Results from ATLAS and CMS: Strong Interactions and New Physics

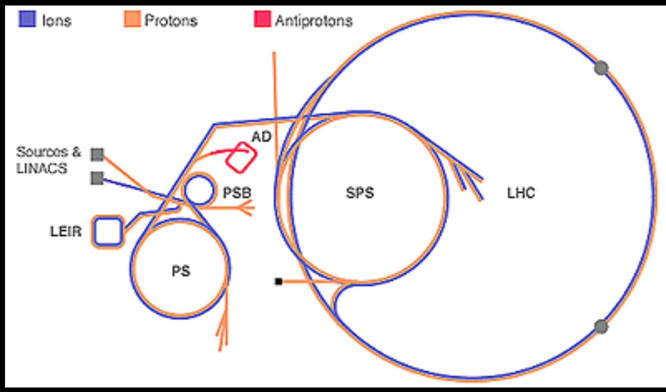
- LHC and operation (run-I, run-II)
- ATLAS detector
- QCD
- top-quark
- Heavy Ion
- new physics (BSM, Exotica)

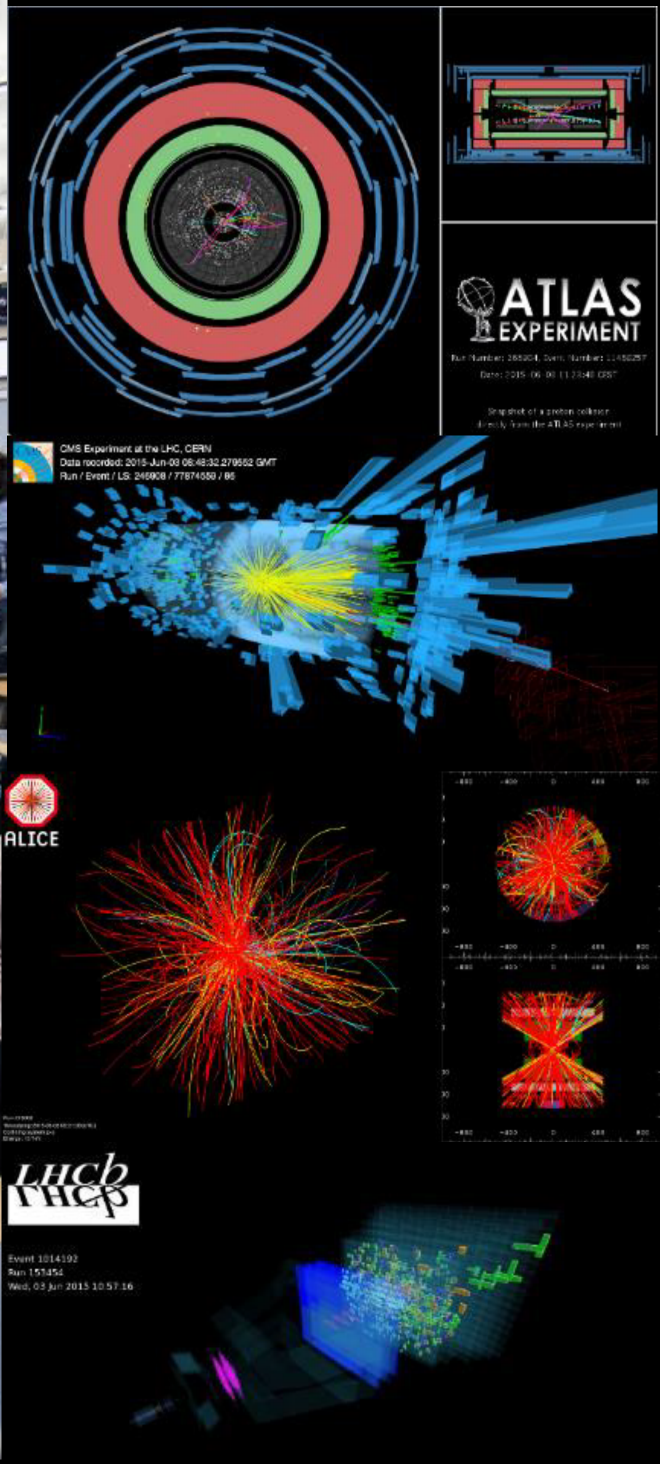
complementary ATLAS & CMS presentations at this workshop:

- **Paolo Azzurri:** **Results from CMS and ATLAS: Electroweak Symmetry Breaking and Beyond**
- Roman Lysak: Soft QCD topics from ATLAS
- Michael Ryan Clark: the Ridge and BE-correlations with ATLAS

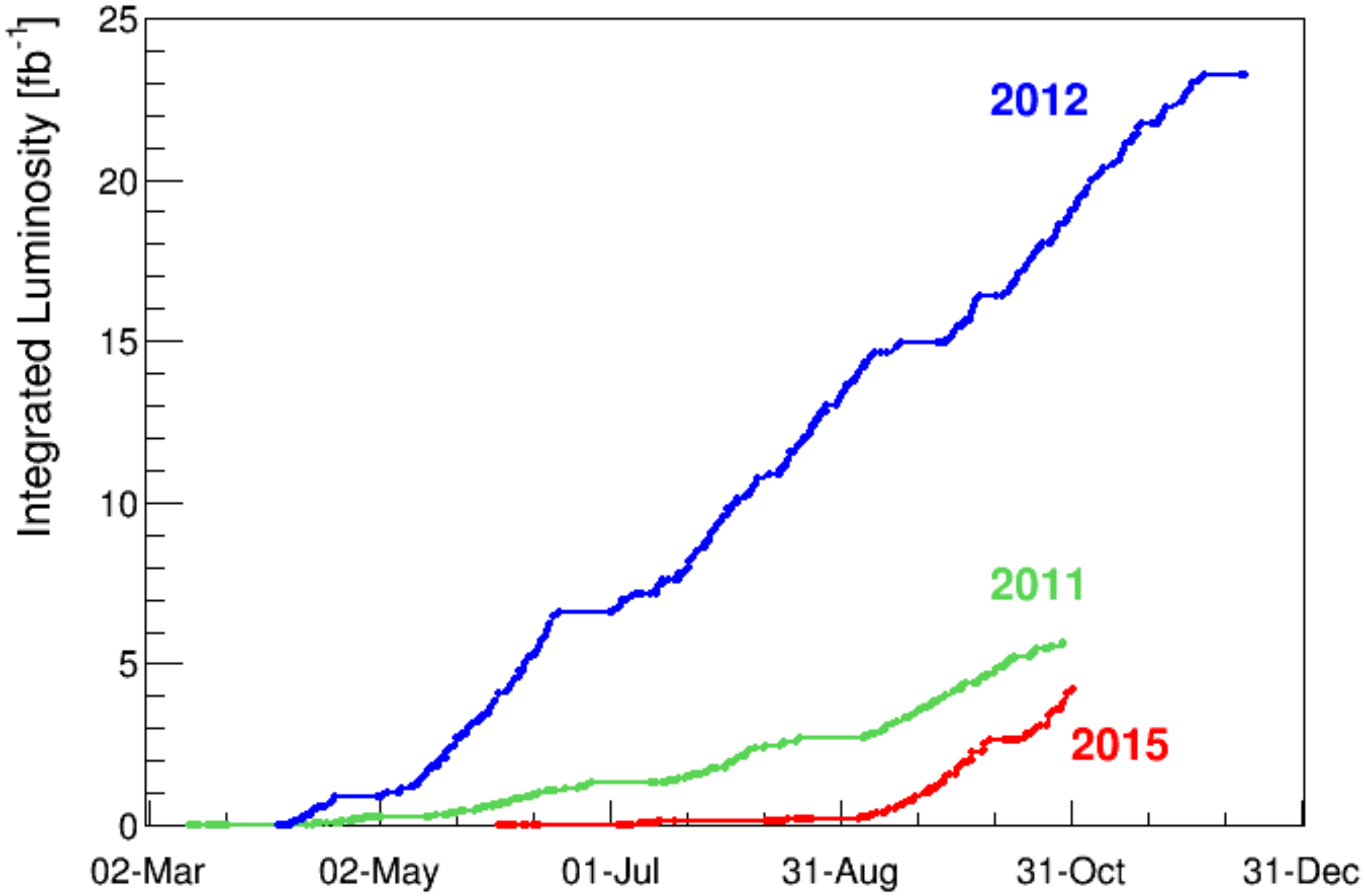
LHC operation

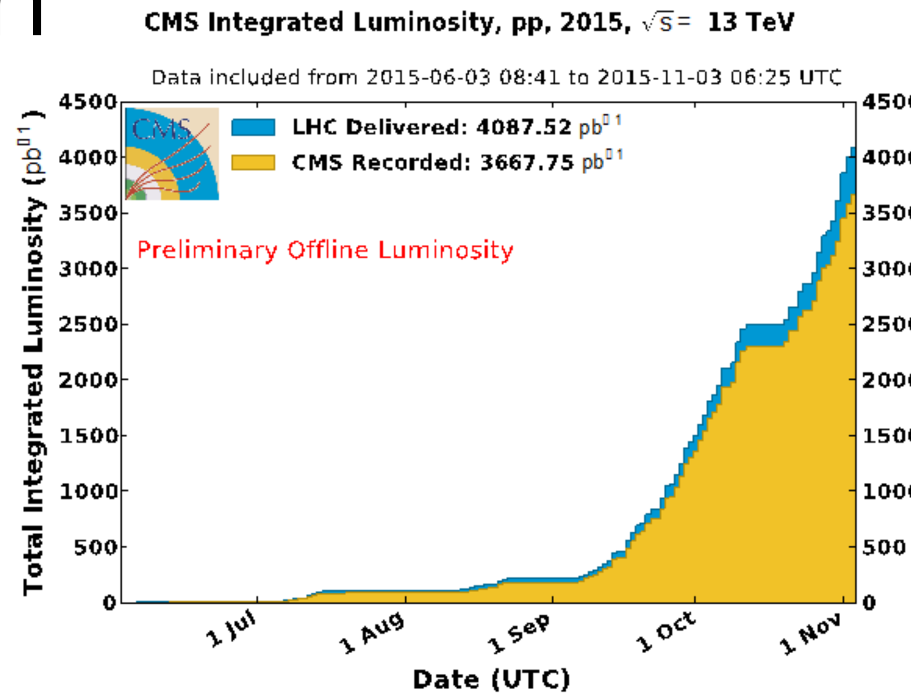
June 2015: LHC back in business with record p-p-collision energy of 13 TeV c.m.

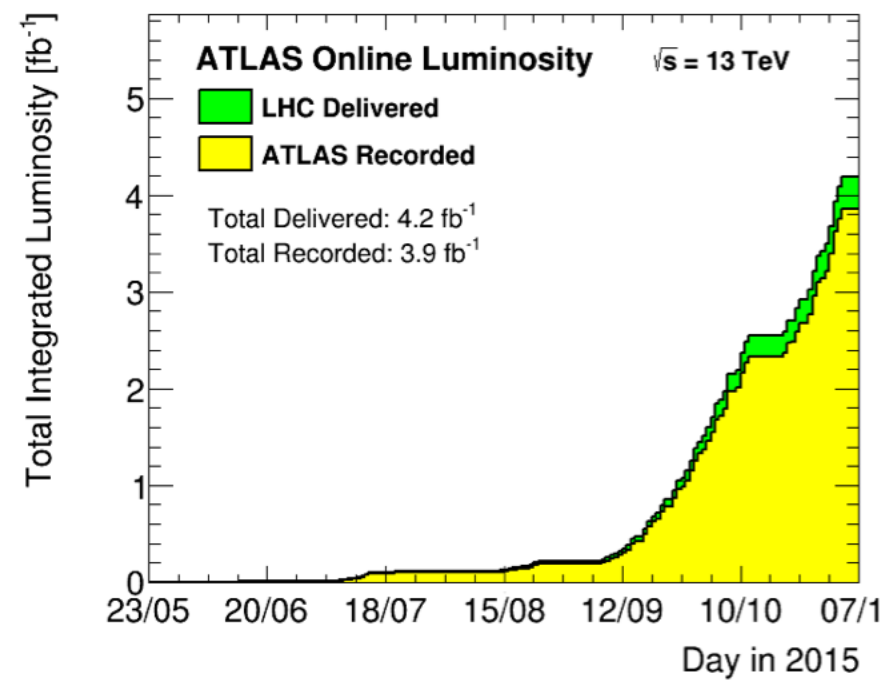


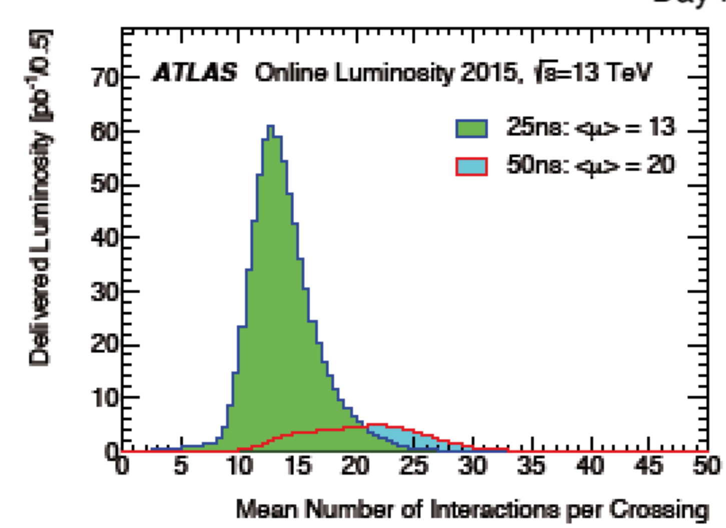


LHC operation









run-I : → 2012, ~25 fb^{-1} @ 7/8 TeV

LS-I : 2013/14, maint. & energy upgrade
> 10^6 working hours in LHC tunnel

run-II : 2015, ~4 fb^{-1} @ 13 TeV
2015-2018: ~100 fb^{-1} @ 13/14 TeV

LS-II : 2019/20 hl-LHC civil engineering

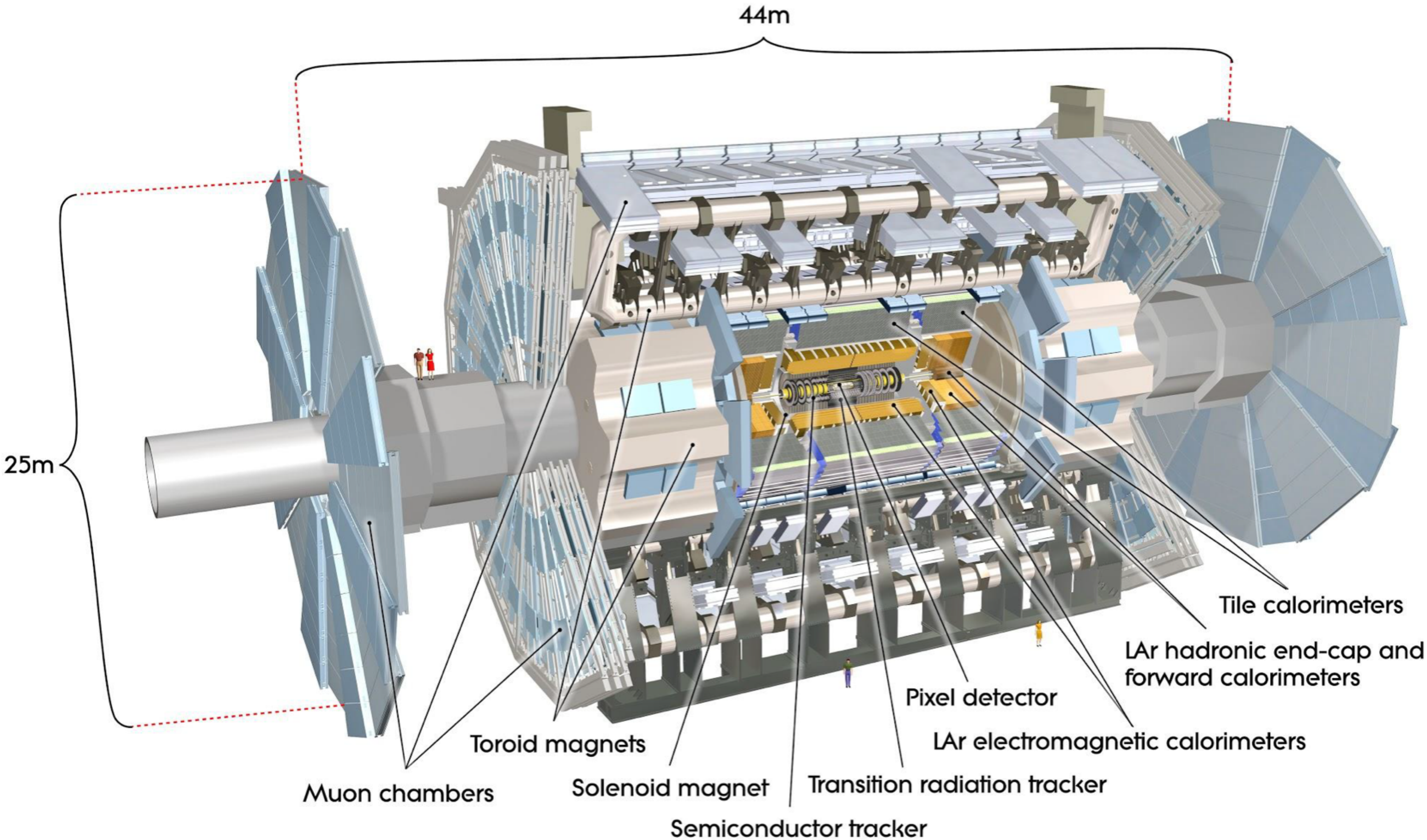
run-III : 2021-23, ~200 fb^{-1} @ 13/14 TeV

ATLAS detector

Length: 44 m
Height: 25 m
Weight: 7000 t

3000 Physicists & Engineers (incl. 1000 Students)
38 Nations, 178 Institutes
~500 papers published

$150 \cdot 10^6$ electronic readout channels
40 MHz collision rate
10^{14} B/s raw data flux

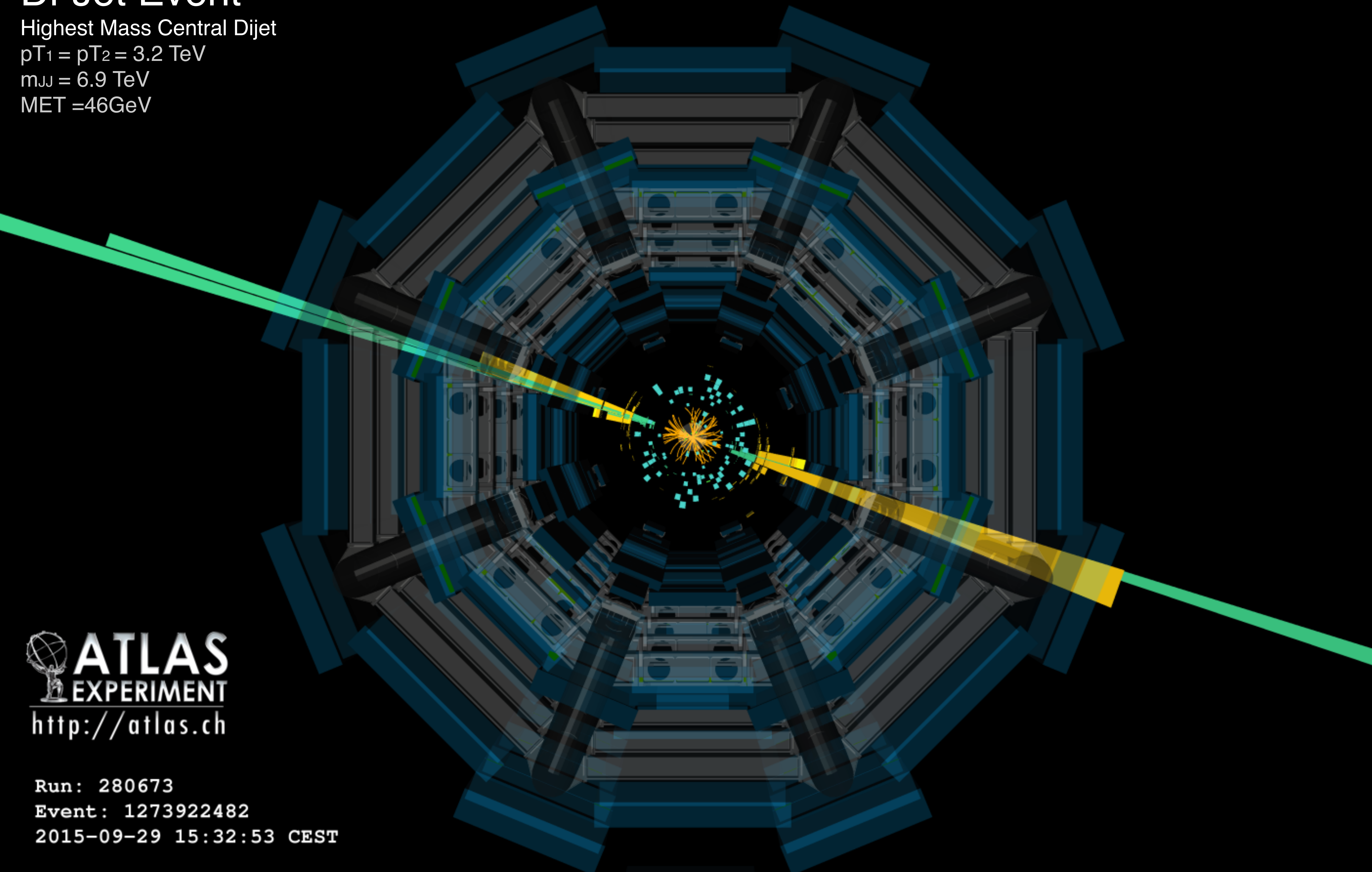


Planning & construction 1990 to 2007, operation from 2009 to ~ 2035

ATLAS detector

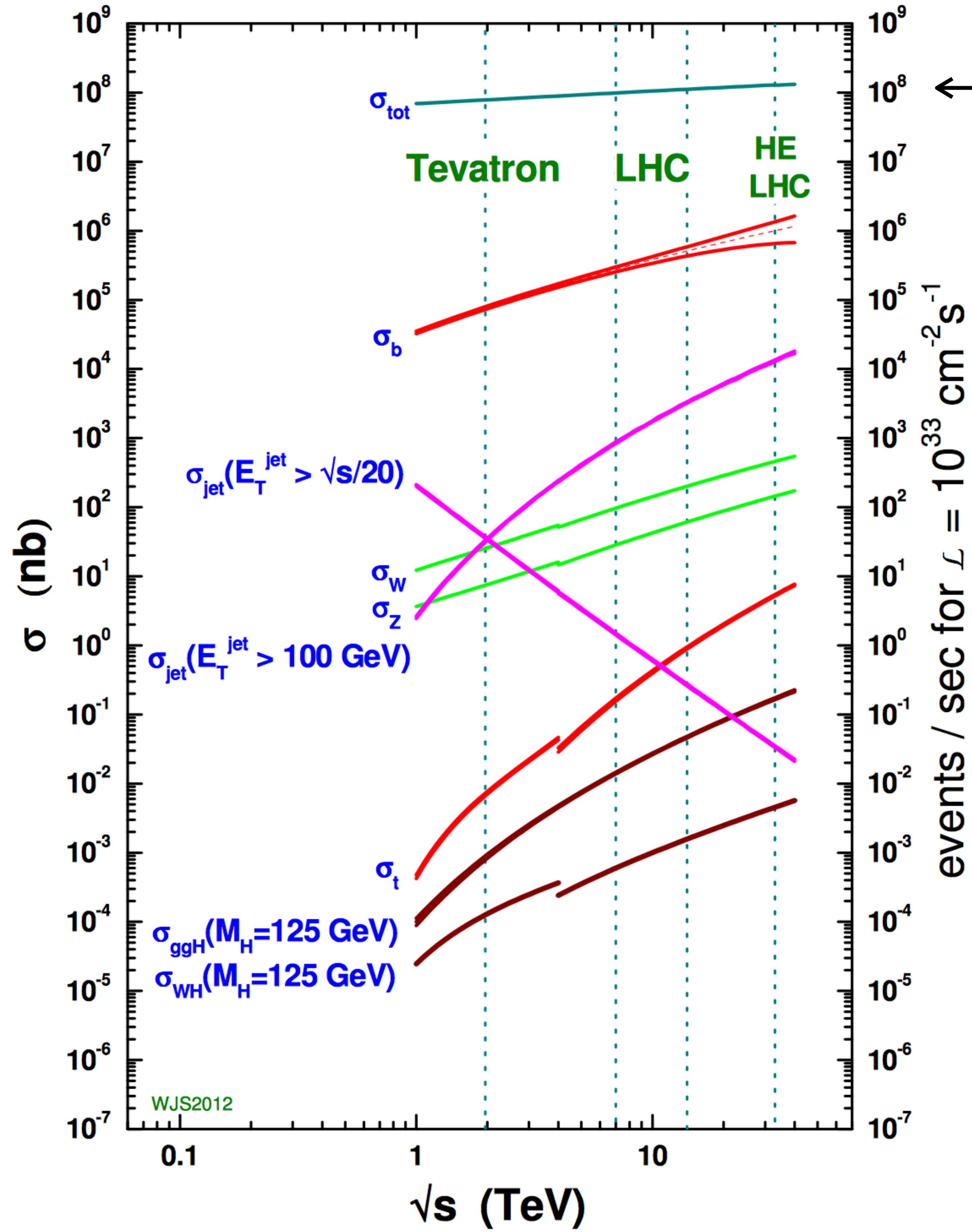
Di-Jet Event

Highest Mass Central Dijet
$p_{T1} = p_{T2} = 3.2$ TeV
$m_{JJ} = 6.9$ TeV
MET =46GeV



production cross sections at the LHC

proton - (anti-)proton cross sections



↔ total cross section: 10^8 evts/s (dominated by strong interaction)

