ALICE Upgrade Activities

Max Rauch for the “Nuclear Physics” group

NorCC Workshop 2023

Bergen, 27th September 2023

Outline

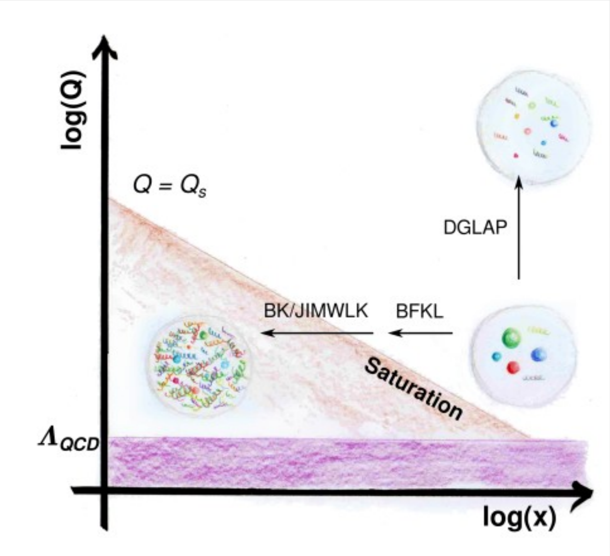
- **ALICE FoCal**
  - Physics performance
  - Pixel layer design and production
  - Readout system
  - Testbeam at CERN

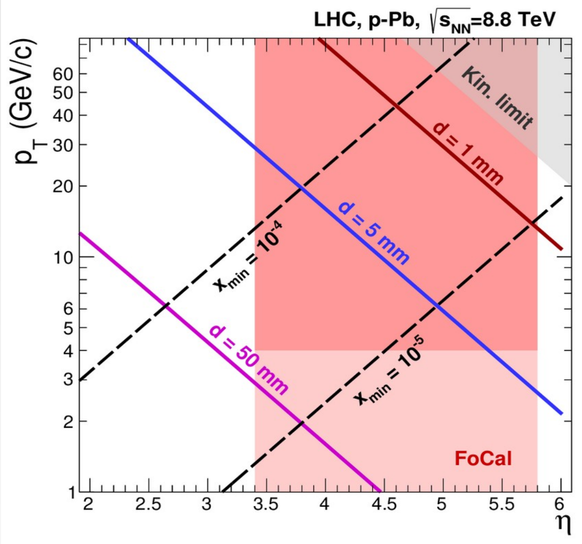
Attiq Ur Rehman: Vertex detector for ALICE 3 (Sep 28, 2023, 3:00 PM)

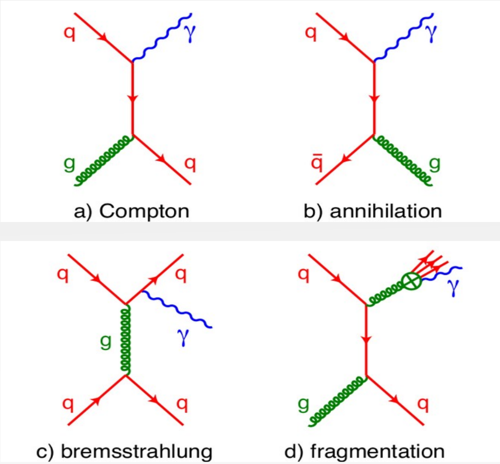
Jørgen Lien: MAPS embedding (Sep 28, 2023, 3:15 PM)

Maksim Melnik Storetvedt : The ALICE Grid framework (Sep 28, 2023, 5:30 PM)

Single isolated photon signal events





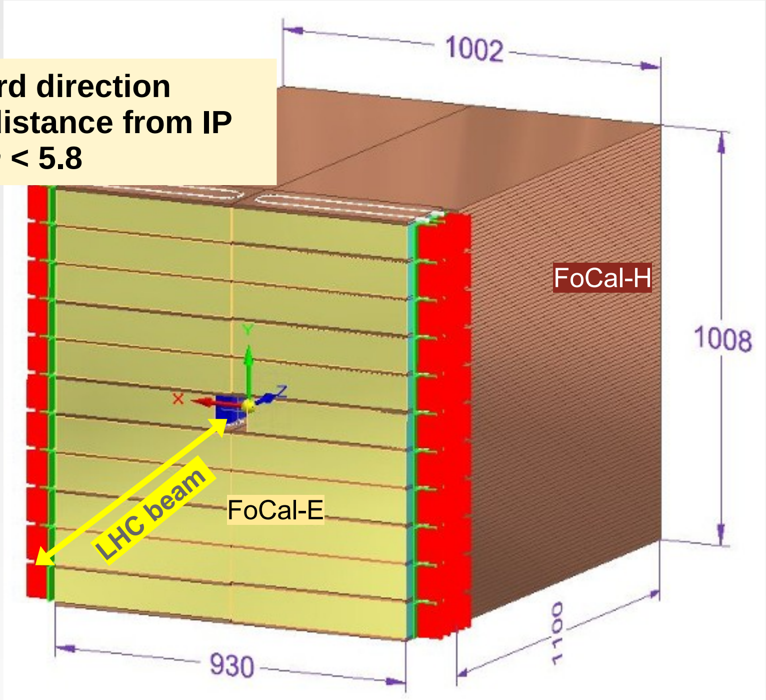


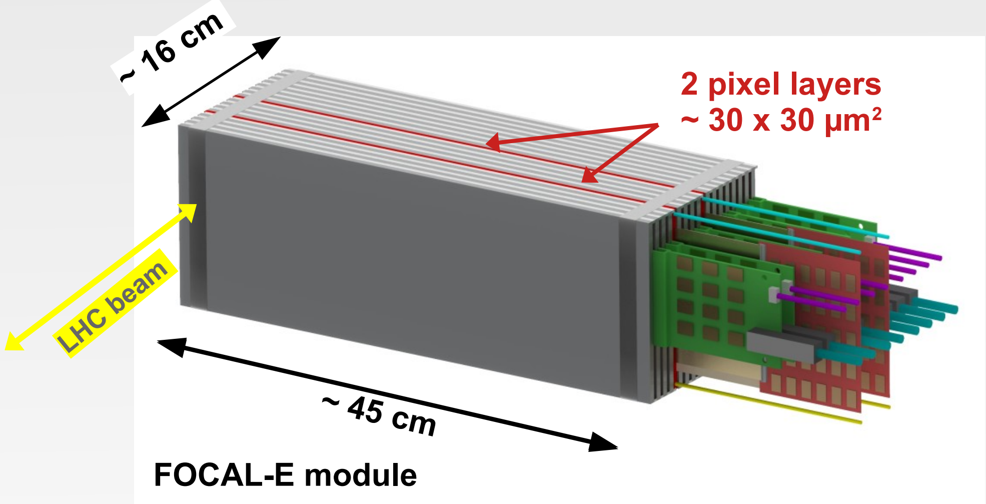
- Flagship measurement: single isolated photons → exploration of **low-x regime** and high **gluon density / gluon stauration**
- Electromagnetic calorimeter
  - **< 5 % resolution at high energies**
  - Discrimination of π^0 decay into two ɣ → **electromagnetic shower separation d < 5mm**
- Hadronic calorimeter, e.g. for isolation measurement, jet measurement
- **ALICE Fo**rward **Cal**orimeter → **ALICE FoCal**

ALICE FoCal detector design

Installation and commissioning 2028
Data taking in Run 4 from 2029

Forward direction
~ 7m distance from IP
3.4 < η < 5.8





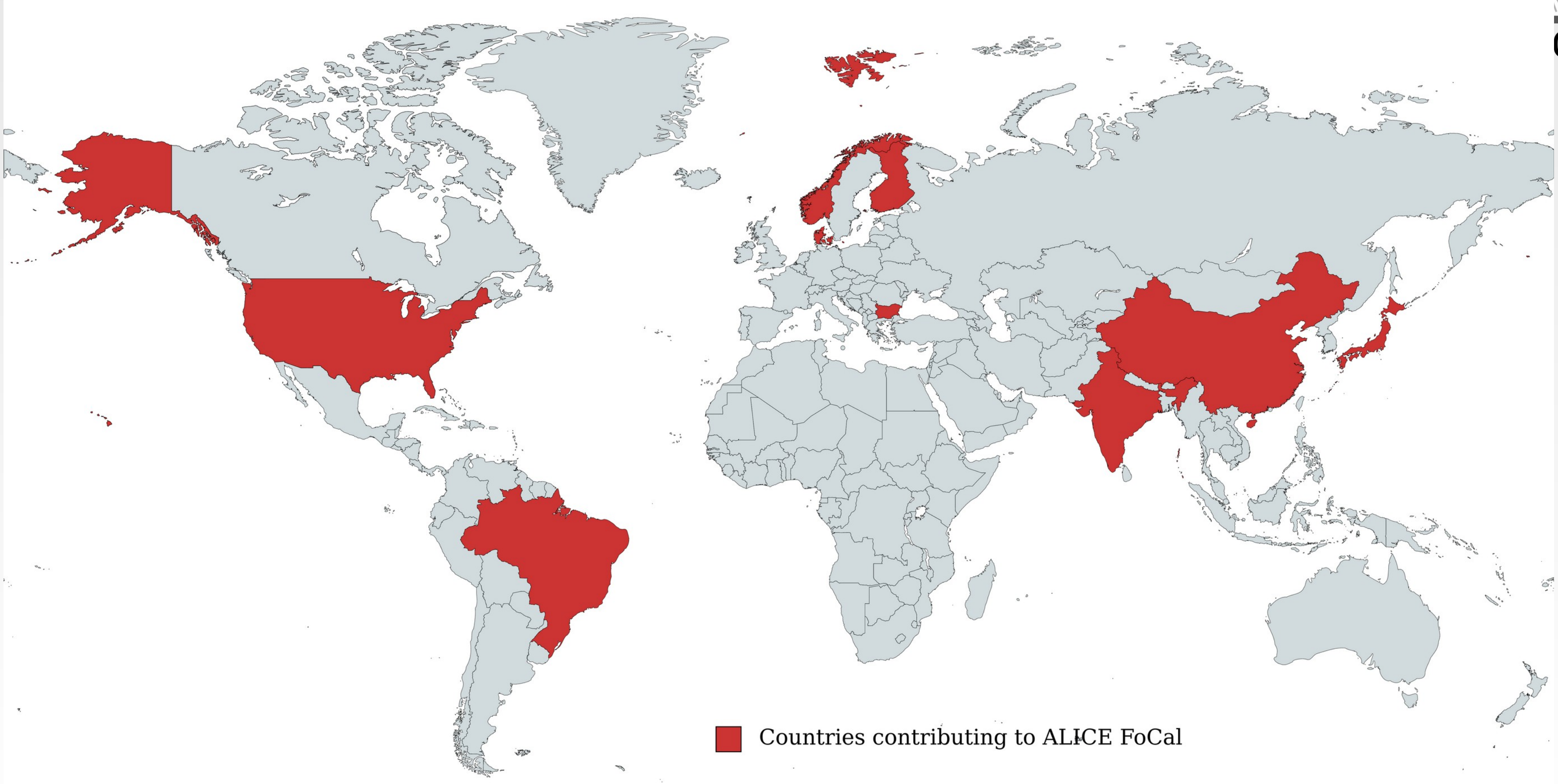
Hadronic calorimeter FoCal-H

- Transversally segmented calorimeter, total length ~ 6 λ_{had}
  - Spaghetti Cu-scintillating fibre design
  - Located directly behind FoCal-E (reduce shower blow-up)

Electromagnetic calorimeter FoCal-E

- 20 layers W absorbers (~ 20 X_0), longitudinally segmented
- Si-W sampling calorimeter (18 low-granularity layers + 2 high-granularity pixel layers)

ALICE FoCal – A global collaboration



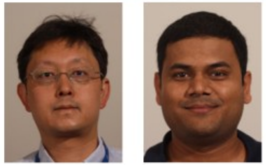
**map made privately, not claiming completeness, subject to changes*

ALICE FoCal – Coordination team

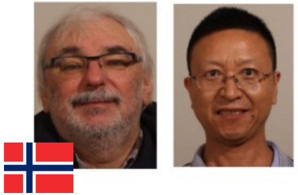
FoCal coordination
(C.Loizides, I.Bearden, T.Chujo)

The FoCal activities are coordinated since Nov 2021 in sub-groups to allow for efficient steering and discussions is (bi-)weekly meetings for preparation of the TDR

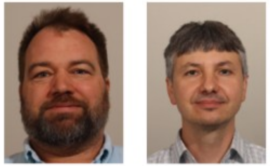
Pad layers
(T.Chujo., G.Tambave)



Pixel layers
(D.Röhrich., Z.-B.Yin)



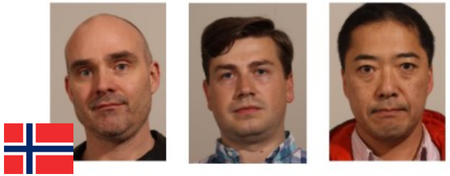
HCal
(I.Bearden, V.Kozhuharov)



Physics simulations/software
(I.Arsene, M. Fasel, T.Peitzmann)

TDR editorial board
(C.Loizides, N.Novitzky, P.Jacobs)

Readout, trigger and O2
(J.Alme, N.Nowitzky, K.Oyama)



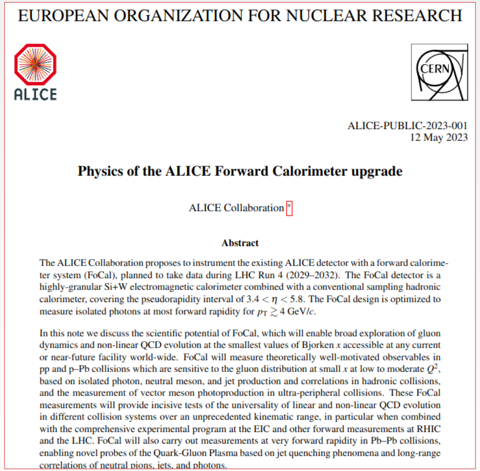
Electronics / Mechanics / Services
(A.Rusu, T.v.d.Brink, M.Bregant)

Testbeam / Calibrations
(M.Rauch, T.Isodori)

+ many more colleagues who are not in the coordination team

ALICE FoCal – important documents 2023

- Physics note: available on CERN Document Server (12th May 2023)
- Physics performance note: available on CERN Document Server (4th Sep 2023)
- Technical Design Report: to be submitted to LHCC (deadline 29th Sep 2023)
- Prototype and testbeam paper: to be submitted as soon as possible to arXiv



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

ALICE-PUBLIC-2023-001
12 May 2023

Physics of the ALICE Forward Calorimeter upgrade

ALICE Collaboration*

Abstract

The ALICE Collaboration proposes to instrument the existing ALICE detector with a forward calorimeter system (FoCal), planned to take data during LHC Run 4 (2029–2032). The FoCal detector is a highly-granular Si+W electromagnetic calorimeter combined with a conventional sampling hadronic calorimeter, covering the pseudorapidity interval of $3.4 < \eta < 5.8$. The FoCal design is optimized to measure isolated photons at most forward rapidity for $p_T \gtrsim 4$ GeV/c.

