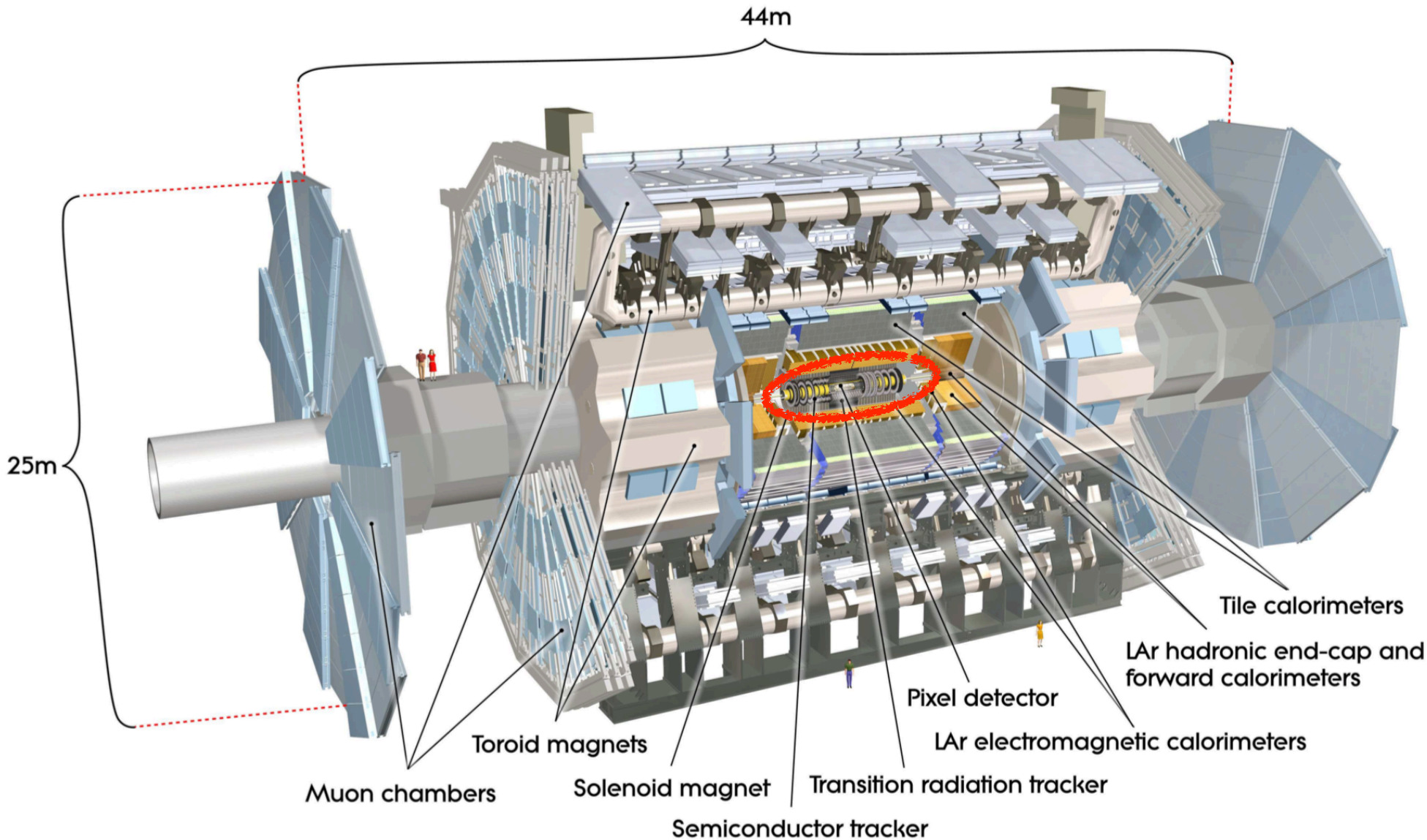
ATLAS Heavy Ion program in the LHC runs 3 & 4

Dominik Derendarz on behalf of the ATLAS

HI town meeting - October 24, 2018

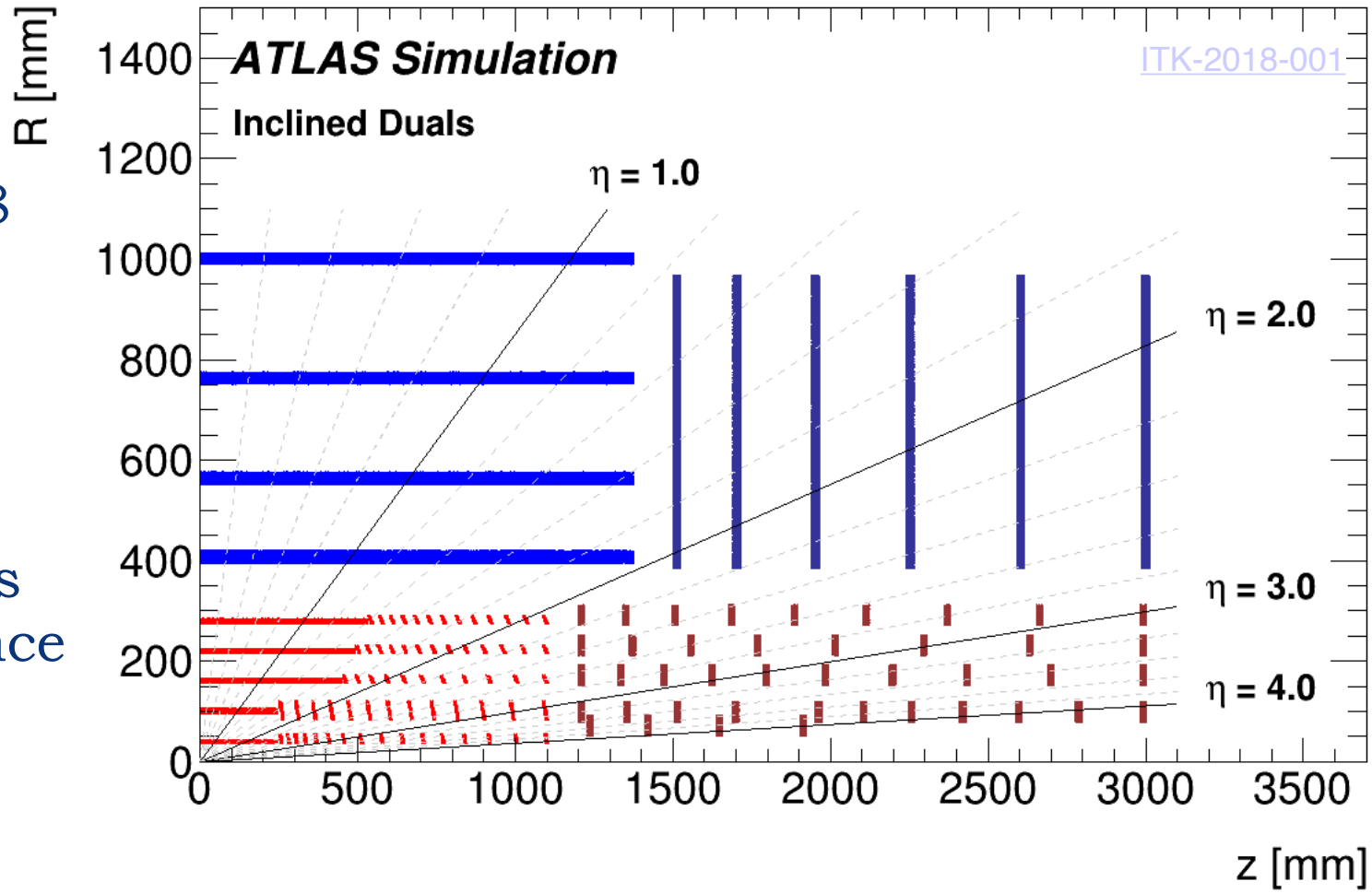
ATLAS detector



- Significant upgrades of the ATLAS detector are expected for the Run 3 & Run 4
- Completely **new tracker** will be installed **before Run4**

ATLAS Inner Tracker (ITk)

- η coverage of 8 units and all silicon design
- ~15 hits per track, approximately uniform across the η acceptance



- 5 pixel and 4 double-sided barrel layers
- 6 strip endcap disks
- Pixel endcap disks in the forward direction

ATLAS Inner Tracker (ITk)

