FSP ALICE - Status und Perspektiven

Kai Schweda (GSI, CERN)

KHuK Jahrestagung 2023

Dezember 7 - 8, 2023, Physikzentrum Bad Honnef

K. Schweda — qualitative considerations

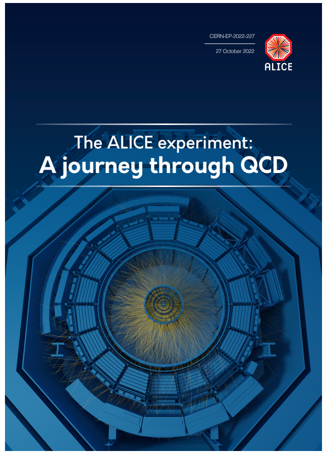
M. Arslandok — full-scale MC simulations

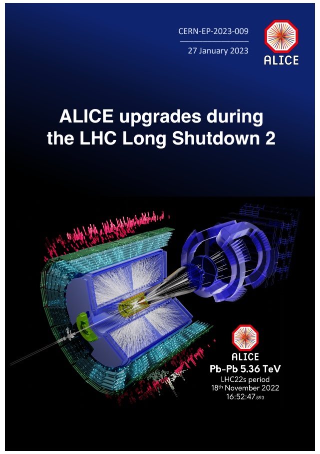
OUTLINE

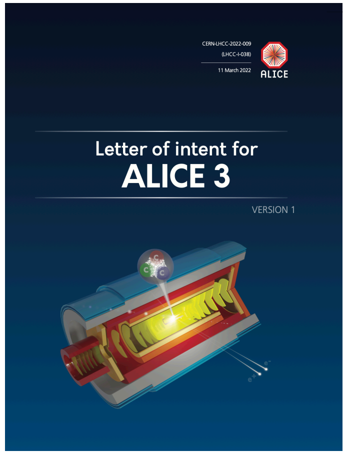
① ALICE 2 (2022 - 2032) — marvels of technology

② Some Selected Highlights — Run 2 (2015 - 2018) and Run 3 (2022 - 2025)

③ Upgrades: FoCal, ITS3 and ALICE 3 — the future





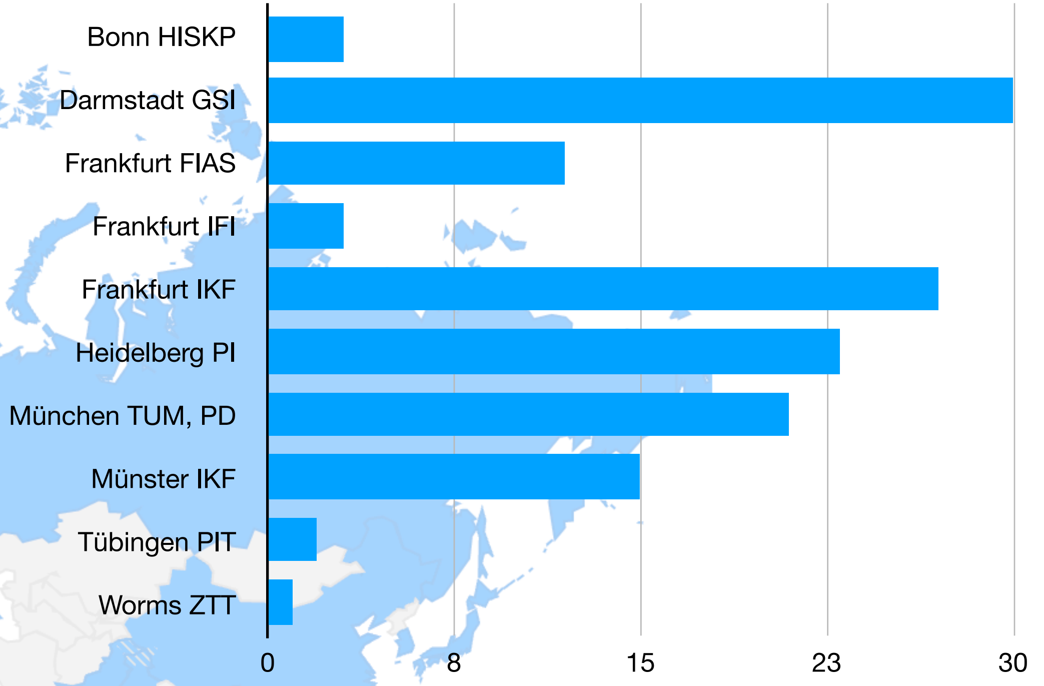


ALICE COLLABORATION

40 countries, 170 institutes

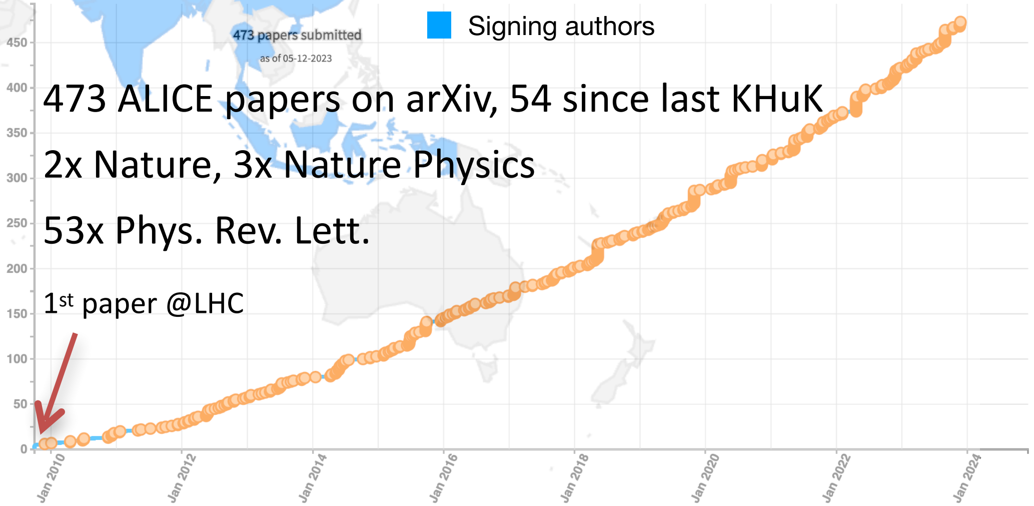
2002 members, 1034 authors

377 doctoral students, 124 postdocs



Run 1 | Run 2

System	Year(s)	$\sqrt{s_{NN}}$ (TeV)	L_{int}
Pb-Pb	2010, 2011 2015, 2018	2.76 5.02	~75 μb^{-1} ~800 μb^{-1}
Xe-Xe	2017	5.44	~0.3 μb^{-1}
p-Pb	2013 2016	5.02 5.02, 8.16	~15 nb^{-1} ~3 nb^{-1}, ~25 nb^{-1}
pp	2009-2013	0.9, 2.76, 7, 8	~200 mb^{-1}, ~100 nb^{-1} ~1.5 pb^{-1}, ~2.5 pb^{-1}
	2015, 2017	5.02	~1.3 pb^{-1}
	2015-2018	13	~36 pb^{-1}



473 ALICE papers on arXiv, 54 since last KHuK

2x Nature, 3x Nature Physics

53x Phys. Rev. Lett.

1st paper @LHC

LEADING ROLES

ALICE

O2-EPN Project Leader: Volker Lindenstruth (FRA)
TPC Project Leader: Harald Appelshäuser (FRA)
TRD Project Leader: Johanna Stachel (HD)

Deputy Physics Coordinator: Igor Altsybeev (TUM)
Deputy Spokesperson: Kai Schweda (GSI)

Physics Working Group Convenors
Electromagnetic Probes: Raphaelle Bailhache (FRA)
Heavy Flavor: Andrea Dubla (GSI)

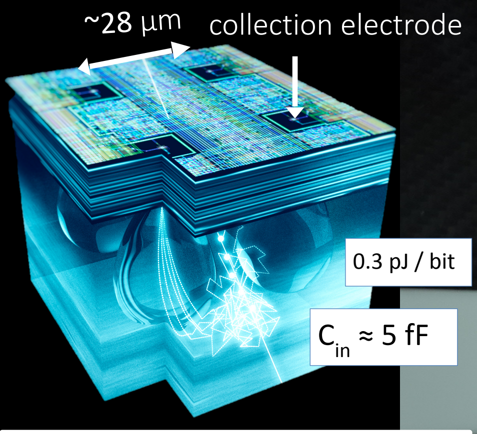
Deputy Run Coordinator (2024): Robert Münzer (FRA)
Junior Representative: Carolina Reetz (GSI)

Junior Committee: Lucia Tarasovicova (MS), Christian Sonnabend (GSI, CERN)

Inner Tracking System (ITS2)

7 layers, 10 m^2 silicon

based on MAPS, 12.5 G pixels



Q_{in} (MIP) ≈ 1300 e ⇨ V ≈ 40mV

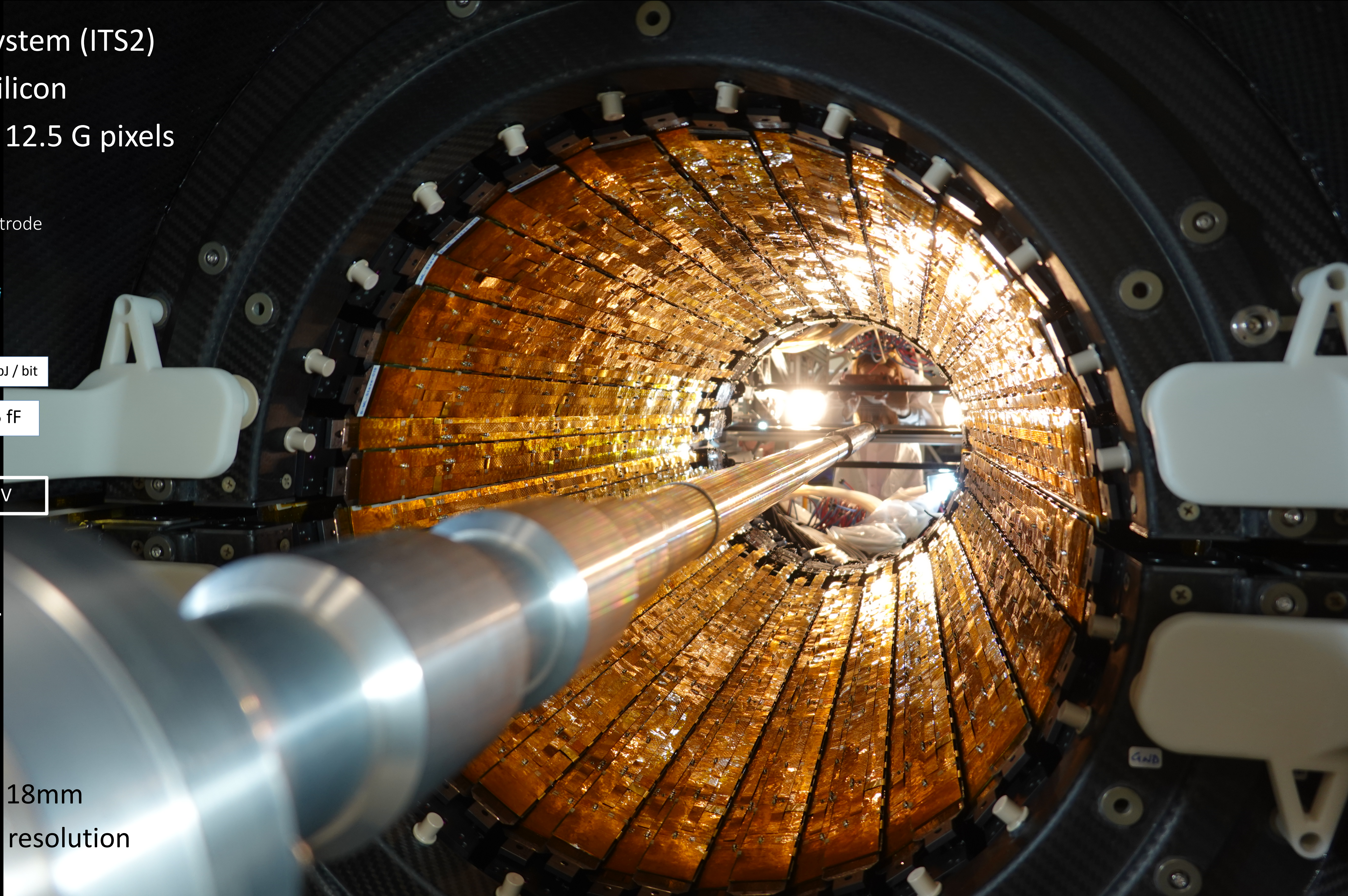
0.36% X_0 per layer

pixel size:

30 x 30 μm^2

beam pipe radius: 18mm

3x higher pointing resolution



Time Projection Chamber (TPC)

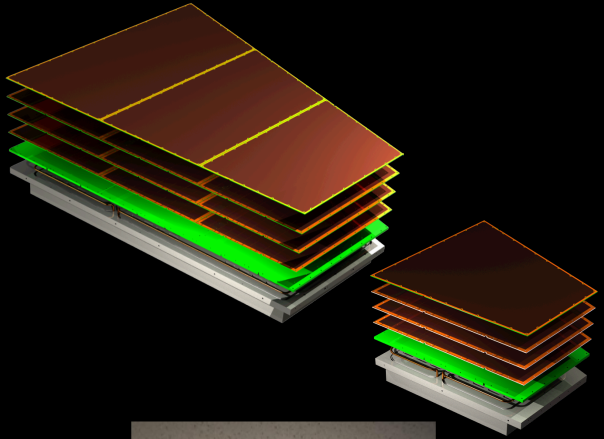
V = 88m³, $\Delta T < 0.1\ \mathrm{K}$

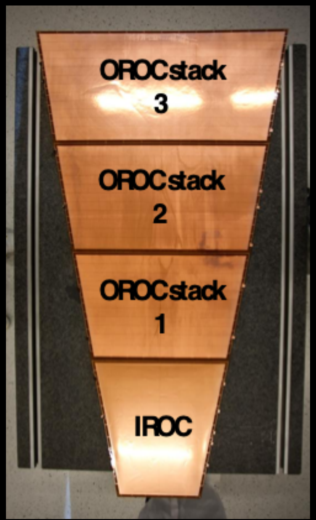
Multiwire proportional chamber

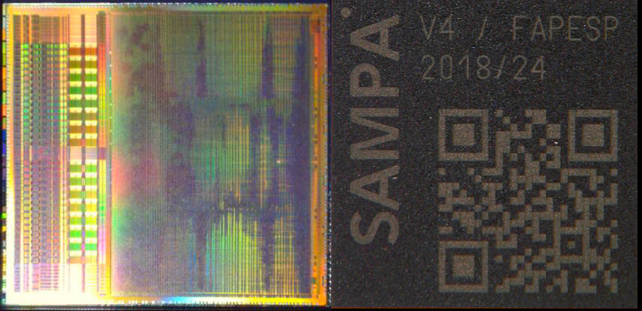
→ quadruple-GEM readout

→ continuous readout (100x faster)

