



R_{PbPb} and R_{pPb} measurements with ALICE

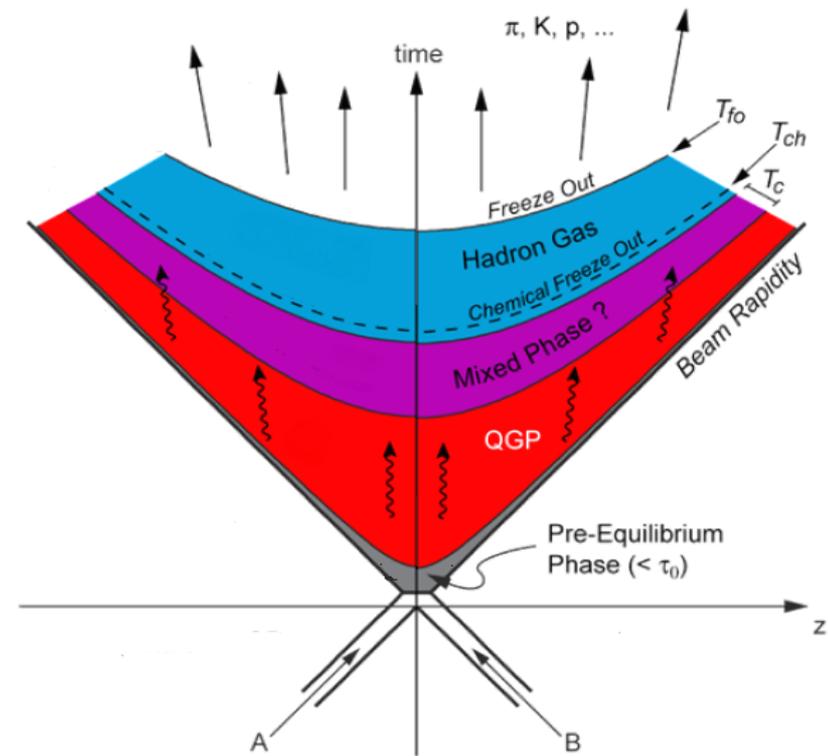
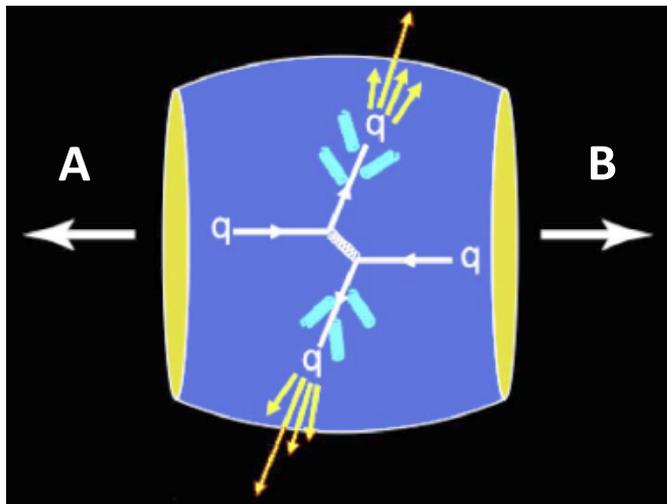
Jacek Otwinowski (GSI)
on behalf of the ALICE Collaboration

Workshop on QCD and Diffraction at the LHC
26 November 2012, Krakow, Poland

Content

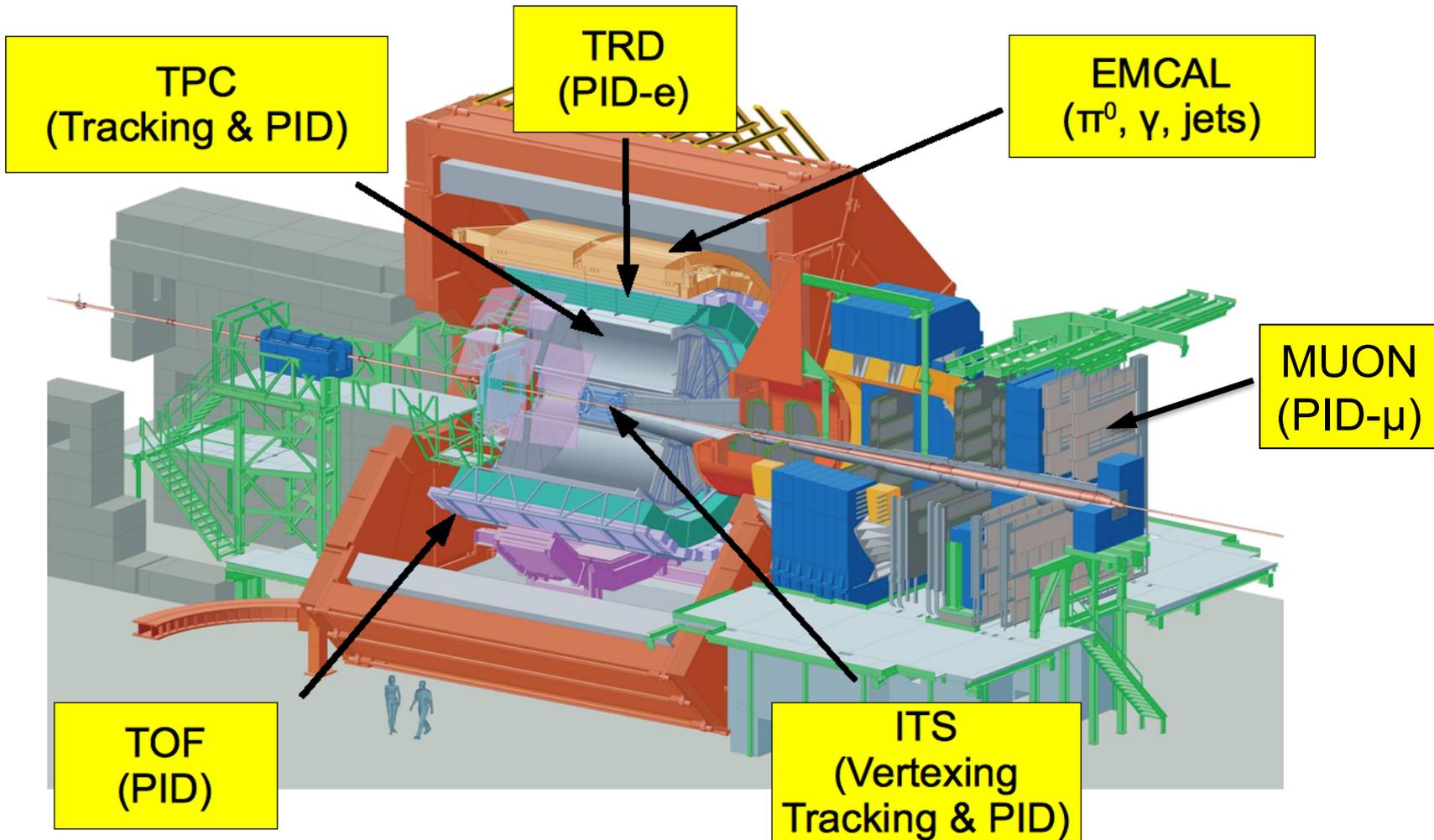
- Nuclear modification factor R_{PbPb}
 - Parton energy loss in the Quark Gluon Plasma
- Firsts results from p-Pb collisions at LHC
- Outlook

Parton energy loss in the Quark Gluon Plasma



- Energy loss in the QGP (high p_T):
 - Medium density and size: dN/dp_T , R_{AA} , v_2
 - Color charge (Casimir factor): $\Delta E_q < \Delta E_g$
 - Parton mass (dead cone effect): $\Delta E_b < \Delta E_c < \Delta E_{u,d,s}$

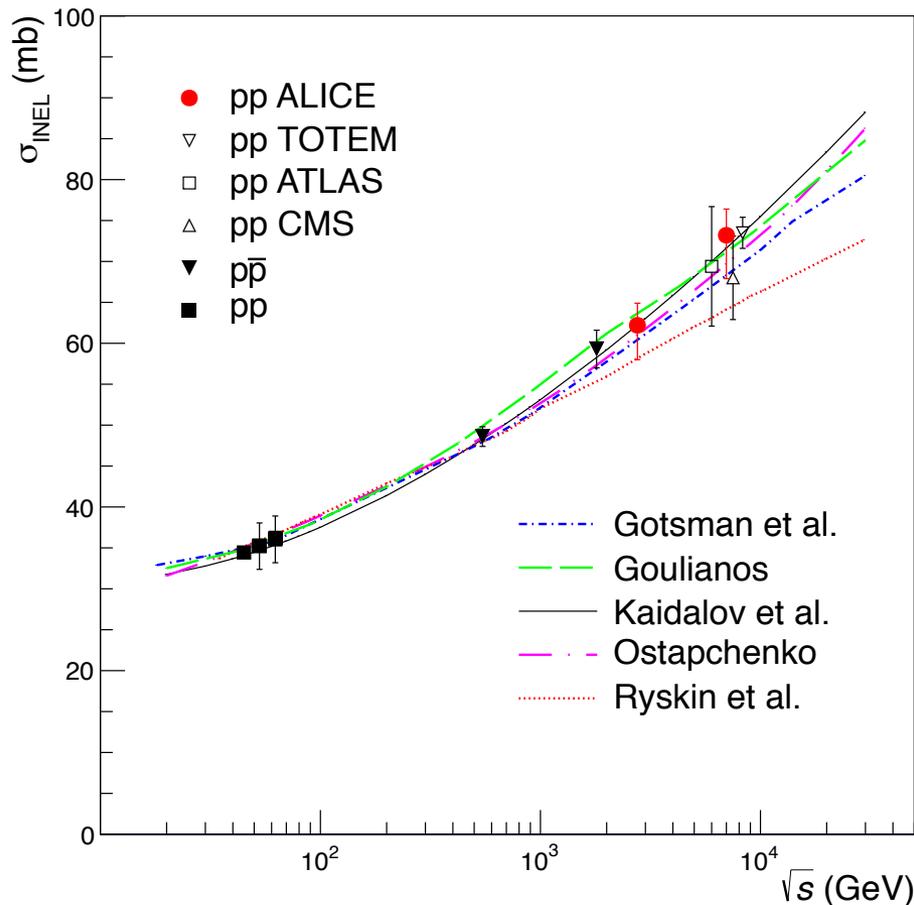
ALICE – A Large Ion Collider Experiment



ALICE has excellent PID capabilities. Particle identification possible in the p_T range **0.1-50 GeV/c**.

pp σ_{INEL} measured with ALICE

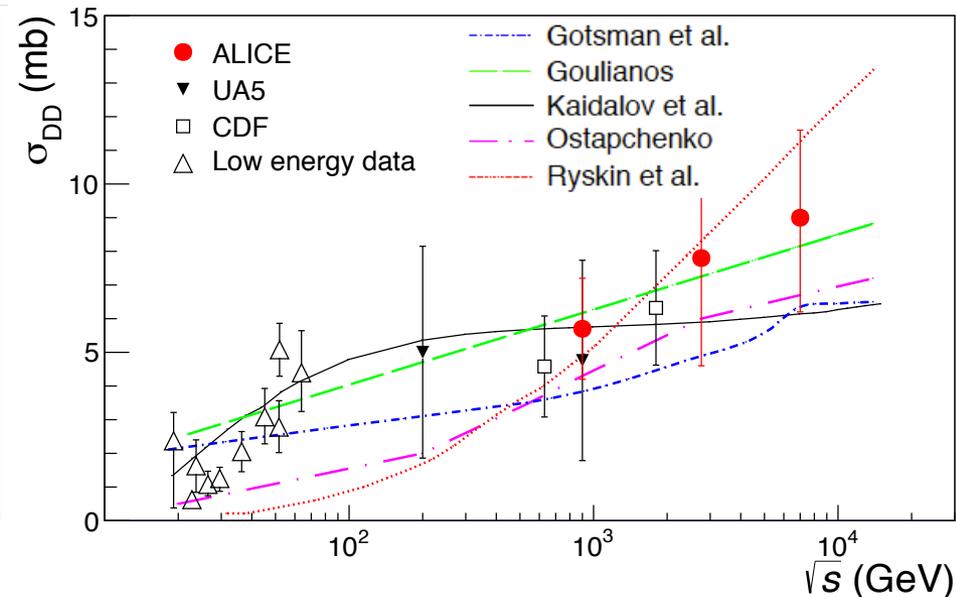
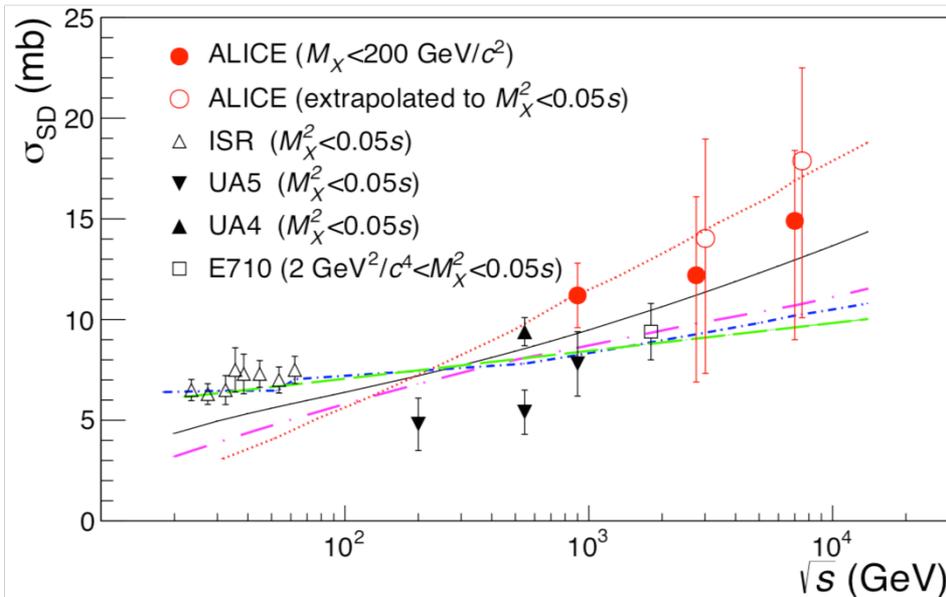
ALICE, arXiv:1208.4968



- σ_{INEL} at $\sqrt{s} = 2.76$ and 7 TeV using van der Meer scan
- σ_{INEL} at $\sqrt{s} = 0.9$ TeV not measured by ALICE ($\sigma_{\text{INEL}} \sim 52.5$ mb from UA5 measurement instead)
- Correction for trigger bias based on simulations with adjusted SD and DD fractions to match data (η -gap analysis)

pp σ_{SD} and σ_{DD} measured with ALICE

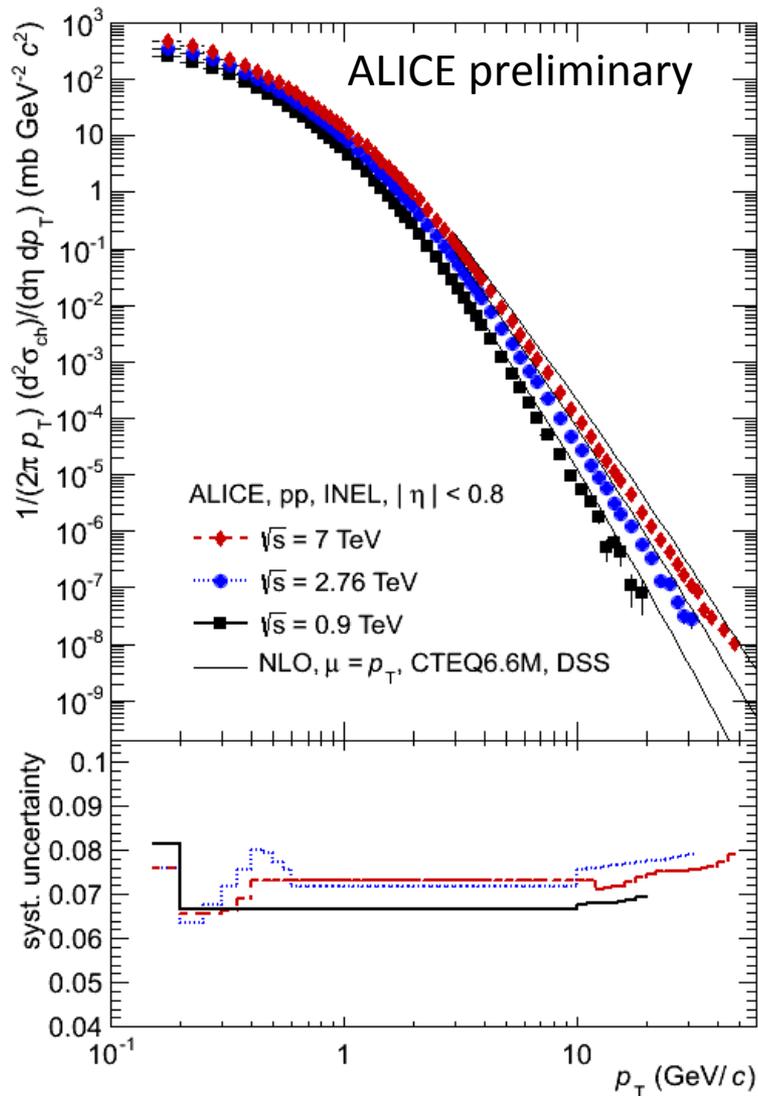
ALICE, arXiv:1208.4968



\sqrt{s} (TeV)	σ_{SD} (mb)	σ_{DD} (mb)
0.9	$11.2^{+1.6}_{-2.1}$	5.6 ± 2.0
2.76	$12.2^{+3.9}_{-5.3}$	7.8 ± 3.2
7	$14.9^{+3.4}_{-5.9}$	9.0 ± 2.6

