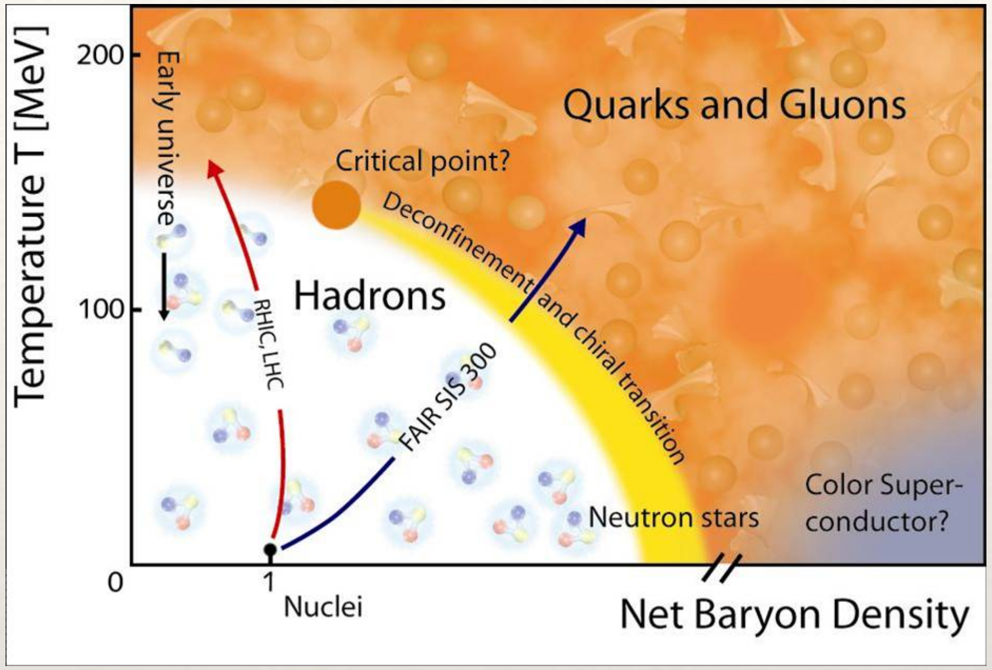
Osservabili pQCD per caratterizzare la materia nucleare “calda e fredda”

D. Caffarri (CERN) **for the ALICE Collaboration.**

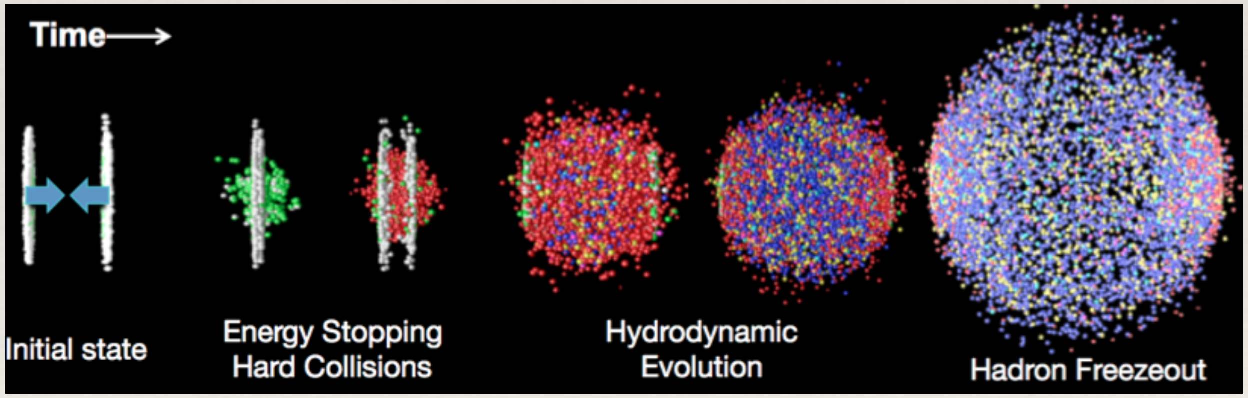
IFAE 2015, Frontiera dell’energia, 09/04/15

Why heavy ions collisions at LHC?

- Ultra-relativistic heavy ions allow to study the phase diagram of the nuclear matter.



- They are “good tools” to compress and heat nuclear matter in order to recreate
  - a very high density
  - strongly interacting
  - deconfined medium.



- Characterization of the state of the nuclear matter with hydrodynamics quantities, given its complexity and its extent.

Hot Nuclear Matter

Ultra-relativistic heavy ions as "tools" to compress and heat nuclear matter in order to recreate

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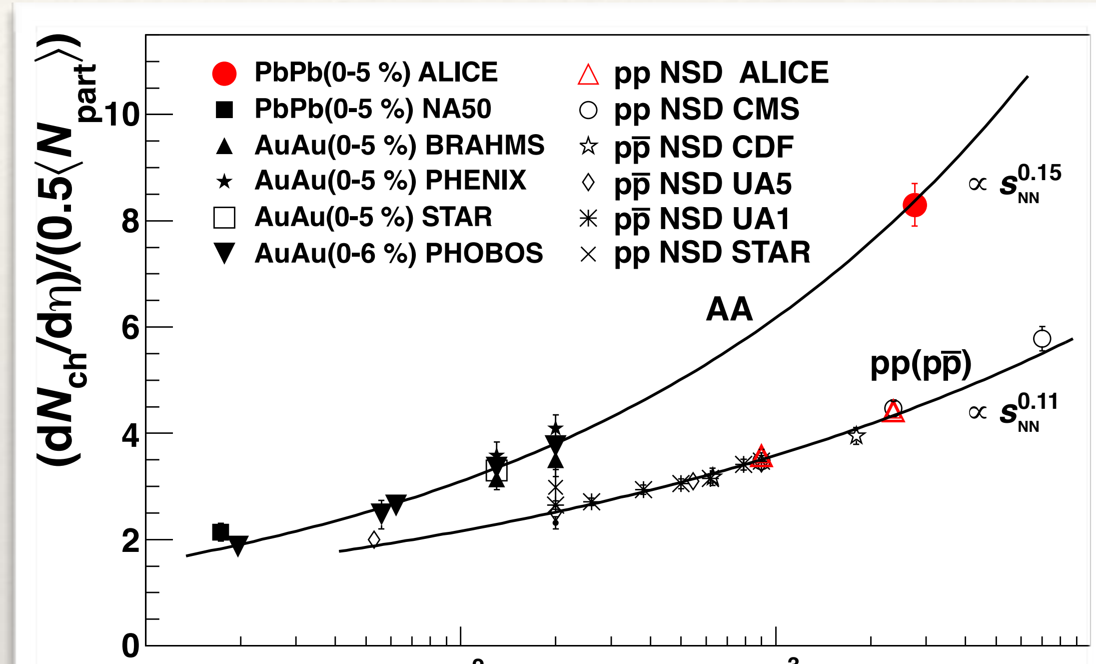
- Multiplicity of particle produced directly proportional to the energy density of the system. **ε ~ 12 GeV/fm³** a LHC



ALICE, PRL 105, 25 (2010)

$$\varepsilon = \frac{E}{V} = \frac{1}{Sc\tau_0}\left.\frac{dE_T}{dy}\right|_{y=0}$$

S = transverse dimension of nucleus

τ_0 = "formation time" ~ 1 fm/c

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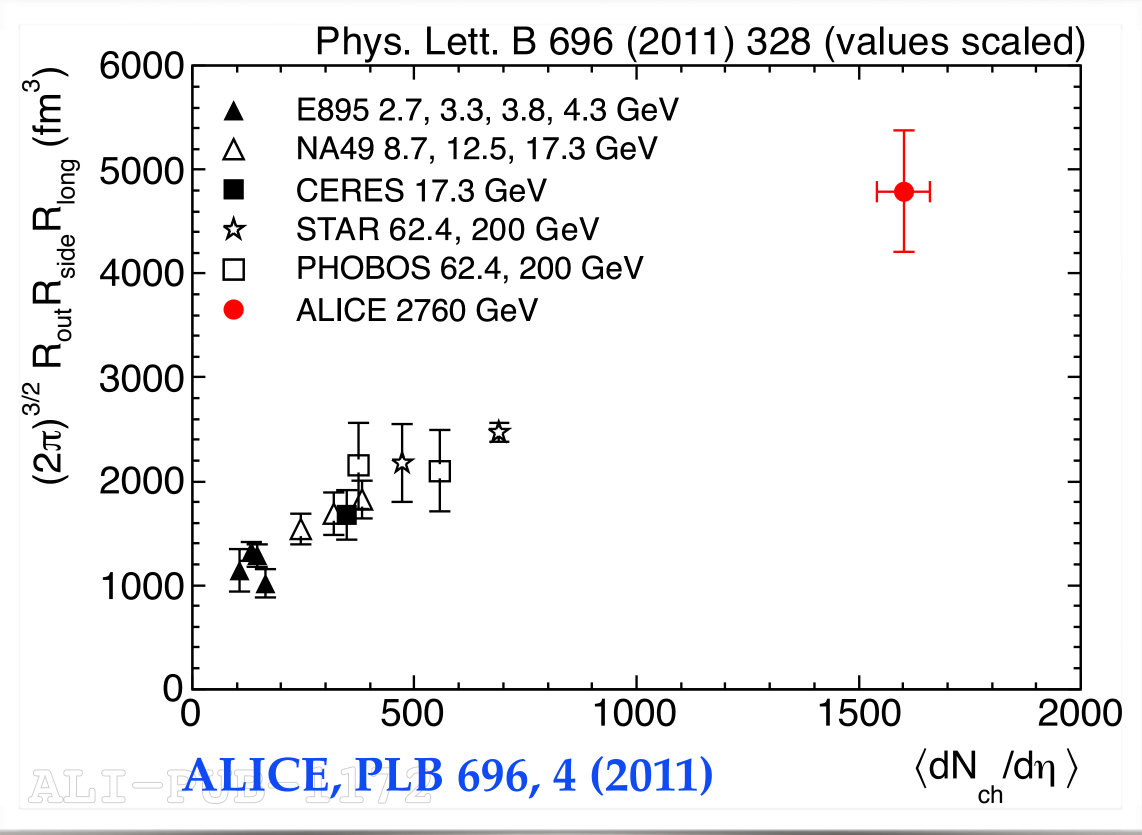
- Bose Einstein correlation between identical bosons allow to study the extension of the system. **"homogeneity"** ***V*** **~ 5000 fm³**



Hot Nuclear Matter

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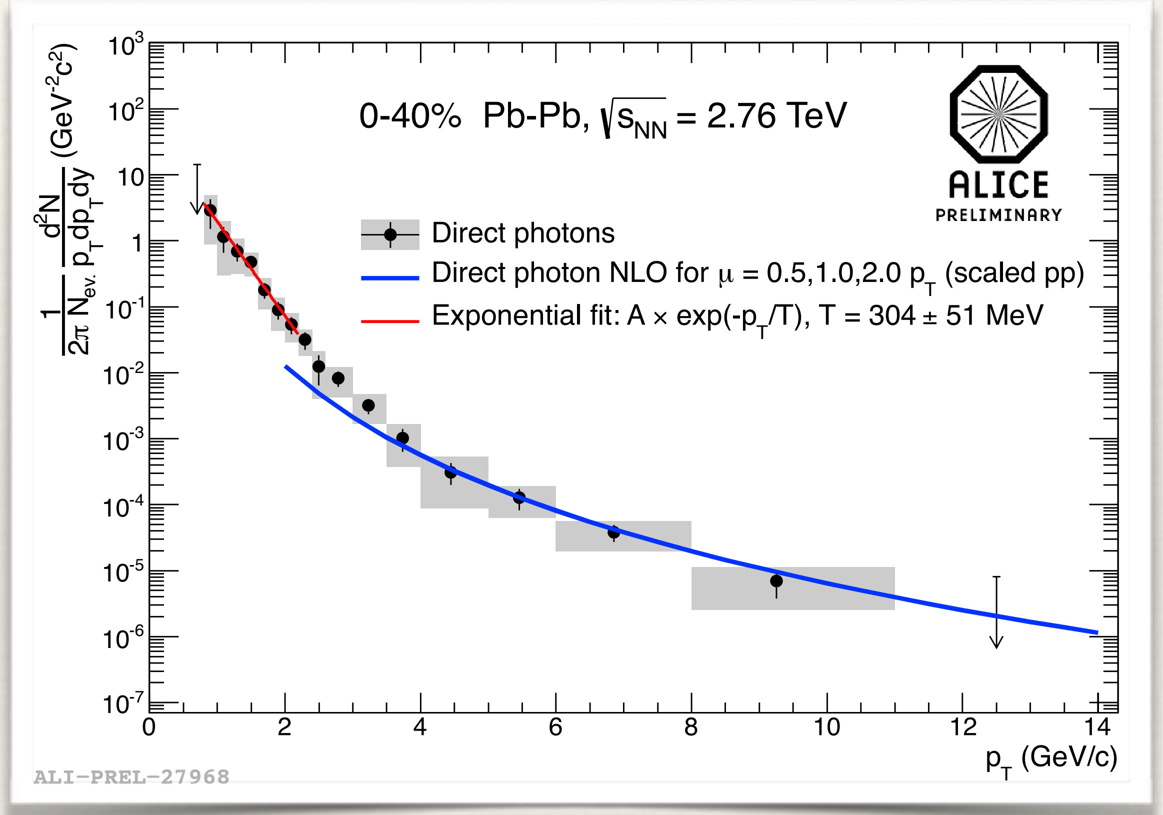
- Bose Einstein correlation between identical bosons allow to study the extension of the system. **"homogeneity" *V* ~ 5000 fm³**
- Direct photon emitted by the hot system (as black body radiation) ***T* ~ 301 ± 51 MeV**



Hard probes in AA and pA collisions

- Hard probes are:
  - produced in **hard parton-parton scatterings** in early collision stages
  - **experience the full evolution** of the system and interact with it if they are color charged.
  - their production can be **computed using pQCD**.
  - their production cross sections are **proportional to the number of possible hard scattering** (i.e. to the number of nucleon-nucleon collisions)

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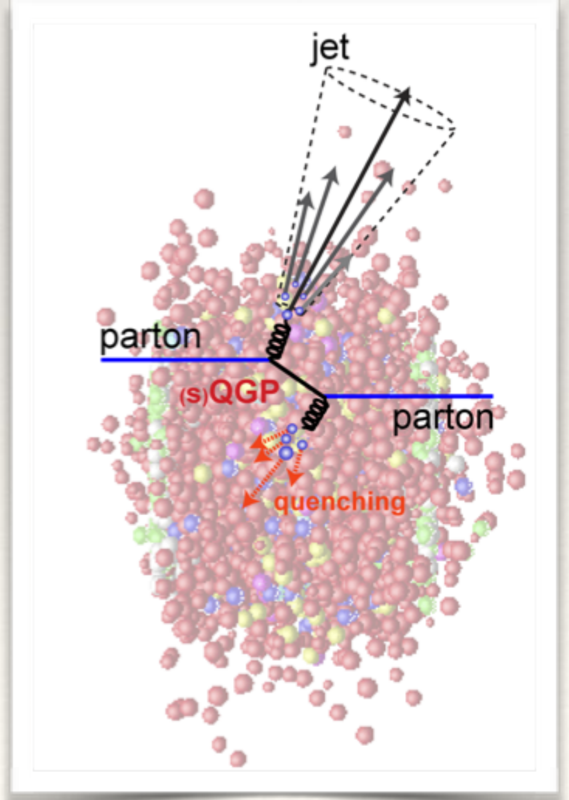
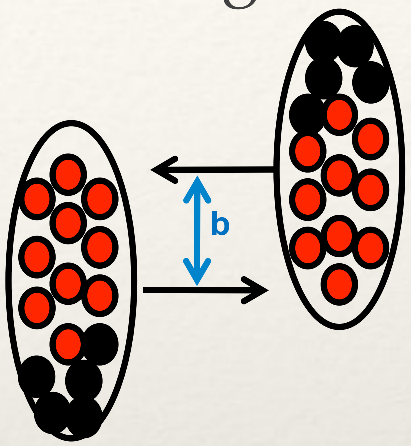
* **Medium - High-pT hadrons**
  Medium pT hadrons mainly correlation studies
* **Jets**
* **Open heavy flavor**
* **Quarkonia**

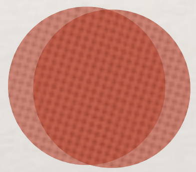
* **Electro-week bosons (W, Z)**
* **Direct photons**



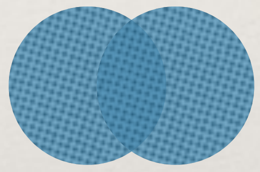
How to quantify modifications on the hard probes?

- **Centrality**:
  - Quantity to determine the overlap region of the two nuclei during the collisions.
  - Geometrical model allow to determine the number of **participant** to the collision.
  - Events are classify in “centrality classes” in terms of the percentiles of the total AA cross section.





Central collisions
ex. 0-10%, 0-5%



Peripheral collisions
ex. 70-80%, 80-100%

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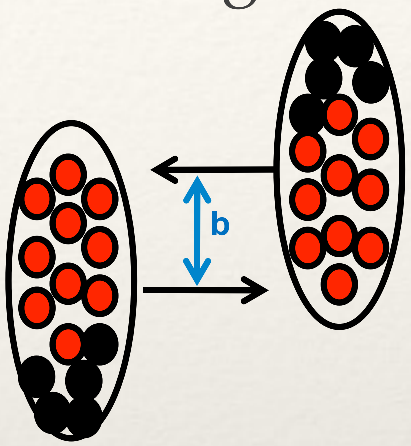


- **Nuclear modification factor (R_{AA}):**
  - Comparison of the spectra in pp and AA collisions
  - If AA collisions would be a "simple" superimposition of many pp collisions $R_{\mathrm{AA}} = 1$

$$R_{\mathrm{AA}}(p_{\mathrm{T}}) = \frac{1}{< N_{coll} >} \times \frac{d^2N_{AA}/dp_T d\eta}{d^2N_{pp}/dp_T d\eta}$$

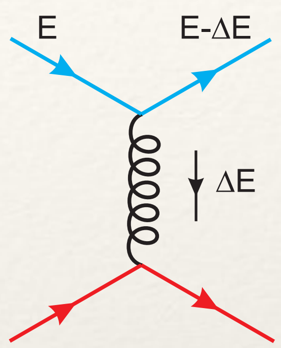
- Similar ratio can be build comparing central and peripheral(*) AA collisions (**R_{CP}**)

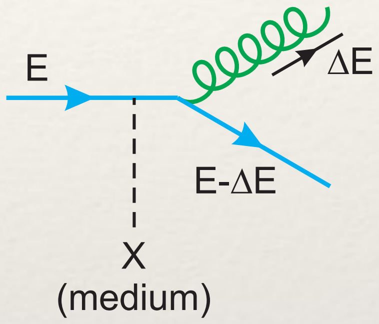
Parton QCD energy loss

- Partons travel ~4 fm in the high colour-density medium.
- In their path they can loose energy for two mechanisms:

  Scatterings with other partons ➜ collisional energy loss
  ➜ dominates at low-pT

  Gluon radiation ➜ radiative energy loss
  ➜ dominates at high energy





Gyulassy, Pluemer, Wang, Baier, Dokshitzer, Mueller, Peigné, Schiff, Levai, Vitev, Zhakarov, Salgado, Wiedemann,...

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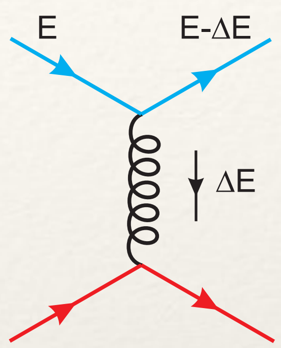

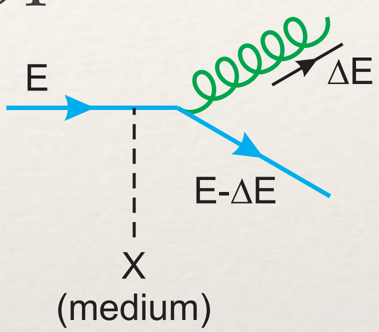

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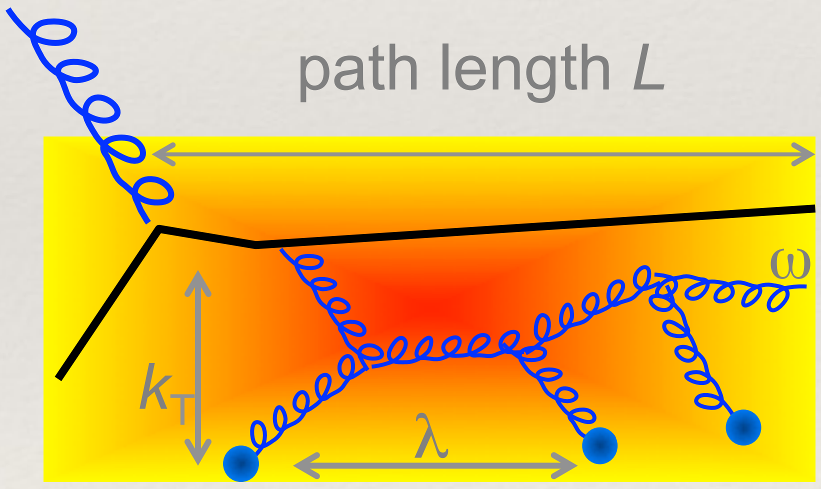
- **An example: BDMPS - Z formalism**

  Baier, Dokshitzer, Mueller, Peigne', Schiff, NPB 483 (1997) 291.
  Zakharov, JTEPL 63 (1996) 952.
  Salgado, Wiedemann, PRD 68(2003) 014008.



Radiated gluon energy distrib:

$$\omega \frac{dI}{d\omega} \propto \alpha_s C_R \begin{cases} \sqrt{\omega_c / \omega} & \text{for } \omega < \omega_c \\ (\omega_c / \omega)^2 & \text{for } \omega \geq \omega_c \end{cases}$$

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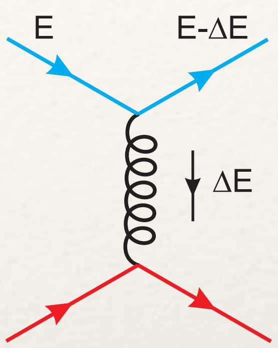

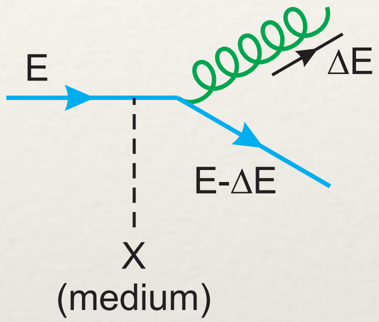

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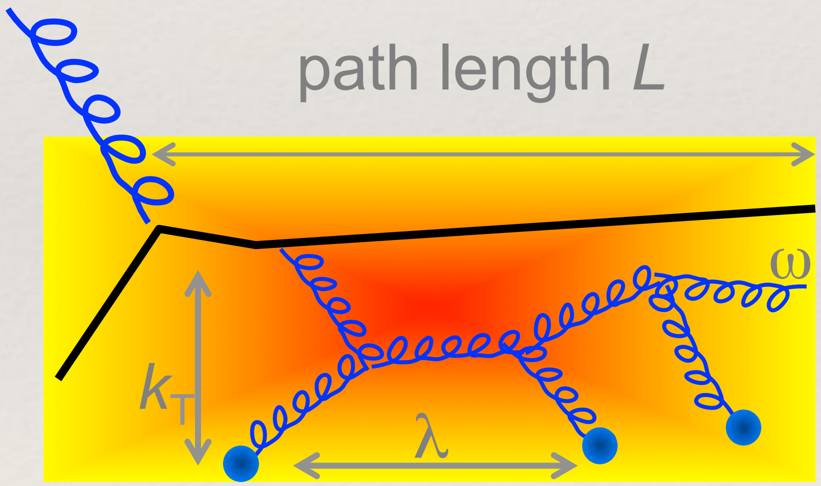

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C_R: Casimir Factor: 4/3 for q, 3 for g

Color charge dependence of the energy loss

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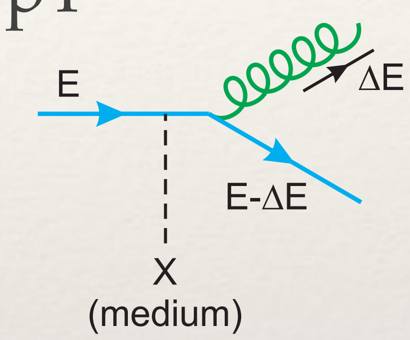

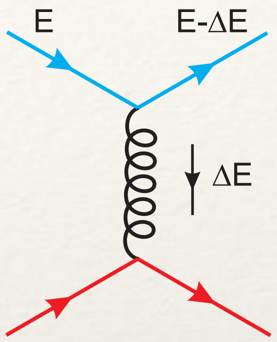

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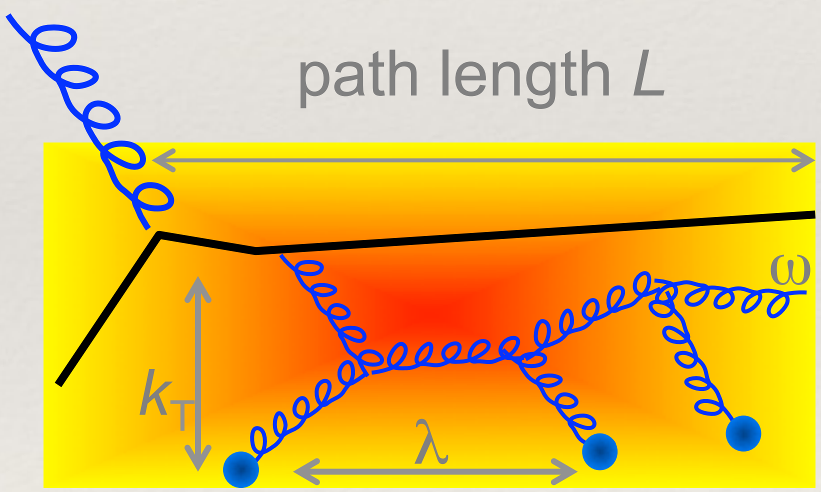

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ω_c : scale of the radiated energy $\propto \hat{q}$

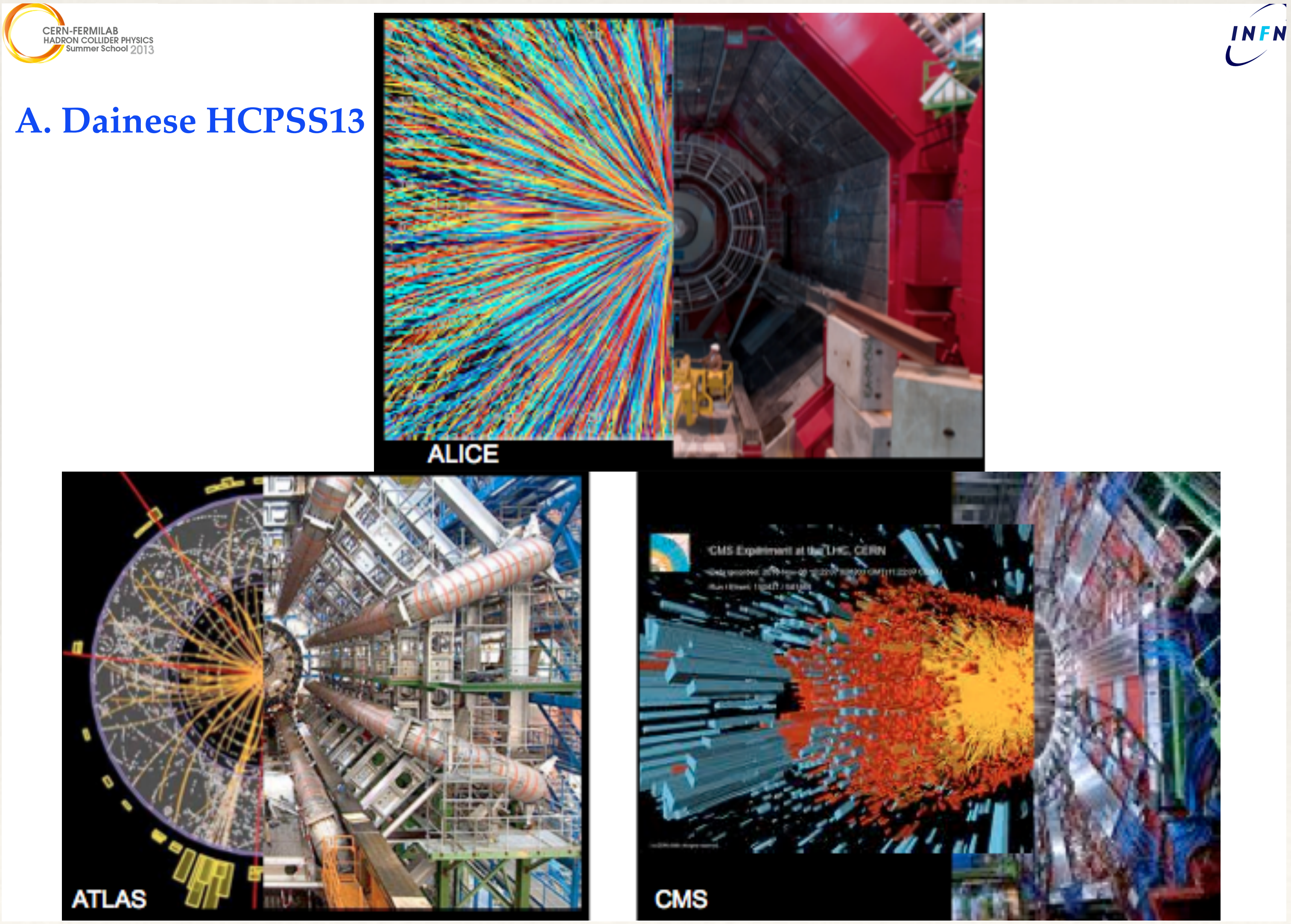
$$\hat{q} = \frac{< k_T^2 >}{\lambda}$$

Transport coefficient related to the **medium characteristics** and to the **gluon density**

Other than pp collisions at the LHC

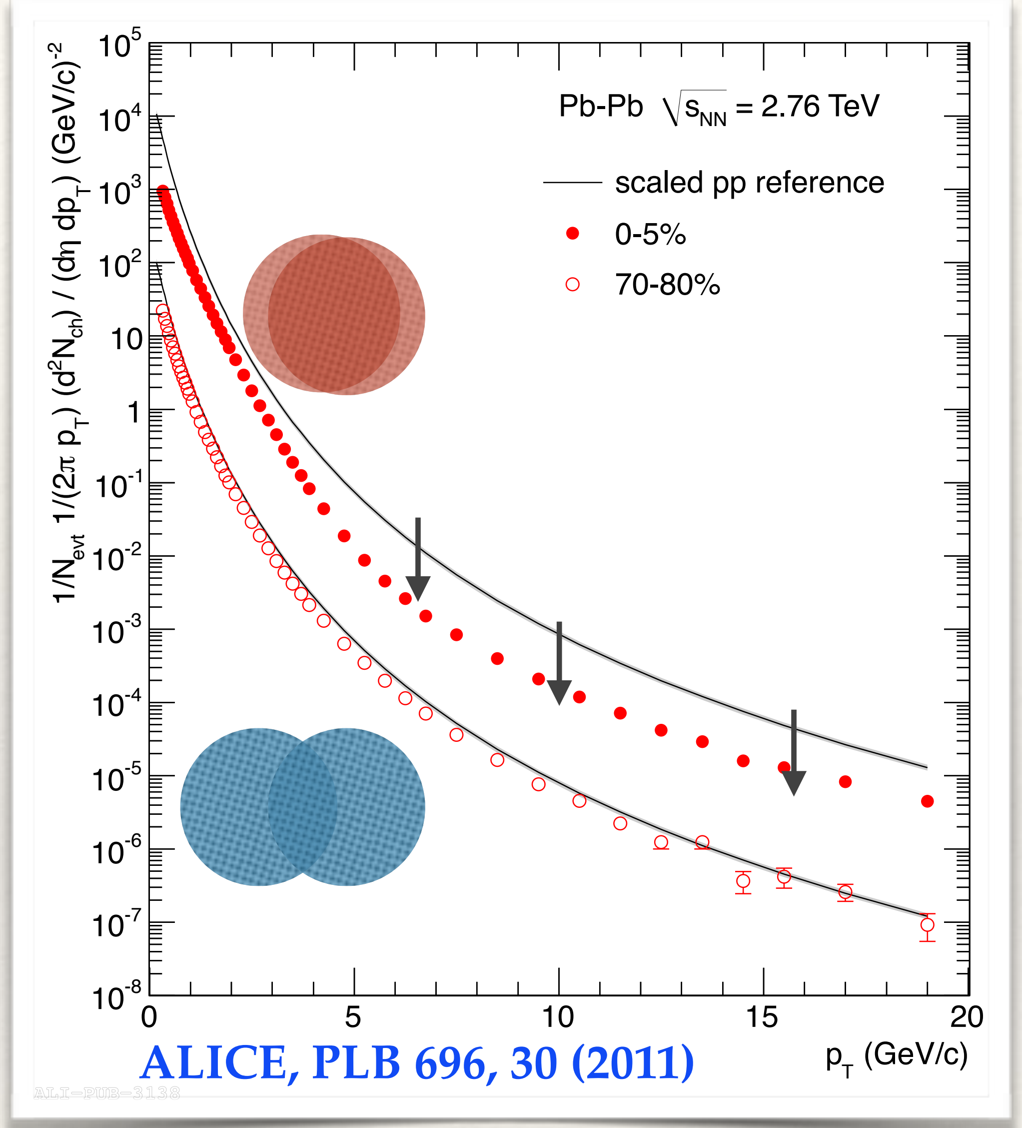
year	system	energy $\sqrt{s_{NN}}$ TeV	integrated luminosity
2010	Pb – Pb	2.76	~ 10 μb^{-1}
2011	Pb – Pb	2.76	~ 150 μb^{-1}
2013	p – Pb	5.02	~ 30 nb^{-1}

*LHCb participated in the p-Pb run!