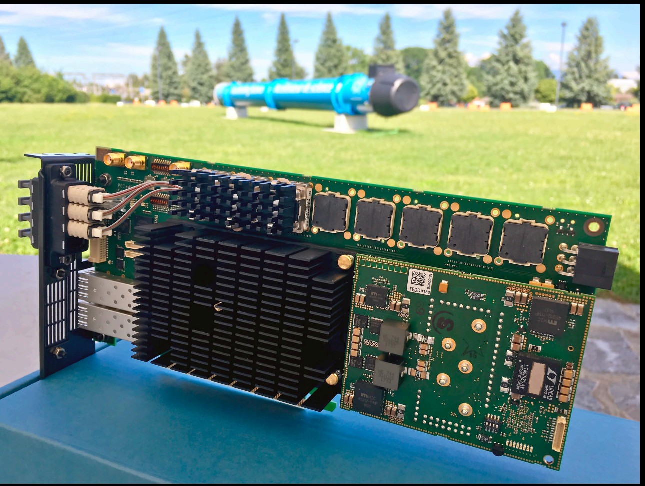
3.4 TeraBytes/second



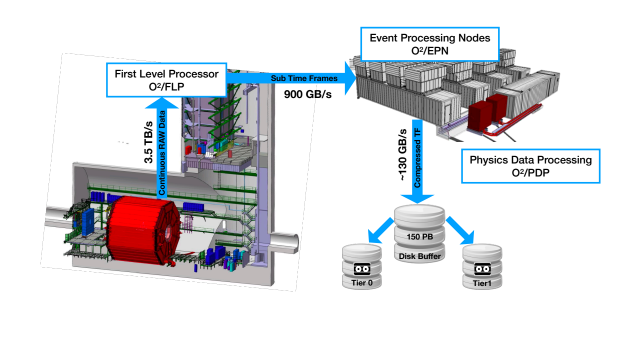




SAMPA chip



common readout unit
(world's largest FPGA)



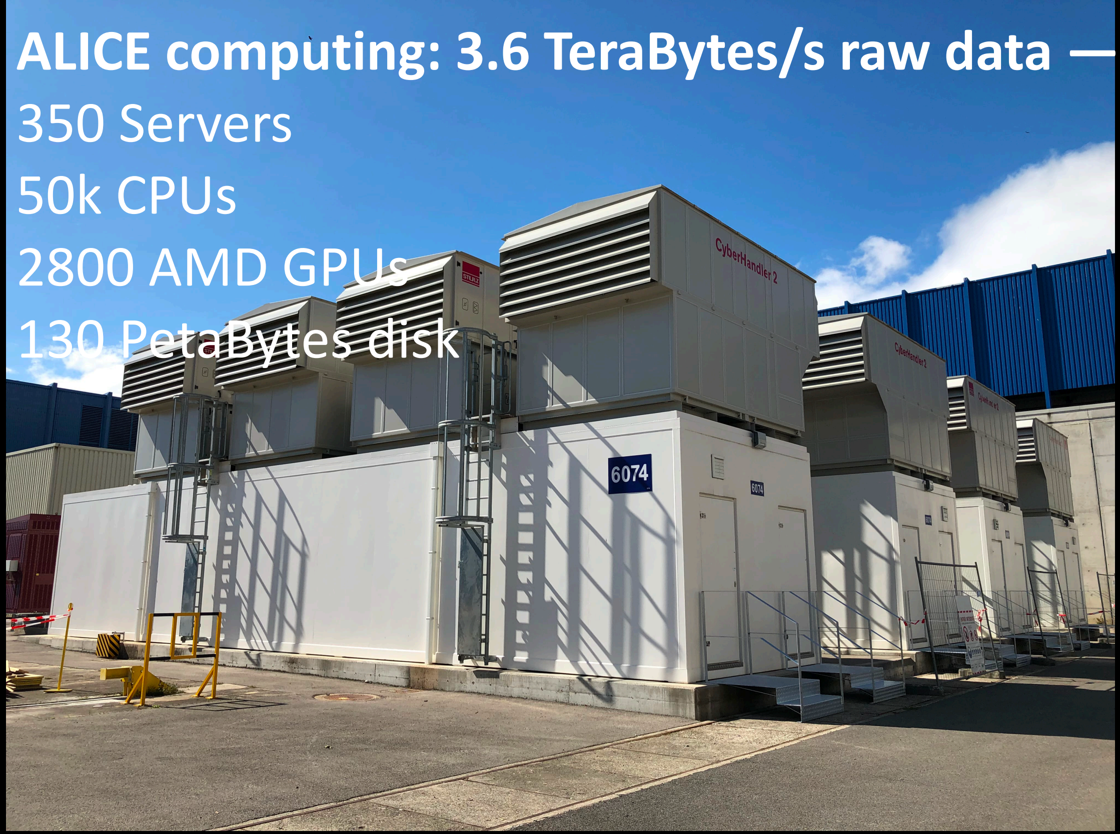
ALICE computing: 3.6 TeraBytes/s raw data —> up to 170 GBytes/s to disk

