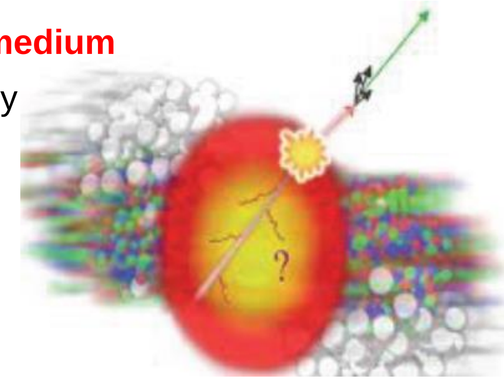
Perspectives for heavy-flavour measurements in ALICE with the upgraded Inner Tracking System

F. Fionda[(a)] on behalf of the ALICE Collaboration
(a) University and INFN – Bari, Italy

Motivations

ALICE (**A L**arge **I**on **C**ollider **E**xperiment) is the dedicated heavy-ion experiment at the LHC.
Goal: study the properties of nuclear matter at extreme conditions of high temperature and density.

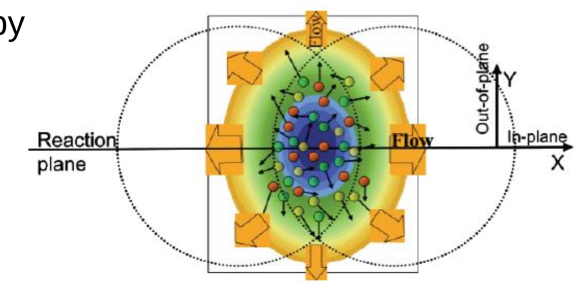
The study of heavy-flavour particles (i.e. containing charm and beauty quarks) is important in several collision systems:
- pp: test of pQCD in a new energy domain and reference for A-A
- p-A: quantify Cold Nuclear Matter (CNM) effects
- A-A: heavy quark pairs are produced at the early stage of the collisions
  → **sensitive to the full evolution of the hot and dense strongly-interacting medium**



✓ medium-induced gluon radiation: $\Delta E \propto \alpha_s C_r \hat{q} L^2$ → gluon radiation of heavy quarks is suppressed (Casimir factor, "dead cone" effect[1])

$\Delta E_g > \Delta E_c > \Delta E_b$ ⇨ Need to compare $R_{AA}(\pi), R_{AA}(D), R_{AA}(B)$

where $R_{AA} = \frac{1}{\langle N_{coll}\rangle} \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T}$ is the **nuclear modification factor**



✓ initial space anisotropy transferred to momentum space → quantified by the second term of the fourier expansion: **elliptic flow (v_2)**

