Measurement of the suppression and v_2 of heavy flavor muons in lead-lead collisions with the ATLAS detector

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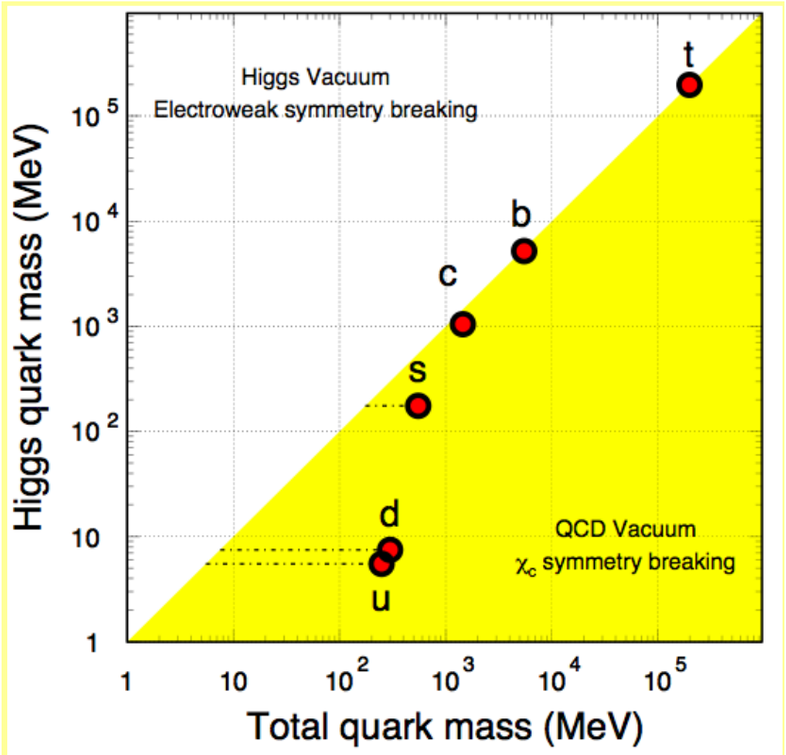
ATLAS EXPERIMENT

Motivation

- c(m~1.3 GeV) and b(m~4.7 GeV). Unique probe to study QGP. Mass not affect by interaction with QCD medium

- Produced at early stage and can used to probe QGP medium properties and evolution

- Suppression and elliptic flow of heavy flavor leptons, originating from semileptonic decays of *D* and *B* mesons, observed at RHIC energy

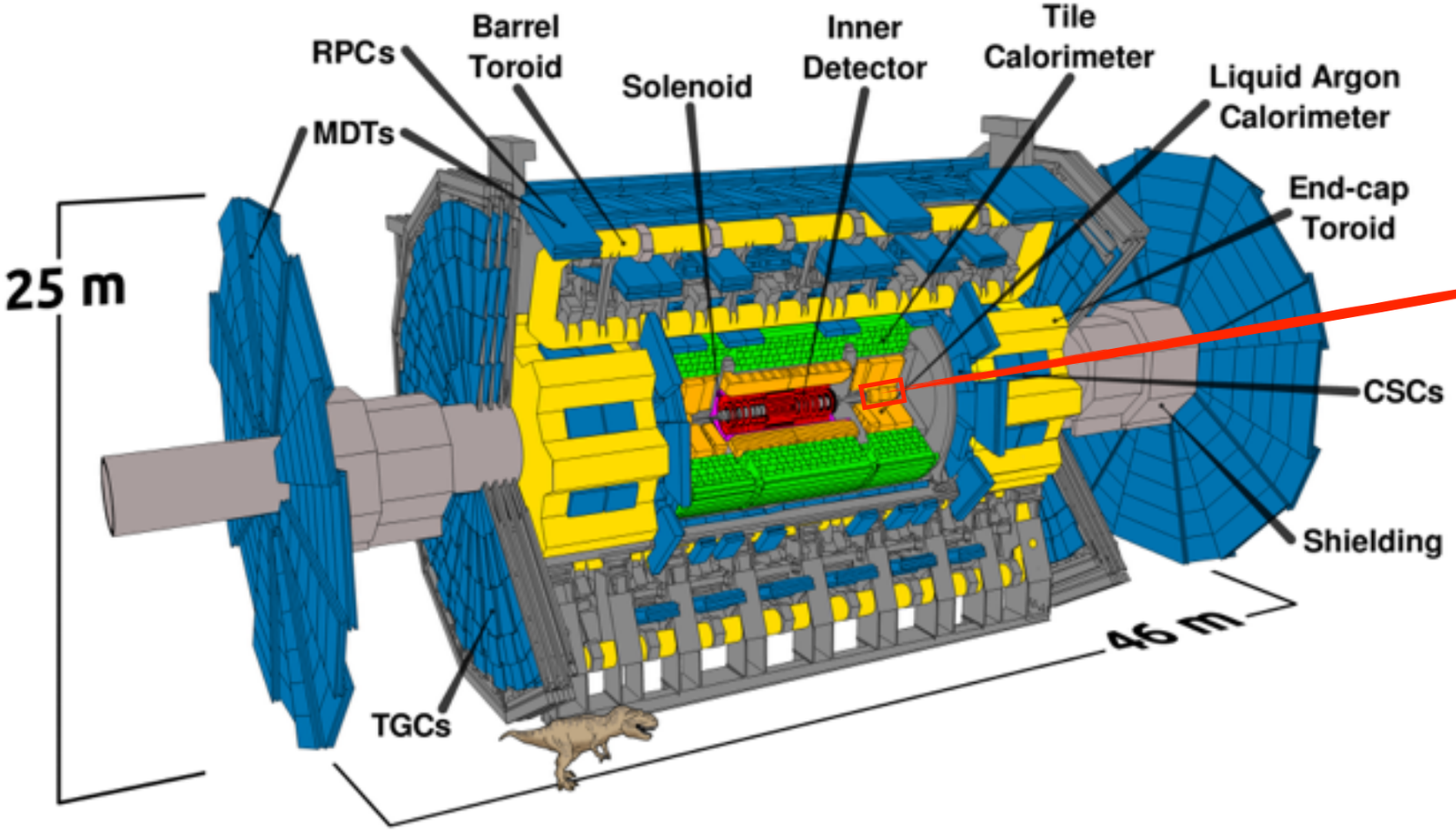


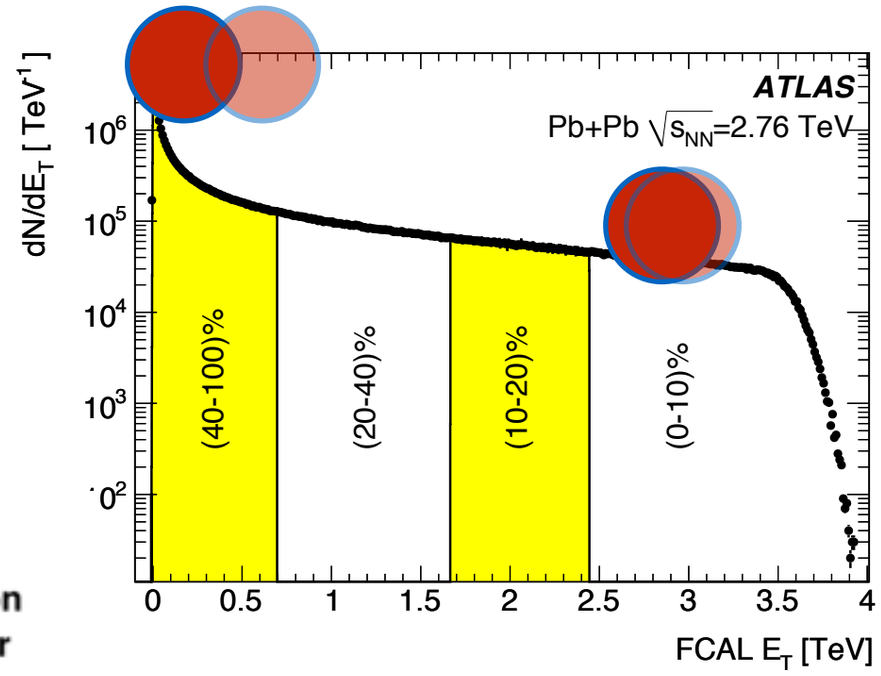
ATLAS detector

Inner Detector (ID) $|\eta| < 2.5$

Calorimeter (CALO) $|\eta| < 4.9$

Muon Spectrometer (MS) $|\eta| < 2.7$

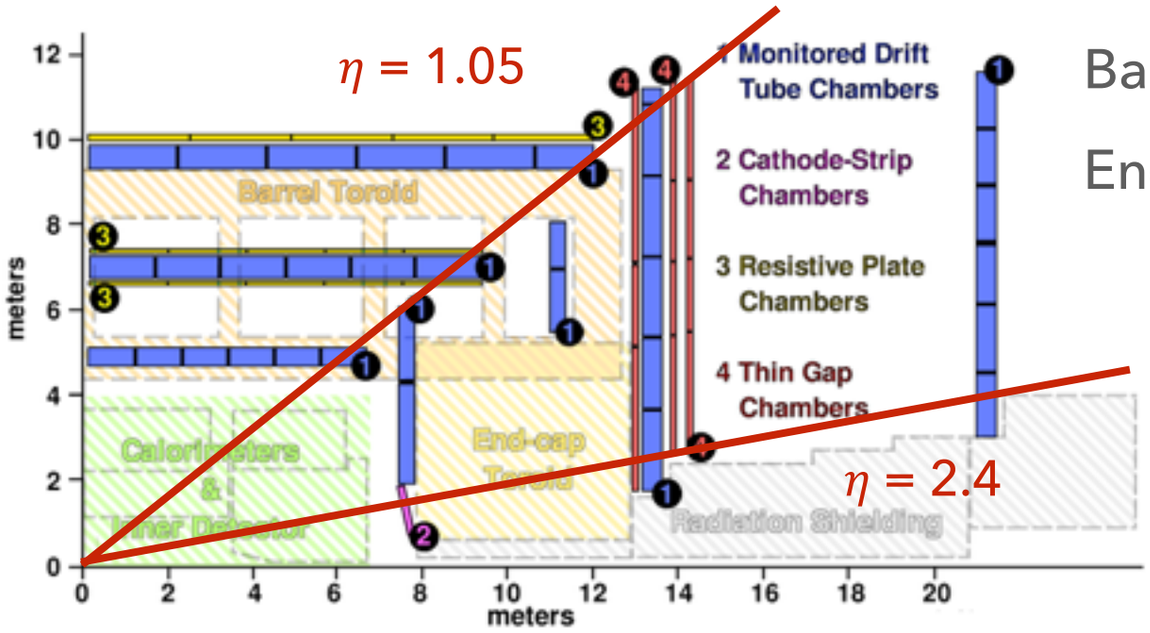




Forward Calorimeter (FCal) $3.1 < |\eta| < 4.9$

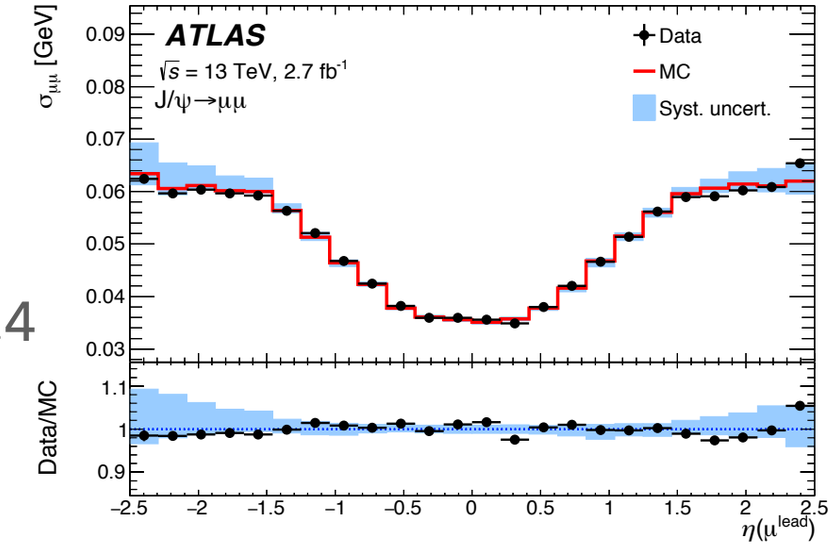
Event characteristics (centrality, event plane)

