Experimental opportunities for heavy-flavour and quarkonium studies for heavy-ion and QGP physics beyond 2030

GDR QCD, Prospective en QCD au delà de 2030
March 11h 2022

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Heavy-ion and QGP perspectives: where do we stand?

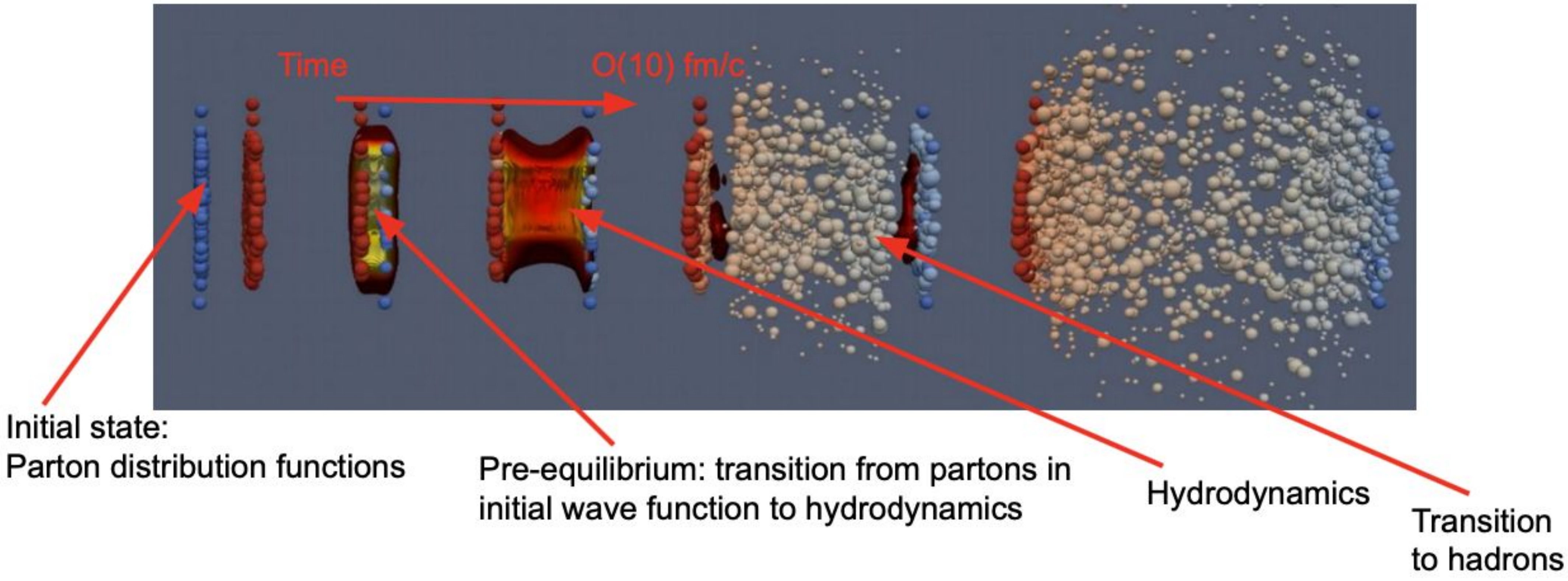
Context:
NuPECC LRP published end of 2017
ESPP update approved in 2020

French side:
Prospectives QGP France Dec. 2019
Séminaire thématique GT03 March 2020
QGP France July 2021
Giens meeting Oct.2021

References:

- QCD HL-LHC yellow report (2018)
- LHC Performance workshop Chamonix (2022)
- Report on the Physics at the HL-LHC and Perspectives for the HE-LHC
- A MIP Timing Detector for the CMS Phase-2 Upgrade (2019)
- New opportunities of heavy-ion physics with CMS-MTD at the HL-LHC (2021)
- ALICE 3 LOI
- The LHCSpin project
- LHCb Phase-II heavy-ion physics case
- LHCb U2 FTDR (to appear)
- EIC Yellow Report
- Exploring high μB with rare probes
- Heavy Ions at the FCC

QGP and open questions in 2030

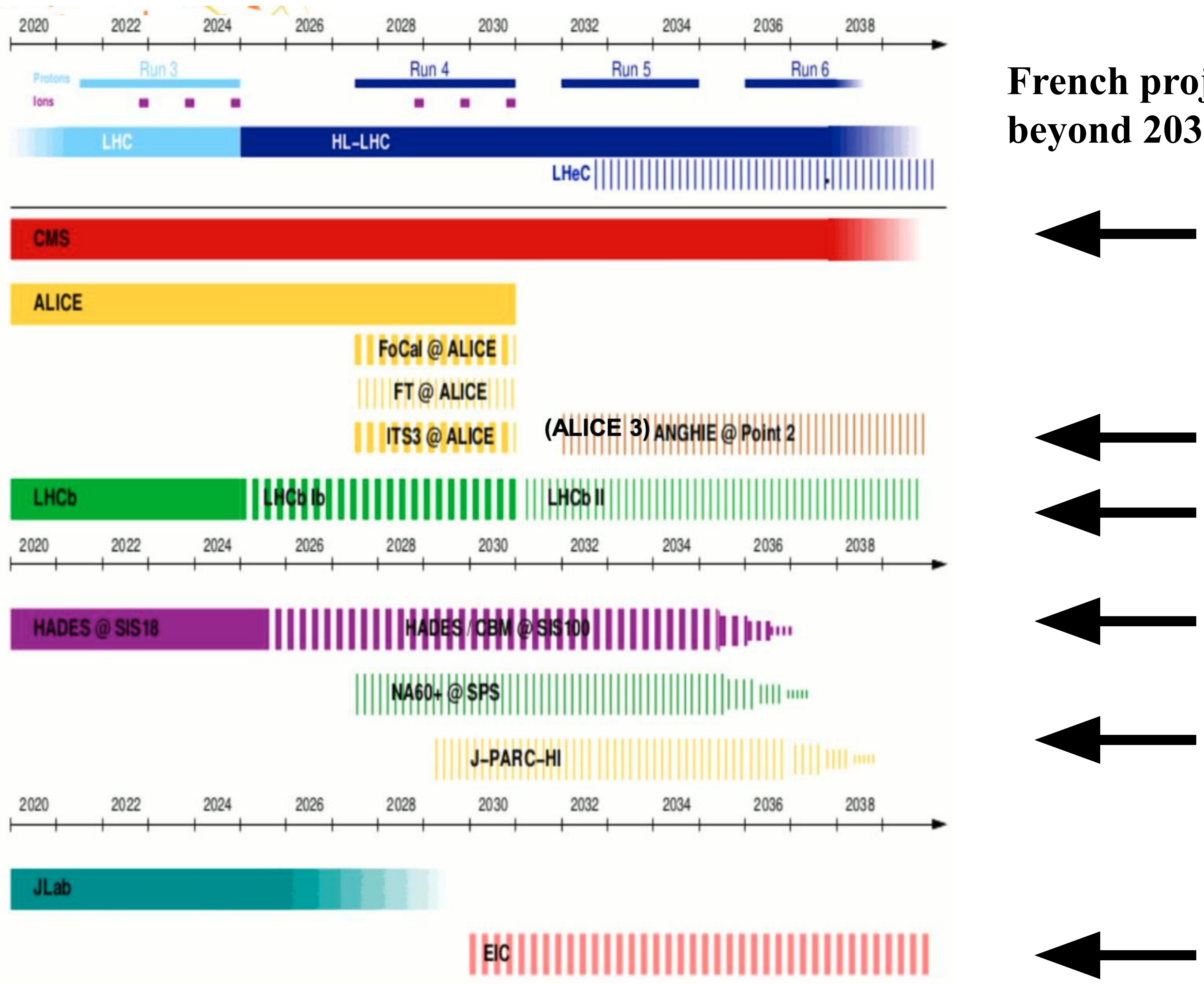


- Characterize the macroscopic long-wavelength properties of the QGP
  → Precise temperature and time evolution of the system
  → **Thermal and preequilibrium radiation**

- Access the microscopic parton dynamics underlying QGP properties
  → Precise experimental assessment of heavy-flavour transport, in-medium QCD force and hadronization mechanism
  → **Heavy-flavour and quarkonia**

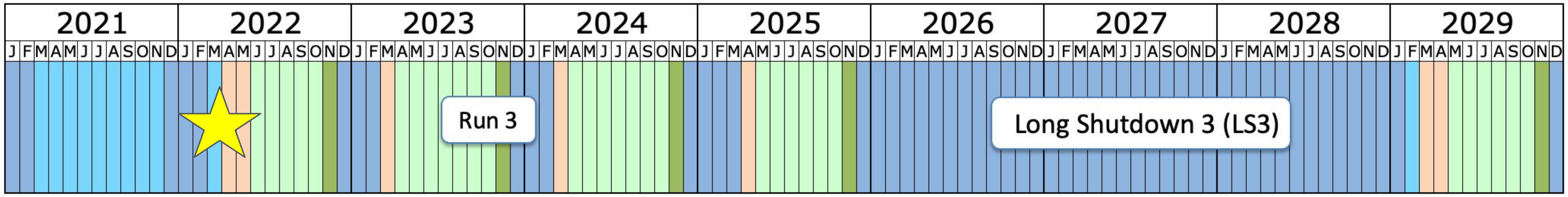
- Develop a unified picture of QCD particle production and initial state from small (pp, pA, γp, γA) to larger (AA) systems
  → **High-luminosity pp, pA and fixed-target programmes**

French projects in hadronic physics

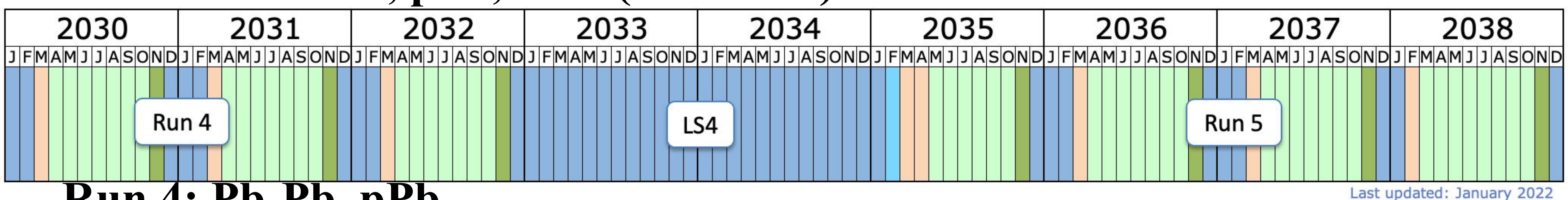


French project beyond 2030

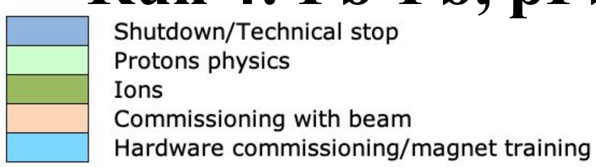
LHC beyond 2030 → beyond Run 4



Run 3: Pb-Pb, pPb, O-O (short run)



Run 4: Pb-Pb, pPb

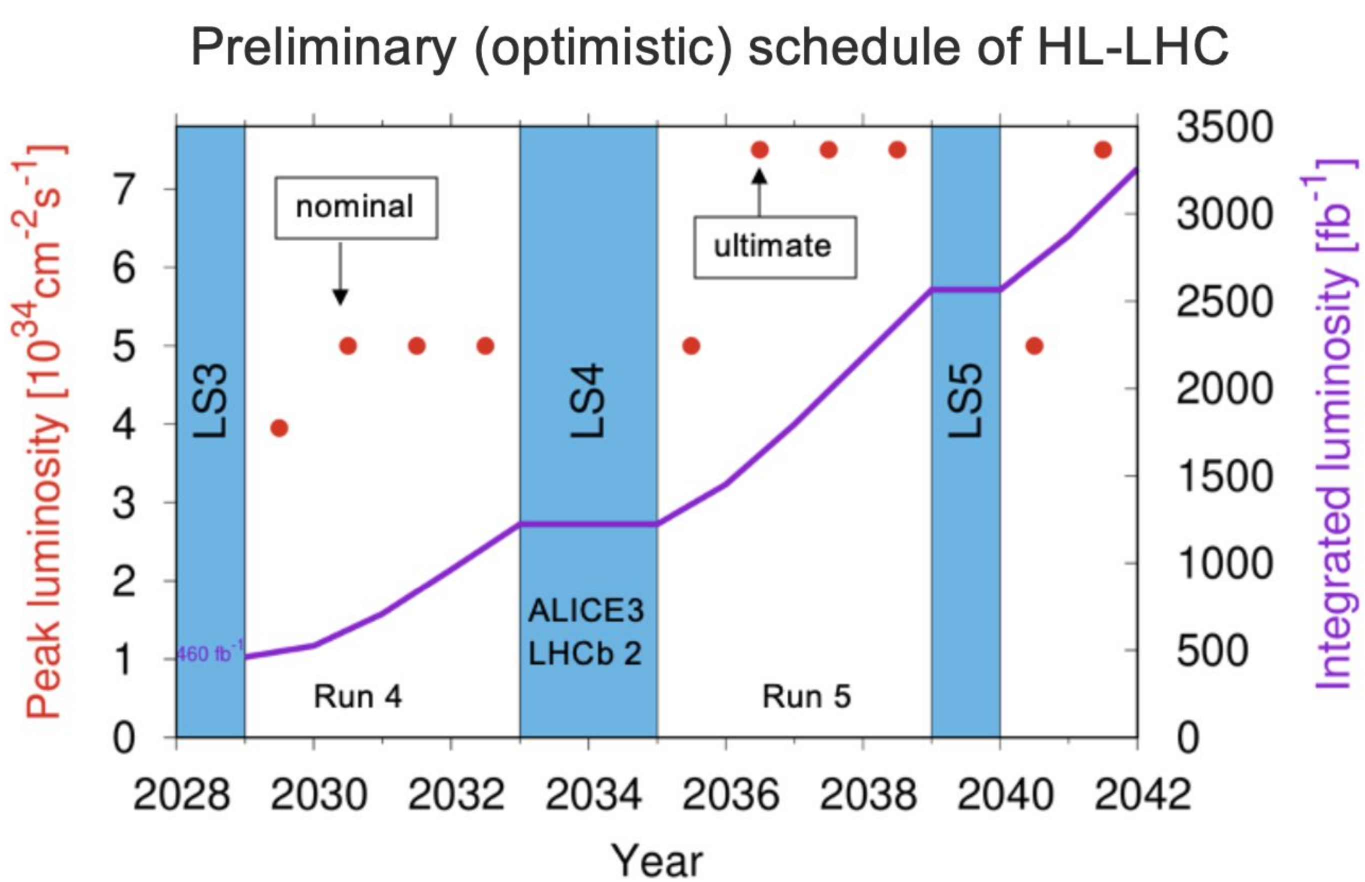


LHC calendar updated in Jan. 2022:

- Run 3 and LS3 extension
- Beyond Run 4 and LS4 = in 2035!
- Heavy ion runs in Run 5 and 6 (6 years)

Major upgrades:

- LS3: ATLAS/CMS HL-LHC Phase-II
- LS4: ALICE 3 (LoI under LHCC review) and LHCb Phase-II (framework TDR under LHCC review)



Luminosity projections with lighter ions

J.Klein Chamonix workshop 2022

[https://indico.cern.ch/event/1078695/]

Nucleon-nucleon luminosity: $\mathscr{L}_{NN} = A^2 \cdot \mathscr{L}_{AA}$

optimistic scenario	O-O	Ar-Ar	Ca-Ca	Kr-Kr	In-In	Xe-Xe	Pb-Pb
$\langle L_{AA} \rangle$ (cm^{-2} s^{-1})	$9.5 \cdot 10^{29}$	$2.0 \cdot 10^{29}$	$1.9 \cdot 10^{29}$	$5.0 \cdot 10^{28}$	$2.3 \cdot 10^{28}$	$1.6 \cdot 10^{28}$	$3.3 \cdot 10^{27}$
$\langle L_{NN} \rangle$ (cm^{-2} s^{-1})	$2.4 \cdot 10^{32}$	$3.3 \cdot 10^{32}$	$3.0 \cdot 10^{32}$	$3.0 \cdot 10^{32}$	$3.0 \cdot 10^{32}$	$2.6 \cdot 10^{32}$	$1.4 \cdot 10^{32}$
$\mathscr{L}_{AA}$ (nb^{-1} / month)	$1.6 \cdot 10^{3}$	$3.4 \cdot 10^{2}$	$3.1 \cdot 10^{2}$	$8.4 \cdot 10^{1}$	$3.9 \cdot 10^{1}$	$2.6 \cdot 10^{1}$	$5.6 \cdot 10^{0}$
$\mathscr{L}_{NN}$ (pb^{-1} / month)	409	550	500	510	512	434	242

Updated heavy-ion scenarii *w.r.t.* LHC Yellow Report

- PbPb luminosity limited by lead bunch intensity due to large electromagnetic interaction
- Lighter ion beams:
  - larger NN luminosity (~x2) than Pb-Pb: but largely reduced luminosities for O to Kr systems *w.r.t.* LHC Yellow Report
  - lower combinatorial background
  - lighter QGP effects
  - find a compromise! Depend on hard probes observables…
- LHC studies and machine developments needed: only Xe and Pb beams have been used so far. O beam will be used in Run 3.

CMS Phase-II

Objective of Phase-II upgrade is to maintain its current performance for an average pile-up of 200 in pp→ will greatly extend the heavy-ion capabilities

Trigger / HLT / DAQ

L1: 750 kHz
HLT: 60 GB/s

New Endcap Calorimeters

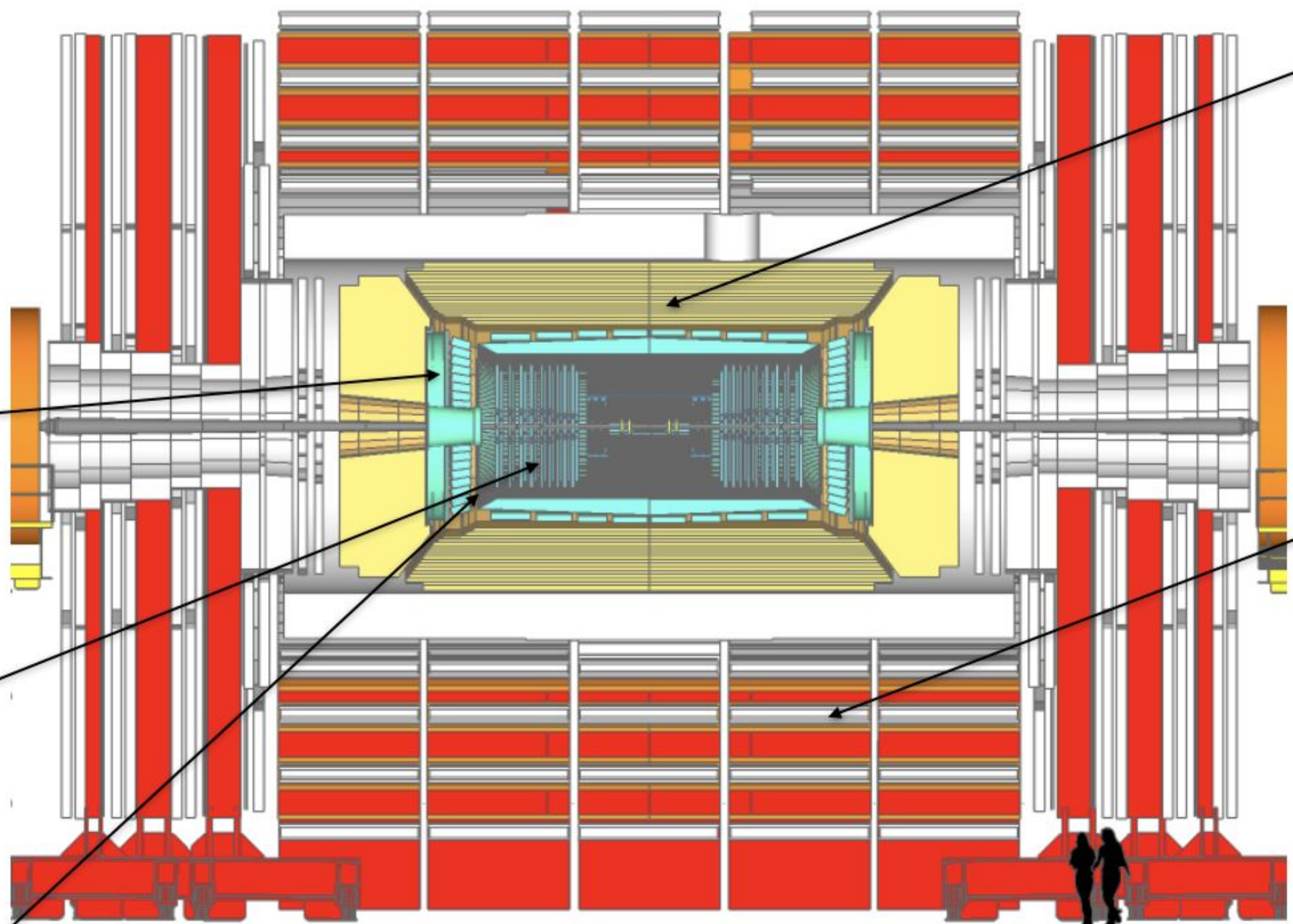
Very good granularity
Up to to $|\eta| = 3$

