Early Run 2 Hard QCD Results from the ATLAS Collaboration

XLV International Symposium on Multiparticle Dynamics
04-09 October 2015, Wildbad Kreuth (DE)

Nicola Orlando on behalf of the ATLAS Collaboration

Aristotle University of Thessaloniki and
The University of Hong Kong

European Union
European Social Fund

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EDUCATION AND LIFELONG LEARNING
investing in knowledge society
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MANAGING AUTHORITY
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NSRF
2007-2013
programme for development
EUROPEAN SOCIAL FUND

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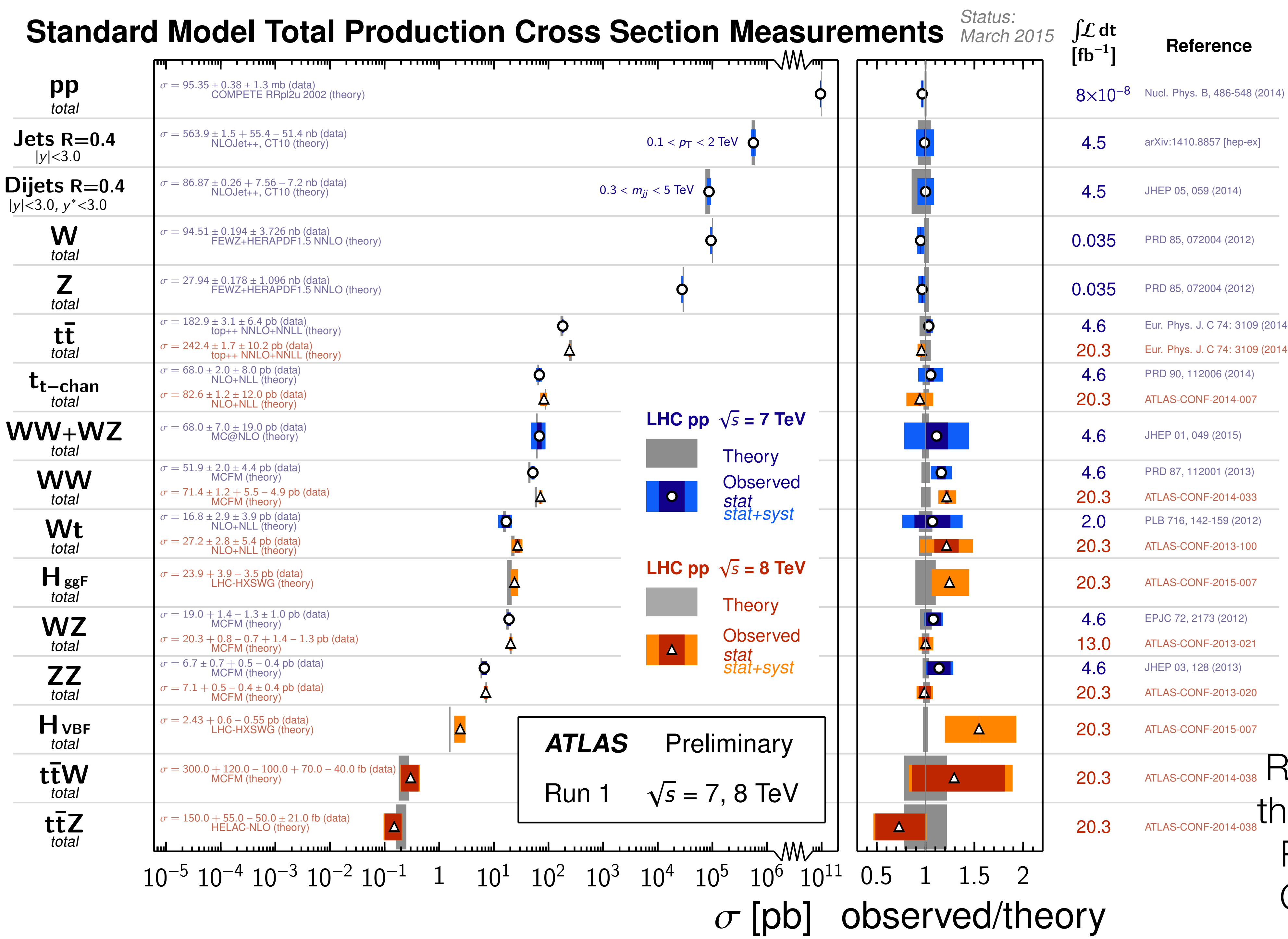
The triumph of hard QCD in Run 1



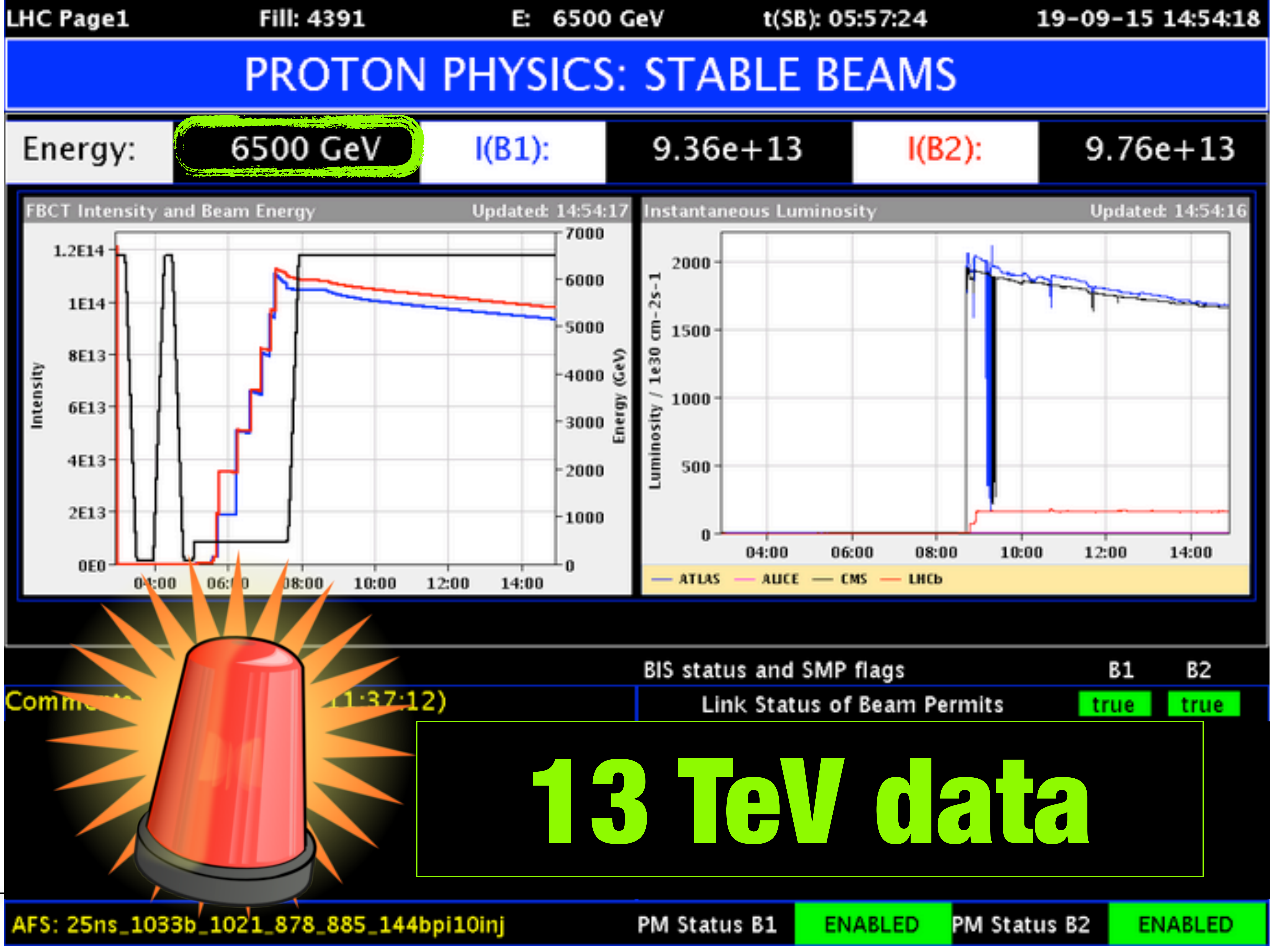
For an overview of the Run 1 ATLAS results see the talks by Enrico, Nuno, Peter, Grzegorz Pawel, Claudia, Yuri, Hideyuki, Sascha, and Henso

Outline

- The status of ATLAS in Run 2
- Jet and photons cross section measurement
- J/ψ non-prompt fraction
- Inclusive W/Z and Z+jets cross sections
- Top pair production
- Outlook

What’s new in Run 2

- Centre of mass energy!
  - Thanks to the LHC machine
- New generators, PDFs, calculations keep coming!
  - Thanks to the theory community
    - Contributions from LHC experiments as well
- Many improvements in the experiment, most notably
  - Insertable B-Layer
  - Algorithms (online and offline) and analysis software



LHC Page1
Fill: 4391
E: 6500 GeV
t(SB): 05:57:24
19-09-15 14:54:18
PROTON PHYSICS: STABLE BEAMS
Energy:
6500 GeV
I(B1):
9.36e+13
I(B2):
9.76e+13
FBCT Intensity and Beam Energy
Updated: 14:54:17
Intensity
Energy (GeV)
1.2E14
1E14
8E13
6E13
4E13
2E13
0E0
7000
6000
5000
4000
3000
2000
1000
0
10:00
12:00
14:00
Instantaneous Luminosity
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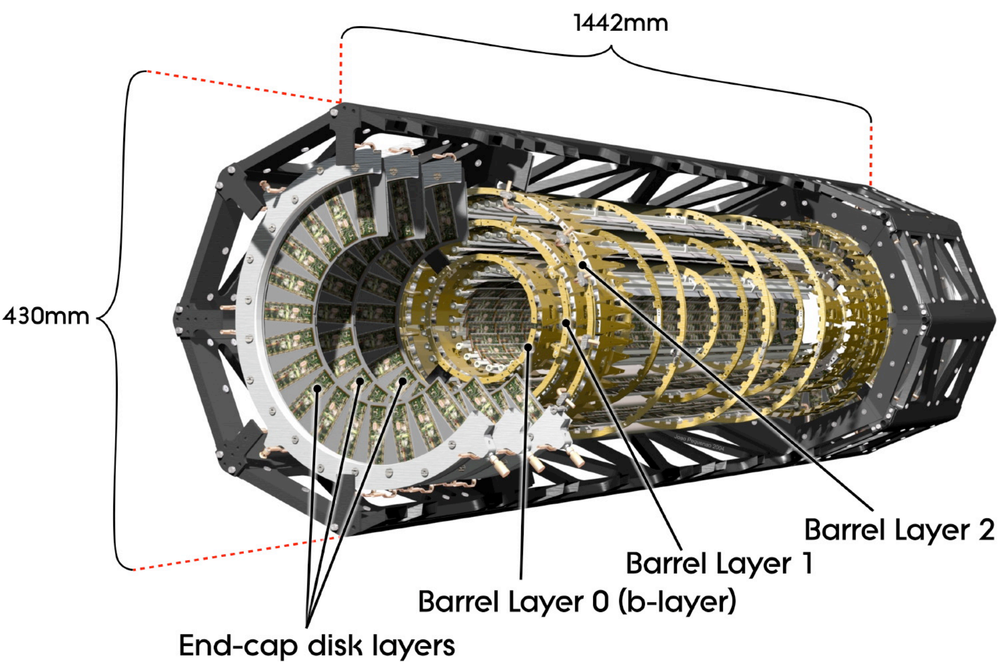
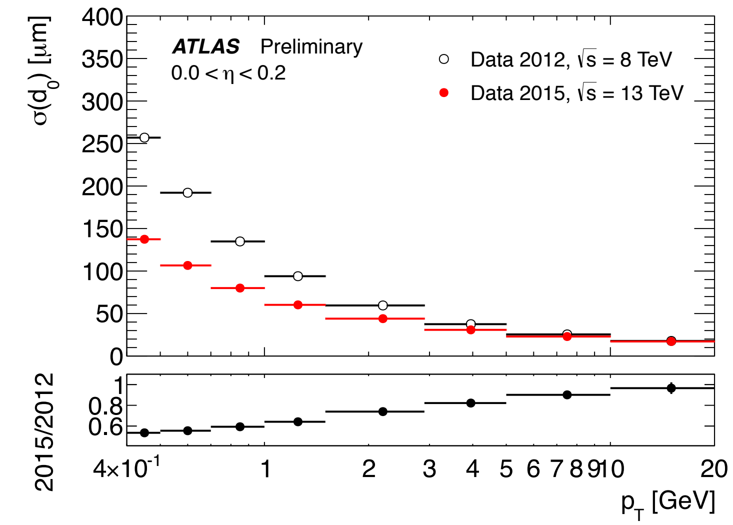
Luminosity / 1e30 cm-2s-1
2000
1500
1000
500
0
04:00
06:00
08:00
10:00
12:00
14:00
ATLAS
ALICE
CMS
LHCb
BIS status and SMP flags
B1
B2
Link Status of Beam Permits
true
true
13 TeV data
AFS: 25ns_1033b_1021_878_885_144bpi10inj
PM Status B1
ENABLED
PM Status B2
ENABLED

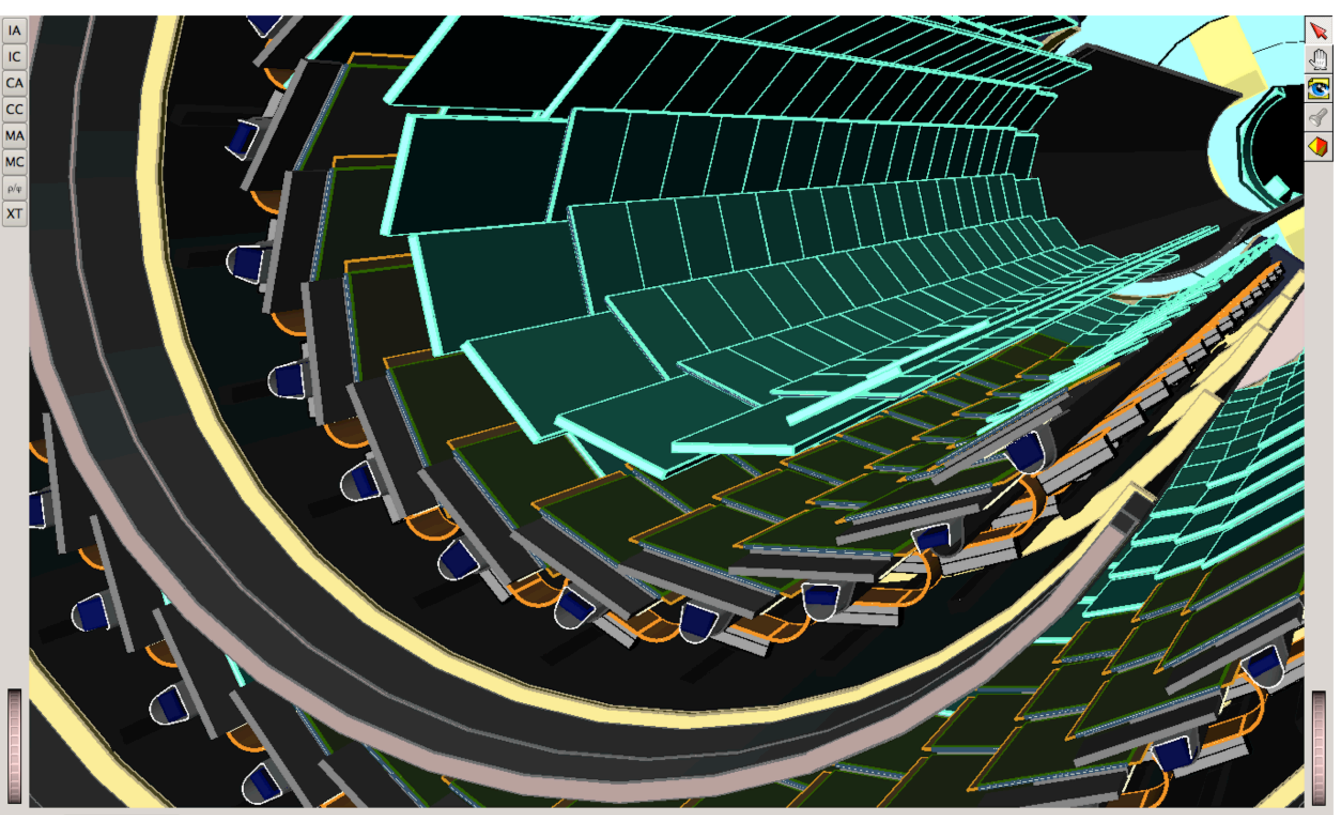
ATLAS-TDR-19

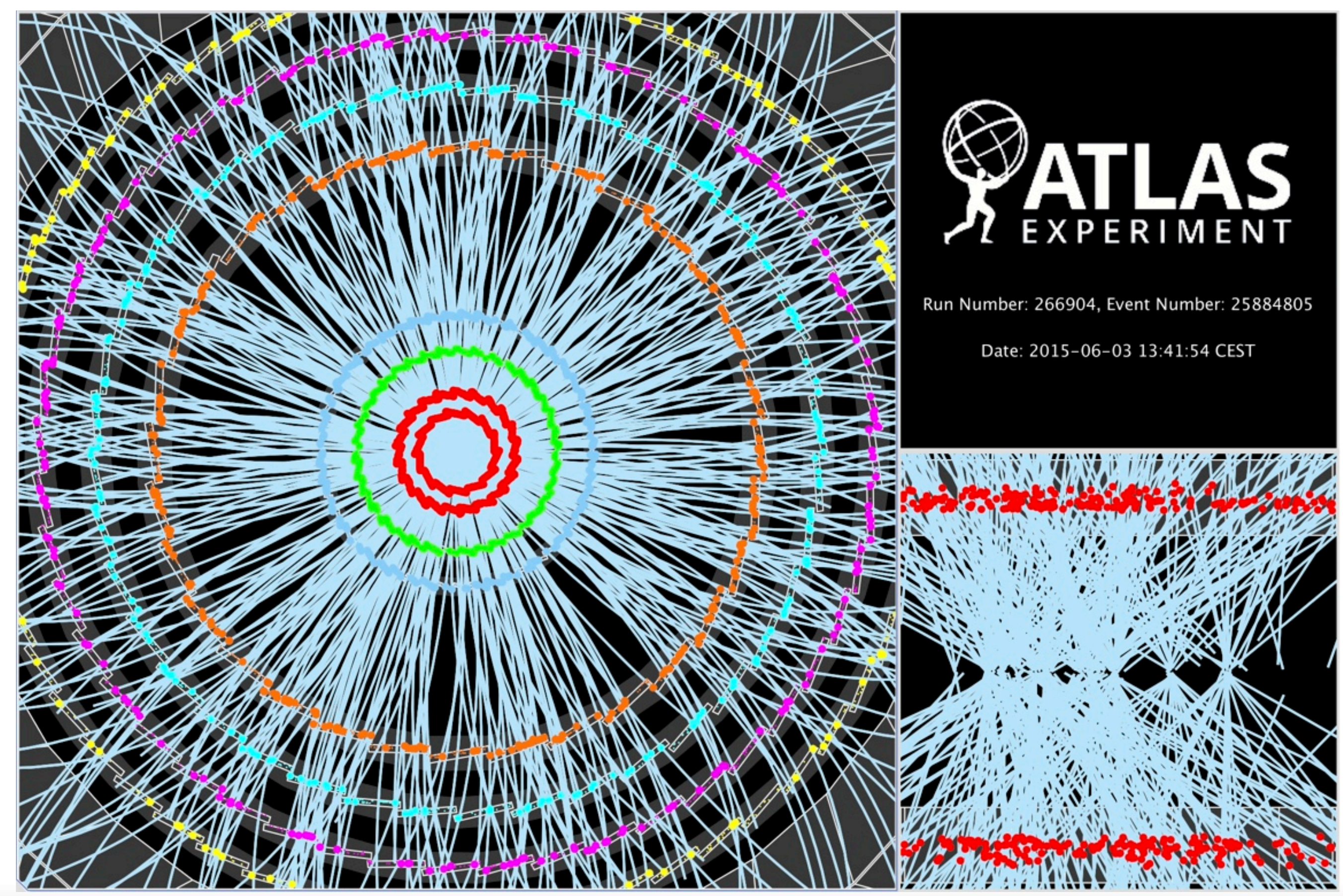
Insertable B-Layer



- New innermost pixel detector layer
- What get better
  - Tracking, in particular impact parameter resolution
  - B-tagging
  - Pile-up suppression

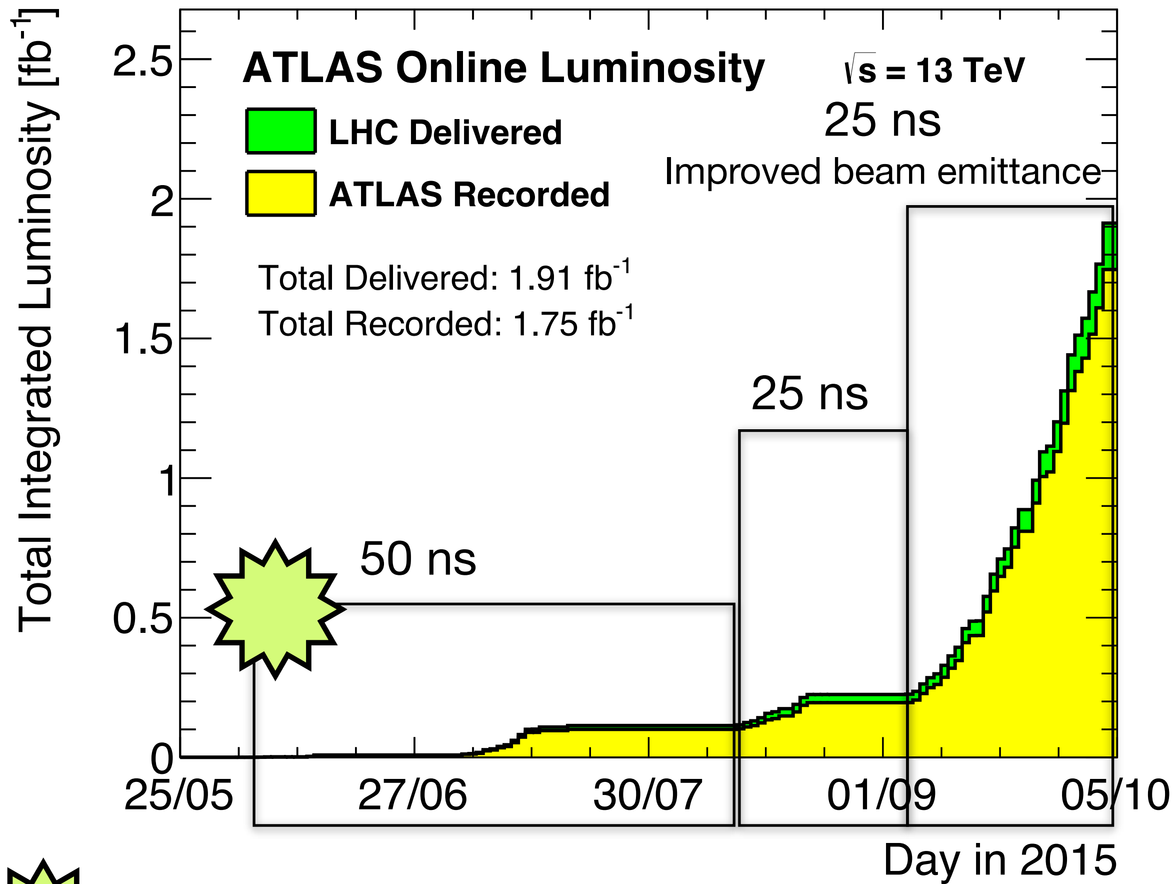






Early data

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResultsRun2



- Early analyses based on “early” data, up to 85 pb^{-1}
  - On average 19 interactions per bunch crossing, 50 ns bunch spacing
- Detector operations running very smoothly

Percentage of operational detector channels above 97%

Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	92 M	99.0%
SCT Silicon Strips	6.3 M	98.9%
TRT Transition Radiation Tracker	350 k	97.3%
LAr EM Calorimeter	170 k	100%
Tile calorimeter	4900	99.2%
Hadronic endcap LAr calorimeter	5600	99.6%
Forward LAr calorimeter	3500	99.8%
LVL1 Calo trigger	7160	100%
LVL1 Muon RPC trigger	370 k	98.7%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	357 k	99.8%
CSC Cathode Strip Chambers	31 k	98.4%
RPC Barrel Muon Chambers	370 k	97.1%
TGC Endcap Muon Chambers	320 k	99.8%