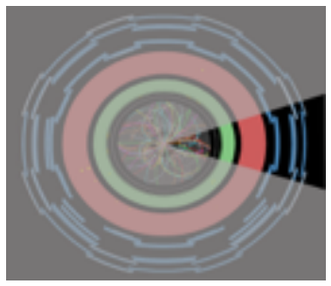
Muon detecting



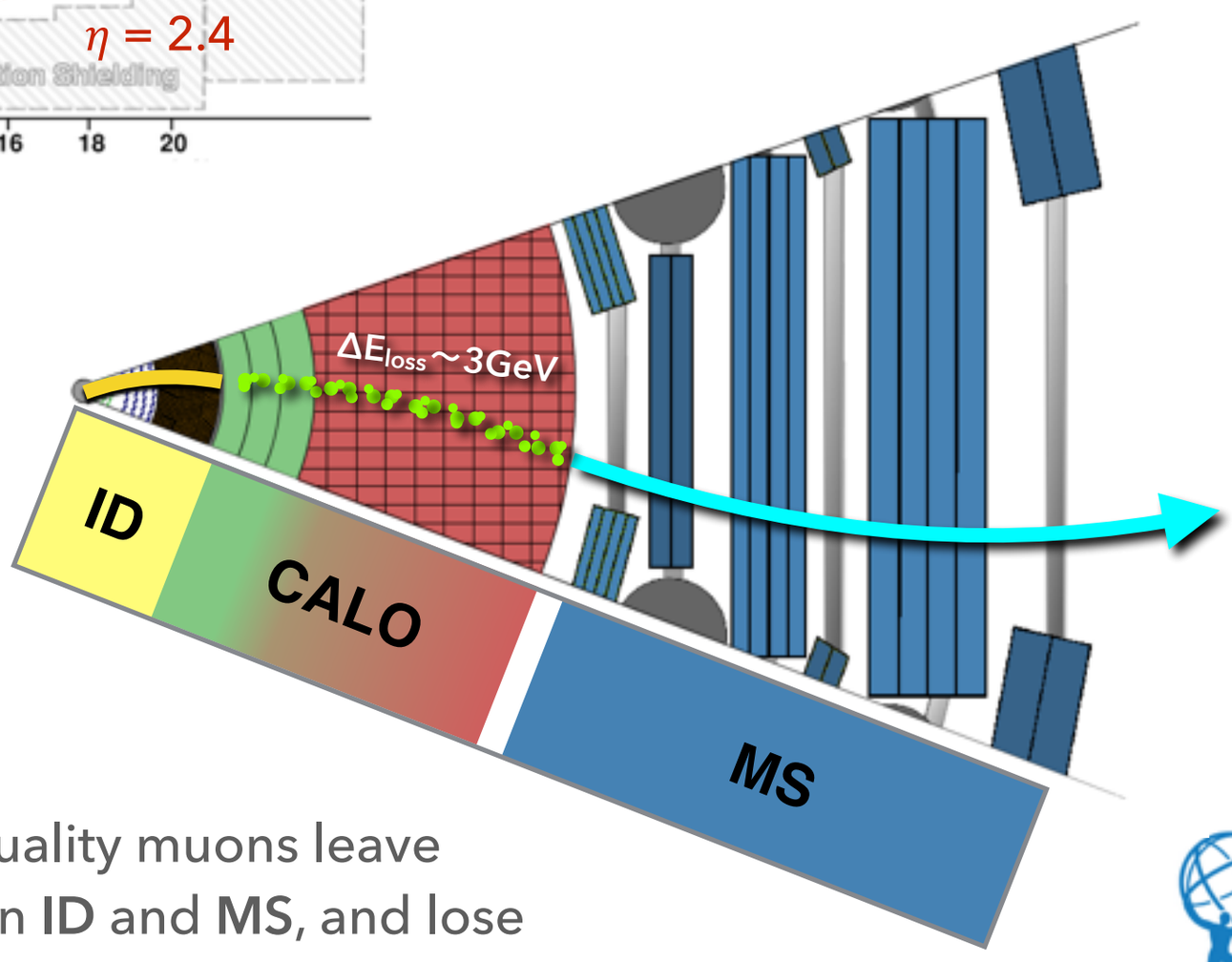
Barrel $|\eta| < 1.05$

End-cap $1.05 < |\eta| < 2.4$



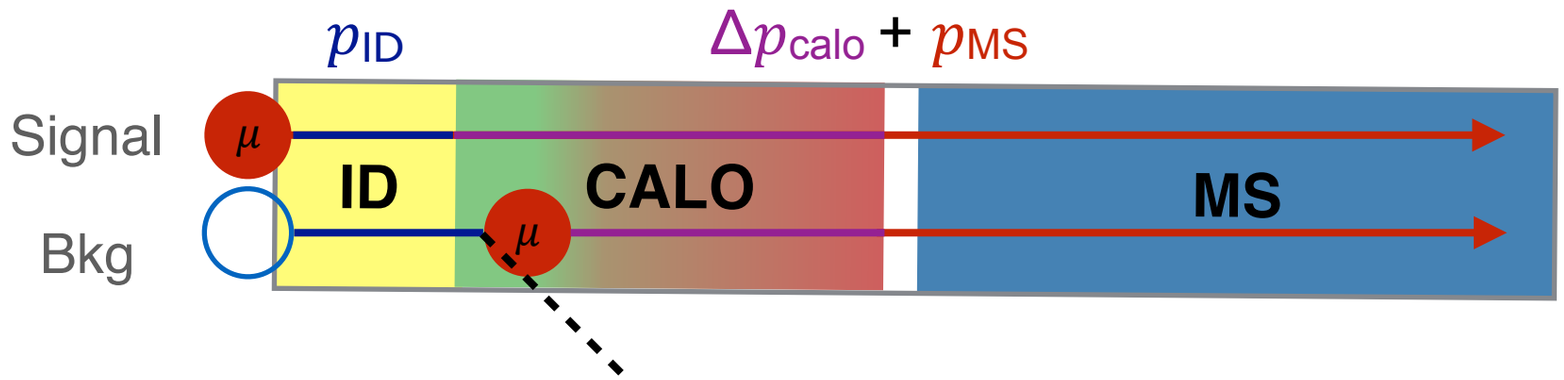


Transverse slice through ATLAS



High quality muons leave tracks in **ID** and **MS**, and lose energy in the **Calorimeter**

Heavy flavor muon extraction

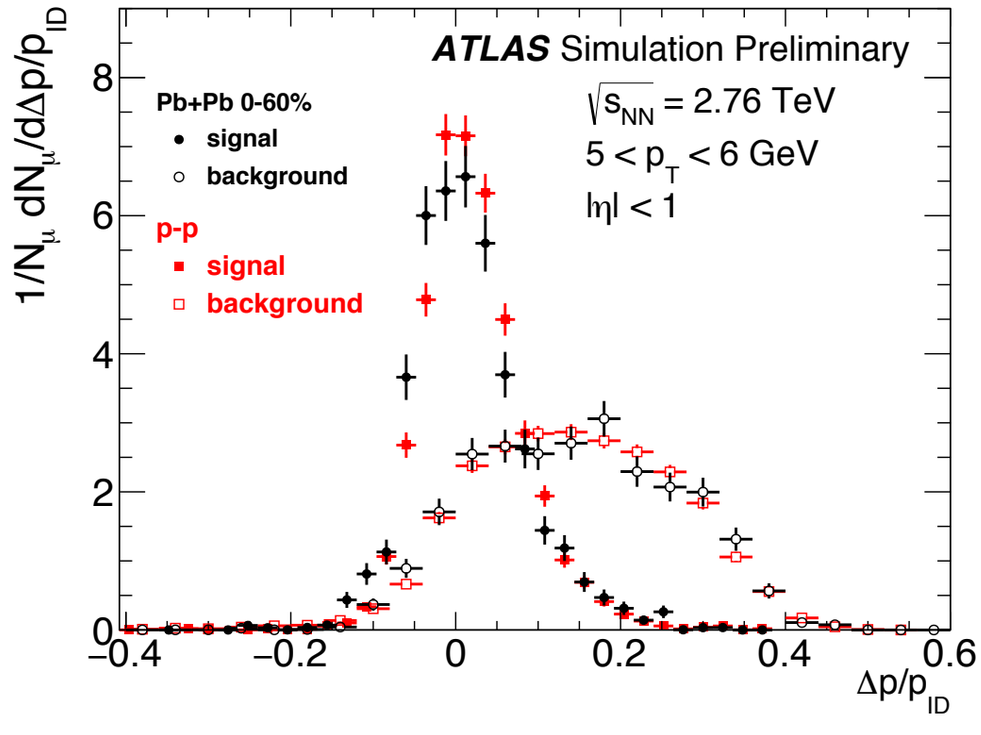


Momentum imbalance:

$$\frac{\Delta p}{p_{\mathrm{ID}}} = \frac{p_{\mathrm{ID}} - (p_{\mathrm{MS}} + \Delta p_{\mathrm{calo}})}{p_{\mathrm{ID}}}$$

- Heavy flavor (**HF**) muons have quite different momentum imbalance distribution from the decay-in-flight
- Sufficient discrimination variable but sensitive to momentum resolution
- Very similar for pp and Pb+Pb, no centrality dependence

ATLAS-CONF-2015-053



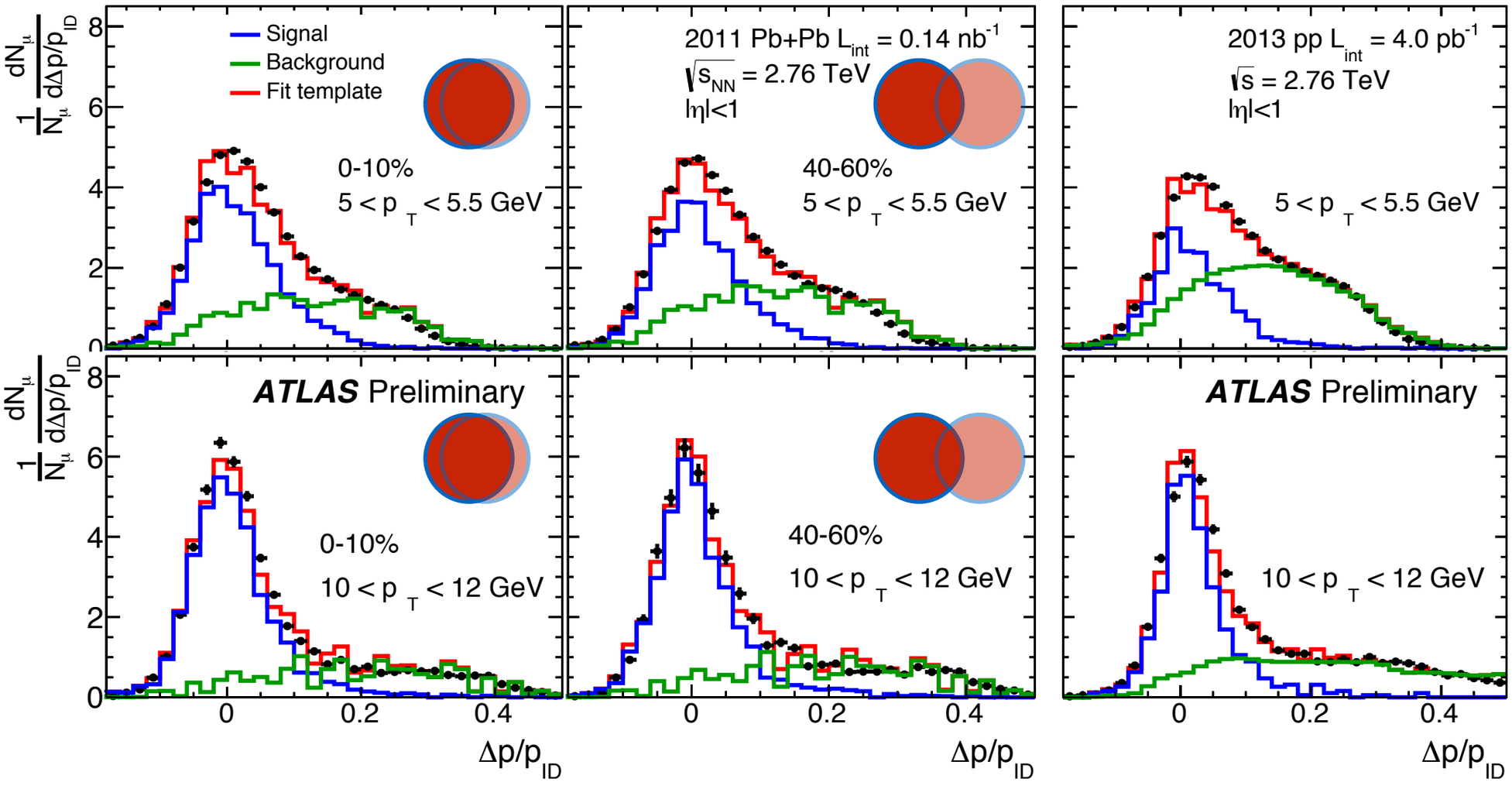
Signal extraction in data

ATLAS-CONF-2015-053

Signal template

Bkg template

Fitted result



- Templates are builded in simulation. Fits performed to extract heavy flavor muon fraction
- Good agreements between data and templates

Other background contamination

- Inclusive single muon p_T spectrum after subtracting decay-in-flight using 2010 *pp* data at 7 TeV
- For p_T < 14 GeV, other sources of background are negligible
- HF muon fiducial volume:

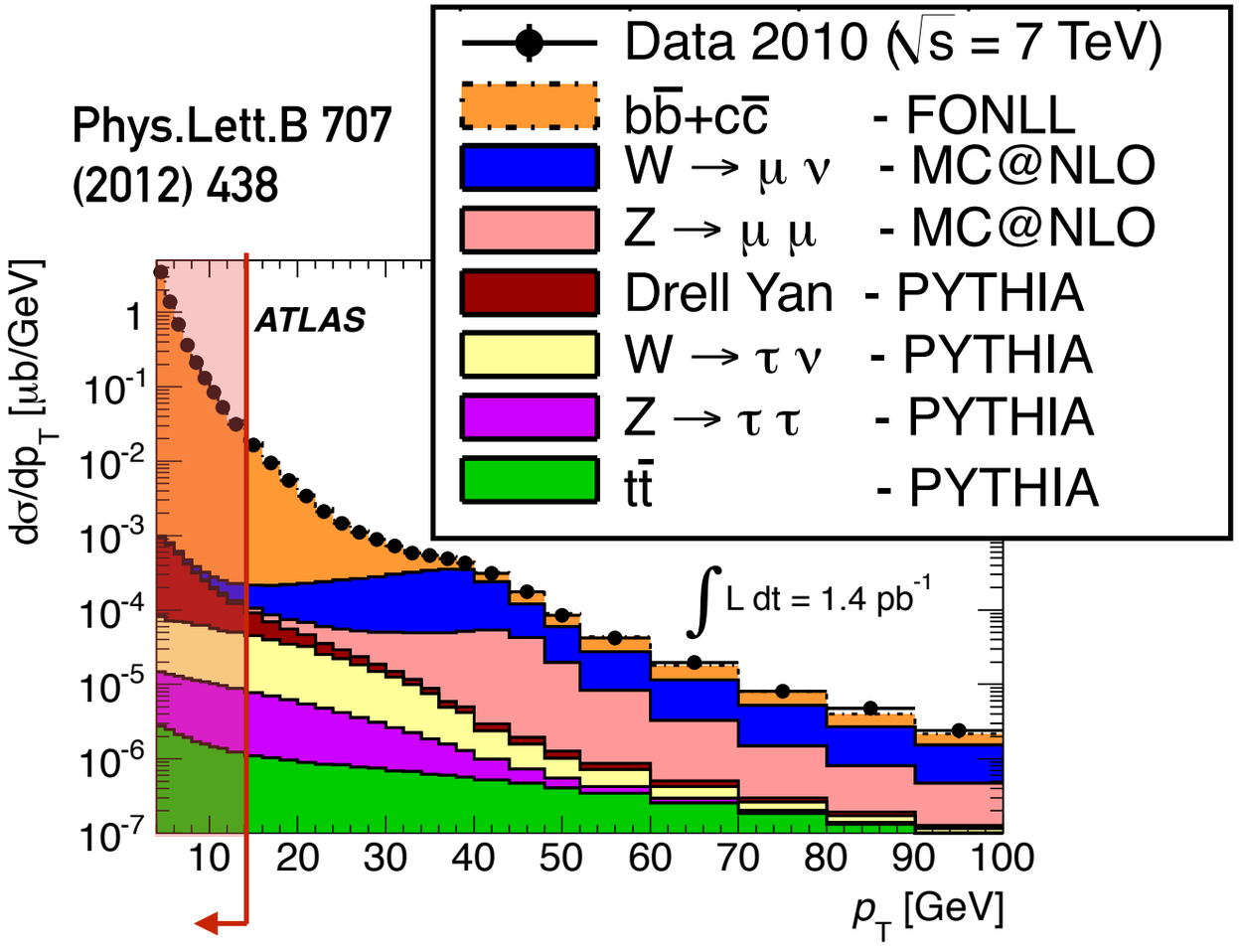
$$4 < p_T < 14 \text{ GeV}$$

$$|\eta| < 1.0$$

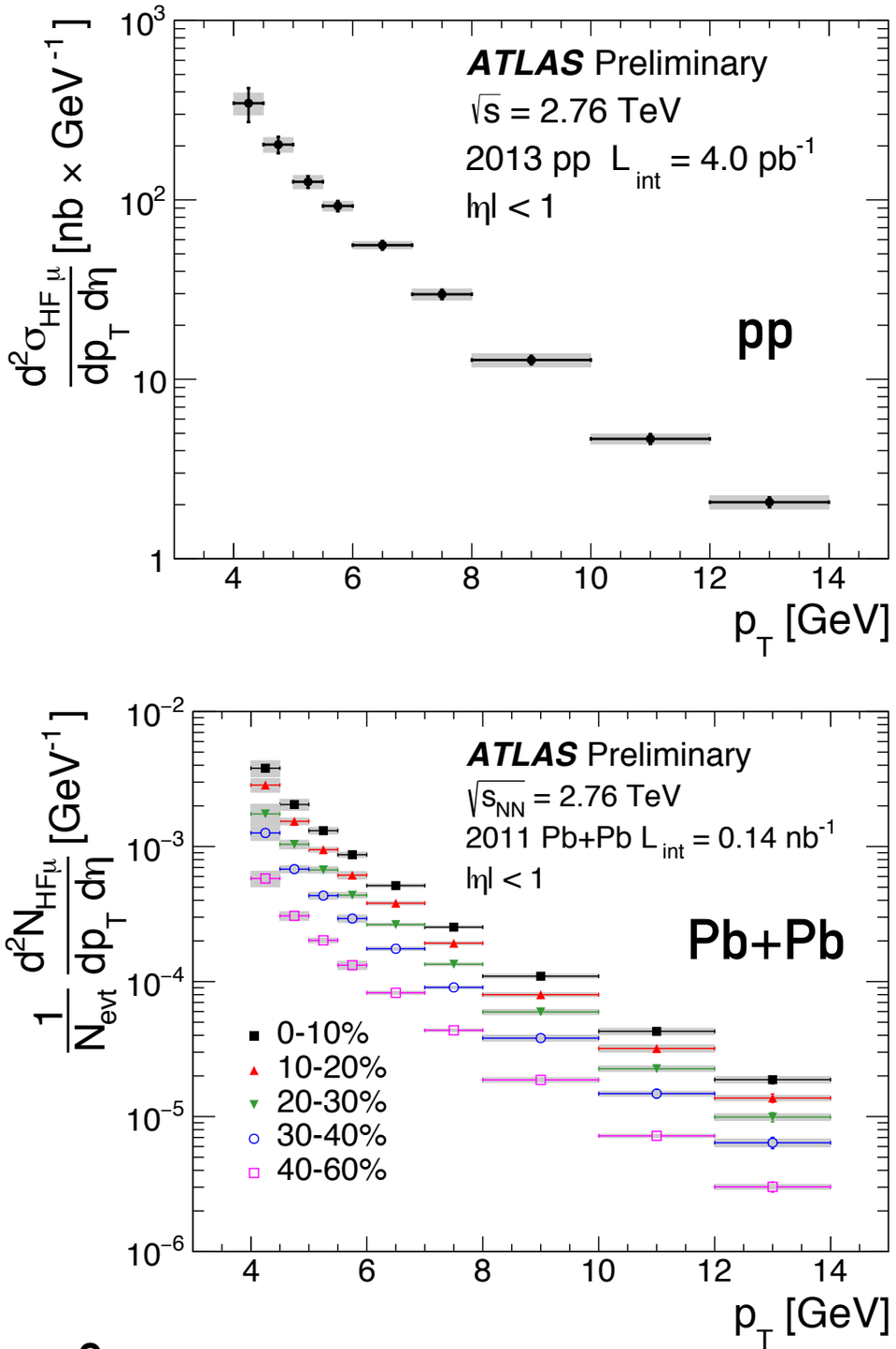
Best momentum resolution

Signal purity ~100%

Small systematic uncertainty



HF muon production



- HF muon differential fiducial cross section in *pp*:

$$\frac{\mathrm{d}^2\sigma_{\mathrm{HF}\mu}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}\eta} = \frac{1}{\mathcal{L}}\frac{\Delta N_\mu f^{\mathrm{sig}}}{\Delta p_{\mathrm{T}}\Delta\eta}\frac{1}{\varepsilon_{\mathrm{trig}}\varepsilon_{\mathrm{reco}}}$$

- HF muon differential fiducial per-event yields in Pb+Pb:

$$\frac{1}{N_{\mathrm{evt}}}\frac{\mathrm{d}^2 N_{\mathrm{HF}\mu}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}\eta}\bigg|_{\mathrm{cent}} = \frac{1}{N_{\mathrm{evt}}^{\mathrm{cent}}}\frac{\Delta N_\mu^{\mathrm{cent}} f^{\mathrm{sig}}}{\Delta p_{\mathrm{T}}\Delta\eta}\frac{1}{\varepsilon_{\mathrm{trig}}\varepsilon_{\mathrm{reco}}}$$

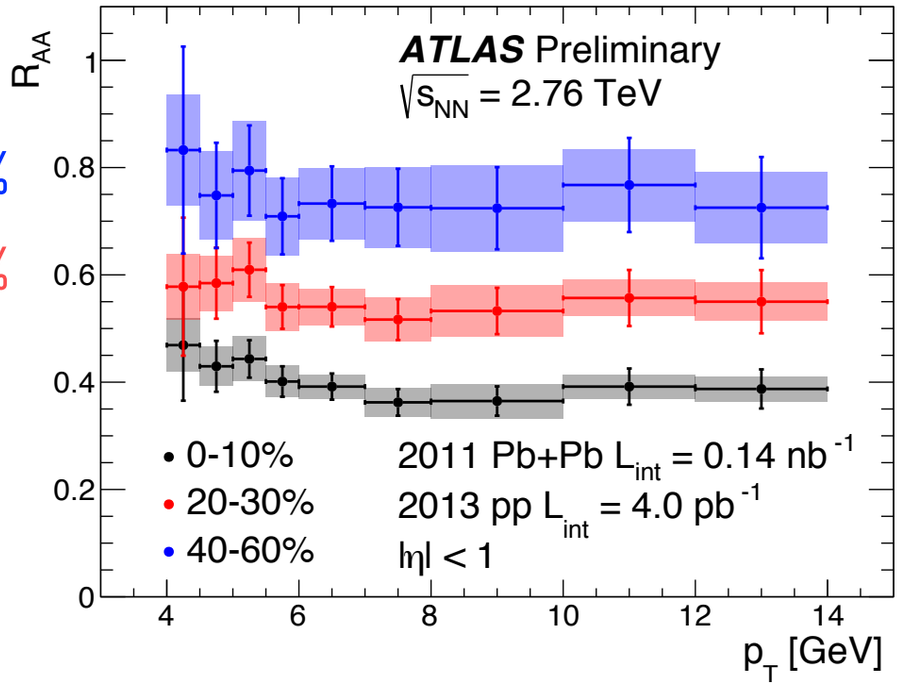
Corrected for muon trigger and reconstruction efficiency per muon

