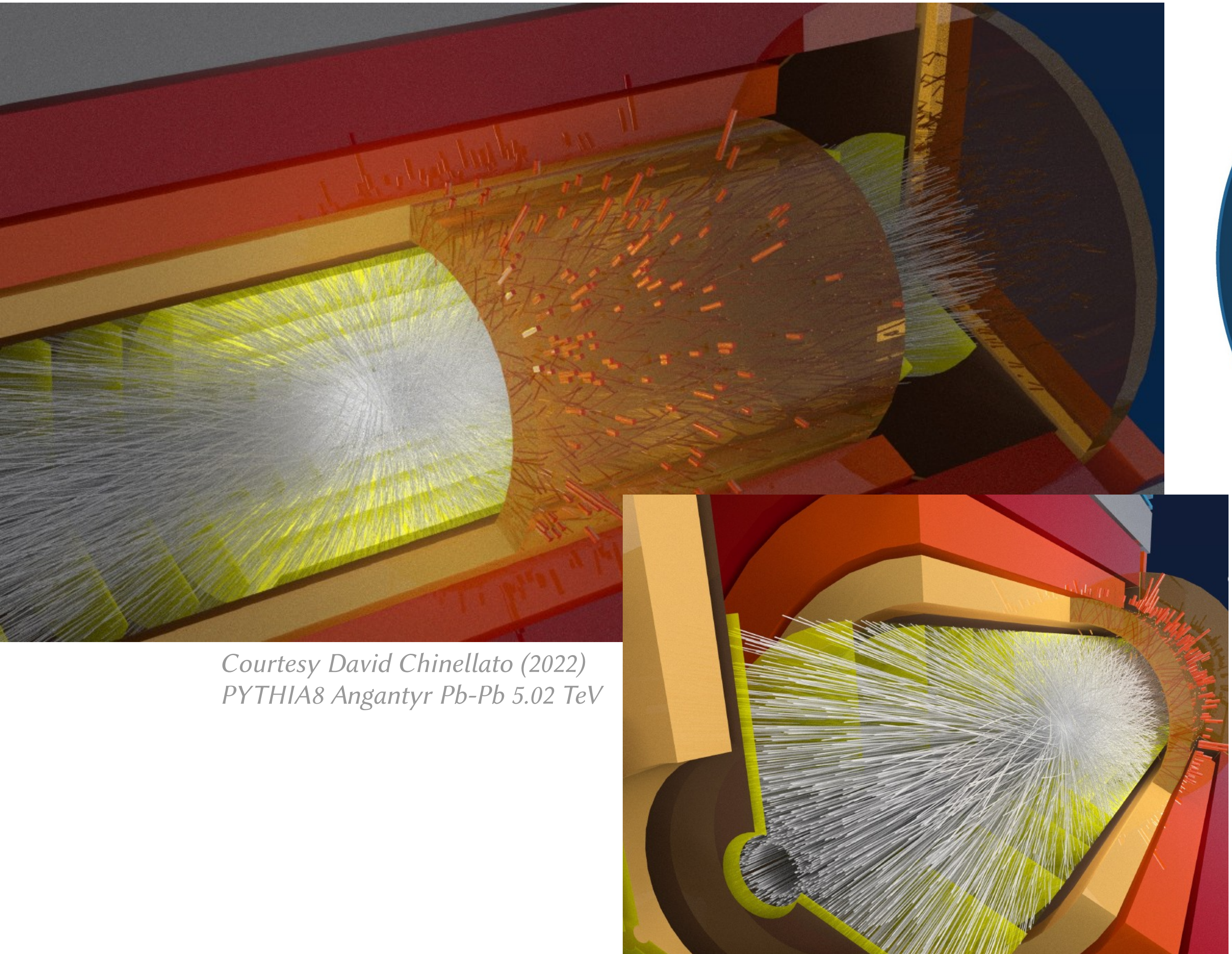
Antonin MAIRE

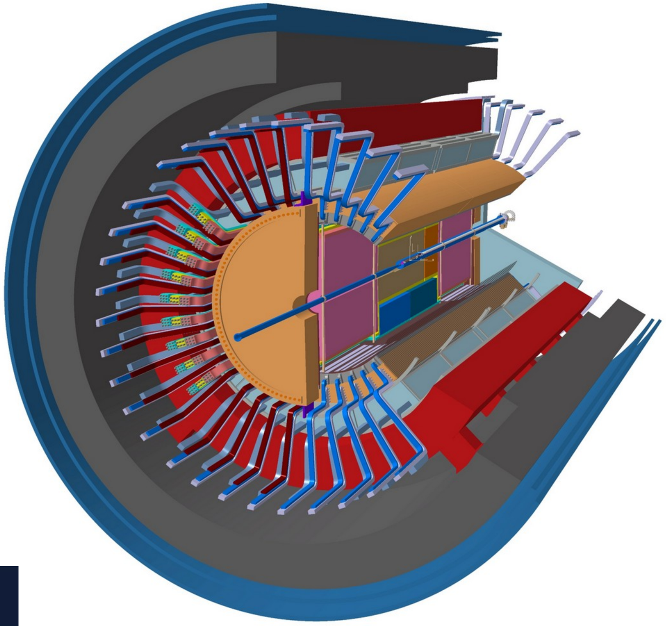
Thursday, 19 Sept. 2024 – **IN2P3 ESPPU 2024-09**

https://indico.in2p3.fr/event/33460/

ALICE3 physics programme



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. Landscape and questions on physics

C. Proposed ALICE3 answers at HL-LHC:

instrumental features to meet given physics questions

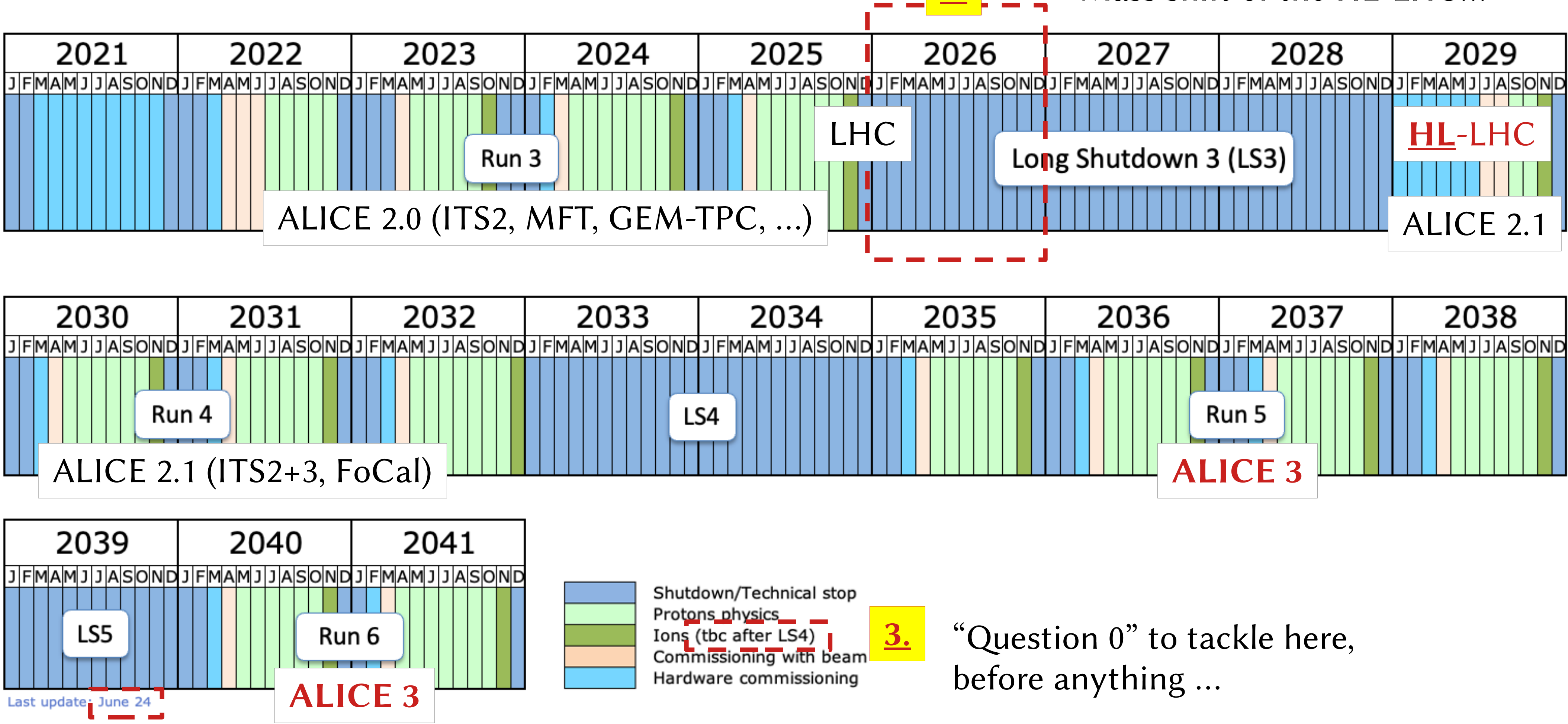
ALICE3 LoI, arXiv:2211.02491
ALICE3 Scoping Document Draft:10248 (LHCC)

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

LHC-commissioning - Long term

Extension of Run 3 ?
→ ≈ Mass shift of the HL-LHC…

2.

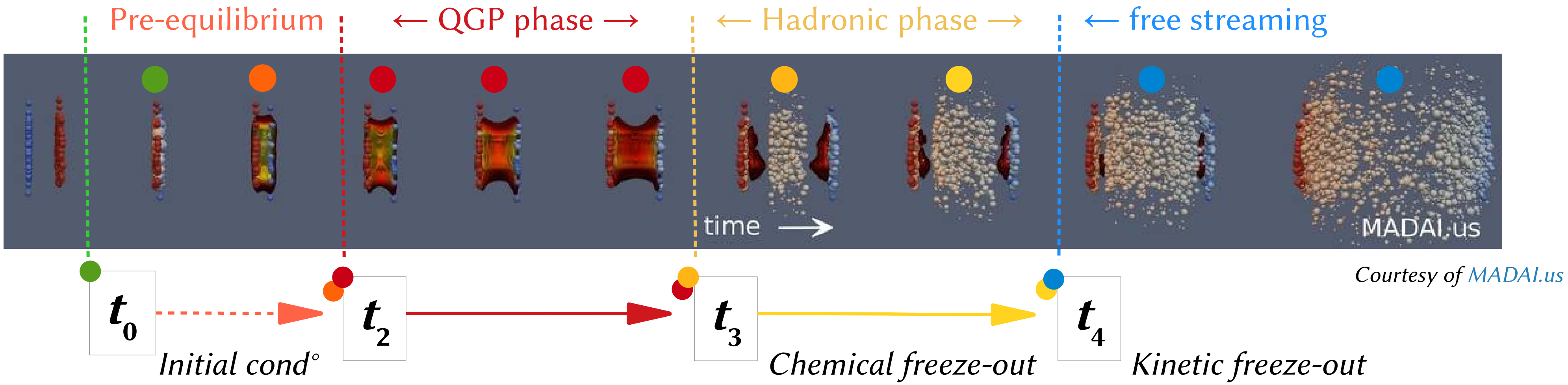


1.

3.

"Question 0" to tackle here,
before anything …

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

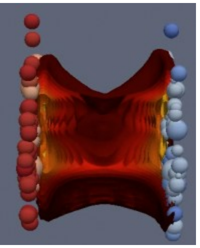
. Recombination/ coalescence

. Hadronic re-interactions

…

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

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



u,d,s

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

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

  + d t $^3He^{2+}$ $^4He^{2+}$ …

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

c

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

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

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

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

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

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

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

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

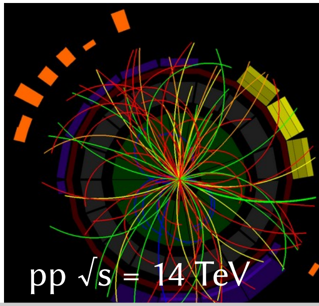
b

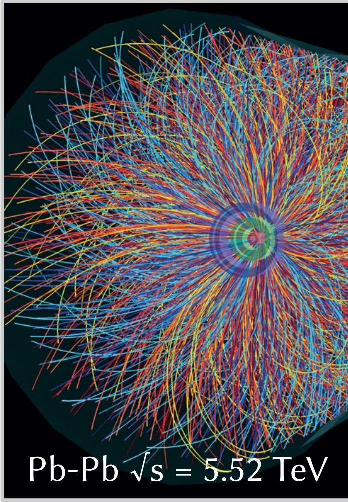
- heavy-flavour $(\mu^\pm, e^\pm)$
- $B^0\ B^\pm\ B^0_S$ … $\Upsilon(1S,2S,3S)$…

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

(• $e^\pm\ \mu^\pm\ \gamma$)

(• $W^\pm\ \gamma/Z^\circ$)





II.3 – Questions in ≈2035 : 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
Outcome Runs 1+2

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

ALICE White Paper, arXiv:2211.04384

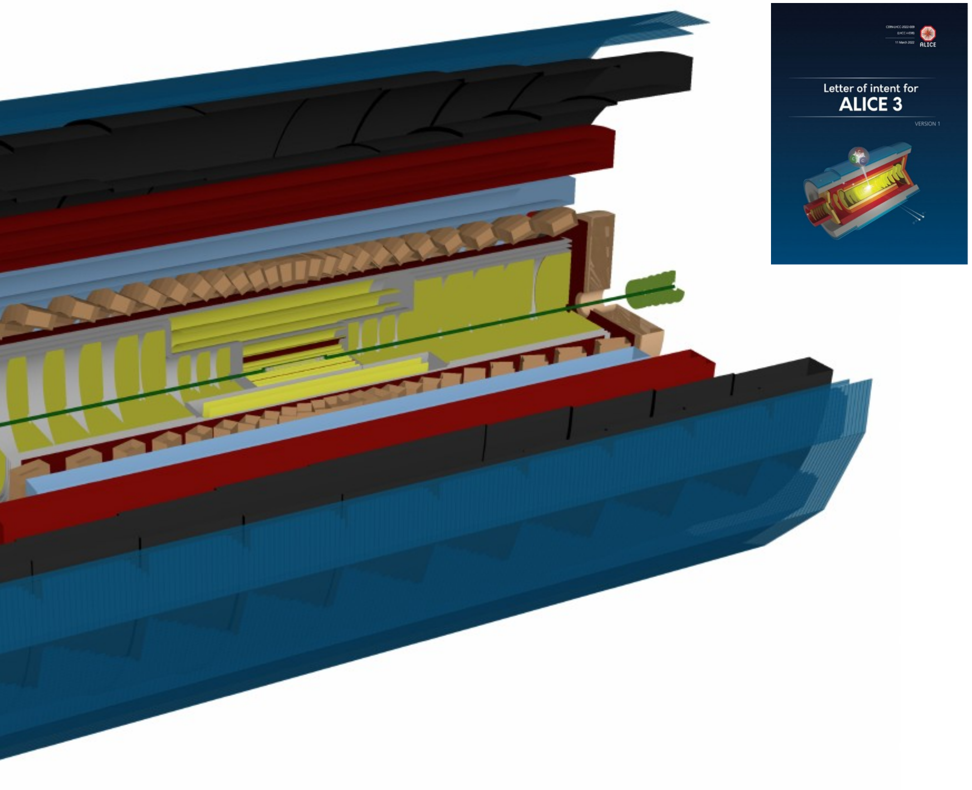
II.3 – Questions in ≈2035 : answers by ALICE3

	Questions	ALICE3 answers (including physics interests by French community)
01	Thermodynamics	T_{e+e-} , net quantum fluctuations
02	Hydrodynamics+ transport	Diffusion coefficent 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-$\bar{D}$ correlations (e.g. D^0-$\bar{D}^0$) in AA, fully-tag HF jets, recoil jet techniques
05	In-medium impact on QCD force	$\eta_C \longrightarrow$ baryons, $J/\psi \longrightarrow \mu\mu$, 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-$\bar{D}$ correlations in pA (e.g. D^0-$\bar{D}^0$), 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 ($\Lambda_C^+ n$)
10	BSM search	γγ scattering with m < 5 GeV/c^2, axion-like particle search

ALICE3 LoI, arXiv:2211.02491
ALICE3 Scoping Document Draft:10248 (LHCC)

III.1 – ALICE3 layout v1 : key features

ALICE3 LoI, *CERN-LHCC-2022-009*



3.

