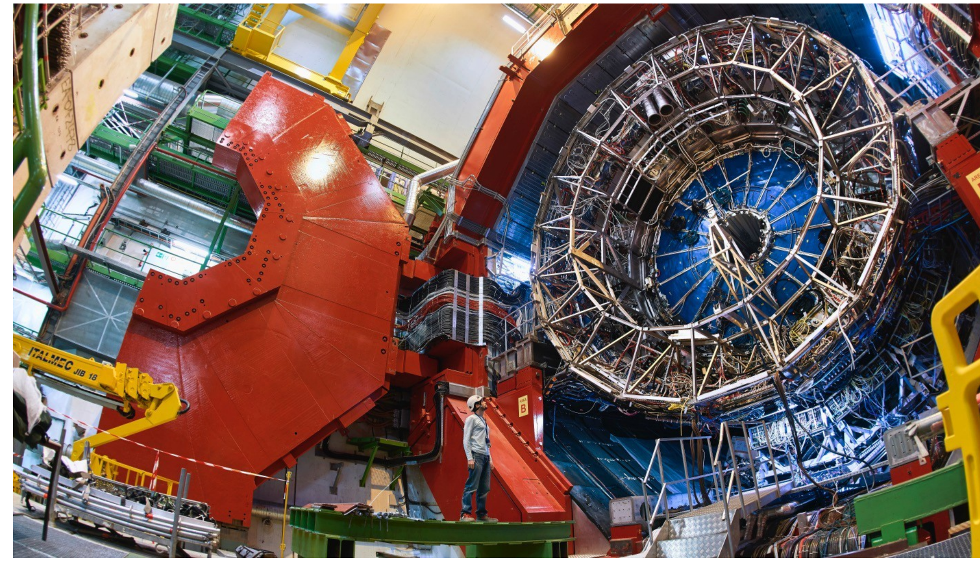
Antonin MAIRE – IPHC Strasbourg
Monday, 02 May 2022– **QGP France**



ALICE overview^3 :

analyse the (recent) *past*,
commission the here and *now*,
conceive and develop the *future*

Outline

A. Recent past : *run-2 recent results*

B. Here and now : *upgrades of LS2 and nascent run 3*

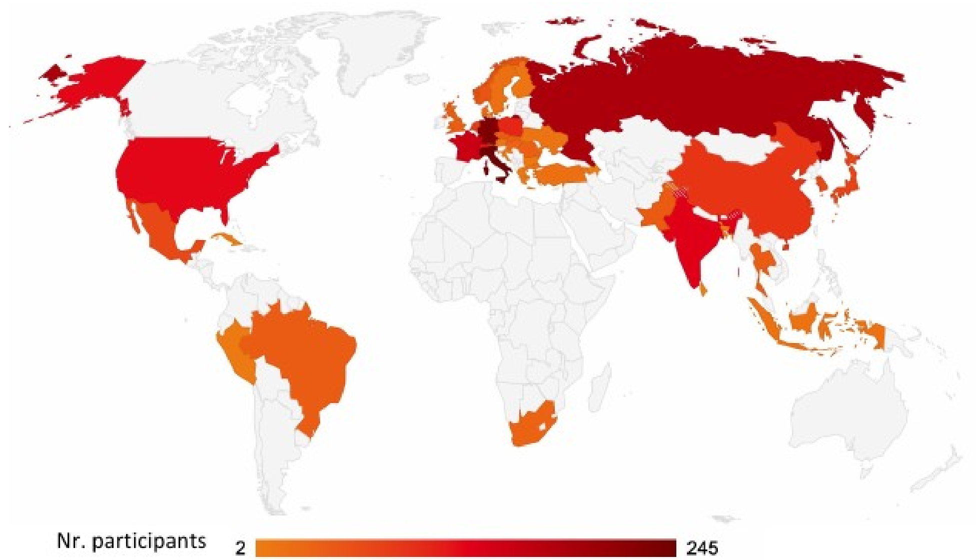
C. Future : *casting ALICE grounds for Run4, for Run 5*

Sources :

- Quark Matter 2022 “press release” (alice-collaboration.web.cern.ch/Quark_Matter_2022)
    - QM, ALICE overview, Maximiliano Puccio (indico.cern.ch/event/895086/contributions/4314623/)
    - QM, LHC exp upgrades, Jochen Klein (indico.cern.ch/event/895086/contributions/4615176/)

    + ALICE Spring 2022 Preliminaries (alice-figure.web.cern.ch/node/21442)
- ALICE Research Review Board 2022-04
- LHCC March 2022 open session (indico.cern.ch/event/1126938/)

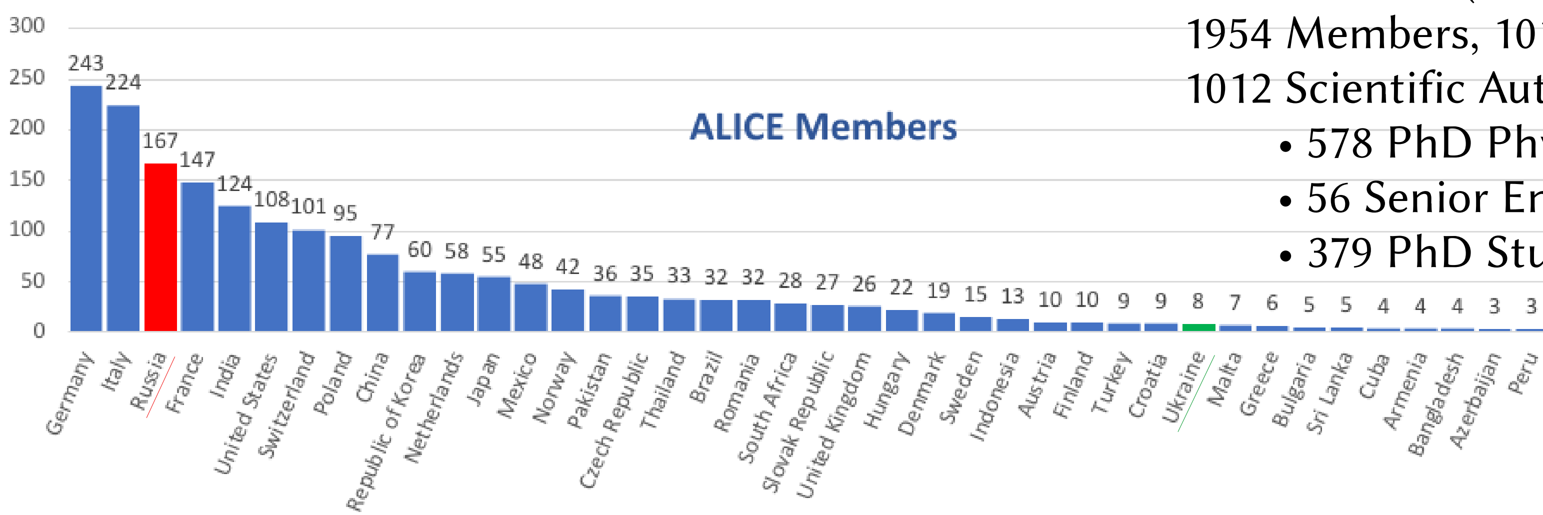
I.1 – ALICE : collaboration



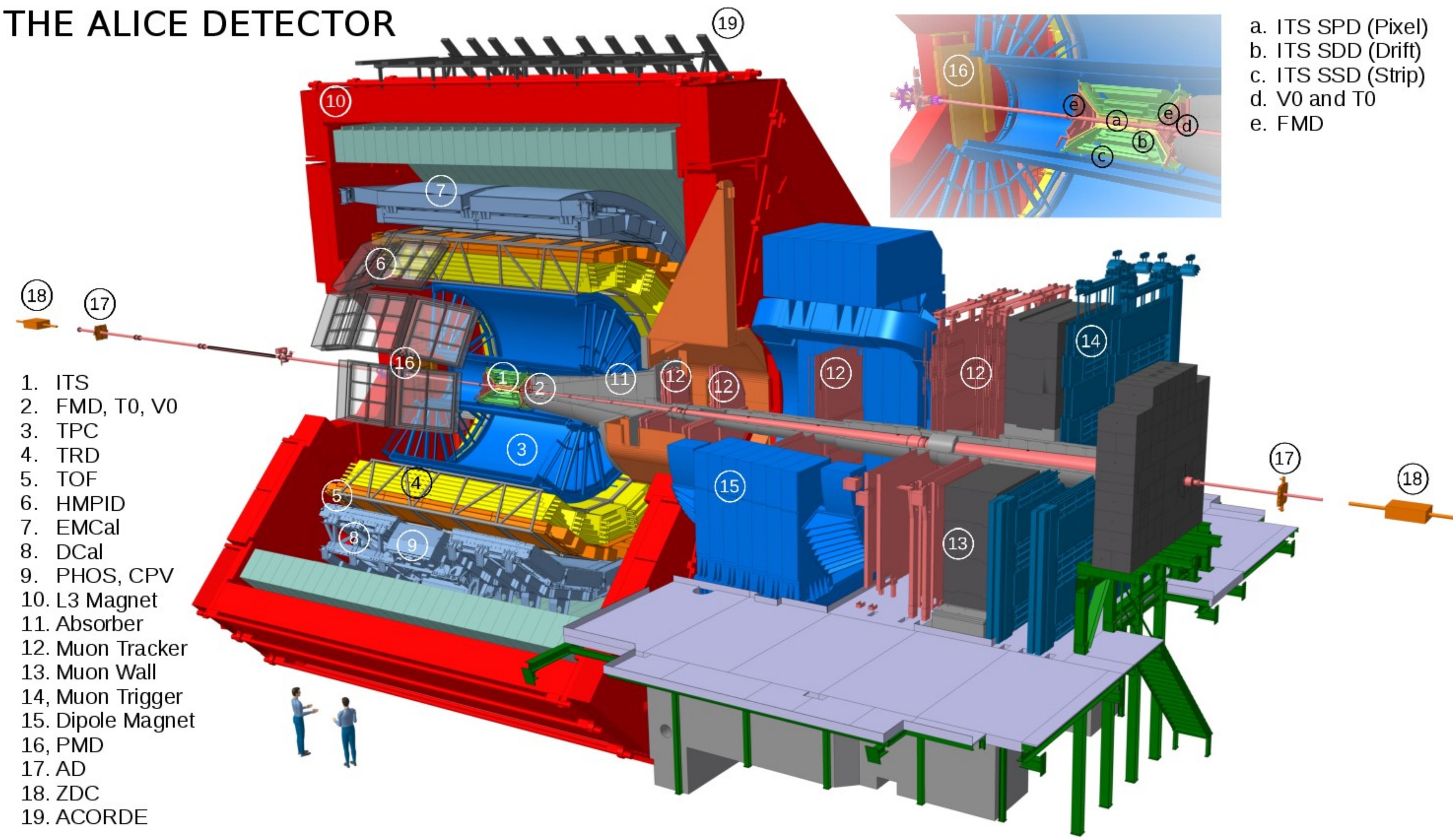
Spokesperson :
Currently : Luciano Musa (CERN)
3-year term: 2020-01 - 2022-12

Next : Marco Van Leeuwen (NIKHEF)
Elected by Collaboration Board on 2 March
3-year term: 2023-01 – 2025-12

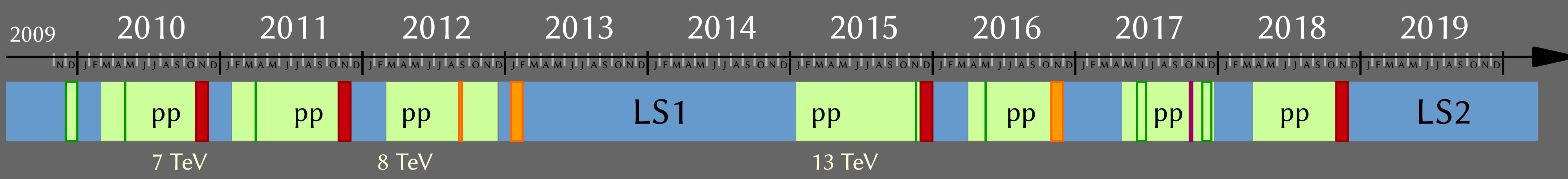
2022 :
40 Countries,
174 Institutes (including 18 Associates)
1954 Members, 1012 Scientific Authors
1012 Scientific Authors :
- 578 PhD Physicists
- 56 Senior Engineers
- 379 PhD Students



