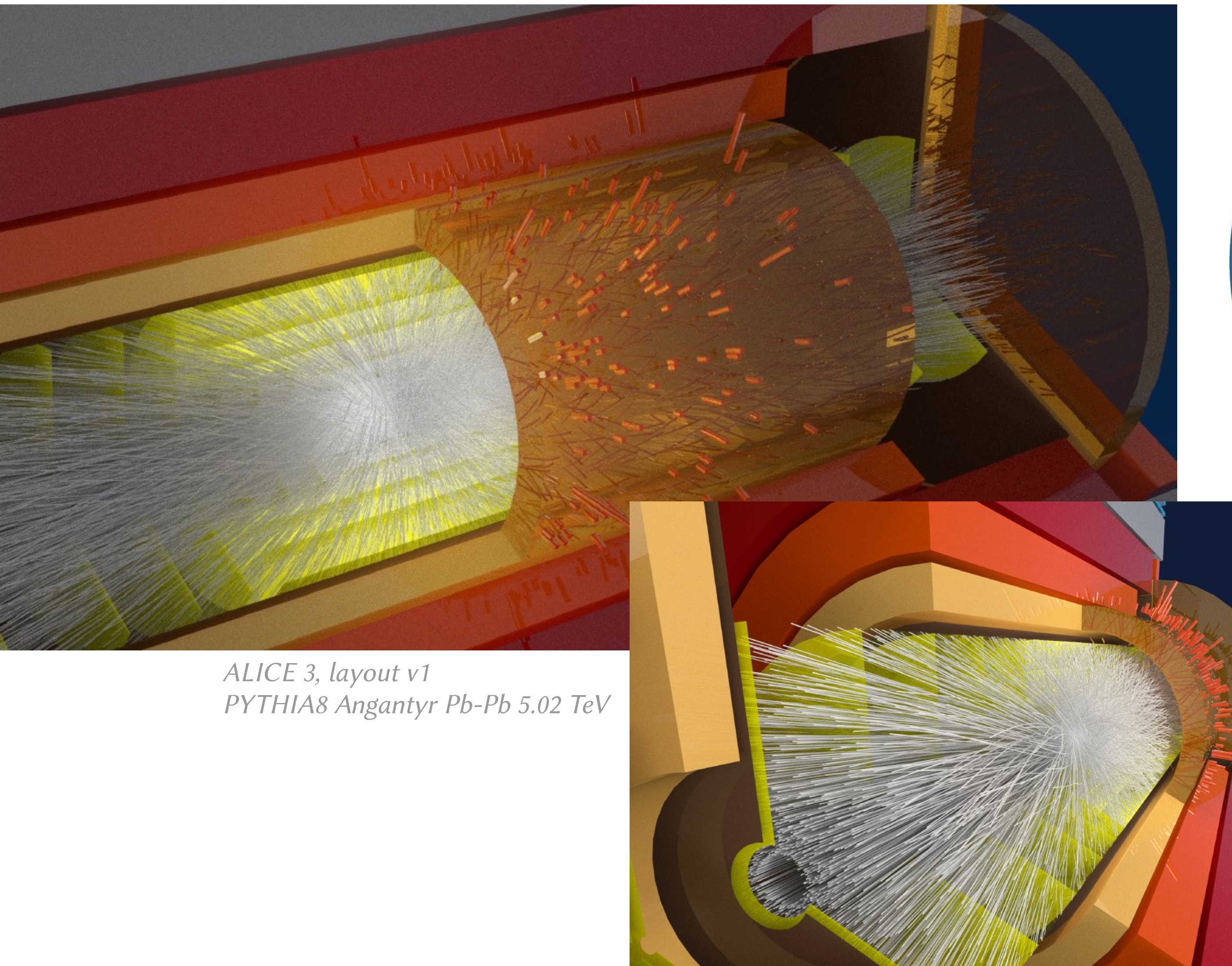
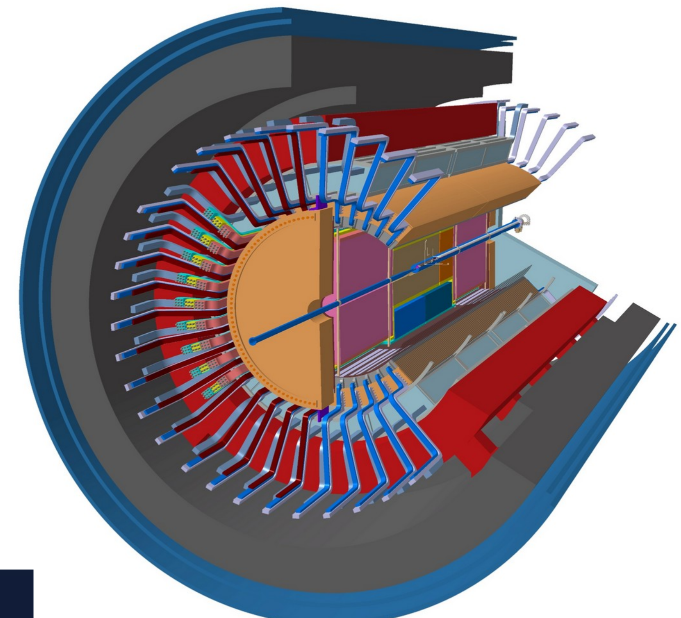
Antonin MAIRE (CNRS/IN2P3Strasbourg), for the ALICE Collaboration
Monday, 07 July 2025 – **EPS-HEP / T11 Detectors**

https://indico.in2p3.fr/event/33627

ALICE 3 : a next generation heavy-ion detector for LHC run 5



ALICE 3, layout v1
PYTHIA8 Angantyr Pb-Pb 5.02 TeV

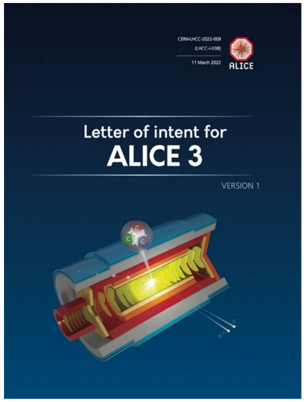


IPHC Institut Pluridisciplinaire Hubert CURIEN STRASBOURG

Some references

Milestone documents :

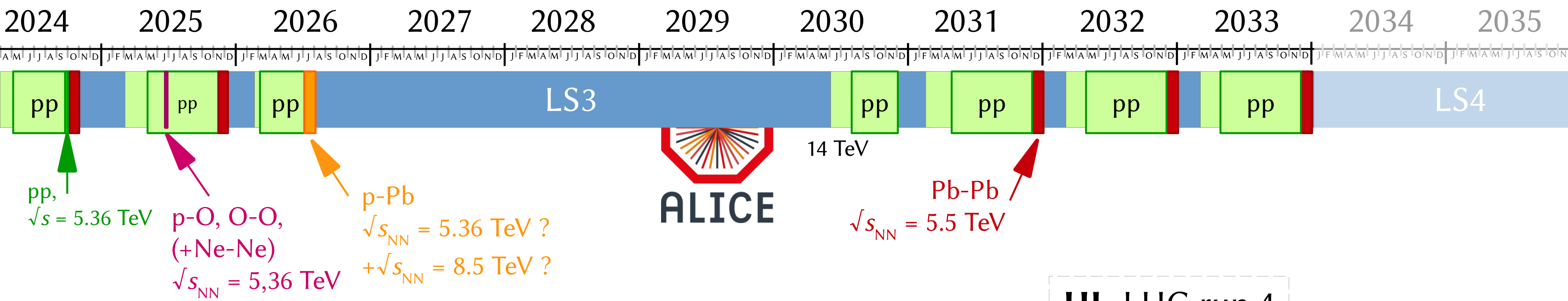
- *ALICE3* ***Letter of Intent****, arXiv:2211.02491*
  - *⟶ LHCC minutes report LHCC-149, 2022-03*
- *ALICE3* ***Scoping Document*** *CERN-LHCC-2025-002*
  - *⟶ LHCC minutes report LHCC-161, 2025-03*



≈ Summary documents :

- ***Frontier sensor R&D*** *for ALICE 3,*
  ESPPU contribution (14 pages, 2025-03)
  = *ALICE-PUBLIC-2025-006*
- ***Input from ALICE collaboration*** (physics with ITS3, FoCal, ALICE 3)
  ESPPU contribution (13 pages, 2025-03)
  = *ALICE-PUBLIC-2025-005*

I.1 – ALICE in HL-LHC : projected timeline and calendar



LHC run 3

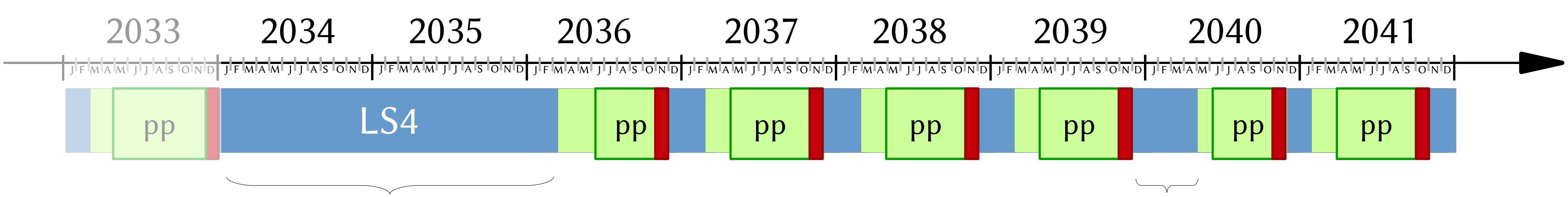
ALICE 2.0

(ITS2, MFT, GEM-TPC, ...)

HL-LHC run 4

ALICE 2.1

- ITS2+3 ⟶ EPS-HEP talk (Jory Sonneveld)
- FoCal ⟶ EPS-HEP talk (Shihai Jia)



HL-LHC runs 5+6

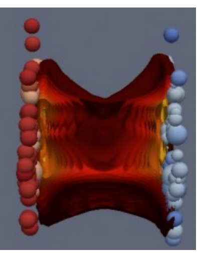
ALICE 3

- no Long Shutdown 5, just Yearly Tech. Stops (notably 2039-40)
- 4+2 years of HL-LHC running
- both pp & heavy-ion HL-LHC data taking, confirmed

II.1 – Motivations : partonic response as *f*(quark flavour, mass)

Quark-Gluon Plasma
or *collective partonic medium*

$g + u,d,s,c,b\ (t)$ <=>



Madai

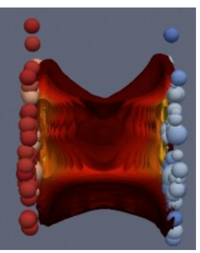
Why mass is relevant ?
e.g. 1. hydrodynamic push by QGP = $f(m_q)$
2. deadcone effect in jet = $f(m_q)$
...

⟶ Explore the scope to its individual extent:
g,u,d ... + s ... + c ... + b ...

II.1 – Physics motivations : response as *f*(quark flavour, mass)

Quark-Gluon Plasma
or *collective partonic medium*

$g + u,d,s,c,b\ (t)$ <=>



Final states

u,d,s

- $\pi^\pm\ \pi^0\ K^\pm\ K^0_S$ … $p\ \Lambda\ \Sigma^\pm(uus)\ \Xi^\mp(dss)\ \Omega^\mp(sss)$ …

  $\eta(547)\ \omega(782)$ … $K^0(892)\ \phi(1020)\ \Sigma^\pm(1385)\ \Lambda(1520)\ \Xi^0(1530)$

  + $d\ t\ {}^3He^{2+}\ {}^4He^{2+}$ …
  + ${}^3_\Lambda H,\ {}^4_\Lambda\overline{He}^{2+} \rightarrow {}^3He^{2+}\ p\ \pi^-$

c

- $D^0\ D^+\ D^{*+}\ D_S^+$ … $\eta_c\ J/\psi\ \chi_{Ci}\ \psi(2S)$ …

  $\Lambda_C^+(udc) \rightarrow pK^-\pi^+$ or pK^0s ($c\tau \approx 60\ \mu m$)

  $\Xi_C^+(usc) \rightarrow pK^-\pi^+$ or $\Xi^-2\pi^+$ ($c\tau \approx 136\ \mu m$)

  $\Xi_C^0(dsc) \rightarrow \Xi^-\pi^+$ ($c\tau \approx 45\ \mu m$)

  $\Omega_C^0(ssc) \rightarrow \Omega^-\pi^+$ ($c\tau \approx 80\ \mu m$)

  $\Xi_{CC}^{2+}(ucc)$ … $\Omega_{CCC}^{2+}(ccc)$

  + *c*-deuteron $(\Lambda_c n)^+ \rightarrow dK^-\pi^+$? *c*-triton $(n\Lambda_c n)^+$?

  tetraquark [$X(3872) \rightarrow J/\psi\ \pi^+\ \pi^-$] T_{CC}^+

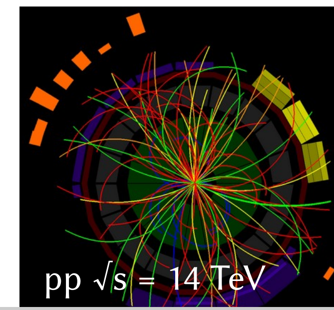
- heavy-flavour $(\mu^\pm, e^\pm)$

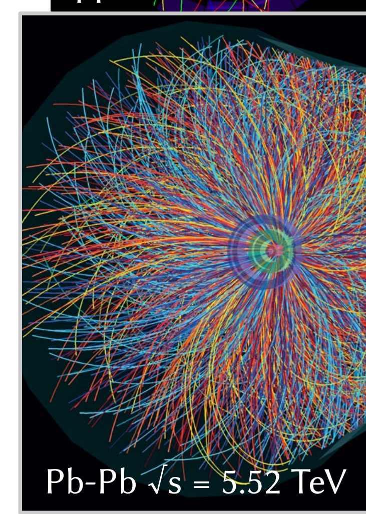
b

- $B^0\ B^\pm\ B^0_S$ … $Y(1S,2S,3S)$…

  $\Lambda_b^0(udb) \rightarrow \Lambda_C^+\pi^-$ … $\Xi_B^-(dsb)\ \Omega_B^-(ssb)$

(• $e^\pm\ \mu^\pm\ \gamma$)
(• $W^\pm\ \gamma/Z^\circ$)

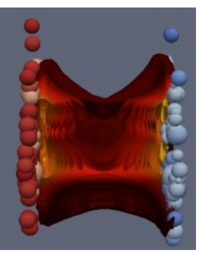




II.1 – Physics motivations : response as f(quark flavour, mass)

Quark-Gluon Plasma
or *collective partonic medium*

$g + u,d,s,c,b\ (t)$ <=>



Madai

u,d,s

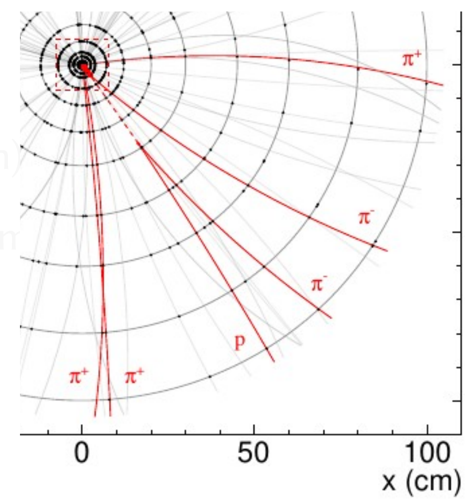
c

b

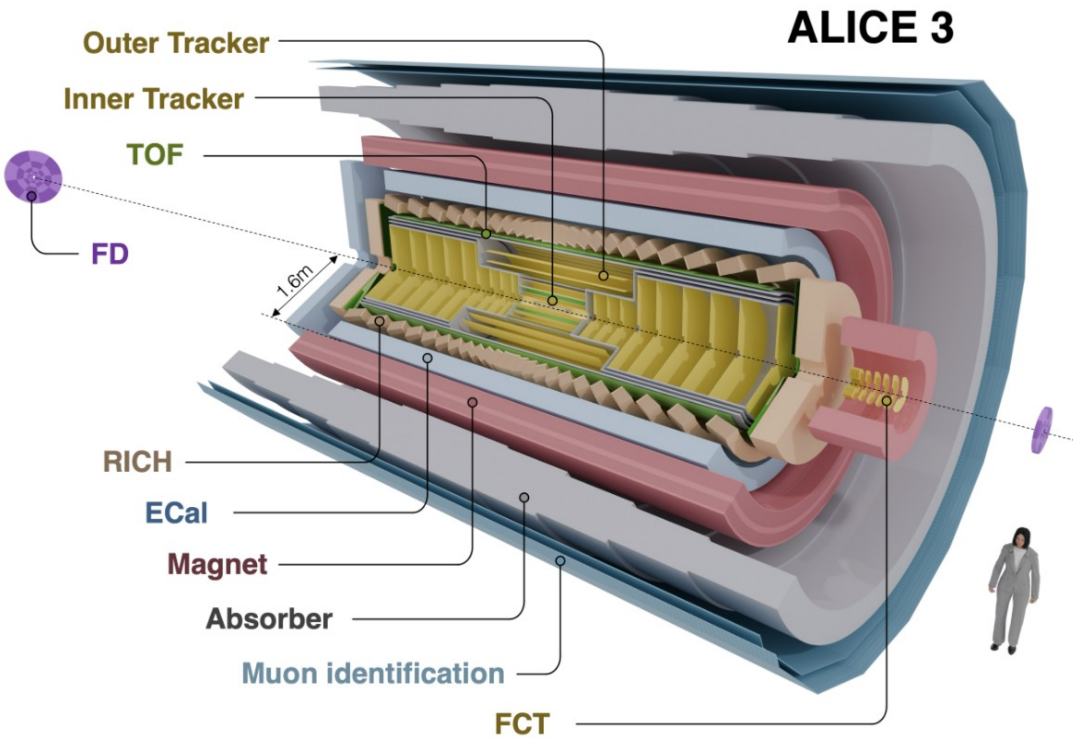
Final states

- **Identified** physics, at particle level
  → PID & tracking
- 1- to **6-final-state** particles
  → acceptance and efficiency
- **Topological** reconstruction, with invariant mass
  → pointing resolution
- Correlation to **bulk** production
  → access to low p_T
- Abundant to scarce probes : "**Zero-Bias**" data collection with high **luminosity**
  → continuous readout

e.g $\Xi_{CC}^{2+}(ucc)$
→ 6 ch. part.



II.2 – ALICE 3 layout : key features in 1 slide



Layout (2024-10)
10.5281/zenodo.13894032

1. $B_{solenoid}$ = **2.0 T**

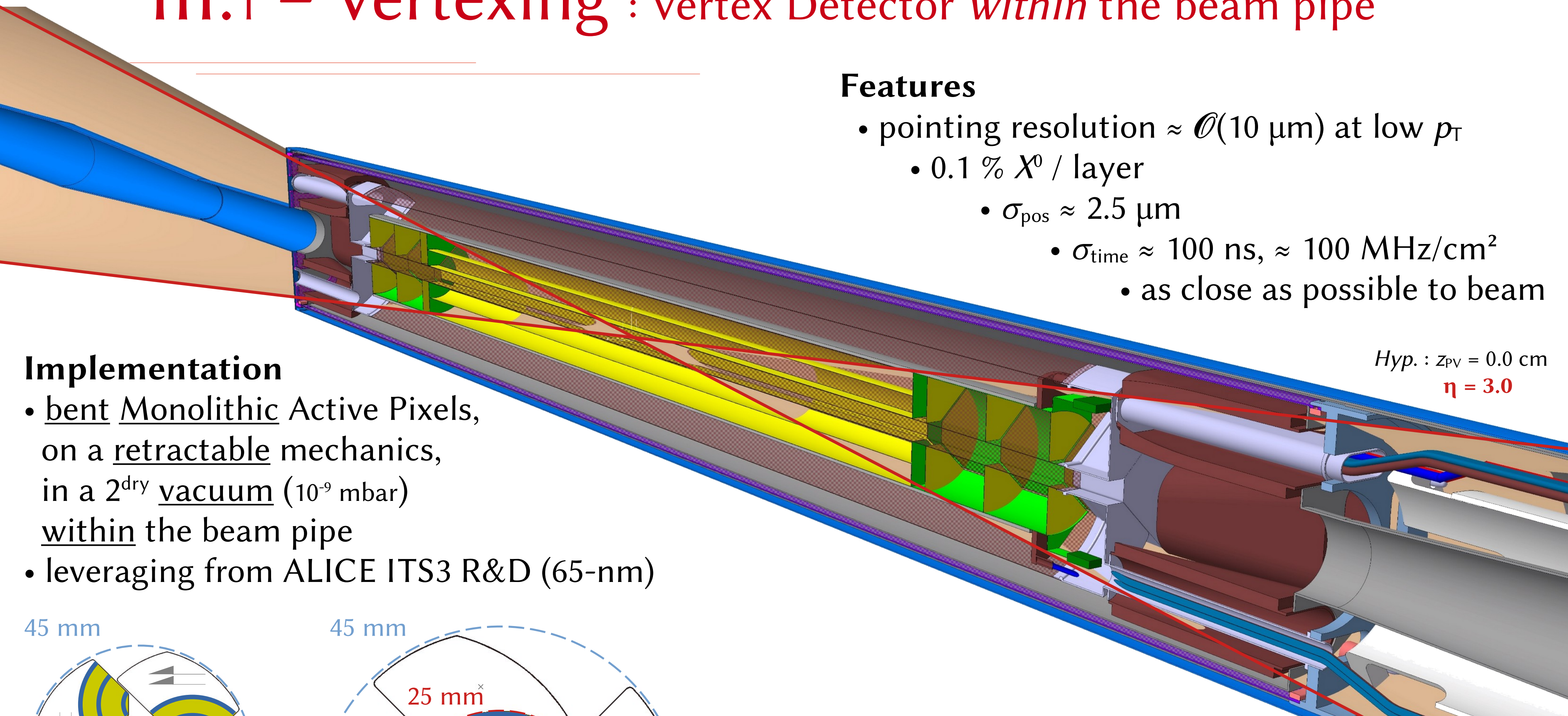
2. **Vertexer+Tracker**,
compact ($R_{outer\ TOF}$ ≈ 85 cm)
ultra-light (layer 0 ~ 0.1 % x/X_0)
Silicon MAPS-based (≈ 60 m²)
with high-performance tracking
(Axε, granularity, ...)