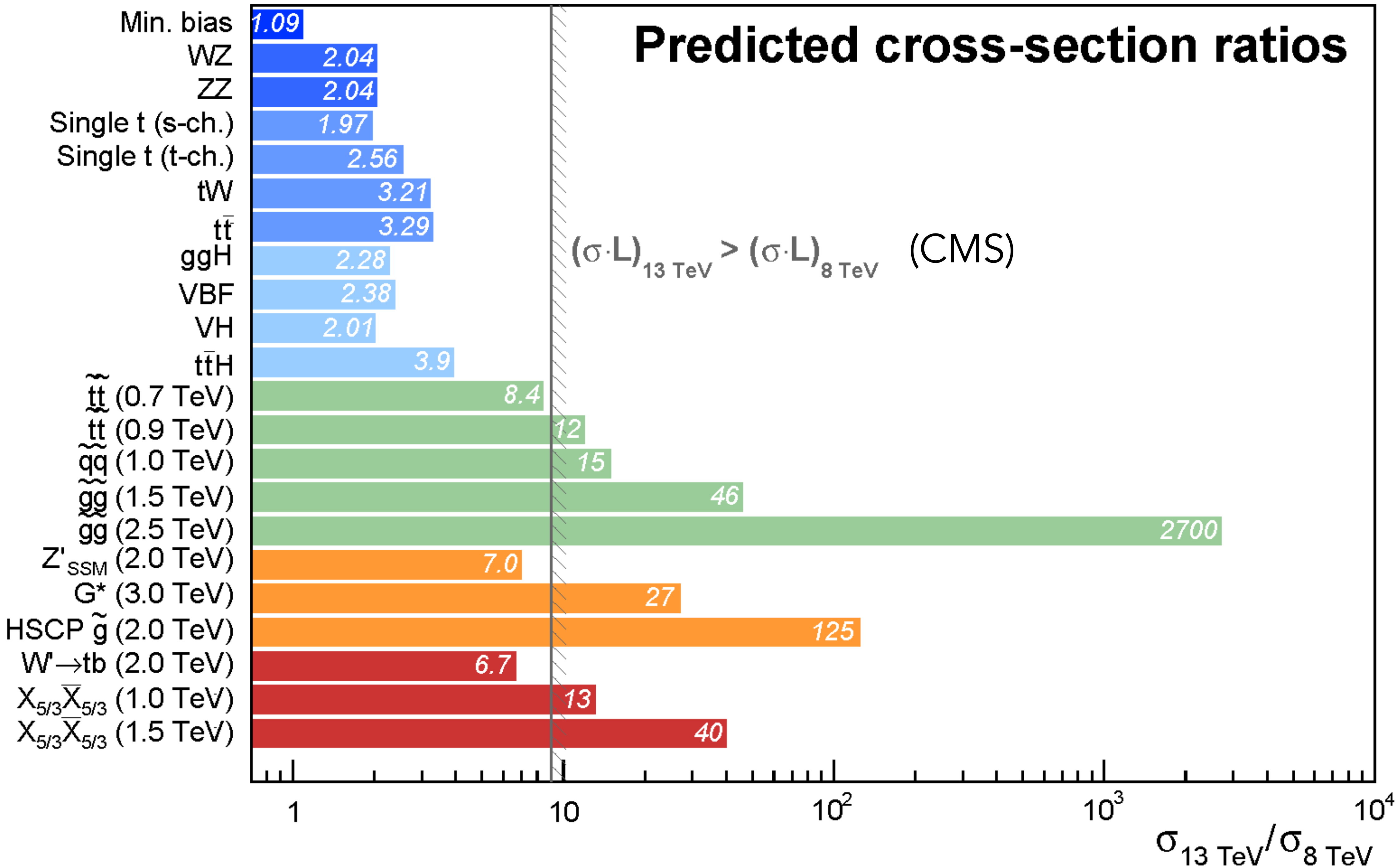
↔ max. read-out: ~ 10^3 evts/sec

↔ O(1) top-event/sec

↔ O(1) Higgs/min

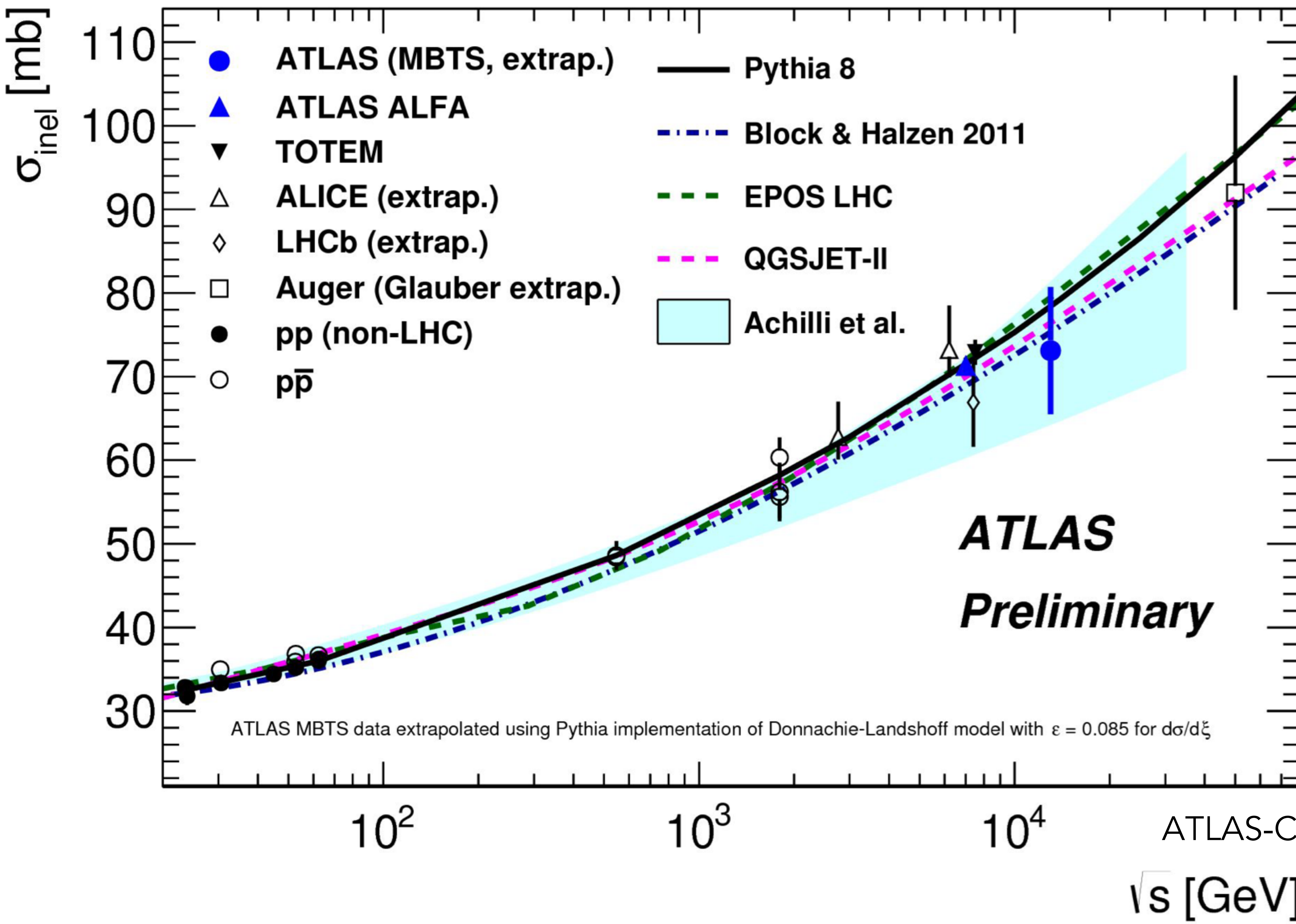
production cross sections at the LHC

cross section ratios 13 TeV / 8 TeV



- for SM processes (top-quark; Higgs): x-sections increase by ~2…3 at 13 TeV
- for new phenomena and masses of O(TeV), increase of ~10 to 100s
- therefor, some early results from run-II already surpass those from run-I

Inelastic pp cross section



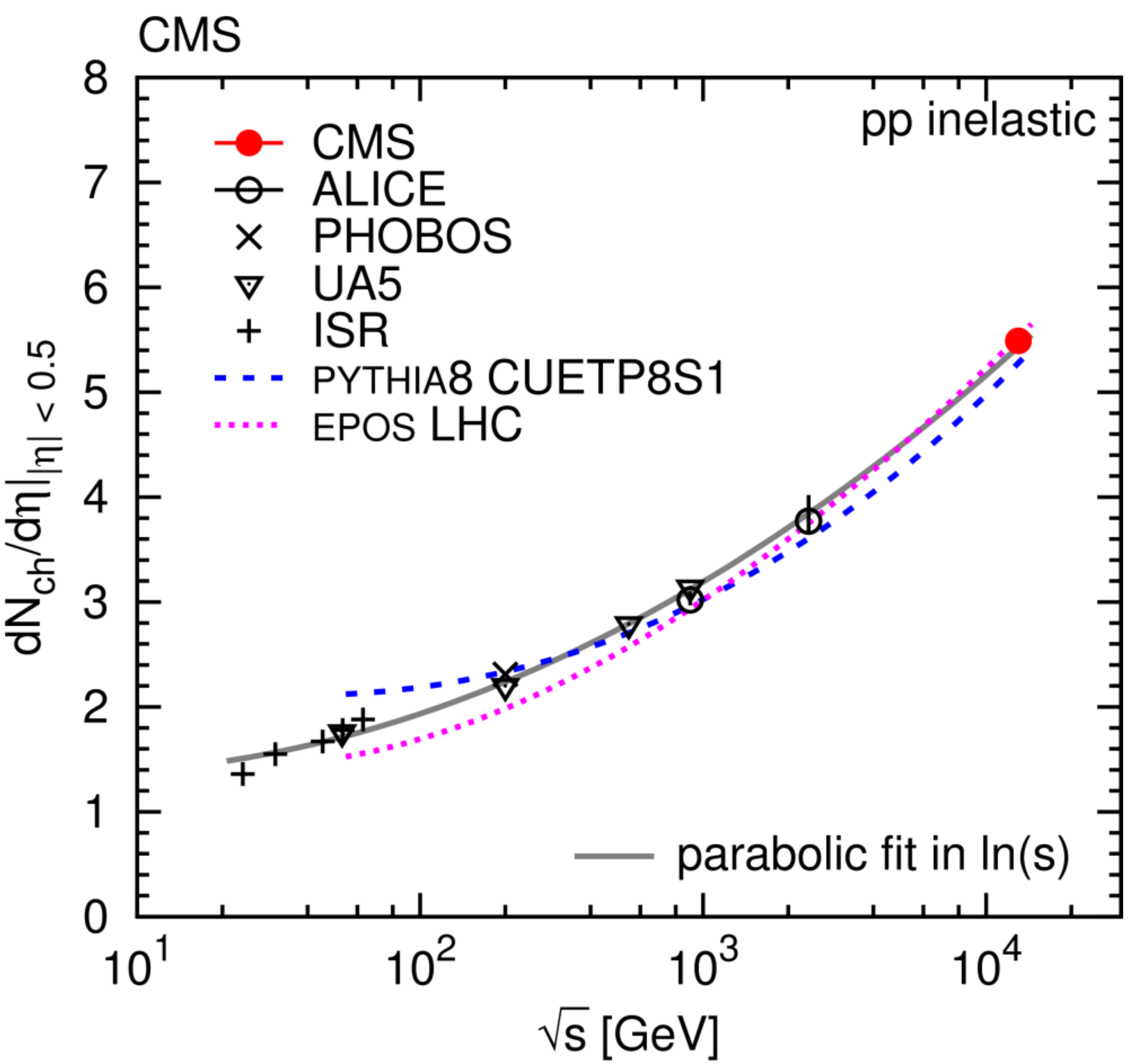
ATLAS-Conf-2015-038

ATLAS measurement at 13TeV performed using Minimum Bias Trigger Scintillators (MBTS) mounted in front of the forward calorimeters

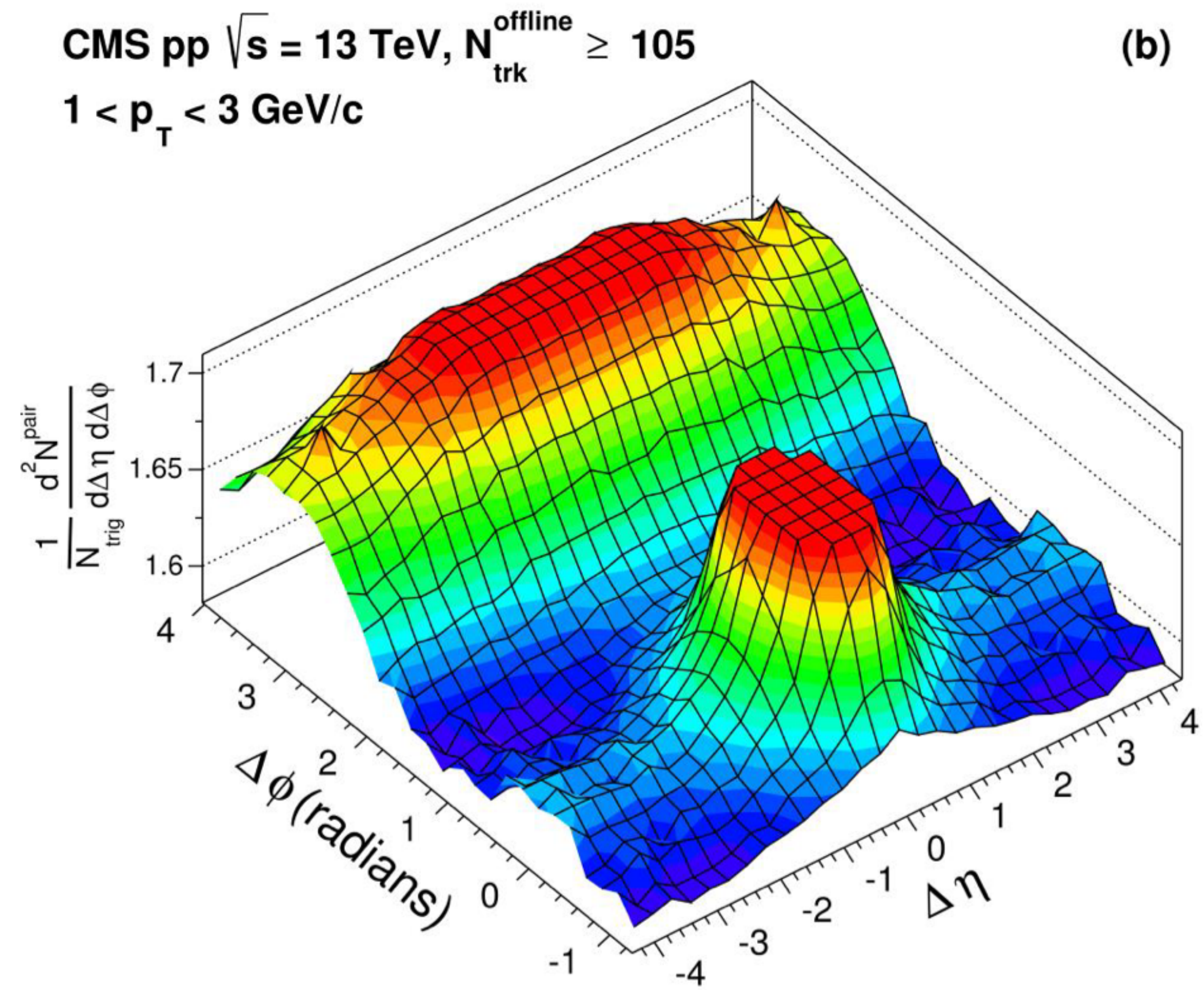
Total cross section:

$\sigma_{inel.}$ = 73.1 ± 0.9 (exp) ± 6.6 (lumi) ± 3.8 (extr) mb

Charged Particle Multiplicities and Correlations



measurement of pseudorapidity distribution of charged hadrons, data consistent with expected dependence on centre-of-mass energy. Published in PLB 751 (2015) 143.

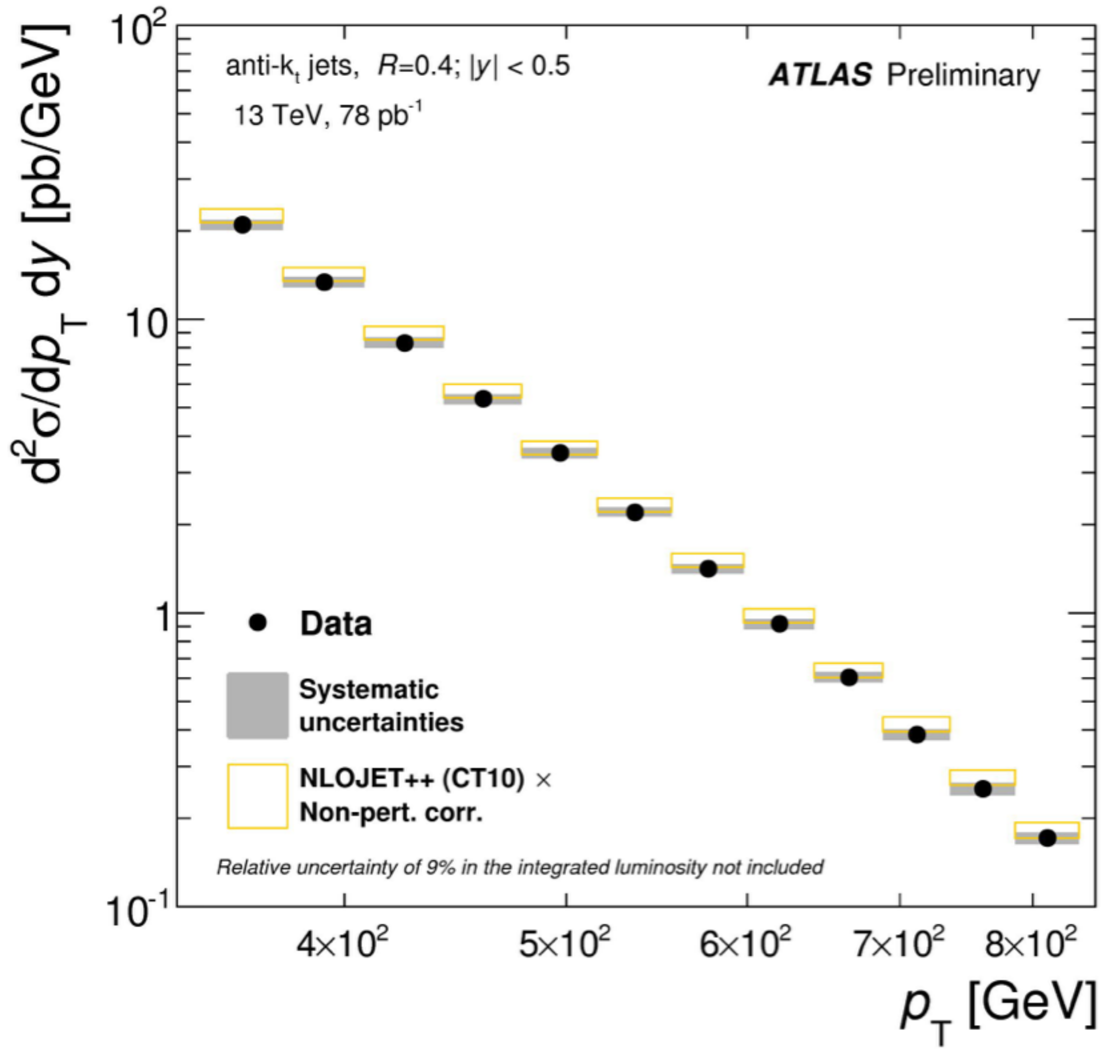


two-particle correlations, confirming the presence of a ridge-like structure for same-side ($\Delta\phi \sim 0$) pairs in high-multiplicity events at 13 TeV. (arXiv:1510.03068)

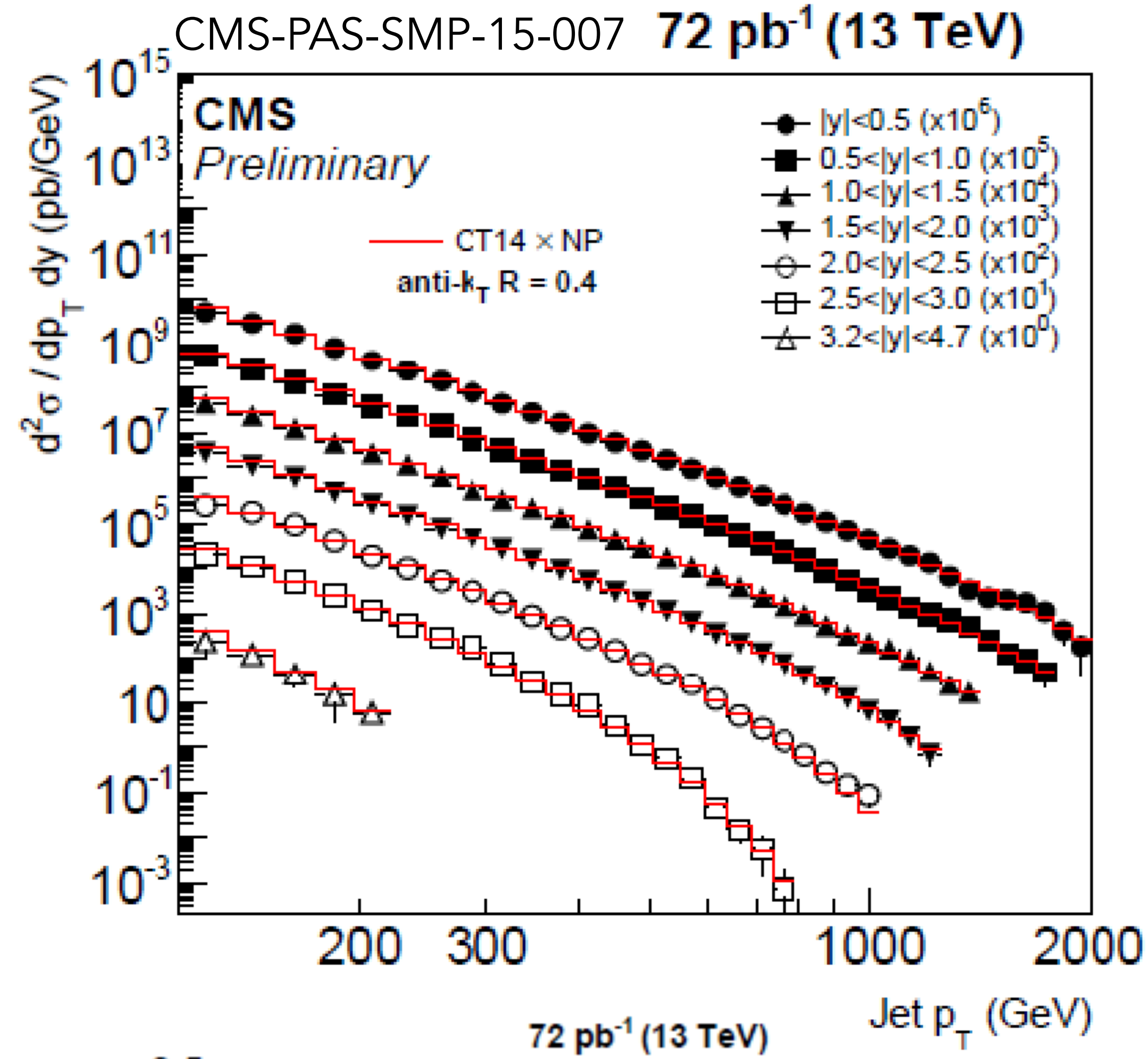
Also reported by ATLAS (arXiv:1509.04776), see Michael Clark's talk