New Tracker

Improved granularity
Reduced material
$|\eta| < 2.4 \rightarrow |\eta| < 4$

New MIP Timing Detector

BTL (barrel) and ETL (endcap)
Hadron PID over $|\eta| < 3$



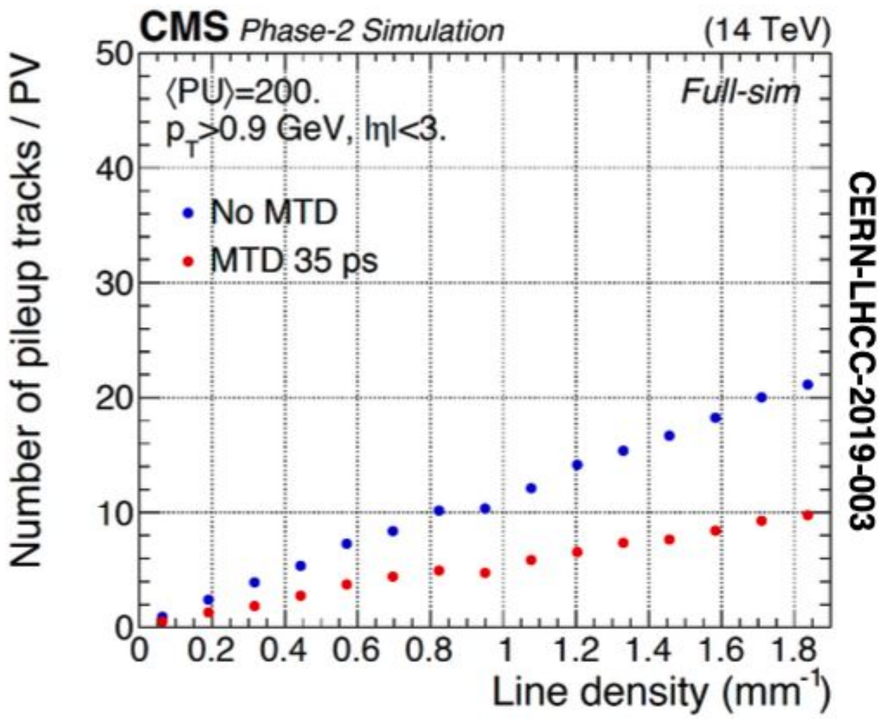
Barrel Calorimeters

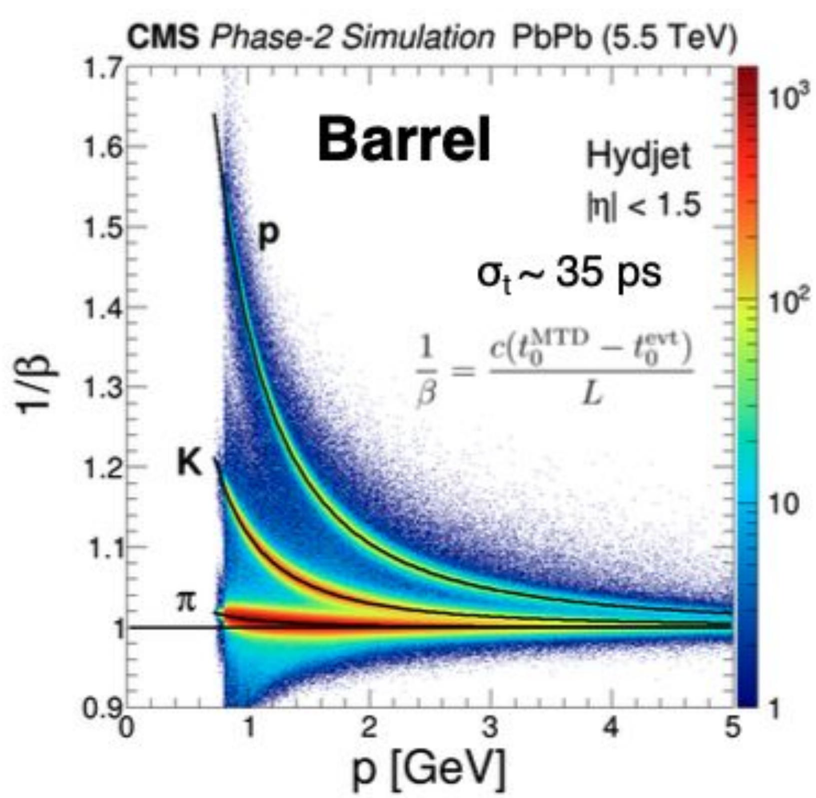
Muon Systems

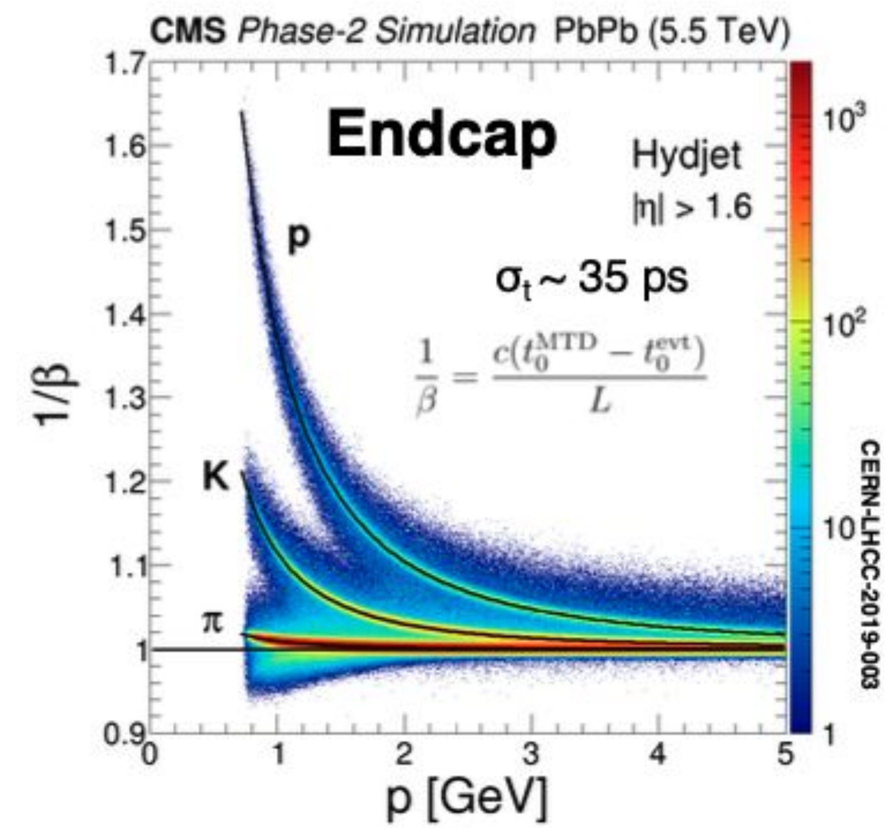
Extended coverage:
$|\eta| < 2.4 \rightarrow |\eta| < 2.8$

- Lighter and more granular tracker
- Extended muon capabilities
- High granular Endcap Calorimeters
- PID over a large rapidity
- Higher rate

MIP Timing Detector (MTD) for hadron PID





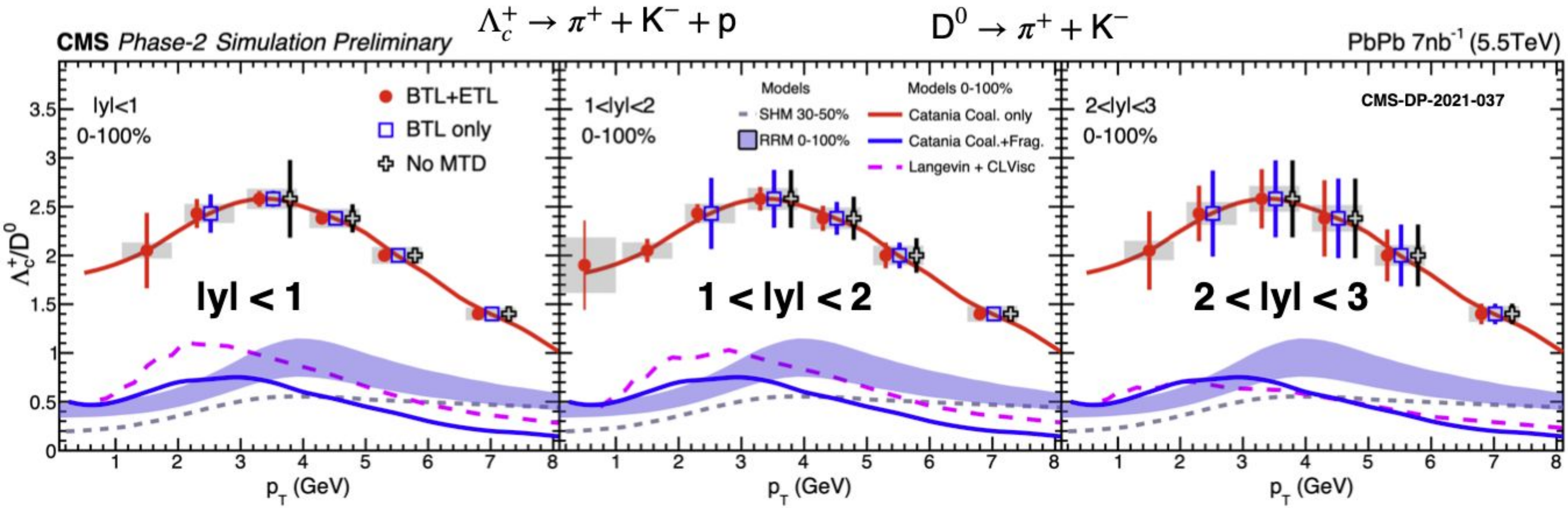


MTD

- Time resolution of 30-40 ps to cope with up to 200 interactions per pp bunch crossing
- Clean pile-up tracks
- 4D vertex reconstruction (improved reconstruction of displaced products and long-live particles)
- Trigger on MIP multiplicity → useful for pp and pPb high multiplicity studies
- PID of charged hadrons π/K/p for |η| < 3
  - down to p ~ 0.7 GeV/c
  - clear ID of π/K up to p ~ 2.5 GeV/c and p/K up to p ~ 5 GeV/c
- Caveat: time resolution degradation up to ~60 ps at the end of HL-LHC

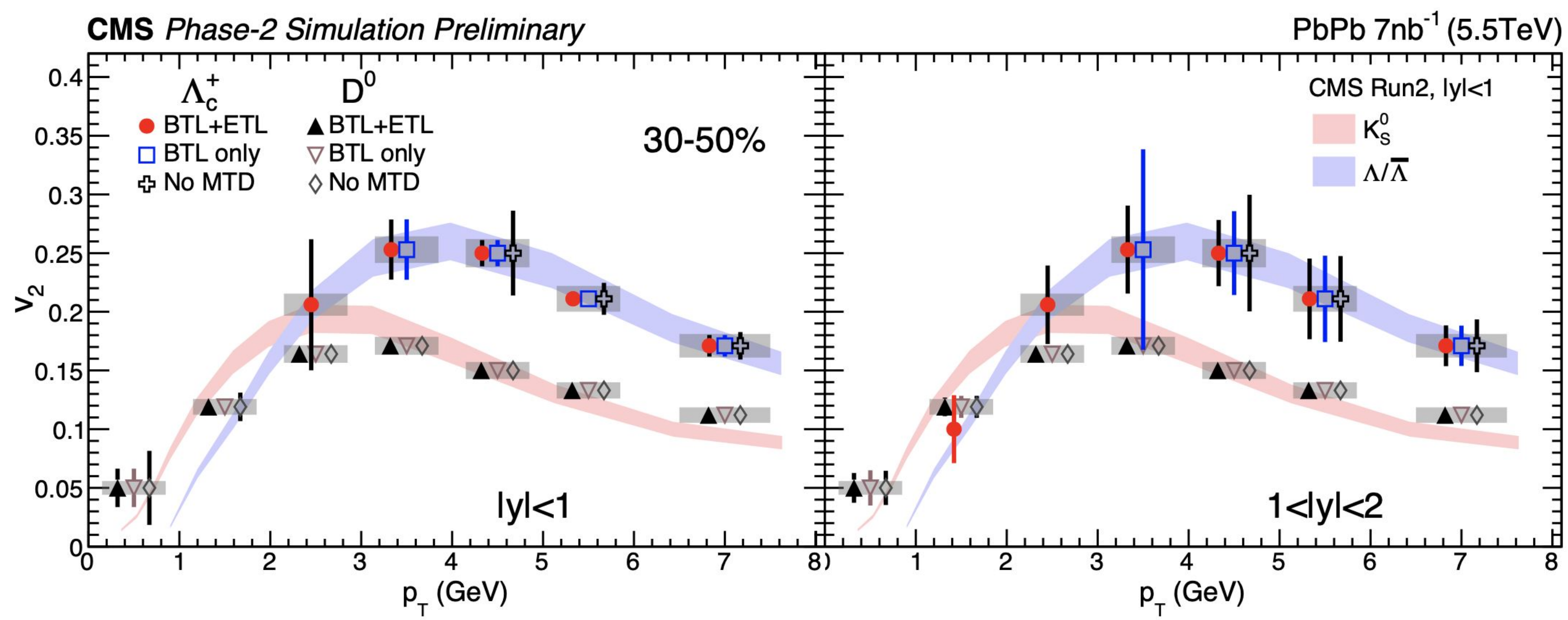
→ **Unique rapidity coverage for PID in Run 4**

Heavy quark dynamics in the QGP



- c- and b-hadrons can be measured with MTD for $|\eta| < 3$ in Run 4+5
- Capability to measure D and Λ_c hadrons down to $p_T \sim 0$ with MTD (BTL+ETL)
- Measurement of production yield and correlation will constrain the HF quarks dynamics in the QGP

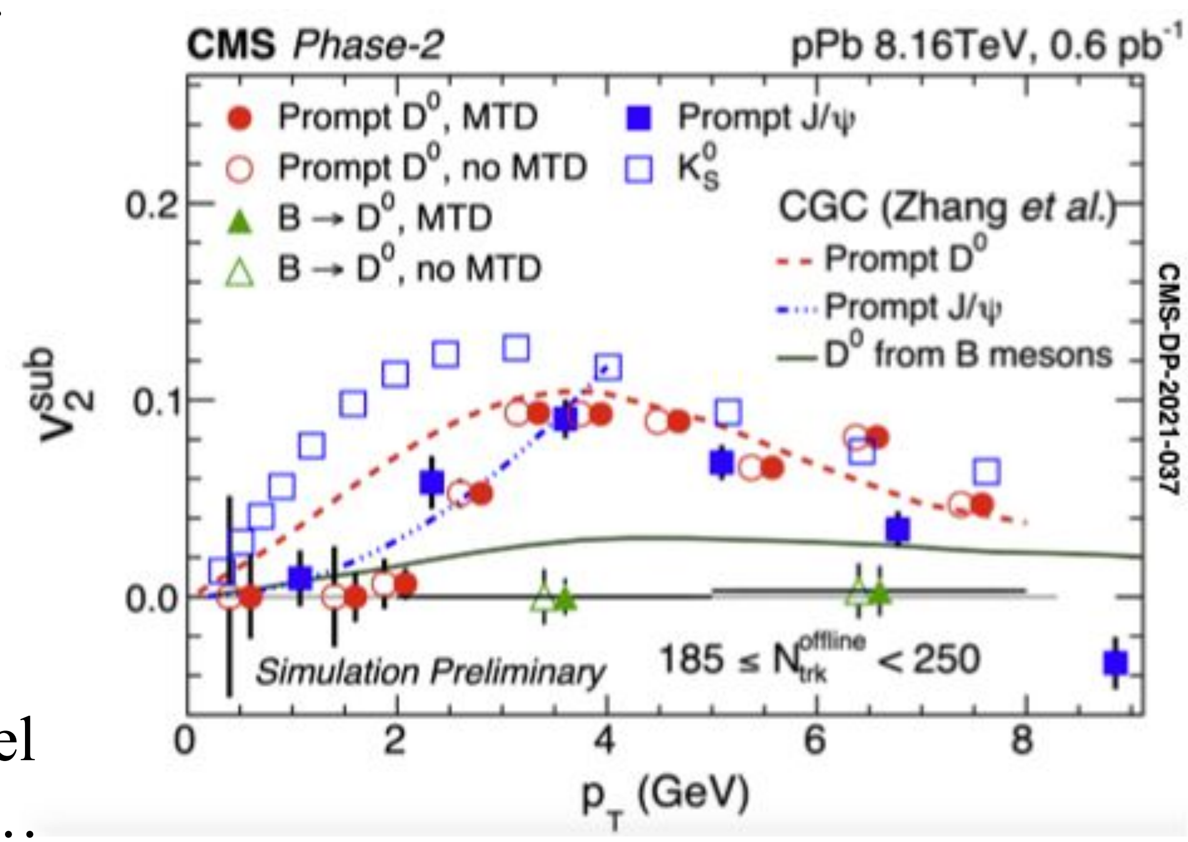
Elliptic flow in PbPb and pPb



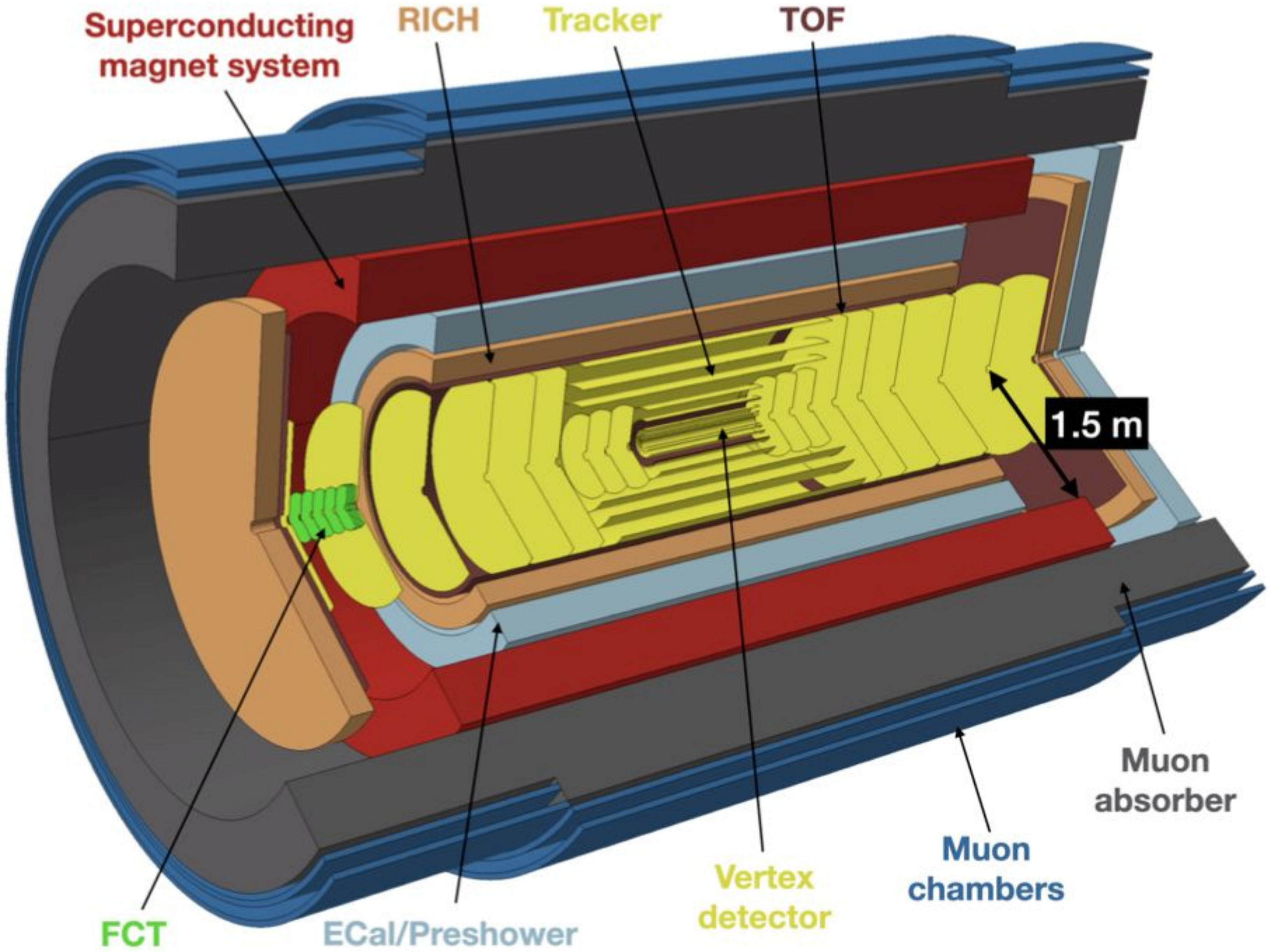
- v_2 of charm baryons and mesons in PbPb to measure the number of constituent quark (NCQ) scaling of in the charm sector