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ApprovedPlotsATLASDetector

Summary of measurements with early data

Process	Final state	Analysis reference	Used integrated luminosity [pb^{-1}]
Multijets	Jets	ATLAS-CONF-2015-034	78
Inclusive photons, di-photons	Photons	ATL-PHYS-PUB-2015-020 ATL-PHYS-PUB-2015-016	6.4
J/ψ	Muons	ATLAS-CONF-2015-030	6.4
W/Z	Muons, electrons, missing E_T	ATLAS-CONF-2015-039	85
Z+jets	Muons, electrons, jets	ATLAS-CONF-2015-041	85
Top	Muons, electrons, jets, b-jets, missing E_T	ATLAS-CONF-2015-033 ATLAS-CONF-2015-049	78-85

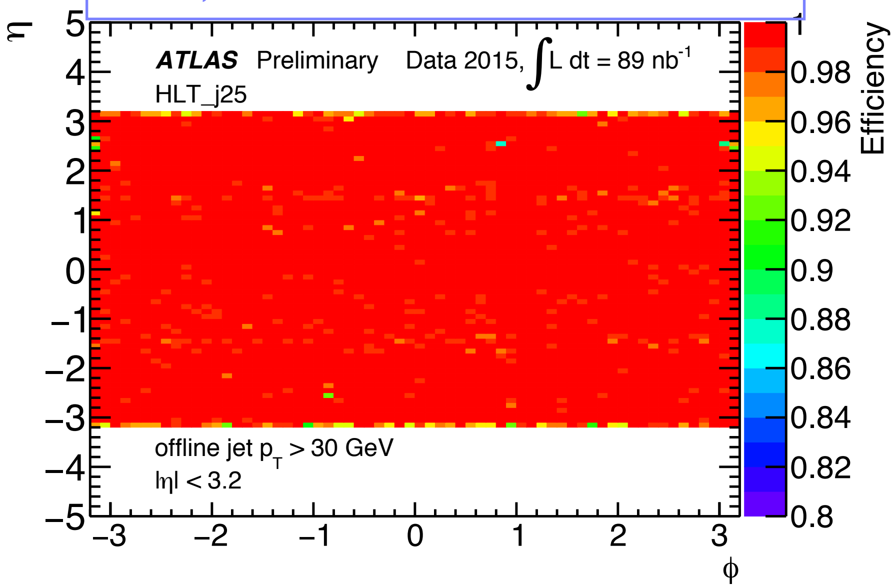
For a full list of 13 TeV ATLAS results consult the web page
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/Summer2015-13TeV

Triggering on 13 TeV collisions

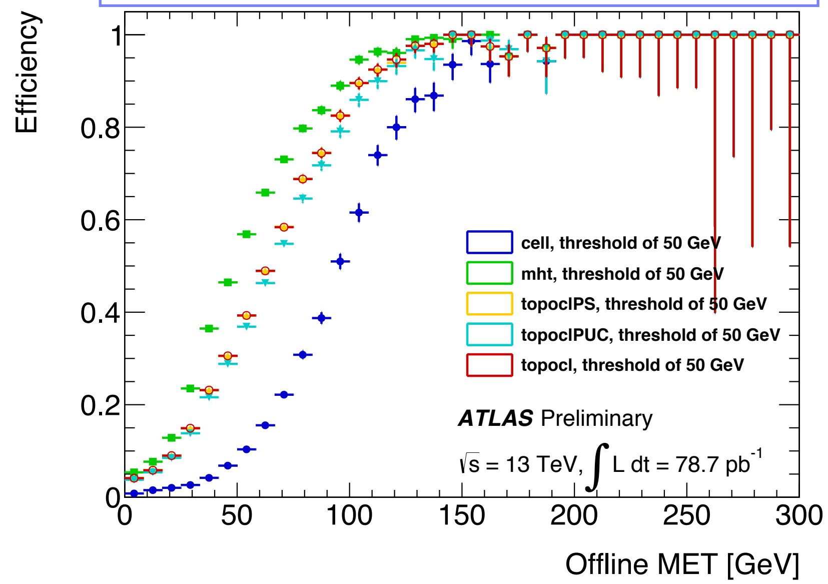
Picking just a few examples

click the links on this slide for many more public plots

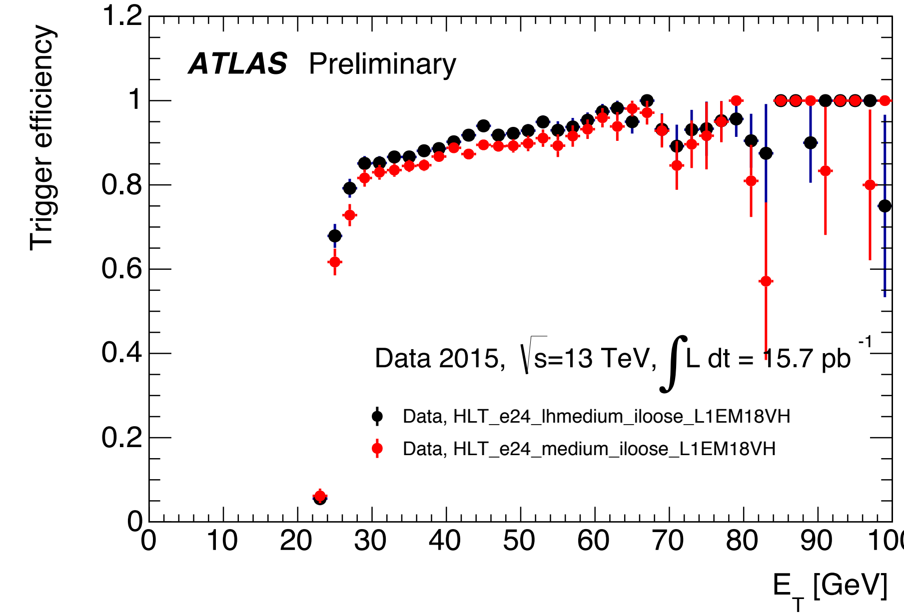
Jets, ATL-COM-DAQ-2015-099



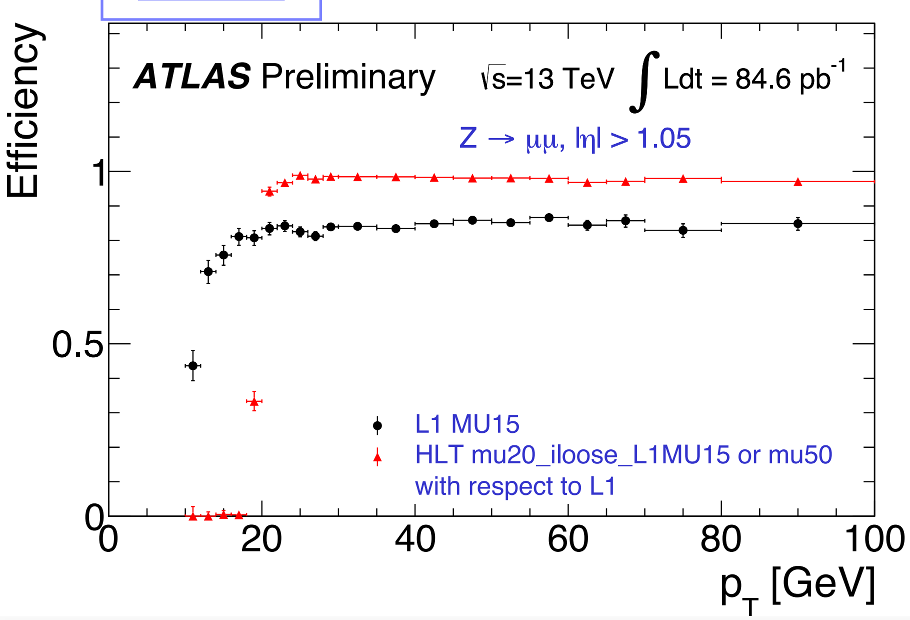
MET, ATL-COM-DAQ-2015-112



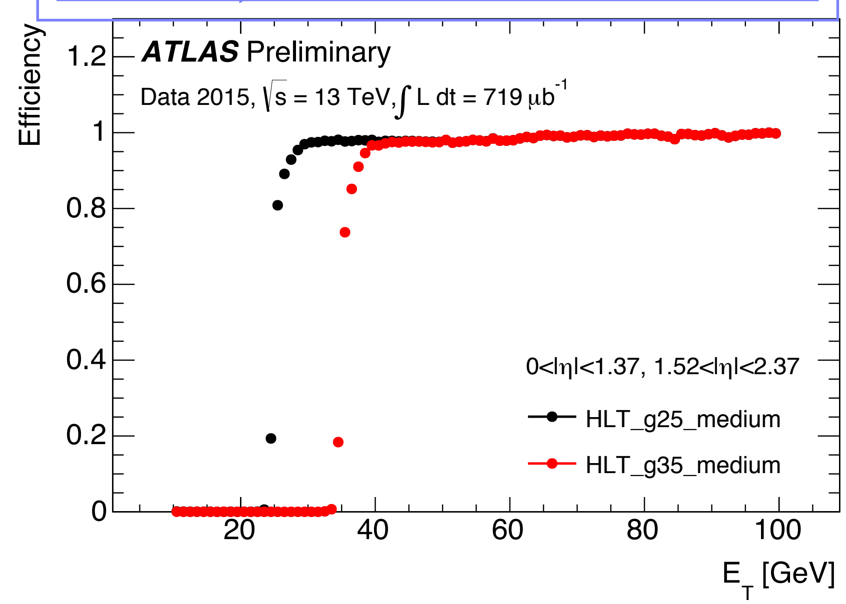
Electrons, ATL-COM-DAQ-2015-101



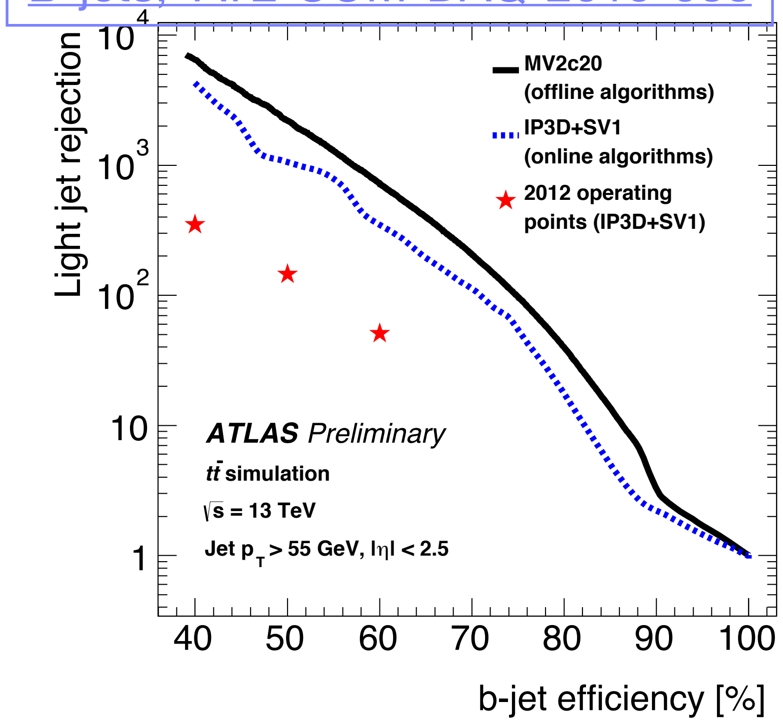
Muons



Photons, ATL-COM-DAQ-2015-101



B-jets, ATL-COM-DAQ-2015-088

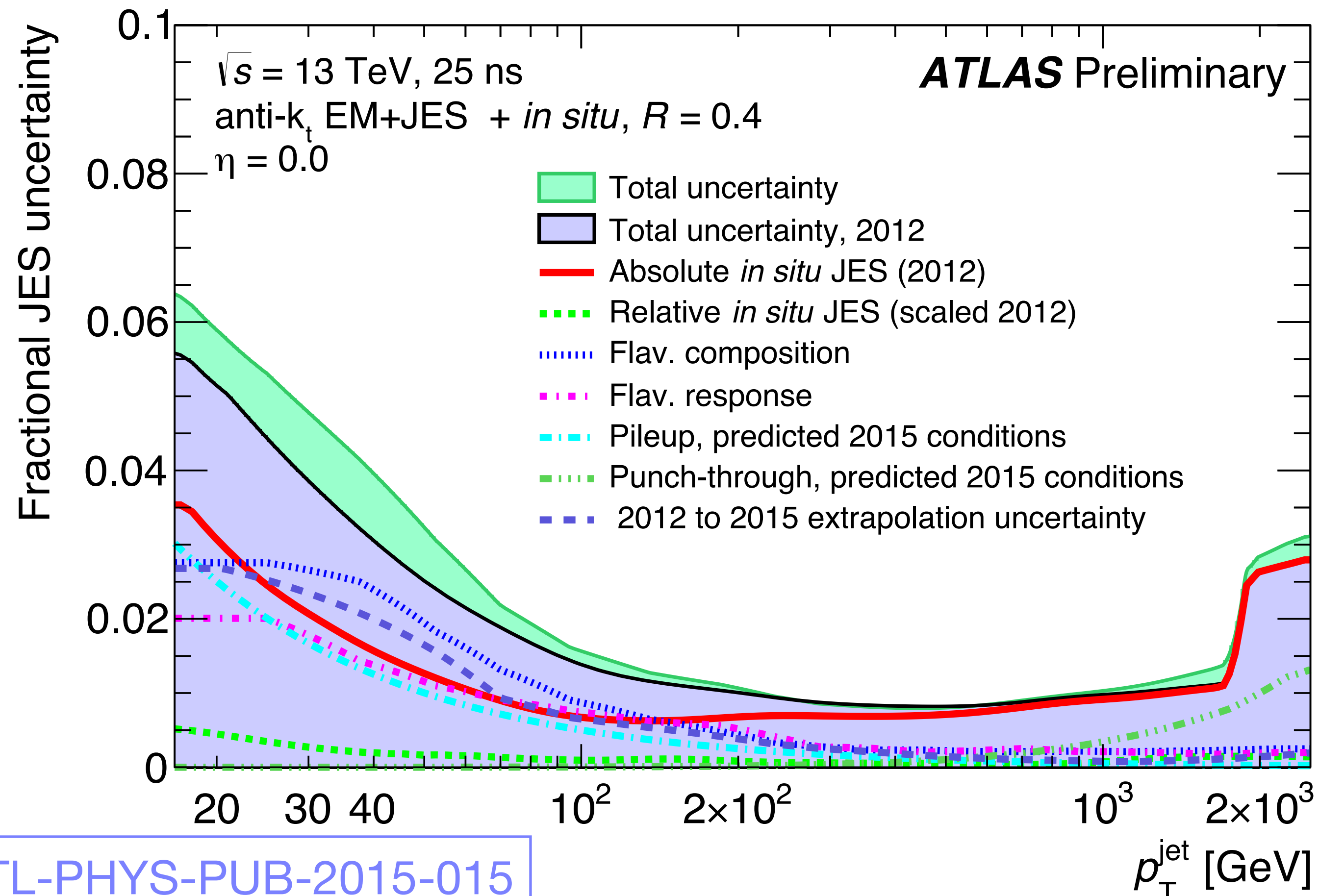


Jets and photons

Di-jet system with invariant mass of 5.2 TeV

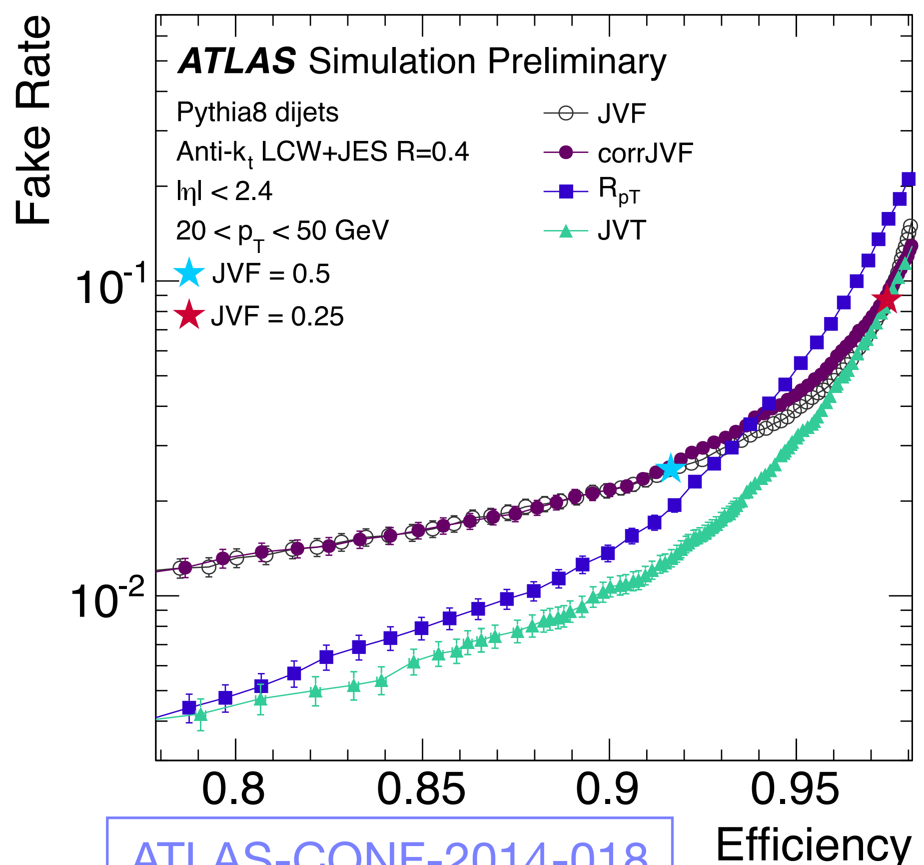
Jets in early data

- Exploit the solid understanding of jet reconstruction performance at 8 TeV
  - Extrapolate it to the new data taking conditions (and new detector) using the MC
- Similar strategy is used in other complicated performance measurements (e.g., b-tagging)



ATL-PHYS-PUB-2015-015

Pile-up suppression with PV-tracks association

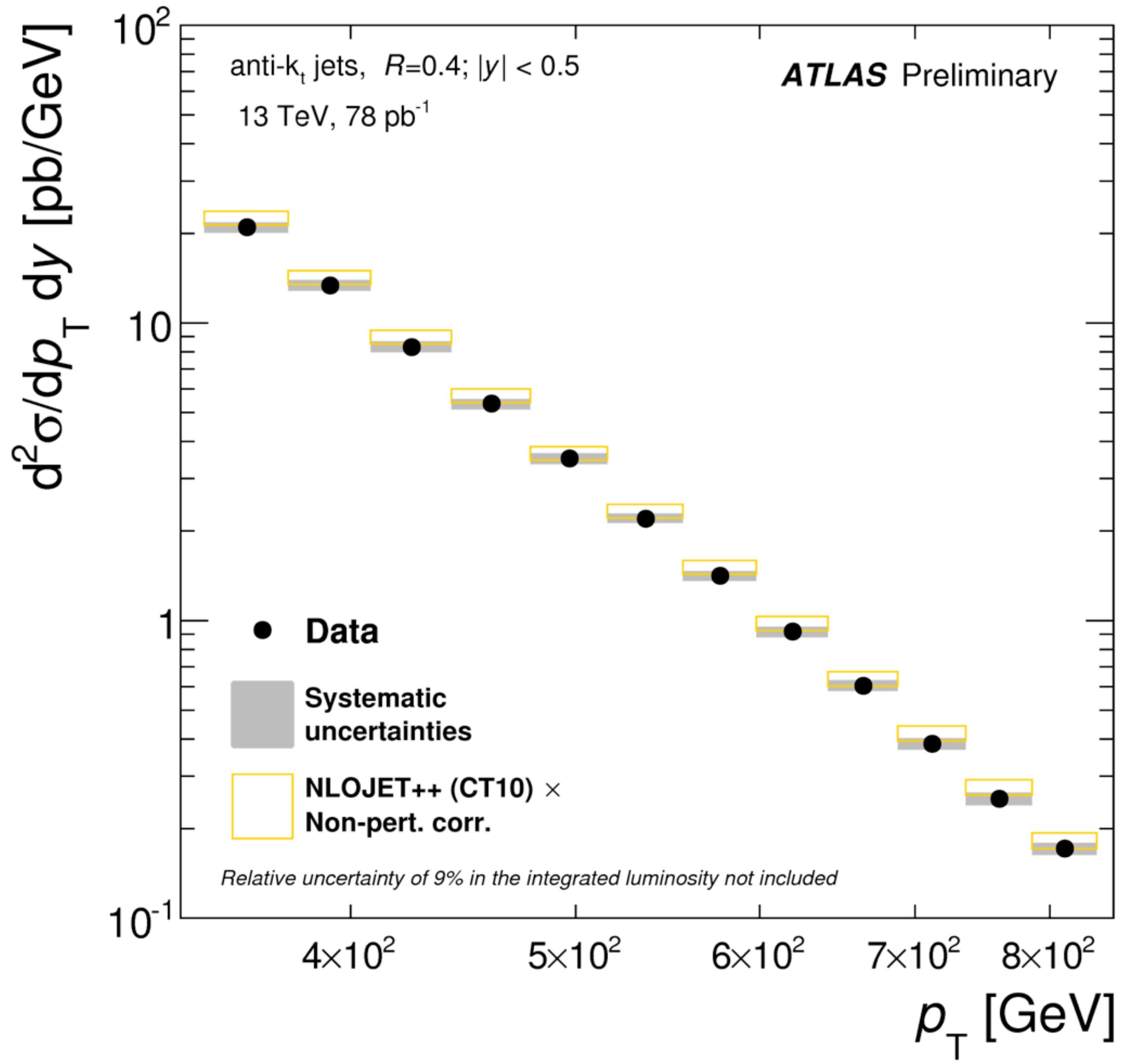


ATLAS-CONF-2014-018

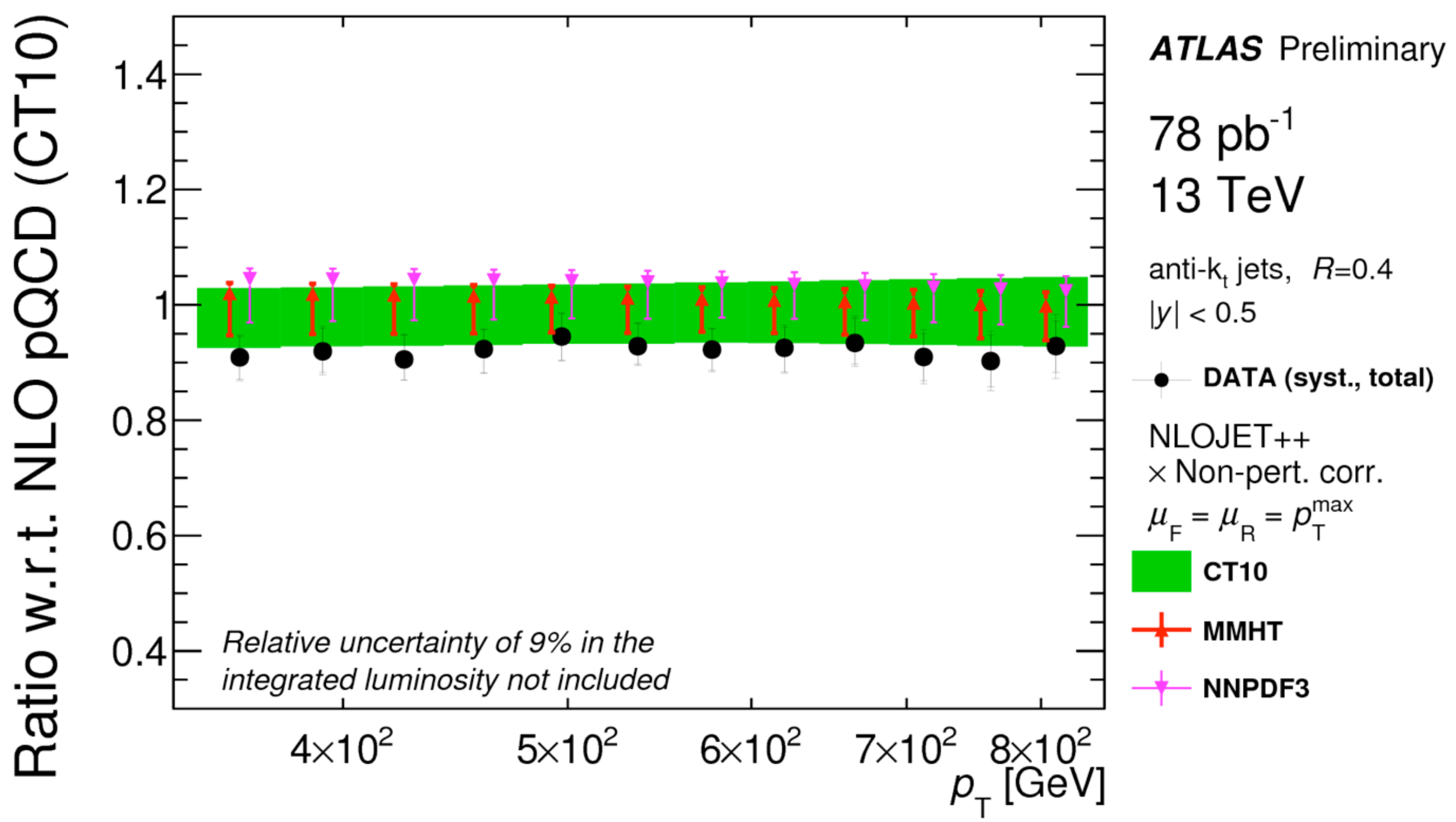
ATLAS-CONF-2015-034

13 TeV Jet cross section

- NLO predictions match the data
- Difference in normalisation covered by luminosity uncertainty, 9%, not shown in the plot

