INFN Istituto Nazionale di Fisica Nucleare

ALICE

ALICE Upgrade for LHC Run 4 and beyond

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on behalf of the ALICE Collaboration

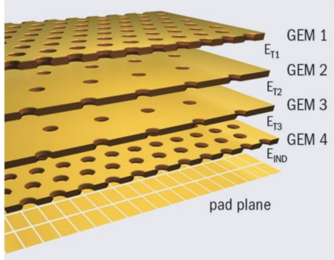
ICHEP 2020 | PRAGUE | ONLINE WORLD

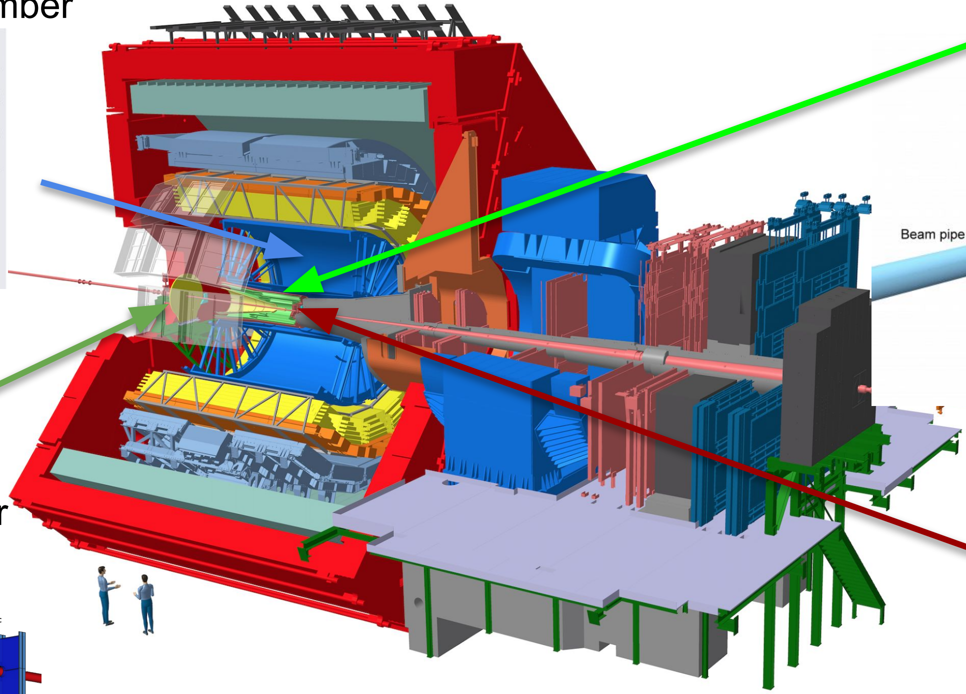
28/07/2020

Ongoing upgrade: ALICE look in Run 3

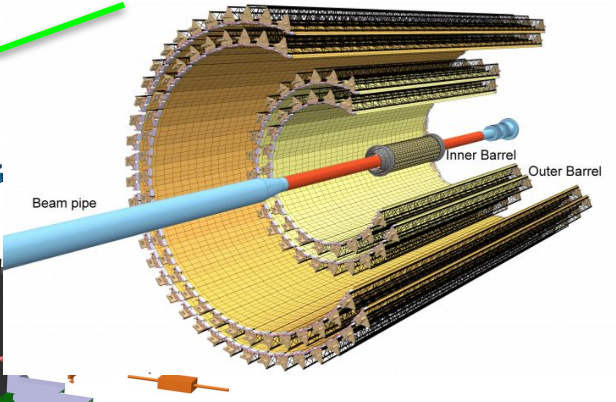
→ **talk by S. M. Panebianco**

Time Projection Chamber

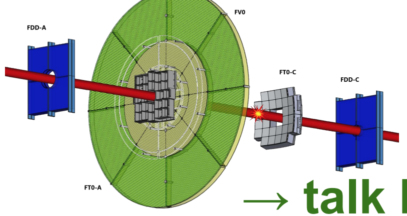




Inner Tracking System 2



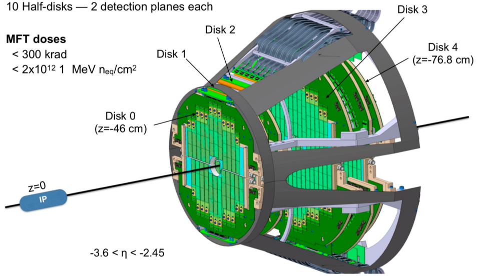
Fast Interaction Trigger



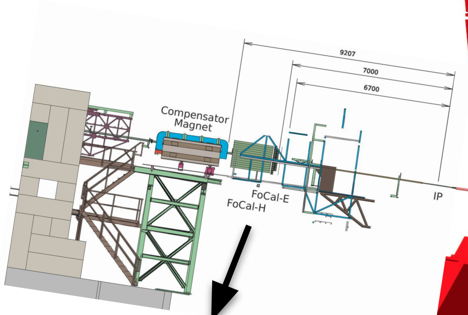
→ **talk by M. Slupecki**

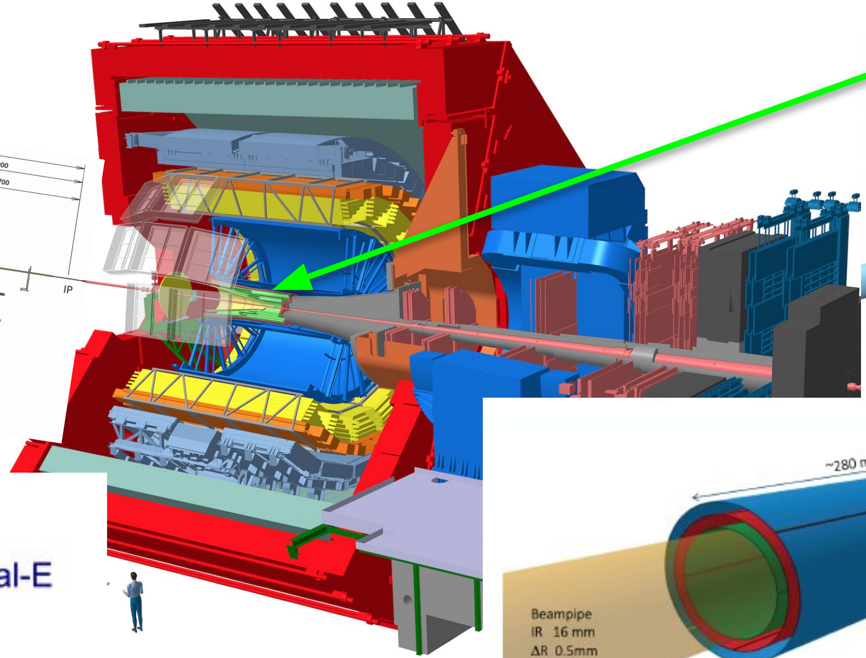
Muon Forward Tracker

10 Half-disks — 2 detection planes each

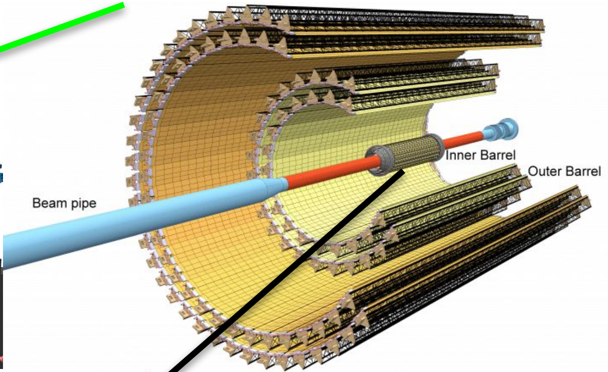


Upgrades for Run 4 (LS3 in 2025)

