Measurement of heavy-flavour decay muon production at forward rapidity in pp and Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with the ALICE experiment

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1. Introduction
   - Motivations
   - Experimental setup
2. Reference: pp collisions at $\sqrt{s} = 2.76$ TeV
   - Analysis strategy
   - p_{t} differential cross-section in $2.5 < y < 4$
3. Nuclear modification factors
   - Analysis strategy in PbPb collisions
   - R_{AA} vs. p_{t} and centrality ($6 < p_{\mathrm{t}} < 10$ GeV/c) in $2.5 < y < 4$
4. Conclusions

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Motivations

Heavy flavours in AA collisions

- A tomographic probe of the medium:
  - produced at the beginning of the collision (large mass)
  - experience the medium evolution (long lived)
  - lose energy in the medium (strong interaction)

$$R_{AA}(p_t) = \frac{1}{\langle T_{AA}\rangle}\frac{dN_{AA}/dp_t}{d\sigma_{pp}/dp_t}$$

- Heavy-flavour decay electrons are suppressed at high-p_t at RHIC

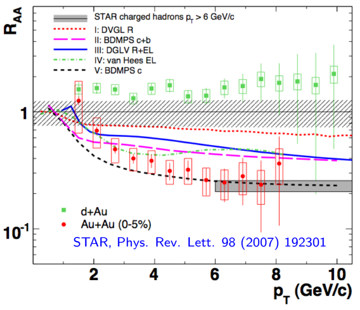
  [PHENIX, PRC **84** (2011) 044905; STAR, PRL 98 (2007) 192301]

- A hierarchy on energy-loss is expected on theoretical ground (color-charge and dead-cone effects):

$$\Delta E_g > \Delta E_{q/c} > \Delta E_b$$

$$R_{AA}^{h} < R_{AA}^{D} < R_{AA}^{B}$$

[Dokshitzer and Kharzeev, PLB 519 (2001) 199
Armesto, Salgado, Wiedemann, PRD 69 (2004) 114003
Djordjevic, Gyulassy, Horowitz, Wicks, NPA 783 (2007) 493...]



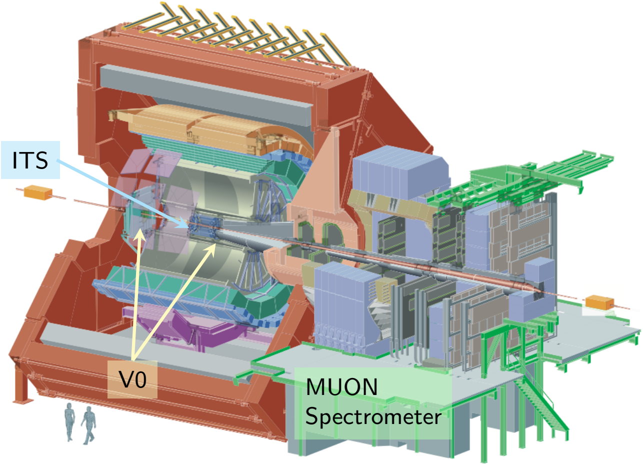
- But observed light-hadron suppression at RHIC is as high as heavy-flavour

- Test models at LHC energies (large c/b-production, small $x_{bjorken}$, c/b separation...)

Heavy flavours in pp collisions

- Reference for AA studies
- Test pQCD in a new energy domain

See also
C. Geuna's talk



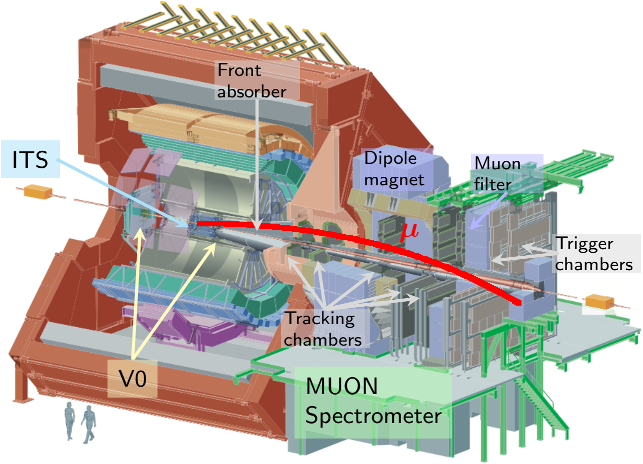
- Centrality selection based on a geometrical Glauber model fit of the V0 scintillators amplitude

