VIII-th Collaboration Meeting MPD

Advances in the design, construction and simulations of the MiniBeBe detector for the MPD

Alejandro Ayala for the

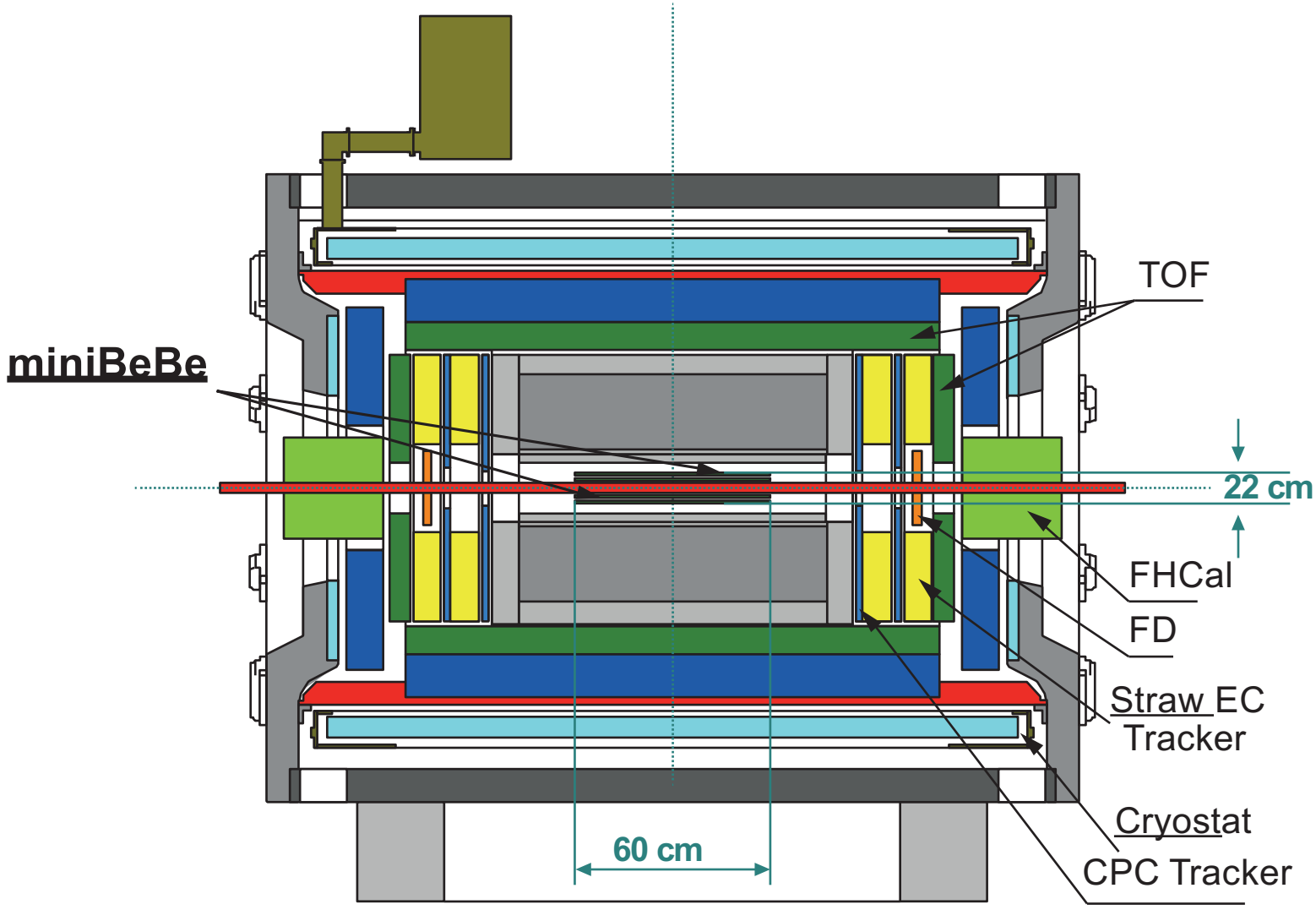
MexNICA collaboration

Precedents

Proposed as a detector to help provide a wake-up trigger signal for events ranging from low to high multiplicities, for the TOF.

- First discussed during NICA Days 2019:
  - “Mini Beam-Beam monitoring: a wake-up trigger detector for the TOF of MPD”.
- Detector Advisory Committee Meeting (*October 19, 2020*):
  - “miniBeBe Conceptual Design Report”.
- “The conceptual design of the miniBeBe detector proposed for NICA-MPD”, R. Acevedo Kado et al., **2021**, JINST 16 P02002. *https://doi.org/10.1088/1748-0221/16/02/P02002*

miniBeBe planned location



Mechanical design

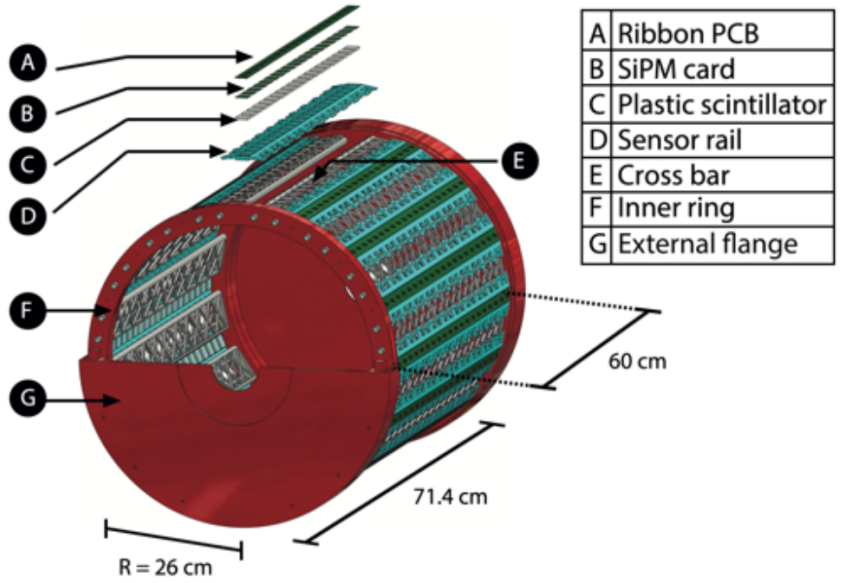
Prototype and progress

Conceptual design

- Baseline design

(*JINST 16 (2021) P02002*)

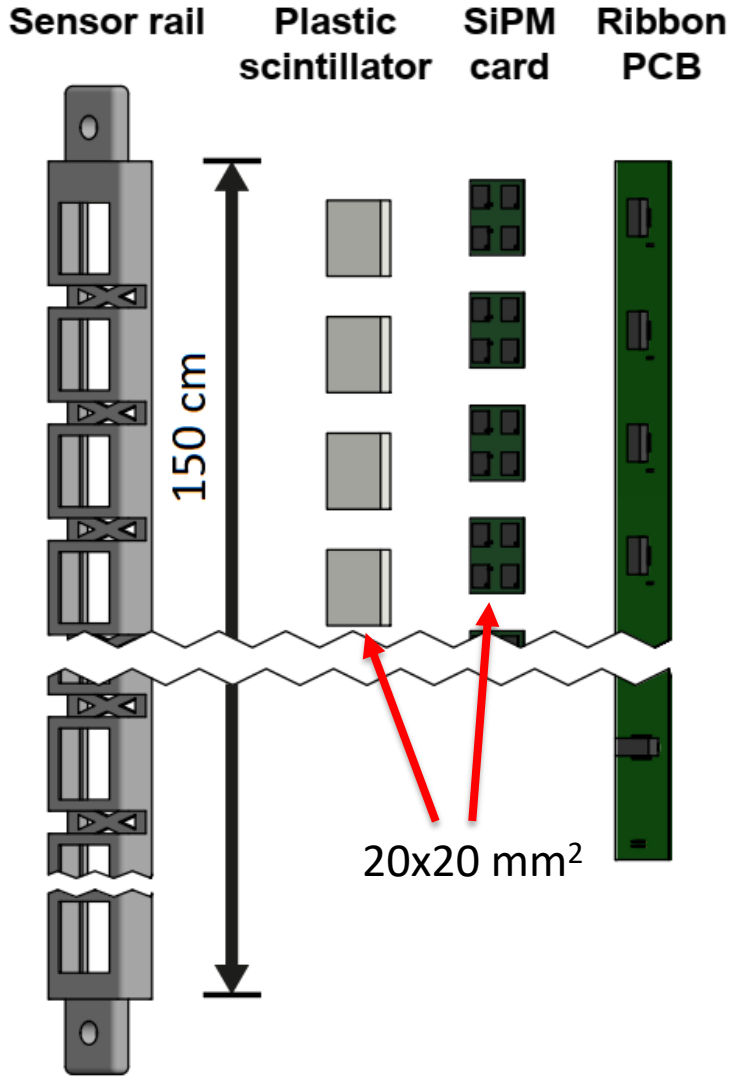
  - 60 cm – Length
  - 26 cm – Radius
  - 20 cells per strip
  - 320 cells