3. with **PID** capabilities
(iTOF, oTOF, fTOF, bRICH, fRICH
ECal, μID)
over an **acceptance** as wide as possible :
- $|\eta| < 4$ (*x5-9 acceptance of ALICE 2 barrel*)
- $p_T \in$ [**0.05** ; (>10)] GeV/c

4. to collect integrated **MB luminosities** :
- recorded readout
  ≈ 24 MHz (pp) (*x25-50 ALICE 2 run 3*)
  100 kHz (Pb-Pb projection by LHC, *x2 /Run 3*)
- $\mathcal{O}$(0.5 fb^{-1}) / month pp
- $\mathcal{O}$(5.6 nb^{-1}) / month Pb-Pb

ALICE3 Scoping Document *CERN-LHCC-2025-002*

III.1 – Vertexing : Vertex Detector *within* the beam pipe



Features

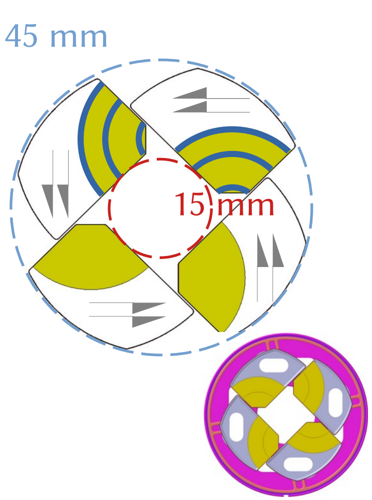
- pointing resolution ≈ $\mathcal{O}$(10 μm) at low p_T
- 0.1 % X^0 / layer
- σ_{pos} ≈ 2.5 μm
- σ_{time} ≈ 100 ns, ≈ 100 MHz/cm²
- as close as possible to beam

Implementation

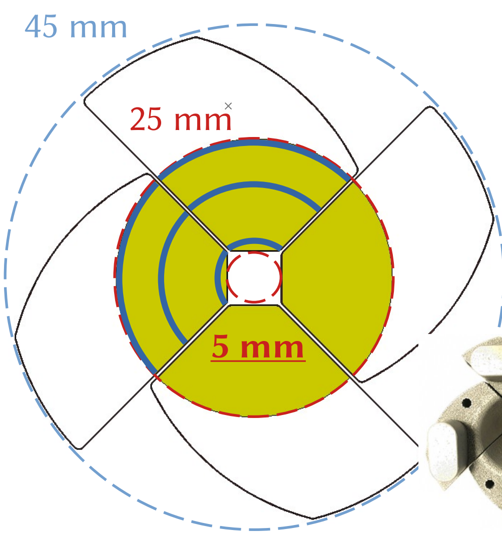
- bent Monolithic Active Pixels, on a retractable mechanics, in a 2^{dry} vacuum (10^{-9} mbar) within the beam pipe
- leveraging from ALICE ITS3 R&D (65-nm)

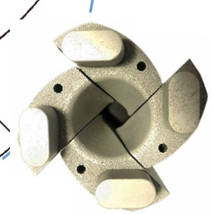
Challenges

- small pitch 10 μm
- radiation tolerance (e.g. 10^{16} 1-MeV n_{eq}/cm²)
- vacuum mechanics, with active cooling
- optimisation of VD impedance to beam



Open IRIS (injection)





Closed IRIS (stable beams)

III.2 – Vertexing : strangeness tracking, example in ALICE 3

V. Greco, EPJC arXiv:2305.03687

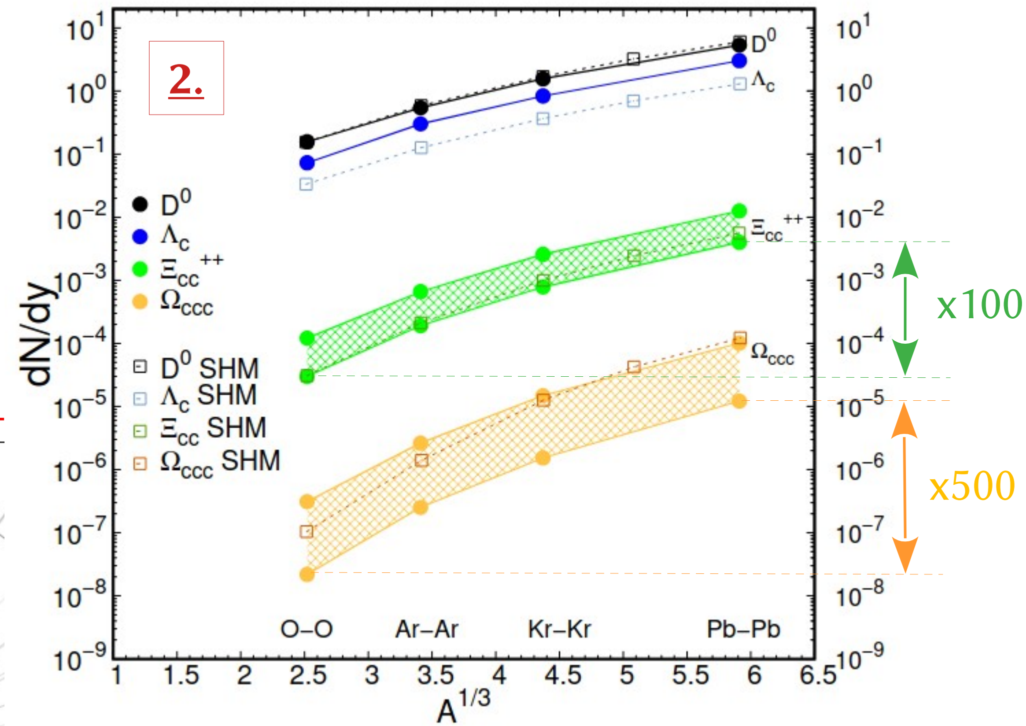
…

1.

- $\Xi_{CC}^{2+}(ucc) \longrightarrow \Xi_{C}^{+}(usc)\,\pi^{+} \longrightarrow [\Xi^{-}(\boldsymbol{dss})\;2\pi^{+}]\;\pi^{+}$
- $\Omega_{CC}^{+}(scc)$ …
- $\Omega_{CCC}^{2+}(ccc) \longrightarrow \Omega_{CC}^{+}(scc)\,\pi^{+} \longrightarrow [\Omega_{C}^{0}(ssc)\,\pi^{+}]\,\pi^{+}$ …
- $\Xi_{B}^{-}(dsb) \longrightarrow \Xi_{C}^{0}(dsc)\,\pi^{-} \longrightarrow [\Xi^{-}(dss)\,\pi^{+}]\,\pi^{-}$ …
- $\Omega_{B}^{-}(ssb) \longrightarrow \Omega_{C}^{0}(ssc)\,\pi^{-} \longrightarrow [\Omega^{-}(dss)\,\pi^{+}]\,\pi^{-}$ …

…

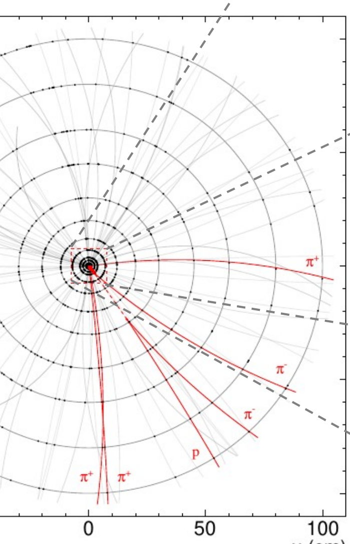
2.

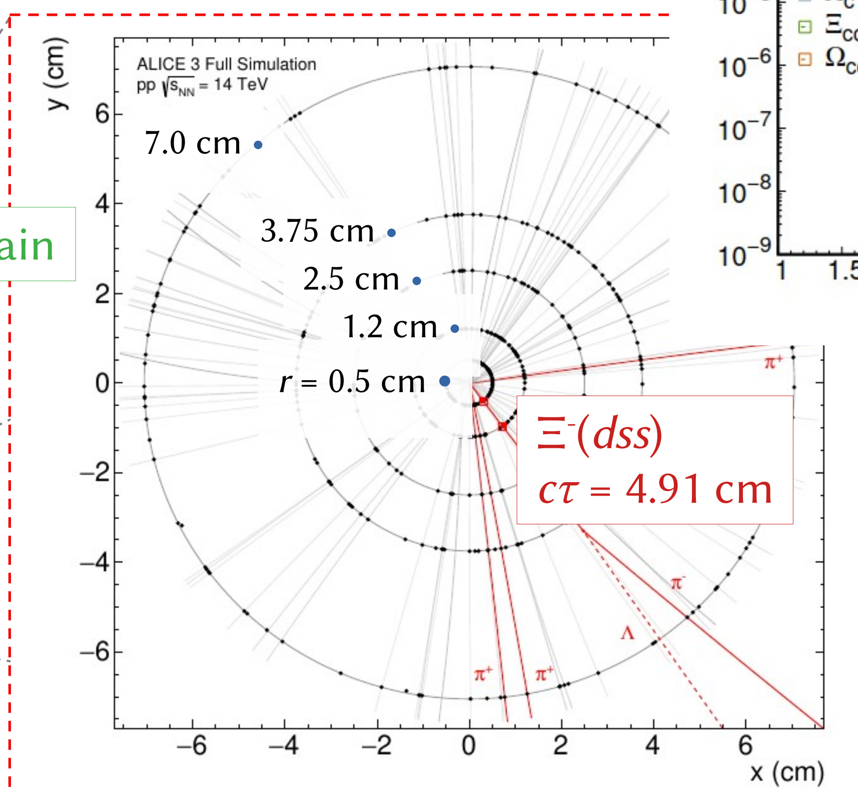


Prediction by Stat.-Hadronisation Model
or Coalescence model

3.

$\Xi_{CC}^{2+}(ucc)$ decay chain





ALICE 3 LoI, CERN-LHCC-2022-009

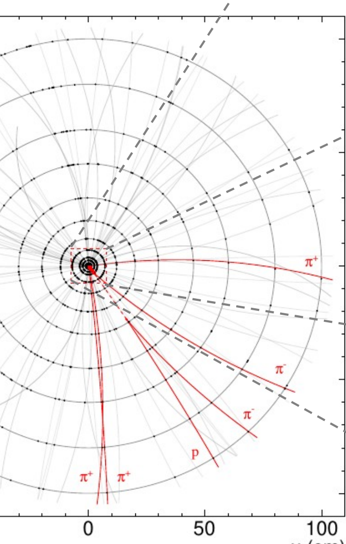
III.2 – Vertexing : strangeness tracking, example in ALICE 3

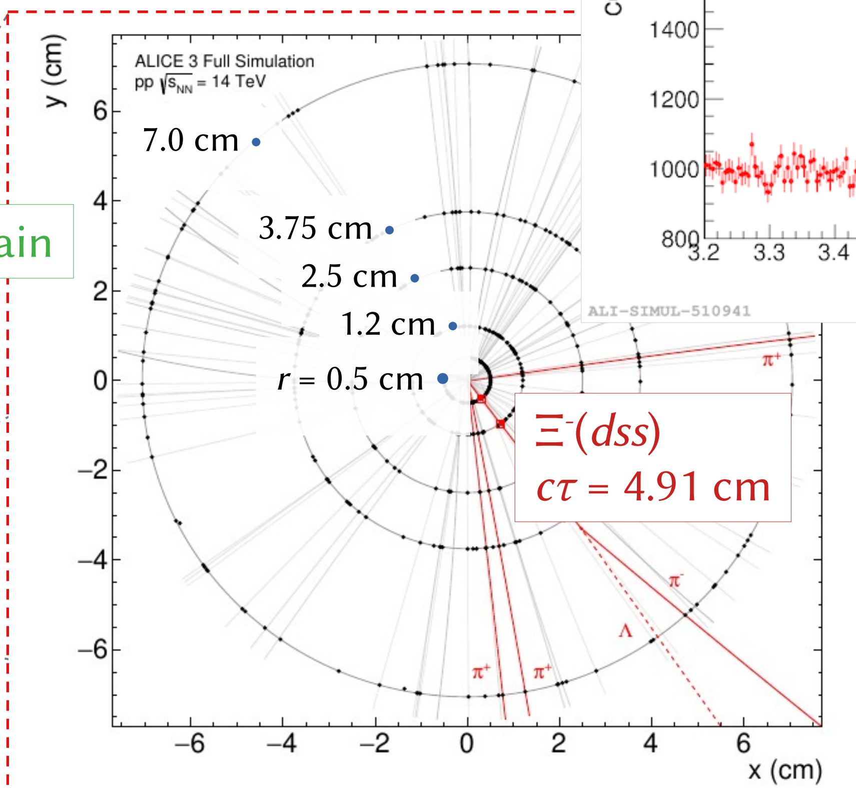
…

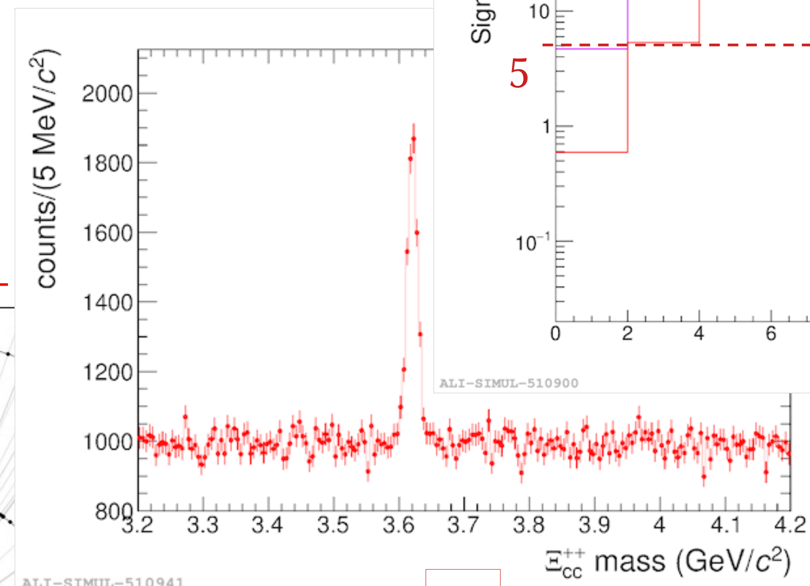
- $\Xi_{CC}^{2+}(ucc) \longrightarrow \Xi_C^{+}(usc)\,\pi^+ \longrightarrow [\Xi^-(\boldsymbol{dss})\ 2\pi^+]\ \pi^+$
- $\Omega_{CC}^{+}(scc)$ …
- $\Omega_{CCC}^{2+}(ccc) \longrightarrow \Omega_{CC}^{+}(scc)\,\pi^+ \longrightarrow [\Omega_C^{0}(ssc)\,\pi^+]\,\pi^+$ …
- $\Xi_B^{-}(dsb) \longrightarrow \Xi_C^{0}(dsc)\,\pi^- \longrightarrow [\Xi^-(dss)\,\pi^+]\,\pi^-$ …
- $\Omega_B^{-}(ssb) \longrightarrow \Omega_C^{0}(ssc)\,\pi^- \longrightarrow [\Omega^-(dss)\,\pi^+]\,\pi^-$ …

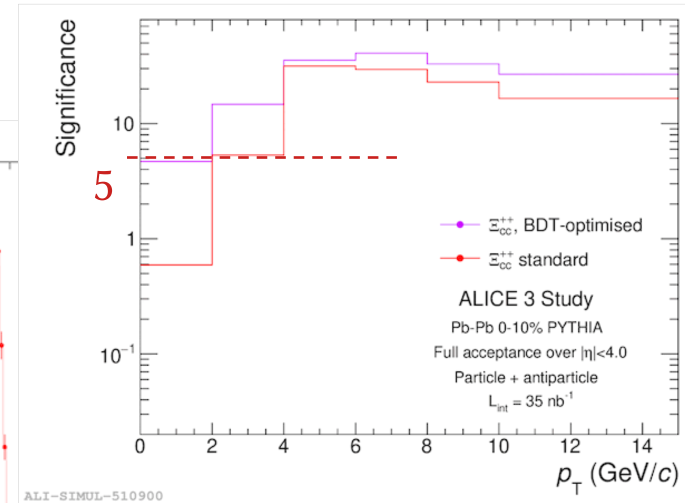
…

$\Xi_{CC}^{2+}(ucc)$ decay chain









4.

ALICE 3 significance for Ξ_{CC}^{2+} in Pb-Pb (for 35 nb^{-1}) :

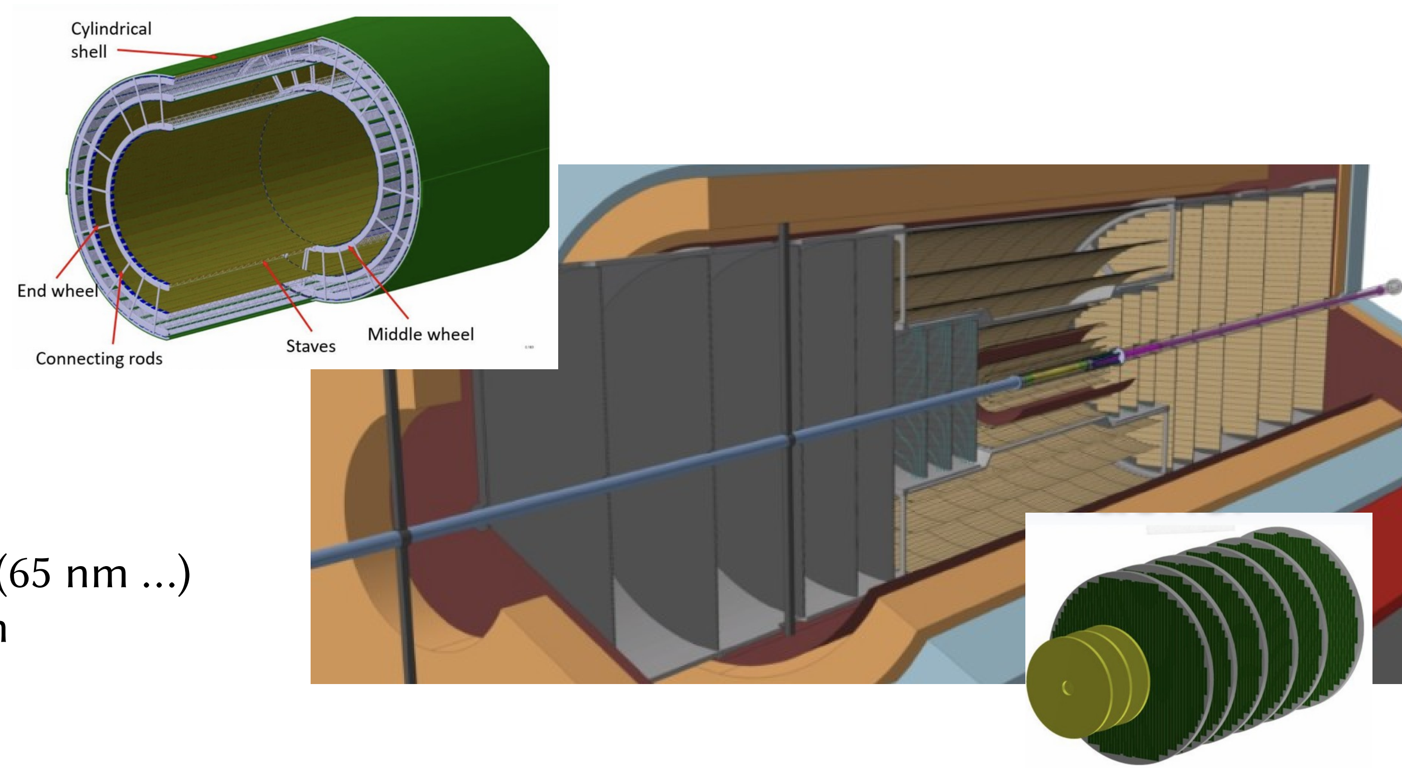
$S/\sqrt{(S+B)} \geq 5$,

for any $p_T > 1$ GeV/c

ALICE 3 LoI, CERN-LHCC-2022-009

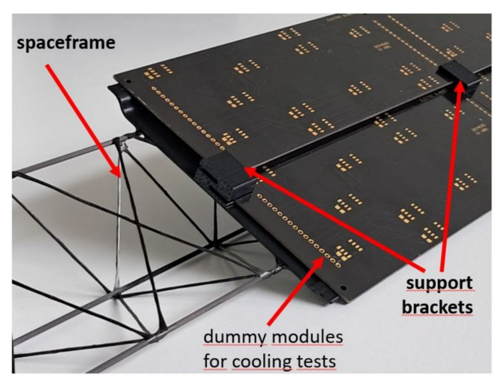
III.3 – Tracking : Middle Layers + Outer Tracker