Nuclear modification factor

40-60%

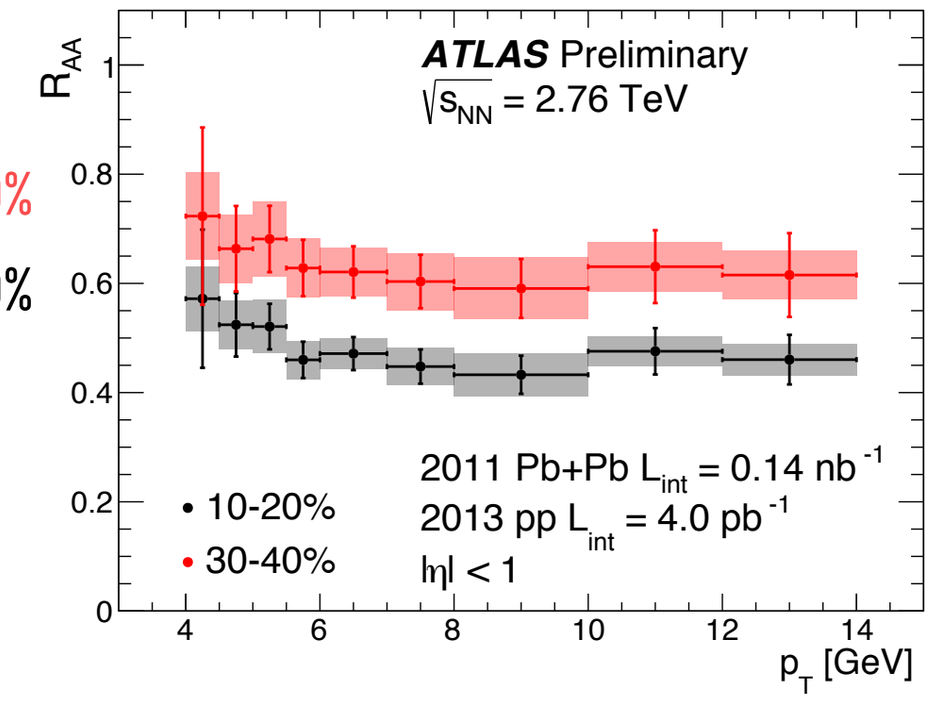
20-30%

0-10%



30-40%

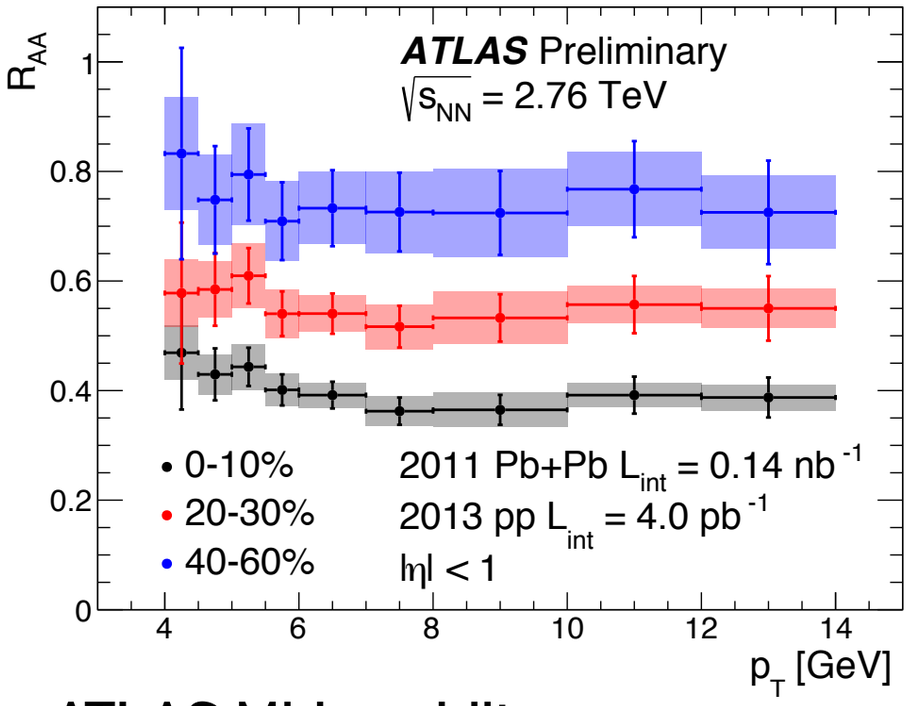
10-20%



$$R_{\mathrm{AA}} = \frac{1}{\langle T_{\mathrm{AA}} \rangle} \frac{(1/N_{\mathrm{evt}})\mathrm{d}^2N/(\mathrm{d}p_{\mathrm{T}}\mathrm{d}\eta)}{\mathrm{d}^2\sigma^{pp}/(\mathrm{d}p_{\mathrm{T}}\mathrm{d}\eta)}$$

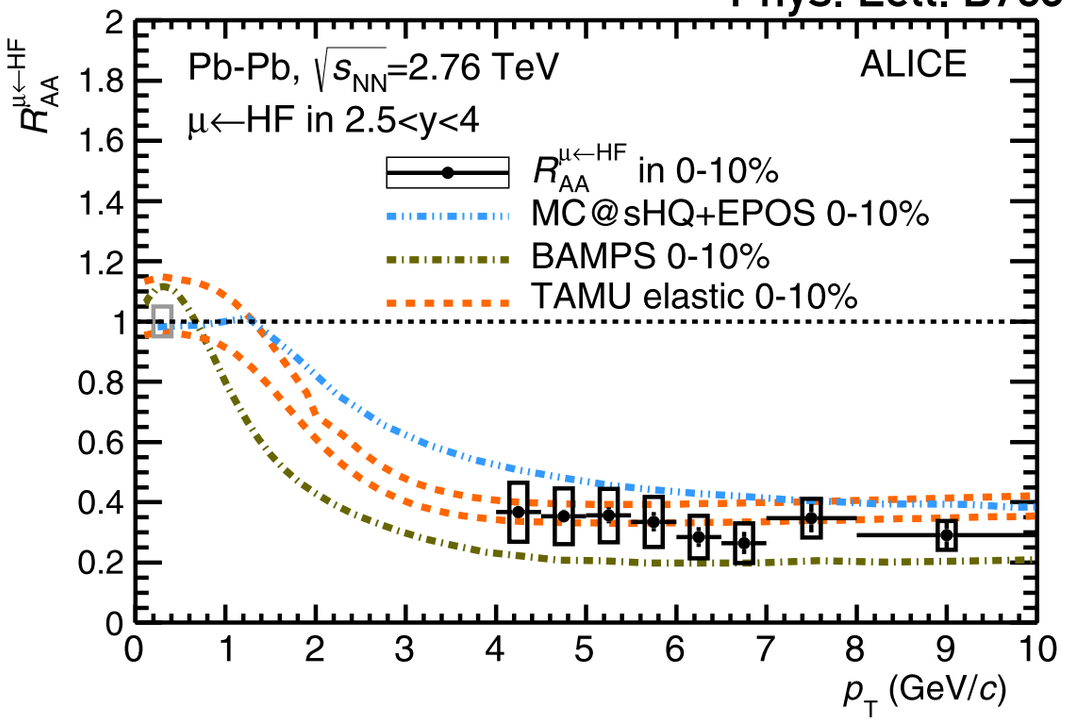
- HF muon R_{AA} measured in 5 centrality slices covers 0-60%
- Significant suppression (0.4) in most central
- Strong centrality dependence. No strong dependence on p_{T}