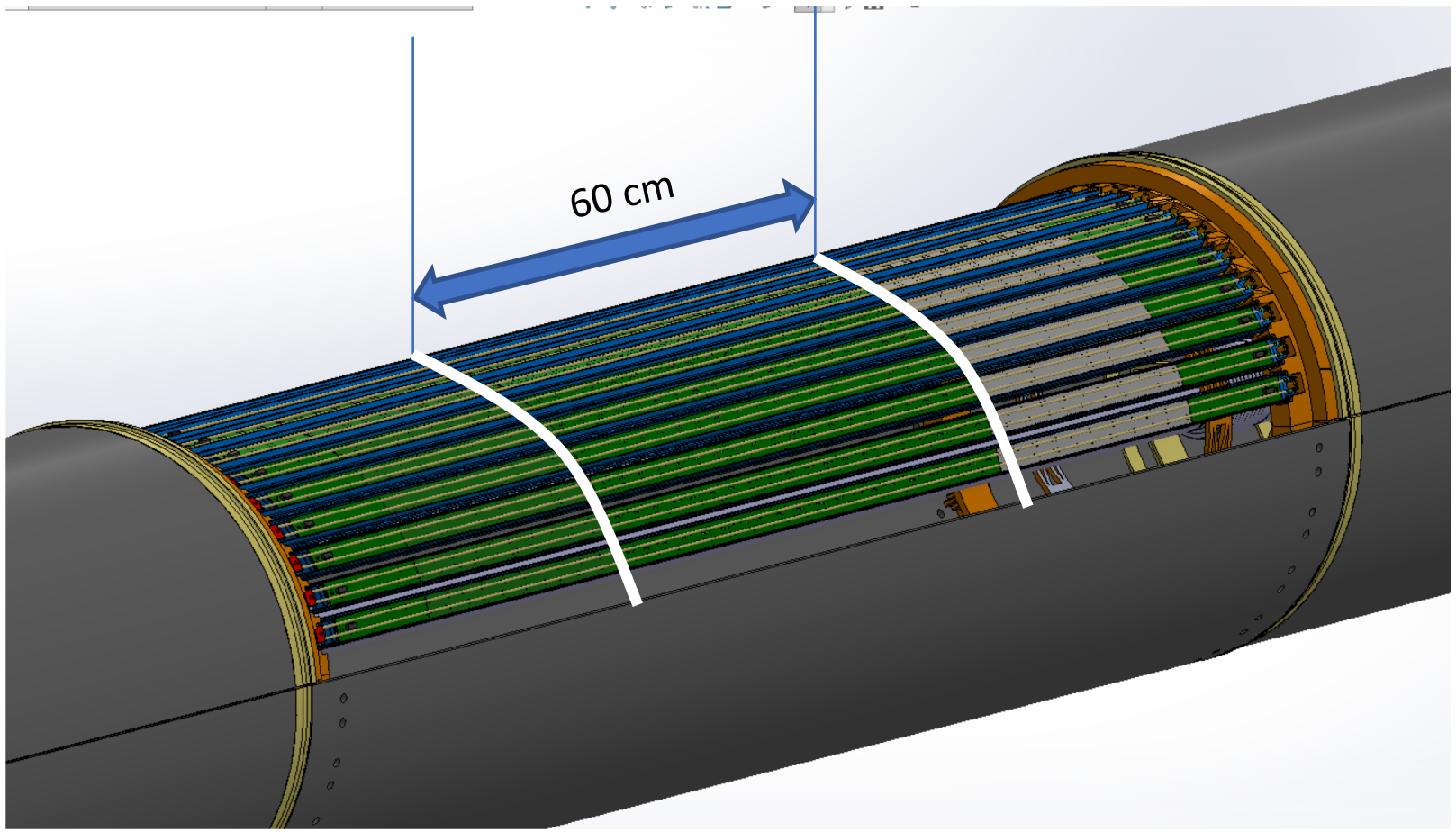


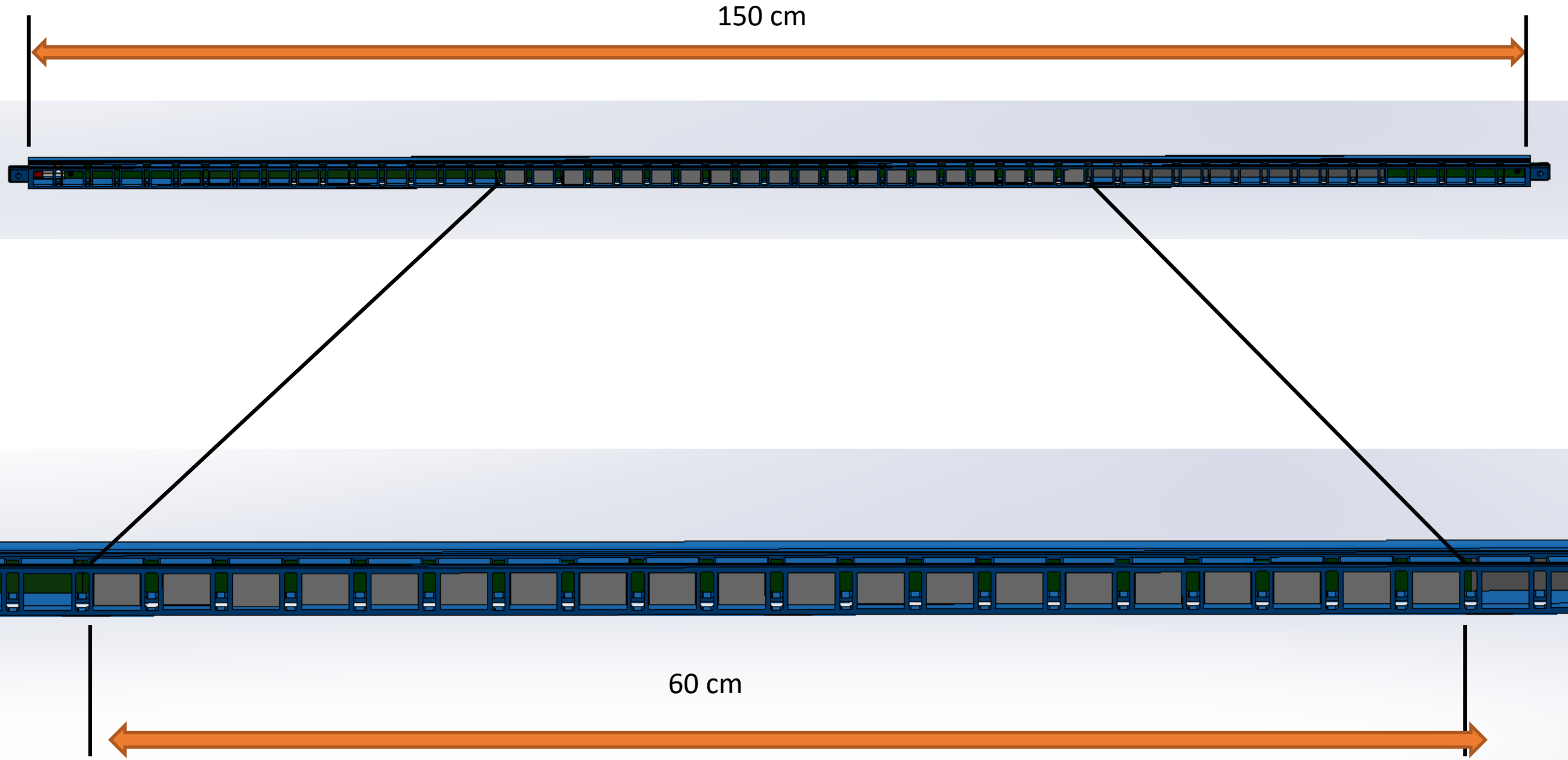
A	Ribbon PCB
B	SiPM card
C	Plastic scintillator
D	Sensor rail
E	Cross bar
F	Inner ring
G	External flange

- Improved design
  - 150 cm – Length (Ribbon card included)
  - 60 cm – Effective active lenght
  - 22 cm – Radius
  - 20 cells per strip
  - 16 strips
  - 320 Cells