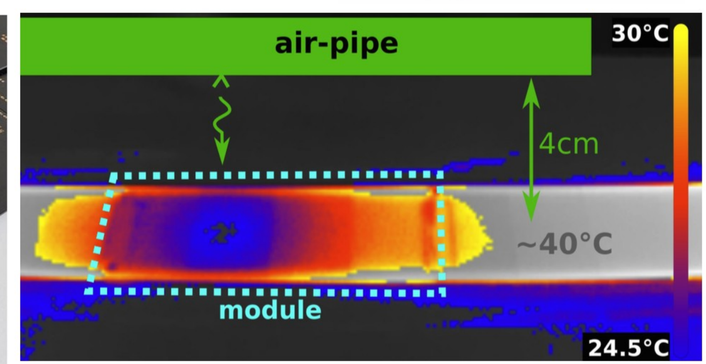
Requirements
- "$\sigma(p_T)/p_T \leq 1\%$", $\forall\ |\eta|$
- $\approx 1\%\ X^0$ per layer / per disc
  (multiple-scattering dominated)
- $\sigma_{pos} \approx 10\ \mu m$
- $\sigma_{time} \approx 100$ ns



Implementation
- CMOS Monolithic Active Pixels (65 nm ...)
- $\approx 60\ m^2$, $R_{out} \approx 0.8$ m, $|z_{disc}| < 3.5$ m
  2/3 barrel (8 layers)
  + 1/3 fwd+bckwd (2x9 discs)

Challenges
- time resolution while 20-40 mW/cm²
- operation at room temperature,
  ideally with *air cooling*
- industrialisation of the production
  of *modules* (2x4 sensors)

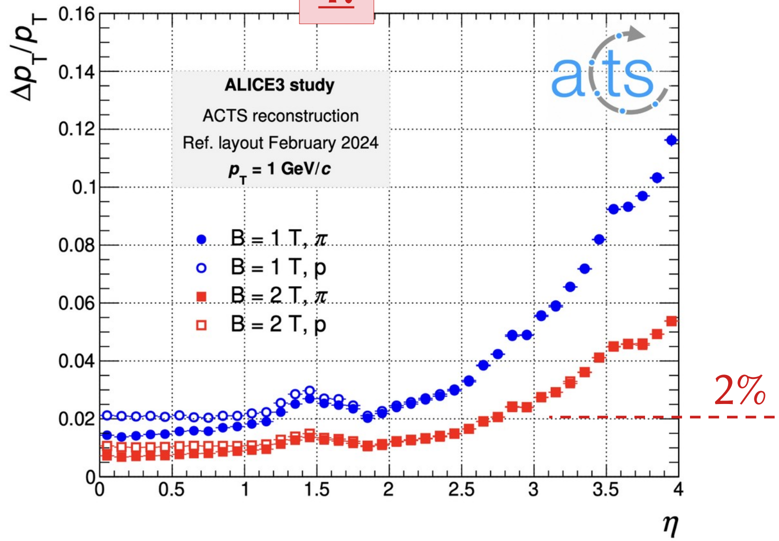




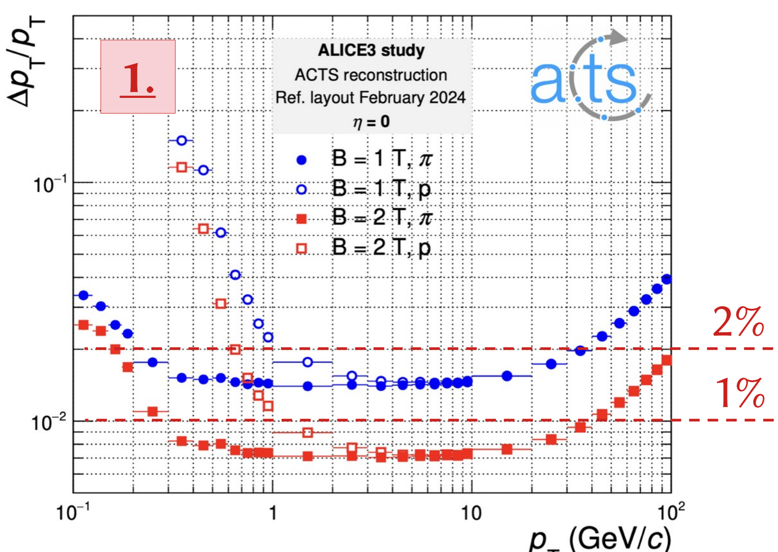
III.4 – Tracking & vertexing : tracking key performances

Thanks to ML+OT **1.**

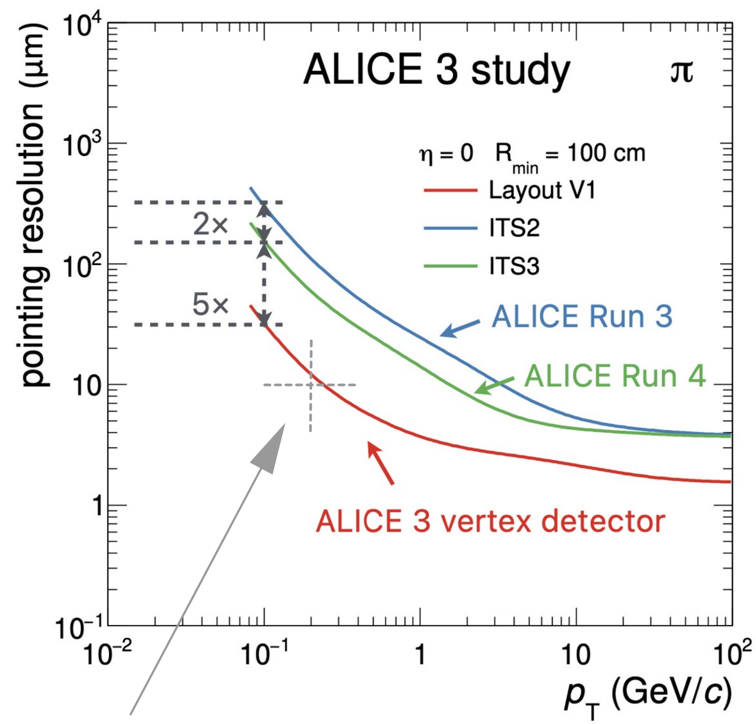
- B = 2 T, for $\pi^{\pm}$
  $\sigma(p_T)/p_T \leq 1\%$,
  up to $|\eta| < 2$
  $\sigma(p_T)/p_T < 4\%$,
  for $2 < |\eta| < 3.5$



p_T resolution < 2% for mid-rapidity $p_T(\pi^{\pm}) \in [0.2 ; 30]$ GeV/c



2. Thanks to VD

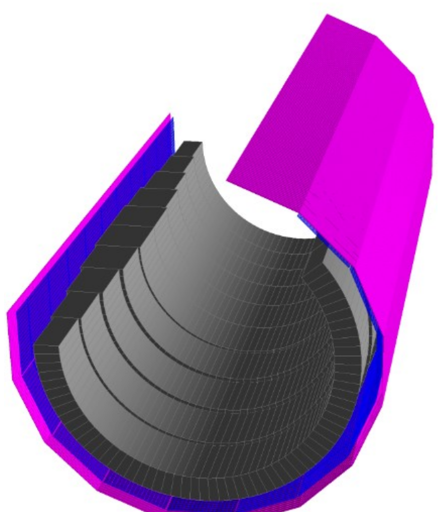


— pointing resolution,
e.g. ≈ 10 μm at p_T ≈ 0.2 GeV/c

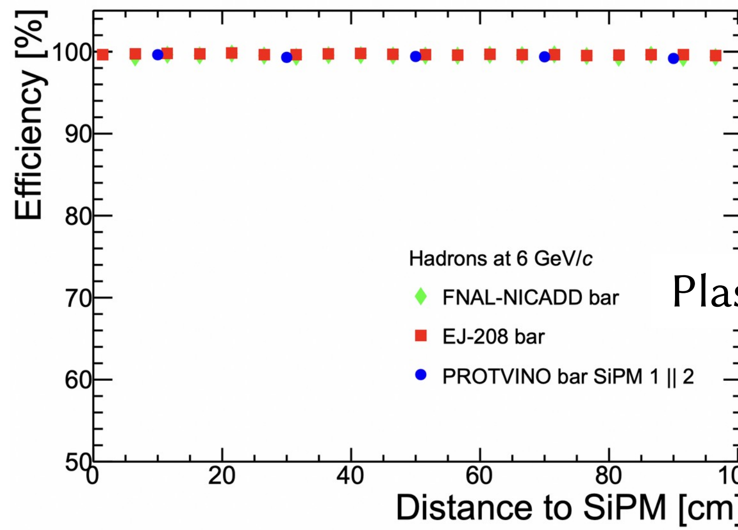
IV.1 – Particle Identification : μID with MID

Requirements
- μID $p_T > ½.m[J/\psi] = 1.5$ GeV/c
- pion rejection >96% for $|\eta| < 1.25$

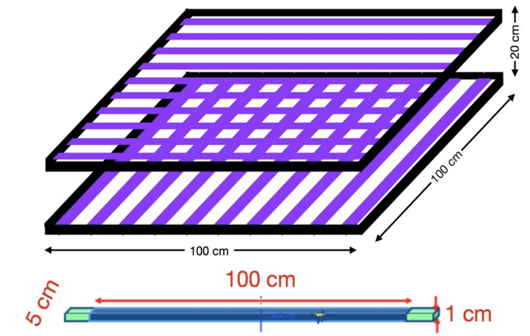
Implementation
- non-magnetic hadronic absorber
- 2 layers of muon chambers
  Default : plastic scintillator
  + SiPM
  Alternatives : MWPCh, RPC
- ΔηxΔφ granularity ≈5x5 cm² cells

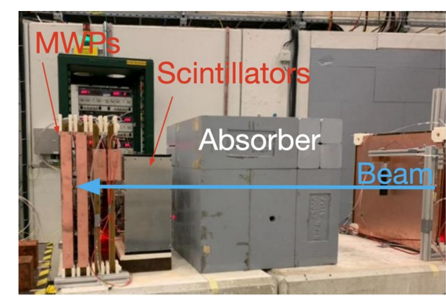


ALICE 3 μID, JINST arxiv:2401.04630

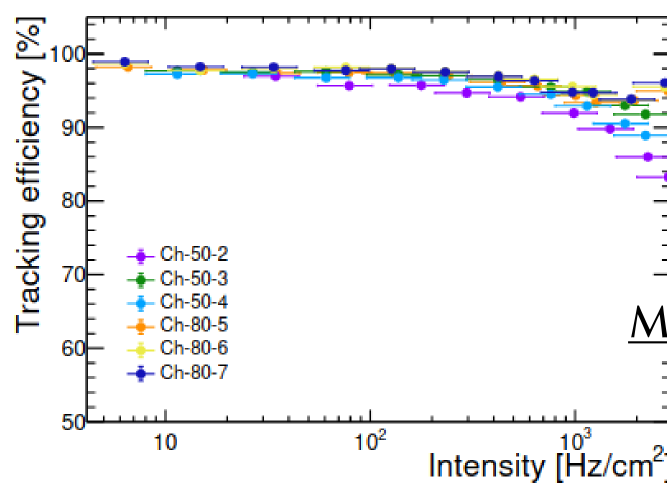


Plastic + SiPM •





ALICE 3 μID, JINST arxiv:2401.04630



MWPC •

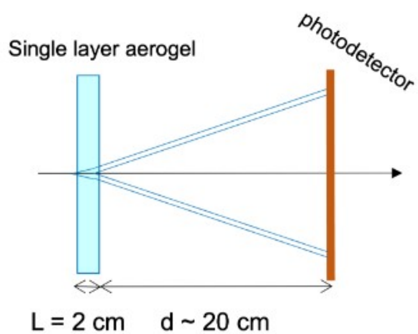
IV.2 – Particle Identification : PID with RICH

Requirements
- PID beyond TOF limits

- 3σ separation e/π, π/K and K/p up to ≈ 2, 10 and 16 GeV/c, respectively
  - ⟶ n = 1.03 (barrel)
  - ⟶ n = 1.015 (forward)
  - ⟶ $\sigma_{RICH} \approx$ 1.5 mrad at saturation

Implementation
- bRICH: Aerogel + SiPMs (≈30 m²)
- fRICH: Aerogel + HRPPDs (≈8 m²)

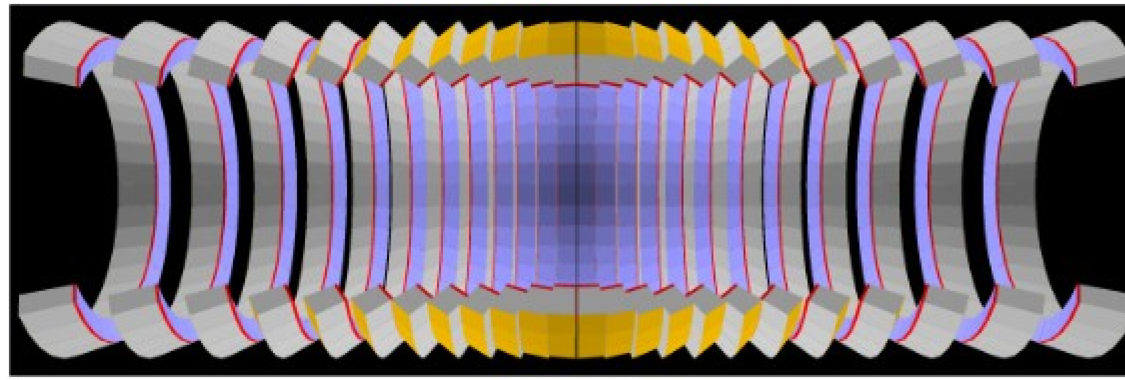
(+include "heavy" gas in the expanding volume? For eID up to 4 GeV/c...)



Challenges
- SiPM radiation tolerance
- Dark Count Rate mitigation,

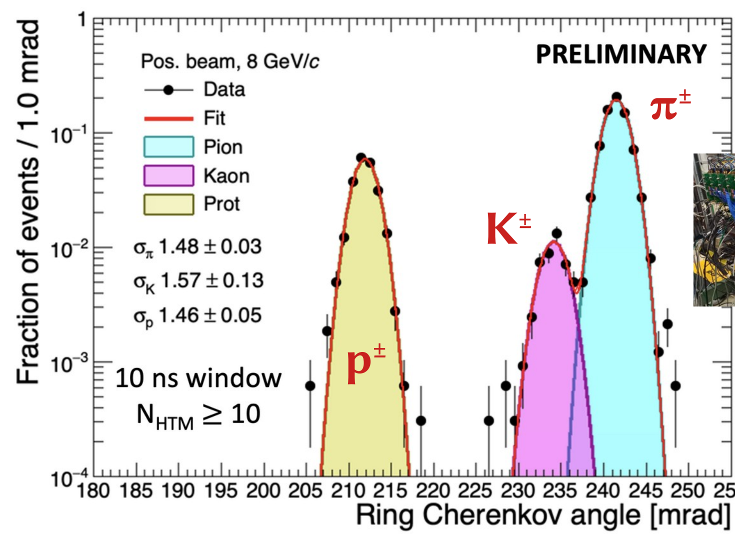
(with cooling + annealing + light concentrators + higher Phot. Det. Eff.)

Projective cylindrical bRICH



Aerogel Photodetector

2024 beam test results (using Radioroc + *PicoTDC*)



VCI 2025

IV.3 – Particle Identification : PID with TOF

Requirements

- e/π, π/K, K/p 3σ separation
  up to ≈ 0.2, 2, 4 GeV/c

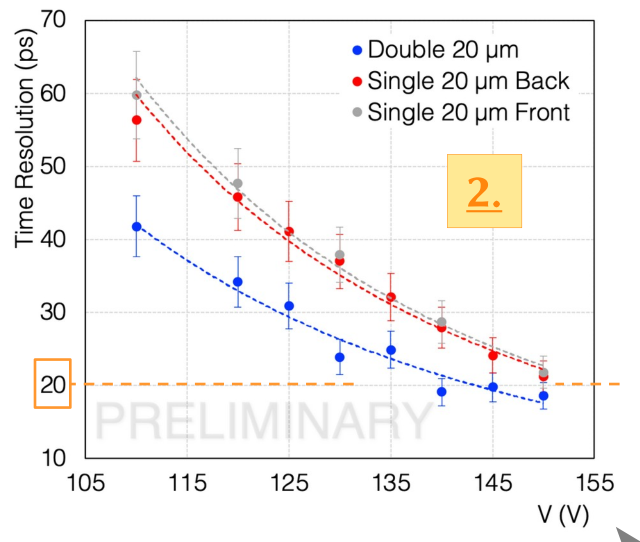
→ *f(L/σ_{TOF}), calling for σ_{TOF} ≈ 20 ps*

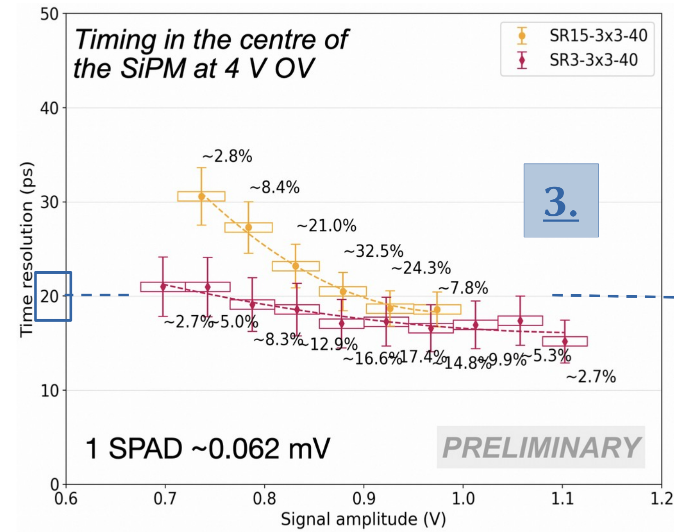
Implementation

- barrel :
  - Inner TOF (1.5 m²)
  - Outer TOF (37 m²)
- forward + backward:
  - disks (2x 3.1 m²)
- three technological options :
  1. - monolithic LGAD "with gain layer"
  2. - single/double hybrid LGAD
  3. - SiPM (combination with RICH)

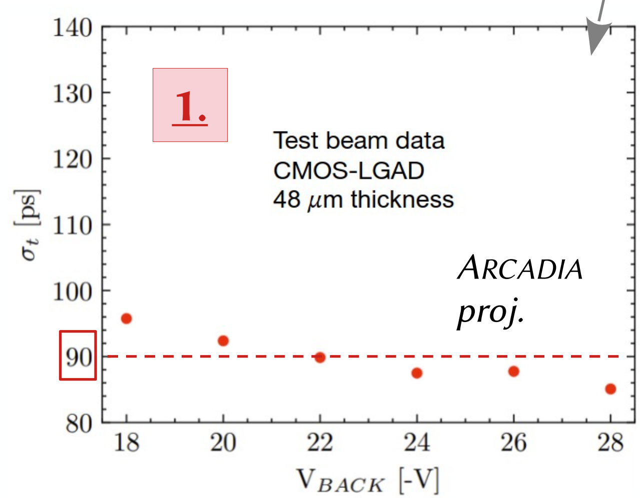
Challenges

- 20-ps target
  at the "system-integrated" level





Test beams

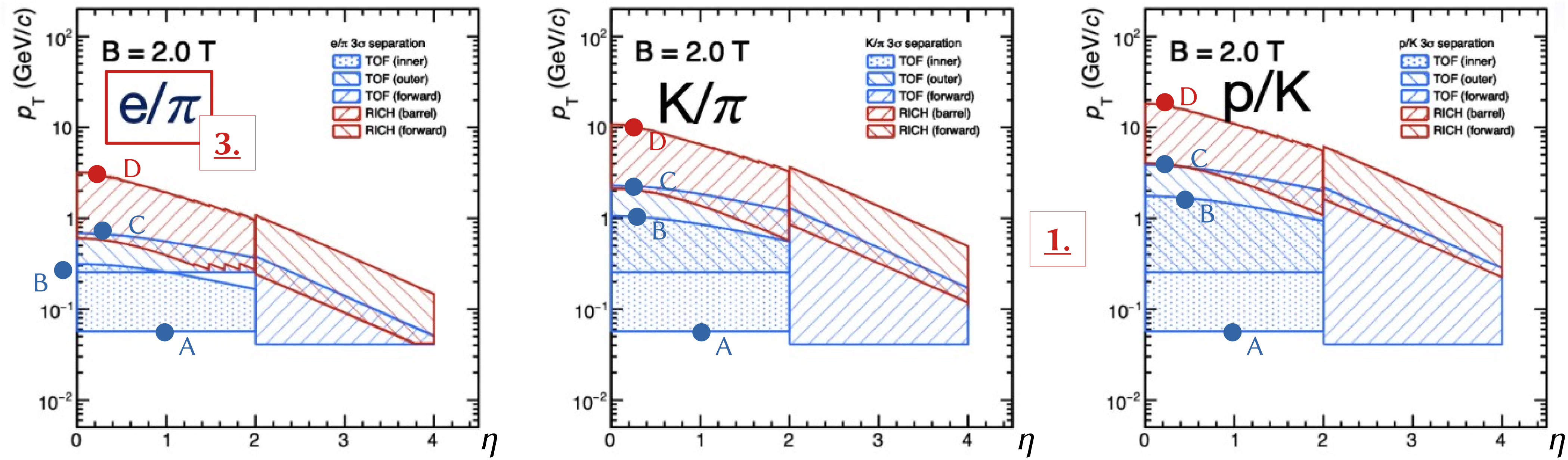


Timing demonstration "with gain" :
promising 20-ps prospects with:

- new sensor layout
- thinning to 15 μm

(*demonstrated* in simulation)

IV.4 – Particle Identification : PID with TOF + RICH

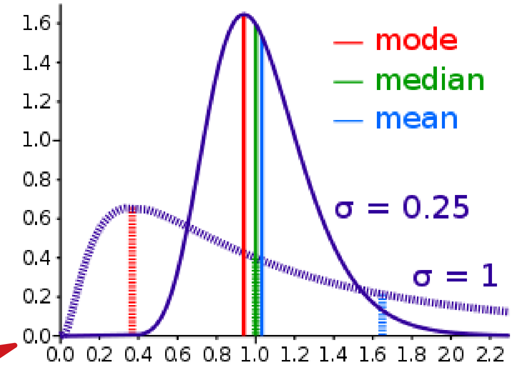


A/ $p_T \approx$ 0.055 GeV/c	A/ $p_T \approx$ 0.055 GeV/c	A/ $p_T \approx$ 0.055 GeV/c
B/ $p_T \approx$ 0.2 GeV/c	B/ $p_T \approx$ 1.0 GeV/c	B/ $p_T \approx$ 1.7 GeV/c
C/ $p_T \approx$ 0.7 GeV/c	C/ $p_T \approx$ 2.0 GeV/c	C/ $p_T \approx$ 4.0 GeV/c
D/ $p_T \approx$ 3 GeV/c	D/ $p_T \approx$ 10 GeV/c	D/ $p_T \approx$ 16 GeV/c

2. [Note the lowest p_T boundaries, at reach due to iTOF and fTOF p_T acceptance ...]