High-pT suppression @ LHC

* Clear **reduction of the charged particles spectra**, in particular in central AA collisions, w.r.t to pp.



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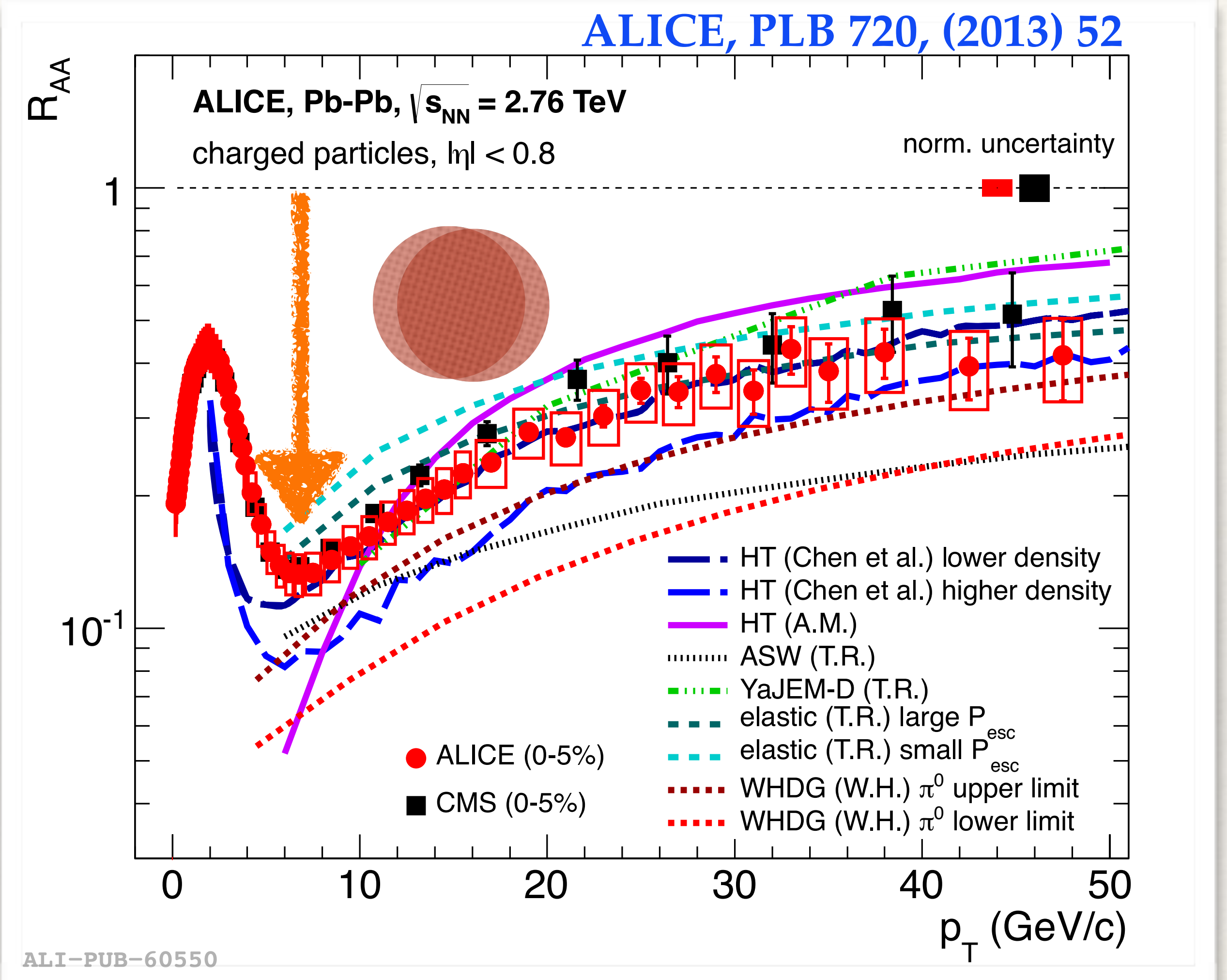
  * **slow increase at high-p_T**
  * **still a significant suppression** (~0.5) at $p_T \sim 50$ GeV/c



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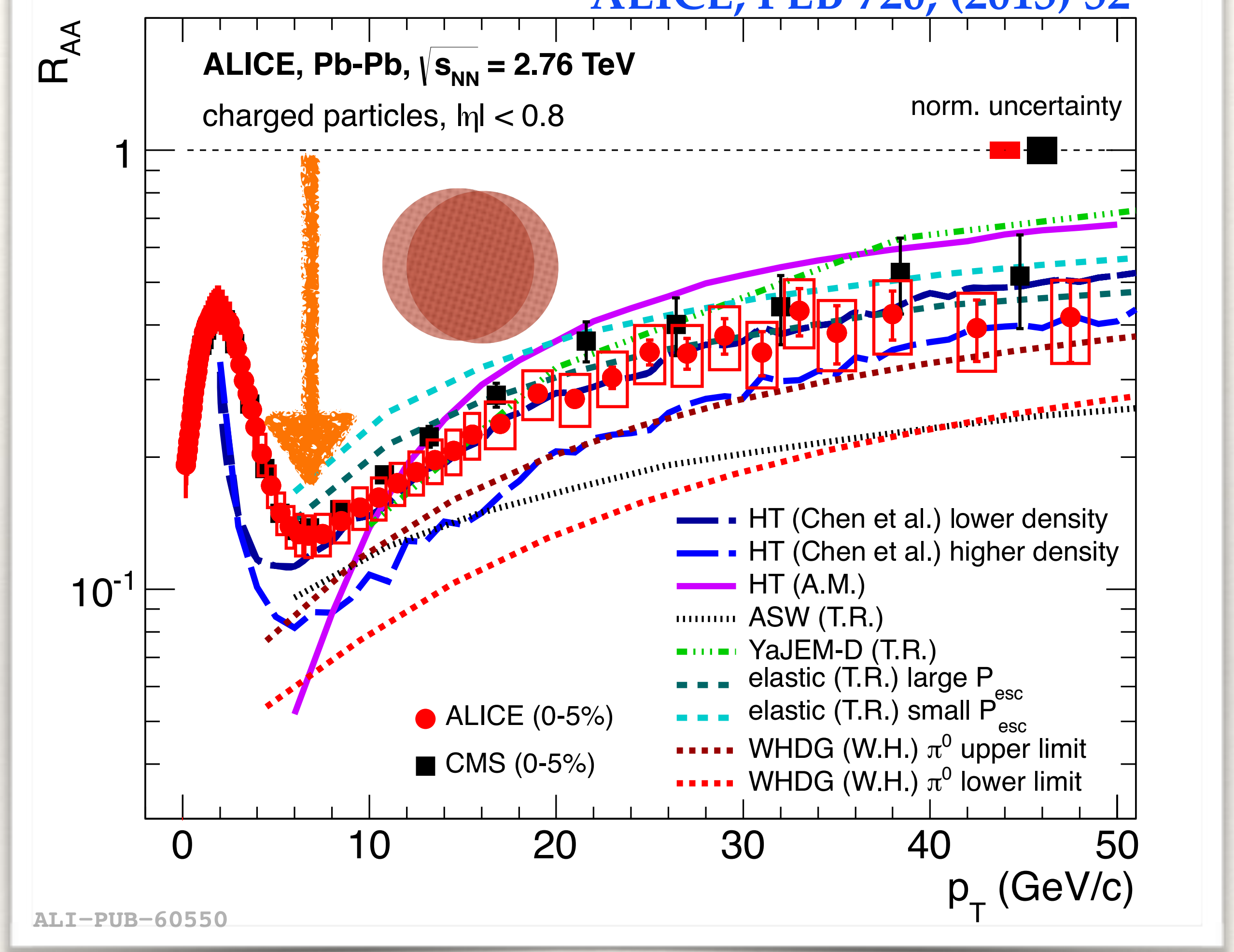
* Charged particle suppression described by models that include **parton energy loss** models

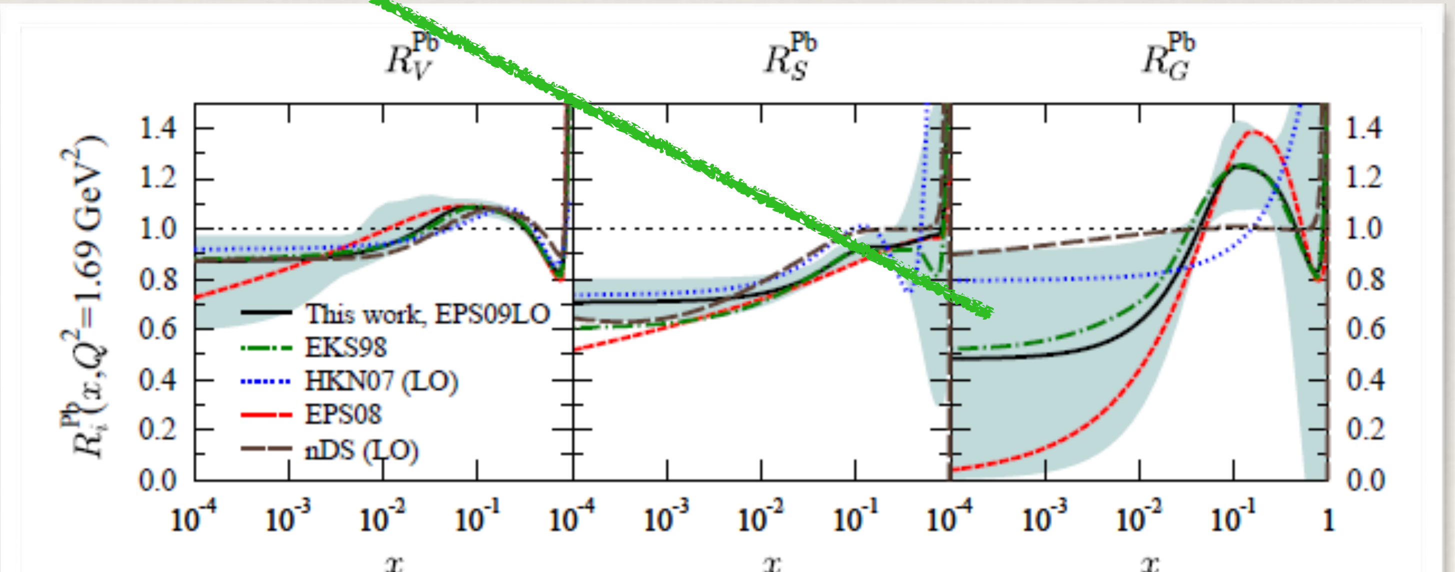
ALICE, PLB 720, (2013) 52



Cold Nuclear Matter

* The observed suppression might come from effects related to the matter that has a different behavior in case of single nucleons or multiple nucleons collision (cold nuclear matter) ?

* **Shadowing**: parton densities in the nuclei are depleted with respect to the free partons ("low-x gluon fusion").



see e.g. Eskola et al. JHEP0904(2009)065

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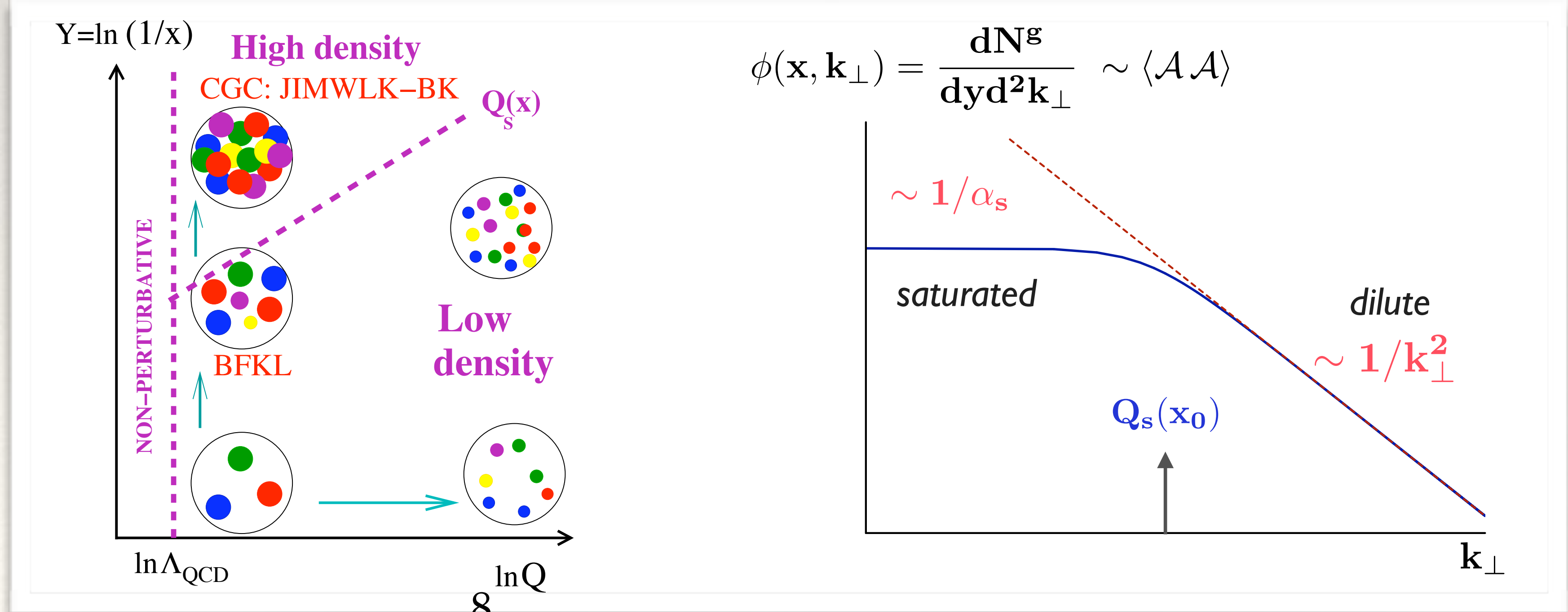
* **Shadowing**: parton densities in the nuclei are depleted with respect to the free partons ("low-x gluon fusion").

* **Gluon Saturation**: if gluons are numerous enough (low-x) and extended enough to overlap, they can recombine in the nucleus and saturate.

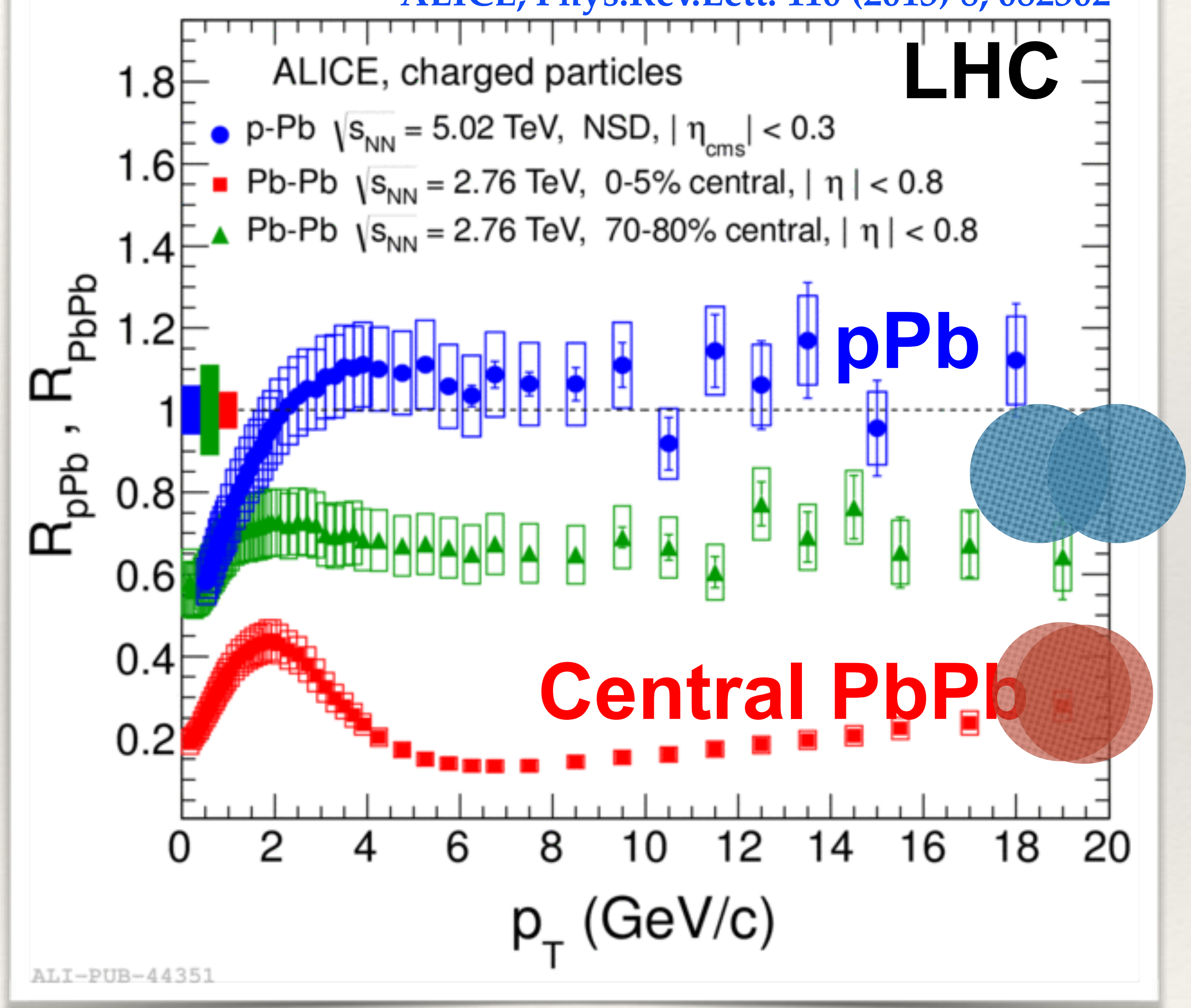


J. Albacete QM12 Student's lectures

pPb: the control experiment

- No high-pT suppression is observed in **pA collisions**.
- The suppression observed in central **AA collisions** comes from a final-state effect
- Charged particles R_{pPb} described by calculations including reduction of low-x gluon flux (saturation, shadowing)

ALICE, Phys.Rev.Lett. 110 (2013) 8, 082302

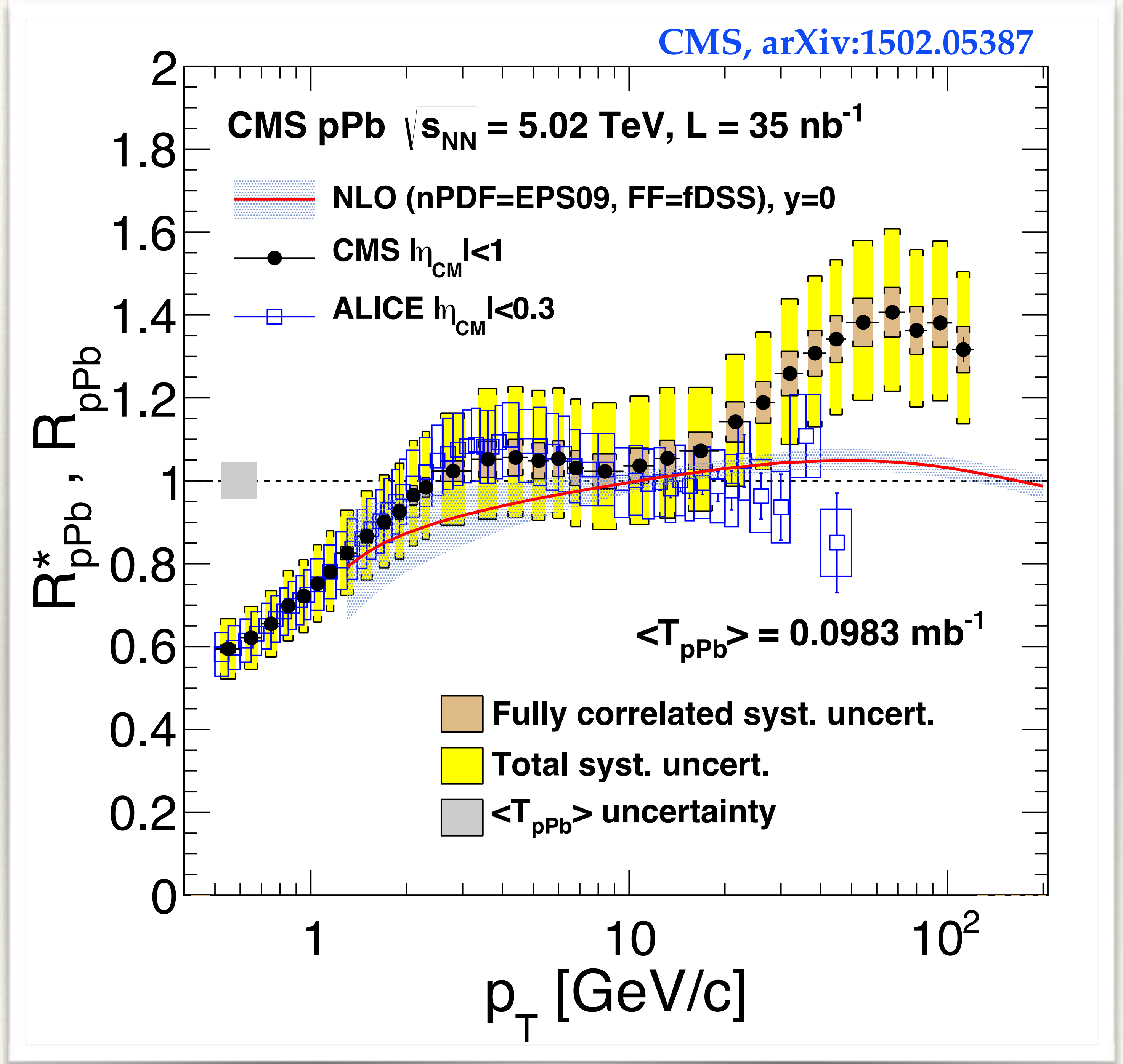


pPb: the control experiment

- … but **enhancement at very high-pT observed by CMS**? Not predicted from pQCD calculation.

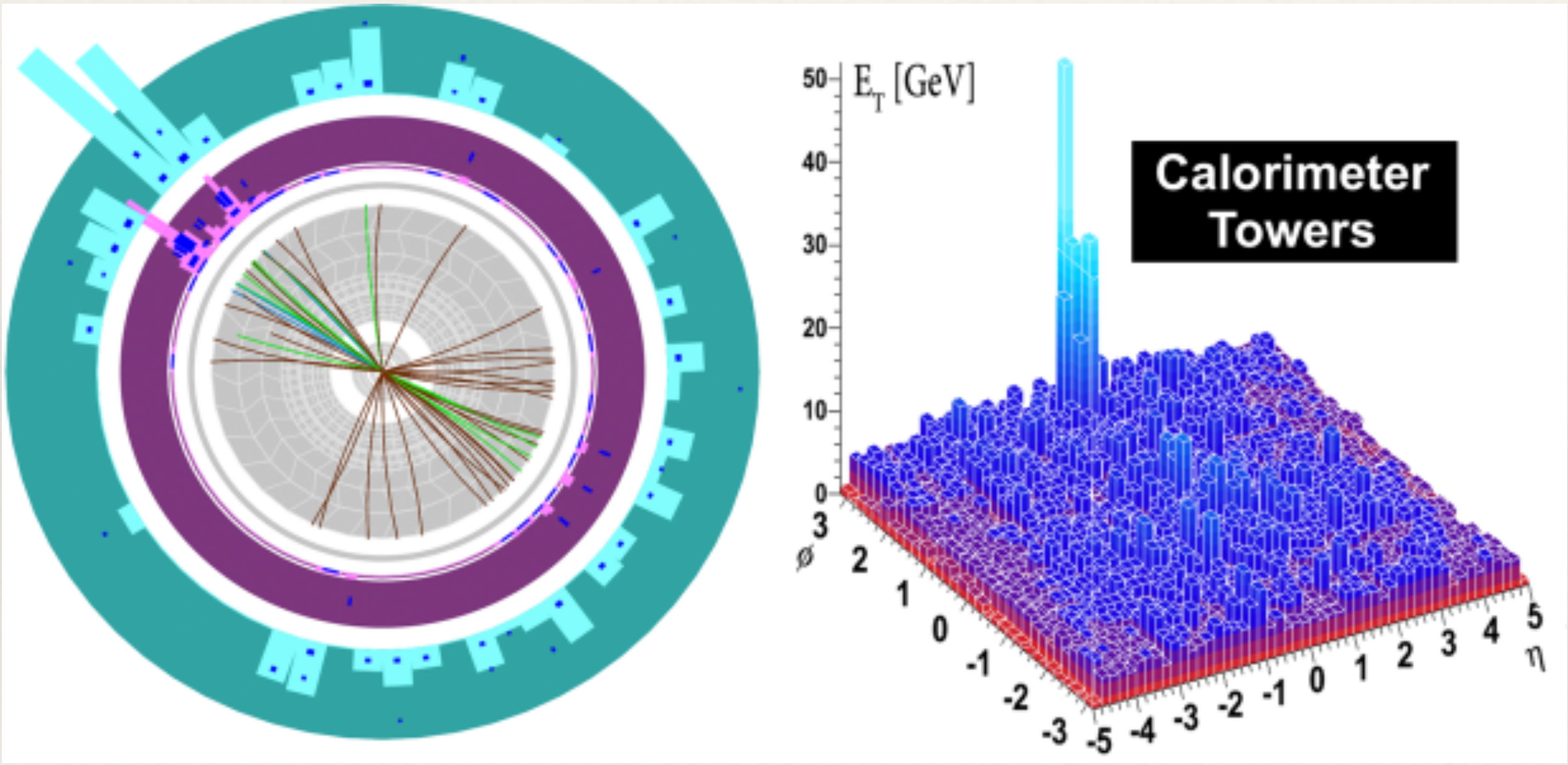
- ALICE seems not to observe a similar pattern.
- ATLAS partially observed an enhancement but within large systematic uncertainties.

- 10% difference come from interpolation at 5 TeV.
- Reference pp run at 5 TeV important!

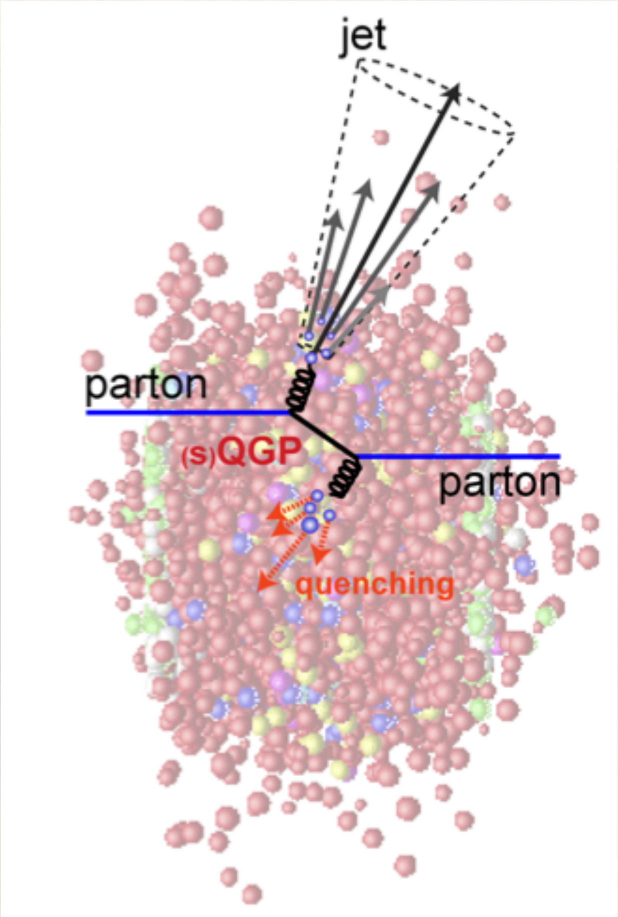


From single particles to jets… jet quenching

- Full jet reconstruction: anti-kT algorithm + background techniques
- Jets and di-jets with ~100 GeV energies
- Pb-Pb events with large di-jet imbalance observed



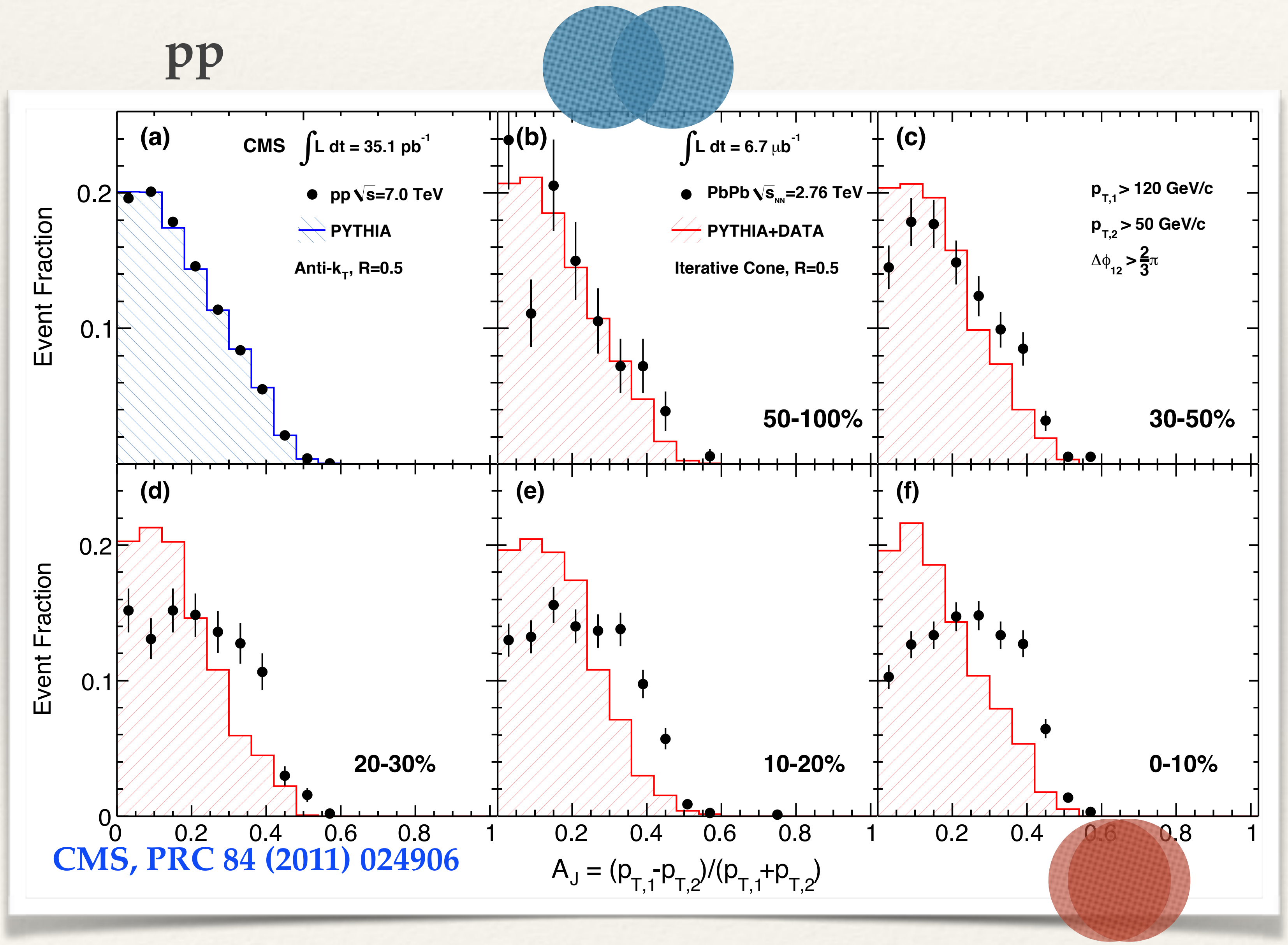
ATLAS, PRL105 (2010) 252303



From single particles to jets… jet quenching

- Detail study of di-jets events, in comparison with pp expectation
- Energy imbalance quantified by the di-jet asymmetry variable

pp

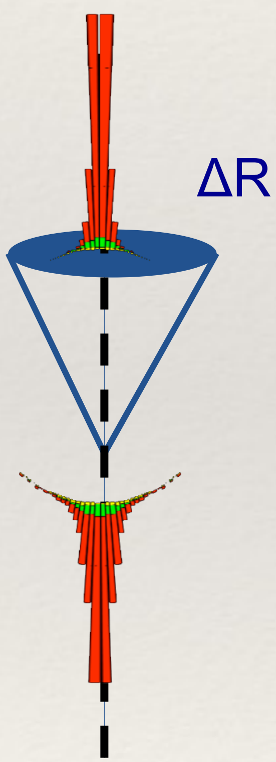


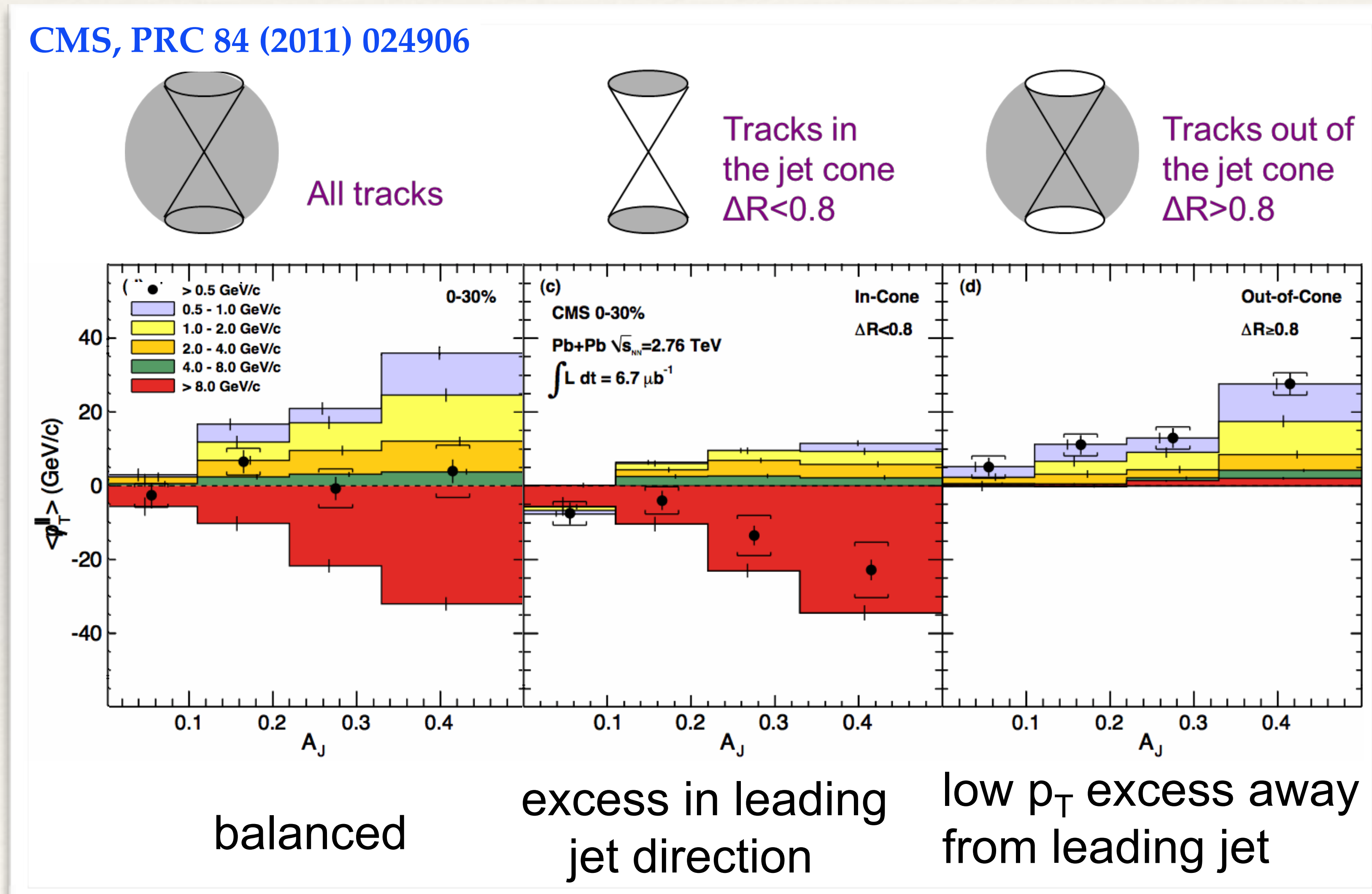
$$A_J = \frac{E_{T1} - E_{T2}}{E_{T1} + E_{T2}} \qquad E_{T1} > 100 GeV \quad E_{T2} > 25 GeV$$

- Going to more central events, **larger asymmetry in di-jets events** with respect to pp.

