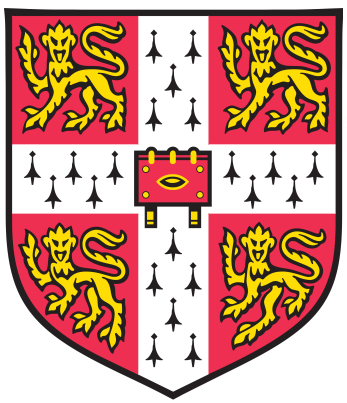
Suppression and elliptic anisotropy of heavy flavor muons in Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

Miguel Arratia
for the ATLAS collaboration



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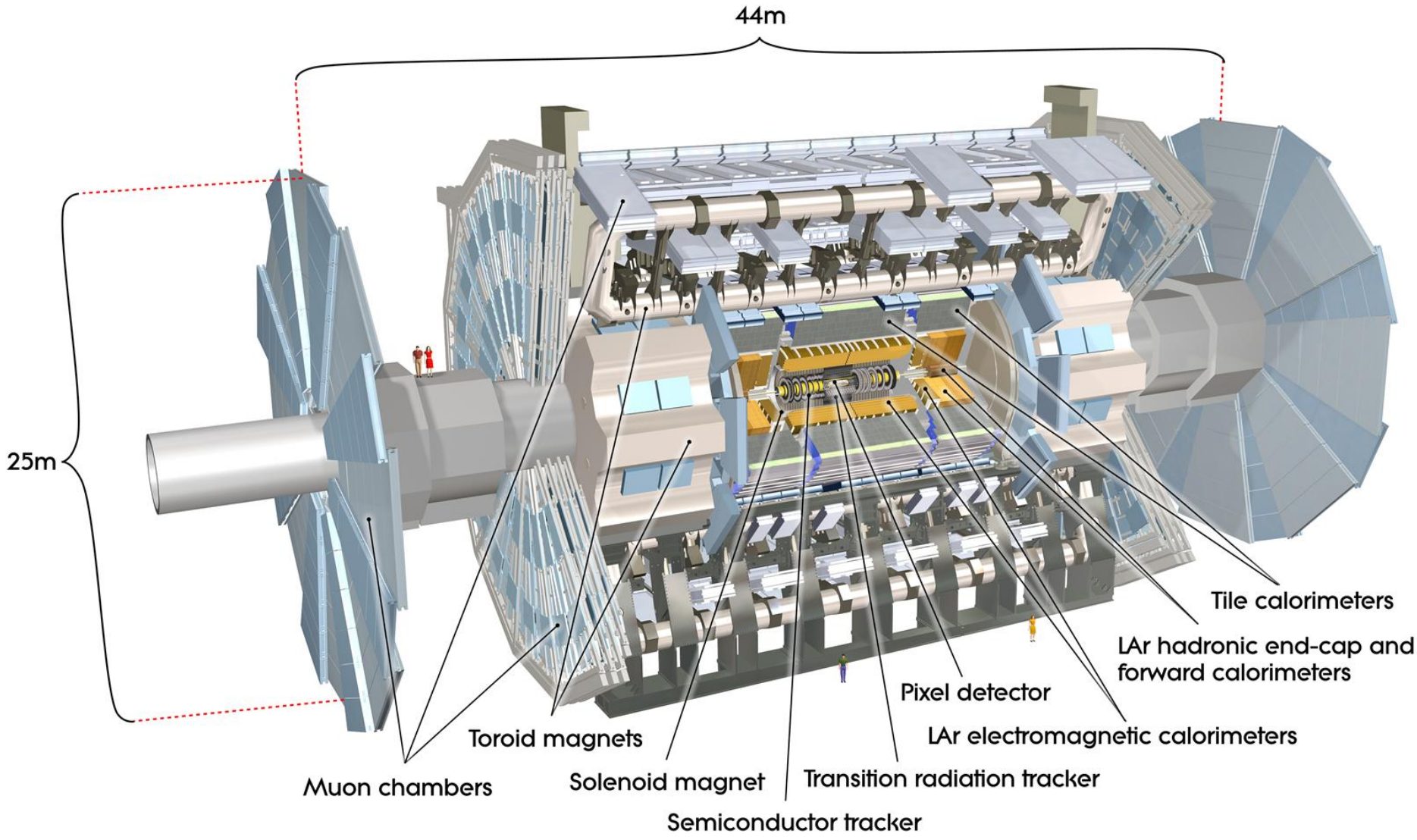
Why study heavy quarks in nuclear collisions

- Heavy quarks are probes for the hot and dense medium, energy loss, diffussion etc.

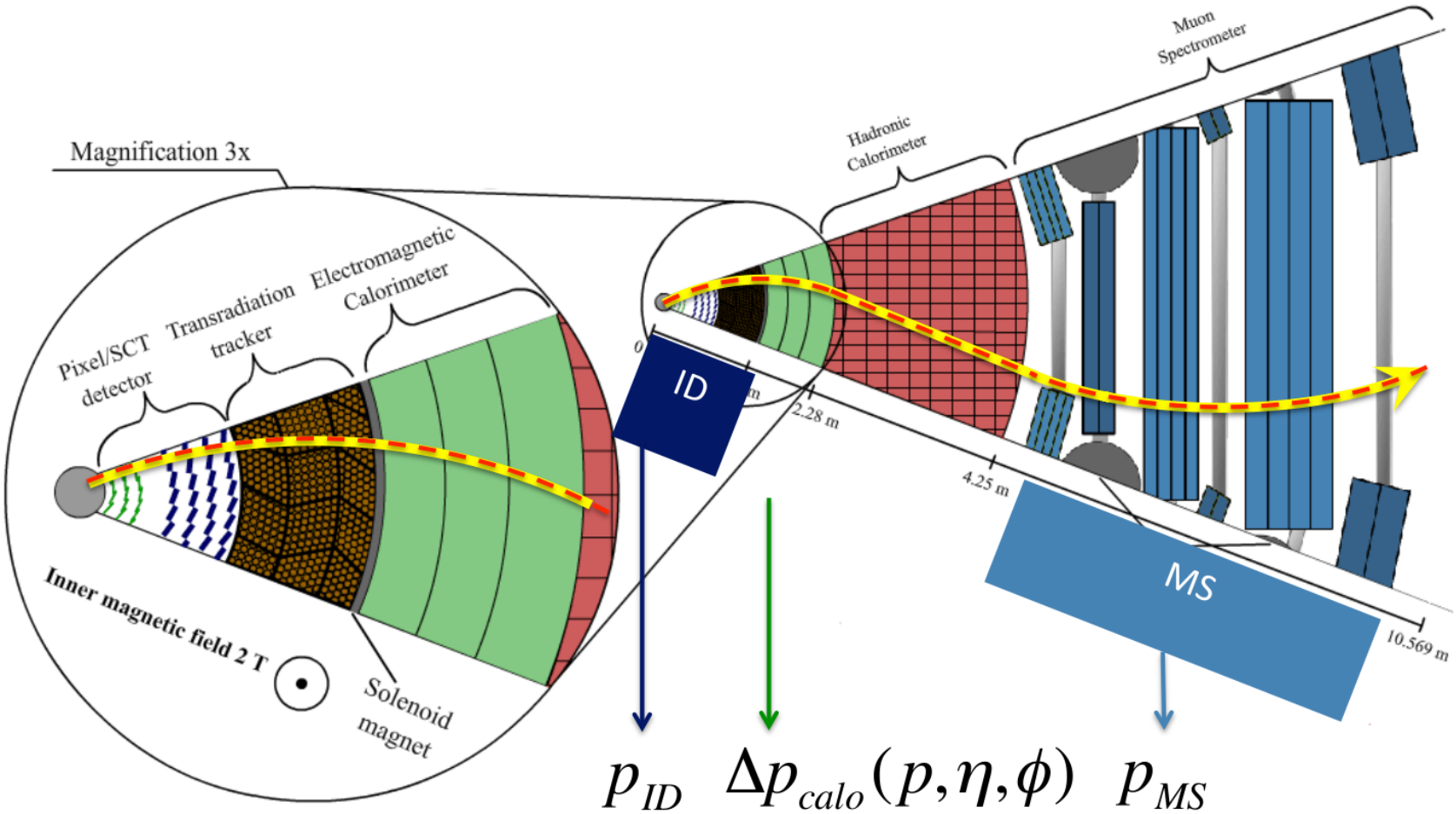
- To what extent do heavy quarks thermalize with the rest of the medium?

Measuring heavy quarks

- Muons from semi-leptonic decays of D and B hadrons (THIS TALK)
- J/ψ from B hadron decays
- Fully reconstructed D and B hadrons
- b-jets, c-jets

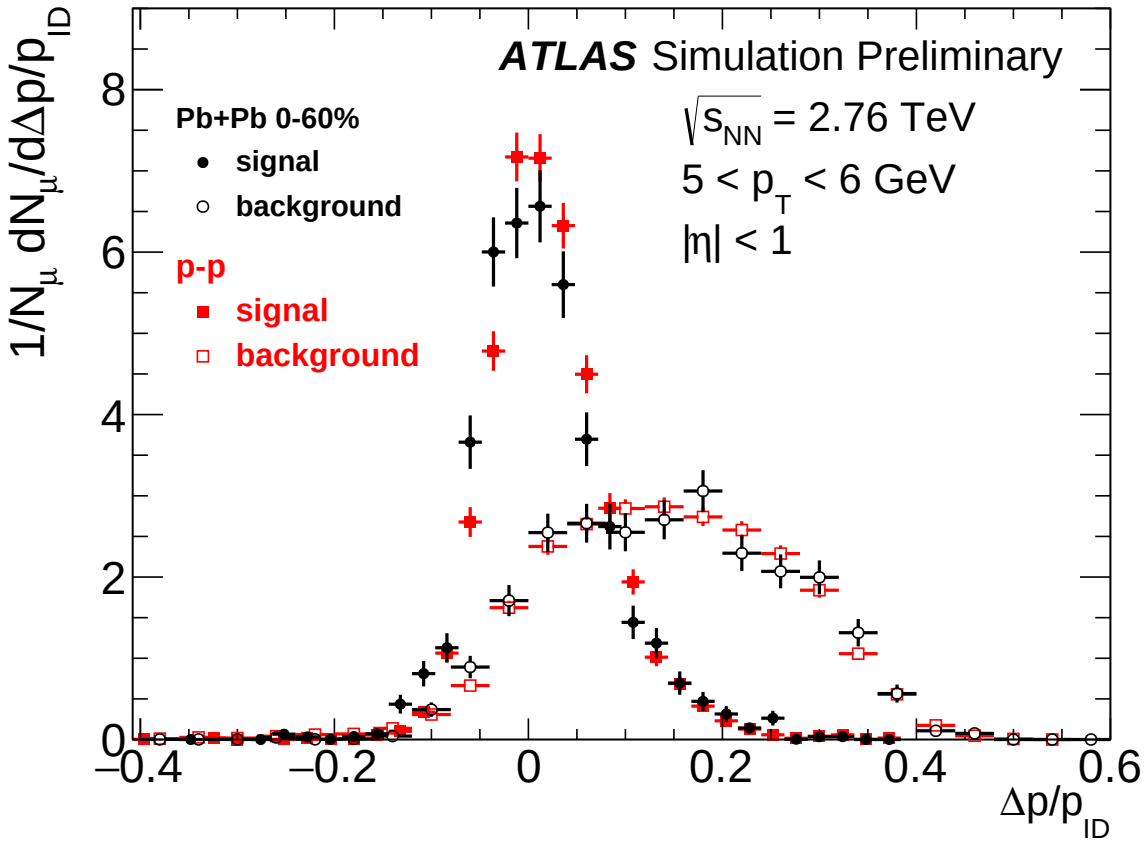

44m
25m
Tile calorimeters
LAr hadronic end-cap and
forward calorimeters
Pixel detector
LAr electromagnetic calorimeters
Toroid magnets
Muon chambers
Solenoid magnet
Transition radiation tracker
Semiconductor tracker

