ALICE experiment
Past, Present & Future

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30 anniversary of ALICE Letter of Intent

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This contribution is supported by the project Centre of Advanced Applied Sciences with the number: CZ.02.1.01/0.0/0.0/16-019/0000778
Project Centre of Advanced Applied Sciences is co-financed by European Union

Overview of the talk

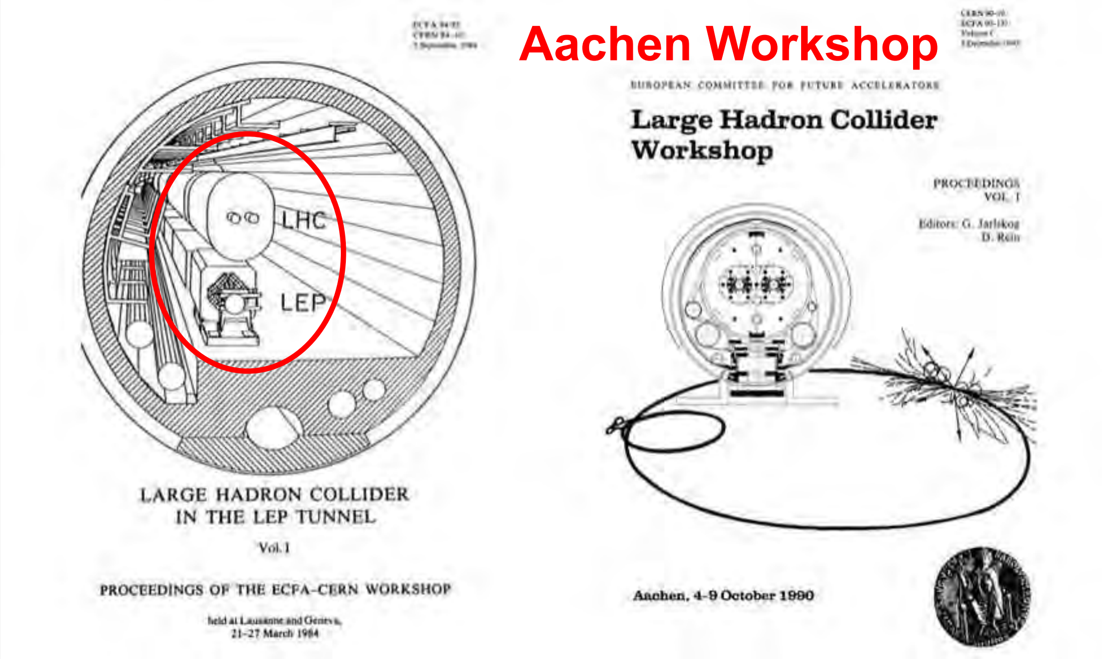
- ALICE experiment – history
- Physics highlights Run 1 and 2
- ALICE upgrade for Run 3
- ALICE future

  Upgrade for Run 2
  ALICE 3 project

Heavy Ions @ LHC

- First (sub-)detector concepts of heavy-ion experiment at the LHC
  - Aachen 1990 conference (E.Quercigh, P.Sondereger, H.Specht, …)
- Heavy-ion detector proposal(s)
  - Evian 1992 workshop (dedicated detector, modified DELPHI, CMS)

- Letter of Intent 1993 – ALICE experiment (addition of muon spectrometer requested by LHCC)
- Technical Proposal 1995 (1996 – 2006 addenda), approved 1997
- 1998 – 2005 Technical Design Reports



Why HI @ LHC ? Energy !

For A-A collisions:

$E_{cms} = 5500\ A$ GeV

$E_{lab} = E_{cms}^2 / (2A\ m_N) = 1.61 \times 10^7\ A$ GeV

for lead ions $E_{lab\ Pb\text{-}Pb} = 3.35 \times 10^9$ GeV $= 3.35 \times 10^{12}$ MeV

Further we need **Harald Fritzsch Identity** (definition of Anglo-Saxon pound $£_{AS}$)

$2 \times 10^{-30}\ £_{AS} = m_e$ (= 0.511 MeV)

and some other definitions (gravitational acceleration g)

$g = 1$ in/tr^2 (1 s = 19.65 tr, trice)

(speed of light c) $c = 6 \times 10^8$ in/tr

$m_e c^2 = 72 \times 10^{-14}\ £_{AS}$ in (= 0.511 MeV)

1 MeV $= 1.41 \times 10^{-12}\ £_{AS}$ in

Finally

$E_{lab\ Pb\text{-}Pb} = 1\ £_{AS} \times 4.7''$ (= 0.45 kg × 12 cm)

LHC Energy

And for pp collisions:

$$E_{lab\ pp(14TeV)} = 0.15\ £_{AS}\ \text{in} \approx ¼\ £_{AS} \times ½'' = ⅛\ £_{AS} \times 1'' = \ldots$$

For those who don't like to be seated on a lead ion (and to fly inside LHC vacuum pipe)

$$E_{cms\ Pb\text{-}Pb} = 5500\ A\ \text{GeV} = 1.14 \times 10^9\ \text{MeV}$$

(HFI, etc.)

$$E_{cms\ Pb\text{-}Pb} = 10^{-3}\ £_{AS} \times 1.6''\ (= 0.45\ \text{g} \times 4\ \text{cm})$$

Still, macroscopic energy !!! (one can actually hear it)

But the size of ions

is by factor more than 10^{-12} smaller

Early ALICE designs

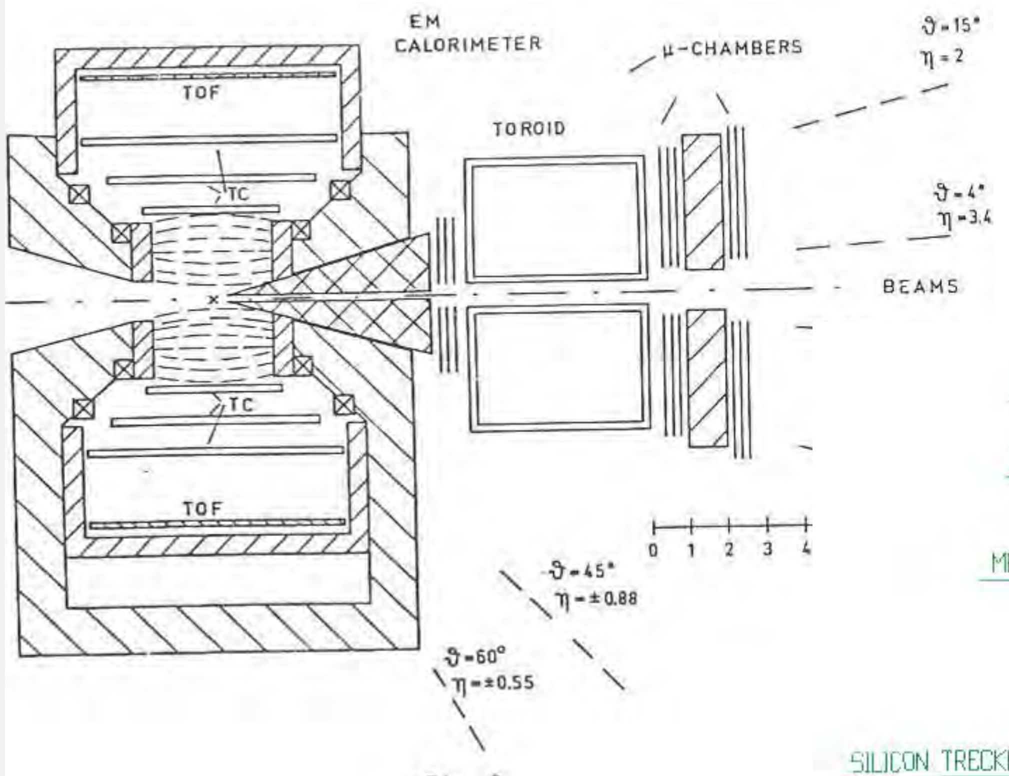
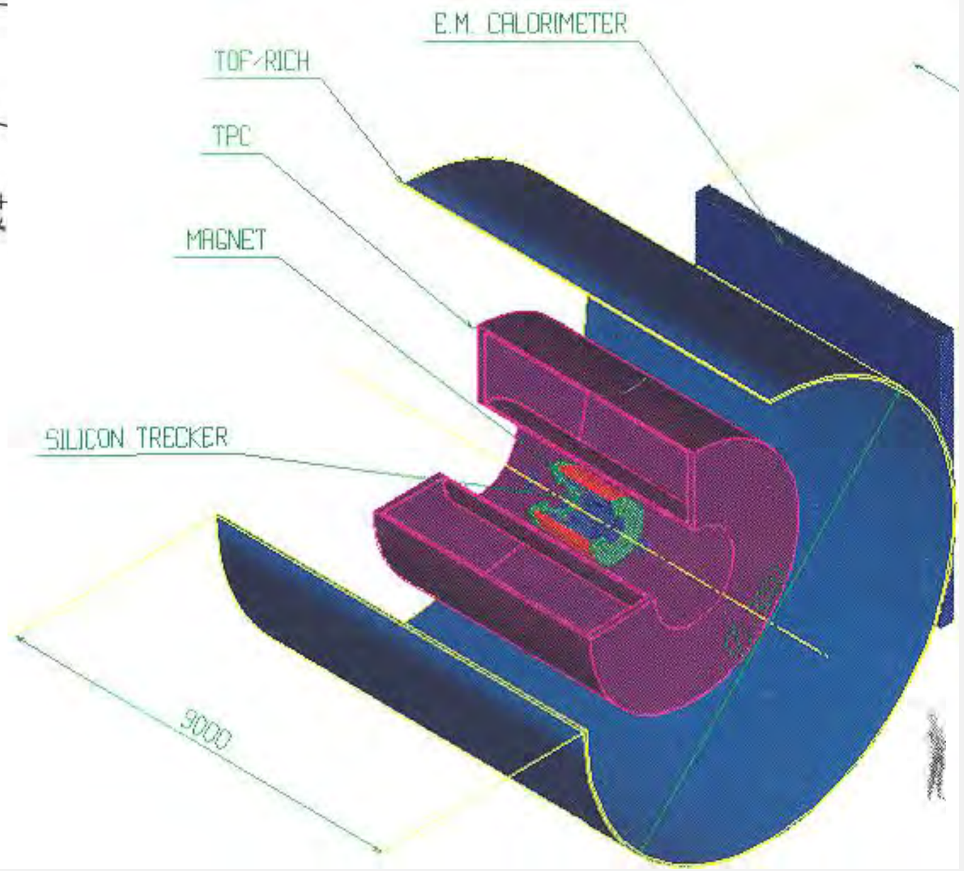


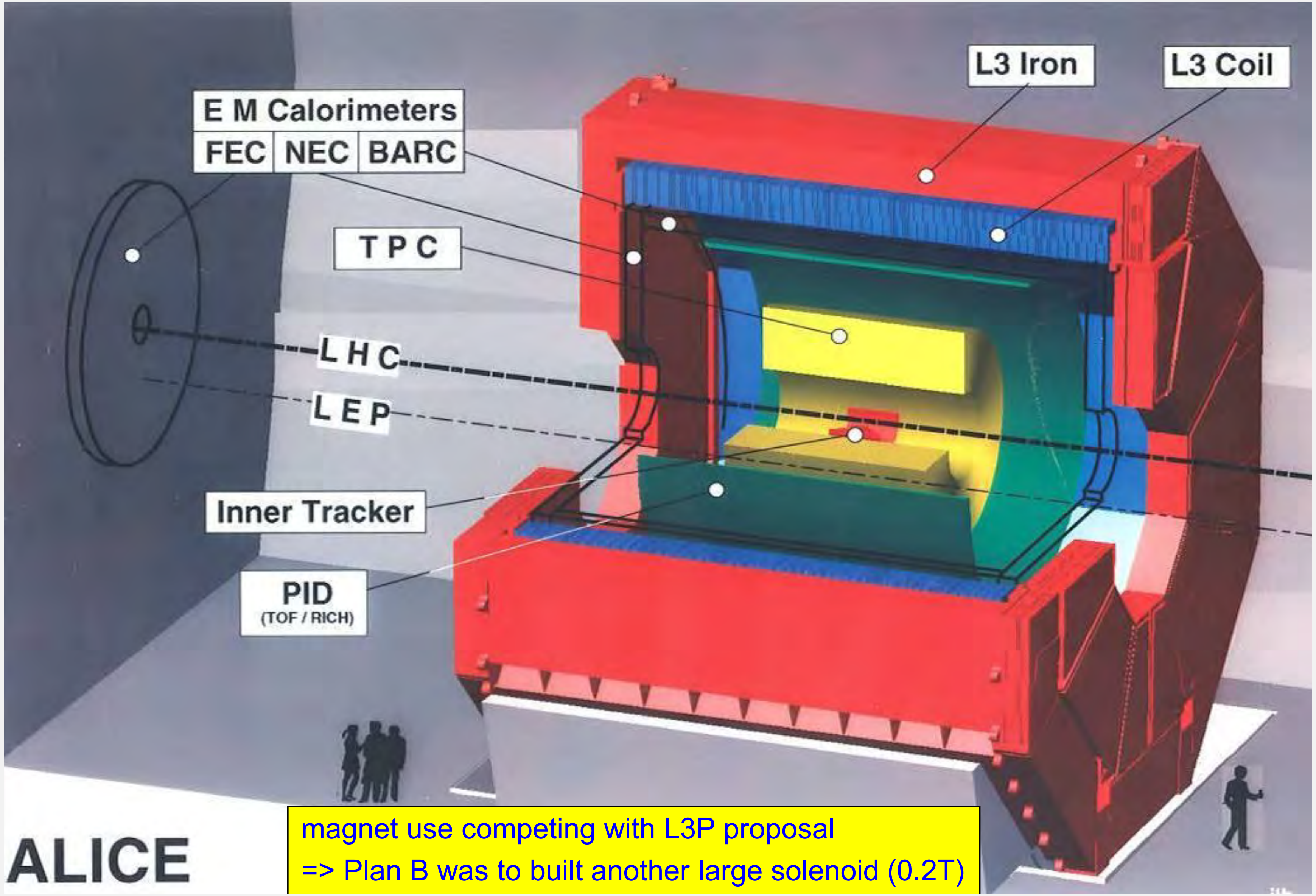
Fig. 3

1990 Design (Aachen)
open axial field magnet
(AFS/ISR, + NA38 muons)

1992 Design (Evian)
no muons
thin (<17%X_0) and small solenoid



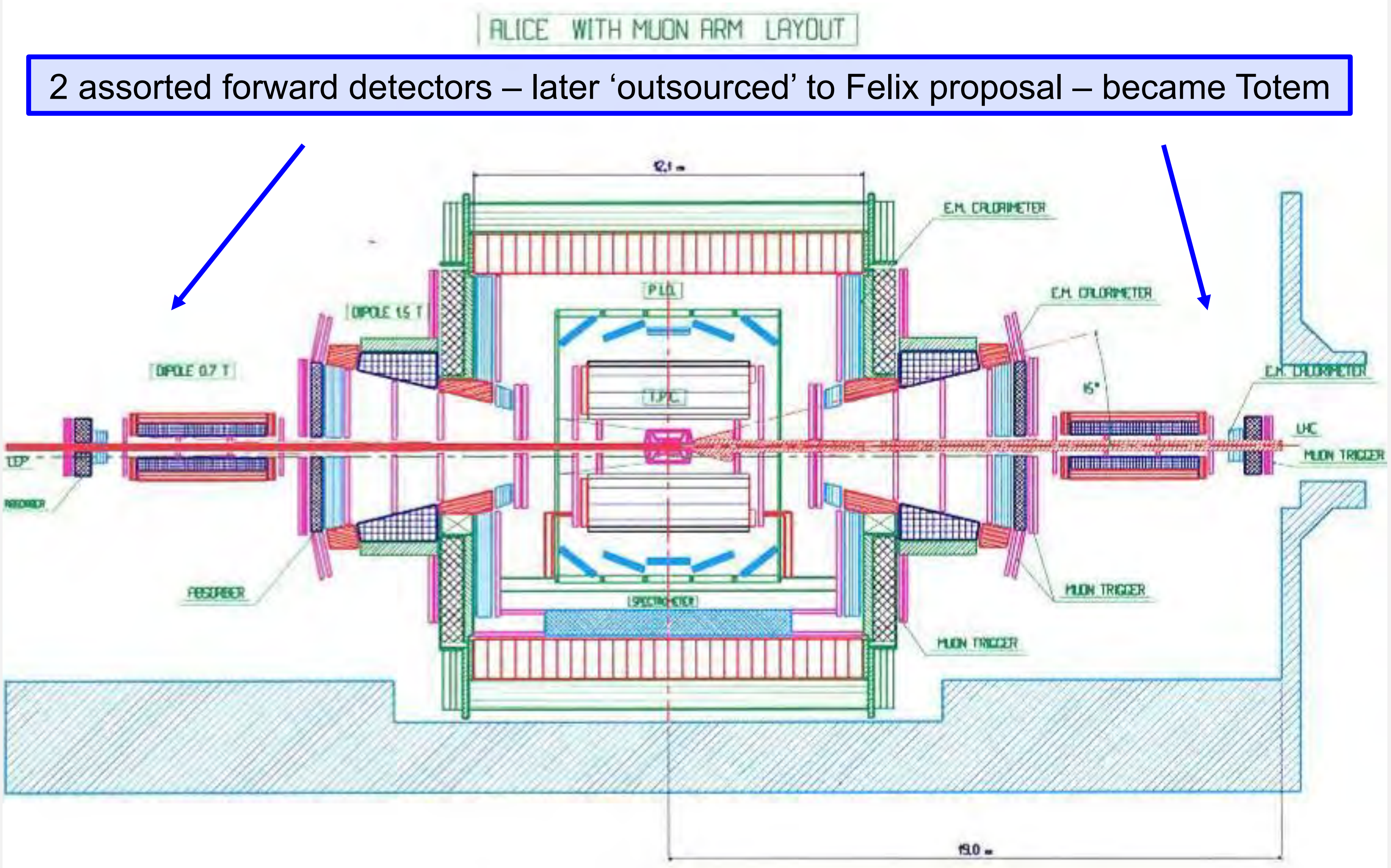
ALICE @ LoI time



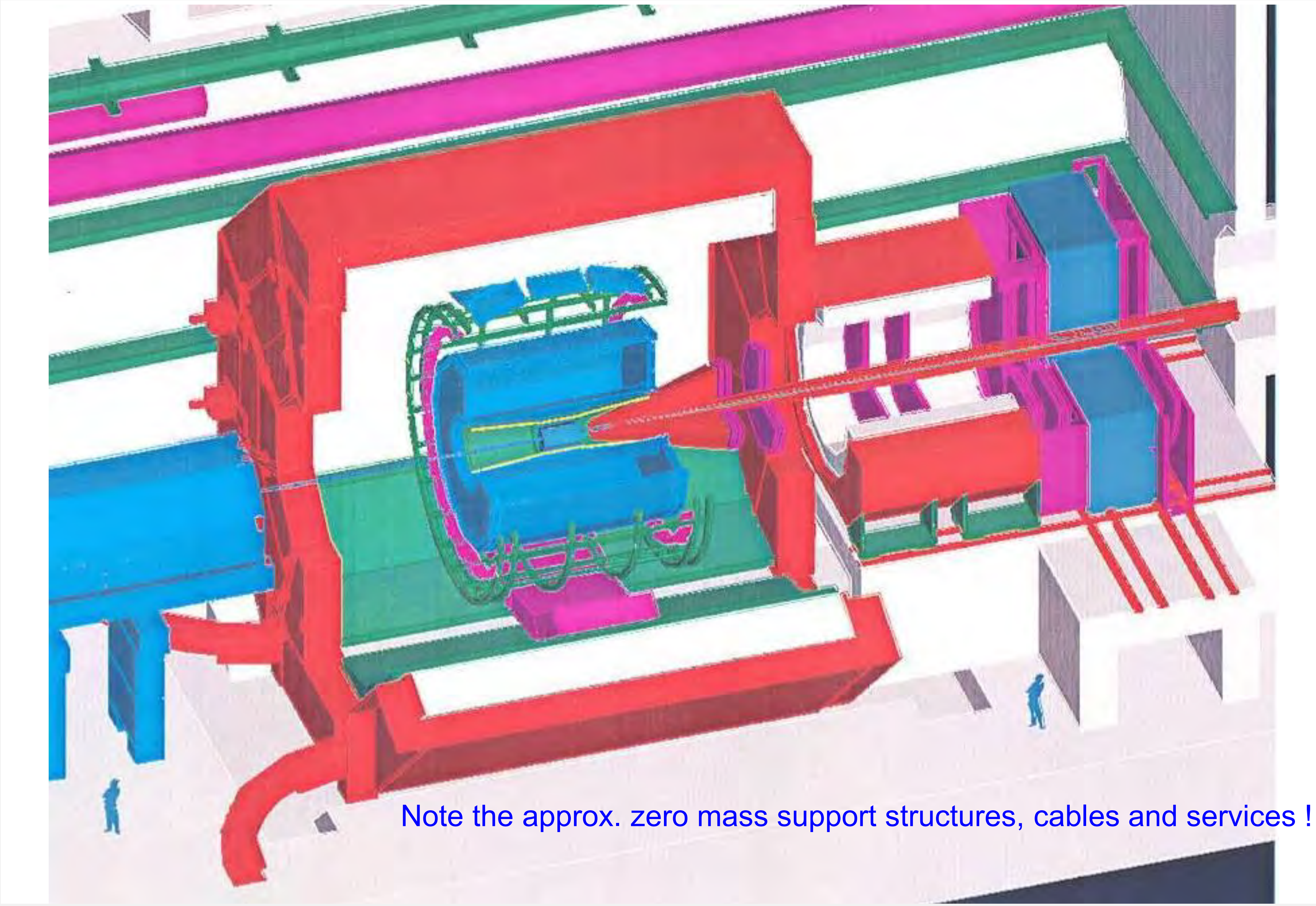
magnet use competing with L3P proposal
=> Plan B was to built another large solenoid (0.2T)

Mega-Alice in 1994

2 assorted forward detectors – later ‘outsourced’ to Felix proposal – became Totem



ALICE in TP (1995)



Many years of R&D

- **Inner Tracking System (ITS)**
  - ⇨ Silicon Pixels (RD19)
  - ⇨ Silicon Drift (INFN/SDI)
  - ⇨ Silicon Strips (double sided)
  - ⇨ low mass, high density interconnects
  - ⇨ low mass support/cooling

RHIC

RHIC

- **TPC**
  - ⇨ gas mixtures (RD32)
  - ⇨ new r/o plane structures
  - ⇨ advanced digital electronics
  - ⇨ low mass field cage

RHIC

- **em calorimeter**
  - ⇨ new scint. crystals (RD18)

- **PID**
  - ⇨ Pestov Spark counters
  - ⇨ Parallel Plate Chambers
  - ⇨ Multigap RPC's (LAA)
  - ⇨ low cost PM's
  - ⇨ CsI RICH (RD26)

RHIC

RHIC

- **DAQ & Computing**
  - ⇨ scalable architectures with COTS
  - ⇨ high perf. storage media
  - ⇨ GRID computing

?

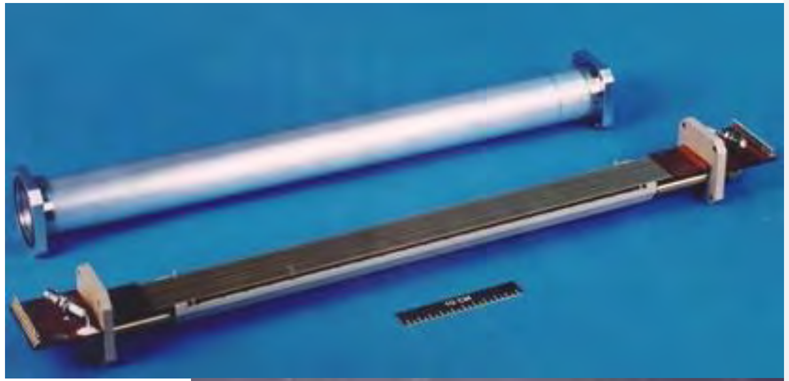
?

