial-vector mediator (Dirac DM)	$0 e, \mu, 1 \gamma$	$1j$	Yes	m_A 710 GeV	$g_{\tau} = 0.25, g_{\mu} = -1.0, m(\chi) < 150 \text{ GeV}$ 1604.01306
	$ZZ_{\chi\chi}$ EFT (Dirac DM)	$0 e, \mu, 1 \gamma$	$1j, \leq 1j$	Yes	M_{ν} 550 GeV	$m(\chi) < 150 \text{ GeV}$ ATLAS-CONF-2015-080
LQ	Scalar LQ 1 st gen	$2 e$	$\geq 2j$	-	LQ mass 1.1 TeV	$\beta = 1$ 1605.06035
	Scalar LQ 2 nd gen	2μ	$\geq 2j$	-	LQ mass 1.05 TeV	$\beta = 1$ 1605.06035
	Scalar LQ 3 rd gen	$1 e, \mu$	$\geq 1b, \geq 3j$	Yes	LQ mass 640 GeV	$\beta = 0$ 1508.04735
Heavy quarks	VLO $TT \rightarrow Ht + X$	$1 e, \mu$	$\geq 2b, \geq 3j$	Yes	T mass 855 GeV	T in (TB) doublet 1505.04306
	VLO $YY \rightarrow Wb + X$	$1 e, \mu$	$\geq 1b, \geq 3j$	Yes	Y mass 770 GeV	Y in (B,Y) doublet 1505.04306
	VLO $BB \rightarrow Hb + X$	$1 e, \mu$	$\geq 2b, \geq 3j$	Yes	B mass 735 GeV	isospin singlet 1505.04306
	VLO $BB \rightarrow Zb + X$	$2 \geq 3 e, \mu$	$\geq 2 \geq 1b$	-	B mass 755 GeV	B in (B,Y) doublet 1409.5500
	VLO $QQ \rightarrow WqWq$	$1 e, \mu$	$\geq 4j$	Yes	Q mass 690 GeV	1509.04261
	VLO $T_{5/3} T_{5/3} \rightarrow WtWt$	$2(SS) \geq 3 e, \mu \geq 1b, \geq 1j$	Yes	3.2	$T_{5/3}$ mass 990 GeV	ATLAS-CONF-2016-032
Excited fermions	Excited quark $q^* \rightarrow q\gamma$	1γ	$1j$	-	q^* mass 4.4 TeV	only u' and d' , $\Lambda = m(q^*)$ 1512.05910
	Excited quark $q^* \rightarrow qg$	$2 e, \mu$	$2j$	-	q^* mass 5.6 TeV	only u' and d' , $\Lambda = m(q^*)$ ATLAS-CONF-2016-069
	Excited quark $b^* \rightarrow bg$	-	$1b, 1j$	-	b^* mass 8.8 TeV	ATLAS-CONF-2016-060
	Excited quark $b^* \rightarrow Wt$	$1 \text{ or } 2 e, \mu$	$1b, 2-0j$	Yes	b^* mass 1.5 TeV	$f_g = f_t = f_r = 1$ 1510.02664
	Excited lepton ℓ^*	$3 e, \mu$	-	-	ℓ^* mass 3.0 TeV	$\Lambda = 3.0 \text{ TeV}$ 1411.2921
	Excited lepton ν^*	$3 e, \mu, \tau$	-	-	ν^* mass 1.6 TeV	$\Lambda = 1.6 \text{ TeV}$ 1411.2921
Other	LSTC $a_T \rightarrow W\gamma$	$1 e, \mu, 1 \gamma$	-	Yes	a_T mass 960 GeV	$m(W_R) = 2.4 \text{ TeV, no mixing}$ 1407.8150
	LRSM Majorana γ	$2 e, \mu$	$2j$	-	H^{\pm} mass 570 GeV	DY production, $BR(H_{\pm}^{\pm} \rightarrow ee)=1$ 1506.06020
	Higgs triplet $H^{\pm\pm} \rightarrow ee$	$2 e$ (SS)	-	-	$H^{\pm\pm}$ mass 400 GeV	DY production, $BR(H_{\pm}^{\pm} \rightarrow \ell\tau)=1$ ATLAS-CONF-2016-051
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\tau$	$3 e, \mu, \tau$	-	-	spin-1 invisible particle mass 657 GeV	$\mathcal{J}_{\text{non-res}} = 0.2$ 1410.5404
	Monotop (non-res prod)	$1 e, \mu$	$1b$	Yes	multi-charged particle mass 785 GeV	DY production, $ q = 5e$ 1504.04188
	Multi-charged particles	-	-	-	monopole mass 1.34 TeV	DY production, $ g = 1g_D, \text{spin } 1/2$ 1509.08059
	Magnetic monopoles	-	-	-		

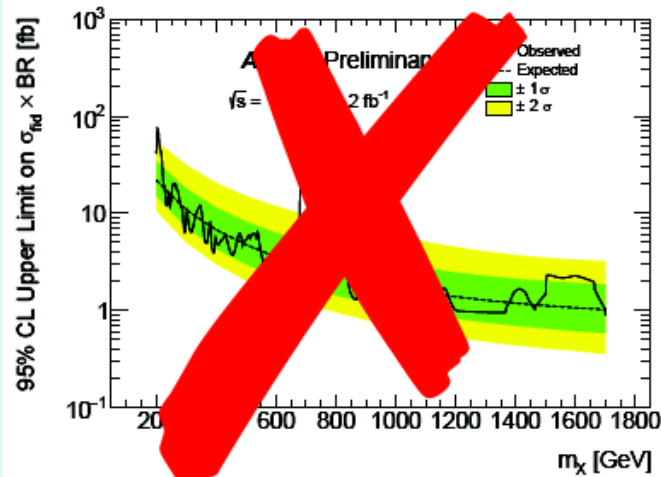
No Hint towards new Physics at the Horizon :-)



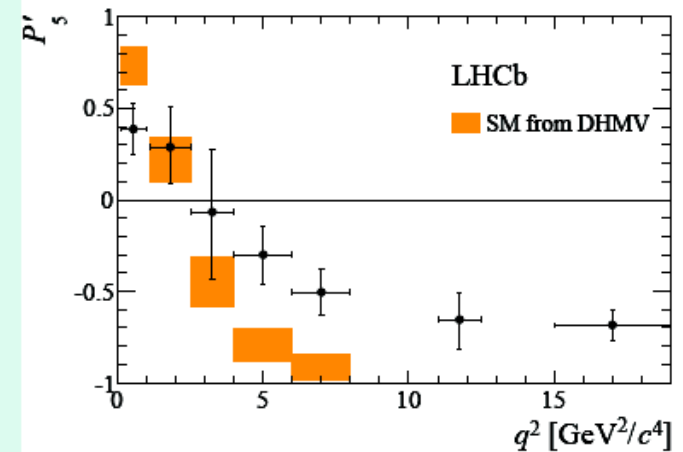
Smoking Gun in Flavor Physics?



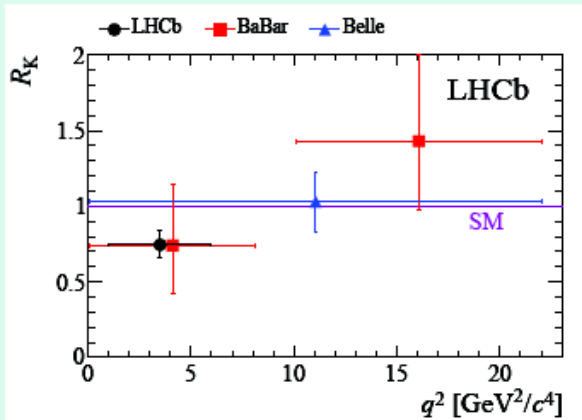
Excess at 2 TeV [CMS, JHEP 08 (2014) 174]



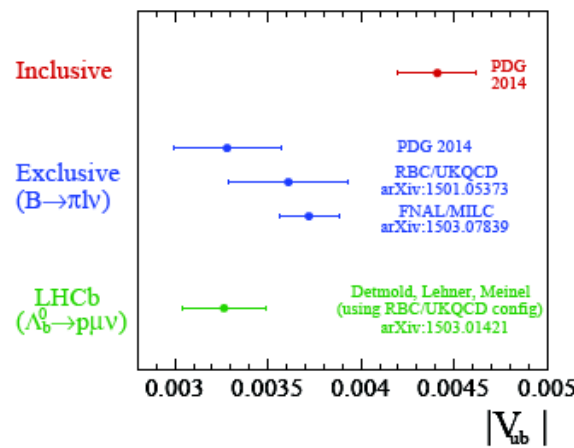
Excess at 750 GeV [ATLAS-CONF-2015-081]



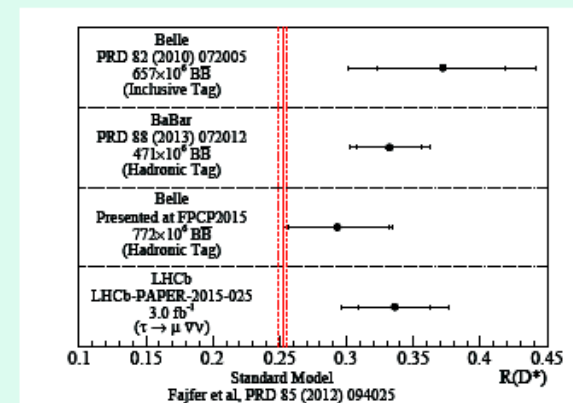
P'_5 in $B \rightarrow K^* \mu^+ \mu^-$ [JHEP 02 (2016) 104]



Lepton universality [PRL 113 (2014) 151601]



V_{ub} puzzle [Nature Physics 11 (2015) 743]



$B \rightarrow D^* \tau \nu$ [PRD 92 (2015) 011102(R)]

P. Koppenburg

There's a handful of intriguing 3–4 σ anomalies



Exotic (anti-)Quark Compounds

G. Cavallero



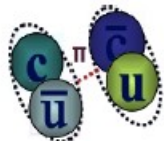
Baryon



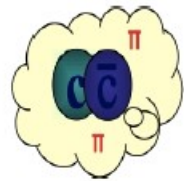
Meson



Tetraquark



Meson-meson molecule



Hadro-quarkonium



Pentaquark

meson-baryon molecule, hexaquark

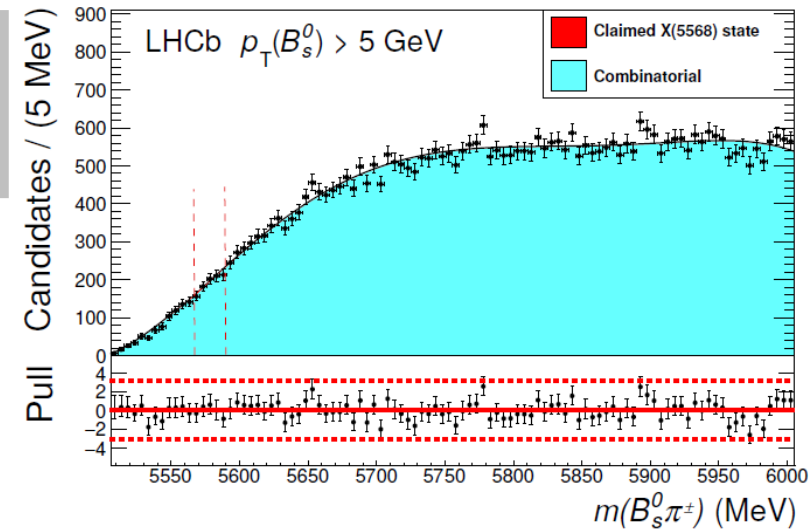


Glueball



Hybrid meson

No confirmation for Tetraquark $B_s^0\pi$, $X(5568)$ state of $D0$



4 $J/\psi\Phi$ structures observed confirming $X(4140)$ reported by CDF

State	M_0 [MeV]	Γ_0 [MeV]	J^{PC}
$X(4140) @ 8.4 \sigma$	$4146.5 \pm 4.5^{+4.6}_{-2.8}$	$83 \pm 21^{+21}_{-14}$	$1^{++} @ 5.7 \sigma$

LHCb Pentaquark Candidates (uudc**c**bar)

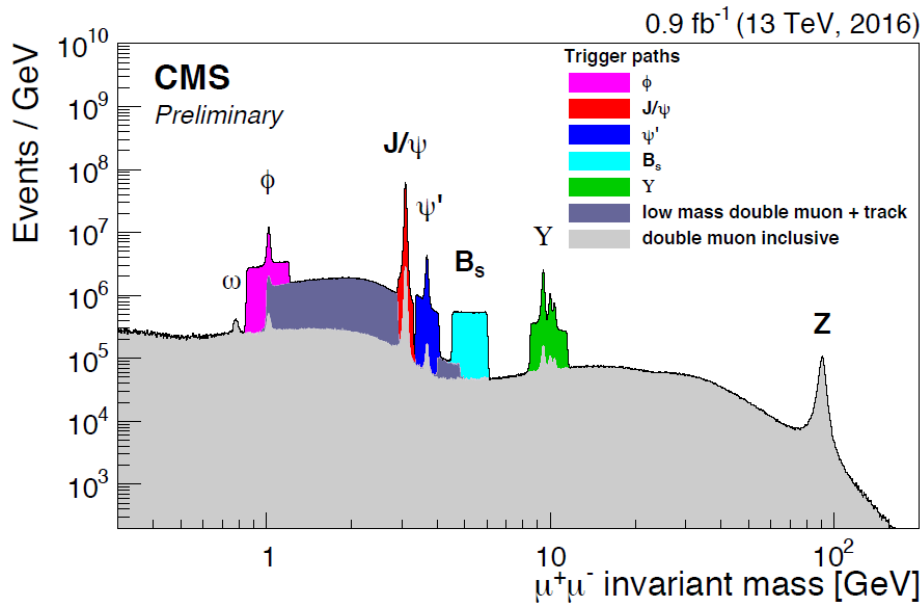
State	M_0 [MeV]	Γ_0 [MeV]	J^P
$P_c(4380)^+ @ 9 \sigma$	$4380 \pm 8 \pm 29$	$205 \pm 18 \pm 86$	$\frac{3}{2}^- \left(\frac{3}{2}^+, \frac{5}{2}^+ \right)$
$P_c(4450)^+ @ 12 \sigma$	$4449.8 \pm 1.7 \pm 2.5$	$39 \pm 5 \pm 19$	$\frac{5}{2}^+ \left(\frac{5}{2}^-, \frac{3}{2}^- \right)$

D. Britzger: ZEUS pentaquark claim (uuddsbar) in pK_s^0 not confirmed

More LHCb results → D. Craik, C. Voss



Onium Production at 13 TeV



$\mu^+\mu^-$ mass spectrum

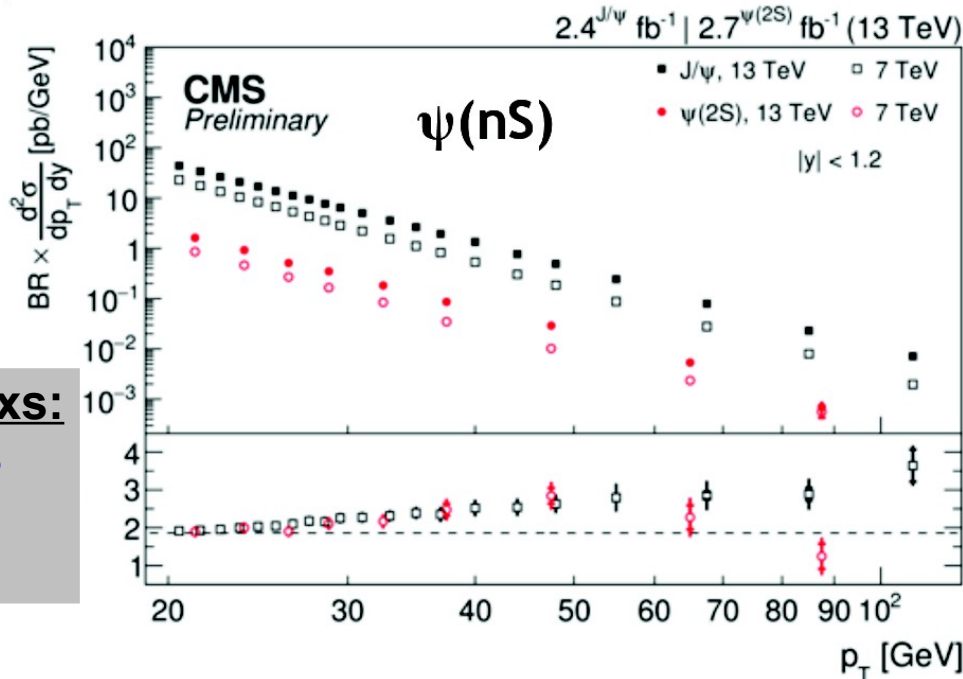
I. Kratschmer, R. Jones

LHCb \rightarrow R. Coutinho

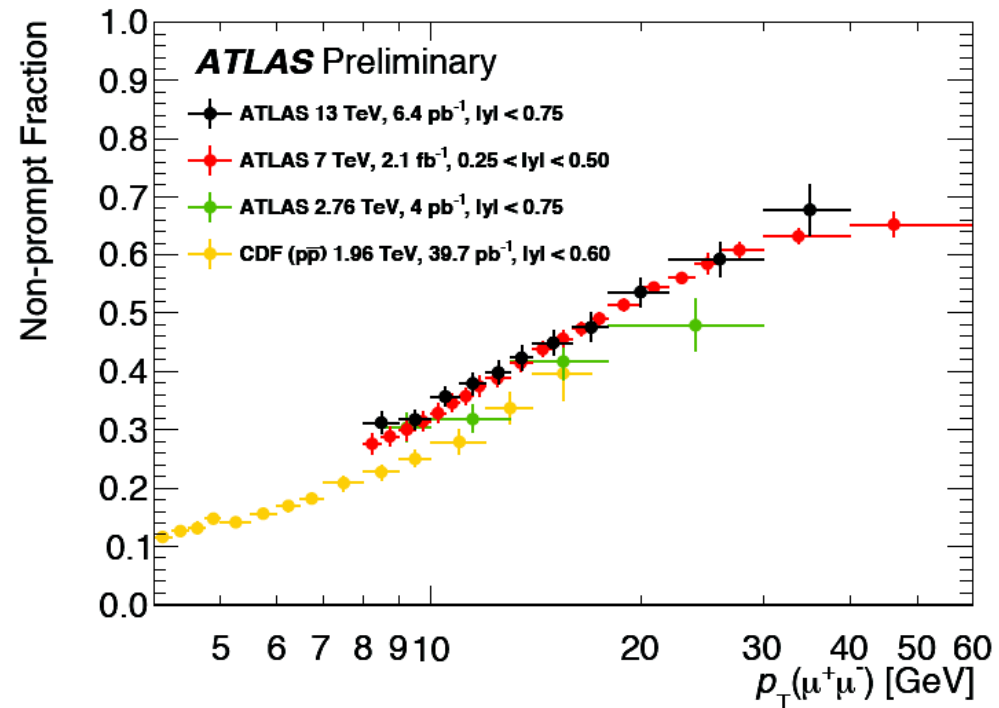
J/ Ψ and DPS \rightarrow R. Bertsche, I. Belyaev

