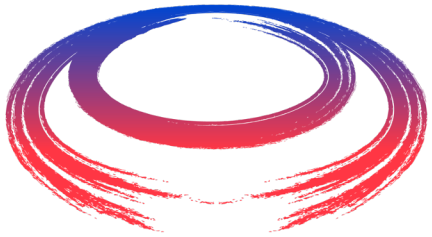


R&D of MPGD-based HCAL

RD_MuColl

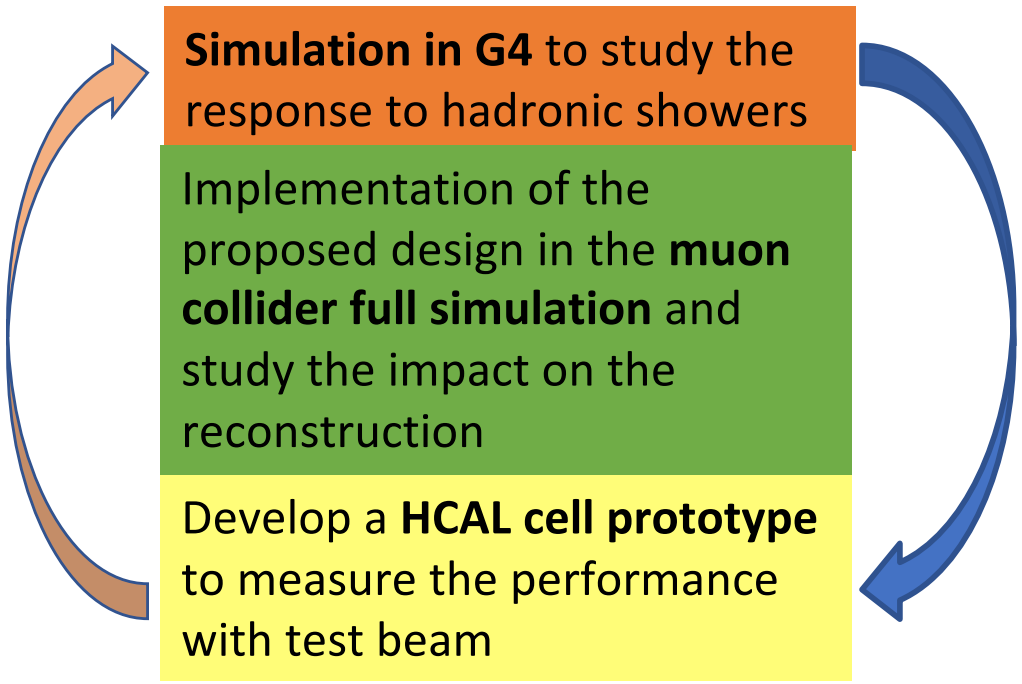
Summary attività 2022

Richieste 2023

INFN-Bari

MPGD-based HCAL development: the strategy

From simulation to prototype

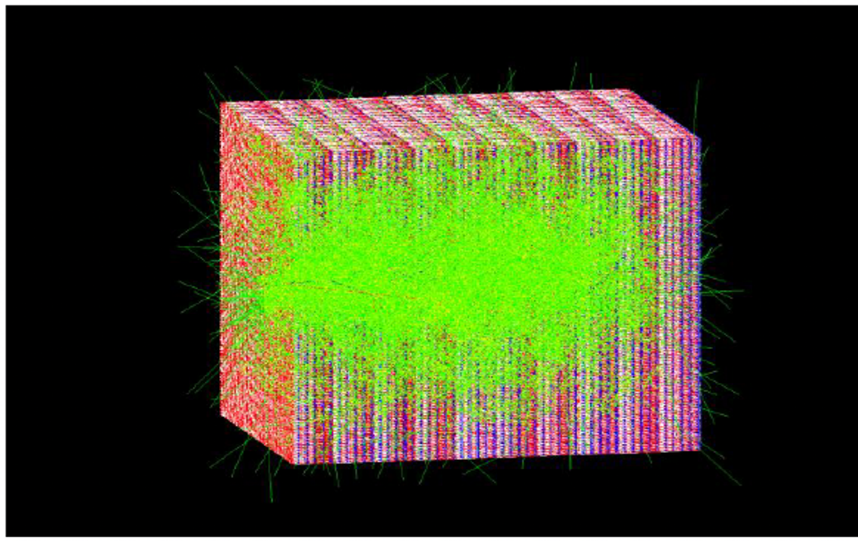


Additional founding:

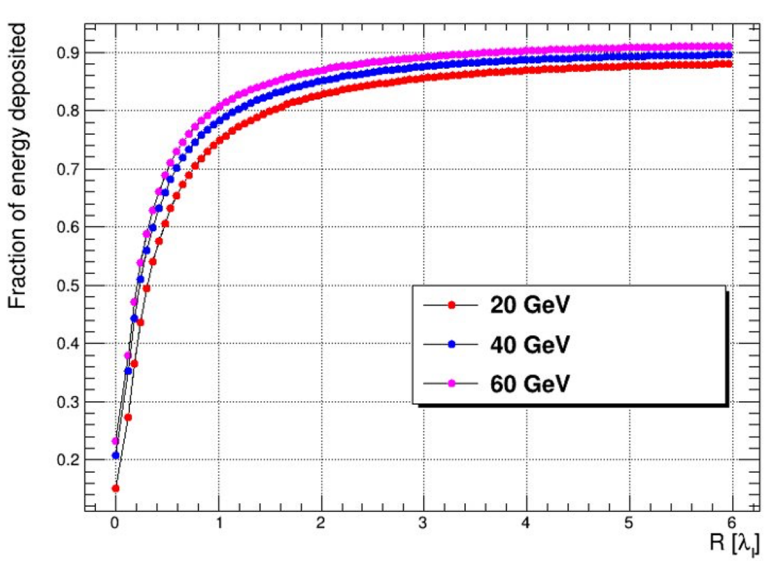
- **Obtained in 2021: R&D51 Common project** (15ke/y, 2y) "*Development or resistive MPGD calorimeter with timing measurement*", P. Verwilligen, INFN (Ba, LNF, Na), RM3

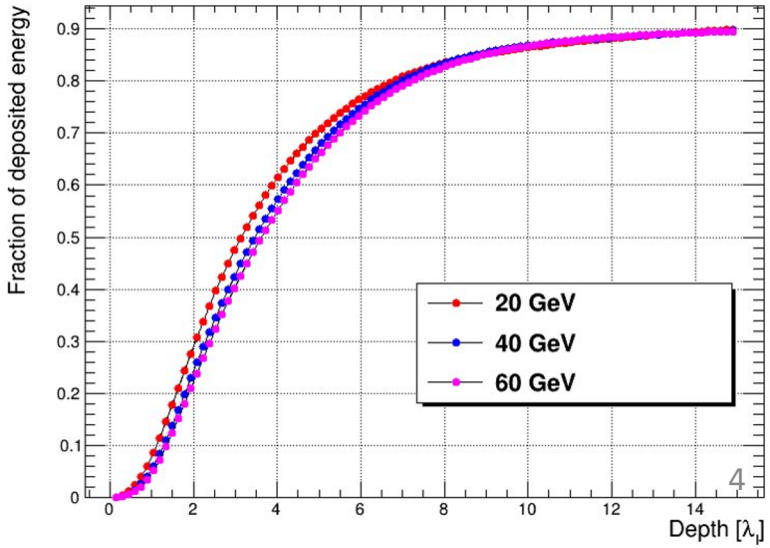
- **Submitted in 2022, PRIN:** «*An Innovative and Radiation Hard Calorimeter Proposal for a future Muon Collider Experiment*», 110k (UniBa) + 140ke INFN

G4 simulations: shower containment



- Implementation of geometry with a sampling
  - 2 cm of Fe (**absorber**)
  - 5 mm of Ar (**active gap**)
- Granularity given by cell of 1x1 cm²
- Geometry optimization for shower containment
  - 3 $\boldsymbol{\lambda}_I$ for 90% transverse containment
  - 14 $\boldsymbol{\lambda}_I$ for 90% longitudinal containment