In this note we discuss the scientific potential of FoCal, which will enable broad exploration of gluon dynamics and non-linear QCD evolution at the smallest values of Bjorken x accessible at any current or near-future facility world-wide. FoCal will measure theoretically well-motivated observables in pp and p–Pb collisions which are sensitive to the gluon distribution at small x at low to moderate Q^2, based on isolated photon, neutral meson, and jet production and correlations in hadronic collisions, and the measurement of vector meson photoproduction in ultra-peripheral collisions. These FoCal measurements will provide incisive tests of the universality of linear and non-linear QCD evolution in different collision systems over an unprecedented kinematic range, in particular when combined with the comprehensive experimental program at the EIC and other forward measurements at RHIC and the LHC. FoCal will also carry out measurements at very forward rapidity in Pb–Pb collisions, enabling novel probes of the Quark-Gluon Plasma based on jet quenching phenomena and long-range correlations of neutral pions, jets, and photons.

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

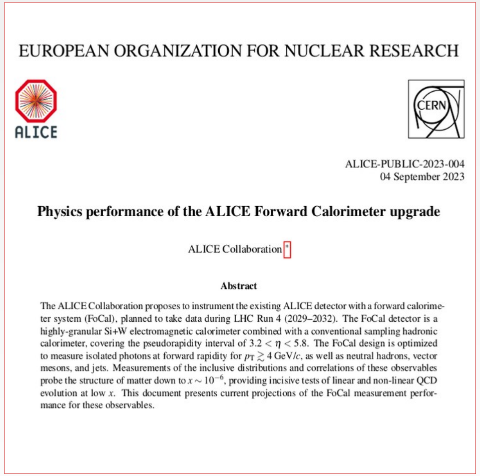
CERN-LHCC-2023-XXX
ALICE-PUBLIC–DRAFT v0.1
September 23, 2023

Technical Design Report
of the ALICE Forward Calorimeter (FoCal)

ALICE Collaboration *

Abstract

The technical design for the ALICE Forward Calorimeter (FoCal) is described. The FoCal is an upgrade of the ALICE experiment foreseen to be installed during Long-Shutdown 3 for data-taking in 2029–2032 at the LHC. The FoCal is a highly granular Si+W electromagnetic calorimeter combined with a Cu+scintillating-fiber hadronic calorimeter covering pseudorapidities of $3.4 < \eta < 5.8$. The FoCal provides unique capabilities to measure direct photon production at forward rapidities, which is sensitive to the small-x gluon distribution in protons and nuclei. Via inclusive and correlation measurements of neutral mesons, photons, and jets, as well as J/ψ production in ultra-peripheral collisions, it will significantly extent the scope of the ALICE physics program to explore the dynamics of hadronic matter at small x down to $\sim 10^{-6}$.



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

ALICE-PUBLIC-2023-004
04 September 2023

Physics performance of the ALICE Forward Calorimeter upgrade

ALICE Collaboration*

Abstract

The ALICE Collaboration proposes to instrument the existing ALICE detector with a forward calorimeter system (FoCal), planned to take data during LHC Run 4 (2029–2032). The FoCal detector is a highly-granular Si+W electromagnetic calorimeter combined with a conventional sampling hadronic calorimeter, covering the pseudorapidity interval of $3.2 < \eta < 5.8$. The FoCal design is optimized to measure isolated photons at forward rapidity for $p_T \gtrsim 4$ GeV/c, as well as neutral hadrons, vector mesons, and jets. Measurements of the inclusive distributions and correlations of these observables probe the structure of matter down to $x \sim 10^{-6}$, providing incisive tests of linear and non-linear QCD evolution at low x. This document presents current projections of the FoCal measurement performance for these observables.

Performance of the electromagnetic and hadronic prototype segments of the ALICE FoCal

M. Inaba[b], N. Novitzky[1], T. Peitzmann[c], T. Isidori[d], A. van den Brink[c], M. van Leeuwen[c], CL: will work on author list when back from vacation[1]

[a] University of Tsukuba, Japan
[b] Tsukuba University of Technology, Japan
[c] Utrecht University, Netherlands
[d] The University of Kansas, United States of America

Abstract

Keywords: Todo

1. Introduction

Todo: CL will write first draft of intro

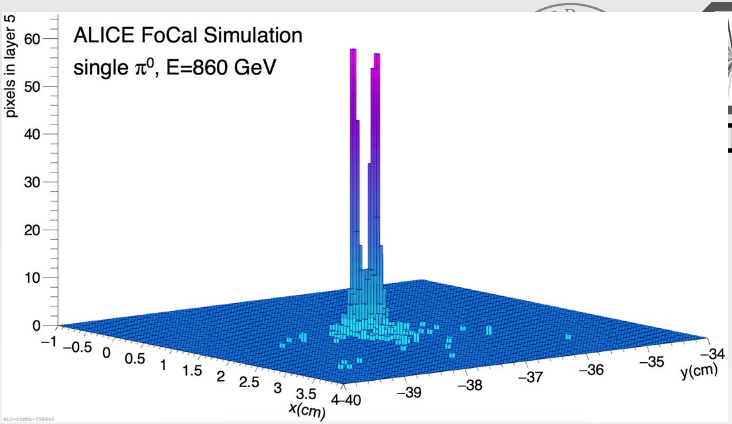
2. Detector prototype

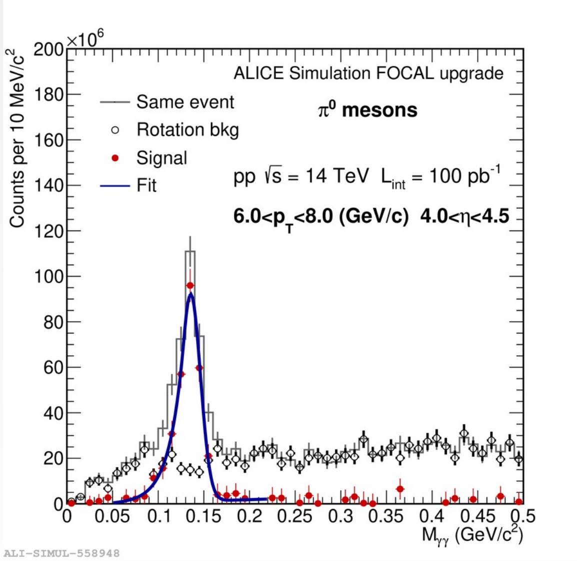
To achieve the optimal detector design needed for the realization of the Forward Calorimeter (FoCal) physics program [?], several performance studies of the detector prototypes have been carried out in the last few years. FoCal consists of both electromagnetic and hadronic components: Electromagnetic Forward Calorimeter (FoCal-E) and Hadronic Forward Calorimeter (FoCal-H), respectively. FoCal-E has two independent subsystems embedded in a longitudinally segmented module, where tungsten absorbers are interleaved to the active layers for detection. Each module comprises 18 layers of Si pad detectors aimed at providing good resolution over a

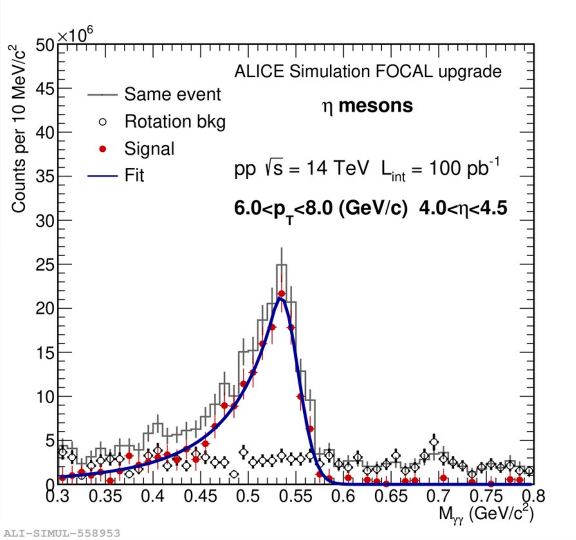
Physics Performance

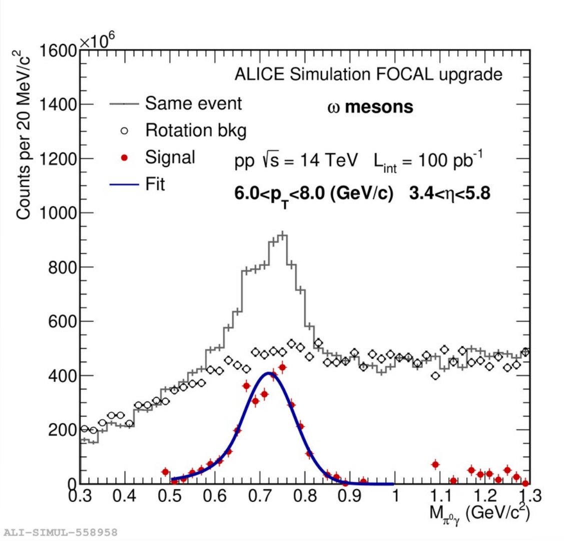
Neutral Meson Reconstruction

- Reconstruction of di-photon signature possible
- Measurment of invariant mass of e.g. π^0, η, ω mesons
- Efficiencies up to 80% for d < 5mm – thanks to high-granular pixel layers



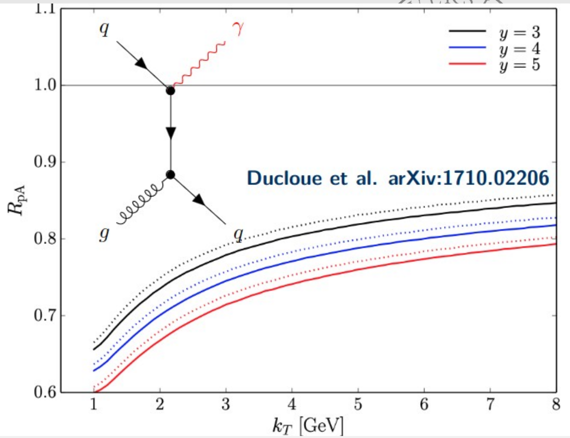


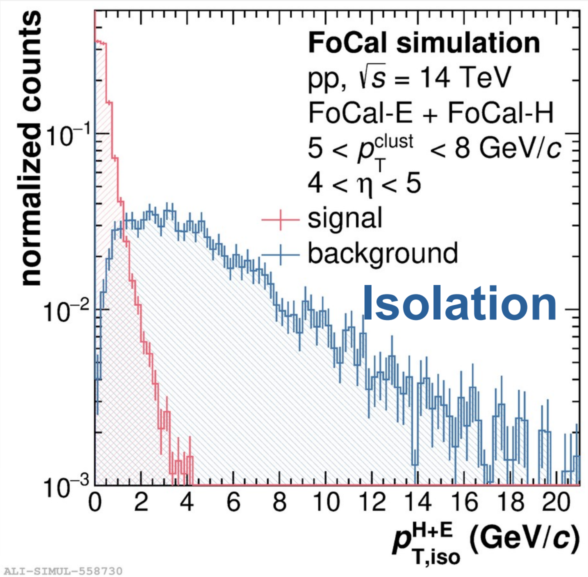


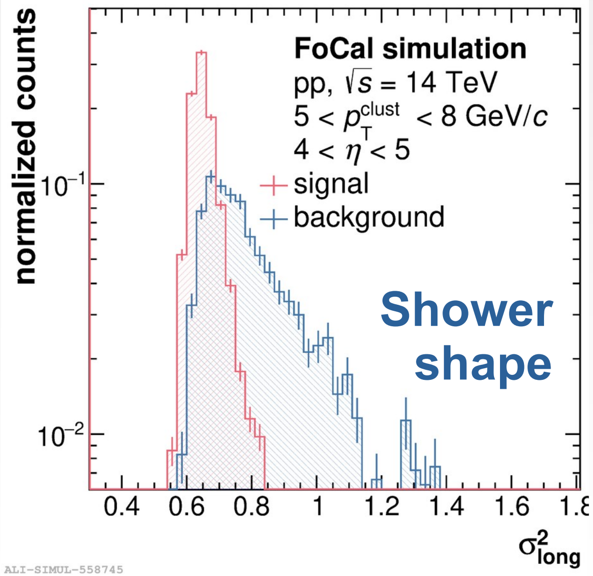


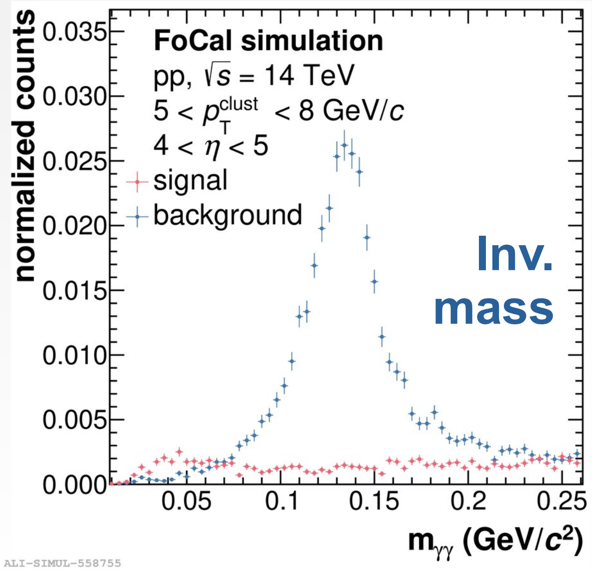
Isolated Photons

- directly produced in hard scattering qg → γq
- at forward y in p–Pb collisions sensitive to gluon saturation
- Isolated (prompt) photons identification by
  1) measurement of isolation energy in FoCal-E and FoCal-H
  2) electromagnetic shower shape in 20 FoCal-E layers
  3) separation of showers from dominant $\pi^0 \to \gamma\gamma$ background