Vertexer+Tracker,
Compact ($R_{\text{outer TOF}} \approx$ 85 cm)
ultra-light (layer 0 ~ 0.1 % x/X_0)
Silicon MAPS-based ($\approx$ 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

To collect integrated **MB luminosities** :

1.

≈ 1 MHz 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 $\mathscr{L}$

ALICE3 LoI, arXiv:2211.02491 Tab. 1 p.18

Quantity	pp	O–O	Ar–Ar	Ca–Ca	Kr–Kr	In–In	Xe–Xe	Pb–Pb
$\sqrt{s_{\mathrm{NN}}}$ (TeV)	14.00	7.00	6.30	7.00	6.46	5.97	5.86	5.52
L_{AA} ($\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	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}
$\langle L_{\mathrm{AA}}\rangle$ ($\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	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}
$\mathscr{L}_{\mathrm{AA}}^{\mathrm{month}}$ (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
$\mathscr{L}_{\mathrm{NN}}^{\mathrm{month}}$ (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
$\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ (MB)	7	70	151	152	275	400	434	682

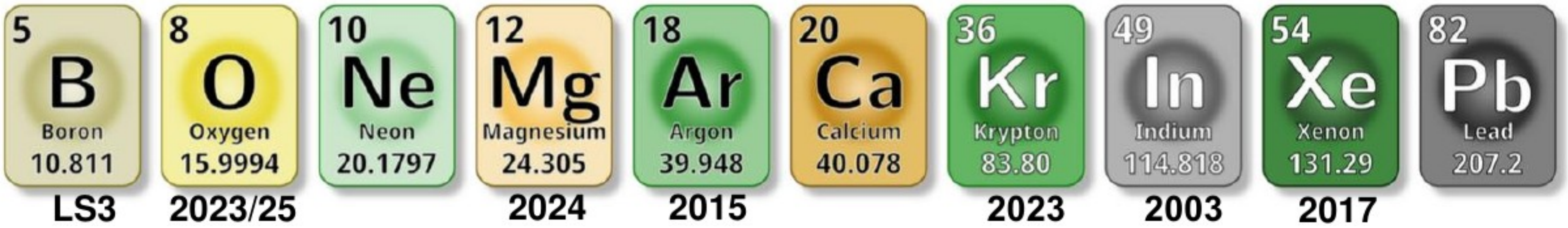
	pp (**2024**) ALICE2	pp (2018) ALICE1	Pb-Pb (**2023**) ALICE2
$\sqrt{s_{\mathrm{NN}}}$ (TeV)	13,6	13	5,36
L_{AA} ($\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	$1\mathrm{x}10^{31}$	$3\mathrm{x}10^{30}$	$3{,}5\mathrm{x}10^{27}$
$\mathscr{L}^{\mathrm{month}}_{\mathrm{AA}}$ (MB nb^{-1})	≈ $5\mathrm{x}10^{3}$ nb^{-1}	≈ 2 nb^{-1}	≈2.0 nb^{-1}
$<R_{\mathrm{max}}>$ (kHz)	500		45
Colliding bunches	≈ 2200	≈ 2200	≈ 875
µ	≤ 0.02	≤ 0.02	≤ 0.01

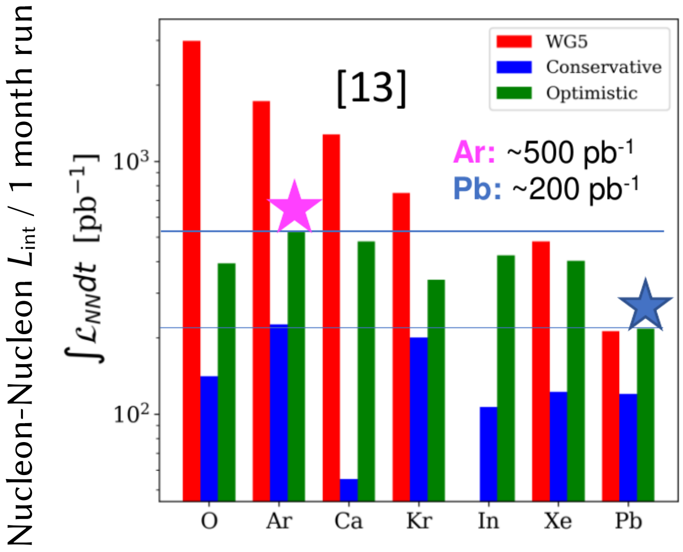
(Beware :
__delivered__ Vs
inspected Vs
actually "__recorded__" luminosity (skip or trigger) …
→ for ALICE3, delivered ≈ recorded)

bpt.web.cern.ch/statistics

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

Alemany Fernandez, LHCP2024





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

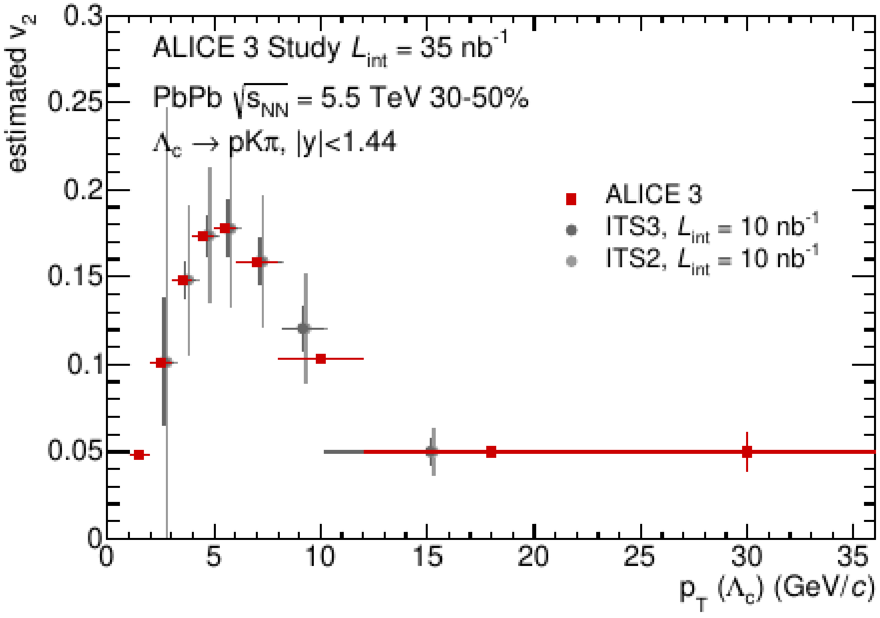
= *publication to appear*

New LHC injector model under development
⟶ more accurate estimates for possible $\int \mathscr{L}_{\text{inst}}$ to come

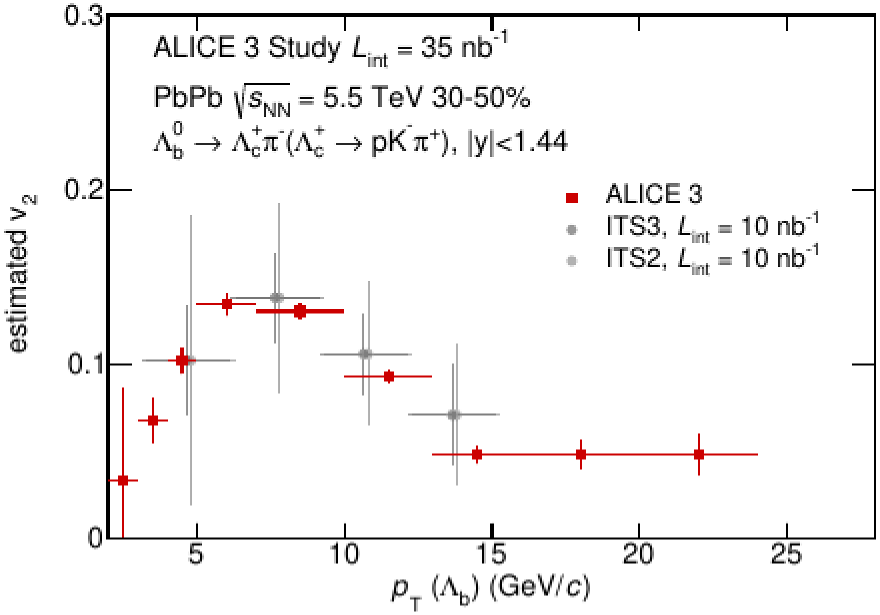
IV.2 – Pb-Pb : why taking still Pb-Pb data ?

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)

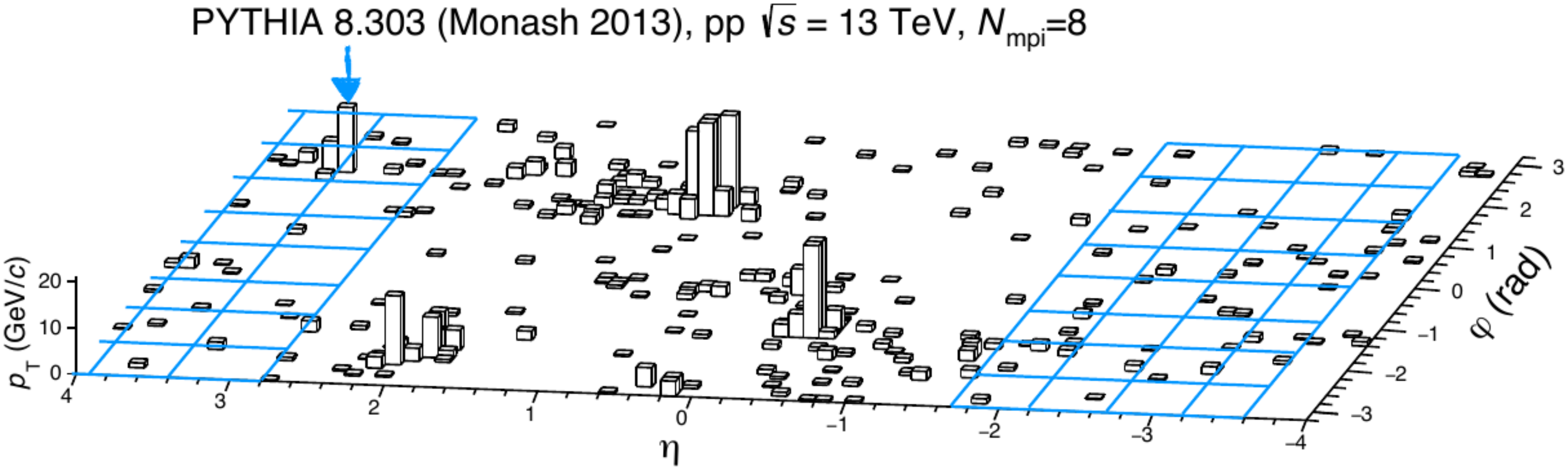


Key of improvement between ALICE2 (run 3), ALICE2.1 (run 4) and ALICE3 ?
≉ L_{int} but rather the instrument : ALICE3 pointing resolution and AxEff

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, …)

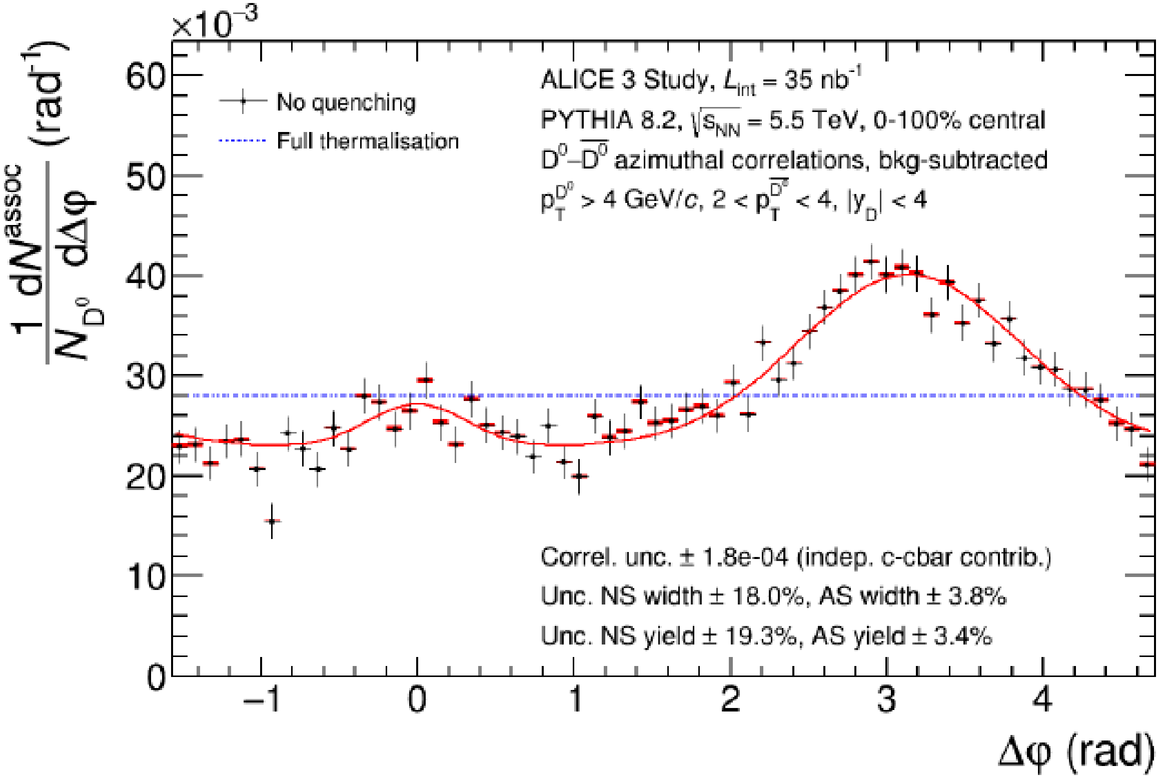


If you look only in the blue windows (*VZERO acceptance ALICE1*)…
You may miss fluctuations in MPI that lead to jets…

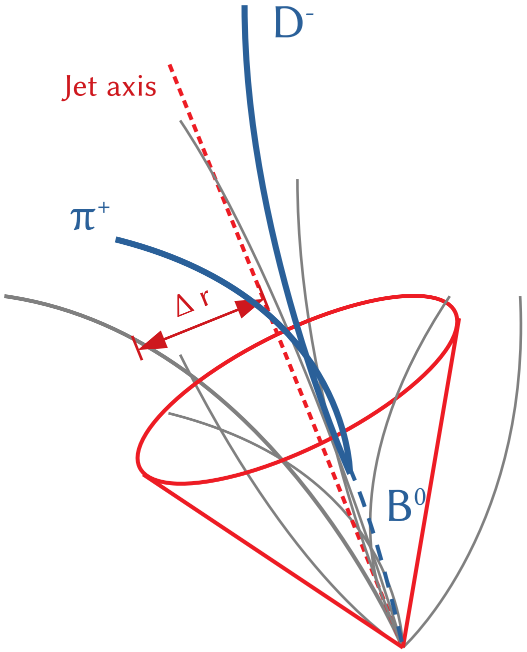
Ortiz, SQM2024

IV.3 – ~~Pb-Pb~~ but sthg else : smaller systems as *opportunities*

Higher raw signal (higher luminosities wrt Pb-Pb) while still ∃ sensitivity to collective medium ?