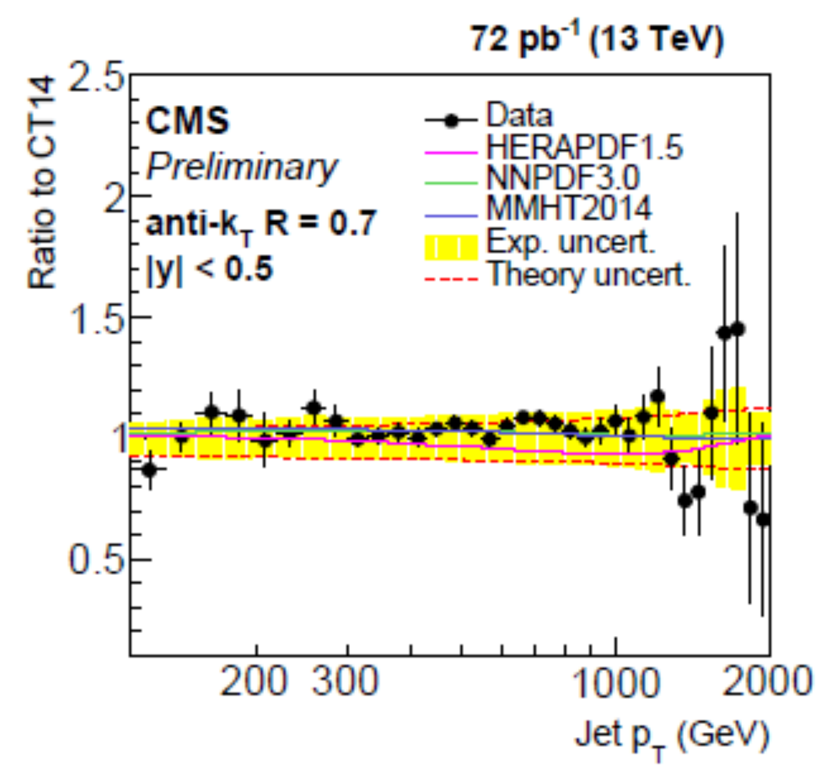
Inclusive Jet Cross Sections

ATLAS-CONF-2015-034



CMS-PAS-SMP-15-007

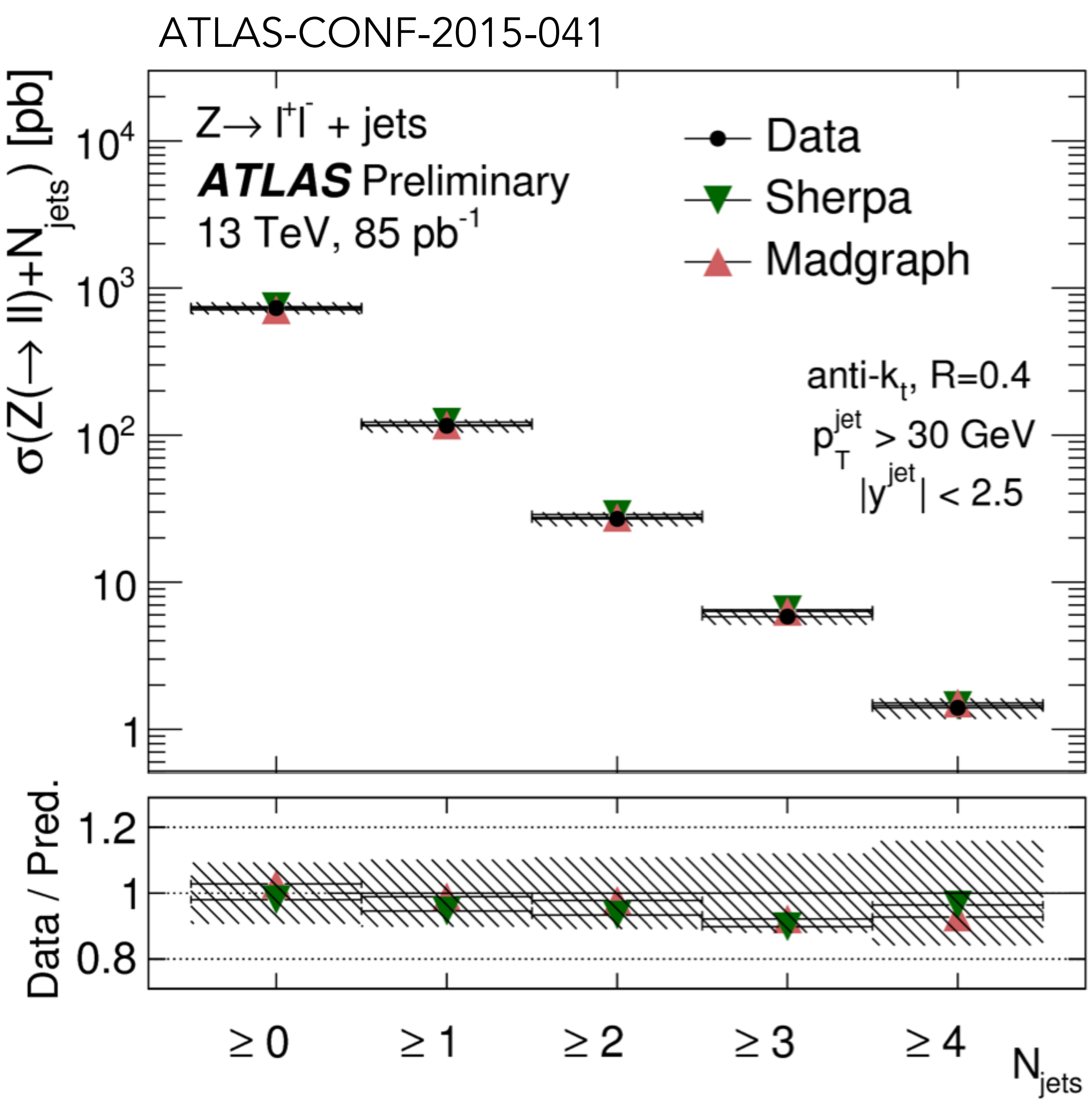


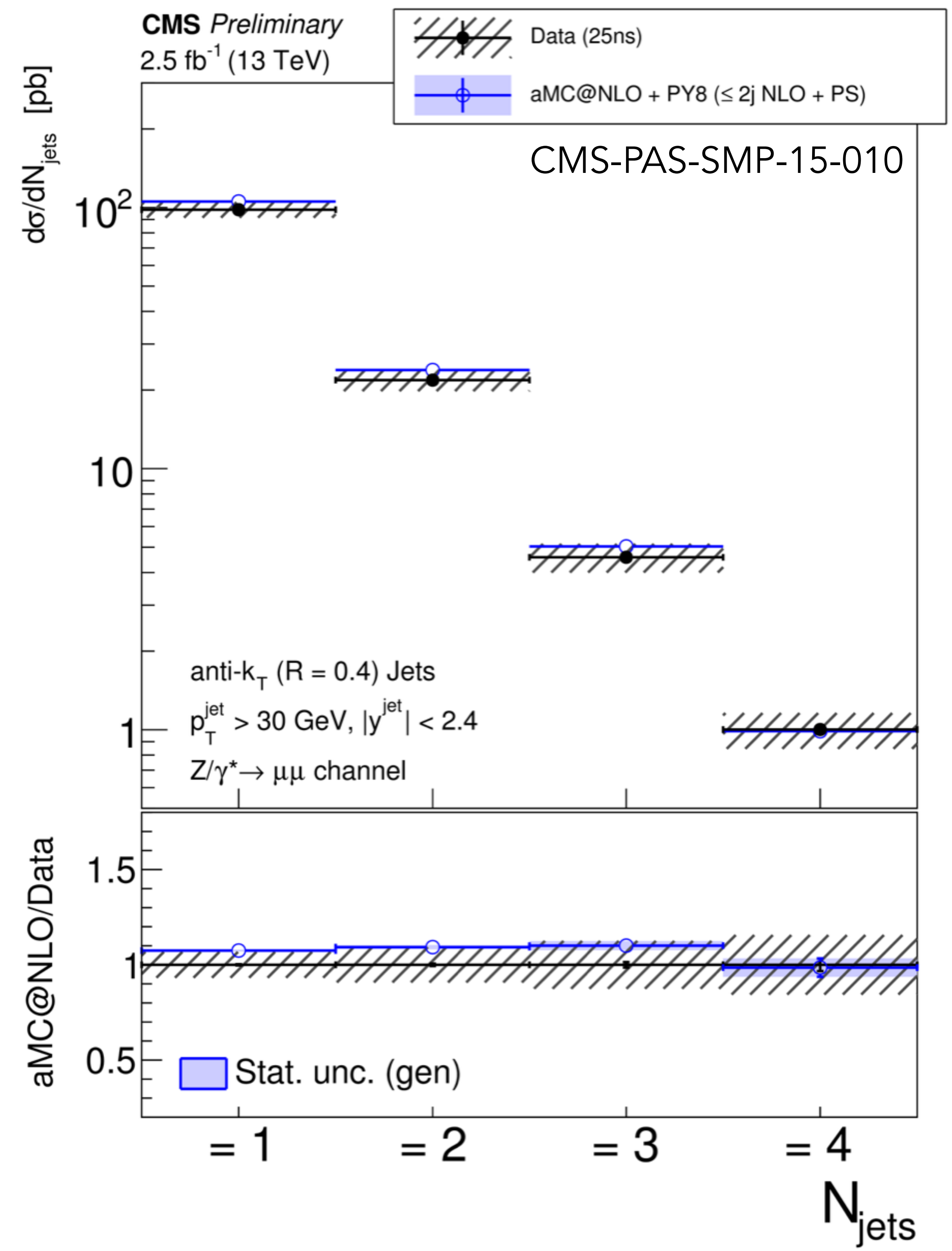


- inclusive jet production cross section in bins of p_T and y
- anti-k_T jets; R=0.4
- good agreement with predictions

Z+jets Production (jet multiplicities)

ATLAS-CONF-2015-041

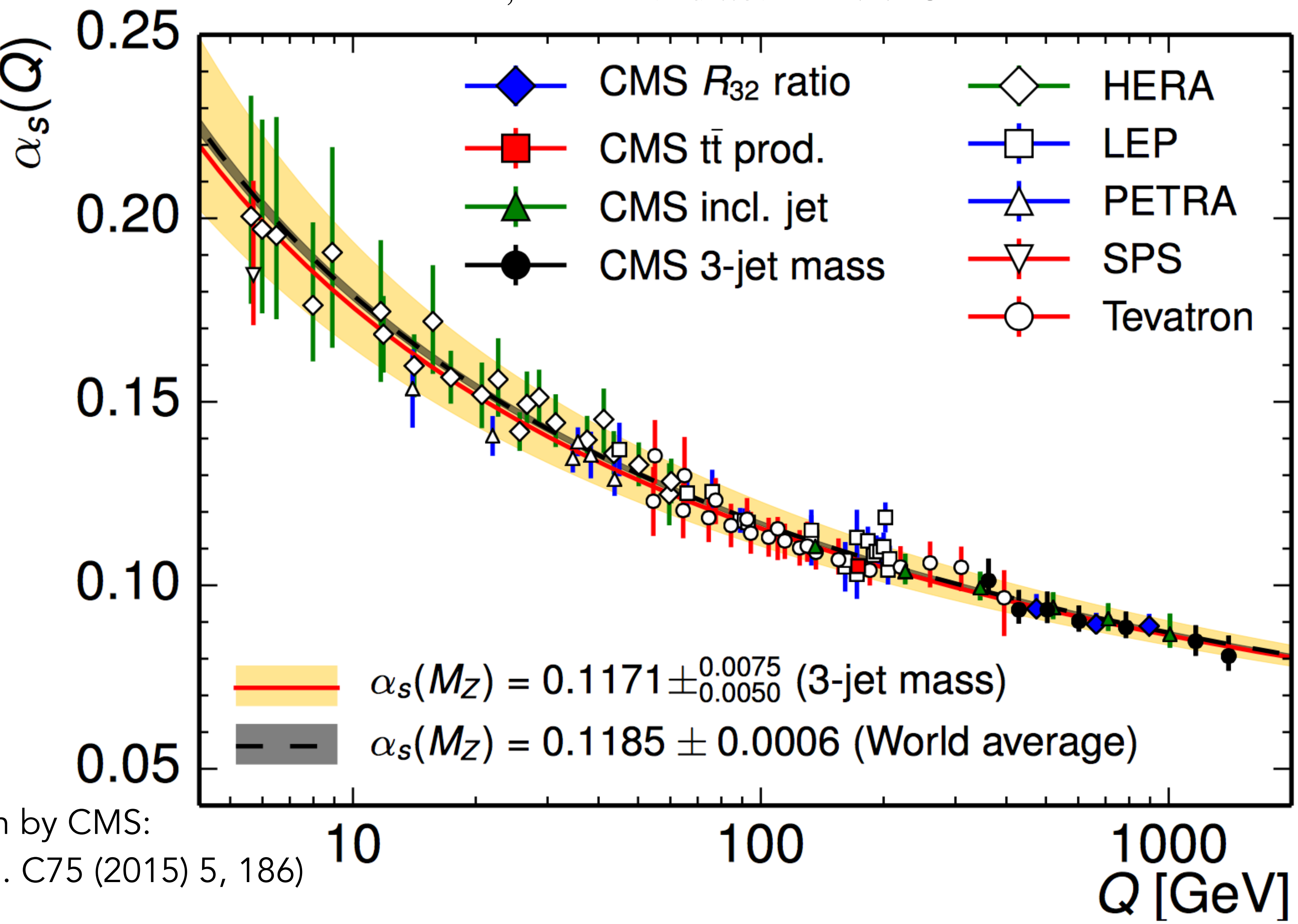




- Z+jets is important background to many Beyond Standard Model (BSM) searches and Higgs studies !
- anti-k_T jets; R=0.4
- good agreement with predictions (NLO QCD MC + parton shower)

determinations of α_s

all hadron collider (except ttbar) and HERA results in NLO
LEP, PETRA and ttbar in NNLO



compilation by CMS:
Eur. Phys. J. C75 (2015) 5, 186)

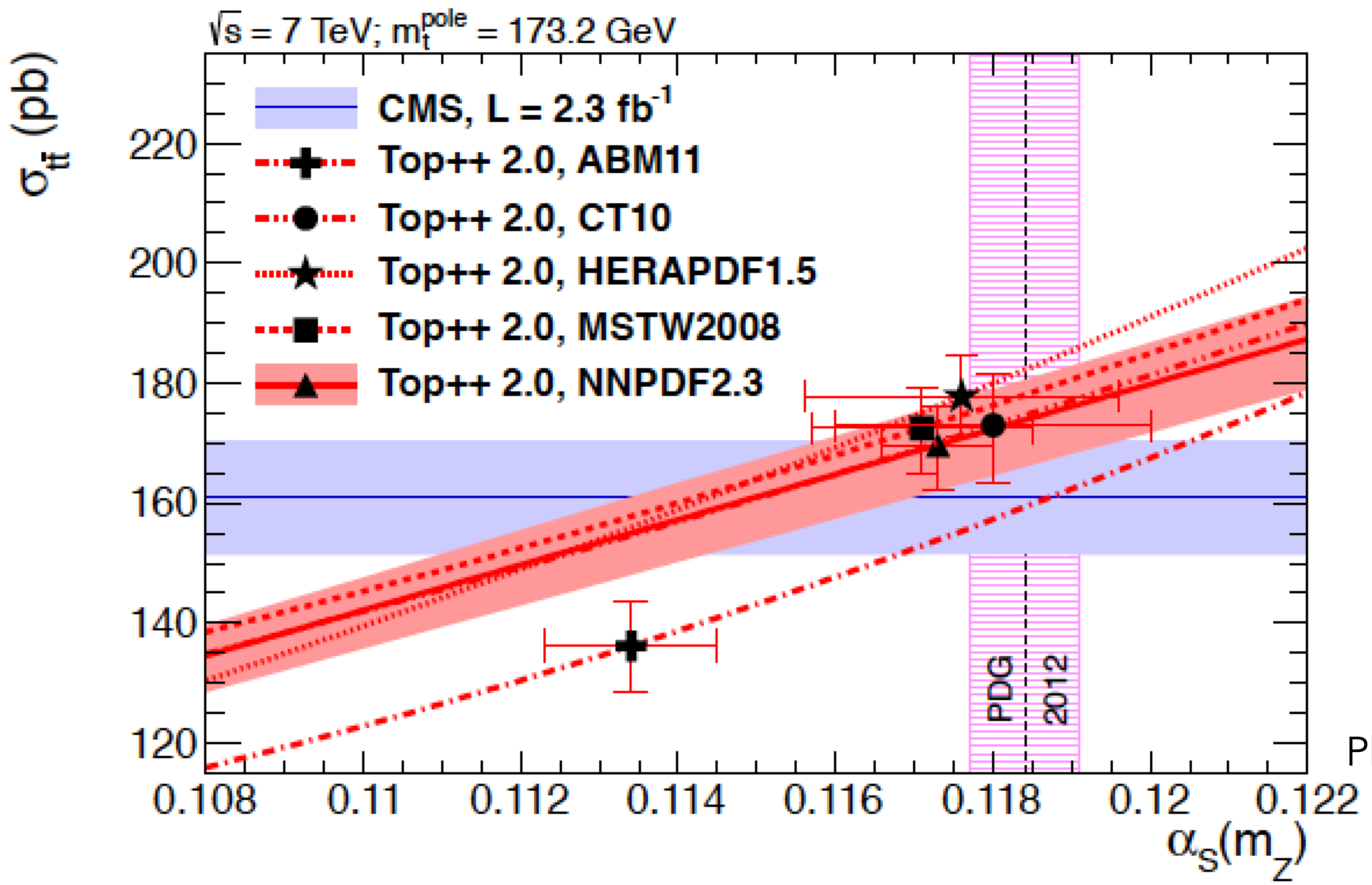
not shown:

ATLAS incl. jet:	$\alpha_s(M_Z)$= 0.115 ± 0.009	
ATLAS TEEC:	$\alpha_s(M_Z)$= 0.1173 + 0.0066 - 0.0028	Phys. Lett. B750, 427
ATLAS ATEEC:	$\alpha_s(M_Z)$= 0.1195 + 0.0065 - 0.0028	

LHC and Tevatron results average to: $\alpha_s(M_Z)$= 0.1172 ± 0.0059

CMS: α_s from ttbar cross section at sqrt(s)=7 TeV (in NNLO + NNLL)

→ relevant for 2016 RPP



Phys.Lett.B728 (2014) 496

	Most likely $\alpha_S(m_Z)$ value	Uncertainty Total	From δm_t^{pole}	From δE_{LHC}
ABM11	0.1187	$^{+0.0027}_{-0.0027}$	$^{+0.0010}_{-0.0010}$	$^{+0.0006}_{-0.0006}$
CT10	0.1151	$^{+0.0034}_{-0.0034}$	$^{+0.0012}_{-0.0013}$	$^{+0.0007}_{-0.0007}$
HERAPDF1.5	0.1143	$^{+0.0024}_{-0.0024}$	$^{+0.0010}_{-0.0010}$	$^{+0.0006}_{-0.0006}$
MSTW2008	0.1144	$^{+0.0031}_{-0.0032}$	$^{+0.0012}_{-0.0013}$	$^{+0.0007}_{-0.0008}$
NNPDF2.3	0.1151	$^{+0.0033}_{-0.0032}$	$^{+0.0013}_{-0.0013}$	$^{+0.0008}_{-0.0008}$

more data available on ttbar cross section; preliminary estimates on α_s :

(S. Bethke, G. Dissertori, T. Klijnsma and G. Salam, arXiv:1512.05194 [hep-ph])

Original cross section measurement used by CMS (7TeV)

`sigma(ttbar) = 161.9pb ± 6.7 (stat+syst+lumi) ± 2.9 (Ebeam) pb`

J. High Energy Phys. 11 (2012) 067

More recent determinations at LHC (dilepton) and Tevatron

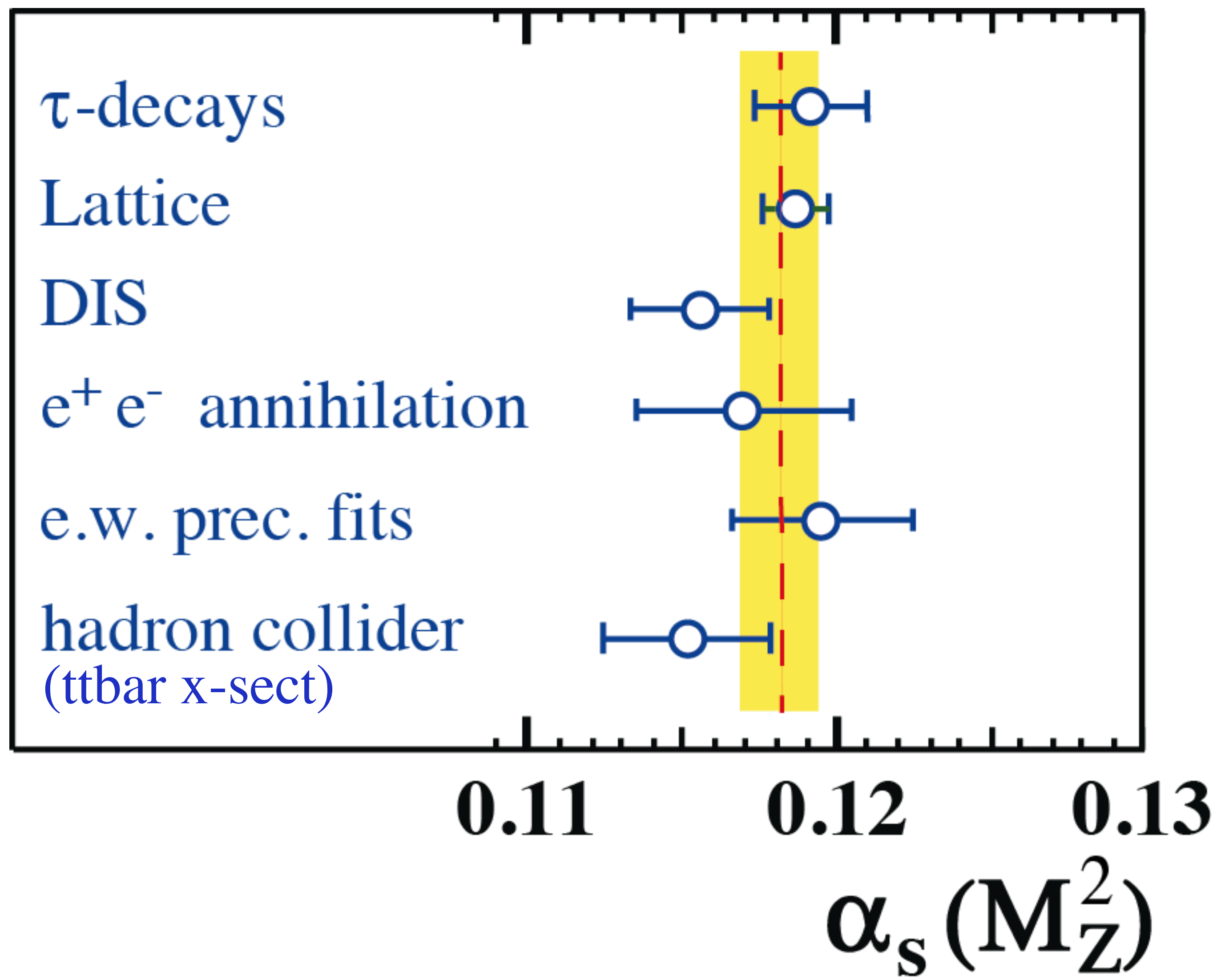
(NB: 7 TeV results 8-13% higher than in original CMS extraction)

