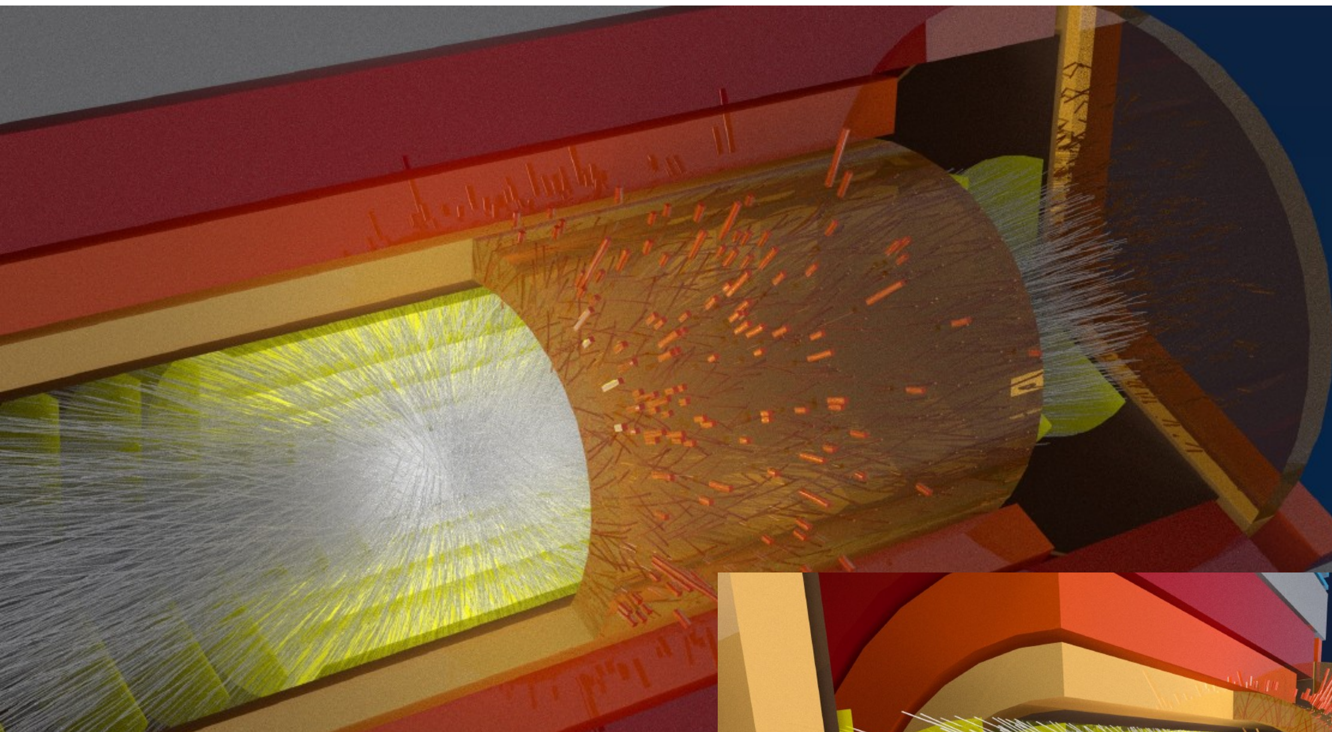
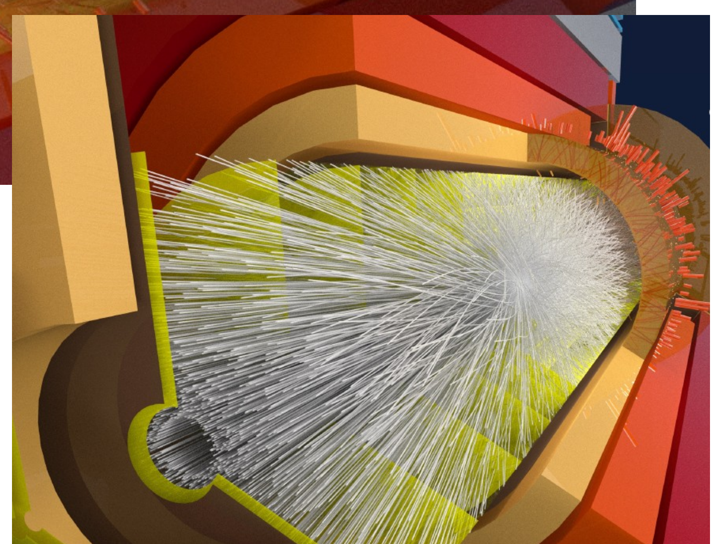
Antonin MAIRE, for the ALICE Collaboration

Monday, 21 Oct. 2024 – **Perspectives in High-Energy Nucl. Phys.**

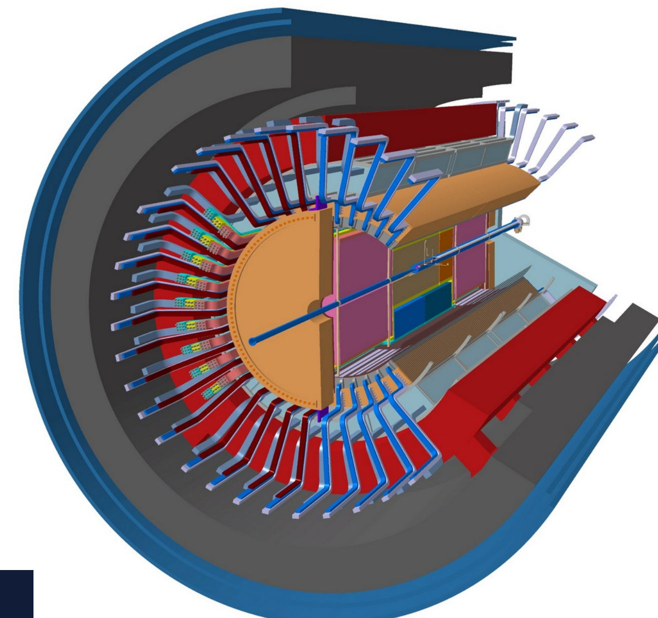
https://indico.cern.ch/event/1430136/

ALICE 3 physics programme, some aspects…





Courtesy David Chinellato (2022)
PYTHIA8 Angantyr Pb-Pb 5.02 TeV



Corrado Gargiulo's courtesy
ALICE3 days 2024-03

Outline

A. HL-LHC calendar (timeline context)

B. Physics landscape and related questions

C. Proposed ALICE 3 answers at HL-LHC:

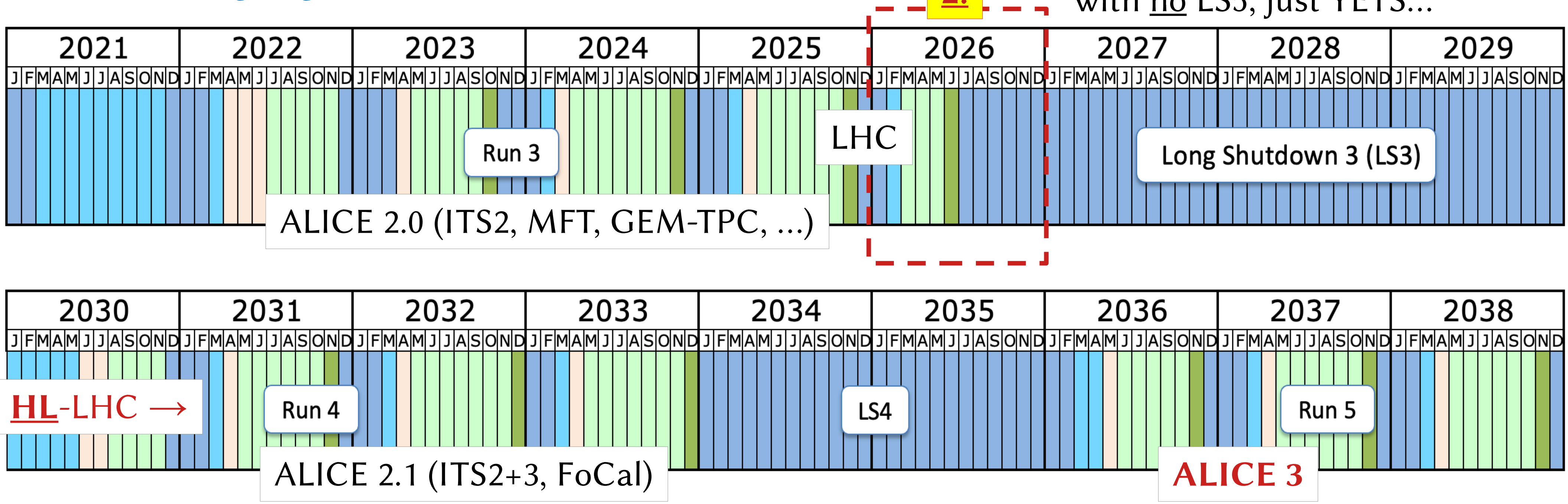
instrumental features to meet given physics questions

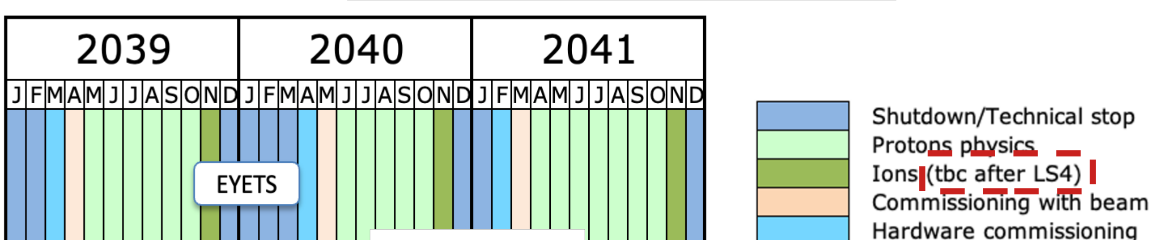
I.1 – HL-LHC : projected timeline and calendar

NEW : Extension of Run 3, now acted !
→ ≈ Mass shift of the HL-LHC…
with no LS5, just YETS…

LHC-commissioning - Long term

2.





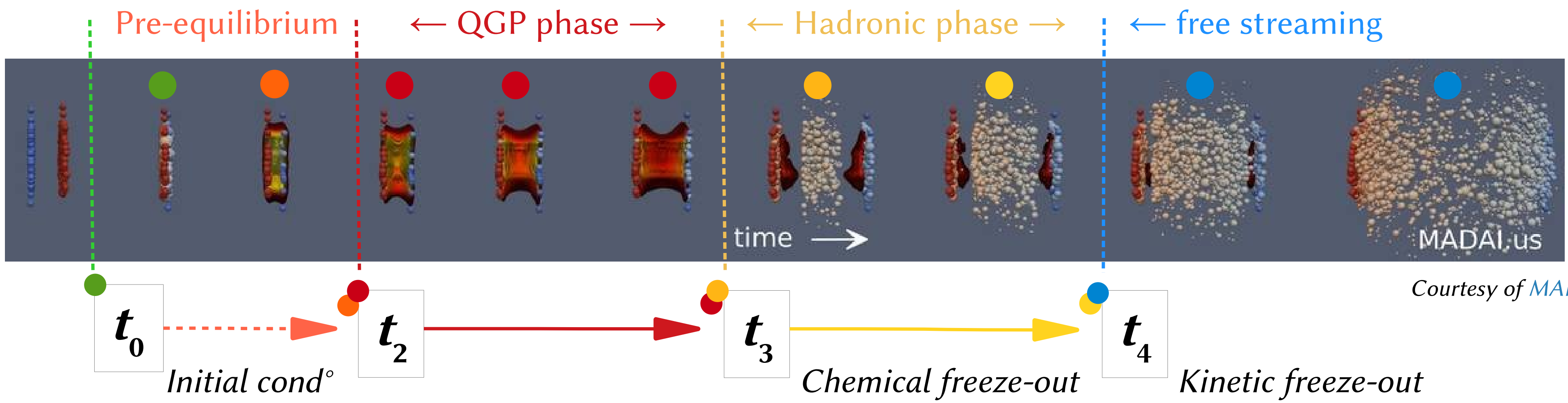
Last update: September 24

1.

3.