I.2 – ALICE : ALICE-1 set of subdetectors

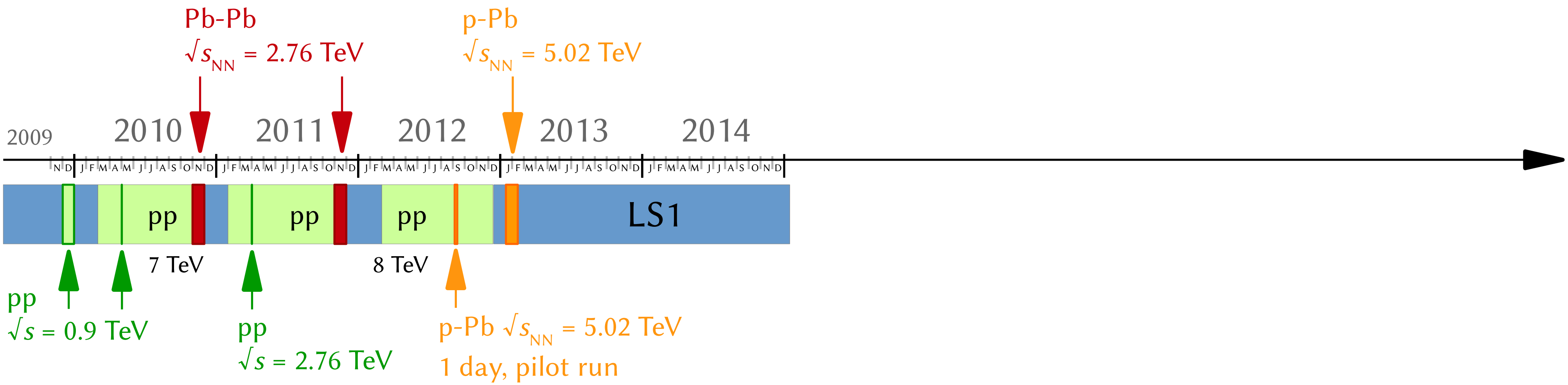


Part A – turn and look back



LHC running plan

II.1 – ALICE : ALICE campaigns in LHC runs 1+2



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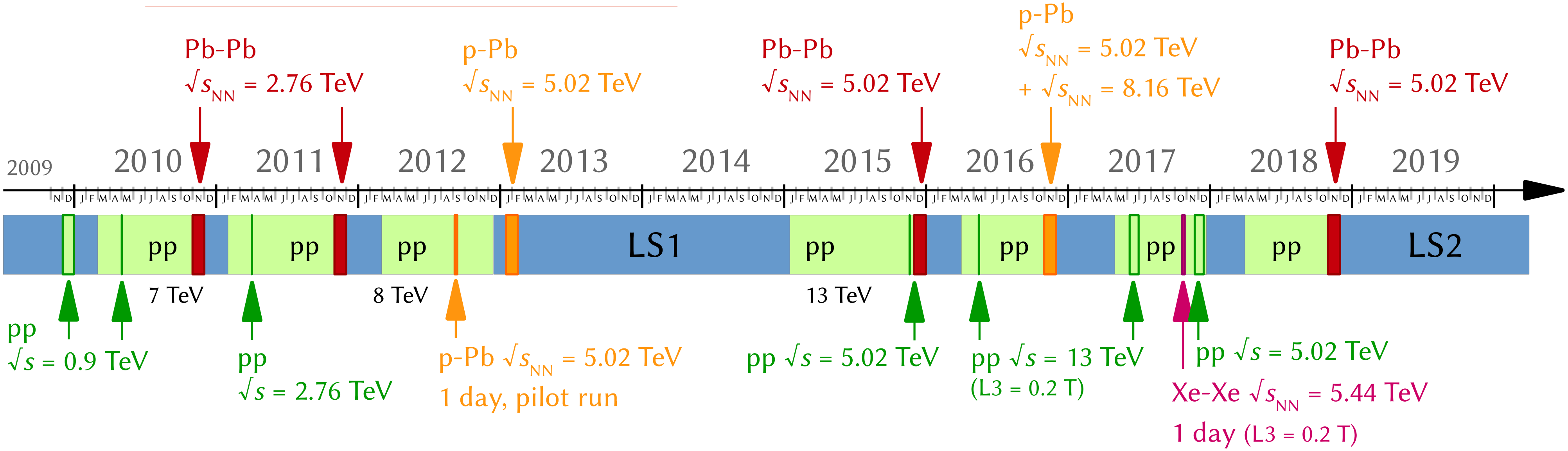

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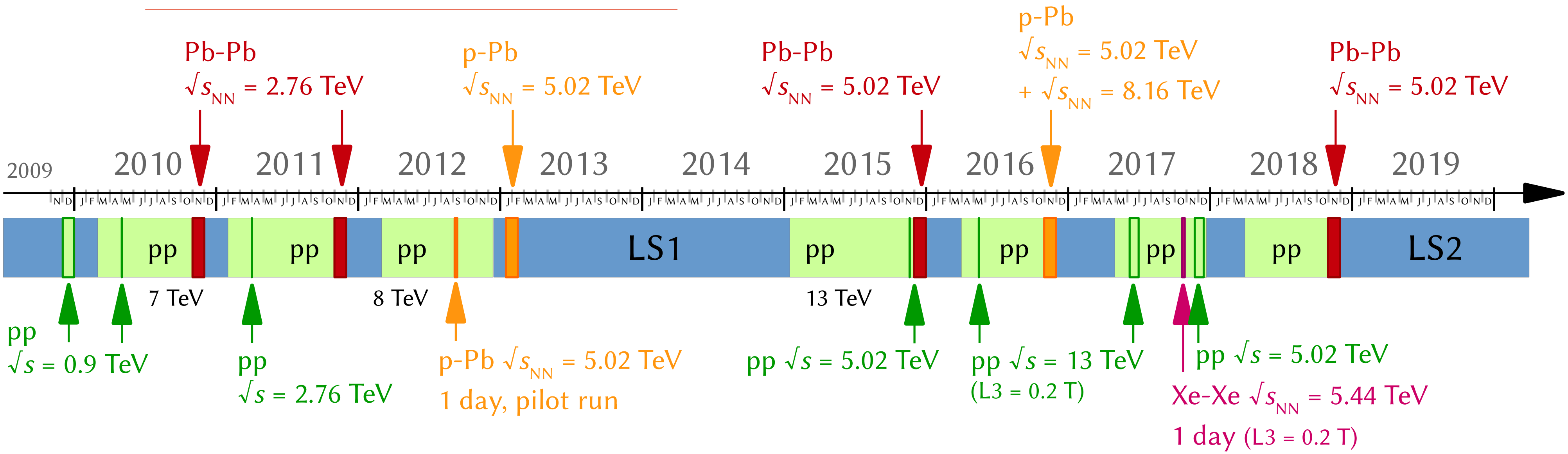

ALICE objectives for Runs 1+2 :

- 1 nb^{-1} in Pb-Pb + "track-equivalent" $\mathscr{L}_{int}$ in pp
- pp campaigns at reference √s
- p-Pb campaigns

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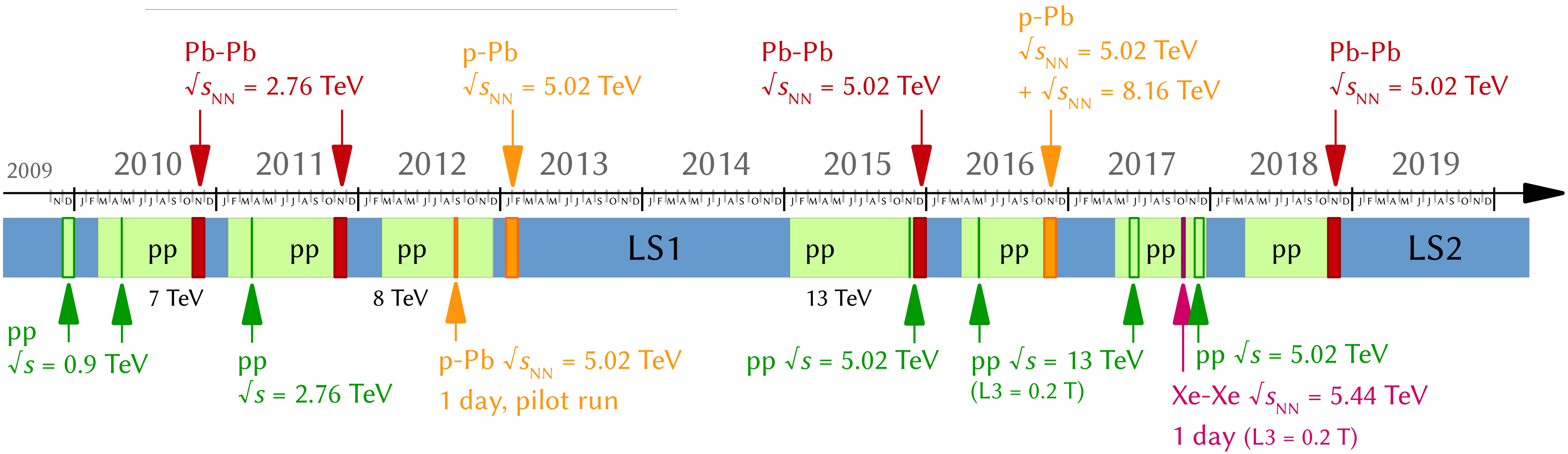

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Remark (~for pp) : delivered Vs. inspected Vs. recorded luminosity

e.g. LHC-delivered $\mathscr{L}_{int}$ pp for 2018 (*bpt.web.cern.ch/statistics*) :

CMS (ATLAS) ≈ 66 440 (64 771) pb^{-1} Vs. LHCb ≈ 2446 pb^{-1} Vs. ALICE ≈ 27,19 pb^{-1}

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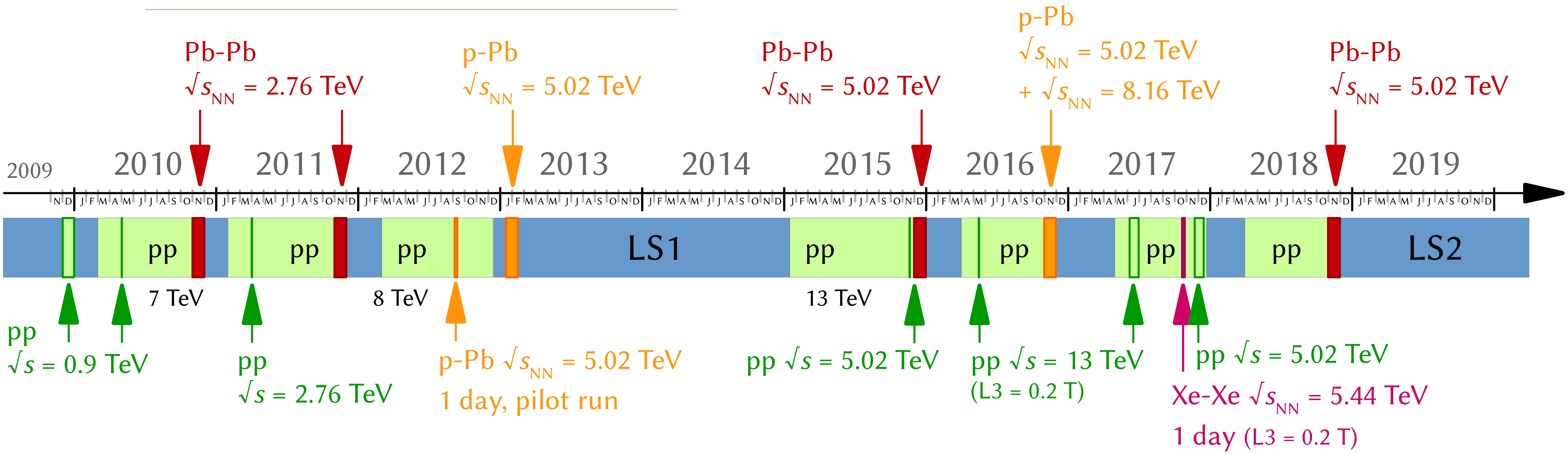

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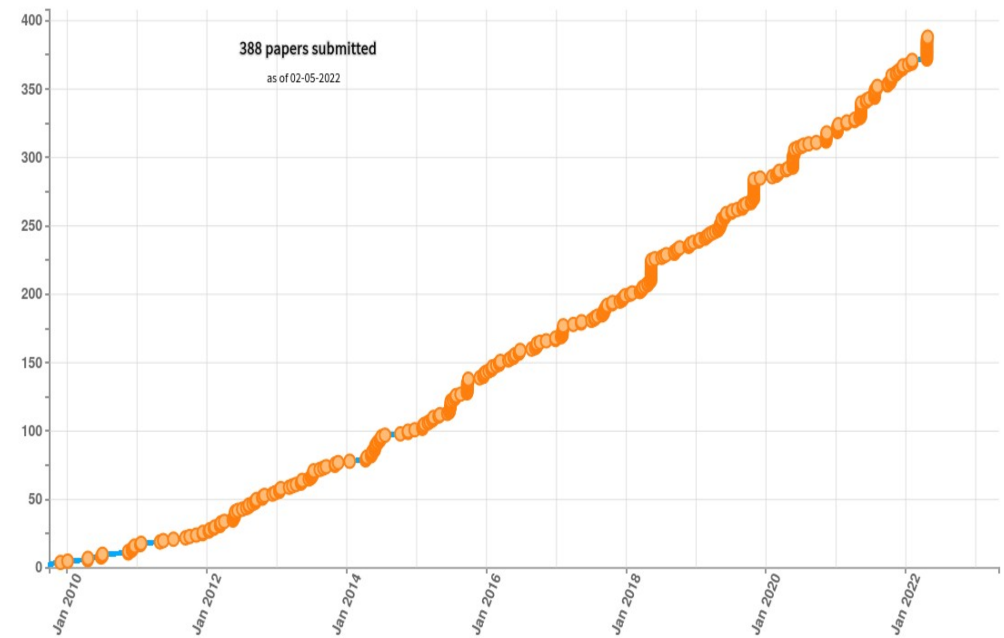
→ ALICE = physics at the event level ≠ physics for particles ~independently of the event

→ specific data taking strategy (campaign planning + $\mathscr{L}_{instantaneous}$ leveled at ≈ 2.6 10^{30} $cm^{-2}s^{-1}$) …

ex : pp pile-up (2015-2018) $\mu_{ALICE} \leq 0.02$ // μ_{CMS} $\mathcal{O}$(40-60)

II.2 – Scientific production : publications, conferences

- 388 publications submitted to arXiv (and thus, to journals)
  https://alice-publications.web.cern.ch/submitted
  2022 > 14 submissions
  2021 = 33 submissions
  2020 = 44 submissions
  2019 …



