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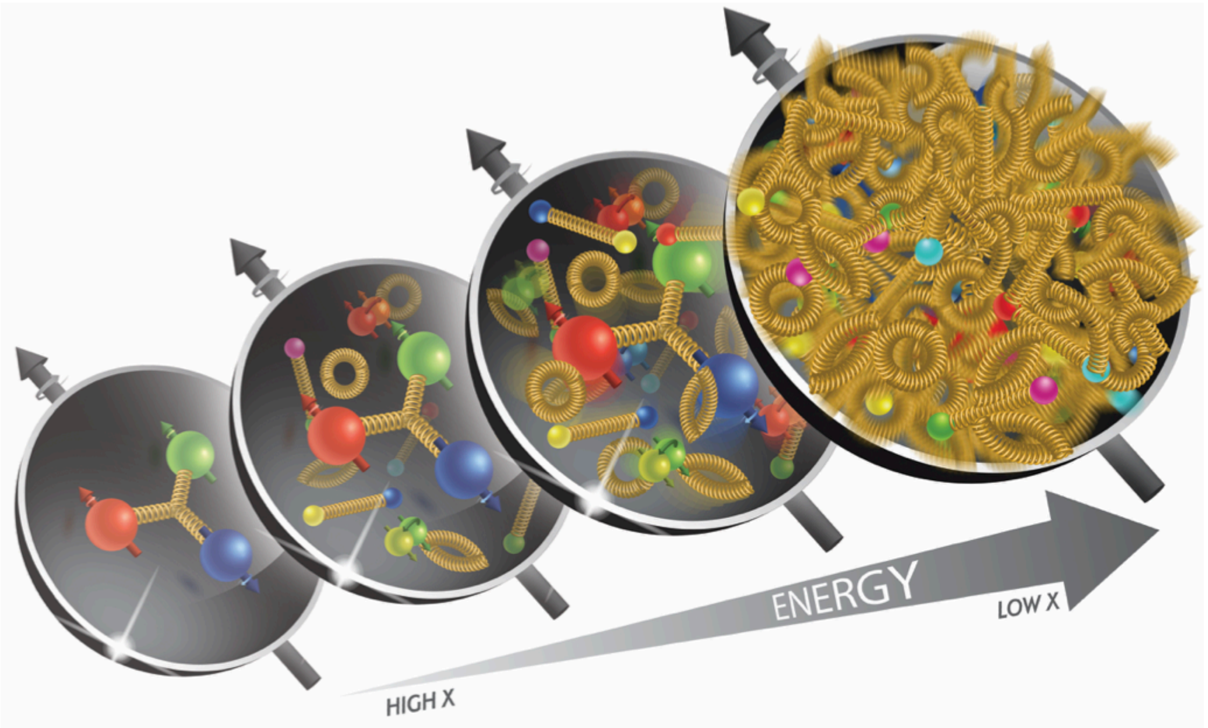
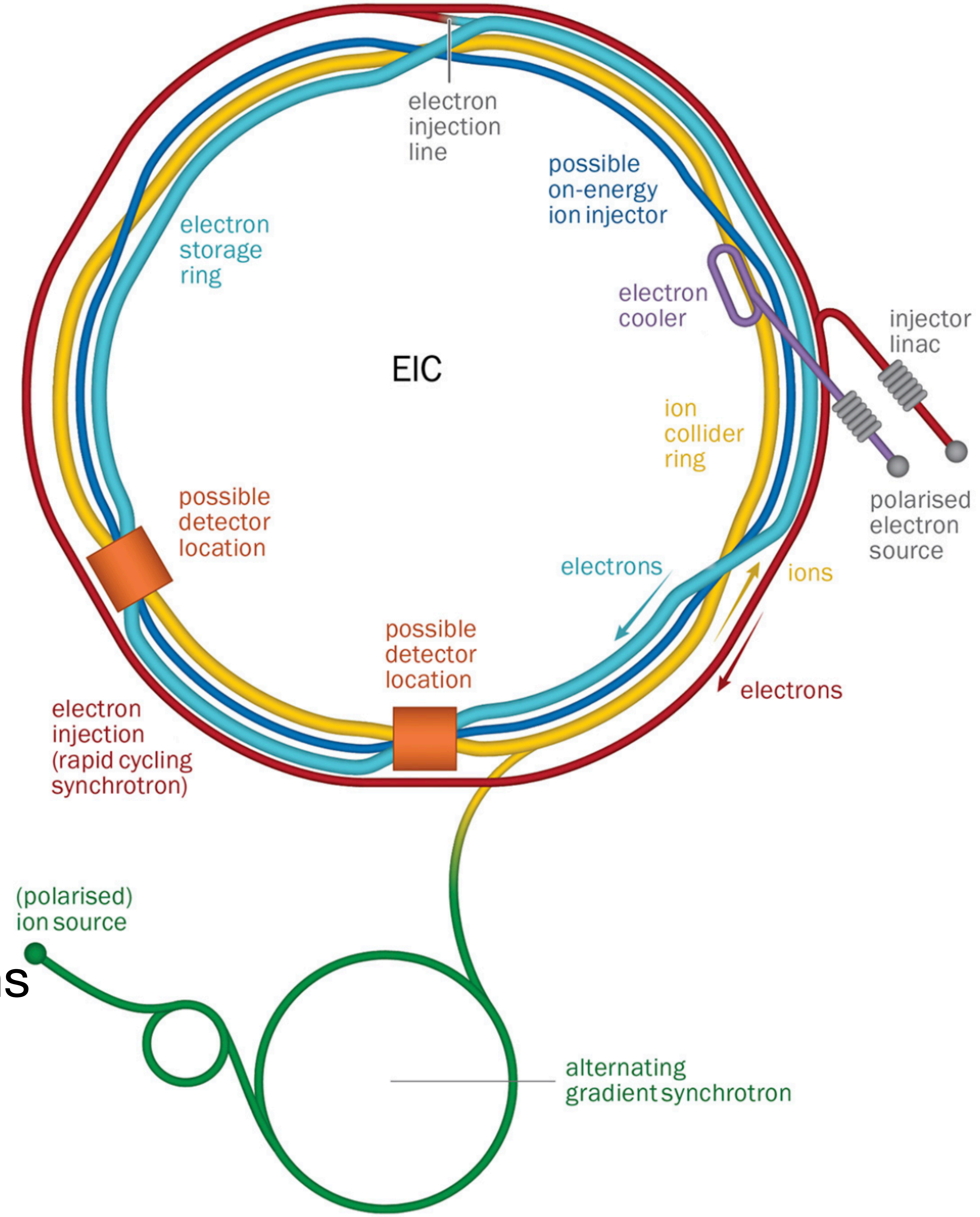
The LFHCAL forward hadronic calorimeter for the EPIC detector at the EIC

Norbert Novitzky
(ORNL)

Electron-Ion Collider (EIC)

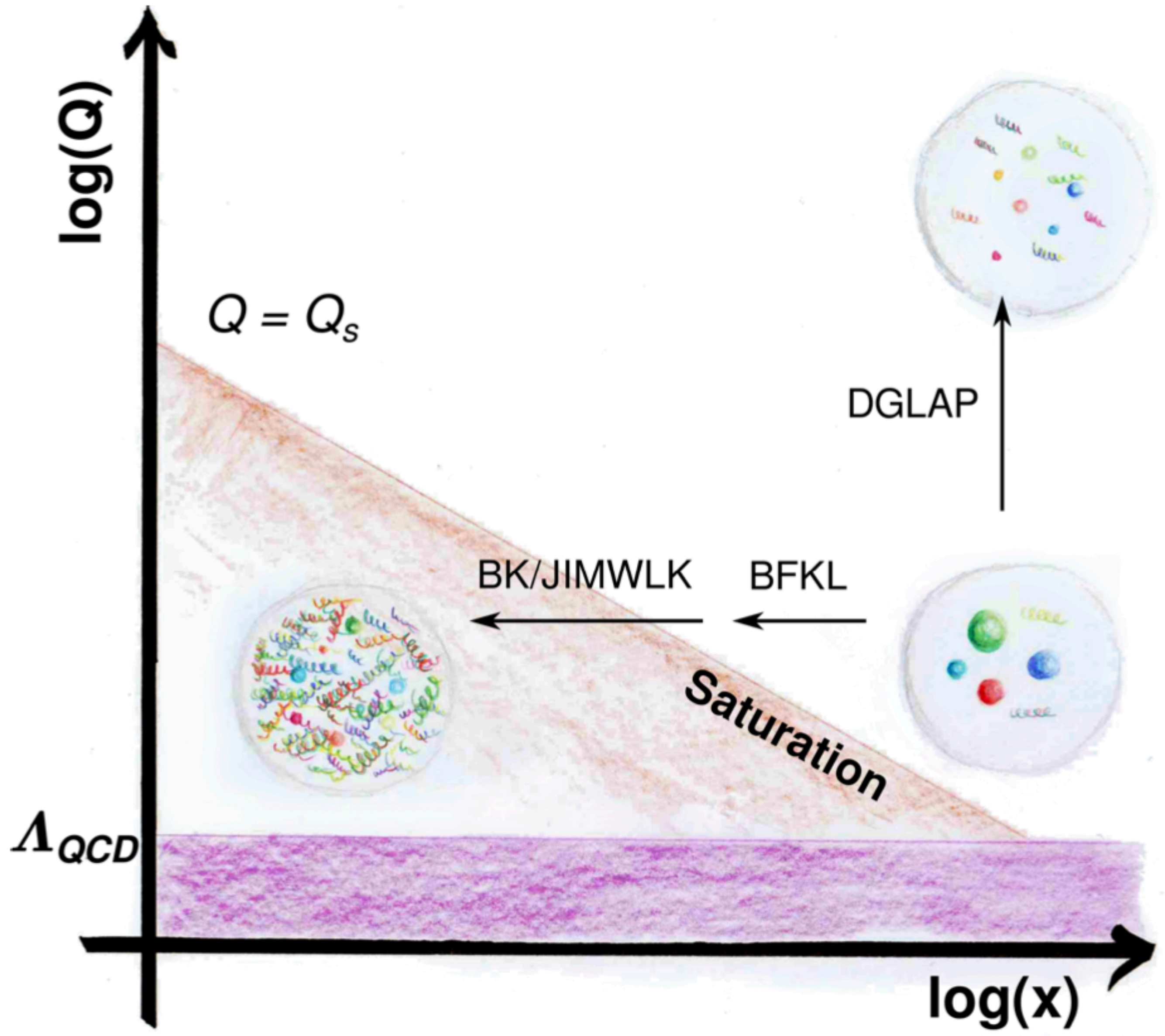


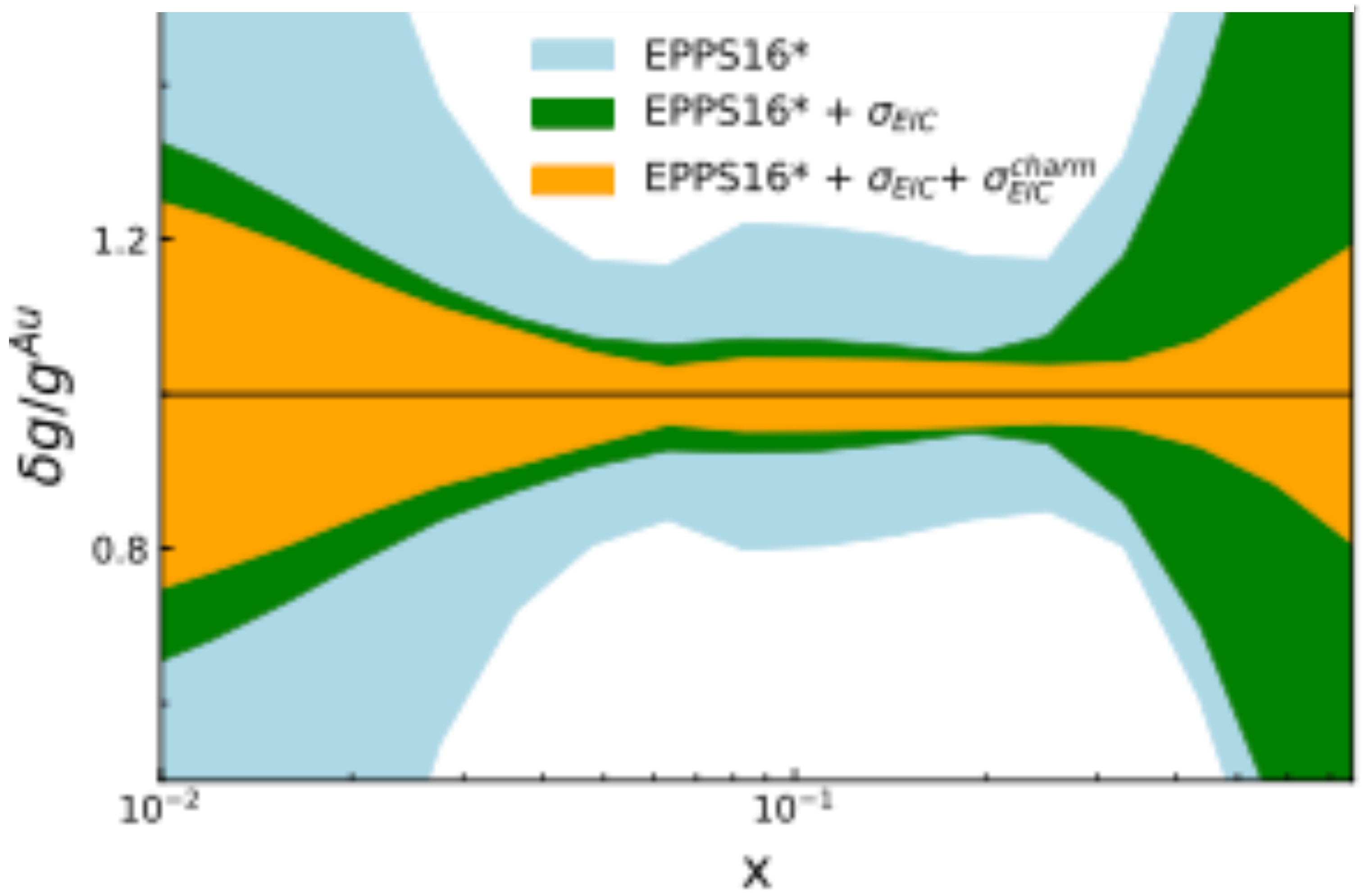
- **New electron accelerator and storage ring at RHIC**
- More than 1300 physicists from over 250 institutions worldwide
- Center-of-mass energies of $\sqrt{s}$ = 20 - 140 GeV
- Very high luminosity 10^{33} - 10^{34} $cm^{-2}s^{-1}$ for e+p and e+A collisions
- High polarization (70%) of both electron and proton beams
- Two interaction points for instrumentation



EIC Yellow Report, 2103.05419

Selected physics motivations





Gluon saturation:
Possible signatures in the back-to-back hadron-jet correlations or nuclear modification factor

Multi-dimensional imaging of the nucleon:
Transverse momentum dependent parton distribution (TMD)
Scale dependence predicted by QCD

Gluon TMDs:
Constrained via quarkonium or charm jet production
Back-to-back jet production