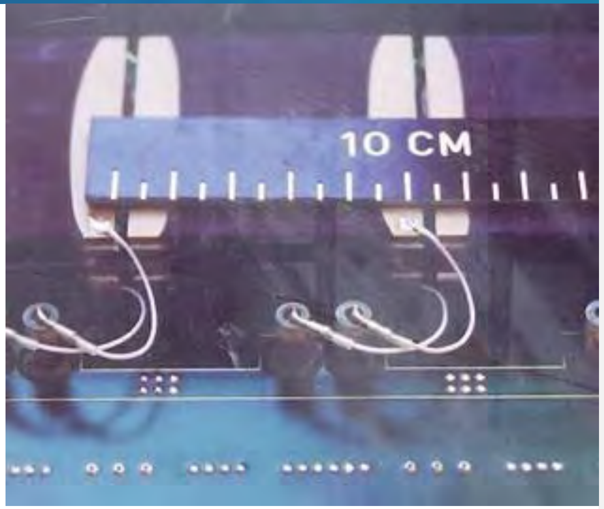
?

- **misc**
  - ⇨ micro-channel plates
  - ⇨ rad hard quartz fiber calo.
  - ⇨ VLSI electronics

R&D example: Time of Flight

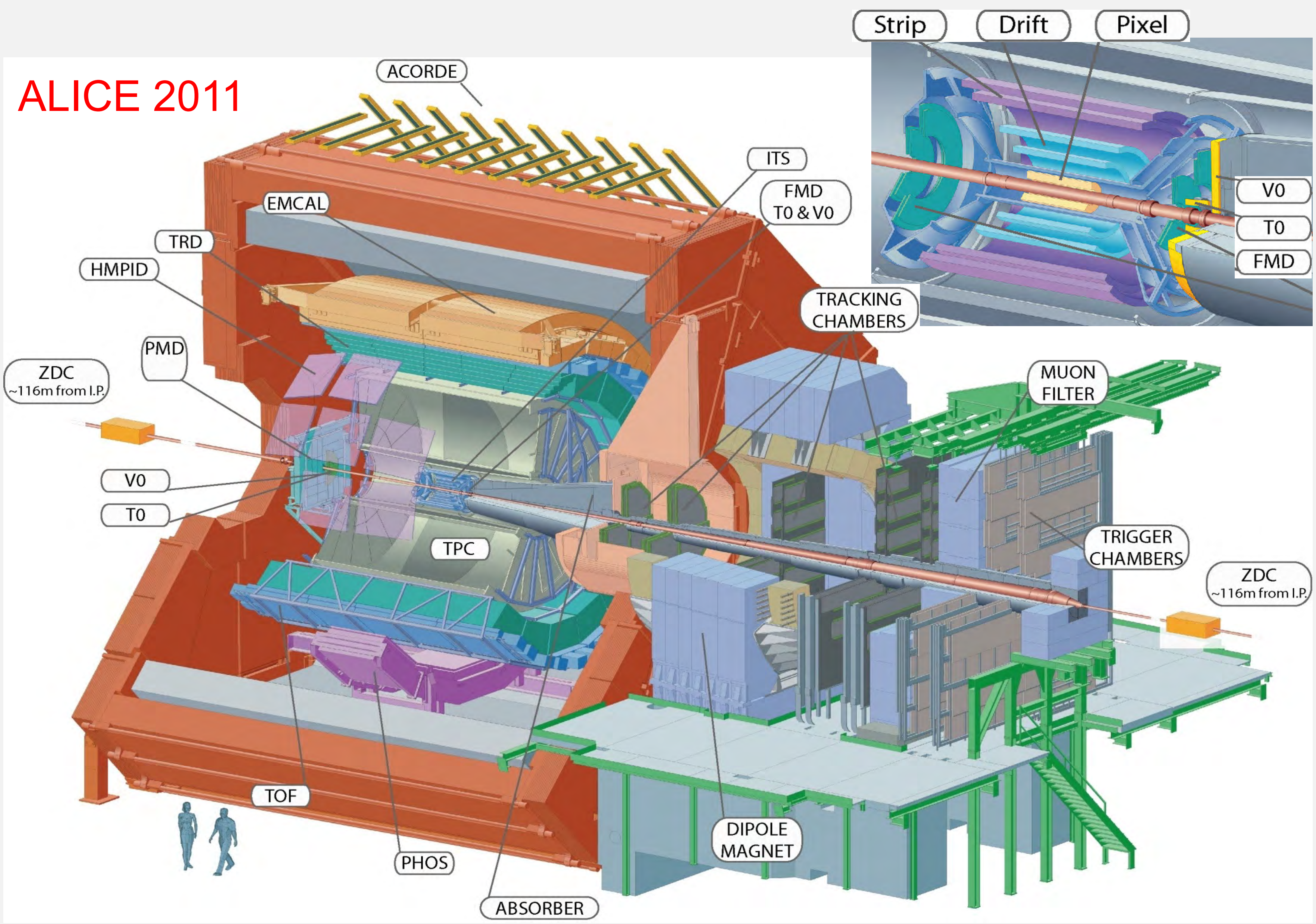
- aim: state-of-the-art TOF at ~1/10 current price !
  - ⇨ requirements: area > 150 m^2, channels ~ 150,000, resolution σ < 100 ps
  - ⇨ existing solution: scintillator + PM, **cost > 150 MSF !**
    - R&D on cheaper fast PM's failed
- gas TOF counters + VLSI FEE
  - ⇨ **Pestov Spark Counter** (PSC) **HIGH TEC**
    - 100 μm gap, > 5 kV HV, 12 bar, sophisticated gas
    - **σ < 50 ps,** but only (!) **~ 1/5 cost**
    - technology & materials **VERY challenging**
  - ⇨ **Parallel Plate Chamber** (PPC) **LOW TEC**
    - 1.2 mm gap, 1 bar, simple gas & materials
    - **1/10 cost,** but only **σ = 250 ps**
    - **unstable operation, small signal**
  - ⇨ **Multigap Resistive Plate Chambers** (MRPC)
    - breakthrough end 1998 after > 5 years of R&D !
    - many small gaps (10x250 μm), 1 bar, simple gas & materials
    - **~ 1/10 cost, σ < 100 ps** , simple construction & operation,..



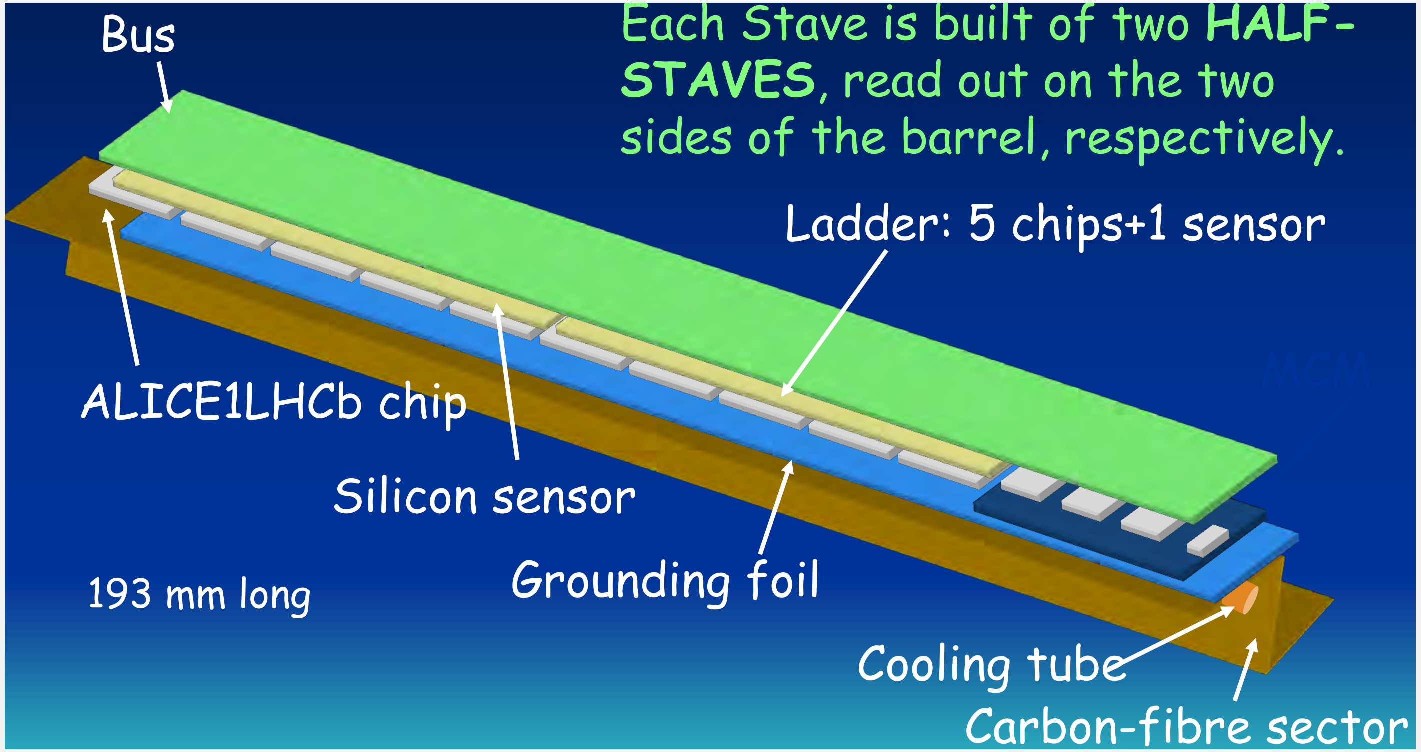


found immediate wide use:
HARP, STAR,PHENIX, HADES/CBM@GSI,..
option for time-stamping at ILC/CLIC

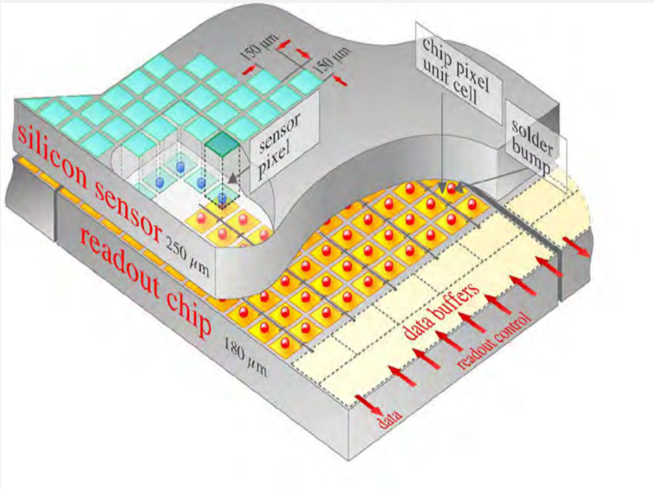
ALICE 2011

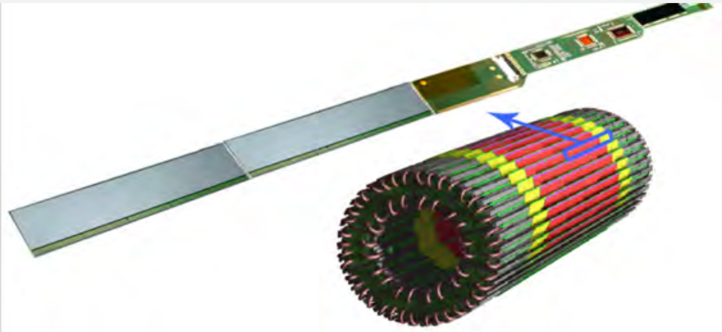

ACORDE
ITS
FMD
T0 & V0
EMCAL
TRD
HMPID
PMD
ZDC
~116m from I.P.
V0
T0
TPC
TOF
PHOS
ABSORBER
TRACKING
CHAMBERS
MUON
FILTER
TRIGGER
CHAMBERS
ZDC
~116m from I.P.
DIPOLE
MAGNET
Strip
Drift
Pixel
V0
T0
FMD

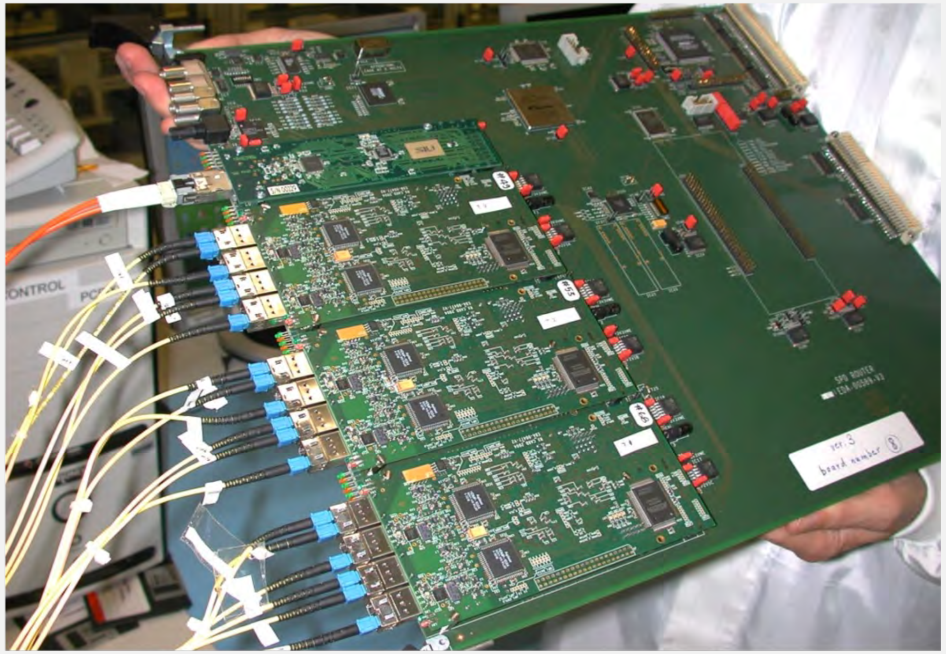
Silicon Pixel Detectors



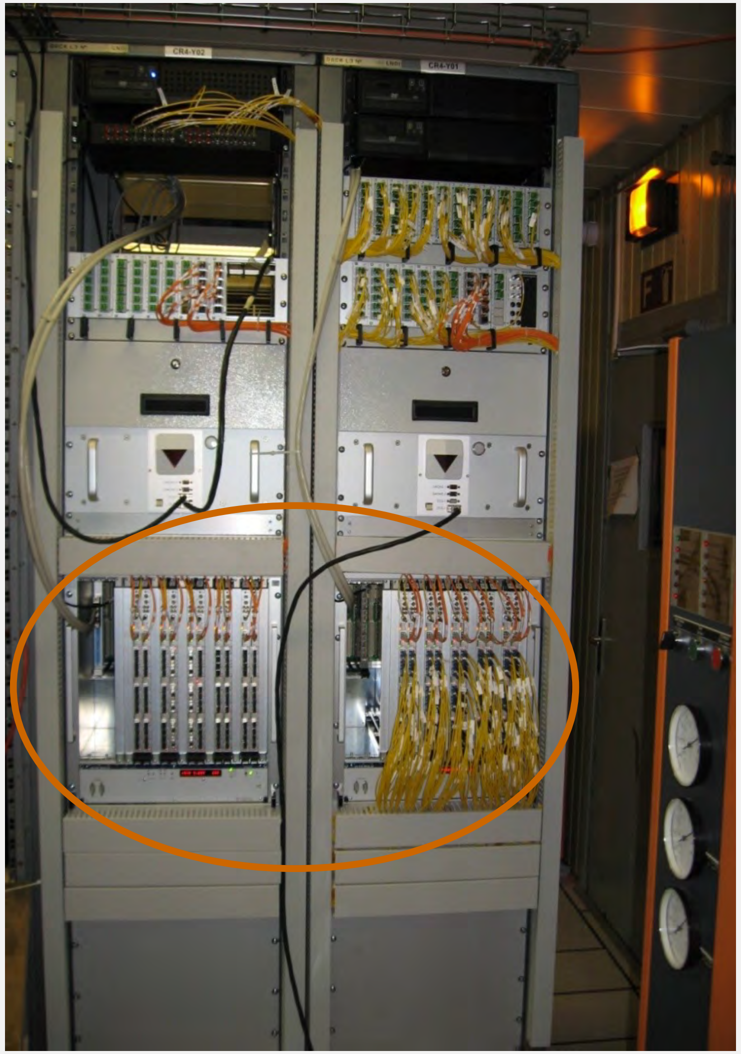
Silicon Pixel Detector assembly







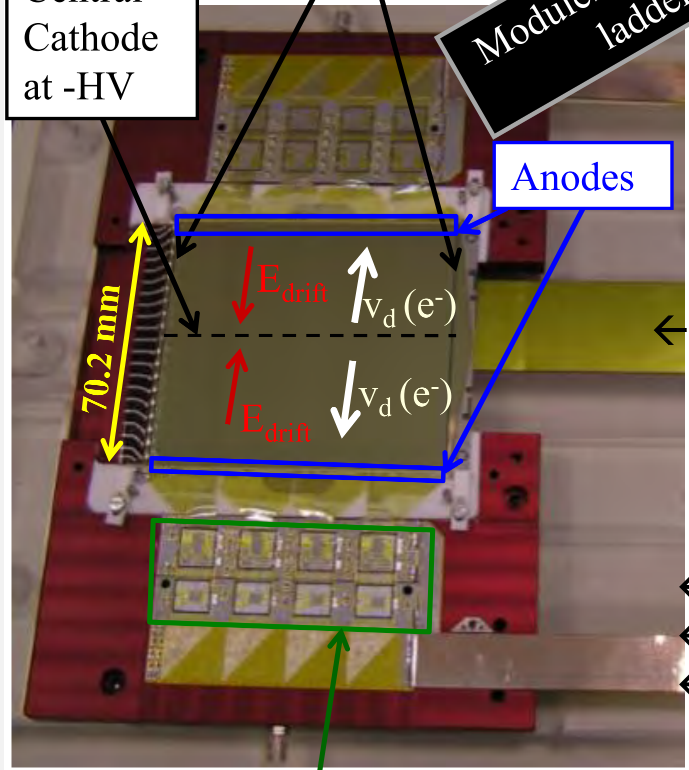
SPD router



Installation in
ALICE experiment

Silicon Drift Detectors

Drift



←HV supply

←LV supply
←Commands
←Trigger
Data →

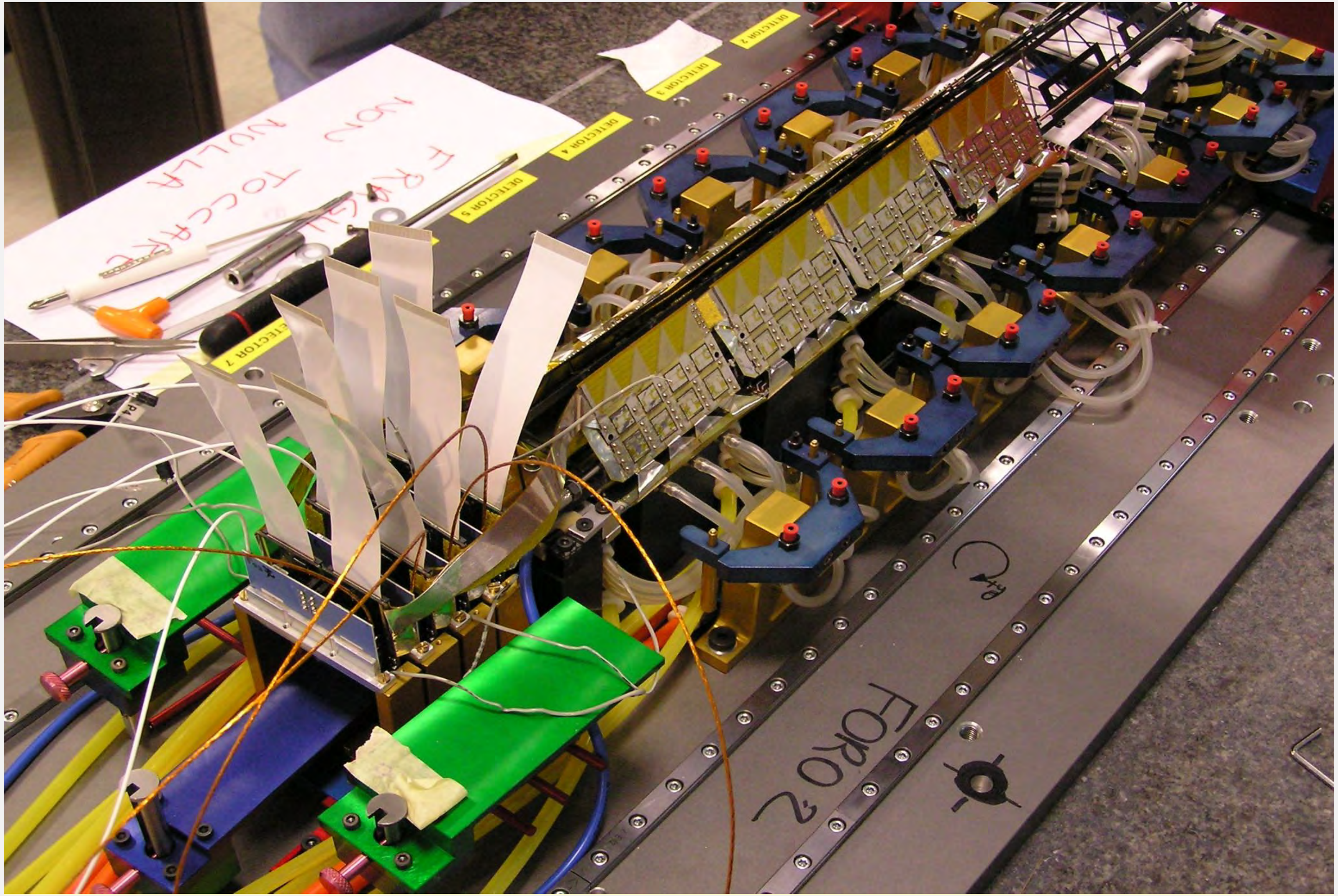
Front-end electronics (4 pairs of ASICs)
-> Amplifier, shaper, 10-bit ADC, 40 MHz sampling
-> Four-buffer analog memory