Experiment	E_{CM}	σ [pb]	Exp err. [pb]	Ebeam [pb]	
ATLAS	7000 GeV	182.9	± 6.3	± 3.3	Eur.Phys.J. C74 (2014) 3109
CMS	7000 GeV	174.5	± 6.1	± 2.9	CMS-PAS-TOP-13-004
ATLAS	8000 GeV	242.4	± 9.5	± 4.2	Eur.Phys.J. C74 (2014) 3109
CMS	8000 GeV	245.6	± 9.0	± 4.1	CMS-PAS-TOP-13-004
CDF&D0	1960 GeV	7.6	± 0.41		Phys.Rev. D89 (2014) 072001

Newer results point to somewhat larger $\alpha_s(M_Z)$ than earlier CMS extraction (prelim: 0.1187–0.1201 v. 0.1151)

preliminary 2016 world average of α_s

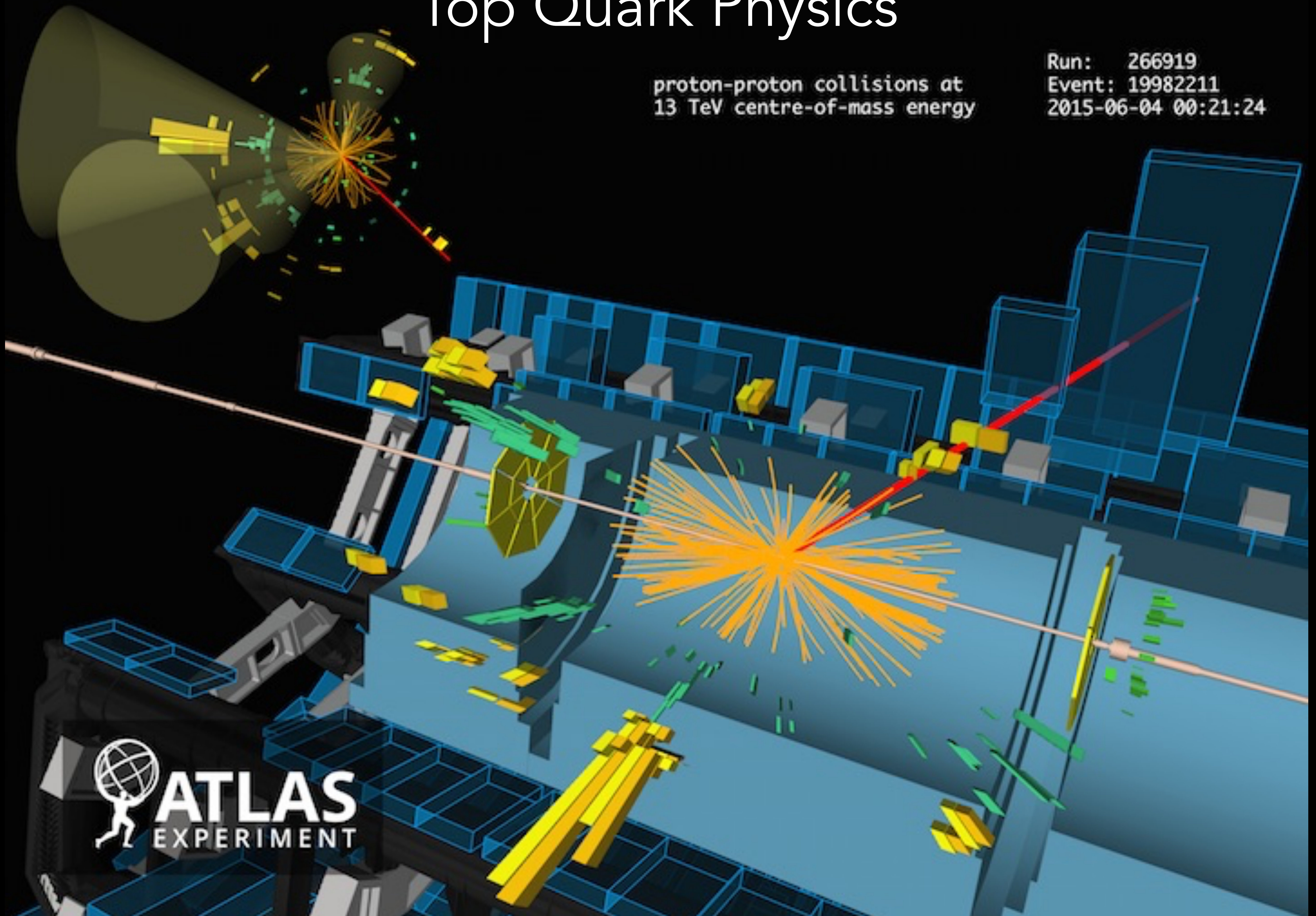
S. Bethke, G. Dissertori, G. Salam in: 2016 edition of PDG's RPP



$\alpha_s(M_z) = 0.1181 \pm 0.0013$

without hadron collider: $\alpha_s(M_z) = 0.1183 \pm 0.0014$

Top Quark Physics

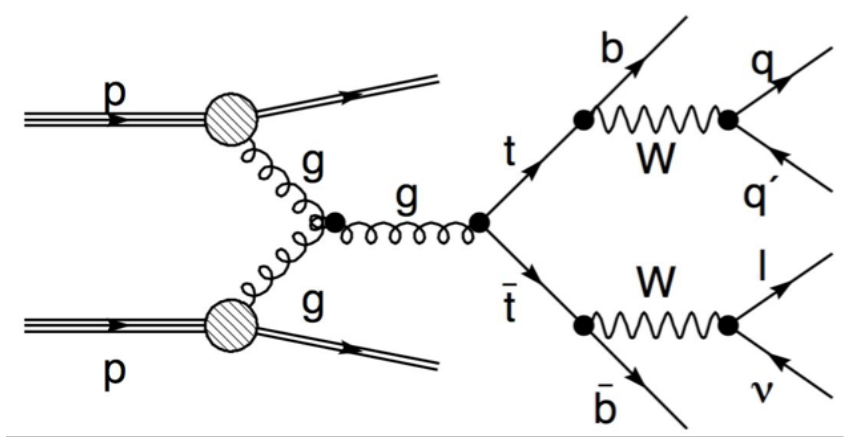


Top Quark Physics

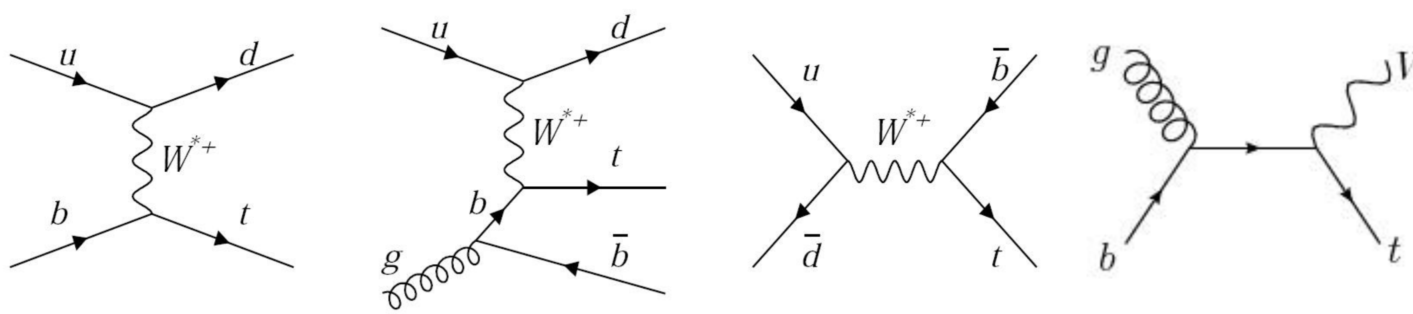
- Top-Quark: the heaviest known fundamental particle

  2014 world combination of top-mass: m_t = 173.34±0.27(stat)±0.73(sys) GeV arXiv:1403.4427
- it decays before hadronisation, so its properties directly transfer to its decay products
- perfect candidate for precision tests of Standard Model and also for searches of physics BSM
- also dominates Higgs-production (through gluon-fusion)

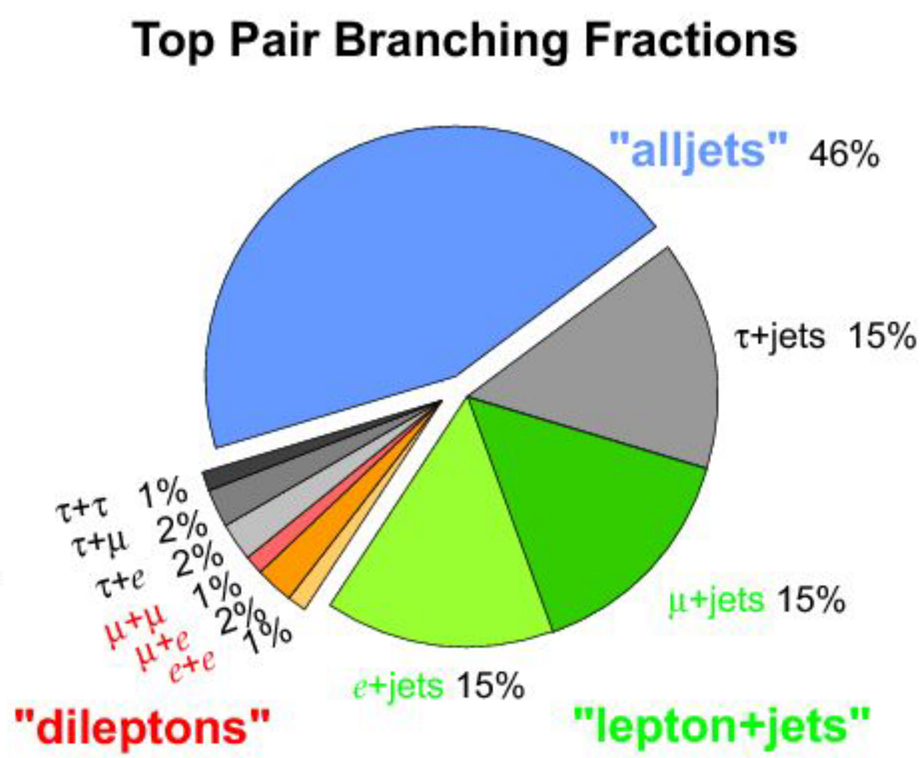
strong:
ttbar pair prod.