- v_2 in pPb to study the emergence of collectivity in small systems
  - background reduction with MTD

- also great opportunities to study:
  - heavy-flavour in-/out-of-jets
  - upsilon family including Y(3S)
  - quarkonia at low p_T in hadronic decay channel
  - dijets and weak bosons to constrain nPDFs, …



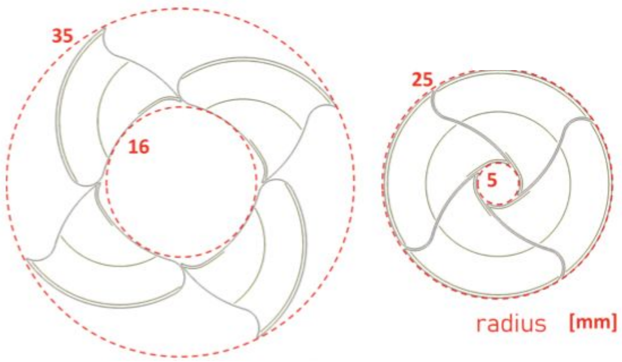
ALICE 3

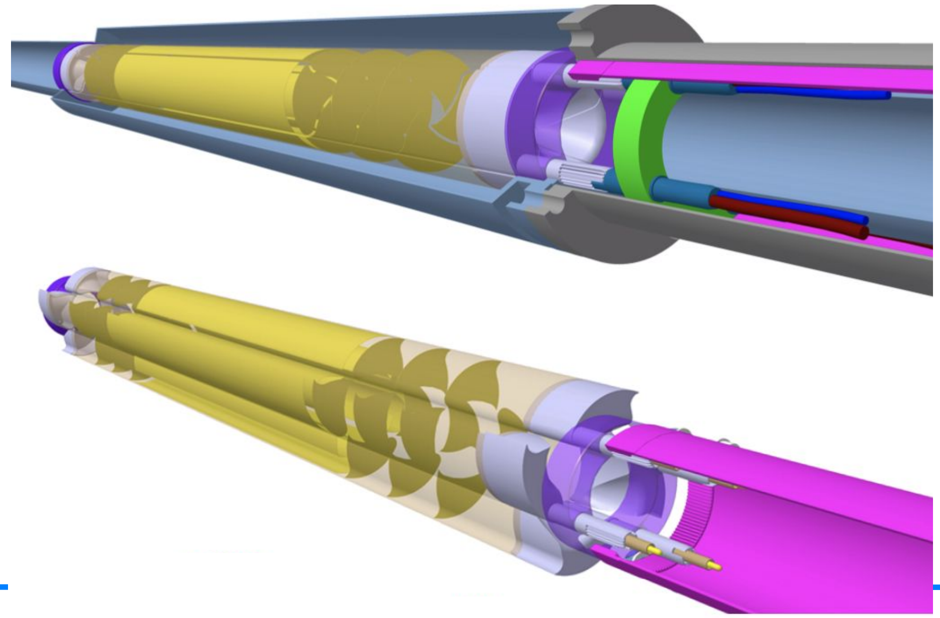


Detector concept:

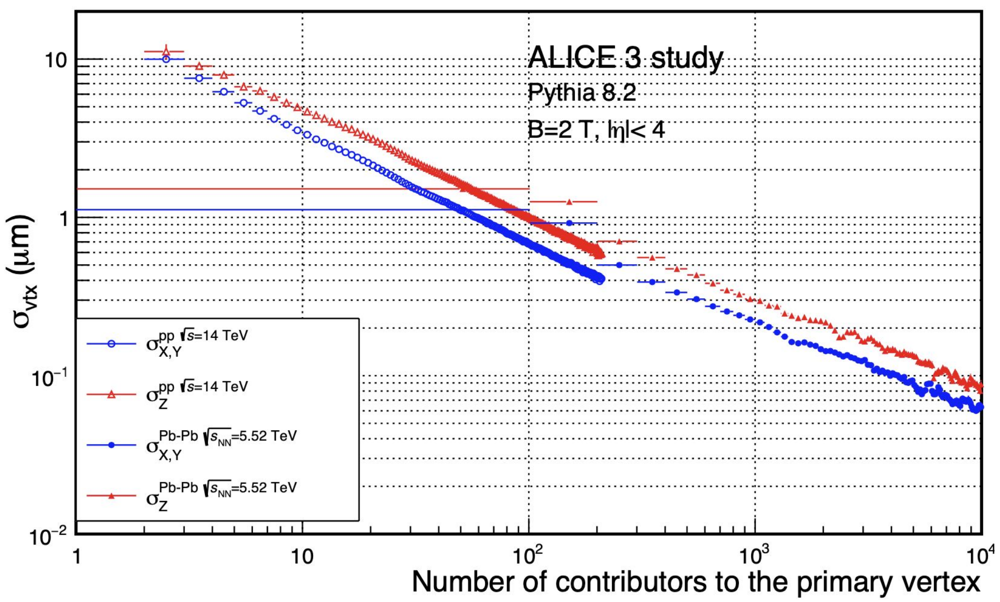
- Compact and light all-silicon tracker with barrel layers and forward disks over a large acceptance: $|\eta| < 4$
- Retractable vertex detector in pipe with first layer at 5 mm from Interaction Point
- Superconducting magnet system (0.5 or 2 T)
- PID systems: RICH and TOF ($|\eta| < 4$), Calorimetry ($-1.6 < |\eta| < 4$), Forward Conversion Tracker (FCT), Muon system ($|\eta| < 1.5$)
- Continuous readout and online processing with large data taking rates

Vertex detector in pipe in secondary vacuum

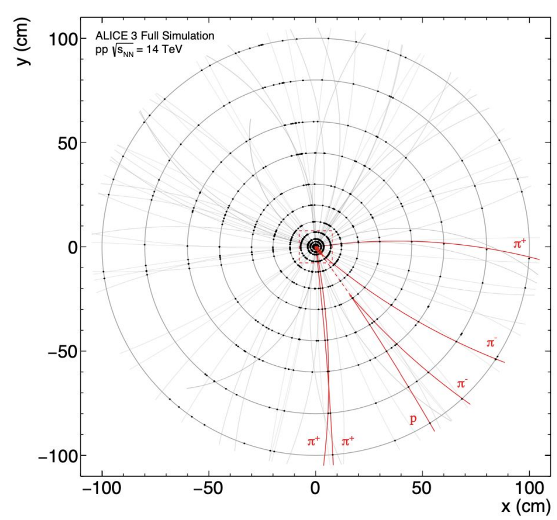


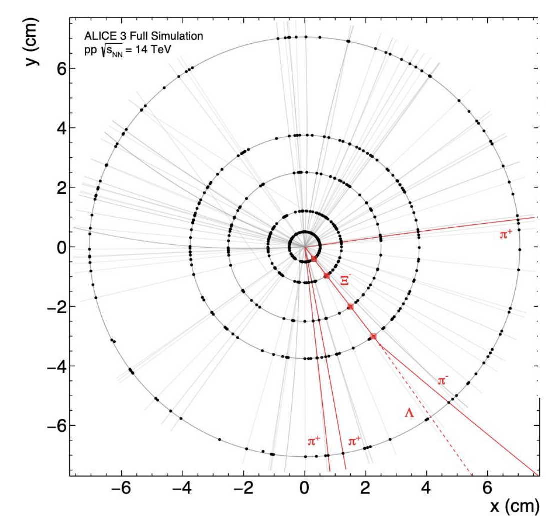


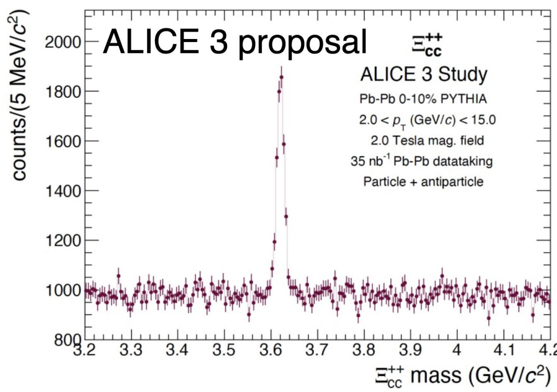
Detector requirement and performance



$\Xi_{cc}^{++} \rightarrow \Xi_c^{+}\pi^{+} \rightarrow \Xi^{-} + 3\pi^{+}$

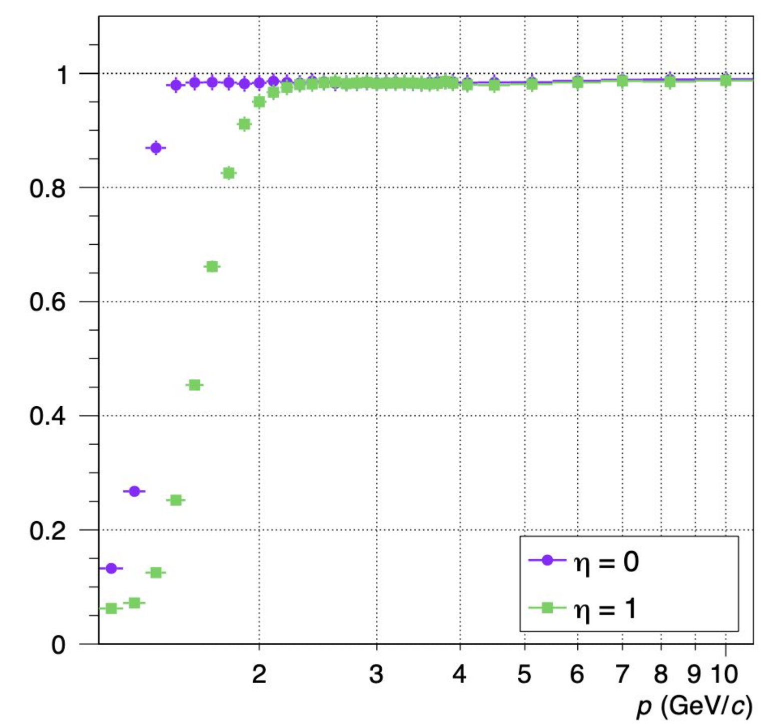






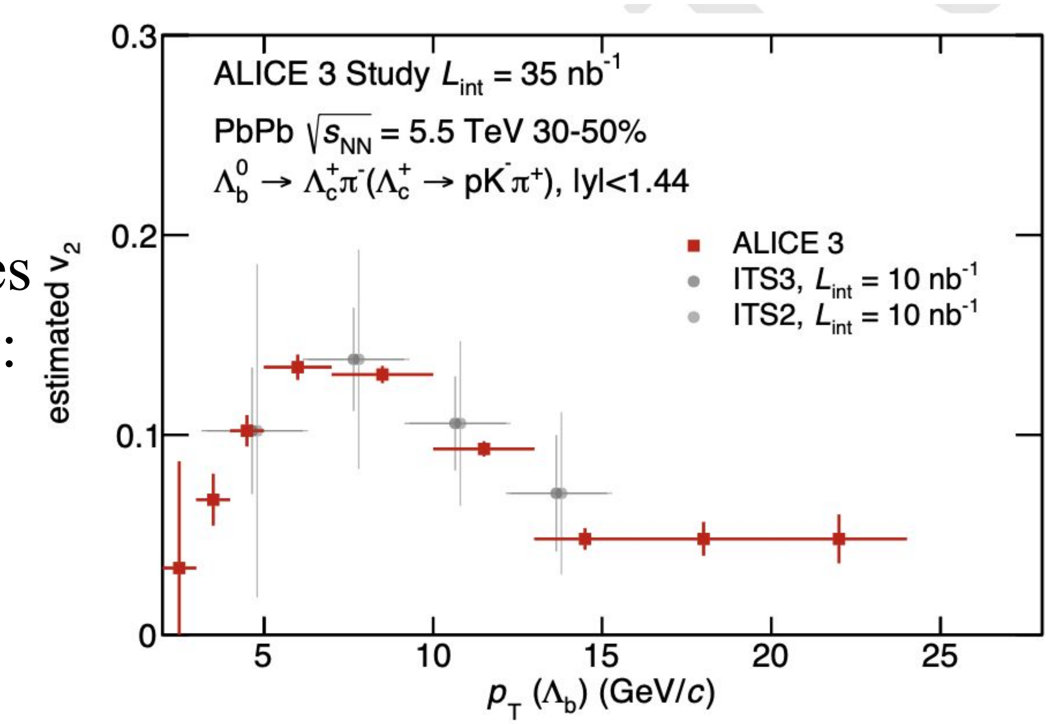
- Good tracking down to $p_T = 0$: $\sigma(p_T)/p_T \sim 0.7\text{-}2\%$
- Very low material budget
- Excellent vertex and pointing resolution: $\sigma_{vertex} < 10$ um, $\sigma_{DCA} \sim 10$ um
- Excellent PID for $|\eta| < 4$: π/K/p separation up to a few GeV/c
- Good muon efficiency down to $p_T \sim 1.5$
- Calorimetry: $-1.6 < |\eta| < 4$ ($|\eta| < 0.3$) for $E_\gamma > 100$ (10) MeV
  - Note: high resolution photon at $|\eta| < 0.3$

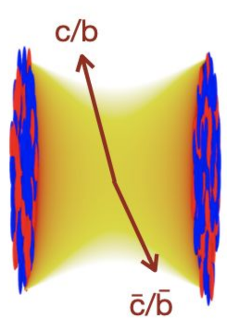
Acc × Eff × μPID for muons

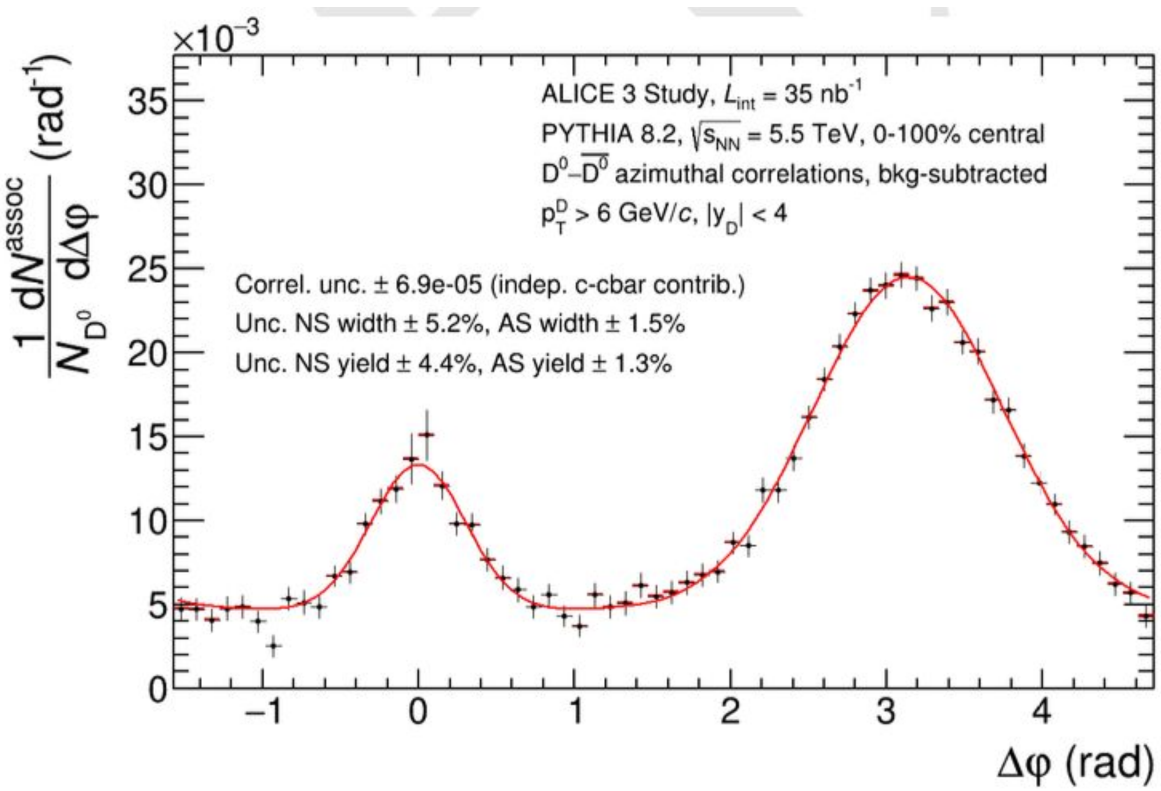


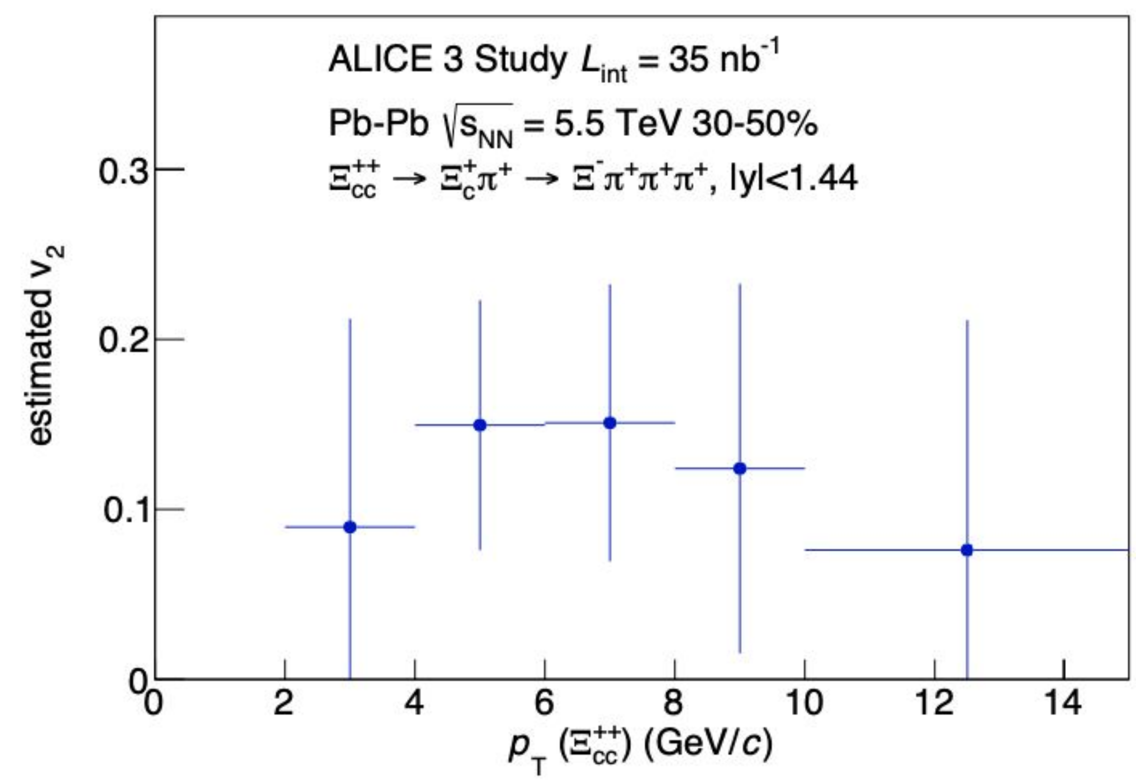
Heavy-quark transport and hadronization

- Charm and beauty baryons: Λ_c and Λ_b down to low p_T
- D-Dbar azimuthal correlation over $|\eta| < 4$: degree of thermalization, radiative energy loss vs collisional processes
- Multi-charm baryons: Ξ_{cc}^{++}, Ω_{cc}^{+}, Ω_{ccc}^{++} (?) at mid-rapidity: hadron formation from QGP (thermalization vs hadronization)
- Momentum correlation with DD pair to investigate strong interaction potential between HF hadrons: *e.g.* femtoscopy measurements with D^0D^*+ to study the nature of $T_{cc}+$