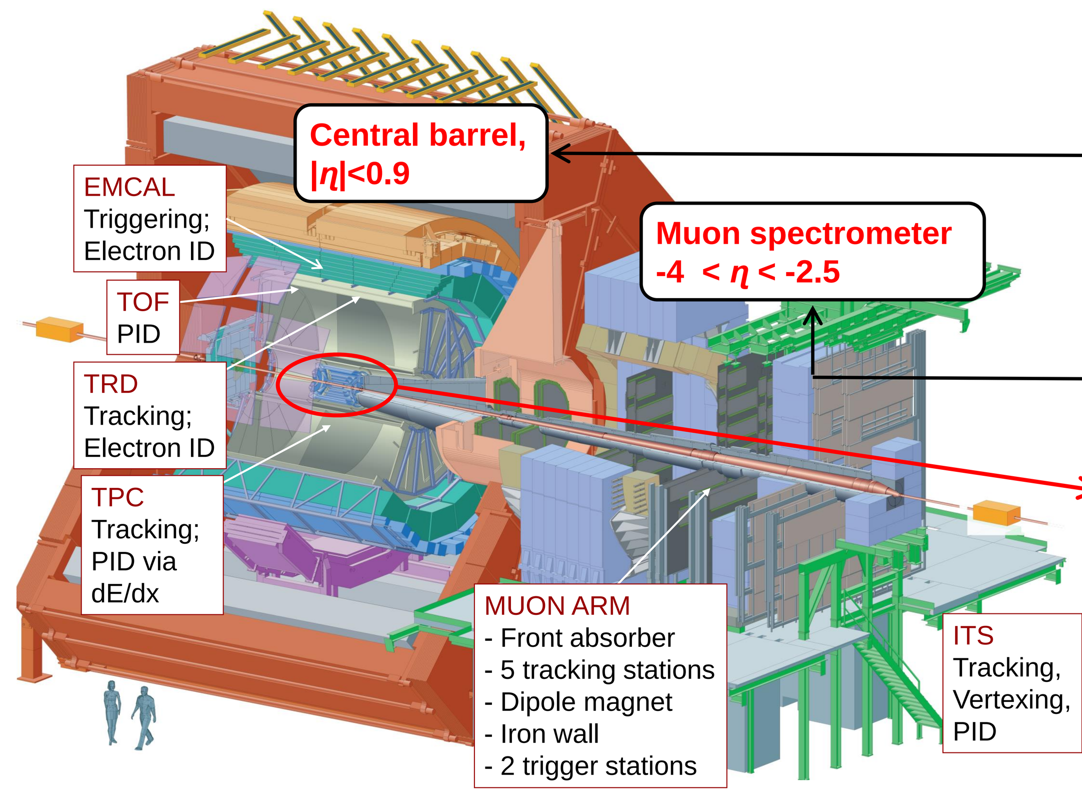
$$\frac{dN}{d\varphi} = \frac{N_0}{2\pi}(1 + 2v_1\cos(\varphi - \Psi_1) + 2v_2\cos[2(\varphi - \Psi_2)] + \cdots)$$

$v_2 > 0$ → heavy quarks take part in the collective expansion of the medium → study their degree of thermalization

✓ quarkonia dissociation in the QGP via Color Debye Screening[2]→ Regeneration mechanisms can counteract suppression at LHC energies[3,4]

Interesting results obtained from the pp, p—Pb and Pb—Pb data collected so far, but there are still open points → need for an upgrade to improve resolution and statistics for Heavy-Flavour measurements → Main targets:
- ✓ achieve a recorded Pb—Pb luminosity $L_{int} \geq 10$ nb^{-1} (about 10^{11} min. bias events) as well as pp and p—Pb reference data needed for Pb—Pb analyses
- ✓ improve vertexing, tracking and read-out rate capabilities

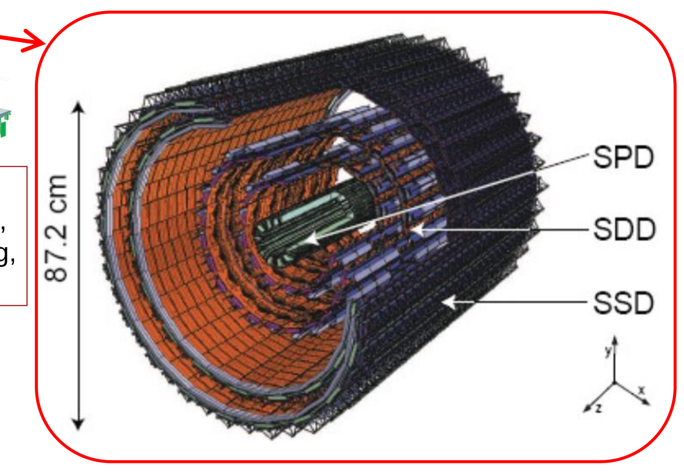
Heavy-flavour measurements in ALICE



Heavy-flavour decay channels currently addressed in ALICE:

$D^0 \to K^-\pi^+, D^+ \to K^+\pi^-\pi^+$
$D_s^+ \to K^-K^+\pi^+,\ D^{*+} \to D^0\pi^+$
$\Lambda_c^+ \to pK^-\pi^+, \Lambda_c^+ \to p K_S^0$ (pp only)
$J/\psi \to e^+e^-, B \to J/\psi + X, D/B \to e + X$

