D-meson reconstruction with ALICE: present results and future perspectives

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Outline

- Heavy Flavours in high energy heavy ion collisions: motivations.
- Nuclear modification factor and azimuthal anisotropy.
- Full reconstruction of D mesons with the ALICE detector:
  - ✓ R_{AA} : comparison with p-Pb, centrality and mass dependence.
  - ✓ Azimuthal anisotropy: v_2 .
  - ✓ Comparison with models.
- ALICE in the high luminosity LHC era: detector upgrade.
- Expected performance for D and B detection in the central rapidity region.

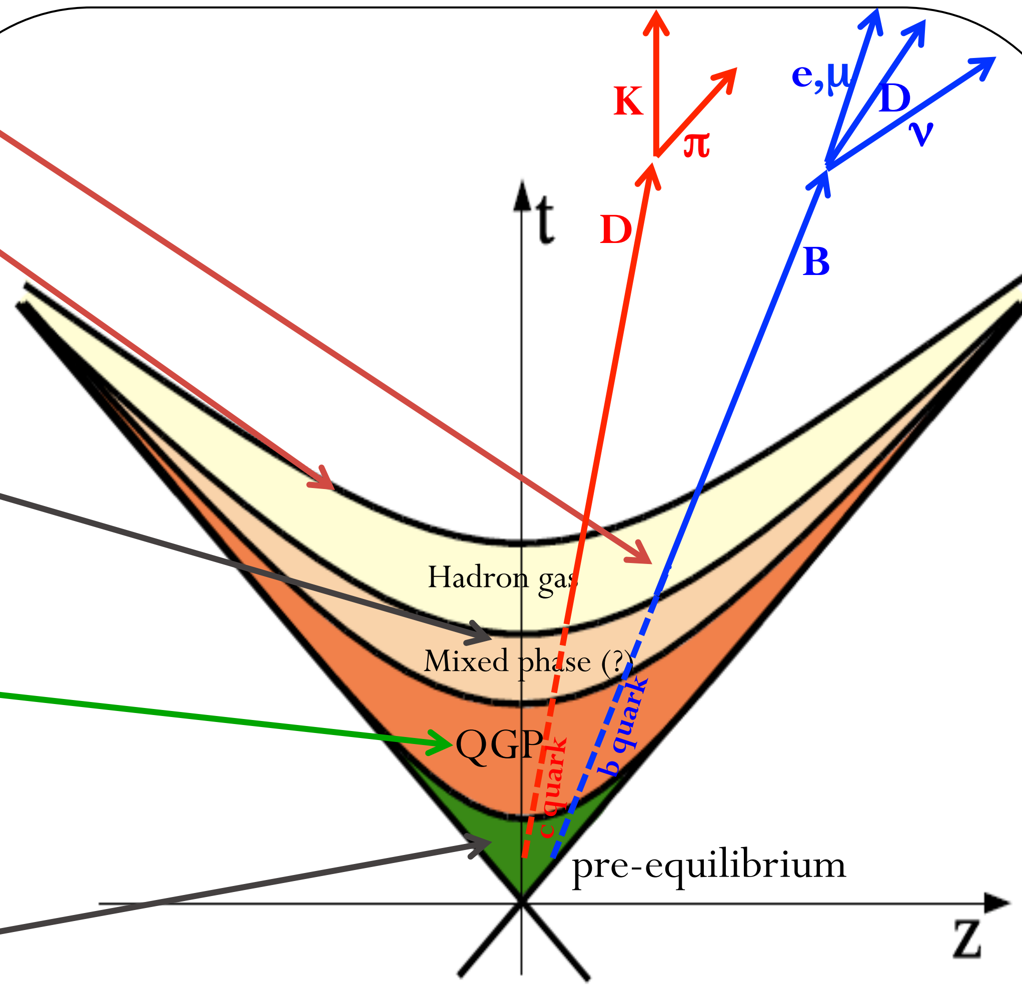
Nucleus-Nucleus collision: a process

Freeze-out:
- chemical: particle composition is fixed (no more inel. collisions) → $T_{ch} \approx 170$ MeV (RHIC)
- thermal: momentum spectra are fixed (no more elastic collisions) → $T_{fo} \approx 110 \div 130$ MeV.

Soft processes:
- high cross section
- decouple late - indirect signals for QGP

Photons (real and virtual): insensitive to the QGP and to the hadronization phase

Hard processes:
- charm, beauty, jets
- probe the whole evolution of the collision
- thermalization time (RHIC) $\tau_{th} \cong 0.6$ fm/c



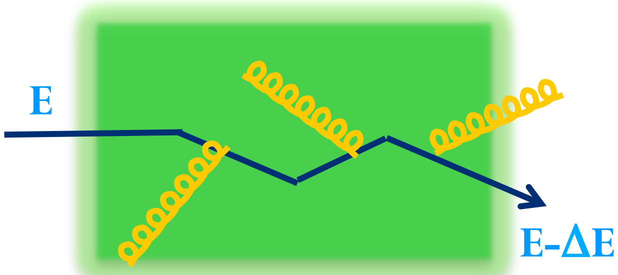
Nuclear modification factor: R_{AA}

- A nucleus-nucleus collision is not simply a superposition of nucleon-nucleon collisions.
- The effect of the produced medium is expressed by the nuclear modification factor R_{AA}

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

with $< T_{AA} > \propto < N_{coll} >$

- The produced partons lose energy through radiative and collisional mechanisms in the hot and dense medium formed in A-A collisions



- Energy loss mechanisms are sensitive to colour charge and to the quark masses. Expectation:

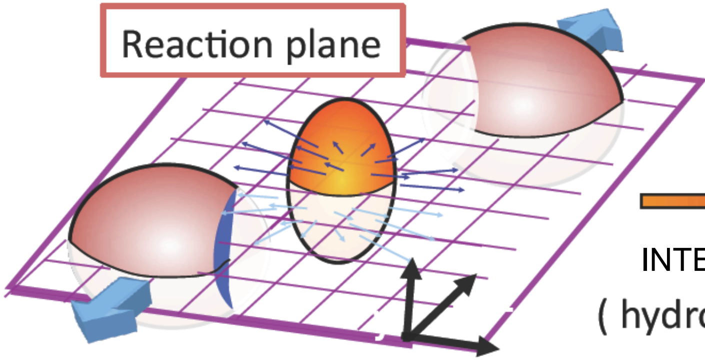
$$\Delta E_{gluon} > \Delta E_{quark}$$

$$\Delta E_{LF} > \Delta E_{HF} \Longrightarrow \Delta E_{uds} > \Delta E_{c} > \Delta E_{b}$$

$$R_{AA}(B) > R_{AA}(D) > R_{AA}(\pi)\ ?$$

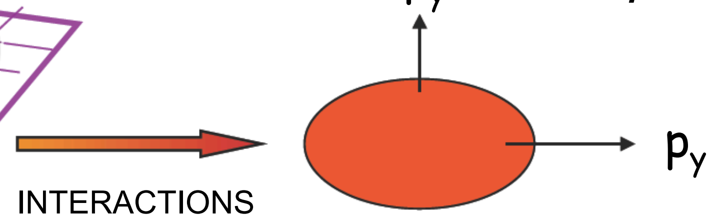
Anisotropic transverse flow

$$\epsilon = \frac{\langle y^2 \rangle - \langle x^2 \rangle}{\langle y^2 \rangle + \langle x^2 \rangle}$$



INTERACTIONS

(hydrodynamics?)



$$\varphi = \arctan \frac{p_y}{p_x}$$

"elliptic" flow

$$v_2 = \frac{\langle p_y^2 \rangle - \langle p_x^2 \rangle}{\langle p_y^2 \rangle + \langle p_x^2 \rangle}$$

Initial spatial asymmetry → Final momentum asymmetry → Azimuthal distribution

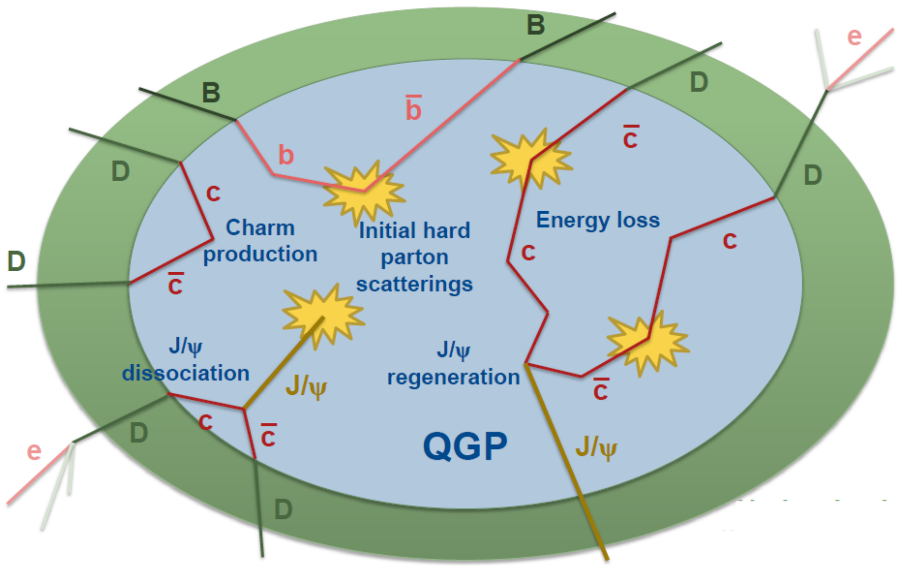
$$\frac{dN}{d(\varphi - \psi_{RP})} \propto 1 + 2\sum_{n=1}^{\infty} v_n \cos(n[\varphi - \psi_{RP}])$$

$$v_n = \langle \cos(n[\varphi - \psi_{RP}]) \rangle$$

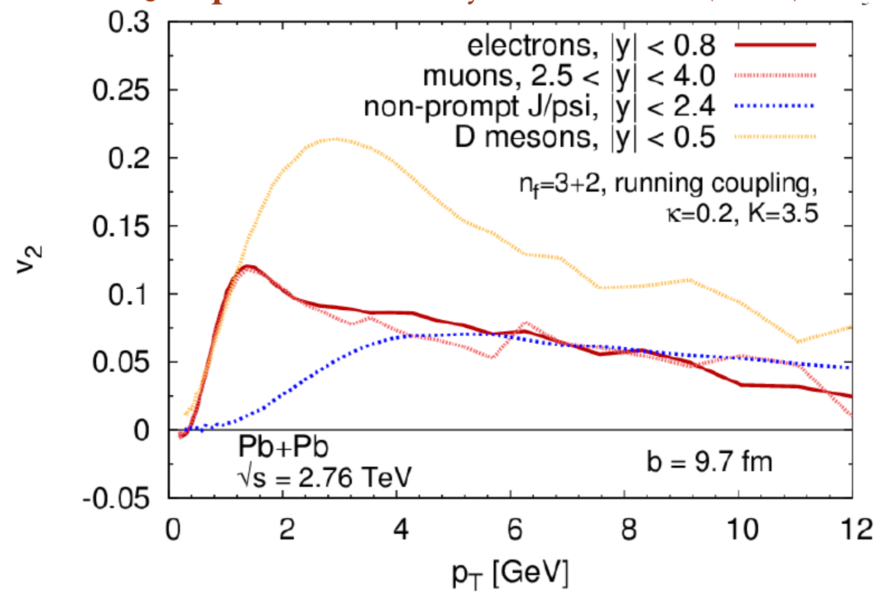
- Fourier decomposition of azimuthal distributions w.r.t. the initial state spatial plane of symmetry
- Observables: Fourier coefficients
- The second Fourier coefficient, v_2 ,is called elliptic flow.
- $v_2 \neq 0$ is expected due to collective motion (thermalization?) at low p_T and to path-length dependence of energy loss at high p_T