- Minimum-Bias (MB) triggers from the coincidence of V0 & SPD (Silicon Pixel Detector)
- Muon triggers in pp

Analyzed data		
	pp @ 2.76 TeV (2011)	PbPb @ 2.76 TeV (2010)
$\mathcal{L}_{int}$	19 nb^{-1}	2.7 μb^{-1}

Muon Spectrometer

- Coverage: $-4 < \eta^{\mu} < -2.5$
- Min. muon momentum: $p^{\mu} \gtrsim 4$ GeV/c
- Min. p_{t} for trigger: $p_{t}^{\mu} \gtrsim 0.5$ GeV/c



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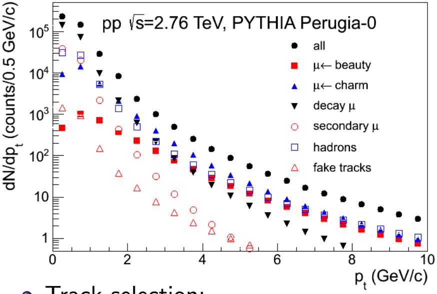
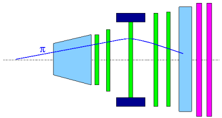
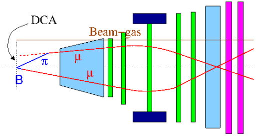


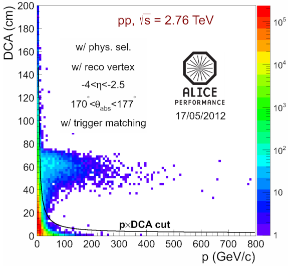
- Track selection
- Background subtraction
- Acceptance × efficiency correction
- Cross-section estimation

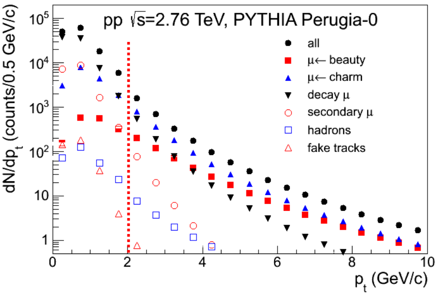
- Track selection:
  - match track with tracklets in the trigger chambers ⇒ reject punch-through hadrons

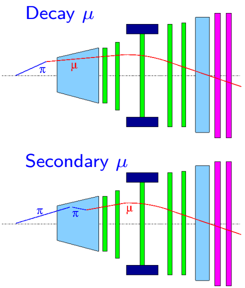


  - cut on $p \times$ DCA of the tracks ⇒ reject tracks from beam-gas interaction

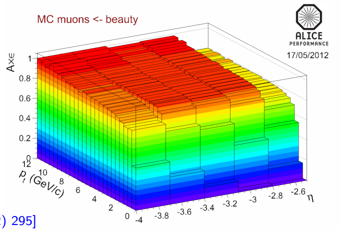




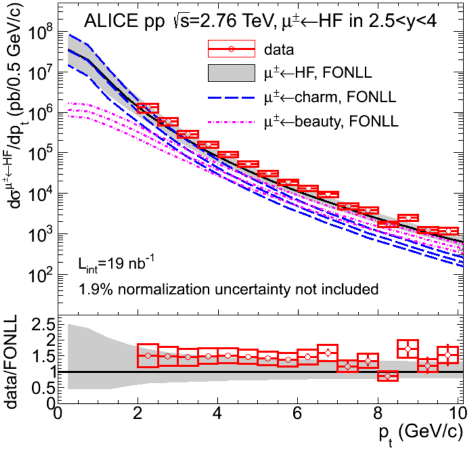




- Background contribution decreases with $p_{\rm t}$: focus on $p_{\rm t} > 2$ GeV/c
- Main background component: decay μ ($\sim$40% for $p_{\rm t} > 2$ GeV/c)
- Subtraction using as input MC simulations
- Systematic uncertainties:
  - models: estimated using different MC inputs (Pythia-Perugia0, Phojet)
  - transport: estimated by varying the secondary μ production by 100%
- Bi-dim. Acc.×Eff. correction from MC simul. of **full detector** based on a parameterization of the $p_{\rm t}$ and y differential cross sections of b-quark from MNR [Mangano,Nason,Ridolfi,Nucl.Phys.B **373** (1992) 295]