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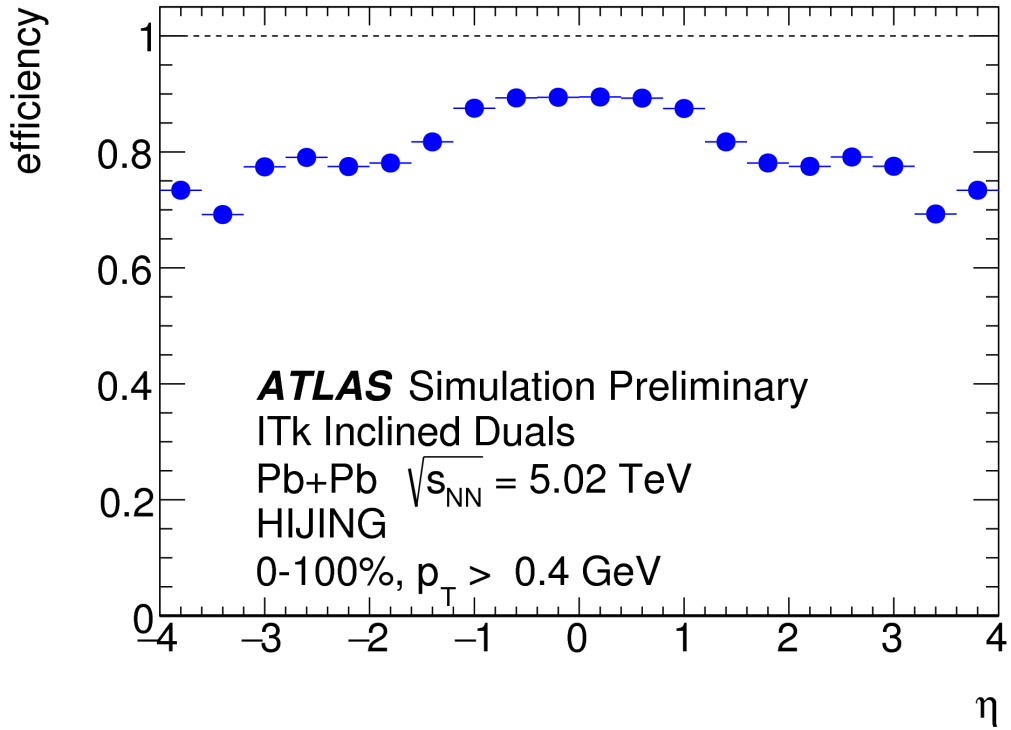
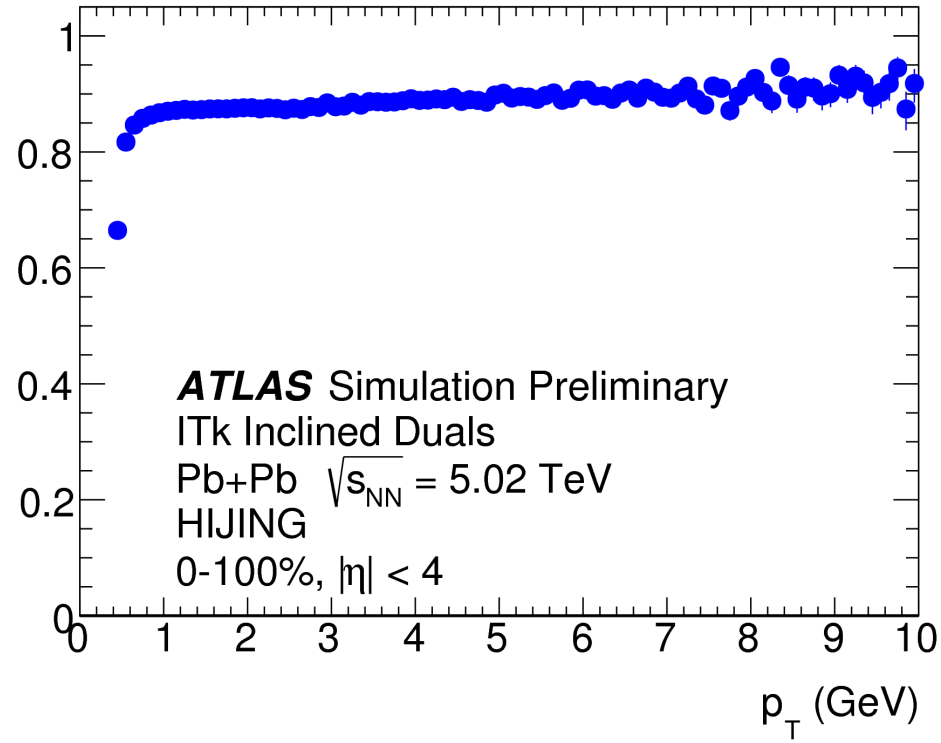




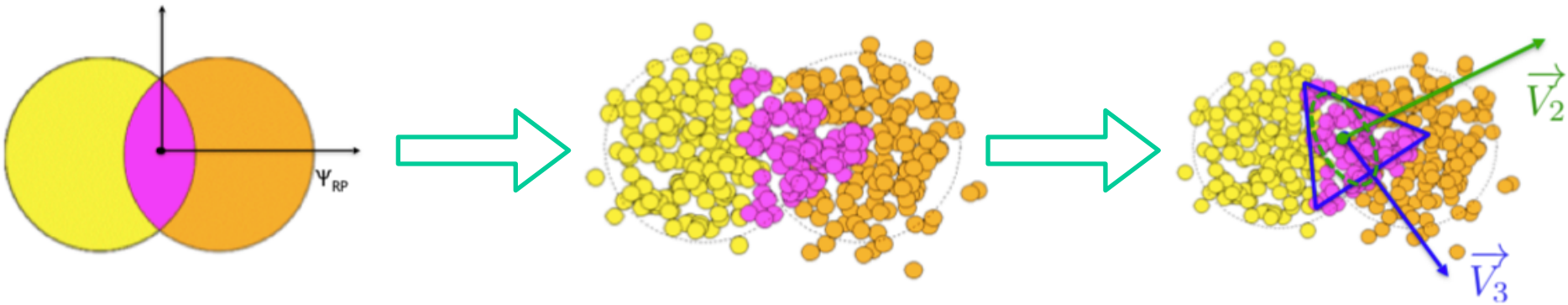
Excellent efficiency for the charged particles reconstruction

- **Improvement** of about **20% for |η|<1 and 30% for |η|~ 2** with respect to current tracker
- Based on the HIJING Pb+Pb simulation at 5.02 TeV
- Full simulation of the ITk using Geant4

ITk **designed to cope** with the **p+p collisions at <μ> =200**

Collectivity

Great progress in understanding the **nature of collectivity** and the **experimental techniques** over past years



- Precise measurements of v_n harmonics, flow harmonics fluctuation and correlations between flow harmonics of different orders
- Importance of the initial state fluctuation
- Properties and space-time evolution of the produced matter
- Collectivity in **small systems** - small QGP droplets?

Heavy-flavor flow

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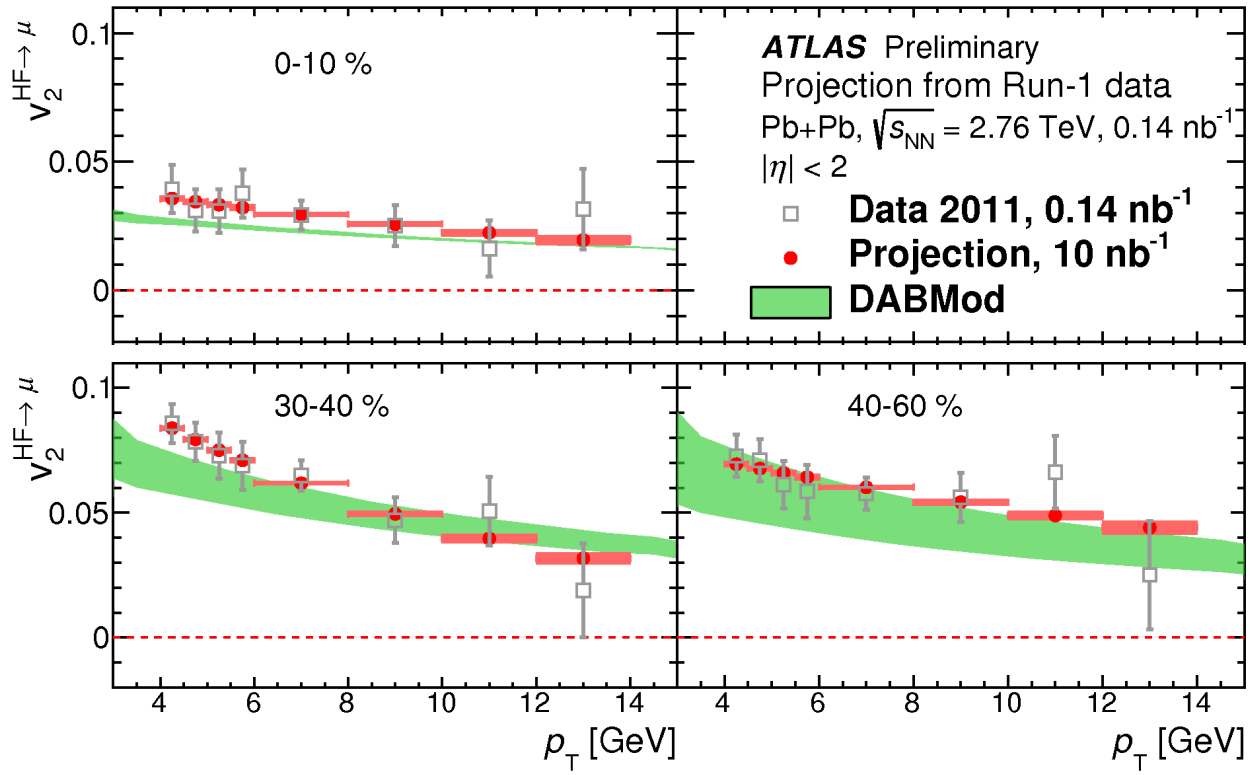
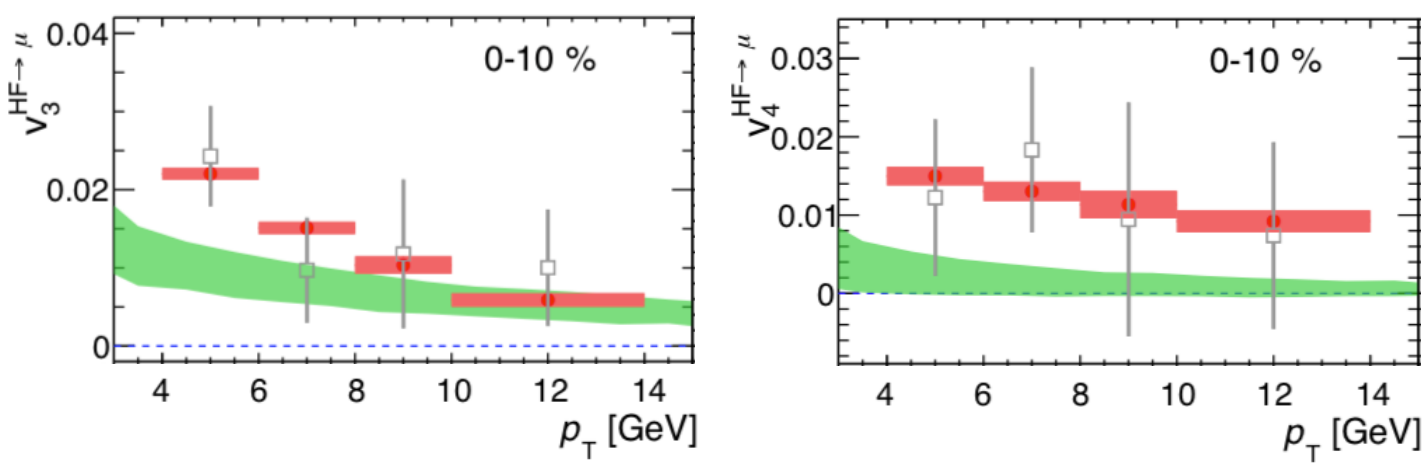
- Flow of muons from heavy flavor - study the interactions of the heavy quarks with QGP

- Projections assuming 10 nb^{-1} of Pb+Pb
- Statistical **precision improved by a factor of 8**



- With the better precision could be **sensitive to non zero higher harmonics v_3 and for v_4**