Heavy-flavour v_2

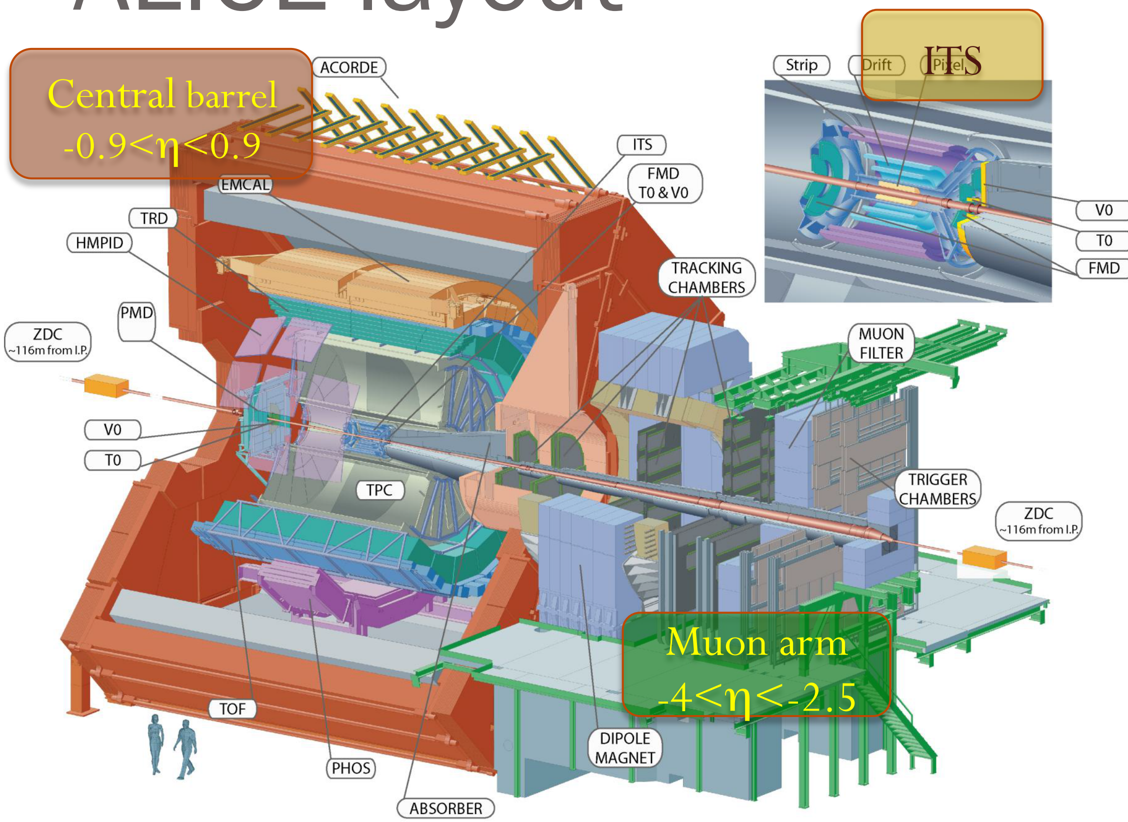
- Due to their large mass, c and b quarks should take longer time (= more re-scatterings) to be influenced by the collective expansion of the medium
  - ✓ $v_2(b) < v_2(c)$
- Uniqueness of heavy quarks: are not destroyed and/or created in the medium
  - ✓ Transported through the full system evolution



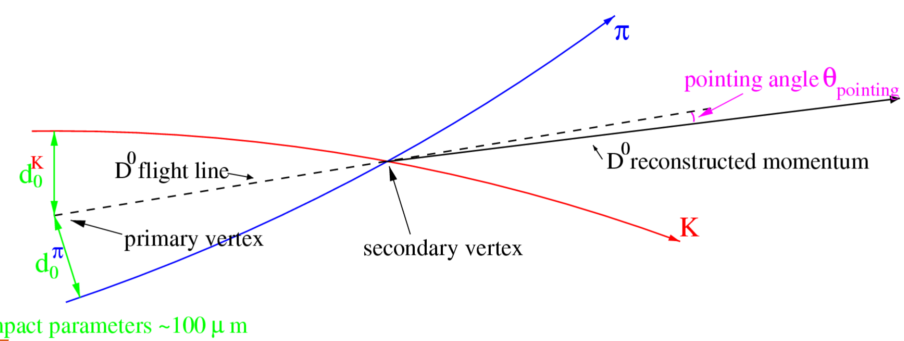
📖 **J. Uphoff et al.,** Phys. Lett. B **717** (2012), 430

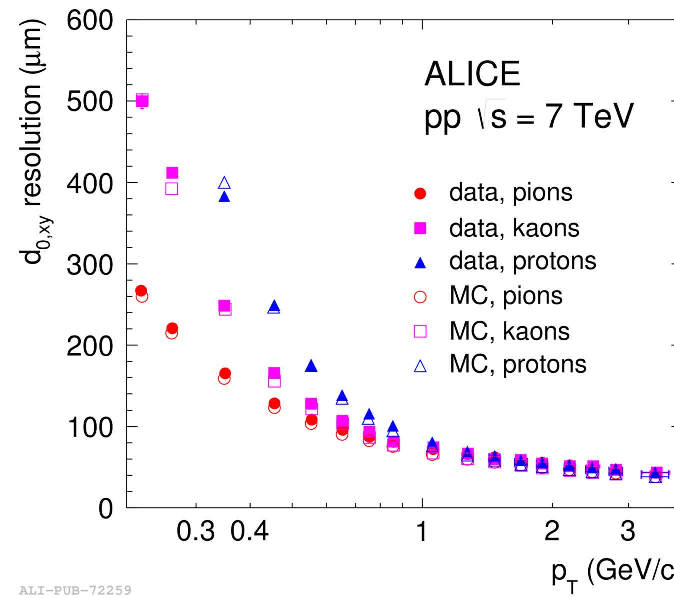


ALICE layout



- Reconstruction of D mesons through their hadronic decay channels in the ALICE barrel.
- $c\tau$ = 100-300 μm
- Key detectos: ITS, TPC, TOF





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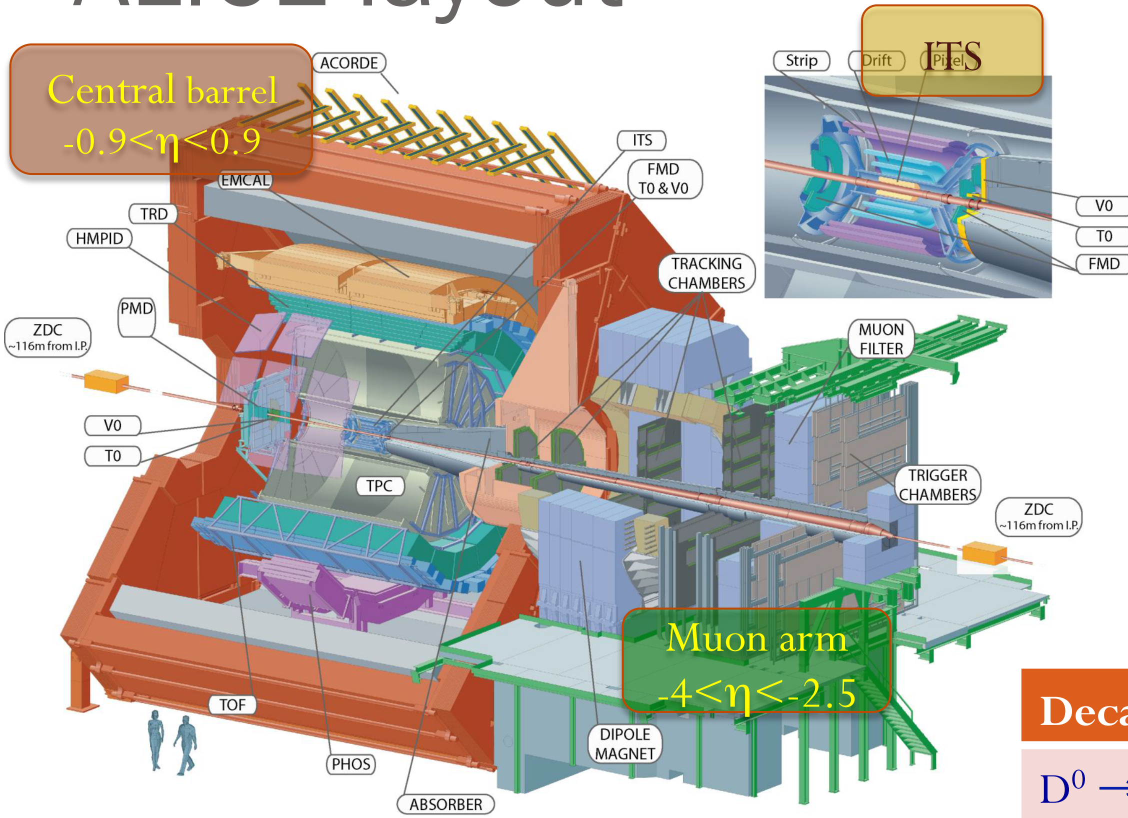

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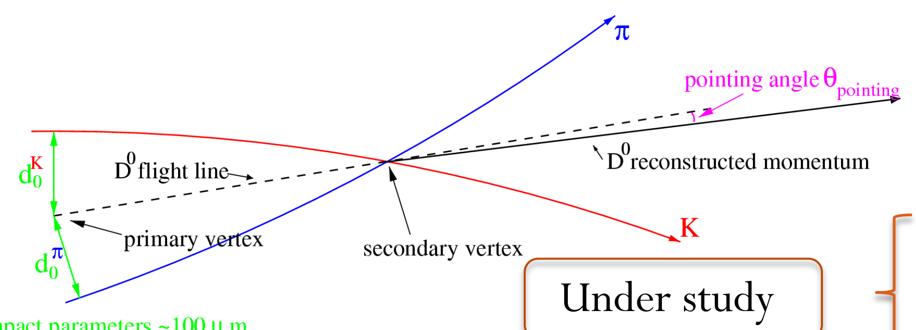
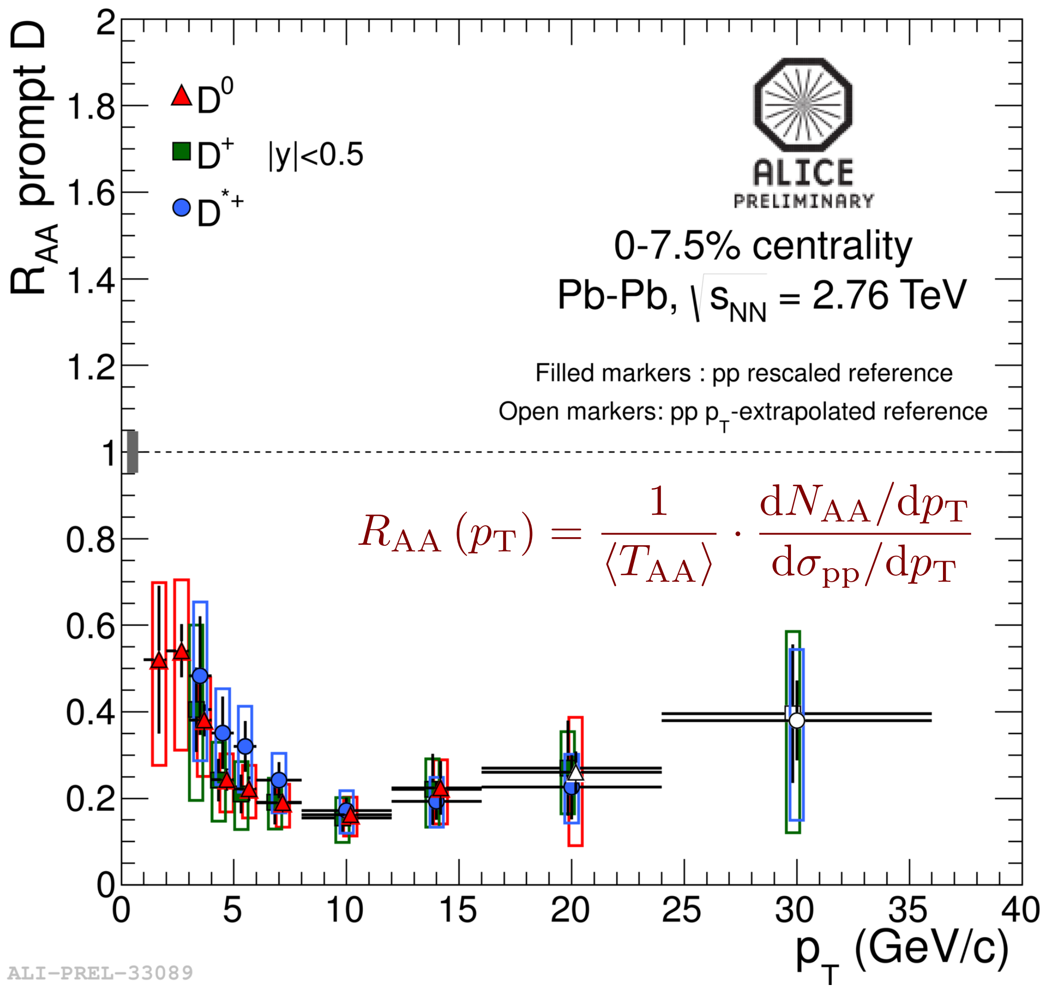
Decay mode	$c\tau$ (μm)	B.R.
$D^0 \rightarrow K^-\pi^+$	123	3.89%
$D^{*+} \rightarrow D^0\pi \rightarrow K\pi\pi^+$	123 (D^0)	67.7%
$D^+ \rightarrow K^-\pi^+\pi^+$	312	9.22%
$D_s^+ \rightarrow \phi\pi^+ \rightarrow K^+K^-\pi^+$	147	2.32%
$\Lambda_c^+ \rightarrow pK^-\pi^+$	60	5.0%
$\Lambda_c^+ \rightarrow p\overline{K^0}$	60	2.3%