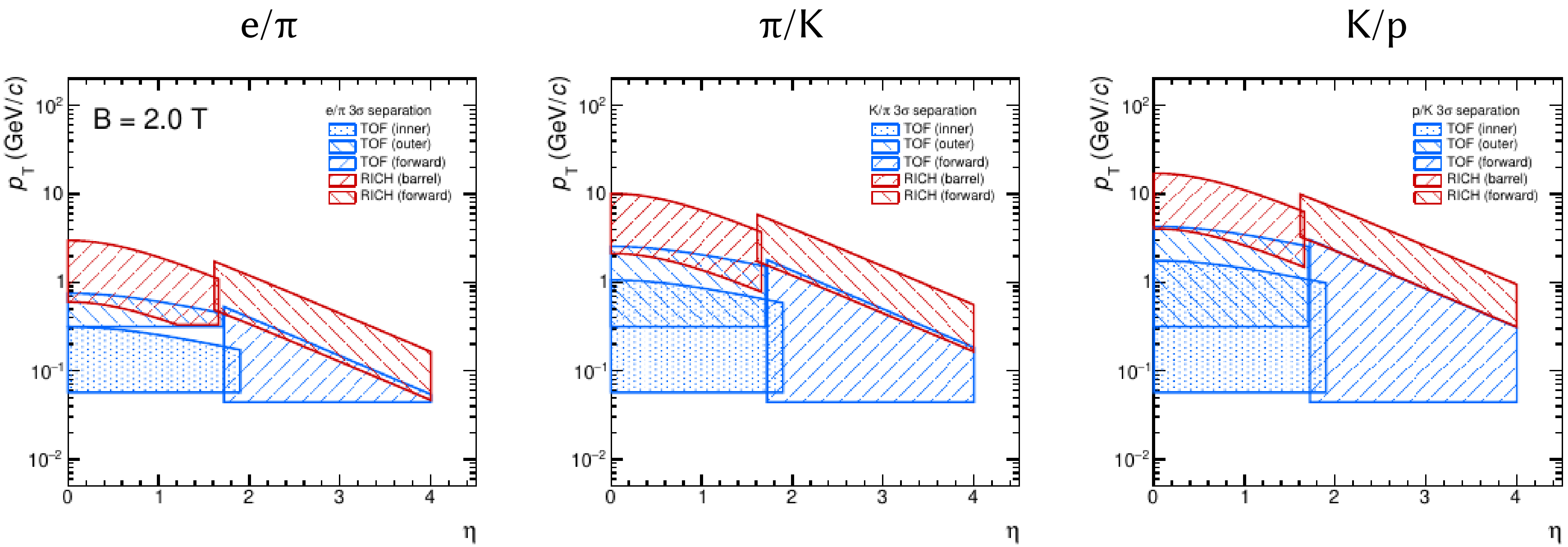


1. D-$\overline{\text{D}}$ (de)correlations in AA



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

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



e/π

π/K

K/p

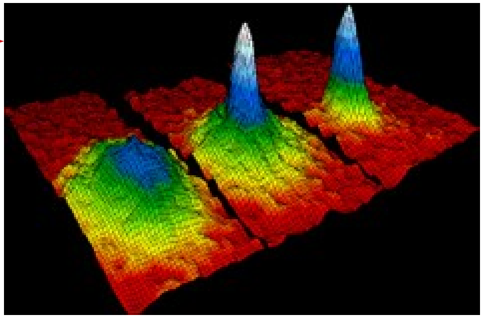
Figure 20: Analytical calculations of the $\eta - p_{\mathrm{T}}$ regions in which particles can be separated by at least 3σ for the ALICE 3 particle-identification systems embedded in a 2.0 T magnetic field. Electron/pion, pion/kaon and kaon/proton separation plots are shown from left to right.

ALICE3 LoI, *CERN-LHCC-2022-009*, *section 3.2.2*

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

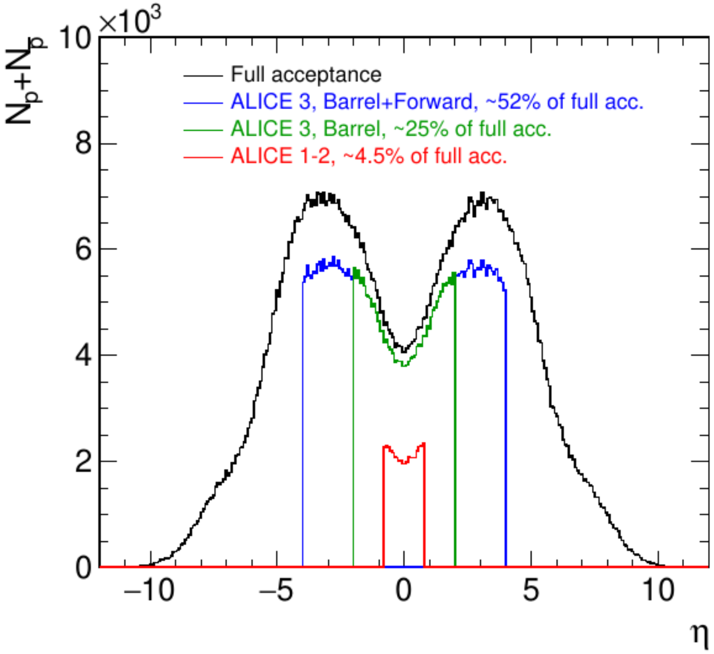
1. Getting $dN/dp_T dy + v_n(h^{\pm})$ down to non-relativistic p_T (e.g. $p_T < 0{,}05$ GeV/$c \longrightarrow \beta_{\pi^{\pm}} \approx 0{,}34$)
$\longrightarrow$ change from non-relativistic (linear) to relativistic hydro. (quadratic behaviour)

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.



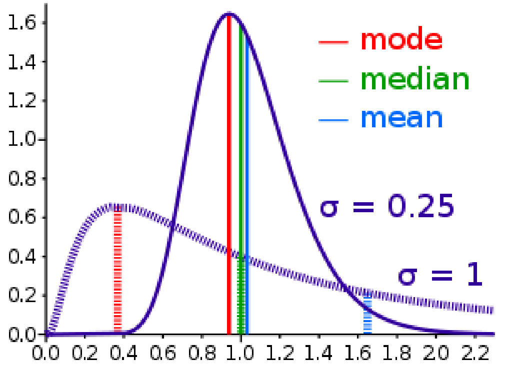
ALICE3 LoI, CERN-LHCC-2022-009, Fig. 62 p.112

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)

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

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

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

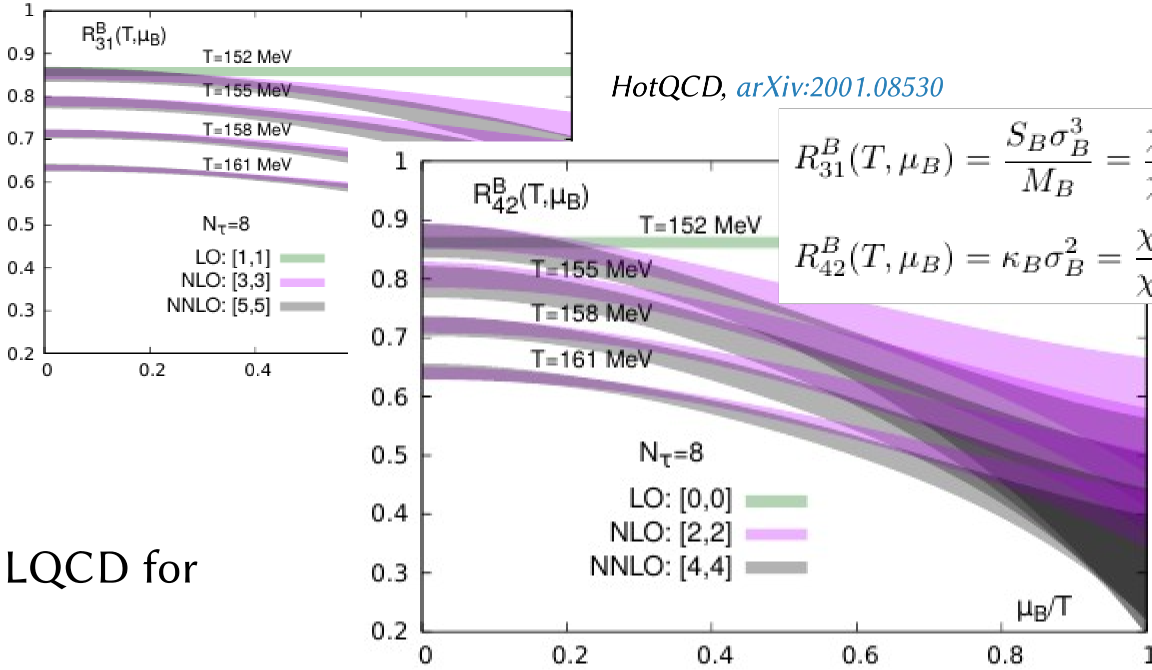


Wikipedia:Skewness

Measure event-by-event fluctuations into distributions with $\underline{p_T > 0}$ GeV/c + over $\underline{\text{large } y}$

(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

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

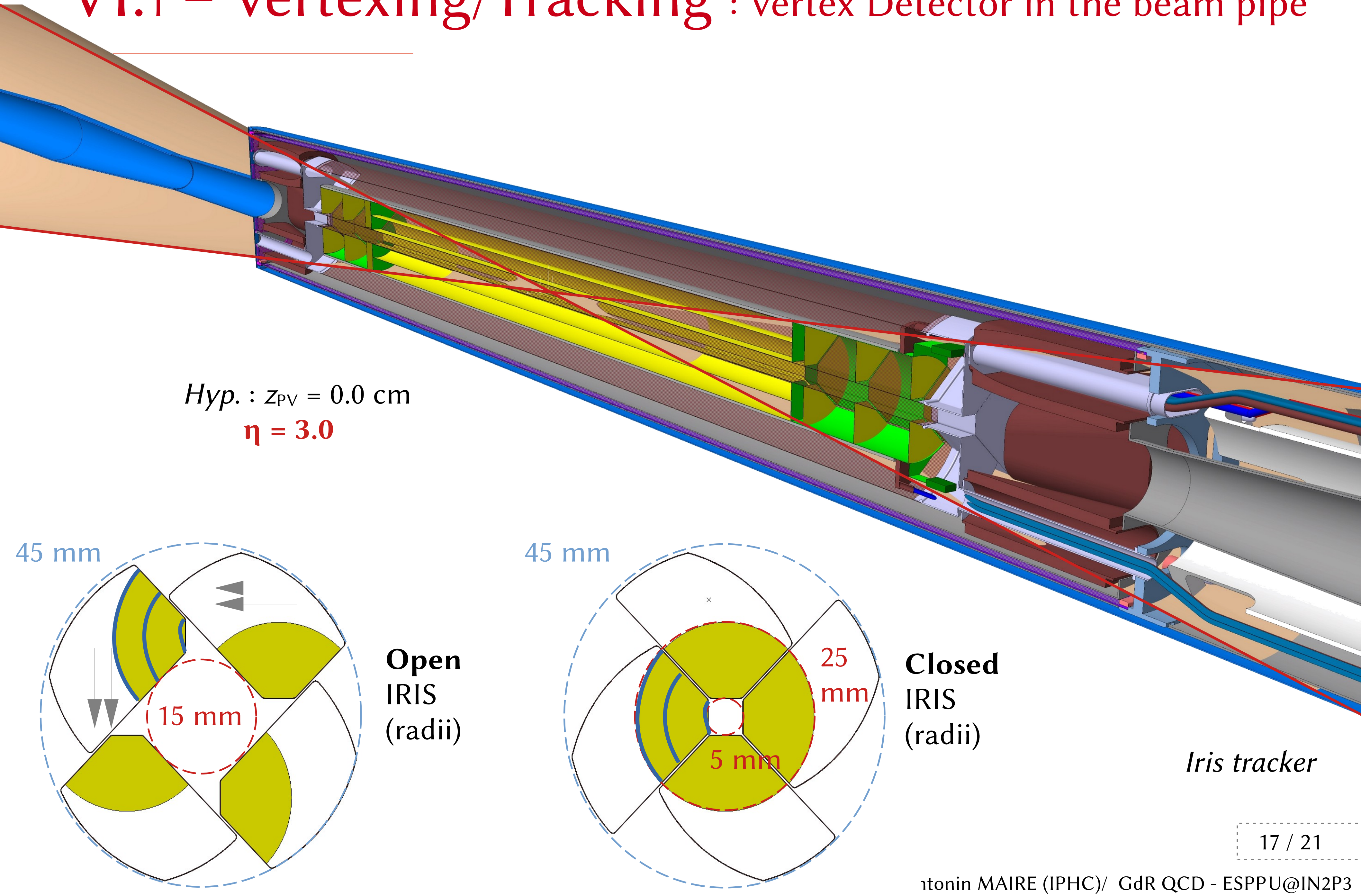
$$R^B_{42}(T,\mu_B) = \kappa_B\sigma^2_B = \frac{\chi^B_4(T,\mu_B)}{\chi^B_2(T,\mu_B)}$$

→ *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



Hyp. : $z_{PV} = 0.0$ cm
$\eta = 3.0$

Open
IRIS
(radii)

Closed
IRIS
(radii)

Iris tracker

VI.2 – Physics : strangeness tracking, example in ALICE3

…

Ξ_{CC}^{2+}(*ucc*)⟶ Ξ_{C}^{+}(*usc*) π^{+} ⟶ [Ξ^{-}(***dss***) $2\pi^{+}$] π^{+}

Ω_{CC}^{+}(*scc*) …

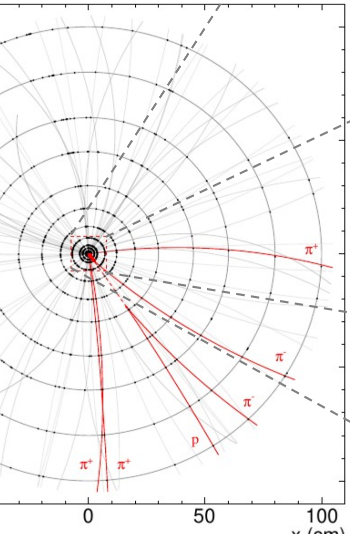
Ω_{CCC}^{2+}(*ccc*)⟶ Ω_{CC}^{+}(*scc*) π^{+} ⟶ [Ω_{C}^{0}(*ssc*) π^{+}] π^{+} …