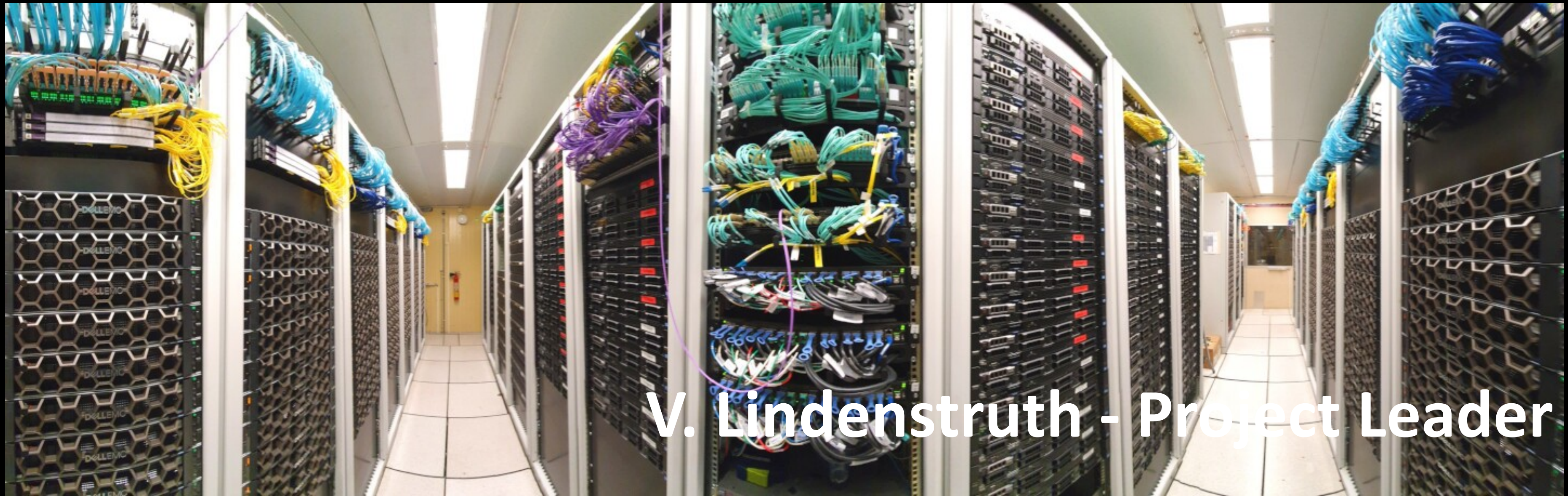
350 Servers

50k CPUs

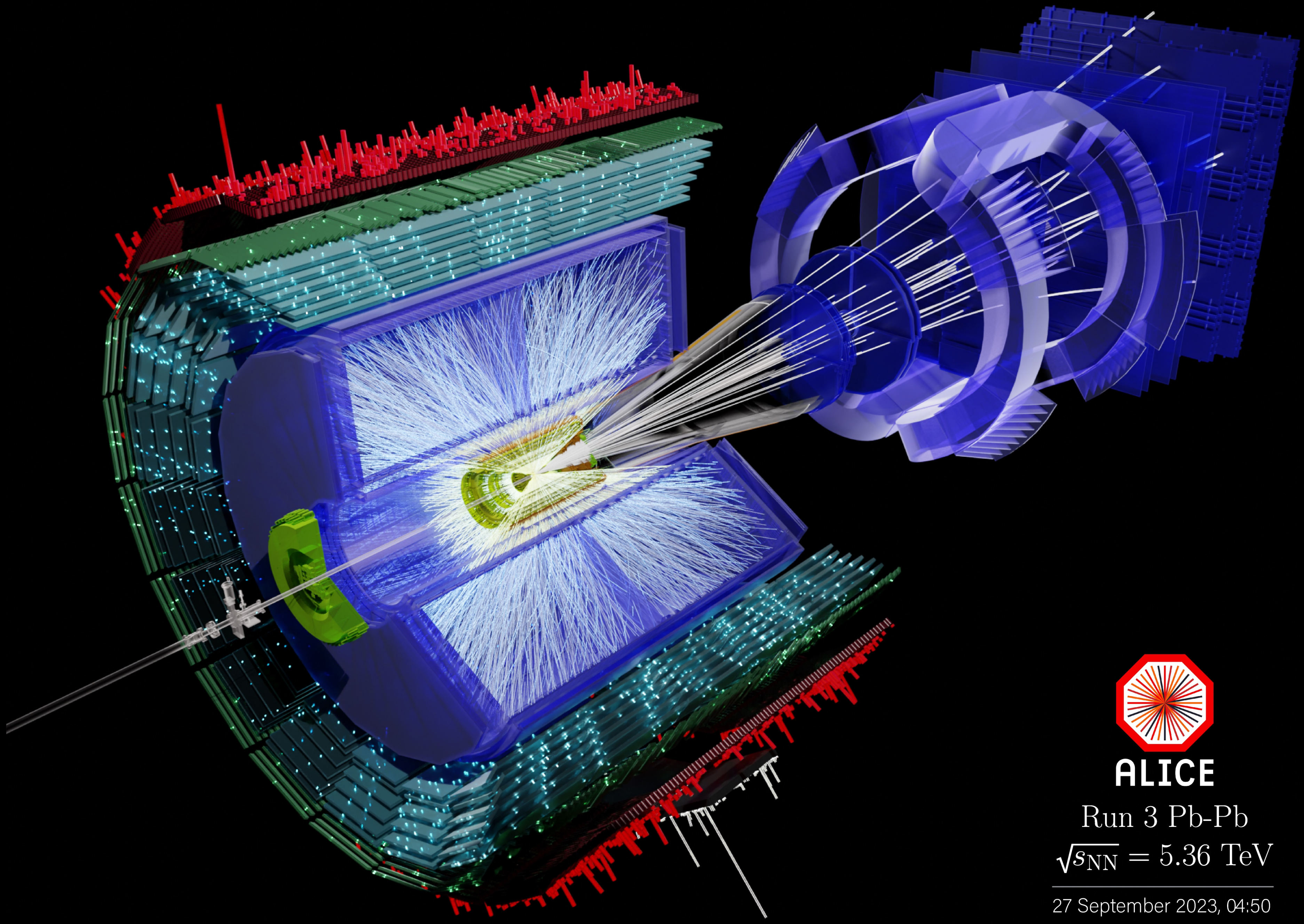
2800 AMD GPUs

130 PetaBytes disk



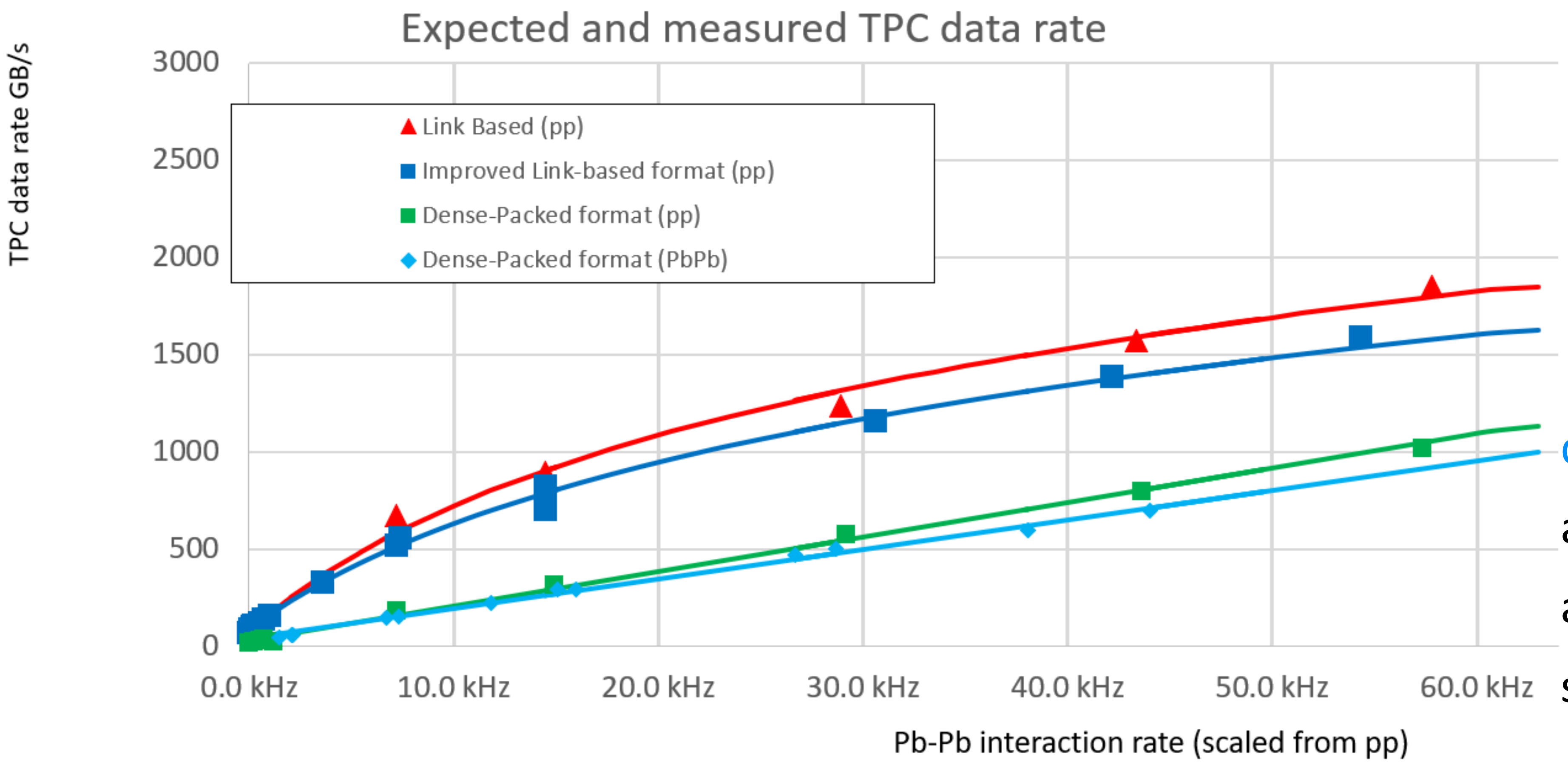


V. Lindenstruth - Project Leader


ALICE
Run 3 Pb-Pb
$\sqrt{s_{\mathrm{NN}}} = 5.36$ TeV
27 September 2023, 04:50

ALICE RUN CONTROL CENTRE AT P2

REAL TIME DATA RATES



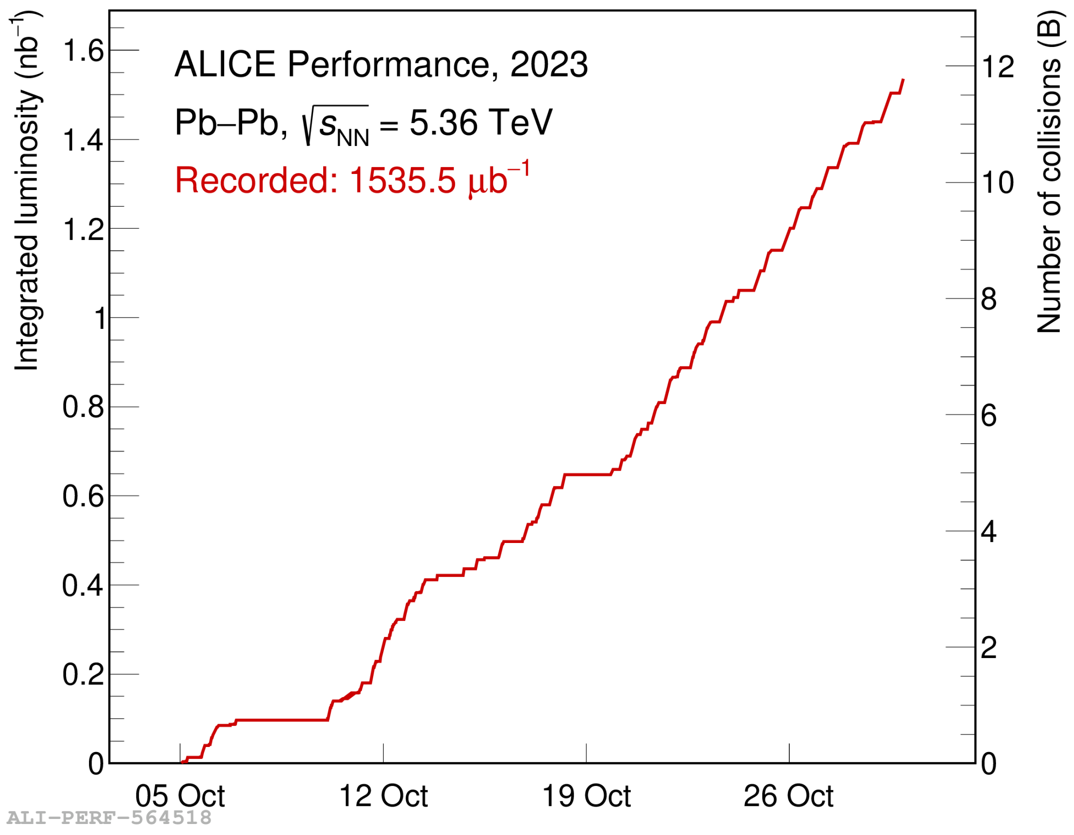
dense packed format

at close to 50 kHz Pb-Pb:

at 800 GBytes/s

still about 20% margin

Pb-Pb - INTEGRATED LUMINOSITY



Run 1 + 2 (2009 - 2018)

pp : 0.032/pb minimum bias collisions, 2 billion events

Pb-Pb : 315 million minimum bias collisions

149 million 0-10% central collisions

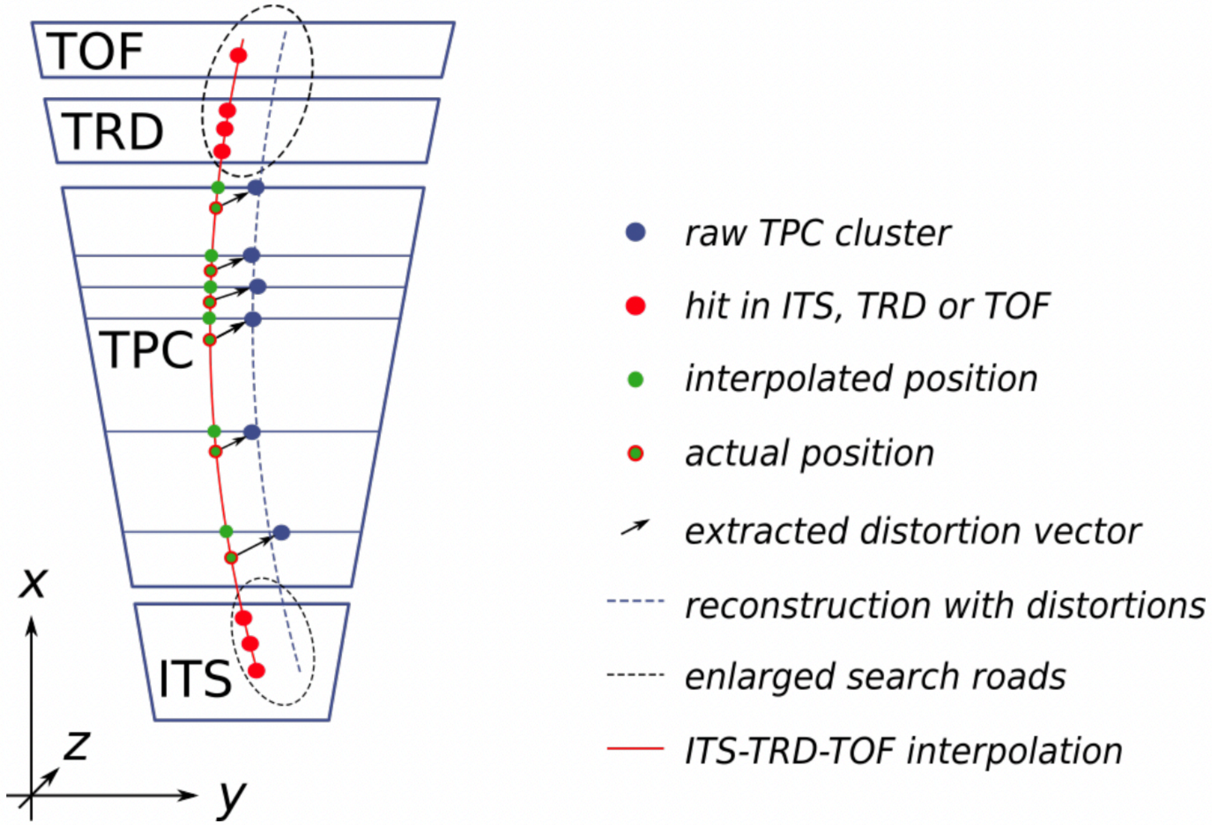
2022 pp: 19.3/pb or 1000 billion minimum bias collisions

2023 pp: 9.7/pb or 500 billion minimum bias collisions

2023 Pb-Pb: 1.5 /nb or 12 billion minimum bias collisions

40x minimum bias, 7x central wrt Run 1 + 2

SPACE CHARGE DISTORTIONS IN TPC

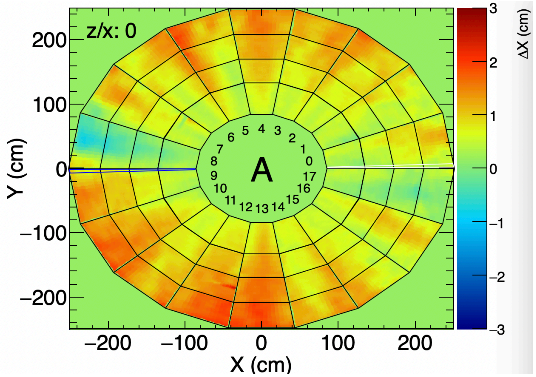


- ions, mainly from amplification regions lead to:
- accumulating space charge in TPC drift volume
- leads to increasingly large spatial distortions of reconstructed hits
- full data driven correction: ITS to TPC extrapolation - residuals in TPC give distortion map
- interaction rate dependent

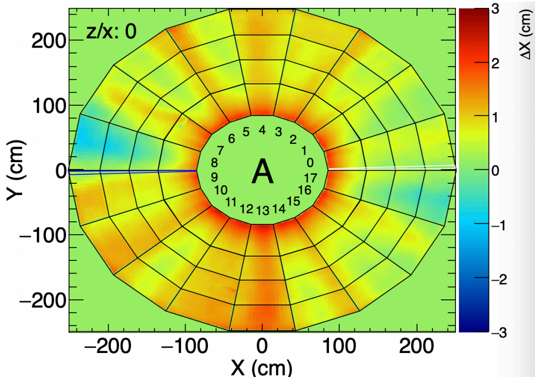
TPC DISTORTION MAP - Pb-Pb

ALICE

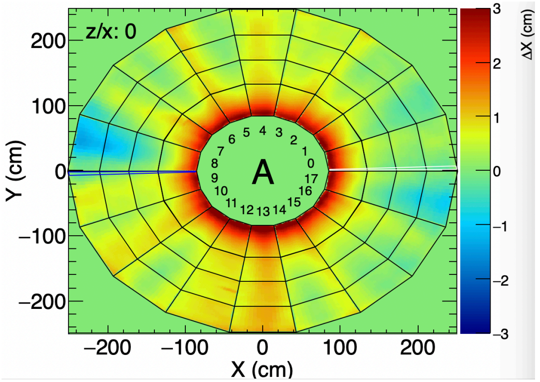
50 Hz



8 kHz



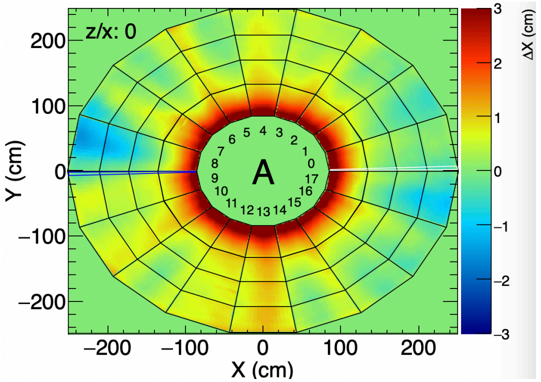
15 kHz



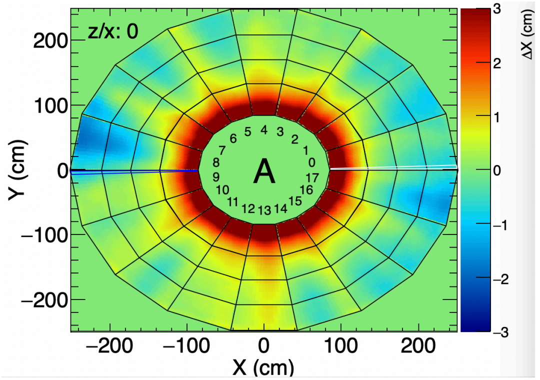
at 50Hz:

static distortions only

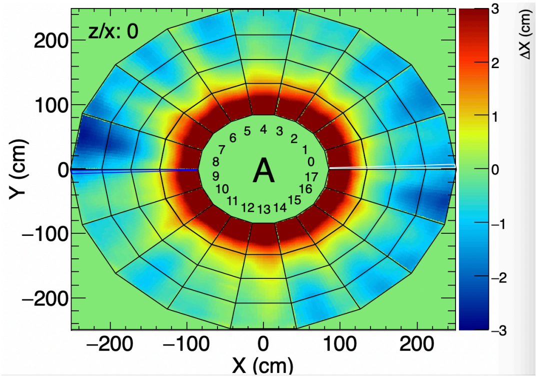
18 kHz



27 kHz



38 kHz



at 38kHz:

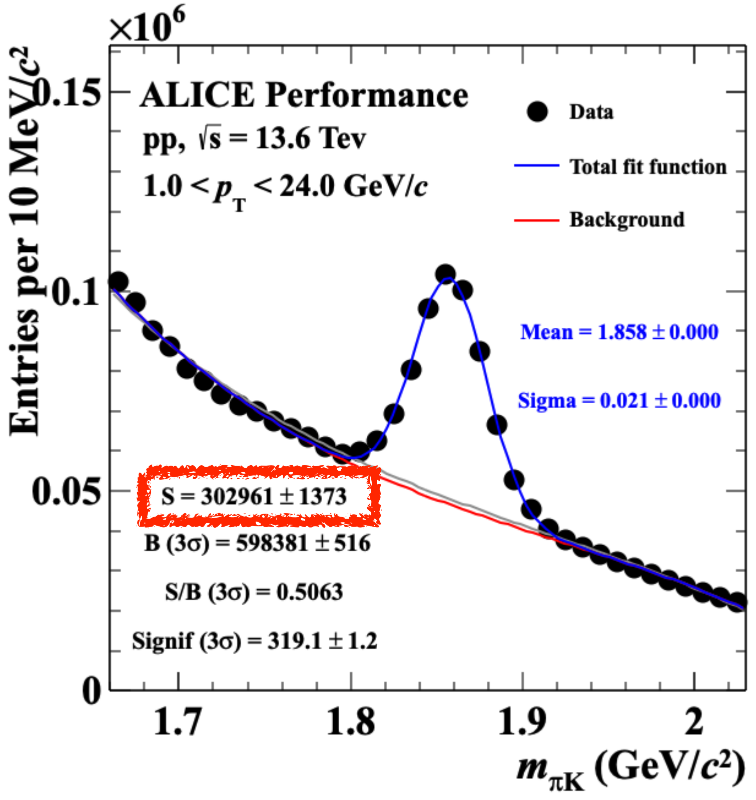
distortions range

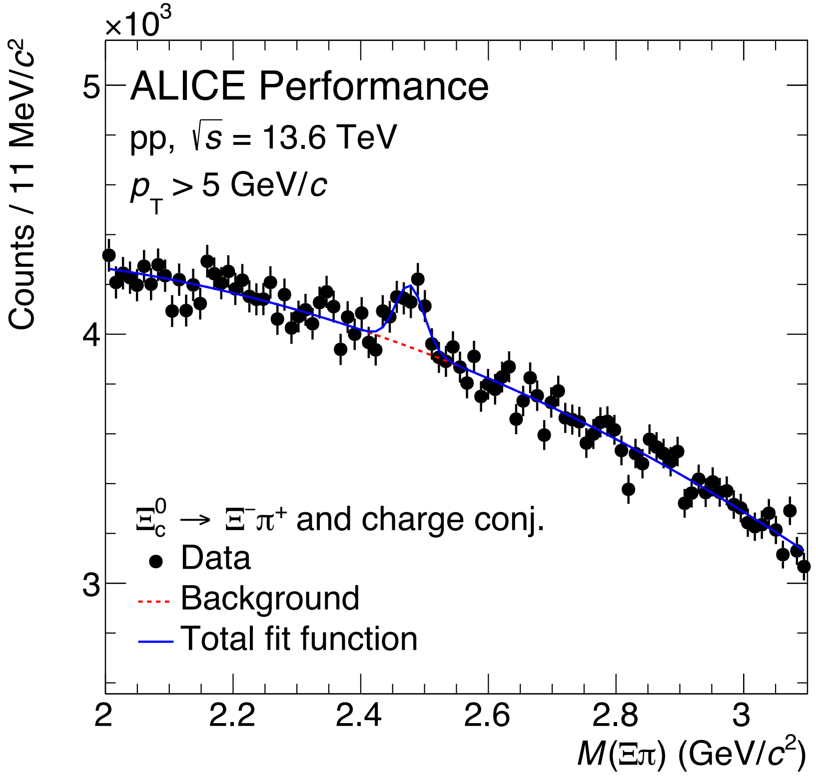
from +8cm to -4cm

so far: analytic maps, scaled with interaction rate, now: fully data driven map used