Muon momentum measurement



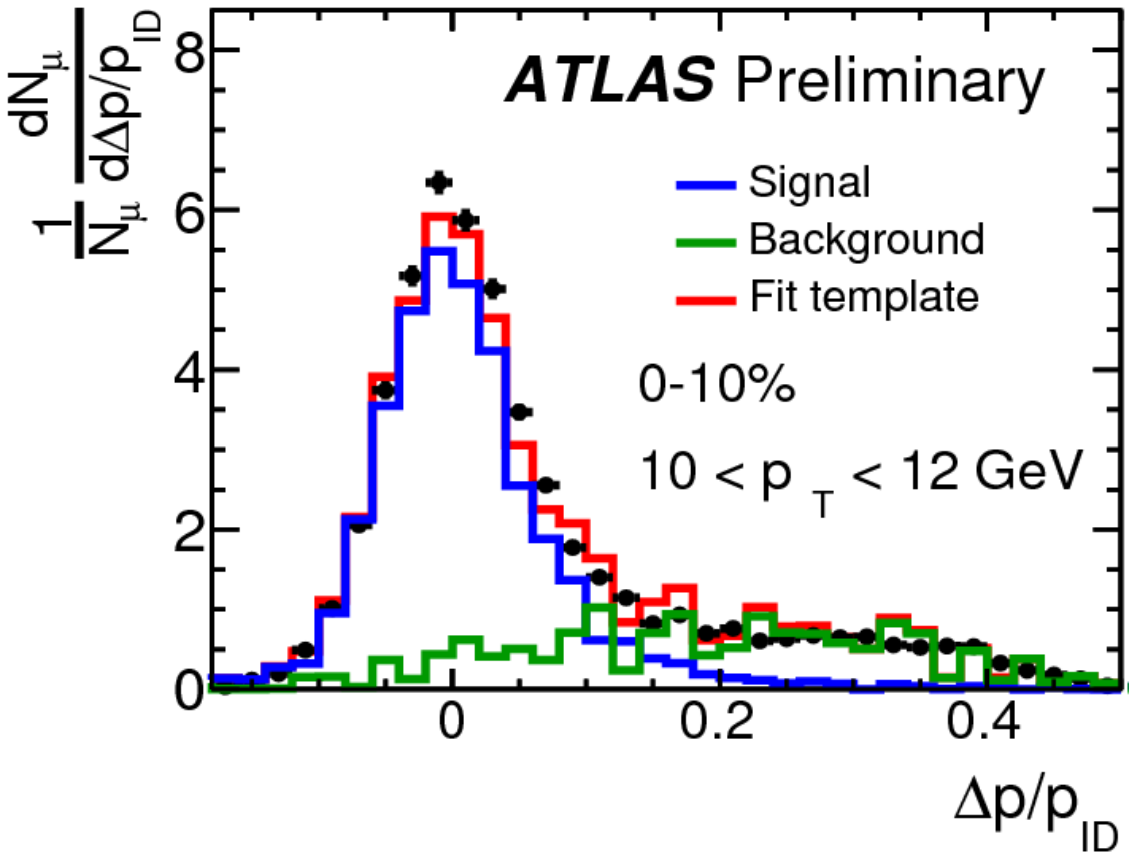
Discriminating variable= $(p_{ID} - \Delta p_{calo} - p_{MS})/p_{ID}$

Background are muons from decays of flight from pions or kaons.



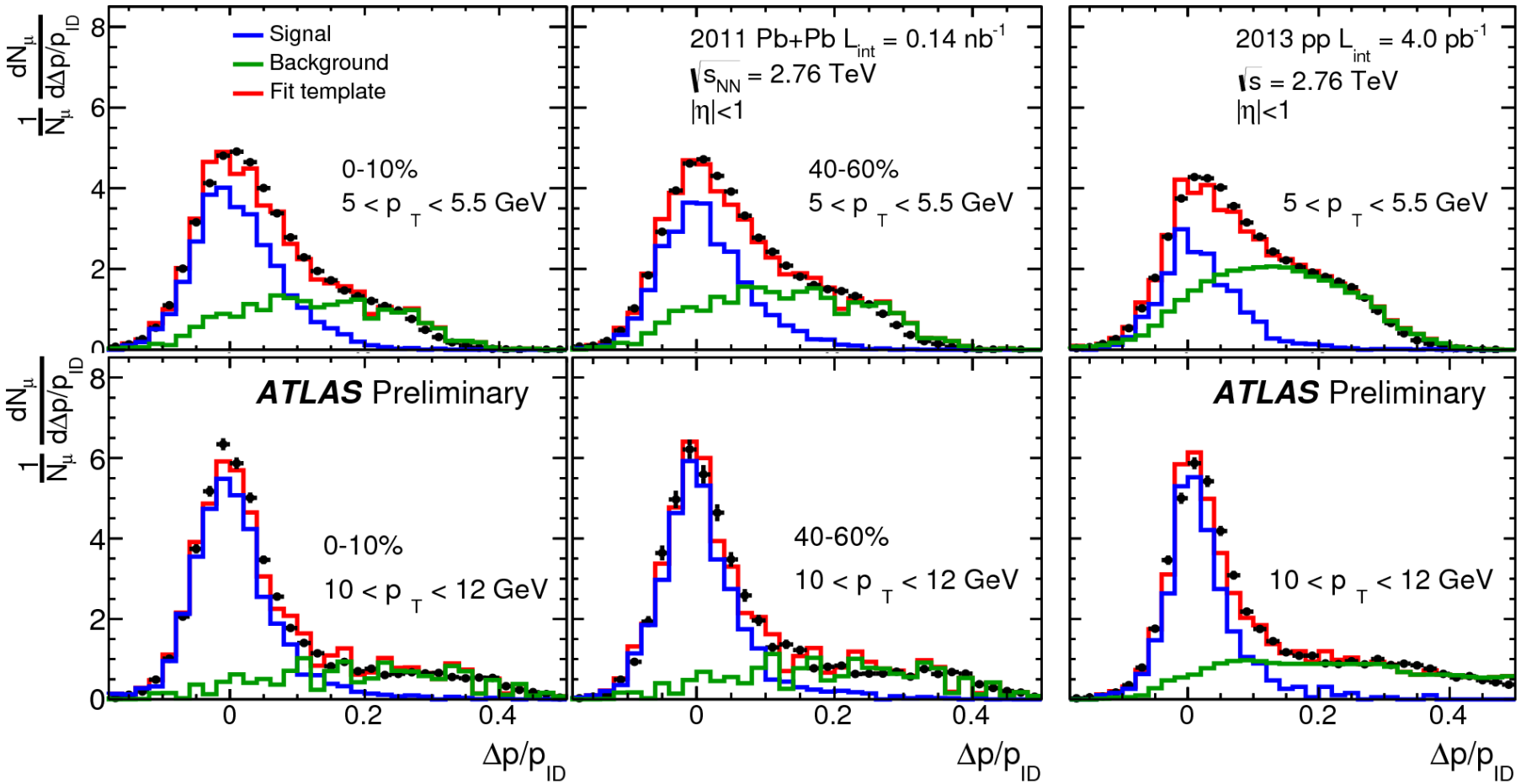
- Signal shape very different from background shape
- Little difference between pp and Pb+Pb templates

Signal Extraction



- Separate signal from background with a template fit

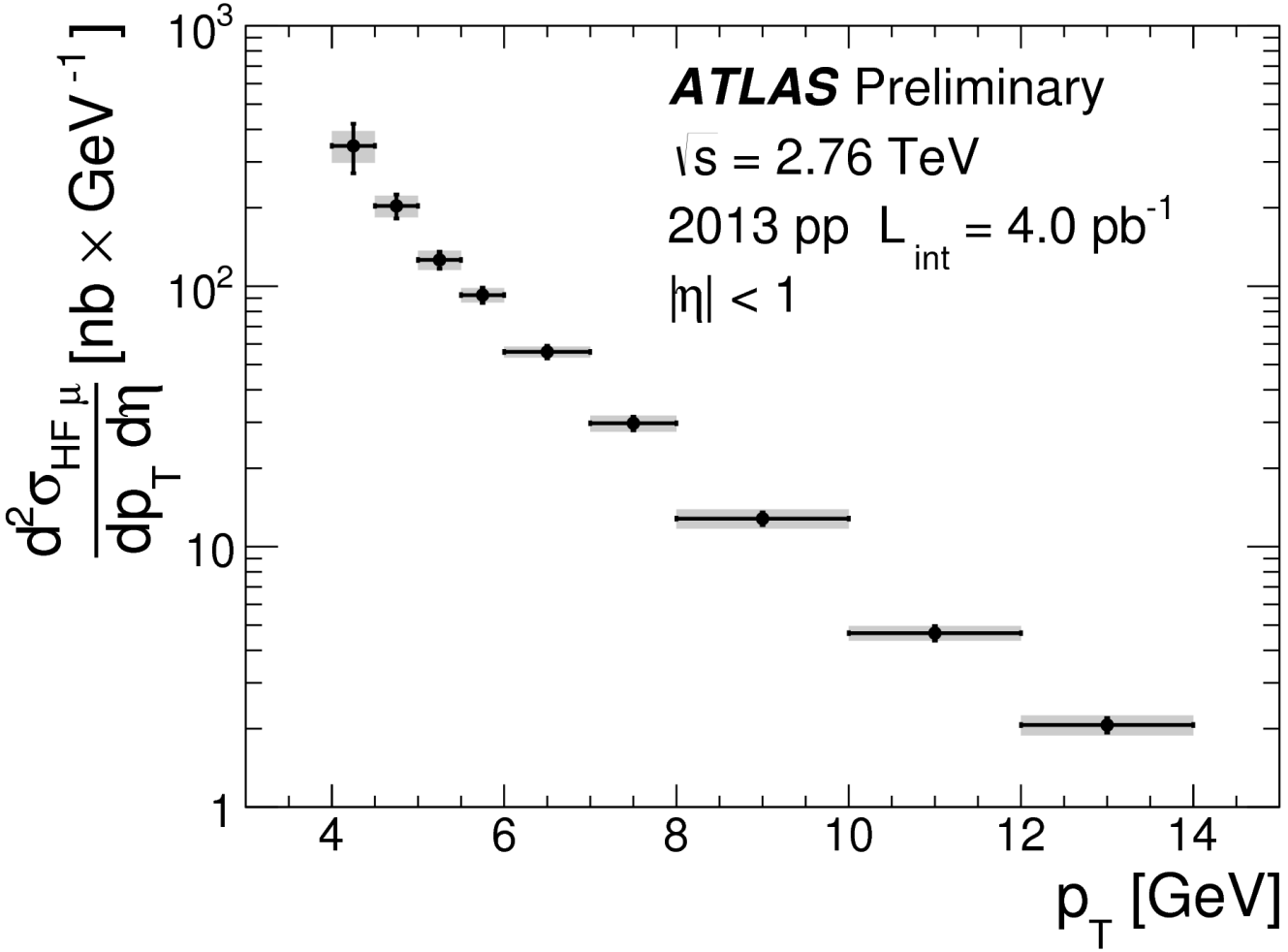
Signal Extraction



- Separate signal from background with a template fit in bins of centrality and muon p_{T}