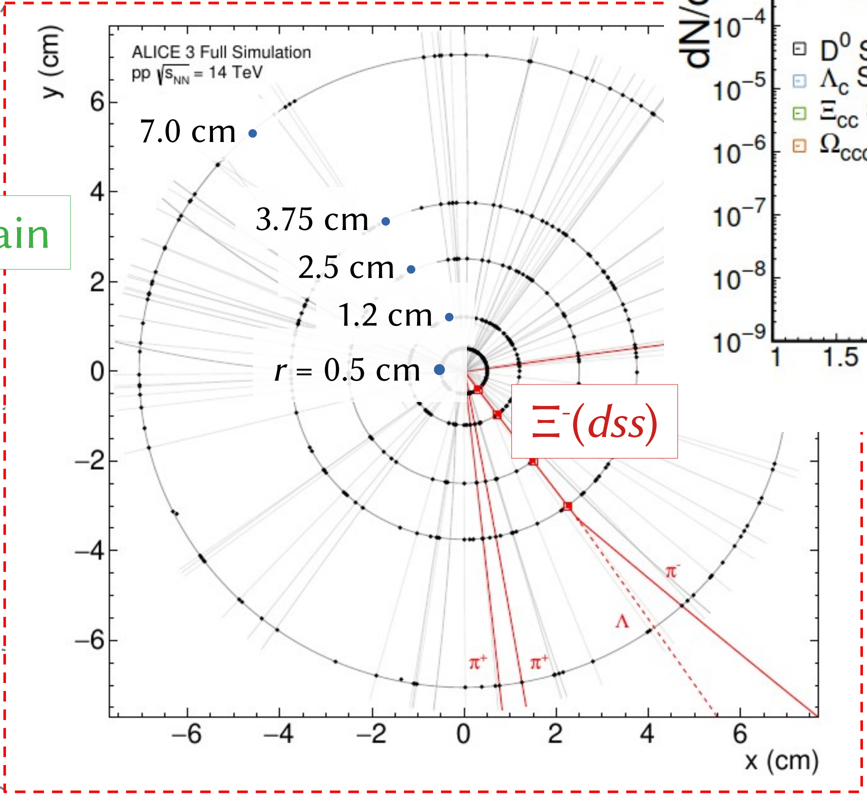
Ξ_{B}^{-}(*dsb*)⟶ Ξ_{C}^{0}(dsc) π^{-} ⟶ [Ξ^{-}(*dss*) π^{+}] π^{-} …

Ω_{B}^{-}(*ssb*)⟶ Ω_{C}^{0}(*ssc*) π^{-} ⟶ [Ω^{-}(*dss*) π^{+}] π^{-} …

…

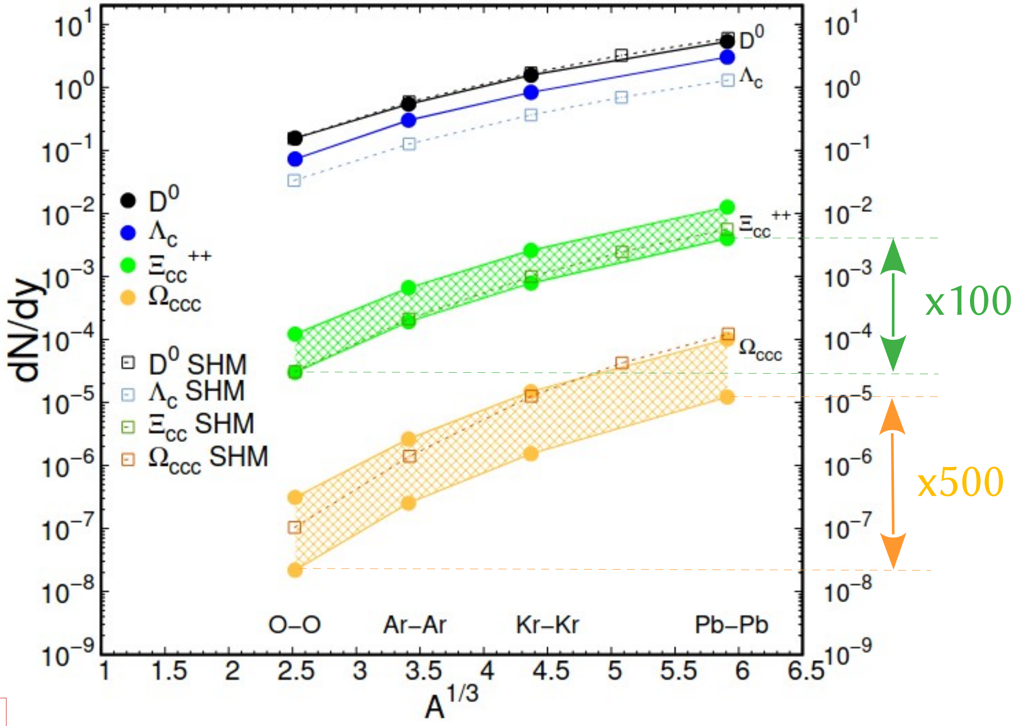
Ξ_{CC}^{2+}(*ucc*) decay chain





ALICE3 LoI, *CERN-LHCC-2022-009*

Greco, *arXiv:2305.03687*



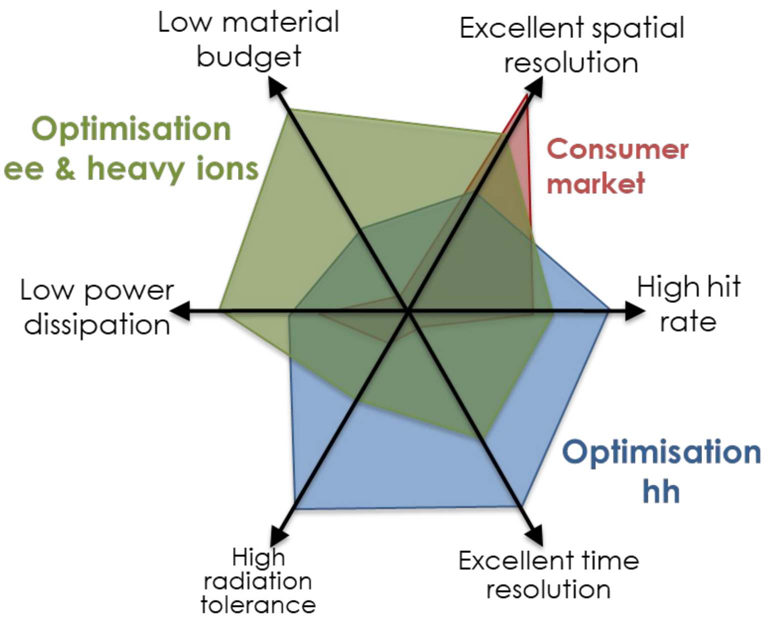
Prediction by SHM
or Coalescence model

VII.1 – Extra reason for ALICE3 : (e^+e^-) Higgs factories

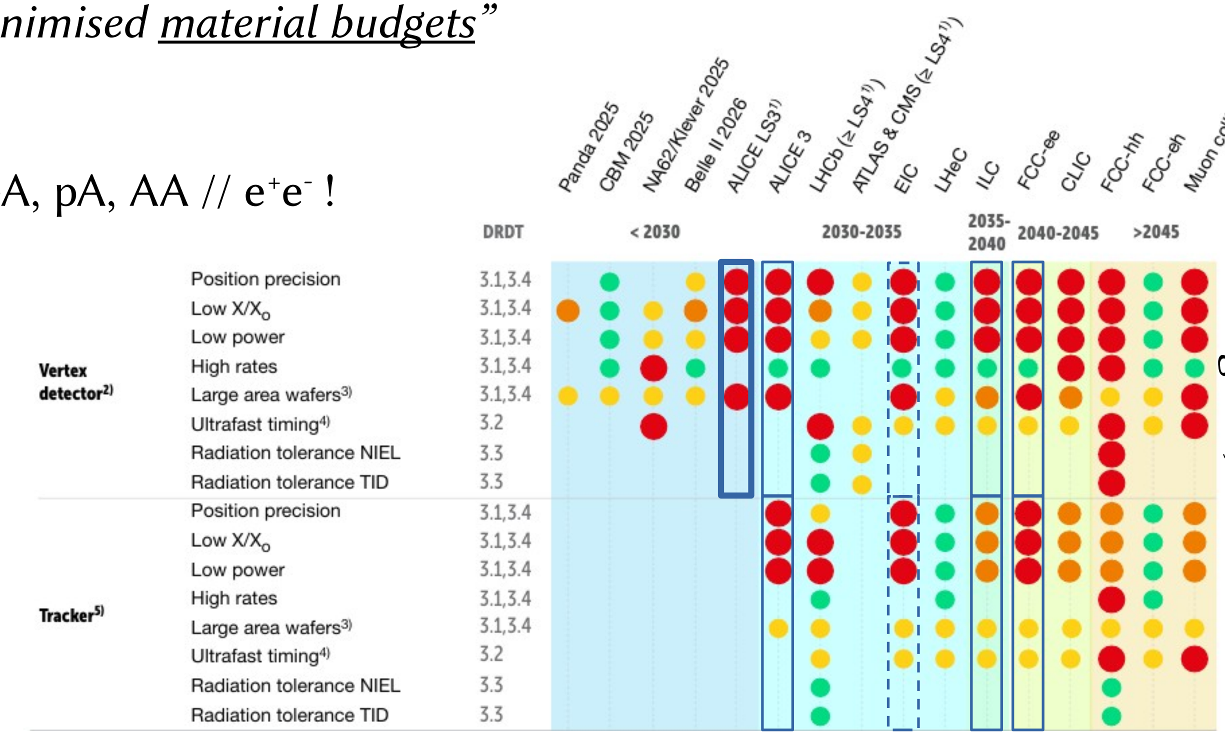
A. Conclusion 1 out of 4 (*2021 ECFA roadmap*) :

> *”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



		DRDT	Panda 2025	CBM 2025	NA62/Klever 2025	Belle II 2026	ALICE LS3[1]	ALICE 3	LHCb (≥ LS4[1])	ATLAS & CMS (≥ LS4[1])	EIC	LHeC	ILC	FCC-ee	CLIC	FCC-hh	FCC-eh	Muon collider
					< 2030					2030-2035			2035-2040	2040-2045			>2045	
Vertex detector[2]	Position precision	3.1,3.4		🟢		🟡	🔴	🔴	🔴	🟡	🔴	🟢	🔴	🔴	🔴	🔴	🟢	🔴
	Low X/X_0	3.1,3.4	🟠	🟢	🟡	🟠	🔴	🔴	🟠	🟡	🔴	🟢	🔴	🔴	🔴	🔴	🟢	🔴
	Low power	3.1,3.4		🟢	🟡	🟡	🔴	🔴	🟡	🟡	🔴	🟢	🔴	🔴	🔴	🔴	🟢	🔴
	High rates	3.1,3.4		🟢	🔴	🟢		🟢	🟢		🟢	🟢	🟢	🟢	🔴	🔴	🟢	🟢
	Large area wafers[3]	3.1,3.4	🟡	🟡	🟡	🟡	🔴	🔴			🔴	🟡	🟠	🔴	🟠	🟡	🟡	🔴
	Ultrafast timing[4]	3.2			🔴				🔴	🟡	🟡	🟡	🟡	🟡	🟡	🔴	🟡	🔴
	Radiation tolerance NIEL	3.3							🟢	🟡						🔴		
	Radiation tolerance TID	3.3							🟢	🟡						🔴		
Tracker[5]	Position precision	3.1,3.4						🔴	🟡		🔴	🟢	🟠	🔴	🟠	🟠	🟢	🟠
	Low X/X_0	3.1,3.4						🔴	🔴		🔴	🟢	🟠	🔴	🟠	🟠	🟢	🟠
	Low power	3.1,3.4						🔴	🔴		🔴	🟢	🟠	🔴	🟠	🟠	🟢	🟠
	High rates	3.1,3.4							🟢			🟢				🔴	🟢	
	Large area wafers[3]	3.1,3.4						🟡	🟡		🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟡
	Ultrafast timing[4]	3.2							🟡		🟡	🟡	🟡	🟡	🟡	🔴	🟡	🔴
	Radiation tolerance NIEL	3.3							🟢							🟢		
	Radiation tolerance TID	3.3							🟢							🟢		

🔴 Must happen or main physics goals cannot be met 🟠 Important to meet several physics goals

🟡 Desirable to enhance physics reach 🟢 R&D needs being met

Fig. 3.1, 2021 ECFA roadmap

Conclusions

Conclusions : ALICE3 …

ALICE3 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 $\mu_{\text{pileup}} = 1$)

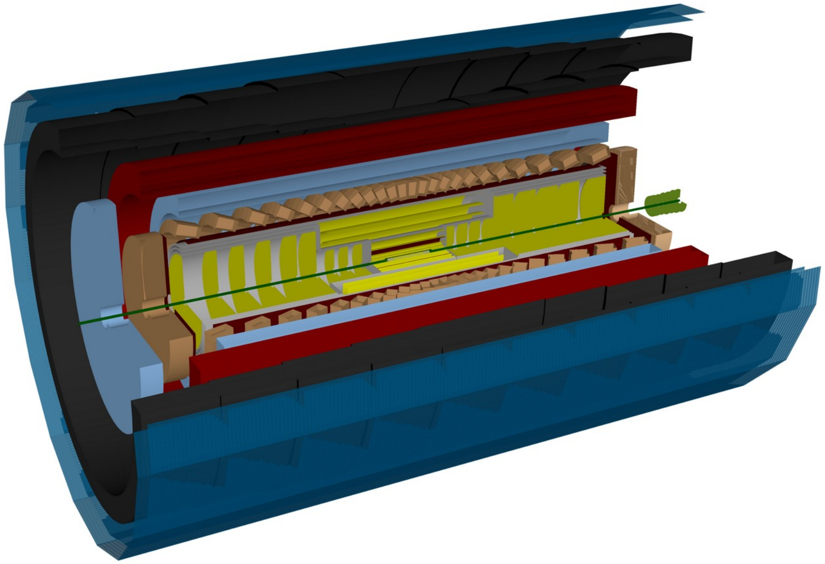
Instrument with desired French participation

IP2I, IPHC, LPSC = ALICE3 Outer Tracker

→ CMOS design, readout electronics, mechanics

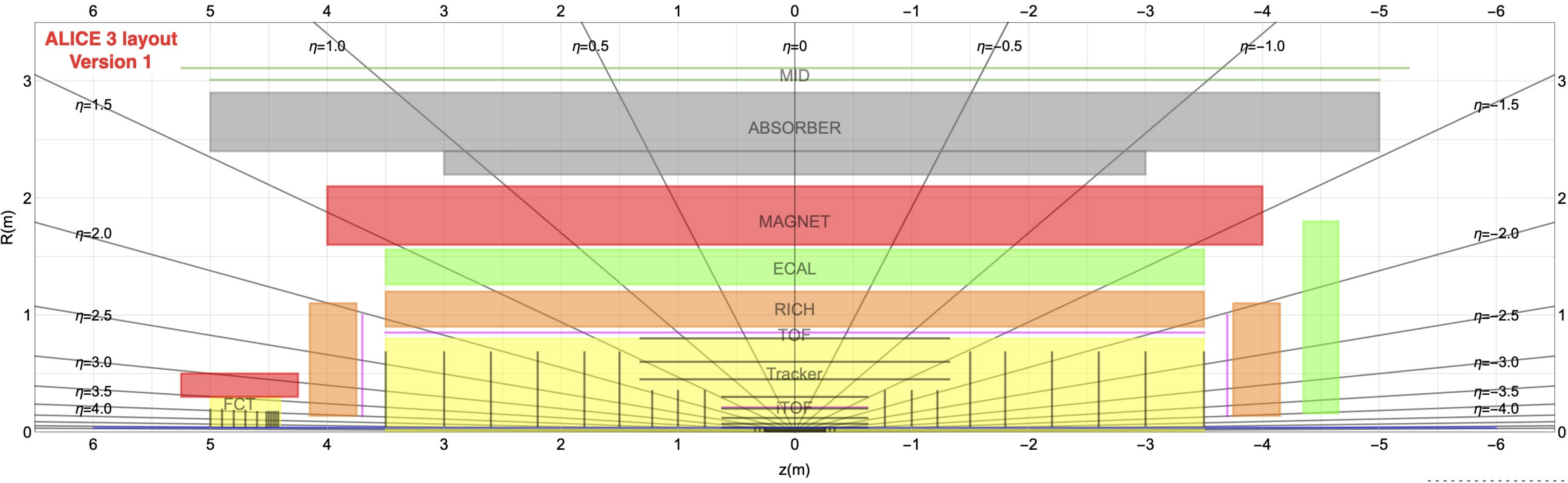
App. A – General layout

I.2 – ALICE3 : default layout overview, v1 SD



Scoping document (2024-03)