- η -gap analysis
 - σ_{SD} for diffractive masses $M_X < 200 \text{ GeV}/c^2$
 - σ_{DD} for $\Delta\eta > 3$

p_T spectra in pp



- $d^2\sigma_{ch}/dp_T d\eta$ measured in INEL pp collisions at $\sqrt{s} = 0.9, 2.76$ and 7 TeV
- pp at $\sqrt{s} = 2.76 \text{ TeV}$ reference for Pb-Pb
- Trigger bias corrections (MB \rightarrow INEL) based on simulations with adjusted SD and DD fractions to match data

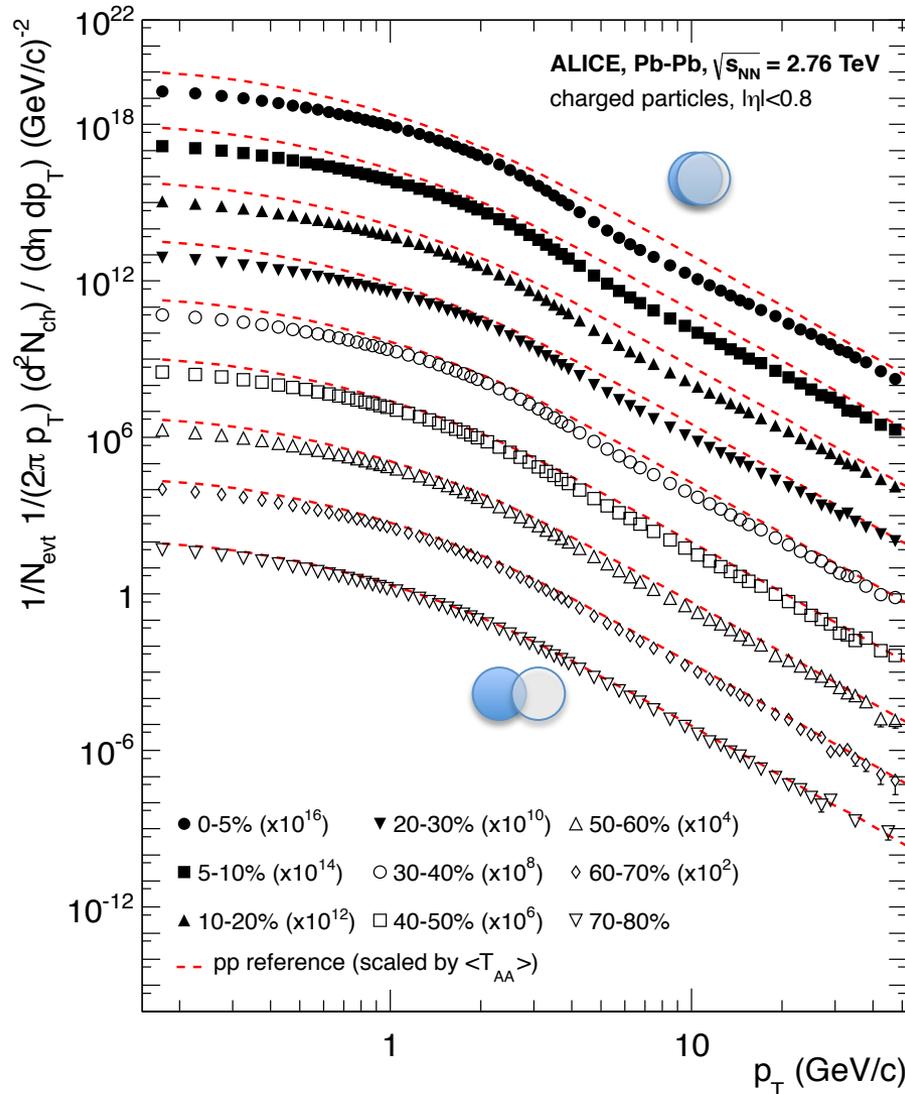
p_T spectra in Pb-Pb

ALICE, arXiv:1208.2711

Charged particles

($p_T = 0.15-50$ GeV/c)

- pp reference measured at the same collision energy ($p_T = 0.15-35$ GeV/c , extrapolation to 50 GeV/c using parameterization (Hagedorn fit)
- p_T spectral shape changes with collision centrality
- p_T spectra in central Pb-Pb dramatically different from pp reference

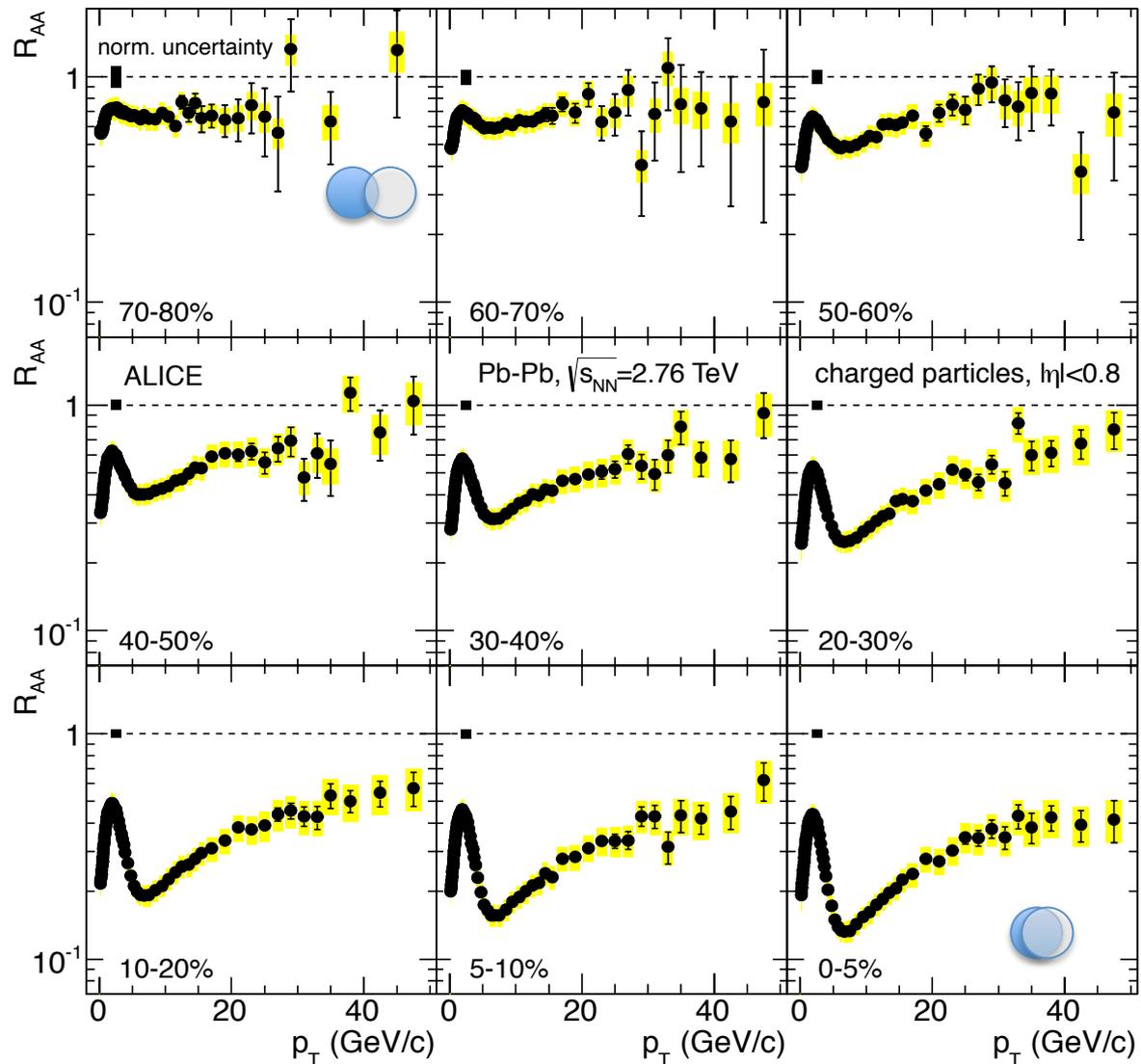


R_{AA} for charged particles

ALICE, arXiv:1208.2711

$$R_{AA} = \frac{1}{\langle T_{AA} \rangle} \frac{dN_{AA}/dp_T}{d\sigma_{pp}/dp_T}$$

- $\langle T_{AA} \rangle$ - nuclear overlap function from Glauber model
- Suppression pattern depends on collision centrality
- Largest suppression in the central collisions (factor 7 at $p_T \sim 7$ GeV/c)



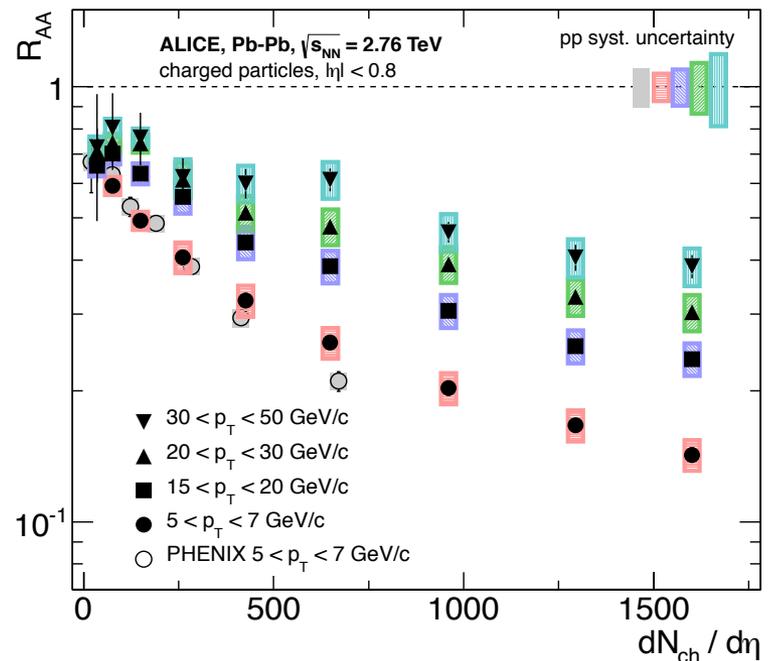
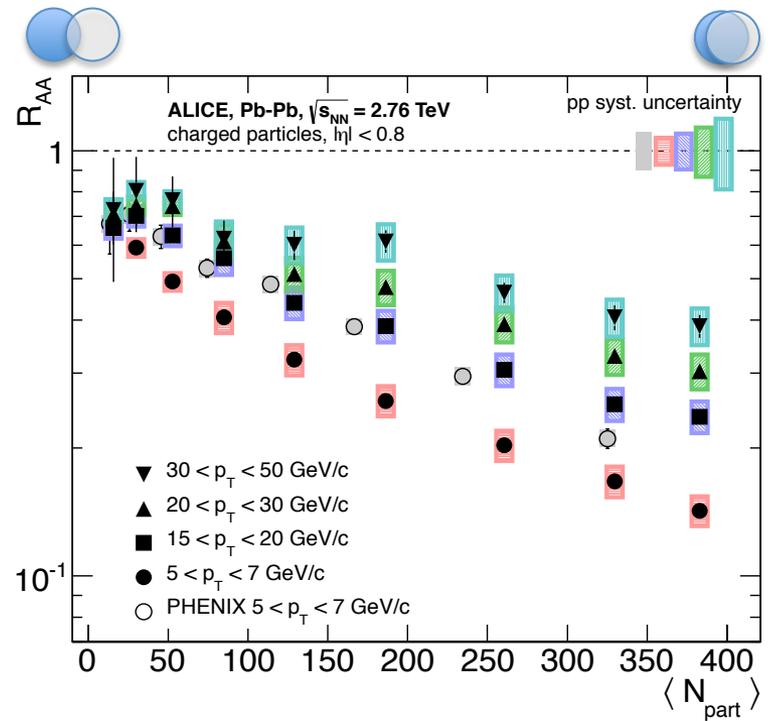


R_{AA} vs. collision centrality

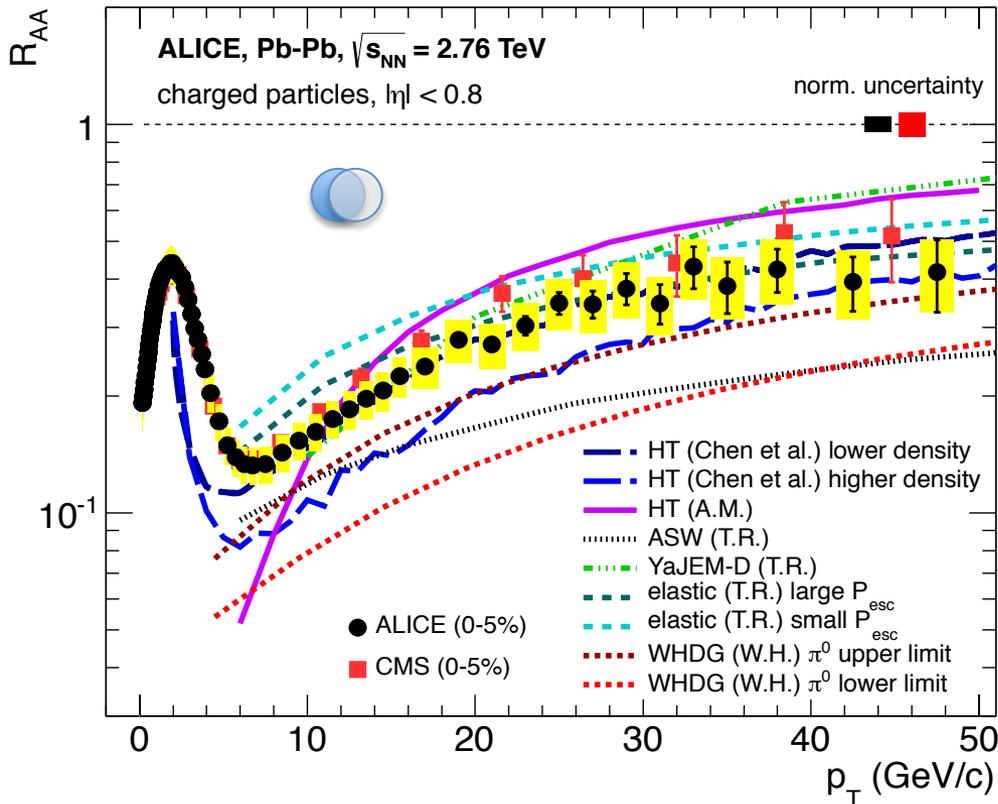
Charged particles

- Strongest suppression vs. collisions centrality for $5 < p_T < 7$ GeV/c
- Factor ~ 1.2 stronger suppression vs. $\langle N_{part} \rangle$ compared to RHIC (at all p_T)
- Similar suppression vs. $dN_{ch}/d\eta$ compared to RHIC

ALICE, arXiv:1208.2711
PHENIX, PRC 69 (2004) 034910



R_{AA} comparison - central collisions



ALICE, arXiv:1208.2711
CMS, EPJ C 72 (2012) 1945

Charged particles

- Selected models available before preliminary data
- A variety of energy loss formalisms are used (radiative, elastic, ...)
- An increase of R_{AA} vs. p_T is seen for all the models
- Agreement with CMS

Radiative:

WHDG (W.H.), Nucl. Phys. A 872 (2011) 265

ASW (T.R.), Phys. Rev. D 68 (2003) 014008

HT (Chen et al.), Phys. Rev. C 84 (2011) 034902

HT (A.M.), Phys. Rev. Lett. 105 (2010) 252002

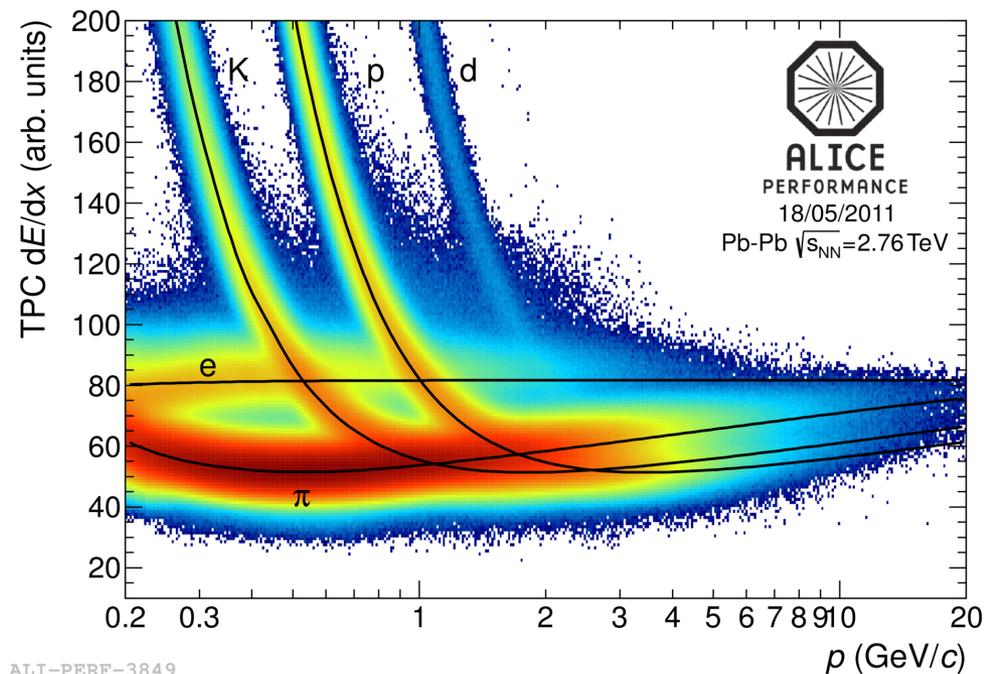
Elastic (T.R.), Phys. Rev. C. 84 (2011) 014906

