Upgrades at the LHC

detector technologies
&
prospects for heavy-ion physics

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Introduction

- **Marvellous performance of LHC and experiments**
  → presentations at this very conference

- **Further progress** relies on
  - **statistics** → accelerator (luminosity) & detectors (rate, occupancy, radiation load, …)
  - **precision** → detector resolution (position, time, …)
  - **analyses** → methods & technologies

In this talk focus on

- detector technologies and choices
- performance improvements
- impact on heavy-ion programme

LHC programme

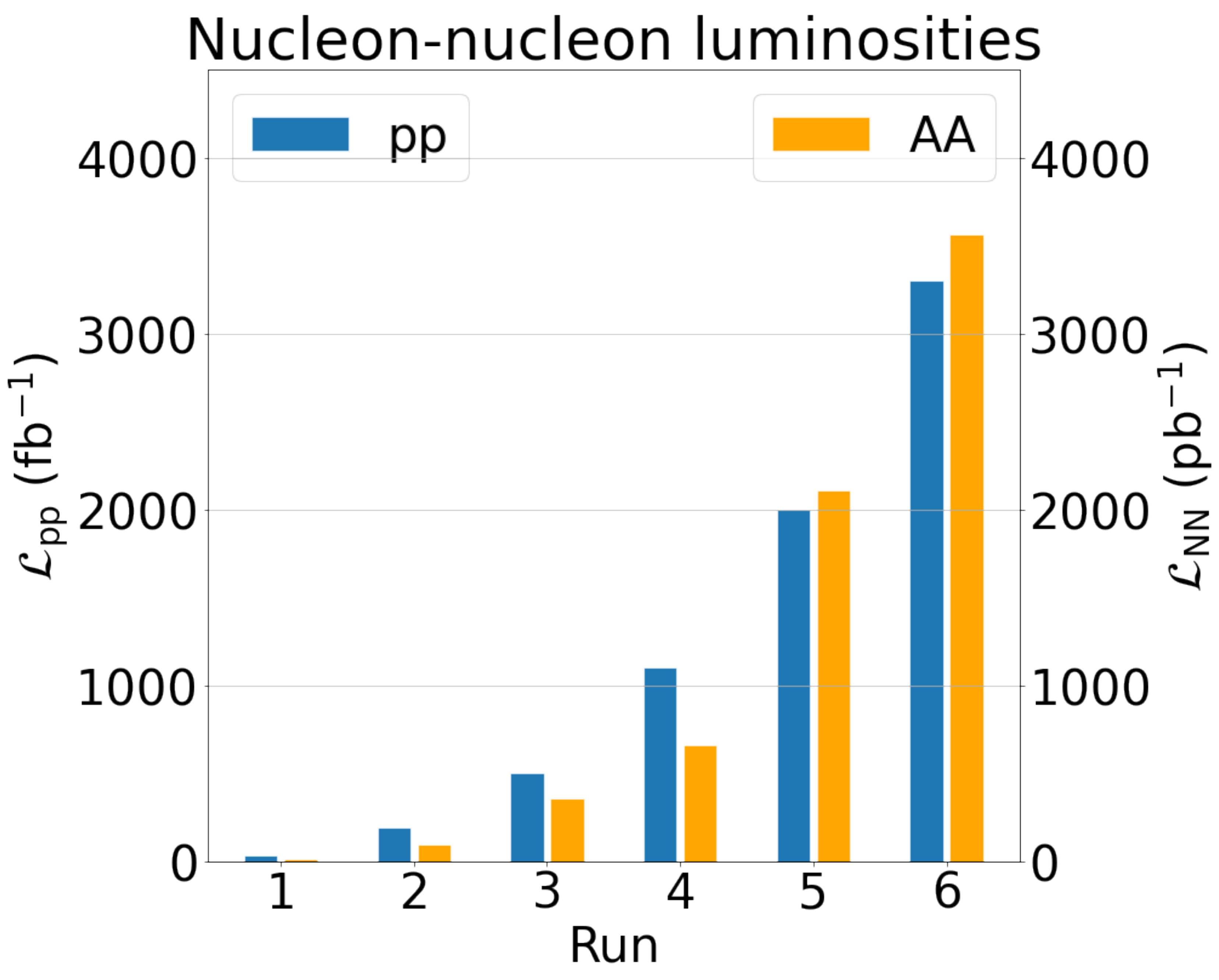
	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
Collision systems	pp, pPb, Pb-Pb	pp, pPb, Xe-Xe, Pb-Pb	pp, pO, OO, pPb, Pb-Pb	pp, pPb, Pb-Pb	pp, pA?, AA	pp, pA?, AA
LHC schedule	2009 - 2013	2015 - 2018	2022 - 2025	2029 - 2032		

HL-LHC

Higher luminosities for ions

LHC provides **ideal and unique environment** to study hot QCD matter with heavy ions

- various collision systems at highest energies $\sqrt{s_{NN}} = 5.36\,\mathrm{TeV}$
- highest energy density (> 12 GeV/fm³) and highest temperature (≳ 300 MeV)
- longest lifetime (≳ 10 fm/c)
- largest heavy-flavour yields (~200 c/$\bar{c}$ in central Pb-Pb)
- vanishing net-baryon density ($\mu_B \approx 0$)



LHC programme

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LHC schedule	2009 - 2013	2015 - 2018	2022 - 2025	2029 - 2032		

HL-LHC (Run 4 – Run 6)

Higher luminosities for ions (Run 5 – Run 6)

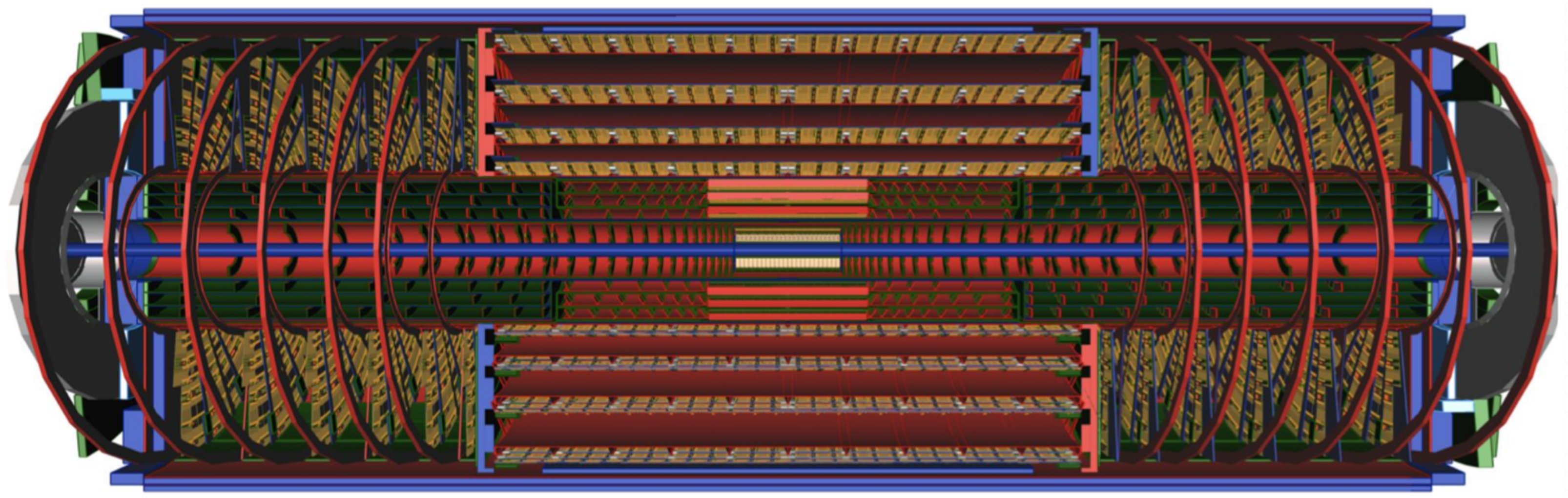
		Run 3	
ATLAS	ATLAS	ATLAS phase I upgrades	ATLAS phase II upgrades
CMS	CMS	CMS phase I upgrades	CMS phase II upgrades
LHCb	LHCb	LHCb upgrade I(a)	LHCb upgrade Ib (Run 4); LHCb upgrade II (Runs 5–6)
ALICE	ALICE 1	ALICE 2 upgrade	ALICE 2.1 upgrade (Run 4); ALICE 3 upgrade (Runs 5–6)

intermediate upgrade | major upgrade

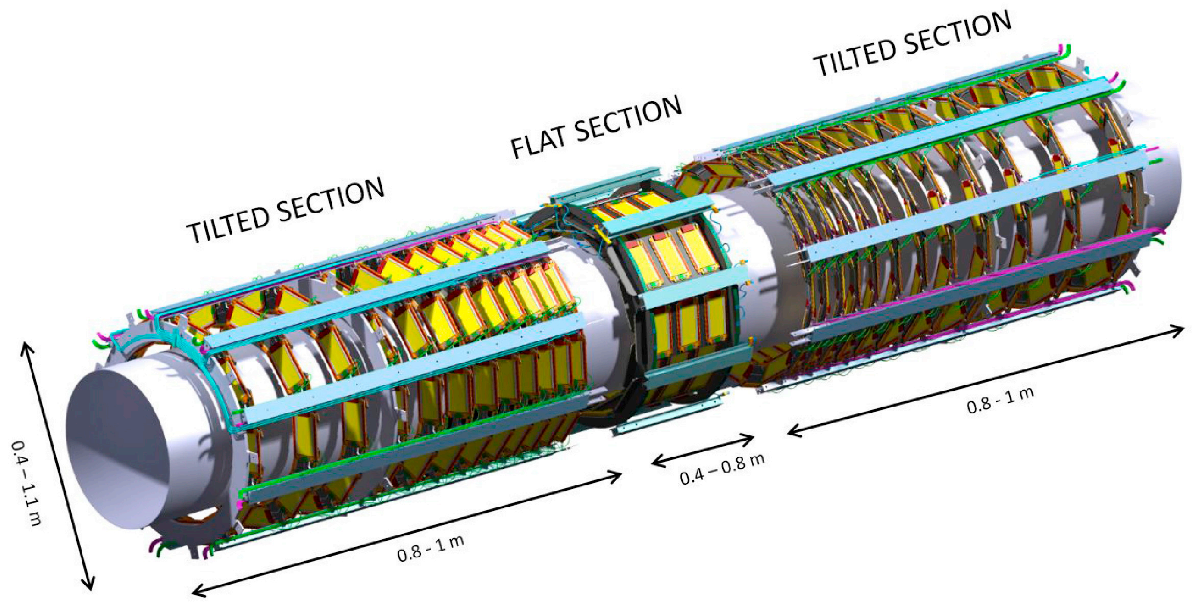
Tracking & Vertexing

Wide adoption of silicon sensors to meet requirements

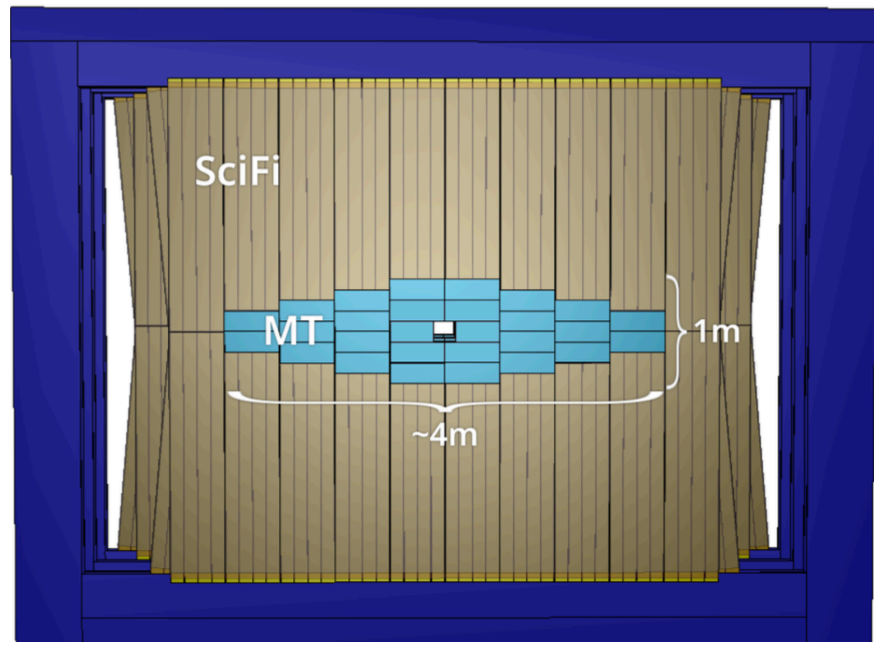
- position & timing resolution (pile-up, pointing)
- bandwidth (fluxes > GHz/cm^2)
- material budget (momentum resolution)
- radiation tolerance (10^{16} n_{eq} cm^{-2} for inner layers)
- large acceptance (~100 m^2 for tracking layers)



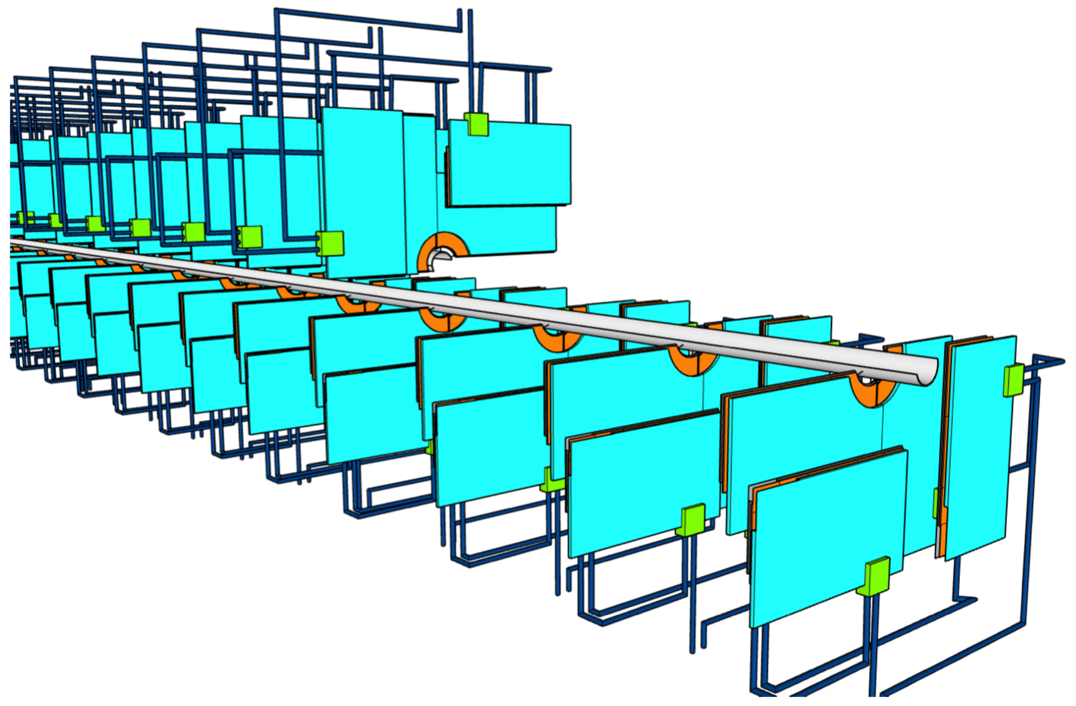
ATLAS ITk



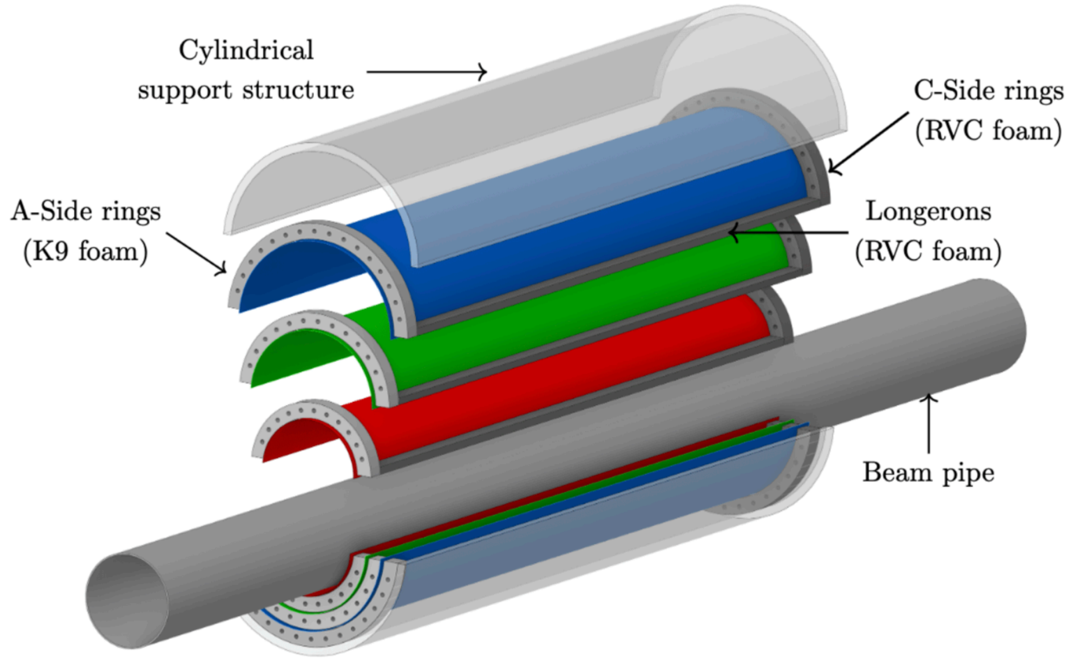
CMS tracker



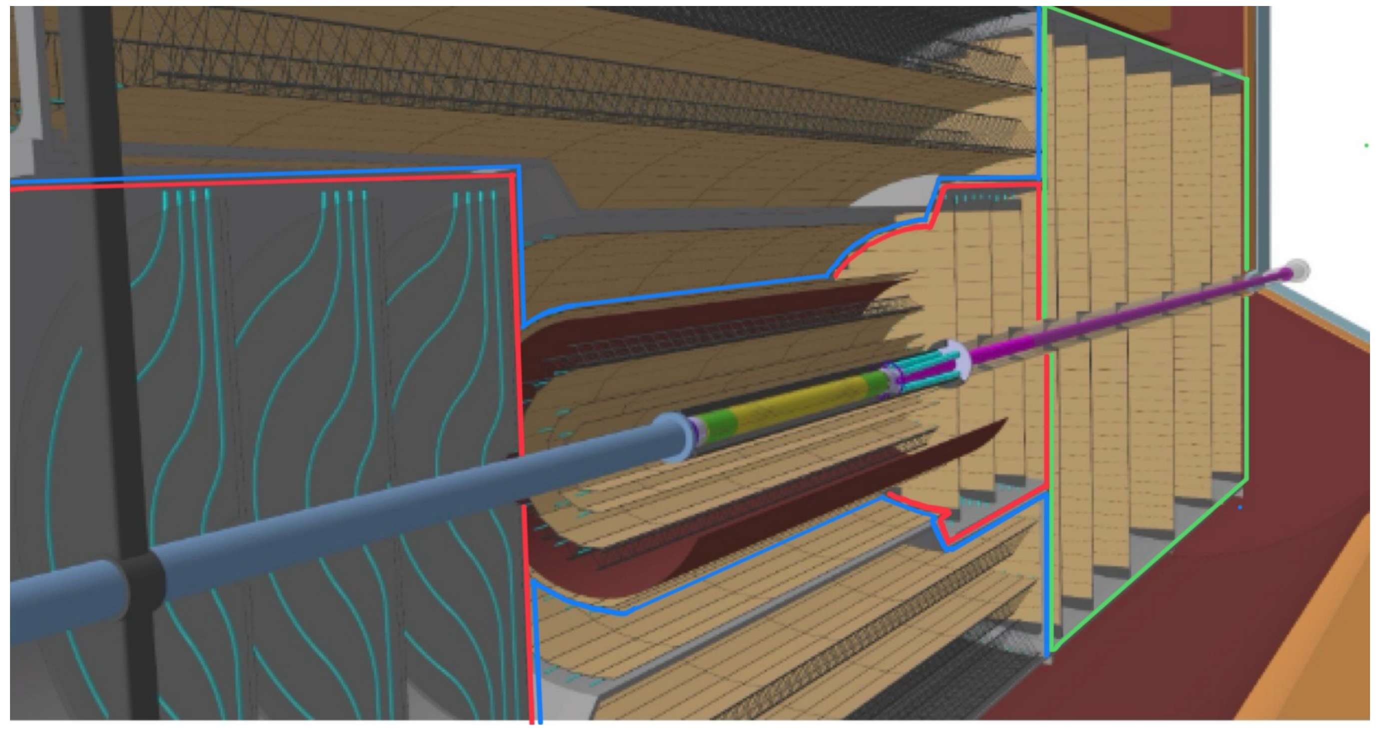
LHCb mighty tracker



LHCb VELO



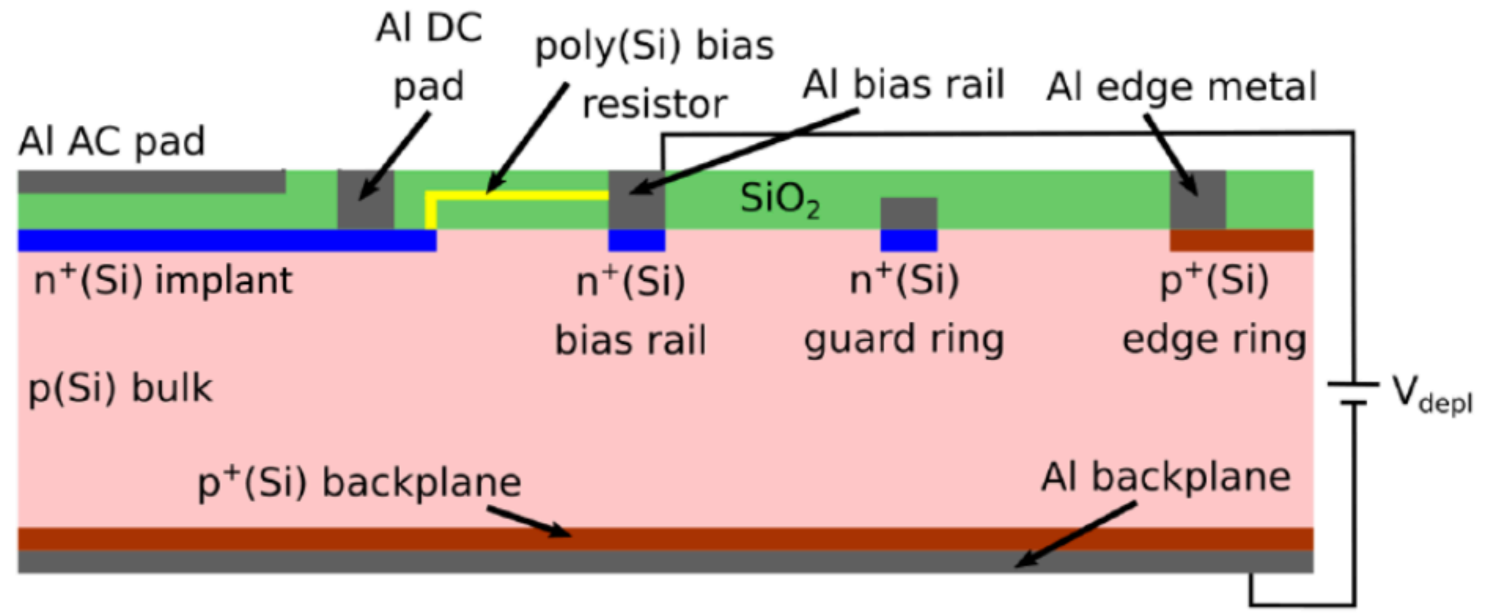
ALICE ITS3



ALICE 3 tracker

Silicon strip sensors

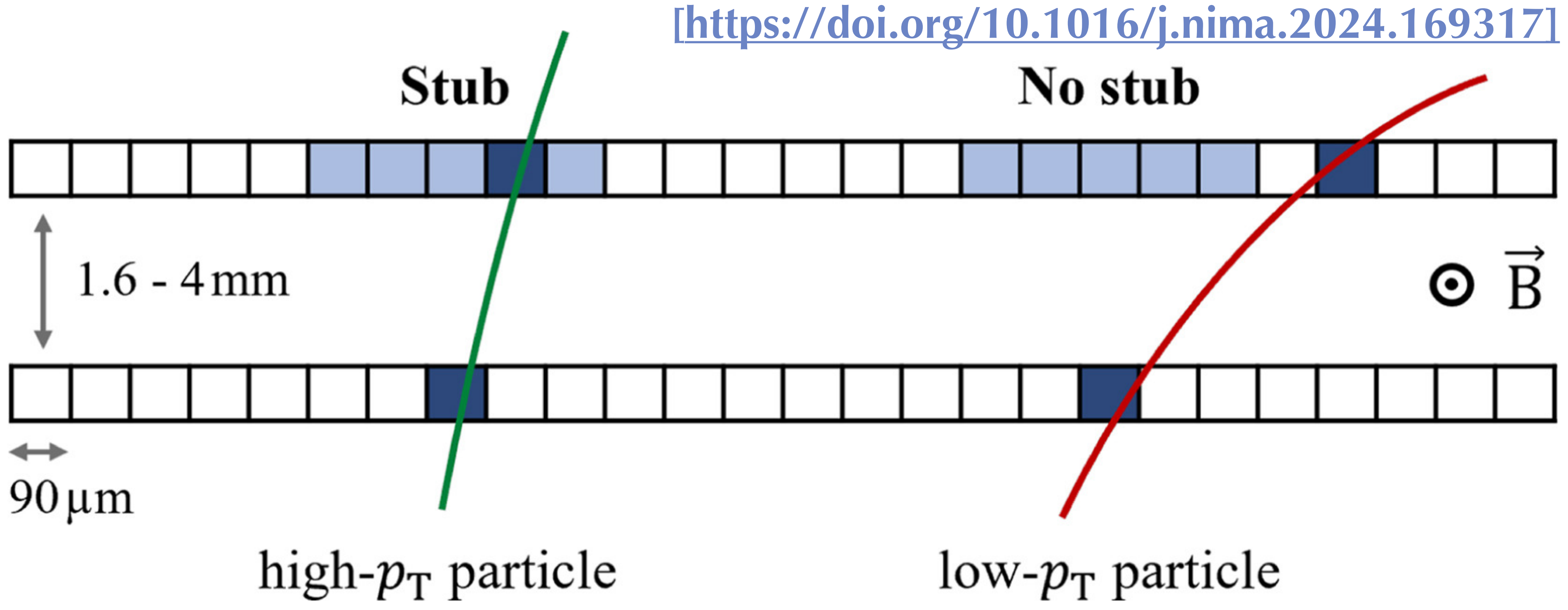
- **Double layers** of **n+-in-p** strip sensors
  (320 µm, $V_{bias} \approx 500 - 800$ V)
  - radiation load at HL-LHC:
    p bulk → no type inversion, larger signals
  - cold operation (-30 °C)
  - $\mathcal{O}$(100 µm x cm) strips, $\mathcal{O}$(100 m²), $\mathcal{O}$(10⁸) channels



ATLAS sensor

[https://doi.org/10.1016/j.nima.2024.169317]

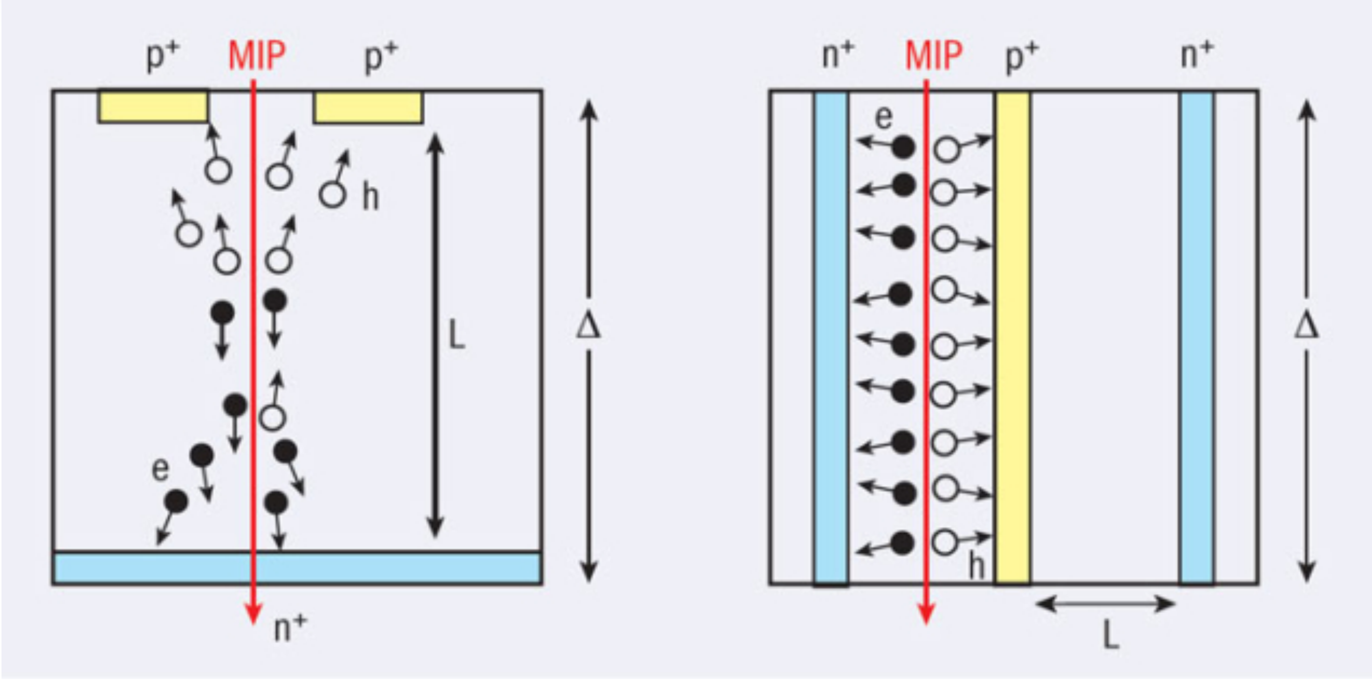
- **Front-end** and **readout** with dedicated chips
  - local processing
    (ATLAS ABCstar + HCCstar, 130 nm GF)
  - correlation of hits to stubs and filtering
    (CMS Binary Chip + CMS Integrator Chip)



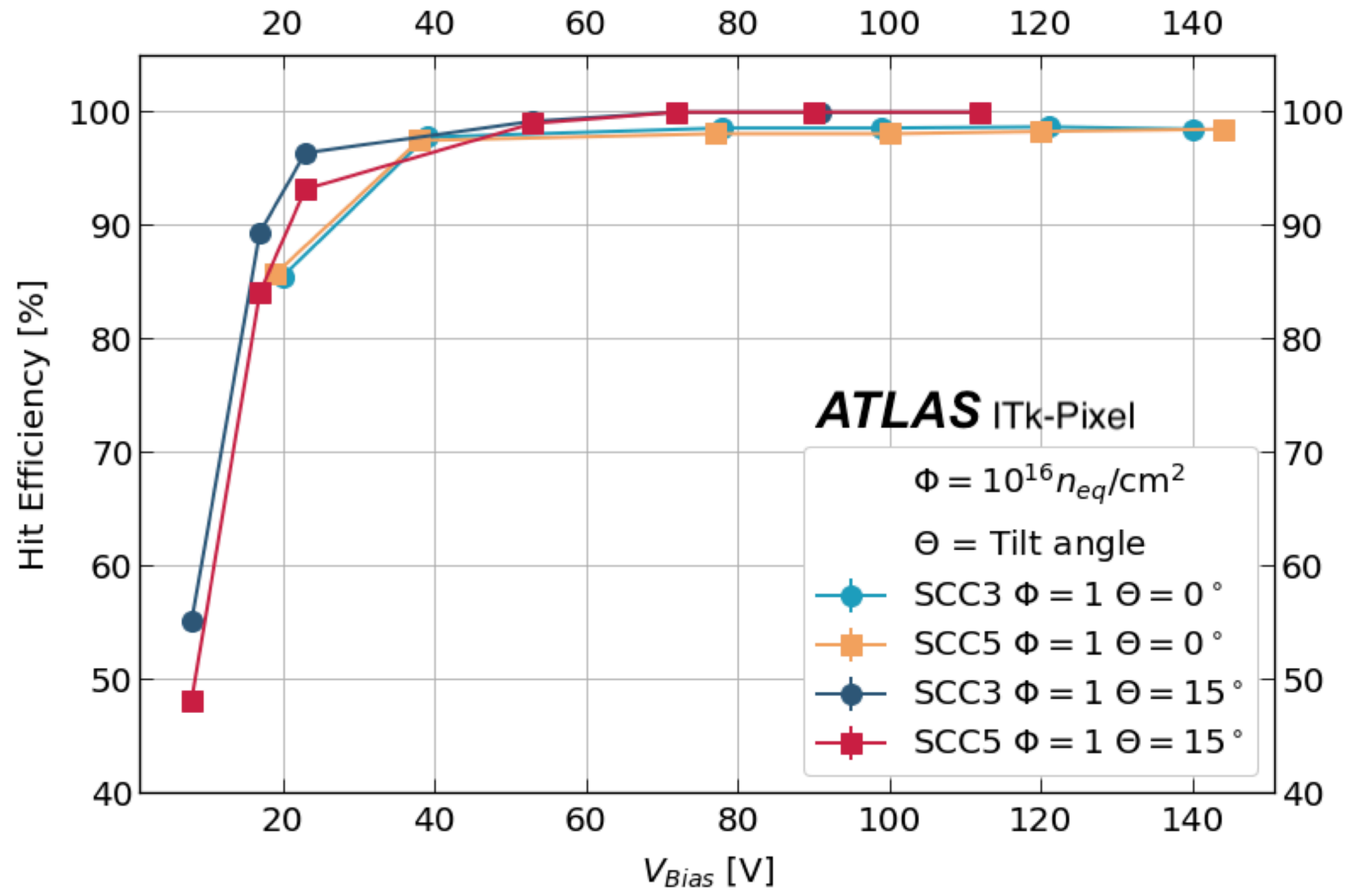
CMS: local filtering

Hybrid pixel sensors

[https://cerncourier.com/a/silicon-sensors-go-3d/]

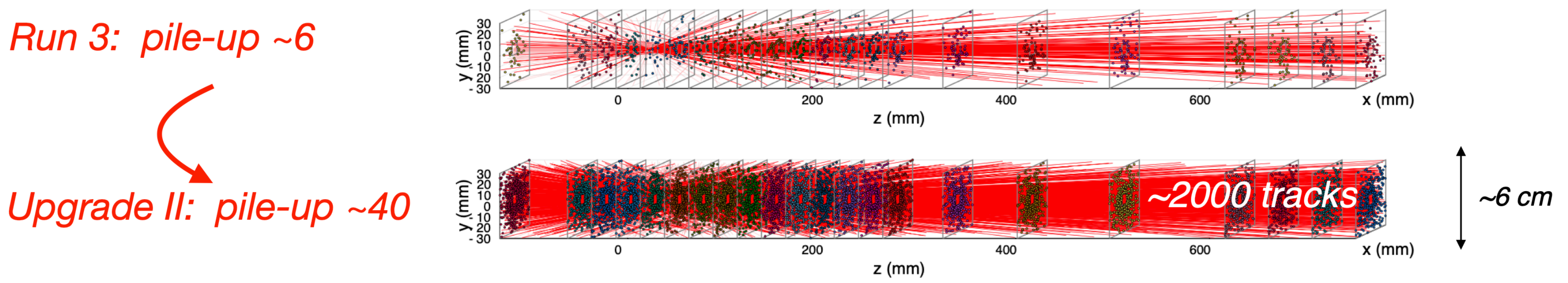


- **Planar and 3d pixel sensors (n⁺-in-p)**
  → trade-off between stability (3d) and efficiency (planar)
  - $\mathcal{O}$(50 x 50) µm² pixels, $\mathcal{O}(10^9)$ channels, first layers 3d (ATLAS, CMS)
  - ongoing R&D (LHCb VELO)
- **Front-end and readout**
  - RD53 → CMS CRORCv2, ATLAS ITkPixV2 (TSMC 65 nm): **ToT ∝ charge**
  - towards **4d tracking** in LHCb VELO:
    - TimePix4 (MediPix; TSMC 65 nm): 55 µm, 195 ps
    - TimeSpot (INFN; 28 nm), $\sigma_t \approx 50$ ps
    - PicoPix (CERN, Nikhef; 28 nm)



[https://doi.org/10.22323/1.420.0025]

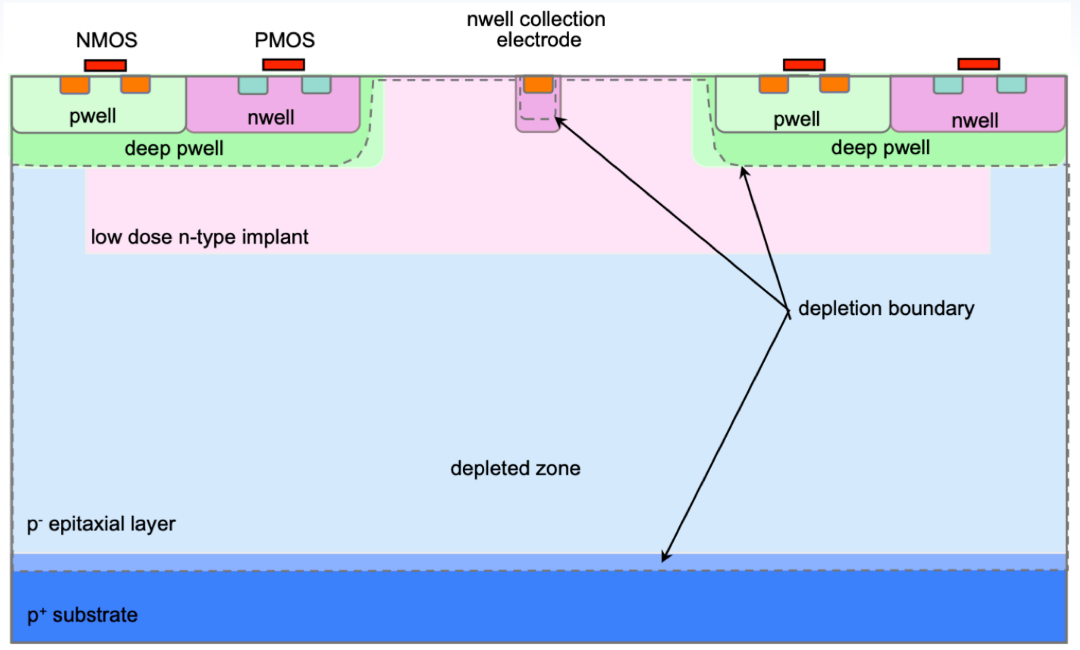
Efficiency ATLAS 3d pixels



LHCb VELO

Monolithic active pixel sensors

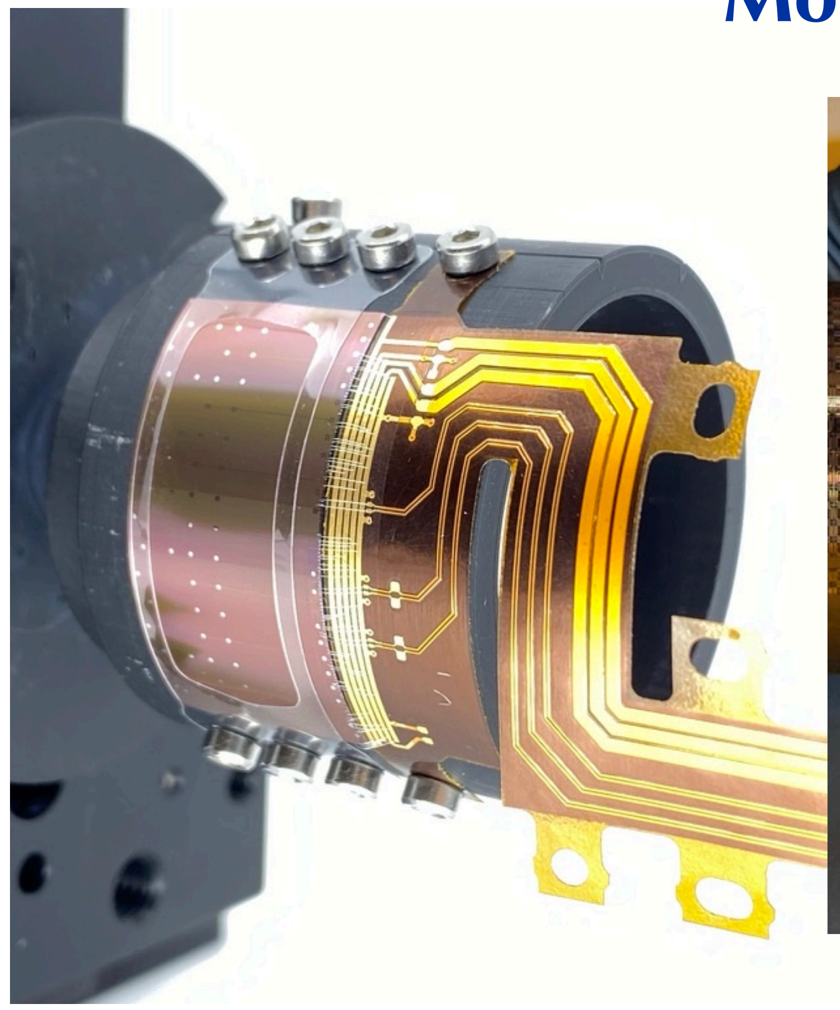
- **Modification of TowerJazz 180 nm process**
  → depletion, radiation tolerance (~10^{15} n_{eq} / cm^2)
  - MALTA, Monopix → LHCb trackers? (originally ATLAS phase II)

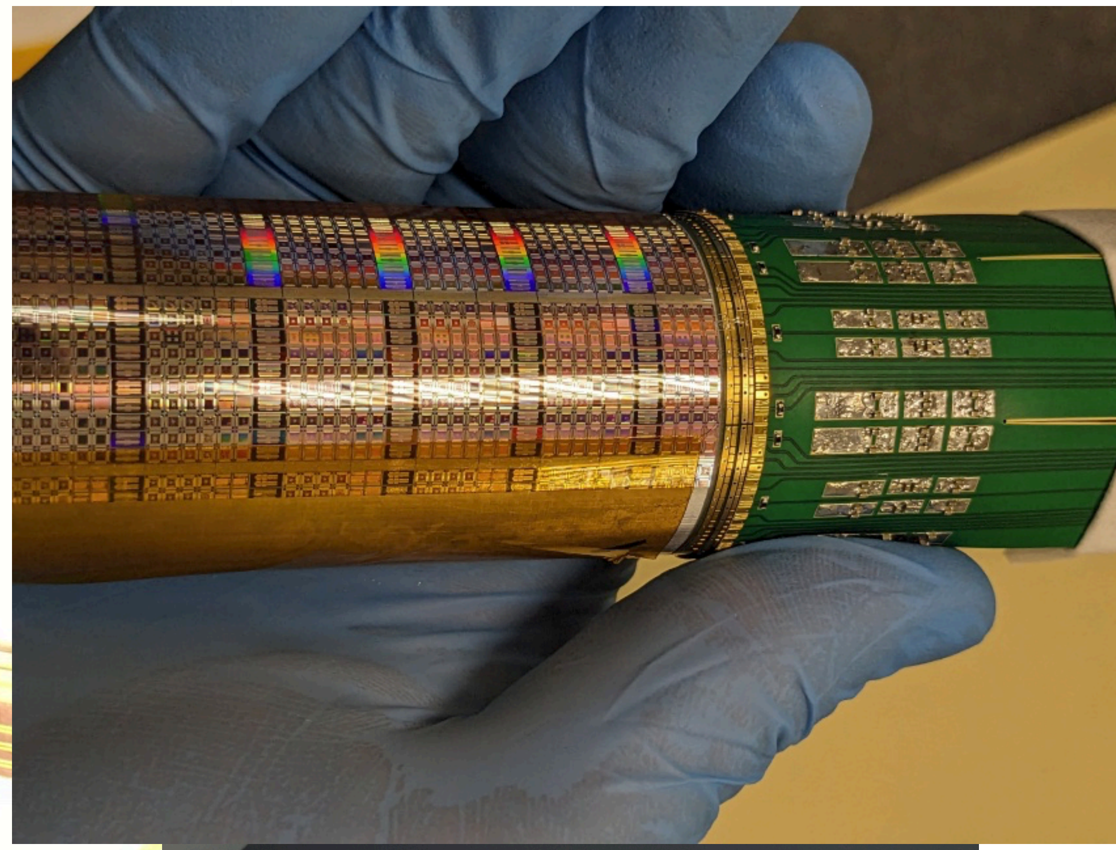


Modified process (depletion)

- **HV-MAPS** (special processes)
  → depletion through bias voltage
  - LHCb trackers?