"Question 0" to tackle, before anything …
Good physics prog. → Ion runs, enabled
(∃ strong recommendation to have ions after LS4 already in European Strategy ESPP 2020.
To be strengthened in ESPPUpgr 2025…)

II.1 – The picture : towards a heavy-ion standard model



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

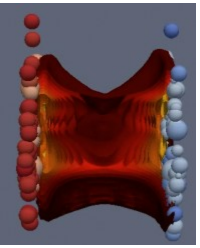
2.
- Degrees of freedom
- Phase transitions :
  . Chiral symm. restoration
  . Deconfinement
- Eq° of State
- Transport coefficients
- Radiative/Collisional E_{loss}

…

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

II.2 – Physics incentives : response as f(quark flavour)

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



u,d,s

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

  η(547) ω(782) … K^{0}(892) ϕ(1020) $\Sigma^{\pm}$(1385) Λ(1520) Ξ^{0}(1530)

  + d t $^{3}He^{2+}$ $^{4}He^{2+}$ …

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

c

- (D^{0} D^{+} D^{*+} D_{S}^{+})… η_{c} J/ψ χ_{Ci} ψ(2S) …

  Λ_{C}^{+}(*udc*) $\longrightarrow$ $pK^{-}\pi^{+}$ or $pK^{0}s$ ($c\tau \approx$ 60 μm)

  Ξ_{C}^{+}(*usc*) $\longrightarrow$ $pK^{-}\pi^{+}$ or $\Xi^{-}2\pi^{+}$ ($c\tau \approx$ 136 μm)

  Ξ_{C}^{0}(*dsc*) $\longrightarrow$ $\Xi^{-}\pi^{+}$ ($c\tau \approx$ 45 μm)

  Ω_{C}^{0}(*ssc*) $\longrightarrow$ $\Omega^{-}\pi^{+}$ ($c\tau \approx$ 80 μm)

  Ξ_{CC}^{2+}(*ucc*), … , Ω_{CCC}^{2+}(*ccc*)

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

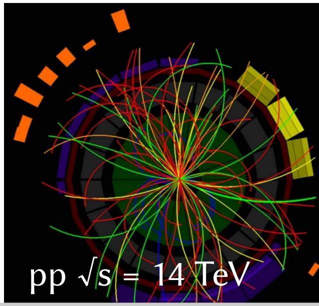
  tetraquark [X(3872) $\longrightarrow$ J/ψ π^{+} π^{-}], T_{CC}^{+}

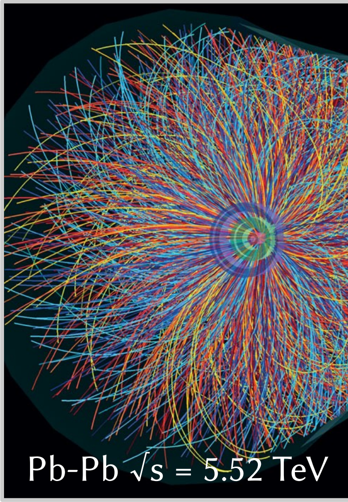
b

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

  Λ_{b}^{0} (*udb*) $\longrightarrow$ $\Lambda_{C}^{+}\pi^{-}$ … Ξ_{B}^{-}(*dsb*), Ω_{B}^{-} (*ssb*)

(• $e^{\pm}$ $\mu^{\pm}$ γ)
(• $W^{\pm}$ γ/Z°)





II.3 – 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

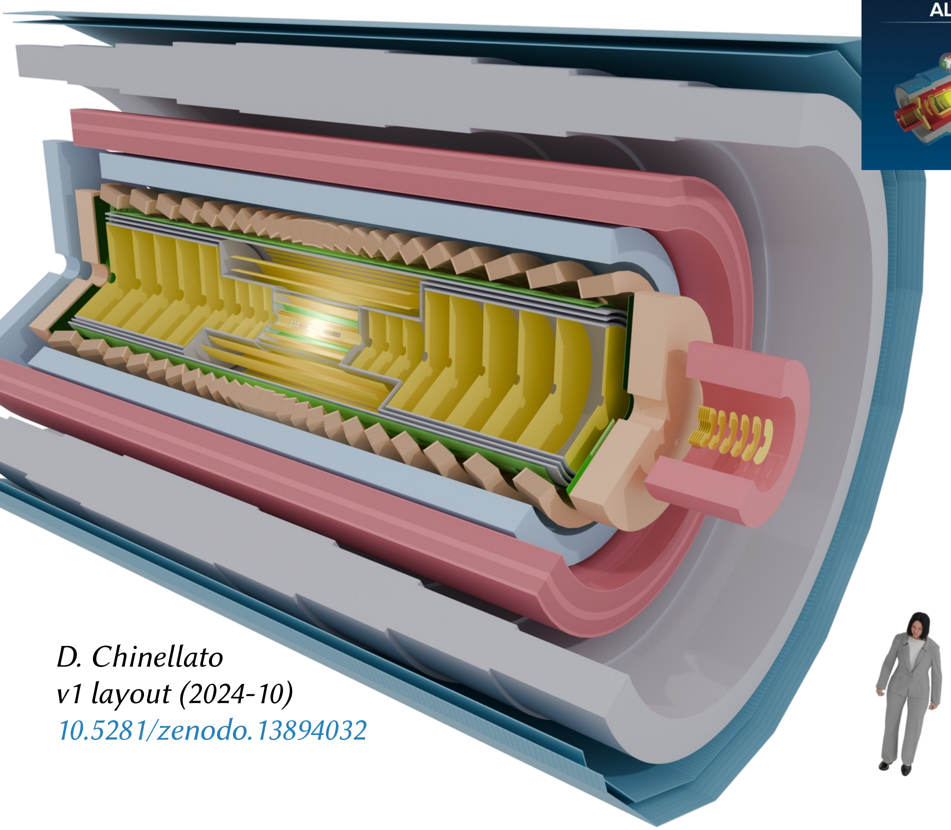
II.3 – Questions in ≈2036 : answers by ALICE 3

	Questions	ALICE 3 answers (including physics interests by French community)
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/ψ → μμ, 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), χ_{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 Draft:10248 (LHCC)

III.1 – ALICE3 layout v1 : key features

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



D. Chinellato
v1 layout (2024-10)
10.5281/zenodo.13894032

3.

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

2.

with **PID** capabilities
(iTOF, oTOF, fTOF, bRICH, fRICH
ECal, μ)
over an **acceptance** as wide as possible :
- $|\eta|$ < **3.5 - 4**
- $p_T \in$ [**0.05** ; $\mathcal{O}$(10)] GeV/c

1.

To collect integrated **MB luminosities** :
≈ 24 MHz (pp)
≈ 100 kHz (Pb-Pb) recorded readout
- $\mathcal{O}$(0.5 fb^{-1}) / month pp
- $\mathcal{O}$(5.6 nb^{-1}) / month Pb-Pb

IV.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

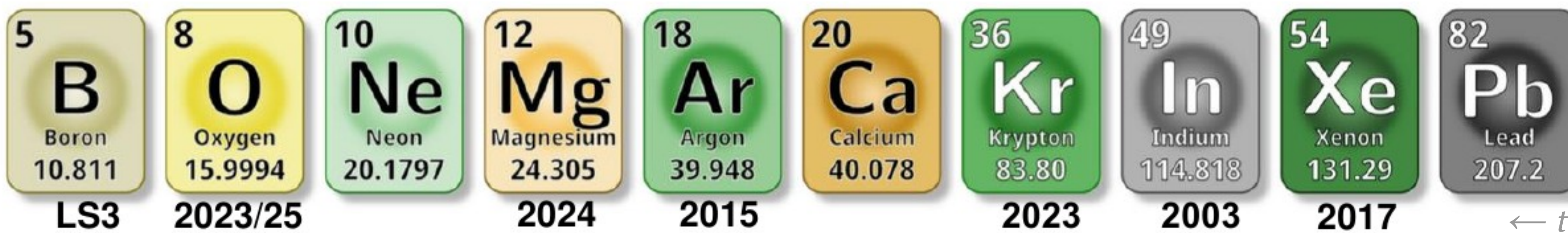
	pp (**2024**) ALICE 2	pp (2018) ALICE 1	Pb-Pb (**2023**) ALICE 2
$\sqrt{s_{NN}}$ (TeV)	13,6	13	5,36
L_{AA} ($cm^{-2}s^{-1}$)	$1\text{x}10^{31}$	$3\text{x}10^{30}$	$3{,}5\text{x}10^{27}$
$\mathscr{L}^{month}_{AA}$ (MB nb^{-1})	≈ $5\text{x}10^{3}$ nb^{-1}	≈ 2 nb^{-1}	≈2.0 nb^{-1}
$\langle R_{max}\rangle$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

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

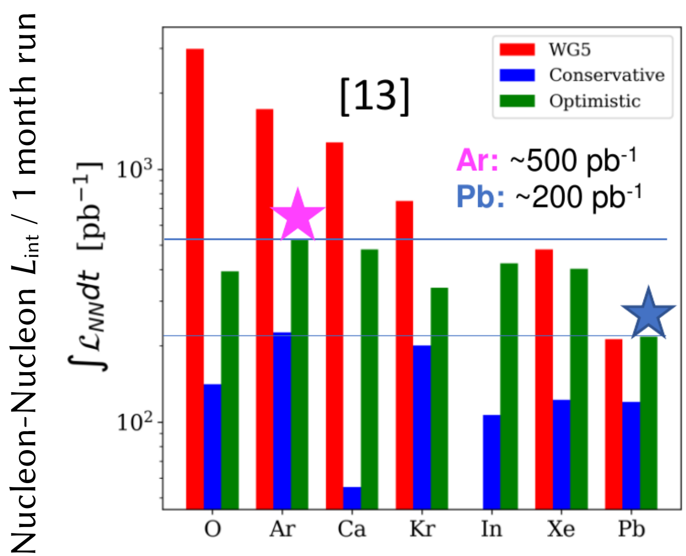
bpt.web.cern.ch/statistics

(Par.1) – HL-LHC : large- to small-ions, uncertainties on $\mathscr{L}$

R. Alemany Fernandez, LHCP2024
(Elias Waagaard, ALICE Upgrade Week 2024-10 + See coming workshop indico.cern:lightions)



← *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/physics performance ?

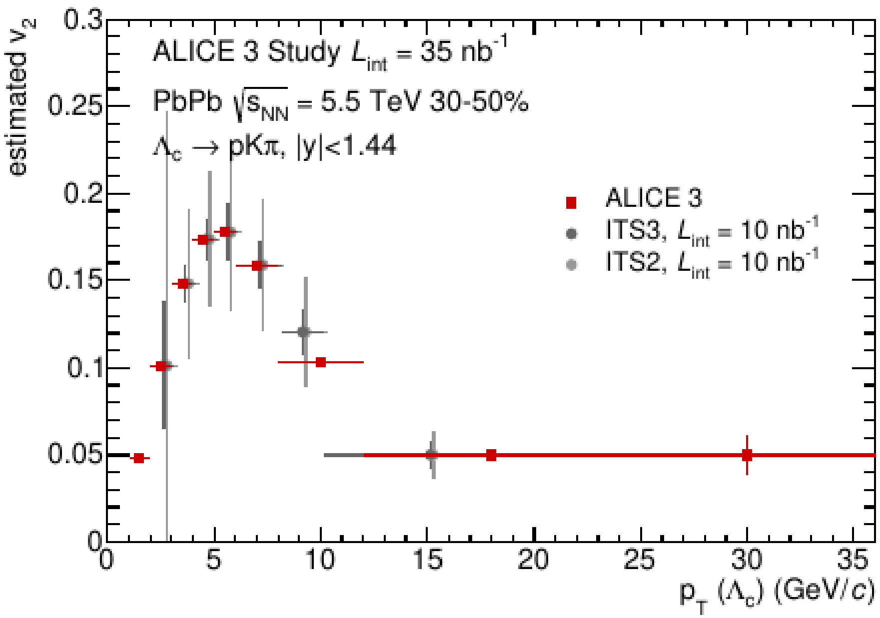
IV.2 – Pb-Pb : why take still Pb-Pb data ?

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

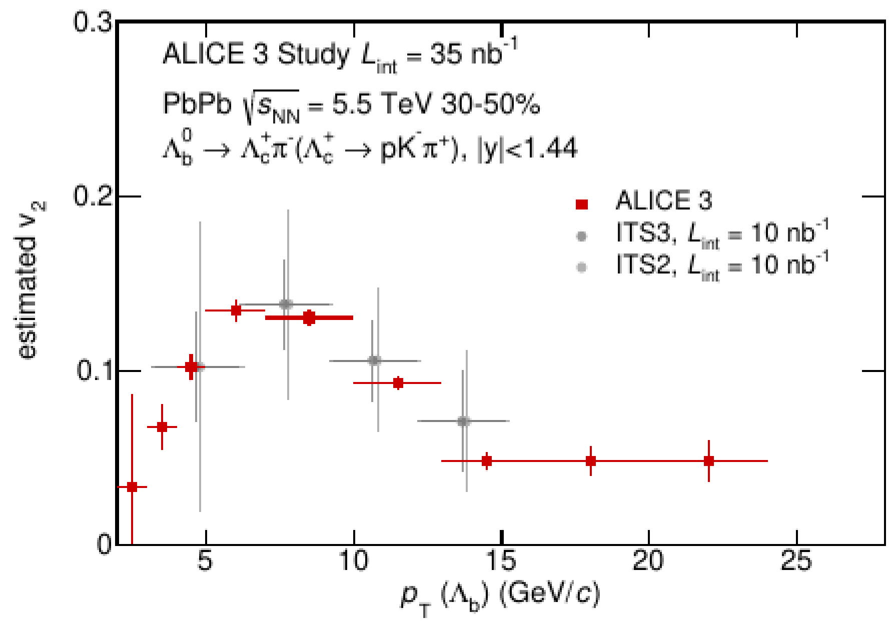
→ Examples of accuracy for single-HF baryons

(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)



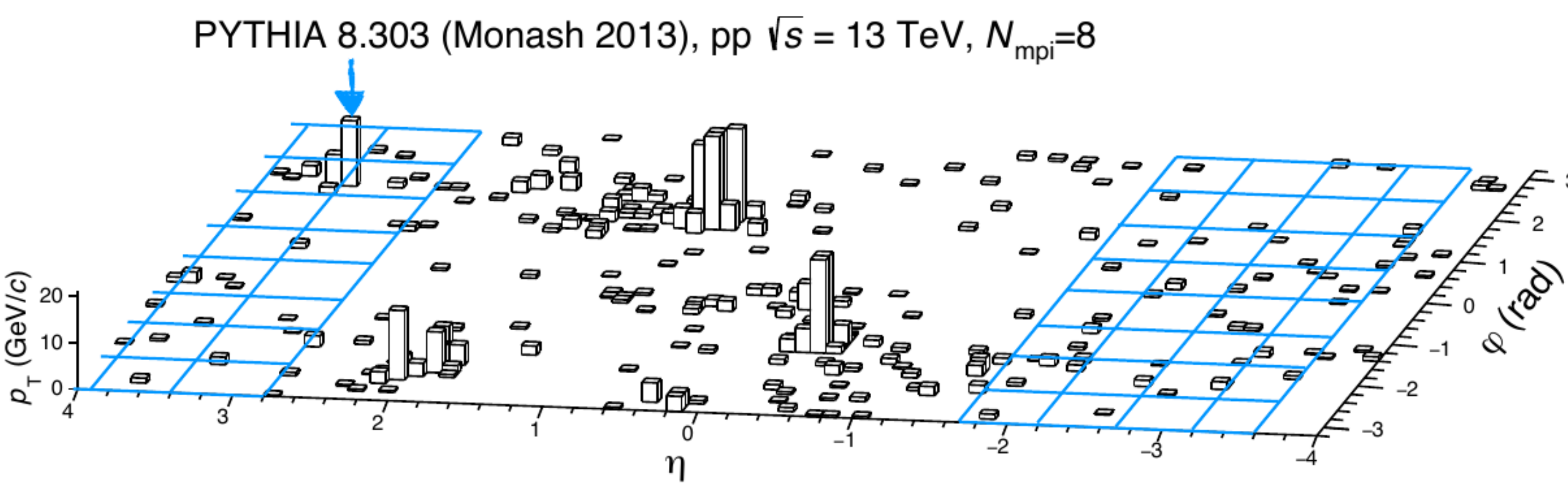
Key of improvement between ALICE 2.0 (run 3), ALICE 2.1 (run 4) and ALICE 3 ?