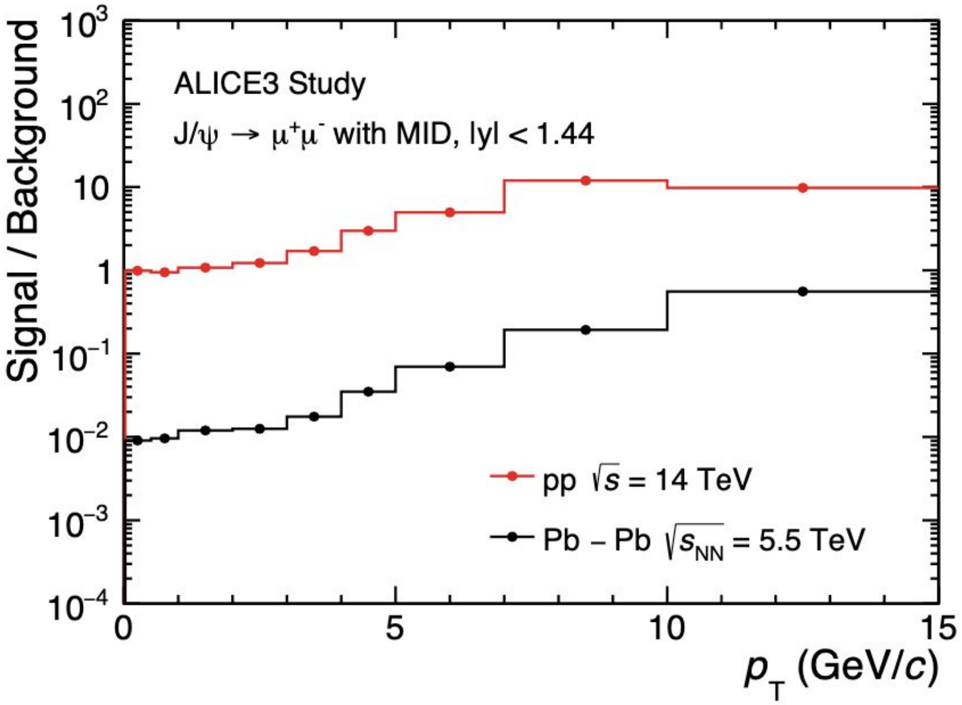


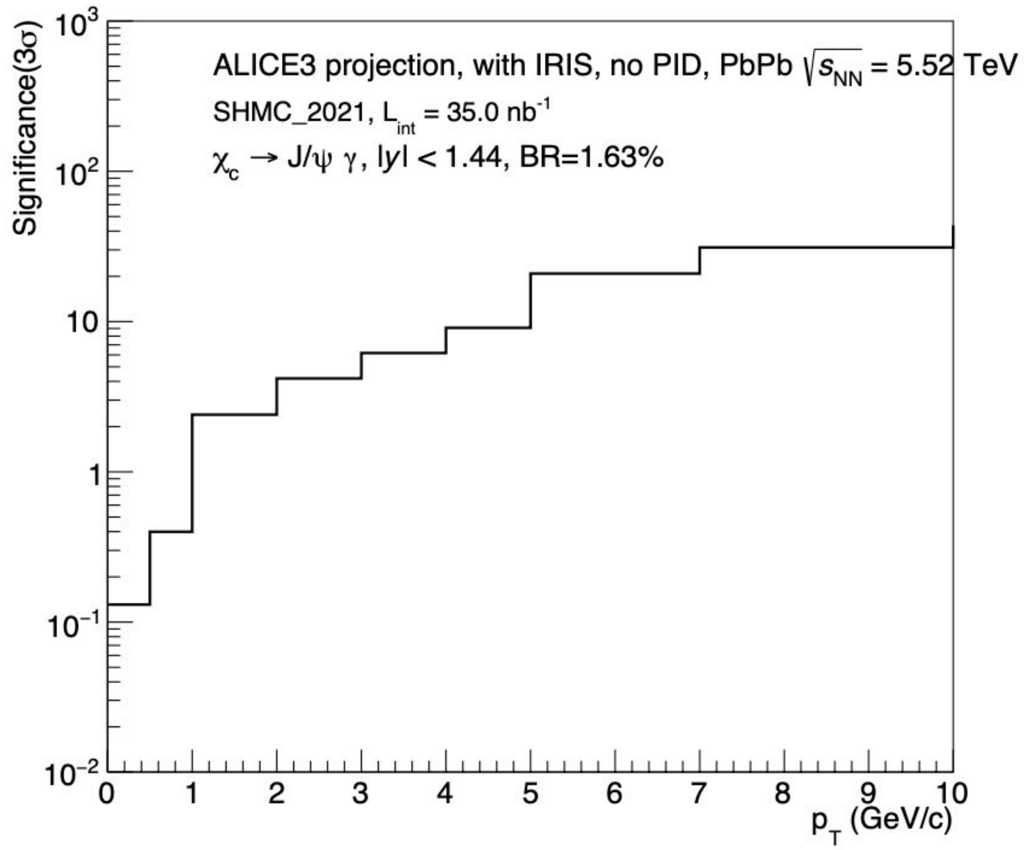


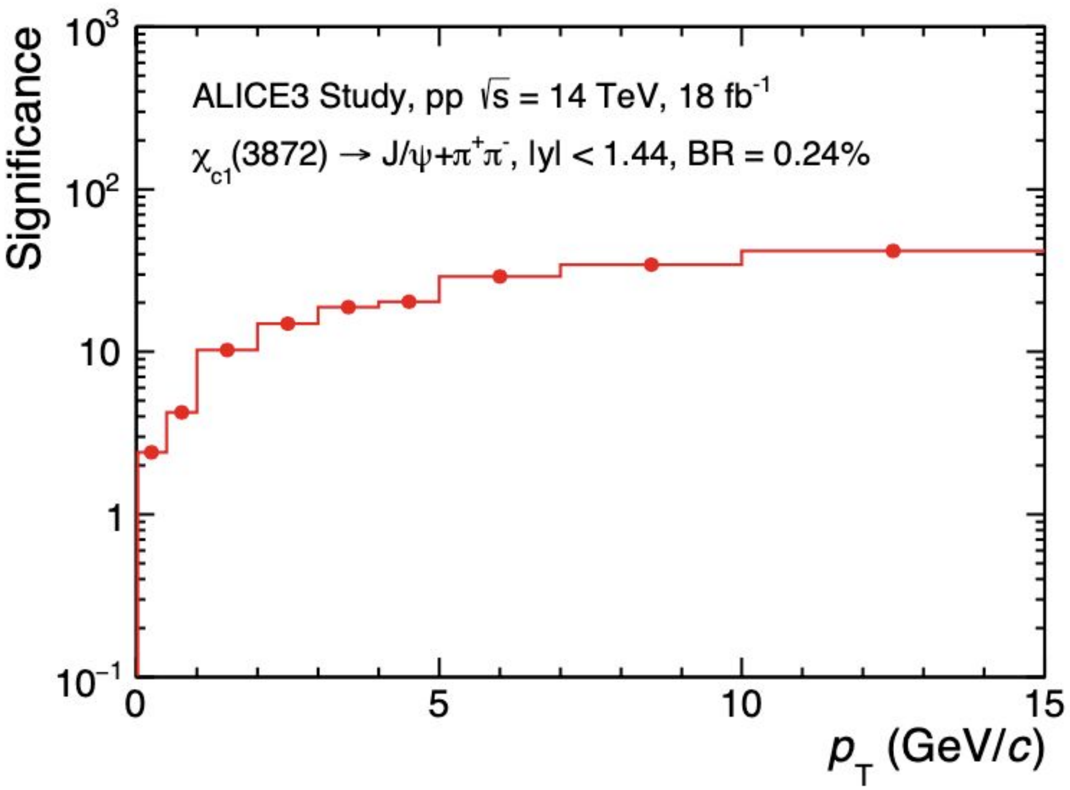


Quarkonia, exotica and UPC

- Using muon decay channels and $|\eta| < 1.44$:
  - P-wave states: $\chi_c \rightarrow J/\psi\ \gamma$ down to $p_T \sim 0$: melting of χ_c at $\sim 1.2\ T_c$ from potential model, probe formation and propagation of bound state in the QGP
  - Exotic hadrons: $\chi_{c1}(3872) \rightarrow J/\psi\ \pi^+ \pi^-$ down to low p_T: QGP effect on charmed meson molecule/tetraquark?
- UPC measurements with large rapidity coverage can ensure exclusivity, *e.g.* exclusive production of heavy-flavour pairs: probe gluon distribution in nuclei



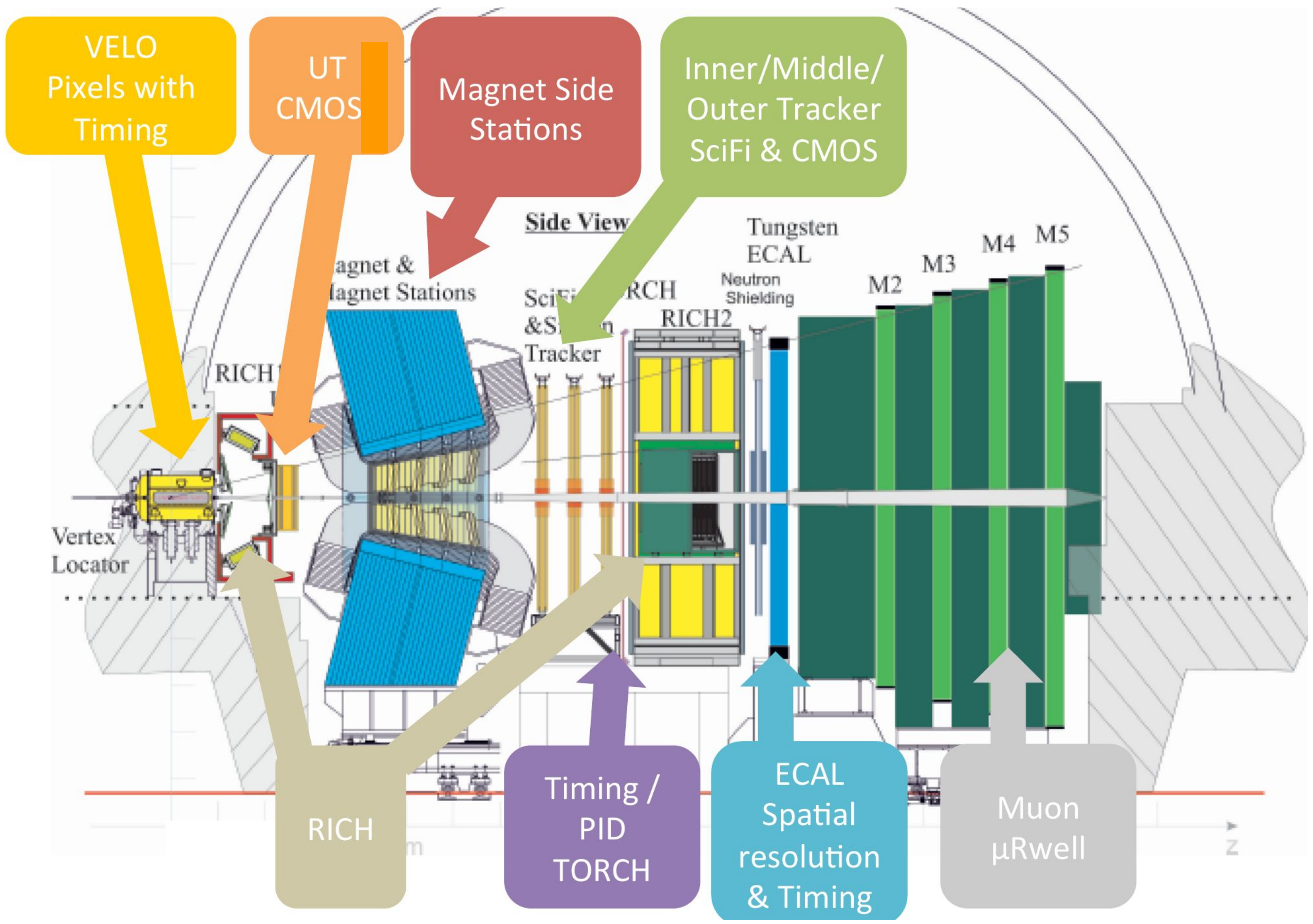




LHCb upgrade 2 general overview

LHCb conceived for beauty and charm physics with PID, calorimetry & muon system in pp
- used as multipurpose forward spectrometer

Run 5 detector
- Detector for pile-up of 40 visible interactions
- Software trigger at full rate
- current pp performance at higher pile-up
- chance to make detector ready for most central heavy-ion collisions



Specifications:

Acceptance: 2 < eta < 5

Vertex silicon telescope at R=0.8 cm (Run1/2), at 0.5 cm (Run 3/4)

$\Delta p/p$ approx. 0.5 % over wide range, starting at around p_{tot} = 2 GeV/c

E.-m. calorimeter for electrons/photons

Muon identification system

hadron-ID via 2 RICH detectors

TOF foreseen for Run 4

LHCb U2 physics case document

QGP physics case

QGP heavy-flavor studies

Heavy-flavor in collider and fixed-target: longitudinal boost & excellent vertexing including cc-correlations, multi-heavy flavour baryons & jet fragmentation/thermalization

Improvement of knowledge on hadronization, initial state & 1 fm/c

Extreme kinematics for hadron structure in collider & fixed-target in inclusive production & UPC
Quarkonia/HF as workhorse, Drell-Yan/intermediate mass dileptons

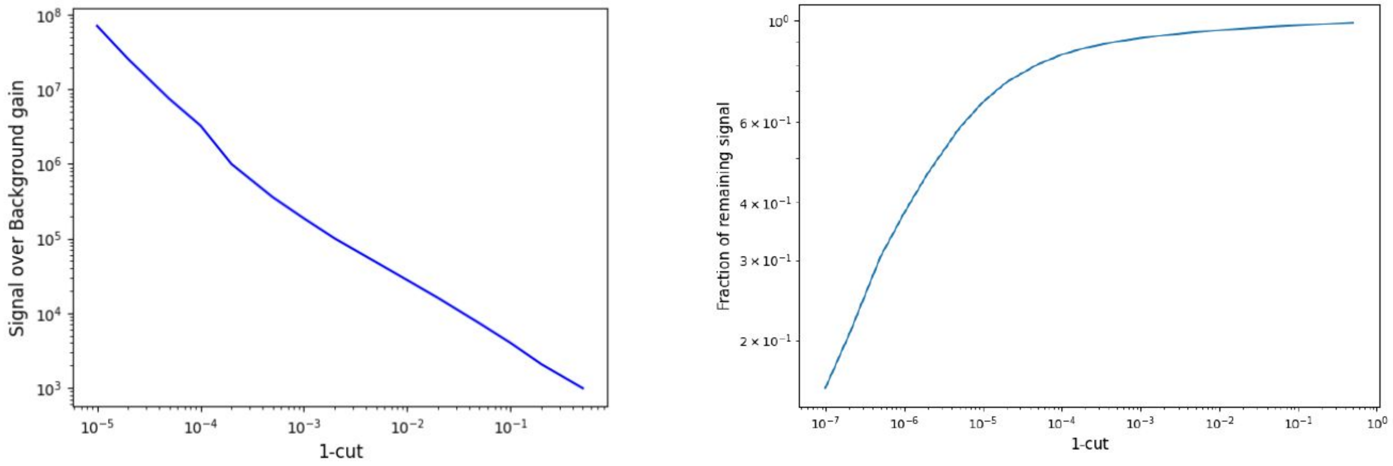


Figure 10: Prediction of the BDT model for $\Xi_{cc}^{++} \rightarrow \Xi_c^+ \pi^+$ signal and main background. (left) Gain in signal/background ratio after BDT classification, as a function of the cutoff value. (right) Fraction of kept signals, as a function of the cutoff value. We can gain at least 8 orders of magnitude on this ratio with a sufficient cutoff

Investigated, not yet accessible observables: χ_c to 4 μ, multi-charm states Ξ_{cc}^{++}. Fast simulations (study by G. Legras at DPhN): very large S/B gain possible (similar for Ξ_{cc}^{++} to Λ_c ππK). Limited by statistics and fast simulation assumptions, require full simulation.

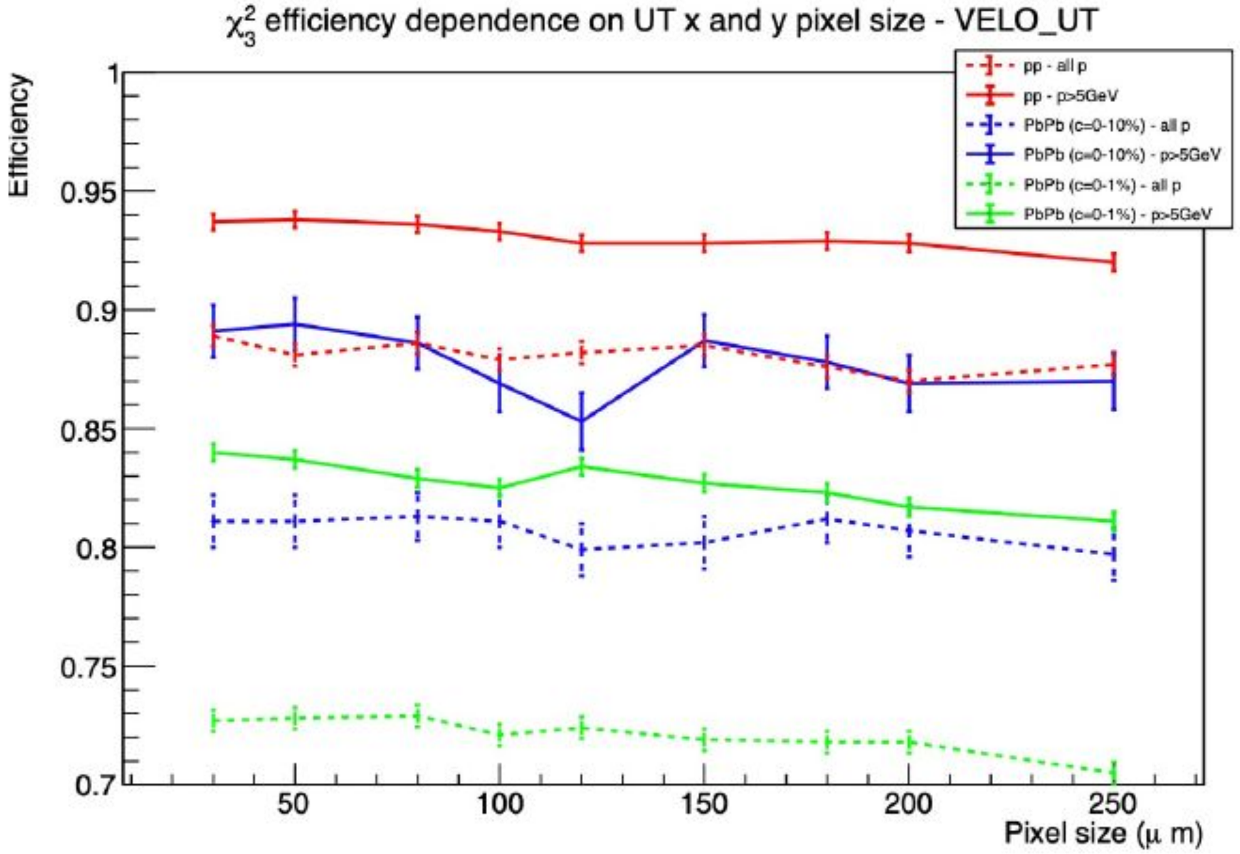
Dilepton physics study (Maurice Coquet et al) https://arxiv.org/abs/2104.07622, PLB 821 (2021) 136626

Project status & performance studies

Framework TDR submitted to LHCC last year

Without optimisation tracking feasible with deteriorated performance in most central PbPb

Ideas already present and work started to optimize layout,
beneficial for robustness in pp