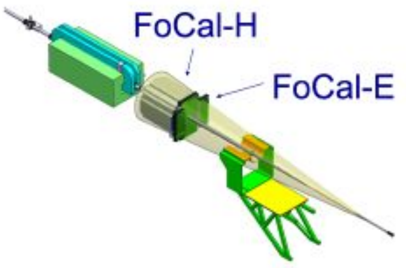


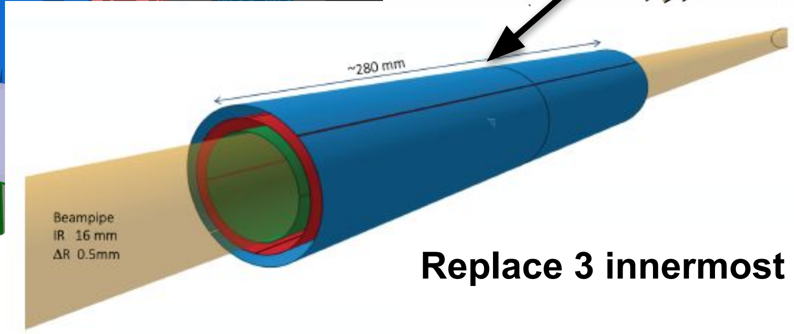


Inner Tracking System 3



Forward Calorimeter



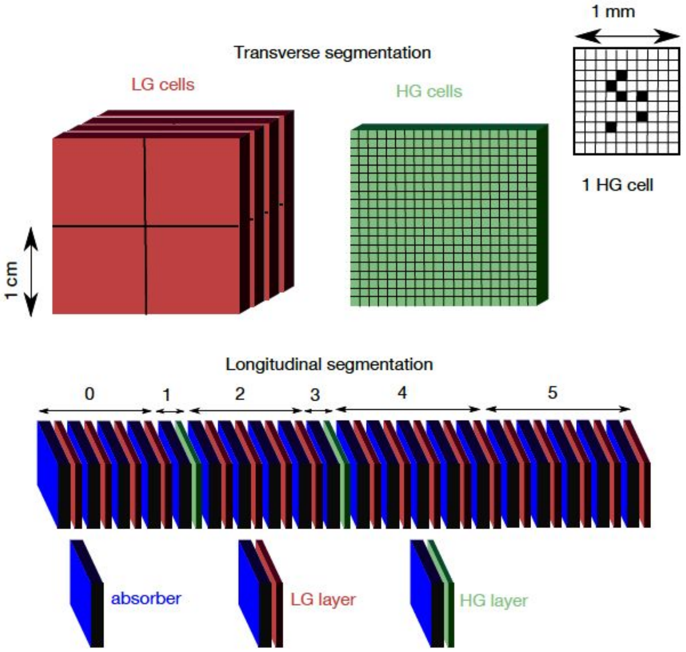


Replace 3 innermost layers

FOCAL

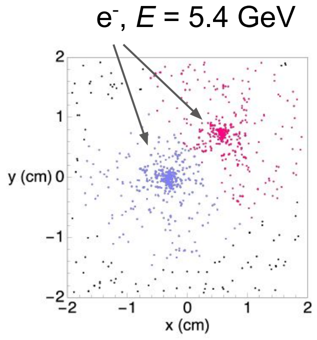
Forward electromagnetic and hadronic calorimeters

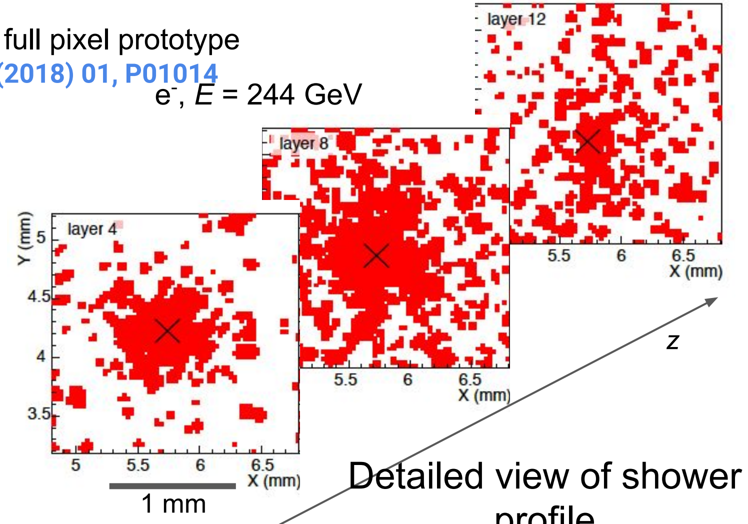
- FoCal-E: high-granularity Si-W sampling calorimeter → direct γ, π^0
- FoCal-H: Pb-Sc sampling calorimeter for photon isolation and jets



Beam test, full pixel prototype

JINST 13 (2018) 01, P01014





LOI: CERN-LHCC-2020-009

Detailed view of shower profile
→ **high-resolution 2-shower separation**

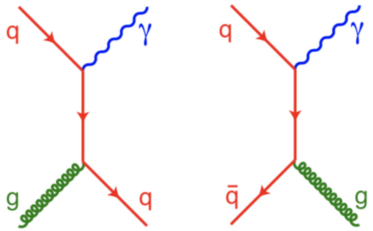
Forward electromagnetic and hadronic calorimeters

- FoCal-E: high-granularity Si-W sampling calorimeter → direct γ, π^0
- FoCal-H: Pb-Sc sampling calorimeter for photon isolation and jets

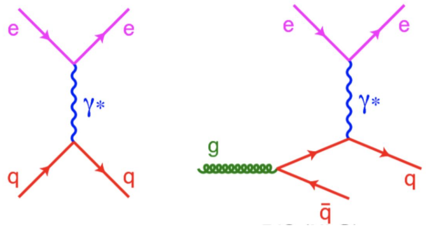
Main goal:

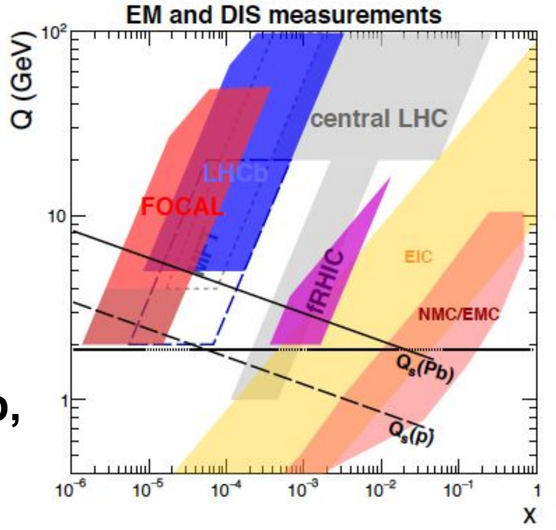
- **Constrain gluon nuclear PDF at small Bjorken-*x***
- Limited information even for proton for $x<10^{-4}$

→ Measure isolated γ at forward y



N.B. DIS experiments: not sensitive to gluon PDF at LO

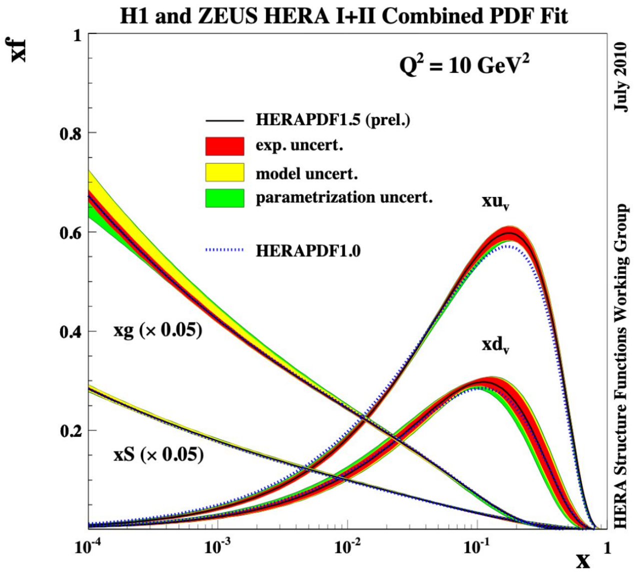




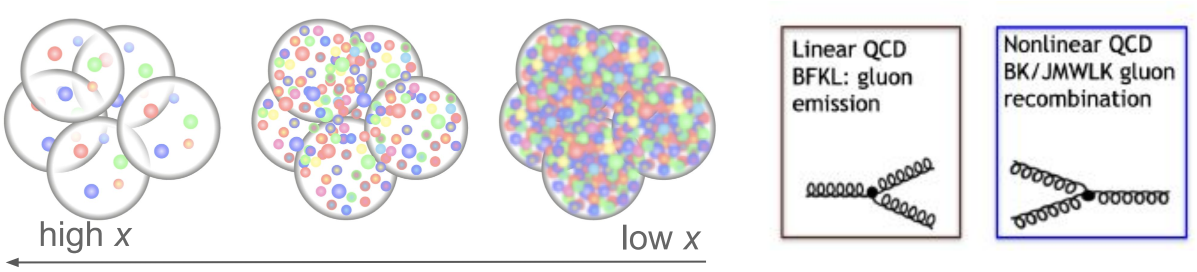
Accessible *x* lower than LHCb, thanks to η coverage