YaJEM-D (T.R.), Phys. Rev. C 83 (2011) 024908

TOWARDS JETS WITH IDENTIFIED PARTICLES

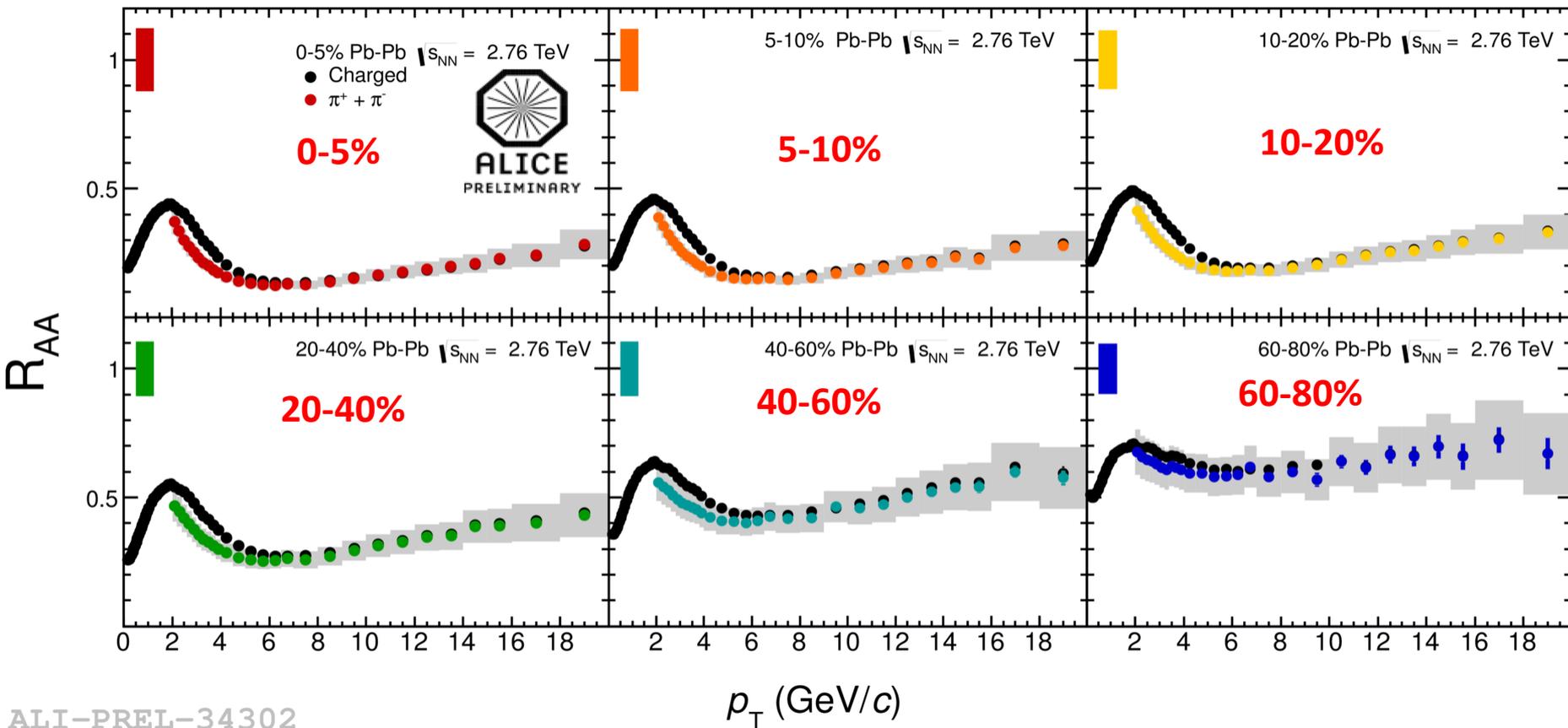
Light flavor (u,d,s)

dE/dx in ALICE TPC



R_{AA} for charged pions

charged particle spectra arXiv:1208.2711

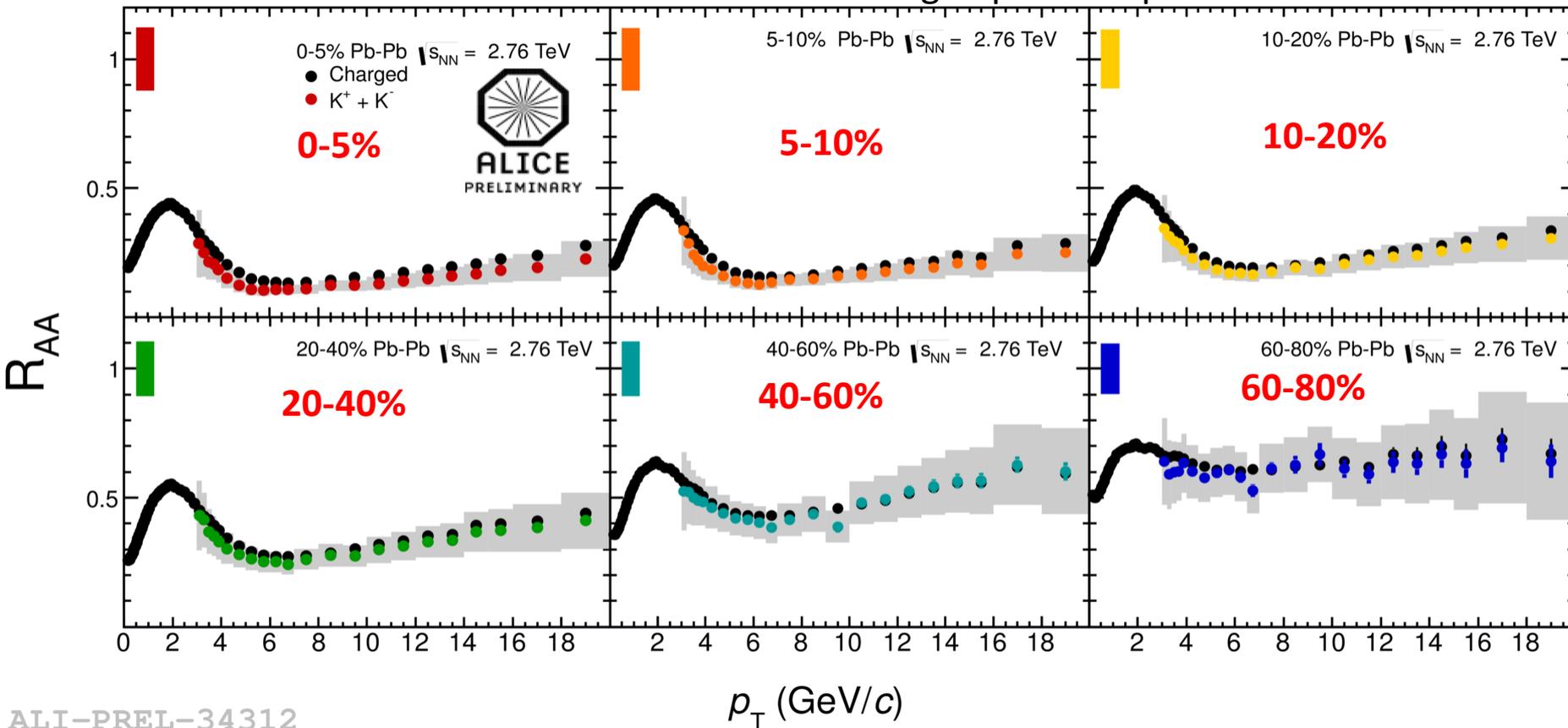


ALI-PREL-34302

- $2 < p_T < 7$ GeV/c: pion $R_{AA} <$ charged particle R_{AA} (centrality dependence)
- $p_T > 7$ GeV/c: pion $R_{AA} =$ charged particle R_{AA}

R_{AA} for charged kaons

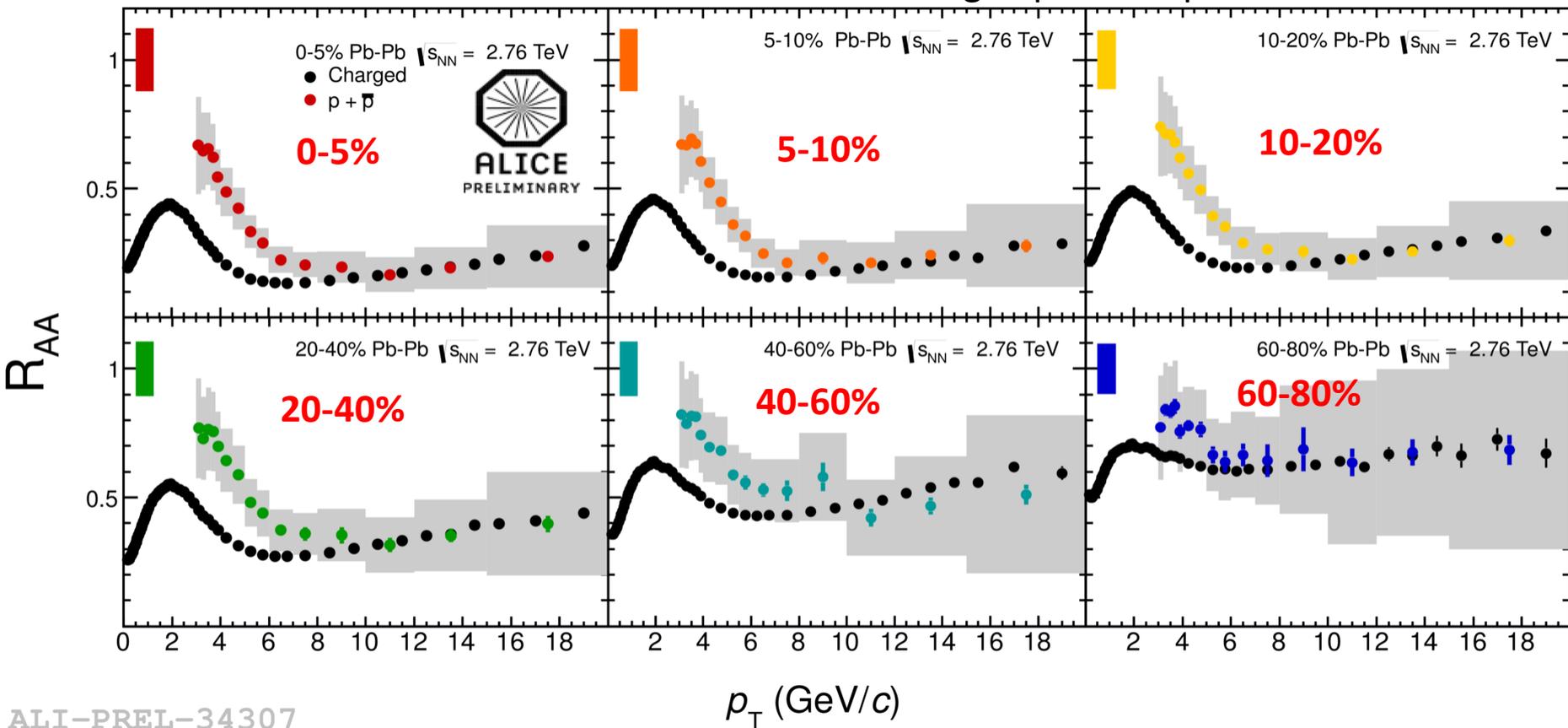
charged particle spectra arXiv:1208.2711



- Kaon $R_{AA} =$ charged particle R_{AA} ($p_T > 3$ GeV/c)

R_{AA} for (anti-)protons

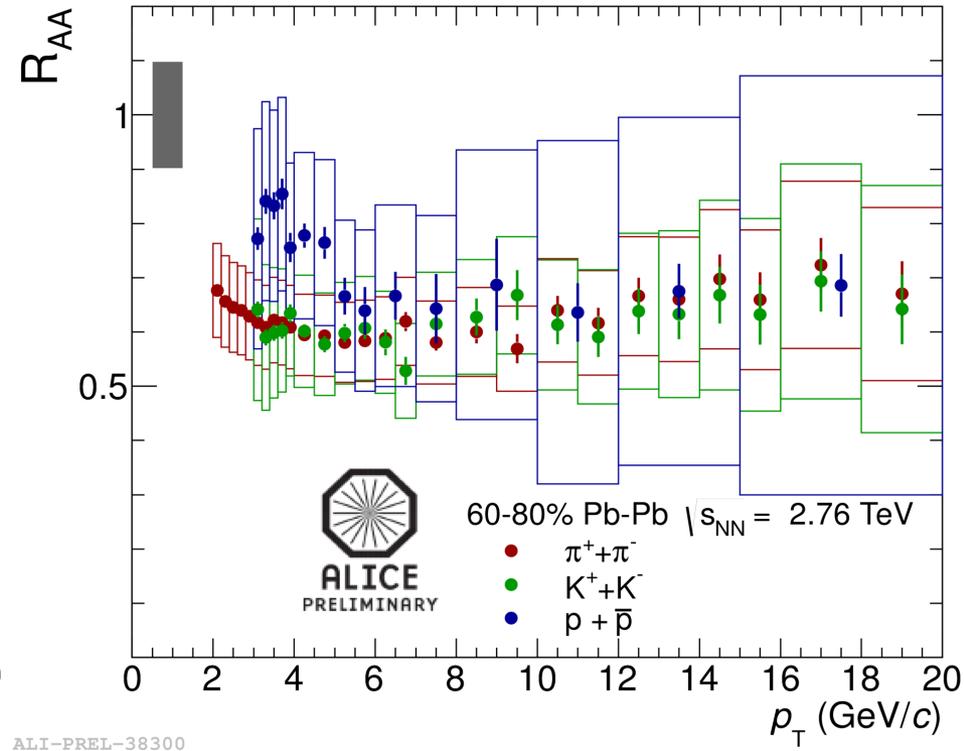
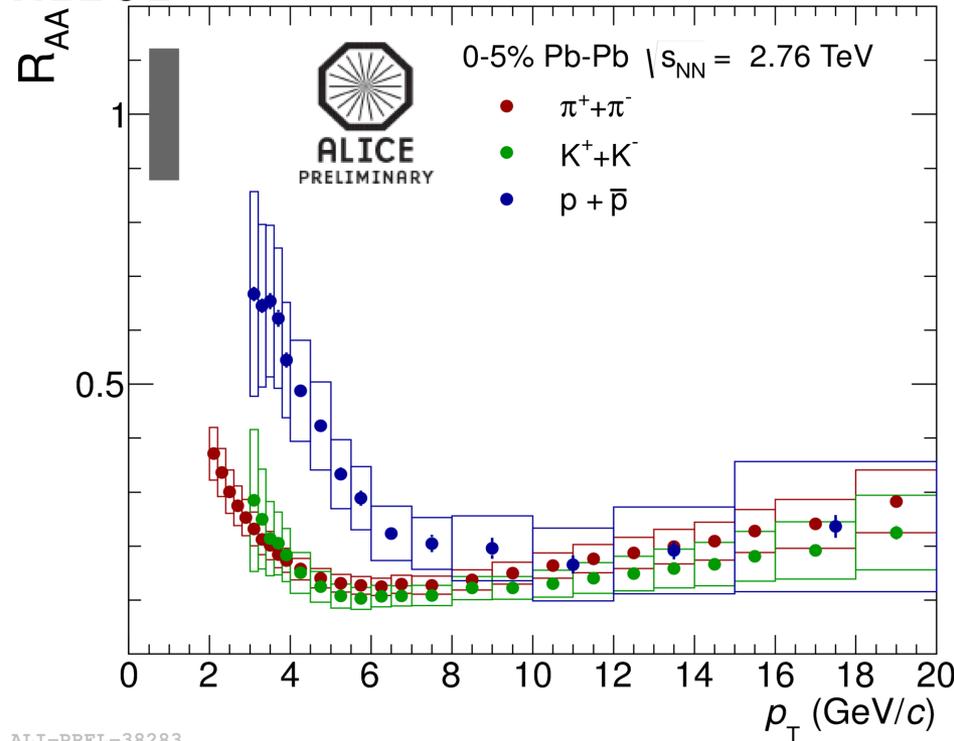
charged particle spectra arXiv:1208.2711