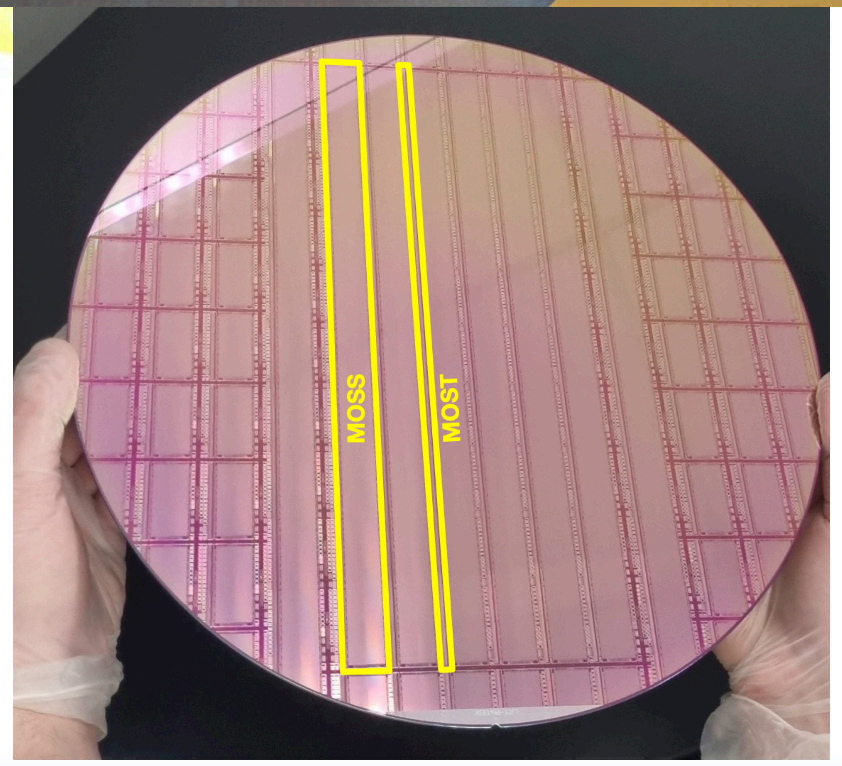
- **Thinning and bending of sensors** → ITS3
  - feasibility and performance demonstrated with ALPIDE





Bent ALPIDE

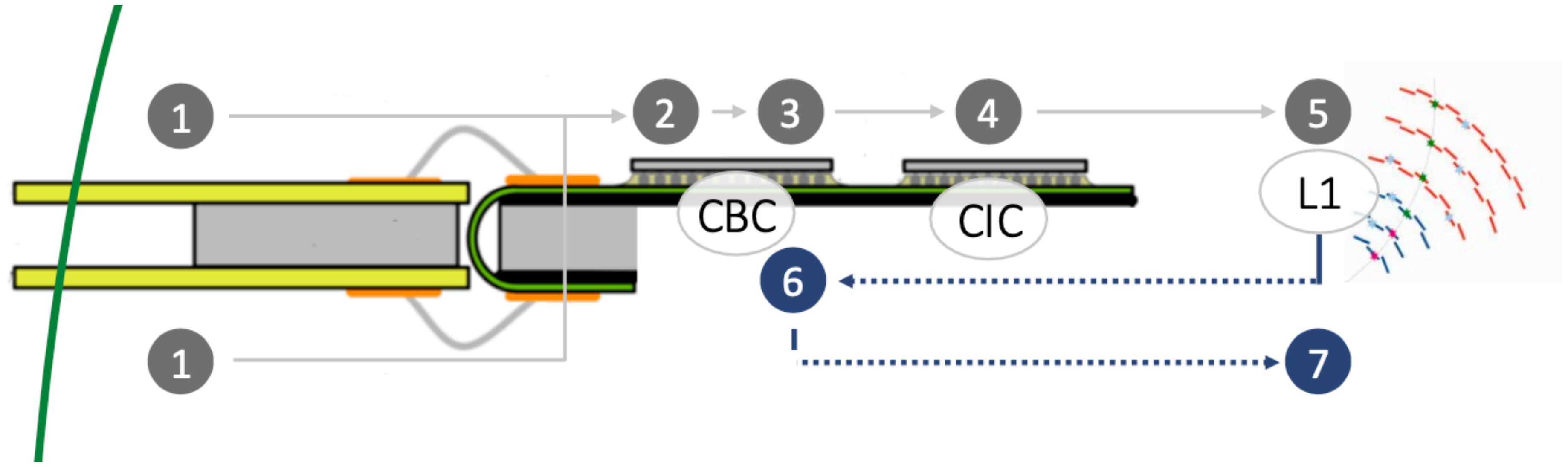
- **65 nm sensors realised** (TPSCo imaging + modification)
  → denser integration, larger wafers, stitching
  - MOSAIX: wafer-sized stitched sensor, $\mathcal{O}(10 \times 10)$ µm^2 pixels → ITS3
  - baseline technology for ALICE 3



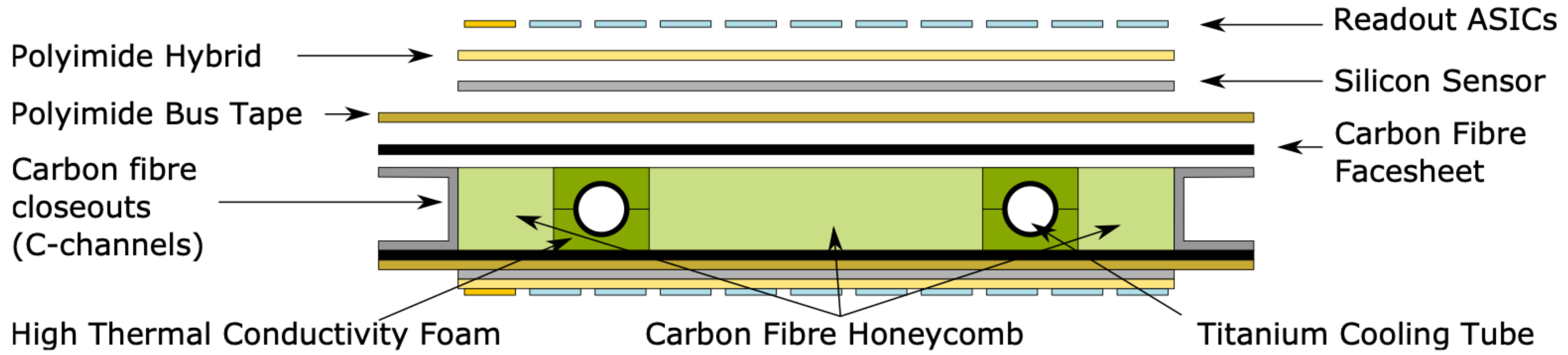
Stitched sensors

Integration

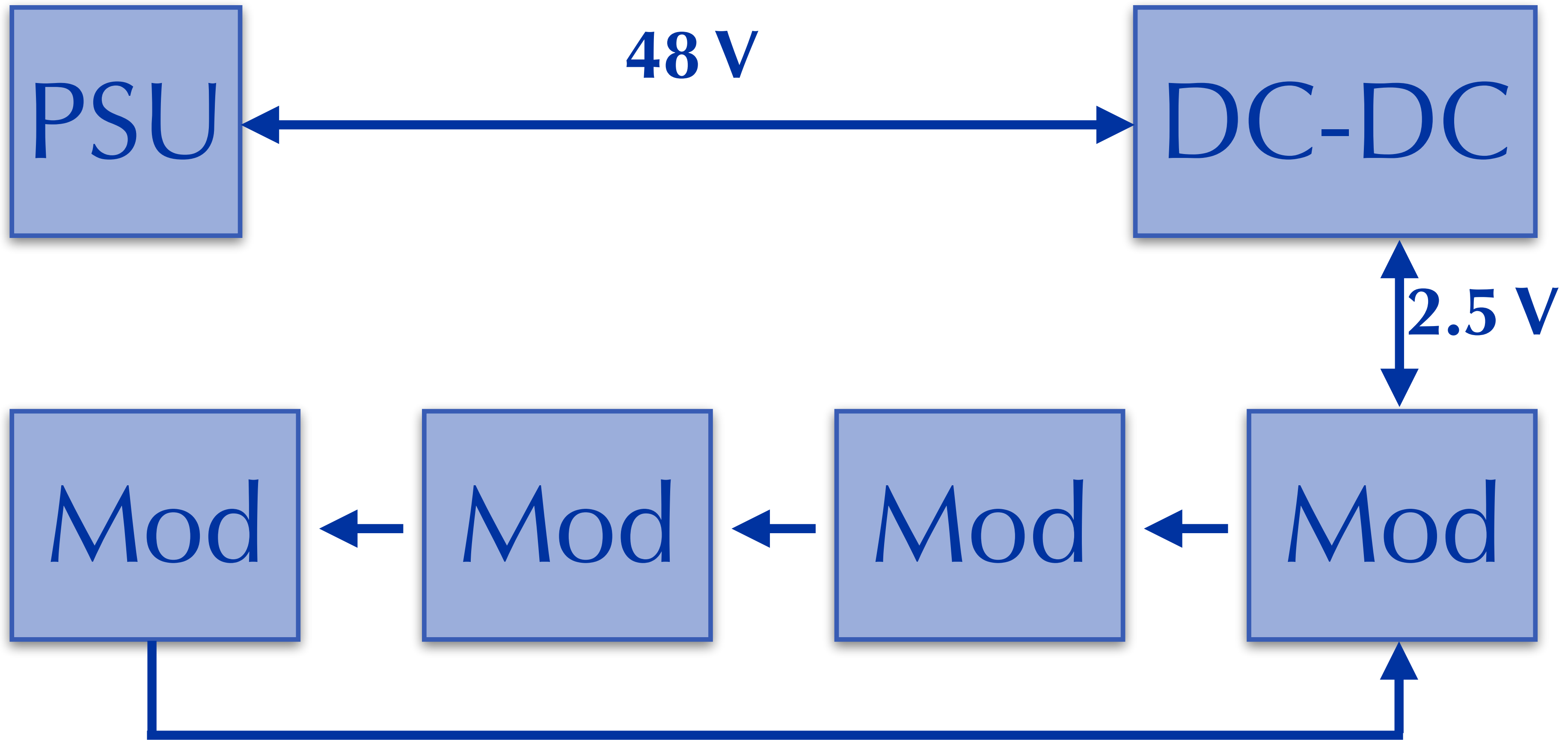
- **Highly-integrated modules:** sensor + readout + power chips
  - industrialised production, possibly wafer-to-wafer bonding
  - thermal stress can cause cracks (cf. ATLAS)
- **Cooling**
  - air → lightweight (ITS3)
  - water → cooling power (ALICE 3)
  - CO_2 → cold (ATLAS, CMS)
- **DC-DC conversion** → reduce current, i.e. material
  - rad. hard buck converters (bPOL…) available
  - ongoing R&D for higher currents (50 A), new processes
- **Serial powering** → reduce material
  - shunt regulators integrated in readout chips (ATLAS, CMS)



CMS strip module



ATLAS strip module

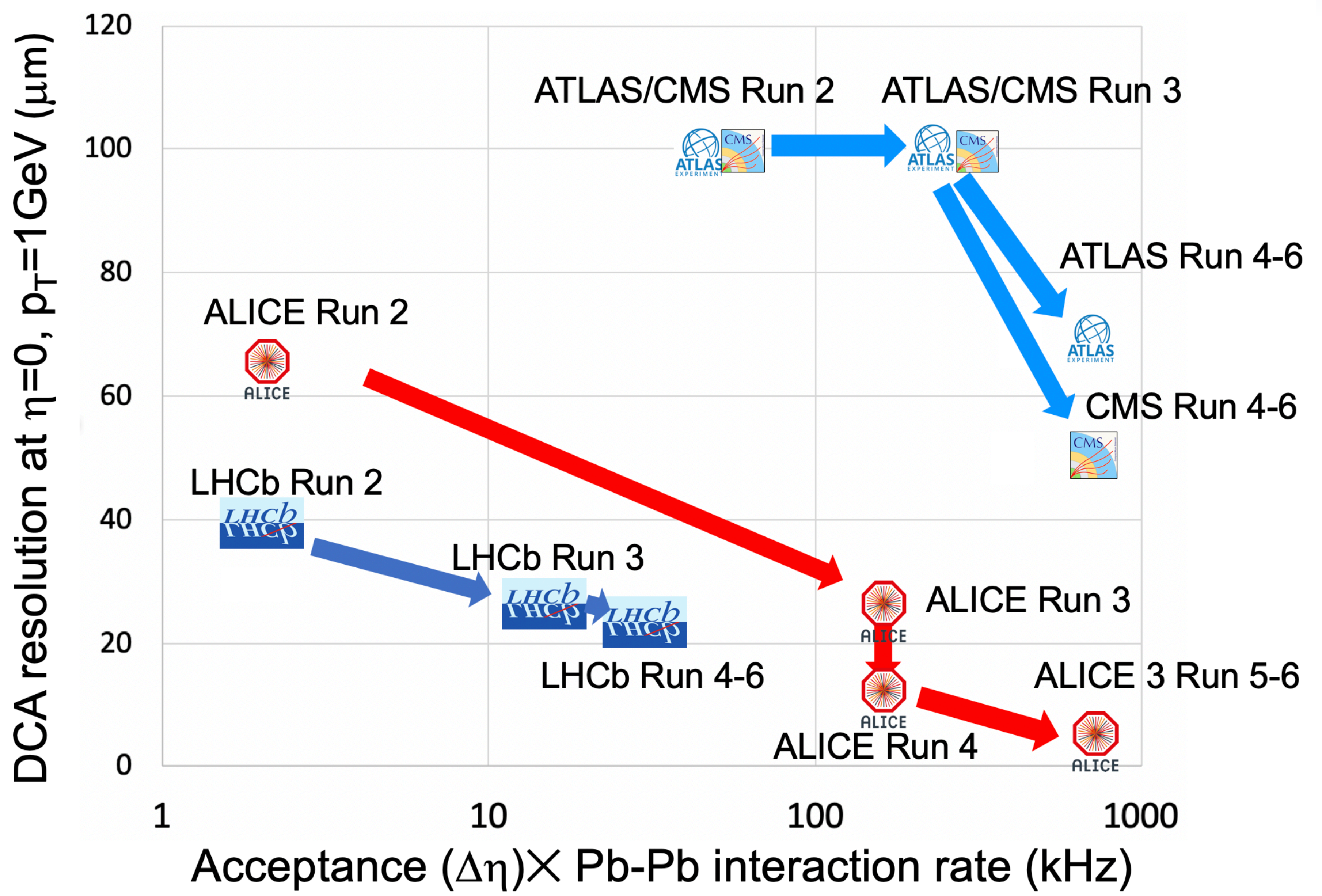


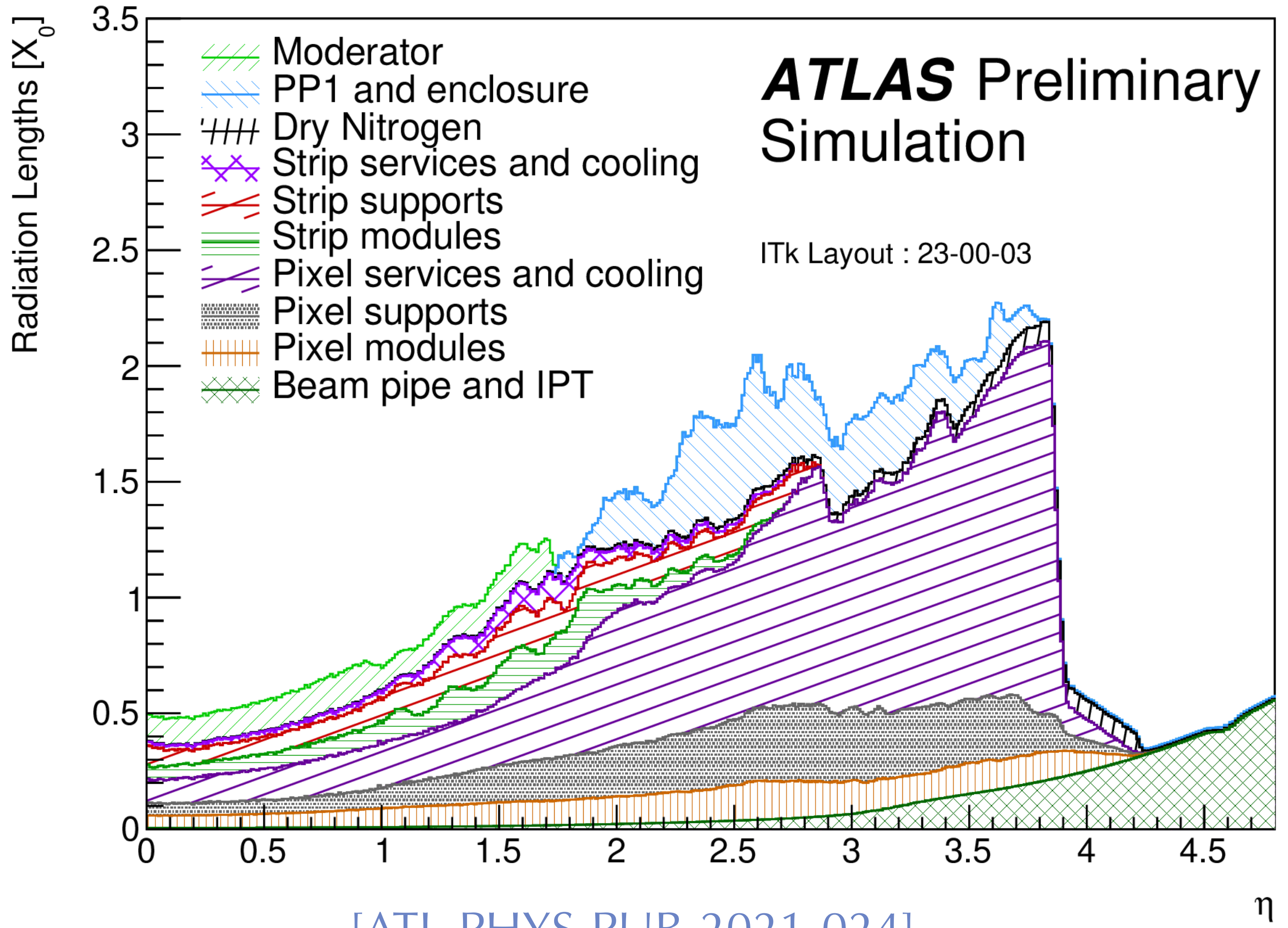
Powering scheme (simplified)

Performance

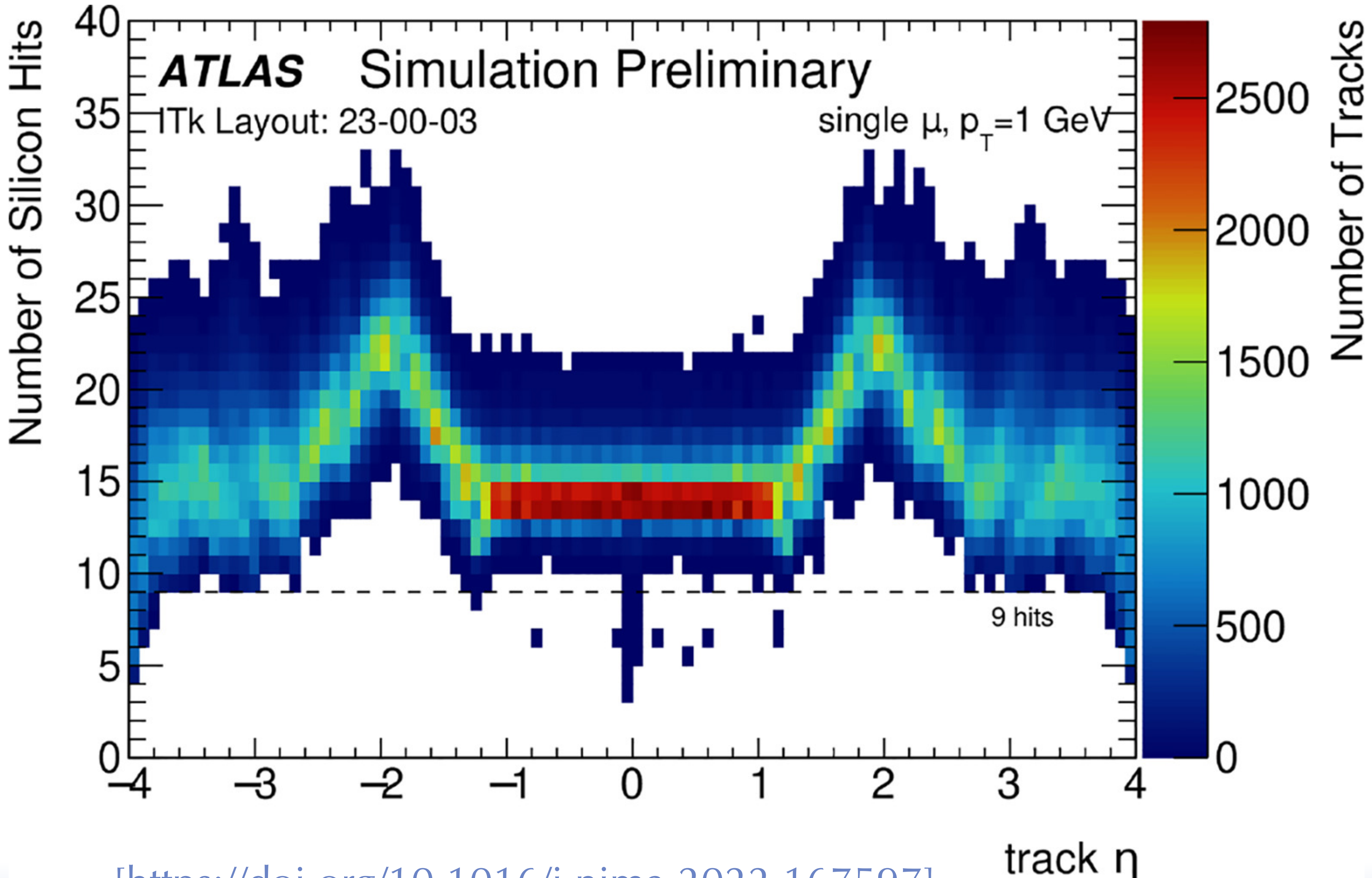
Complementary optimisations of experiments

- **Efficiency, fake tracks** → occupancy, N_{hits}, 4d resolution
- **Pointing resolution** $\propto r_0 \cdot \sqrt{x/X_0}$
- **Relative p_T resolution** (mult. scatt.) $\propto \dfrac{\sqrt{x/X_0}}{B \cdot L}$
- **Relative p_T resolution** (pos. res.) $\propto \dfrac{\sqrt{x/X_0}}{B \cdot L^2}$

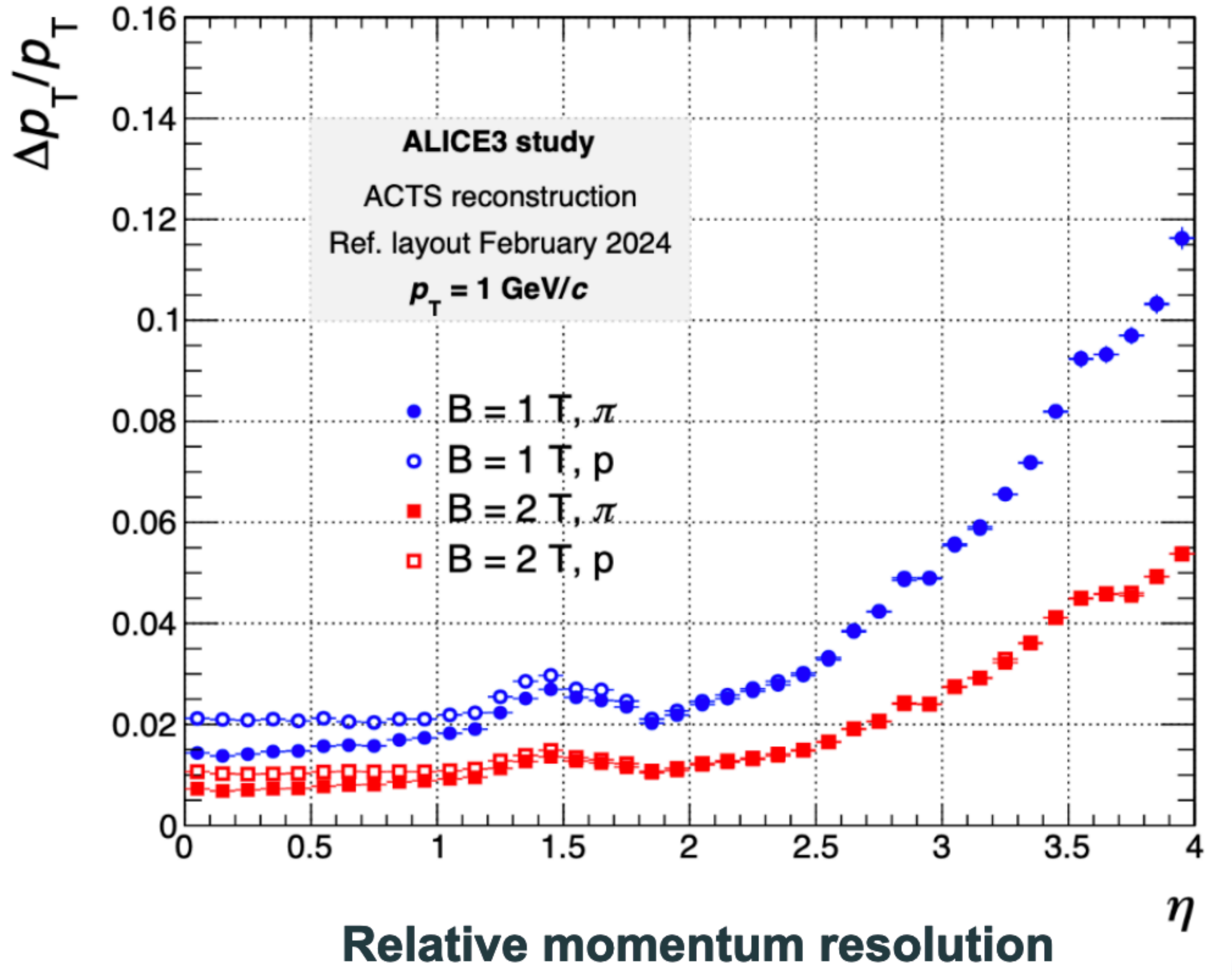




[ATL-PHYS-PUB-2021-024]

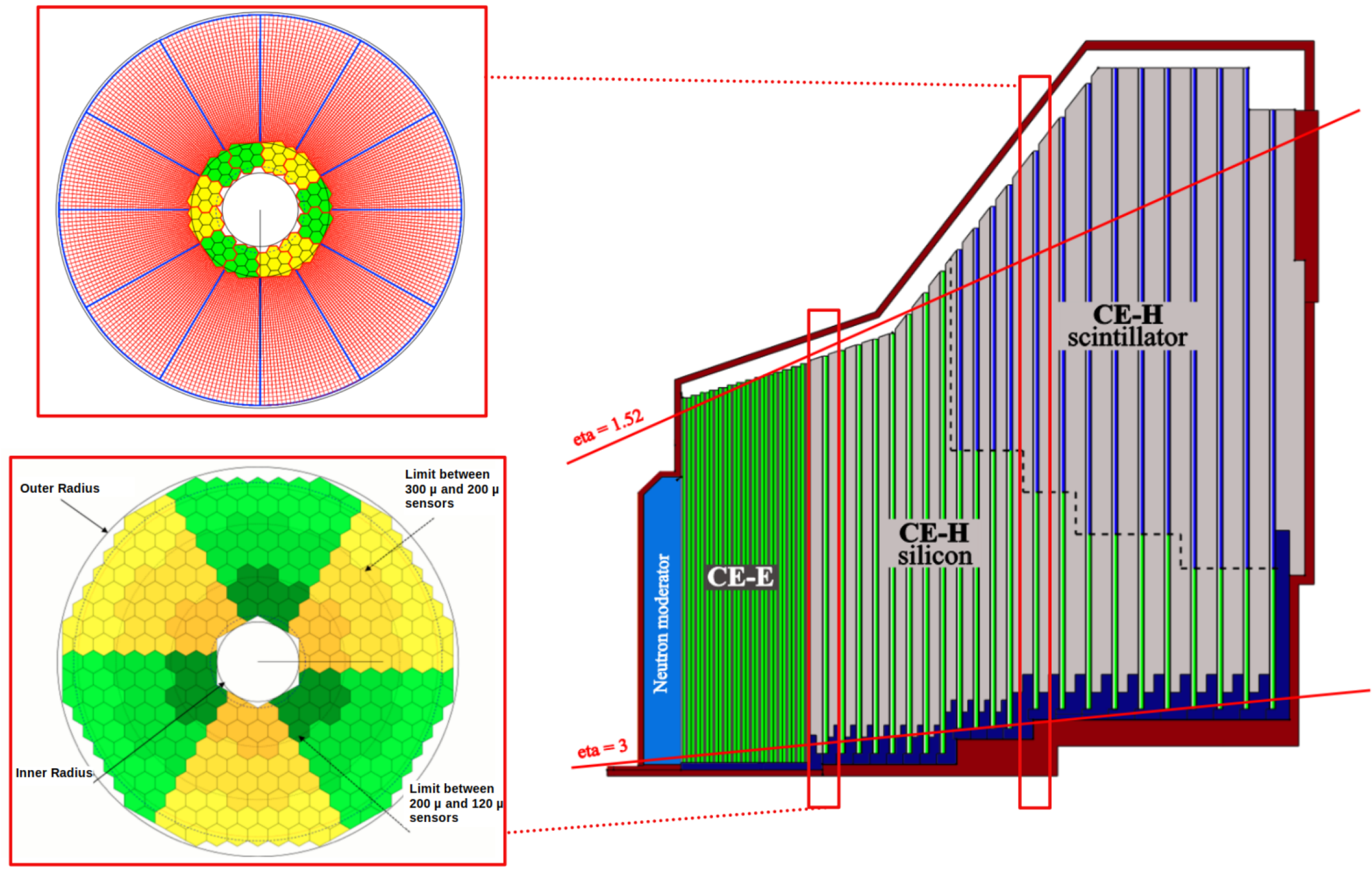


[https://doi.org/10.1016/j.nima.2022.167597]

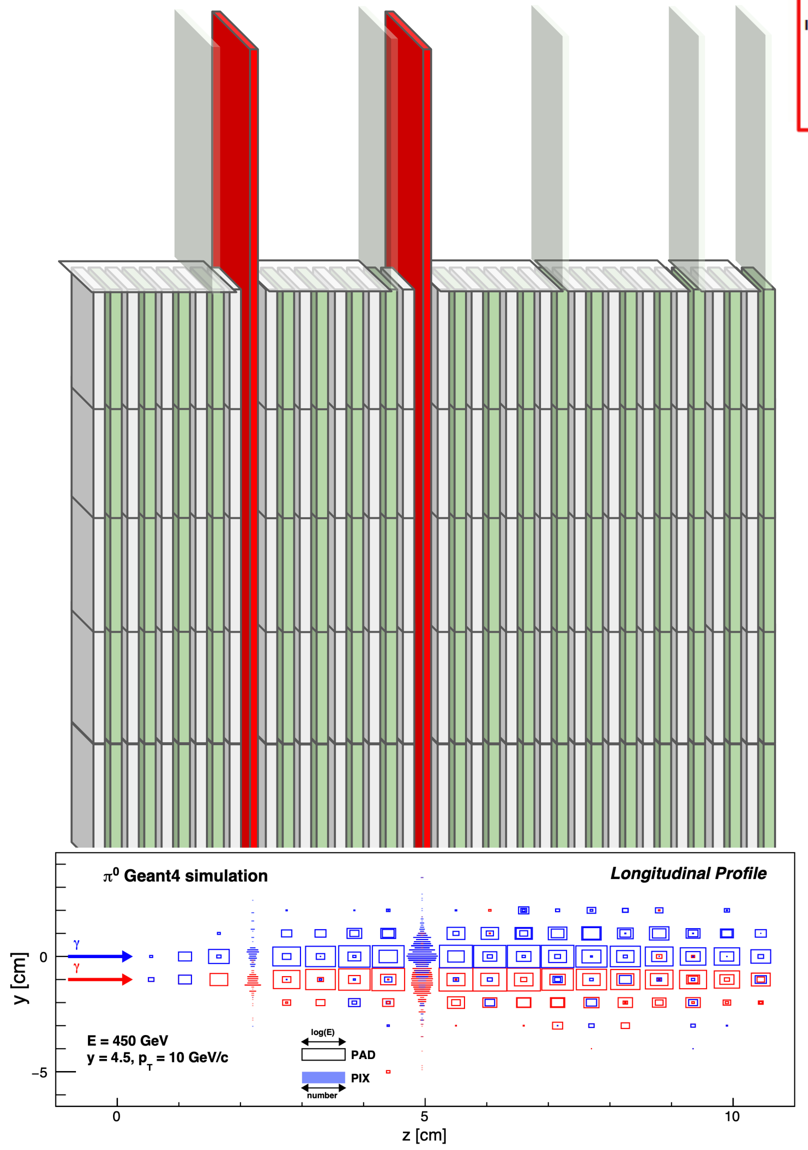


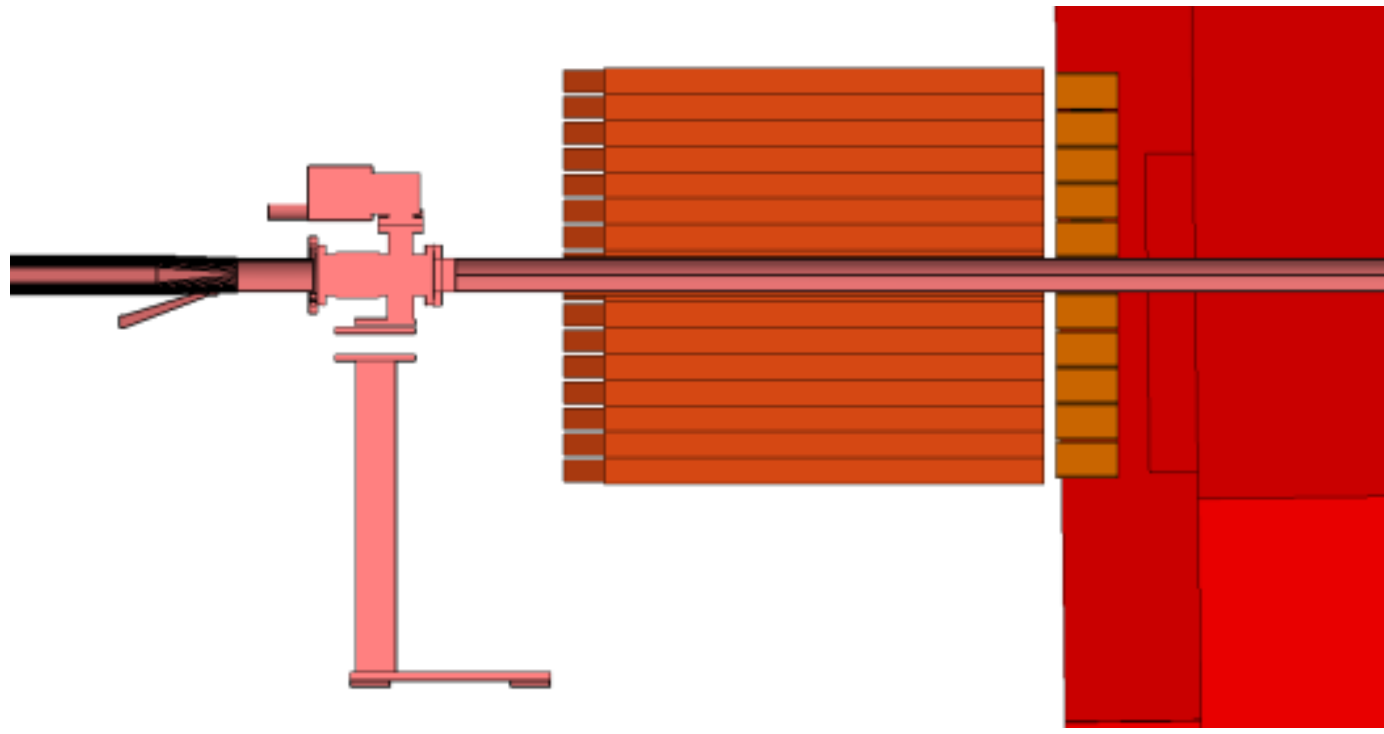
Calorimetry

- **Increase granularity and add timing**
  → usage of silicon (pixel) layers
  - **ATLAS**: faster and finer readout of LAr + Tile calorimeters
  - **CMS**: high-granularity endcap calorimeter silicon and scintillator + SiPM
    → 4d showers ($\sigma_t \approx 20$ ps)
  - **ALICE**: Forward Calorimeter sampling ECal with Si pad + pixel layers
    → photon separation
  - **LHCb**: SpaCal (or Shashlik) with PMT, 3d printed absorbers
    → precision timing