NB :
ALICE white paper runs 1+2
The ALICE experiment – A journey through QCD
≈ 230 pages
in preparation (collaboration round 1)

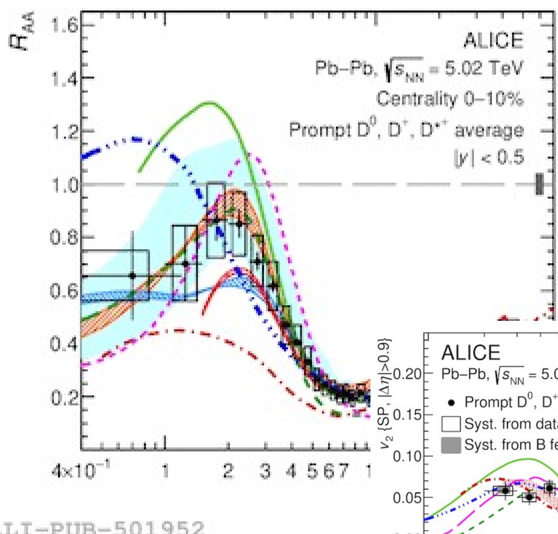
- ≈ 300 talks per year in conferences
  usually linked to ALICE preliminaries, https://alice-figure.web.cern.ch/index.php/preliminary_fig_pub

III.1 – An ALICE glimpse : Charmed-quark diffusion in QGP

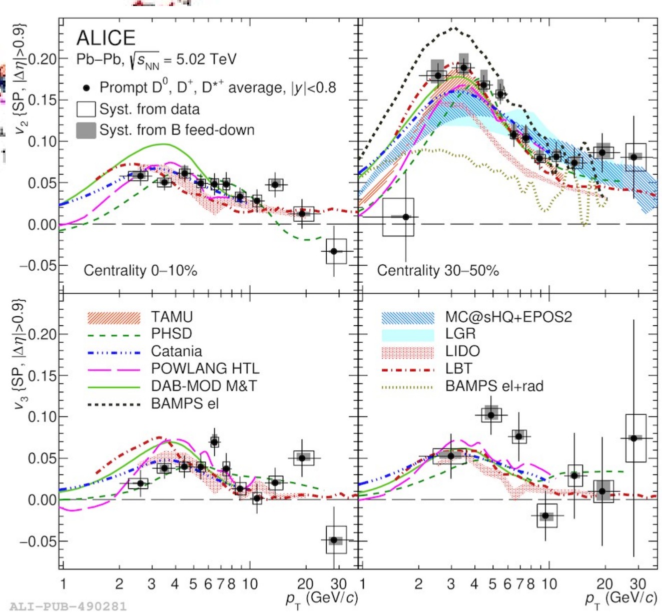
ALICE, arXiv:2110.09420, R_{AA}
ALICE, arXiv:2005.11131, v_2, v_3

ALICE, Pb-Pb 2018 data, D°, D⁺, D*

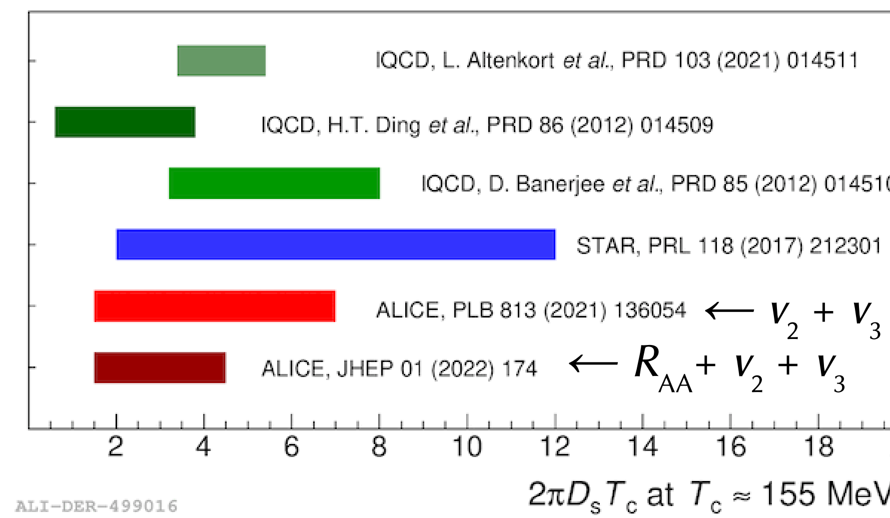
E_{loss} (c quark) : constraints from $R_{AA} + v_2 + v_3 \longrightarrow 1.5 < 2\pi D_s T_c < 4.5$ (hyp. : $T_C \approx 155$ MeV)



\+



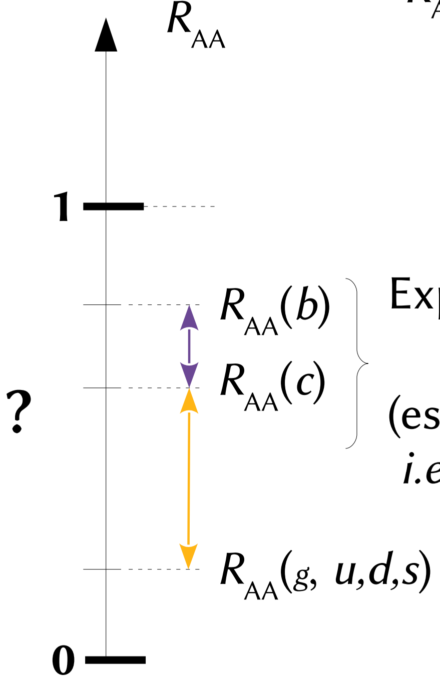
→



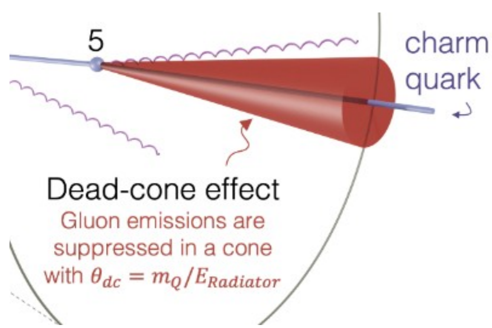
III.1 – ALICE glimpse : (c,b) flavours Vs in-medium E_{Loss}

ALICE, arXiv:2202.00815

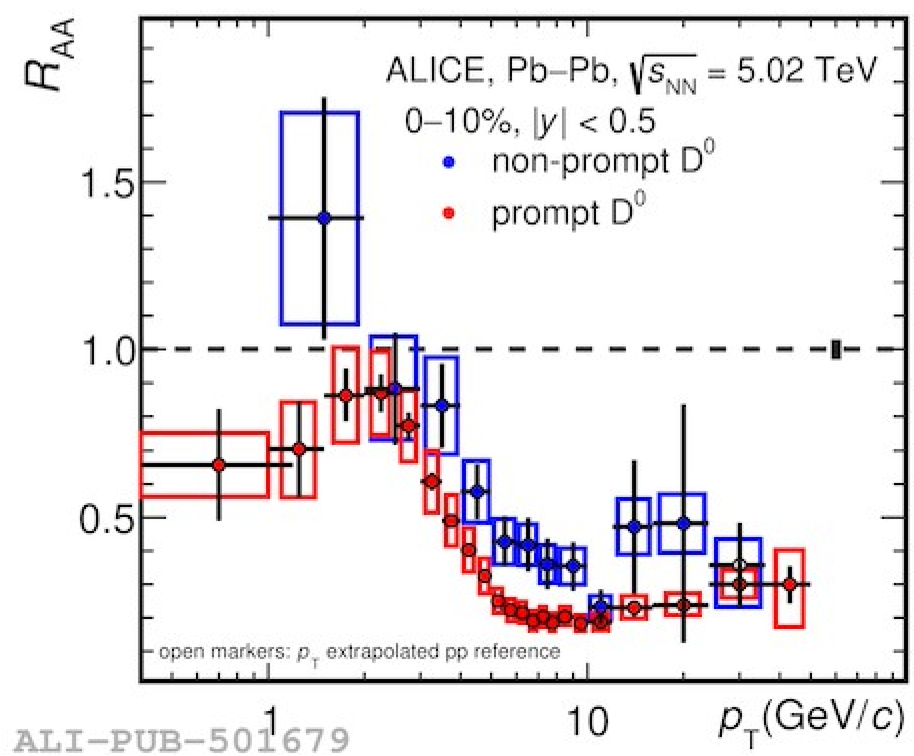
R_{AA}(prompt D°) ≈ proxy for R_{AA}(c quarks)
R_{AA}(non-prompt D°) ≈ proxy for R_{AA}(b quarks)



Expectation :
R_{AA}(c quarks) < R_{AA}(b quarks)
(essentially due to <u>*dead cone effect*</u>
i.e. less radiative E_{loss} for b than for c)



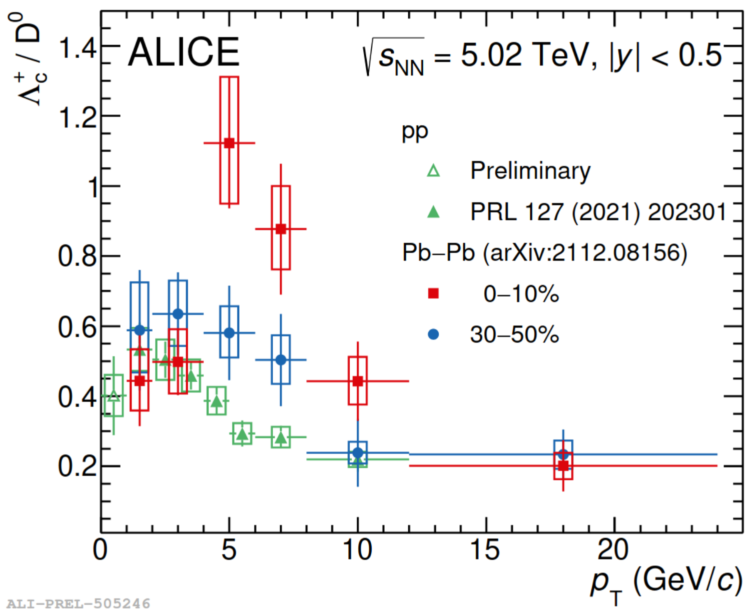
ALICE, arXiv:2106.05713
(dead cone in pp)



Beware p_T(B) ≠ p_T(non-pr. D°)

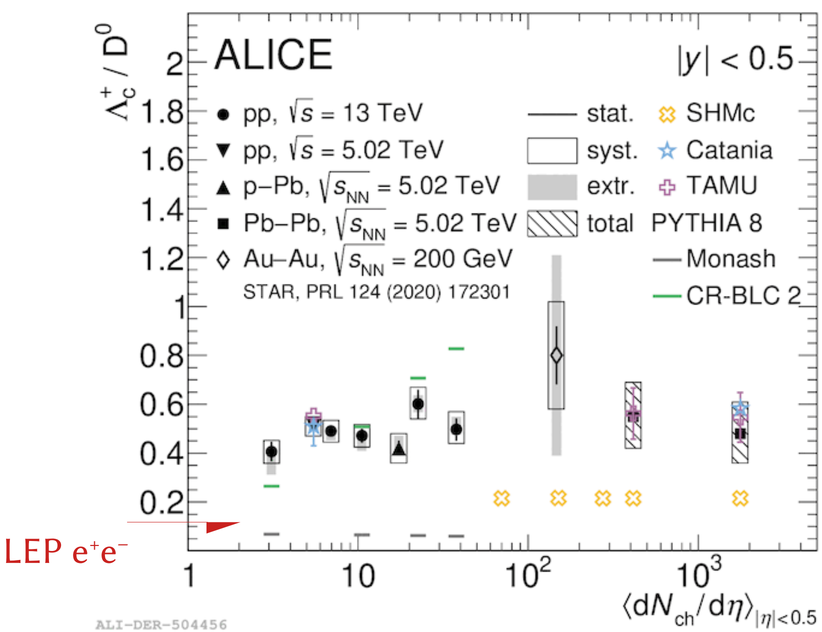
III.2 – Glimpse : charm hadronisation, charm baryons