ALI-PREL-34307

- $3 < p_T < 7$ GeV/c: proton $R_{AA} >$ charged particle R_{AA} (centrality dependence)
- $p_T > 7$ GeV/c: proton $R_{AA} =$ charged particle R_{AA}

R_{AA} for $\pi/K/p$



Central collisions (0-5%):

- $3 < p_T < 7$ GeV/c: proton $R_{AA} >$ pion or kaon R_{AA}
- $p_T > 7$ GeV/c: pion $R_{AA} =$ kaon $R_{AA} =$ proton R_{AA}

Peripheral collisions (60-80%):

pion $R_{AA} =$ kaon $R_{AA} =$ proton R_{AA}

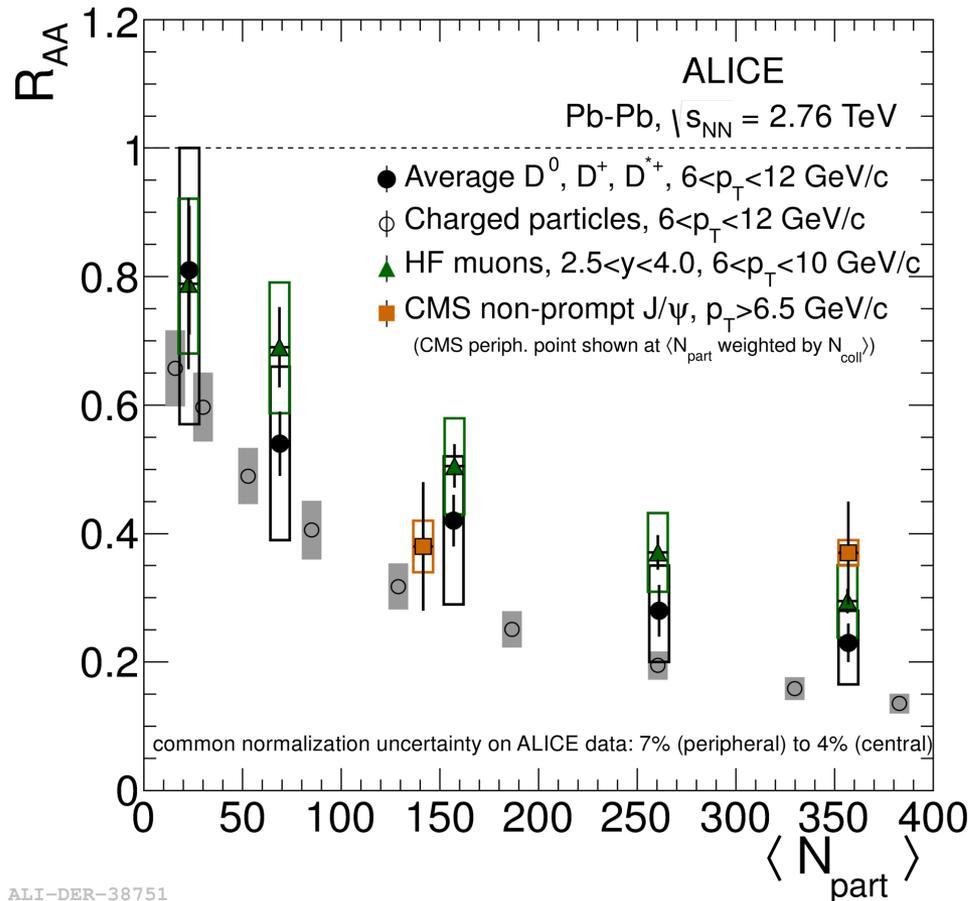
- Different particle spectra in Pb-Pb at $p_T < 7$ GeV/c
- High- p_T parton fragmentation seems not to be affected by the medium

TOWARDS JETS WITH IDENTIFIED PARTICLES

Heavy flavor (c,b)

- * $c, b \rightarrow e$
- * $b \rightarrow e$ $c\tau \sim 500 \mu\text{m}$
- * $c, b \rightarrow \mu$
- * $D^0 \rightarrow K \pi$ $c\tau \sim 122.9 \mu\text{m}$
- * $D^+ \rightarrow K \pi \pi$ $c\tau \sim 311.8 \mu\text{m}$
- * $D^{*+} \rightarrow D^0 \pi$
- * $D_s^+ \rightarrow K K \pi$ $c\tau \sim 149.9 \mu\text{m}$

Heavy flavor R_{AA} vs. collision centrality



- Similar suppression pattern of D mesons and heavy flavor muons
- Beauty R_{AA} : suppression of non-prompt J/ψ consistent with heavy flavor muons
- Light flavor $R_{AA} <$ heavy flavor R_{AA} ?
 - Not conclusive from these data...

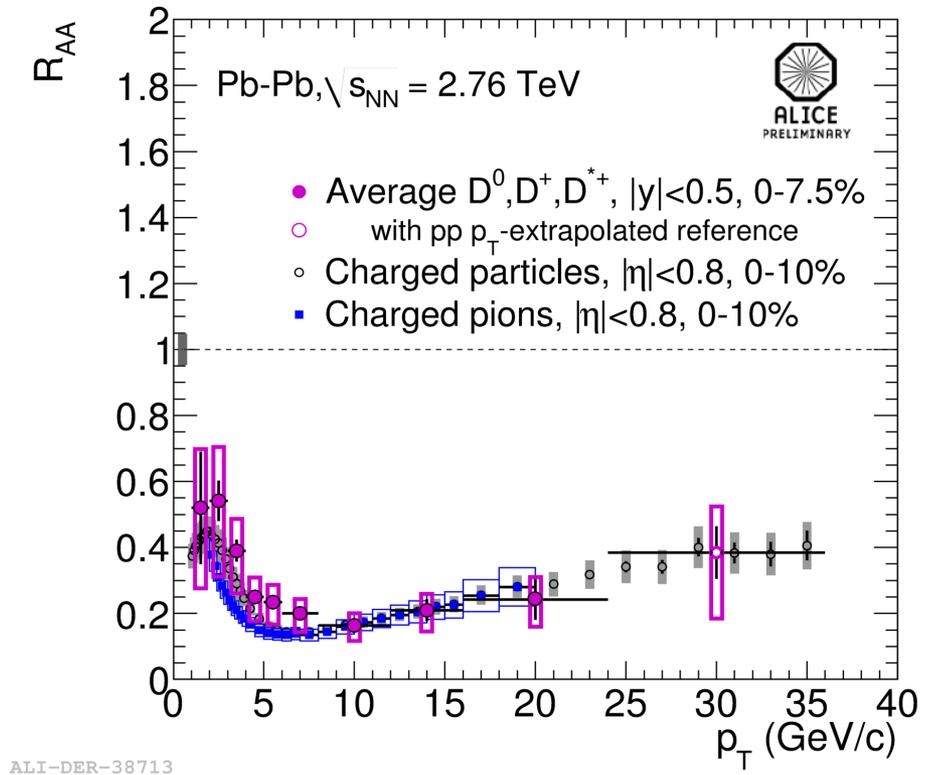
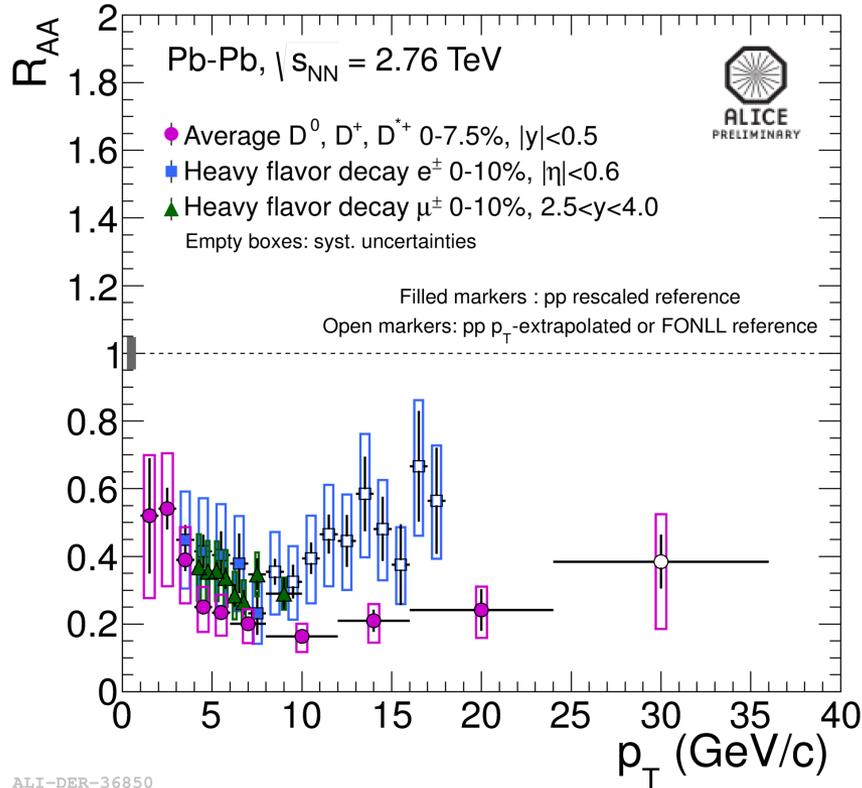
ALI-DER-38751

ALICE, arXiv:1203.2160

ALICE, PRL 109(2012)112301

CMS, JHEP 05 (2012)063

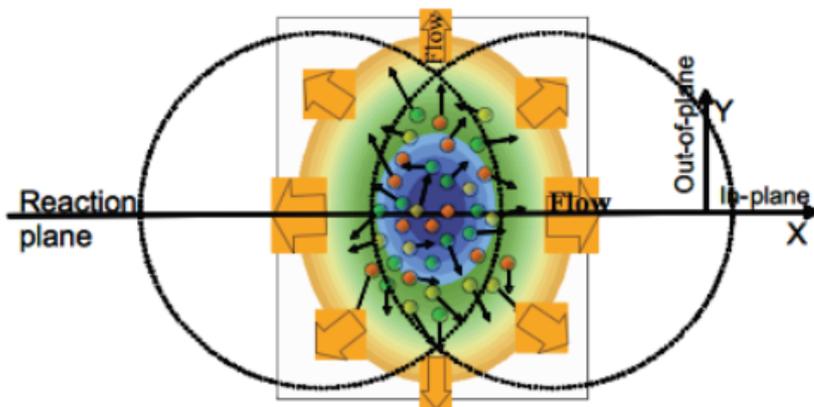
Heavy flavor R_{AA} vs. p_T in central collisions



- Similar suppression of heavy flavor in central Pb-Pb collisions
- D meson R_{AA} consistent with R_{AA} of heavy flavor decay e/μ taking into account $p_T^e \sim 0.5 p_T^{HF}$ at high- p_T
- **D meson $R_{AA} =$ pion $R_{AA} =$ charged particle R_{AA}**

R_{AA} vs. reaction plane - D mesons

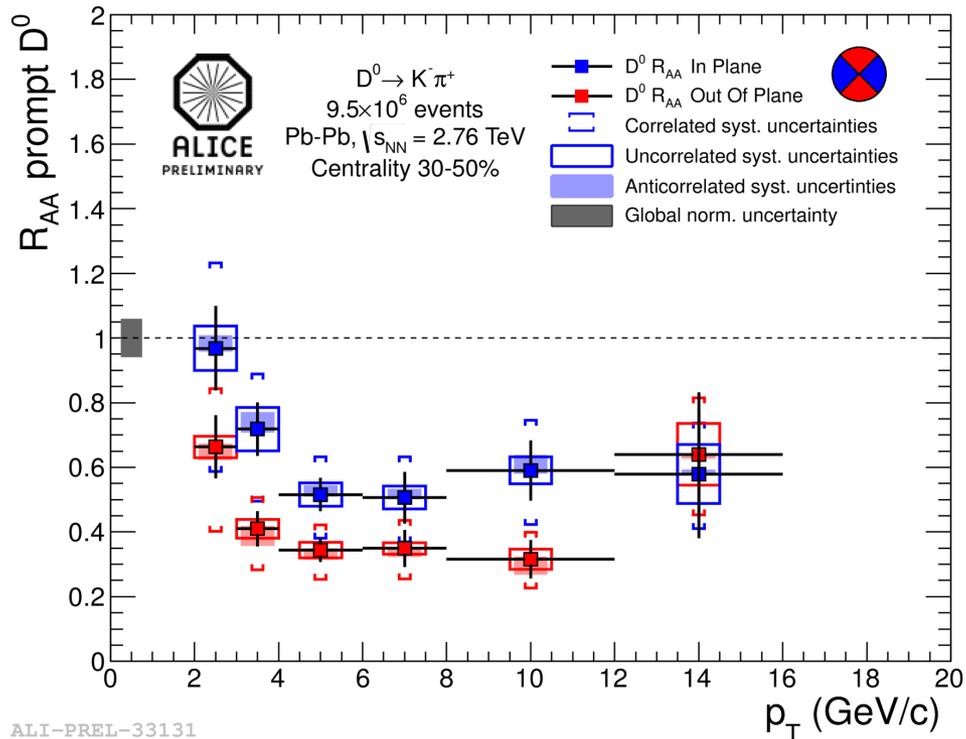
Path length dependence of the heavy quark energy loss.



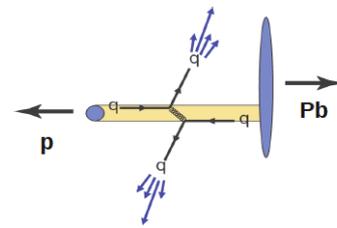
$$R_{AA}(\phi) = R_{AA}(1 + 2v_2 \cos(2\phi))$$

$\phi \sim 0$ (in-plane)

$\phi \sim \pi/2$ (out-of-plane)



- R_{AA} in-plane $>$ R_{AA} out-of-plane (centrality 30-50%)
 - contribution from elliptic flow at low p_T ?
 - path length dependence of energy loss at high p_T ?



FIRST P-PB COLLISIONS AT THE LHC

- Initial state effects on particle production (coherence effects in the nuclear wave function)
- Probing nuclear wave function at small parton fractional momentum x (gluon saturation)
- Input to distinguish initial and final state effects on particle production in Pb-Pb collisions

Experimental conditions:

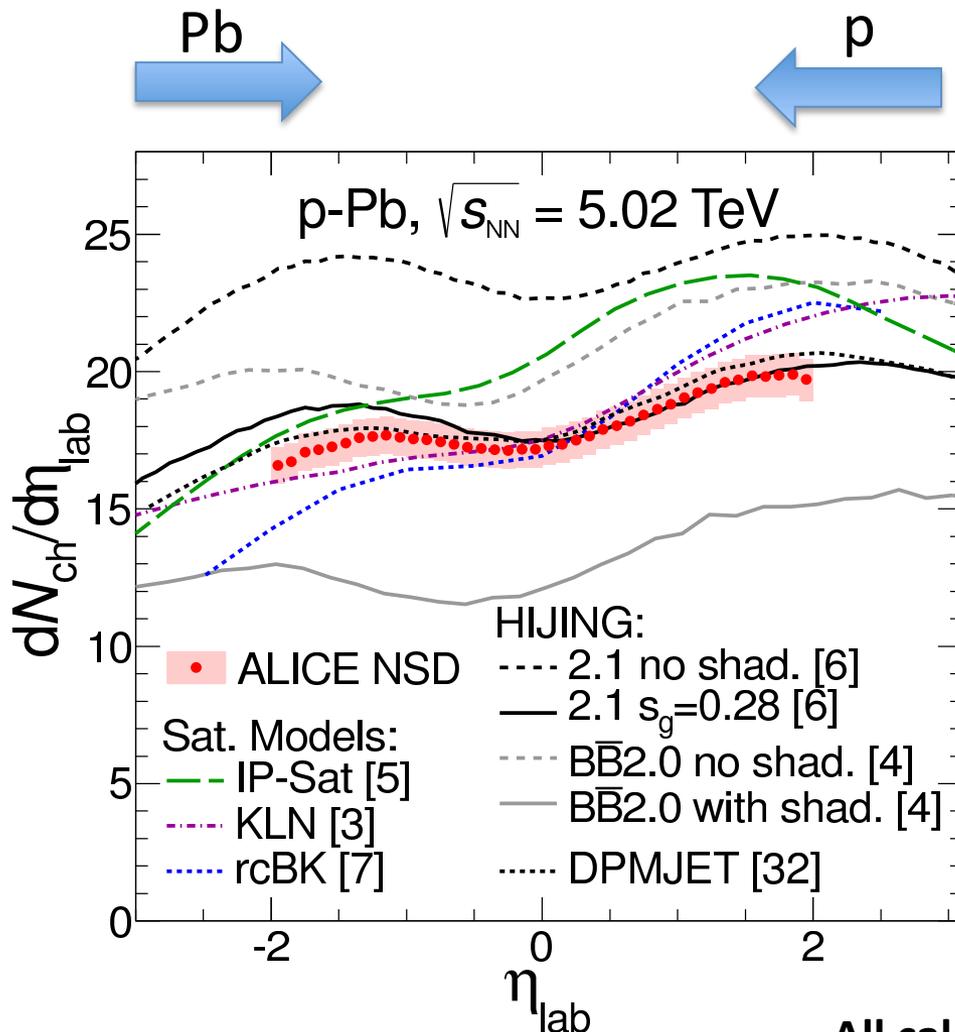
Different energy per nucleon for proton and Pb beams \rightarrow cms frame is shifted with rapidity $y_{NN} = 0.465$ in the direction of proton beam:

$$\eta_{\text{cms}} = \eta_{\text{lab}} + y_{NN}$$

This relation is valid only for massless particles or at high transverse momenta p_T . At low p_T the corrections are applied based on simulations.

