Minimum bias measurement at 13 TeV

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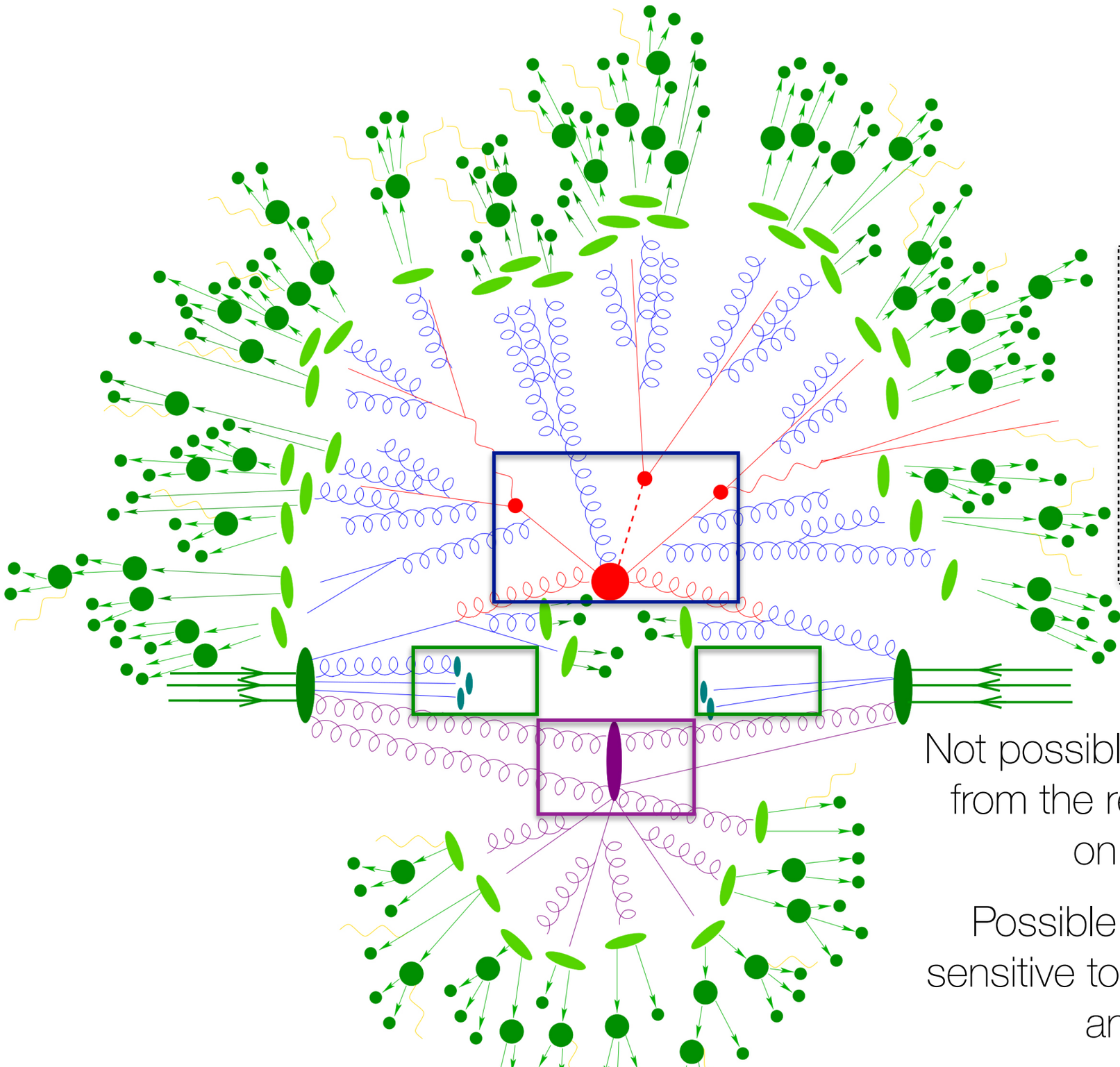
Workshop on forward physics and high-energy scattering at zero degrees 2017

Nagoya (JP) September 26–29 , 2017

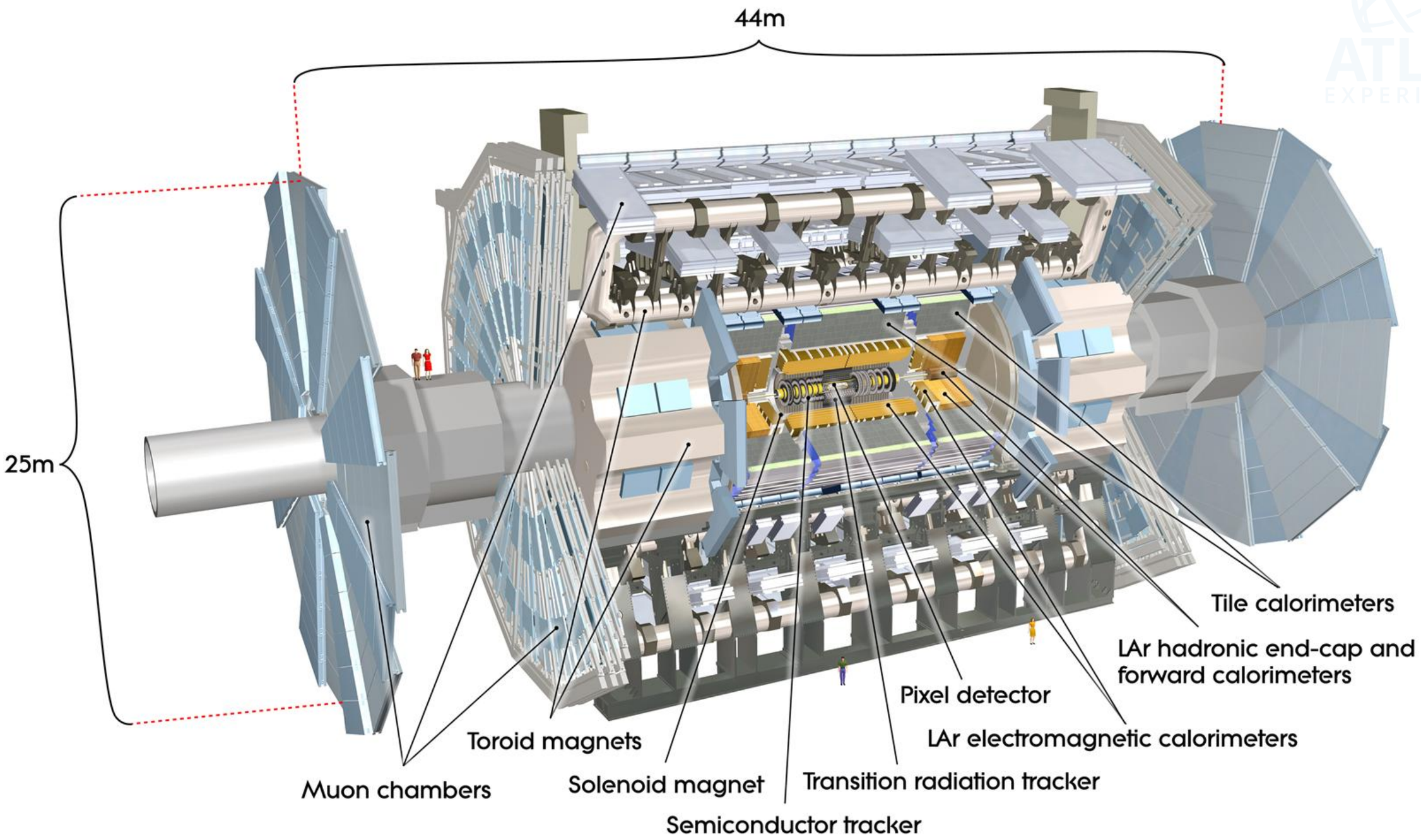
LHC collisions



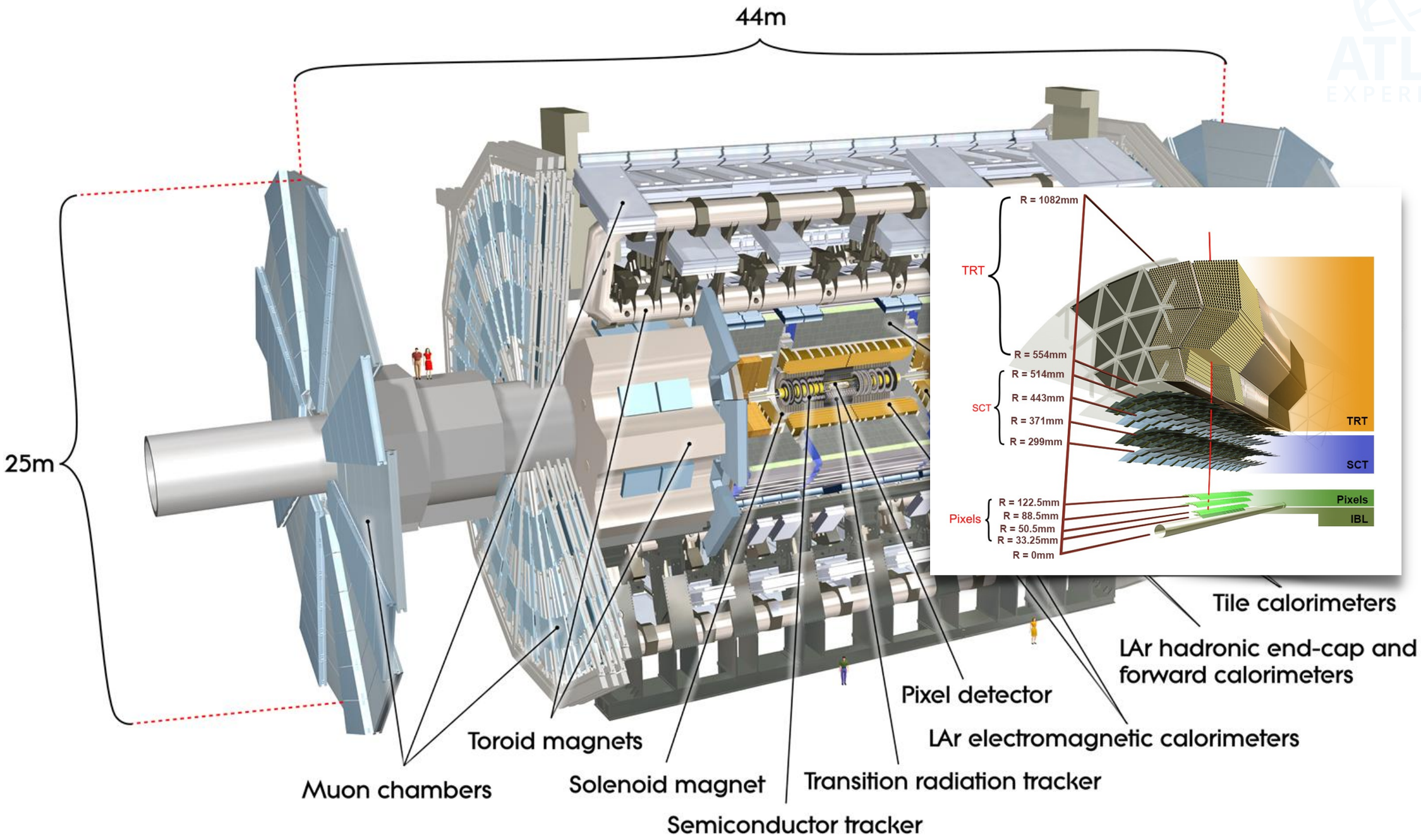
Not possible to distinguish the hard process from the rest of the soft QCD interactions on an event by event basis

Possible to define specific observables sensitive to different mixture of hard process and underlying event (UE)