Under study

D-meson reconstruction



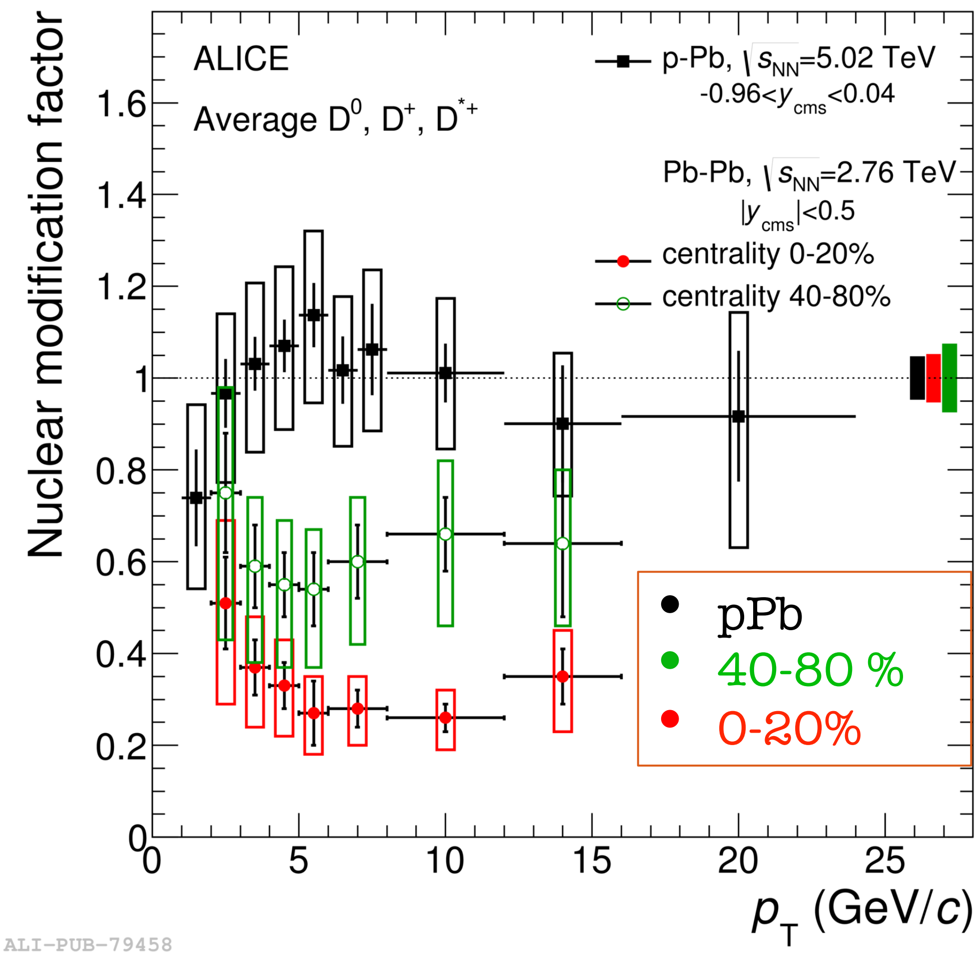
- D^0, D^+ and D^{*+} R_{AA} agree within uncertainties
- pp reference from measured D^0, D^+ and D^* p_T-differential cross sections at 7 TeV scaled to 2.76 TeV with FONLL
  - ✓ Extrapolated assuming FONLL p_T shape to highest p_T bins not measured in pp

Strong suppression of prompt D mesons in central collisions at intermediate – high p_T
→ up to a factor of 5 for $p_T \approx 10$ GeV/c

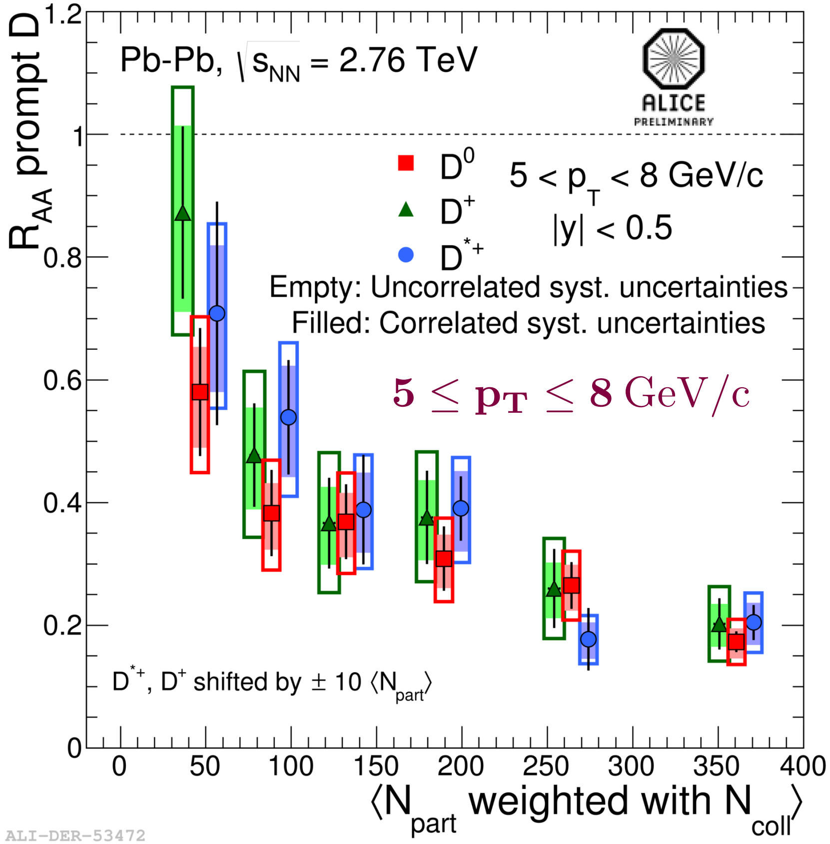
Comparison with p-Pb

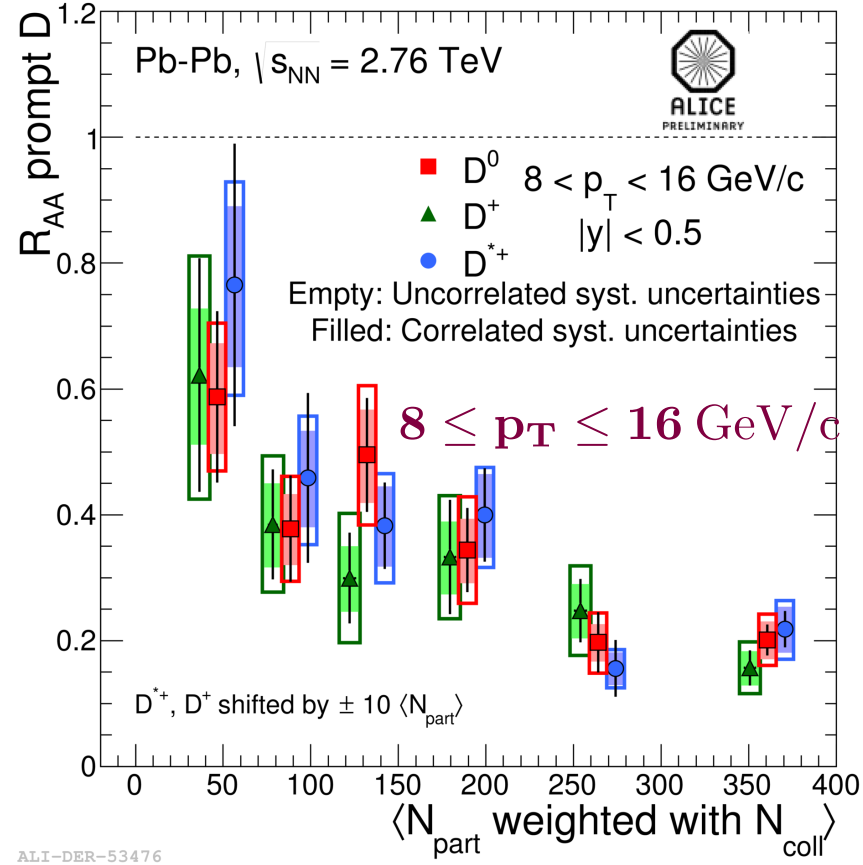
- D suppression is larger in central than in peripheral Pb-Pb collisions
- R_{pPb} for D mesons → compatible with unity within uncertainties
- Comparison of Pb-Pb with p-Pb results indicates that the observed suppression in Pb-Pb collisions is due to final state effects induced by the partonic medium

p-Pb: ALICE Coll. arXiv:1405.3452 [nucl-ex], accepted by PRL



R_{AA} vs centrality

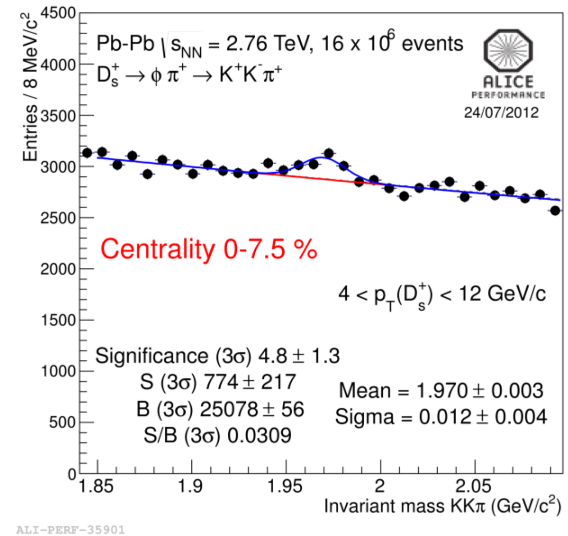


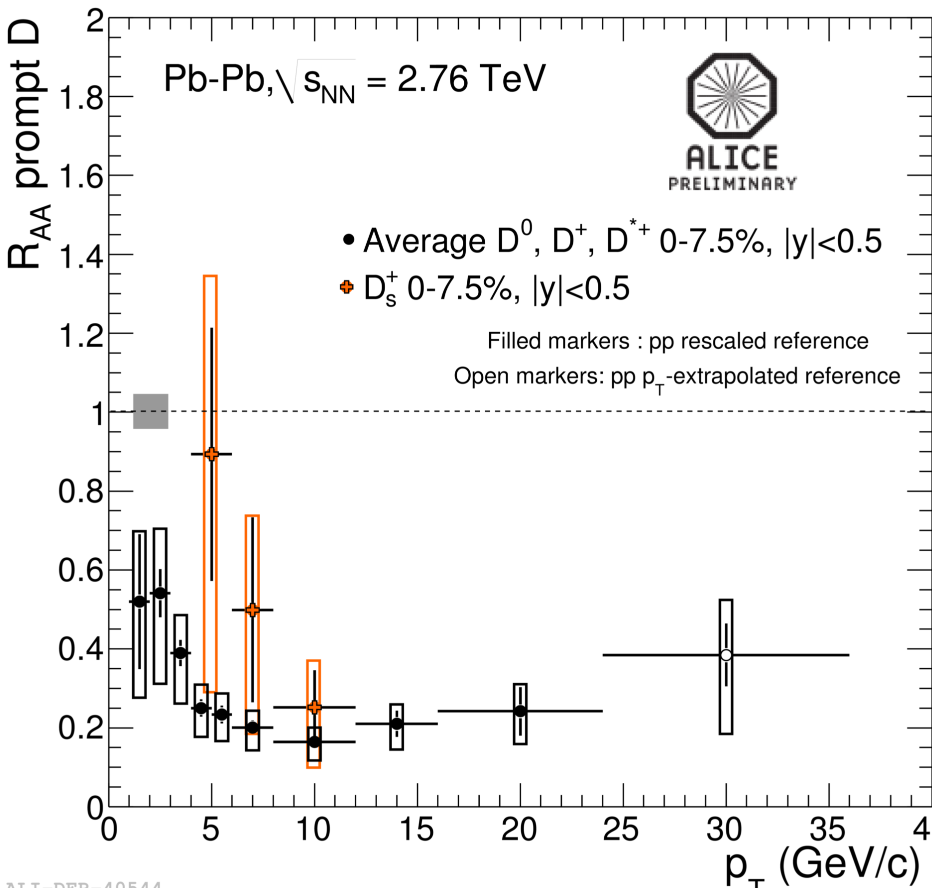


- The results for the three D meson species are consistent within uncertainties. The suppression increases with centrality and reaches a factor of 5–6 in the most central events for both p_T intervals.