Charged particle density in p-Pb

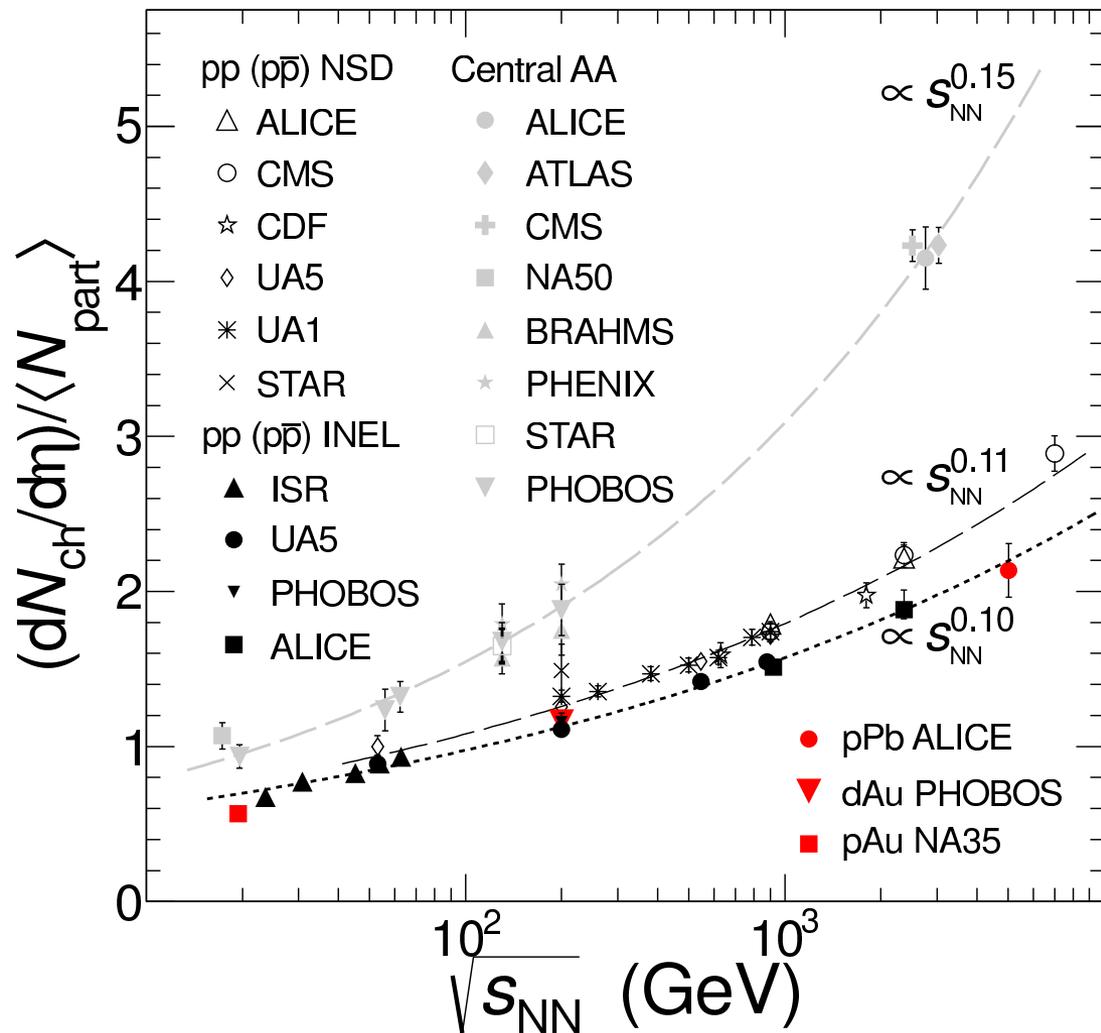
ALICE, arXiv:1210.3615v1



- Charged particle density for non-single diffractive events (NSD)
- Comparison to several model predictions (HIJING, DPMJET, saturation models)
- Agreement within 20% by models including shadowing [6] or saturation [3,7]
- Best agreement with DPMJET and HIJING with shadowing

All calculations shifted to the lab frame.

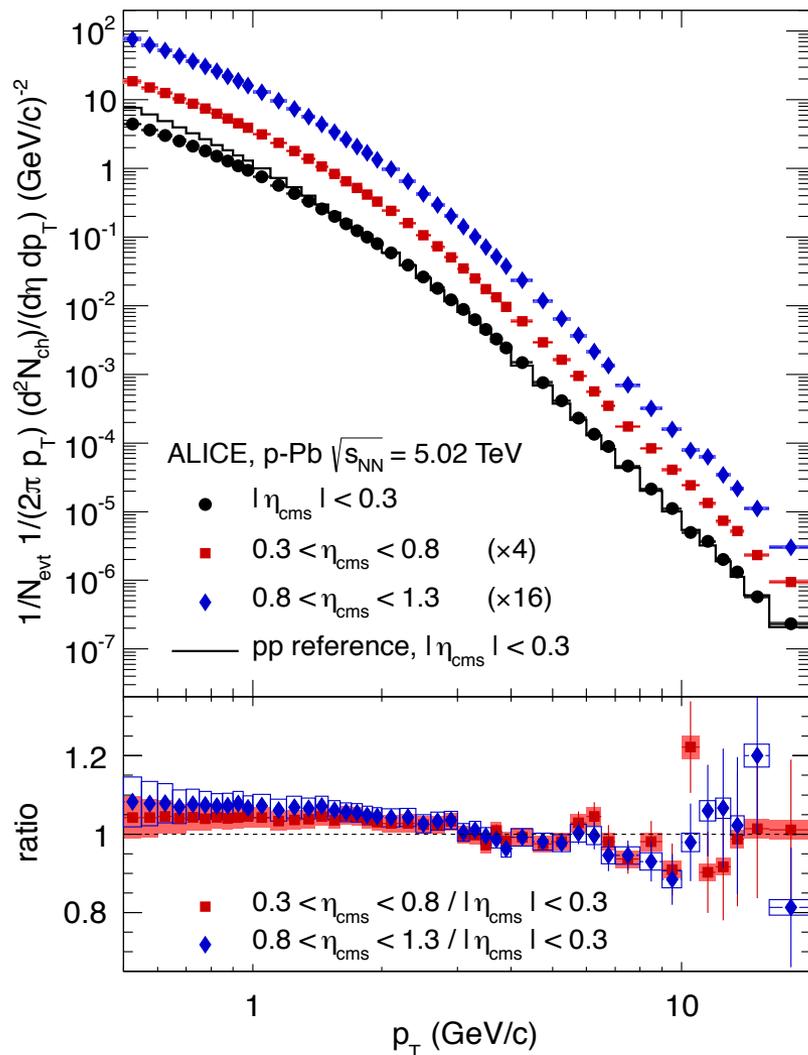
Charged particle density vs collision system



ALICE: arXiv:1210.3615v1

- Charged particle density normalized to $\langle N_{\text{part}} \rangle$ in pp, dAu, pPb and AA collisions
- Comparison shown for inelastic (INEL) and NSD events
- $\sim s_{NN}^{0.11}$ ($\sim s_{NN}^{0.15}$) superimposed on NSD pp and AA data and $\sim s_{NN}^{0.10}$ on INEL pp data

p_T spectra in p-Pb



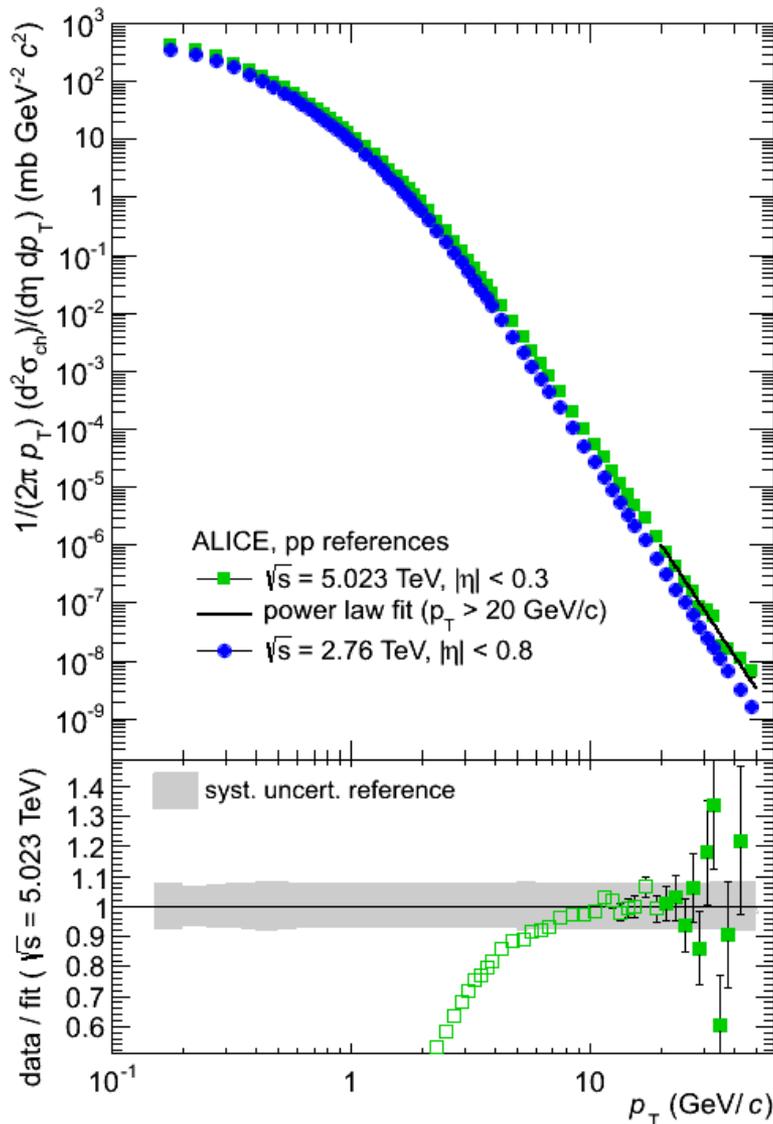
ALICE, arXiv:1210.4520v1

- p_T spectra (NSD) in three pseudorapidity intervals
 - Weak pseudorapidity dependence
- Show is also pp reference (solid line)

pp reference for R_{pPb}

$$R_{pPb}(p_T) = \frac{d^2 N_{ch}^{pPb} / d\eta dp_T}{\langle T_{pPb} \rangle d^2 \sigma_{ch}^{pp} / d\eta dp_T}$$

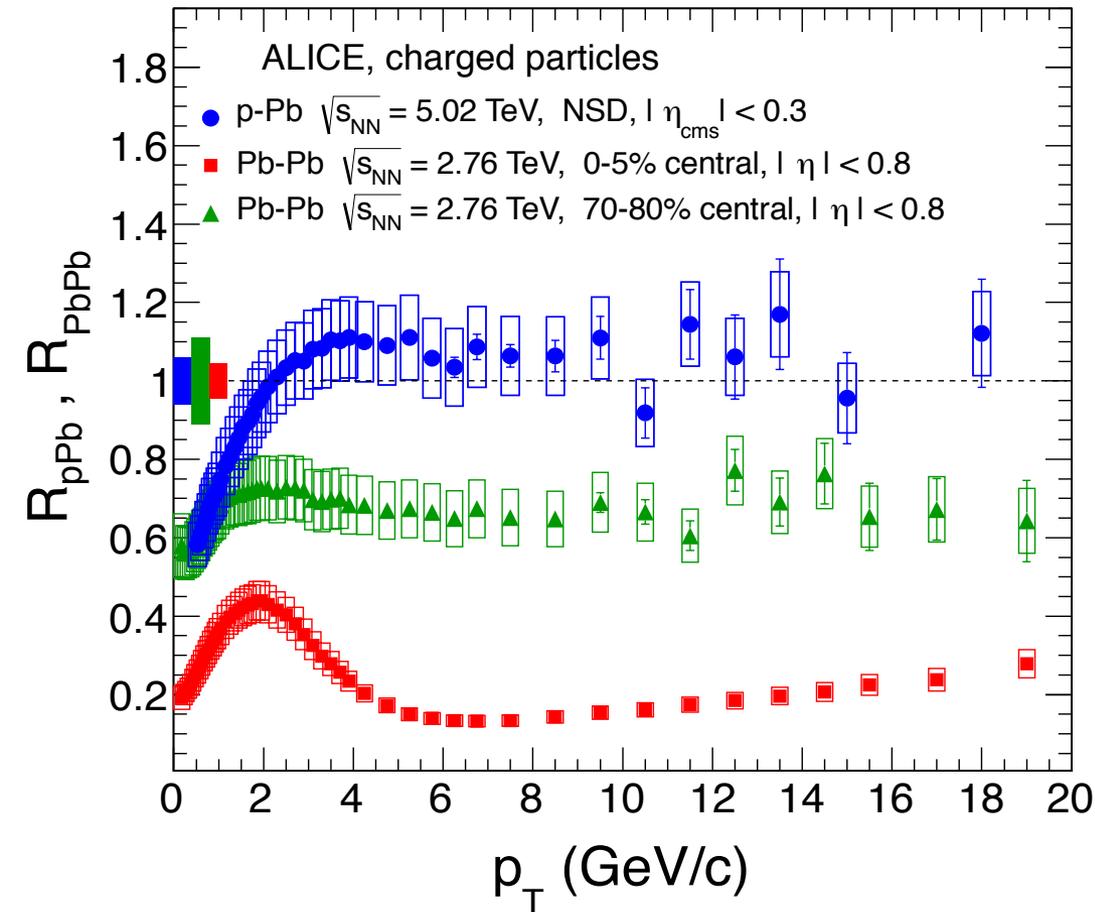
- No pp measurements at $\sqrt{s} = 5$ TeV
- pp reference constructed using pp measurements at $\sqrt{s} = 2.76$ and 7 TeV and NLO calculations
 - For $p_T < 5$ GeV/c, interpolation between $d\sigma_{pp}/dp_T$ measured at 2.76 and 7 TeV by using powerlaw function
 - For $p_T > 5$ GeV/c, scaling of the $d\sigma_{pp}/dp_T$ at 7 TeV to 5 TeV by factors obtained from NLO calculations



Nuclear modification factor R_{pPb}

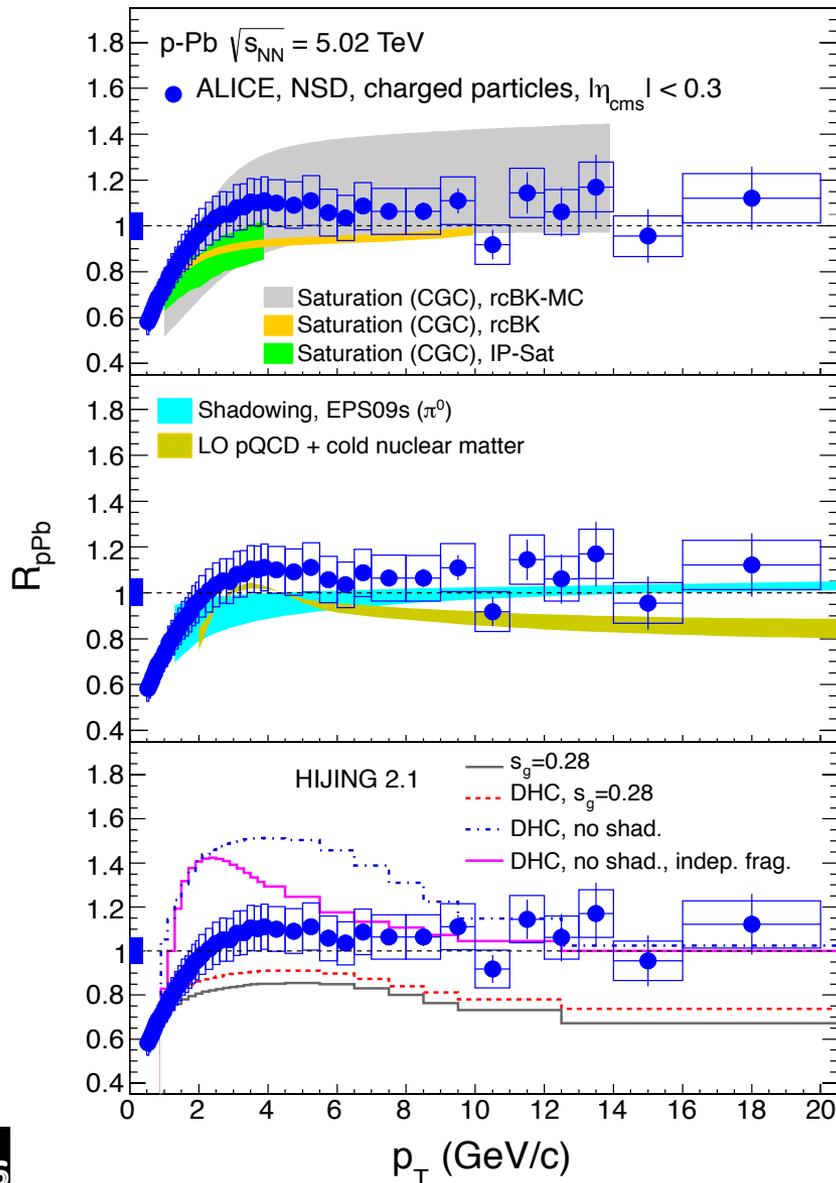
ALICE arXiv:1210.4520v1

$$R_{pPb}(p_T) = \frac{d^2 N_{ch}^{pPb} / d\eta dp_T}{\langle T_{pPb} \rangle d^2 \sigma_{ch}^{pp} / d\eta dp_T}$$