ATLAS detector



ATLAS detector



Data taking

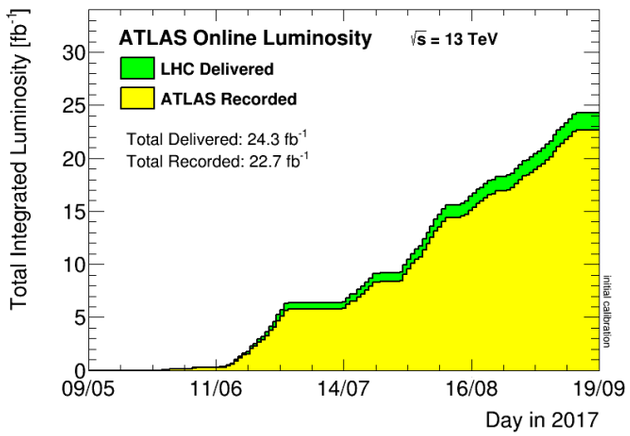
- Here focusing on a small fraction of dataset collected in 2015 with special, low instantaneous luminosity, conditions
  - Allows to reduce the effect of pile-up on the measurement

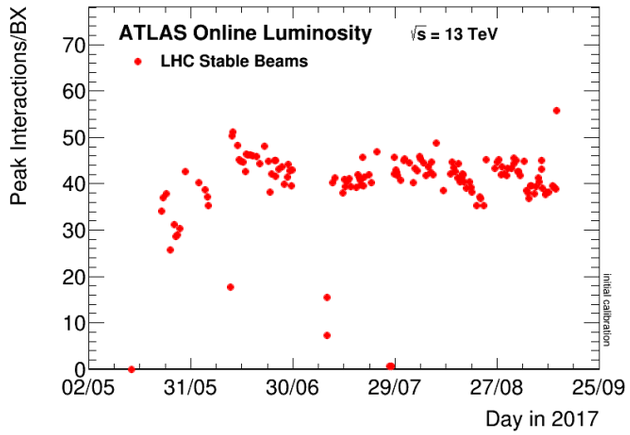
ATLAS pp run: June-August 2015

Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
98.5	99.7	100	99.1	100	100	99.3	100	100	100	99.6

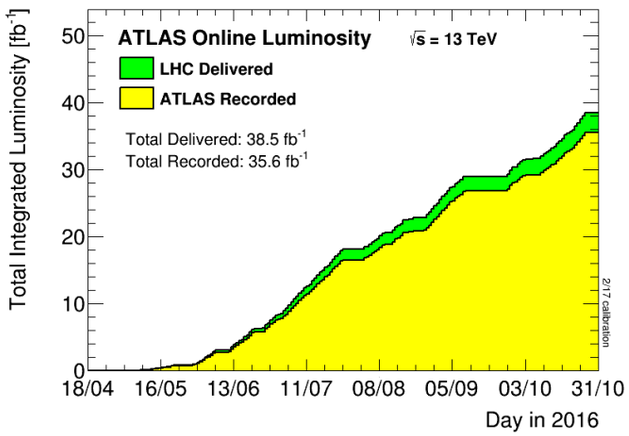
Luminosity weighted relative detector uptime (in percent) and good quality data delivery during the stable beams in pp collisions at 13 TeV between June-August 2015, corresponding to 173 pb^{-1} recorded luminosity.

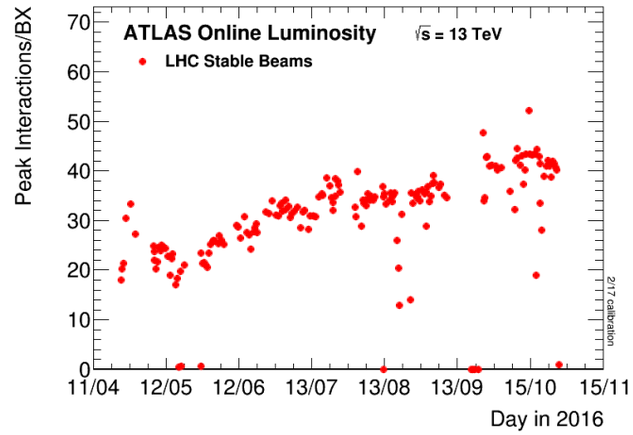
2017



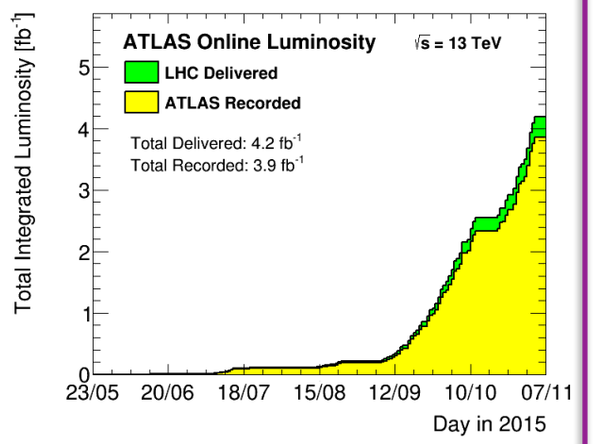


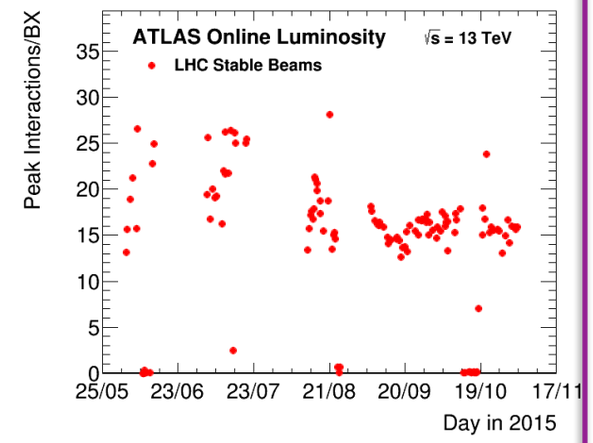
2016

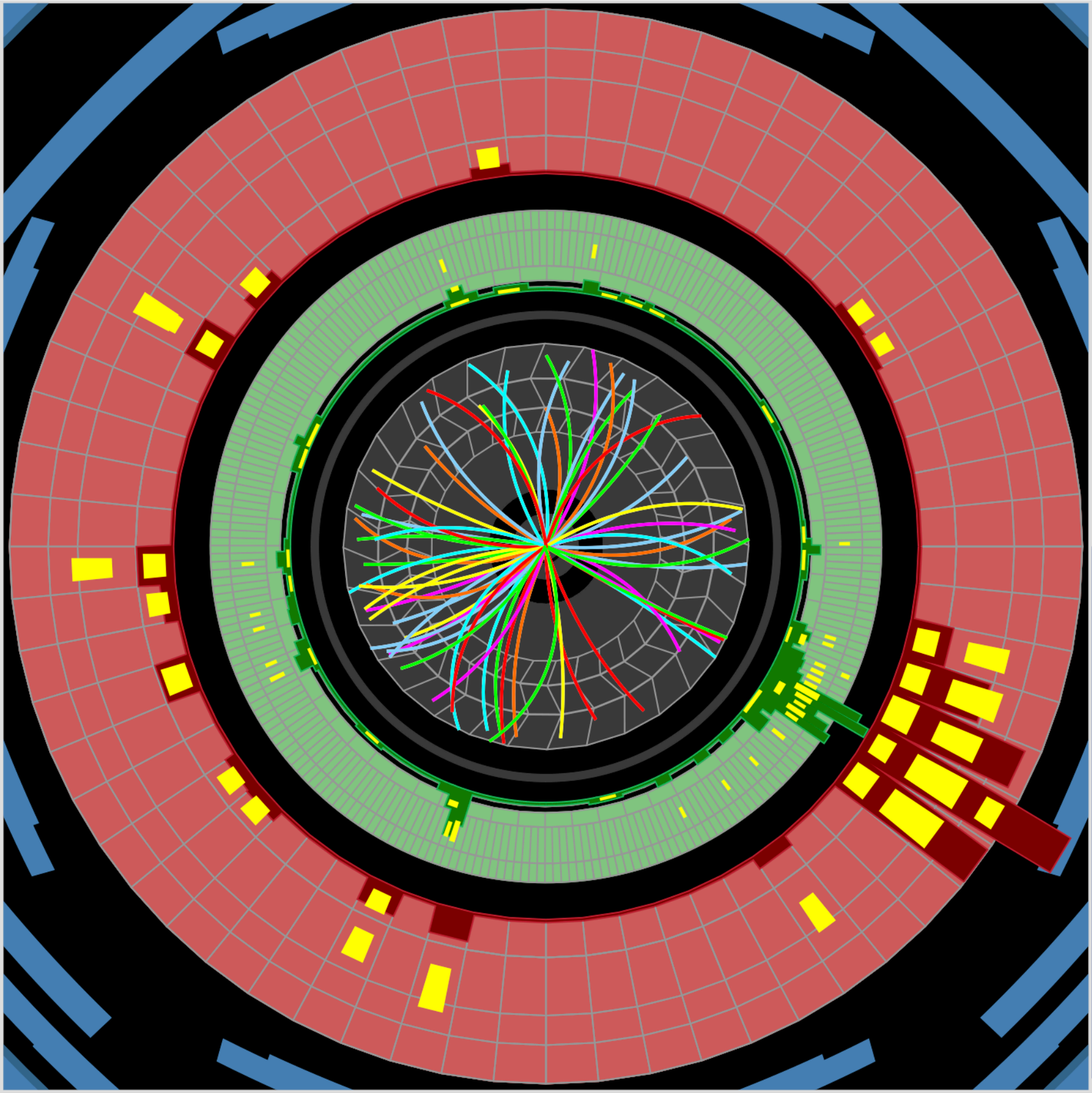




2015



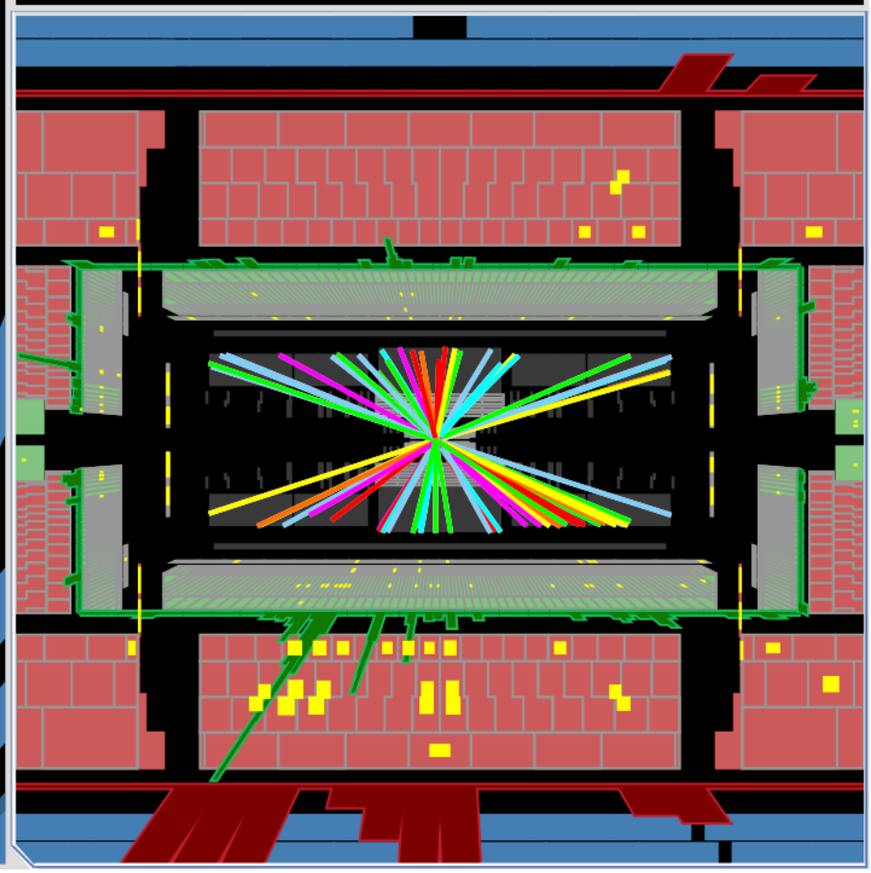




ATLAS EXPERIMENT

Run Number: 265532, Event Number: 3280065

Date: 2015-05-20 22:51:50 CEST



Introduction

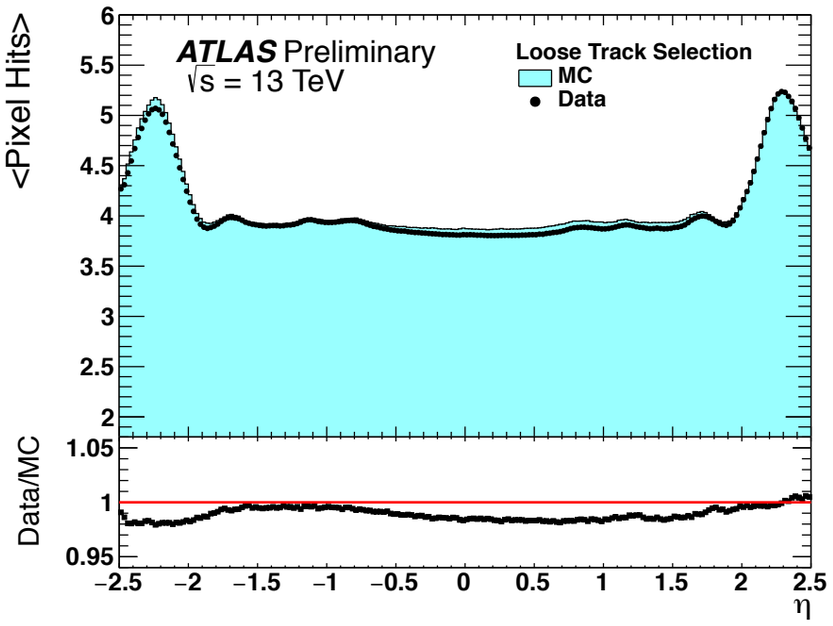
- Here focusing on a few results, most recent
- More information here https://twiki.cern.ch/twiki/bin/view/AtlasPublic/StandardModelPublicResults#Soft_QCD_and_Diffractive_Physics