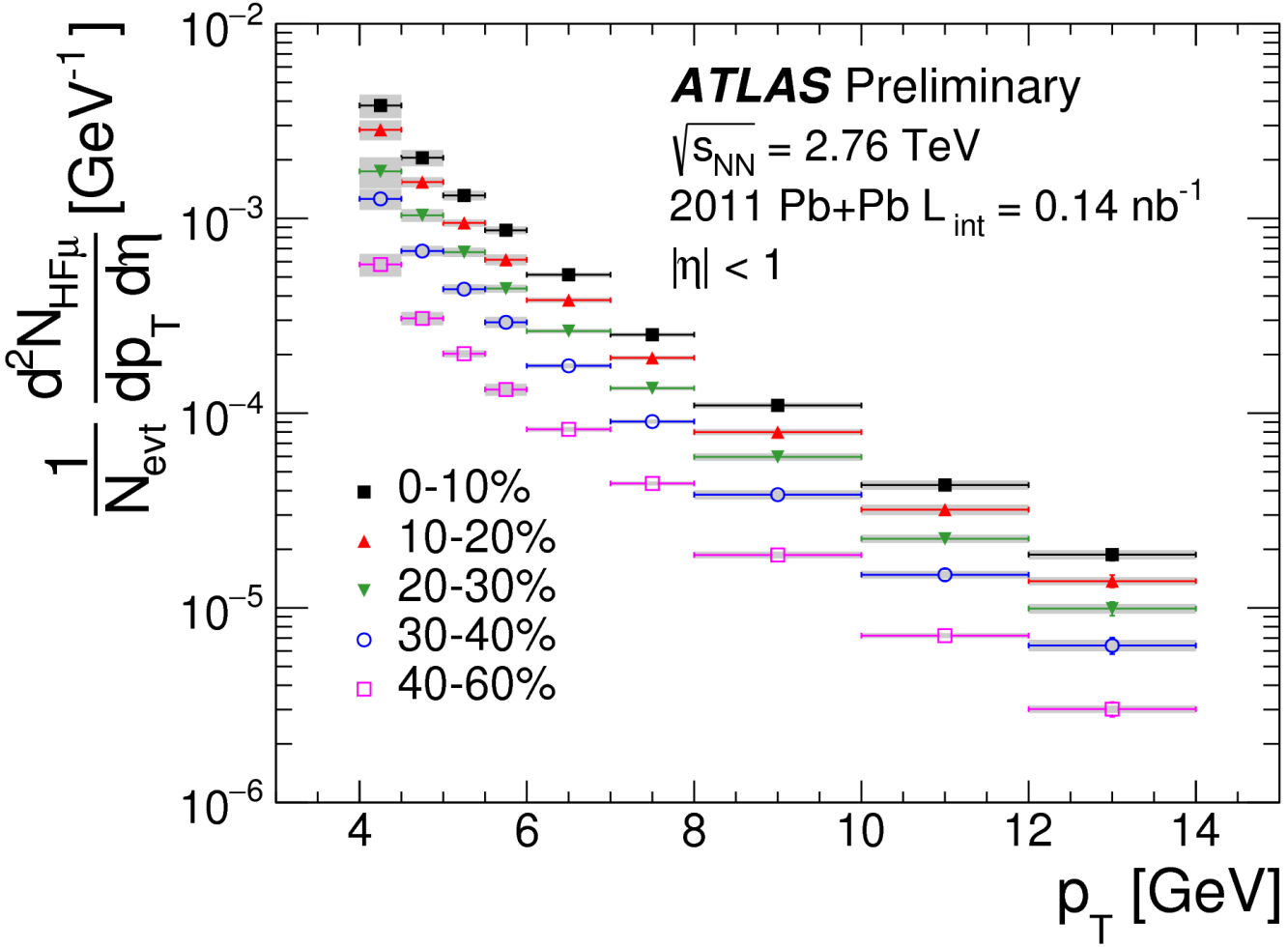
Cross-section in pp collisions

$$\frac{d^2\sigma_{HF\mu}}{dp_{\mathrm{T}}d\eta} = \frac{N_\mu}{\Delta p_{\mathrm{T}}\Delta\eta}\frac{1}{\epsilon_{\mathrm{trigger}}\epsilon_{\mathrm{rec}}}\frac{1}{\mathcal{L}}$$



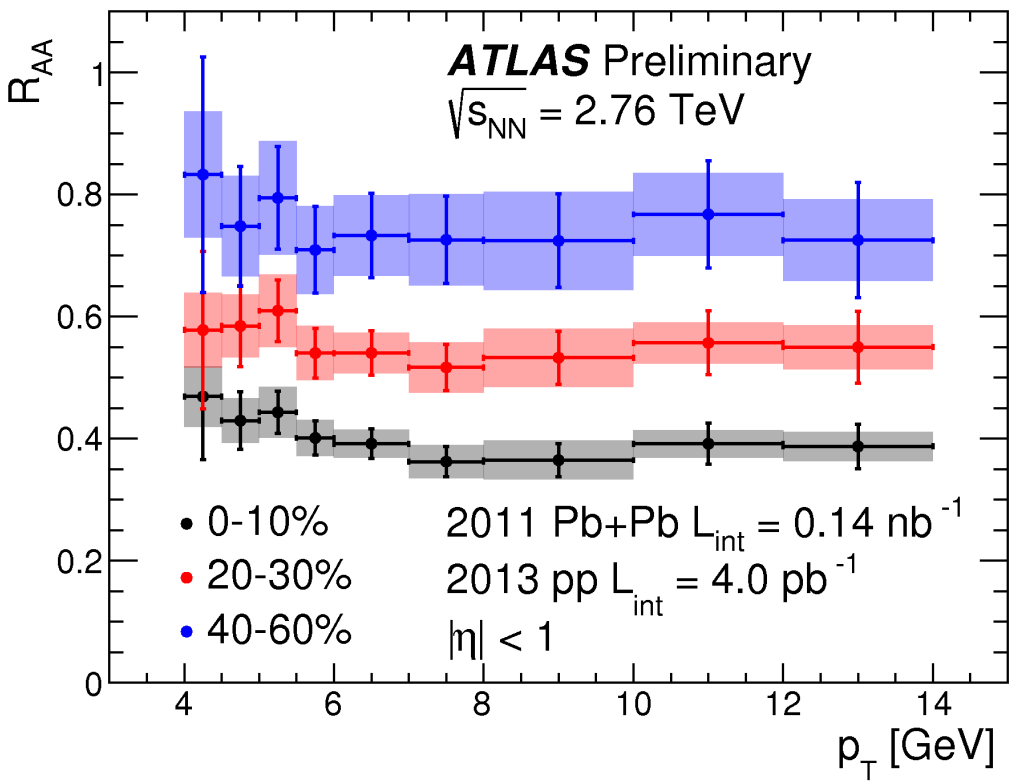
Yields in Pb+Pb collisions

$$\frac{1}{N_{evt}}\frac{d^2N_{HF\mu}}{dp_{\mathrm{T}}d\eta} = \frac{1}{N_{evt}}\frac{N_\mu}{\Delta p_{\mathrm{T}}\Delta\eta}\frac{1}{\epsilon_{\mathrm{trigger}}\epsilon_{\mathrm{rec}}}$$



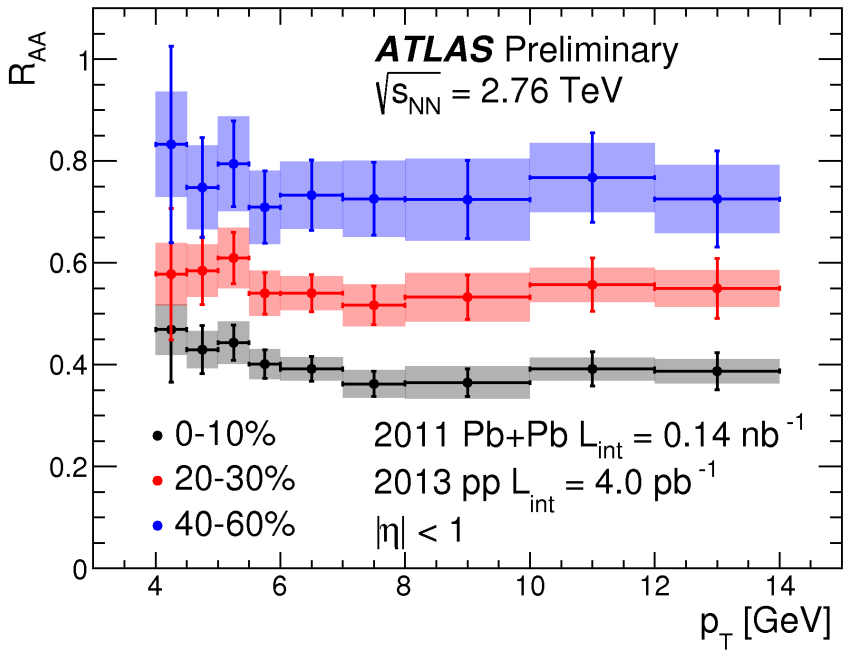
Nuclear suppression factor

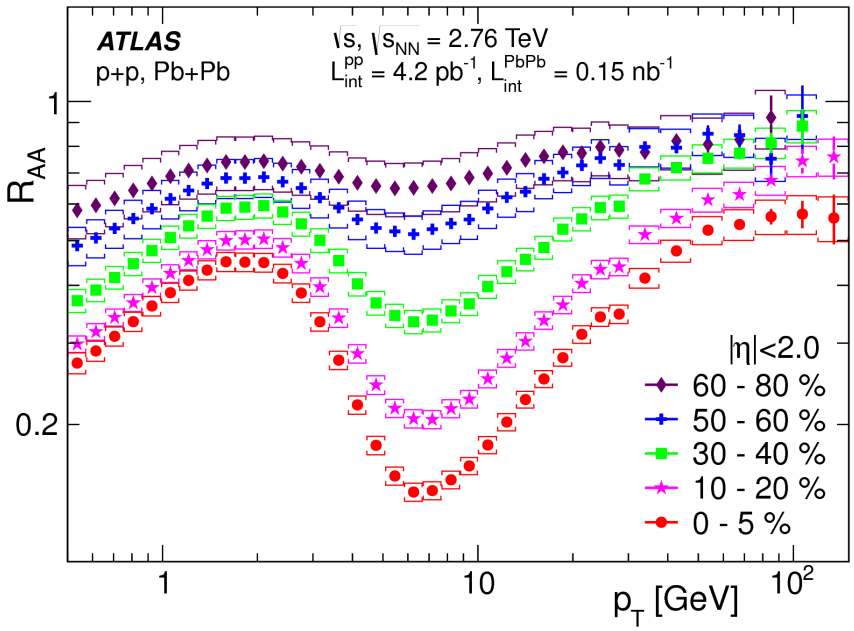
$$R_{\mathrm{AA}} = \frac{1}{\langle T_{\mathrm{AA}} \rangle} \frac{\frac{d^2\sigma_{HF\mu}}{dp_{\mathrm{T}}d\eta}}{\frac{d^2N_{HF\mu}}{dp_{\mathrm{T}}d\eta}}$$