J/ Ψ non-prompt production fraction:

- strong p_T dependence
- no $|y|$ dependence
- similar as at 7 TeV

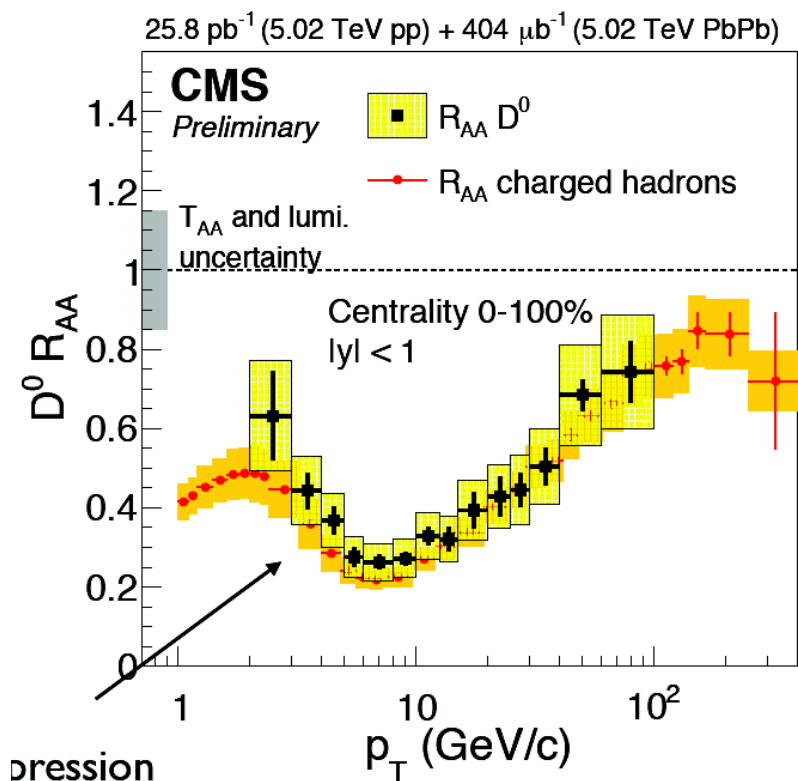
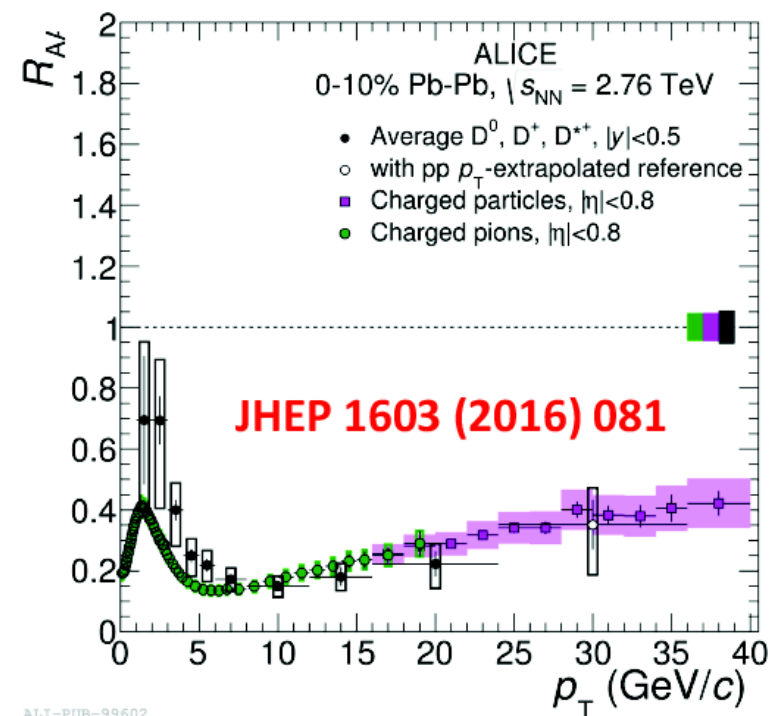


J/ Ψ 13/7 xs:
2-3 times larger





Heavy Ion Collisions



PbPb at 5.02 TeV

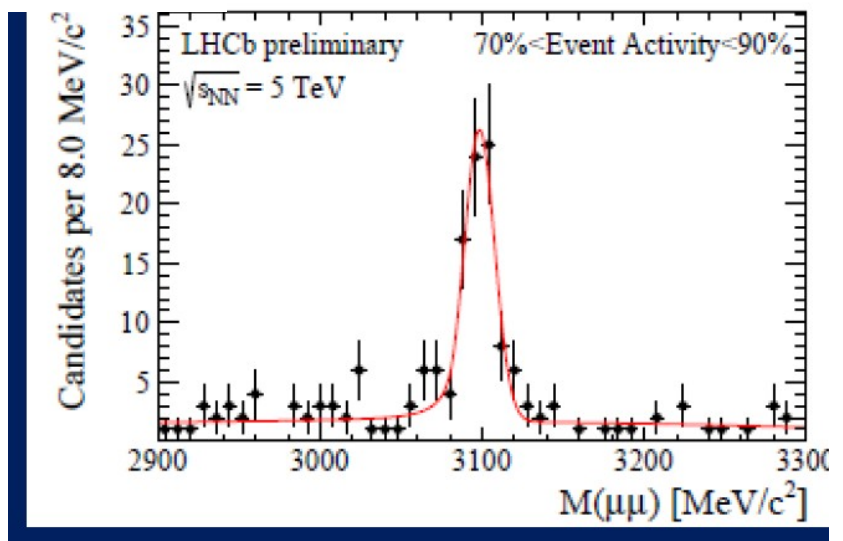
First participation of LHCb in HI running December 2015

$\mu^+ \mu^-$ <https://>

ALICE & CMS:
Strong interaction of charm mesons with QGP
Nuclear suppression R_{AA} very similar between charm and light quarks

C. Jahnke, G. Innocenti, B. Schmidt

More HI results → E. Chapon



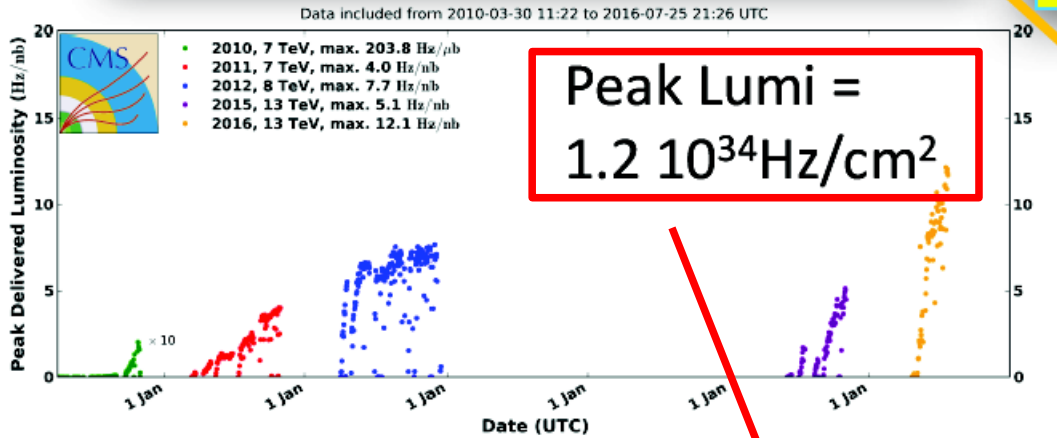


Excellent LHC Performance

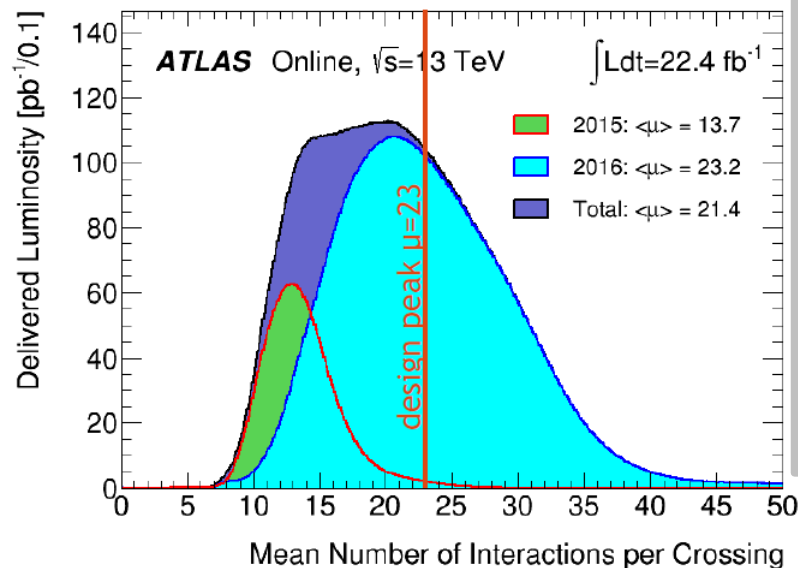
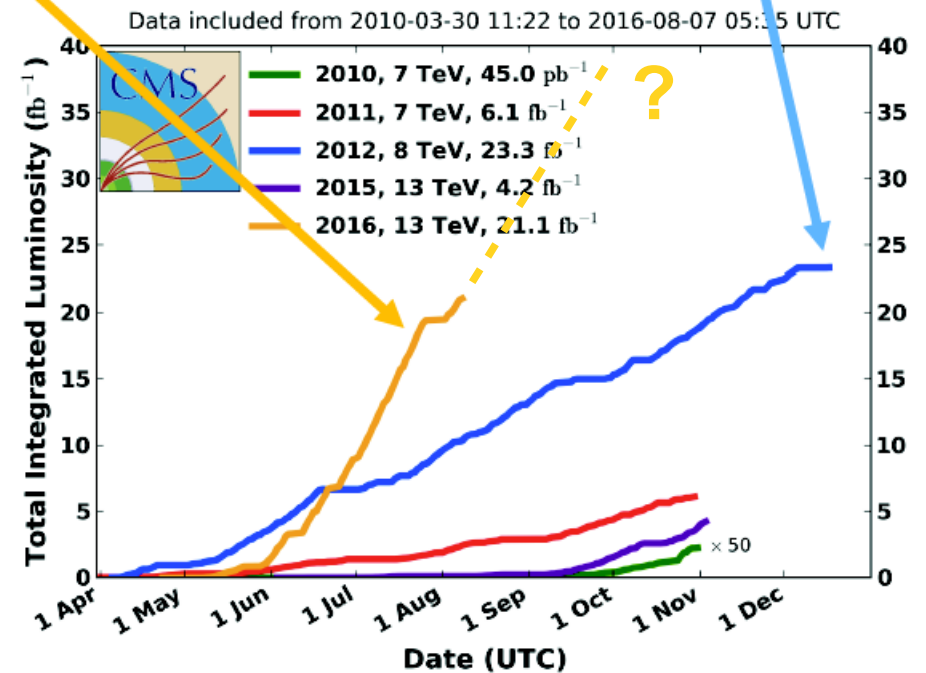
Luminosity used for the results presented today 12.9 fb^{-1}

The estimate prior to the start of the 2016 campaign were to achieve something similar to the previous best (2012)

CMS Peak Luminosity Per Day, pp



CMS Integrated Luminosity, pp



Beyond original design goals!

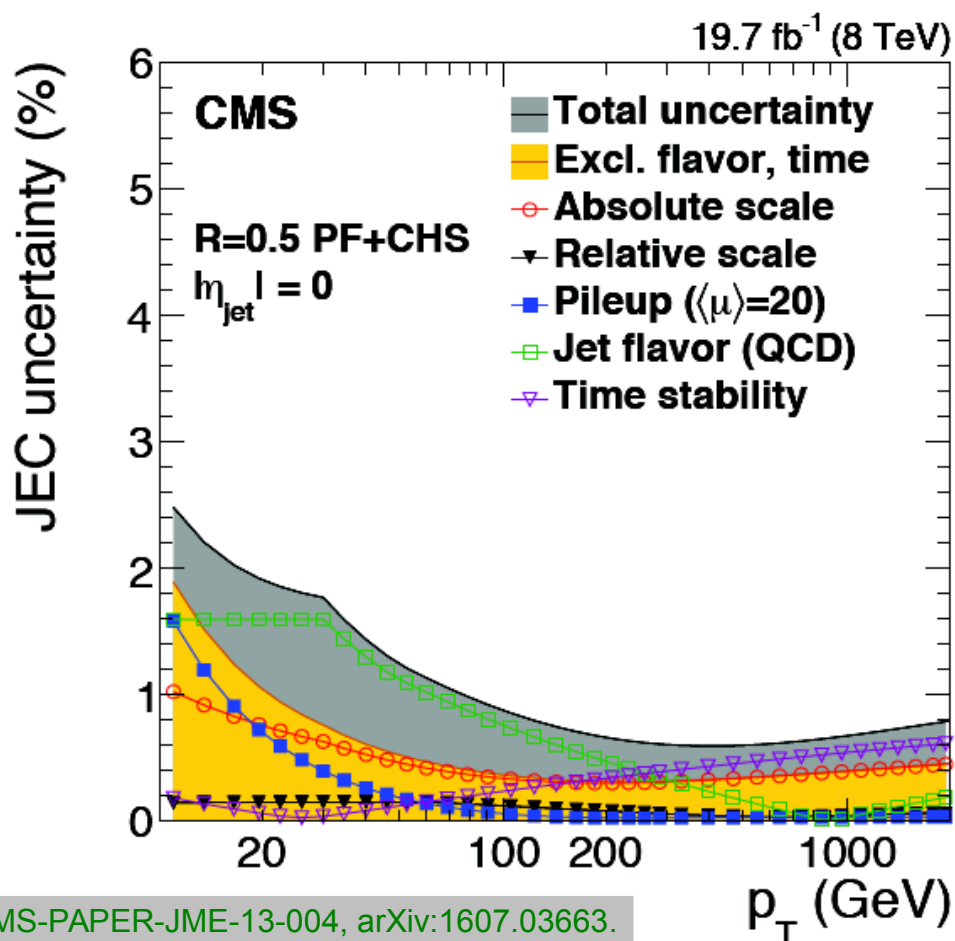
Pileup often above LHC design in 2016

Adapted from T. Camporesi & D. Charlton, ICHEP2016

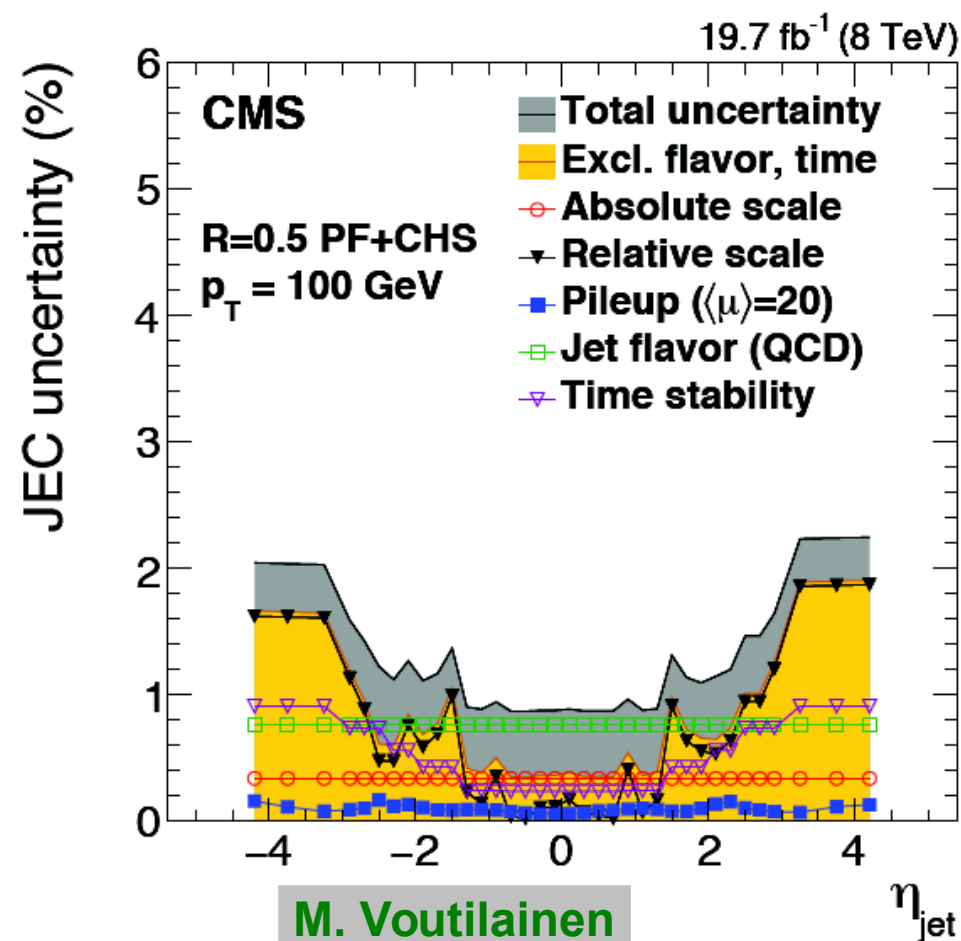


CMS Run 1 Jet Energy Calibration

- Lowest uncertainty at $y \sim 0$, $p_T \sim 200$ GeV is **0.32%** (excluding flavor and time dependence)
- Well below 1% across much of the kinematic range
- For jet physics, the relevant uncertainty is golden band + green curve, “Jet flavor (QCD)”
 - ▶ this is entirely driven by MC-based uncertainty on gluon jet response



CMS-PAPER-JME-13-004, arXiv:1607.03663.