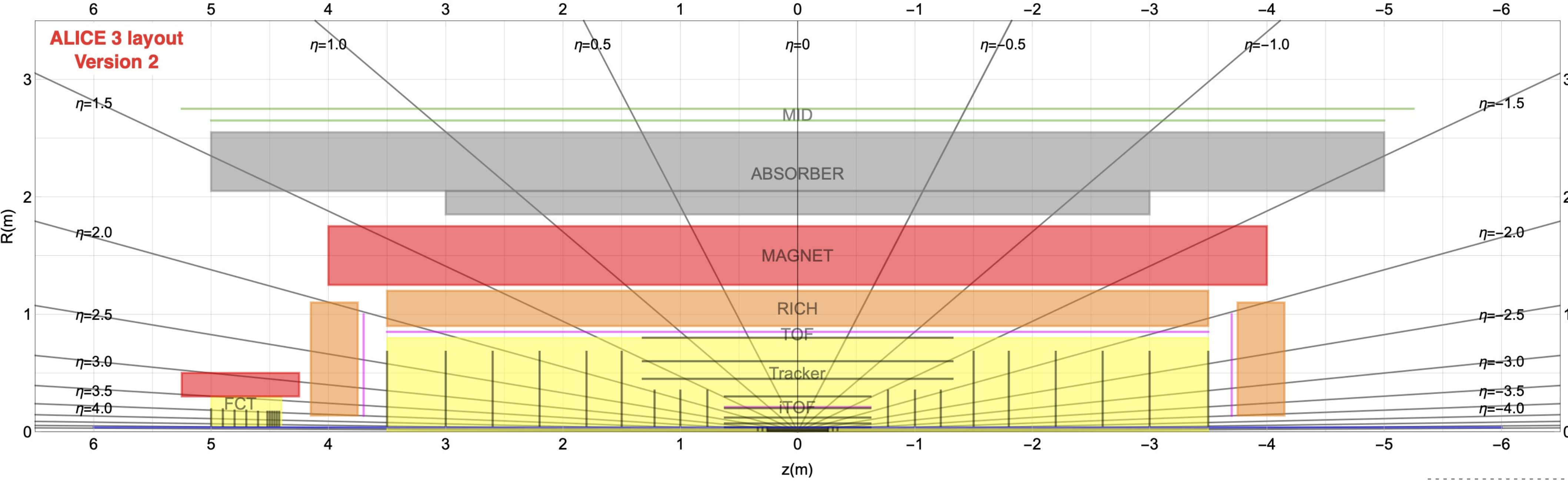
~~ALICE3 LoI, *CERN-LHCC-2022-009*, *Fig. 1*~~
+ ALICE3 Scoping document *Fig.1 [LoIv1] update = default config.*



I.3 – ALICE3 : layout overview, v2 SD

Scoping document (2024-03)

~~*ALICE3 LoI, CERN-LHCC-2022-009, Fig. 1*~~
~~+ ALICE3 Scoping document *Fig.1 [LoIv1] update = default config.*~~
+ ALICE3 Scoping document *Fig.12 [v2] = a scoping option = No ECal = new default in practice*



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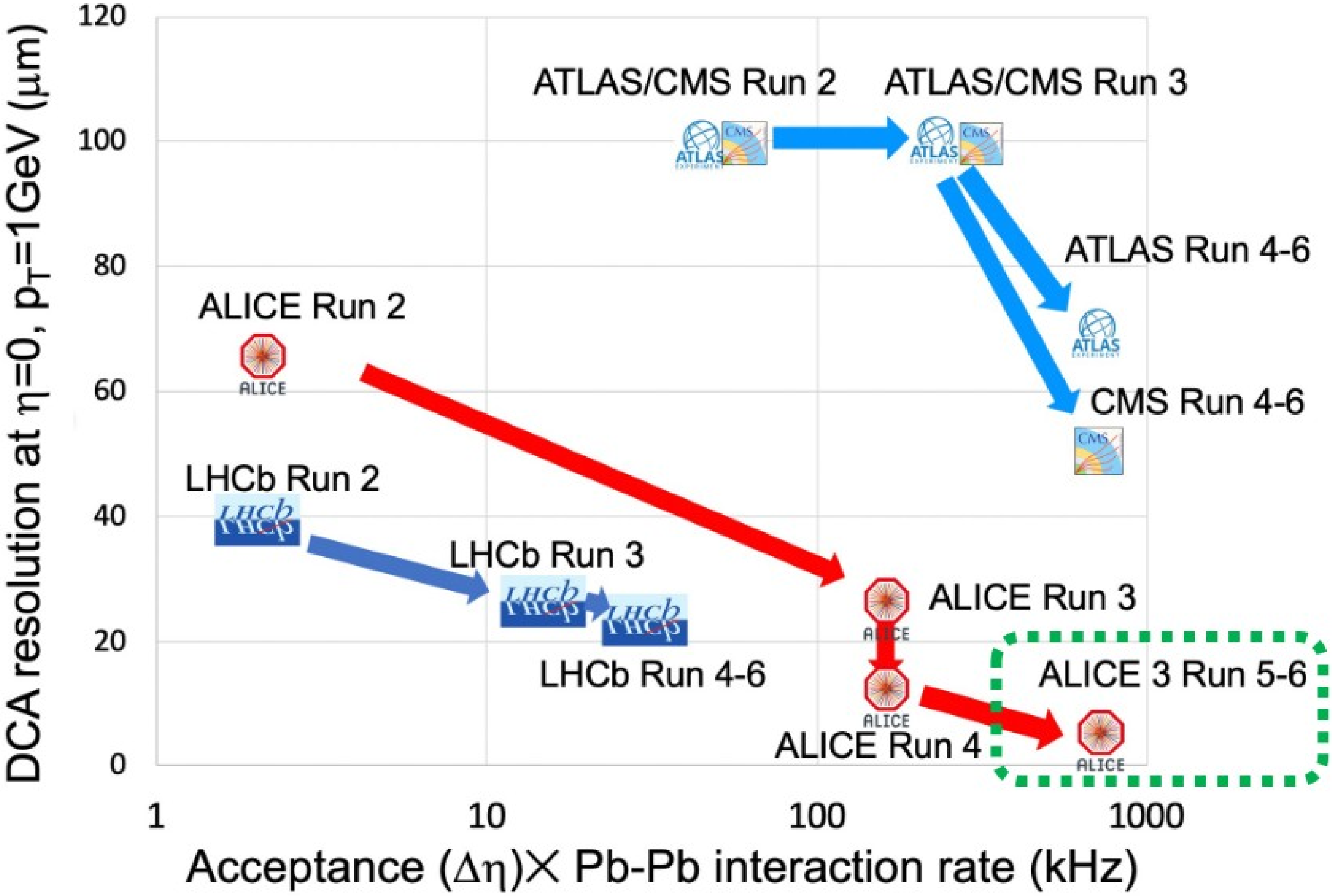
App. B – ALICE3

I.1 – XX : ...


DCA resolution at η=0, p_T=1GeV (μm)
120
100
80
60
40
20
0
1
10
100
1000
Acceptance (Δη)X Pb-Pb interaction rate (kHz)
ATLAS/CMS Run 2
ATLAS/CMS Run 3
ATLAS Run 4-6
CMS Run 4-6
ALICE Run 2
LHCb Run 2
LHCb Run 3
LHCb Run 4-6
ALICE Run 3
ALICE Run 4
ALICE 3 Run 5-6

(PaR.x – Reading : $3 < |\eta| < 4$ landscape)

Beware :

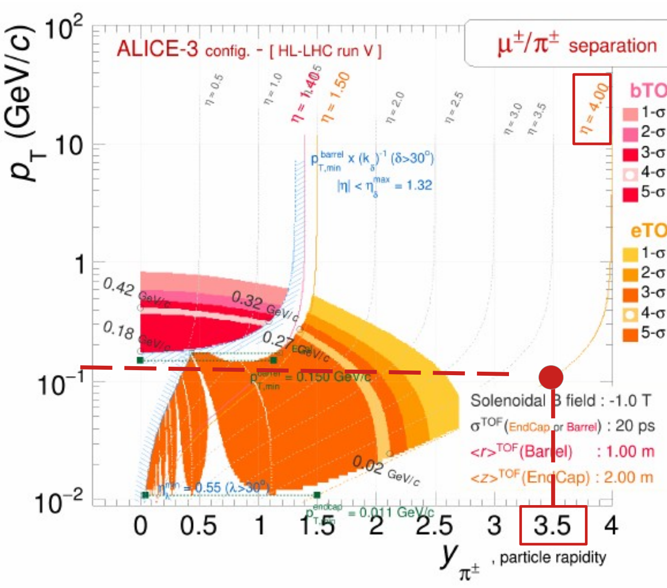
pseudo-rapidity $\eta \neq$ rapidity y, especially at low p_T

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

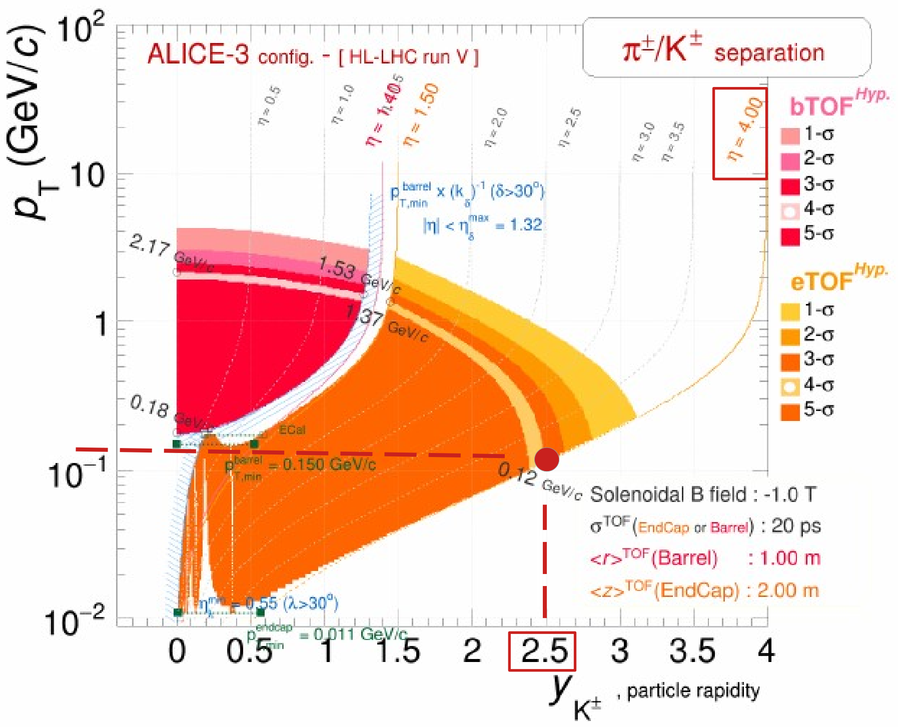
→ Looking at <u>forward η</u> may be less <u>forward *rapidity*</u> physics than one could imagine naïvely

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

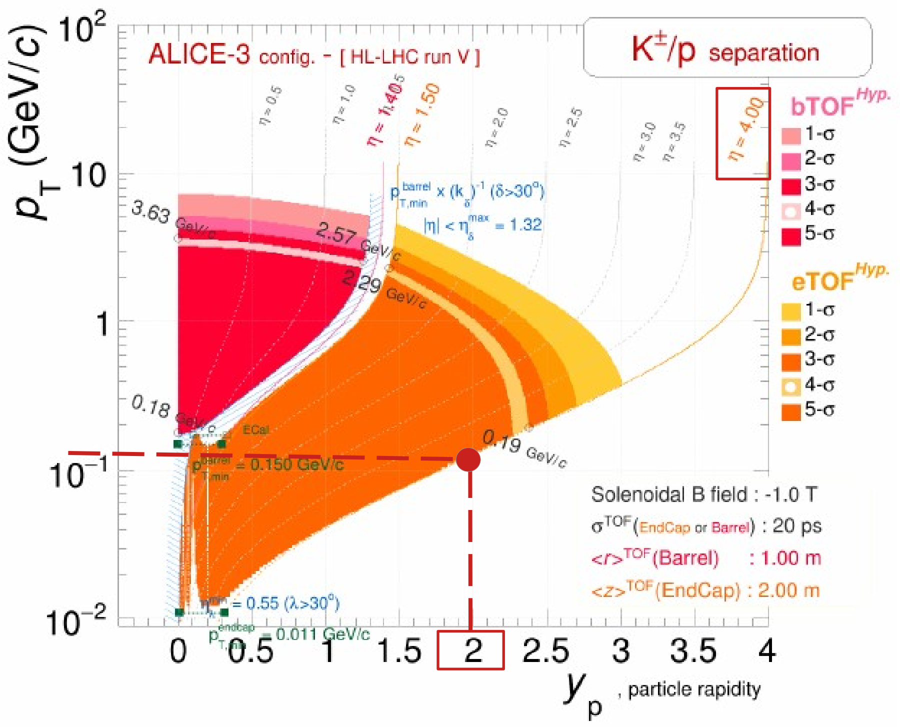
(*b*)



(*c*)



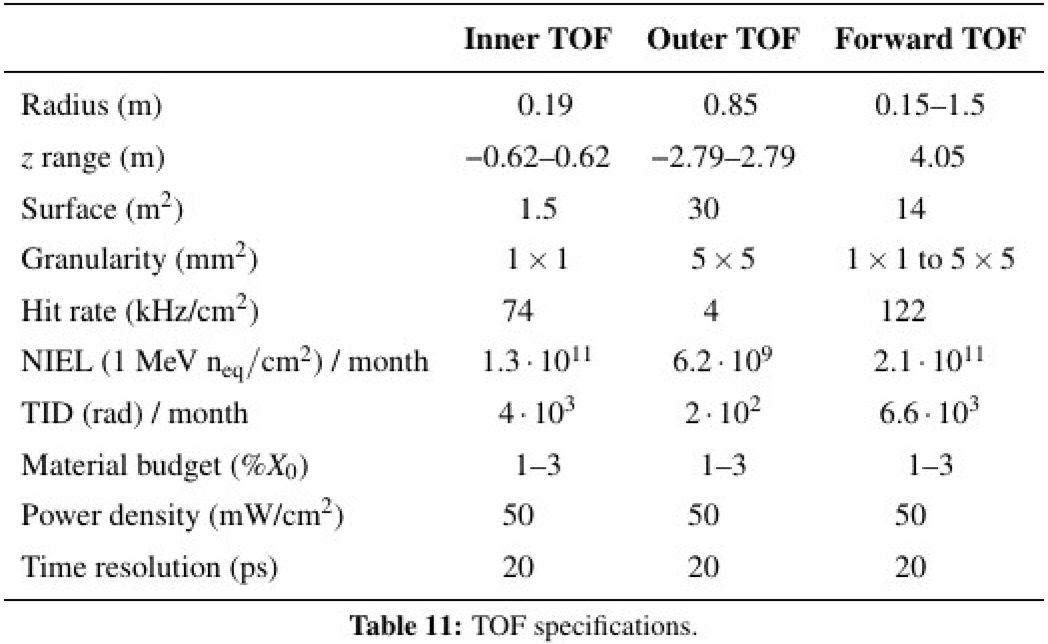
(*d*)



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

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

H.4 – ALICE3 : 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.