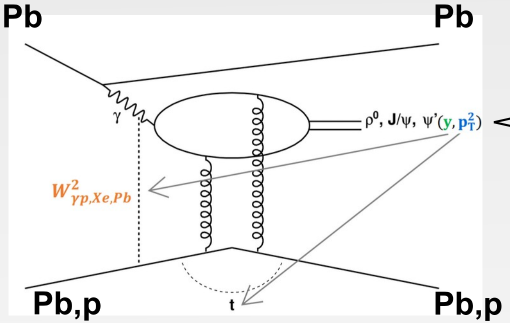


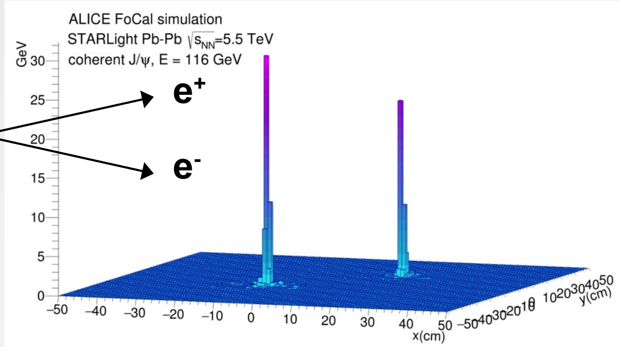


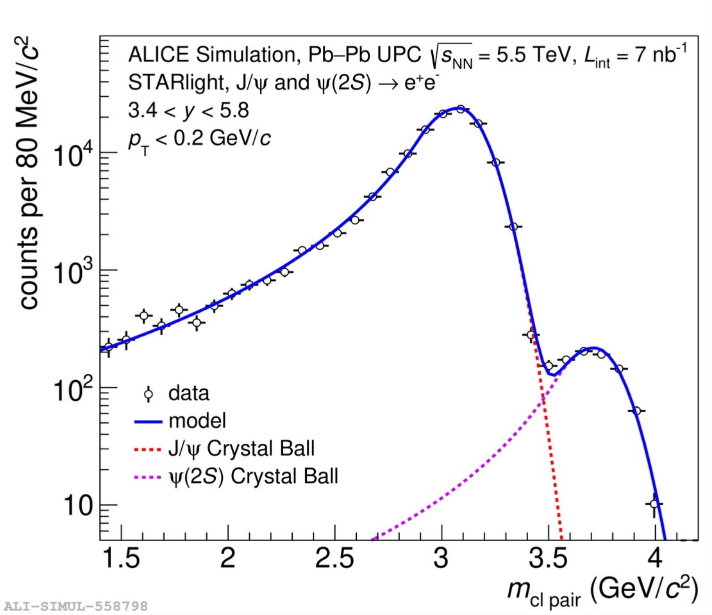




Ultra-peripheral Pb-Pb and p-Pb collisions



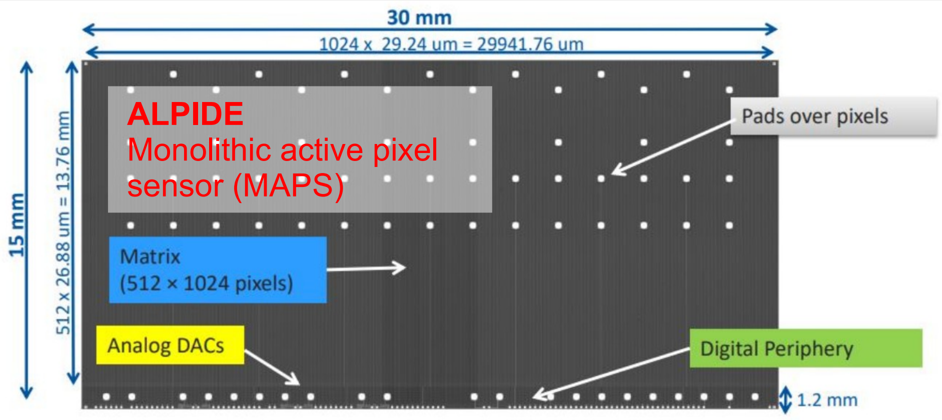


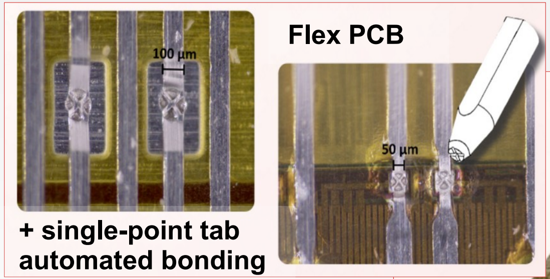


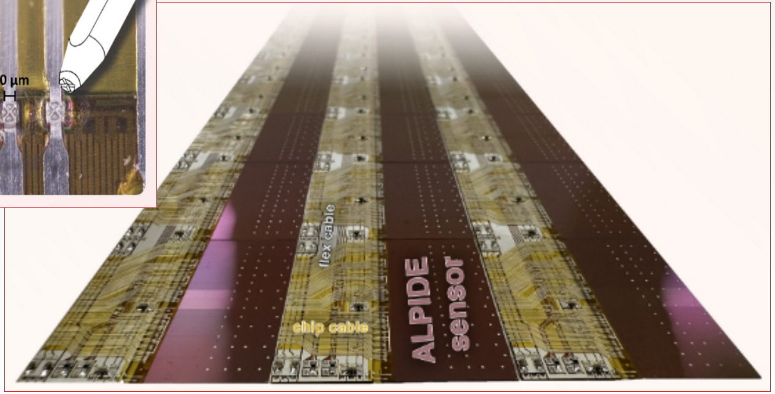
- Photo-production of vector mesons (e.g. J/ψ, ψ(2S)) proportional to gluon density
  - Access to measurement of gluon saturation
- FoCal gives access to unprecedented regimes of $W_{\gamma p}$
  - $W_{\gamma p}$ ~ 10 GeV in Pb-p collisions
  - $W_{\gamma p}$ ~ 2 TeV in p-Pb collisions
- Successful reconstruction of J/ψ and ψ(2S) states simulated

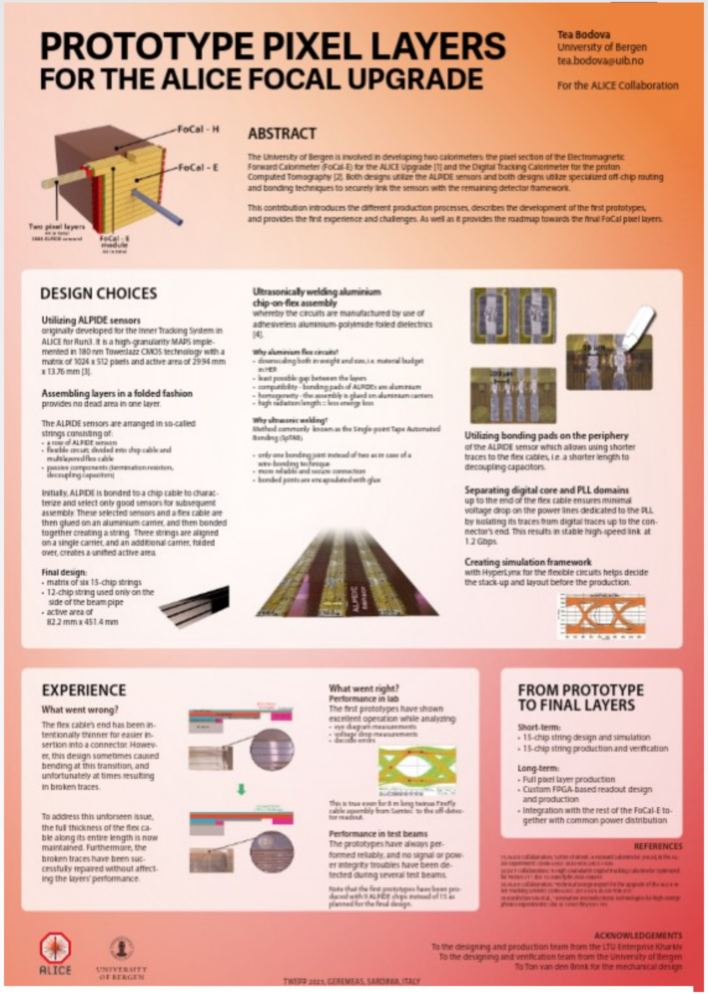
FoCal Pixel Layer Design and Production

Prototype FoCal-E Pixel Layers



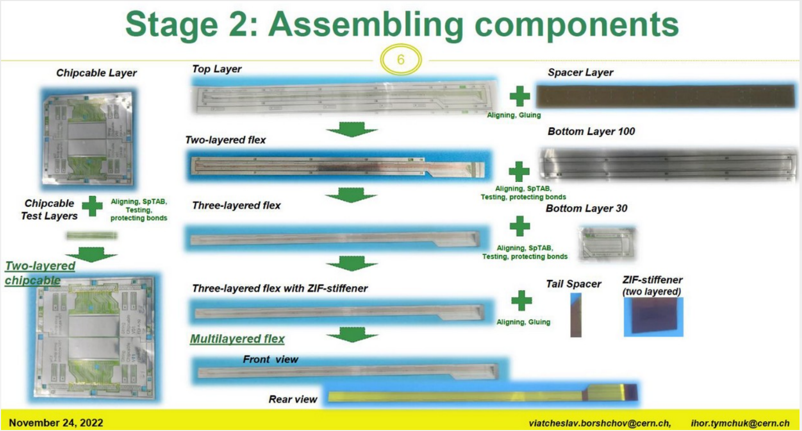


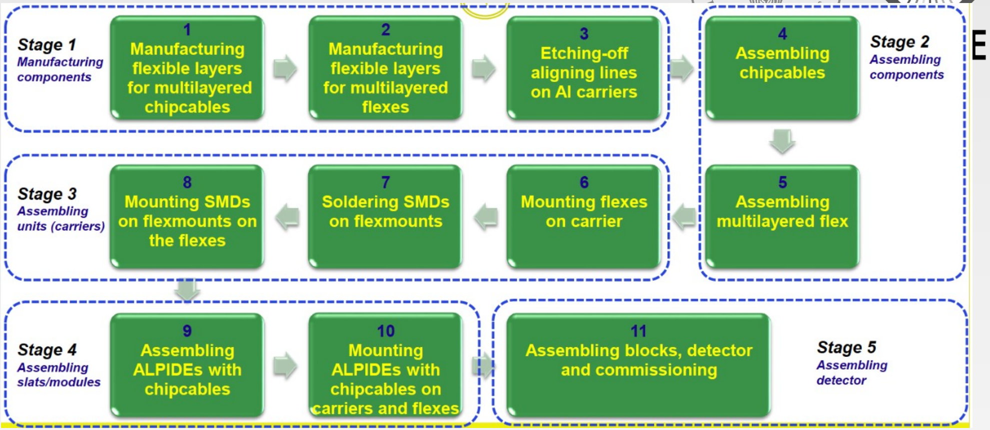


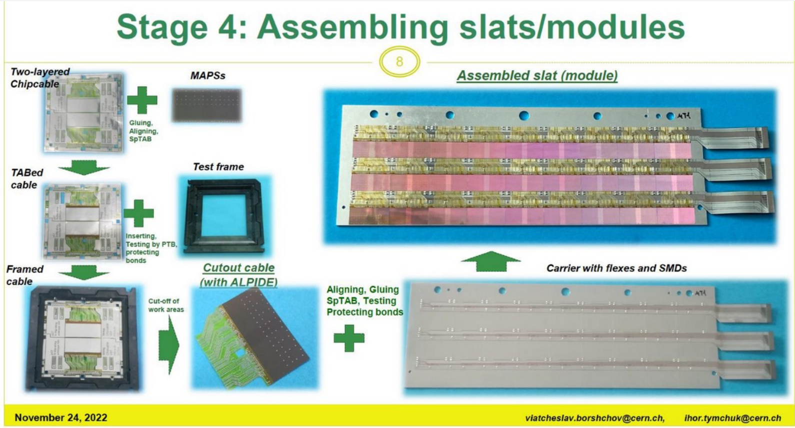


Tea Bodova, TWEPP 2023, poster

Prototype FoCal-E Pixel Layers

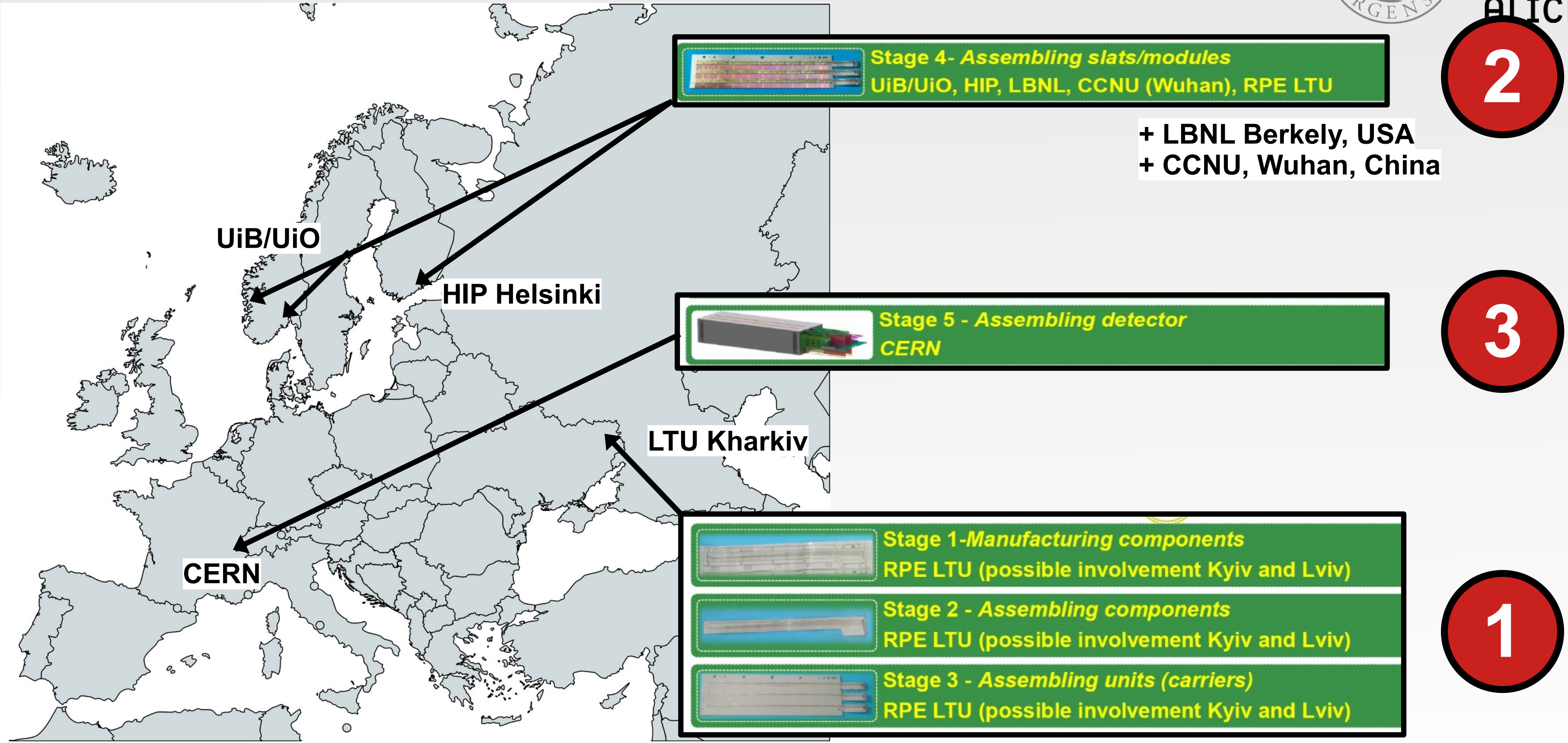






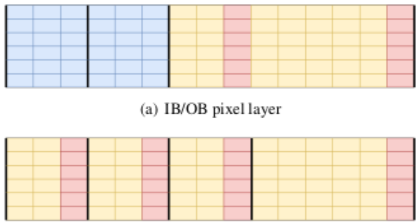
- **Planning of the full production chain**
  - Manufacturing components
  - Component assembly
  - Assembling units (carriers)
  - Assembling slats/modules
  - Detector assembly