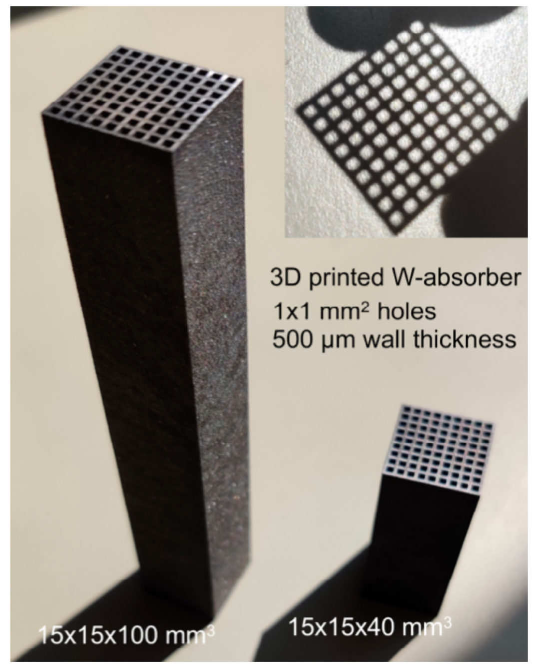


CMS HGCal

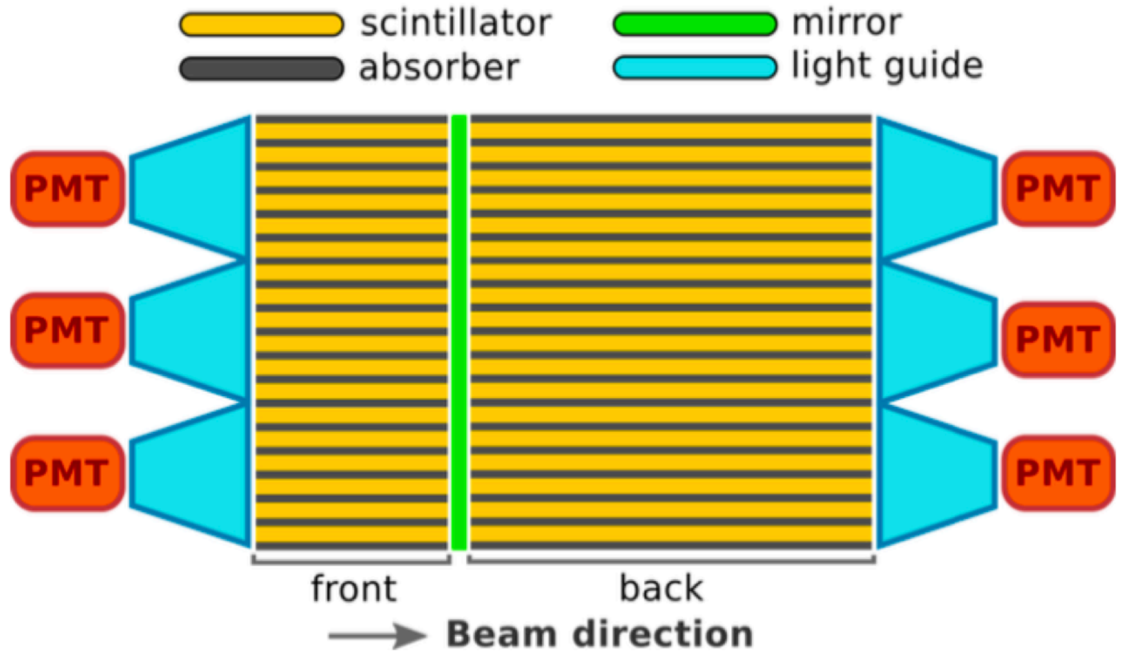




ALICE FoCal



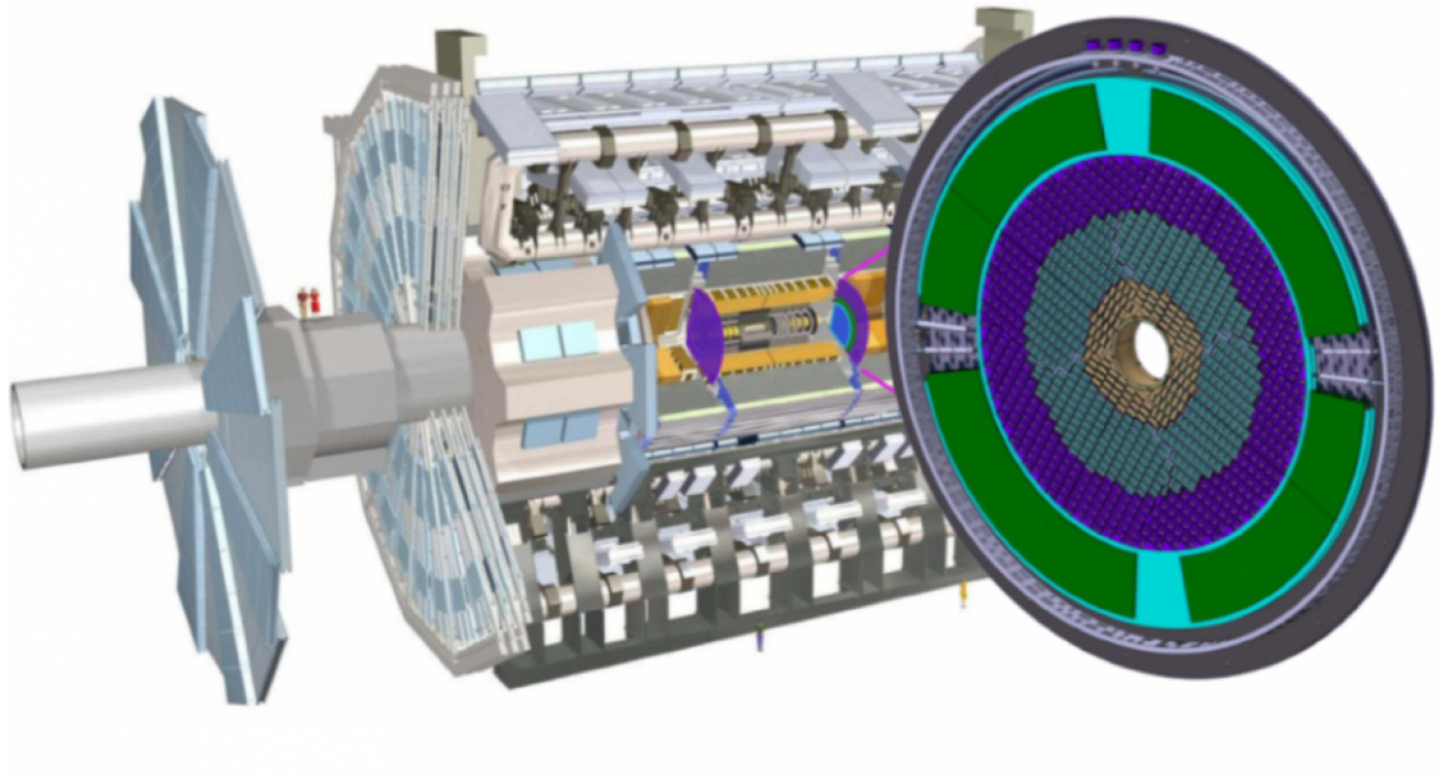
3d printed absorbers



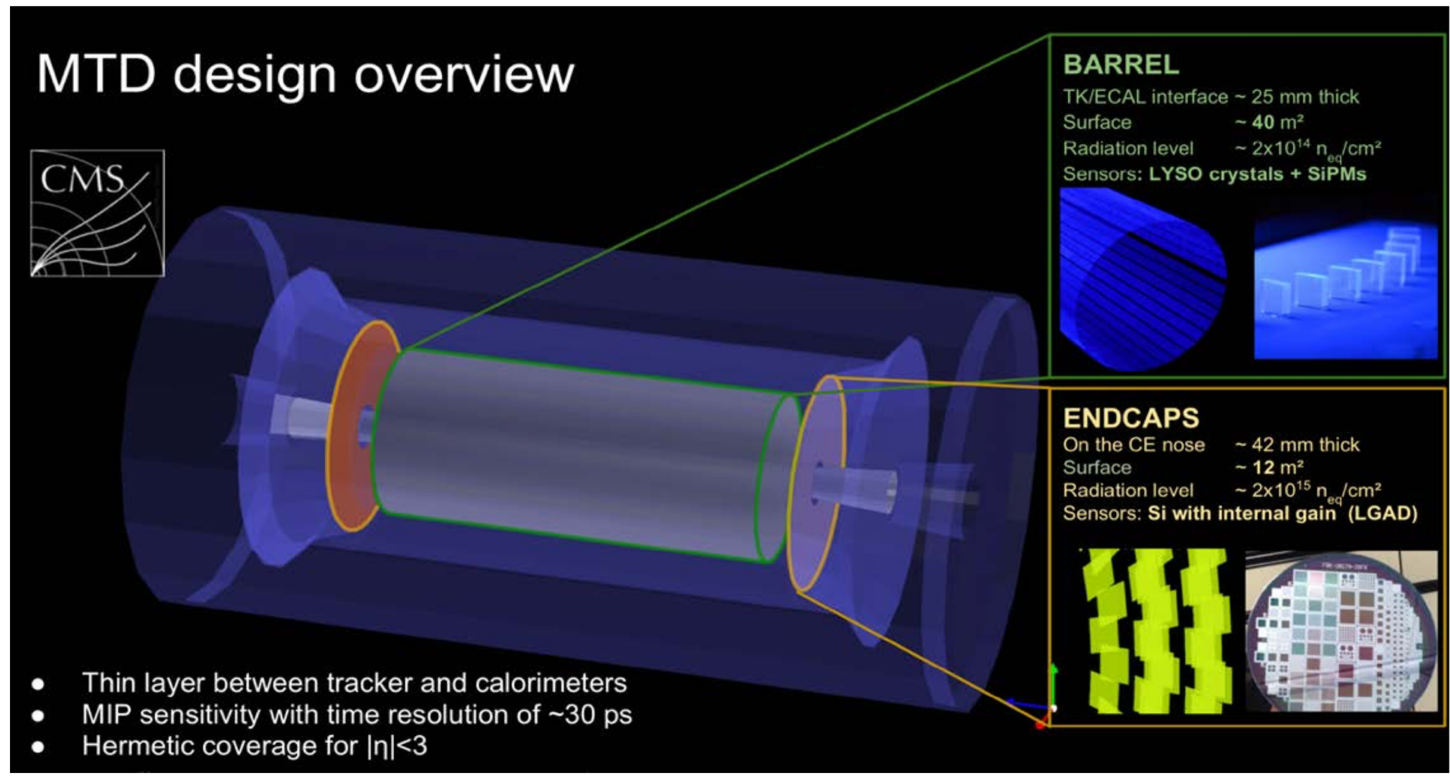
LHCb ECal

Particle identification

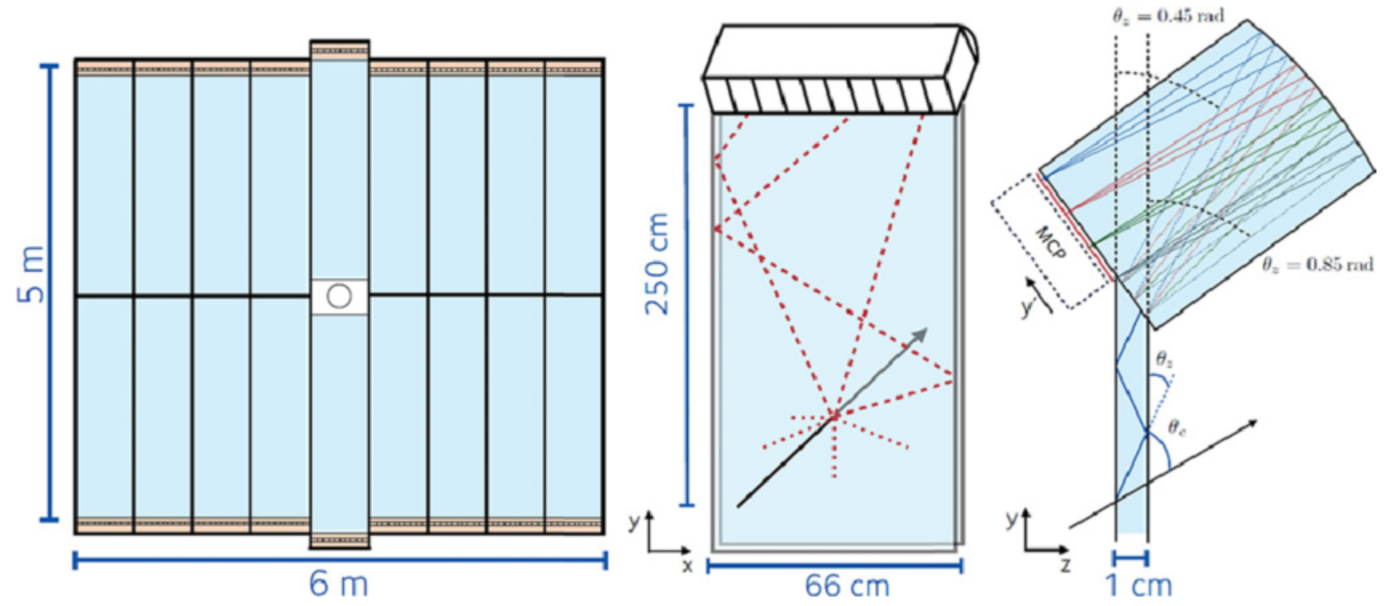
- **dE/dx**
  - time-over-threshold in silicon sensors
- **Time-of-flight** (also pile-up rejection)
  - silicon sensors (all experiments)
  - scintillators (LYSO) + SiPMs (CMS)
- **Cherenkov** → radiator + photon detection
  - threshold or angle
- **Need for fast sensors with**
  - time resolution ~20 ps
  - low noise (dark count rate)
  - good radiation tolerance
  - single photon sensitivity



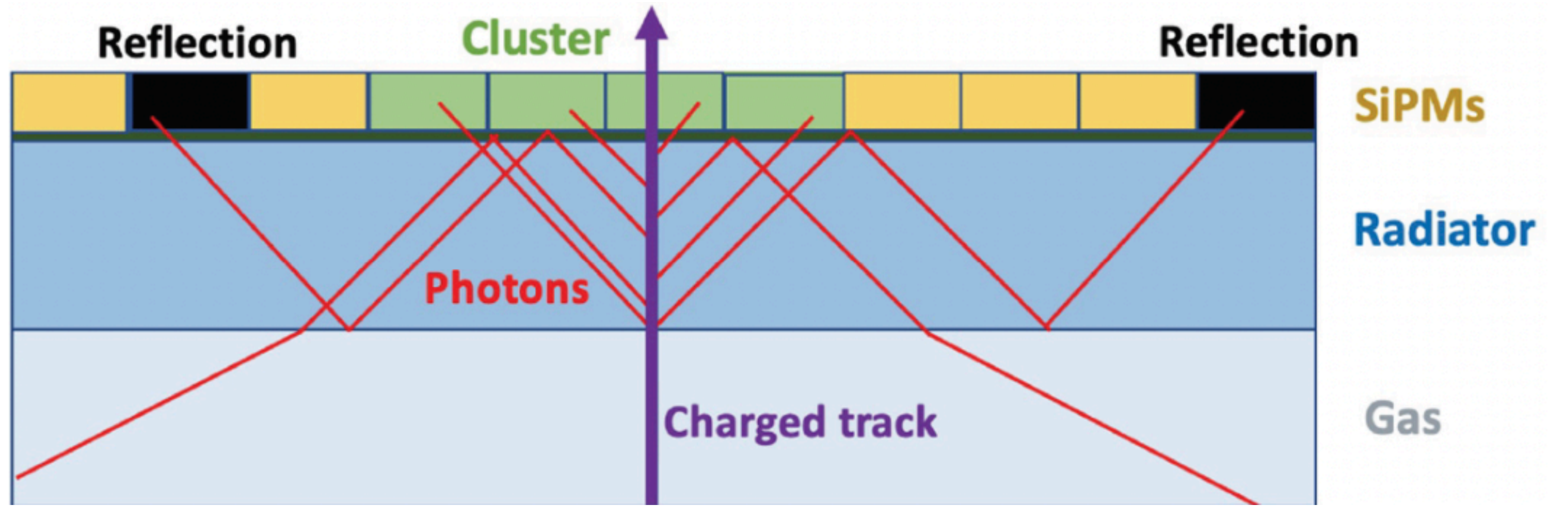
ATLAS HGTD



CMS MTD



LHCb TORCH



ALICE 3 TOF

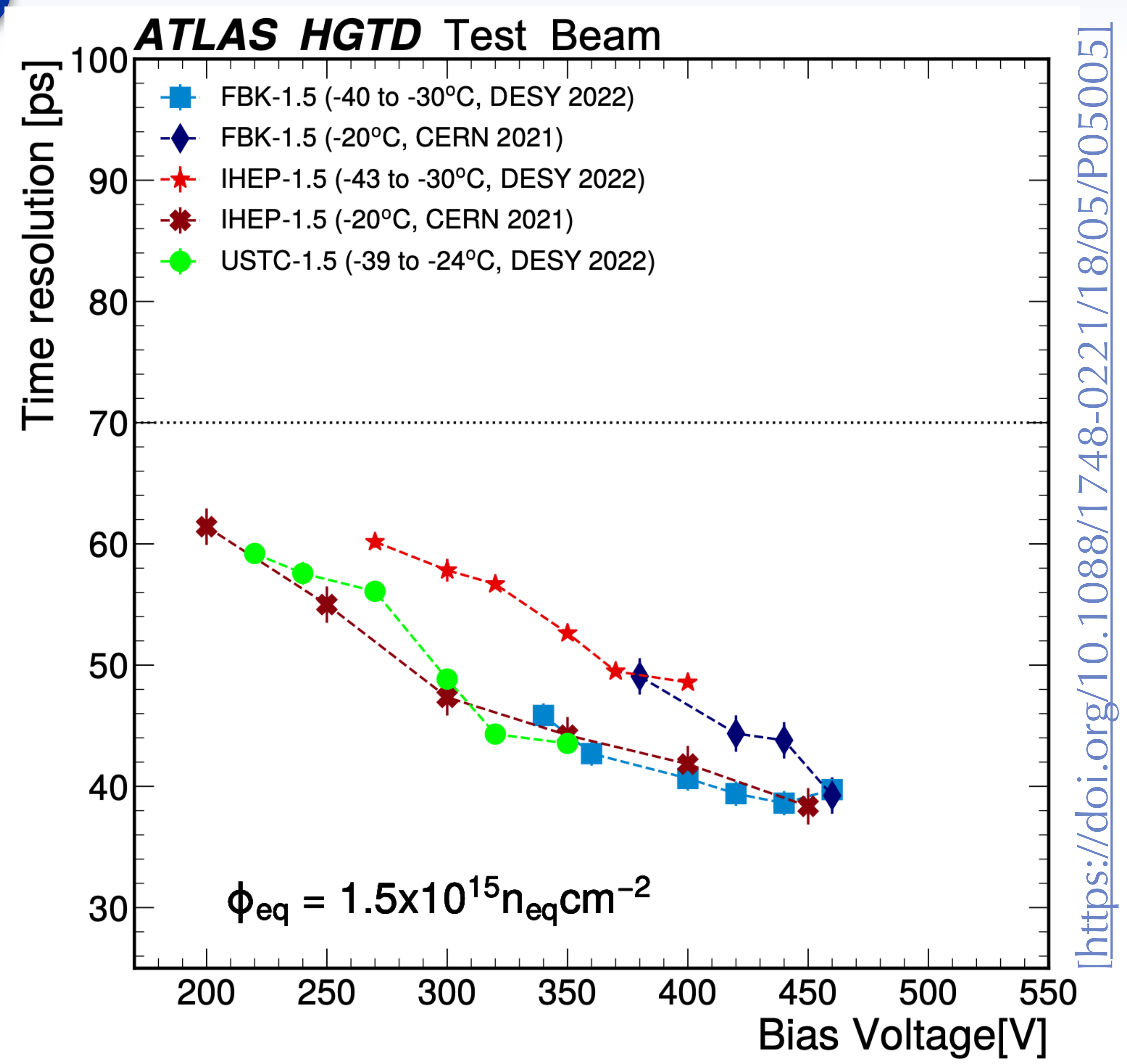
Silicon sensors with gain

- Additional layer to **amplify primary ionisation signal**
  → fast response (from charged particle or photon)

- **Low-Gain Avalanche Diode** (LGAD)
  → limited gain to mitigate large dark count rates
  - timing endcaps for ATLAS/CMS

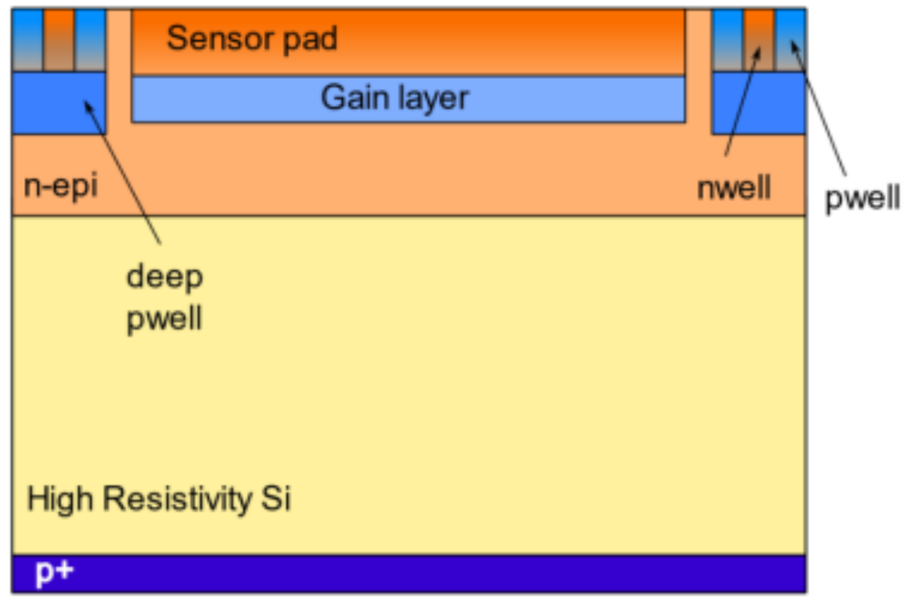
- **Single-Photon Avalanche Diode** (SPAD, array → SiPM)
  → large gain + quenching to achieve single photon efficiency
  - considered also for charged particle detection

- **Monolithic sensors with gain**
  → CMOS process with additional gain layer
  - promising results with LFoundry 110 nm (ALICE 3)

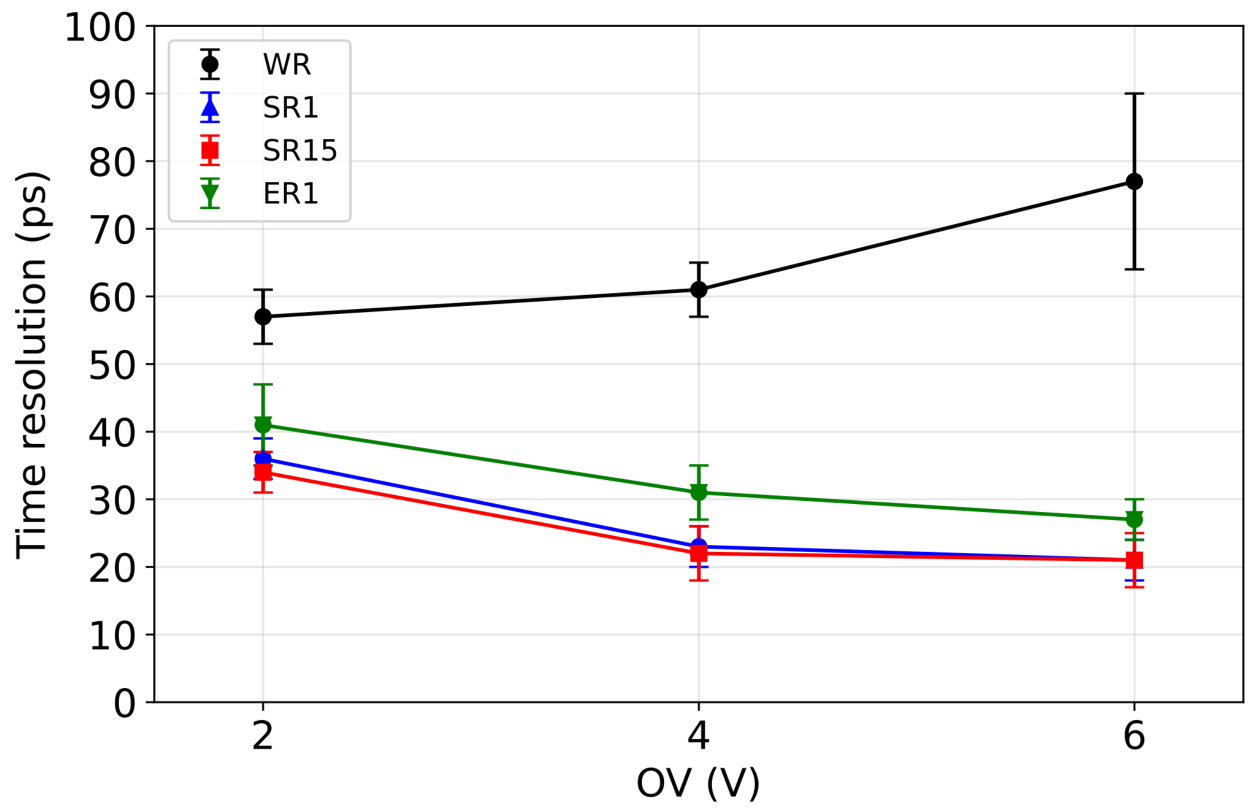


[https://doi.org/10.1088/1748-0221/18/05/P05005]

ATLAS HGTD



Gain layer in CMOS



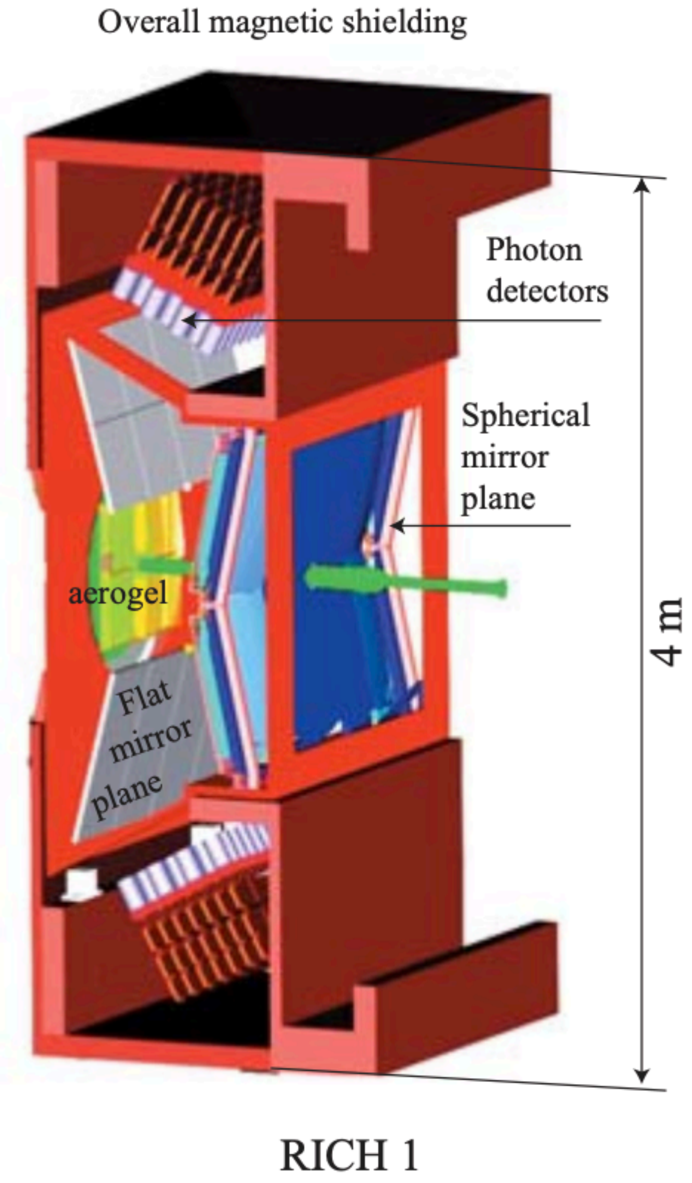
[arXiv:2305.17762]

SPADs w/ and w/o resin layers

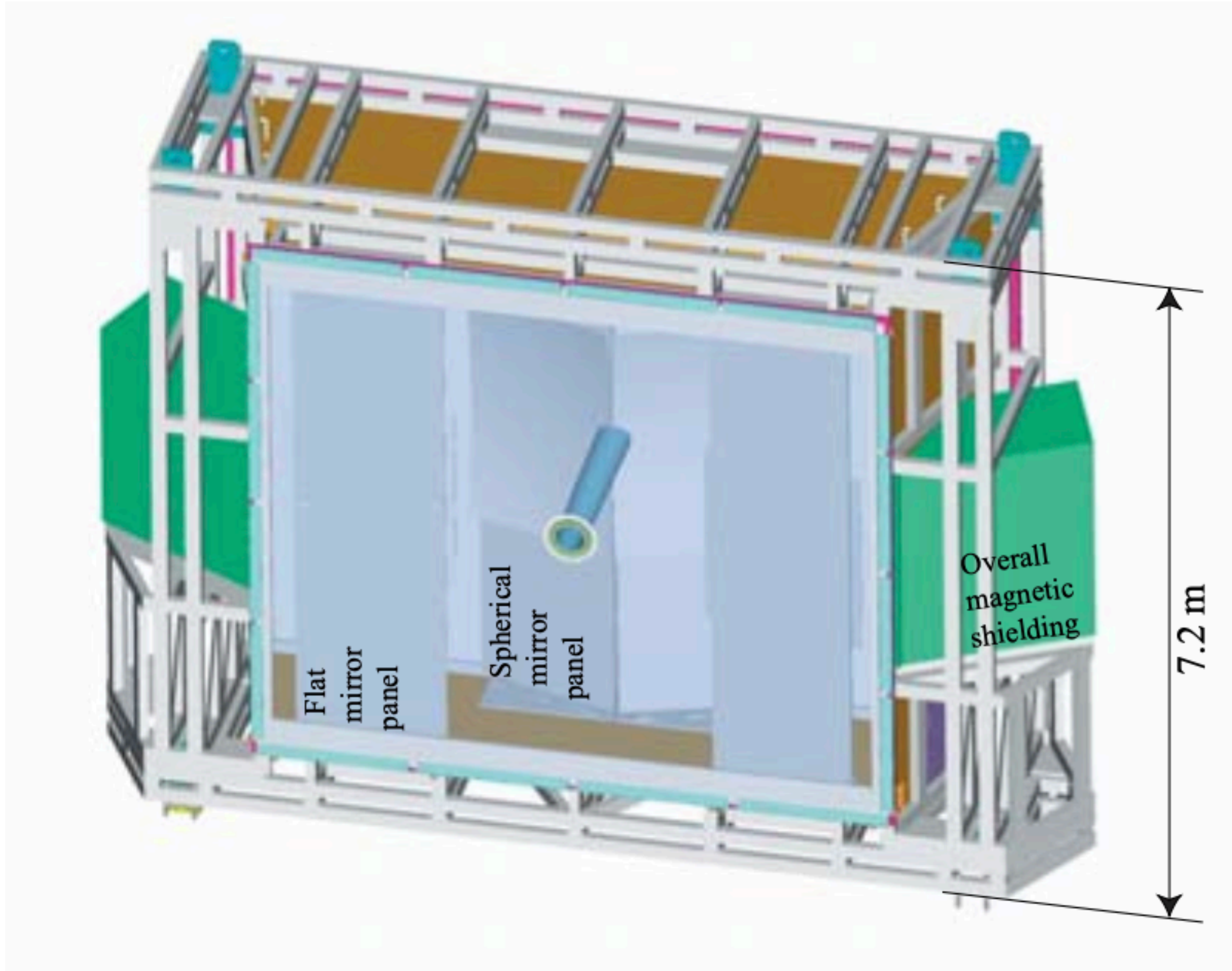
Ring-Imaging Cherenkov

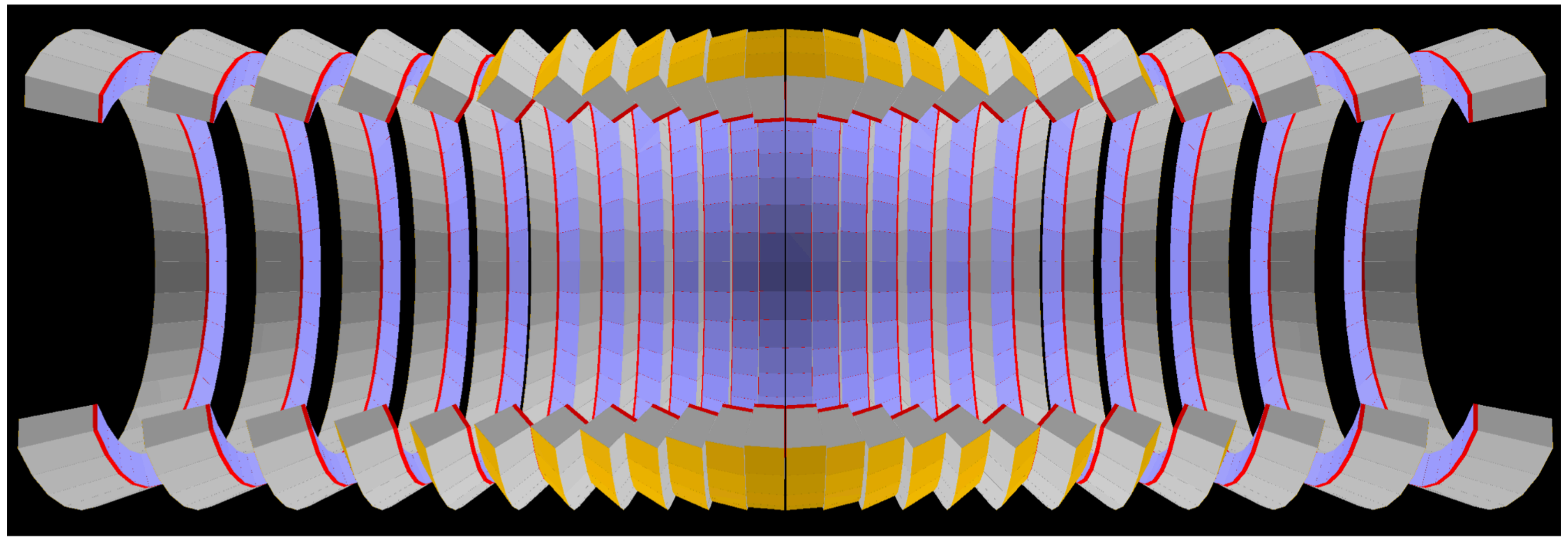
- Combination of **radiators** (LHCb, ATLAS)
  - gas (n ≤ 1.001 → large *p*)
  - aerogel (n ≈ 1.006 - 1.1 → intermediate *p*)
- **Single photon detection**
  - MCP-PMTs (LHCb)
  - SiPMs (LHCb, ALICE 3)
  - Monolithic SiPMs? (ALICE 3)

LHCb RICH1

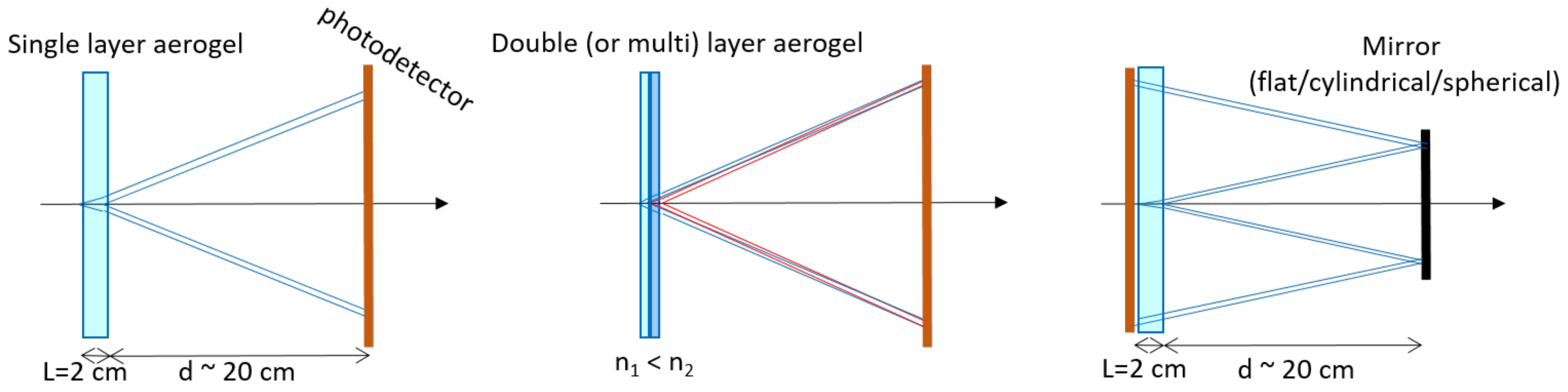


LHCb RICH2





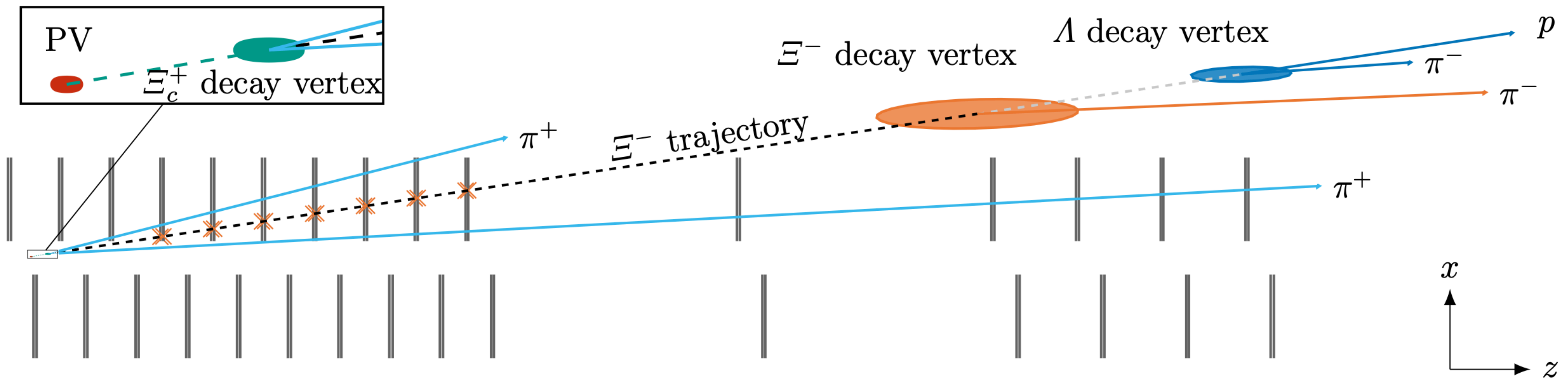
ALICE 3 barrel RICH



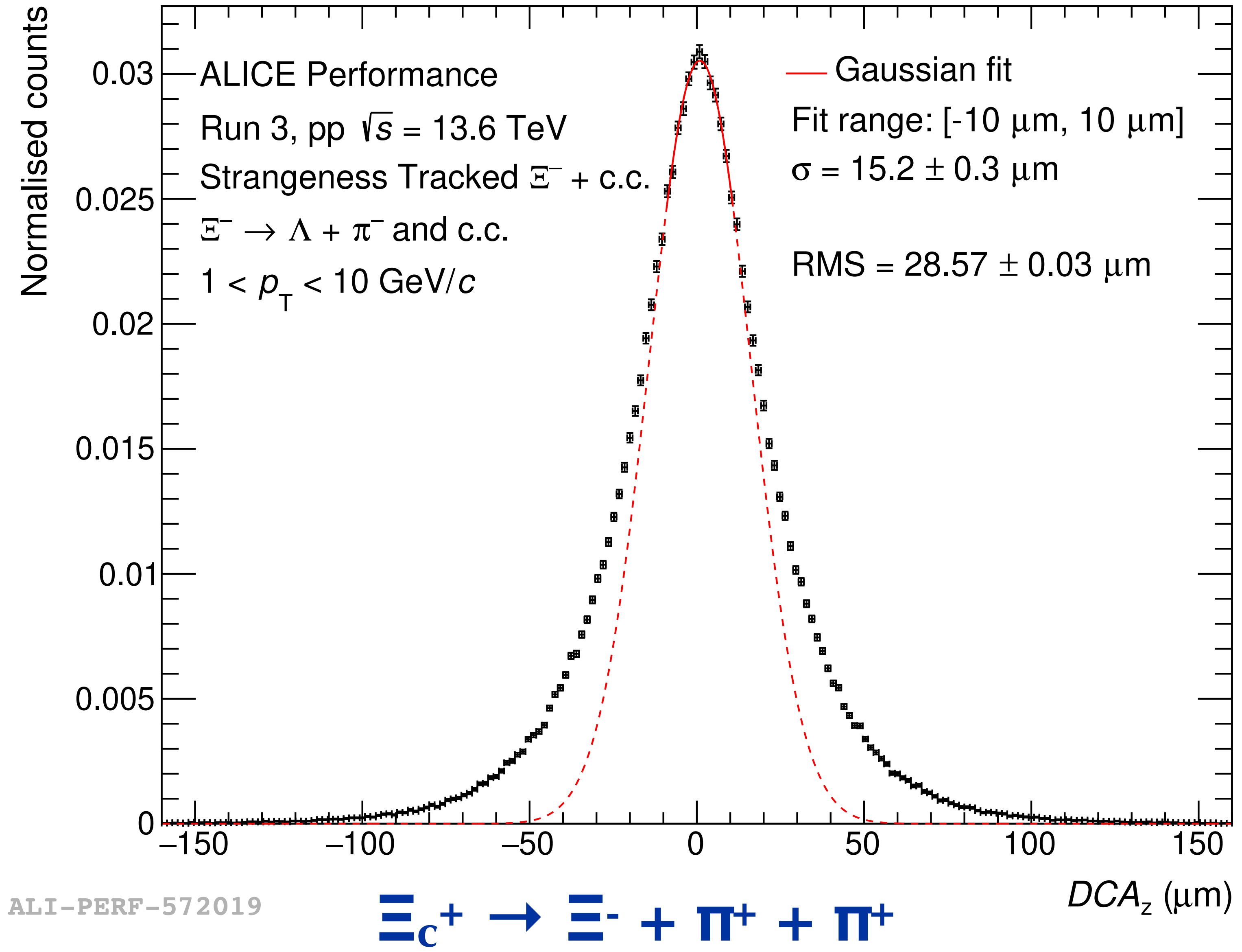
RICH configurations

Strangeness tracking

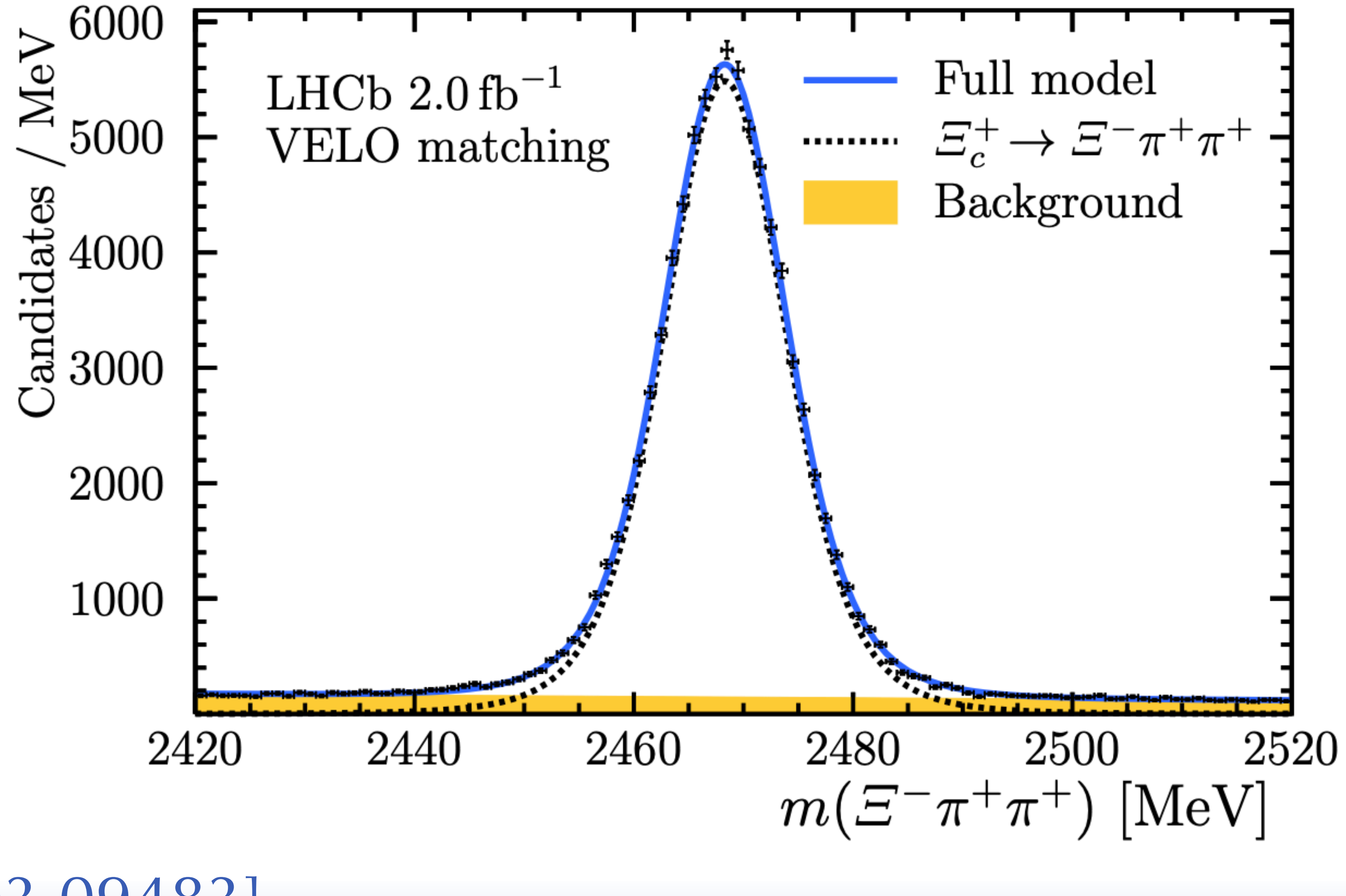
- **Challenging probes with decays of strange hadrons**
  - rare, large background
  - limited pointing resolution for vertexing
- **Strangeness tracking** before decay
  → improved pointing resolution
  - Ξ_c, Ω_c, hypertriton (Run 3 & 4)
  - Ξ_{cc}, Ω_{cc}, Ω_{ccc} (Run 5 & 6)