3 options :

- 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

ALICE3 LoI, *CERN-LHCC-2022-009, section 4.3*

App. C – OT staves & discs

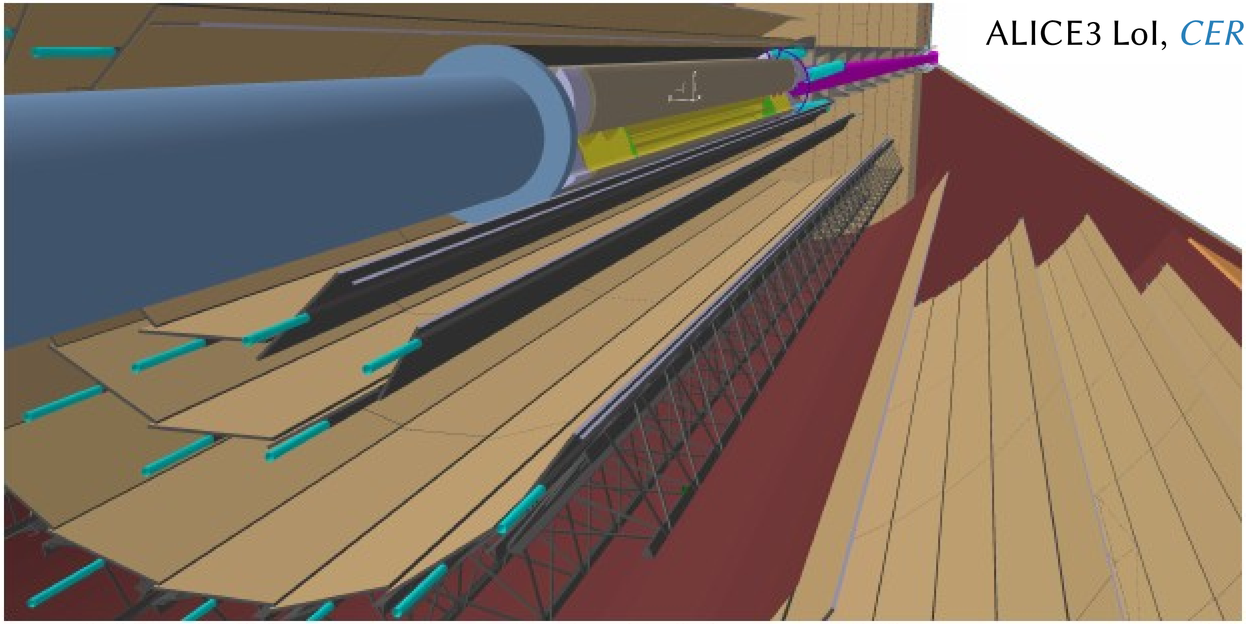


Figure 83: Sketch of the outer tracker mechanics. Modules assembled in staves structures are visible as well as services and power lines. Furthermore, the overlap of the staves can be seen.

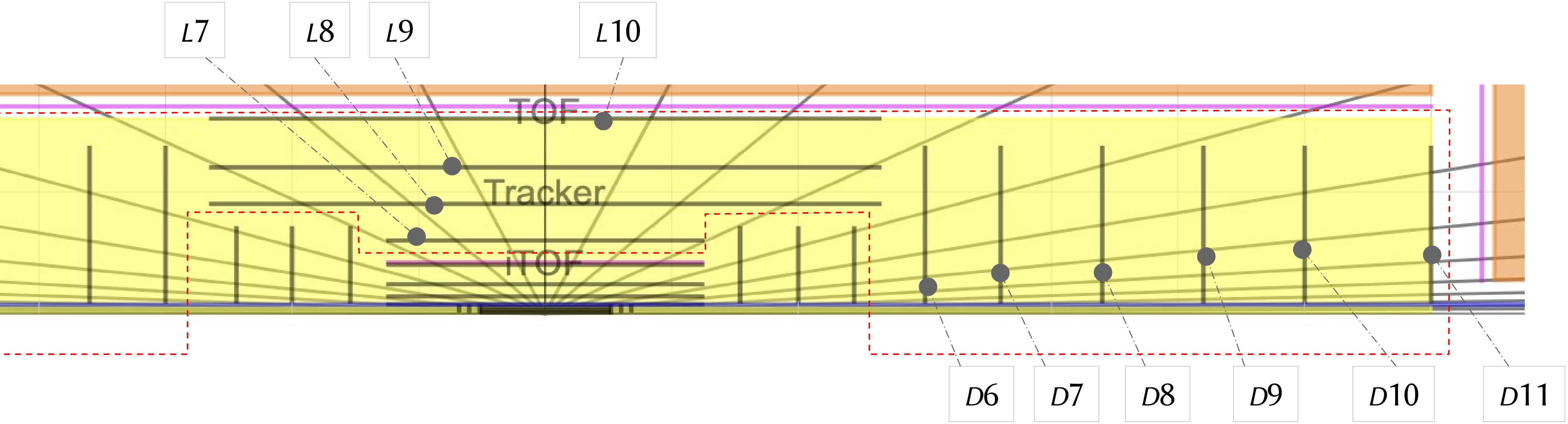
ALICE3 LoI, *CERN-LHCC-2022-009*

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

III.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

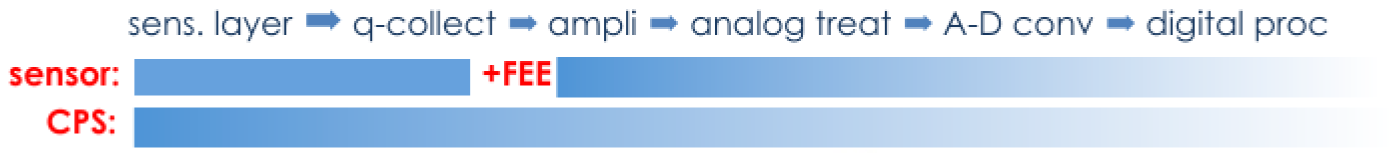
→ OT ≈ **50 m²** of plain acceptance geometry in total (*i.e.* naïve discs and cylinder models)

- 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

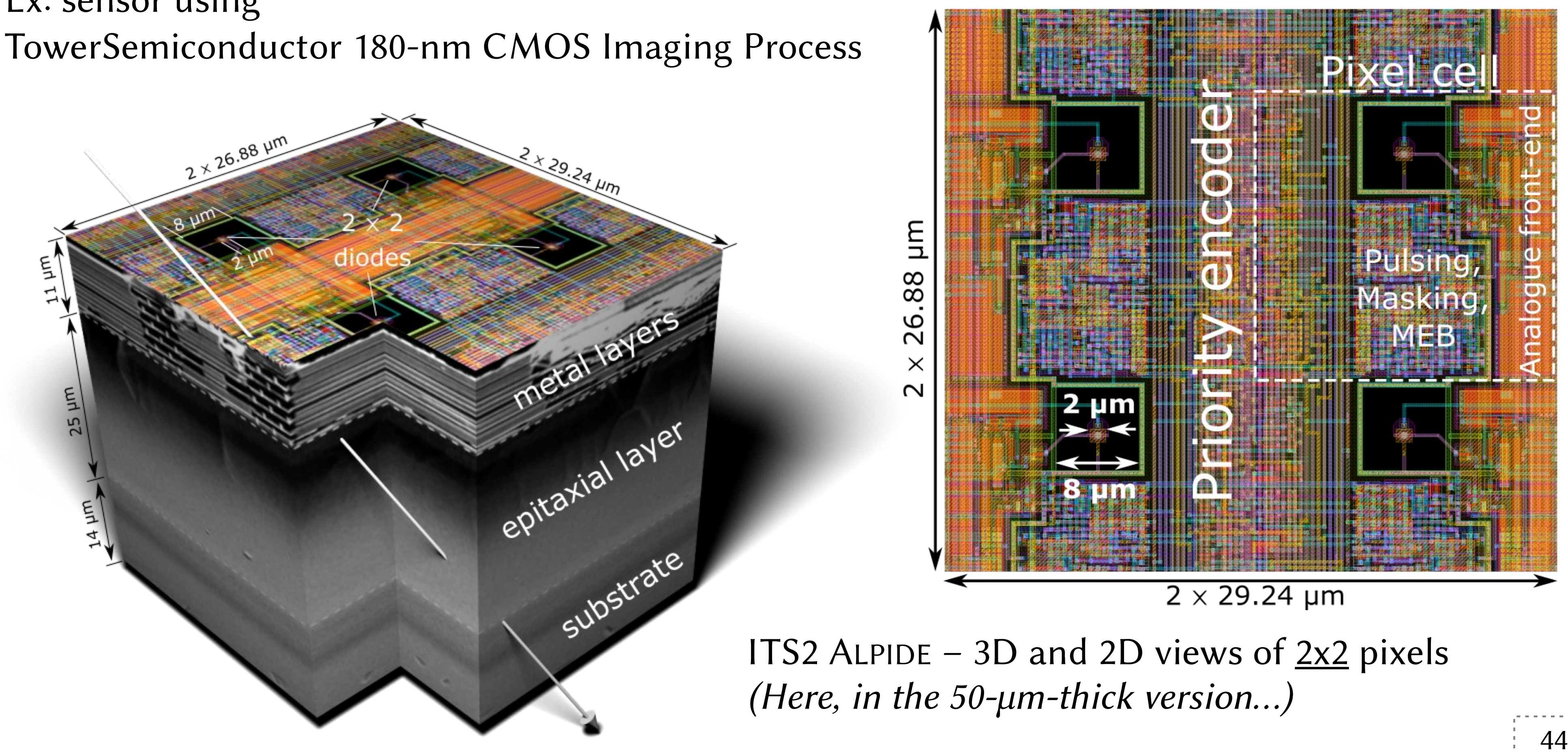
App. D – CMOS sensor

I.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...)

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

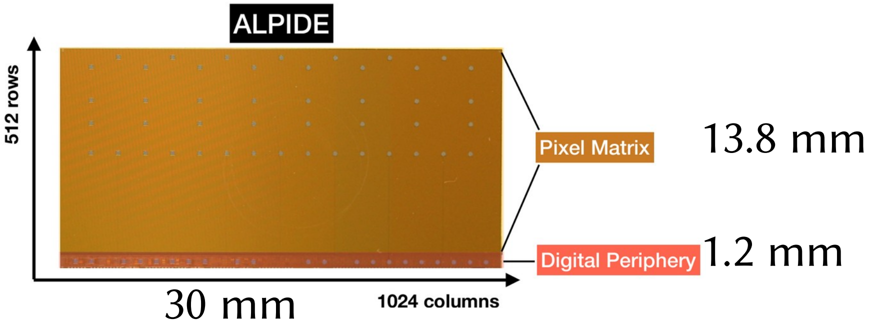
MFT

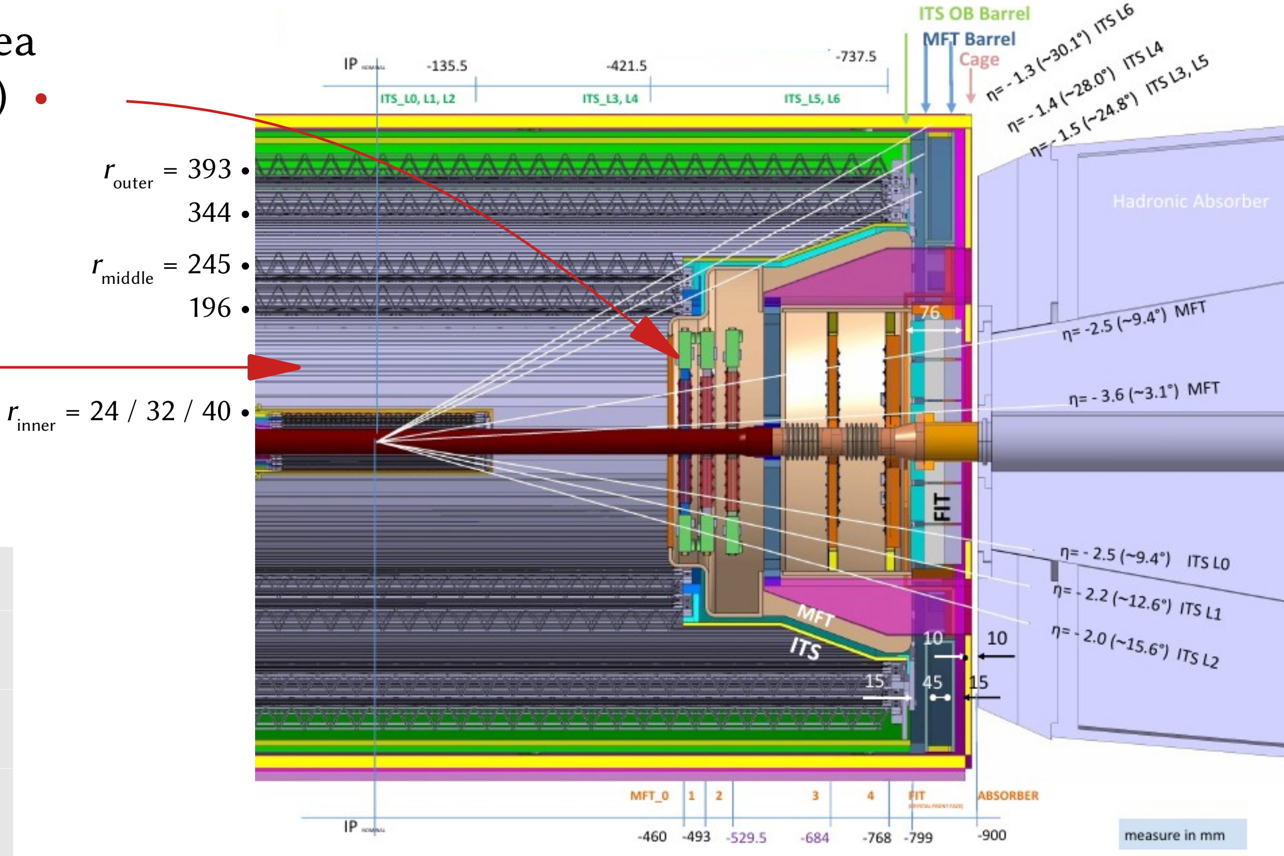
5 double-sided vertical discs
<u>896</u> ALPIDE chips
0.47 x10^9 pixels
= 0.37 m² of *sensitve* area
(3.7% of ITS2 area) •