Sites (?) for FoCal Pixel Layer Production



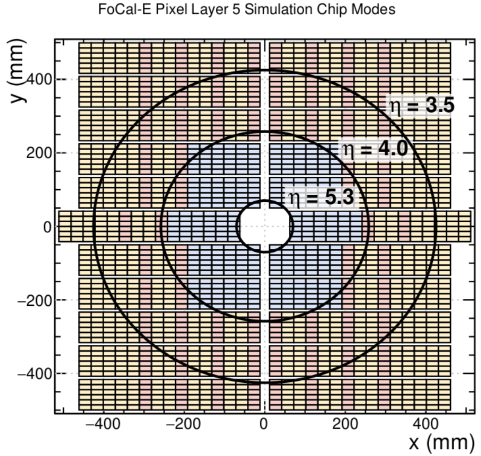
FoCal Readout System

Readout System Design

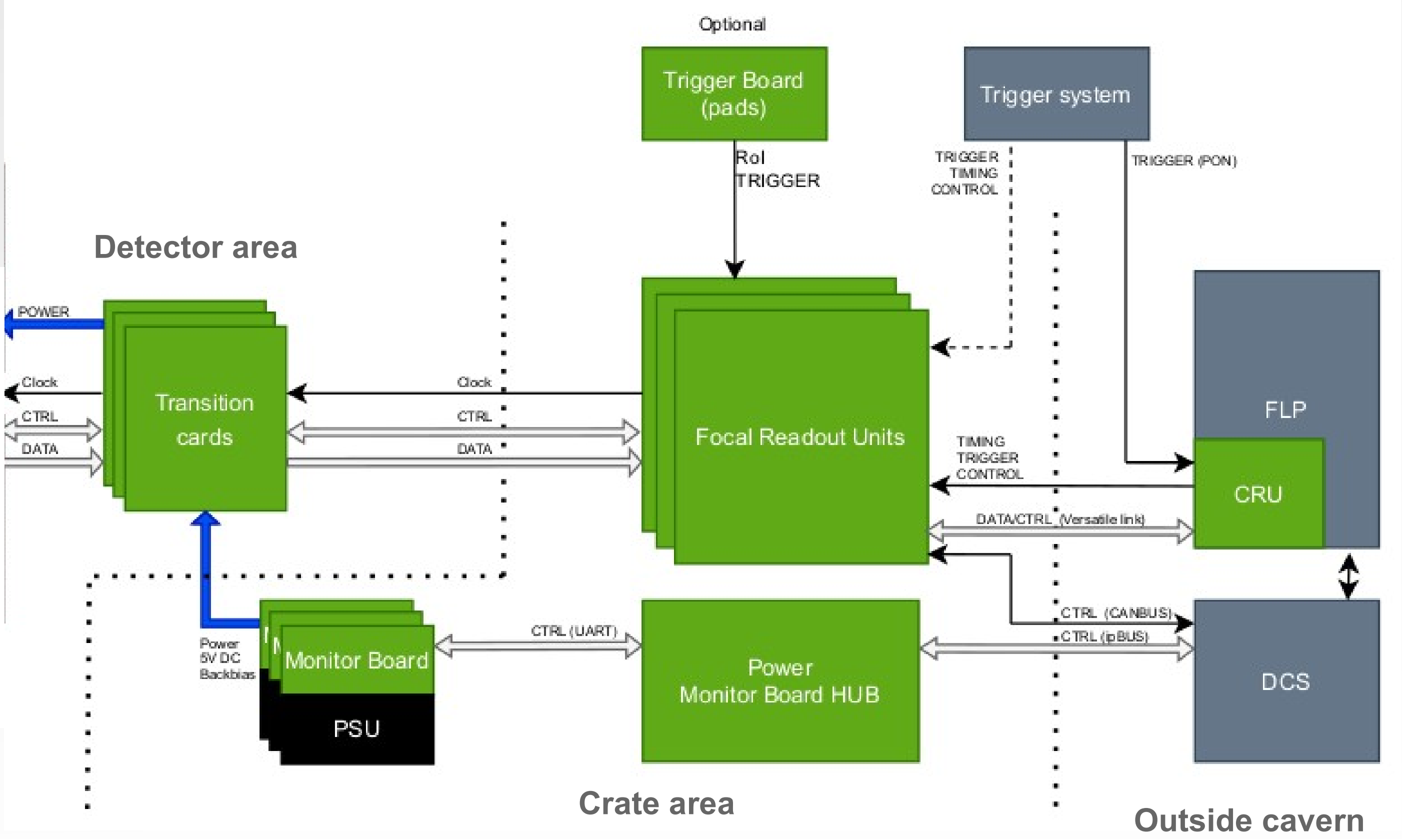


(a) IB/OB pixel layer

(b) OB pixel layer

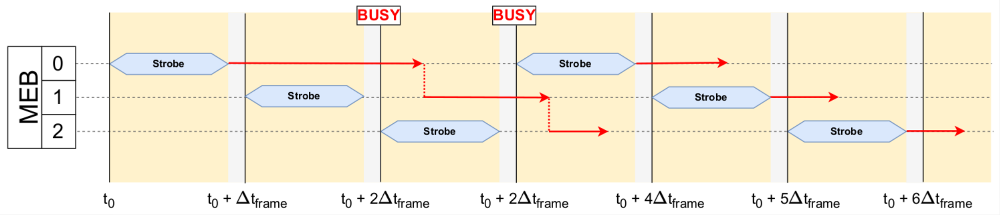


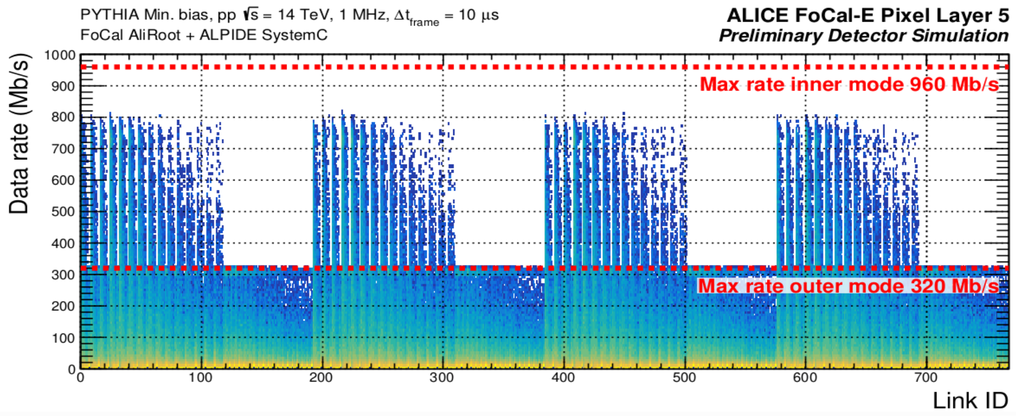
1 FoCal-E Pixel plane
~2000 ALPIDE chips

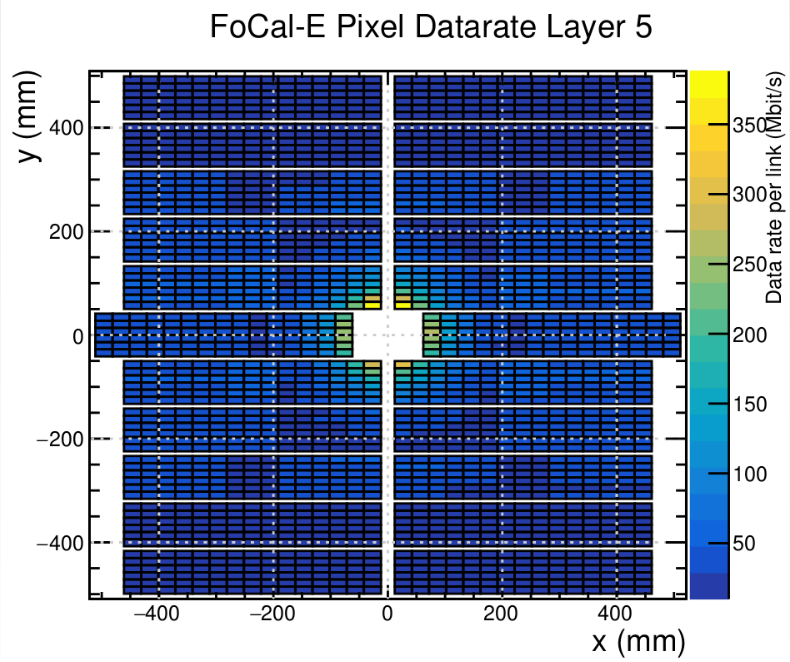


FoCal-E Pixel SystemC Simulation

- Physics event and detector simulation with PYTHIA
- Feeding of simulated particle hits into a digital ALPIDE model based on SystemC
  - *Thesis by Simon V. Nesbø (UiB, 2022) "Readout Electronics for the Upgraded ITS Detector in the ALICE Experiment"*



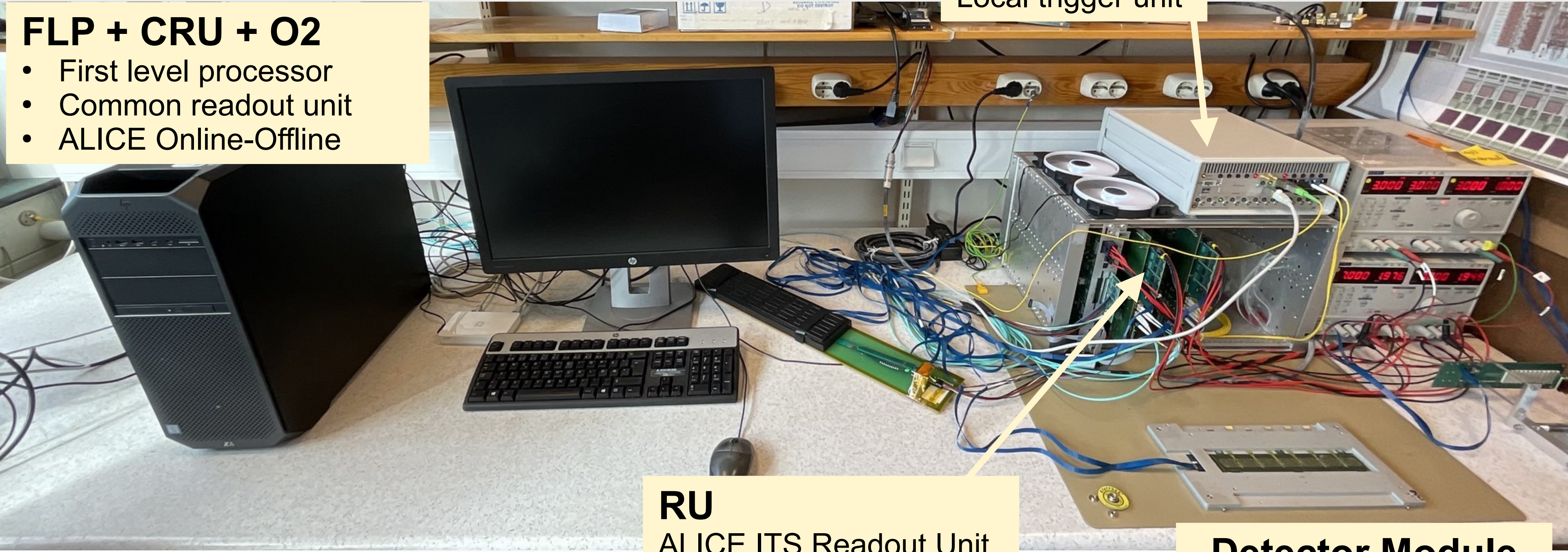




FoCal Lab Setup @ UiB

LTU
Local trigger unit

FLP + CRU + O2
- First level processor
- Common readout unit
- ALICE Online-Offline