Submitted to arXiv



Systematic uncertainties	
Alignment	1% × p_t (in GeV/c)
Detector response	3%
Bkg. subtraction: model	13%
Bkg. subtraction: transport	5-20% depending on p_t

- Well described by FONLL pQCD calculations within errors

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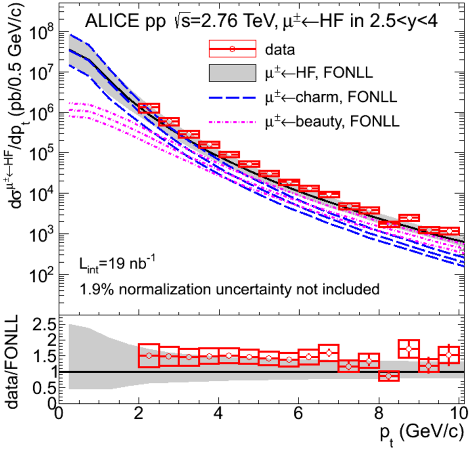
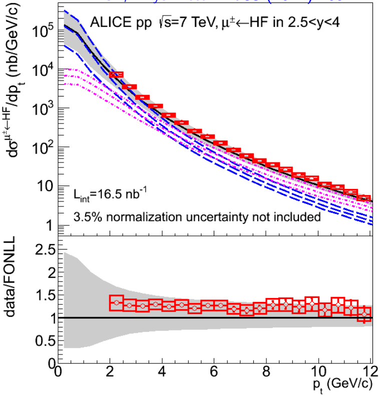


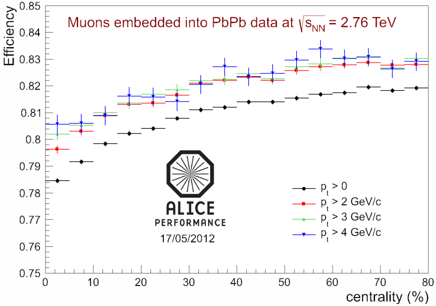
Systematic uncertainties	
Alignment	$1\% \times p_{\mathrm{t}}$ (in GeV/c)
Detector response	3%
Bkg. subtraction: model	13%
Bkg. subtraction: transport	5-20% depending on p_{t}

- Well described by FONLL pQCD calculations within errors
- Similar result obtained in pp collisions at $\sqrt{s} = 7$ TeV

ALICE, Phys. Lett. B **708** (2012) 265



- Track selection as in pp collisions
- Correction of inclusive muon yields:
  - Bi-dim. Acc.×Eff. correction from MC simulations of full detector based on a param. of the $p_{\rm t}$ and y differential cross sections of b quark from MNR
  - Efficiency dependence on detector occupancy using embedding:



- decrease of the efficiency by $4\% \pm 1\%$ in the 10% most central collisions with respect to peripheral collisions, independent of $p_{\rm t}$

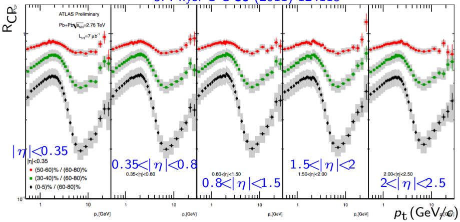
- Calculate R_{AA} as:

$$R_{AA}(p_{\rm t}) = \frac{1}{\langle T_{AA} \rangle} \frac{dN_{AA}^{\mu \text{ inclusive}}/dp_{\rm t} - dN_{AA}^{\mu\leftarrow\pi/K}/dp_{\rm t}}{d\sigma_{pp}^{\mu\leftarrow HF}/dp_{\rm t}}$$

- Estimation of the (background) contribution of muons from light hadron decay ($dN_{AA}^{\mu\leftarrow\pi/K}/dp_{\rm t}$): data driven method

- ATLAS results suggest small dependence of R_{CP} of charged hadrons with rapidity $\Rightarrow$ assume no dependence up to $y = 4$