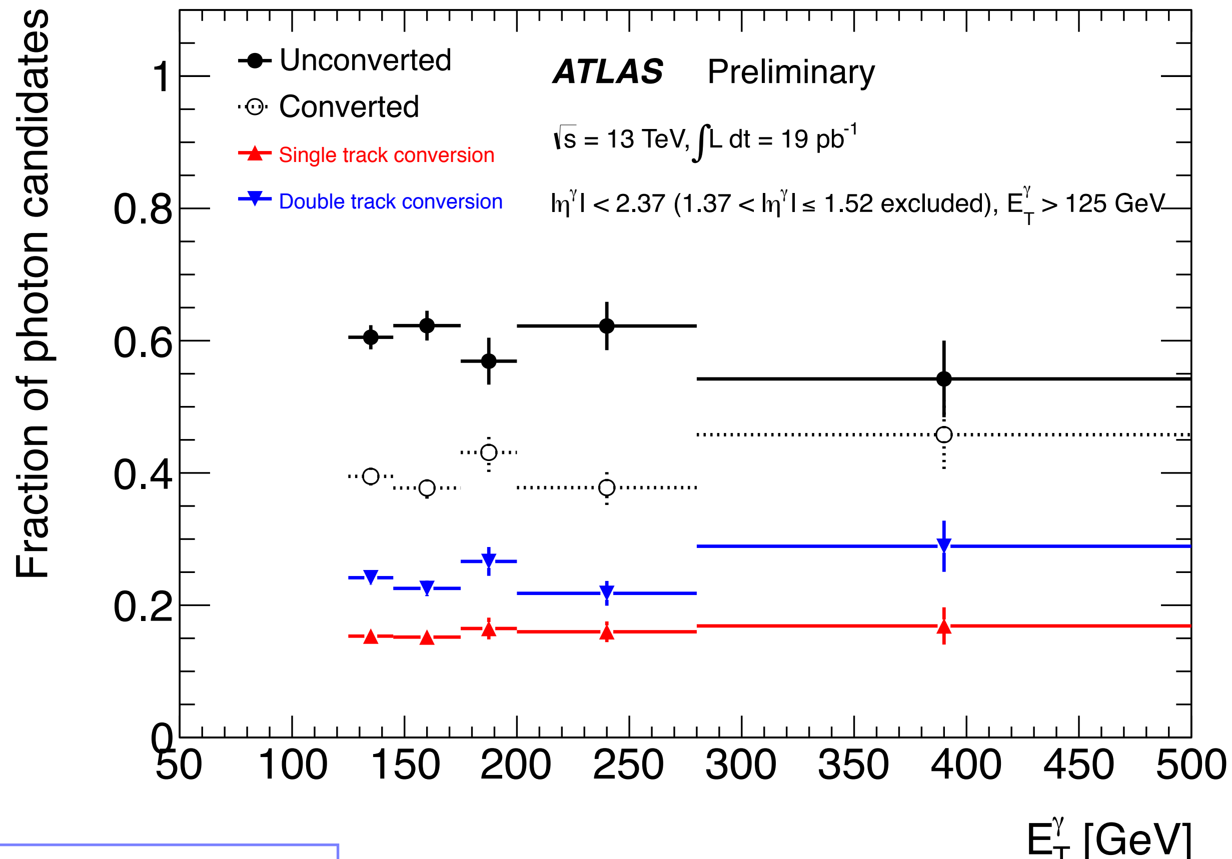


Only central jets, already very promising

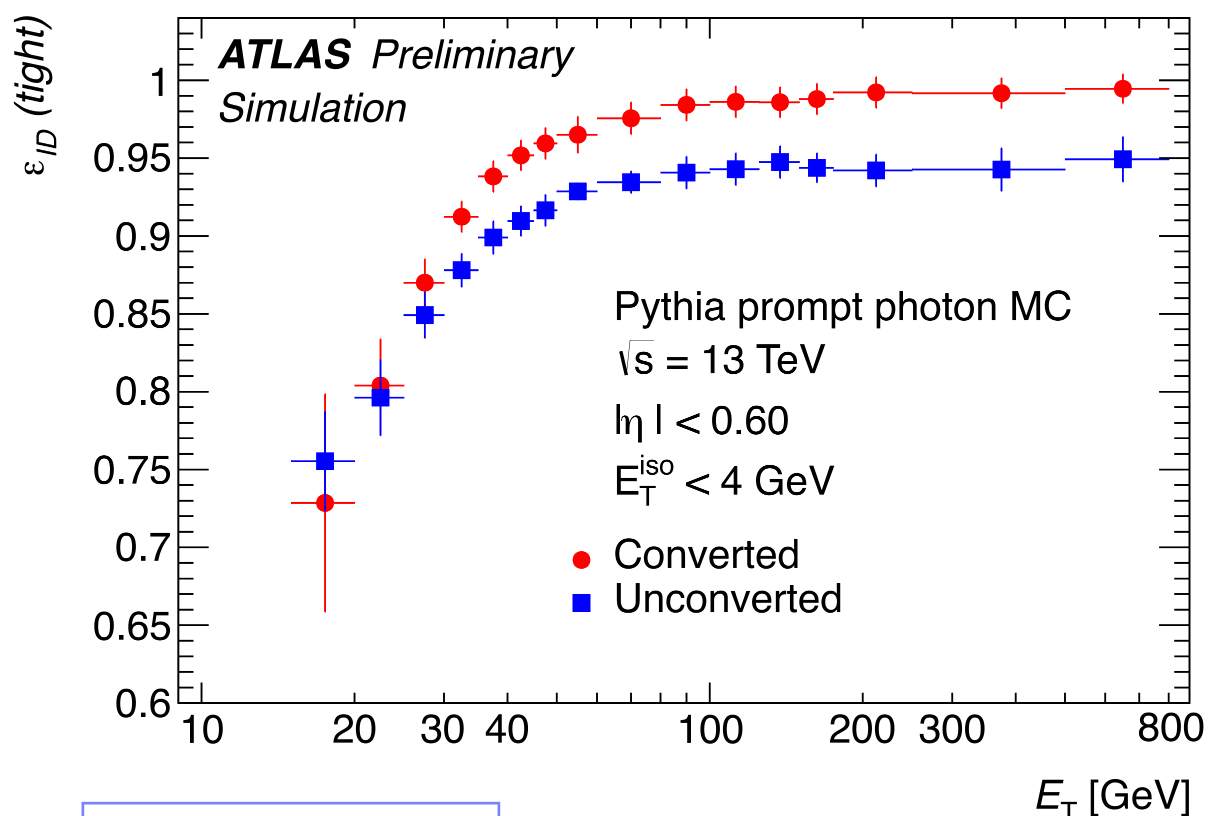


Photon

- Detailed photons performance studies are ongoing
- For E_T above 100 GeV more than 90% identification efficiency is expected



EGAM-2015-004

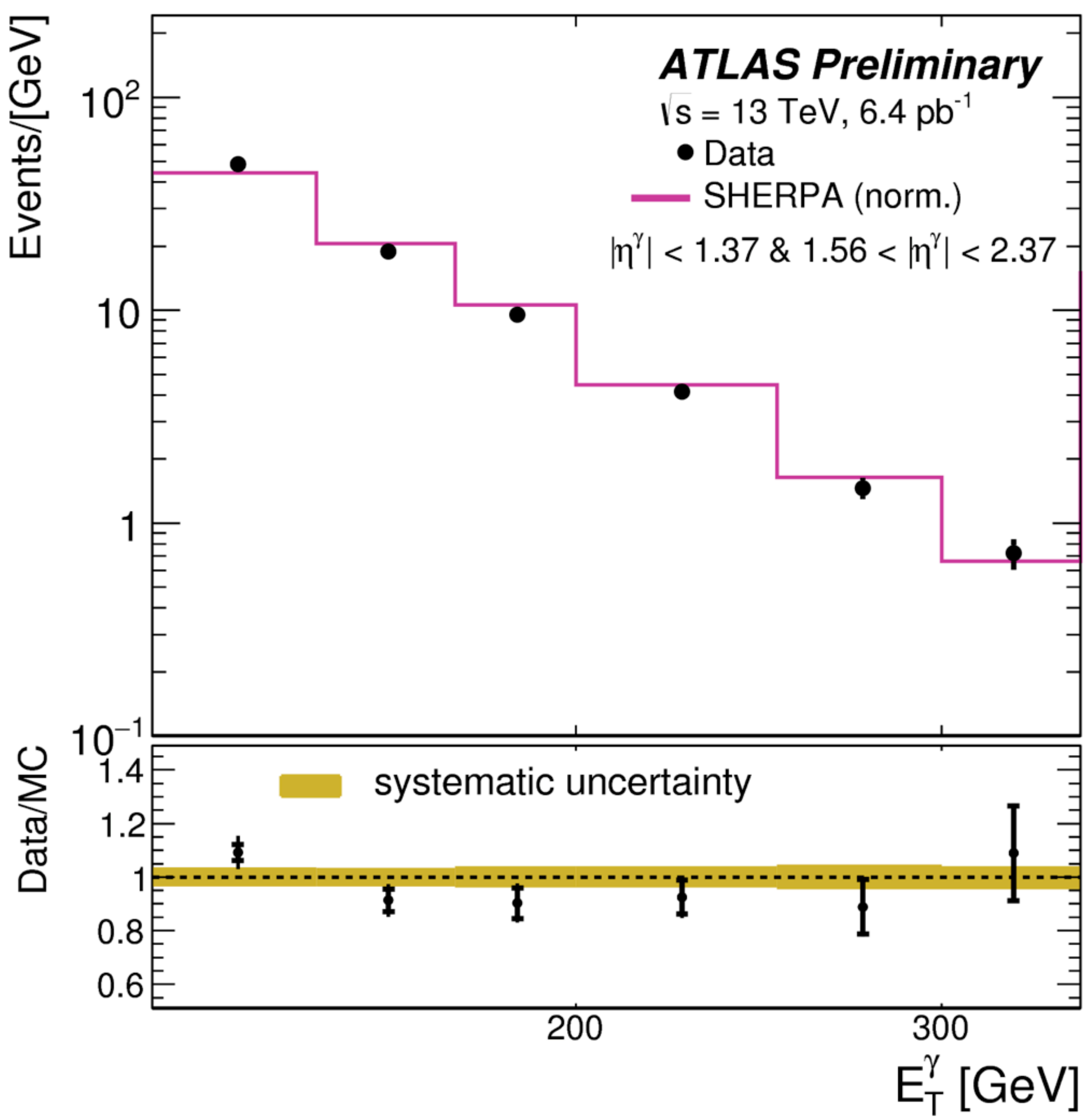


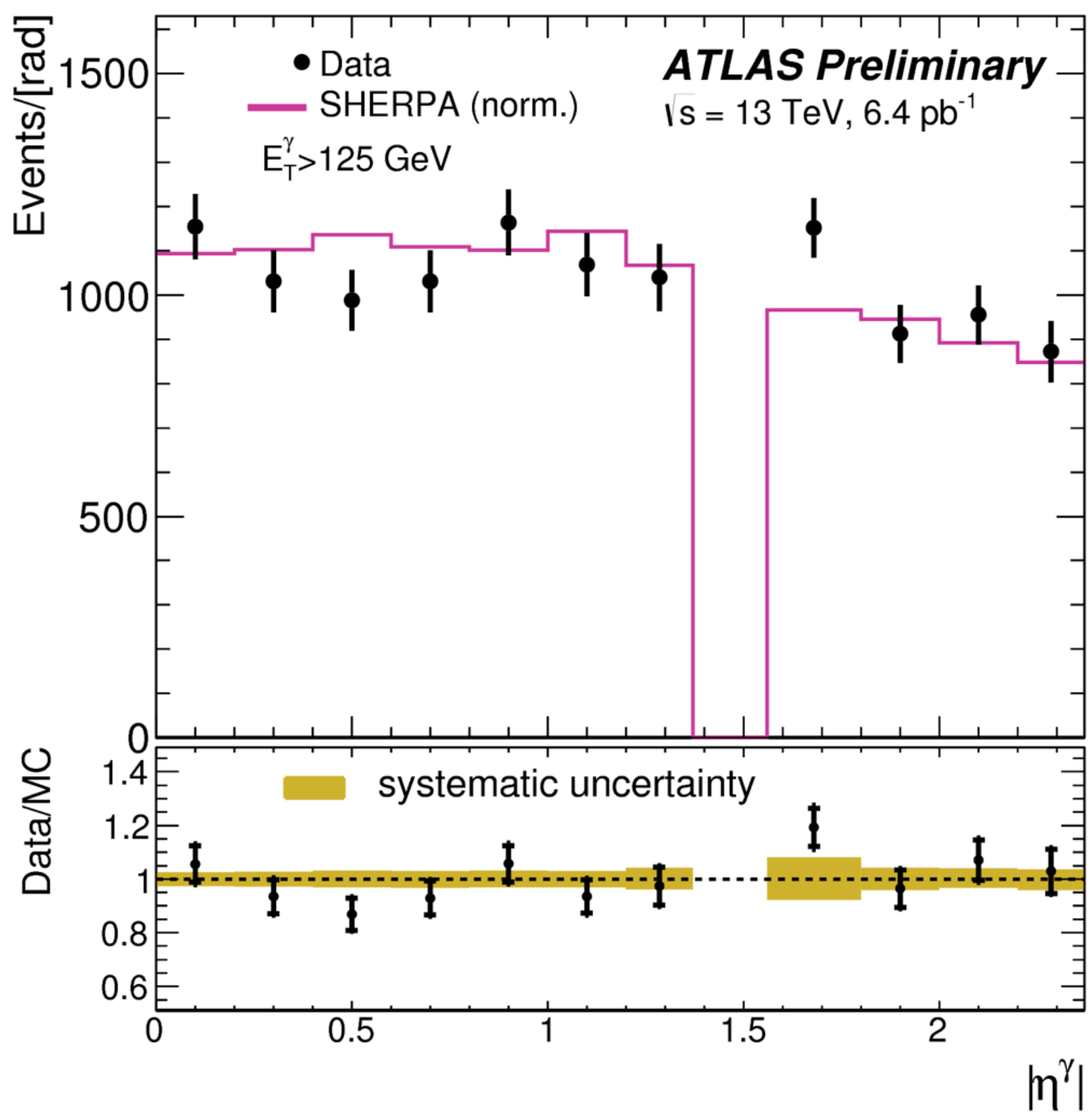
EGAM-2015-002

ATL-PHYS-PUB-2015-016

Inclusive photon production

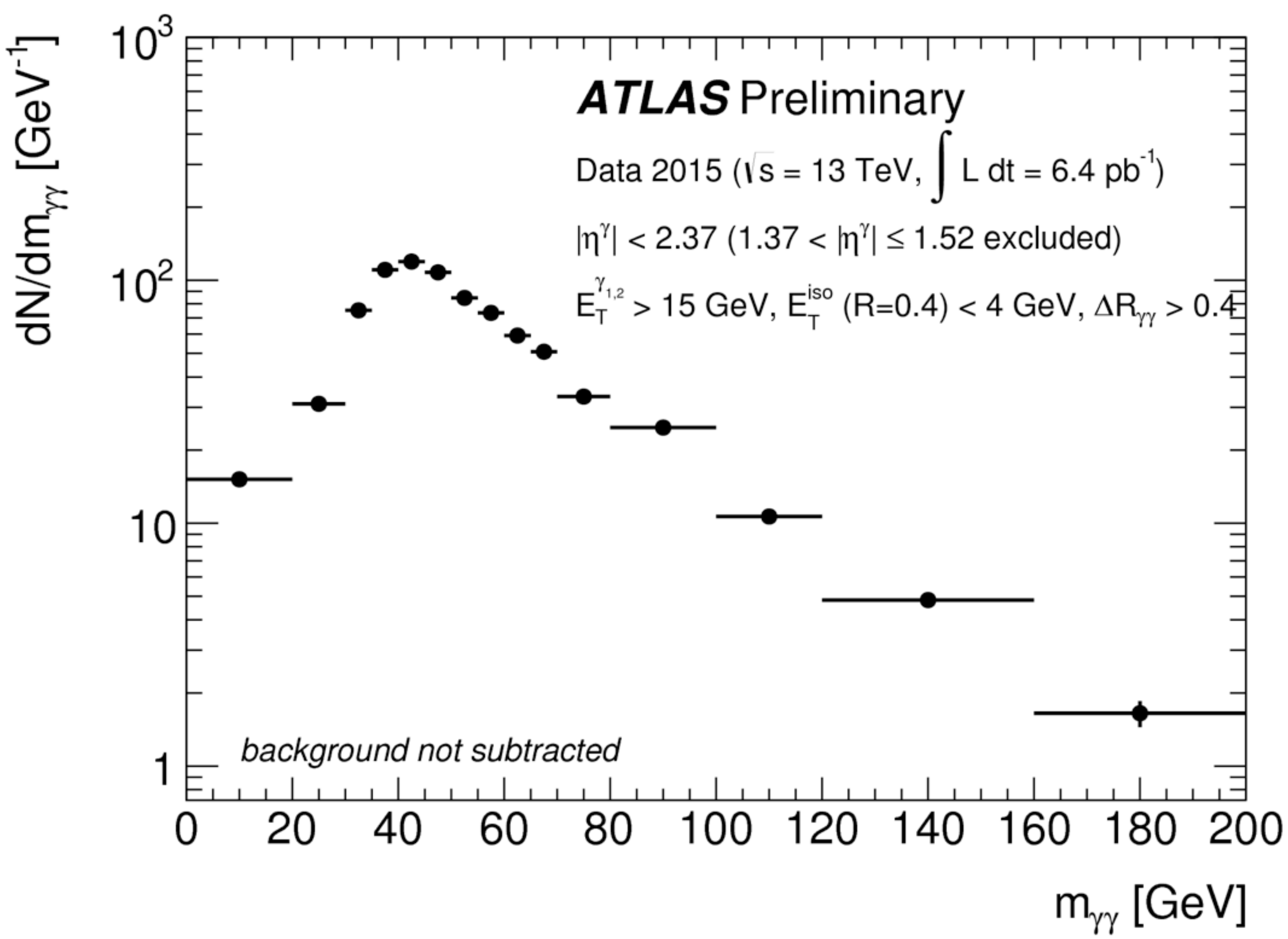
- Detector level distributions for inclusive photon production (backgrounds are subtracted)
- Satisfactory agreement with Sherpa prediction

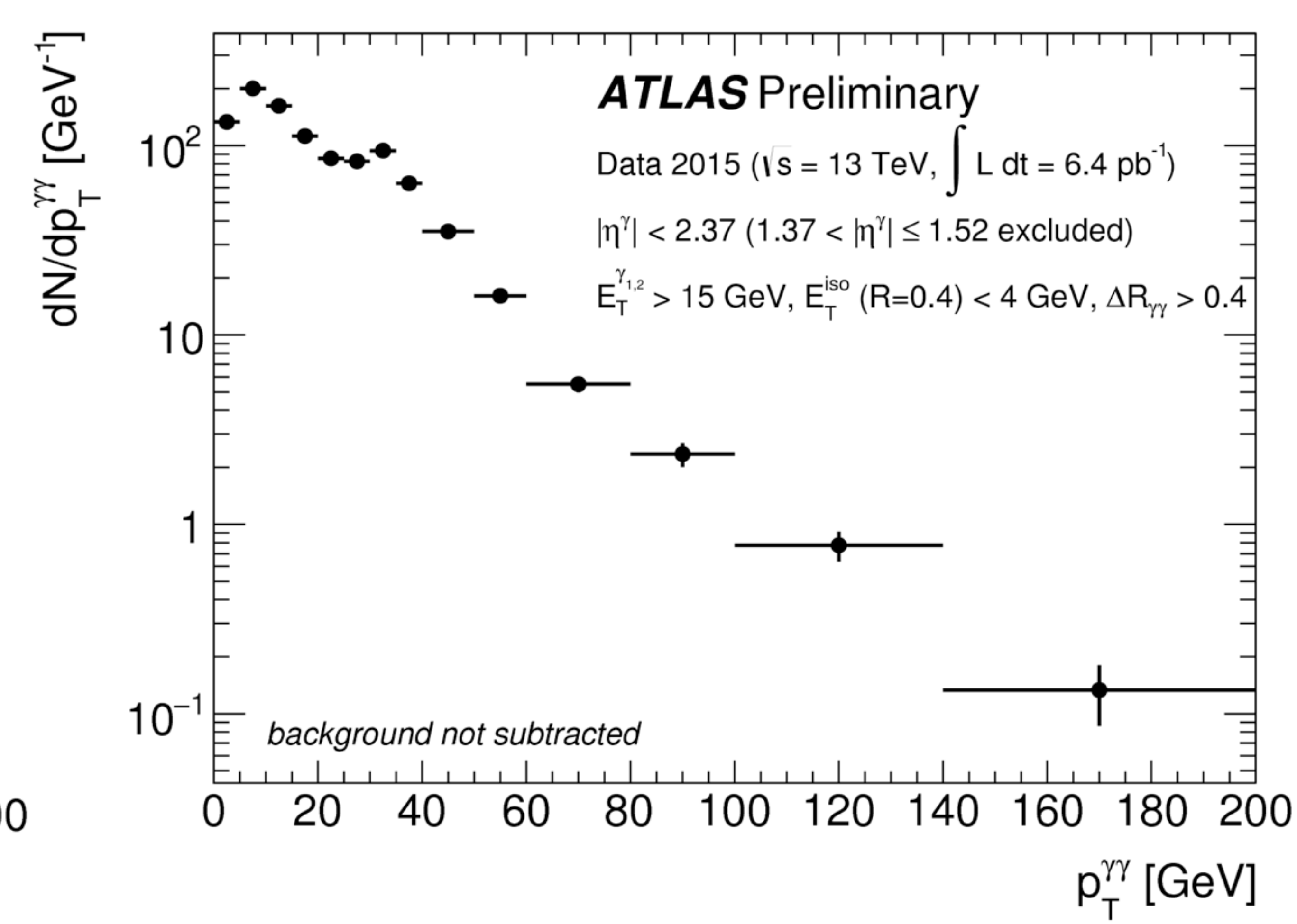




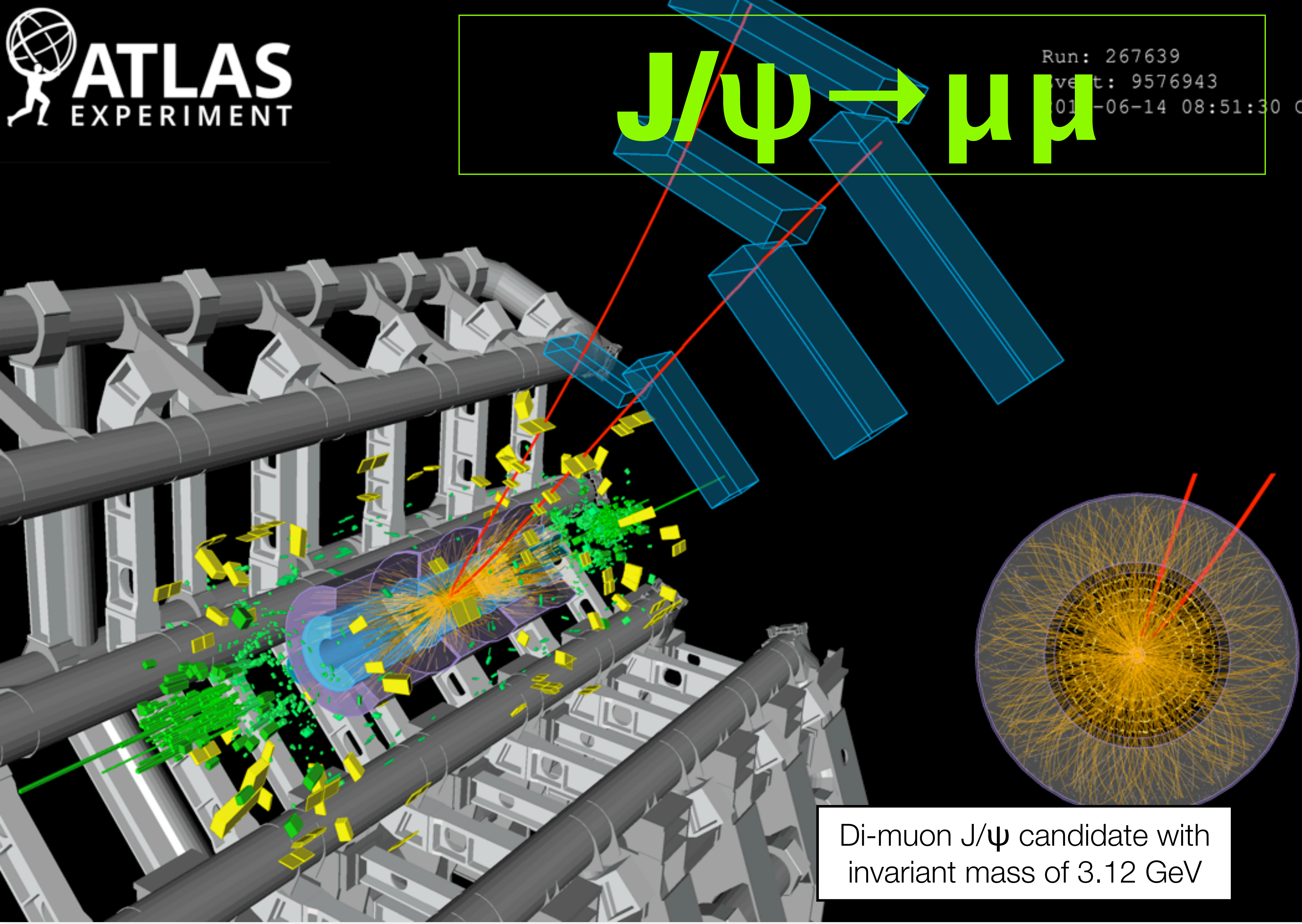
Di-photons

- Control distributions for di-photon selection
- More results and unfolded spectra to come!