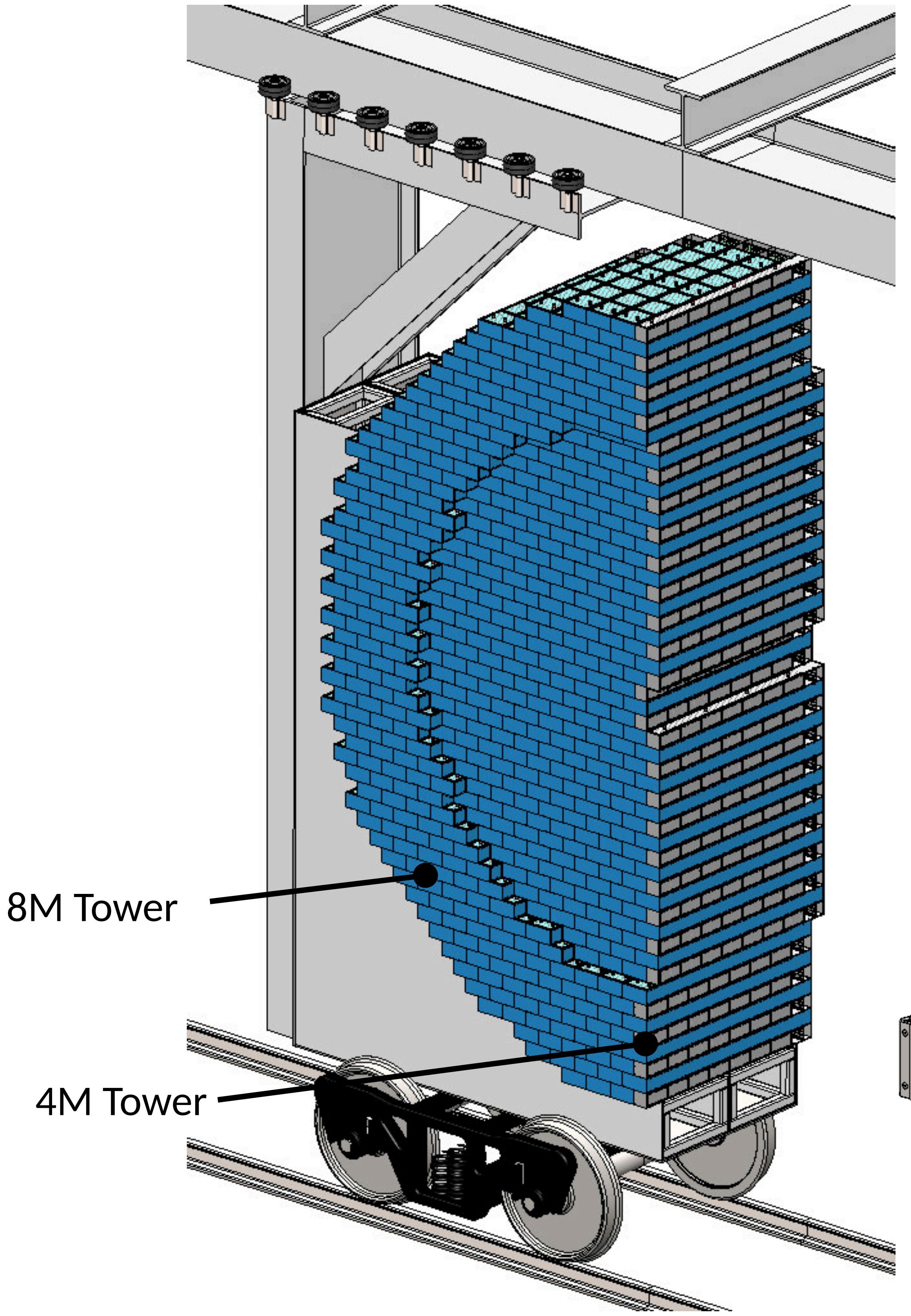
Measuring of color propagation through the cold nuclear matter
Lepton-jet measurement will allow dialing of nuclear size and energy dependence

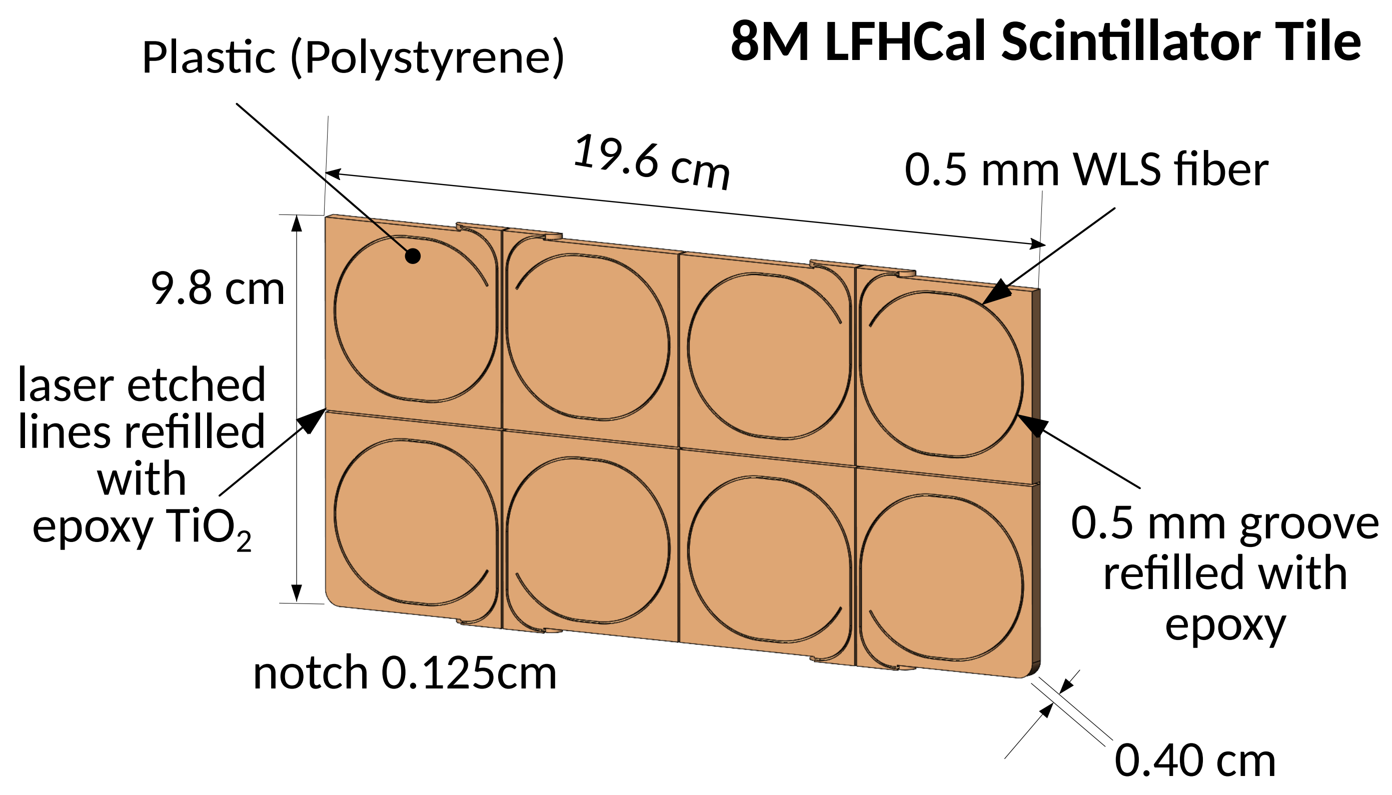
Longitudinally segmented Forward Hadronic Calorimeter (LFHCal)

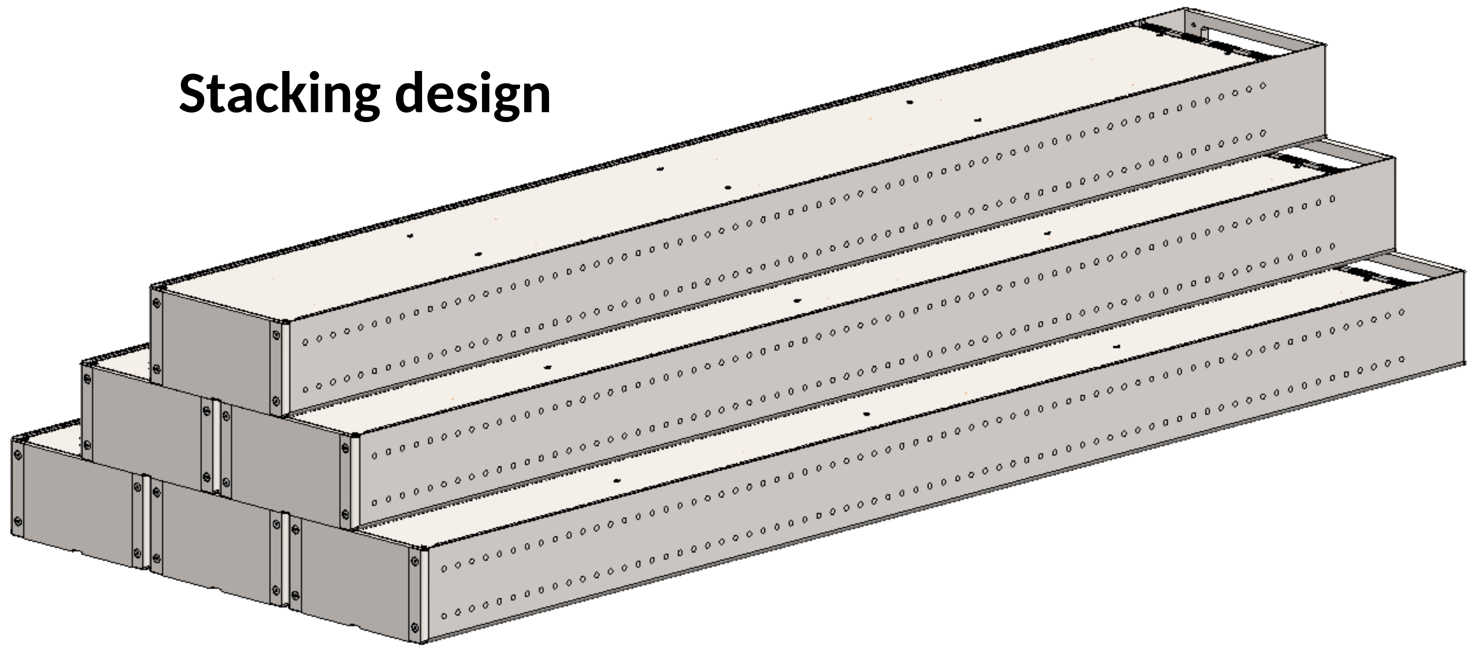
For better performance:

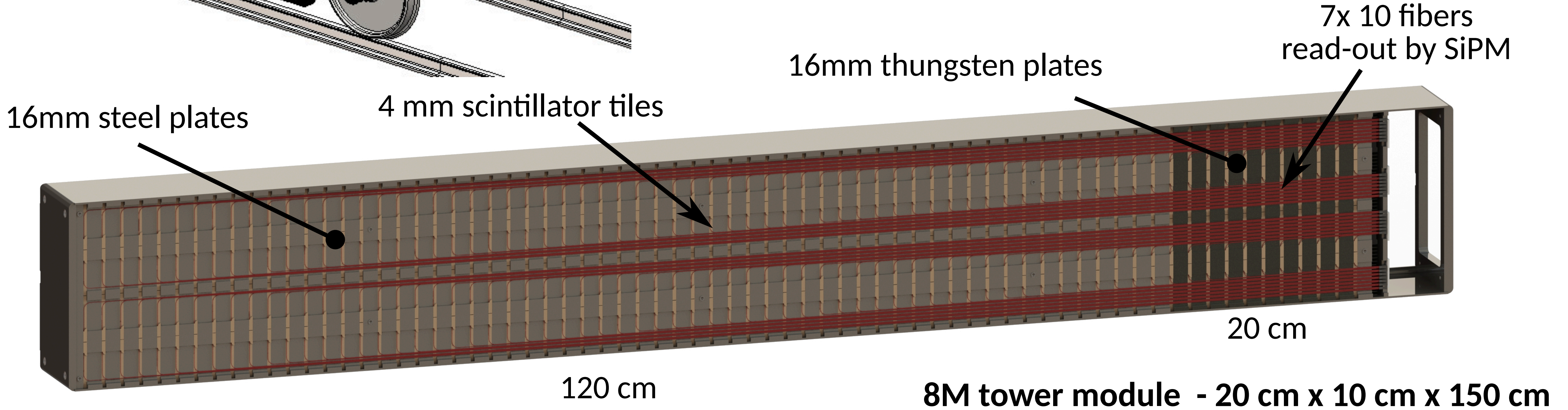
- sub-Moliere radius towers
- Longitudinal separation:
  - 7 longitudinally segmented regions
  - Better resolution for hadrons
  - Identification of muons

parameter	**LFHCal**
inner radius (envelope)	17 cm
outer radius (envelope)	270 cm
η acceptance	$1.2 < \eta < 3.5$
tower information	
x, y (R </> 0.8 m)	5 cm
z (active depth)	140 cm
z read-out	10 cm
# scintillor plates	70 (0.4 cm each)
# aborber sheets	60 (1.6 cm steel)
	10 (1.6 cm tungsten)
weight	$\sim$ 30.6 kg
interaction lengths	6.9 λ/λ_0
Molière radius R_M	21.1 cm ($\pi^{\pm}$ shower)
Sampling fraction f	0.040
# towers (inner/outer)	9040
# modules	
8M	1091
4M	76
2M	2
1M	4
# read-out channels	7 x 9,040 = 63,280