Scoping document (2024-08), Fig.30
CERN-LHCC-2025-002

IV.5 – Part. Identification : ex. of net quantum fluctuations



Wikipedia:Skewness

Net quantum number fluctuations at ($\mu_B = 0$)

1.

- **Q** : net charge (h^+ - h^-),
- **B** : net baryon (p - $\bar{\text{p}}$, Λ - $\bar{\Lambda}$, …)
- **S** : net strangeness (K^+ - K^-, Λ - $\bar{\Lambda}$, …)

Measure event-by-event fluctuations into **distributions** with $p_T > 0$ GeV/c + over large y

2.

(i.e. p_T-integrated quantities)

1st moment, m_1 : mean M

2nd moment, m_2 : variance σ^2

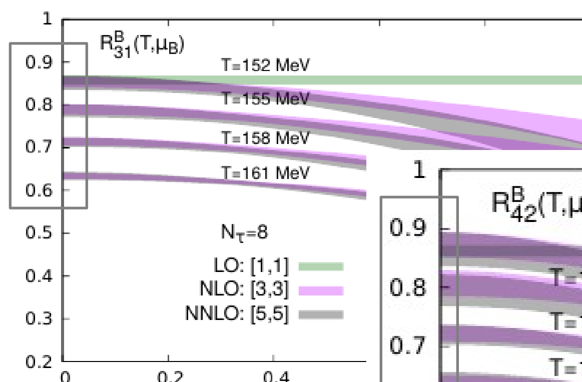
3rd moment, m_3 : ∝ skewness S

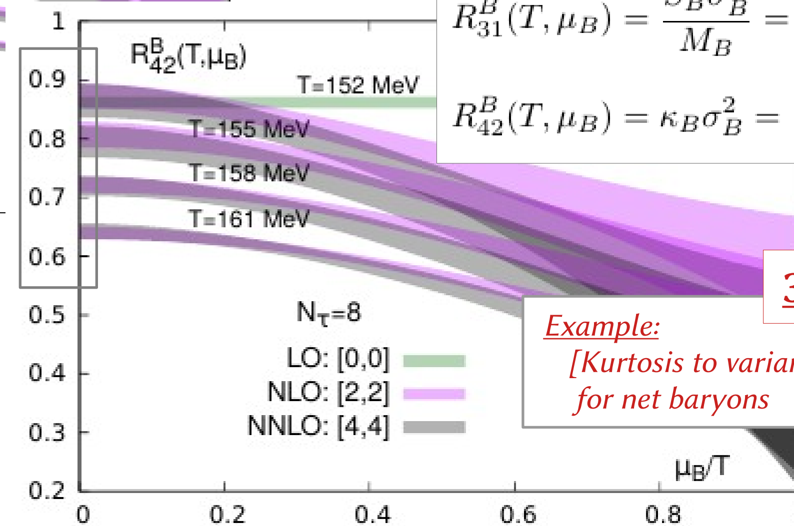
4th moment, m_4 : ∝ kurtosis κ

5th moment, m_5 : *no name*

6th moment, m_6 : …

7th moment, m_7 : …





$$R^B_{31}(T,\mu_B) = \frac{S_B\sigma^3_B}{M_B} = \frac{\chi^B_3(T,\mu_B)}{\chi^B_1(T,\mu_B)}$$

$$R^B_{42}(T,\mu_B) = \kappa_B\sigma^2_B = \frac{\chi^B_4(T,\mu_B)}{\chi^B_2(T,\mu_B)}$$

3.

Example: [Kurtosis to variance] ratio, for net baryons

HotQCD, arXiv:2001.08530

→ *key* : ratios m_j/m_i (e.g. m_4^B/m_2^B) to access direct comparison to LQCD for (deconfinement d.o.f. + chiral restoration + nature of transitions)

4.

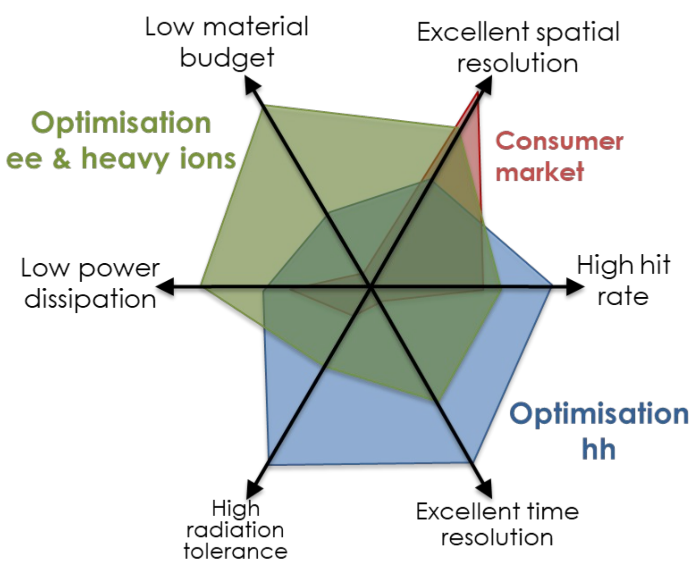
See also EMMI, arXiv:2001.08831

V.1 – ALICE 3 as stepping stone : (e^+e^-) Higgs factories

A. Conclusion 1, out of 4 (*2021 ECFA roadmap*) :

"Develop cost-effective detectors matching the precision physics potential of a next-decade Higgs factory with beyond state-of-the-art performance, optimised granularity, resolution and timing, and with ultimate compactness and minimised material budgets"

B. ∃ **colinearity** of specifications : [eA, pA, AA // e^+e^-] !
→ calling for **overlap** of R&D on vertexing, tracking, timing, ...



Courtesy J. Baudot

	ITS3	ALICE 3 VTX	ALICE 3 TRK	ePIC	FCC-ee
Single-point res. (μm)	5	2.5	10	5	3
Time res. (ns RMS)	2000	100	100	2000	20
In-pixel hit rate (Hz)	54	96	42		few 100
Fake-hit rate (/pixel/event)	10^{-7}	10^{-7}	10^{-7}		
Power cons. (mW / cm^2)	35	70	20	<40	50
Hit density (MHz/cm^2)	8.5	96	0.6		200
NIEL (1 MeV n_{eq}/cm^2)	$4 \cdot 10^{12}$	$1.0 \cdot 10^{16}$	$4.6 \cdot 10^{13}$	few 10^{12}	10^{14} (/year)
TID (Mrad)	0.3	300	1.7	few 0.1	10 (/year)
Material budget (X_0/layer)	0.09%	0.1%	1%	0.05%	~0.3%
Pixel size (μm)	20	10	50	20	15-20

- *Daniela Bortoletto, Si Vertex, Tracking & Timing Sl. 2, ESPPU Venice*
- *ALICE, Frontier sensor R&D for ALICE 3, Tab.4 ESPPU contrib*

Conclusions

Conclusions : ALICE 3 features ...

ALICE 3 : a cornerstone experiment to exploit fully the QGP+QCD physics programme at HL-LHC,
up to its end,
be it in pp, pA and AA collisions

ALICE 3 equation

- **ultralight** detector (0.1 – 1 % X_0 per layer)
- **hypergranular** tracking (spatial resolution 3-10 μm, = *f* (layer))

  ⟶ prevailing role of CMOS MAPS

- extension towards (ultra) low p_T ($p_T \in$ [**0.05** ; (>10)] GeV/c)
- extension towards (much) more units in η / in y ($|\eta| < 4$)

  ⟶ bridge and overlap wrt LHCb η coverage, with a single experiment

- **PID** = a cornerstone (from iTOF to RICH)

- fast reading / very fine time resolution (**25-ns** bunch tagging for $\mu_{pileup} = 1$)

App. A – HL-LHC, which ion choices ?

A.1 – HL-LHC : large- to small-ion candidates, for which $\mathscr{L}$

ALICE 3 LoI, arXiv:2211.02491 Tab. 1 p.18

Quantity	pp	O–O	Ar–Ar	Ca–Ca	Kr–Kr	In–In	Xe–Xe	Pb–Pb
$\sqrt{s_{NN}}$ (TeV)	14.00	7.00	6.30	7.00	6.46	5.97	5.86	5.52
L_{AA} ($cm^{-2}s^{-1}$)	3.0×10^{32}	1.5×10^{30}	3.2×10^{29}	2.8×10^{29}	8.5×10^{28}	5.0×10^{28}	3.3×10^{28}	1.2×10^{28}
$\langle L_{AA}\rangle$ ($cm^{-2}s^{-1}$)	3.0×10^{32}	9.5×10^{29}	2.0×10^{29}	1.9×10^{29}	5.0×10^{28}	2.3×10^{28}	1.6×10^{28}	3.3×10^{27}
$\mathscr{L}_{AA}^{month}$ (nb^{-1})	5.1×10^{5}	1.6×10^{3}	3.4×10^{2}	3.1×10^{2}	8.4×10^{1}	3.9×10^{1}	2.6×10^{1}	5.6
$\mathscr{L}_{NN}^{month}$ (pb^{-1})	505	409	550	500	510	512	434	242
R_{max} (kHz)	24 000	2169	821	734	344	260	187	93
μ	1.2	0.21	0.08	0.07	0.03	0.03	0.02	0.01
$dN_{ch}/d\eta$ (MB)	7	70	151	152	275	400	434	682

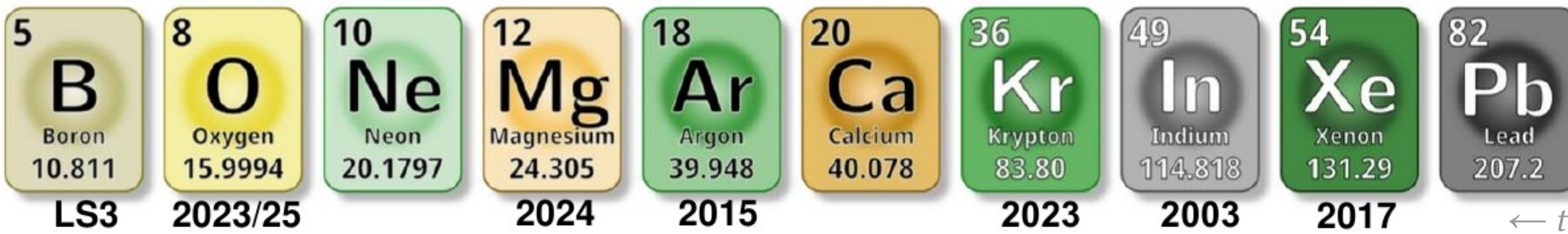
	pp (**2024**) ALICE 2	pp (2018) ALICE 1	Pb-Pb (**2023**) ALICE 2
$\sqrt{s_{NN}}$ (TeV)	13,6	13	5,36
L_{AA} ($cm^{-2}s^{-1}$)	1×10^{31}	3×10^{30}	$3{,}5\times10^{27}$
$\mathscr{L}^{month}_{AA}$ (MB nb^{-1})	≈ 5×10^{3} nb^{-1}	≈ 2 nb^{-1}	≈2.0 nb^{-1}
<R_{max}> (kHz)	500		45
Colliding bunches	≈ 2200	≈ 2200	≈ 875
µ	≤ 0.02	≤ 0.02	≤ 0.01

(Beware :
<u>delivered</u> Vs
inspected Vs
actually "<u>recorded</u>" luminosity (skip or trigger) …
⟶ for ALICE 3, delivered ≈ recorded)

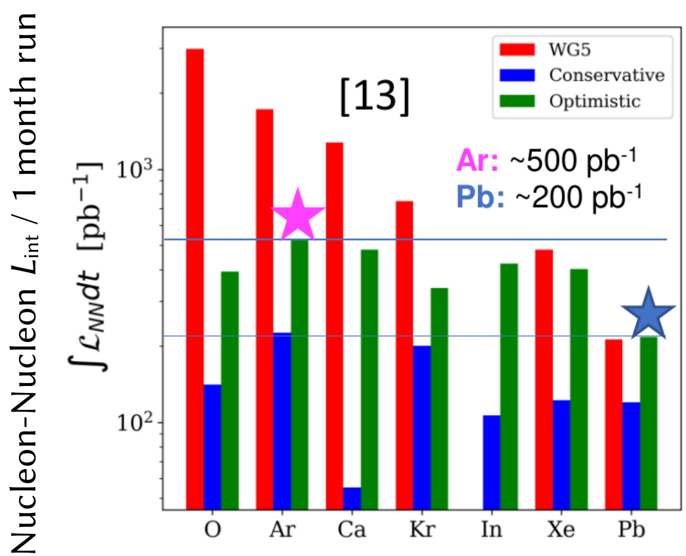
bpt.web.cern.ch/statistics

A.2 – HL-LHC : large- to small-ions, uncertainties on $\mathscr{L}$

R. Alemany Fernandez, LHCP2024
(Elias Waagaard, ALICE Upgrade Week 2024-10 + IPAC 24. See also workshop Light Ions at LHC indico.cern:1436085 2024-11)



← tested already at ~SPS



WG5 (2018):
too optimistic no Beam Dynamics Limits (BDL) in the injectors

= *WG5 AA in HL-LHC, arXiv:1812.06772*

Conservative:
today's Ion Complex

Optimistic:
- LEIR-PS stripping
- PS no-splitting
- Isotope optimization

NB : Both Conservative and Optimistic includes BDL

= *publication to appear*

New LHC "injector model" under devlopm^t
→ more accurate estimates
for possible $\int \mathscr{L}_{inst}$ to come

Question :
different species, to achieve better LHC and/or physics performance ?

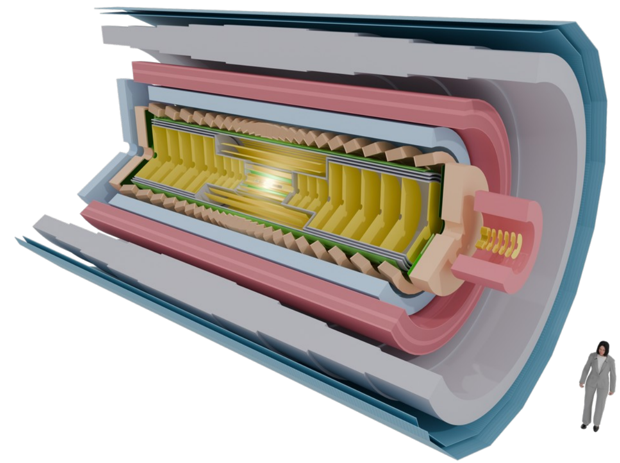
App. B – General layout

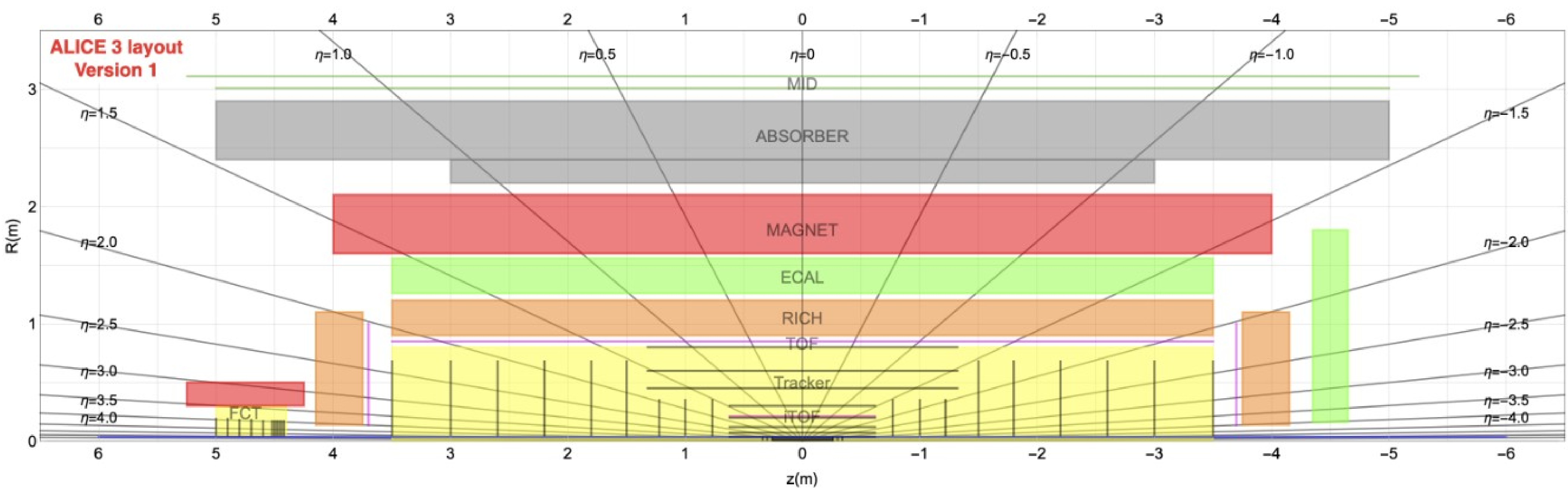
B.1 – ALICE 3 : layout overview, *version 1* Scop. Doc.

Scoping document (2024-08)

[CERN-LHCC-2025-002]

+ ALICE 3 Scoping document *Fig.1 version 1 layout [~LoI]*

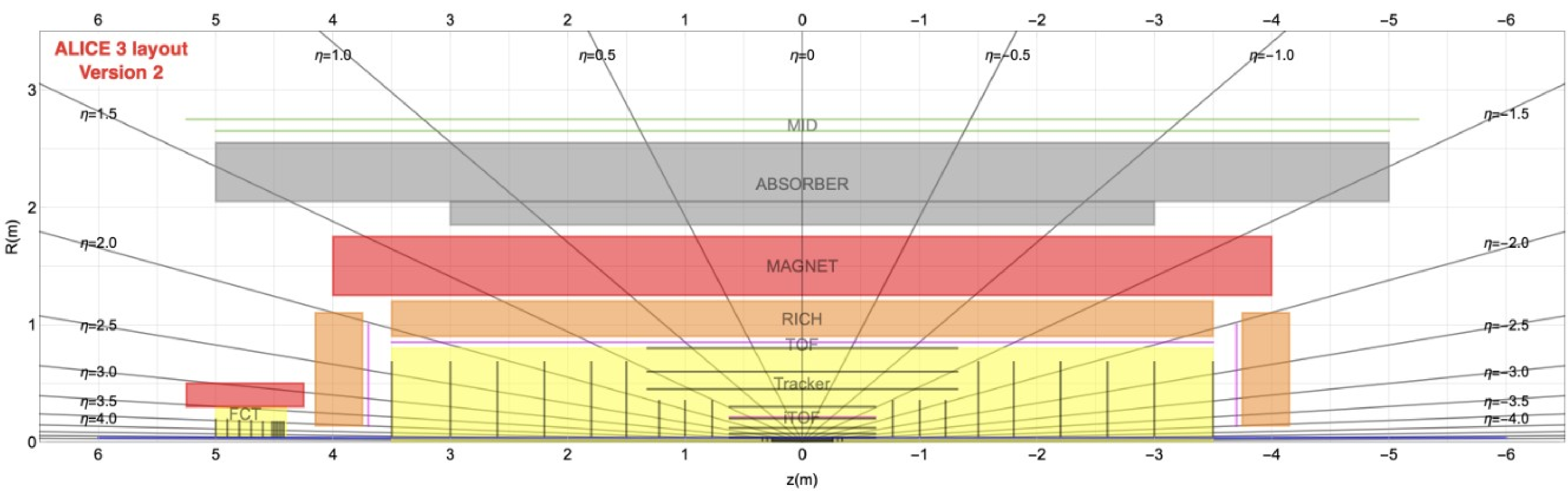




B.2 – ALICE 3 : layout overview, *version 2* Scop. Doc.