J. Phys. G G **38** (2011) 124113



Estimate $\mathrm{d}\sigma_{pp}^{\mu\leftarrow\pi/K}/\mathrm{d}p_t$ at forward rapidity in pp collisions:

- input: π, K distributions measured in pp collisions at central rapidities [J.Phys.G G **38** (2011) 124014]
- extrapolate to forward rapidities via [PHENIX, PRD **76** (2007) 092002]:

$$\frac{\mathrm{d}^2 N_{pp}^{\pi,K}}{\mathrm{d}p_t \mathrm{d}y} = \left[\frac{\mathrm{d}^2 N_{pp}^{\pi,K}}{\mathrm{d}p_t \mathrm{d}y}\right]_{y=0} \exp\left(\frac{-y^2}{2\sigma_y^2}\right)$$

with $\sigma_y = 3.18$ estimated from PYTHIA and Phojet (error $\sim$ 15%)

- fast MC for generation of decay muon

Estimate $\mathrm{d}N_{AA}^{\mu\leftarrow\pi/K}/\mathrm{d}p_t$ at forward rapidity in PbPb collisions

- input: $\mathrm{R_{AA}}^{\pi,K}$ measured at central rapidities [J.Phys.G G **38** (2011) 124014 and 124080]
- get the $\mathrm{d}N_{AA}^{\pi,K}/\mathrm{d}p_t$ of pions at forward rapidities via:

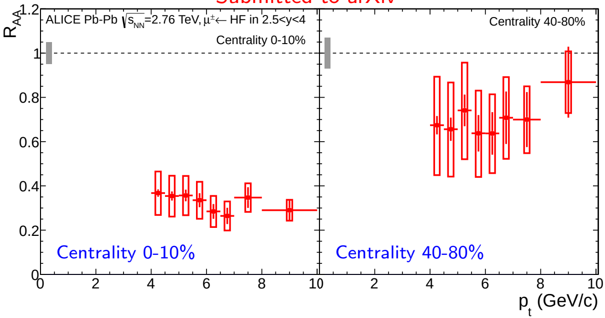
$$\mathrm{d}N_{AA}^{\pi,K}/\mathrm{d}p_t = \langle T_{AA}\rangle \cdot \mathrm{d}\sigma_{pp}^{\pi,K}/\mathrm{d}p_t \cdot \left[\mathrm{R_{AA}}^{\pi,K}\right]_{y=0}$$

- fast MC for generation of decay muon
- systematic (unknown quenching at forward y): vary input $\mathrm{R_{AA}}^{\pi,K}$ by $\pm$100%

- Focus on the region $p_{\mathrm{t}} > 4$ GeV/c to limit the systematics from background subtraction

pp reference	
Detector response	3%
Alignment	1% $\times$ p_{t} (in GeV/c)
Bkg. subtraction	14–17% (depending on p_{t})
Inclusive muon yields in PbPb collisions	
Detector response	3.5%
Alignment	1% $\times$ p_{t} (in GeV/c)
Centrality dependence of efficiency	1%
Decay muon background in PbPb collisions	
$d\sigma^{\mu\leftarrow\pi/K}/dp_{\mathrm{t}}$ in pp	17%
$R_{AA}{}^{\mu\leftarrow\pi/K}$	14–17%
$R_{AA}{}^{\mu\leftarrow\pi/K}/R_{AA}{}^{\mu\leftarrow\pi}$	up to 9% at $p_{\mathrm{t}} = 10$ GeV/c
Unknown quenching at forward y (varying $R_{AA}{}^{\mu\leftarrow\pi/K}$ of $\pm$100%)	bkg. contrib. from 0 to 14% (21%) in central (peripheral) collisions
Normalization	
pp cross-section @ 2.76 TeV	1.9%
$\langle T_{AA}\rangle$	4–7% (depending on centrality)

Submitted to arXiv



- Empty boxes: uncorrelated systematic uncertainties
- Filled box at 1: correlated systematic uncertainty on pp normalization and $\langle T_{AA} \rangle$

- Larger suppression in central than peripheral collisions
- No significant dependence on p_t