$\Xi^- \rightarrow \Lambda + \pi^-$



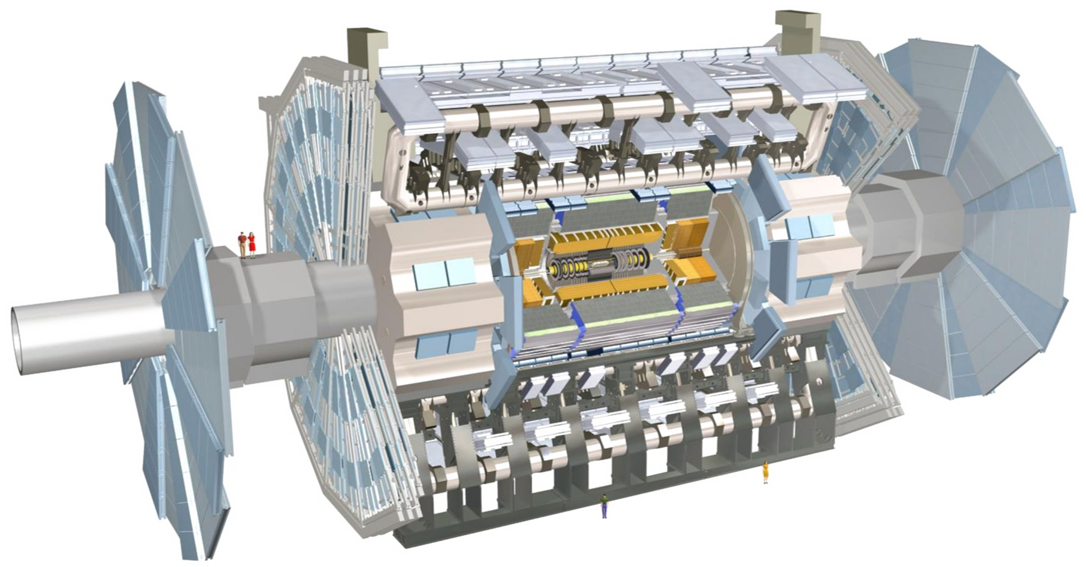
$\Xi_c^+ \rightarrow \Xi^- + \pi^+ + \pi^+$



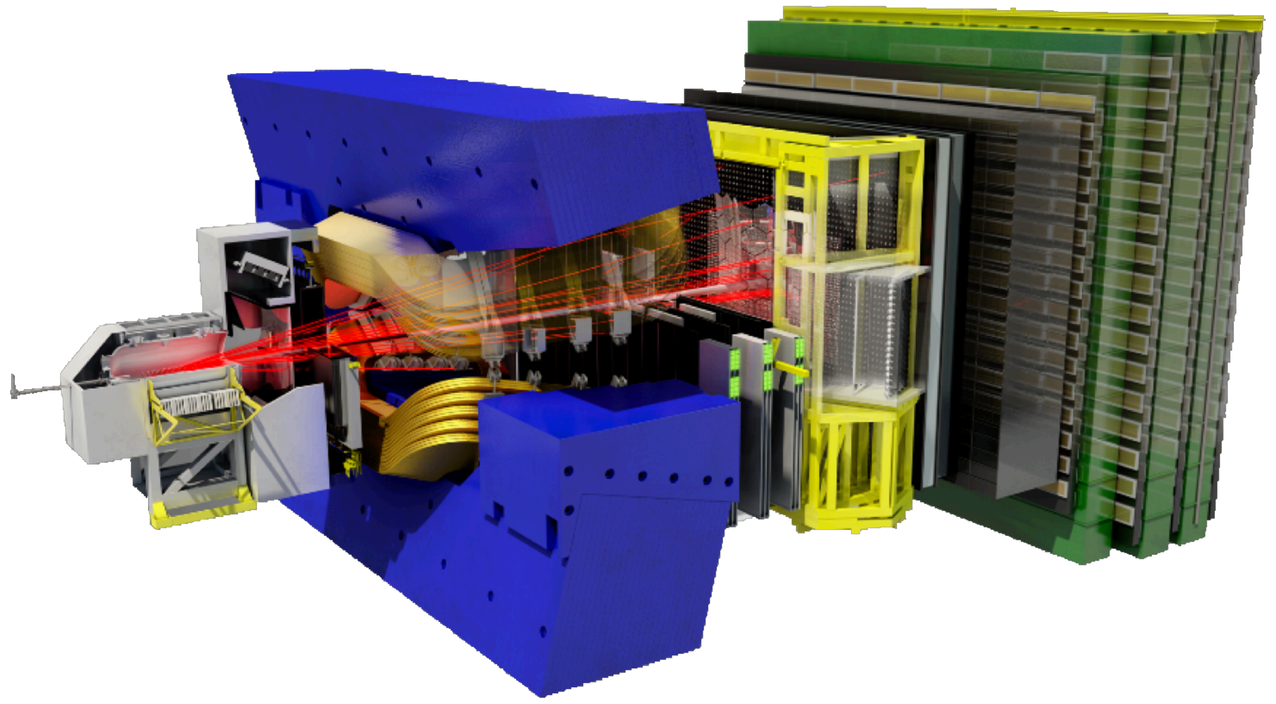
[arXiv:2403.09483]

Upgraded experiments

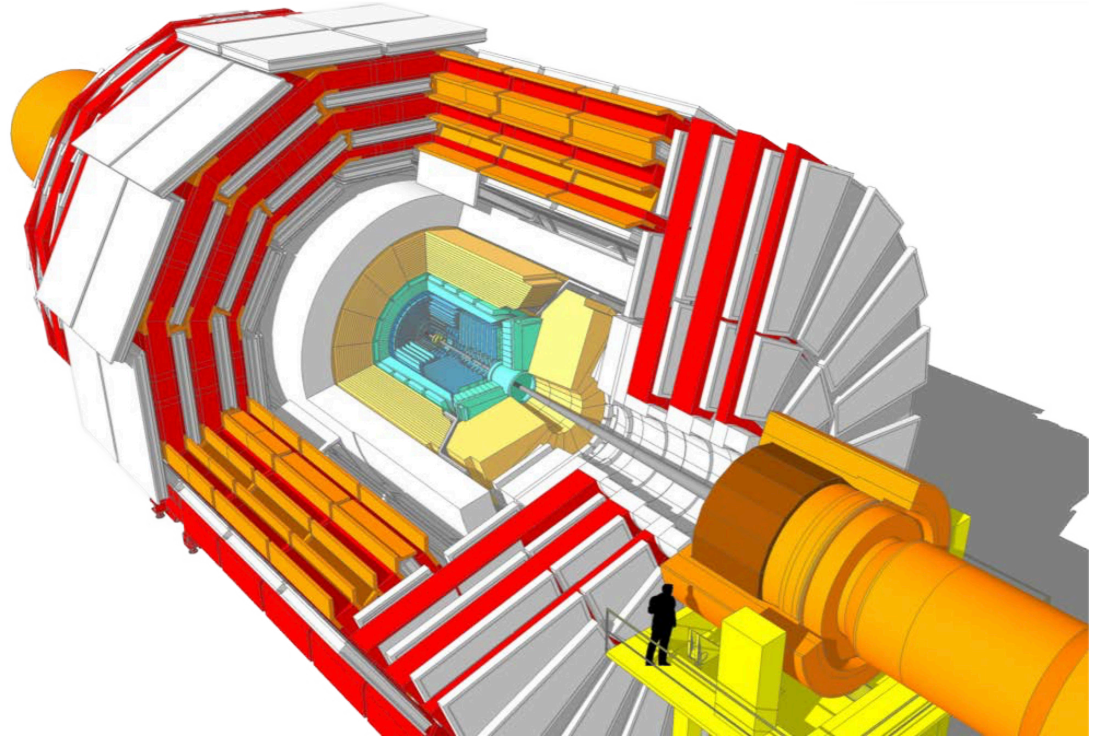
LS3



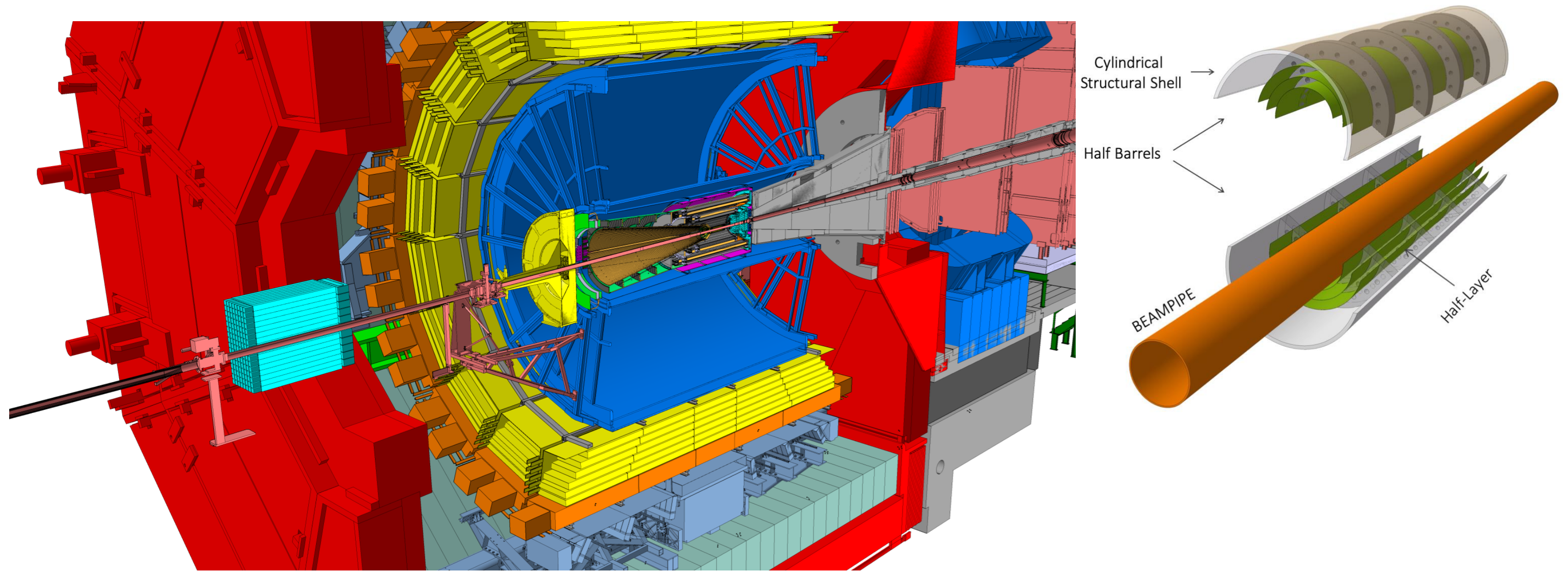
ATLAS phase II
ITk, HGTD, HL-ZDC, TDAQ, muon chambers



LHCb phase Ib
preparation for phase II, possibly magnet stations

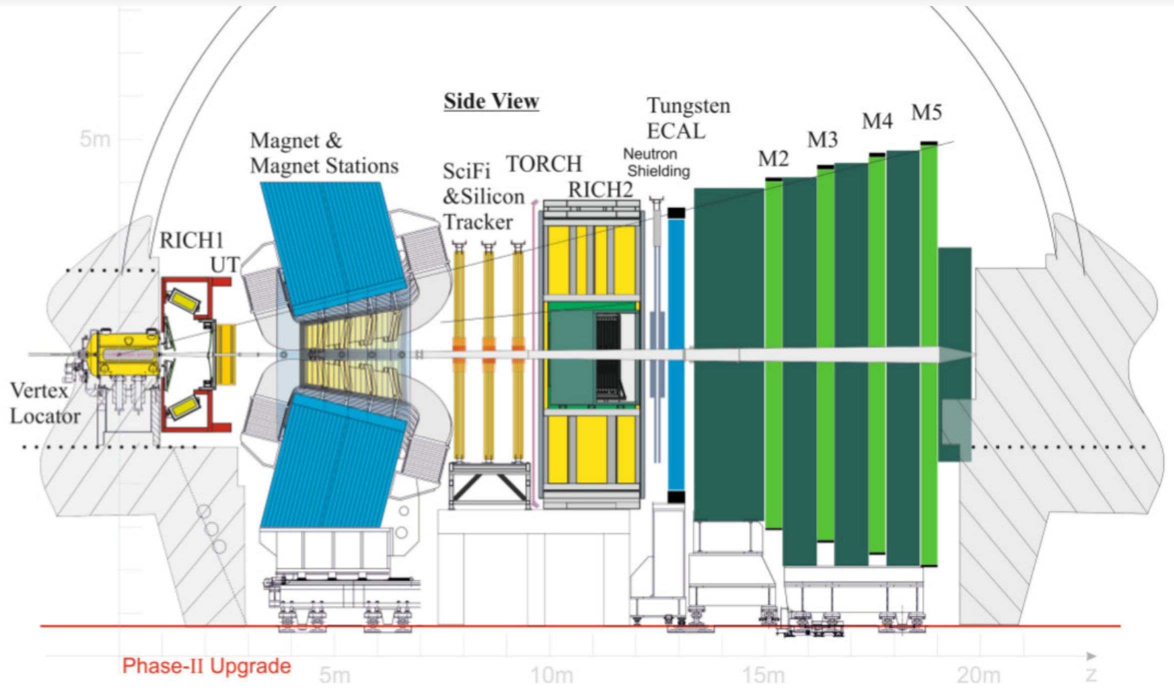


CMS phase II
tracker, MTD, HL-ZDC, DAQ, trigger, μ chambers

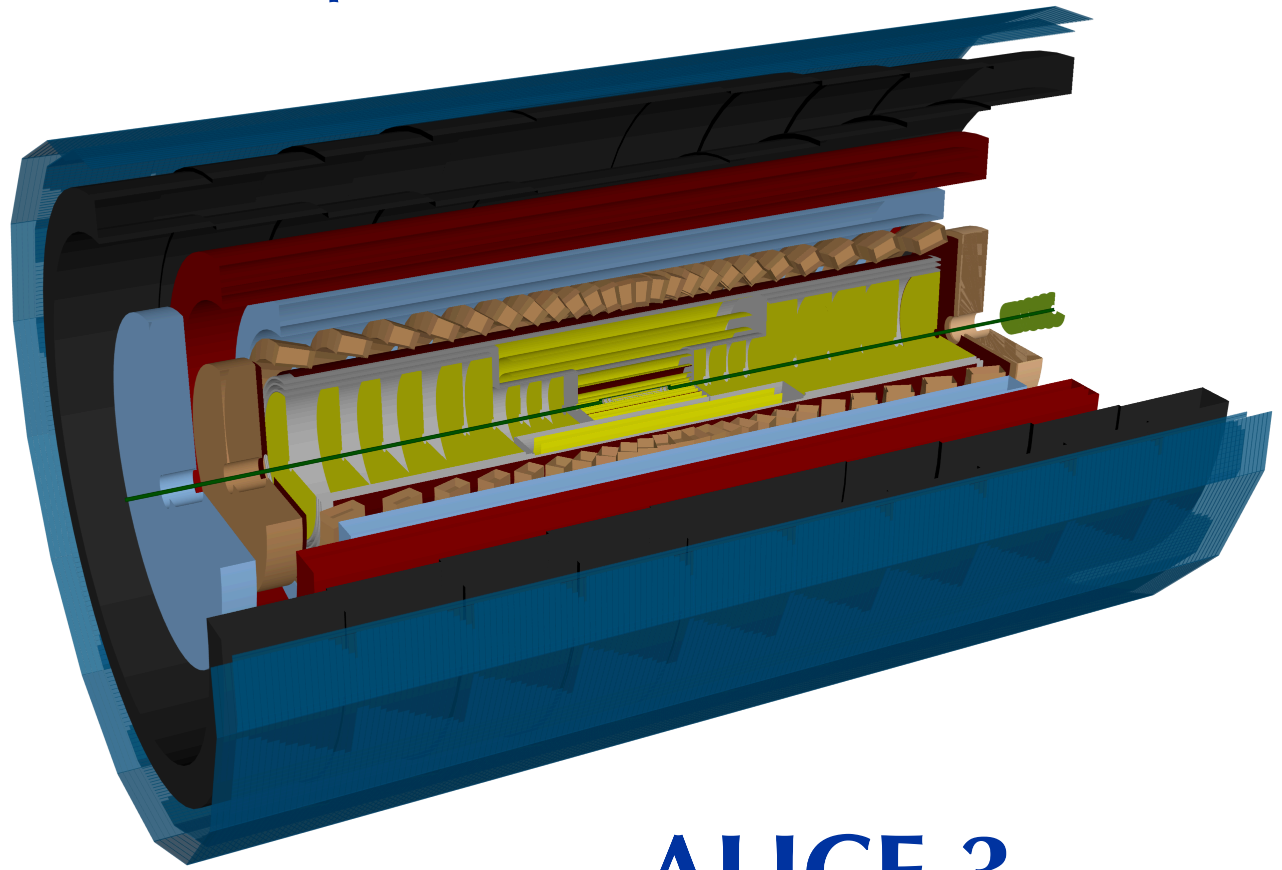


ALICE 2.1
FoCal, ITS3

LS4



LHCb phase IIb
VELO, RICH, TORCH, calo, μ stations, UT, MT



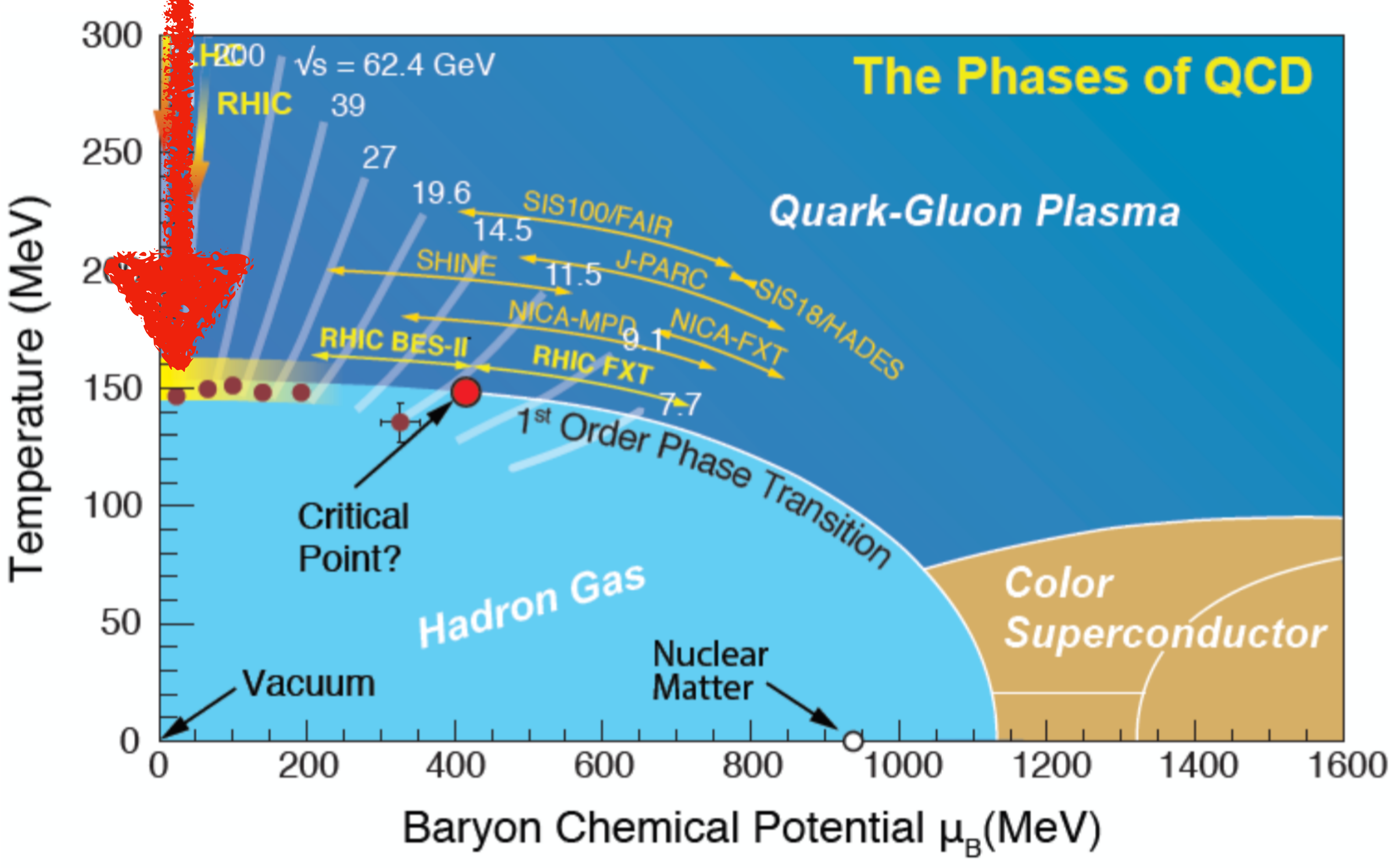
ALICE 3
vertexing, tracking, TOF, RICH, ECal, μID, FCT

Impact on heavy-ion physics

- **Nuclear PDFs**
  → Ultra-peripheral collisions, pA
- **Quenching** and **connection to collectivity in small systems**
  → systematic measurements of different collision systems
- **Transport properties and thermalisation in the QGP**
  → precision measurements of heavy-flavour probes
- **QGP evolution from early phase onwards: temperature, chiral symmetry restoration, …**
  → precision measurements of dilepton spectra
- **Transition of partons from the QGP to hadrons**
  → charmed baryons, exotic states
- **Many more opportunities**
  → BSM searches, Low's theorem, …

LHC for heavy-ion physics

- **Unique potential**
  → high T, low μ_B, large HF yields
- **Progress enabled** by
  - increased **luminosity**
  - improved **detector performance**, e.g. vertexing, acceptance

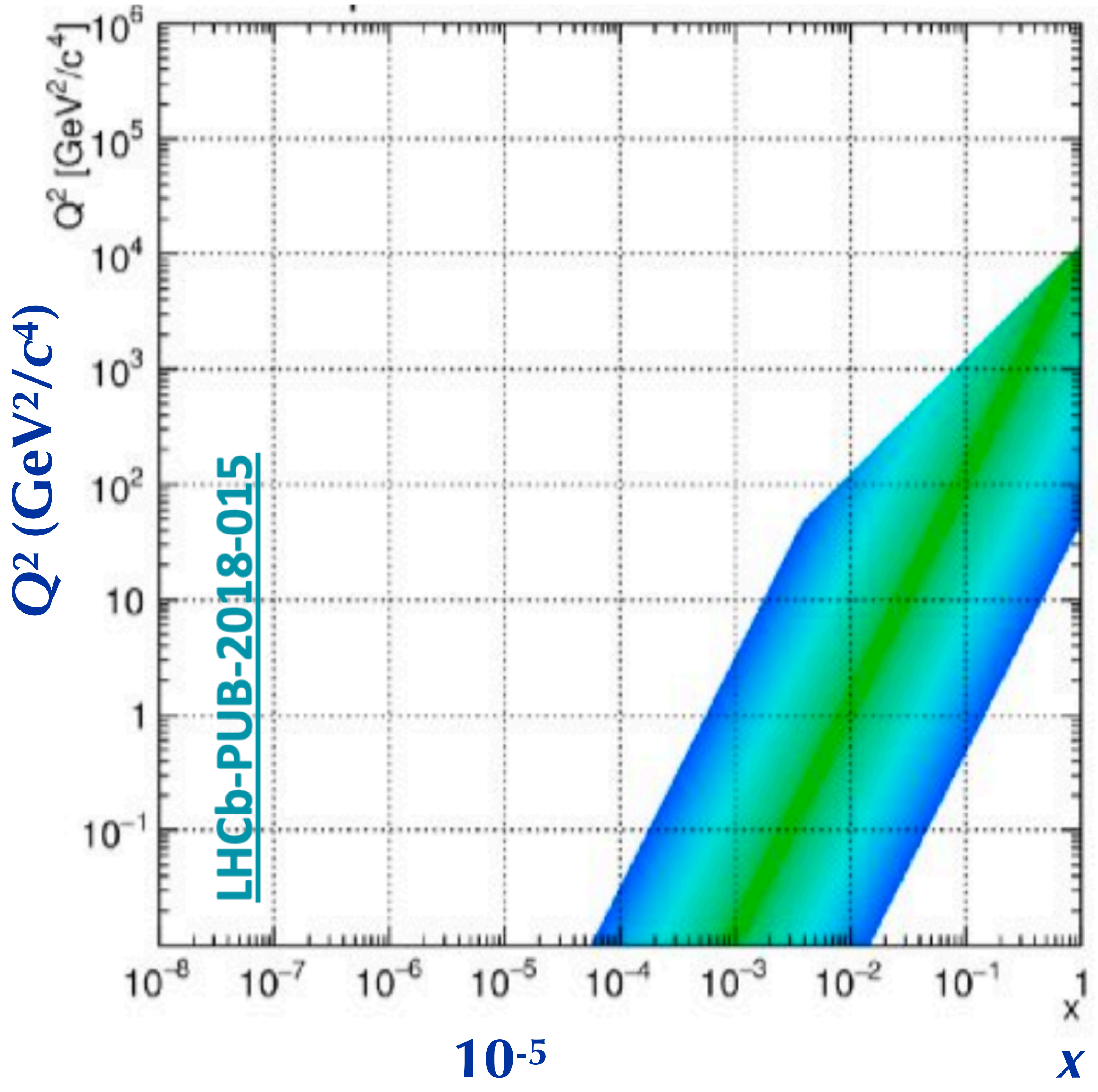


Nuclear PDFs

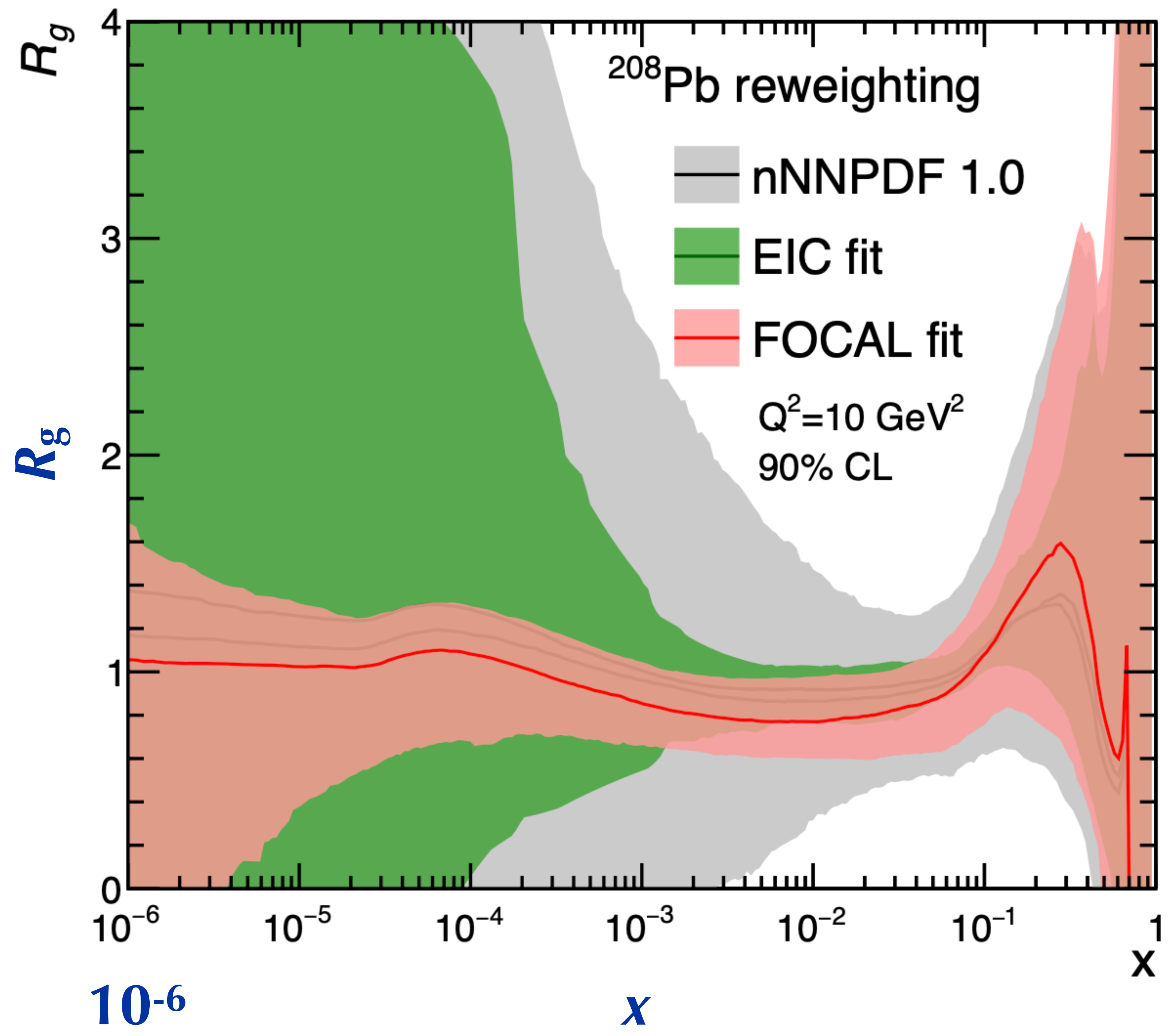
- **Constrain gluon densities down to low *x***
  → new measurements of gluon-probing processes in p-Pb and Pb-Pb
  → increased luminosities, new detectors

Run 3 & 4 (LHCb SMOG 2)

Various collision systems (fixed target)



Isolated photons (forward) in p-Pb collisions



[CERN-LHCC-2020-009]

Run 4 (ALICE FoCal)

Thermal radiation

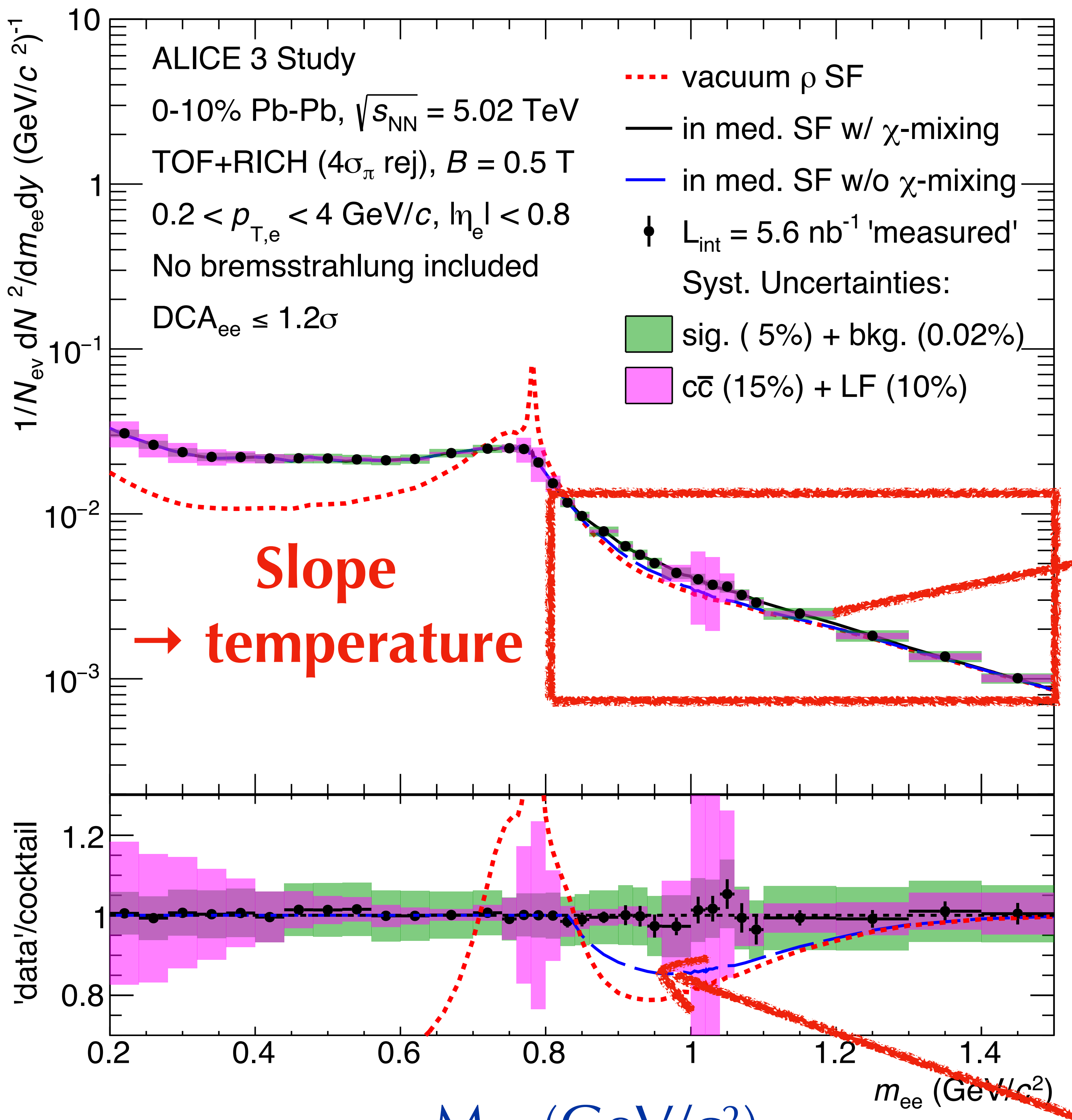
- **Understand time dependence and mechanisms of chiral symmetry restoration**
  → high-precision measurements of dileptons, also multi-differentially
  → further reduced material; excellent heavy-flavour rejection

Also pursued by LHCb

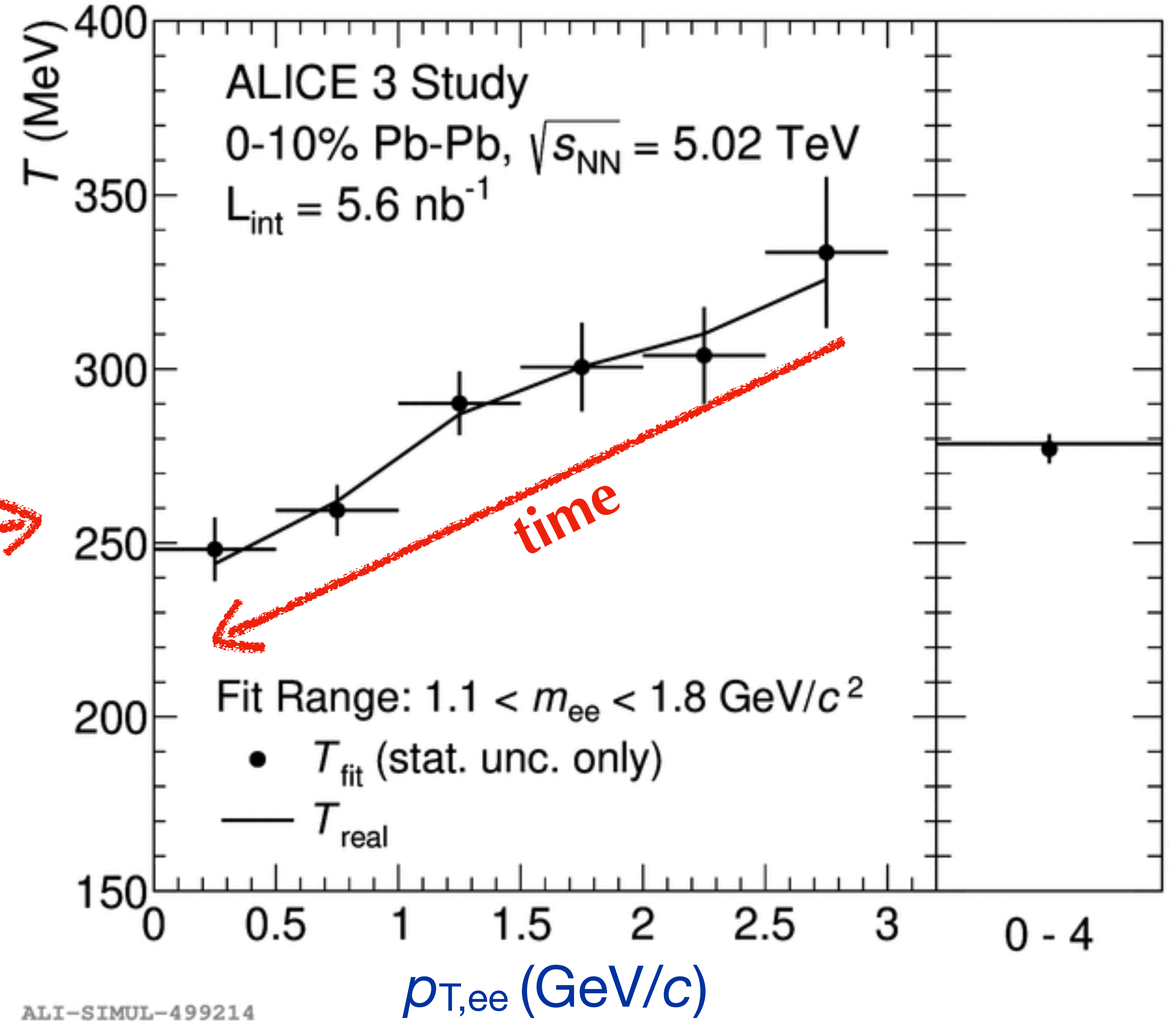
[CERN-LPCC-2018-07]

Run 5 & 6

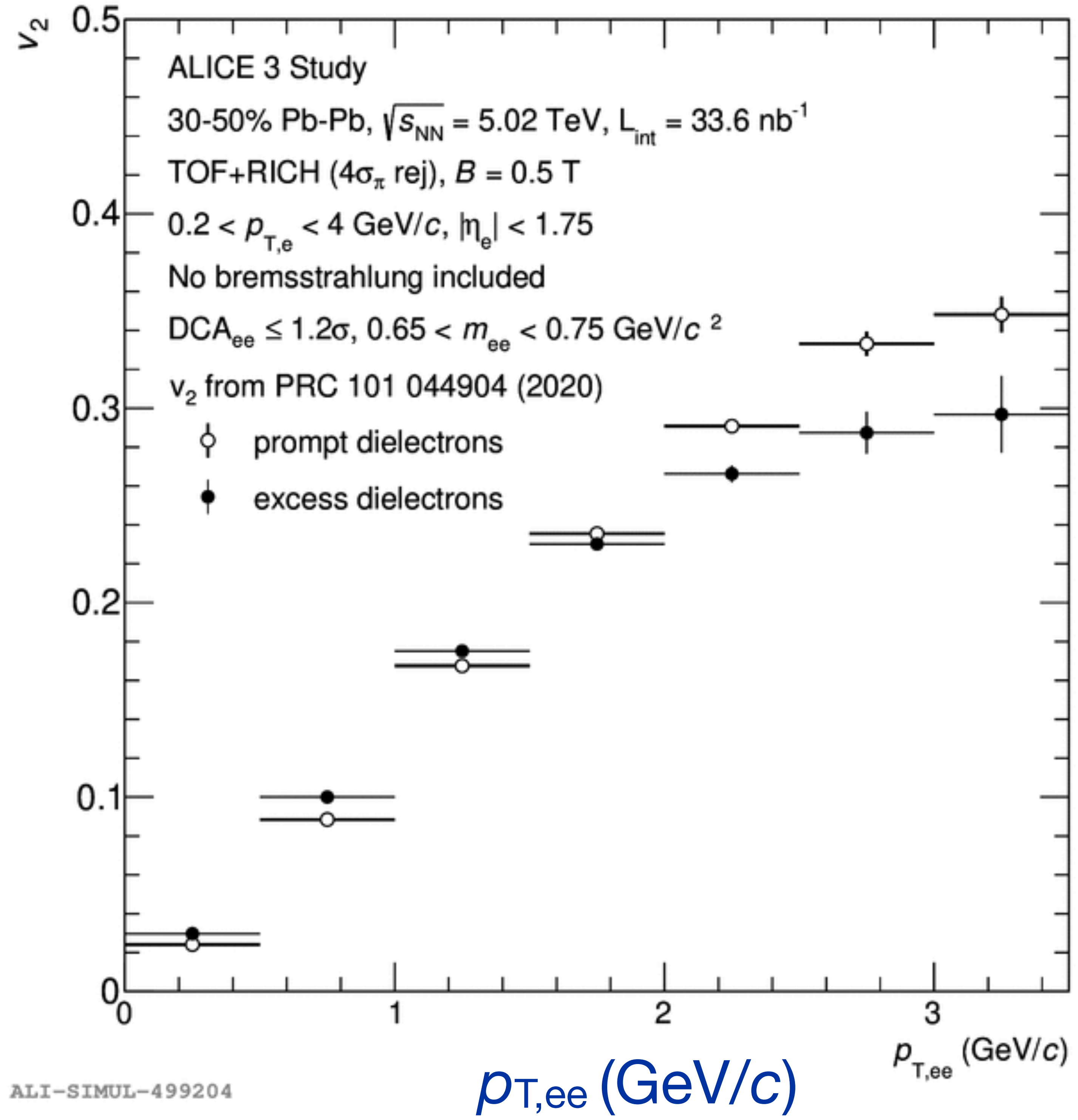
Invariant mass spectrum of dielectrons



$T(p_{T,ee})$
→ control on emission time



Dilepton v_2
→ temporal emission profile



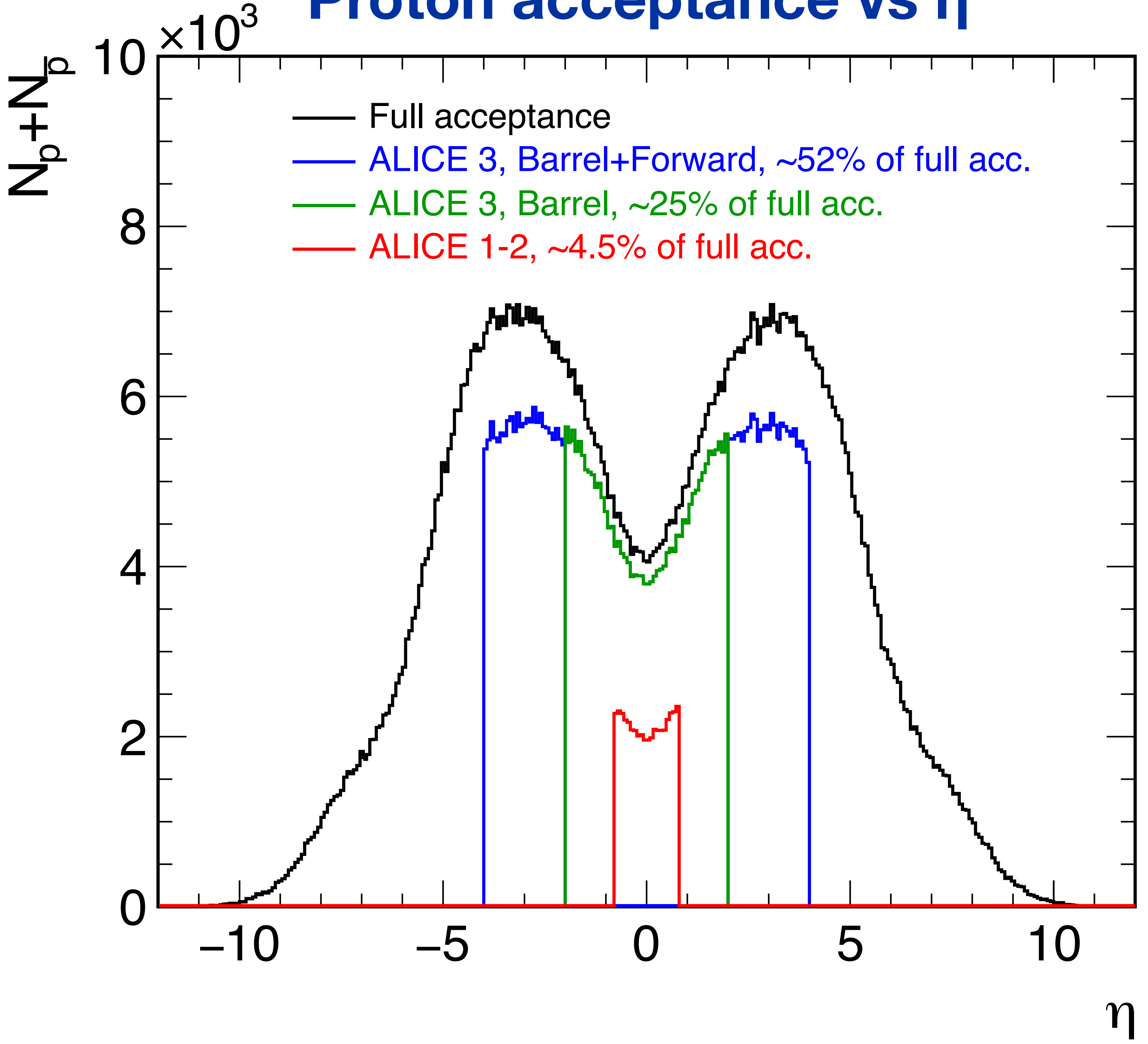
Without ρ-a_1 mixing
→ dip in thermal spectrum