Charm + strange: D_s^+

- First measurement of D_s^+ in A-A collisions
- Expectation: enhancement of the strange/non-strange D meson yield at intermediate p_T if charm hadronizes via recombination in the medium



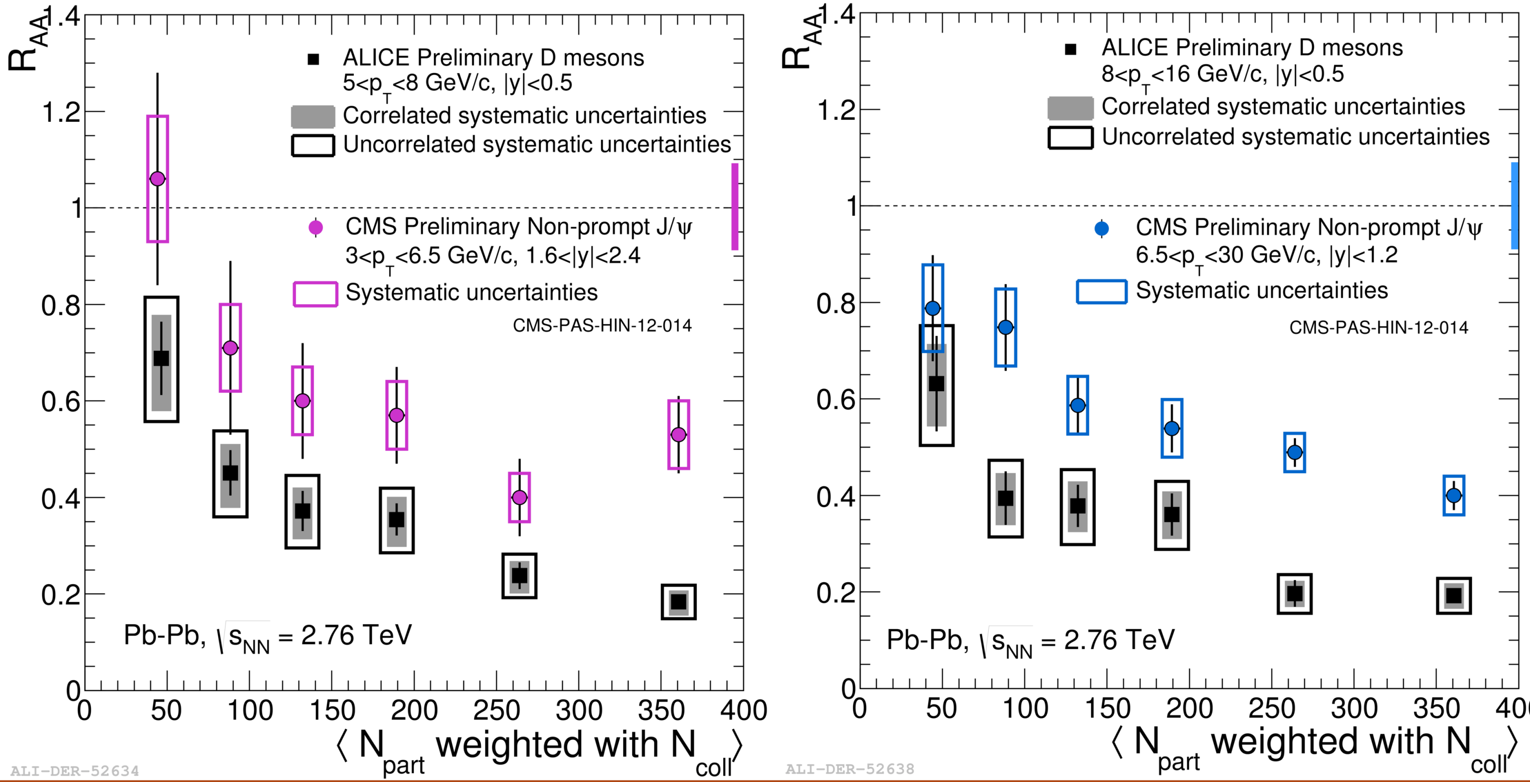


- Strong D_s^+ suppression (similar as D^0, D^+ and D^{*+}) for 8< p_T <12 GeV/c
- R_{AA} seems to increase (=less suppression) at low p_T
  - ✓ Current data do not allow a conclusive comparison to other D mesons within uncertainties

📖 **Kuznetsova, Rafelski, EPJ C 51 (2007) 113**

📖 **He, Fries, Rapp, Phys. Rev. Lett. 110 (2013) 112301**

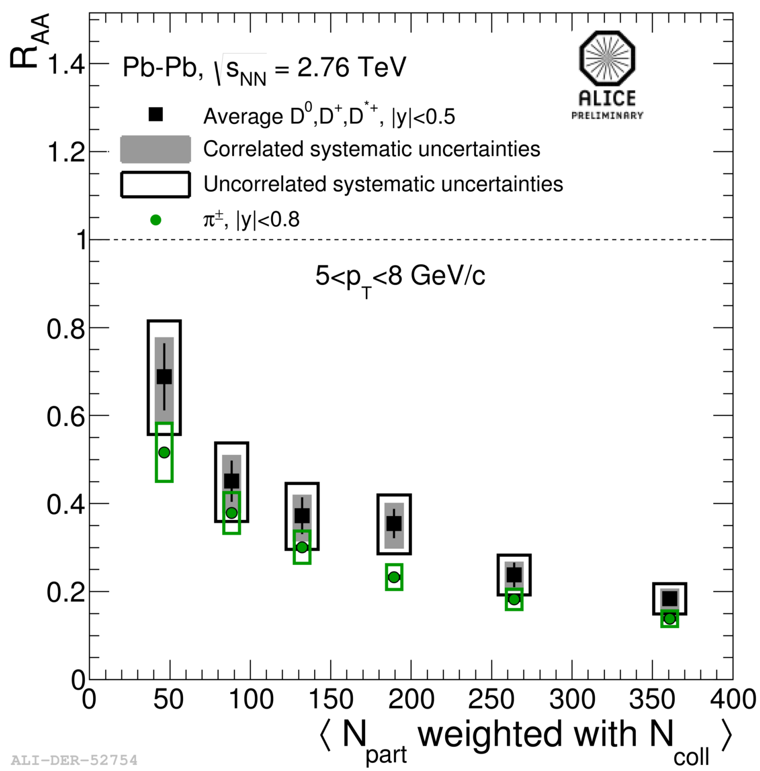
Mass dependence of R_{AA}

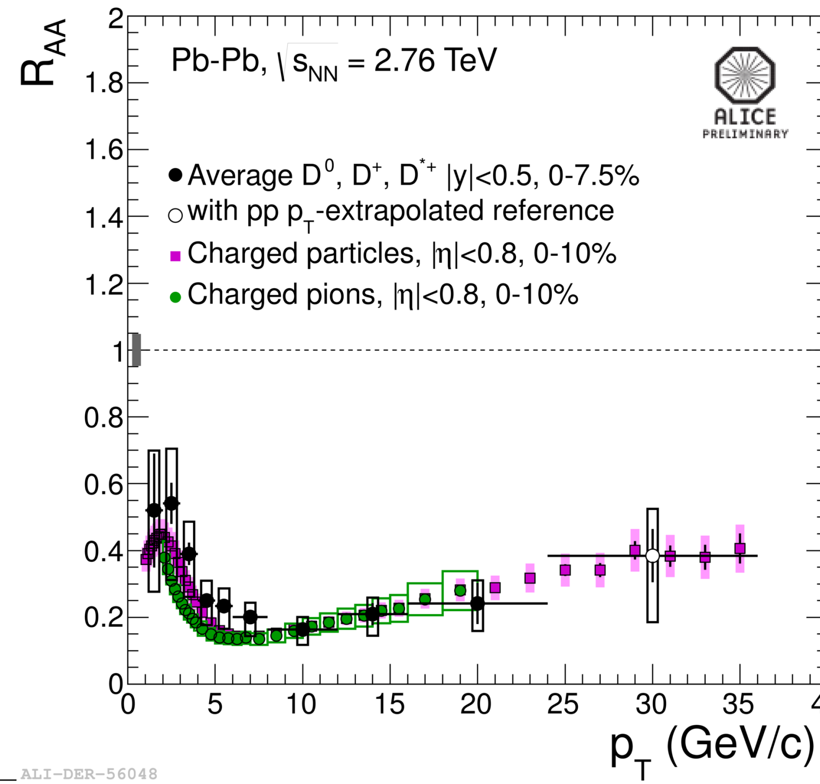


- Comparison with beauty hadrons through their decay into J/ψ (CMS non-prompt J/ψ).
- p_T ranges chosen to have similar kinematics for D and B mesons, though with different rapidity ranges.
- **Smaller R_{AA} of D mesons w.r.t. B mesons, as expected from mass-dependent energy loss**

Mass dependence of R_{AA}

- R_{AA} vs. p_T compatible within errors for D, charged particles and $\pi^{\pm}$
  - ✓ possibly a hint of $R_{AA}{}^{D} > R_{AA}{}^{\pi}$ for p_T<5-6 GeV/c
- Better precision needed to draw conclusions on the expected difference between D and π suppression: R_{AA}(D)>R_{AA}(π) from mass hierarchy and colour charge dependence of energy loss
- The different energy loss could be compensated by the softer fragmentation of gluons combined with the increase of the charged hadron R_{AA} towards high transverse momenta



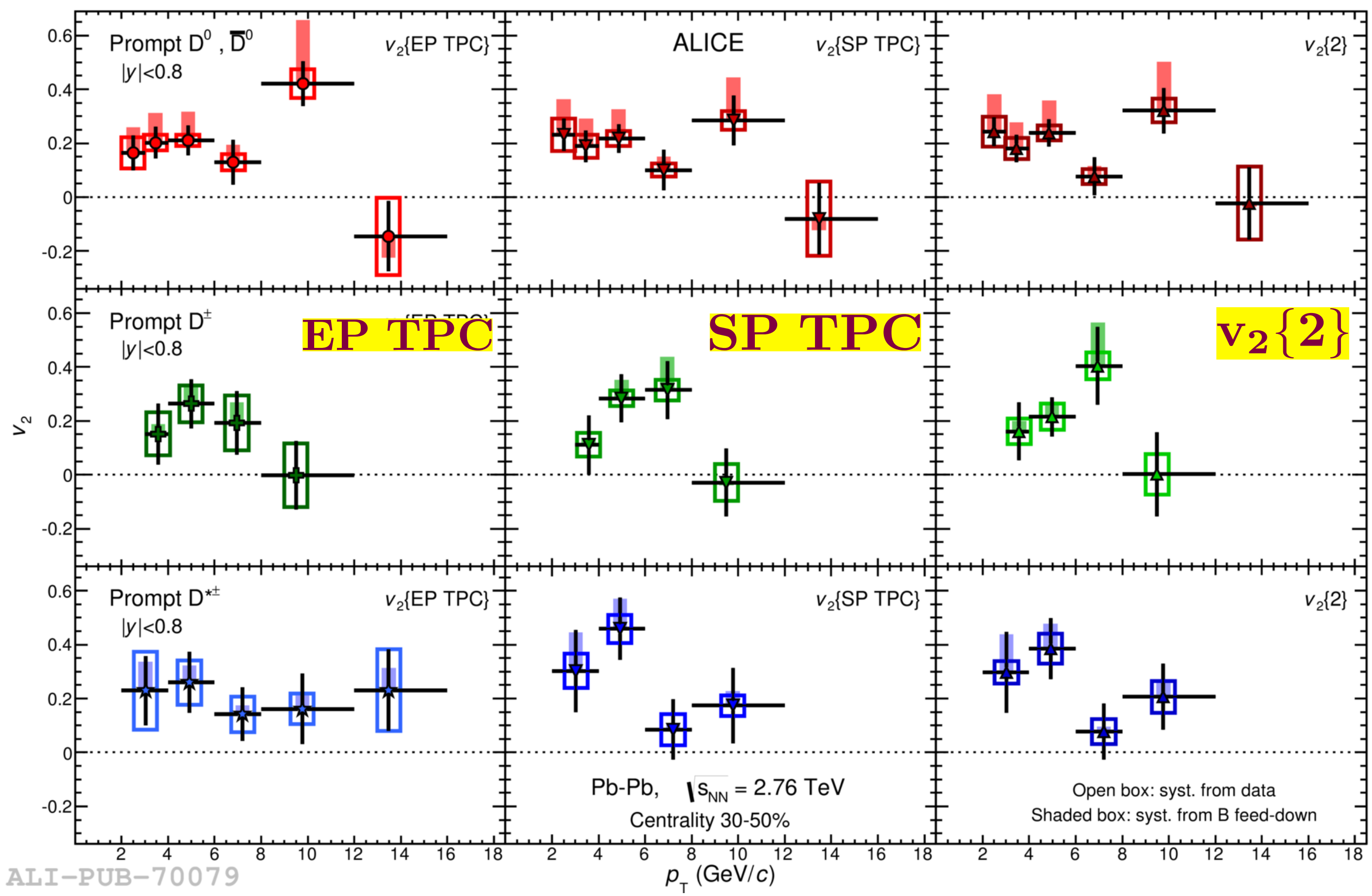


v_2 for D mesons

- Azimuthal anisotropy measured with Event Plane, Scalar Product and 2-Particle Cumulant techniques in 3 different centrality classes.

