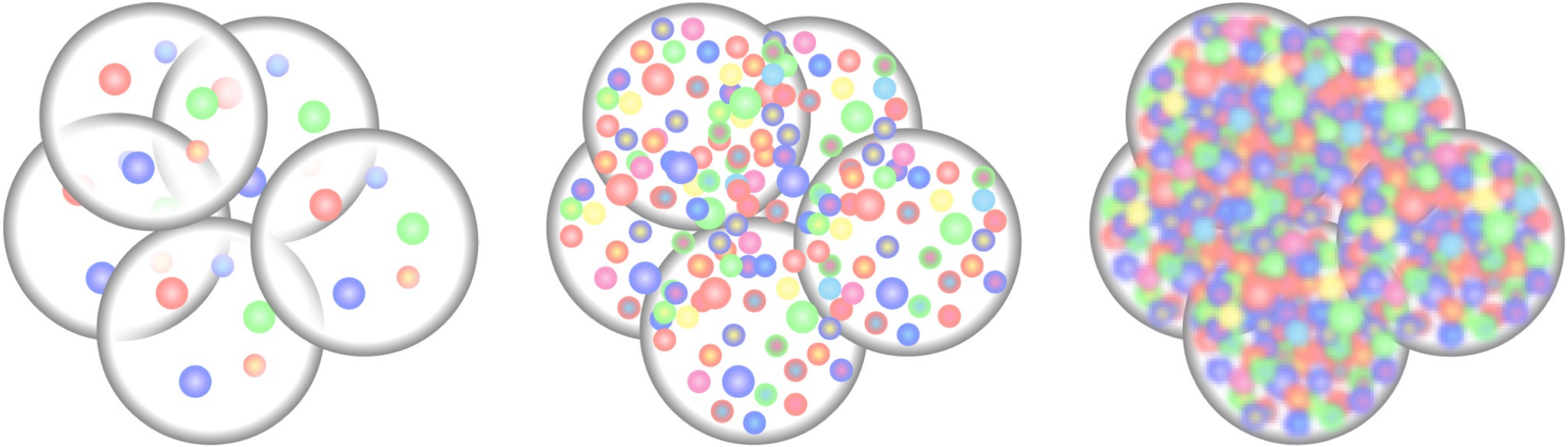

# FoCal: Forward Calorimeter for ALICE

May 24 2022


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HEHI
Experimental Subatomic Physics
Niels Bohr Institute
For the FoCal collaboration
KØBENHAVNS UNIVERSITET

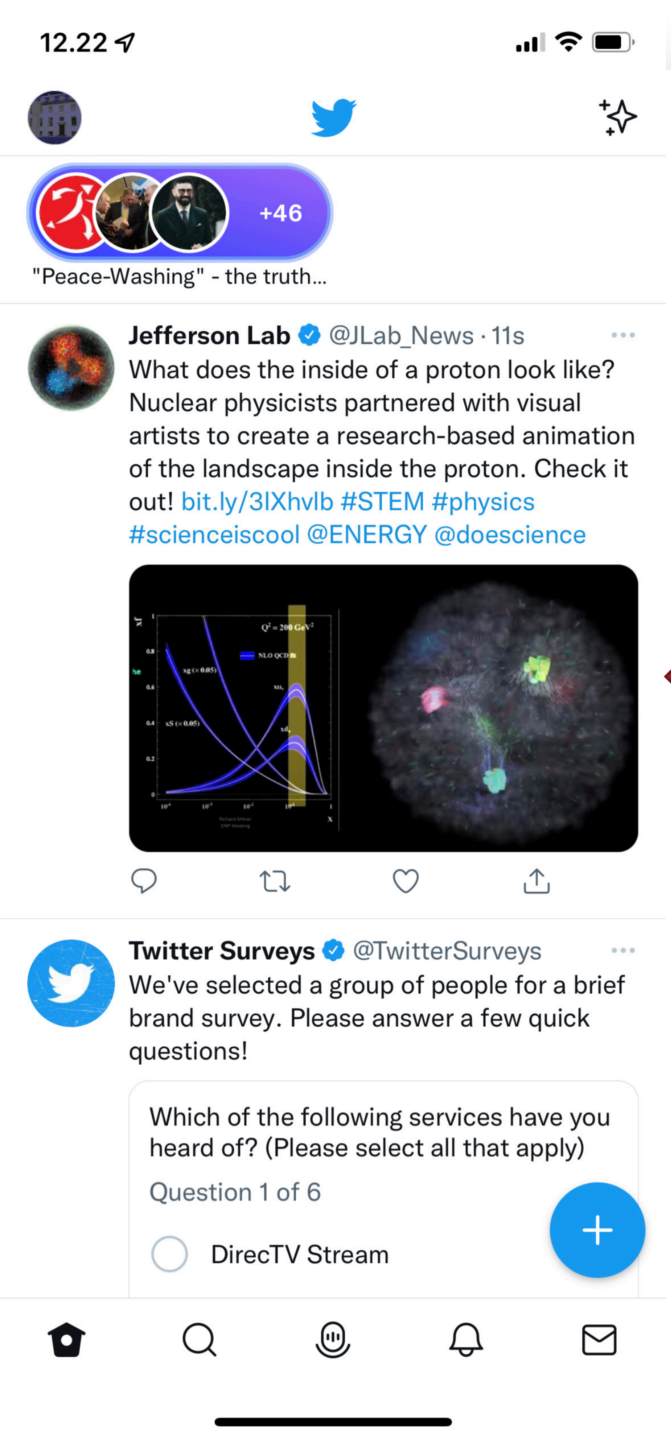

ALICE

# The FoCal Collaboration

| | |
|---|---|
| BARC | Bhaba Atomic Research Centre, Mumbai, India |
| Berkeley | Lawrence Berkeley National Laboratory, Berkeley, USA |
| Bhubaneswar | Institute of Physics, Bhubaneswar, India |
| Bergen | University of Bergen, Bergen, Norway |
| Bose | Bose Institute, Kolkata, India |
| CCNU | Central China Normal University |
| Detroit | Wayne State University, Detroit, USA |
| Gauhati | Gauhati University, India |
| Grenoble | LPCS Grenoble, France |
| Hiroshima | Hiroshima University, Hiroshima, Japan |
| Houston | University of Houston, Houston, USA |
| HVL | Western Norway University of Applied Sciences, Bergen Norway |
| IITB | Indian Institute of Technology Bombay, Mumbai, India |
| Indore | Indian Institute of Technology Indore, Indore, India |
| INR RAS | Inst. f. Nuclear Research Russian Acad. of Science, Moscow, Russia |
| Jammu | Jammu University, Jammu, India |
| Jyväskylä | University of Jyväskylä, Jyväskylä , Finland |

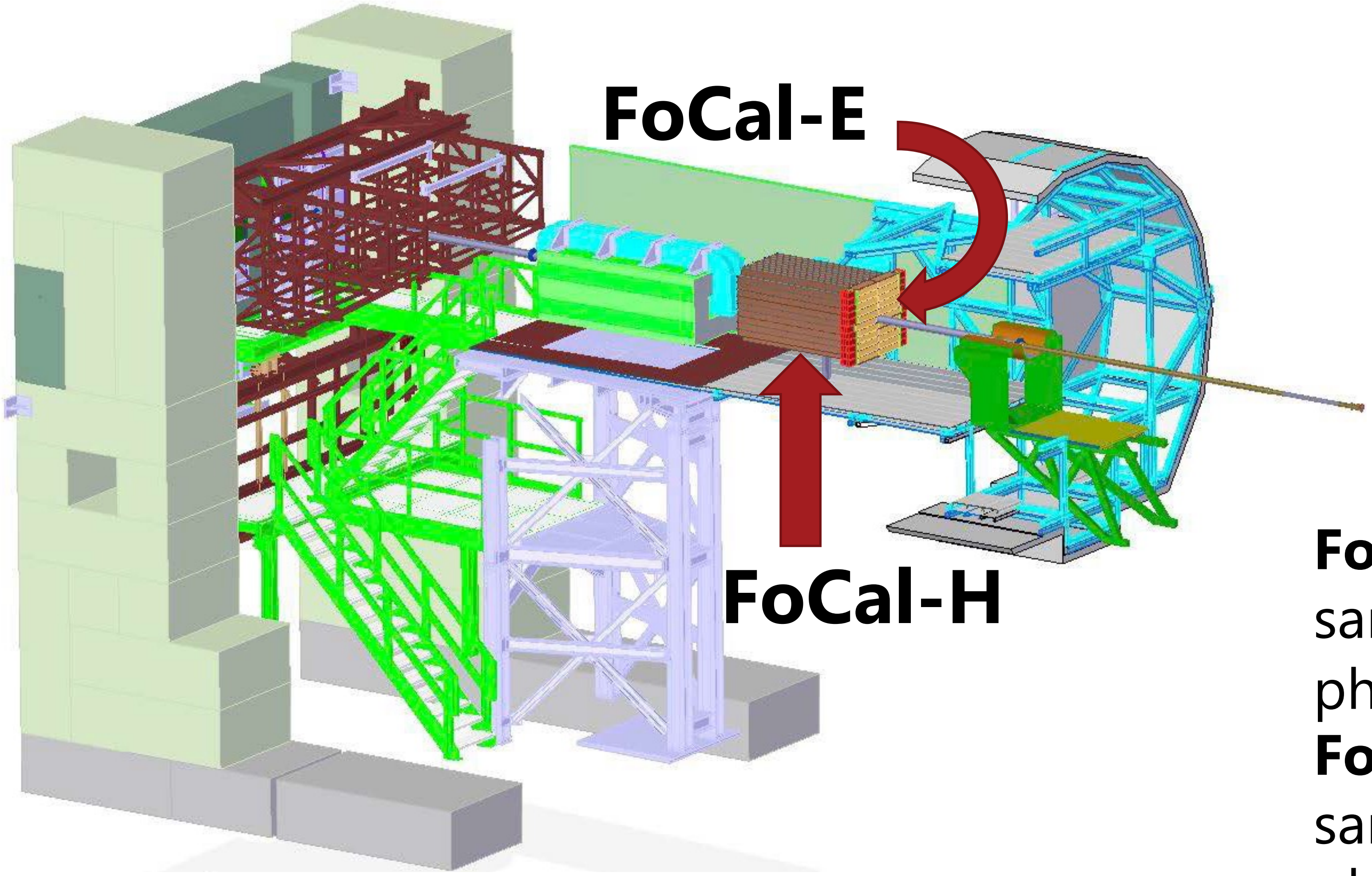
| | |
|---|---|
| Knoxville | University of Tennessee, Knoxville, USA |
| Nara | Nara Women's University, Nara, Japan |
| NBI | Niels Bohr Institute, Copenhagen, Denmark |
| MEPhI | National Research Nuclear University, Moscow, Russia |
| NISER | National Institute of Science Education and Research (NISER) |
| Oak Ridge | Oak Ridge National Laboratory (ORNL),Oak Ridge, USA |
| Oslo | University of Oslo, Oslo, Norway |
| Panjab | Panjab University, Chandigarh, India |
| RIKEN | Institute of Physical and Chemical Research, Toky, Japan |
| Sao Paulo | Universidade de Sao Paulo (USP), Sao Paulo, Brazil |
| Tsukuba | University of Tsukuba |
| Tsukuba Tech | Tsukuba University of Technology |
| UFRGS | Universidade Federál Do Rio Grande Do Sul |
| UU/Nikhef | Utrecht University, Utrecht, and Nikhef, Amsterdam, Netherlands |
| VECC | Variable Energy Cyclotron Centre, Kolkata, India |
| USN | University of South-Eastern Norway, Konsberg, Norway |
| Yonsei | Yonsei University, Seoul, Korea |

In case you thought the topic of this meeting is only interesting to few people, welcome to my twitter feed today




!