J/ψ → μ μ

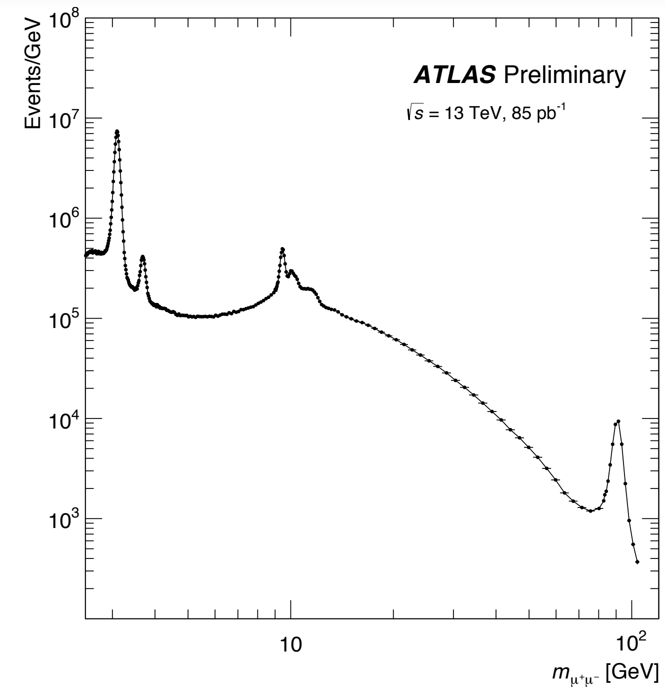


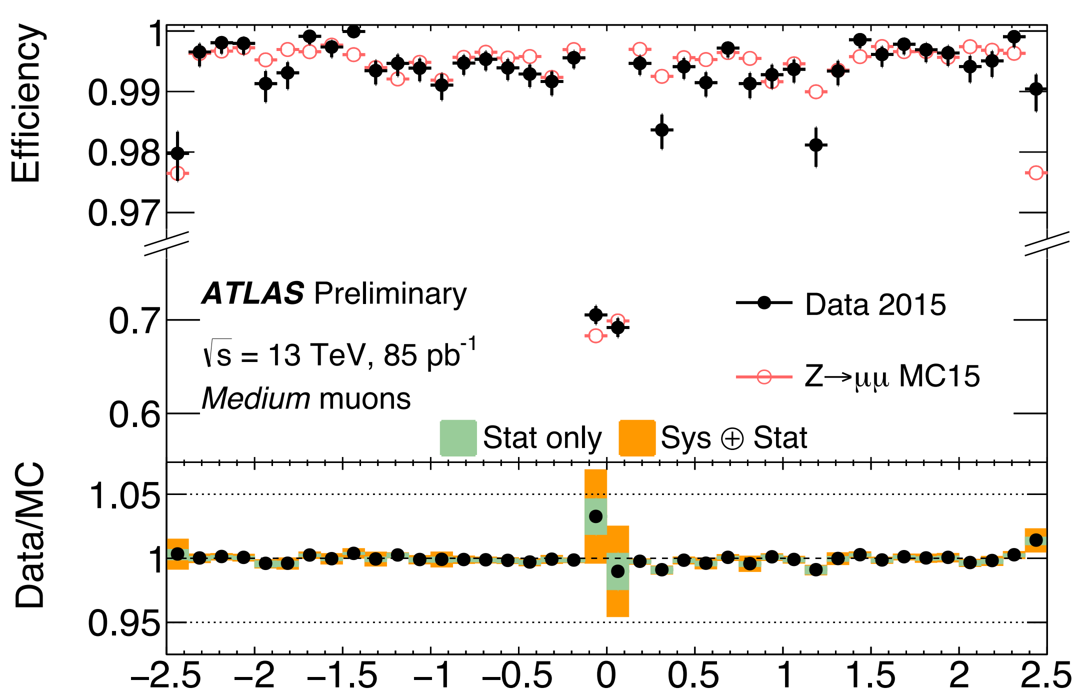
Di-muon J/ψ candidate with invariant mass of 3.12 GeV

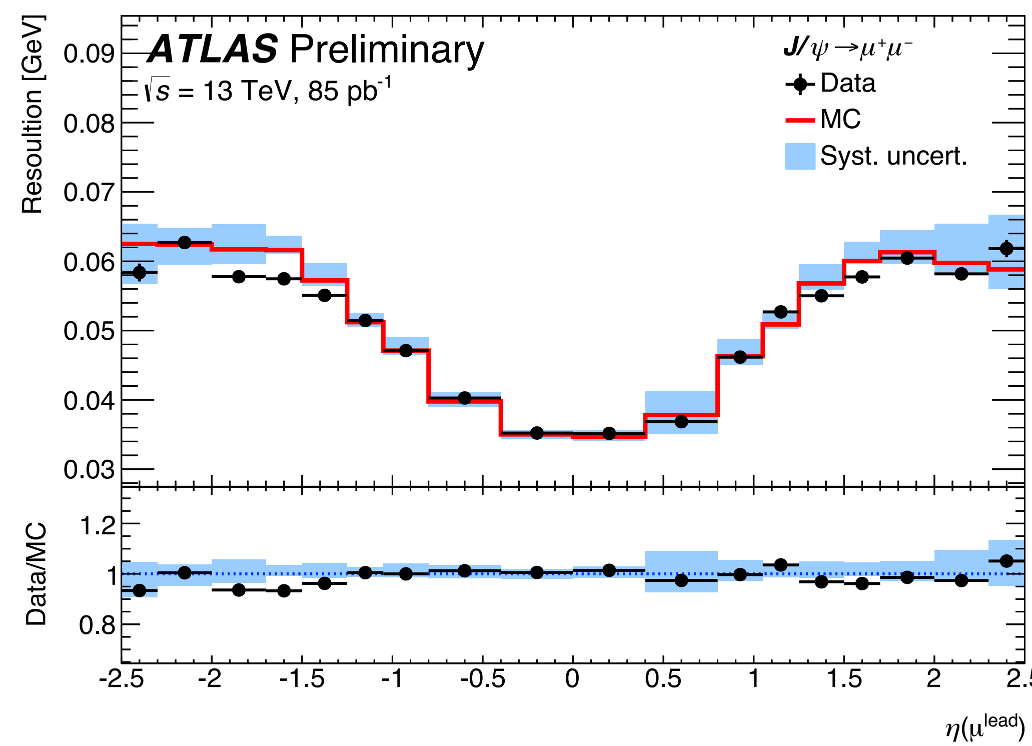
ATL-PHYS-PUB-2015-037

Muons

- Consolidated understanding of muon performance already with less than 100 pb^{-1}
- First insitu calibrations are already available
  - Based on J/ψ and Z control samples
- Uncertainties are already at per-cent level

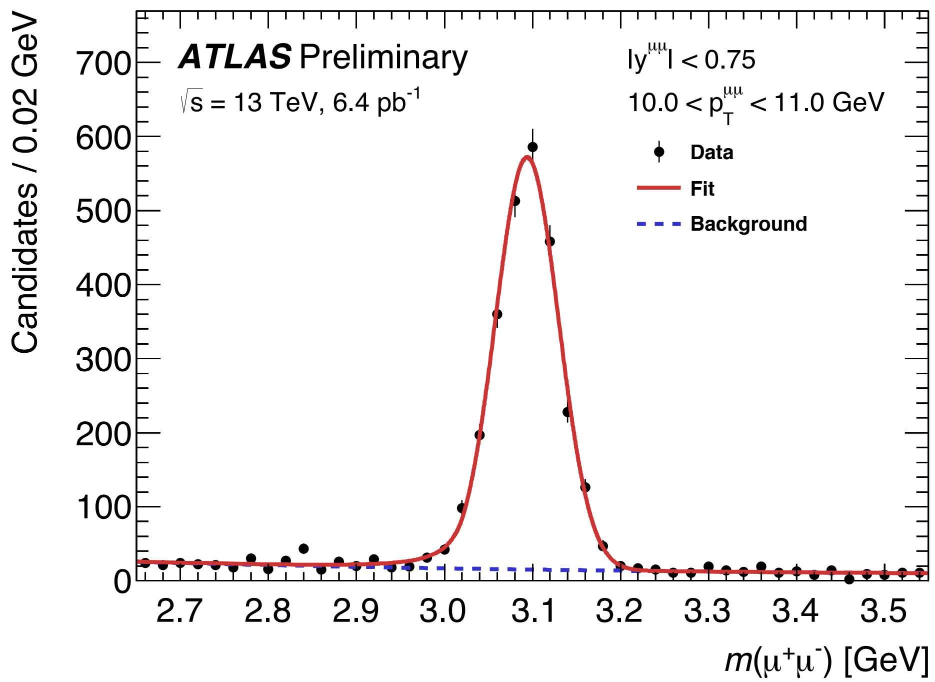


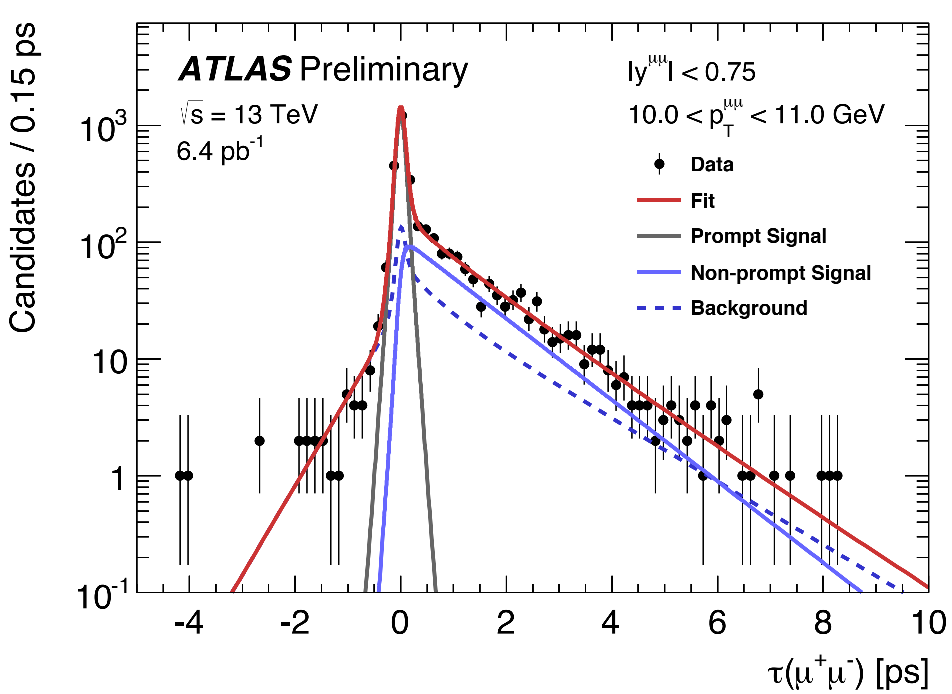




ATLAS-CONF-2015-030

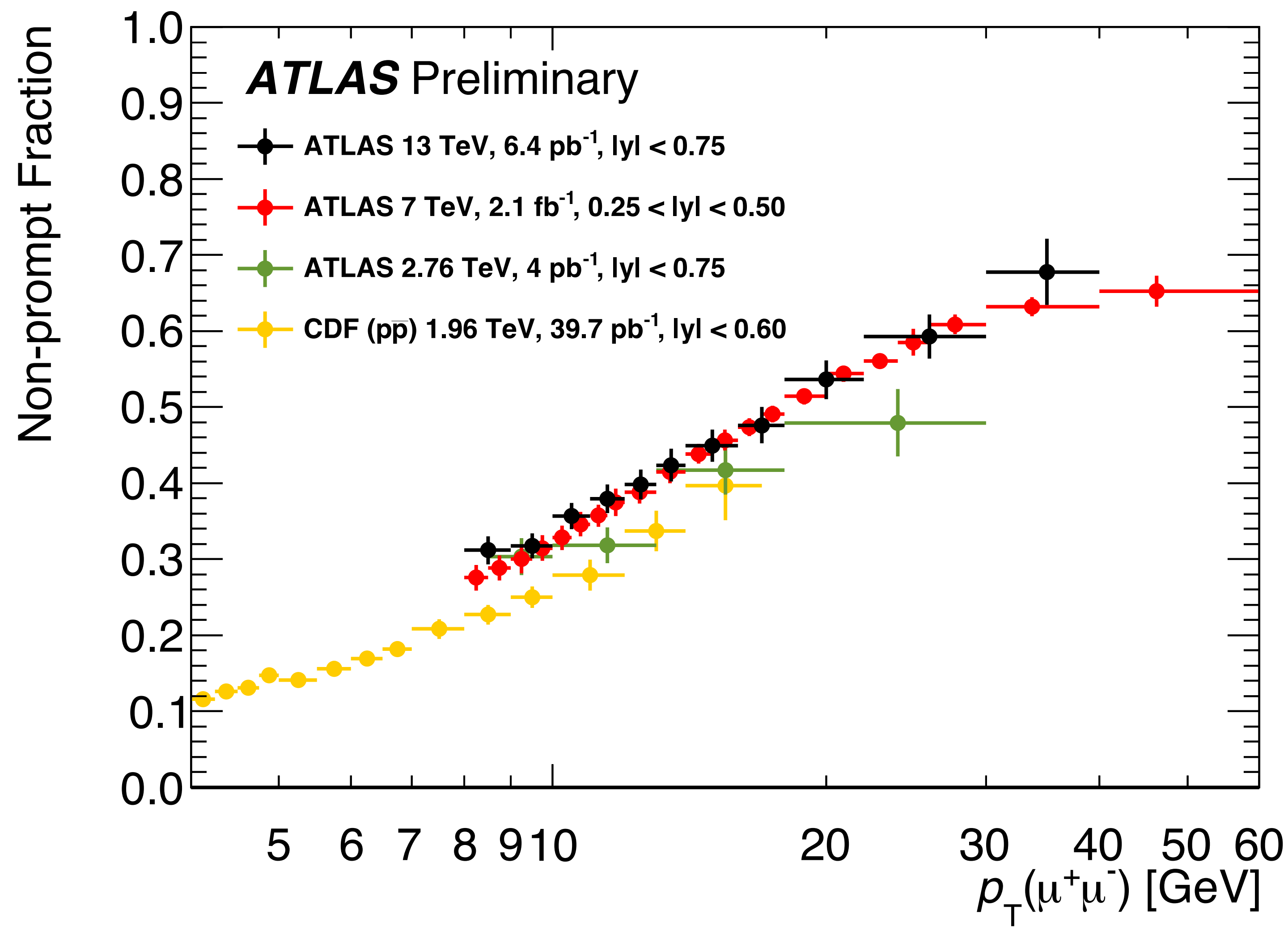
Non-prompt J/ψ fraction



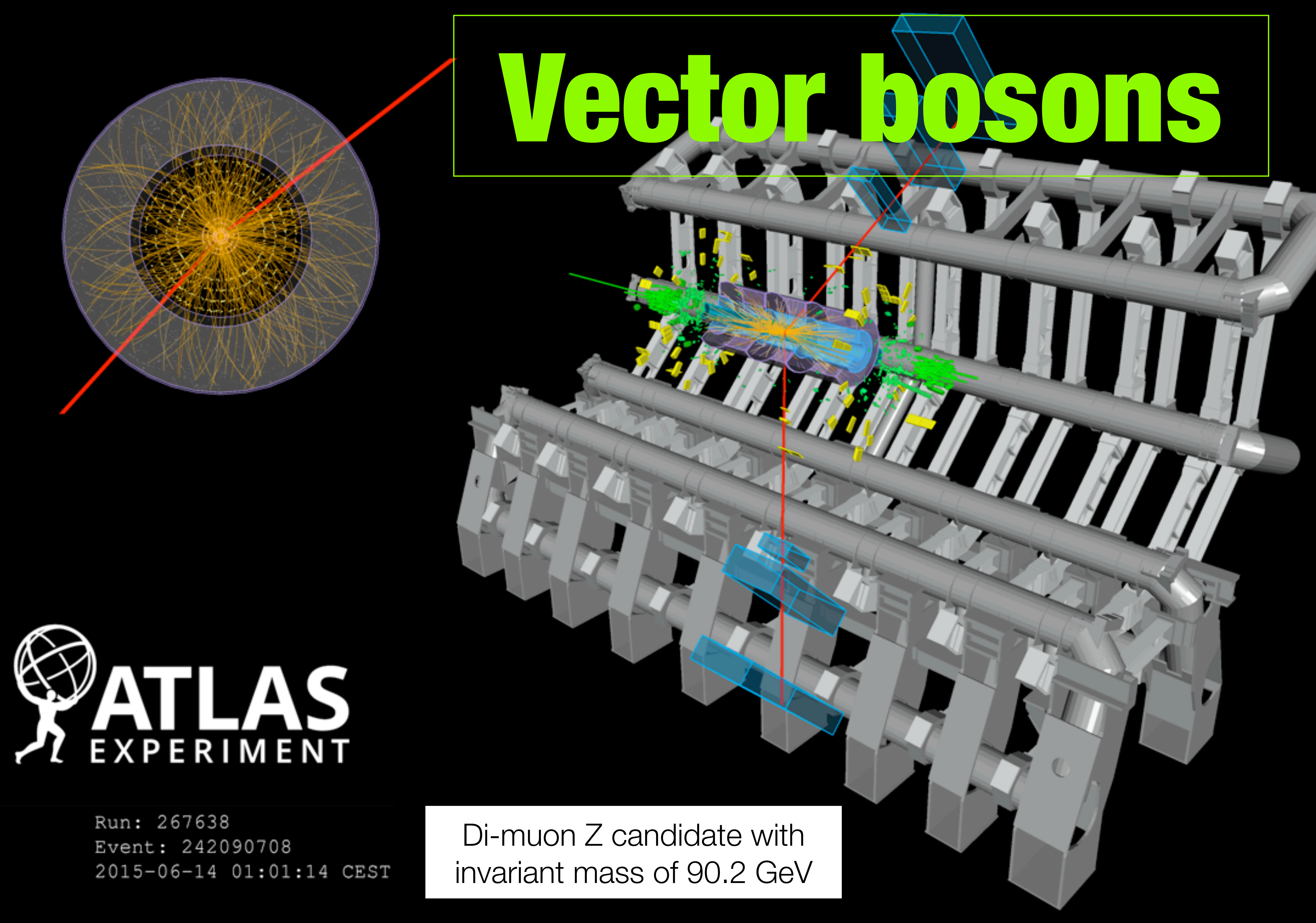


No significative change between 7 and 13 TeV data

$$f_b^{J/\psi} \equiv \frac{pp \rightarrow b + X \rightarrow J/\psi + X'}{pp \xrightarrow{\text{Inclusive}} J/\psi + X'} = \frac{N^{NP}_{J/\psi}}{N^{NP}_{J/\psi} + N^{P}_{J/\psi}}$$



Vector bosons

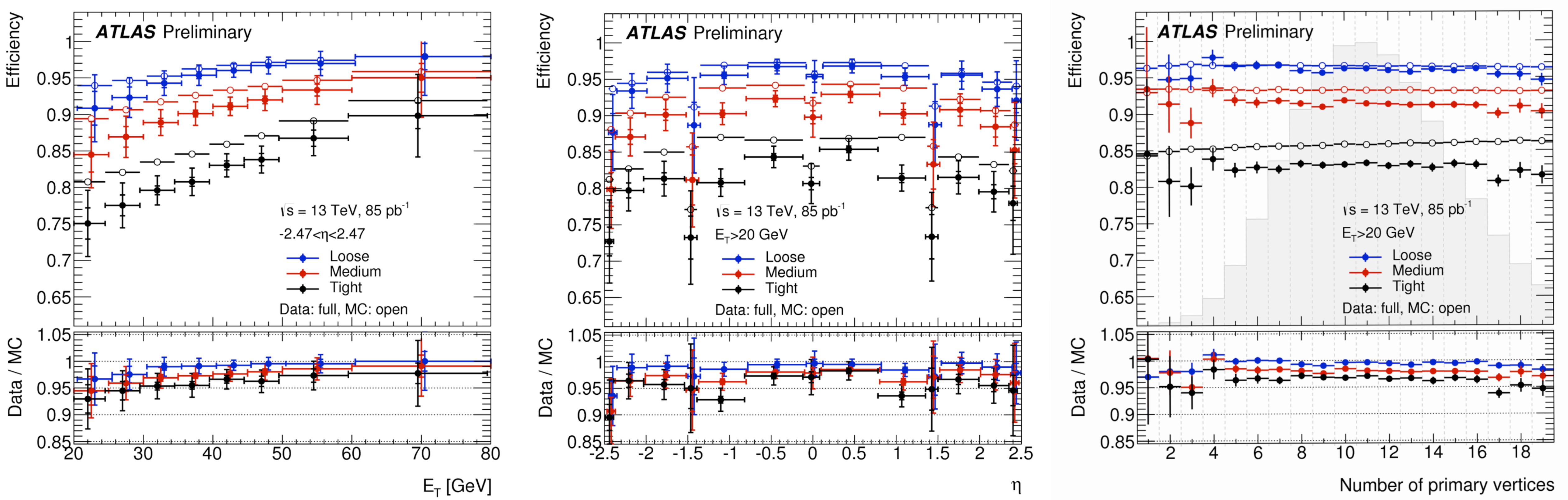


Di-muon Z candidate with invariant mass of 90.2 GeV

Electrons

- Likelihood selection based on three identification working points
- Pile-up dependence well modeled by simulation