ALICE Coll. Phys. Rev. C 90, 034904 (2014)

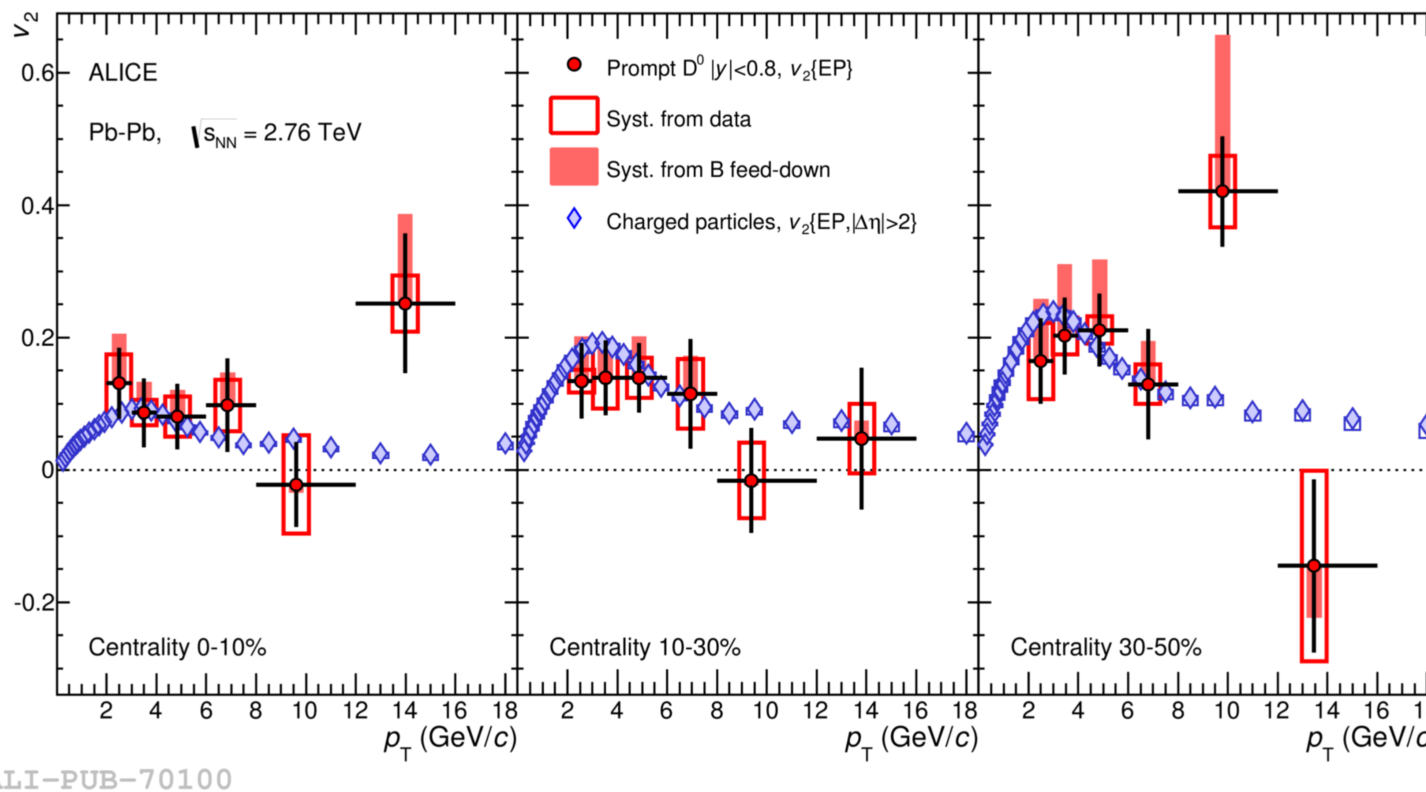
- Compatible results for D^0, D^+ and D^{*+} mesons
- Here: v_2 results for centrality class 30-50%



v_2 for D mesons

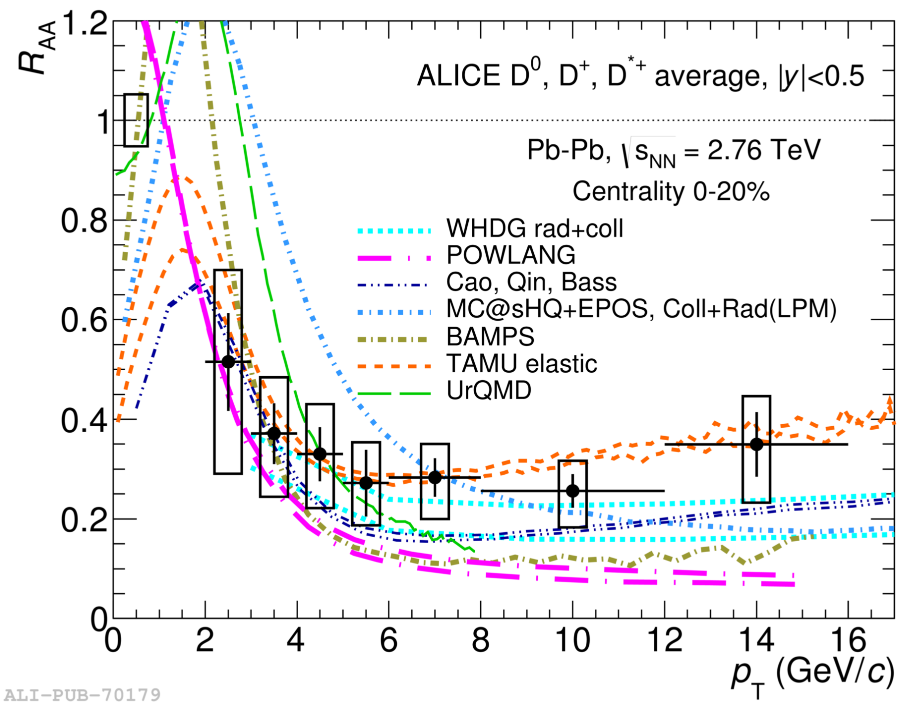
- The magnitude of v_2 is similar for charmed hadrons and light-flavour hadrons.
- $v_2>0$ → ~5σ effect for $2<p_T<6$ GeV/c (30-50% centrality class, average of the three meson species).
- Results consistent with a strong coupling of c quark with the medium.

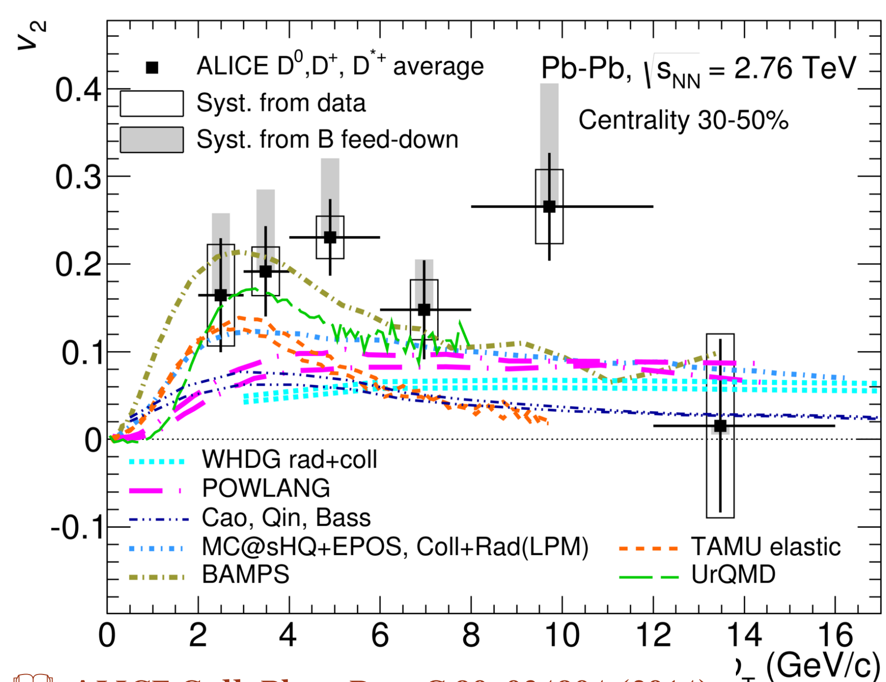
ALICE Coll. Phys. Rev. C 90, 034904 (2014)



Comparison with models: R_{AA} and v_2

- The anisotropy is best described by models that include mechanisms like collisional energy loss and/or hadronization via recombination.
- Challenge: successful models should provide a simultaneous description of D meson R_{AA} and v_2.

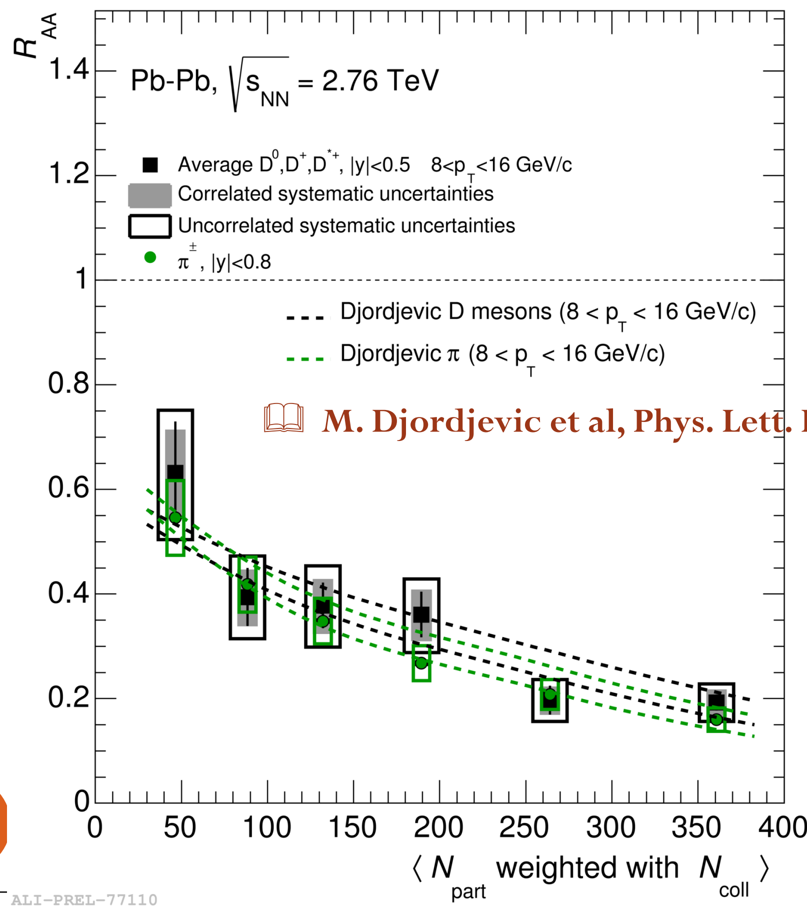




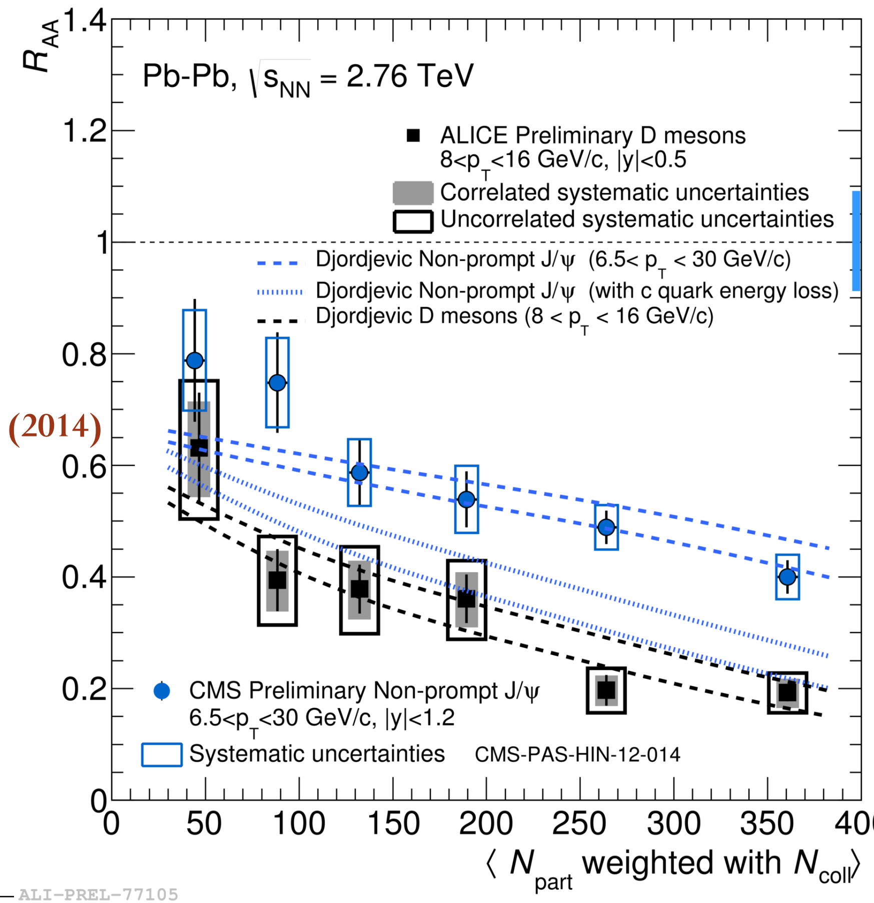
ALICE Coll. Phys. Rev. C 90, 034904 (2014)

Comparison with models: centrality dependence

- The R_{AA} centrality dependence of heavy and light flavours is compared to calculations by Djordjevic et al.
- The model includes radiative and collisional energy loss
- Fair agreement with data. The higher suppression of D w.r.t. B mesons is due to the mass hierarchy