ITS2

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

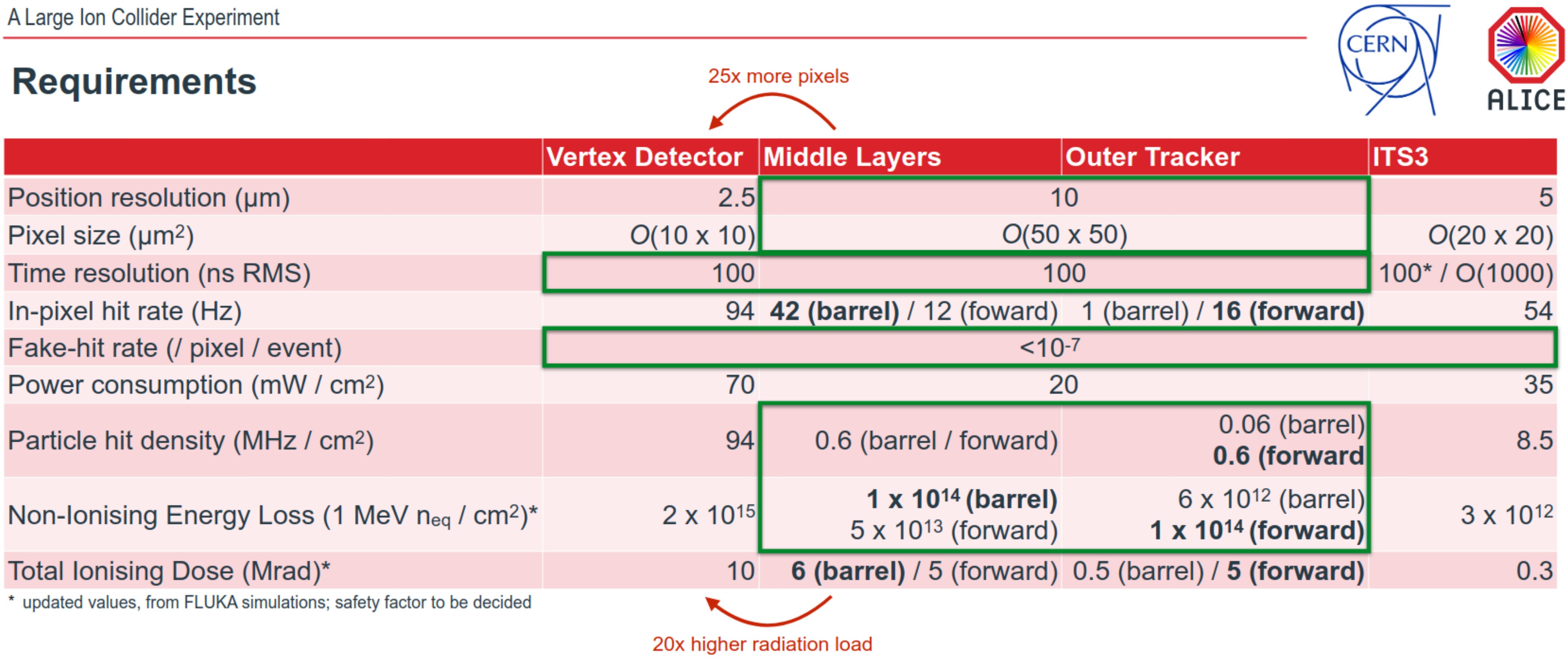
	L0,L1,L2	L3+L4	L5+L6
Layers	*Inner*	Middle	Outer
Chips	432	6048	17640
Active surface	0.18 m²	2.50 m²	7.30 m²
Fraction	1.8%	25%	73%





VI.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 (µm^2)	*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 / cm^2)	70	20		35
Particle hit density (MHz / cm^2)	94	0.6 (barrel / forward)	0.06 (barrel) **0.6 (forward**	8.5
Non-Ionising Energy Loss (1 MeV n_{eq} / cm^2)*	2 x 10^{15}	**1 x 10^{14} (barrel)** 5 x 10^{13} (forward)	6 x 10^{12} (barrel) **1 x 10^{14} (forward)**	3 x 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

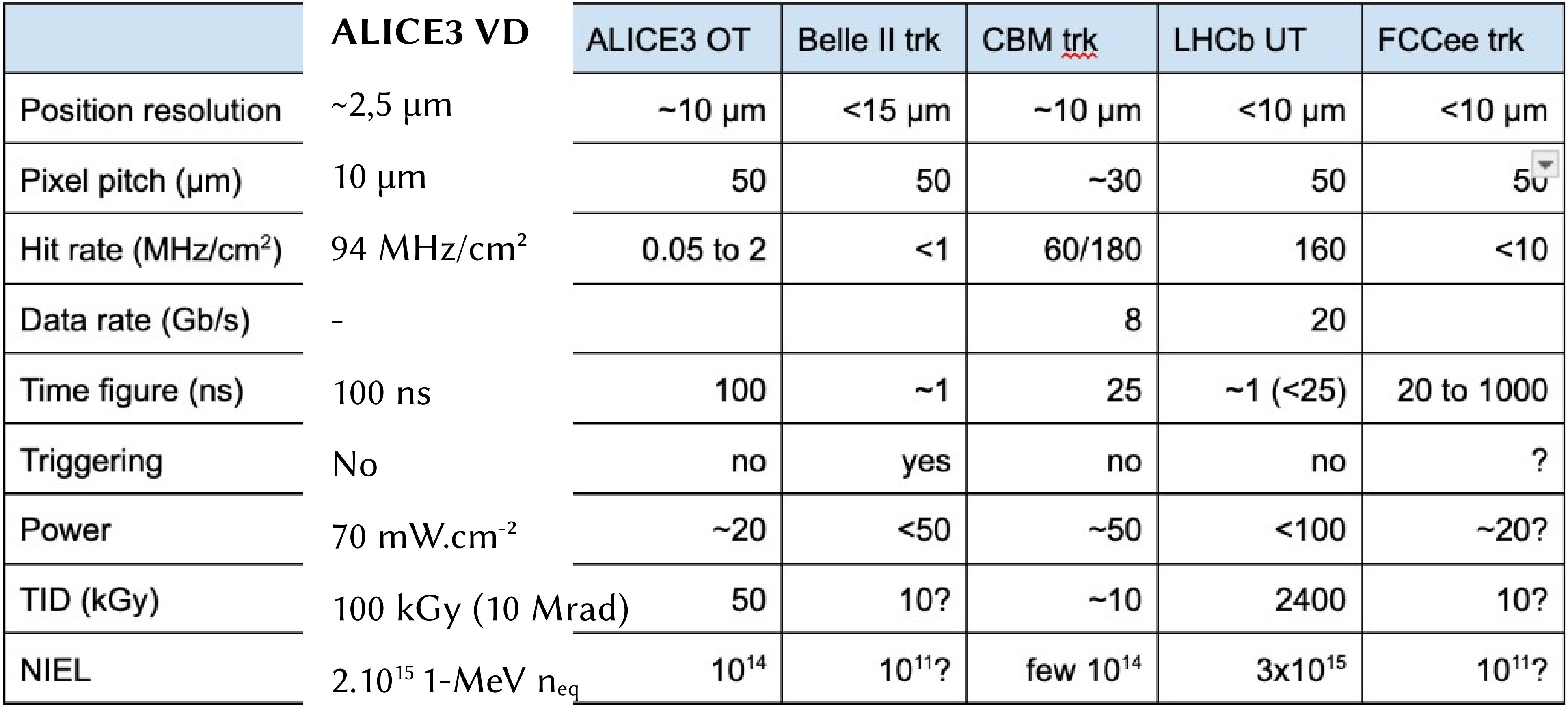
. Table courtesy Felix Reidt

. See also FLUKA studies of radiation loads in ALICE" by Jesus Mendez

ALICE$_3$ days 2024-03 [*indico.cern.ch/event/1372735*](https://indico.cern.ch/event/1372735)

VIII.1 – DRD3.1 spider chart : MAPS specifications

J. Baudot DRD3 Collab Week June 2024
Indico.cern.ch:1402825

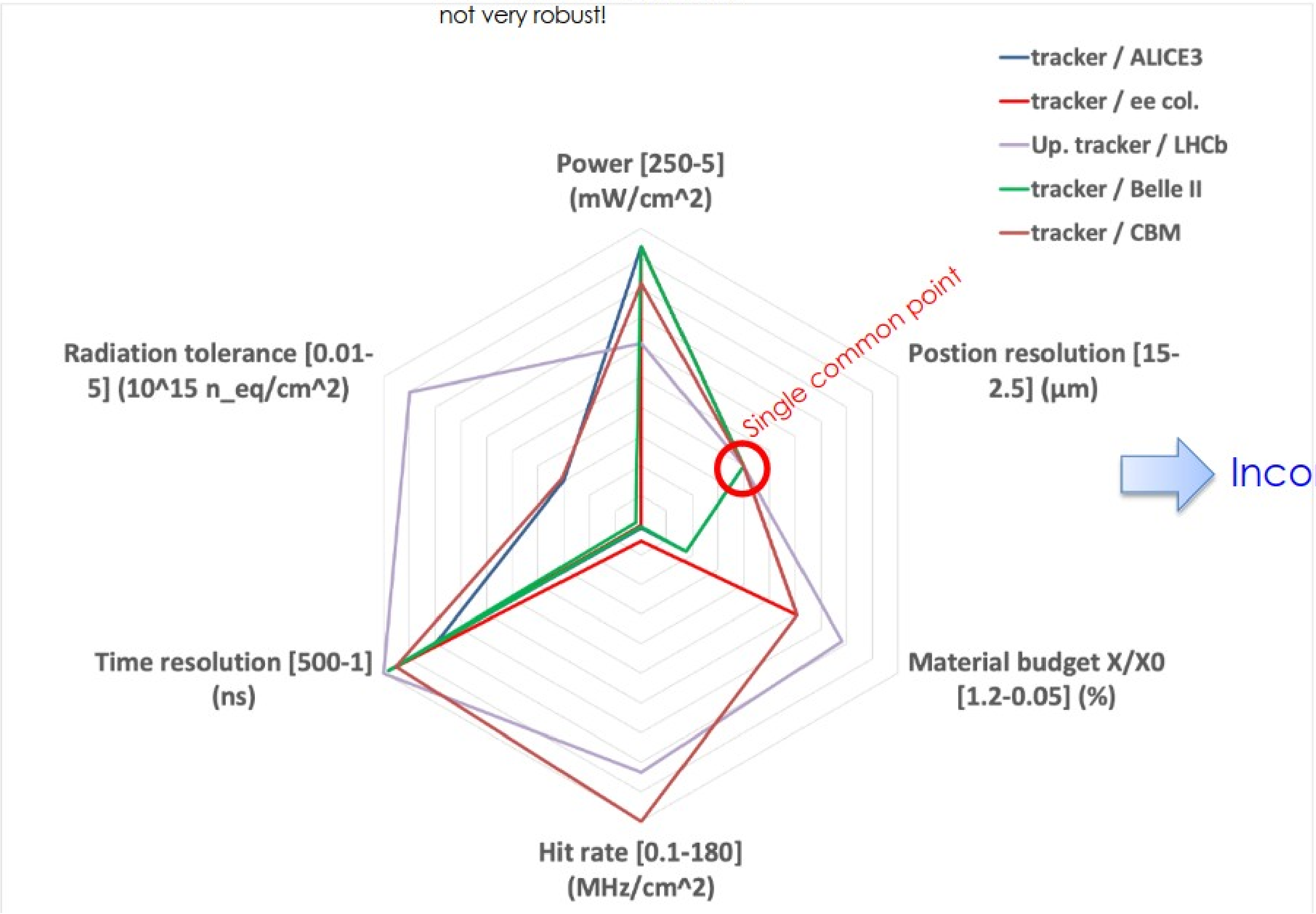


	ALICE3 VD	ALICE3 OT	Belle II trk	CBM trk	LHCb UT	FCCee trk
Position resolution	~2,5 µm	~10 µm	<15 µm	~10 µm	<10 µm	<10 µm
Pixel pitch (µm)	10 µm	50	50	~30	50	50
Hit rate (MHz/cm^2)	94 MHz/cm^2	0.05 to 2	<1	60/180	160	<10
Data rate (Gb/s)	-			8	20	
Time figure (ns)	100 ns	100	~1	25	~1 (<25)	20 to 1000
Triggering	No	no	yes	no	no	?
Power	70 mW.cm^{-2}	~20	<50	~50	<100	~20?
TID (kGy)	100 kGy (10 Mrad)	50	10?	~10	2400	10?
NIEL	2.10^{15} 1-MeV n$_{eq}$	10^{14}	10^{11}?	few 10^{14}	3x10^{15}	10^{11}?

Source: Jérôme's [own mix of LOI, recent talks and private communication]

VIII.2 – DRD3.1 spider chart : the starting pointS

J. Baudot DRD3 Collab Week June 2024, “Versatile pixel matrix TPSCo 65nm”
Indico.cern.ch:1402825



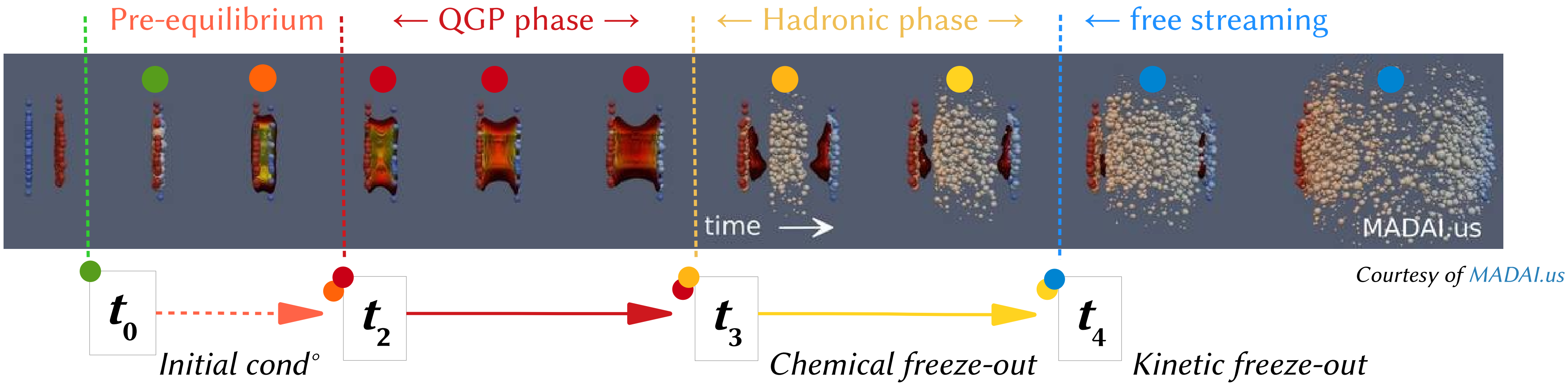
Pay attention to axis scales, not very robust!

Incompatible requirements?