electroweak:
single t prod

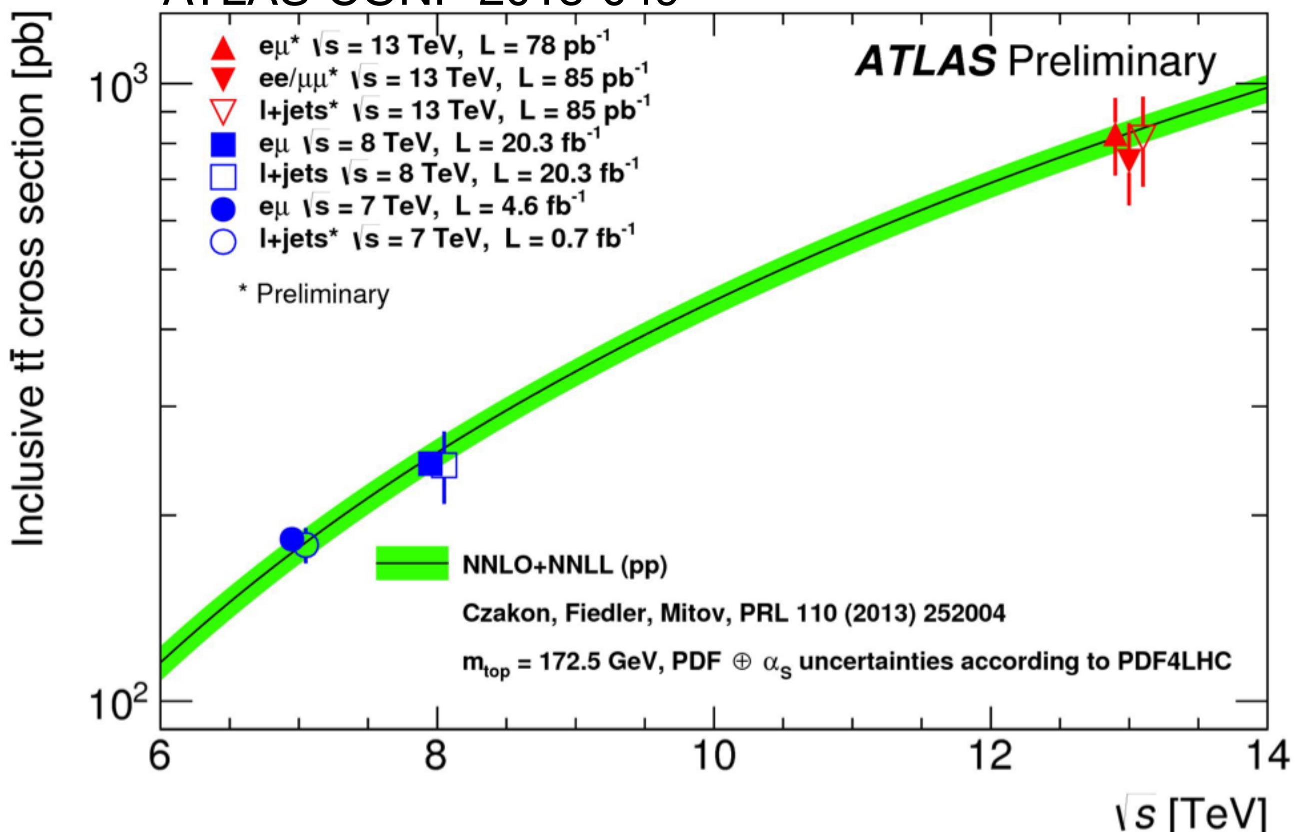


t-channel s-channel Wt

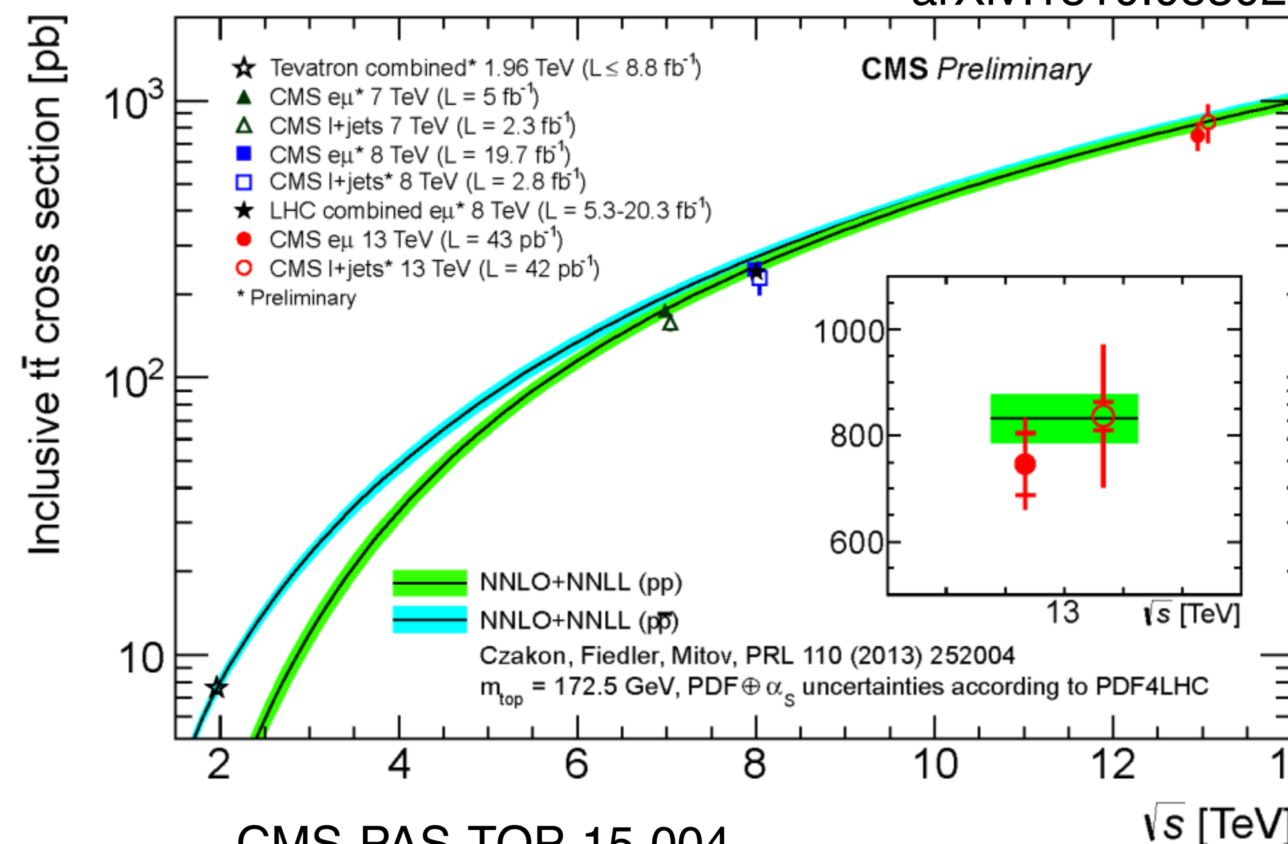


Top Quark Physics
production cross sections

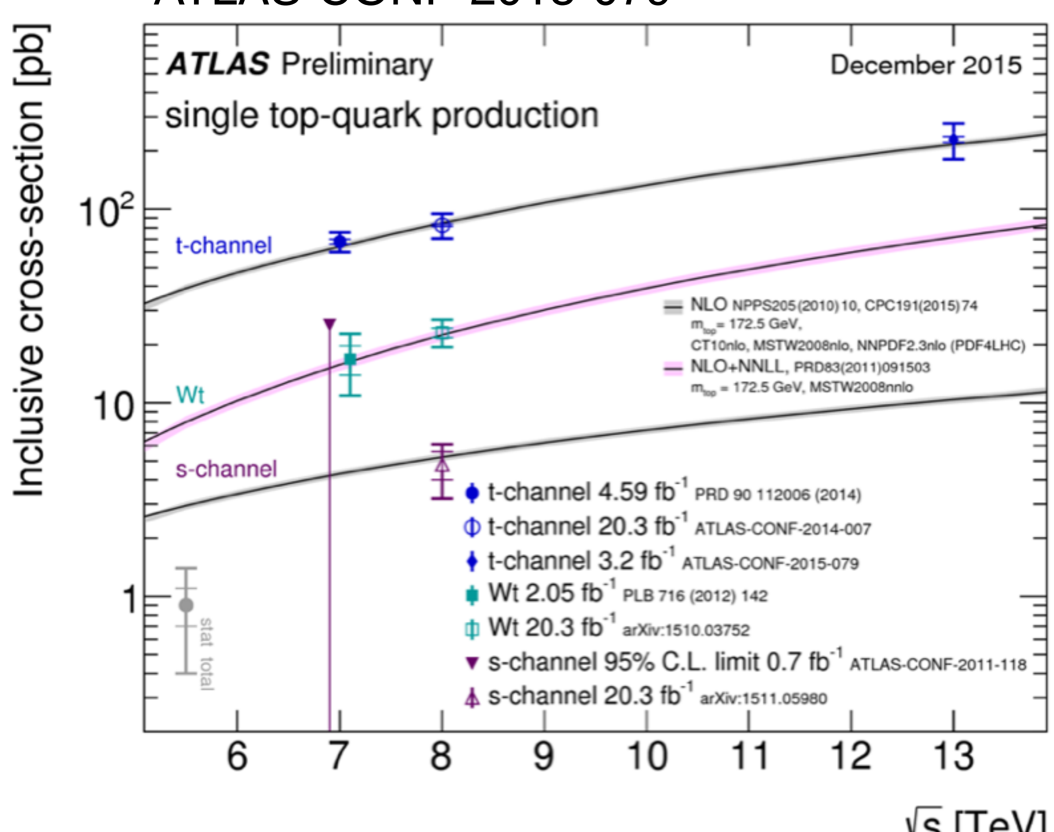
ATLAS-CONF-2015-049



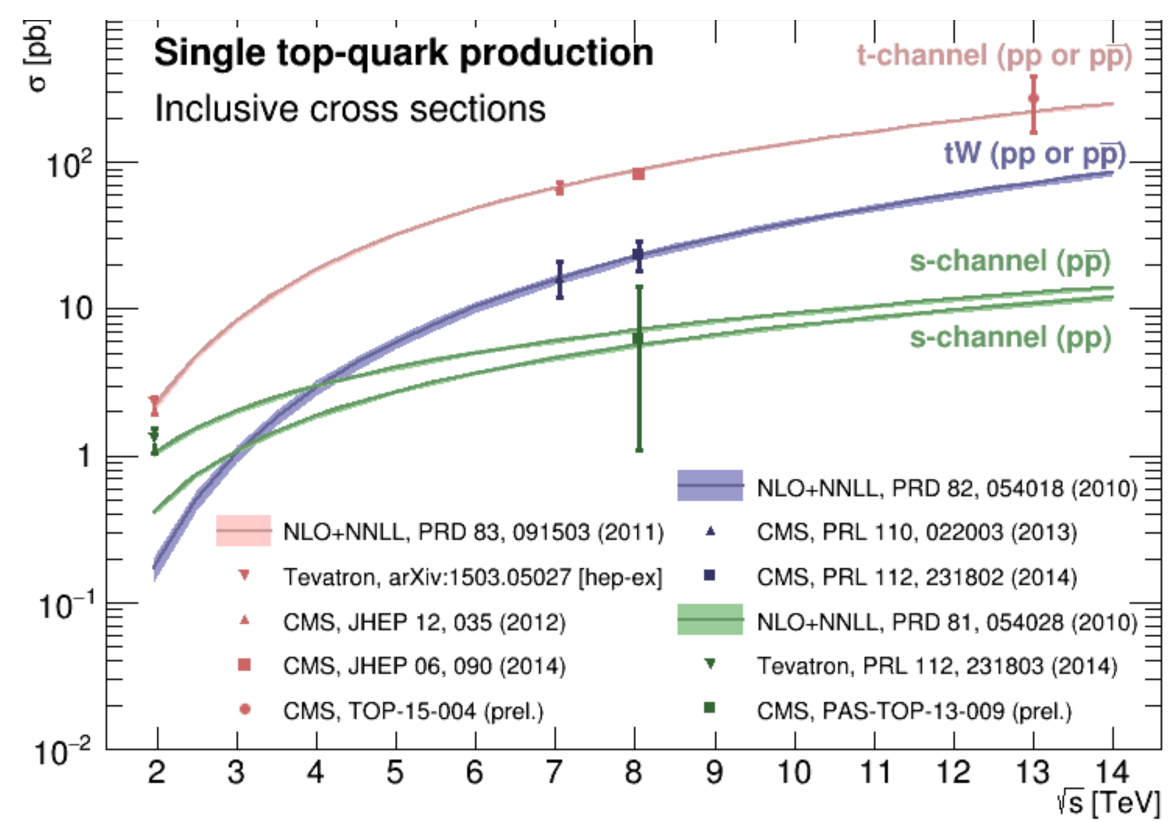
arXiv:1510.05302



ATLAS-CONF-2015-079



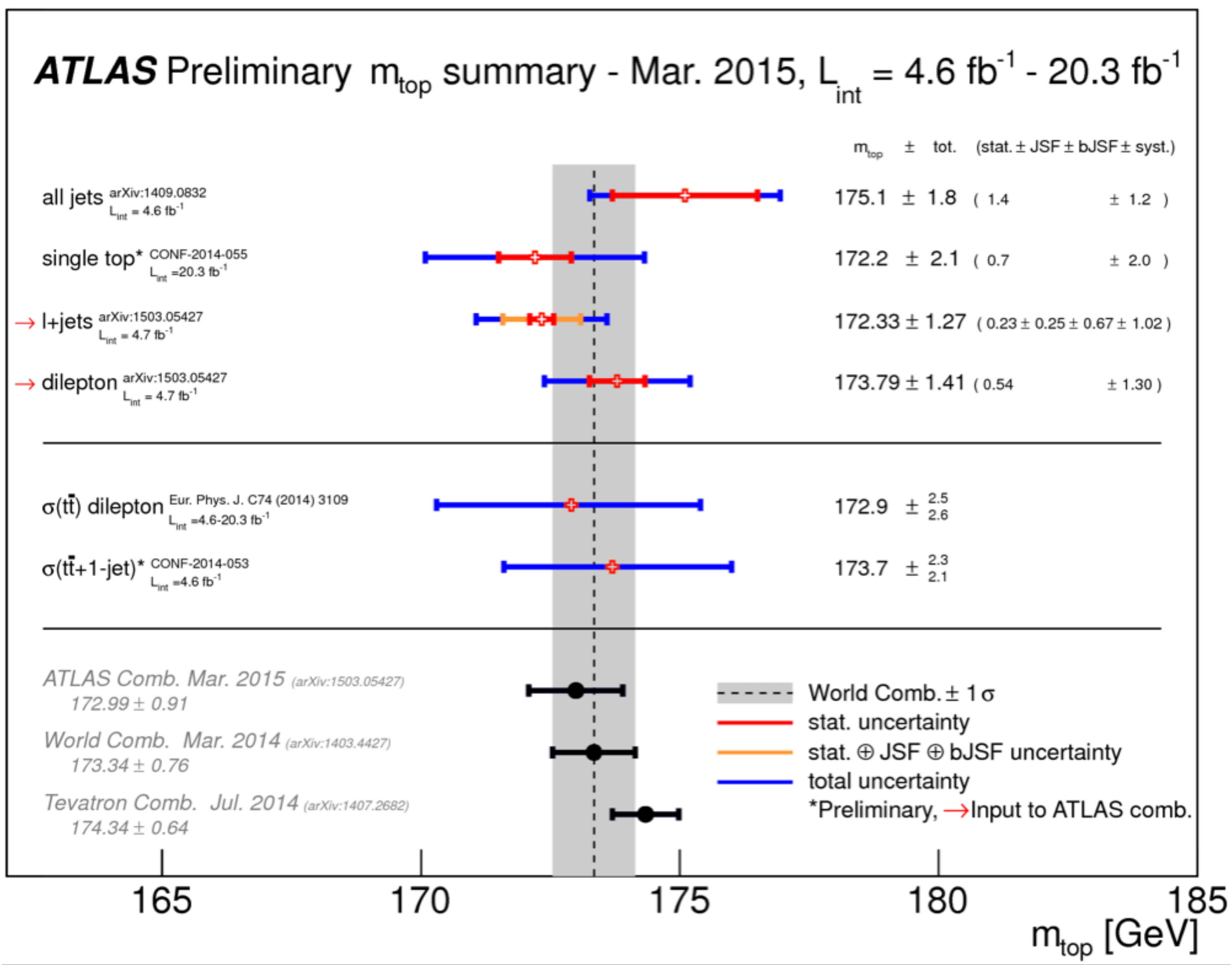
CMS-PAS-TOP-15-004

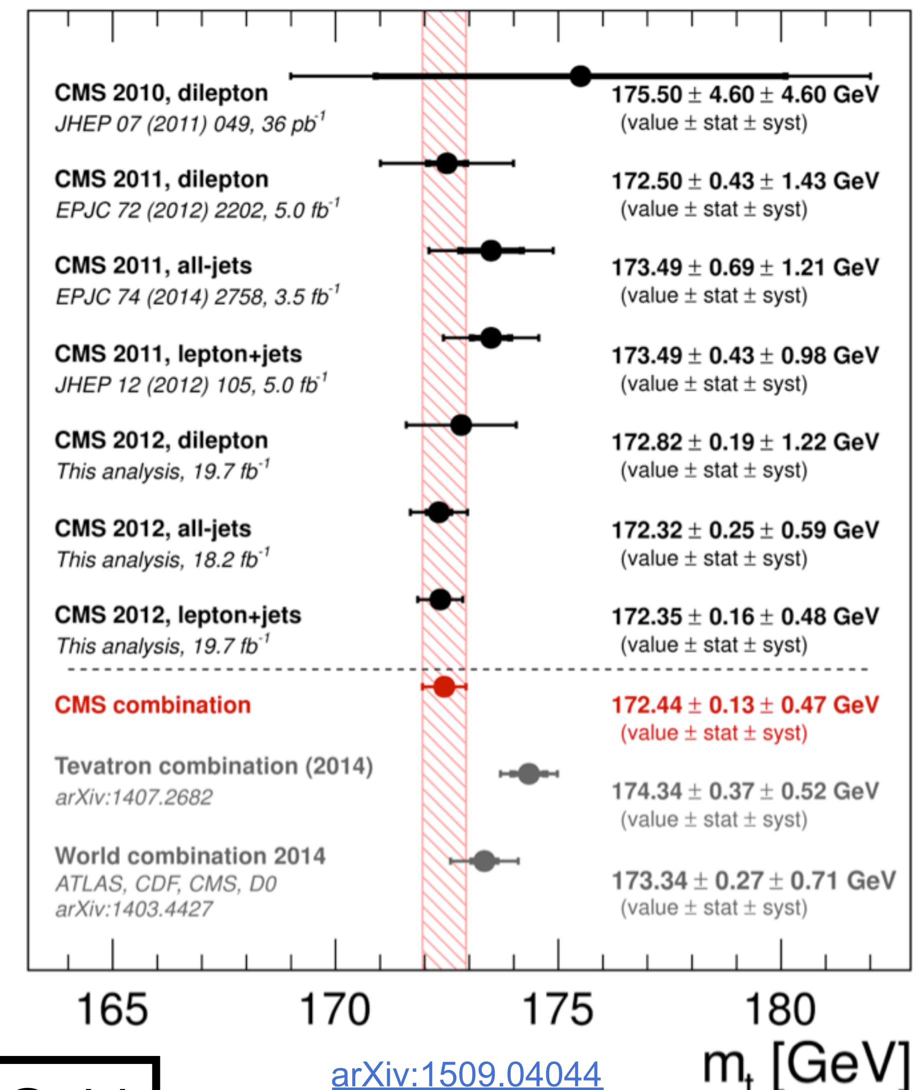


Top Quark Physics

mass determination

- standard measurements are based on template methods
  - – adjust MC-defined top-quark mass to data
  - – relation between MC-defined and theoretical pole mass intensively discussed, argued to be close or even identical.



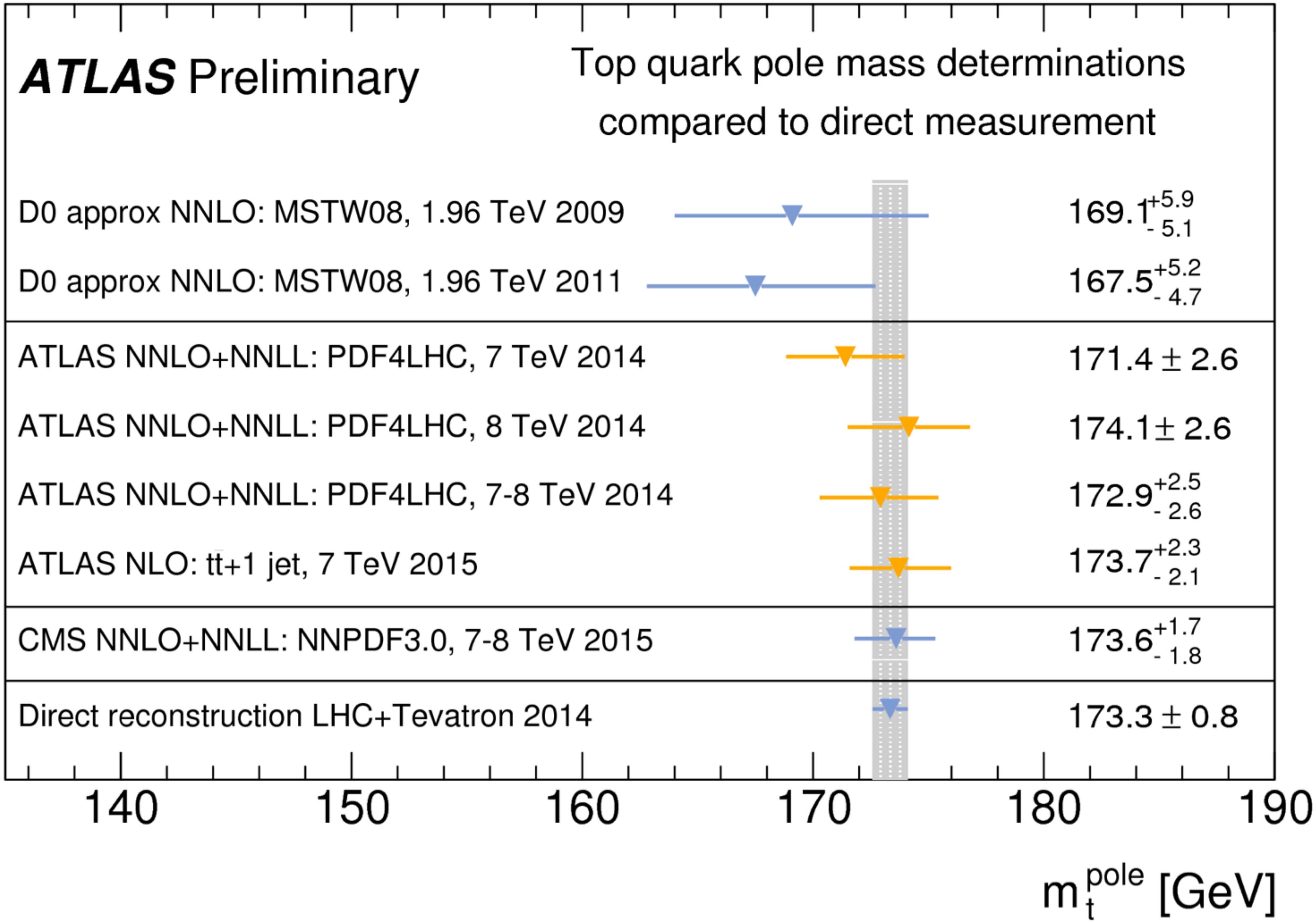


arXiv:1509.04044

world ave (2014):	m_t = 173.3±0.8 GeV	
ATLAS (2015):	m_t = 173.0±0.9 GeV	"direct mass"
CMS (2015):	m_t = 172.4±0.5 GeV	

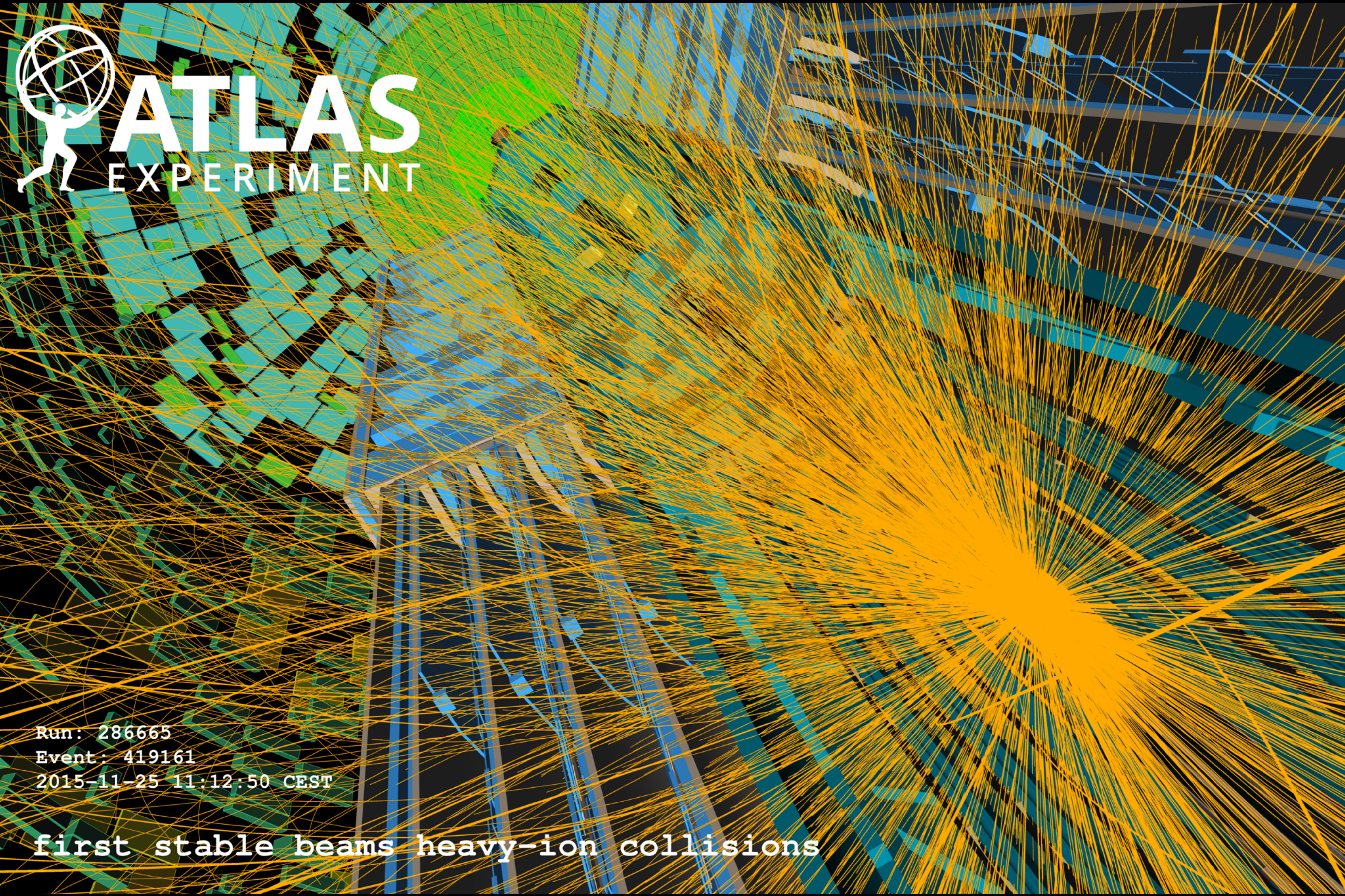
Top Quark Physics
mass determination

- measurements of pole mass through σ_{tt} become increasingly precise



"direct" (MC) mass and (theoretically well defined) pole mass agree within uncertainties (currently <~2 GeV)

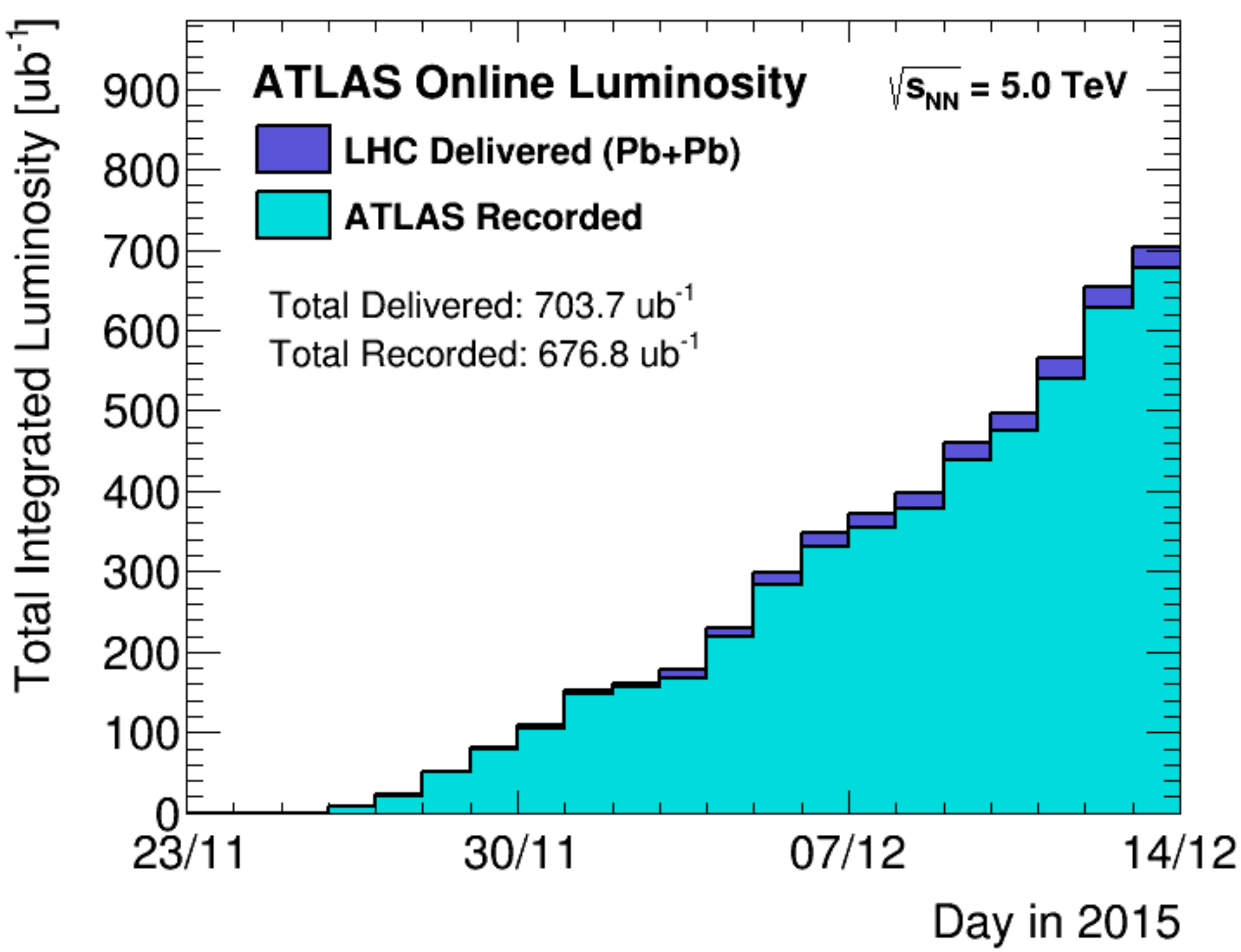
Heavy Ion Physics

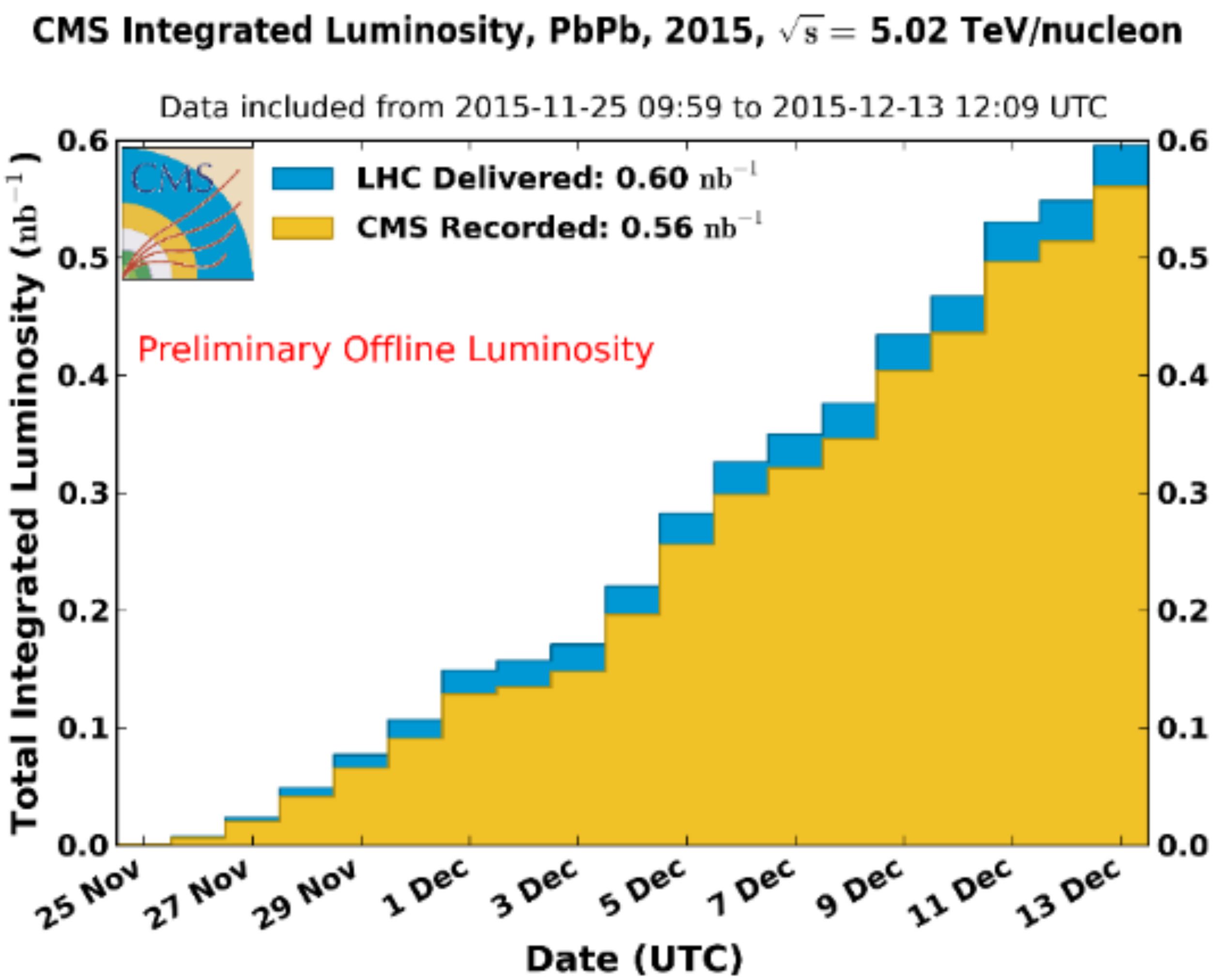


Heavy Ion Physics

study of the hot and dense medium produced in h.e. ion collisions

2015: Pb-Pb collisions at $\sqrt{(s_{NN})}$ = 5.00 TeV   ($\sqrt{(s_{PbPb})}$ = 1.1 PeV)