Susceptibilities

- **Comparison of critical behaviour with lattice QCD predictions**
  → measurements of net-baryon fluctuations (cumulants κ_n)
  → excellent particle identification over large acceptance

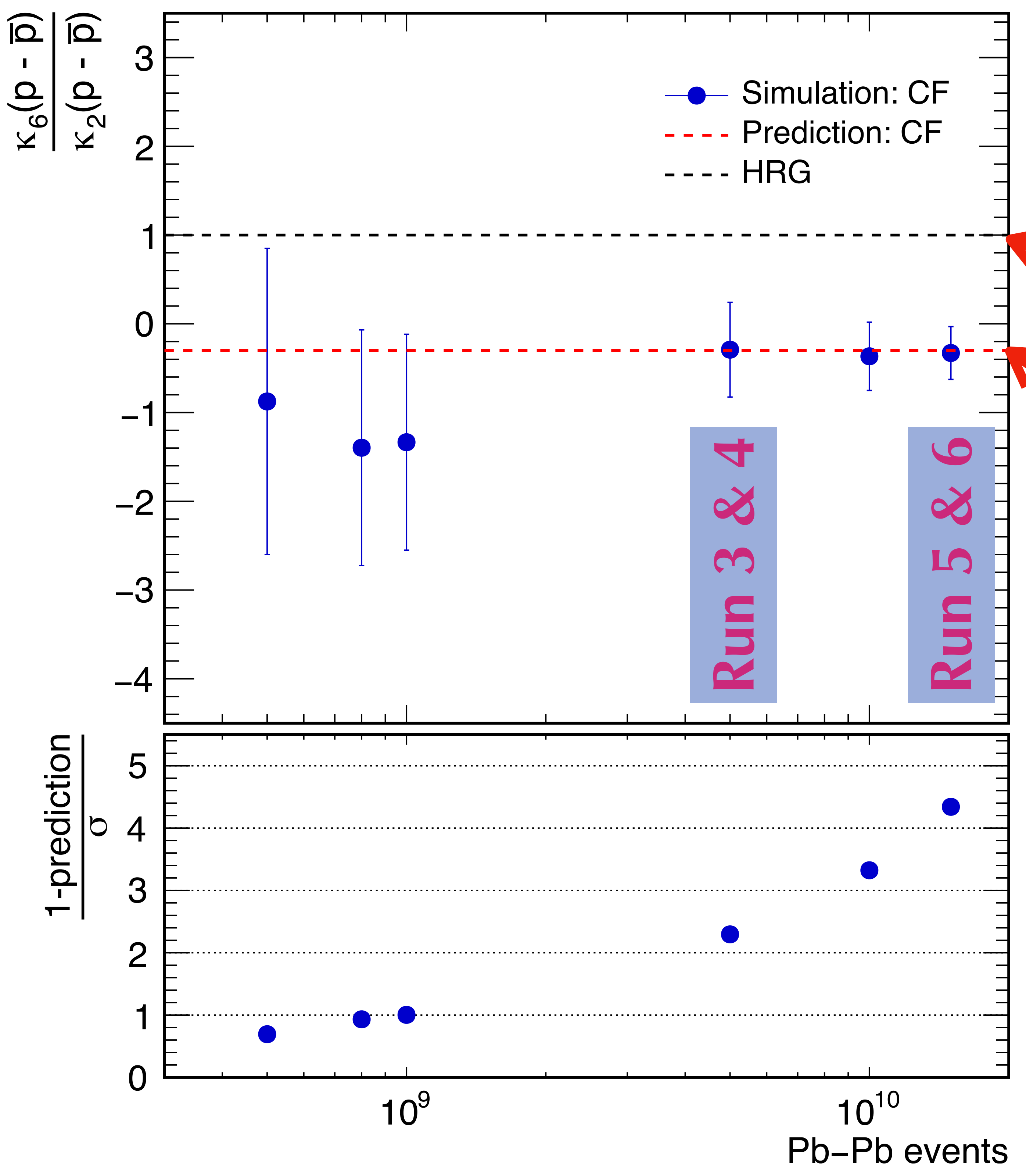
CMS MTD
→ C_4/C_2

Proton acceptance vs η

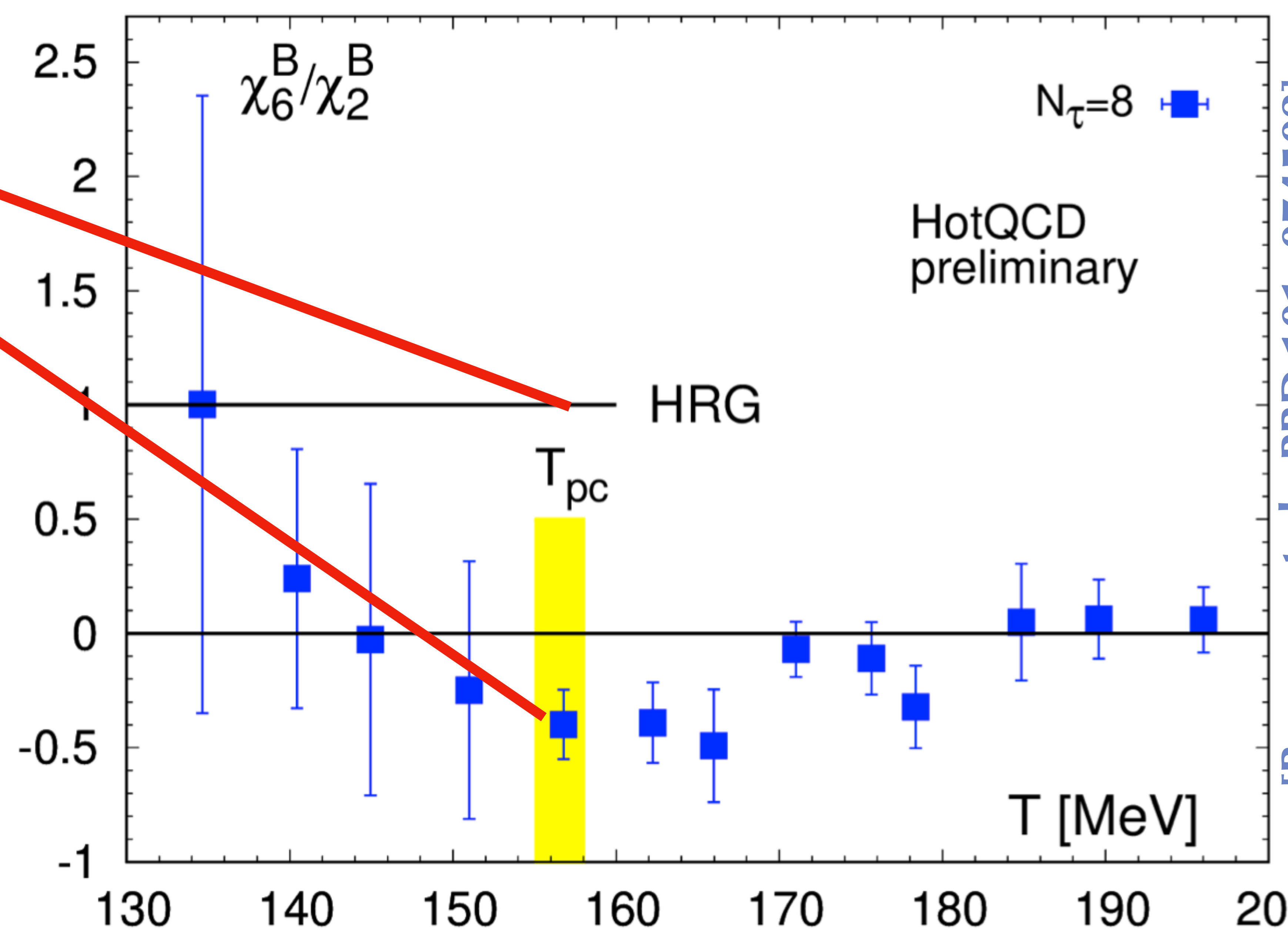


Run 3 & 4: limited Eff. x Acc.
Run 5 & 6: large Eff. x Acc.

Projection for 6th cumulant



Predictions from lattice QCD

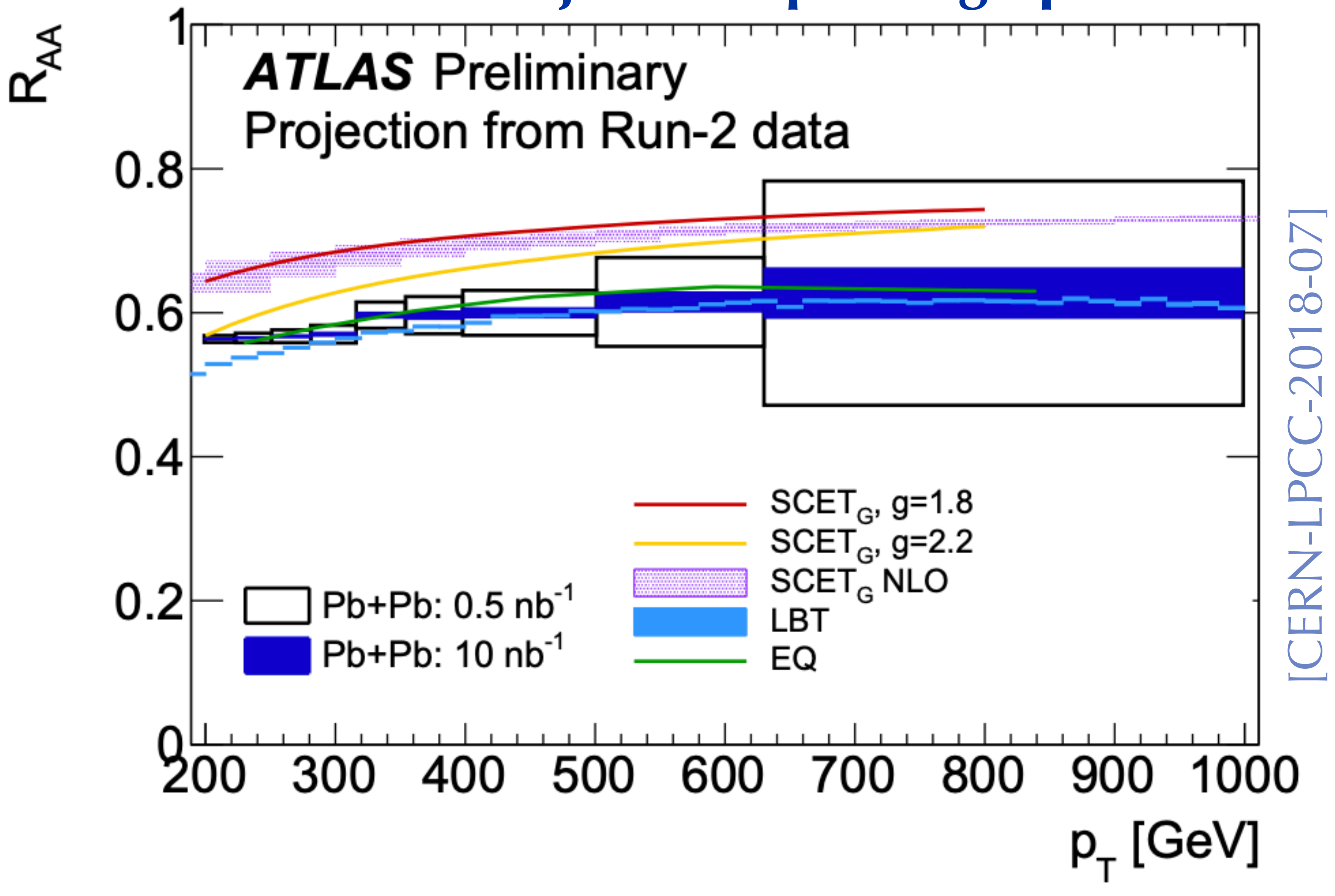


[Bazavov et al., PRD 101, 074502]

Quenching

- **Understand mass and time dependence as well as onset in small systems**
  → precision measurements, also with new probes and in intermediate systems
  → statistics, new collision systems (OO, pO, HM pp), HF reconstruction/tagging

Precise jet R_{AA} up to high p_T

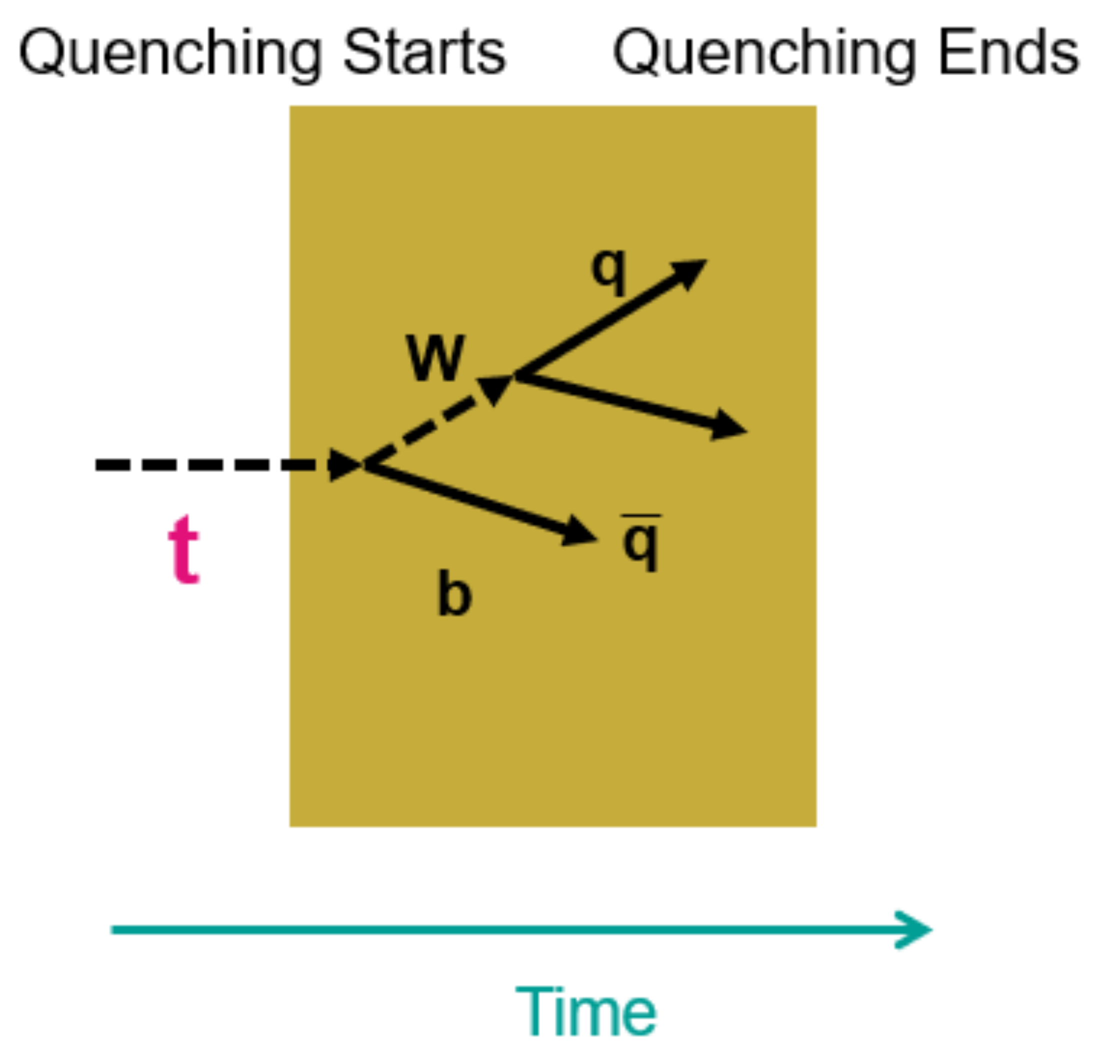


[CERN-LPCC-2018-07]

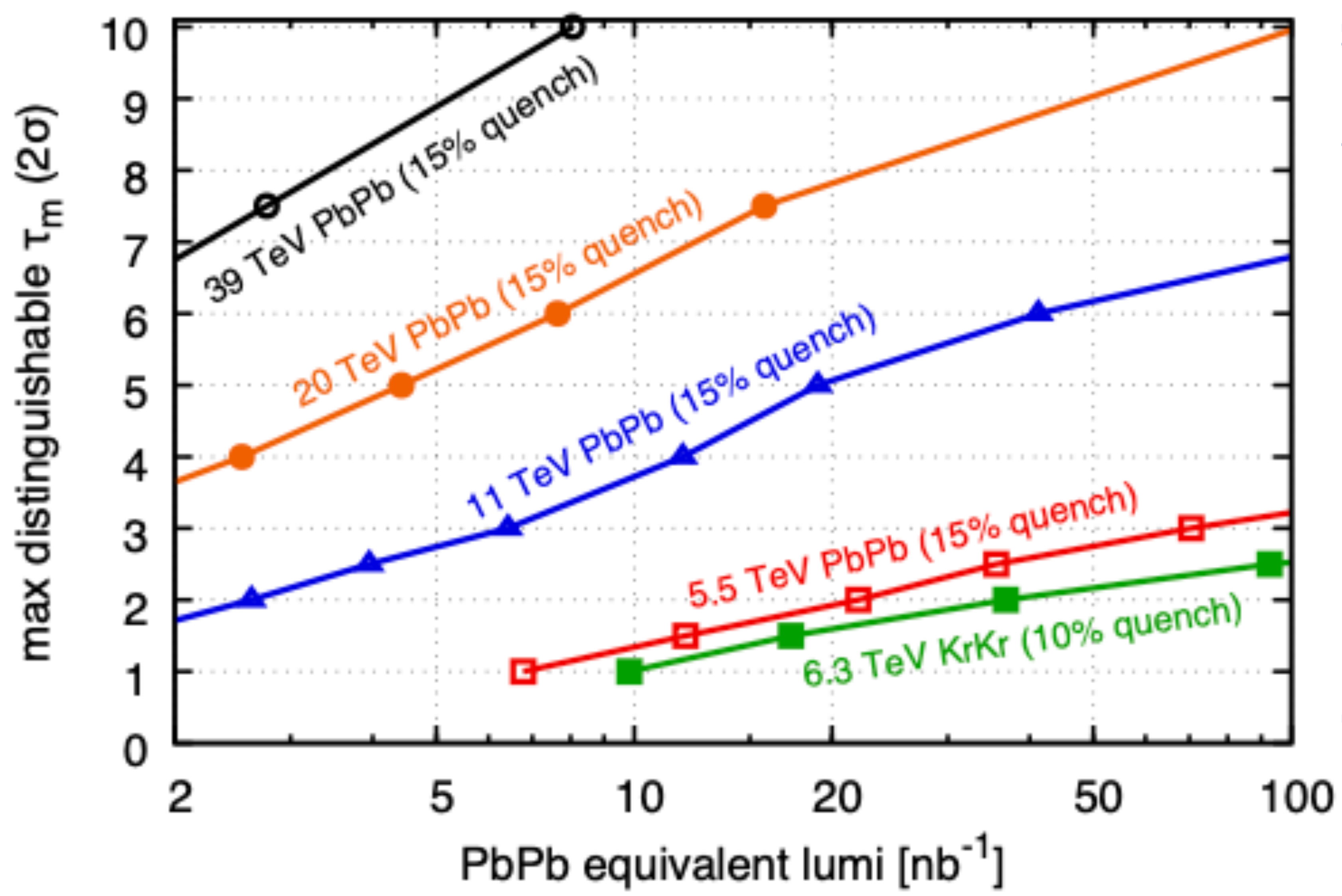
also HF jets (tagged and reconstructed), substructure, modification, …

Run 3 & 4

Boosted Top



probe medium after τ_m



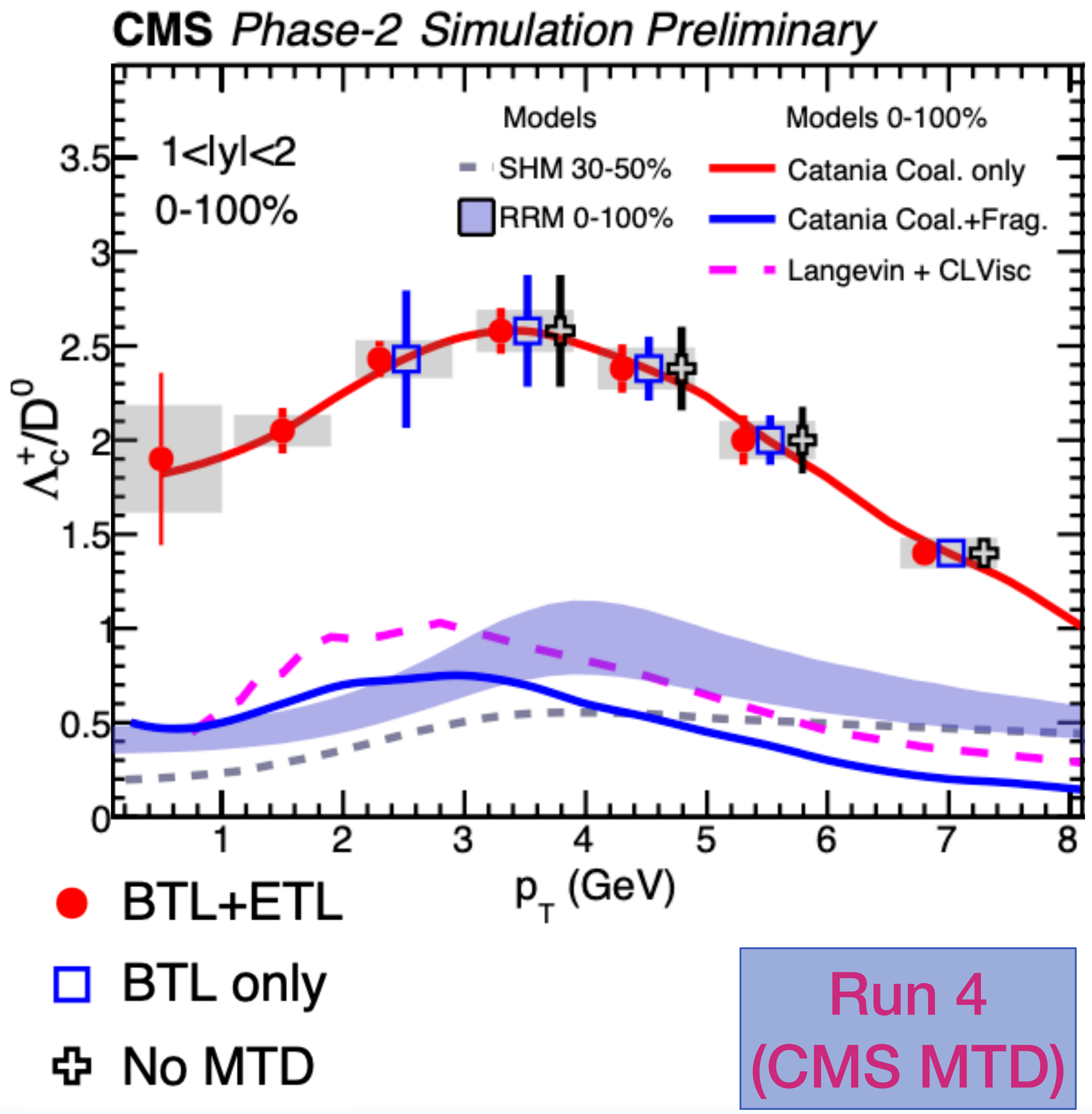
[Phys. Rev. Lett. 120, 232301 (2018)]

Run 3 & 4: proof of concept

Heavy-flavour hadronisation

- **Constrain hadronisation models**
  → measurements of baryon/meson ratios, nuclear suppression, and flow
  → luminosity, vertexing, PID

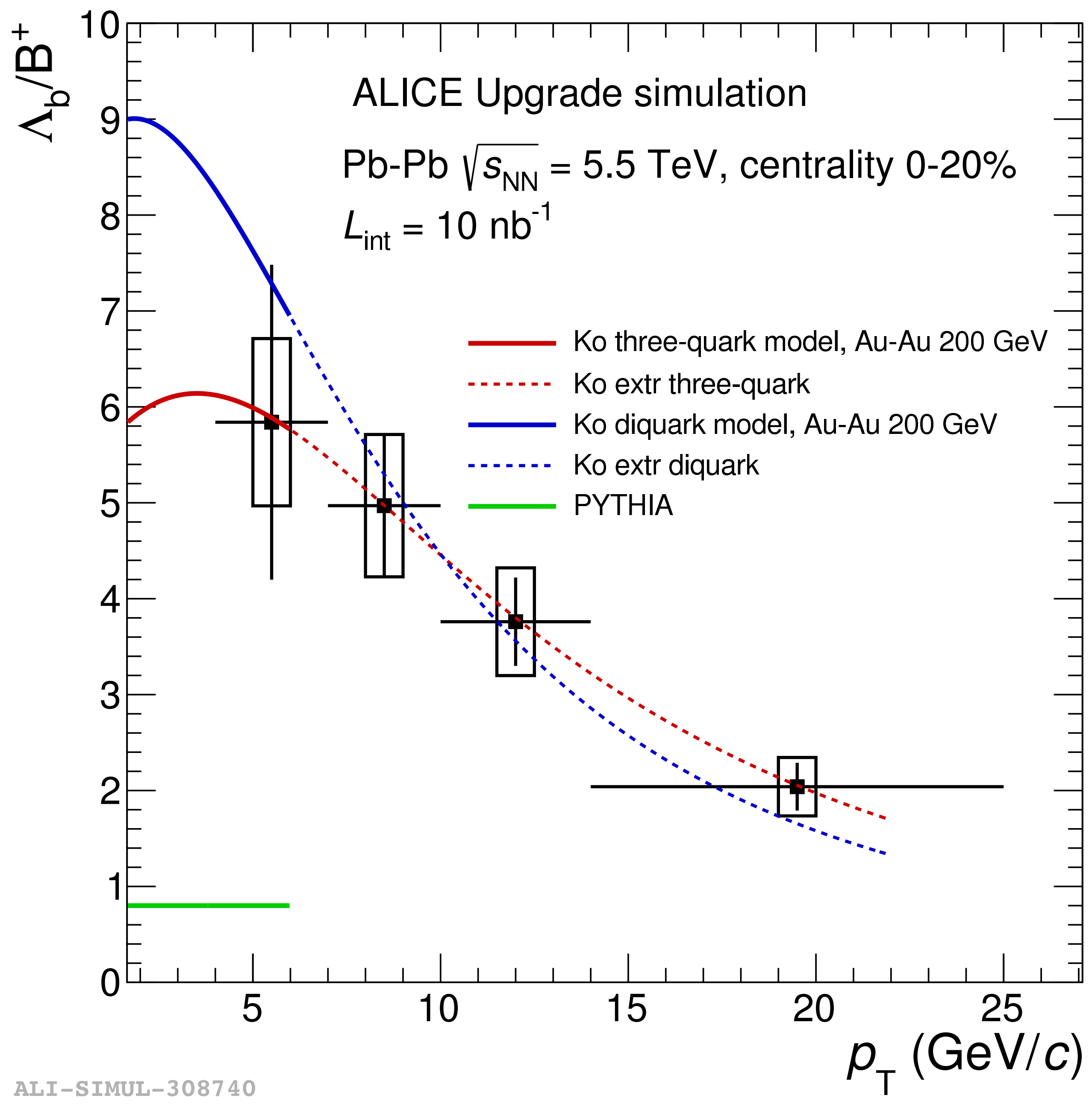
Λ_c/D^0



[CMS DP -2021/037]

Run 4 (CMS MTD)

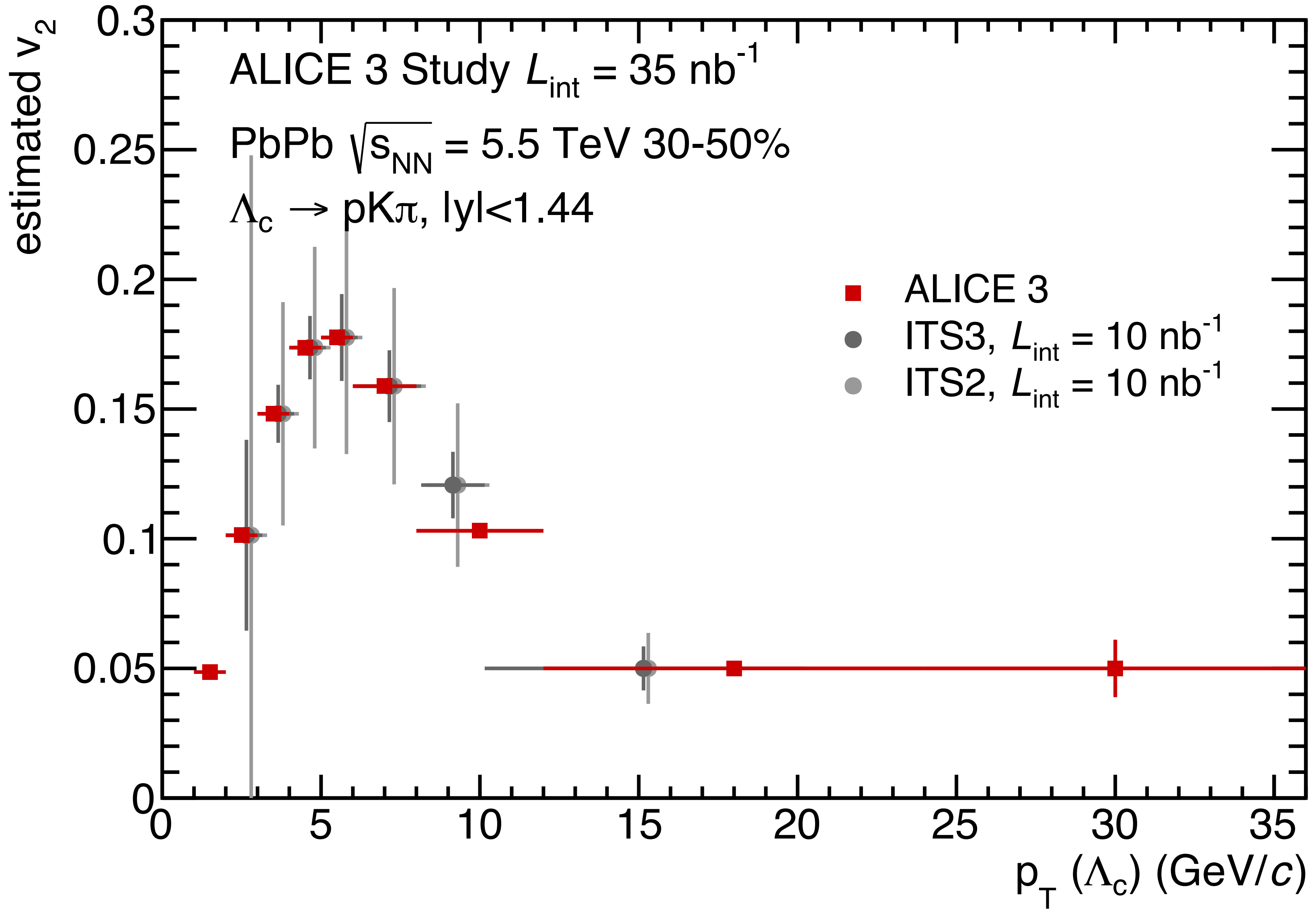
Λ_b/B^+



[CERN-LPCC-2018-07]

Run 3 & 4

Λ_c v_2



[CERN-LHCC-2022-009]

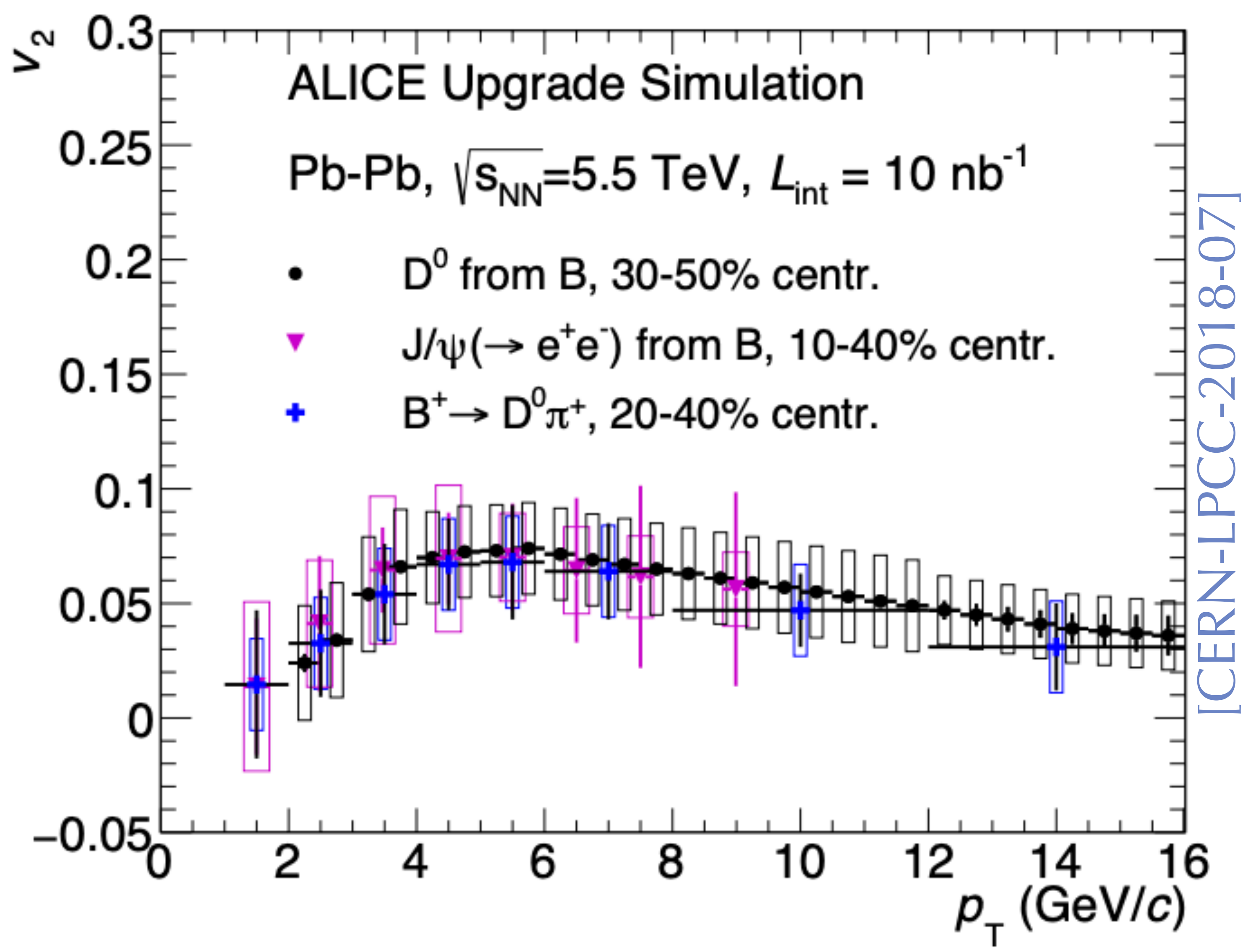
Run 3 & 4 → constraints,
Run 5 & 6 → precision

Heavy-flavour transport

- **Understand transport and thermalisation in the QGP**
  → measurements of $D\bar{D}$ correlations and in the beauty sector
  → statistics and vertexing