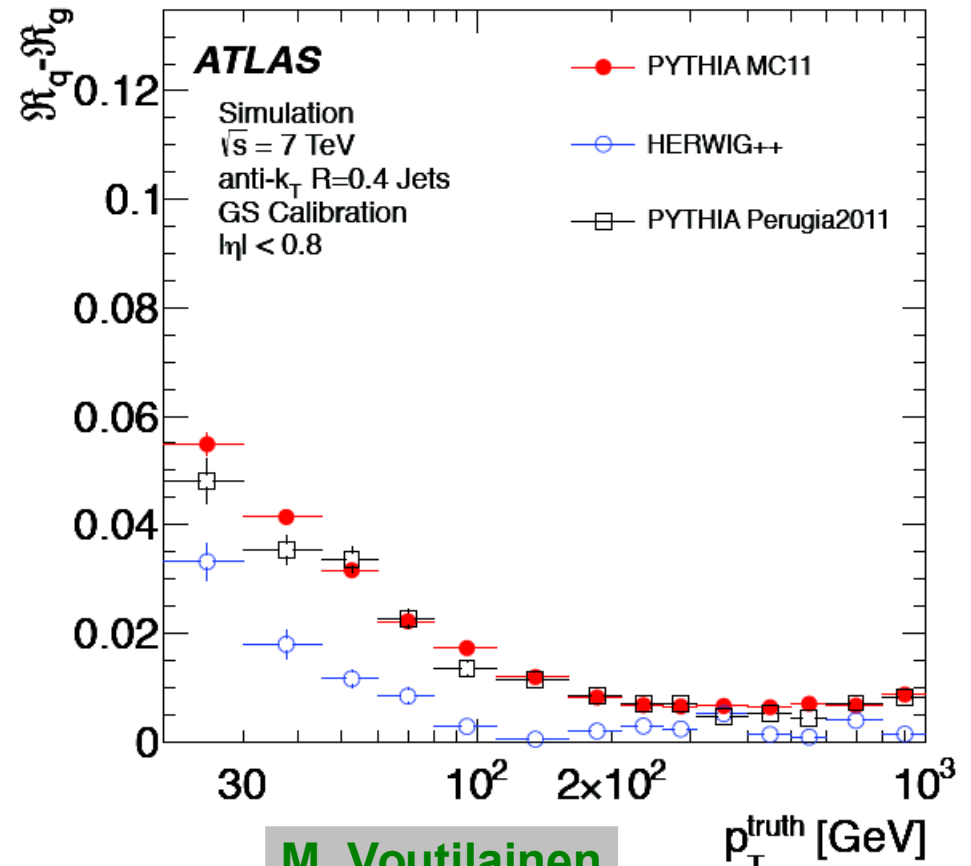
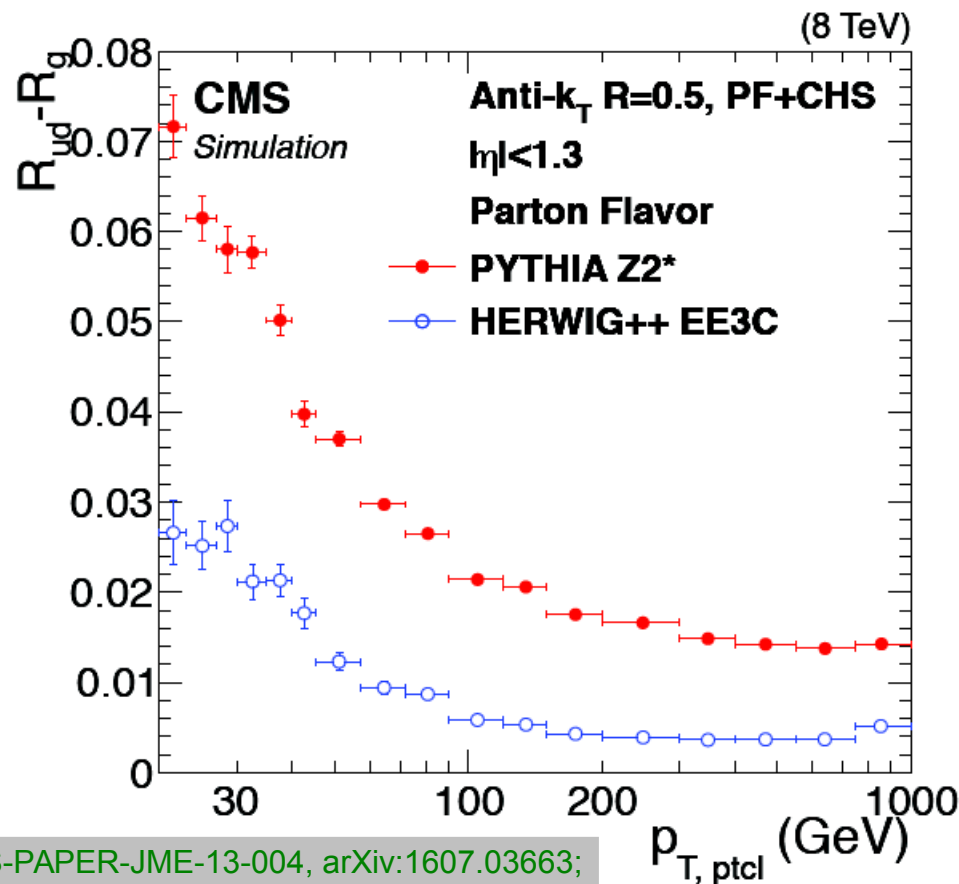
M. Voutilainen

Gluon Jet Response from MC

Significant portion of JEC uncertainty common to ATLAS and CMS!

- “Jet flavor (QCD)” uncertainty mostly from gluon jets
- Not a feature unique to CMS: parton shower (or fragmentation) in Pythia6 and Herwig++, affects ATLAS response in a very similar fashion (GS vs PF, EM+JES vs Calo)

<https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/PERF-2012-01/>



CMS-PAPER-JME-13-004, arXiv:1607.03663;
 ATLAS, Eur. Phys. J. C (2015) 75:17.

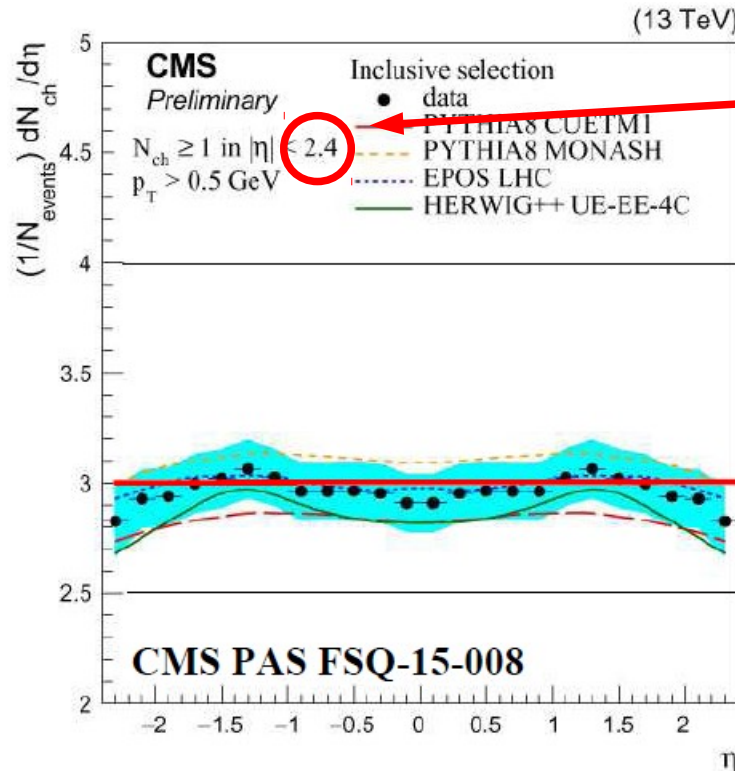
M. Voutilainen



MC Tuning

A. Salzburger,
A. Mehta, R. Field

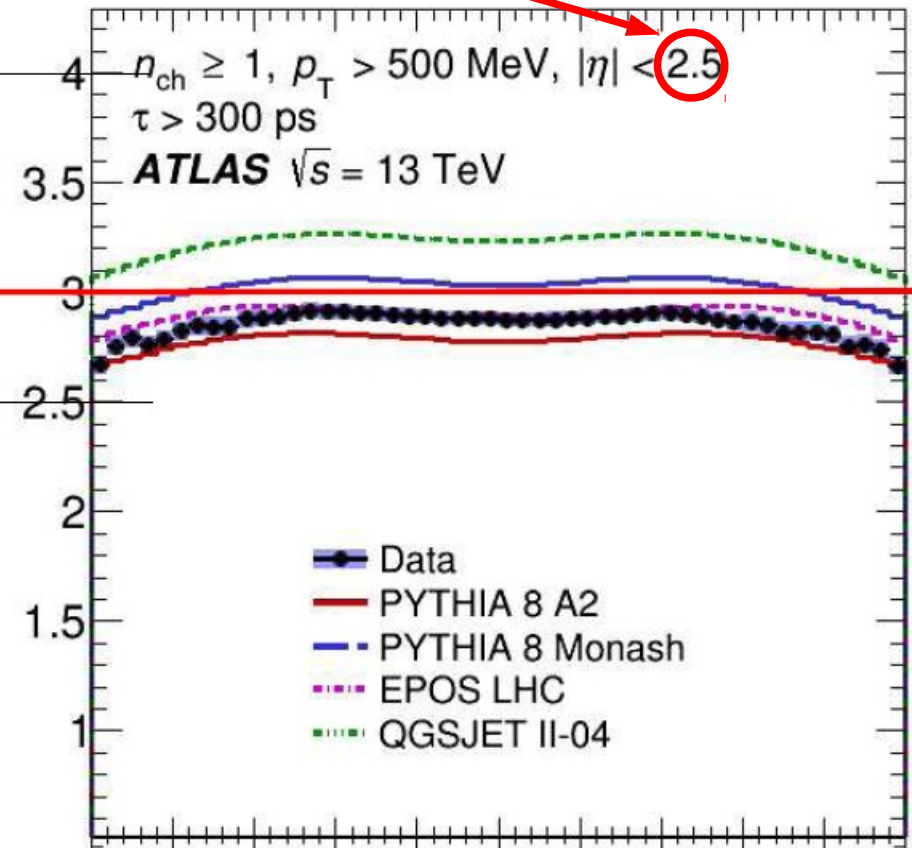
New E_{cms} to tune
E-dependence
→ improve
- simulation
- UE & pile up
- jet calibration



13 TeV

Pay attention to details ...

arXiv:1602.01633



\sqrt{s} [TeV]	$dN_{\text{ch}}/d\eta _{\eta=0}$	\pm stat	\pm sys
0.9	1.343*	0.004	0.027
2.36	1.74*	0.019	0.058
7	2.43*	0.001	0.050
8	2.477	0.001	0.031
13	2.874	0.001	0.033

Input from unique LHCb phase space → A. Grecu
UE in ttbar events → E. Yazgan
Total x section → K. Hiller

MC Tunes, preferably simultaneously for
MBias, UE, and DPS → R. Field



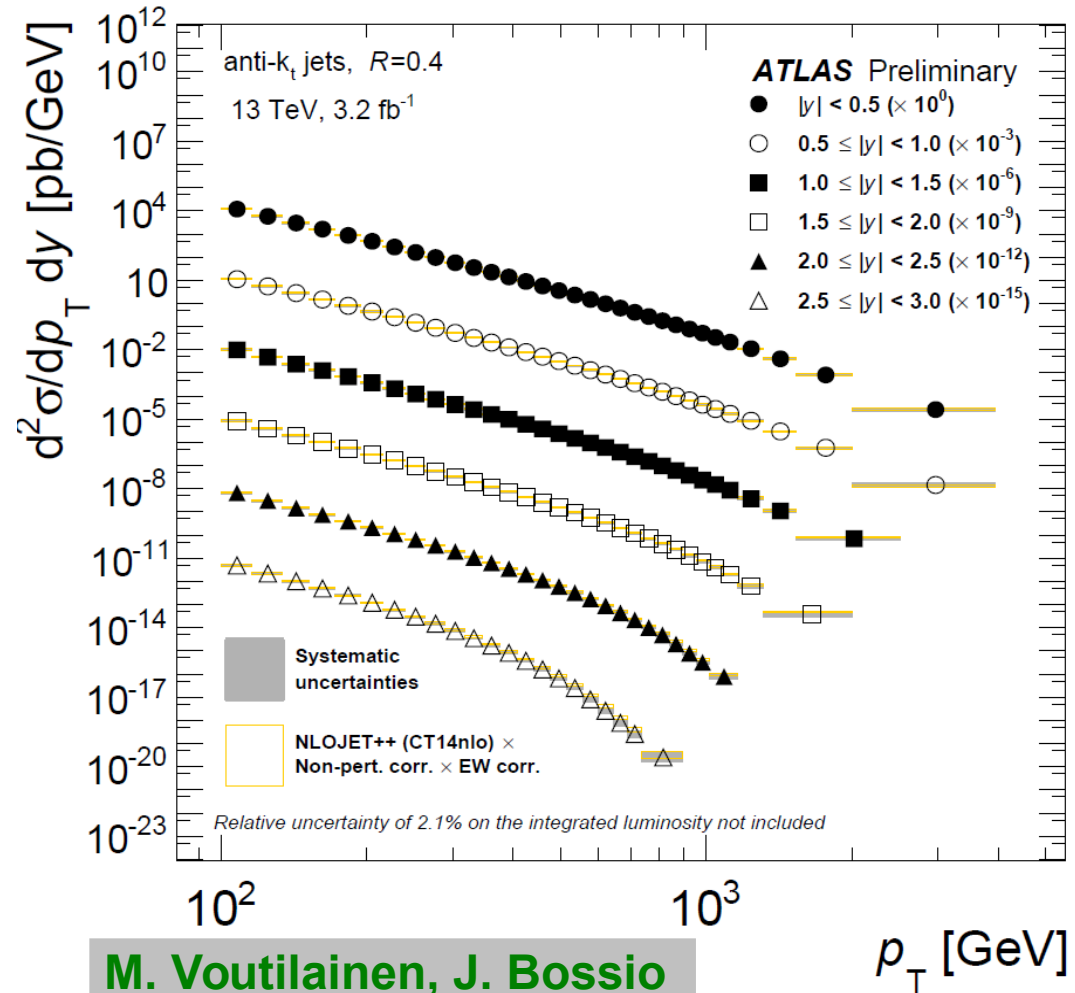
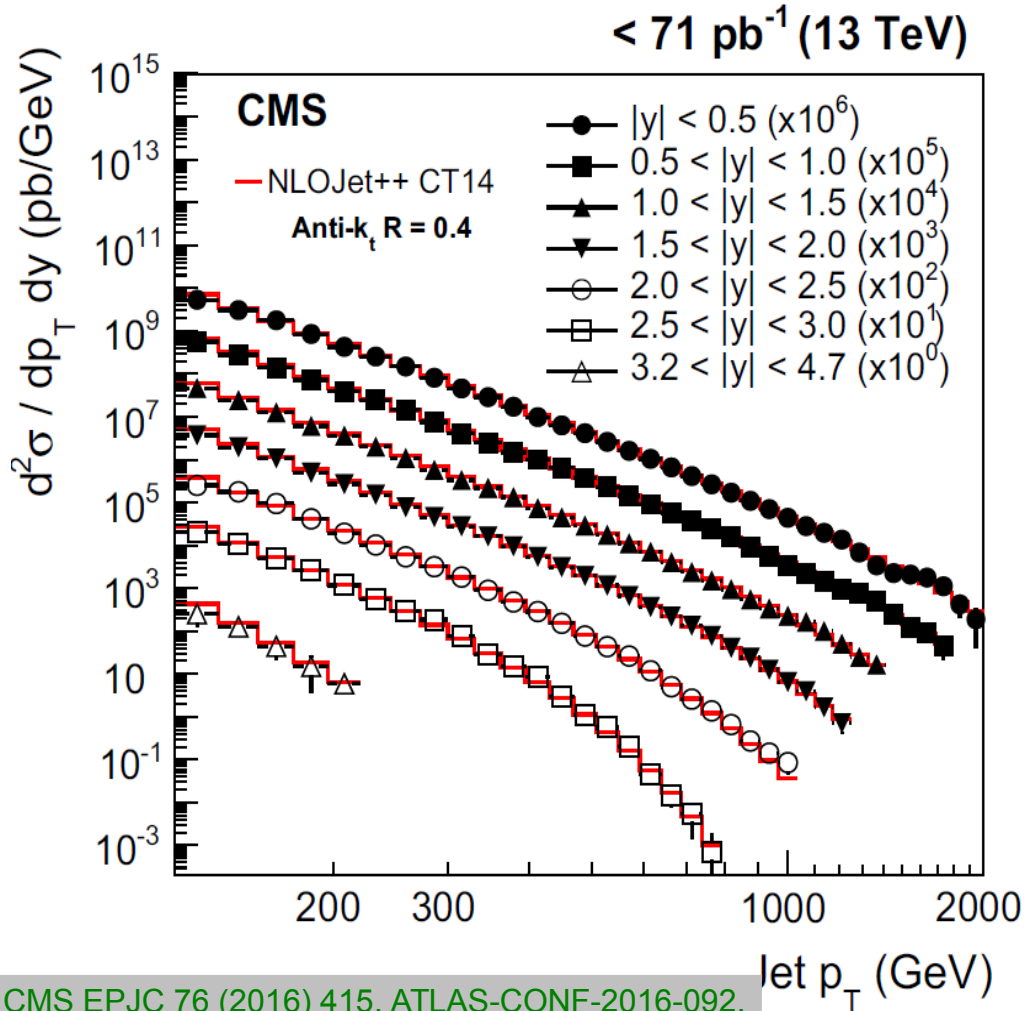
Inclusive Jets at 13 TeV

New publication from CMS, < 71/pb, jets up to 2 TeV,
New preliminary from ATLAS, 3.2/fb, jets up to 4 TeV.

$$\frac{d^2\sigma}{dp_T dy} \propto \alpha_s^2$$

anti-k_T, R=0.4, 13 TeV, 2015

anti-k_T, R=0.4, 13 TeV, 2015



CMS EPJC 76 (2016) 415, ATLAS-CONF-2016-092.

M. Voutilainen, J. Bossio



DIS Jets versus NNLO

First comparison of jets in DIS to NNLO predictions

→ fully include jet data with NNLO theory into future fits of gluon PDF & α_s !