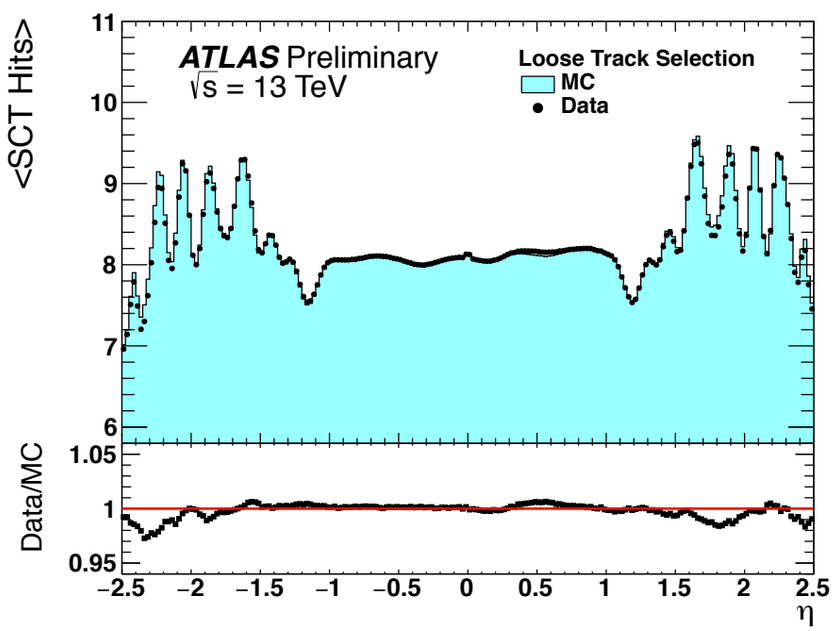
Analysis	Reference	Integrated luminosity	Average interactions per bunch crossing
Low-p_T track-based 'Minimum Bias' analysis	Eur.Phys.J. C76 (2016) no.9, 502	151μb^{-1}	0.005 in average
Track-based Underlying Event analysis	JHEP 1703 (2017) 157	1.6nb^{-1}	0.003-0.03

Extra information on tacking performance can be found here
https://cds.cern.ch/record/2037683

Track reconstruction performance

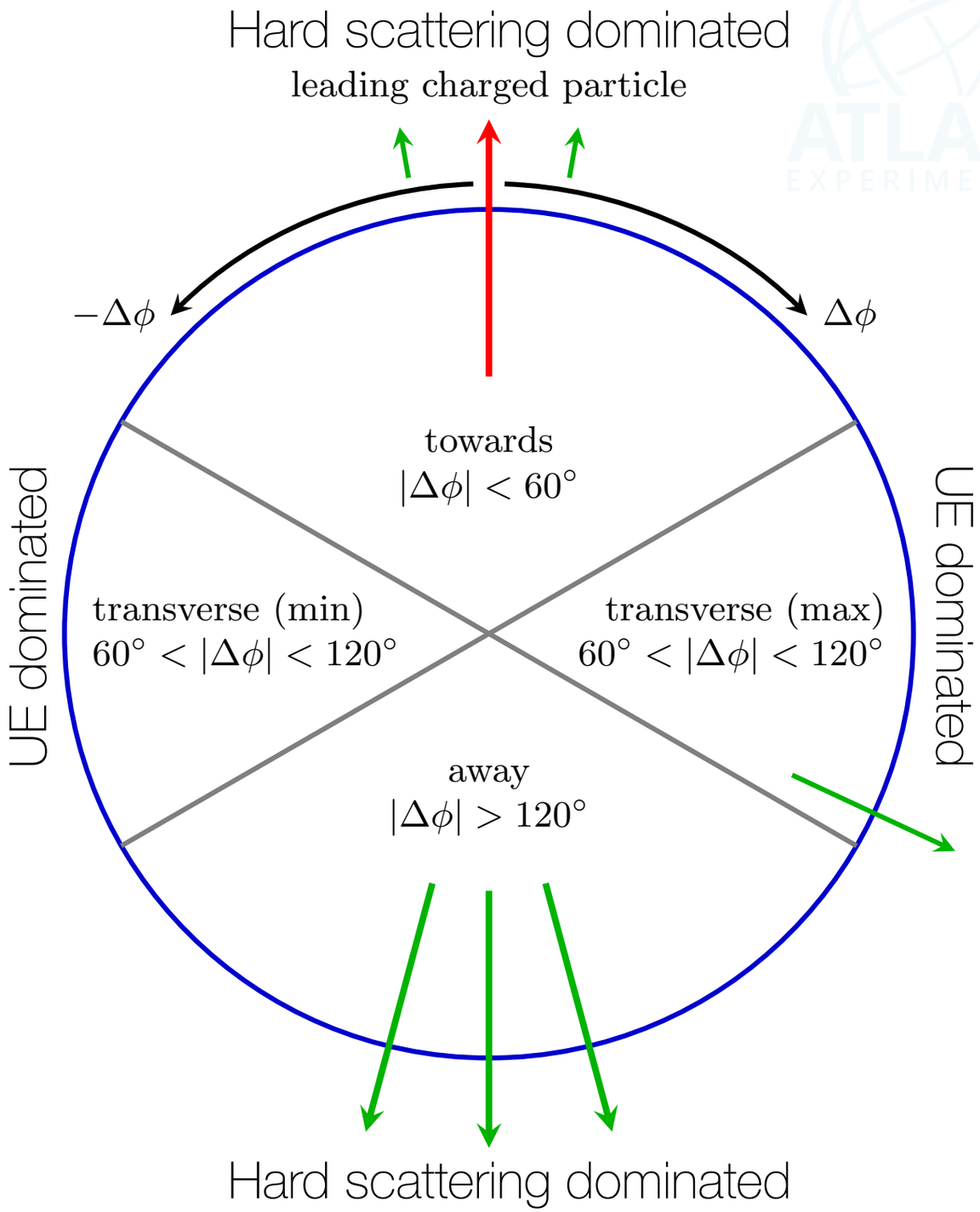
- Evaluate in early, low pile-up, data
  - Track selection, dataset, trigger strategy similar to the ATLAS 13 TeV minimum bias measurement
- Comparing data and simulation for basic observables entering in the track reconstruction (e.g., silicon hits multiplicity)
  - Validation of the passive material description: plays a major role in the UE measurements
- Residual discrepancies covered by uncertainties of passive material description or dead modules emulation in simulation





Analysis strategy

- **Low-p_T track-based 'Minimum Bias' analysis**: based on selection of events with at least two tracks with p_T>100 MeV and $|\eta|$<2.5
  - Observables built out of all tracks with p_T>100 MeV and $|\eta|$<2.5
- **Track-based Underlying Event analysis**: based on selection of events with at least one track with p_T>1 GeV and $|\eta|$<2.5
  - Observables built out of all tracks with p_T>500 MeV and $|\eta|$<2.5
  - Underlying event (UE) sensitive observables measured in different azimuthal regions defined based on the direction of the leading charged particle
  - Measuring observables also in “trans diff” region (event by event difference between trans-max and trans-min) to isolate the contribution from the hard process



Particle level definition and correction

- Particle level definition uses two set of particles
  - Charged prompt particles with lifetime τ>300ps
  - Charged particles coming form decays of particles with lifetime τ<30ps
    - Exclude poorly reconstructed strange baryons (typical reconstruction efficiency below 1%), avoid application of a large efficiency correction

$$w_{\mathrm{trk}}(p_{\mathrm{T}},\eta) = \frac{1}{\varepsilon_{\mathrm{trk}}(p_{\mathrm{T}},\eta)} \cdot [1 - f_{\mathrm{fake}}(p_{\mathrm{T}},\eta) - f_{\mathrm{sb}}(p_{\mathrm{T}},\eta) - f_{\mathrm{sec}}(p_{\mathrm{T}},\eta) - f_{\mathrm{okr}}(p_{\mathrm{T}},\eta)]$$

Tracking efficiency	Fraction of fake tracks	Fraction of strange baryons	Fracking of secondary tracks	Outside-of-kinematic correction

An additional correction used per event basis to remove vertex reconstruction and trigger efficiencies

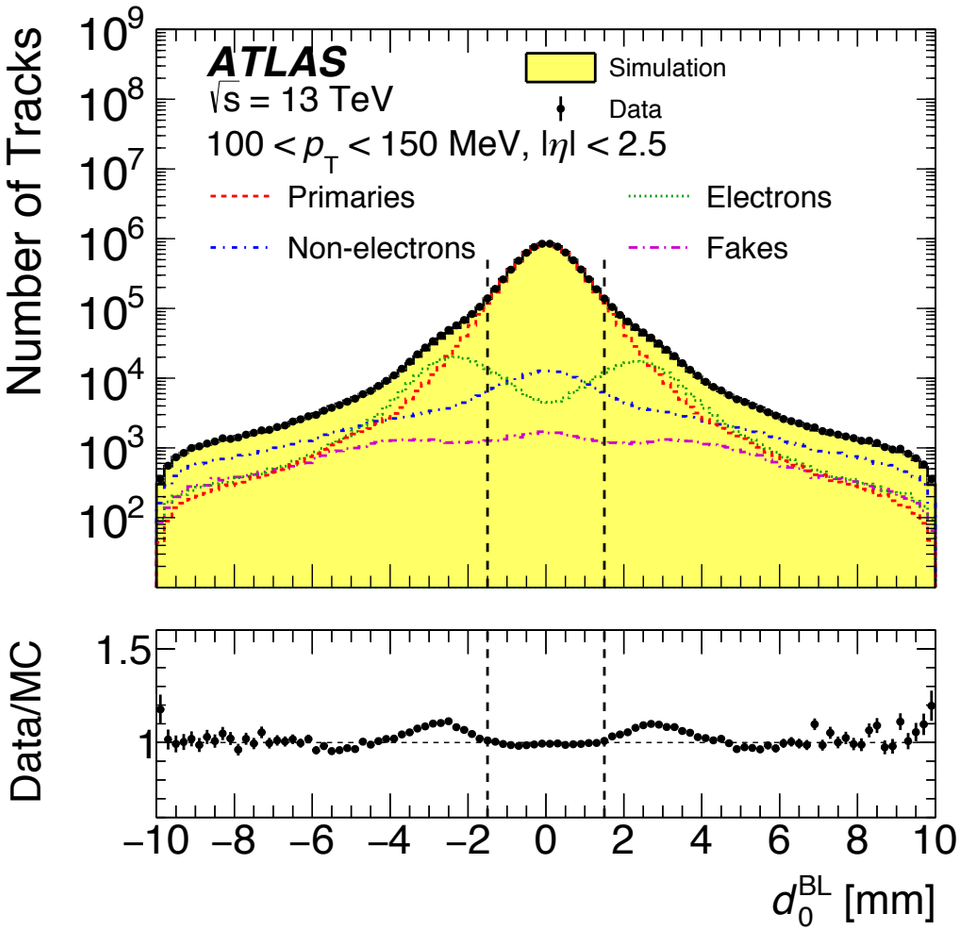
$$w_{\mathrm{ev}}(n_{\mathrm{sel}}^{\text{no-z}}, \Delta z_{\mathrm{tracks}}) = \frac{1}{\varepsilon_{\mathrm{trig}}(n_{\mathrm{sel}}^{\text{no-z}})} \cdot \frac{1}{\varepsilon_{\mathrm{vtx}}(n_{\mathrm{sel}}^{\text{no-z}}, \Delta z_{\mathrm{tracks}})}$$