$J/\psi, \psi(2S), \Upsilon, \Upsilon(2S) \to \mu^+\mu^-$
$D/B \to \mu + X$

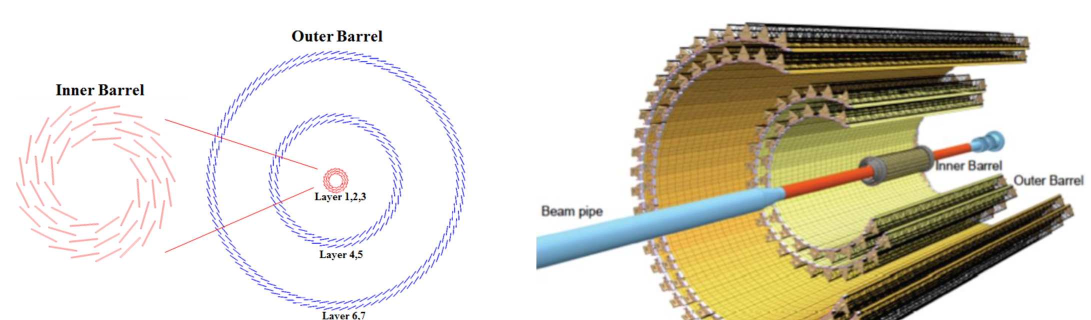


At central rapidity:
- Tracking made by ITS+TPC (+TRD)
- Particle IDentification
  - ✓ combination of energy loss measurements in the TPC and time-of-flight from TOF
  - ✓ further for electrons: transition radiation signal from TRD; EMCAL used for both triggering and PID at high p_T

Heavy flavour measurements rely on ITS

- Excellent impact parameter resolution at low p_T (~ 65 μm for p_T = 1 GeV/c in Pb—Pb) thanks to the two layers of silicon pixel detectors (SPD)
  - ✓ open heavy flavour: analysis based on secondary vertex reconstruction (mean proper decay length $c\tau$ ~ 123 μm for D^0, $c\tau$ ~ 312 μm for D^+, $c\tau$ ~ 59 μm for Λ_c) → tracking and vertexing precision crucial
  - ✓ quarkonia: measurement of non-prompt J/ψ coming from beauty hadron decays

The upgrade of the Inner Tracking System[5]

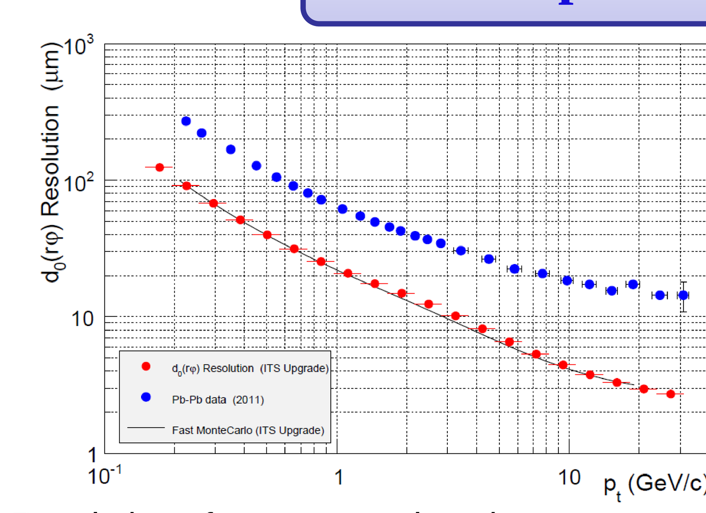


New ITS layout
- 7 cylindrical layers of Monolithic Active Pixel Sensors (MAPS)
- Coverage:
  - ✓ $|\eta| < 1.22$
  - ✓ $22 < r < 430$ mm

