ALICE

ALICE
From RUN 2 to RUN 3 and beyond

Sarah Porteboeuf Houssais for ALICE-France

Conseil Scientifique IN2P3 – 06/02/2023

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Outline

- ➢ Why to study the Quark-Gluon Plasma ?
- ➢ What we learned from RUN 2 ?
- ➢ What are the plans for RUN 3 ?
- ➢ What was done to prepare for RUN 3 challenges ?
- ➢ What are the plans for RUN 4 ?
- ➢ What we expect from the ALICE-France community at the horizon of RUN 4 ?

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ALICE

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Presented by Francois

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Presented by Francois

Presented at Conseil Scientifique IN2P3 27th Oct. 2022

Projet de participation à une jouvence de l'expérience ALICE

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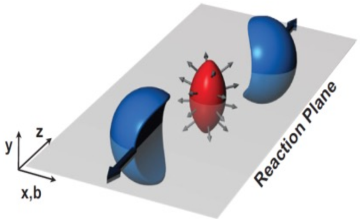
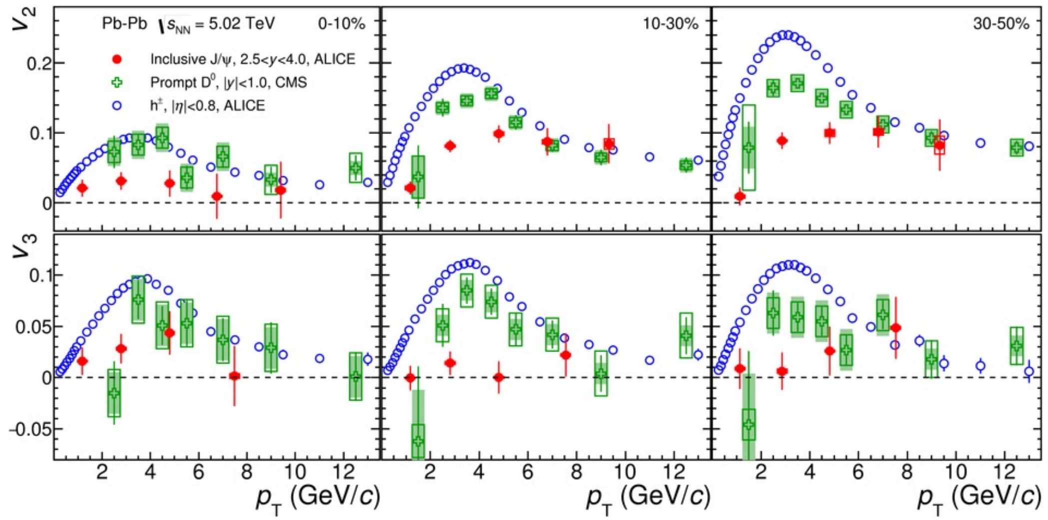
Collective behavior with charm and beauty



$$\frac{dN}{d\varphi} \propto 1 + 2\sum_{n=1}^{\infty} v_n \cos(n(\varphi - \Psi n))$$

If quarkonium are regenerated,
they acquire collective properties of the expanding medium
$v_2 > 0$

JHEP 1902 (2019) 012

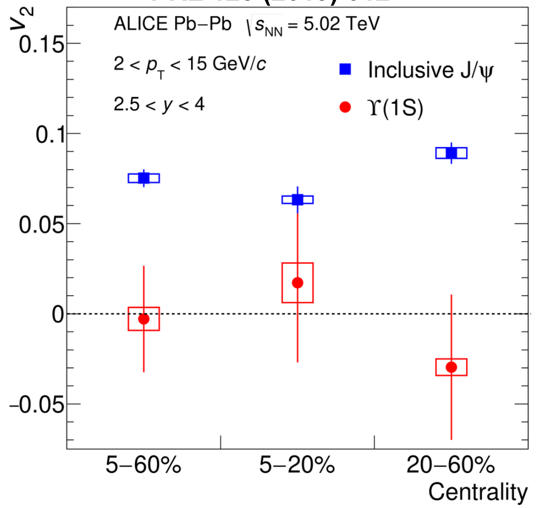


Unambiguous observation of non-zero J/ψ v_2

At high p_T, stronger effect than expected: possible path-length dependence effect

At low and intermediate p_T: v_n(J/ψ) < v_n(D) < v_n(h)

PRL 123 (2019) 012



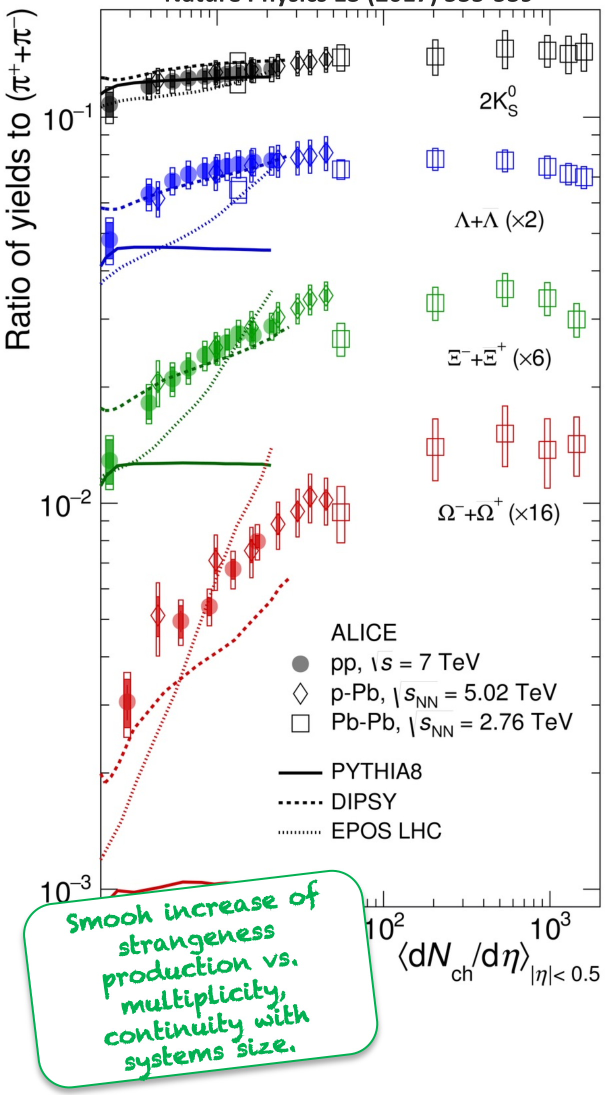
Υ(1s) – *b* quark – not regenerated

Opposite to J/ψ – *c* quark

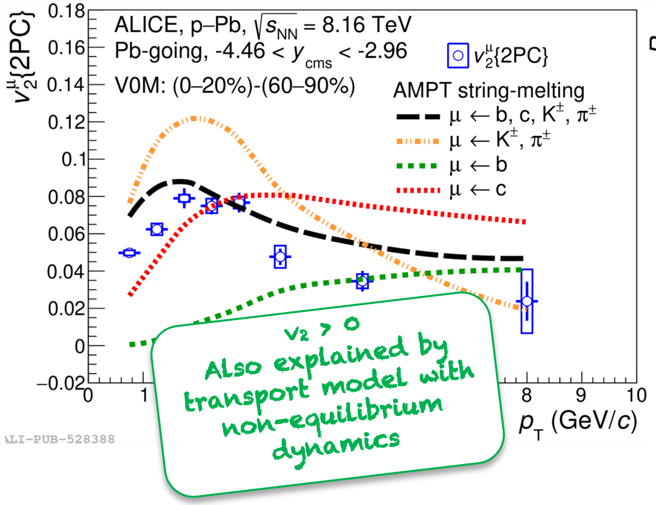
Also
Jet azimuthal anisotropy, submitted to PRL arXiv:2110.15852
φ meson in Pb-Pb EPJC 78 (2018) 559 and pp EPJC 81 (2021) 772

QGP droplets in p-Pb and pp?

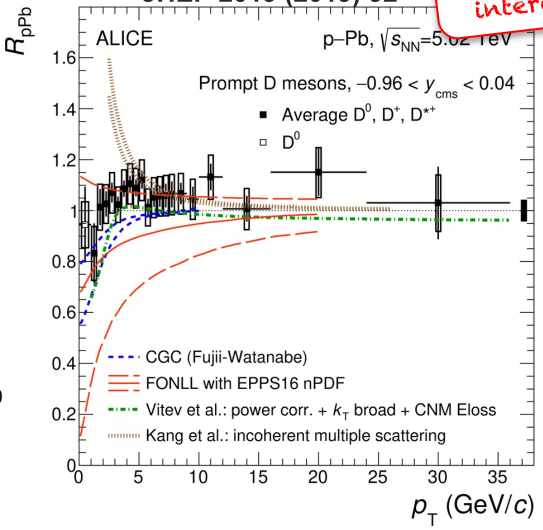
Nature Physics 13 (2017) 535-539



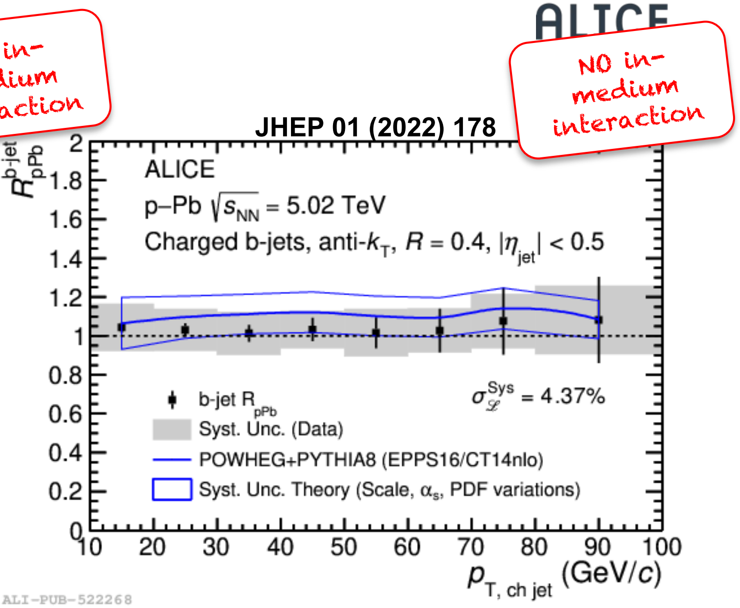
Submitted to PLB arXiv:2210.08980



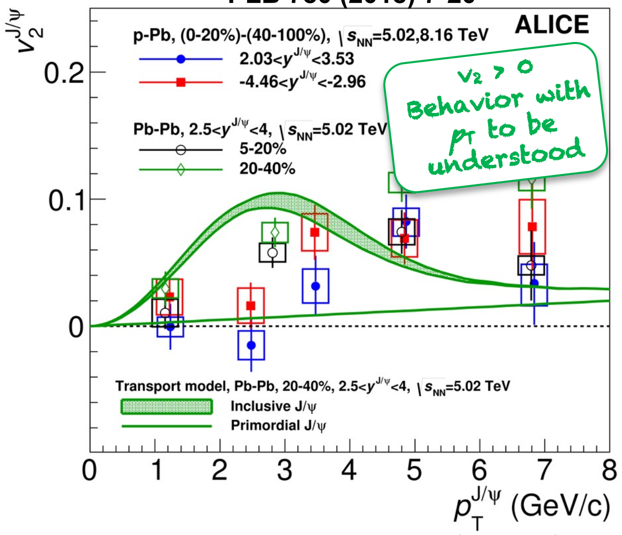
JHEP 2019 (2019) 92



JHEP 01 (2022) 178



PLB 780 (2018) 7-20



- **Ambiguous results for probes** directly related to a possible formed hot medium
- **No sign of in-medium interaction with energy loss** within the current experimental precision
- Role of initial state, saturation, final stat, hadronization, fluctuations under investigation

Also azimuthal anisotropy of jet particles in p-Pb and Pb-Pb submitted to PRL
single-μ azimuthal anisotropy to be submitted to PLB
J/ψ – hadron correlations in pp to be submitted to JHEP
Quarkonium inclusive production submitted to EPJC arXiv:2109.15240
Jet cross section in pp PRD 100, 092004 (2019)

RUN 3

- **Better probe QGP with heavy flavor quarks**
- **Study hadronic collision scaling quantity from pp to Pb-Pb and onset of collectivity in hadronic collisions**

  - **Improve vertexing capabilities** in the central barrel allowing better reconstruction of primary and secondary vertices
    - Better rejection of background
    - Better reconstruction of decay chain, especially at low p_T
  - **Charmonia and Open heavy flavors: separation of charm and beauty**
    - **Prompt Charmonium production**
      Prompt/non-prompt J/ψ separation down to $p_T = 0$. $\psi(2S)$ measurement in central Pb-Pb collisions
    - **In the HF sector**
      Charm and Beauty measurement down to p_T = 1 GeV/c in the single muon channel
      Beauty measurement down to p_T = 0 in the non-prompt J/ψ channel
  - **Low-mass dimuons**
    Improved mass resolution for light resonances. Sensitivity to prompt continuum
  - **Open possibilities for central-forward correlation of many probes**
  - **Increase statistics by a factor 10 (muons) to 50 (central barrel)**

RUN 3 challenges

ALICE

RUN 1 2009-2013	LS1	RUN 2 2015-2018	LS2	RUN 3 2022-2025	LS3	RUN 4 2029-2032
pp 7 TeV, pPb, Pb-Pb		pp 13 TeV, pPb, Xe-Xe Pb-Pb		pp 13.6 TeV, pO, O-O, pPb,Pb-Pb		pp, pPb, Pb-Pb

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RUN 3 challenges

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Total integrated Luminosity RUN 1+2

Pb-Pb: 1.5 nb^{-1} in ALICE

2.54 nb^{-1} in ATLAS/CMS, 0.26 nb^{-1} in LHCb

p-Pb: 75 nb^{-1} in ALICE

~220 nb^{-1} in ATLAS/CMS, 36 nb^{-1} in LHCb

In ALICE, Pb-Pb: interaction rate ~8 kHz with trigger event → Readout ≈ 1 kHz

→

Target Luminosity RUN 3+4

Pb-Pb: 13 nb^{-1} in ALICE/ATLAS/CMS,

2 nb^{-1} in LHCb

p-Pb: 0.5 pb^{-1} in ALICE

1 pb^{-1} in ATLAS/CMS, 0.2 pb^{-1} in LHCb

In ALICE, Pb-Pb: interaction rate 50 kHz, continuous readout

Statistics from x10 to x50 depending on probe

Online data reconstruction

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RUN 3 plan adaptation

- **In 2022 major events impacting LHC operation**
  - LHC cryo issue, LHC stopped 4 weeks, 3 weeks of data taking lost (1 week shadowed by planned Technical Stop)
  - War in Ukraine and Energy crisis in Europe : 2022 operation stopped 2 weeks earlier for energy saving

- **RUN 3 plan adapted**
  - 2022 devoted to pp data taking
  - HI run postponed to 2023 with extended running time: 5 weeks instead of 4

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RUN 3 plan adaptation

- **Detailed RUN 3 plan under discussion**
  - 20% reduction of running time every year as a baseline
  - Several scenarios under discussion

p-Pb in 2024 as initially planned
2 Pb-Pb period extended to 5 weeks

3w p-Pb in 2025, after completion of the PbPb program

4w Pb-Pb in 2024 and 2025
p-Pb postpone to RUN 4
To ensure the PbPb plans

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RUN 3 plan adaptation

- **Thanks to reduce set-up times and higher performances of the machine in longer run**
- **ALICE integrated luminosity target remains**
  - **2023 Pb-Pb: target $L_{int}^{Pb\text{-}Pb}$= 3.25 nb^{-1}**
  - Target Pb-Pb lumi for Run 3: **$L_{int}^{Pb\text{-}Pb}$= 6.5 nb^{-1}**
  - If achieved in 2023+2024 : run p-Pb in 2025 with **$L_{int}^{p\text{-}Pb}$= 150 nb^{-1}**

Considerations on performance

- **Estimated performance has large uncertainties**
  - Especially from machine availability and beam parameters in collision
- Depending on scenario, estimate about
  - 2.7-3.6 nb^{-1} at ALICE
    - Goal by experiment: 3.25 nb^{-1}
  - 2.4-3.2 nb^{-1} at ATLAS/CMS
    - Goal by experiment: 3 nb^{-1}
  - 0.3-0.5 nb^{-1} at LHCb
    - Goal by experiment: 0.4 nb^{-1}
- **The goals set by the experiments are challenging and ambitious**
  - Could be feasible, but also clear risk that we cannot reach the goals for some or all experiments
  - If we do not reach the 2023 goal, could compensate by doing Pb-Pb instead of p-Pb
  - If we have 4 ion runs in Run 4, it will be easier to reach the overall Run3 + Run 4 goal
- **3-5% loss in integrated luminosity at 6.37 Z TeV**

R. Bruce, 2023.01.23 20

ALICE

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ALICE 2 is a new experiment !