Mid-rapidity vs. forward



ATLAS Mid-rapidity

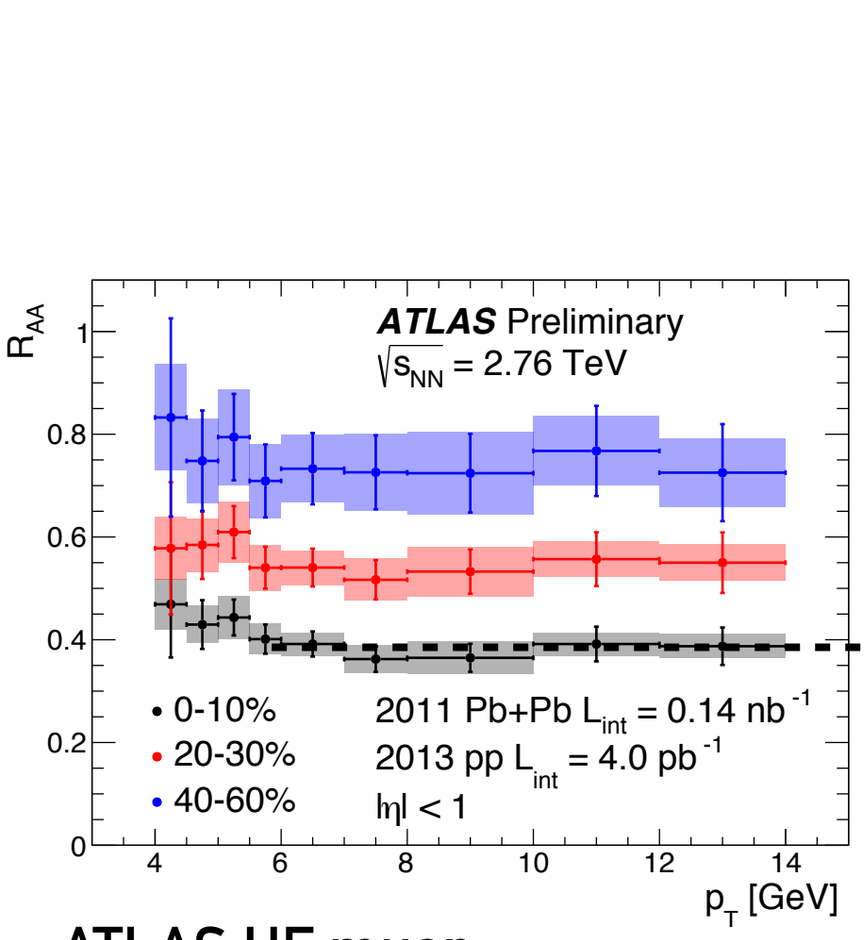
Phys. Lett. B753 (2016) 41



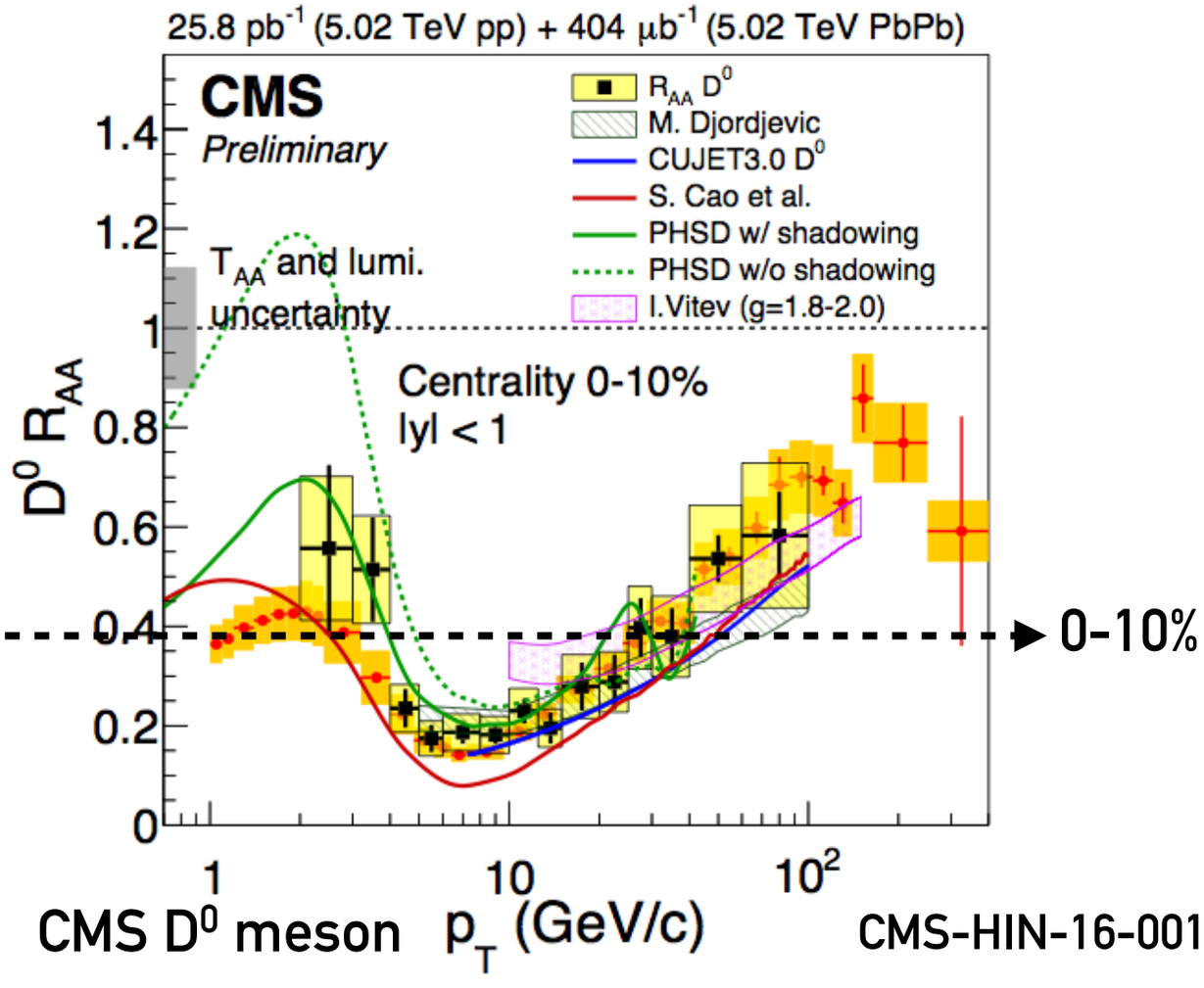
ALICE Forward Rapidity

- Good agreement between ATLAS and ALICE
- No obvious rapidity dependence

HF muon vs. D meson



ATLAS HF muon



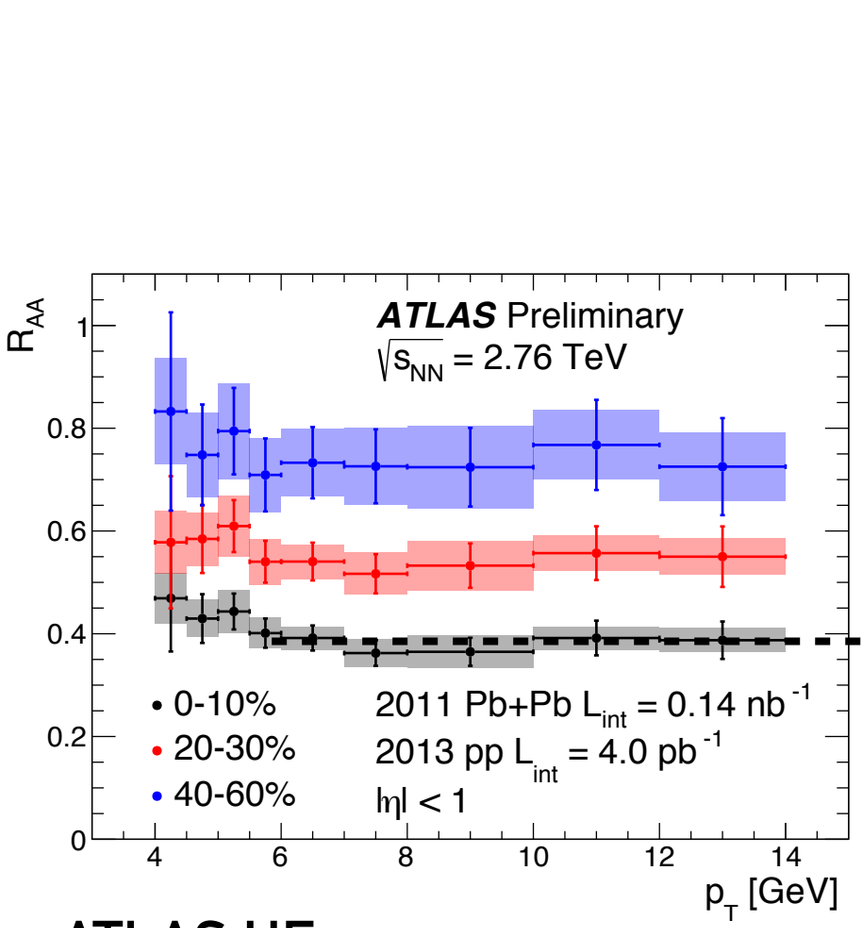
0-10%

CMS D^0 meson

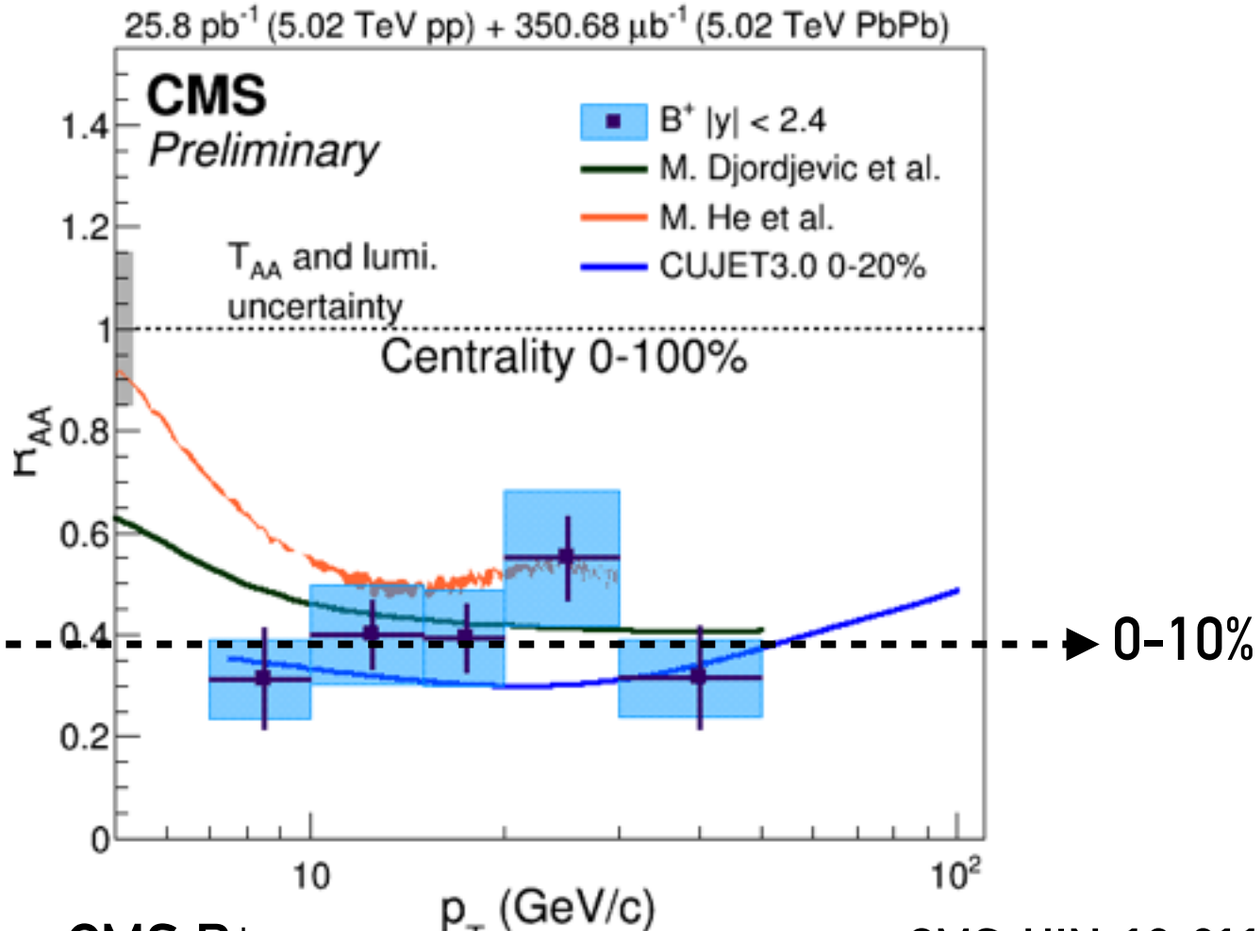
CMS-HIN-16-001

- Very different behavior compared to the D^0 or inclusive hadron
- Significantly smaller suppression for inclusive HF muons
- Strong momentum dependence for hadrons and D^0

HF muon vs. B meson



ATLAS HF muon

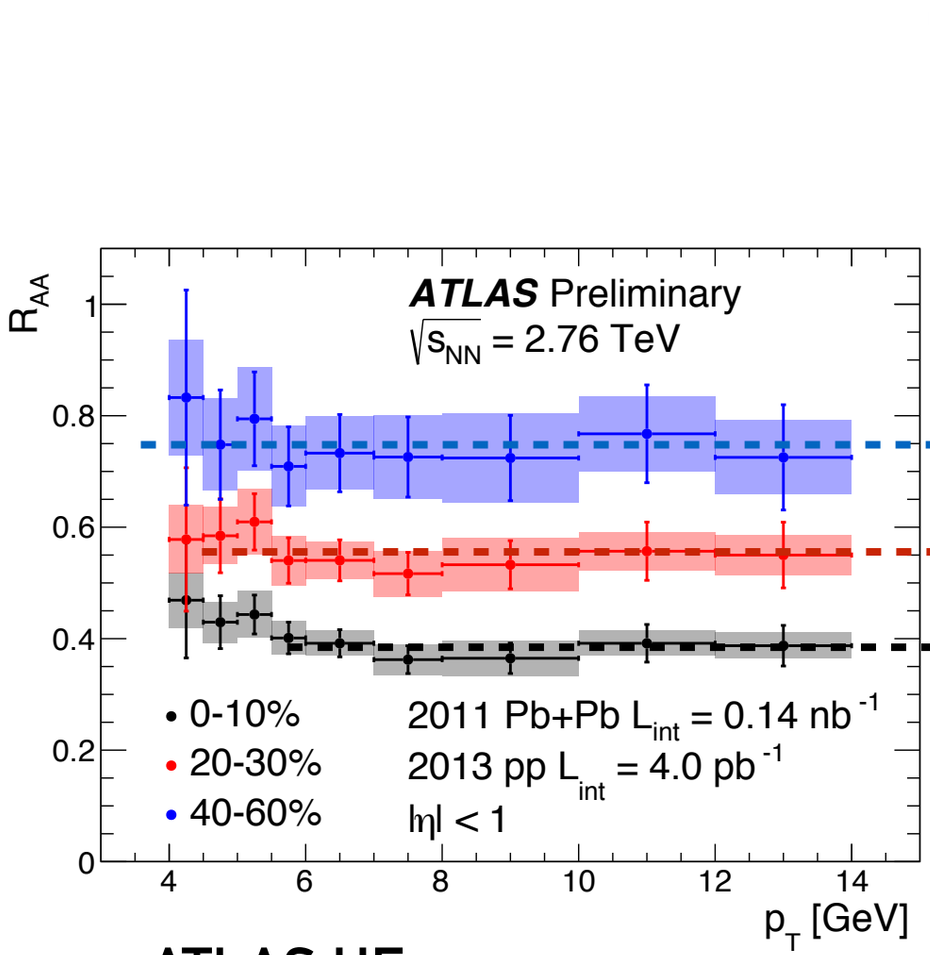


CMS B^+ meson

CMS-HIN-16-011

- Different energy and different centrality
- Similar behavior within uncertainties