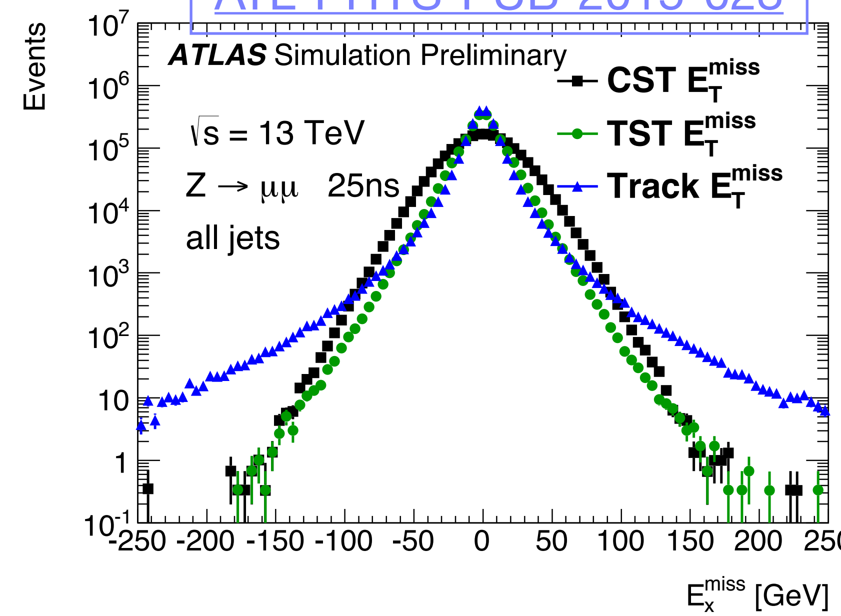
Data: full markers; MC open markers



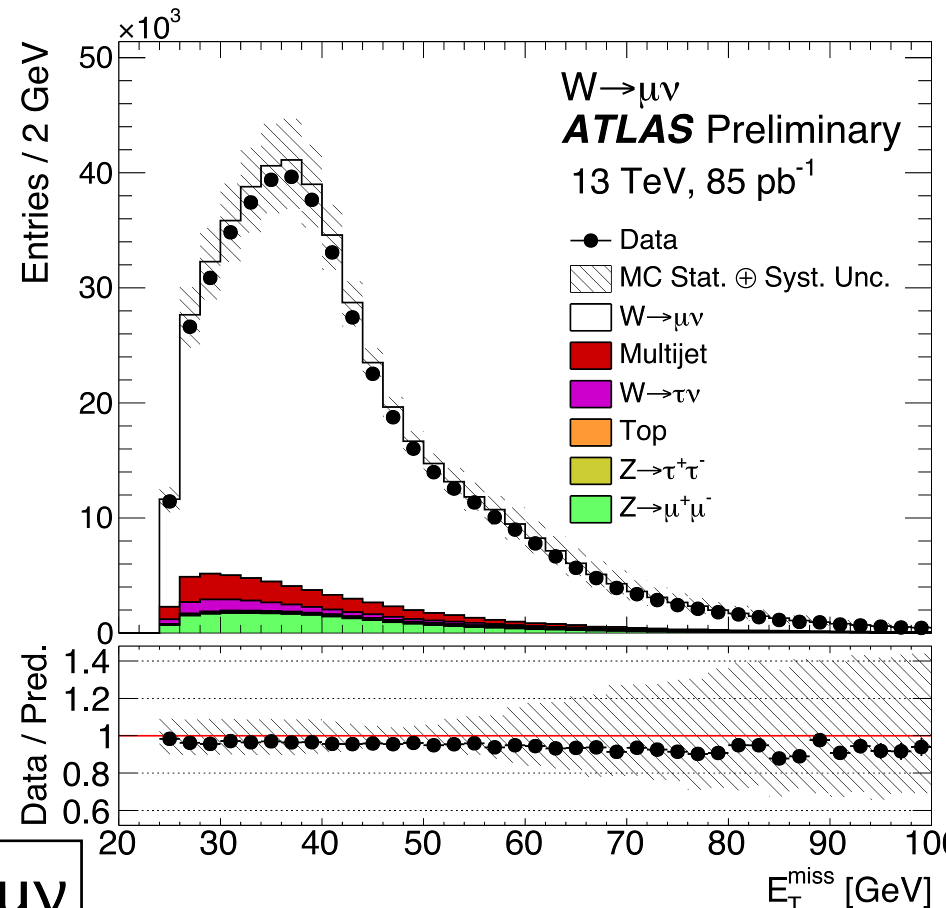
Missing E_T

- Redundant E_T algorithms for early Run 2 operation
  - Validation of algorithms robust against pile-up

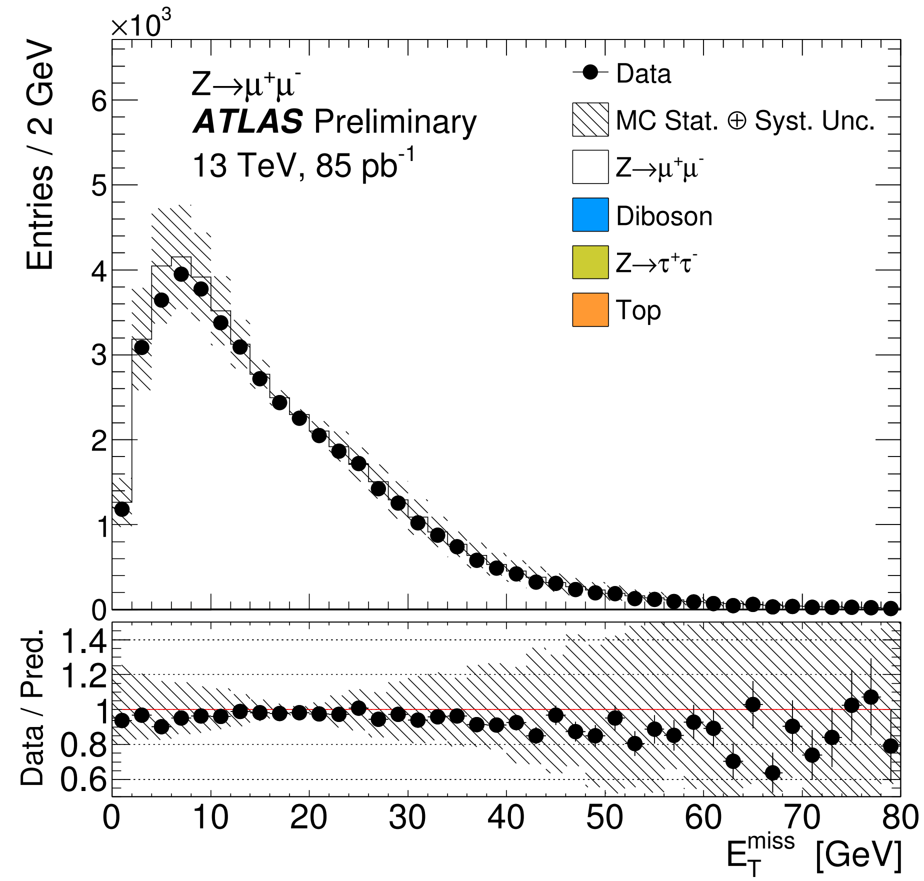
ATL-PHYS-PUB-2015-023



ATLAS-CONF-2015-039



W→μν

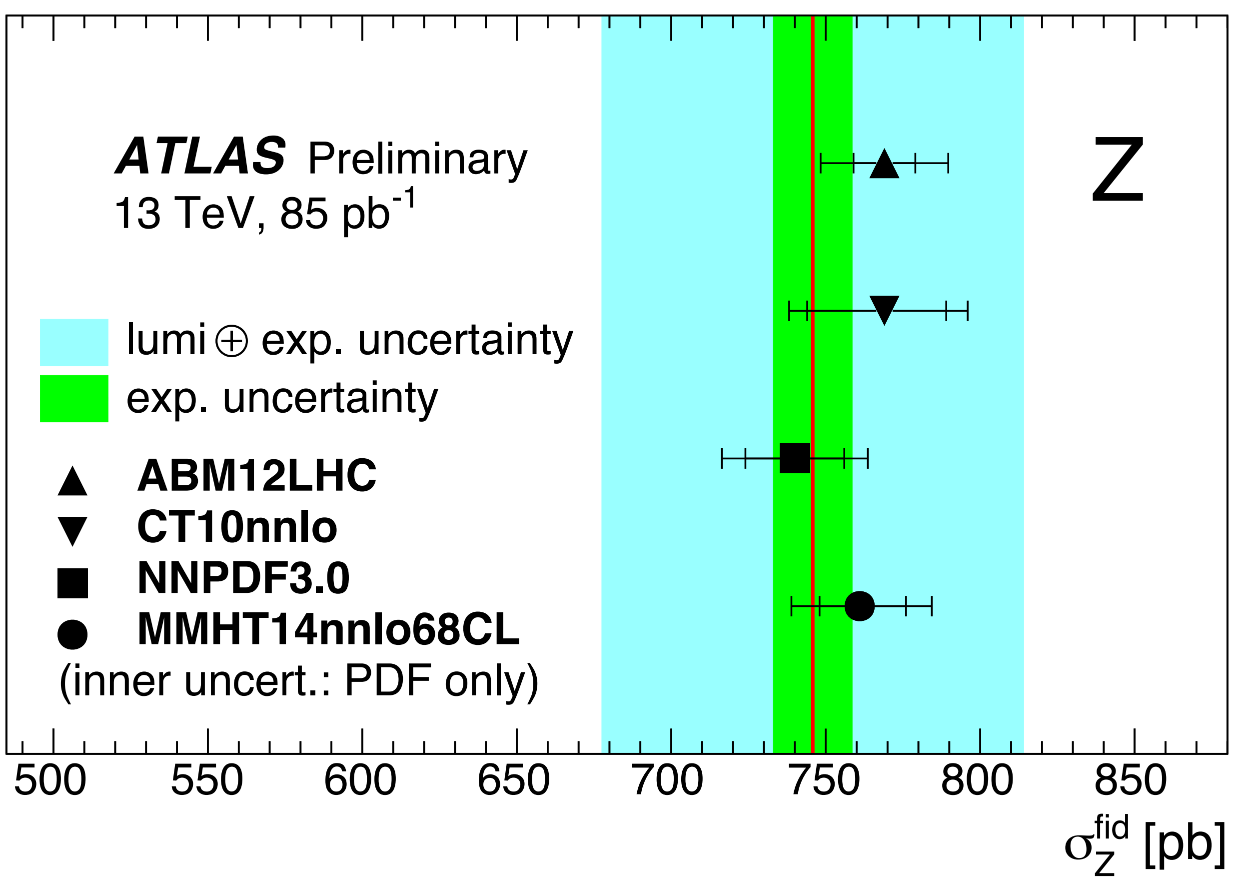


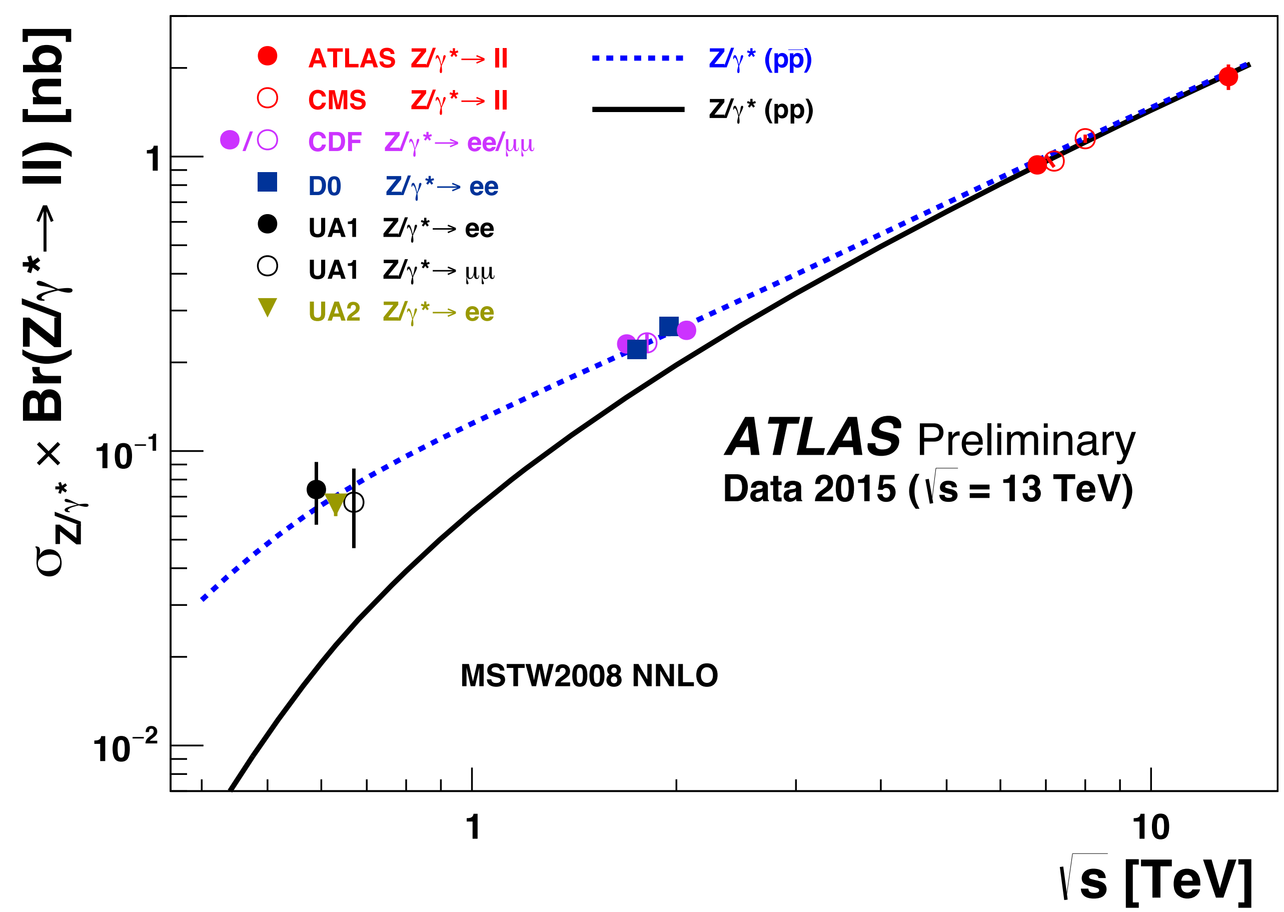
Z→μμ

ATLAS-CONF-2015-039

Z boson cross section

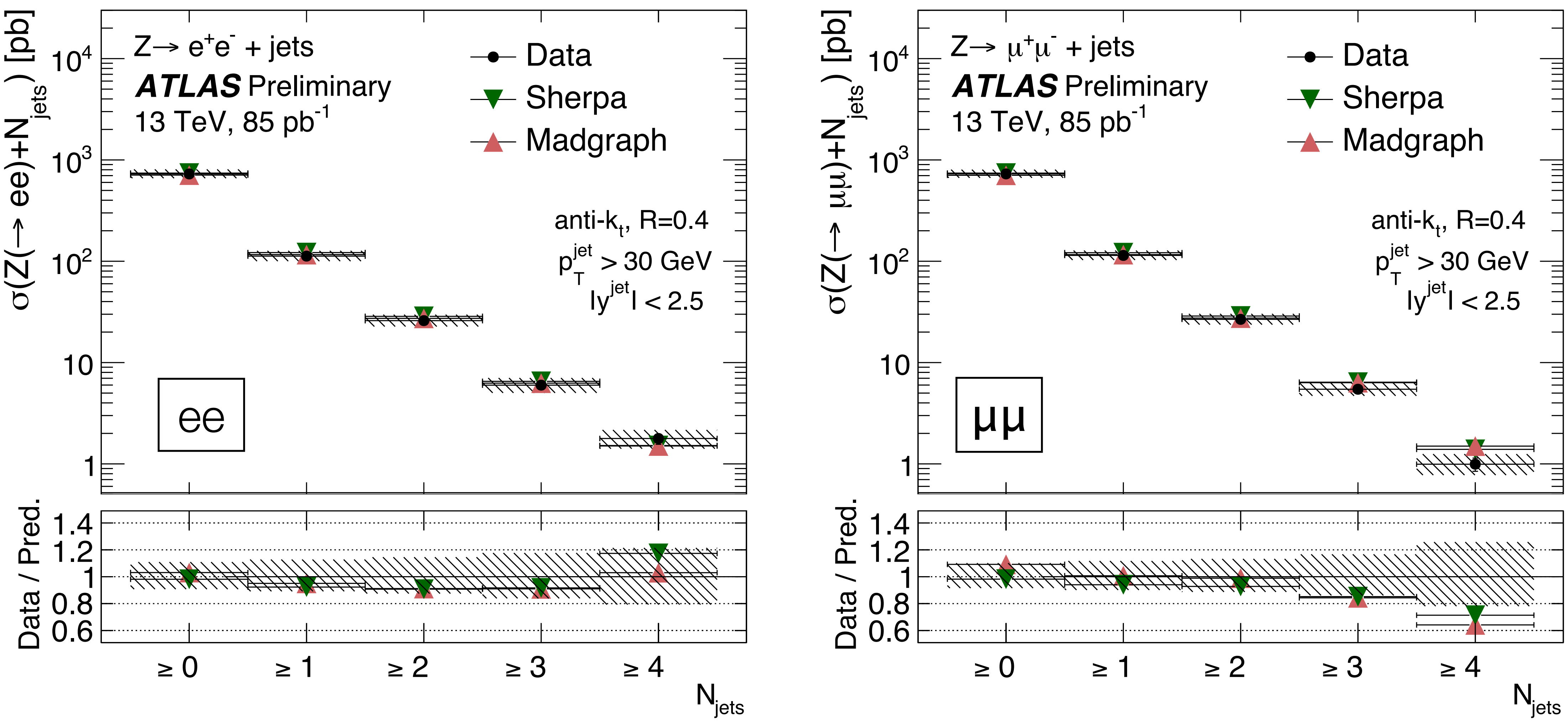
- Data show already the potential to discriminate between PDFs
- Luminosity uncertainty limits the precision of the measurement





Z+jets measurement

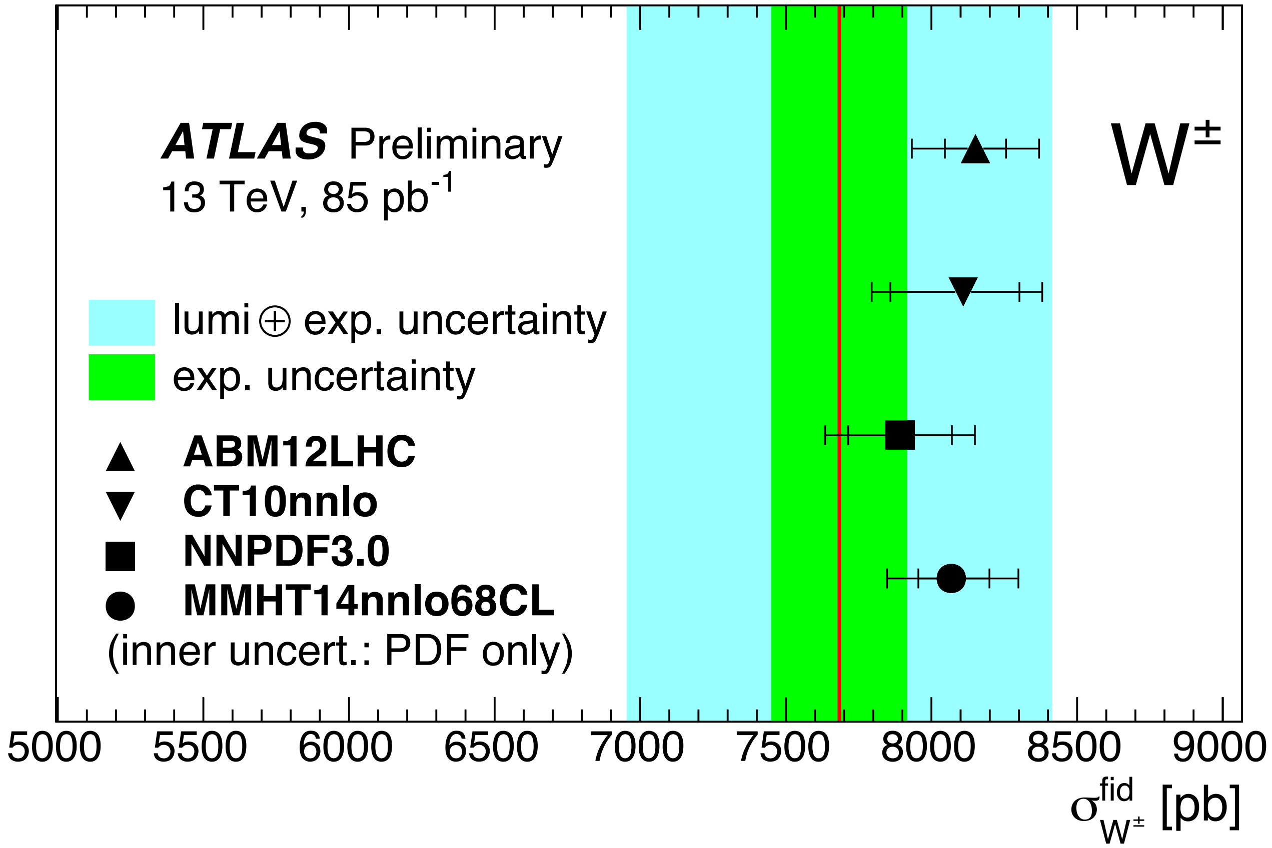
- High priority is to test the new set-up for the MC event generators
  - Madgraph and Sherpa perform already very well

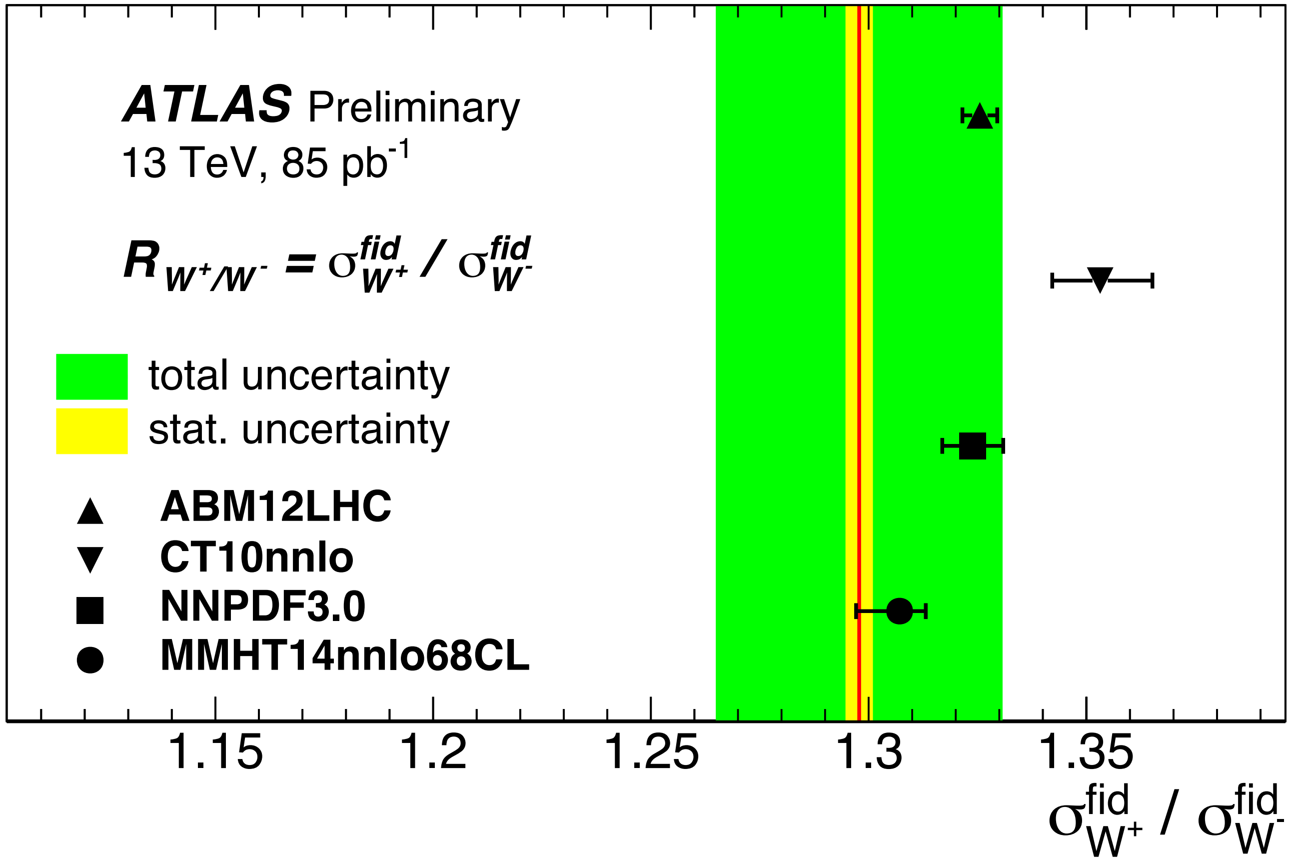


ATLAS-CONF-2015-039

W boson cross section

- Data precision affected by luminosity uncertainty
  - Measure cross section ratios
- Sensitivity to PDFs