Backgrounds

- **Fake tracks** due to random silicon hits combinations
  - Low p_T analysis: checked in simulation and data, found to be less than 1%
  - Standard analysis: fully negligible, checked on simulation
- **Strange baryons**, not included in the measurements definition, are subtracted using EPOS which provides the best description of ALICE strange baryon data
  - Up to 3% for tracks of 20 GeV p_T, deceasing with p_T down to 0.01% on average for the low p_T analysis
- **Non collision backgrounds** checked in simulation, found to be negligible

Secondary particles due to hadronic interaction with the detector material and photon conversion

Used sidebands of the transverse impact parameter distribution to estimate it to be 2.3% ±0.7%

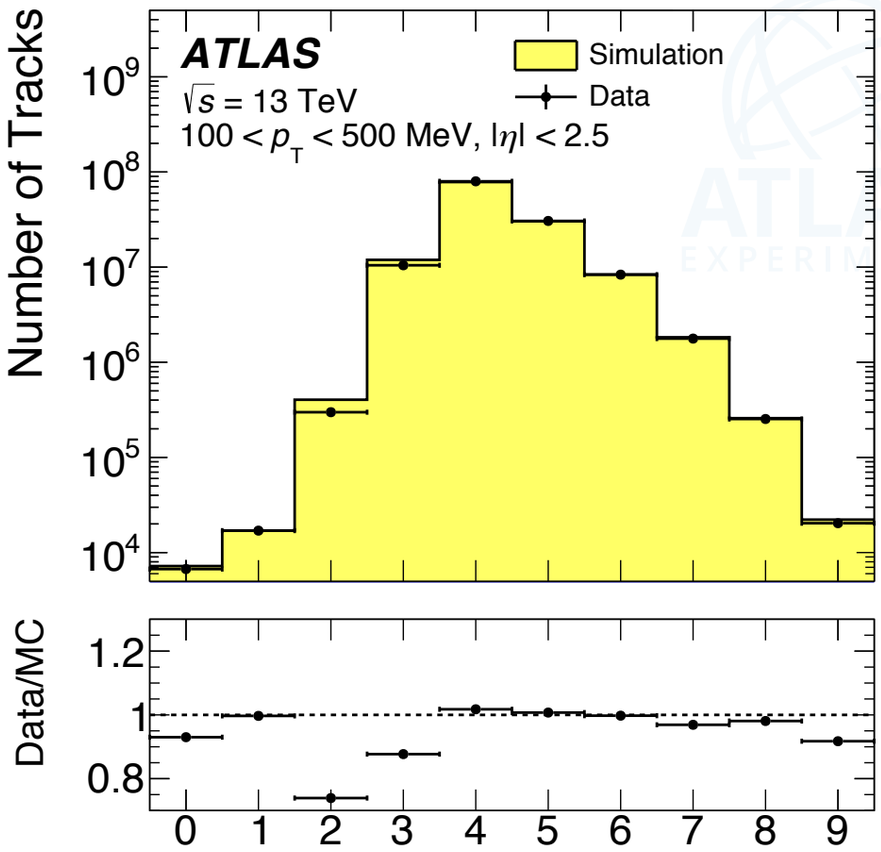


Monte Carlo predictions

Generator (version)	Tune	PDF	Tune features
Pythia8	A2	MSTW2008LO	Built on top of Pythia8 C4 tune, used ATLAS minimum bias 7 TeV data for MPI
Pythia8	A14	NNPDF2.3LO	ATLAS tune on UE and high p_T measurements (jets, Drell-Yan, top-quark pair cross sections)
Pythia8	Monash	NNPDF2.3LO	Includes ATLAS Drell-Yan and UE data, plus CMS, SPS, Tevatron data
Herwig7	UE-MMHT	MMHT2014LO	Based on LHC and Tevatron UE as well as MPI data
EPOS	LHC	-	Based on LHC data, including Totem cross section measurement
QGSJET II-04	Default	-	Includes LHC data

Low-p_T track-based 'Minimum Bias' analysis: selection and observables

- Targeting events with at least two tracks with p_T greater than 100 MeV
- Special track reconstruction to cope with the low p_T region
  - Requiring at least five silicon hits (instead of seven as in the default reconstruction)
  - Other set of cuts (e.g. impact parameter cuts) applied to suppress secondary tracks
- Events with more than one reconstructed vertex are vetoed
- Trigger based on random L1 items and, HLT requiring at least one track with p_T>200 MeV, typical efficiency above 95% for all selected events

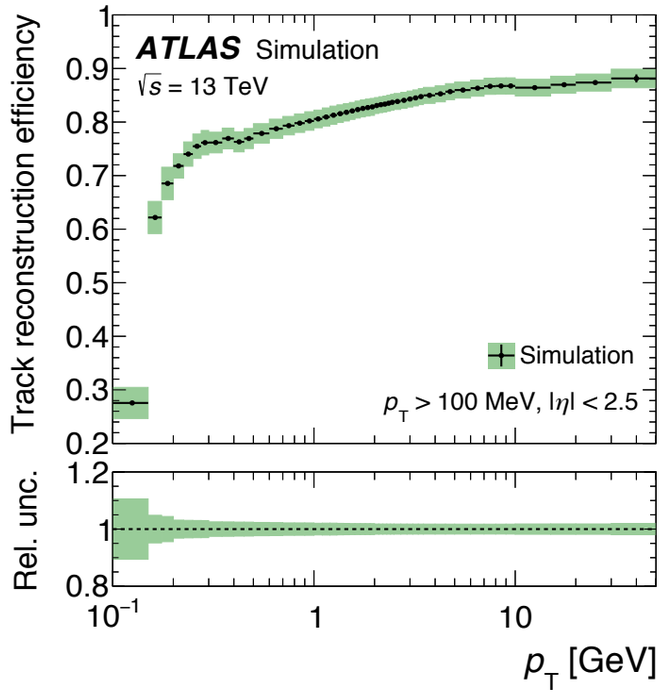


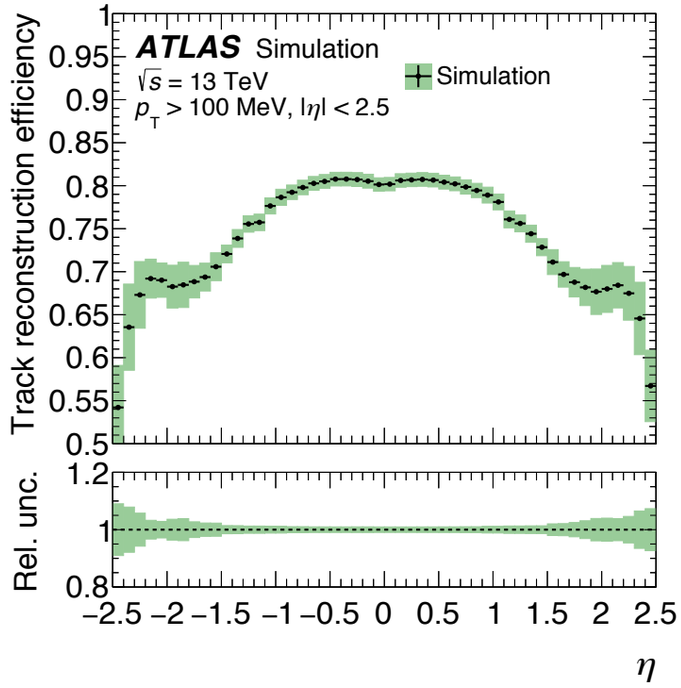
Observable	Description
$\frac{1}{N_{ev}} \cdot \frac{dN_{ch}}{d\eta}$	Charged particle multiplicity vs **η**
$\frac{1}{N_{ev}} \cdot \frac{1}{2\pi p_T} \cdot \frac{d^2N_{ch}}{d\eta dp_T}$	Charged particle multiplicity vs **η** and p_T
$\frac{1}{N_{ev}} \cdot \frac{dN_{ev}}{dn_{ch}}$	Charged particle multiplicty
$\langle p_T \rangle$ vs. n_{ch}	Average p_T vs charged particle multiplicity

Low p_T analysis: systematic uncertainties

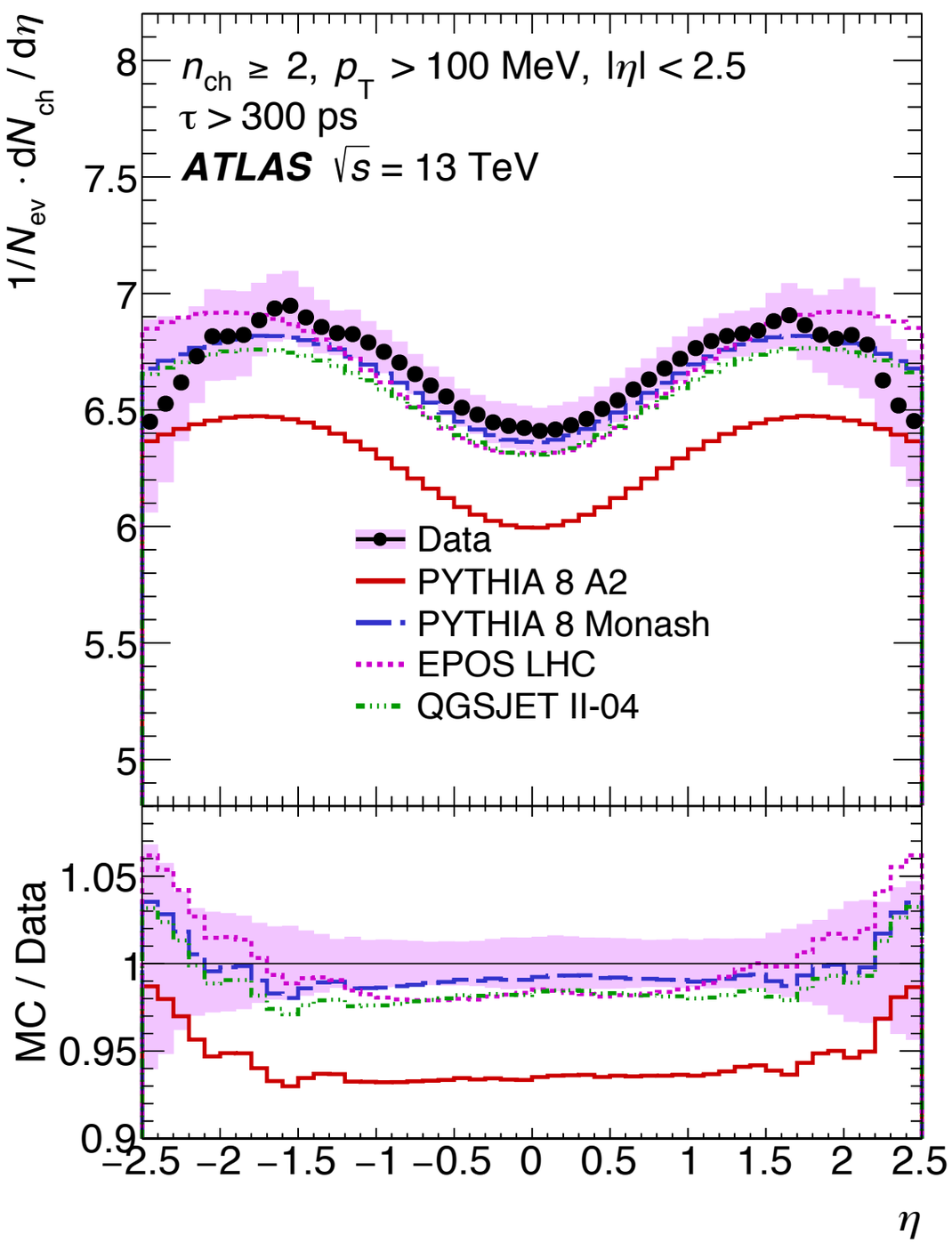
- Track reconstruction efficiency studied in simulation as a function of p_T and **η**
  - Main uncertainty due to description of passive material: from 1% to 10% (depending on **η**) per track
  - Other components due to track selection efficiency, resolution, alignment
- Other minor uncertainties due to background estimation, track p_T modeling, model dependence on the unfolding (non-closure)