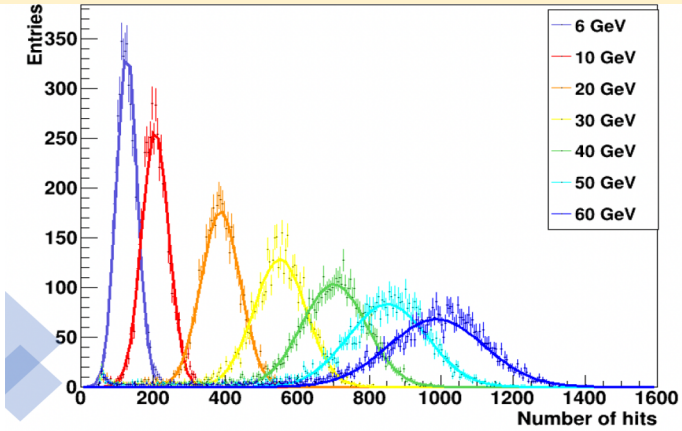
G4 simulations: energy resolution

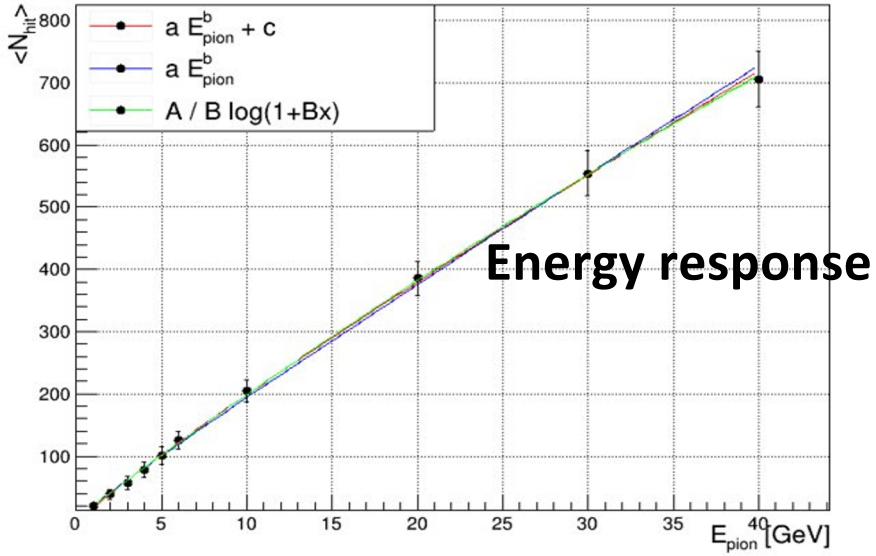
- Pion guns with energy in 1-60 GeV
- Detector Geometry:
  - 50 layers, 1x1 m^2
  - 1x1 cm^2 cell
- **Digital RO** (single threshold) 1 hit = 1 cell with deposited energy higher than 30 eV
- Response function

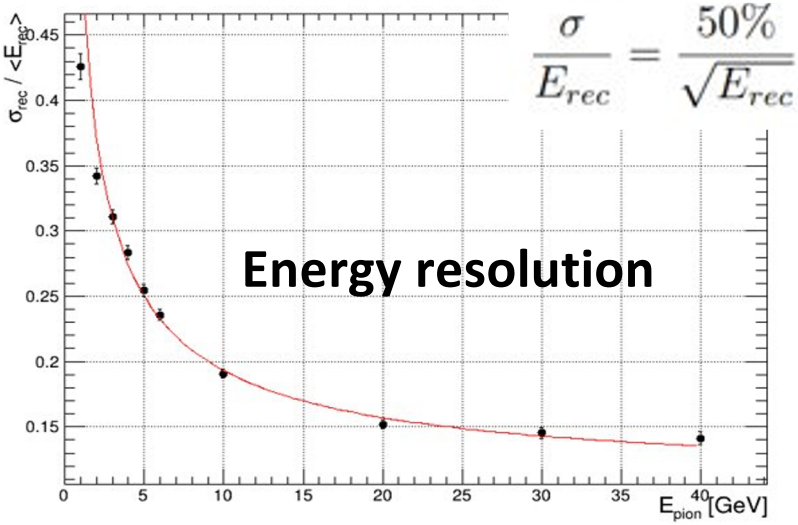
$$N_{hit} = f(E_{pion}) \rightarrow E_{rec} = f^{-1}(N_{hit})$$

Results presented at PM22:

"***Design and simulation of a MPGD-based hadronic calorimeter for Muon Collider", A. Stamerra***





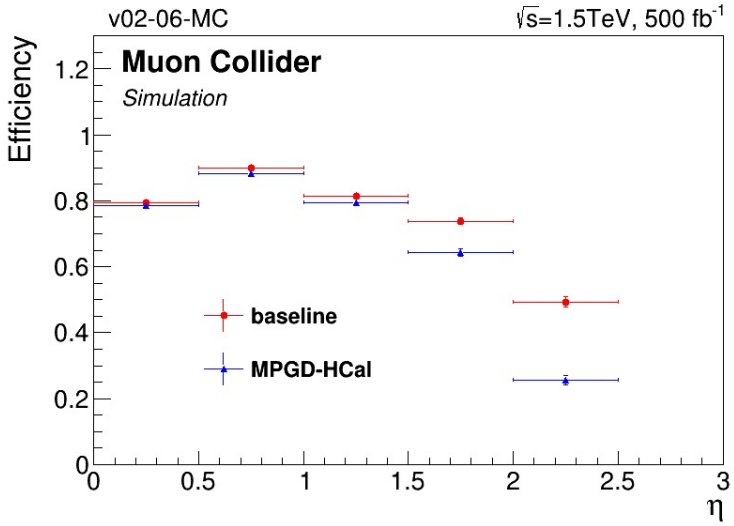


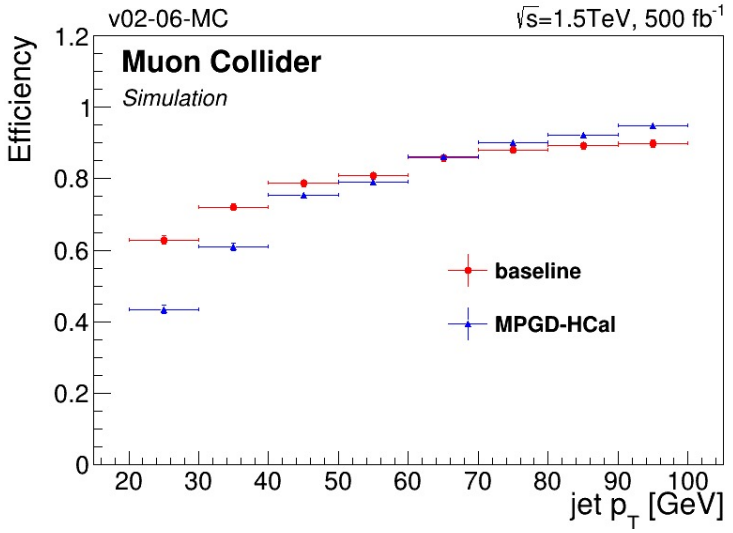
$$\frac{\sigma}{E_{rec}} = \frac{50\%}{\sqrt{E_{rec}}} \oplus 11\%$$