LOI: CERN-LHCC-2020-009

FOCAL



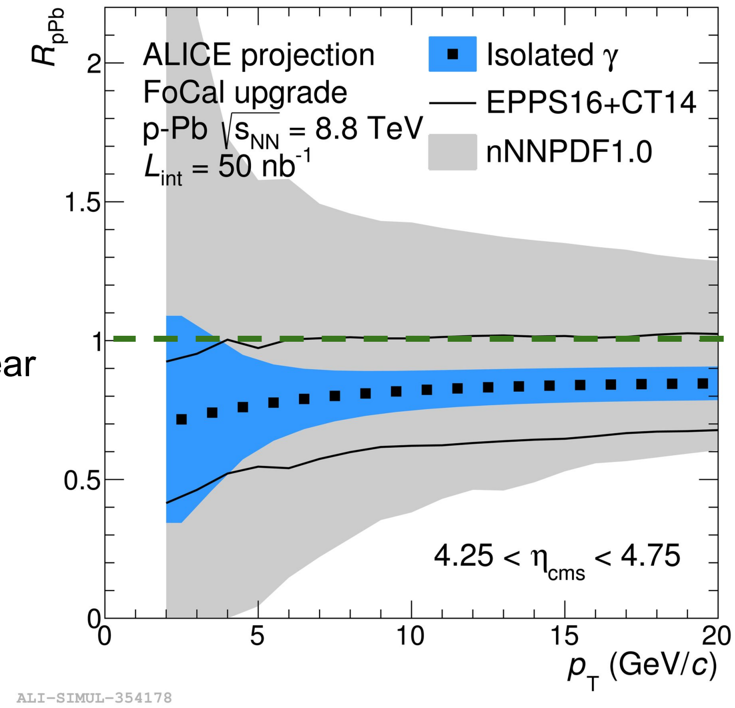
- DIS, HERA: gluon PDF increases at low x
- Infinite growth expected from DGLAP and BFKL evolution equations, including only splitting terms
- “Gluon recombination” (→ non-linear terms) can be important and may “tame” the gluon pdf



Gluon fusion/saturation?

Limited information on nPDF at low *x* → **large uncertainties on theoretical predictions**
→ **difficult to disentangle QGP-induced effects from “cold-nuclear matter” effects**.

FOCAL: performance for isolated γ



R_{pPb}=1
no nuclear effects

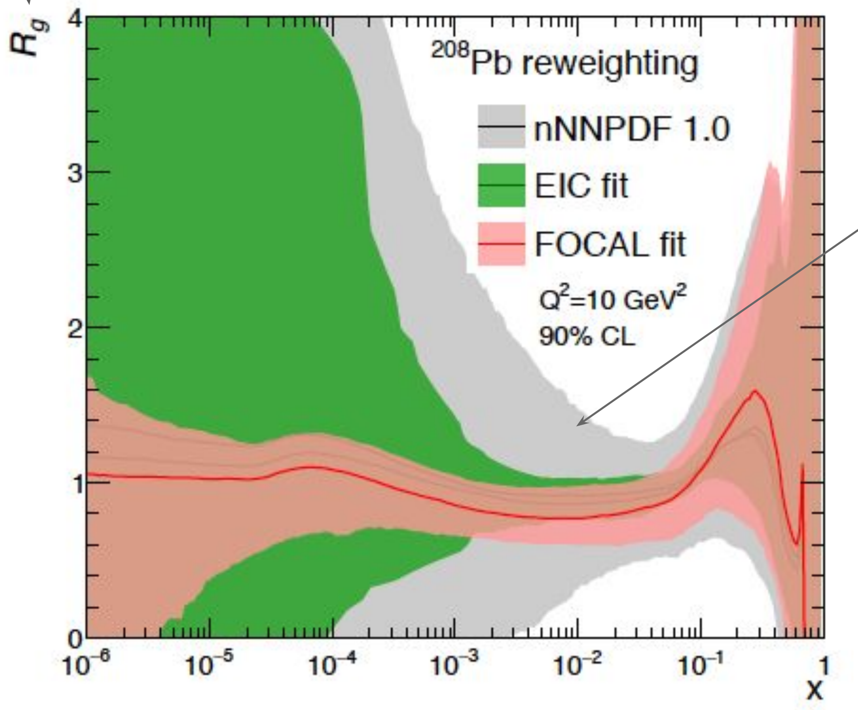
$$R_{pPb} = \frac{1}{\langle N_{coll} \rangle} \cdot \frac{dN_{pPb}/dp_T}{dN_{pp}/dp_T}$$

- Less than 20% relative uncertainty above 6 GeV/c
- Significantly better than theoretical uncertainties from nuclear PDF

LOI: ALICE-PUBLIC-2019-005

FOCAL: expected constraints on gluon nPDF

Nuclear/proton gluon PDF ratio



Recent nNNPDF fit to DIS measurements

- unconstrained for $x < 10^{-2}$
- N.b. constraints from HF measurements by ALICE and LHCb not used

- **With FOCAL: significant constraints at ~ $10^{-5} < x < 10^{-2}$**

- More precise than **electron-ion collider (EIC) experiments** for $x < 10^{-3}$

LOI: ALICE-PUBLIC-2019-005

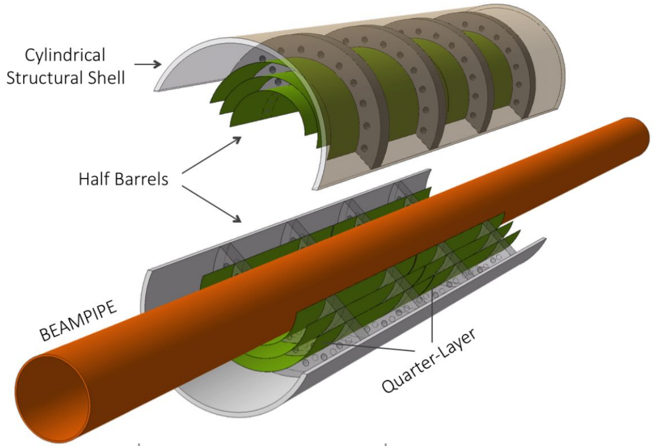
Inner Tracking System 3

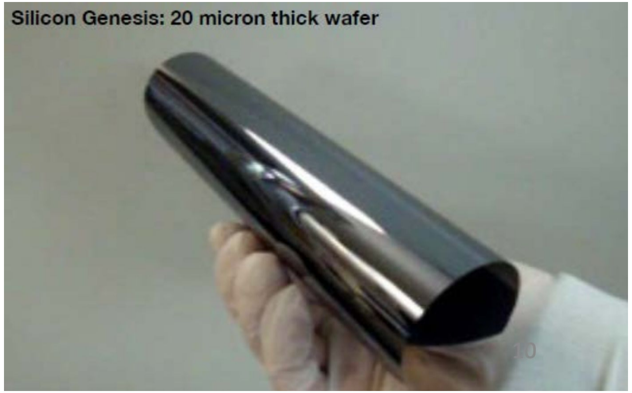
Novel vertex detector consisting of **wafer-scale, ultra-thin Monolithic Active Pixel Sensor (MAPS)** in **curved, perfectly (half-)cylindrical layers**.