From single particles to jets… jet quenching

* Detail study of di-jets events, in comparison with pp expectation
* Energy imbalance quantified by the di-jet asymmetry variable
* Study of the recoil energy looking at other particles in the event.



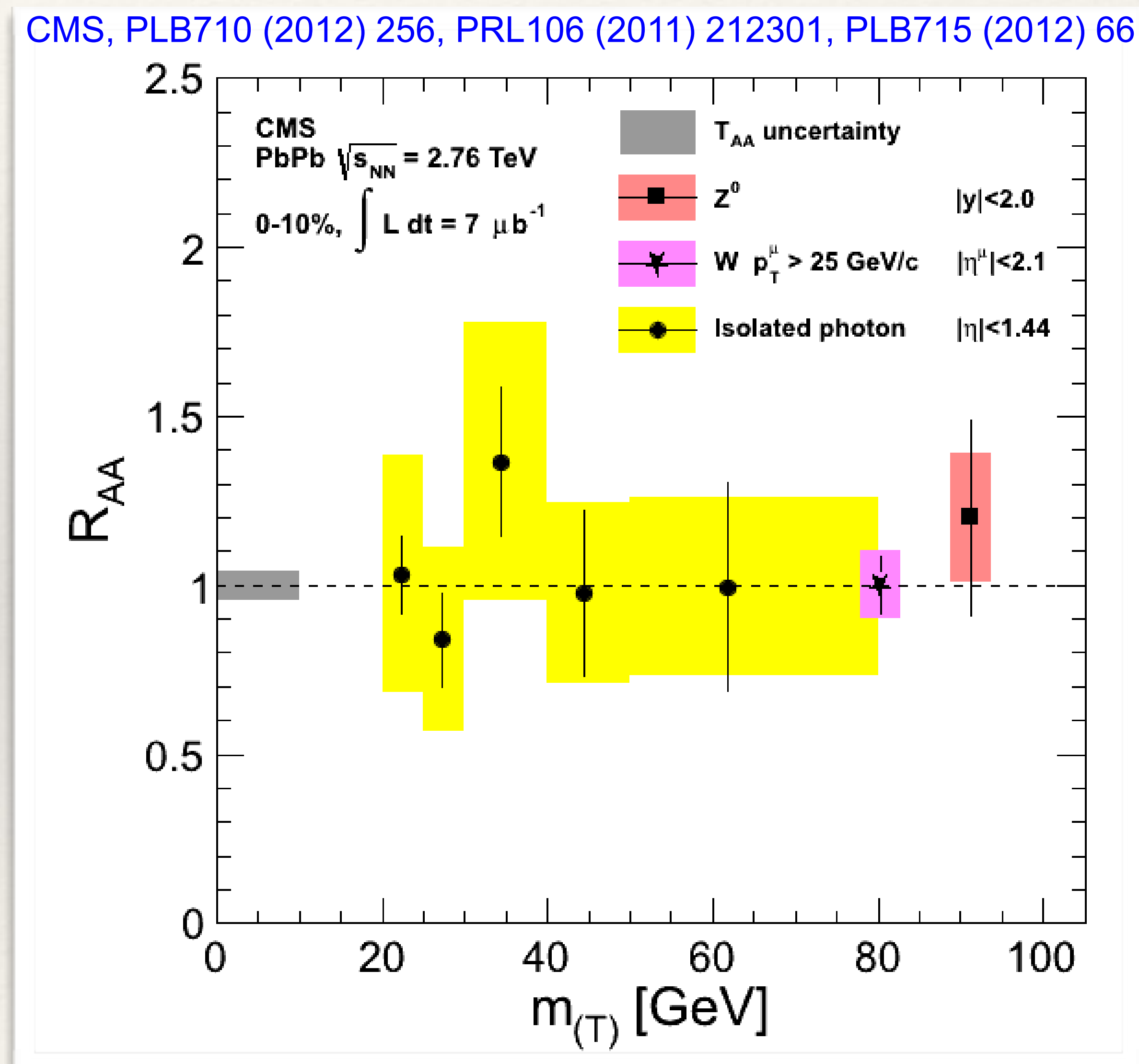


Unbalanced jet energy moved from high to lower p_T ($\sim p_T < 8$ GeV/c) small to large angles ($\Delta R > 0.8$)

"Transparent probes"

- Particles without color charge (produced in hard scatterings) should not be affected by the interaction with the medium:
  - Photons
  - Electro week bosons (W, Z)

- CMS measured in central Pb-Pb collisions:
  - Direct photons $R_{AA} \sim 1$ ($p_T > 20$ GeV/c)
  - W and Z $R_{AA} \sim 1$
  - No modification observed



Mass dependence of the energy loss

- Heavy quarks are produced in large virtuality process at the initial stage of the collisions, with short formation time.
  $\Delta t > 1/m_c \approx 0.1 \text{ fm} << \tau_{\mathrm{QGP}}\ 5 - 10 \text{ fm}$

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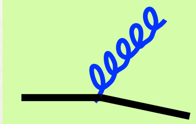
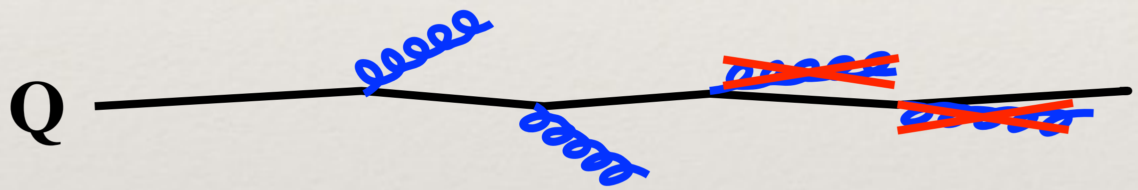
  - **Dead cone effect**

Gluonsstrahlung probability



$$\propto \frac{1}{[\theta^2 + (m_Q / E_Q)^2]^2}$$

$$\omega \frac{dI}{d\omega}\bigg|_{HEAVY} = \omega \frac{dI}{d\omega}\bigg|_{LIGHT} \times \left(1 + \left(\frac{m_Q}{E_Q}\right)^2 \frac{1}{\theta^2}\right)^{-2}$$



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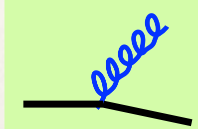

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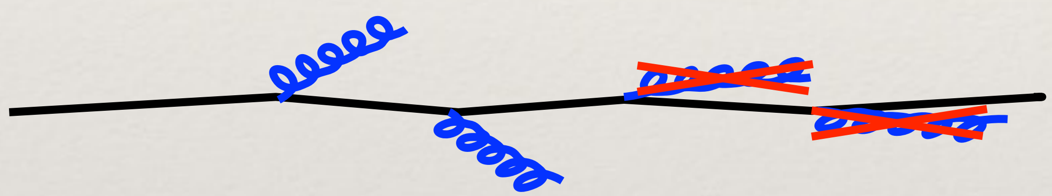
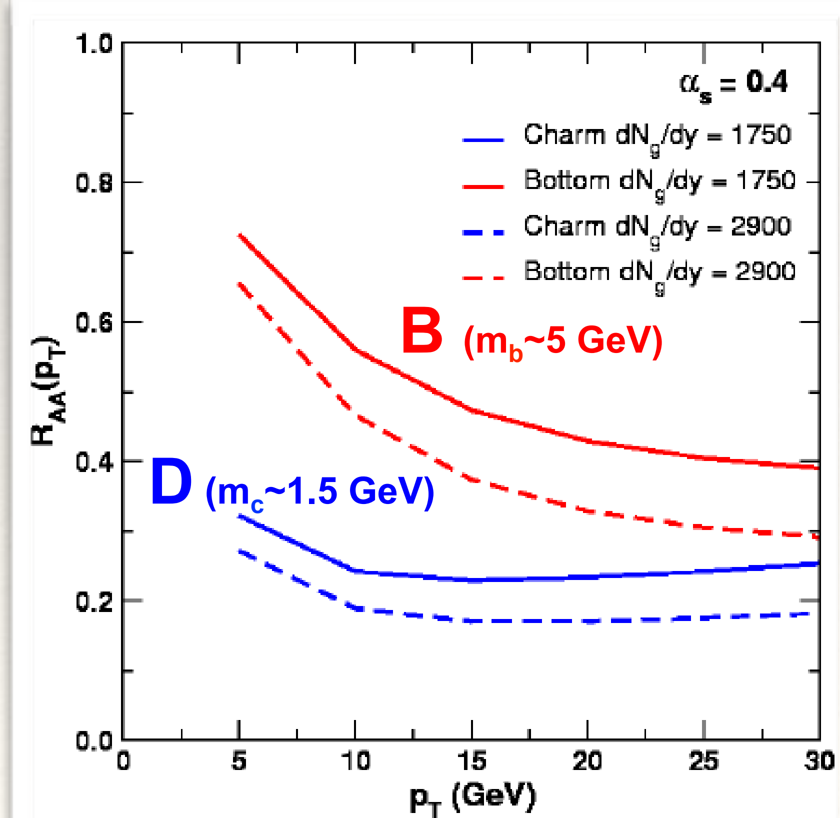
Q



- Energy distribution of radiated gluons is suppressed by an angle-dependent factor: **heavy quarks might lose less energy in the medium ?**

Dokshitzer, Khoze, Troyan, JPG 17 (1991) 1602.
Dokshitzer and Kharzeev, PLB 519 (2001) 199.



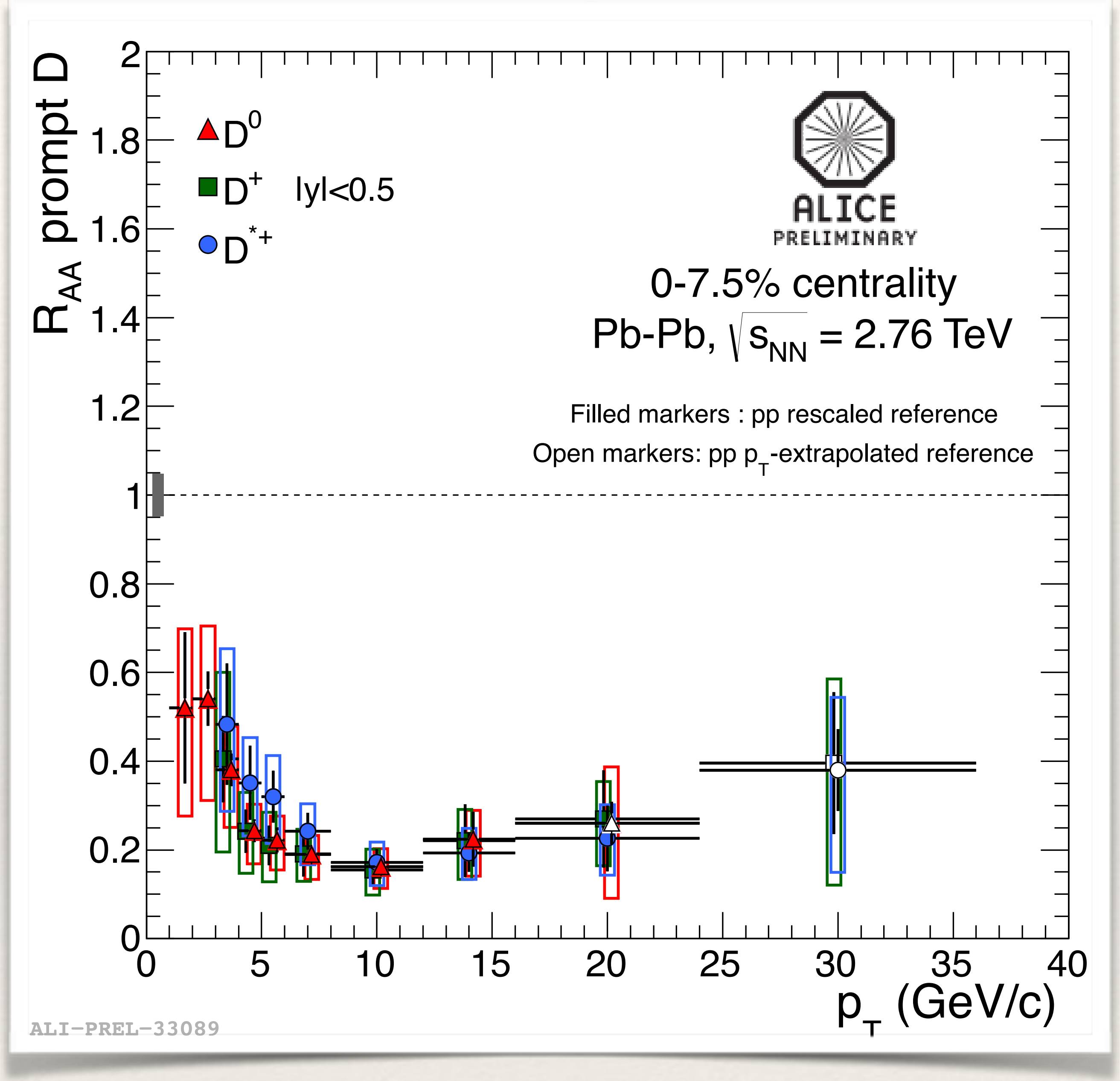
Wicks, Gyulassy, "Last Call for LHC Predictions" workshop, 2007

?

ΔE(light) >ΔE(c) > ΔE(b) ➔ R_{AA} (π) < R_{AA} (D) < R_{AA} (B)

D mesons in ALICE

- First D R_{AA} measurement in heavy-ion collisions.
- Strong suppression observed:
  - ~ factor 5 for p_T ~ 10 GeV/c
  - possible rise at high-p_T ?



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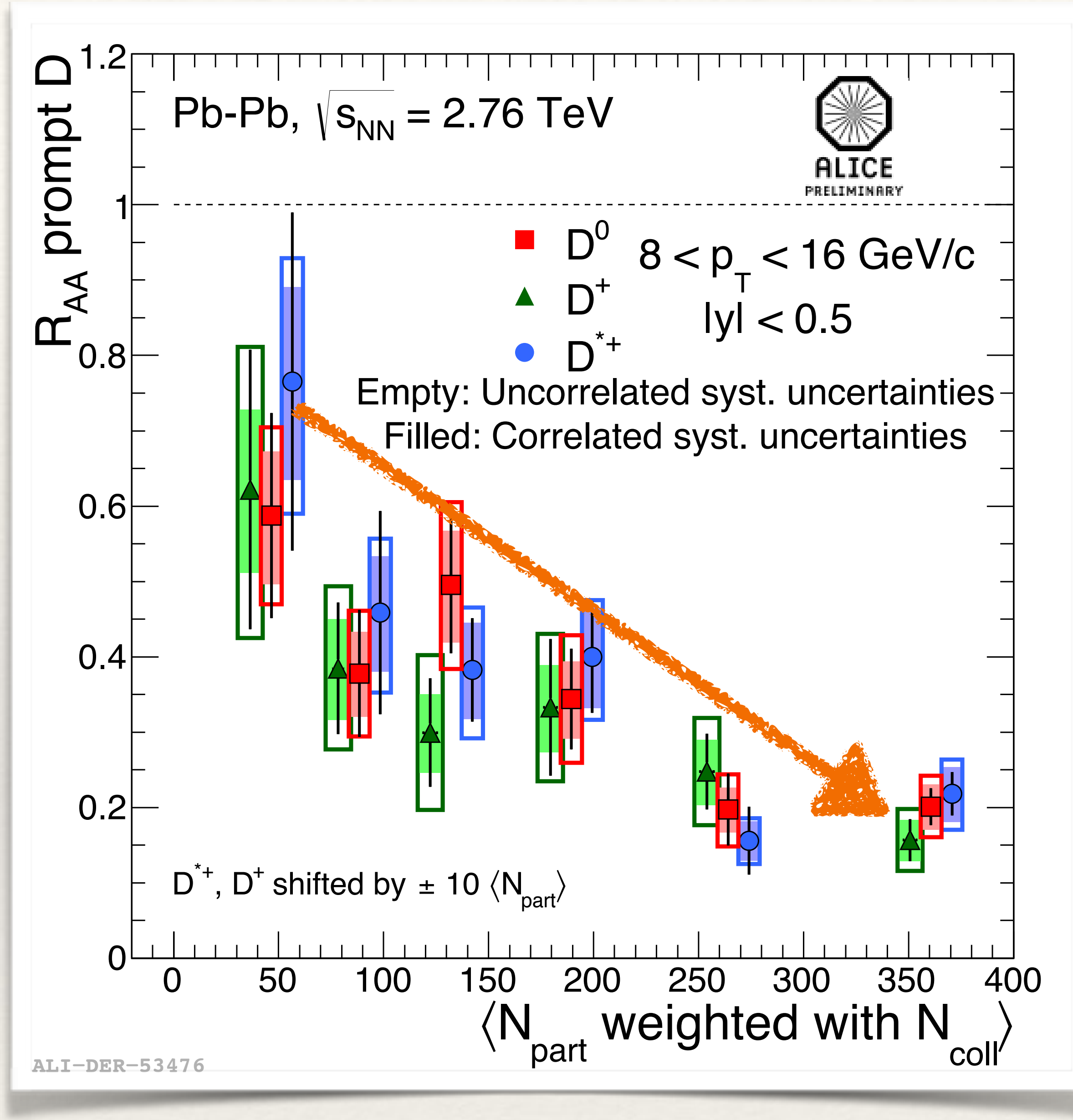

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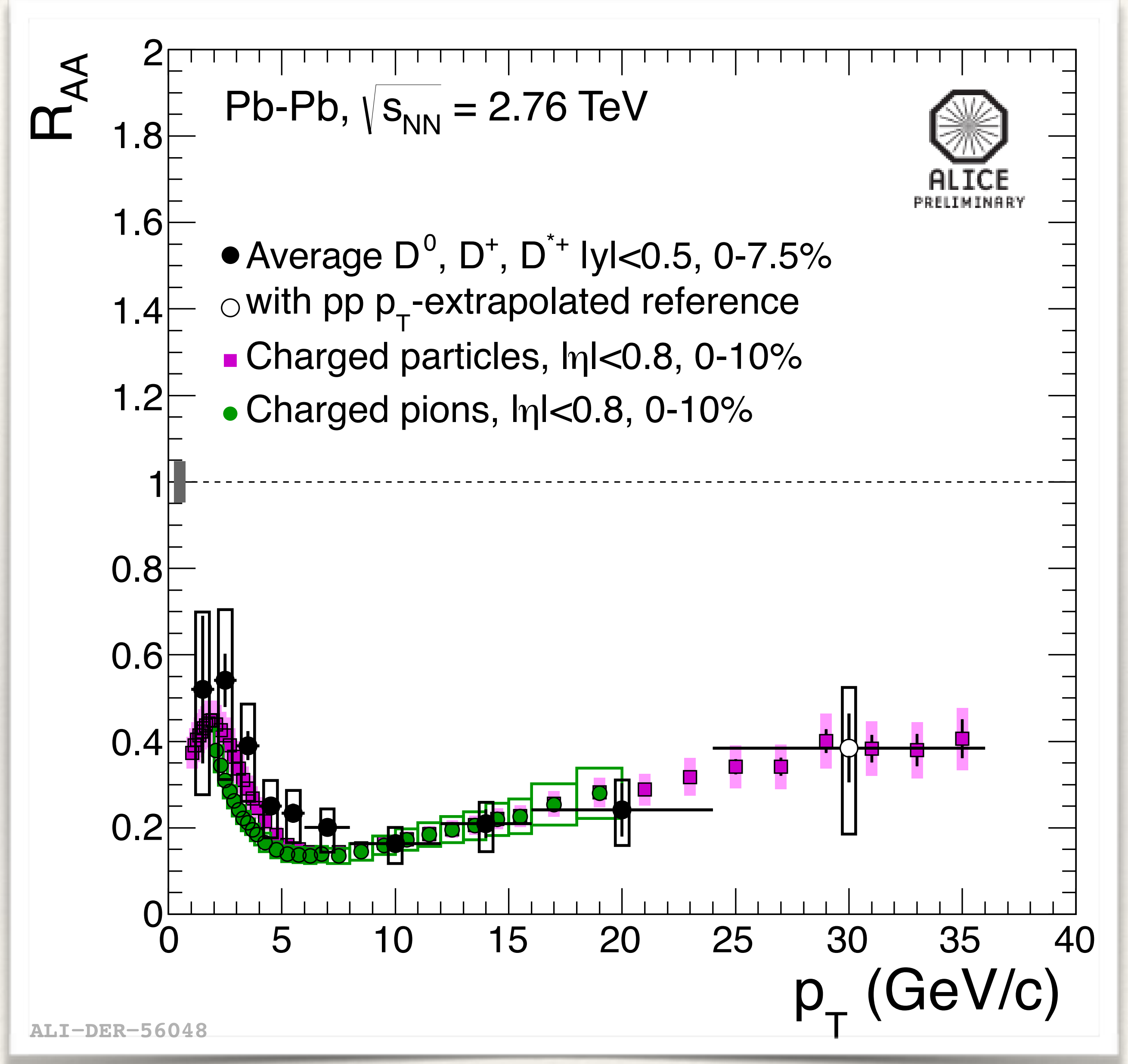
- For $p_T > 5$ GeV/c similar suppression for **D mesons** and **pions**



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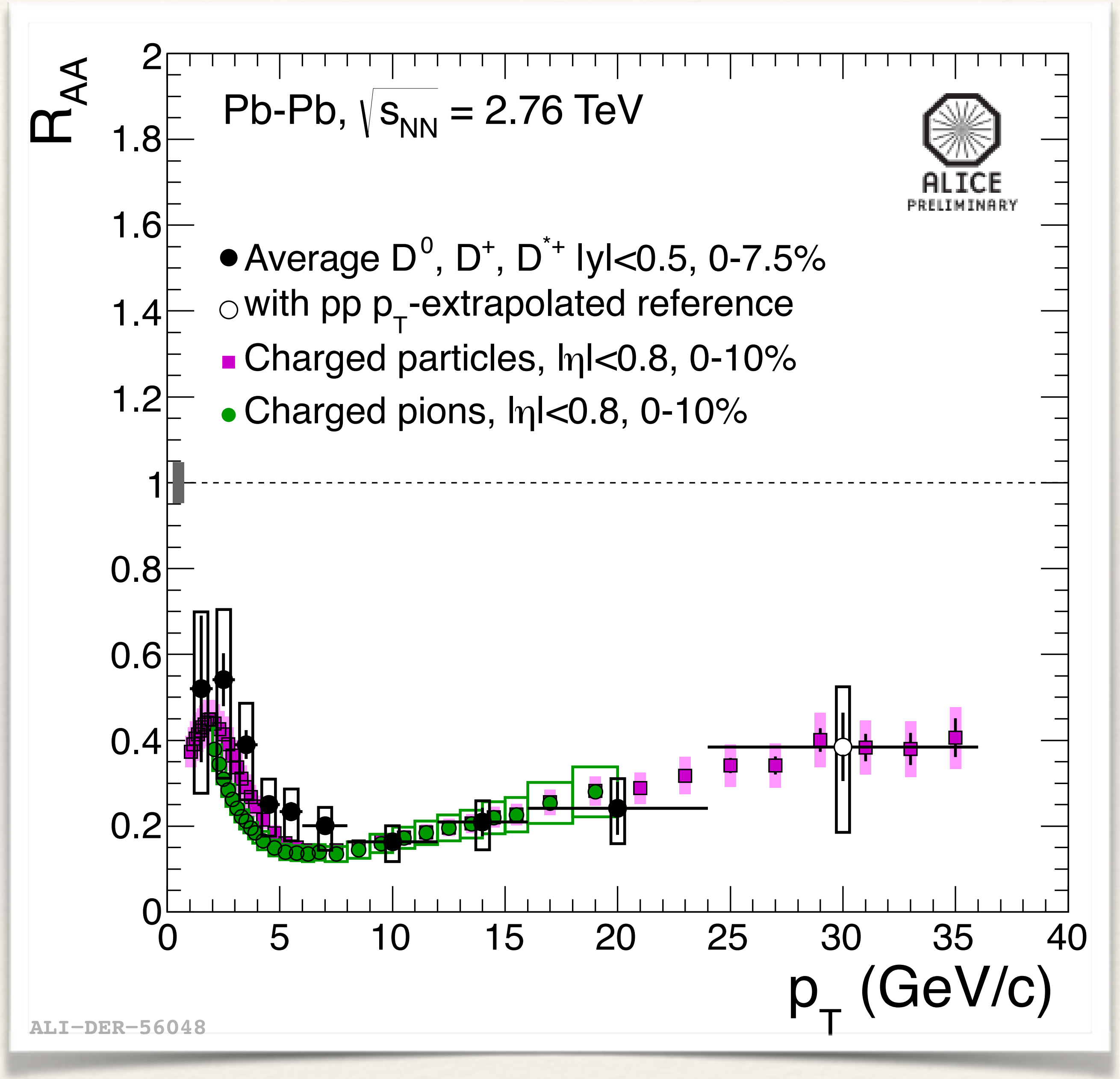
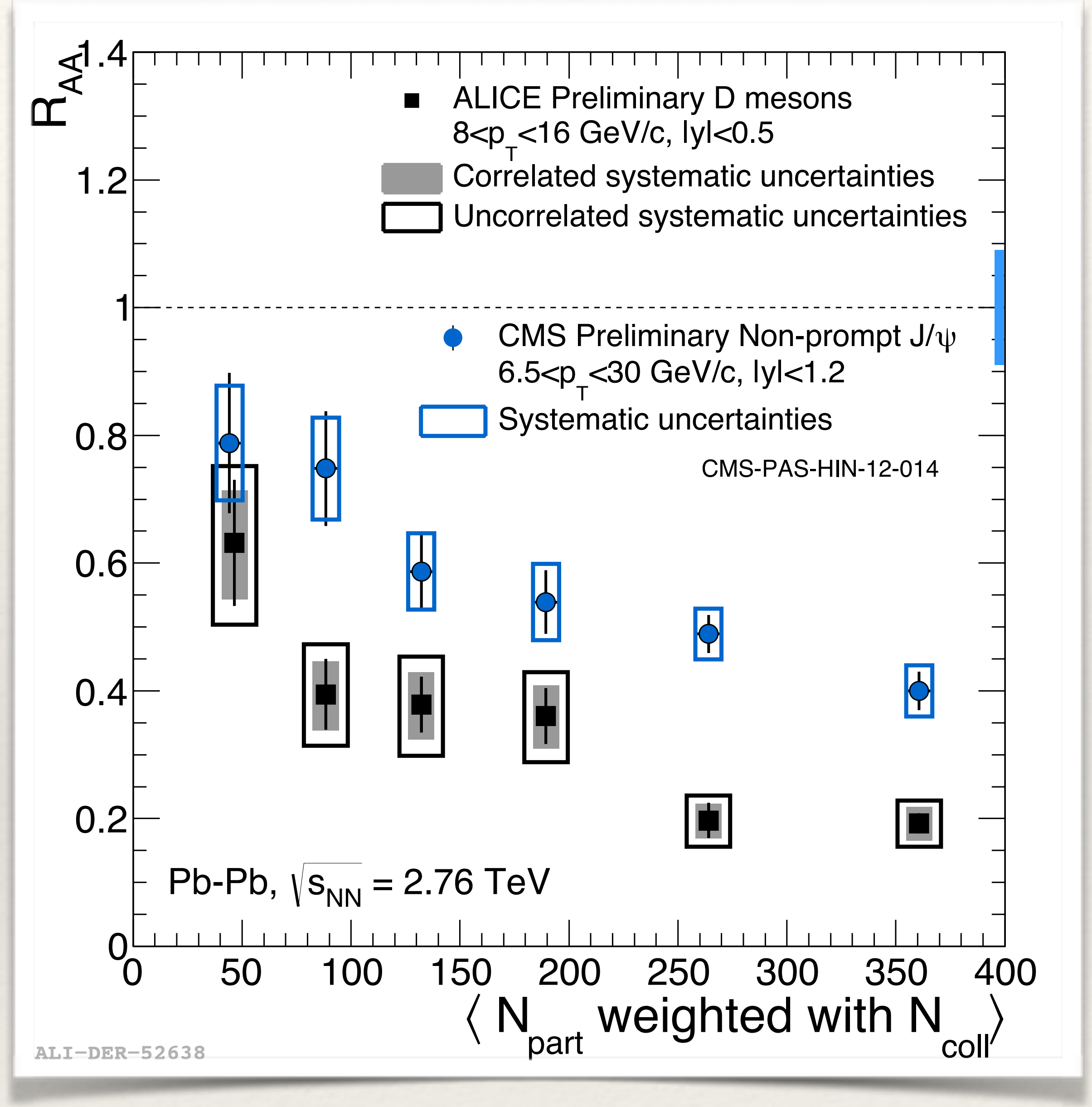
- For $p_T > 5$ GeV/c similar suppression for **D mesons** and **pions**
- For $p_T < 5$ GeV/c uncertainties are too large to conclude on possible energy loss mass effect



D mesons and non prompt J/ψ

- ALICE **D-mesons** results compared with CMS **non-prompt J/ψ** in a similar kinematic range:
  - central rapidity region
  - B and D mesons $<p_T>$ ~10 GeV/c

- **Indication of larger suppression for D mesons than B mesons:**
  - R_{AA} **(B) >** R_{AA} **(D)**