Modules mounted on ladders

Layer	# ladders	Mod./ladder	# modules
3	14	6	84
4	22	8	176

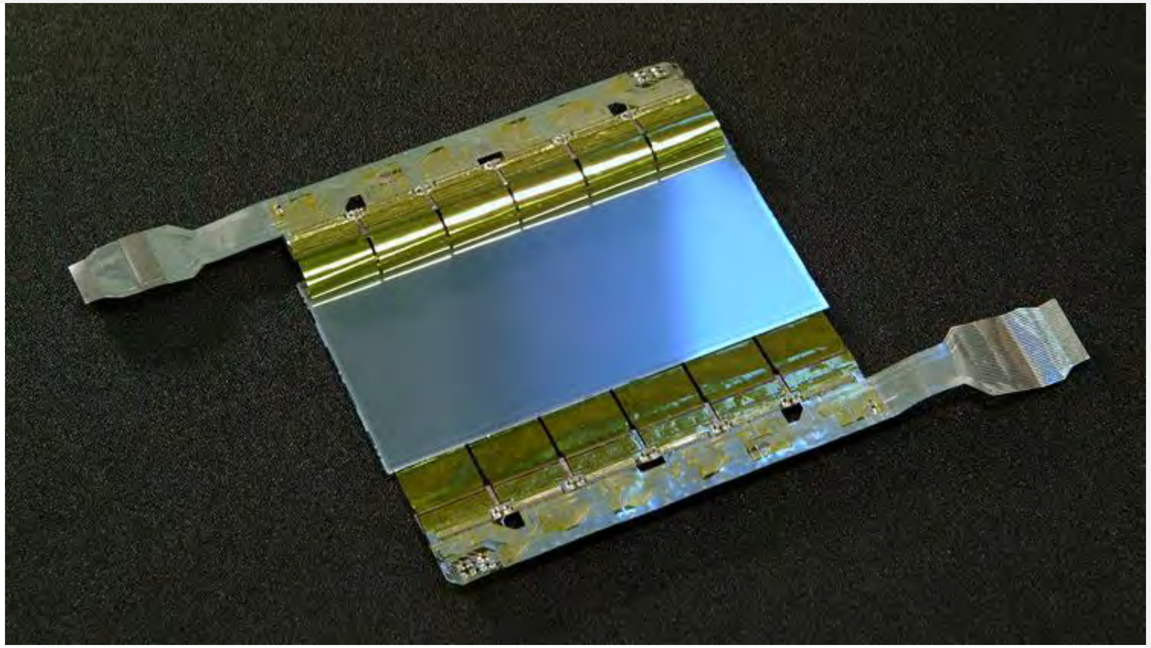
SDD layers into SSD

Silicon Drift Detector Ladder



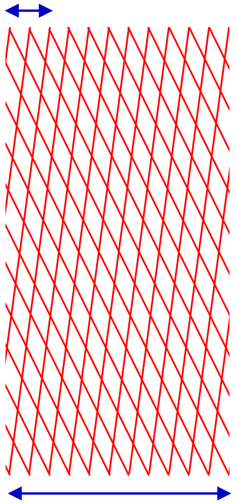
Silicon Strip Detectors

SSD Detector



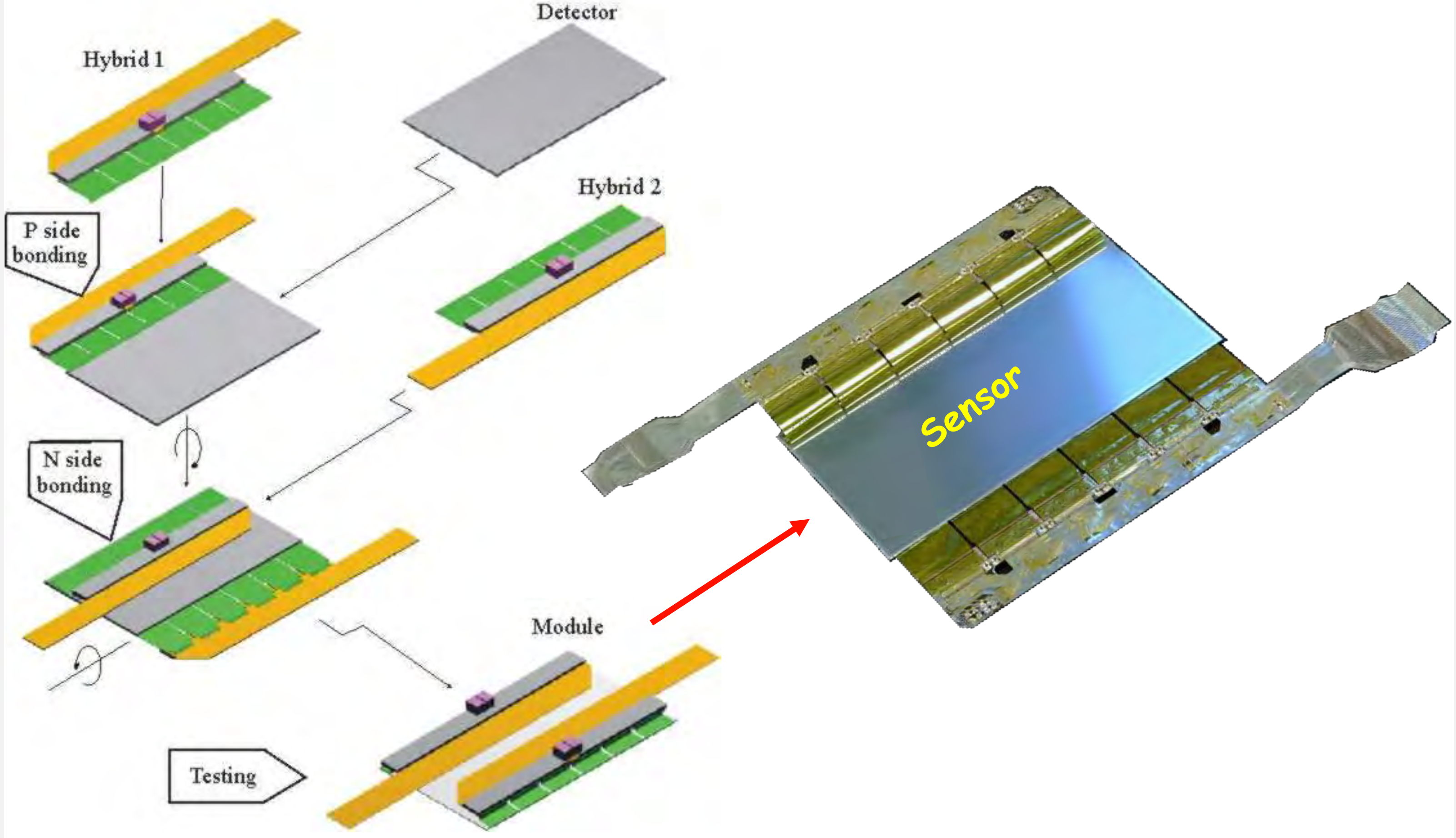
P: 3 short strips
7.5 mrad

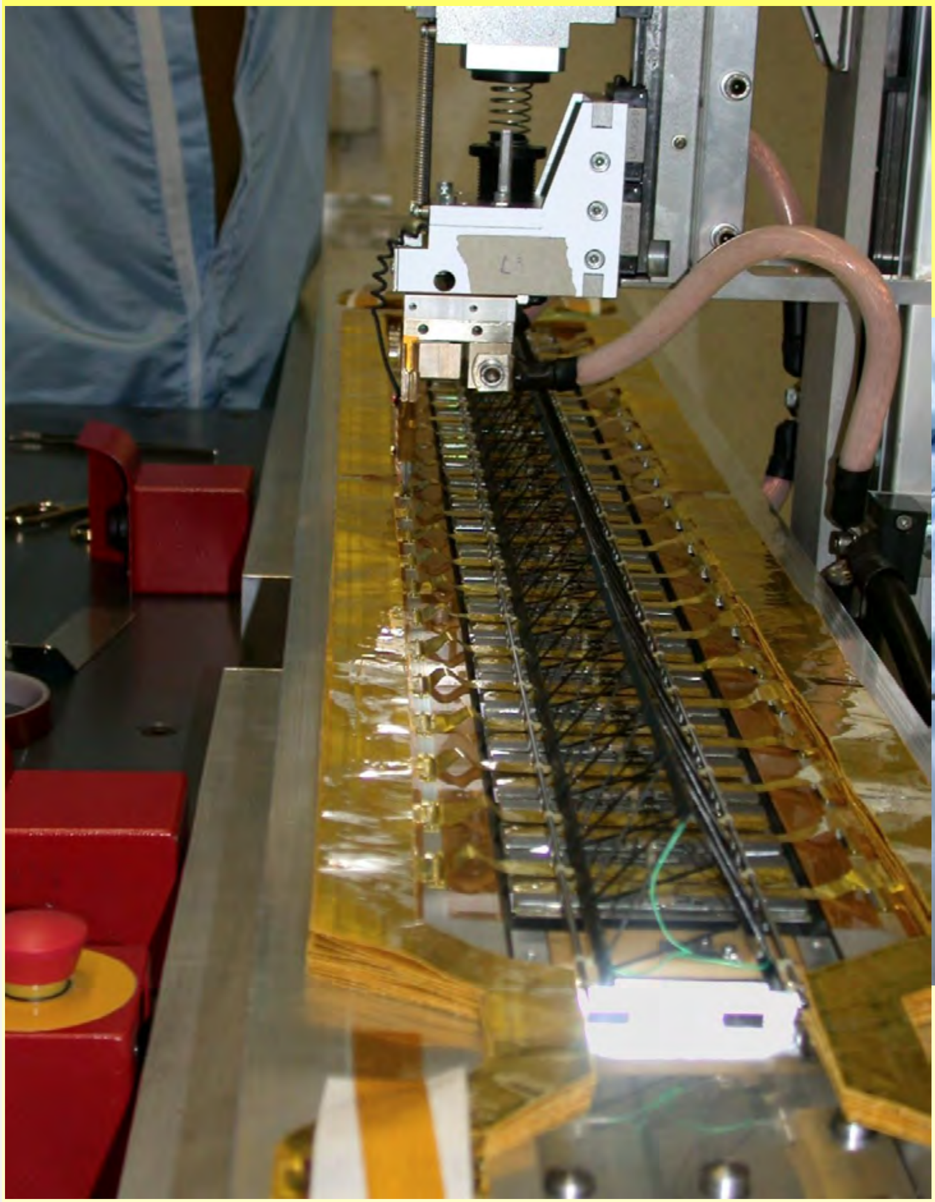
N: 11 short strips
27.5 mrad



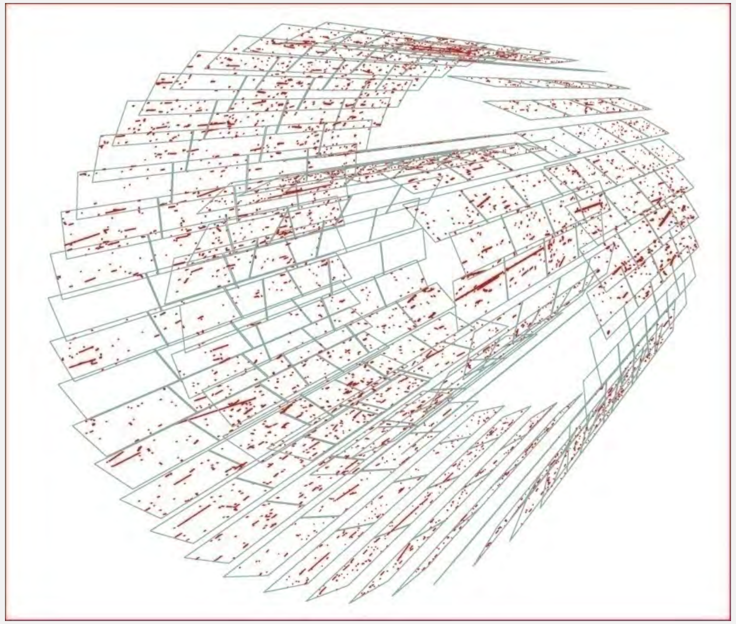
- Stereo Double-sided short strips , asymmetric
- Produced at IRST, Canberra and Sintef

Silicon Strip Detector assembly

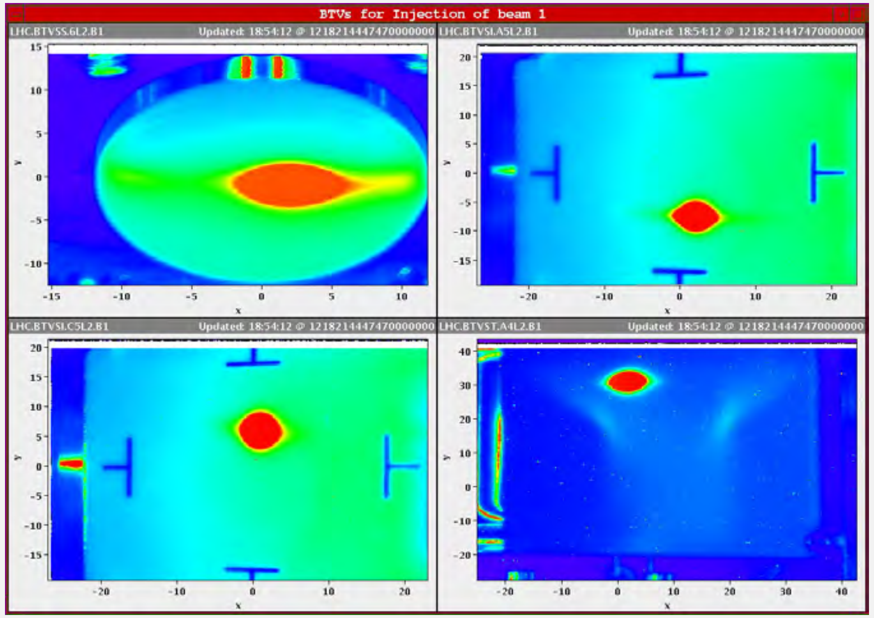




SPD test at LHC



Hictoricaly the first particles in the LHC detected by SPD during injection test 15.06.2008



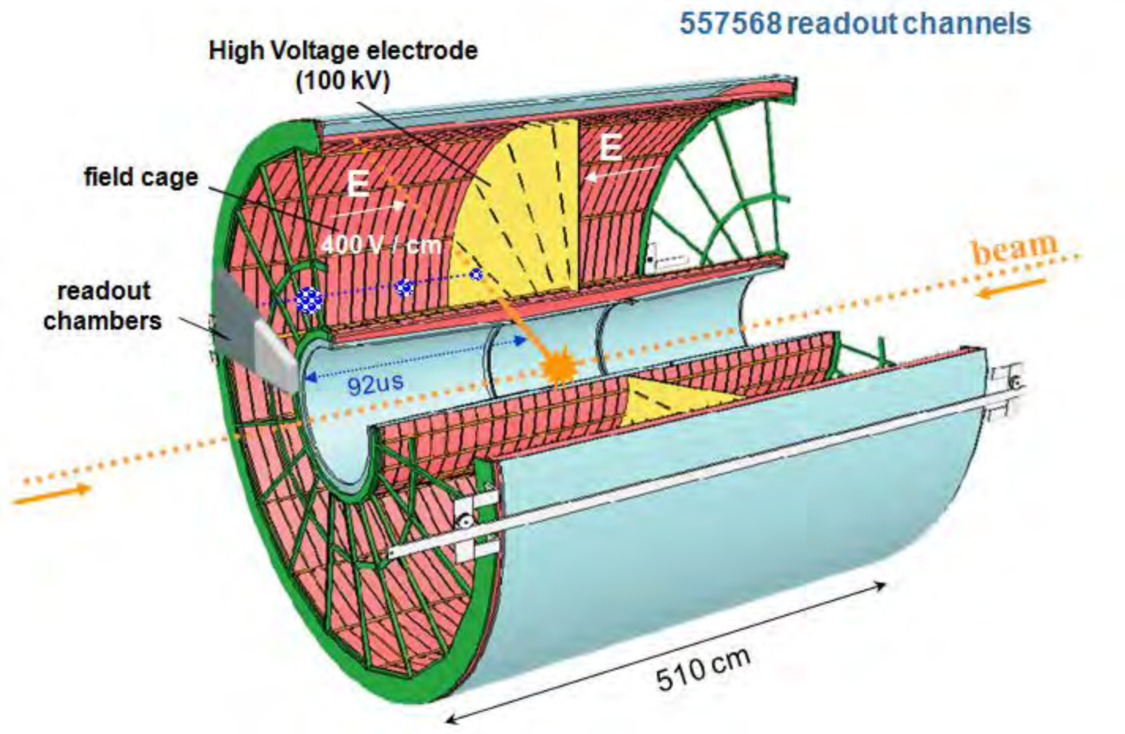
First beam passing through ALICE (up to 3 km) 08.08.2008

…was celbrated all around the world 08.08.2008 8pm Beijing

Time Projection Chamber

General features

- Diameter × Length : 5 m × 5 m
- Azimuth angle coverage: 2π
- Pseudo-rapidity interval: $|\eta|<0.9$
- Readout chambers: 72
- Drift field: 400 V/cm
- Maximum drift time: 96 μs
- Central electrode HV: 100 kV



Gas

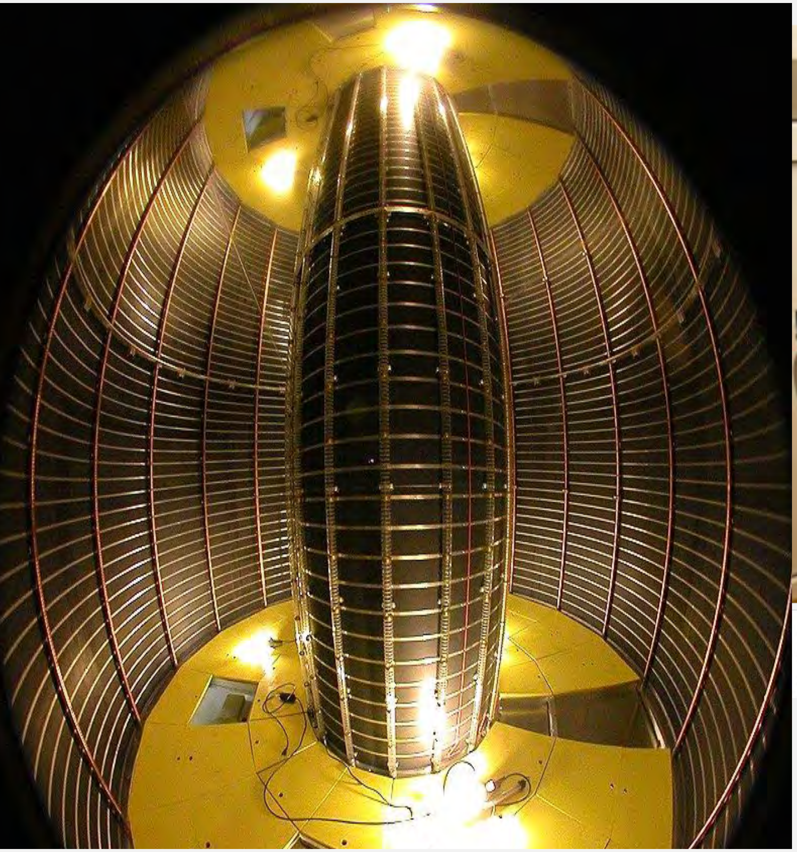
- Active volume: 90 m^3
- $Ne-CO_2-N_2$: 85.7% - 9.5% - 4.8%
- Cold gas - low diffusion
- Non-saturated drift velocity

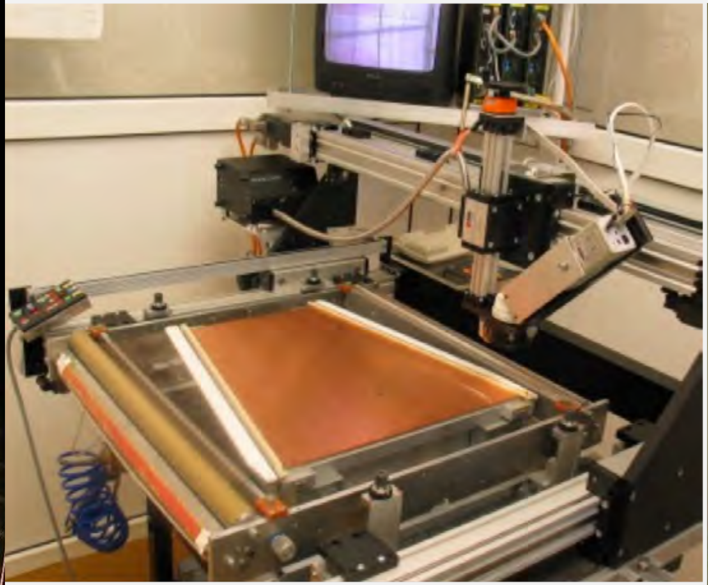
  ⇒ temperature stability and homogeneity ≤ 0.1 K

Readout

- Pads (3 types): 557 568
- Samples in time direction: 1000
- Data taking rate:
  - ~ 2.8 kHz for p-p
  - ~ 300 Hz for Pb-Pb

Time Projection Chamber assembly



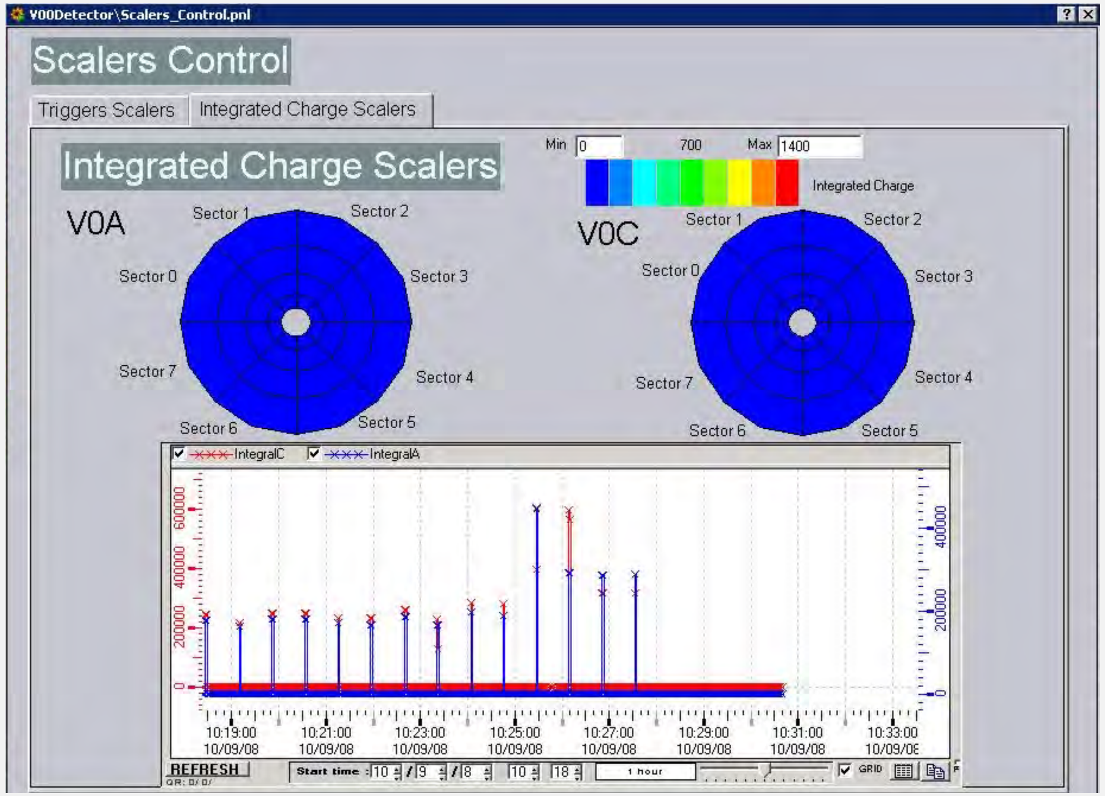


Production of IROC
in a high precision Assembly system

Installation at CERN

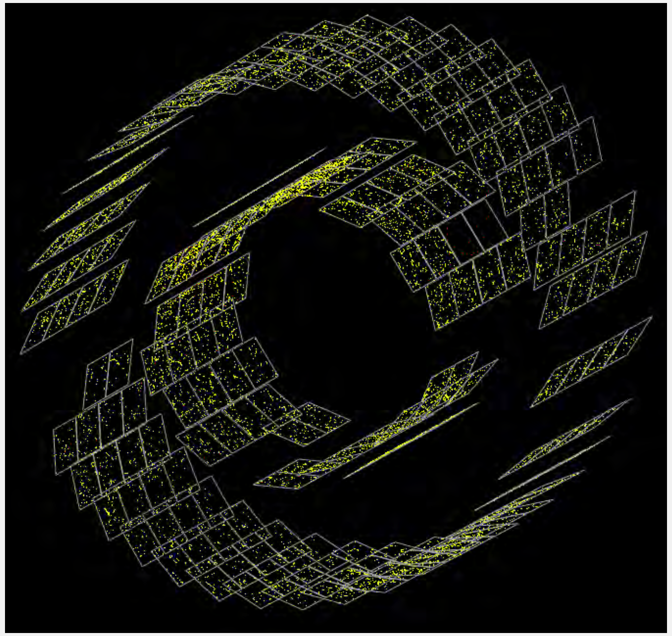
Time September 10th 2008: circulating beams!