- Control logic, data buffers & links at the edge of the sensor
- Air-flow cooling

New beam pipe (r_{out} = 1.65 cm)

LOI: CERN-LHCC-2019-018





Inner layers	ITS1 (Run 1-2)	ITS2 (Run 3)	ITS3 (Run 4)
X/X_0	1.14%	0.38%	0.05%
innermost radius	39 mm	22 mm	18 mm
pixel size	50x425 μm^2	~27x29 μm^2	O(15x15 μm^2)

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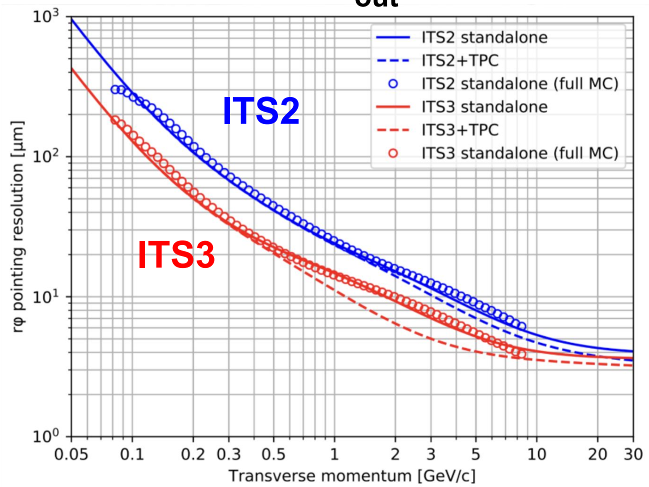
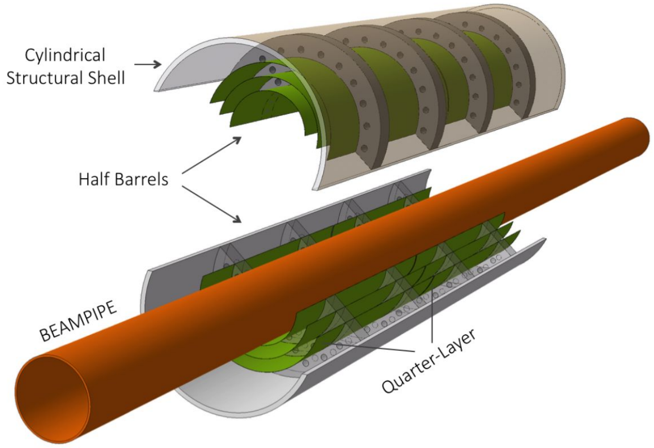
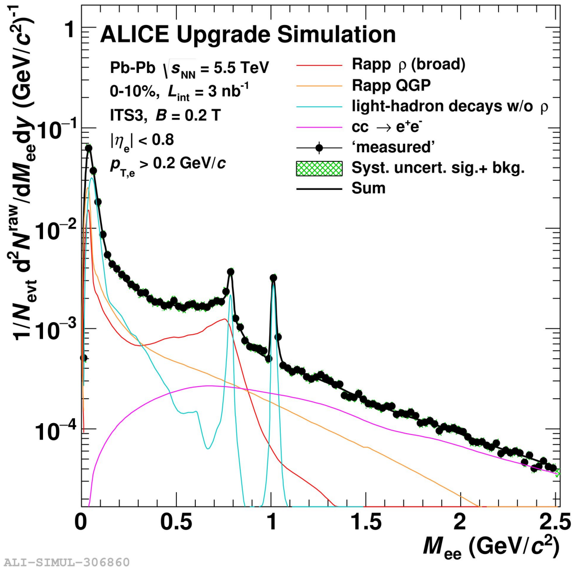


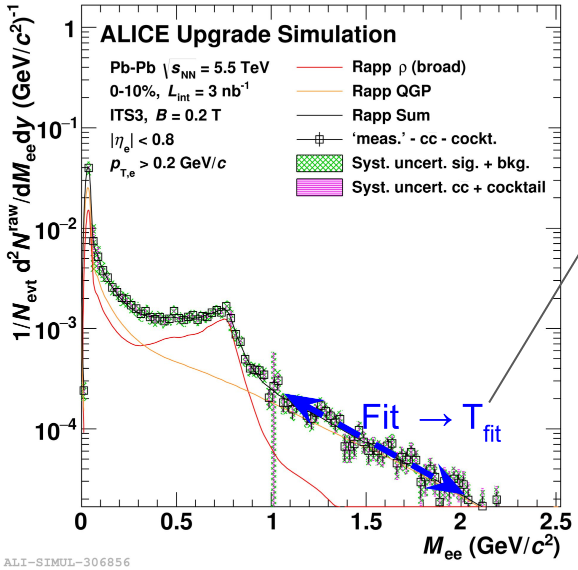


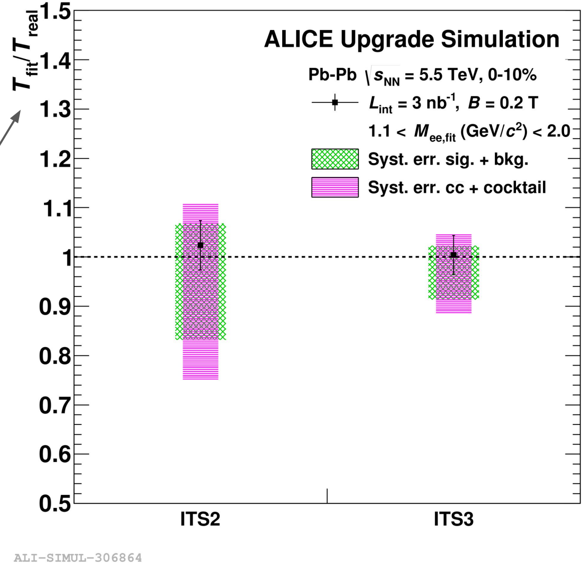
- Improvement by ~factor 2 on DCA resolution
- Significant improvement of tracking efficiency for p_T < 200 MeV/c

LOI: CERN-LHCC-2019-018

ITS3 performance: low-mass dielectrons







Dielectrons → study **electromagnetic radiation from QGP**

M_{ee} slope → **QGP temperature**

ITS3:

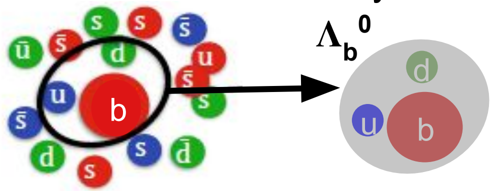
- reduced combinatorial background from conversions
- better charm rejection

Reduction of statistical (~ factor 1.3) and systematic (~ factor 2) uncertainties on QGP temperature

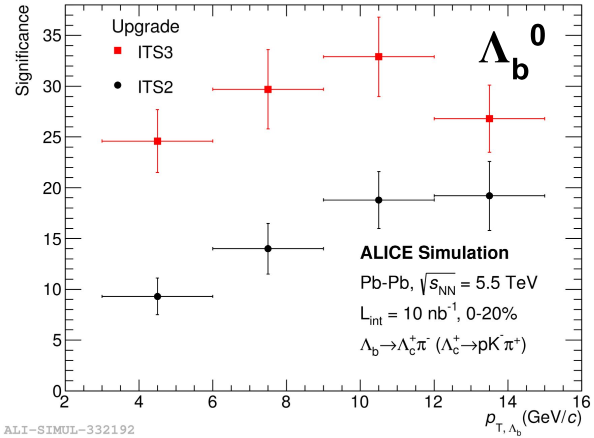
ITS3 performance: beauty-quark hadronisation

Study **beauty-quark hadronisation mechanism**

→ coalescence



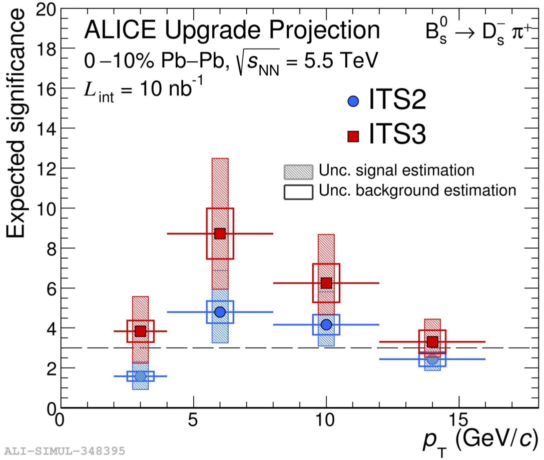
Baryon-over-meson enhancement

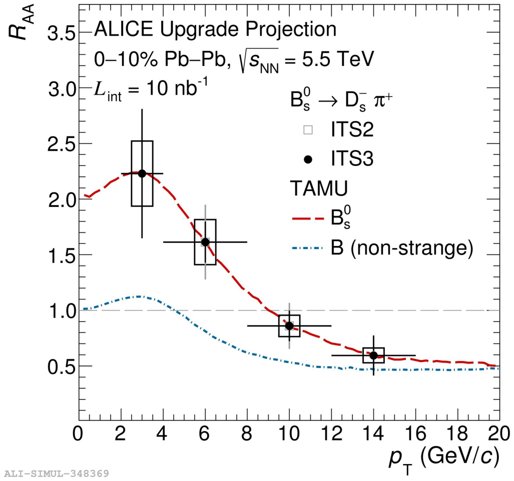


Performance on strange and charmed baryons (Ξ_c, Ω_c^0) under study

B_s^0 enhancement from enhanced strange-quark production in the QGP

$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \cdot \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T}$$