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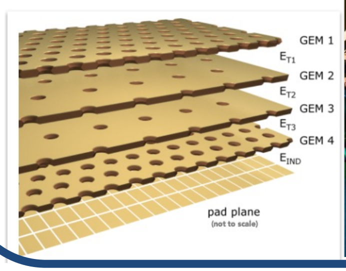
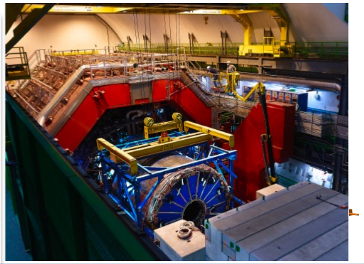
In ALICE, Pb-Pb: interaction rate 50 kHz, continuous readout
Statistics from x10 to x50 depending on probe
Online data reconstruction

ALICE 2 – Upgrades for RUN 3

Time Projection Chamber (TPC)

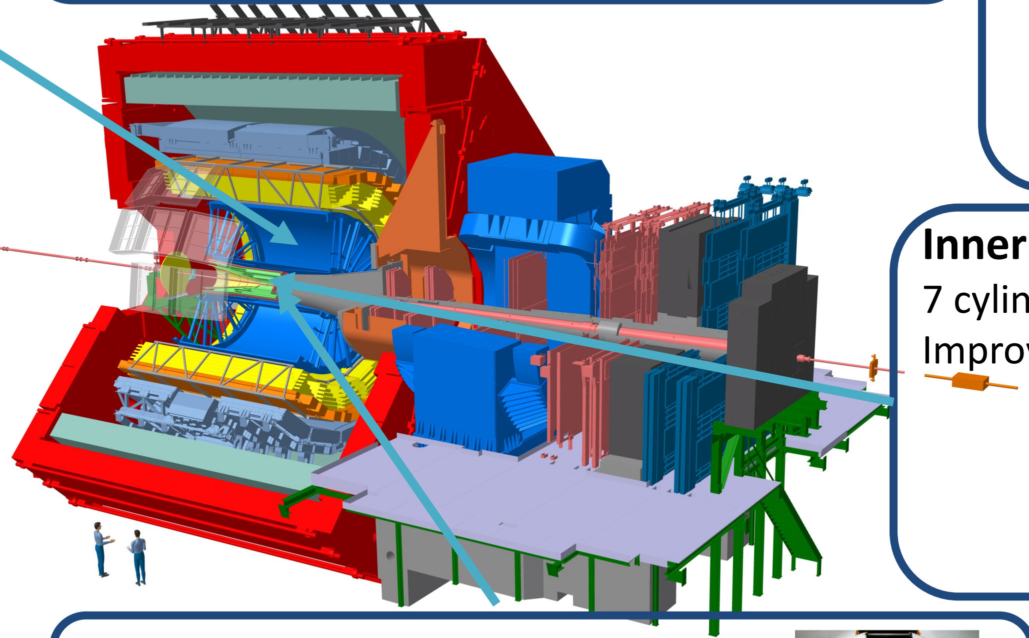
New readout chambers: from Multi Wire Proportional Chamber (MWPC) to Gas Electron Multiplier (**GEM**)



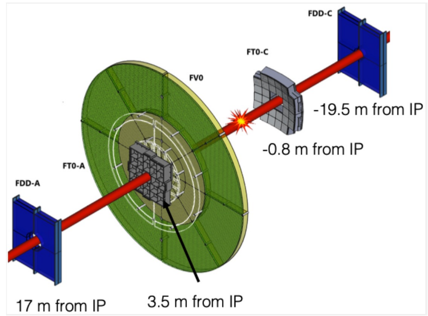


Consolidation and readout upgrade of all subsystems with Common Readout Unit (CRU)

- **MCH** upgrade with SAMPA ASIC
- **MID** (upgrade of MTR) with FEERIC ASIC



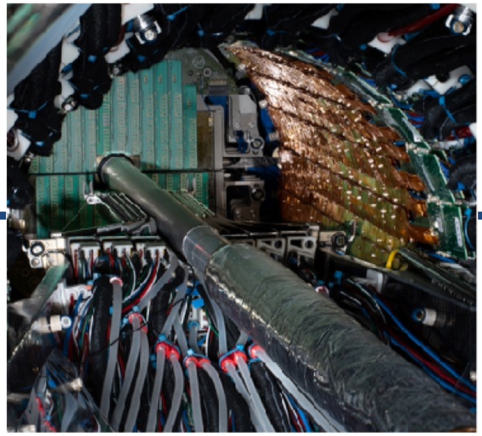
Fast Integration Trigger



Inner Tracking System (ITS 2)

7 cylindrical layer of MAPS (~ $10m^2$)

Improved vertexing at high rate



Integrated on-/off-line System

Continous Readout with First Level Processors (FLPs), O2-CRU

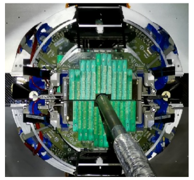
Event Processing Nodes (EPNs) for GPU-based Synchronous reconstruction

Online Data Compression

Muon Forward Tracker (MFT)

5 double planes of MAPS

Forward vertexing for Muons



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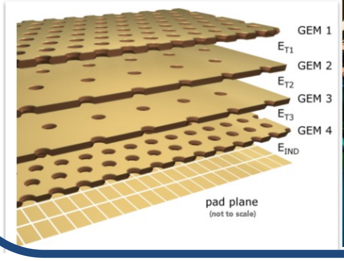

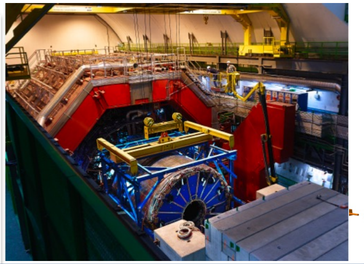

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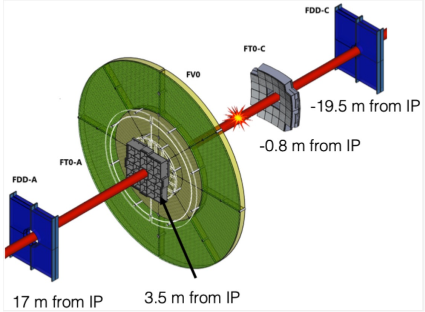

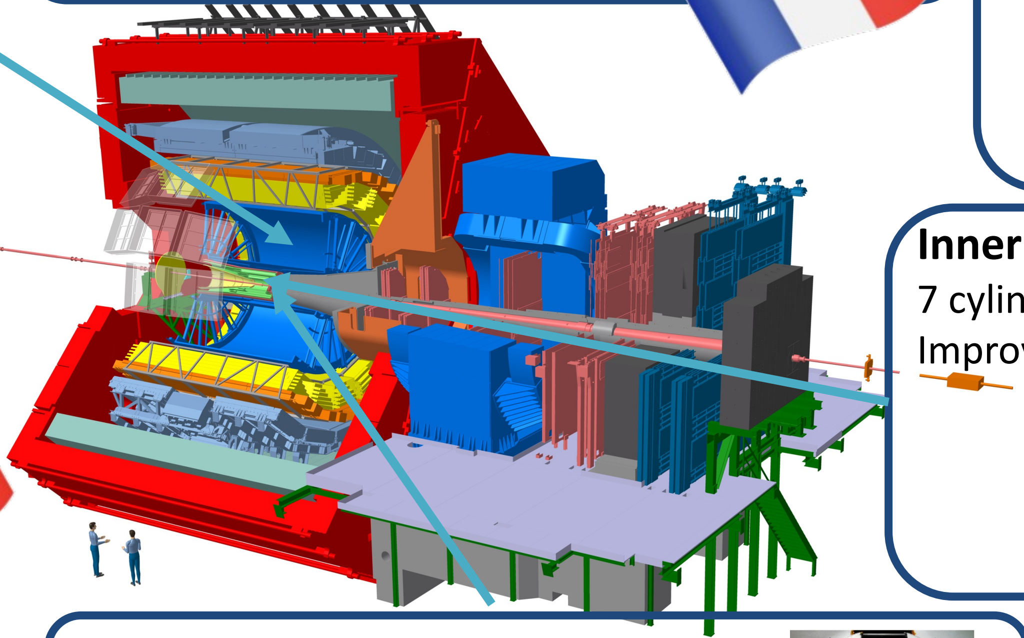

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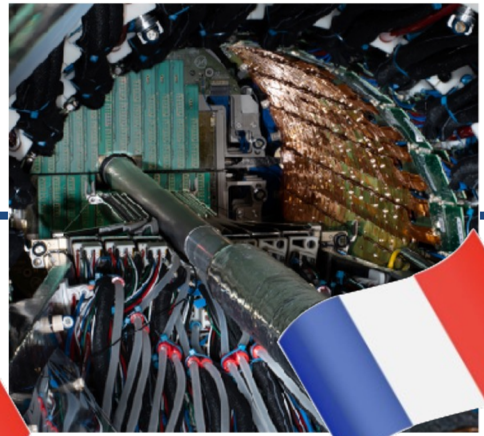

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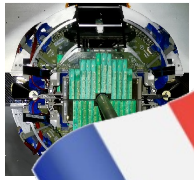
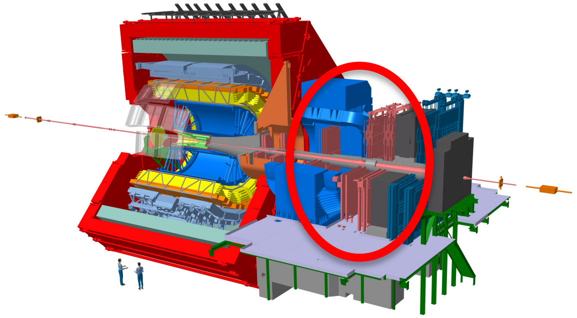
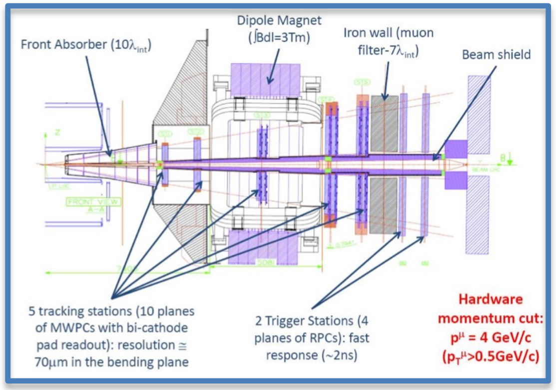
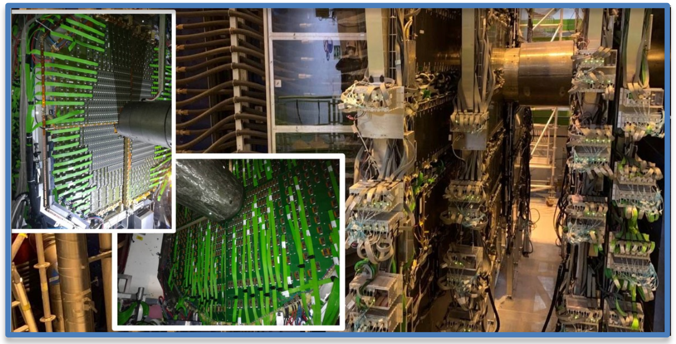


MUON CHAMBER - MCH



- 5 tracking stations (2x5 Multi-Wire Proportional Chambers)
- complemented with an absorber system





- **Redesign of Readout electronic with DualSampa cards**

IJCLab Production of Dual Sampa cards. Design and production of PCB

- **Rejuvenation of high/low voltages** (quadrant opening and cleaning)

IJCLab station 1

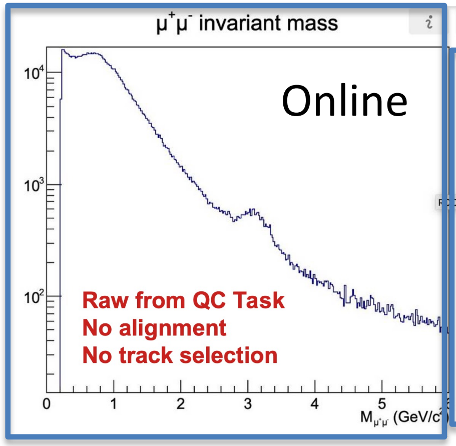
- **Successfully Installed, cabled and integrated**

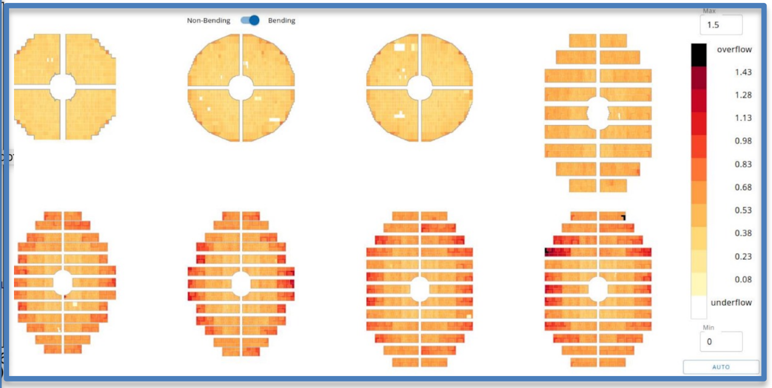
IJCLab station 1
Subatech station 3,4,5

- **Software**

Subatech

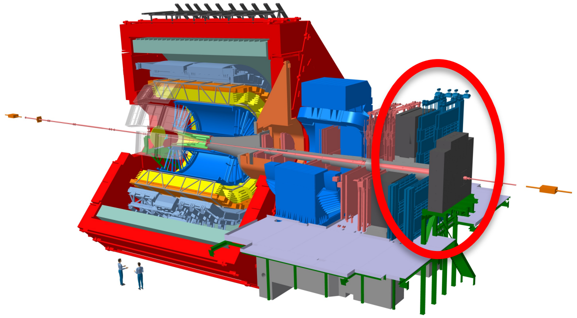
  - Simulation
  - Simulation & Reconstruction
  - Calibration

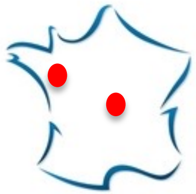




- **Commissioning finalised**, successful data taking at 500 kHz pp interaction rate

MUON IDENTIFIER - MID





- 72 Resistive Plate Chambers (RPCs) in 2 stations of 2 planes
- total surface ~150 m^2
- 21k readout channels.

- **Upgrade of Front-End electronic with amplification** (FEERIC) **to prevent ageing**:
  - Design
  - Production LPC
  - Installation
  - Distribution of the thresholds via wireless systems

- **Upgrade of readout electronics**, slow control, detector simulation Subatech

- **Software**
  - reconstruction Subatech
  - QC LPC

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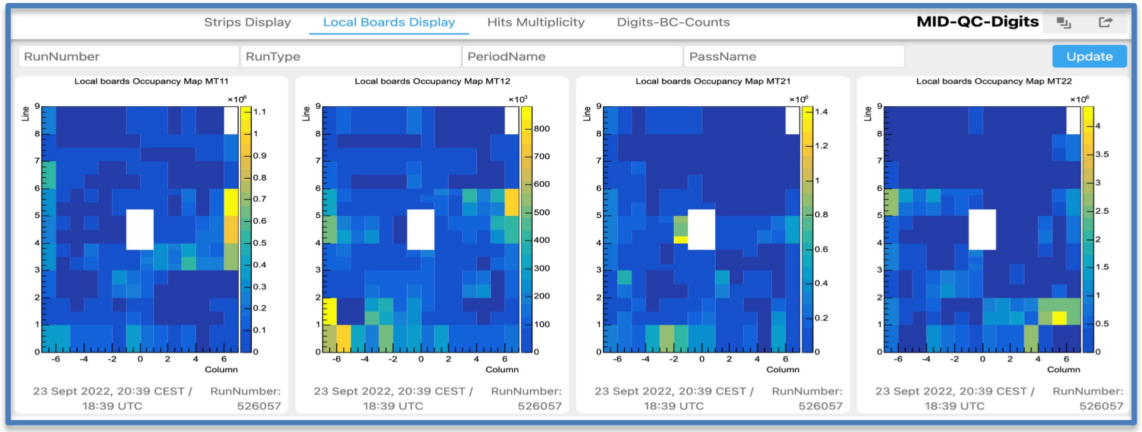
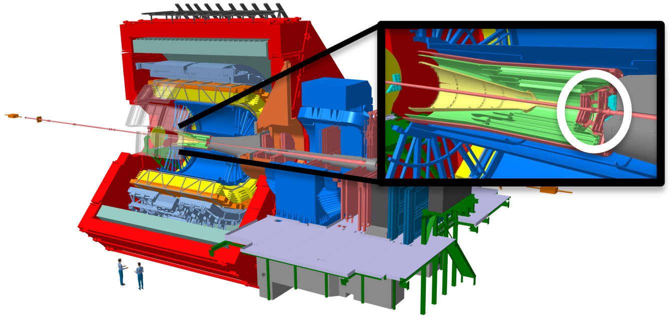
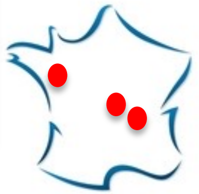
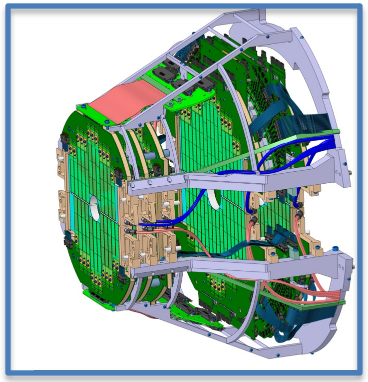


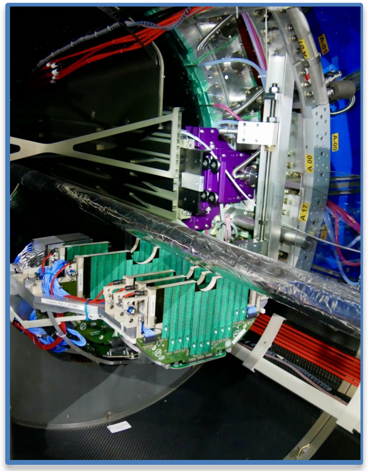
MUON FORWARD TRACKER - MFT

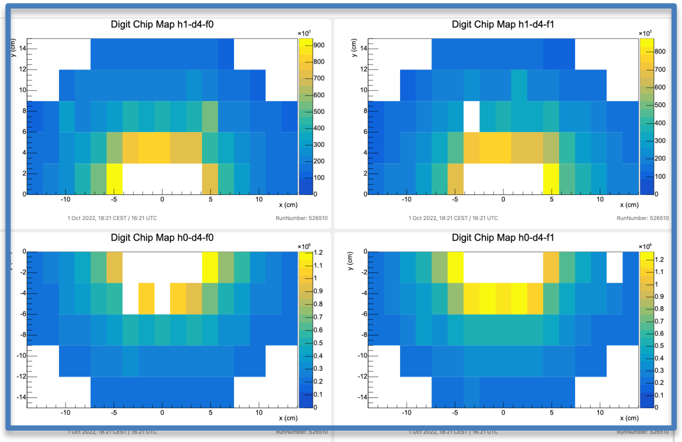


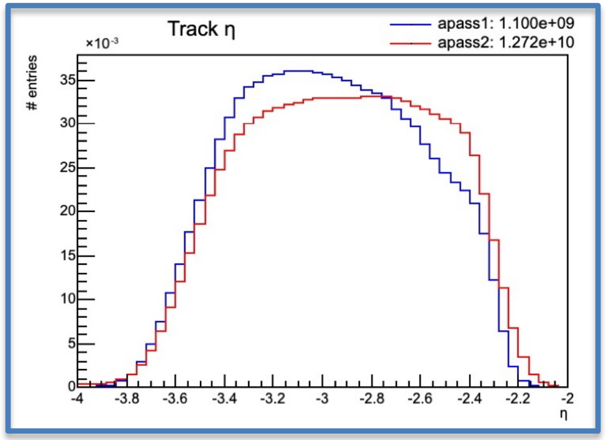


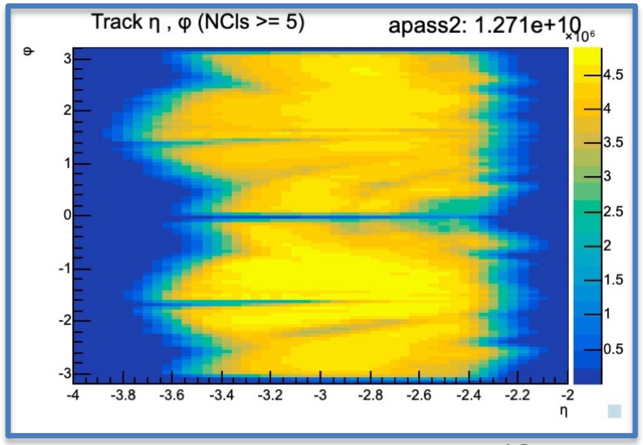
- Vertex tracker for the Muon Spectrometer, installed between the interaction point and the hadron absorber ($-3.6 < \eta < -2.5$)
- 920 ALPIDE silicon pixel sensors (0.4 m^2) in 280 ladders of 2 to 5 sensors each (same sensor as ITS2)
- **Hardware and Services**
  - Ladder assembly LPC
  - Cooling system Subatech
  - Power Supply Unit Subatech
  - Readout System and Firmware IP2I
  - Slow Control (ALF-FRED) Subatech + IP2I
- **Installation and commissioning** Subatech + IP2I + LPC
- **Software**
  - Geometry LPC
  - Reconstruction Subatech + LPC
  - Tracking
  - MCH-MFT matching Subatech
- **Commissioning finalized**, successful data taking at 500 kHz pp interaction rate