Flow decorrelation

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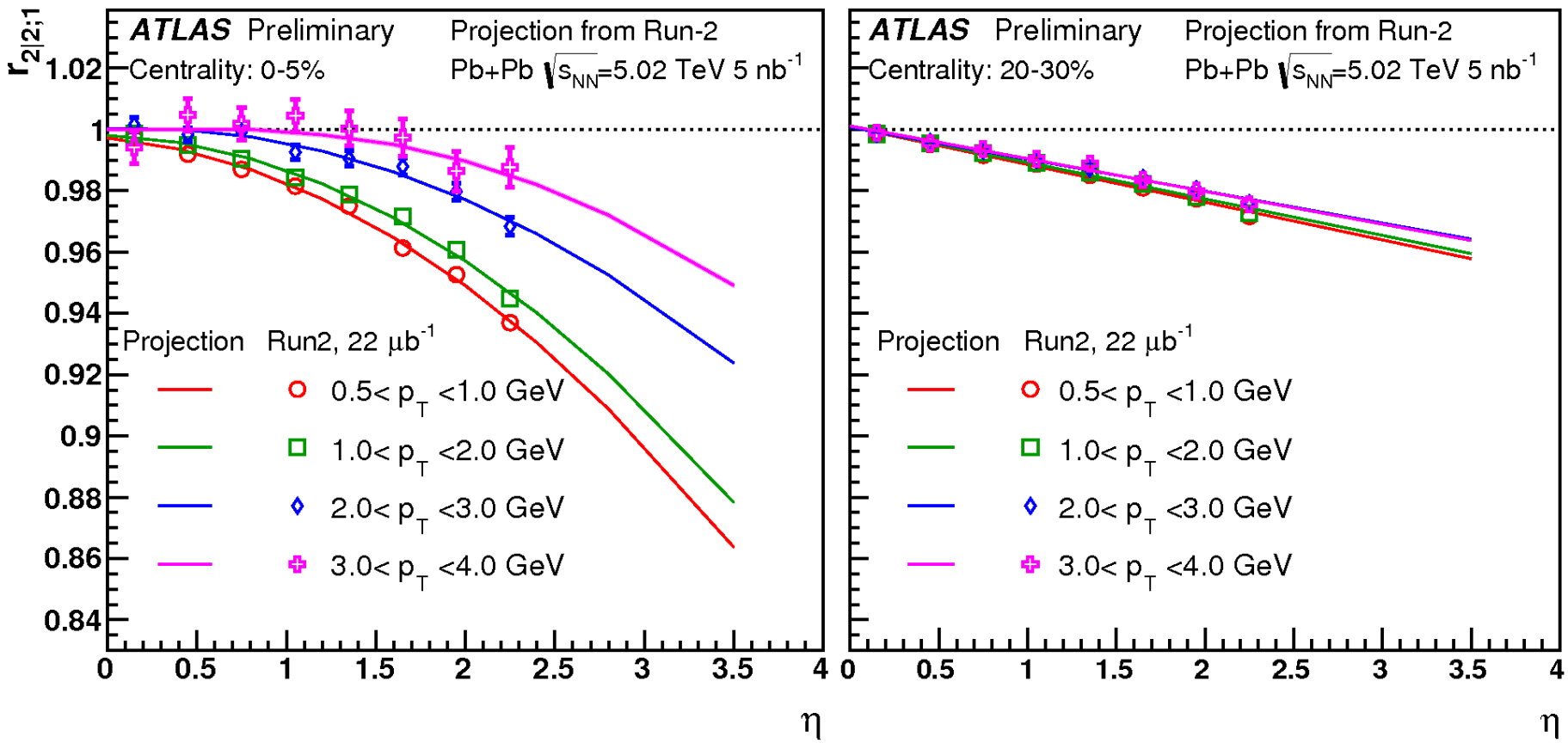

- Breakdown of the factorization of two-particle flow into single-particle flow harmonics
- **Increased ITk acceptance** allow to extend the measurement **to forward rapidity**
    - **Explore the non-linear behavior of flow decorrelation in the most central collisions**

Flow in small system

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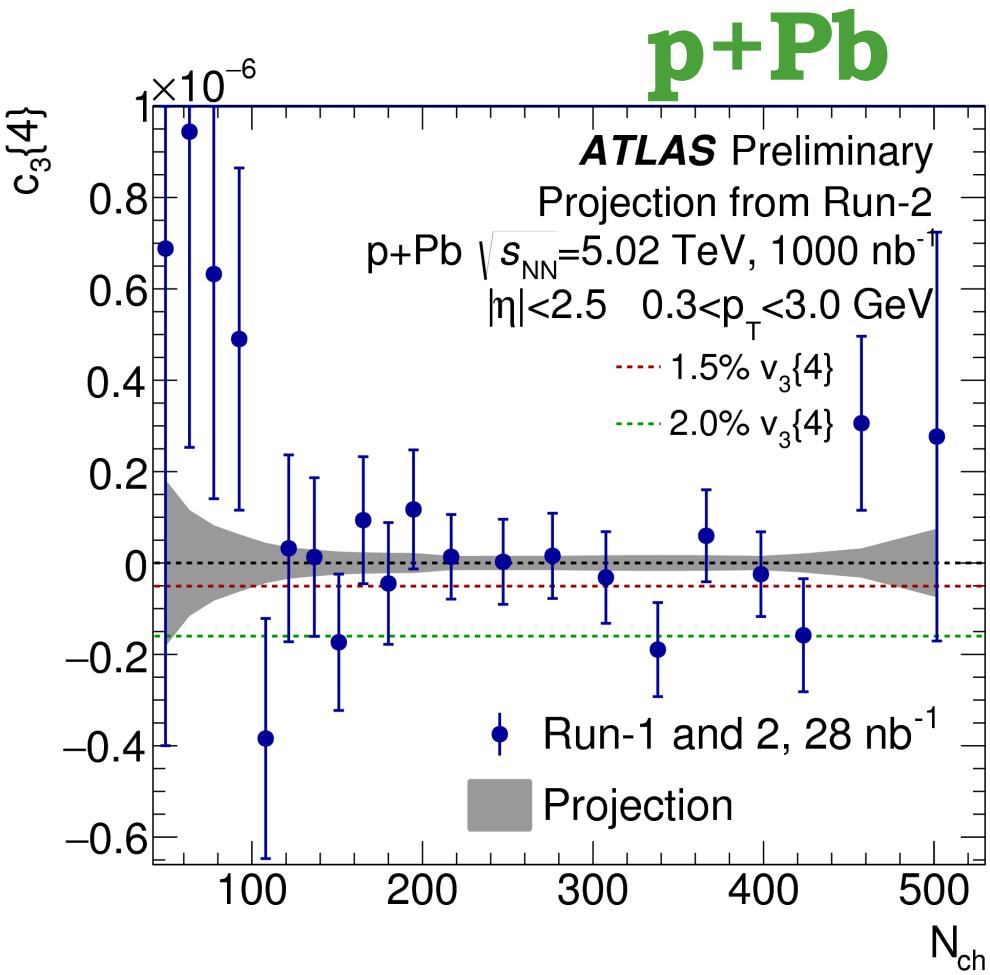
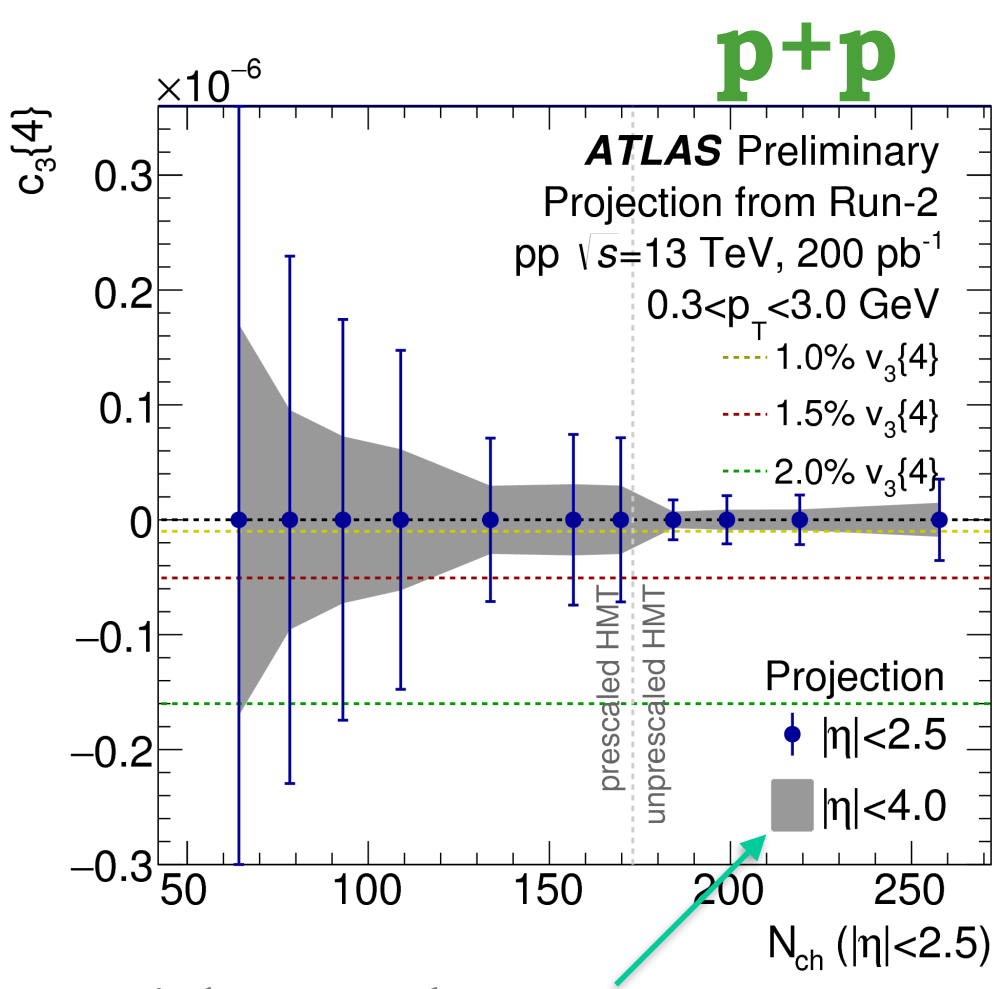