- beam 1: 1st complete orbit ~ 10:30



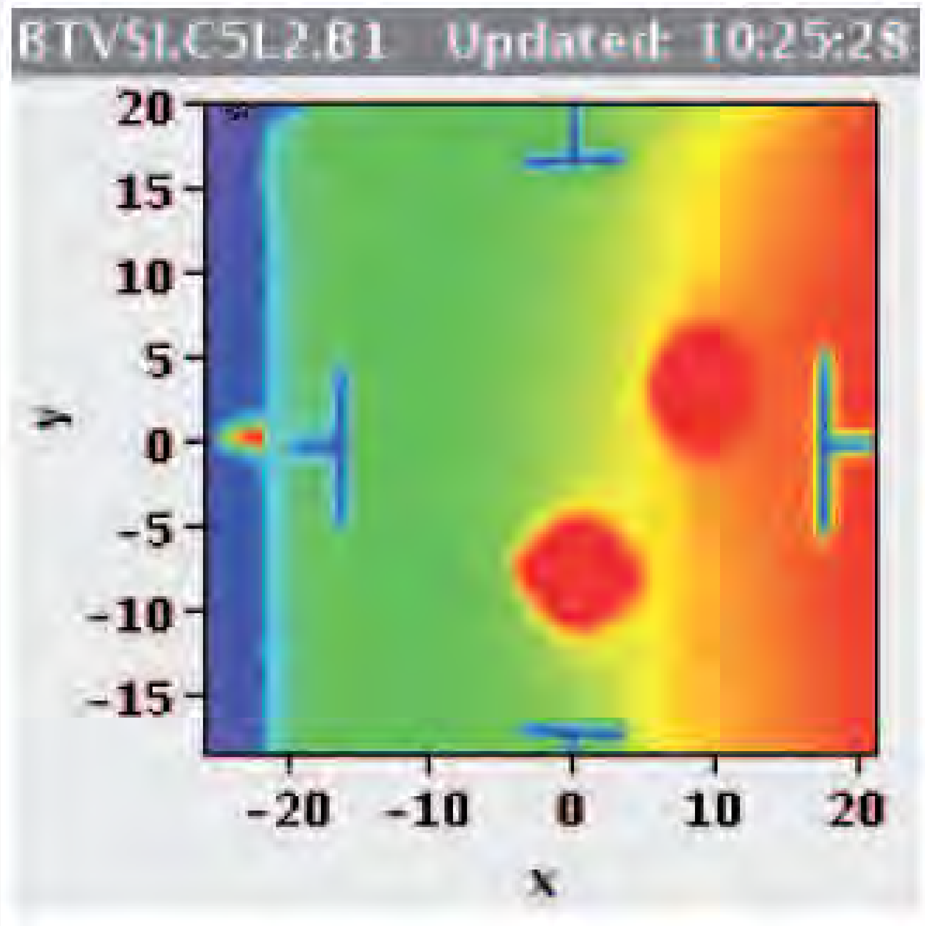
- beam 2: 1st complete orbit ~ 15:00

First signals from ALICE

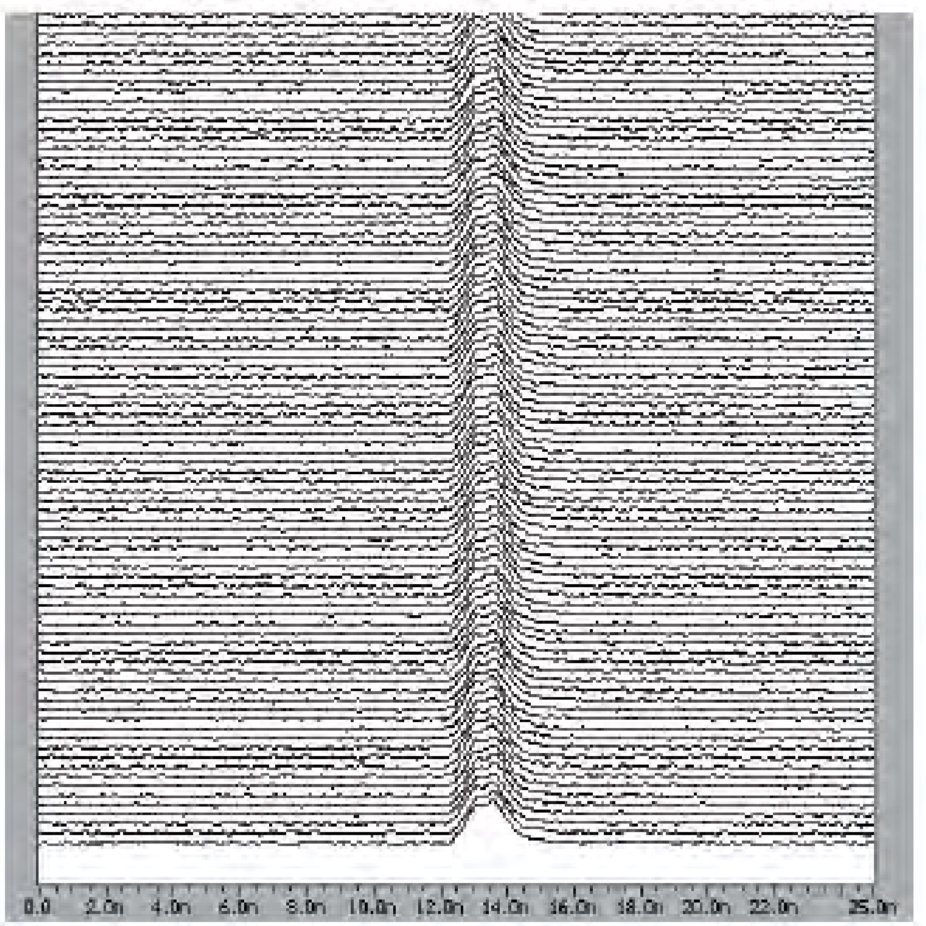


LHC 11th September 2008 "RF-capture"

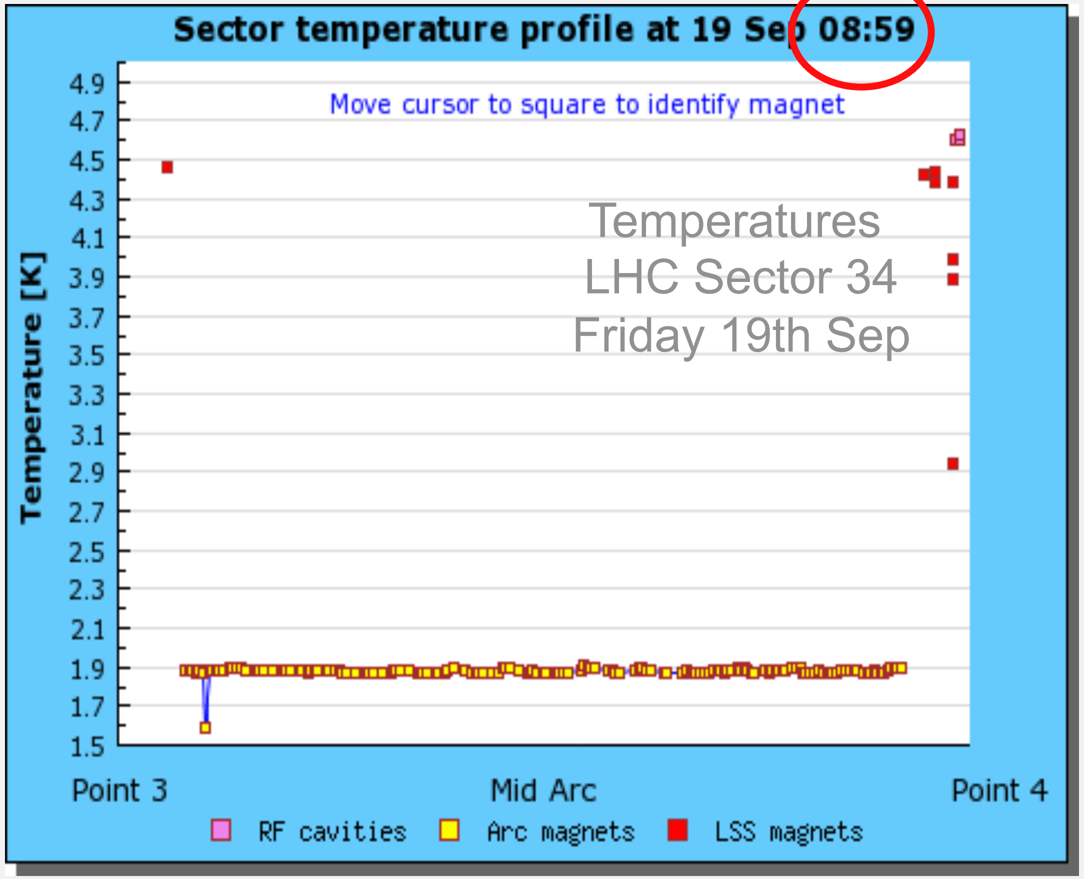
First orbit



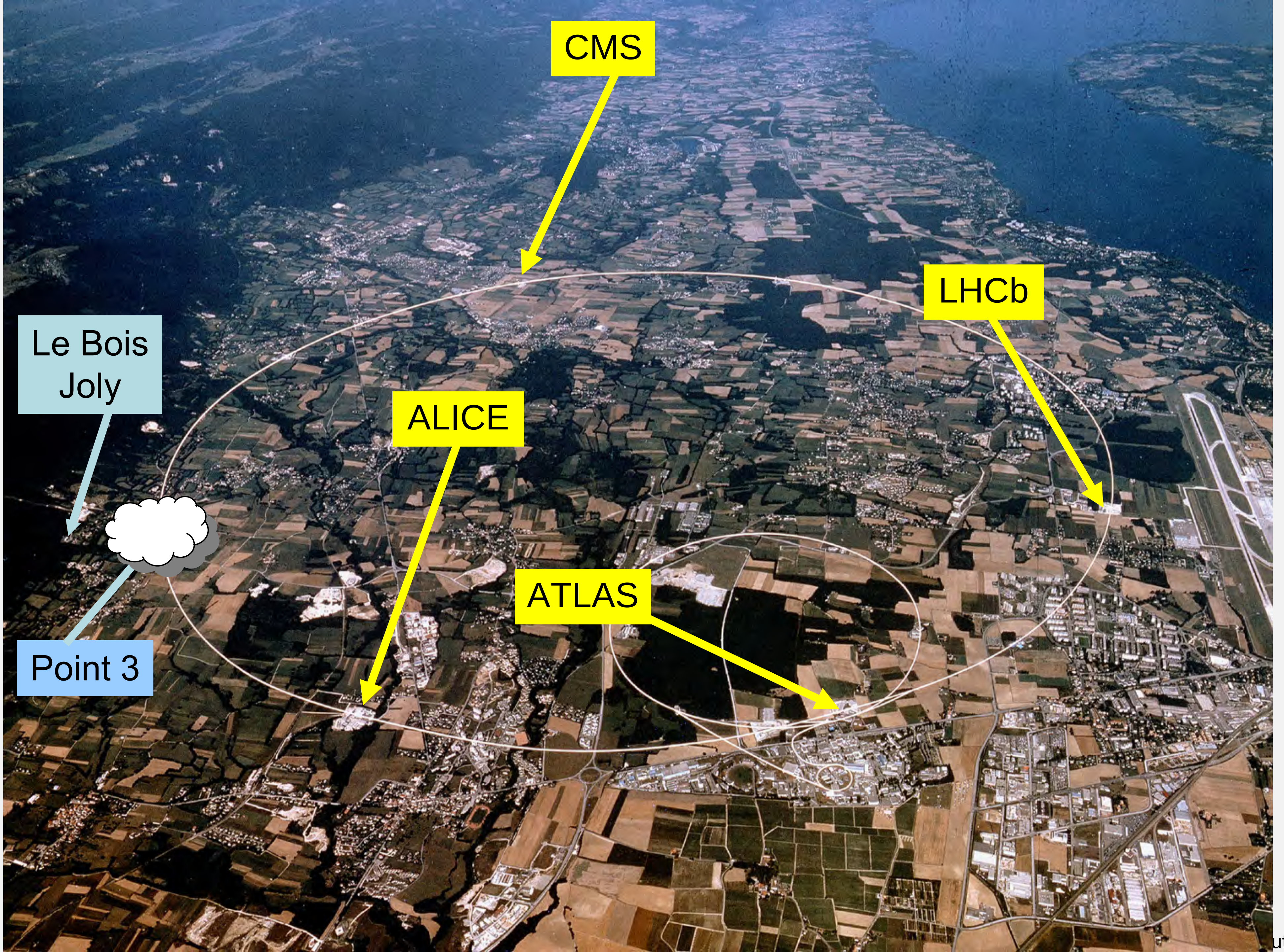
RF capture



19th September 2008

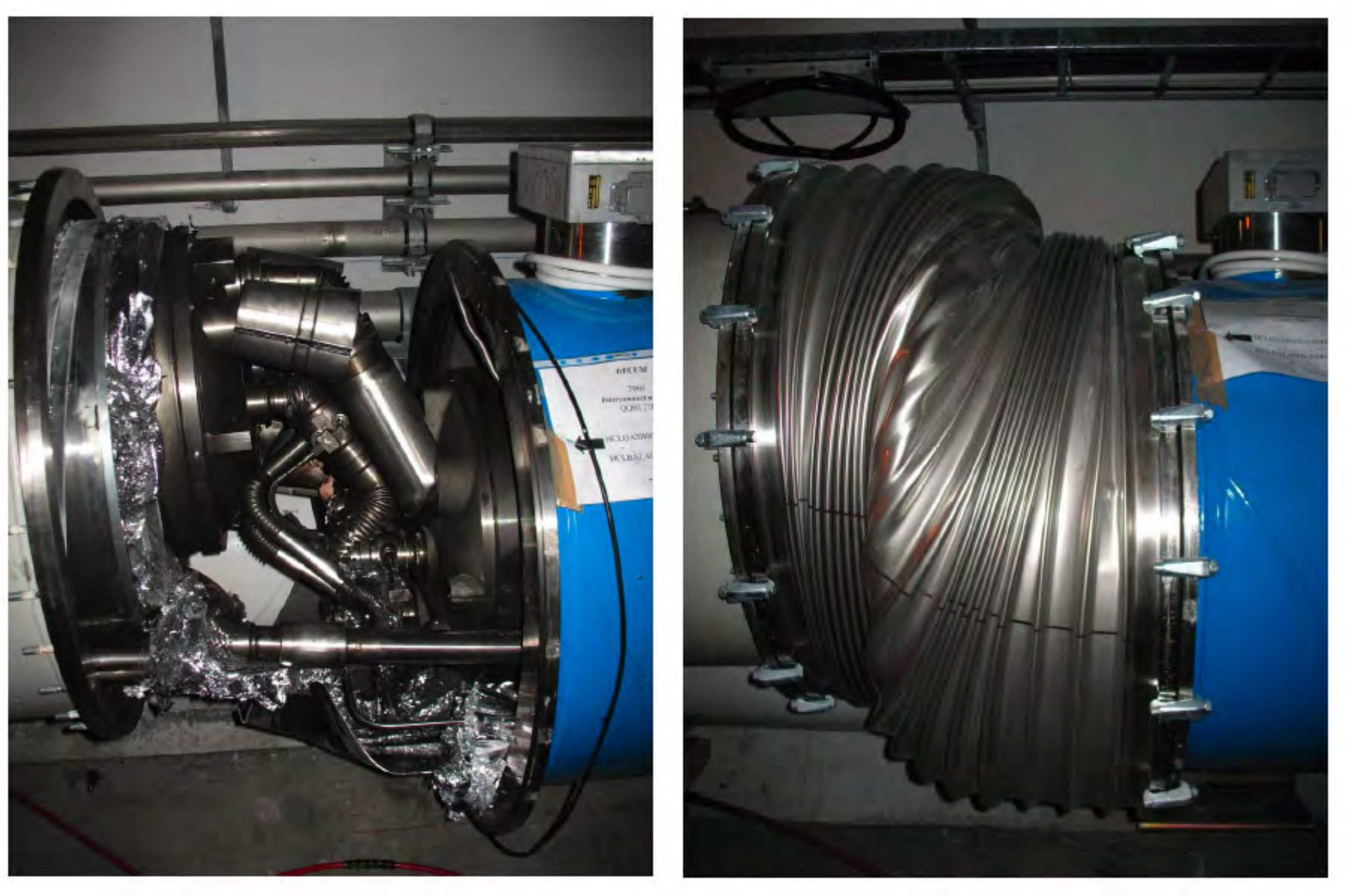


Jan Fiete Grosse-Oetringhaus


CMS
LHCb
Le Bois Joly
ALICE
ATLAS
Point 3

Tunnel after 19th September

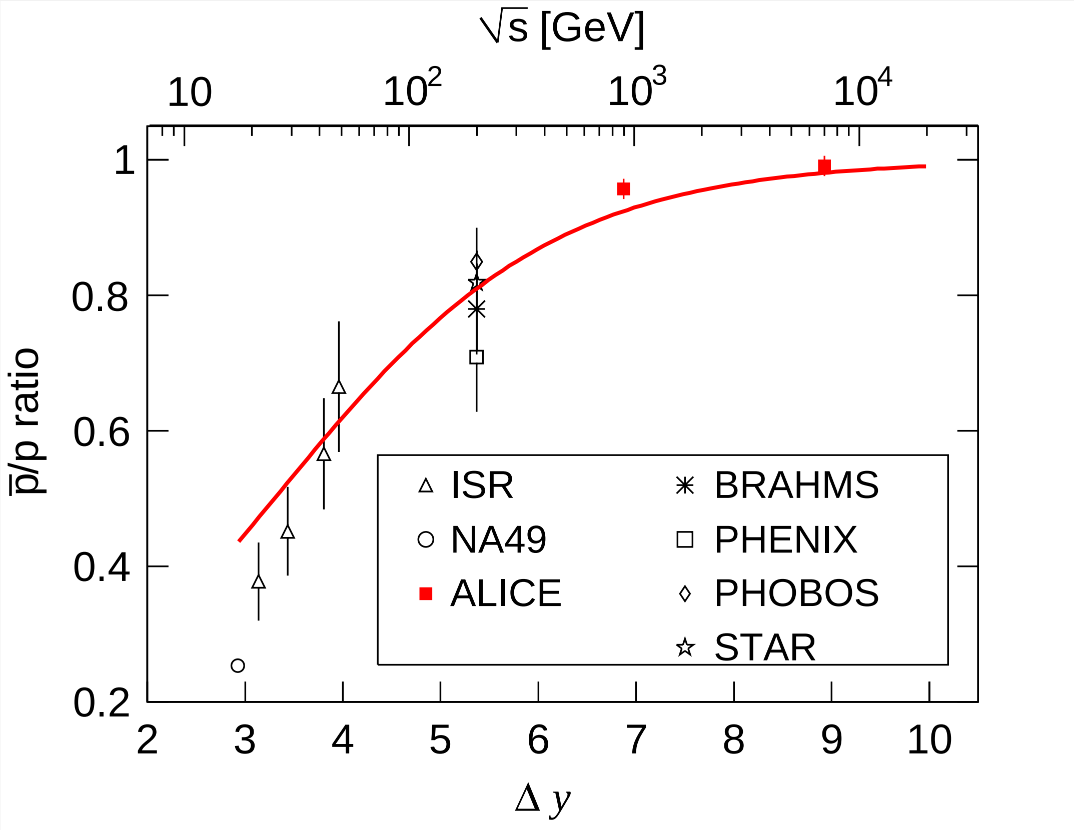
Dipole-Quadrupole Joint after Incident



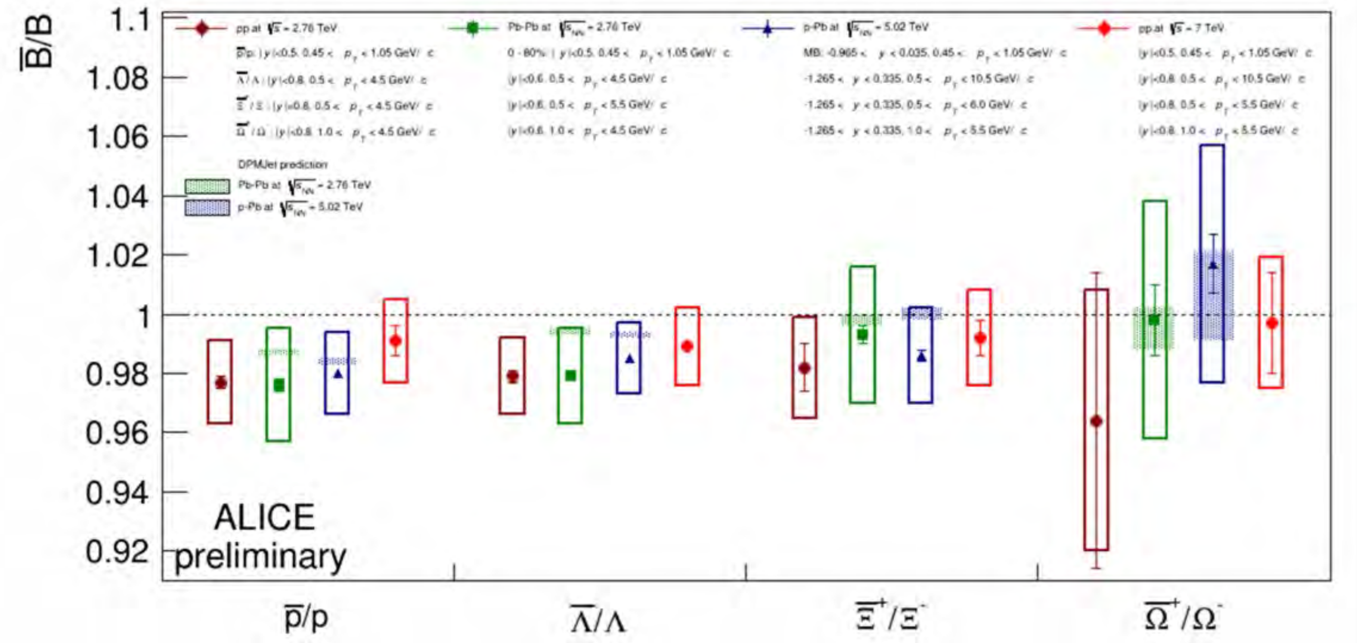
Physics highlights ALICE 1
Run 1 & 2

Anti-p to p ratio at midrapidity

- How easy/difficult is to transfer baryon number at large rapidity distances?
  - is baryon number transported by quarks or a “string junction”?
  - what’s corresponding Regge trajectory intercept?