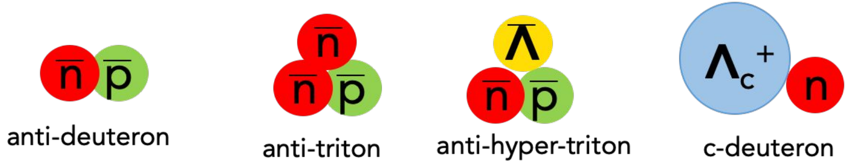


Improvement by a factor ~2-2.5 on statistical precision with ITS3

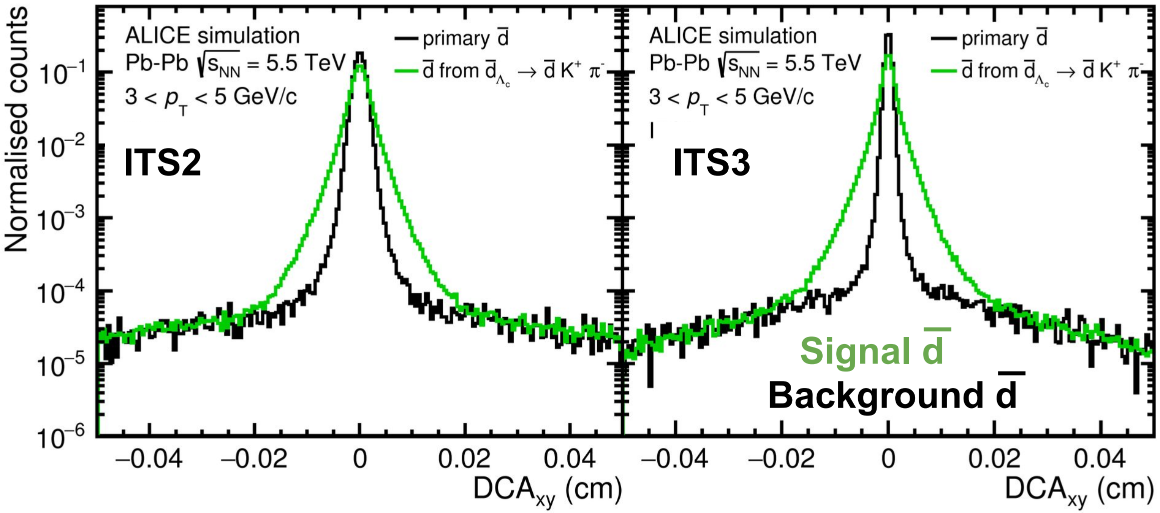
Extend p_T-reach down to 2 GeV/c for B_s^0

→ Access the **most sensitive region for coalescence**

ITS3 performance: charm nuclei



Predicted already in the 70s (PRL 39, 1506 (1977))
Never observed
Production **enhancement expected in Pb-Pb** w.r.t. pp



ALI-SIMUL-350334

Tiny and very challenging signal!

- Assumed cτ~ cτ (Λ_c) ~ 60 μm.
- Unknown decay channels $d_{\Lambda c} \rightarrow dK^-\pi^+$ (as $\Lambda_c \rightarrow pK\pi$)
  - Expected very small BR

ITS3 better resolution on (anti-)deuteron impact parameter crucial to discriminate signal from background

Run 5: ALICE "next-generation" possibilities

"Ambition to design a new experiment to continue with a rich heavy-ion programme at the HL-LHC" mentioned in the Update of the European strategy for particle physics

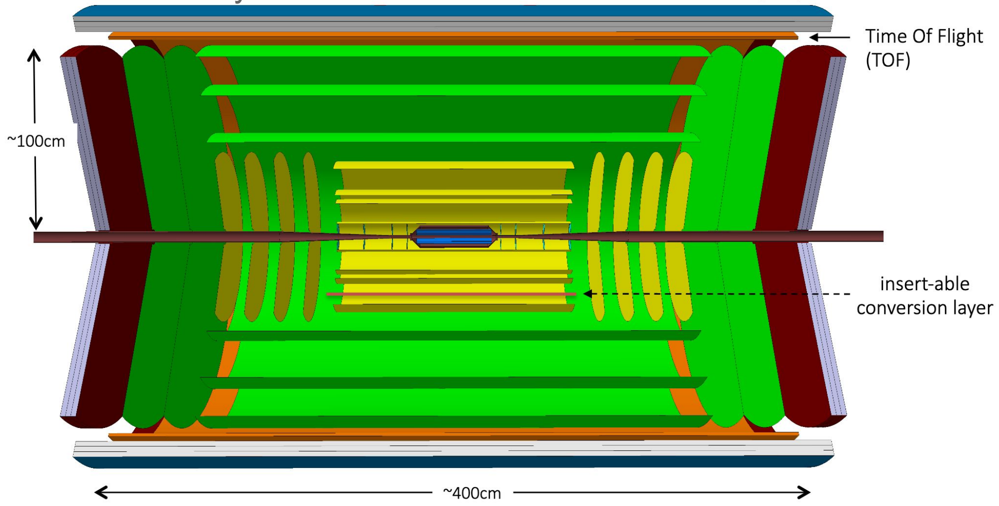
Goal: studies of pp, pA, and AA collisions at **luminosities x20-x50 higher** than in ALICE in Run 3-4.

2019: first document outlining possible concept and physics opportunities https://arxiv.org/abs/1902.01211

Compact, all-silicon **"nearly massless"** detector with **excellent low-p_T tracking capabilities**

- Truly-cylindrical layers with curved wafer-scale ultra-thin MAPS + endcaps ($|\eta|<4$ coverage)
- Innermost layers possibly **inside beam pipe**
- Outer layers: **PID via time-of-flight** with 20 ps resolution

"ALICE3" layout



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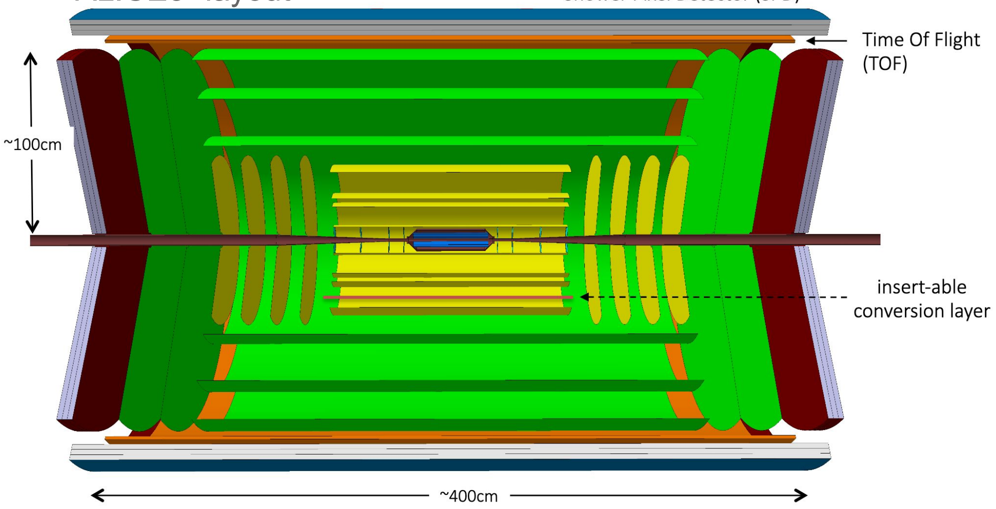
- Innermost layers possibly **inside beam pipe**
- Outer layers: **PID via time-of-flight** with 20 ps resolution

→ Access **doubly and triply heavy-quark hadrons**
→ **Precise dielectron measurements**
→ **soft and ultra-soft photons**

“ALICE3” layout



⇨ **Unprecedented insight into QGP world:**
heavy-quark coalescence, medium temperature, chiral-symmetry restoration