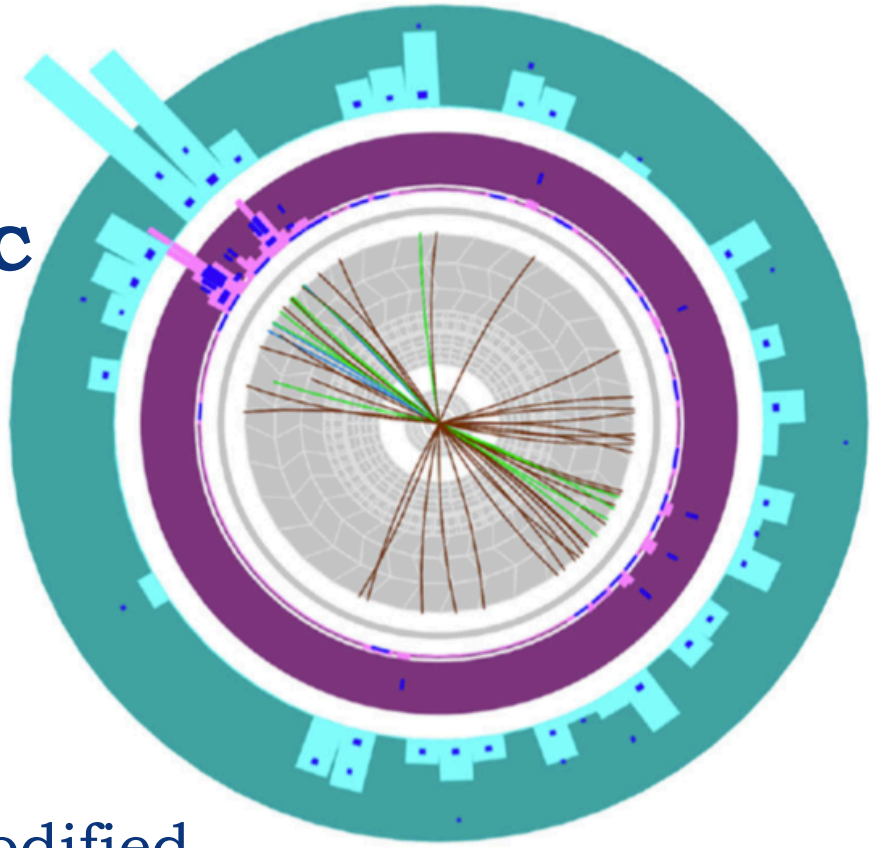
Higher tracker acceptance

- **Precise measurement of the higher order harmonics** with multi-particle correlations and subverts method to suppress non-flow

Energy loss in the QGP

Phys.Rev.Lett. 105 (2010) 252303

Jet quenching observed from the earliest days of HI running at LHC

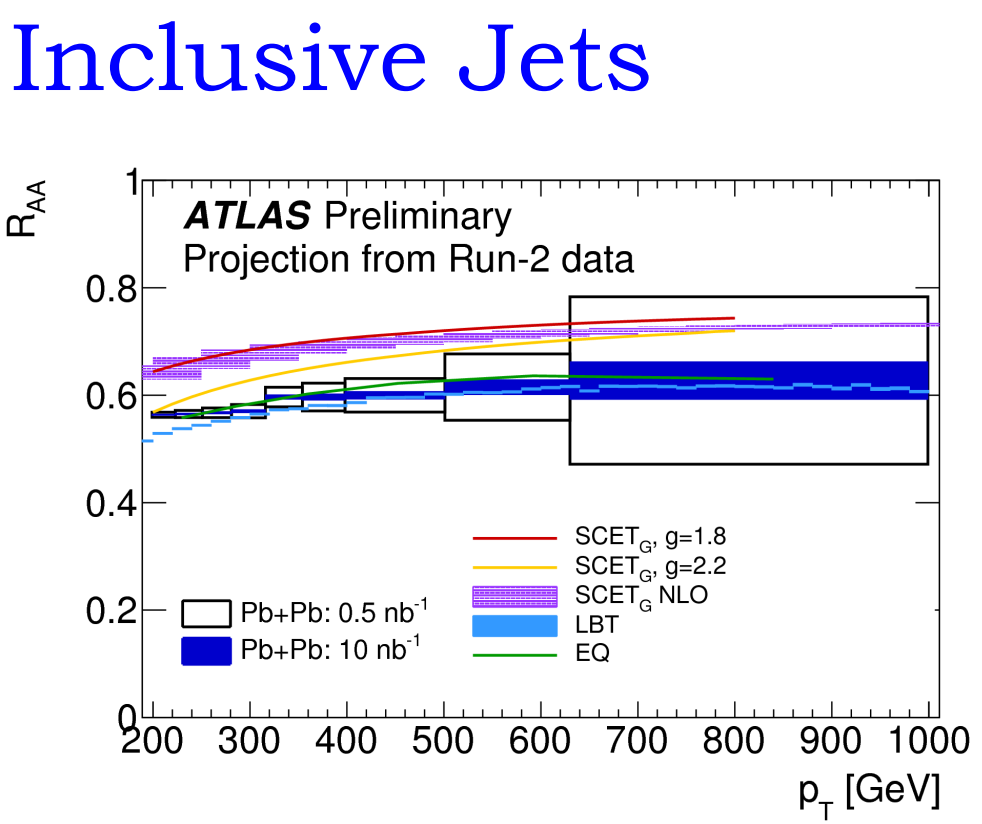


Rich experimental program to address the questions

- How much energy is lost be the jets in QGP ?
- How is the parton shower modified with the interaction with the medium ?

Inclusive Jets

$$R_{AA} = \frac{1}{N_{\mathrm{coll}}} \frac{\quad}{\quad}$$



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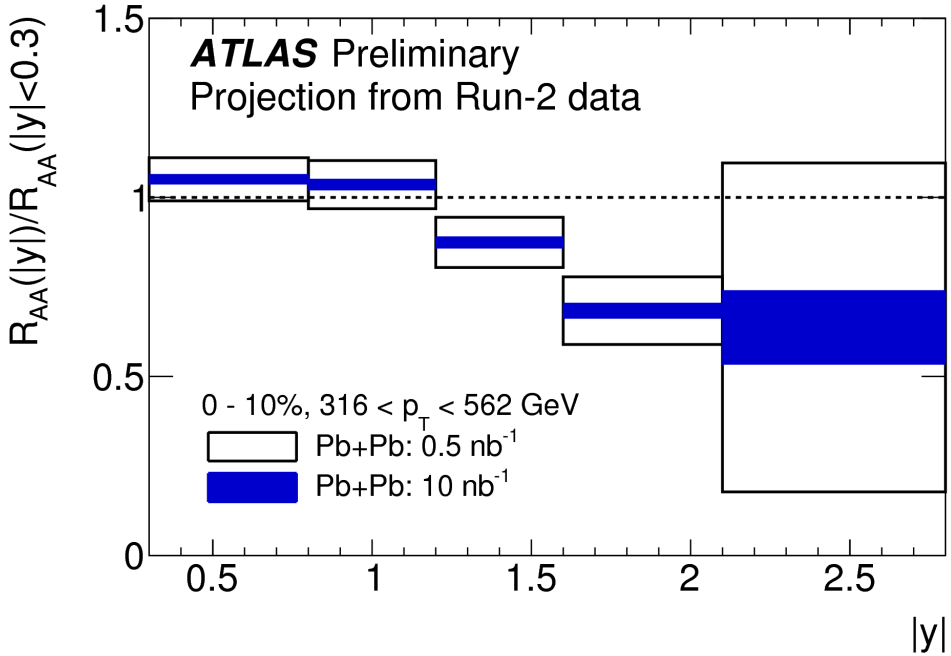


- Projections account only for improvement of the statistical precision due increase of the integrated luminosity

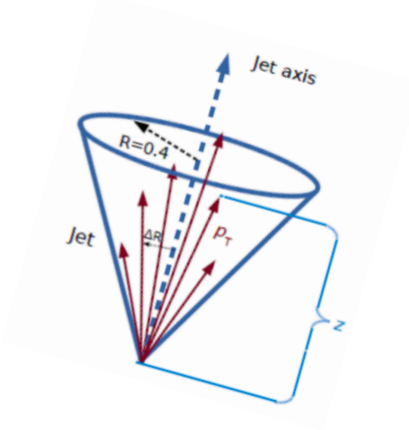
- Extend the kinematic range to improve precision of the measurement
  - Probing posible saturation of R_{AA}
  - Explore η dependence of R_{AA} - fraction of quark jets increases with |y| at fixed jet pT

Jets Fragmentation

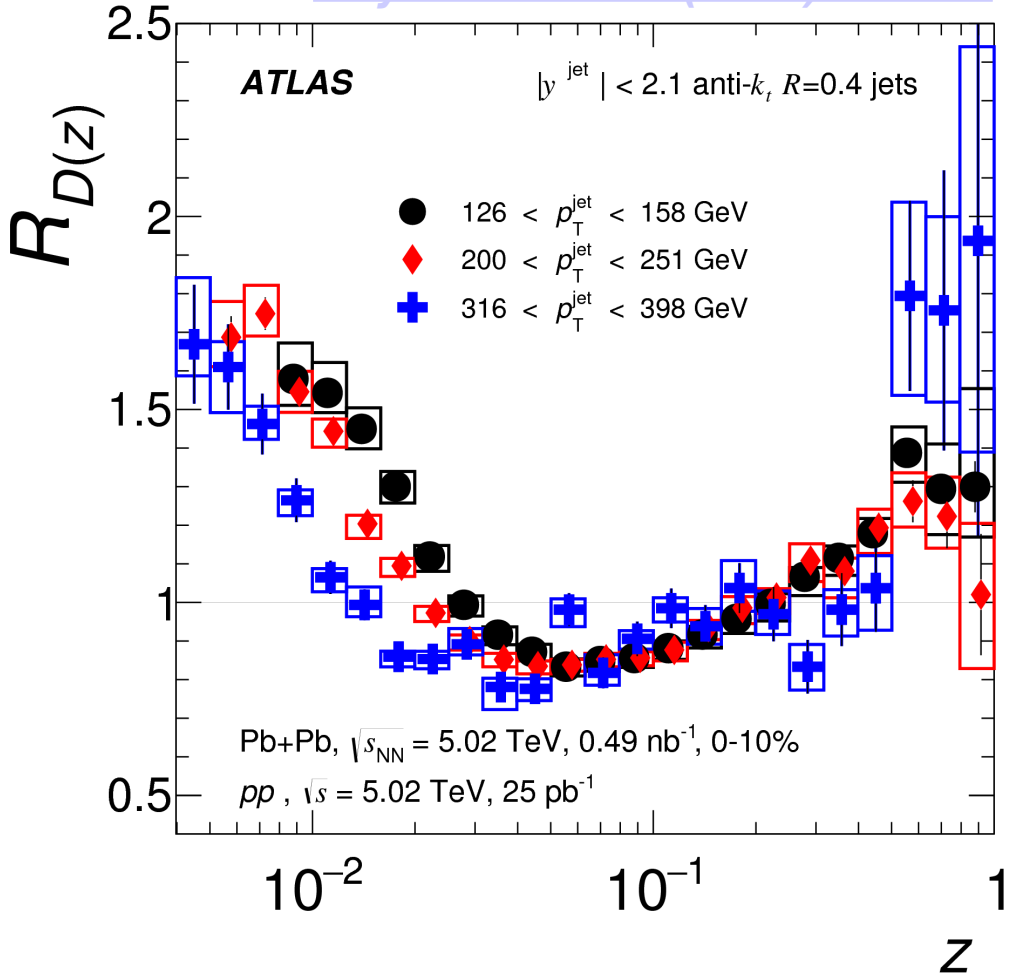
Jet structure modification observed in
Pb+Pb @ 2.76 & 5.02 TeV