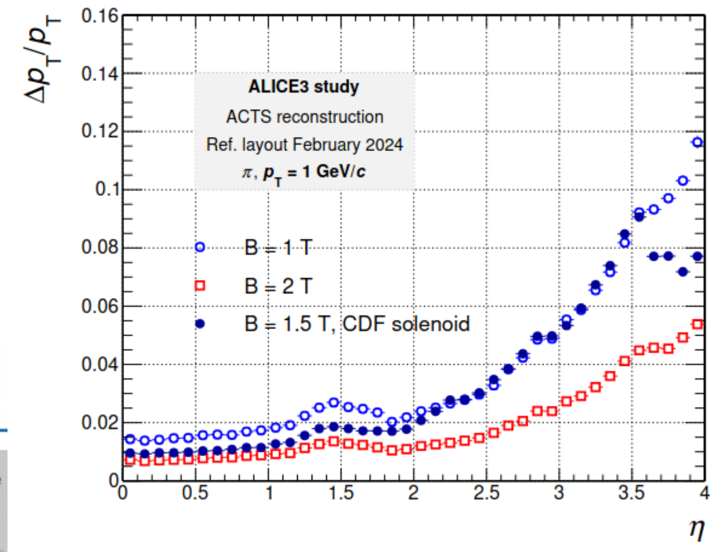
Scoping document (2024-08)
CERN-LHCC-2025-002

+ ALICE 3 Scoping document *Fig.12 [v2] = a scoping option = No ECal = new default in practice*

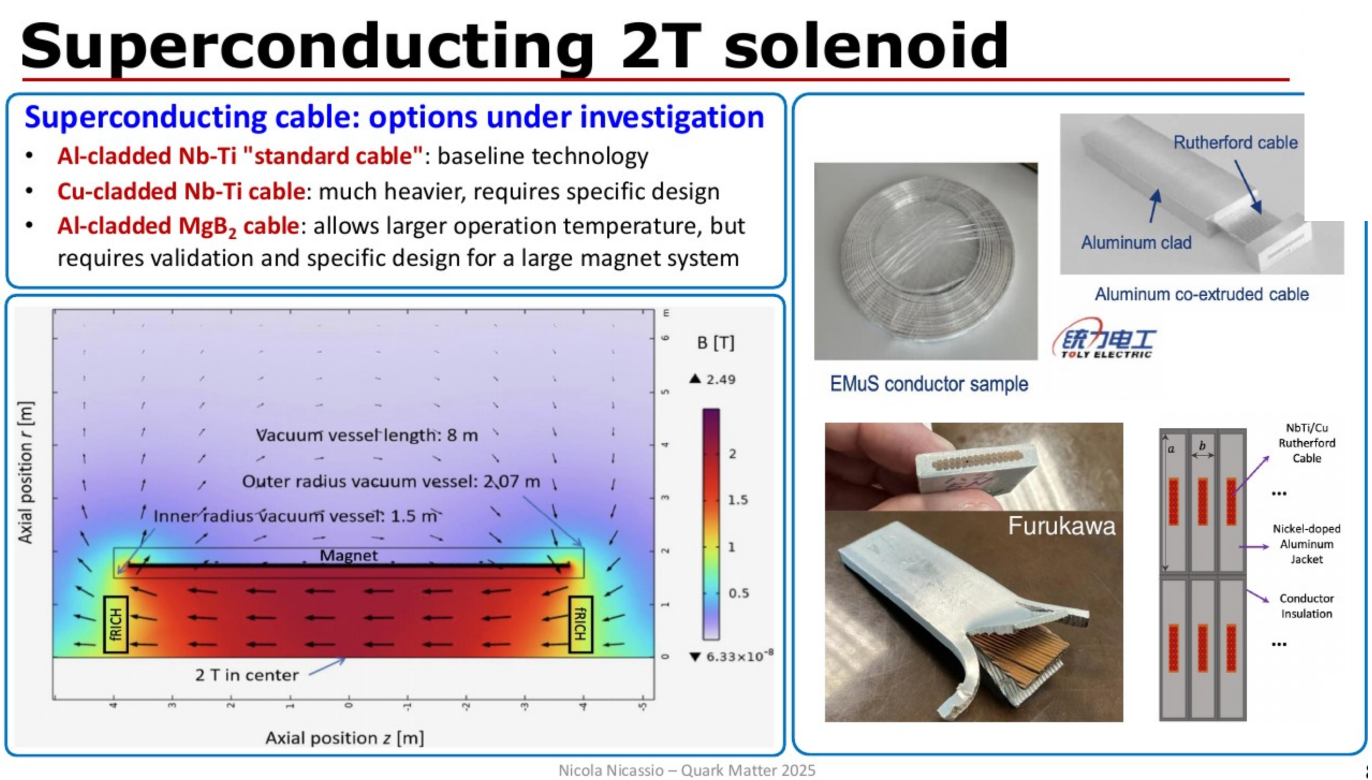


B.3 – ALICE 3 : superconducting magnet, *version 2* Scop. Doc.

Scoping document (2024-08), Fig.34
CERN-LHCC-2025-002

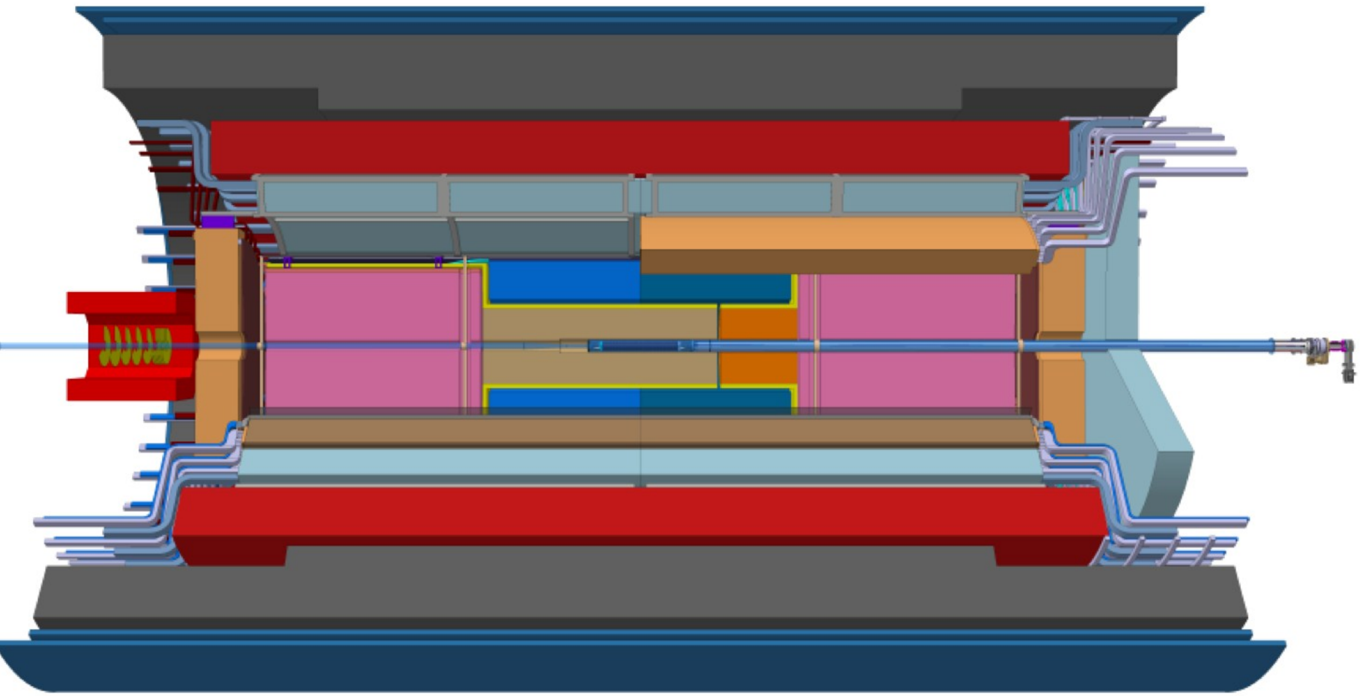


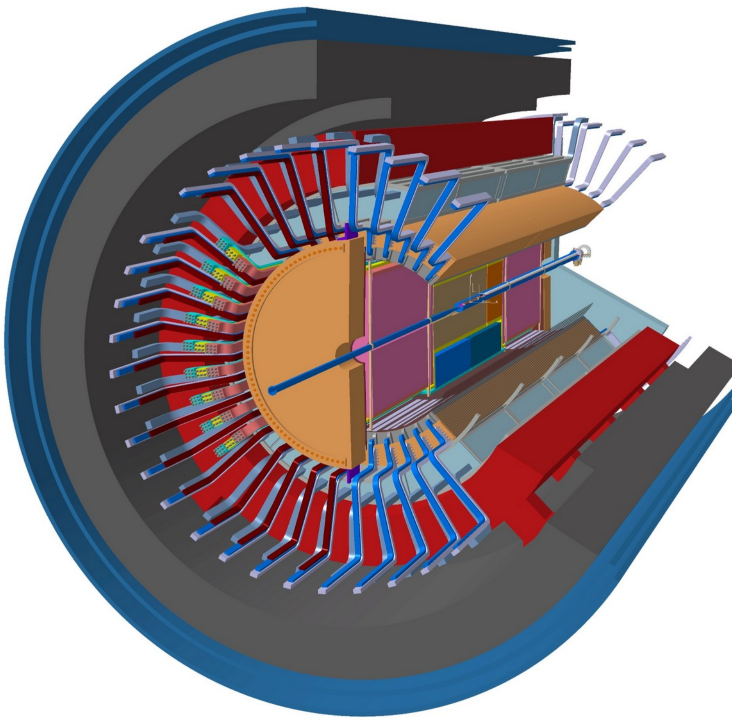
ALICE 3 talk, QM 2025



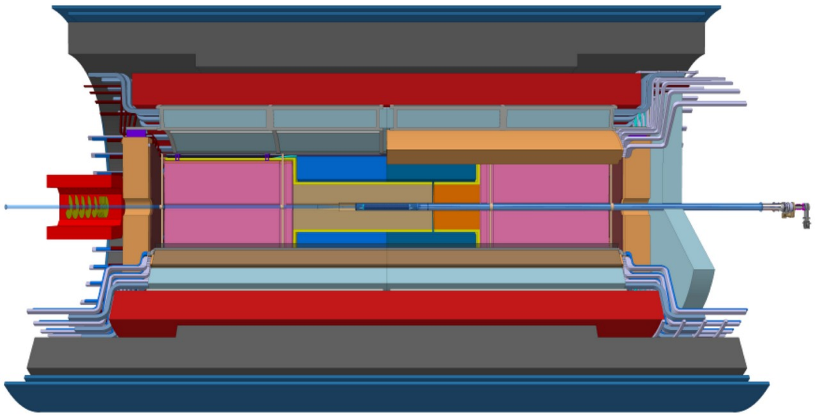
B.4 – ALICE 3 : “peacock” installation layout

ALICE-PHO-GEN-2025-005





B.4 – ALICE 3 : “peacock” installation layout



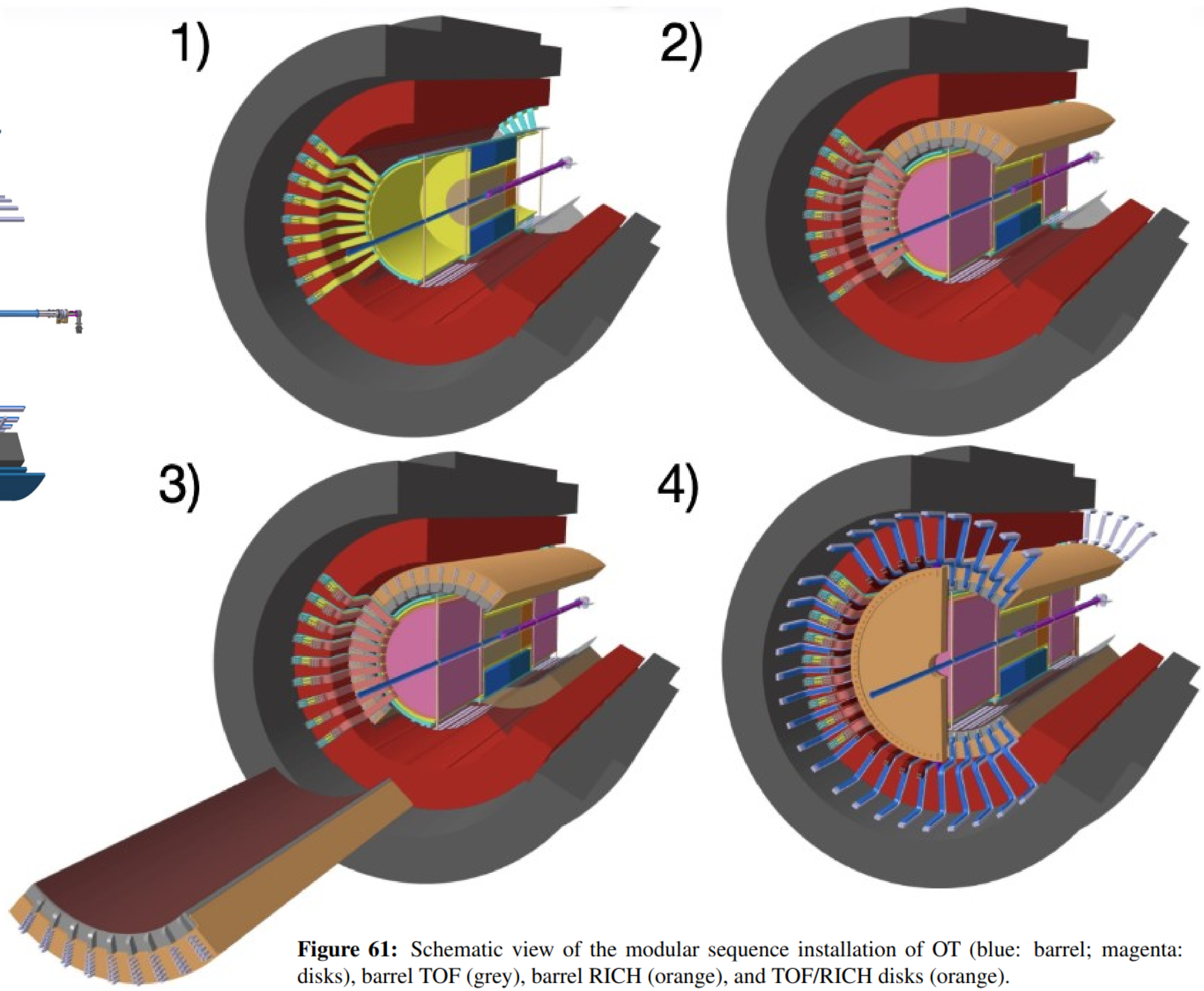


Figure 61: Schematic view of the modular sequence installation of OT (blue: barrel; magenta: disks), barrel TOF (grey), barrel RICH (orange), and TOF/RICH disks (orange).

Scoping document (2024-08), Fig.61
CERN-LHCC-2025-002

App. C – ALICE 3 sub-systems

ALICE 3 LoI, *CERN-LHCC-2022-009*

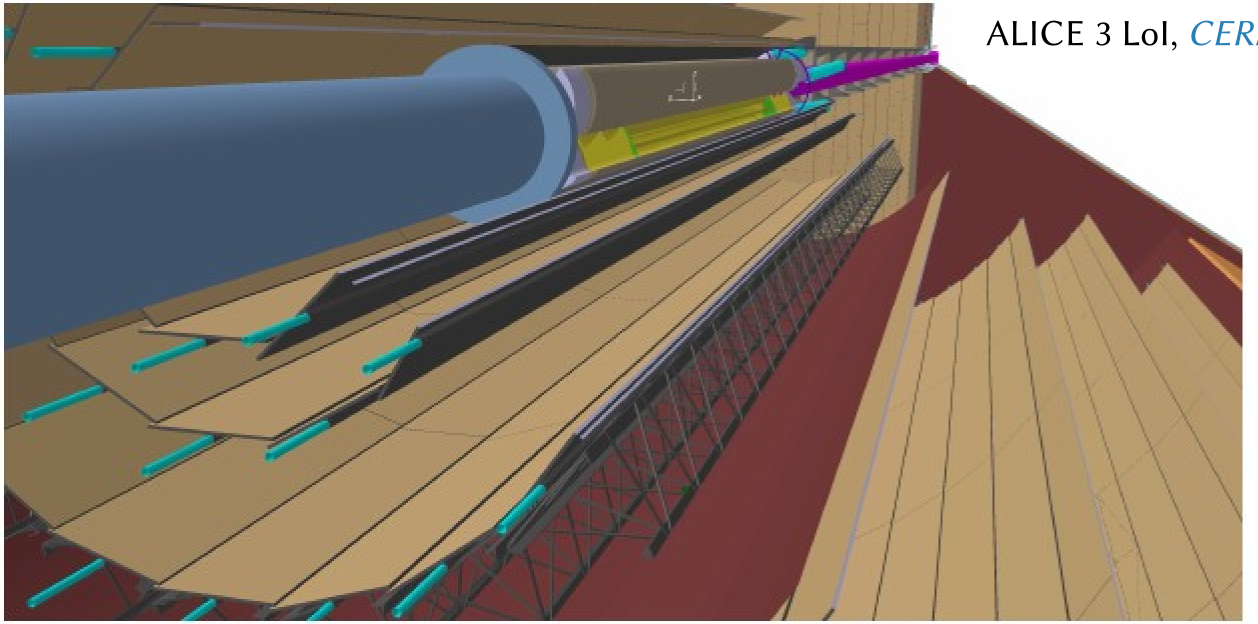


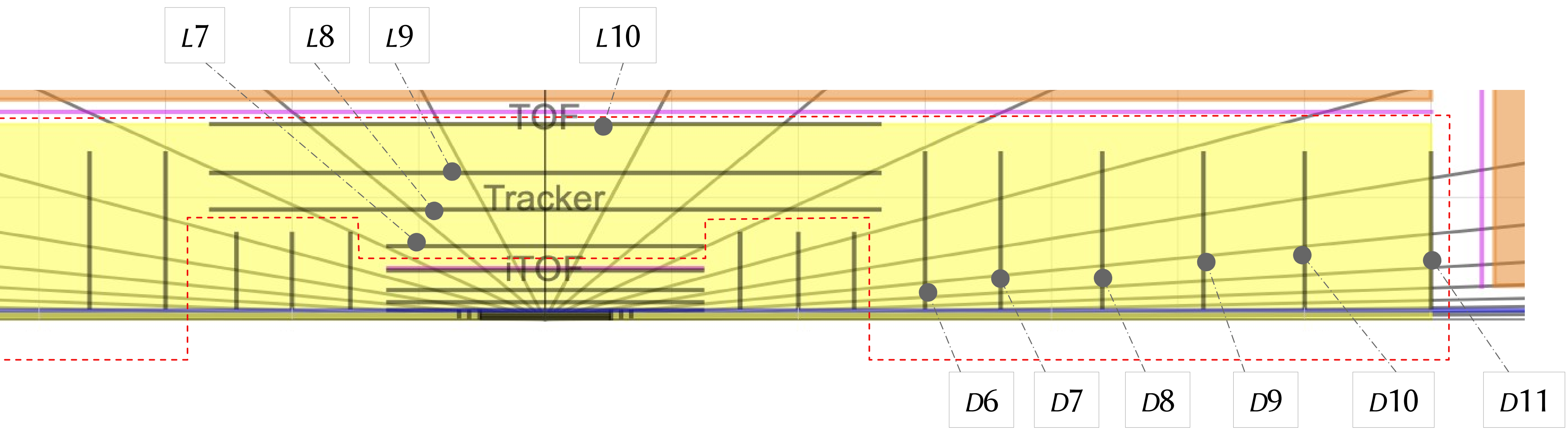
Figure 83: Sketch of the outer tracker mechanics. Modules assembled in staves structures are visible as well as services and power lines. Furthermore, the overlap of the staves can be seen.

- Barrel basis = carbon spaceframes (ITS2-like)
- Endcap basis = double-side sandwich with alternate column of modules

C.1 – OT staves & discs : layout and surfaces

Zoom on [Outer Tracker] + [Inner tracker- Middle Tracker]

Scoping document (2024-08)
CERN-LHCC-2025-002



ALICE 2 preamble :

° ITS2 sensitive area (*i.e.* active silicon without periphery on ALPIDE) ≈ 9.99 m^2

° MFT sensitive area ≈ 0.37 m^2

⟶ ALICE 3 OT ≈ **50 m^2** of plain acceptance geometry in total (*i.e.* naïve discs and cylinder models)

- OT Barrel ≈ **33 m^2** ⟶ *O*[3x ITS2]
- OT forward discs ≈ 6x(2m^2/disc plane) = ~~**12 m^2**~~ **8.7 m^2** ⟶ *O*[1x ITS2 or 23x MFT]
- OT backward discs = same ≈ ~~**12 m^2**~~ **8.7 m^2** (~~*may depend on FCT requirements*~~)
- IT-Middle Tracker ≈ **5.95 m^2** ⟶ *O*[½ x ITS2]

4-layer barrel ≈ 3,73 m^2

2x3-disc endcaps ≈ 2,22 m^2

C.2 – TOF : specifications and layout

Table 10: TOF specifications. The Outer TOF barrel length, the Forward TOF radius and the hit rates have been updated with respect to the LoI values.