ALICE, arXiv:2112.08156
ALICE, arXiv:2111.11948



Enhancement of Λ_C^+/D^0 at intermediate momentum,
Further increased, while going from pp to larger systems
but
No strong multiplicity dependence of dN/dy (p_T>0)

i.e. change in the dynamics
rather than in the pT-integrated chemistry

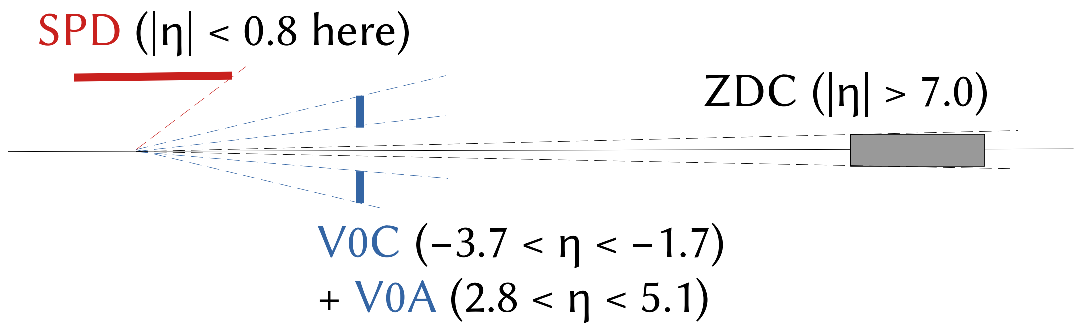


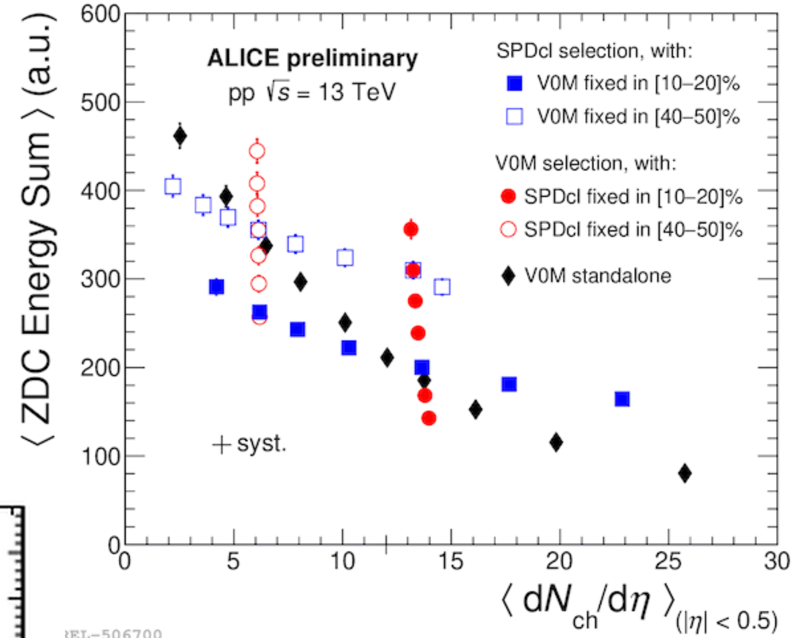
1. Baryon anomaly in charm sector very much similar as for (*u,d,s*) sector, like p/π, Λ/K^0s

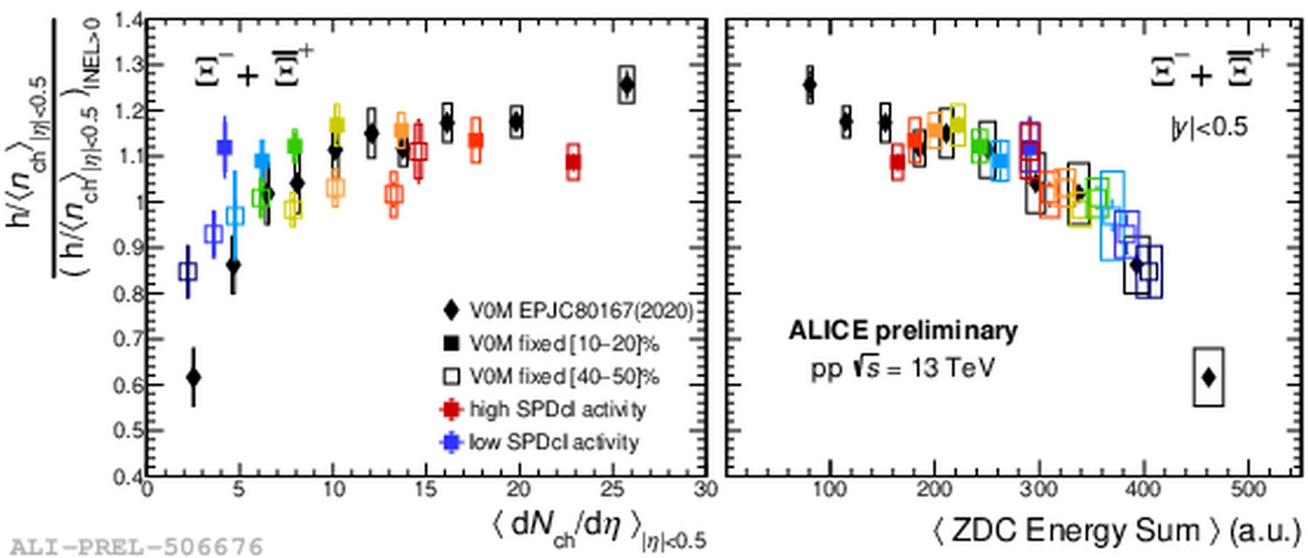
2. favour charm recombination? at least sthg with happening with baryons…

3. modified p_T-integrated ratio w.r.t. LEP e+e⁻ value

III.3 – Glimpse : strangeness enhancement Vs forward energy





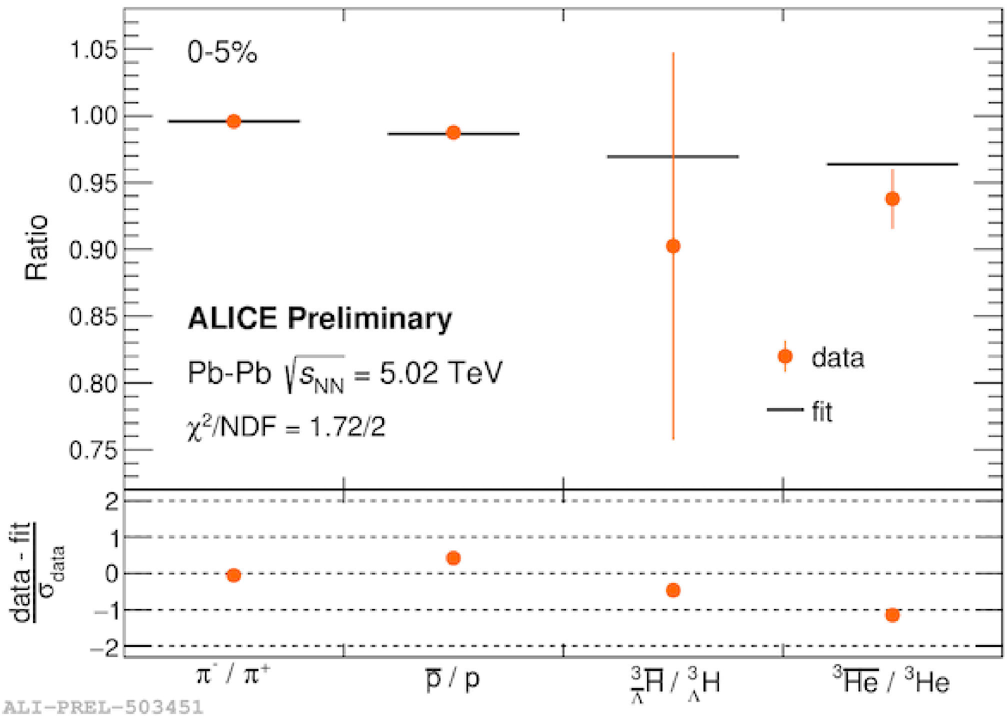


Double-differential analysis...

Strangeness enhancement is **anticorrelated** with forward E_{ZDC}, even at fixed midrapidity multiplicity

⟶ Early stages (large rapidity gap) matter in strangeness enhancement

III.4 – Glimpse : antimatter-matter assymetry at LHC energies



Baryon number, B; Strangeness, S

[B = 0, S = 0] ⟶ π imbalance < 0.5 %

[B = 1, S = 0] ⟶ p imbalance ≈ 1 %

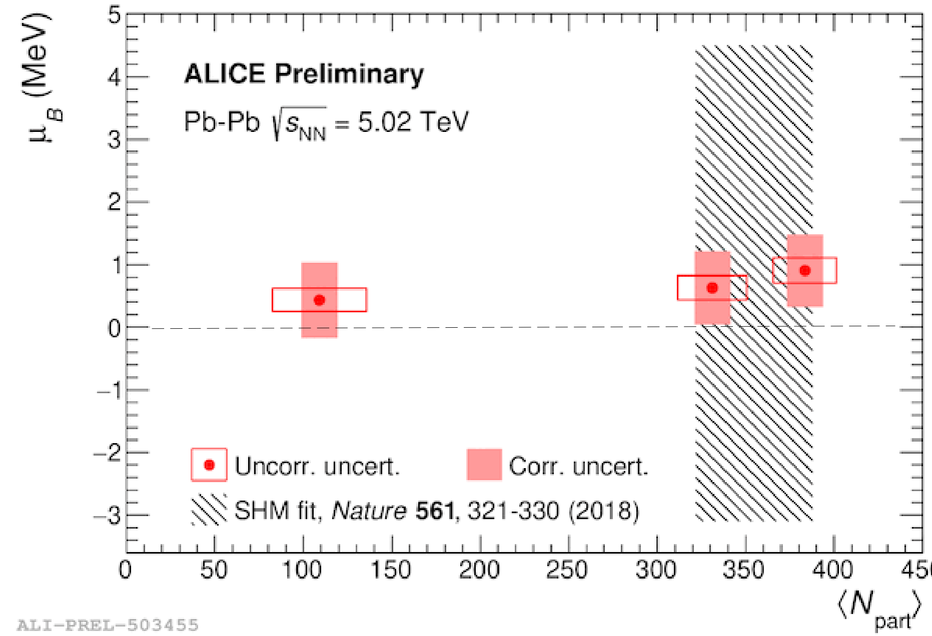
[B = 3, S = 0] ⟶ ^{3}He imbalance ≈ 6 %

[B = 3, S = 1] ⟶ $_\Lambda^3$H imbalance ≈ 10 %

SHM expectation :

$$\bar{h}/h \propto \exp\left[-2\left(B+\frac{S}{3}\right)\frac{\mu_B}{T} - 2I_3\frac{\mu_{I_3}}{T}\right]$$

with $T = 156.2 \pm 2$ MeV



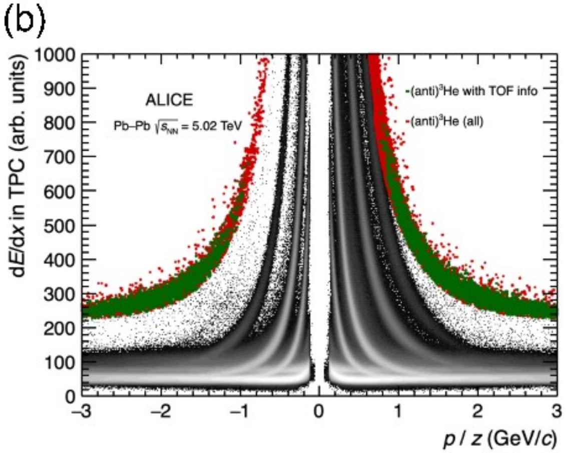
(μ_B near 0 !)

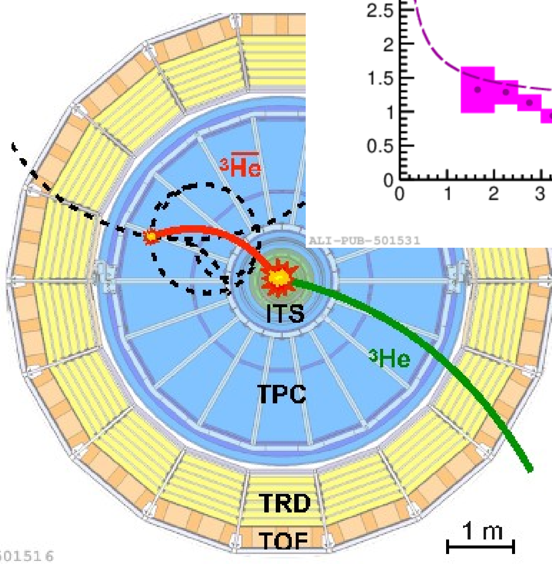
⟶ Improvement of the precision on the baryochemical potential by almost an order of magnitude

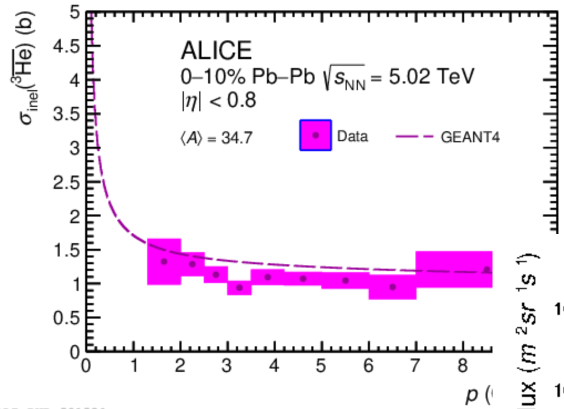
http://alice-figure.web.cern.ch/node/21620

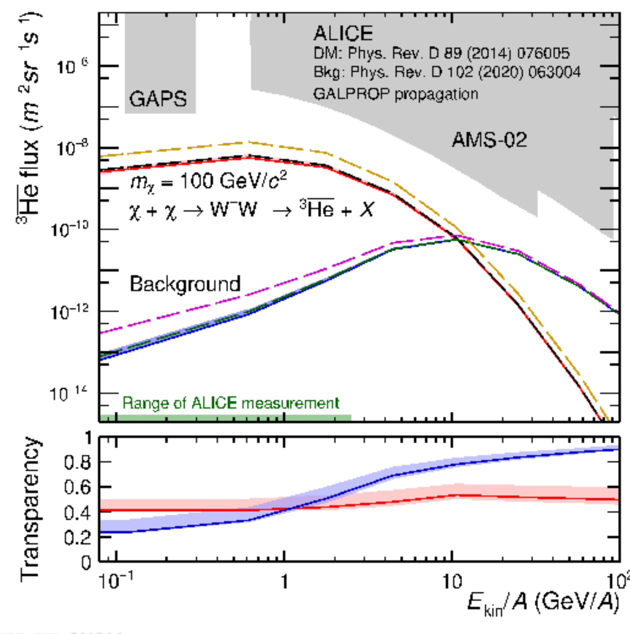
III.5 – Glimpse : $^{3}\overline{\text{He}}$ absorption in ALICE // in the Galaxy