- Large suppression with respect to proton-proton collisions
- Suppression varies with centrality, reaching 0.4 for the most central collisions

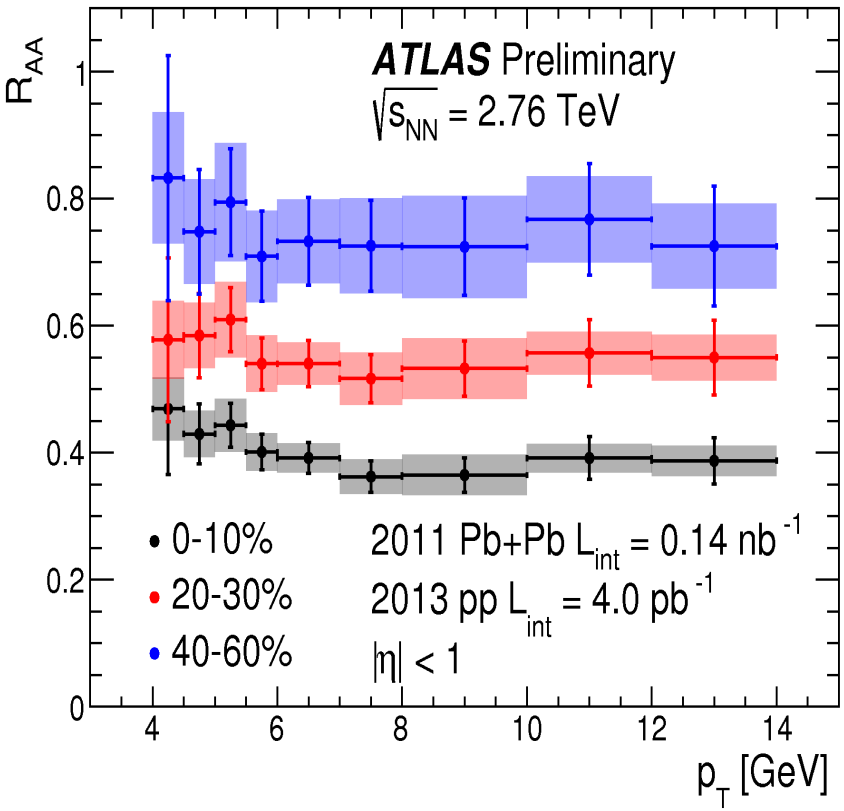
Comparison with inclusive hadrons

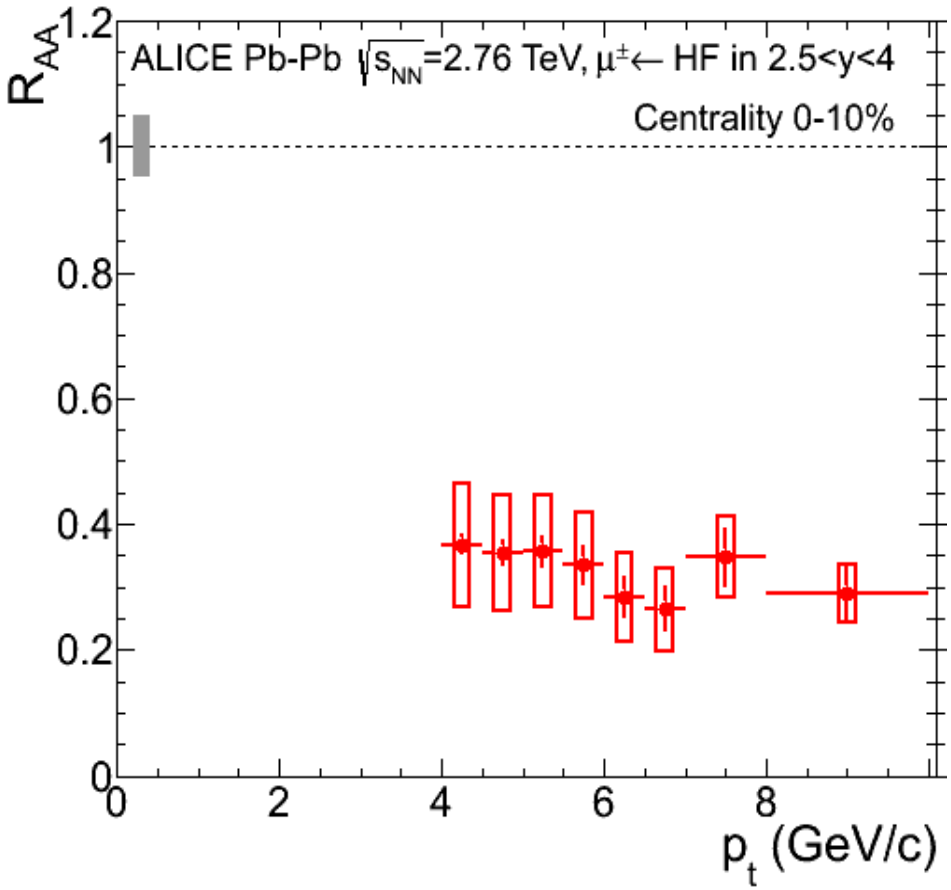




- More suppression of inclusive hadrons, ATLAS **JHEP09(2015)050**
- Much stronger momentum dependence for inclusive hadrons

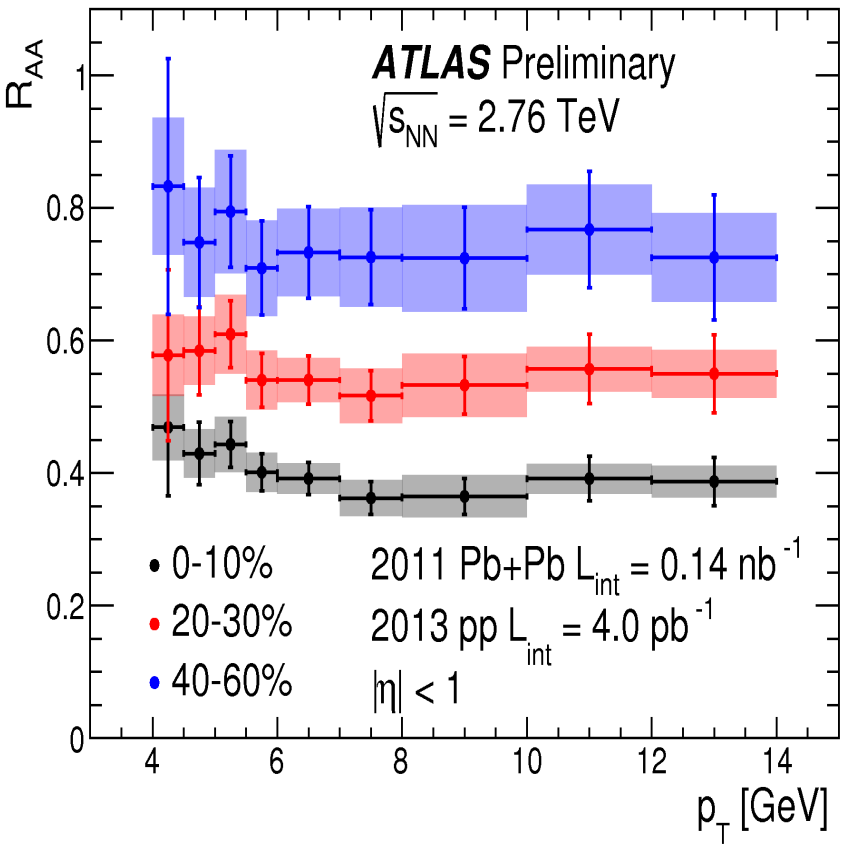
Comparison with forward production

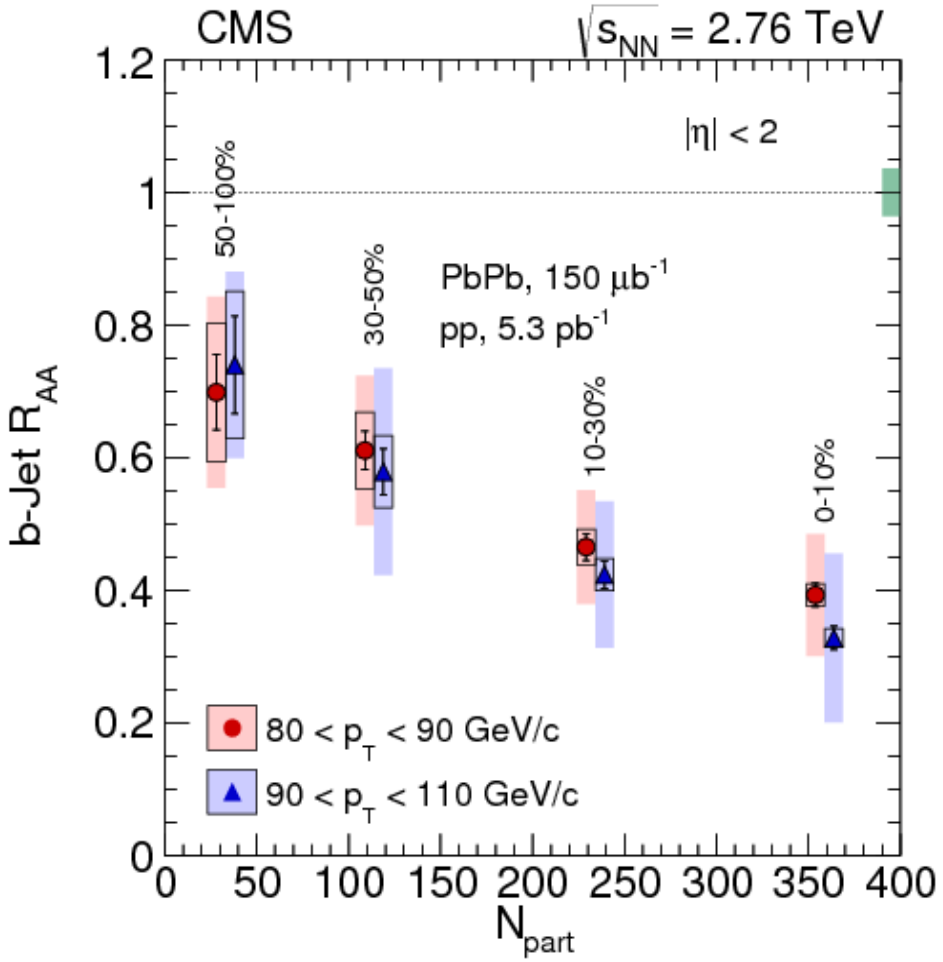




- Magnitude of suppression is compatible with ALICE measurement
  Phys.Rev.Lett. 109 (2012) 112301
- Both experiments see no momentum dependence