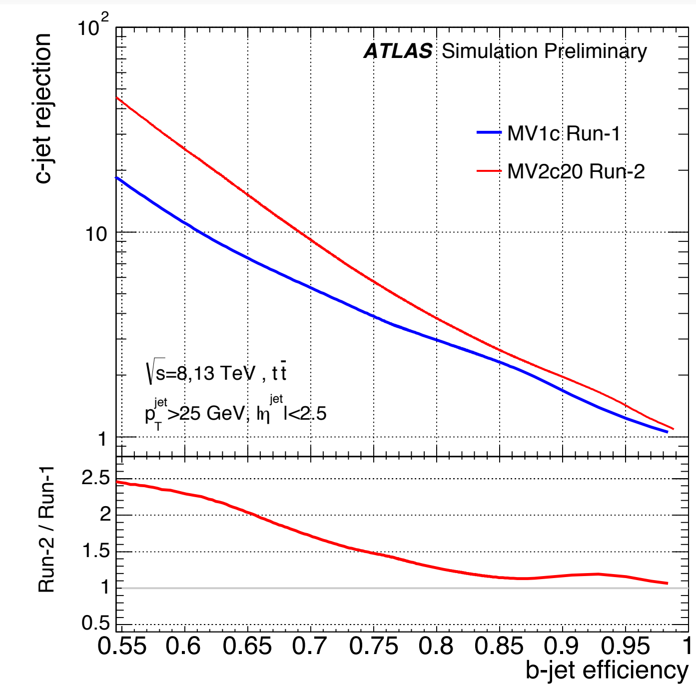


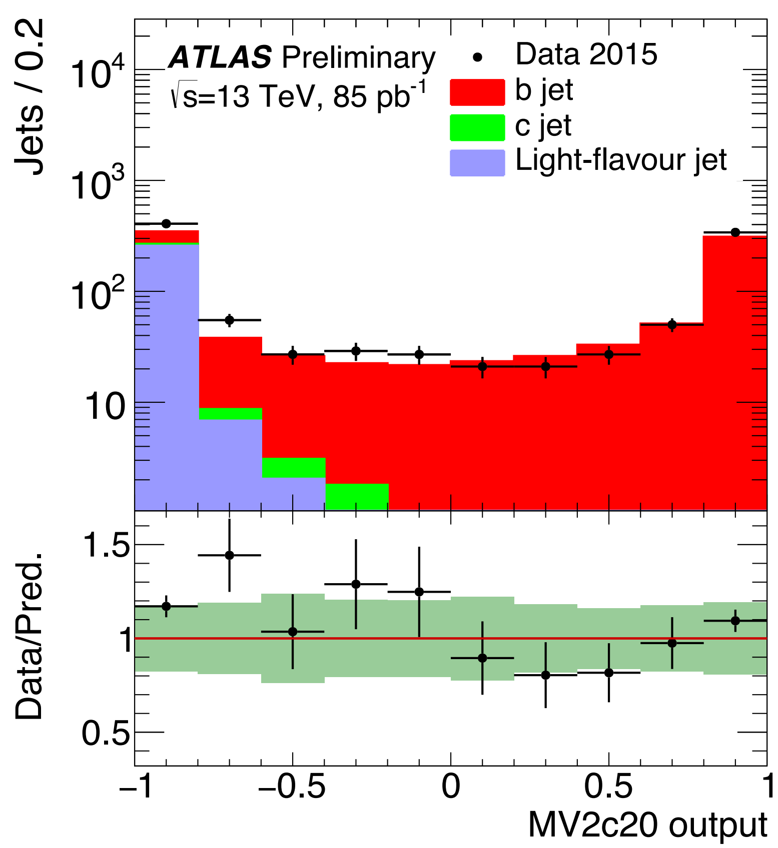
The top

ATL-PHYS-PUB-2015-022

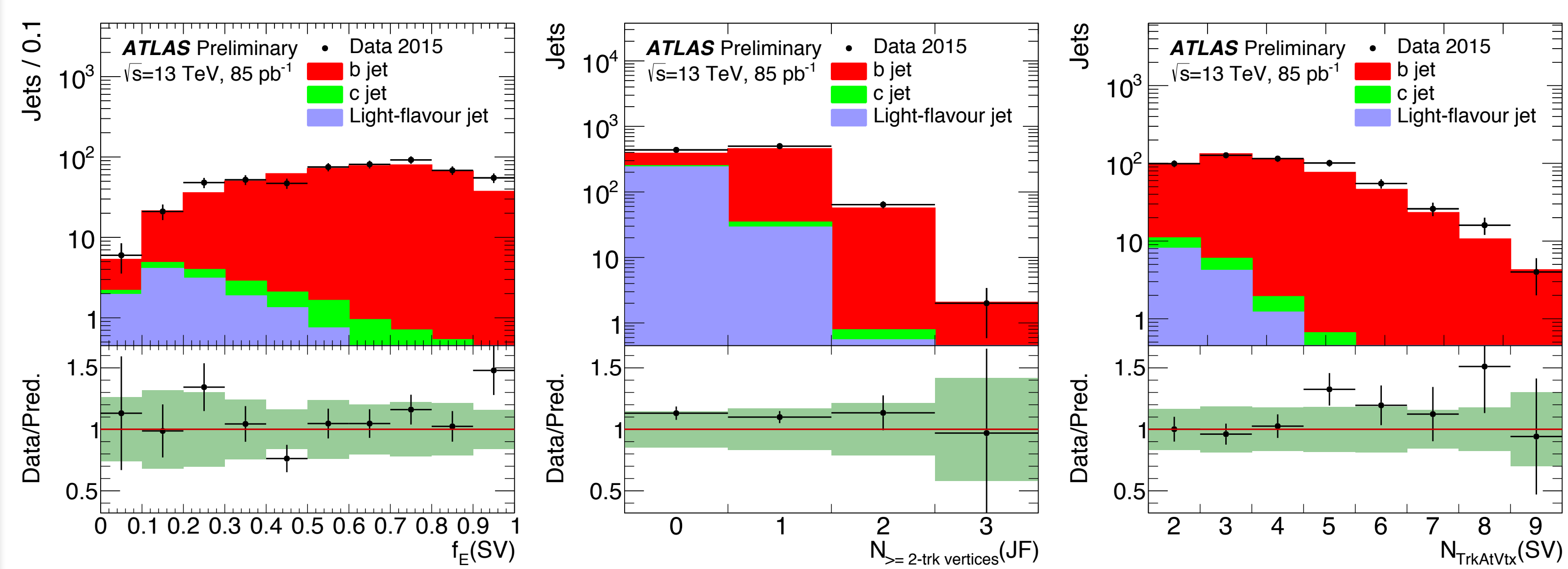
B-tagging

- ("New") B-tagging in Run 2 benefits from the new IBL detector and improvement in the algorithms
- An early calibration already underway by using $t\bar{t}$ control samples



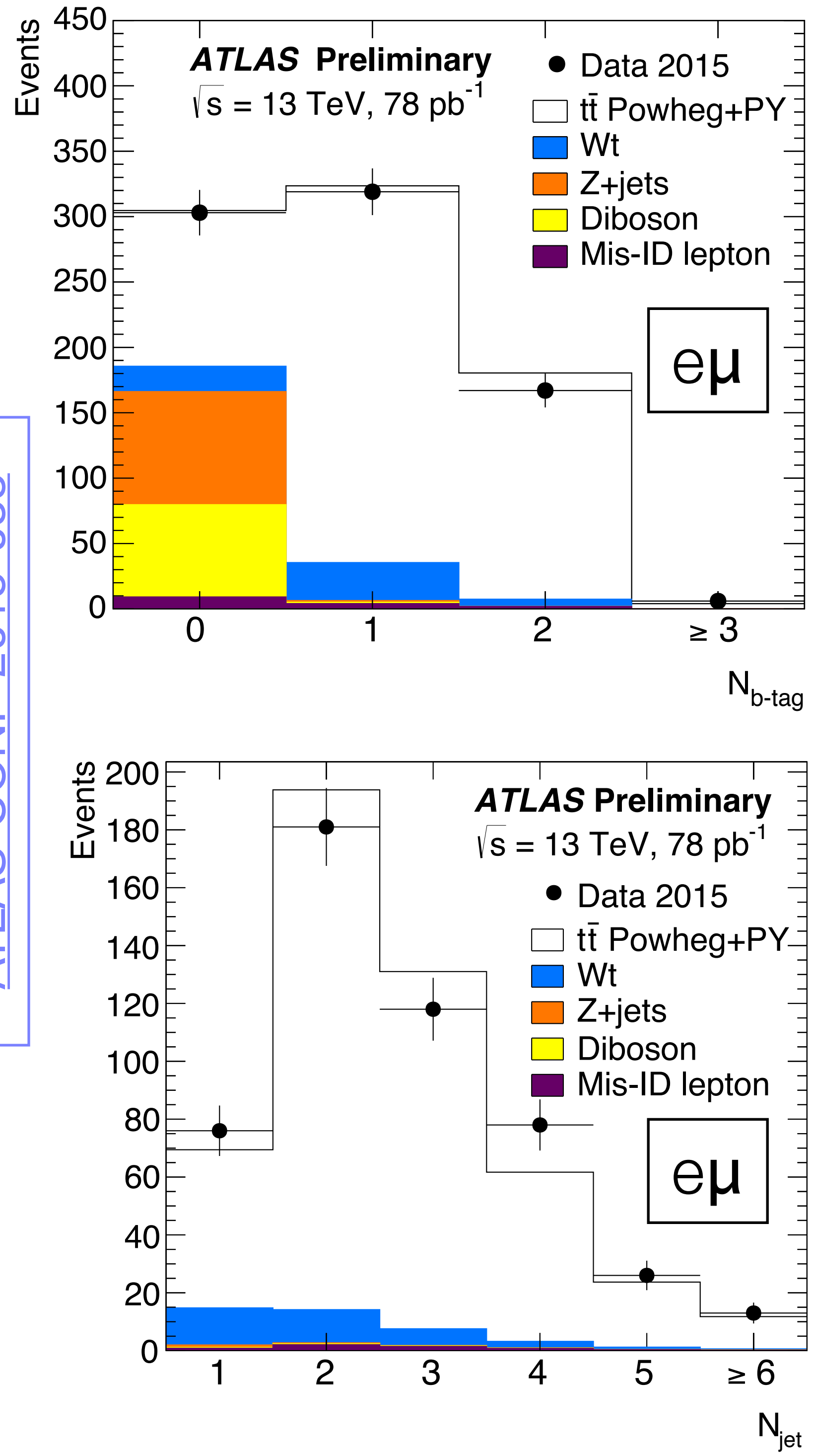


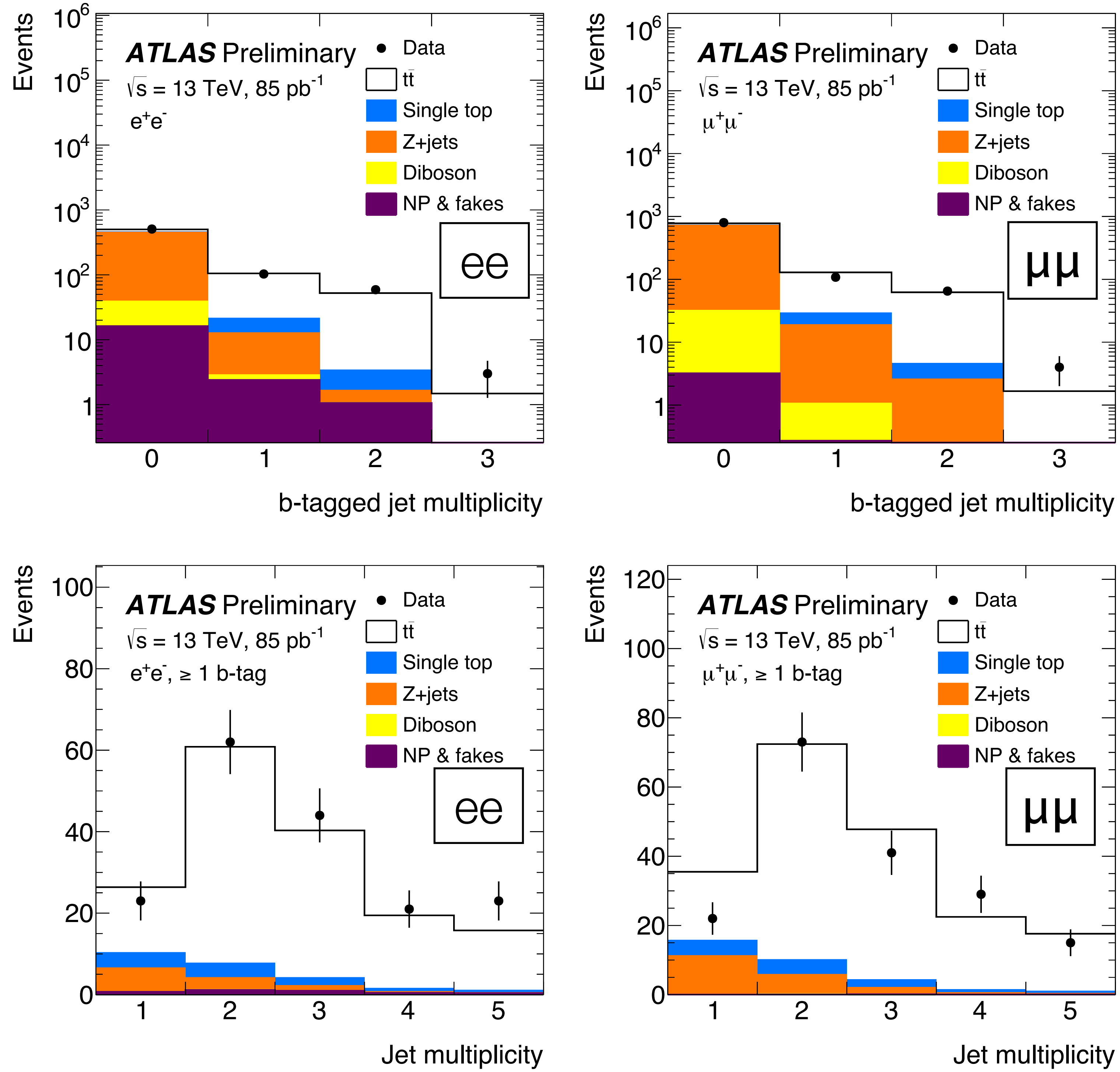
Example of input variables for the b-tagging algorithms