Detailed ratio to NLO prediction

- Data reasonably described by NLO theory, but NLO scale uncertainty large

New predictions: NNLO from NNLOJET

- NNLO predictions for inclusive jet and dijet production in NC DIS (*PRL 117 (2016) 042001*)
- Normalised with NC DIS predictions from APFEL using FONLL-C

NNLO

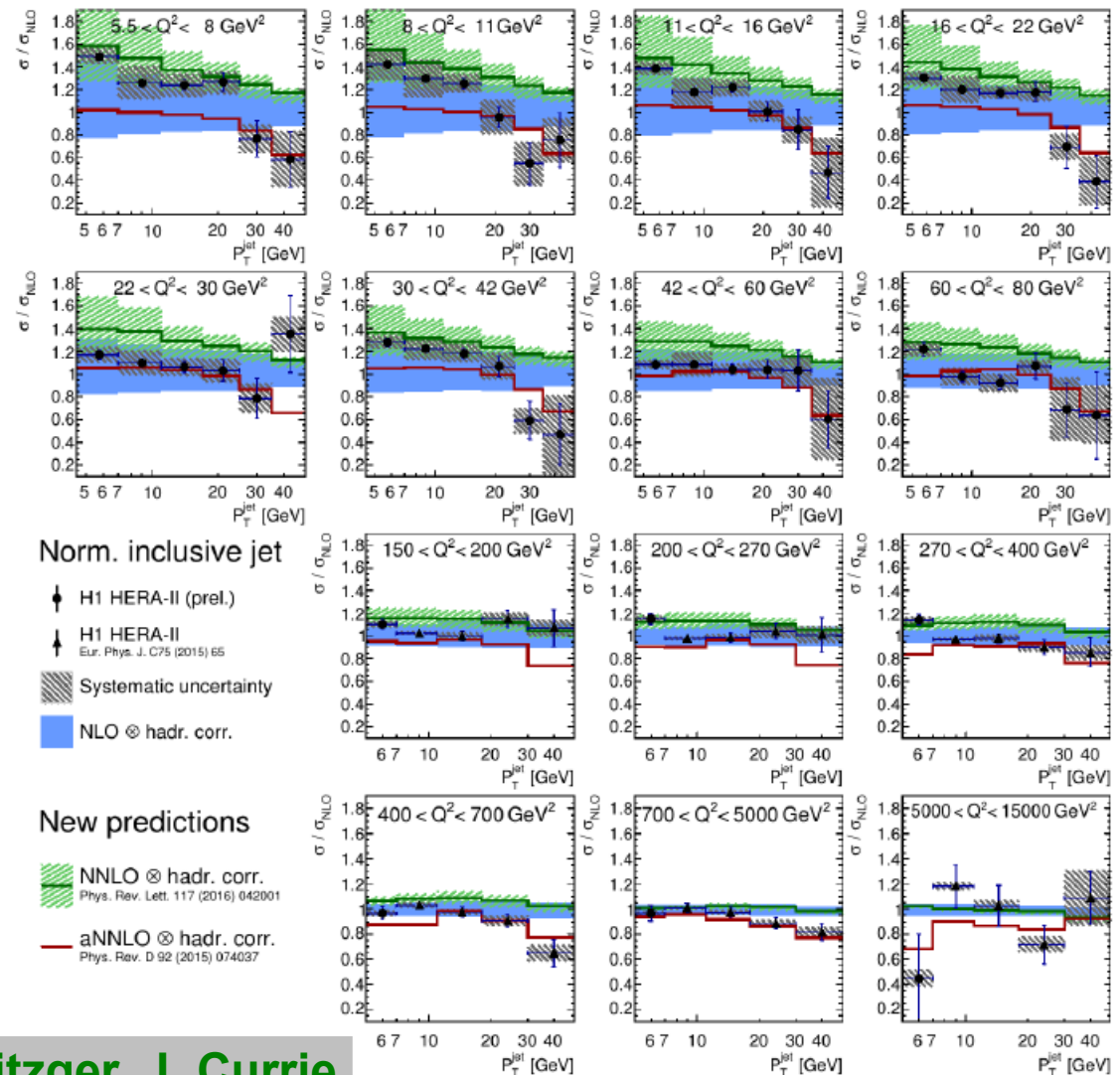
- Improved description of data by NNLO
- Significantly reduced scale uncertainty (particularly for higher scales)

aNNLO from JetViP

- Approximate NNLO using threshold resummation (*PR D 92 (2015) 074037*)
- Improved data description at high- p_T

High- Q^2 inclusive jets

- New datapoints for $5 < p_T < 7$ GeV plus *EPJ C75 (2015) 65*



H1prelim-16-062.

D. Britzger, J. Currie



Data Sets for PDF Extraction

V. Radescu.	CT14	MMHT14	NNPDF3.0	HERAPDF2.0	ABM12(ABMP)	CJ12(15)	JR14
HERA data	HERA I+ charm	HERA I charm jets	HERA I+ H1 and ZEUS II charm	HERA I+II	HERA I charm	HERA I	HERA I charm jets
Fix. Target DIS	✓	✓	✓	✗	✓	JLAB, high x ✓	JLAB, high x ✓
Tevatron W,Z	✓	✓	✓	✗	✗/✓	✓	✗
Tevatron Jets	✓	✓	✓	✗	✗	✗	✓
Fix. Target DY	✓	✓	✓	✗	✓	✓	✓
LHC WZ	✓	✓	✓	✗	✓	✗	✗
LHC jets	✓	✓	✓	✗	✗	✗	✗
LHC top	✗	✓	✓	✗	✓	✗	✗
LHC charm	✗	✗	✓	✗	✗/✓	✗	✗
References	arXiv:1506.07443	arXiv:1412.3989	arXiv:1410.8849	arXiv:1506.06042	arXiv:1310.3059	arXiv:1212.1702	arXiv:1403.1852

Type of processes:

- ❖ inclusive / purely leptonic
- ❖ processes with jets
- ❖ current precision of data $\sim < 5\%$

see: E. Rizvi, R. Placakyte, K. Lohwasser, S. Glazov, K. Mueller
S. Camarda, J. Bossio ...

EW effects become more and more important → need Photon PDF → need sensitive measurements:

High mass DY production → E. Rizvi



Inclusive W^\pm, Z Production & Ratios

13 TeV data compared to NNLO

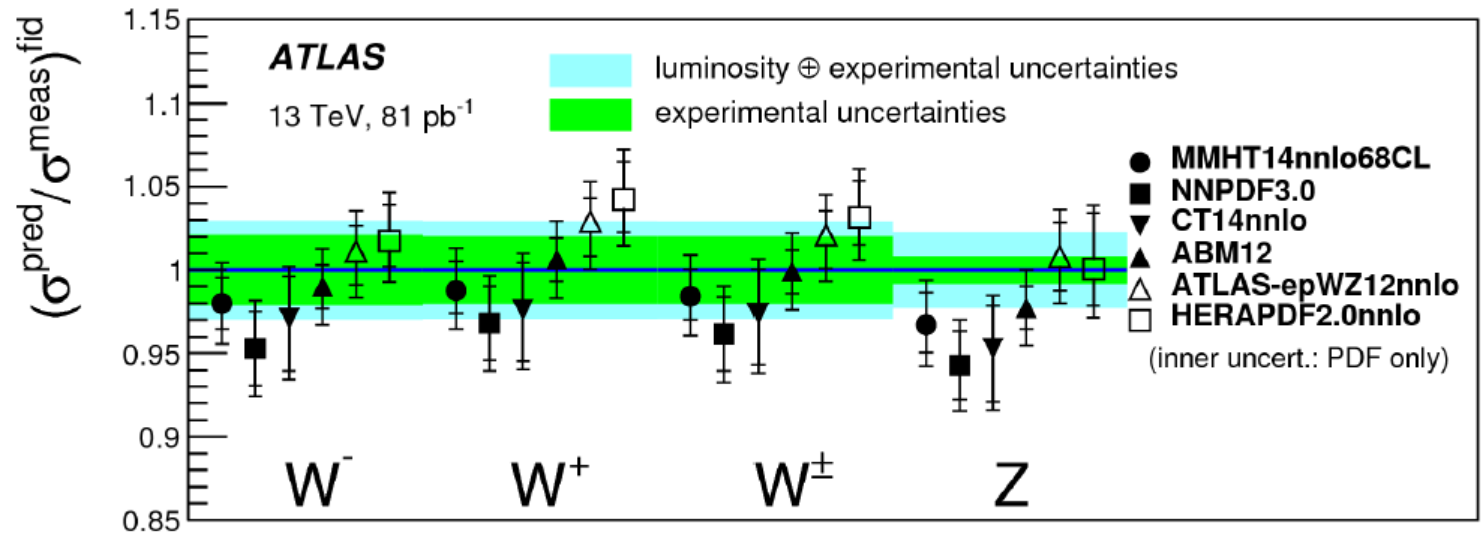
Uncertainties:

exp W: ~2%

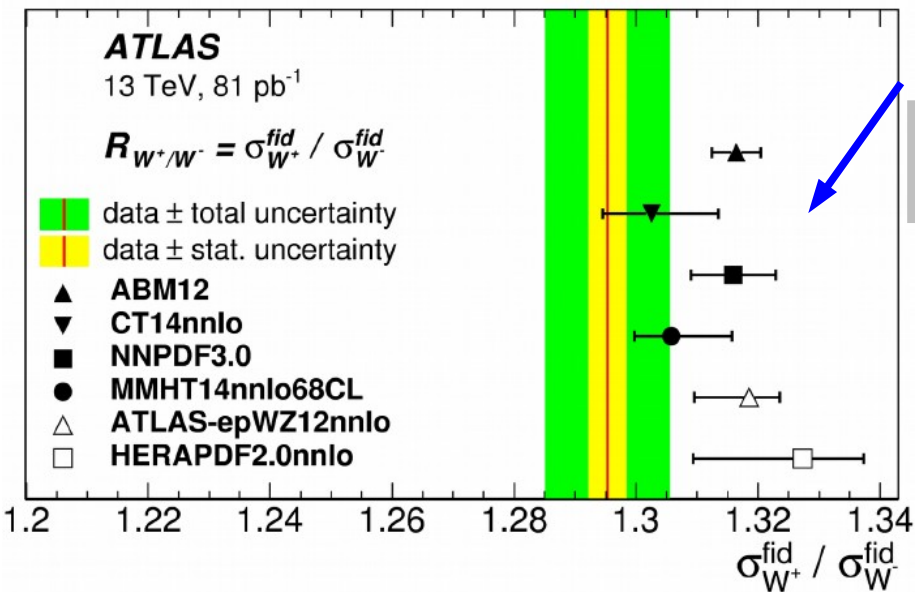
exp. Z: ~1%

Lumi: 2.1%

→ Ratios



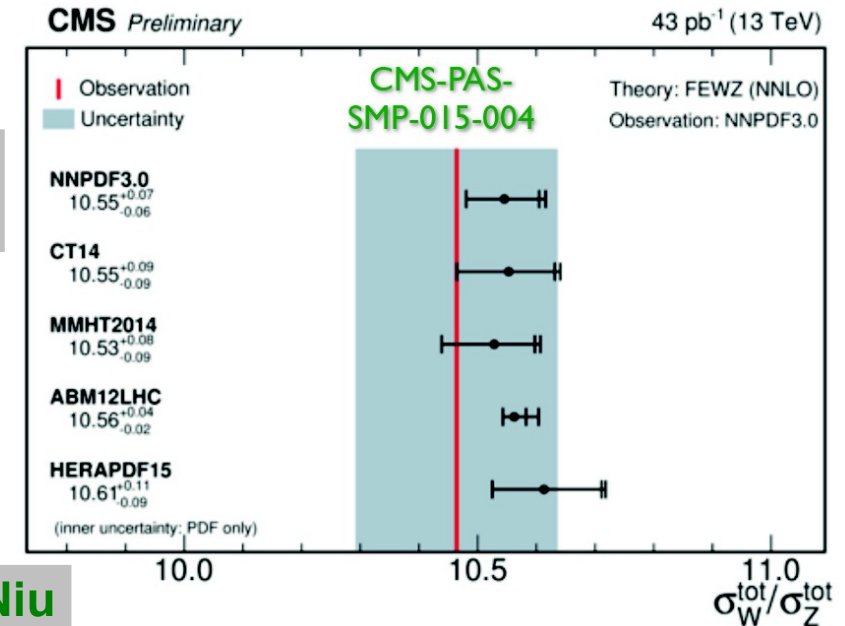
W^+/W^- sensitive to u_v/d_v PDF



similar behavior in ATLAS & CMS

S. Camarda, X. Niu

W/Z sensitive to strange PDF





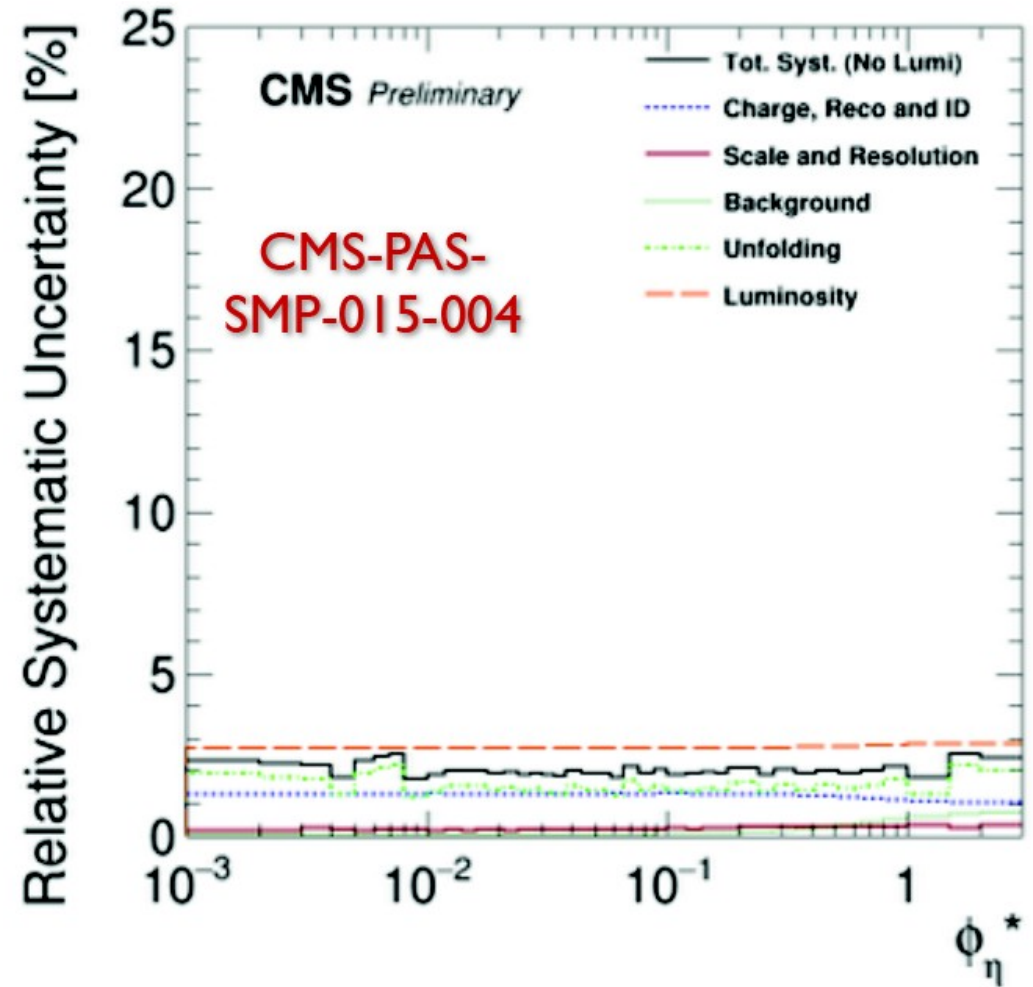
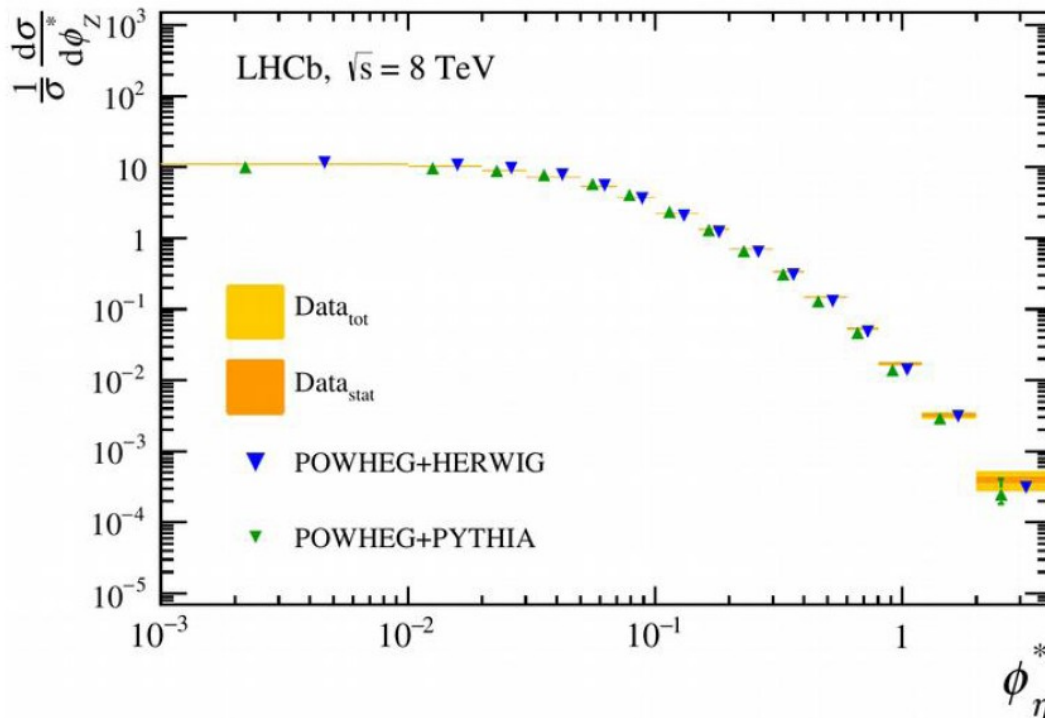
Differential W,Z Production

Differential in ϕ_η^* instead of $p_{T,Z}$:
roughly $\sim p_{T,Z}/M_Z$ but only angular \rightarrow smaller uncertainties

S. Camarda, X. Niu,
A. Greco

$$\phi_\eta^* = \tan\left(\frac{\pi - \Delta\phi}{2}\right) \cdot \sin(\theta_\eta^*)$$
$$\cos(\theta_\eta^*) = \tanh\left(\frac{\eta^- - \eta^+}{2}\right),$$

LHCb Forward Region

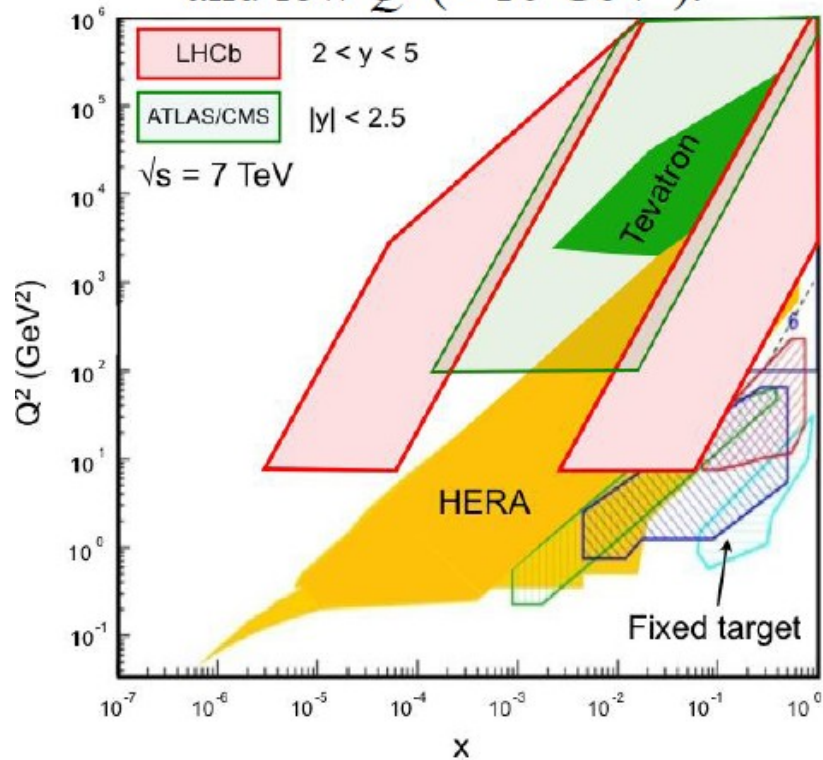


PDF constraints \rightarrow V. Radescu, R. Placakyte
V+HF \rightarrow R. Gold, R. Silva, G. Chiodini