Comparison with inclusive b-jets





- Compatible results between heavy flavour μ and b-jets
  PRL 113 (2014) 132301

Elliptic Flow

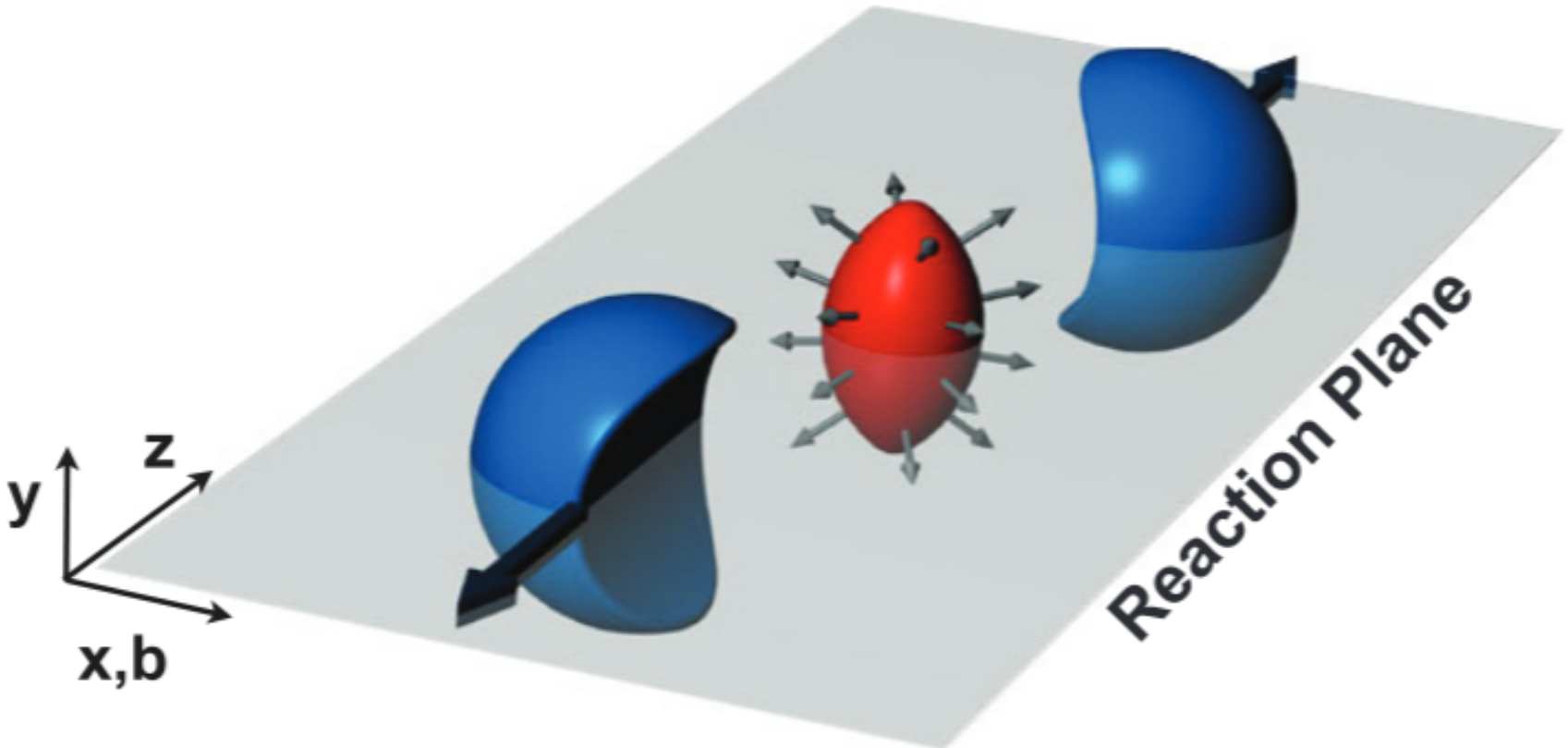
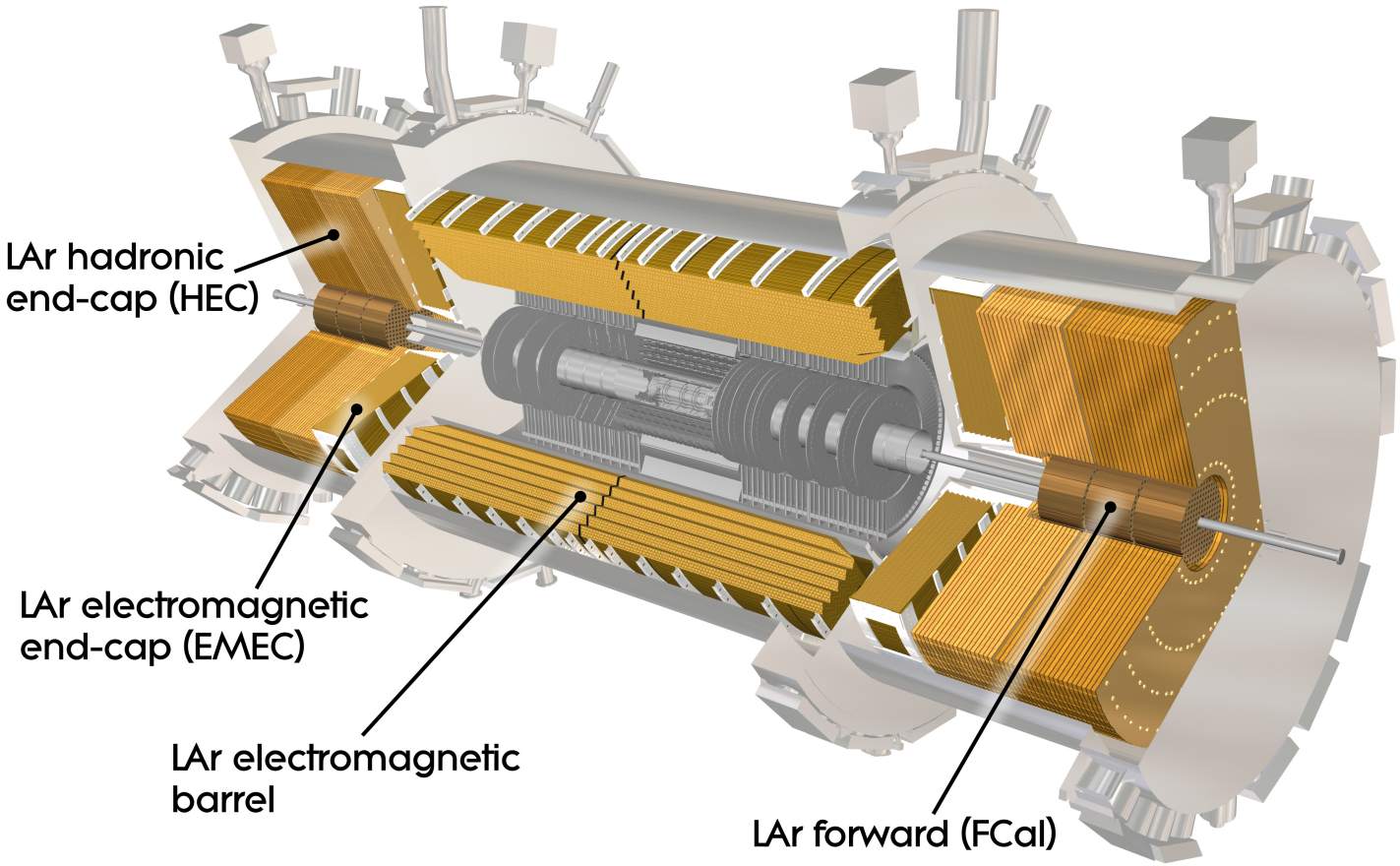
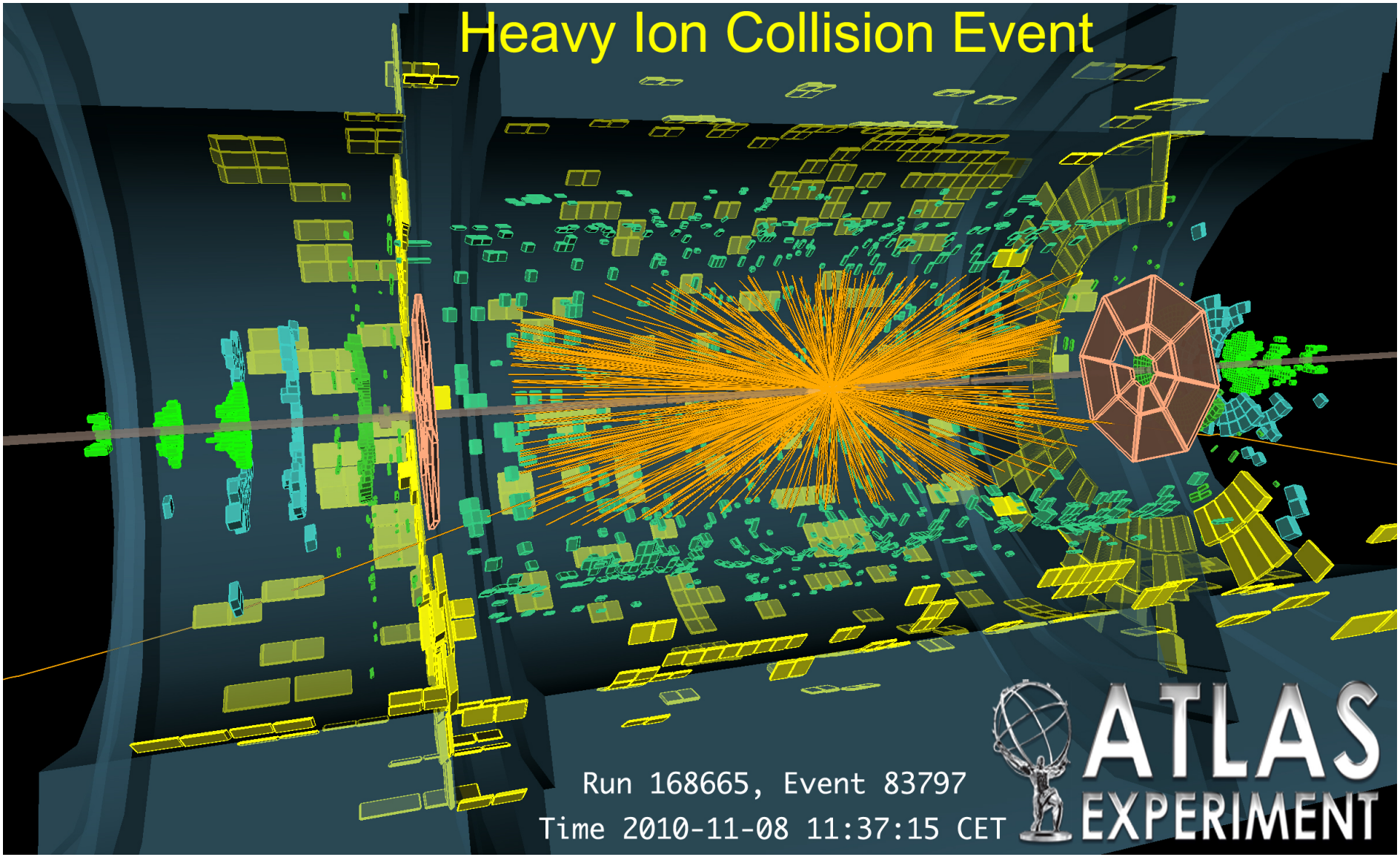


figure from http://inspirehep.net/record/889692.