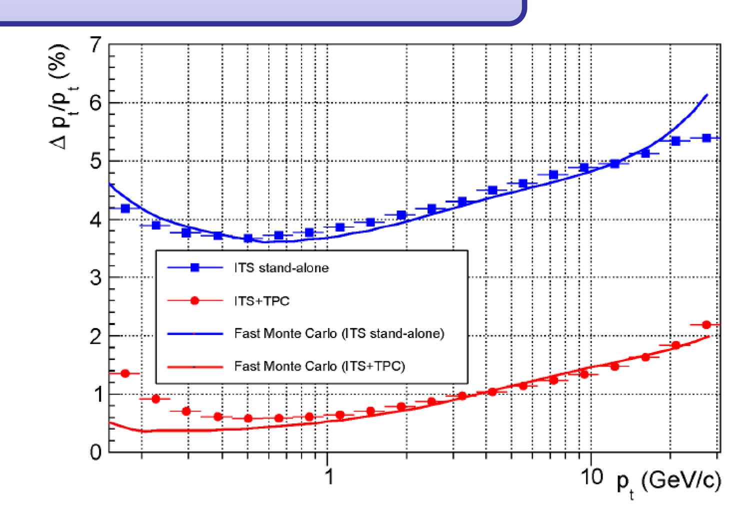
Design goals of the new ITS:
- Improve impact parameter resolution by a factor ~3 (5) in rφ (z)
  - ✓ get closer to the IP: first layer at r_0 = 22 mm (currently 39 mm) and beam pipe radius r_{bp} = 18.2 mm (currently 29 mm)
  - ✓ material budget minimized: 0.3% X_0 for the three innermost layers (currently 1.14% X_0)
  - ✓ smaller pixel size: o(20μm × 30μm) (currently 50μm × 425μm)
- Improve tracking efficiency and p_T resolution especially at low p_T: increase number of layers to 7 (currently 6 layers) and granularity
- Fast readout: up to 100 kHz in Pb—Pb, up to 2 MHz in pp (currently 1 kHz in Pb—Pb)
- Simplify maintenance allowing insertion/removal of detector components

Other ALICE central barrel readout upgrades:
- Upgrade of the Time Projection Chamber (TPC) (replacing MWPCs with micro-pattern gaseous detectors + upgrade of read-out electronics)
- Read-out electronics upgrade for Transition Radiation Detector (TRD) and Time of Flight (TOF)
- Online systems upgrade

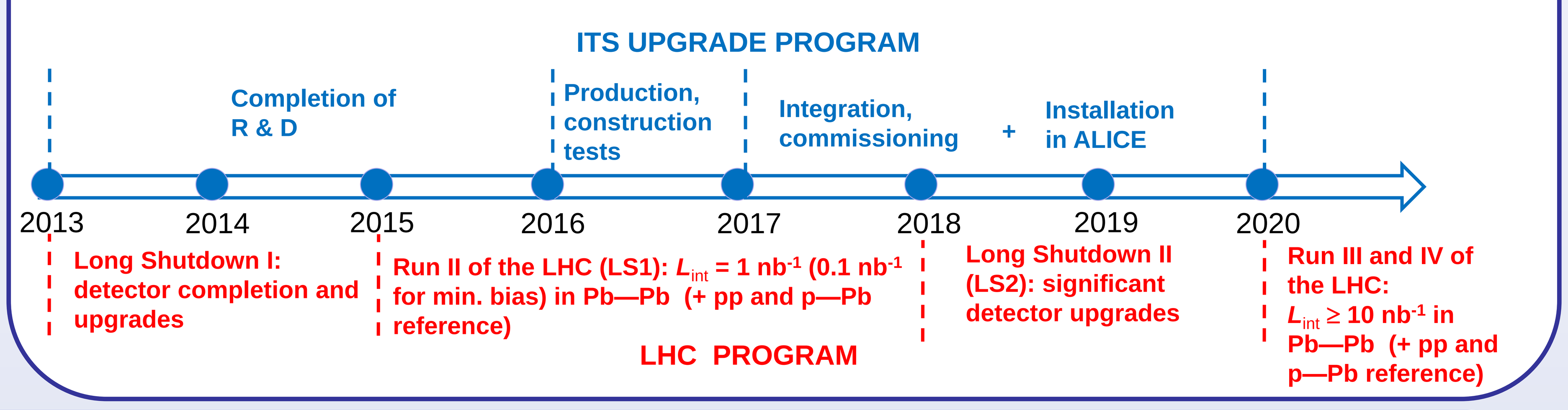
Detector performance studies and timeline