Muon Collider full sim: jet reconstruction

- Hcal modified Geometry
  - Argon for active layers + Iron for absorber
  - Default segmentation (cell size: 3 cm, layer width: 3mm)
- HCAL modified digitization and reconstruction to include signal generation in MPGD and electronics
  - Still preliminary
- SIMULATED PROCESS: **H → bb @ 1.5 TeV**
  - Baseline (Scint+steel) and MPDG-Hcal geometries
  - BIB simulated with standard modified geometry

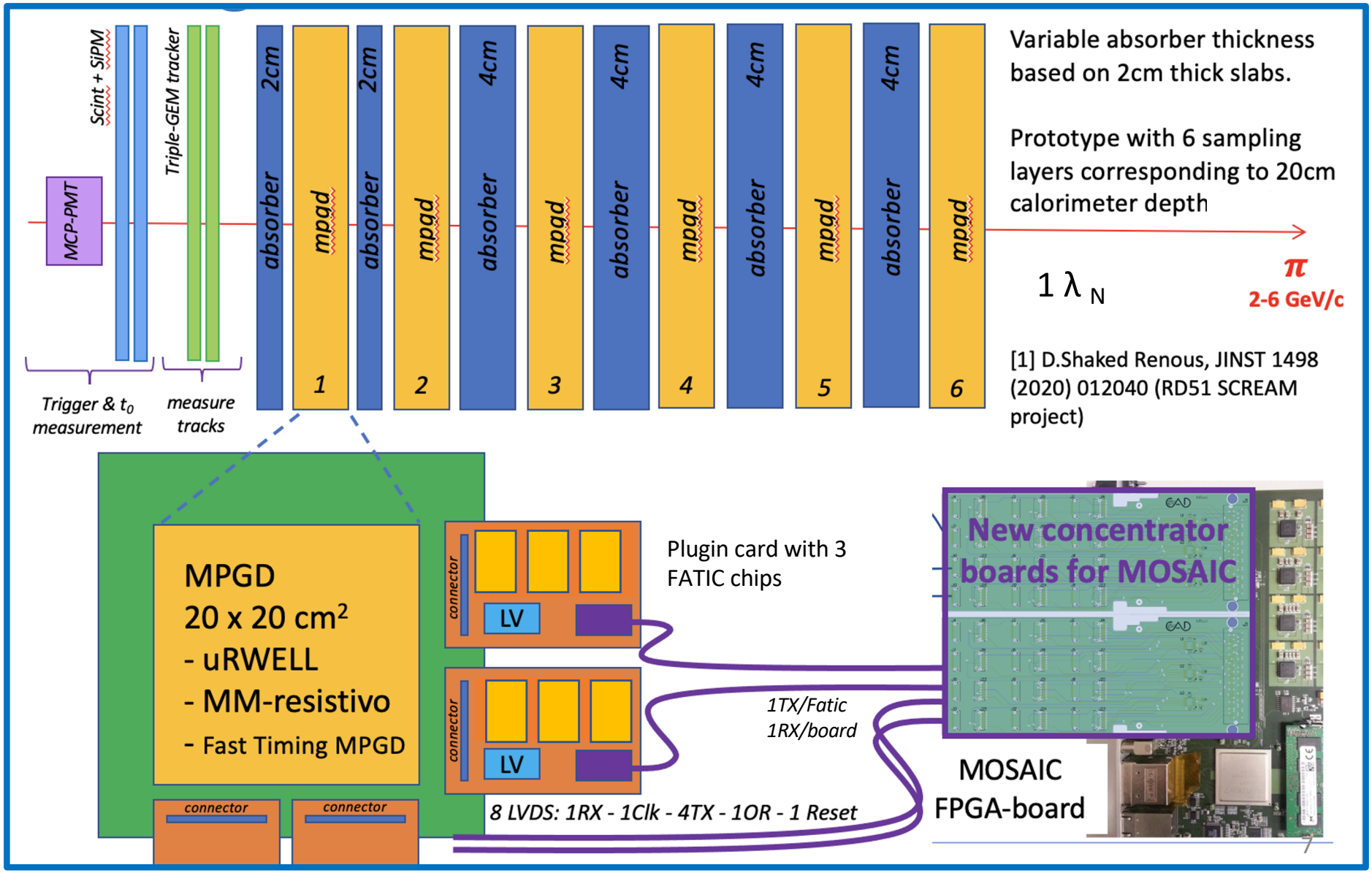
Overall agreement between baseline and MPGD-based simulation (prelimary!!)