ATLAS Liquid Argon Calorimeter



- Forward Calorimeter (FCAL) used to determine reaction plane


Heavy Ion Collision Event
Run 168665, Event 83797
Time 2010-11-08 11:37:15 CET
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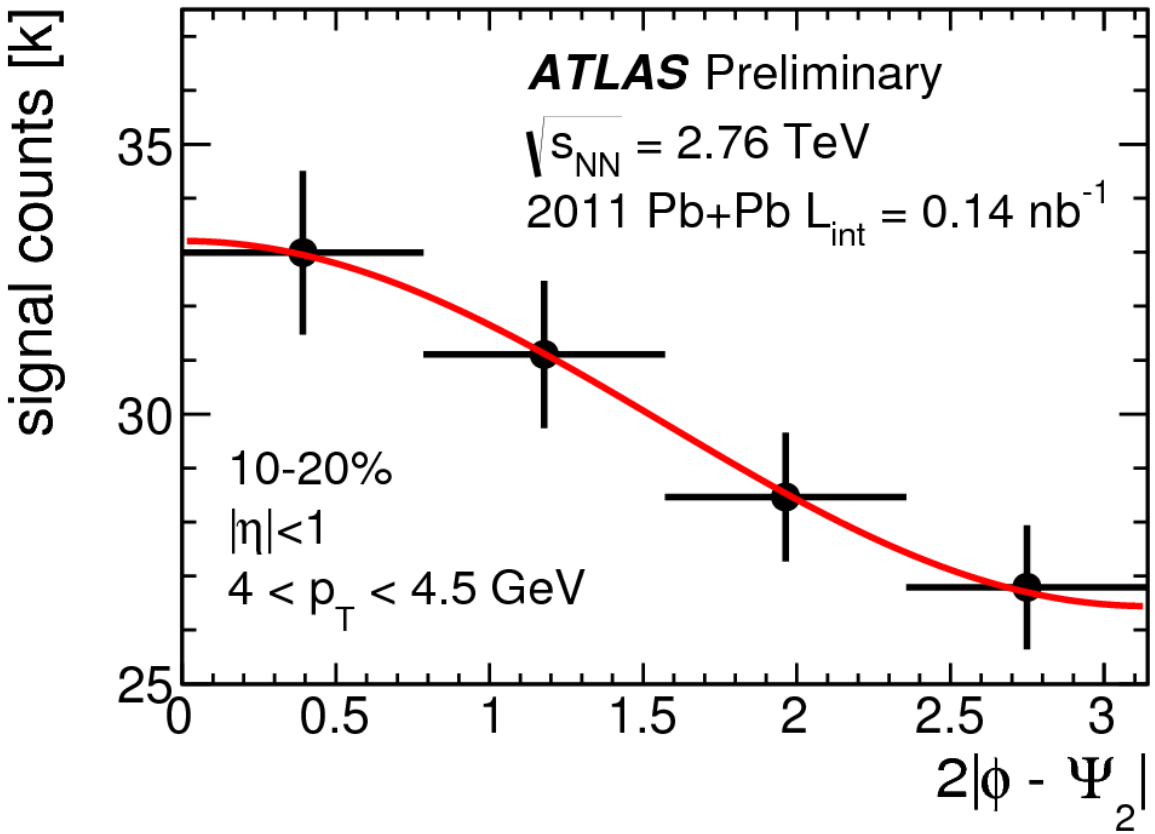
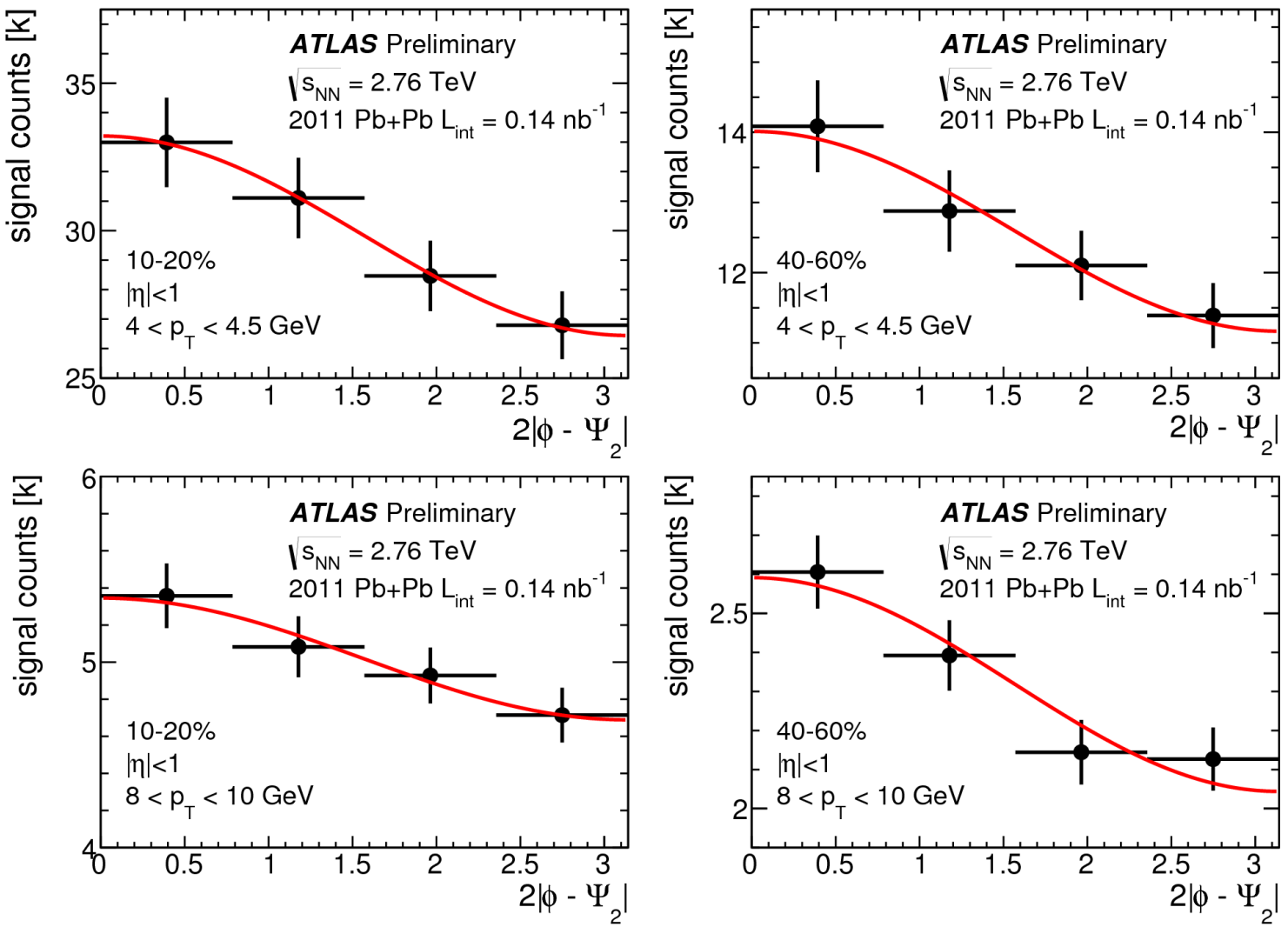
EXPERIMENT

Azimuthal anisotropy



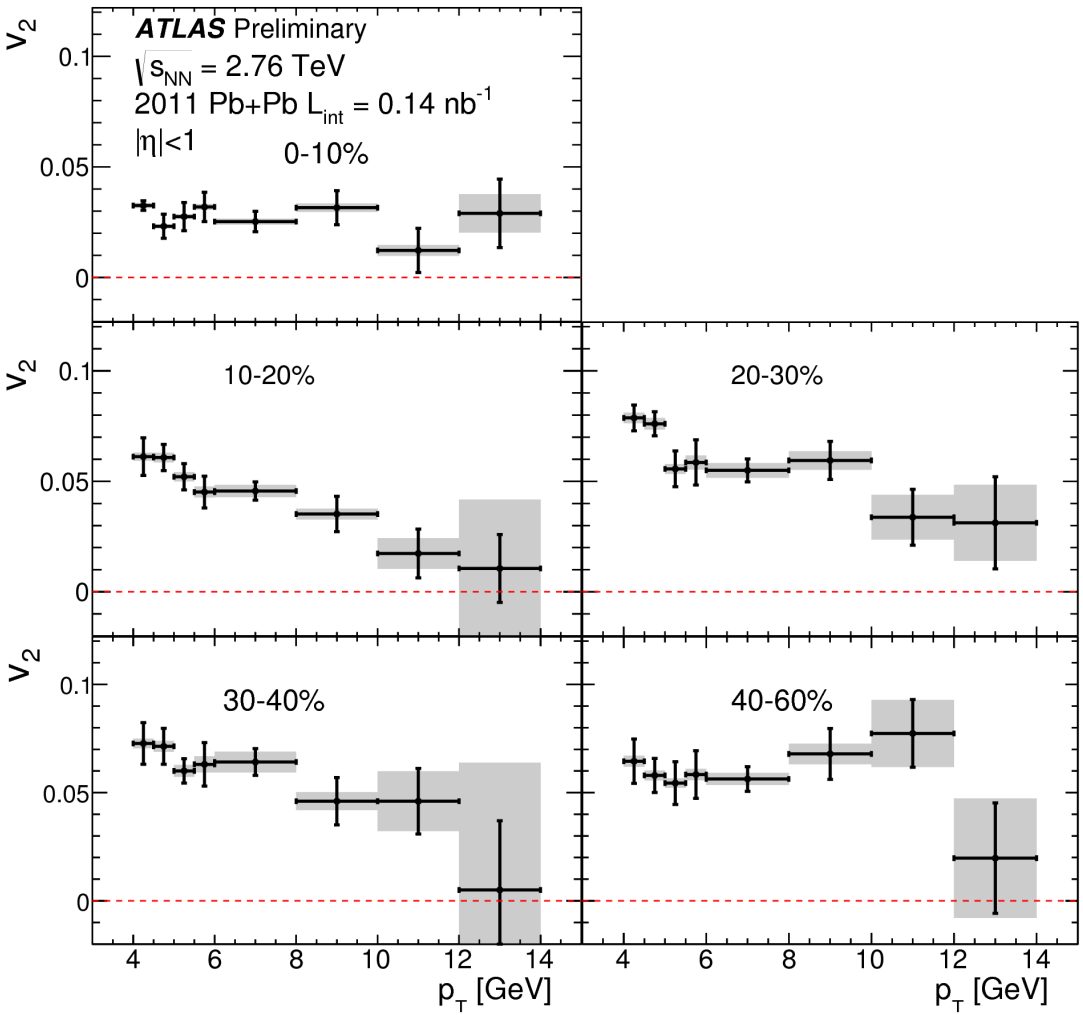
- Strong azimuthal anisotropy; **more muons in plane than out of plane**