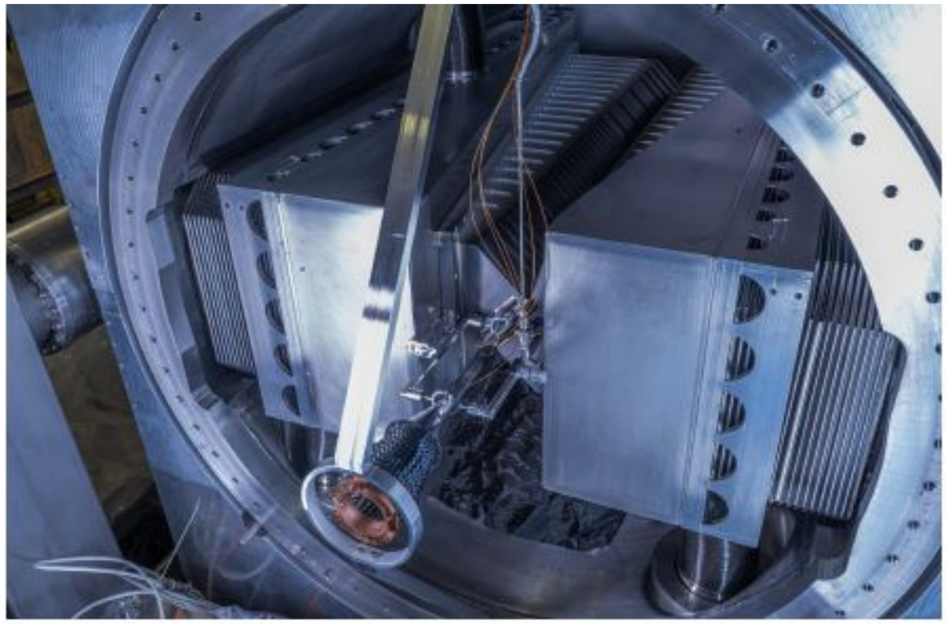
French envisaged hardware contributions
Calorimeter: 10 ps timing
DAQ/RTA: large data transfer rate, pcie400
tracker: radiation hard & granular pixel, time for bunch-ID

HCb FTDR material,
see S. Panebianco´s slides at
Etretat

Fixed-target opportunities

Run 3 SMOG 2: unpolarized internal gas target

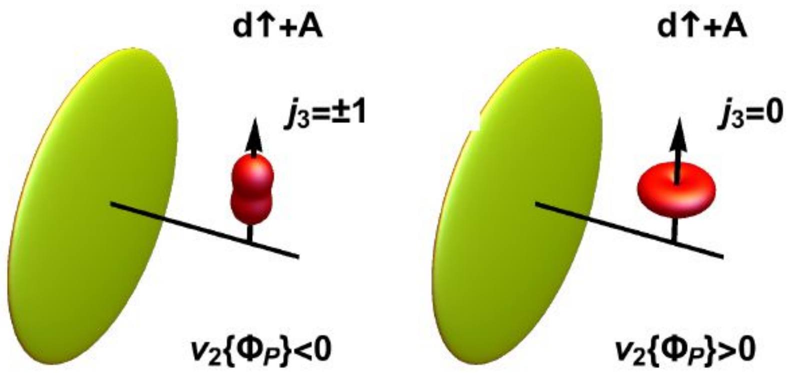
increase luminosities up to 10^2 with respect to SMOG (Run2) with noble gases and hydrogen



SMOG2 attached to VELO

Run 4 project: polarized gas target LHCSpin

Current main drive: hadron structure measurements, focus on DY and gluons with HF/quarkonia
Example for heavy-ion physics with polarization:
possible to measure single-particle v2 w.r.t. polarization axis
in heavy-small systems



D polarised along Φ_p, perpendicular to the beam

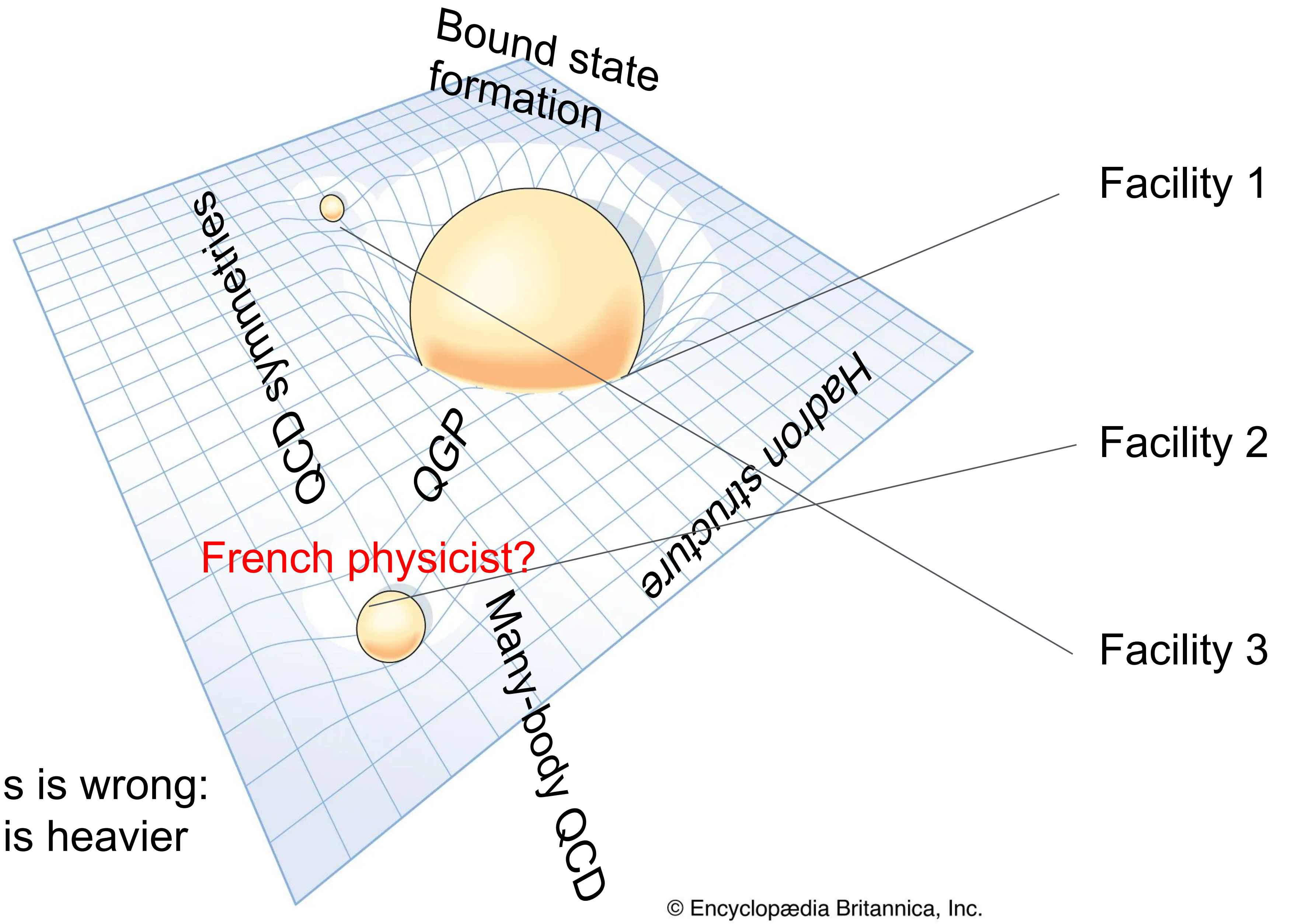
Run 5:

natural continuation & possible extensions

Orsay workshop with overview on fixed-target projects at LHC:
https://indico.ijclab.in2p3.fr/event/7201/

https://arxiv.org/pdf/1906.09045.pdf

High-energy QCD physics landscape in 2030ies away from the energy frontier at the LHC



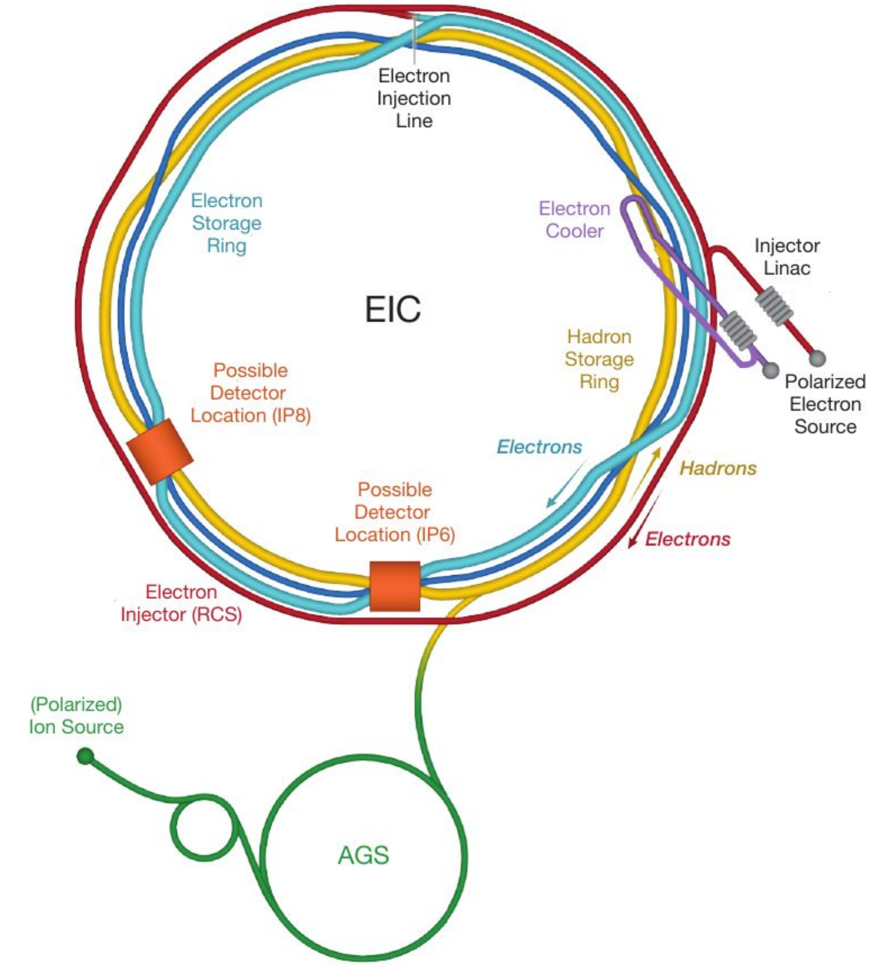
Let´s hope that this is wrong:
That the question is heavier than the facility …

And that it is right: that there is no singularity that let the physicists and questions disappear…

Electron-Ion collider in the US

Physics questions

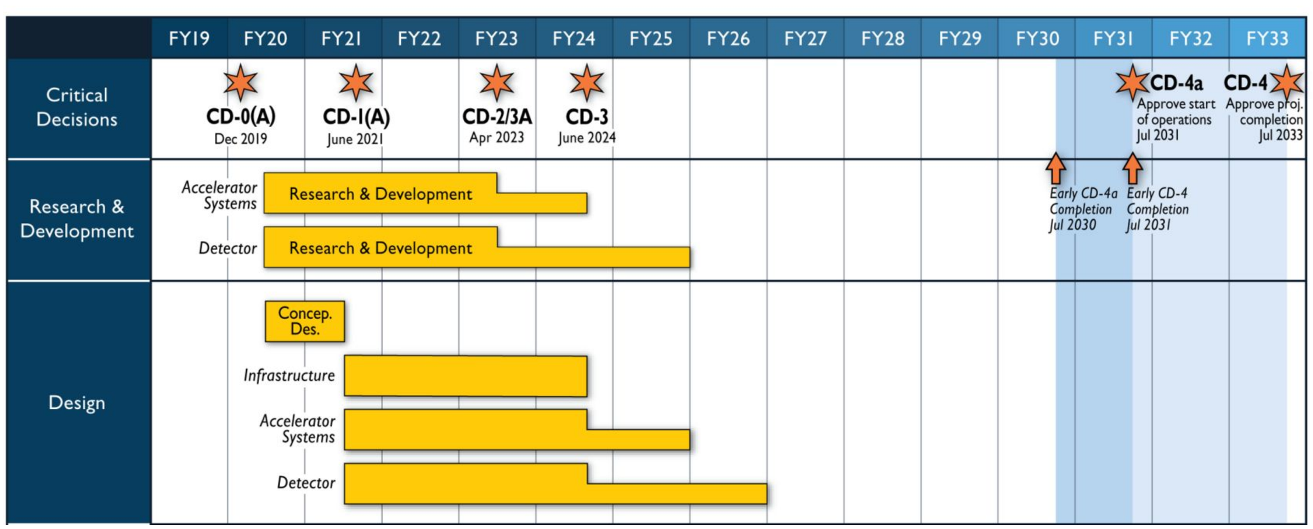
- Spin and mass of nucleons from partons
- Parton distribution in momentum and space
- Interaction of color charge with nucleus, hadronization & nuclear binding
- Dynamics of partons inside nuclei and saturation



[EIC Yellow Report]

Parameters

- Highly polarized electron (~70%) and proton (~70%) beams
- Ion beams from deuterons to heavy nuclei (gold, lead or uranium)
- Variable e+p center-of-mass energies from 20−100 GeV, upgradable to 140 GeV
- High collision electron-nucleon luminosity 10^{33}–10^{34} cm^{-2} s^{-1}

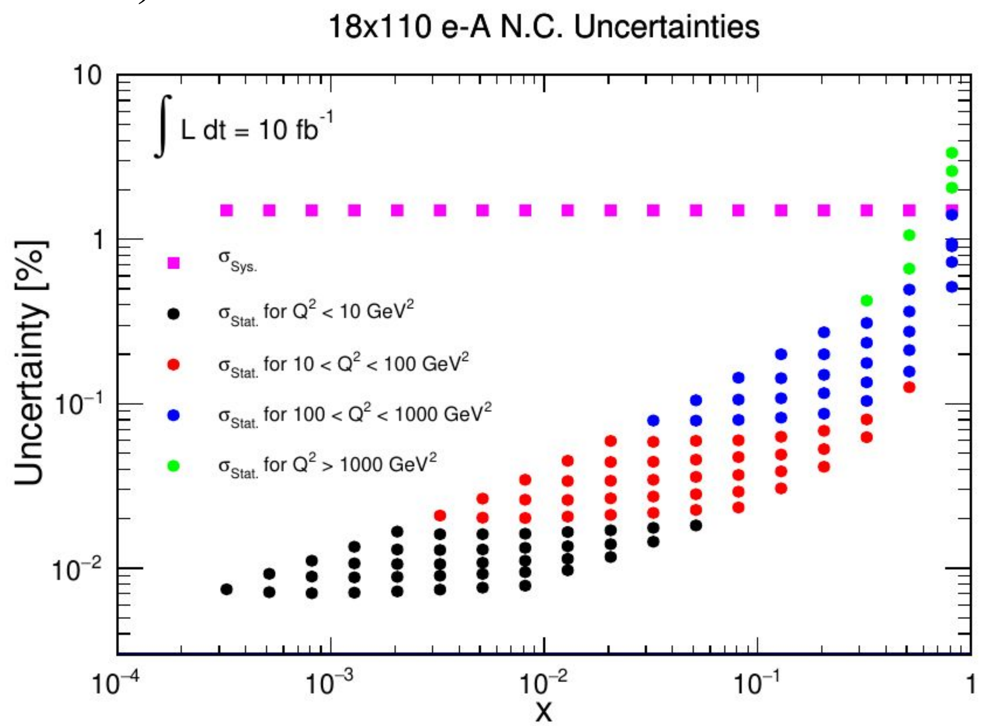


[Fall 2021 time-line update]

EIC & heavy-flavour: connections to LHC initial state and related measurements

Nuclear parton distributions and saturation

- Precision measurements, not as low-x as at the LHC
- Complementary to LHC fixed-target (high-x) and LHC collider (low-x)
- Charm production enhancing sensitivity to gluons at high-x
  https://arxiv.org/pdf/1708.01527.pdf
- relevant for fixed-target charm/beauty QGP studies



EIC Yellow Report

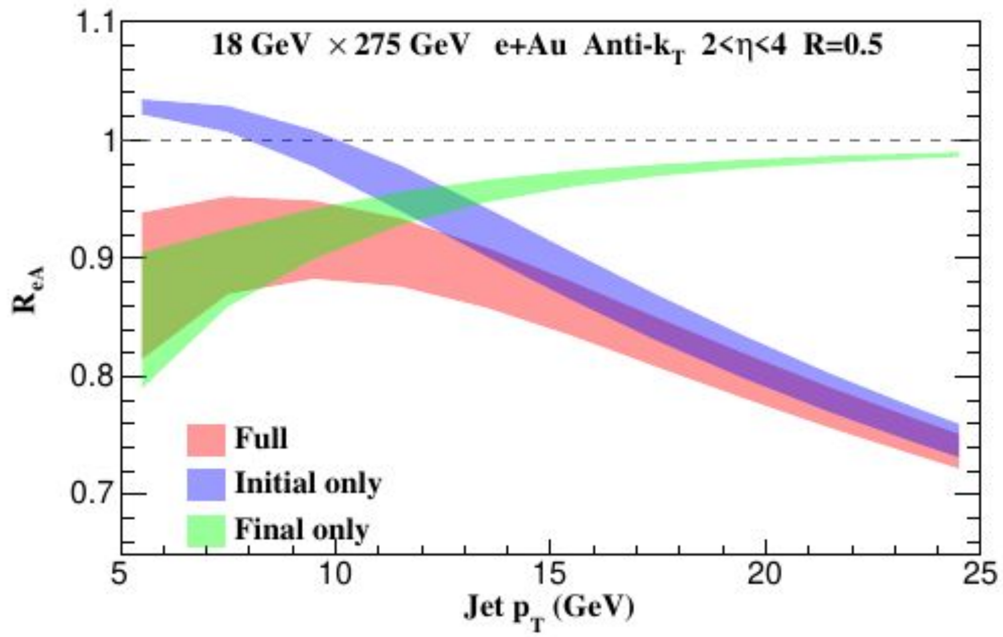
Geometry and shape fluctuations of hadrons

- Relevant for initial conditions of fluctuations, see https://arxiv.org/abs/2001.10705
- Measurements from HERA available already used as input for hydro-models in pPb
- Quarkonium as gluon-sensitive measurement: synergy with UPC measurements

EIC & heavy-flavour: connections to LHC energy loss, hadronization and collectivity

Hadronization and energy loss in the nucleus

- Concepts on cold energy loss testable with Q^2 control
- Test hypotheses developed in the description of cold-energy
- Hadronization studies in less dense environment
- Charm particles useful to tag different partonic original parton composition



EIC Yellow Report

Testing ground for quarkonium production ansätze

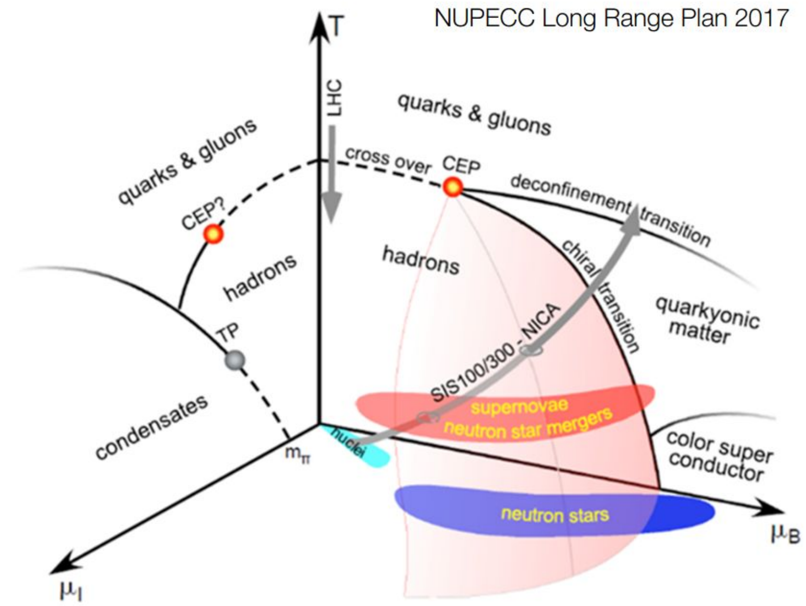
Collectivity studies with fixed Q^2 in DIS

- No long-range ´collective´ azimuthal correlations found in e-p data so far:

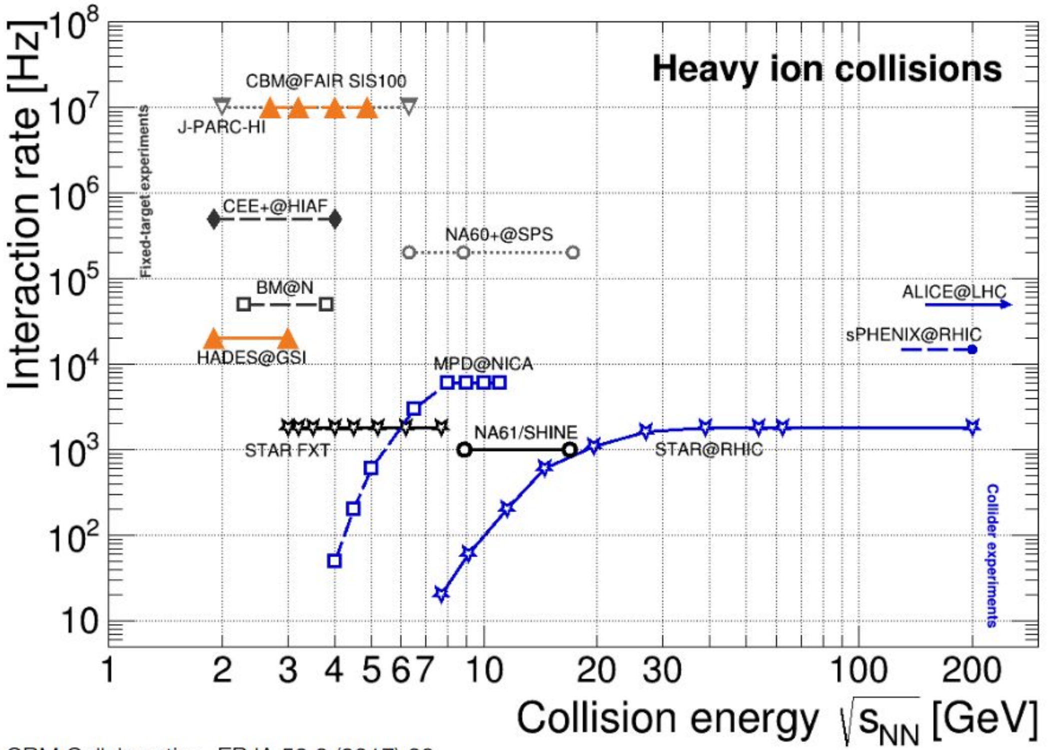
ZEUS publication driven by GSI-ALICE group

- Testing ground for long-range correlation concepts related to hadron structure rather than to hydrodynamic response, synergy with similar studies in photoproduction in UPC at the LHC
- charm/beauty: ´trigger´ gluons, study mass effects

Heavy-flavour at FAIR & other high-μ_B facilities



Physics questions
- Equation-of-state at neutron star densities
- Phase structure of QCD matter
- Bound states with strangeness
- Chiral restoration at large densities



CBM Collaboration, EPJA 53 3 (2017) 60
T. Galatyuk, NPA982 (2019), update (2021)

Charm in dense baryonic matter
- Sub-threshold production mechanisms (pA, AA)
- Cold nuclear matter effects (pA)
- Propagation of charm in dense matter
- Thermalization/participation in collective expansion?
  - **require high-luminosity for charm**

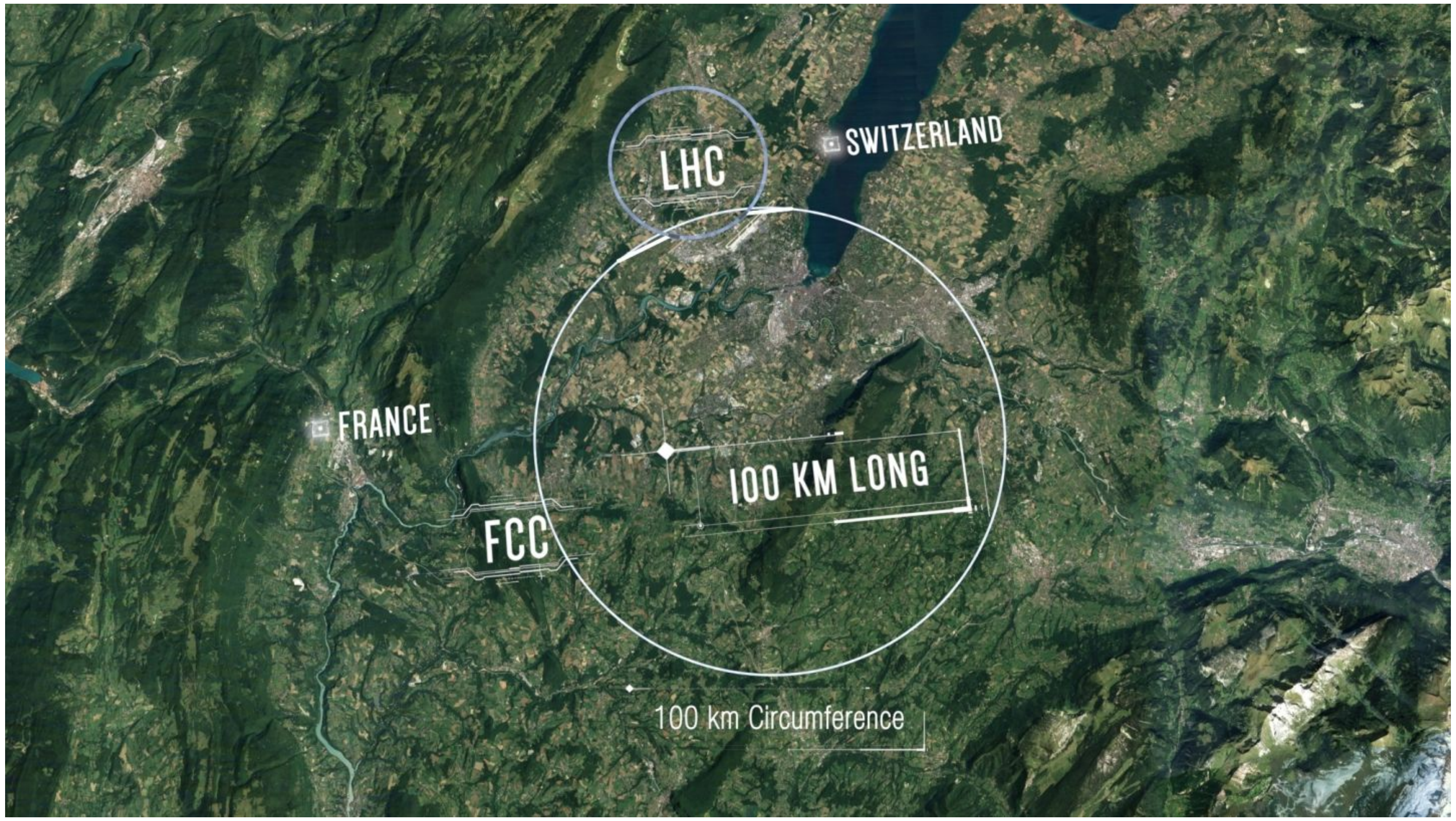
Timeline

2022: Buildings/shell construction complete (including CBM cave)

2025: Start of operations

Plots from C. Blume at recent workshop 10/2021: https://indico.ectstar.eu/event/93/

Future circular collider heavy-ion programme



Physics questions

- QGP characterisation via:
  - Single event characterization
  - high-pt probes: boosted tops and others
  - charm as ´active´ d.o.f.
- Parton densities in extreme kinematics
  - Saturation
  - Large Q^2 and nonetheless low-x

Parameters

High-energy Pb beams:
PbPb $\sqrt{s_{NN}}$=39.4 TeV, pPb $\sqrt{s_{NN}}$=62.8 TeV
8000 nb^{-1}/run (LHC Run 3: ca 3 nb^{-1})

FCC heavy-ion physics 2017: https://e-publishing.cern.ch/index.php/CYRM/article/view/515

2021-2025: technical and financial feasibility due for next European strategy update (plan A as future collider facility), European strategy update on HEP 2020

Current end of HL-LHC with lumi goal by 2041, Next European Strategy update (2025) will need to update planning based on HL-LHC performance & physics, community interest and progress for next facility etc.

Upcoming events and workshops

LHCb Upgrade heavy-ions tracking, 13/14.04.2022, IJCLab
https://indico.ijclab.in2p3.fr/event/8156/

Synergy between EIC and LHC experiments, CERN, 20-21.2022
https://indico.ph.tum.de/event/7004/

Fixed-target at the LHC (STRONG 2020), open workshop, CERN, 22.-24.06.2022

Heavy-flavours from small to large systems (Institut Pascal), 3-21.10.2022
https://indico.ijclab.in2p3.fr/event/7656/

From initial gluons to hydrodynamics - Gluons inside hadrons and their thermalization (Gluodynamics), open workshop at Institut Pascal, 21.-25.10.2022

ALICE upgrade week, ALICE collaboration internal, 19.09.2022

LHCb U2: QCD with ions and fixed-target in Fall/Winter 2022: open workshop, details to be announced after Quark Matter

Summary

Ambitious upgrade programmes by all three LHC collaborations

ALICE3:
large acceptance, multipurpose heavy-ion detector
full exploitation of silicon for optimized vertexing and hadron-PID over large acceptance
- heavy-flavour observables: one of the main drivers of performance requirements
- highlights: multi-charm baryons and correlations

CMS:
main upgrade already for Run 4, earliest and most advanced
strongly improved tracking in heavy-ions and much larger bandwidth
New: improved PID in barrel
- heavy-flavour and jet observables main show case for opportunities

LHCb U2:
forward multipurpose detector (including low-momentum) adapting from pile-up 5 to 40 in pp
chance to make it ready for nucleus-nucleus collisions
- focus so far on heavy-flavour forward, initial state and hadron structure
- extended gas fixed-target programmes planned for Run3/4 with natural extension for Run 5

Programmes in parallel with EIC and FAIR:
important cross talk and impact of respective programme focus

Discussion: starting point

- LHC performance

	Charged particles	Hadron PID	Muon	Electron	Photon	Tracking resolution	$DCA_{x,y}$ resolution	pp lumi Run 5+6	PbPb lumi Run 5+6
ALICE 3	$\vert\eta\vert<4$	$\vert\eta\vert<4$	$\vert\eta\vert<1.5$, $p_T > 1.5$ GeV	$\vert\eta\vert<1.75$, $0.05 < p_T < 3$ GeV (B=0.5 T)	standard reso: $-1.6 < \eta < 4$ high reso: $\vert\eta\vert<0.3$	0.7% at $p_T = 1$ GeV and $\eta\sim0$	4 μm at $p_T = 1$ GeV and $\eta\sim0$	18/fb	35/nb
CMS	$\vert\eta\vert<4$	$\vert\eta\vert<3$	$\vert\eta\vert<2.8$, $p_T > 3$ GeV at $\eta\sim0$	high energy electron	converted photon at low p_T	0.6% at $p_T = 1$ GeV	50 μm at $p_T = 1$ GeV and $\eta\sim0$	3000/fb (HL-LHC)	35/nb
LHCb	$2<\eta<5$	$2<\eta<5$	$2<\eta<5$, $p > 3$ GeV	$2<\eta<4.5$	$2<\eta<4.5$	0.5% at low p and 1% at p = 200 GeV GeV	(11+ 13/p_T[GeV]) μm	> 300/fb	3-12/nb

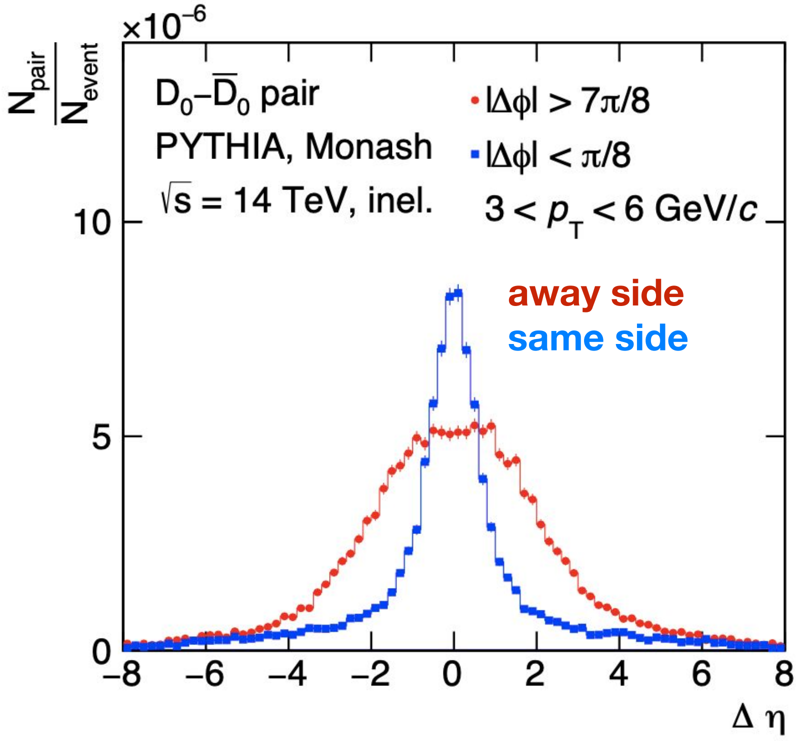
Probes in heavy-ion	ALICE 3	CMS	LHCb
Y(3S)	Good	Very good	Very good
Low p_T χc	Good ($J/\psi+\gamma$)		Good ($J/\psi+2\mu$)
Multi-charm baryons	Very good	Good (high p_T)?	Very good
Charm and beauty baryons	Very good	Very good	Very good
Open HF correlations	Very good	Good?	Good?
Total charm cross-section	Very good	Good	Very good

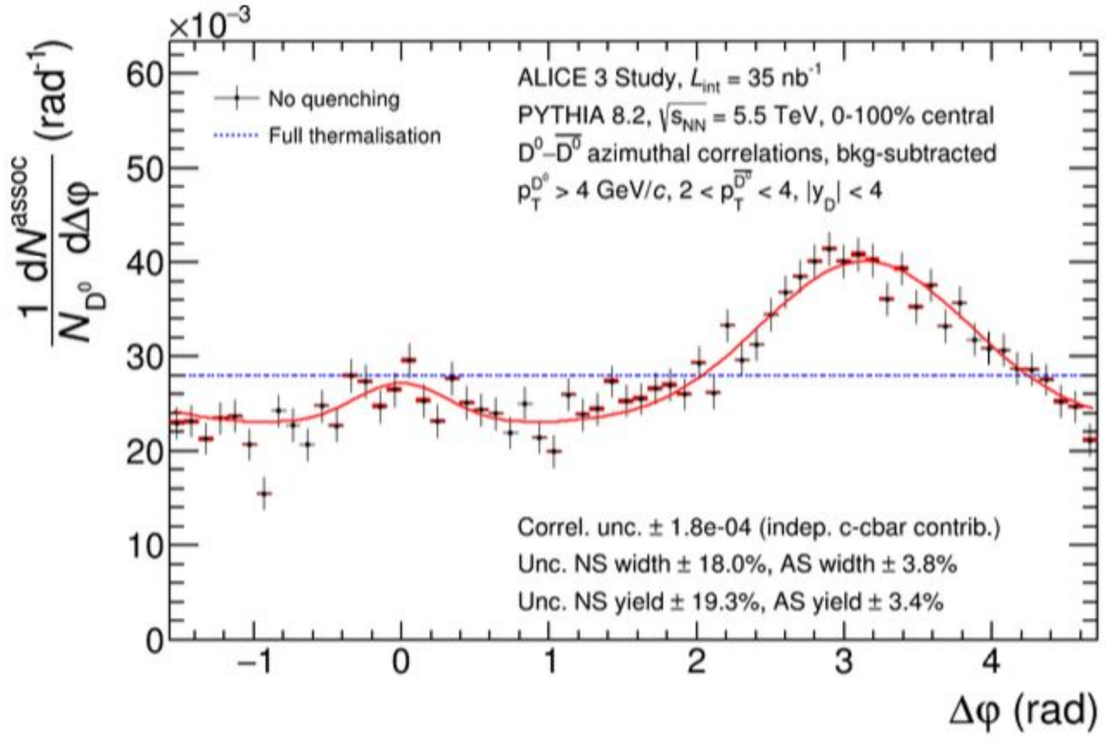
Cold nuclear matter probes	ALICE 3	CMS	LHCb
Drell-Yan (M = 2-5 GeV)	Good	Good	Very good
Electroweak bosons	Good	Very good	Very good
Dijet	Good	Very good	Good?
UPC	Very good	Good	Very good

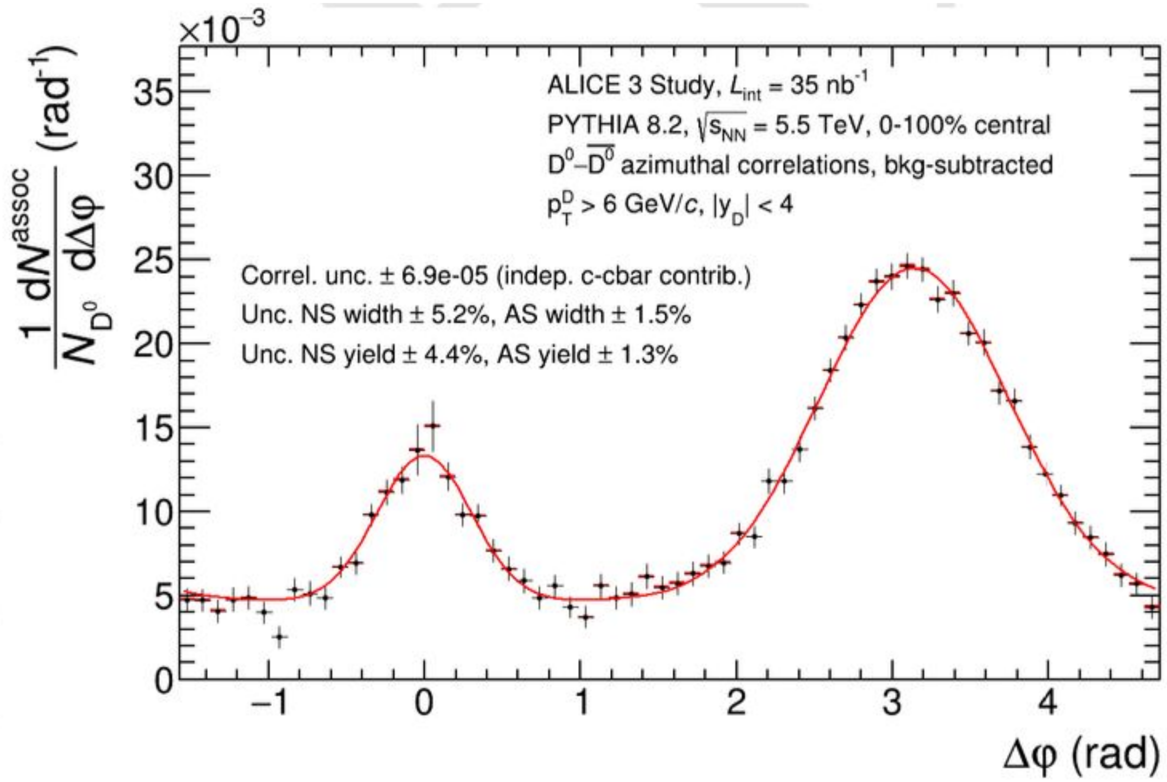
- Complementarity LHC vs. EIC programme?
- Local vs. global (approx. 4 pi)