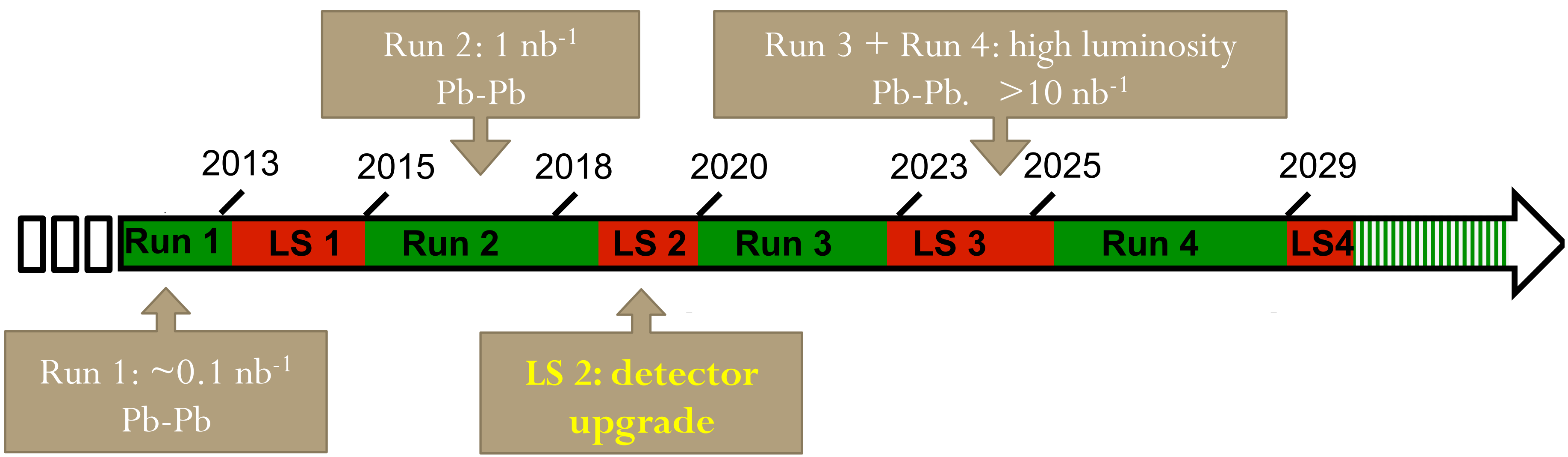
M. Djordjevic et al, Phys. Lett. B 737 (2014)



Heavy-ion LHC and ALICE plans

- The LHC heavy-ion programme will extend beyond Run 2 to Run 3 and Run 4
- High interaction rate: 50 kHz
- Expected integrated luminosity: >10 nb^{-1} (x100 w.r.t. Run 1)
- A major detector upgrade has been approved for the LS2 to fully exploit the higher rate and to improve the physics performance

goals of the experiments



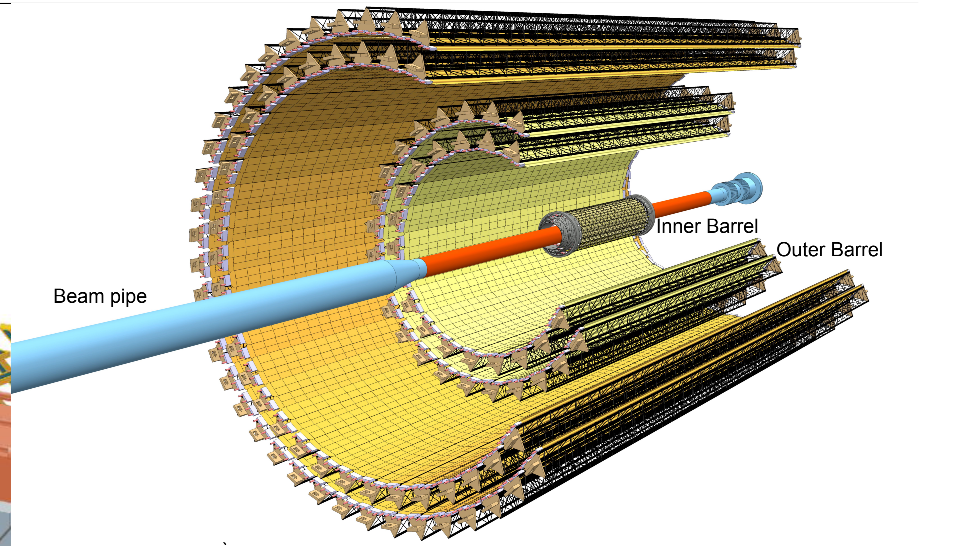
ALICE Upgrade: strategy

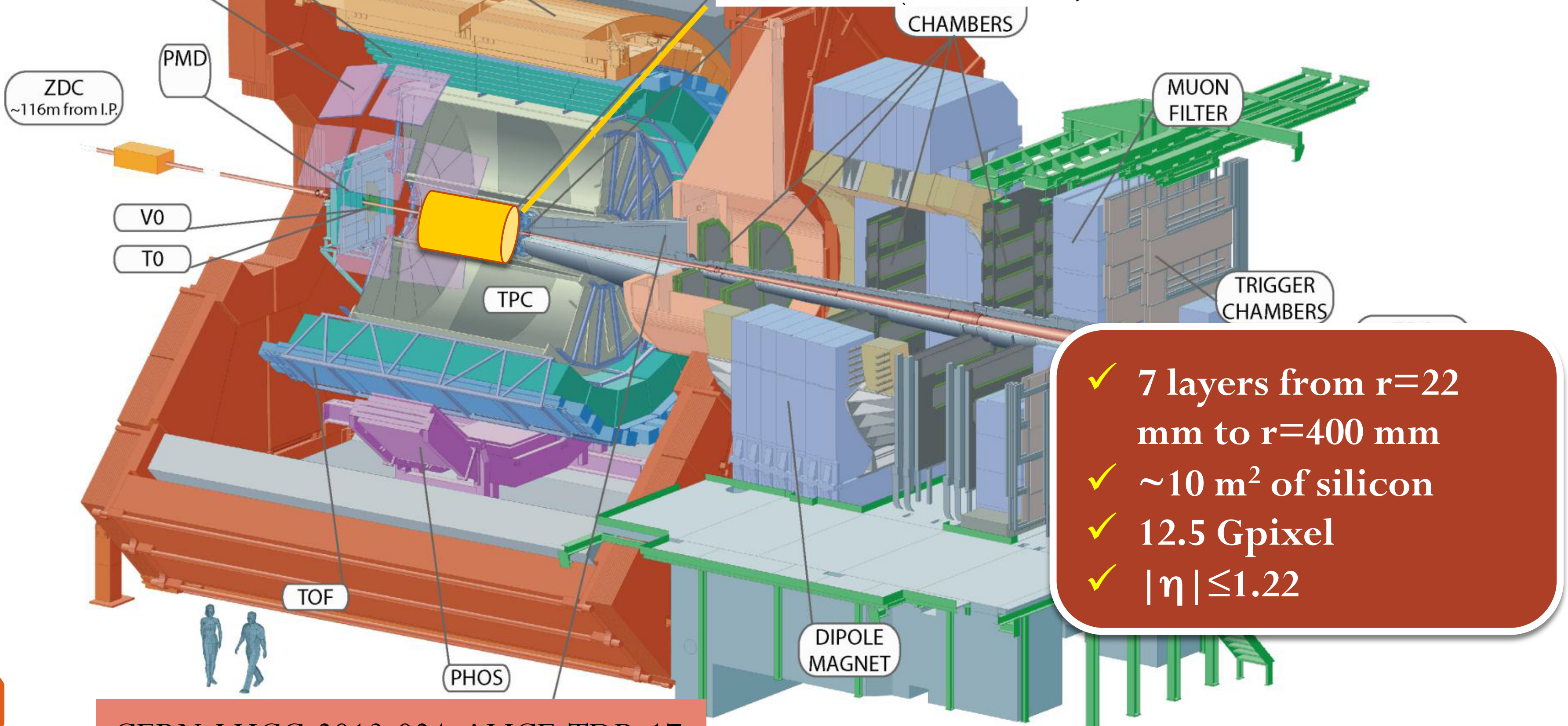
- **ALICE will carry out high precision measurements of rare signals with main focus on the low p_T region.**
- **Boundary conditions and requirements:**
  - ✓ very low signal/background ratio for most of the physics signals → no trigger selection possible.
  - ✓ large minimum bias samples required: L_{int}>10 nb^{-1}
  - ✓ High rate: $\mathcal{L} = 6 \times 10^{27}\ \mathrm{cm}^{-2}\mathrm{s}^{-1} \Longrightarrow R = 50\ \mathrm{kHz}$
  - ✓ Focus on heavy flavours →improve track resolution and vertexing thanks also to a smaller beam pipe.
  - ✓ With the upgrade: reconstruction of beauty hadrons.
  - ✓ HF baryons will be accessible.

  new
- **Strategy:**
  - ✓ New Inner Tracking System at midrapidity
  - ✓ New Muon Forward Tracker in front of the muon absorber
  - ✓ New readout chambers for the TPC. Readout upgrades for several detectors and the online systems
  - ✓ Integrate Online and Offline (**O^2 project**) → data reconstruction online

New ITS

The new ITS will be the key detector for HF reconstruction in the barrel





- ✓ 7 layers from r=22 mm to r=400 mm
- ✓ ~10 m^2 of silicon
- ✓ 12.5 Gpixel
- ✓ $|\eta| \leq 1.22$

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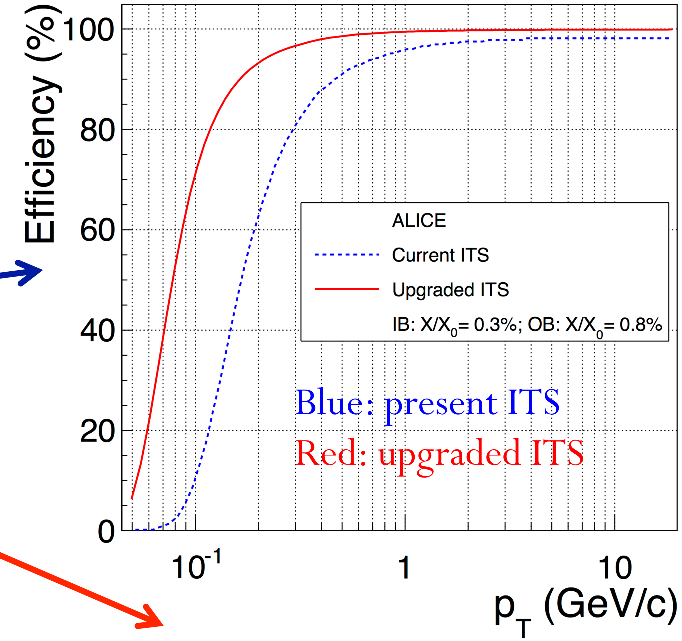
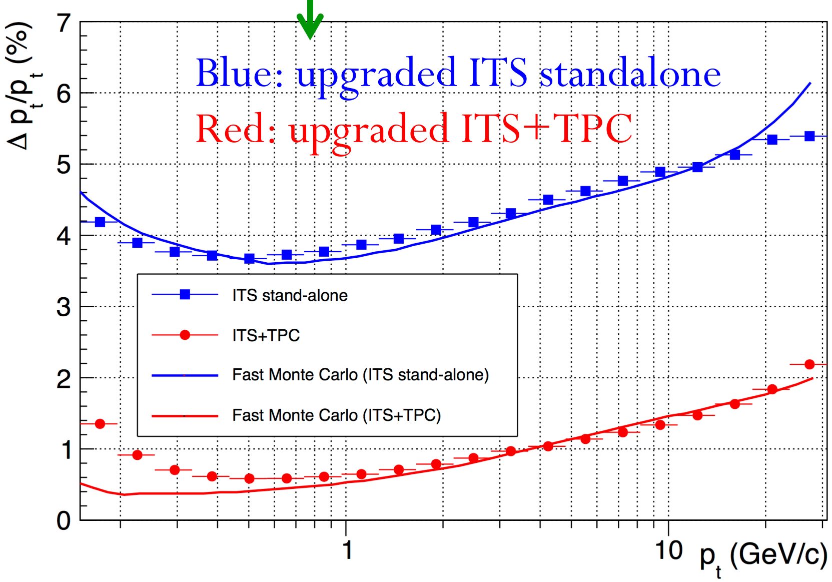
New ITS

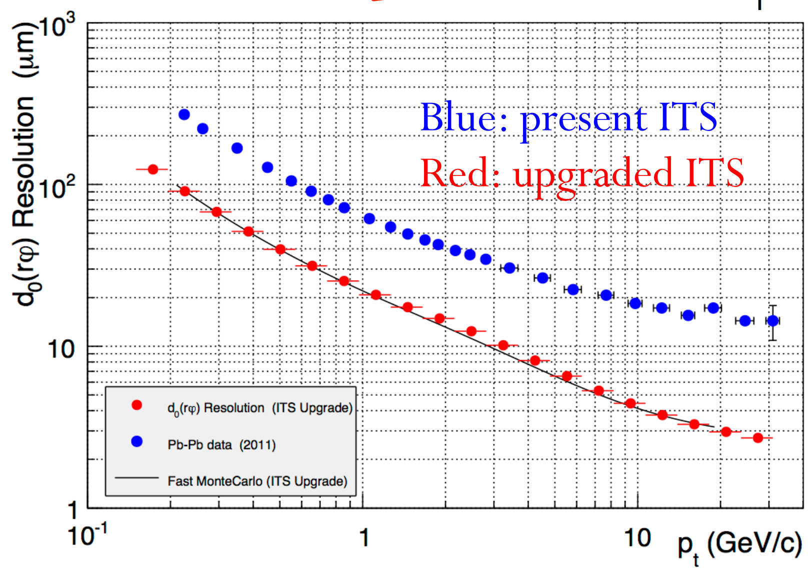
- **Better pointing resolution by a factor of 3(5) in rϕ (z) at p_T=500 MeV/*c***
  - ✓ innermost layer is closer to the IP: from 39 mm → 22 mm
  - ✓ reduced material budget from ~1.14%X_0 → 0.3% X_0 for the 3 inner layers (0.8% X_0 for the other 4 layers)
  - ✓ Reduced pixel size: from 50×425 μm^2 → ~(30×30 μm^2)
  - ✓ max silicon thickness: 50 μm
  - ✓ Monolithic Active Pixel Sensors (MAPS) in TowerJazz 0.18 μm CMOS technology
- **Better tracking efficiency and p_T resolution at low p_T**
  - ✓ Thanks to the higher granularity
  - ✓ Thanks to an additional layer: from 6 to 7 layers
- **Faster readout: 50 kHz (200 kHz) for Pb-Pb (pp). Now limited to 1 kHz**
- **Accessible for maintenance during winter shutdowns**