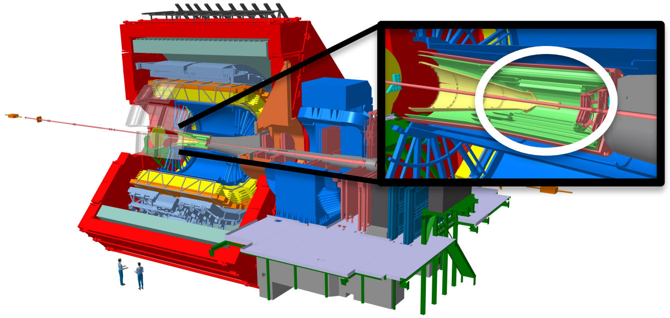






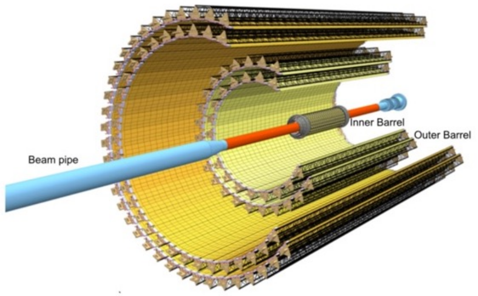


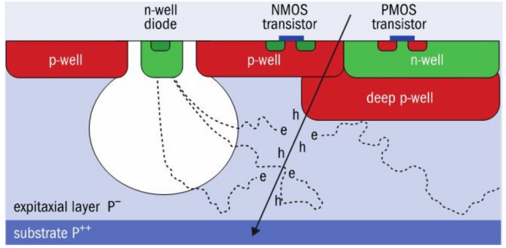
INNER TRACKING SYSTEM 2 – ITS2



- **Monolithic active sensors** (MAPS) called **ALPIDE**, integrating both pixel sensor and read-out electronics in a single device

IPHC ALPIDE Design participation



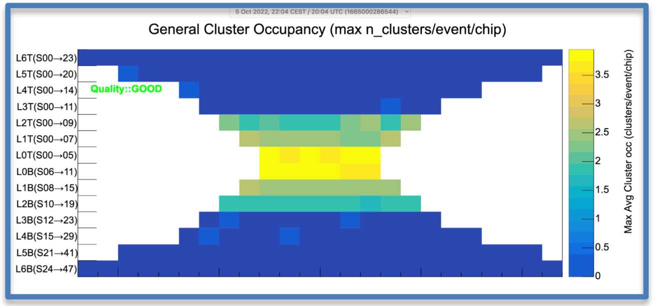


- **7 coaxial layers to cover** $|\eta| < 1.3$ divided into 2 groups:
  - the 3 internal layers installed closest to the beam pipe
  - 4 outer layers

IPHC Module assembly

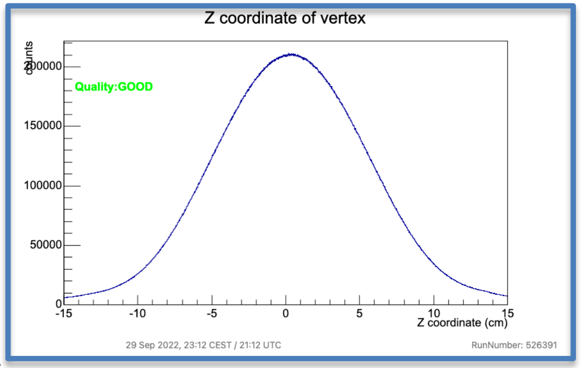
- **Successfully installed**, cabled and integrated in May 2021,

IPHC installation + cabling



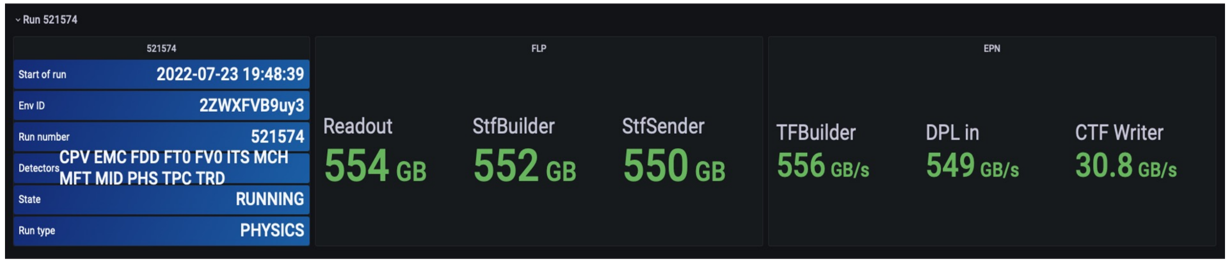
- **Commissioning finalized**, successful data taking at 500 kHz pp interaction rate
  - Online reconstruction and data compression
  - Tracking and dedicated QC
  - Performance studies with comparison to Monte Carlo
  - Alignment

IPHC chair of software working group

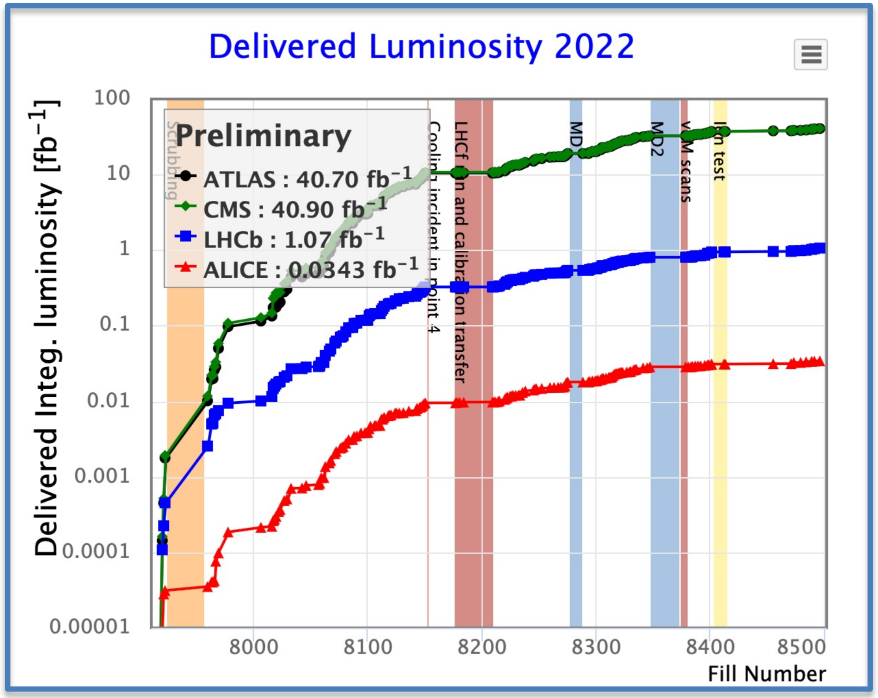


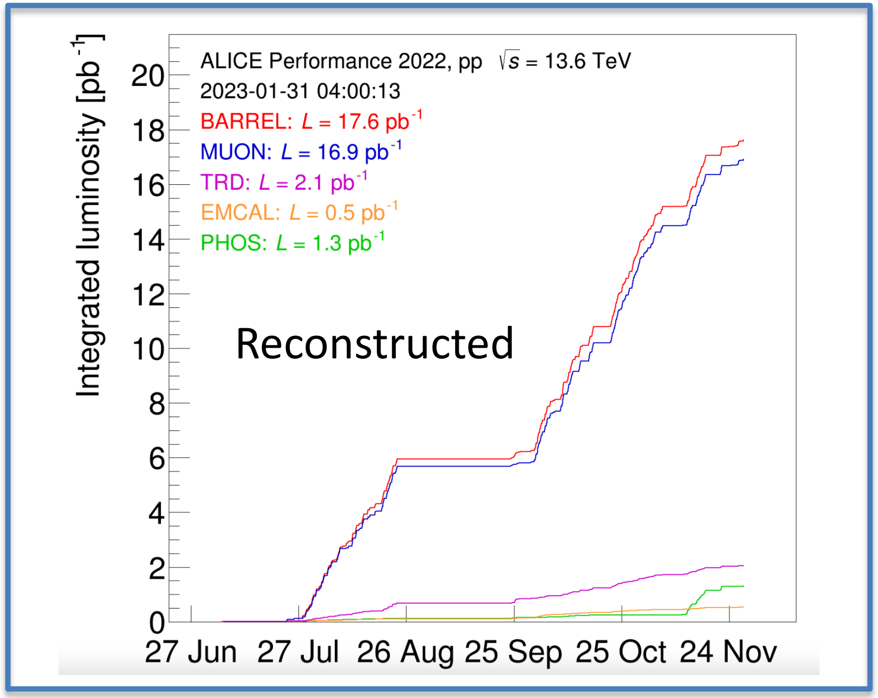
ALICE 2 pp Data Taking 2022

- **Physics data taking at 500 kHz**
  - Online data compression of a factor 18
  - Commissioning and validation of all components
  - Preparation of Physics



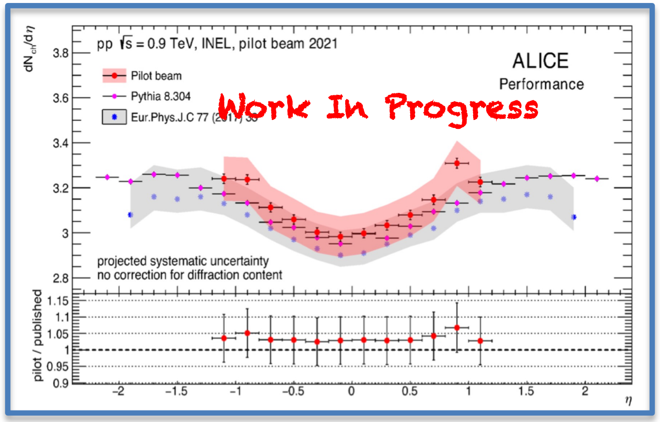
- **Preparation of Pb-Pb program**
  - 1 MHz (pp ref run)
  - Intensity scan up to 4 MHz in pp (equivalent track load of Pb-Pb 50 KHz)

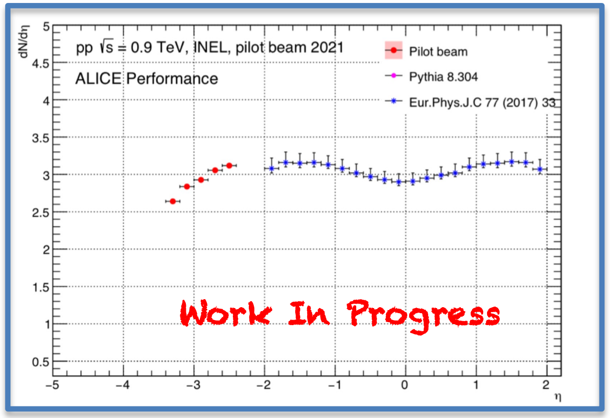


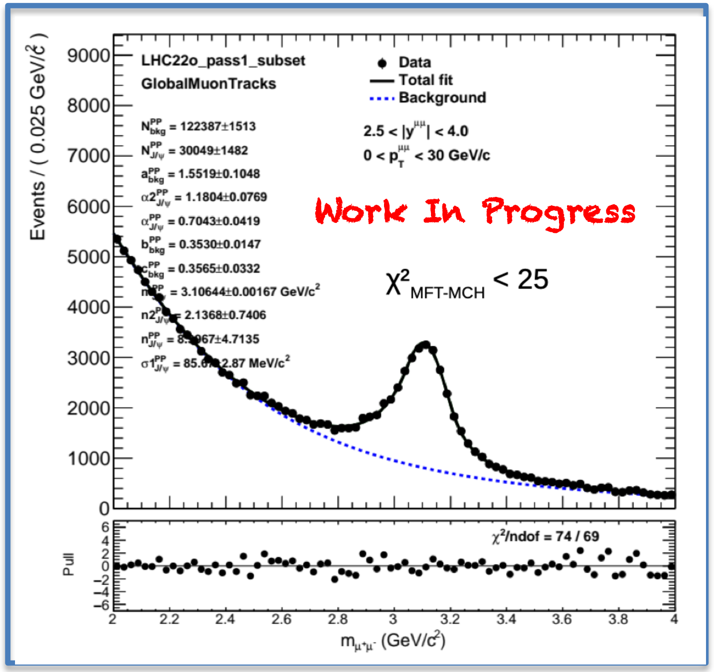


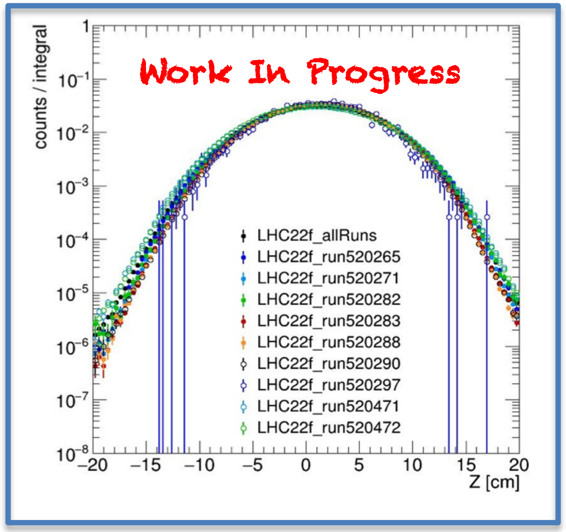
ALICE 2 pp Data Taking 2022

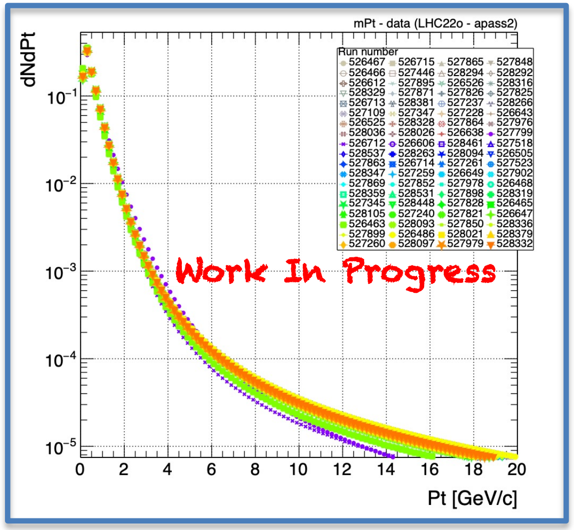
- 2022 pp data under reconstruction on EPN Farm (Event Processing Node) and the Grid
- Performance study and analysis preparation ongoing