Resolution of transverse plane impact paramenter for **current** and **upgraded** ITS[5] (fast and full MC simulation results shown)



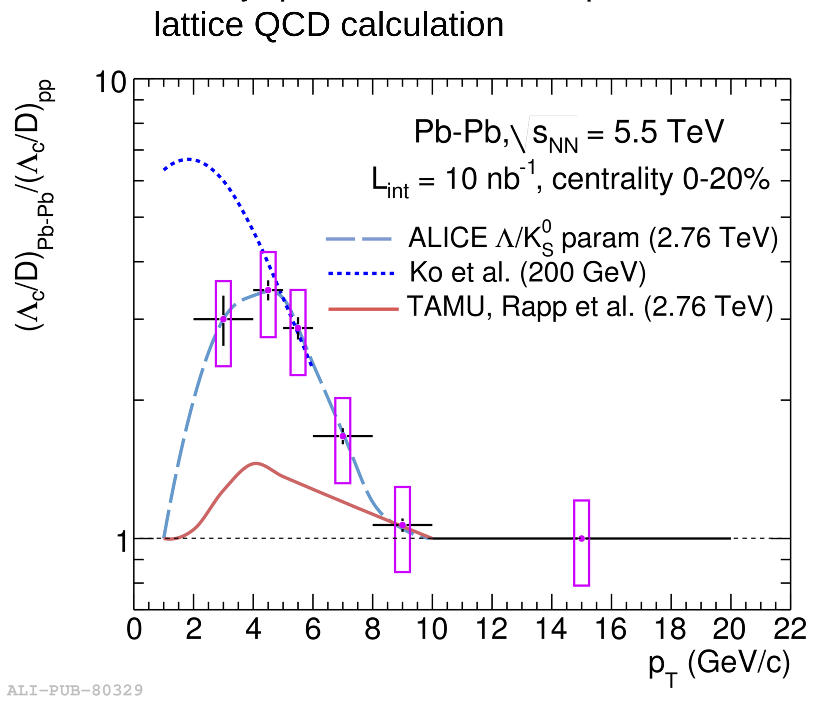
Transverse momentum resolution for the upgraded ITS, in particular for **ITS stand-alone** and **ITS-TPC combined**[5] (fast and full MC simulation results shown)