Prototype development: MPGD-based HCAL cell

Common project
Cofounded by RD-51



Overview of the work

- **Design of the 20x20 uRWELL and resistive uMegas**
  - Design: Feb-May 2022
  - Order of Readout board placed (ELTOS)
  - Assembled detectors expected 15/09
- **Front-End Electronics**
  - Design: done in 2021
  - Production: finished in 2022
  - Wire-bounding of FATIC2 asic on plugin-cards: ongoing
  - Order of SAMTEC Firefly Cables: done 2022
  - Test FATIC plugin card with MOSAIC

Done/ongoing

- **Design & Construction of Mechanics**
  - Design ongoing (final version had to wait for final DET)

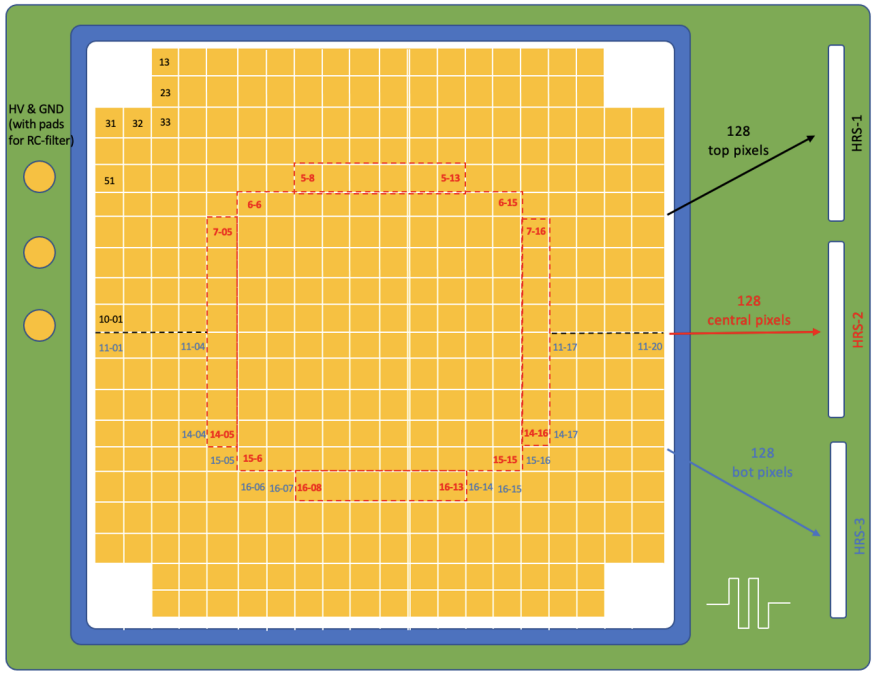
Done

- **Test resistive uRWELL and resistive uMM Detectors**
  - Test in laboratory – gas leak test – Gain Test
  - Test with beams – at SPS with MIPs = test of the DAQ
- **DAQ SW Development for MOSAIC board**
  - Need FW code to talk to FATIC chips
  - Need SW code to make up entire DAQ for MOSAIC reading out several plugin cards

Design 20x20 uRWELL & uMegas

Detectors and ROB design by CERN MPT Workshop:

- 20x20 cm^2 detectors
- 1cm^2 pixels→ 384 pixels → read all channels with 3 FATIC chips
- Common Readout board (uRWELL, uMEgas)
- Status: production ROB PCB ELTOS July ’22
- Delivery detectors by Rui: mid-end Sept.



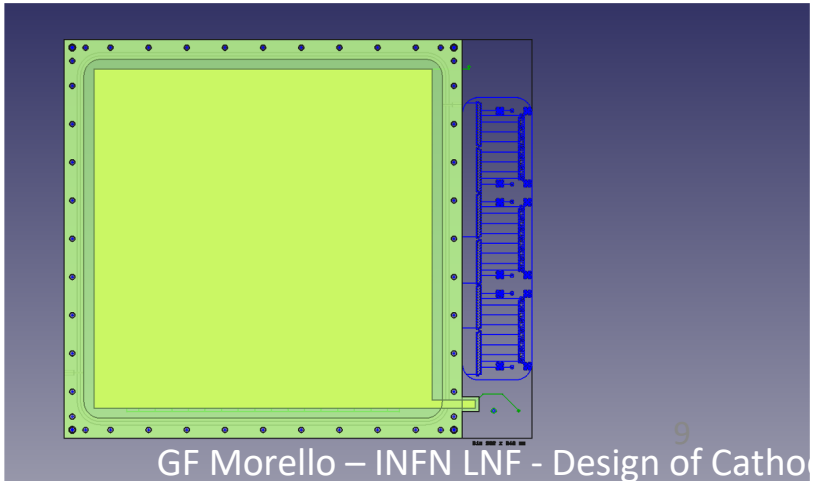
Gas Frame and Cathode board design by INFN