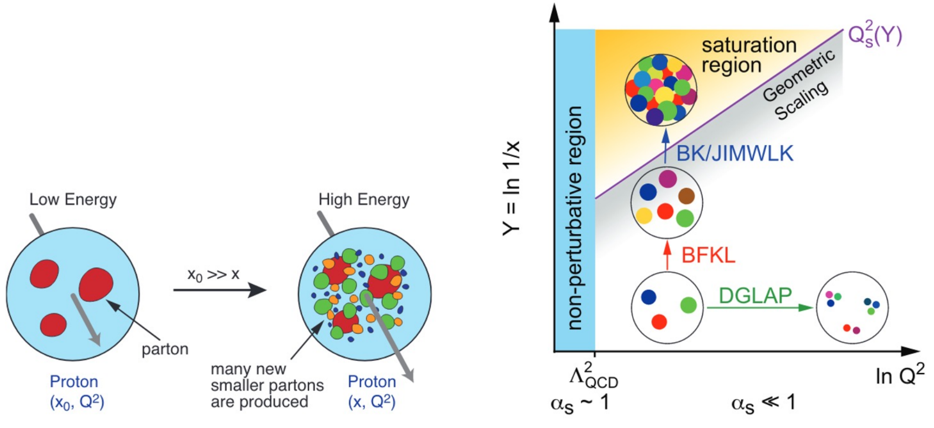
# The Forward Calorimeter (FoCal):




**3.4 < η < 5.8**

**FoCal-E**: high-granularity Si-W sampling calorimeter for photons and $\pi^0$
**FoCal-H**: absorber-scintillator sampling calorimeter for photon isolation and jets

# FoCal physics



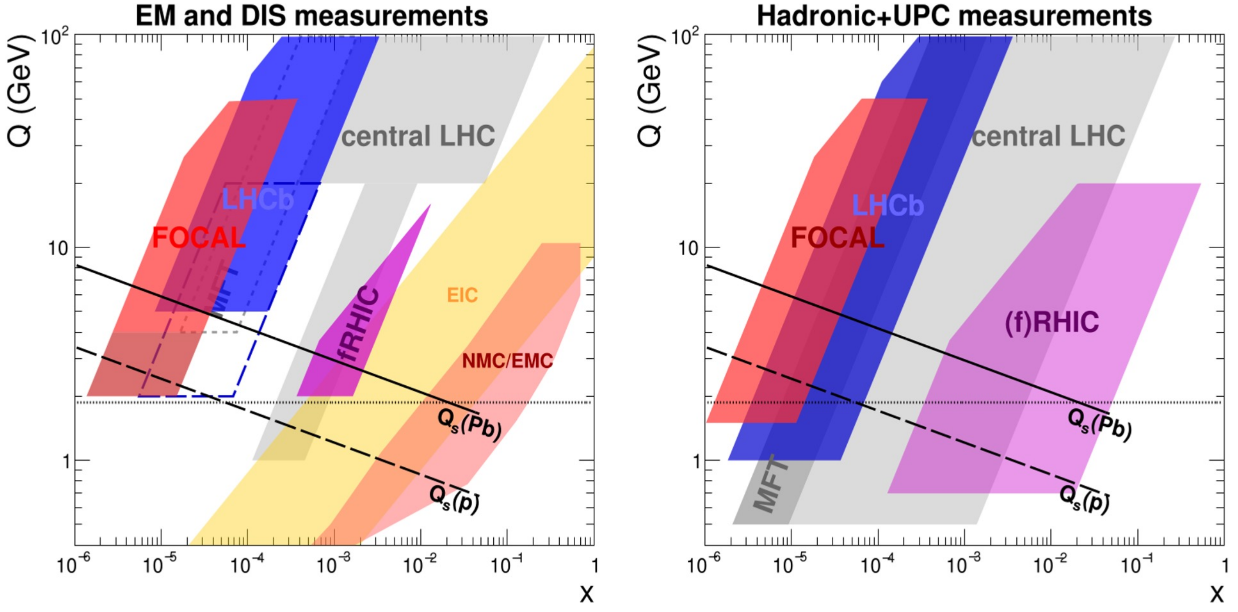

**1. Quantify nuclear modification of the gluon density at small-x**
- Isolated photons in pp and pPb collisions

**2. Explore non-linear QCD evolution**
- Azimuthal $\pi^0$-$\pi^0$ and isolated photon-$\pi^0$ (or jet) correlations in pp and pPb collisions

**3. Investigate the origin of long range flow-like correlations**
- Azimuthal $\pi^0$-h correlations using FoCal and central ALICE (and muon arm?) in pp and pPb collisions

**4. Explore jet quenching at forward rapidity**
- Measure high $p_T$ neutral pion production in PbPb

## Explore the small-x structure of nucleons inside nuclei down to Bjorken-x of ~$10^{-6}$

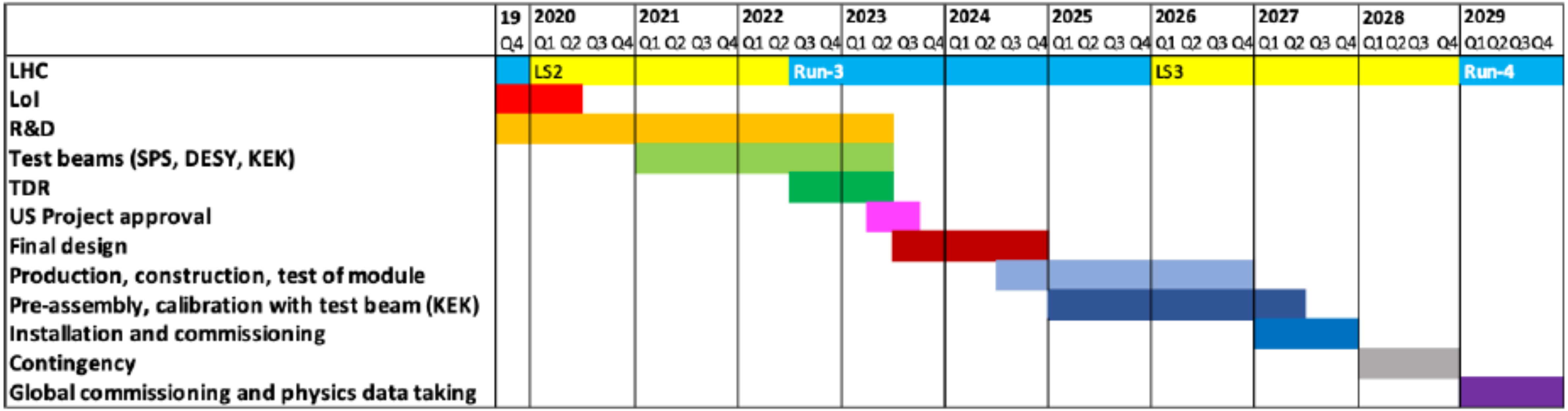



$$x \approx \frac{2p_T}{\sqrt{s}} \exp^{-\eta}$$

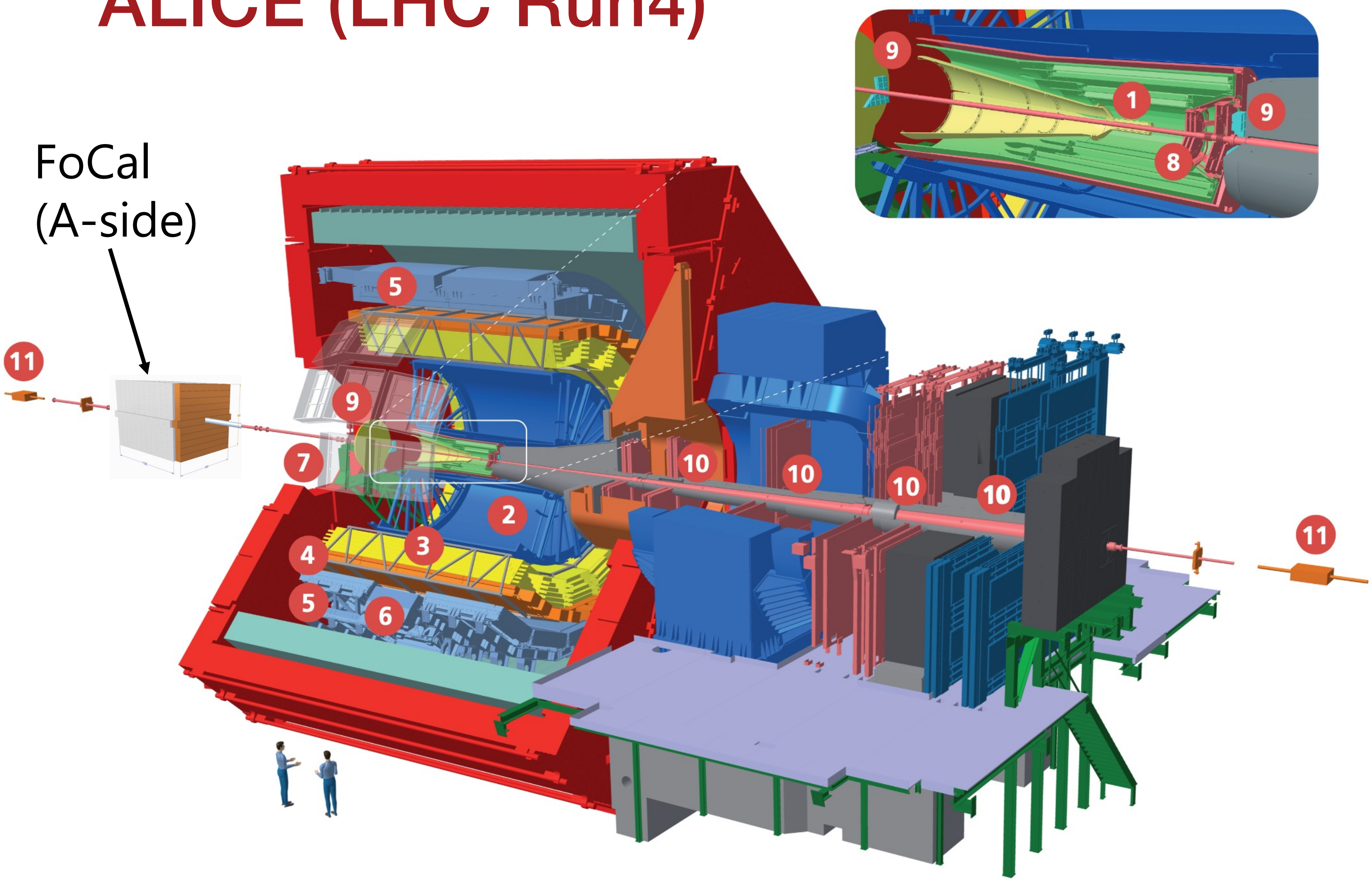
What is the correct description of gluon saturation?