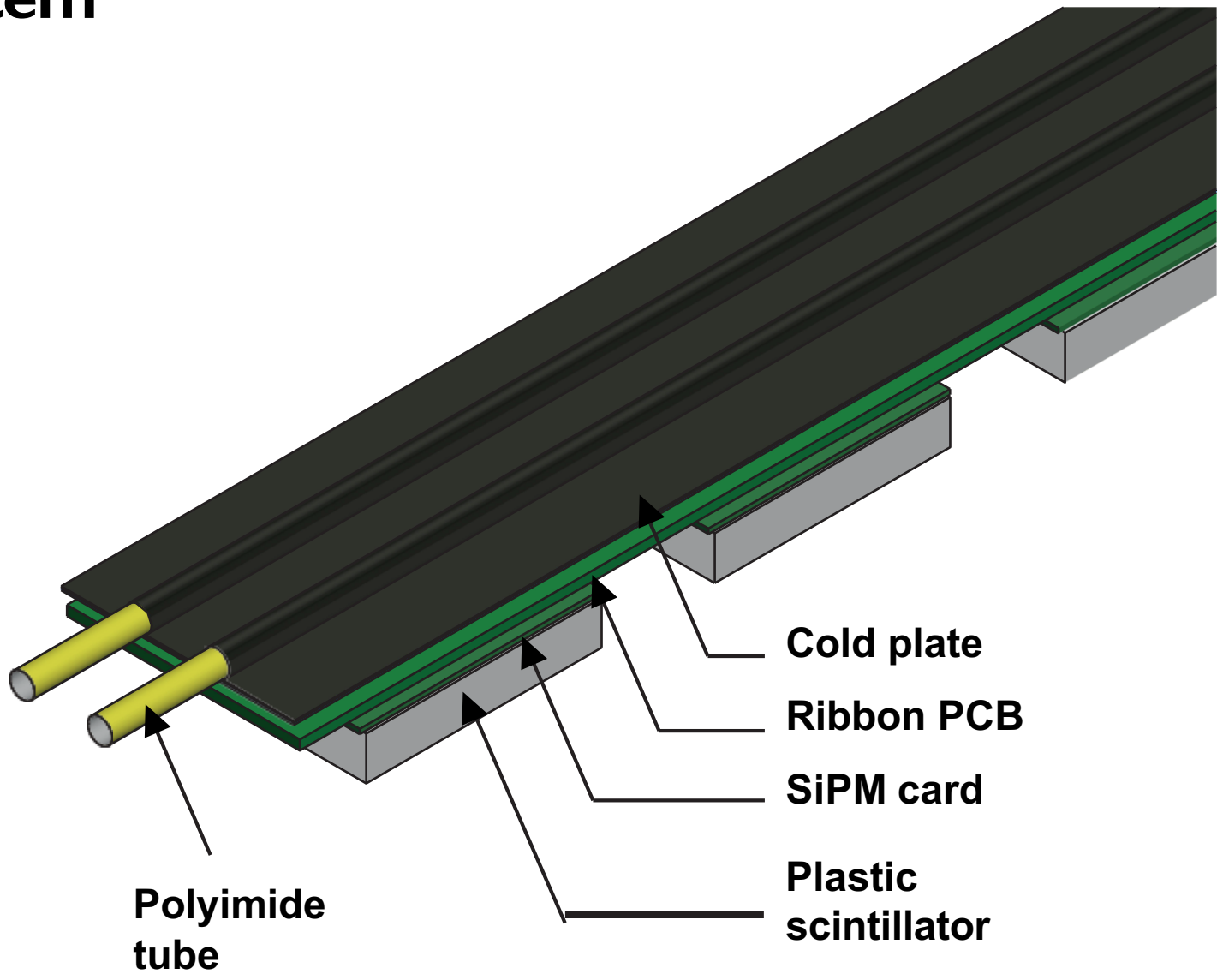
Improved structure



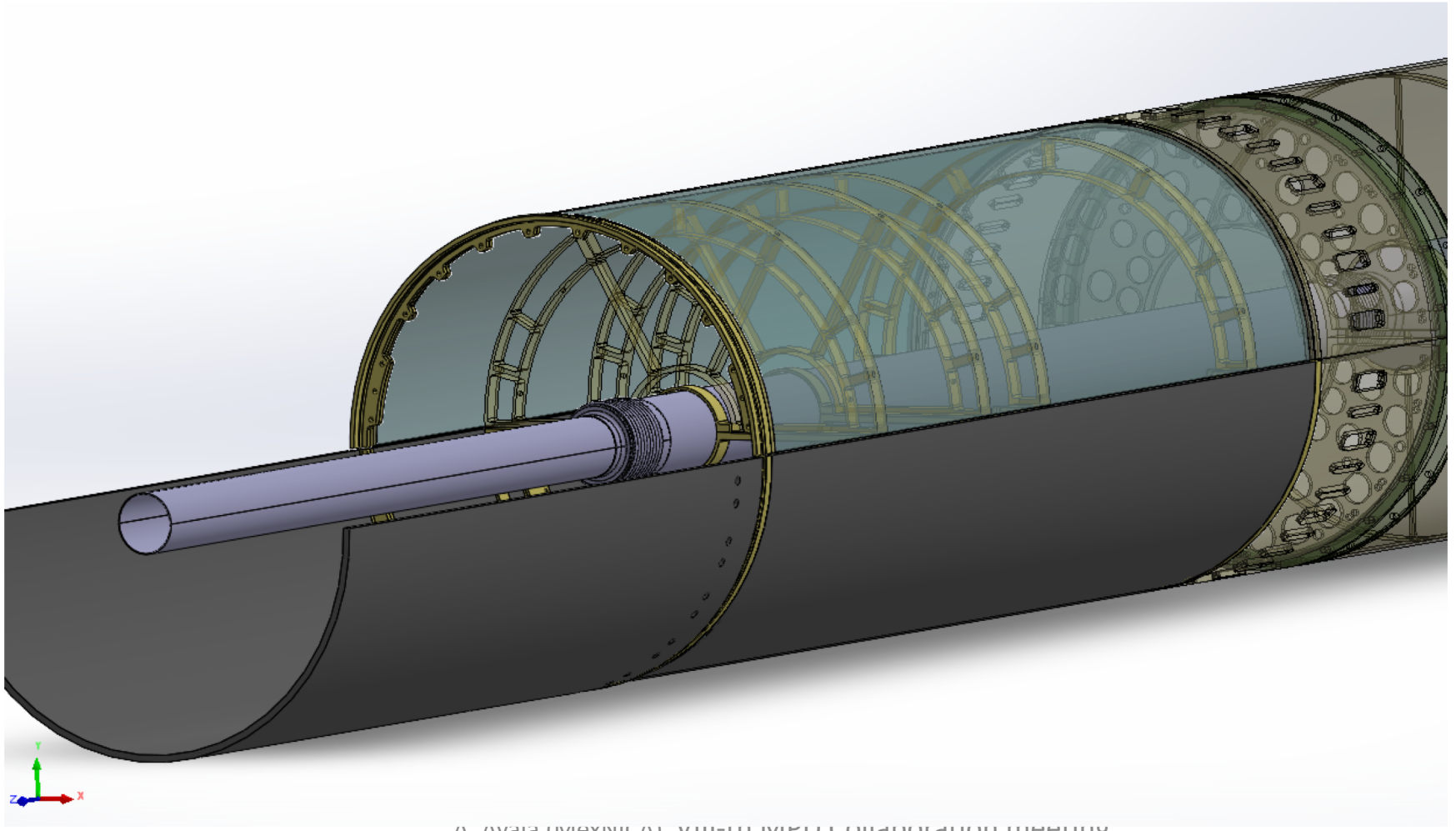



150 cm
60 cm

Cooling system



Location with respect to the beam pipe

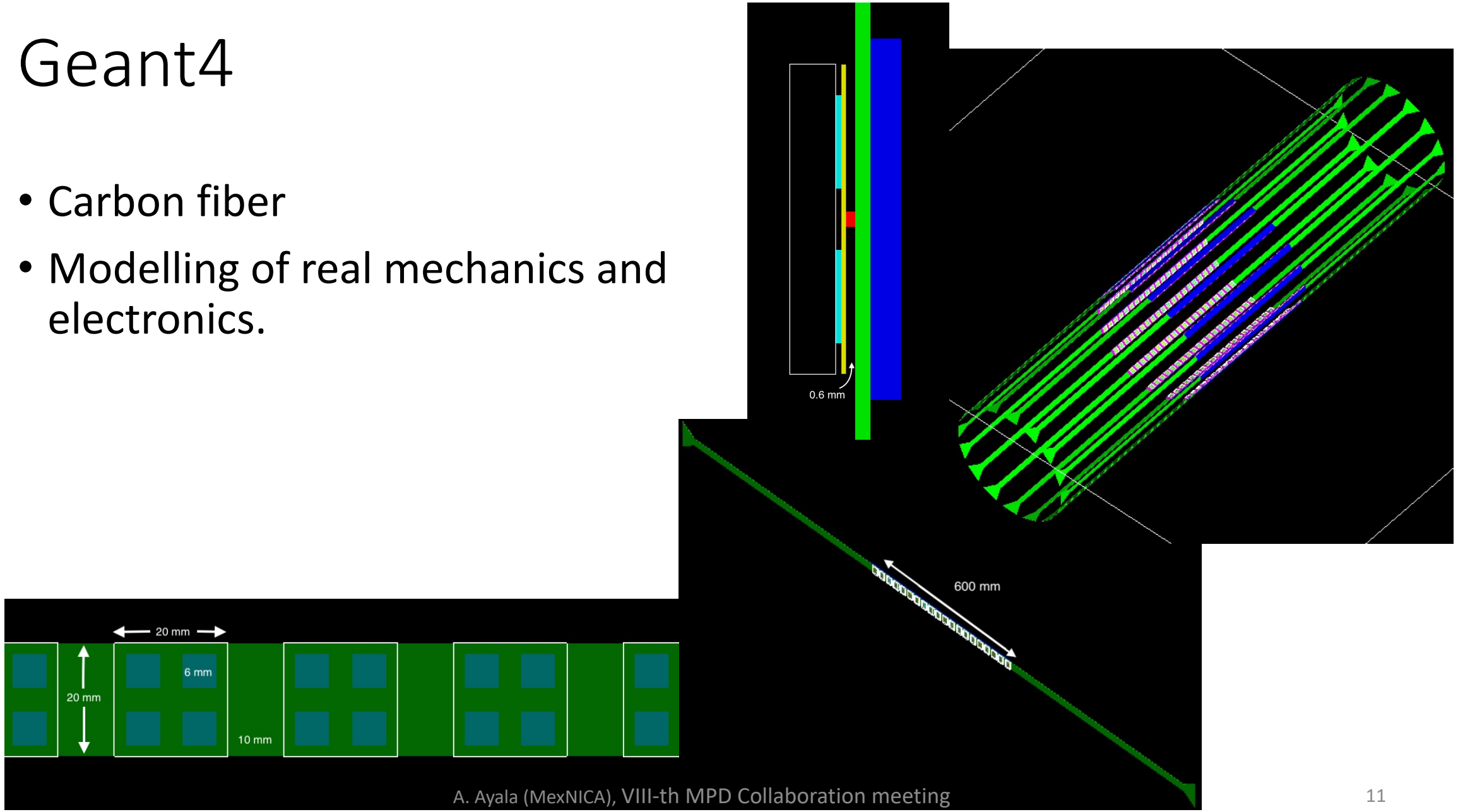


Simulations

Geant4 and MPDRoot

Geant4

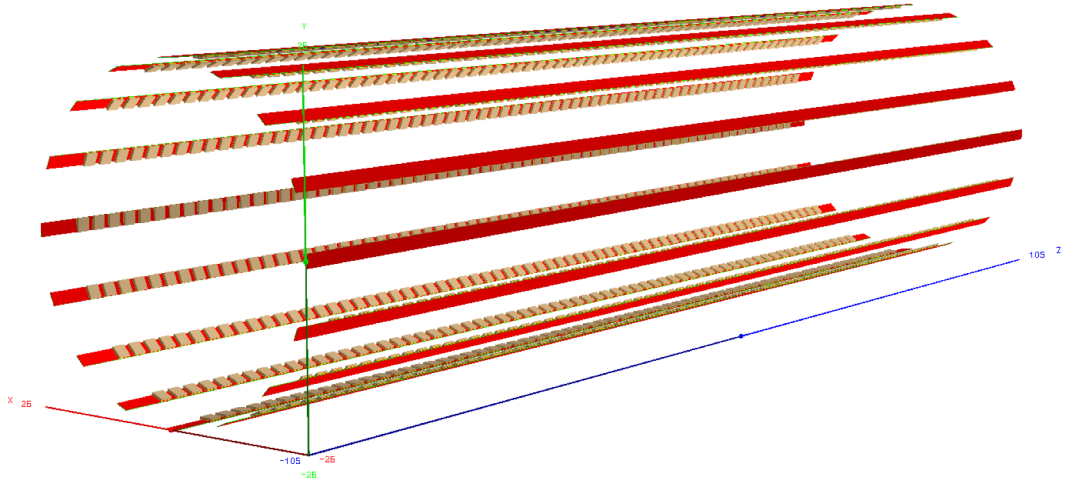
- Carbon fiber
- Modelling of real mechanics and electronics.

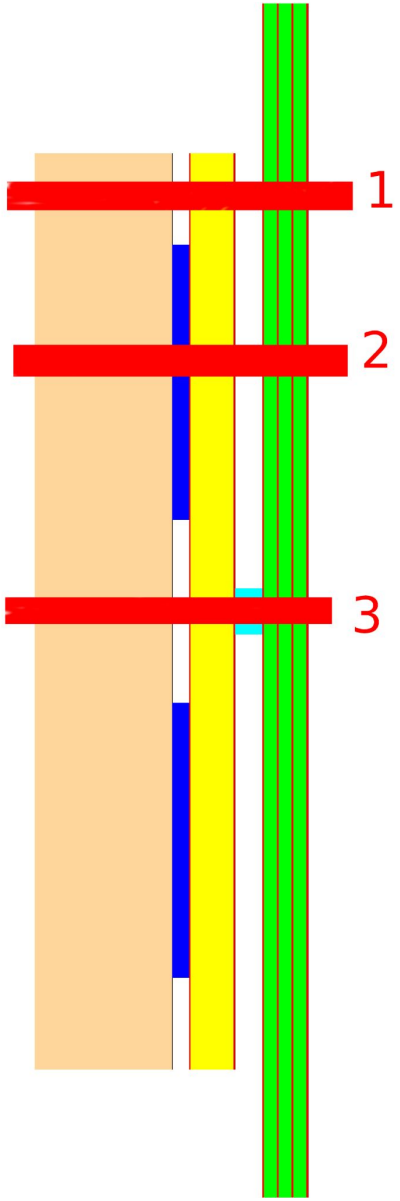


Geant4 to MpdRoot

- Studied the baseline design on MpdRoot (*JINST 16 (2021) P02002*).
- Fiber carbon mechanical framework for prototyping
- Geometry already exported and loaded onto MpdRoot.
- Work on detection efficiency and material budget in progress.

In MPDroot event display and cell schematics in GEANT4





- BC-404
- Silicon
- Copper
- Plastic
- Copper
- Plastic

Current implemented cooling: AIR.
In evaluation of alternative solutions that adapt to electronics design.

Radiation Length

The radiation length can be approximated by:

$$X_0 = \frac{716.4 \times A}{Z(Z+1)ln(\frac{287}{\sqrt{Z}})} \qquad \left[\frac{g}{cm^3}\right] \tag{1}$$

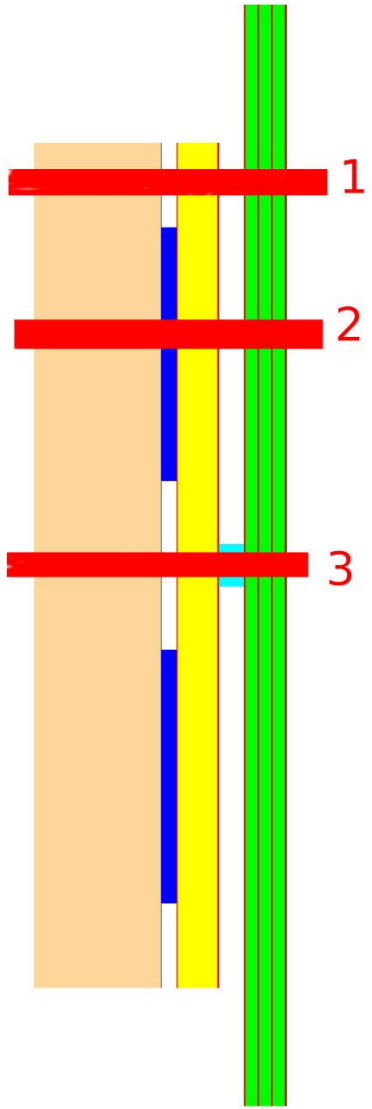
For different materials:

$$\frac{W_0}{X_0} = \sum_i \frac{W_i}{X_i} \tag{2}$$

Material	Z	A $[g/mol]$	Density $[g/cm^3]$	Radiation Length $[g/cm^2]$
Air	7 — 8 — 18	14.01 — 16 — 39.95	1.205e-3	36.62
Copper	29	63.54	8.96	13.16
Silicon	14	28.0855	2.33	22.07666
Plastic	6 — 1	12 — 1	1.032	~ 53
BC-404	6 — 1	12.011 — 1.00794	1.032	~ 54

https://www.crystals.saint-gobain.com/sites/imdf.crystals.com/files/documents/bc440-bc448-series-data-sheet.pdf