- Gas frame → in production at CERN
- Cathode board design completed → quotation asked to ELTOS

Production of:

- 6-8 uRWELL
- 3-4 uMegas
- 4 RO PCB

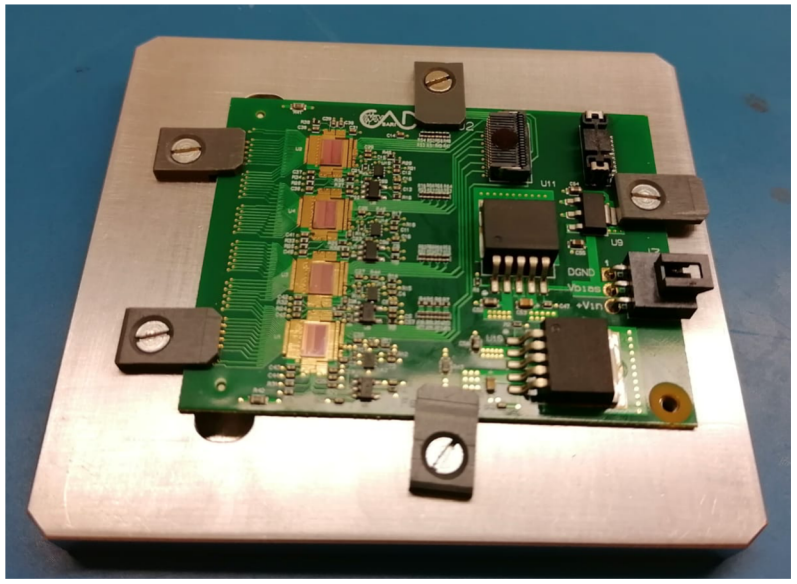
At the end of 2022 we could have 9-12 detectors + 4 ROB



Front-End Electronics

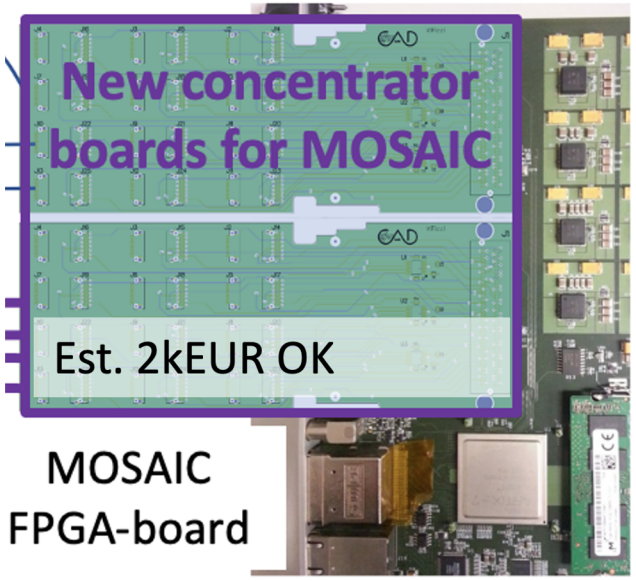
18 Plugin card produced

- HRS connector processes signals from 128 channels
- Will host 3 FATIC2 asics32 channels each
- Currently: chip glueing and wirebounding on 1 card (demonstrator) in Bari