Back to App. TOC

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

I.1 – Observables : Layer 1 / as a function of the collision time



Pre-equilibrium

← QGP phase →

← Hadronic phase →

← free streaming

time ⟶

MADAI.us

Courtesy of MADAI.us

t_0 Initial cond°

t_2

t_3 Chemical freeze-out

t_4 Kinetic freeze-out

●

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

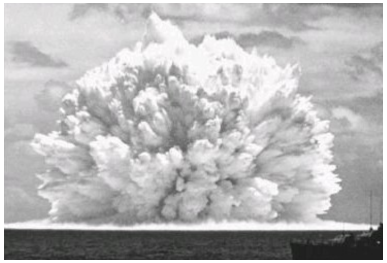
. Recombination/ coalescence

. Hadronic re-interactions

…

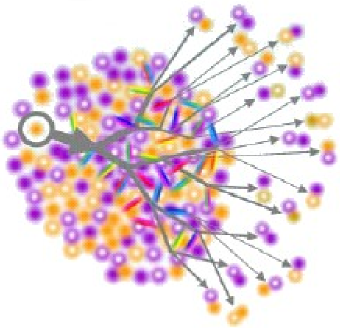
I.2 – Observables : Layer 2 / as a function of *momentum*

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

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

Initial state

I. ultra-low x_B ($x_B \leq 10^{-5}$)

II. low x_B ($x_B \in [10^{-5} ; 10^{-3}]$)

III. moderate x_B ($x_B \in [10^{-3} ; 10^{-1}]$)

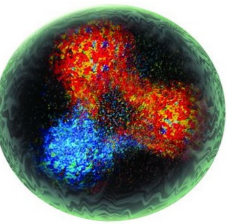
Longitudinal dynamics

I'. $|y| < 2$: max = rapidity plateau in $dN_{ch}/d\eta$

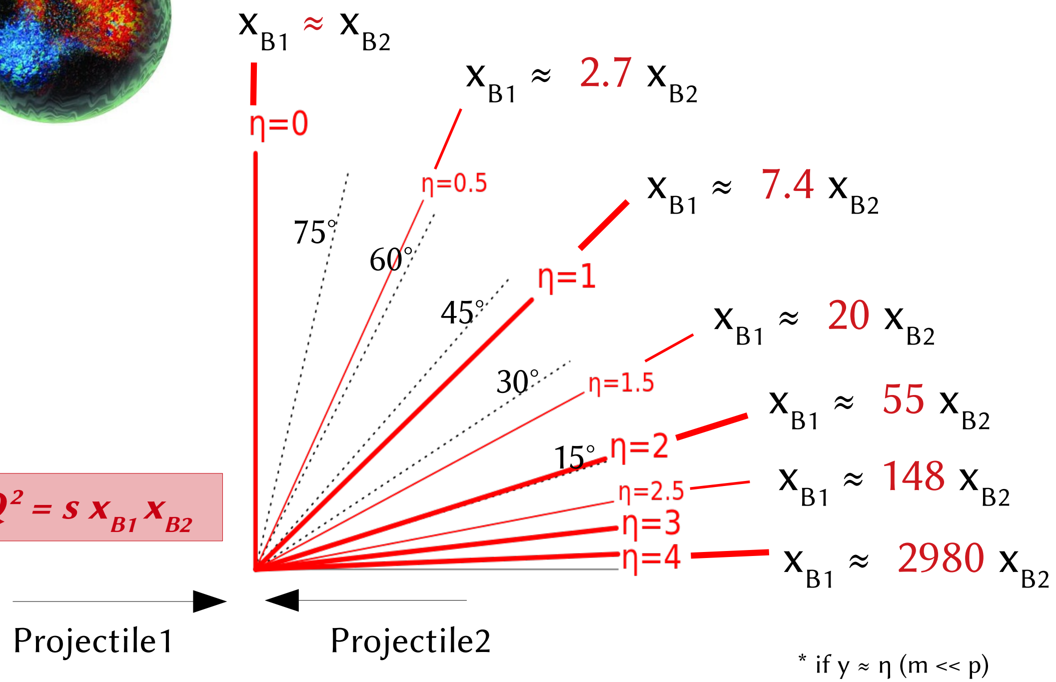
II'. $|y| \approx 3.5$: 75% $(dN_{ch}/d\eta)_{max}$

III'. $|y| \approx 5.0$: 45% $(dN_{ch}/d\eta)_{max}$

JLab

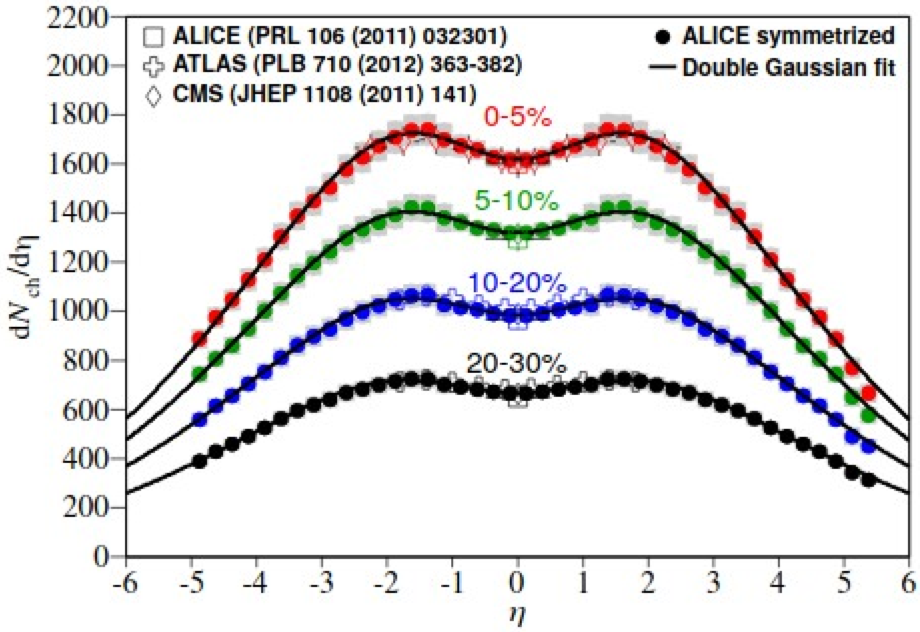


$Q^2 = s\, x_{B1} x_{B2}$



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

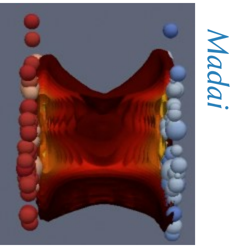
ALICE, arXiv:1304.0347



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

« *hadron-quark duality* »

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

c

- (D^0 D^+ D^{*+} D_S^+)… η_c J/ψ χ_{Ci} ψ(2S) …

  Λ_C^+(*udc*), Ξ_C^+(*usc*), Ξ_C^0(*dsc*), Ω_C^0(*ssc*)

  $+$ *c*-deuteron $(\Lambda_c n)^+$, *c*-triton $(n\Lambda_c n)^+$?

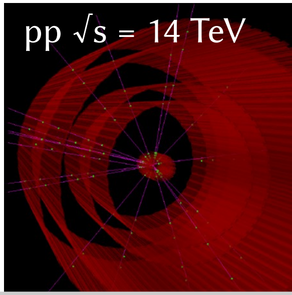
- heavy-flavour ($\mu^\pm$, $e^\pm$)

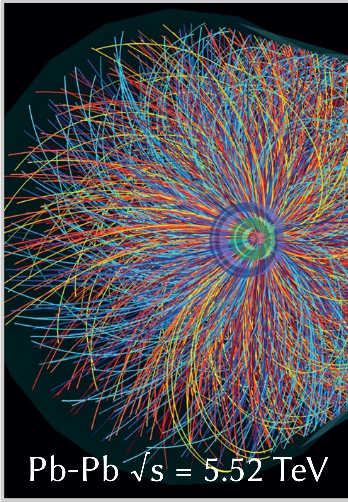
b

- B^0 $B^\pm$ B^0_S … Υ(1S,2S,3S)…

  Λ_b^0 (*udb*)…

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

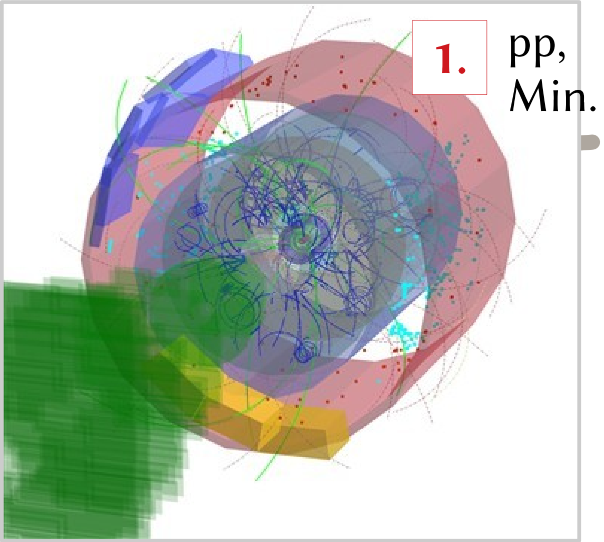




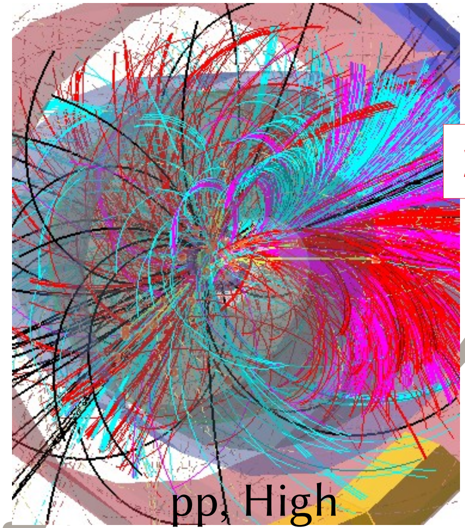
NB :

baryons Vs mesons
mixed flavours (s+c, s+b, … c+b …)

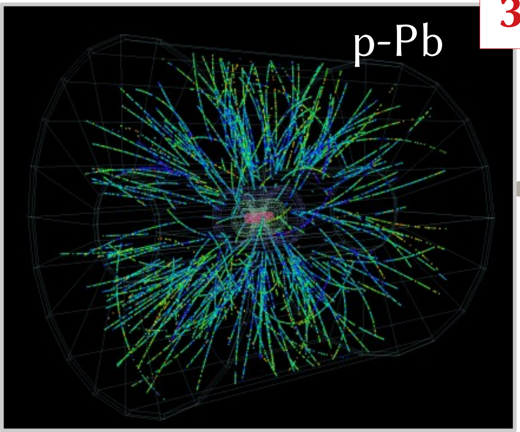
I.5 – Observables : Layer 5 / as a funct° of the collision system



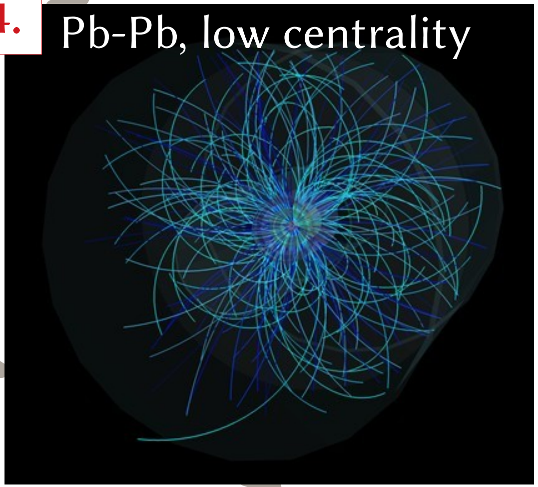
1. pp,
Min. Bias



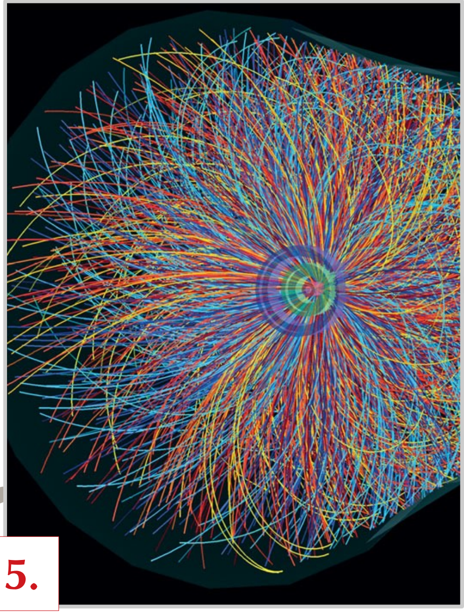
2. pp, High
Multiplicity



3. p-Pb



4. Pb-Pb, low centrality

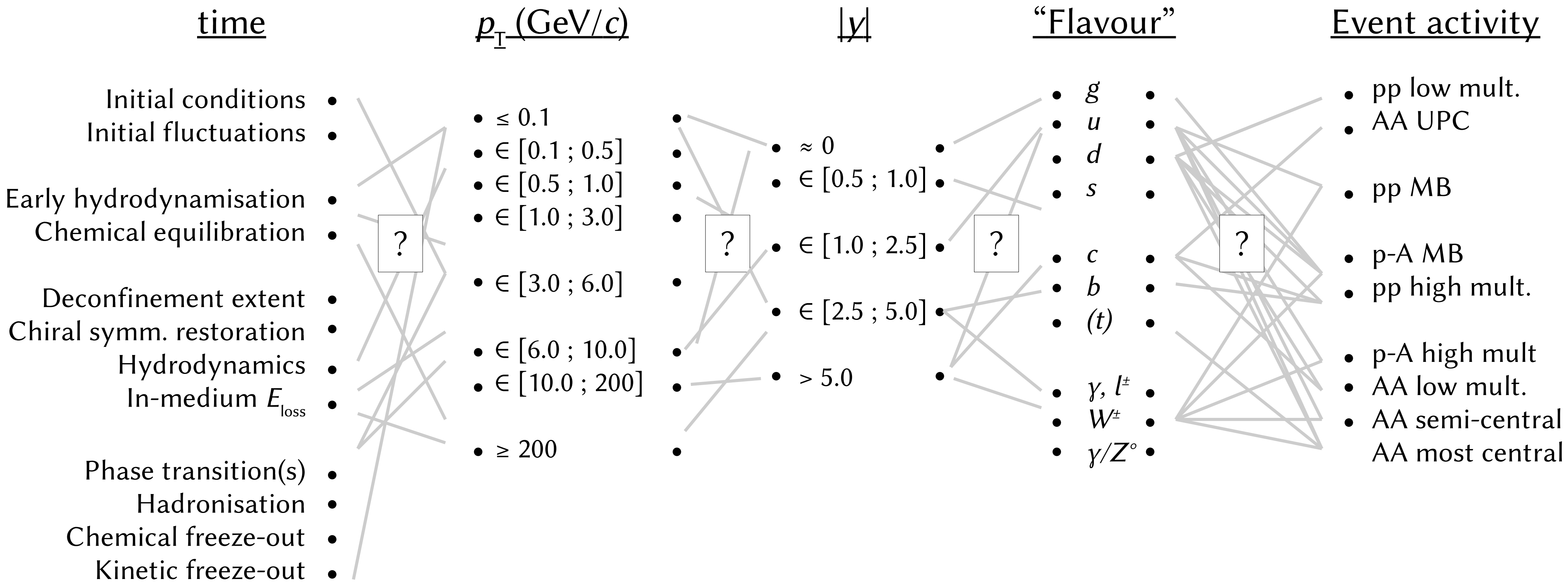


5. Pb-Pb,
most central events

CDS/record-1305398

I.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 ($\sigma_{\text{stat}} \approx$ negligible) ⊗ ($\sigma_{\text{syst}} \leq$ 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 ...*)