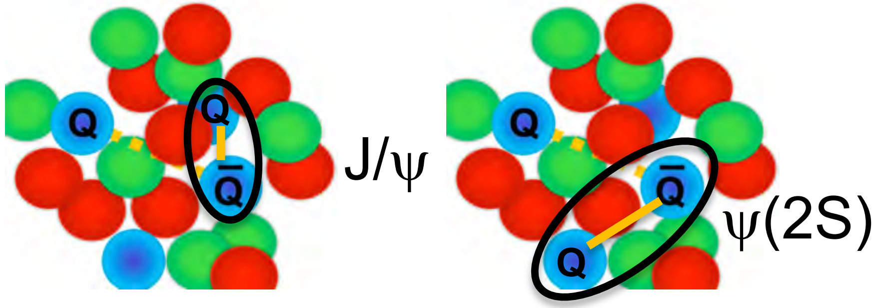
ALICE Collaboration : Midrapidity Antiproton-to-Proton Ratio in pp Collisions at √s=0.9 and 7 TeV Measured by the ALICE Experiment; **Phys. Rev. Lett. 105, 072002 (2010)**



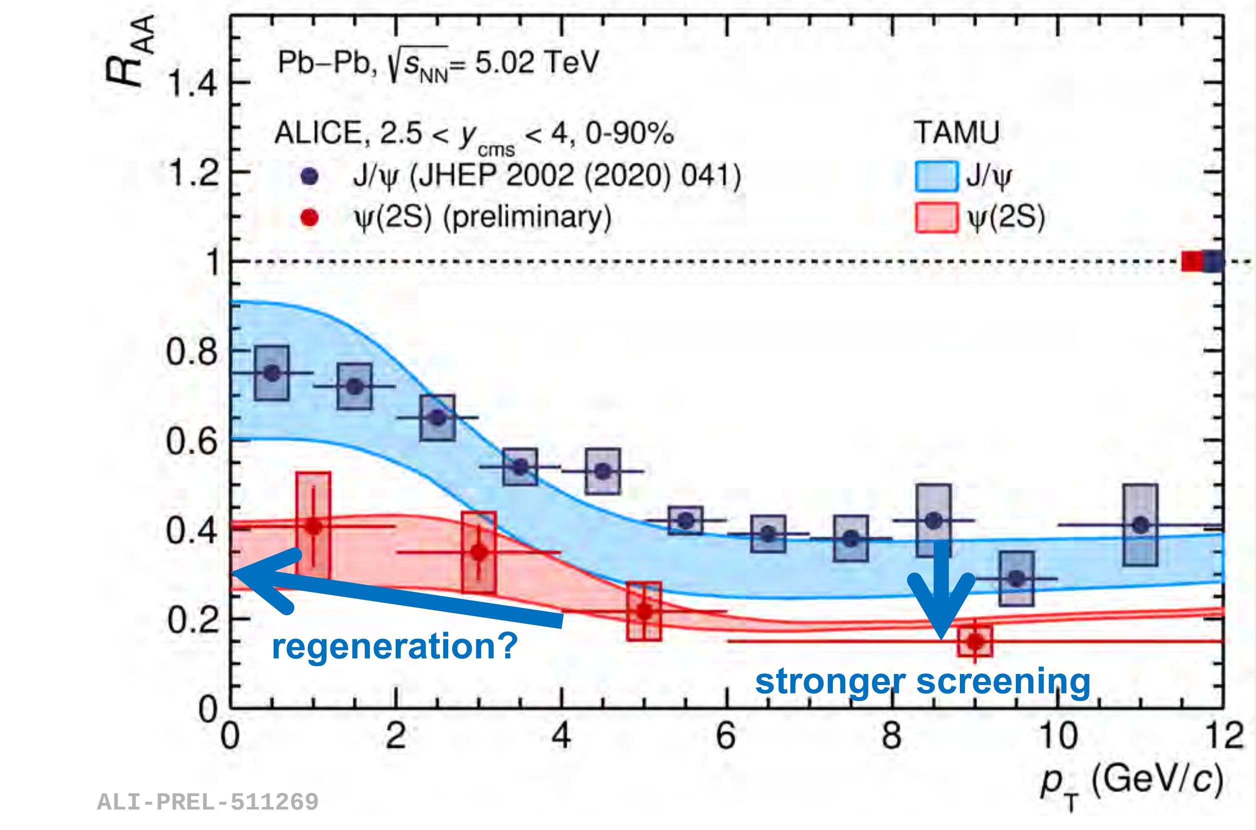
M.Broz (Bratislava, Prague)
M.Mereš (Bratislava)

J/ψ dissociation vs. regeneration

- Reminder: J/ψ suppression due to **colour screening** in the QGP reduced at low p_T and at central rapidity by **$c\bar{c}$ regeneration**
  - ~100 $c\bar{c}$ pairs per central Pb-Pb

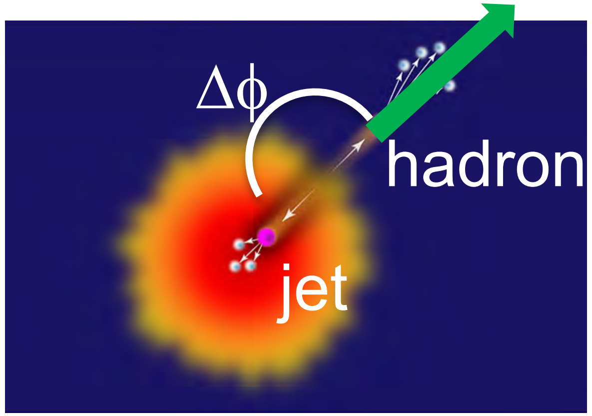


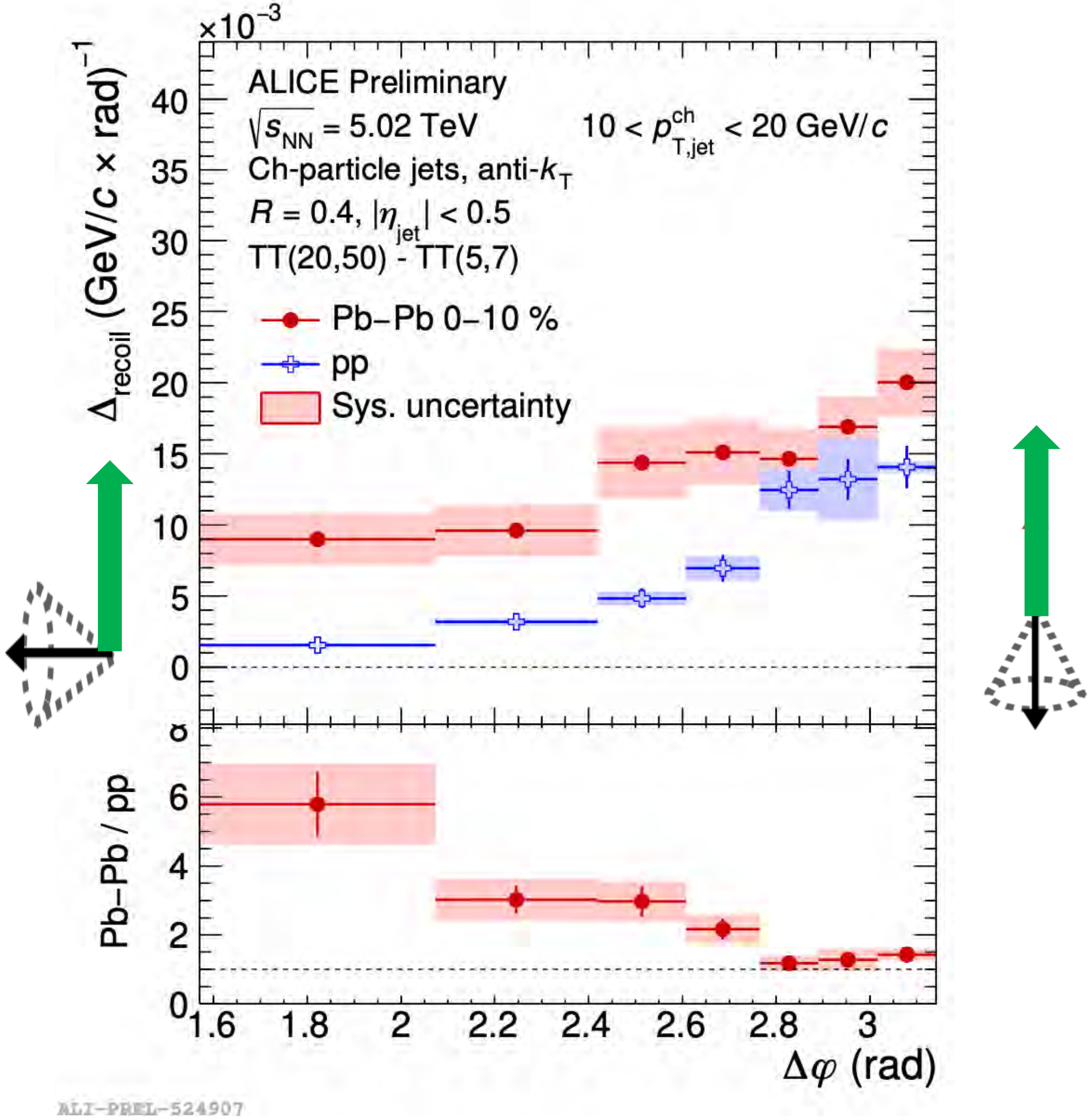
- New result: measured ψ(2S) – ×10 lower binding energy! – to pin down the role of these two mechanisms
- ψ(2S) ~ ×2 more suppressed than J/ψ
- Hint of regeneration at low p_T



Jet deflection

Jets recoiling against a high-p_T hadron
→ down to jet p_T ~ 10 GeV/c



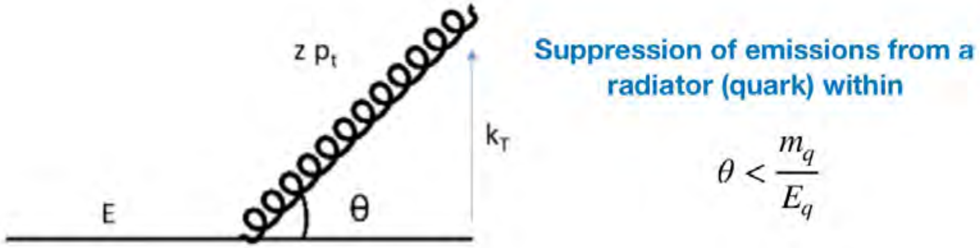


Δ_{recoil} vs Δϕ broader in Pb-Pb than in pp

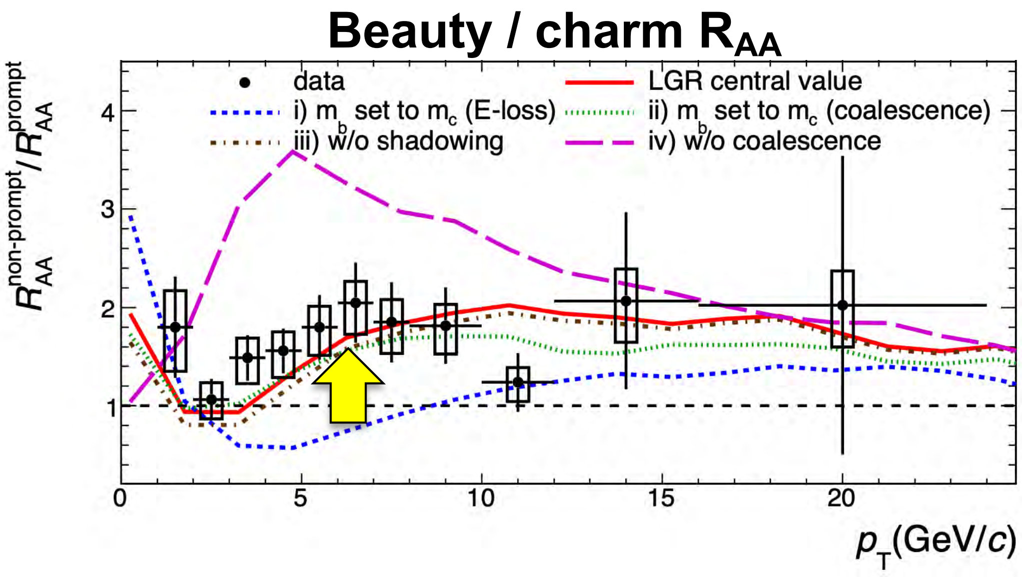
Angular deflection of soft large-R jets:
Scattering on QGP constituents?
Medium response to energy loss?

Energy loss: charm vs. beauty

- Energy loss predicted to depend on QGP density, but also on quark mass
- "Dead cone" effect reduces small-angle gluon radiation for high-mass quarks



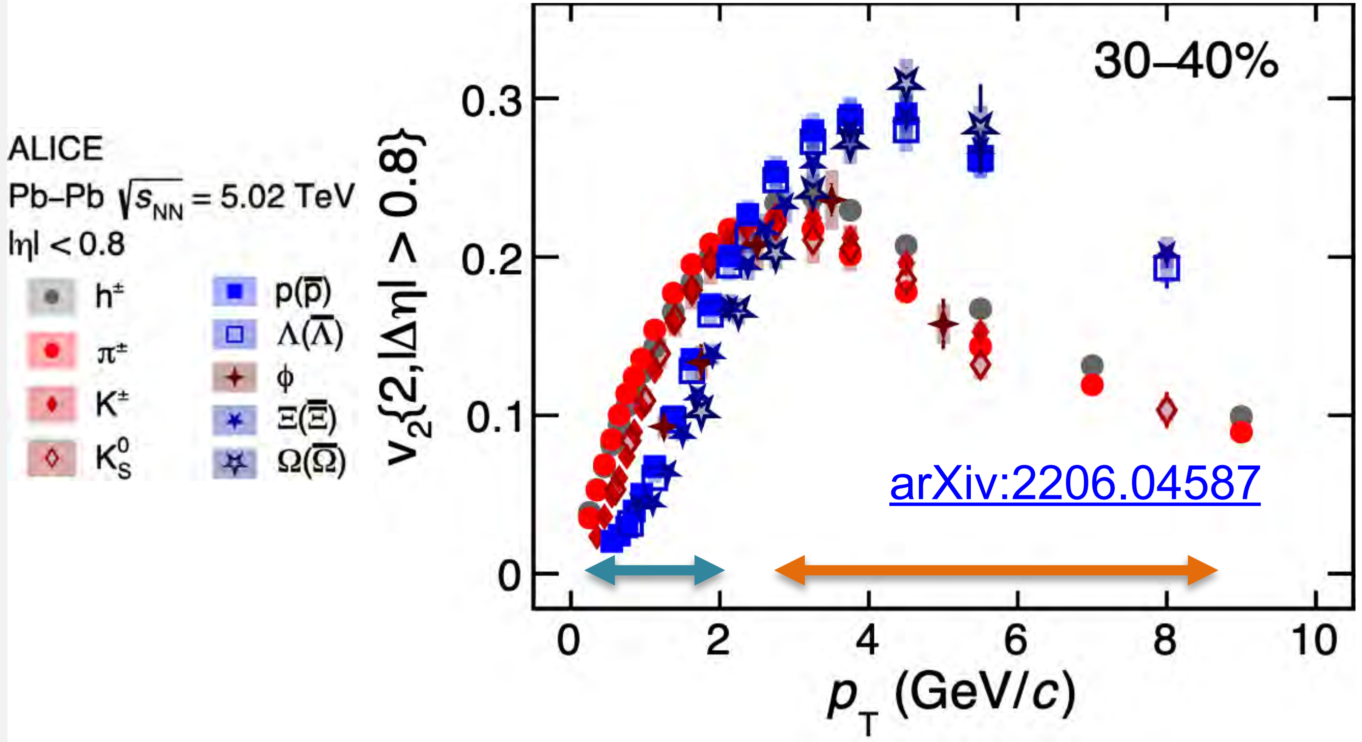
- Less suppression for (non-prompt) D mesons from B decays than prompt D mesons
- Smaller energy loss for b quarks needed to describe the ratio of R_{AA}

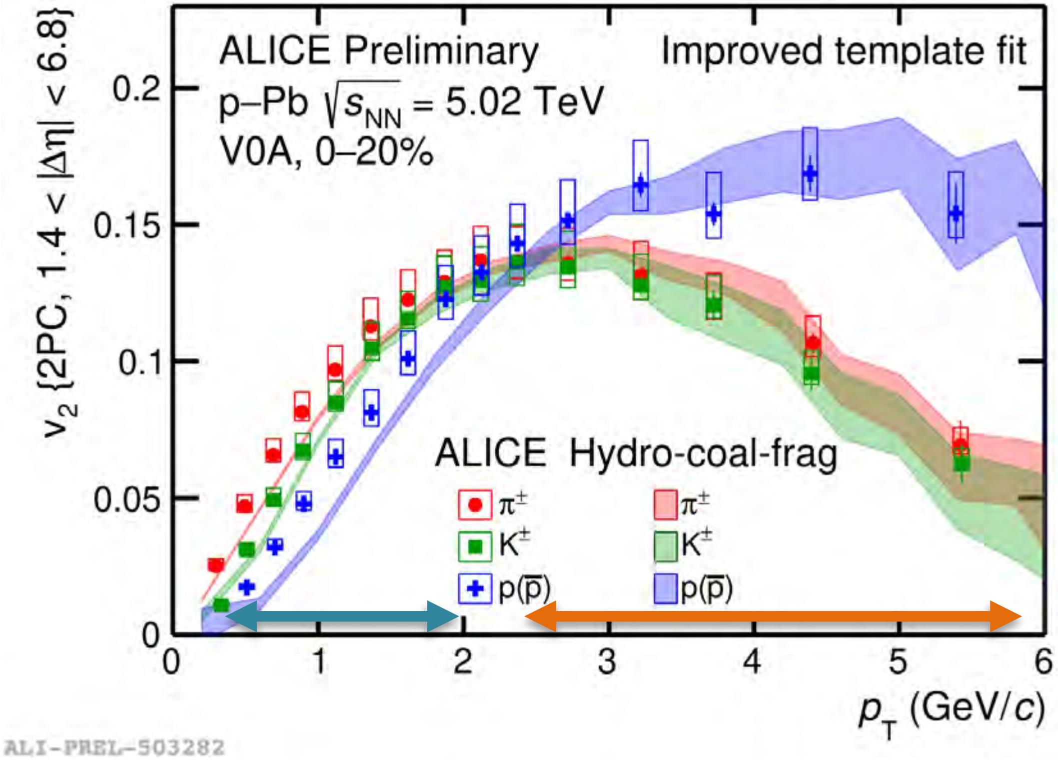


Elliptic flow

- Non-central collisions: elliptical geometry → expansion (flow) → azimuthal modulation in momentum

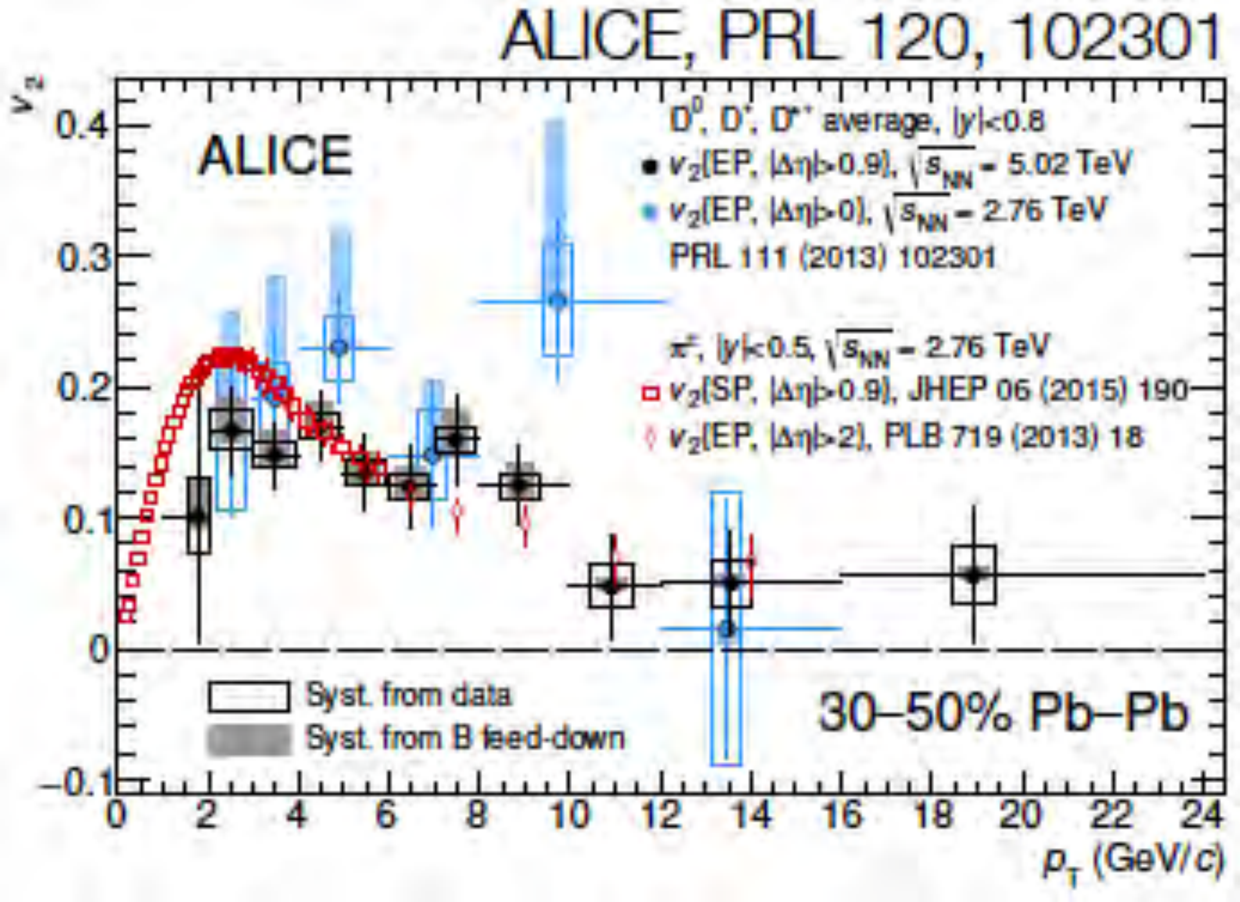
$$\frac{dN}{Nd\phi} = 1 + 2v_2 \cos\left(2(\phi - \Psi_{RP})\right) + \textit{higher harmonics } (v_3, v_4, \ldots)$$





→ quark-level flow + recombination in high-multiplicity p-Pb (and pp)

Heavy-flavour flow

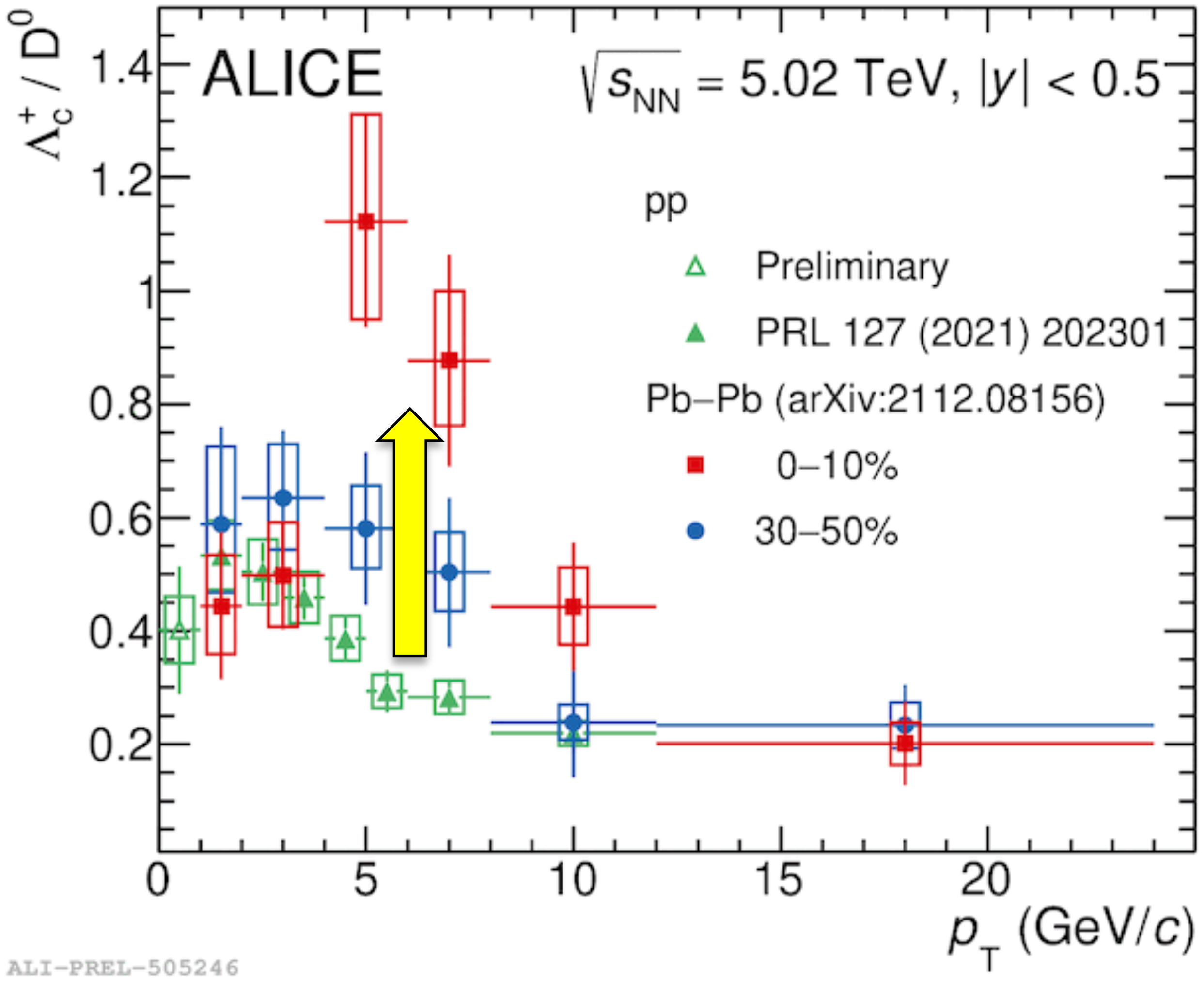


Heavy flavour participates in the collective dynamics at LHC energies

Flow strength like the light hadrons

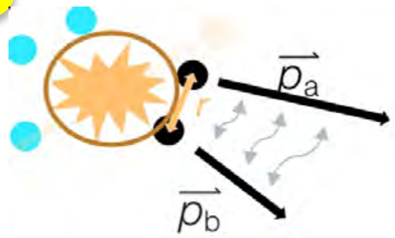
Baryon to meson in charm sector

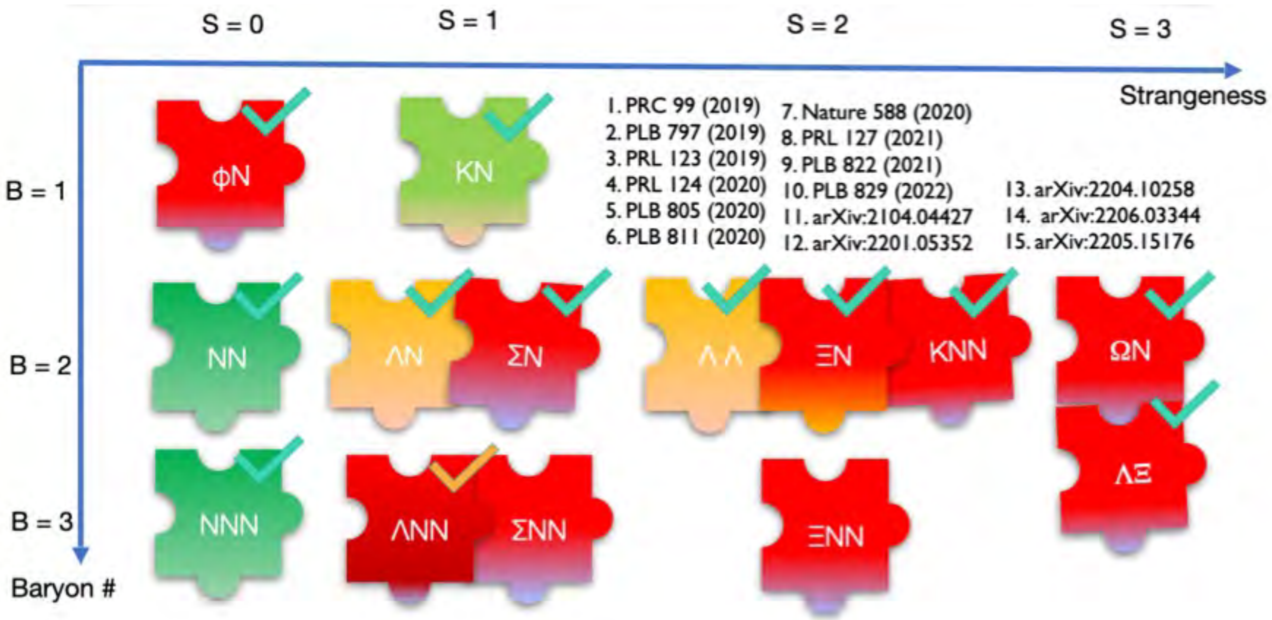
- Additional dynamics in central Pb-Pb collisions: Λ_c/D^0 enhancement at intermediate p_T
- Suggests hadronization by recombination + mass-dependent p_T shift from collective expansion
- Prospects: high-precision, and other baryons, from Run 3 data