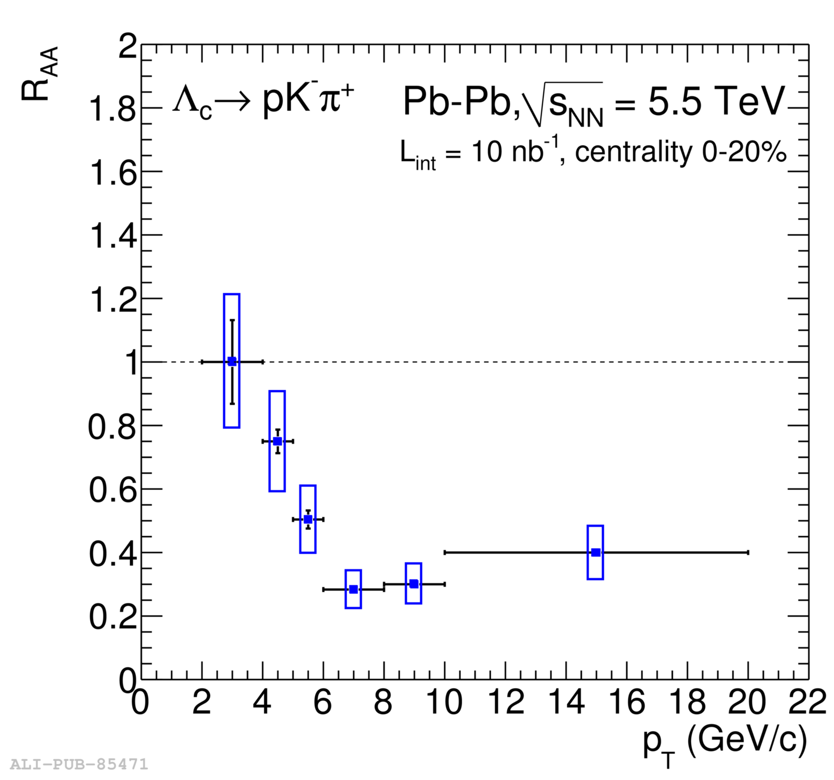


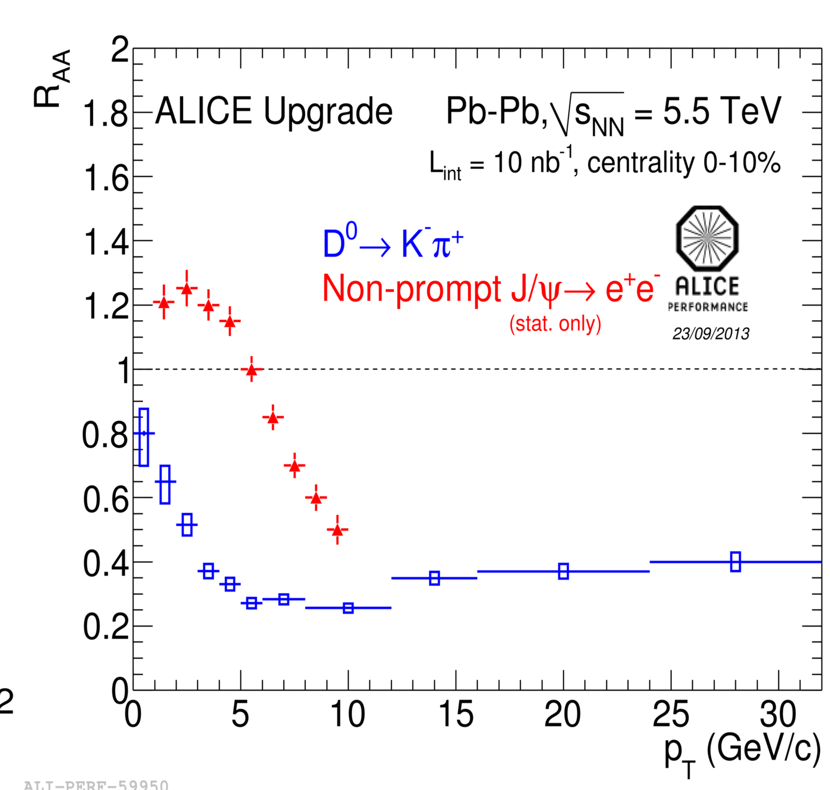
Expected performance for heavy-flavour measurements