Public Note: ALICE-PUBLIC-2019-005

# FoCal Timeline



# ALICE (LHC Run4)




1 **ITS** | Inner Tracking System

2 **TPC** | Time Projection Chamber

3 **TRD** | Transition Radiation Detector

4 **TOF** | Time Of Flight

5 **EMCal** | Electromagnetic Calorimeter

6 **PHOS / CPV** | Photon Spectrometer

7 **HMPID** | High Momentum Particle Identification Detector

8 **MFT**| Muon Forward Tracker

9 **FIT** | Fast Interaction Trigger

10 **Muon Spectrometer**

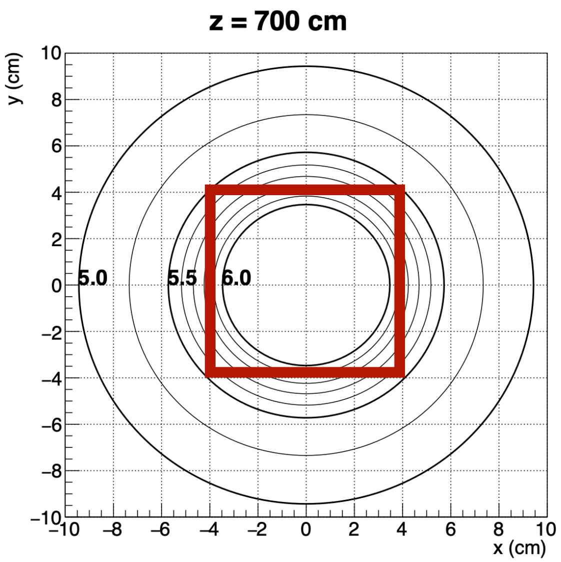
11 **ZDC** | Zero Degree Calorimeter

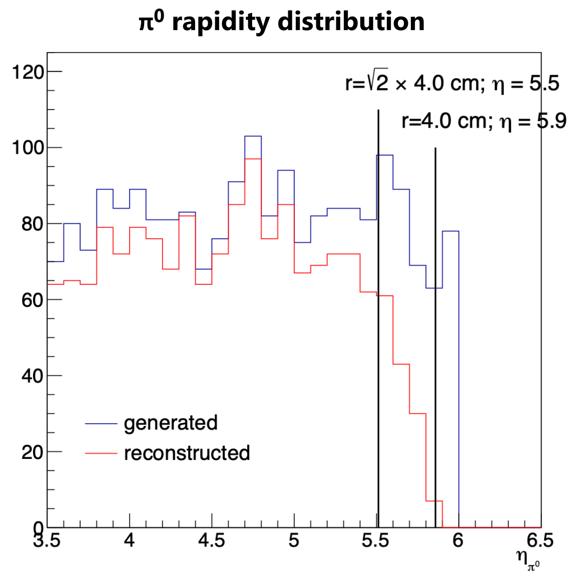
# Rapidity coverage and $\pi^0$ efficiency

**position z = 7m**
beam pipe radius 3.5cm

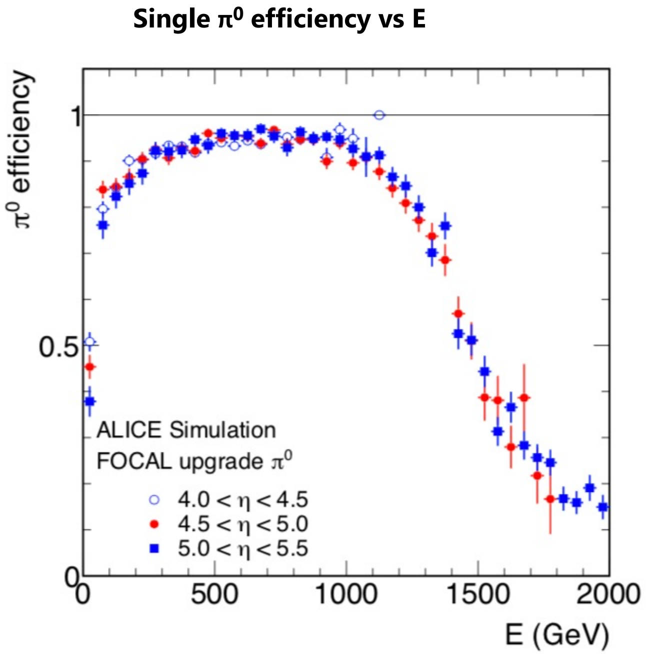
8x8cm square around beam:
maximum rapidity 5.5-5.8

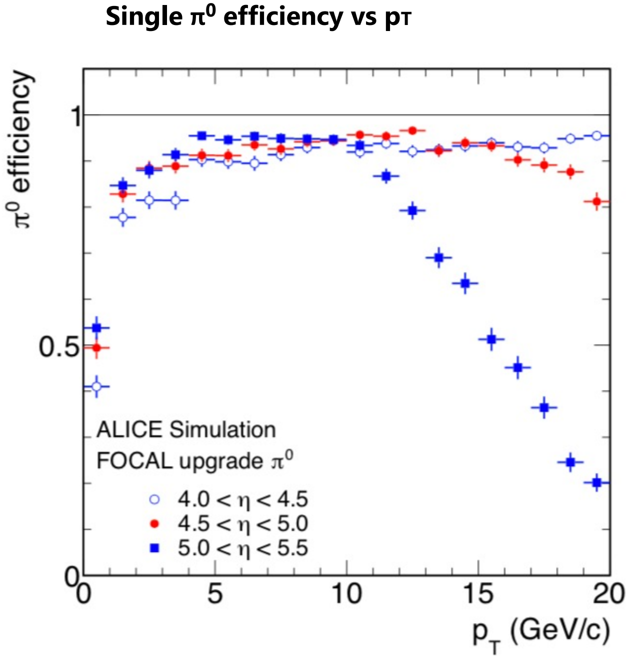
2-gamma distance gets small beyond η=5.5:
→ sharp drop at $R_{min}$ plus effect of circle vs square



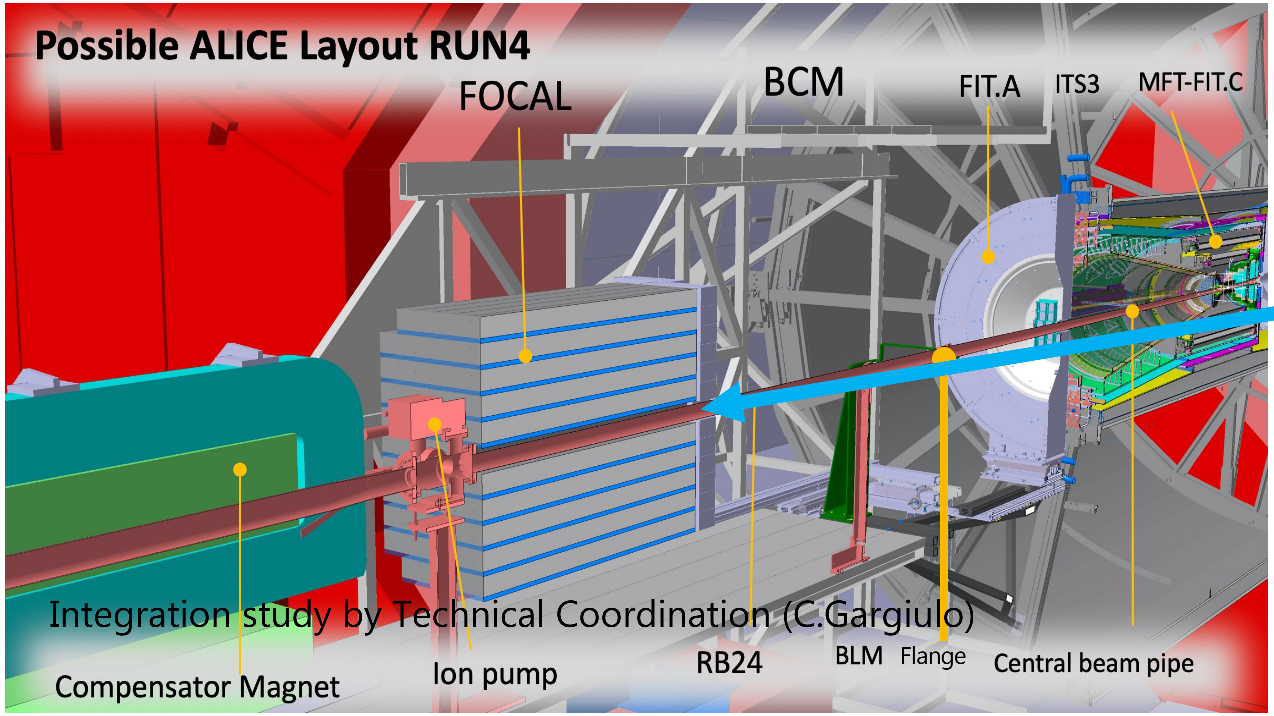

Very good $\pi^0$ efficiency up to η = 5.5 (falls off above $p_T$ = 10 GeV due to 2-gamma distance)

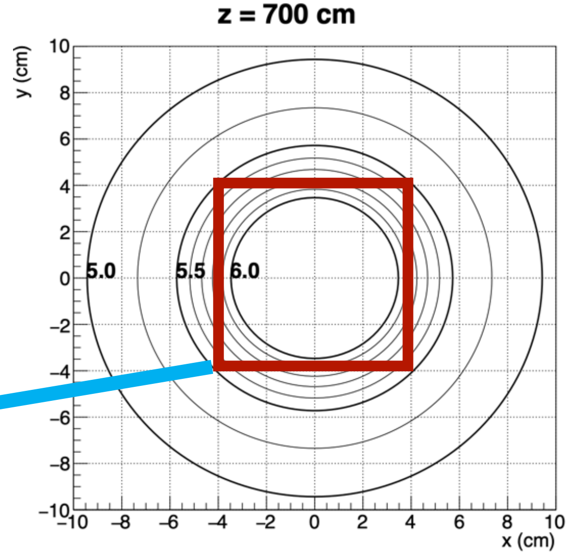


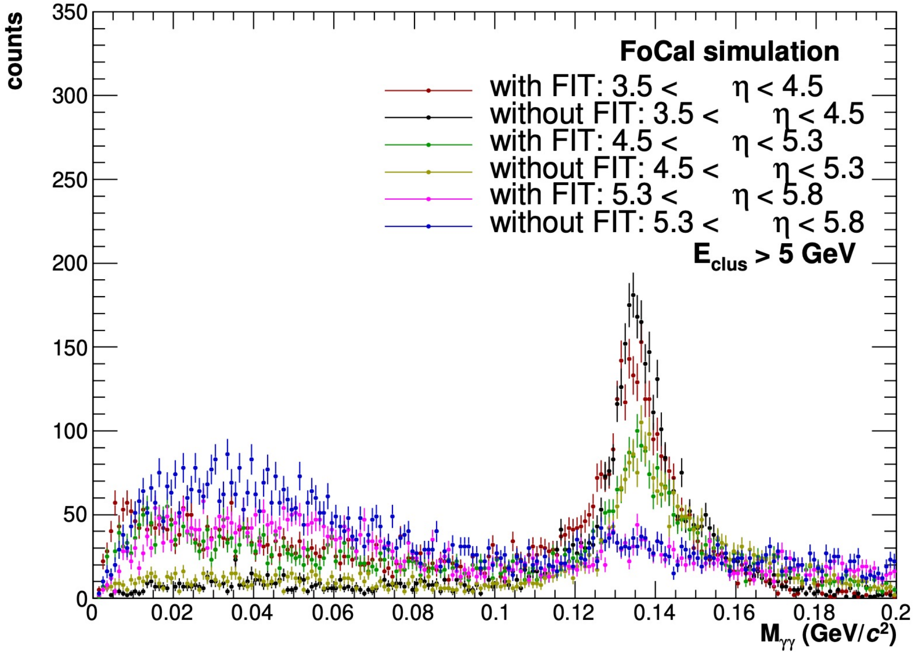



# Integration in ALICE

Integration into ALICE (Run-4)