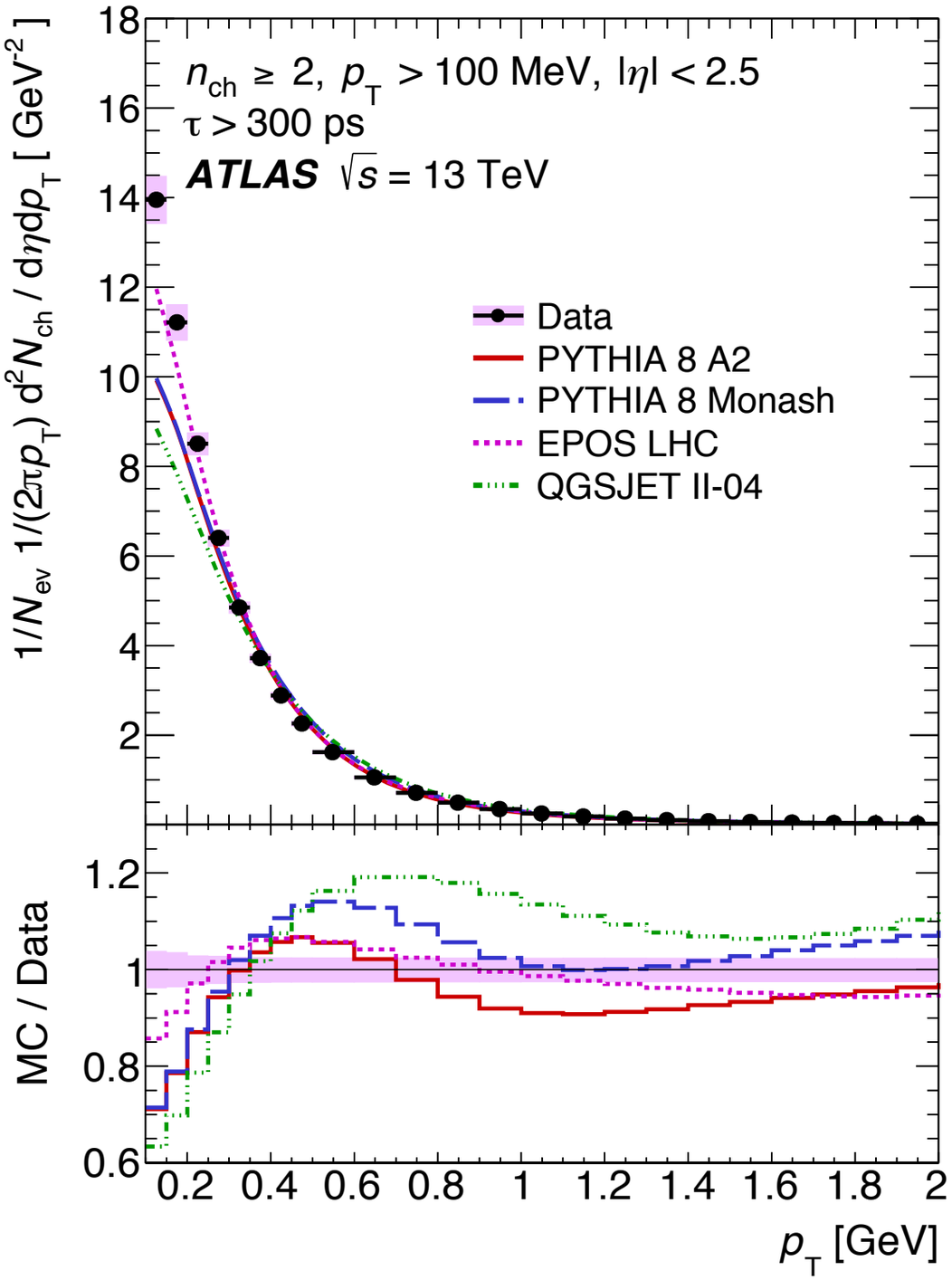
Distribution	$\frac{1}{N_{ev}} \cdot \frac{dN_{ch}}{d\lvert\eta\rvert}$	$\frac{1}{N_{ev}} \cdot \frac{1}{2\pi p_T} \cdot \frac{d^2N_{ch}}{d\eta dp_T}$	$\frac{1}{N_{ev}} \cdot \frac{dN_{ev}}{dn_{ch}}$	$\langle p_T \rangle$ vs. n_{ch}
Range	0–2.5	0.1–50 GeV	2–250	0–160 GeV
Track reconstruction	1%–7%	1%–6%	$0\%-^{+38\%}_{-20\%}$	0%–0.7%
Track background	0.5%	0.5%–1%	$0\%-^{+7\%}_{-1\%}$	0%–0.1%
p_T spectrum	–	–	$0\%-^{+3\%}_{-9\%}$	$0\%-^{+0.3\%}_{-0.1\%}$
Non-closure	0.4%–1%	1%–3%	0%–4%	0.5%–2%



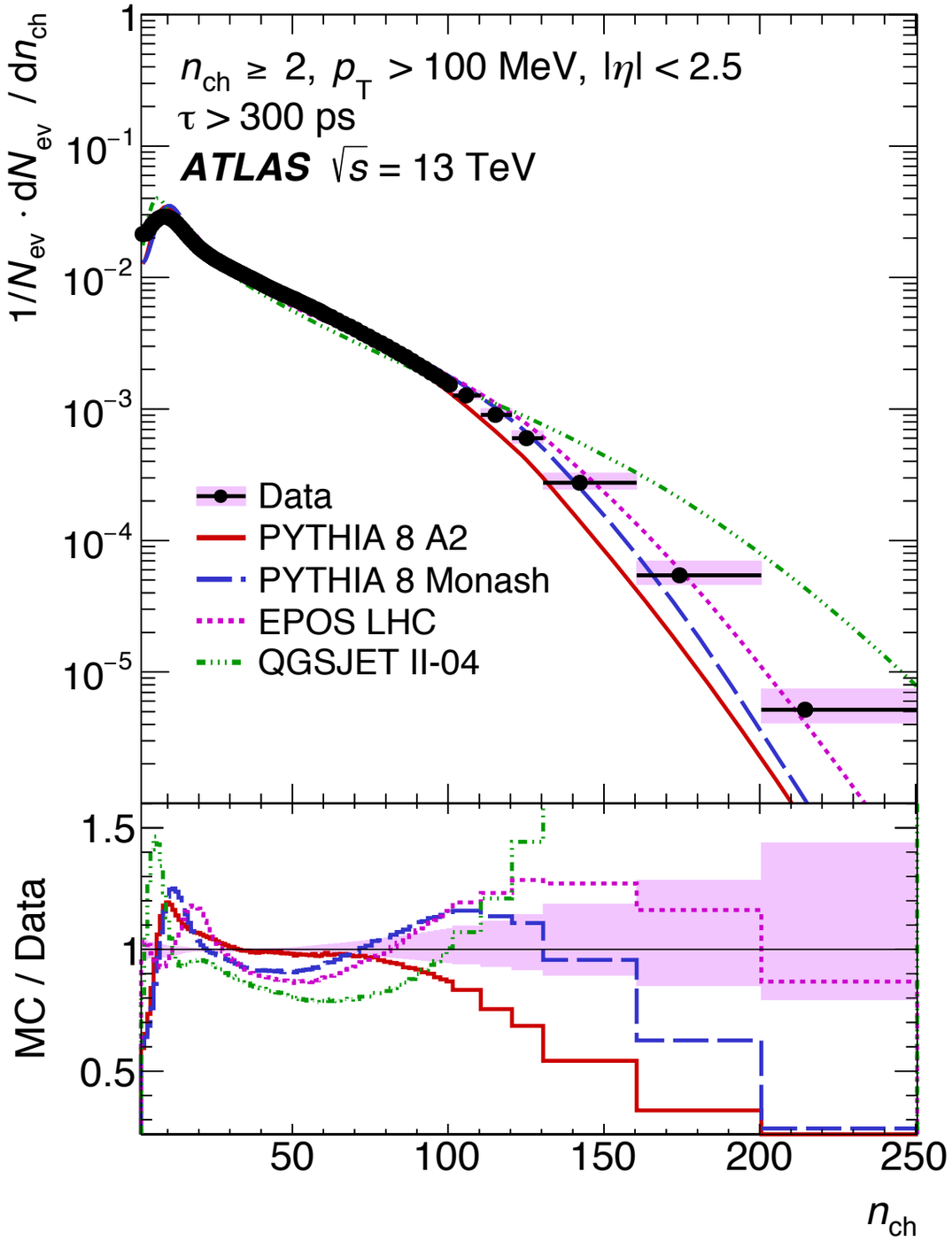


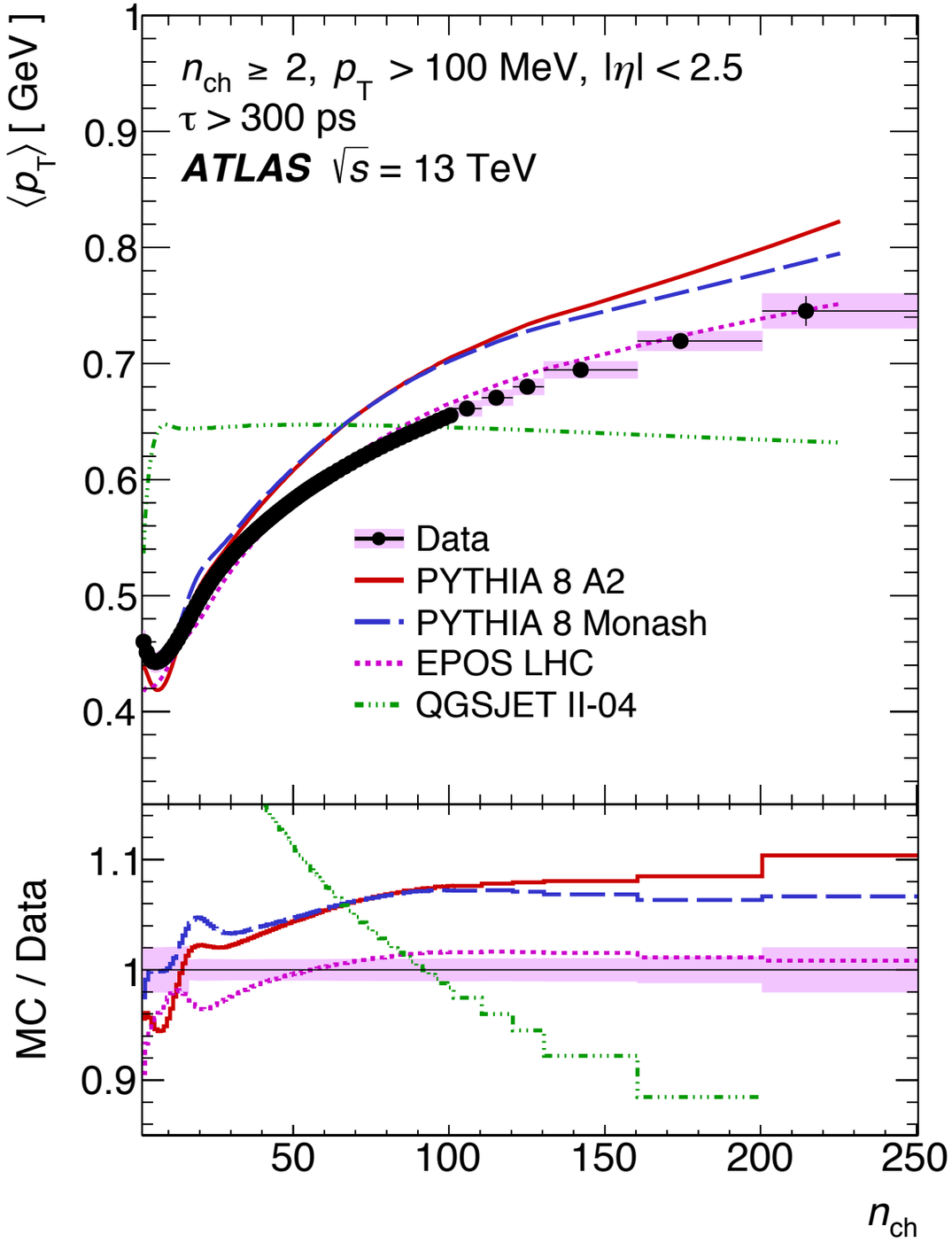
Low-p_T track-based 'Minimum Bias' analysis: results