Top control distributions: di-lepton channels

ATLAS-CONF-2015-033

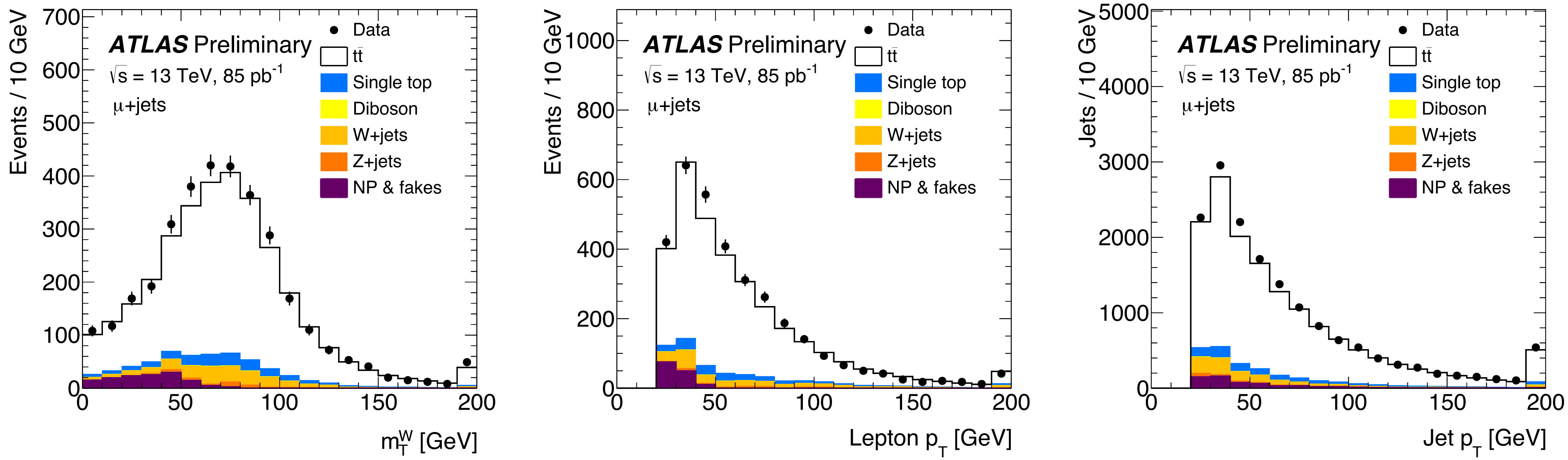




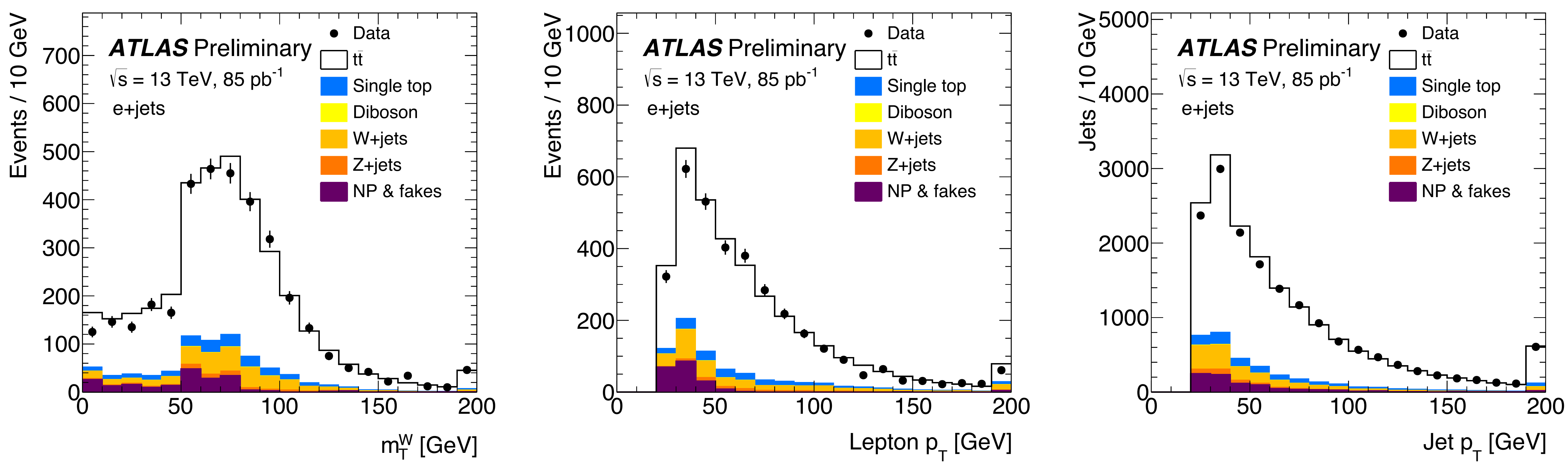
ATLAS-CONF-2015-049

Top control distributions: ℓ+jets channels

μ+jets

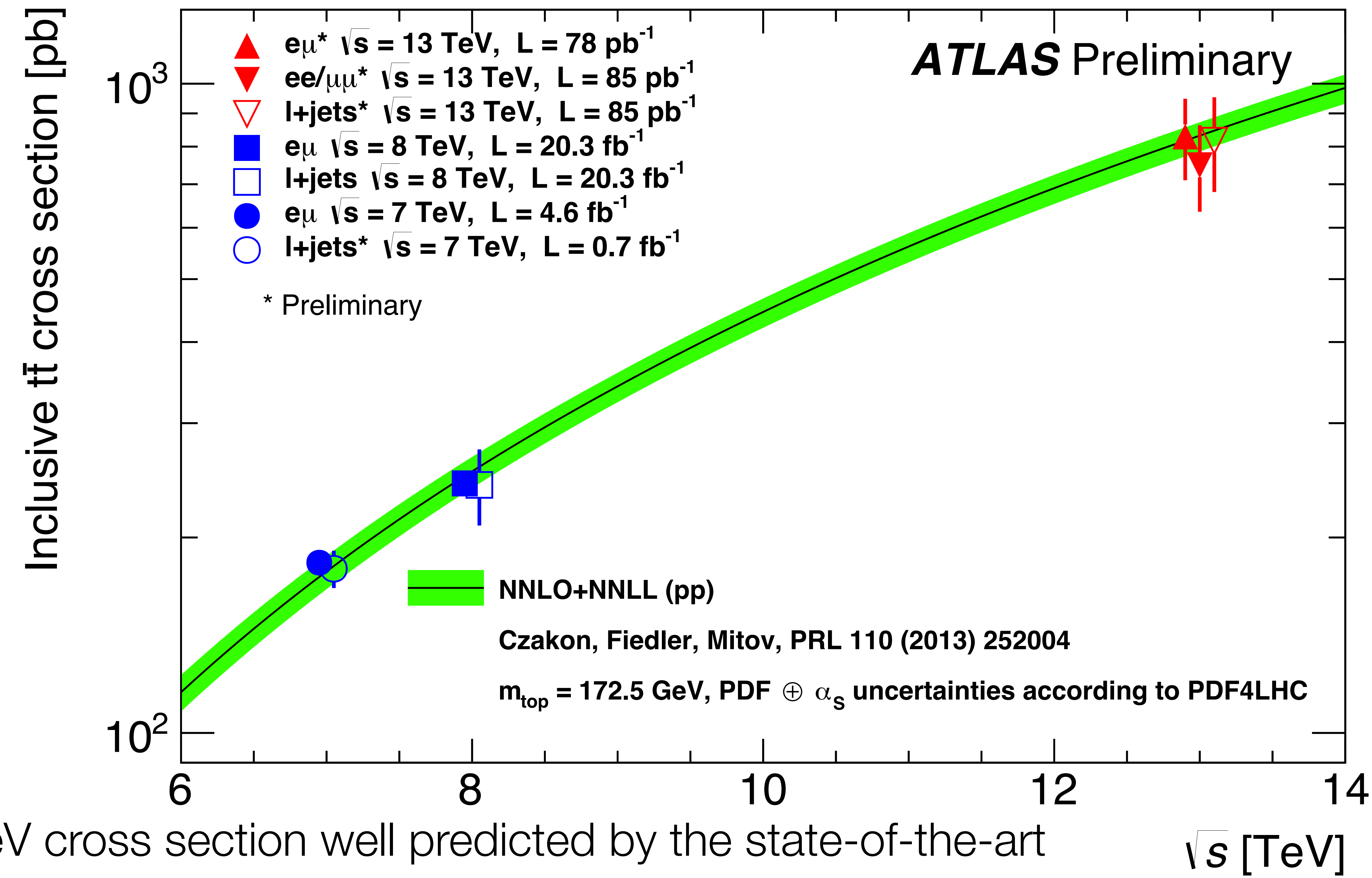


e+jets



ATLAS-CONF-2015-049

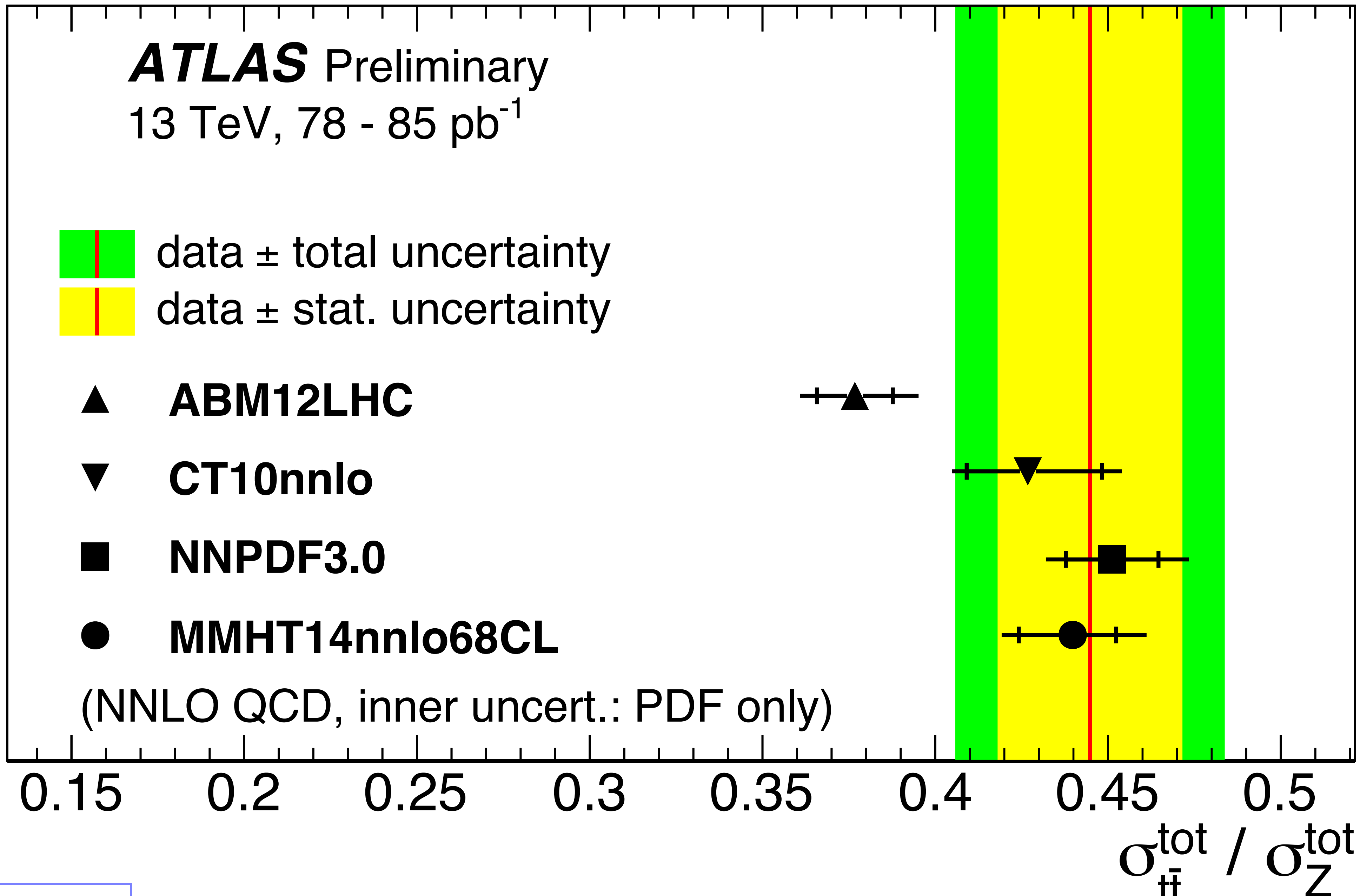
Cross sections



13 TeV cross section well predicted by the state-of-the-art Standard Model calculation

$t\bar{t}$/Z cross section ratio

Sensitive to the ration between gluon and sea-quarks PDFs



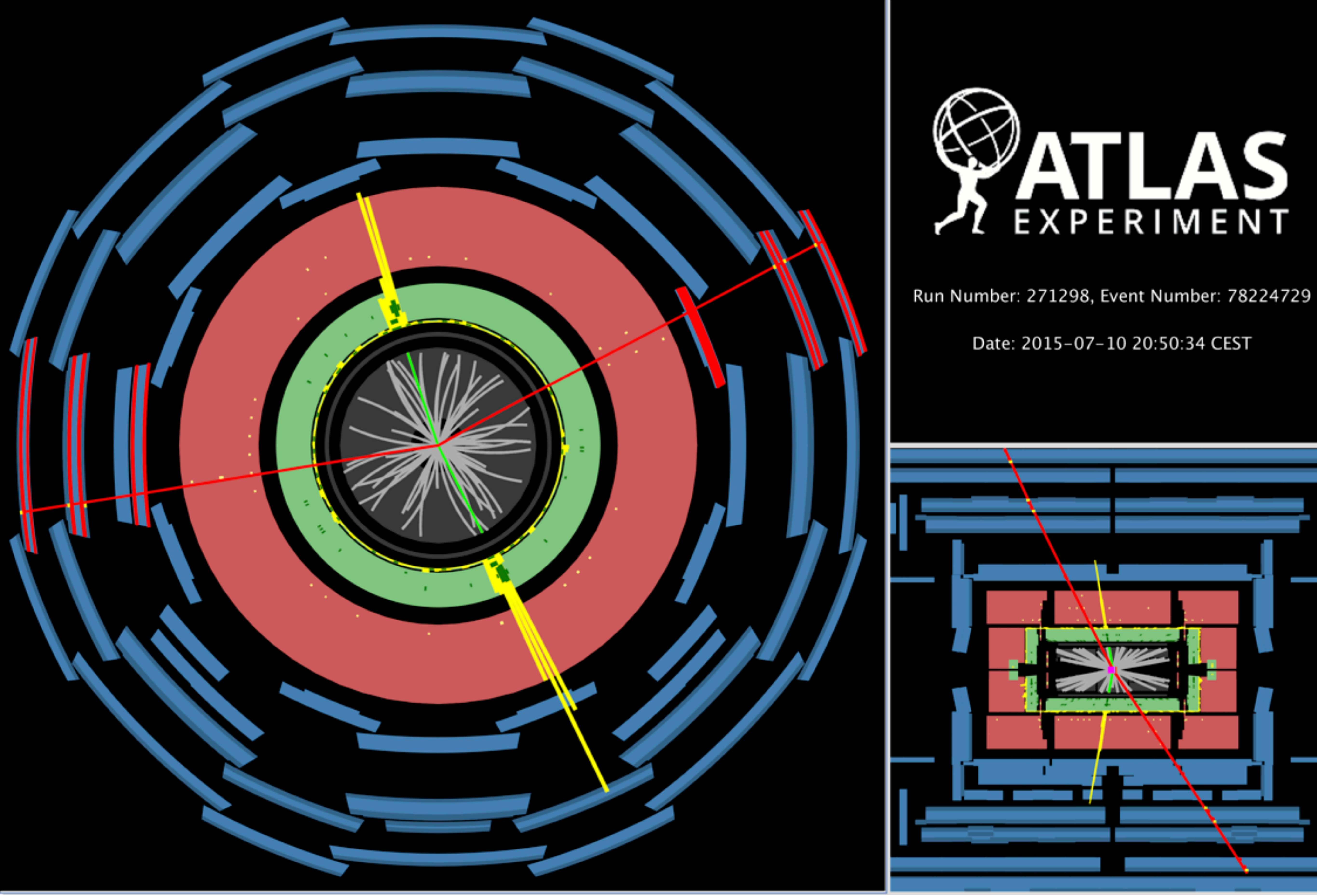
ATLAS-CONF-2015-049

Outlook

Outlook

- First Run 2 LHC stable beam on 3 June 2015
- After three months many hard QCD measurements already presented
  - Jets, photons, J/ψ, W/Z, Z+jets, top-pair
  - Used at most 85 pb^{-1}
- Much more data to be analysed in the pipeline (more than 1.5 fb^{-1} to be analyses)
  - **The best is yet to come!**


Thank you


ATLAS
EXPERIMENT
Run Number: 271298, Event Number: 78224729
Date: 2015-07-10 20:50:34 CEST

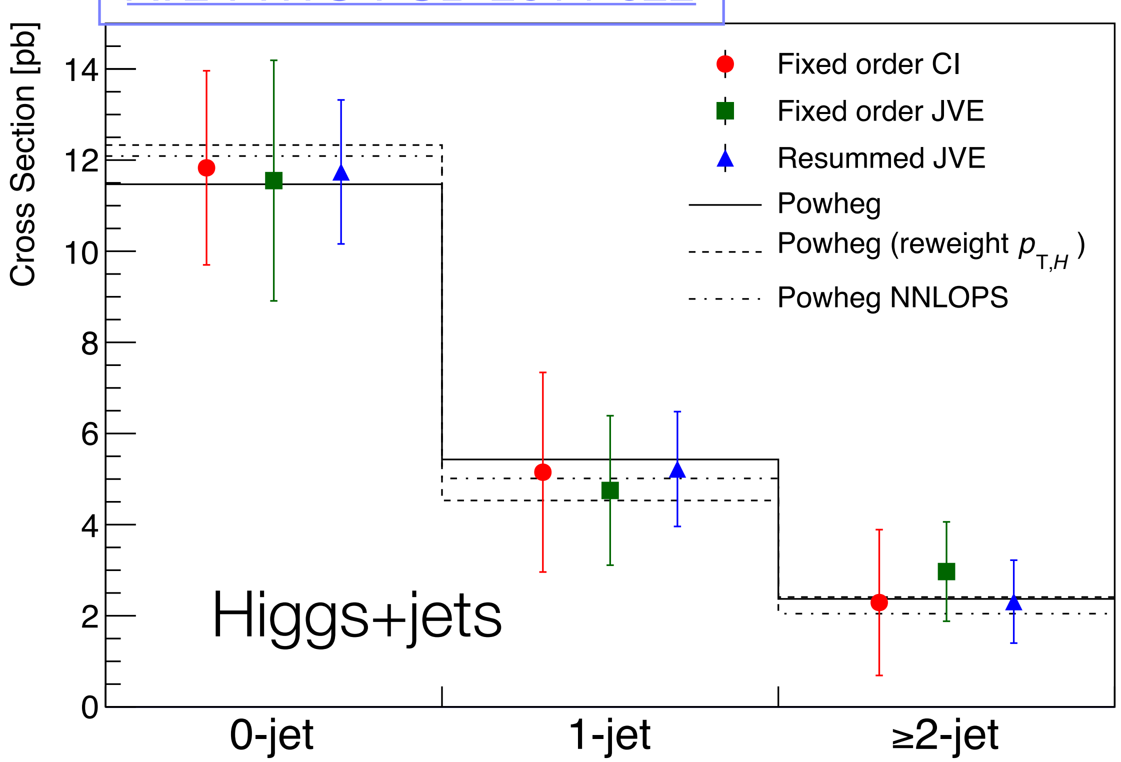
Insertable B-Layer

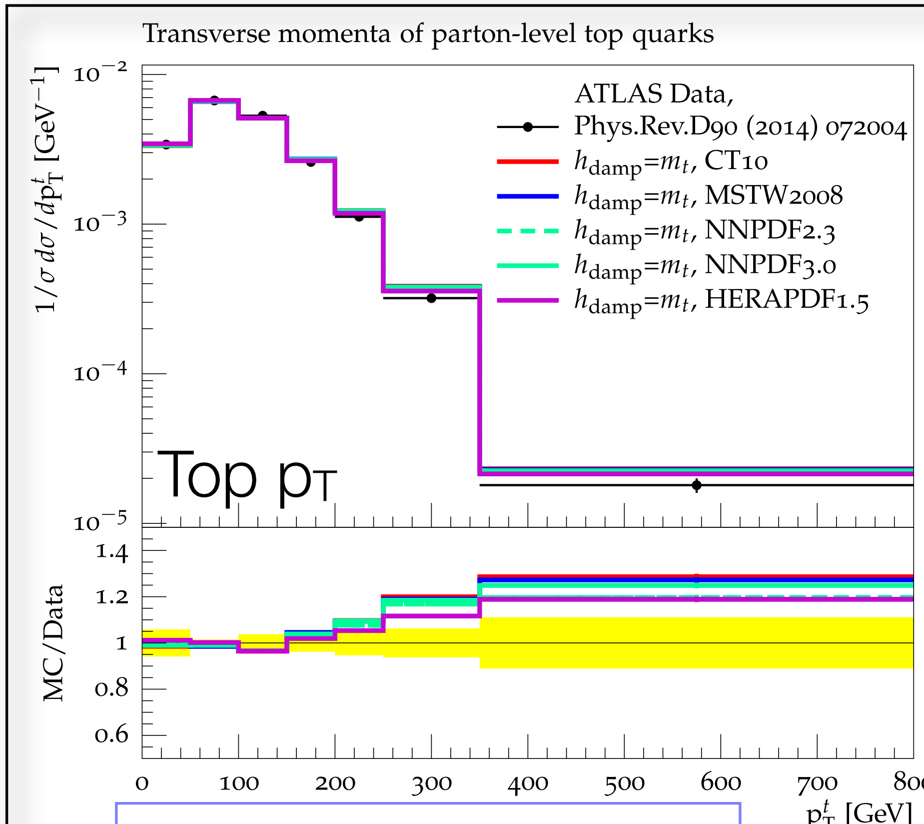
Item		Radial Extension [mm]	Length [mm]	Staves / Sectors	Modules	Pixels ($\times 10^6$)
Beam pipe (today)		$29 < R < 36$				
Beam pipe (with IBL)		$25 < R < 29$				
IBL	Envelope	$31.0 < R < 40.0$				
	Sensitive	$< R > = 25.7$	$\lvert Z \rvert < 332$	14	224	6.02
Pixel	Envelope	$45.5 < R < 241.0$	$\lvert Z \rvert < 3092$			
B-layer	Sensitive	$< R > = 50.5$	$\lvert Z \rvert < 400.5$	22	286	13.2
Layer 1	Sensitive	$< R > = 88.5$	$\lvert Z \rvert < 400.5$	38	494	22.8
Layer 2	Sensitive	$< R > = 122.5$	$\lvert Z \rvert < 400.5$	52	676	31.2
Disk 1	Sensitive	$88.8 < R < 149.6 = 88.5$	$< Z > = 495$	8×2	48×2	4.4
Disk 1	Sensitive	$88.8 < R < 149.6 = 88.5$	$< Z > = 580$	8×2	48×2	4.4
Disk 1	Sensitive	$88.8 < R < 149.6 = 88.5$	$< Z > = 650$	8×2	48×2	4.4
					Pixel Total	*80.4*

MC modeling

- New generators introduced in the ATLAS production system
- **Run 1** experience has a leading impact
  - New tunes or checks based on **Run 1** data
  - Understanding better V+jets, top, and Higgs modeling
- Benchmarking exercises for generators

ATL-PHYS-PUB-2014-022



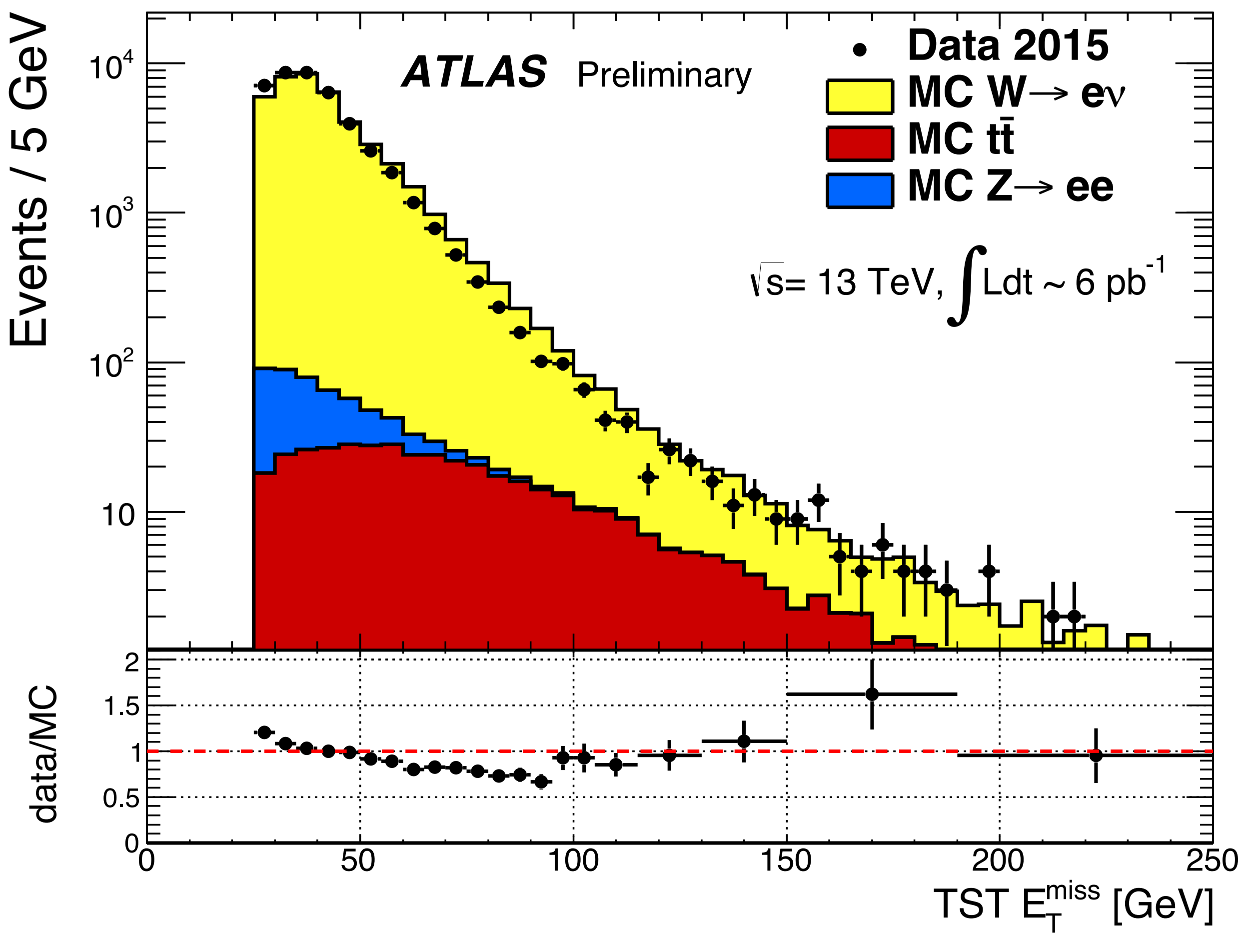


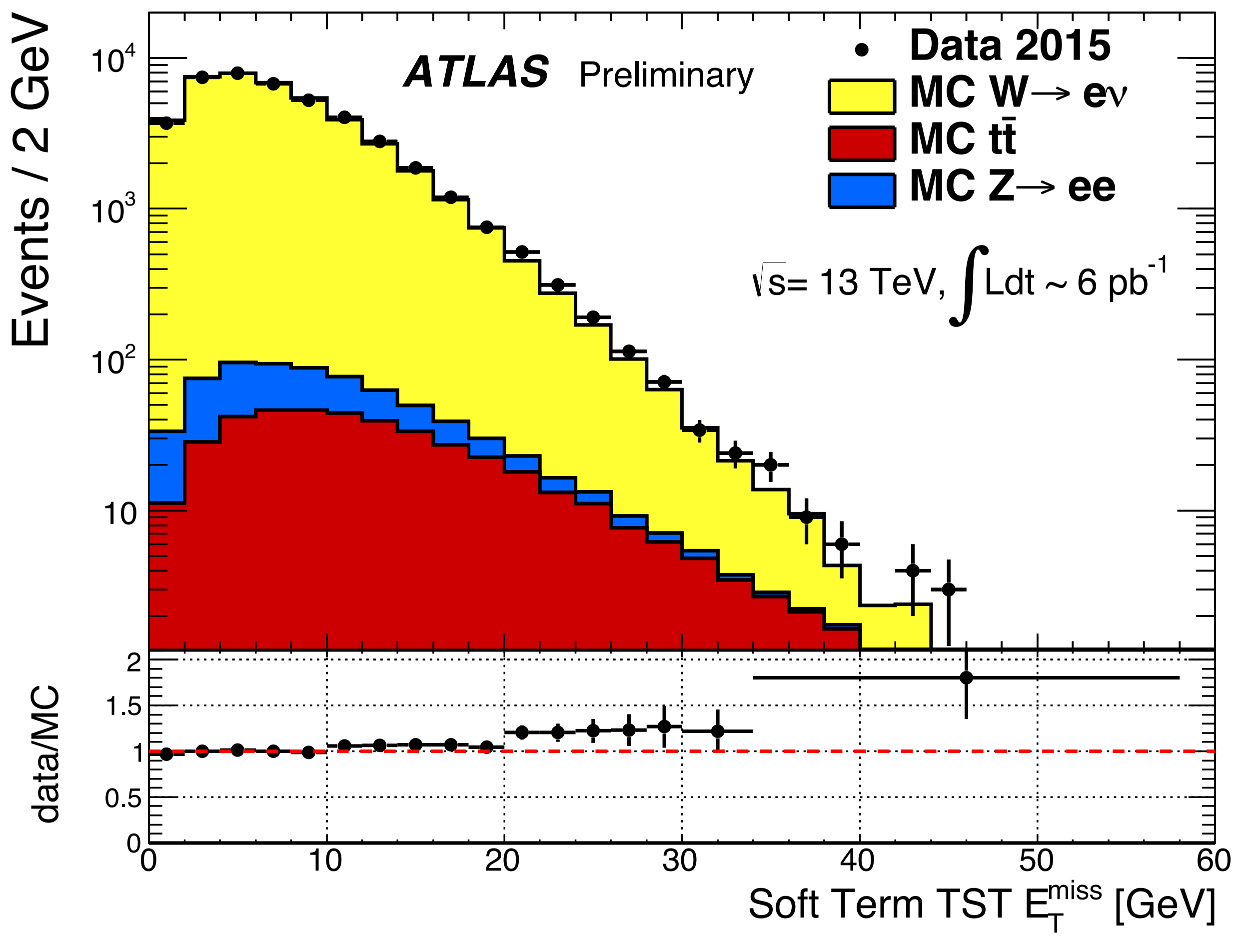
ATL-PHYS-PUB-2015-002

Still valuable input for theoretical developments, see TOP 2015 http://indico.cern.ch/event/351006/

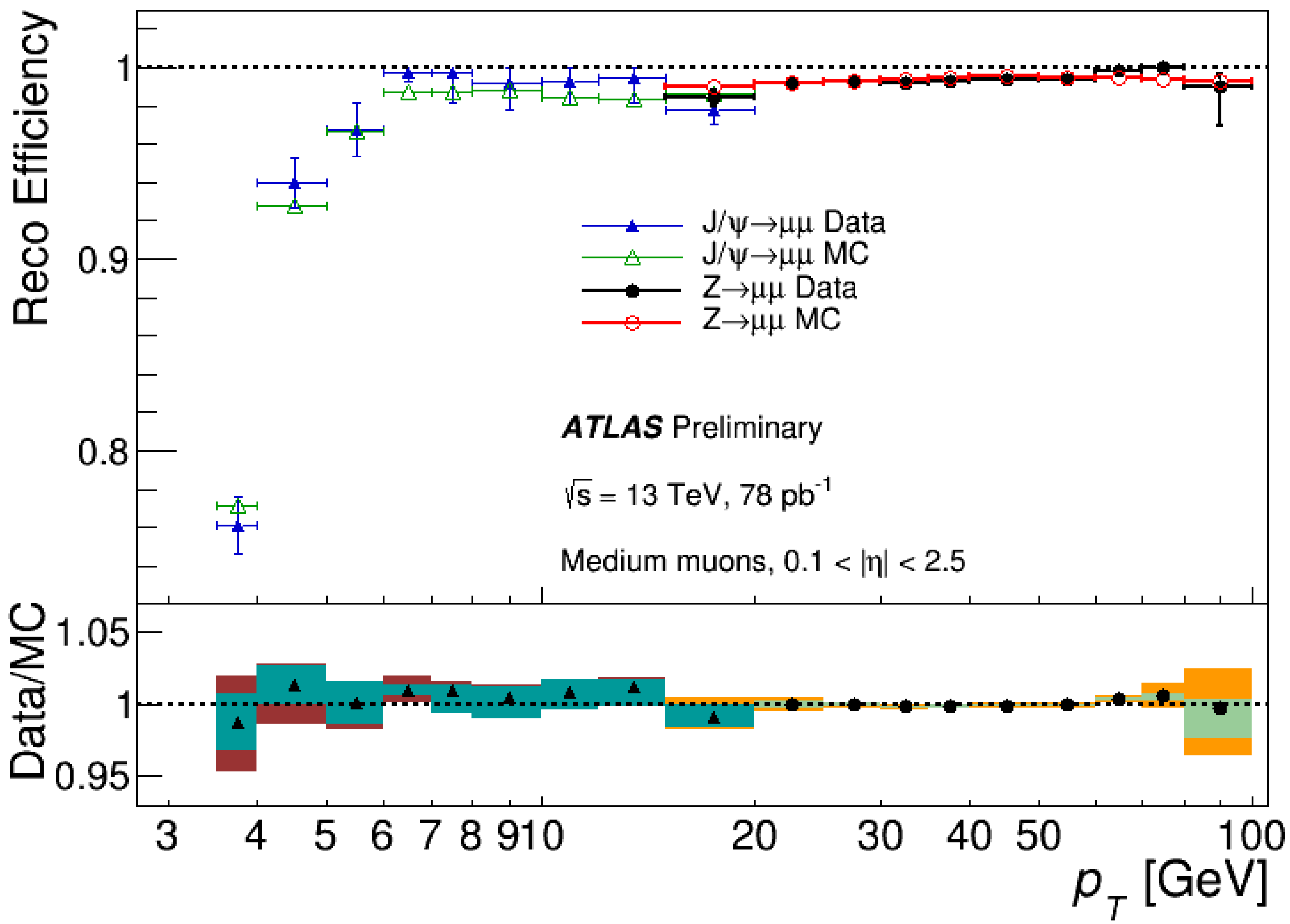
ATL-PHYS-PUB-2015-027

Missing E_T control plots

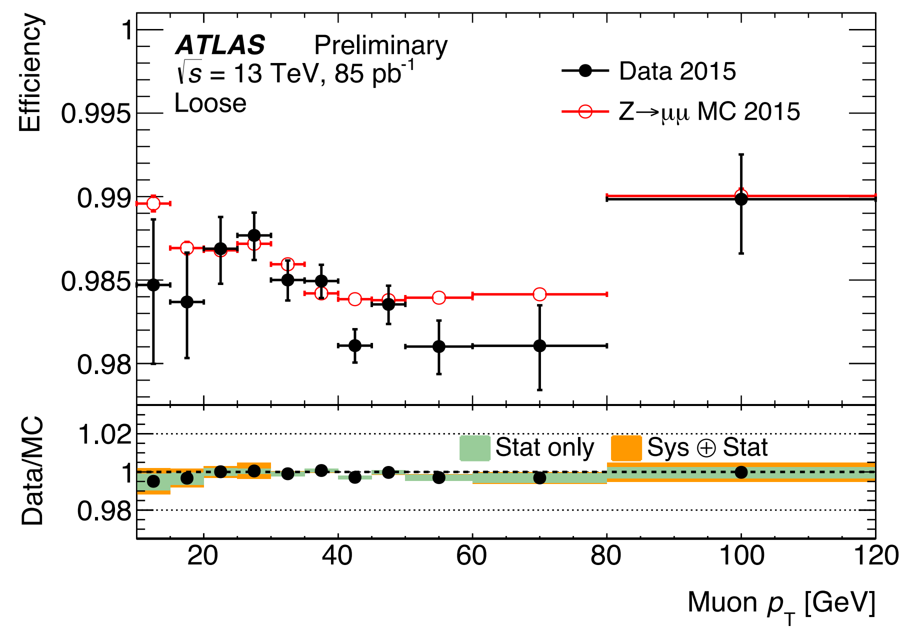




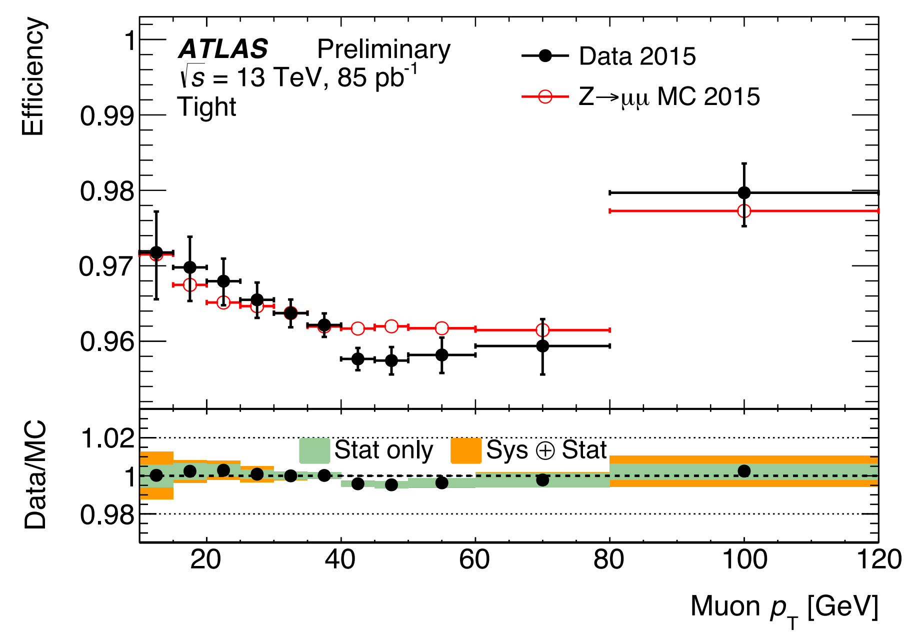
Muons extra



Reco Efficiency
Data/MC
J/ψ→μμ Data
J/ψ→μμ MC
Z→μμ Data
Z→μμ MC
ATLAS Preliminary
√s = 13 TeV, 78 pb⁻¹
Medium muons, 0.1 < |η| < 2.5
p_T [GeV]