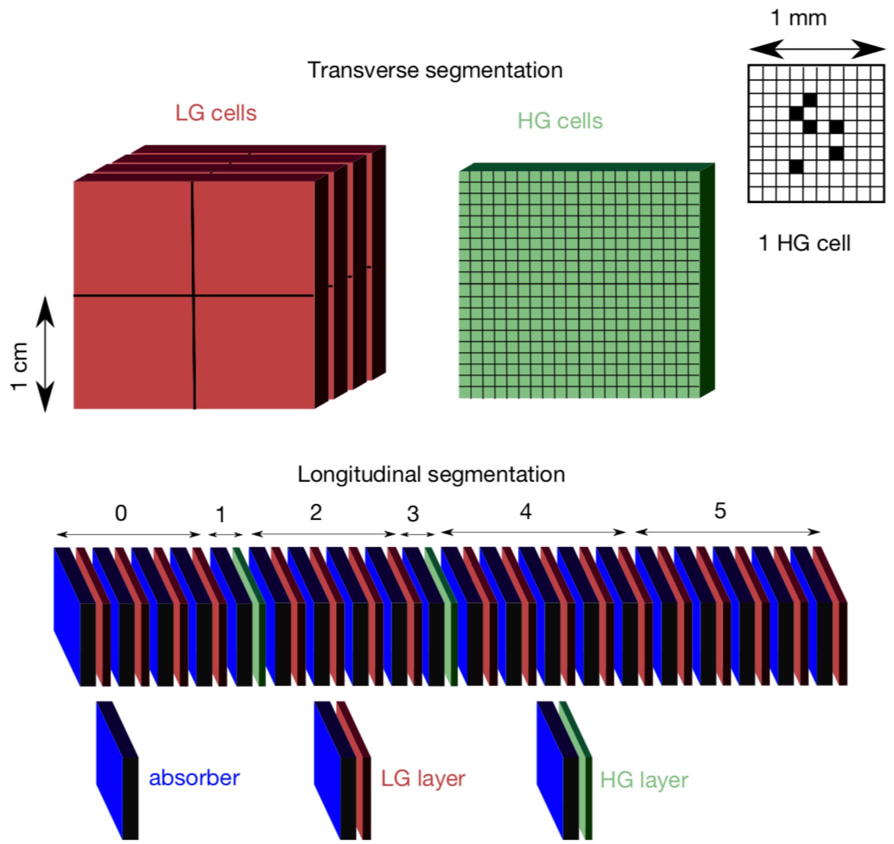



- Installing FoCal implies challenging but feasible changes
- All key simulations with realistic beam-line setup in LOI
  - Impact on $\pi^0$ reconstruction only beyond $\eta > 5.3$
  - Not crucial for key physics but may be recoverable with by optimizing cluster reconstruction

# FoCal-E conceptual design

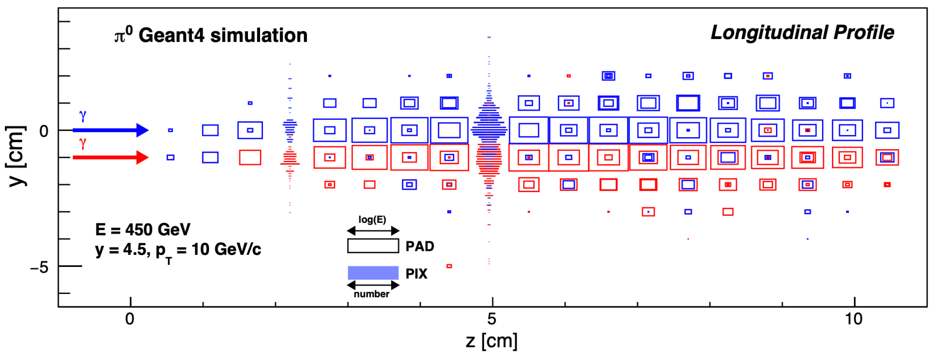



Studied in simulations 20 layers:
W(3.5 mm ≈ $1X_0$) + silicon sensors
Two types: Pads (LG) and Pixels (HG)

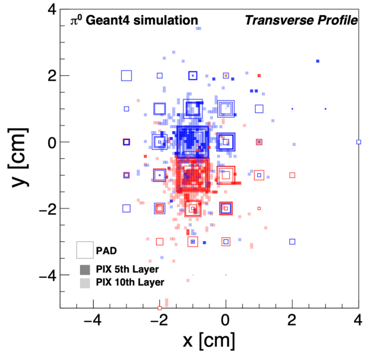
- Pad layers provide shower profile and total energy
- Pixel layers (ALPIDE) provide position resolution to resolve overlapping showers

- Main challenge: Separate $\gamma/\pi^0$ at high energy
  - Two photon separation from $\pi^0$ decay ($p_T$=10 GeV, η=4.5) ~5mm
  - Requires small Molière radius and high granularity readout
  - Si-W calorimeter with effective granularity ≈ $1mm^2$

Longitudinal profile (2γ showers)




Trans. profile



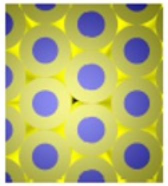

## Further optimization left for TDR:

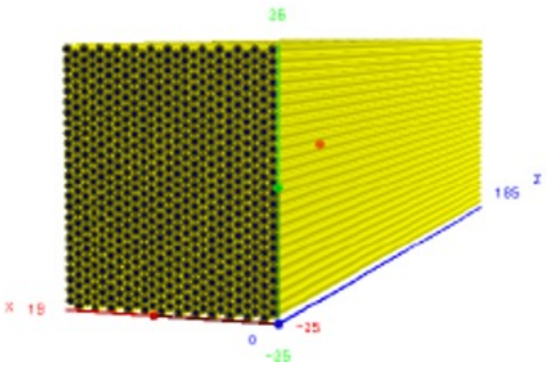
- Location of pixel layers
- Number of pad layers
- Sensitive area at front for CPV/eID

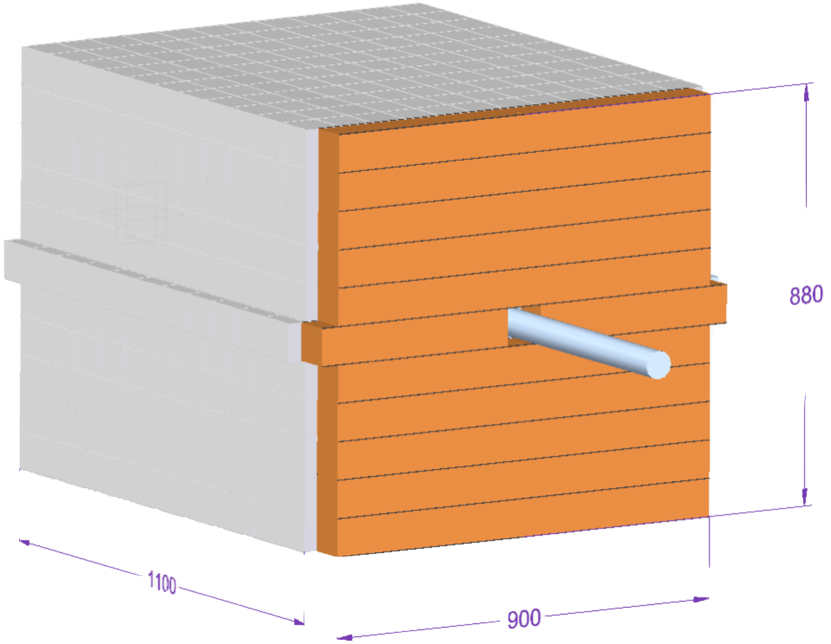
# FoCal-H conceptual design

- Discussion with industry and looking at "Dual Readout Calorimeter for IDEA:

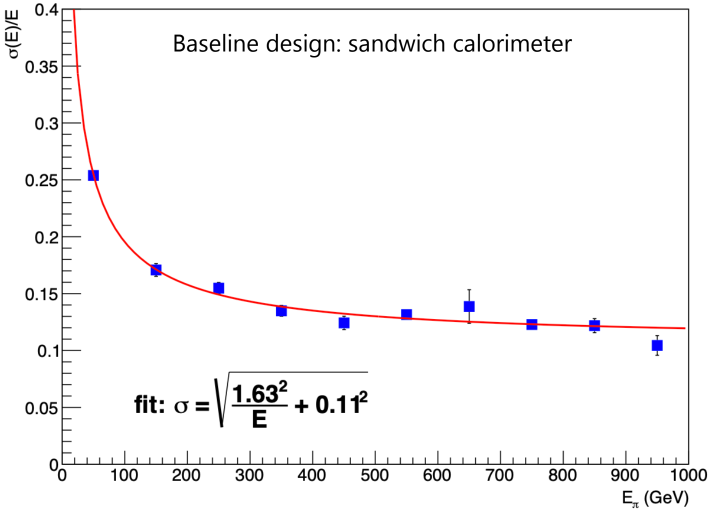
Build calorimeter out of commercially available Cu capillary tubes with scintillating fibers







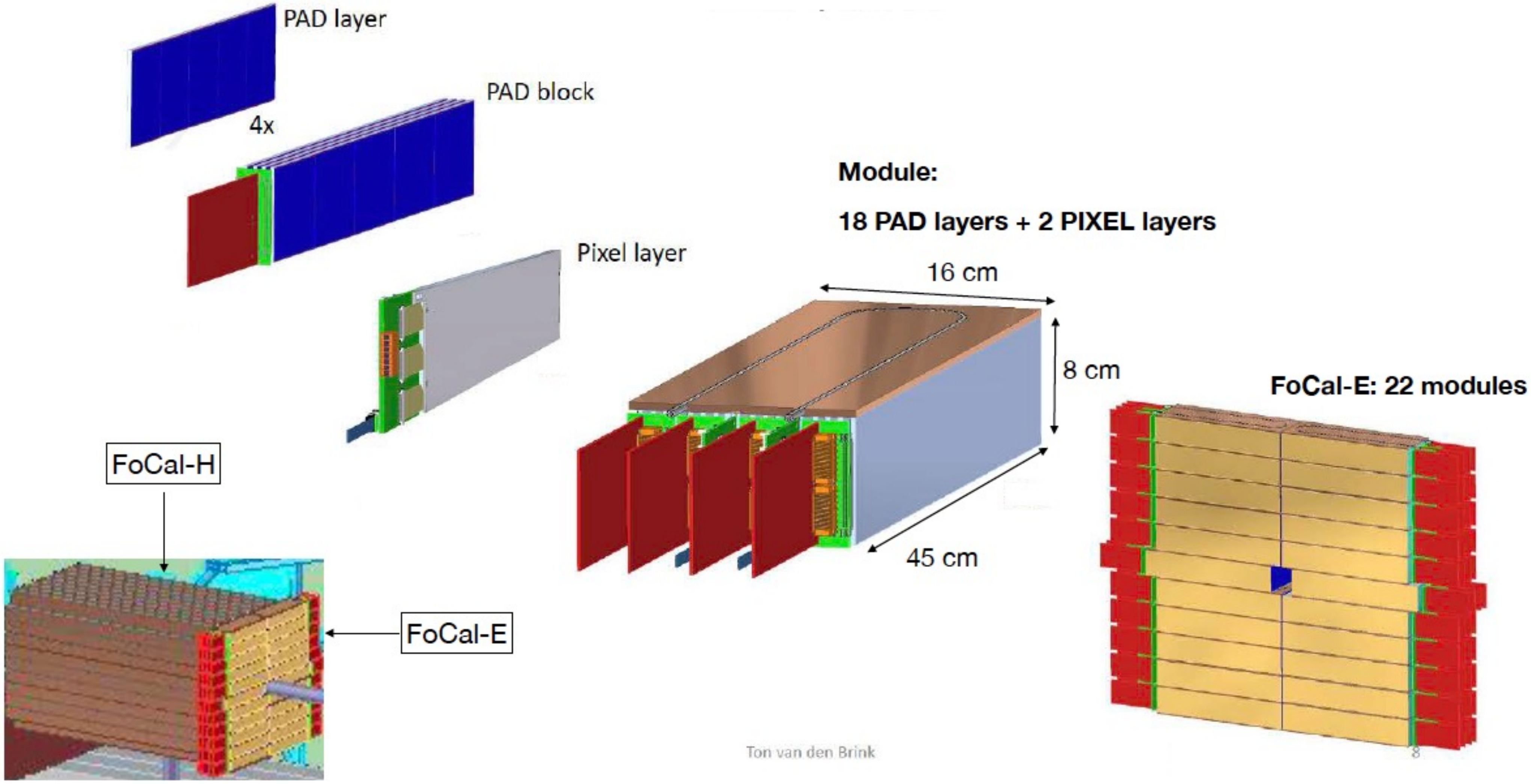

Energy resolution for charged pions




- Simulation uses sandwich-structure:
  - 34 layers of 3cm absorber and 0.2cm scintillator
- Good performance for isolation and jets
  - Single hadron energy resolution of 10-25%
  - $E_T$ = 2 GeV for isolation about E = 100 GeV at η = 4.5
  - Constant term (e/h compensation) more, sampling-fraction less important
- Conventional metal-scintillator design
  - Sampling / tower structure not yet defined
  - No longitudinal readout required