- Suppression for $p_T < 2$ GeV/c
- No suppression for $p_T > 2$ GeV/c
- Different suppression pattern compared to Pb-Pb
- Strong suppression in Pb-Pb collision not related to initial state effects

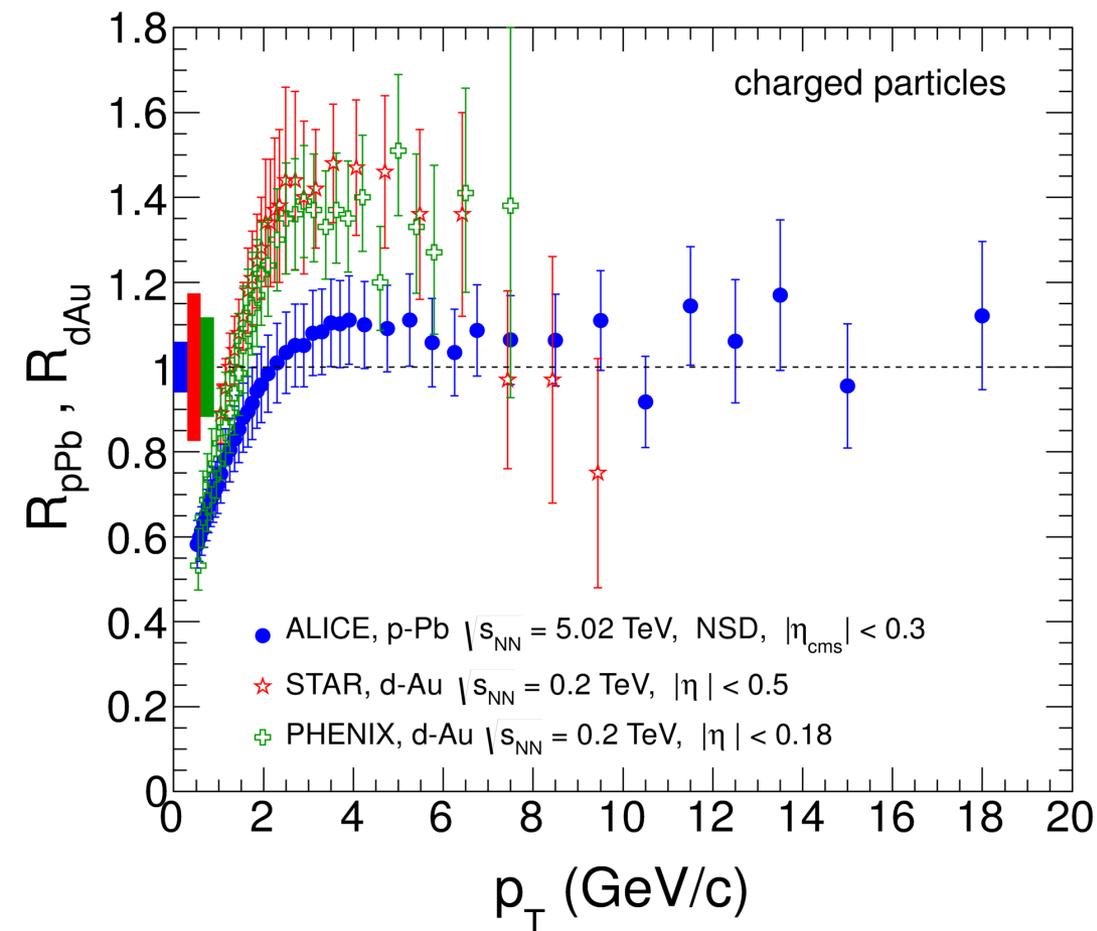
R_{pPb} comparison to model predictions



ALICE arXiv:1210.4520v1

- CGC saturation models:
 - rcBK and IP-Sat slightly underpredict the data
 - rcBK-MC consistent with data (but large uncertainties)
- Calculations with shadowing (NLO + EPS09s PDF + DSS FF) consistent with data
- Model with LO + cold nuclear matter effects disagrees for $p_T > 6$ GeV/c
- HIJING calculations with shadowing describes the trend but underpredict the data

R_{pPb} comparison to R_{dAu} at RHIC



- Different suppression pattern compared to RHIC measurements at low p_T (smaller Cronin effect at LHC)

ALICE, arXiv:1210.4520v1
 STAR, Phys.Rev.Lett.91:072304,2003
 PHENIX, Phys.Rev.Lett.91:072303,2003

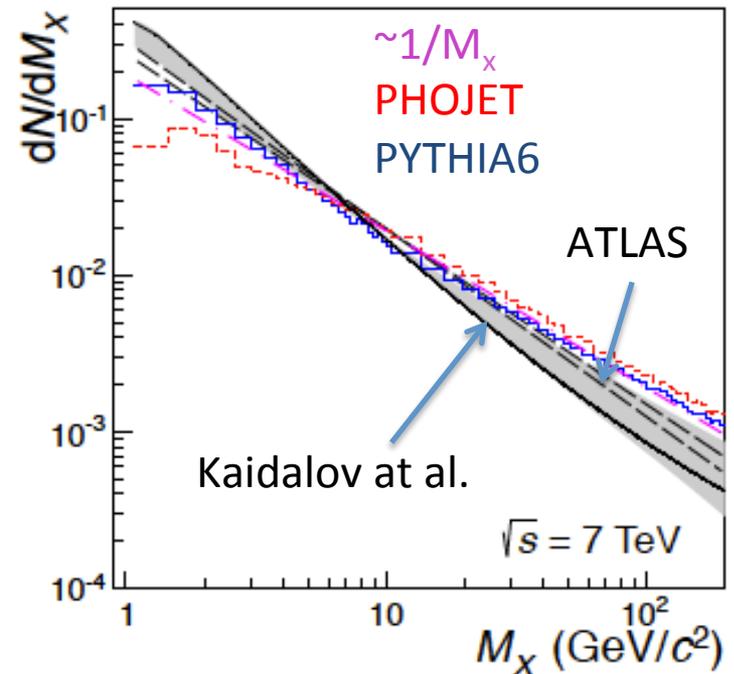
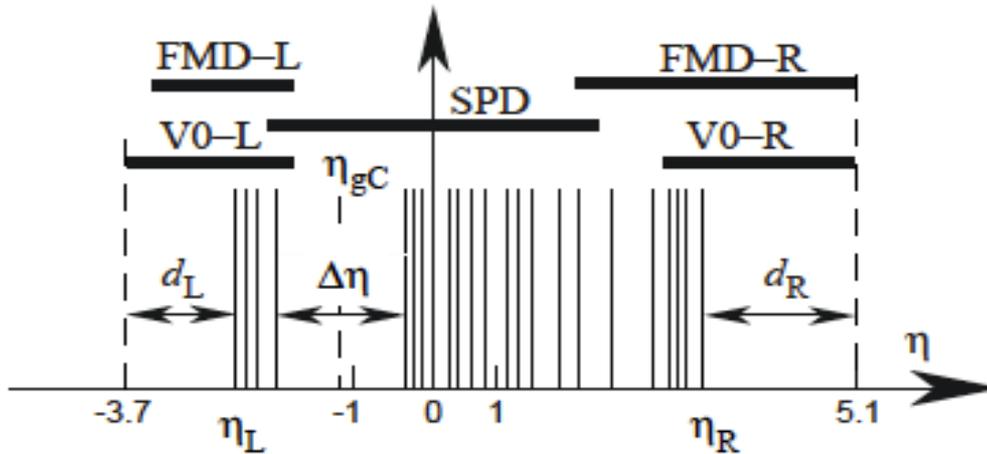
Outlook

- Strong suppression of light and heavy flavor production at high p_T in central Pb-Pb collisions
- Different suppression for protons compared to pions and kaons at $p_T < 7$ GeV/c (different particle spectra in Pb-Pb)
- Similar suppression of pions, kaons and protons at high p_T (parton fragmentation seems not to be modified by the medium)
- Light flavor $R_{AA} = D$ meson R_{AA} at high p_T in central Pb-Pb collisions
- First p-Pb collisions at LHC
 - First measurement of the $dN_{ch}/d\eta$ in p-Pb collision at LHC
 - Suppression pattern different from Pb-Pb and dAu collisions (smaller Cronin effect at LHC)
 - No suppression for $p_T > 6$ GeV/c (strong suppression in Pb-Pb not related to initial state effects)

BACKUP

η -gap analysis

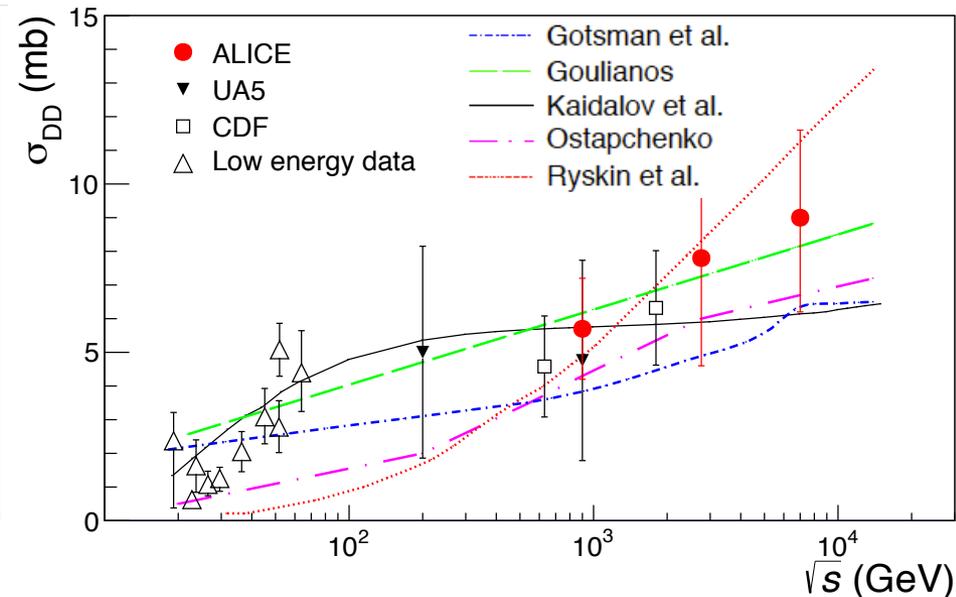
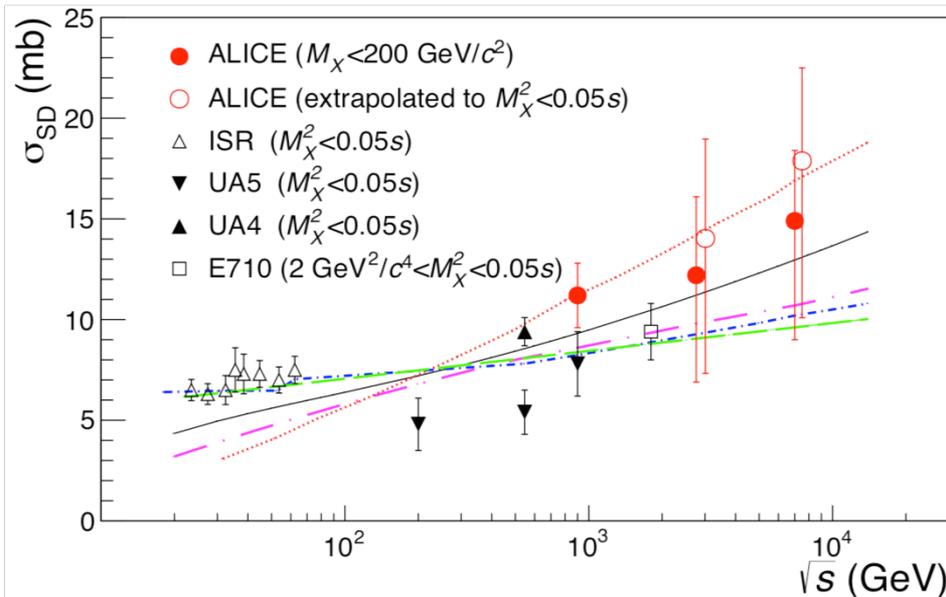
ALICE, arXiv:1208.4968



- Adjust DD fraction in simulation (PYTHIA6, PHOJET) to match data (<10% agreement for $\Delta\eta > 3$)
- Adjust SD fractions separately for Left/Right sides using ratios (Left-SD/NSD and Right-SD/NSD) to match data
- Repeat procedure by varying $d\sigma_{SD}/dM_x \sim M_x$ dependence (Kaidalov arXiv:0909.5156) in simulation

pp σ_{SD} and σ_{DD} measured with ALICE

ALICE, arXiv:1208.4968



\sqrt{s} (TeV)	σ_{SD} (mb)	σ_{DD} (mb)
0.9	$11.2^{+1.6}_{-2.1}$	5.6 ± 2.0
2.76	$12.2^{+3.9}_{-5.3}$	7.8 ± 3.2
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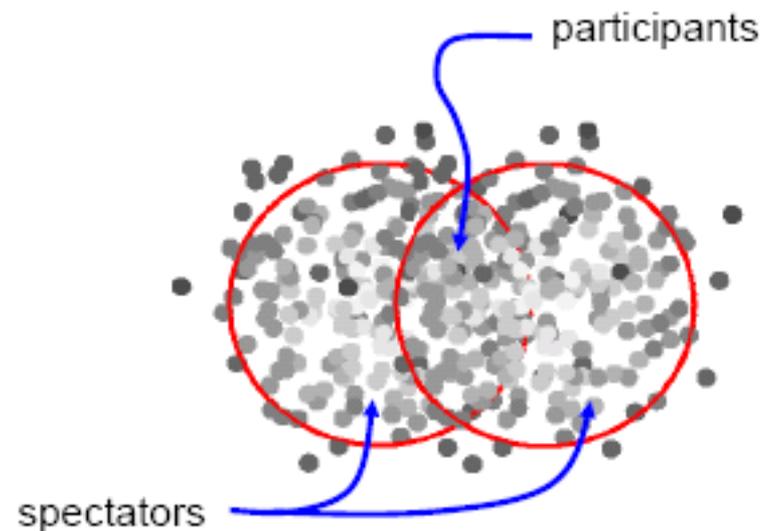
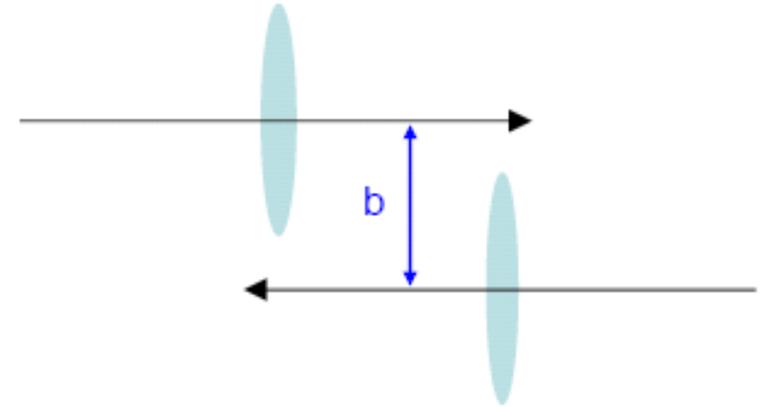
- η -gap analysis
 - σ_{SD} for diffractive masses $M_X < 200 \text{ GeV}/c^2$
 - σ_{DD} for $\Delta\eta > 3$