$$D(z) \equiv \frac{1}{N_{\rm jet}} \frac{{\rm d}N_{\rm ch}}{{\rm d}z} \quad z \equiv p_{\rm T} \cos \Delta R \,/\, p_{\rm T}^{\rm jet}$$

$$R_{D(z)} \equiv \frac{D(z)_{/\rm Pb\,Pb}}{D(z)_{pp}}$$



Phys. Rev. C 98 (2018) 024908

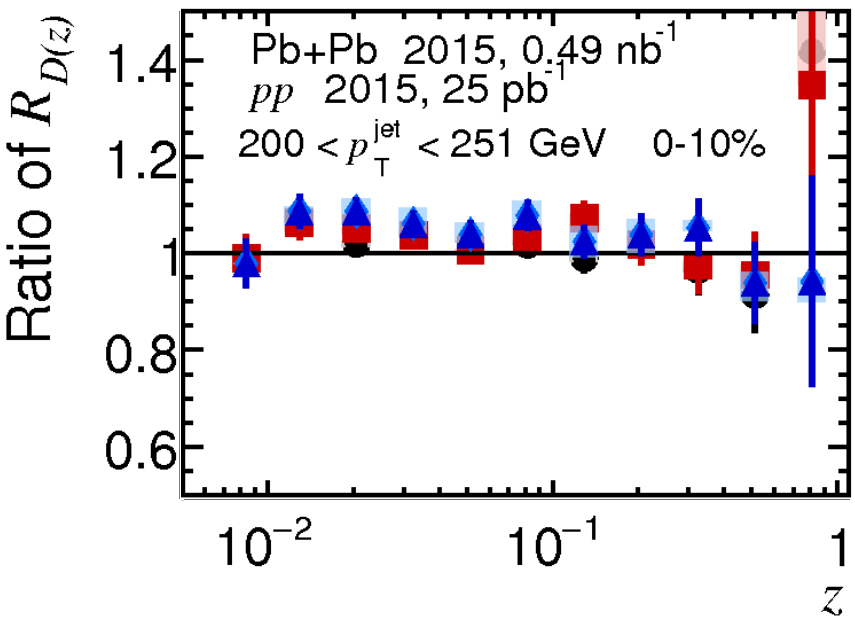


- Enhancement at high and low z
- Suppression around ~0.1
- Independent of $\sqrt{s_{NN}}$

- Improvement in precision especially for hard fragments (high z)

Jets Fragmentation

Phys. Rev. C 98 (2018) 024908



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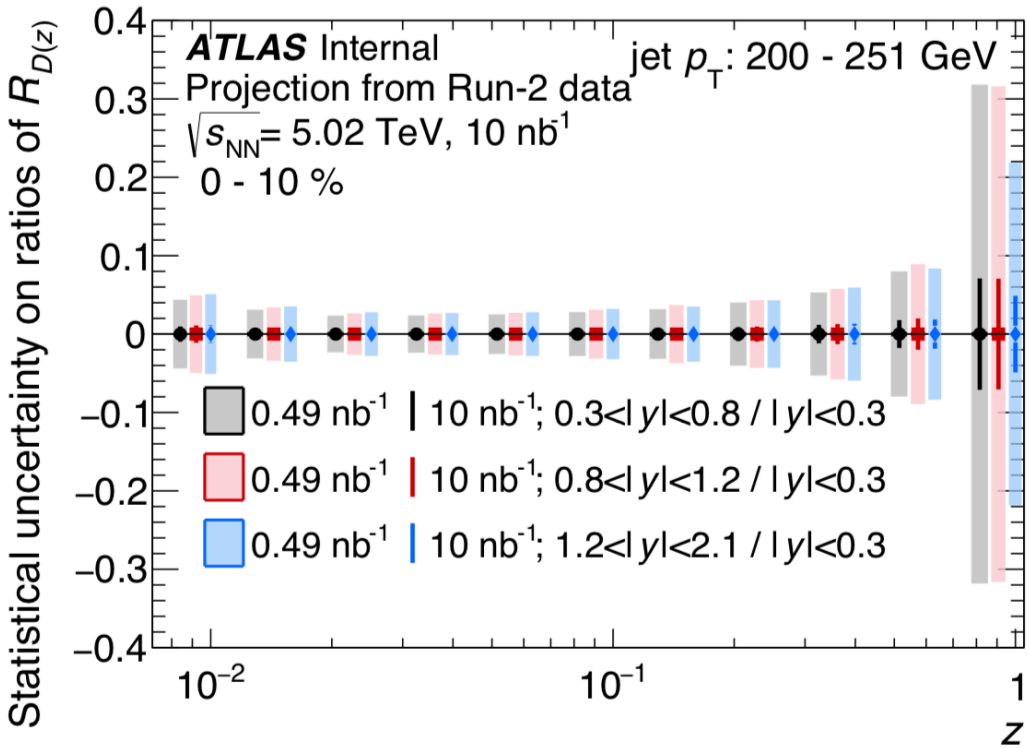

Comparison of statistical uncertainties 0.49 nb^{-1} and expected 10 nb^{-1} of the Pb+Pb

- Rapidity dependence in 2015 data is statistically limited
- $R_{D(z)}$ studied in rapidity intervals with respect to the reference at central rapidity
    - Measurement benefits from the large cancelation of systematic uncertainties

Fragmentation of γ-tagged jets

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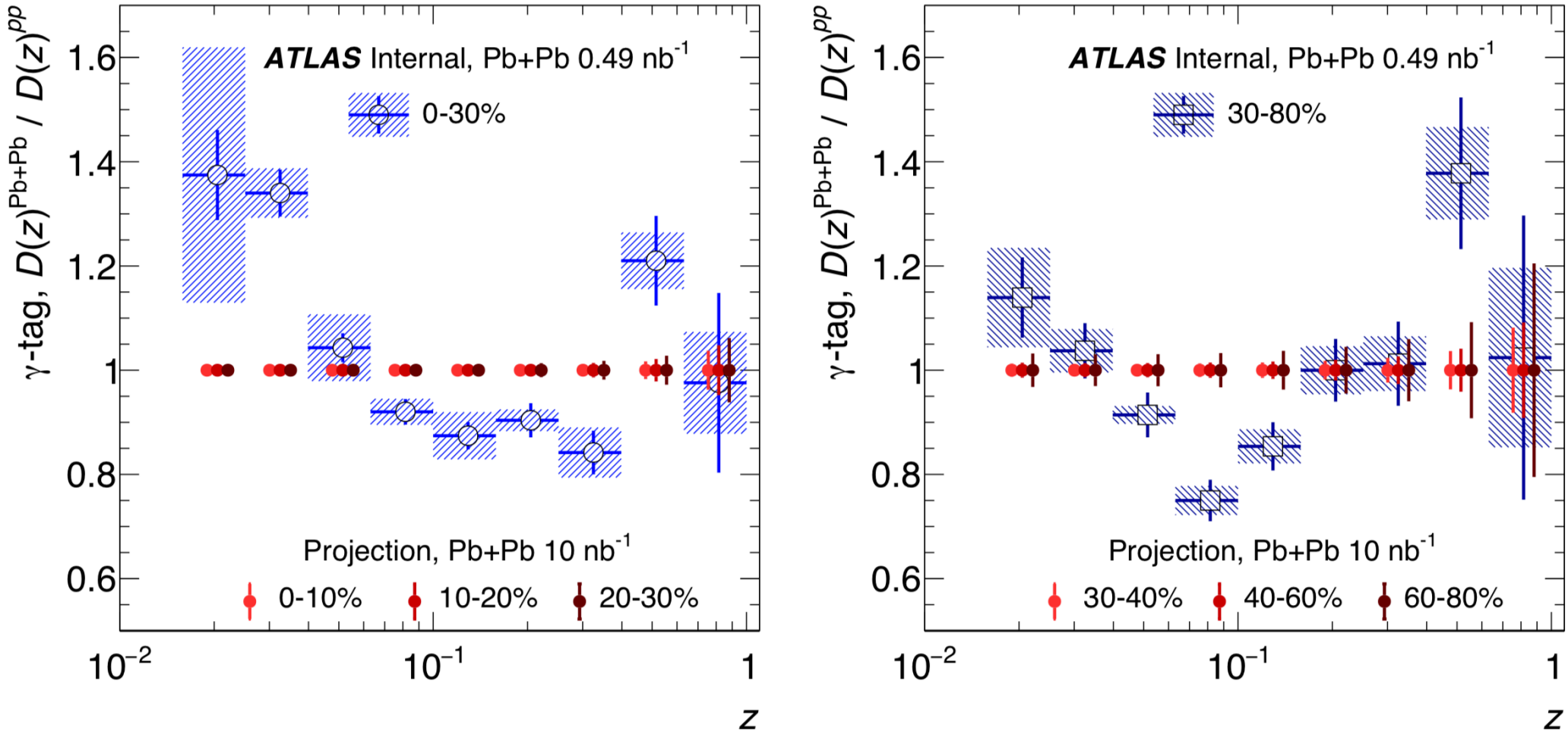