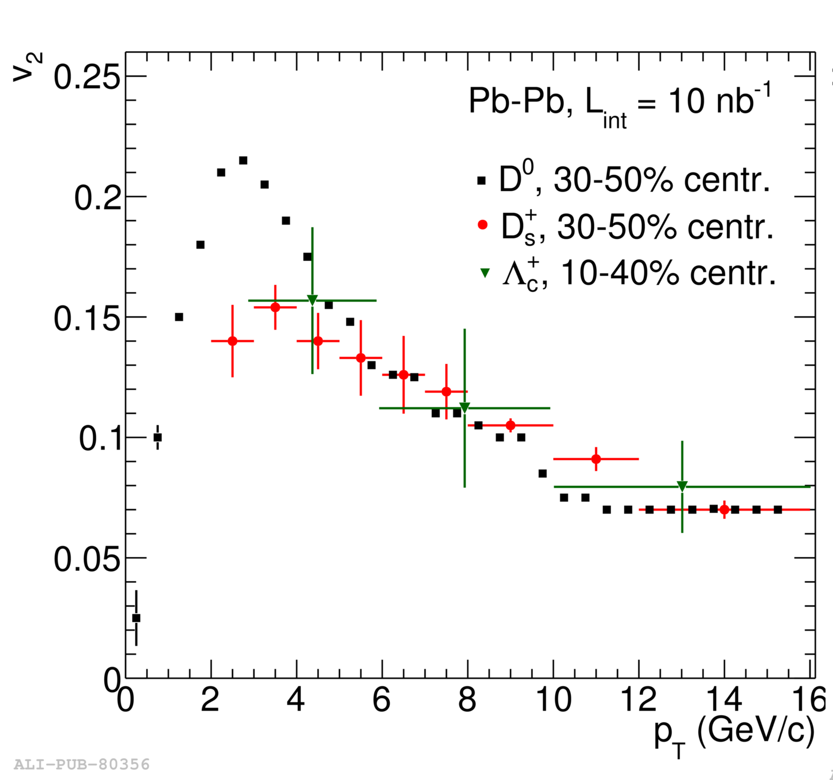
- Prompt D meson R_{AA} and v_2 will be measured with high accuracy down to p_T = 0
- Λ_c measurements will be available for the first time in Pb—Pb
  - ✓ R_{AA} (v_2) for Λ_c available down to p_T = 2 GeV/c (3 GeV/c)
  - ✓ the feasibility of Λ_c will give also the possibility to measure Λ_b (→ Λ_c π) in Pb—Pb
  - ✓ the ratio baryon / meson (which probes the hadronization mechanisms) for charm (Λ_c/D) and beauty (Λ_b/B) will be available for the first time in Pb—Pb
- Beauty hadron R_{AA} and v_2 will be available for the first time at low p_T by studying:
  - ✓ full reconstruction of $B^+ \to \bar{D}^0\pi^+ (\bar{D}^0 \to K^+\pi^-)$
  - ✓ inclusive decay channels $B \to D^0 + X, B \to J/\psi + X$

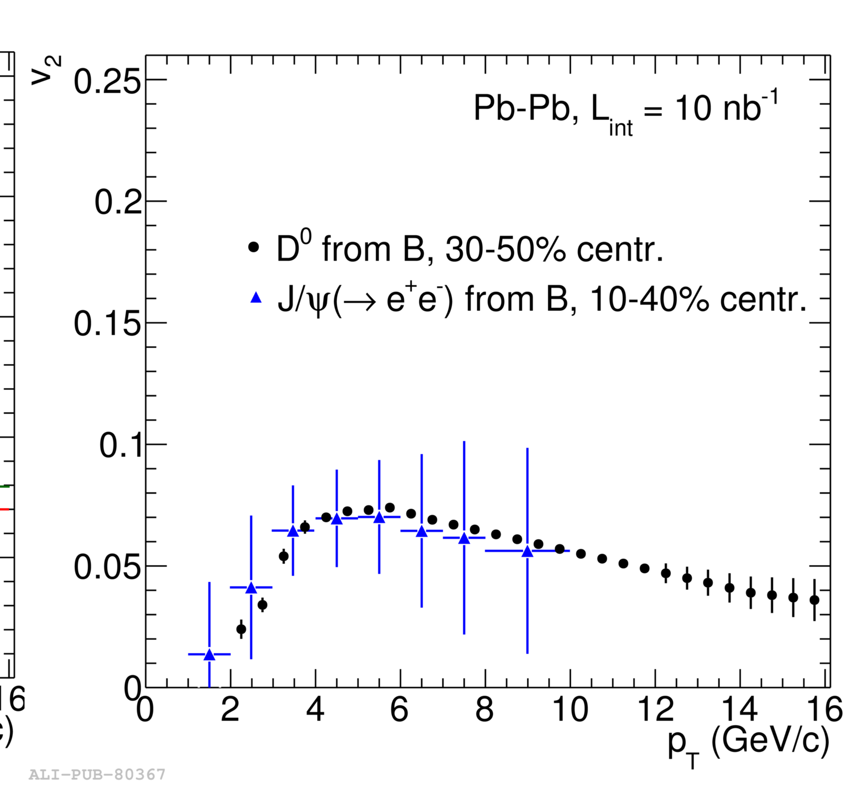
⇨ **R_{AA} and v_2 will be available for both charm and beauty hadrons:**
- ✓ probe mass dependence of R_{AA} and v_2
- ✓ precise measurement of transport coefficient of the QGP for charm and beauty quarks → direct comparison with lattice QCD calculation