New ITS: expected performance

- Expected performance of the new ITS is compared to the current performance
  - ✓ tracking efficiency
  - ✓ impact parameter resolution
  - ✓ transverse momentum resolution





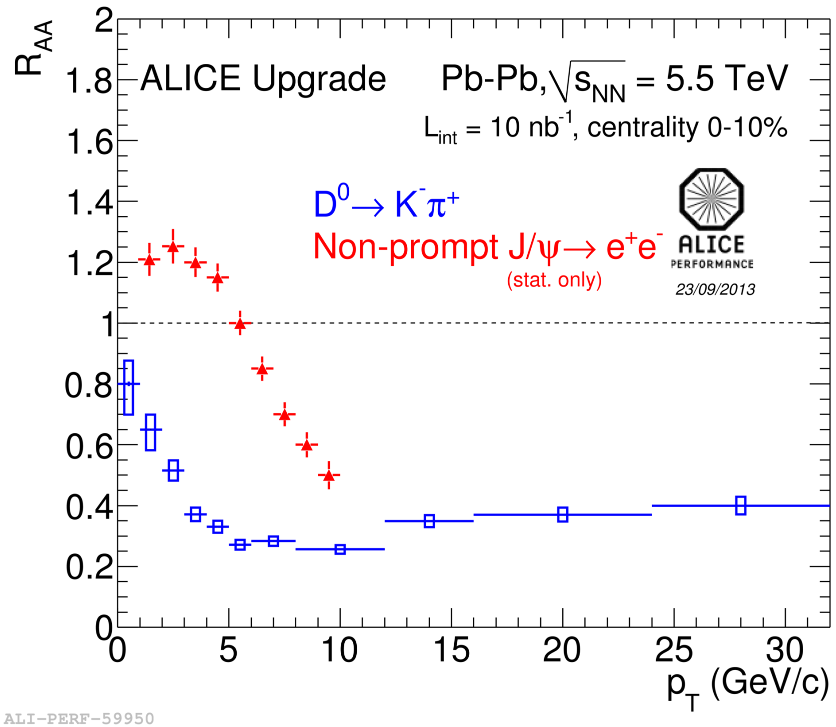


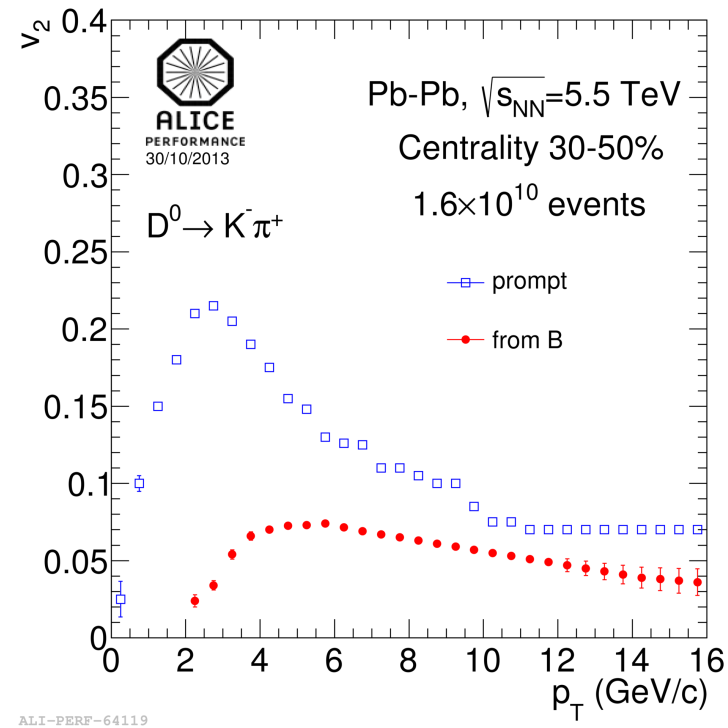
Expected Physics Performance

- ✓ **With the upgrade: reconstruction of beauty hadrons.**
- ✓ **Also HF baryons will be accessible.**
- ✓ **Beauty signal accessible both at midrapidity and in the muon spectrometer (single muons, displaced J/ψ)**
- ✓ **D mesons: improved precision down to p_T~0**

D and B-meson reconstruction

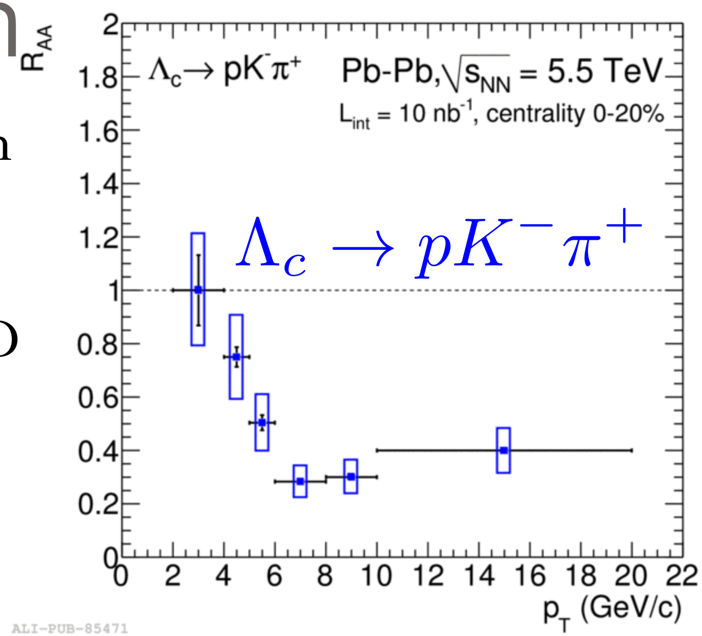
- D-meson reconstruction with the upgraded detector:
  - ✓ D^0 R_{AA} down to p_T=0 with higher precision
- B measurement: non-prompt D^0 and J/ψ
- Precise measurement of v_2 for prompt (down to p_T=0) and displaced D^0

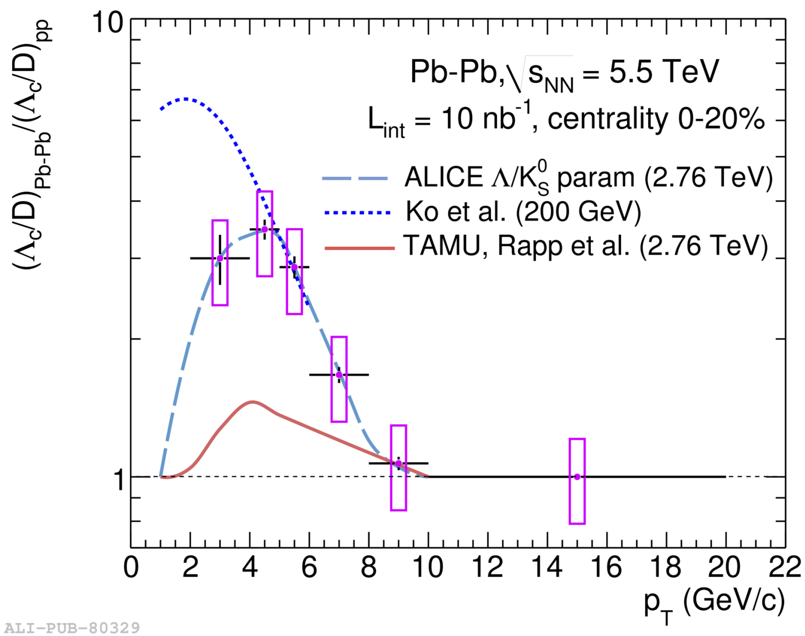


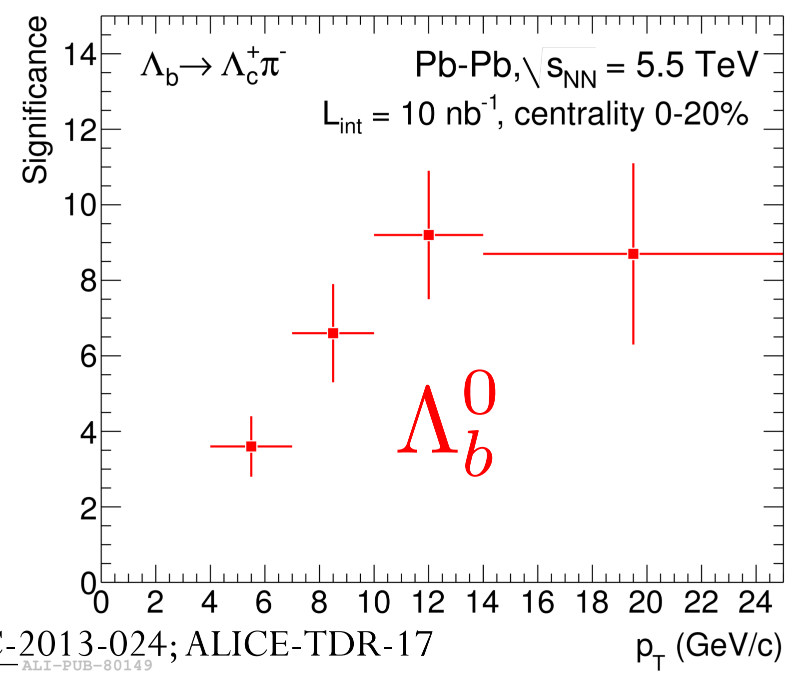


Λ_c and Λ_b reconstruction

- The upgraded ITS will allow the reconstruction of Λ_c and Λ_b baryons
- Baryon/meson enhancement measured in p/π and Λ/K → extend measurement to HF (Λ_c/D and Λ_b/B)
- Λ_c full reconstruction down to p_T~2 GeV/c
- $\Lambda_b \rightarrow \Lambda_c\pi$







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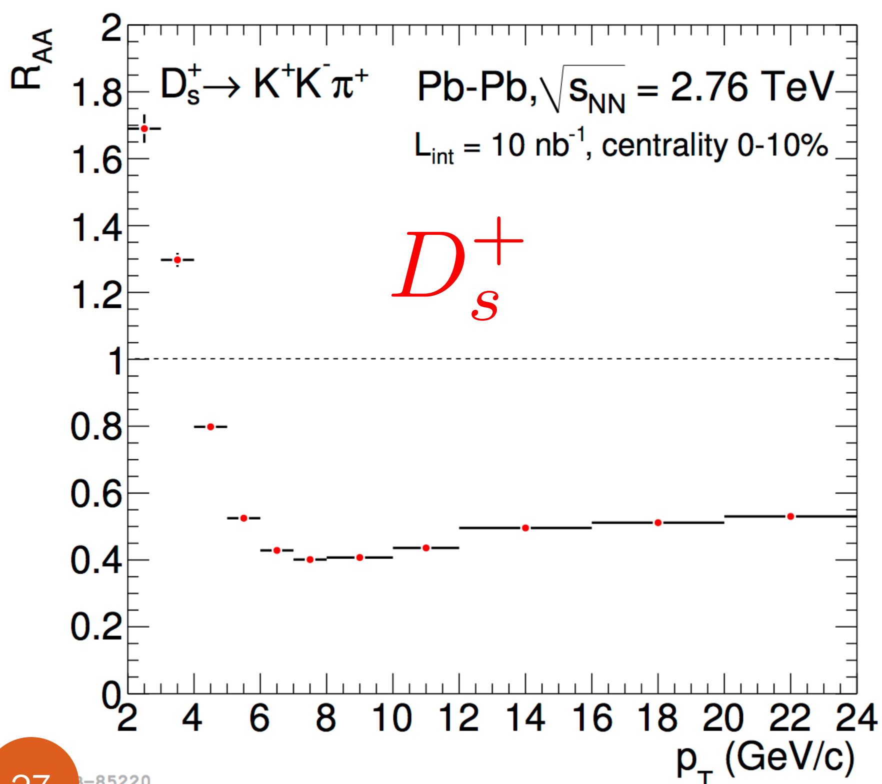
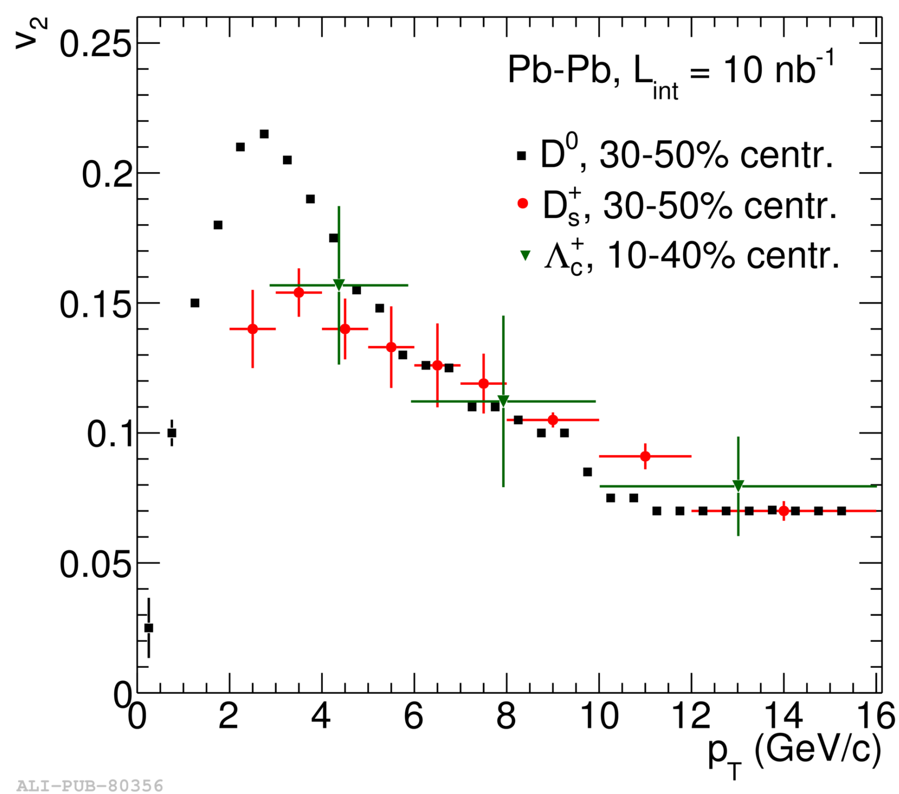
HF: D_s^+