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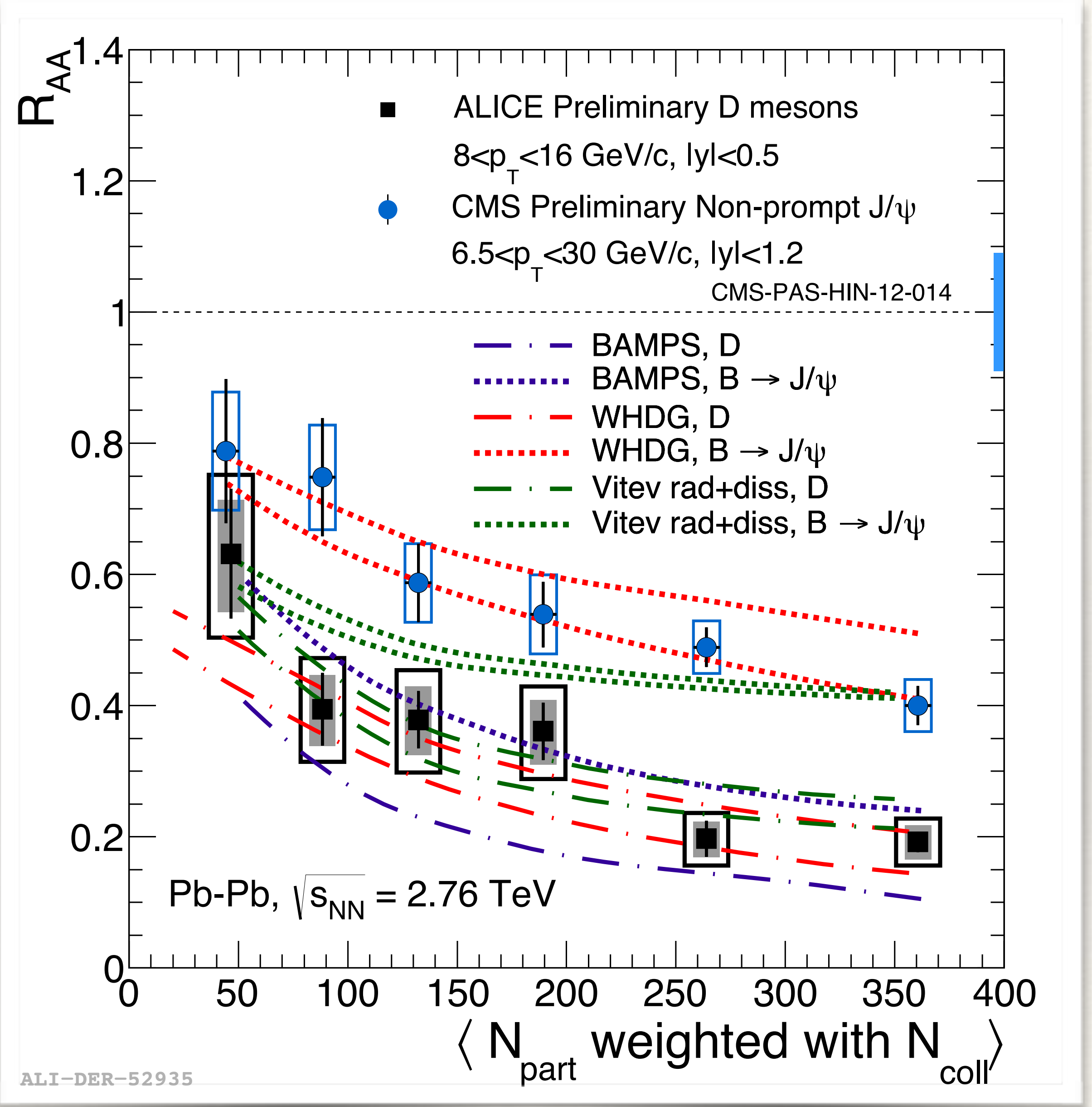
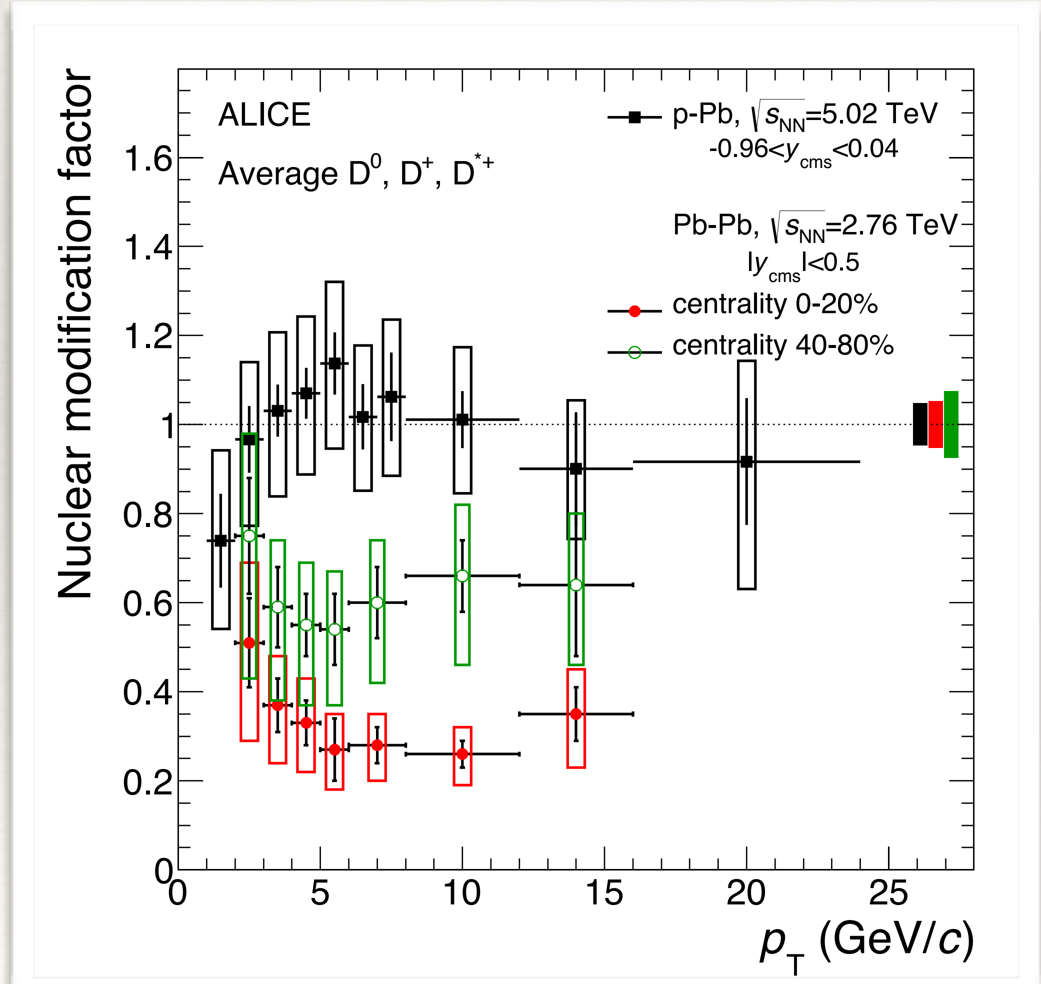


- **Indication of larger suppression for D mesons than B mesons:**
  - R_{AA} **(B) >** R_{AA} **(D)**

- **Models that include mass dependence of the energy loss predict a difference in the** R_{AA} **of D and B mesons**

D mesons: control experiment

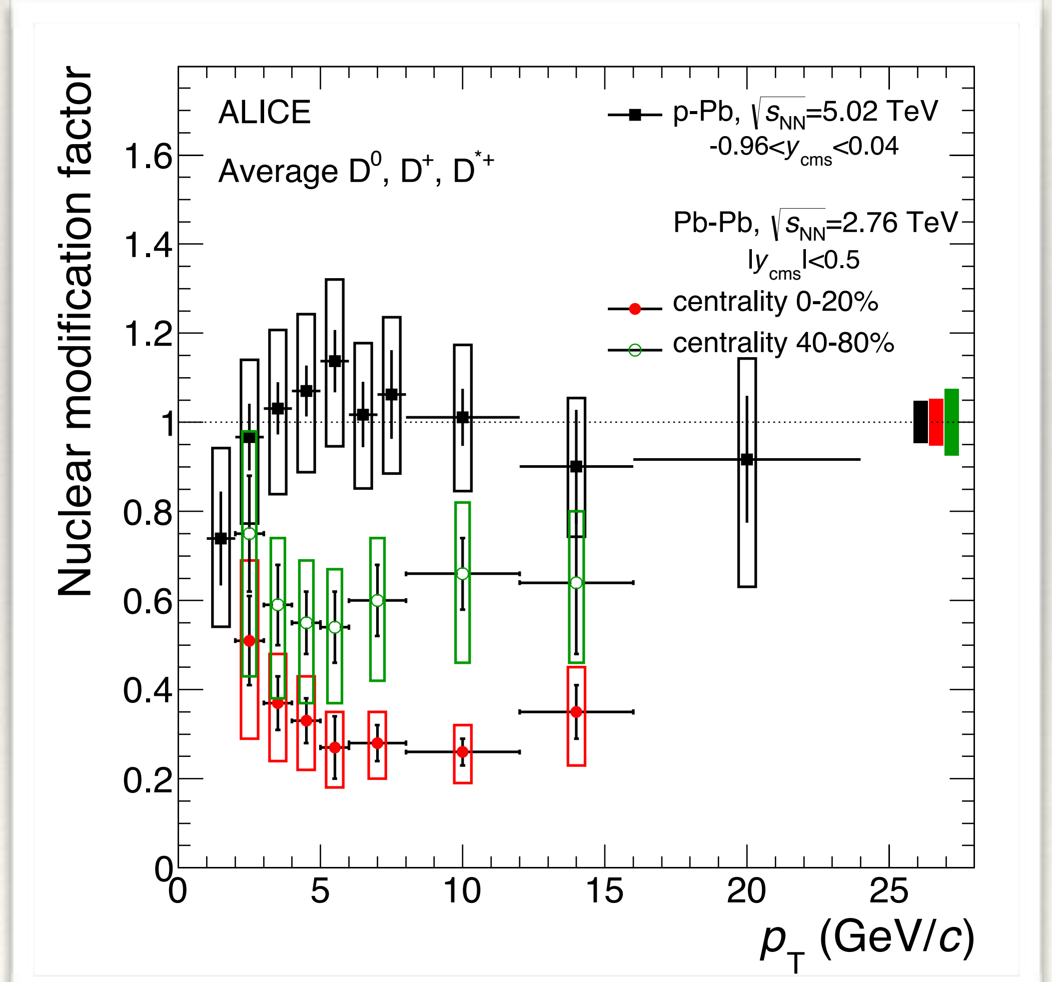
- ALICE D-mesons R_{pPb} compatible with unity.
- The **D mesons suppression** observed in central Pb-Pb collisions comes from **hot nuclear matter effects.**

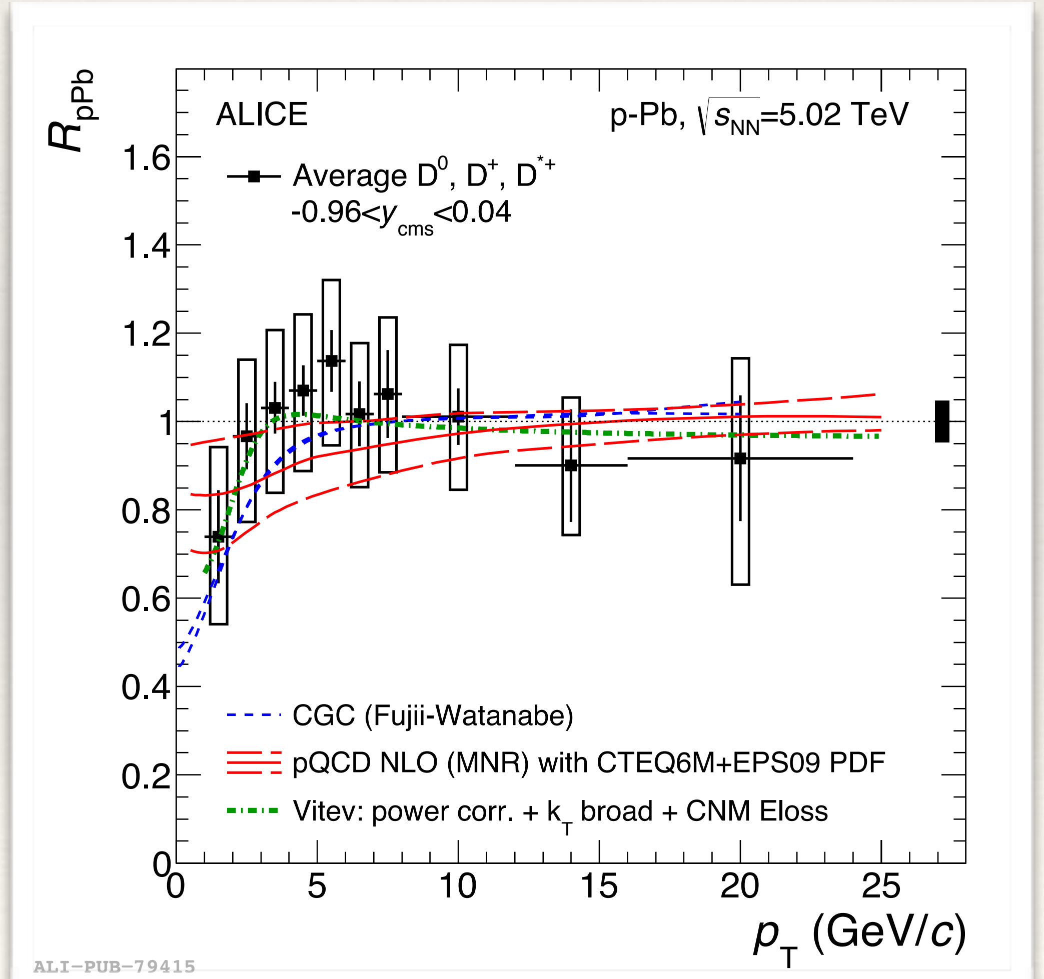


ALICE, Phys.Rev.Lett. 113 (2014) 23, 232301

D mesons: control experiment

- ALICE D-mesons R_{pPb} compatible with unity.
- The **D mesons suppression** observed in central Pb-Pb collisions comes from **hot nuclear matter effects.**
- Models including CNM effects (both saturation and shadowing can describe the data)





ALICE, Phys.Rev.Lett. 113 (2014) 23, 232301

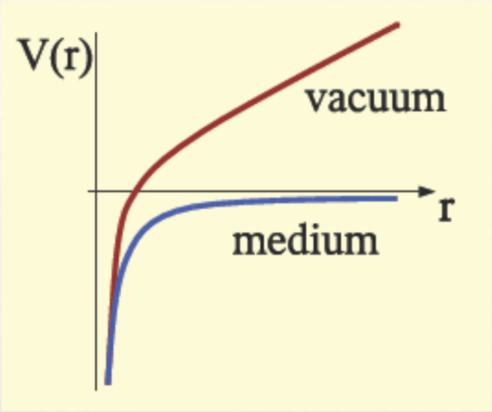
Quarkonia

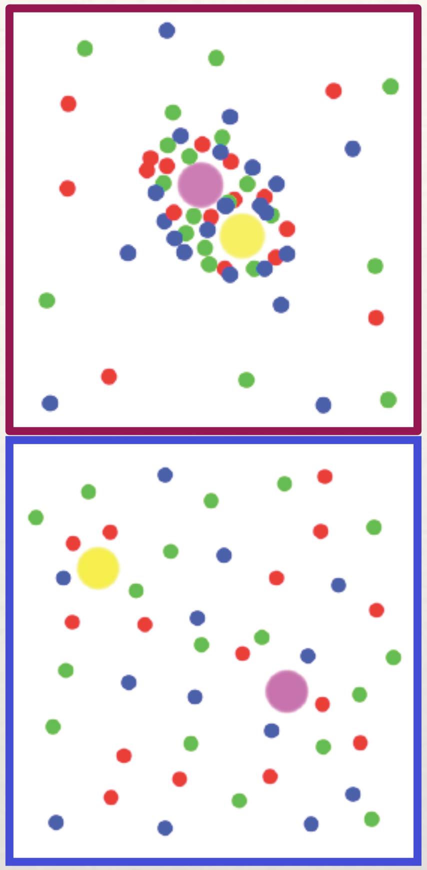
* QGP signature proposed by Matsui and Satz in 1986.

* In the plasma phase the interaction potential is expected to be screened beyond the Debye length λ_D (analogous to the e.m. Debye screening).

* Charmonium and bottomonium states with $r > \lambda_D$ will not bind, expected suppressed production.

* … but if many charm pairs are produced, uncorrelated c quarks from the medium could bind at the hadronization of the system and form charmonium.



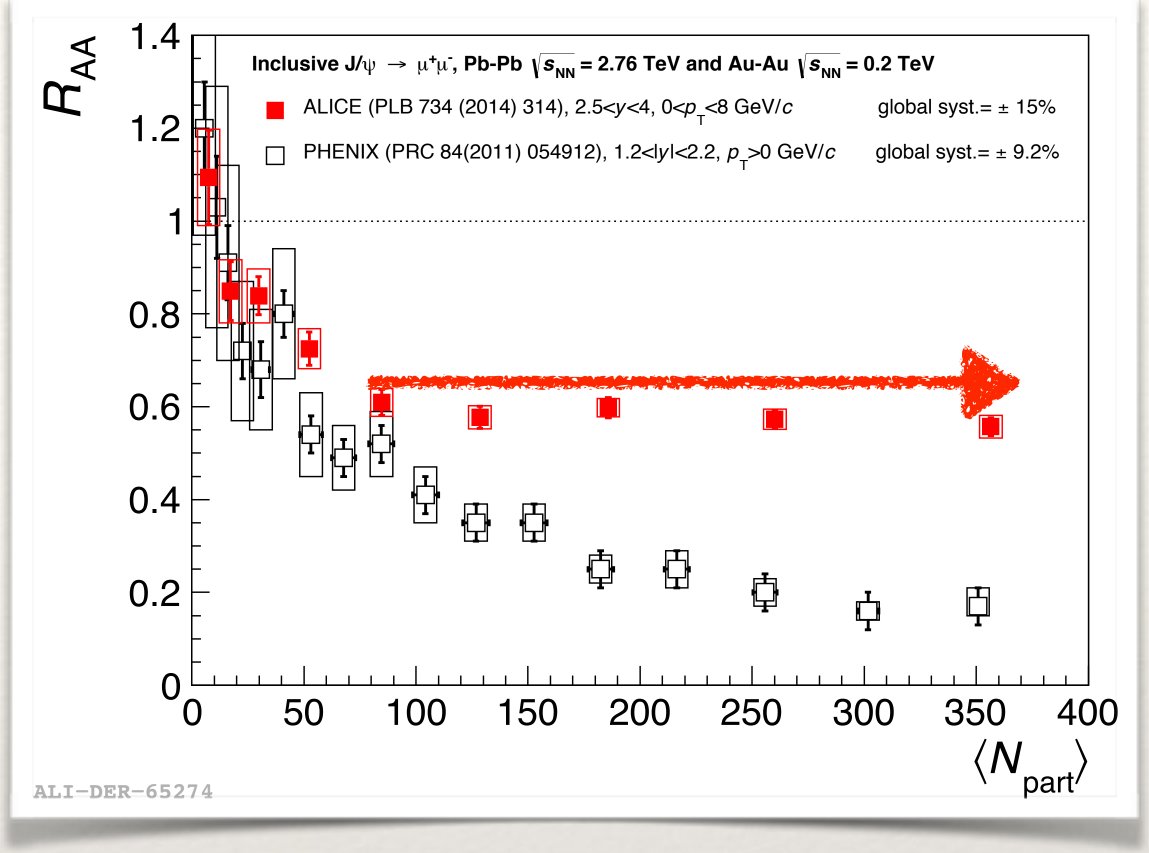


Matsui, Satz, PLB178 (1986) 416

	SPS 20 GeV	RHIC 200 GeV	LHC 2.76 TeV
Ncc	~0.1	~10	~100

Quarkonia

- **At the low-p_T ($p_T > 0$) :**
  - ALICE observes a constant suppression vs centrality.
  - The suppression is smaller than what was observed at RHIC:
    - predicted signature for regeneration



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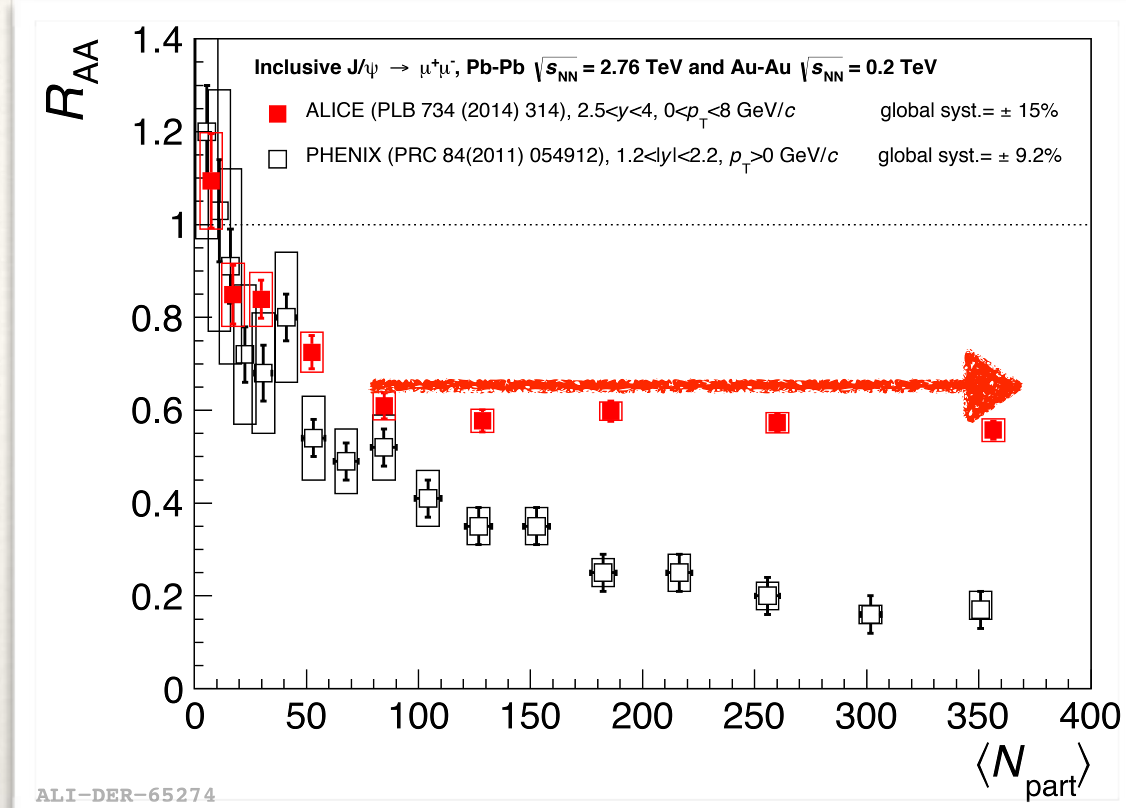
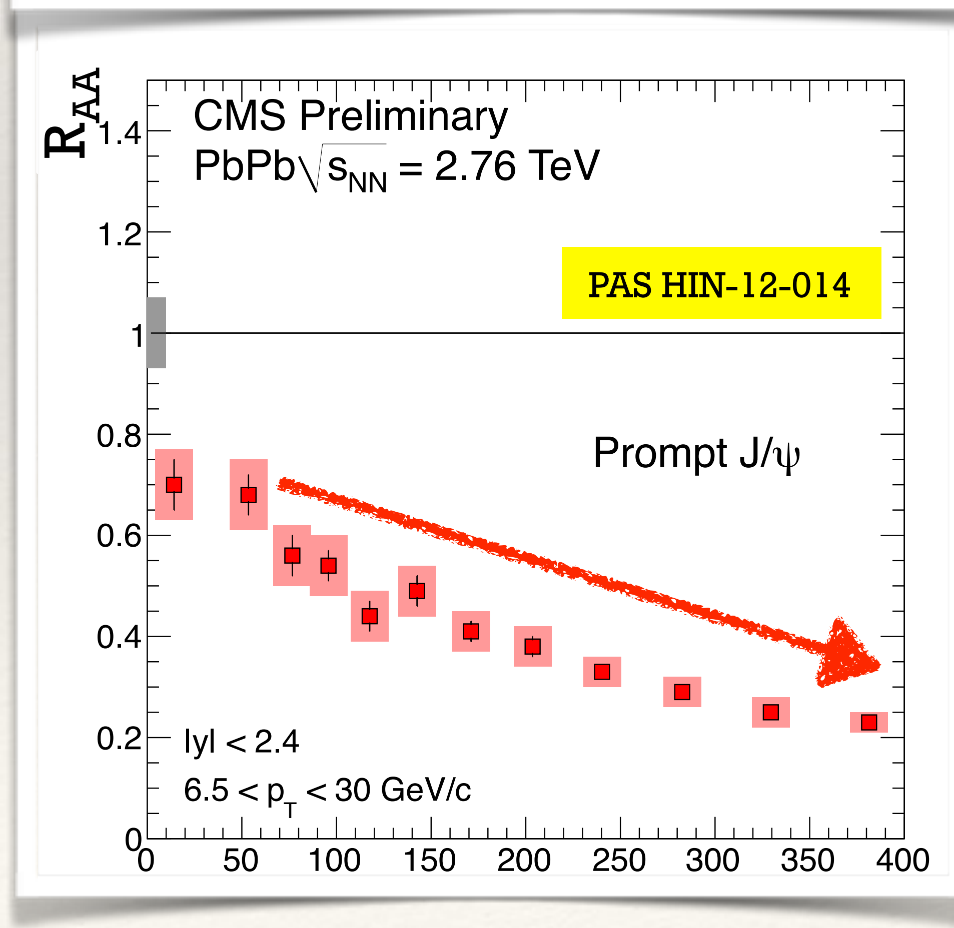


- **At high-p_T ($p_T > 6.5$ GeV/c)** :
  - CMS observed a suppression for J/ψ with $p_T > 6.5$ GeV/c.
  - Similar (but slightly smaller) suppression than at RHIC.



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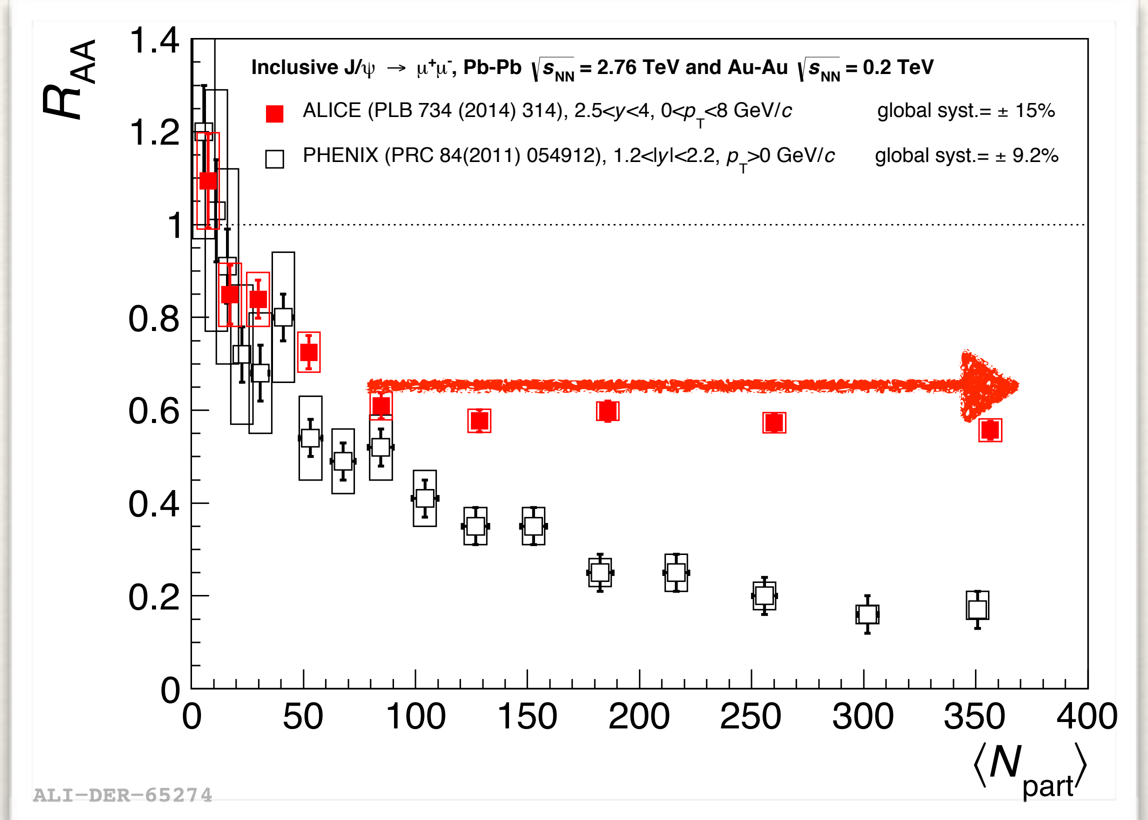
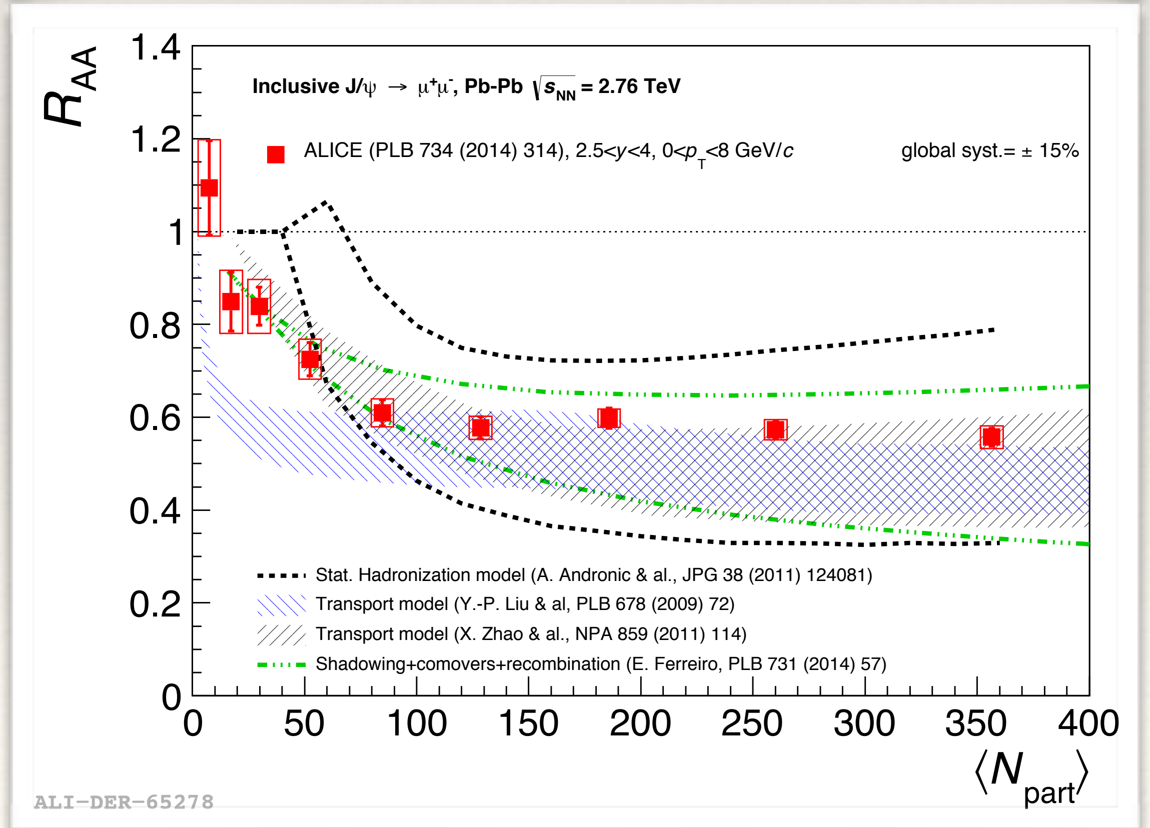


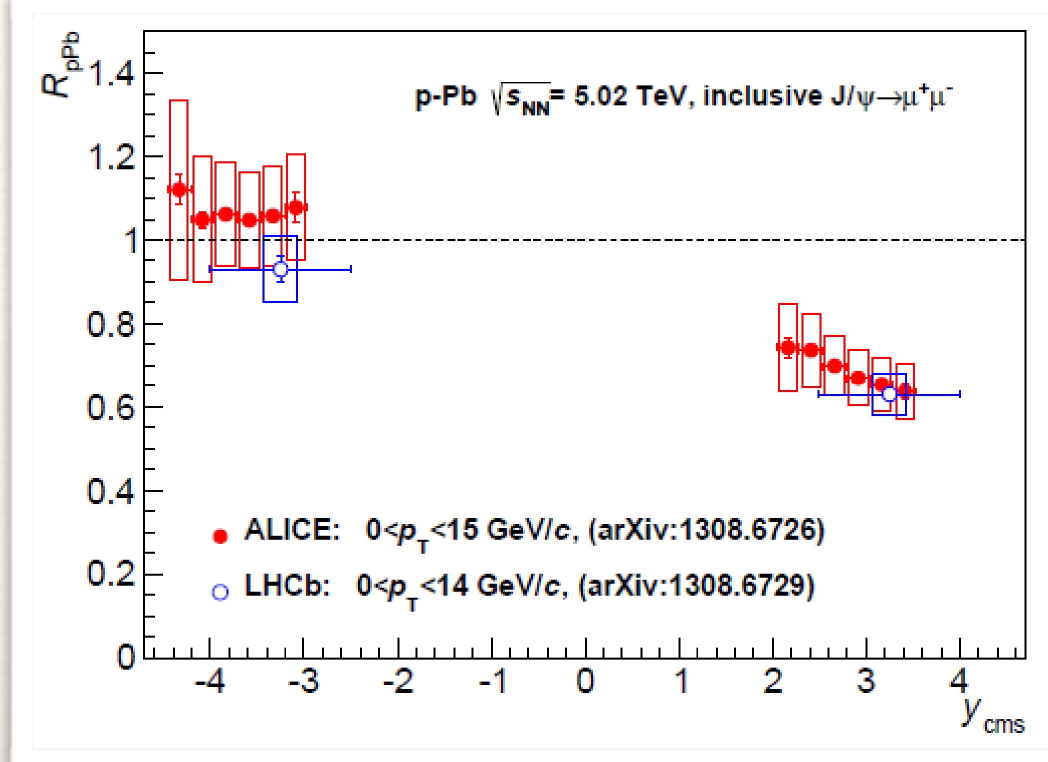
Regeneration involves mainly low-p_T charm quarks?
Charm quarks take part in the evolution of the system?