Summary

LS2 (now): Upgrade of ALICE on track → talk by S. M. Panebianco

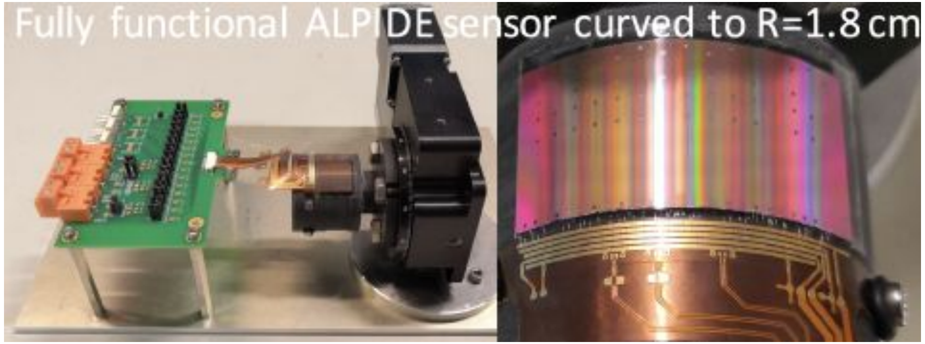
LS3 (2025): new upgrades for LHC run 4

- FOCAL: γ, π^0, jets in the forward region to constrain gluon nPDF at low Bjorken-x
- ITS3: truly cylindrical silicon layers made of ultra-thin wafer-size MAPS
  - low-mass dielectrons (→ QGP temperature)
  - improve HF-particle performance + search for exotic charm nuclei

Beyond 2030: continue heavy-ion programme in HL-LHC era

Possibility of a “nearly-massless” silicon detector

- multi-HF particles
- low-mass dielectrons and soft photons

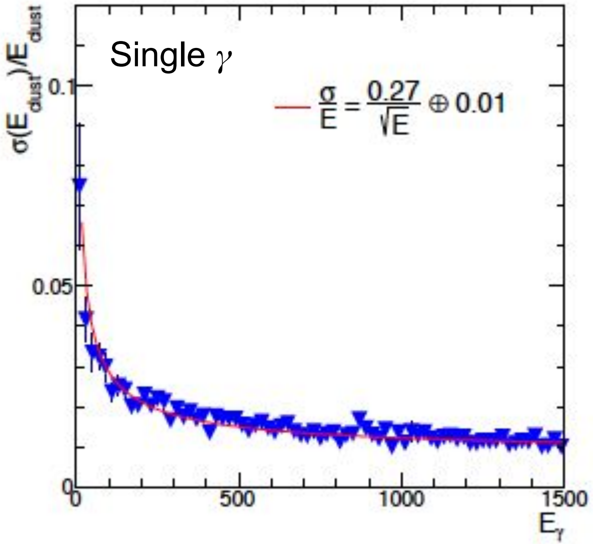


Unprecedented insight into QGP world expected ahead of us!