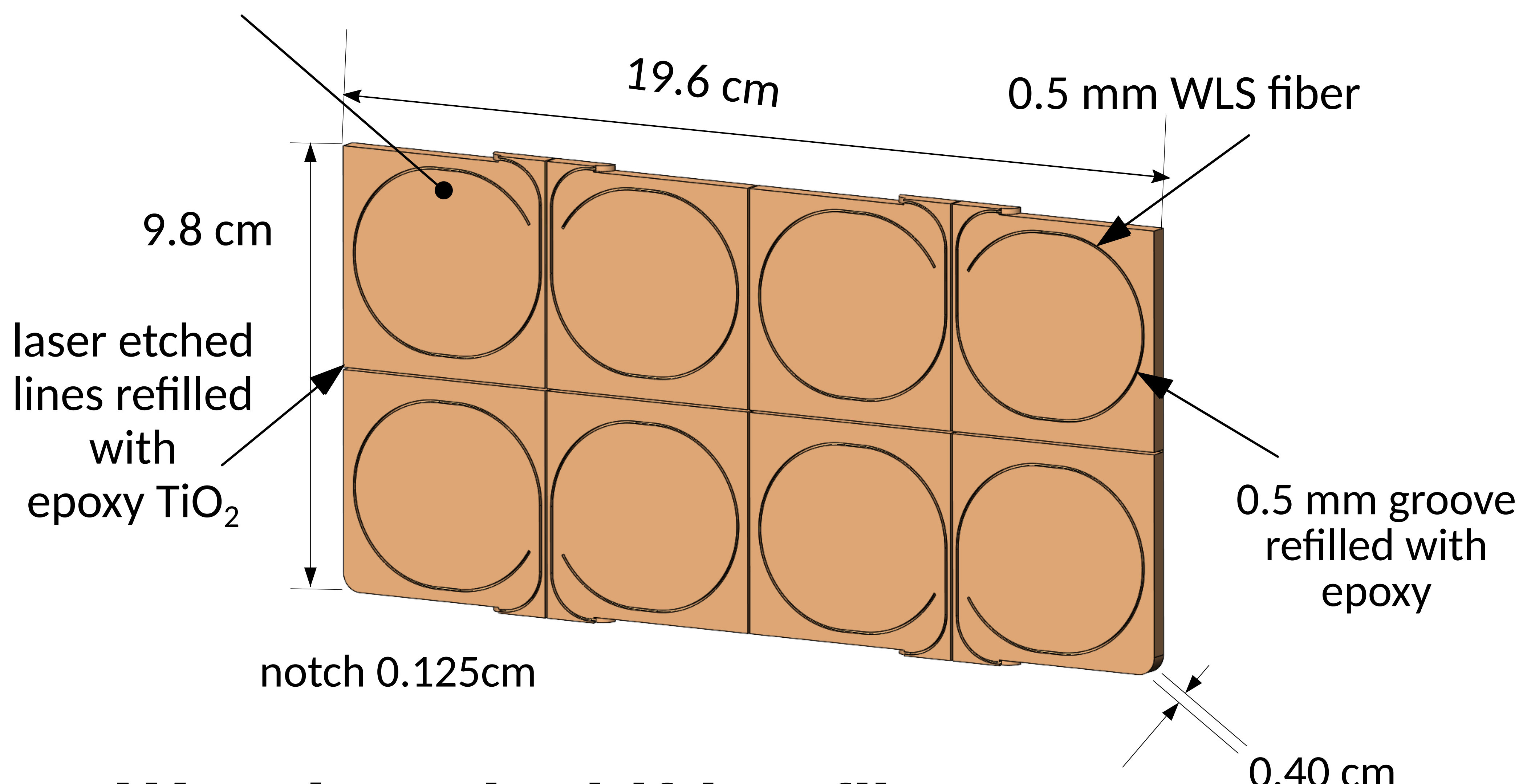




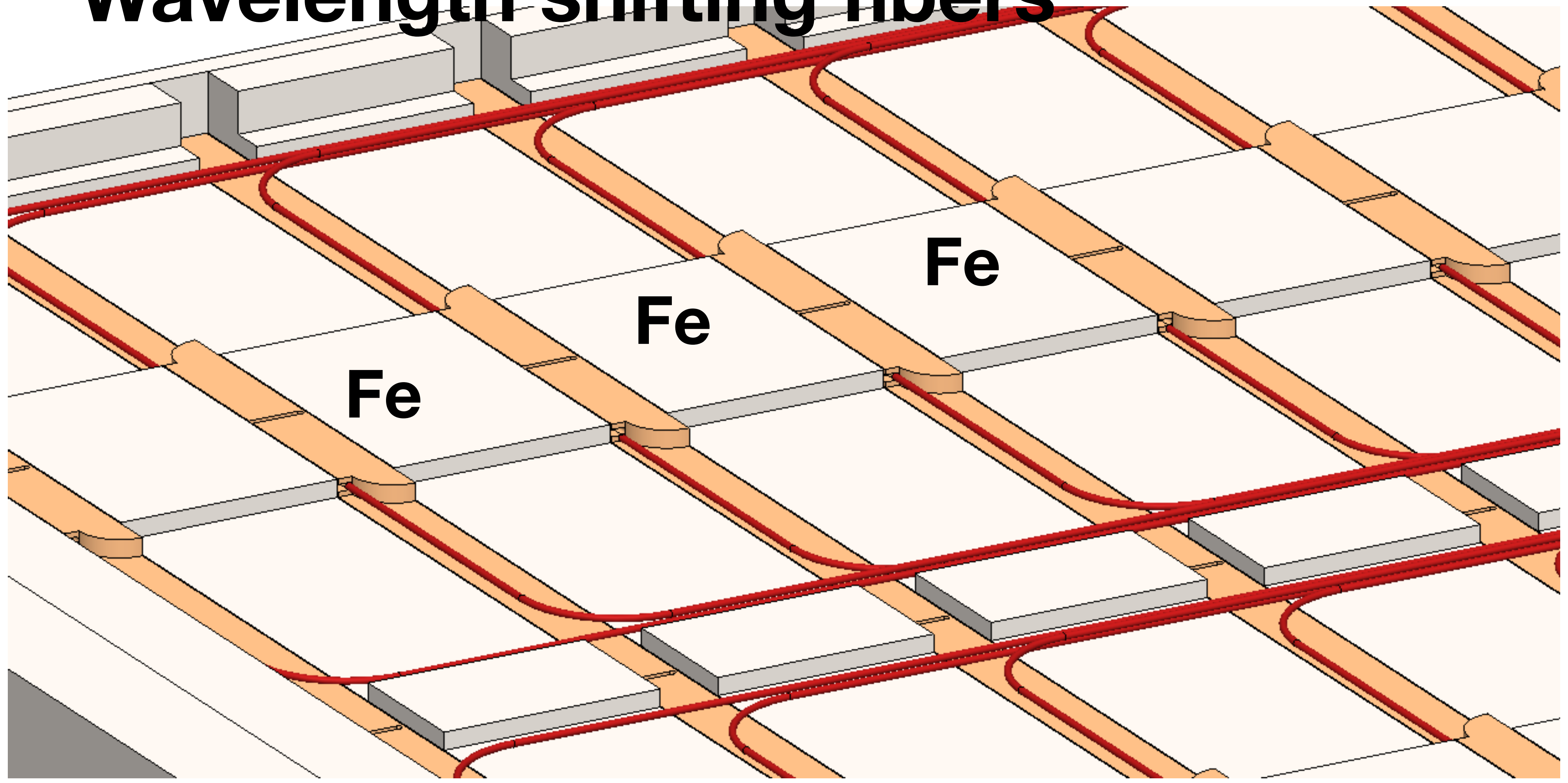
8M tower module - 20 cm x 10 cm x 150 cm
- 8 5 cm x 5 cm LFHCal towers

arXiv:2207.09437

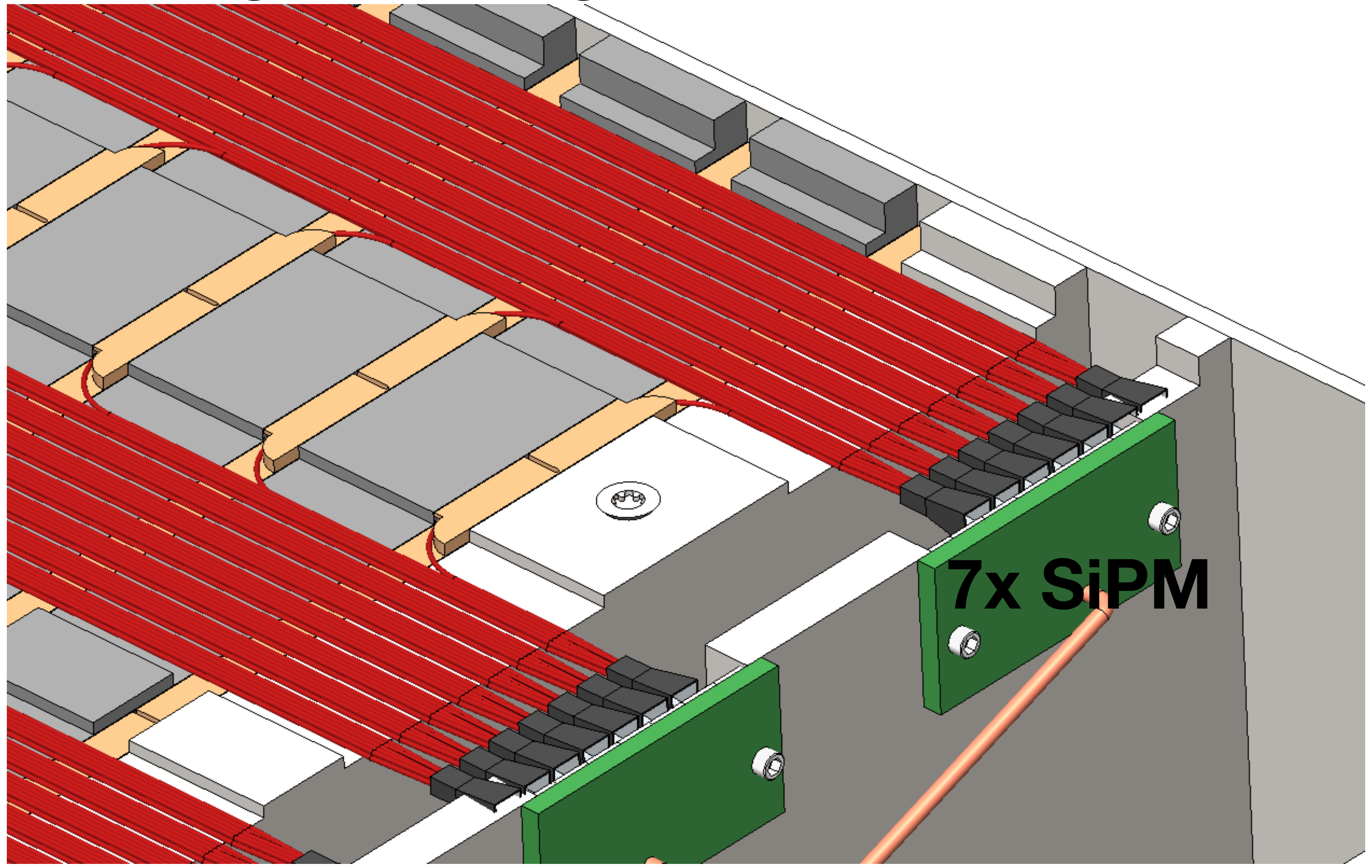
Assembly of the LFHCal detector

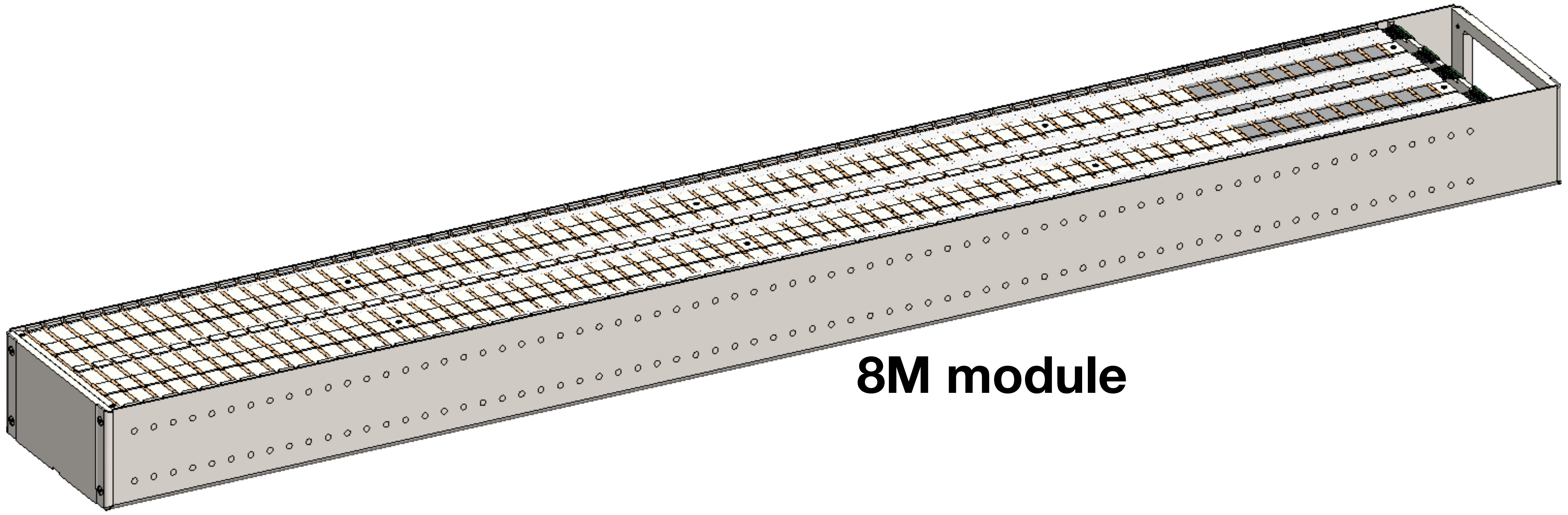


Wavelength shifting fibers

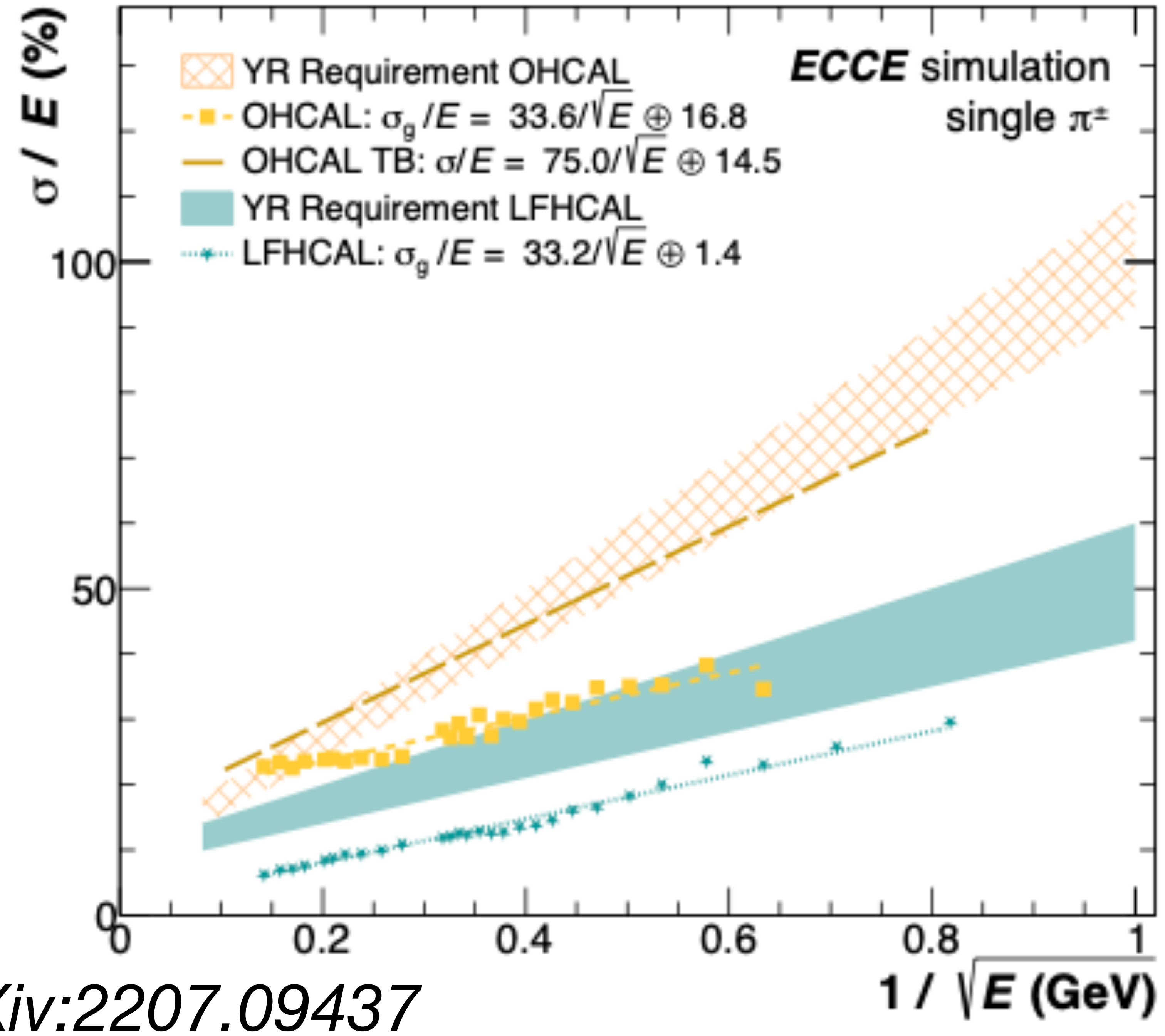


Wavelength shifting fibers *arXiv:2207.09437*





Energy resolution



arXiv:2207.09437

Energy resolution depends on the particle (π or proton) and the pseudo rapidity acceptance

$$\frac{\sigma(E)}{E} \approx \frac{33-44\,\%\,(\eta)}{\sqrt{E}} \oplus 1.4\,\%$$

The simulation also shows factor 1.5 offset due to timing

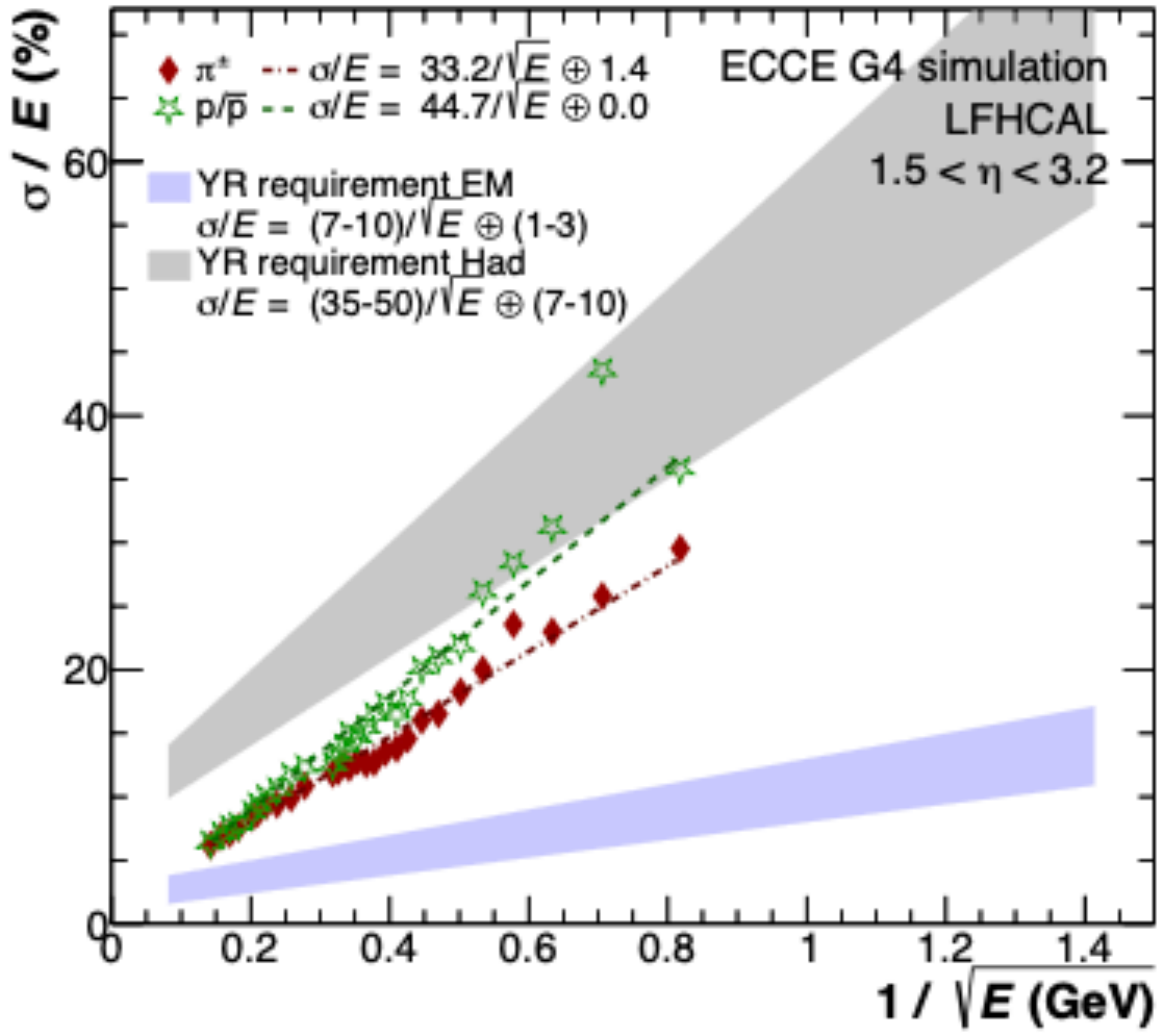
Yellow report of EIC identified the forward hadron resolution should be:

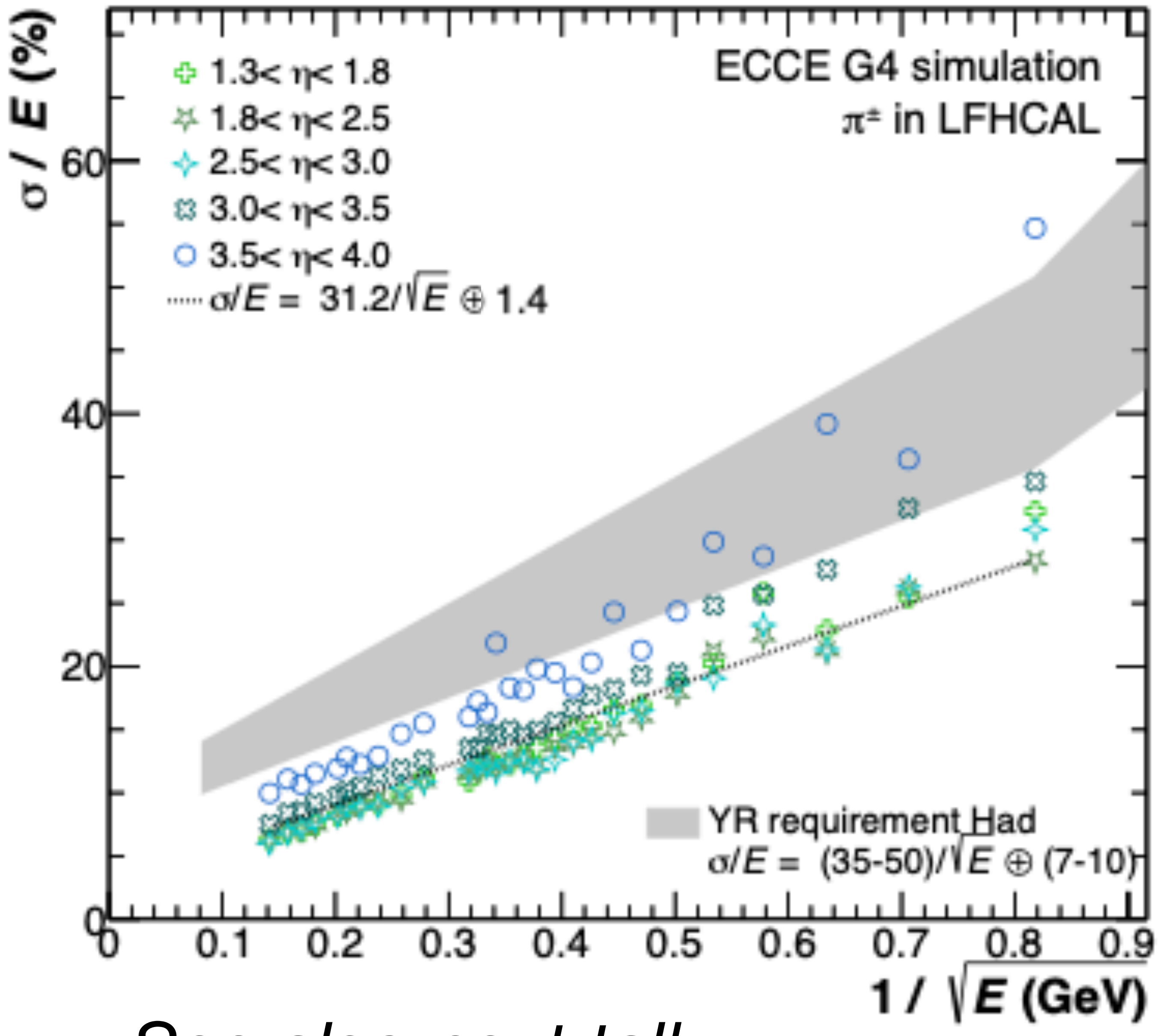
$$\frac{\sigma(E)}{E} \approx \frac{50\,\%}{\sqrt{E}} \oplus 10\,\%$$

The longitudinal segmentation and tail containment:

$$\frac{\sigma(E)}{E} \approx \frac{33.2\,\%}{\sqrt{E}} \oplus 1.4\,\%$$

arXiv:2207.09437

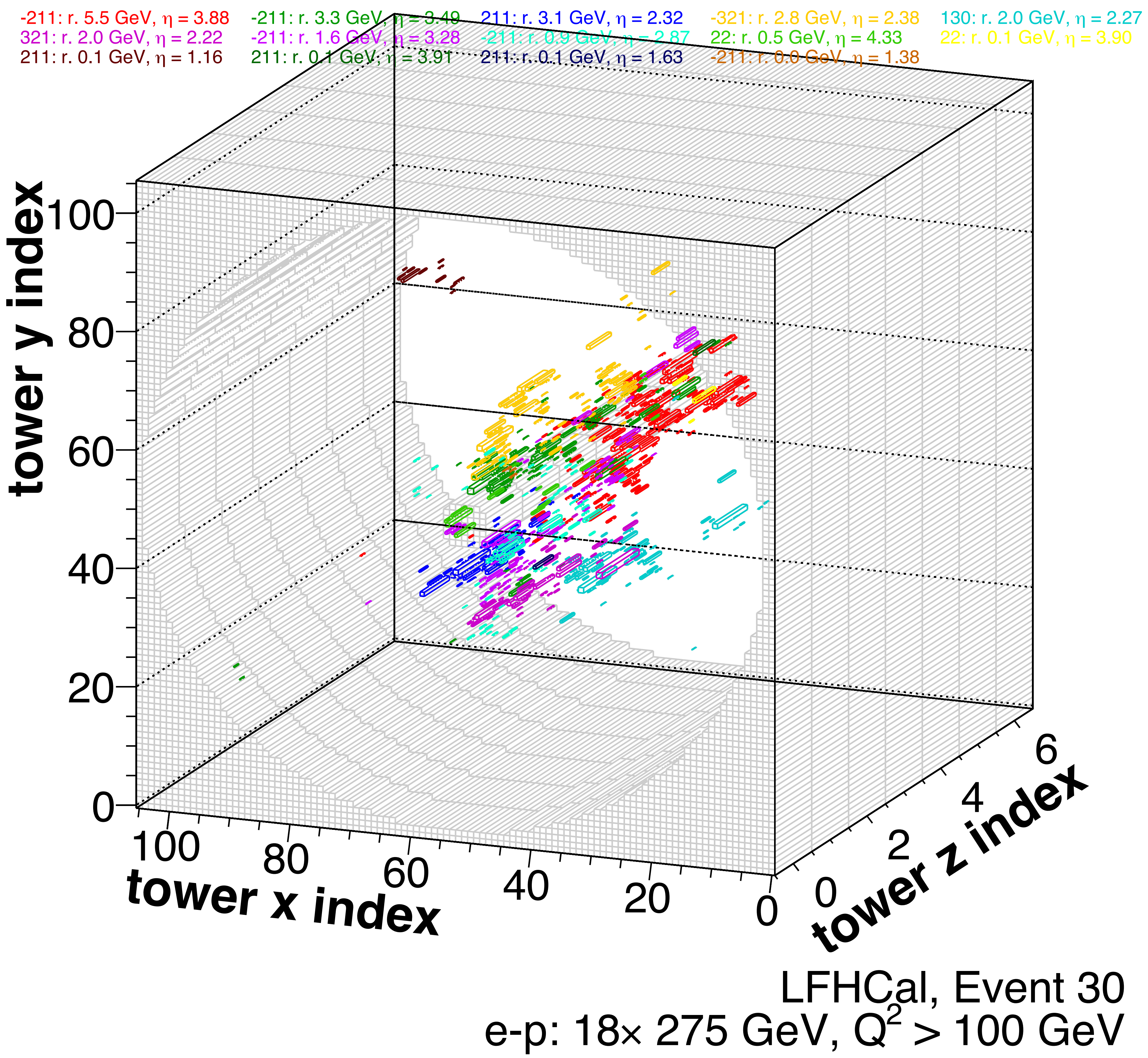




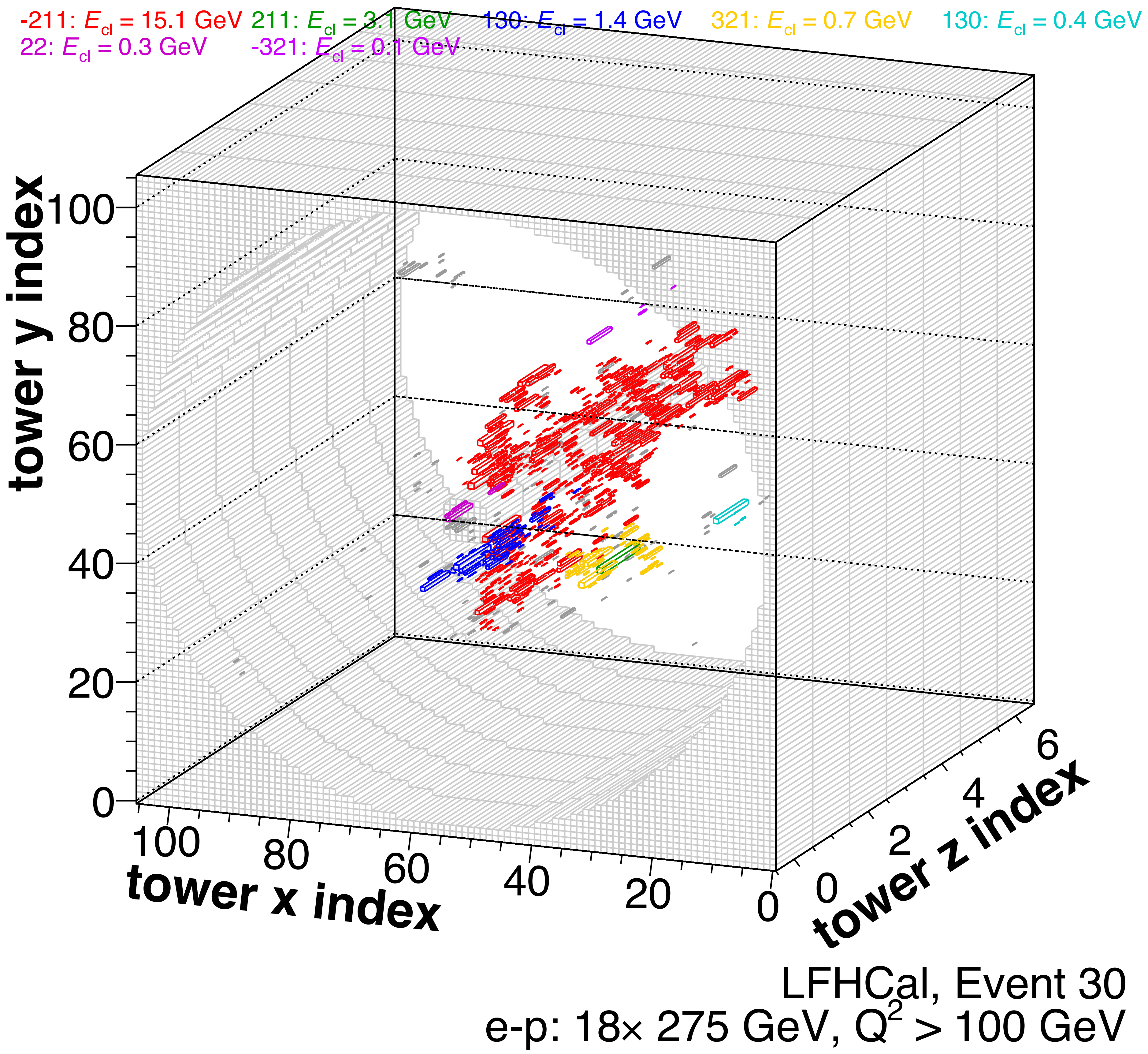
See also next talk

Clusterization and longitudinal segmentation

MC particles



Modified aggregation clusterizer



Longitudinal shower development:

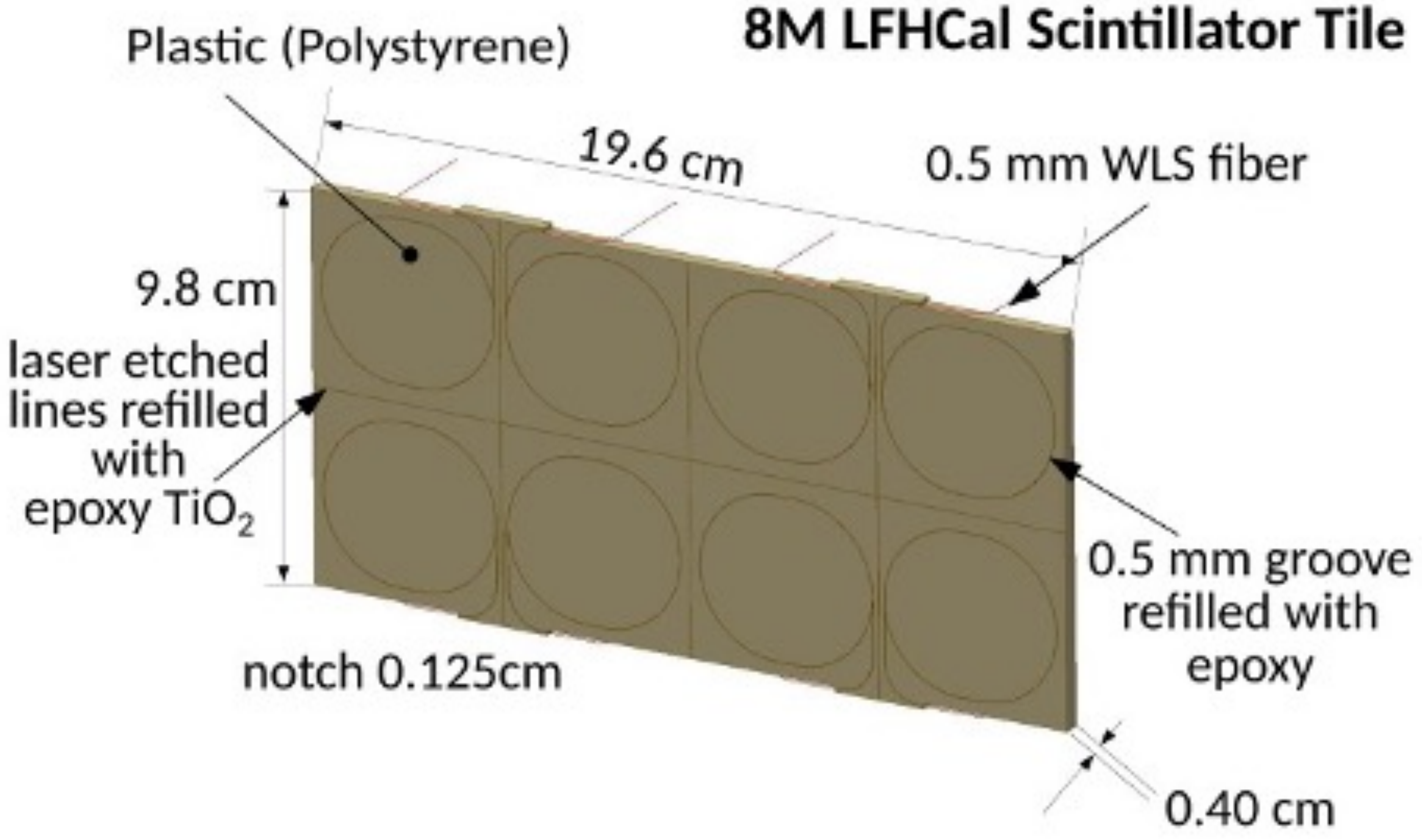
- More information about the particle ID
- Timing information could further help with particle ID