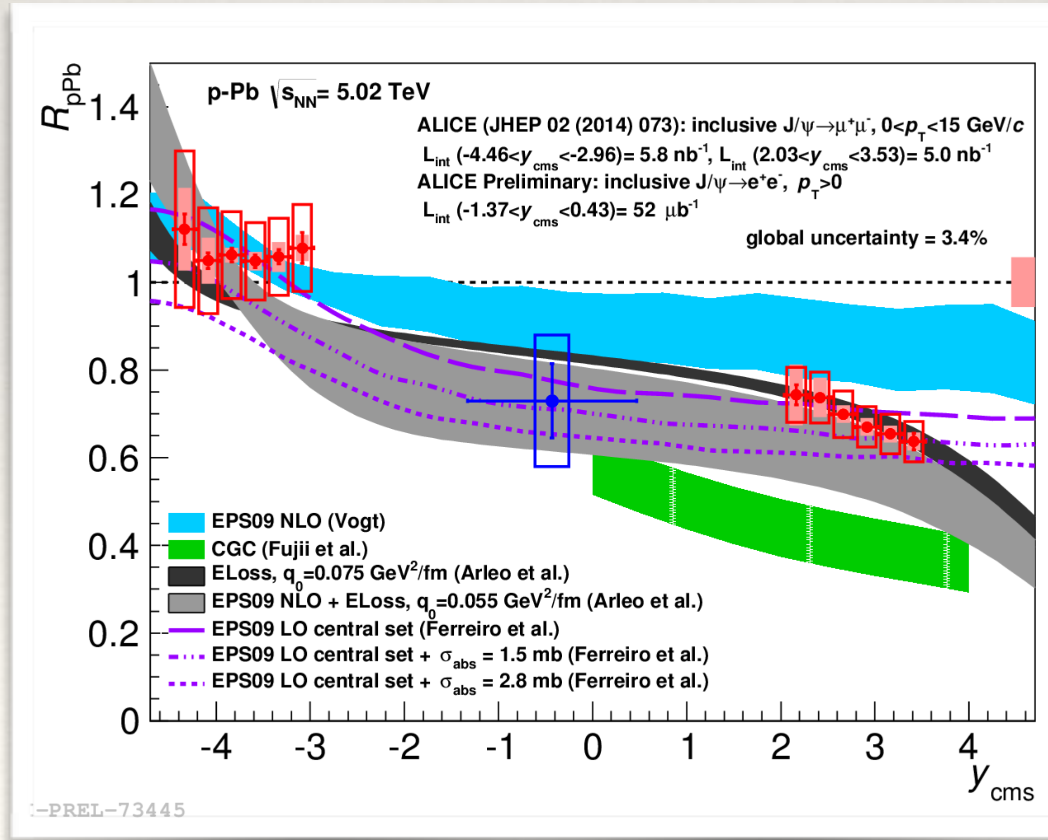
* Models that include recombination of charm quark in a deconfined system can describe J/ψ suppression.

Quarkonia in pPb

arXiv:1308.6726



- Differently from open HF, J/ψ production is sensitive to cold nuclear matter effects:
- at forward rapidity the J/ψ production is suppressed by about 20%
- models including shadowing and coherent energy loss

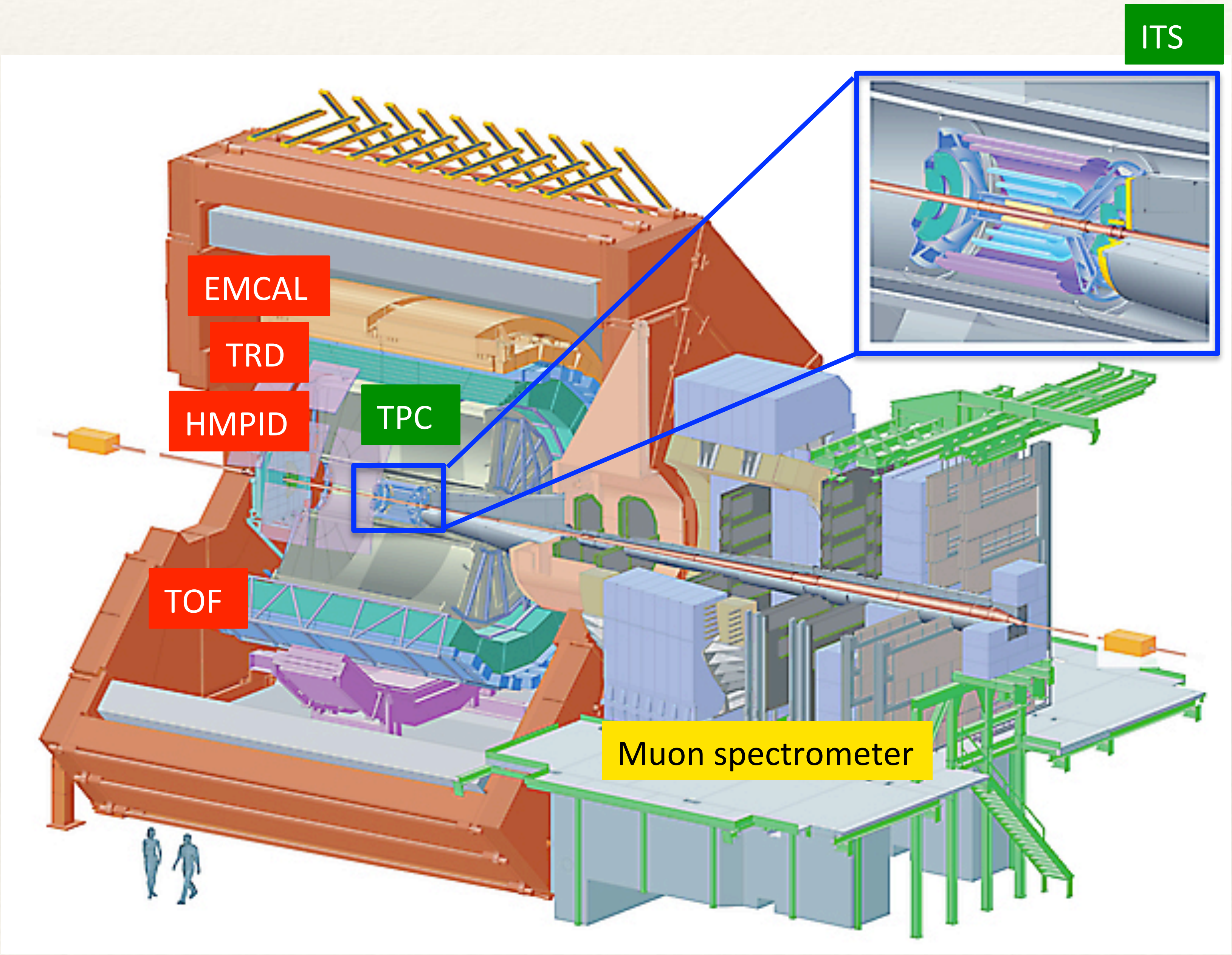


Conclusions

- "Color less" probes don't interact with the medium
- **High-pT particles are suppressed** also at $p_T > 20$ GeV/c
  - Compatible with models that include gluon radiative energy loss
- Jet quenching observed at event-by-event level
  - **quenched energy radiated out of the jet cone at large angles** via low-p_T particles
- **D mesons are more suppressed than non-prompt J/ψ** in central Pb-Pb collisions. This can be explained by **models that include mass dependent energy loss.**
- J/ψ seems to be:
  - **"regenerated" at low-p_T ?**
  - **suppressed at high-p_T**
- For (almost) all hard probes the **pA results indicate** that are **not much affected by initial state effects**
  - Only J/ψ is affected in particular in forward region.

Backup

The ALICE experiment



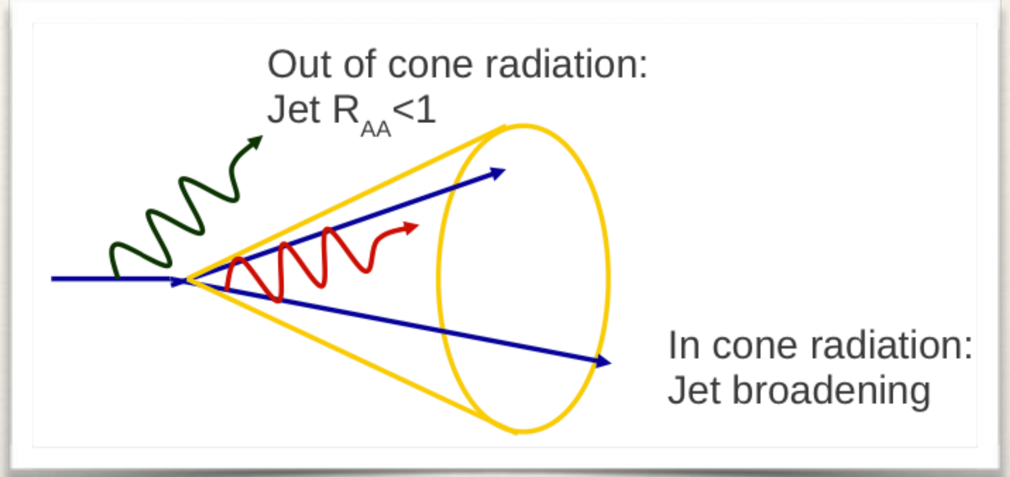
Central barrel: |η| < 0.9
Tracking Detectors: ITS - TPC
PID: TOF - HMPID
Calo/PID: EMCAL - TRD

Muon spectrometer:
$-4 < \eta < -2.5$
μ-ID via tracks matched between tracking and trigger system

Trigger and centrality determination detector in forward region.

From single particles to jets...

- Jets can be used as a tool to understand where the radiated energy went.
- **In cone radiation**:
  - particles would be quenched inside the jet increasing his "area": jet broadening
- **Out of cone radiation**:
  - particles would be emitted outside of the jet cone, suggesting a $R_{AA\ \mathrm{jets}} < 1$



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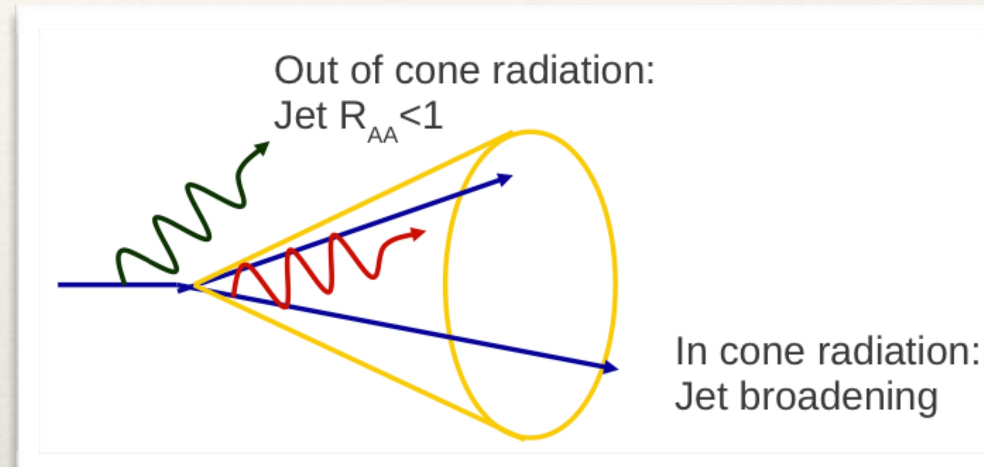
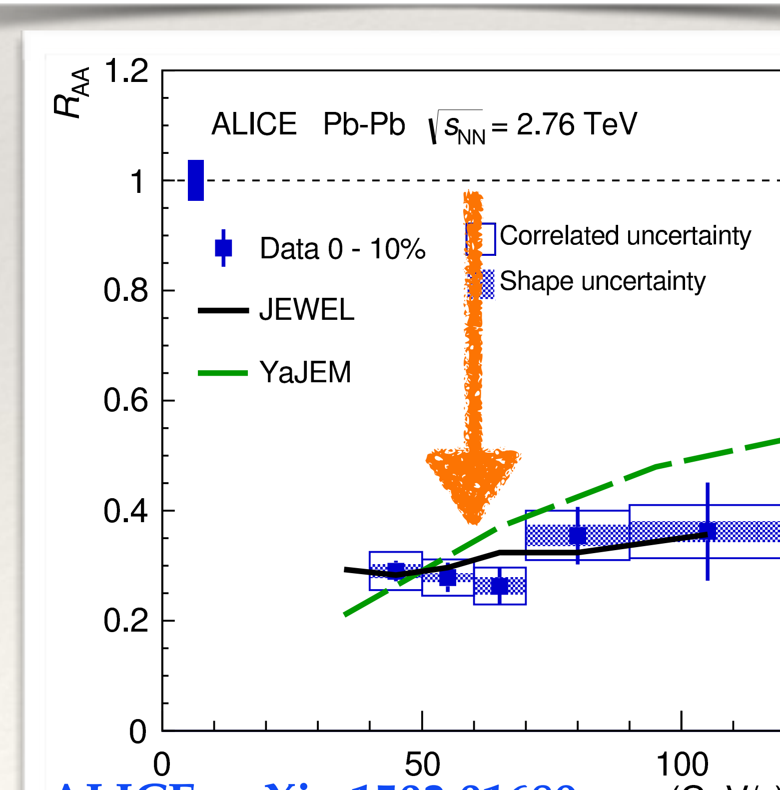


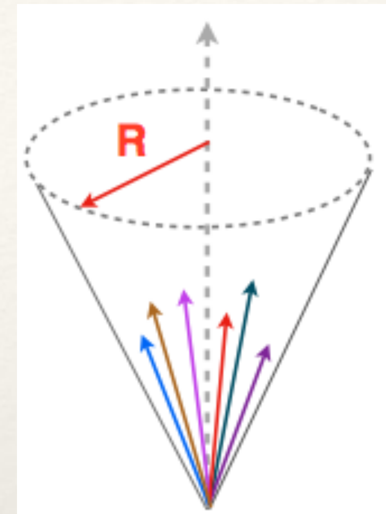
- Measured $R_{AA\,\mathrm{jets}} < 1$!!
- **Energy radiated at large angles, outside the jet**



ALICE, arXiv:1502.01689

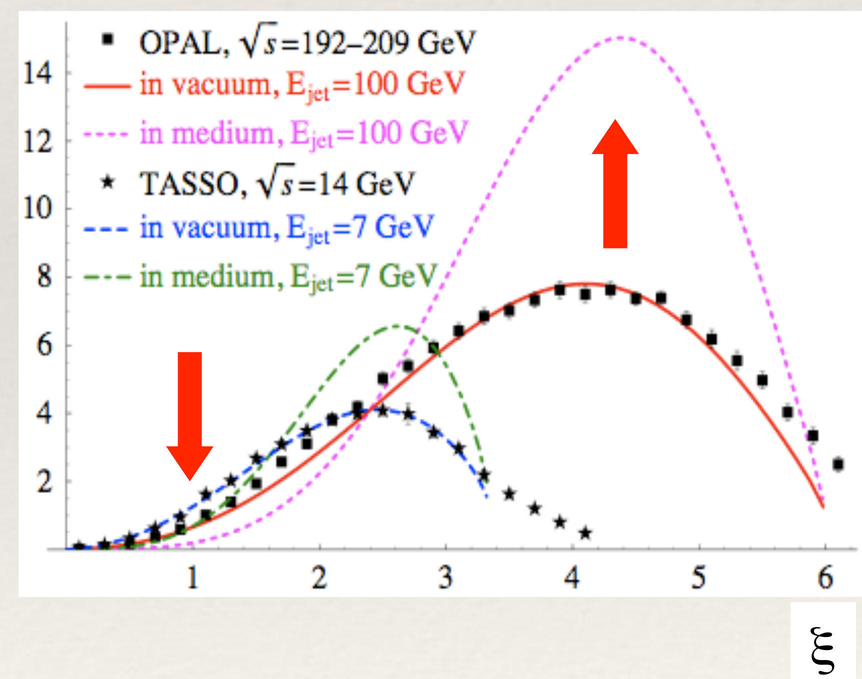
Jet shape modification

* Jet fragmentation function
    * energy distribution of particles within the jet
* Expectations from parton energy loss: fragmentation should get softer
    * Depletion at high-z
    * Enhancement at low-z



$$z = \frac{P_T^{particle}}{P_T^{Jet}}$$

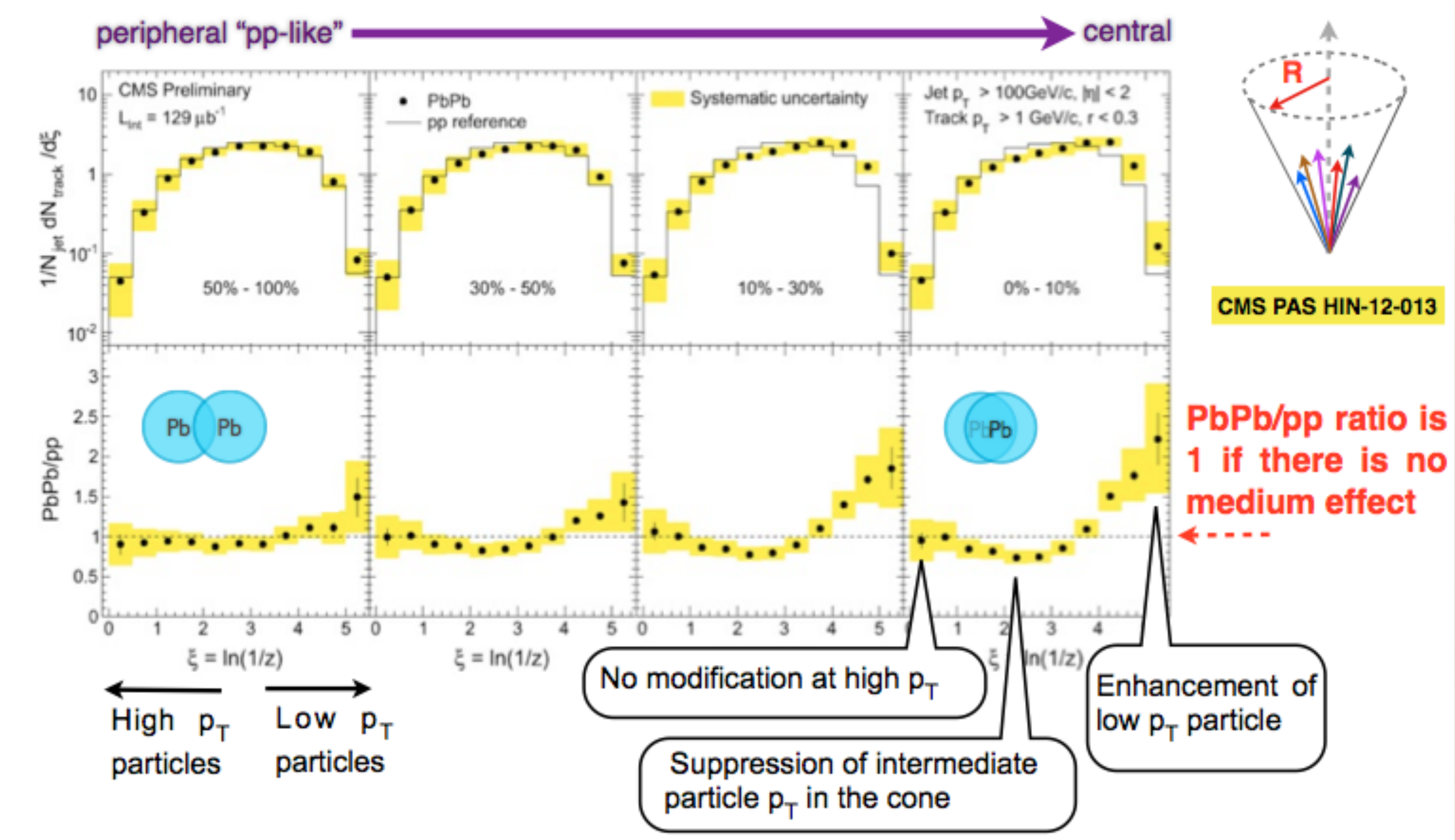
$$\xi = log\frac{1}{z}$$



Borghini,Wiedemann, hep-ph/0506218

Jet shape modification

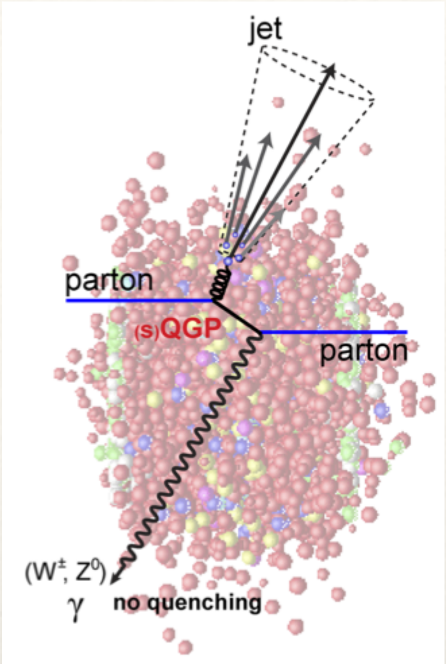
* Jet fragmentation function measured at the LHC

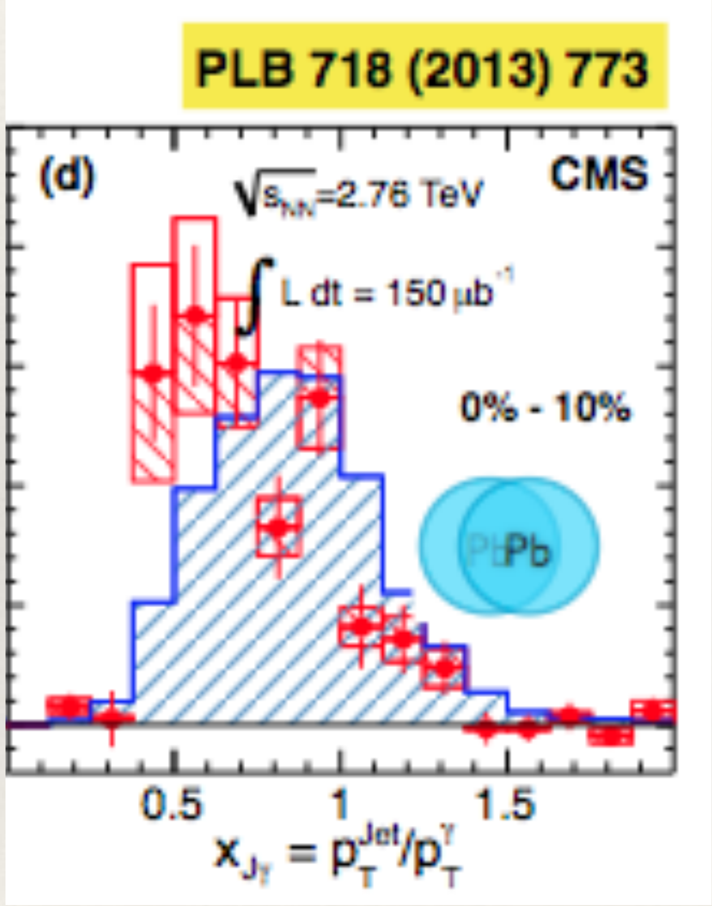


A clear centrality dependent modification of the inclusive jet fragmentation functions in PbPb collisions!

Jet-boson (γ, Z) correlation

* $E^{\gamma} = E^{jet}$ Direct measurement of total jet energy
* First measurement of γ-jet pT imbalance pT^{jet} / pT^{γ}

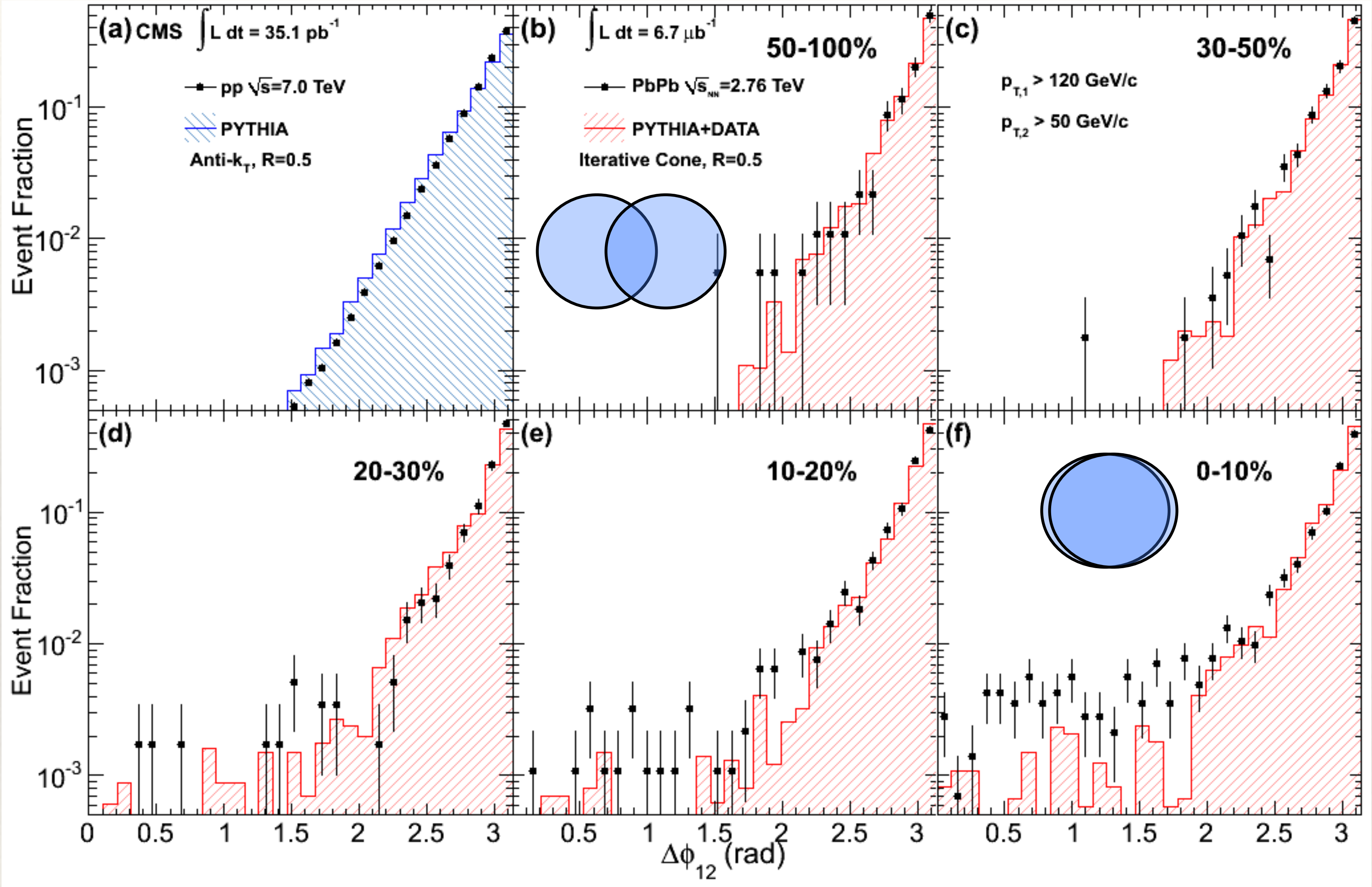




* Large imbalance observed in central collisions!
* With future LHC runs:
  * very precise measuement of medium modified fragmentation functions
  * Differential studies as a function of event geometry and shape

Di-jet azimuthal correlations

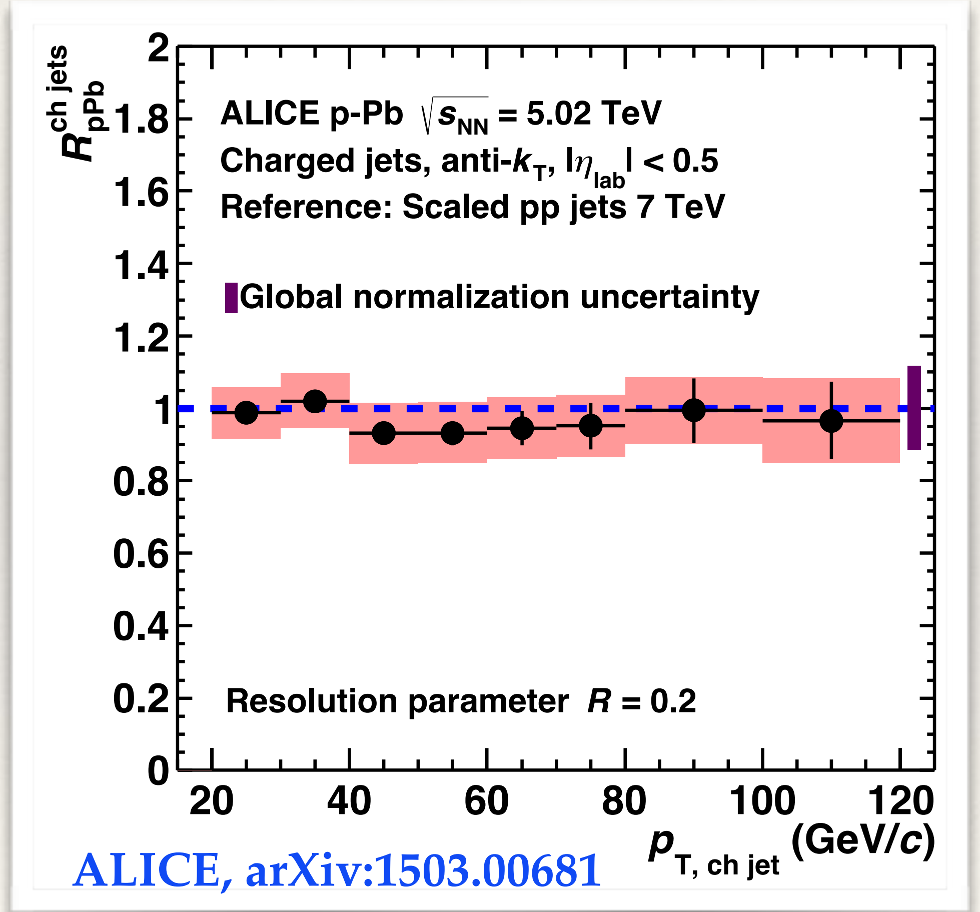
* No visible angular de-correlation in Δϕ wrt pp collisions

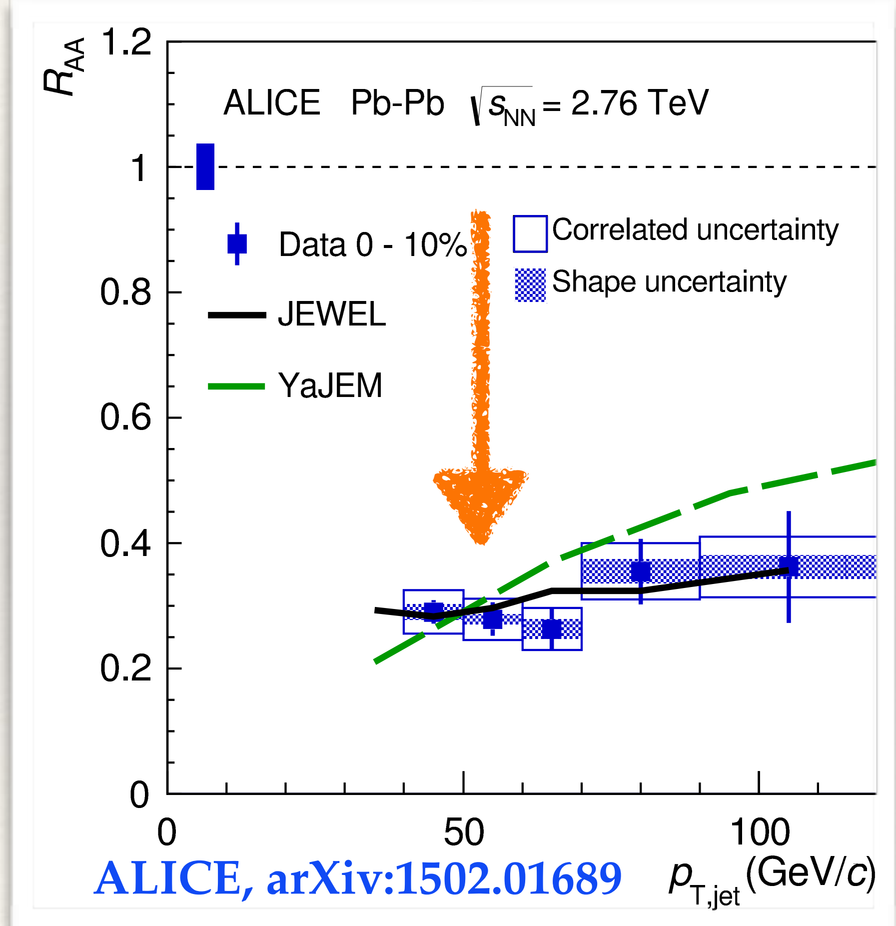


* Large imbalance on jet energy but small effect on jet direction.