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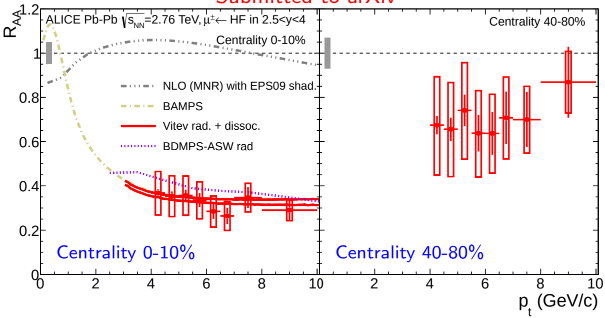
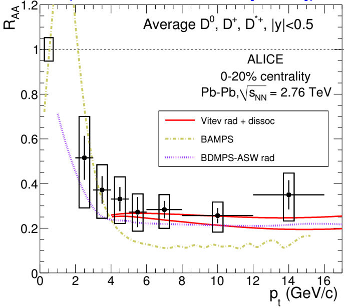


- Empty boxes: uncorrelated systematic uncertainties
- Filled box at 1: correlated systematic uncertainty on pp normalization and $\langle T_{AA} \rangle$

- Larger suppression in central than peripheral collisions
- No significant dependence on p_t
- Small contribution of shadowing expected
- BAMPS [Uphoff,Fochler,Xu,Greiner,arXiv:1205.4945v1 [hep-ph]] calculation reproduce the muon data (but tends to underestimate D meson R_{AA} at mid-rapidity)
- Radiative energy loss + dissociation [Sharma,Vitev,Zhang,PRC **80** (2009) 054902] and BDMPS-ASW [Armesto,Dainese,Salgado,Wiedemann, PRD **71** (2005) 054027], in agreement with both muons and D meson data

D meson in $|y| < 0.5$
(ALICE, arXiv:1203.2160 [nucl-ex])



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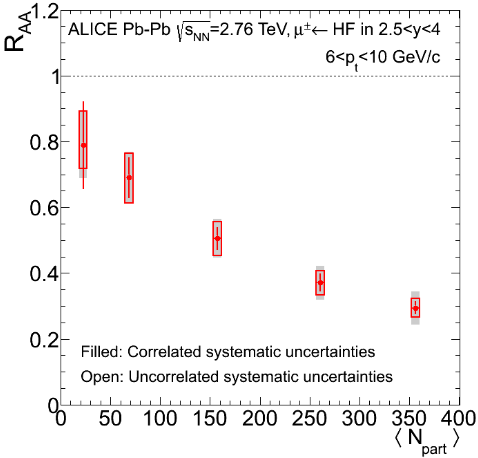
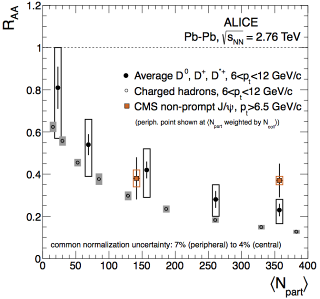


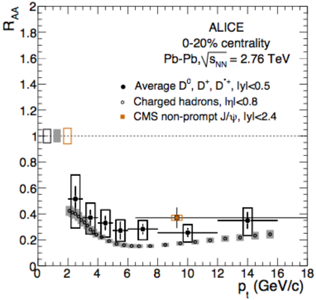
- Empty boxes: uncorrelated systematic uncertainties
- Filled boxes: uncertainty on pp reference and normalization

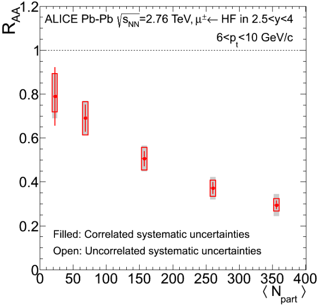
- Results obtained for $p_t > 6$ GeV/c: region dominated by beauty production, according to FONLL
- Strong increase of suppression with centrality, down to a factor of 3-4 in the 10% most central collisions

Comparison with other LHC results

ALICE, arXiv:1203.2160 [nucl-ex] and CMS, arXiv:1201.5069 [nucl-ex]







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- Strong suppression measured at mid-rapidity in central collisions for:
  - D meson at mid-rapidity in $6 < p_{\rm t} < 12$ GeV/c
  - charged hadrons at mid-rapidity in $6 < p_{\rm t} < 12$ GeV/c
  - non-prompt J/ψ in $|y| < 2.4$ and $6.5 < p_{\rm t} < 30$ GeV/c
- Muons from heavy-flavour decay exhibit a similar suppression although in a different rapidity range