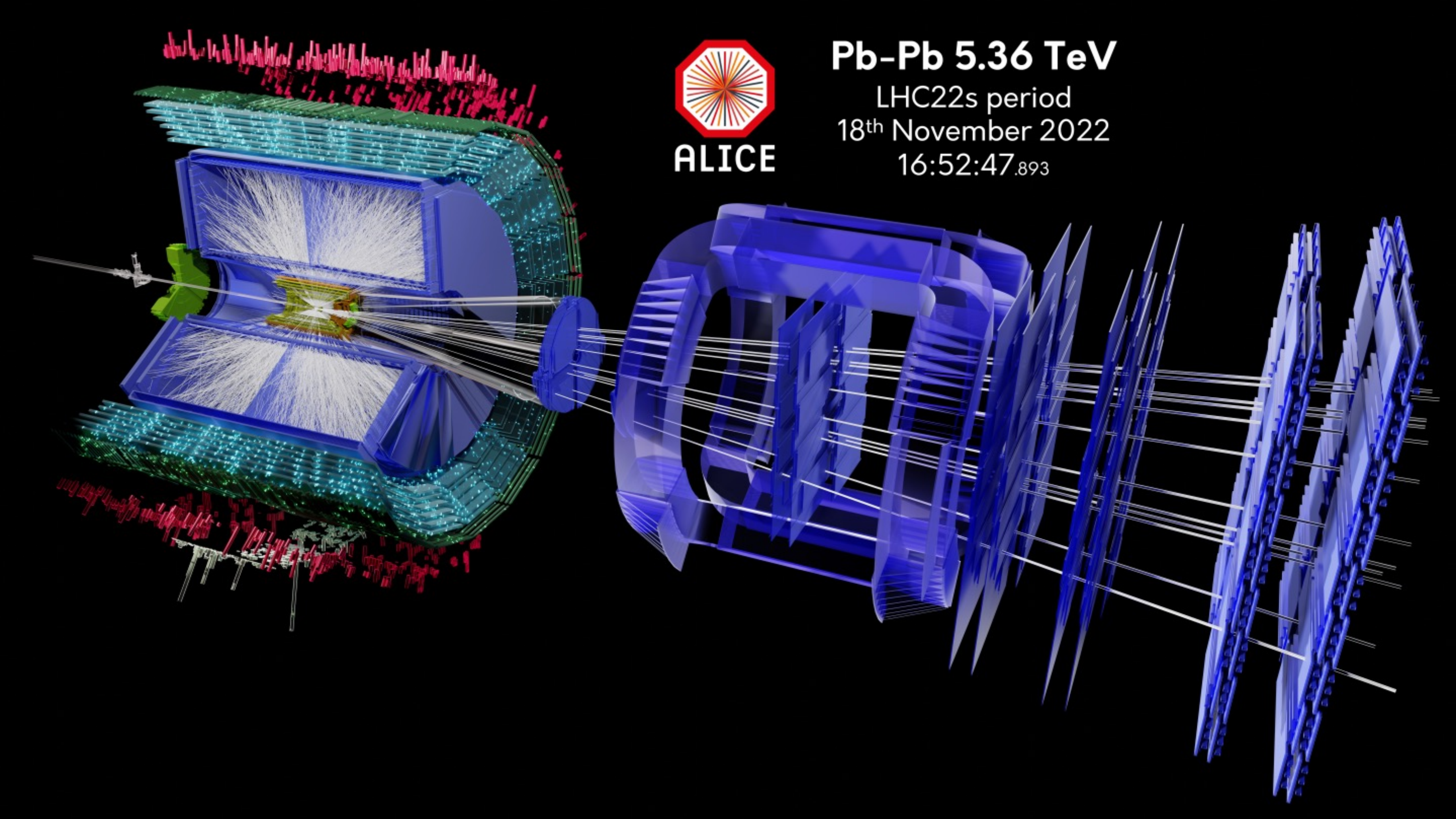










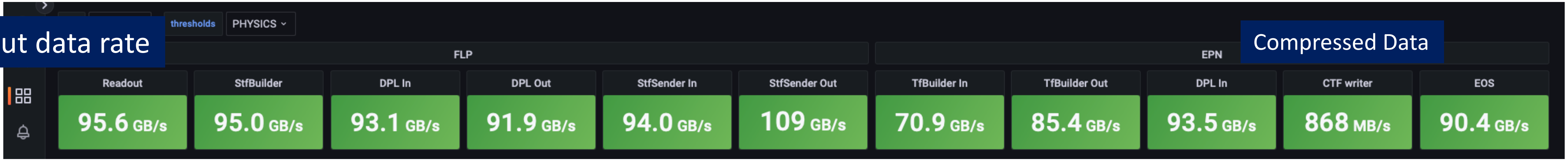

ALICE
Pb-Pb 5.36 TeV
LHC22s period
18th November 2022
16:52:47.893

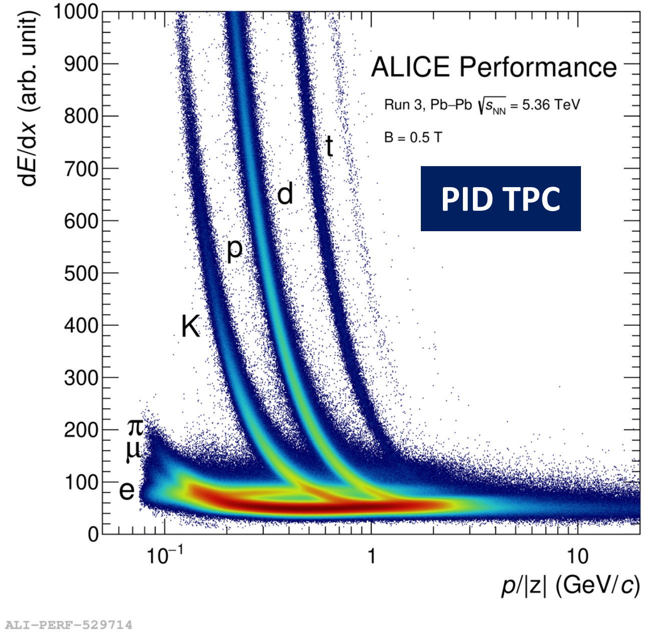
ALICE

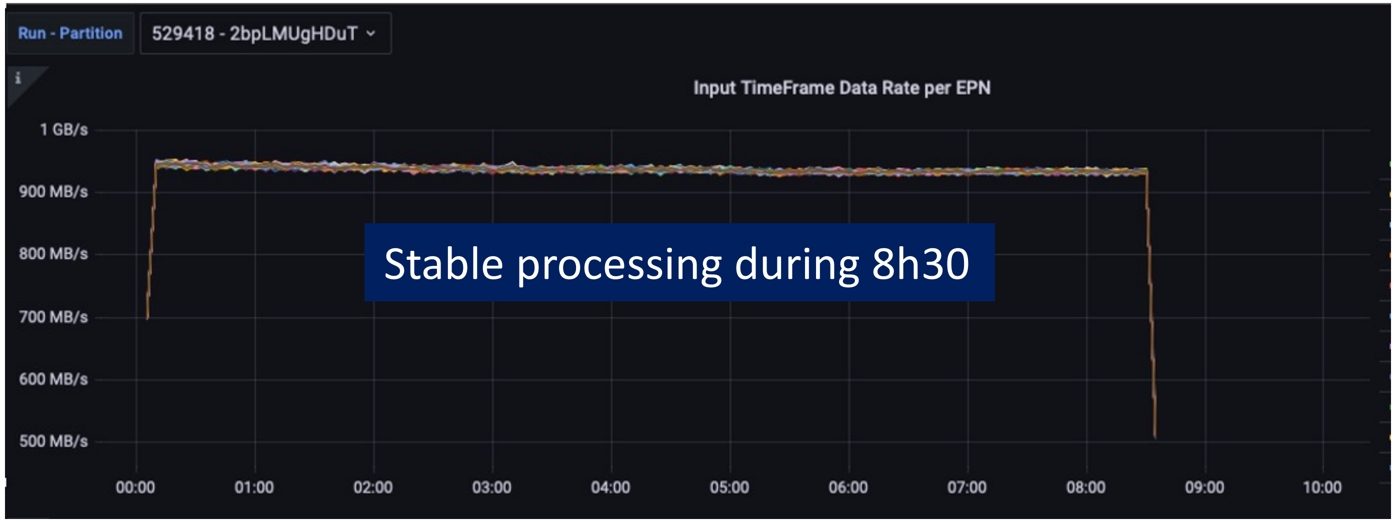
ALICE 2 Commissioning Pb-Pb test beam

- **2 fills at top energy 5.36 TeV**
- **Machine commission slip stacking and crystal cleaning**
- **All ALICE 15 detectors in the data taking**
- **Online calibrations and reconstruction (including most central events)**
- **3.68 pb^{-1} of data recorded (Compressed and Raw Time Frame)**

1.1 M MB Events







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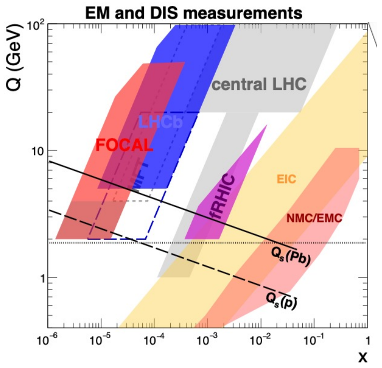
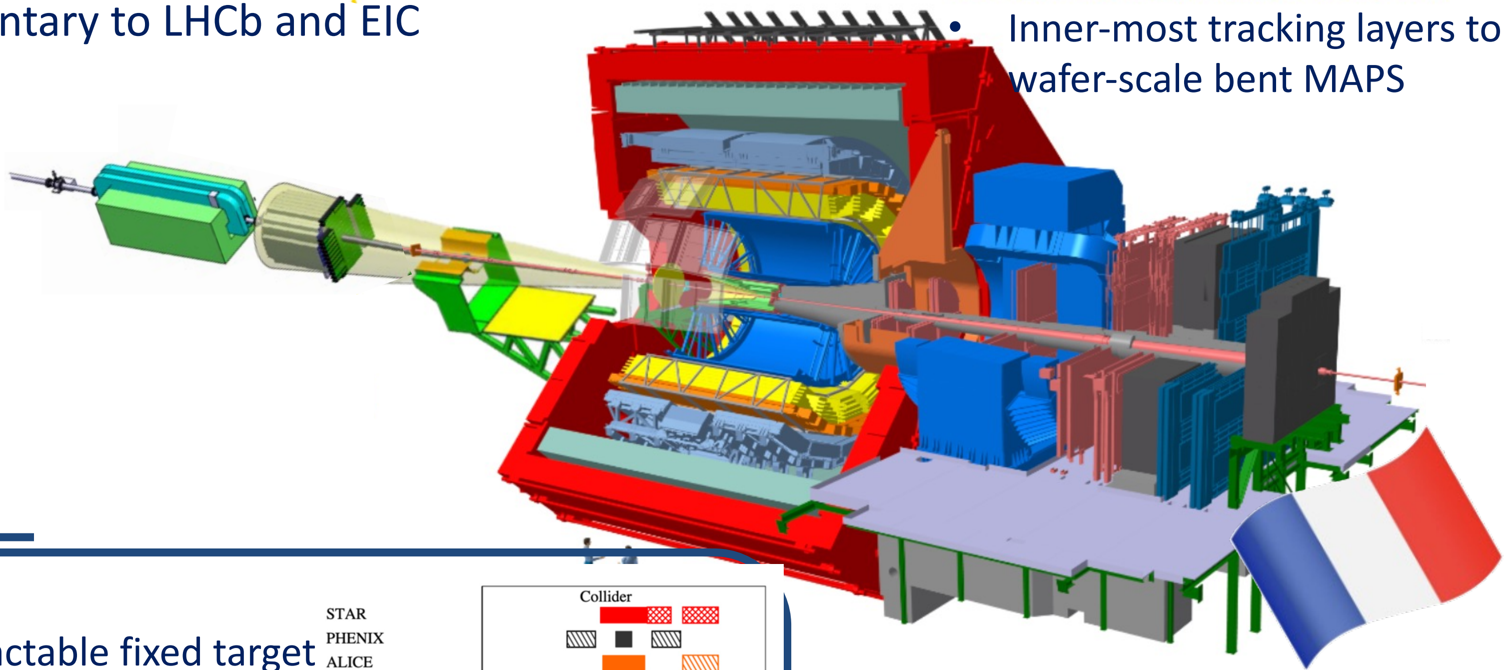
ALICE 2.1 – Upgrades for RUN 4

FoCal
- FoCal-E, Si-W high granular elem. calorimeter
- FoCal-H, Cu-fibre hadronic calorimeter

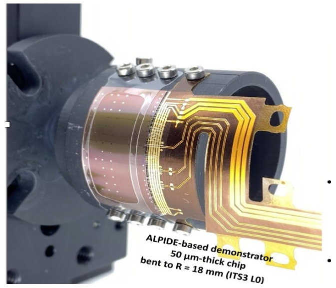
Small-x complementary to LHCb and EIC

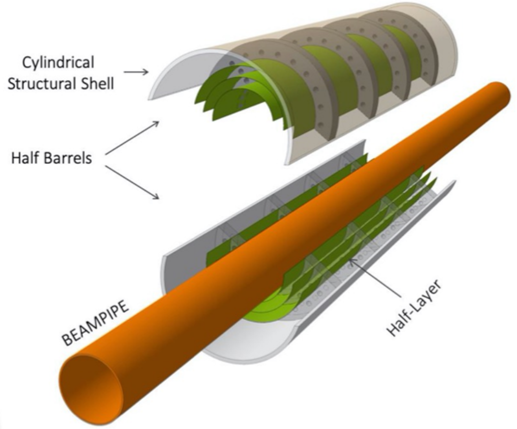
CERN-LHCC-2020-009



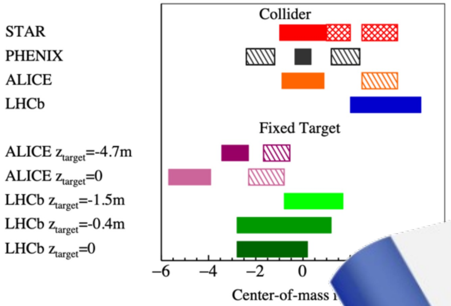


ITS 3
- B- & c-strange mesons+baryons: B^0_s, Λ_b^0, Λ_C^+, Ξ^0_C, Ξ^+_C
- **Heavy-flavour vertexing at low p_T** with prompt Λ_C^+, Ds^+, Ξ_C
- By reducing the material budget and getting closer to IP
- Inner-most tracking layers to be replaced by ultra-thin, wafer-scale bent MAPS





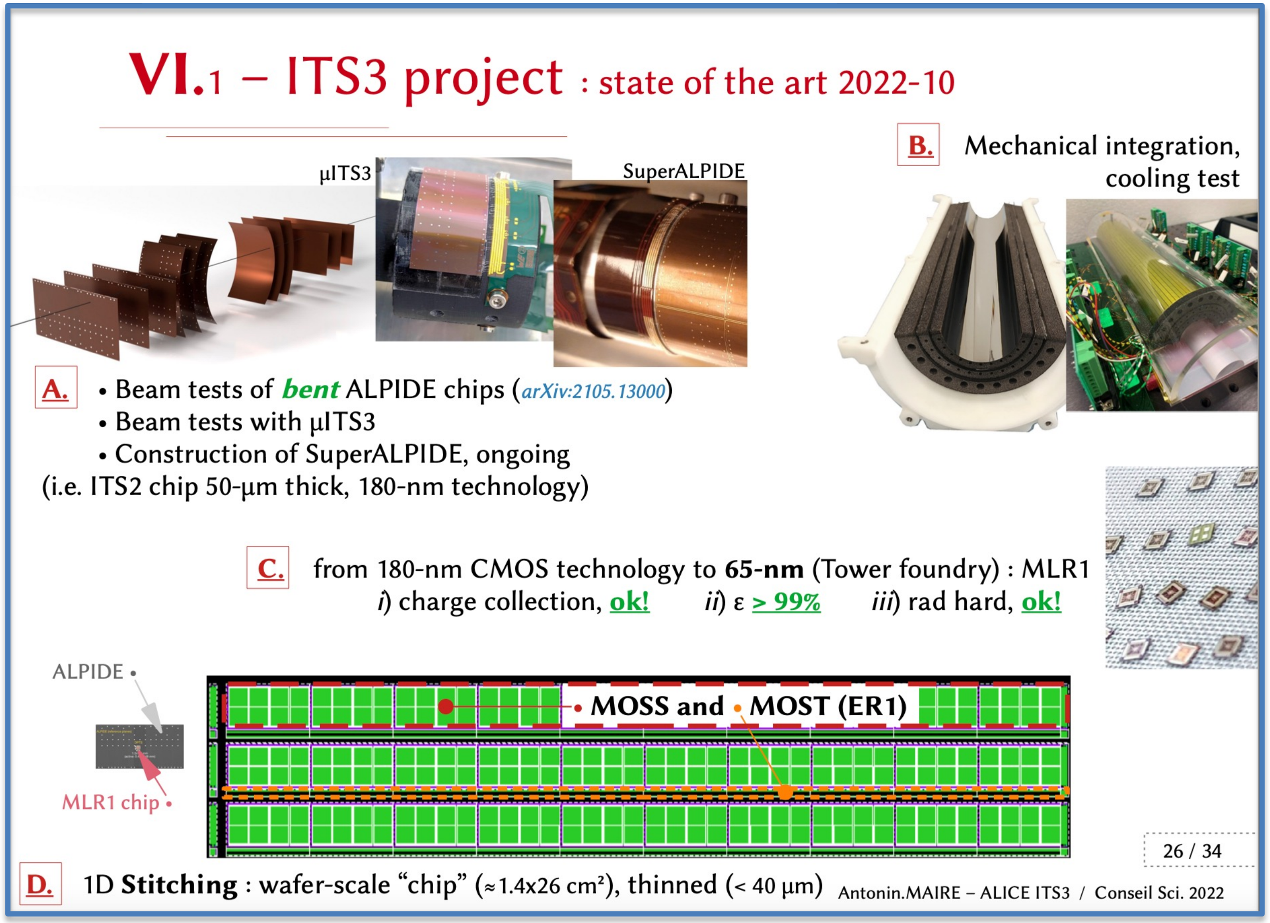
Fixed Target
- Proposal for a retractable fixed target
- Target position z ~ 4.8 m on A side
- Use of bent crystals
- Conceptual design and perf. studies
- ANR JCJC by L. Massacrier
- Continuation of integration studies by ALICE Technical Coordination not supported by ALICE MB

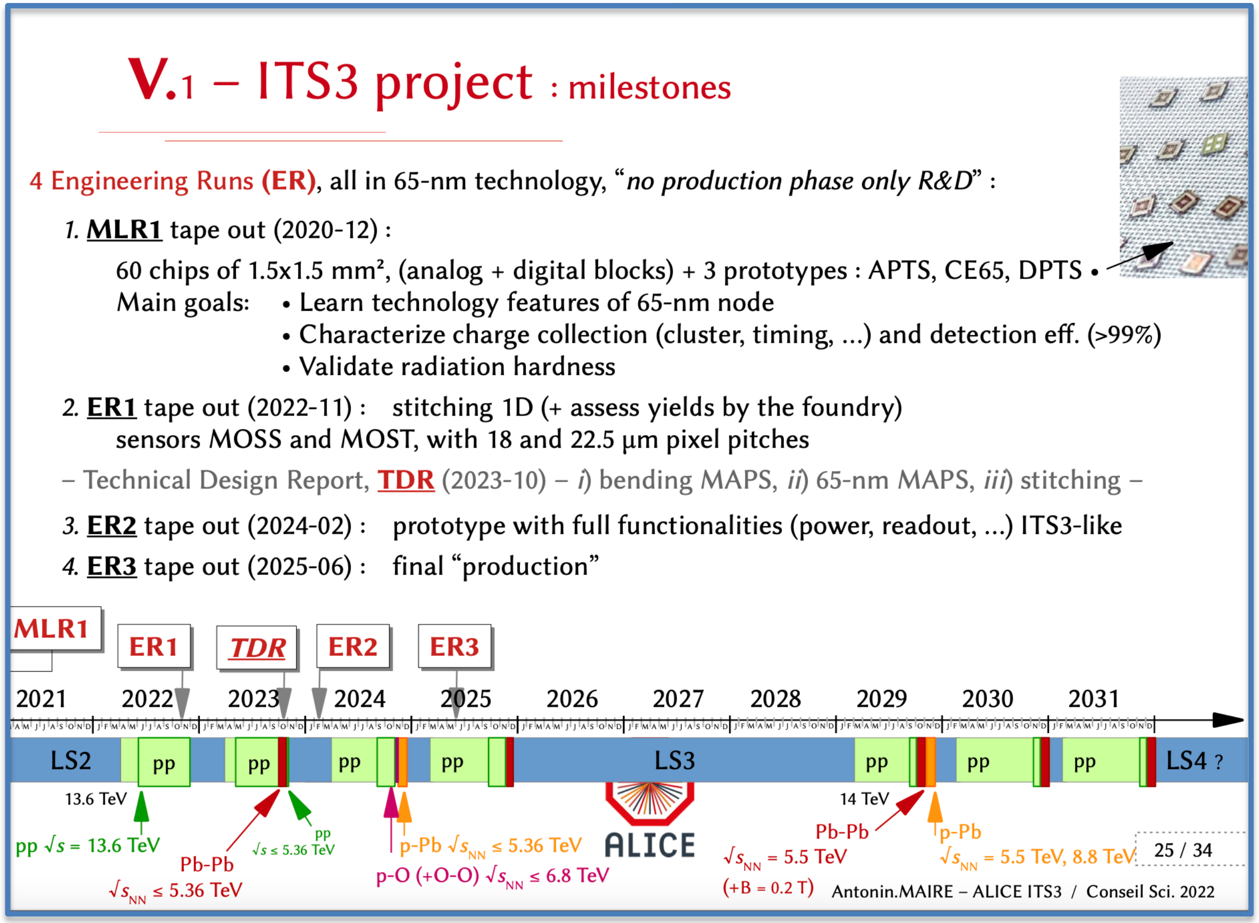


Presented at Conseil Scientifique IN2P3 27/10/22

Projet de participation à une jouvence de l'expérience ALICE

ALICE 2.1 – ITS 3



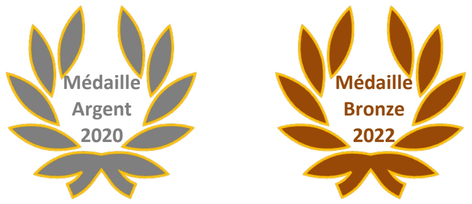


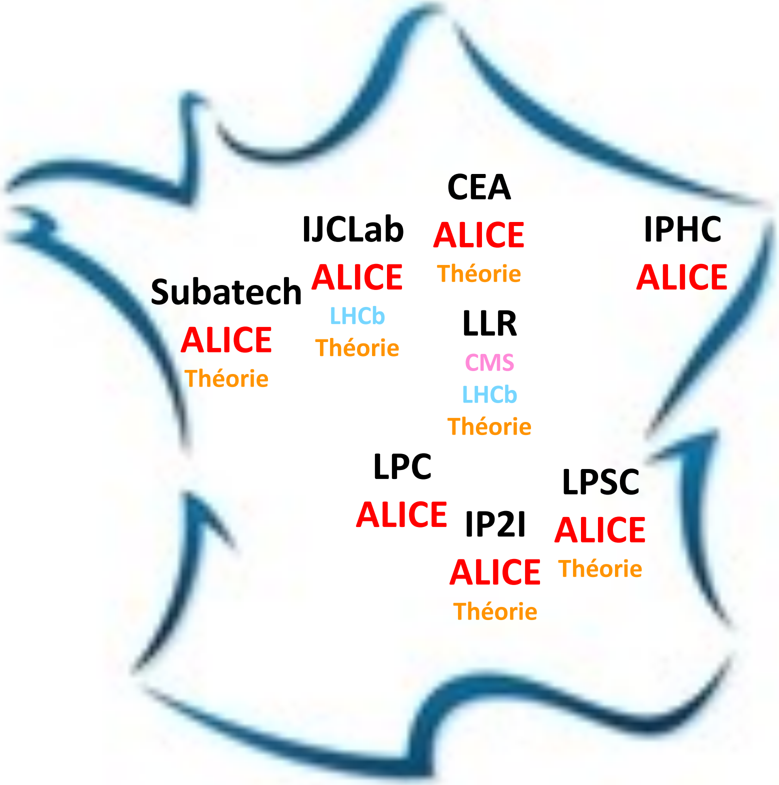
➢ Presented by A. Maire at CS IN2P3 27/10/22 *Projet de participation à une jouvence de l'experience ALICE*
https://indico.in2p3.fr/event/28308/