Radiation Length



1. 29.018 g/cm^3
2. 28.029 g/cm^3
3. 30.153 g/cm^3

Geometry materials:

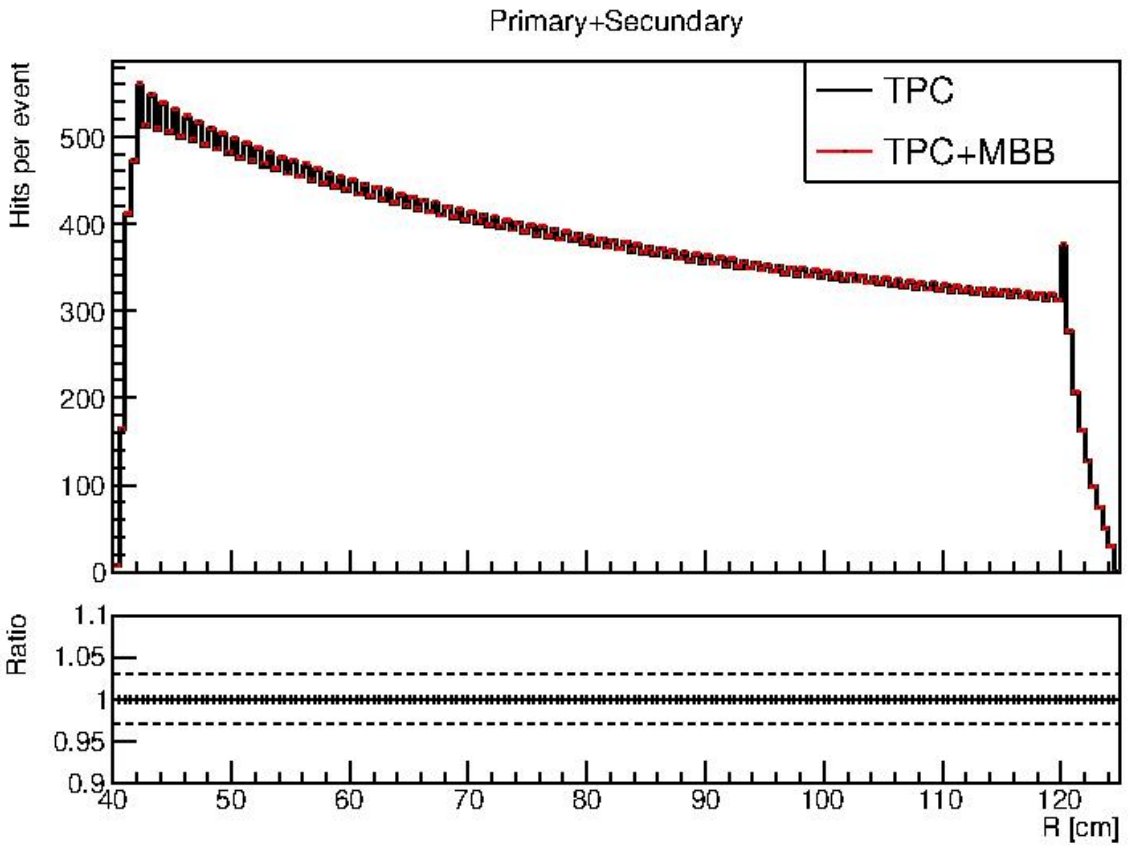
- BC-404
- Silicon
- Copper
- Plastic
- Copper
- Plastic

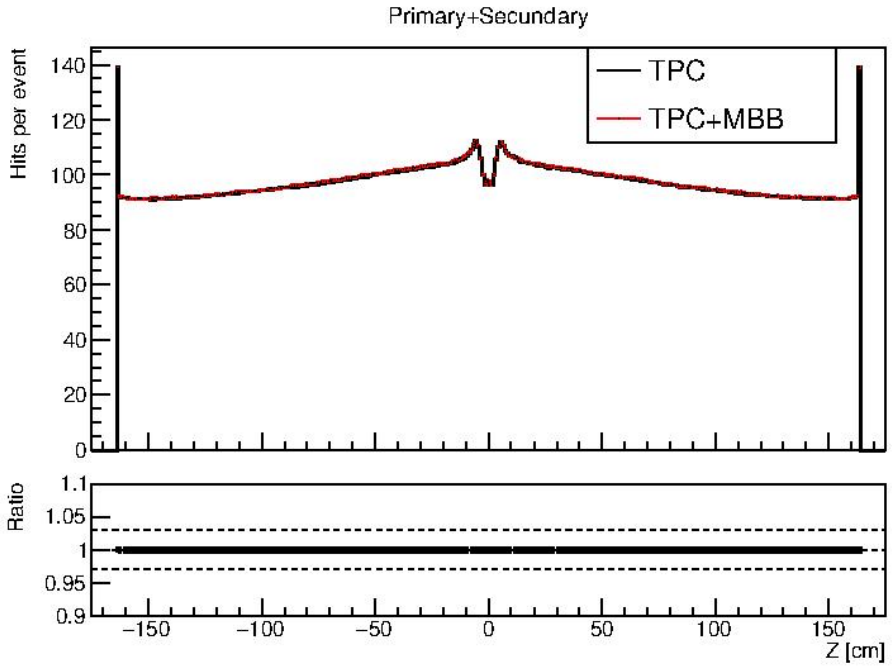
Summary of simulation details for particles on TPC or EMC, with and without miniBeBe (60 cm nominal)

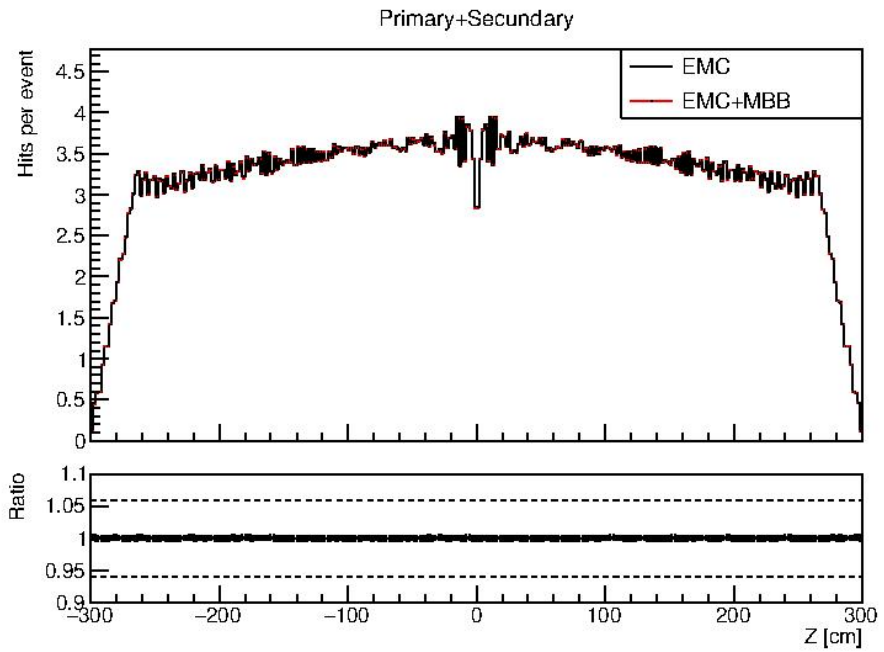
- UrQMD Bi + Bi collisions at 11 GeV
- No vertex smearing, no B-field, no pt_cut
- Transport in MPDroot framework (08/2021)
- TPC and EMC with and without miniBeBe
- 100K events, ICN-UNAM cluster - MexNICA

Hits per event on TPC and EMC with and without miniBeBe

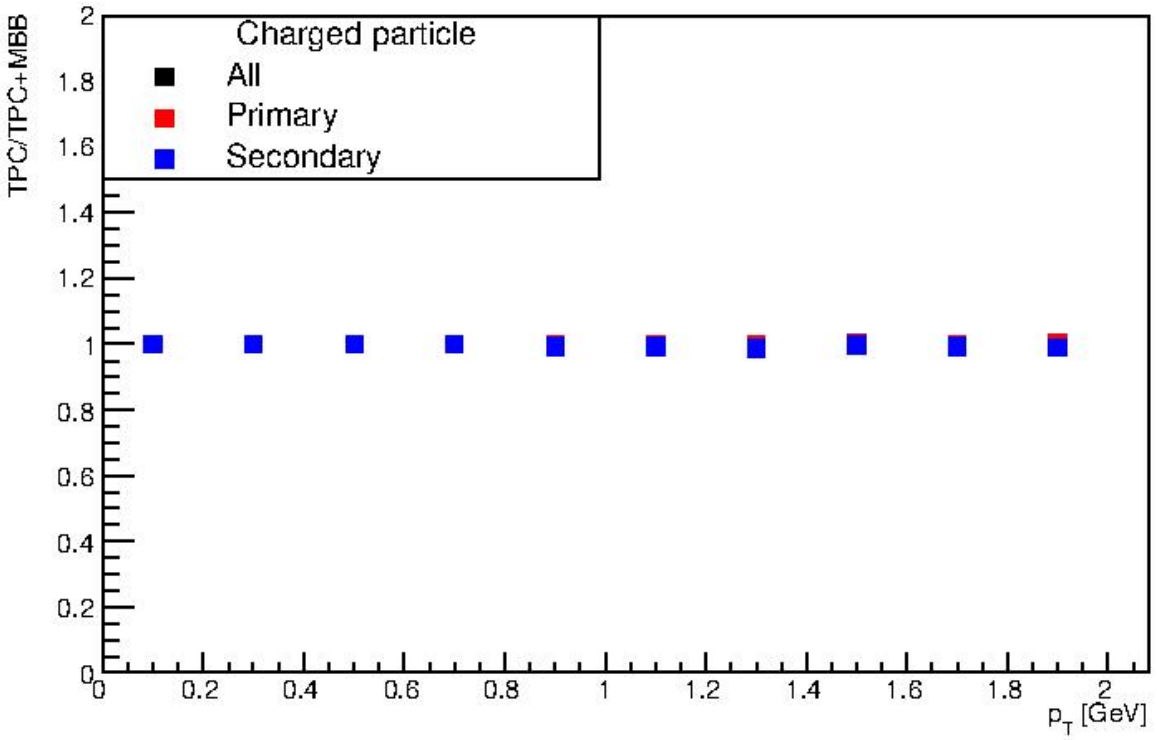
LEFT COLUMN: radial direction, RIGHT COLUMN: Z (beam) direction