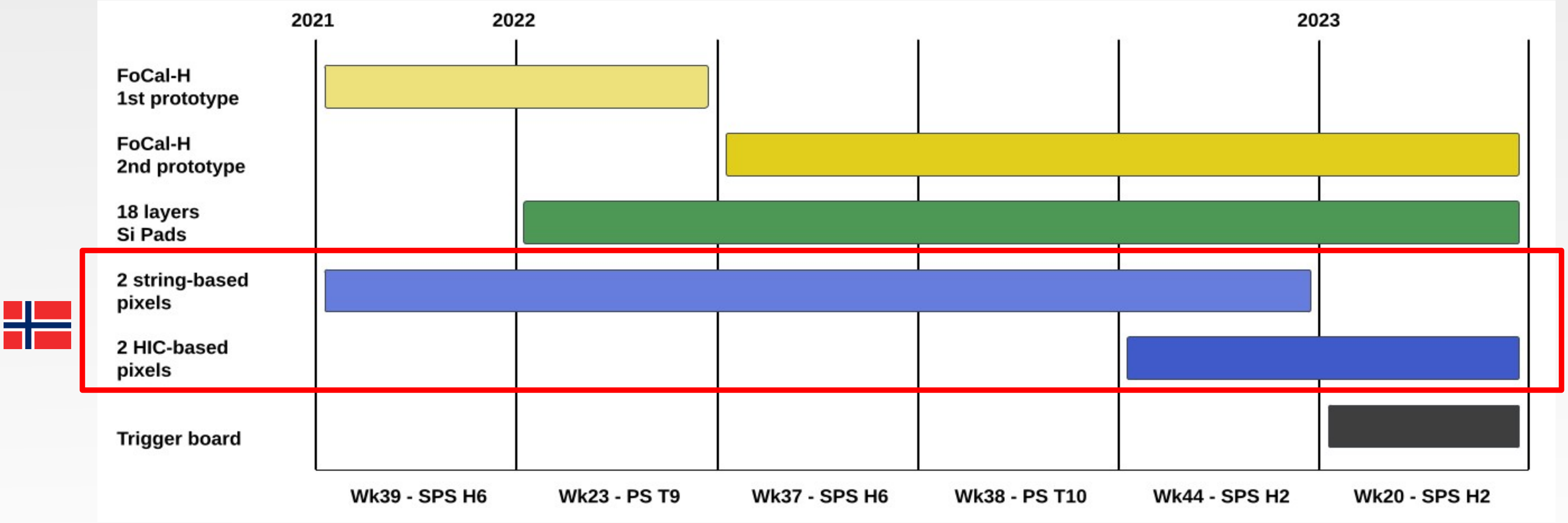
RU
ALICE ITS Readout Unit

Detector Module

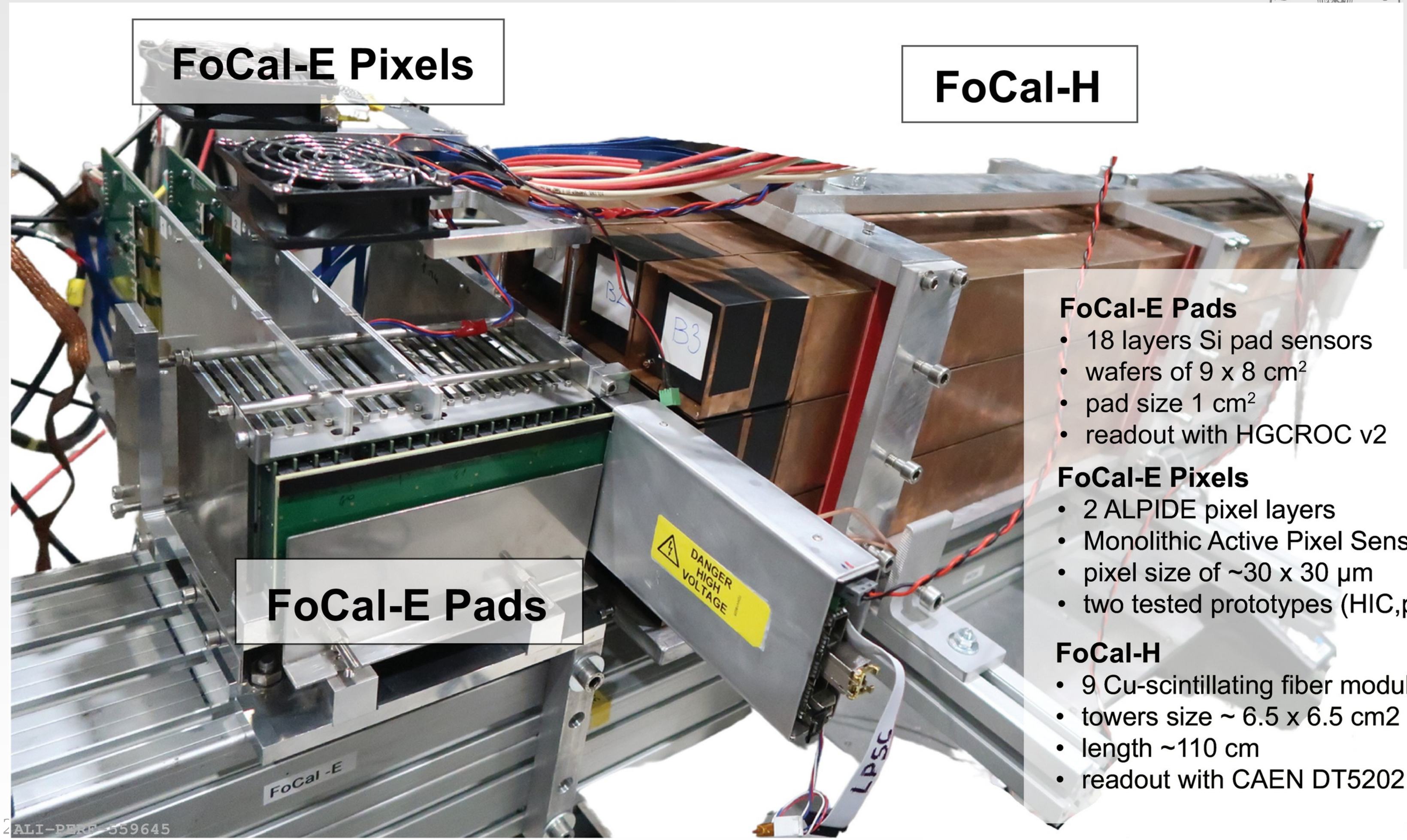
FoCal Testbeam

Testbeam Campaign

- Intensive participation at testbeams at CERN during the last two years
- Testing of pixel string prototypes and “HIC based” modules



ALICE FoCal prototype installed at CERN SPS H2

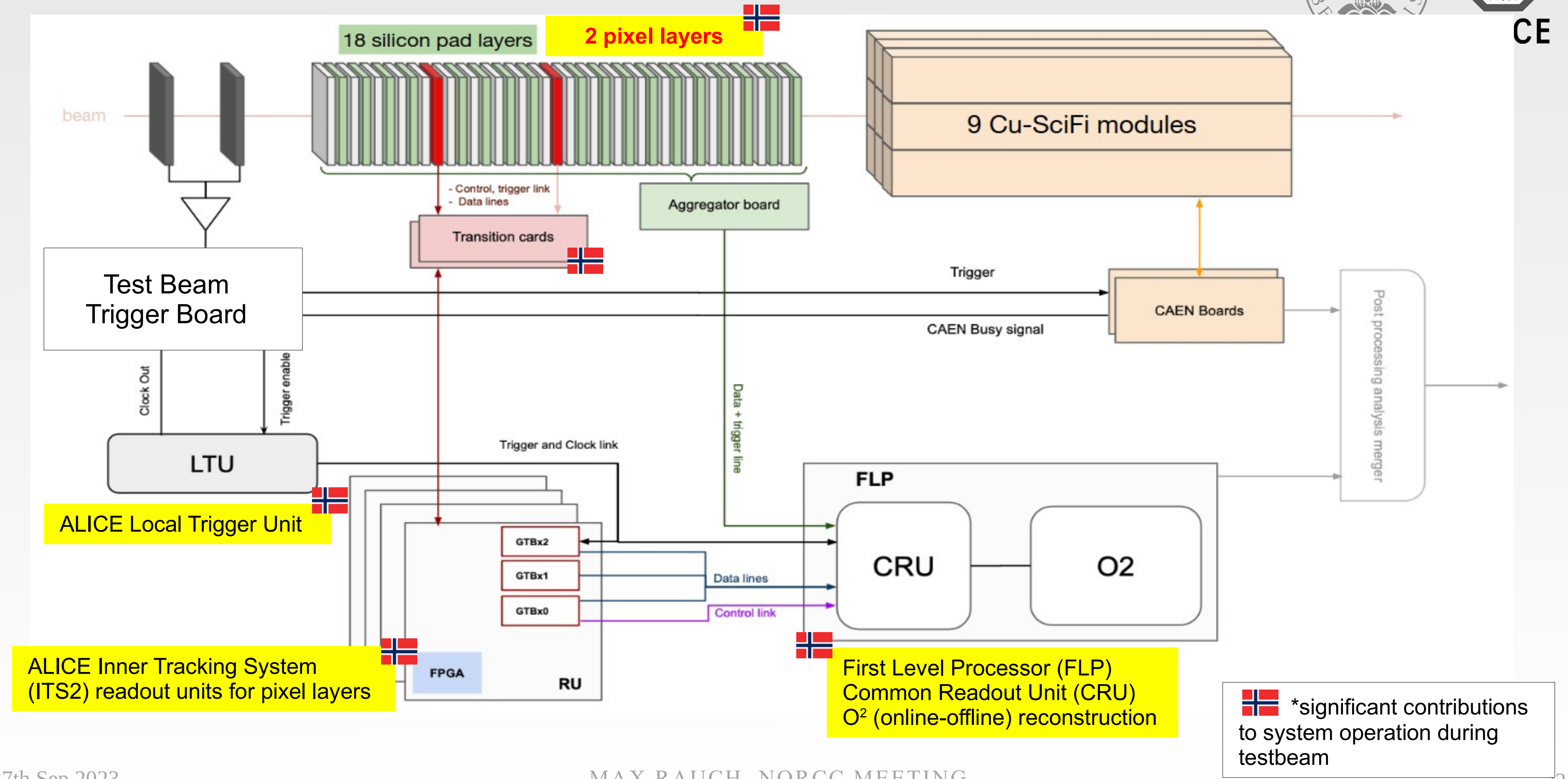


FoCal-E Pads
- 18 layers Si pad sensors
- wafers of 9 x 8 cm^2
- pad size 1 cm^2
- readout with HGCROC v2

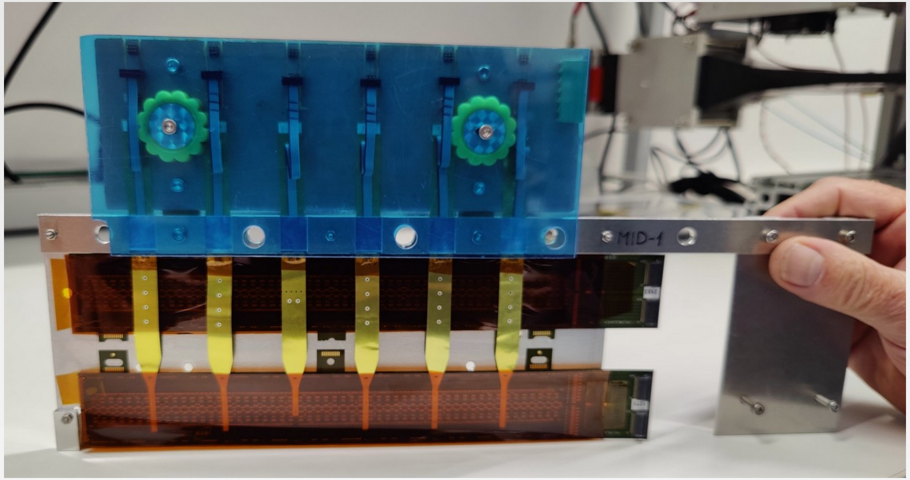
FoCal-E Pixels
- 2 ALPIDE pixel layers
- Monolithic Active Pixel Sensors
- pixel size of ~30 x 30 μm
- two tested prototypes (HIC,pCT)

FoCal-H
- 9 Cu-scintillating fiber modules
- towers size ~ 6.5 x 6.5 cm2
- length ~110 cm
- readout with CAEN DT5202