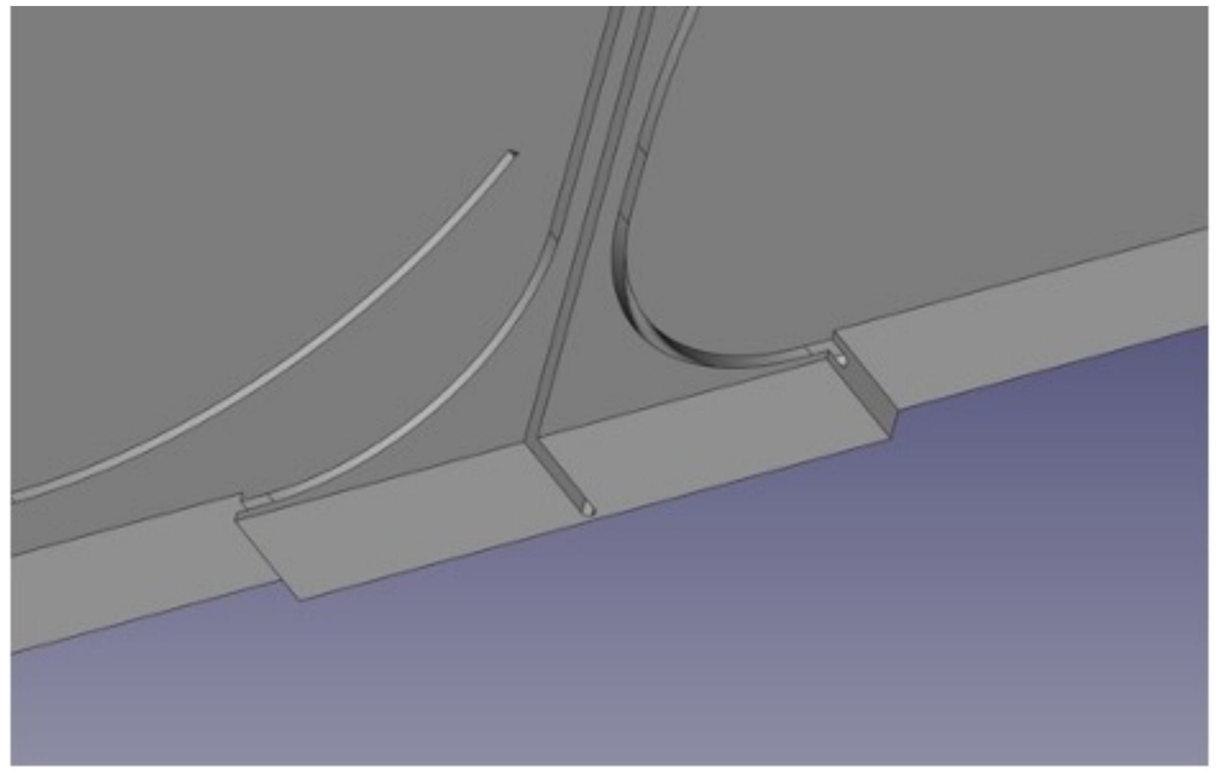
arXiv:2207.09437

Optical quality injection molding

Injection molding of large plastic scintillator tiles at optical quality:

- Part of the R&D effort of the LFHCAL:
  - 80,000 pcs of 20x10 cm^2 tiles
- Benefits:
  - 90% cost reduction:
    - Machined tile 65$/tile (material, machining) —> 5.2 M$
    - Molded tiles would be < 500 k$
  - 90% less production time:
    - Machined tiles: 2-4 years for raw material
    - Molded tiles: 4 months
- Each tile can be separated with ridges:
  - TiO_2 + epoxy
- Focus is on the optical quality:
  - Avoiding weld lines and other imperfections
  - 3D printed molds (ORNL MDF facilities)





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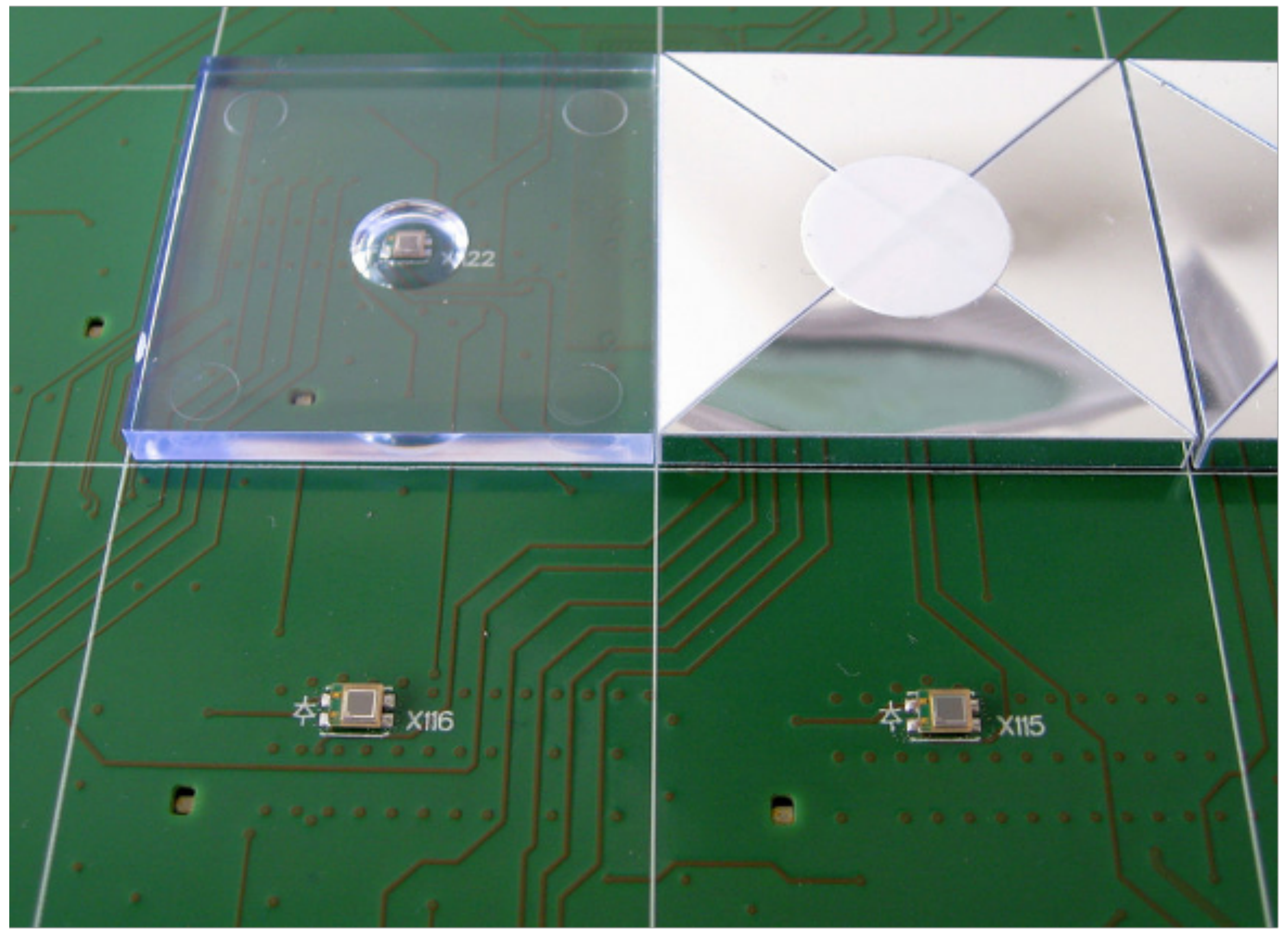
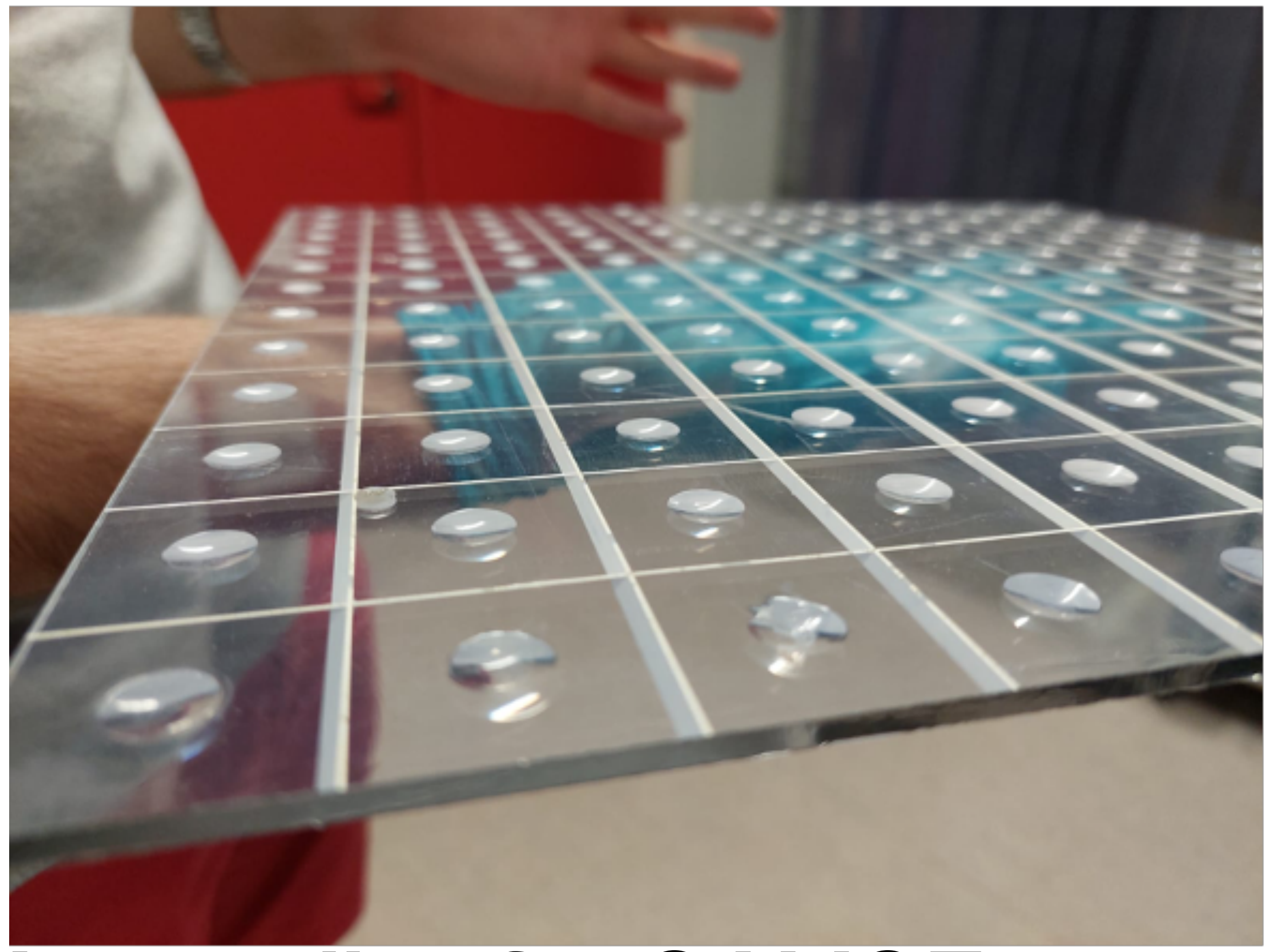
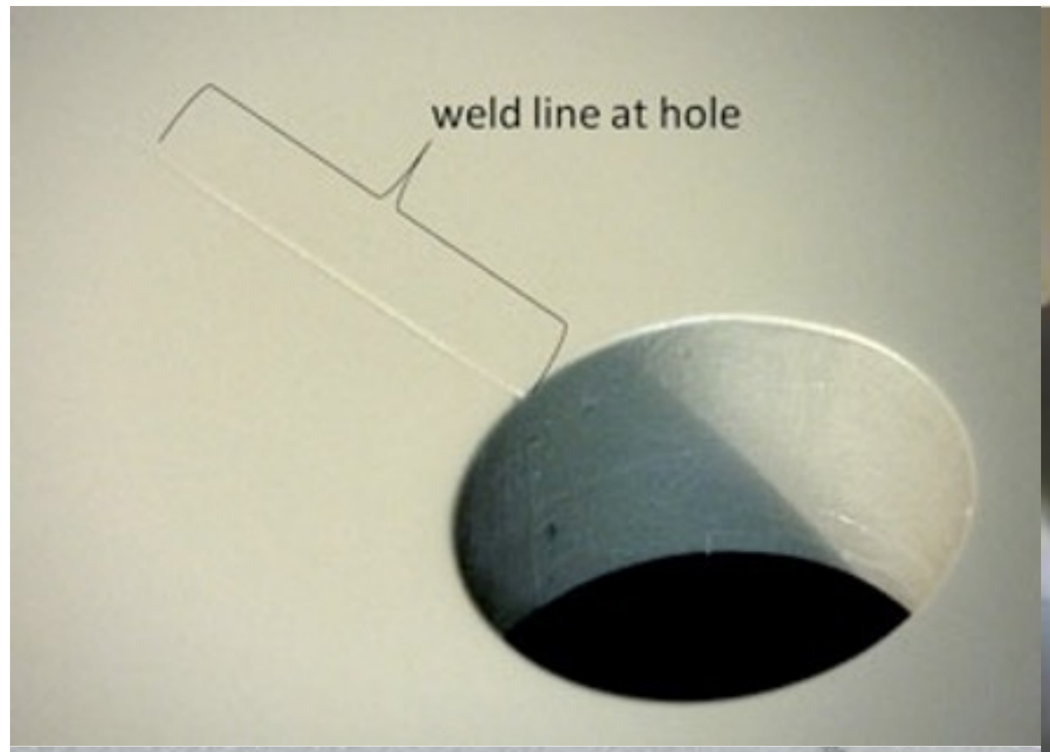
Future R&D - Large scale injection molding challenges