Jet R_{AA}: control experiment

- Jets R_{pPb} measured by ALICE shows consistency with R_{AA} = 1
- **Jets R_{AA} suppression** measured in Pb-Pb collisions **is a medium effect**

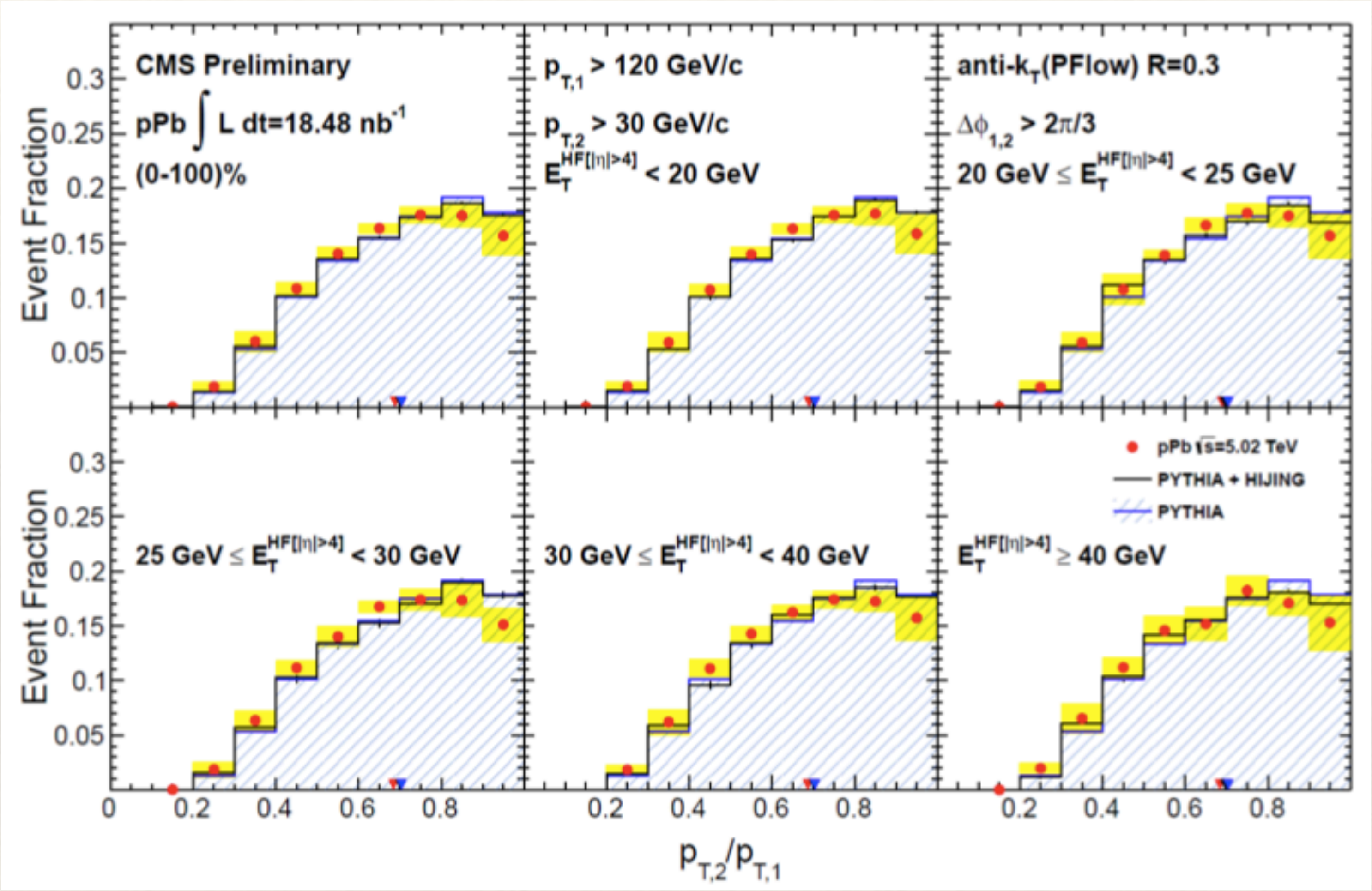




Di-jet energy imbalance: control experiment

* In p-Pb collisions no significant difference wrt pp collisions for di-jet events
* No significant imbalance for high-pT di-jets in p-Pb collisions

* **Di-jet imbalance** observed in Pb-Pb collisions **is an effect of the medium**

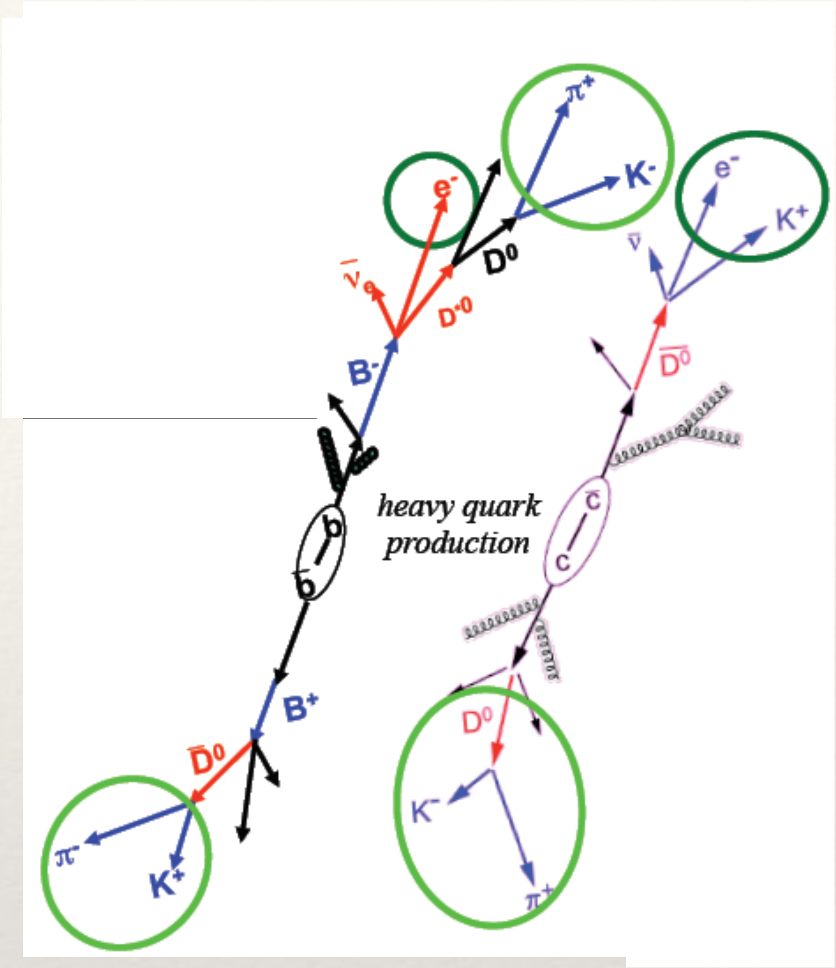


CMS, PLB712(2012) 176
CMS, PAS HIN 13-001

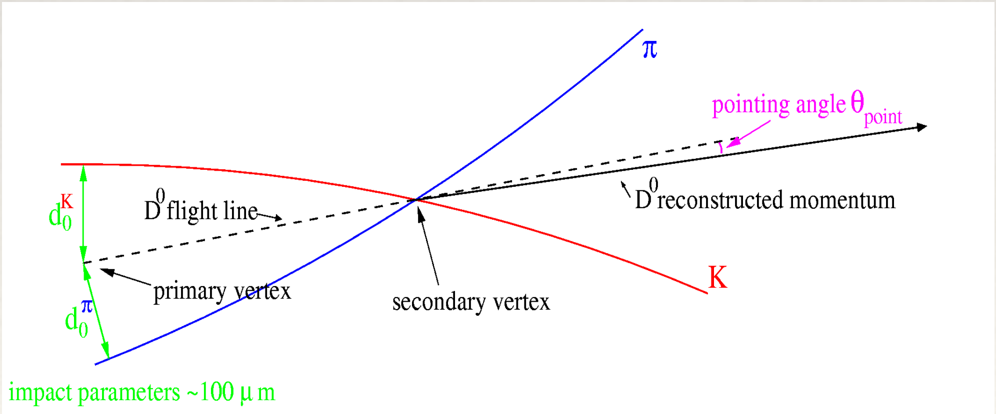
* Caveat: instead of A_j here the ratio of the two jets pT is considered

How to measure heavy quarks?

* **Leptons** (e, μ) from semileptonic decays of hadrons containing heavy quarks.
  * **Inclusive measurement** (i.e. cannot distinguish between charm and beauty decay)
  * Larger BR for those channels than exclusive reconstruction.
  * Broad correlation between leptons and hadron.

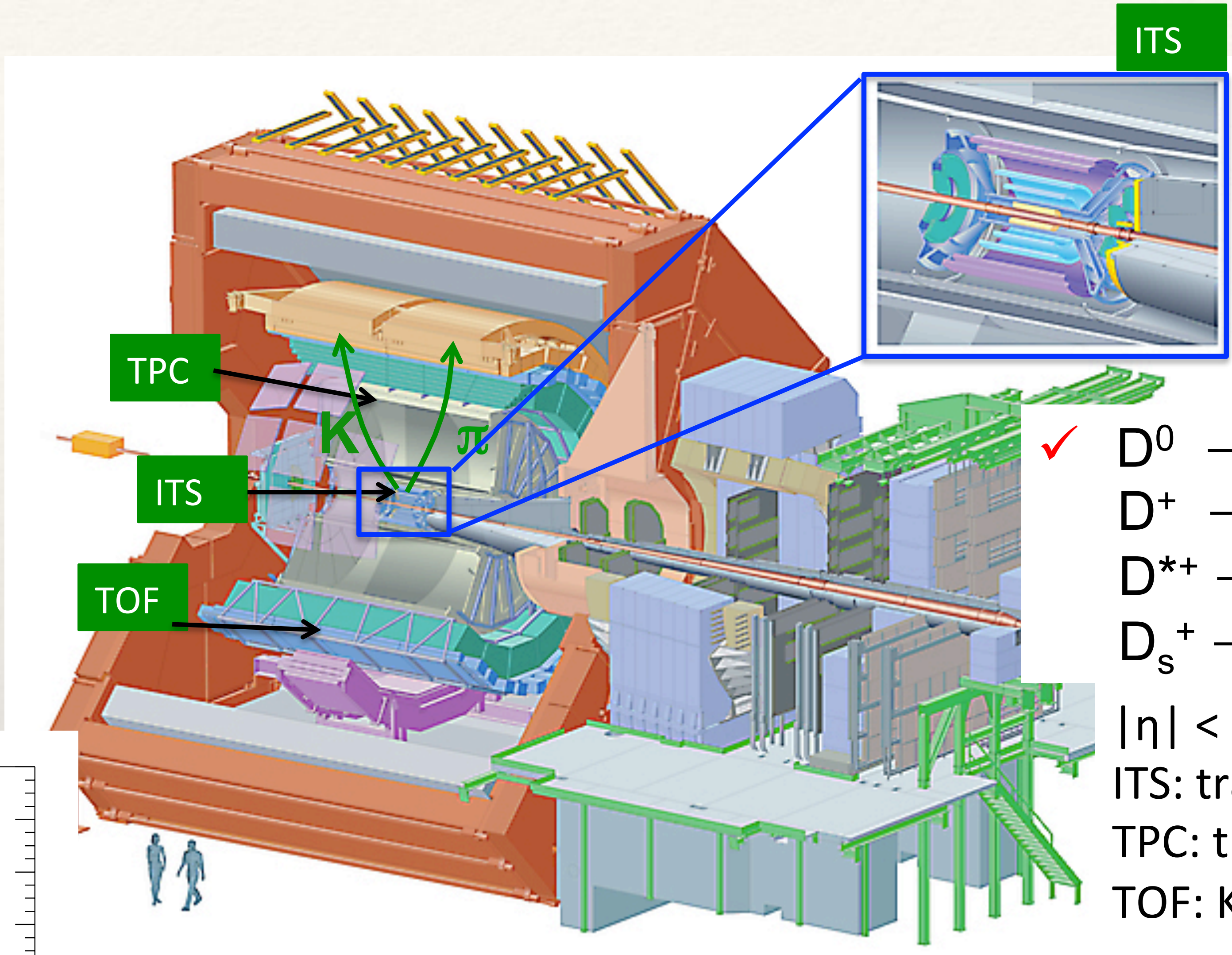


* **Fully reconstructed D mesons:**
  * **Exclusive measurement** (charm only !)
  * Secondary vertex reconstruction important to reduce the background!
    * Vertex detector !!



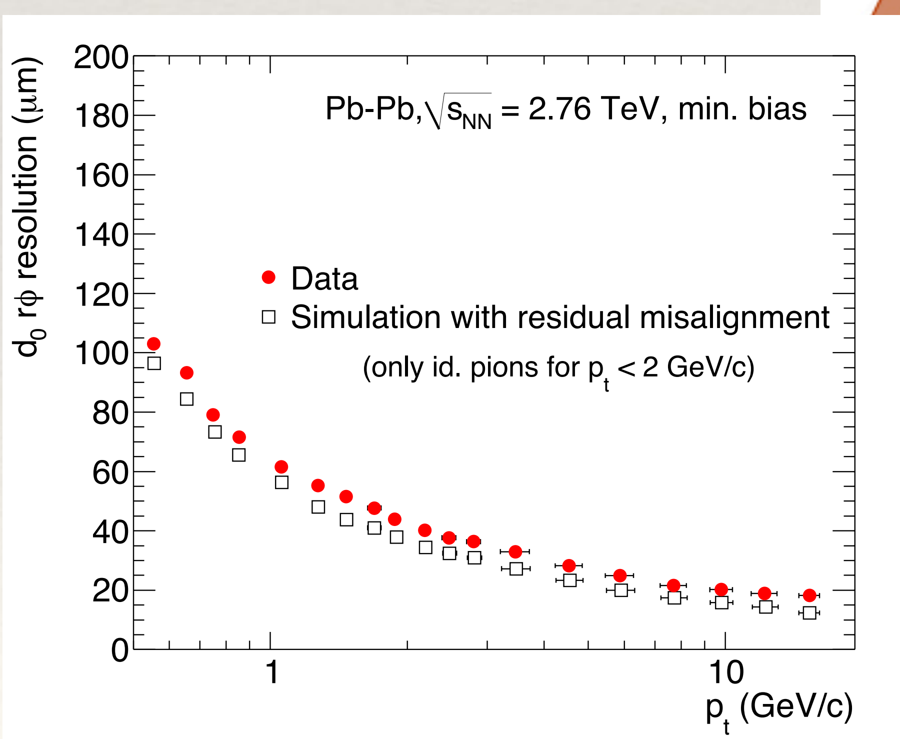
D mesons in ALICE

- Displaced vertex topology used in the reconstruction.
- Inner Tracking System with 6 Si layers: two pixels layers at 3.9 and 7 cm



✓ $D^0 \rightarrow K^- \pi^+$
$D^+ \rightarrow K^-\pi^+\pi^+$
$D^{*+} \rightarrow D^0\pi^+$
$D_s^+ \rightarrow \phi\pi^+ \rightarrow K^-K^+\pi^+$

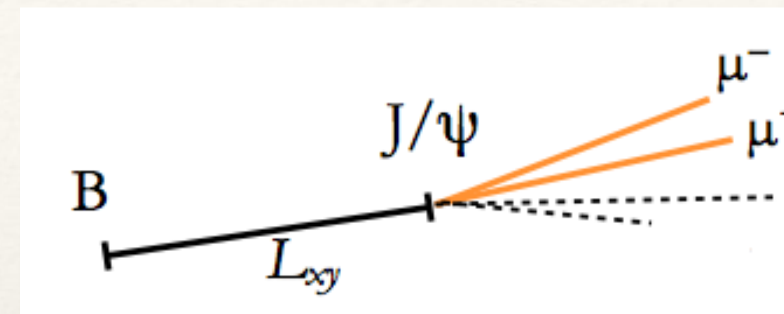
$|\eta| < 0.9$
ITS: tracking, vertexing
TPC: tracking, PID
TOF: K-ID



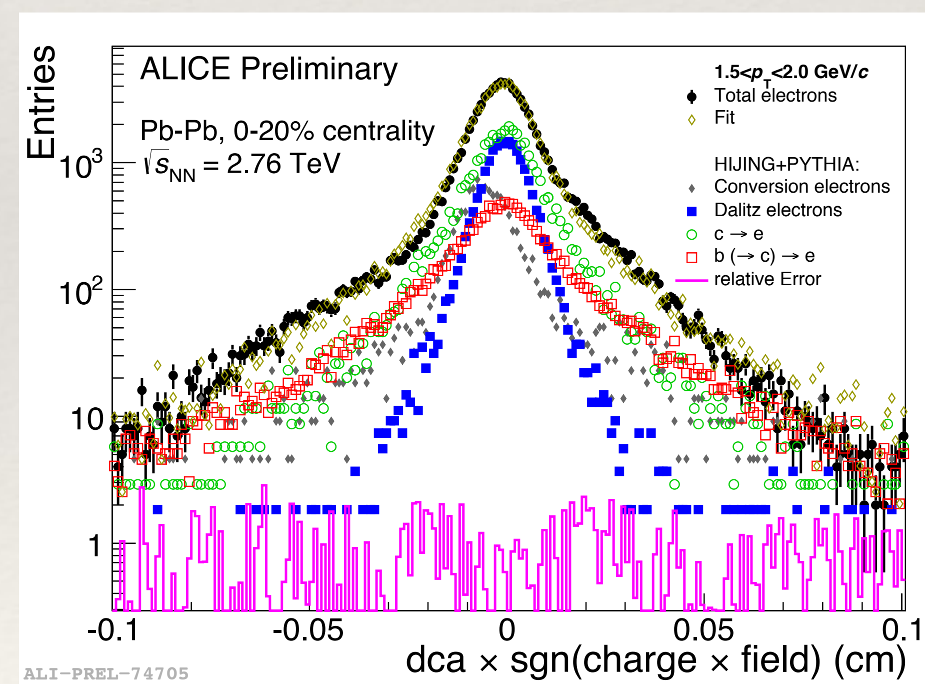
- Impact parameter resolution ~60μm for pT = 1 GeV/c

How to measure heavy quarks?

- Non-prompt J/ψ from B hadron decays.
  - First "direct" beauty measurement
  - Exploit the displacement of J/ψ of ~hundreds μm in the transverse plane.
  - Simultaneous fit of pseudo-proper decay length (L_{xy}) and invariant mass.

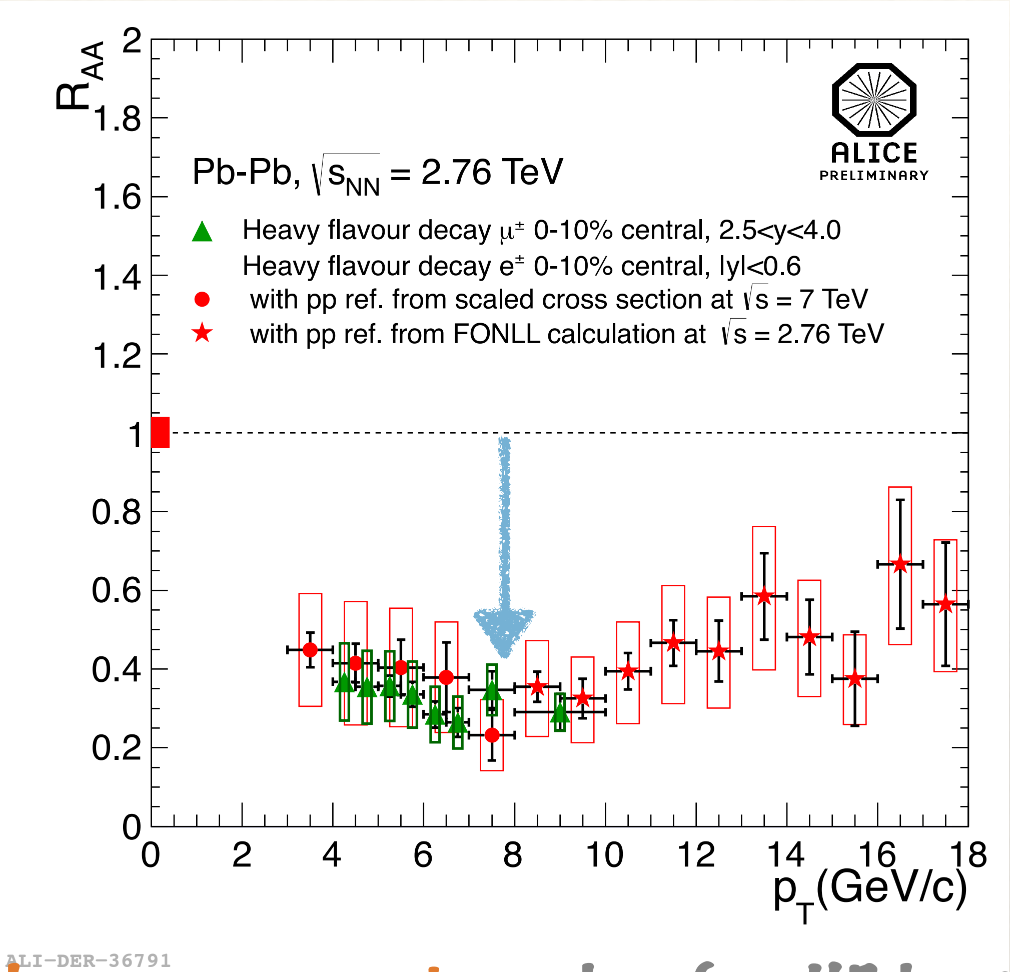


- Displaced electrons coming from B hadron decays.
  - Isolate the contribution of electrons coming for B hadrons using the larger impact parameter.
  - Fit of the different component in the impact parameter distributions.



HF electrons @ LHC

* Inclusive measurement (c+b) using electrons and muons



* Clear suppression also for HF leptons at the LHC.
  * Rise at high pT? Need more stat.

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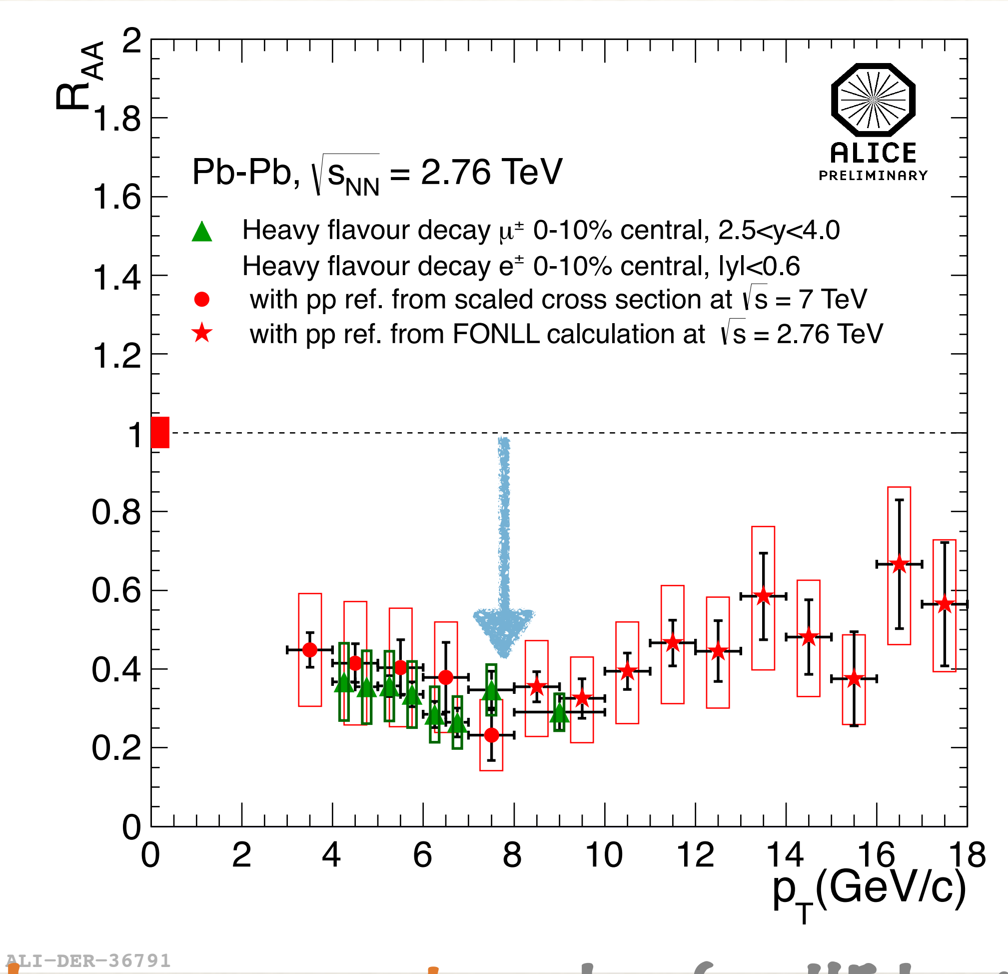
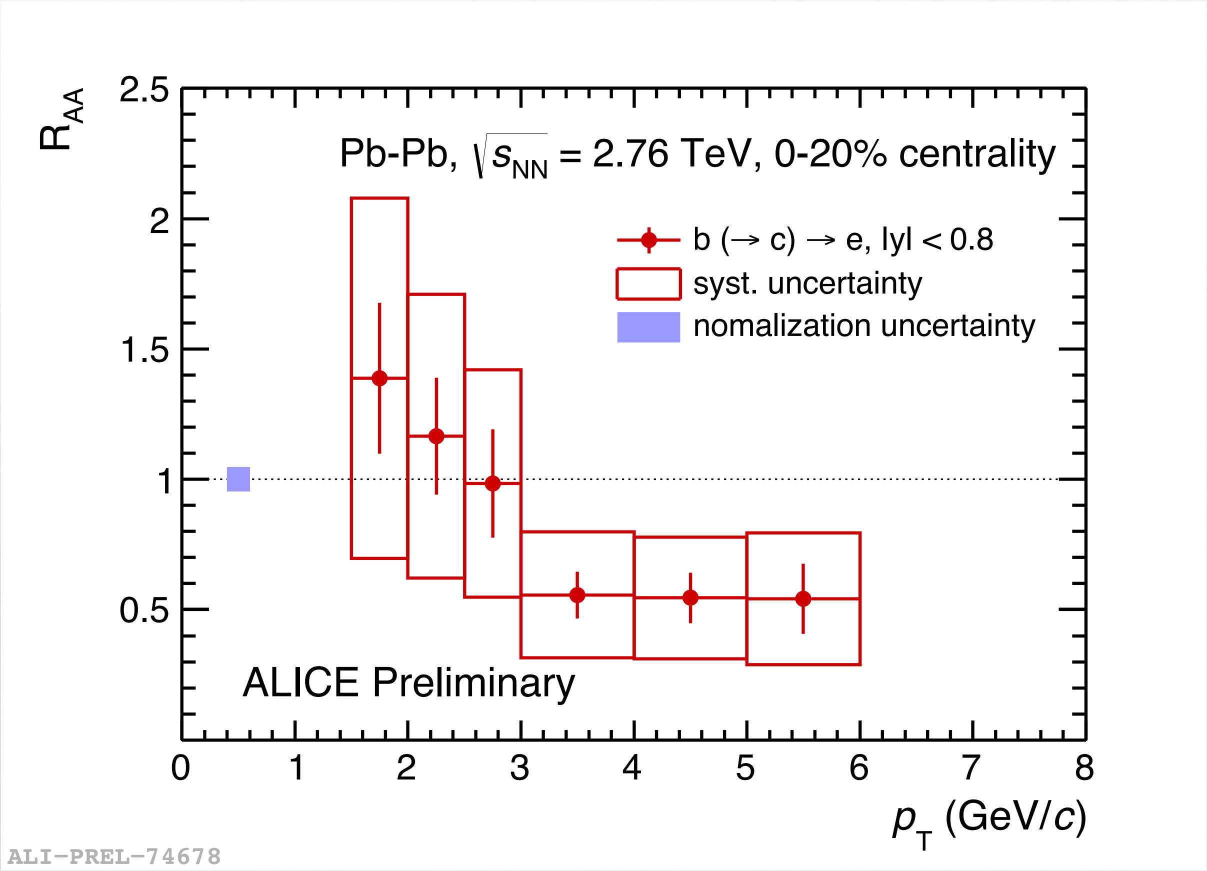


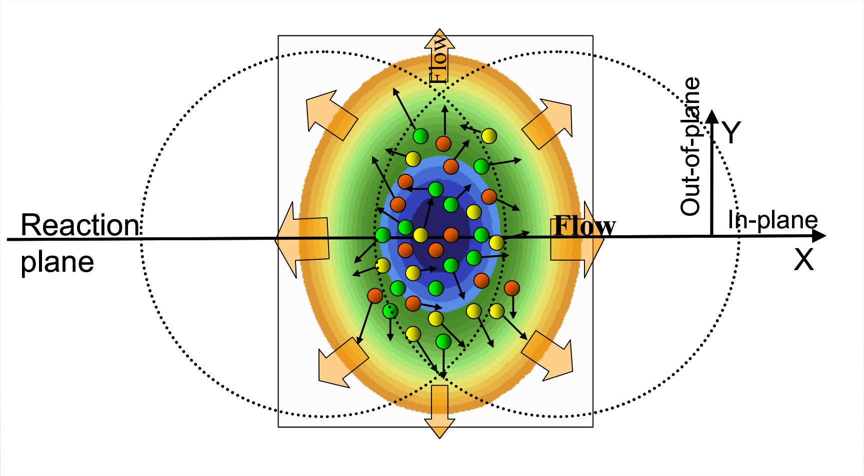


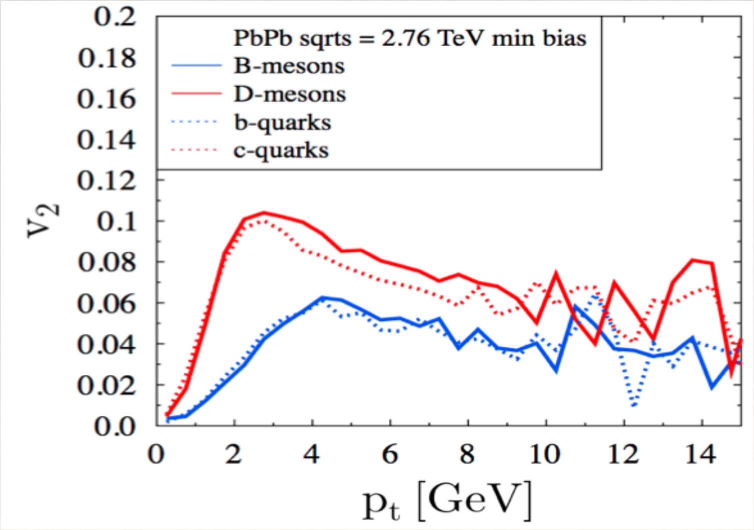
* Clear suppression also for HF leptons at the LHC.
  * Rise at high pT? Need more stat.
* Suppression also for HFe from B decays but systematics still large to conclude

Heavy flavour v_2

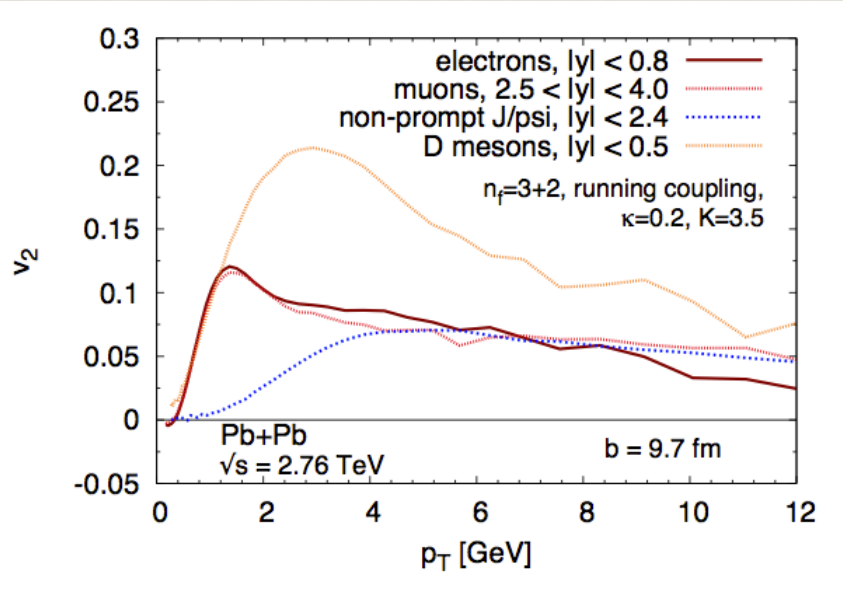
* Low-pT: do heavy quarks take part in the collectivity?
  * Due to their large mass they should "feel" less the collective expansion

