Nuclear Modification Factor of Muons From Open Heavy Flavour Decays and Single Muon Elliptic Flow at Forward Rapidity in Pb-Pb Collisions at $\sqrt{s_{NN}}$=2.76 TeV with ALICE

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Outline

- Heavy Flavour Physics at LHC
- ALICE Setup
- R_{AA} of Muons From Heavy Flavour Decays
- Elliptic Flow of Inclusive Muons
- Summary

Heavy Flavour Physics at LHC

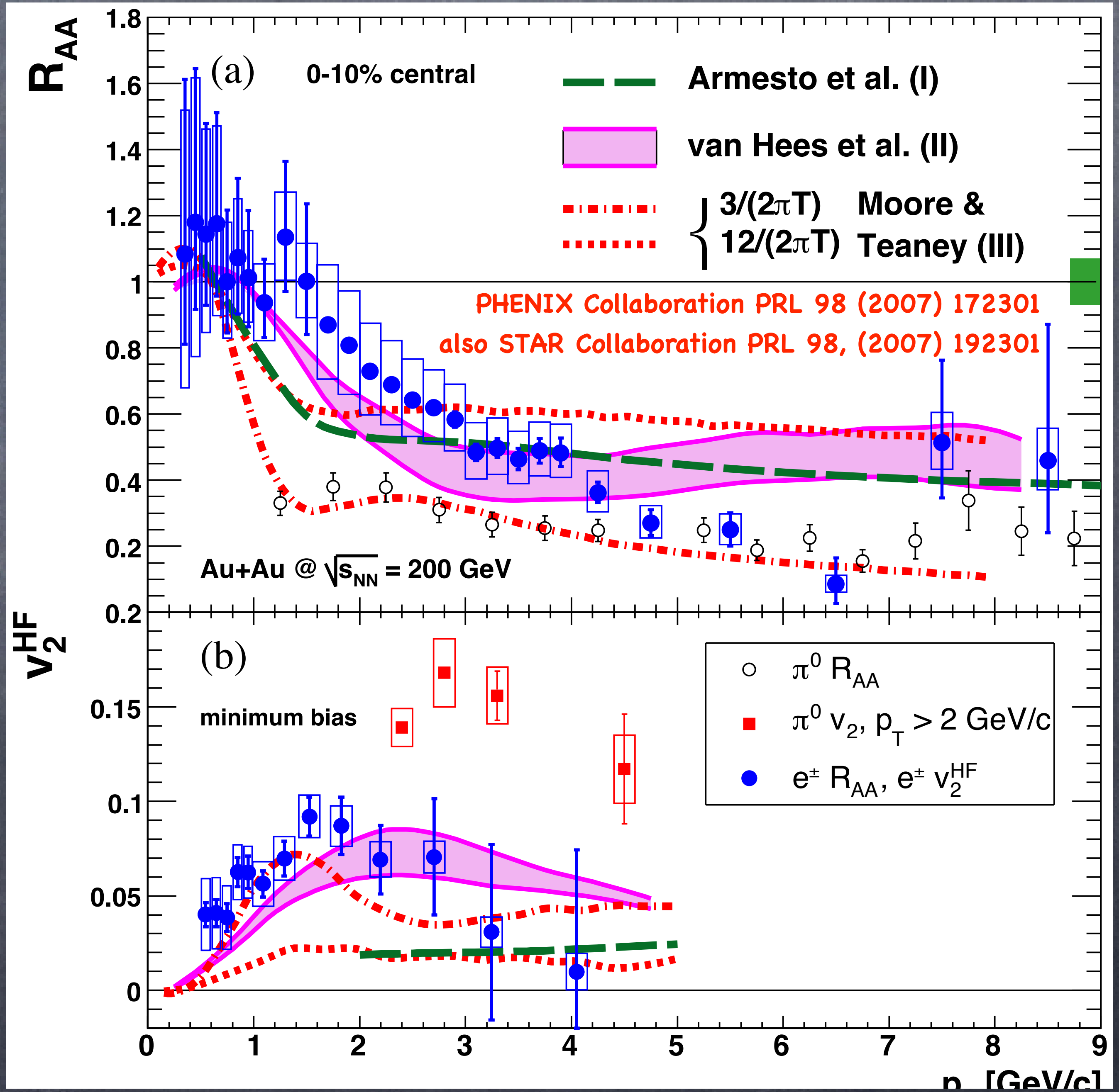
$$R_{AA} = \frac{1}{< T_{AA} >} \times \frac{dN_{AA}/dp_T}{d\sigma_{pp}/dp_T}$$

Heavy flavours in pp collisions:

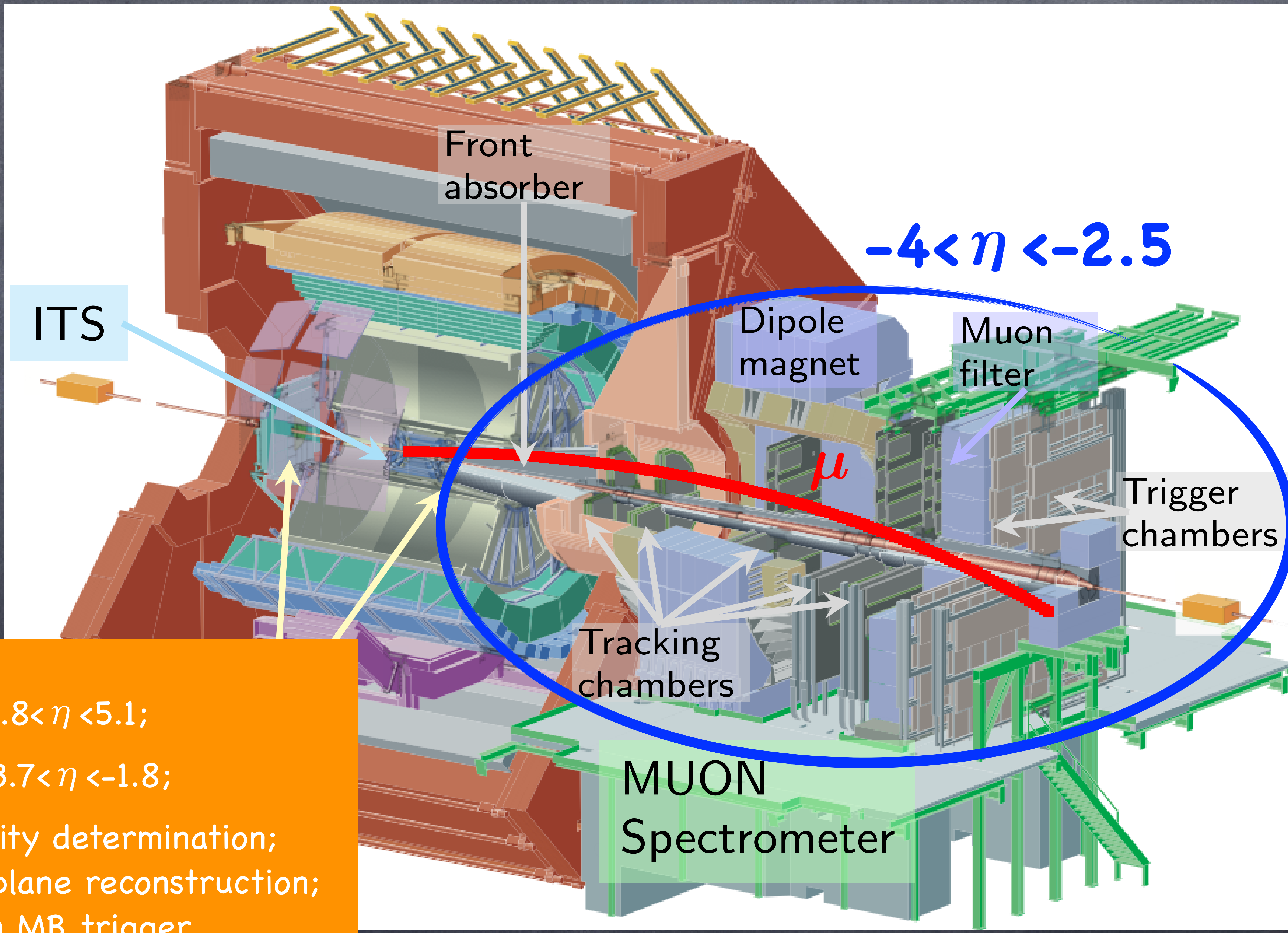
- baseline for pA and AA collisions;
- test NLO pQCD in a new energy domain.

Heavy Flavours in AA collisions:

- tomography of QCD medium,
  - mass and color charge dependence of parton energy loss,
    R_{AA}(light hadron)<R_{AA}(D)<R_{AA}(B)
    [Phys. Rev. D69 (2004) 114003, Phys. Rev. D71 (2005) 054027];
- azimuthal anisotropic flow, $v_n(p_t, \eta)$,
  - low p_T region: initial conditions of QCD medium, degree of thermalization of heavy quarks in QGP,
  - high p_T region: path length dependence of heavy flavour energy loss.