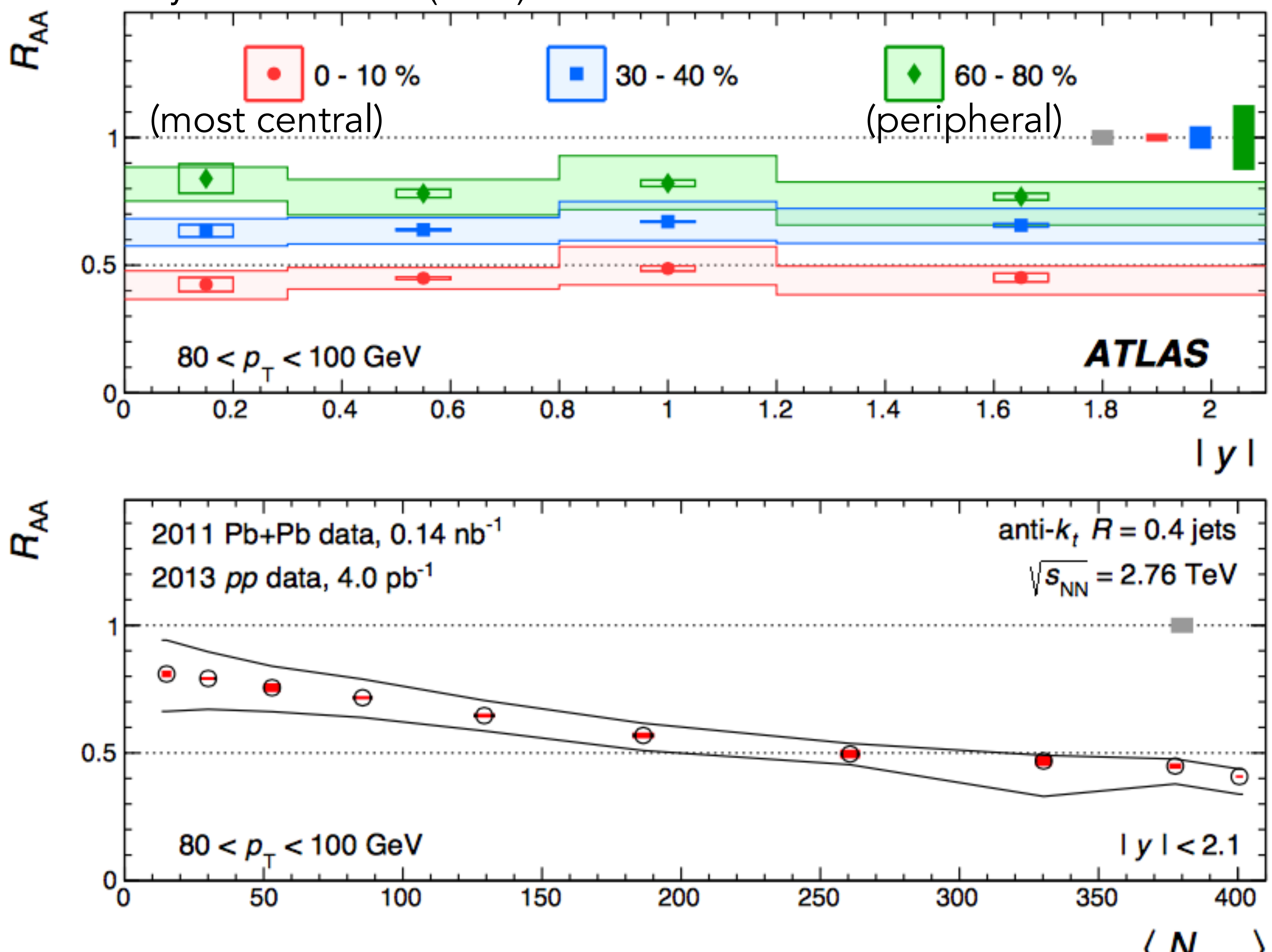


data taken in Nov/Dec 2015; no results with new data published yet

Heavy Ion Physics

jet suppression in PbPb collisions at sqrt(s[NN]) = 2.76 TeV

Phys.Rev.Lett. 114 (2015) 072302



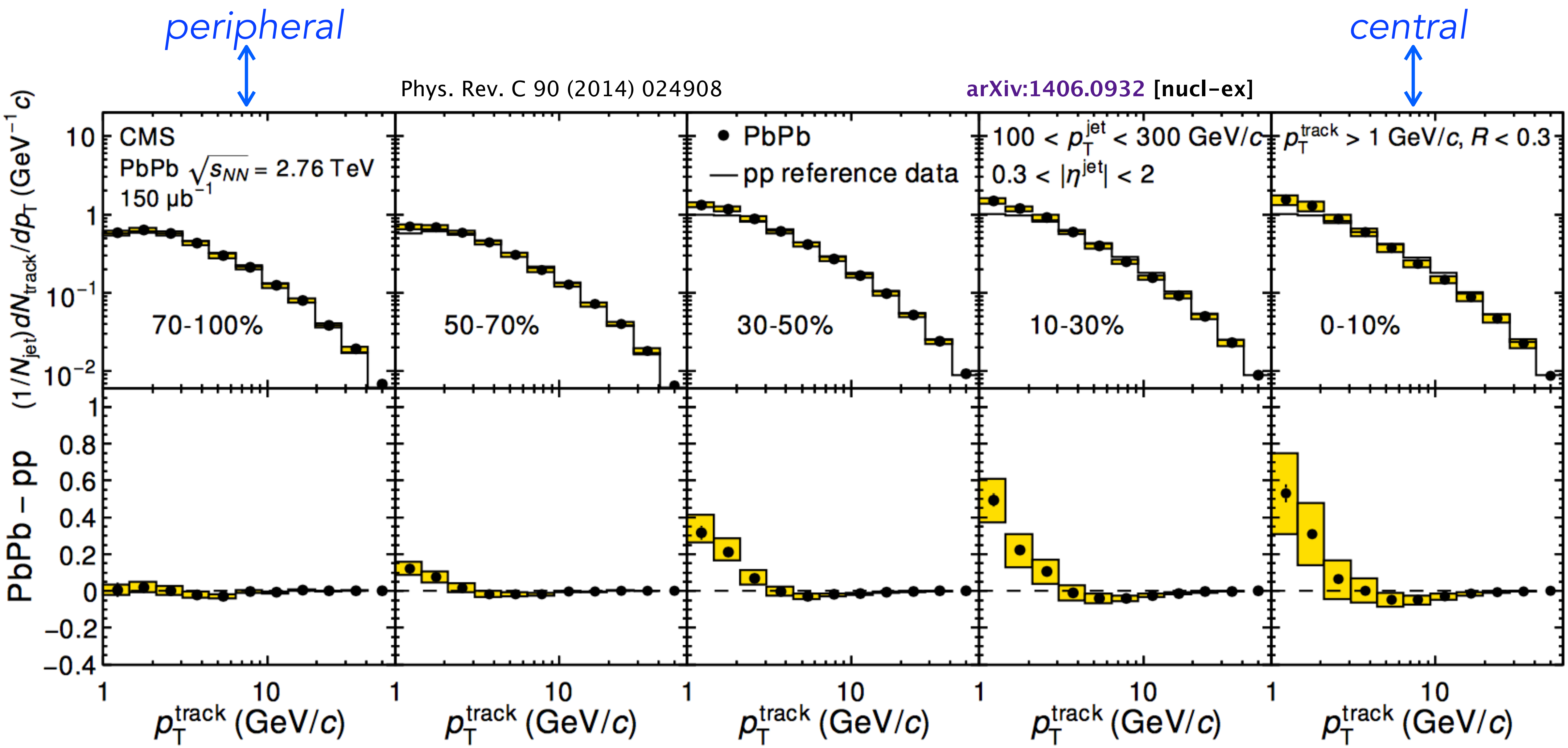
R_{AA}: jet nucleon modification factor; ratio of yields (heavy ion / pp)

N_{part}: number of participating nucleons in heavy ion collisions

➔ significant suppression of jets (50%) observed for Pb-Pb central collisions (large N_{part})

Heavy Ion Physics

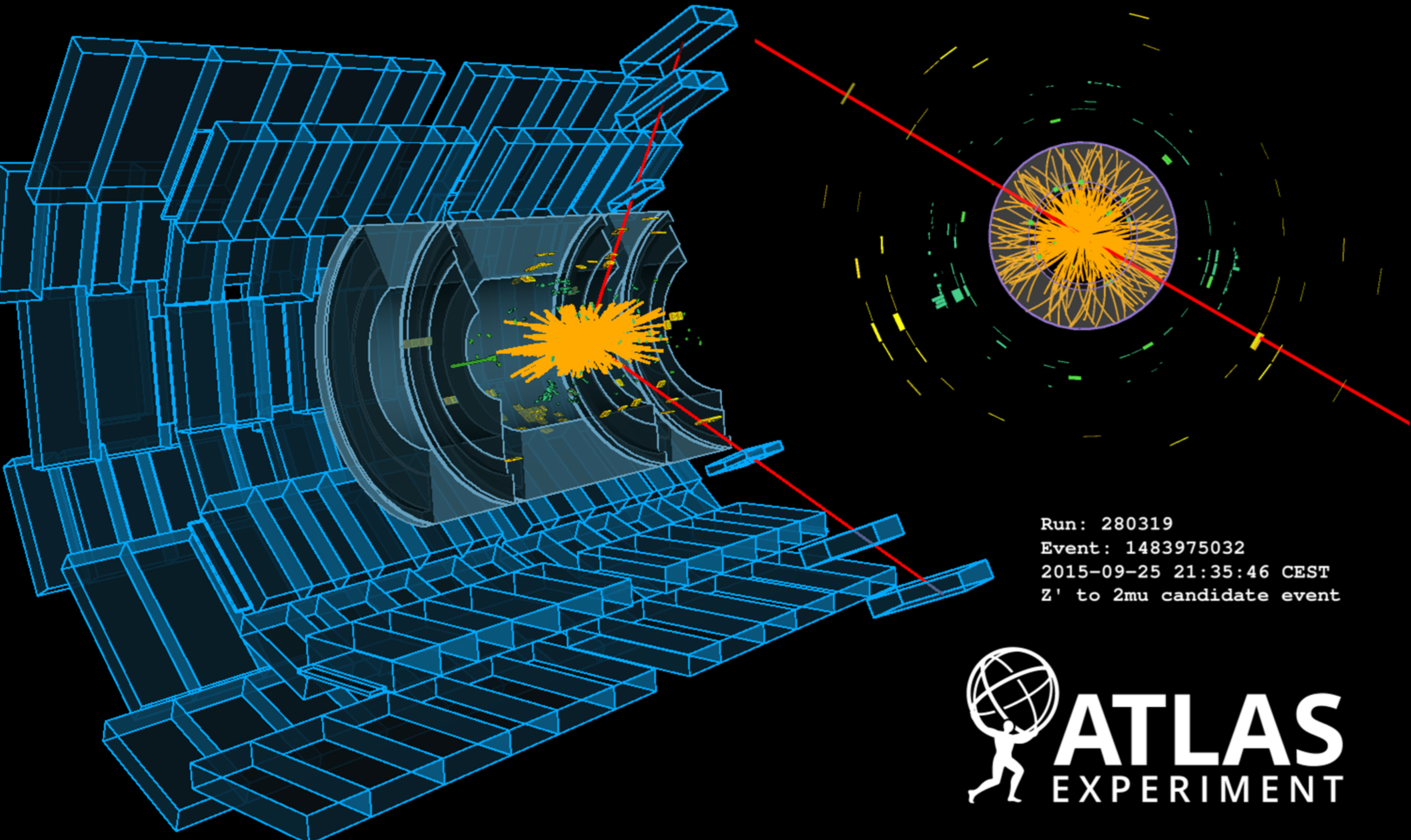
jet fragmentation in PbPb and pp collisions at sqrt(s[NN]) = 2.76 TeV



p_T of charged particles inside jet cone (100 <p_{Tjet} < 300 GeV)

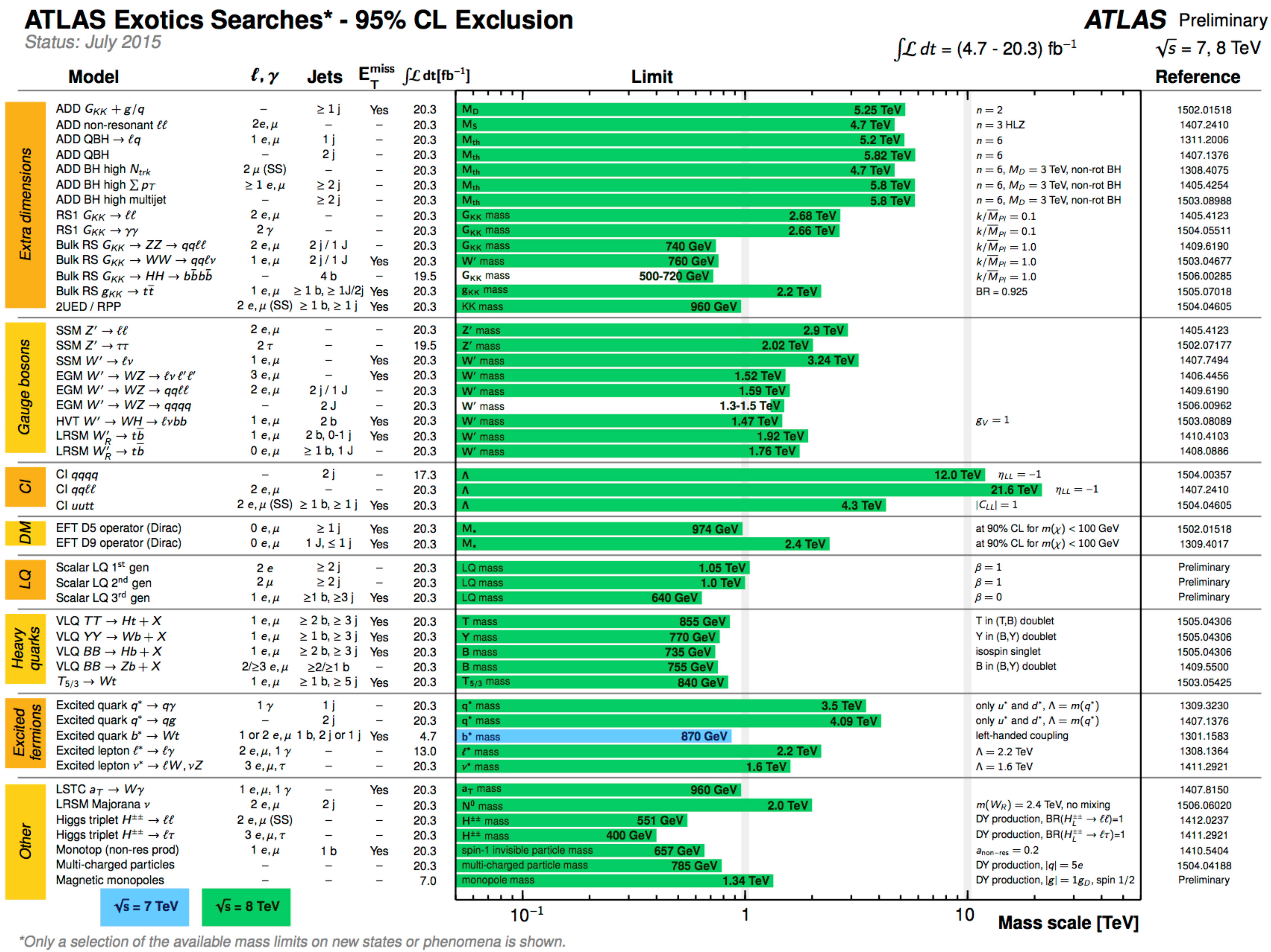
➔ significant enhancement of fragmentation function of charged particles with pT<3 GeV in most central Pb-Pb-collisions

Searches for New Phenomena



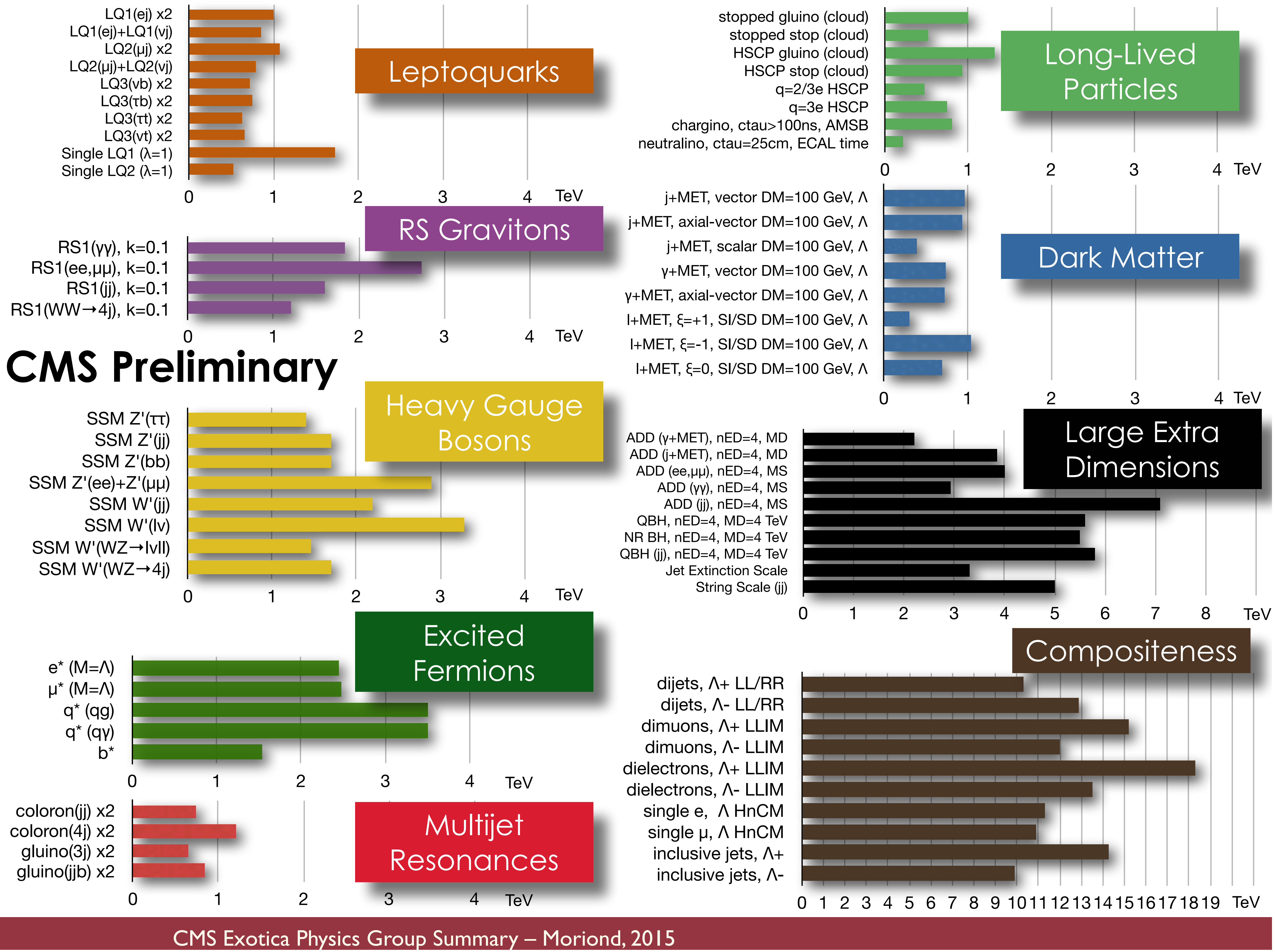
highest mass dimuon event ($m_{\mu\mu}$ = 1.46 TeV)