≉ L_{int} but rather the instrument : ALICE 3 pointing resolution and AxEff

IV.3 – ~~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, ...)

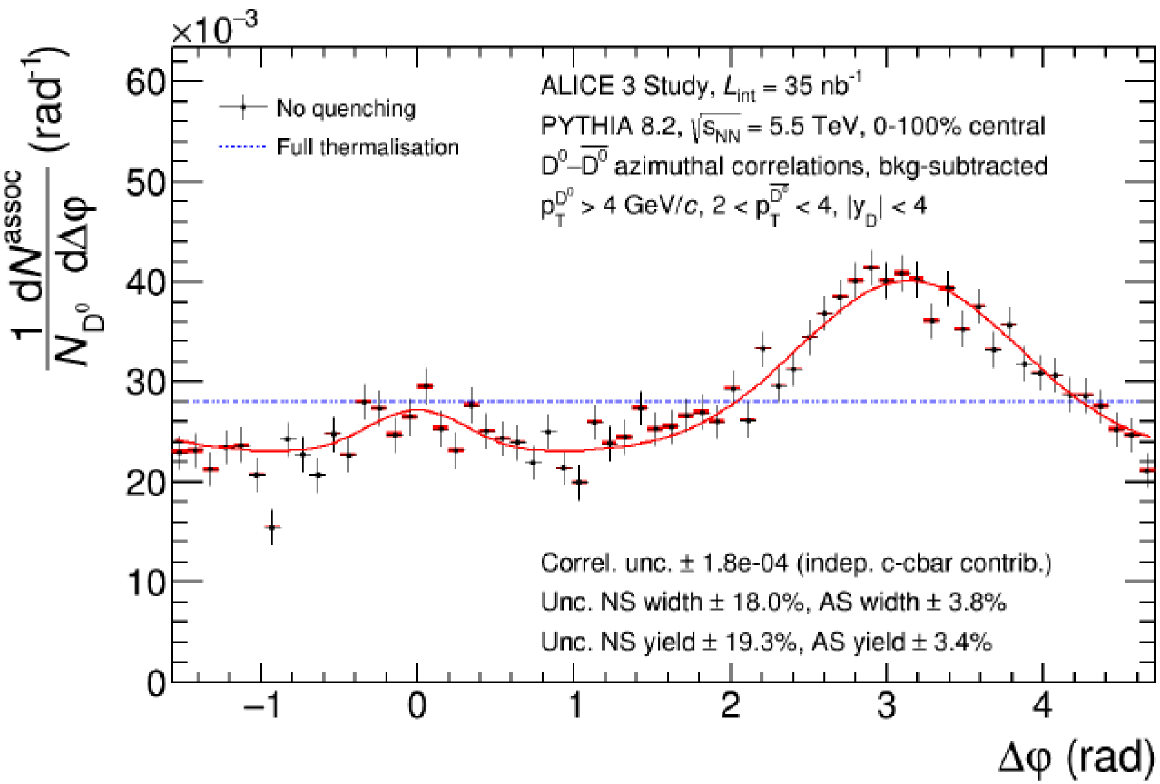


If you look only in the blue windows (*VZERO acceptance ALICE1*)...
You may miss fluctuations in MPI that lead to jets...

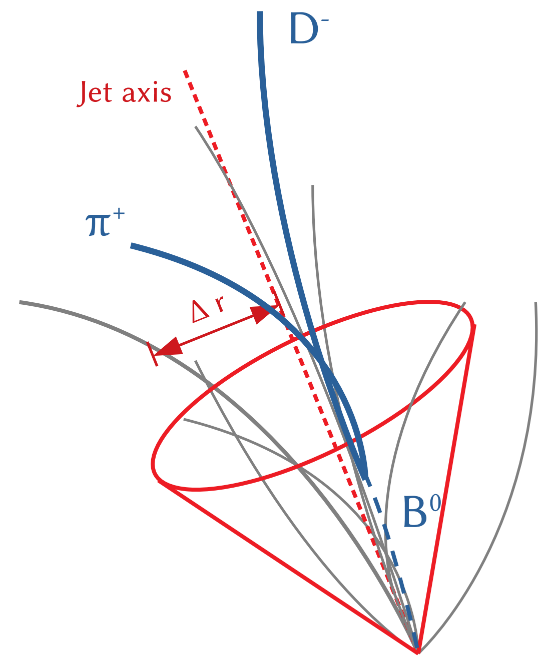
Ortiz, SQM2024

IV.3 – ~~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)

V.1 – Particle Identification : PID with TOF + RICH

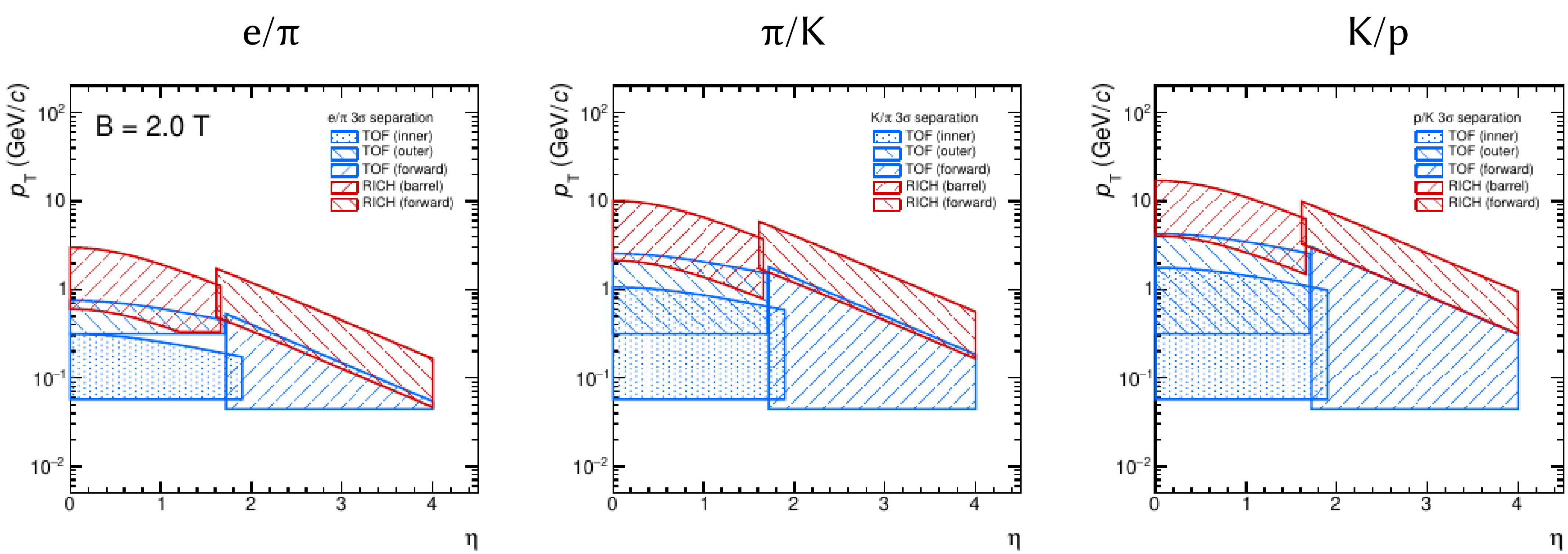


Figure 20: Analytical calculations of the $\eta - p_T$ regions in which particles can be separated by at least 3σ for the ALICE 3 particle-identification systems embedded in a 2.0 T magnetic field. Electron/pion, pion/kaon and kaon/proton separation plots are shown from left to right.

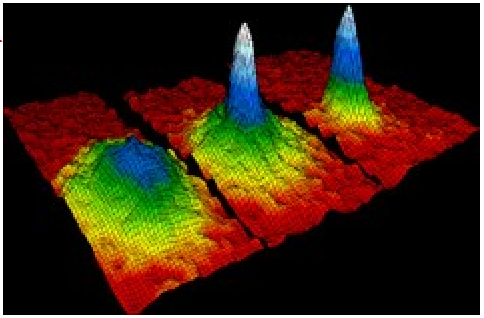
[Note the <u>lowest</u> p_T boundaries ...]

ALICE 3 LoI, *CERN-LHCC-2022-009*, *section 3.2.2*

V.2 – Particle Identif° : why care about the low-p_T (π,K,p)

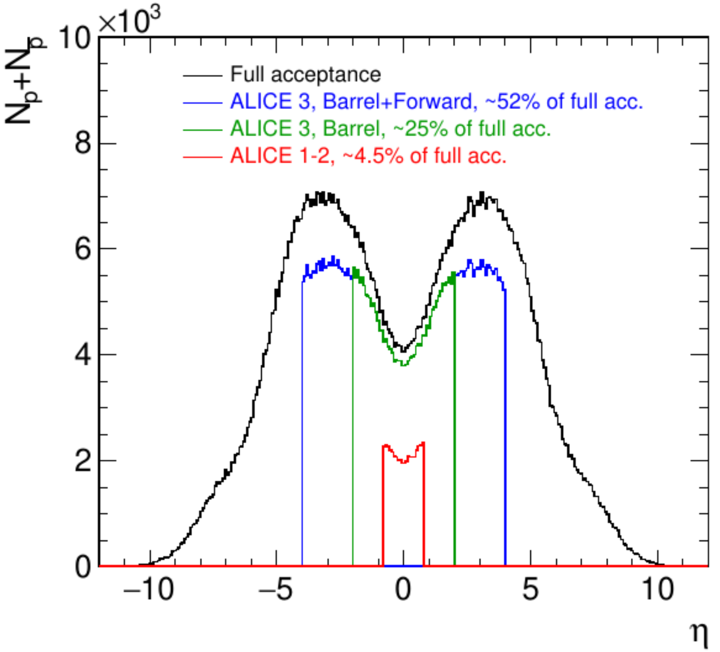
1. Getting $dN/dp_T dy$ + $v_n(h^\pm)$ down to non-relativistic p_T (e.g. $p_T < 0{,}05$ GeV/c ⟶ $\beta_{\pi^\pm} \approx 0{,}34$)
⟶ change from non-relativistic (linear) to relativistic hydro. (quadratic behaviour)

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.



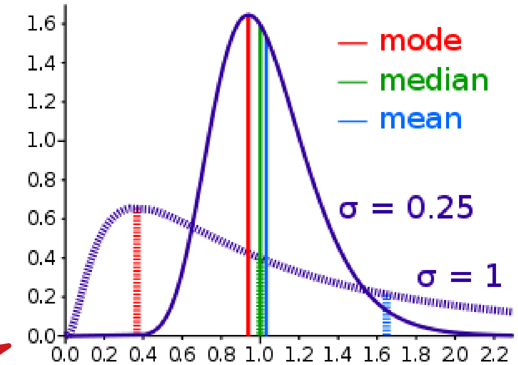
ALICE 3 LoI, CERN-LHCC-2022-009, Fig. 62 p.112

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 ? ⟶ clarify with Mesut...)