Azimuthal anisotropy, different intervals



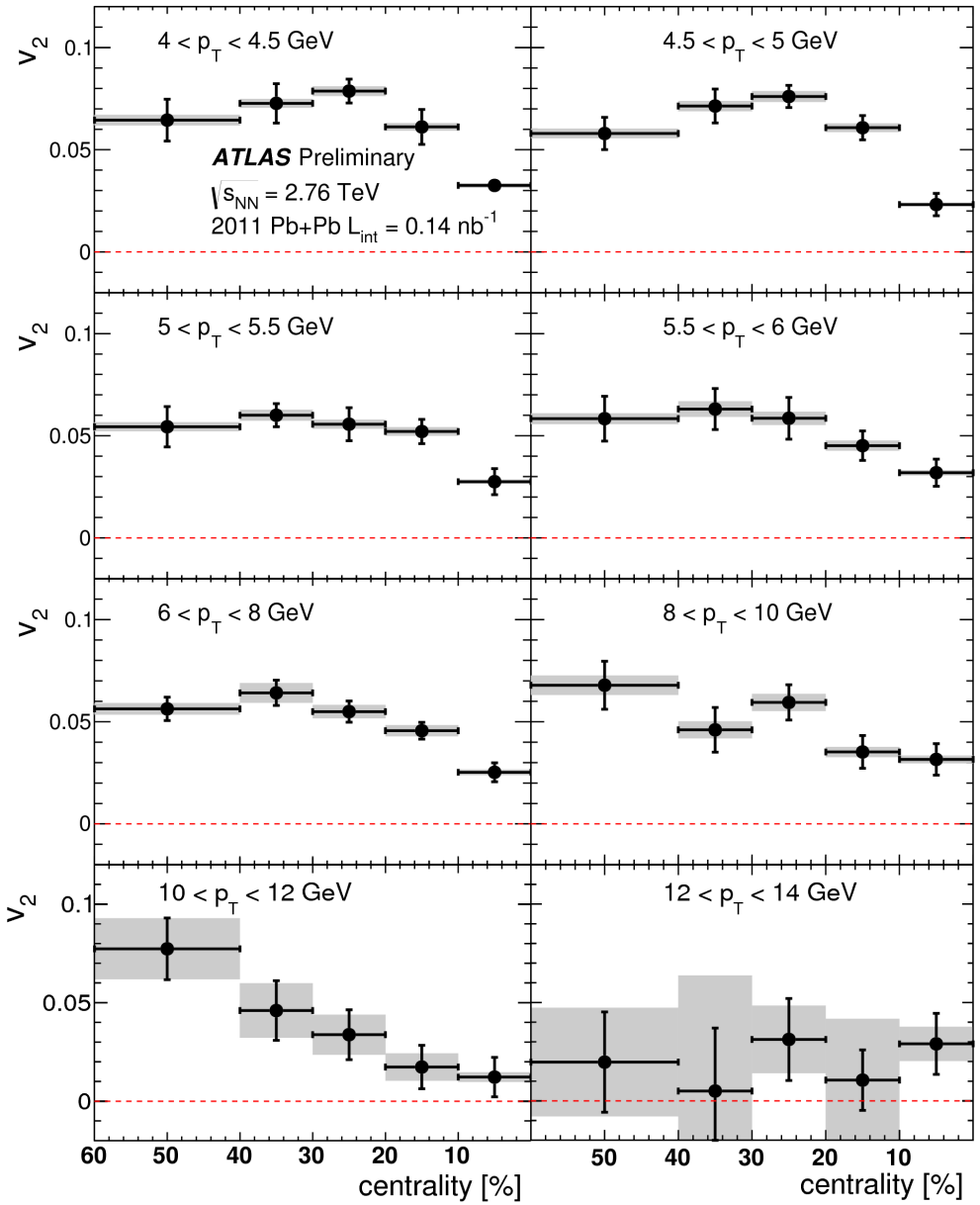
- Strong azimuthal anisotropy; **more muons in plane than out of plane**

Fourier elliptic term v_2 vs momentum



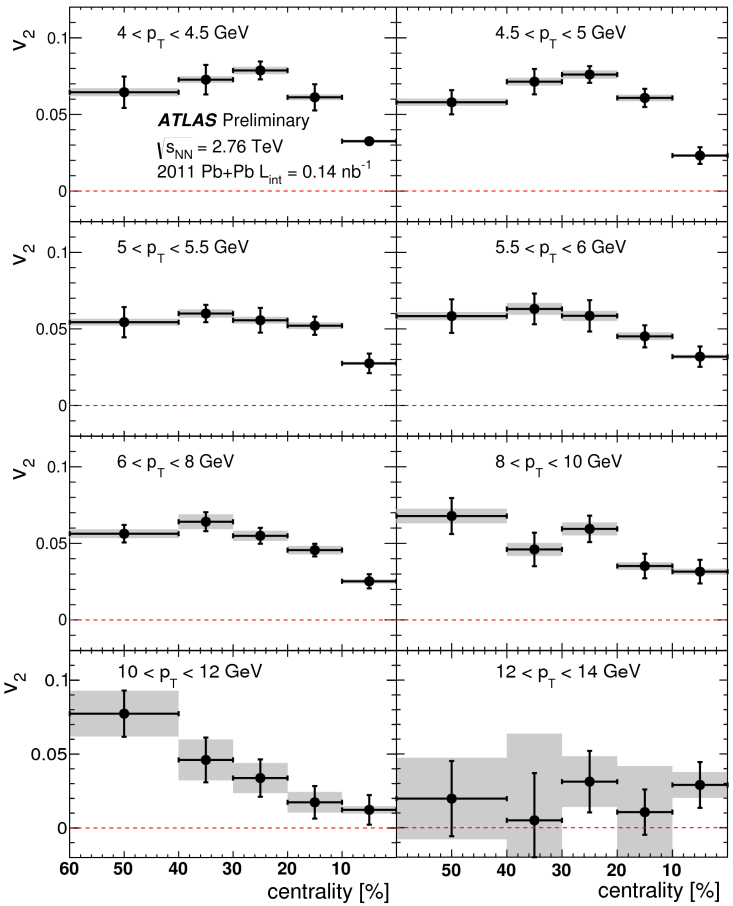
- Largest v_2 at the smallest measured p_T
- Non-zero v_2 even at highest p_T
- Highest amplitude at 10–40% centrality

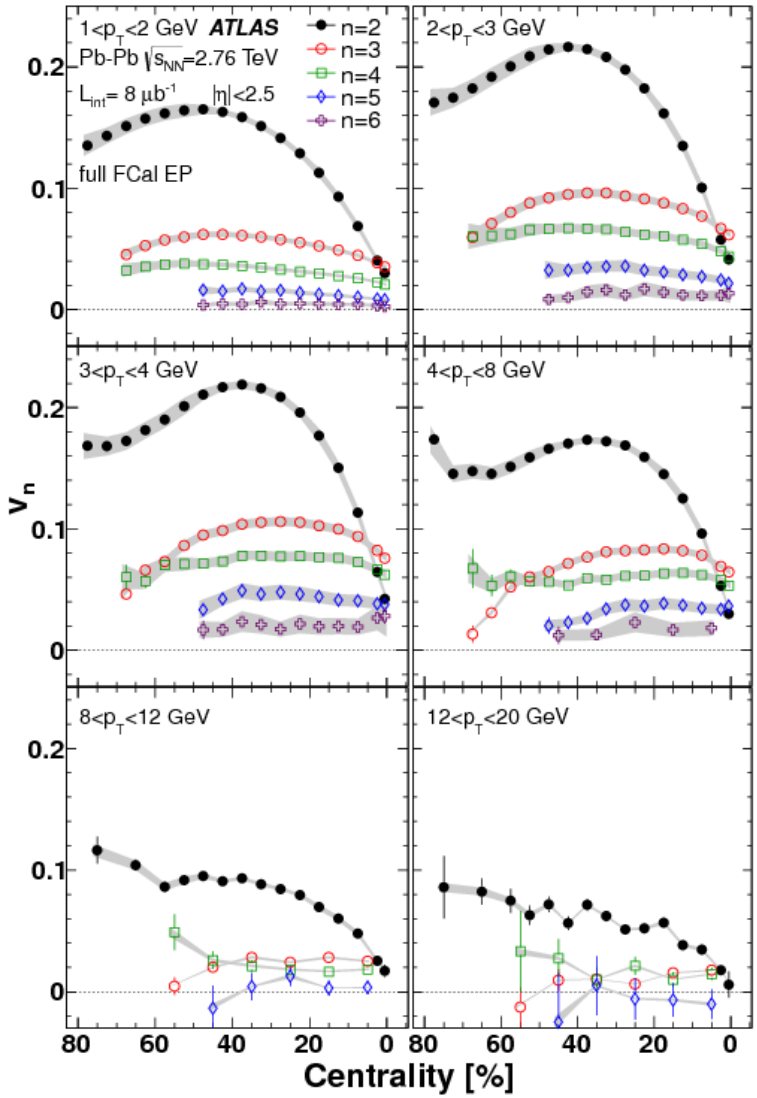
Fourier elliptic term v_2 vs centrality



- Strong centrality dependence, similar across momentum intervals
- Highest momentum bin qualitatively different (large uncertainty)

Comparison with inclusive hadrons





- v_2 is smaller for muons than for inclusive hadrons
- Larger differences at lower p_{T}