ALICE, arXiv:2202.01549
+ https://alice-collaboration.web.cern.ch/node/35283





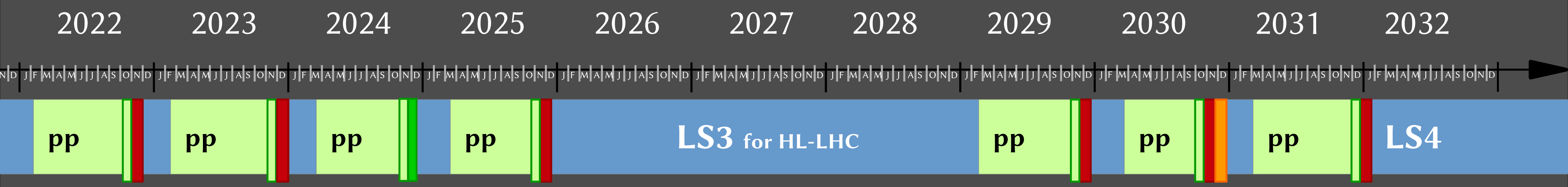




1. LHC Pb-Pb collisions :
   production(light nuclei) ≈ production(antinuclei)
2. ALICE measured the $^{3}\overline{\text{He}}$ absorption cross section in the detector material (ALICE as target…) for the first time, at low momentum 1.17 < pT < 10 GeV/c

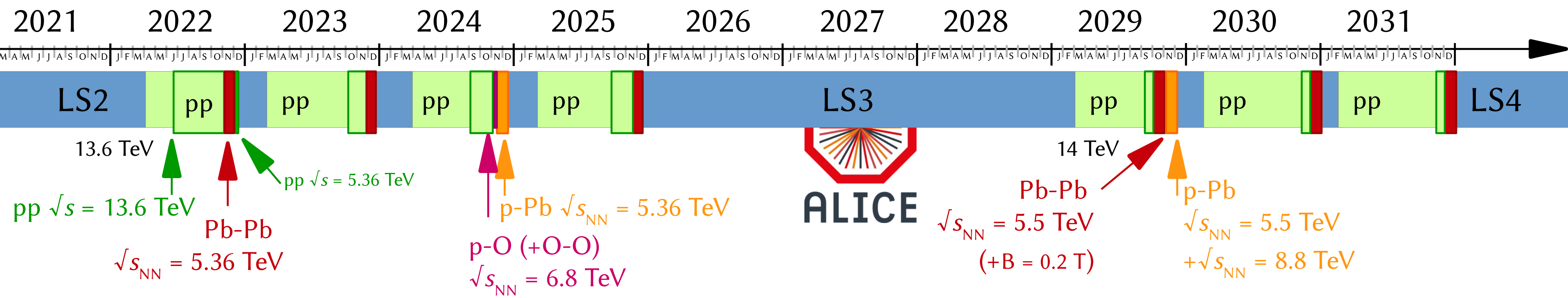
3. ⟶ experiment-driven estimate of absorption probability of anti-nuclei
   from dark mattter decays and from cosmic-ray background in the Galaxy

Part B – LHC run 3, here we go !



LHC running plan

IV.1 – ALICE-2 : ALICE campaigns in LHC run 3+4



<u>Runs 1+2</u>

= 1 nb^{-1} MB Pb-Pb delivered
⟶ 0.1 nb^{-1} recorded

<u>Runs 3+4</u>

= 10+3 nb^{-1} MB Pb-Pb delivered
⟶ 10+3 nb^{-1} recorded

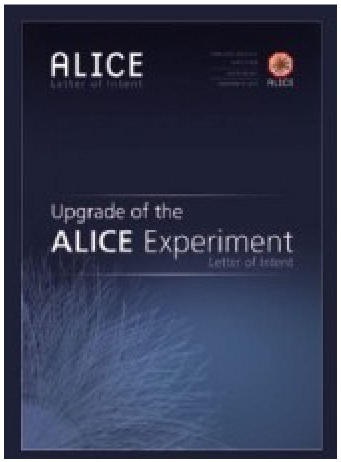
Consequence : **50 kHz in Pb-Pb** // ~200 kHz in pp, p-Pb

⟶ preserve ALICE features (PID, material budget, μ arm, ...)
+ improve tracking precision (ITS, MFT)
+ improve data rate (pile-up challenge)

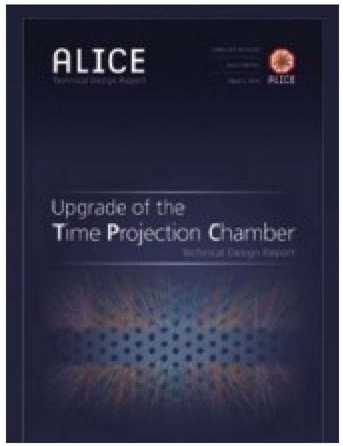
⟶ **specific data taking strategy** :

- "<u>triggerless</u>" readout (small S/S+B ⟶ ≈ no online trigger)
- *Readout+recorded : <u>50 kHz</u>* Min Bias Pb-Pb
  + a <u>*few 100 kHz*</u> pp, p-Pb collisions
  Runs 3+4 = 100x Run 2
- no more 8-month/year of pp data taking...
  ALICE pp campaign = <u>$\mathcal{O}$(weeks)</u>
  (*main limit : computing capacity*)

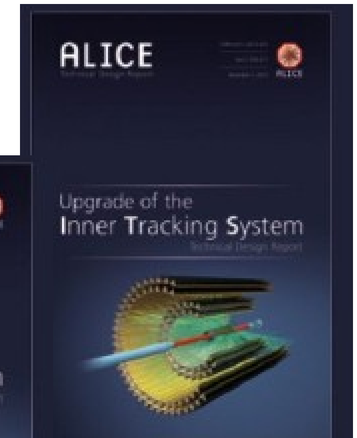
IV.2 – ALICE-2 : TDRs for run 3 detectors