Photon tagged jet fragmentation allow to study flavor composition

- Sample dominated by quark-initiated jets

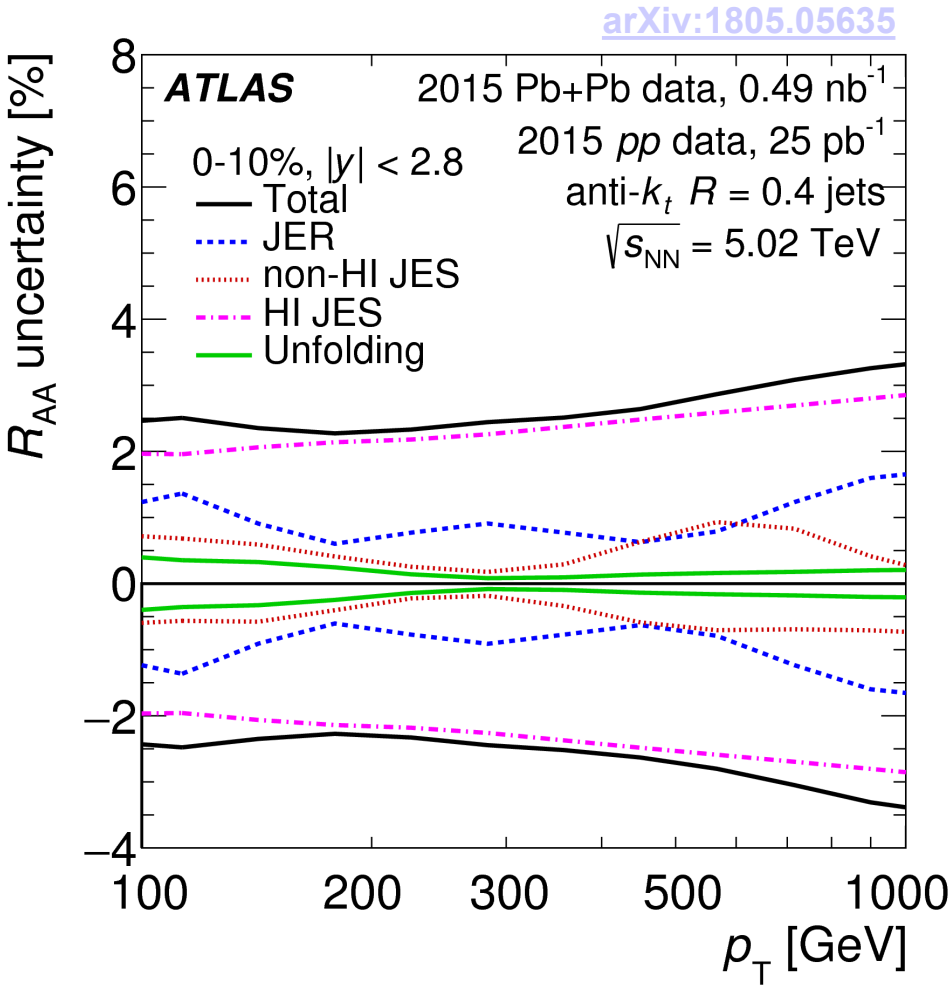
Photon-tagged jet fragmentation is statistics hungry

- 2015 measurement - broad centrality classes (0-30%, 30-80%)
- Much finer centrality selection with 10 nb^{-1}

Expected improvements in the analysis

Possible reduction of the systematic uncertainties in the Jets measurements

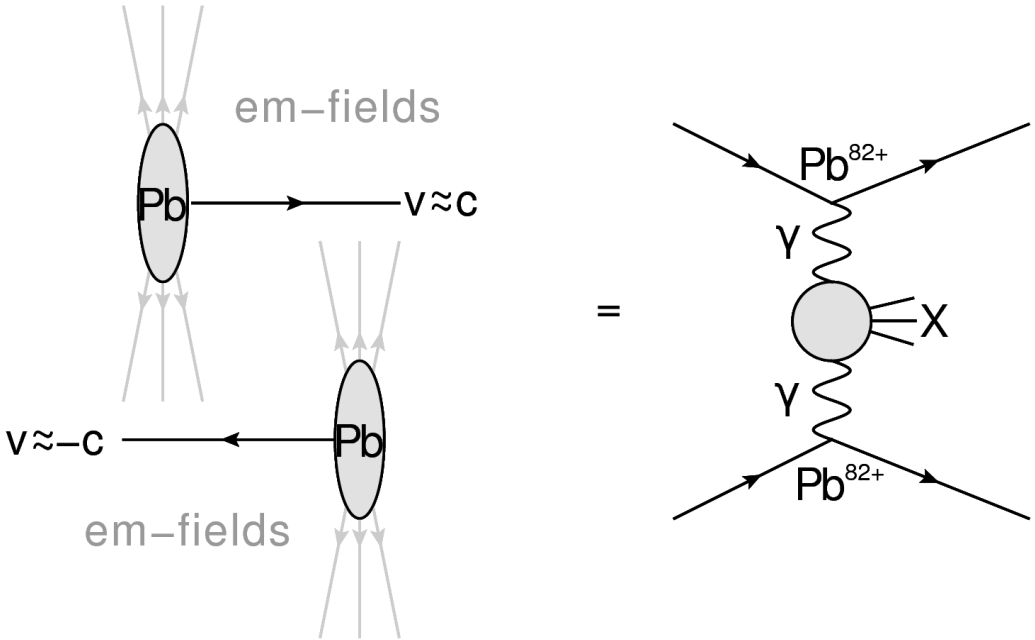
- **Jet Energy Scale** is a dominant source of systematic
  - Improvements on the proton-proton baseline
  - Use of MC generators which realistically simulate jet quenching
- **Uncertainty on track reconstruction** is expected to be reduced by the use of the **upgraded tracker (ITk)**
- Uncertainty on the **determination of the nuclear overlap function**
  - Data-driven techniques for the centrality determination

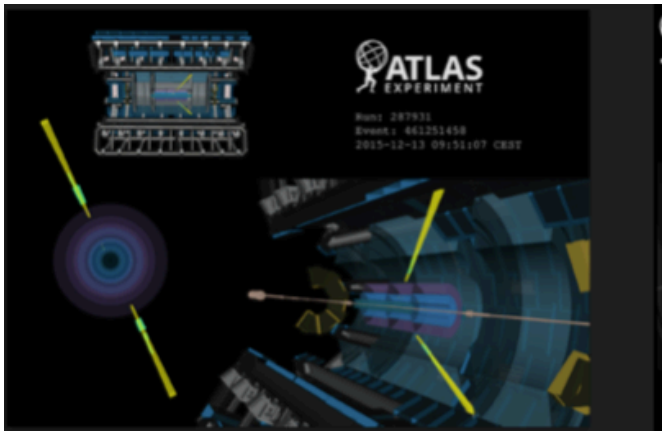


Ultra-peripheral collisions (UPC)

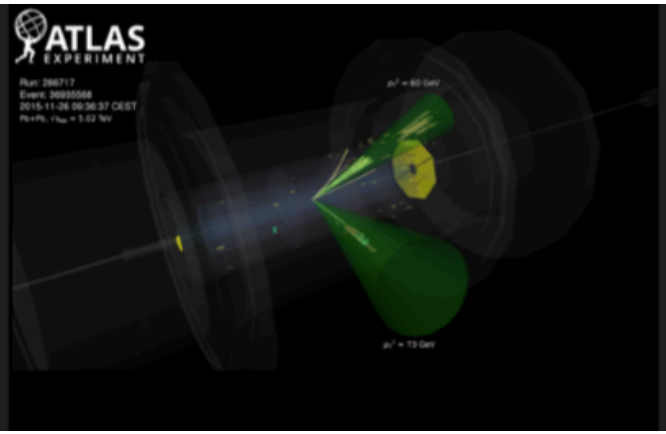
Boosted nuclei are intense source of quasi-real photons

- Leads to **photon-photon and photon-nucleus collisions**
- Opens up the possibility for the **QED, QCD or event QGP studies**