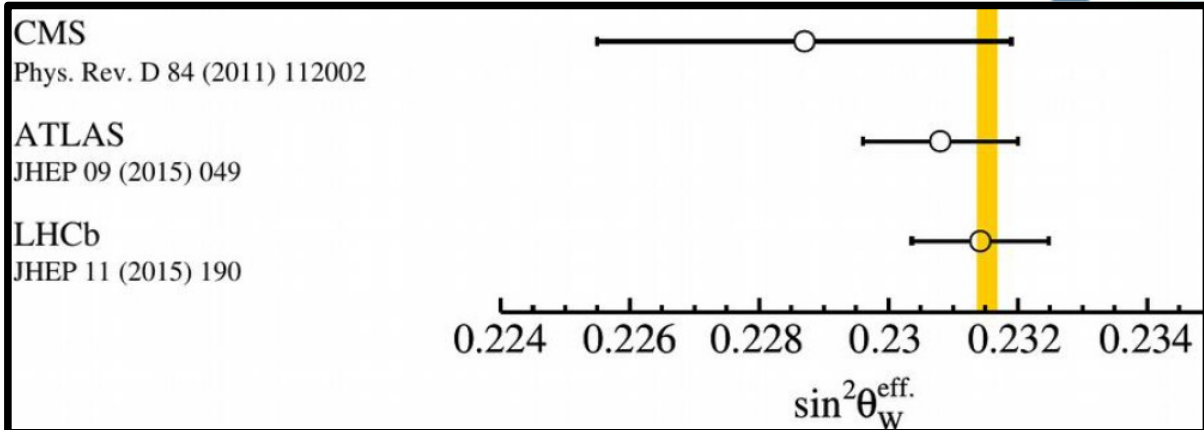
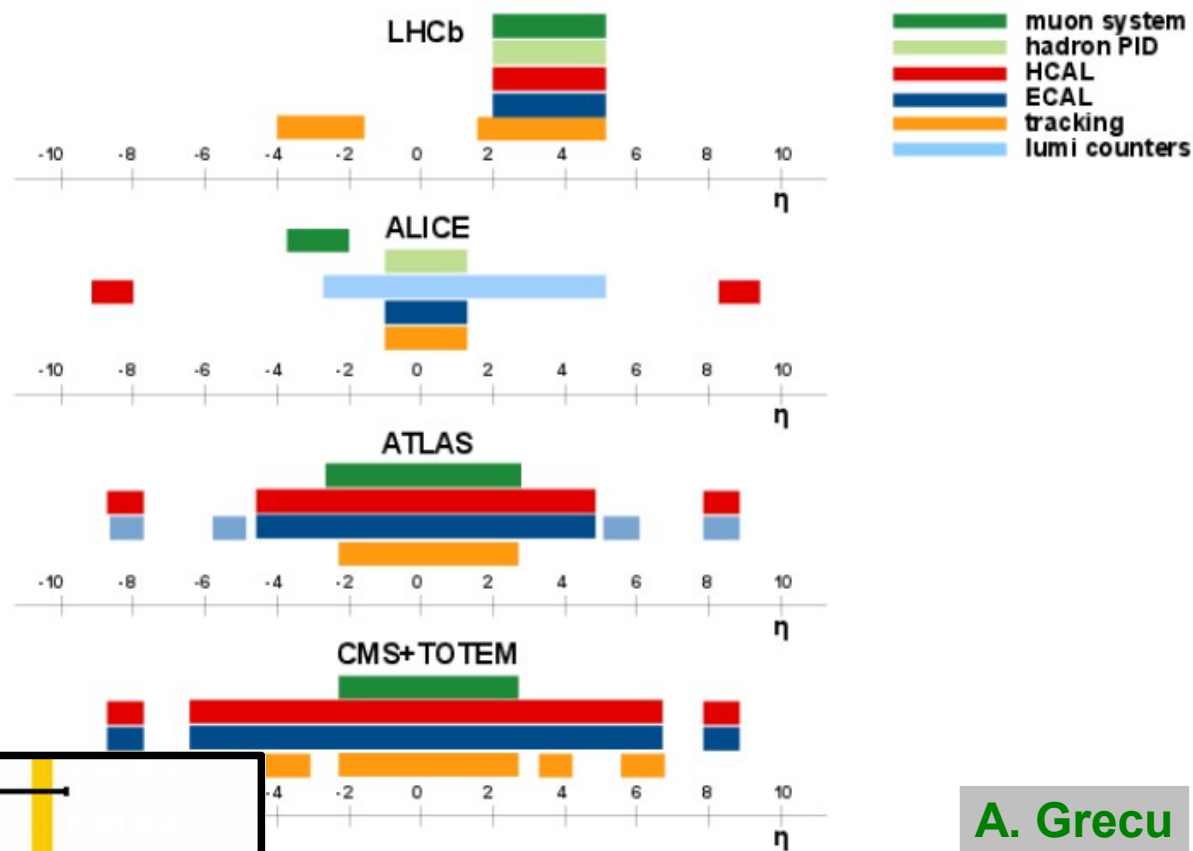


LHC Phase Spaces, $\sin^2\Theta_W$

Also access low x_{Bj} ($\sim 10^{-6}$) and low Q^2 ($> 10 \text{ GeV}^2$).



LHCb covered phase-space region complementary to other detectors at LHC



A. Greco

Also use Z asymmetry A_{FB} to determine $\sin^2\Theta_W$

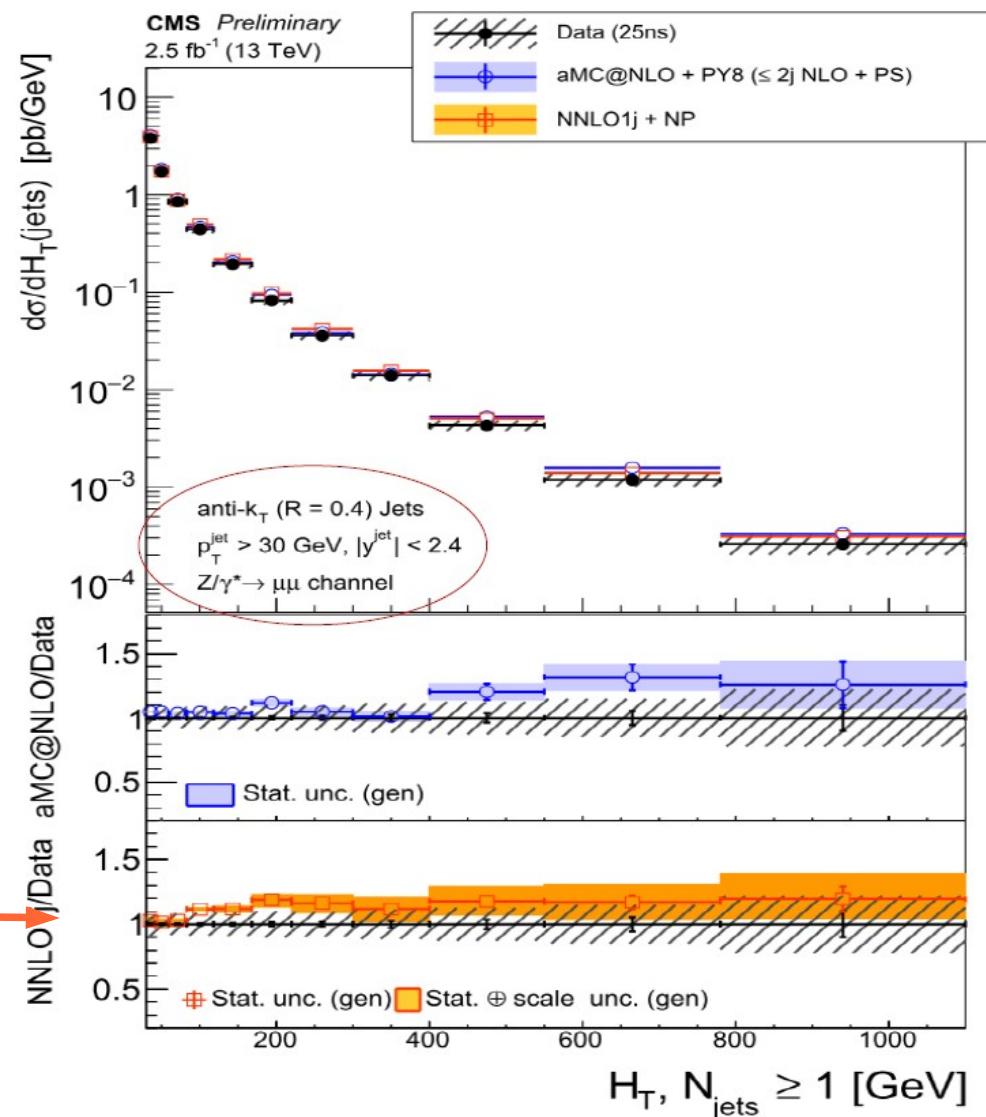
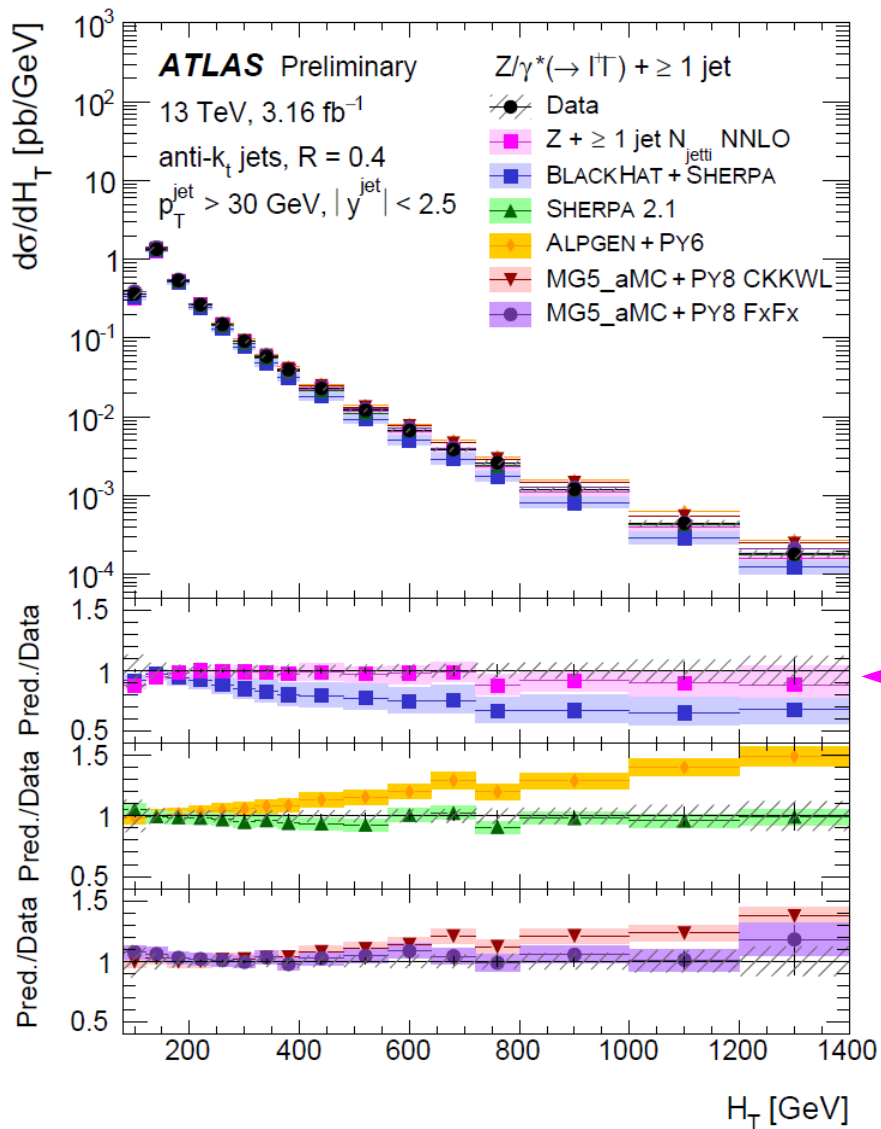


Z+jets at 13 TeV

Agreement with new NNLO Calculations

Also: Run 1 data for W/ γ +jets and Z/W + b/c jets

J.Bossio, F. Zang



← NNLO

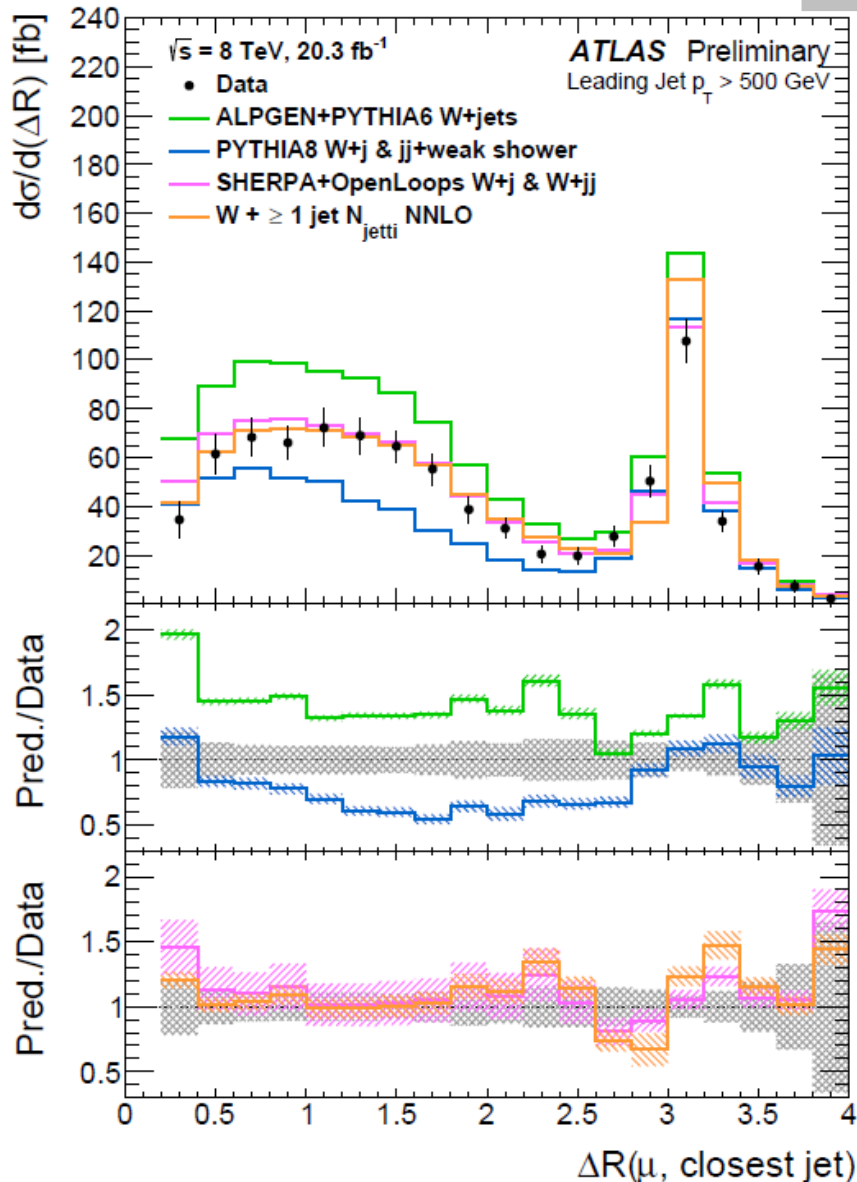
→ NNLO



W+jet at high p_T low ΔR

Test of real W emission process

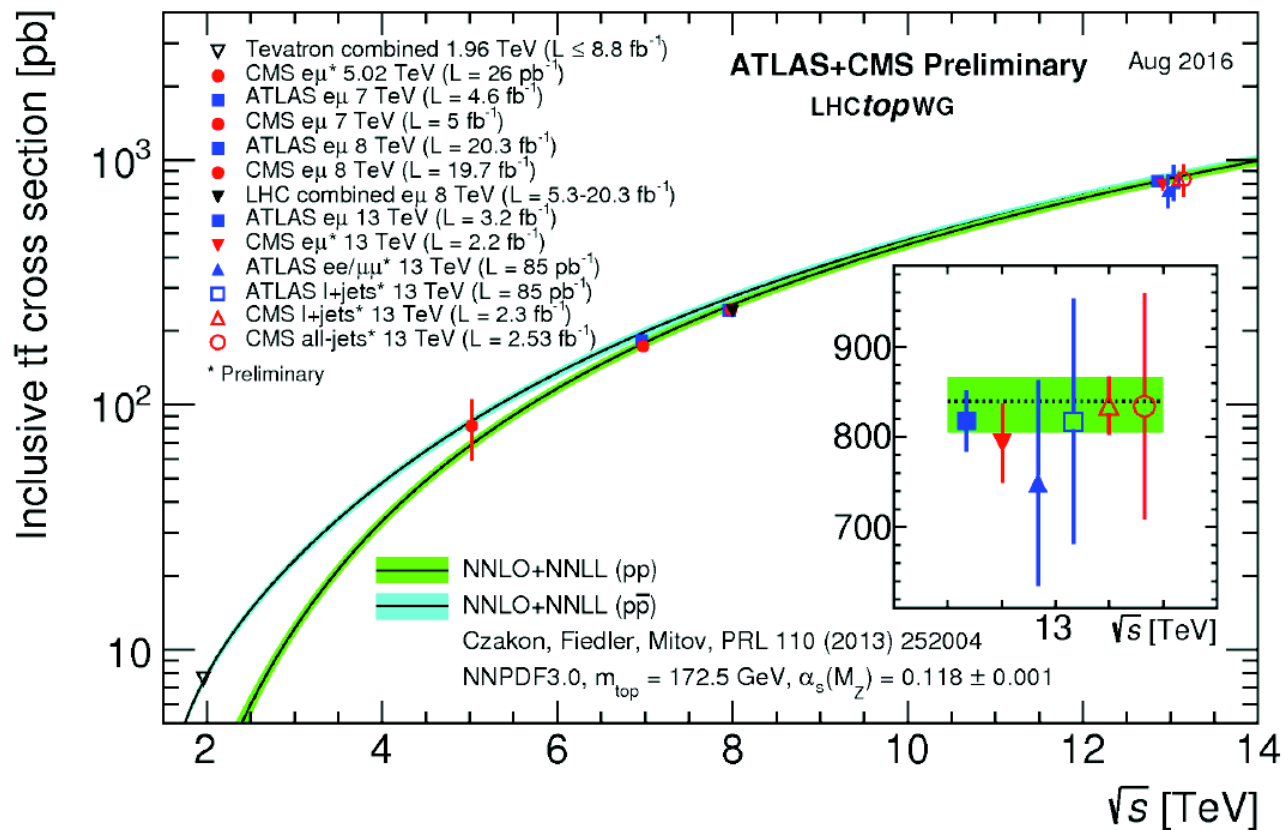
Well described by NNLO or Sherpa+OpenLoops