EXTRA

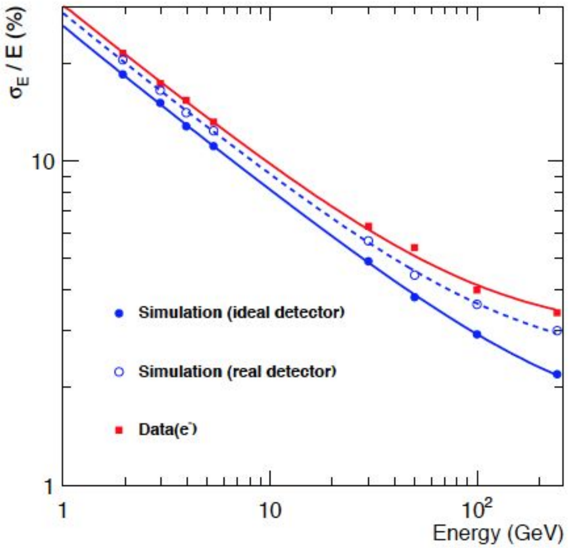
FoCal-E: performance examples

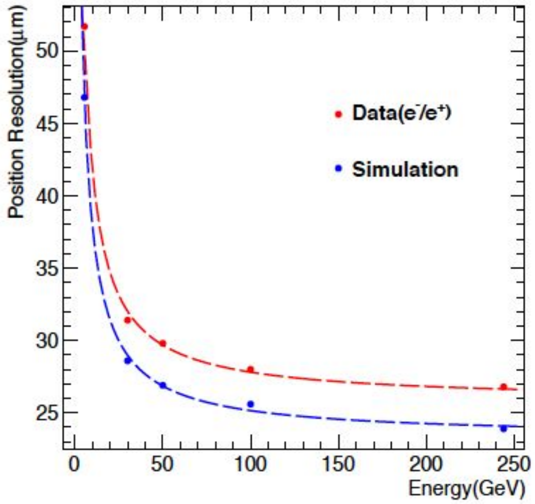
Simulation with realistic Run 4 setup



Test beam (e^-), full-pixel prototype

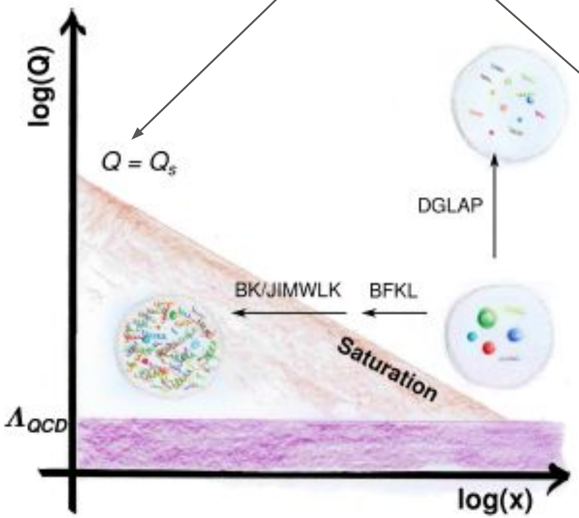
JINST 13 (2018) 01, P01014

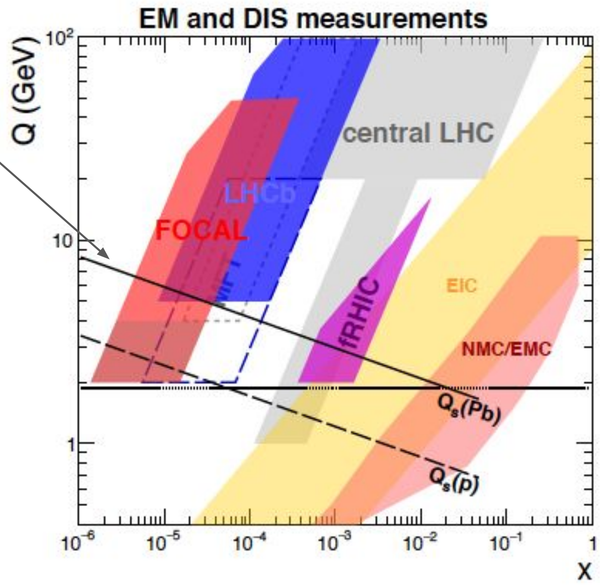


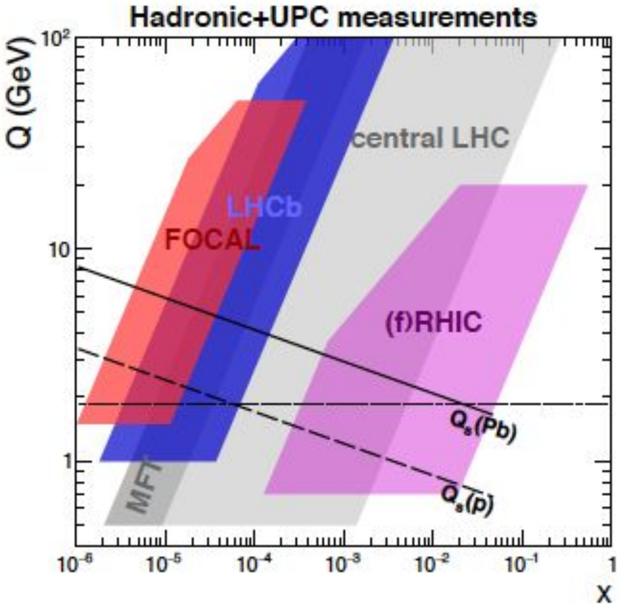


Bjorken-x range coverage

Saturation scale

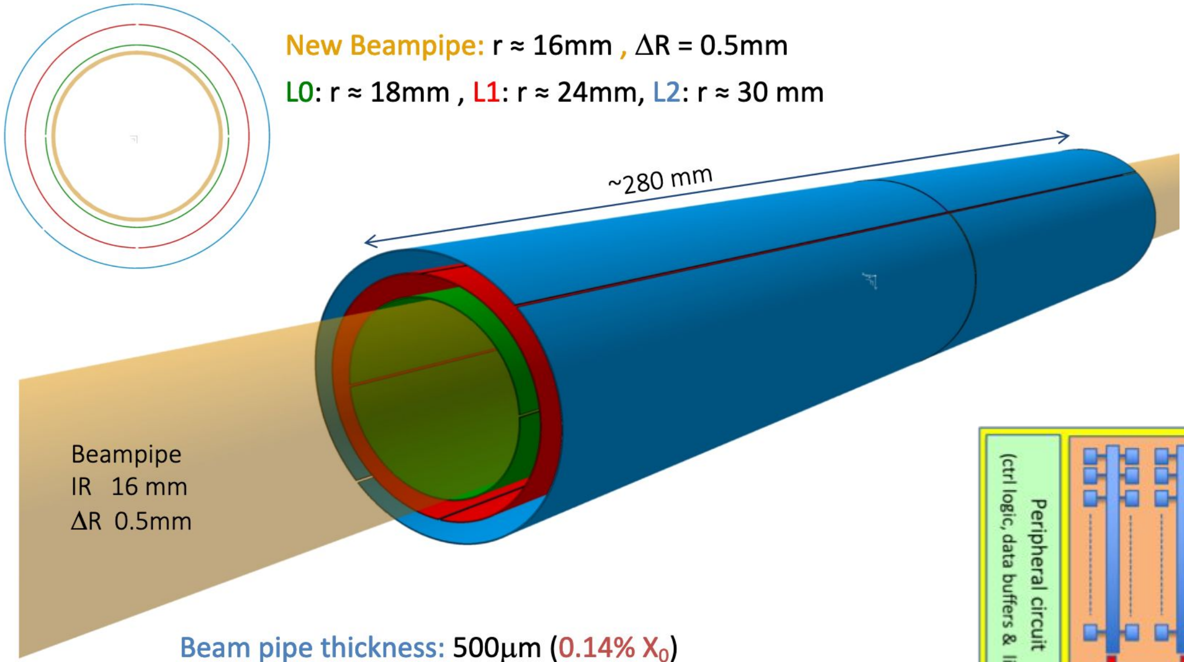






$Q_s^2 \sim (xA)^{1/3}$

ITS3 details



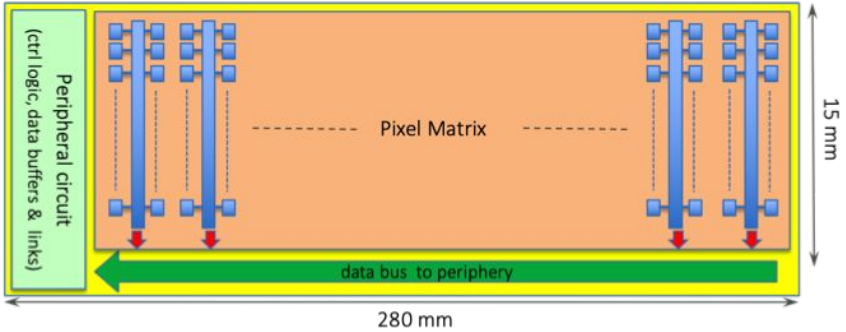
Beam pipe thickness: 500μm (0.14% X_0)

Sensor thickness: 20 – 40μm (0.03 - 0.05% X_0)

Beampipe inner/outer radius (mm)		16.0/16.5	
IB Layer parameters	Layer 0	Layer 1	Layer 2
Radial position (mm)	18.0	24.0	30.0
Length (sensitive area) (mm)	270	270	270
Pseudo-rapidity coverage[a]	±2.5	±2.3	±2.0
Active area (cm^2)	305	408	508
Pixel sensors dimensions (mm^2)	280×56.5	280×75.5	280×94
Number of pixel sensors / layer		2	
Pixel size (μm^2)		$O(15 \times 15)^b$	

[a] The pseudorapidity coverage of the detector layers refers to tracks originating from a collision at the nominal interaction point ($z = 0$).

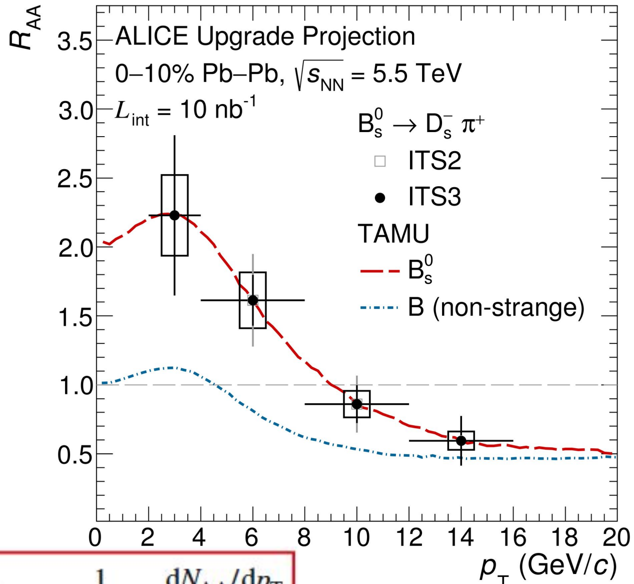
[b] For the fallback solution the pixel size is about a factor two larger ($O(30 \times 30)$ μm^2).



ITS3 Expected performance: B^0_s

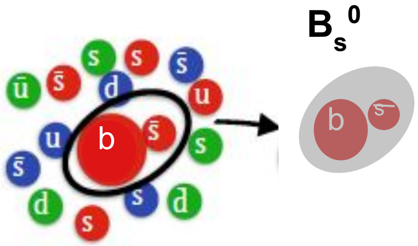
Study **beauty-quark hadronisation mechanism**

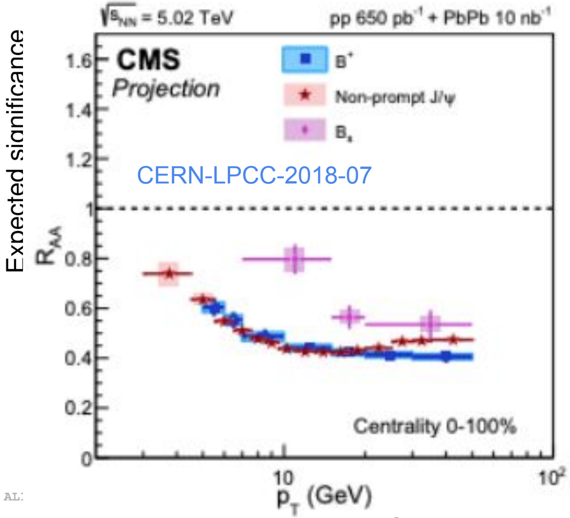
→ B_s^0 production enhancement from hadronisation of beauty quarks via **recombination + enhanced strange-quark production in the QGP**



$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \cdot \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T}$$

TAMU: PLB 735, 445-450 (2014)





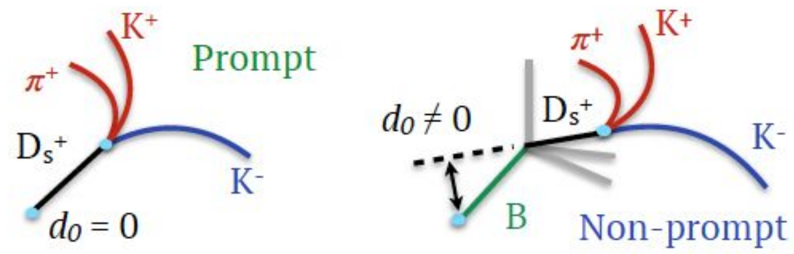
Improvement by a factor ~2 on statistical precision with ITS3
Extend p_T-reach down to 2 GeV/c with~ 25% statistical uncertainty
Expected systematic uncertainty ~10%

→ Access to B_s^0 at low p_T, the **most sensitive region for coalescence**
Better than CMS expectations reported in Yellow Report: improved p_T reach, centrality differential measurement

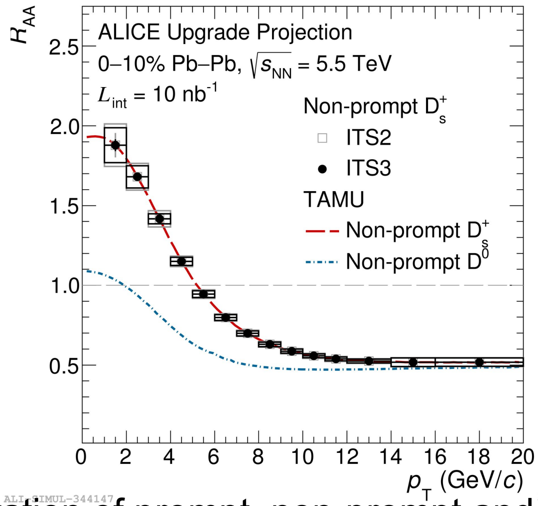
ITS3 expected performance: non-prompt D_s^+