Searches for New Phenomena



run-I data (7 and 8 TeV): no positive signals ➔ mass range exclusions

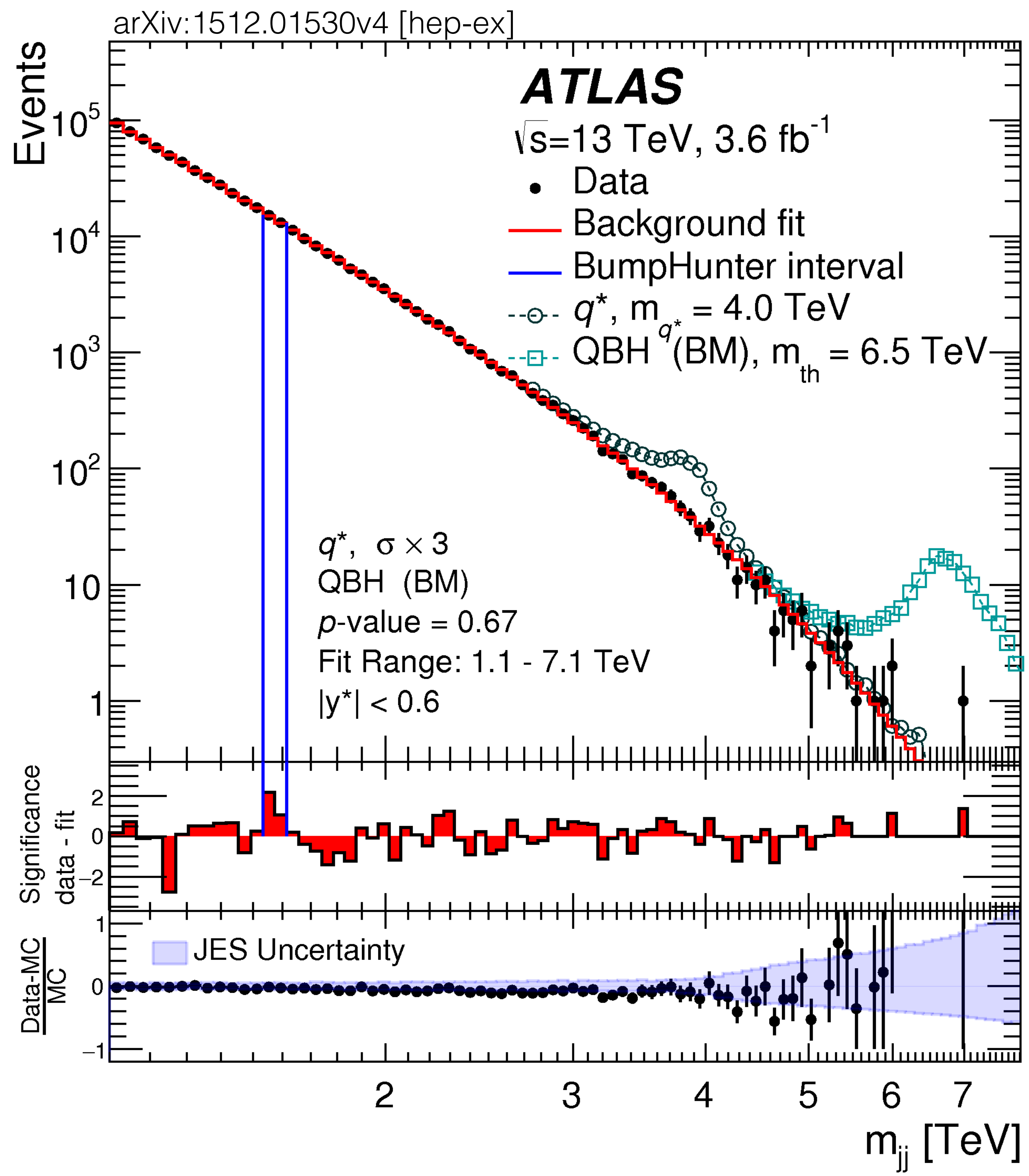
Searches for New Phenomena

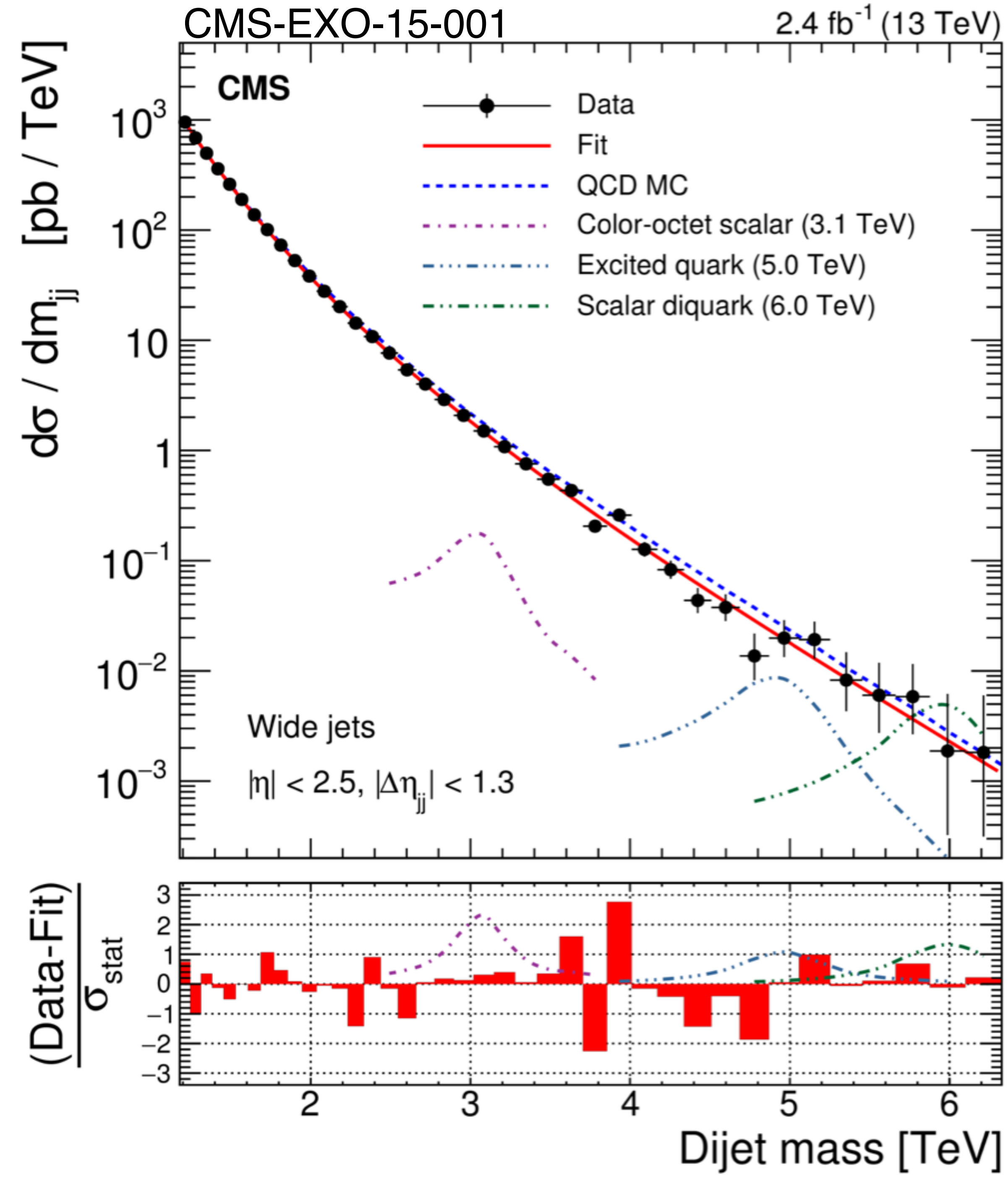


run-I data (7 and 8 TeV): no positive signals ➔ mass range exclusions

Searches for New Phenomena

13 TeV data: Dijet Resonant Searches





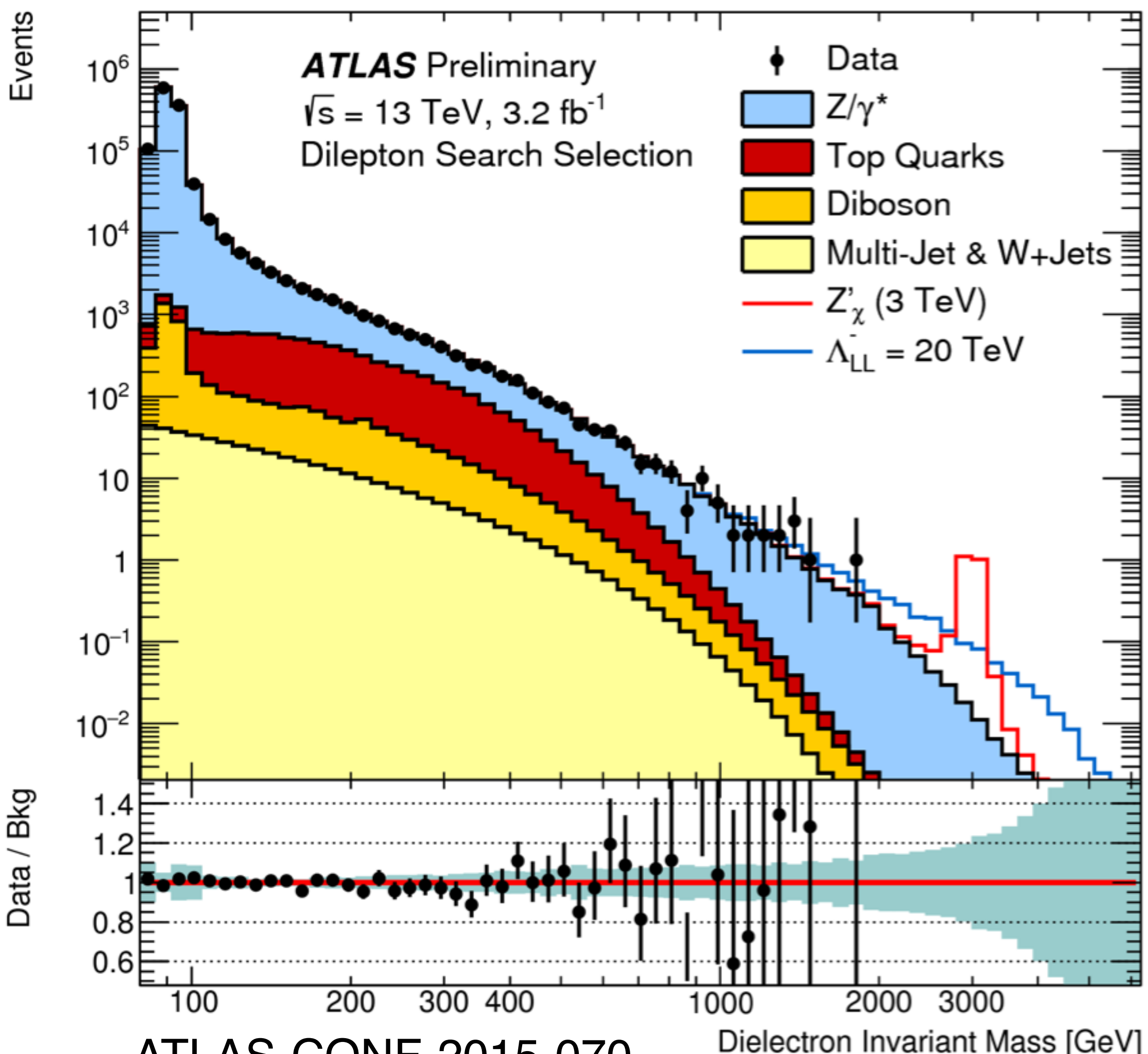
excludes e.g. excited quarks with masses < 5.2 TeV, and quantum BHs with masses < 5.1 … 8.3 TeV

Model	Final State	Obs. Mass Limit [TeV]	Exp. Mass Limit [TeV]
String	qg	7.0	6.9
Scalar diquark	qq	6.0	6.1
Axigluon/coloron	$q\bar{q}$	5.1	5.1
Excited quark (q^*)	qg	5.0	4.8
Color-octet scalar	gg	3.1	3.3
Heavy *PW* (W′)	$q\bar{q}$	2.6	2.3

Searches for New Phenomena

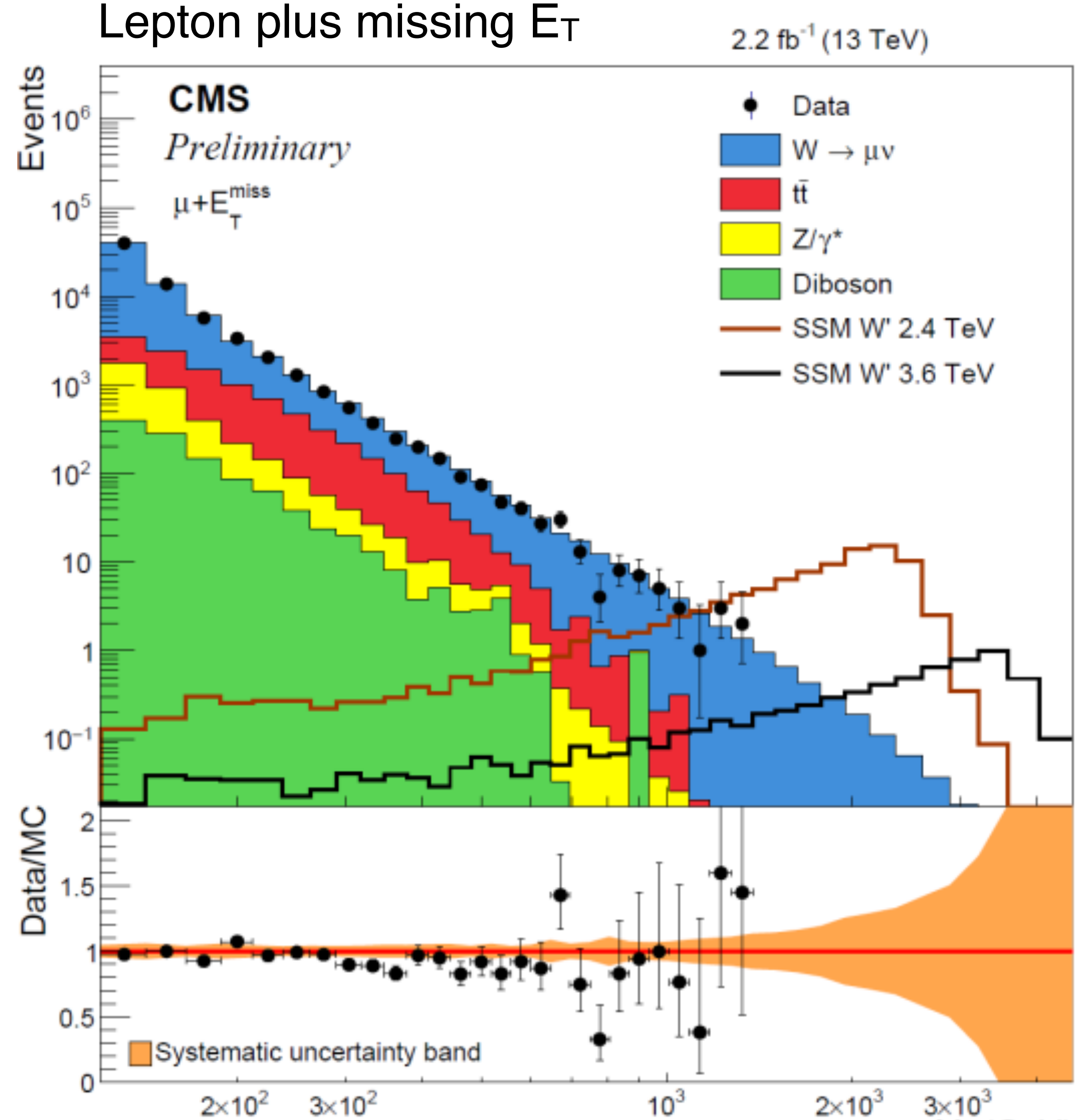
13 TeV data: Search for Heavy Gauge Bosons (Z' and W')

Dilepton Resonance Search



ATLAS-CONF-2015-070

Lepton plus missing E_T



CMS-PAS-EXO-15-006

excludes e.g. Z′ with $m_{Z'} < 3.4$ TeV, and llqq contact interactions with scales $\Lambda_{llqq} < 20$ TeV

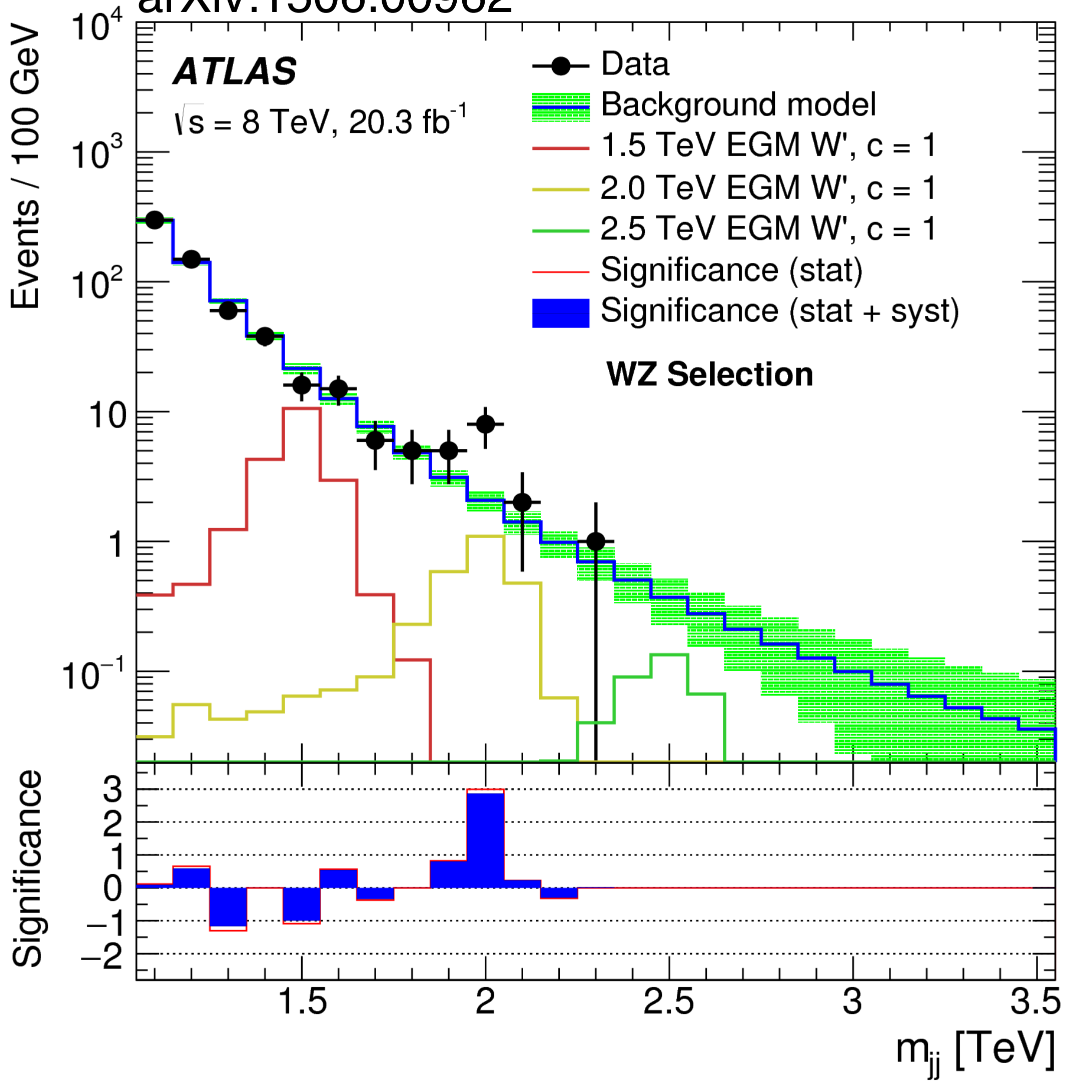
excludes W′→lν with $m_{W'} < 4.4$TeV

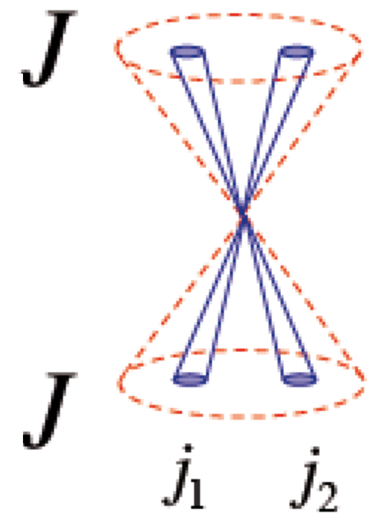
Searches for New Phenomena

Diboson Resonant Searches

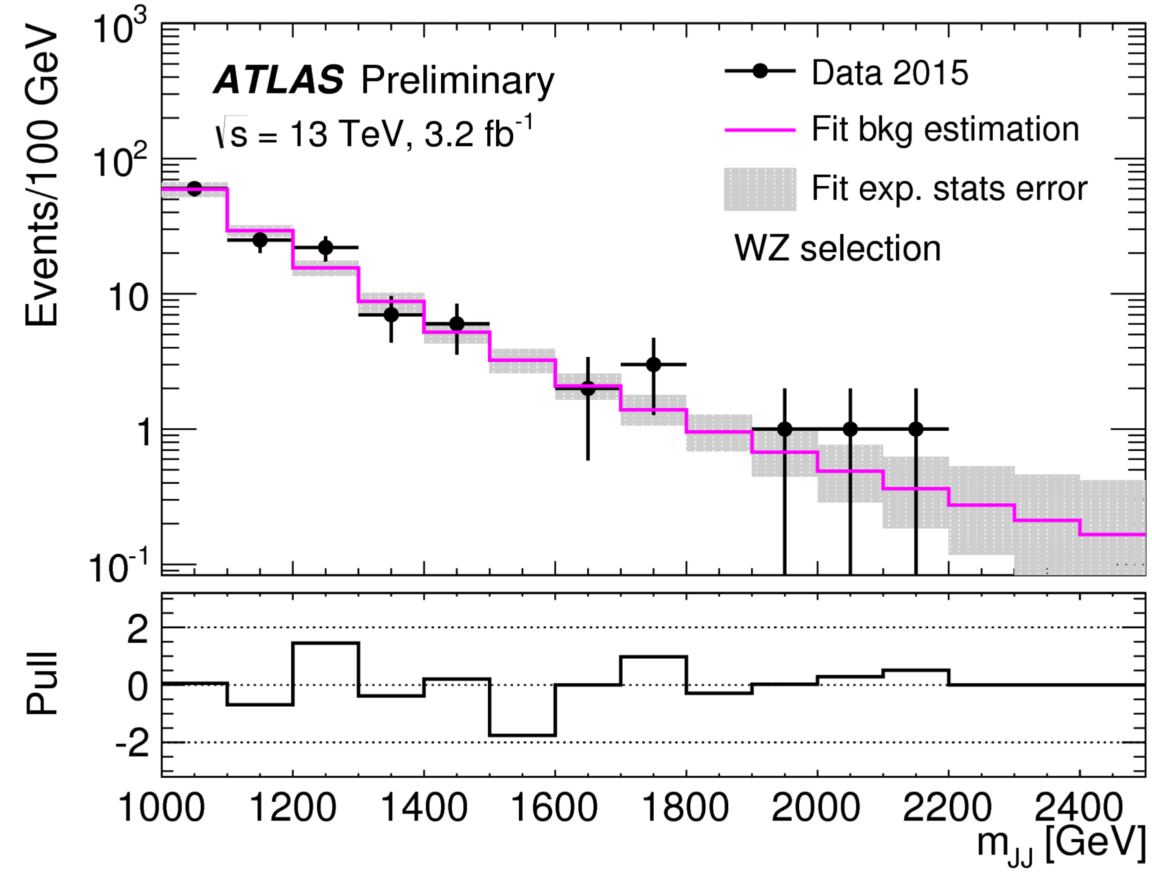
VV to JJ

arXiv:1506.00962





ATLAS-CONF-2015-073



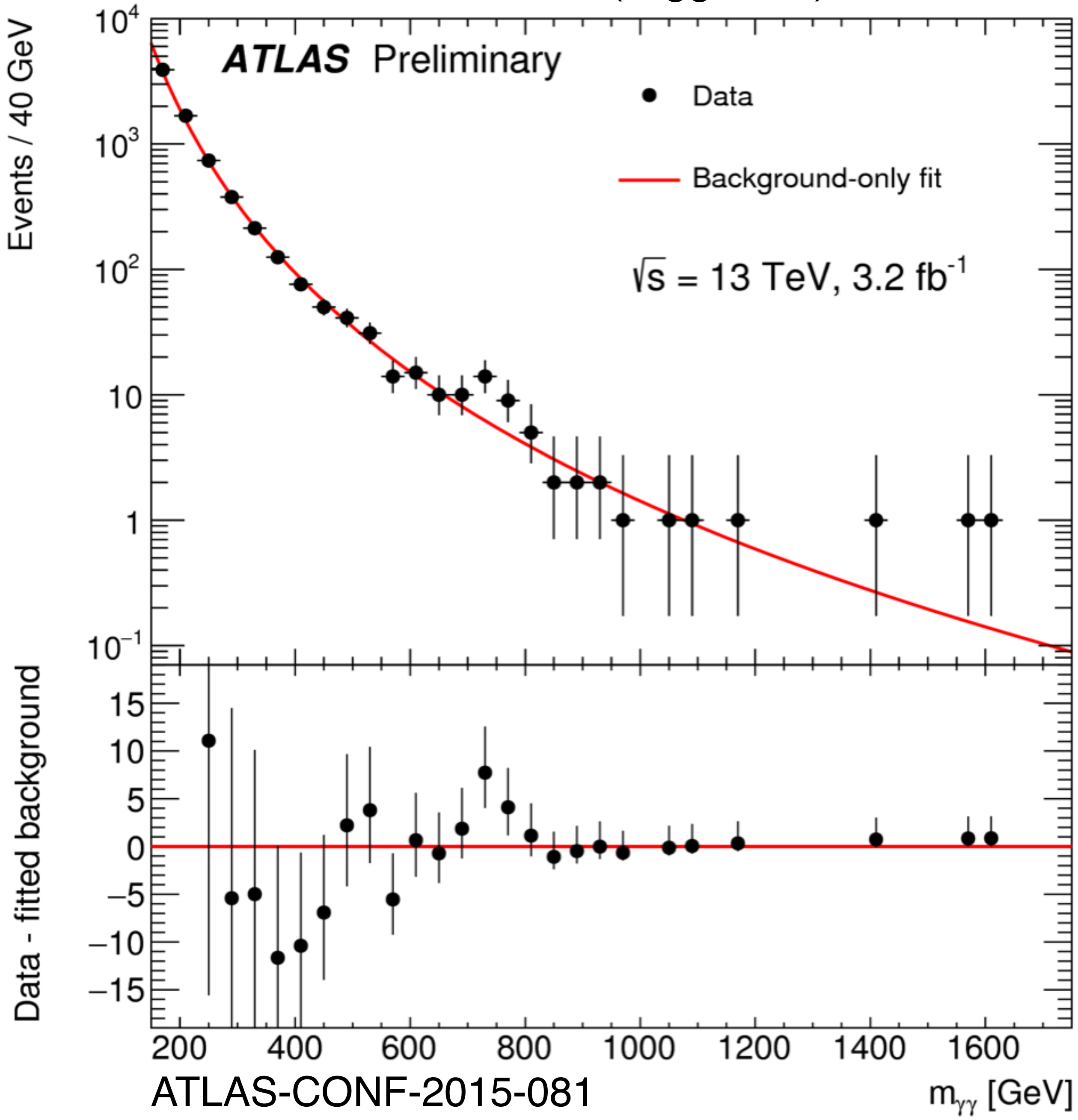
modest excess observed in run-I: 3.4 σ local, 2.5 σ global significance

no excess observed, but sensitivity still too low for conclusive probe (similar for CMS)