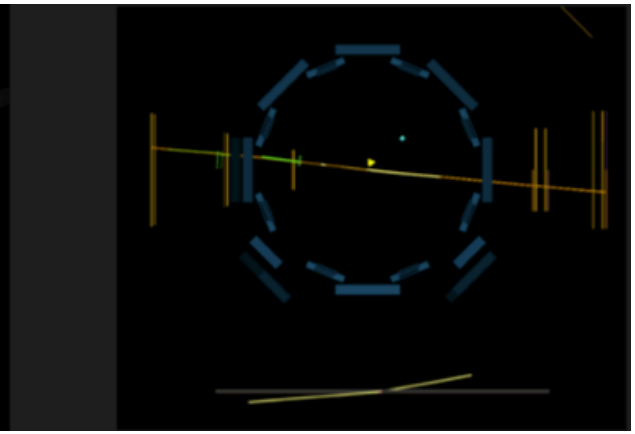




light-by-light



photonuclear dijets

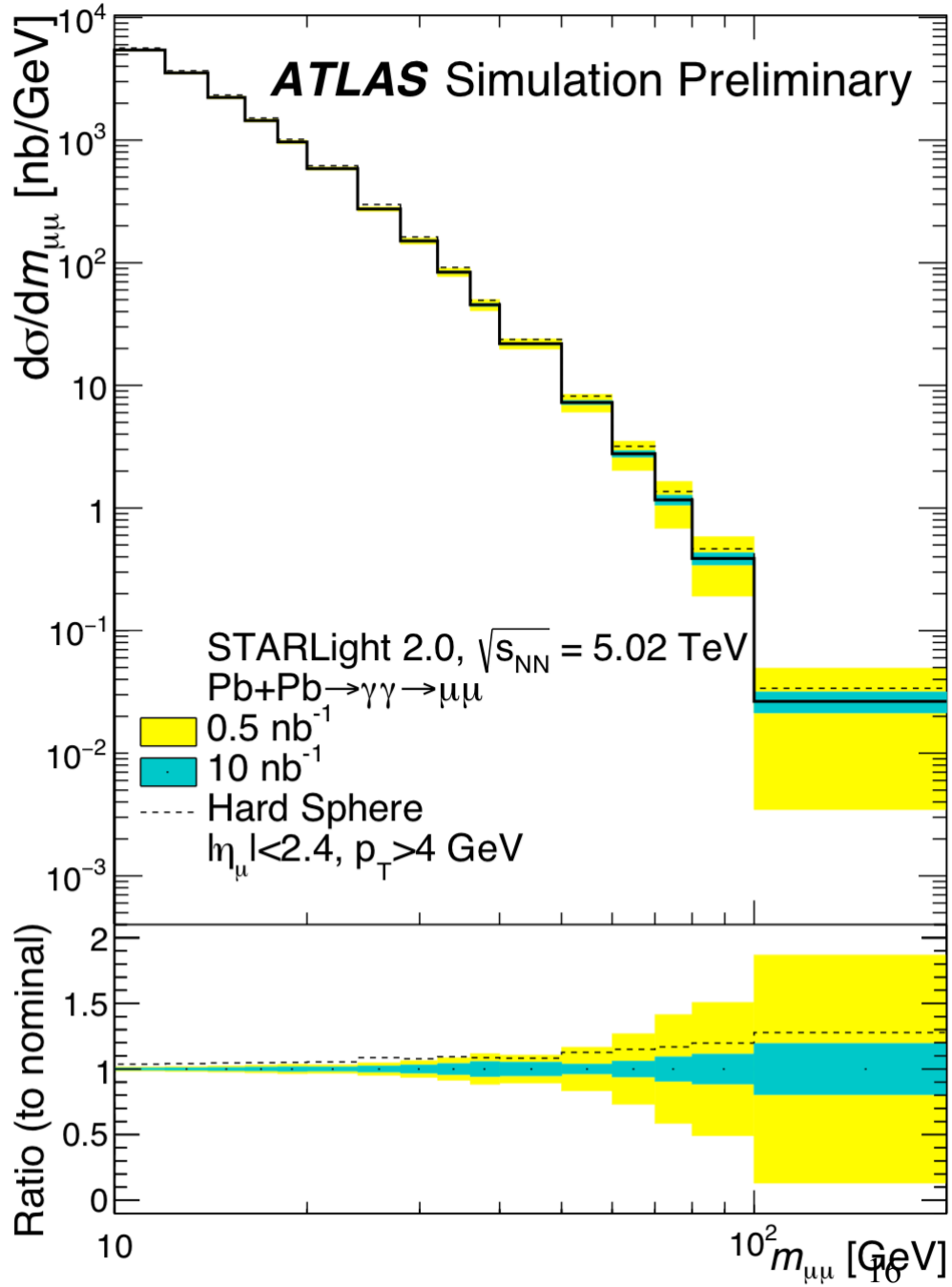


exclusive dimuons

Exclusive di-muons in UPC

ATL-PHYS-PUB-2018-018

- Expected exclusive production of di-muon pairs $\gamma\gamma \rightarrow \mu^+ \mu^-$ with the sample of 10 nb^{-1}
  - Provide calibration to other UPC processes
- Projection of the uncertainties for 0.5 nb^{-1} and 10 nb^{-1}
- Two scenarios for the nuclear geometry - realistic skin depth of the nucleus or a hard sphere
  - Increased precision at the highest $m_{\mu\mu}$ will help in modeling

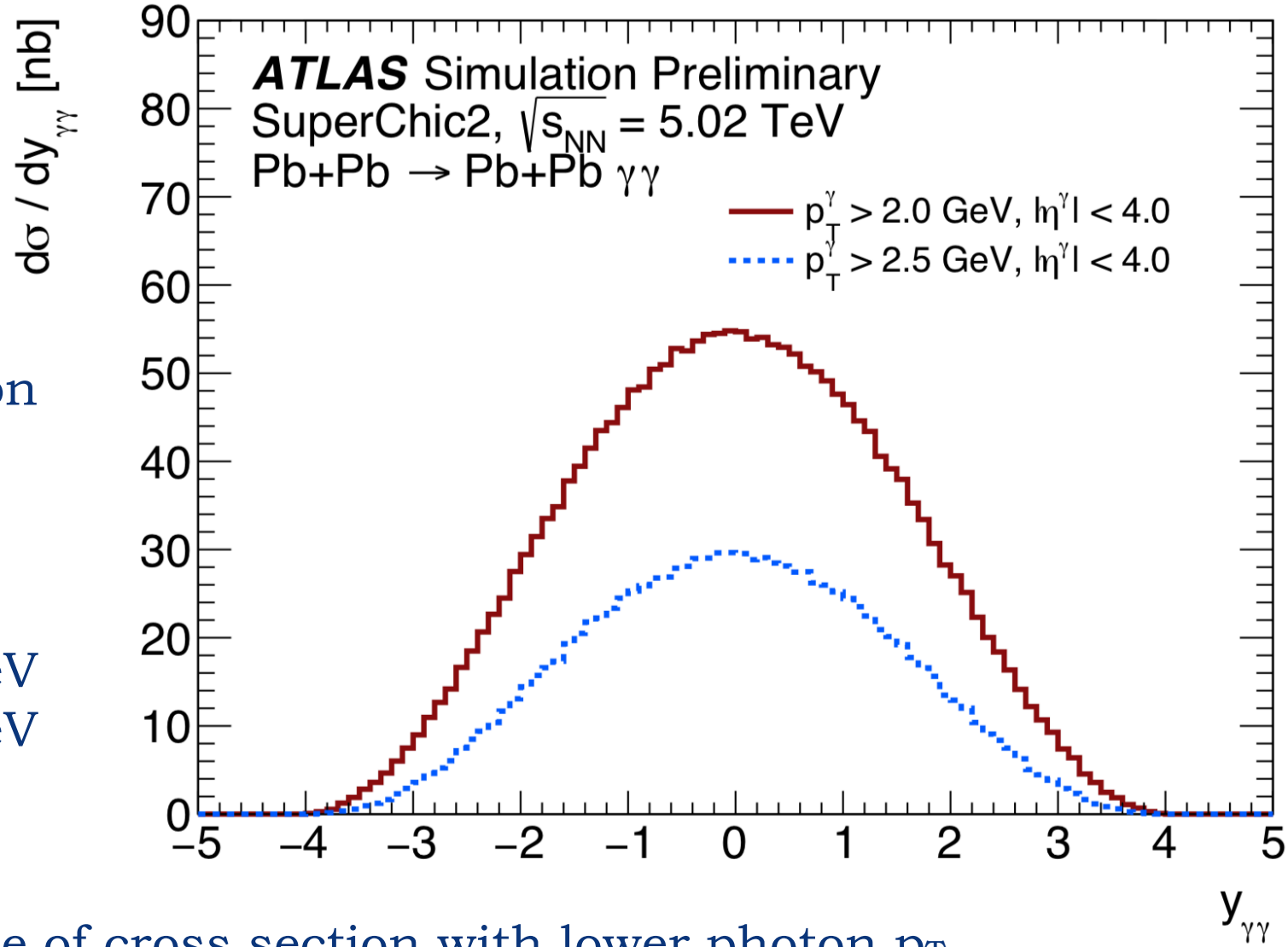


Light-by-light scattering

ATL-PHYS-PUB-2018-018

Differential cross section as a function of the di-photon rapidity for LbyL scattering and photon selection

- $p_T^\gamma > 2.5$ GeV
- $p_T^\gamma > 2.0$ GeV

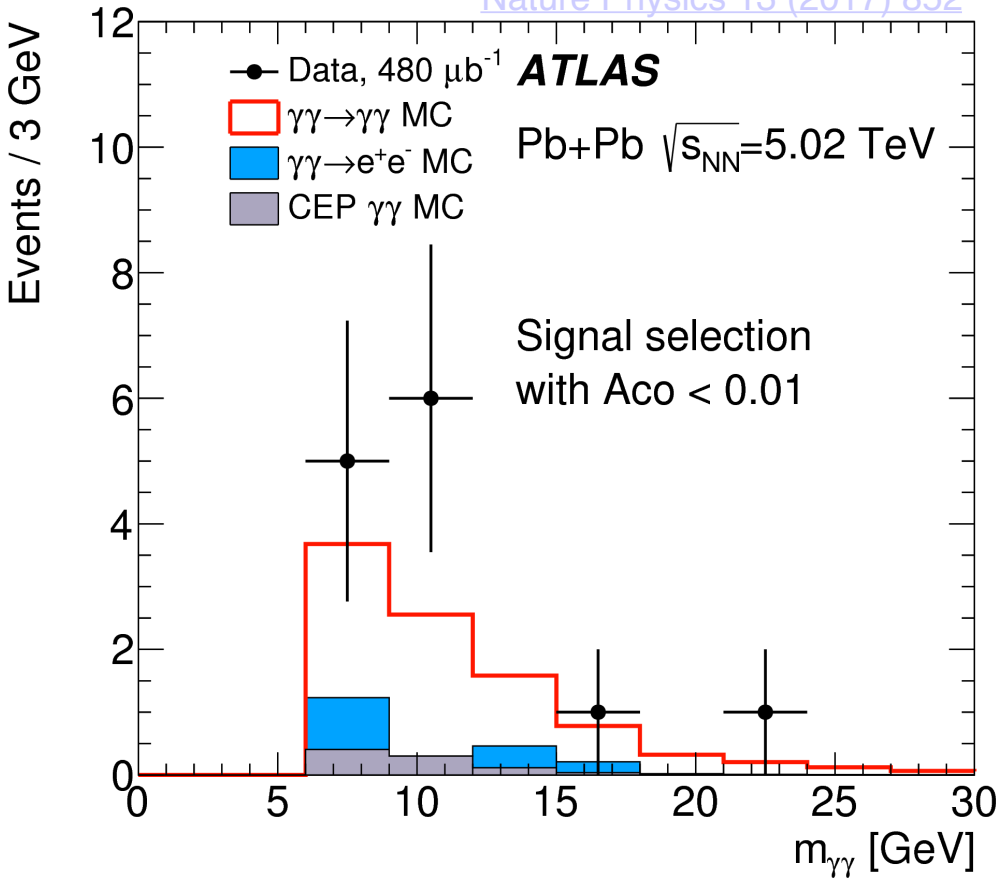


Significant increase of cross section with lower photon p_T

- Measurement will benefit for the **improvement in the reconstruction**
- **Reduced amount of inactive material in new tracker** (smaller probability of photon conversion)