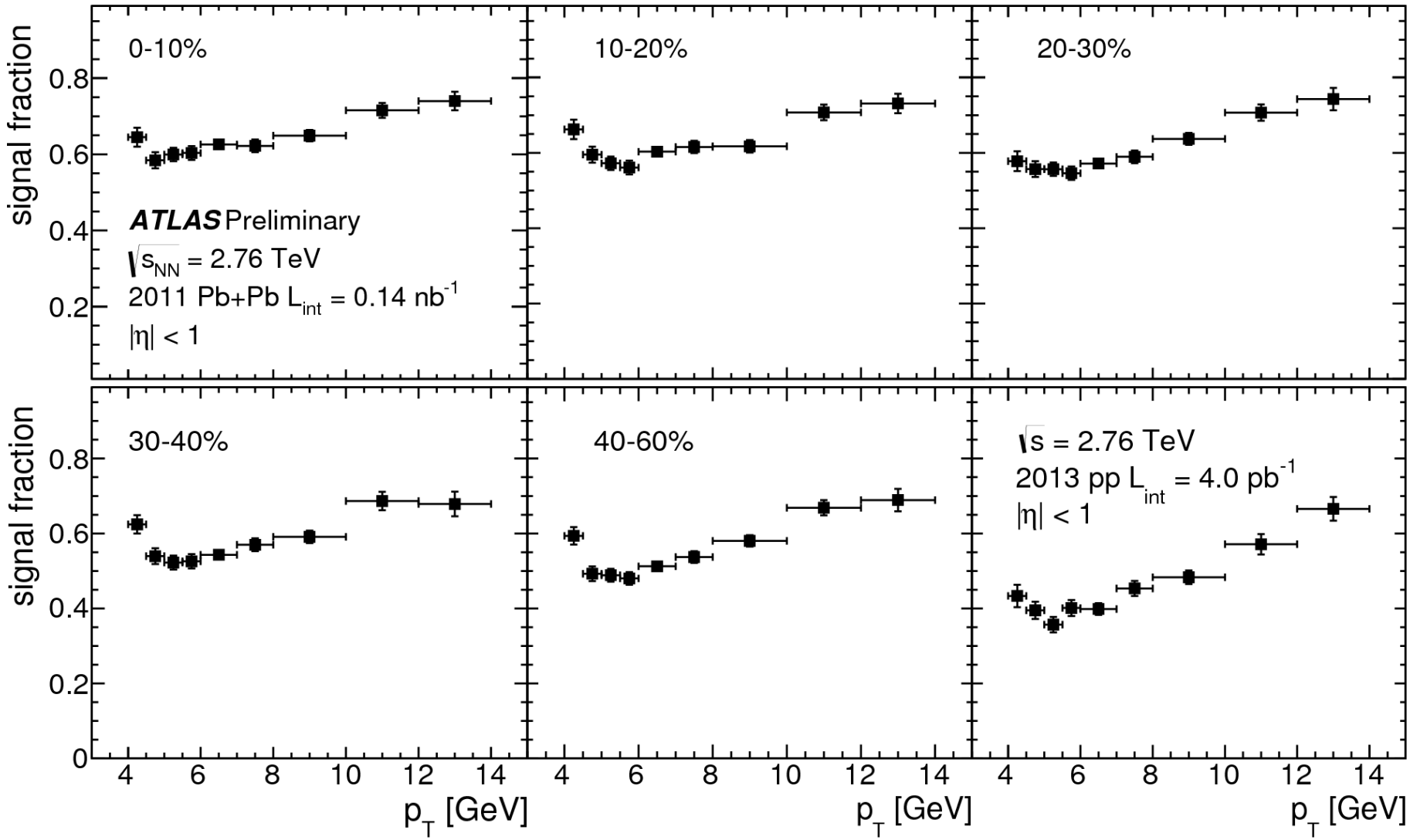
Conclusions

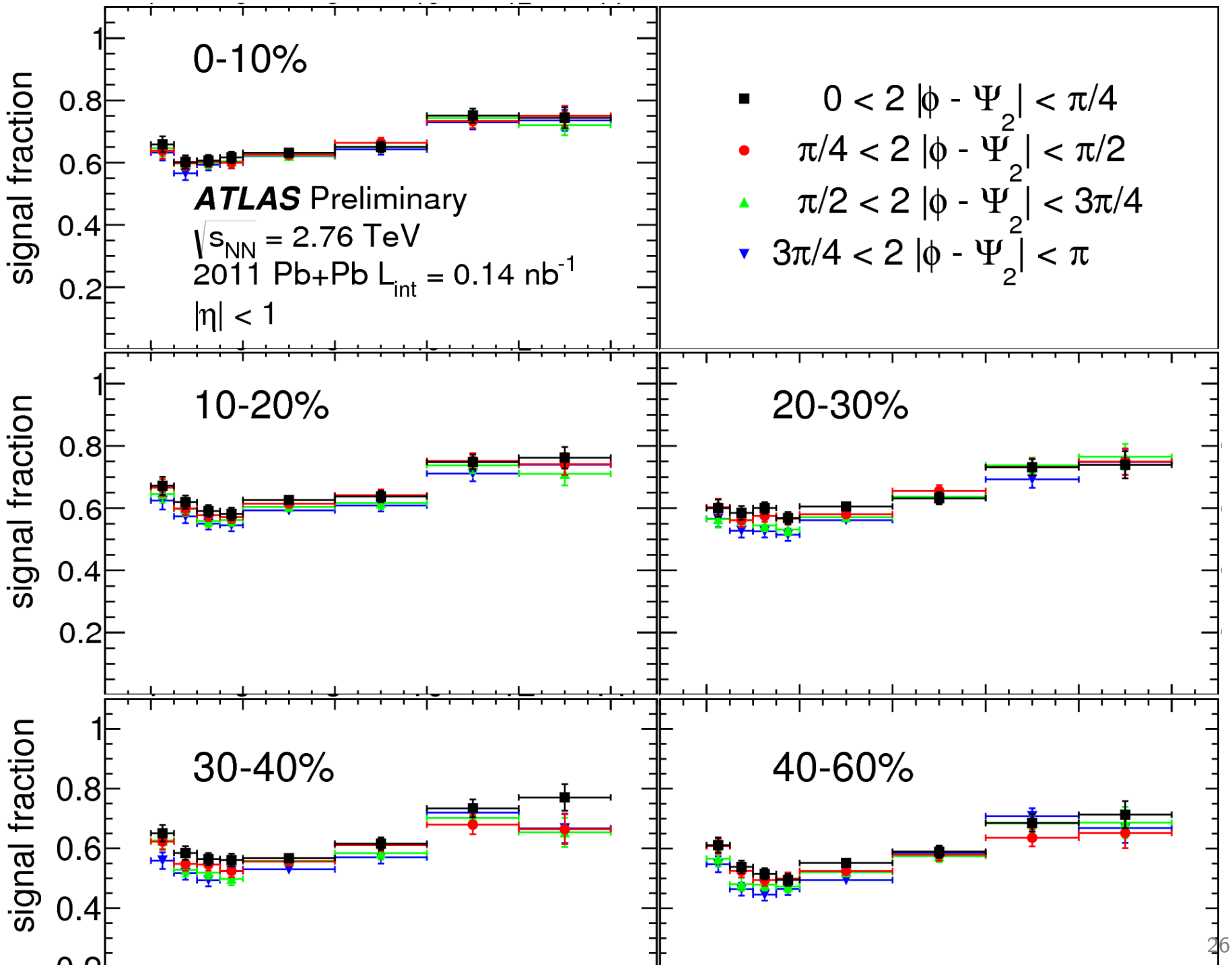
ATLAS measured muons from heavy-flavor decays
in Pb+Pb and pp systems at $\sqrt{s_{NN}} = 2.76$ TeV

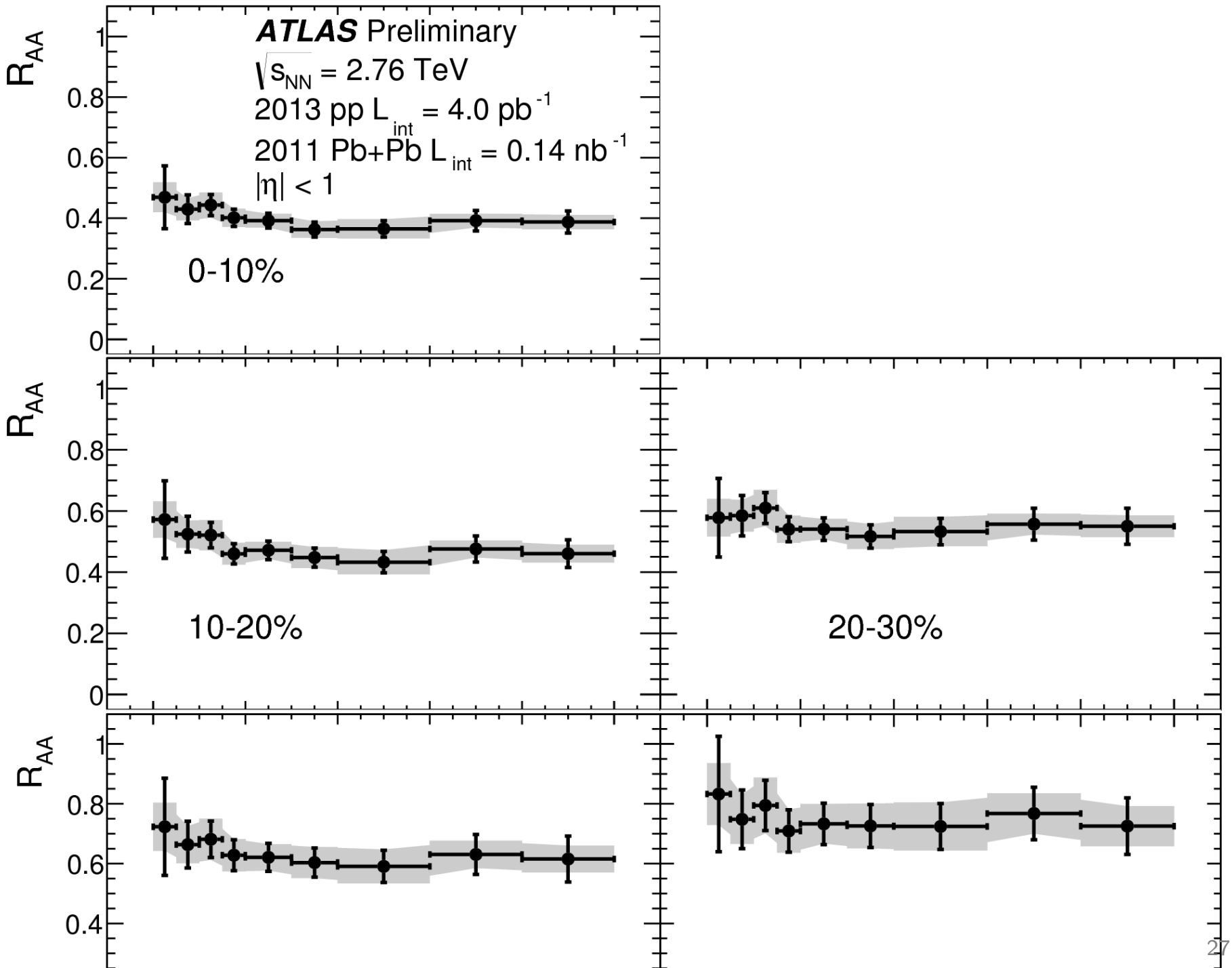
- Strong suppression that depends on centrality, reaches 0.4 at more central collisions
- At most weak momentum dependence
  - Very different from inclusive hadrons, ATLAS **JHEP09(2015)050**
  - Similar to b-jets , CMS **PRL 113 (2014) 132301**
  - Similar to measurements at forward rapidity, ALICE **Phys.Rev.Lett. 109 (2012) 112301**
- Strong anisotropy visible with strong momentum and centrality dependence

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

BACKUP SLIDES


0-10%
10-20%
20-30%
30-40%
40-60%
signal fraction
ATLAS Preliminary
√sNN = 2.76 TeV
2011 Pb+Pb Lint = 0.14 nb-1
|η| < 1
√s = 2.76 TeV
2013 pp Lint = 4.0 pb-1
|η| < 1
pT [GeV]


0-10%
10-20%
20-30%
30-40%
40-60%
signal fraction
ATLAS Preliminary
√sNN = 2.76 TeV
2011 Pb+Pb Lint = 0.14 nb-1
|η| < 1
0 < 2 |φ - Ψ2| < π/4
π/4 < 2 |φ - Ψ2| < π/2
π/2 < 2 |φ - Ψ2| < 3π/4
3π/4 < 2 |φ - Ψ2| < π


ATLAS Preliminary
√s_NN = 2.76 TeV
2013 pp L_int = 4.0 pb^-1
2011 Pb+Pb L_int = 0.14 nb^-1
|η| < 1
0-10%
10-20%
20-30%
R_AA