Searches for New Phenomena

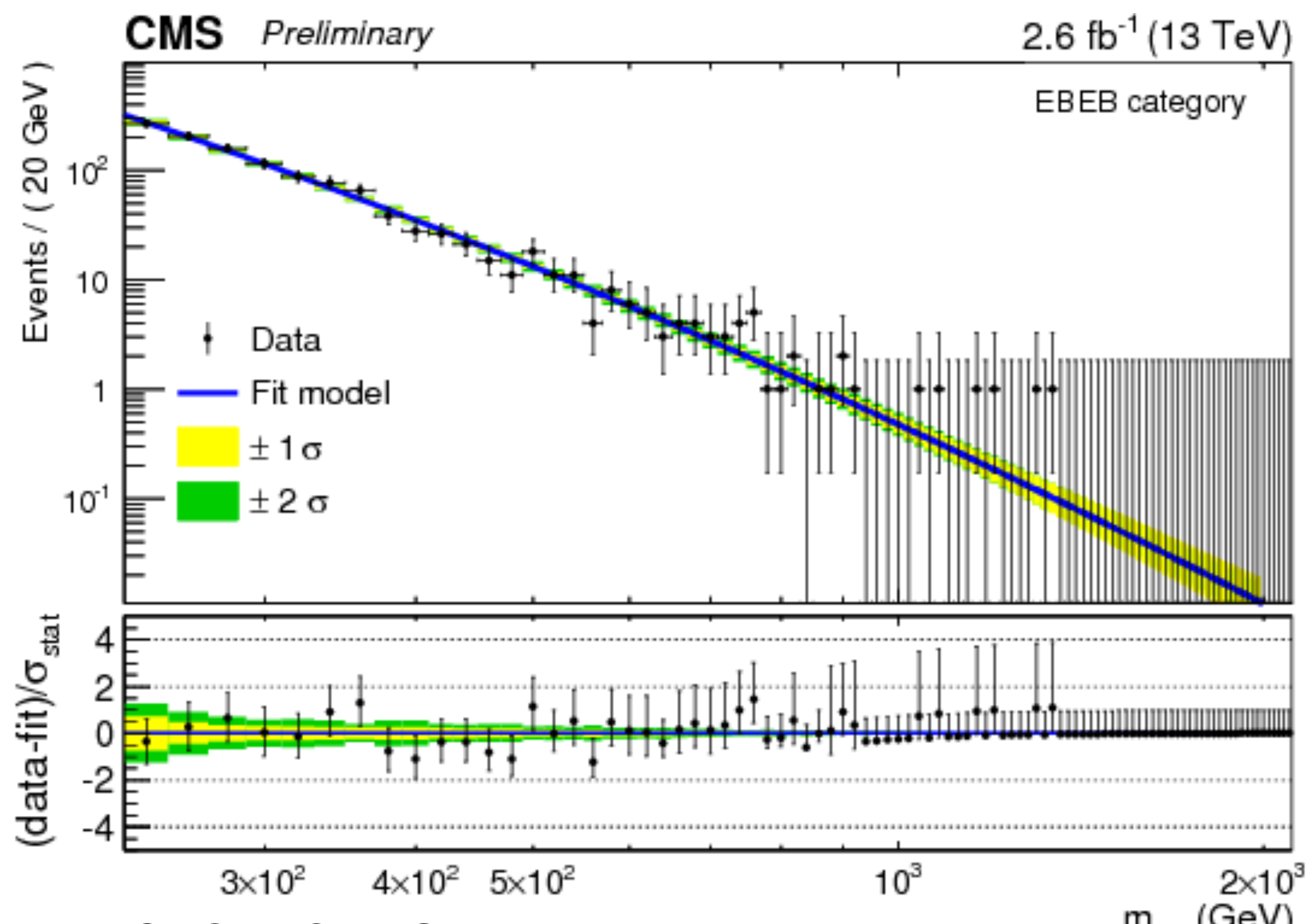
13 TeV data: Diphoton Resonant Searches

search for narrow width (Higgs-like) resonance



ATLAS-CONF-2015-081

search for narrow to wide width (graviton-like) resonance



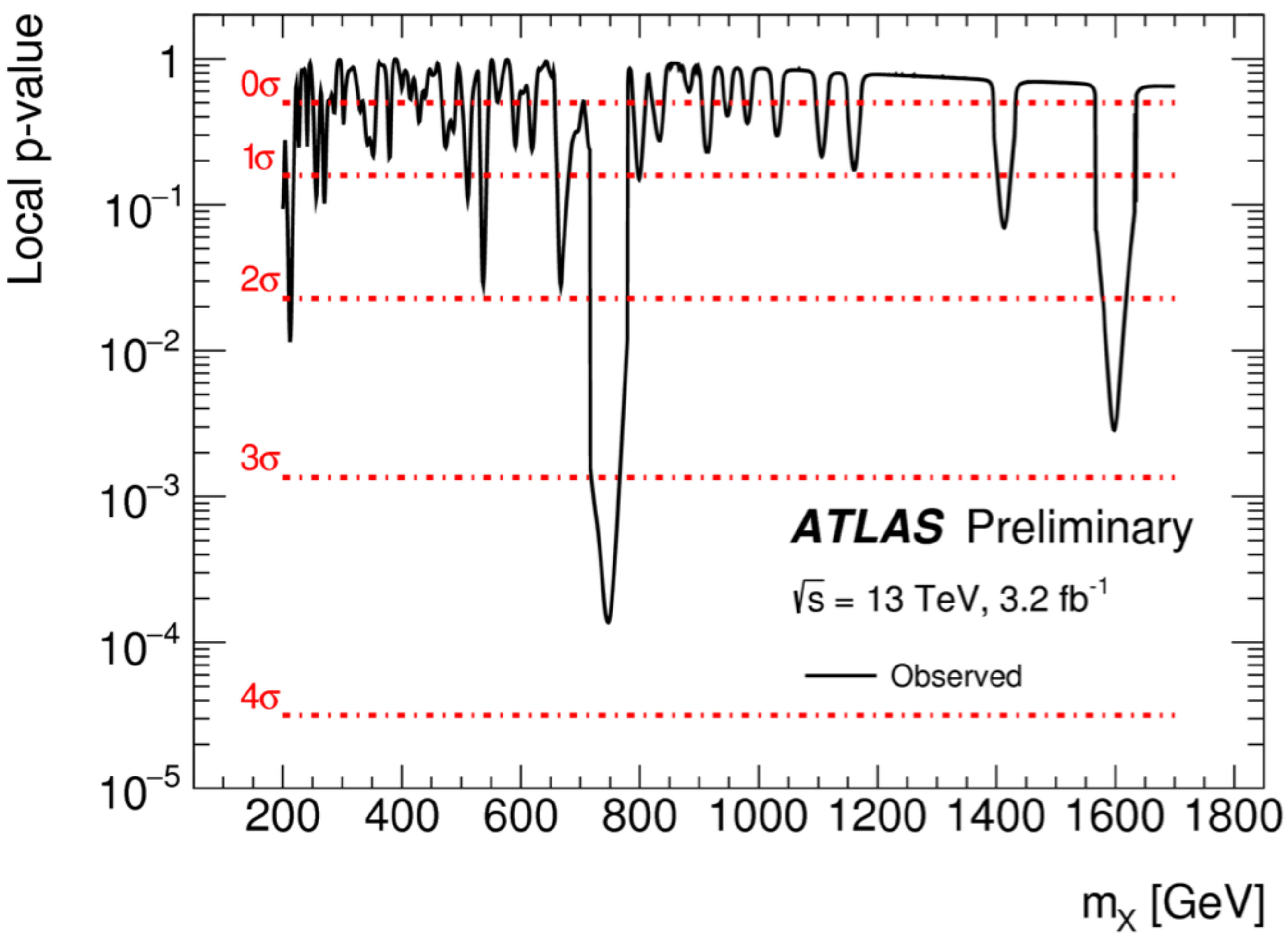
CMS-PAS-EXO-15-004

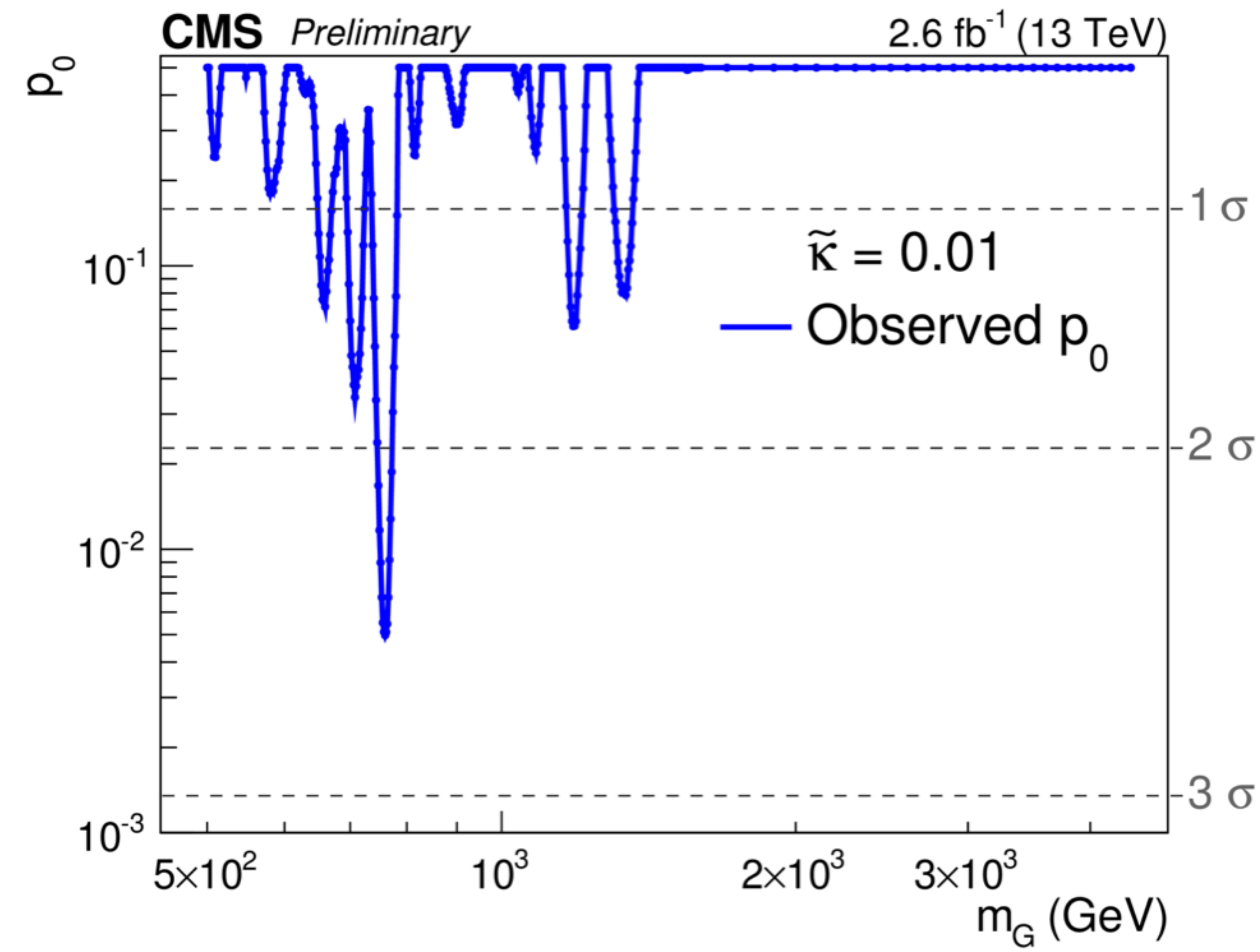
– $m_{\gamma\gamma}$ resolution: ~1% (ATLAS) ~1.1 / 1.8 % (CMS)

– different bin sizes: 40 GeV (ATLAS) 20 GeV (CMS)

Searches for New Phenomena

13 TeV data: Diphoton Resonant Searches





local p-value: 3.6 σ at 750 GeV

global p-value: 2.0 σ (200-2000 GeV)
[for narrow width assumption (Γ ~ 0.004 GeV)

best fit (largest p-value):
Γ~45 GeV, p-value 3.9 (2.3) σ

local p-value: 2.6 σ at 760 GeV

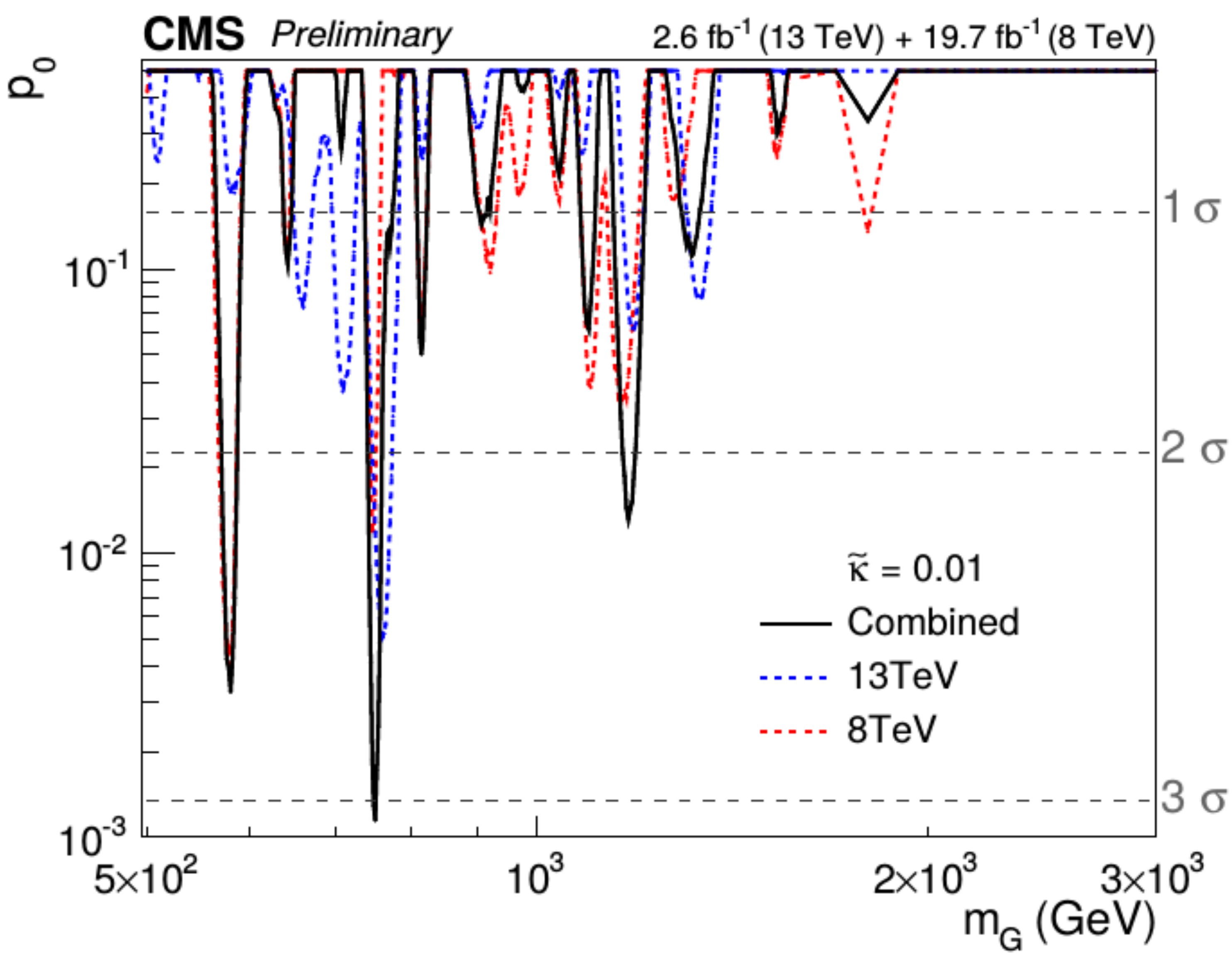
global p-value: <1.2 σ (500-4500 GeV)
[for narrow width assumption (Γ ~ 0.1 GeV)]

for large width (Γ ~ 42 GeV):
p-value 2.0 (< 1) σ

Searches for New Phenomena

13 TeV data: Diphoton Resonant Searches

Consisteny Check with 8 TeV data

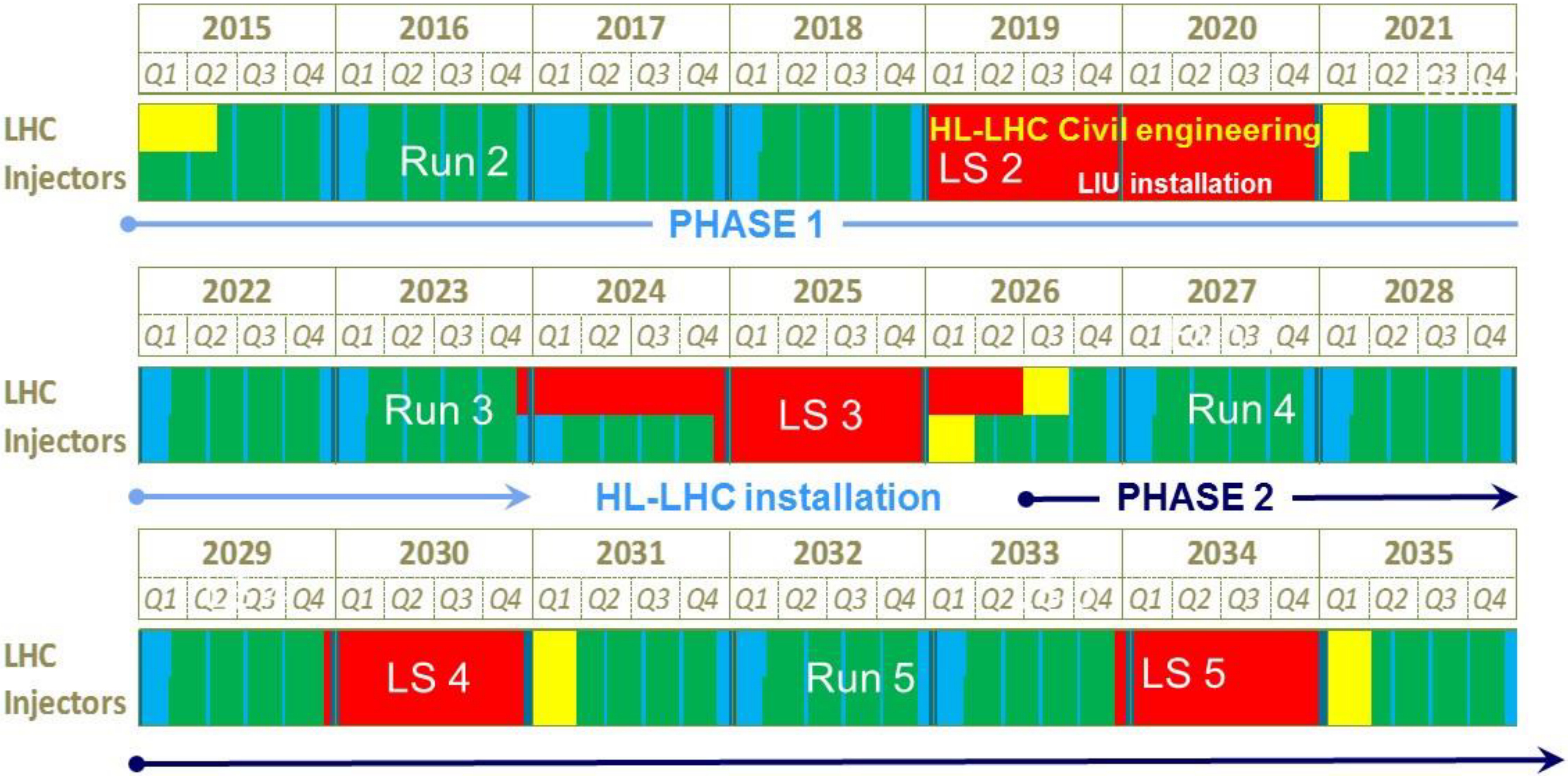


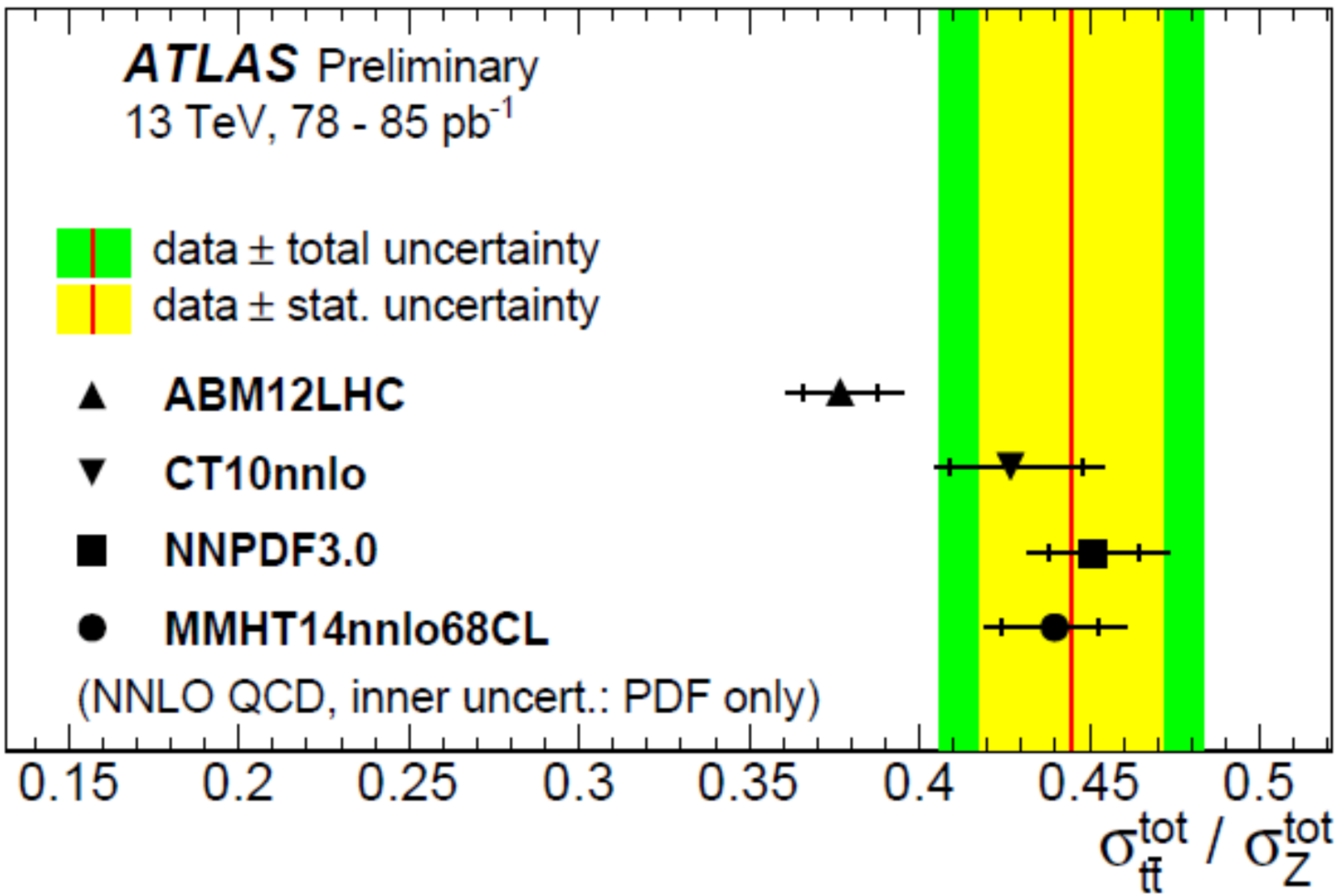
- CMS: combined analysis improves 13 TeV limits :
  local significane: 3.05 σ ; global significance: < 1.7 σ

- ATLAS: repeated analysis of 8 TeV data with same conditions as at 13 TeV;
  ➔ results for narrow-width hypothesis and a spin-0 object from gg-fusion are consistent at 2.2 σ level (1.4 σ for Γ/m = 6%)

Summary

- run II at $\sqrt{s}$ = 13 TeV successfully started in 2015
- results from new 2015 data significantly extend and - in some cases - already exceed results obtained from run-I data ($\sqrt{s}$ = 7 and 8 TeV)
- SM still in very good shape at 13 TeV
- precision results for fundamental SM parameters like m_{top}, α_s, σ_{top} … (Higgs: see talk by Paolo Azzurri)
- no significant signal of physics BSM seen; some limits from run-II already exceed those from run-I
- modest excess signal seen in run-I di-boson mass (and others) need more statistics
- modest "bump" in $m_{\gamma\gamma}$ distribution at ~750 GeV boosts hopes and imagination - desperately waiting for more data!


2015 2016 2017 2018 2019 2020 2021
LHC
Injectors
Run 2
HL-LHC Civil engineering
LS 2
LIU installation
PHASE 1
2022 2023 2024 2025 2026 2027 2028
Run 3
LS 3
Run 4
HL-LHC installation
PHASE 2
2029 2030 2031 2032 2033 2034 2035
LS 4
Run 5
LS 5


ATLAS Preliminary
13 TeV, 78 - 85 pb-1
data ± total uncertainty
data ± stat. uncertainty
ABM12LHC
CT10nnlo
NNPDF3.0
MMHT14nnlo68CL
(NNLO QCD, inner uncert.: PDF only)
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
$\sigma_{t\bar{t}}^{tot} / \sigma_{Z}^{tot}$