1.1 m long: ~6 $\lambda_I$
Tower size: 2-5 cm
~1k towers

# Putting them together



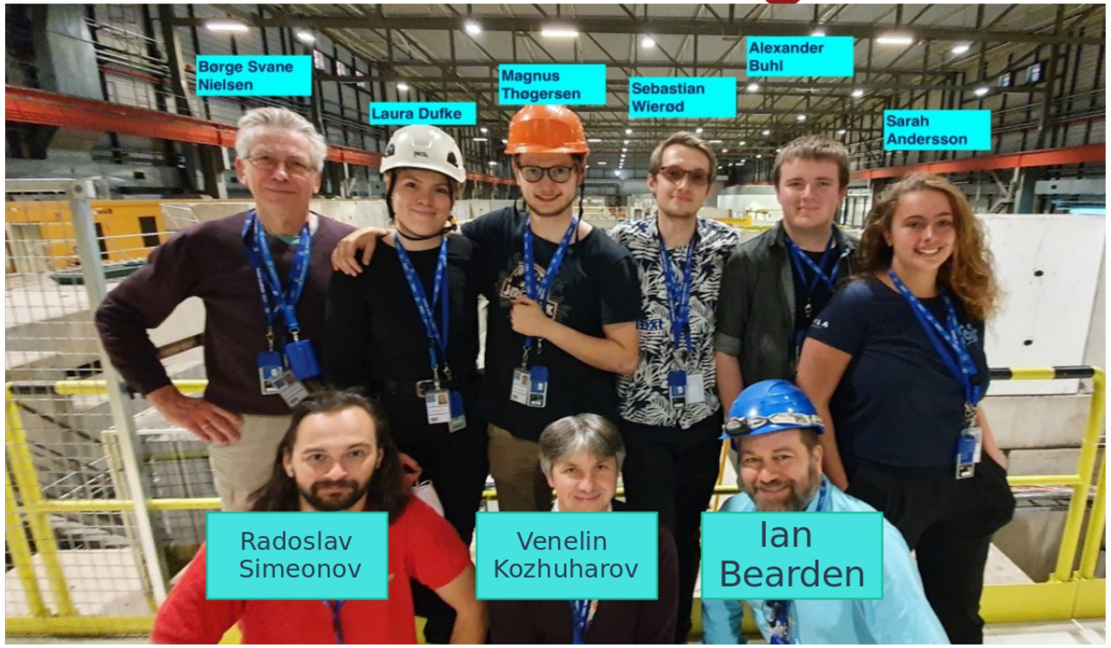
# FoCal-H development

Niels Bohr Institute

UNIVERSITY OF COPENHAGEN

Your Logo Here

1st Beam Test




Focal-H funded by:

CARLSBERG FOUNDATION

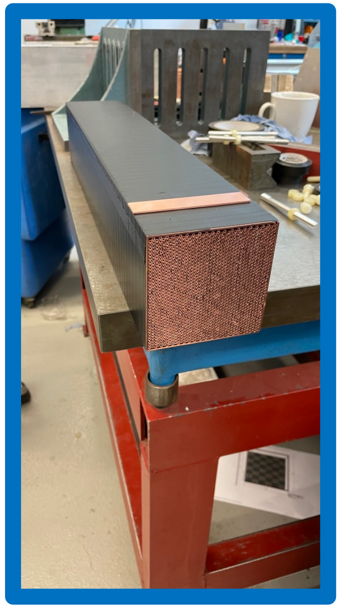
† CF21-0606, Hadronic Calorimeter for Forward Physics

РЕПУБЛИКА БЪЛГАРИЯ
МИНИСТЕРСТВО НА ОБРАЗОВАНИЕТО И НАУКАТА

** partially supported by National Roadmap for Research Infrastructures – CERN D01-374/18.12.2020 г.*

# FoCal-H prototype 1

"proof of concept"