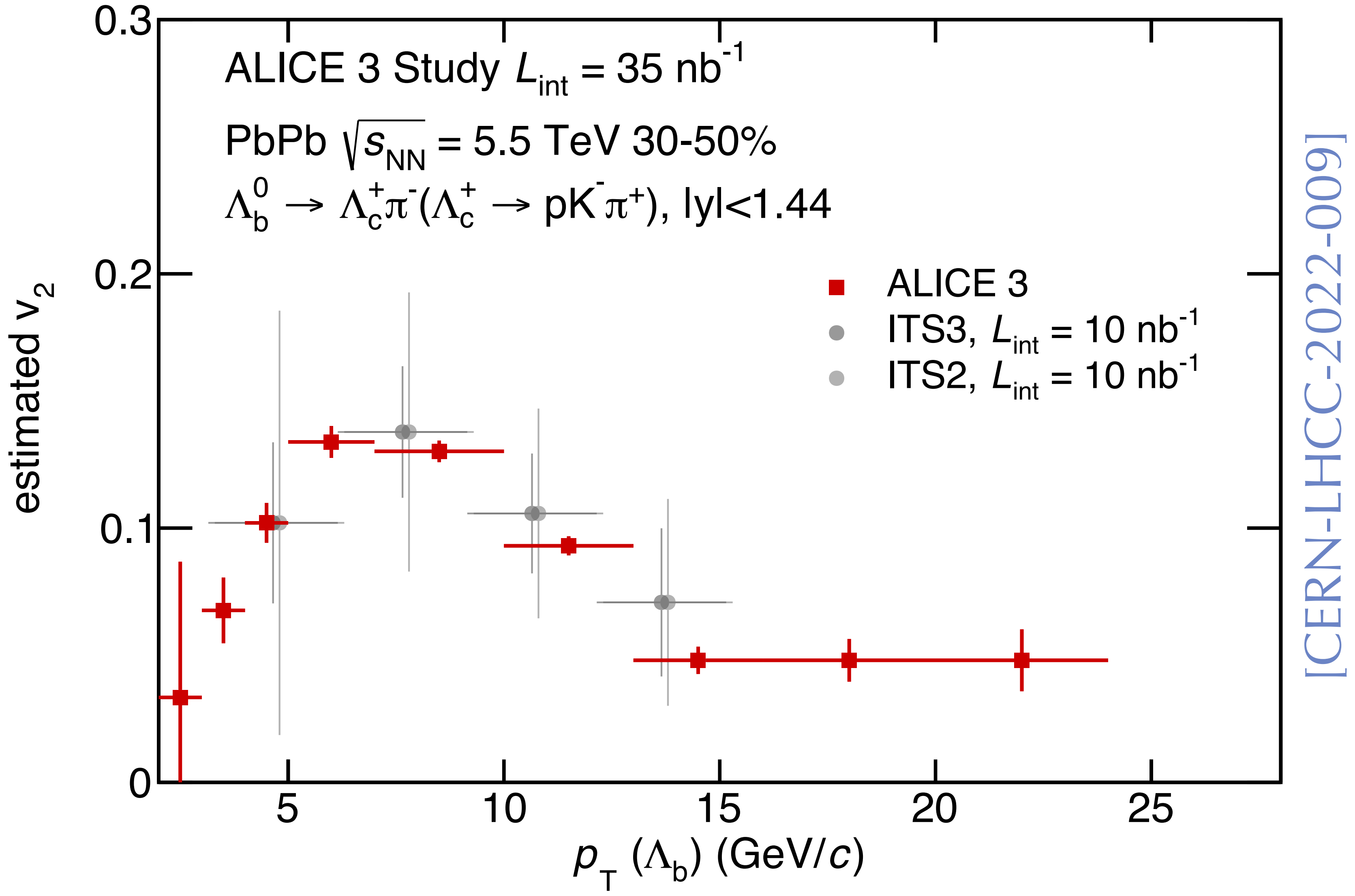
$$\tau_Q = (m_Q/T)\,D_s$$

B meson v_2



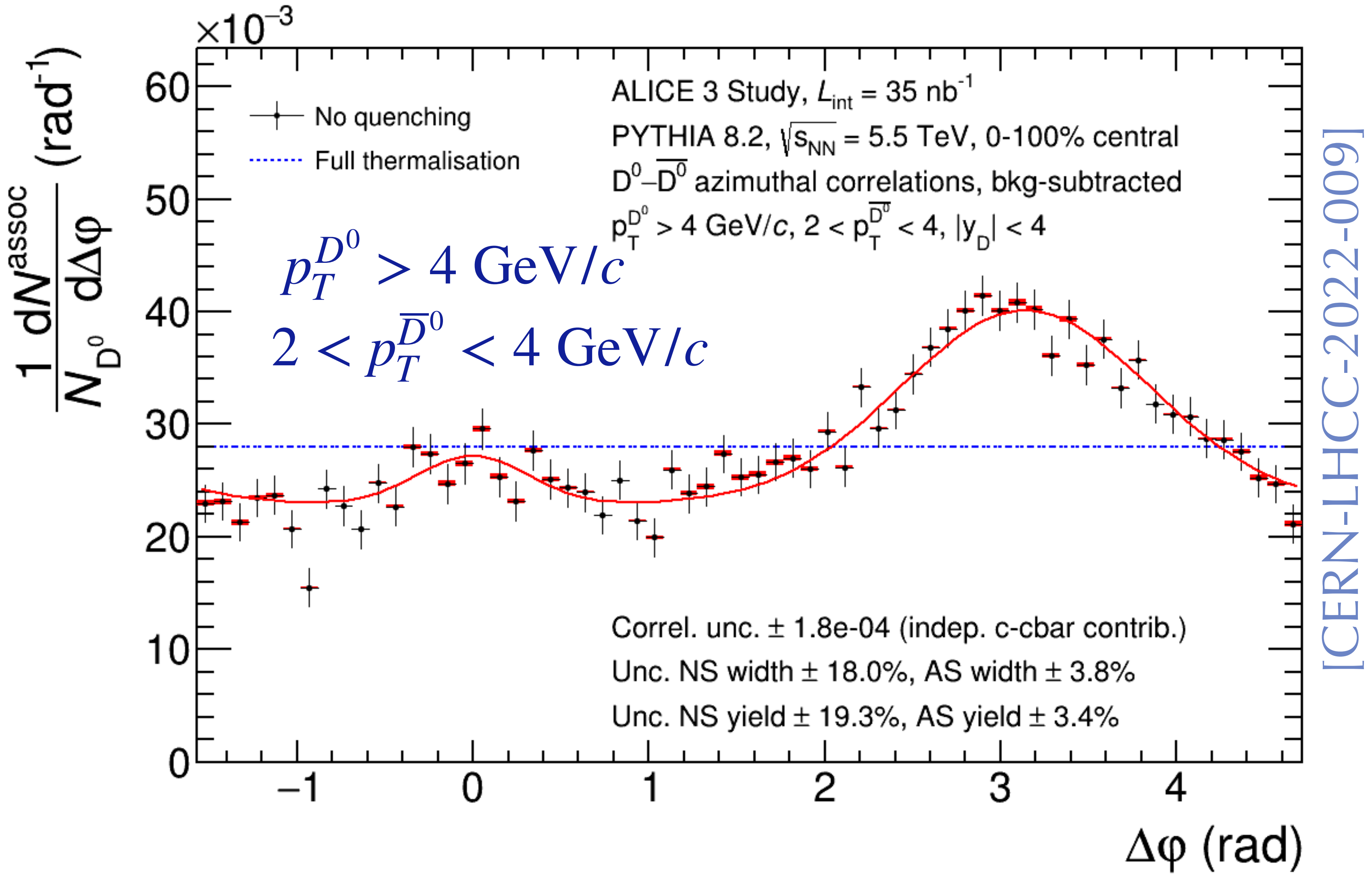
Run 3 & 4

Λ_b v_2



Run 3 & 4: constraints
Run 5 & 6: precision

$c\bar{c} \rightarrow D^0\bar{D}^0$ correlations

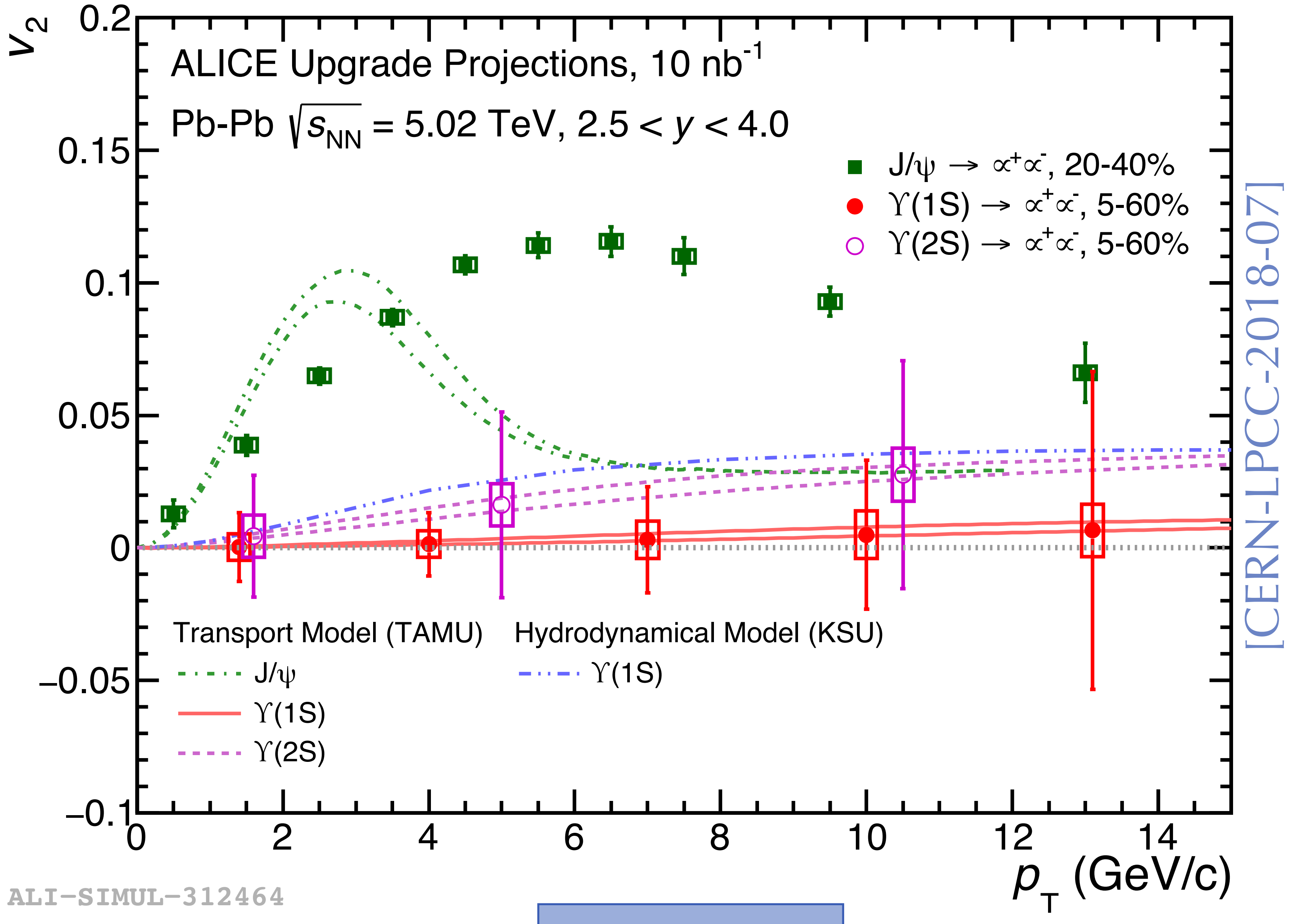


Run 5 & 6

Quarkonia

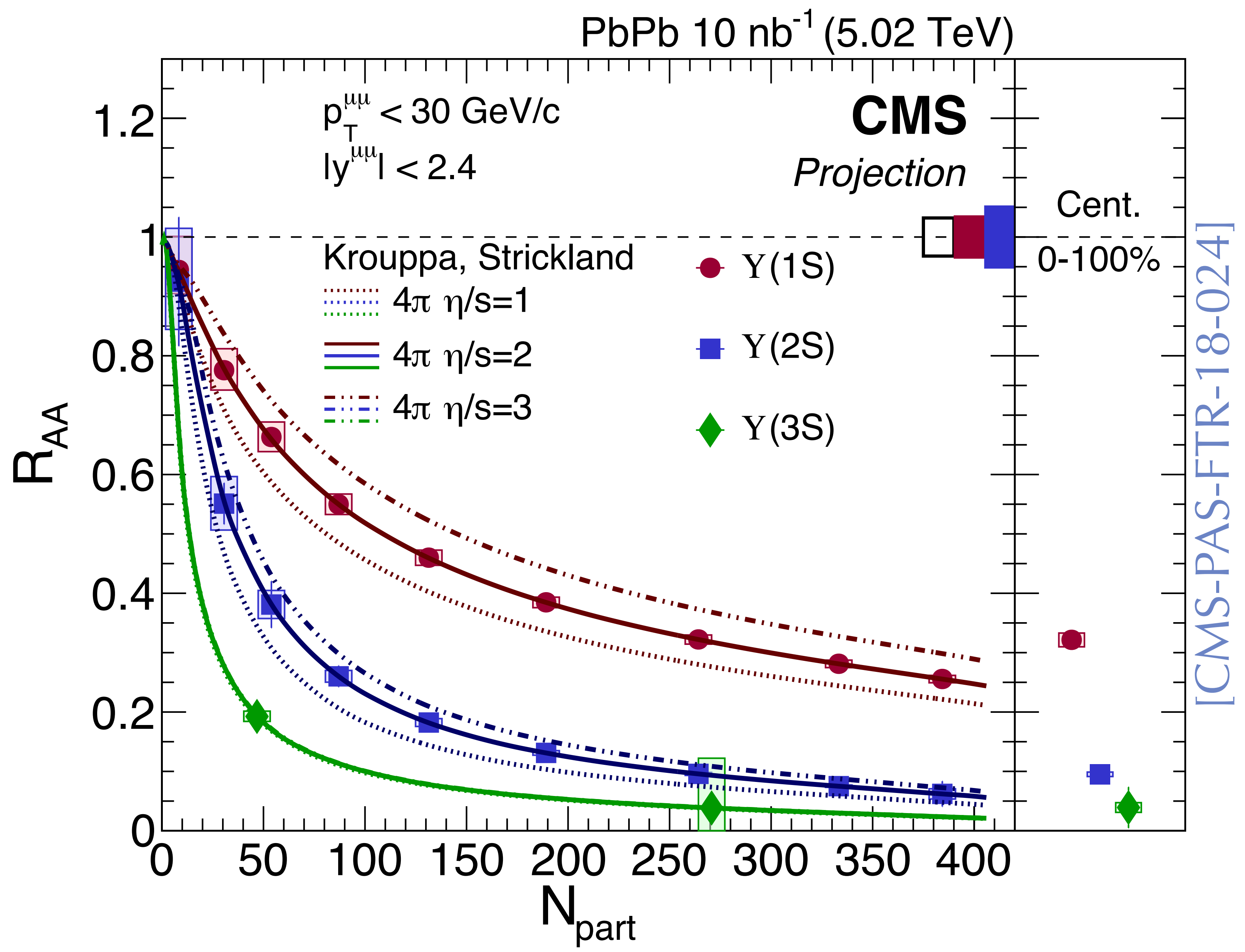
- **Understand heavy-quark dynamics in the QGP**
  → precision measurements of bottomonium and P-wave charmonium states
  → luminosity and PID

v_2 for J/ψ, Υ



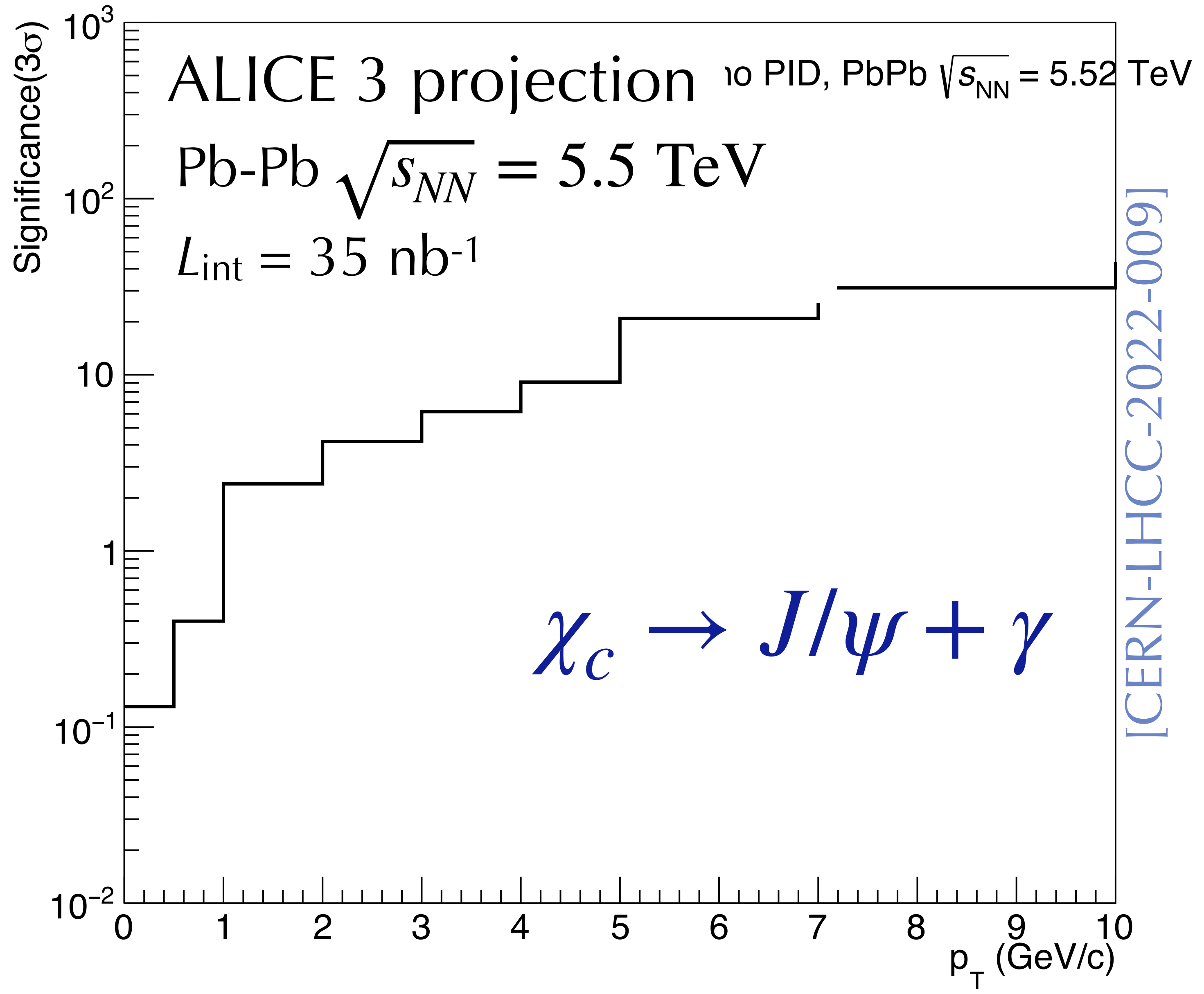
Run 3 & 4

R_{AA} for Υ states



Run 3 & 4

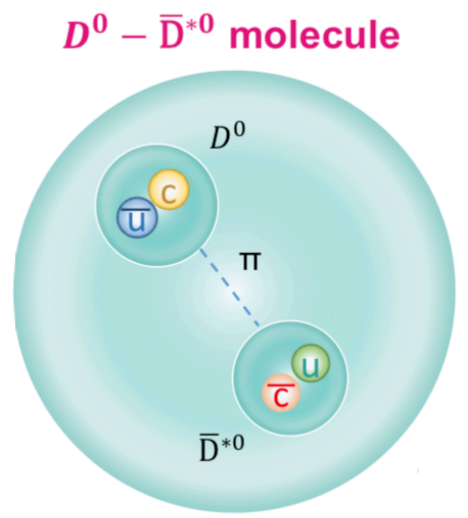
χ_c in Pb-Pb collisions



Run 5 & 6

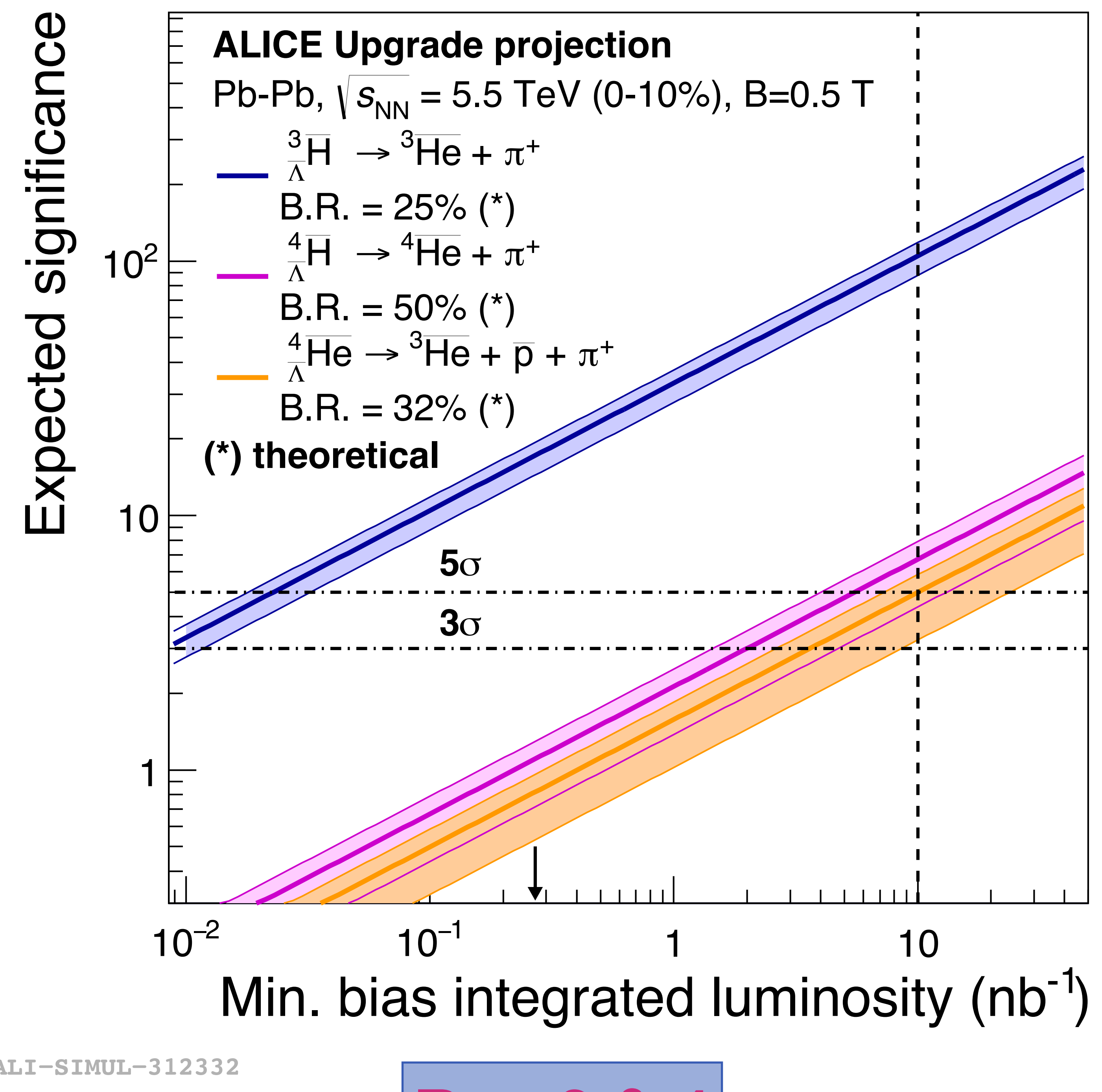
Further bound states

- **Understand formation and behaviour of bound states in the QGP**
  → measurements of exotic states and hadron-hadron correlations
  → requires luminosity, acceptance, PID



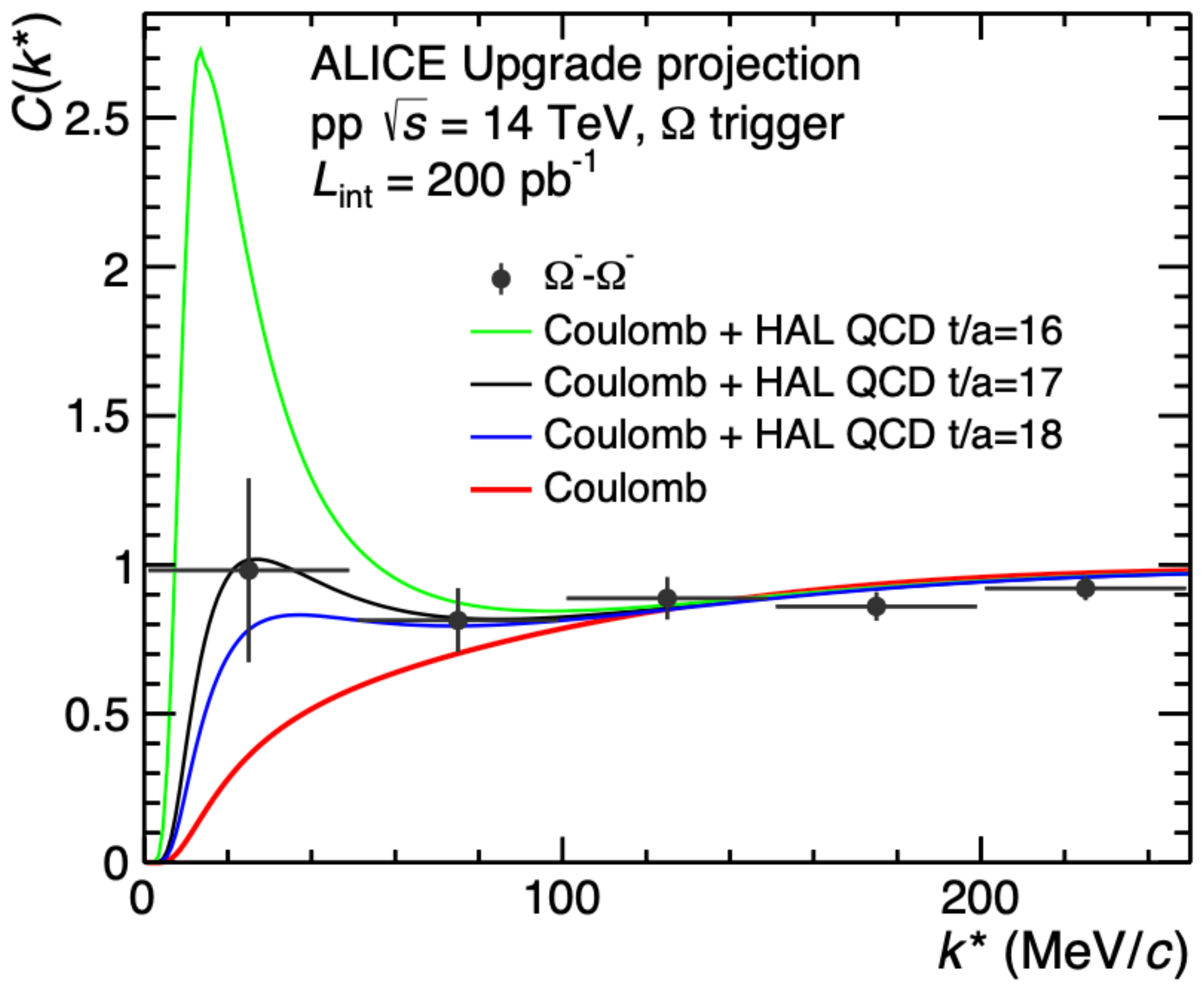
$r_{molecule}$ as large as 5 fm

anti-hyper-nuclei



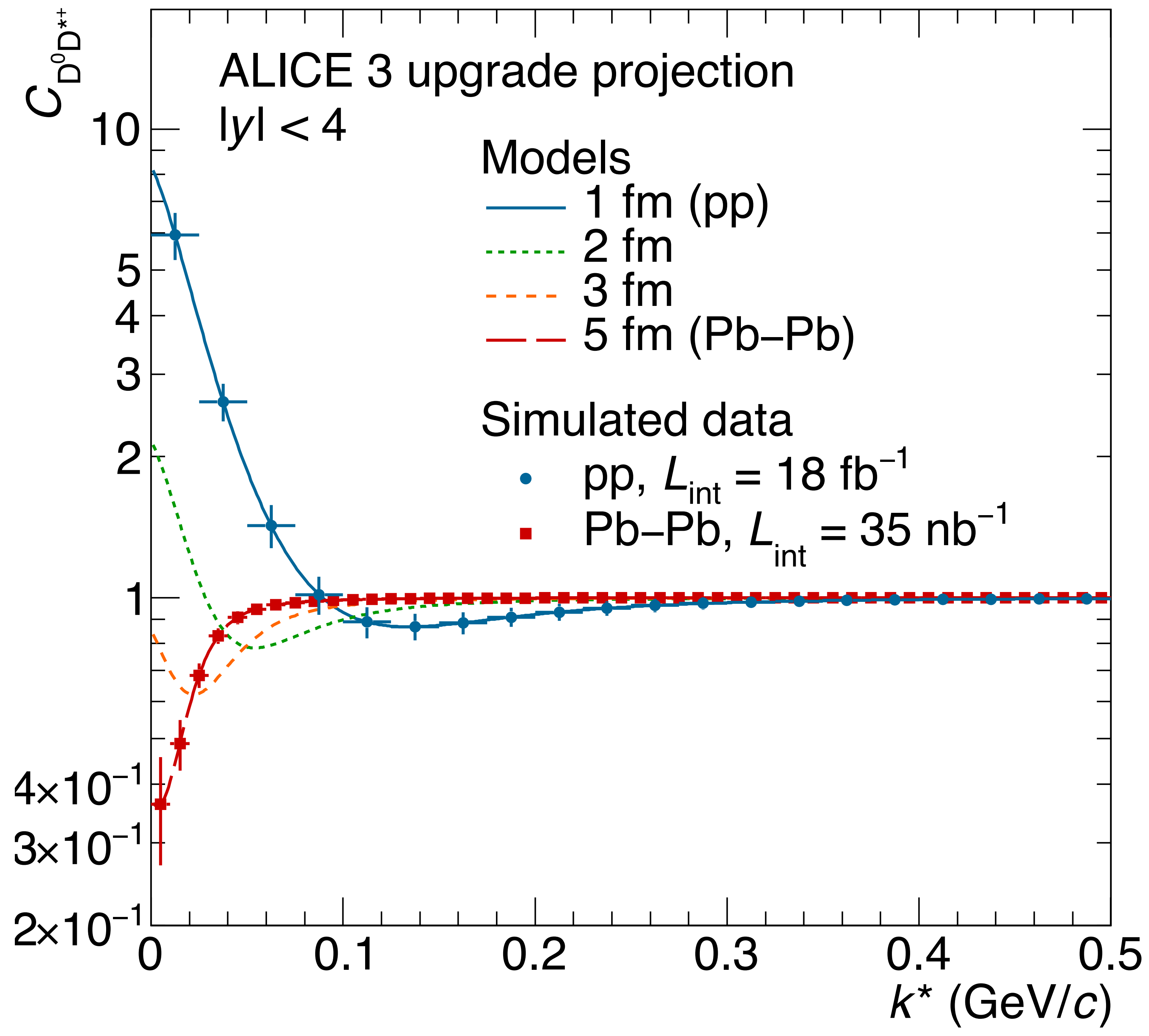
Run 3 & 4

Ω-Ω interactions



Run 3 & 4

D^0D^{*+}: nature of T_{cc}^+

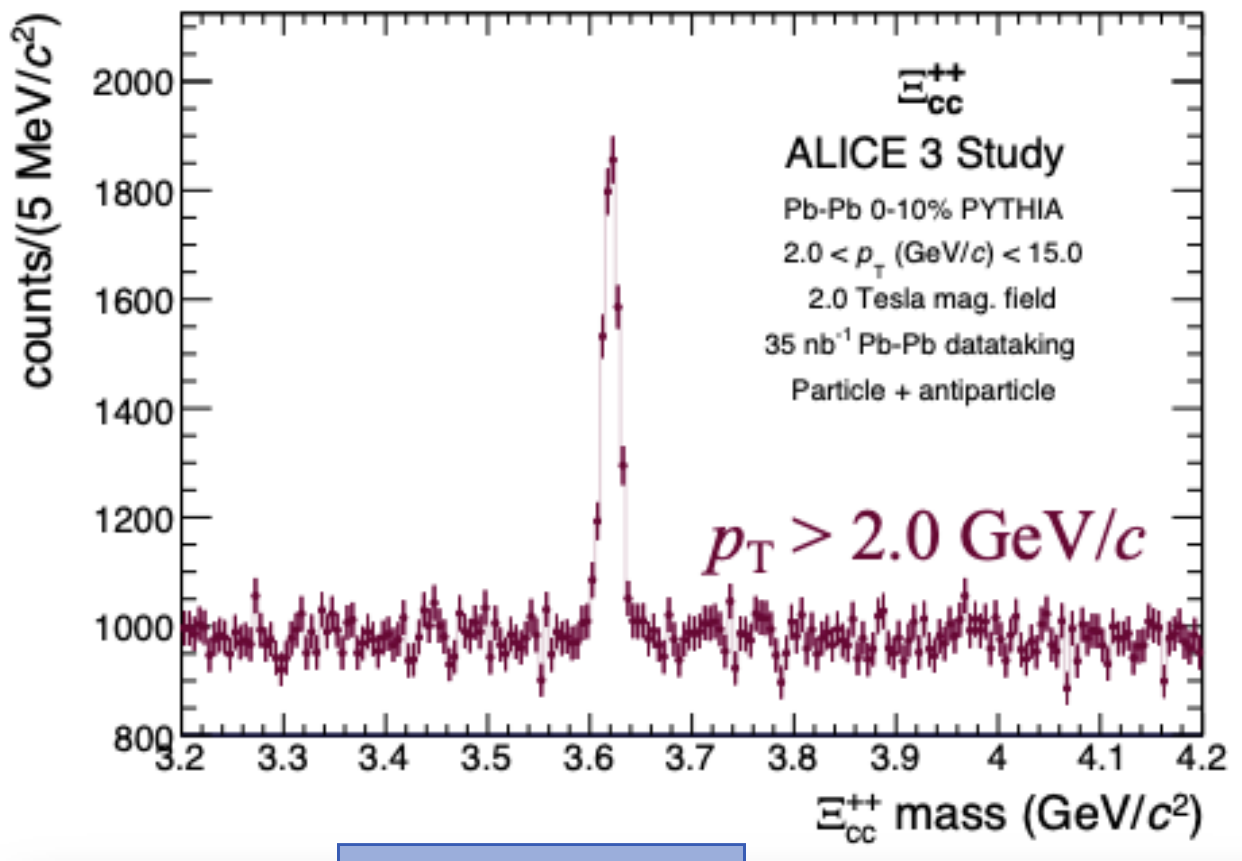


Run 5 & 6

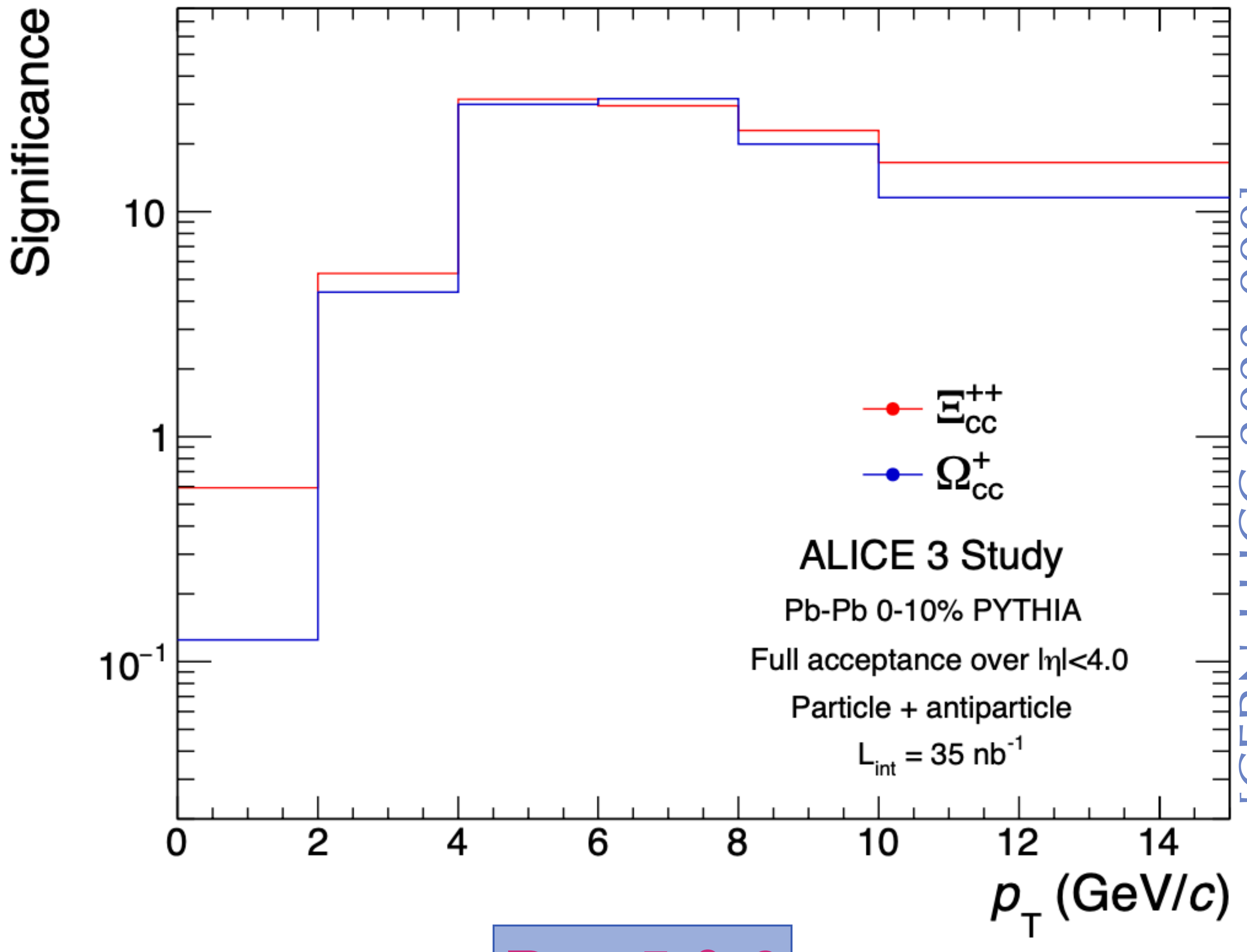
Multi-charm baryons

- **Expected enhancement of multi-charm states provides high sensitivity to equilibration**
  → systematic measurement of hadron yields
  → luminosity, acceptance, vertexing, PID, strangeness tracking

$$\Xi_{cc}^{++} \rightarrow \Xi_c^{+} + \pi^{+}$$
$$\Xi_c^{+} \rightarrow \Xi^{-} + 2\pi^{+}$$



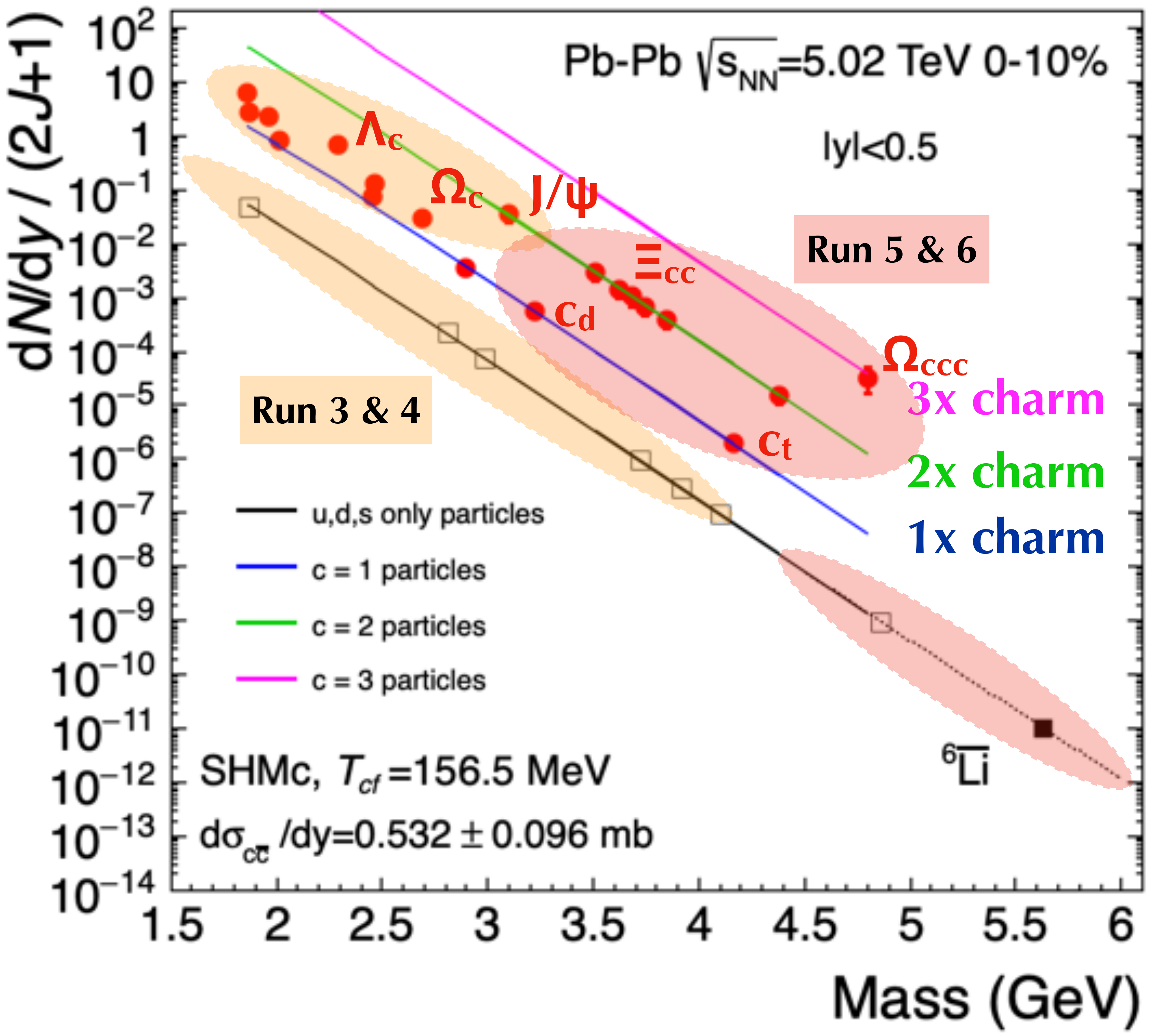
Run 5 & 6



[CERN-LHCC-2022-009]

Run 5 & 6

Hadron yields in statistical hadronisation model



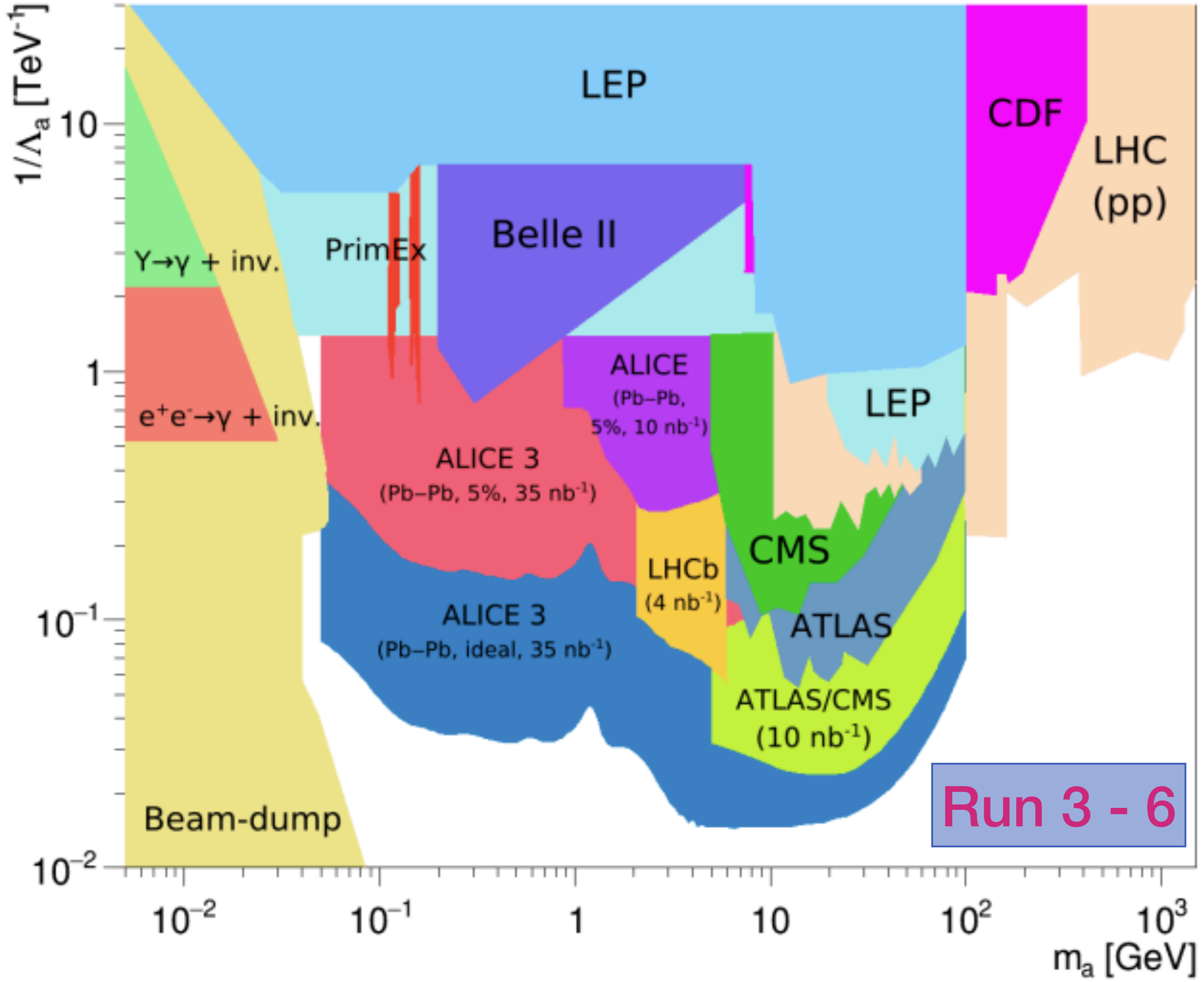
[A. Andronic et al., JHEP 07 (2021) 035]

Further opportunities

- **Fully exploit LHC for opportunities arising from the detectors**
  → BSM searches (L-by-L, …), Low's theorem, …
  → statistics, new detectors

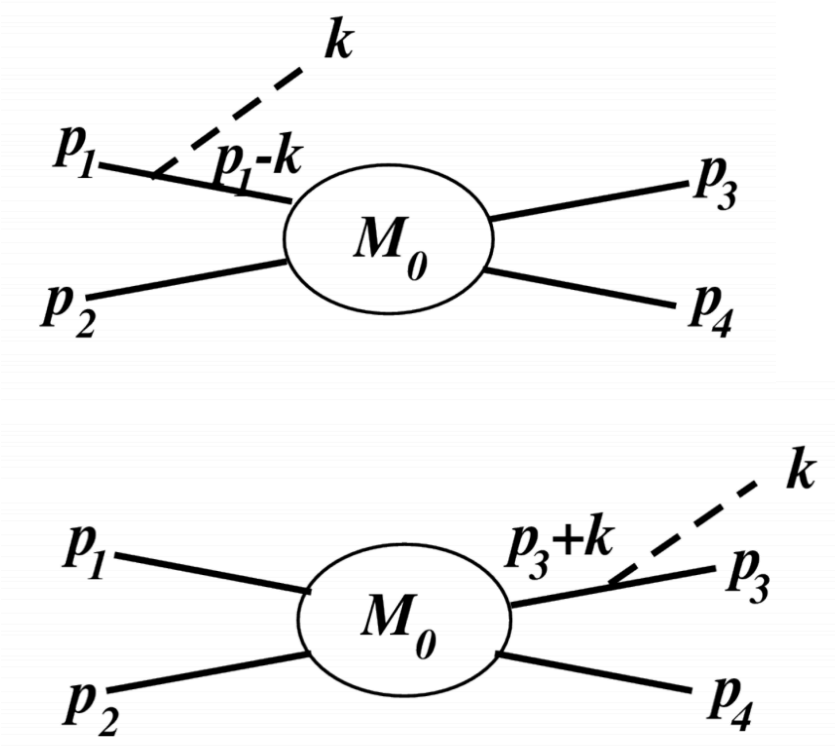
Search for axion-like particles $\gamma\gamma \rightarrow a \rightarrow \gamma\gamma$

[CERN-LHCC-2022-009]