ALICE

Collision centrality

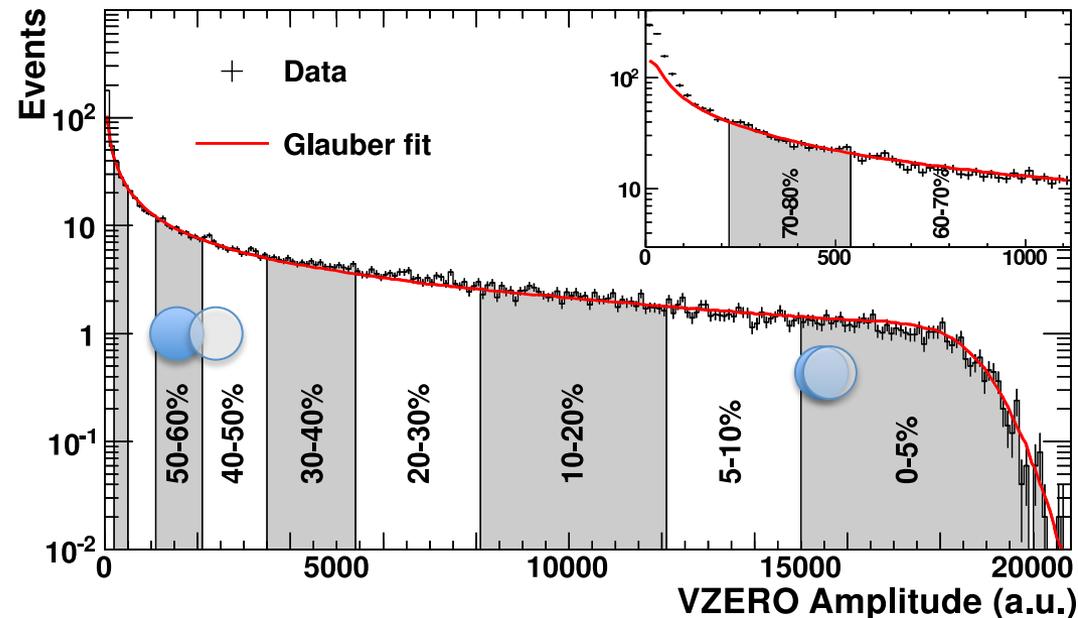
- Centrality
 - Impact parameter b
 - Large b : **peripheral collisions** 
 - Small b : **central collisions** 
 - b is not measured, must be derived through models
- Quantitative measures of the collision centrality
 - Number of participant nucleons: N_{part}
 - Number of binary nucleon-nucleon collisions: N_{coll}
 - Number of spectator nucleons:
$$N_{\text{spec}} = 2A - N_{\text{part}}$$
 - Forward hadronic energy: E_{ZDC}



Collision centrality determination

- Centrality measures (V0 ampl., tracks, hits, ZDC vs V0, V0 vs tracks)
- Glauber fit: $NBD(\mu, \kappa) * [f * N_{part} + (1-f) N_{coll}]$
 - Number emitting sources: $[f * N_{part} + (1-f) * N_{coll}]$
 - Each source emits from NBD (μ, κ)
- Determine percentage intervals of hadronic cross section σ / σ_{tot} (%)
- Relation between collision centrality and $\langle N_{part} \rangle$, $\langle N_{coll} \rangle$, $\langle T_{AA} \rangle \dots$) from Glauber model

ALICE, PRL 106, 032301 (2011)



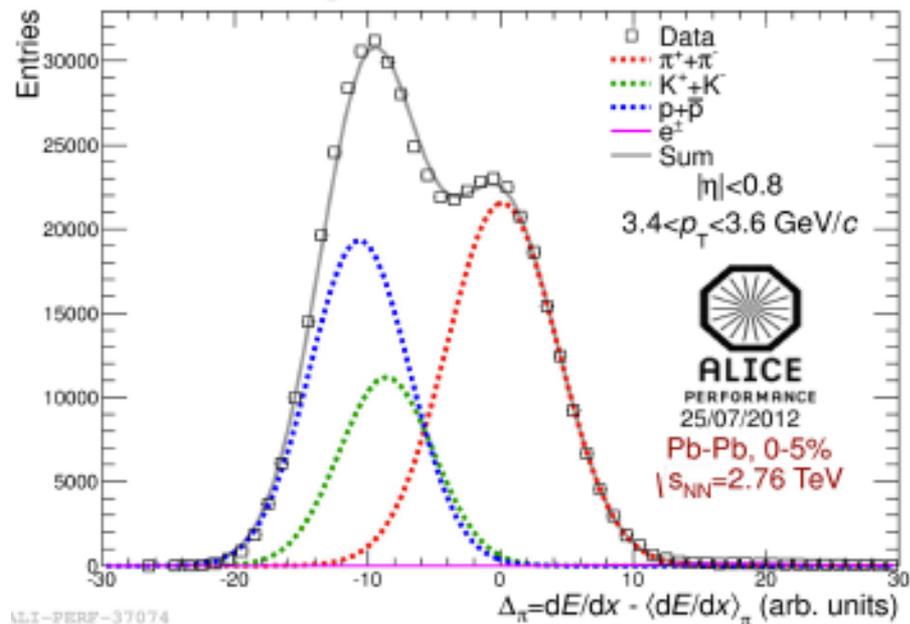
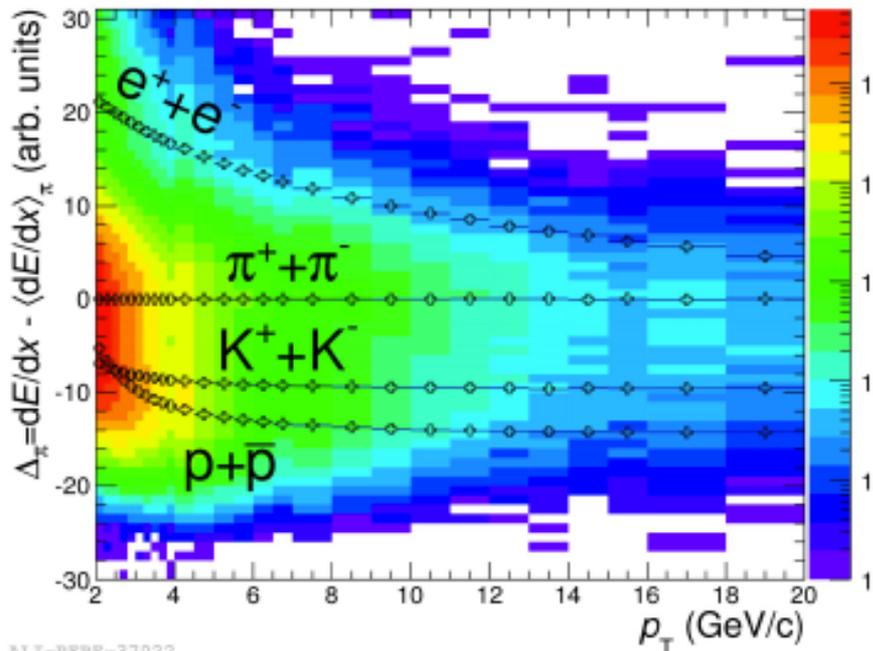
High- p_T particle identification: TPC dE/dx

$$\frac{d^2 N_i}{dy dp_T} = \frac{d^2 N_{ch}}{d\eta dp_T} \times \frac{\epsilon_i}{\epsilon_{ch}} \times \frac{N_i}{N_{ch}} \times \frac{\eta}{\sinh^{-1}\left(\frac{p_T \sinh(\eta)}{\sqrt{p_T^2 + m_i^2}}\right)}$$

arXiv:1208.2711v1 [hep-ex]

$(i = \pi, K, p)$

Pb-Pb 0-5%, $\sqrt{s_{NN}}=2.76$ TeV
25/07/2012



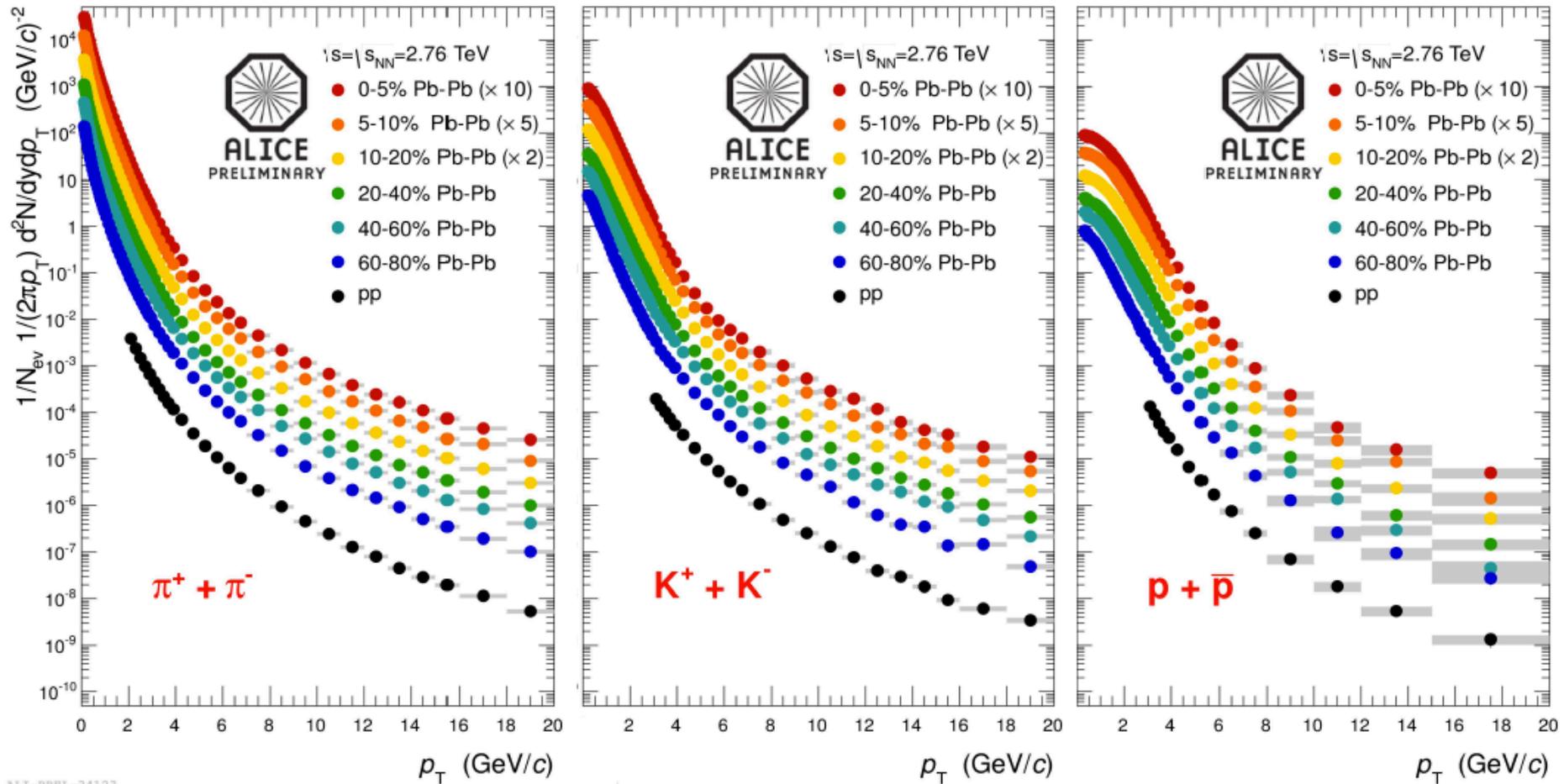
ALI-PERF-37022

ALI-PERF-37074



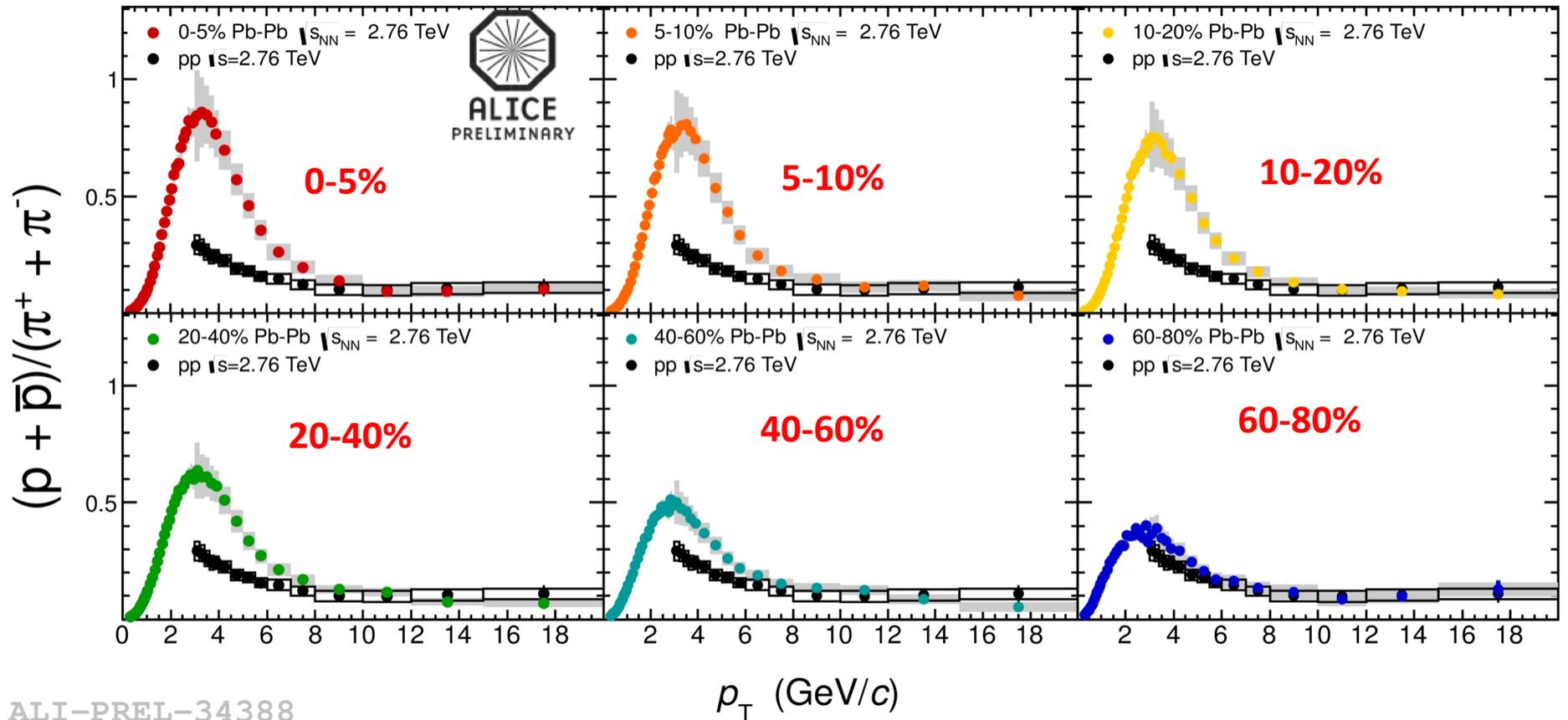
ALICE
PERFORMANCE
25/07/2012
Pb-Pb, 0-5%
 $\sqrt{s_{NN}}=2.76$ TeV

p_T spectra for $\pi/K/p$

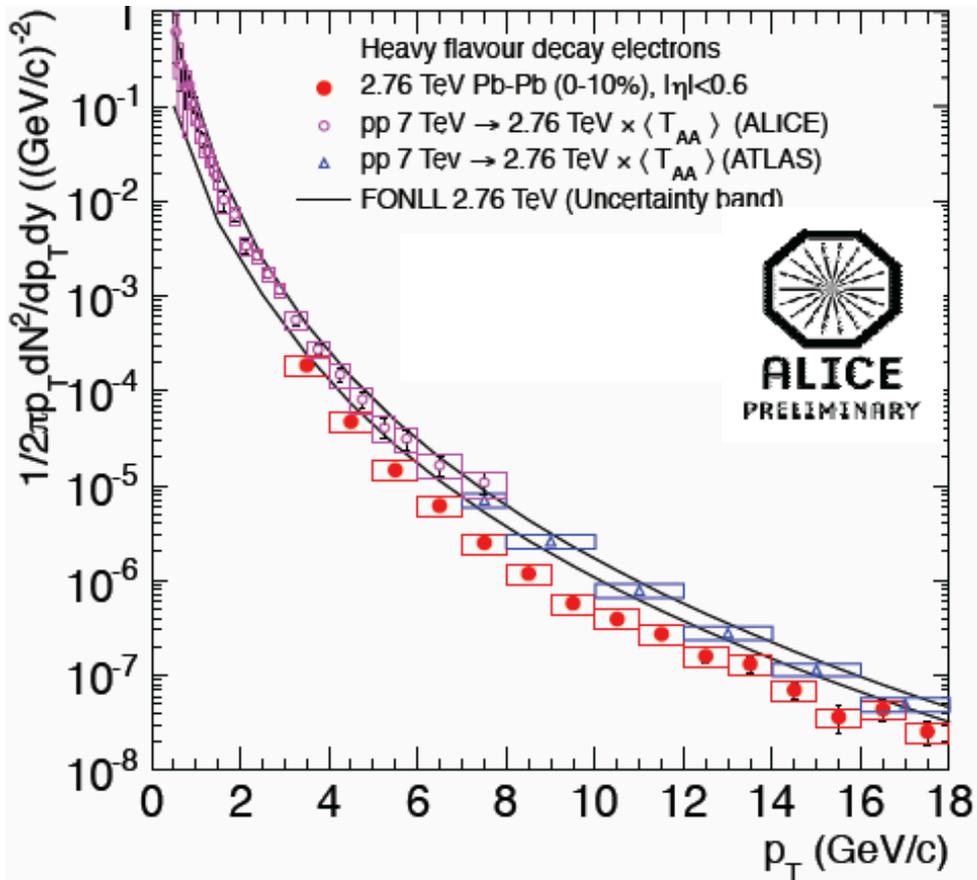


- High- p_T particle identification using TPC dE/dx : π ($p_T > 2$ GeV/c) and K, p ($p_T > 3$ GeV/c)
- Possible p_T reach up to 50 GeV/c