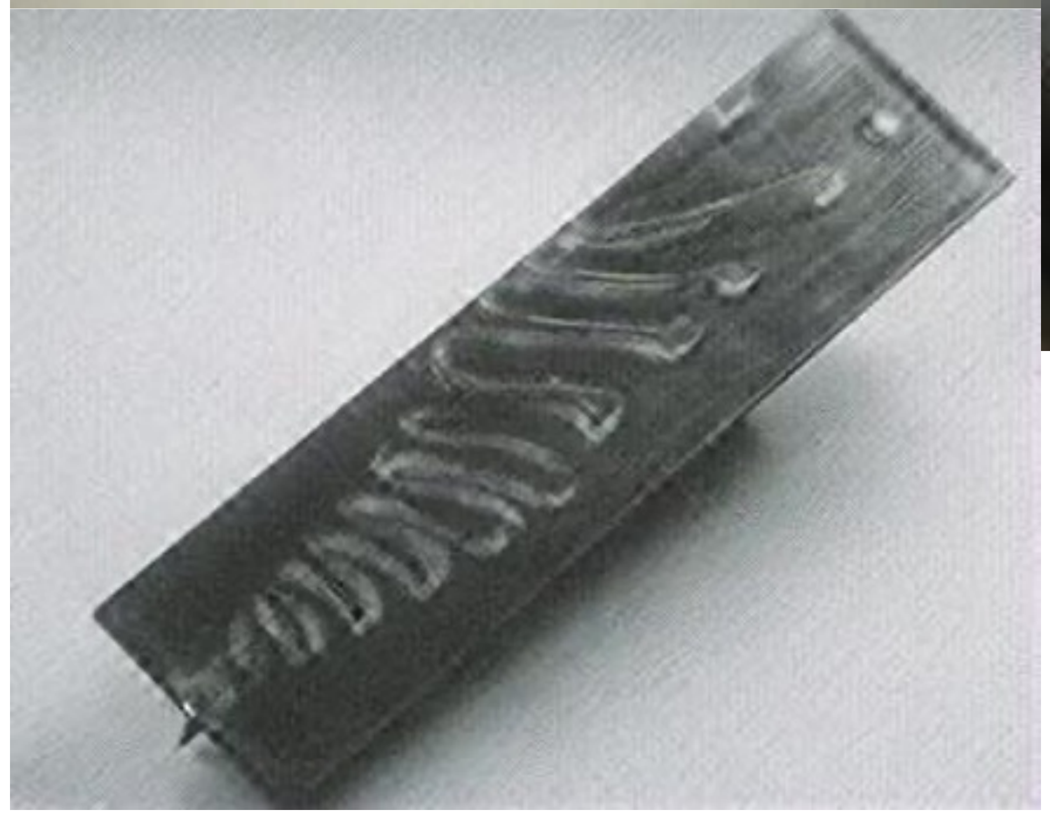
Imperfections of injection molds

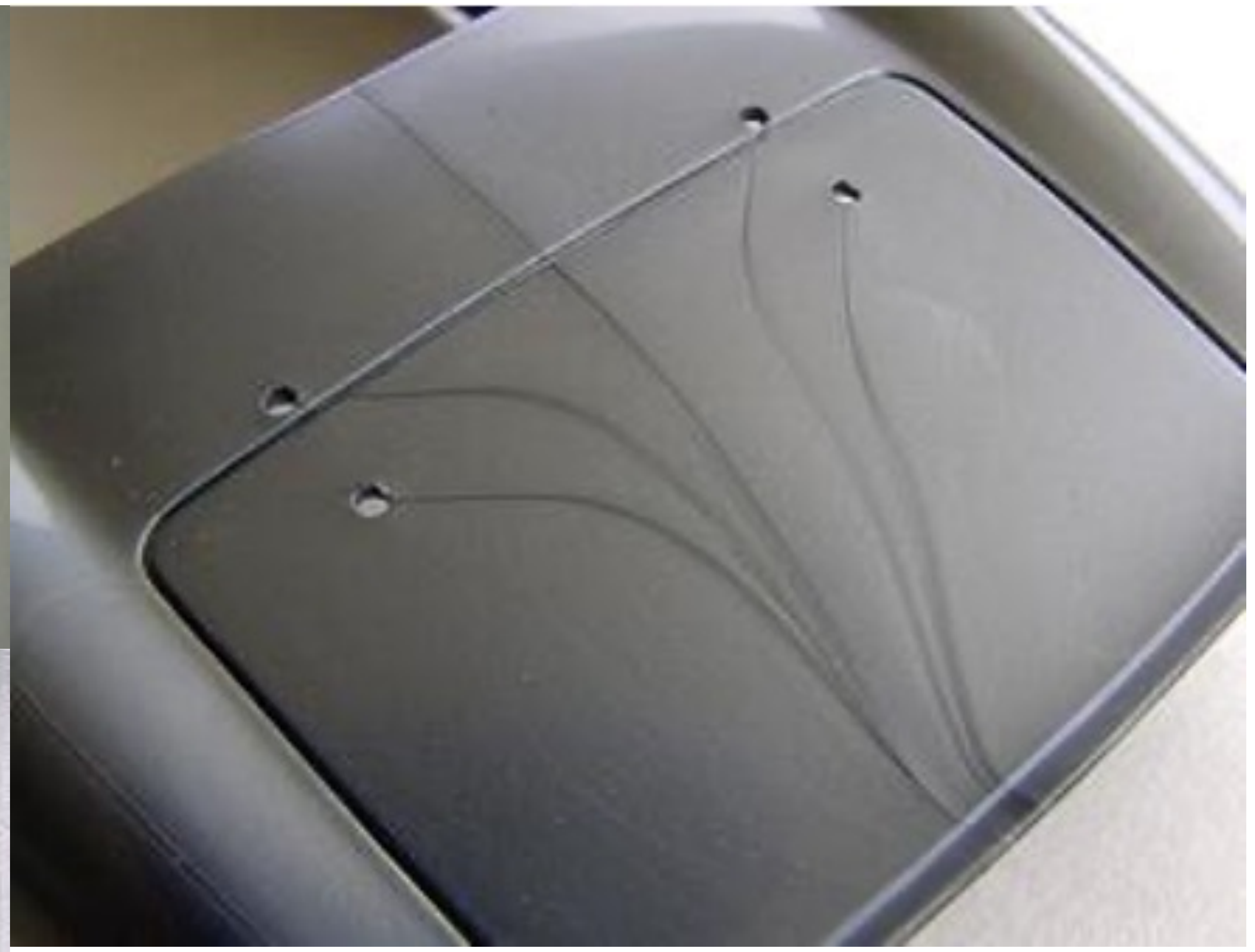




Large tiles for CALICE







MDF @ ORNL
Experience with the injection molding and 3D printed molds

Readout electronics requirement

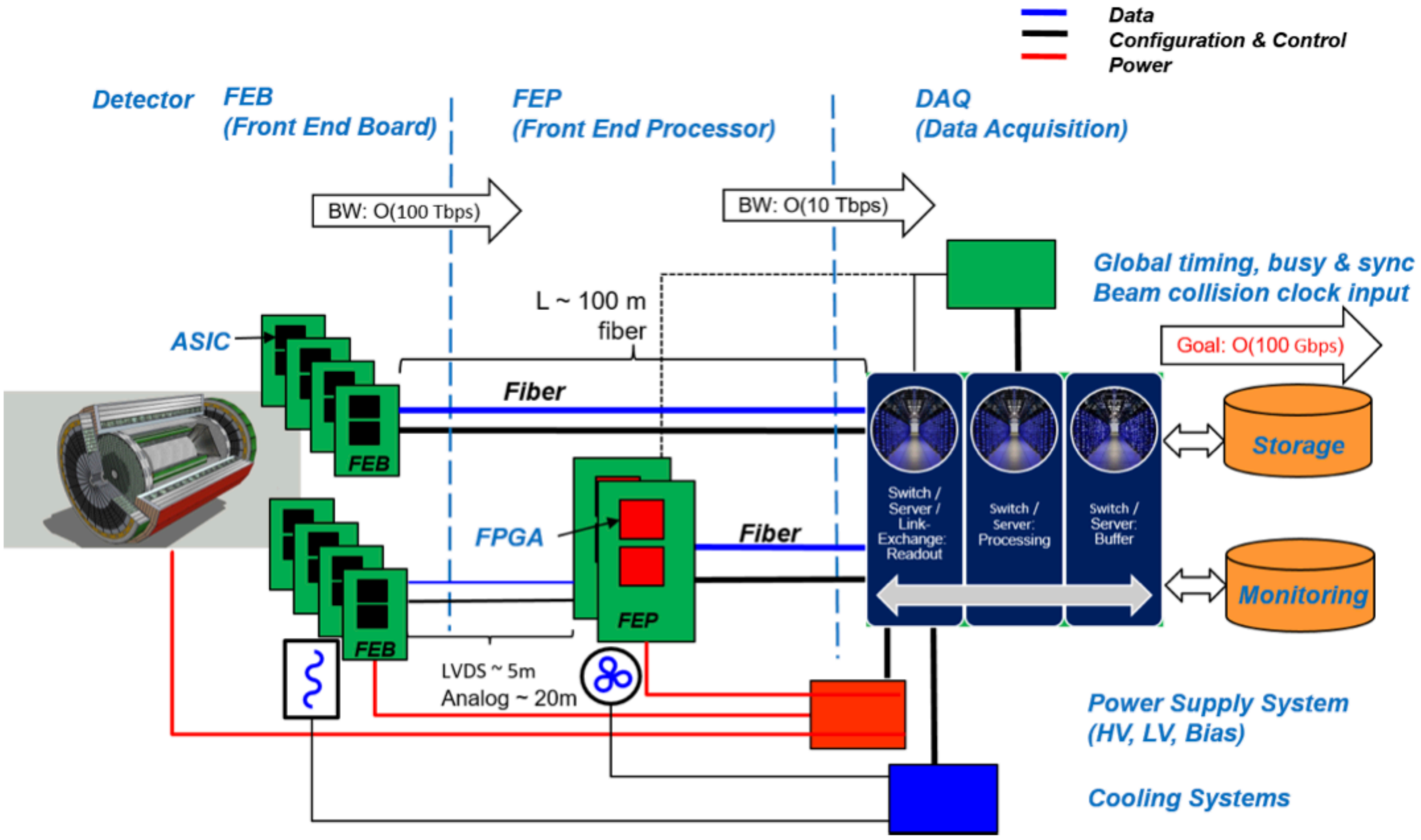


Figure 11.134: Possible scheme for the EIC Readout Architecture

EIC Yellow Report, 2103.05419

Yellow report place requirements on the readout system:

- Streaming readout:
  - Calorimeters usually are not streaming (ALICE, sPHENIX)
- Online reconstruction of events:
  - Online four-vector reconstruction and PID of particles

- Store all raw data directly to the disk
- Noise reduction required
- Zero suppression required (hit-detection)
- Careful calibration is required:
  - MIP peak monitoring:
    - Environmental influences
  - Particle mass reconstructions

AI/ML tools can be implemented to further enhance the detector performance

ASIC - H2GCROCv3 architecture

Overall chip divided in two symmetrical parts:

- One half is made of:
  - 36 channels + 2 CMN + 2 Calib
  - Bandgap, voltage reference close to the edge

Measurements:

- Charge:
  - ADC peak measurement, 10 bits at 40 MHz
    - 0.4 fC resolution
  - TDC: (Time over Threshold), 12 bits
    - 2.5fC resolution
- Time:
  - Time of arrival, 10 bits (25ps)

Data flow:

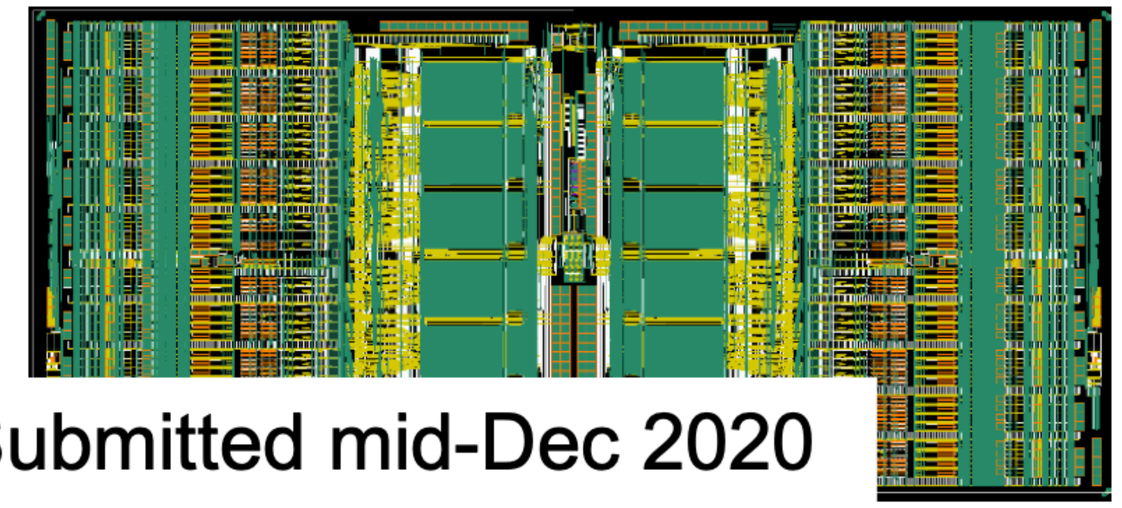
- DAQ path:
  - 512 depth RAM1, circular buffer
  - Secondary RAM2, 32 depth
- Trigger path:
  - Sum of 4 or 9 channels