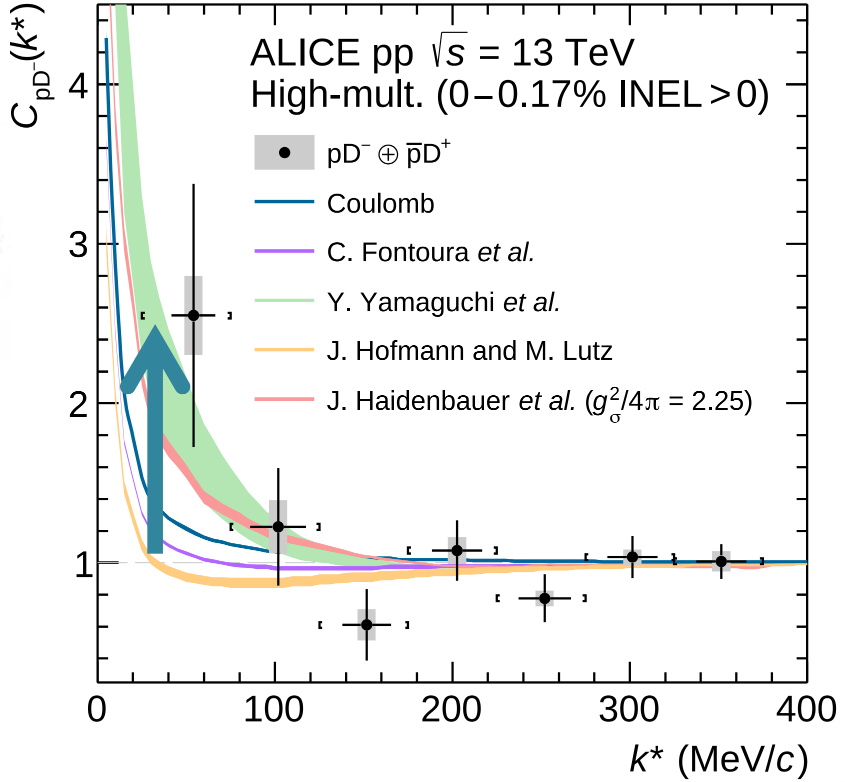


QCD interactions among hadrons

- **Use femtoscopy technique to assess residual strong interaction in h-h and h-h-h**
  - Poorly known for strange baryons
    - Relevant for neutron star modeling
  - Unknown for charm hadrons and 3-body





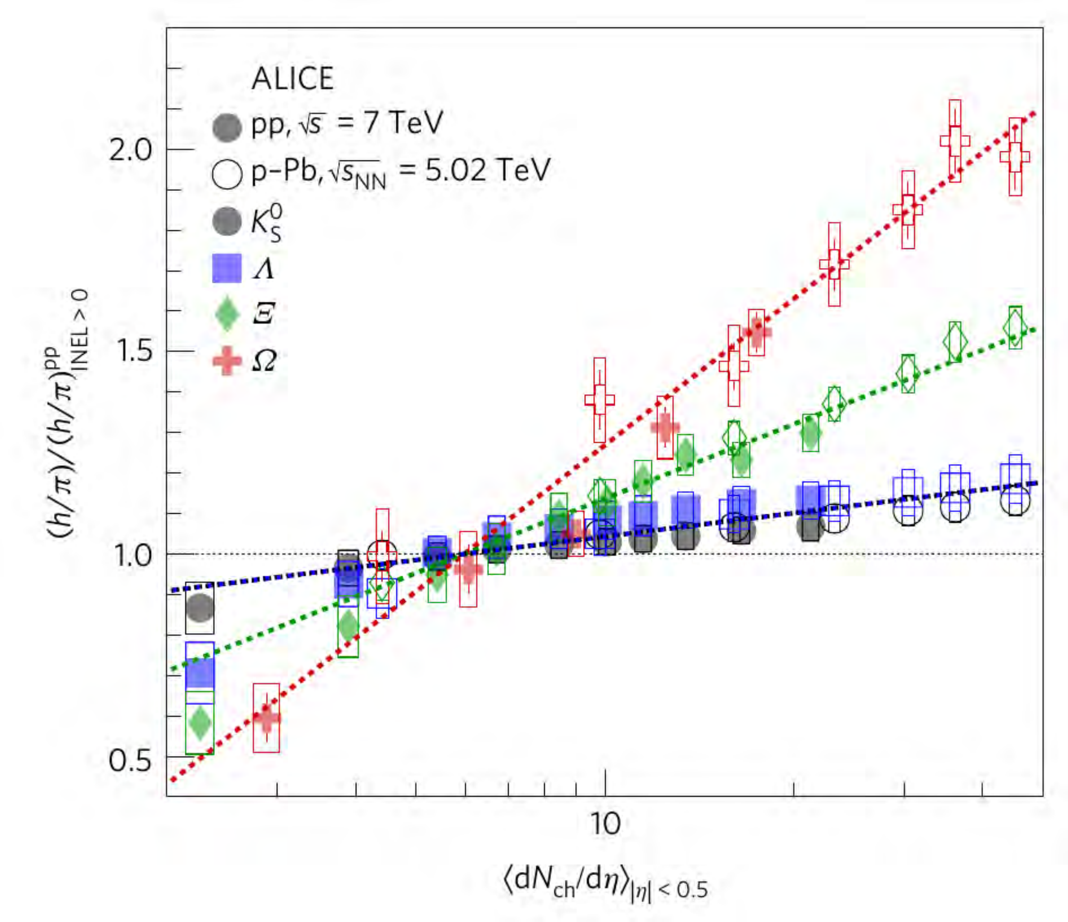


First measurement of p-D correlation function:

- Attractive interaction
- Estimate of QCD scattering parameters

Strange particle production

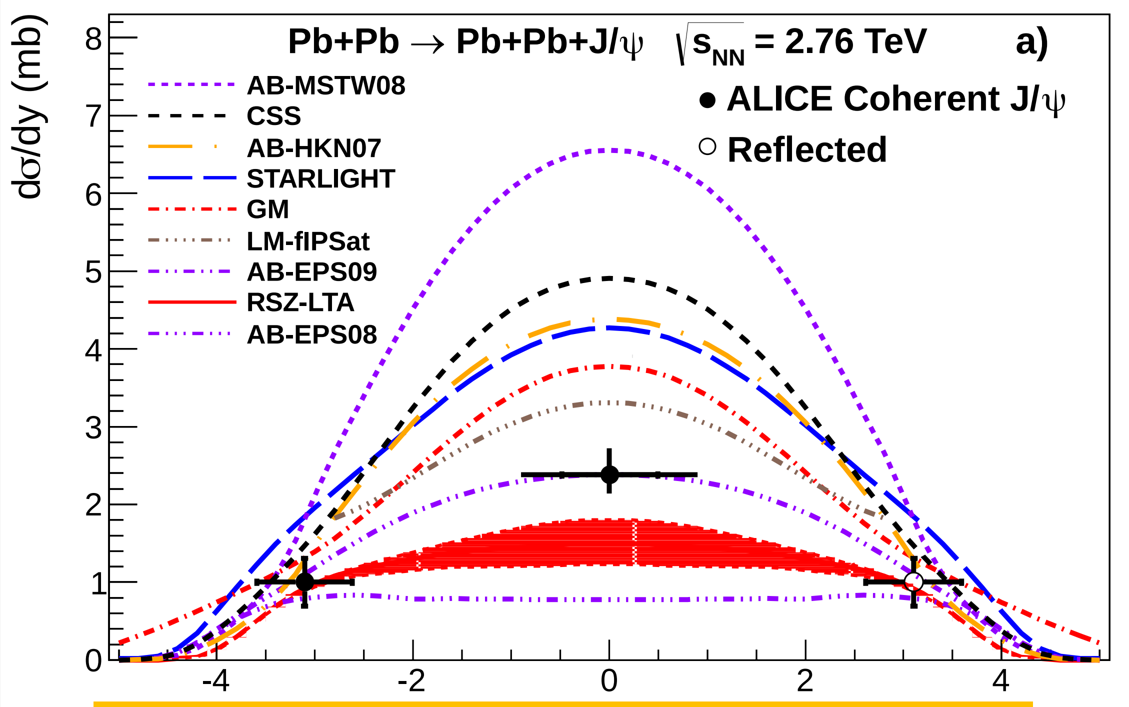
- Is there a strangeness enhancement?
- Or is just a continuous development from pp to AA



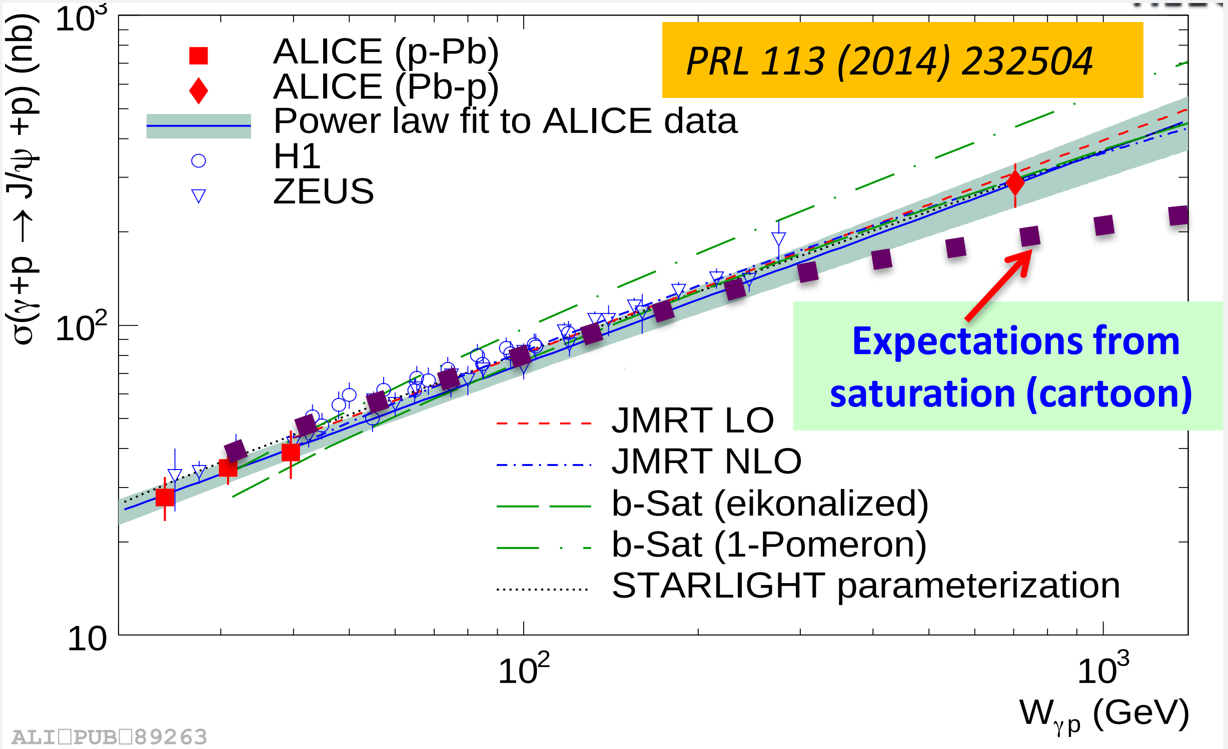
Nature Physics 13 (2017) 535-539

Ultra-peripheral collisions

- Insight into shadowing and saturation
- gamma–nucleus interactions



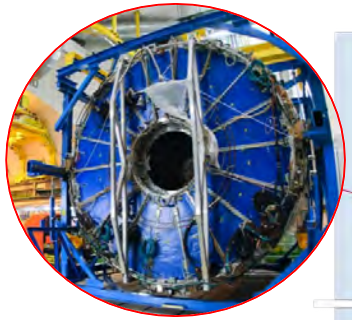
e-channel: EPJC 73 (2013) 2617
μ-channel: PLB 718 (2013) 1273



CTU group, J.G.Contreras Nuno et al.

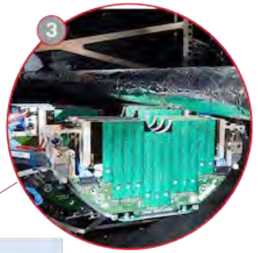
ALICE upgrade for Run 3

ALICE-2 upgrades

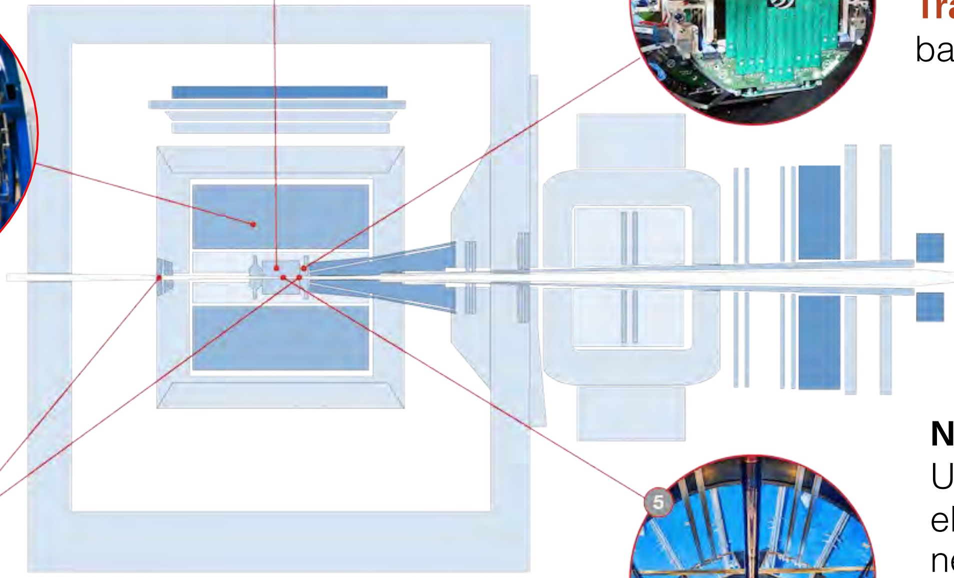


New GEM-based TPC
with continuous readout

New Inner Tracking System (ITS)
– 7 barrels, 10 m² silicon tracker
based on MAPS (12.5 G pixels`



New Muon Forward Tracker (MFT) - 5 disks
based on MAPS



New Trigger and Readout
Upgrade of readout electronics of all detector, new Central Trigger Processor

New Fast Interaction Trigger (FIT)
– 3 detector technologies: interaction trigger, online luminometer, forward multiplicity

New Online/Offline (O2)

New Beampipe
smaller diameter (36.4 mm), first detection layer at 20 mm

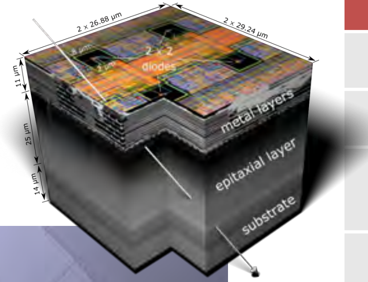
ALICE 2 Upgrade

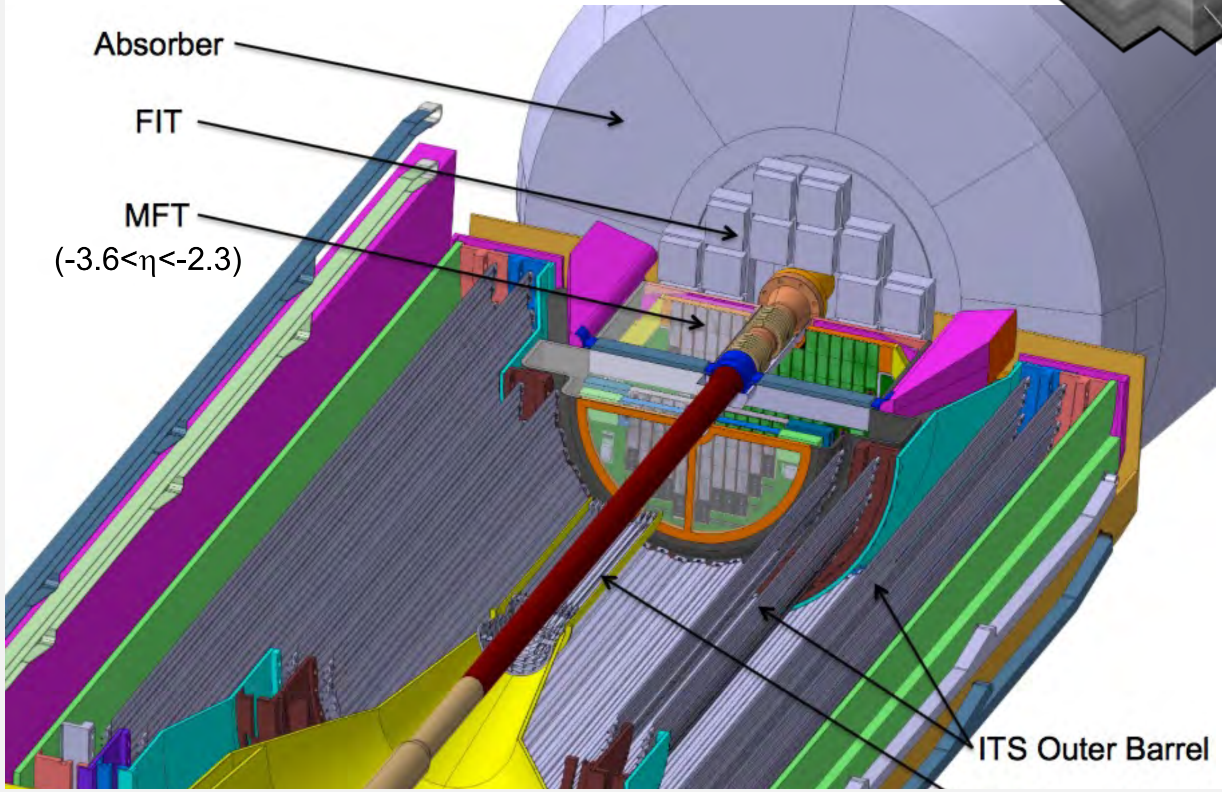
→ Tracking precision ×3
→ Pb-Pb rate ×50

New all-pixel trackers: ITS-2 and MFT

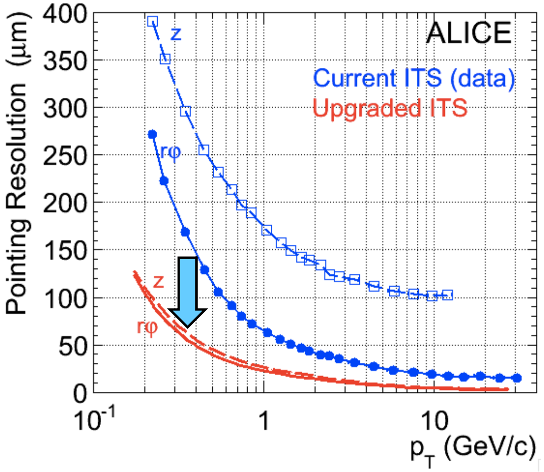
- ITS-2 seven layers monolithic active pixel sensors
- MFT five layers Muon Forward Tracker in front of absorber

- Monolithic Active Pixel Sensors (MAPS)
  - Low resistivity, high efficiency, low thickness, low power consumption
  - Also chosen by sPHENIX and MPD@NICA

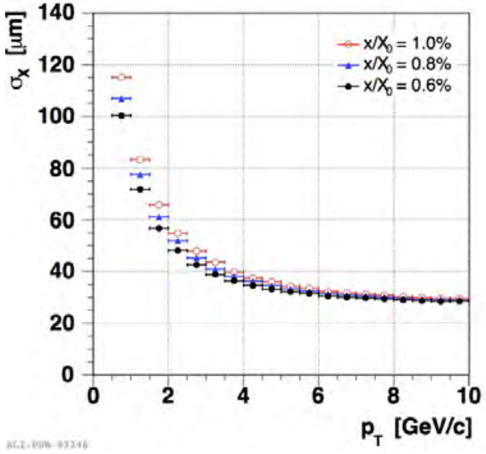




	Current ITS	New ITS2	MFT
N Layers	6	7	5
Inner radius	3.9 cm	2.3 cm	/
Layer thickness	~1.1% X_0	0.3-1.0% X_0	0.8% X_0
Spatial resolution	12x100 μm^2 35x20 μm^2 20x830 μm^2	~5x5 μm^2	~5x5 μm^2



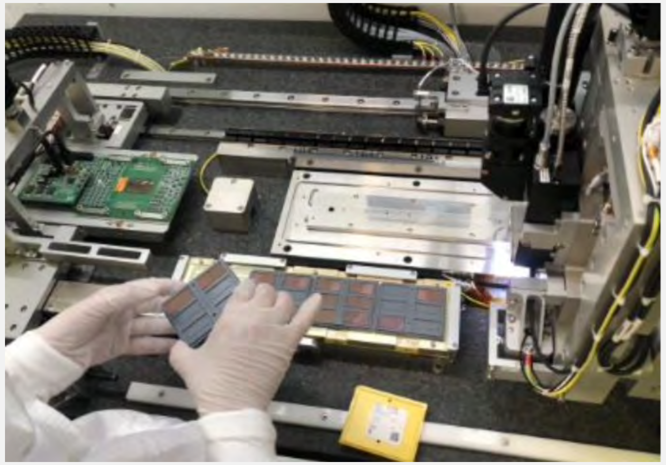
ITS2 tracking precision x3 better in rφ plane, <20 μm above 1 GeV/*c*