	Inner TOF	Outer TOF	Forward TOF disks
Radius (m)	0.19	0.85	0.15 to 1.0
z range (m)	–0.62 to 0.62	–3.50 to 3.50	±3.70
Area (m^2)	1.5	37	6
Acceptance	$\|\eta\| < 1.9$	$\|\eta\| < 2$	$2 < \|\eta\| < 4$
Granularity (mm^2)	1×1	5×5	1×1 to 5×5
Hit rate (kHz/cm^2)	200	15	280
Material thickness ($\%X_0$)	1 to 3	1 to 3	1 to 3
Power density (mW/cm^2)	50	50	50
Time resolution (ps)	20	20	20

Scoping document (2024-08), Tab.10
CERN-LHCC-2025-002

C.3 – RICH : specifications and layout

Table 12: RICH specifications. The RICH barrel length and the Forward RICH radius have been updated with respect to the LoI values.

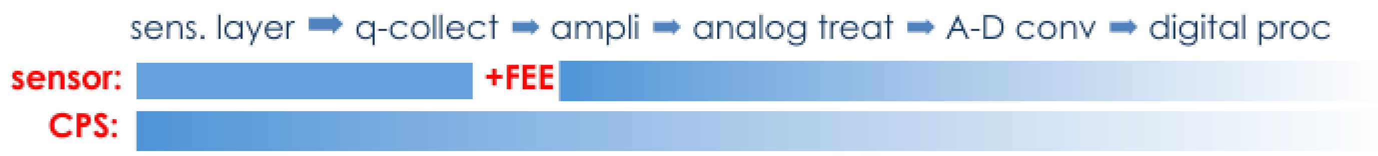
	barrel RICH	forward RICH disks
Radius (m)	0.9 to 1.2	0.15 to 1.15
z range (m)	–3.50 to 3.50	$3.75 < \|z\| < 4.15$
Surface (m^2)	28	9
Acceptance	$\|\eta\| < 2$	$2 < \|\eta\| < 4$
Granularity (mm^2)	2×2	2×2

Scoping document (2024-08), Tab.12
CERN-LHCC-2025-002

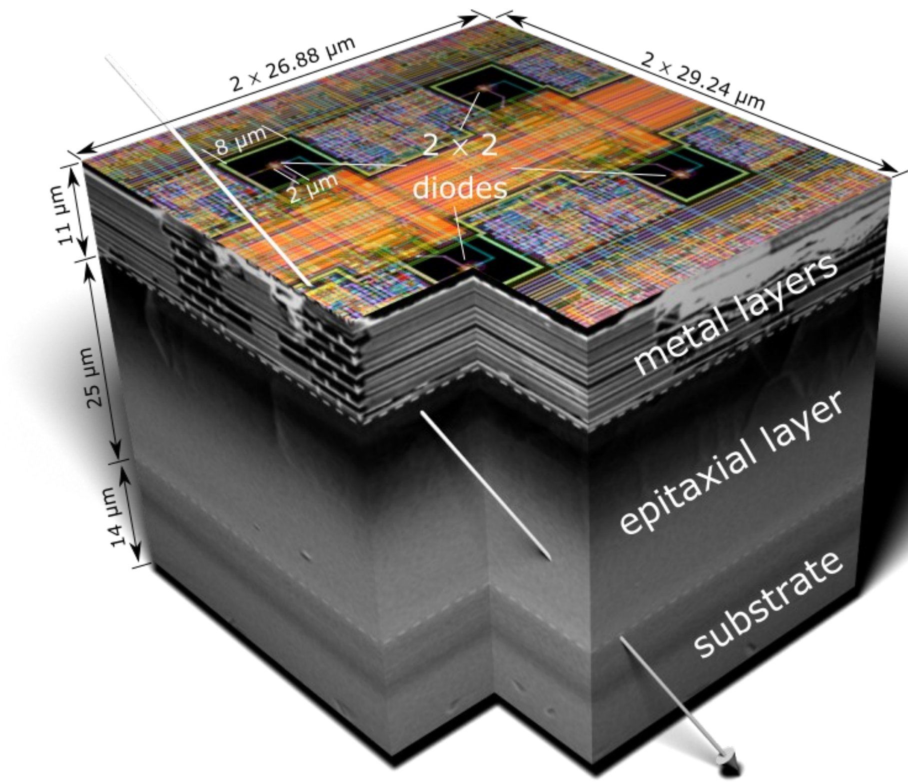
App. D – CMOS sensor

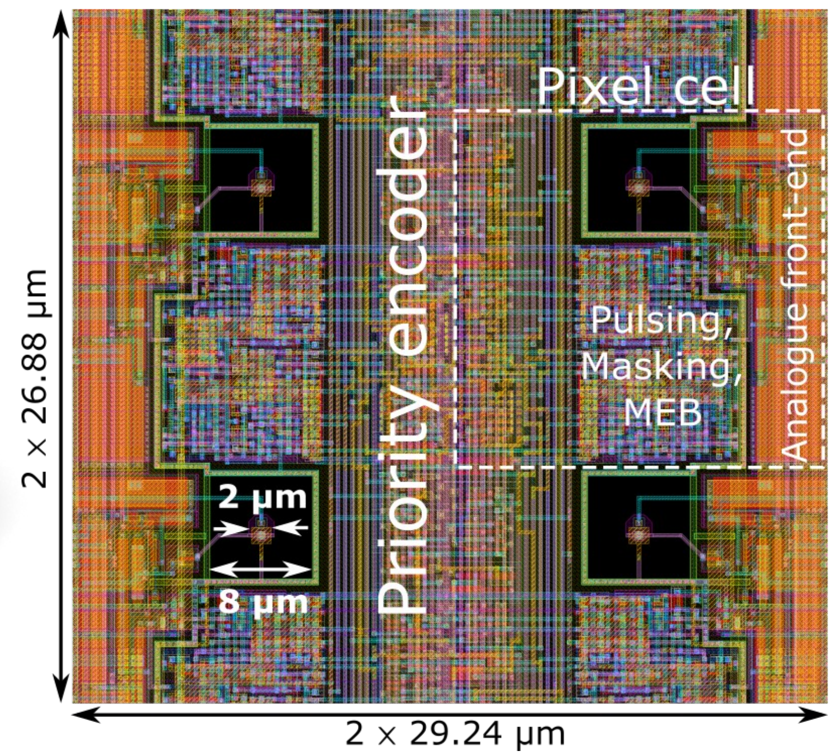
D.1 – Background : MAPS, Monolithic Active Pixel Sensors

Hybrid pixel sensor ⟶
CMOS pixel sensor ⟶



Ex: sensor using
TowerSemiconductor 180-nm CMOS Imaging Process



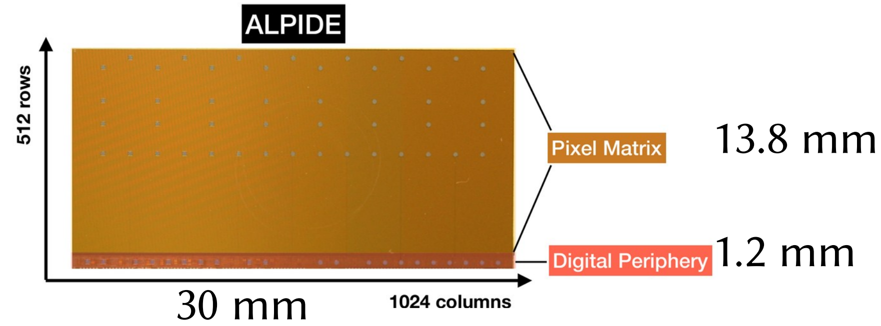


ITS2 ALPIDE – 3D and 2D views of 2x2 pixels
(Here, in the 50-µm-thick version...)

D.2 – Background : ITS2+MFT, MAPS-based detectors for Run 3

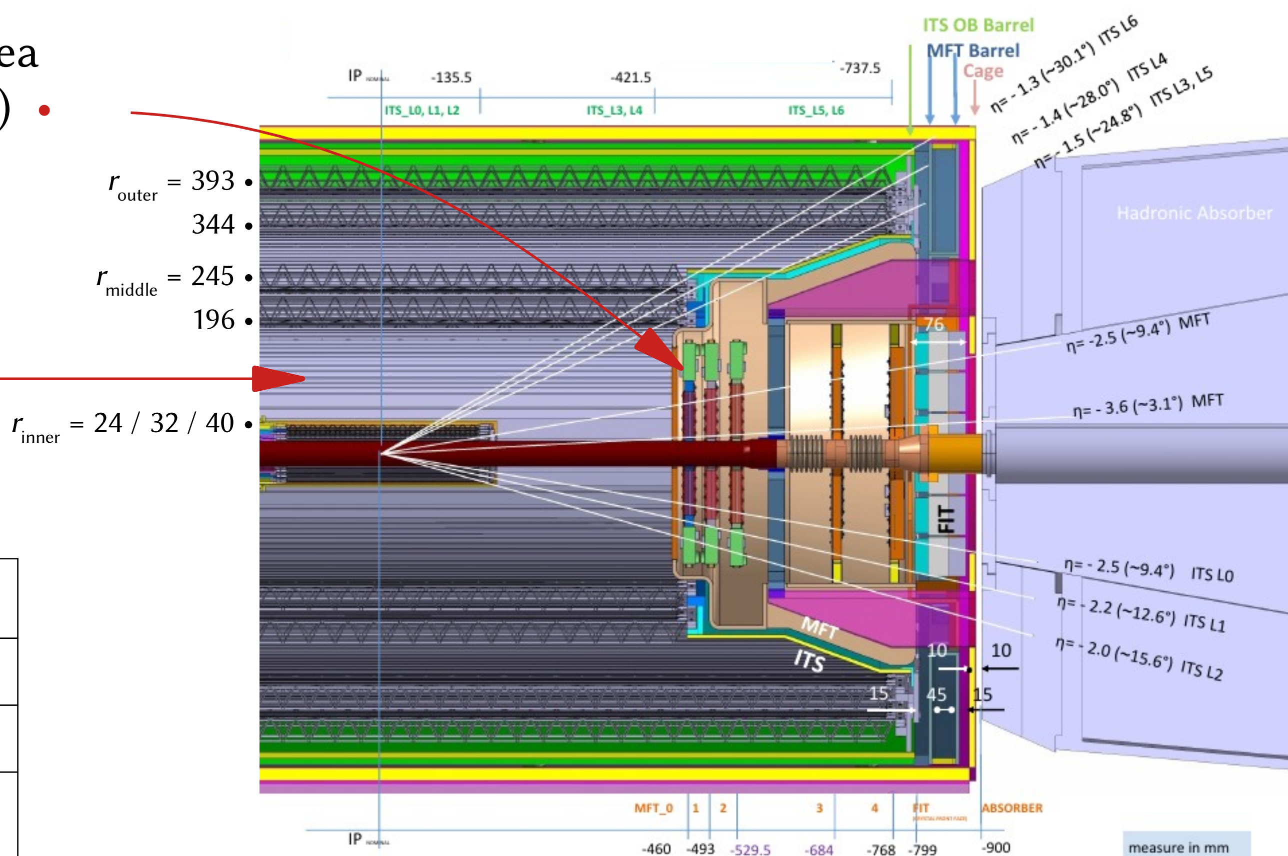
MFT

5 double-sided vertical discs
896 ALPIDE chips
0.47 x10^9 pixels
= 0.37 m² of *sensitve* area
(3.7% of ITS2 area)



ITS2

7 layers as barrel structure
24120 ALPIDE chips,
12,6 x10^9 pixels
= 9.99 m² of *sensitive* area
(10.85 *m² of* active *silicon, incl. periphery*)



	L0,L1,L2	L3+L4	L5+L6
Layers	*Inner*	Middle	Outer
Chips	432	6048	17640
Active surface	0.18 m²	2.50 m²	7.30 m²
Fraction	1.8%	25%	73%

D.3 – CMOS : vertexer and tracker specifications

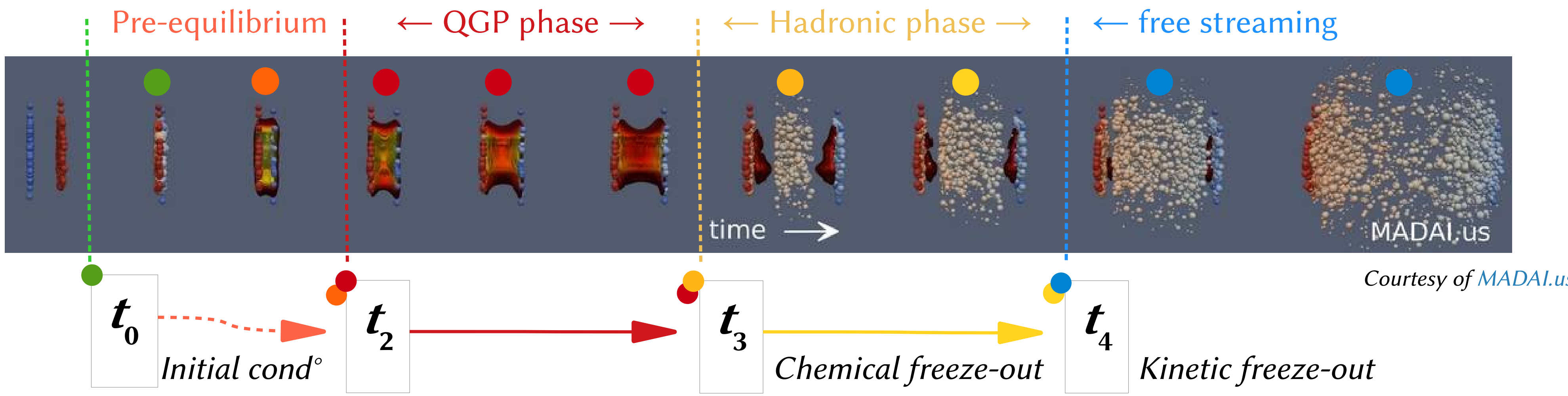
	ALICE ITS3	ALICE 3		FCC-ee
		Vertex Detector	Tracker (ML/OT)	
Position resolution (µm)	5	2.5	10	3
Pixel size (µm²)	*O*(20 x 20)	*O*(10 x 10)	*O*(50 x 50)	*O*(25 x 25) ?
Time resolution (ns RMS)	O(1000)	100	100	20 ?
In-pixel hit rate (Hz)	54	94	42 (barrel)	2350
Fake-hit rate (/ pixel / event)	$<10^{-7}$			?
Power consumption (mW / cm²)	35	70	20	50
Particle hit density (MHz / cm²)	8.5	94	0.6	400
Non-Ionising Energy Loss (1 MeV n_{eq} / cm²)	3×10^{12}	1×10^{16}	6×10^{13}	~ 6×10^{12} / year
Total Ionising Dose (Mrad)	0.3	300	3 (barrel)	~ 4 / year
X/X_0 / layer	0.09% (average) 0.07% (most of active region)	0.1%	1.0%	0.15%

. *Felix Reidt, FCCee vertexer workshop v2024-07*

Back to App. TOC

App. E – Template for QCD+QGP phys. cases

E.1 – Observables : Layer 1 / as a func. of the collision time



Courtesy of MADAI.us

0.
- Coherent E_{loss}
- nPDF
- shadowing
- CGC
+ fluctuations

…

1.
- Level of :
  . (non)Hydrodynamisation
  . chemical (non)equilibration
  . (non)Thermalisation

via

Multi-Parton Interactions
+ Colour Reconnections
+ Multiple parton scatterings
+ Rope shoving
+ Glasma …

Vs parton showering

2.
- Degrees of freedom
- Phase transitions :
  . Chiral symm. restoration
  . Deconfinement
- Eq° of State
- Transport coefficients
- Radiative/Collisional E_{loss}

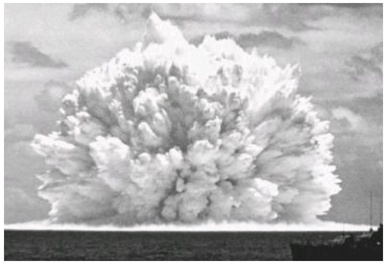
…

3+4.
. Sudden freeze-out
. HBT/Femtoscopy
. Recombination/ coalescence
. Hadronic re-interactions

…

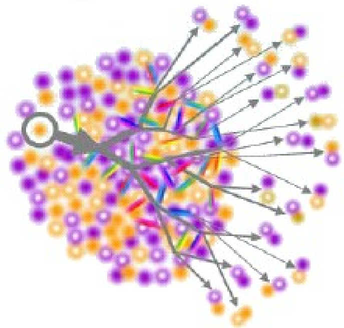
E.2 – Observables : Layer 2 / as a function of *momentum*

A. low-p_T "collectivity" ($p_T \leq$ 2-3 GeV/c)



≈ relativistic hydrodynamics,
barely viscous

B. high-p_T "collectivity" ($p_T \geq$ 6-8 GeV/c)

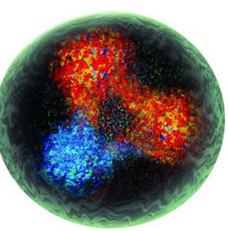


≈ in-medium energy losses for energetic particles

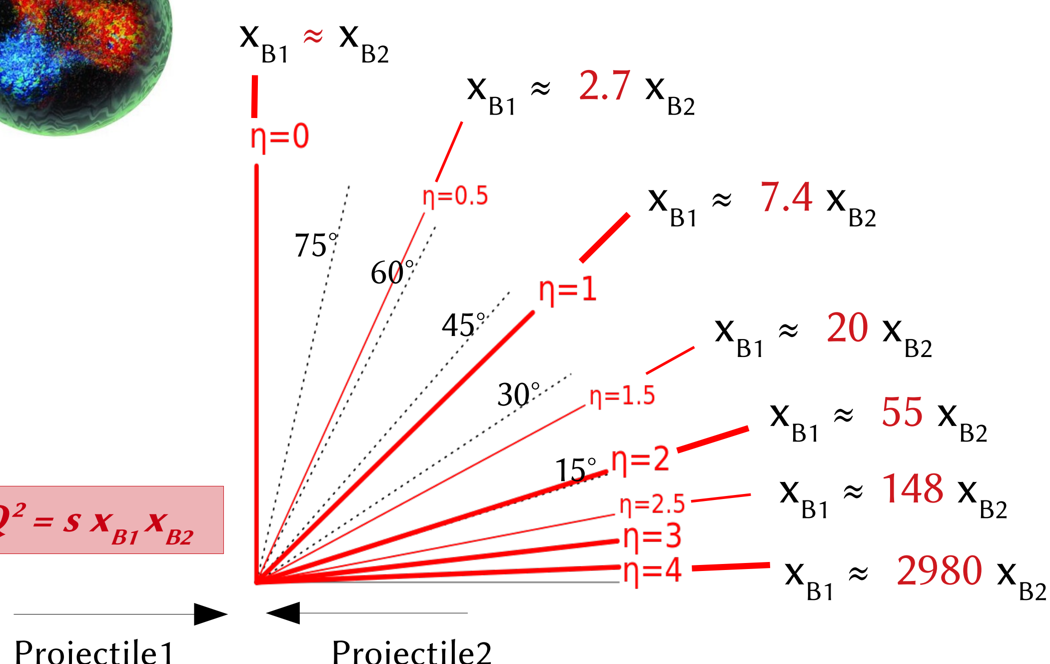
E.3 – Observables : Layer 3 / as a function of y (twice)

Initial state			*Longitudinal dynamics*		
I.	ultra-low x_B	($x_B \leq 10^{-5}$)	I'.	$\|y\| < 2$	: max = rapidity plateau in $dN_{ch}/d\eta$
II.	low x_B	($x_B \in [10^{-5} ; 10^{-3}]$)	II'.	$\|y\| \approx 3.5$	: 75% $(dN_{ch}/d\eta)_{max}$
III.	moderate x_B	($x_B \in [10^{-3} ; 10^{-1}]$)	III'.	$\|y\| \approx 5.0$	: 45% $(dN_{ch}/d\eta)_{max}$

JLab

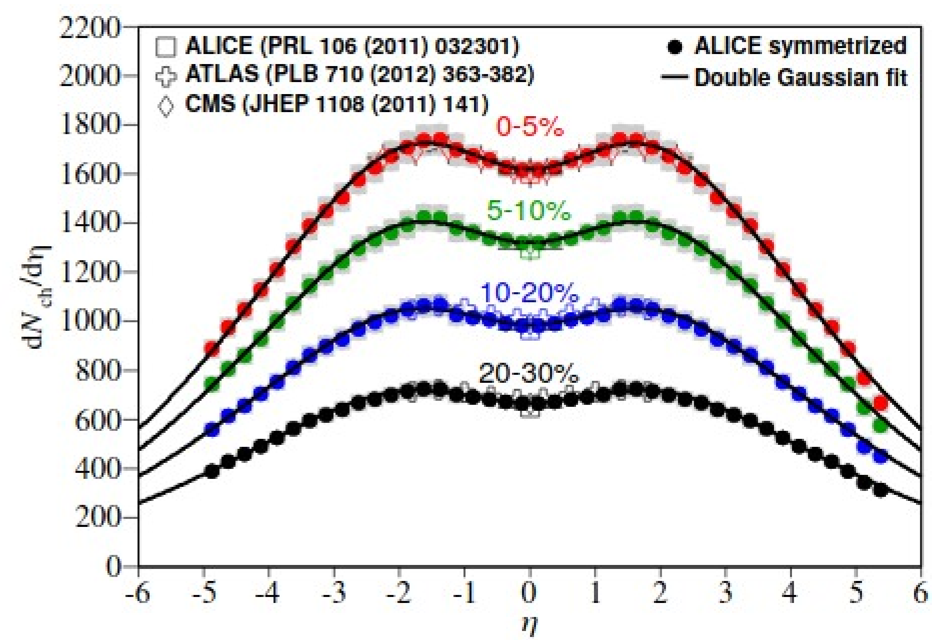


$Q^2 = s\, x_{B1} x_{B2}$



* if y ≈ η (m << p)
+ same type of beams (A_i/Z_i)