FIRST RUN 3 RESULTS

Run 3 pp: Basic performance (GSI-HD)

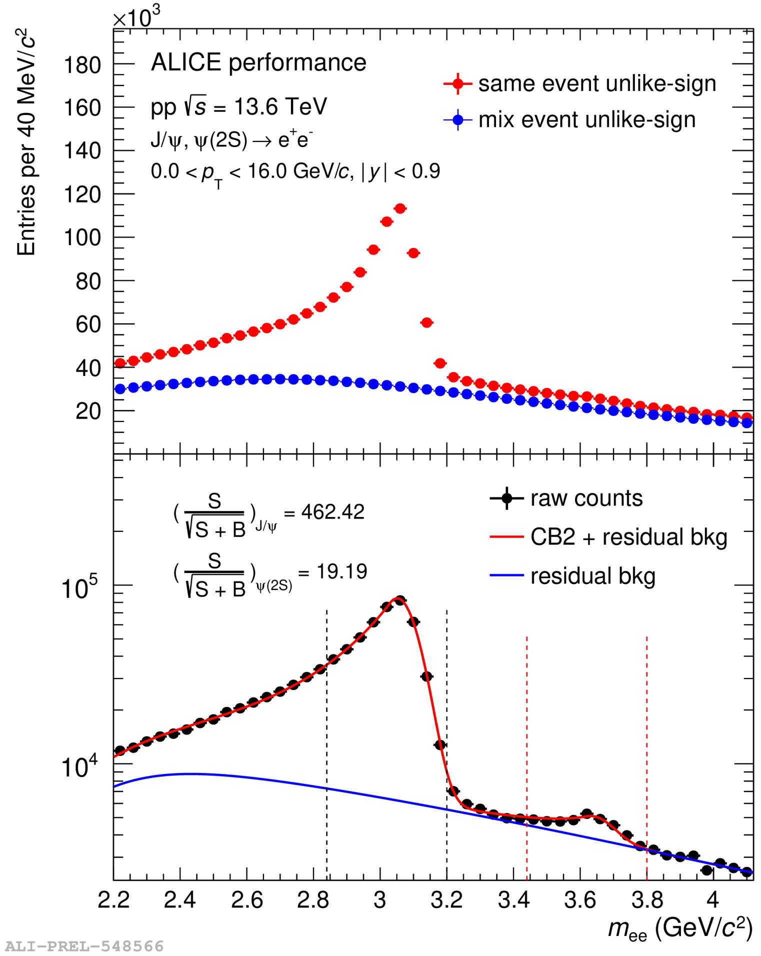


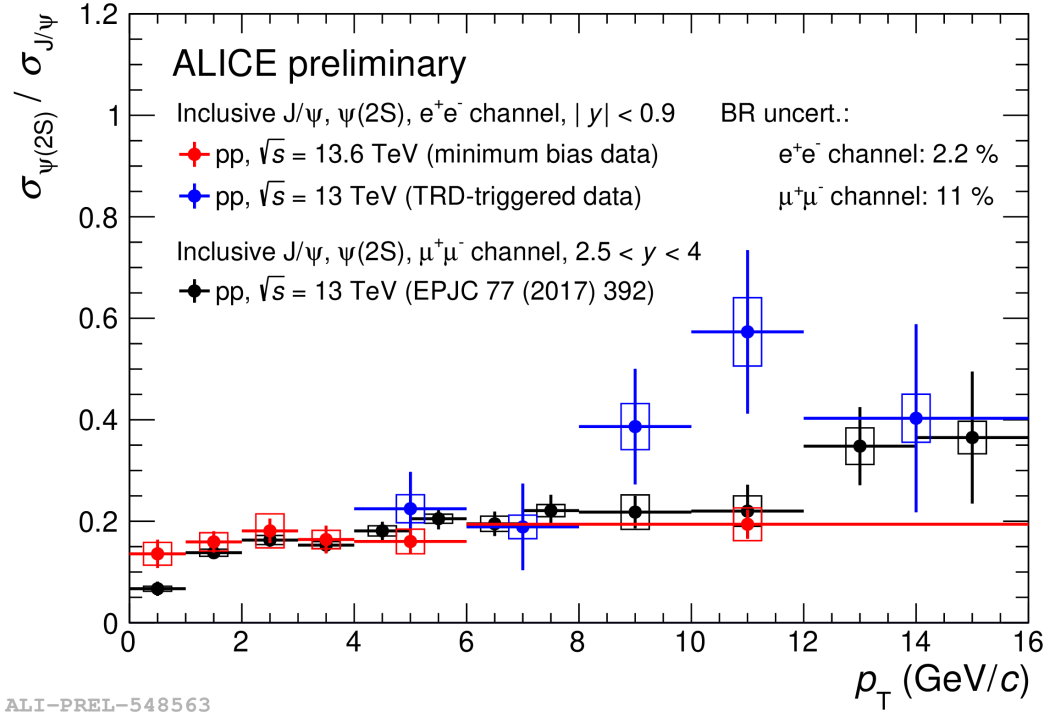


charmed hadrons reconstructed in l**arge amounts**, opens new dimension for **charmed baryons**

→ allows for differential studies, **branching ratios**, …

CHARMONIUM PRODUCTION (GSI-HD)



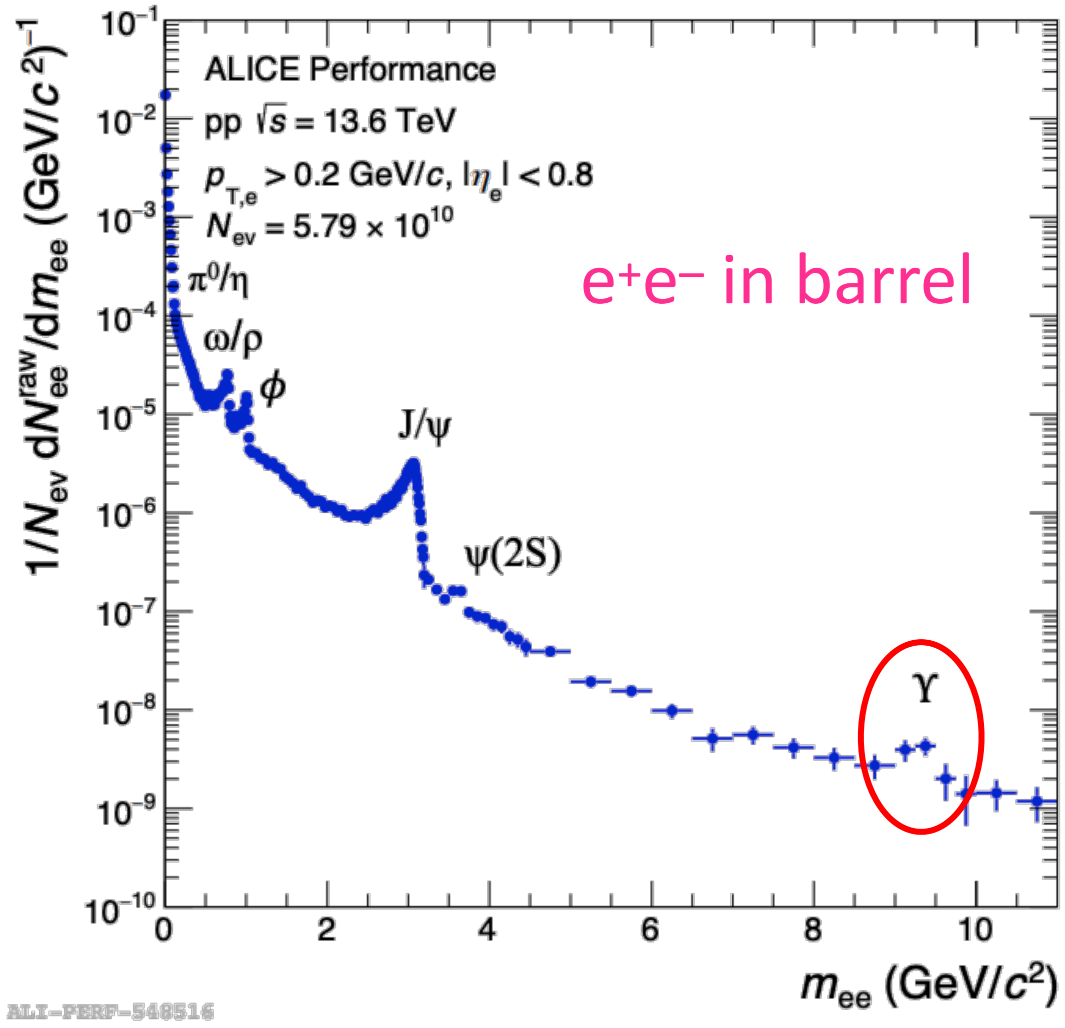


New measurements of the $\psi(2S)/J/\psi$ ratio

in pp collisions at central and forward rapidities

→ consistent with existing measurements

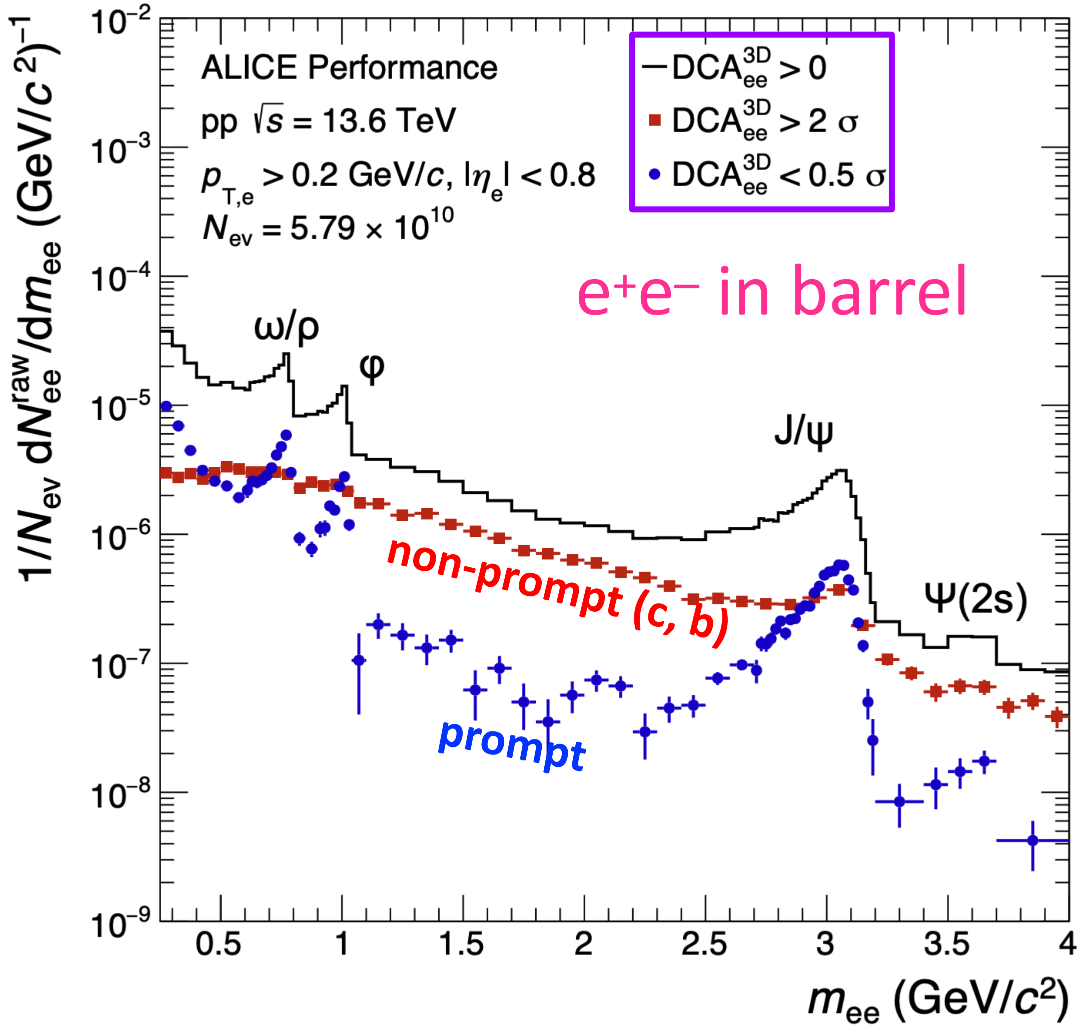
Run 3 pp: Low-mass dielectrons (FRA)



Huge pp statistics analyzed:

- 0.97 pb^{-1} (2022) for this figure
- 0.03 pb^{-1} in Run 2

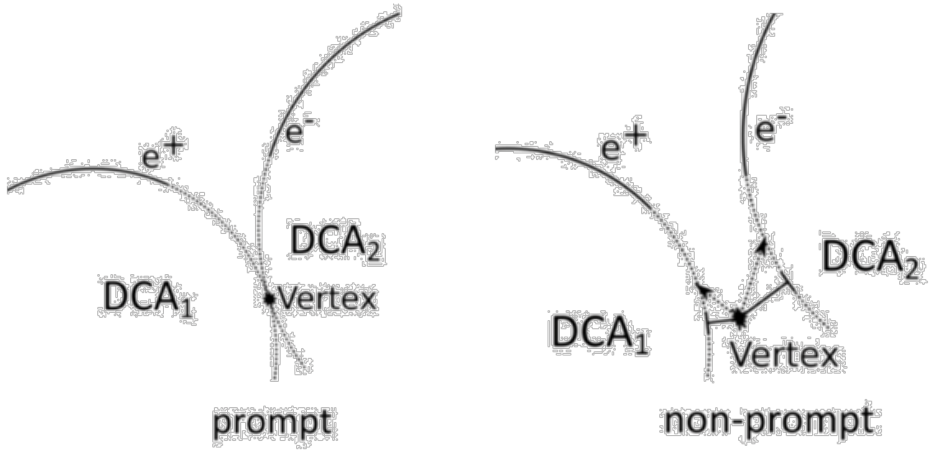
Run 3 pp: Low-mass dielectrons (FRA)



Run 2 analysis: arXiv:2308.16704

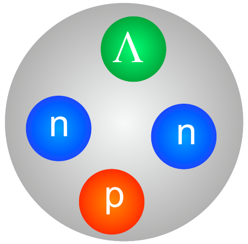
Huge pp statistics analyzed:

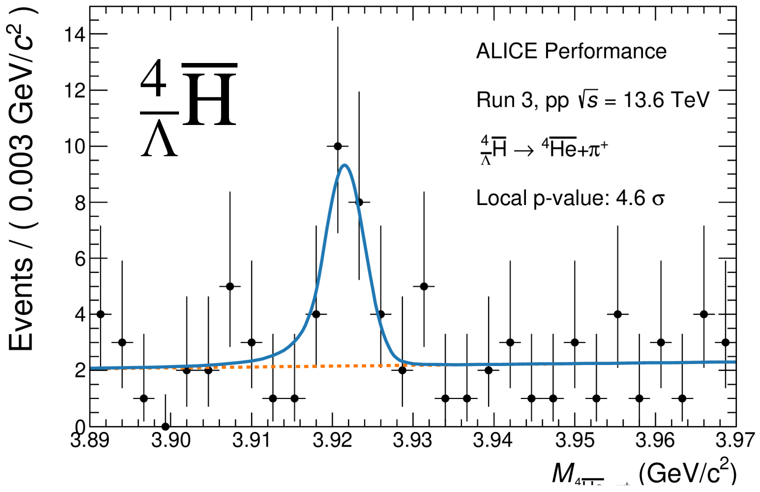
- 0.97 pb^{-1} (2022) for this figure
- 0.03 pb^{-1} in Run 2
- New ITS → improved DCA resolution, better control of charm & beauty background!
- Promising to look for thermal radiation in pp

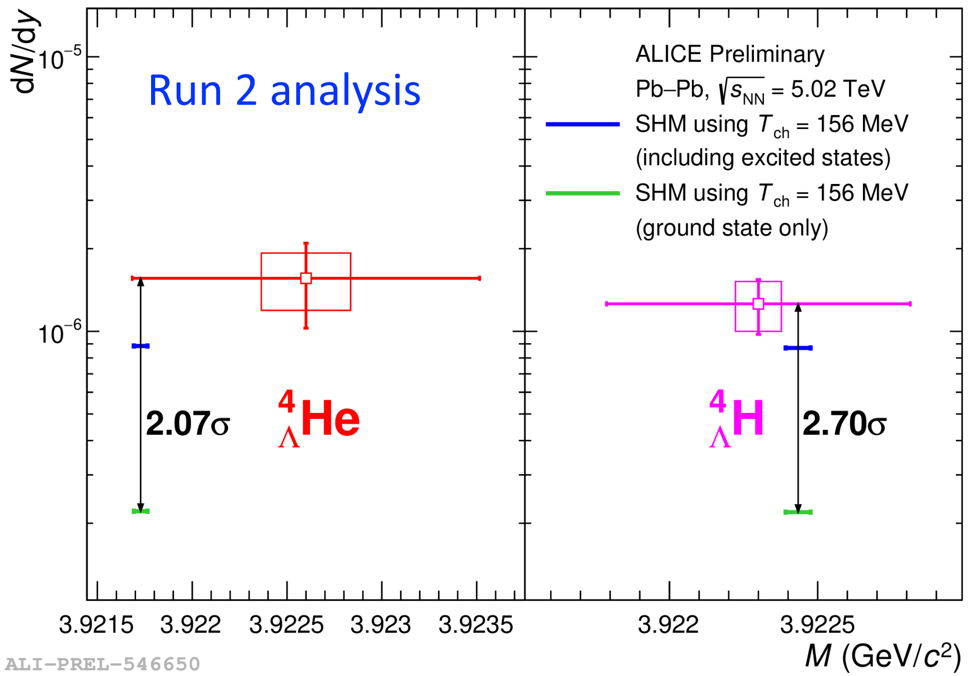


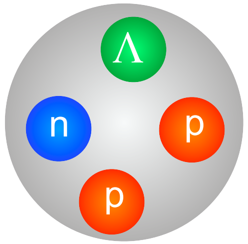
cτ ~150 µm for D mesons
cτ ~500 µm for B mesons

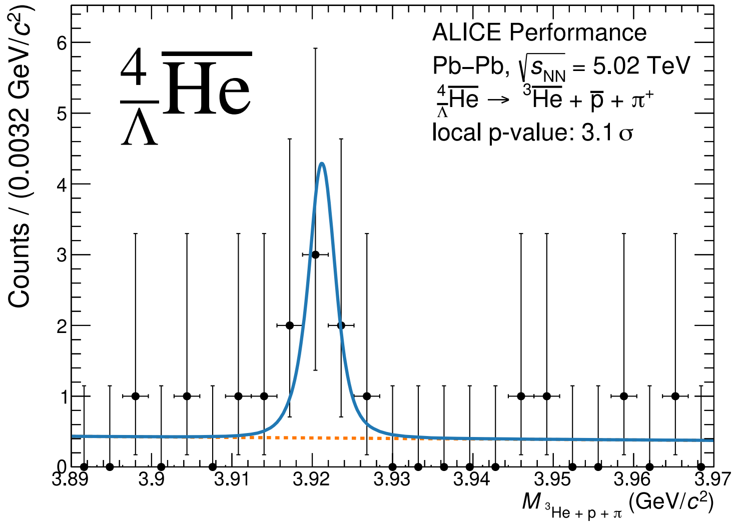
ANTIHYPERNUCLEI IN SMALL SYSTEMS (FRA)







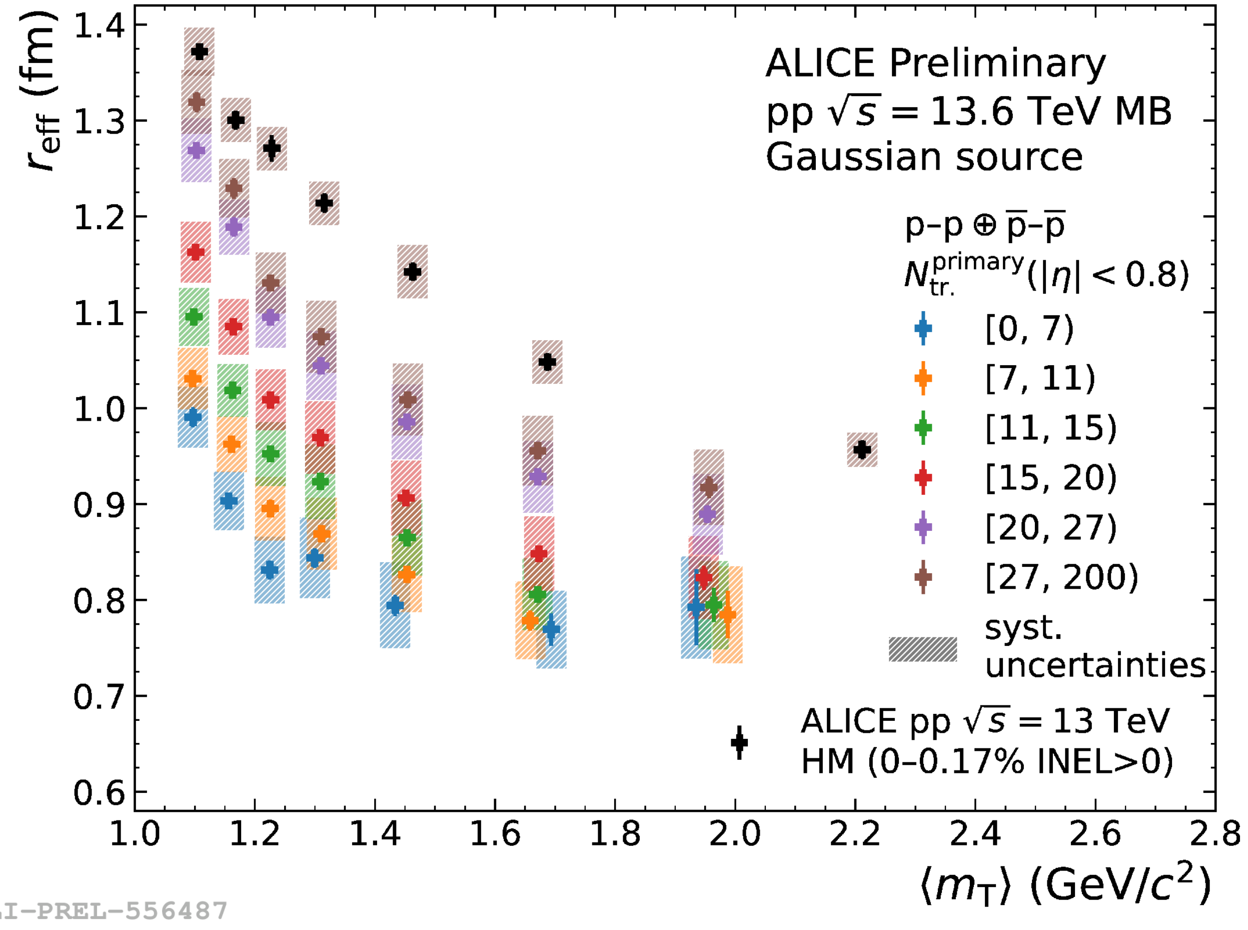




Observation of $^{3}_{\Lambda}\overline{\mathrm{H}}$ and $^{4}_{\Lambda}\overline{\mathrm{H}}$ in Run 3 minimum-bias pp collisions at 13.6 TeV

Crucial to constrain production models heavy and loosely-bound states - excited states also contribute → spectroscopy

FEMTOSCOPY (TUM)



600 billion pp collisions **analyzed**

source radius from function of m_T and multiplicities

2D map for the source determination for femto studies

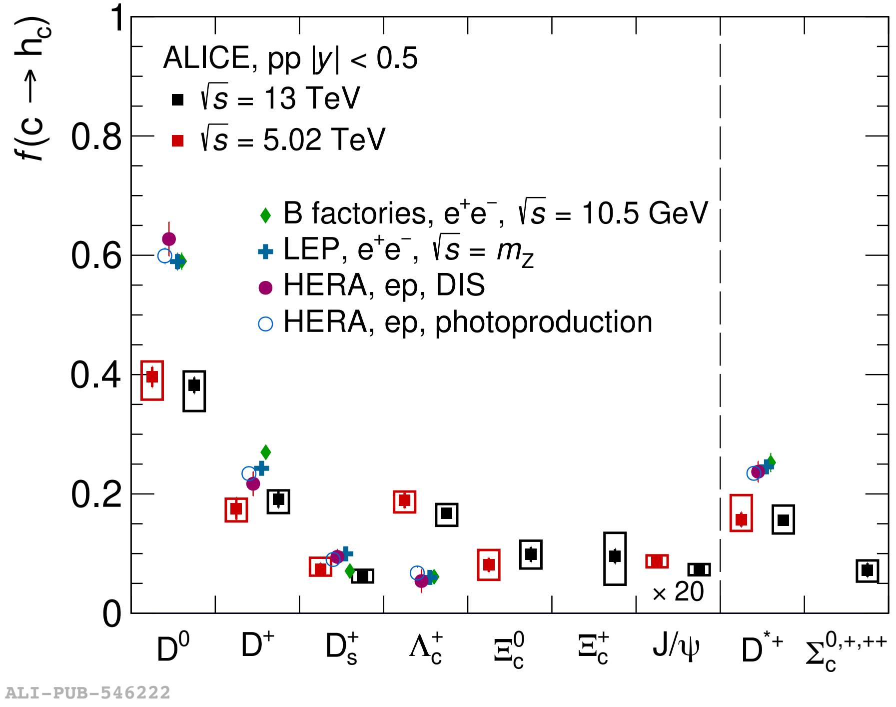
two and three particle interactions; nuclear coalescence

A FEW SELECTED PAPER HIGHLIGHTS

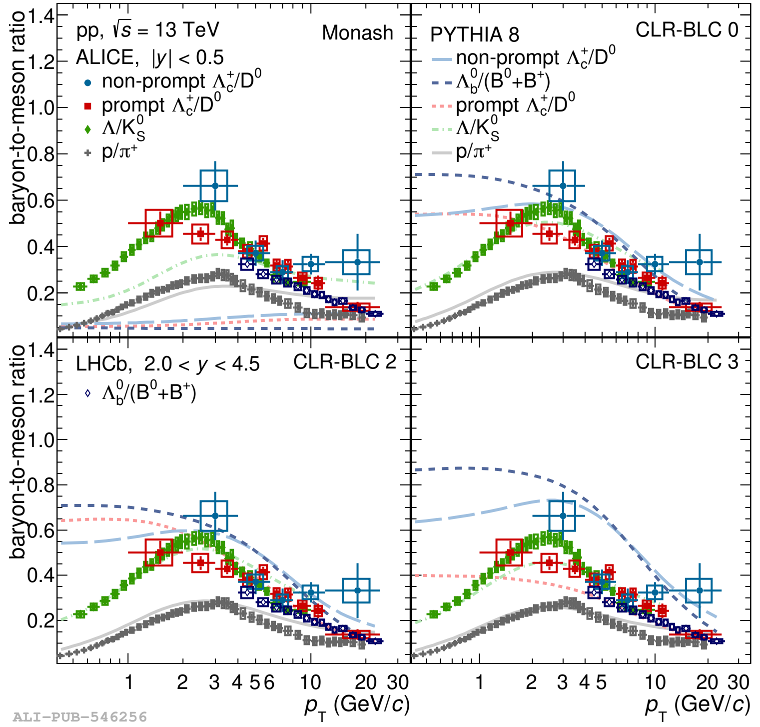
CHARM PRODUCTION AND FRAGMENTATION (GSI)

ALICE

Charm fragmentation fraction



Prompt and non-prompt Λ_c/D



Baryon production larger in pp than e^+e^-

Λ_c, Ξ_c, Σ_c measured

charm hadronization not universal

arXiv:2308.04877

$\sigma_{c\bar{c}}$ experimental precision much better than theory

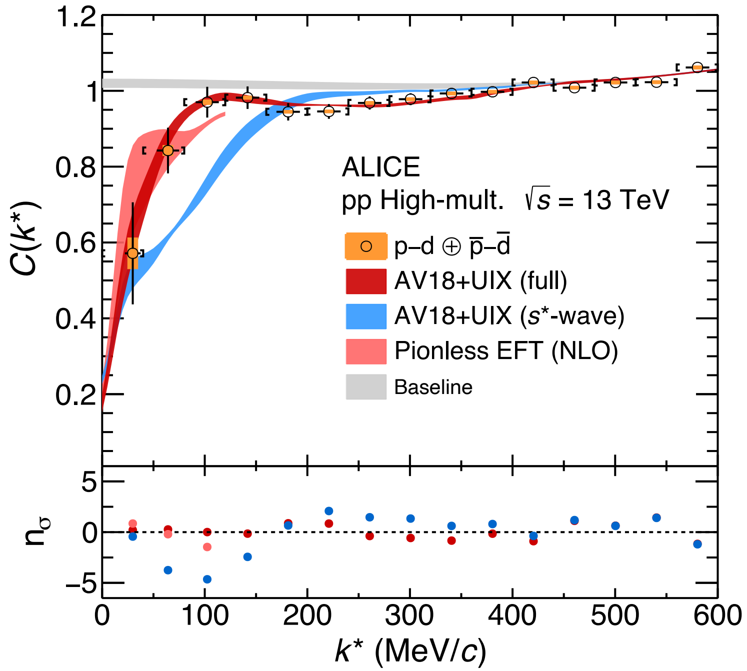
—> calls for N^3LO calculations

arXiv:2308.04873

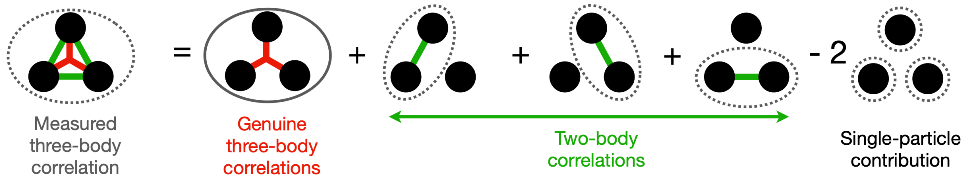
Baryon enhancement also present in beauty sector