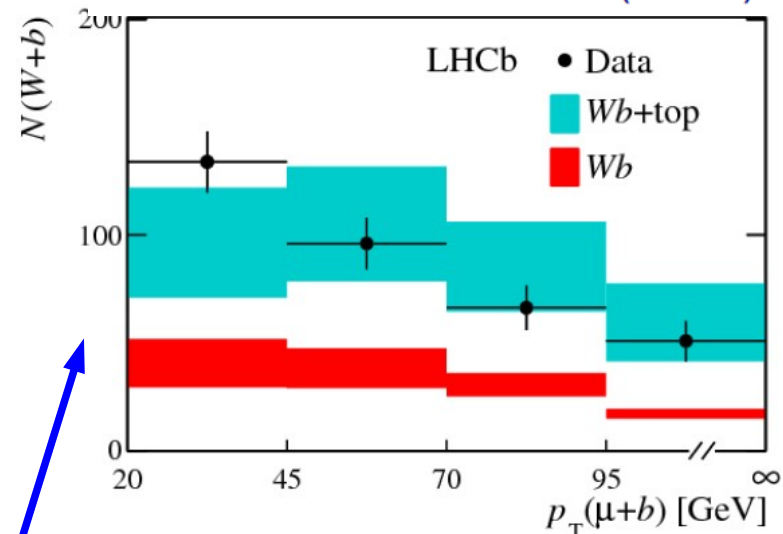
- ▶ Unfolded data
- ▶ Reasonably small data uncertainties:
 - ▶ Dominant systematic uncertainties: jet energy scale (5%) and b-tagging efficiency (3%)
- ▶ Substantial differences between theory predictions
- ▶ New theory calculations (SHERPA+OpenLoops and NNLO) perform well

J. Bossio

top Quark Production



👉 First observation (5.4σ)

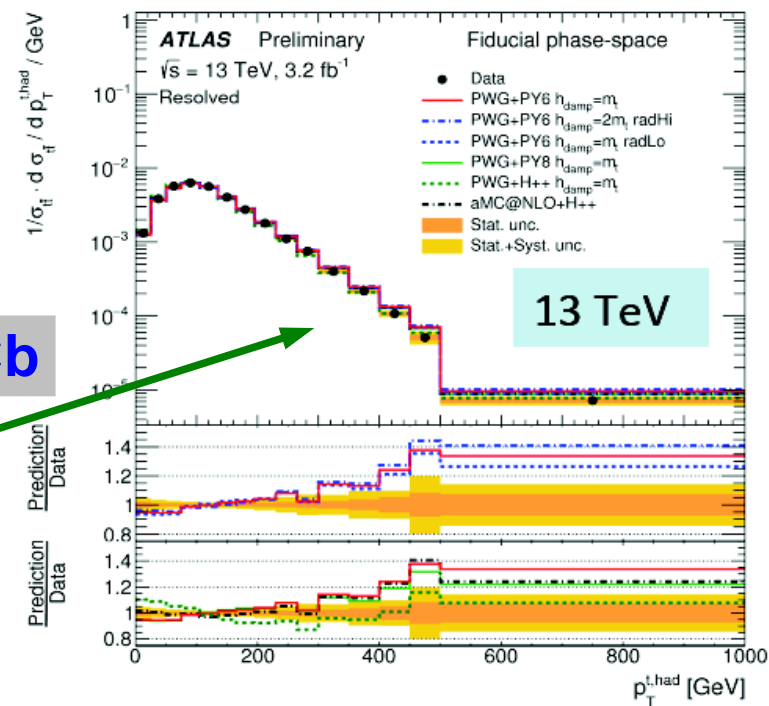


G. Krintiras, K. Lie, N. Castro, W. Hulsbergen, R. Coutinho

New x sections at 13 TeV & 5 TeV (CMS)

top in forward region: LHCb

Differential fiducial cross sections at 13 TeV: top p_T



For single-top → S. Stamm, M. Komm



$t\bar{t} + (\text{jets}, W, Z)$ at 13 TeV

K. Lie

$t\bar{t} + W/Z$: 13 TeV

Motivation

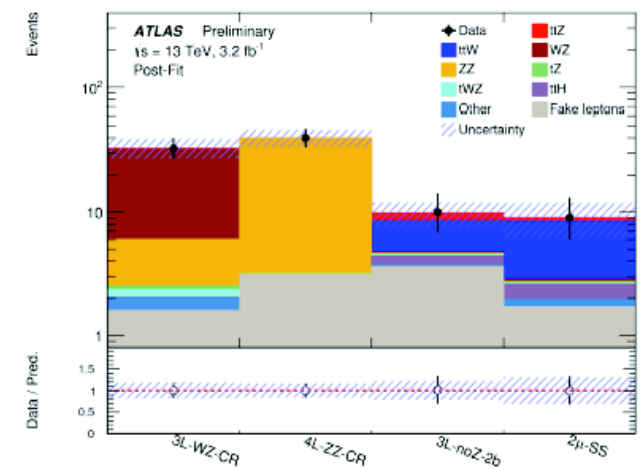
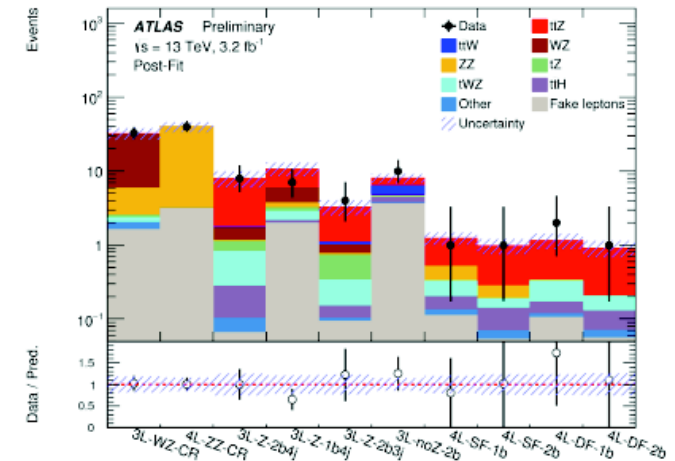
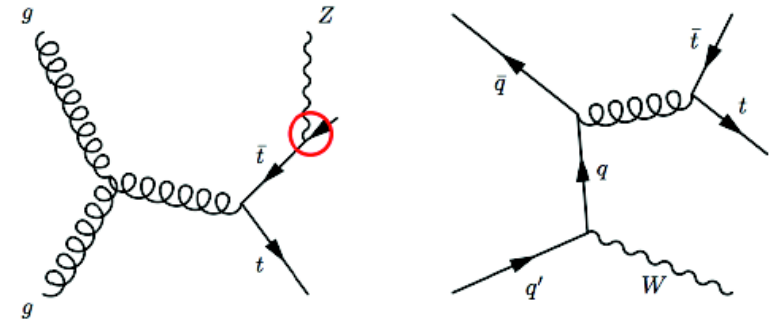
- $t\bar{t}Z$: probe tZ coupling
- $t\bar{t}W$: background to many searches

Main features

- Use 2(SS), 3 or 4 leptons
- Separate fit for $t\bar{t}Z$ and $t\bar{t}W$

Results

- $\sigma_{t\bar{t}Z} = 0.9 \pm 0.3 \text{ pb}$
- $\Sigma_{t\bar{t}W} = 1.4 \pm 0.8 \text{ pb}$
 - Still statistically limited
- NLO prediction (JHEP 07 (2014) 079)
 - $\sigma_{t\bar{t}Z} = 0.76 \text{ pb} \pm 11\% \text{ pb}$
 - $\sigma_{t\bar{t}W} = 0.57 \text{ pb} \pm 11\% \text{ pb}$





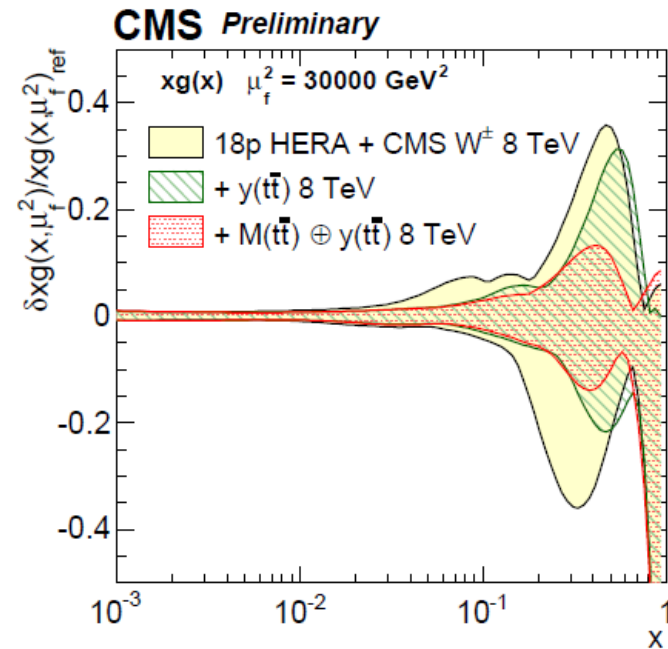
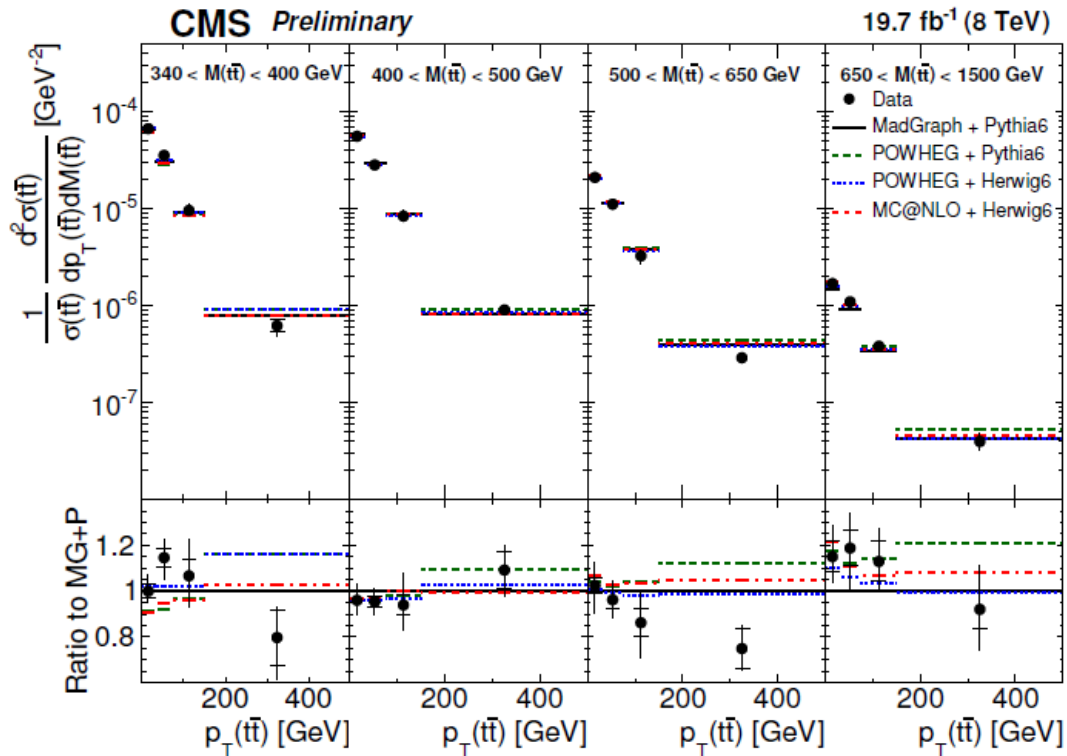
top & PDFs

$\sqrt{s} = 8 \text{ TeV}$

[CMS PAS TOP-14-013]

- Double differential cross sections: bin $t\bar{t}$ events
e.g. $p_T(t\bar{t})$ vs. $y(t\bar{t})$, $p_T(y)$ vs. $y(t\bar{t})$, etc

1. Use of differential top measurements for PDFs
2. Even double-differential \rightarrow better constraints



- $m(t\bar{t})$ vs. $y(t\bar{t})$ especially sensitive to PDFs
(2D distributions provide stronger constraints than 1D)
- Significant reduction of the uncertainty at high- x

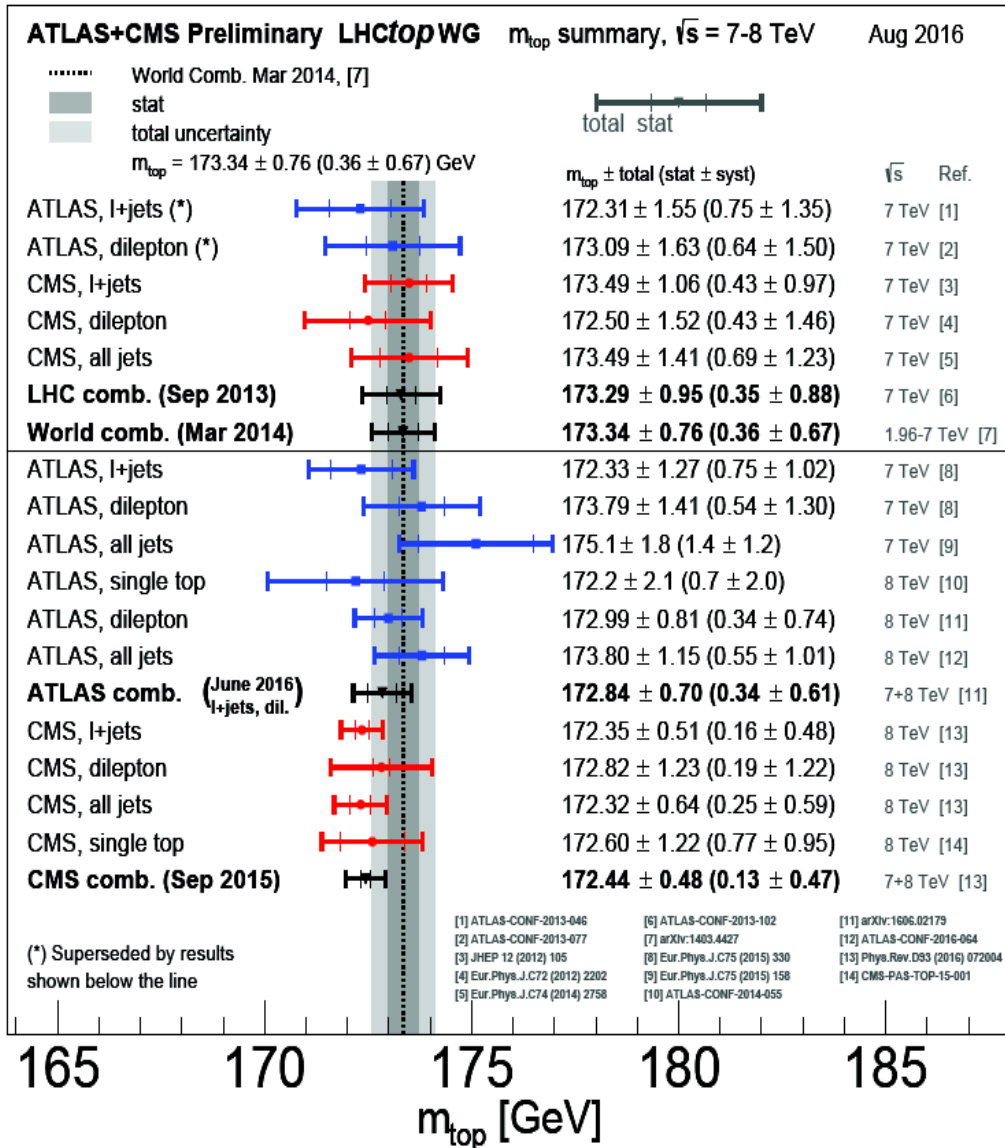
N. Castro, G. Krintiras



top Mass

Updated combinations

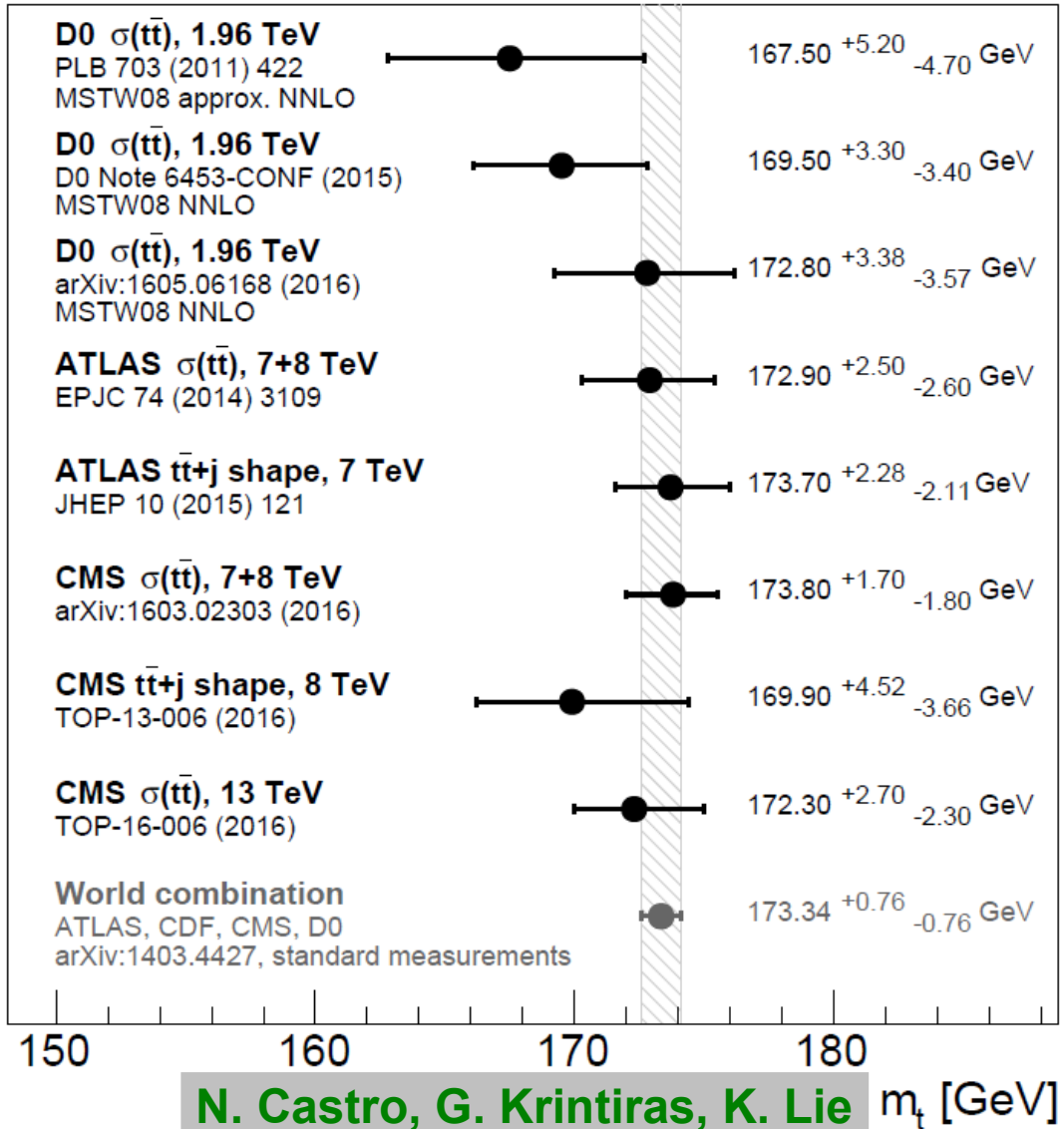
→ O(0.5 GeV) uncertainty on “MC mass”