Backup slides

Open charm correlation with ALICE 3

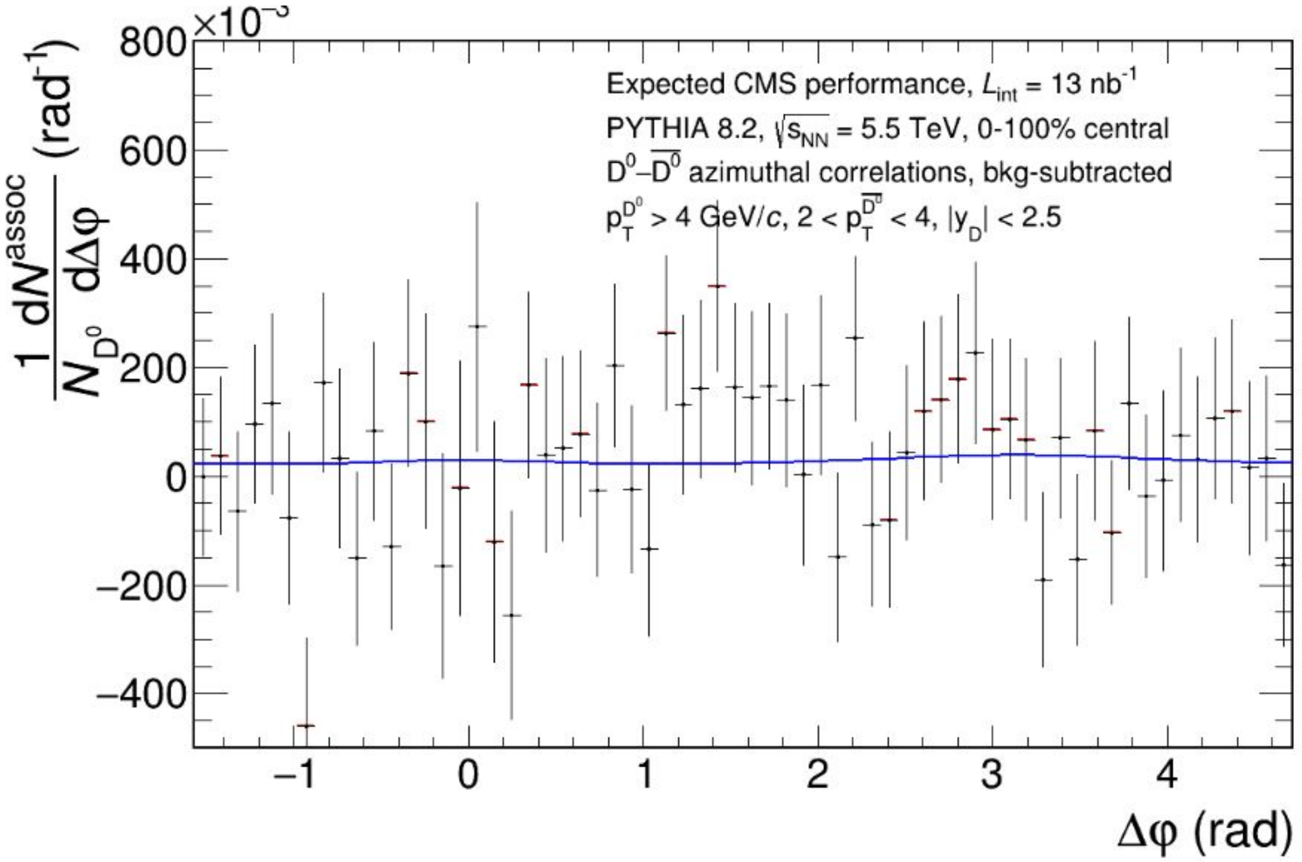






Open charm correlation expected with CMS

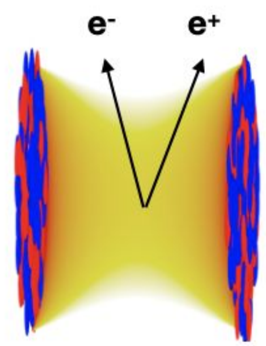
Expected performance, degraded *wrt* ALICE 3 mainly due to larger background

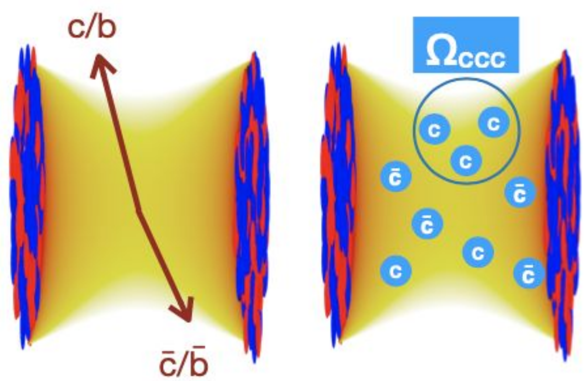


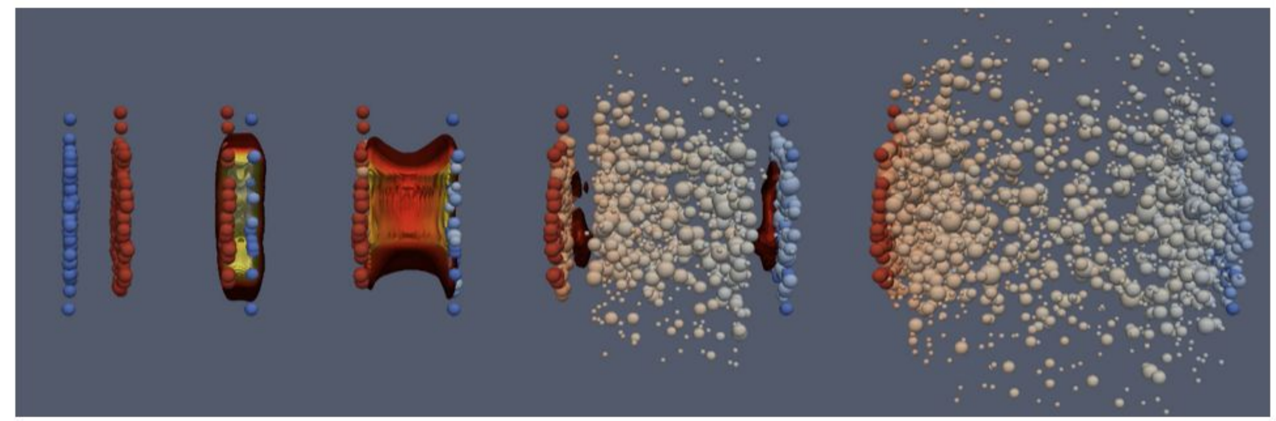
ALICE 3 physics motivations

Physics beyond Run 4

- Further progress relies on
  - **precision measurements of dileptons**
    - ➡ evolution of the quark gluon plasma
    - ➡ mechanisms of chiral symmetry restoration in the quark-gluon plasma
  - **systematic measurements of (multi-)heavy-flavoured hadrons**
    - ➡ transport properties in the quark-gluon plasma
    - ➡ mechanisms of hadronisation from the quark-gluon plasma
  - **hadron correlations**
    - ➡ interaction potentials
    - ➡ fluctuations
  - …







Electromagnetic radiation ($\propto T^2$)

Hadron momentum distributions, azimuthal anisotropy

Hadron abundances ‘hadrochemistry’

Hadron correlations, fluctuations

Heavy-ion collisions exhibit rich phenomenology and give access to many more topics,
e.g. strong interaction potentials, BSM searches

CMS heavy-ion physics motivations (Run 4)

- Precise measurement of jet quenching
  - High-statistic boson (Z/γ) and jet measurements
  - Full energy measurement of recoiling jets (thanks to large acceptance calorimeters)

- Bulk particle production
  - Long-range correlation over 8 units of rapidity
  - Hadrochemistry (thanks to MTD)

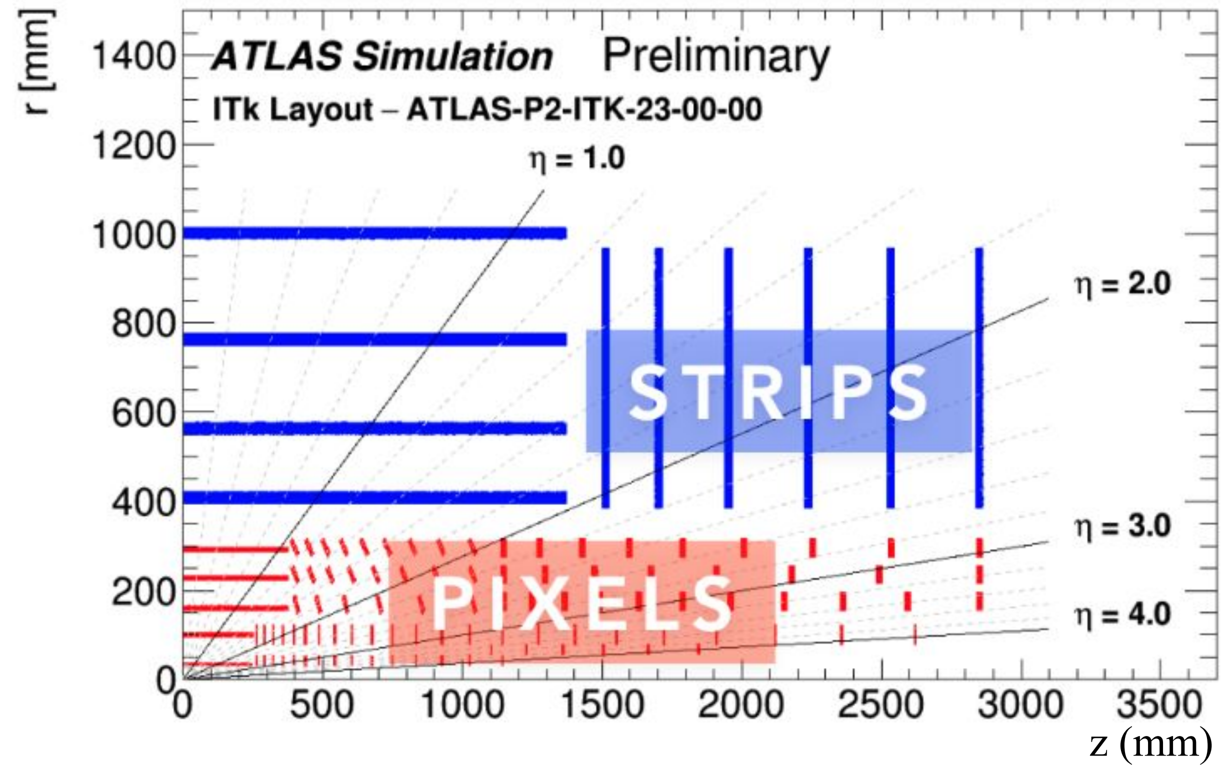
- Heavy-flavour open mesons/baryons at low pT
  - PID thanks to MTD

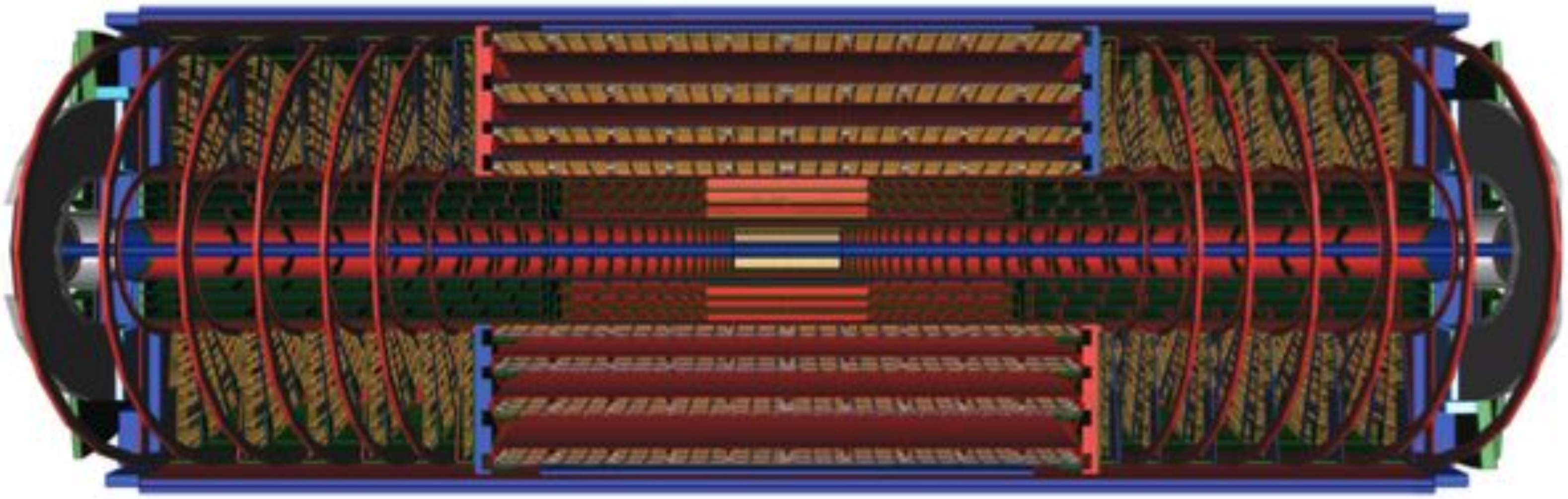
- Quarkonium states
  - Precisely measure Υ family (including Υ(3S))
  - Low pT quarkonium with hadronic decay

ATLAS Phase-II

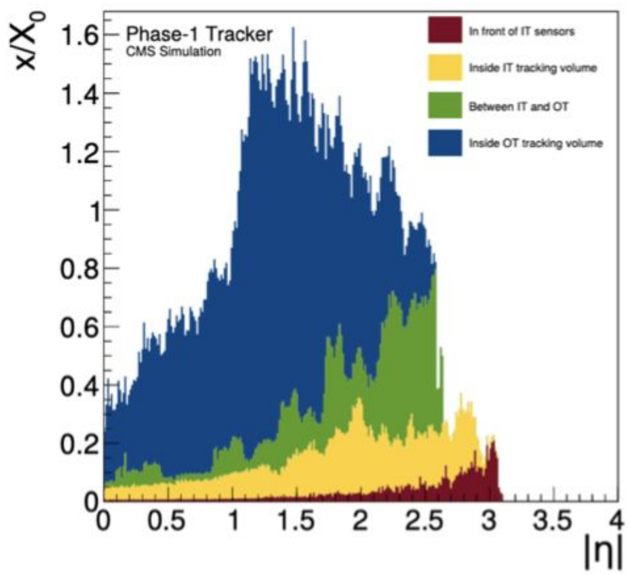
Heavy-ion physics will benefit from Phase-II upgrade:

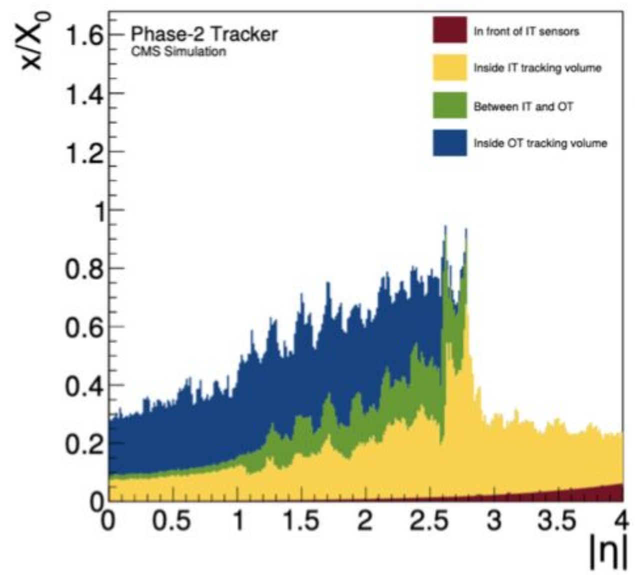
- Silicon-based inner tracker with wide eta coverage
- Forward high granularity timing detector: time-of-flight





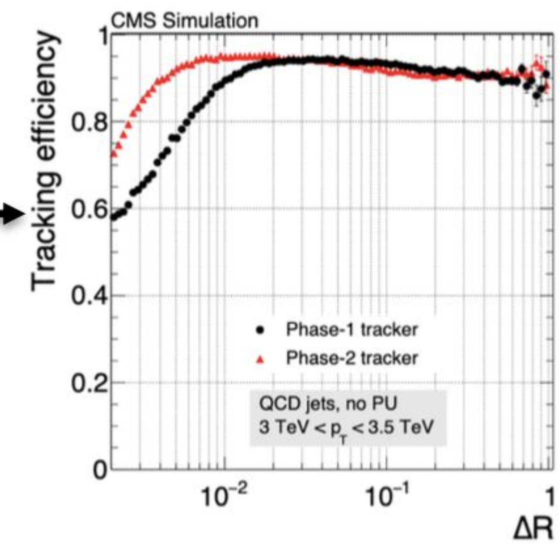
CMS tracker upgrade

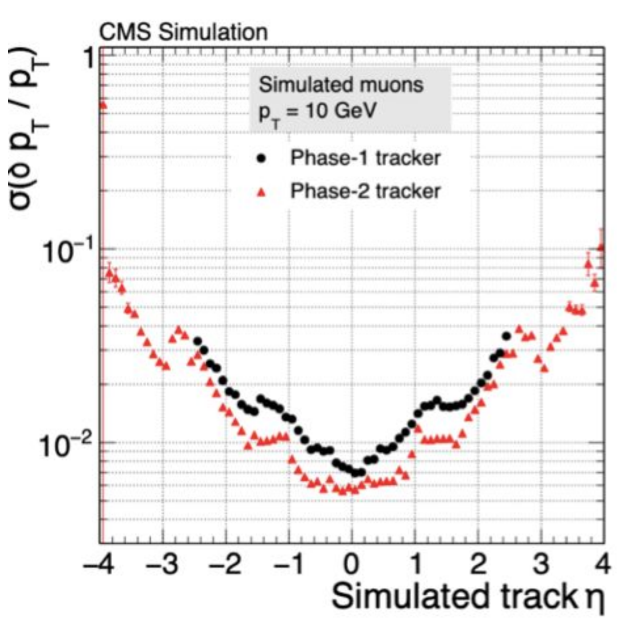


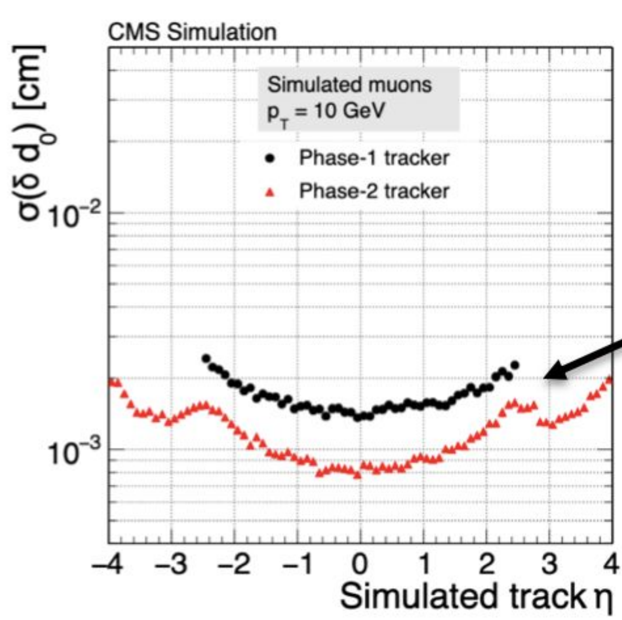


Reduced material budget by up to 2x
→ improved tracking efficiency in AA

… as evidenced by the improved separation of nearby tracks







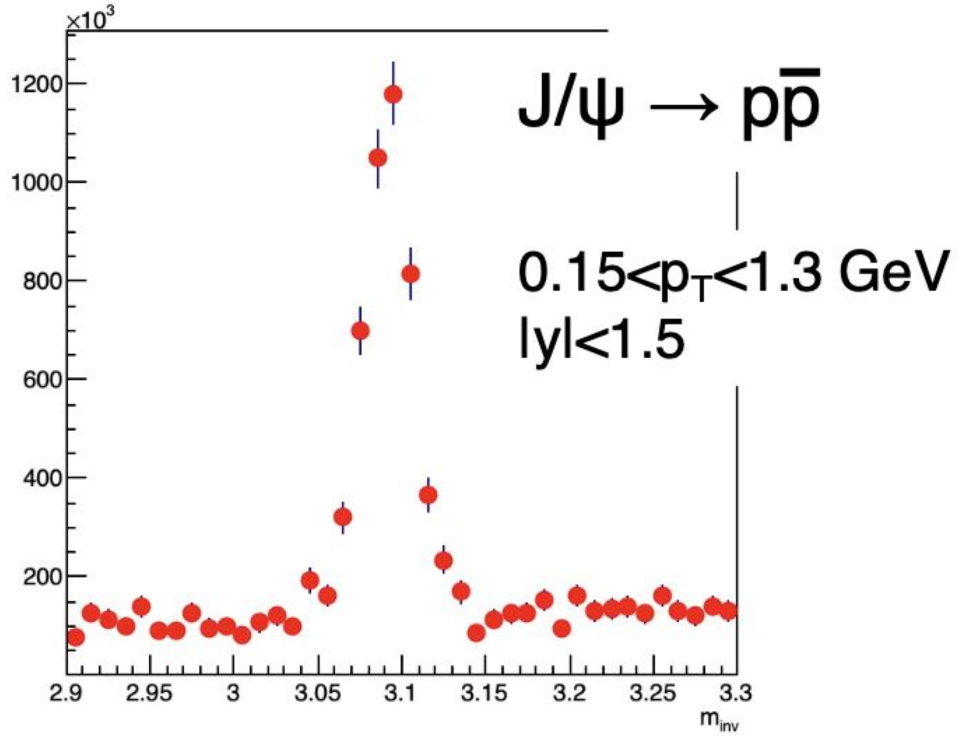
Improved p_T resolution by about 25%
→ Improved mass resolution for resonances