ALICE Setup

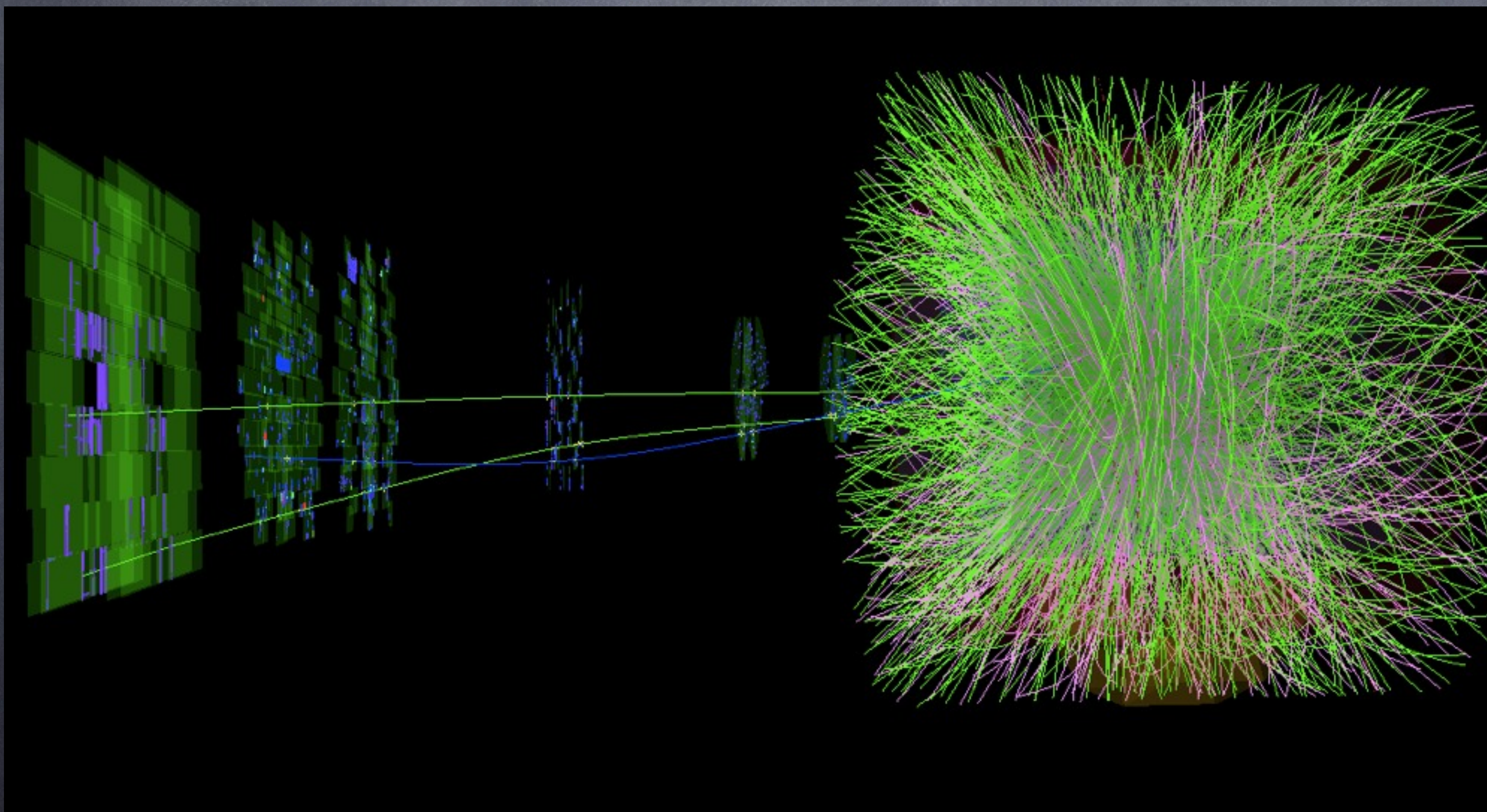


VZERO:

- V0A, $2.8<\eta<5.1$;
- V0C, $-3.7<\eta<-1.8$;
- centrality determination;
- event plane reconstruction;
- used in MB trigger.

Heavy Flavour Muon R_{AA}

arXiv:1205.6443, accepted for publication in Phys. Rev. Lett.



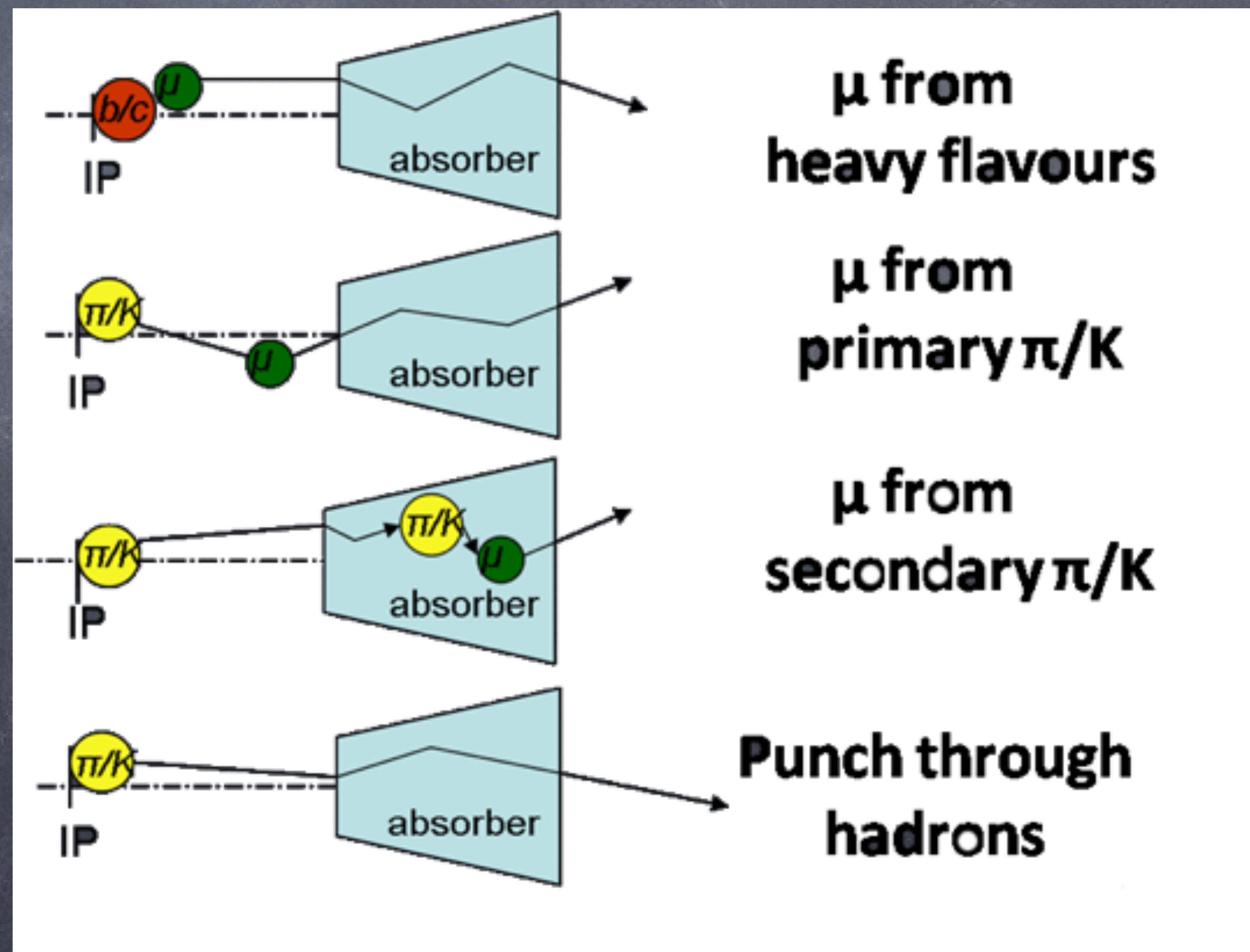
Data Samples and Muon Selection

Data Samples:

- pp collisions, muon trigger, $\mathcal{L}_{int}$=19 nb^{-1};
- Pb–Pb collisions, minimum bias trigger, $\mathcal{L}_{int}$=2.7 μb^{-1}.

Track selection:

- $-4<\eta<-2.5$: acceptance of ALICE MUON spectrometer;
- muon trigger matching: reject hadrons that cross the absorber;
- pointing angle to the vertex: remove beam-gas and particles produced in the absorber.



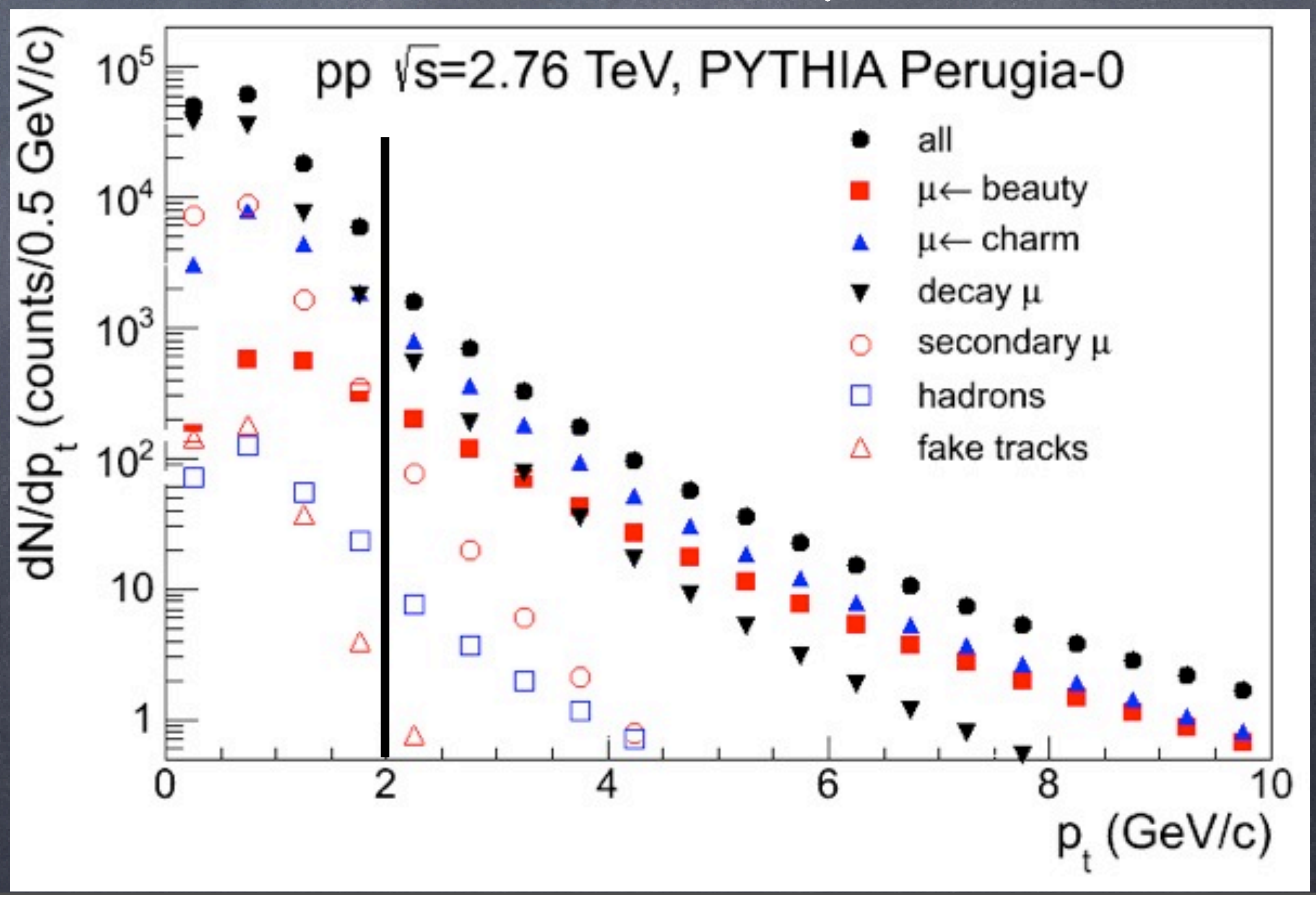
Background Subtraction: pp

Strategy:

- extract dN/dp_T of K/π decay muons from simulation (PYTHIA or Phojet);
- normalize it to measured muon yield at low p_T;
- subtract from inclusive dN/dp_T to obtain heavy flavour decay muon spectrum.