AGH

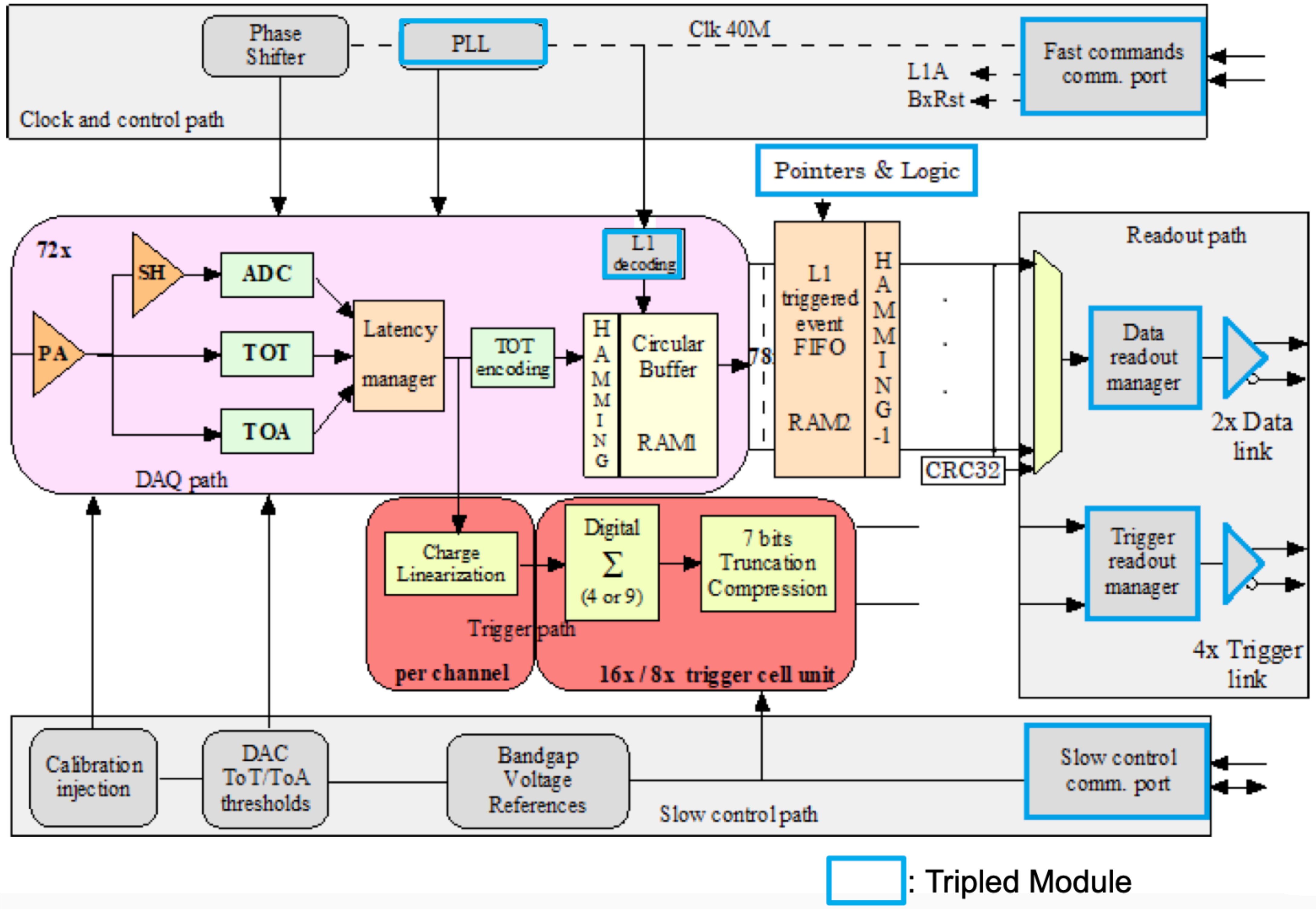
CERN

Irfu

ΩMEGA Microelectronics



Submitted mid-Dec 2020



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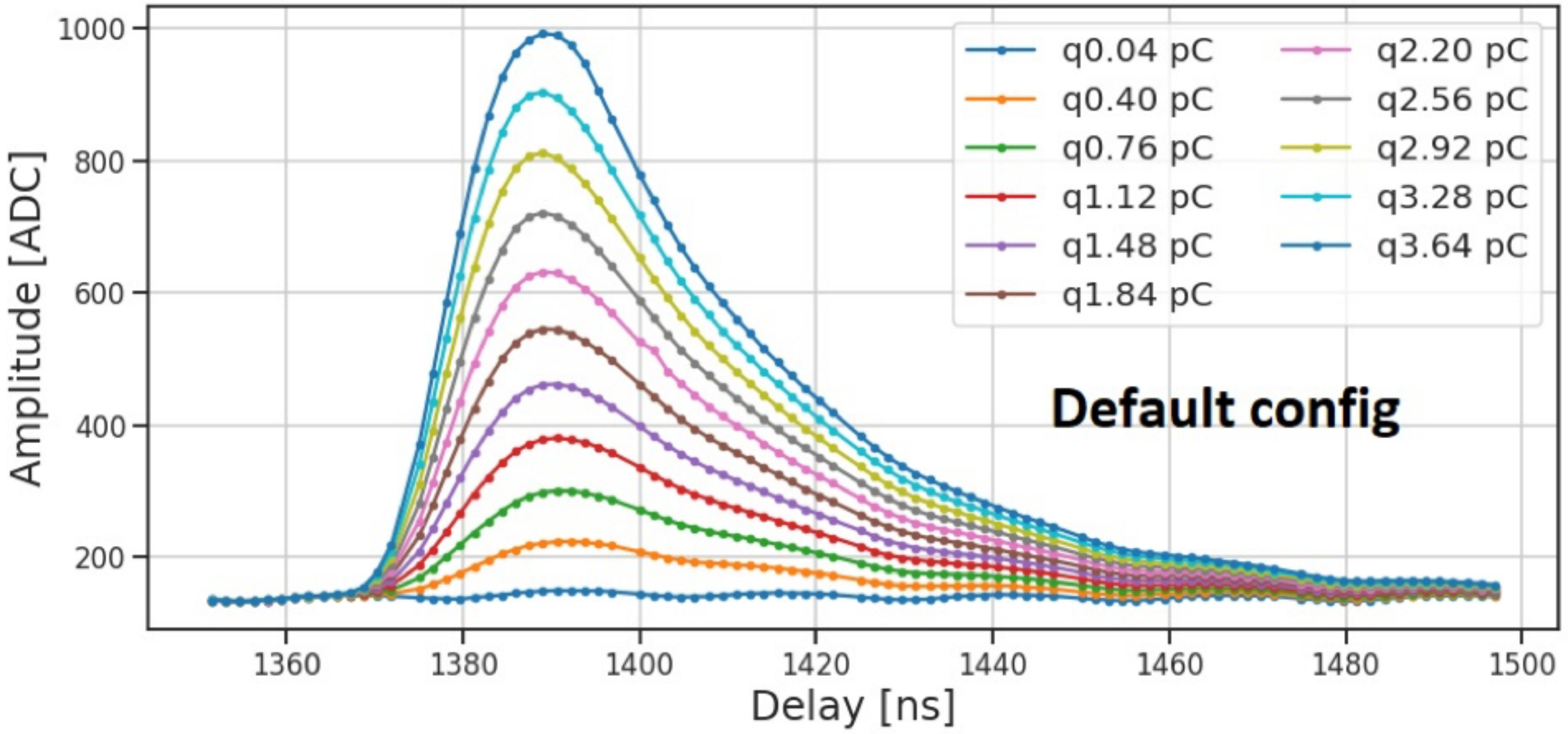
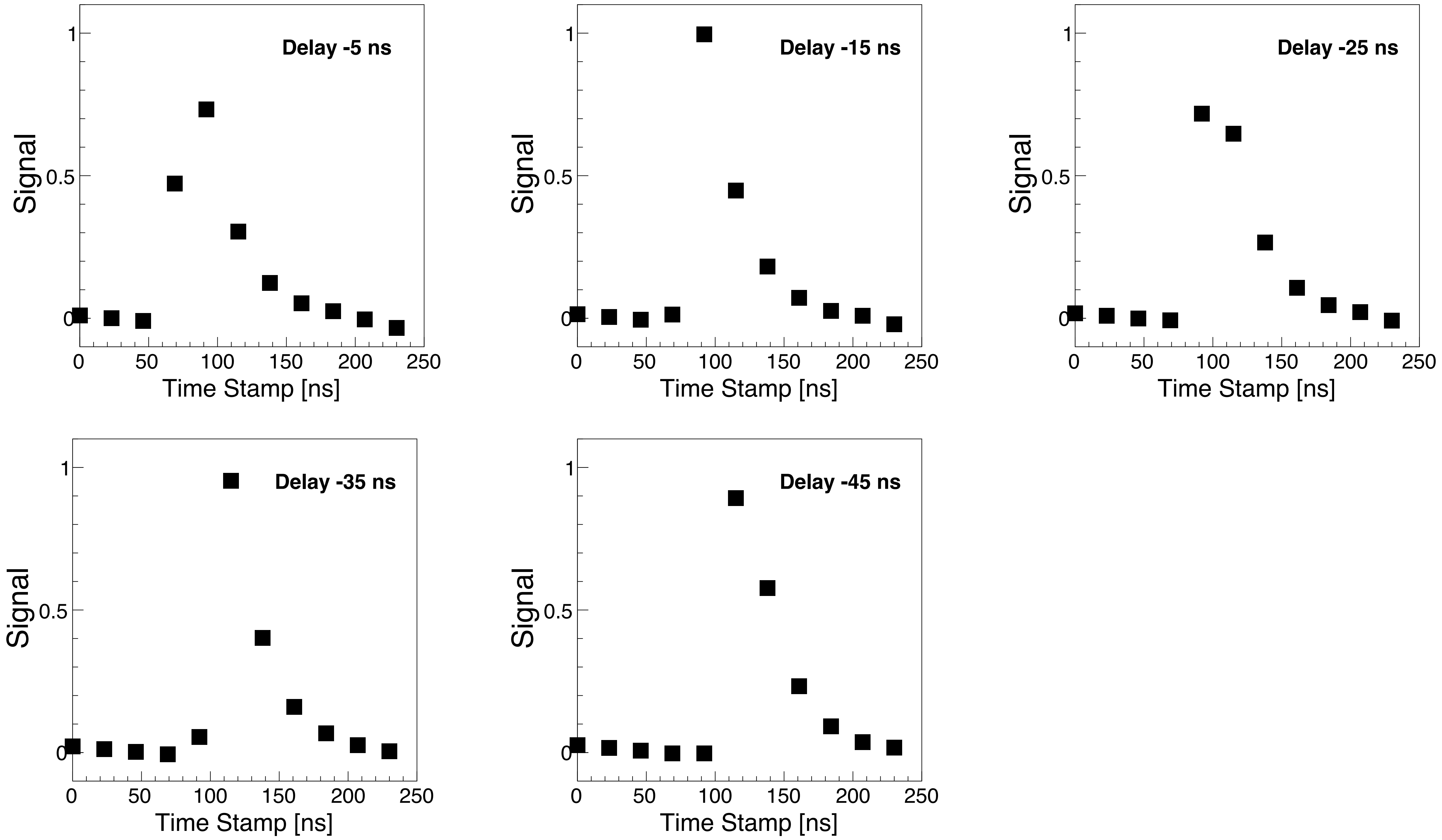
HGCROC use in EIC



Signal from the shapers:

- Fast shaper
- Signal max reached within 25 ns

- Several gain setups available in the HGCROC



EIC clock is 100MHz, therefore there are 5 different phases of the signal sampled with the 40 MHz clock:

- The new version of the H2GCROCv3 can read out multiple consecutive bunch crossings
- For good signal reconstruction, we plan to save 3 (or 4) samples for each signal
- Total: 3 ADC, 3 TOA and 3 TOT values, 32x3-bit words for each physics signal

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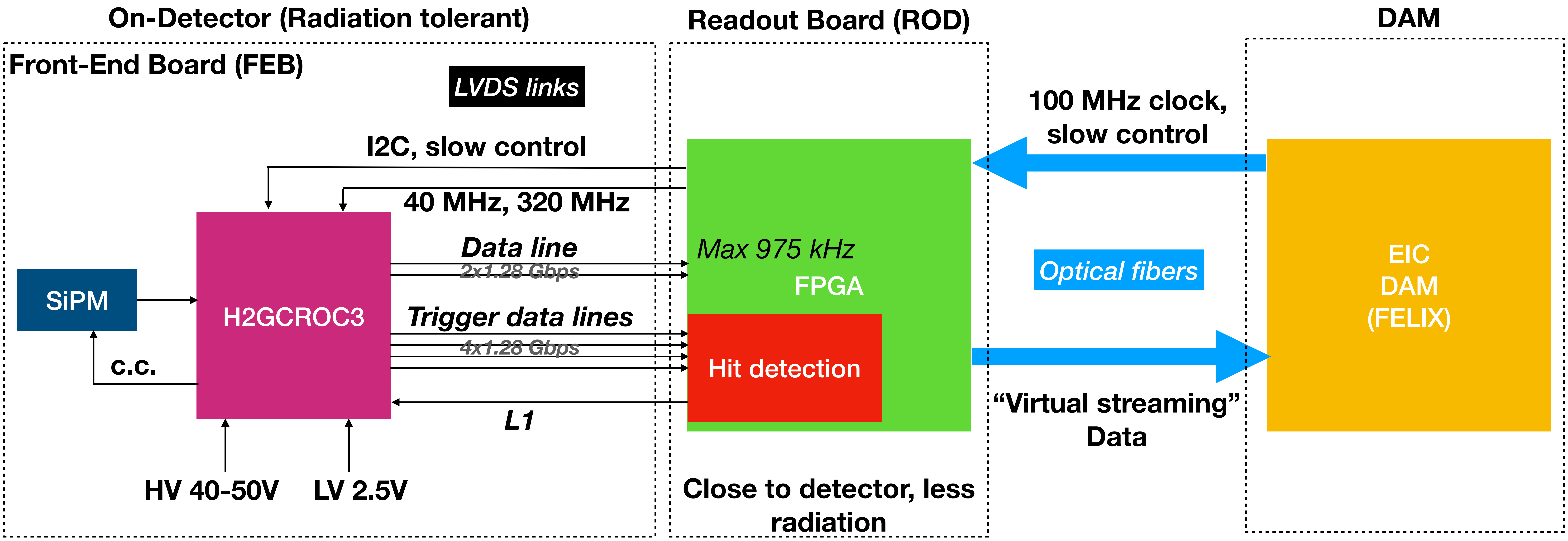
LFHCal readout hierarchy



Data propagation from the detector to the EPIC DAQ system:

- The H2GCROC3 requires the L1 trigger for readout, with the maximum speed of 960 kHz
- The expected hit rate in **one channel of LFHCal** is up to 50 kHz:
  - With possible 4 sample readout we would reach a maximum of 200 kHz
  - "*Virtual*" streaming readout towards the EPIC DAQ system

Summary

EIC will map the 3D picture of protons and nuclei

- Precision 3D imaging of protons and nuclei
- Solving the proton spin puzzle
- Discovery of the gluon saturation
- Quarks and gluon confinement
- Cold nuclear matter energy loss

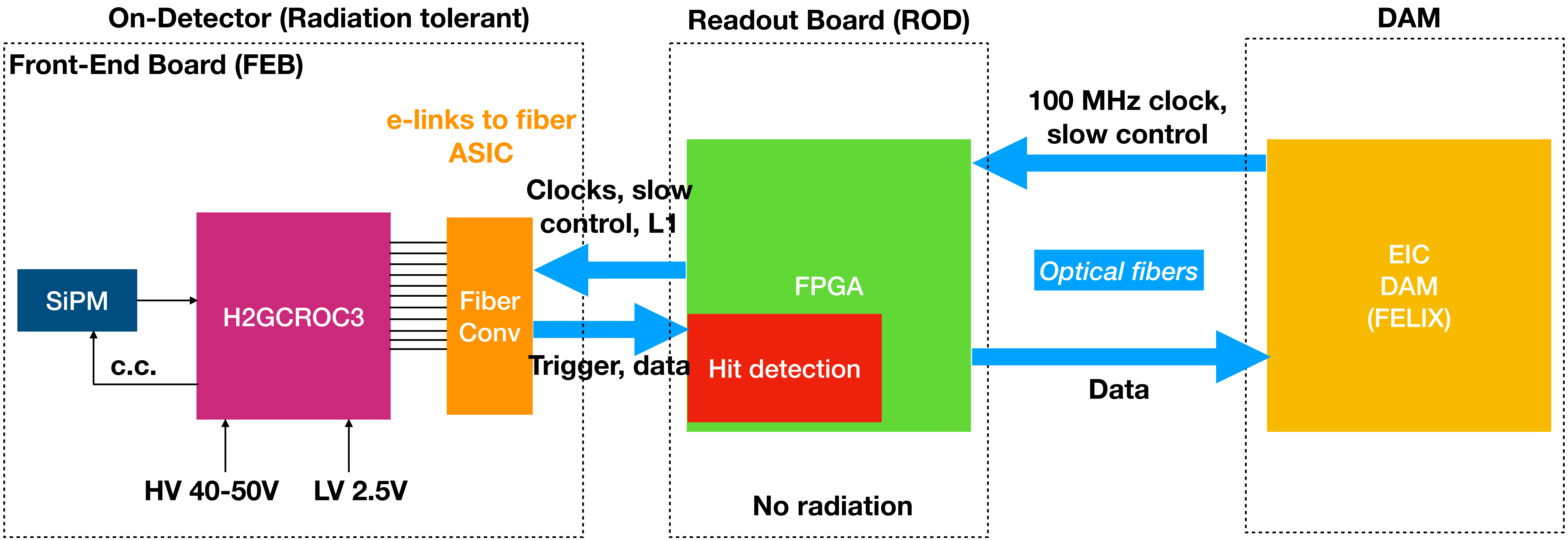
LFHCal is crucial to identify the neutral energy component of jets

- Longitudinally segmented to increase performance
- Innovative R&D to use **injection molding** for the scintillator tiles:
  - Reducing cost and time of building future large scale calorimeters
- **“Virtually” streaming** calorimeter:
  - Using ASIC developed at CMS for high luminosity LHC run
  - Locally triggered, globally streaming
  - Including timing information

Backup

ORNL is managed by UT-Battelle LLC for the US Department of Energy

LFHCal readout hierarchy - Service reduction



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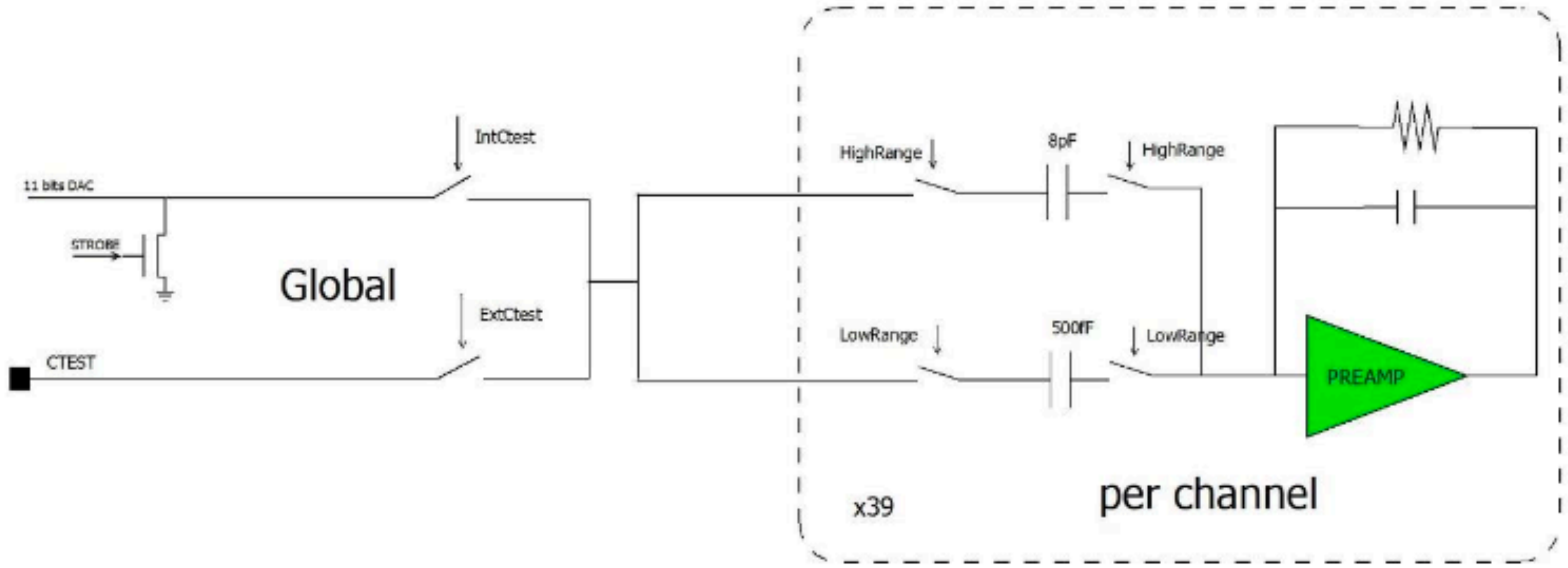
  - "*Virtual*" streaming readout towards the EPIC DAQ system

Service reduction for H2GCROC3 would allow significant simplification on the cabling

Internal Calibration Circuit



Internal Calibration circuit implemented in the H2GCROCv3:

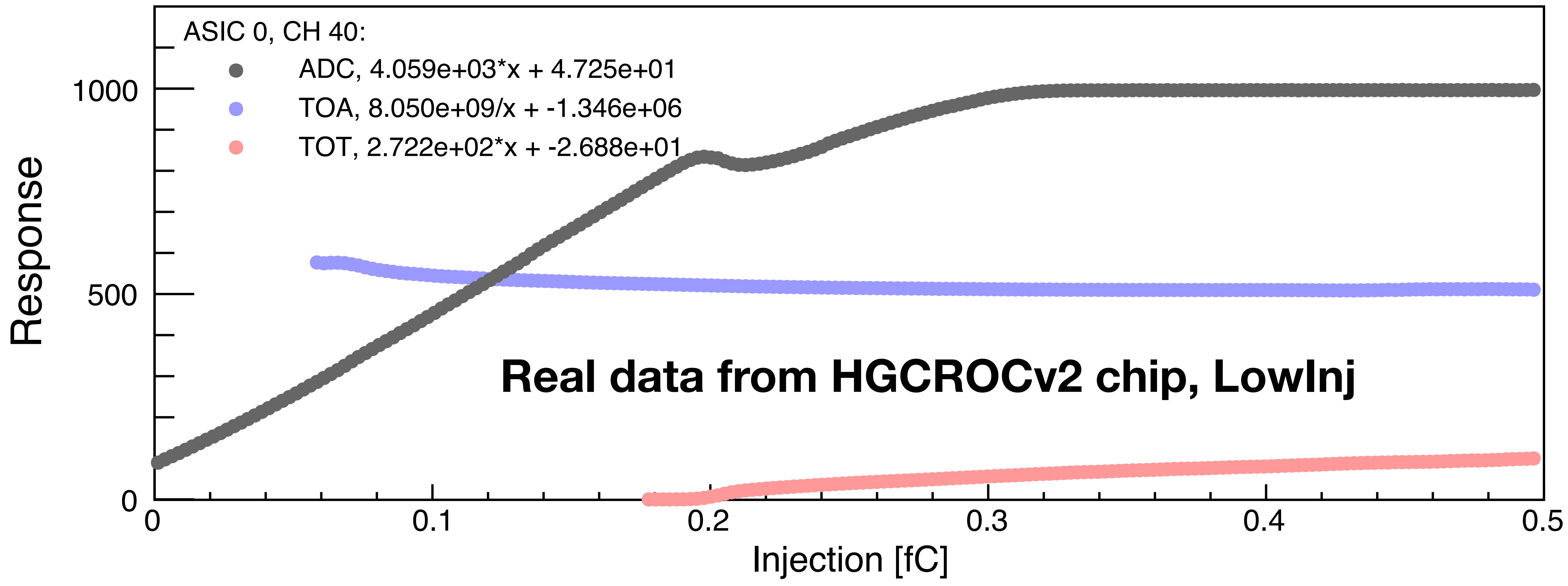
- Almost the full dynamic range. Reference voltage 0-1V:
  - 0.5 pF Low Range: 0 - 0.5 pC
  - 8 pF High Range: 0- 8 pC

Calibration circuit injection value of 11-bit:
Can be used to identify the thresholds for TOA and TOT, check linearity, etc.