* High-pT" probe the path length dependence of the heavy quarks energy loss



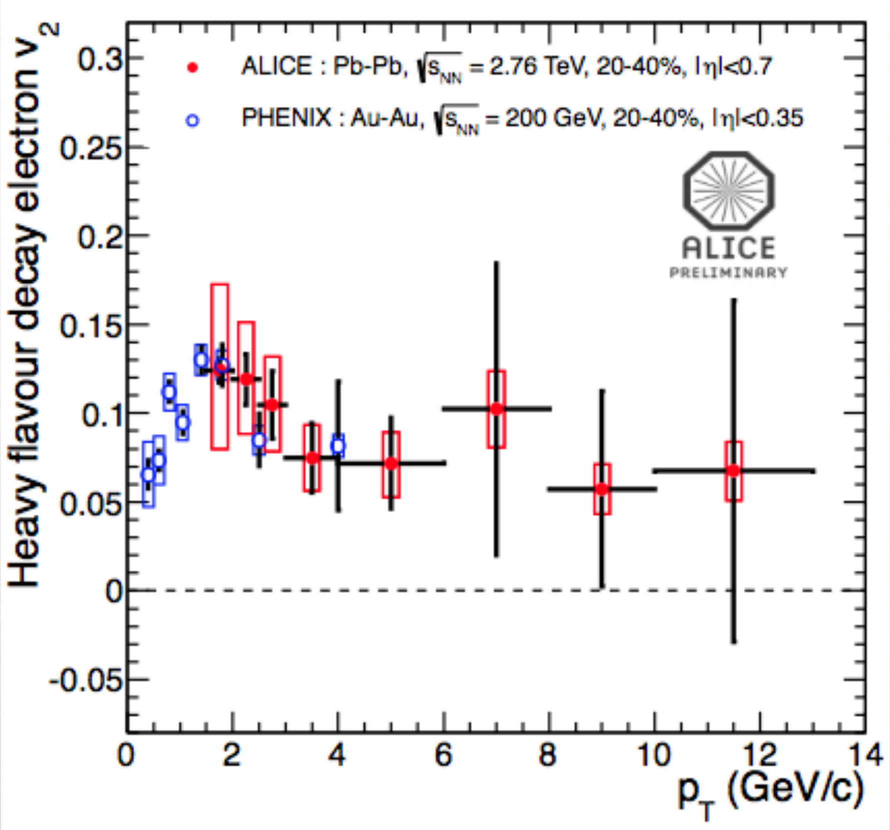


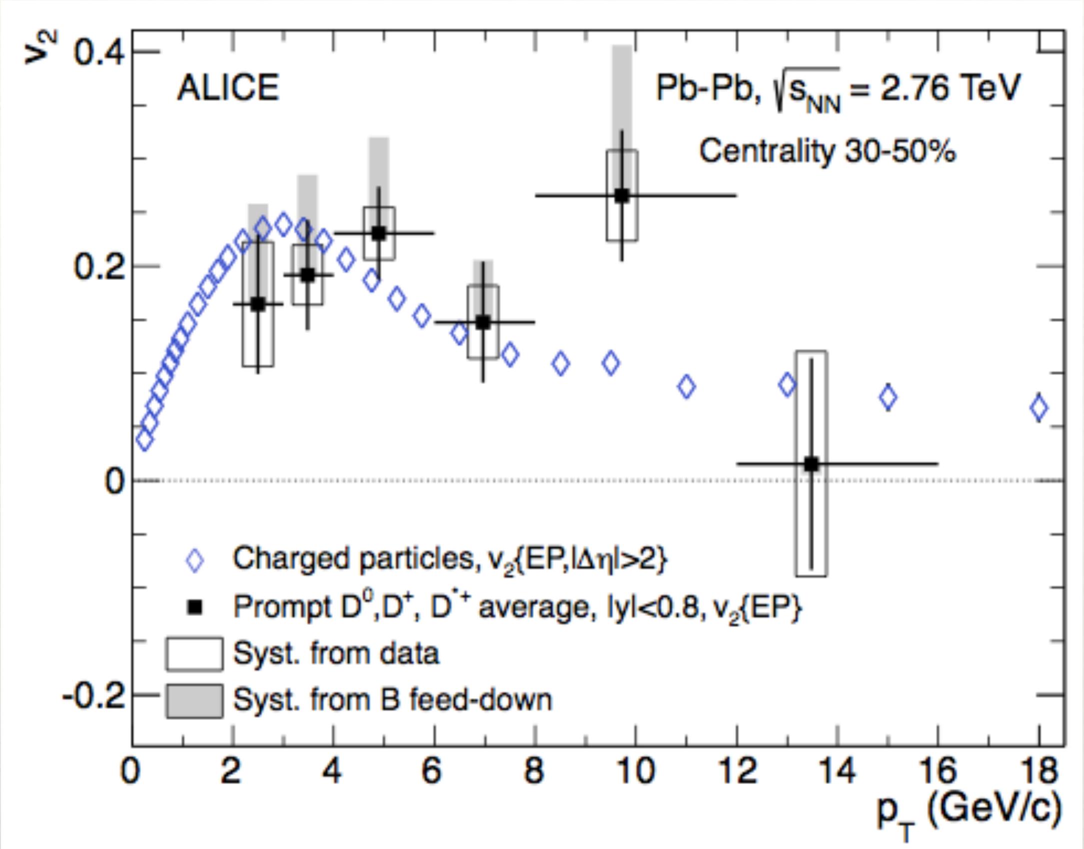
J. Aichelin et al. in arXiv:1201.4192



J. Uphoff et al. in arXiv:1205.4945

Heavy flavour v_2

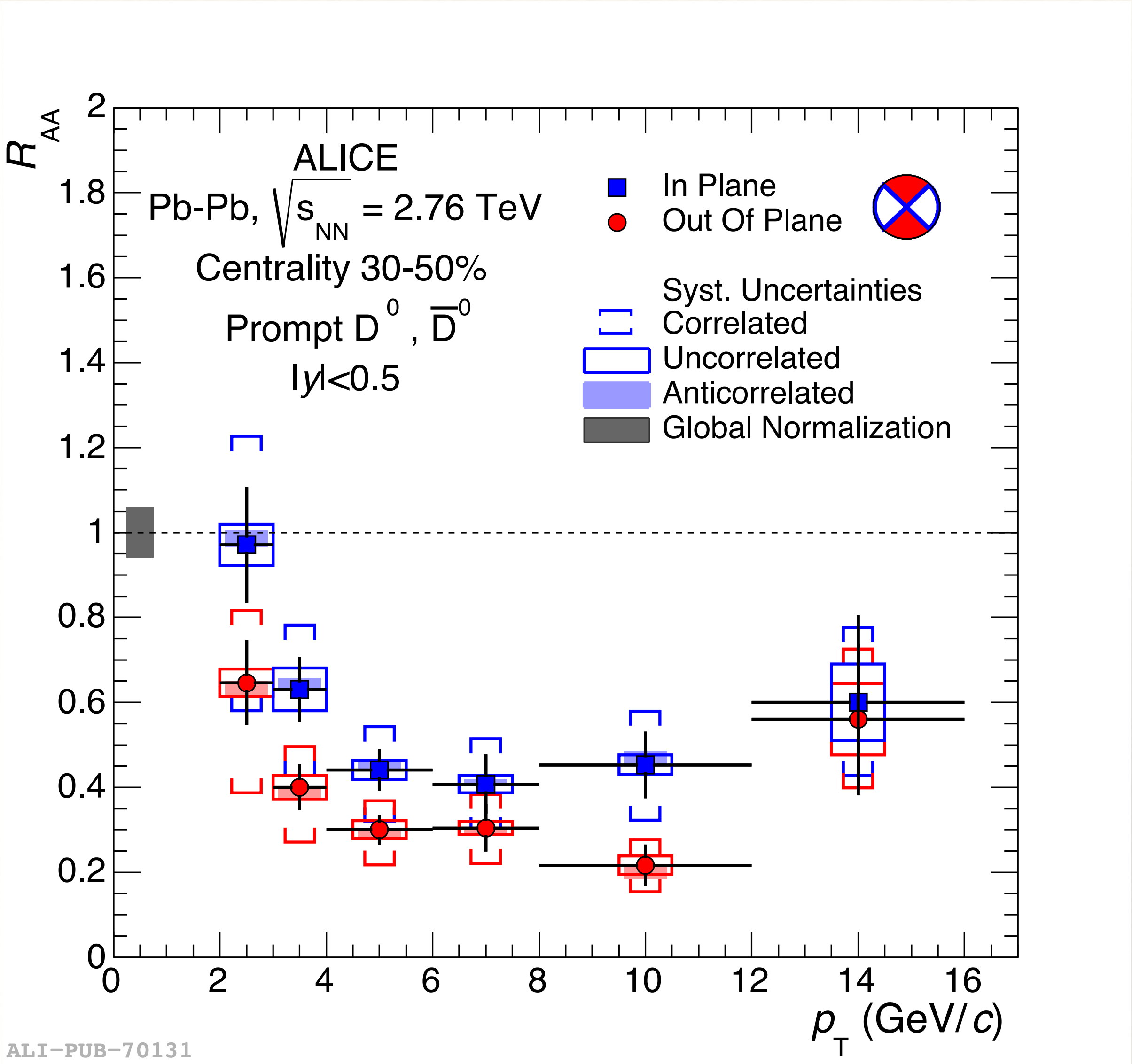


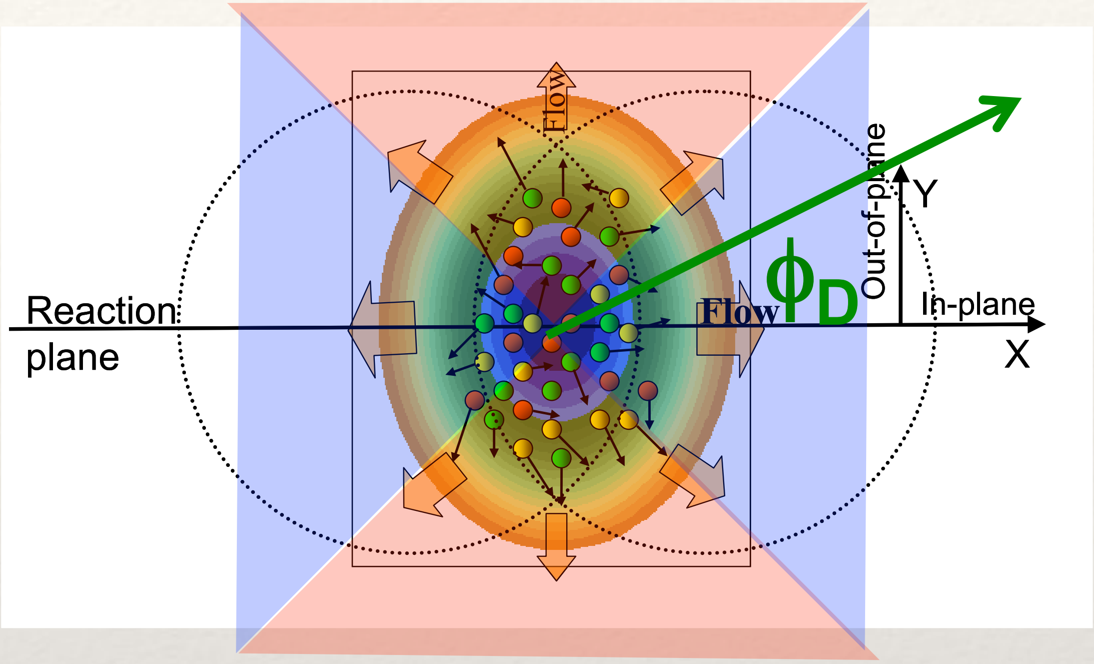


PHENIX, PRC84 (2011) 044905
Z.Conesa (ALICE), NPA 904-905 (2013) 178c

- What is the origin of this v_2 ? charm quark flow?
- Important precision measurement with future runs
- Do beauty quarks show similar pattern ?

R_{AA} vs Event Plane

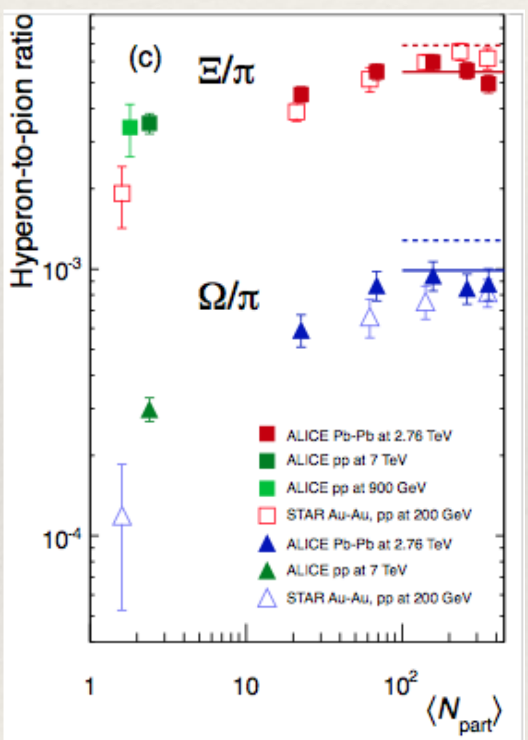




* Larger suppression if quarks has to travel in a larger "part" of matter.

Ds in PbPb collisions

- Abundance of strange quarks in the QGP (strangeness enhancement)
- Large D_s enhancement expected if c quarks recombine in the QGP (recombination/coalesence models)



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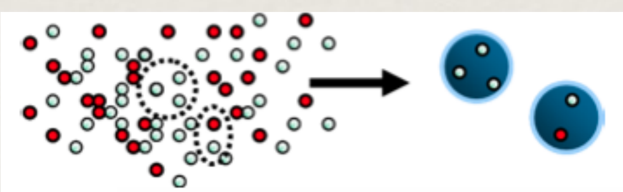

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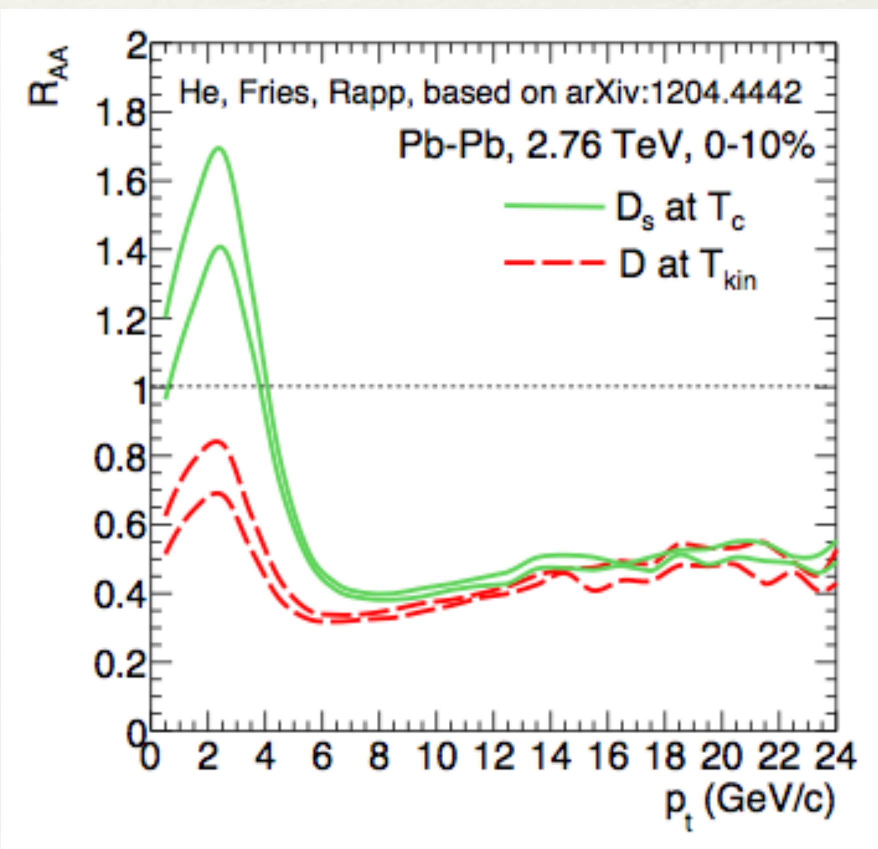
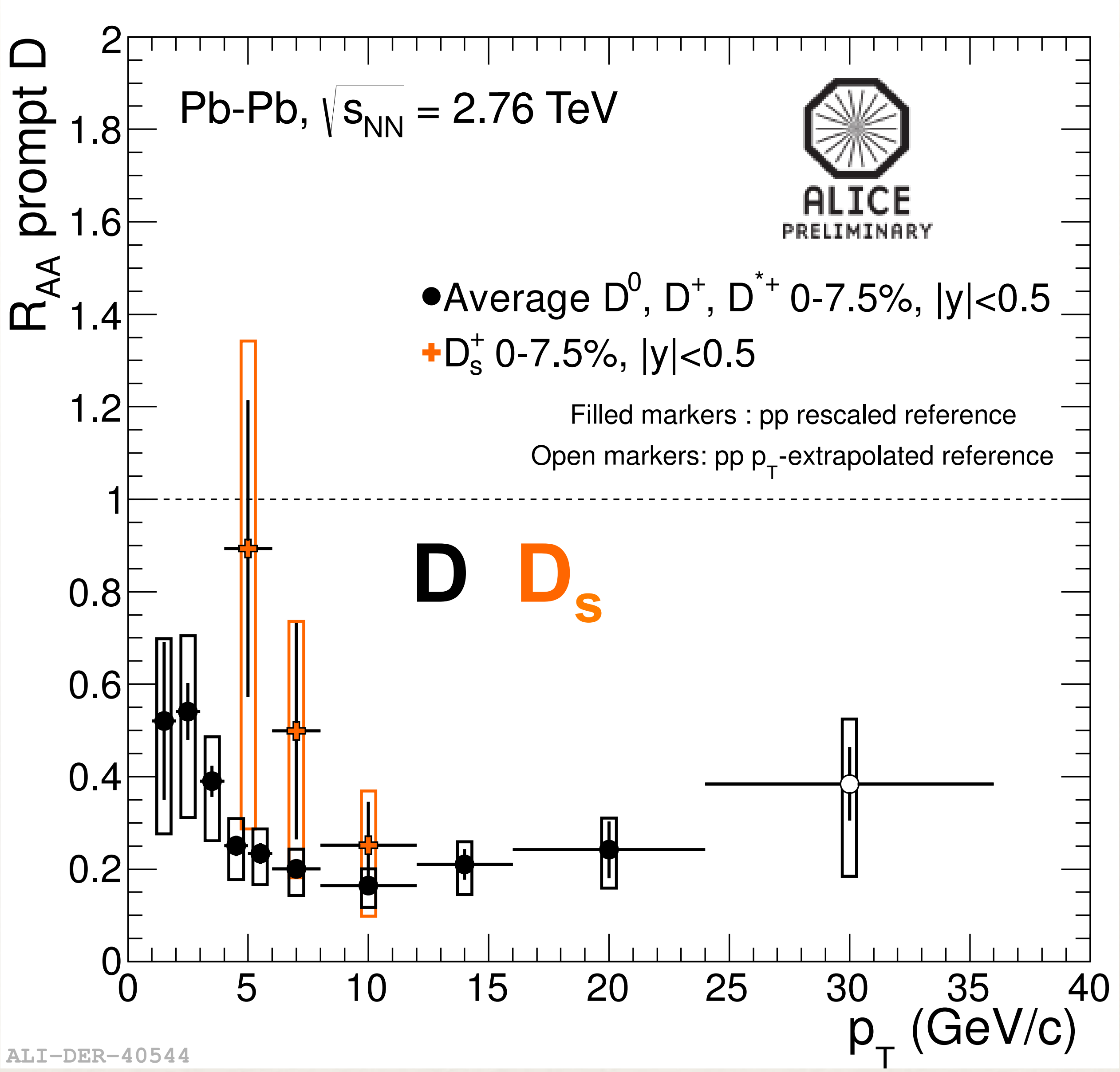


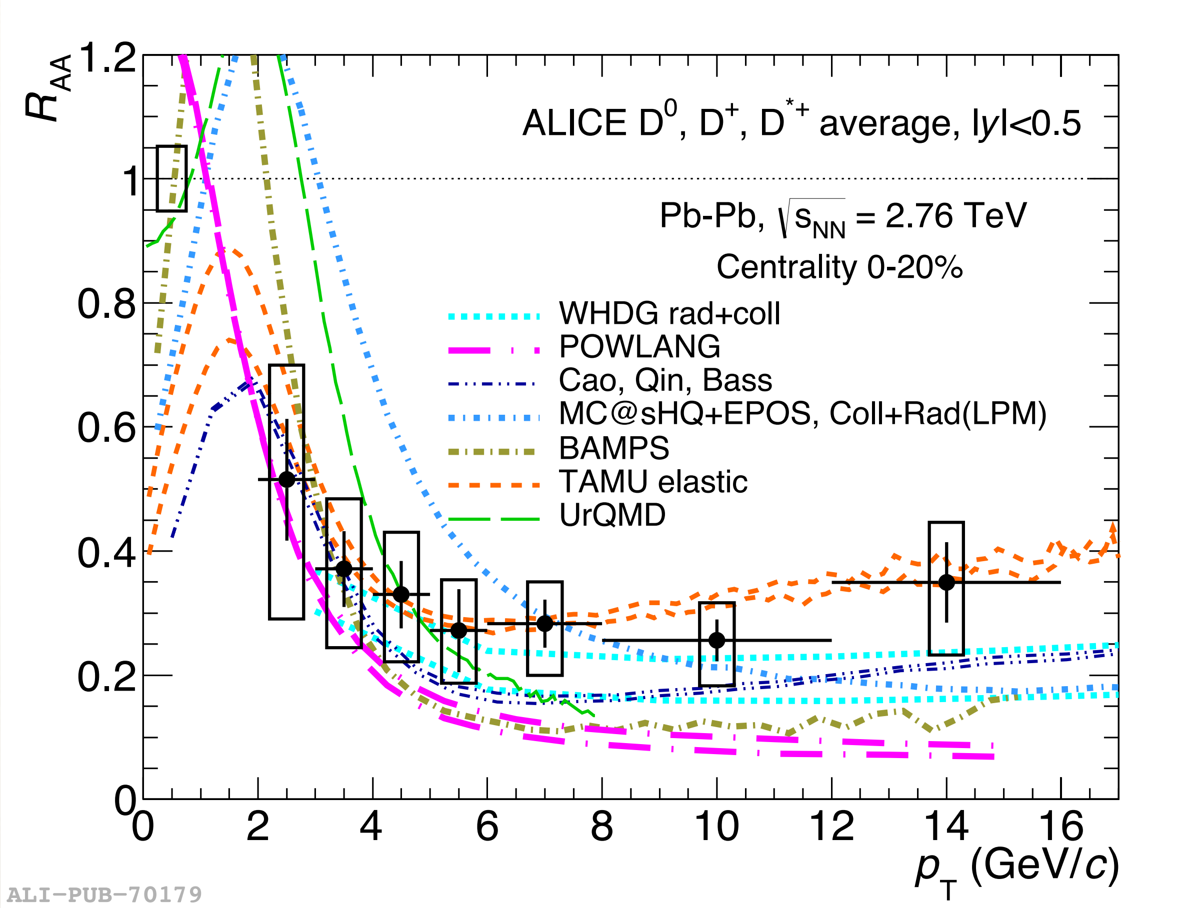
I. Kuznetsova and J. Rafelski, EPJC51, 113 (2007)
M. He et al. arXiv:1204.4442

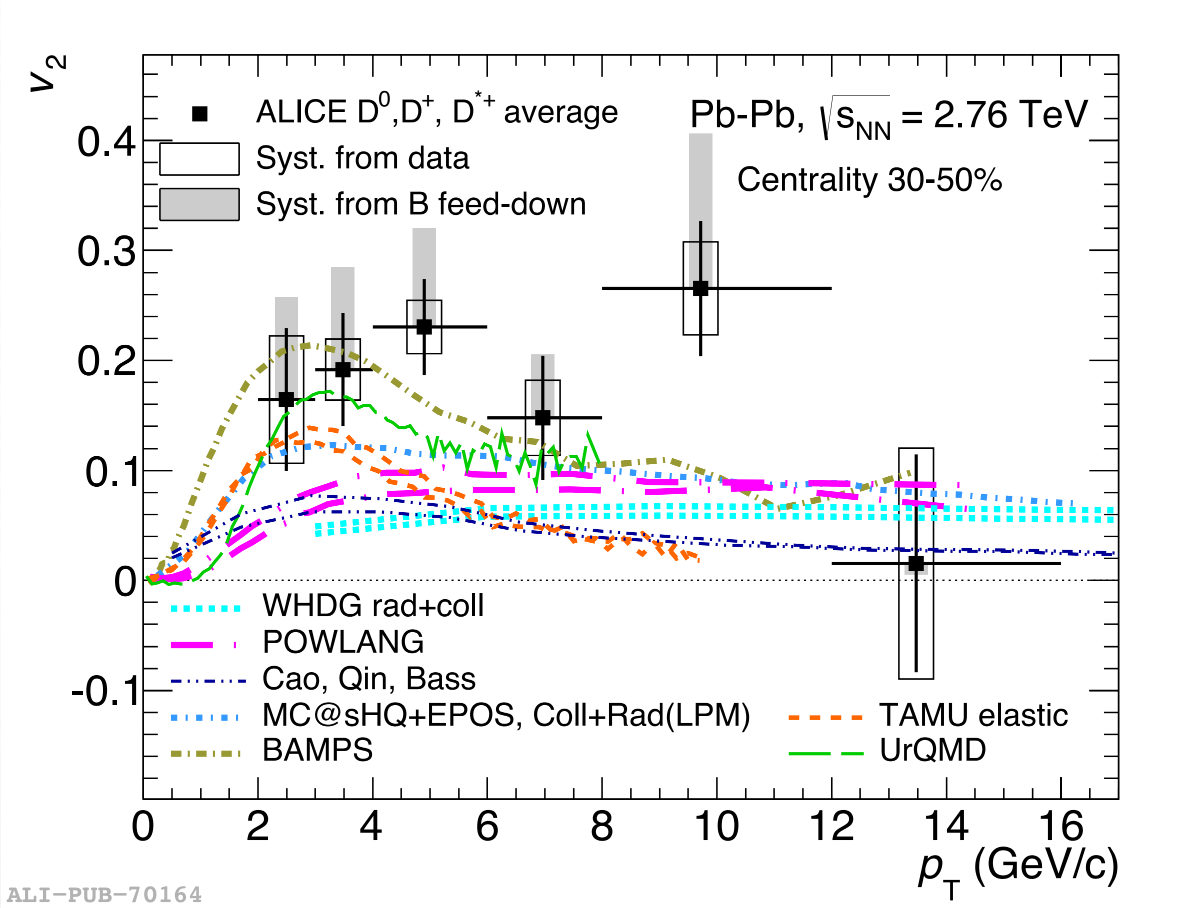
Ds in PbPb collisions

- From the experimental point of view is quite difficult to measure the Ds
  - $c\tau \sim 150\mu m$
  - very high combinatorial background

- First measurement (ALICE):
  - Ds seems to be less suppressed than other D mesons but data are not conclusive.
  - Need next LHC run!



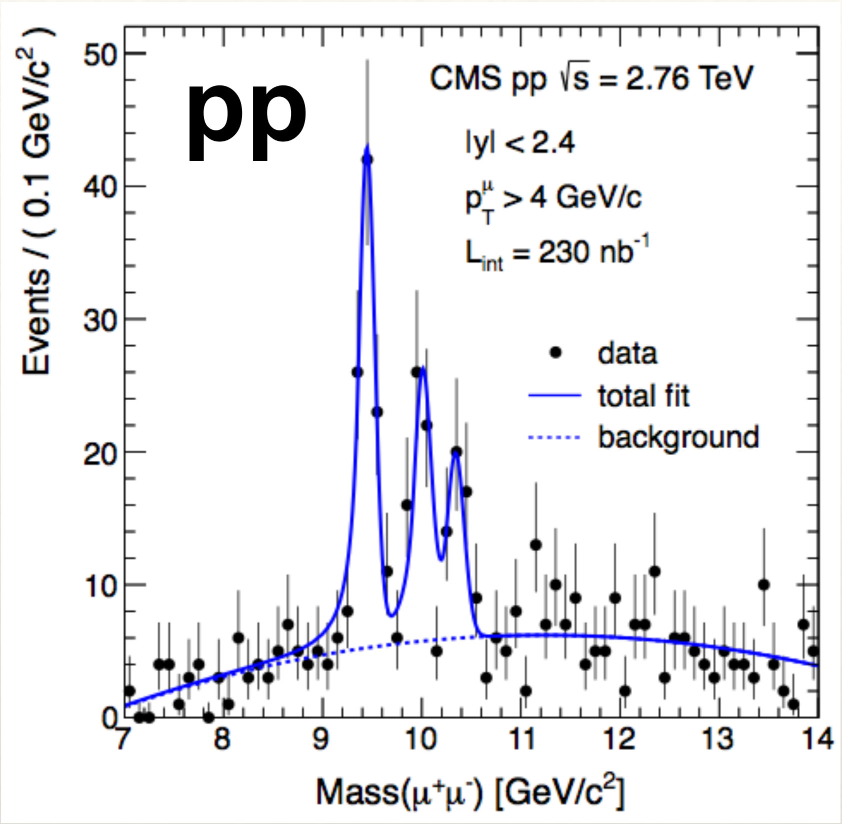




D mesons observables: models comparison

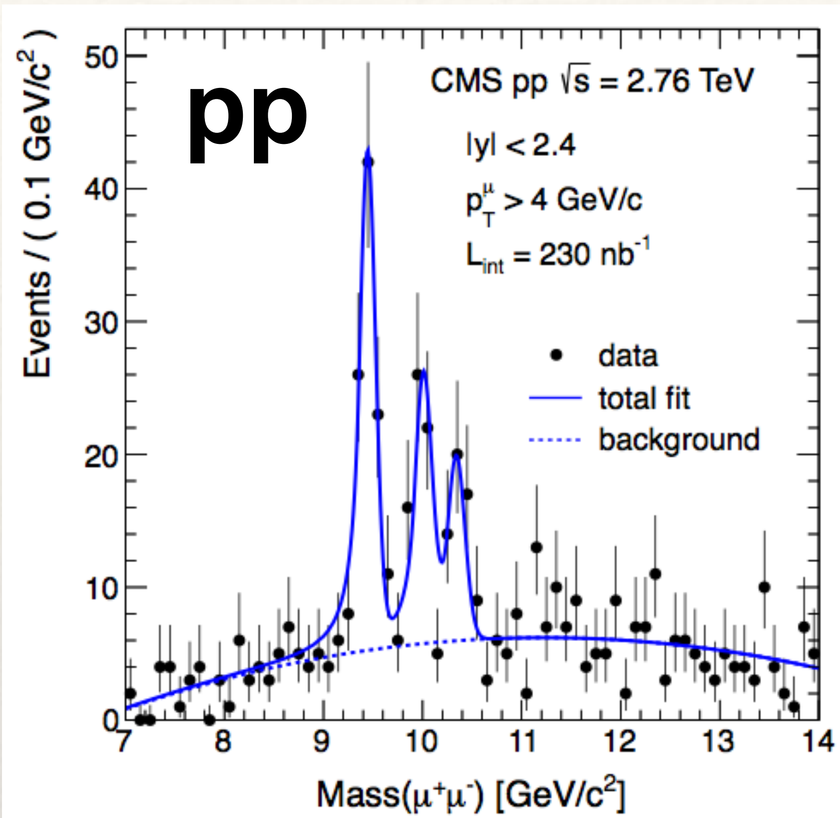
	HQ production	Medium Modeling	Heavy quarks interactions	Hadronization
WHDG (AIP Conf Proc. 1441 (2012) 889	FONLL, no shadowing	Glauber model collision geometry, no hydro evolution	radiative + collisional energy loss	fragmentation
POWLANG (J. Phys. G 38 (2011) 124144)	POWEG (NLO) + EPS09 shadowing	2+1d expanding medium with viscos hydro evolution	HQ transport (Langevin) + collisional energy loss	fragmentation
Cao, Quin, Bass (Phys Rev C 88 (2013) 044907)	LO pQCD + EPS09 shadowing	2+1d expanding medium with viscous hydro evolution	HQ transport (Langevin) + quasi elastic scattering + radiative energy loss	recombination + fragmentation
MC@sHQ+EPOS2 (Phys Rev C 89 (2014) 014905)	FONLL, no shadowing	3+1d fluid dynamical expansion (EPOS)	HQ transport (Boltzmann) + radiative + collisional energy loss.	recombination + fragmentation
BAMPS (Phys Lett B 717 (2012) 430)	MC@NLO, no shadowing	3+1d fully dynamic parton transport model	HQ transport (Boltzmann) + collisional energy loss	fragmentation
TAMU elastic (arXiv:1401.3817)	FONLL + EPS09 shadowing	transport + 3+1d ideal hydro evolution	HQ transport (Langevin) + collisional energy loss + diffusion in hadronic phase	recombination + fragmentation
UrQMD (arXiv:1211.6912)	PYTHIA, no shadowing	3+1d ideal hydro evolution	HQ transport (Langevin) + collisional energy loss	recombination + fragmentation

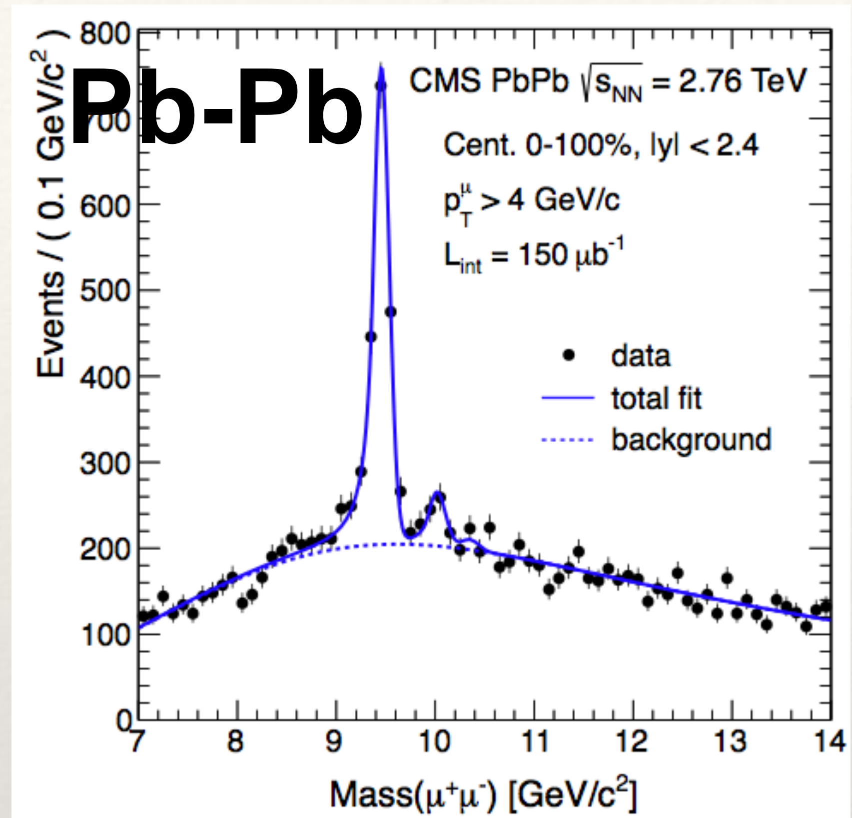
Bottomonia at LHC



- Very good muon reconstruction and momentum resolution to allow Υ states discrimination.