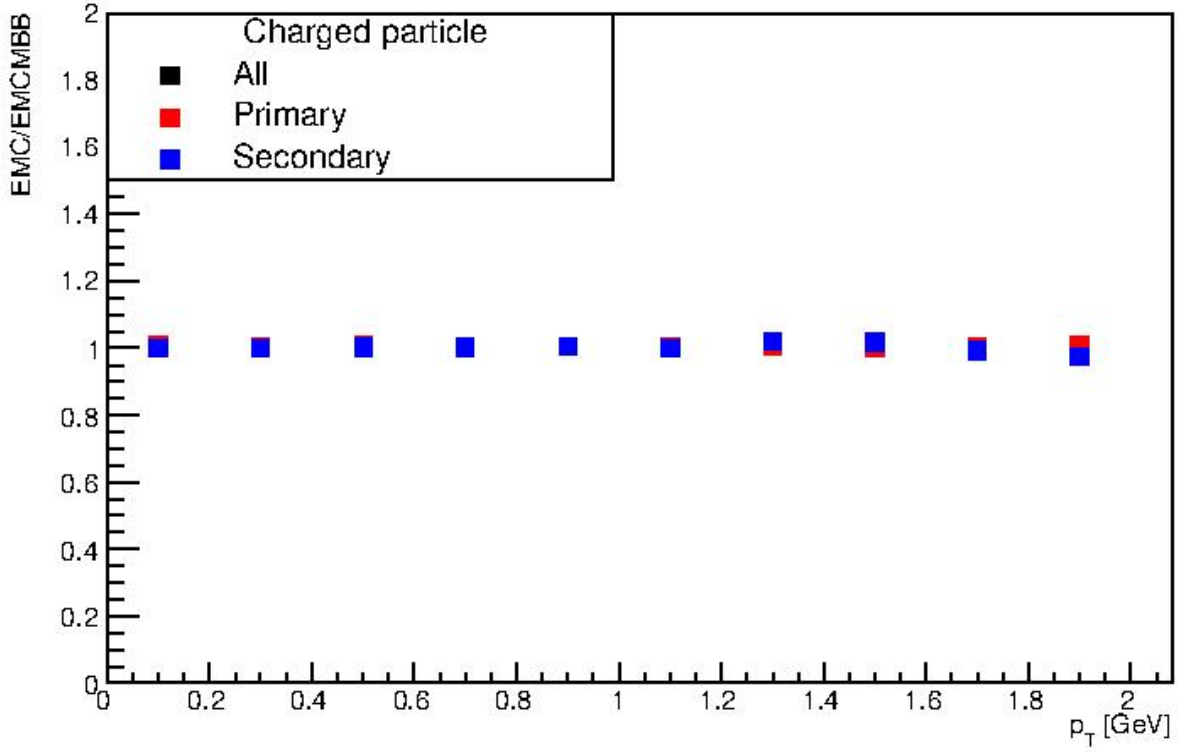






LEFT COLUMN: Ratio TPC to TPC AND miniBeBe; RIGHT COLUMN: Ratio EMC to EMC AND miniBeBe, as a function of pT





Trigger Eficiency miniBeBe and/or FFD

Summary of simulation details for trigger efficiency: miniBeBe and/or FFD

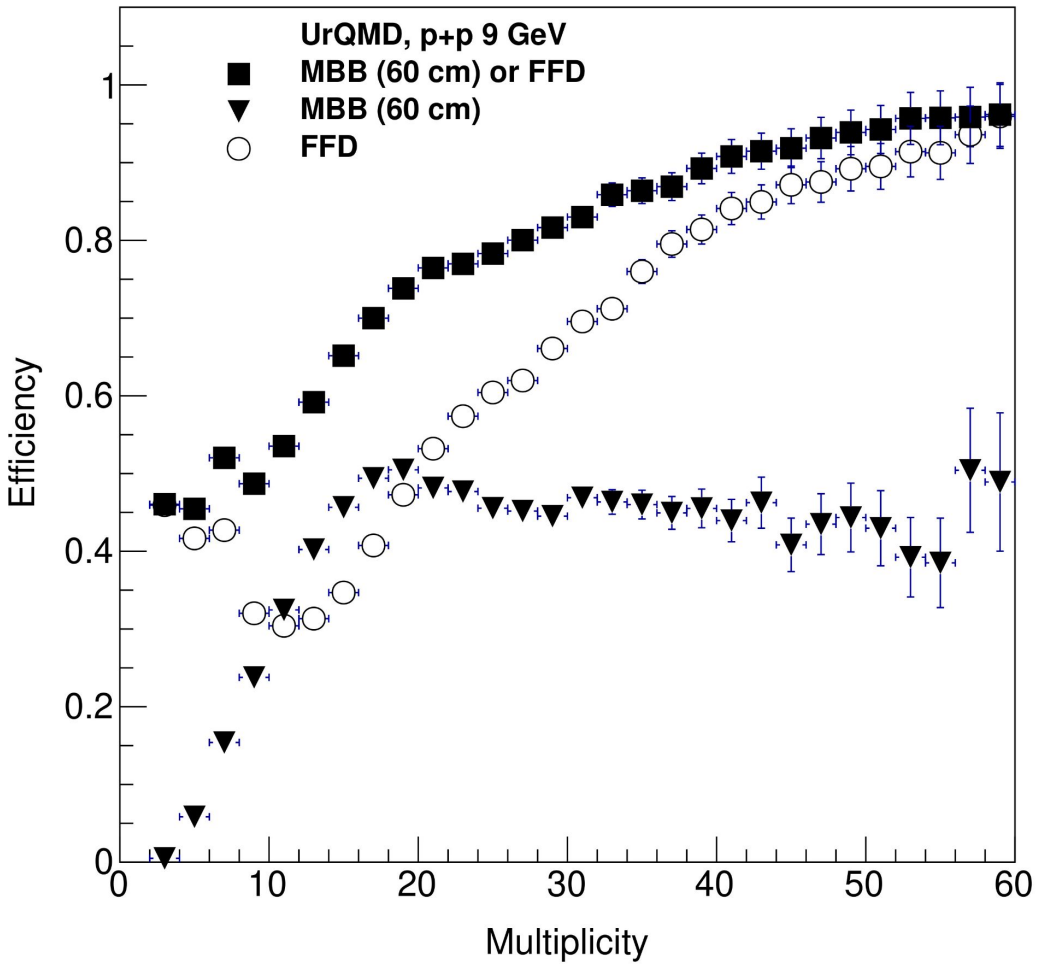
- UrQMD p + p collisions at 9 GeV
- 24 cm uniform vertex smearing along Z beam direction
- Transport in MPDroot framework
- MBB *AND* FFD, MBB *OR* FFD
- 150K events, ICN-UNAM cluster - MexNICA

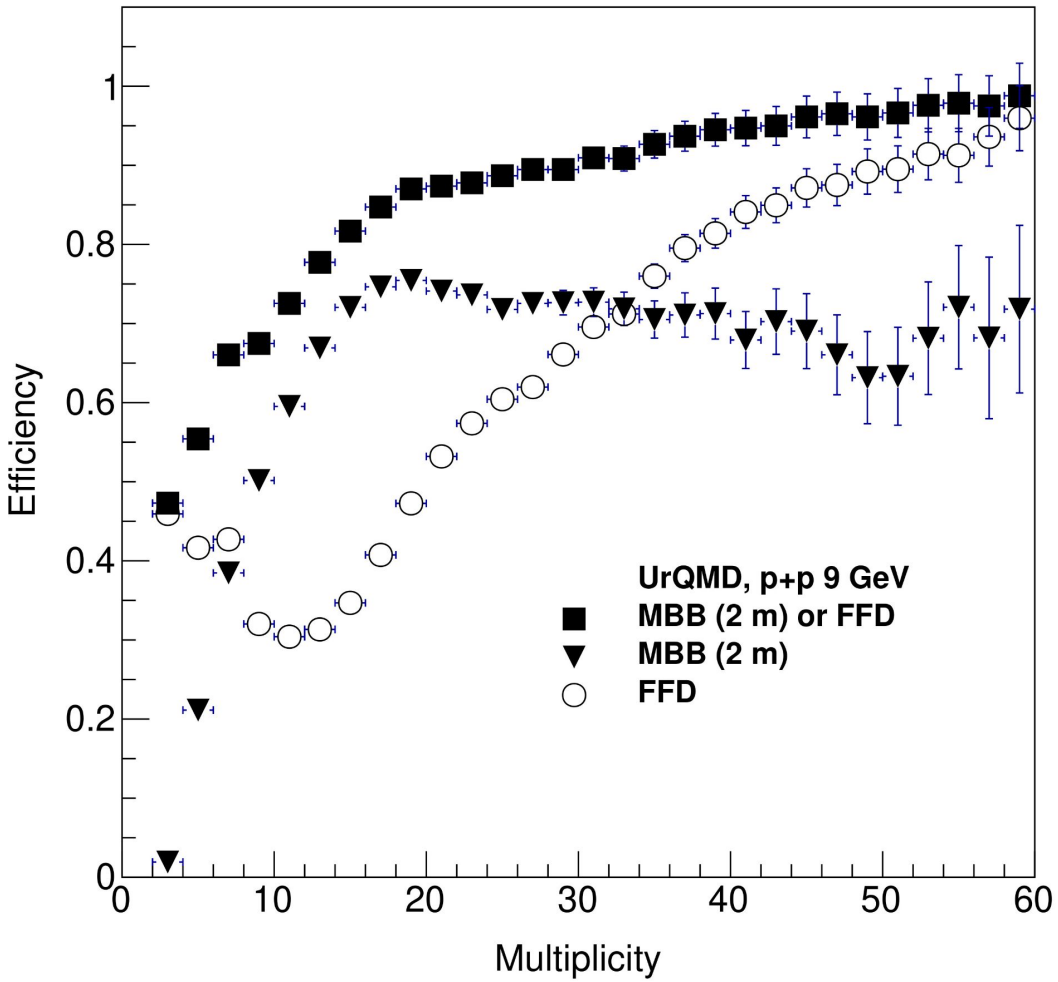
The available trigger efficiency analysis presented here PER MULTIPLICITY BIN:

$$\text{Efficiency} = \frac{\text{Events with at least one hit in detector}}{\text{Total number of events}}$$

WORK IN PROGRESS: digitalization of MBB to have a complete integration with MPD root.