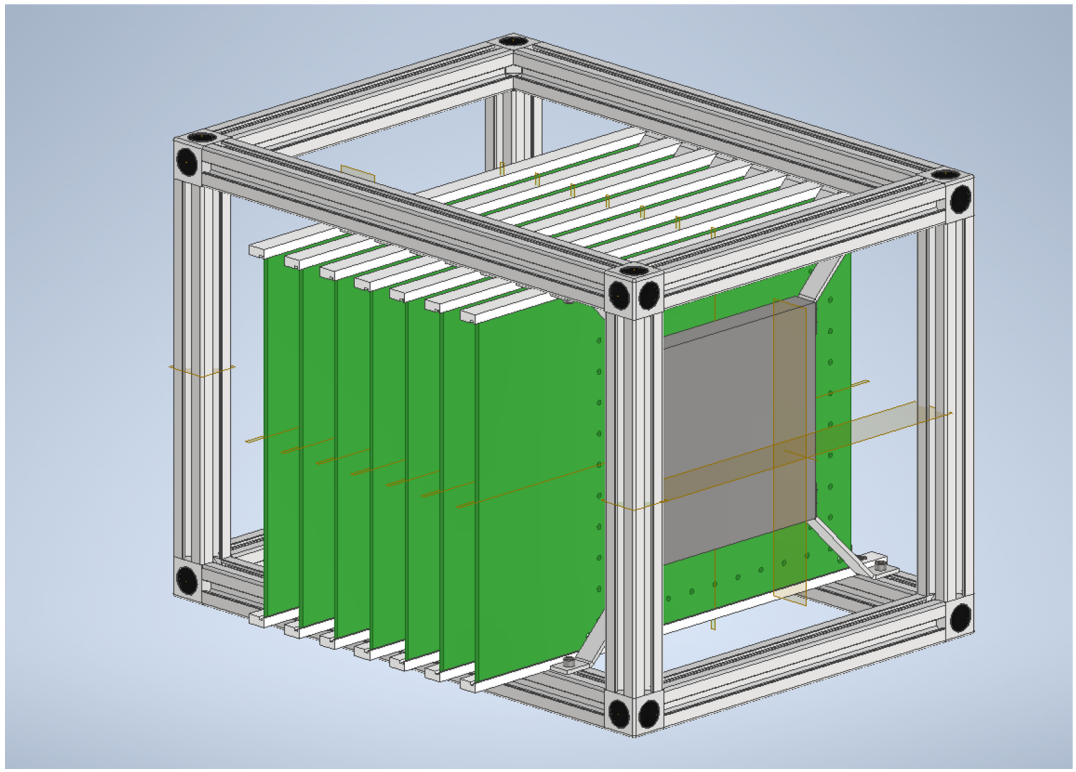
Backend: Concentrator board + MOSAIC

- Each Concentrator board receives signals from 4 plugin-cards (12 asics)
  - 4 boards ordered in Feb'22 – PCB produced and components mounted Jun'22
- Each Mosaic can mount 2 Concentrator boards (32 asics)
  - 2 MOSAIC boards available



Final MPGD-based calo cell prototype

Goal: 1 λ_N in longitudinal direction



- Final prototype will be a stack of
  - 6 detectors (μ-rwell/μmegas)
    - Readout-board (in production at CERN, expected in September)
    - Cathode (quotation asked)
    - Gas frame (in production at CERN)
  - 1 λ_N steel absorber, in layer of 2cm-4cm: (0.25 λ_N in Bari)
  - Readout:
    - 18 FATIC chips (in Bari)
    - 6 plugin cards (in Bari)
    - 2 concentrator cards (in Bari)
    - 2 MOSAIC (in Bari)
- Cell design and mechanics almost finalized, based on frozen detector design (Jun'22)

- All components have been realized/delivered in Bari or we requested quotation
- What is missing: absorber to reach 1 λ_N

→ request for 2023

Obiettivi 2022

Milestone	Description	Expected	Achieved
MS1	Design of 20x20 readout board	Feb ’22	*June ‘22*
MS2	Production uRWELL & MM dets	Jun ’22	*All components in Bari in October ‘22 ?*
MS3:	Lab tests of produced detectors (gas tightness, IV curve, gain, uniformity)	December 22	
MS1-Sim:	GEANT simulation of MPGD-HCAL	July 22 Containment and Energy resolution without BIB, with digital RO.	**December 22 *?*** Containment and Energy resolution with BIB and analogic and semidigital readout
MS2-Sim:	Impact on charged hadrons/jet reconstruction in Muon Collider full simulation	July 22 Preliminary results with BIB (small stat) with modified geometry	**December 22 *?*** Update the digitization and reconstruction.

Richieste 2023

Obiettivi il 2023

Milestone	Description	Expected	Richieste finanziarie
MS4	Test dei layer attivi su fascio a SPS con MIPs	March 2023	Missione al CERN
MS5	Assemblaggio del prototipo ($1\lambda_N$) di cella calorimetrica	June 2023	Assorbitore
MS6	Test su fascio del prototipo ($1\lambda_N$) di cella calorimetrica	Oct 23	Missione al CERN
MS7	Realizzazione prototipo con $2\ \lambda_N$	Dec 23	1 rivelatore (+altro assorbitore)
MS1-Sim:	GEANT simulation of MPGD-HCAL	Dec 23: Study the response to multiple MIPs, introduce timing.	
MS2-Sim:	Impact on charged hadrons/jet reconstruction in Muon Collider full simulation	Dec 23: Define optimal time and spatial resolution in a particle flow approach	

Misure su fascio

MS4: MPGD active layers test with 130 GeV/c charged hadrons/muons

- **Goal: Measure efficiency, cluster size, spatial resolution, time resolution of micromegas and micro-rwell**
- Task-1: DAQ software preparation
- Task-2: mechanical infrastructure preparation
- Task-3: data analysis

MS6: HCAL prototype test with 1-6 GeV/c charged hadrons

- Goal: **Measurement of energy resolution, shower containment**
- Task-1: mechanical infrastructure preparation
- Task-2: data analysis

Toward 2 λ_N prototype

- $5\lambda_N$ needed for full shower containment (assuming infinite transverse size)
- In order to improve shower containment and make more reliable energy resolution measurement, we ask to extend the prototype at least to 2 λ_N
- What we need
  - 2 detectors (1 founded by RD51-CP)
    - we are limited by available electronics (we have material to read 2 further detectors)
  - $1\lambda_N$ steel absorber (we can find material for $0.25\lambda_N$)