Efficiency
ATLAS Preliminary
√s = 13 TeV, 85 pb⁻¹
Loose
Data 2015
Z→μμ MC 2015
Data/MC
Stat only
Sys ⊕ Stat
Muon p_T [GeV]



Efficiency
ATLAS Preliminary
√s = 13 TeV, 85 pb⁻¹
Tight
Data 2015
Z→μμ MC 2015
Data/MC
Stat only
Sys ⊕ Stat
Muon p_T [GeV]

Electrons

Type	Description	Name
Hadronic leakage	Ratio of E_T in the first layer of the hadronic calorimeter to E_T of the EM cluster (used over the range $\|\eta\| < 0.8$ or $\|\eta\| > 1.37$)	R_{Had1}
	Ratio of E_T in the hadronic calorimeter to E_T of the EM cluster (used over the range $0.8 < \|\eta\| < 1.37$)	R_{Had}
Back layer of EM calorimeter	Ratio of the energy in the back layer to the total energy in the EM accordion calorimeter	f_3
Middle layer of EM calorimeter	Lateral shower width, $\sqrt{(\Sigma E_i \eta_i^2)/(\Sigma E_i) - ((\Sigma E_i \eta_i)/(\Sigma E_i))^2}$, where E_i is the energy and η_i is the pseudorapidity of cell i and the sum is calculated within a window of 3×5 cells	$W_{\eta 2}$
	Ratio of the energy in 3×3 cells over the energy in 3×7 cells centered at the electron cluster position	R_ϕ
	Ratio of the energy in 3×7 cells over the energy in 7×7 cells centered at the electron cluster position	R_η
Strip layer of EM calorimeter	Ratio of the energy difference between the largest and second largest energy deposits in the cluster over the sum of these energies	E_{ratio}
	Ratio of the energy in the strip layer to the total energy in the EM accordion calorimeter	f_1
Track quality	Number of hits in the innermost pixel layer (the newly added B layer), discriminates against photon conversions	n_{Blayer}
	Number of hits in the pixel detector	n_{Pixel}
	Number of total hits in the pixel and SCT detectors	n_{Si}
	Transverse impact parameter with respect to the beamspot	d_0
	Significance of transverse impact parameter defined as the ratio of d_0 and its uncertainty	σ_{d_0}
	Momentum lost by the track between the perigee and the last measurement point divided by the original momentum	$\Delta p/p$
TRT	Likelihood probability based on transition radiation in the TRT	TRTPID
Track-cluster matching	$\Delta\eta$ between the cluster position in the strip layer and the extrapolated track	$\Delta\eta_1$
	$\Delta\phi$ between the cluster position in the middle layer and the extrapolated track, where the track momentum is rescaled to the cluster energy before extrapolating the track to the middle layer of the calorimeter	$\Delta\phi_{res}$

W/Z cross sections

$\ell^{\pm}$	Observed candidates	Background (EW+top)	Background (Multijet)	Background-subtracted events N_W^{sig}
e^+	256923	10100 ± 600	15200 ± 300 ± 6700	231600 ± 500 ± 6700
e^-	206140	8900 ± 500	15600 ± 300 ± 6900	181600 ± 500 ± 6900
μ^+	272841	20420 ± 920	12200 ± 200 ± 3500	240300 ± 500 ± 3600
μ^-	214249	18210 ± 830	11500 ± 100 ± 3100	184500 ± 500 ± 3200

$\ell^{\pm}$	Observed candidates	Background (EW+top)	Background (Multijet)	Background-subtracted events N_Z^{sig}
$e^{\pm}$	34955	229 ± 1 ± 24	$< 0.1\%$	34730 ± 190 ± 20
$\mu^{\pm}$	44899	296 ± 2 ± 31	$< 0.1\%$	44600 ± 210 ± 30

W/Z cross sections

Process $\delta C/C$ (%)	$Z \to \mu^+\mu^-$	$W^+ \to \mu^+\nu$	$W^- \to \mu^-\overline{\nu}$	$Z \to e^+e^-$	$W^+ \to e^+\nu$	$W^- \to e^-\overline{\nu}$
Electron Trigger	–	–	–	0.5	3.0	3.2
Electron Reconstruction, Identification	–	–	–	3.8	2.0	2.1
Electron Isolation	–	–	–	1.0	0.5	0.5
Electron Scale and Resolution	–	–	–	0.2	0.4	0.5
Charge Identification	–	–	–	0.8	0.1	0.1
Muon Trigger	1.0	2.0	2.0	–	–	–
Muon Reconstruction, Identification	0.9	0.4	0.4	–	–	–
Muon Isolation	0.5	0.3	0.3	–	–	–
Muon Scale and Resolution	0.1	0.1	0.1	–	–	–
JES and JER	–	1.5	1.5	–	1.9	1.8
MET Soft Term	–	0.1	0.1	–	0.1	0.1
Pileup Modeling	0.9	1.2	1.2	0.9	1.4	1.4
Total	1.7	2.8	2.8	4.1	4.4	4.5

W/Z cross sections

Channel	value ± stat ± syst ± lumi [pb]
W^-	8380 ± 20 ± 350 ± 750
W^+	10960 ± 20 ± 440 ± 990
$W^\pm$	19350 ± 20 ± 760 ± 1740
Z	1869 ± 7 ± 42 ± 168

Z+jets

N_{jet}	σ	$\pm$ stat	$\pm$ syst	$\pm$ lumi
	[pb]			
≥ 1	115.7	1.3	4.9	10.4
≥ 2	27.0	0.6	1.4	2.4
≥ 3	5.8	0.3	0.4	0.5
≥ 4	1.40	0.14	0.11	0.13

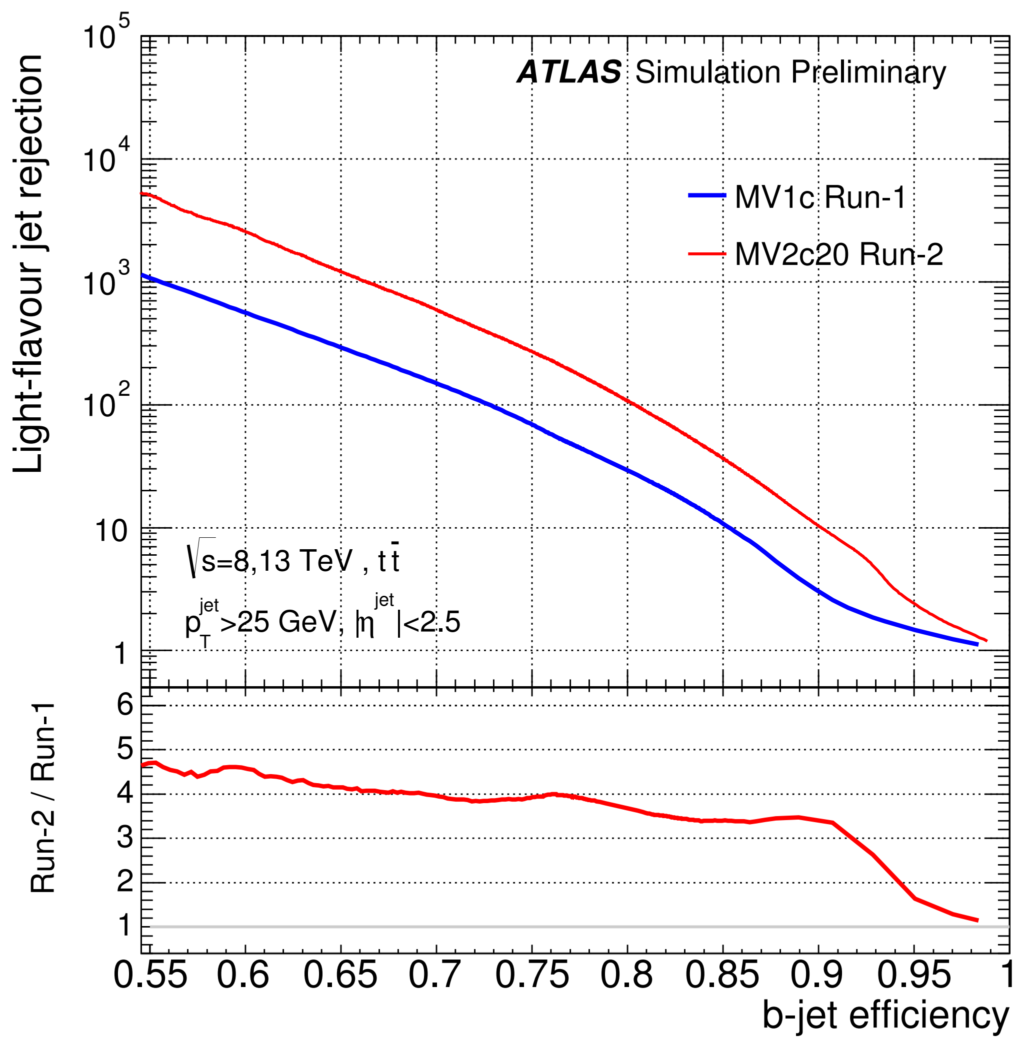
Generators

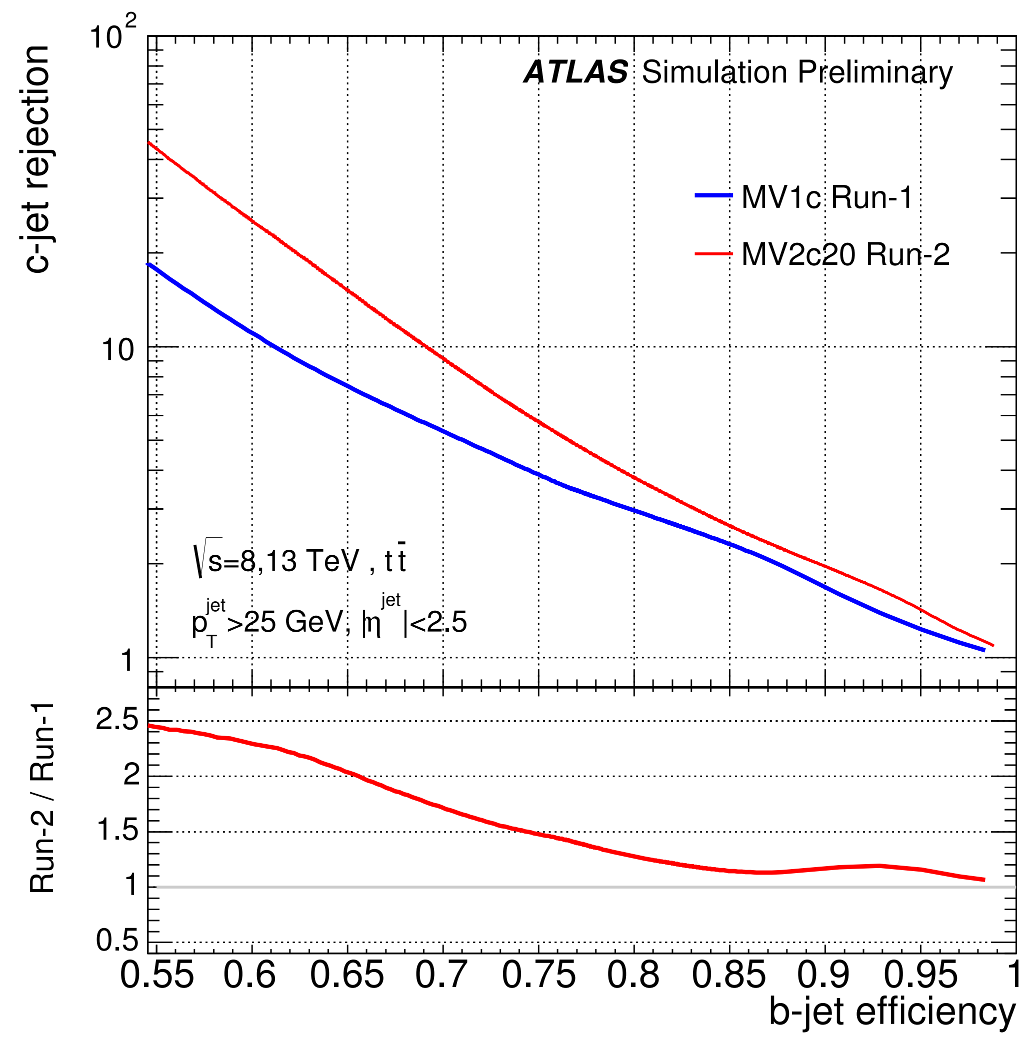
Physics process	Generator	$(\sigma \cdot \mathrm{BR})$[pb]	Order	Reference
$Z \to \ell^+\ell^-$+jets $(m_{\ell\ell} > 40$ GeV)	Sherpa v2.1.1	$2091 \pm 5\%$	NNLO	[16–19]
$Z \to \ell^+\ell^-$+jets $(m_{\ell\ell} > 40$ GeV)	MadGraph5	$2091 \pm 5\%$	NNLO	[16–19]
$W \to \ell\nu$ $(\ell = e, \mu, \tau)$	Powheg +Pythia 8	$20400 \pm 5\%$	NNLO	[16–19]
$Z \to \ell^+\ell^-$ $(m_{\ell\ell} > 60$ GeV)	Powheg +Pythia 8	$1979 \pm 5\%$	NNLO	[16–19]
$t\bar{t}$ $(m_t = 172.5$ GeV)	Powheg +Pythia 6	$830 \pm 6\%$	NNLO+NNLL	[26]
Dibosons	Sherpa	$99 \pm 6\%$	NLO	[6]
Dijet (e channel, $\hat{p}_{\mathrm{T}} > 21$ GeV)	Pythia 8	180×10^3	LO	[13]
$b\bar{b}$ (μ channel, $\hat{p}_{\mathrm{T}} > 15$ GeV)	Pythia 8	188	LO	[13]
$c\bar{c}$ (μ channel, $\hat{p}_{\mathrm{T}} > 15$ GeV)	Pythia 8	58	LO	[13]

B-tagging inputs

Input	Variable	Description
Kinematics	$p_T(jet)$	Jet transverse momentum
	$\eta(jet)$	Jet pseudo-rapidity
IP2D, IP3D	$\log(P_b/P_{\text{light}})$	Likelihood ratio between the *b*- and light jet hypotheses
	$\log(P_b/P_c)$	Likelihood ratio between the *b*- and *c*-jet hypotheses
	$\log(P_c/P_{\text{light}})$	Likelihood ratio between the *c*- and light jet hypotheses
SV	$m(\text{SV})$	Invariant mass of tracks at the secondary vertex assuming pion masses
	$f_{\text{E}}(\text{SV})$	Fraction of the charged jet energy in the secondary vertex
	$N_{\text{TrkAtVtx}}(\text{SV})$	Number of tracks used in the secondary vertex
	$N_{\text{2TrkVtx}}(\text{SV})$	Number of two track vertex candidates
	$L_{xy}(\text{SV})$	Transverse distance between the primary and secondary vertices
	$L_{xyz}(\text{SV})$	Distance between the primary and secondary vertices
	$S_{xyz}(\text{SV})$	Distance between the primary and secondary vertices divided by its uncertainty
	$\Delta R(\text{jet}, \text{SV})$	ΔR between the jet axis and the direction of the secondary vertex relative to the primary vertex
Jet Fitter	$N_{\text{2TrkVtx}}(\text{JF})$	Number of 2-track vertex candidates (prior to decay chain fit)
	$m(\text{JF})$	Invariant mass of tracks from displaced vertices assuming pion masses
	$S_{\text{xyz}}(\text{JF})$	Significance of the average distance between the primary and displaced vertices
	$f_{\text{E}}(\text{JF})$	Fraction of the charged jet energy in the secondary vertices
	$N_{\text{1-trk vertices}}(\text{JF})$	Number of displaced vertices with one track
	$N_{\geq\text{2-trk vertices}}(\text{JF})$	Number of displaced vertices with more than one track
	$N_{\text{TrkAtVtx}}(\text{JF})$	Number of tracks from displaced vertices with at least two tracks
	$\Delta R(\vec{p}_{\text{jet}}, \vec{p}_{\text{vtx}})$	ΔR between the jet axis and the vectorial sum of the momenta of all tracks attached to displaced vertices

B-tagging


ATLAS Simulation Preliminary
MV1c Run-1
MV2c20 Run-2
√s=8,13 TeV , tt̄
p_T^{jet}>25 GeV, $|\eta^{jet}|$<2.5
Light-flavour jet rejection
Run-2 / Run-1
b-jet efficiency


ATLAS Simulation Preliminary
MV1c Run-1
MV2c20 Run-2
√s=8,13 TeV , tt̄
p_T^{jet}>25 GeV, $|\eta^{jet}|$<2.5
c-jet rejection
Run-2 / Run-1
b-jet efficiency

Top eμ

Uncertainty	$\Delta\epsilon_{e\mu}/\epsilon_{e\mu}$ (%)	$\Delta C_b/C_b$ (%)	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)
Data statistics			6.0
$t\bar{t}$ NLO modelling	1.9	-0.3	2.2
$t\bar{t}$ hadronisation	-4.0	0.5	4.5
Initial/final state radiation	-1.1	0.1	1.2
Parton distribution functions	1.3	-	1.4
Single-top generator*	-	-	0.5
Single-top/$t\bar{t}$ interference*	-	-	0.1
Single-top Wt cross-section	-	-	0.5
Diboson modelling*	-	-	0.1
Diboson cross-sections	-	-	0.0
Z+jets extrapolation	-	-	0.2
Electron energy scale/resolution	0.2	0.0	0.2
Electron identification	3.6	0.0	4.0
Electron isolation	1.0	-	1.1
Muon momentum scale/resolution	0.0	0.0	0.1
Muon identification	1.1	0.0	1.2
Muon isolation	1.0	-	1.1
Lepton trigger	1.3	0.0	1.3
Jet energy scale	-0.3	0.0	0.3
Jet energy resolution	-0.1	0.0	0.1
b-tagging	-	0.1	0.3
Misidentified leptons	-	-	1.3
Analysis systematics	6.4	0.6	7.3
Integrated luminosity	-	-	10.0
Total uncertainty	6.4	0.6	13.7

Top

Uncertainty (%)	$\sigma_{Z\to ee}$	$\sigma_{Z\to\mu\mu}$	$\sigma_{t\bar{t}}$	$R_{t\bar{t}/Z}$
Data statistics	0.5	0.5	6.0	6.0
$t\bar{t}$ NLO modelling	-	-	2.2	2.2
$t\bar{t}$ hadronisation	-	-	4.5	4.5
Initial/final state radiation	-	-	1.2	1.2
Parton distribution functions ($t\bar{t}$, Wt)	-	-	1.4	1.4
Single-top modelling	-	-	0.5	0.5
Single-top/$t\bar{t}$ interference	-	-	0.1	0.1
Single-top Wt cross-section	-	-	0.5	0.5
Diboson modelling	-	-	0.1	0.1
Diboson cross-sections	-	-	0.0	0.0
Z+jets extrapolation	-	-	0.2	0.2
Electron energy scale/resolution	0.2	-	0.2	0.1
Electron identification	3.8	-	3.2	1.3
Electron charge identification	0.8	-	-	0.4
Electron isolation	1.0	-	1.1	1.2
Muon momentum scale/resolution	-	0.1	0.1	0.0
Muon identification	-	0.9	0.5	0.1
Muon isolation	-	0.5	1.1	1.1
Lepton trigger	0.5	1.1	0.8	0.7
Jet energy scale	-	-	0.3	0.3
Jet energy resolution	-	-	0.1	0.1
b-tagging	-	-	0.3	0.3
Misidentified leptons	-	-	1.4	1.4
Pileup modelling	0.9	0.9	-	0.9
Z acceptance	1.5	1.5	-	1.5
Z backgrounds	0.1	0.1	-	0.1
Analysis systematics	4.4	2.3	6.7	6.3
Integrated luminosity	9.0	9.0	10.0	1.0
Total uncertainty	10.0	9.3	13.5	8.8

Di-lep

Uncertainty	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)
Data statistics	7.6
$t\bar{t}$ NLO modelling	2.6
$t\bar{t}$ hadronisation	7.9
Initial/final state radiation	1.5
PDF	3.7
Single-top Wt cross-section	0.6
Single-top interference	<0.05
Diboson cross-section	0.4
Z+jets $\to ee/\mu\mu$ modelling	1.5
Z+jets $\to \tau\tau$ modelling	0.1
Electron energy scale	0.3
Electron energy resolution	0.2
Electron identification	3.6
Electron trigger	0.2
Electron isolation	1.0
Muon momentum scale	0.1
Muon momentum resolution	1.1
Muon identification	0.8
Muon trigger	0.6
Muon isolation	1.0
Jet energy scale	1.2
Jet energy resolution	0.2
b-tagging efficiency	0.8
Missing transverse momentum	0.3
NP & fakes	1.5
Analysis systematics	11
Integrated luminosity	10
Total uncertainty	16

l+jets

Uncertainty	$\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ (%)
Data statistics	1.5
$t\bar{t}$ NLO modelling	0.6
$t\bar{t}$ hadronisation	4.1
Initial/final state radiation	1.9
PDF	0.7
Single top cross-section	0.3
Diboson cross-sections	0.2
Z+jets cross-section	1.0
W+jets method statistics	1.7
W+jets modelling	1.0
Electron energy scale/resolution	0.1
Electron identification	2.1
Electron isolation	0.4
Electron trigger	2.8
Muon momentum scale/resolution	0.1
Muon identification	0.2
Muon isolation	0.3
Muon trigger	1.2
$E_{\mathrm{T}}^{\mathrm{miss}}$ scale/resolution	0.4
Jet energy scale	$^{+10}_{-8}$
Jet energy resolution	0.6
b-tagging	4.1
NP & fakes	1.8
Analysis systematics	$^{+13}_{-11}$
Integrated luminosity	$^{+11}_{-9}$
Total uncertainty	$^{+17}_{-14}$