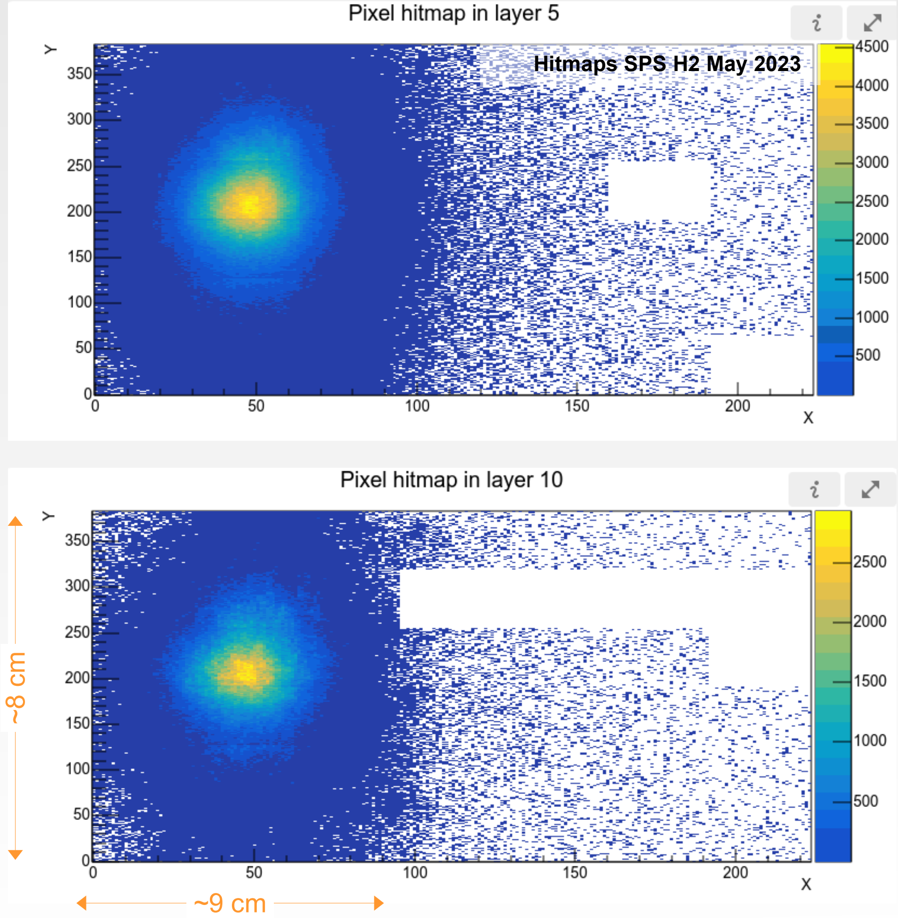
FoCal prototype DAQ May 2023



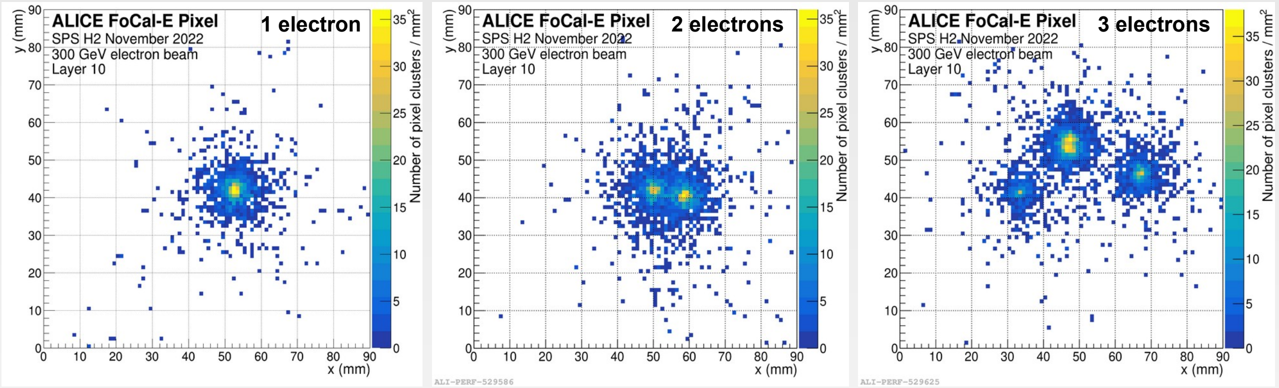
Pixel Layers

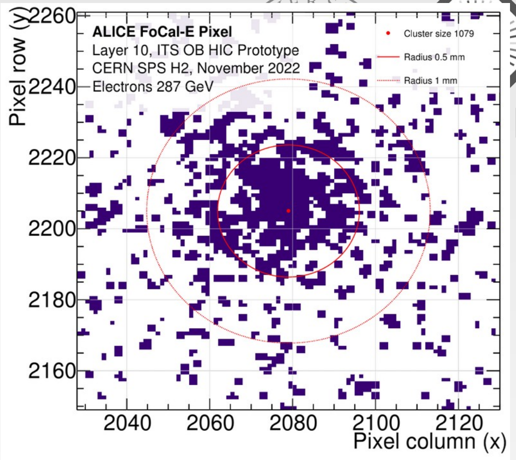


- Difficulties to have prototype layers shipped and repaired in Kharkiv
- Developed and built an alternative pixel layer solution based on ALICE ITS2 Outer Barrel Modules

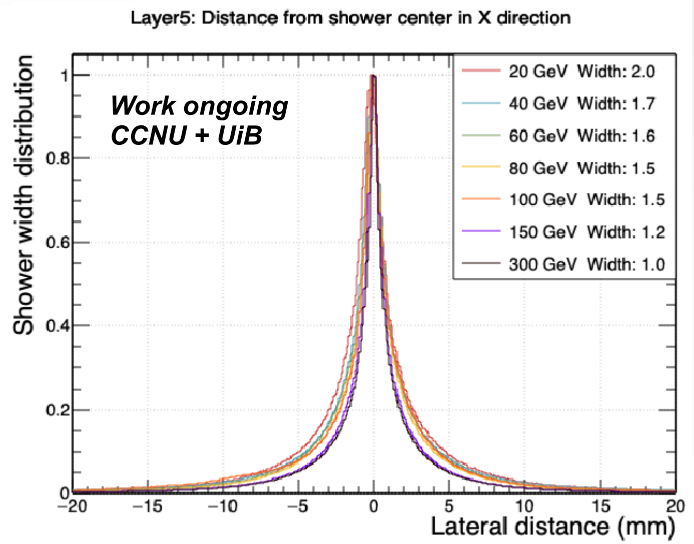


FoCal-E Pixel: electron showers

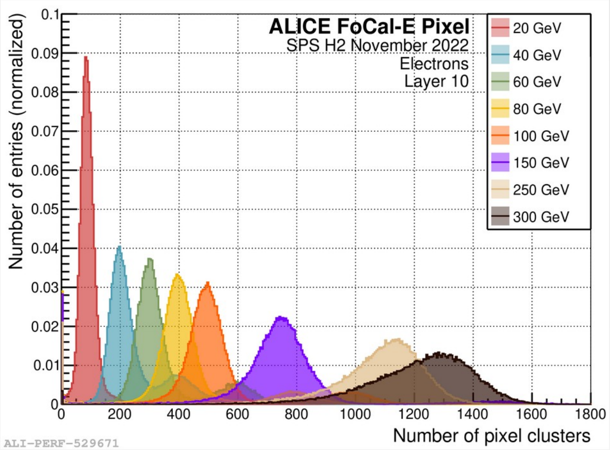


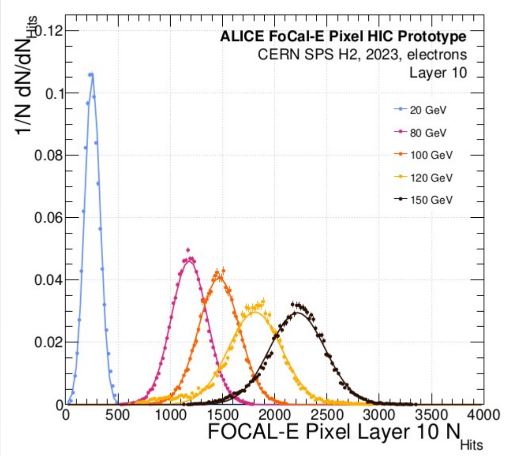


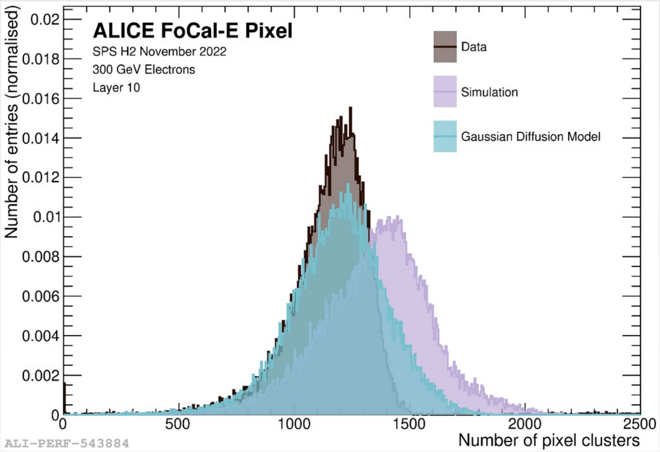
- Electron energies between 20 and 300 GeV
- Multiple electron shower events observed
- <100μm resolution of the shower structure
- Transverse shower width approx. few millimeters
- Subject of ongoing analyses → implications for π^0 separation very exciting



FoCal-E Pixel electromagnetic showers

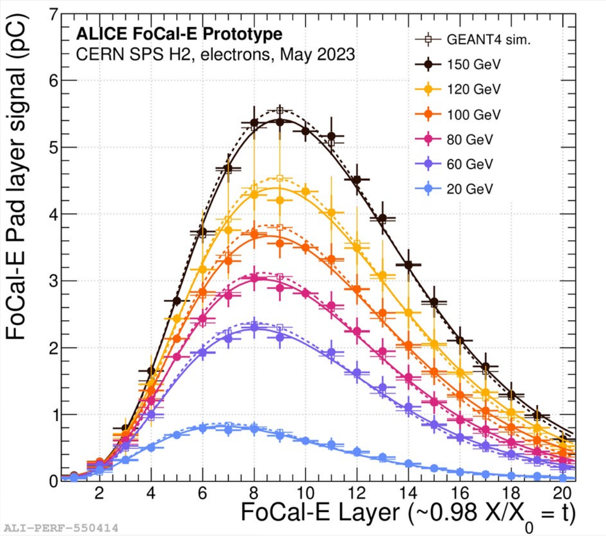


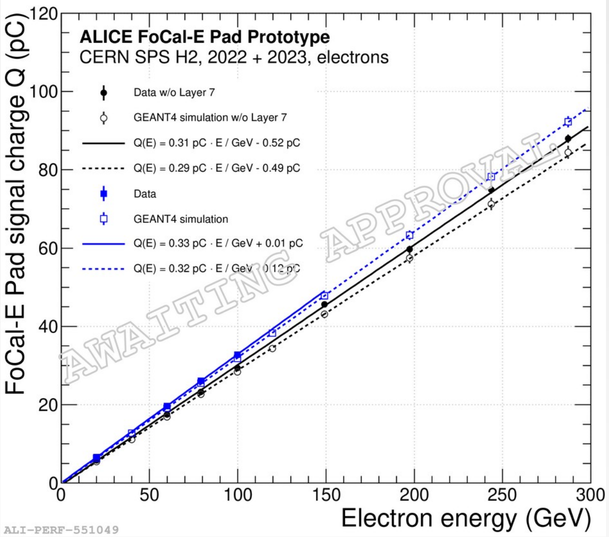


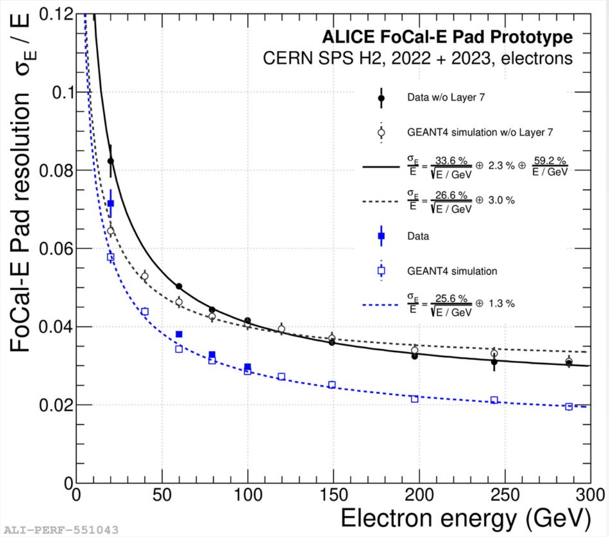


- Process of understanding pixel layer response (pixel clusters vs. pixel hits)
  - Saturation effects at high energies
  - Contribution to FoCal-E energy resolution
- Ongoing work for modelling pixel cluster generation
  - e.g. with a Gaussian charge diffusion model

FoCal-E Prototype Performance







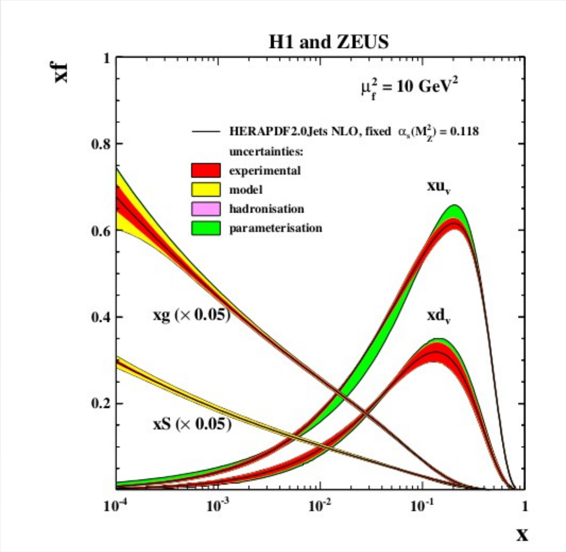
- Good peformance in longitudinal shower performance, linearity, and energy resolution
  - Energy resolution well below for energies > 100 GeV
- Work on pixel layer integration ongoing into overall FoCal-E performance ongoing

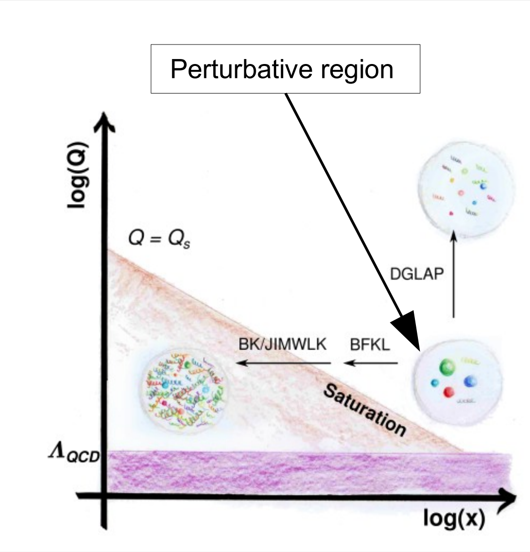
Summary

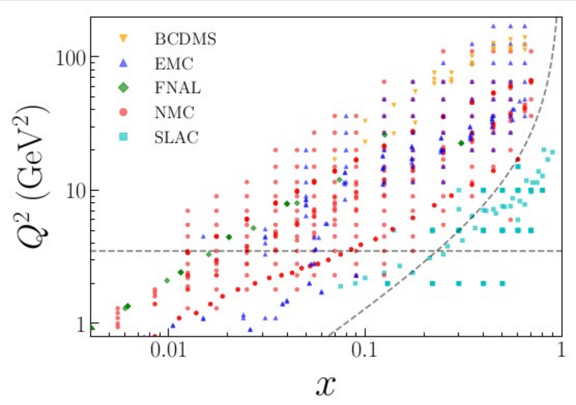
- Exciting times for the ALICE FoCal Upgrade!
  - *Technical Design Report, Physics Performance Note, Prototype Performance Paper*
- Working hard for data taking in 2029
- Unique chance to explore forward isolated photons at LHC
  - *But also e.g. ultra-peripheral collisions, neutral mesons, ...*
- Norwegian groups contribute in many fields of the collaboration
  - *Physics program, pixel layers, readout,and testbeam*