V.3 – Particle Identif° : ex. 3 – net quantum fluctuations

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

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

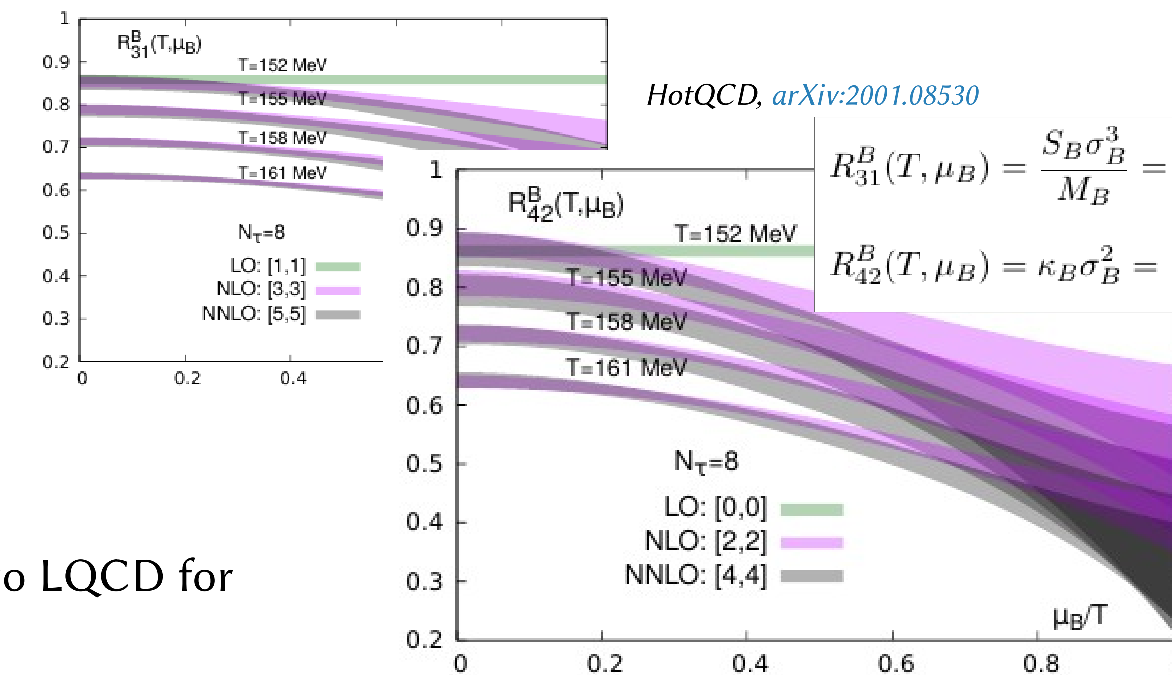


Wikipedia:Skewness

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

(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 : …



HotQCD, arXiv:2001.08530

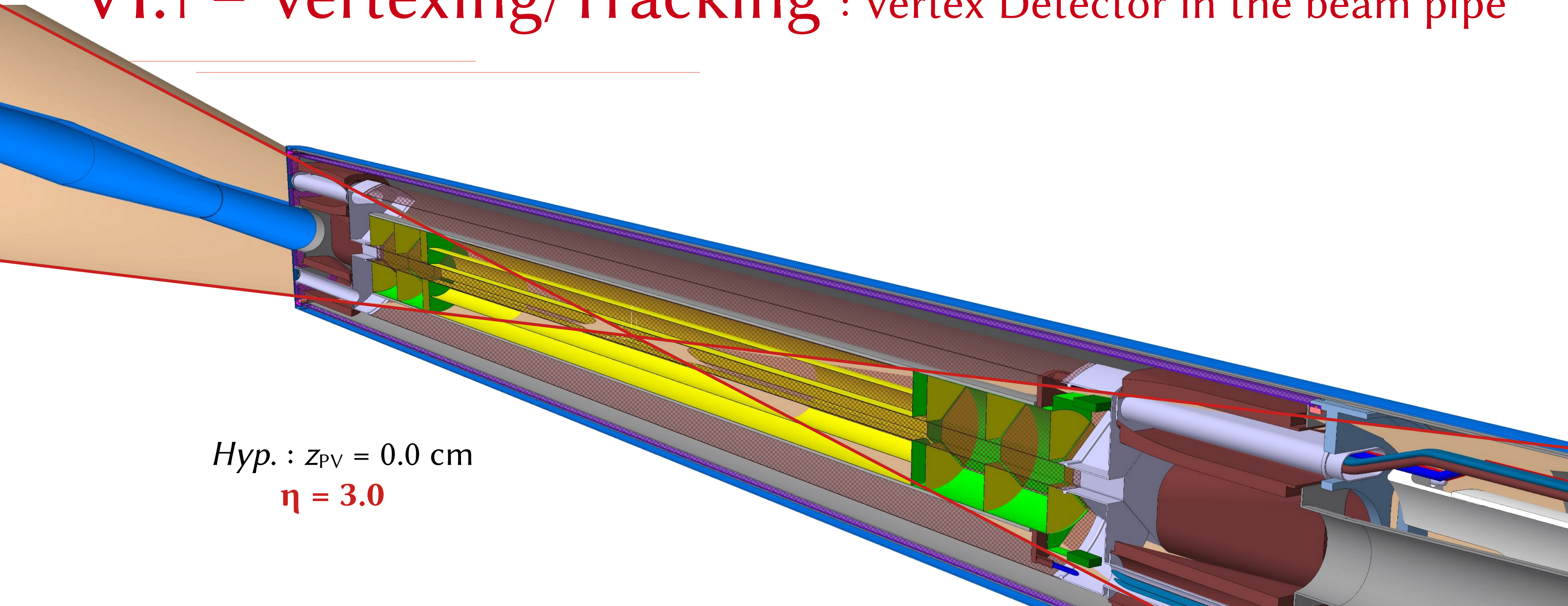
$$R^B_{31}(T,\mu_B) = \frac{S_B\sigma^3_B}{M_B} = \frac{\chi^B_3(T,\mu_B)}{\chi^B_1(T,\mu_B)}$$

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

→ *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)

See also EMMI, arXiv:2001.08831

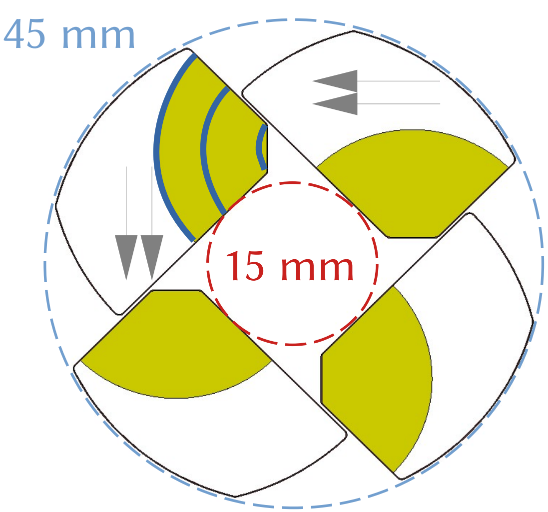
VI.1 – Vertexing/Tracking : Vertex Detector in the beam pipe



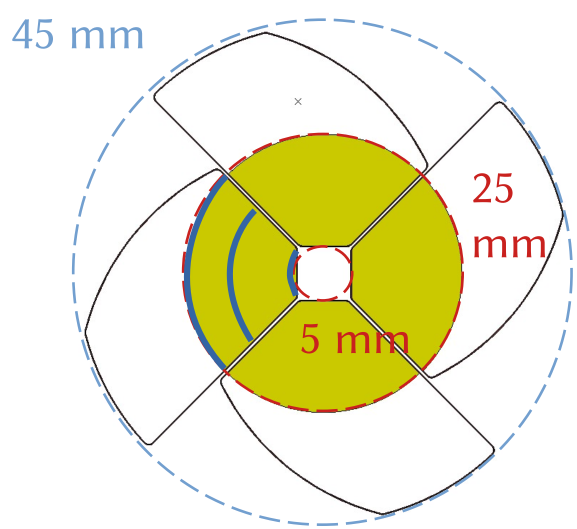
Iris tracker

Hyp. : z_{PV} = 0.0 cm

η = 3.0



Open
IRIS
(radii)



Closed
IRIS
(radii)

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

…

$\Xi_{CC}^{2+}(ucc) \longrightarrow \Xi_C^{+}(usc)\,\pi^+ \longrightarrow [\Xi^-(\boldsymbol{dss})\ 2\pi^+]\ \pi^+$

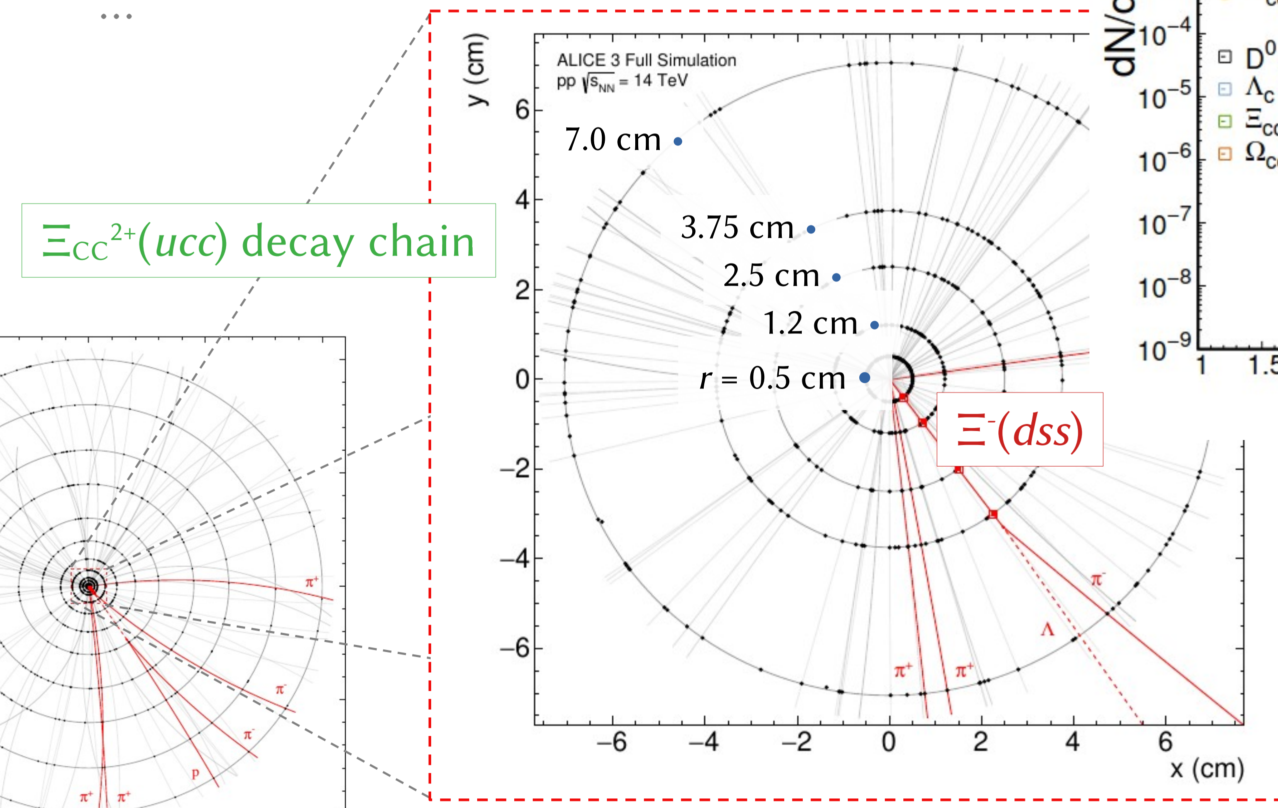
$\Omega_{CC}^{+}(scc)$ …

$\Omega_{CCC}^{2+}(ccc) \longrightarrow \Omega_{CC}^{+}(scc)\,\pi^+ \longrightarrow [\Omega_C^{0}(ssc)\,\pi^+]\ \pi^+$ …

$\Xi_B^{-}(dsb) \longrightarrow \Xi_C^{0}(dsc)\,\pi^- \longrightarrow [\Xi^-(dss)\,\pi^+]\ \pi^-$ …

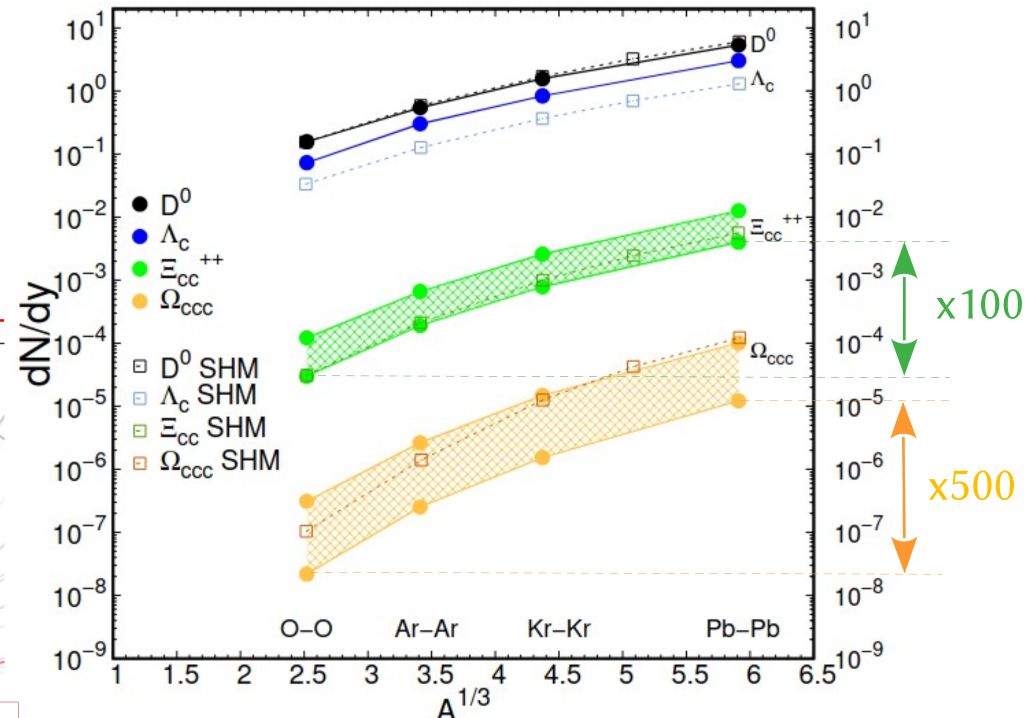
$\Omega_B^{-}(ssb) \longrightarrow \Omega_C^{0}(ssc)\,\pi^- \longrightarrow [\Omega^-(dss)\,\pi^+]\ \pi^-$ …

…



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

Greco, arXiv:2305.03687



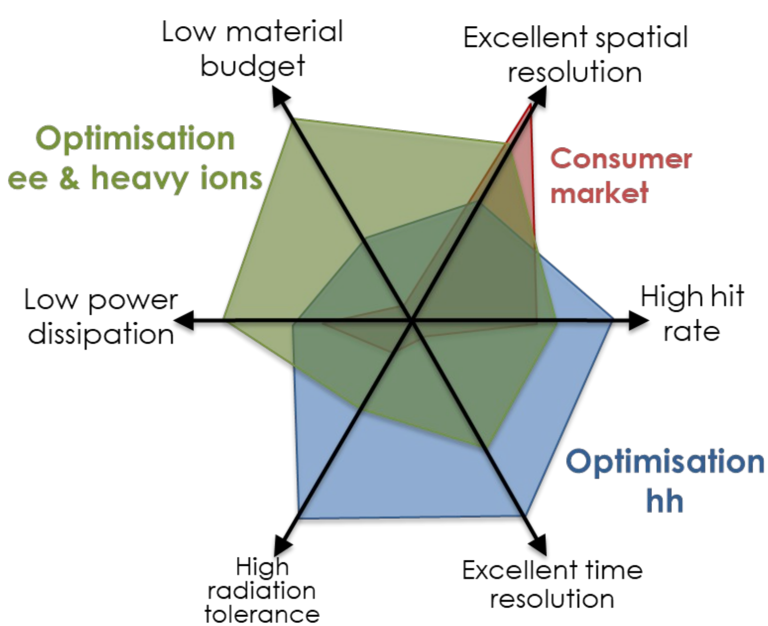
Prediction by SHM
or Coalescence model

VII.1 – Extra reason for ALICE 3 : (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. Overlap of specifications : eA, pA, AA // e^+e^- !