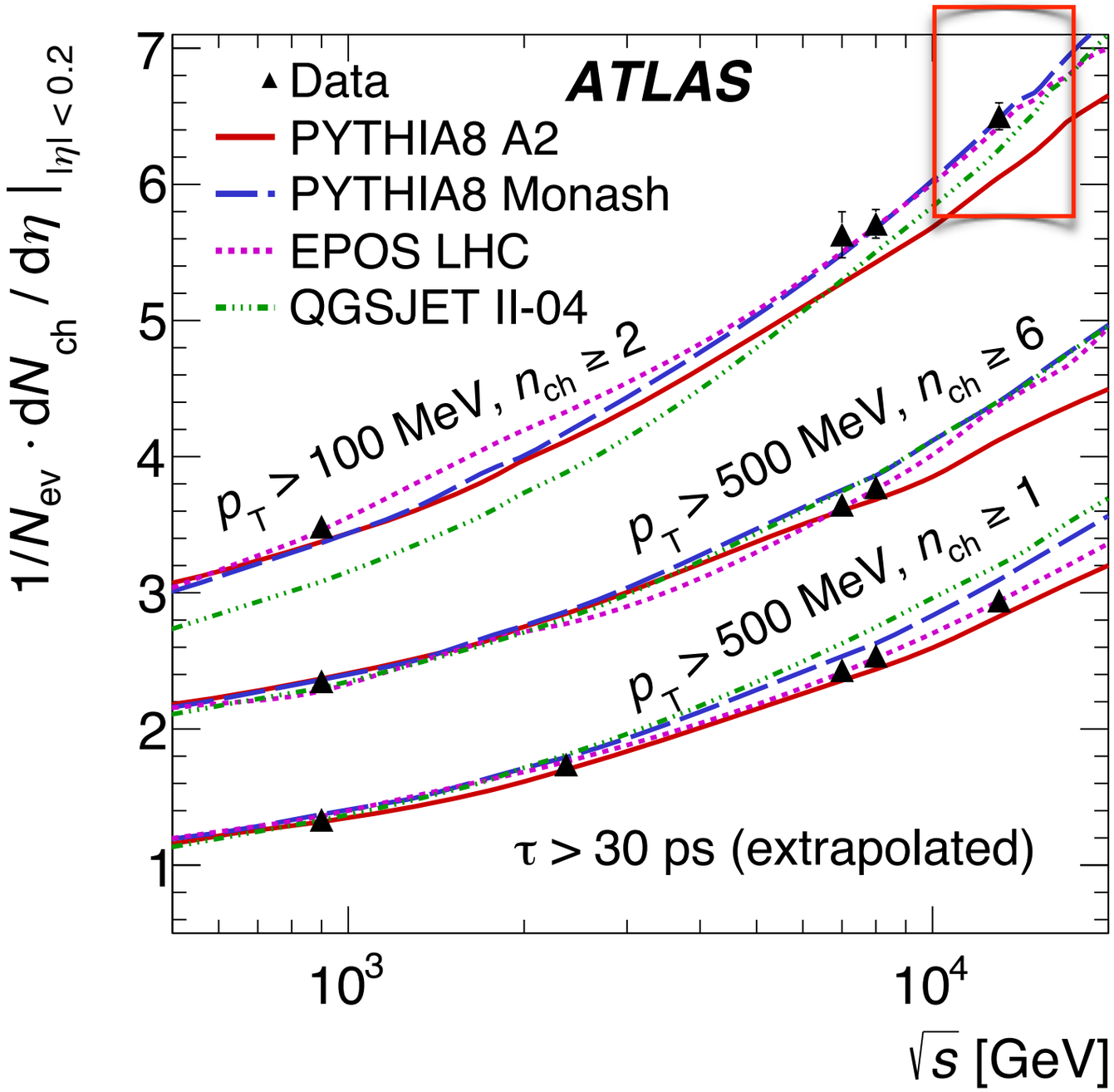


Low-p_T track-based Minimum Bias analysis: results





Energy evolution



Extrapolating the measurement to include strange baryons contribution and averaging in $|\eta|<0.2$ to compare with previous results

At low p_T the A2 tune of Pythia8 and QGSJET II-04 don't describe the data well

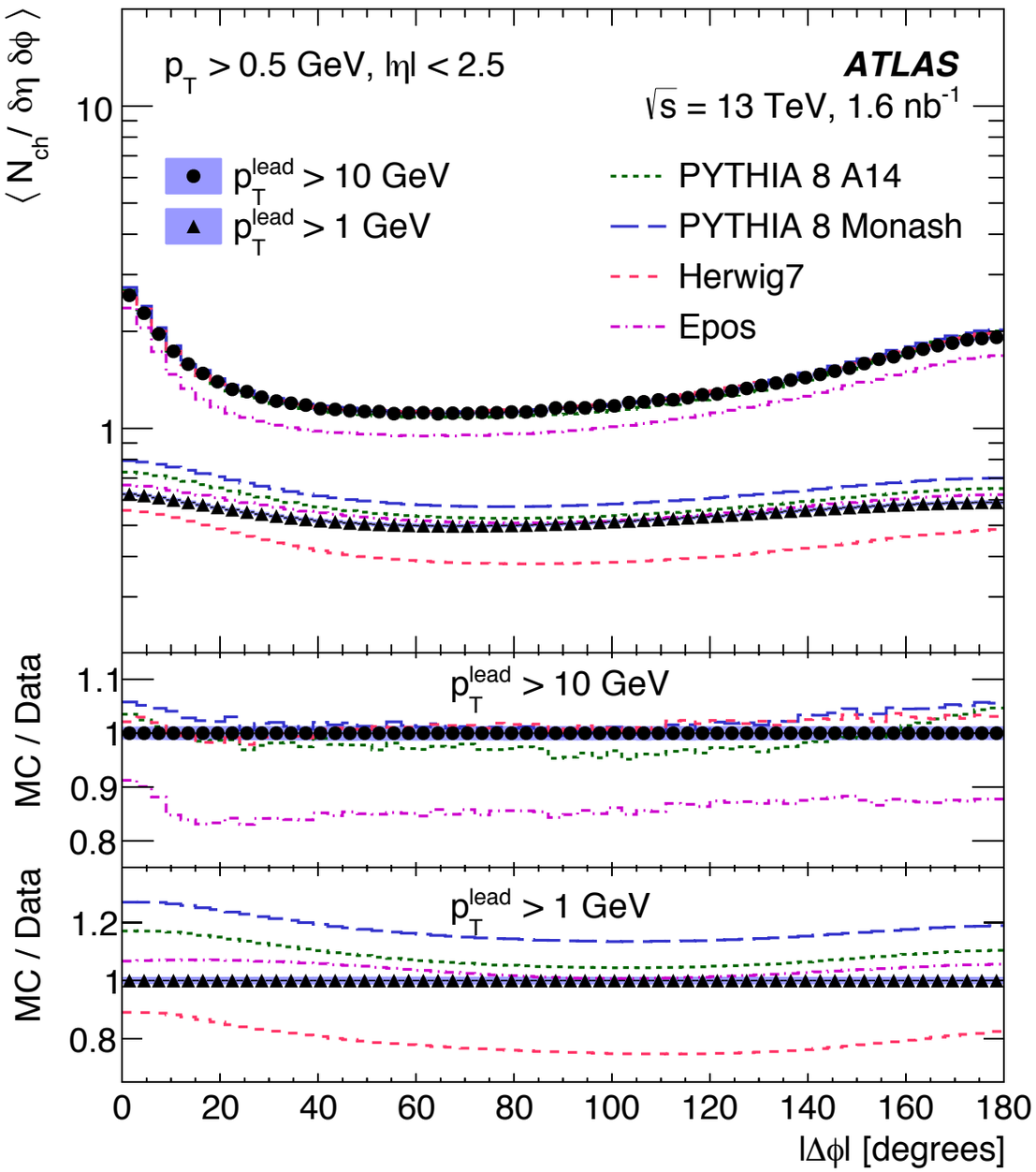
Track-based Underlying Event analysis

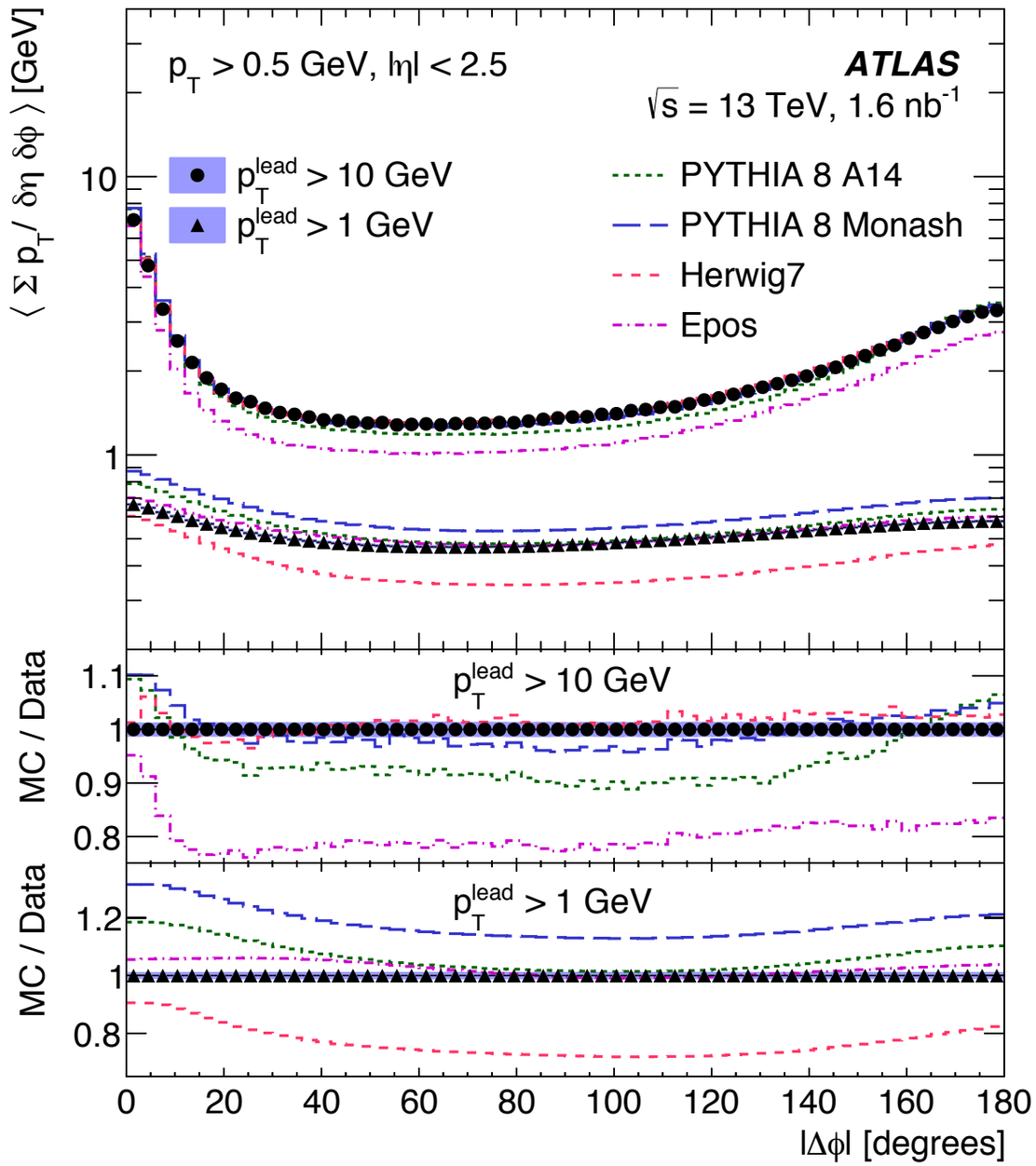
- MBTS used for trigger, efficiency above 99%
- Pile-up suppressed by vetoing events with more than two vertices
- Same background estimation for the low-p_T analysis