Systematic uncertainty:

- models: estimated by using different inputs;
- transport codes, estimated by varying yield of muons from secondary K/π between 0 and 200%.



Background Subtraction: Pb-Pb

- Input: K/π spectra in pp collisions and R_{AA} in Pb-Pb collisions at central rapidity measured with ALICE [J. Phy. G, G38 (2011) 124014 & 124080];
- extrapolate K/π spectra in pp collisions to forward rapidity:

$$\frac{d^2N_{\rm pp}^{\rm K/\pi}}{dp_{\rm T}dy} = \frac{d^2N_{\rm pp}^{\rm K/\pi}}{dp_{\rm T}dy}|_{y=0} \times \exp[-\frac{1}{2}(\frac{y}{\sigma_y})^2]$$

[Phys. Rev., D76, (2007) 092002]

with σ_y=3.3 estimated from PYTHIA and PhoJet (error≃15%);

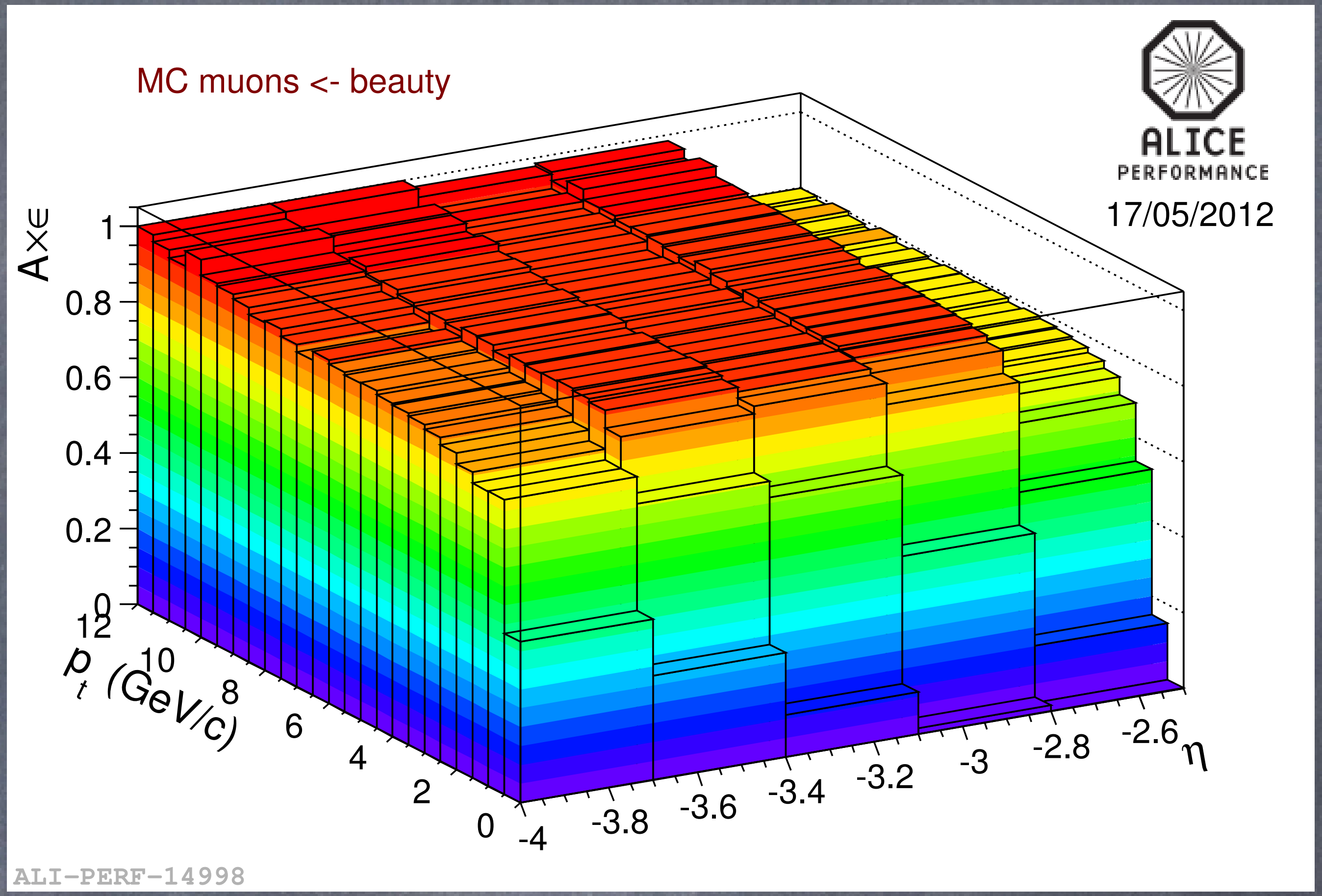
- get K/π spectra in Pb-Pb collisions at forward rapidity via:

$$\frac{d^2N_{\rm AA}^{\rm K/\pi}}{dp_{\rm T}dy} =< T_{\rm AA} > \times R_{\rm AA}^{K/\pi}|_{y=0} \times \frac{d^2\sigma_{\rm pp}^{\rm K/\pi}}{dp_{\rm T}dy}$$

varying K/π R_{AA} between 0 and 200% to estimate the systematic uncertainty on unknown quenching effect at forward rapidity.

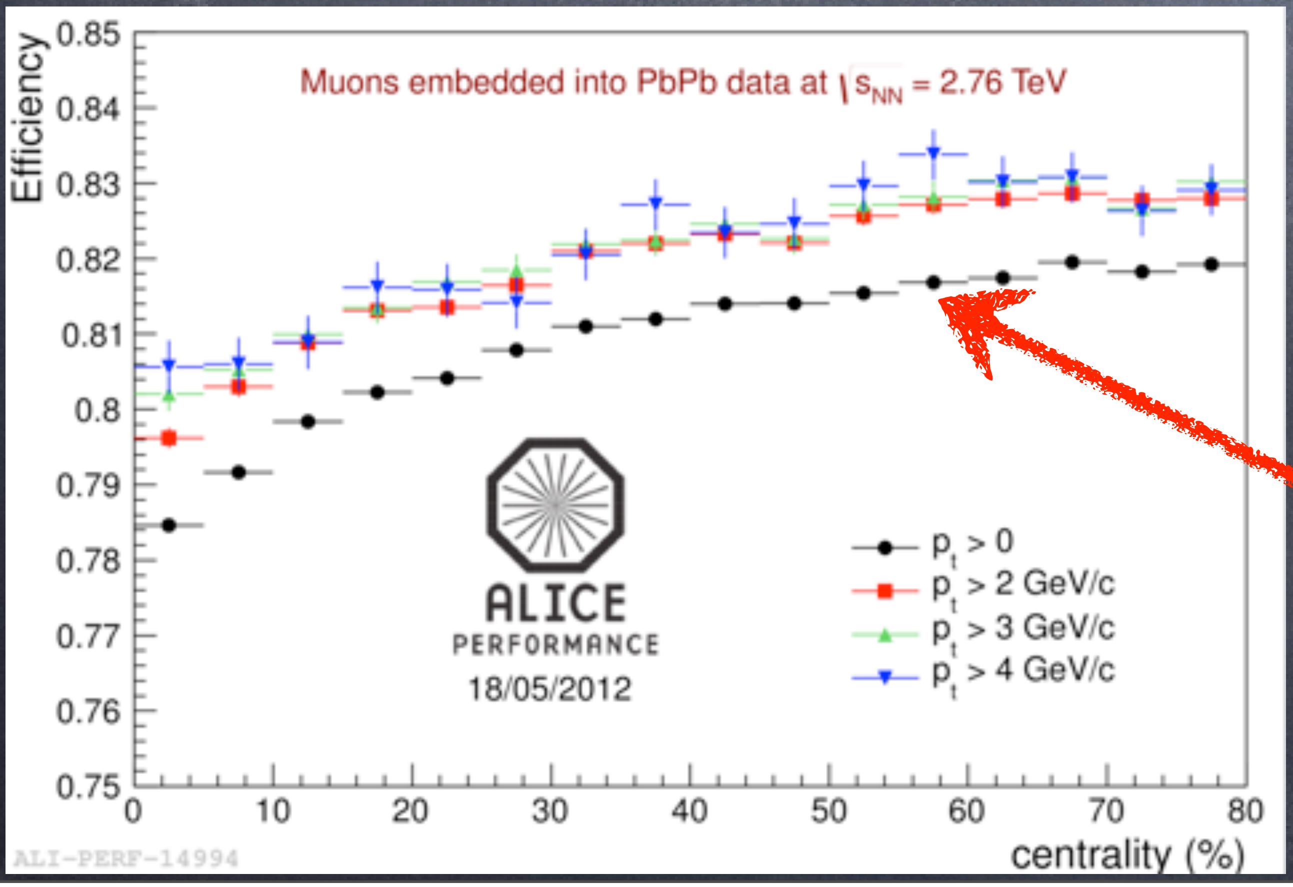
- produce the K/π decay muon background in Monte-Carlo with fast detector simulation.