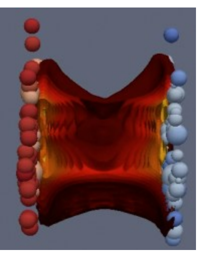
ALICE, arXiv:1304.0347



E.4 – Observables : Layer 4 / as a function of flavours

« hadron-quark duality »

$g + u,d,s,c,b\ (t)$ <=>



u,d,s

- $\pi^{\pm}\ \pi^{0}\ K^{\pm}\ K^{0}_{S}$ … $p\ \Lambda\ \Sigma^{\pm}(uus)\ \Xi^{\mp}(dss),\ \Omega^{\mp}(sss)$ …

  $\eta(547)\ \omega(782)$ … $K^{0}(892)\ \phi(1020)\ \Sigma^{\pm}(1385)\ \Lambda(1520)\ \Xi^{0}(1530)$

  $+\ d\ t\ {}^{3}He^{2+}\ {}^{4}He^{2+}$ …

  $+\ {}^{3}_{\Lambda}H,\ {}^{4}_{\Lambda}\overline{He}^{2+} \longrightarrow {}^{3}He^{2+}\ p\ \pi^{-}$.

c

- $D^{0}\ D^{+}\ D^{*+}\ D_{S}^{+}$… $\eta_{c}\ J/\psi\ \chi_{Ci}\ \psi(2S)$ …

  $\Lambda_{C}^{+}(udc) \longrightarrow pK^{-}\pi^{+}$ or $pK^{0}s$ $(c\tau \approx 60\ \mu m)$

  $\Xi_{C}^{+}(usc) \longrightarrow pK^{-}\pi^{+}$ or $\Xi^{-}2\pi^{+}$ $(c\tau \approx 136\ \mu m)$

  $\Xi_{C}^{0}(dsc) \longrightarrow \Xi^{-}\pi^{+}$ $(c\tau \approx 45\ \mu m)$

  $\Omega_{C}^{0}(ssc) \longrightarrow \Omega^{-}\pi^{+}$ $(c\tau \approx 80\ \mu m)$

  $\Xi_{CC}^{2+}(ucc)$, … , $\Omega_{CCC}^{2+}(ccc)$

  + *c*-deuteron $(\Lambda_{c}n)^{+} \longrightarrow dK^{-}\pi^{+}$? *c*-triton $(n\Lambda_{c}n)^{+}$?

  tetraquark $[X(3872) \longrightarrow J/\psi\ \pi^{+}\ \pi^{-}]$, T_{CC}^{+}

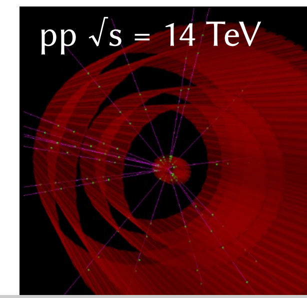
b

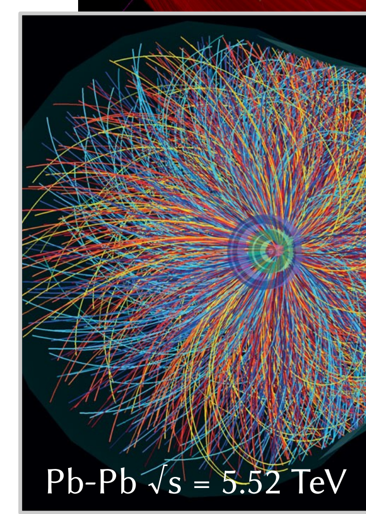
- heavy-flavour $(\mu^{\pm}, e^{\pm})$
- $B^{0}\ B^{\pm}\ B^{0}_{S}$ … $\Upsilon(1S,2S,3S)$…

  $\Lambda_{b}^{0}(udb) \longrightarrow \Lambda_{C}^{+}\pi^{-}$ … $\Xi_{B}^{-}(dsb),\ \Omega_{B}^{-}(ssb)$

(• $e^{\pm}\ \mu^{\pm}\ \gamma$)

(• $W^{\pm}\ \gamma/Z^{\circ}$)





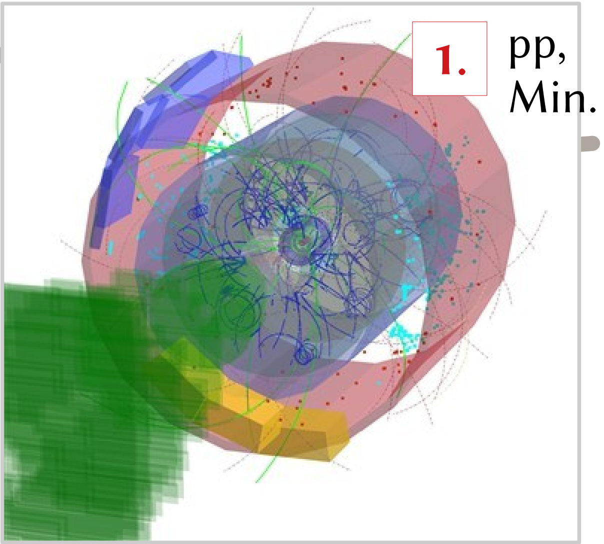
NB :

baryons Vs mesons

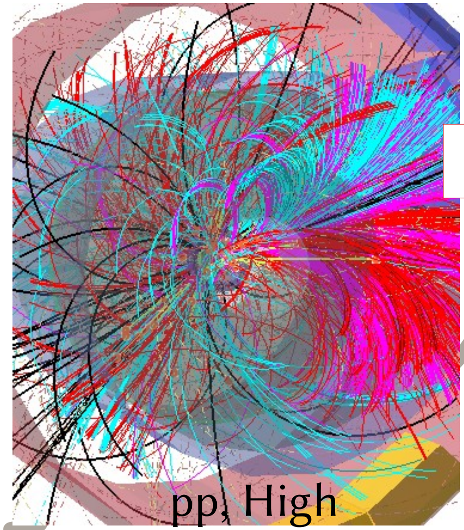
mixed flavours (s+c, s+b, … c+b …)

E.5 – Observables : Layer 5 / as a funct° of the coll° system

1. pp,
Min. Bias

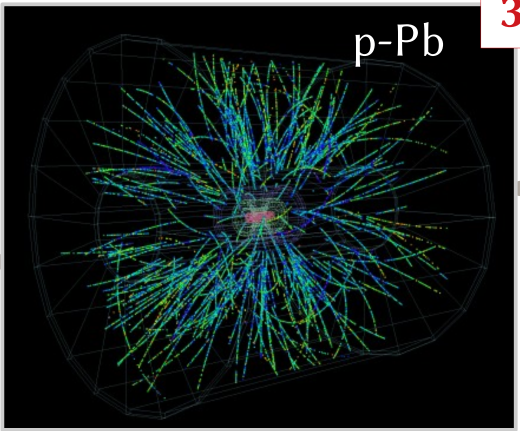


2.

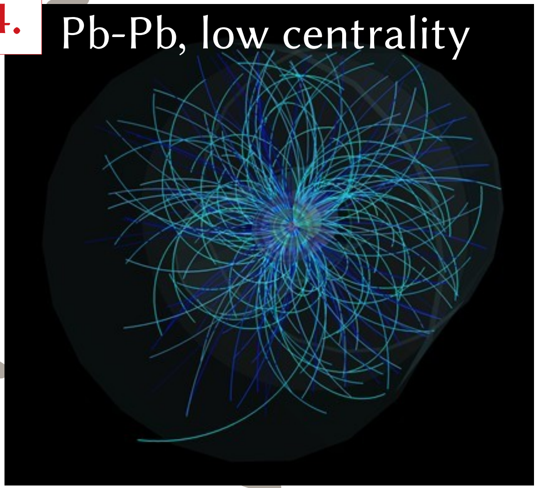


pp, High
Multiplicity

3. p-Pb

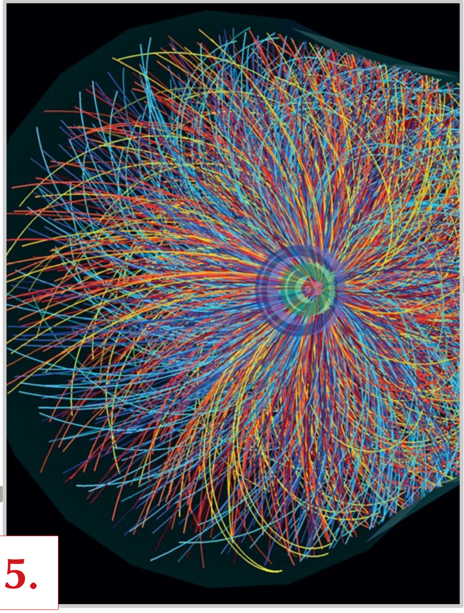


4. Pb-Pb, low centrality



Pb-Pb,
most central events

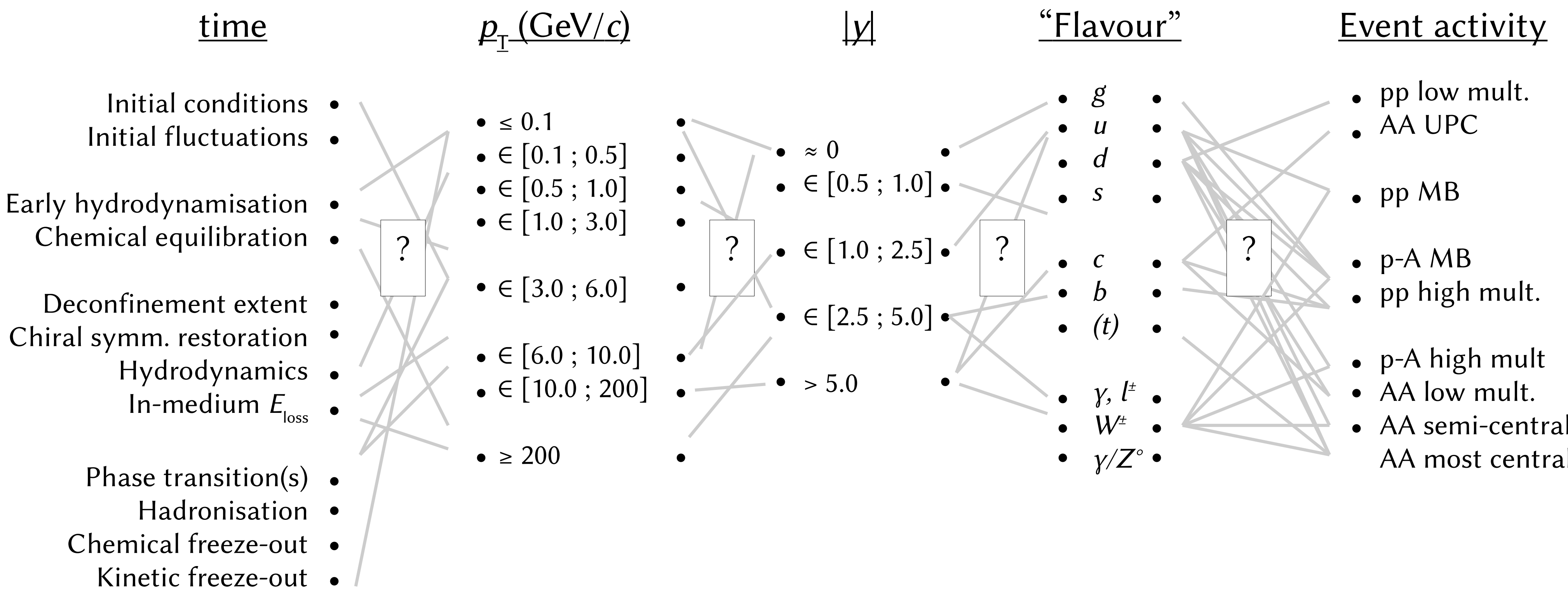
5.



CDS/record-1305398

E.6 – Observables : paths through the multi-layer mesh

The multi-variate and interleaved families of QCD+QGP observables :



(HL-)LHC watchword for (≥Run III) : "precision era" pushed on many fronts

i.e. fight for (σ_{stat} ≈ negligible) ⊗ (σ_{syst} ≤ 1-5%) as much as possible

Note : QCD+QGP physics is both i) a bulk physics + ii) a rare-probe physics
⟶ Nowadays, precision then implies extreme cases on both fronts ... (*i.e.* also for abundant observables)
(e.g. *multi-differential, multi-correlated probes, ≤ 1 High-Mult. evt every [10^6-10^9] MB pp evts ...*)

App F . – Physics cases

F.1 – Questions in ≈2036 : 10 benchmark questions

01. What are the thermodynamic properties of the QGP at the LHC?

02. What are the hydrodynamic and transport properties of the QGP?

03. How does the QGP affect the formation of hadrons?

04. How does the QGP affect the propagation of energetic partons ?

05. How does deconfinement in the QGP affect the QCD force ?

06. Can the QGP lead to discovery of novel QCD effects?

07. What are the limits/minimal conditions of QGP formation?

08. What is the nature of the initial state of heavy-ion collisions ?

09. What is the nature of hadron–hadron interactions?

10. Can ALICE tackle some BSM physics ?

Benchmarking our Research through the years

e.g.
ALICE white paper
= Runs 1+2 outcome

Questions present in:
- Introduction (where we were before /outside LHC)
- Conclusion (where we are after ALICE Runs1+2)

ALICE Review Paper, arXiv:2211.04384

F.2 – Questions in ≈2036 : answers by ALICE 3

	Questions	ALICE 3 answers
01	Thermodynamics	T_{e+e-} , net quantum fluctuations
02	Hydrodynamics+ transport	Diffusion coefficient for c,b, v_n(HF baryons and mesons)
03	Hadronisation	Family of multi-HF hadrons (Ξ_{CC} et al), beauty hadrons beyond $B^{0,\pm}$
04	Energetic-parton propagation	D-$\overline{D}$ correlations (e.g. D^0-$\overline{D}^0$) in AA, fully-tag HF jets, recoil jet techniques
05	In-medium impact on QCD force	$\eta_C \rightarrow$ baryons, $J/\psi \rightarrow \mu\mu$, χ_{Cj}
06	Novel QCD effects	Chiral Magnetic Effect (CME), Disoriented Chiral Condensate (DCC)
07	Roots of collectivity	High multiplicity (pp, pA) with low bias, light-ion "scan"
08	Initial stage	UPC γ-Pb vector mesons (J/ψ, ...), D-$\overline{D}$ correlations in pA (e.g. D^0-$\overline{D}^0$), CGC with FoCal
09	Hadron-hadron interaction	D^x-D^y pairs (x≠y), $\chi_{C1}(3872)$, T_{CC}, nuclei A≤6, hypernucl A=4, charm nuclei c-deuteron (Λ_C^+n)
10	BSM search	γγ scattering with m < 5 GeV/c^2, axion-like particle search

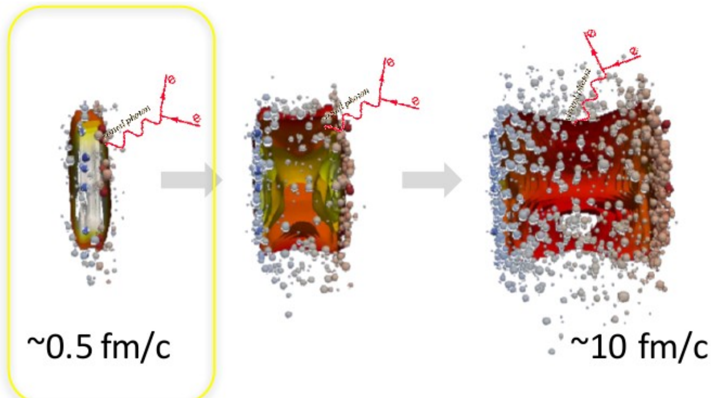
ALICE 3 LoI, arXiv:2211.02491
ALICE Review Paper, arXiv:2211.04384, Outlook
ALICE 3 Scoping Document CERN-LHCC-2025-002

F.3 – HL-LHC QCD+QGP : for which physics cases ?

1. Measuring QGP temperature = f(time) [low mass e^+e^-]
2. Nature of phase transitions (deconfinement + chirality) :
   Connecting to LQCD + asserting Hydrodynamics [ultra low p_T]
3. Understanding in-medium energy loss [Jets shapes and structures]
4. Challenging the flavour dependence of collectivity [*s*,*c*,*b*]
5. Searching for "SM/BSM" [...]

F.4 – HL-LHC QCD+QGP : low mass (e^+e^-) as virtual γ

1. QGP temperature = *f*(time) via thermal virtual photons ($m_{e+e-} \in [0;2.5]$ GeV/c^2)
   → high m_{e+e-} = high T, *i.e.* early times



R. Rapp Acta Phys.Polon. B42 (2011)

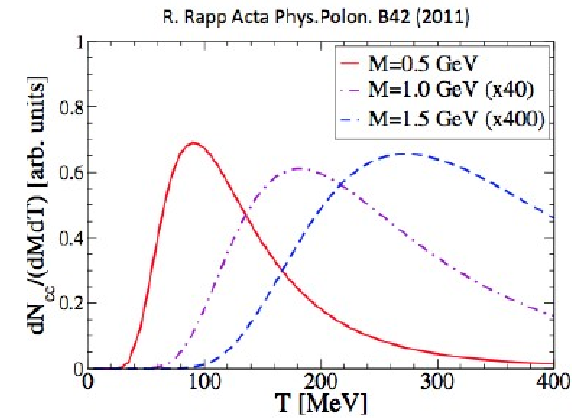
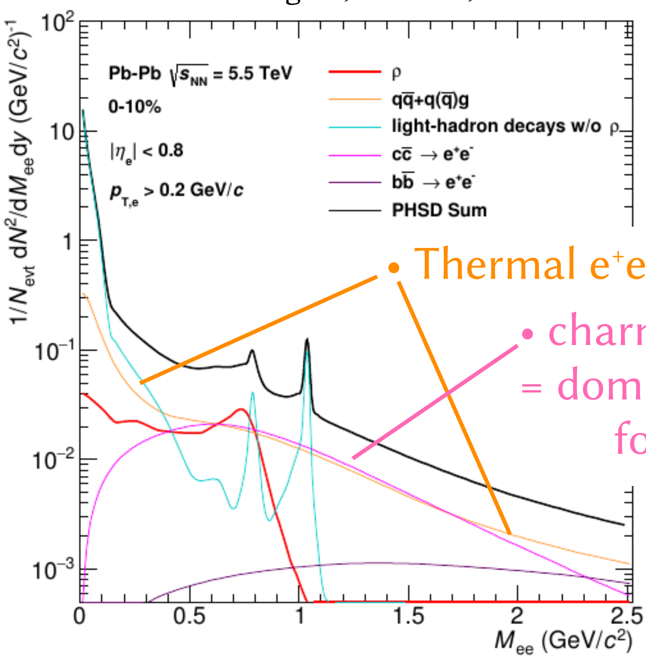


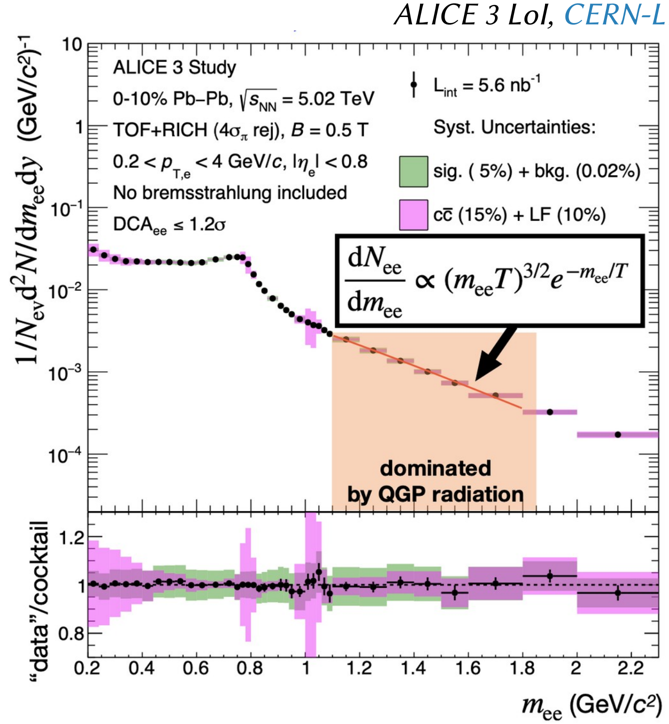
Fig. 54, YR WG5, arXiv:1812.06772



- Thermal e^+e^- signal
- charm semi-leptonic decays = dominant bckgnd for $m_{ee} > 1$ GeV/c^2

NB :
→ so, very good control on charm = a must

ALICE 3 LoI, CERN-LHCC-2022-009



$$\frac{dN_{ee}}{dm_{ee}} \propto (m_{ee}T)^{3/2} e^{-m_{ee}/T}$$

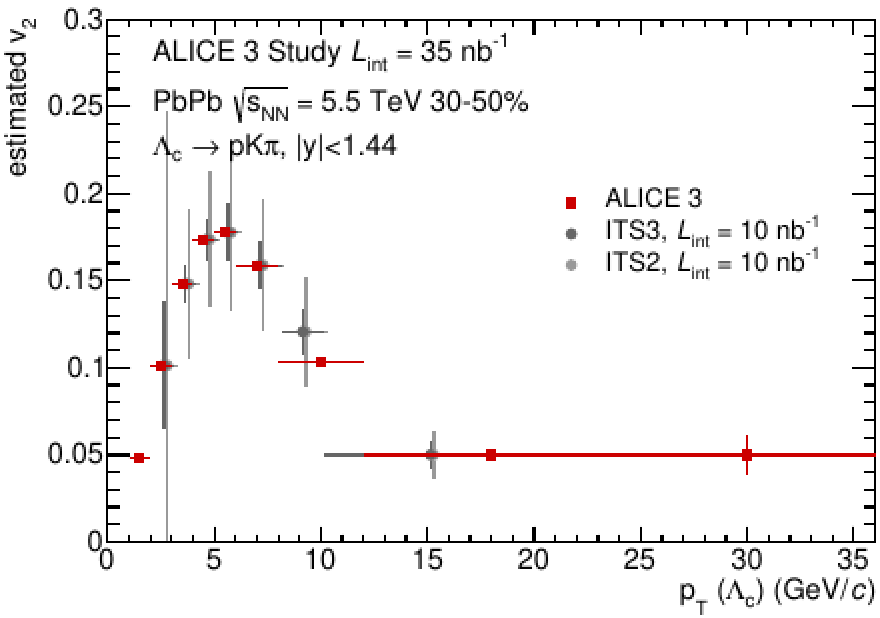
F.5 – Pb-Pb : why take still Pb-Pb data ?