9,8x9,8x55cm$^3$

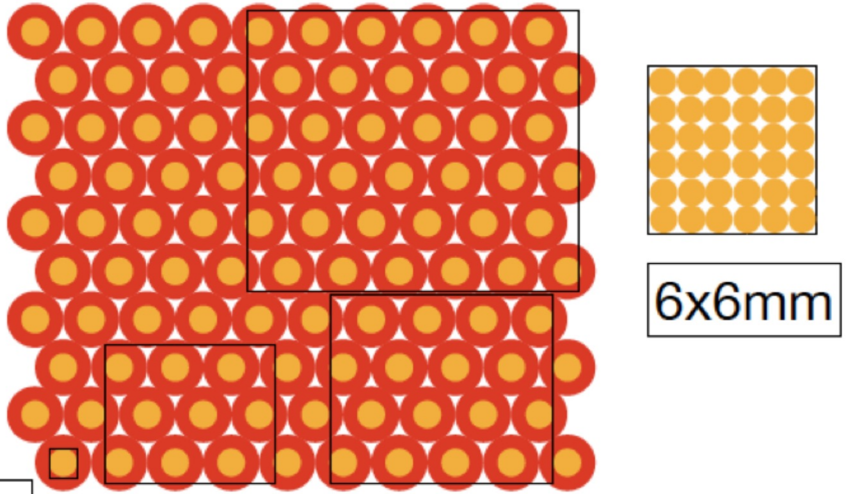
1440 tubes

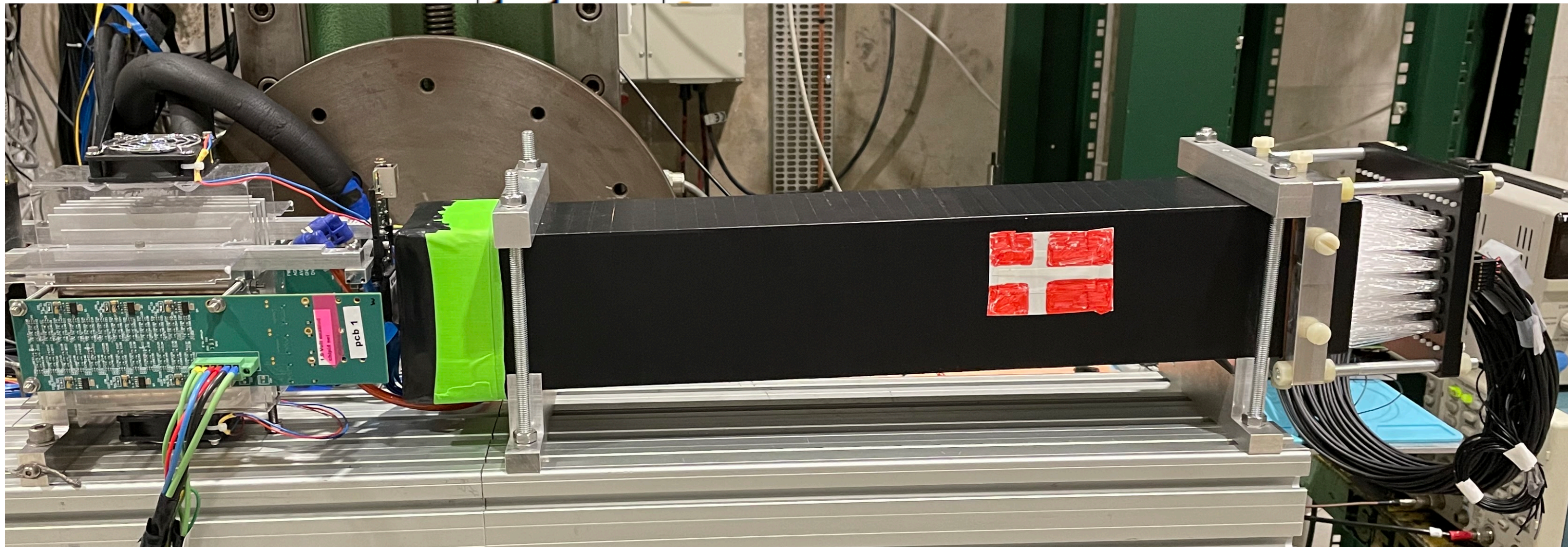
≈12 hours
Fiber: BCF10
OD:1mm

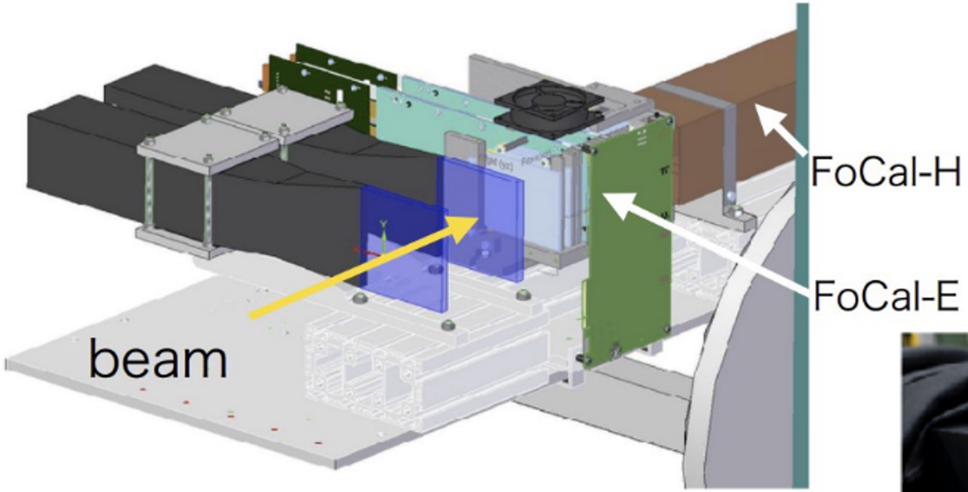
ON MicroFC 60035 SiPMs

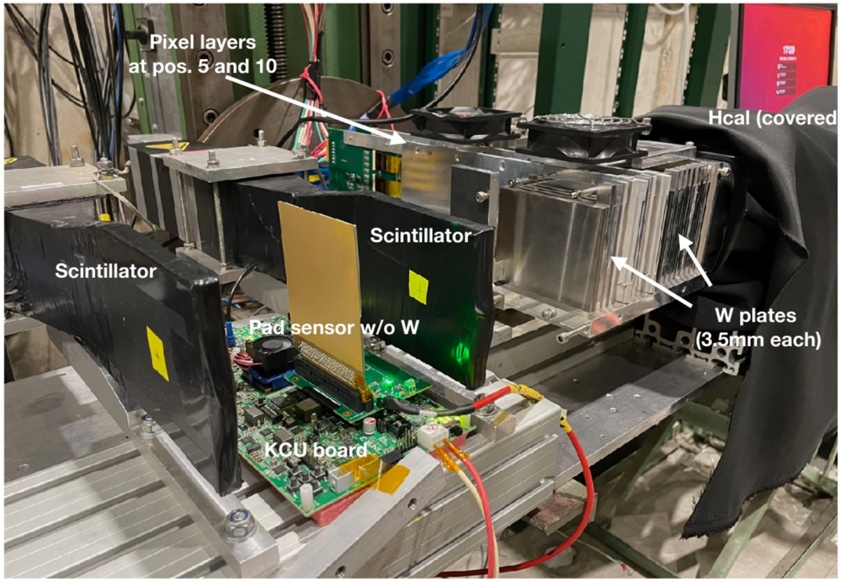
48 Bundles of 30 fibers

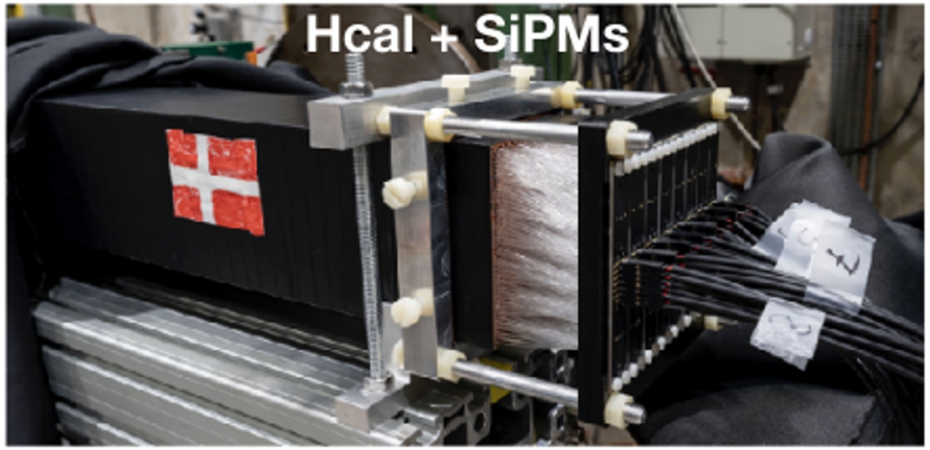
Available SiPM sizes:
1x1, 3x3, 4x4, 6x6 mm



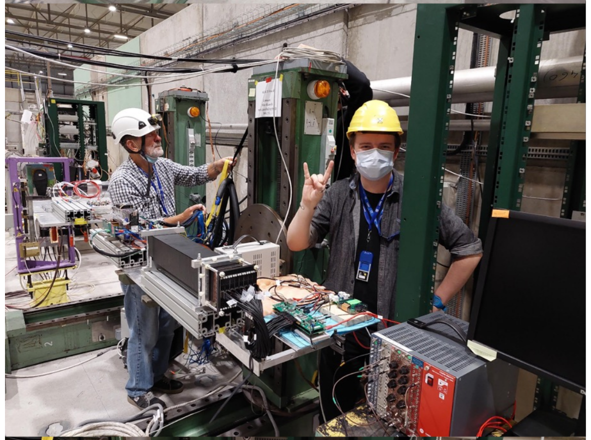



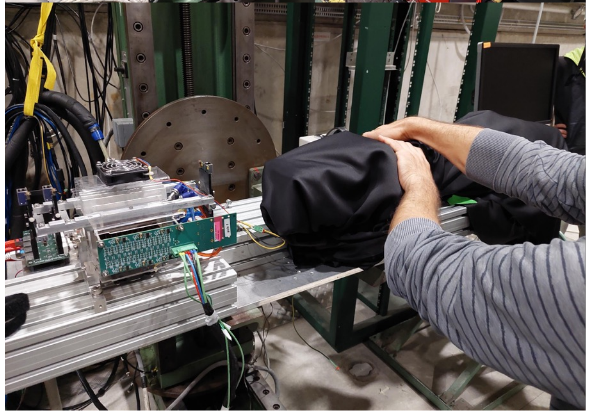


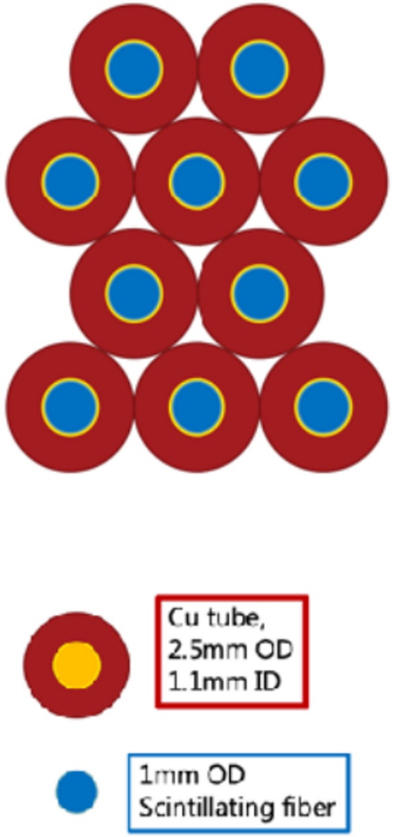




- SPS H6 Beamline
  EHN1 (building 887, Prevessin site), CERN
  - up to ~120 GeV
    - 4 different systems
    - various different configurations
    tested in 13 days





# Two potential problems with Capillary Tube design



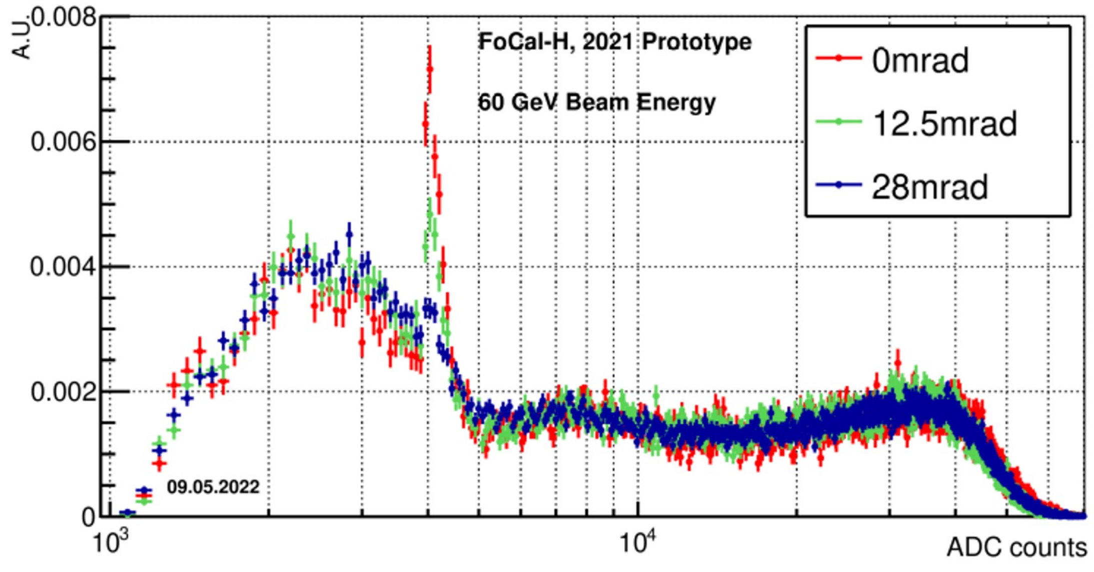

1. Inefficiency due to voids between tubes
2. Particles can traverse length of scintillator (“channeling”)

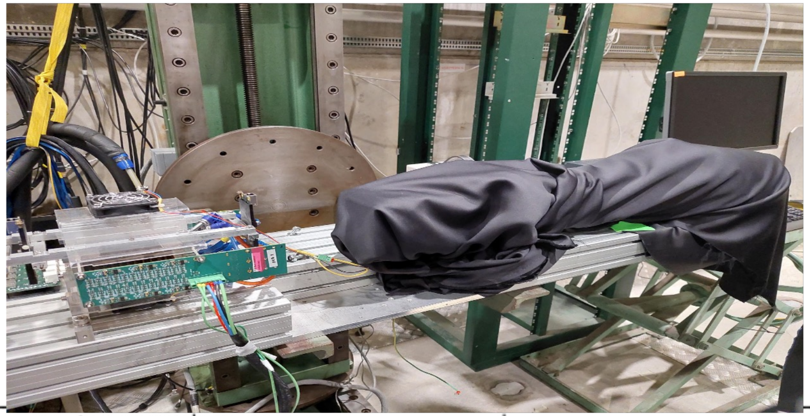
Fair to ask: why use capillary tubes?

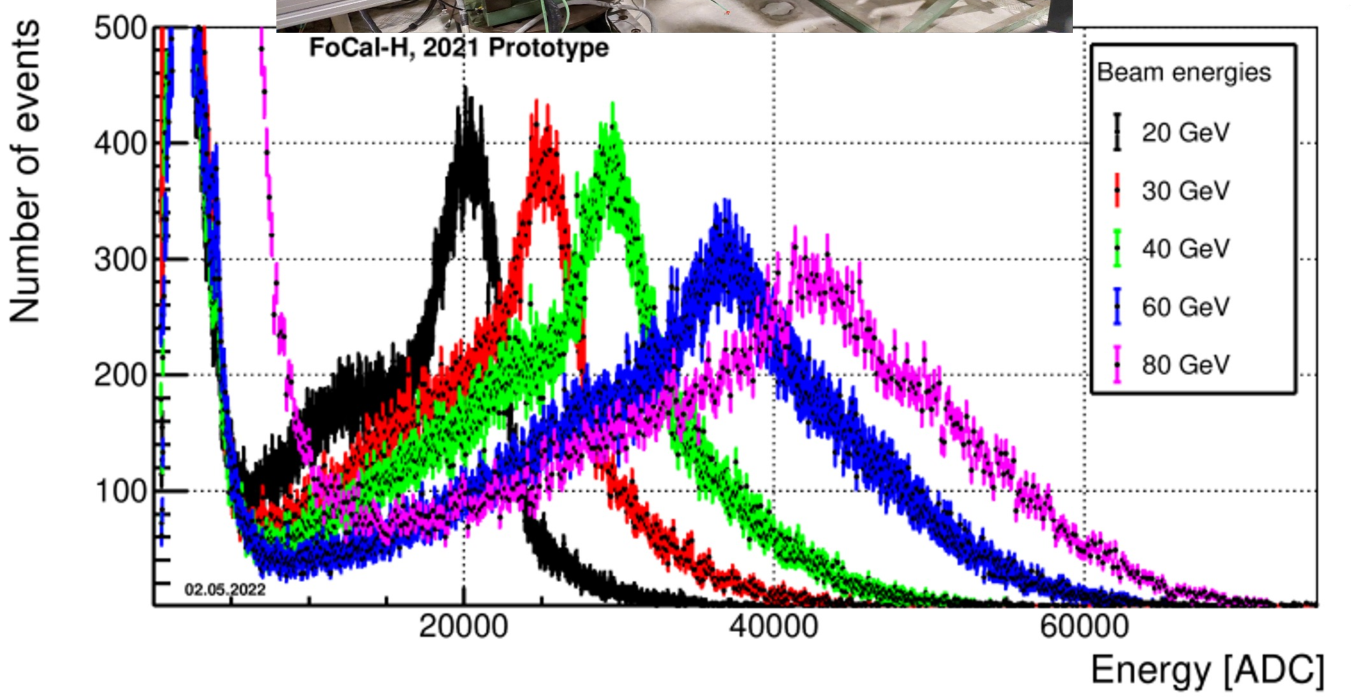
1. Arbitrary granularity
2. Low machining cost

# First Results

- Channeling:
- Particles traversing along the scintillating fiber – result as peak in the total energy distribution
- Change incident angle to reduce effect
- Reproduced in MC