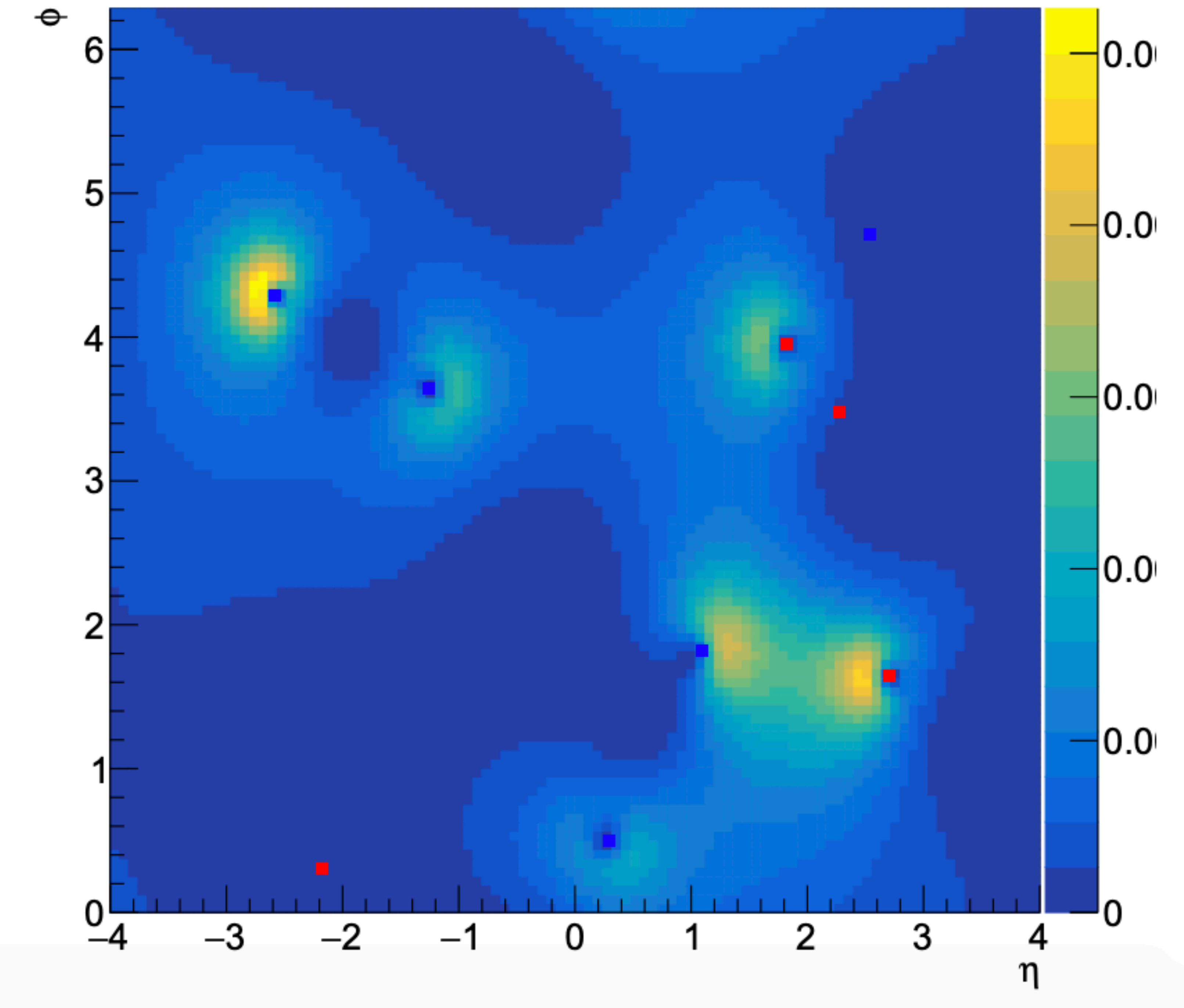
Measure ultrasoft photons $p_T \approx \mathcal{O}$(1 MeV/c), fundamentally linked to charged particle final state

Low's theorem



Run 5 & 6

[PRD 105 (2022) 1, 014022]



Luminous future at the LHC

Higher luminosities for ions

HL-LHC

High luminosity for ions

	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
LHC schedule	2009 - 2013	2015 - 2018	2022 - 2025	2029 - 2032		
Collision systems	pp, pPb, Pb-Pb	pp, pPb, Xe-Xe, Pb-Pb	pp, pO, OO, pPb, Pb-Pb	pp, pPb, Pb-Pb	pp, pA?, AA	pp, pA?, AA

- LHC provides ideal and unique opportunities to study hot QCD matter
- Extensive heavy-ion programme with all four LHC experiments
- Rich R&D programmes on technologies of interest beyond LHC

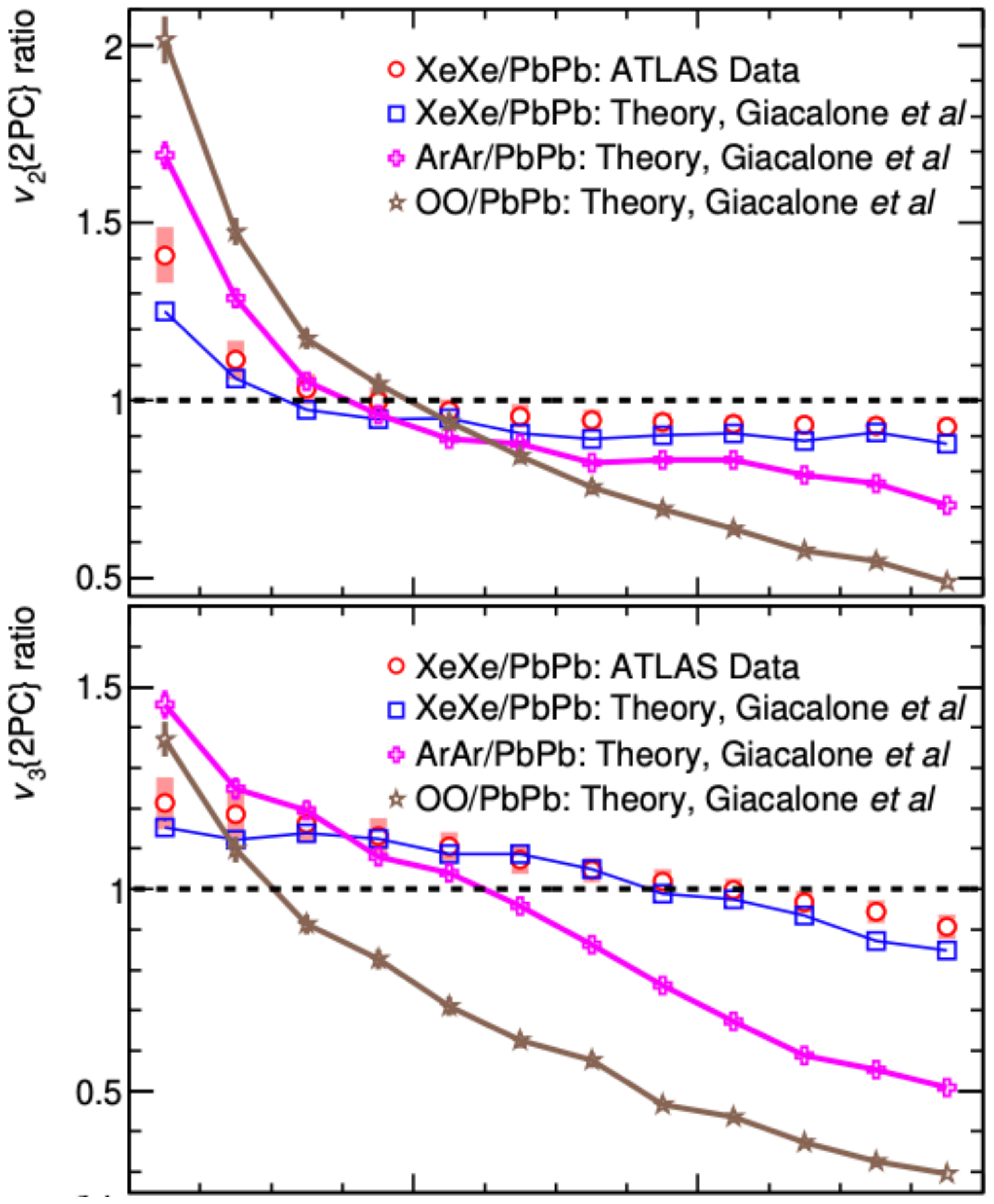
Thank you for your attention!

Backup

Small systems

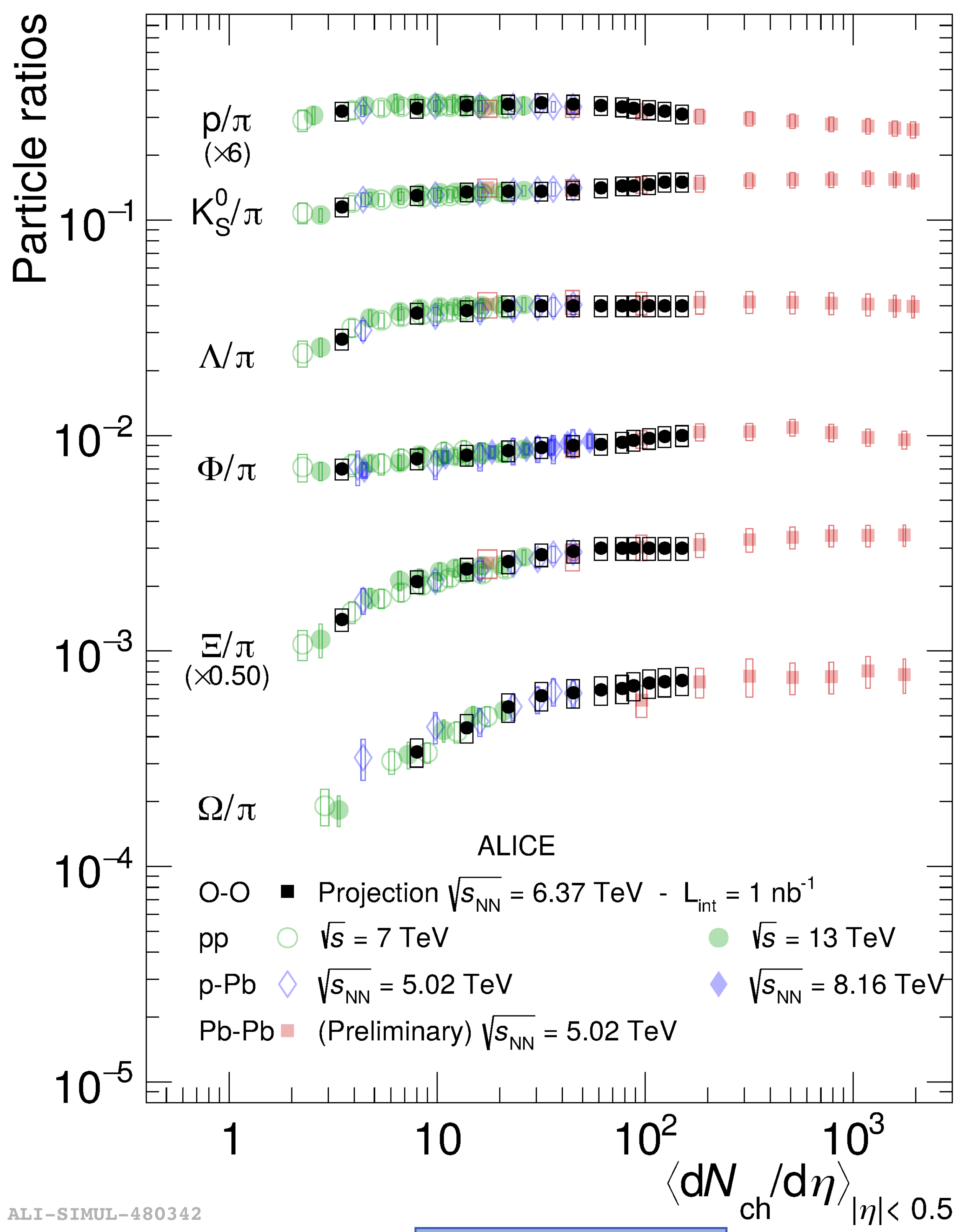
- **Understand evolution from small to large systems**
  → systematic measurements of flow and particle production
  → large high-multiplicity pp sample and new collision systems

Flow



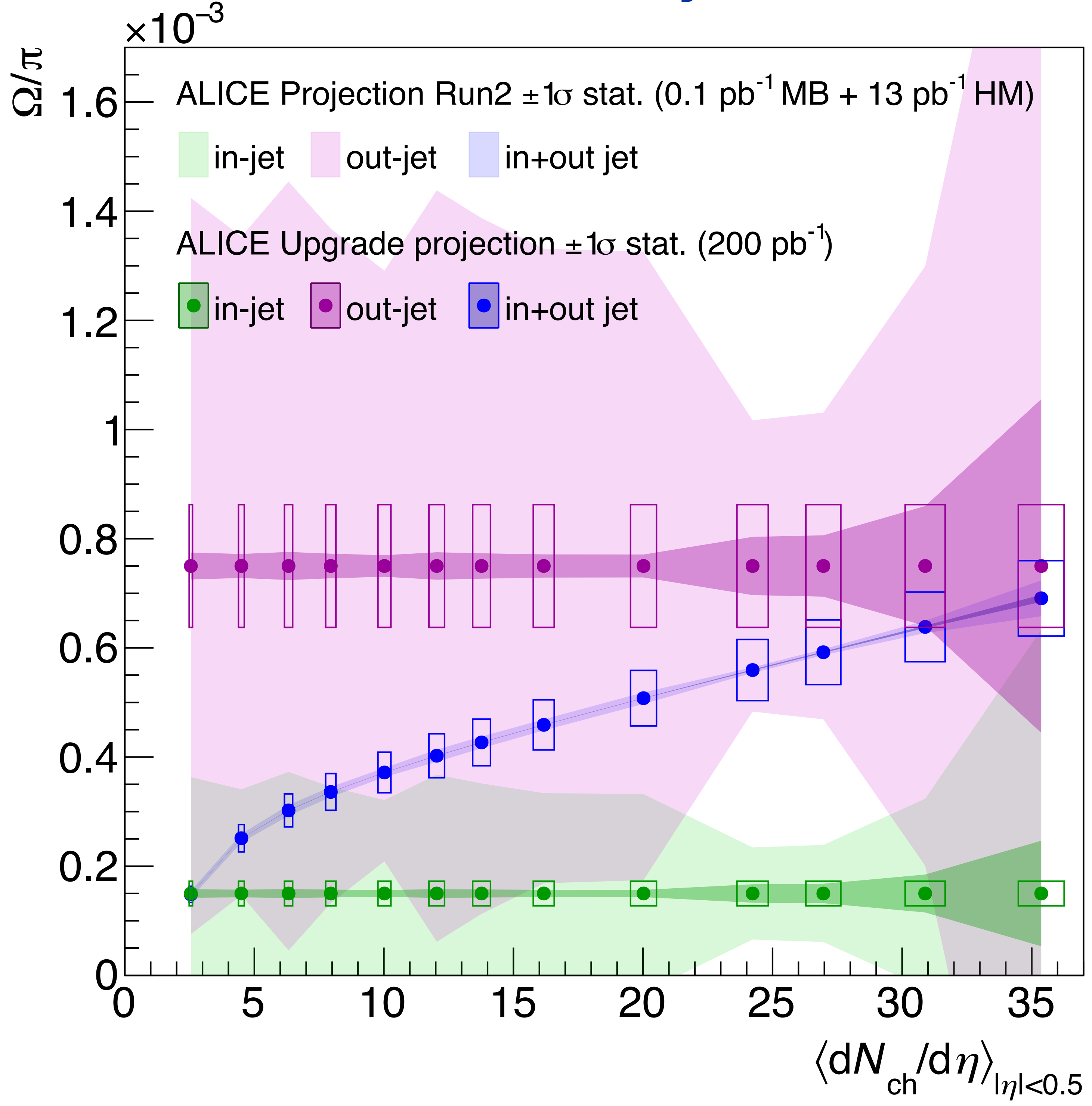
Run 3 & 4

Strangeness/baryon enhancement



Run 3 & 4

Production of particles in and out-of jets

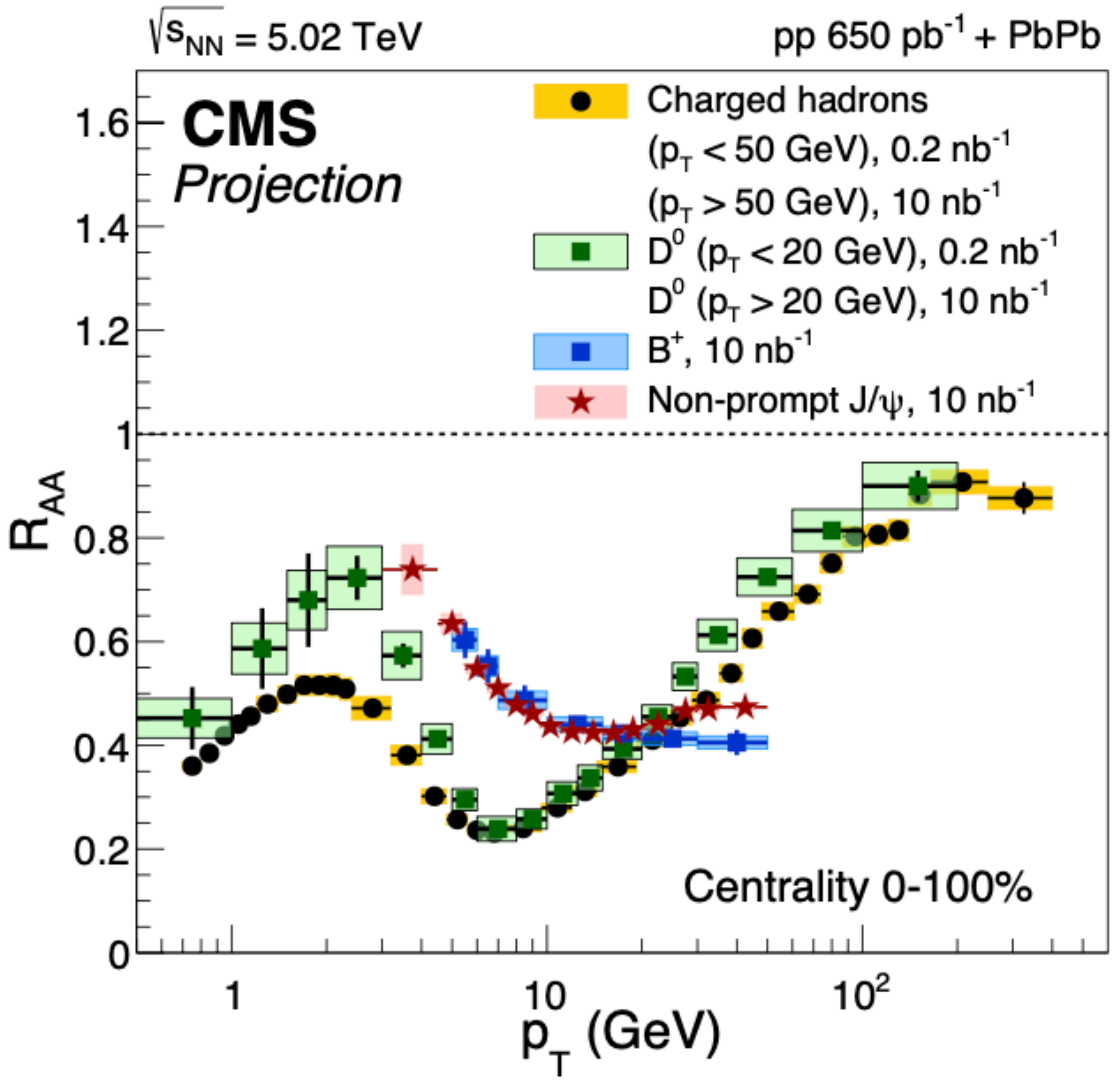


Run 3 & 4

Heavy-flavour transport

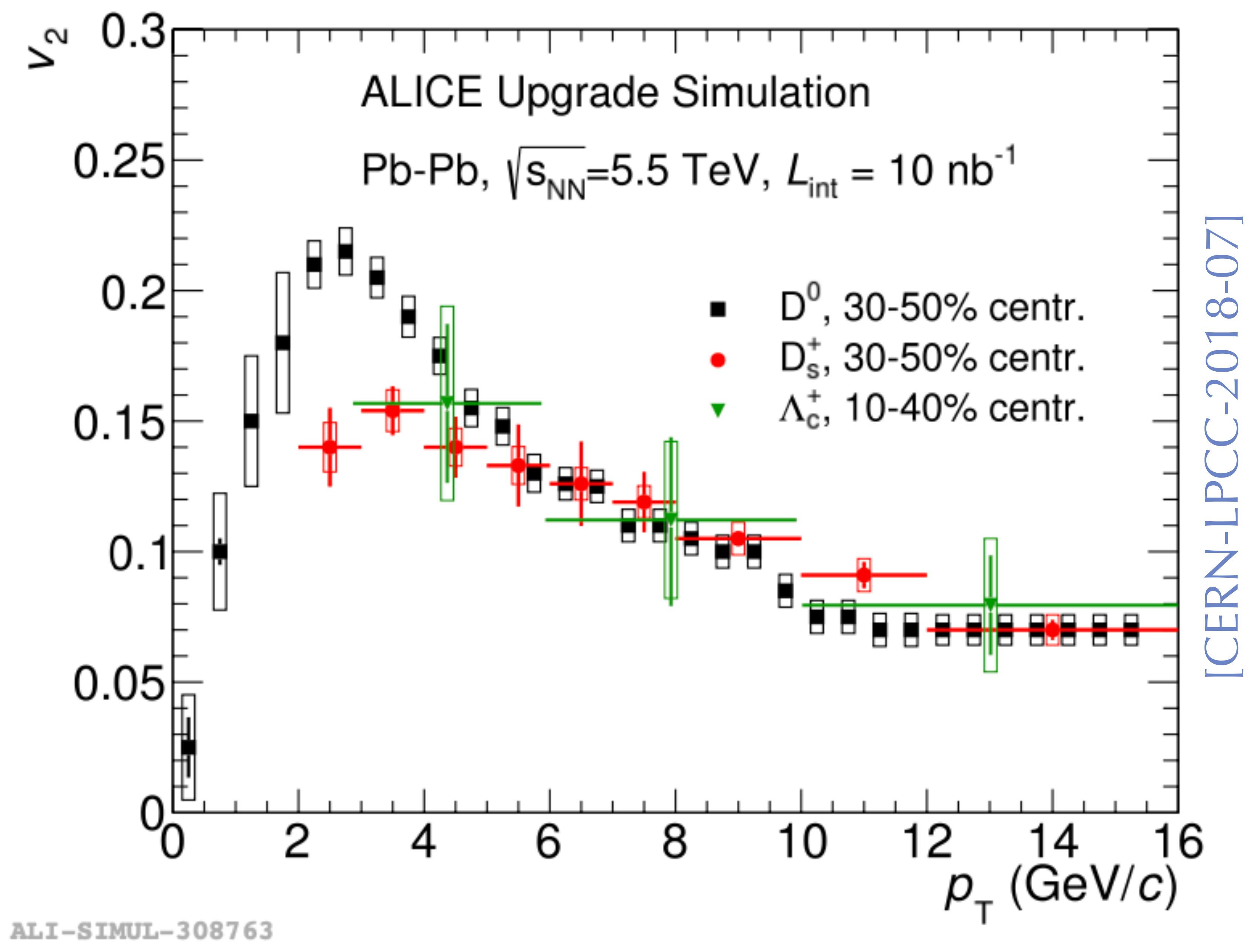
- **Measure spatial diffusion coefficient in the QGP**
  → precision measurements of R_{AA} and v_2 for charm and beauty
  → statistics and vertexing

Precise R_{AA} for c and b mesons



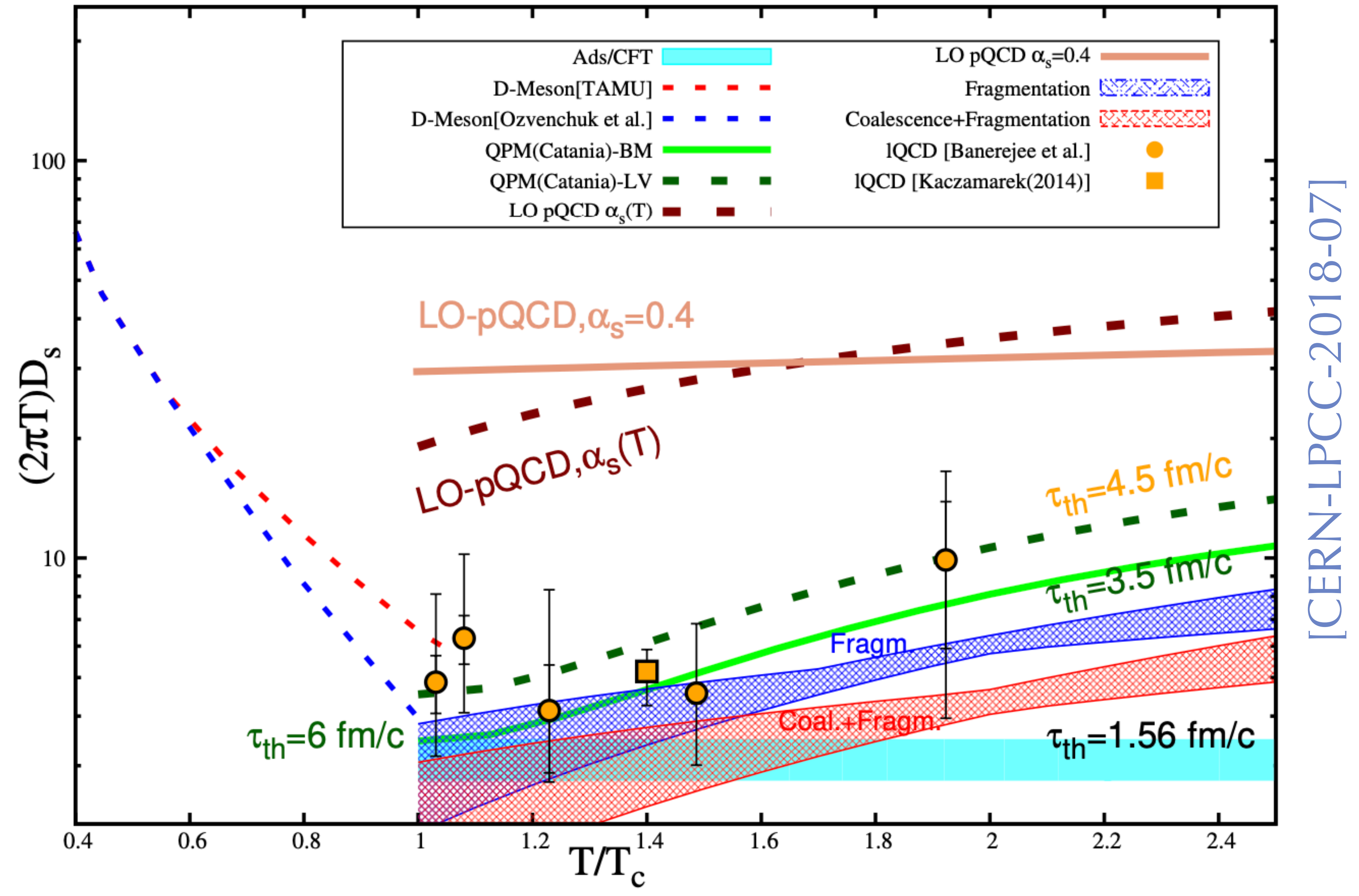
Run 3 & 4

v_2 for charm hadrons



Run 3 & 4

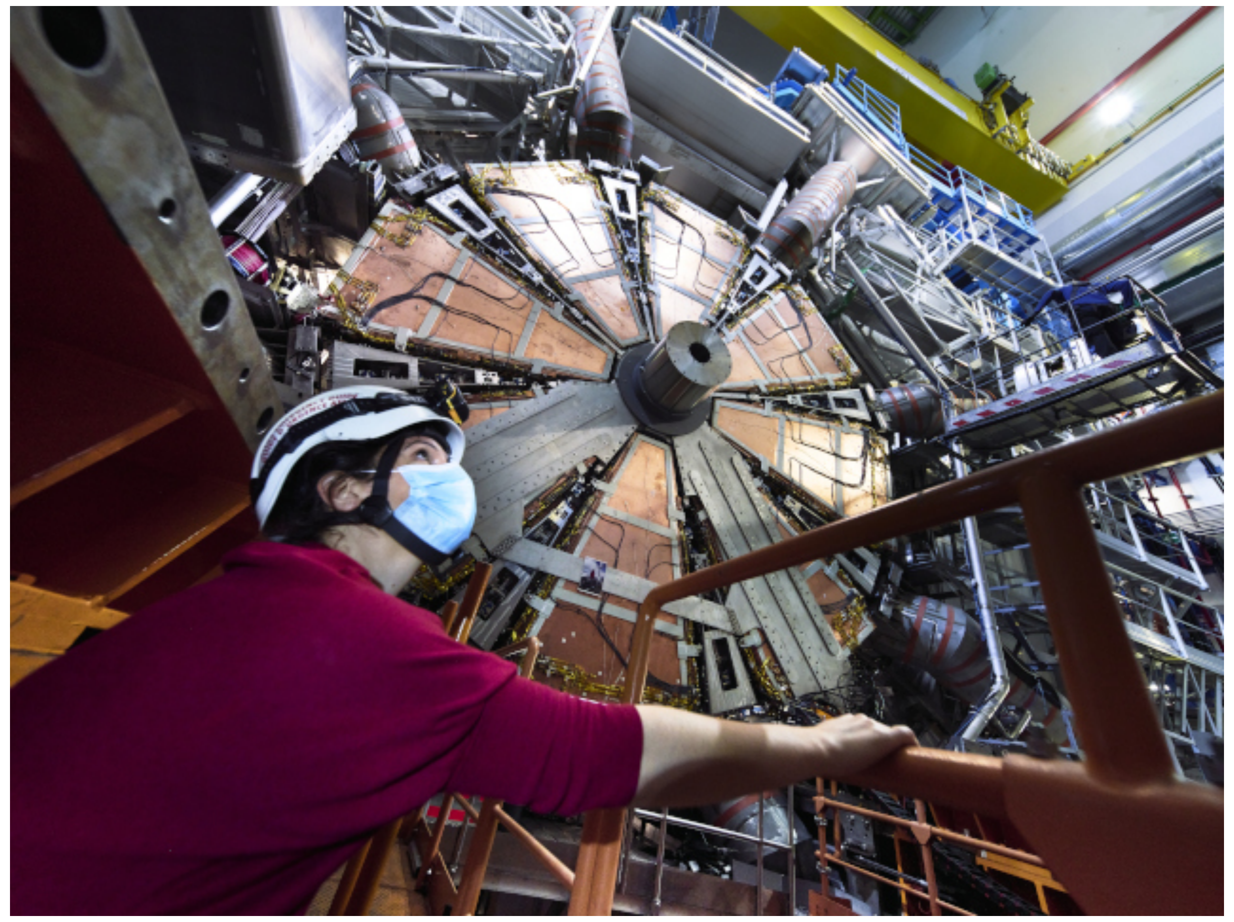
R_{AA} and v_2 → D_s



ATLAS phase I upgrades

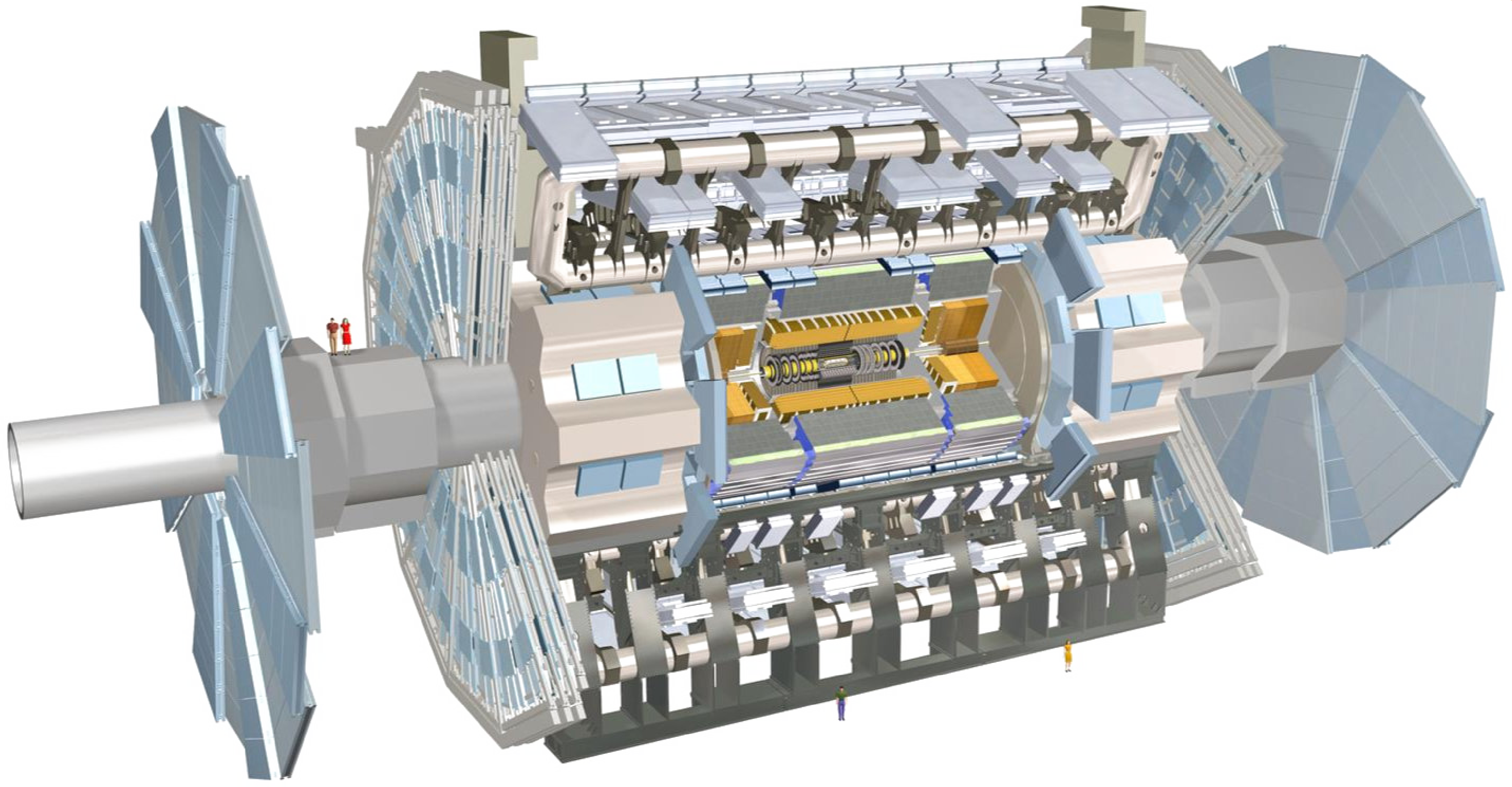
Muon system

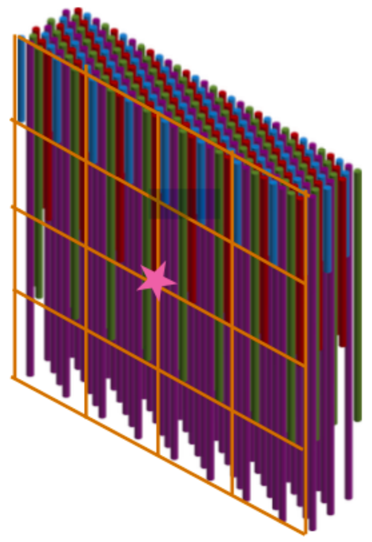
- **New Small Wheels** installed
  → sTGC + MicroMegas



Trigger and DAQ

- L1 and HLT improvements



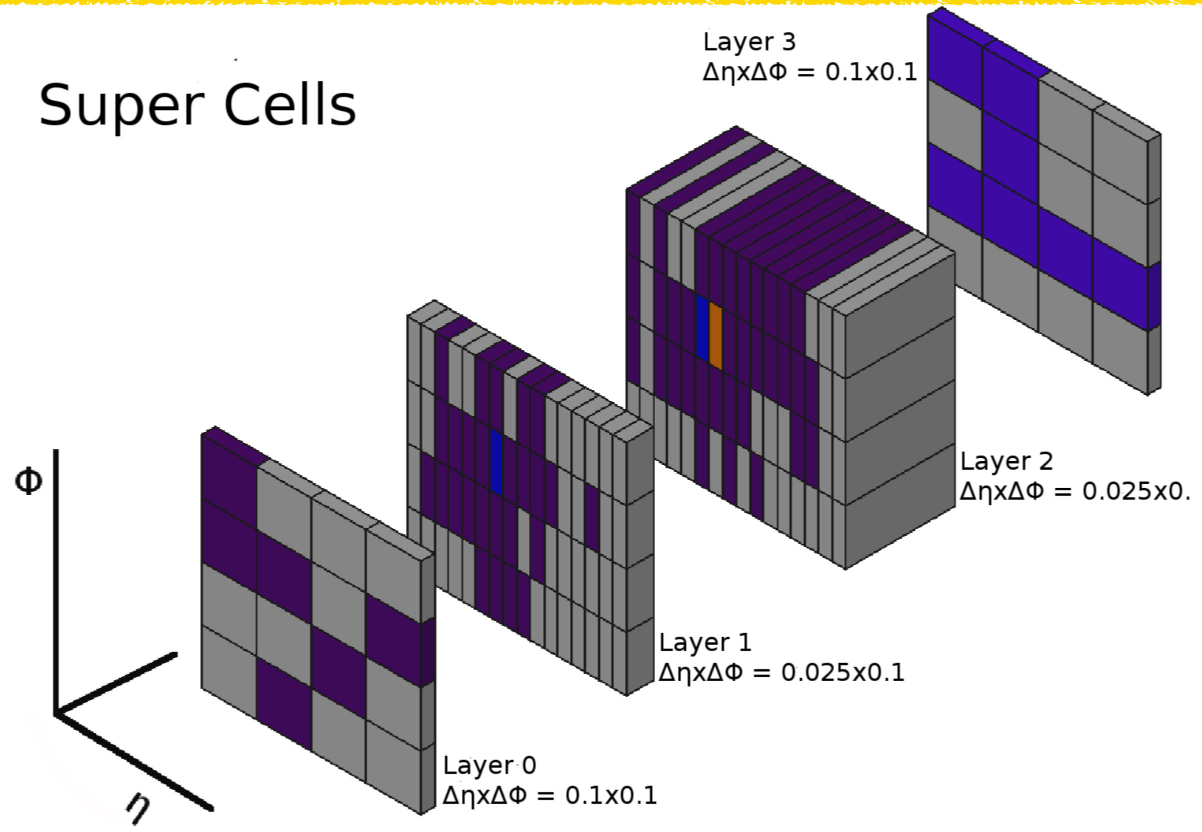


ZDC

- Fused silica rods for radiation tolerance
- On-detector processing
- Reaction plane detector

LAr calorimeter

- **Segmented super-cells:** shower-shape discrimination at trigger level



➡ **Increased statistics**

➡ **Improved ZDC**

ATLAS phase II upgrades

LAr calorimeter

- **Segmented super-cells:** shower-shape discrimination at trigger level

Trigger and DAQ

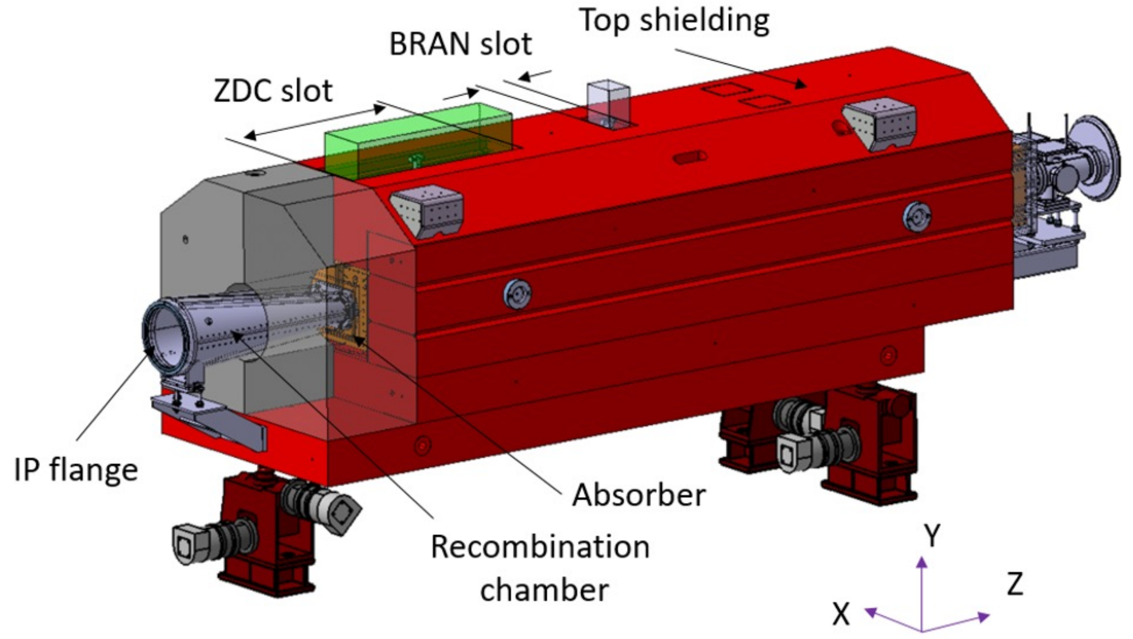
- L1 and HLT improvements
- Further upgrades

Electronics upgrades

Luminosity detectors

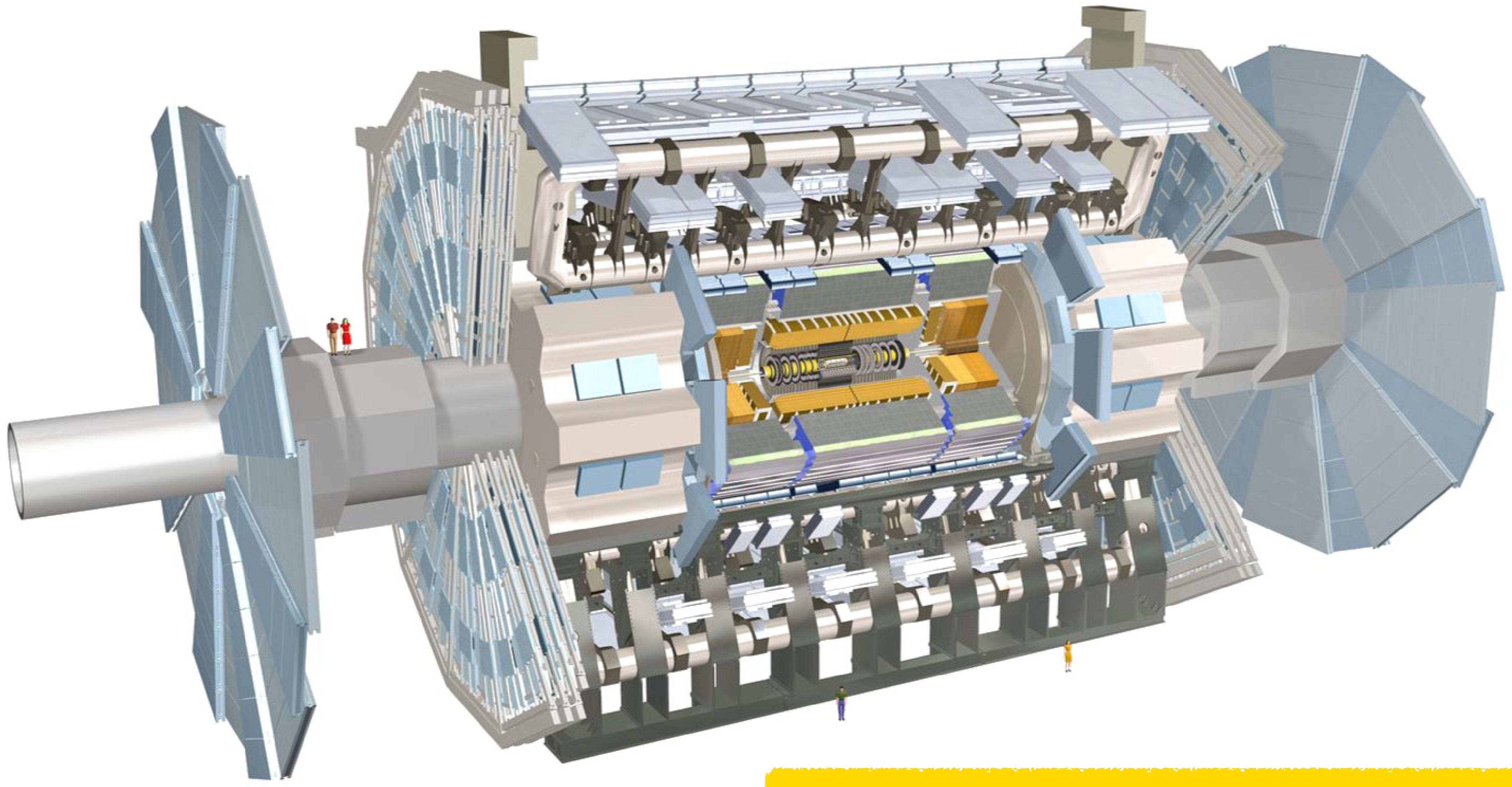
HL-ZDC

- JZCaP (jointly with CMS)
- adapt to new optics
- increase radiation hardness
- Reaction plane detector