proton / pion ratio in pp and Pb-Pb



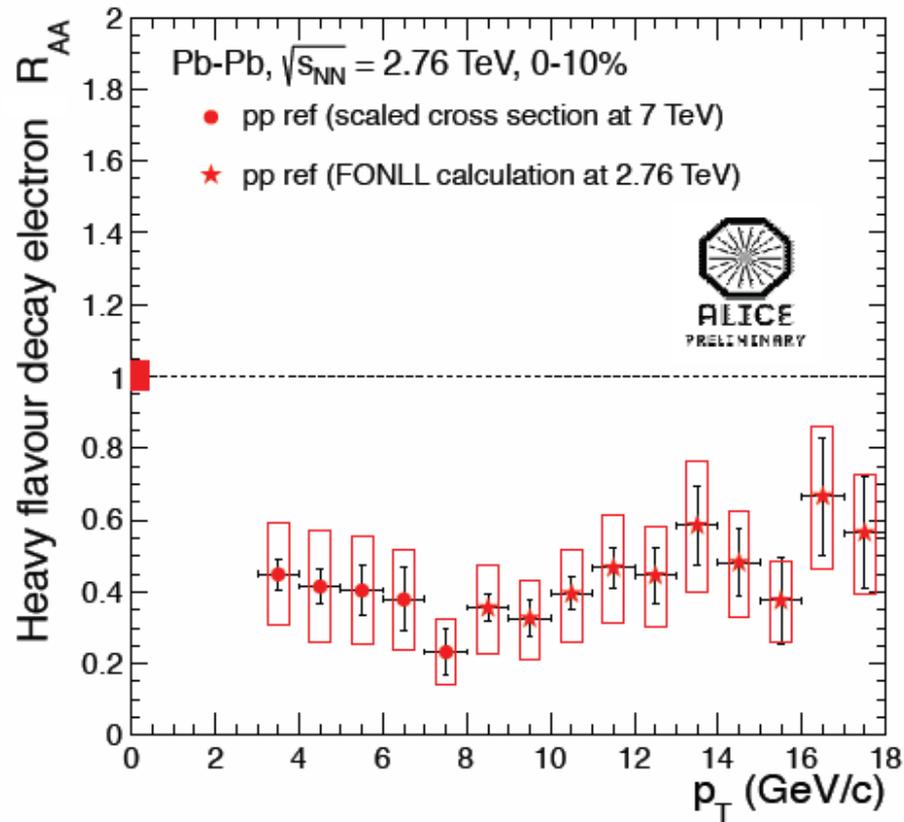
R_{AA} - heavy flavor decay electrons



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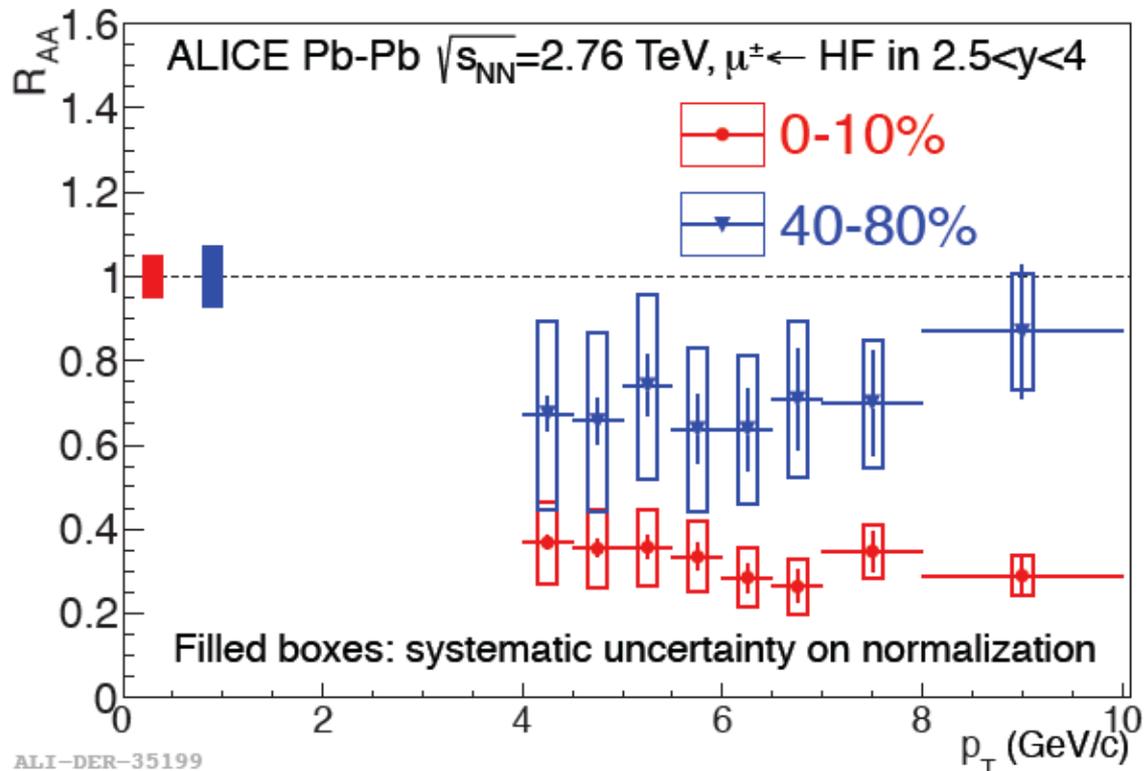
ALICE, arXiv. 1205.5423 (2012)

ATLAS, PLB 707 (2012) 438



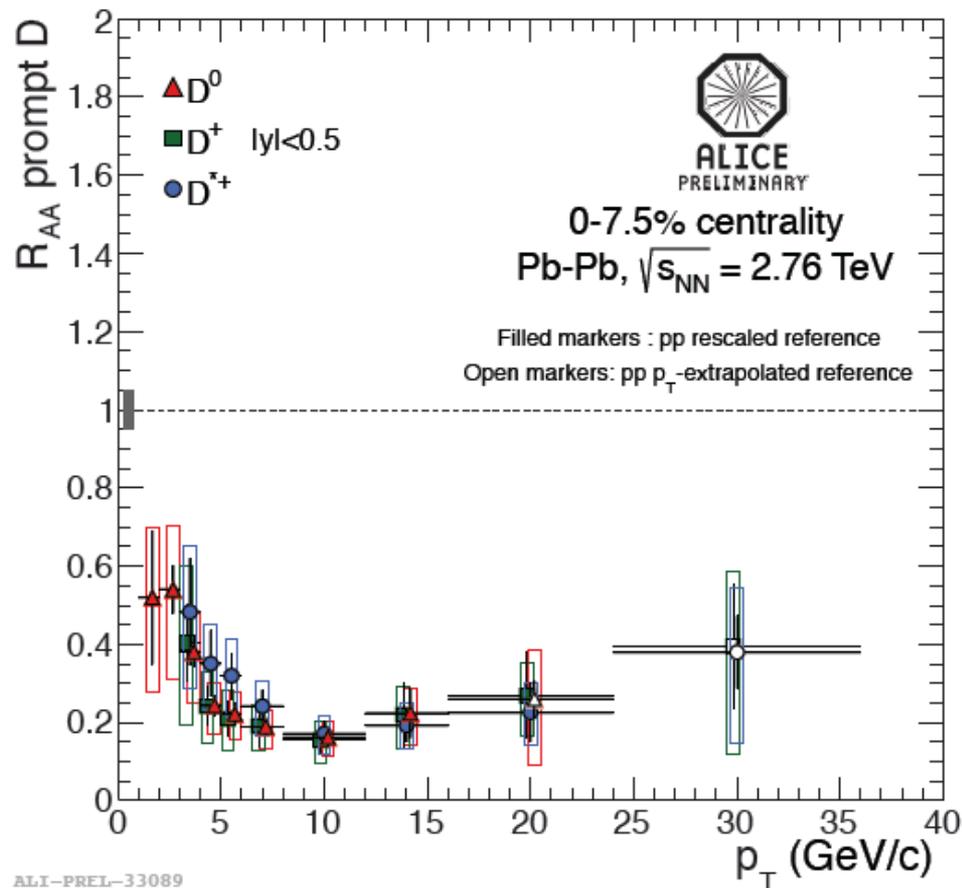
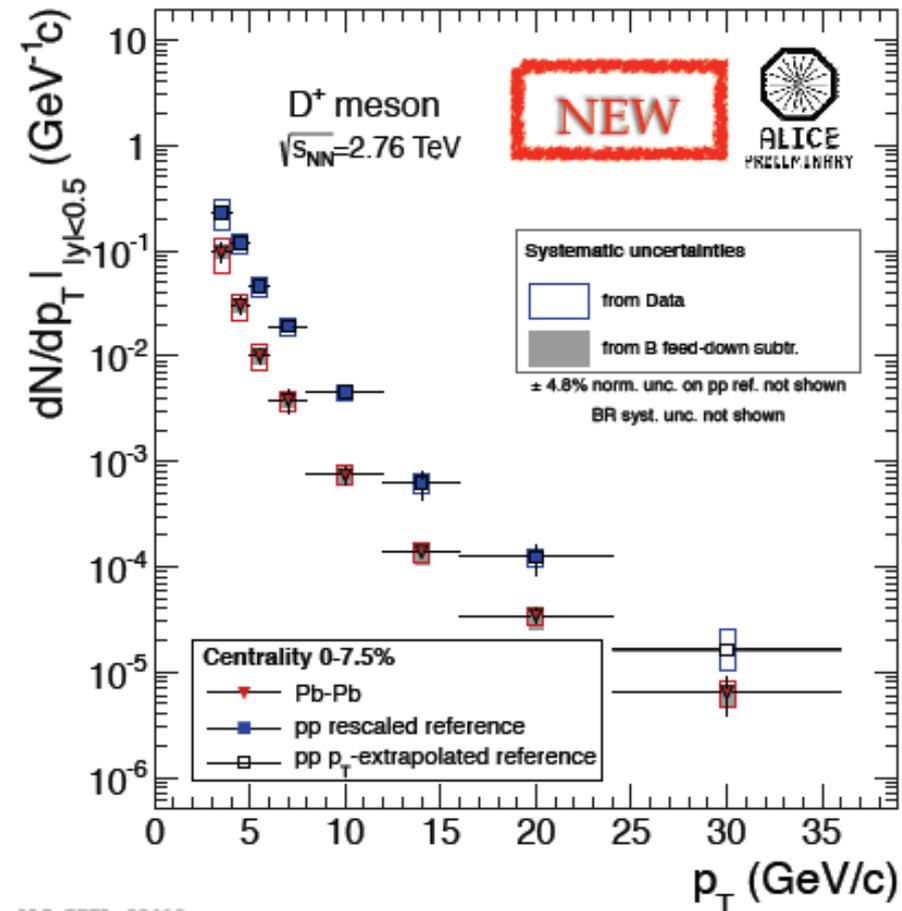
Suppression around factor of 1.5-3 for $p_T > 3$ GeV/c

R_{AA} - heavy flavor decay muons



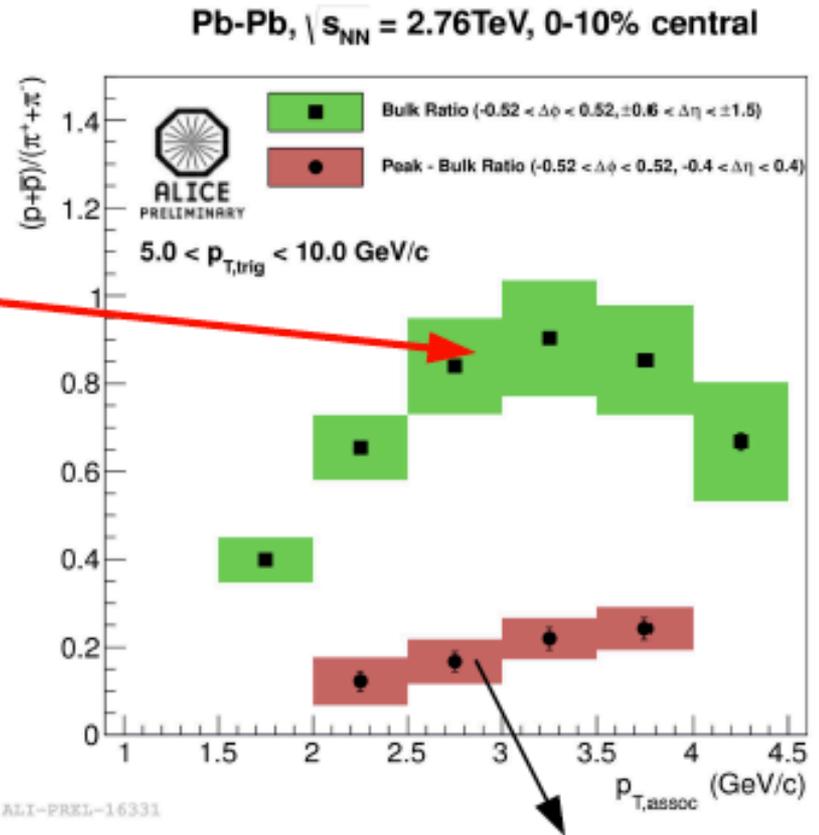
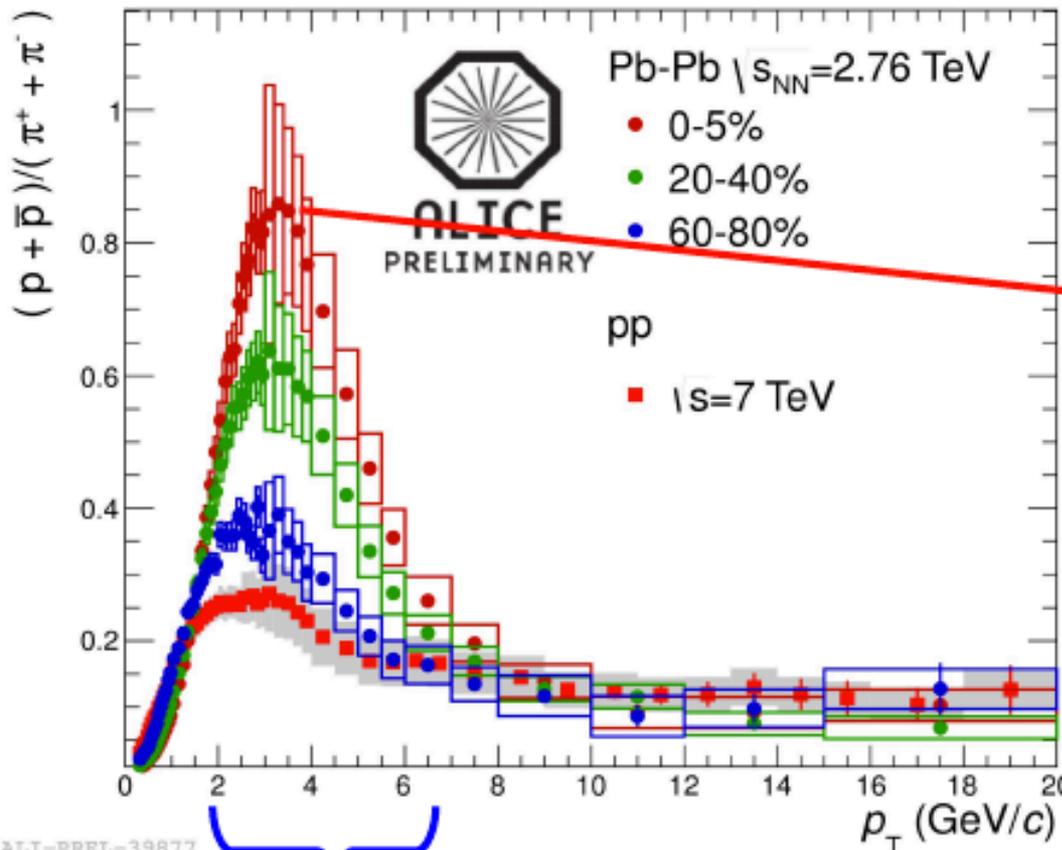
- pp reference measured at the same collision energy
- Suppression in central collisions around factor of 2-4 for $p_T > 4$ GeV/c
- Weaker suppression ($R_{AA} \sim 0.7$) in semi-peripheral (40-80%) collisions

R_{AA} - D mesons



- pp reference (7 TeV pp scaled for $p_T < 20$ GeV/c, extrapolation for $p_T > 20$ GeV/c)
- Suppression in central collisions (0-7.5%) around factor of 5 at $p_T = 10$ GeV/c

Proton / pion enhancement – bulk matter



The enhancement seems to be a bulk effect
(Misha Veldhoen, arXiv:1207.7195).

Particle production in jets is
not affected by medium.