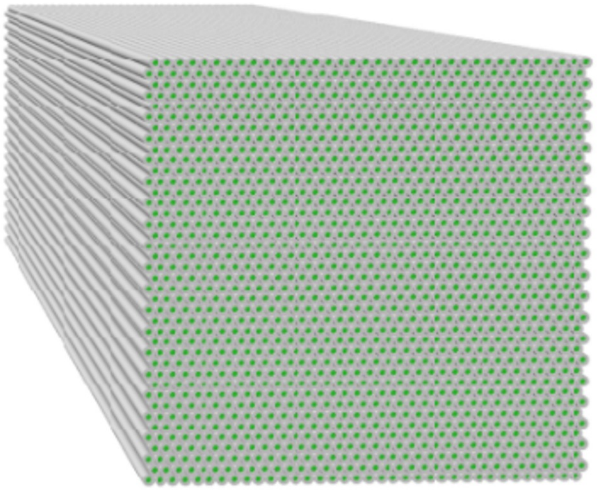





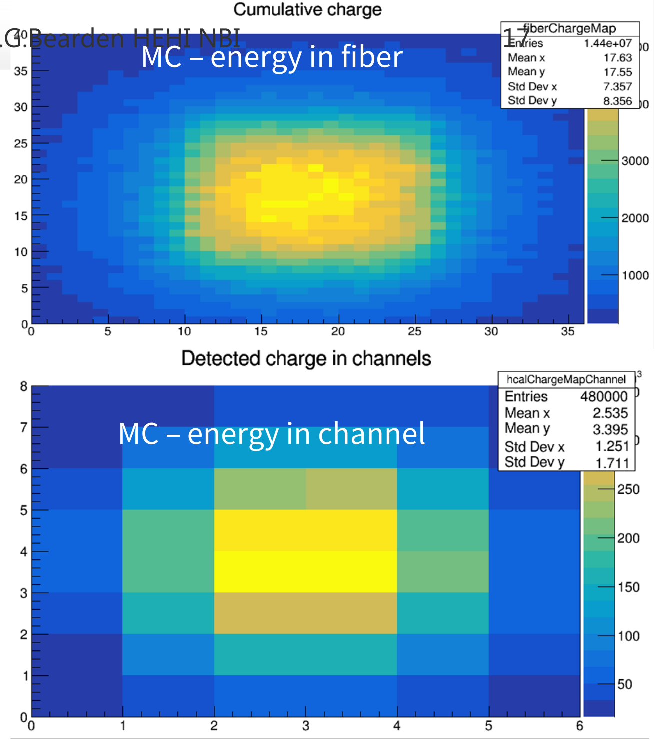

- Charge reconstruction
- Beam energy dependence follow qualitatively expected trend

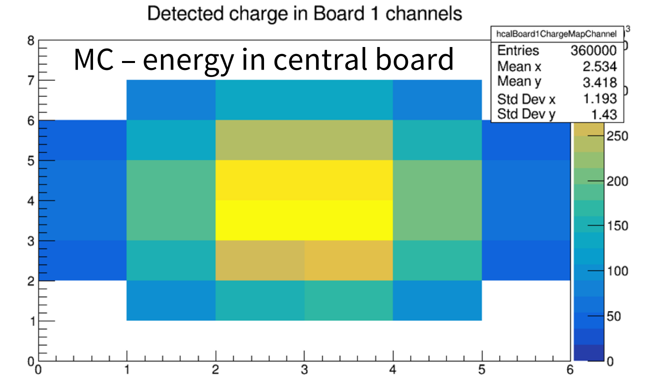
# Monte-Carlo studies

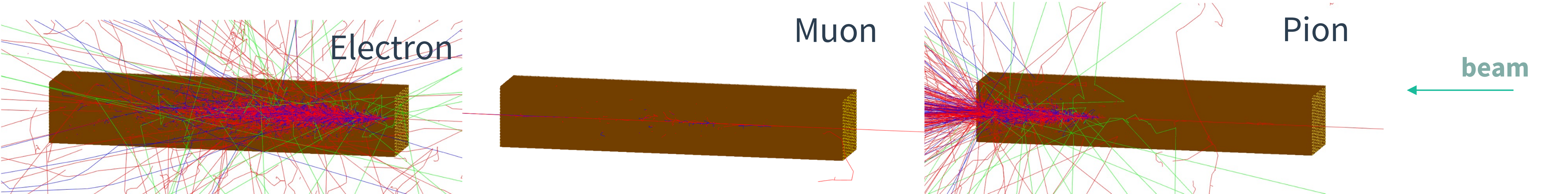
- **GEANT4 based simulation**
  - Geometry and materials description
  - Physics list: FFTP_BERT (also QGSP_BERT checked)
  - Signal: energy deposit in the plastic scintillator fibers
  - Scintillation, light propagation,
    SiPM response, digitization - considered
    in an effective manner
- **Main goals**
  - - precise data analysis
  - - total charge studies
  - - saturation estimation
  - - beam decomposition
- **Tests for future prototype designs**



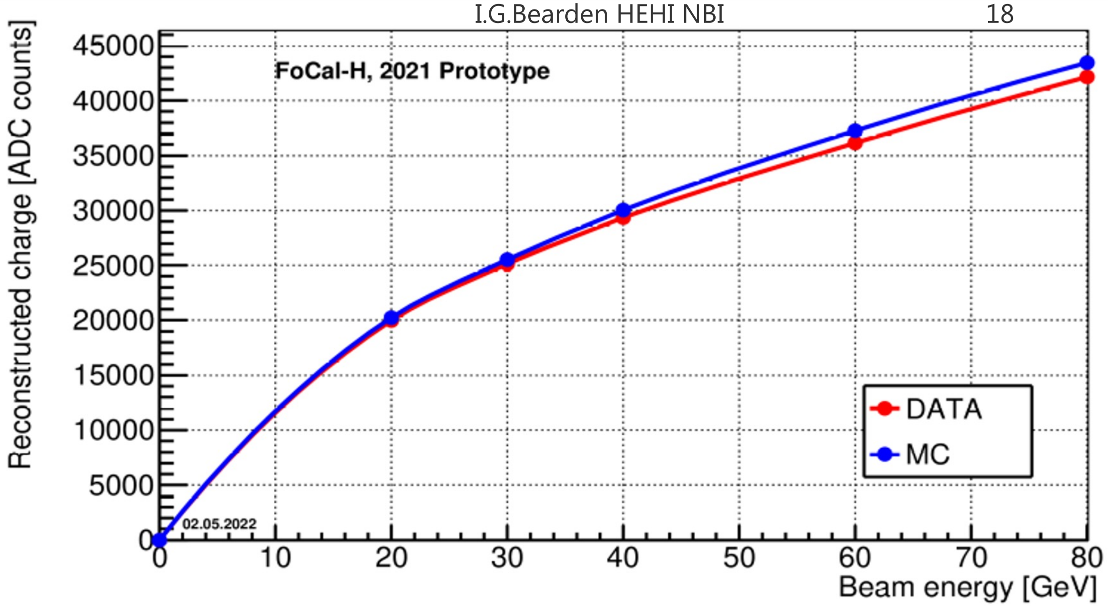
Energy [MeV]