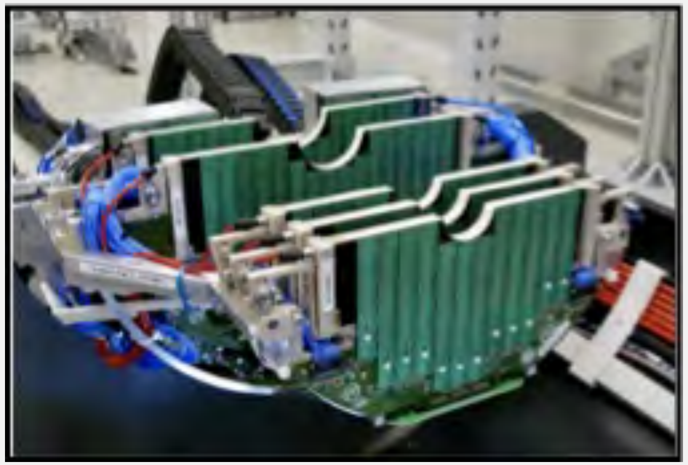


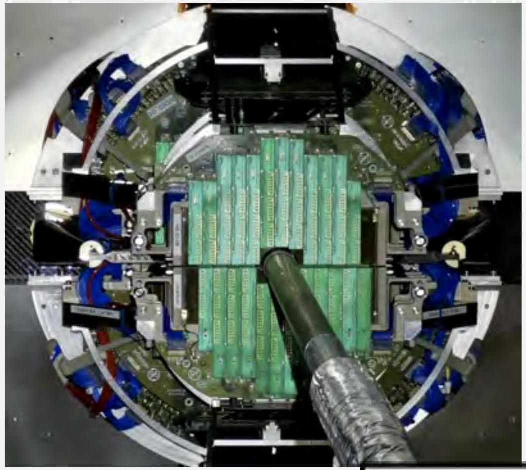
MFT: <100 μm above 1 GeV/*c*

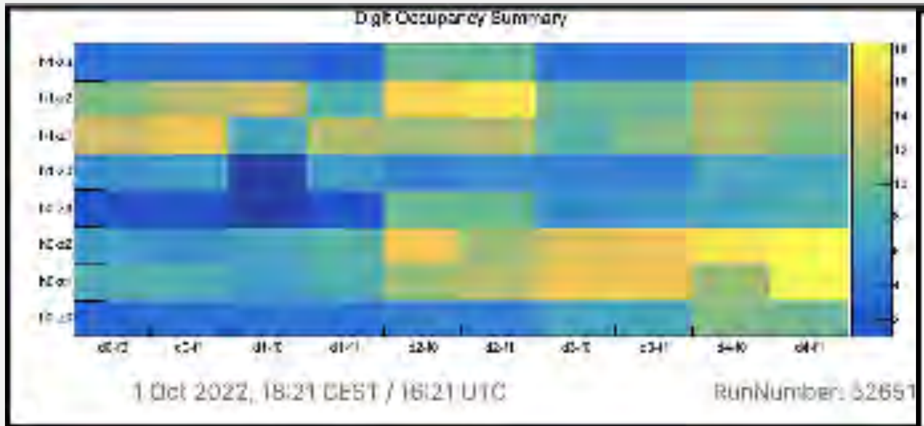
MFT – CTU Prague contribution

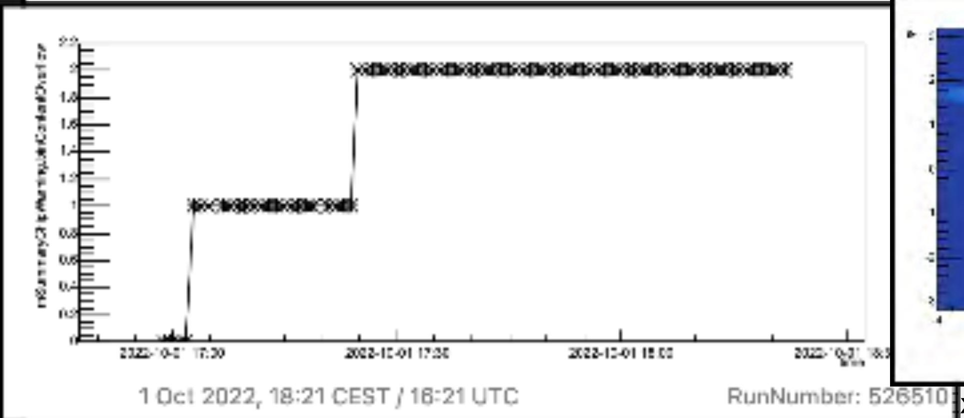
- Muon Forward Tracker at CERN
  - completely new detector for precise tracking in front of muon absorber
  - participation in construction and commissioning
  - system run coordination
  - development of quality control software

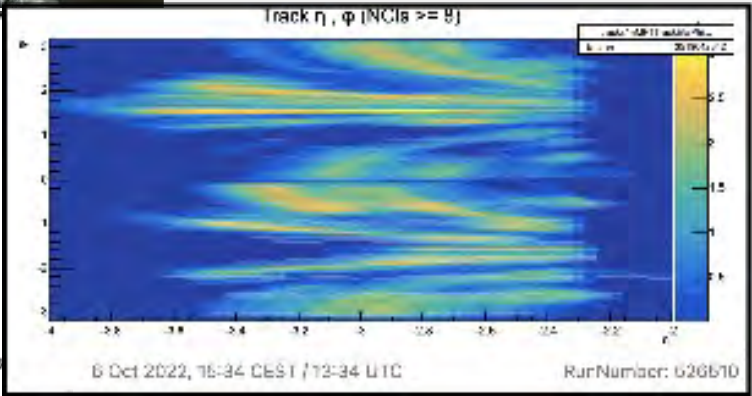








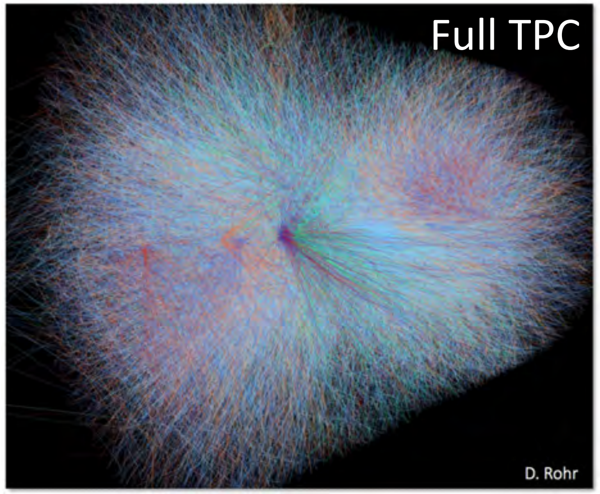


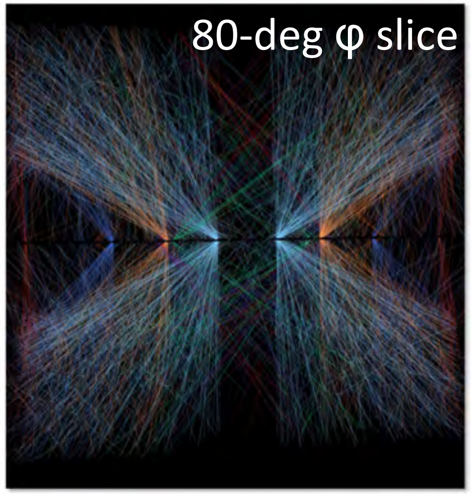


TPC upgrade – GEM readout

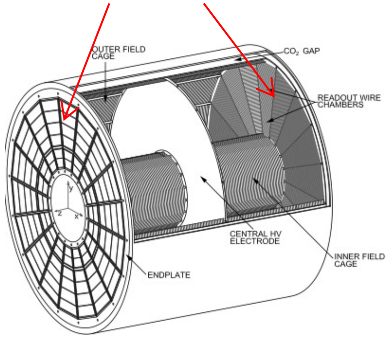
- Time Projection Chamber change to continuous readout
  - readout MWPC replaced with GEM chambers
  - Pb–Pb up to 50 kHz

- Current MWPC: readout rate limited by ion backflow
- New readout chambers (GEM): continuous readout of Pb-Pb at interaction rate of 50 kHz
  - preserve p_T and dE/dx resolution
- 5 interactions on average during TPC drift time (90 μs)
- Calibration and track-to-event assignment in O^2 system

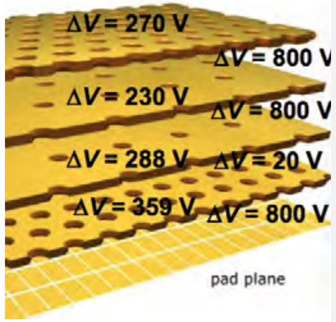


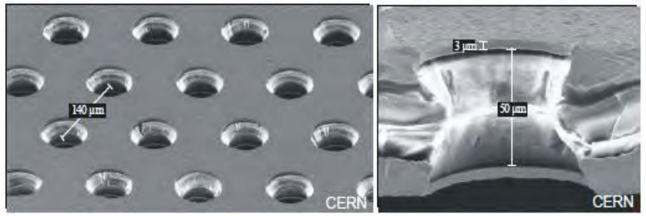


72 readout chambers



Stack of 4-GEM-foils





Electron microscope photograph of a GEM foil

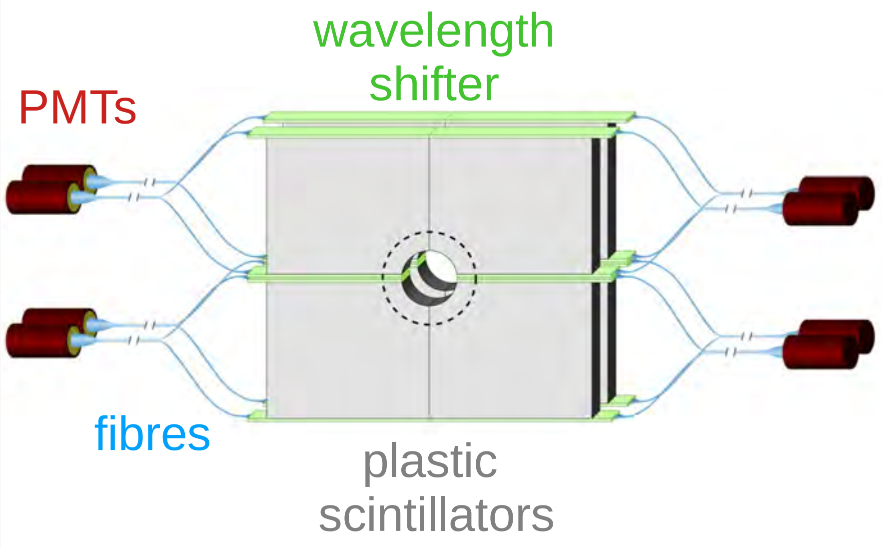
CERN-LHCC-2013-020

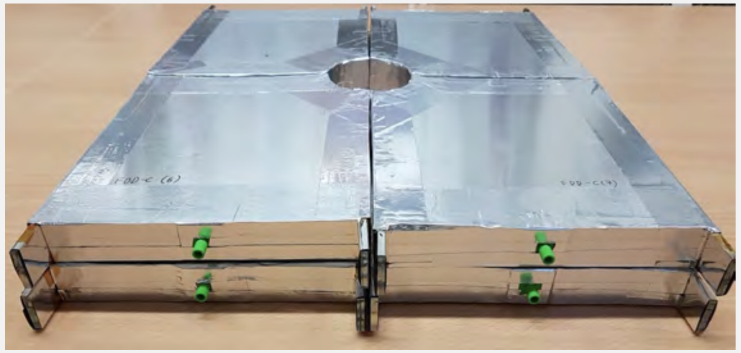
ion feedback from amplificatio region

Small TPC for drift measurement

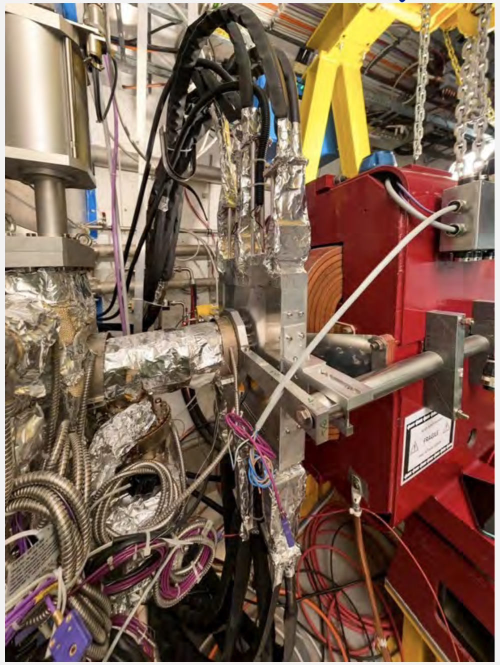
Forward Diffractive Detector – CTU Prague

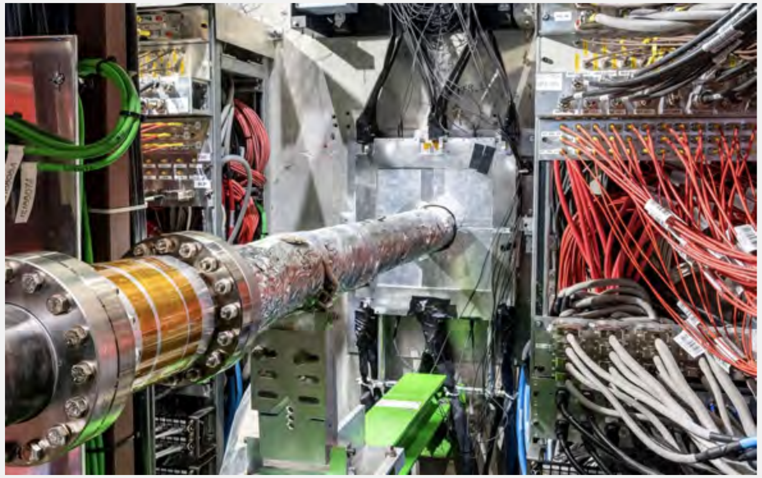
- Forward Diffractive Detector (CTU Prague)
  - new detector, completely built in Prague
  - selects diffractive events
  - participate in triggers
  - acts as luminometer, monitors beam conditions





Scintilator assembly





- installed at CERN C-side in February 2021, A-side in July 2021

ALICE Future

ALICE Upgrade

Prague institutions organized ALICE Upgrade Week last year

Upgrade Projects

FoCal

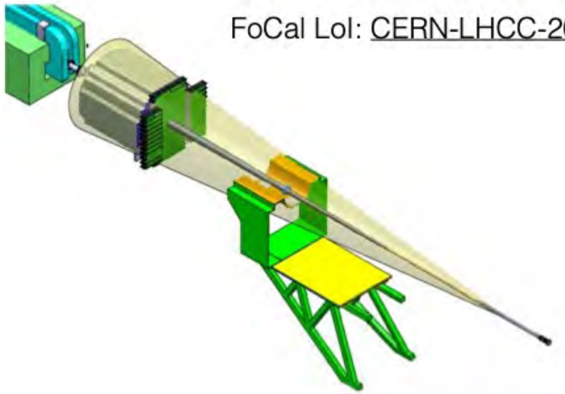
- Test beams with full prototypes
- Sensor radiation tests

ITS3

- Characterisation of 65 nm sensors
- Finalisation of Engineering Run 1
- Testing of engineering models

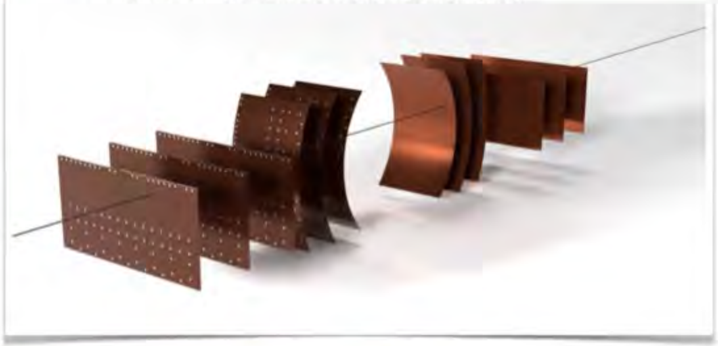
ALICE 3

- R&D programme
- Preparation of scoping document
- **Formation of projects and work packages**

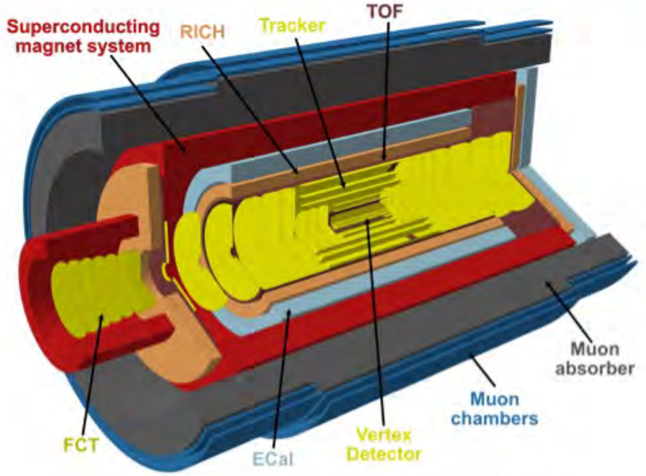


FoCal LoI: CERN-LHCC-2020-009

ITS3 LoI: CERN-LHCC-2019-018

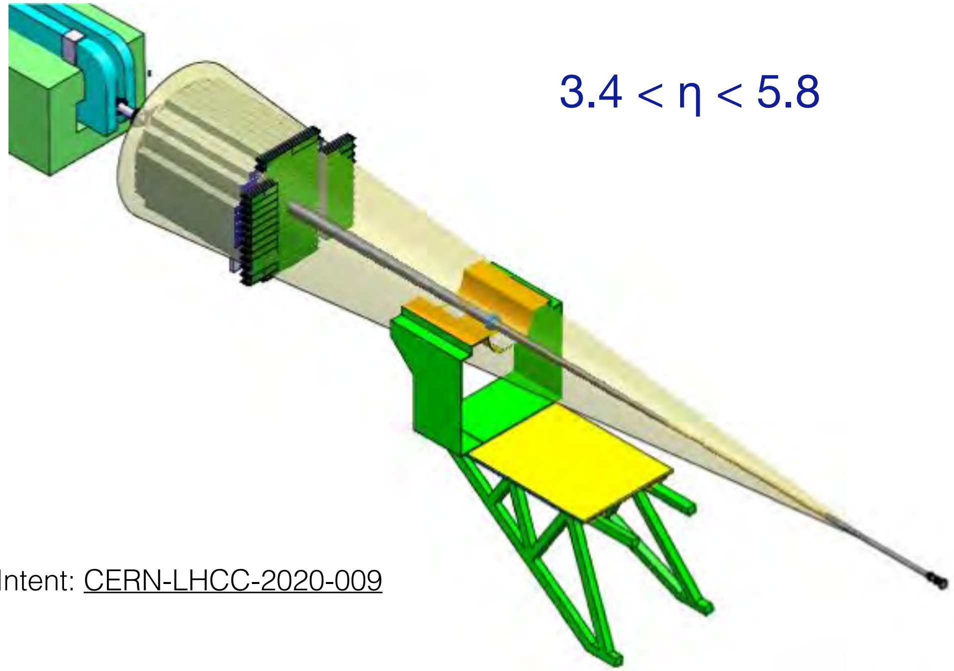


In addition:
Studies on **Fixed Target programme** at IP2



ALICE 3 LoI: CERN-LHCC-2022-009

Forward Calorimeter

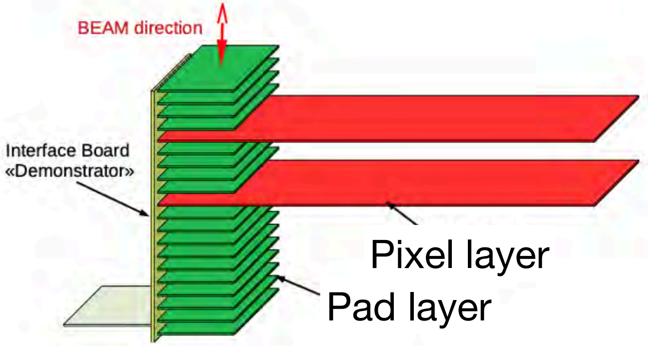


Letter-of-Intent: CERN-LHCC-2020-009

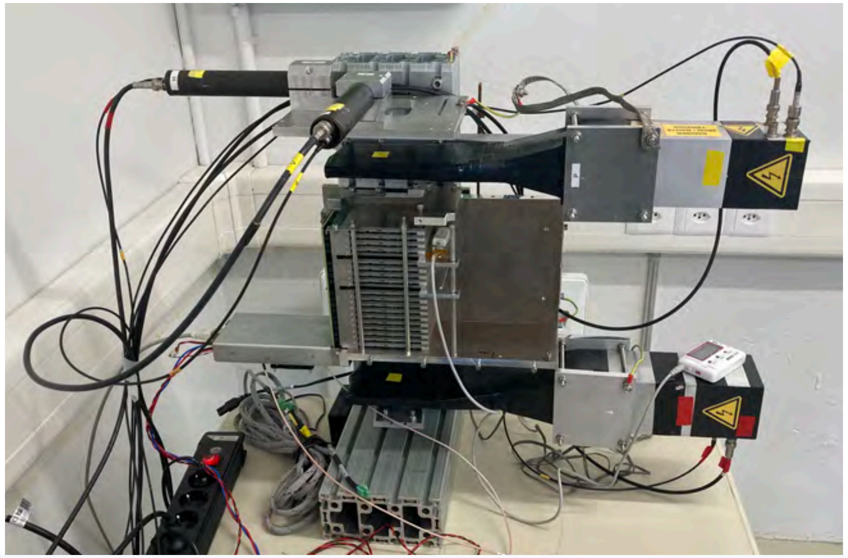
EMCal: Si-W for photon detection
HCal: Cu-scintillator: direct photon isolation and jets

- Goals: direct photon detection to probe gluon density at small *x*, forward π^0 in pp, pPb, Pb-Pb
- Current focus: beam tests with prototypes

Schedule:
2023: TDR
2023/2024: final design for production
2024-2027: production and calibration in beam
2027: installation