Advanced precision of M_{top} demands theory-safe definition

Top-quark pole mass measurements

July 2016



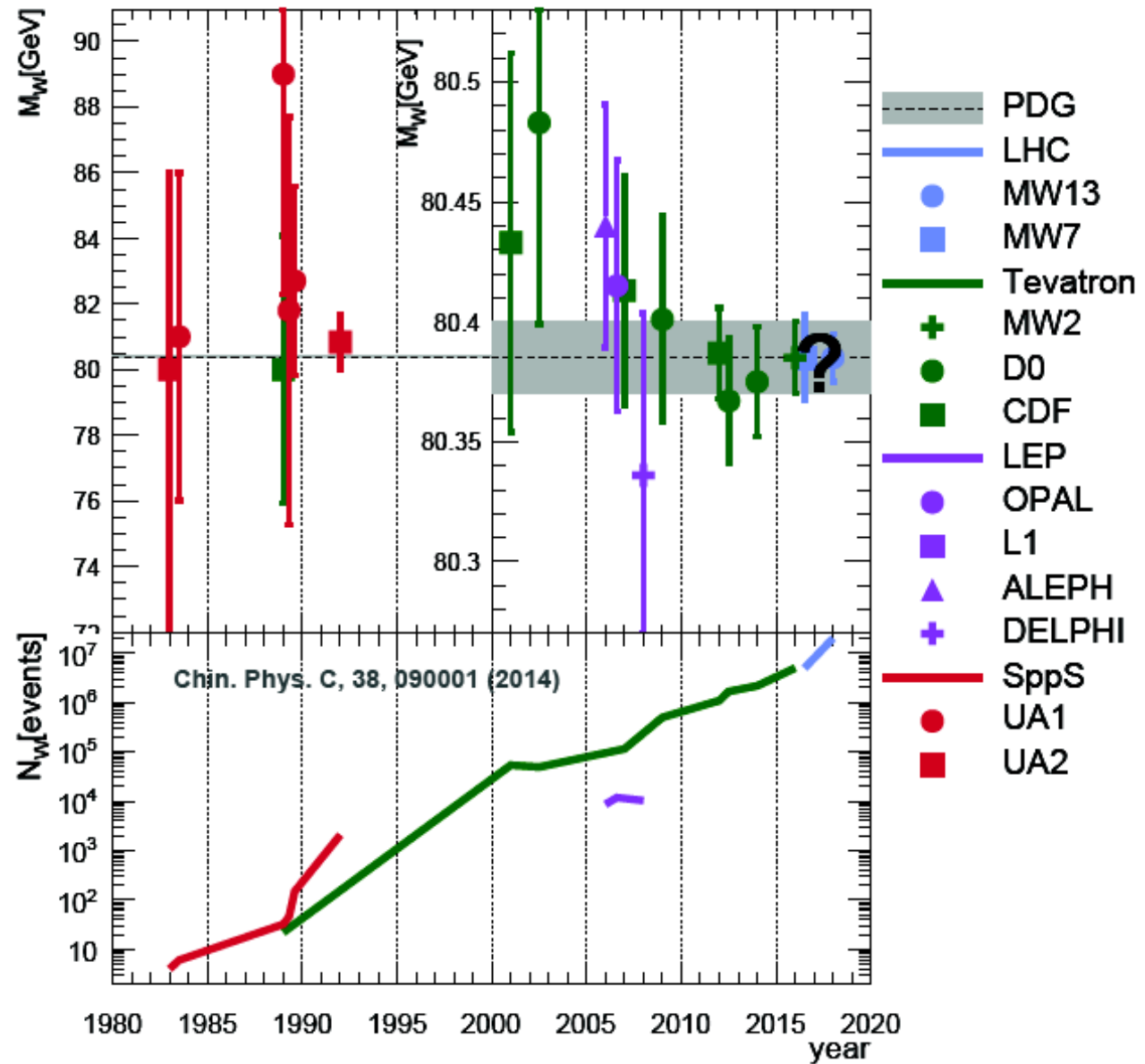
N. Castro, G. Krintiras, K. Lie m_t [GeV]



Challenge: W Mass

Highly untrivial, long-term combined effort required to improve precision

- Long term effort to M_W measurement from many teams and experiments.
- Theoretical predictions more precise than measurement.
- With CMS we showed proof of concept for detector performance and fit methodology.
- Very close cooperation between theoretical and experimental groups



J. Cuth



Higgs rediscovered at 13 TeV

New 13 TeV $H \rightarrow ZZ^* \rightarrow 4l$

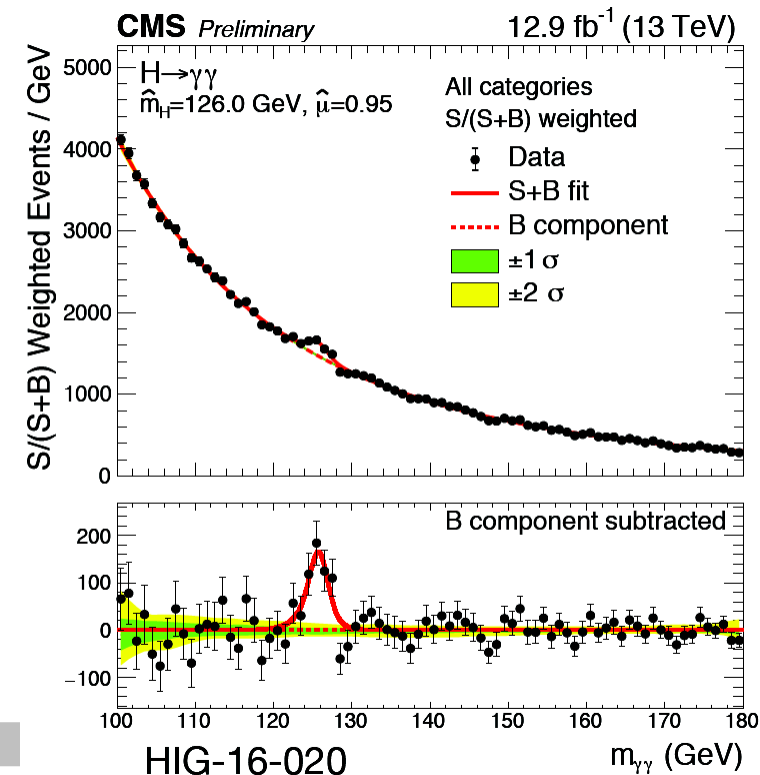
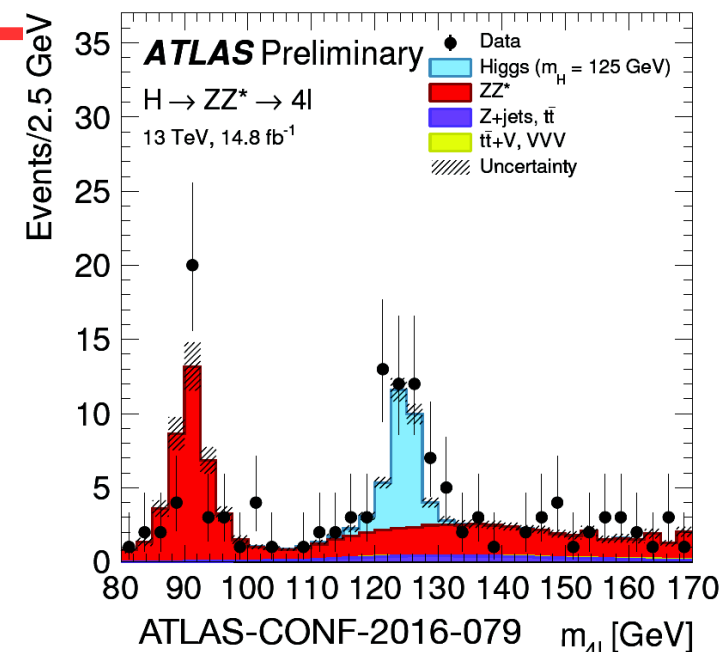
Run 1:

- Higgs mass determined to 0.2%
- Higgs signal strength ~ 1 , determined to 10%
- Higgs couplings tested for many scenarios and assumptions (consistent with SM).
- Higgs spin-parity is compatible with SM from all studies
- Fiducial/Differential cross-section measurement at 8TeV

Higgs boson is very consistent with SM predictions, but measurements are still statistically limited.

New 13 TeV $H \rightarrow \gamma\gamma$

Y. Huang
Fermionic decay modes \rightarrow N. Chernyavskaya



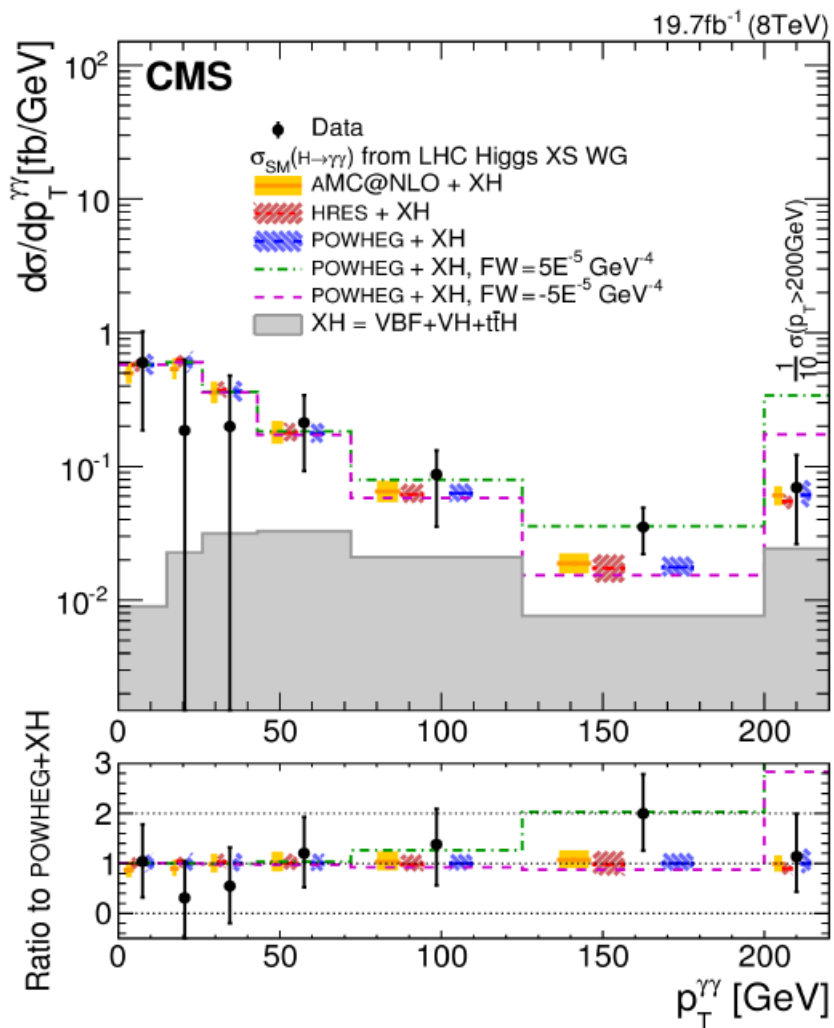


“Differential” Higgs

Move from discovery mode towards precision mode
→ measure Higgs differentially, e.g. $p_T^{\gamma\gamma}$

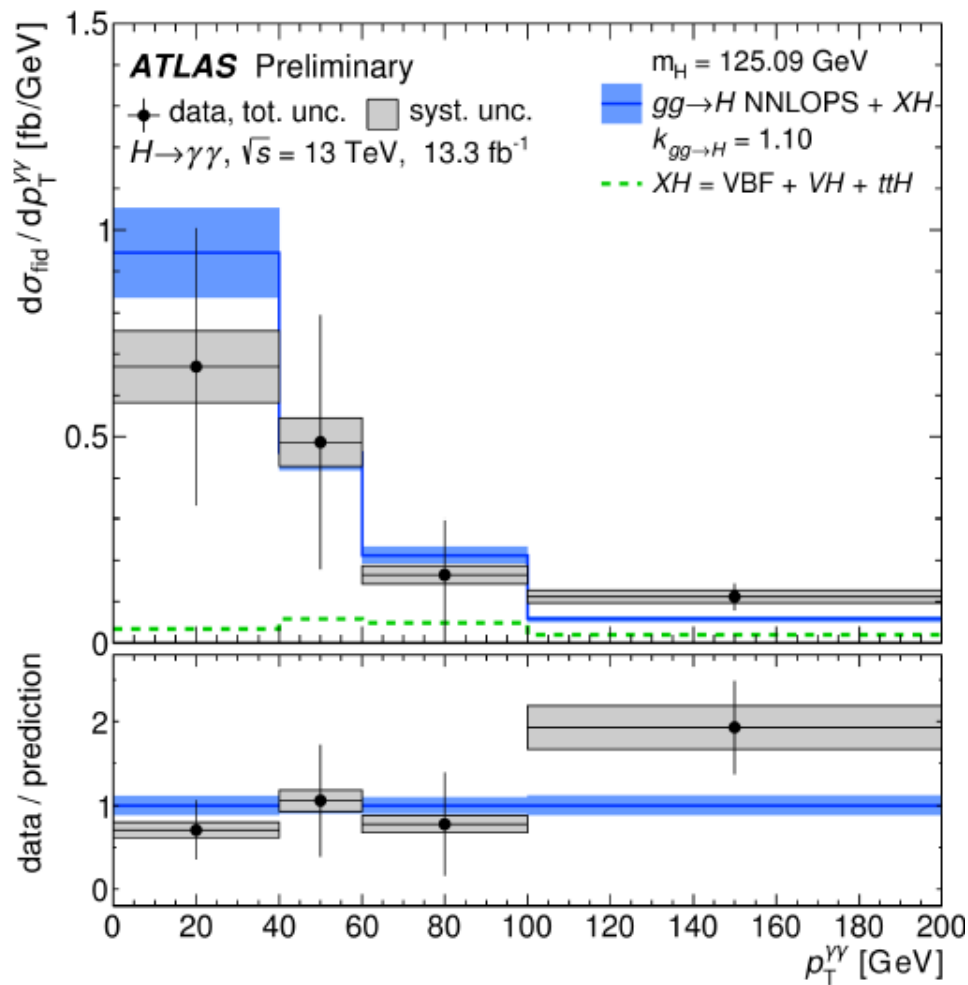
8 TeV

13 TeV



CMS:
spectrum
as SM exp.