Bottomonia at LHC





$$\frac{\Upsilon(1S)_{AA}}{N_{bin}\Upsilon(1S)_{pp}} = 0.56 \pm 0.08 \pm 0.07$$

$$\frac{\Upsilon(2S)_{AA}}{N_{bin}\Upsilon(2S)_{pp}} = 0.12 \pm 0.04 \pm 0.02$$

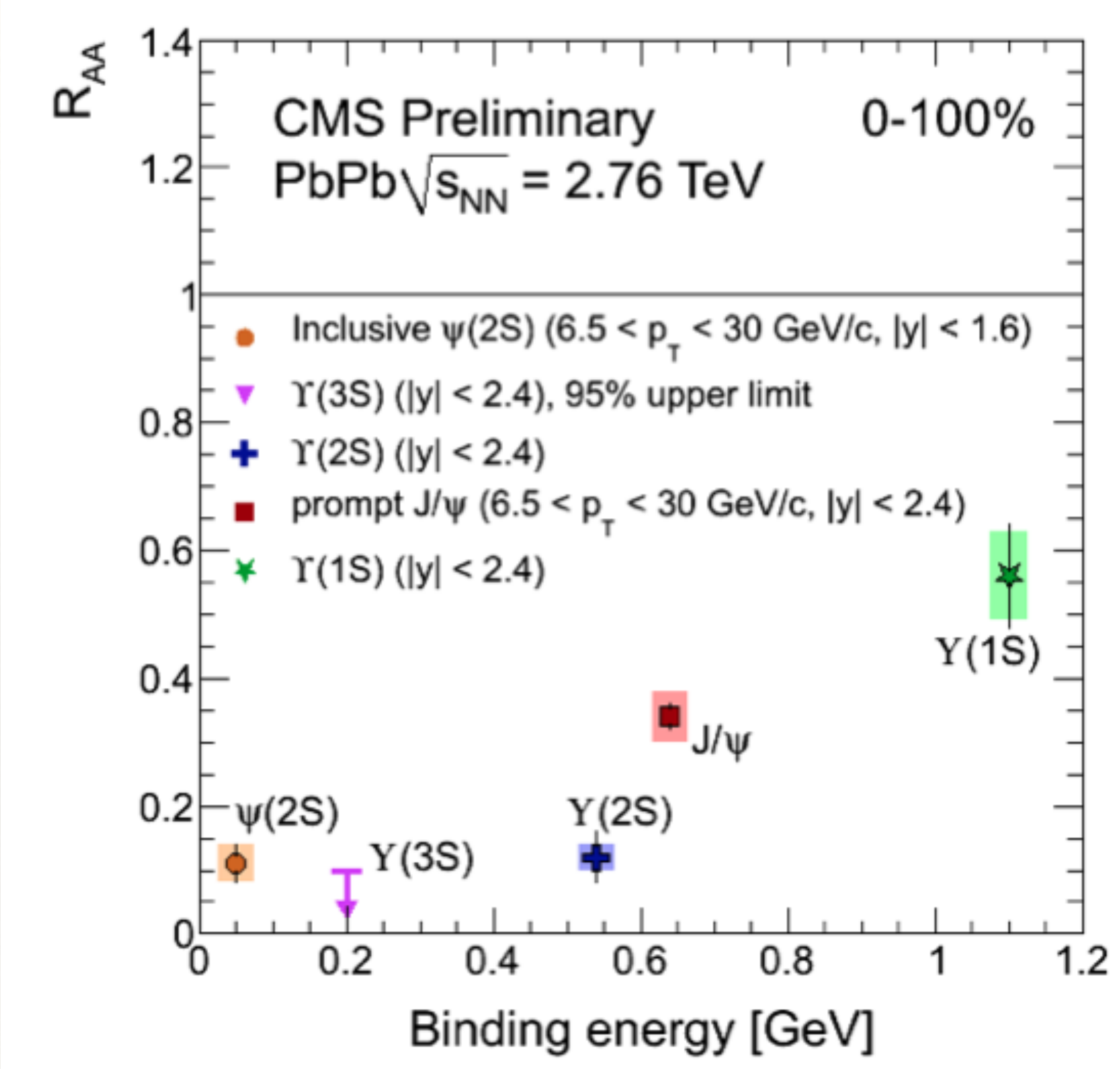
$$\frac{\Upsilon(3S)_{AA}}{N_{bin}\Upsilon(3S)_{pp}} < 0.1(95\%)$$

- Very good muon reconstruction and momentum resolution to allow Υ states discrimination, in both pp and PbPb collisions.
- Clear suppression of the excited Υ states that are less bounded than the Υ(1S) one.

CMS, arXiv:1208.2826 and PRL 109 (2012) 222301

-onia suppression at LHC

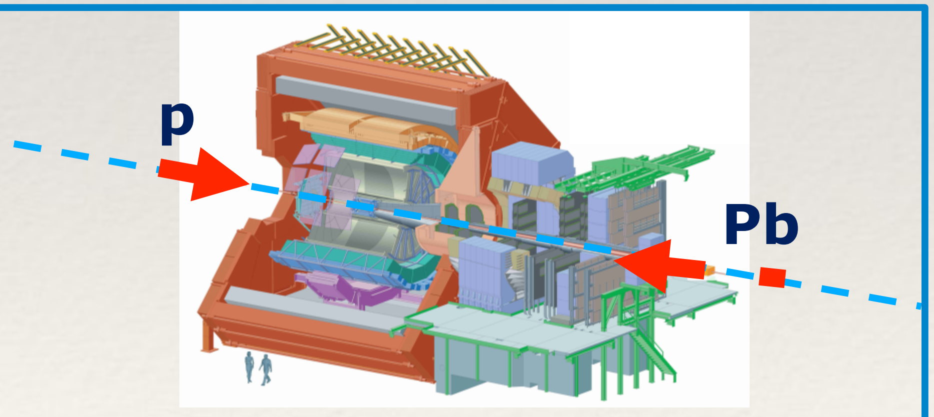
* Putting all quarkonia results together from the CMS experiment:
  * Excited states are always more suppressed than the ground state.
  * Is really binding energy driving the quarkonia suppression?
  * Important caveats:
    * centrality and pT ranges
    * regenerations
    * initial state effects (pA!!)



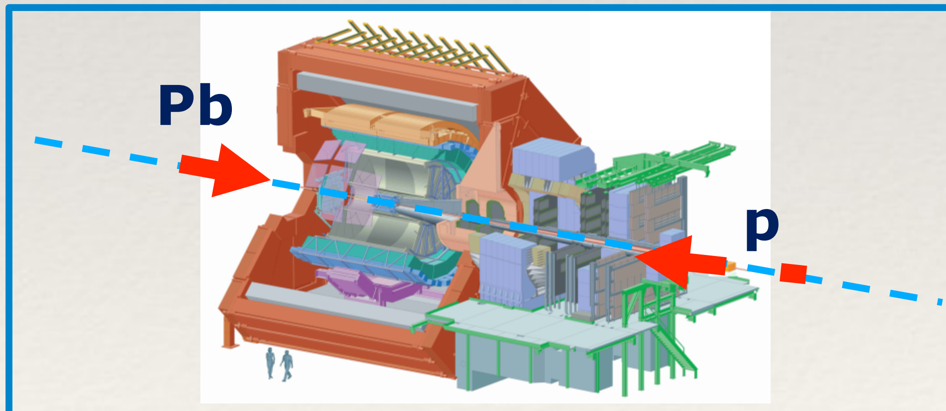
J/ψ in pA collisions

* J/ψ production in pA collisions measured by the ALICE and LHCb detectors.
  * Both of them are "asymmetric" detector for what concerns J/ψ reconstruction.

* Data collected in two configurations:
  * p-Pb:
    * p going through the muon arm (forward direction)
    * x investigated:
  * Pb-p:
    * Pb going though the muon arm (backward direction)
    * x investigated:



$2.03<y_{CMS}<3.53$

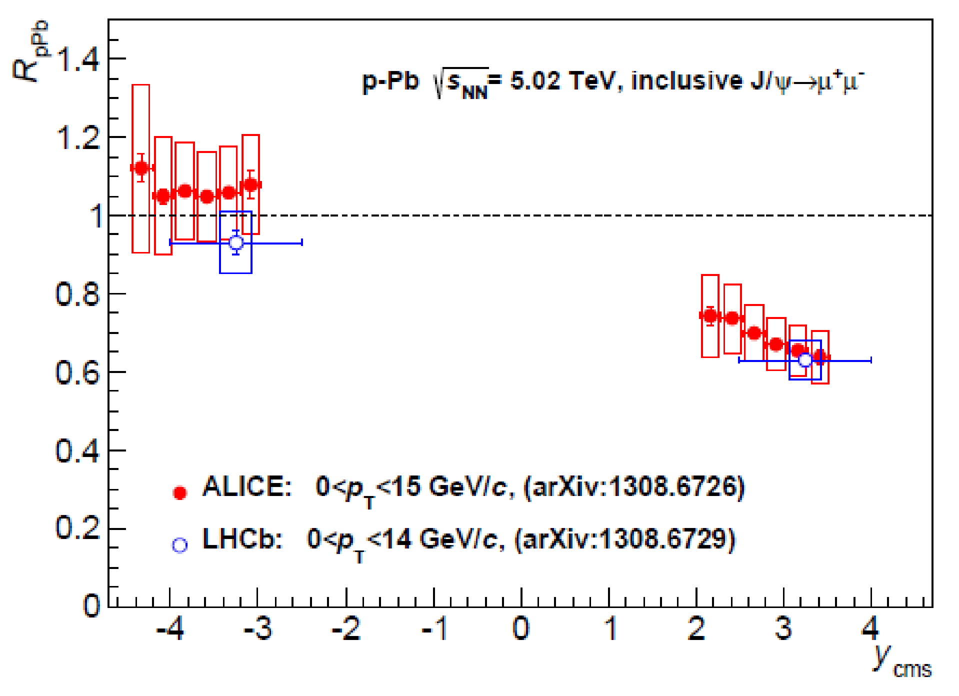


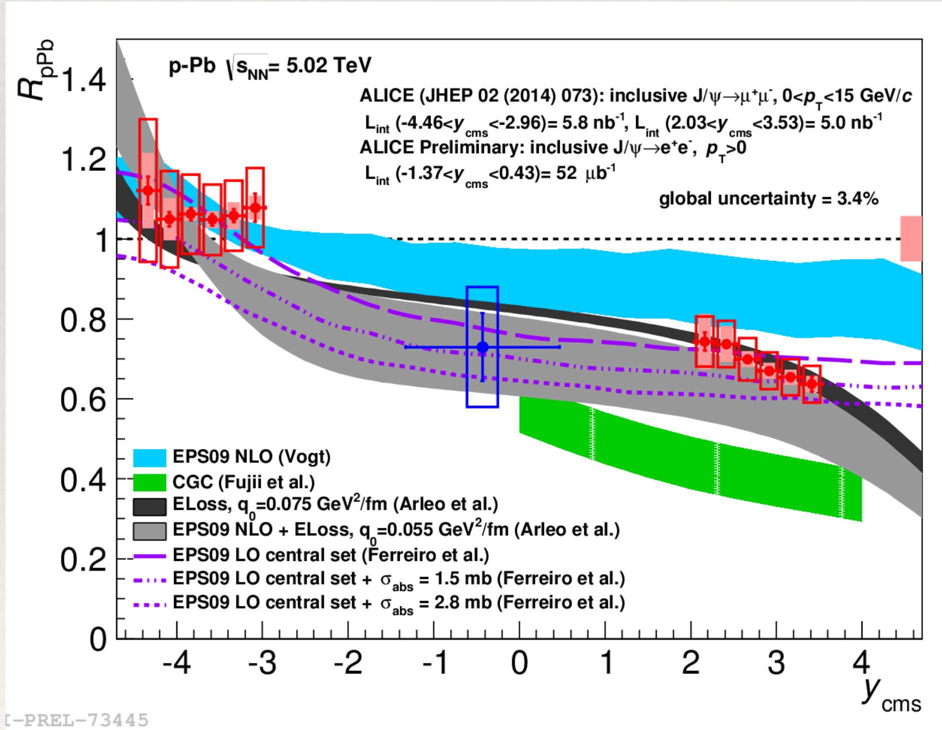
$-4.46<y_{CMS}<-2.96$

J/ψ in pA collisions

- Differently from open HF, J/ψ production is sensitive to cold nuclear matter effects:
  - at forward rapidity the J/ψ production is suppressed by about 20%
  - models including shadowing and coherent energy loss

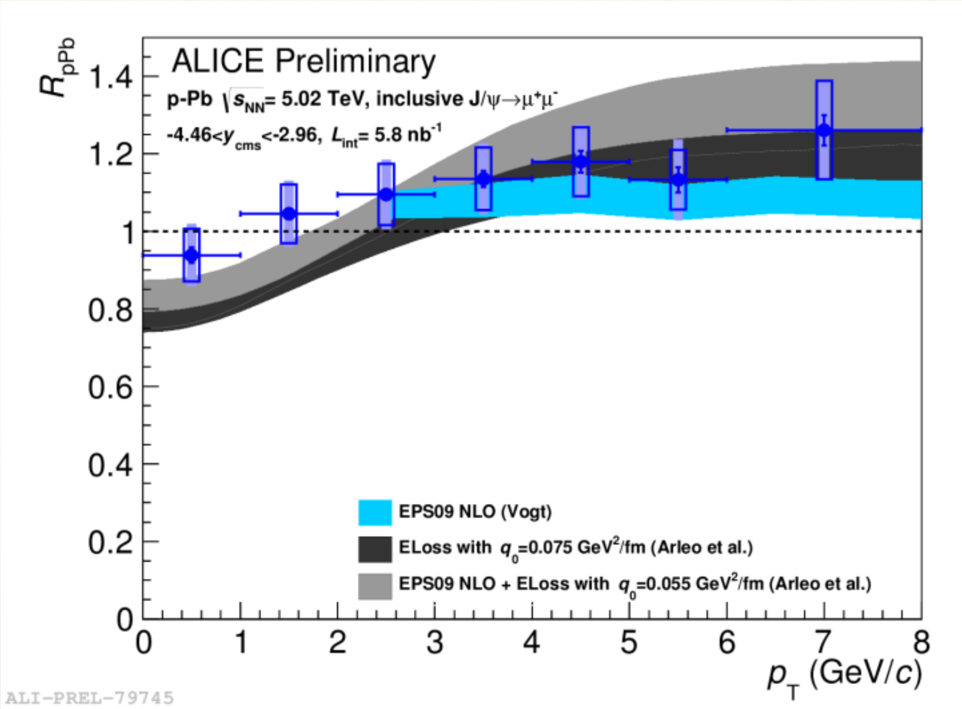
arXiv:1308.6726

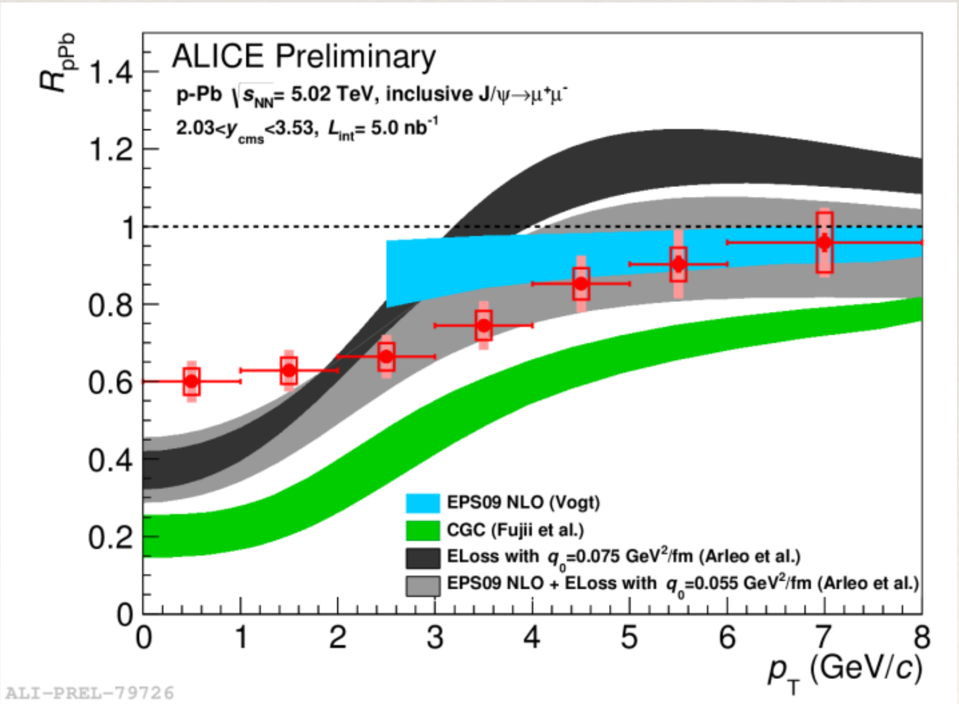




J/ψ in pA collisions

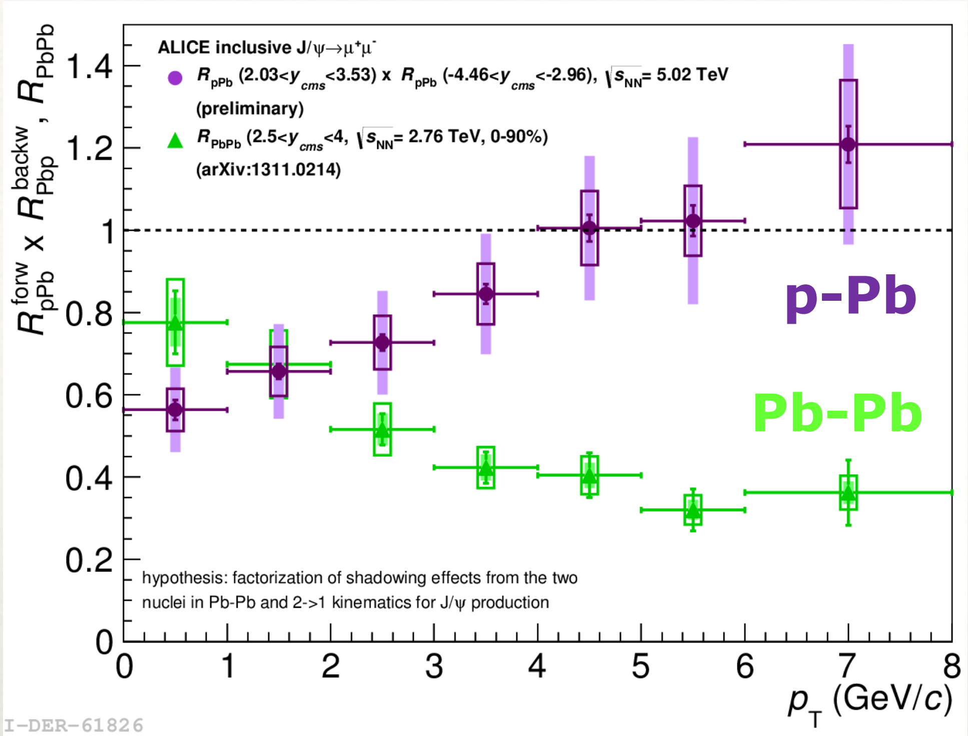
* Differently from open HF, J/ψ production is sensitive to cold nuclear matter effects:
  * at forward rapidity the J/ψ production is suppressed by about 20%
  * models including shadowing and coherent energy loss
  * at forward rapidity the suppression seems to be driven by low-pT J/ψ
  * at backward rapidity the slight enhancement seems to be driven by high-pT J/ψ

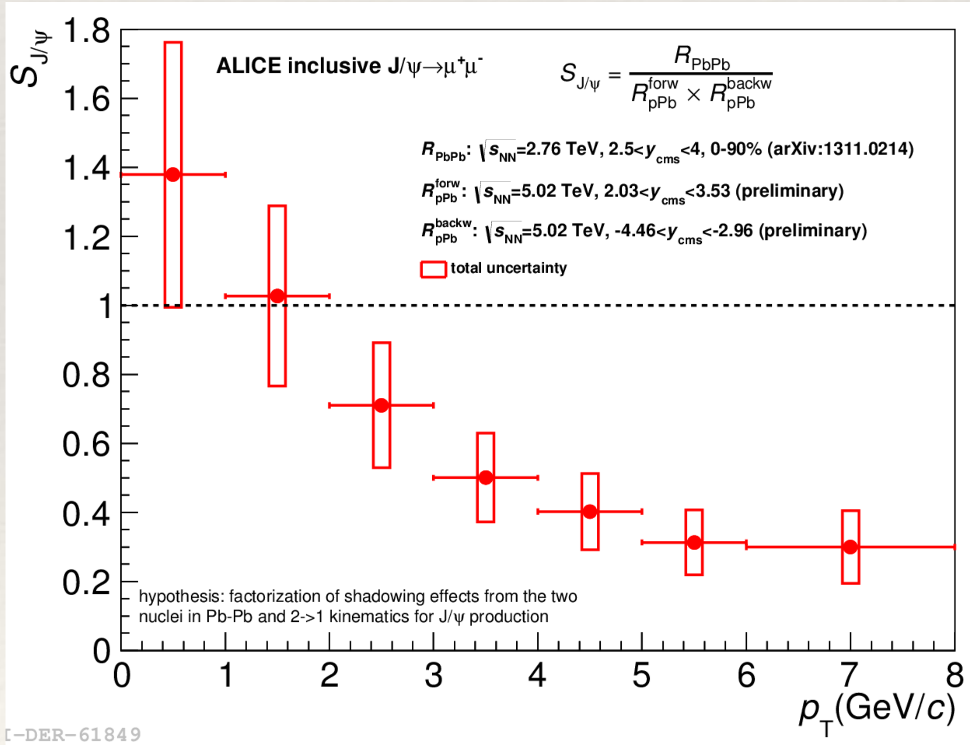




When we consider all data together…

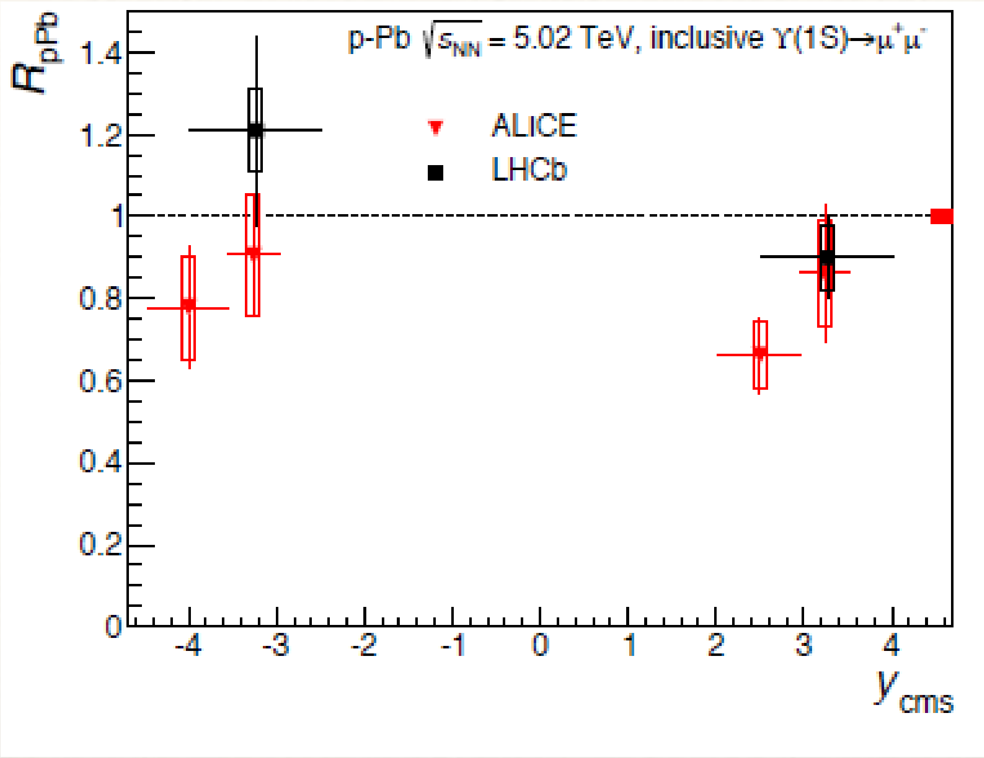
- Evaluate CNM effects with pA data:
  - 2 → 1 kinematics for J/ψ production
  - CNM effects factorize in pA
  - CNM evaluated as $R_{pA} \times R_{Ap}$ since the x coverage is similar as PbPb
- CNM effects don't explain the suppression observed at high-pT, that it is then coming from hot medium effects.
- Clear pT trend observed when considering the ratio of the R_{AA} in the two collisions system:
  - suppression at high-pT
  - enhancement at low-pT

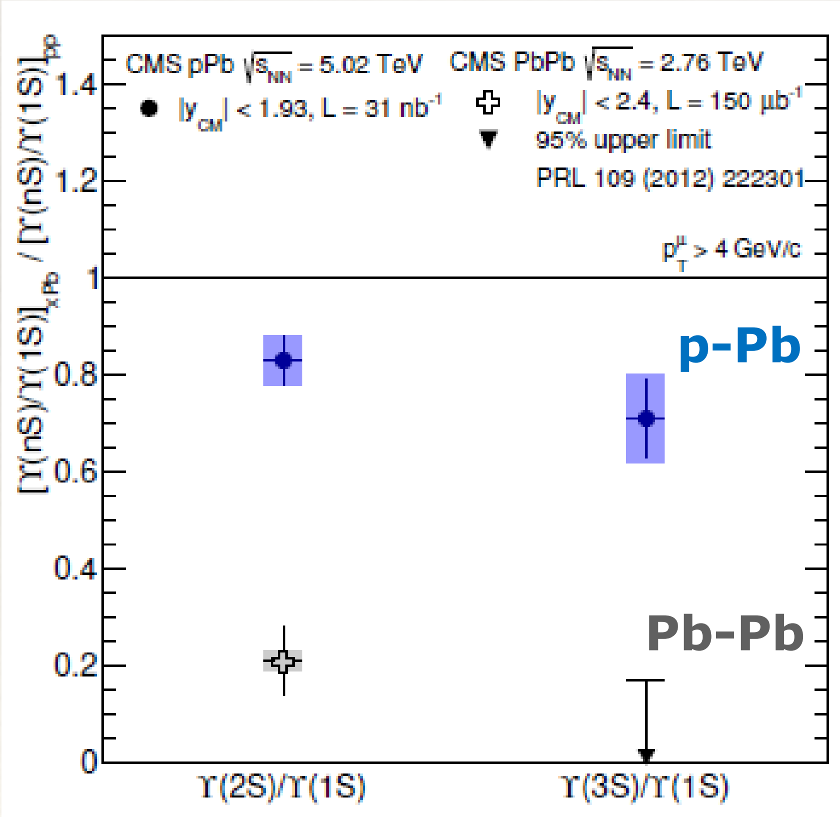




Υ production in p-Pb

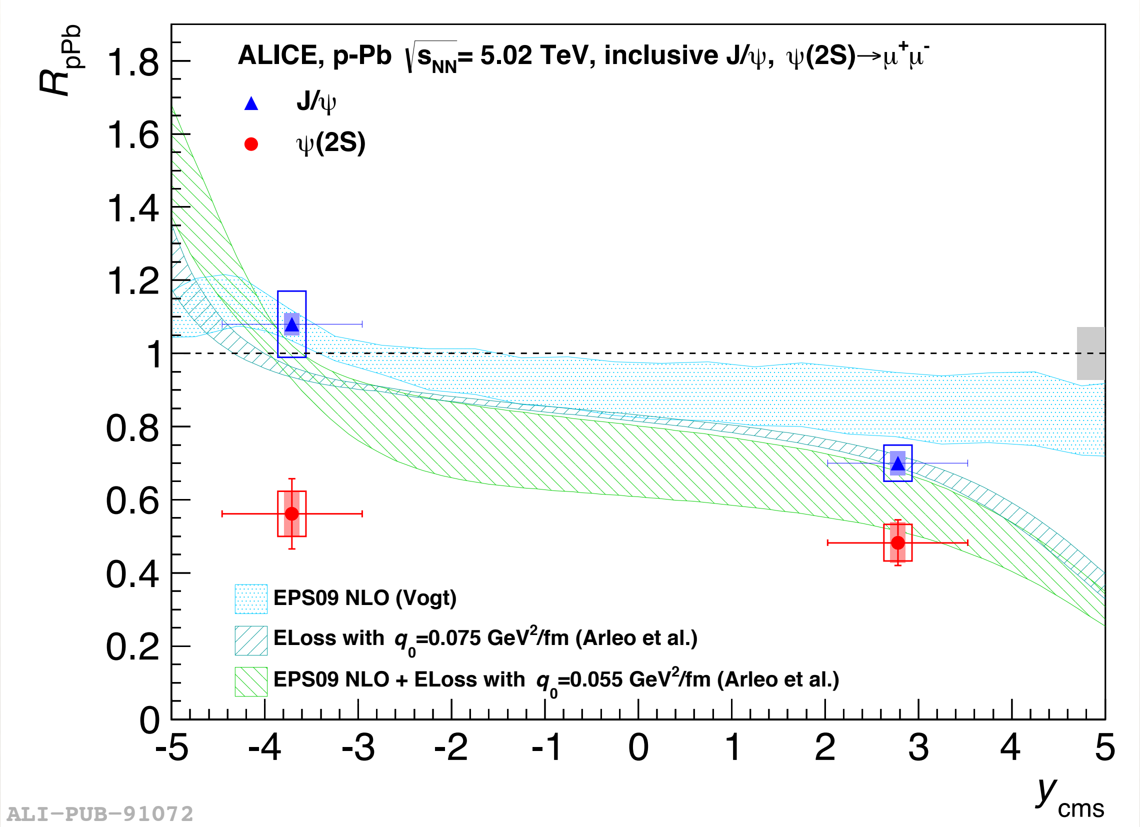
* Υ production in p-Pb collisions measured by ALICE and LHCb at forward rapidity, by CMS at mid-rapidity.
  * Similar suppression for Υ(1S) at forward and backward rapidity, even if LHCb data systematically higher than ALICE ones
  * In p-Pb collisions excited Υ states suppressed with respect to pp collisions.
  * Similar effects for the Υ(2S) and Υ(3S) with respect to the ground state.





$\psi(2S)$ in pPb

- R_{pPb} multiplicity and momentum integrated:
  - Both backward and forward rapidity clear suppression observed. Final state effect?



$\psi(2S)$ measured in

- **forward rapidity region**
  - **2.03 < y_{CMS} < 3.53 (forward)**
  - **-4.46 < y_{CMS} < -2.96 (backward)**
  - **p_T > 0**