ALICE-France (IN2P3) community

- O(100) physicists in the French QGP community
- + Engineers and technicians
- **ALICE-IN2P3 permanent physicists = 34**
- QGP-France annual meeting
- **High level of implication and recognition in the ALICE Collaboration**
  - **Projects : ITS2, MCH, MID, MFT, O2**
  - **Implied at many levels of the collaboratio**
    - Spokesperson office
    - Management Board
    - Physics Board
    - Technical Board
    - Conference committee
    - Run coordination
    - Scientific coordination
      - Physics Coordination
      - Physics Working Group
      - Physics Analysis Group

Level of responsibility	2021	2022
L1	4	3
L2	4	6
L3	16	15





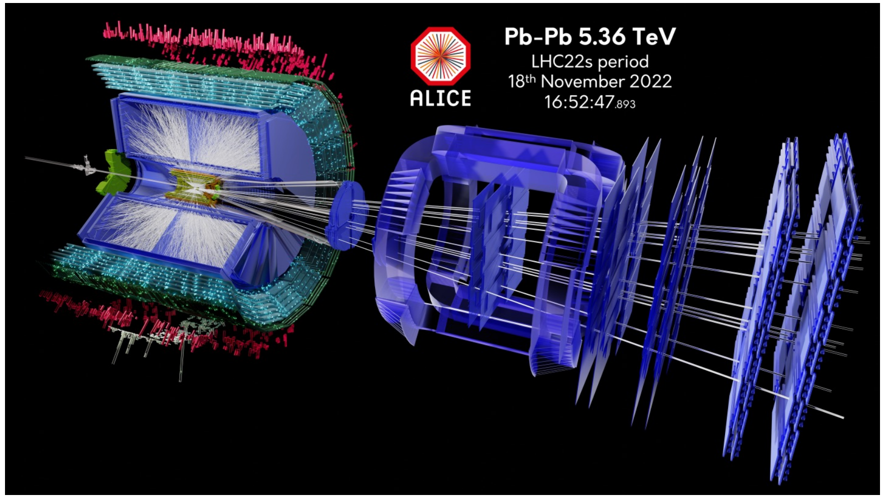
+ Linked to the GDR QCD
+ Linked to the SFP Division Nucléaire and Division Champs et particules

Conclusions

- **Important physics results** for the comprehension of QGP physics have emerged **during RUN 2** data analysis with strong leading role from the French community

- **Successful upgrade** conducted during LS2 in preparation for RUN 3
  - Leading role in major ALICE projects MCH, MID, MFT, ITS2
  - Upgrade in time despite worldwide situation (Covid pandemic)

- **Successful installation and integration** into the global ALICE data taking



- **Preparation of RUN 3 physics analysis** ongoing

- **Engagement of the French community until end of RUN 4**
  - Maintenance and operations of ITS2, MCH, MID, MFT, O2-CRU
  - Exploitation of physics data through data analysis

- **Preparation of LS3/LS4 and upgrades upon IN2P3 approval**

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Thanks

Thanks to the ALICE-France community for the help in preparing the slides !

And more specifically to

Antonin, Antonio, Boris, Christophe, Cvetan, Cynthia, Diego, Marie, Nicole, Philippe, Xavier

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ALICE-France for RUN 3 and RUN 4

1. Ensure the maintenance and operations of all projects handled by French teams

2. Exploit the full physics output

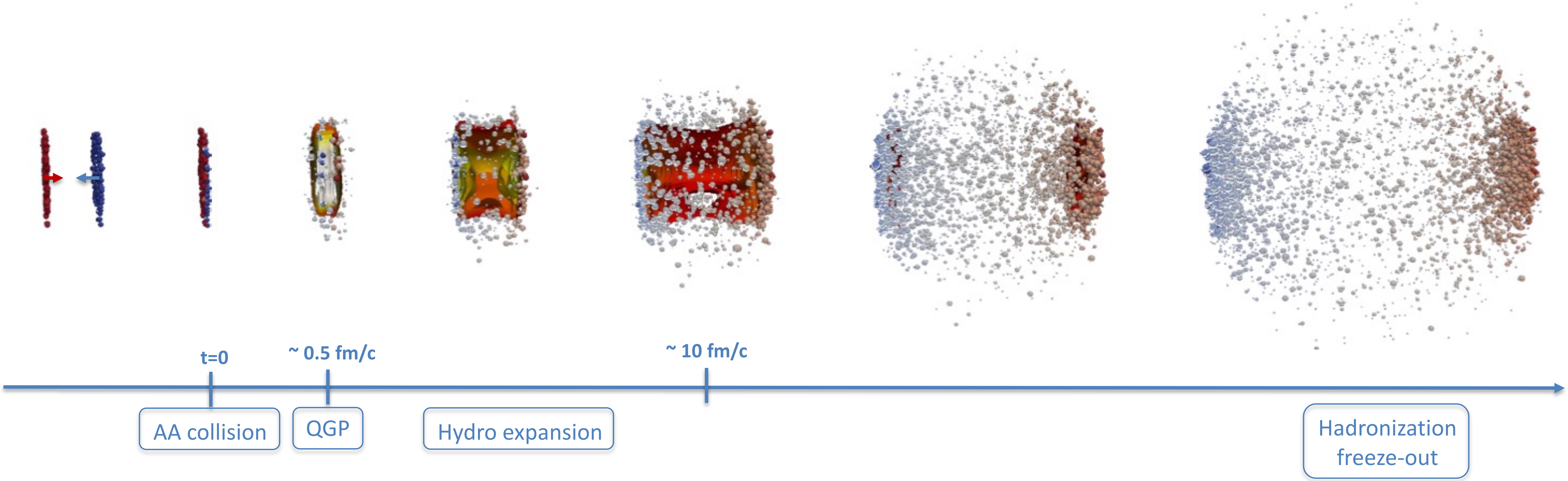
Person–power anticipated evolution

Permanent only (not including post-doc, PhD and emeritus)
Including known retirements and thematic changes
No permanent recruitment taken into account

Team	"M&OA" (2022)		Due service work FTE/year (2022)	Main detector activities in Runs 3 *(+ Run 4)*	"M&OA" *(projected end Run 3, 2026)*		"M&OA" *(projected early Run 4, 2029)*	
IJClab Orsay	4 + 1	5	1.5	MCH, O^2	4 + 1	5	4 + 1	5
IPHC Strasbourg	5 + 1	6	1.5	ITS2 *(+ ITS3)*	4 + 1	5	4 + 1	5
IP2I Lyon	3 + 0	3	0.75	MFT *(+ ITS3)*	2 + 0	2	2 + 0	2
LPC Clermont	2 + 5	7	1.75	MID, MFT	2 + 5	7	1 + 4	5
LPSC Grenoble	2 + 2	4	1	readout, DPG *(+ ITS3)*	2 + 2	4	2 + 1	3
Subatech Nantes	7 + 2	9	2.75	MID, MCH, MFT	4 + 2	6	3 + 2	5
TOTAL	23 + 11	34	9.25		18 + 11	29	16 + 9	25

Studying the Quark-Gluon Plasma

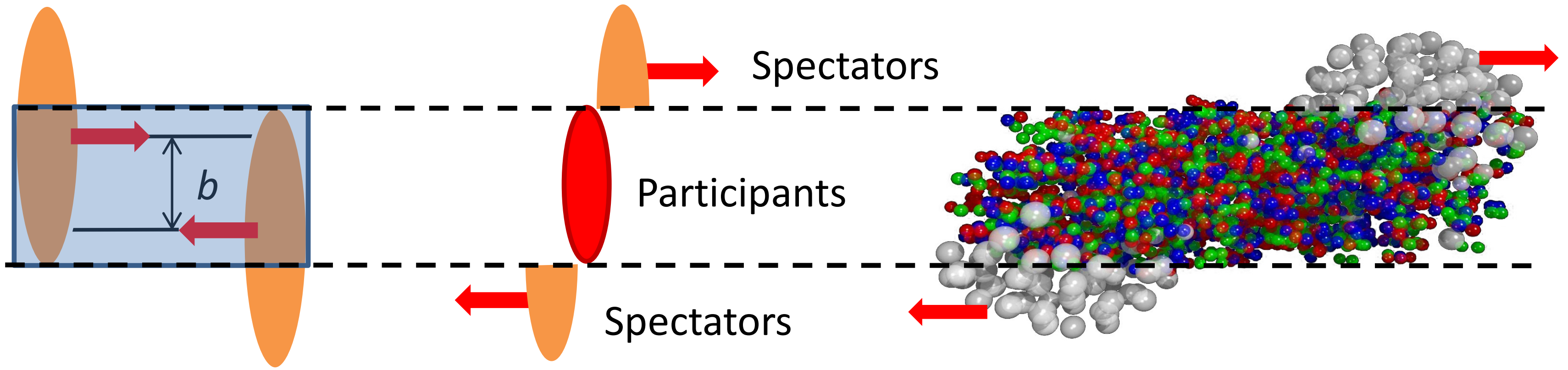
Quark-Gluon Plasma (QGP) is a deconfined state of quarks and gluons (asymptotic freedom regime) predicted by QCD and studied in high-energy heavy-ion collisions



Rendering by H. Elfner & J.E. Bernhard arXiv:1804.06469

Historical approach for QGP studies

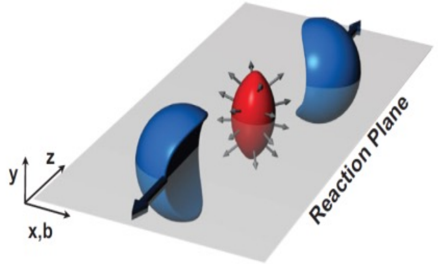
- pp collisions were considered as the vacuum reference
- p-A collisions are a control experiment to estimate cold matter effects
- AA collisions are described by a (geometrical) Glauber model defining the number of participants and the number of binary collisions (N_{coll}) for a given impact parameter b



- Emblematic observables for hard and soft probes

Nuclear modification factor

$$R_{AA} = \frac{dN_{AA}/dp_T}{< N_{coll} > \times dN_{pp}/dp_T}$$



Elliptic flow

Initial spatial anisotropy transferred into a momentum anisotropy of particles

$$\frac{dN}{d\varphi} \propto 1 + 2\sum_{n=1}^{\infty} v_n \cos(n(\varphi - \Psi n))$$

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Characterizing the medium

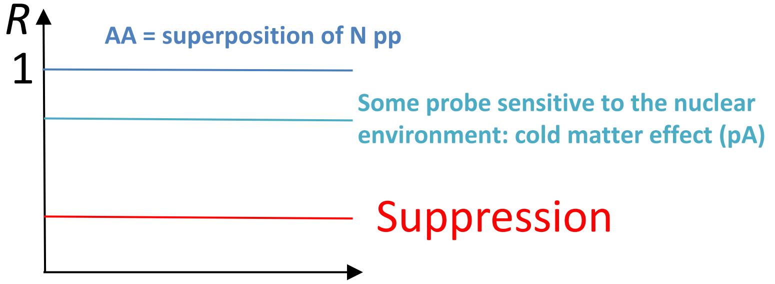
Nuclear modification factor

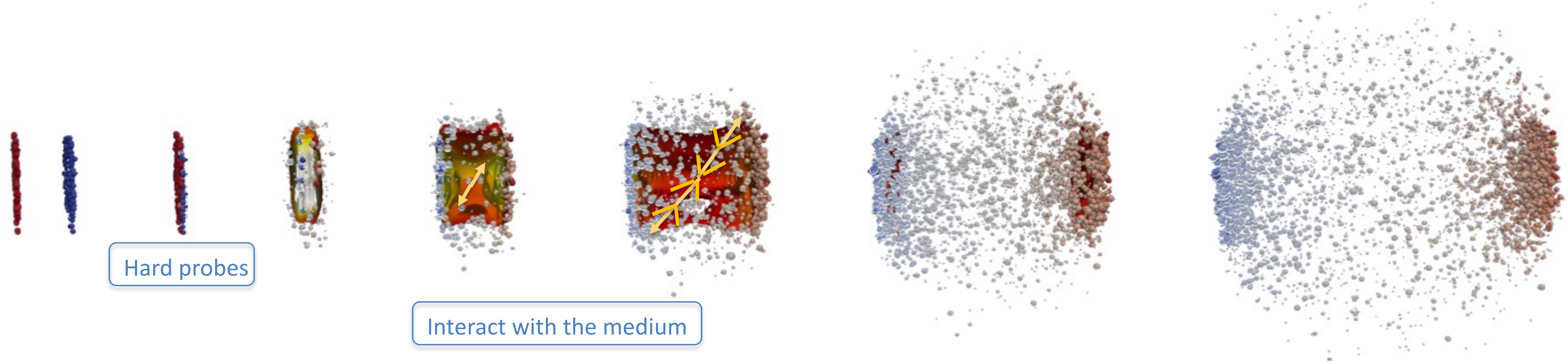
$$R_{AA} = \frac{dN_{AA}/dp_T}{<N_{coll}> \times dN_{pp}/dp_T}$$

Measurement in AA

Normalization by the number of collision (N_{coll})

Same measurement in min-bias pp





Characterizing the medium

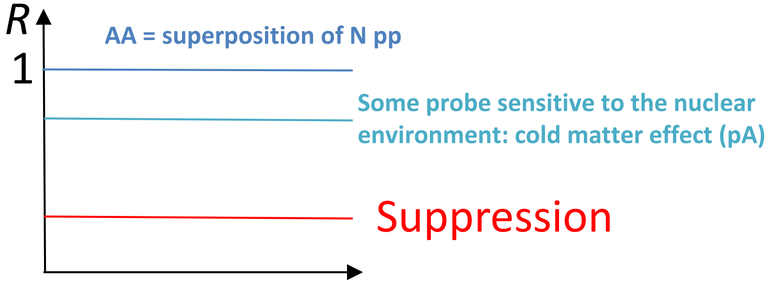
Nuclear modification factor

$$R_{AA} = \frac{dN_{AA}/dp_T}{< N_{coll} > \times dN_{pp}/dp_T}$$

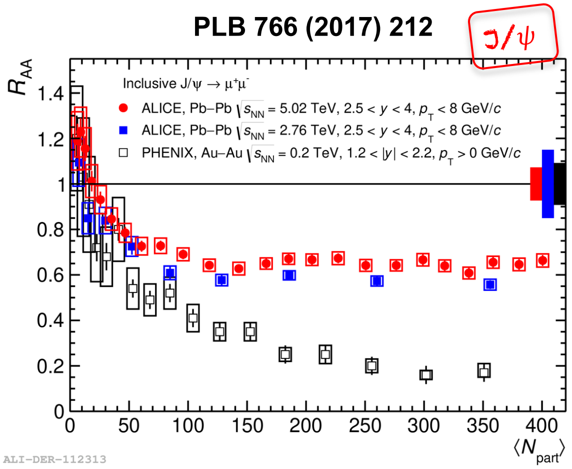
Measurement in AA

Normalization by the number of collision (N_{coll})