Efficiency Correction



In pp collisions:

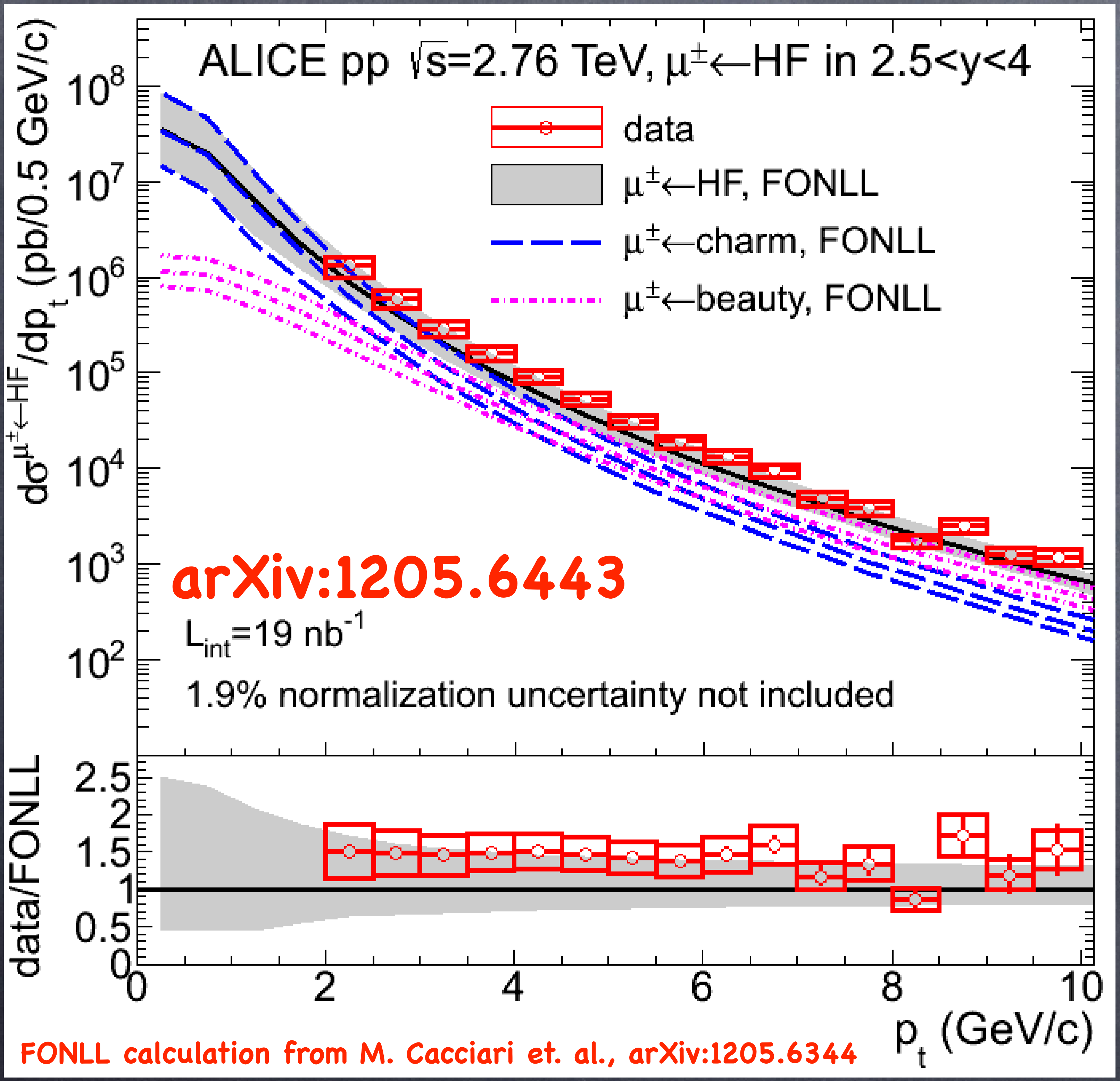
- efficiency from simulation using beauty signals from NLO pQCD predictions as inputs;
- systematic uncertainty on mis-alignment 1%p_T (in GeV/c).



In Pb-Pb collisions:

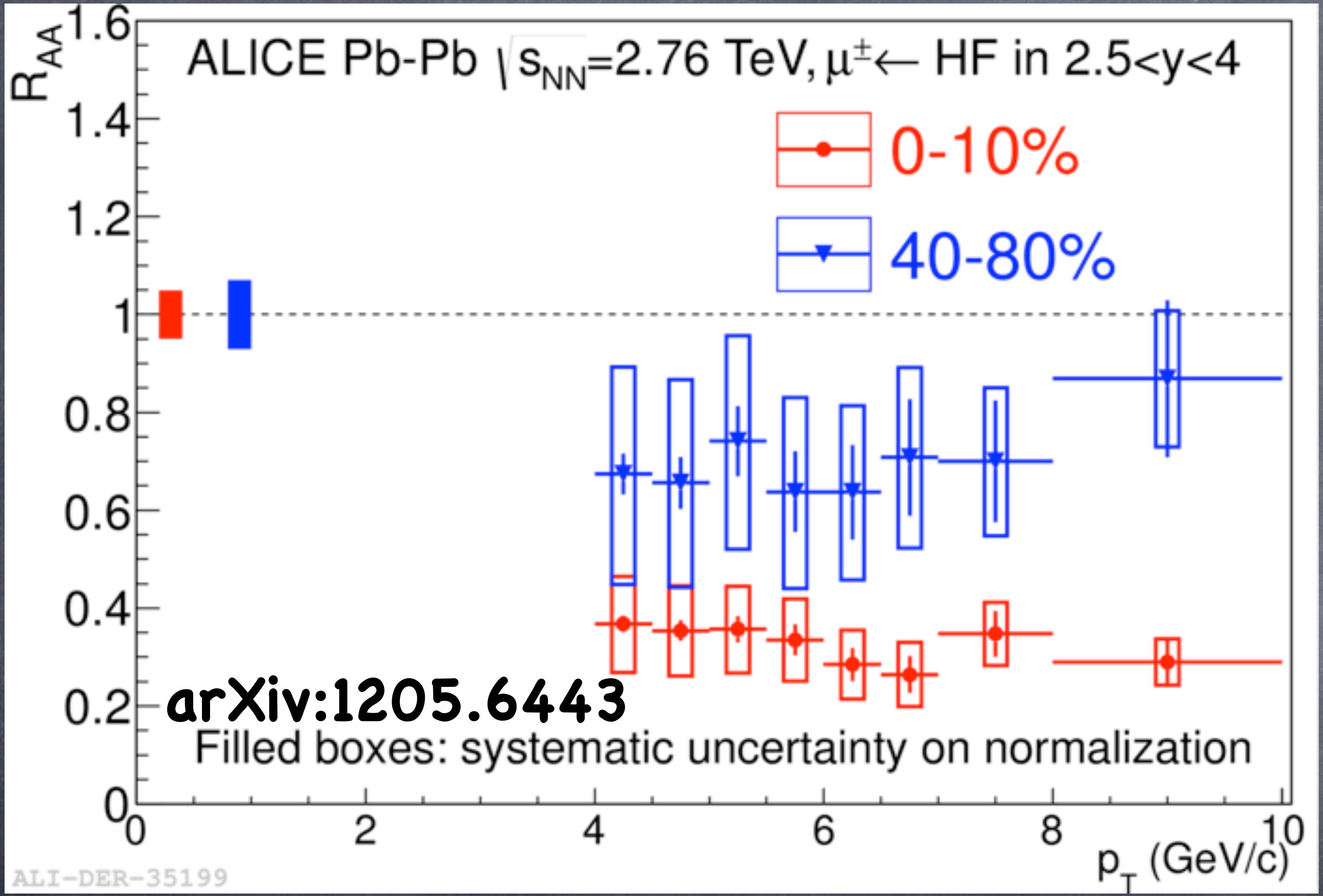
- the centrality dependence of tracking efficiency is estimated via embedding procedure;
- efficiency drops by 4±1% in the 10% most central collisions w.r.t. peripheral collisions.

Reference in pp collisions



- Data well described by FONLL calculations in pp collisions at $\sqrt{s}$=2.76 TeV, similar agreement found in pp collisions at $\sqrt{s}$=7 TeV [Phys. Lett. B708 (2012) 265];
- FONLL predicts that muons from beauty decays dominate for $p_T \gtrsim 6$ GeV/c.