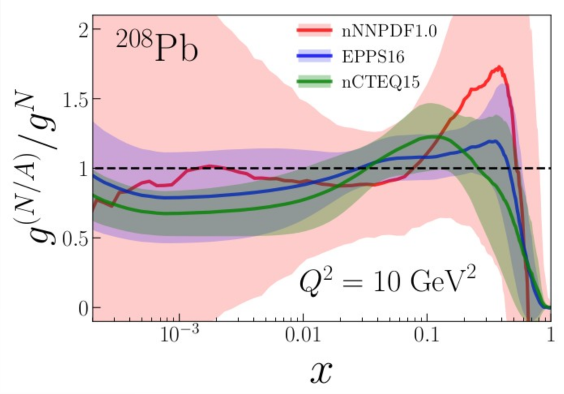
Additional Material

Nature of gluon saturation at low x



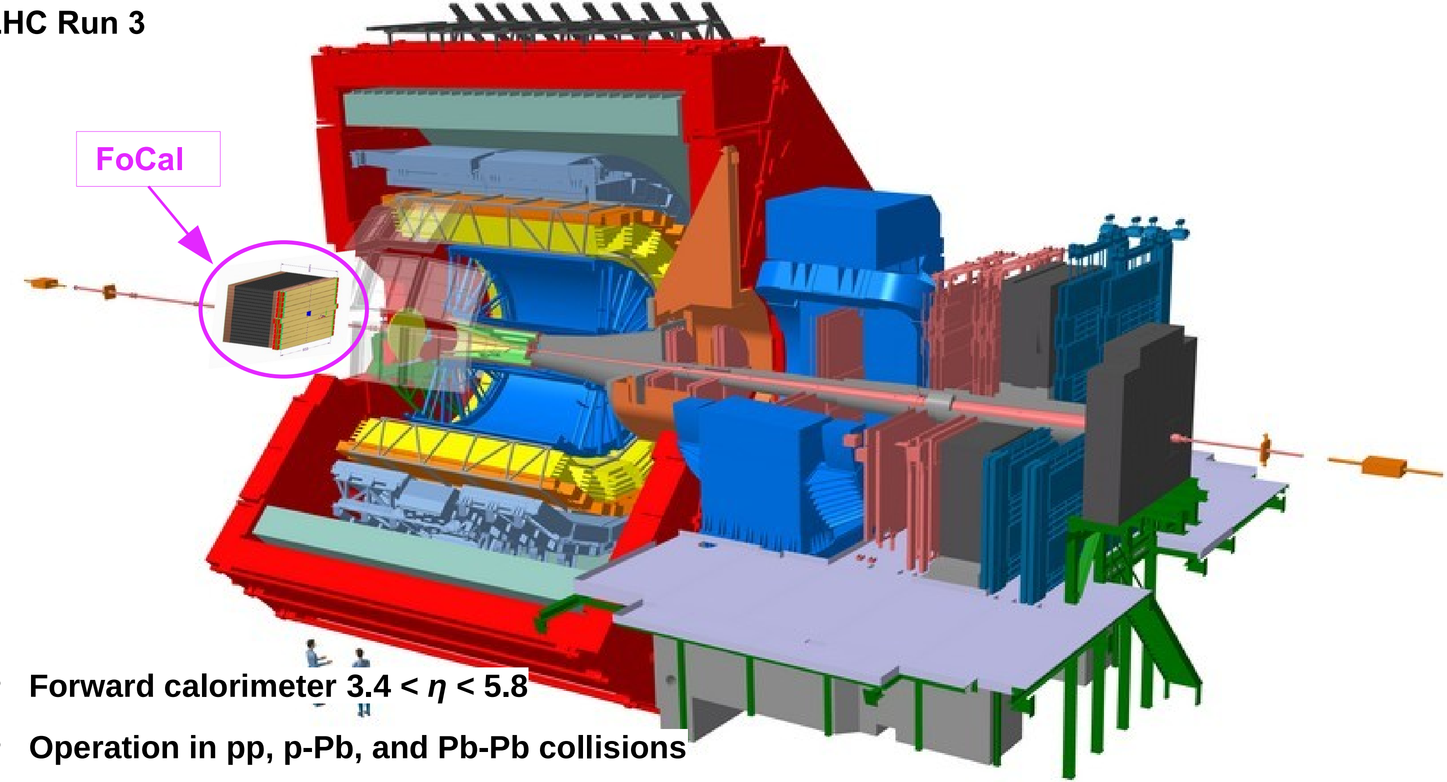






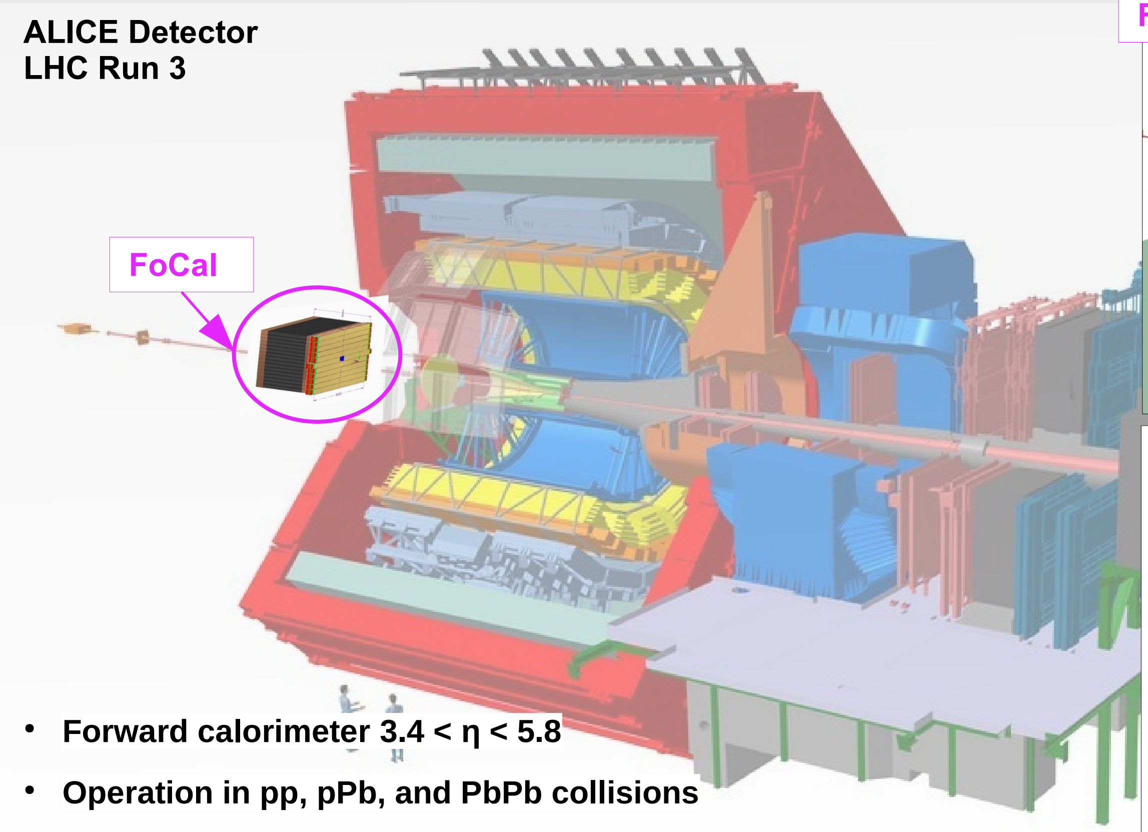
- PDFs determined from deep inelastic scattering, neutral current or DY processes → region of perturbative QCD
- Linear evolution towards higher Q^2 ("DGLAP") and towards lower ***x*** ("BFKL")
- At even lower ***x*** with higher **gluon densities (saturation)** non-linear evolution becomes relevant ("BKJ/JIMWLK")

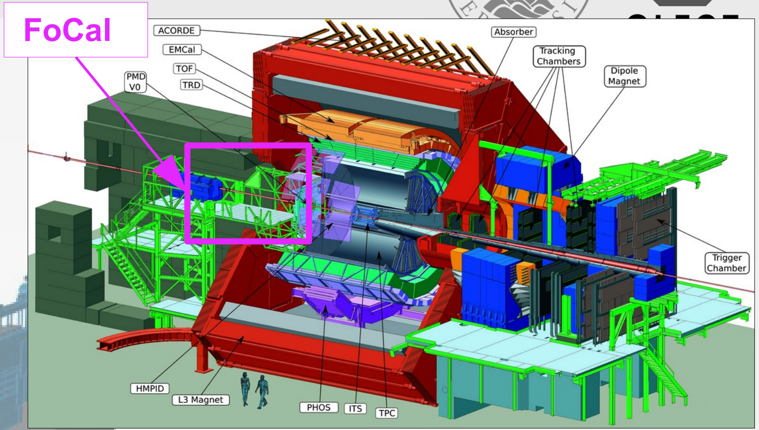
The FoCal detector in ALICE



- Forward calorimeter $3.4 < \eta < 5.8$
- Operation in pp, p-Pb, and Pb-Pb collisions
- Installation in ALICE foreseen for LHC Run 4 (2029)

The FoCal detector in ALICE





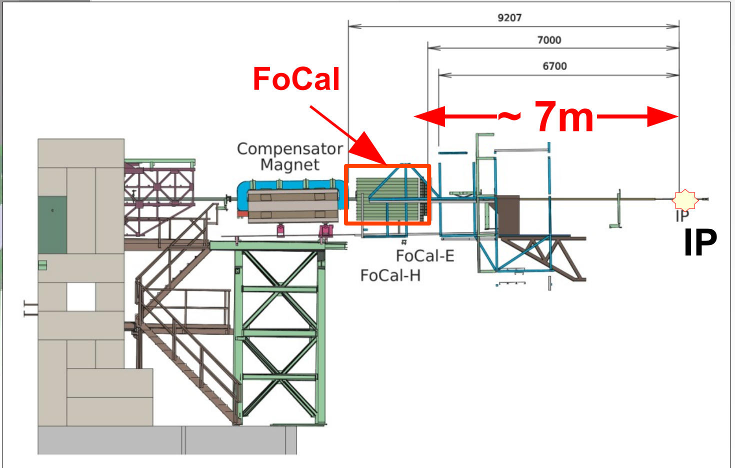
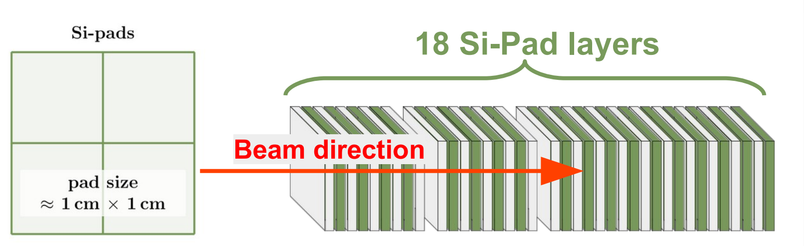


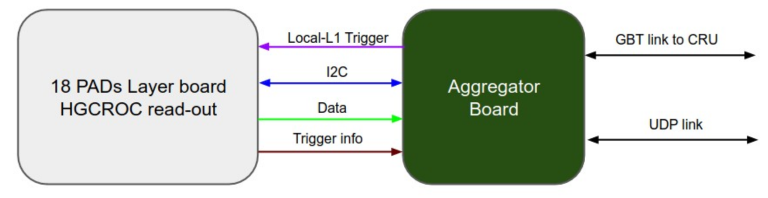
Fig. 19: Installation of the FoCal at the 7m location with FoCal-E and FoCal-H detectors.

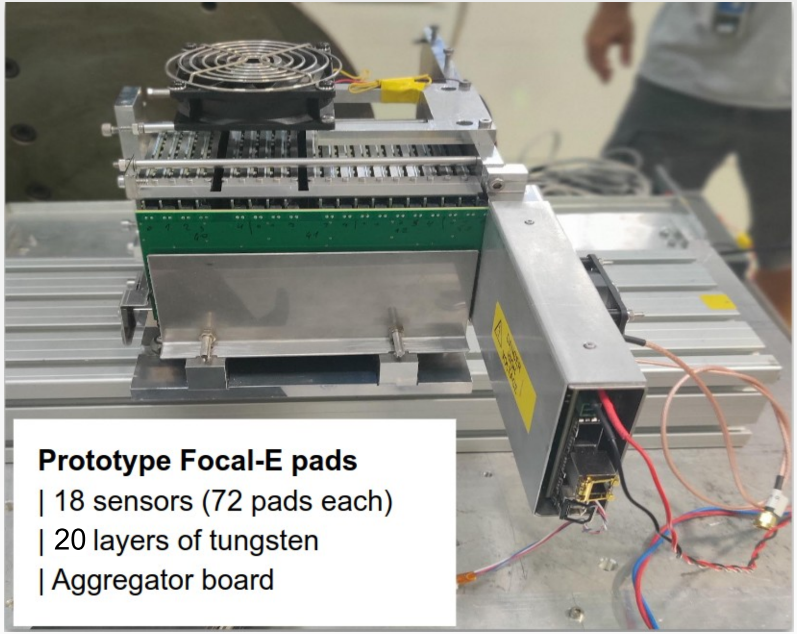
- **Forward calorimeter 3.4 < η < 5.8**
- **Operation in pp, pPb, and PbPb collisions**
- **Installation in ALICE foreseen for LHC Run 4 (2029)**

FoCal-E Pad prototype

- 18 layers of 9 x 8 silicon pad sensors (pad size 1 x 1 cm^2)
- Charge measurement per pad with ADC, ToT, and ToA
- High dynamic range: MIP ↔ 10 pC
- Fast trigger signal derived from HGCROCv2
- Longitudinal shower profile information for each layer