CERN-LHCC-2012-012



CERN-LHCC-2013-020

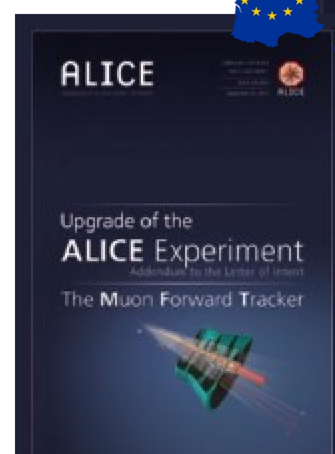


CERN-LHCC-2013-024

CERN-LHCC-2012-005

CERN-LHCC-2015-006

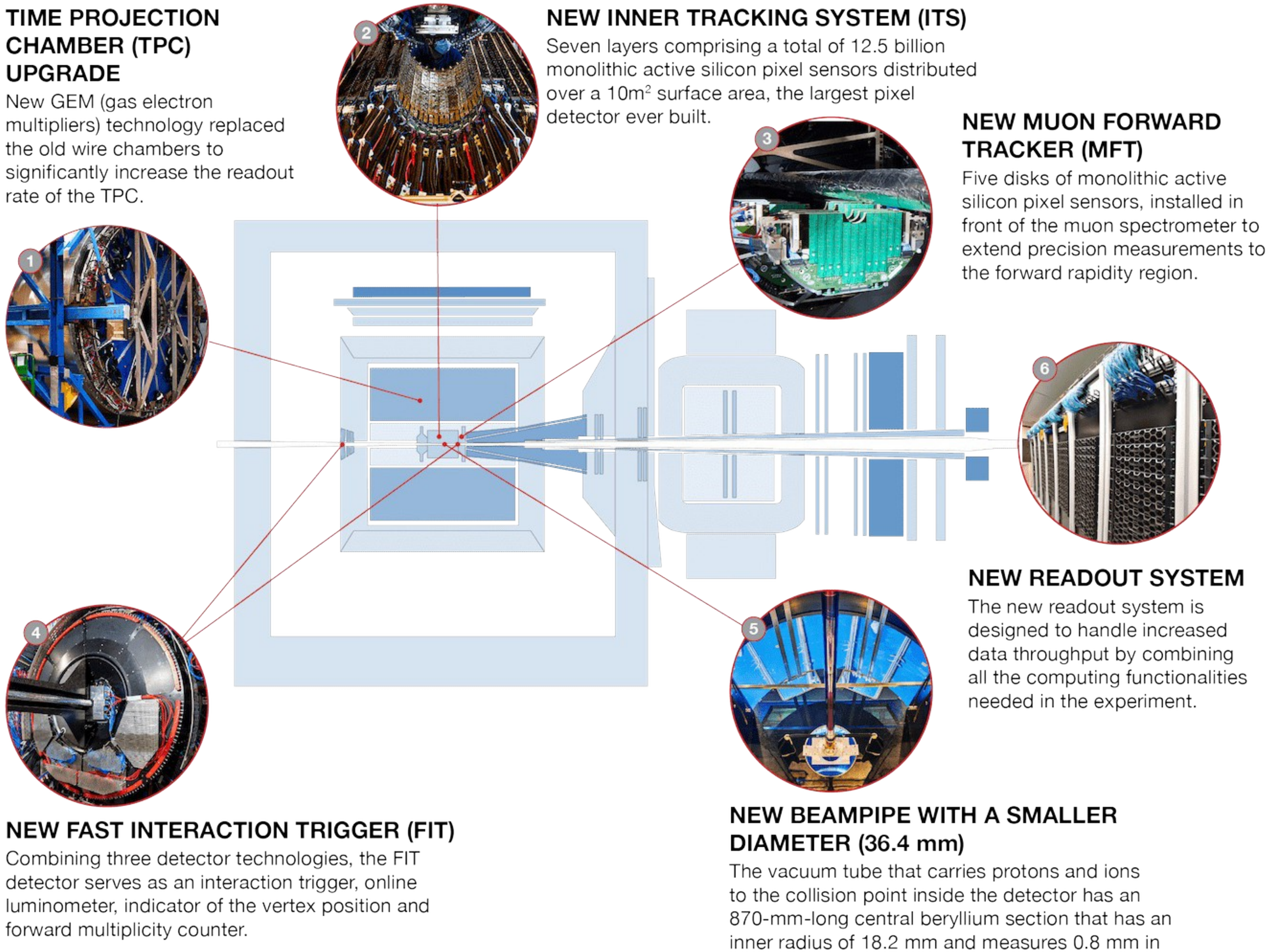
CERN-LHCC-2013-019



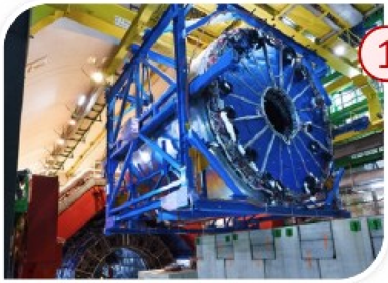
CERN-LHCC-2013-014

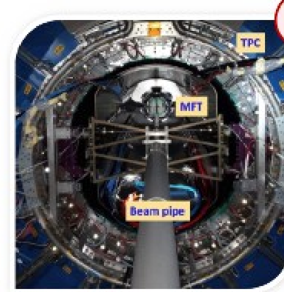
CERN-LHCC-2015-001

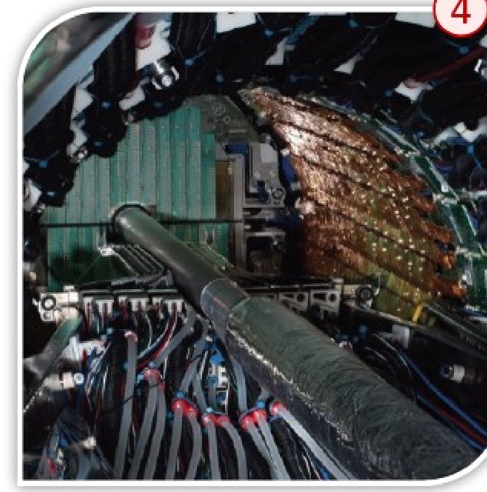
IV.3 – ALICE-2 upgrades : overview

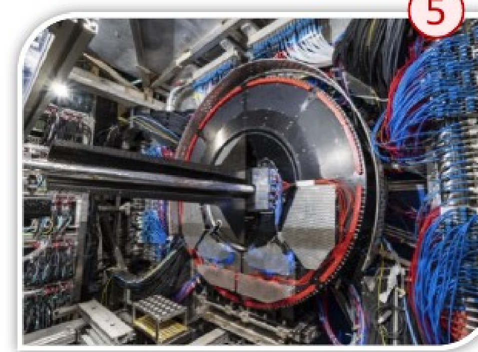


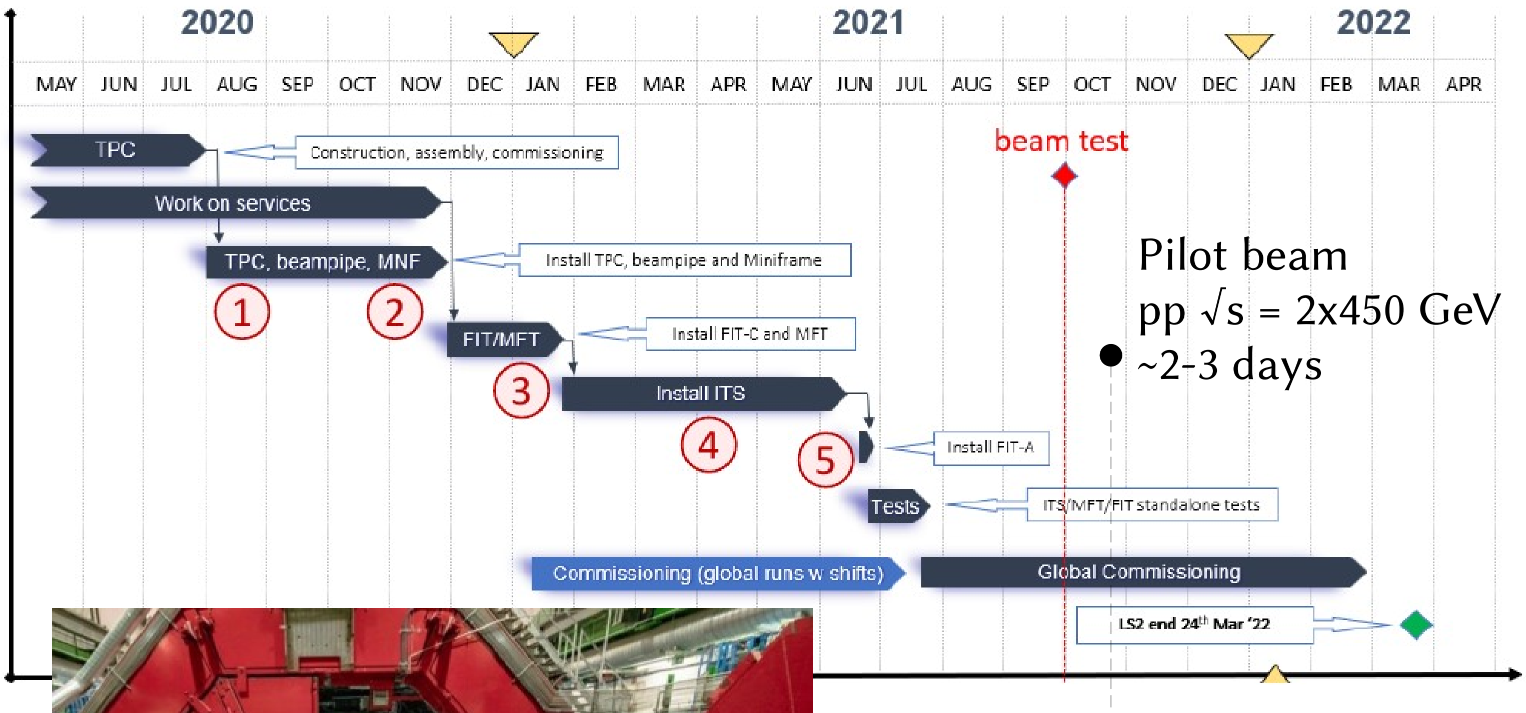
IV.4 – From LS2 (2019-21) into Run 3 (2022-…) : on time !



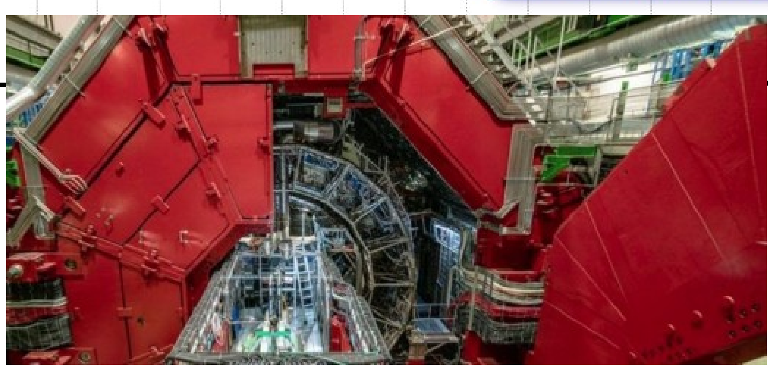






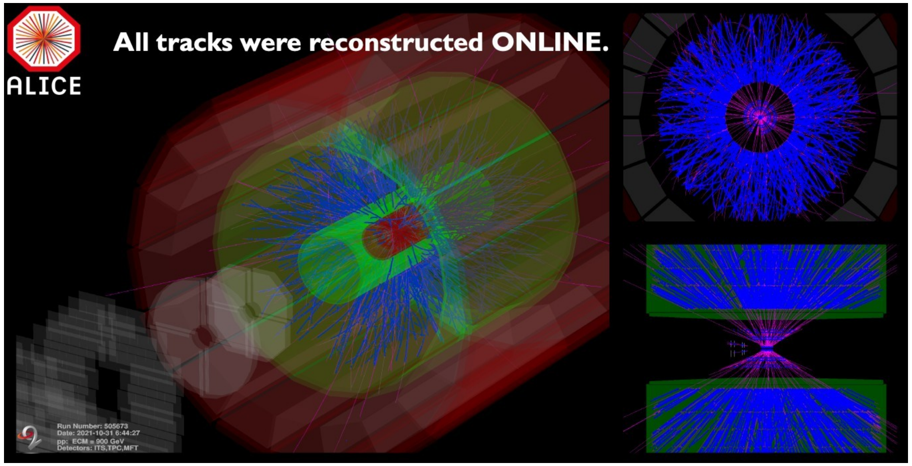


Pilot beam
pp $\sqrt{s}$ = 2x450 GeV
~2-3 days



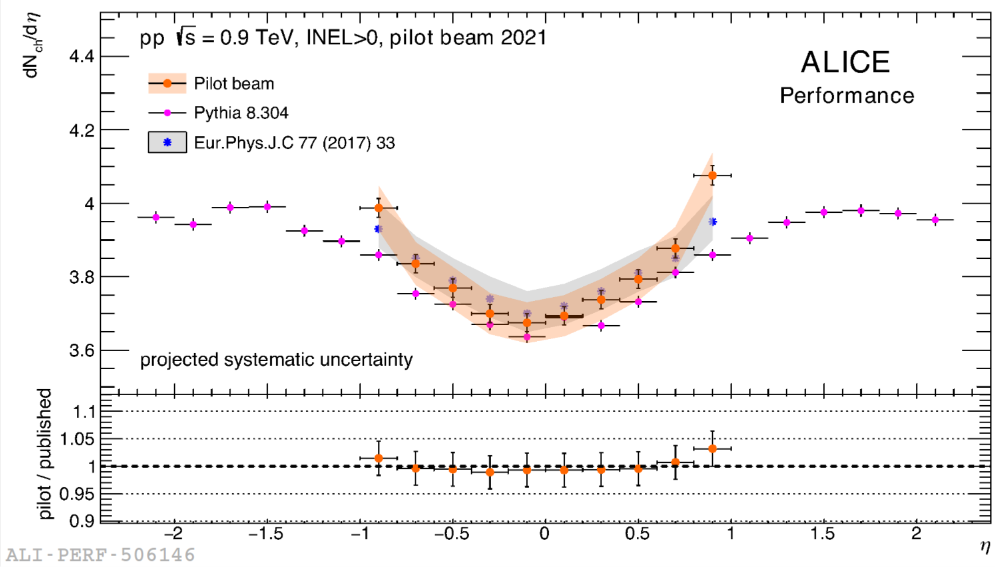
(L3 door closed on 14 Feb)

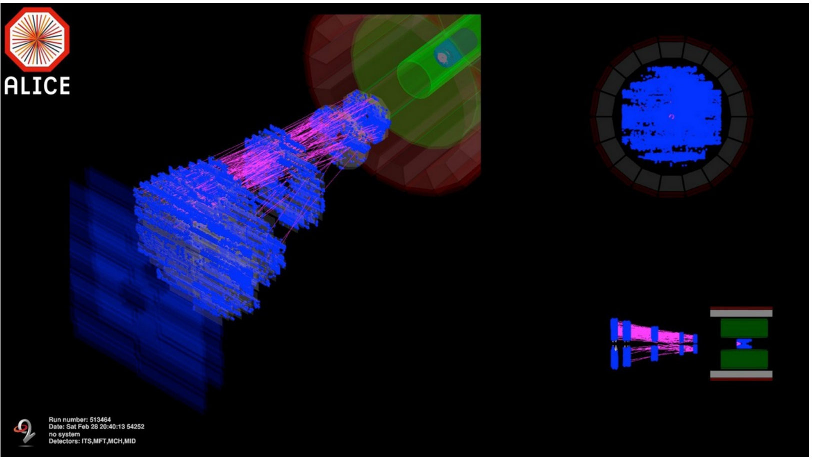
IV.5 – Commissioning : pilot beam oct 2021, pp $\sqrt{s}$ = 900 GeV



pp event from pilot beam 2021

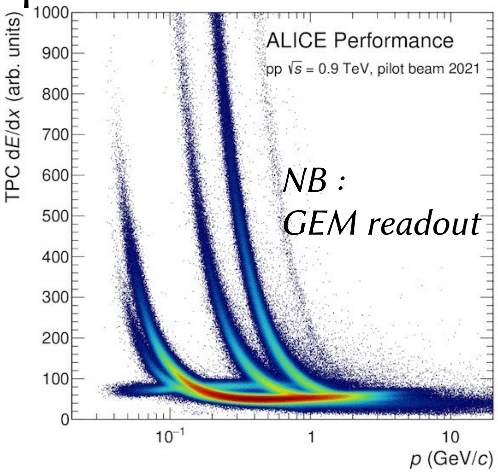
$dN_{ch}/d\eta$ 2021-10 Vs 2010-05 (*arXiv:1509.07541*)

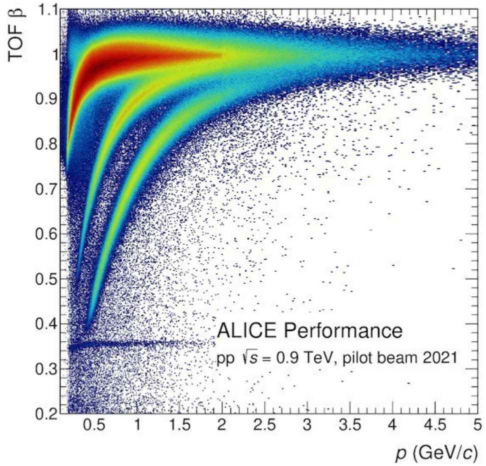




muon splash (μFT, μCH, μID) from TED shots (Apr 2022)

PID capabilities maintained



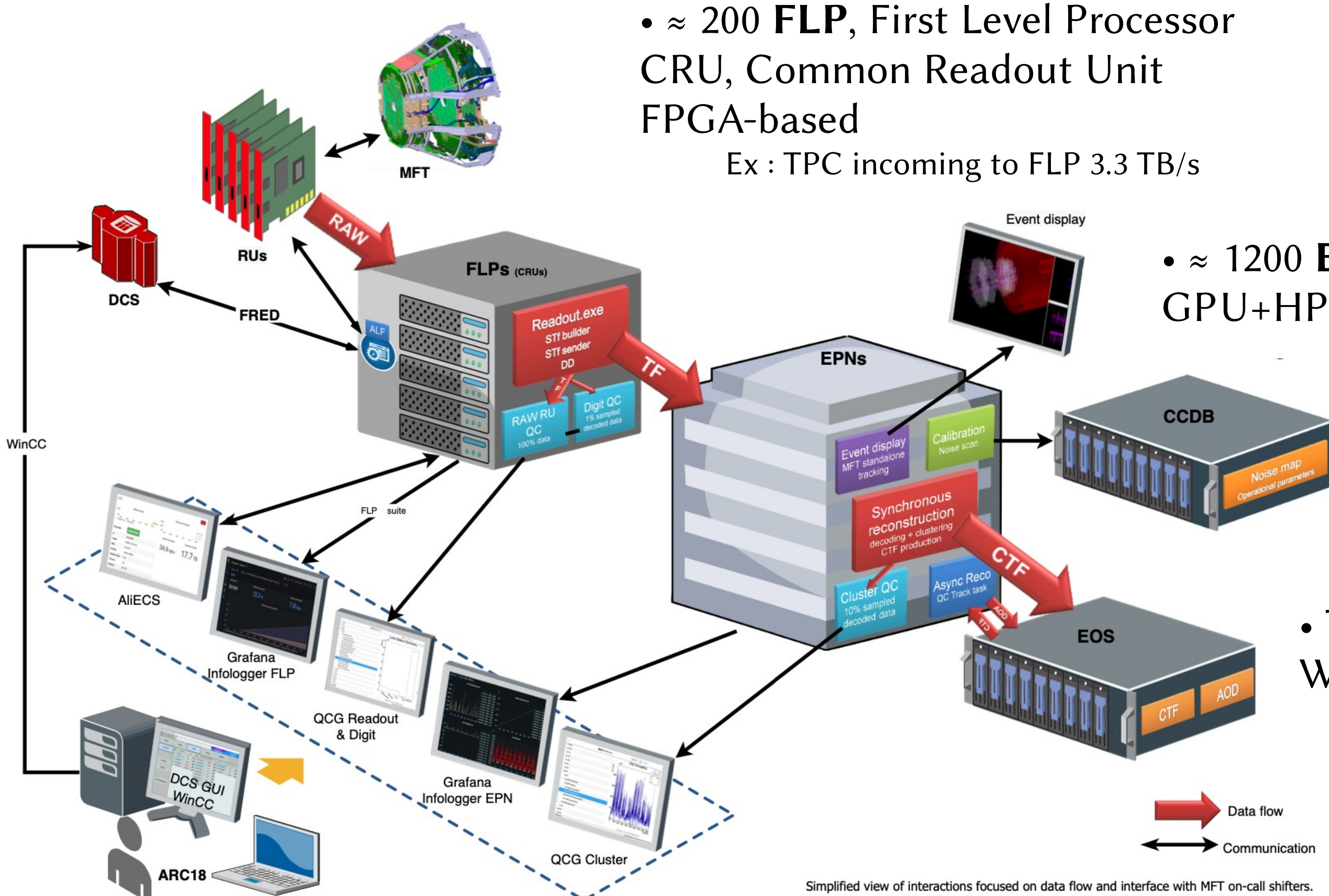


IV.6 – ALICE-2 continuous readout ? : what it costs…

- ≈ 200 **FLP**, First Level Processor
CRU, Common Readout Unit
FPGA-based
  Ex : TPC incoming to FLP 3.3 TB/s