In line with expectation from color-reconnection models

THREE-PARTICLE CORRELATIONS (TUM)



Three-body effects extracted using Kubo's cumulant method by subtracting pair-wise interactions



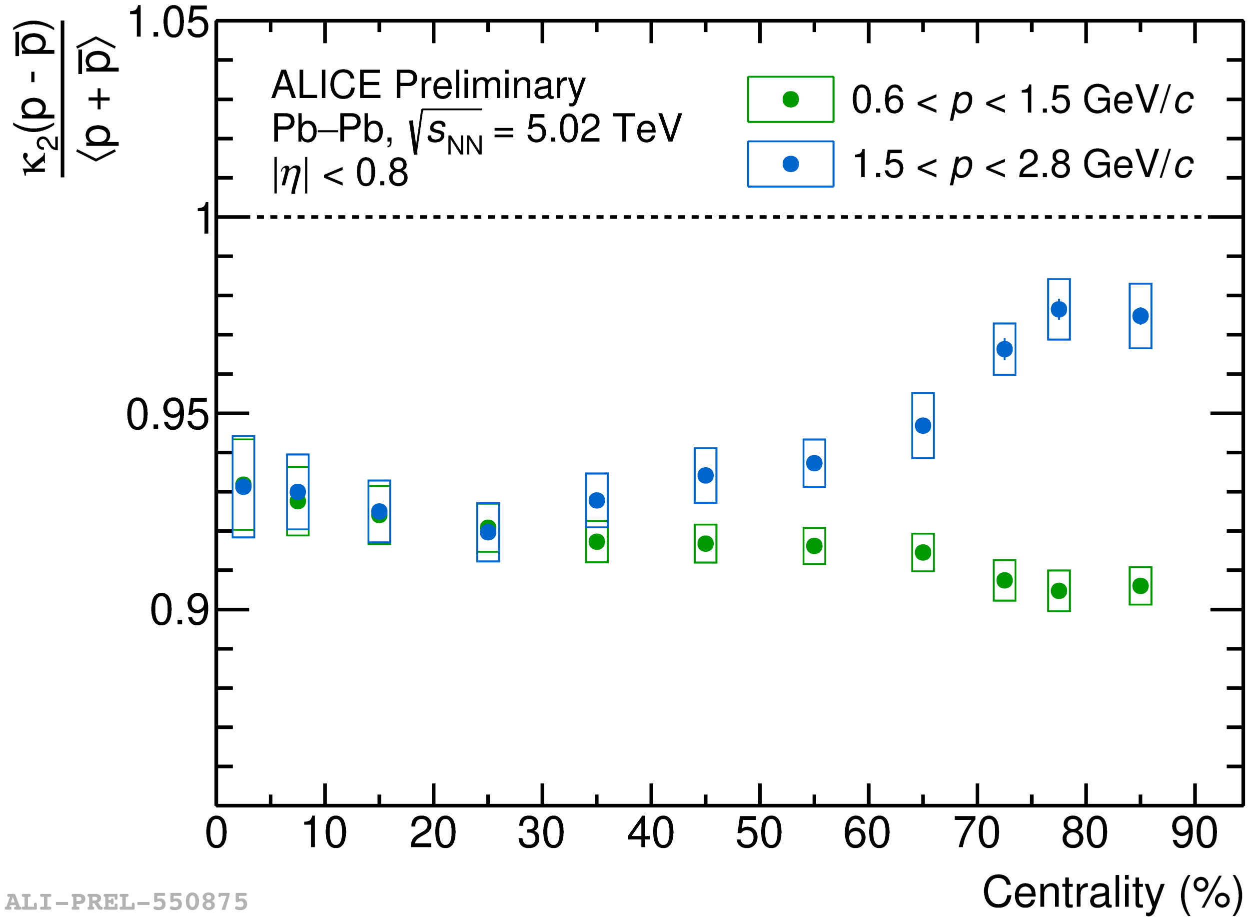
p-d system: negative three-body correlation (Pauli blocking, 3-body force, Coulomb)

Genuine 3-body forces at short distances can be studied at LHC!

Also: Lambda-kaon coupling [Phys. Lett. B 845 (2023) 138145]

submitted to Nature Phys.:[arXiv:2308.16120]

FLUCTUATIONS (HD)



Increase indicates a correlation amongst protons (anti-protons)

thermalized component

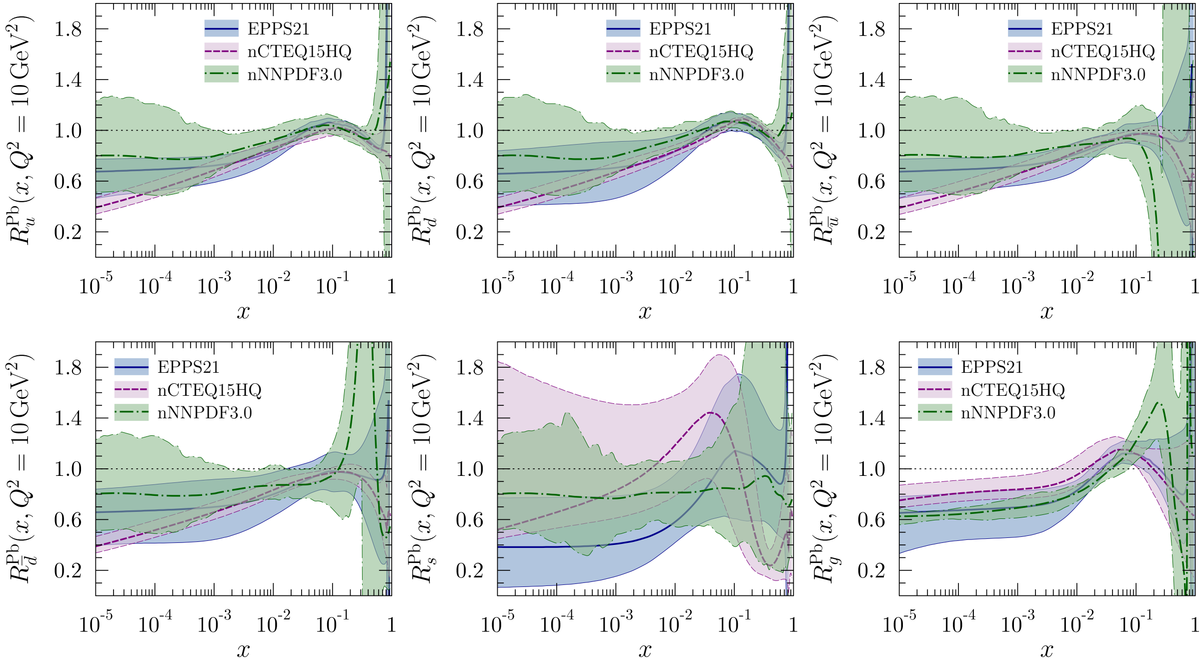
might come from the early stage and

maybe be induced by a magnetic field

FSP ALICE - THEORY

ALICE

- Univ. Bielefeld (Sören Schlichting)
- Univ. Münster (Michael Klasen)
- Univ. Tübingen (Werner Vogelsang)



Ann. Rev. Nucl. Part. Sci. 2024. 74:1–41

Nuclear quark and gluon densities in Pb (nPDF)

from global fit to LHC data

Photons and dileptons from the early stage (see Sören’s talk)

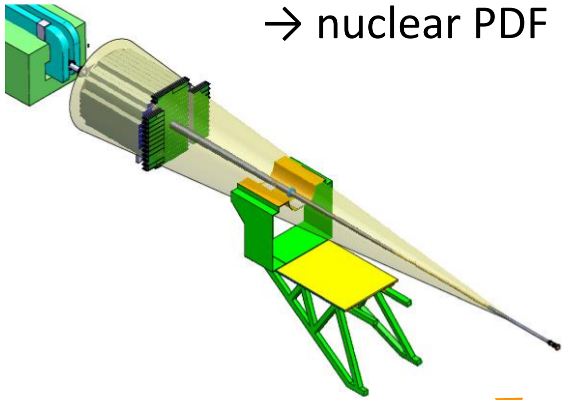
2308.09747
2309.00555
2309.00555

ALICE UPGRADES

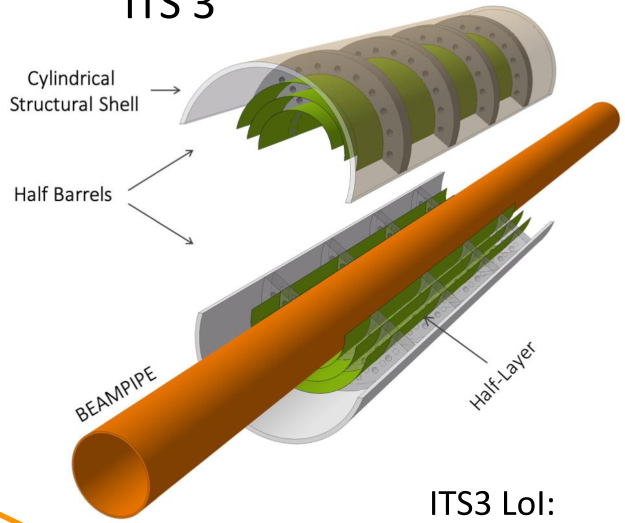
LS3 upgrades - No direct participation from German groups - but R&D

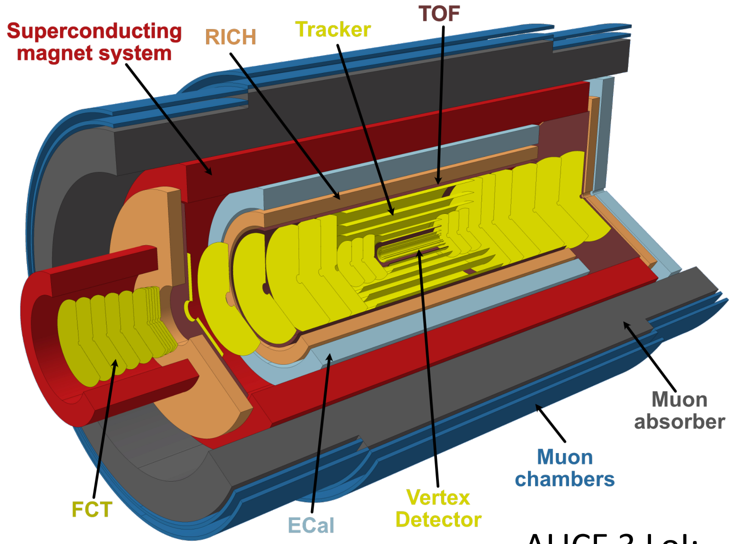
ALICE 3: LS4

Forward Calorimeter
→ nuclear PDF



ITS 3

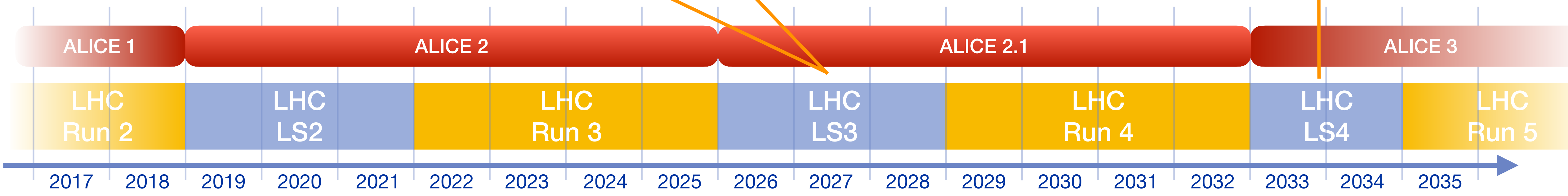




FoCal LoI:
CERN-LHCC-2020-009

ITS3 LoI:
CERN-LHCC-2019-018

ALICE 3 LoI:
CERN-LHCC-2022-009



ITS3 - CHIP DEVELOPMENT ROADMAP

ALICE

past

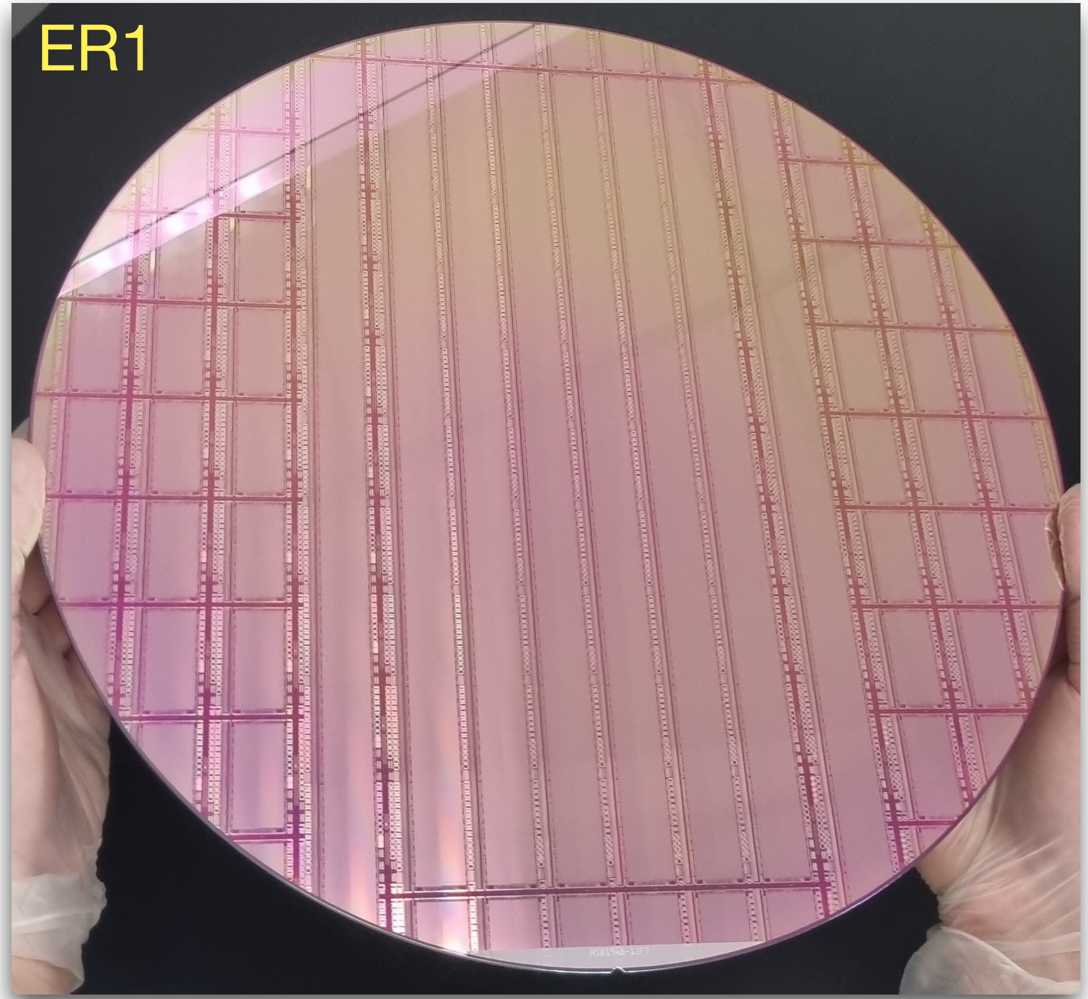
- **MLR1: first MAPS in TPSCo 65nm**
  - successfully qualified the 65nm process for ITS3 (and much beyond)