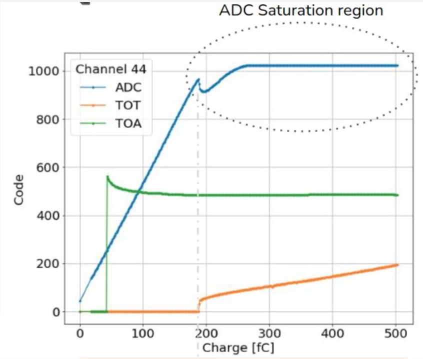




Analog-digital converter (ADC): 0 – 200 fC

Time over threshold (TOT): 0.2 – 10 pC

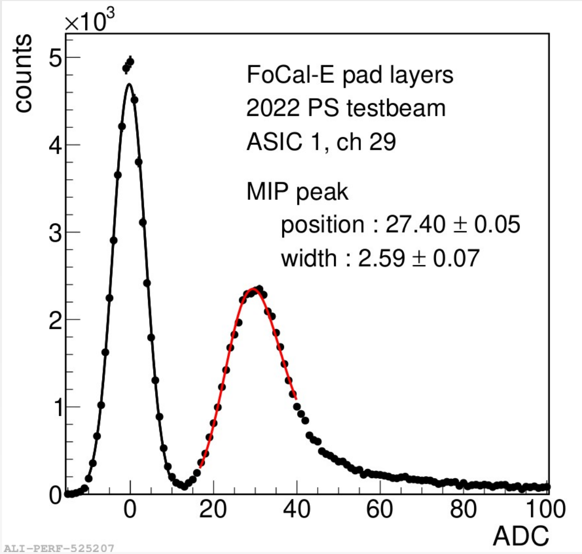
Time of arrival (TOA): 25ps resolution

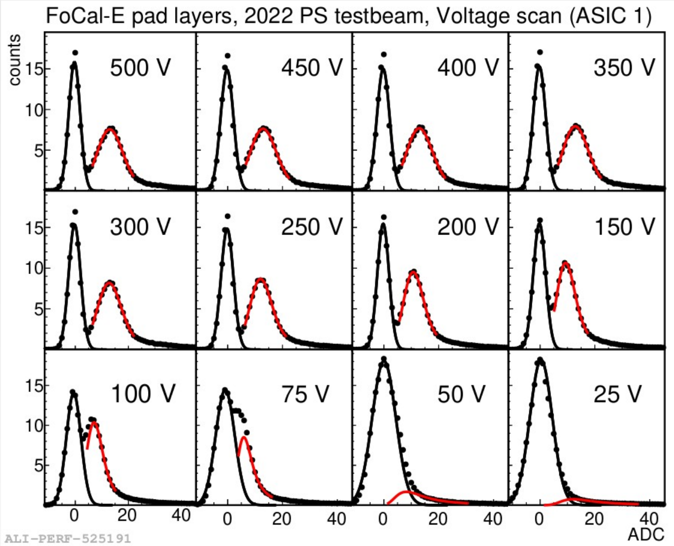


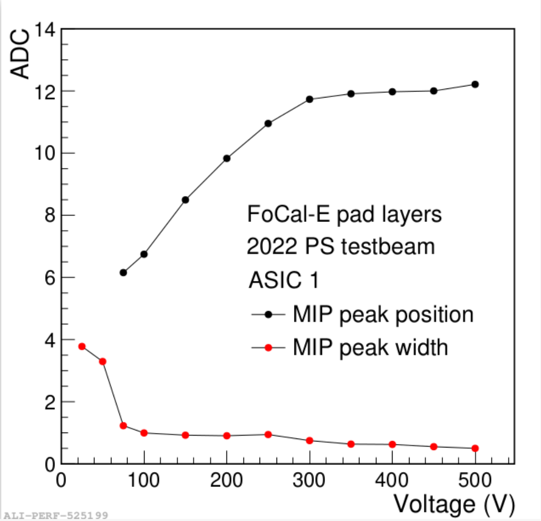
[1] Performance study of HGCROC-v2: the front-end electronics for the CMS High Granularity Calorimeter, D. Thienpont and C. de La Taille 2020 JINST 15 C04055

[2] Prototype electronics for the silicon pad layers of ALICE experiment at the LHC, O. Bourrion et al 2023 JINST 18 P04031

FoCal-E Pad MIP response



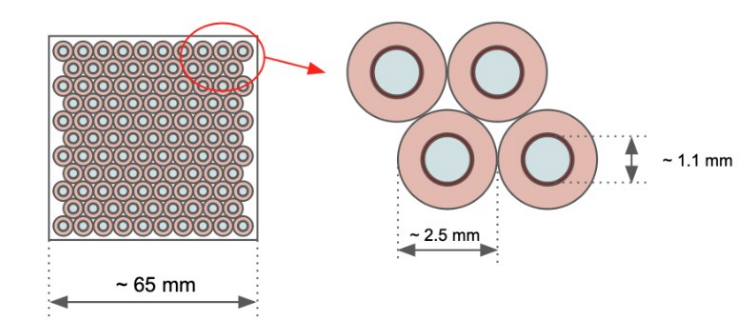


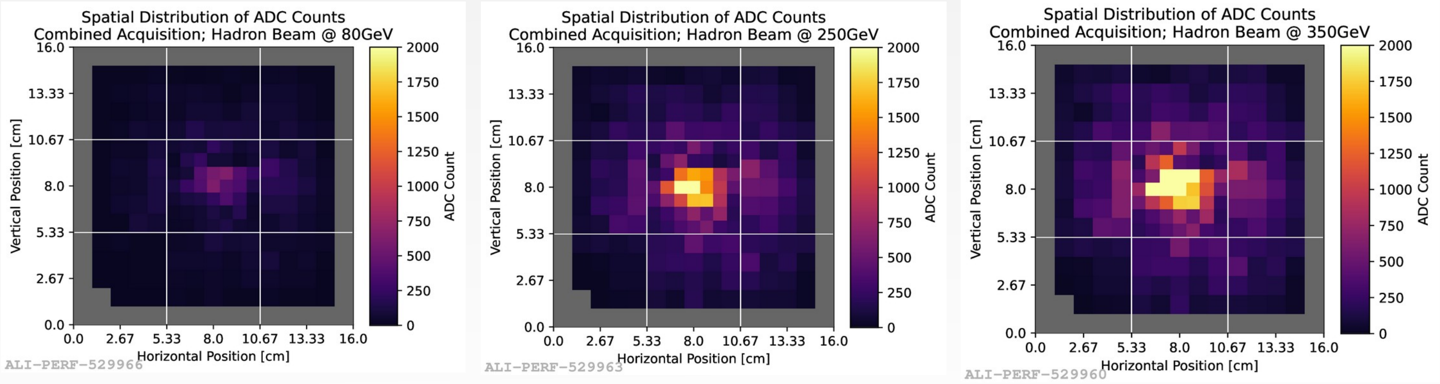


- Clear separation of MIP peak and pedestal noise measured in ADC distribution
  - → Sensitivity to a single MIP
- Separation measured in HV scan from 0 V to 500 V
- MIP Peak position stable at full depletion (~300V)

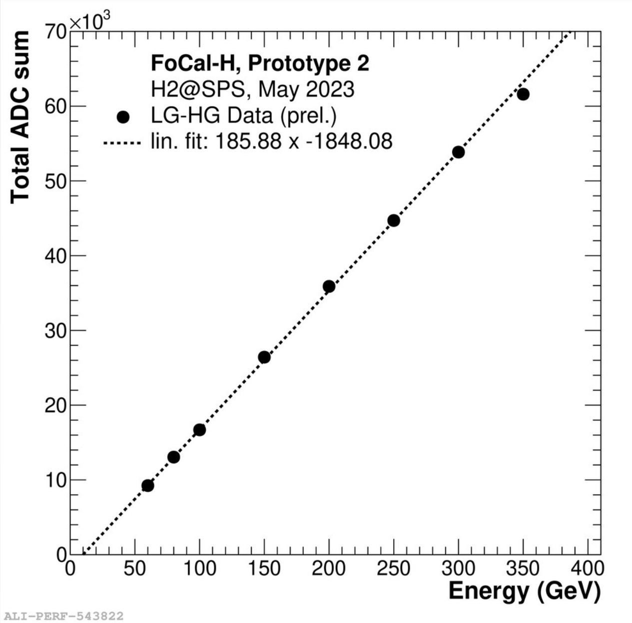
FoCal-H Prototype 2

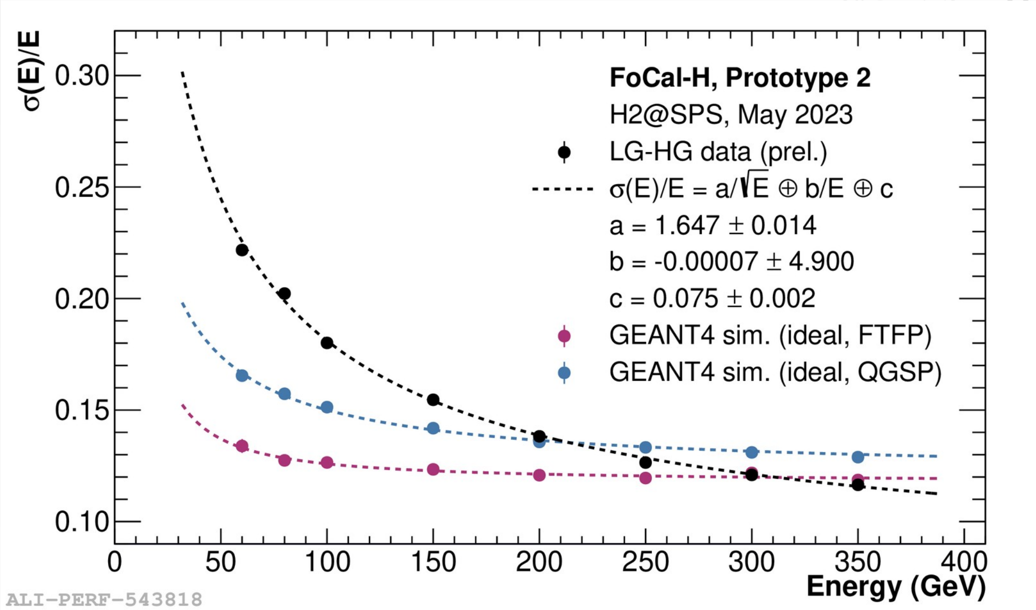
- Prototype 2 ready for testing in 2022
- 9 full length modules at 6.5 cm x 6.5 cm x **110 cm**
- Copper tubes filled with BCF12 scintillating fibers
- Fibres grouped to bundles of SiPMs
  - 49 readout bundles in central modules
  - 25 readout bundles for each outer module
- Readout with CAEN DT5202 boards
- Overall weight > 300 kg





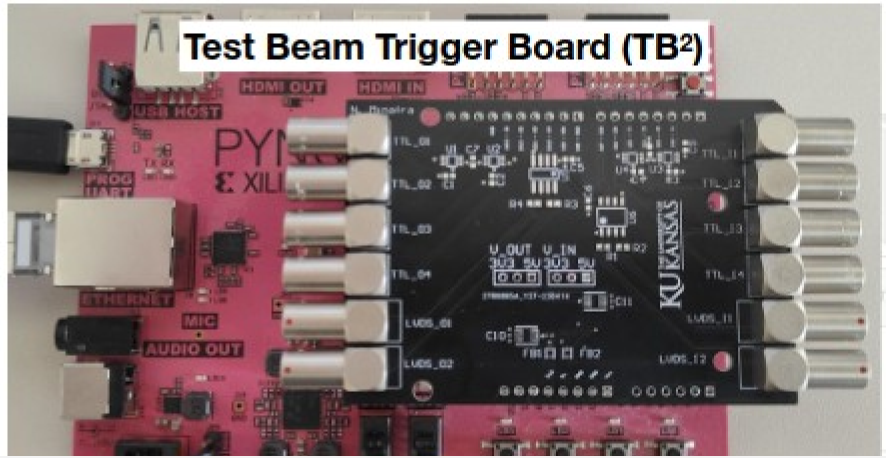
FoCal-H linearity and resolution

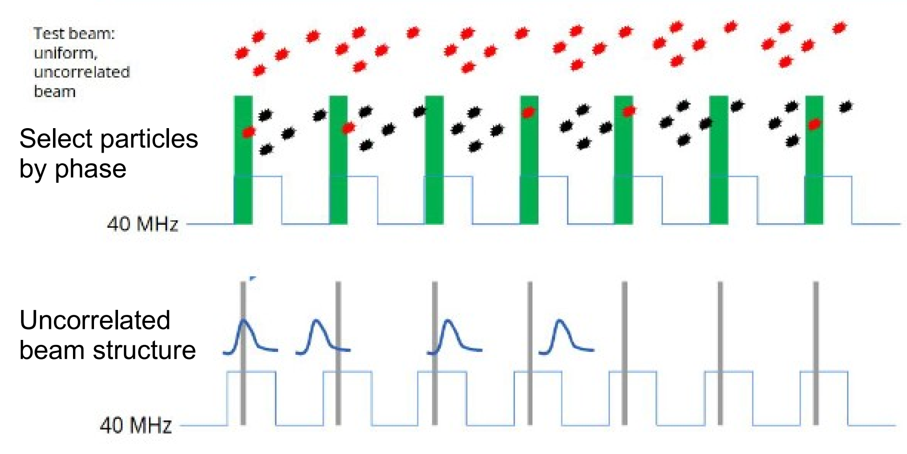




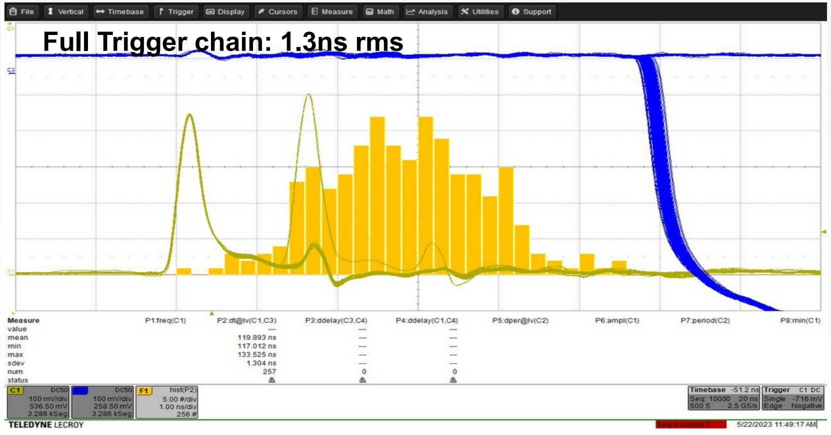
- Resolutions simulated in GEANT4 with two different physics lists: QGSP + FTFP: Constant term ~12%
- Measured resolutions show different behavior, to be investigated
  - Resolution **< 25 %** for hadrons > 60 GeV
  - Resolution **< 15 %** for hadrons > 200 GeV

Test Beam Trigger Board





- At LHC, particles arrive synchronously with 40 MHz clock
- Beam particles at CERN NA beamlines arrive asynchronously
- Test beam trigger board phase locks triggers from incoming particles to a window of 2.5ns
- Sampling of detector signal at constant phase possible → reproducibility of results
- Handles busy veto logic and trigger delay for FoCal-H and FoCal-E pixels



HGCROC Channel Calibration