Light-by-light scattering

Nature Physics 13 (2017) 852



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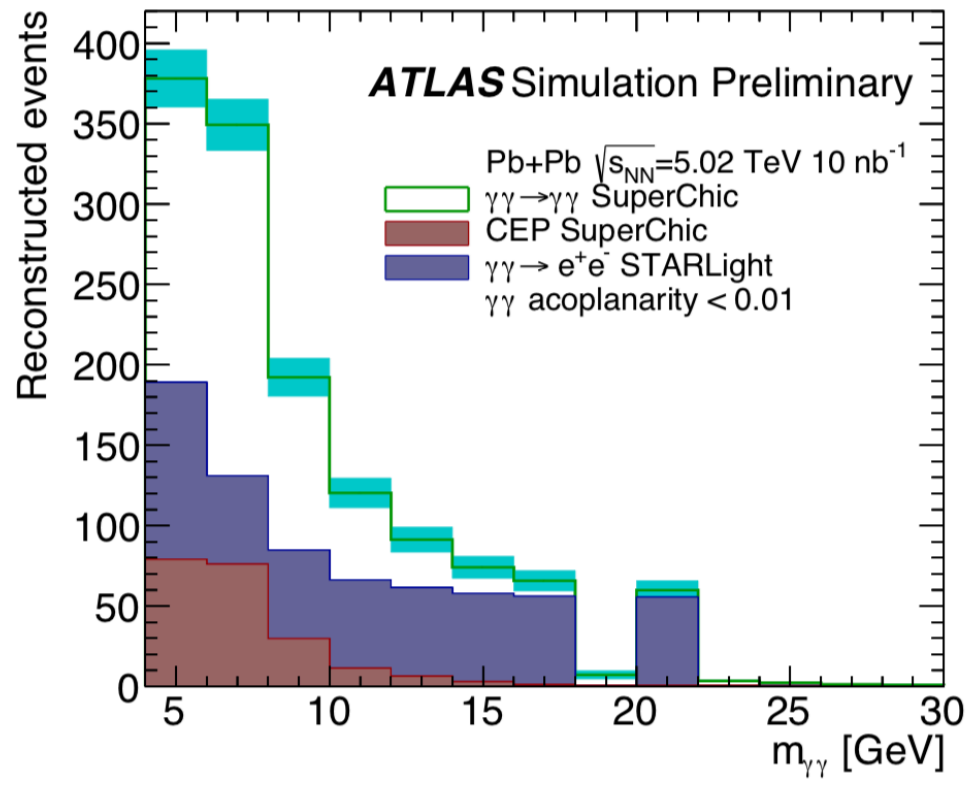


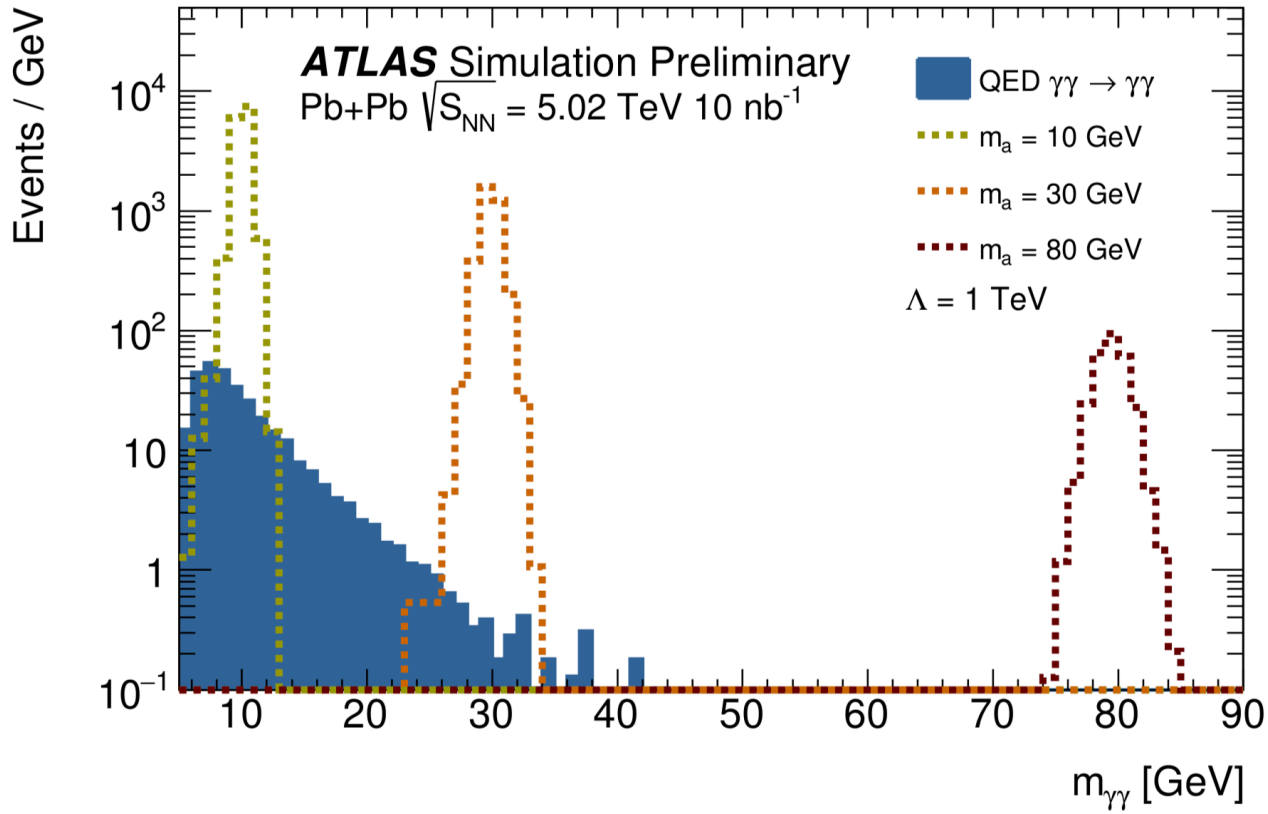
- Invariant mass distributions for the di-photons from LbyL signal and background components
- **Expected 640 events** in 5.02 TeV Pb+Pb collisions with an integrated luminosity of **10 nb^{-1}**
    - **13 events observed** in the 2015

Search for Axion-like particles (ALP) in UPC

ATL-PHYS-PUB-2018-018

ALP (a) with masses above 1GeV could induce an anomalous contribution to the LbyL

- $\gamma\gamma \rightarrow a \rightarrow \gamma\gamma$
- Due to high enough electric field produced by ultra relativistic Pb



- Three ALP signal mass values, and the main background from LbyL
  - Could provide strong limits in the absence of signal

Collisions of light ions at LHC

Successful Xe+Xe run in 2017

- Few hours of data taking
- Precise measurements of bulk and jets

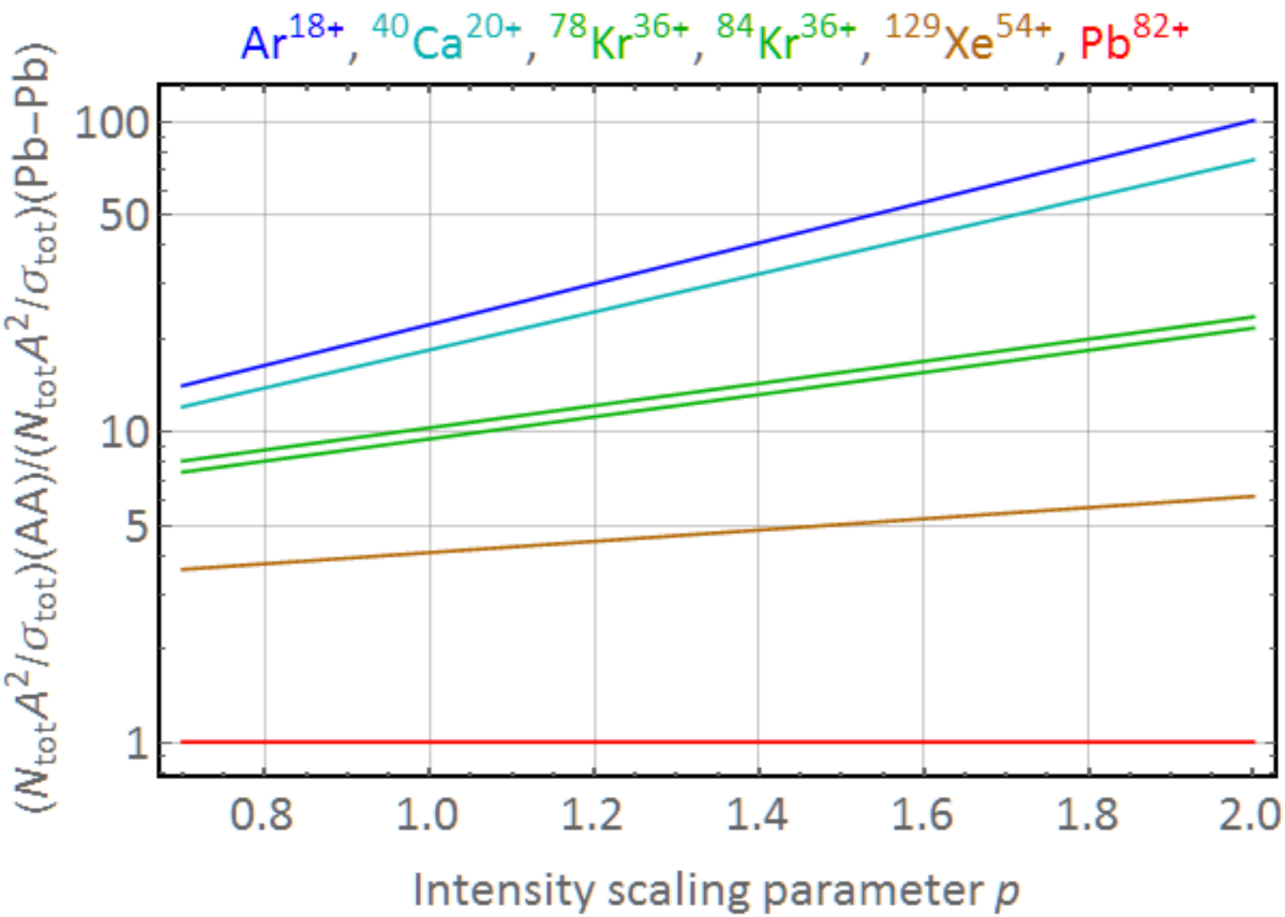
Similar short run with small ions like O+O

- Better constrain on small systems
- Measurable energy loss?

Lighter ions could provide **more jets & rare probes at the LHC**

- Detailed studies of energy loss in for example Ar+Ar

Gains in integrated nucleon-nucleon luminosity PER FILL wrt. Pb-Pb



From John Jowett QM18

Summary

- Expected integrated luminosity of **10 nb^{-1} in Run3&4** leads to improvements in precision for measurements which suffer from lack of statistics
    - **Many interesting physics results to be delivered!**
    - **New discoveries maybe waiting around the corner!**

- Significant improvement in the future measurements thanks to the installation of the ATLAS detector upgrade
    - **Looking forward for ITk in Run4**

ATLAS public results twiki - new Run3&4 pub notes:
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults

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Backup