Courtesy J. Baudot

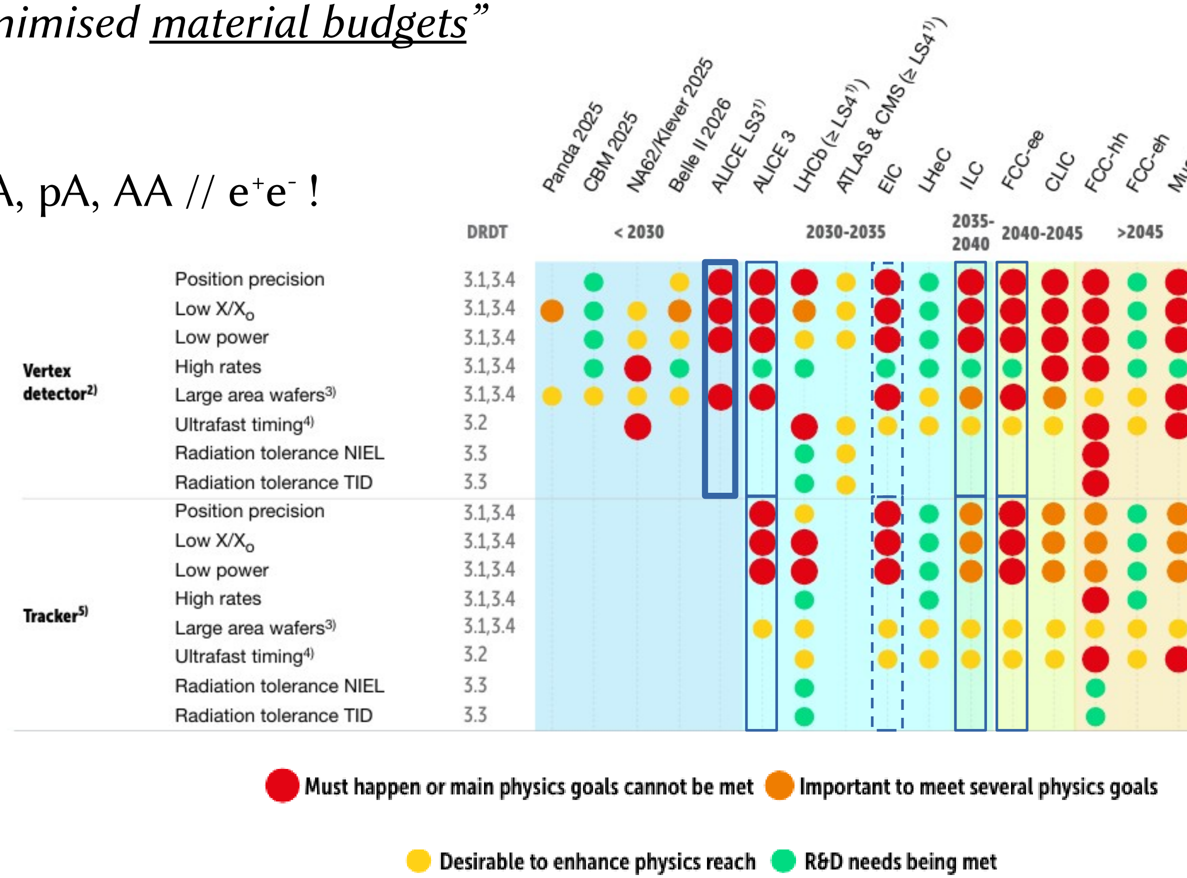


Fig. 3.1, 2021 ECFA roadmap

Conclusions

Conclusions : ALICE 3 features …

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** ; $\mathcal{O}(10)$] GeV/c)
- extension towards (much) more units in η / in y ($|\eta| <$ **3.5 - 4**)

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

- PID = a cornerstone (iTOF)
- fast reading / very fine time resolution (bunch tagging for $\mu_{pileup} = 1$)

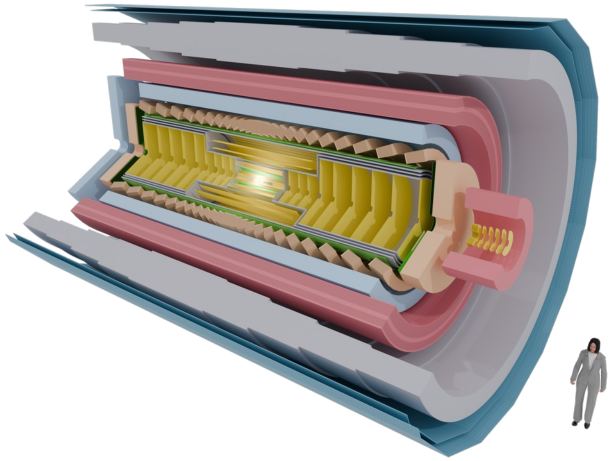
Instrument with desired French participation

Lyon, Strasbourg, Grenoble = in ALICE 3 Outer Tracker
⟶ CMOS design / readout electronics / mechanics

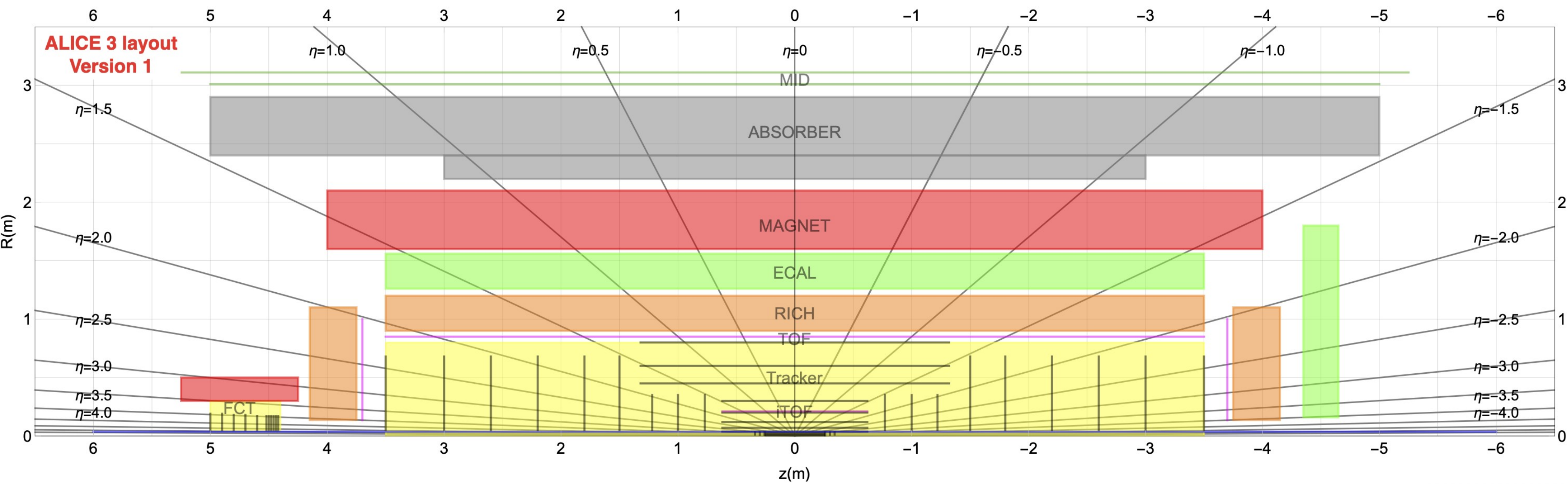
App. A – General layout

A.1 – ALICE 3 : default layout overview, v1 SD

Scoping document (2024-03)



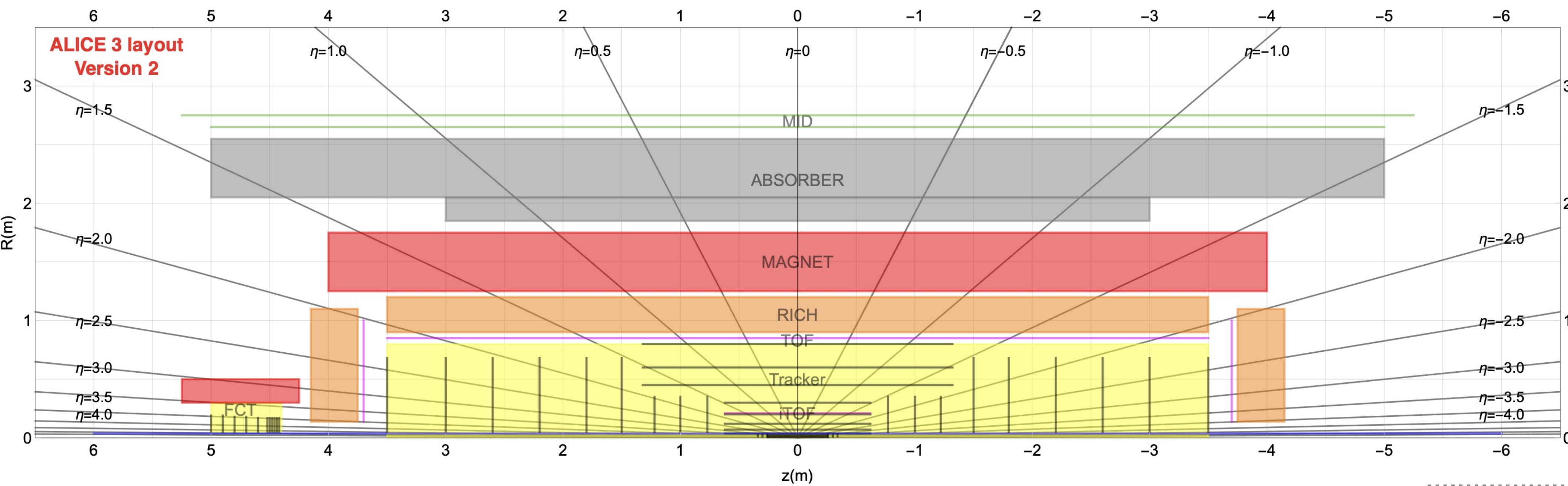
~~ALICE 3 LoI, *CERN-LHCC-2022-009*, *Fig. 1*~~
+ ALICE 3 Scoping document *Fig.1 [LoIv1] update = default config.*



A.2 – ALICE 3 : layout overview, v2 SD

Scoping document (2024-03)

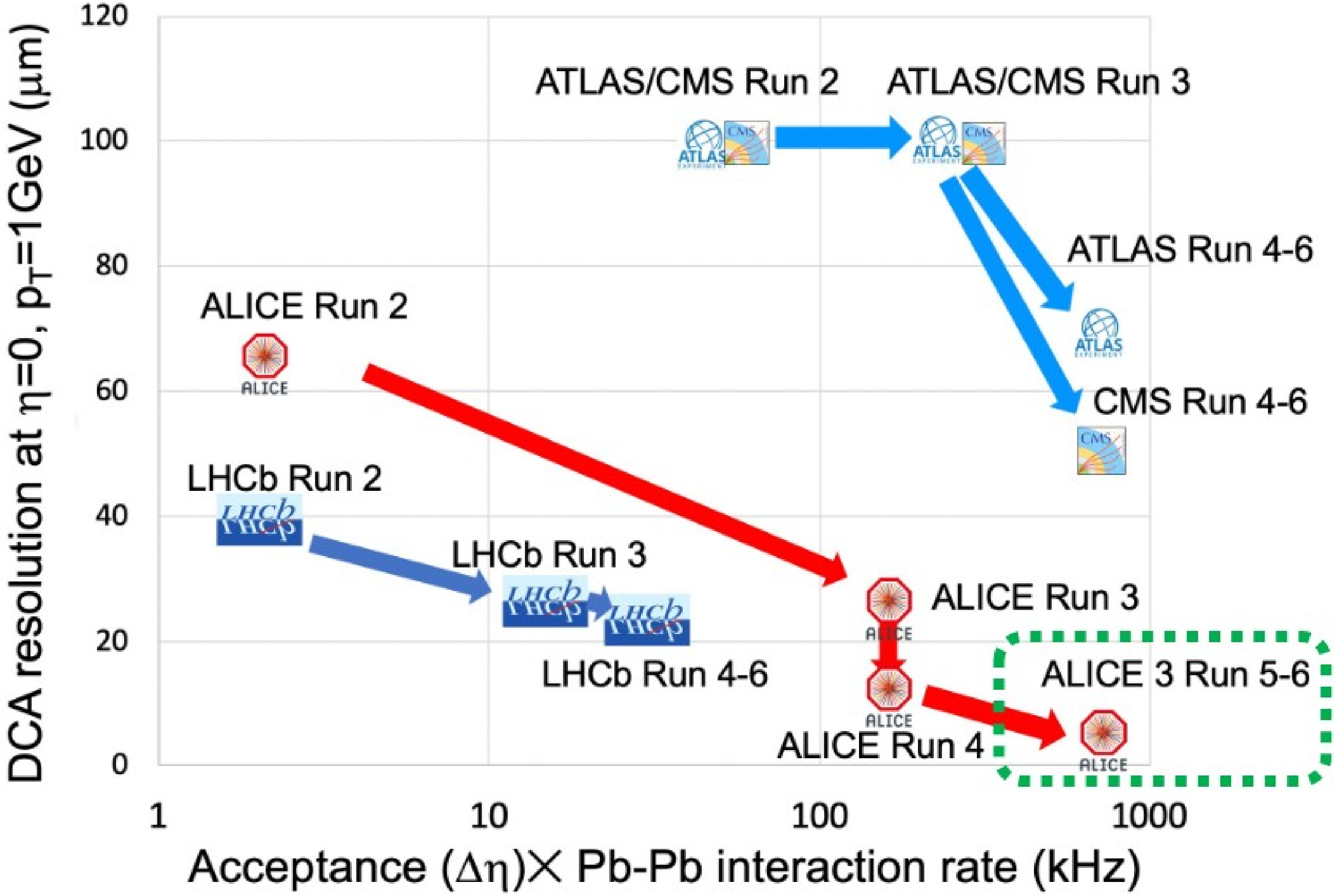
~~*ALICE 3 LoI*, CERN-LHCC-2022-009, *Fig. 1*~~
~~+ ALICE 3 Scoping document *Fig.1 [LoIv1] update = default config.*~~
+ ALICE 3 Scoping document *Fig.12 [v2] = a scoping option = No ECal = new default in practice*