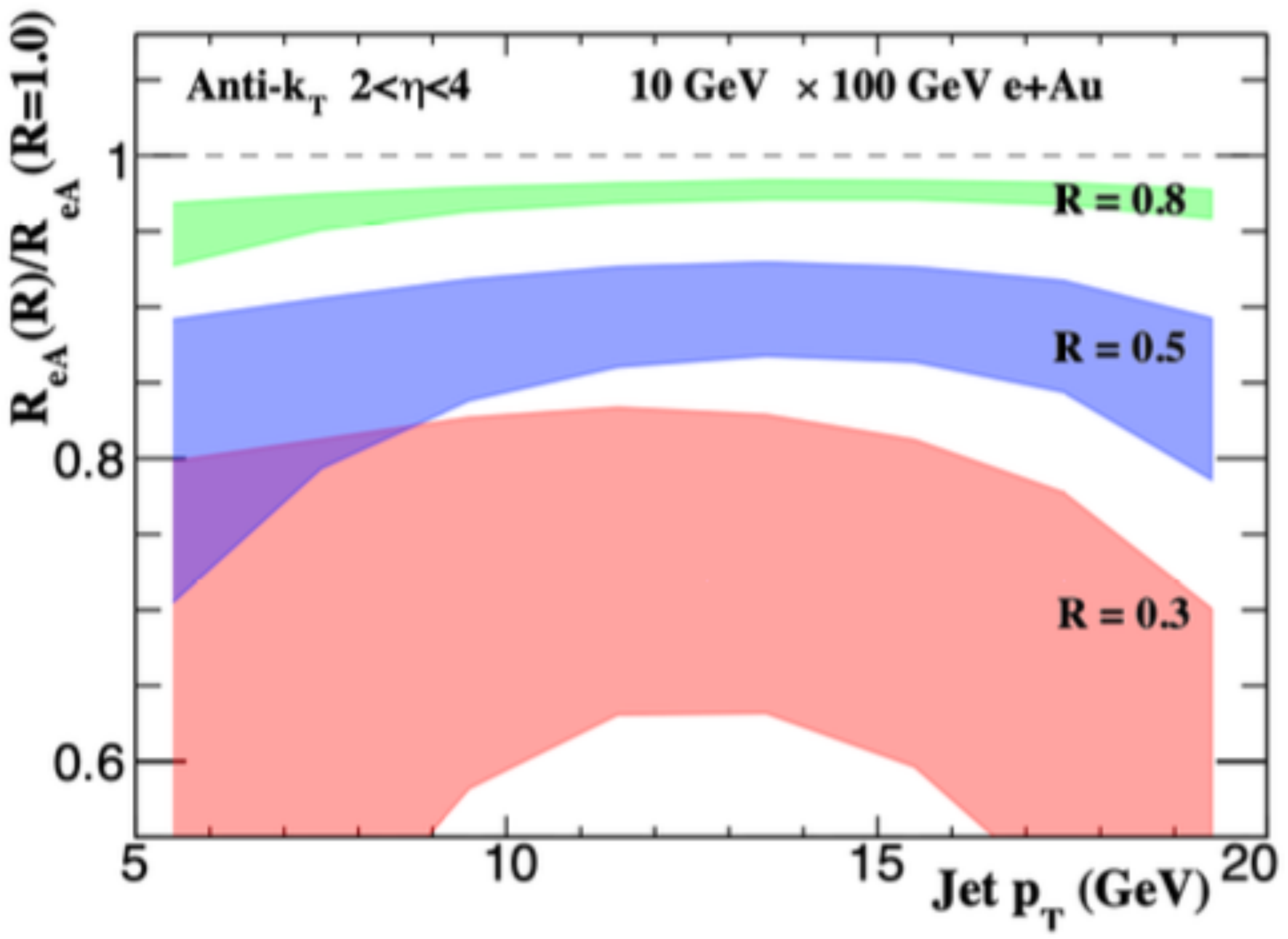
Dynamic range of the HGCROC:

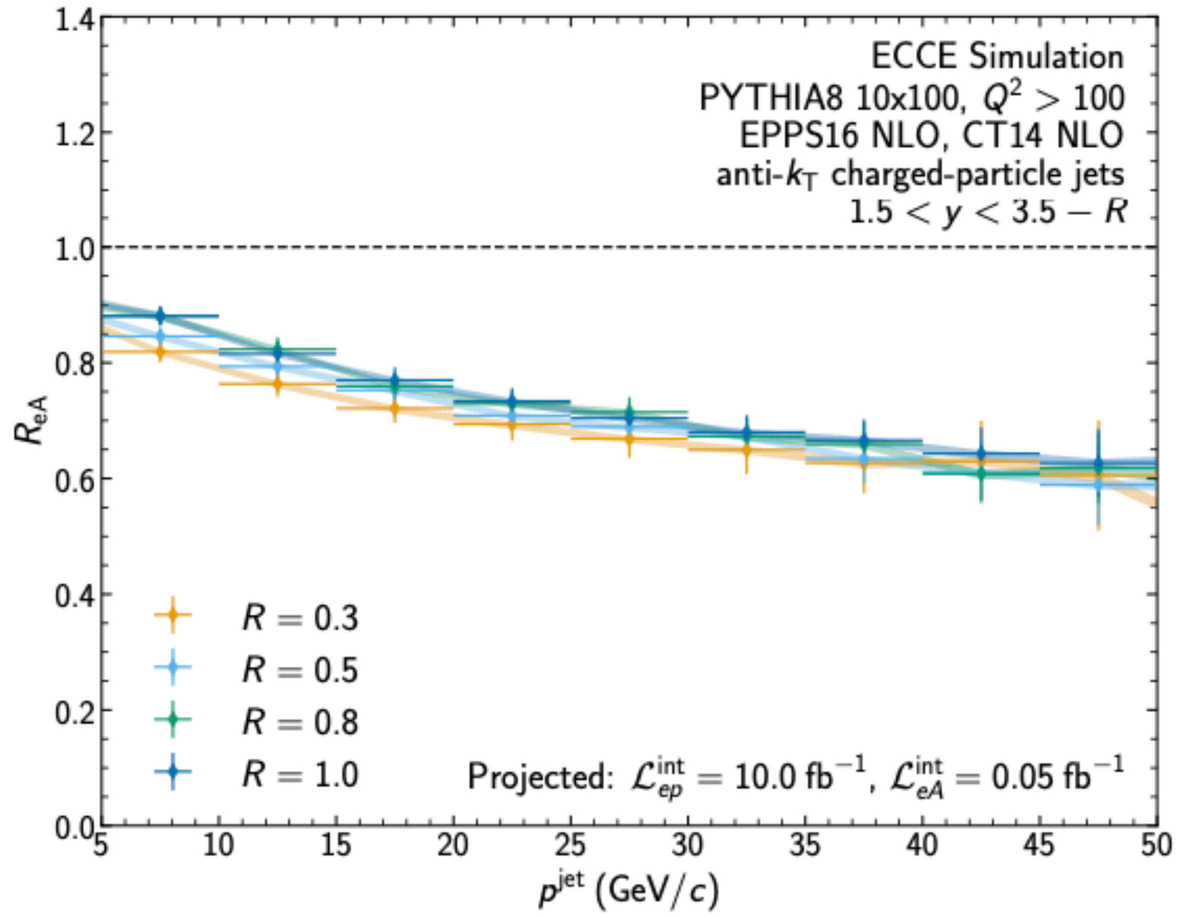
- Real data from the v2 chip
- Silicon variant
- ADC set to saturate around 850:
  - Small dip in the ADC happens when the TOT circuit comes online
  - TOT values are shown only to 100 (out of the 4095 range)
  - TOA have a small walk from threshold to 0.18 fC, then it is stable

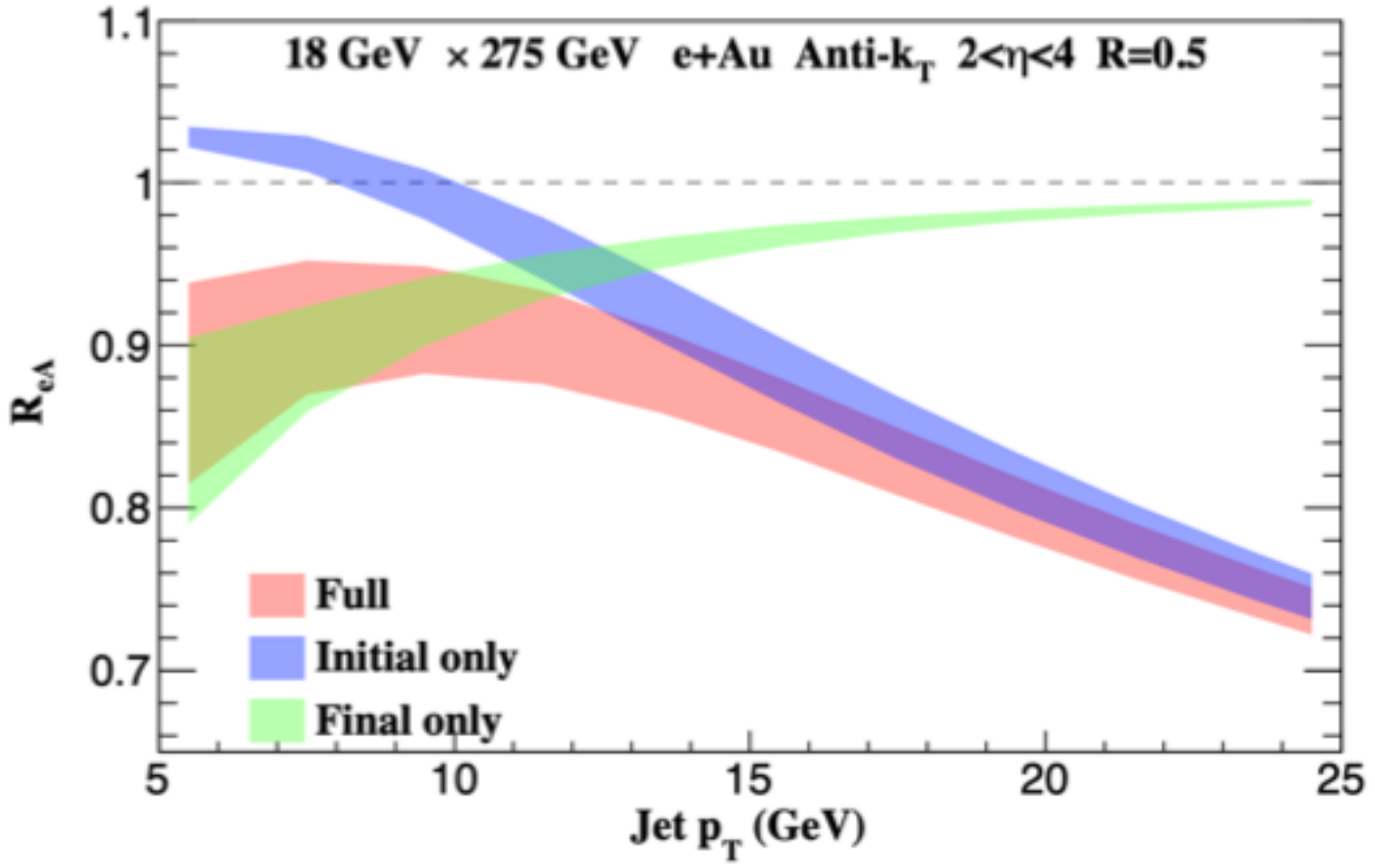
We are currently working on the same data for the H2GCROCv3 chip

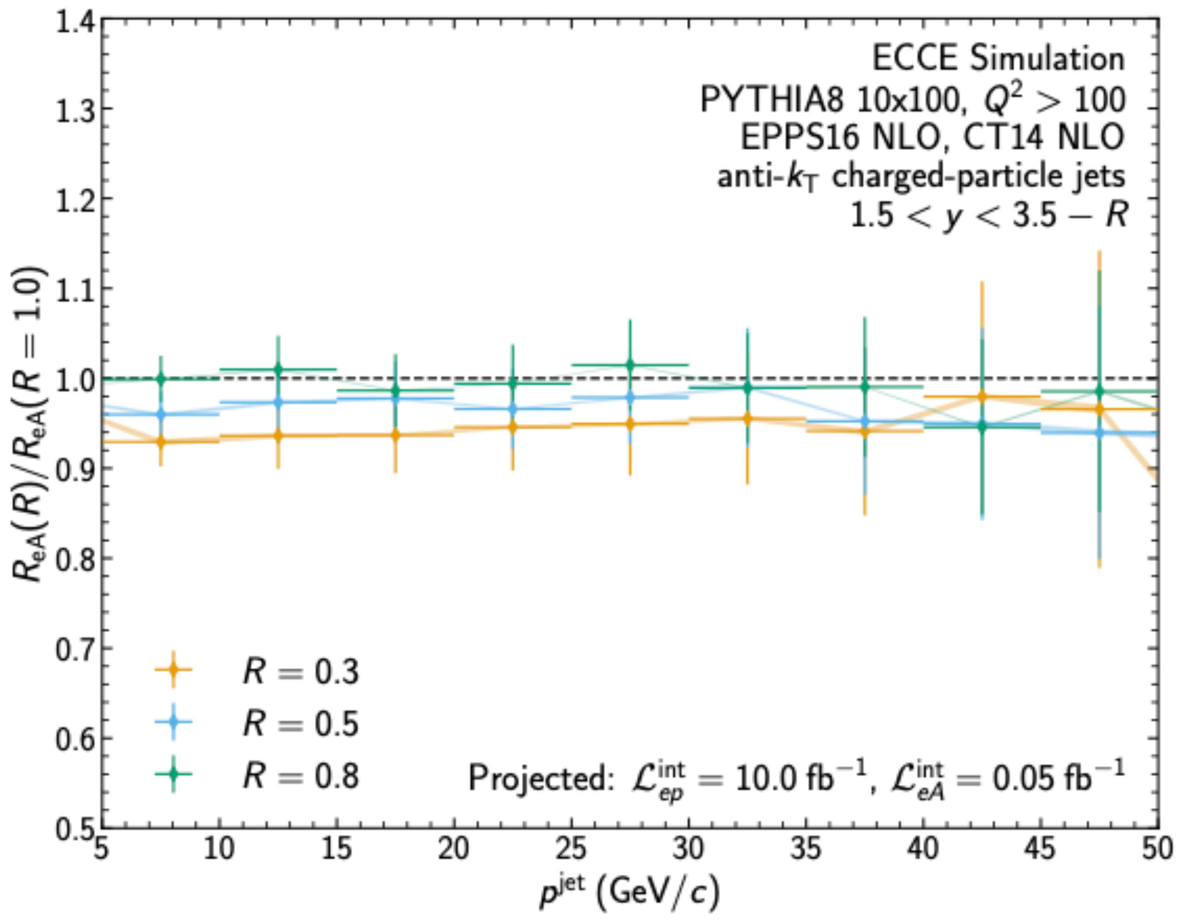


Physics performance









Jet reconstruction performance of the LFHCAL

Studies of jet modification in the medium, p_T broadening, etc via R_{eA}

- Jet R_{eA} probes with anti-shadowing and EMC nPDF at larger-*x* region
- Jet R_{eA} double ratio approximately flat in p_T

Probes final state effects, but insensitive to <10 % effects in uncertainties

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