miniBeBe (60cm, left; 2m, right), ALL PARTICLES

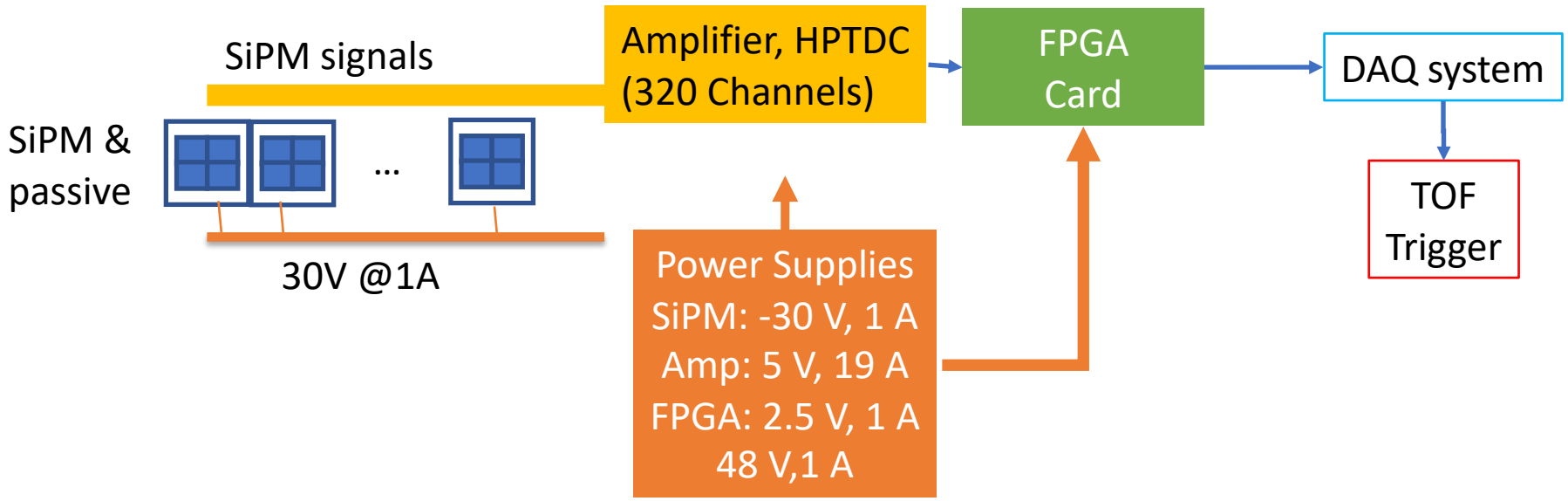




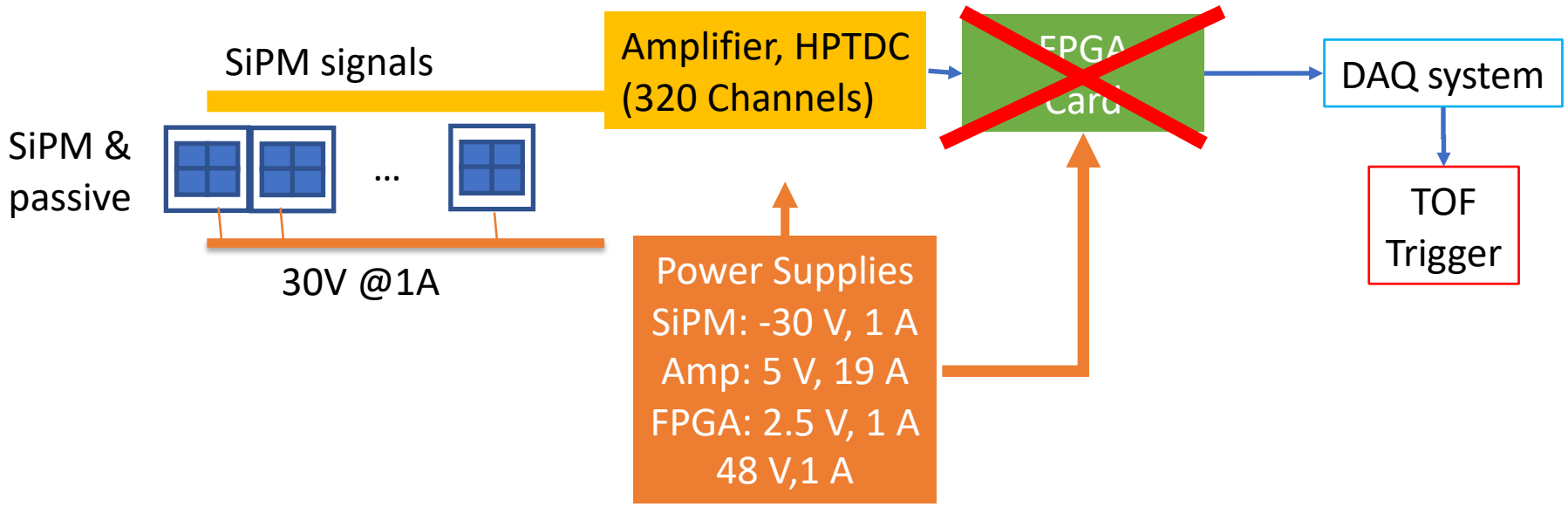
Front-end electronics

Prototypes

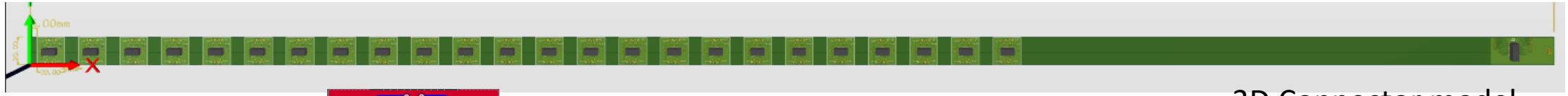
General Front-end

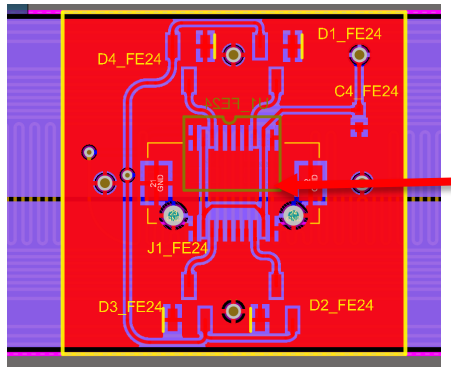
- 

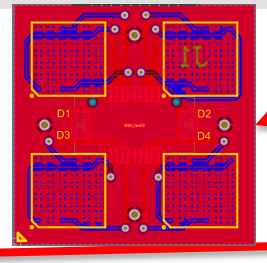
General Front-end

- 

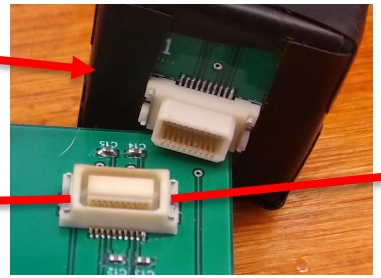
Strip card



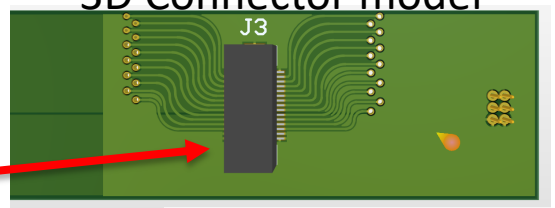


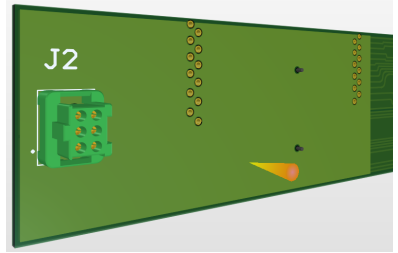


SFED card

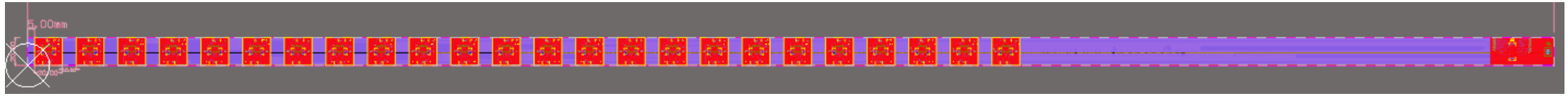


3D Connector model

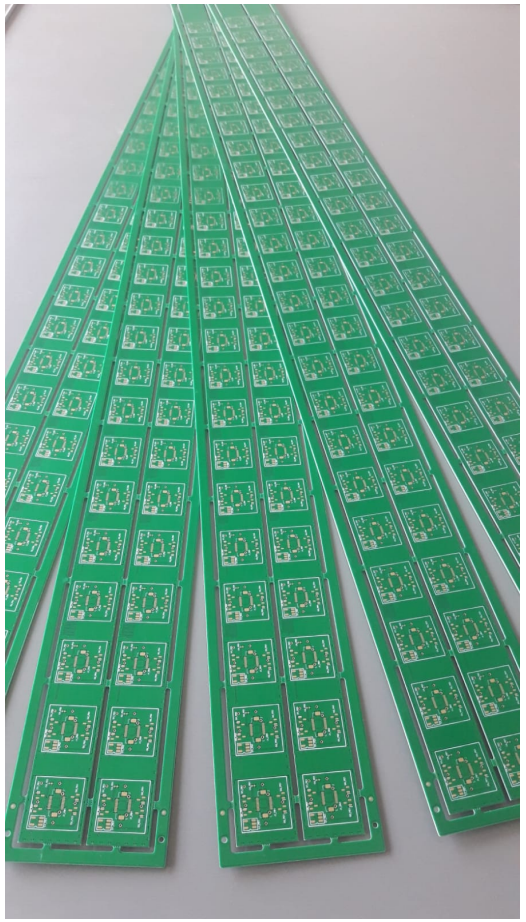




FR4 strip card

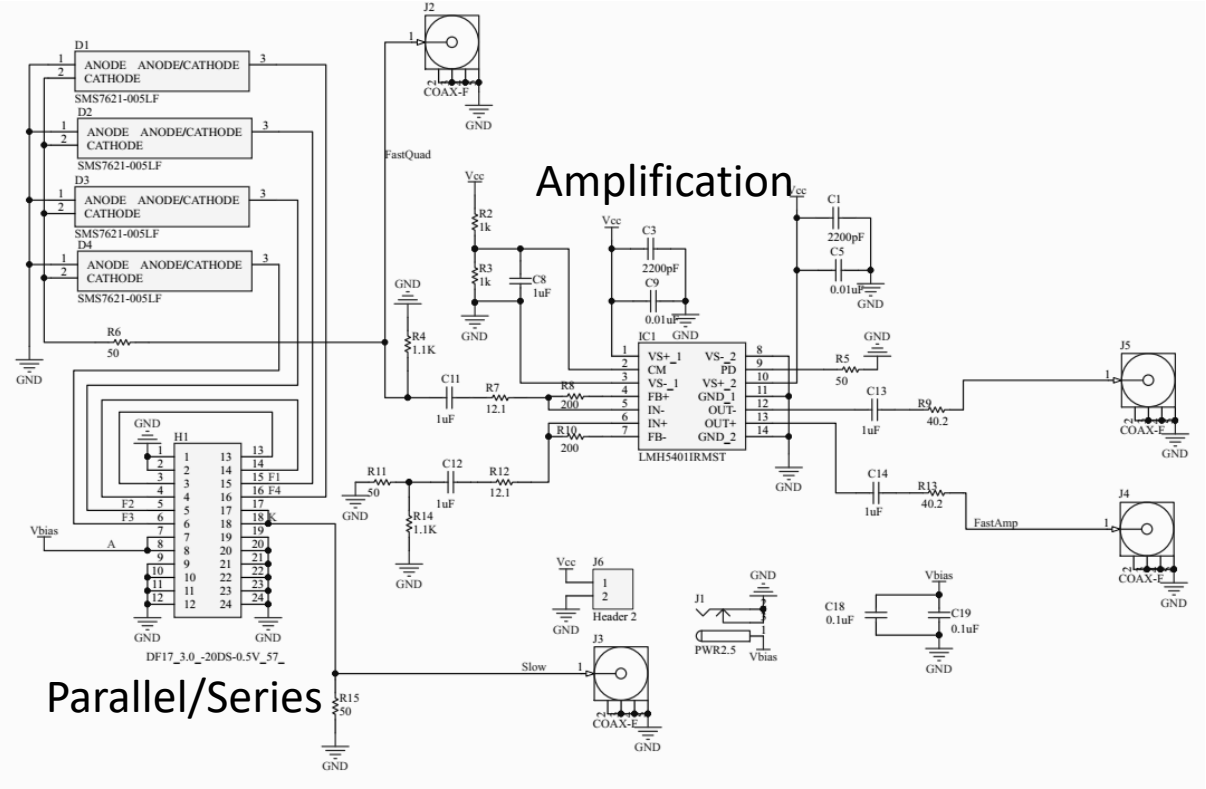


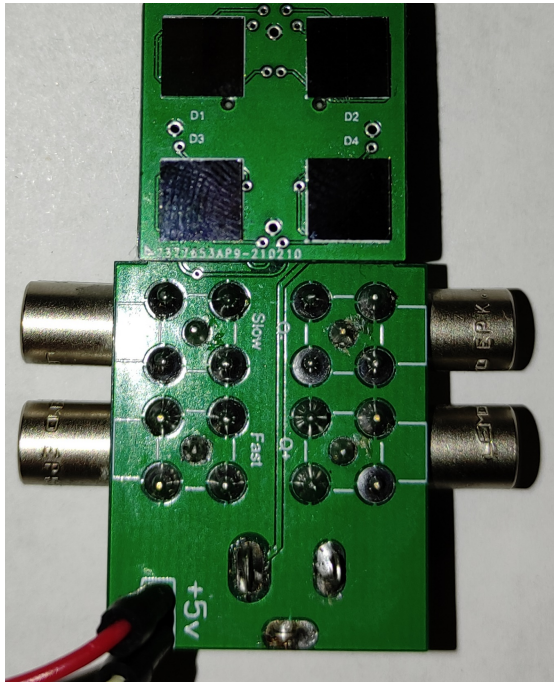
Strip cards

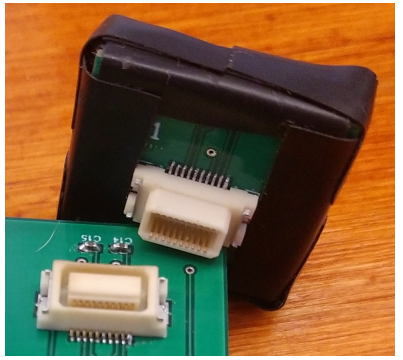


- First cards of 90 cm have arrived to laboratory.
- Designed for 50 Omhs impedance matching.
- No amplification is integrated.
- Signal degradation will be tested.
- Signal delay will be tested.