- Hadronization mechanisms and strangeness enhancement: D_s/D
- D_s^+: R_{AA} and also azimuthal asymmetry (v_2) with high precision
- v_2 measurement will be possible also for Λ_c baryon





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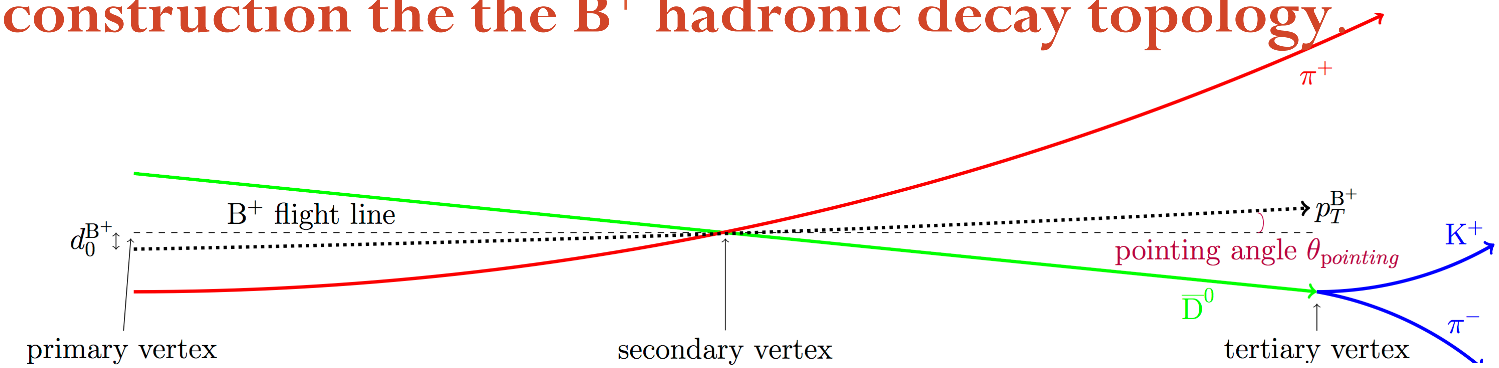
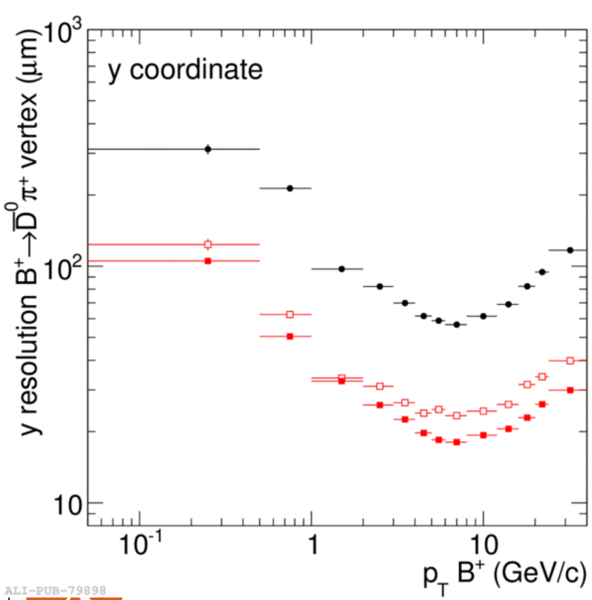
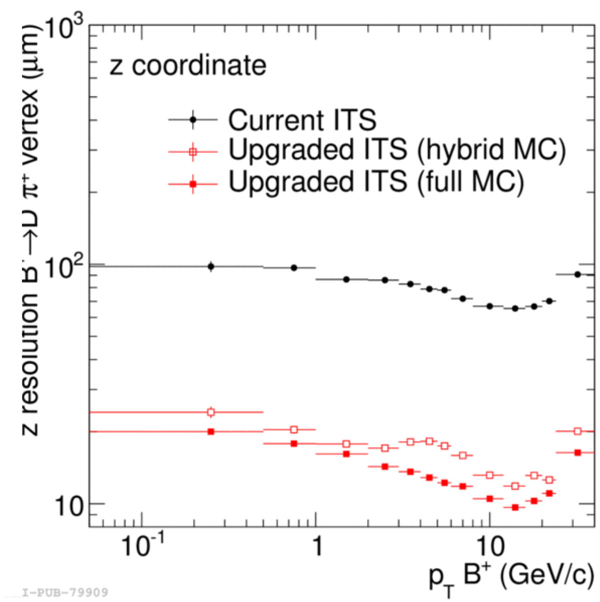
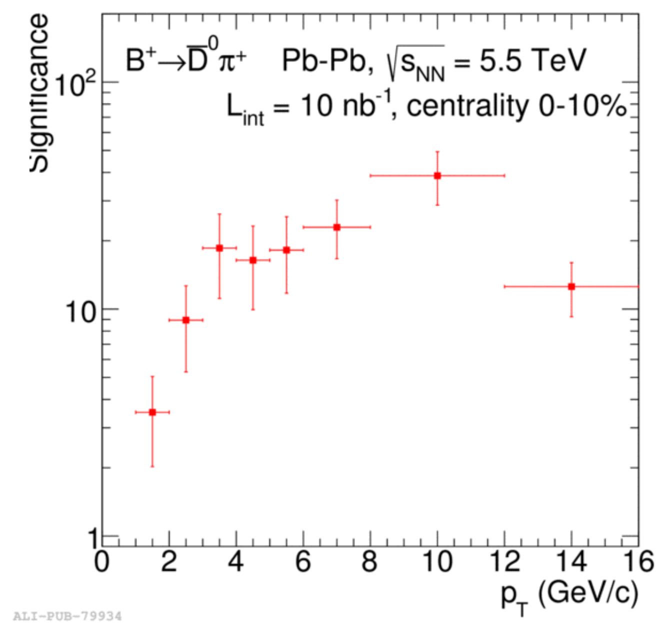
$B^+ \to \bar{D}^0\pi^+$

- The high integrated luminosity (L_{int}=10 nb^{-1}) combined with the improved pointing resolution of the upgraded ITS will allow for the **full reconstruction the the B$^+$ hadronic decay topology.**







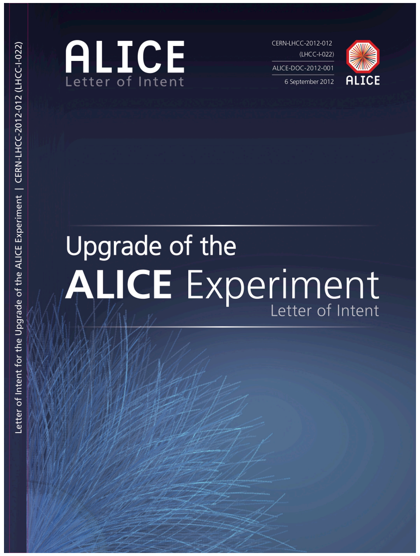


CERN-LHCC-2013-024; ALICE-TDR-17

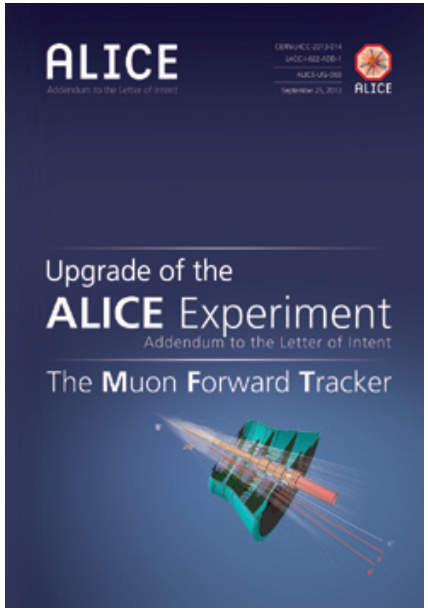
Summary

- Strong suppression of D mesons for p_T>5 GeV/c in central Pb-Pb collisions w.r.t. the binary scaled pp reference in the same range.
- **R_{pPb}~1** → suppression due to the quark charm energy loss in the QGP.
- Larger suppression of charm than beauty: **$R_{AA}(D)<R_{AA}(B)$**
- Comparison with light hadrons not conclusive with present statistics.
- D-meson v_2 ($2<p_T<6$ GeV/*c*) compatible with light hadrons → strong coupling of charm quarks with the medium.
- Major detector upgrade in LS2 and strong physics programme for Runs 3-4:
  - ✓ new physics channels: HF baryons and B full reconstruction.
  - ✓ high precision R_{AA} and v_2 measurements down to p_T~0

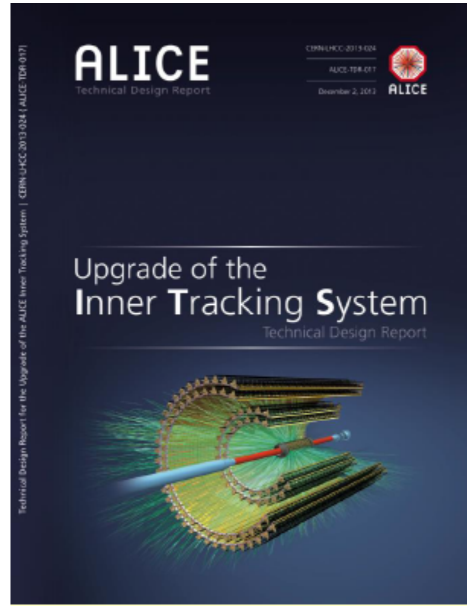
Upgrade documents



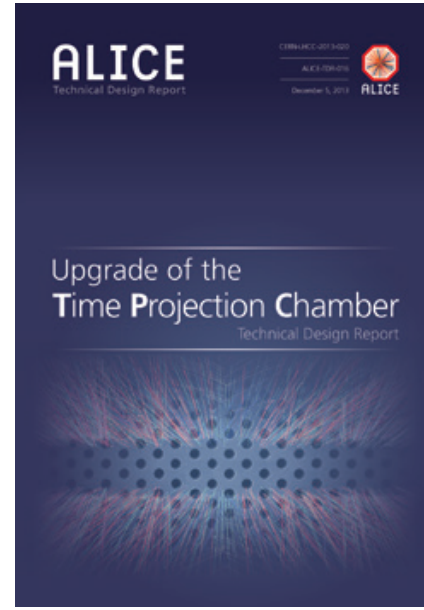
CERNLHCC-2012-012, LHCC-I-022, 2012.



CERN-LHCC-2013-014 ; LHCC-I-022-ADD-1



CERN-LHCC-2013-024 ; ALICE-TDR-017



CERN-LHCC-2013-020 ; ALICE-TDR-016

CERN-LHCC-2013-019 ; ALICE-TDR-015

- The upgrade is entering the production phase
- Technical Design Reports have been published
- O^2 TDR in preparation

Backup

ALICE data samples in Run 1

System	Energy $\sqrt{s_{NN}}$ (TeV)	Year	Delivered Integrated luminosity	Main Goal
Pb-Pb	2.76	2010	9 μb^{-1}	First Pb-Pb data taking at LHC
Pb-Pb	2.76	2011	146 μb^{-1}	Study hot & dense QCD matter
p-Pb & Pb-p	5.02	2013	15 nb^{-1} 17 nb^{-1}	Study Cold Nuclear Matter effects
pp	0.9	2009-10	0.33 nb^{-1}	Commissioning
pp	7	2010	0.5 pb^{-1}	Reference for Pb-Pb and p-Pb
pp	2.76	2011	46 nb^{-1}	
pp	7	2011	4.9 pb^{-1}	
pp	8	2012	9.7 pb^{-1}	