p_T-differential R_{AA} of Muons from HF Decays

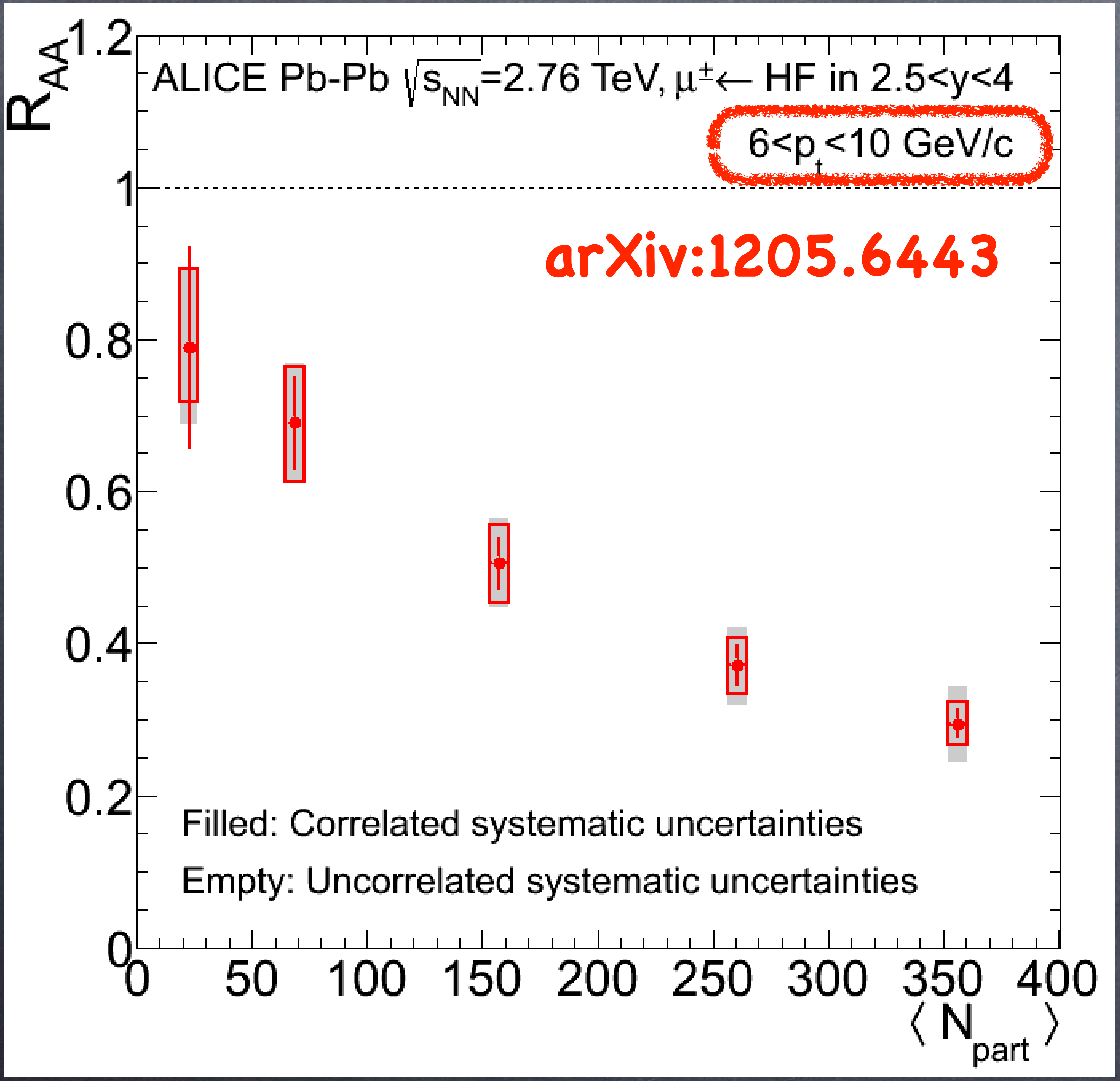


40-80%

0-10%

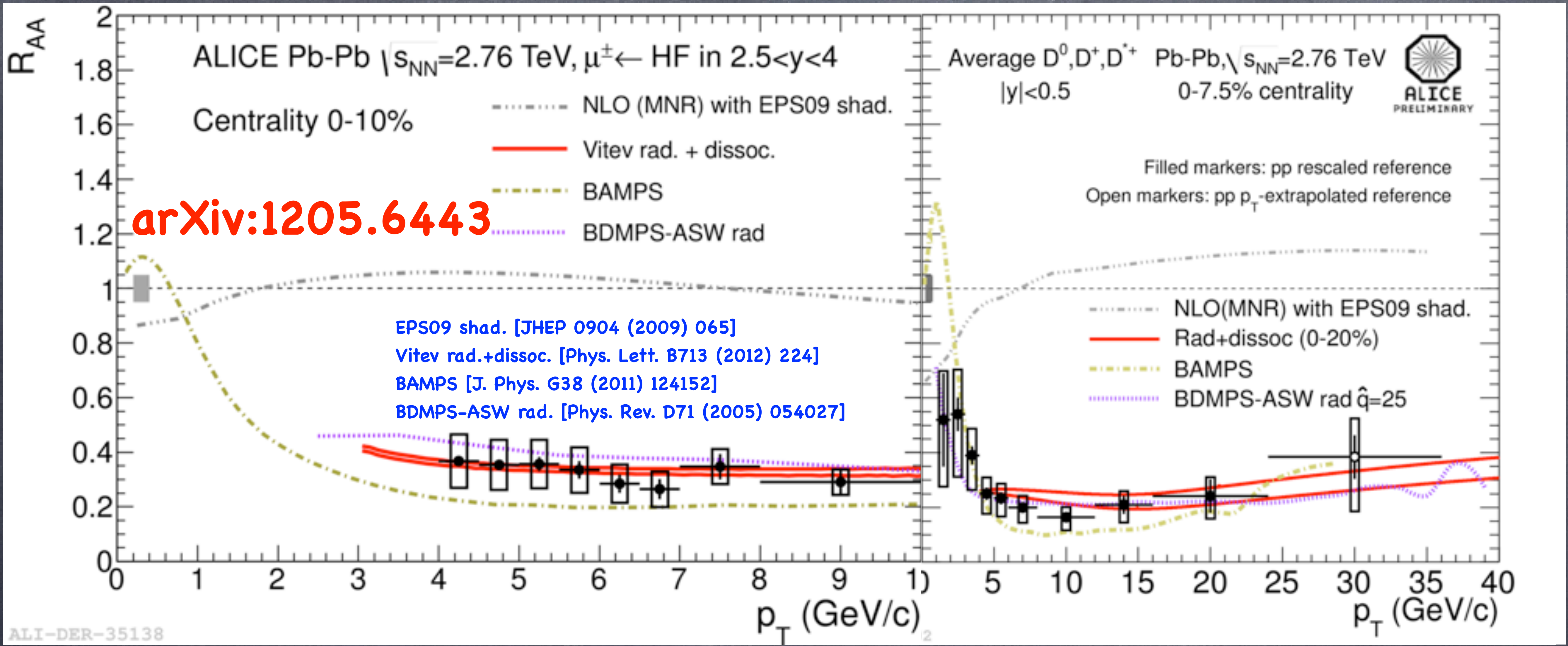
- Suppression is observed and is independent of p_T;
- stronger suppression in central collisions than in peripheral collisions.

Centrality Dependence of R_{AA} of HF-Decay Muons



- The suppression of muons from heavy flavour decays in high p_T range at forward rapidity exhibits a strong increase with increasing centrality;
- reaching a factor of about 3-4 in the 10% most central collisions;
- in this p_T region, beauty contribution is dominant in pp collisions, according to FONLL calculations.

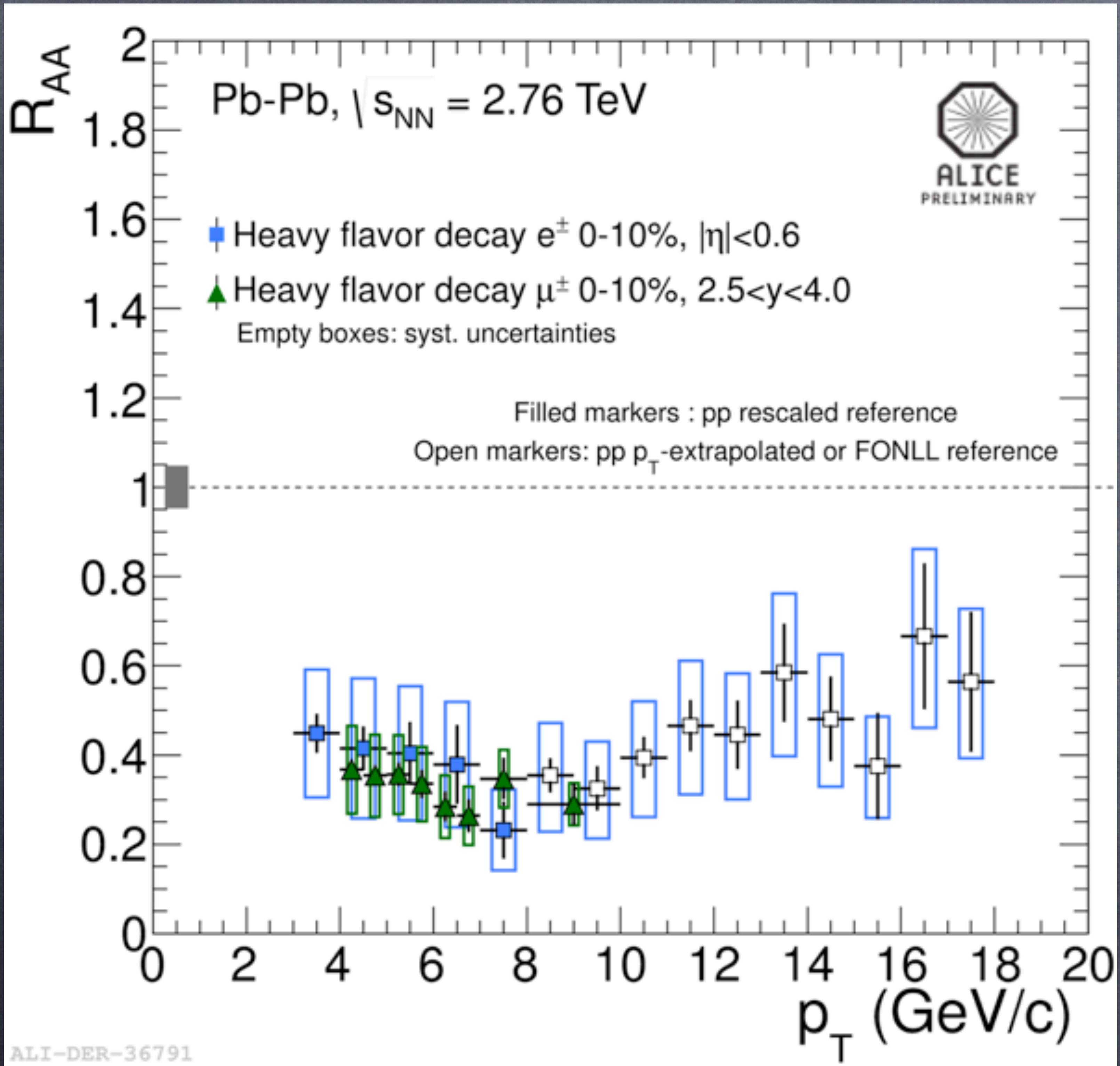
Comparison with Energy Loss Calculations



talk in this session A. Grelli, Friday August 17th 14:00

- suppression of muons from heavy flavour decays at forward rapidity is similar to that of D mesons at central rapidity;
- model implementing radiative energy loss (BDMPS-ASW) and rad.+dissoc. (Vitev) can describe both muon and D meson data;
- small contribution of shadowing is expected.