Single channel





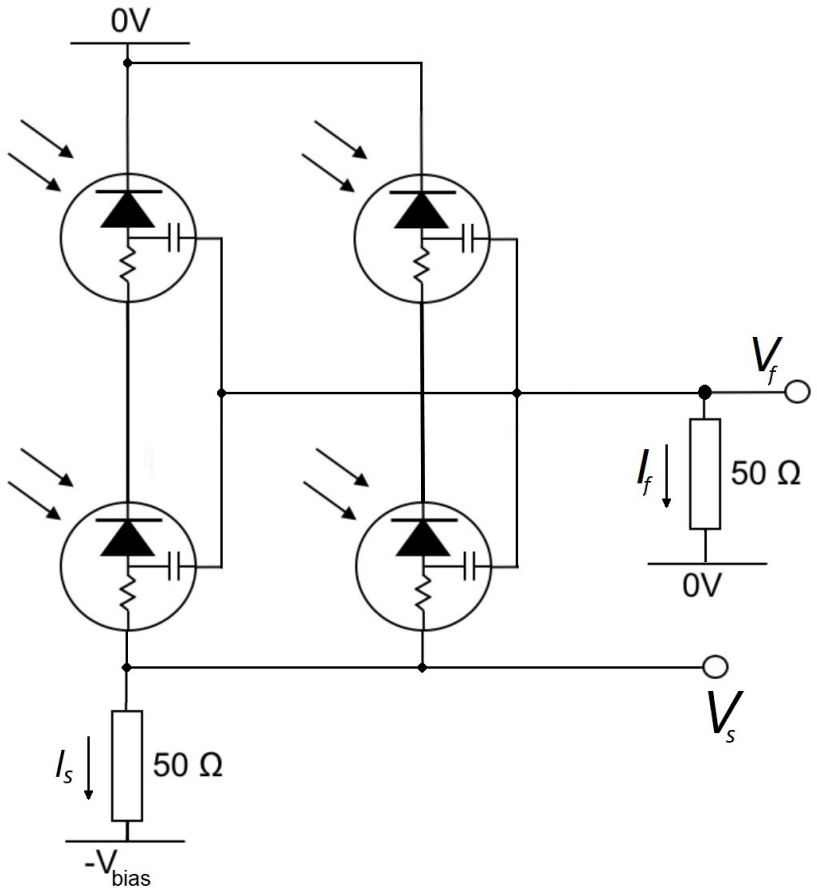


Time resolution

- BC404 – 20x20x3 mm^3
- SiPM MicrofC-60035 (6 mm).
- 4 SiPM in parallel.
- LMH5401 amplifier (single ended to differential ended).
- Cosmic rays muons.

  - **Result:** Time resolution ≈ 200 ps with *Standard signal*
    - 300 ps with *fast signal*

Improvements while keeping the geometry



- EJ232 (BC422).
- SiPM MicrofJ-60035 (6 mm).
- 4 SiPM in series parallel interconnection.
- LMH5401 amplifier (single ended to differential ended).
    - Experiments Will be developed
- Possible geometry changes in plastics.
- Possible SiPM change.

Radiation test

- Irradiation with:
  - Neutrons
    - Energy:
    - Particle flux: 10^5 cm $^{-2}$ sec $^{-1}$
  - Protons
    - Energy: 135 MeV
    - Proton flux 5 x 10^6 cm $^{-2}$ sec $^{-1}$
      - 100 s
      - 1000 s
      - 5573 s
      - 20 s
  - Heavy Ions (^{40}Ar)
    - Energy: 13.26 MeV
    - Particle flux: 10^6 cm $^{-2}$ sec $^{-1}$
      - 20 s
      - 100 s
      - 300 s

- First results:
  - There exist damage on SiPM after longer irradiation with protons and Heavy Ions.
  - Posible damage on amplifier as well.
  - In contrast to technical datasheets withs test made with a flux of 10^{13} cm $^{-2}$ sec $^{-1}$

Future work

- Impedance and signal degradation test on Strip PCB.
- Repeat time resolution measure with the series-parallel SiPM interconnection and EJ232 plastic scintillators.
- Change the geometry of SiPMs attached to plastics scintillators to enhance time resolution.
- Characterize the front-end design after radiation testing.
- During visit to Dubna (L. Rebolledo), HPTDC was proposed to use for DAQ interconnection. This idea will be tested.

Summary

- Baseline miniBeBe geometry was created and simulated in Geant4 and MPDroot.
- Time resolution must enhanced.
- Geometry changes and SiPM selection must be reviewed.
- Radiation hardness of SiPM, scintillator and amplifier will be studied with the irradiation results.

Thank you!

- Special thanks to:
- Marcin Bielewicz for continuing collaboration during radiation tests.
- Svyatouslav Buzin for continuing collaboration in mechanical and electronics design and tests.

Backup slides

Characteristics

- Required time resolution of 30 ps
- Stripe of sensors
- 16 sensor stripes
- 20 cells per stripe, made of:
  - BC422 Scintillator of 20x20x3 mm^3
  - 4- 3x3mm^2 SiPMs

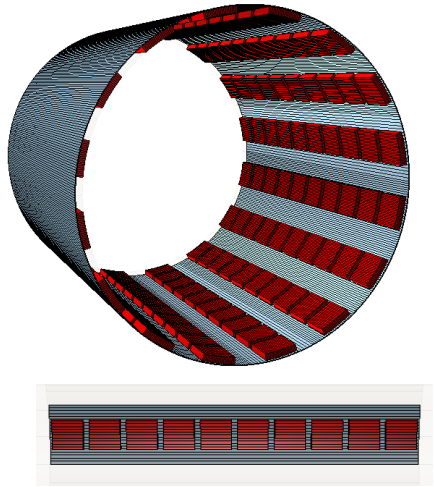


Figure1: Schematics of MBB detector

$$\sigma_{total} = \sqrt{\sigma^2_{miniBeBe} + \sigma^2_{TOF}} \leq 100\ ps$$

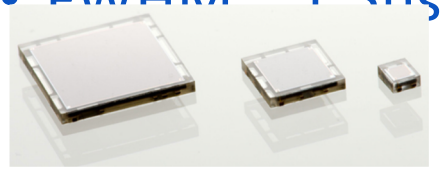
$$\sigma_{miniBeBe} \leq 30\ ps$$

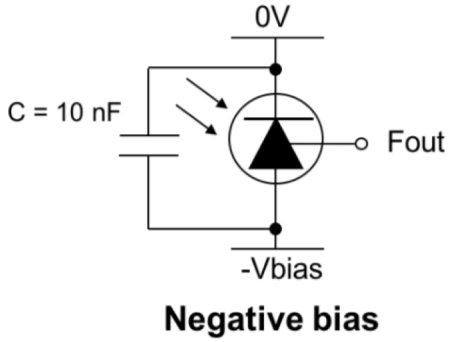
Proposed Scintillator

	BC422	BC404
RISE TIME (ns)	0.35	0.7
DECAY TIME (ns)	1.6	1.8
PULSE WIDTH, FWHM (ns)	1.3	2.2

Proposed SiPM

- **SensL MicroFJ-30035**
- Rise Time = 90ps
  - (2.5 V Over-voltage)
- FWHM = 1.5ps

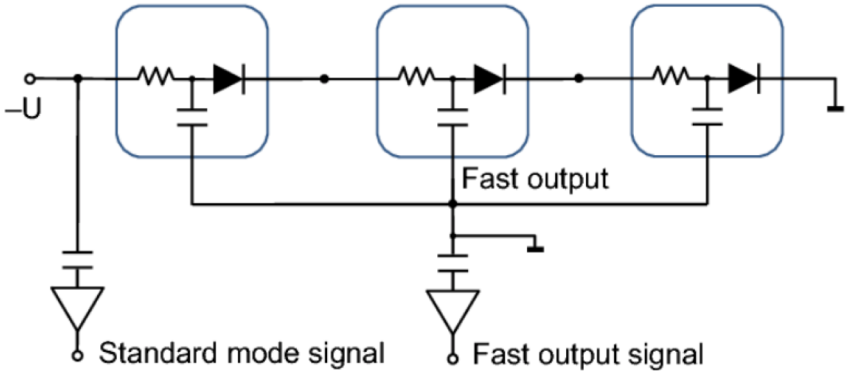


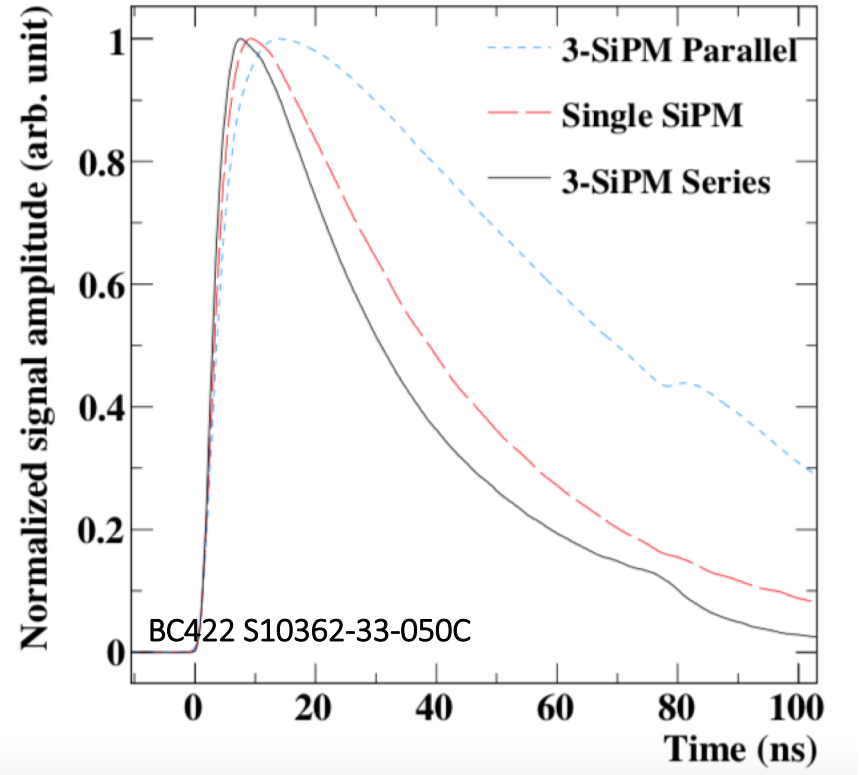


- SensL MicroFJ-30035 (3x3 mm^2)
- Breakdown voltage max (Vbr): 24.7V
- Photon Detection Efficiency (PDE):
  - 38% Vbr+2.5 V
  - 50% Vbr+6.0 V
- Gain: 6.3×10^{16}
- Crosstalk: 8%