Observable	Description
$p_{\mathrm{T}}^{\mathrm{lead}}$	pT of the leading charged particle
$N_{\mathrm{ch}}(\mathrm{transverse})$	Number of charged particles in the transverse regions
$\lvert\Delta\phi\rvert$	Azimuthal angle difference between particles and leading particle
$\langle N_{\mathrm{ch}}/\delta\eta\delta\phi\rangle$	Mean number of charged particles per **η-ϕ**
$\langle\sum p_{\mathrm{T}}/\delta\eta\delta\phi\rangle$	Mean scalar p_T sum of charged particles per **η-ϕ**
$\langle\mathrm{mean}\ p_{\mathrm{T}}\rangle$	Mean per event average p_T of charged particles

Track-based Underlying Event analysis

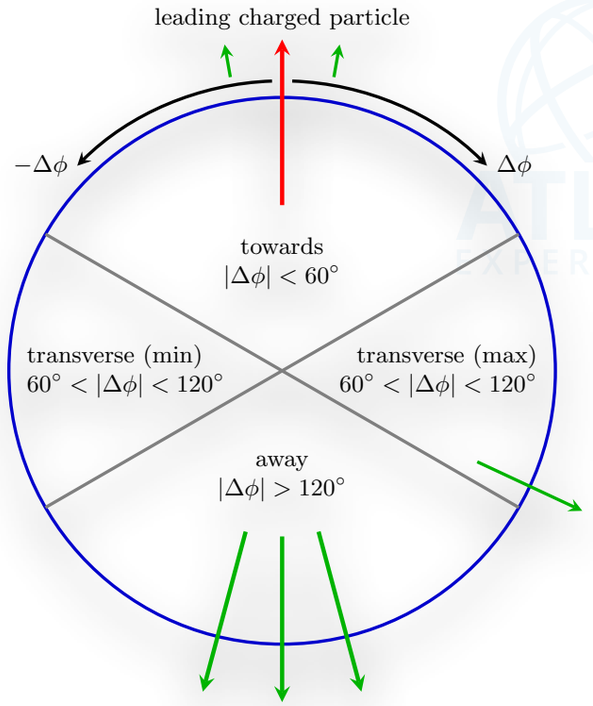
Two different selections illustrate the transition between isotropic particle distribution, minimum-bias like, and hard scattering

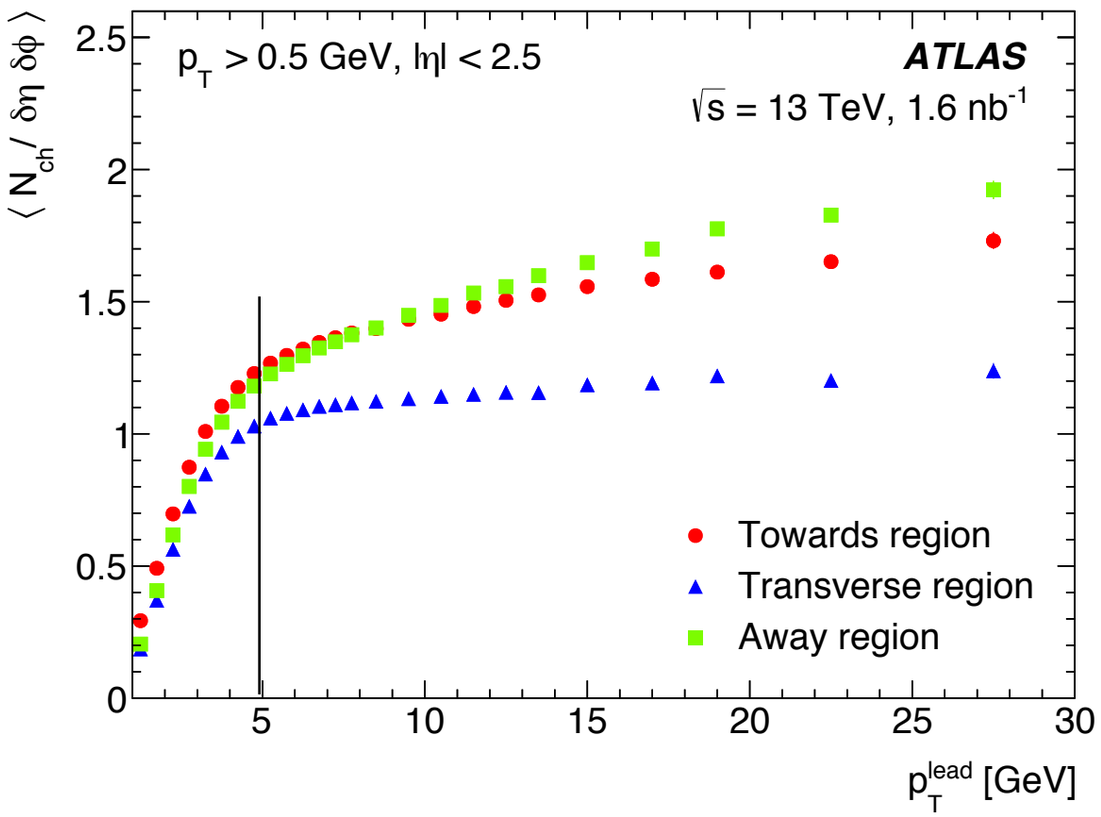


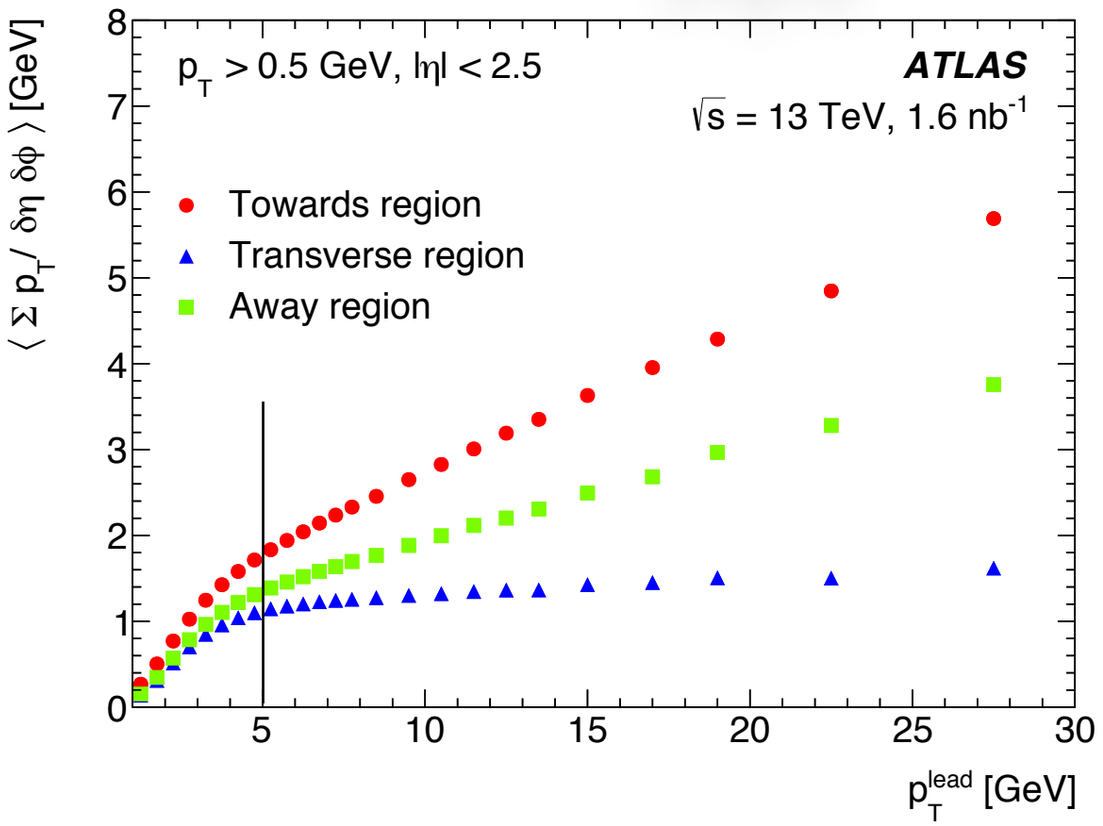


Track-based Underlying Event analysis

- Similar scaling of all regions at low p_T, transition at about 5 GeV
  - Then the distributions in the transverse regions flatten, indicating UE dominance in those regions
- The hard process dominated regions show a clear p_T dependence also at high p_T