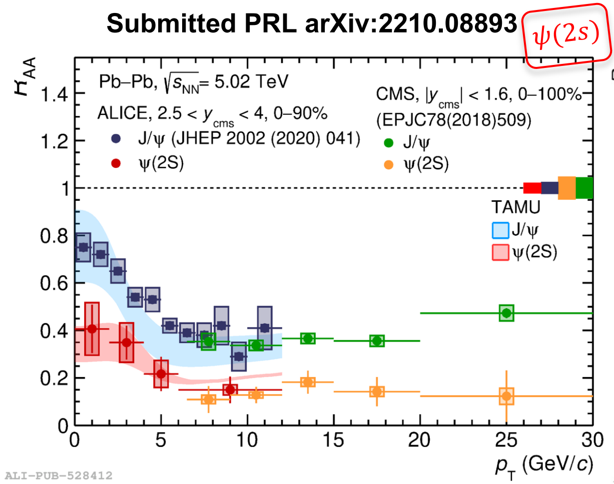
Same measurement in min-bias pp



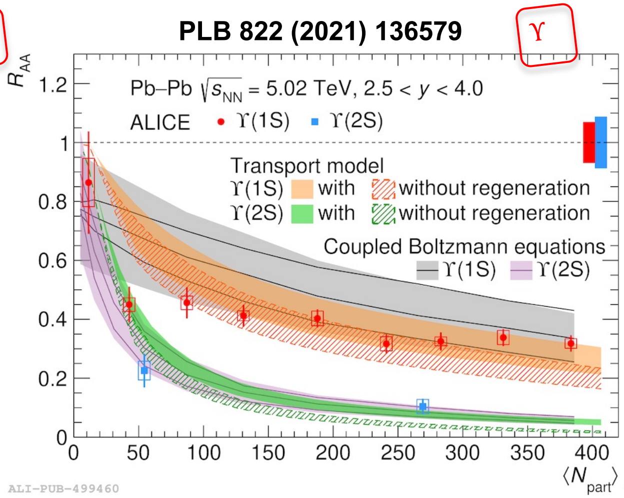
PLB 766 (2017) 212



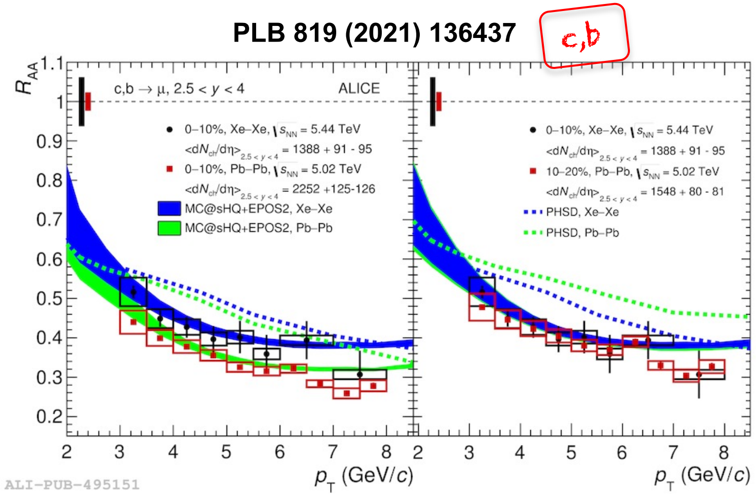
Submitted PRL arXiv:2210.08893



PLB 822 (2021) 136579



PLB 819 (2021) 136437



J/ψ less suppress than at RHIC energies
Understood with regeneration

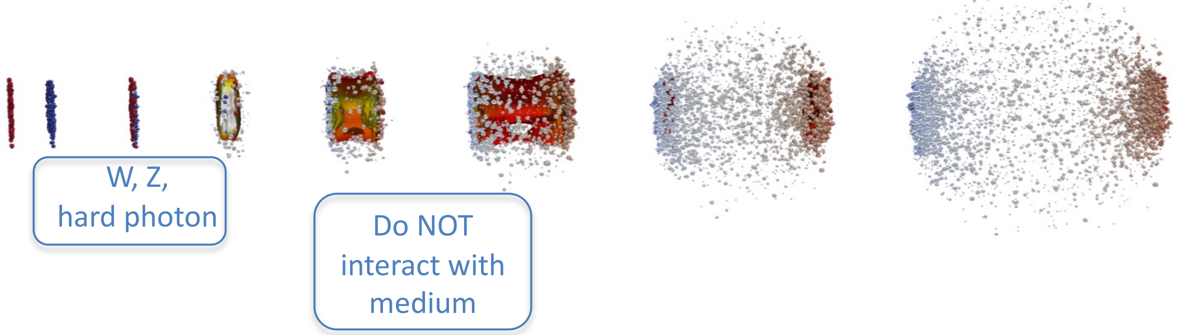
$\psi(2s)$ more suppress than J/ψ
Sign of regeneration at low p_T

Υ(1s) suppressed by a factor ~ 3 w.r.t pp
Υ(2s) suppressed by a factor ~ 2 w.r.t Υ(1s)
Sequential dissociation scenario

Open Heavy Flavor in Xe-Xe help to understand **system-size and geometry dependence of medium-induced parton energy loss**

Also single-μ in Pb-Pb: PLB 820 (2021) 136558
J/ ψ R_{AA} PLB 805 (2020) 135434

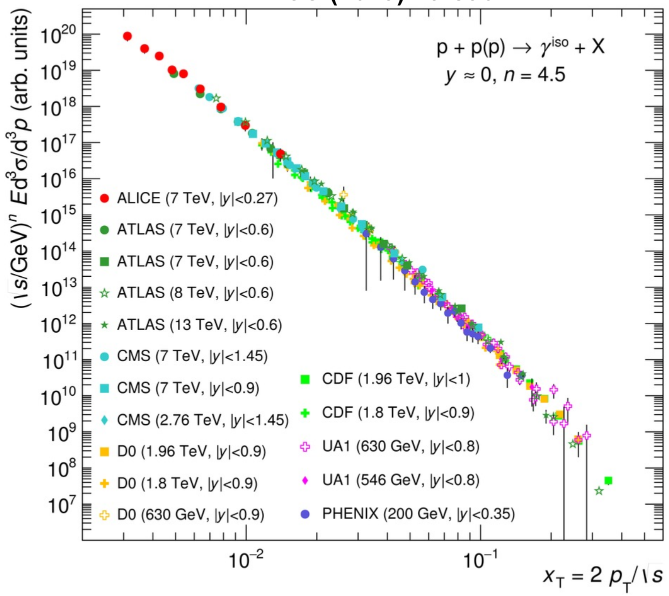
Hard and electroweak probes as reference



Allow to understand the nuclear structure with PDF in pp and nPDF in nucleus.

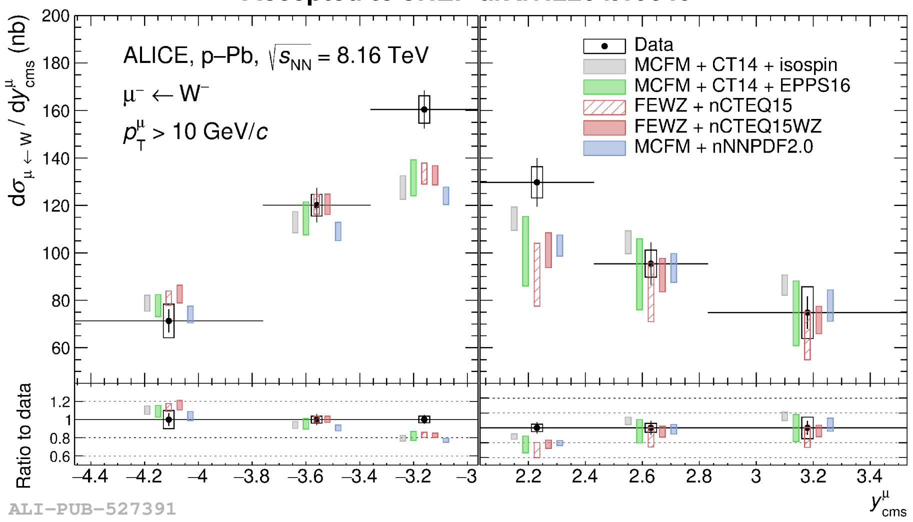
Also Z0: PLB 780 (2018) 372-383
J/ photoproduction in Pb-Pb: accepted by PLB arXiv:2204.10684

EPJC (2019) 79:896



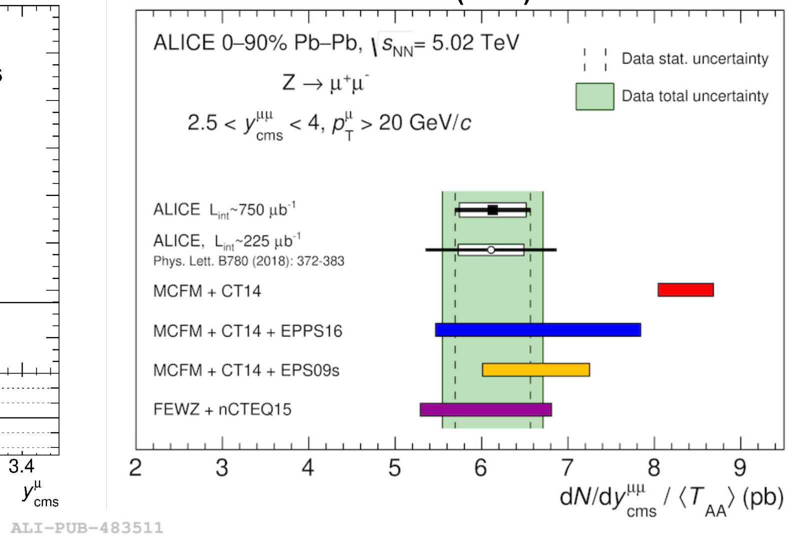
Isolated photons extend x_T world coverage and confirm n = 4.5 scaling: same production mechanism

Accepted to JHEP arXiv:2204.10640



Significant deviations from the free-nucleon PDF predictions, up to 3.5σ. Correspond to the shadowing region of the nuclear modifications at low Bjorken-x.

JHEP 09 (2020) 076

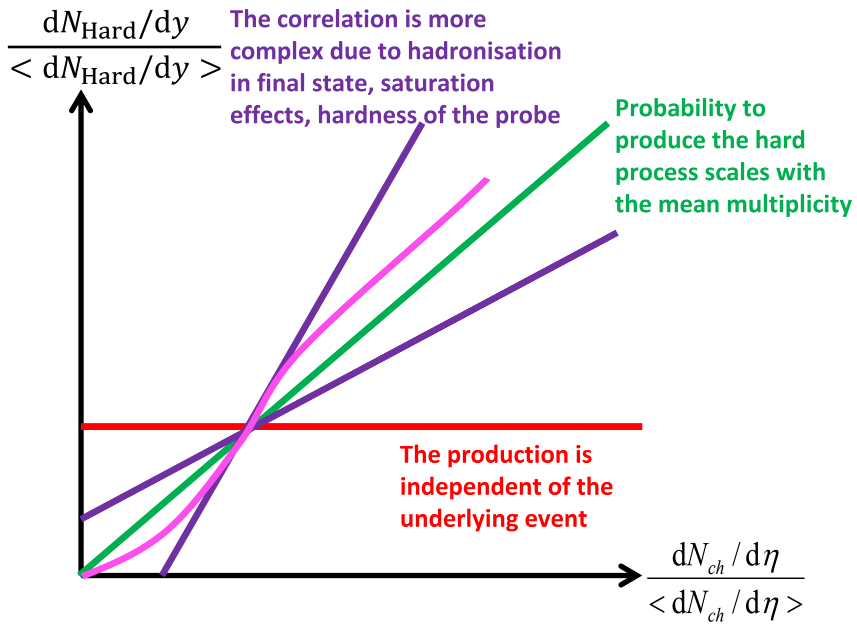


The **calculations using nuclear PDFs describe the yield** measured in Pb–Pb collisions.

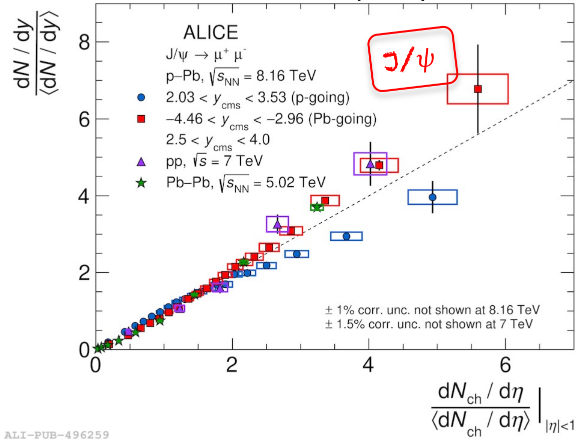
Searching new scaling paradigm in pp and p-Pb

- Differential study of hard probe production **as a function of charged particle multiplicity**

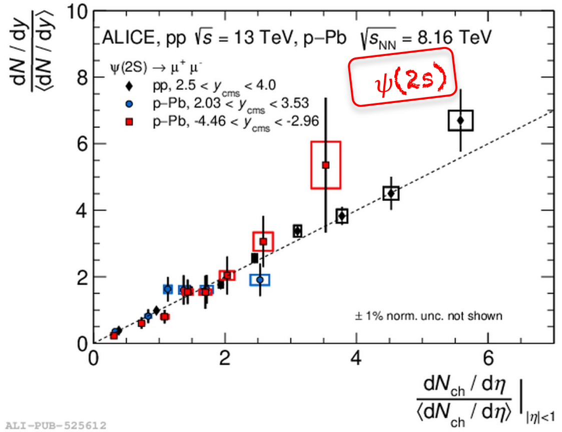
- **Similar behavior measured for all probes**
  - Close to linear when the hard probe is measured in the forward-*y* and multiplicity in central-*y* region
  - Deviation from linearity when both are measured in central-*y* region



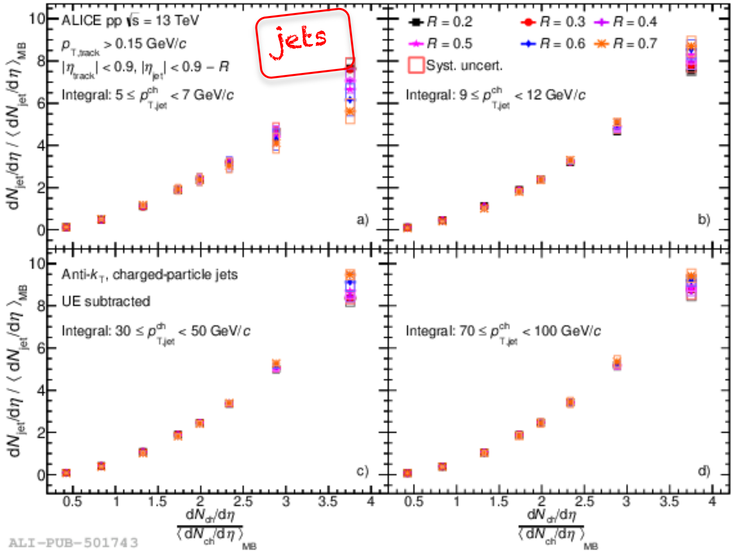
JHEP 2009 (2020) 162



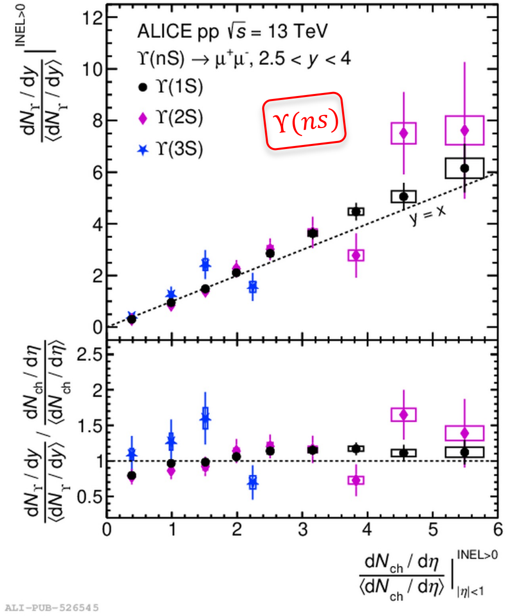
Submitted to JHEP arXiv 2204.10253



EPJC (2022) 82:514

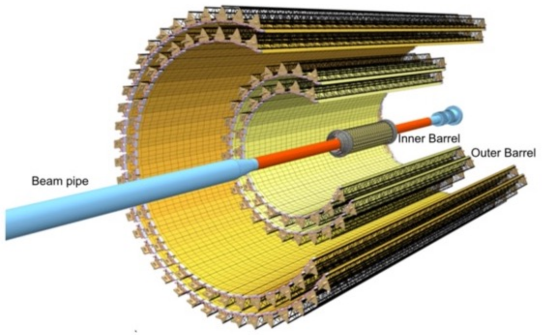


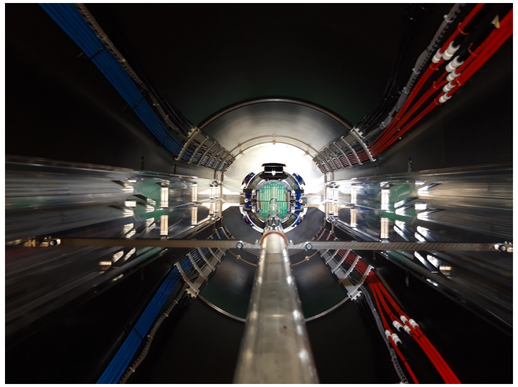
Submitted to PLB arXiv :2209.04241



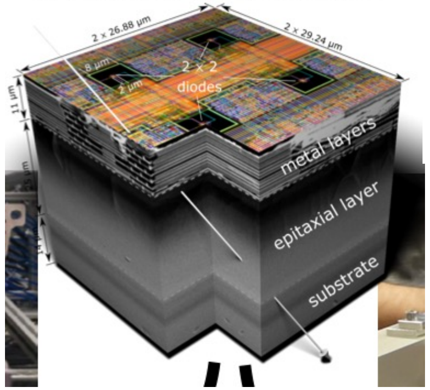
Also strangeness: submitted to EPJC arXiv:1908.01861

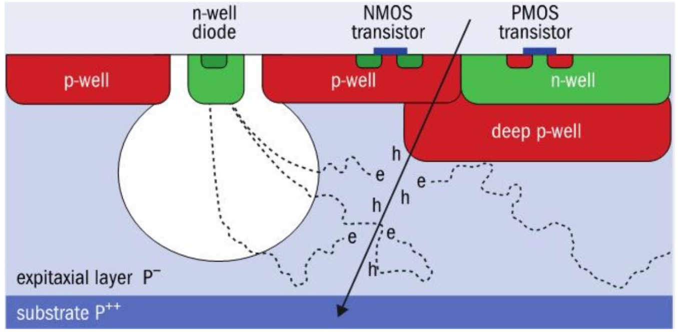
ITS2 and MFT : ALPIDE





ALPIDE/MAPS-based trackers





- monolithic active pixel sensor chip (MAPS), called ALPIDE, integrating both pixel sensor and read-out electronics in a single device
- p-type substrate with a thin, high-resistivity epitaxial layer (see diagram) in a 180 nm CMOS process provided by Tower Semiconductor
- includes a 512 x 1024 matrix of 29.24 x 26.88 mm^2 pixel cells, together with analogue biasing, control, readout and interfaces

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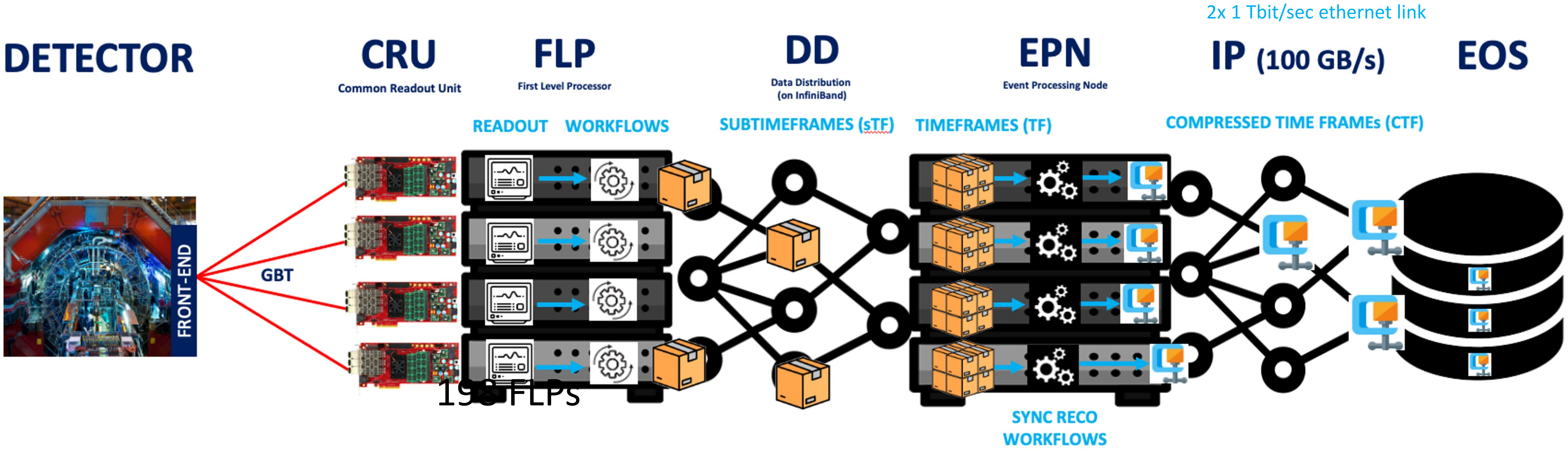
READOUT TO RECONSTRUCTION