HF muon vs. b-jet

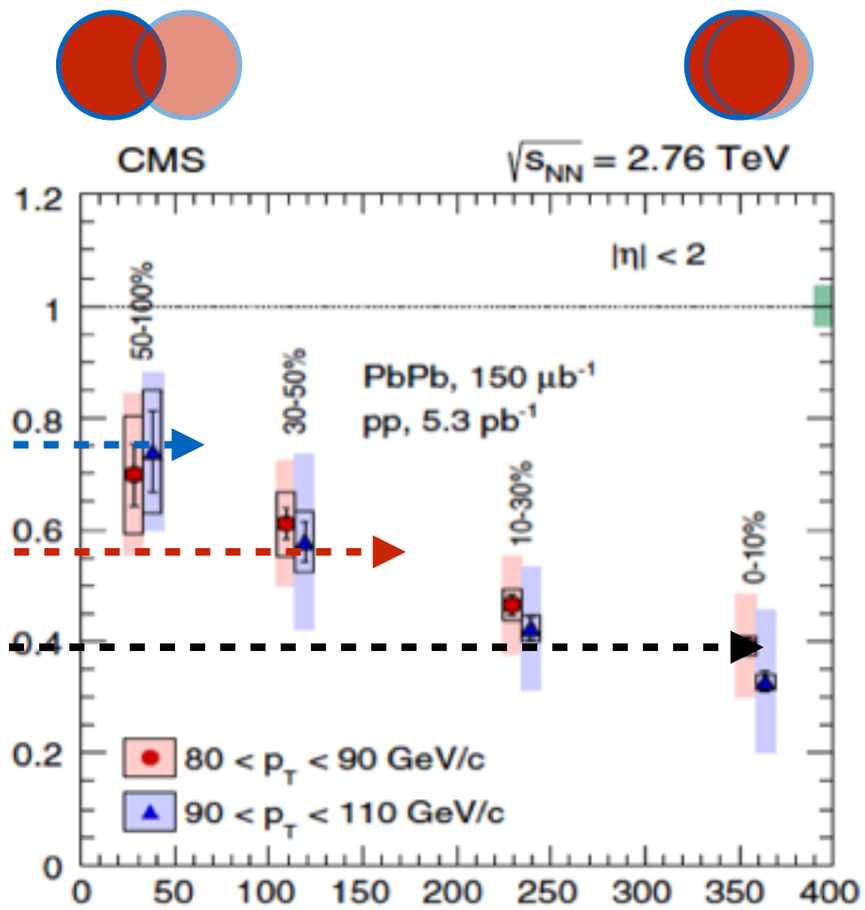


ATLAS HF muon

40-60%

20-30%

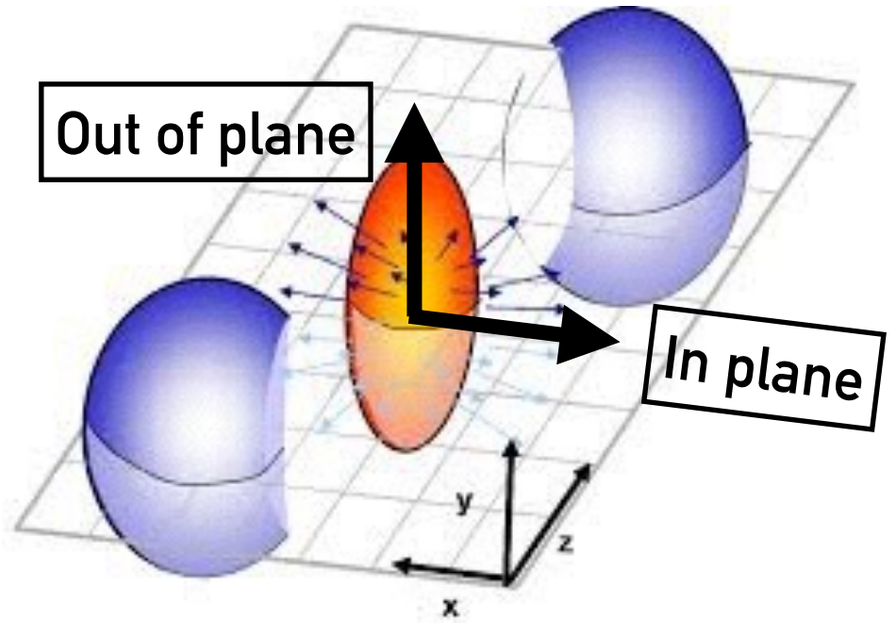
0-10%

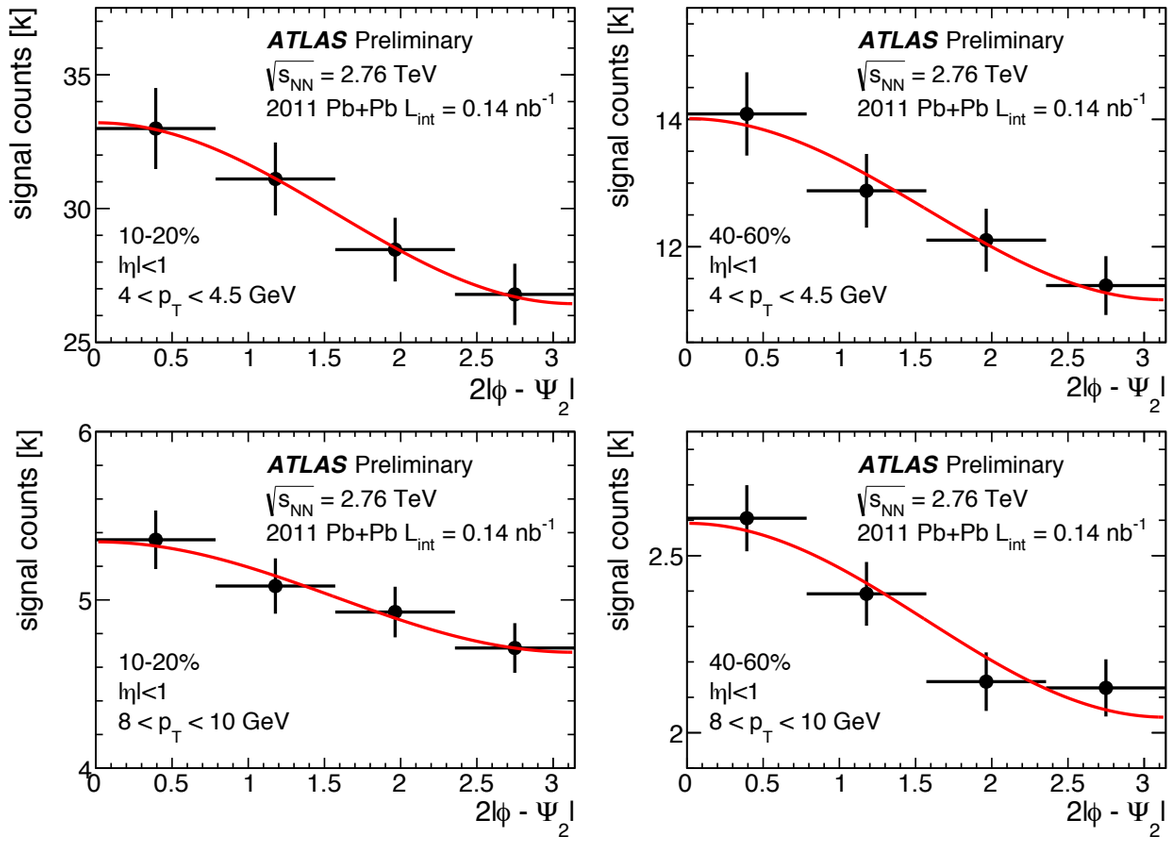


CMS b-jet PRL 113(2014)132301

- Centralities (averaged over measured ranges) are similar
- Weak (or none) p_T dependence in both measurements

Elliptic flow of HF muons





- Event plane method is used to extract HF muon elliptic flow
- Reaction plane angle ψ_2 is determined based on FCal energy deposition
- Decay-in-flight subtracted
- EP resolution correction applied

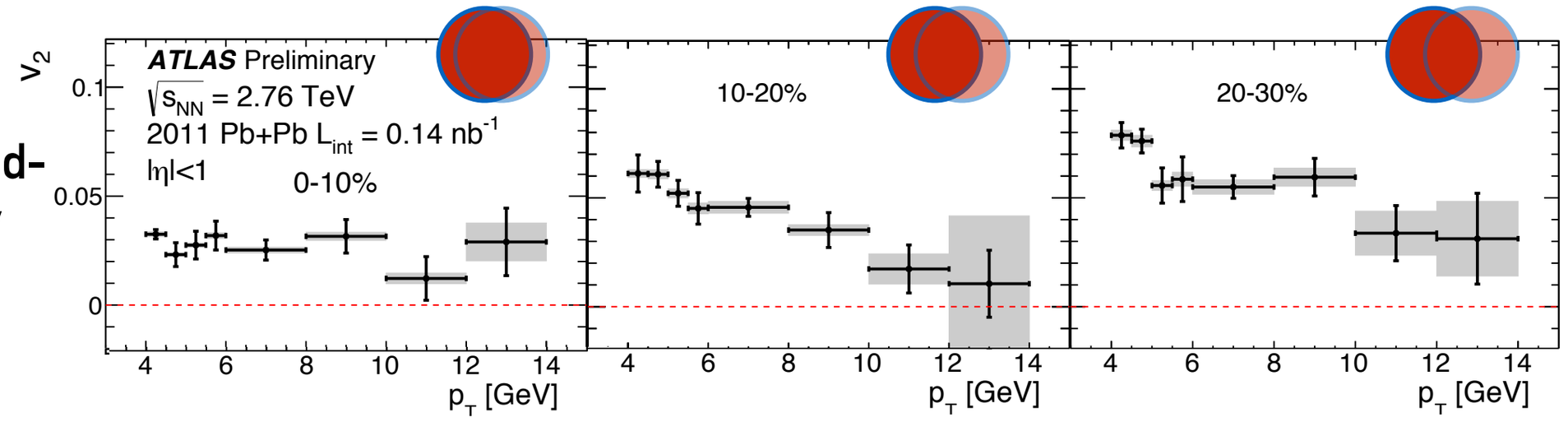
$$\frac{\mathrm{d}N}{\mathrm{d}\phi} = N_0\left[1 + 2v_2^{\mathrm{obs}}\cos(2(\phi - \Psi_2))\right]$$

$$v_2 = \frac{v_2^{\mathrm{obs}}}{\mathrm{Res}\{2\Psi_2\}}$$

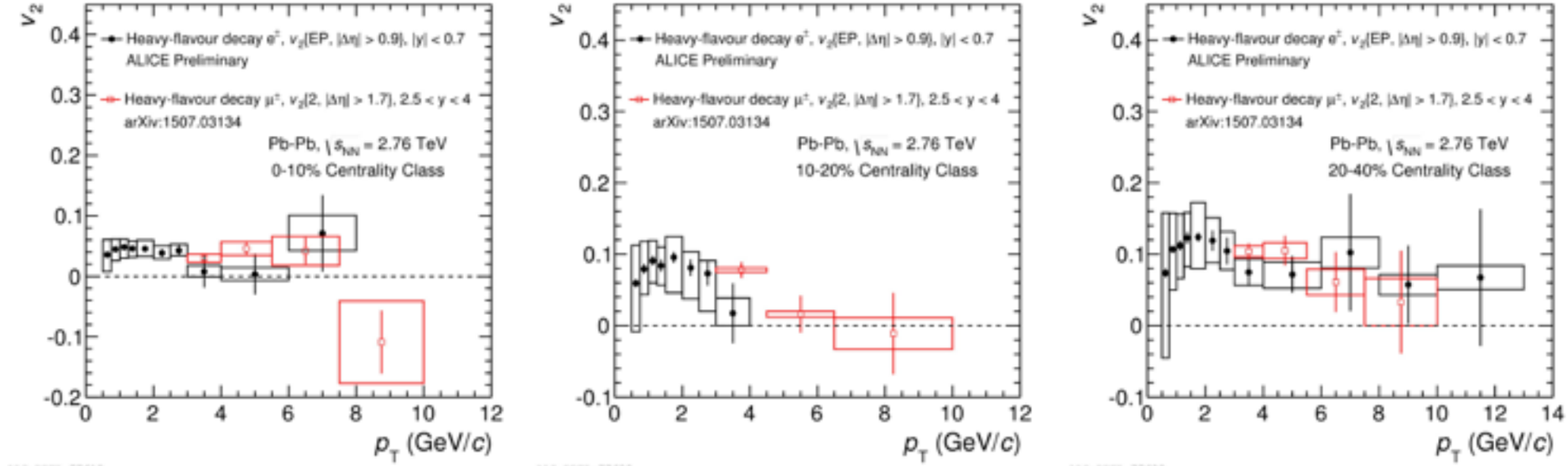
HF muon flow

ATLAS-CONF-2015-053
ALICE Phys.Lett.B 753 (2015) 41

ATLAS Mid-rapidity



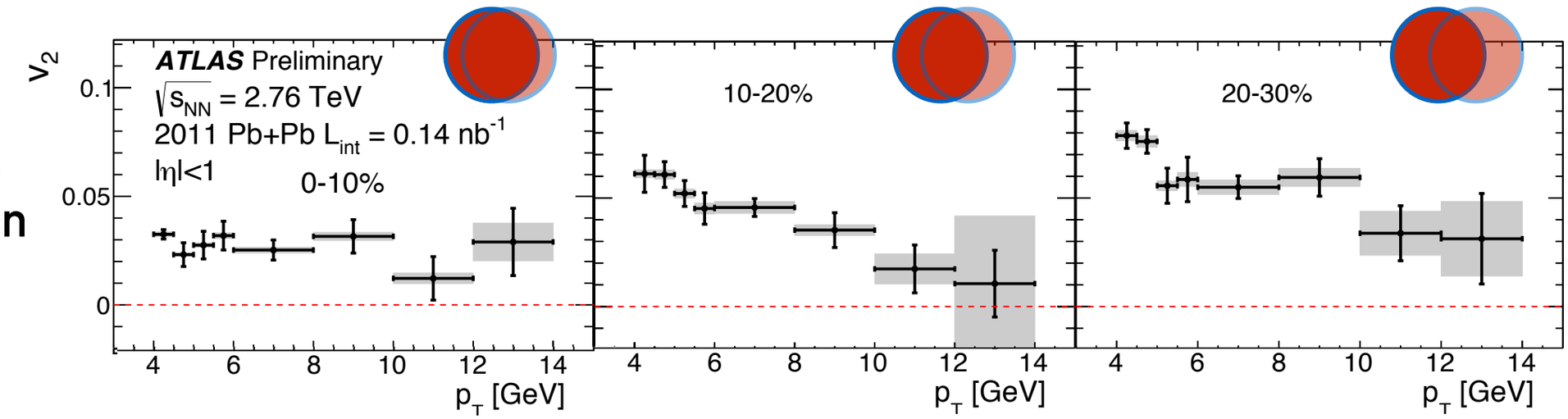
ALICE Forward Rapidity



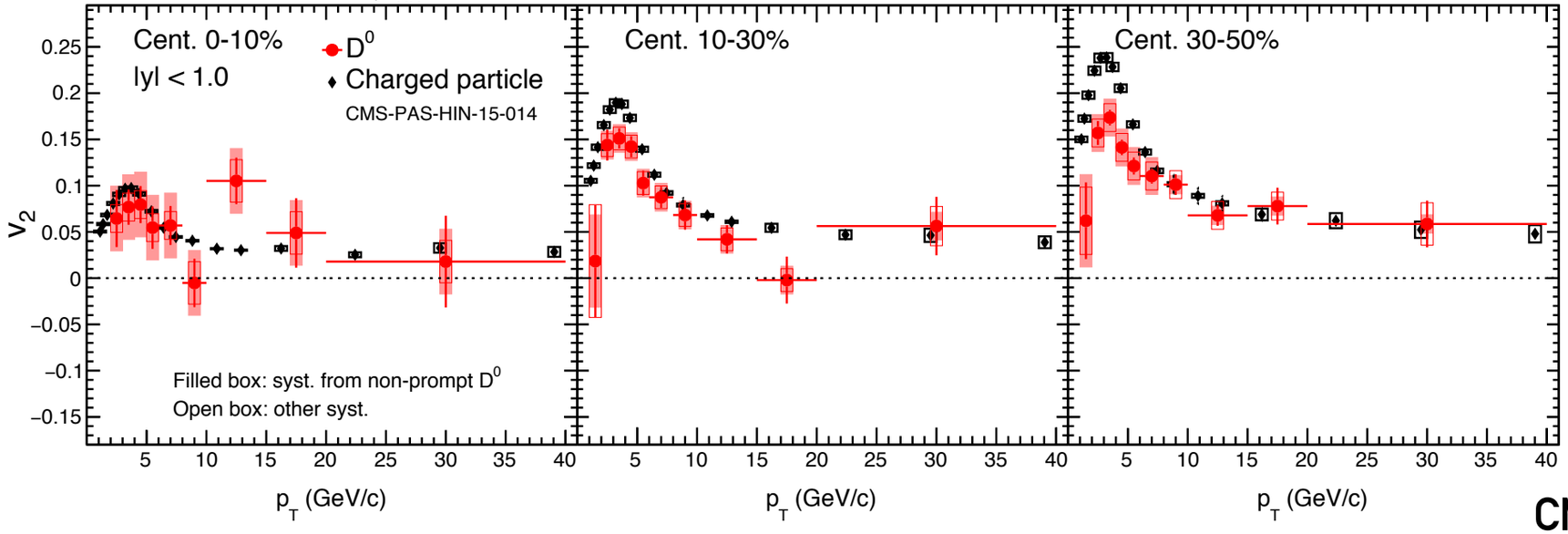
- Significant v_2 (~8%) at lower p_T. Still significant up to p_T ~10 GeV
- Good agreement between ATLAS and ALICE

HF muon flow vs. D^0 flow

ATLAS
HF muon



CMS
D^0 meson



CMS-HIN-16-007

- Similar decrease trend for p_T > 4 GeV
- v_2 (HF muon) < v_2 (D^0)