How much smaller than v_2(charm) is v_2(beauty) ? Is v_2(beauty) ≠ 0 ?

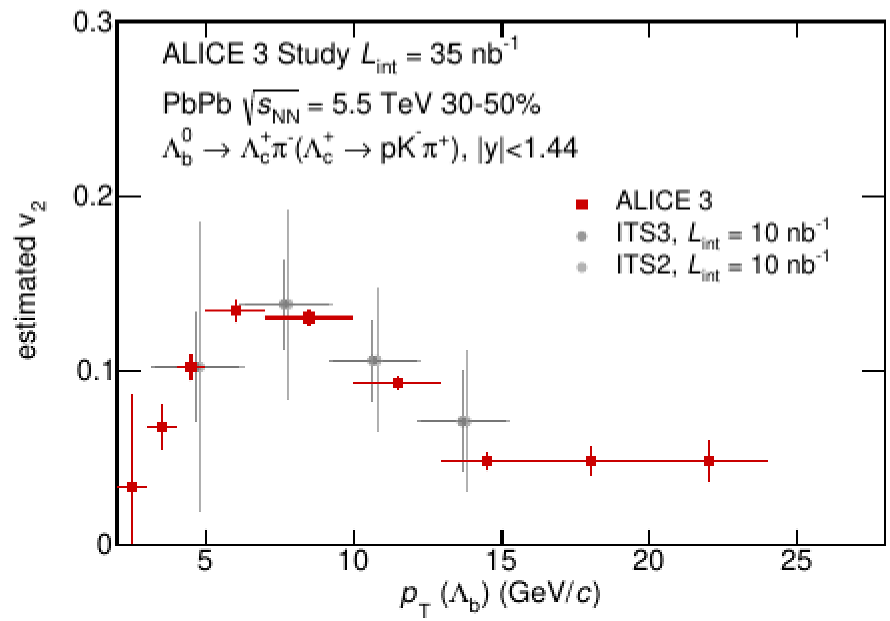
→ Examples of accuracy for single-HF baryons

(Note: some hypotheses for scale of v2 for charm, for beauty below… but important = size of σ_{tot})

Λ_C^+(*udc*) (m = 2.286 GeV/c^2 / cτ = 60 µm)



Λ_B^0 (*udb*) (m = 5.619 GeV/c^2 / cτ = 441 µm)



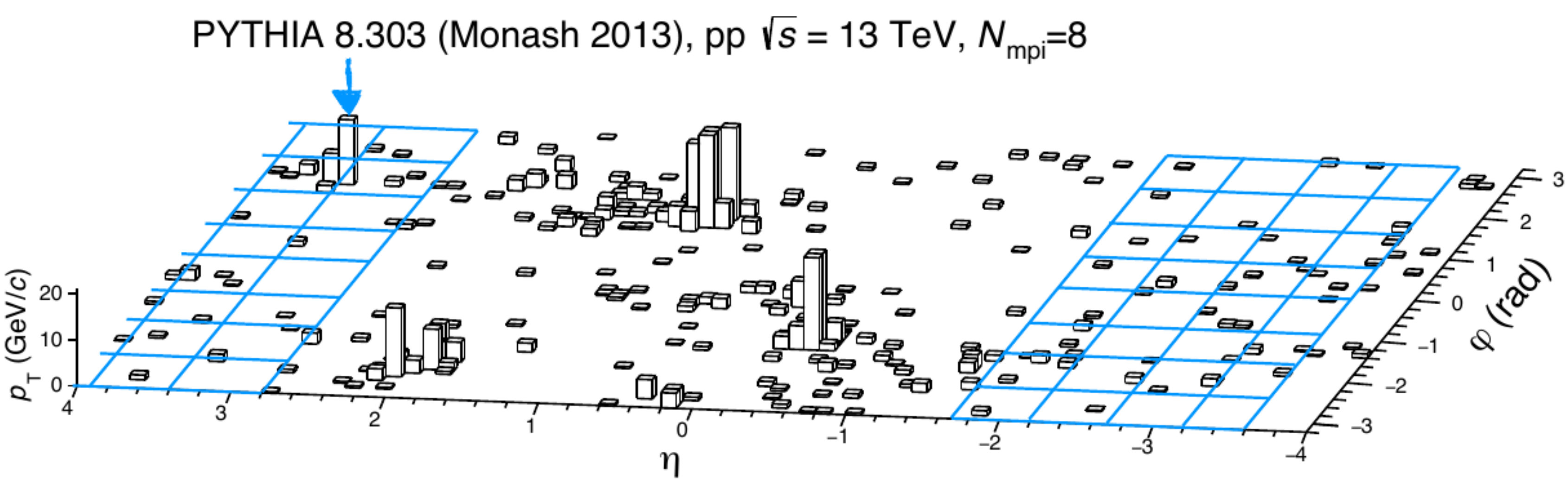
Key of improvement between ALICE 2.0 (run 3), ALICE 2.1 (run 4) and ALICE 3 ?

$\not\approx L_{int}$, but rather the instrument: ALICE 3 pointing resolution and AxEff

F.6 – ~~Pb-Pb~~ but sthg else : smaller systems for *themselves*

"Root of collectivity"

1. Collect higher luminosities of small systems …
2. with a more suitable camera :
Investigate lighter ions (Xe, Kr, Ar, O, …) down to pp
with a large acceptance in [η, (ultra) low pT]
i.e. with less bias in the event activitiy estimator
(multiplicity, R_T, jet veto, flattenicity, …)

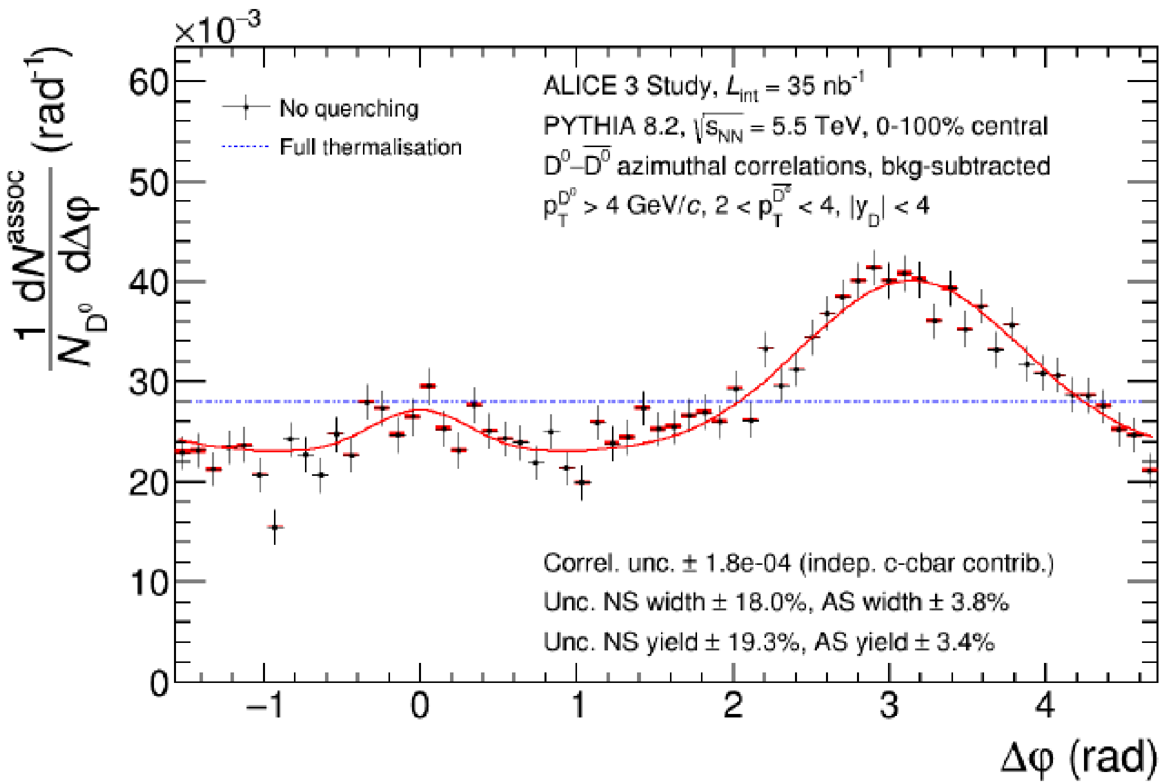


If you look only in the blue windows (*VZERO acceptance ALICE1*)…
You may miss fluctuations in MPI that lead to jets…

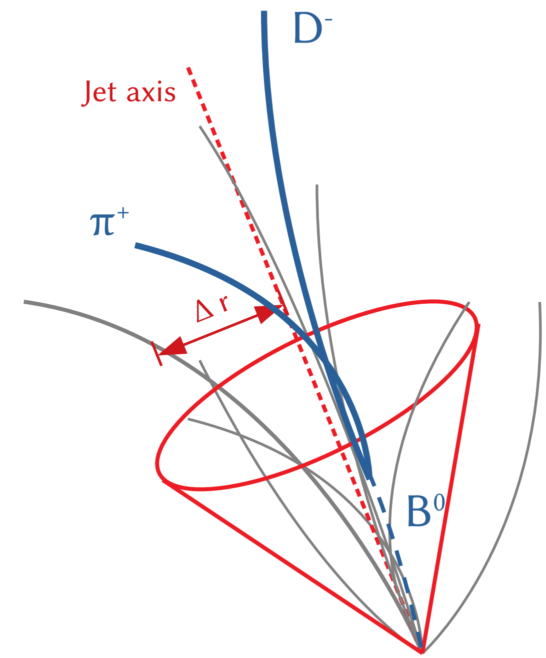
Ortiz, SQM2024

F.7 – ~~Pb-Pb~~ but sthg else : smaller systems as *opportunities*

Higher raw signal (higher luminosities wrt Pb-Pb/ less background) vs. still ∃ sensitivity to collective medium ?



1. D-$\overline{\text{D}}$ (de)correlations in AA



2. Fully-tagged HF jets
(full topological reconstruction
of HF hadrons, within/near jets)

F.8 – Particle Identification : PID with TOF + RICH

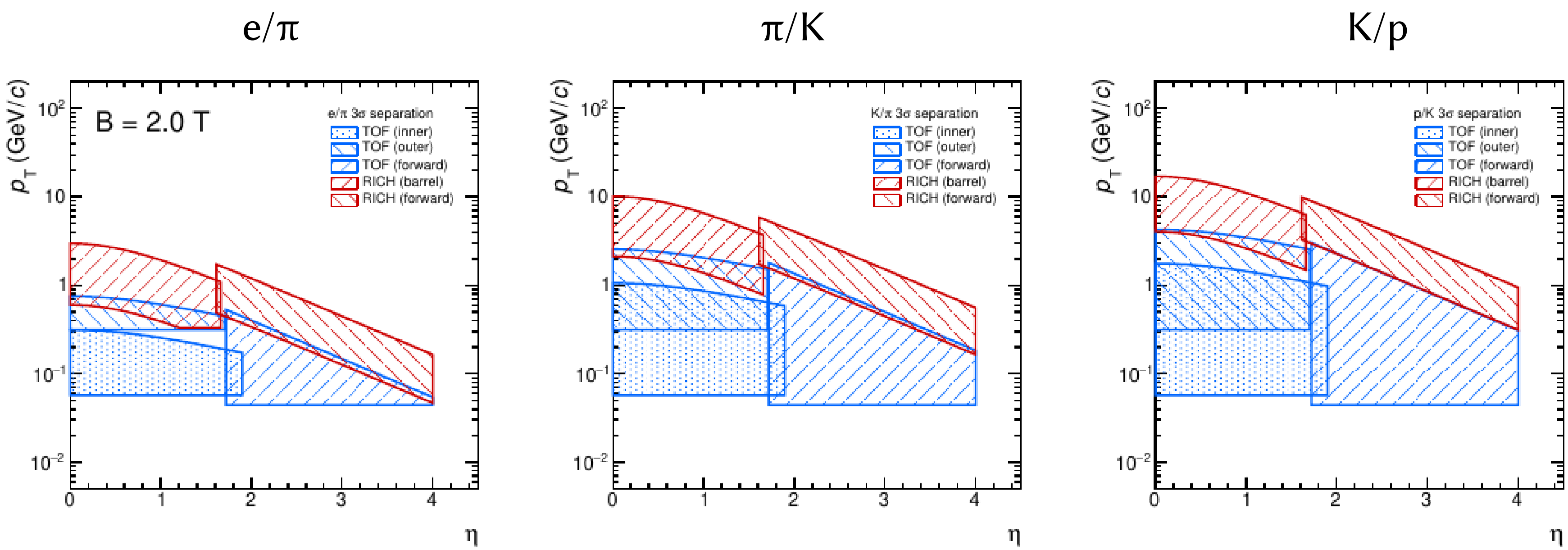


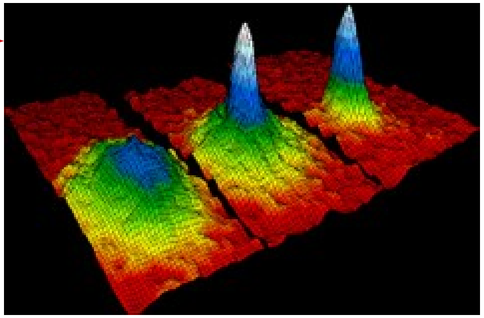
Figure 20: Analytical calculations of the $\eta - p_T$ regions in which particles can be separated by at least 3σ for the ALICE 3 particle-identification systems embedded in a 2.0 T magnetic field. Electron/pion, pion/kaon and kaon/proton separation plots are shown from left to right.

[Note the lowest p_T boundaries ...]

F.9 – Particle Identif° : why care about the low-p_T (π,K,p)

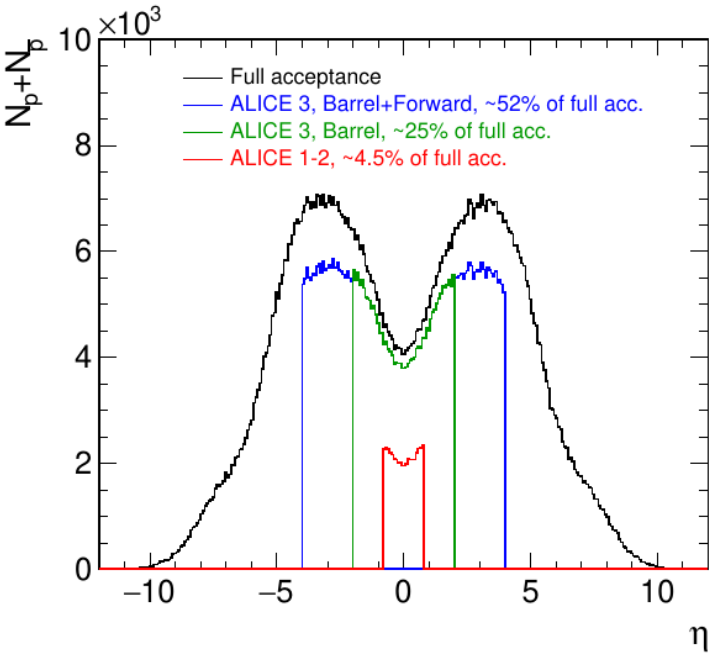
1. Getting $dN/dp_T dy$ + $v_n(h^{\pm})$ down to non-relativistic p_T (e.g. $p_T < 0{,}05$ GeV/$c \longrightarrow \beta_{\pi^{\pm}} \approx 0{,}34$)
$\longrightarrow$ change from non-relativistic (linear) to relativistic hydro. (quadratic behaviour)

2. Disoriented Chiral Condensate or π condensate
if present at all, will be at $p_T < 1/2\ m_{\pi}$



Wikipedia: Bose-Einstein condensate

3.



ALICE 3 LoI, CERN-LHCC-2022-009, Fig. 62 p.112

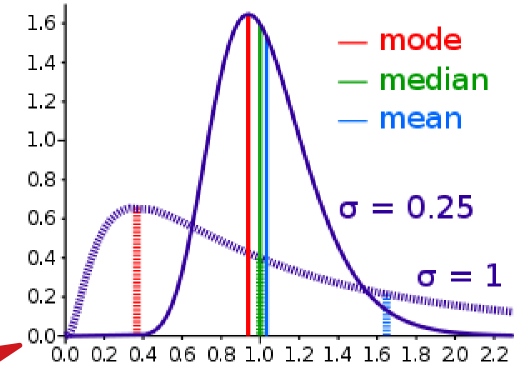
Increase of acceptance when moving from
$0.6 < p_T < 1.5$ GeV/c, in $|\eta| < 0.8$ (ALICE2)
to
$0.3 < p_T < 10.0$ GeV/c, in $|\eta| < 4.0$ (ALICE3)
(0.3 ?! why not lower ?
$\longrightarrow$ to get AxEff. ~flat with p_T for identity method)

IV.5 – Part. Identification : ex. of net quantum fluctuations

Net quantum number fluctuations at ($\mu_B = 0$)

1.

- **Q** : net charge (h^+ - h^-),
- **B** : net baryon (p - $\bar{\text{p}}$, Λ - $\bar{\Lambda}$, ...)
- **S** : net strangeness (K^+ - K^-, Λ - $\bar{\Lambda}$, ...)



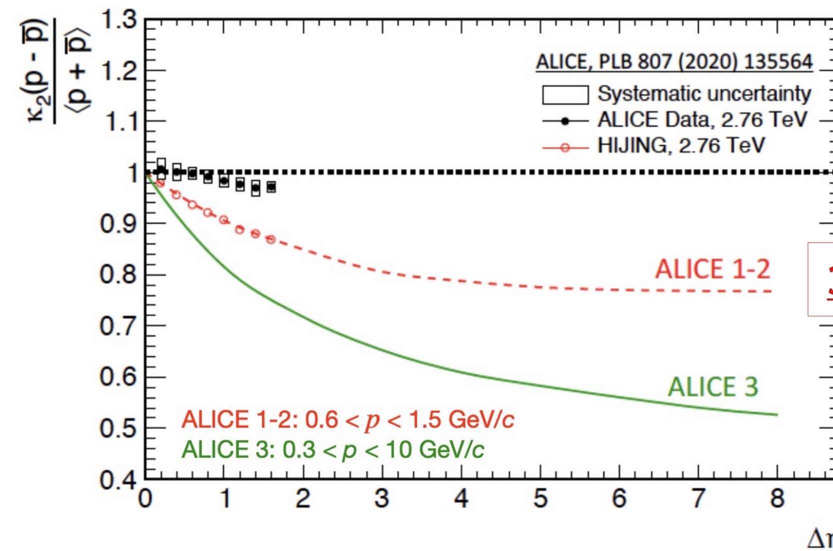
Wikipedia:Skewness

Measure event-by-event fluctuations into **distributions** with $p_T > 0$ GeV/c + over large y

2.

(i.e. p_T-integrated quantities)

- 1st moment, m_1 : mean M
- 2nd moment, m_2 : variance σ^2
- 3rd moment, m_3 : $\propto$ skewness S
- 4th moment, m_4 : $\propto$ kurtosis κ
- 5th moment, m_5 : *no name*
- 6th moment, m_6 : ...
- 7th moment, m_7 : ...



3.

+ 4σ observation at reach for κ6(p-p)/κ2(p-p)...

→ *key* : ratios m_j/m_i (e.g. m_4^B/m_2^B)

to access direct comparison to LQCD for

(deconfinement d.o.f.

+ chiral restoration

+ nature of transitions)

4.

See also EMMI, arXiv:2001.08831