Back to App. TOC

App. B – ALICE3

B.1 – ALICE3 : one particular figure of merit



(PaR.x – Reading : 3 < |η| < 4 landscape)

Beware :

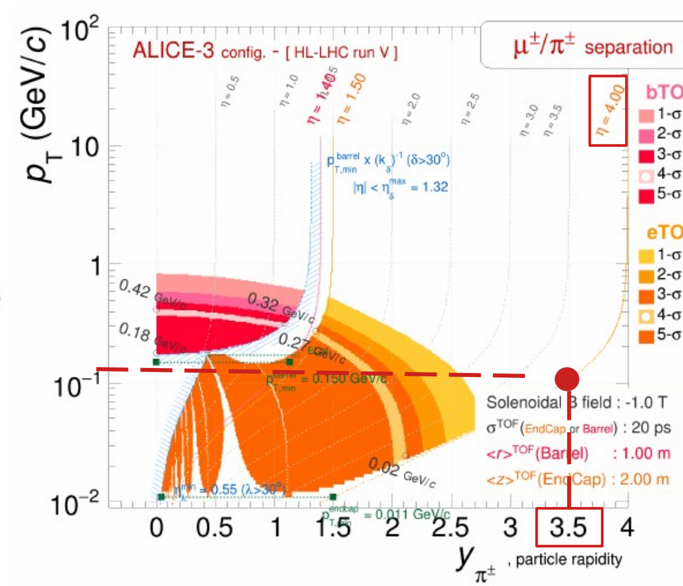
pseudo-rapidity $\eta \neq$ rapidity y, especially at low p_T

(in fact, one has *always* $|y| < |\eta|$...)

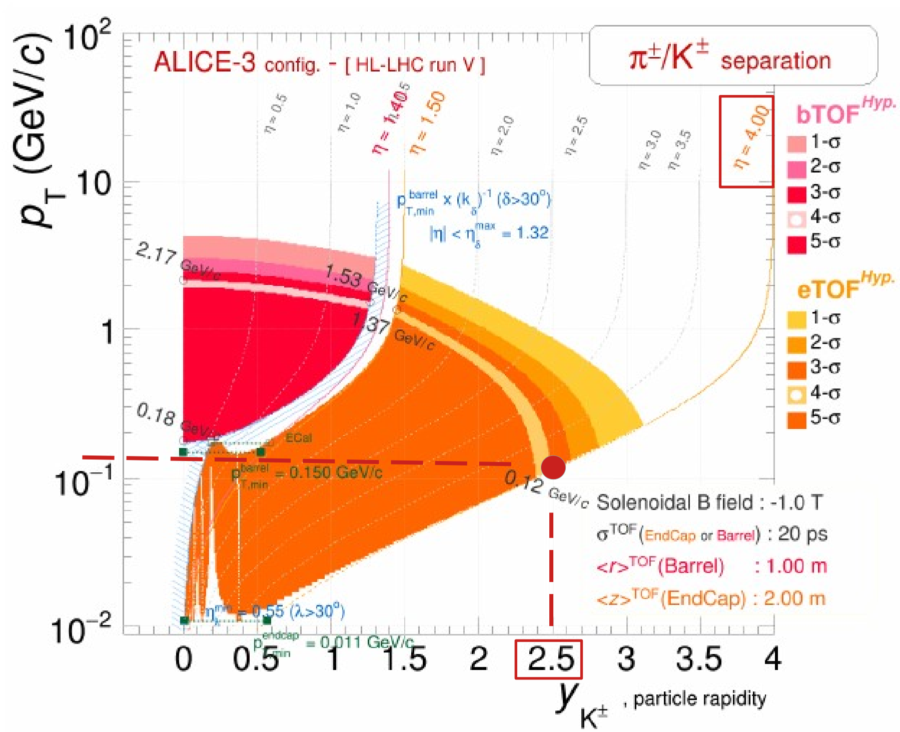
$\rightarrow$ Looking at <u>forward η</u> may be less <u>forward *rapidity*</u> physics than one could imagine naïvely

(hiatus more and more sensible at low p_T, for the heavier hadrons)

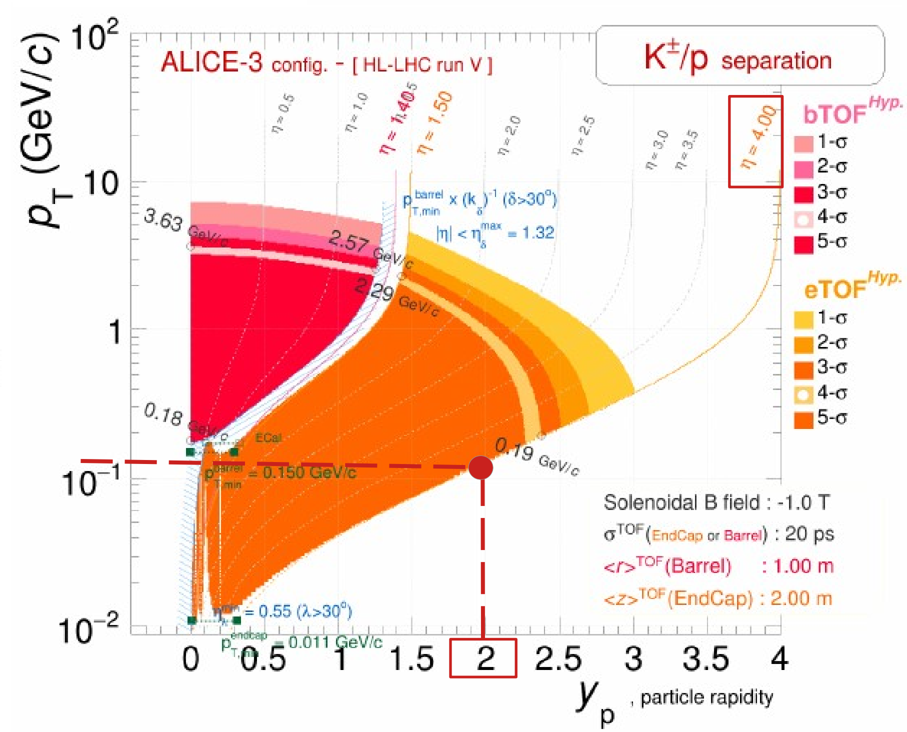
(*b*)



(*c*)



(*d*)



A. Maire, CERN-OPEN-2021-003, Fig.36

Red lines here = examples of η =4 with $p_T \approx$ 120 MeV/c for π,K,p

B.2 – ALICE 3 : PID with (CMOS) TOF

	Inner TOF	Outer TOF	Forward TOF
Radius (m)	0.19	0.85	0.15–1.5
z range (m)	−0.62–0.62	−2.79–2.79	4.05
Surface (m^2)	1.5	30	14
Granularity (mm^2)	1×1	5×5	1×1 to 5×5
Hit rate (kHz/cm^2)	74	4	122
NIEL (1 MeV n_{eq}/cm^2) / month	$1.3 \cdot 10^{11}$	$6.2 \cdot 10^{9}$	$2.1 \cdot 10^{11}$
TID (rad) / month	$4 \cdot 10^{3}$	$2 \cdot 10^{2}$	$6.6 \cdot 10^{3}$
Material budget ($\%X_0$)	1–3	1–3	1–3
Power density (mW/cm^2)	50	50	50
Time resolution (ps)	20	20	20

Table 11: TOF specifications.

<u>3 options :</u>

- MAPS with gain layer
  (≈ ARCADIA project)
- Low Gain Avalanche Diodes (LGAD)
  (CMS MTD fwd, ATLAS HGTD)
- Single Photon Avalanche Diode (SPAD)
  for a combined TOF+RICH reading
  by a single sensor

ALICE 3 LoI, *CERN-LHCC-2022-009*, *section 4.3*

App. C – OT staves & discs

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

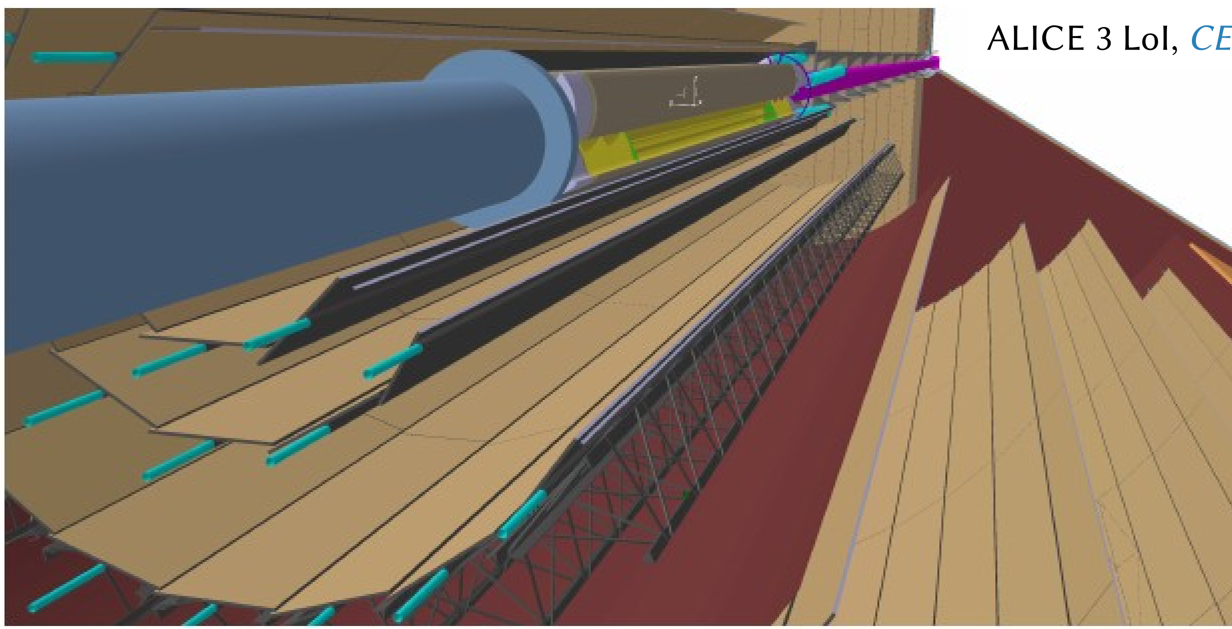


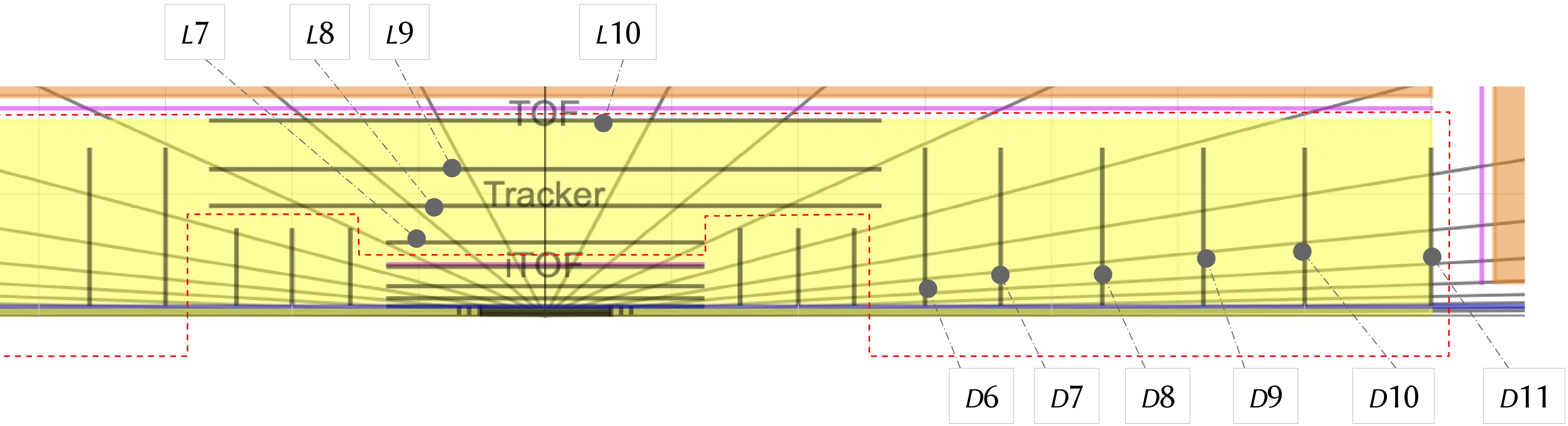
Figure 83: Sketch of the outer tracker mechanics. Modules assembled in staves structures are visible as well as services and power lines. Furthermore, the overlap of the staves can be seen.