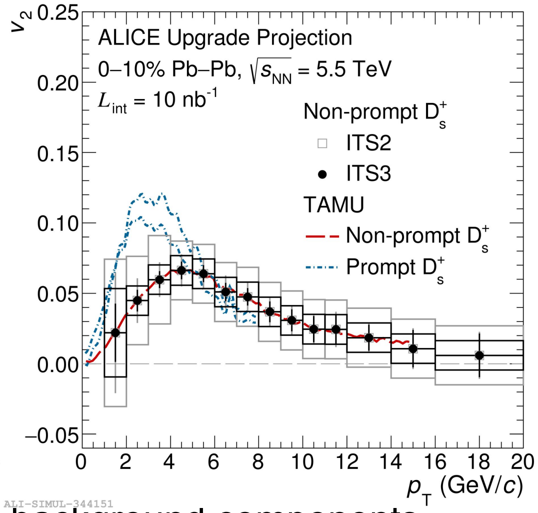
Study **beauty-quark hadronisation mechanism**

→ B_s^0 production enhancement from hadronisation of beauty quarks via **recombination + enhanced strange-quark production in the QGP**



Less direct than B_s^0 but better statistical precision





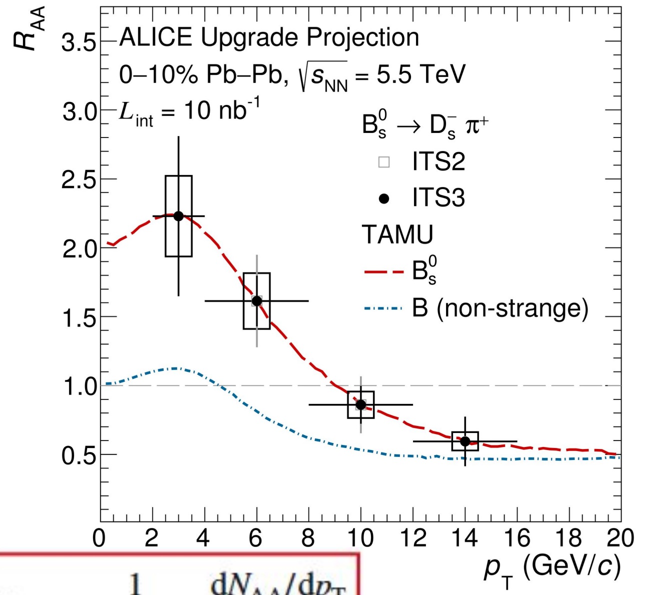
ITS3 ⇨ improve background rejection and separation of prompt, non-prompt and background components.
Reduction (> x2) of statistical and systematic uncertainty

⇨ Possibility to distinguish prompt and non-prompt D_s^+ azimuthal anisotropy (v_2)
→ **constraints to beauty-quark thermalisation and diffusion coefficient**

ITS3 performance: B^0_s

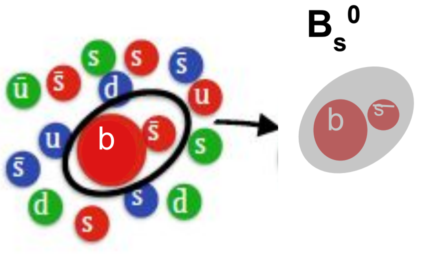
Study **beauty-quark hadronisation mechanism**

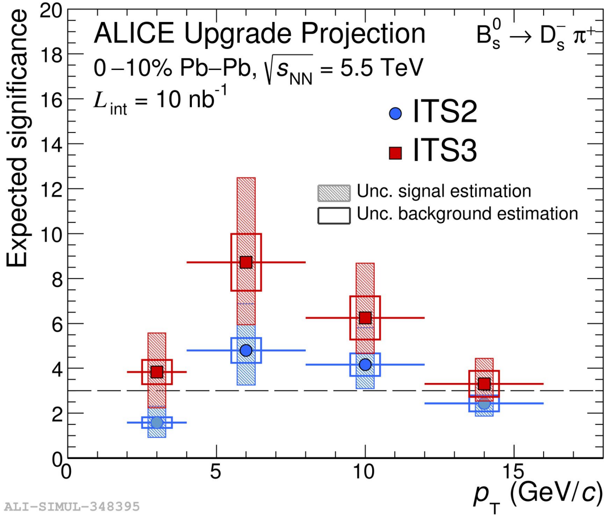
→ B_s^0 production enhancement from hadronisation of beauty quarks via **recombination + enhanced strange-quark production in the QGP**



$$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \cdot \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T}$$

TAMU:
PLB 735, 445-450 (2014)



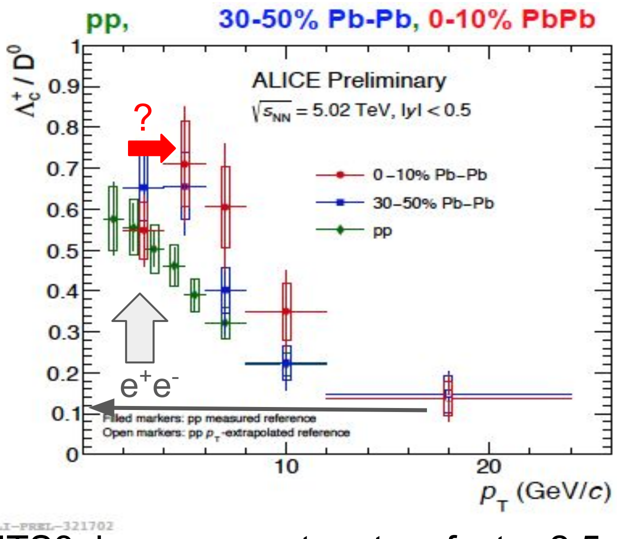


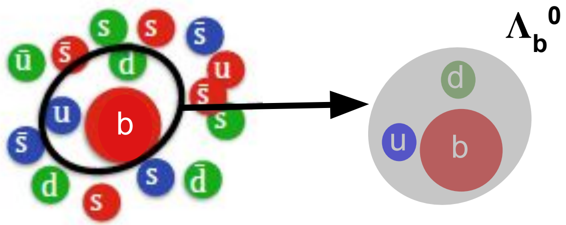
Improvement by a factor ~2 on statistical precision with ITS3
Extend p_T-reach down to 2 GeV/c with~ 25% statistical uncertainty
Expected systematic uncertainty ~10%

→ Access to B_s^0 at low p_T, the **most sensitive region for coalescence**

ITS3 performance: Λ_b

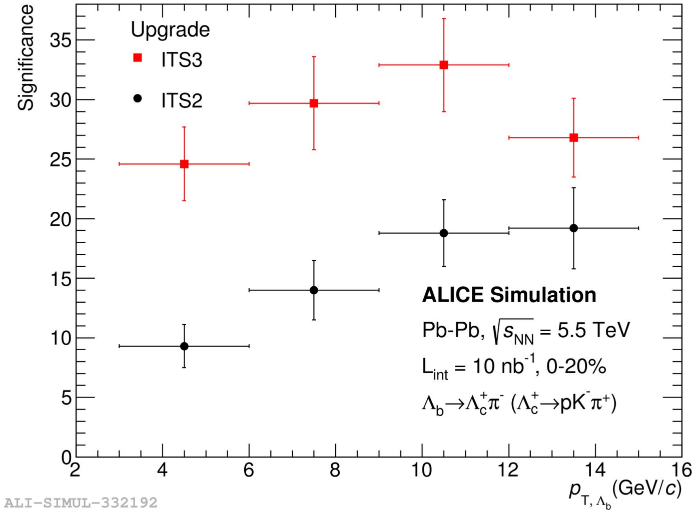
Charm **baryon-over-meson**: enhancement pattern from e^+e^- to pp to Pb-Pb indicate **different heavy-flavour hadronisation mechanism in hadronic environment w.r.t. "vacuum" e^+e^- case**





Λ_c/D^0 measured in Run 2

Beauty baryons in Pb-Pb in Run 3,4



ITS3: improvement up to a factor 2.5 on Λ_b statistical significance

Performance on strange and charmed baryons (Ξ_c, Ω_c^0) under study