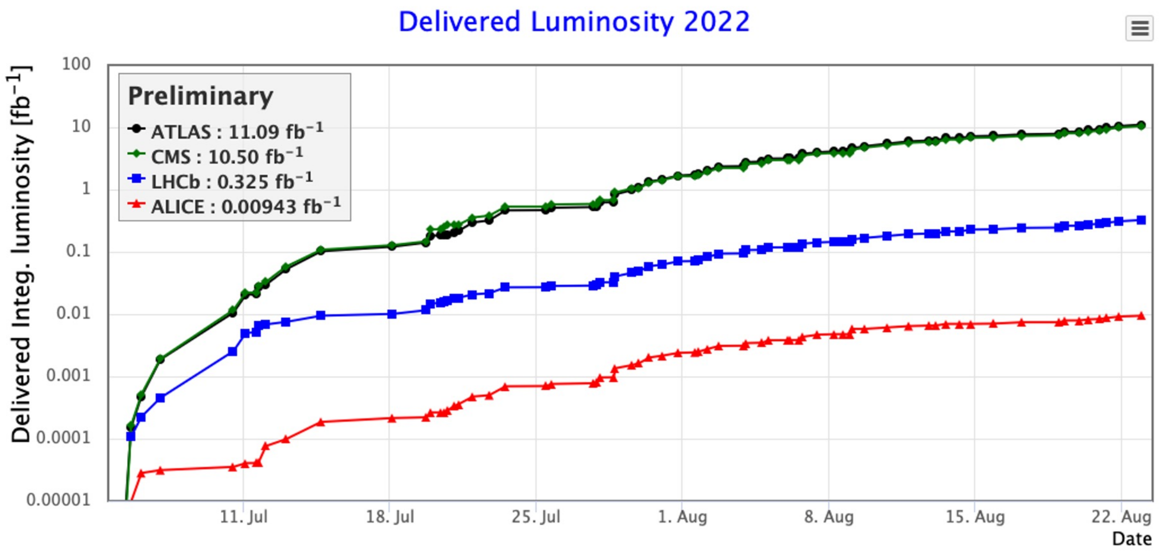


Stable 500 KHz running was achieved with further optimisation of :

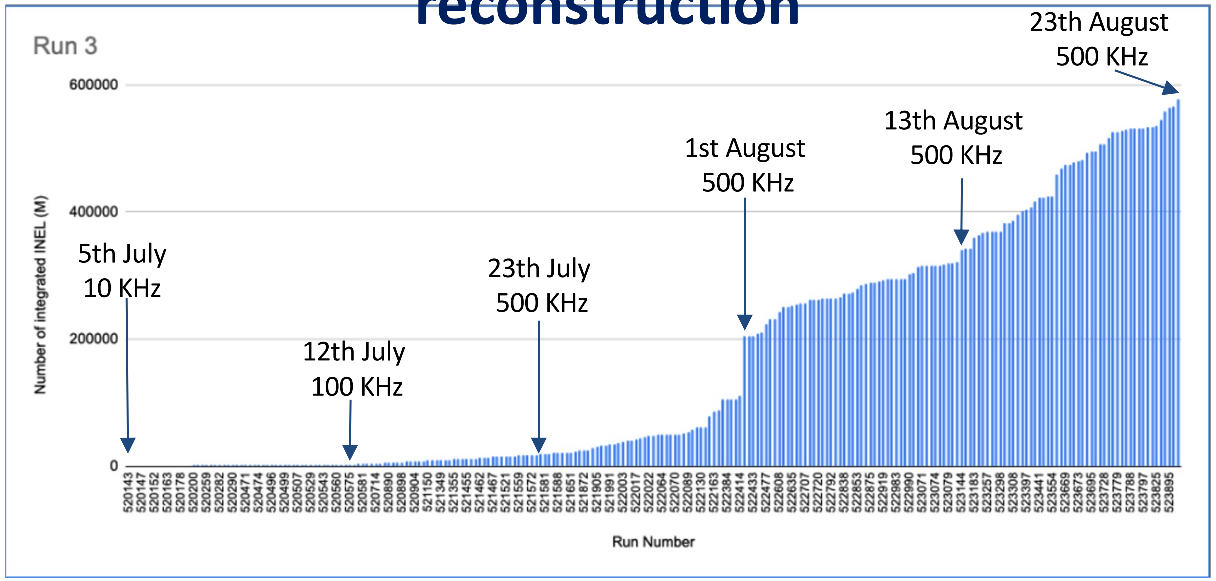
- The Common Readout Unit (CRU) FirmWare (FW) **to prevent from data corruption**
- The ReadOut process configuration with **better memory buffers allocation**
- The Data Distribution software and its **shared Memory Management**

COLLECTED 13.6 TeV DATA until end of August

Delivered integrated luminosity 9.4 pb^{-1}



Statistics collected used for asynchronous reconstruction



Ongoing:

- **Allocation of EPN resources for Async Reconstruction**: started async pool of 20 nodes.
- Use the LHC downtime to allocate more nodes (not needed by COSMIC runs) and to automate the management

Publications

- Total de 401 publications soumises

avec 41 publications soumises en 1 an

(49 publications soumises pour 2020→21)

(46 publications soumises pour 2019→20)

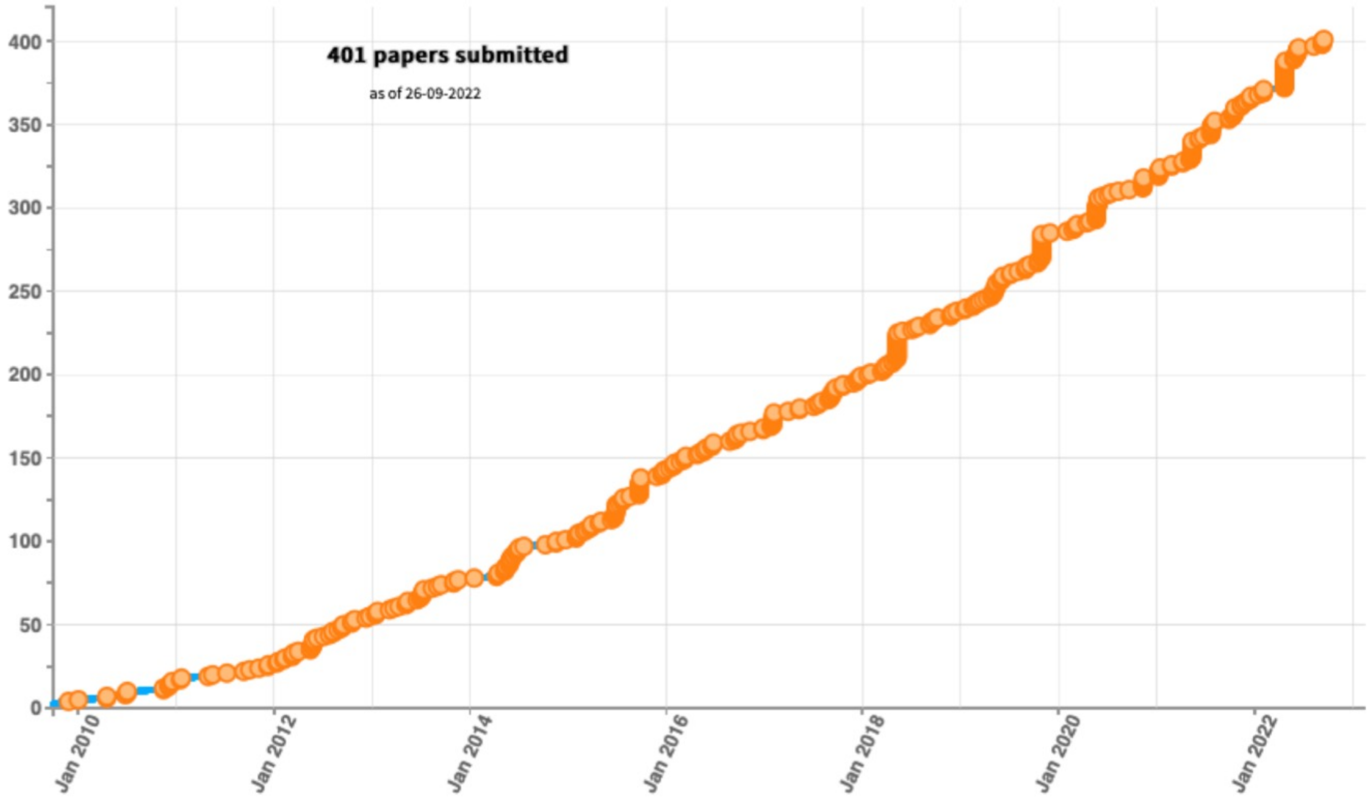
(32 publications soumises pour 2018→19)

  - 13 (11) renommées
  - 35 (33) célèbres
  - 74 (68) réputées

- “pics" corrélés avec QM, SQM et ICHEP 2022

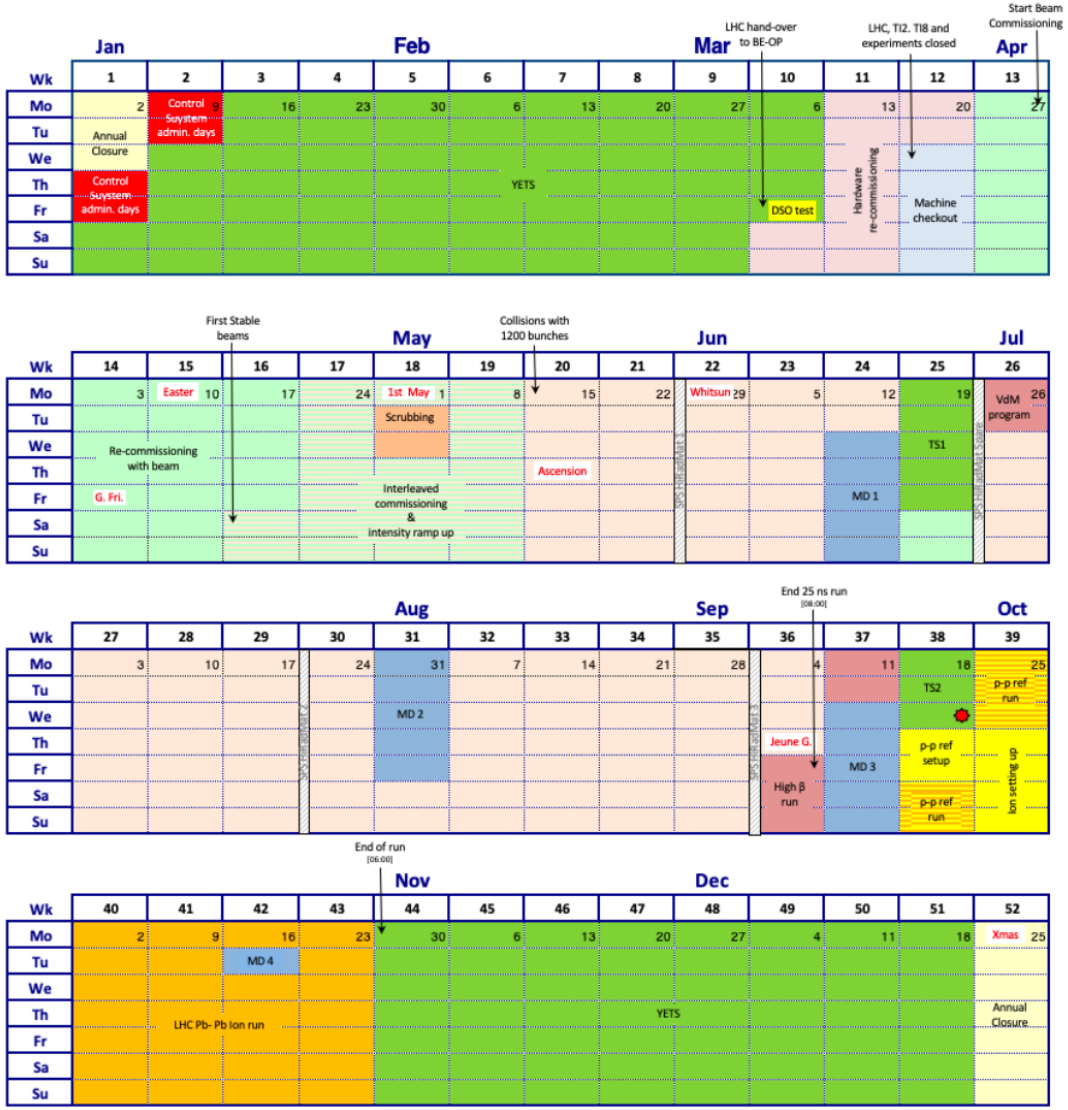
(QM en avril à Cracovie, SQM en juin à Pusan et ICHEP en juillet à Bologne)

- 13 sur 29 publications avec au moins un collaborateur/trice français/e dans le “Paper Committee" ou l’ “Internal Review Committee” (en général restreint à 3 personnes)

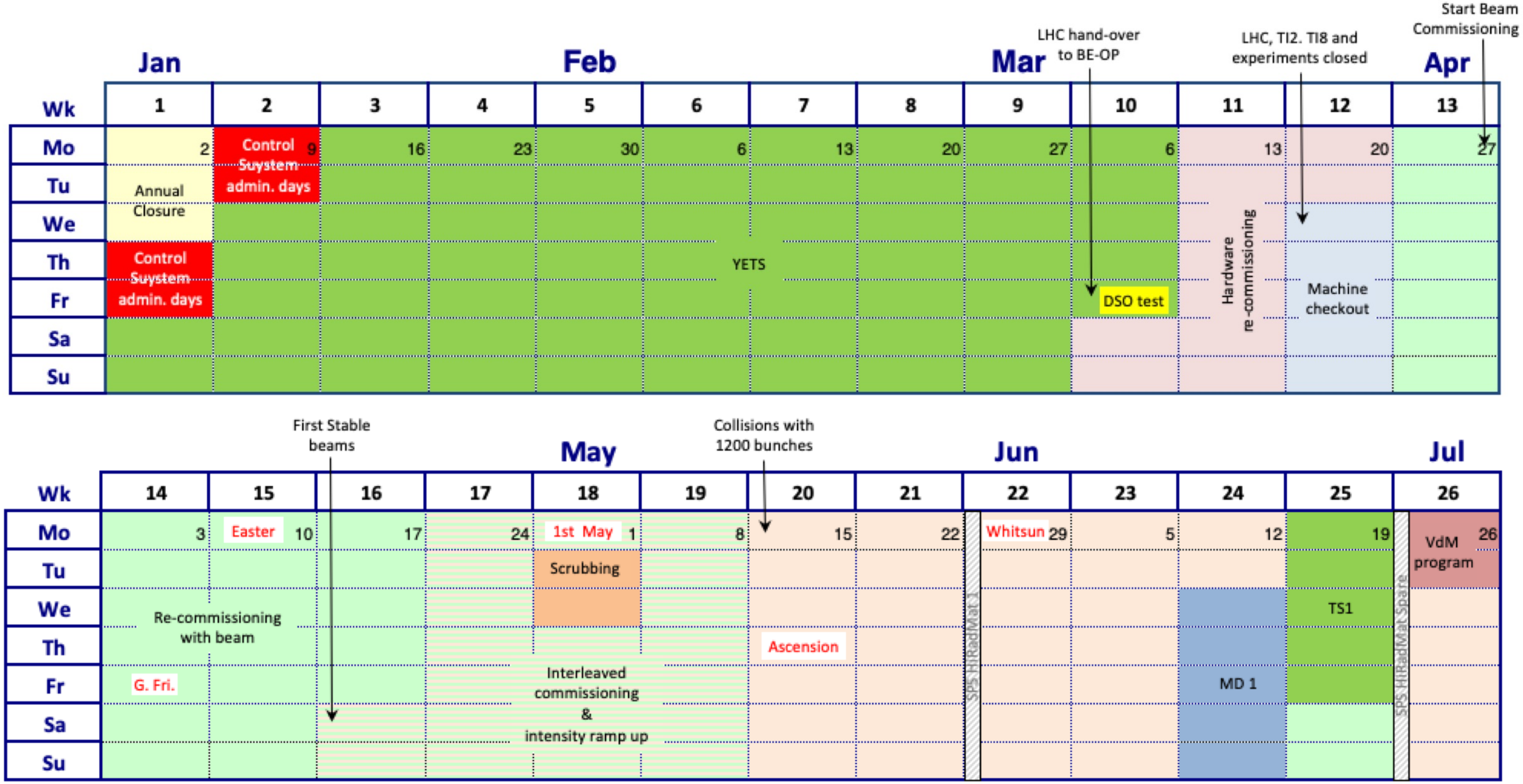


The 2023 Draft LHC Schedule in Numbers

Activity	Duration [days]	Ratio [%]
Beam Commissioning & Intensity ramp-up	47	21.7
Scrubbing	2	0.9
25 ns physics (>1200 bunches)	**97**	**44.7**
Special physics runs (incl. setting-up)	**7**	**3.2**
Pb-Pb ions & p-p ref. setting-up	6	2.8
Pb-Pb ions physics & p-p ref. run	**32**	**14.7**
Technical stop	8	3.7
Technical stop recovery	2	0.9
Machine Development blocks (incl. floating MDs)	16	7.4
Total:	**217**	**100%**



2023



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2023

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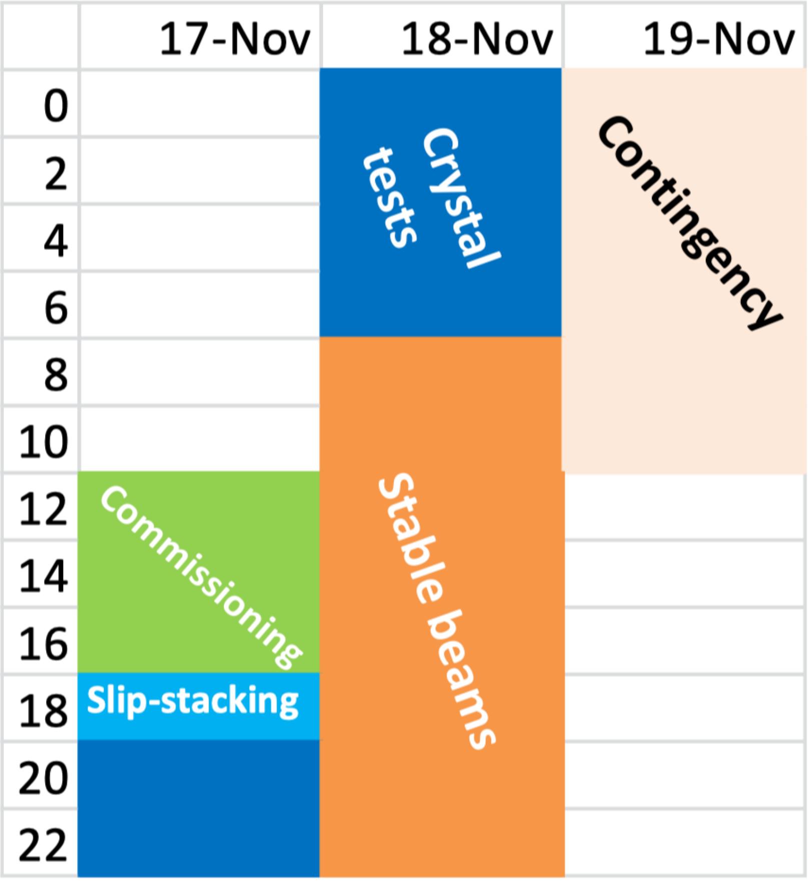
Pb-Pb TEST (USING PROTON CYCLE)