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

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

ALICE3 SD, Fig.1, *DraftID:10248*

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



Preamble :

° ITS2 sensitive area (*i.e.* active silicon without periphery on ALPIDE) ≈ 9.99 m²

° MFT sensitive area ≈ 0.37 m²

→ OT ≈ **50 m²** of plain acceptance geometry in total (*i.e.* naïve discs and cylinder models)

- OT Barrel ≈ **33 m²** → *O*[3x ITS2]
- OT forward discs ≈ 6x(2m²/disc plane) = ~~**12 m²**~~ **8.7 m²** → *O*[1x ITS2 or 23x MFT]
- OT backward discs = same ≈ ~~**12 m²**~~ **8.7 m²** (~~*may depend on FCT requirements*~~)
- IT-Middle Tracker ≈ **5.95 m²** → *O*[½ x ITS2]

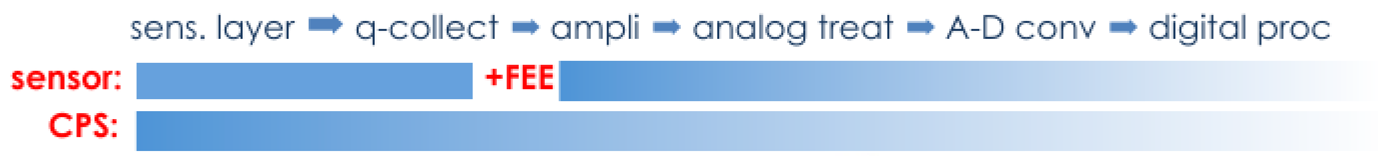
  4-layer barrel ≈ 3,73 m²

  2x3-disc endcaps ≈ 2,22 m²

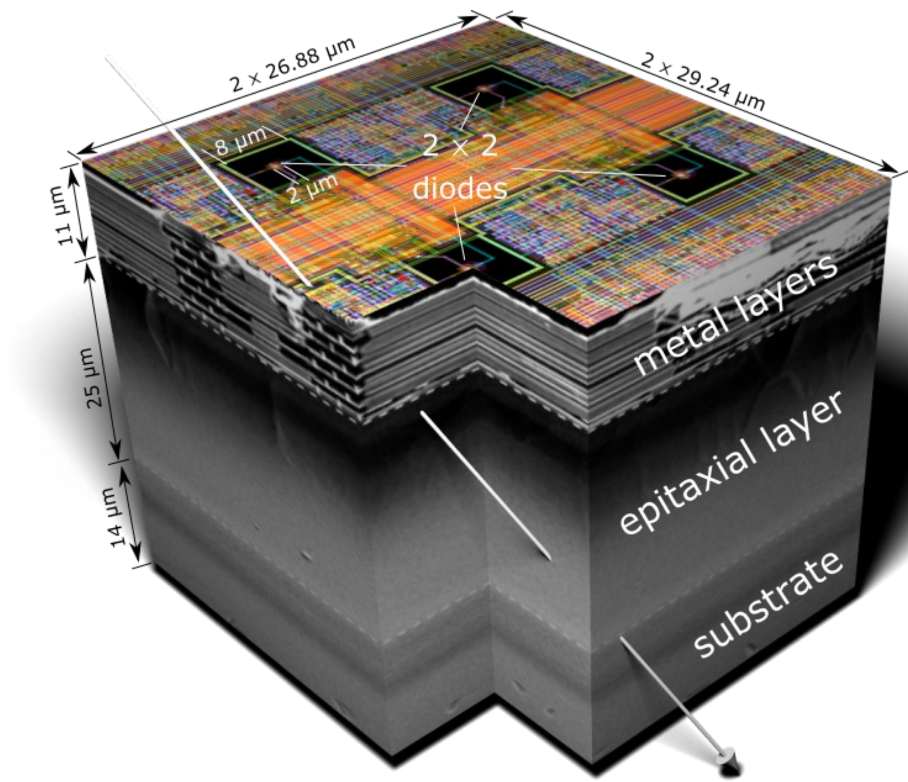
App. D – CMOS sensor

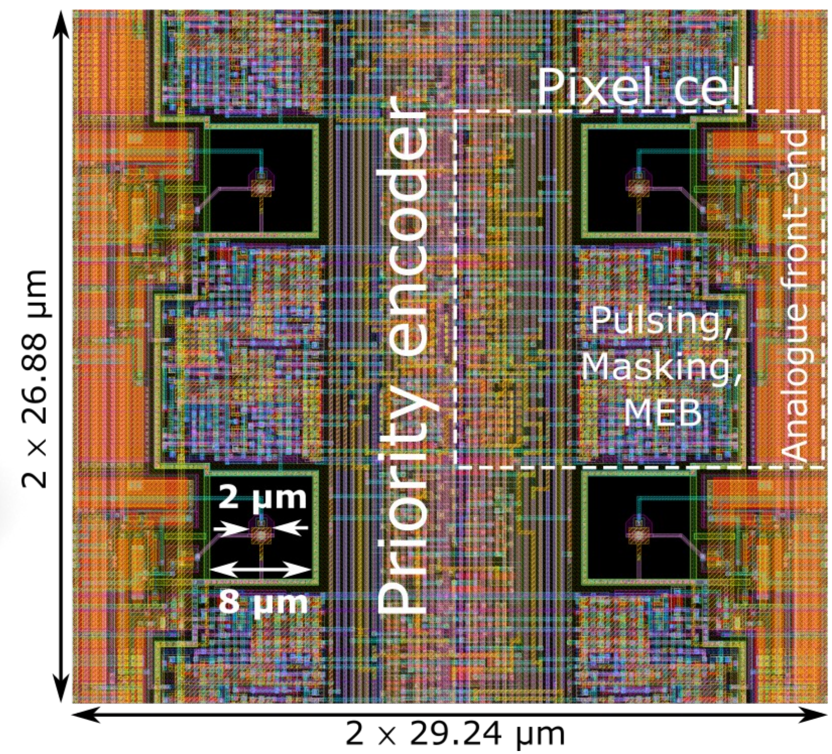
D.1 – Background : MAPS, Monolithic Active Pixel Sensors

Hybrid pixel sensor ⟶
CMOS pixel sensor ⟶



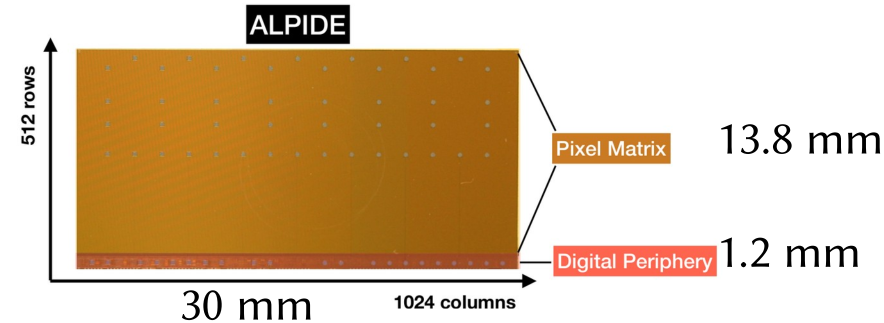
Ex: sensor using
TowerSemiconductor 180-nm CMOS Imaging Process





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

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

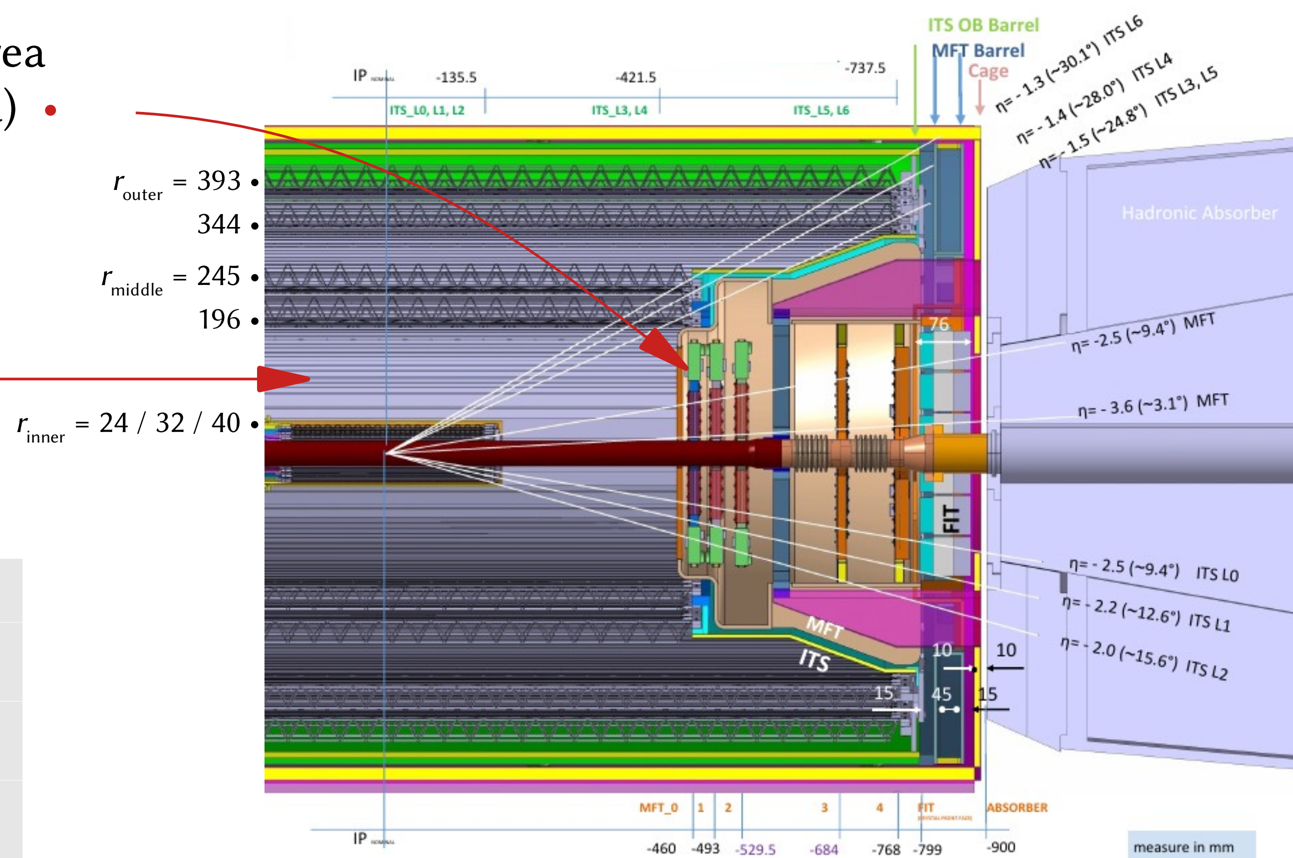


MFT

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

Time resolution: bunch tagging, *i.e.* O(100 ns)

A Large Ion Collider Experiment

Requirements

25x more pixels

	Vertex Detector	Middle Layers	Outer Tracker	ITS3
Position resolution (µm)	2.5	10		5
Pixel size (µm²)	O(10 x 10)	O(50 x 50)		O(20 x 20)
Time resolution (ns RMS)	100	100		100* / O(1000)
In-pixel hit rate (Hz)	94	**42 (barrel)** / 12 (foward)	1 (barrel) / **16 (forward)**	54
Fake-hit rate (/ pixel / event)	$<10^{-7}$			
Power consumption (mW / cm²)	70	20		35
Particle hit density (MHz / cm²)	94	0.6 (barrel / forward)	0.06 (barrel) **0.6 (forward**	8.5
Non-Ionising Energy Loss (1 MeV n_{eq} / cm²)*	2×10^{15}	**1×10^{14} (barrel)** 5×10^{13} (forward)	6×10^{12} (barrel) **1×10^{14} (forward)**	3×10^{12}
Total Ionising Dose (Mrad)*	10	**6 (barrel)** / 5 (forward)	0.5 (barrel) / **5 (forward)**	0.3