Serial array

- Expected time resolution enhancement with serial interconnections

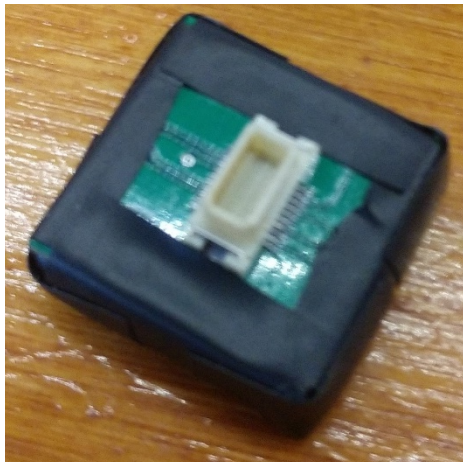


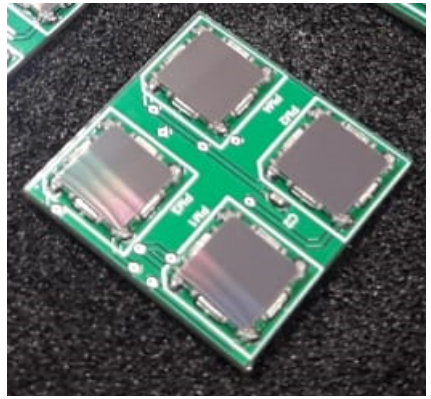


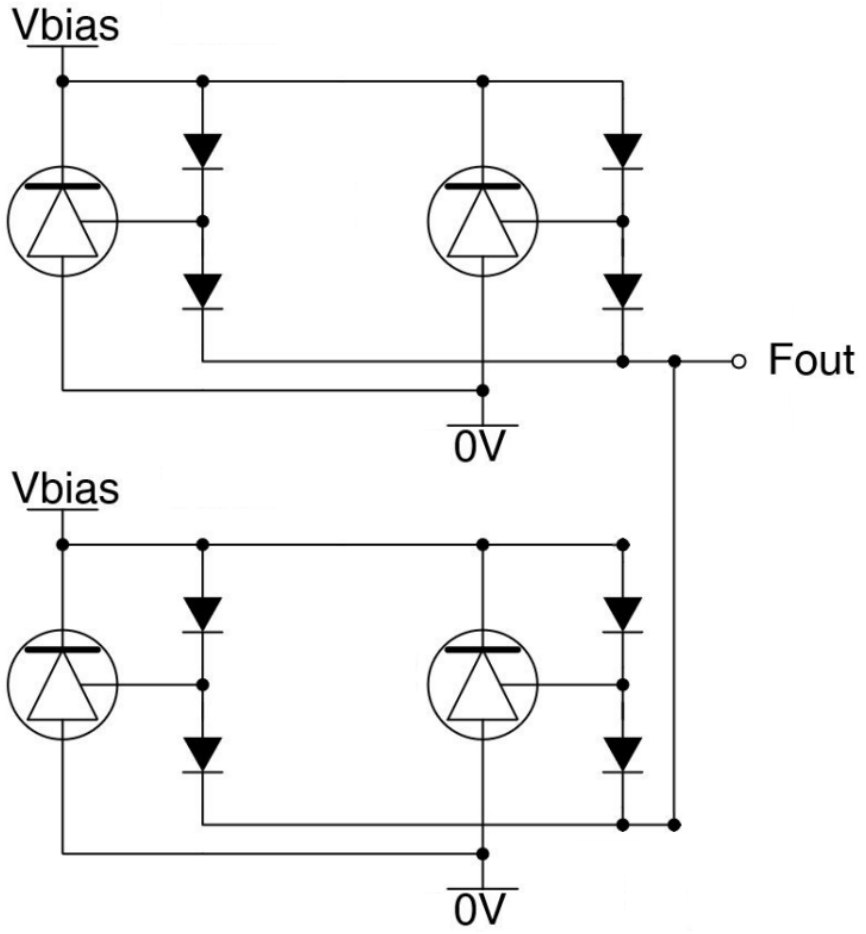
Development of High Precision Timing Counter Based on Plastic Scintillator with SiPM Readout, Paolo W. Cattaneo, Matteo De Gerone, Flavio Gatti, Member, IEEE, Miki Nishimura, Wataru Ootani, Massimo Rossella, and Yusuke Uchiyama, IEEE TRANSACTIONS ON NUCLEAR SCIENCE,VOL.61 , NO.5 , FEBRUARY 2014

SiPM parallel interconnection

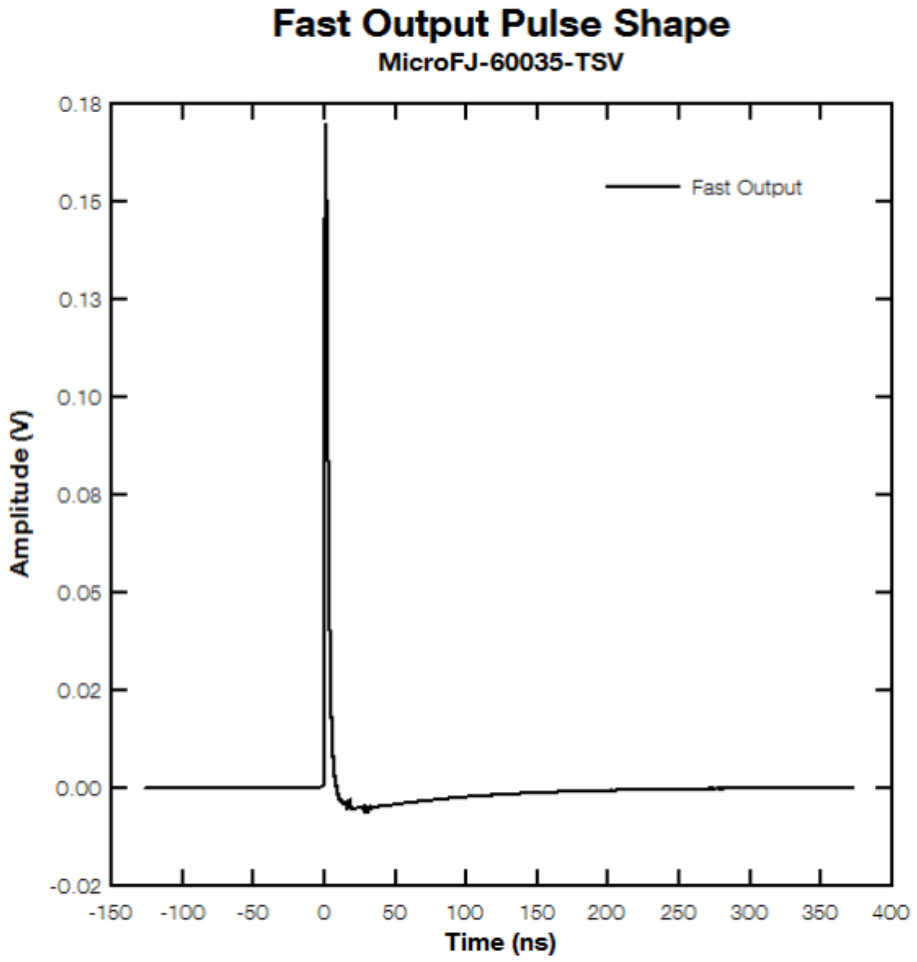
- Only fast output signals
- Capacitance effects if direct parallel
- Schottky diodes for interconnection
- Lower capacitance effect
- Affects the pulse width and rise time

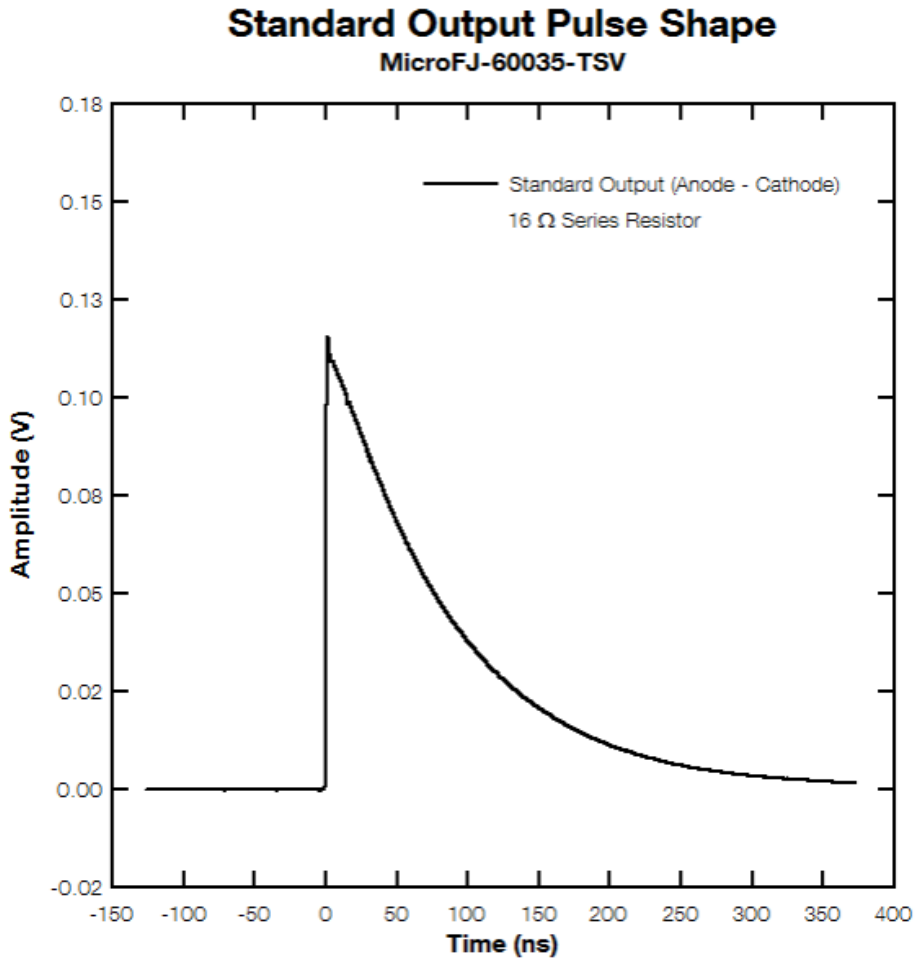






SensL signals





Dynamic range

- Given a 0.5 GeV pion:
  - For BC-404 – 551 photons are expected on each SiPM
  - For BC-422Q – 509 photons are expected on each SiPM
- Deposited charge expected depends on:

Source	Over voltage (5V)	Over voltage (2.5 V)
PDE	41%	31%
Total number of cells	18,980	-
Gain	$3x10^6$	-
Number of photons	551	-

Dynamic Range SensL C-Series SiPM