ATLAS:
spectrum
slightly
harder



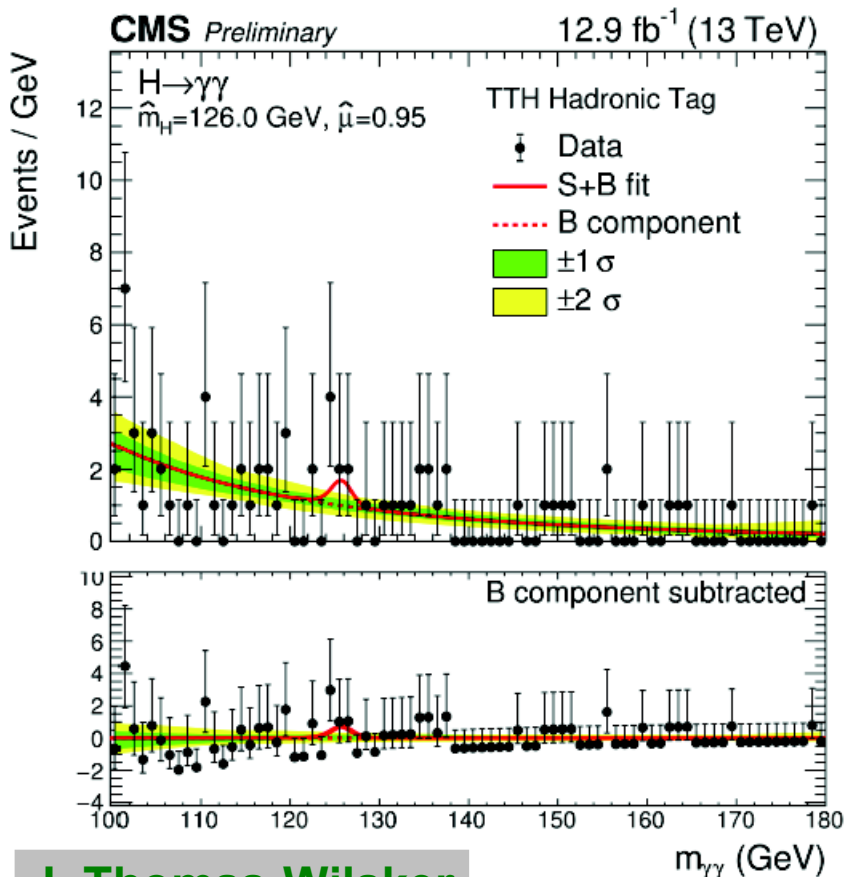
L. Viliani



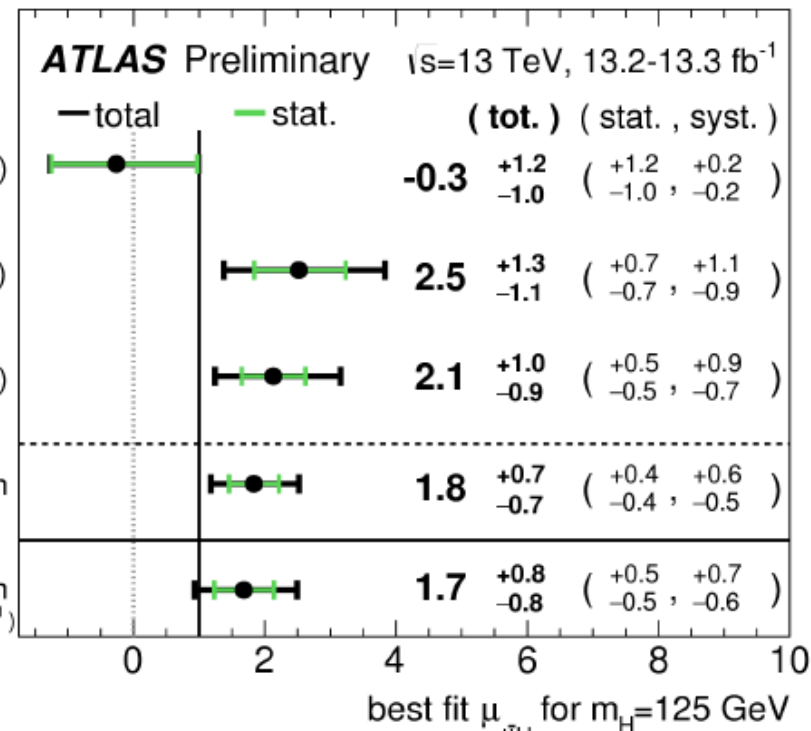
ttbar Production Mode of H

x section enhanced by factor ~4 at 13 TeV
still huge statistical uncertainties

E.g.: $\gamma\gamma$ decay mode



J. Thomas-Wilsker



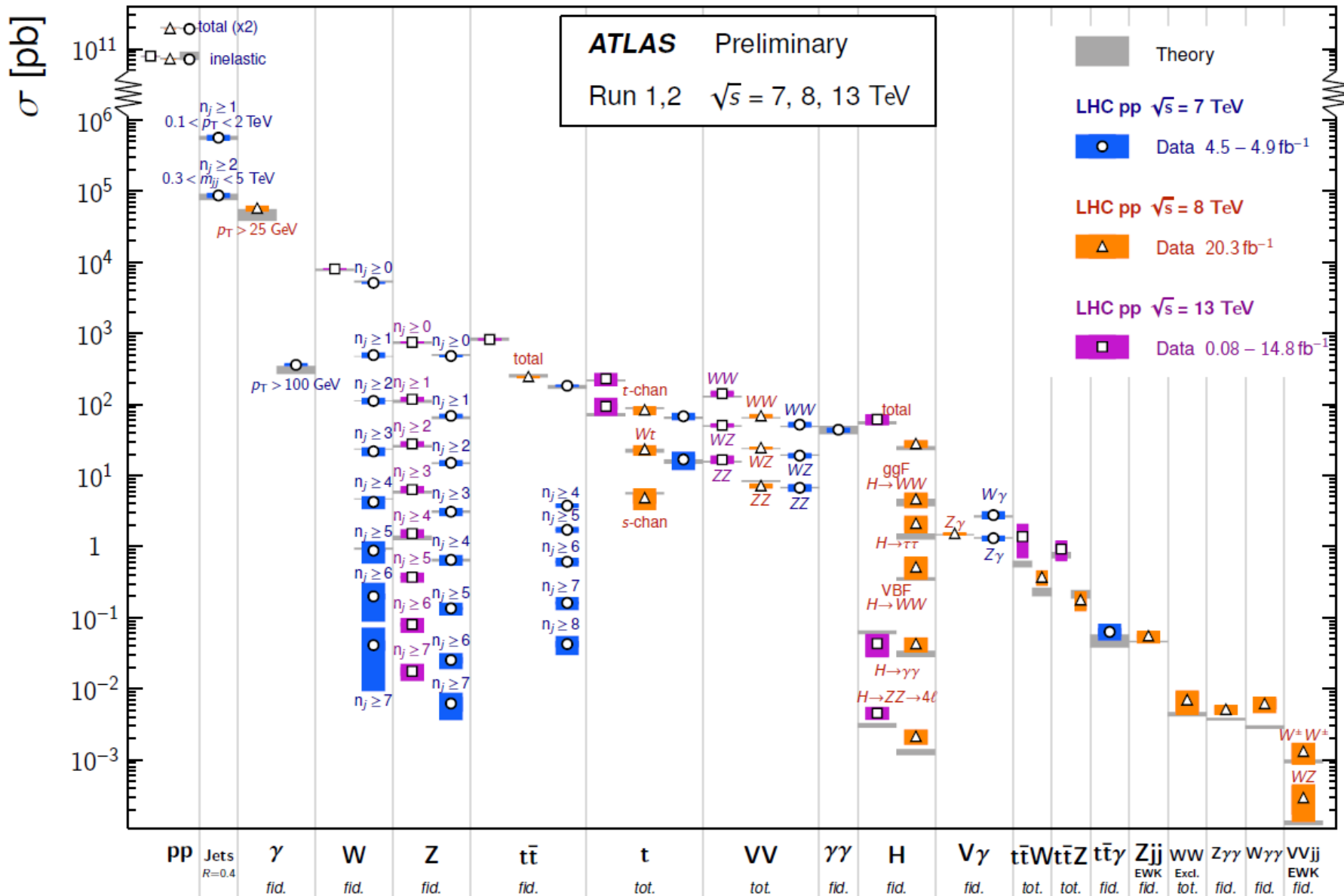
CMS	μ (2.3 - 2.7 fb $^{-1}$)	μ (12.9 fb $^{-1}$)
multilepton	$0.6^{+1.4}_{-1.1}$	$2.0^{+0.8}_{-0.7}$
$\gamma\gamma$	$3.8^{+4.5}_{-3.6}$	$1.91^{+1.5}_{-1.2}$
bb	$-2.0^{+1.8}_{-1.8}$	
Combination	$0.15^{+0.95}_{-0.81}$	



Latest ATLAS Summary

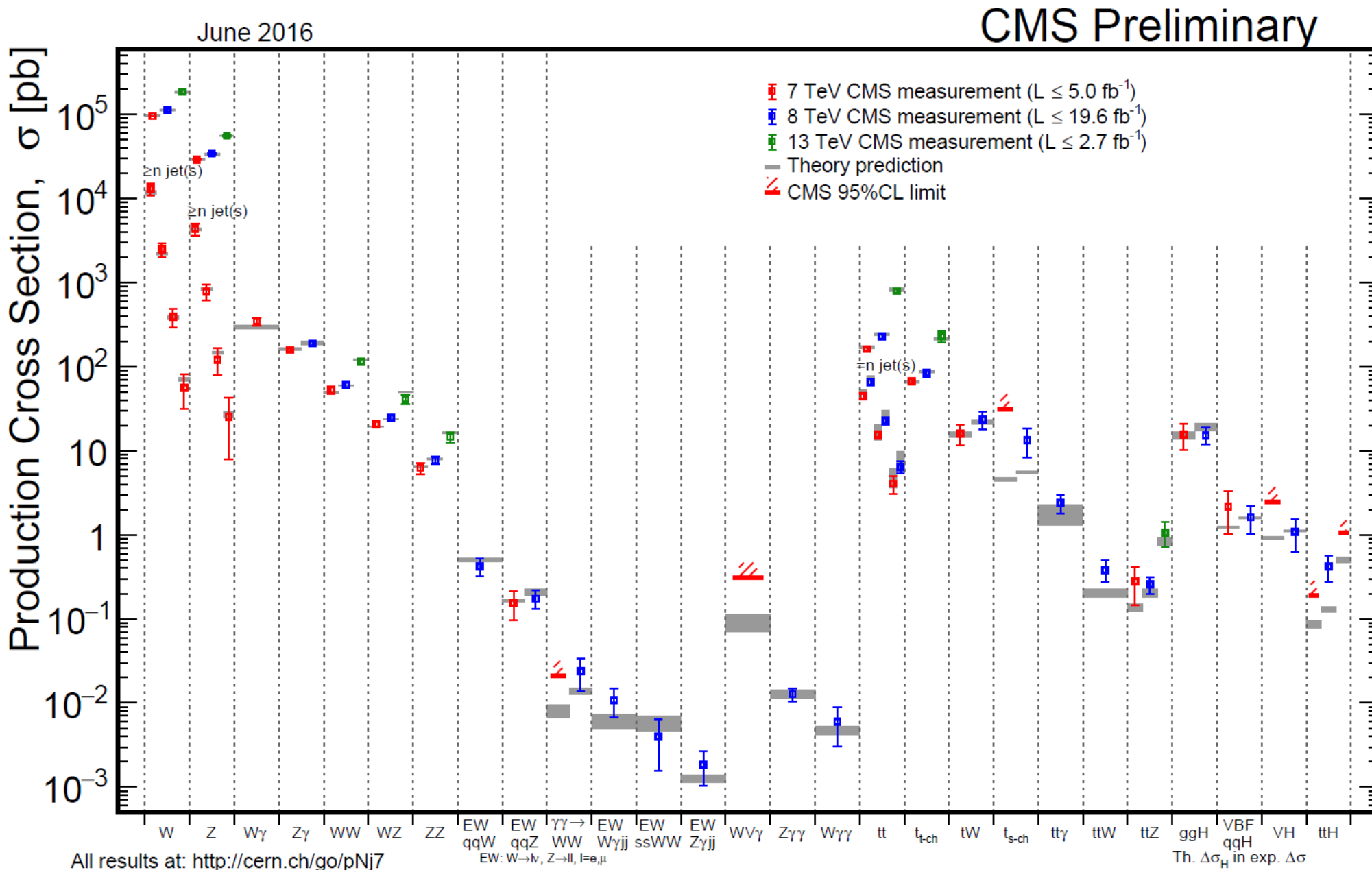
Standard Model Production Cross Section Measurements

Status: August 2016





Latest CMS Summary





HERA EW Fit: q -Z Couplings

Exploit final HERA datasets to constrain electroweak parameters: light quark couplings, M_W , $\sin^2\theta_W$

Results from H1 and ZEUS collaborations

- χ^2/ndf typically around 1
 - ZEUS: 2946 datapoints
 - H1: 1388 datapoints
- u -type coupling better constrained than d -type coupling
 - > sensitivity from valence quarks
- d -type coupling:
 - > benefit from polarisation

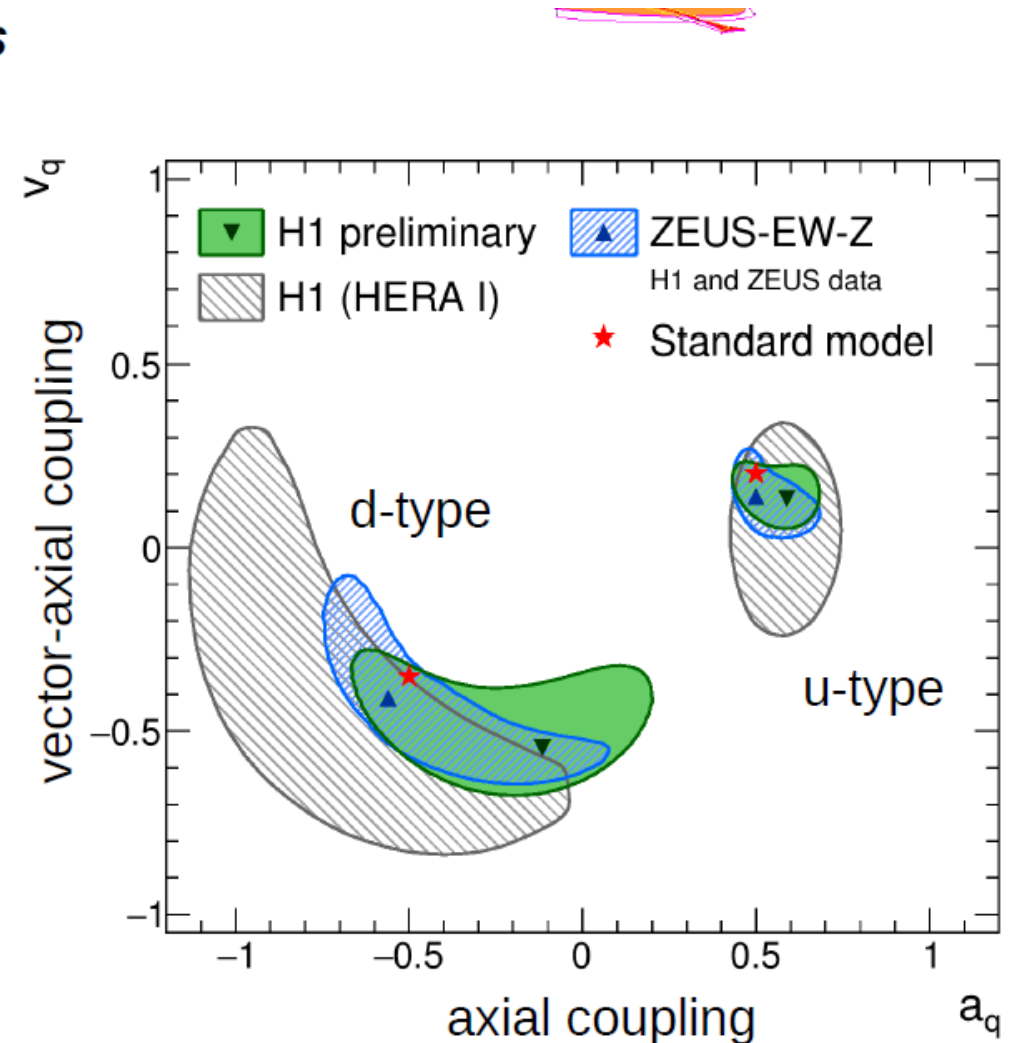
Results from H1 and ZEUS compatible

- Results compatible with SM expectation

Comparison to H1 HERA-I

Phys.Lett.B 632 (2006) 35

- Considerably improved sensitivity using polarised HERA-II data
- Polarisation in HERA-II important for axial-vector couplings



D. Britzger



Tools needed for Fits

APPLfast-NNLO

→ M. Sutton



→ V. Radescu

Simultaneous fit to jet data from multiple experiments

Avoids simple α_s averaging!

Input to combined fit

- choose H1, DØ (pure NLO) and CMS
 - no correlations assumed for exp. uncertainties across experiments
- PDF choice: MMHT2014nlo (others very similar)

Result

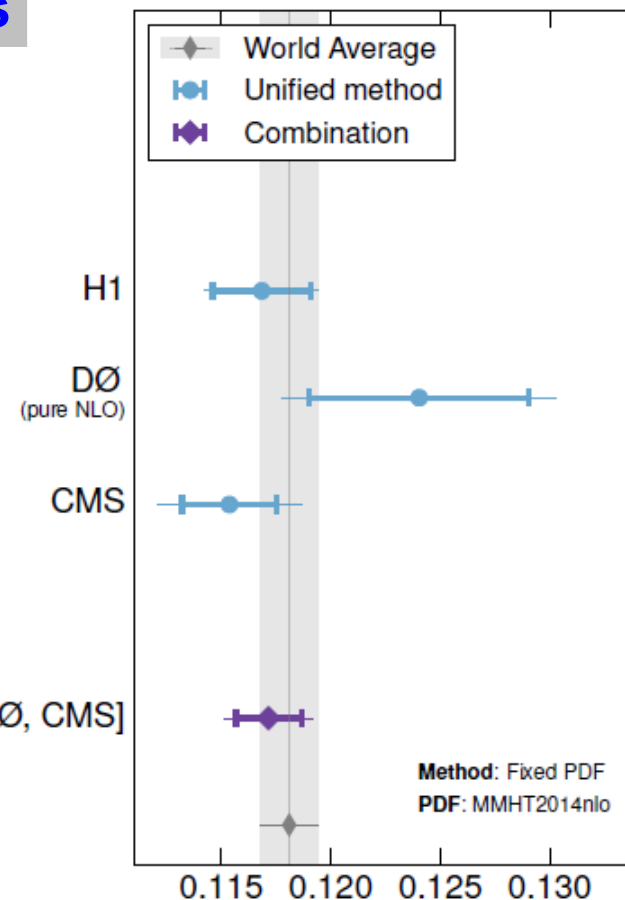
$$\alpha_s(M_Z) = 0.1172 (15)_{\text{exp}} (5)_{\text{NP}} (9)_{\text{PDF, MMHT}} (8)_{\text{PDF set}} (5)_{\text{PDF } \alpha_s} (50)_{\text{scale}}$$

$$= 0.1172 (15)_{\text{exp}} (14)_{\text{theo (except scale)}} (50)_{\text{scale}} \quad [\text{H1, DØ, CMS}]$$

$$\chi^2_{\text{min}}/\text{ndf} = 152.2/178 = 0.855$$

Conclusions

- combined fit shows reasonable χ^2/ndf
- combined result compatible with individual fits
- uncertainties reduced



experimental uncertainty
 total uncertainty (except scale)
 $\alpha_s(M_Z)$

D. Savoiu



Summary & Outlook

- Beyond design performance of the LHC and the experiments
- **But no sign of new physics so far :-)**
- A plethora of new measurements, many at 13 TeV
- Sometimes limited in precision already by syst. effects and/or luminosity
 - ➔ Ratios of cross sections
 - ➔ Improve on PDFs and MC models
- Numerous (multi-)differential measurements and in fiducial volume!
- MC simulations use NLO+PS as a default and in almost all cases theory at least at NNLO is at hand
- ➔ Go find the odd-looking deviation from the SM
- ➔ Excellent playground for studies with more data, more ideas, and more precision in the future



Thank you for your attention!





Backup Slides



Input to HERA EW Fits

Input data to ZEUS fit



HERA-I: NC and CC

- All **H1** and **ZEUS** HERA-I datasets
 - e^+ and e^-
 - NC and CC; low and high- Q^2
 - unpolarised

HERA-II: NC and CC

- **ZEUS** high- Q^2 polarised data
- **H1** high- Q^2 unpolarised data
- **ZEUS** Reduced- E_p (unpolarised)
- **H1** Reduced- E_p (unpolarised)

Correlations as in HERAPDF2.0

- More than 2900 data points

ZEUS-Fitter as fitting framework

Input data to H1 fit



H1 Low- Q^2 data

- NC and CC, e^+ and e^-
- All H1 HERA-I and HERA-II data are combined into one dataset

H1 High- Q^2 data

- NC and CC, e^+ and e^-
- HERA-I
 - H1 unpolarised data
- HERA-II
 - H1 polarised data

Polarisation measurements

- treated as measurement on its own

Alpos used as fitting framework

D. Britzger