Summary

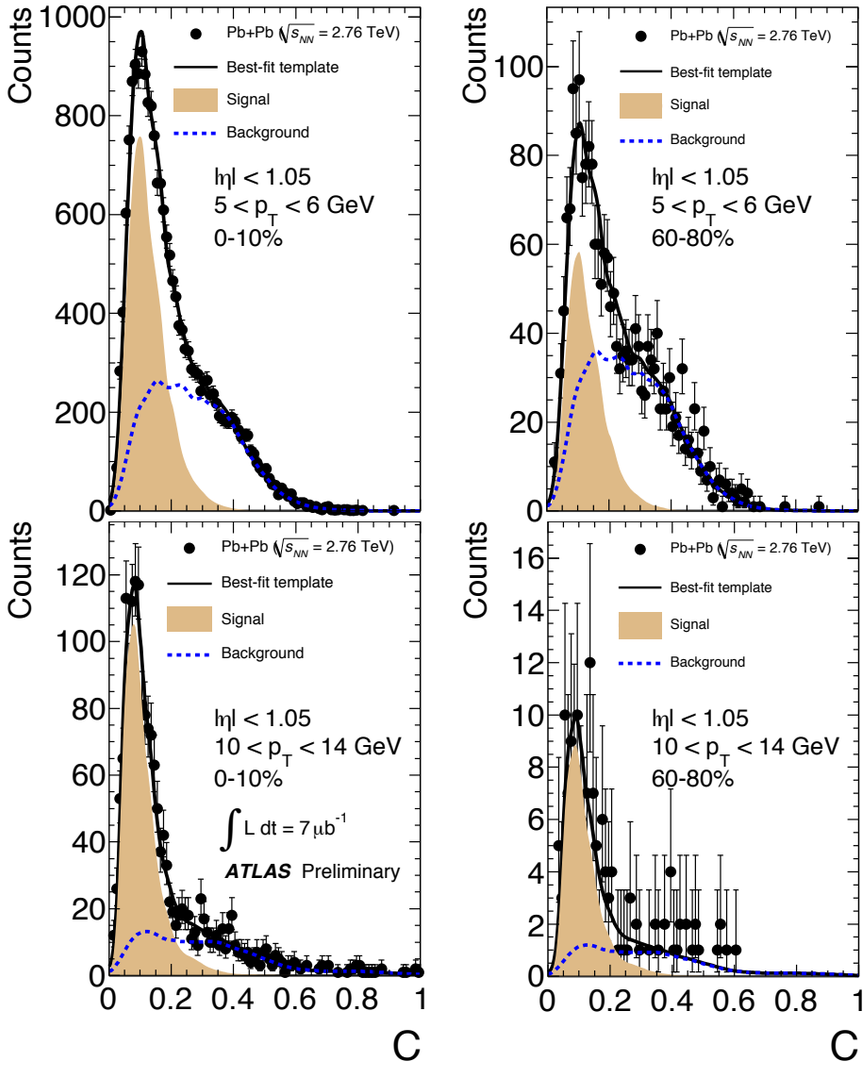
- HF muons found to be suppressed in Pb+Pb collisions with a strong centrality dependence
- HF muon R_{AA} similar with b-jet, but different from D^0 and charge hadron
- Significant non-zero v_2 of HF muons up to 10 GeV. Good agreement between ATLAS and ALICE.
- v_2 (HF muon) < v_2 (D^0)

Thanks!

ATLAS EXPERIMENT

BACKUP

HF muon extraction for 2010 data



ATLAS-CONF-2012-050

$$\frac{\Delta p}{p_{\mathrm{ID}}} = \frac{p_{\mathrm{ID}} - (p_{\mathrm{MS}} + \Delta p_{\mathrm{calo}})}{p_{\mathrm{ID}}}$$

momentum imbalance

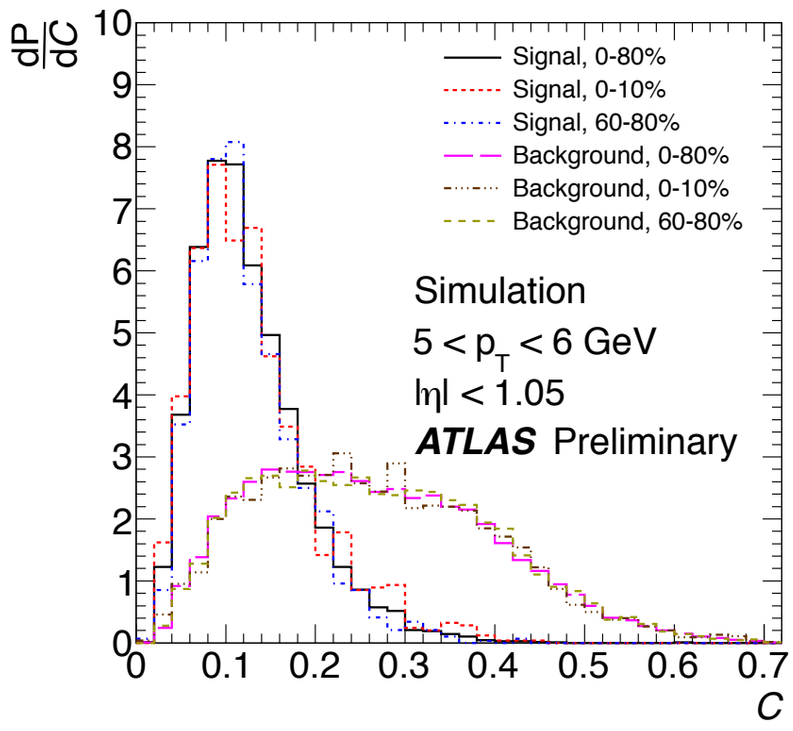
$$S = \frac{1}{\sqrt{n}}\left(\sum_{1}^{j} s_i - \sum_{j+1}^{k} s_i\right) \quad s_i = q\frac{\Delta\phi_i}{\phi_i^{msc}}$$

scattering angle significance

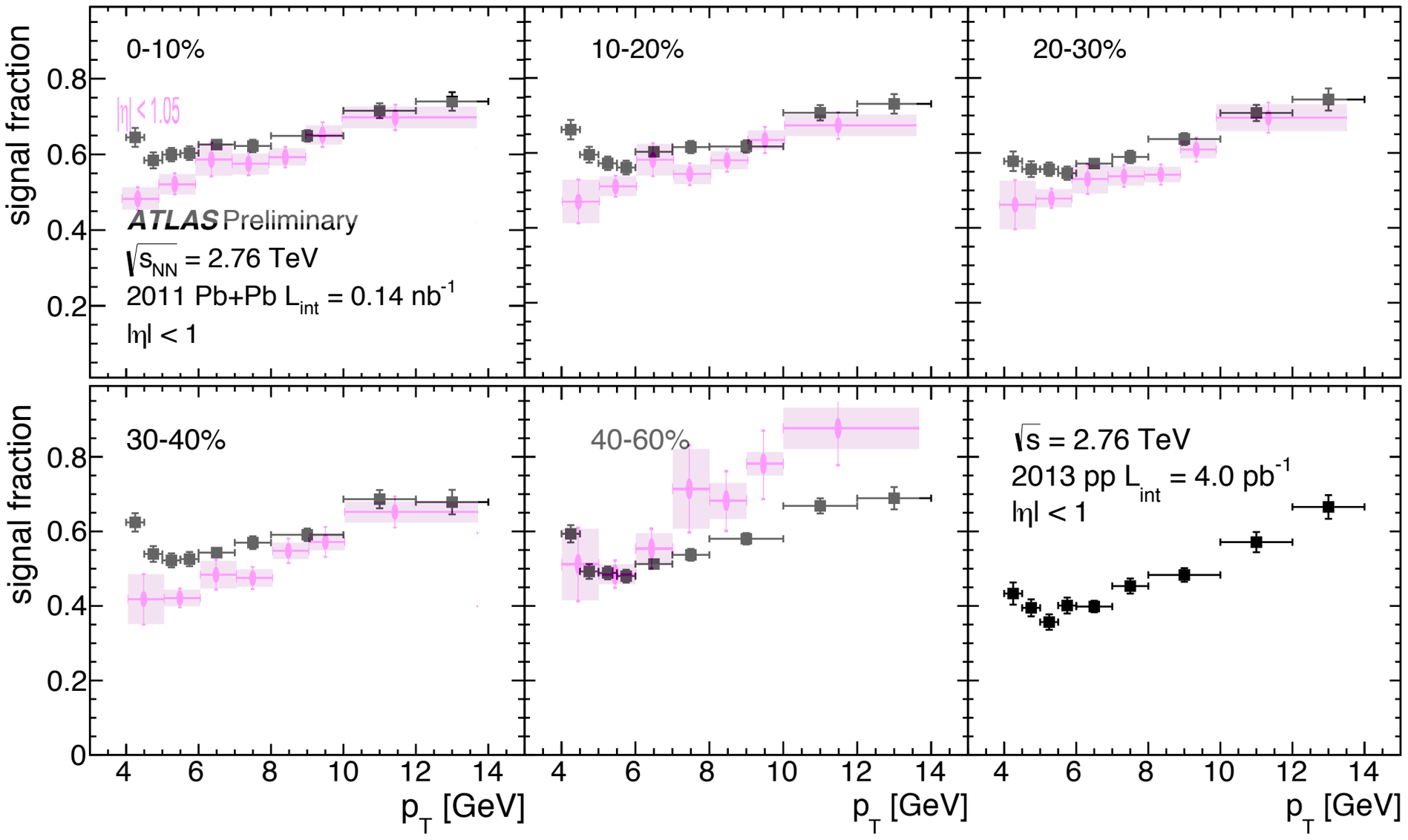
decay-in-flight would case large deflection, useful for very low p_T (≲ 4 GeV)

$$C = \left|\frac{\Delta p_{\mathrm{loss}}}{p_{\mathrm{ID}}}\right| + 0.07 \cdot S$$