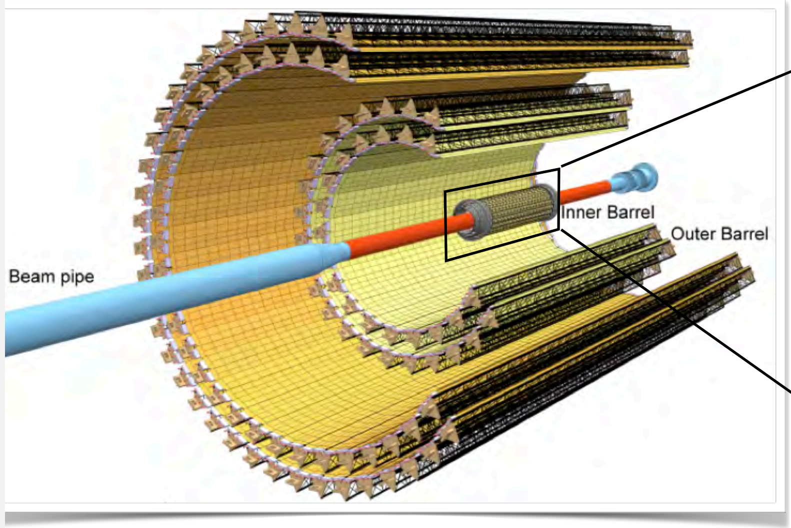
Complete pad layer setup

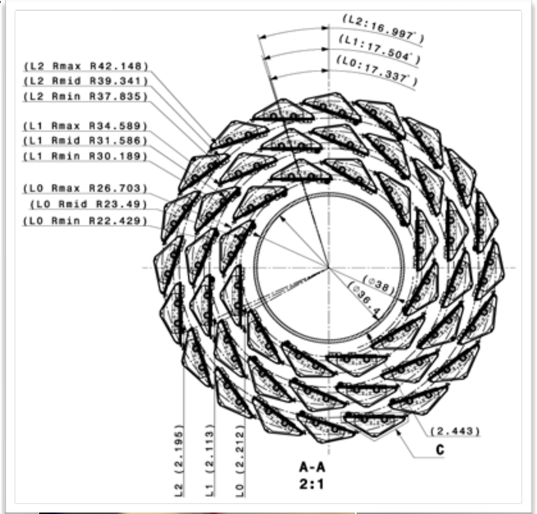


From ITS 2 to ITS 3

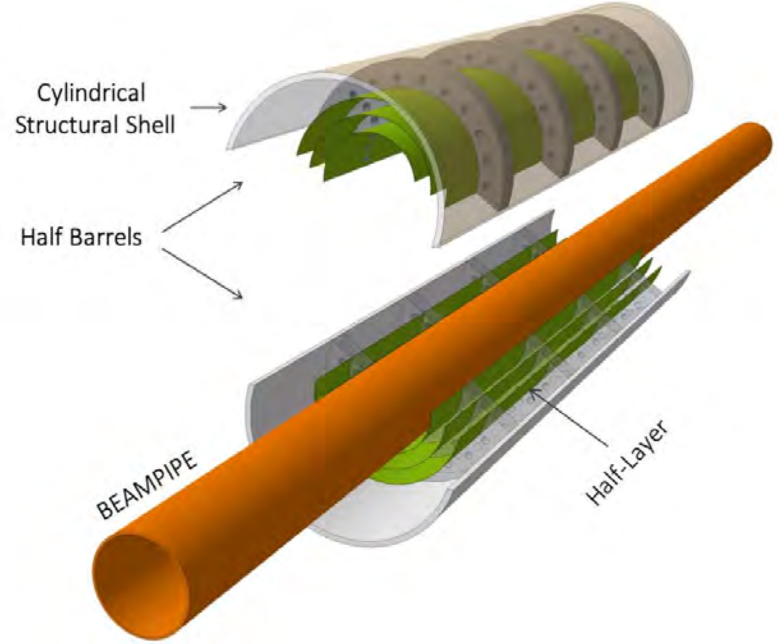
From stave-based inner barrel to truly cylindrical layers

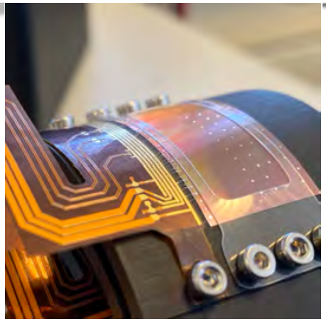
ITS2





ITS3





- **Improve Inner Tracker performance** by
  - moving closer to the interaction point
  - reducing material budget
- Replace Inner Barrel with **truly cylindrical layers** (ITS3)
  - requires low-power, wafer-scale, bendable sensors (MAPS: 65 nm TowerJazz ISC, stitching, thinning)

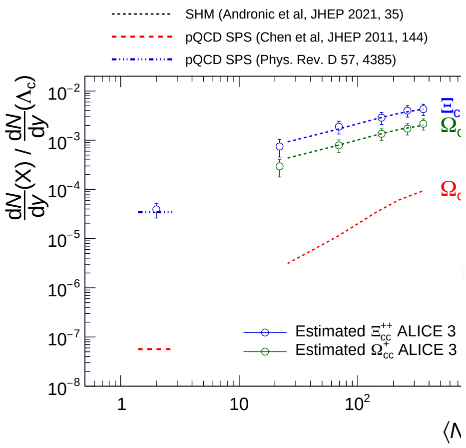
- Operation of bent sensors (ALPIDE) established in many testbeam campaigns
  - Stitching for wafer-scale sensors to be demonstrated with Engineering Run 1 → submission being finalised
  - TDR in preparation for Q4 2023

ALICE 3 Physics Programme

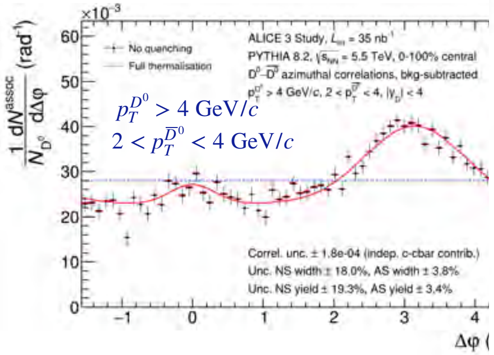
- ALICE 3 – LoI submitted recently – completely new detector for heavy-ion physics at the LHC
  - high-rate, high-resolution, large-acceptance heavy-ion experiment for Run-5 (~2035)

- Thermal radiation, chiral symmetry restauration
  - Di-electron mass, p_T spectra, v_2
- Heavy flavour transport, thermalisation
  - Beauty meson, baryon v_2
  - $D\overline{D}$ azimuthal correlations
  - Multi-charmed baryons
- Hadron interactions, structure
- Net-quantum-number fluctuations
- (Forward) Ultra-soft photon production
- BSM searches, e.g. ALPs

multi-charm baryons



$D\overline{D}$ correlations




EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-LHCC-2022-009
LHCC-I-038

Letter of intent for ALICE 3:
A next-generation heavy-ion experiment at the LHC
Version 2

ALICE Collaboration

arXiv:2211.02491v1 [physics.ins-det] 4 Nov 2022

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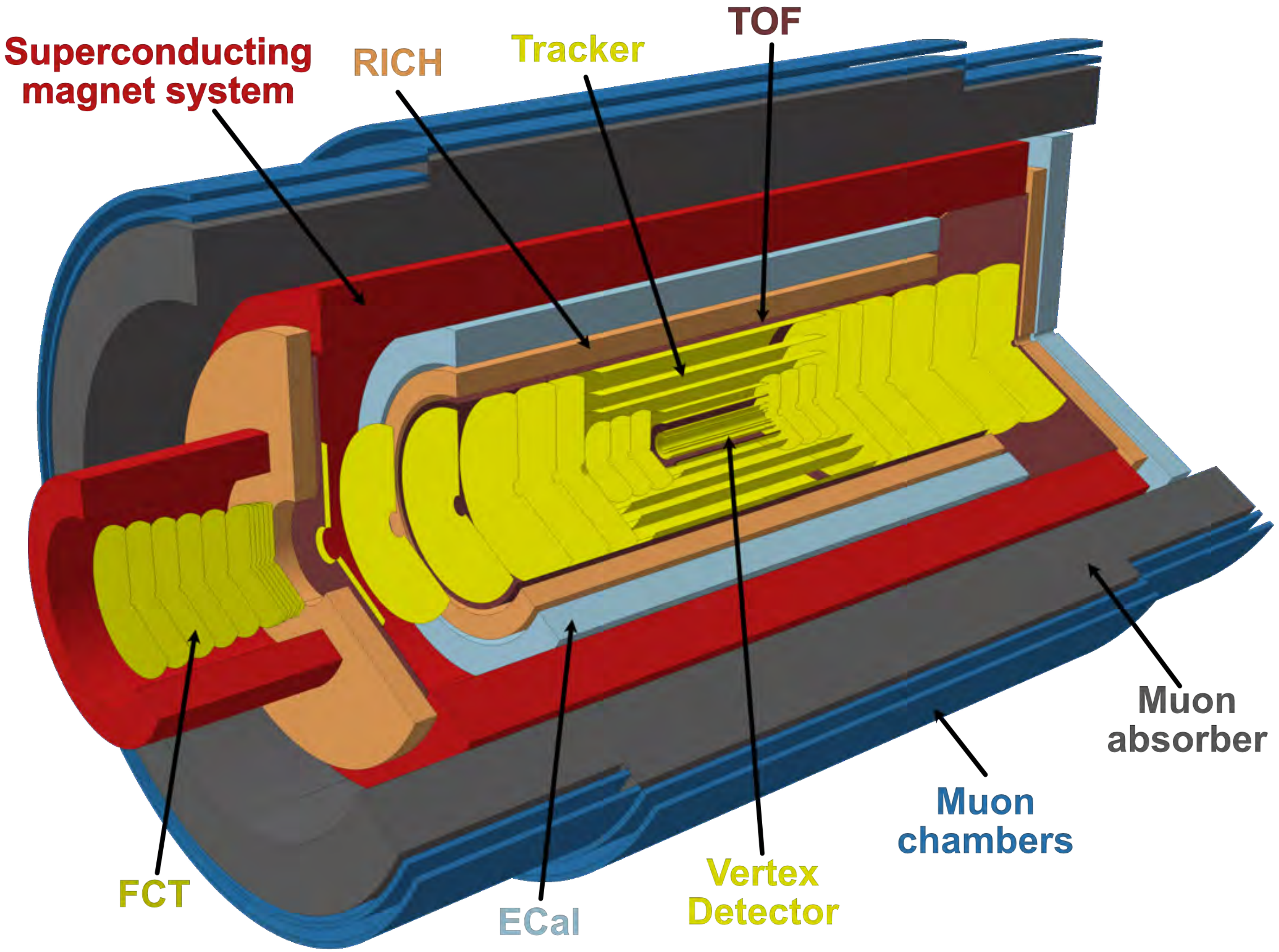
ALICE 3 Detector

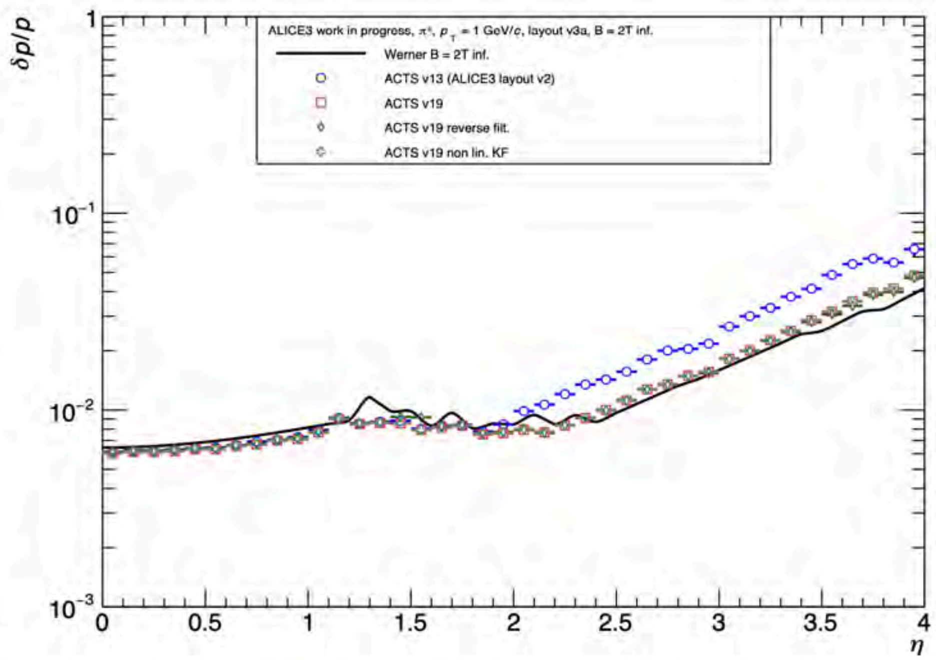
- **Vertex tracker: excellent pointing resolution**
  - Heavy flavour mesons/baryons, multi-charm (yields, flow, correlations)
  - HF rejection in dielectron, dimuon measurements
- **Large acceptance tracker and PID**
  - Correlation measurements
  - Rapidity dependence measurements
- **TOF and RICH**
  - Hadron ID for heavy flavour decays, net-baryon measurements
  - Electron ID (with ECAL) for dielectron radiation (and J/ψ)
- **Muon ID** down to p_T = 1.5 GeV: quarkonia, including P-wave (with ECAL), exotic hadrons
- **ECAL** (+conversions): photon detection for P-wave quarkonia, photon radiation, jets
- **FCT**: ultra-soft photons

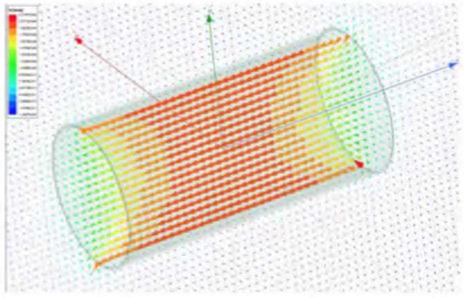


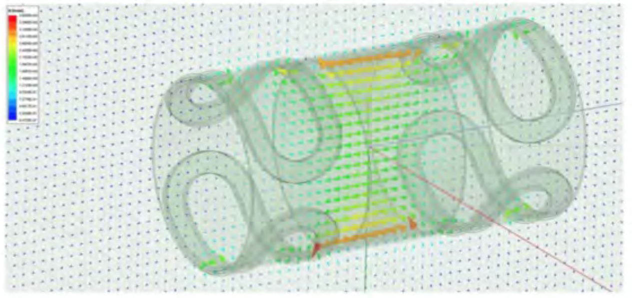
Magnet

- Existing LoI results for
  - Heavy flavour: 2 T solenoid + dipole
  - Dielectrons: 0.5 T
- Evaluate performance with updated magnet configuration and field strengths
  - 1 T solenoid
  - 2 T solenoid
- Quantify impact on heavy flavour
  - mass resolution (esp forward eta)
  - efficiency for decay daughter (esp strangeness tracking)
- Quantify impact on dielectrons
  - low mass acceptance: conversion tagging
  - PID coverage inner/outer TOF

Relative momentum resolution as function of η



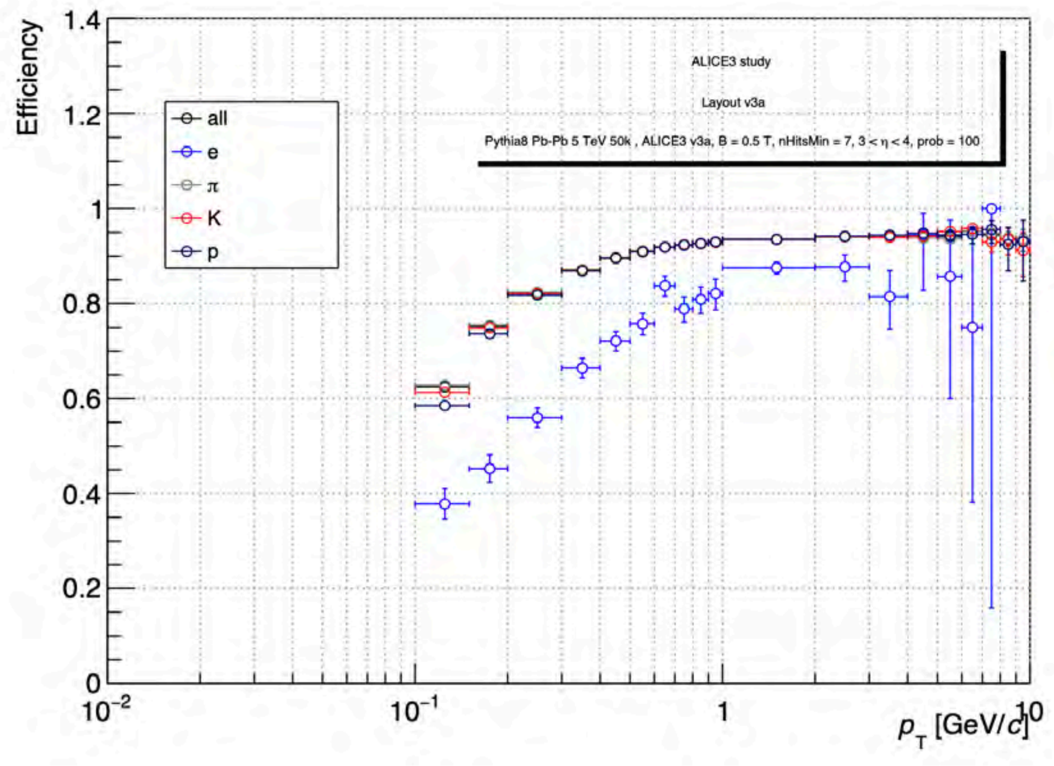




Tracking system

- Optimise/refine **tracker layout** incl. number and placement of layers
  - Barrel and endcap layers
- Strategy
  - ACTS to evaluate efficiency and resolution, produce tables for fast simulation
  - O^2 for matching algorithms and strangeness tracking
- Consider:
  - Efficiency and momentum resolution
  - Redundancy: robustness against failing chips/ladders
  - Strangeness tracking: efficiency for secondary tracks

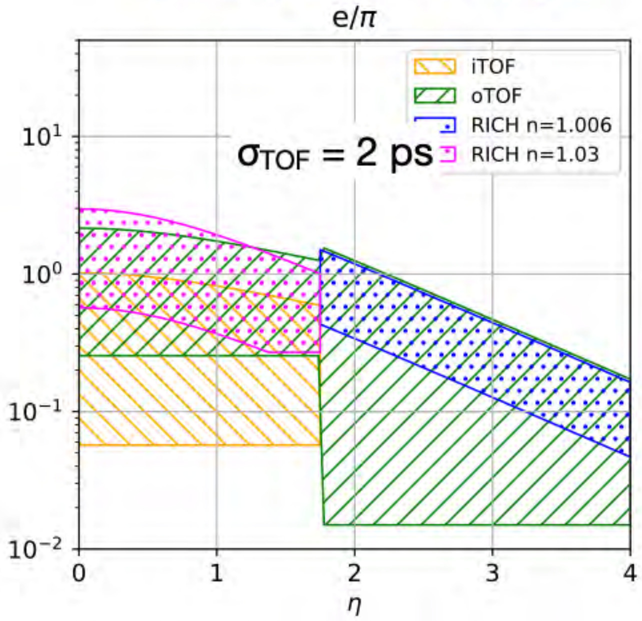
Tracking efficiency with ACTS



Particle Identification

- Refine forward PID detector setup
  - e.g. expect very high occupancy in forward RICH
- Evaluate/illustrate impact of RICH and TOF separately (scoping)
  - refine overlap/transition region
- Muon identification
  - update simulation with detector material, absorber, and matching
- Evaluate performance of ECAL for electron ID
  - for quarkonia
  - for thermal radiation

e/π separation vs η, p_T



Example study: improve TOF resolution to cover electron ID up to 1.5 GeV would need 2 ps TOF resolution
$\Rightarrow$ need multiple technologies to cover range

Electromagnetic calorimetry

- Evaluate physics performance with only sampling calorimeter
  - initiative for $PbWO_4$ segment (Russian institutes) currently on hold
- Implement ECAL response in simulation for electron ID
- Evaluate performance impact of shower overlaps
- Jet and γ-jet performance projections

Long-term schedule

- **2023-25**: selection of technologies, small-scale proof of concept prototypes (~ 25% of R&D funds)
- **2026-27**: large-scale engineered prototypes (~75% of R&D funds) → Technical Design Reports
- **2028-31**: construction and testing
- **2032**: contingency
- **2033-34**: Preparation of cavern, installation

ALICE 3 Integration and Runing

Installation of ALICE 3 around nominal IP2

L3 magnet can remain, ALICE 3 to be installed inside
Cryostat of ~8 m length, free bore radius 1.5 m,
magnetic field configuration to be optimized

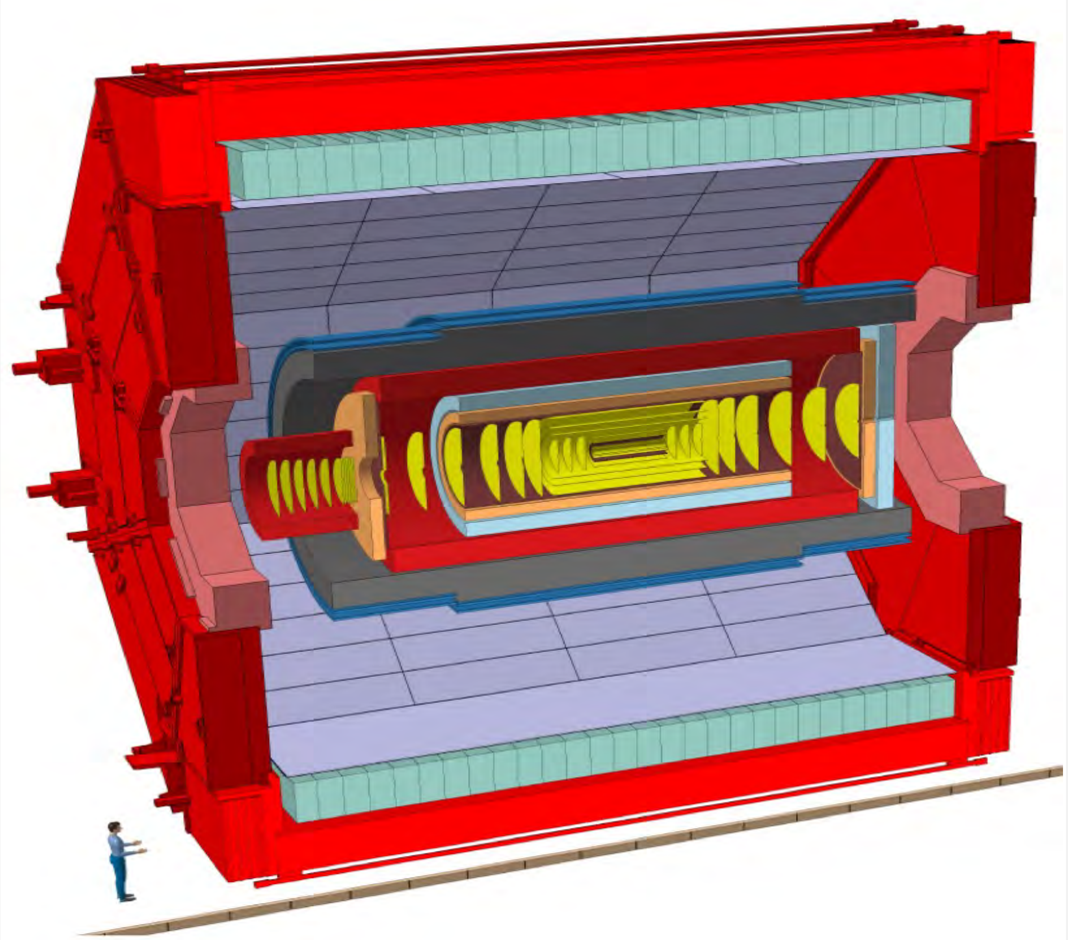
Running scenario:

6 running years with 1 month / year with heavy-ions

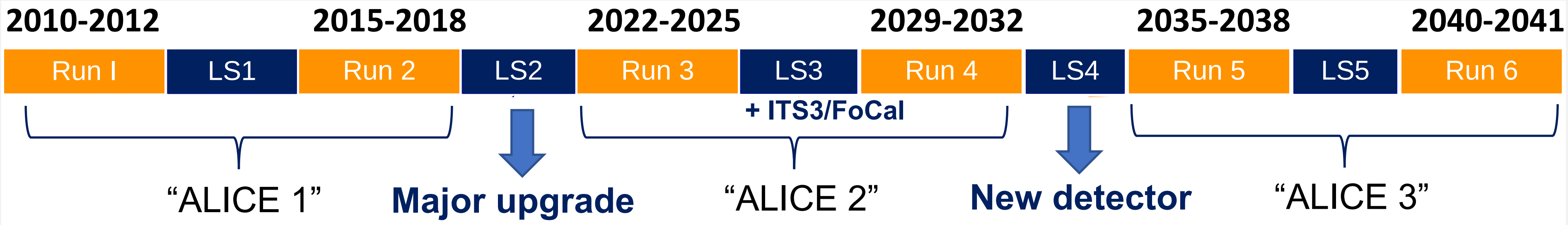
- 35 nb^{-1} for Pb—Pb x 2.5 compared to Run 3 + 4
- Lighter species for higher luminosity under study

pp at s = 14 TeV:

- 3 fb^{-1} / year x 100 compared to Run 3 + 4



Pushing Frontiers of Precision



Enhance physics reach by improving:

- **rate capabilities & acceptance**
- **tracking precision**

→ high precision, reduce backgrounds, access rarer probes