present

- **ER1: first stitched MAPS**
  - large design “exercise”, stitching was new!
  - tests ongoing

future

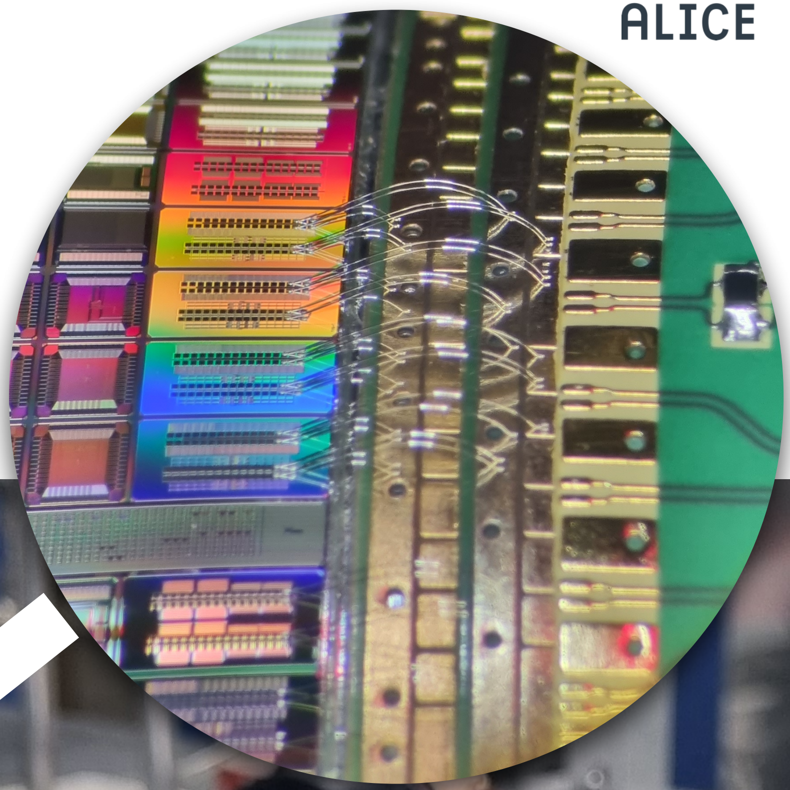
- **ER2: first ITS3 sensor prototype**
  - specifications frozen
  - design ongoing
- **ER3: ITS3 sensor production**

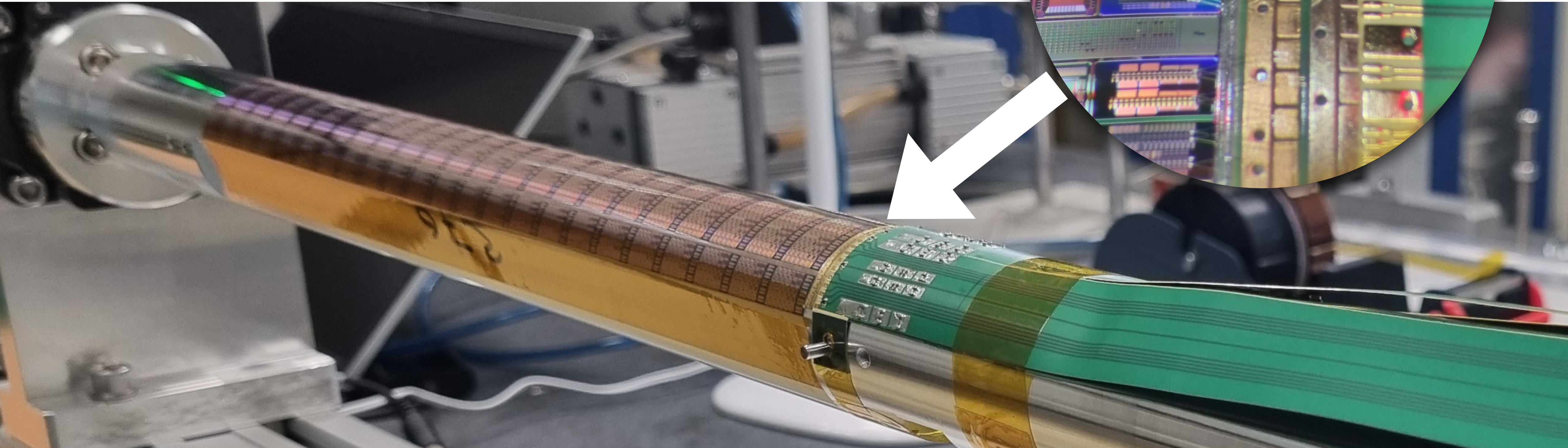


ELECTROMECHANICAL INTEGRATION

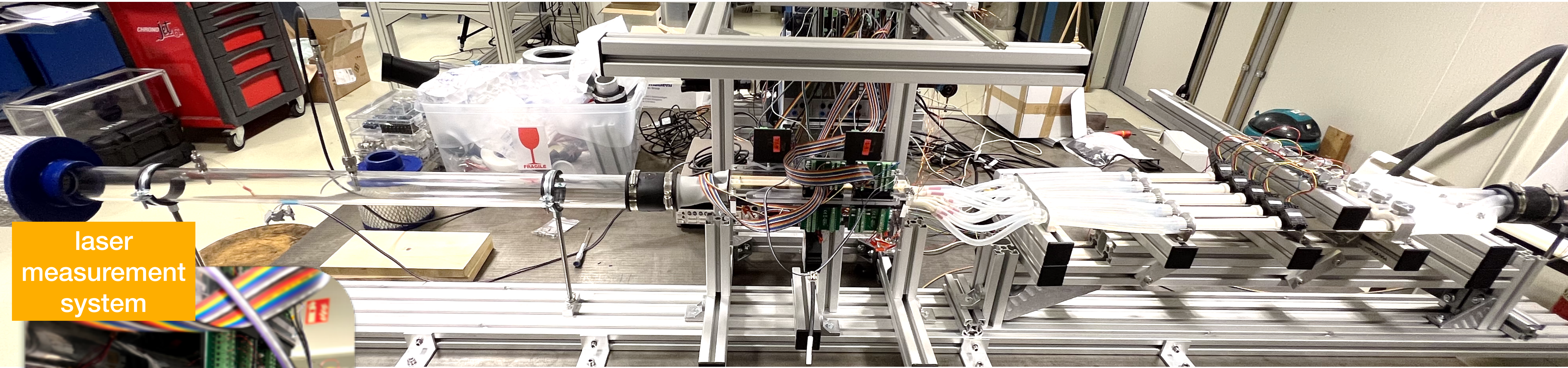
ALICE

- Latest assembly: L0 using “chips”/a section from an existing CMOS wafer
- Wire-bonded to an FPC after bending

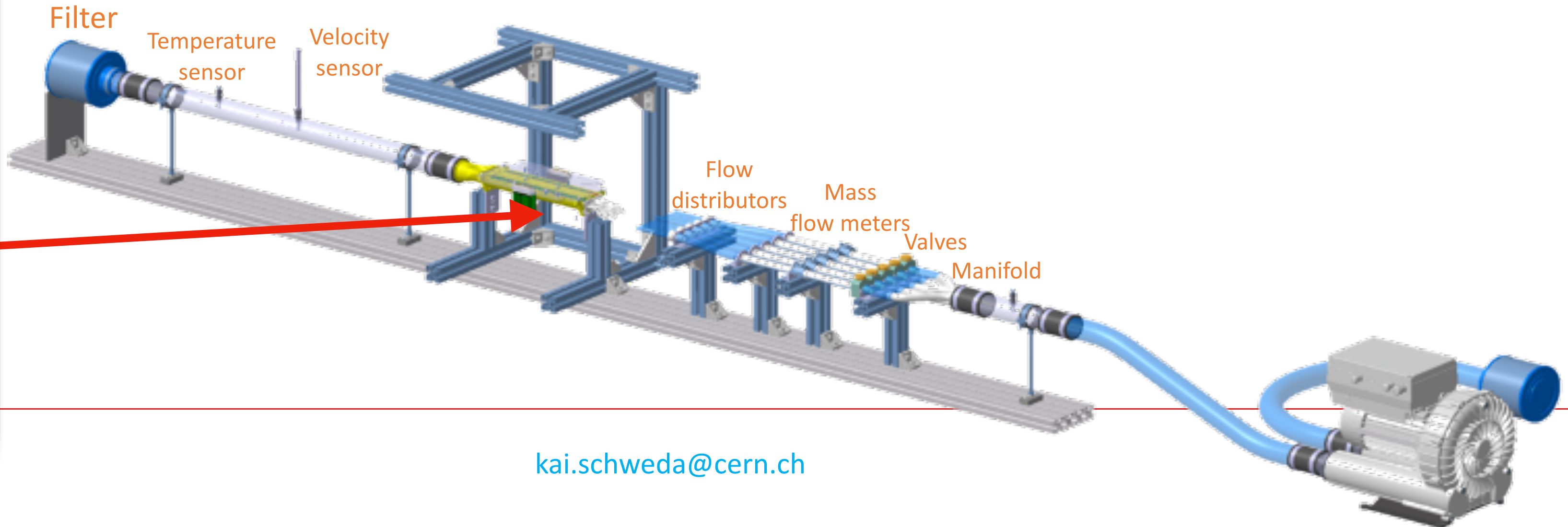




WIND TUNNEL

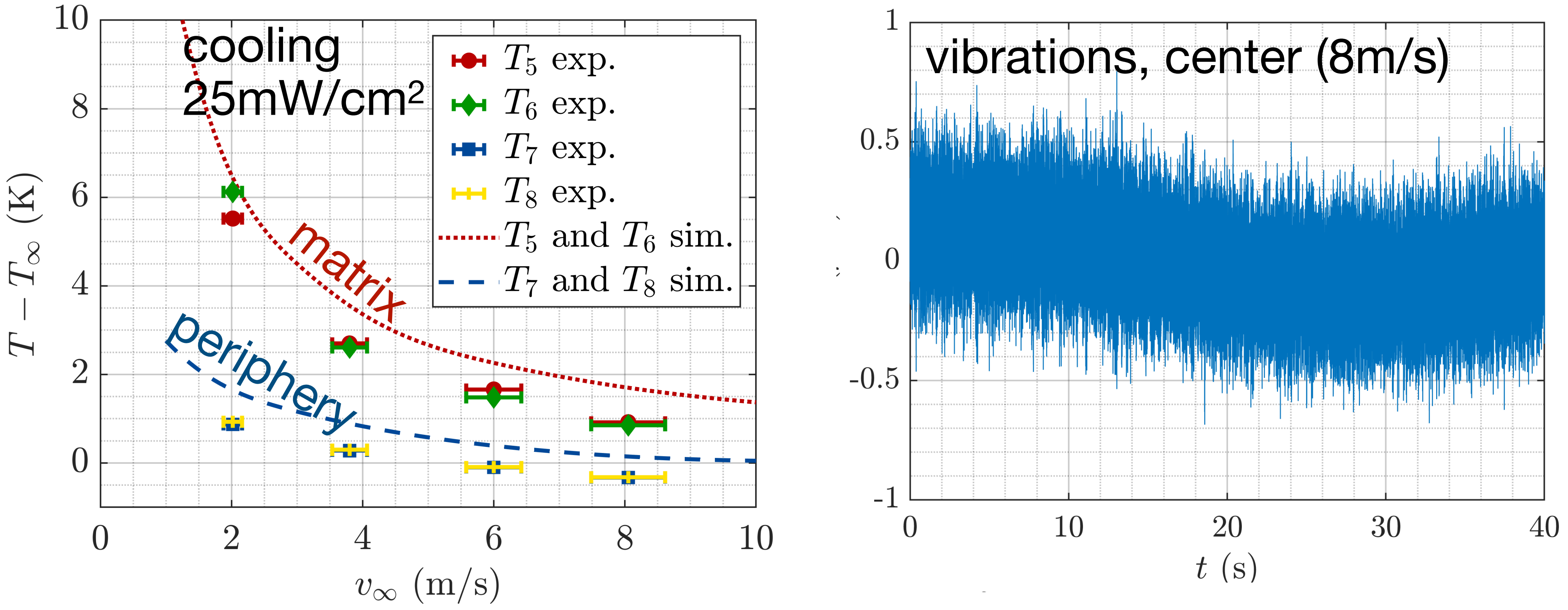



laser
measurement
system


Filter
Temperature
sensor
Velocity
sensor
Flow
distributors
Mass
flow meters
Valves
Manifold

WIND TUNNEL

ALICE



very good results with quite some margin: current target 40 mW/cm²

ALICE 3 DETECTOR

high-efficiency for heavy-quark identification
and reconstruction of low-mass dielectrons
e.g. **chiral symmetry restoration, proton mass**

vertexing close to the beam with
unprecedentedly low material budget

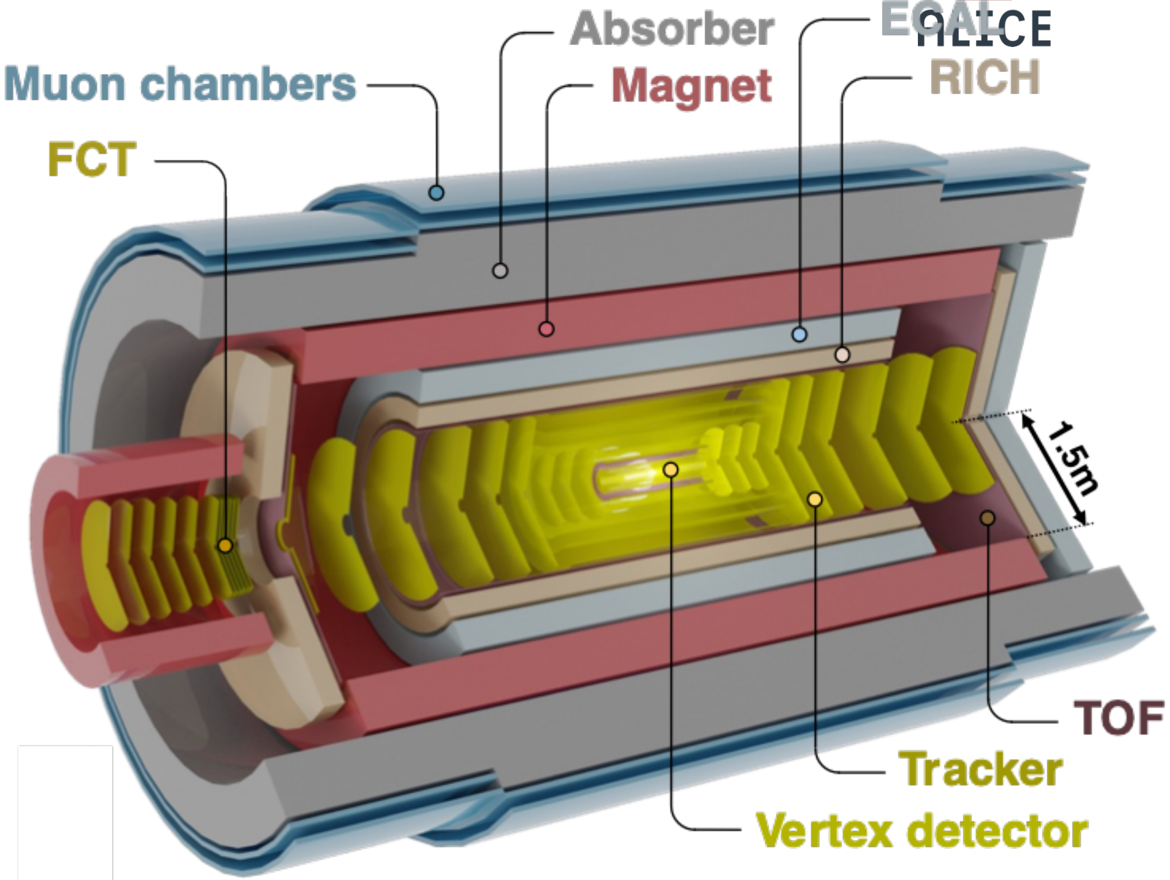
large acceptance with excellent coverage down to low p_T

excellent particle ID (muons, electrons, photons, hadrons)