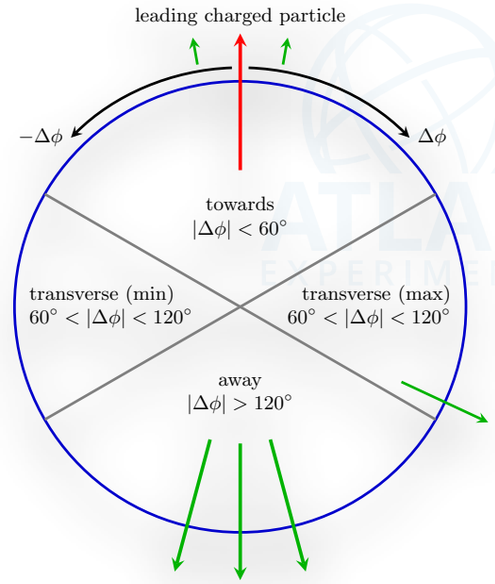




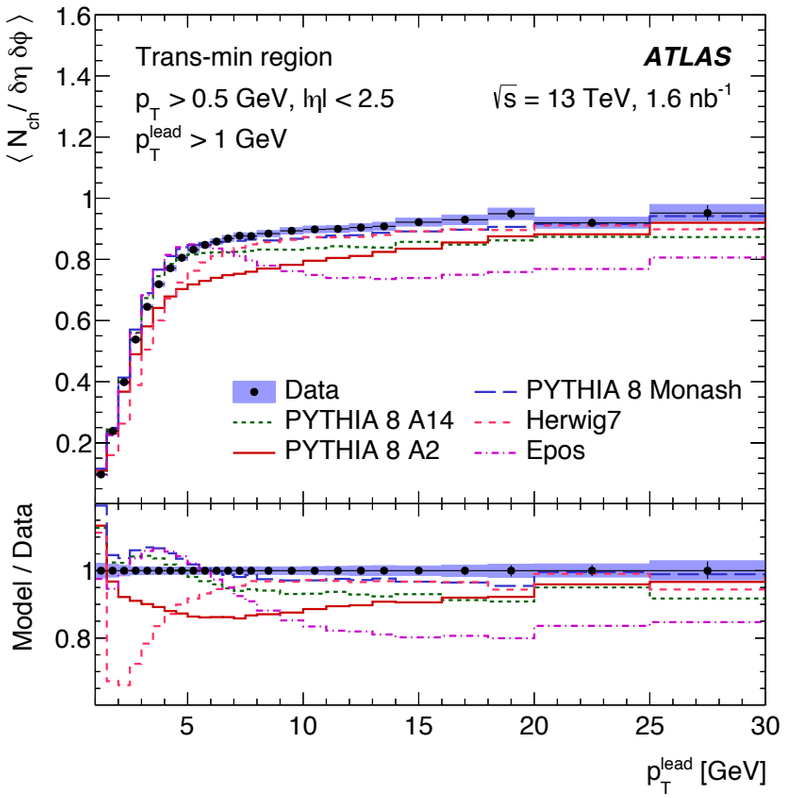


Track-based Underlying Event analysis

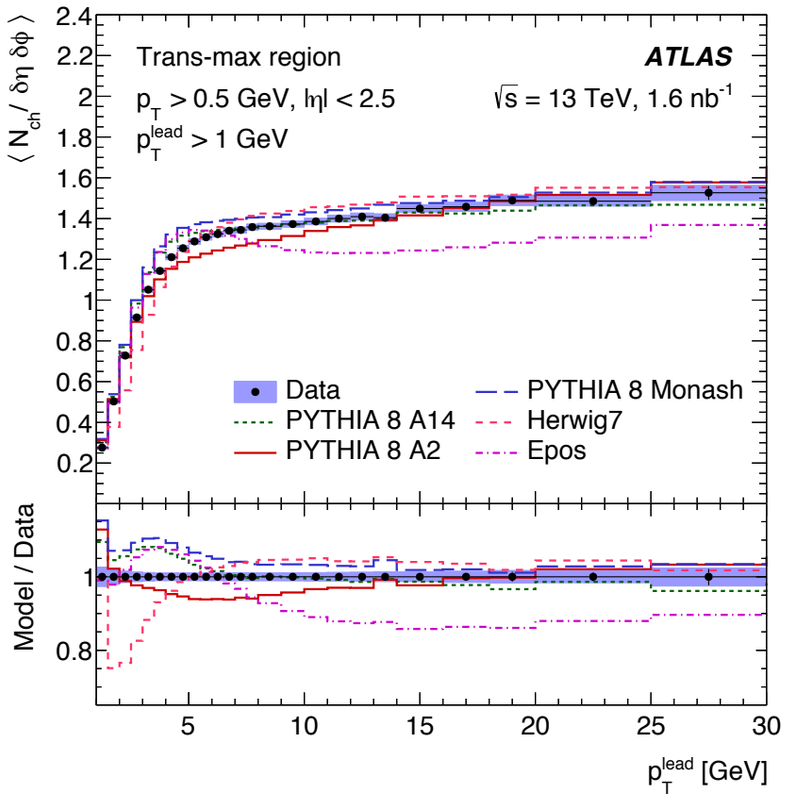
- No generator is able to describe well the data
  - UE+hard scattering are collectively well described by all generators (but EPOS) for p_T>10GeV
  - Trans-diff region for p_T>10GeV is well described only by EPOS



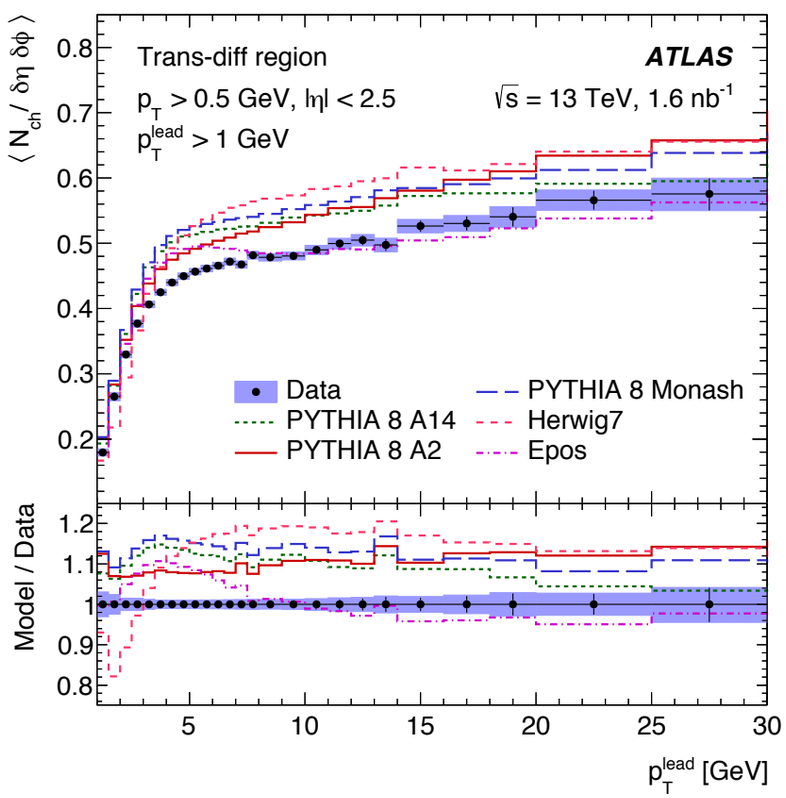
Trans-min region



Trans-max region

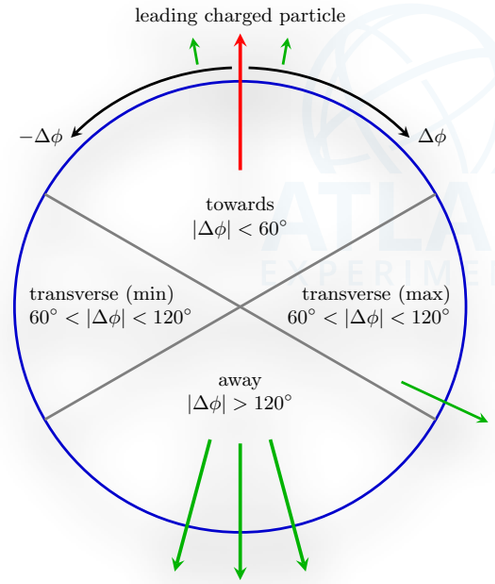


Trans-diff region

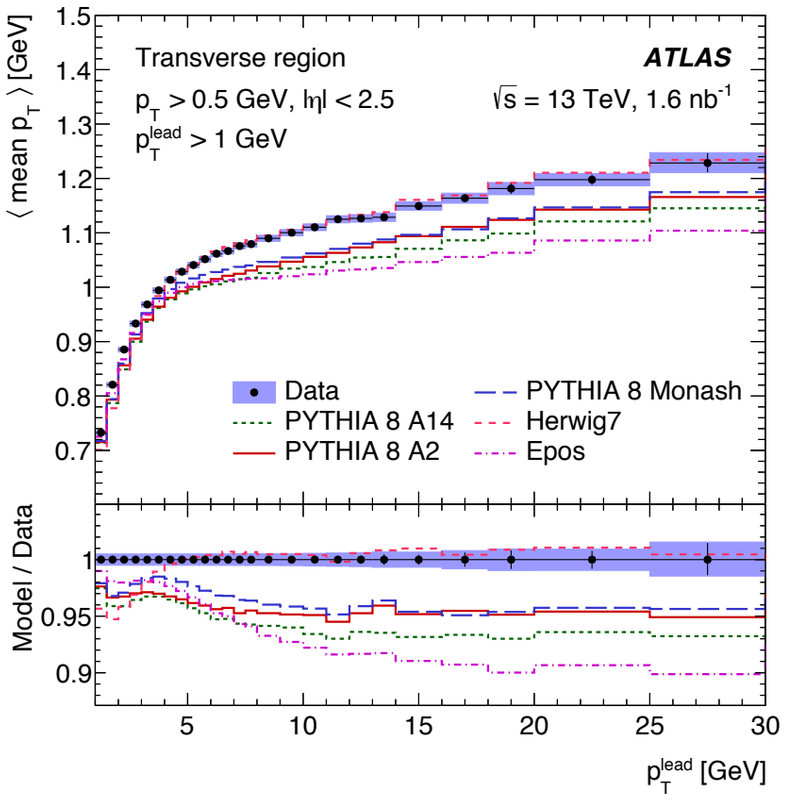


Track-based Underlying Event analysis

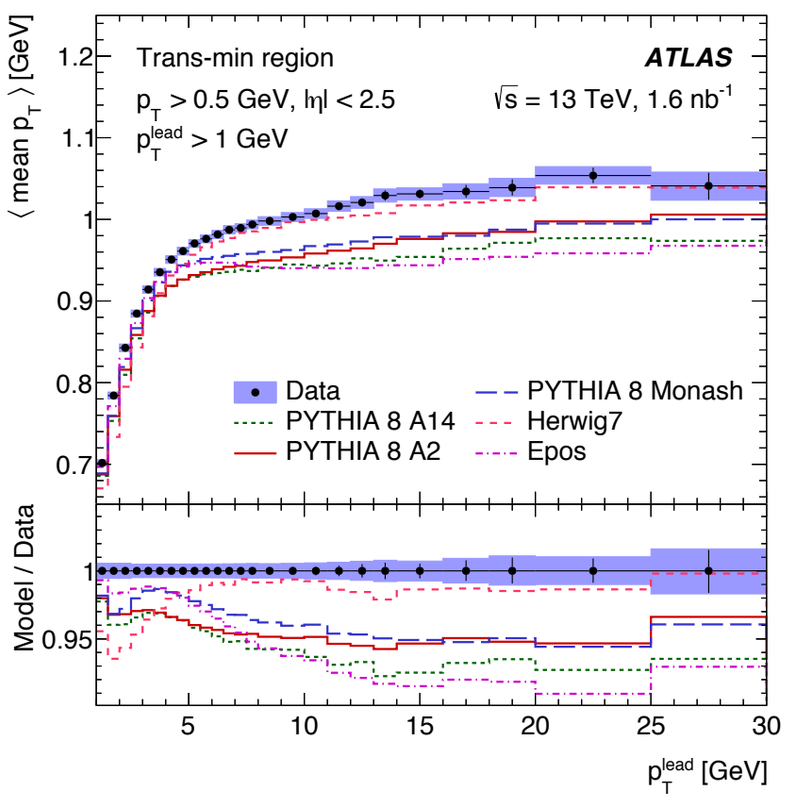
- Sensitive to the energy distribution in the UE
- No generator describe the data well in all regions, data typically described within 10% by all generators
  - Monash tune performs best across the Pythia8 tunes



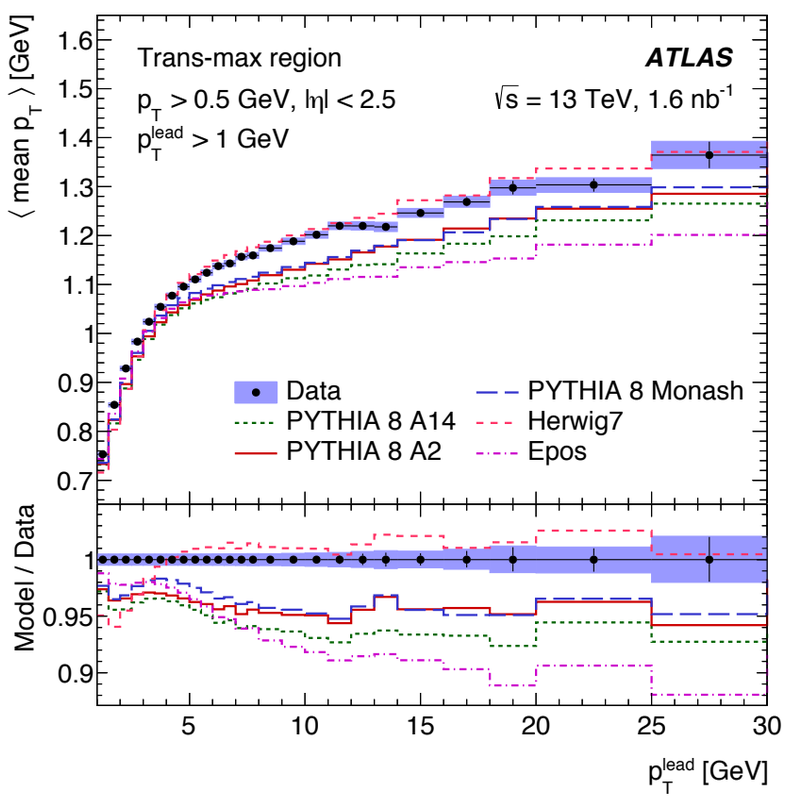
Trans-min region



Trans-max region



Trans-diff region



Summary

- New 13 TeV measurement of underlying-event and minimum-bias sensitive observables performed by the ATLAS collaboration

- The description of the data is typically good within a few percent but clear evidence of room for improvement from several observables

- Data have percent level precision and offer constraining power for generator tuning