- ≈ 1200 **EPN**, Event Processing Nodes
GPU+HPC CPU based
  Ex : TPC incoming to EPN 570 GB/s

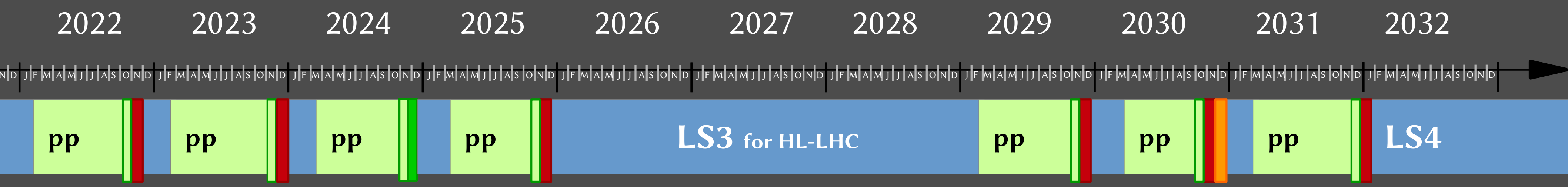
- Tier-0+Tier-1
Whole ALICE2 : 360 GB/s



Simplified view of interactions focused on data flow and interface with MFT on-call shifters.
Internal components are missing, detector control via PSUI/PSU not displayed.
Simplified view of calibration

NB : Time frames ≈ **10 ms** Vs bunch spacing at LHC ≈ **25 ns**

Part C – run 4+5 preparation and perspectives



LHC running plan

V.1 – ALICE 2.1 : FoCal, keys + physics cases

<u>Keys :</u>
EmCal = W+CMOS sensors high granularity readout
HCal = Cu-Sci or Pb-Sci, (i.e. conventional HCalorimeter)

$3.4 < \eta < 5.8$ at $z = +7$m

- forward π^0
  → correlations forward Vs mid-y
- isolated γ
  → ultra-low x in nPDF ($x < 10^{-5}$)

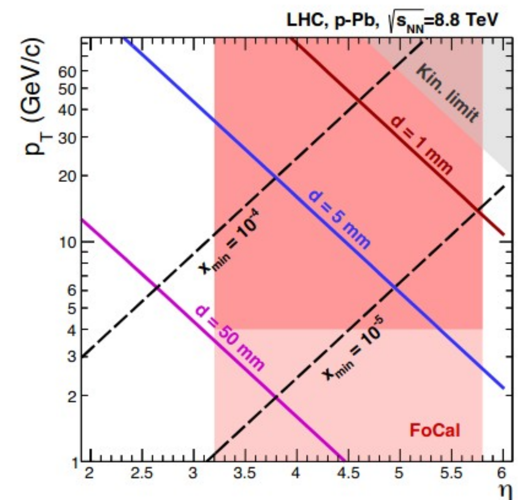
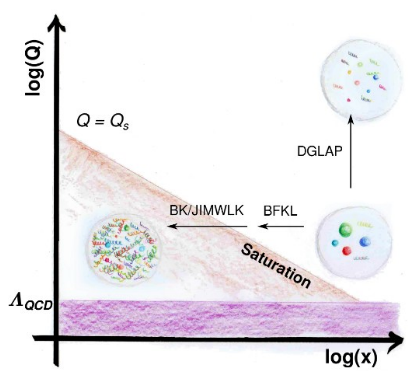
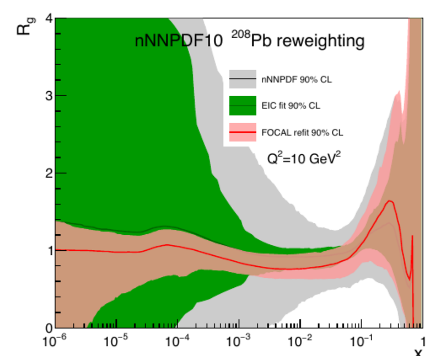


Fig. 20, LoI
CERN-LHCC-2020-009

Fig. 1, LoI





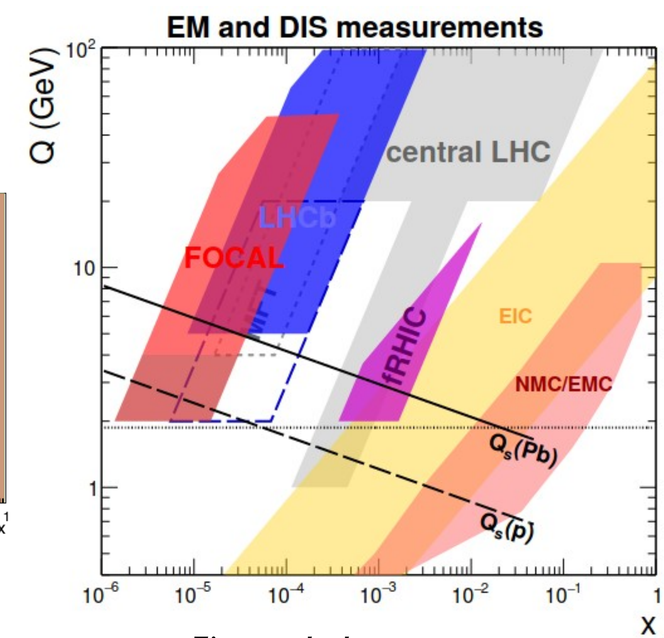
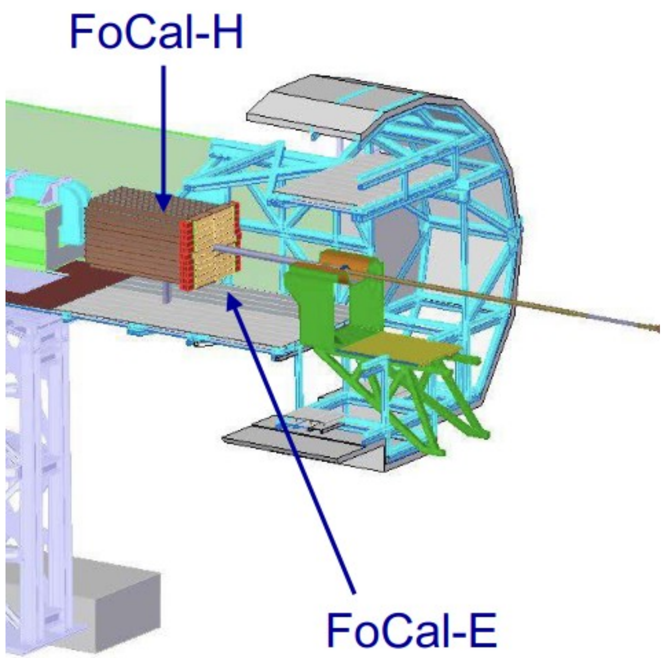


Fig. 13, LoI

<u>Project milestones :</u>
. LoI *arXiv:1708.05164*
. CDR *ALICE-PUBLIC-2019-005*
. LHCc final review, 2020-06 = LoI : *CERN-LHCC-2020-009*
. TDR expected by summer 2023

V.1 – ALICE 2.1 : FoCal



Test beam in September 2021

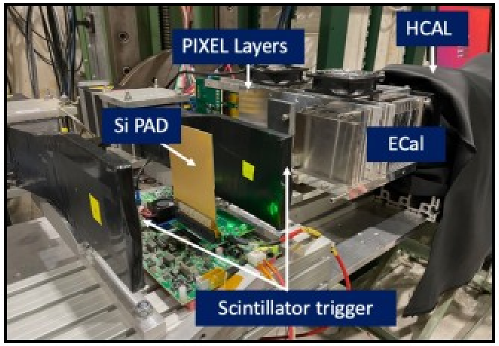
- **FoCal-E**: 2 pixel (ALPIDE) layers, 1 pad layer
- **FoCal-H**: complete prototype, commercial readout system
- Full-pixel prototype: **EPICAL-2**

Next steps:

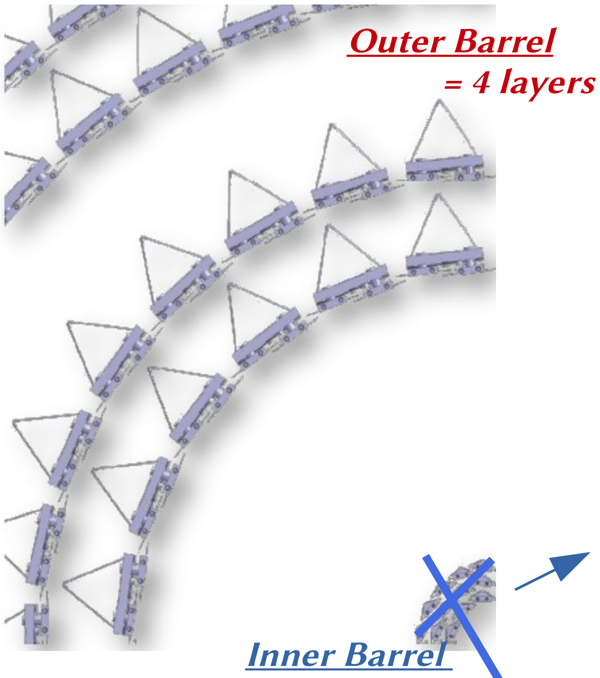
- Further laboratory tests of pad readout
- **Construct full FoCal-E tower prototype**
- 2 test beams planned in 2022 (June for pad electronics, Sep/Oct for full demonstrator)

HCAL prototype

SPS Test beam Sep/Oct



V.2 – ALICE 2.1 : ITS-3, keys + physics cases



Outer Barrel
= 4 layers of ITS2 kept !

Inner Barrel
= 3 layers

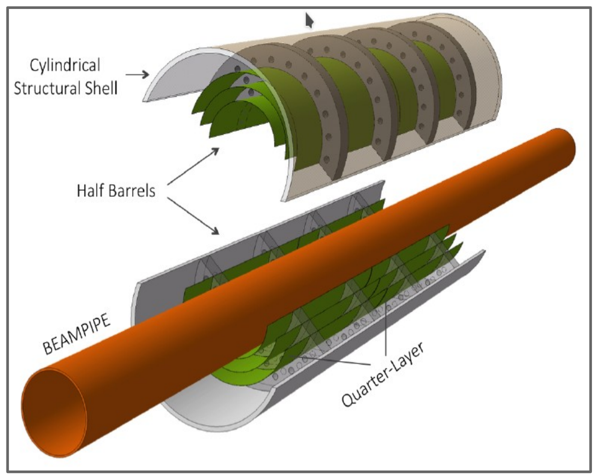
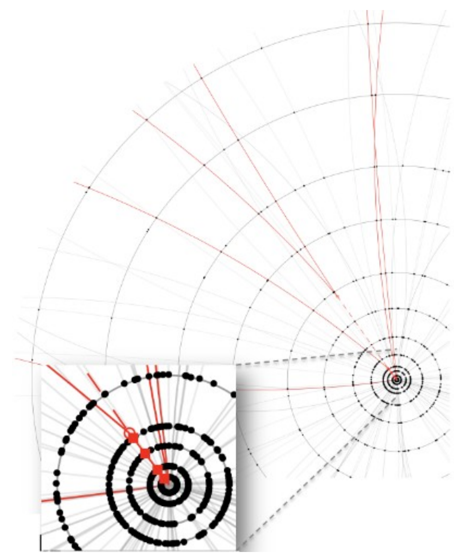


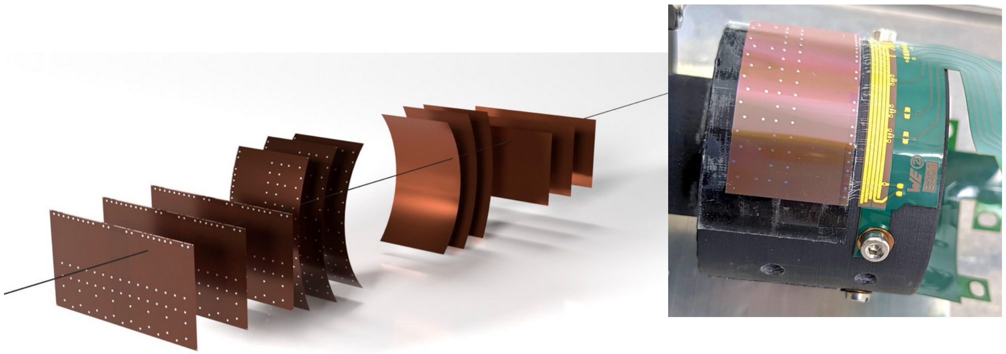
Fig.7 EoI ITS3
ALICE-PUBLIC-2018-013

Keys :
. $|\eta| < 2.0$
News wrt Run 3
. finer : $\mathcal{O}(15\text{x}15)$ μm²
. lighter : ultra-low material budget
(< 0.05% x/X° per layer)
. closer (r_{ITS3} > 1.8 cm)