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Conclusions

- First measurement of muons from heavy-flavour decay at forward rapidities ($2.5 < y < 4$) in pp and PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV

Heavy flavours in pp collisions

- Comparison with FONLL pQCD predictions: good agreement within errors

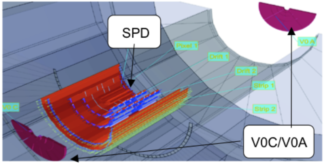
Heavy flavours in PbPb collisions

- R_{AA} of muons from heavy-flavour decay measured as a function of transverse momentum and centrality:
  - no significant dependence with p_t in $4 < p_t < 10$ GeV/c
  - strong suppression with centrality (up to a factor of 3–4)
- Same suppression pattern as the one measured for D mesons at mid-rapidity ($|y| < 0.5$, $6 < p_t < 12$ GeV/c) and of non-prompt J/ψ in a wider rapidity range ($|y| < 2.4$, $6.5 < p_t < 30$ GeV/c)

Perspectives:

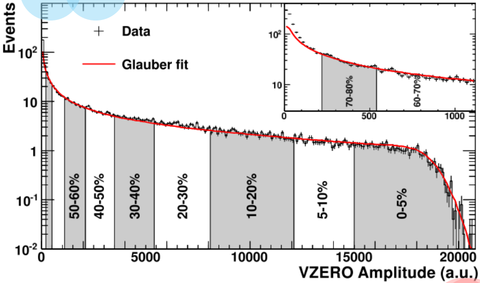
- Measurement of the muon v2 in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV
- Measurement in p–Pb, Pb–p collisions: cold nuclear matter effects

Centrality selection



- Minimum-bias triggers from the coincidence of SPD & V0A & V0C

- Centrality selection based on a geometrical Glauber model fit of the V0 amplitude

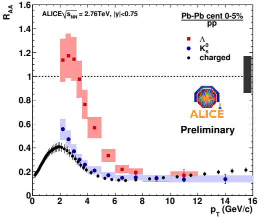


Centrality	$\langle N_{part} \rangle$	$\langle T_{AA} \rangle$ mb^{-1}
0–10%	357 ± 4	23.48 ± 0.97
10–20%	261 ± 4	14.43 ± 0.57
20–40%	157 ± 3	6.85 ± 0.28
40–60%	69 ± 2	2.00 ± 0.11
60–80%	23 ± 1	0.42 ± 0.03
40–80%	46 ± 2	1.20 ± 0.07

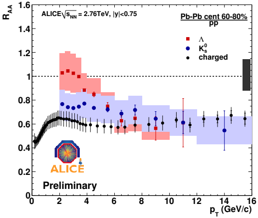
- Centrality classes used in this analysis

- Mid-rapidity $\pi^{\pm}$ measured at all centralities and up to $p_{\mathrm{t}} = 20$ GeV/c
- $\mathrm{K}^{\pm}$ measured only at low p_{t} $\Rightarrow$ use K^0, considering $N(\mathrm{K}^+) + N(\mathrm{K}^-) = 2N(\mathrm{K}^0)$
- Issue: K^0 measured only in 0-5% and 60-80%

K^0, 0-5%



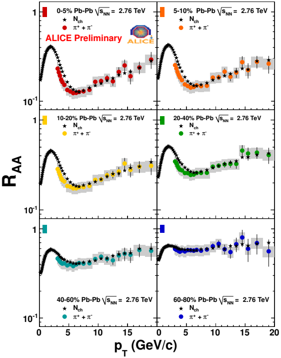
K^0, 60-80%



J. Phys. G G **38** (2011) 124014

$\pi^{\pm}$

J. Phys. G G **38** (2011) 124080



- However:
  - Small dependence with p_{t}
  - Similar $\mathrm{R_{AA}}$ for kaons and pions at different centralities
- Strategy: use $\mathrm{R_{AA}}$ from π and correct for double ratio $\mathrm{R_{AA}}^{\mu\leftarrow\pi} / \mathrm{R_{AA}}^{\mu\leftarrow\pi/K}$