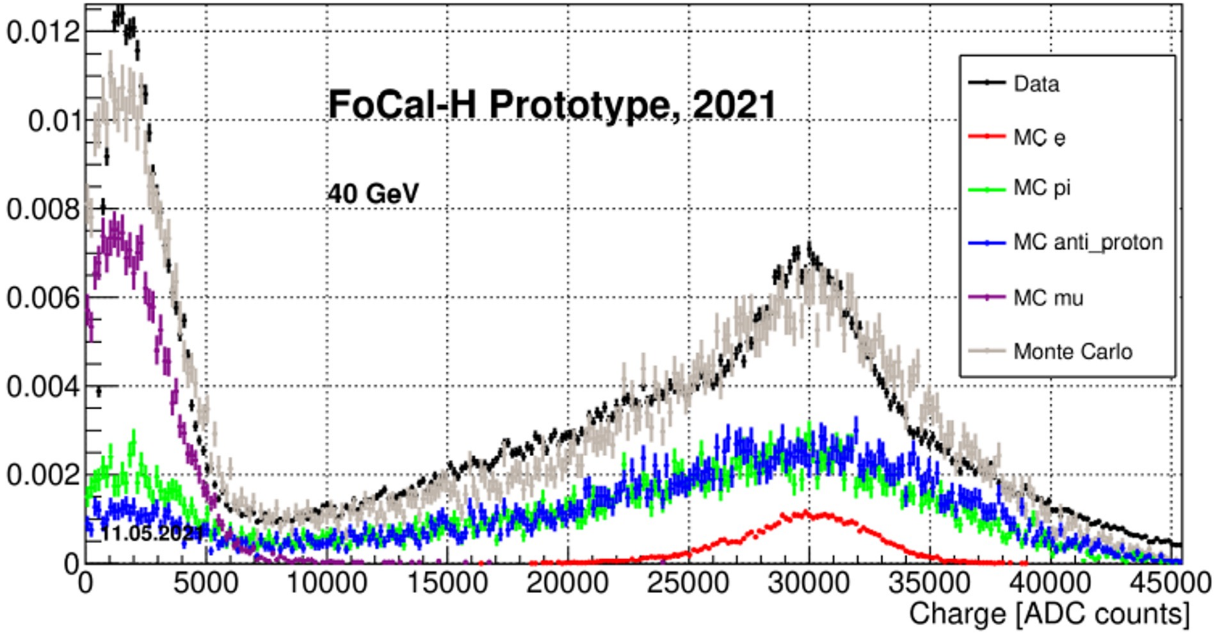



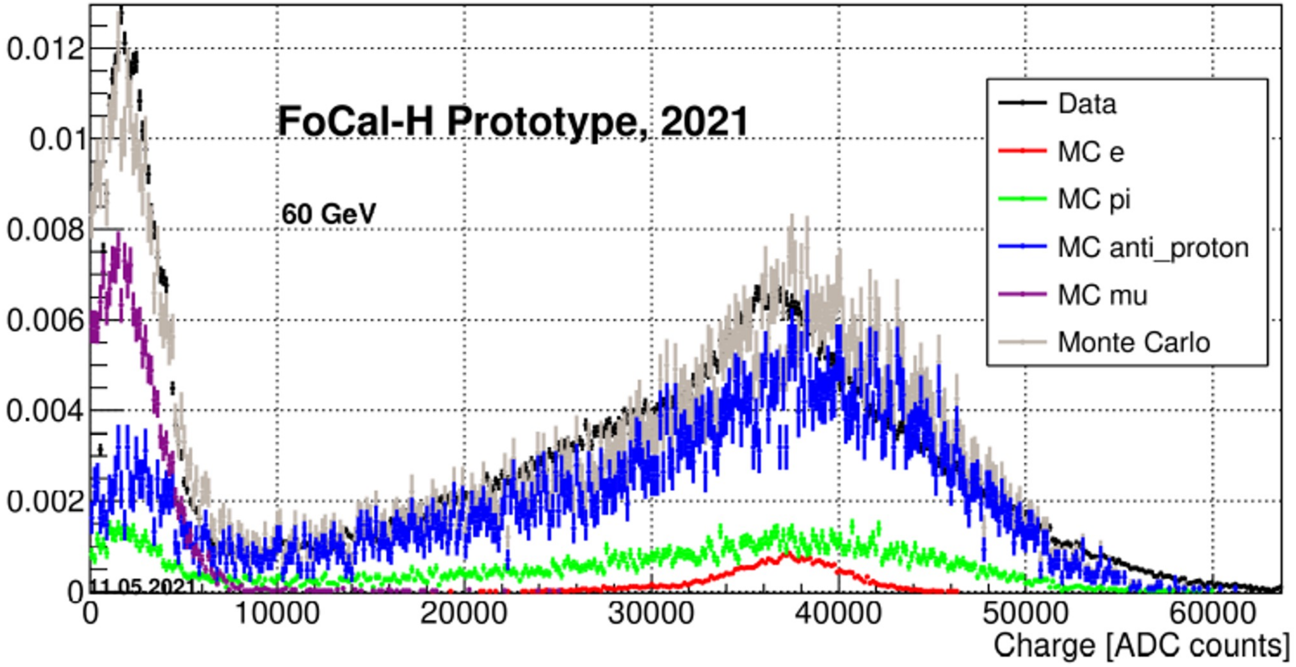



# FoCal-H 2021 Prototype Final results

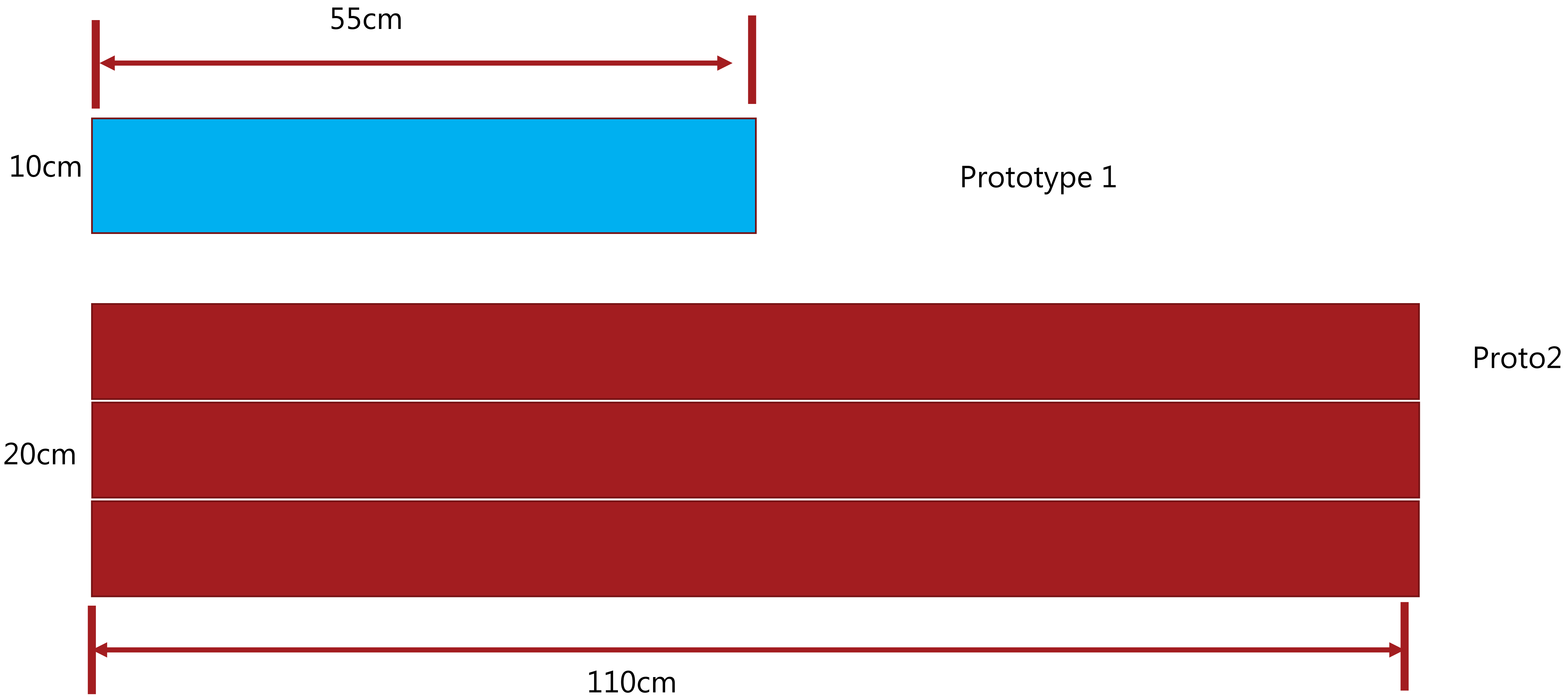



- Electrons peak position in MC matches the DATA
- DATA total charge distribution described by a weighted sum of simulated e, π, μ, p
- Consistency between MC and DATA

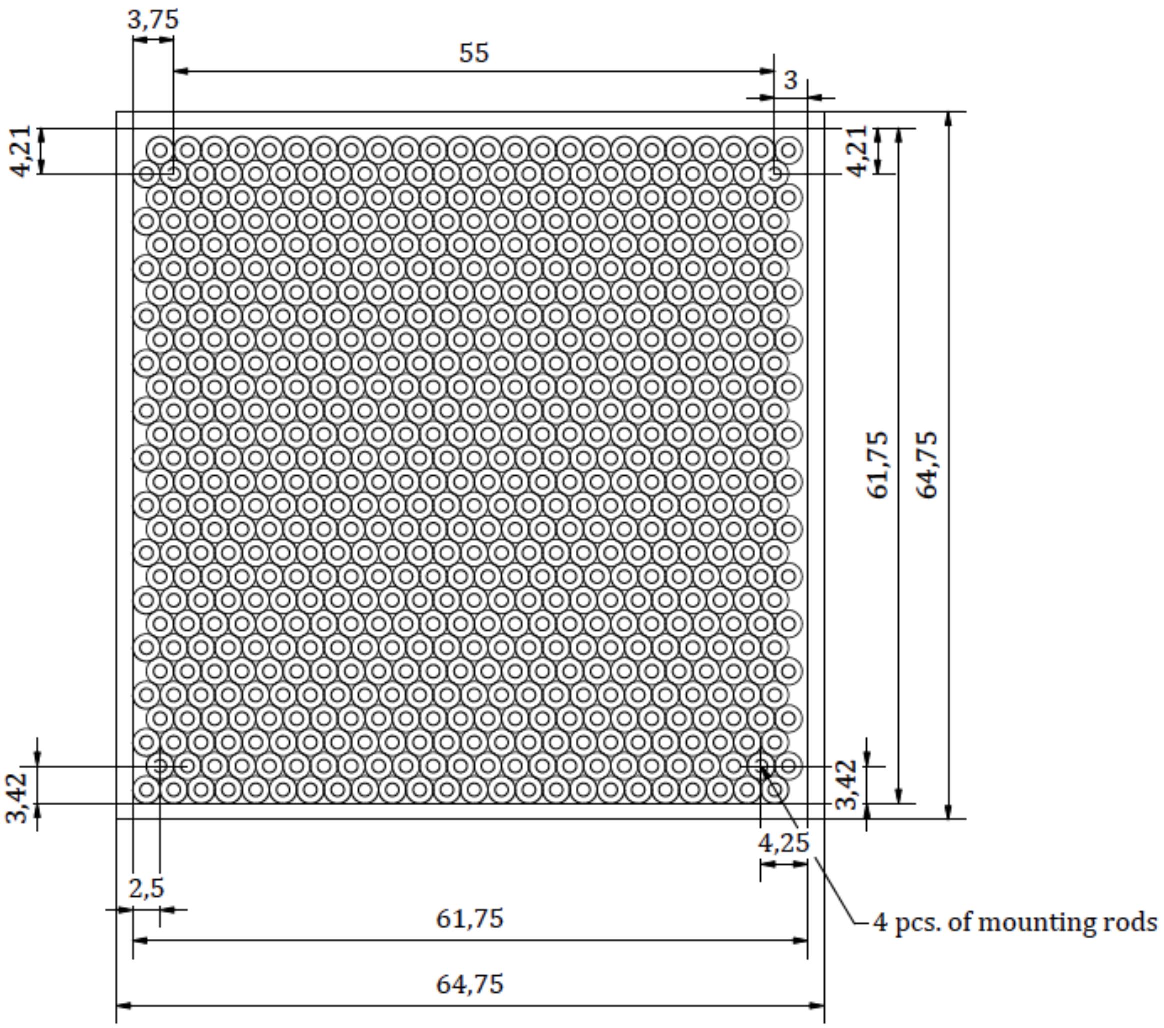


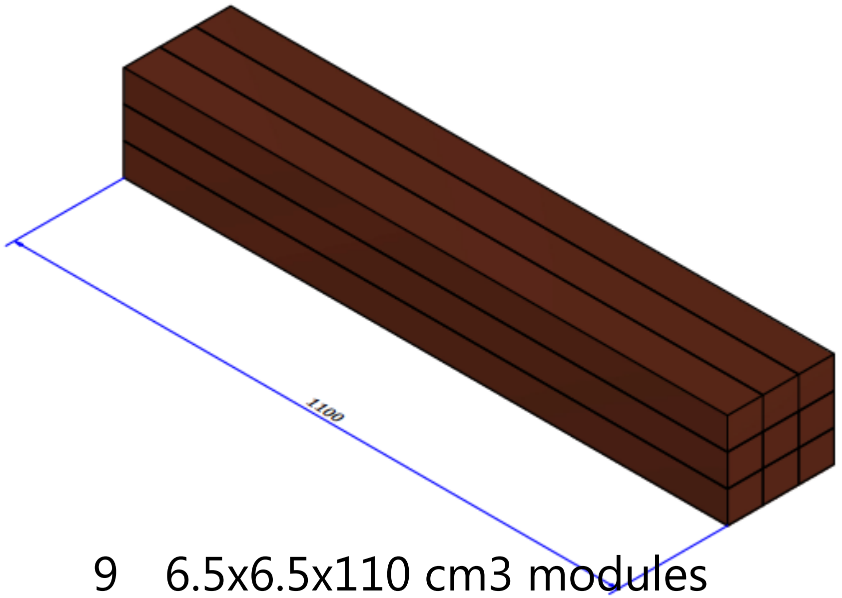



# Prototype 2: Longer, thicker, better!



# FoCal-H Prototype 2




9 6.5x6.5x110 cm3 modules

- each module ≈31,7 kg Cu 6.87gm/cm3
- 668 fibers/module

14 fibers/SiPM center module
21-30 fibers/SiPM outer modules

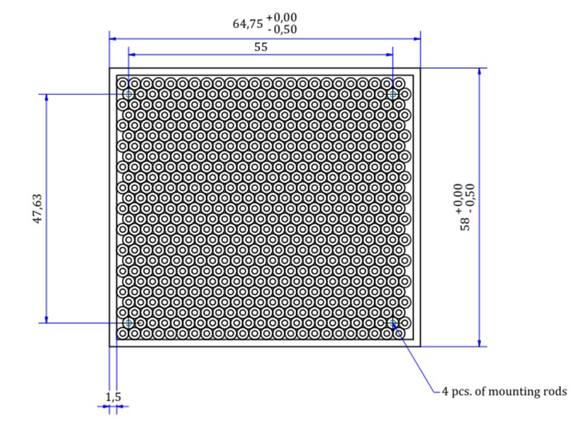
StGobain BCF12 Scintillating fiber (OD 1mm)
Hamamatsu S13360-6025 SiPMs

Fill voids with Cu wire.

# Plans 2022

- PS TestBeam, 8 – 16 June 2022
  - Readout studies (CAEN A1702->CAEN 5502)
  - Work with additional detector system

- SPS TestBeam, Autumn 2022
- - 9 modules, 3x3 construction
  - Each module – 6,5 x 6,5 x 110 $cm^3$
  - Capillary tubes, inner diameter 1.1mm, 668 * 1mm scintillating fiber
- **Shower containment**
- **Energy resolution**
- **Energy calibration 20-250 GeV**
- **Test HGCROC SiPM readout?**



# Summary

- FoCal: Unique window on small-x region in LHC collisions
- R&D ongoing but nearing completion.
- FoCal-H proof of principle, now look at detailed performance
- FoCal TDR in ≈one year.