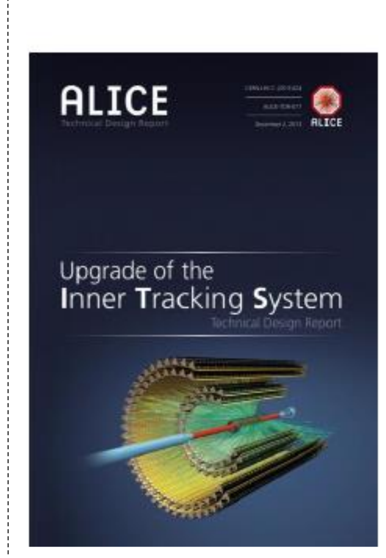




In summary[5]

Observable	Current, 0.1 nb^{-1} p_T^{min} (GeV/c)	Current, 0.1 nb^{-1} statistical uncertainty	Upgrade, 10 nb^{-1} p_T^{min} (GeV/c)	Upgrade, 10 nb^{-1} statistical uncertainty
Heavy Flavour				
D meson R_{AA}	1	10 %	0	0.3 %
D_s meson R_{AA}	4	15 %	< 2	3 %
D meson from B R_{AA}	3	30 %	2	1 %
J/ψ from B R_{AA}	1.5	15 % (p_T-int.)	1	5 %
B^+ yield	not accessible		3	10 %
Λ_c R_{AA}	not accessible		2	15 %
Λ_c/D^0 ratio	not accessible		2	15 %
Λ_b yield	not accessible		7	20 %
D meson v_2 (v_2 = 0.2)	1	10 %	0	0.2 %
D_s meson v_2 (v_2 = 0.2)	not accessible		< 2	8 %
D from B v_2 (v_2 = 0.05)	not accessible		2	8 %
J/ψ from B v_2 (v_2 = 0.05)	not accessible		1	60 %
Λ_c v_2 (v_2 = 0.15)	not accessible		3	20 %
Dielectrons				
Temperature (intermediate mass)	not accessible			10 %
Elliptic flow (v_2 = 0.1) [4]	not accessible			10 %
Low-mass spectral function [4]	not accessible		0.3	20 %
Hypernuclei				
$^3_\Lambda$H yield	2	18 %	2	1.7 %

Conclusions



- Detector layout and several construction aspects well defined → **TDR[5] approved by CERN committees**
- Physics performance studies show that after the ALICE detector upgrade
  - ✓ heavy-flavour R_{AA} and v_2 measurements will be available at low p_T with high precision
  - ✓ new observables will become available, including the production of HF baryons, HF correlations and HF production in association with jets

References

[1] Y.L. Dokshitzer and D.E. Kharzeev, Phys. Lett. B 519, 199 (2001)
[2] T. Matsui, H. Satz, Phys. Lett B 178, 416 (1986)
[3] X. Zhao and R. Rapp, Phys. Lett.B664, 253-257 (2008)
[4] P. Braun-munzinger and J. Stachel, Phys Lett. B490, 196 (2000)
[5] CERN-LHCC-2013-024 / ALICE-TDR-017