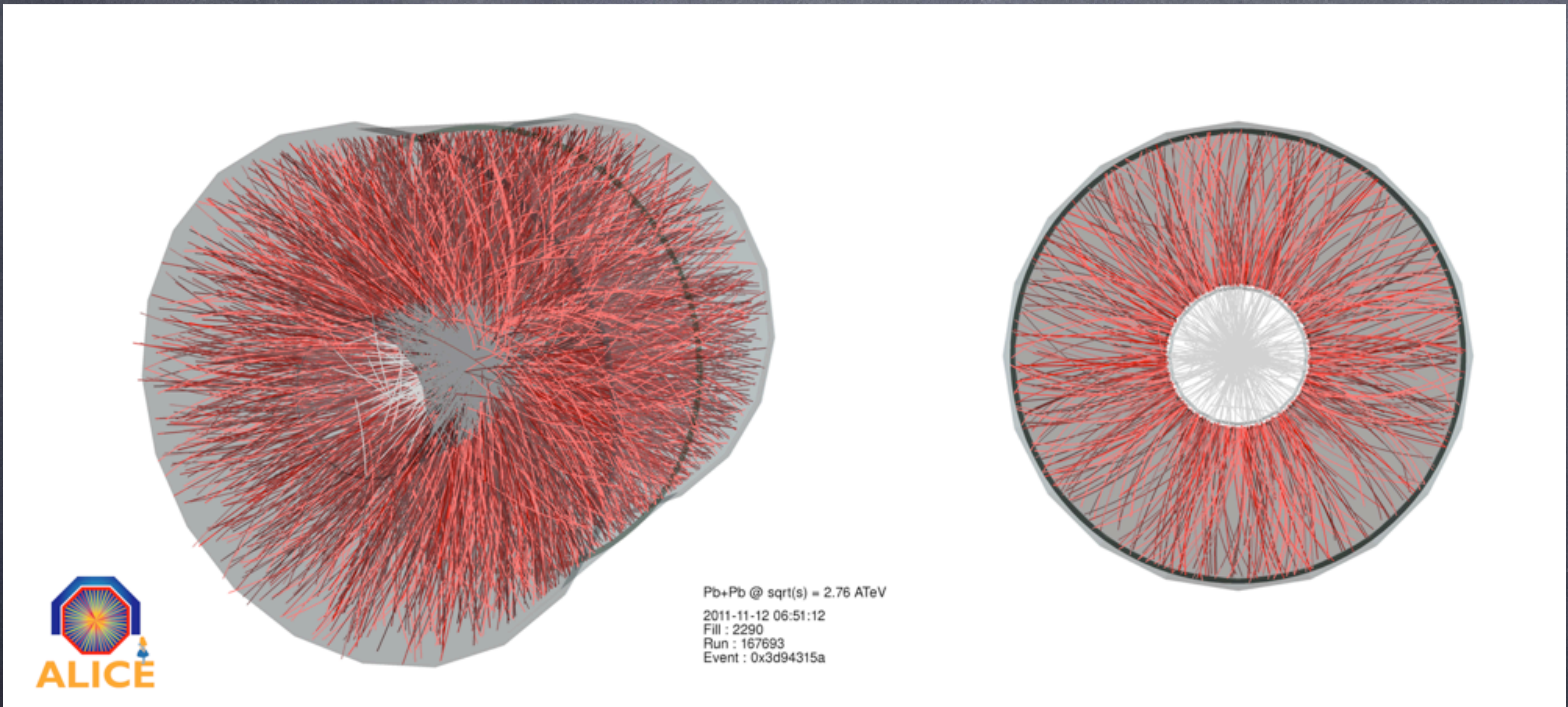
Comparison with Electrons



talk in this session S. Sakai, Friday August 17th 16:30

The suppression of muons from heavy flavour decays at forward rapidity also consistent with that of heavy flavour decay electrons at central rapidity within uncertainties.

Inclusive Muon Elliptic Flow



Data Sample & Analysis Method

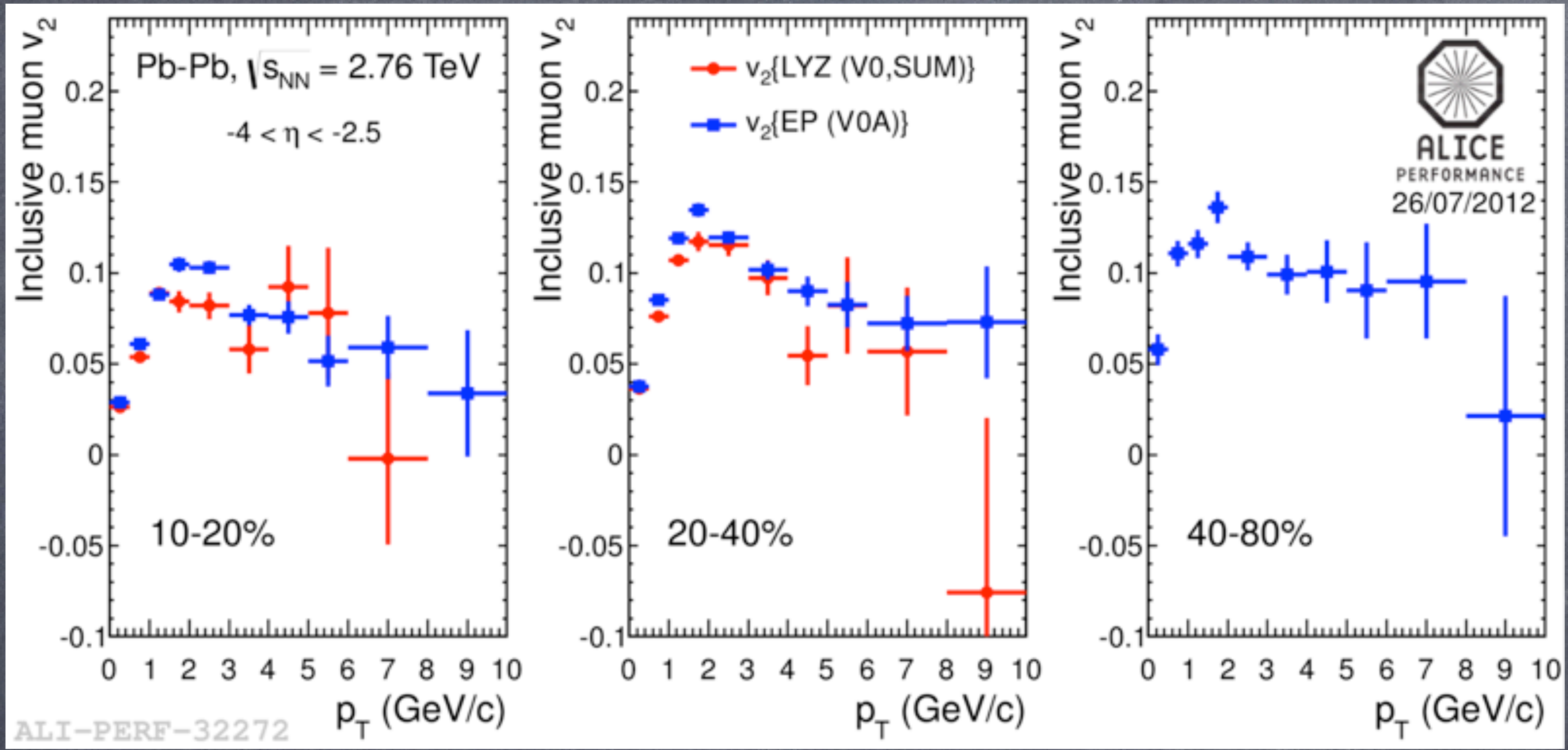
Pb–Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV collected in Nov. 2011.

Event and inclusive muon selections:

- the same as those in R_{AA} analysis (in 0-80%);
- 1.8x10^{7} events with muon high p_T trigger.

analysis method	reference flow
Event Plane (EP)	VZERO (η >0)
Lee-Yang Zeros (LYZ)	full VZERO

p_T-differential v_2 of Inclusive Muons



- Inclusive muon v_2 is measured up to 10 GeV/c (the background is not subtracted);
- results from LYZ are systematically lower than those from EP method: fluctuations or non-flow correlations are suppressed;
- indication for larger v_2 in semi-central collisions than in central collisions.

Summary

- R_{AA} of muons from heavy flavour decays measured as a function of p_T and centrality:
  - a strong suppression of high p_T muons from heavy flavour decays is observed;
  - no significant dependence on p_T in $4<p_T<10$ GeV/c;
  - it is similar to that of electrons from heavy flavour decays and D mesons at central rapidity.
- Observed non-zero v_2 for inclusive muons: background subtraction ongoing to obtain HF-decay muon v_2.

Thanks!

Backup

Heavy Flavour Physics at LHC

Heavy flavours in pp collisions:

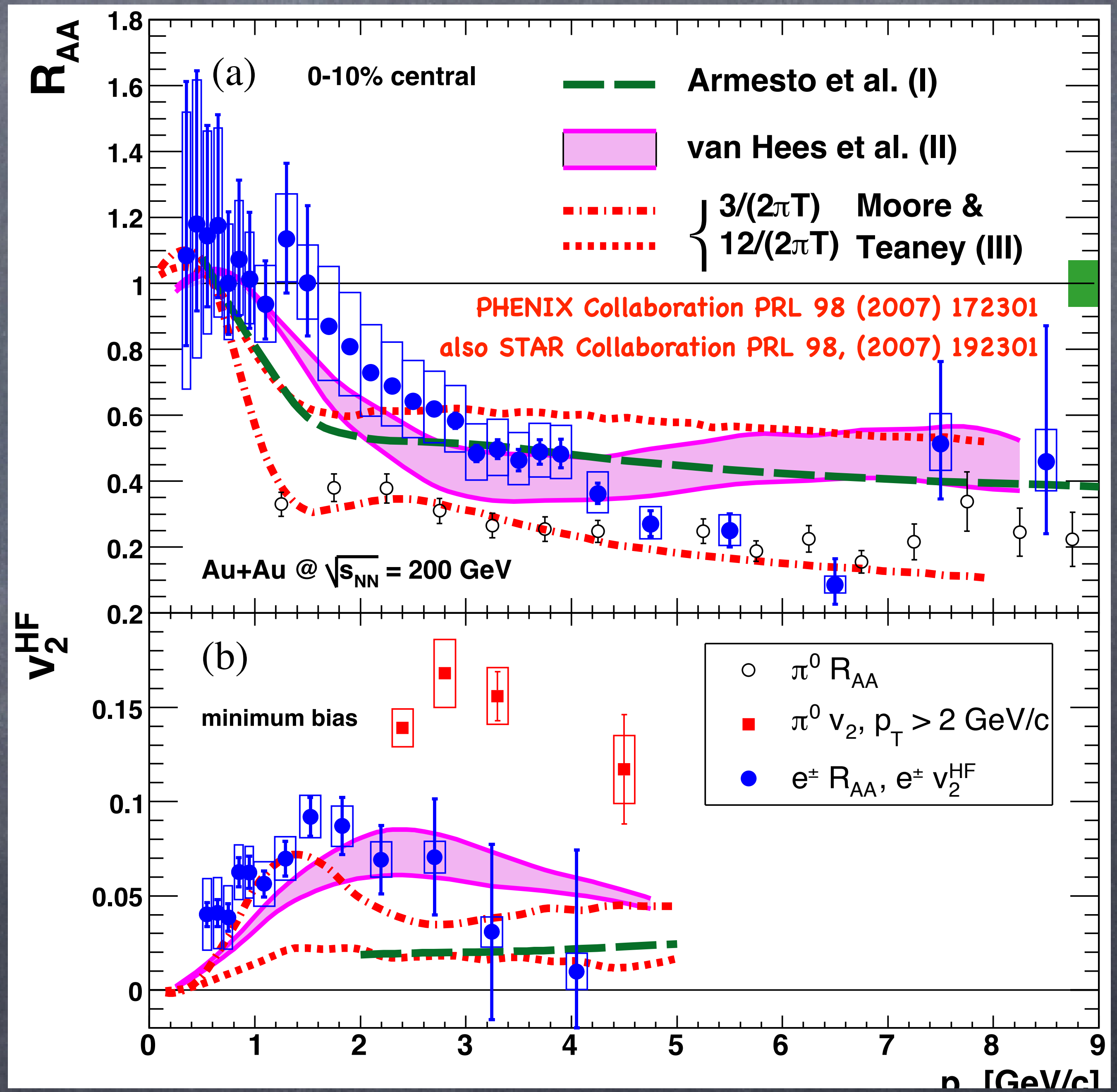
- baseline for pA and AA collisions;
- test NLO pQCD in a new energy domain.

$$R_{AA} = \frac{1}{< T_{AA} >} \times \frac{dN_{AA}/dp_T}{d\sigma_{pp}/dp_T}$$

Heavy Flavours in AA collisions:

tomography of QCD medium,

- open heavy flavour quenching in QCD medium,
  - heavy flavours expected to lose less energy than light flavours (dead cone effect), not observed at RHIC [Phys. Rev. D69 (2004) 114003],
  - color charge dependence of parton energy loss, $\Delta E_g > \Delta E_q$ [Phys. Rev. D71 (2005) 054027],
  - R_{AA}(light hadron)<R_{AA}(D)<R_{AA}(B);



azimuthal anisotropic flow, $v_n(p_t, \eta)$,

- low p_T region: initial conditions of QCD medium, degree of thermalization of heavy quarks in QGP,
- high p_T region: path length dependence of heavy flavour energy loss.

Analysis Strategy: R_{AA} of muons from HF Decays

- Extrapolate K/π spectra from central to forward region in Pb-Pb collisions:

$$\frac{1}{N^{\mathrm{ev}}_{\mathrm{AA}}} \cdot \frac{dN^{\mathrm{K}/\pi}_{\mathrm{AA}}}{dp_{\mathrm{t}}dy} = n_y \times \frac{1}{N^{\mathrm{ev}}_{\mathrm{AA}}} \cdot \frac{dN^{\mathrm{K}/\pi}_{\mathrm{AA}}}{dp_{\mathrm{t}}}\Big|_{y=0} \times \exp[-\frac{1}{2}(\frac{y}{\sigma_y})^2]$$

- Produce decay muon at forward rapidity:

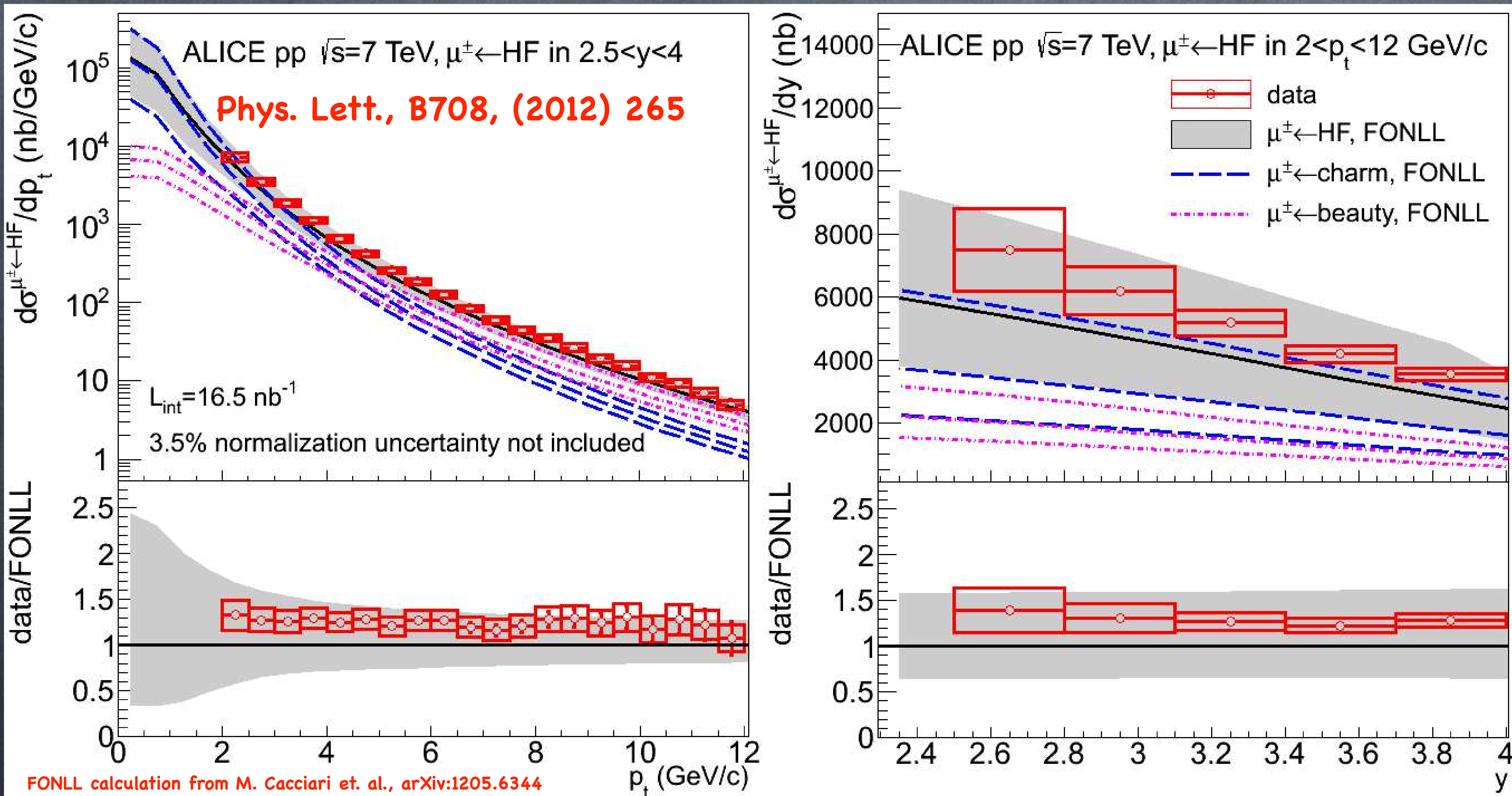
$$\frac{1}{N^{\mathrm{ev}}_{\mathrm{AA(pp)}}} \frac{dN^{\mu\leftarrow\mathrm{K}/\pi}_{\mathrm{AA(pp)}}}{dp_{\mathrm{t}}}\Big|_{-4<\eta<-2.5} = \frac{1}{N^{\mathrm{ev}}_{\mathrm{AA(pp)}}} \int_{\Delta\eta} d\eta \frac{dN^{\mu\leftarrow\mathrm{K}/\pi}_{\mathrm{AA(pp)}}}{dp_{\mathrm{t}}d\eta} \Leftarrow \frac{1}{N^{\mathrm{ev}}_{\mathrm{AA(pp)}}} \frac{dN^{\mathrm{K}/\pi}_{\mathrm{AA(pp)}}}{dp_{\mathrm{t}}dy}$$

- Background subtraction and calculate R_{AA} of $\mu\leftarrow$HF:

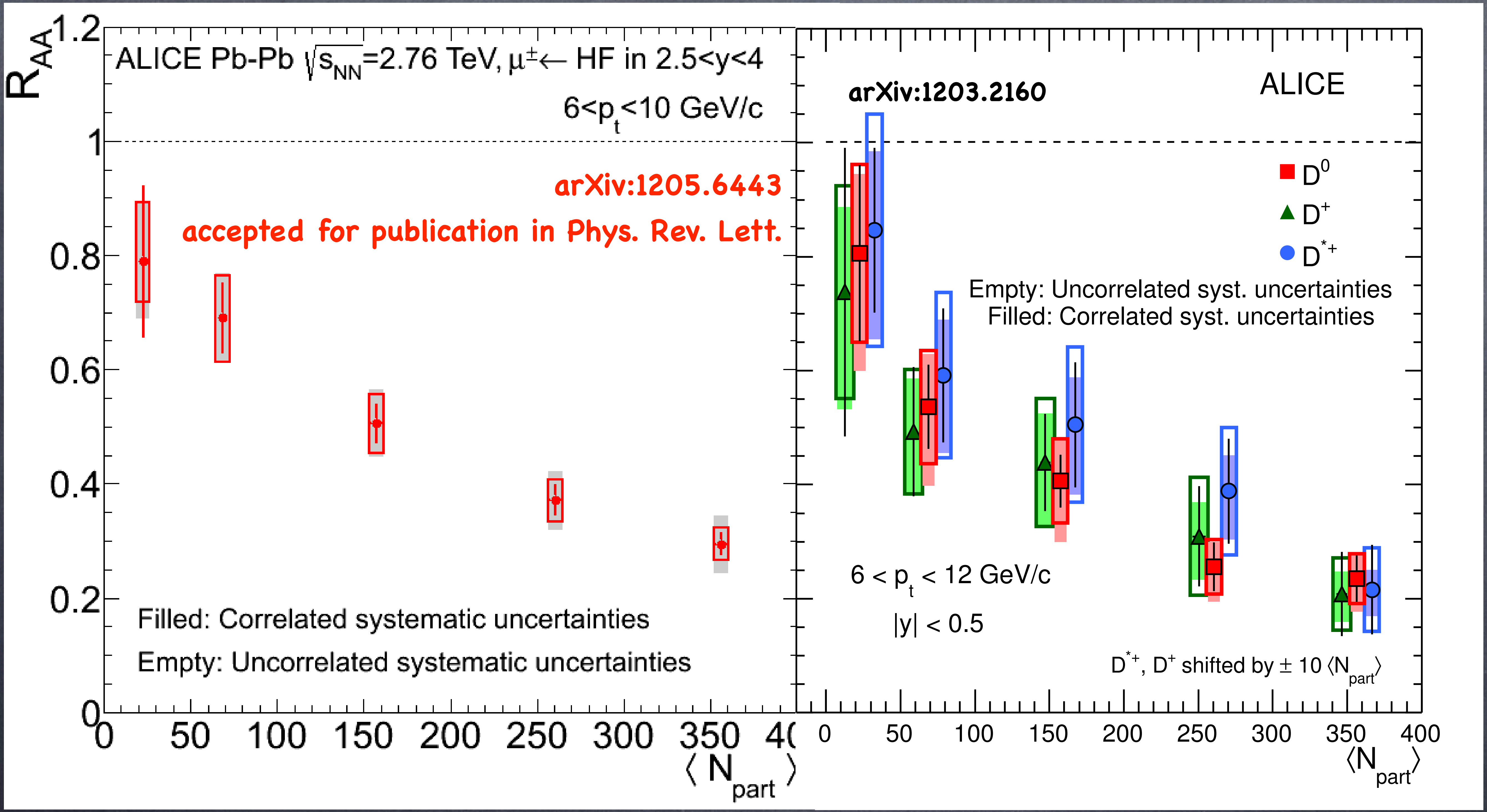
$$R^{\mu\leftarrow\mathrm{HF}}_{\mathrm{AA}} = \frac{1}{<T_{\mathrm{AA}}>} \cdot \frac{1}{N^{\mathrm{ev}}_{\mathrm{AA}}} \cdot \frac{dN^{\mathrm{incl}\ \mu}_{\mathrm{AA}}/dp_{\mathrm{t}}}{d\sigma^{\mu\leftarrow\mathrm{HF}}_{\mathrm{pp}}/p_{\mathrm{t}}} - n_y \times D_{\mathrm{AA}}(p_{\mathrm{t}}) \cdot R^{\mu\leftarrow\pi}_{\mathrm{AA}}(p_{\mathrm{t}}, n_y = 1) \cdot \frac{d\sigma^{\mu\leftarrow\mathrm{K}/\pi}_{\mathrm{pp}}/dp_{\mathrm{t}}}{d\sigma^{\mu\leftarrow\mathrm{HF}}_{\mathrm{pp}}/dp_{\mathrm{t}}}$$

Systematic Uncertainty

pp reference	
detector response	3%
alignment	1%xp_t (in GeV/c)
background subtraction	14-17% (depending on p_t)
inclusive muon yields in Pb–Pb collisions	
detector response	3.5%
alignment	1%xp_t (in GeV/c)
centrality dependence of efficiency	1%
background estimation in Pb–Pb collisions	
decay muon yields in pp collisons	17%
decay muon R_{AA}	14-17%
K/π difference	up to 9% at p_t=10 GeV/c
rapidity extrapolation	0-14% (20%) in central (peripheral) collisions
normalization	
cross section in pp collisions	1.9%
$\langle T_{AA} \rangle$	4-7% depending on centrality


ALICE pp √s=7 TeV, μ±←HF in 2.5<y<4
Phys. Lett., B708, (2012) 265
L_int=16.5 nb^-1
3.5% normalization uncertainty not included
dσ^{μ±←HF}/dp_t (nb/GeV/c)
data/FONLL
p_t (GeV/c)
FONLL calculation from M. Cacciari et. al., arXiv:1205.6344
ALICE pp √s=7 TeV, μ±←HF in 2<p_t<12 GeV/c
data
μ±←HF, FONLL
μ±←charm, FONLL
μ±←beauty, FONLL
dσ^{μ±←HF}/dy (nb)
y

Comparison to D-mesons Data



The centrality dependence of muon from heavy flavour decays at forward rapidity is similar to that of D mesons at mid-rapidity

Event Plane Fattening & Resolution Estimation

Event Plane Fattening:

- Equalization of the signal from all the 64 VZERO channels (32 per hodoscope);
- Recentering, twisting and rescaling of VZERO event-plane cumulants,

$$Q_{2,x} =< Q_{2,x} > +A^{+}[\cos 2\Psi_2 + \Lambda^{+} \sin 2\Psi_2], \quad Q_{2,y} =< Q_{2,y} > +A^{-}[\cos 2\Psi_2 + \Lambda^{-} \sin 2\Psi_2]$$

parameters extracted from mean & RMS of $Q_{2,x}$, $Q_{2,y}$ & $Q_{2,x}Q_{2,y}$;

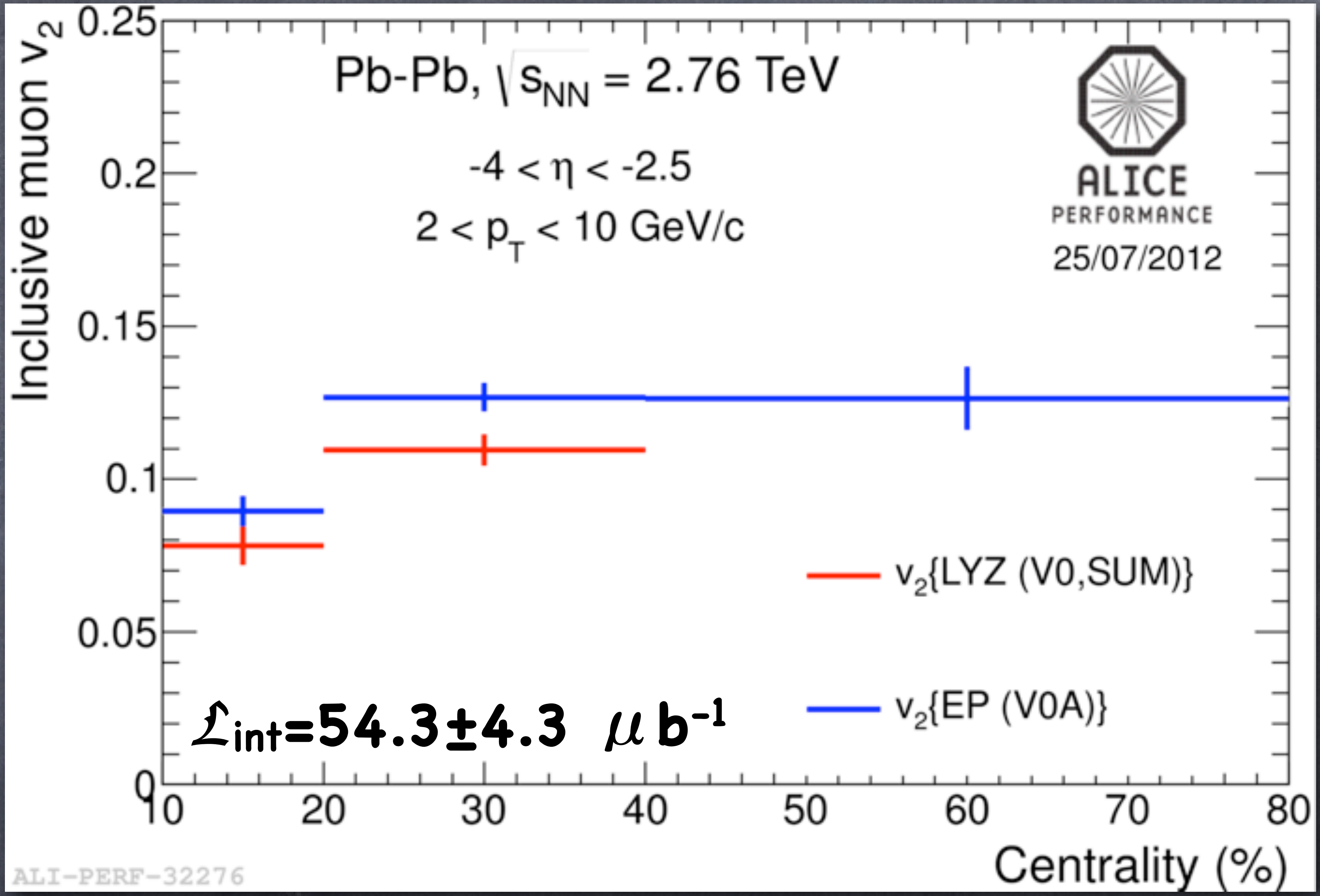
- Fourier flattening technique using one single parameter $<\sin 8\Psi_2>$

Event Plane resolution estimation:

- 3 sub-events method (V0A inner rings, V0A outer rings and V0C),

$$< \cos n(\Psi_m^a - \Psi_R) >= \sqrt{\frac{< \cos n(\Psi_m^a - \Psi_m^b) >< \cos n(\Psi_m^a - \Psi_m^c) >}{< \cos n(\Psi_m^b - \Psi_m^c) >}}$$

Centrality Dependence of Inclusive Muon v_2



- Magnitude of v_2 is larger in semi-central collisions than that in central collisions.
- outlook: implement Background Subtraction and obtain v_2 of muons from heavy flavour decays.