Composite



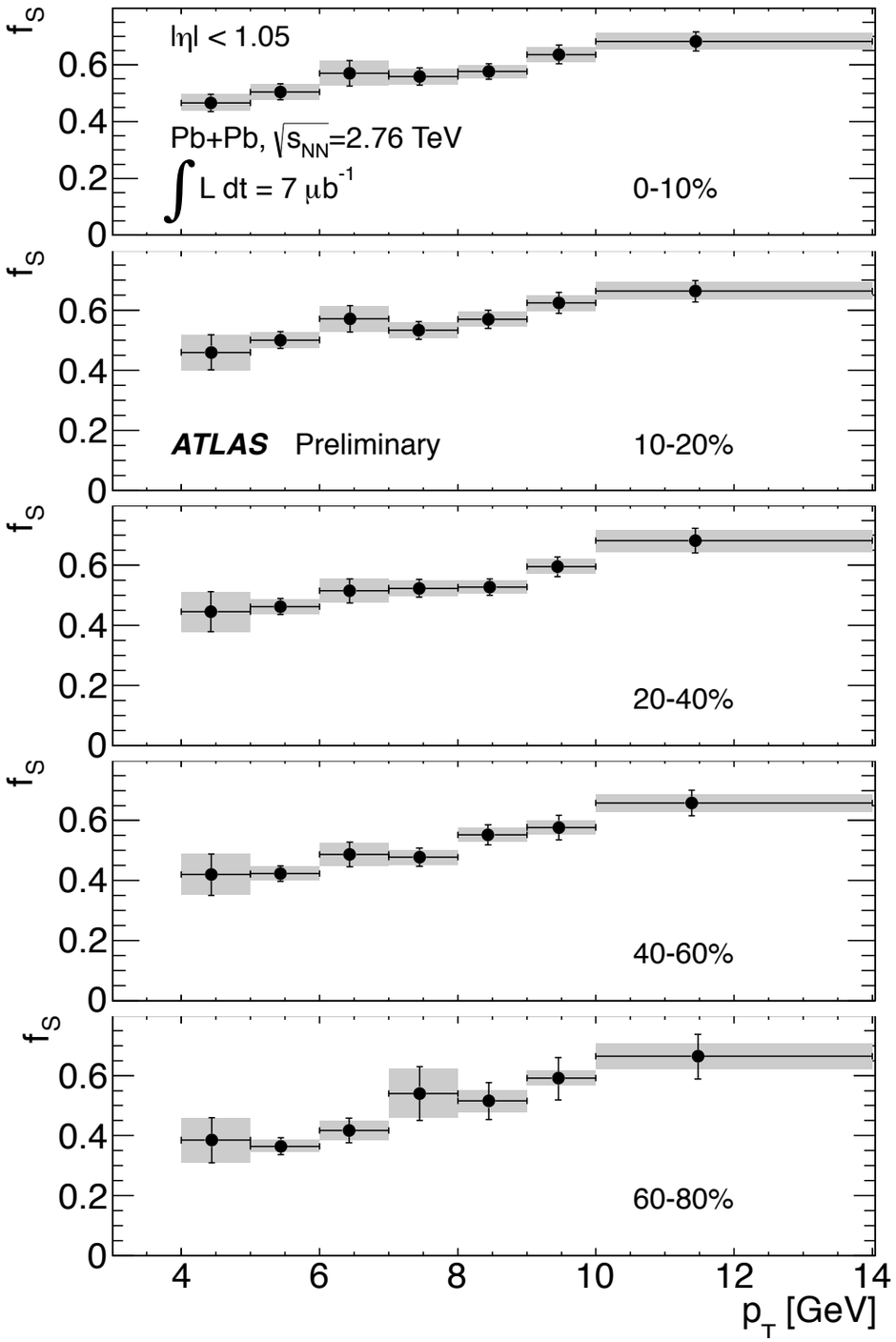
Signal fraction and spectra

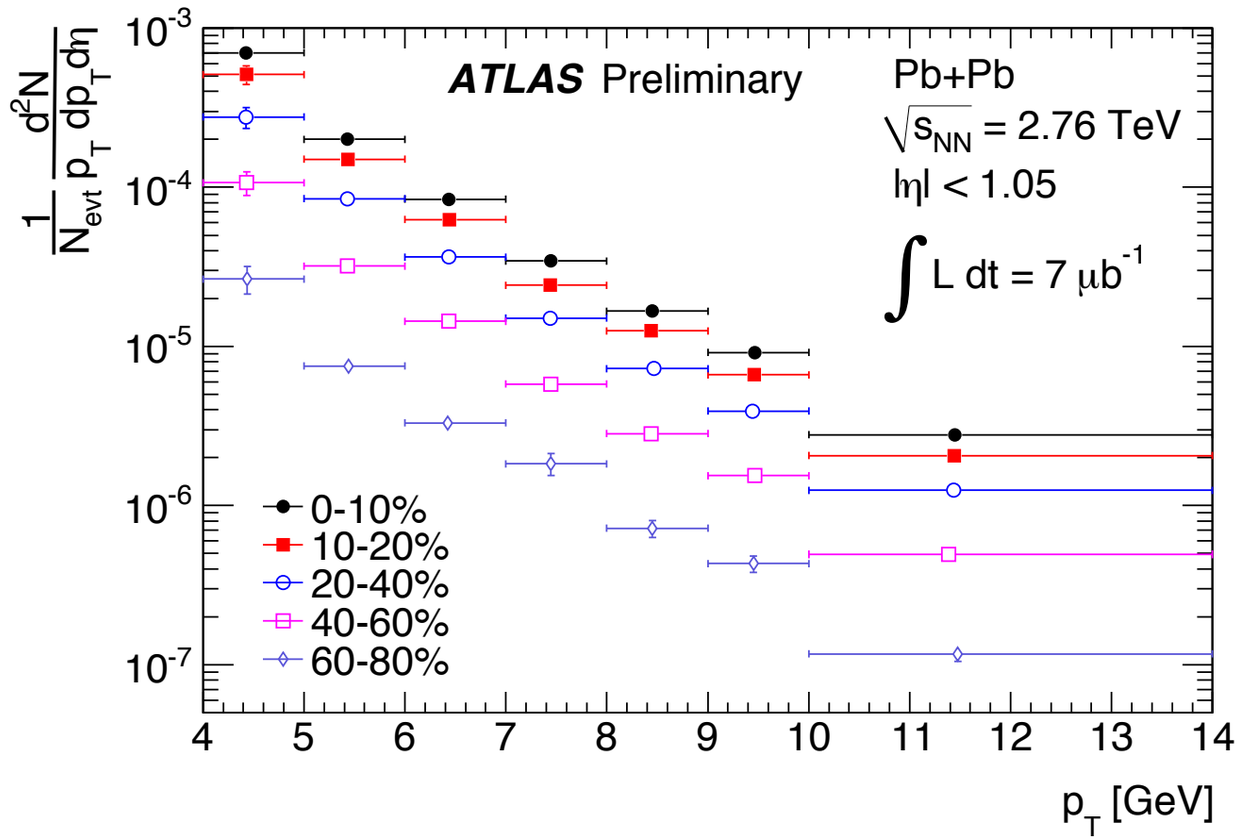


2010 Data

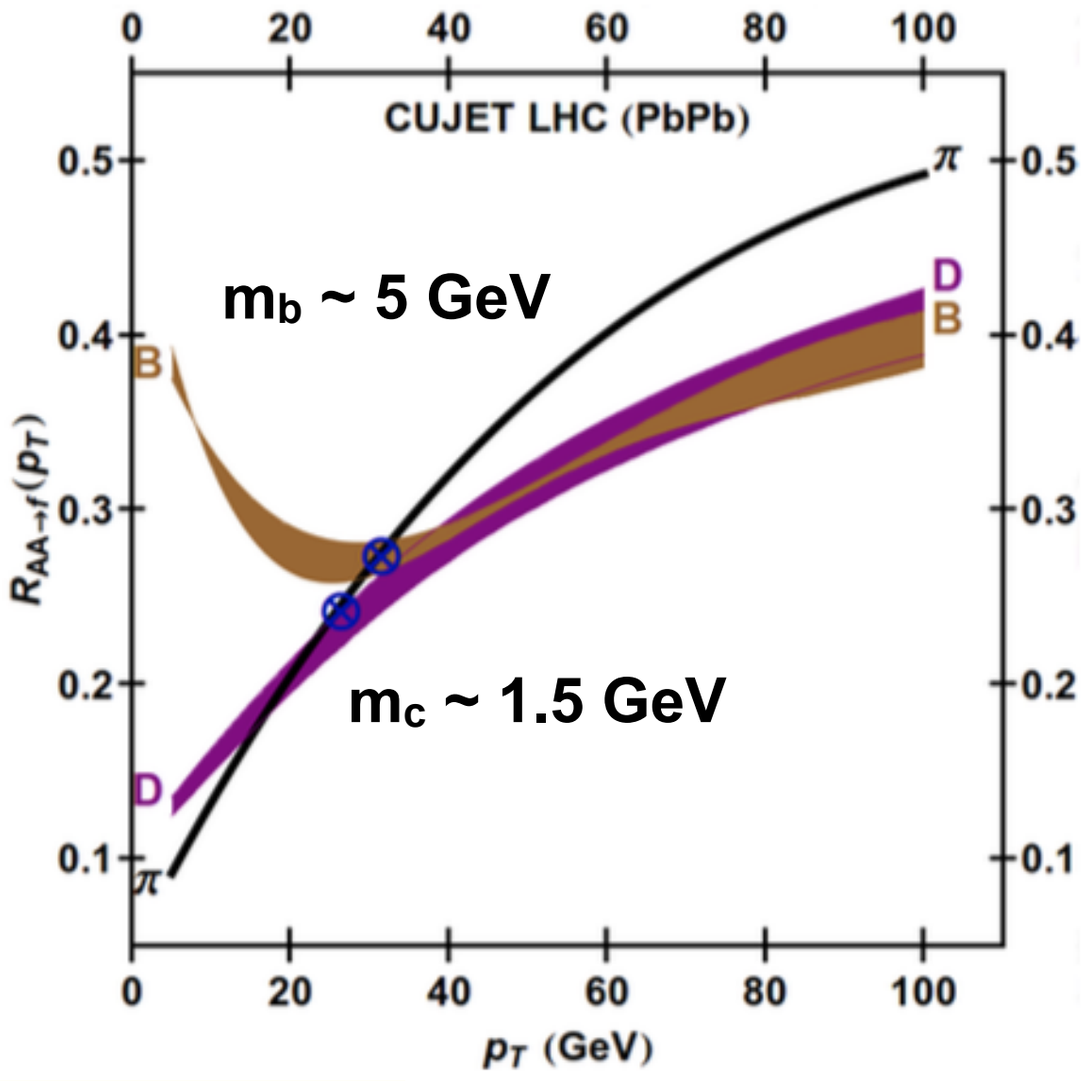
2011 Data

HF fraction and spectra in 2010 data





Mass ordering of R_{AA}



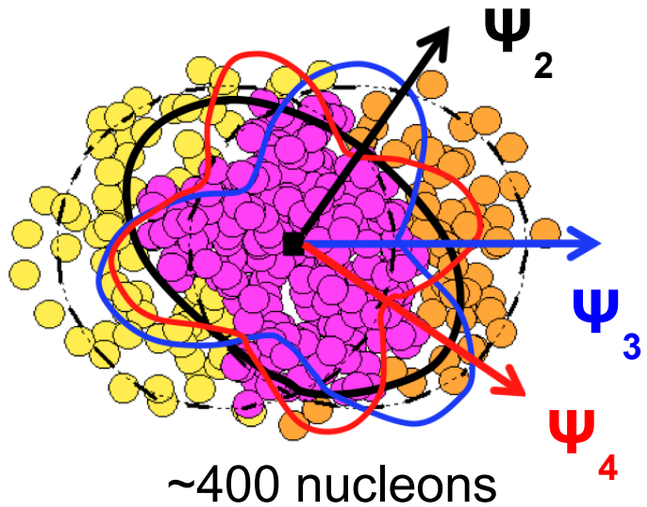
Bugatti, Gyulassy 2011

ATLAS EXPERIMENT

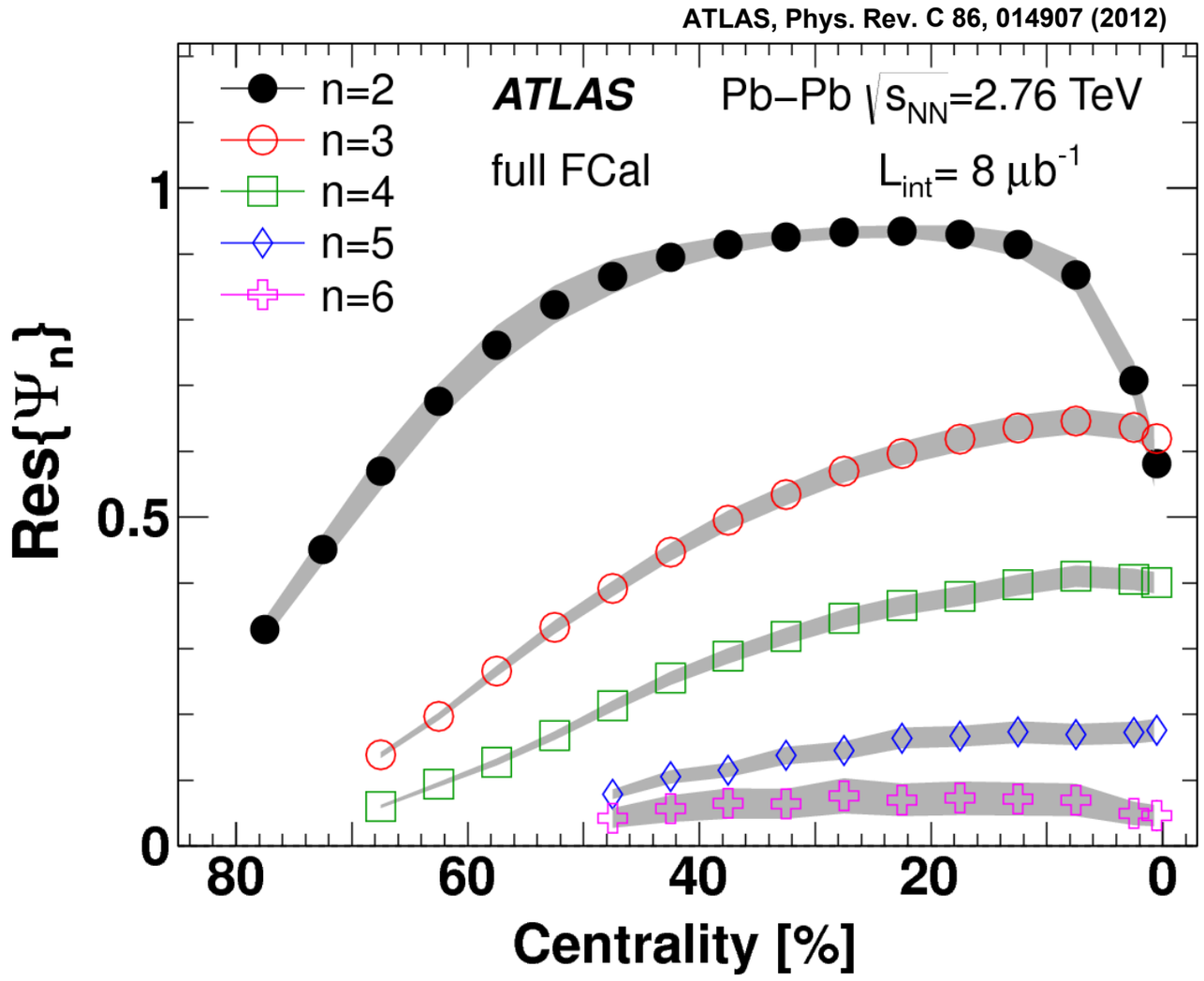
Event plane determination

- **Reaction plane (Ψ^{RP}) is approximated by event plane (Ψ_n^{EP}) measured in FCal:**

$$\Psi_n^{EP} = \frac{1}{n}\tan^{-1}\frac{\sum_i E_{T,i}^{tower} w_i \sin(n\phi_i)}{\sum_i E_{T,i}^{tower} w_i \cos(n\phi_i)}$$



~400 nucleons



- **The event plane resolution correction factor R is obtained using two-sub event and various tree-subevent method**
- **Significant resolution for harmonics n=2 – 6**
- **Resolution corrected harmonics:**

$$v_n = \langle \cos\left(n\left(\Phi - \Psi_n\right)\right)\rangle / R$$