Tentative Plan (36h)



Commissioning → 6h

- **Proton cycle: 6.8 Z TeV (5.36 TeV)** ☺
- **β* = 10 m in IP2** ☹
- Slip-stacking tests at injection → **2h**
- Crystal collimation test → **12h**

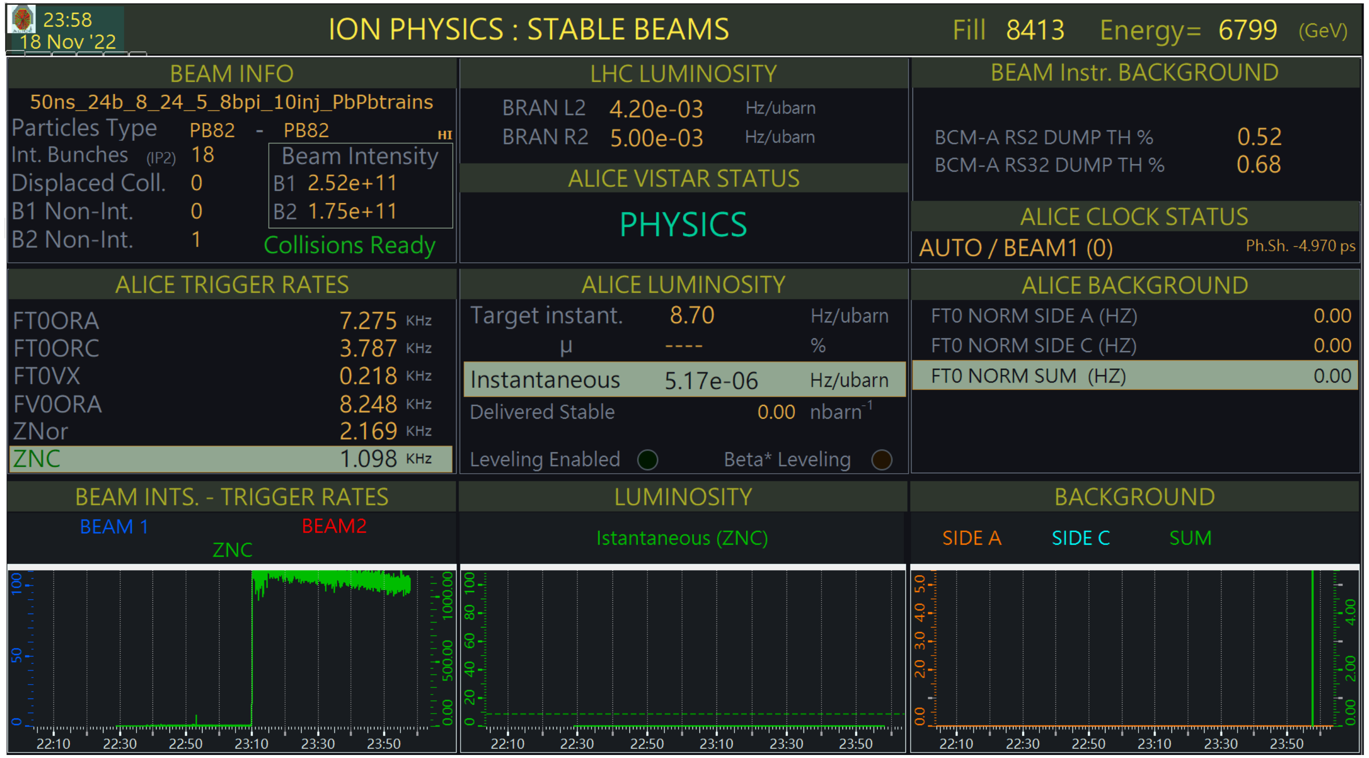
Stable Beams → 16h → 2 fills

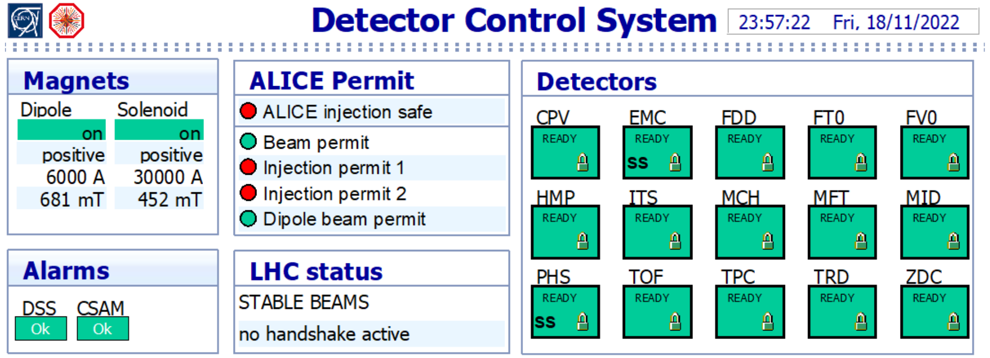
- **ALICE Magnets +/+ polarity → small angles**
- **First fill: Individual bunches**
- Half-crossing angle in IP2 = -72(int) + 172(ext) = +100 ur
- Validation of new position of TCLIA collimator right of IP2 and ZDC operation
- **Second fill: 50 ns slip stacked trains**
- half crossing angle at IP2 = -72(int) + 128(ext) = +56 ur

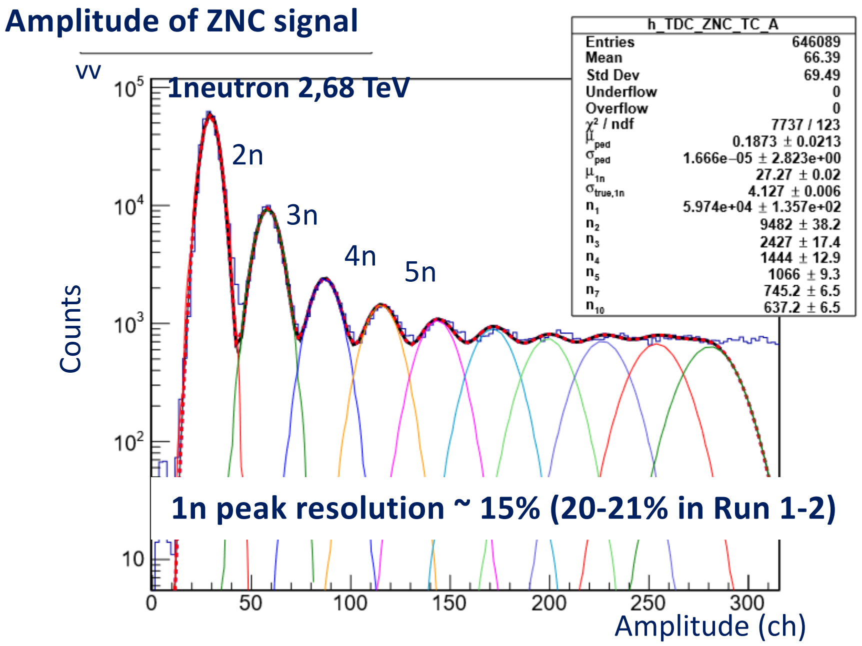
Pb-Pb: ALICE OPERATION

Final set-up for Pb-Pb:

- FT0 Calibration + FDD mezzanine cards installed
- ZDC Operation and calibration as luminometer
- ALL detectors ON and in readout
- LHC Interface for lumi publication

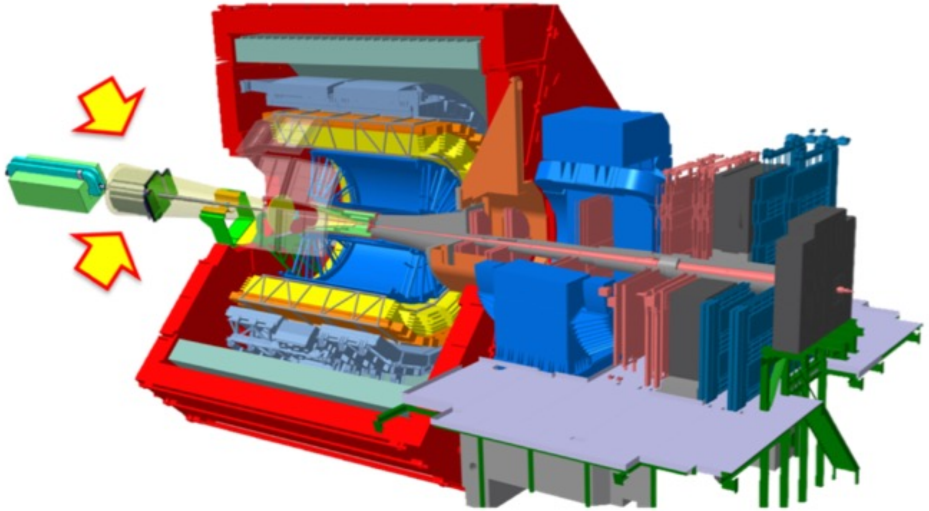


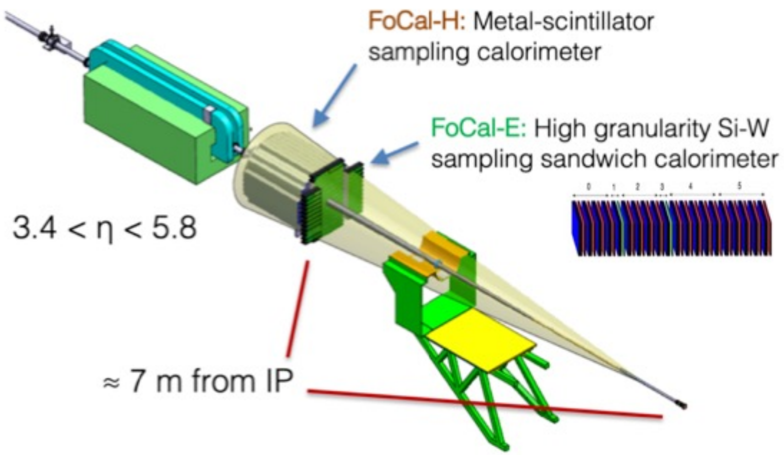




En prévision du LS3: FoCal-E

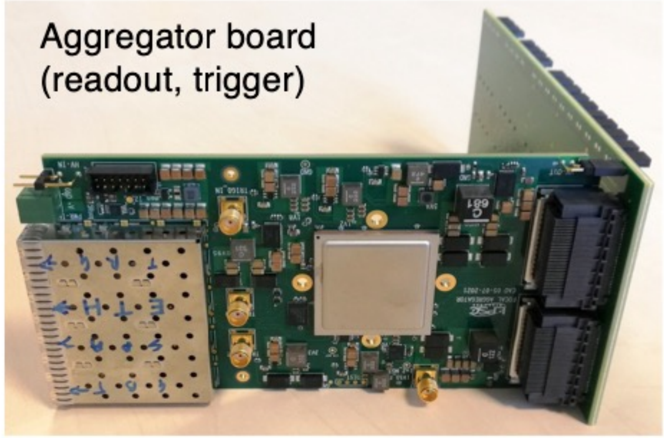
ALICE LoI LHCC-I-036 CERN-LHCC-2020-009

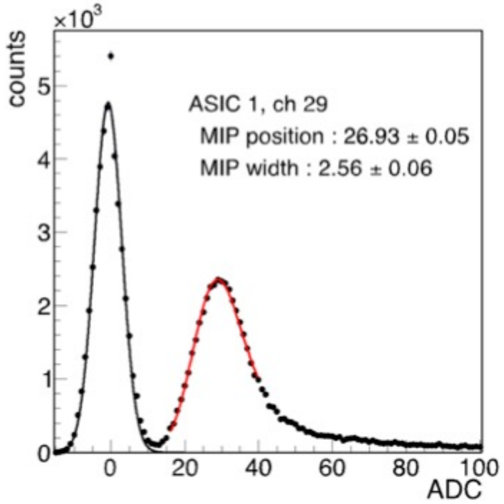




- **Calorimètre EM en région avan avec lecture Si-W de haute granularité**
- Dédié à la mesure de photons directs en région avant

- **Démonstrateur FoCal-E PAD**
- Construction d'un prototype (1/5 du module final) en collaboration avec le C4Pi
- Tests sous faisceau au CERN (PS & SPS) avec readout O2 (CRU)





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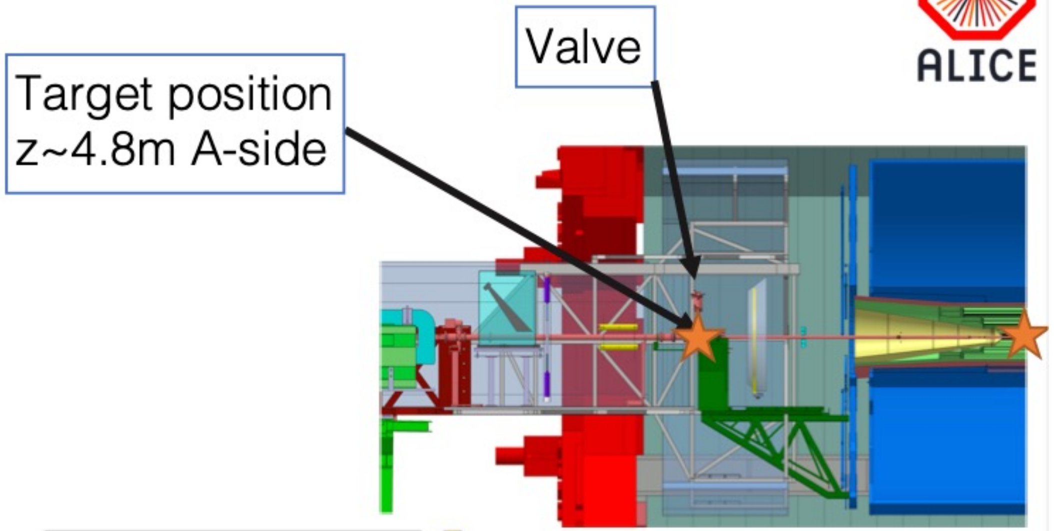
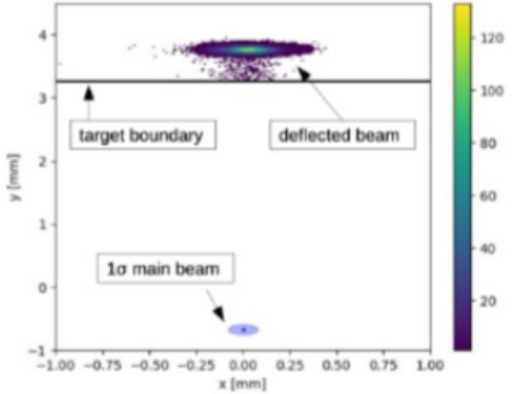
En prévision du LS3: Fixed Target

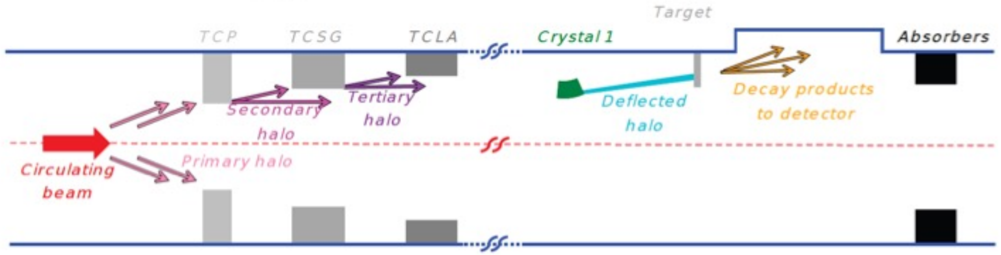


- Dispositif de fonctionnement en Cible Fixe non polarisée
- **Proposed layout for ALICE with bent crystal**
  - → Beam splitting thanks to a bent crystal
  - → LHC collimation studies done for ALICE with proton beam, started with Pb beam
  - → Coupled to a retractable solid target in front of ALICE



- Aim at an installation in LS3 (2026-2027)

- Probe high-*x* gluon, antiquark and heavy-quark content in the nucleon and nucleus
- Provide inputs for astrophysics (charm and antiproton production)
- Study the nuclear matter properties in heavy-ion collisions towards large rapidity

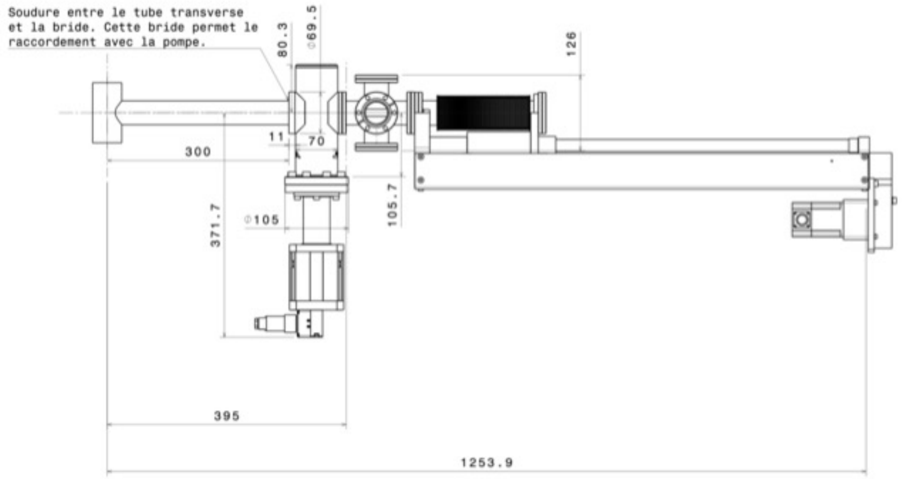


ALICE

En prévision du LS3: Fixed Target

Target design and integration

– Target position: ~5 m from IP2 with material budget outside of FoCal acceptance
– Conceptual design of the target system performed
– Mechanical integration within ALICE ongoing



Physics performance in pW at 115 GeV

– Tracking performance of the central barrel with displaced vertex for charged particles D and Λ
– PID performance ongoing

Towards a LoI (2022)

Next studies

– Vacuum and impedance integration, machine protection studies

ANR JCJC 2022 (Laure Massacrier): 2 years postdoc (performance studies), 1 IE (2 years) for vacuum studies, 1 AI (1 year) for impedance studies, material and missions