- improve low p_T AxEff
- improve track pointing resolution
  (Heavy-flavour vertexing at low p_T)
  prompt/non-pr Λ_C^+, D_s^+, Ξ_C ...
  + Λ_b° ... + Λ_cn (c-deuteron), nΛ_cn (c-triton) ?
- "strangeness tracker", 1st implementat° ($\Xi^\pm$, $\Omega^\pm$, $\Sigma^\pm$)

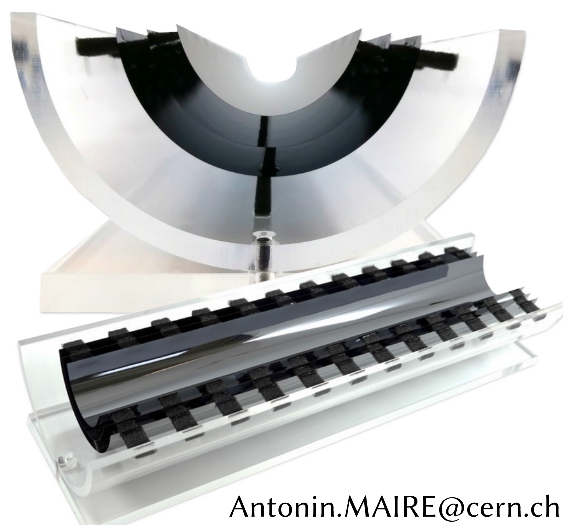
V.2 – ALICE 2.1 : ITS3

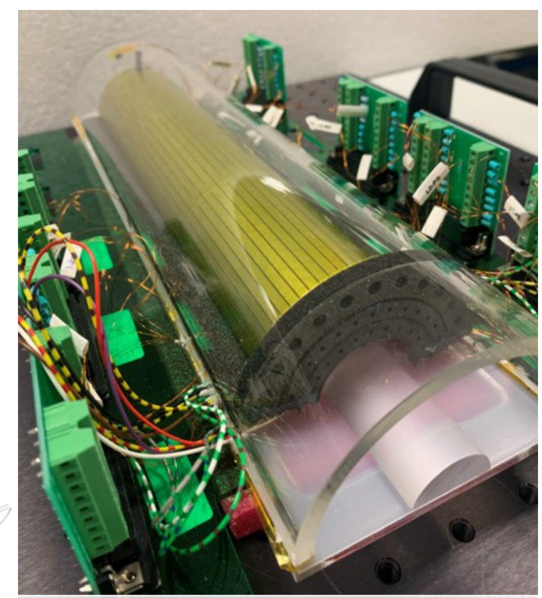


Beam test of ***bent*** ALPIDE chips
(i.e. ITS2 chip 50-µm thick, 180 nm technology)
(*arXiv:2105.13000*)

Move from 180 nm CMOS technology to 65 nm (Tower foundry)
→ Wafer-scale chip,
thinned (< 50 µm) + to be bent

Mechanical integration
cooling test





Project milestones :

. EoI *ALICE-PUBLIC-2018-013*

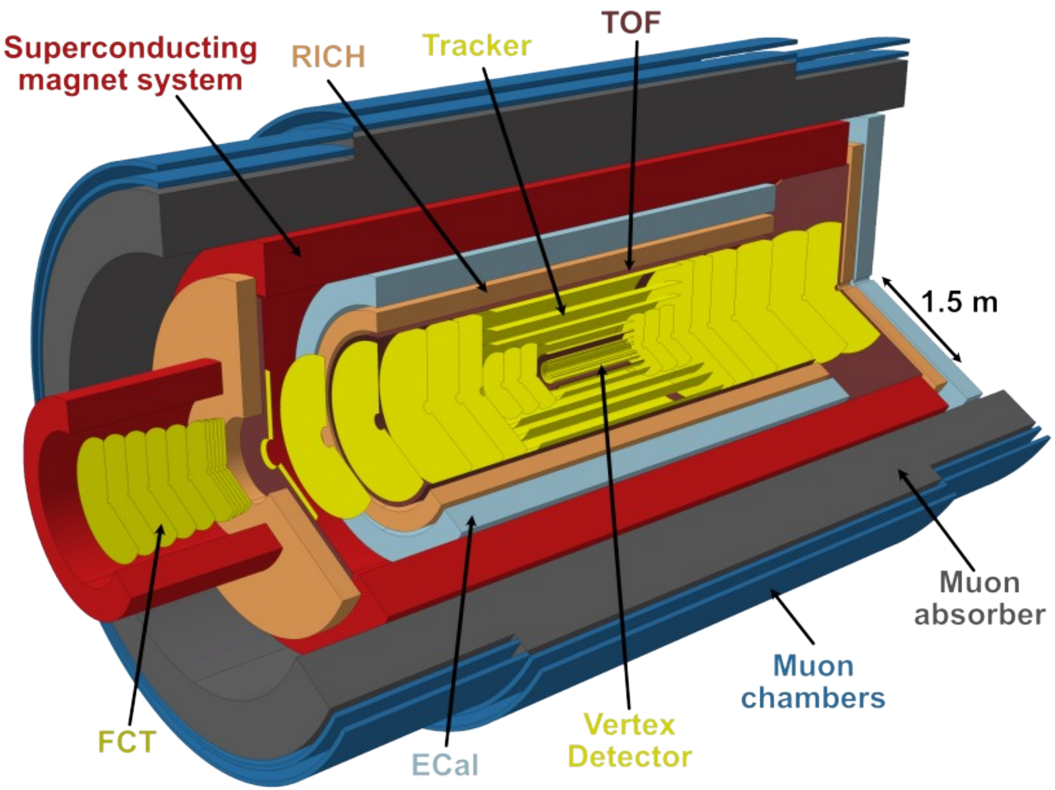
. LoI *CERN-LHCC-2019-018*

. 2019 : LHCc blessing for R&D

→ Engineering run 2 = 2022-05,
on-wafer stitching among chips

. TDR by spring 2023

VI.1 – ALICE 3 : Letter of Intent, (Run 5, >2032)



The "conceptual" beauty of the instrument ?

Tracker,

Compact ($R_{\text{outer TOF}} \approx 85$ cm)

ultra-light (layer 0 ~ 0.1 % x/X_0)

All-Si (≈ 60 m²)

with high-performance tracking

(Axε, granularity, ...)

with **PID** capabilities

(iTOF, oTOF, RICH, Ecal, μ)

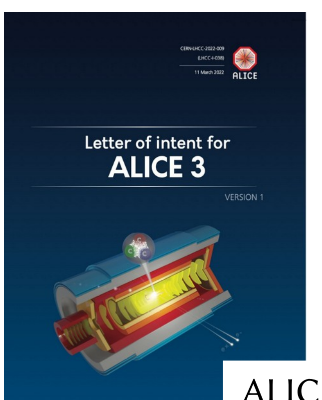
over wide **acceptance** :

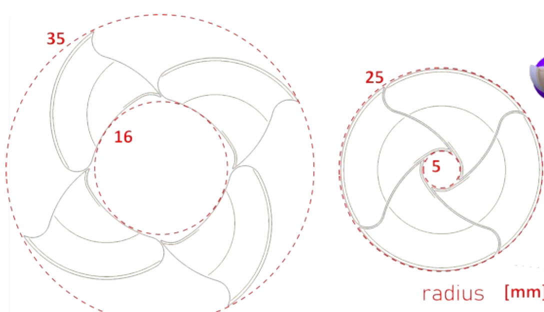
- $|y| < 4$
- $p_T \in [$ **0.05** ; $\mathcal{O}(10)$] GeV/c

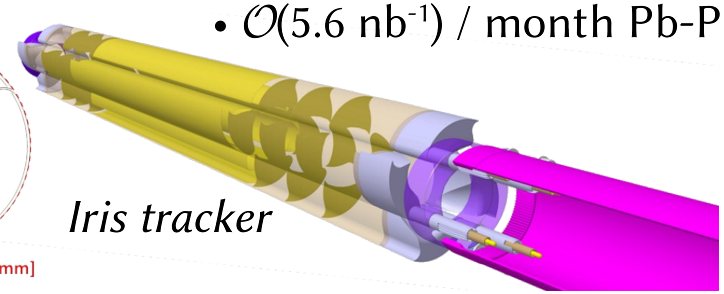
To collect integrated **MB luminosities** :

≈ 1 MHz recorded readout

- $\mathcal{O}(0.5\ \text{fb}^{-1})$ / month pp
- $\mathcal{O}(5.6\ \text{nb}^{-1})$ / month Pb-Pb







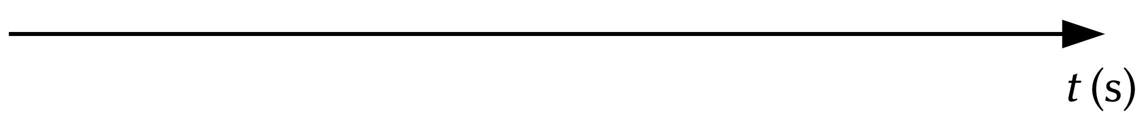
Iris tracker

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

Conclusions and Prospects

It's likely all about time

Time lapse ...
Timing ...
Time frames ...
Timeline ...



Appendix

Annexe 1

Annexe 2

A.1 – Synopsis : ITS1 Vs ITS2 Vs ALICE3

	ITS-2 [*TDR*]			ITS-3 [*LoI*]			ALICE3 [*LoI*]		
Période LHC	Run III + IV (2022-31)			Run IV (2029-31)			≥ Run V (>2032)		
Nombres de couches	3+4			3 (+4 ITS-2)			O(3+8)		
R_{tube}	1,82 cm			1,6 cm			(2,9)		
r_{L0} / r_{L1} / r_{L2} ... r_{Last} (cm)	2,3 / 3,2 / 3,9 ... 39,3			1,8 / 2,4 / 3,0 ... 39,3			0,5 / ... ≈ 100		
Champ magnétique $B_{solénoïde}$	0,2 ou 0,5 T			0,2 ou 0,5 T			0,2 à 2 T		
Matière par couche (x/X_0)	0,3 % à 0,8 %			0,05 % à 0,8 %			0,1 % à 0,8 %		
Taille d'un pixel (µm²)	≈ 30 x 30			≈20 x 20 (+ 30 x 30)			≈10 x 10 (+ 30 x 30)		
CMOS technology	180 nm			65 nm			65 nm		
Résolution temporelle	≥ 2-5 µs			2-5 µs			≤ 1 µs		
Résolution spatiale	5 µm			5 µm			≈ 3-5 µm		
Couverture en η	|η| < 2,0 à 1,3			|η| < 2,0 à 1,3			|η| < 4,0		
	1	0,1	0,05	1	0,1	0,05	1	0,1	0,05
	98 %	60 %	10 %	98 %	75 %	20 %	98 %	75 %	20 %
Coûts totaux (R&D + Constr.)	≈ 15 MCHF			5,3 MCHF			≈ 141 MCHF		
Nb d'instituts / Nb de pays	30 / 16			30 / 16			(> X signataires)		

B.1 – HL-LHC QCD+QGP : towards an ideal detector

By 2032, ≈ any inclusive identified measurements ≈ done.

⟶ Stakes = multi-differential and/or correlated measurements
(vn, HBT, double production, f(mult), f(event activities) ...)

QGP physics = a particle of interest wrt to its context, i.e. QCD surroundings in the event

⟶ Need a focus on :
- all identified particles (*u*,*d*,*s*,*c*,*b*)
- access to [ultra]low pT ([0.05-0.15]- O(10) GeV/*c*)
- ∀ p_T, ∀ y, AxEff(tracks) ≈ 100%
- ideally on an event-by-event basis,
- made available through huge integrated luminosities, both in AA and in pp

Define how the ideal experiment(s) should look like...

B.2 – HL-LHC QCD+QGP *: for which physics cases ?*

- Degrees of freedom within the QGP via LQCD (deconfinement dof + transition + chiral restoration) ?
  - net quantum-charge fluctuations at (μ_B = 0)
    - $\longrightarrow$ Q : (h^+ - h^-), B : (p - $\bar{\text{p}}$, Λ - $\bar{\Lambda}$, ...), S : (K^+ - K^-, Λ - $\bar{\Lambda}$, ...)
  - direct e^+e^- ($m_{inv} \in$ *[2-5]* GeV/c^2) to access initial state (cf. Ollitrault, Winn *arXiv:2104.07622*)

- Probe the effect of chiral symmetry restoration ?
  - e^+e^- at $m_{inv} \approx m(\rho)$ (~0.8 GeV/c^2)
  - ultra-low p_T $\pi^{\pm}$ (p_T < 0.05-0.1 GeV/c)

- Evolution of the thermodynamic param. (*T*, elec. conductivity, ...) within the system ?
  - Thermal e^+e^- (m_{inv} < 0.05-3 GeV/c^2)

- Roots of collectivity (hydrodynamisation, chem. equilibration, thermalisation) ?
  - *u,d,s,c,b* = f[event-activity (mult, spherocity, R_T, ...) + system pp, pA, AA]

- Alterations of parton shower by the medium ?
  - *PID* decomposition within *flavour-tagged* jets

- Interplay between mechanisms of hadronisation ?
  - Ξ_{cc}^{2+}(*ucc*), ... , Ω_{ccc}^{2+}(*ccc*)
  - χ_{c1}(3872)($c\bar{c}u\bar{u}$), T_{cc}^{+}($cc\bar{u}\bar{d}$)