High-granularity timing detector

- Based on LGADs
- PID with $\sigma_{TOF} \approx 35$ ps
- Baseline trigger for HI

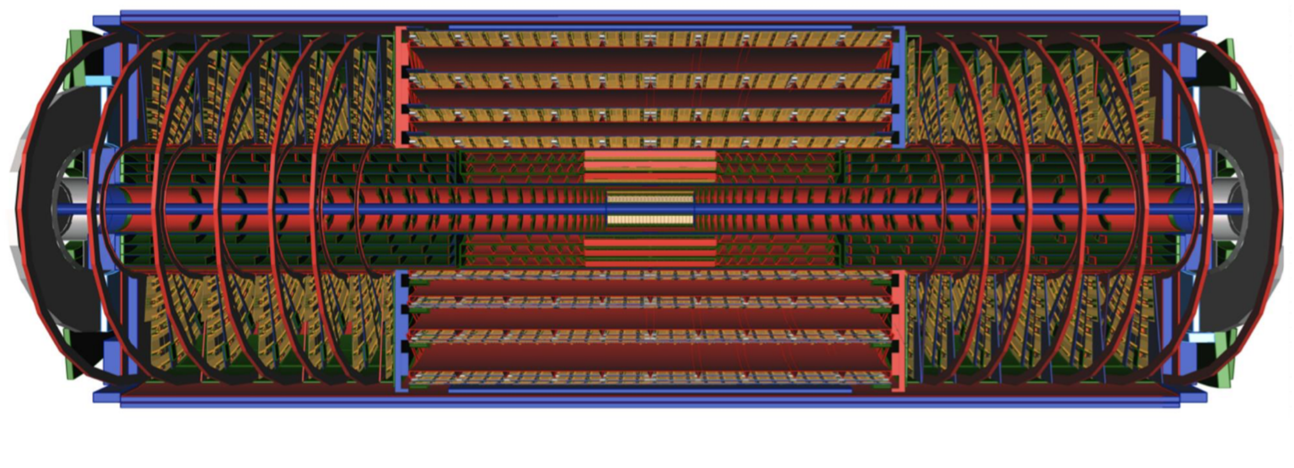


New Inner Tracker (ITk)

- hybrid silicon pixel and strip sensors
- coverage up to $|\eta| < 4$

Endcap calorimeters

- higher granularity



Muon system

- **New Small Wheels** installed → sTGC + MicroMegas
- **New muon chambers**

➟ **Extend tracker acceptance to $|\eta| < 4$**

➟ **Time-of-flight PID $2.5 < |\eta| < 4$**

➟ **Endcap calorimeters with higher granularity**

CMS phase I upgrades

Tracker

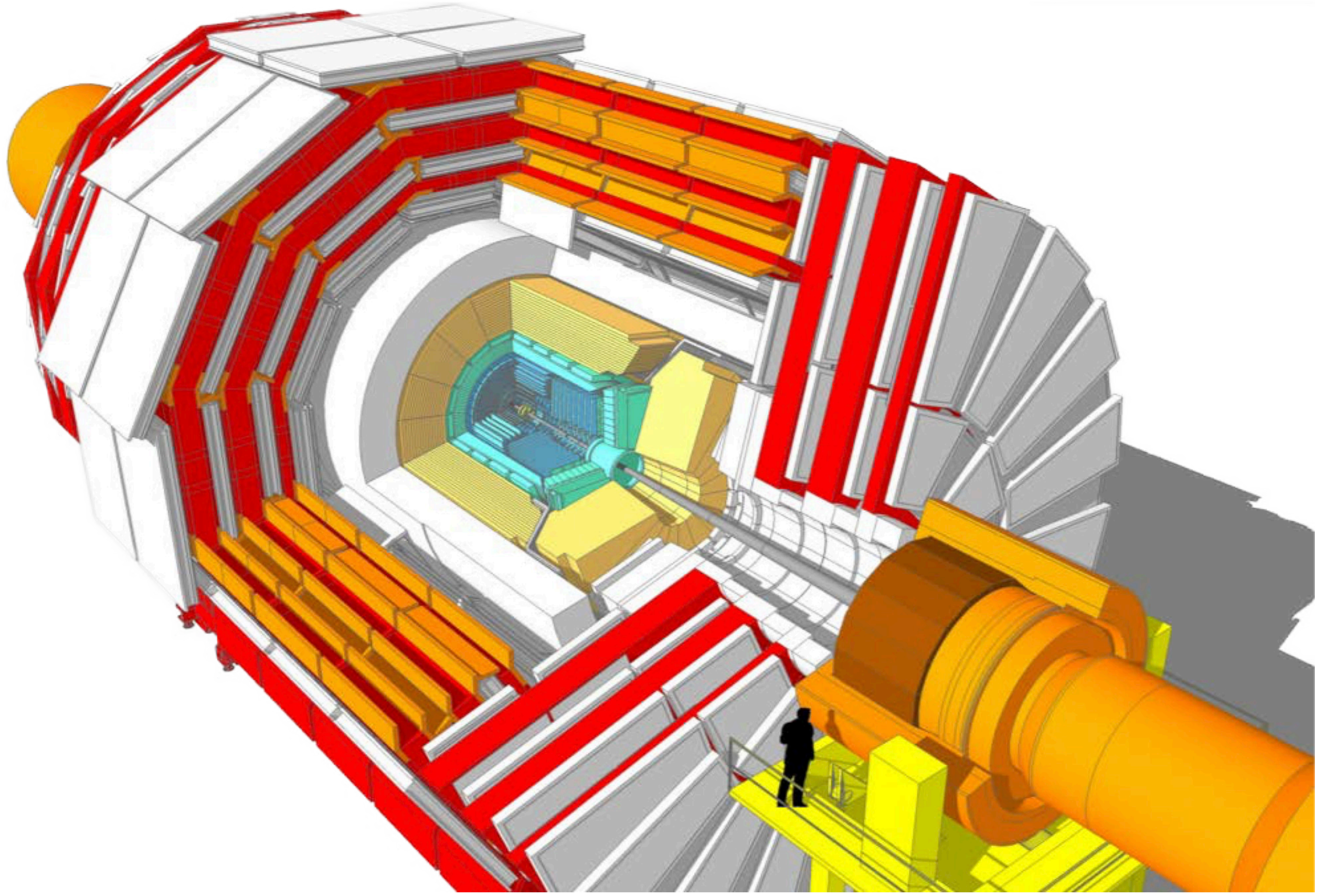
- Phase-I pixel detector:
  3 → 4 barrel layers
  2 → 3 forward disks
  30 → 22.5 mm beampipe

HCal

- HPD → SiPMs
- Upgraded readout

Trigger

- FPGAs for L1 trigger
- Inclusion of CSC and GEM for track algorithm for L1
- GPU modules for HLT



Forward muon system

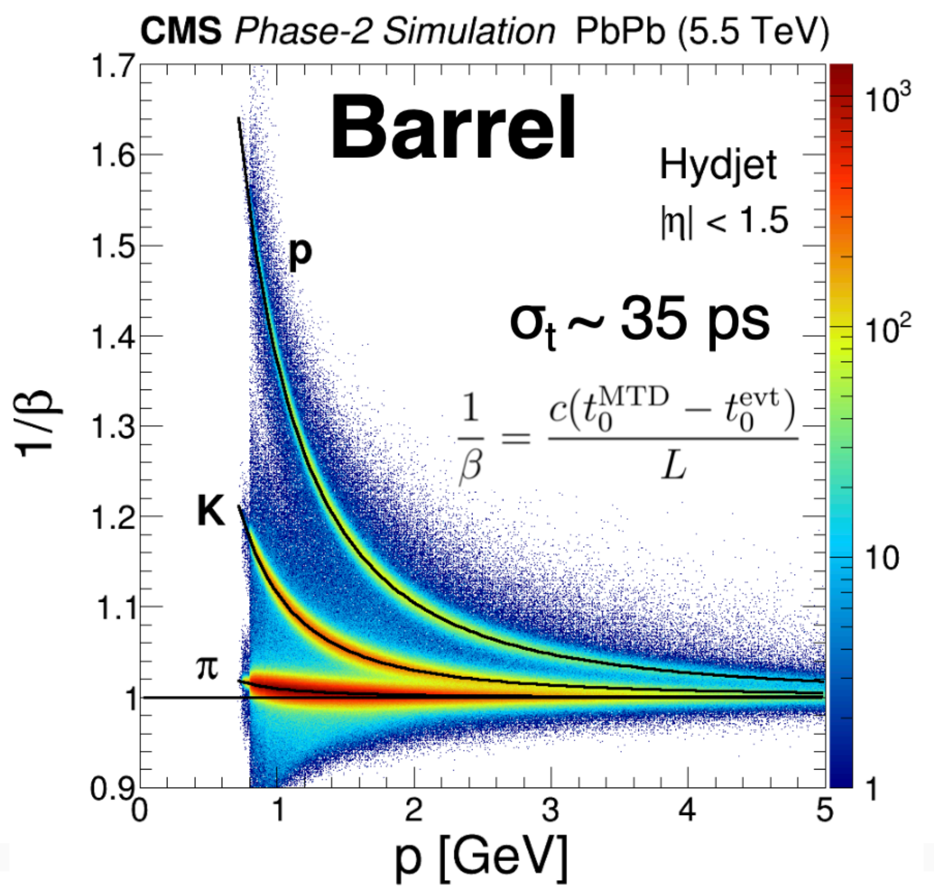
- 144 GEM chambers installed
- new frontend electronics for CSC endcaps

➟ **Increased bandwidth and larger MB statistics**

CMS phase II upgrades

MIP timing detector

- barrel: LYSO + SiPMs
- endcaps: LGADs
- $\sigma_{TOF} \approx 30$ ps



Tracker

- inner: hybrid silicon pixels
- outer: hybrid silicon pixels + strips

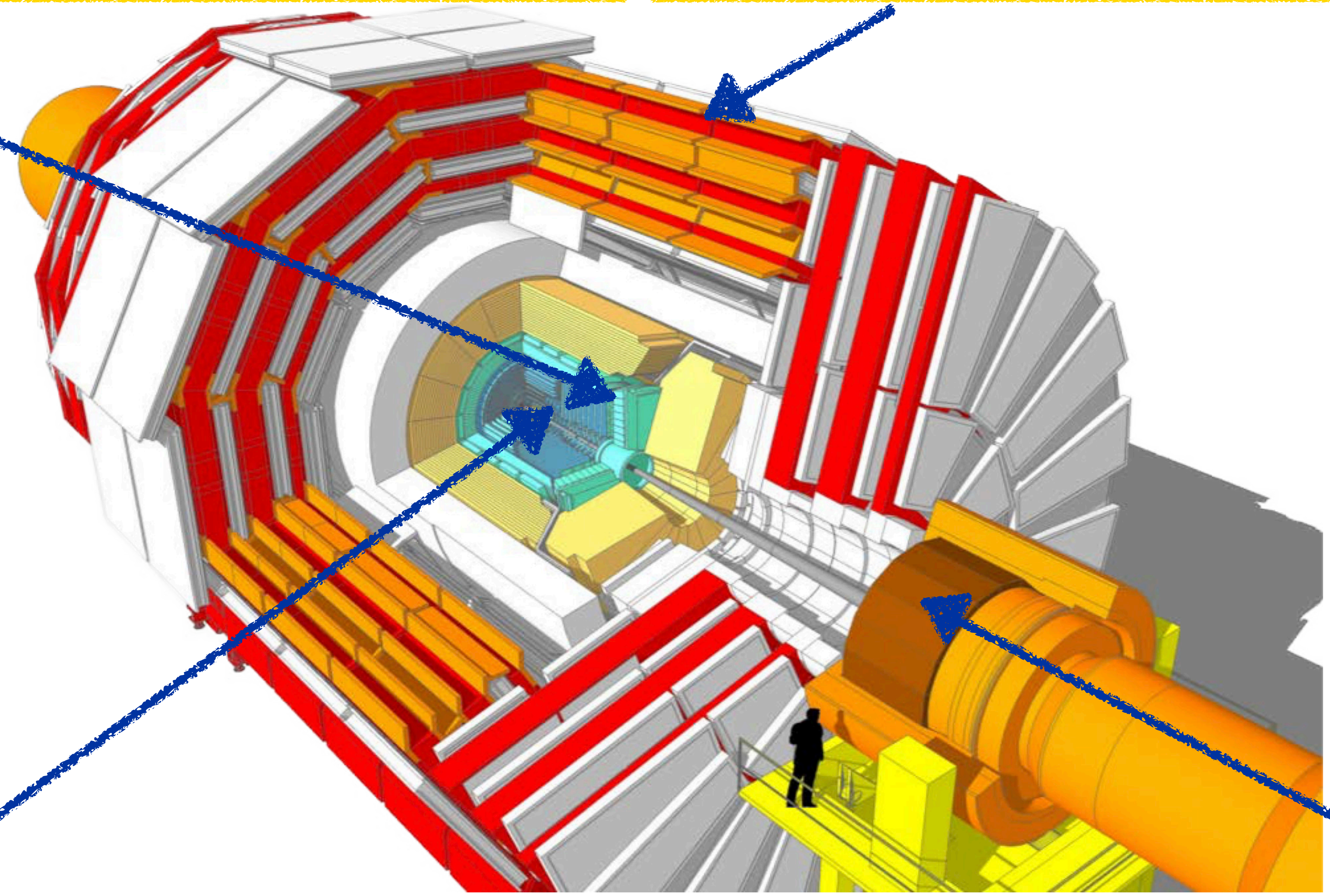
HCal

- HPD → SiPMs

L1 trigger, HLT, DAQ

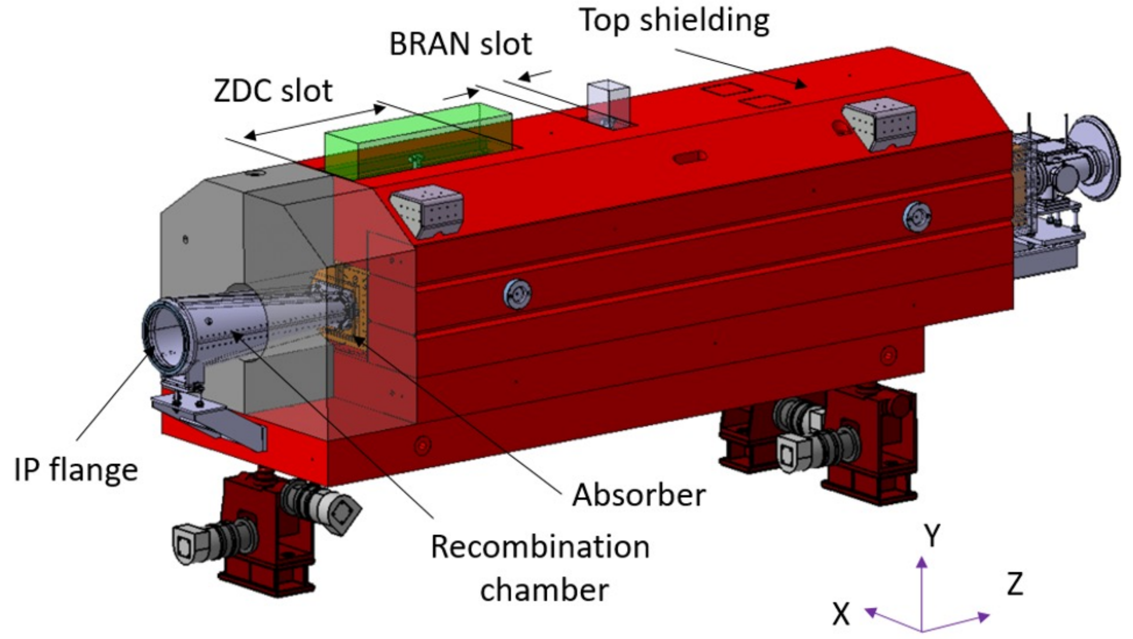
Luminosity detectors

New readout for muon system



HL-ZDC

- JZCaP (jointly with CMS)
- adapt to new optics
- increase radiation hardness
- Reaction plane detector



Endcap calorimeter

- **High-granular ECal + HCal → 4d showers ($\sigma_t \approx 20$ ps)**

➡ Charged particle tracking up to |η| < 4, muons up to |η| < 3
➡ Time-of-flight PID up to |η| < 3
➡ High-precision vertexing
➡ Wide coverage calorimetry

Forward muon system

- All GEM chambers
- new frontend electronics for CSC endcaps

Run 1 Run 2 Run 3 Run 4 Run 5 Run 6

LHCb upgrade Ib

RICH

- RICH1 (C_4F_{10}) renewed, RICH2 (CF_4) upgraded
- HPD → MaPMTs
- new readout ASIC (CLARO)
- timing

Readout and data processing

- sw trigger on GPUs → readout at 40 MHz

Infrastructure for Run 5 & 6

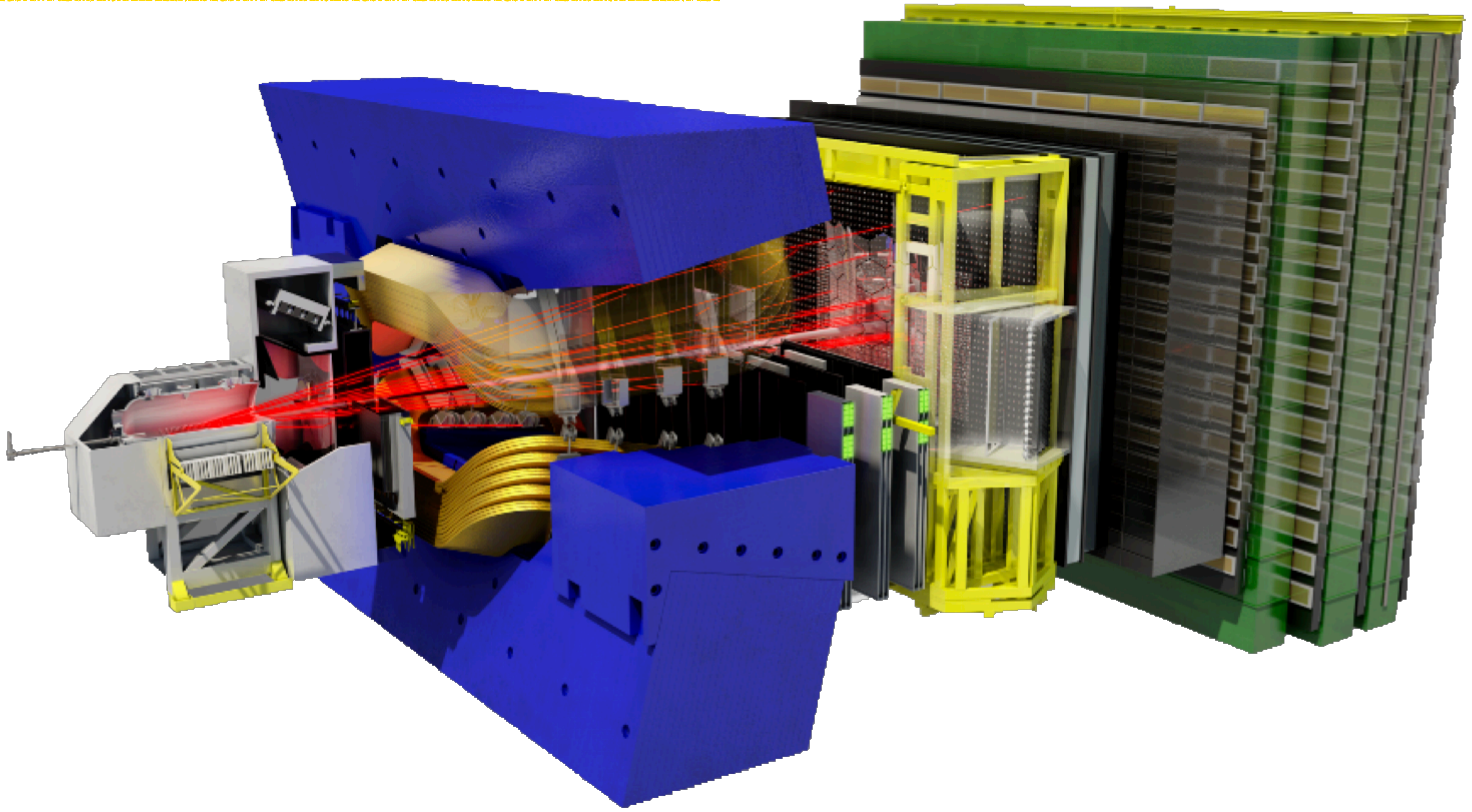
- engineering, mechanical support, shielding

Muon stations

- M1 (GEM) removed
- new electronics (triggerless)

Vertex Locator

- new VeloPix sensor
- closer to beam (8.1 mm → 5.1 mm)
- thin RF foil



Tracking

- Upstream tracker
- SciFi tracker → replace two inner modules (possibly with MAPS)
- Magnet stations (possibly) → p_T below 5 GeV/c

SMOG 2

- parallel operation with pp
- higher pressure
- also non-noble gases

Calorimeters

- new electronics (triggerless, non-zs data)
- reduced PMT gain

➡ **50 kHz Pb-Pb (> 30 % centrality)**

➡ **Improved vertexing**

➡ **Higher luminosities for fixed target**

[CERN-LHCC-2021-012]

LHCC review of Framework TDR completed in March 2022

LHCb Upgrade II

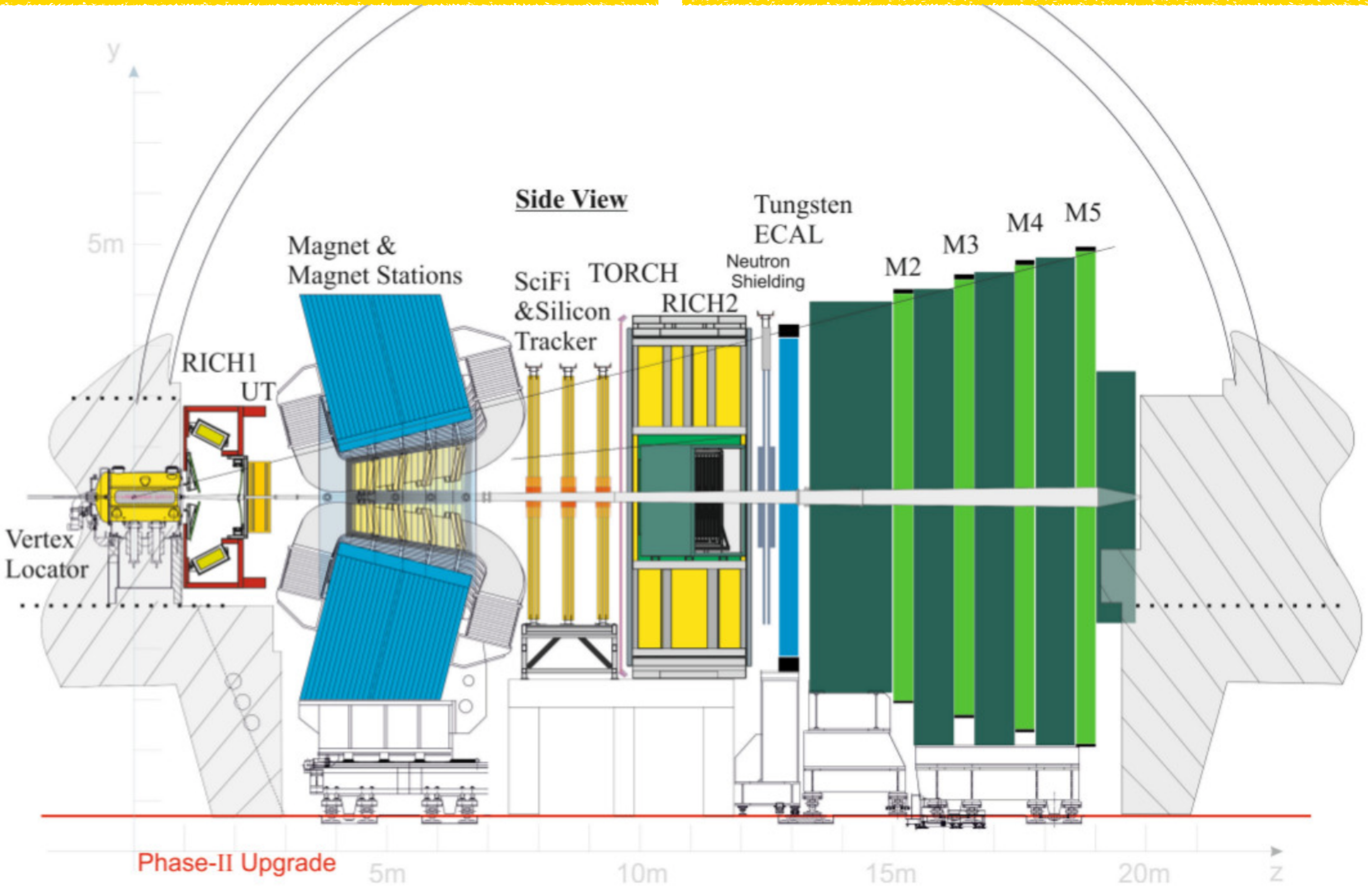
RICH
- RICH1 and RICH2
- precision timing

TORCH
- Time-of-flight wall
- precision timing

Run 5 infrastructure
- engineering, mechanical support, shielding

Muon stations
- M2 - M5
- additional shielding (instead of HCal)

Vertex Locator
- new VELO
- precision timing



Tracking
- new Upstream Tracker (timing)
- Mighty Tracker (SciFi + silicon)
- Magnet stations (possibly) → p_T below 5 GeV/c

Fixed target
- possible extension with polarised gas target, solid target

➡ **No centrality limitation for AA**

➡ **Excellent vertexing capabilities**

Calorimeters
- SPACAL or Shashlik
- precision timing

ALICE 2.1 upgrade

Time Projection Chamber

- new readout chambers: **MWPC → GEM**

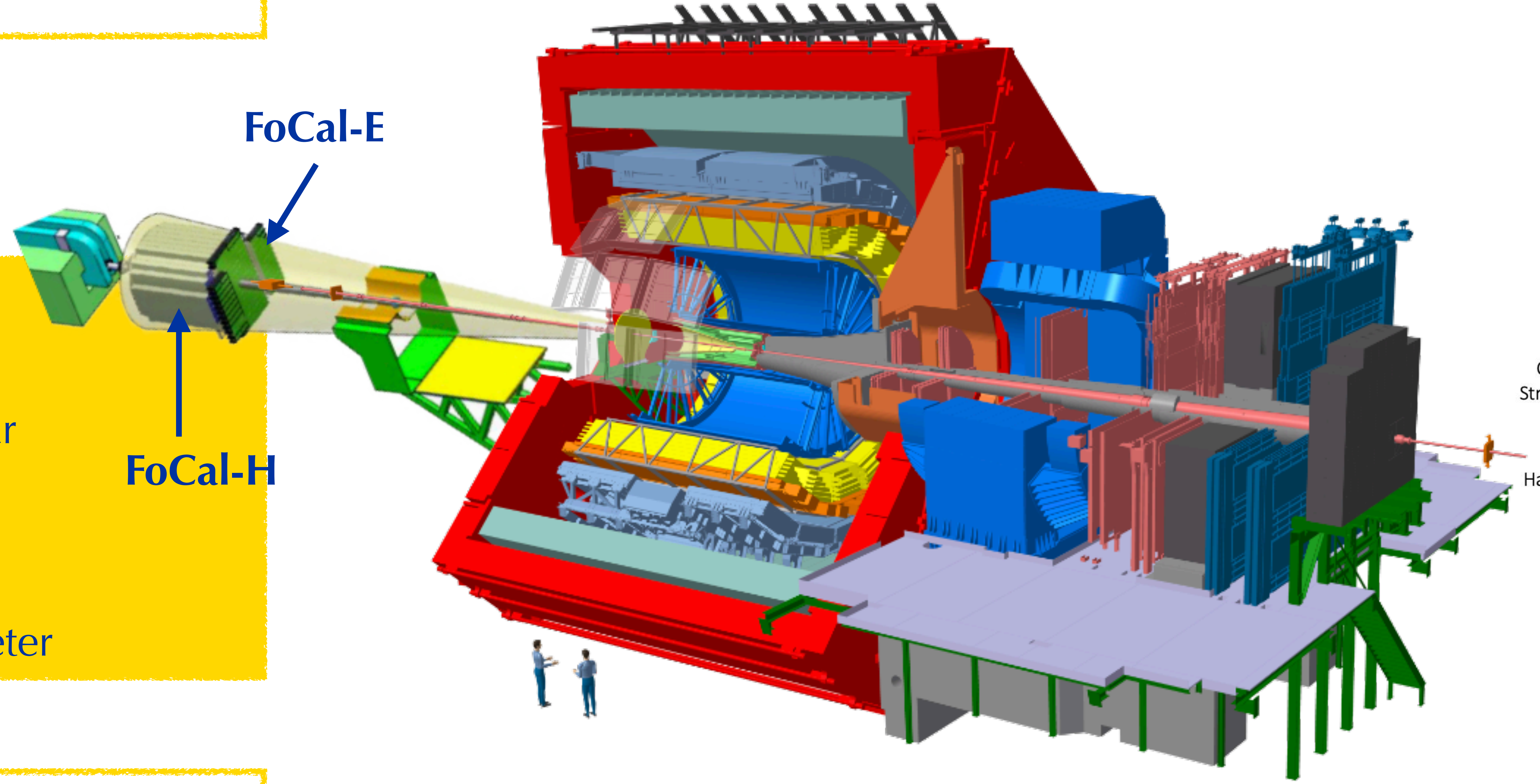
Consolidation and readout upgrade of all subsystems

Fast Interaction Trigger

- new detectors

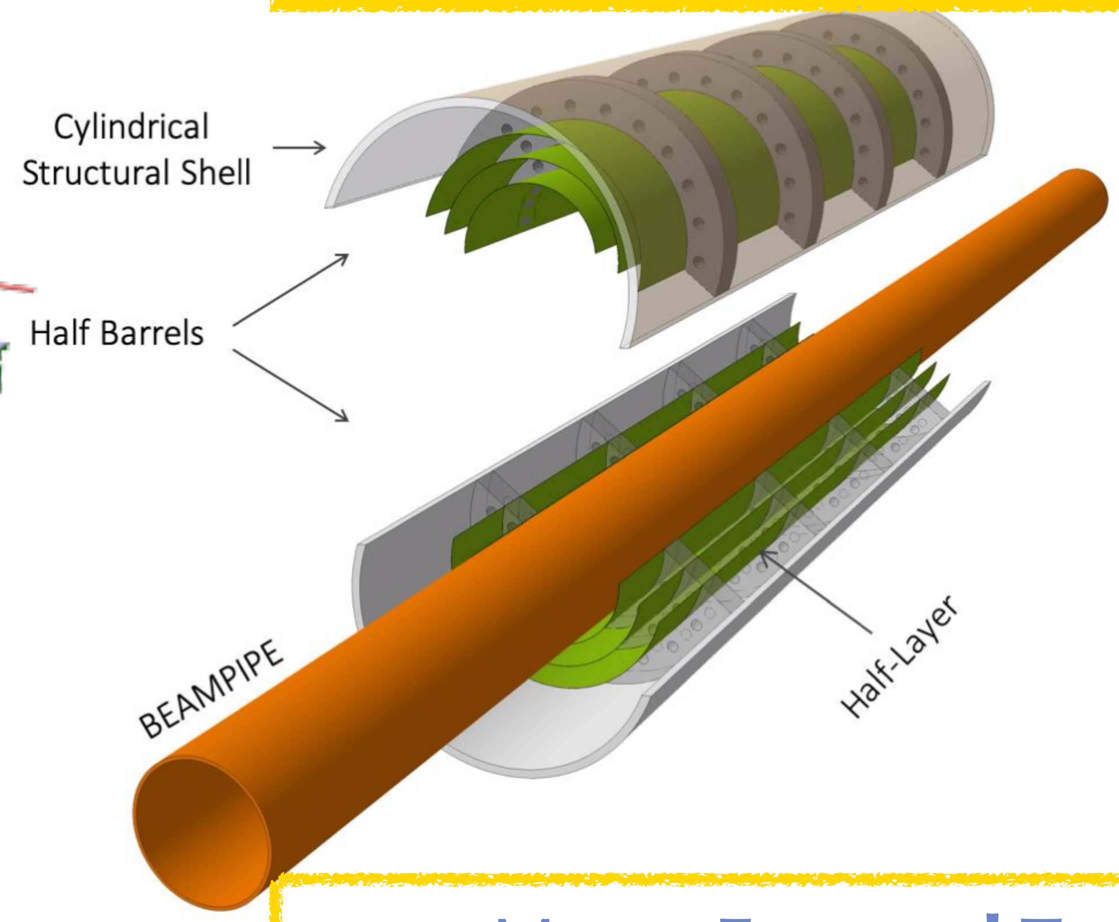
Inner Tracking System

- **3 + 2 + 2 layers of MAPS (~10 m²)**
- improved vertexing at higher rates
- **ITS3 → Bent, wafer-scale monolithic pixel sensors for 3 innermost layers**



FoCal

- **FoCal-E**: Si-W high-granular elm. calorimeter
- **FoCal-H**: Cu-fibre hadronic calorimeter



Integrated on-/off-line system

- **continuous readout**
- **GPU-based reconstruction** parallel with data taking
- online event selection

➡ **Continuous readout** with Pb-Pb @ 50 kHz
➡ **Better vertexing** (central and forward)

Muon Forward Tracker

- **MAPS-based tracker** installed
- vertexing in forward acceptance (muon arm)

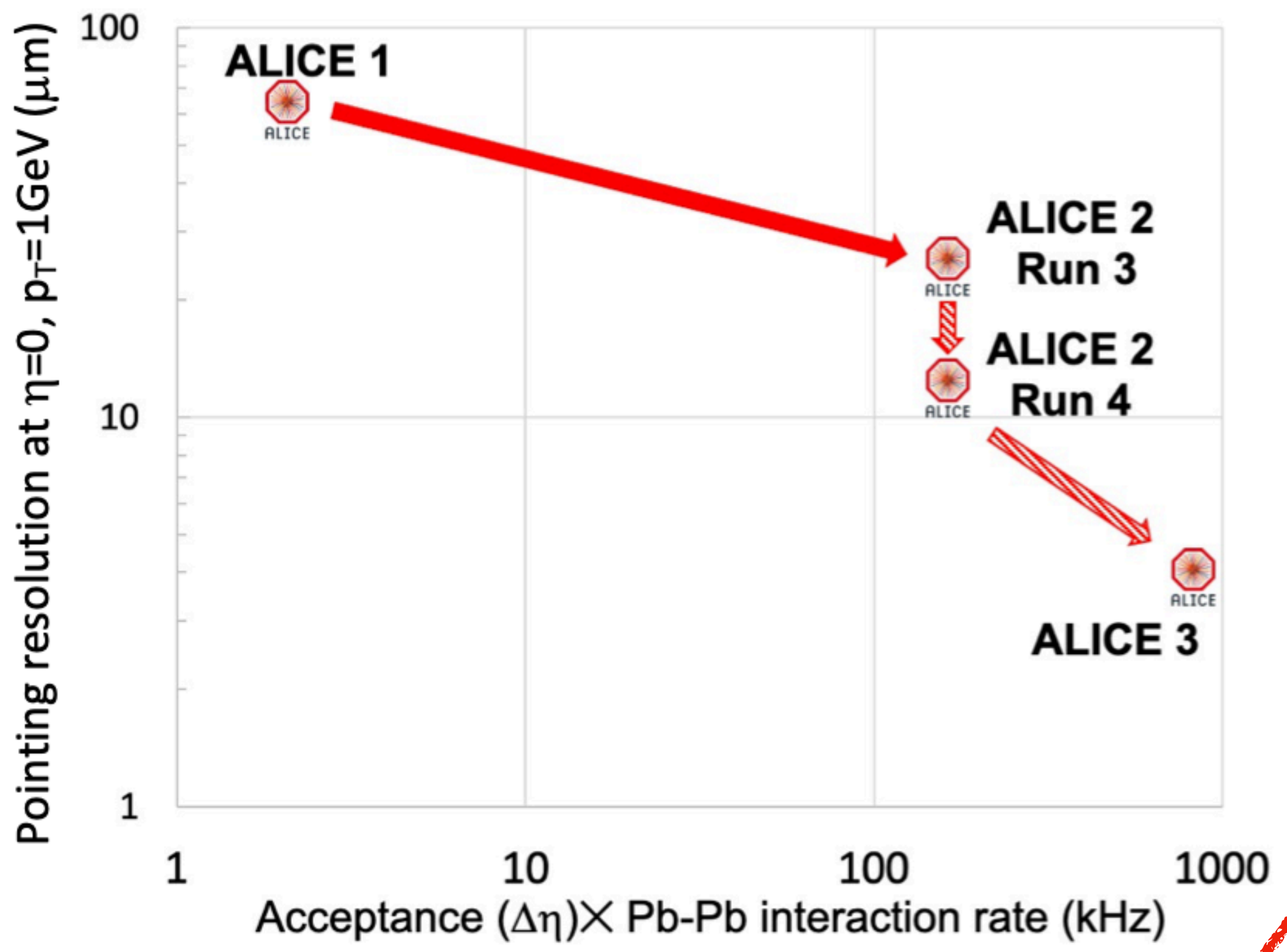
[CERN-LHCC-2022-009]

LHCC review of Letter of Intent completed March 2022

ALICE 3 upgrade

→ S. Scheid (Thu 16:00)

Vertex detector
- Retractable detector $R_{in} \approx 5$ mm
- Wafer-scale monolithic CMOS sensors

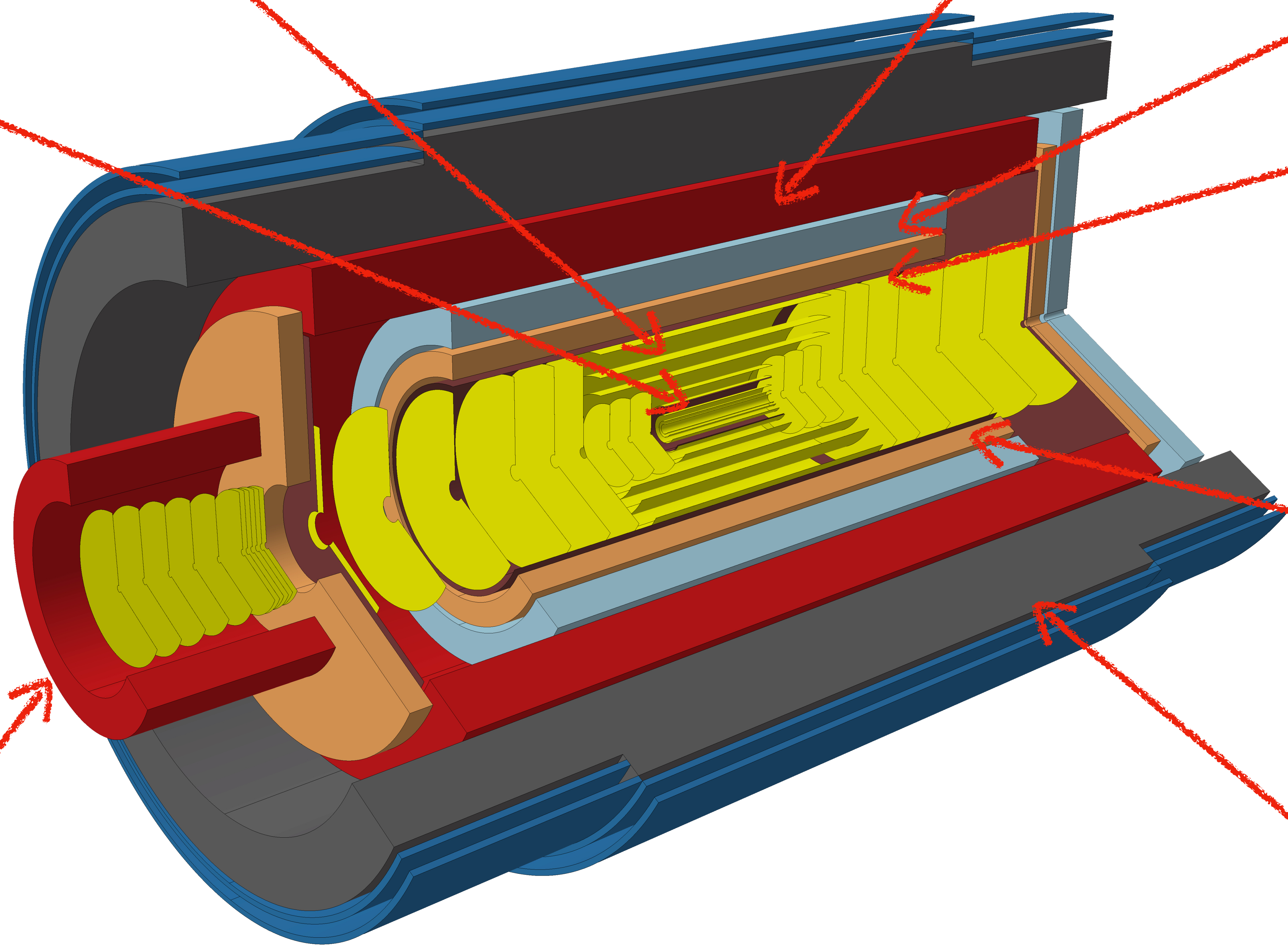


Tracker
- Monolithic CMOS sensors

Superconducting magnet system

Elm. calorimeter
- $PbWO_4$ in central region
- Pb/Sci for large acceptance

Time-of-flight detector
- monolithic CMOS sensors with gain layer



Ring-imaging Cherenkov detector
- Aerogel radiator
- SiPM read-out

Muon ID
- Iron absorber
- Scintillating bars, WLS, SiPM

Forward Conversion Tracker
- Tracking disks (MAPS)

➡ **Tracking and PID over large acceptance**
➡ **Excellent vertexing**
➡ **Continuous readout**