⇨ **Vertexing precision x 3**: 10μm at p_T = 200 MeV/c

⇨ **Acceptance x 4.5**: $|\eta| < 4$ (with particle ID)

⇨ **A-A rate x 5 (pp x 25)**



Forward conversion tracker (FCT) : **ultrasoft photons, test gauge invariance of QFTs**

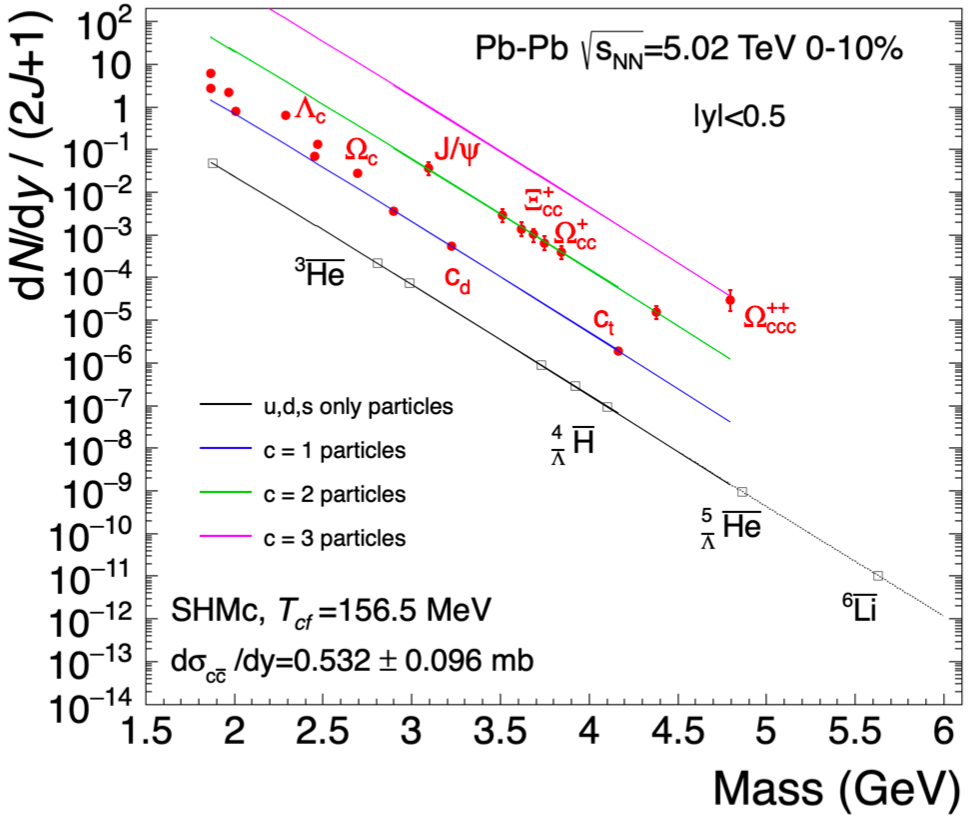
⇨ **novel technologies relevant for future HEP and NP programs**

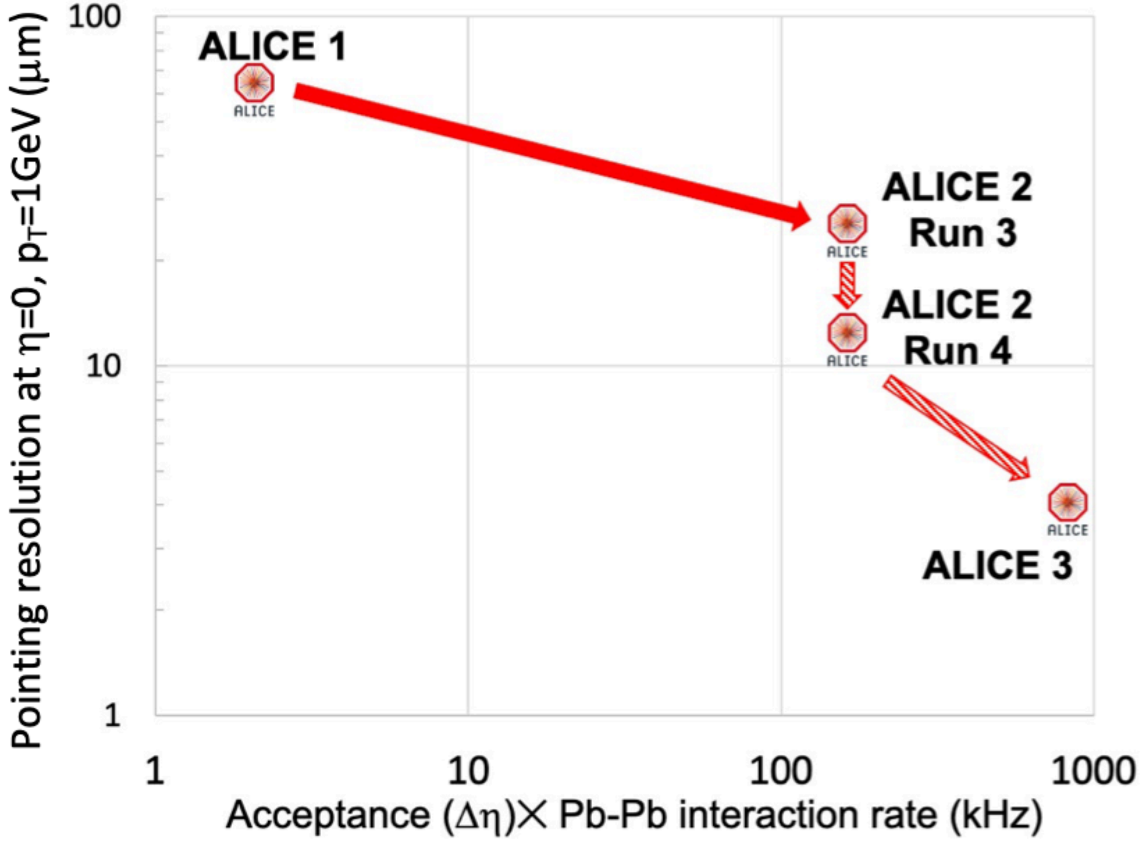
ACCEPTANCE × INTERACTION RATE: NEW OPPORTUNITIES

ALICE

Multiply-charmed baryons (predictions by HD-MS)

CERN-LHCC-2022-009

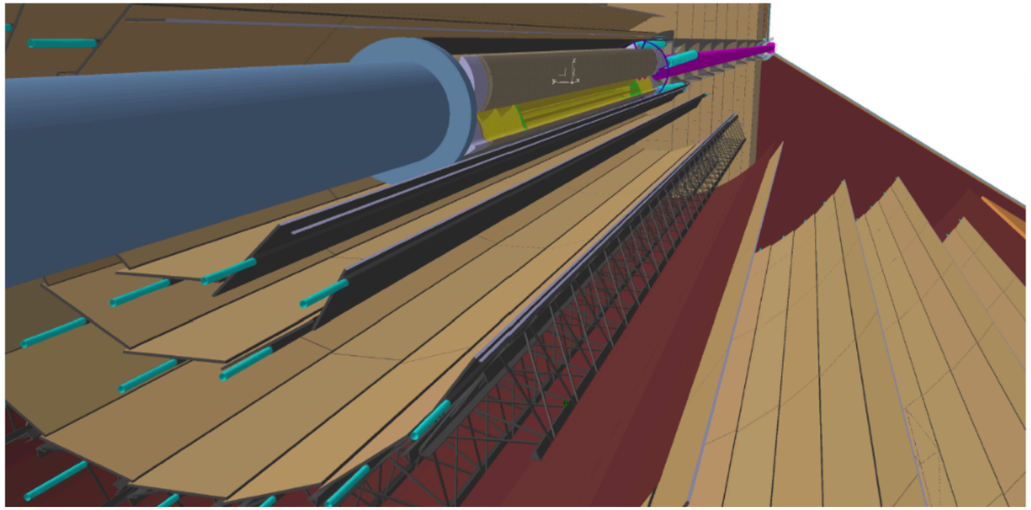




→ discovery potential

ALICE 3 - OUTER TRACKER

ALICE



	Layer	Material thickness ($\%X_0$)	Intrinsic resolution (µm)	Barrel layers Length ($\pm z$) (cm)	Barrel layers Radius (r) (cm)	Forward discs Position ($\|z\|$) (cm)	Forward discs R_{in} (cm)	Forward discs R_{out} (cm)
	0	0.1	2.5	50	0.50	26	0.50	3
Vertex Detector	1	0.1	2.5	50	1.20	30	0.50	3
	2	0.1	2.5	50	2.50	34	0.50	3
	3	1	10	124	3.75	77	5	35
Middle Layers	4	1	10	124	7	100	5	35
	5	1	10	124	12	122	5	35
	6	1	10	124	20	150	5	80
	7	1	10	124	30	180	5	80
	8	1	10	264	45	220	5	80
Outer Tracker	9	1	10	264	60	279	5	80
	10	1	10	264	80	340	5	80
	11	1				400	5	80

- 33 m² (Barrel) + 12 m² (forward discs) CMOS MAPS detector: Largest ever built of this kind!
- Maximum 1% radiation length per layer
- Power consumption 30 mW/cm² → Total 8 kW (only sensors)
- Envisaged spatial resolution of 10 µm

ALICE 3 - OUTER TRACKER & FCT

Participation / Ineters from German GroupsWork
Coordination: TUM - FRA

A3-WP1: Cooling - TUM -HD

A3-WP2: Development of staves and end-wheels: HD - FRA

A3-WP3: Industrialized module fabrication

A3-WP4: Powering

A3-WP5: Design of read out section of chips and of large pixels: Bonn - GSI - HD

A3-WP6: Simulations HD - TUM

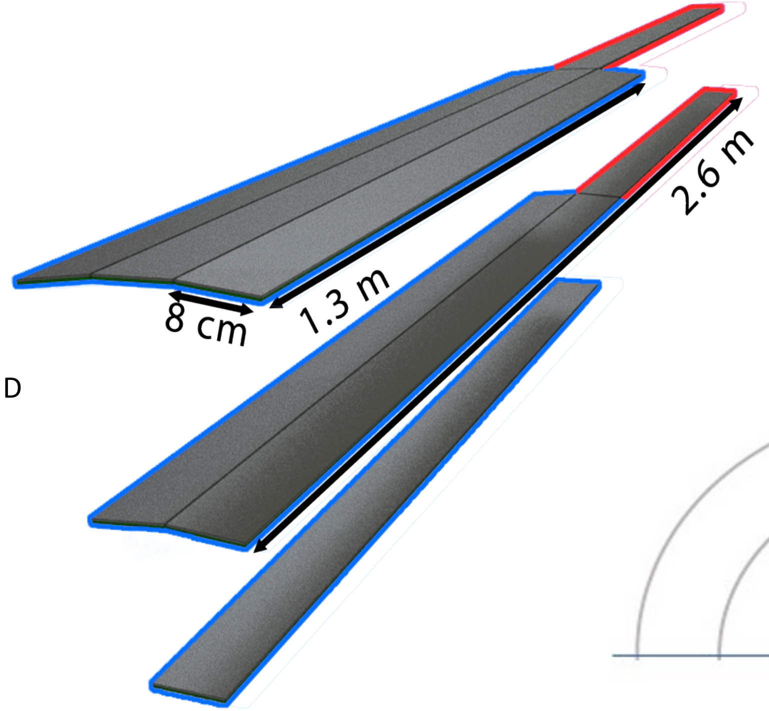
A3-WP7: Detector control system (DCS)

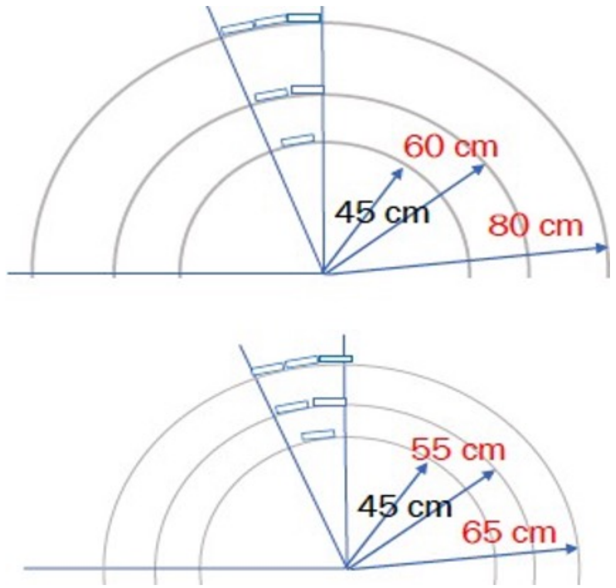
A3-WP8: Testing of module components at accelerator facilities

Readout: FIAS / FRA

Goal: Build a 10 staves prototype between 2023-2027

Funding application submitted to BMBF 01/07/2023





PROVISIONAL SUMMARY OF SCOPING

ALICE

Detector versions	Cost [MCHF]	%	Impact on physics programme
Layout v1-LoI	**141.5 (LoI)**	**-**	
Layout v2-2T: w/o ECal		**approx -12% wrt v1**	Large degradation of BSM searches, charmonia, jets
Layout v2-1T: same as above but B=1T		**approx -23% wrt v1**	Significant impact on heavy-flavour studies, especially at forward rapidity

→ Full assessment will be prepared for Scoping Document

UPCOMING EVENTS

- **Upgrade week**: 4-7 December in Turin, Italy, 160 participants (!)
- Next **ALICE week**: 4-8 March 2024 at CERN
- Strange Quark Matter: 3-7 June 2024, Strasbourg, France
- LHC Physics Conference: 3-7 June 2024, Boston, USA

CONCLUSION

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RUN 3 (2022 - 2025)

ALICE collected an enormous amount of high-quality data with the upgraded detector

29 /pb in pp, 1.5 /nb in Pb-Pb

physics analysis under way, getting ready for the summer conferences

RUN 4 (2028 - 2032)

FoCal and ITS 3 Upgrades progressing well, Technical Design Reports on Track

RUN 5 + 6 (2033 - 2042)

ALICE 3 scoping document well advanced, submission to LHCC in Q1/2024