* updated values, from FLUKA simulations; safety factor to be decided

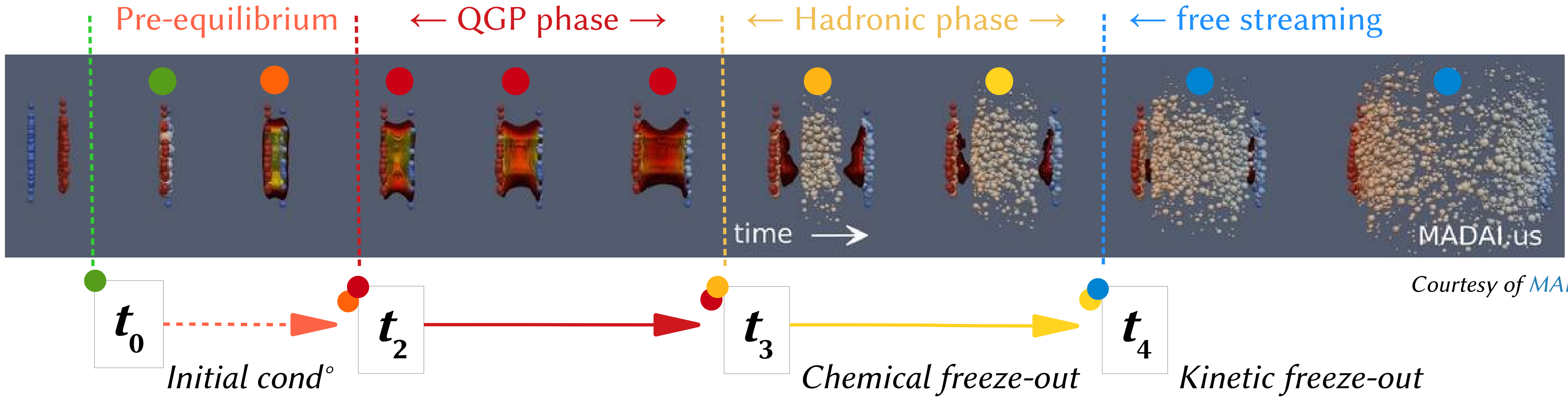
20x higher radiation load

. Table courtesy Felix Reidt
. See also FLUKA studies of radiation loads in ALICE" by Jesus Mendez ALICE3 days 2024-03 indico.cern.ch/event/1372735

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 :
  . Hydrodynamisation
  . Chemical equilibration
  . Thermalisation

via

Multi-Parton Interactions

+ Colour Reconnections

+ Multiple parton scatterings

+ Rope shoving

+ Glasma

…

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

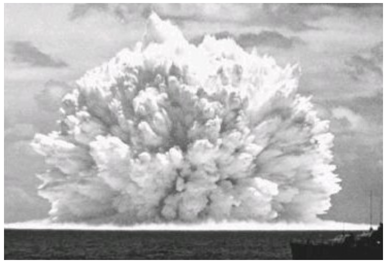
. Recombination/ coalescence

. Hadronic re-interactions

…

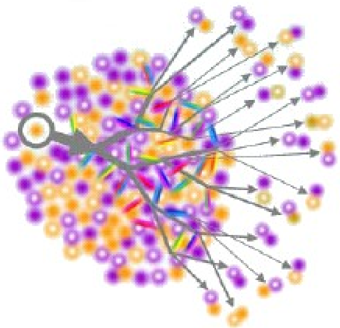
E.2 – Observables : Layer 2 / as a function of *momentum*

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)

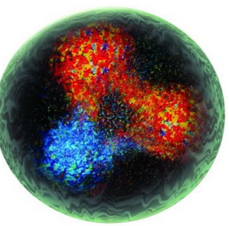


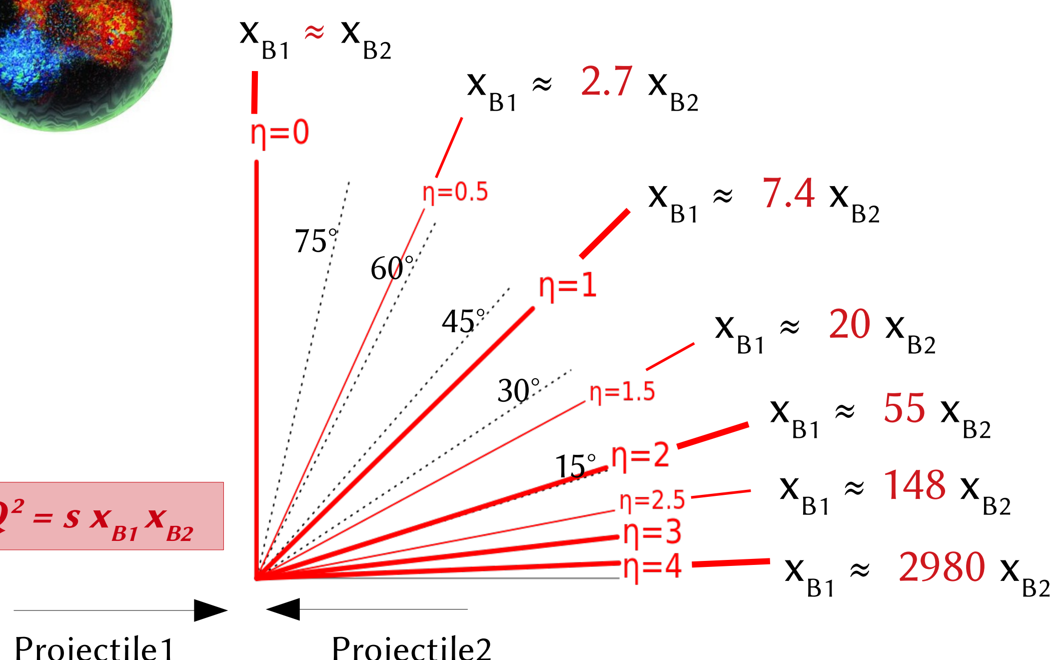
≈ in-medium energy losses for energetic particles

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% $(dN_{ch}/d\eta)_{max}$

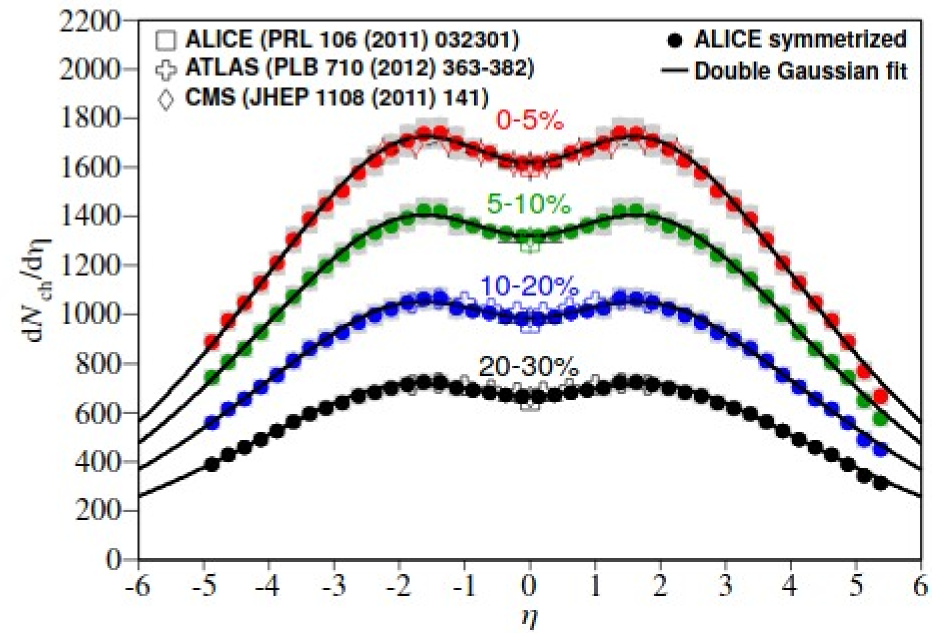
JLab





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

ALICE, arXiv:1304.0347

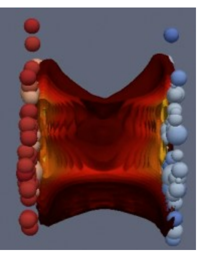


* if y ≈ η (m << p)
+ same type of beams (A_i/Z_i)

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

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

  $\Lambda_{C}^{+}(udc),\ \Xi_{C}^{+}(usc),\ \Xi_{C}^{0}(dsc),\ \Omega_{C}^{0}(ssc)$

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

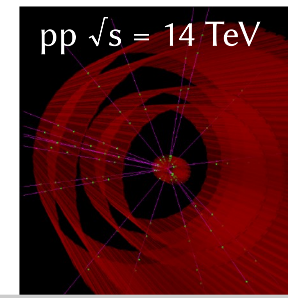
b

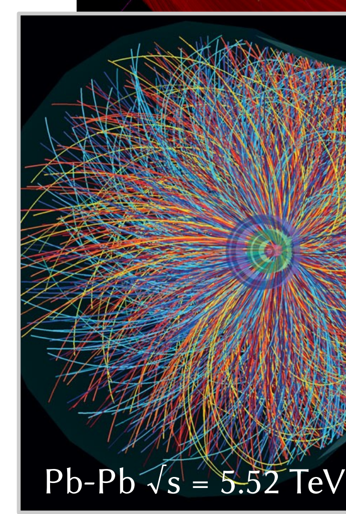
- heavy-flavour $(\mu^{\pm}, e^{\pm})$
- $B^{0}\ B^{\pm}\ B^{0}_{S}$ … $\Upsilon(1S,2S,3S)$…

  $\Lambda_{b}^{0}(udb)$…

(• $e^{\pm}\ \mu^{\pm}\ \gamma$)

(• $W^{\pm}\ \gamma/Z^{\circ}$)



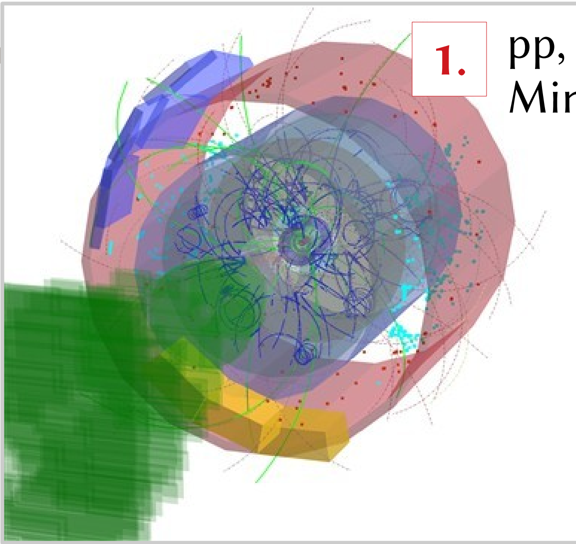


NB :

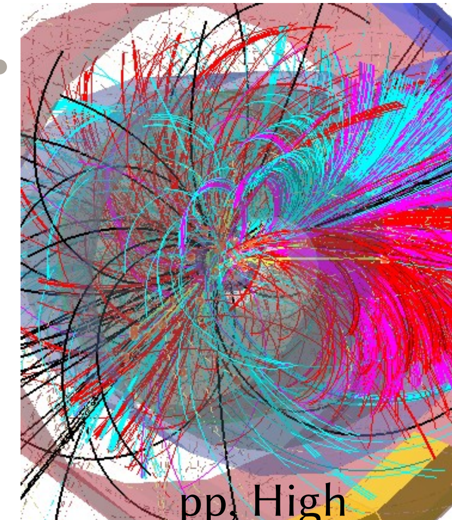
baryons Vs mesons

mixed flavours (s+c, s+b, … c+b …)

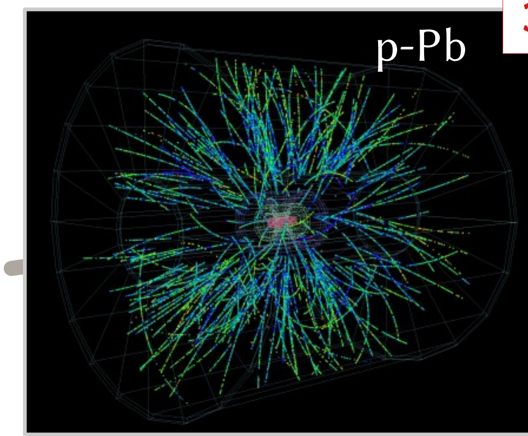
E.5 – Observables : Layer 5 / as a funct° of the collision system



1. pp, Min. Bias

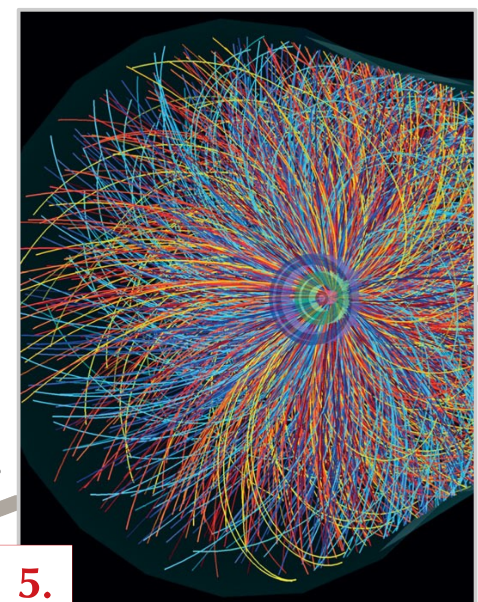


2. pp, High Multiplicity



3. p-Pb

4. Pb-Pb, low centrality



5. Pb-Pb, most central events

CDS/record-1305398

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

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

time
- Initial conditions
- Initial fluctuations
- Early hydrodynamisation
- Chemical equilibration
- Deconfinement extent
- Chiral symm. restoration
- Hydrodynamics
- In-medium E_{loss}
- Phase transition(s)
- Hadronisation
- Chemical freeze-out
- Kinetic freeze-out

p_T (GeV/c)
- ≤ 0.1
- $\in [0.1 ; 0.5]$
- $\in [0.5 ; 1.0]$
- $\in [1.0 ; 3.0]$
- $\in [3.0 ; 6.0]$
- $\in [6.0 ; 10.0]$
- $\in [10.0 ; 200]$
- ≥ 200

$|y|$
- ≈ 0
- $\in [0.5 ; 1.0]$
- $\in [1.0 ; 2.5]$
- $\in [2.5 ; 5.0]$
- > 5.0

"Flavour"
- g
- u
- d
- s
- c
- b
- (t)
- γ, $l^{\pm}$
- $W^{\pm}$
- γ/Z°

Event activity
- pp low mult.
- AA UPC
- pp MB
- p-A MB
- pp high mult.
- p-A high mult
- AA low mult.
- AA semi-central
- AA most central

? ? ? ?

(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 …*)