Impact parameter resolution improved by 40%
→ Improved heavy flavor measurements
(B/D hadrons & b/c-jet tagging)

https://indico.in2p3.fr/event/25854/

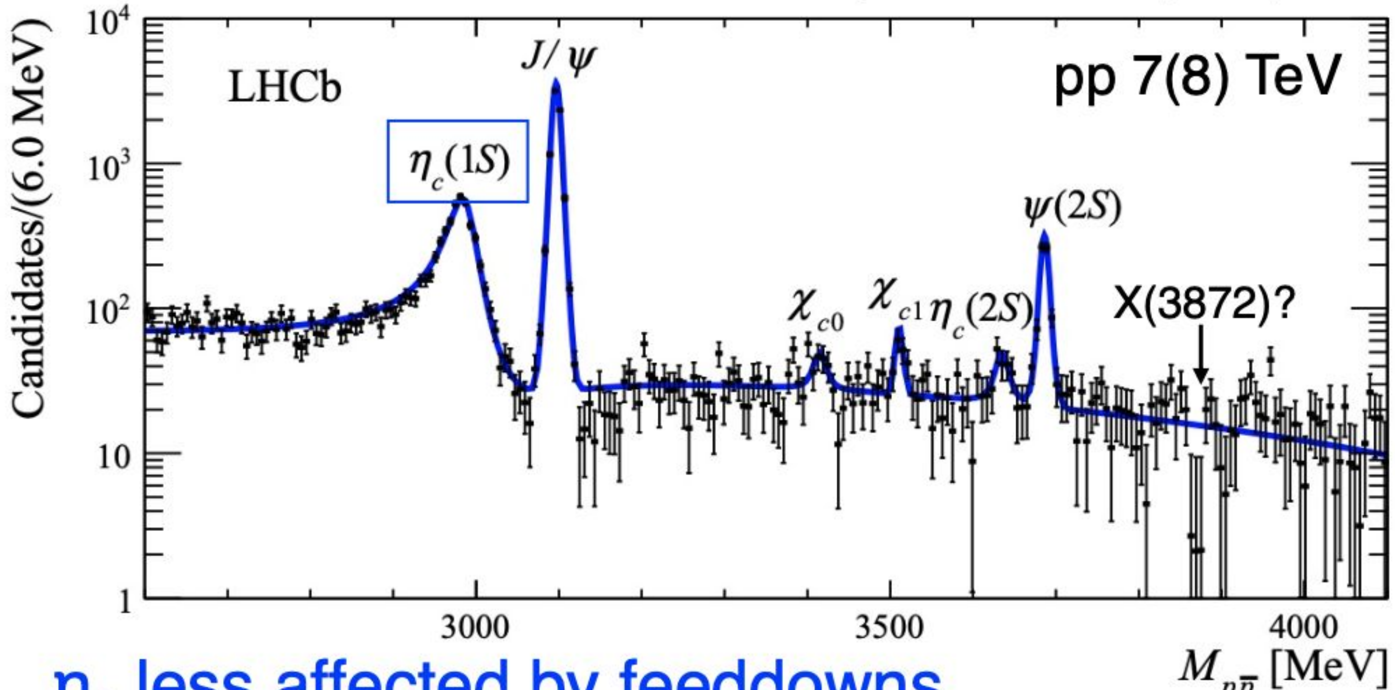
Quarkonia and Exotica with MTD

CMS-MTD simulation



(not accessible by $\mu^+\mu^-$)

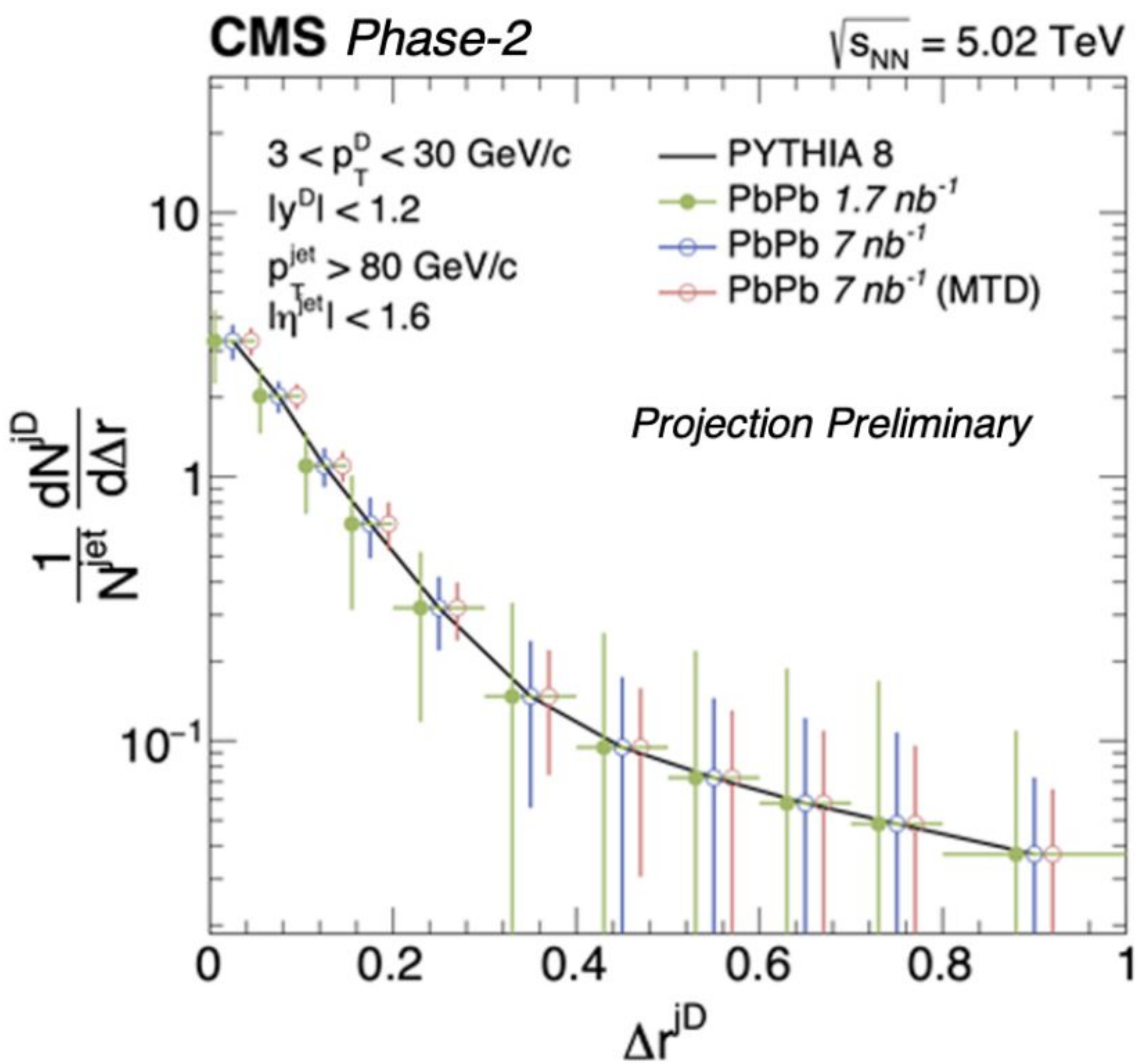
Phys. Lett. B 769 (2017) 305



η_c less affected by feeddowns

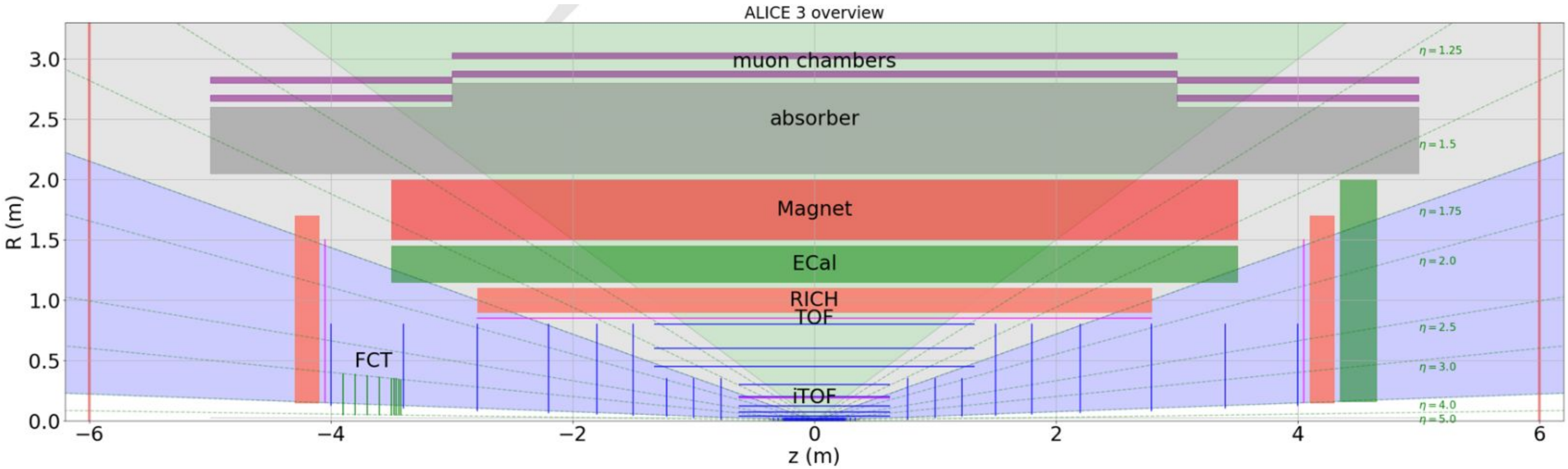
Opportunities in quarkonia and exotica with hadronic decays in pp and AA!

CMS: correlated jet yields for D meson in Pb-Pb

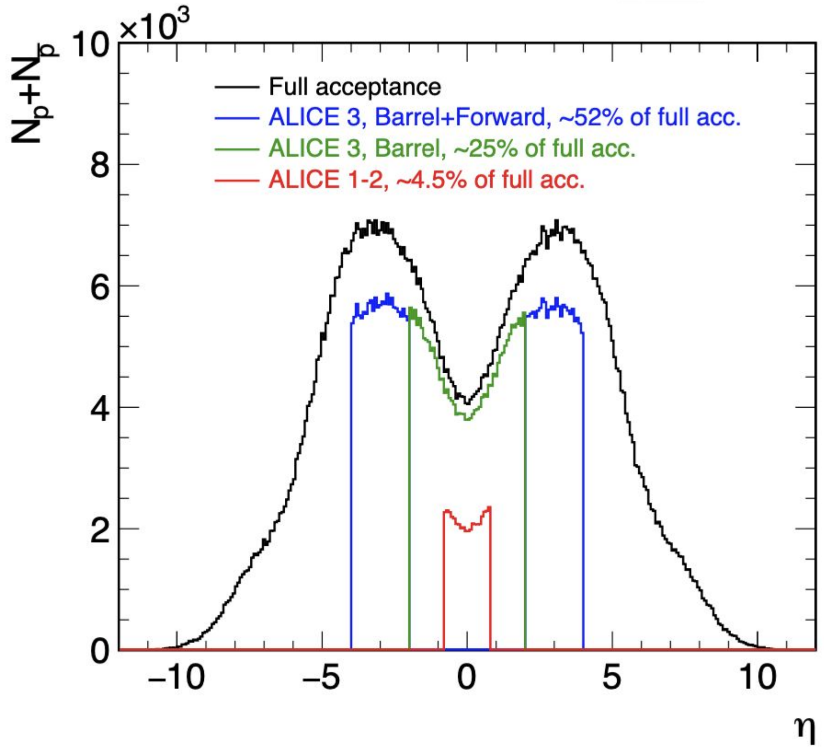


The correlated jet yields as a function of Δr, where $\Delta r = \sqrt{\Delta\eta^2 + \Delta\phi^2}$, for D meson in PbPb events at 5 TeV, estimated to an integrated luminosity of 7 nb^{-1} from the Run 4. Estimated statistical uncertainties are shown as bars.

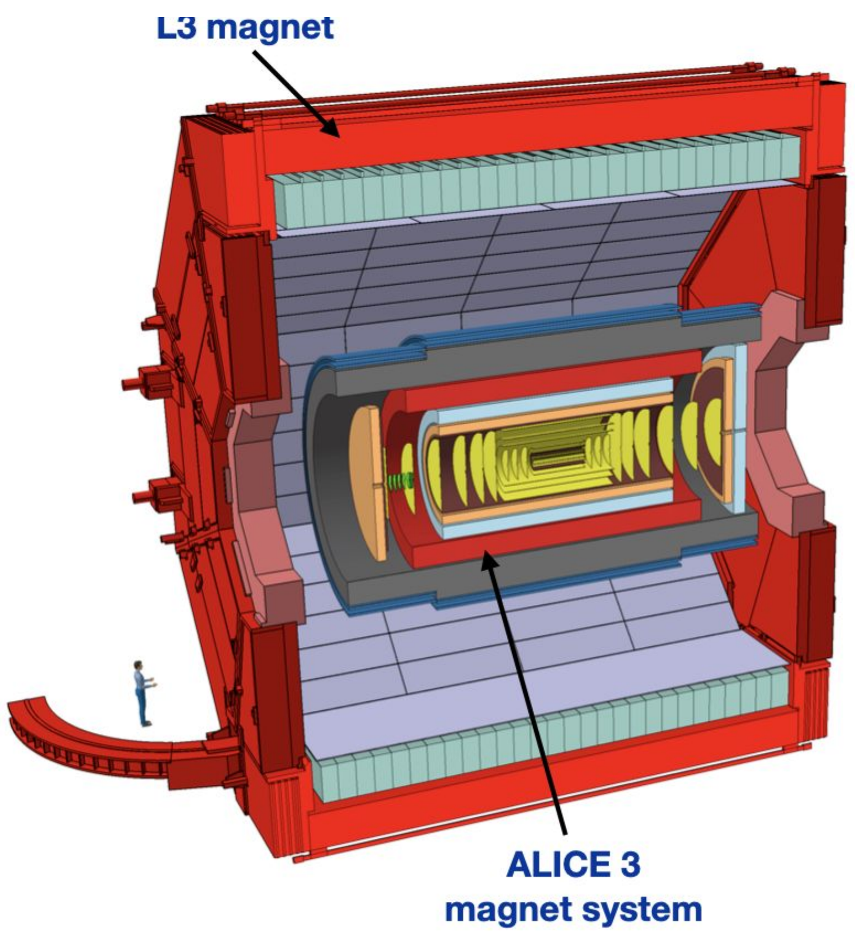
ALICE 3



ALICE 3 overview
muon chambers
absorber
Magnet
ECal
RICH
TOF
FCT
iTOF
R (m)
z (m)
η = 1.25
η = 1.5
η = 1.75
η = 2.0
η = 2.5
η = 3.0
η = 4.0
η = 5.0

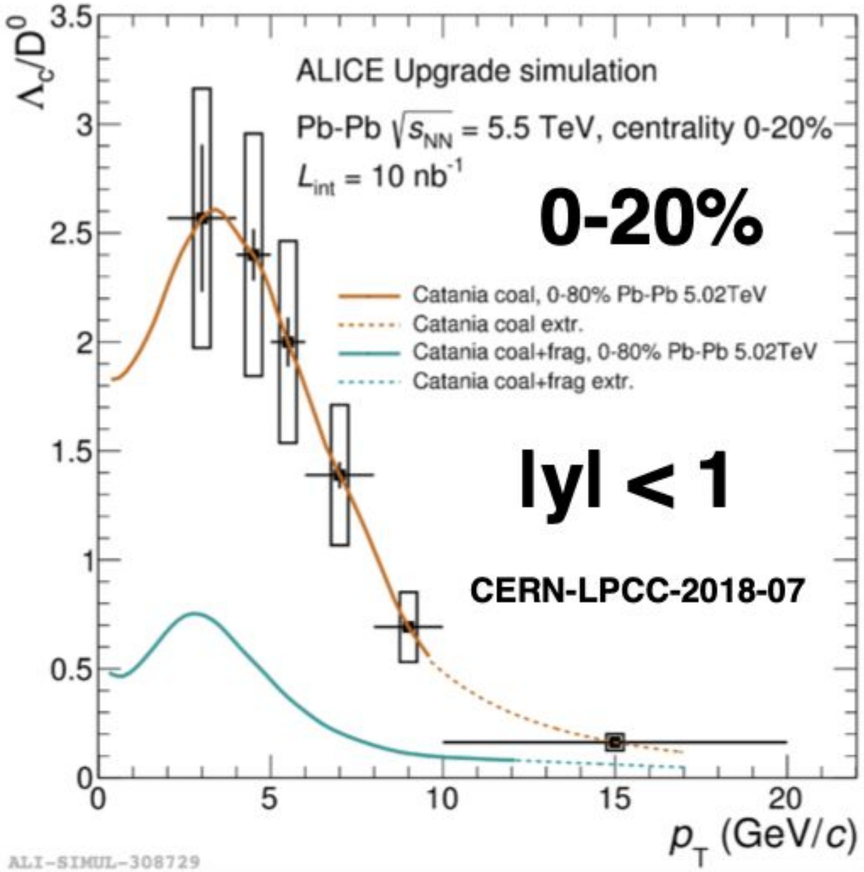


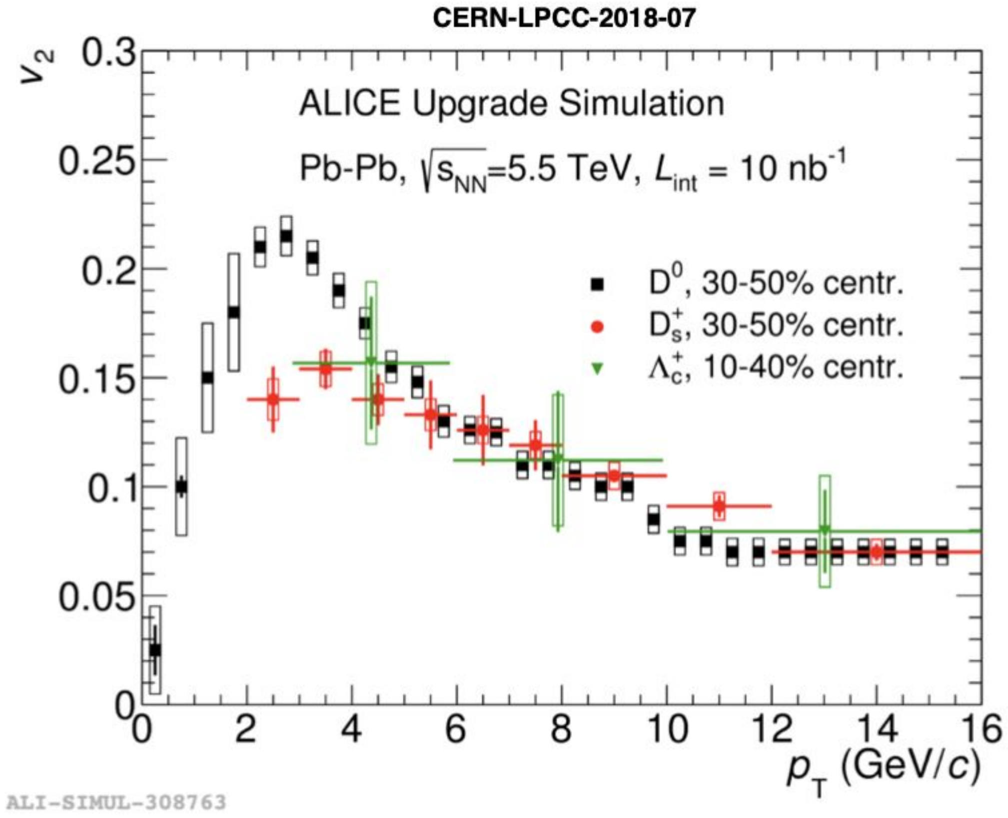
$N_p + N_{\bar{p}}$
×10³
Full acceptance
ALICE 3, Barrel+Forward, ~52% of full acc.
ALICE 3, Barrel, ~25% of full acc.
ALICE 1-2, ~4.5% of full acc.
η



L3 magnet
ALICE 3
magnet system

ALICE Run 3-4: heavy-flavour





Back-up: new (B)SM physics observables in UPC

light-by-light scattering in ALICE and LHCb

https://journals.aps.org/prd/abstract/10.1103/PhysRevD.99.093013

g-2 with UPC tau-tau ATLAS/CMS, ALICE & LHCb (including upgrades):

https://arxiv.org/abs/2203.00990

Tauonium observation

https://arxiv.org/pdf/2202.02316.pdf