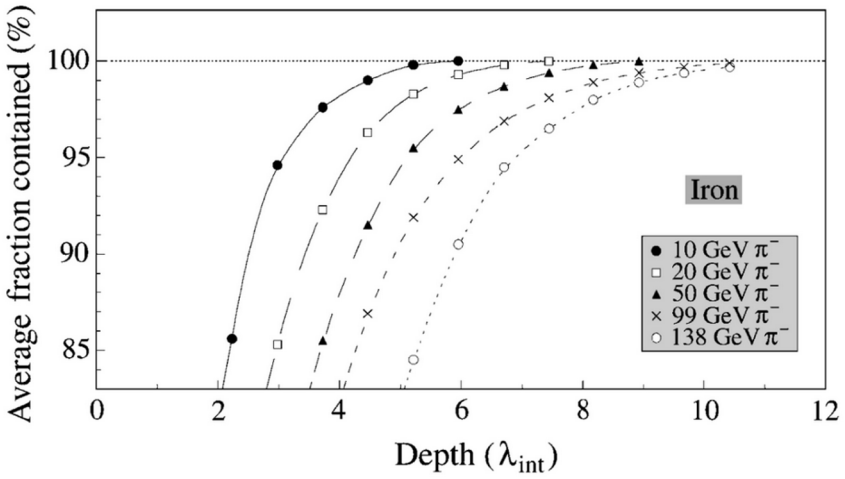
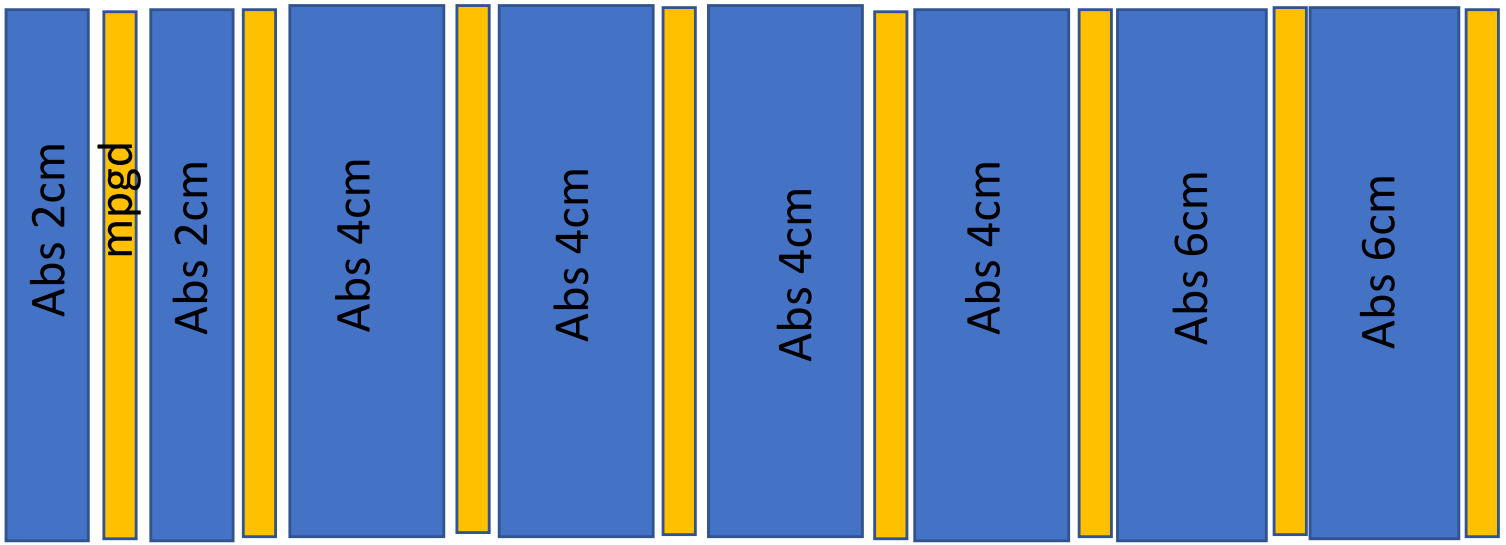


FIG. 2.43. Average energy fraction contained in a block of matter with infinite transverse dimensions, as a function of the thickness of this absorber, expressed in nuclear interaction lengths. Shown are results for showers induced by pions of various energies in iron absorber. Experimental data from [Abr 81].



Richieste finanziarie

- MISSIONI:
  - Test Beam dei layer attivi (MS4): 2 settimane x 2 persone al CERN = 4 keuro
  - Test Beam del prototipo (MS6): 2 settimane x 2 persone al CERN = 4 keuro
- CONSUMI:
  - 10 layer di acciaio inossidabile 500 mm x 300 mm x 10 mm → 20 cm = 1.3λ~3 keuro (quotazioni di RS)
    - Assorbitore per finalizzazione prototipo 1λ (MS5)
    - Assorbitore per finalizzazione prototipo 2λ (MS7):
  - 1 rivelatore MPGD-resistivo per estensione prototipo a 2λ →5 keuro
- Licenza COMSOL: 5keuro

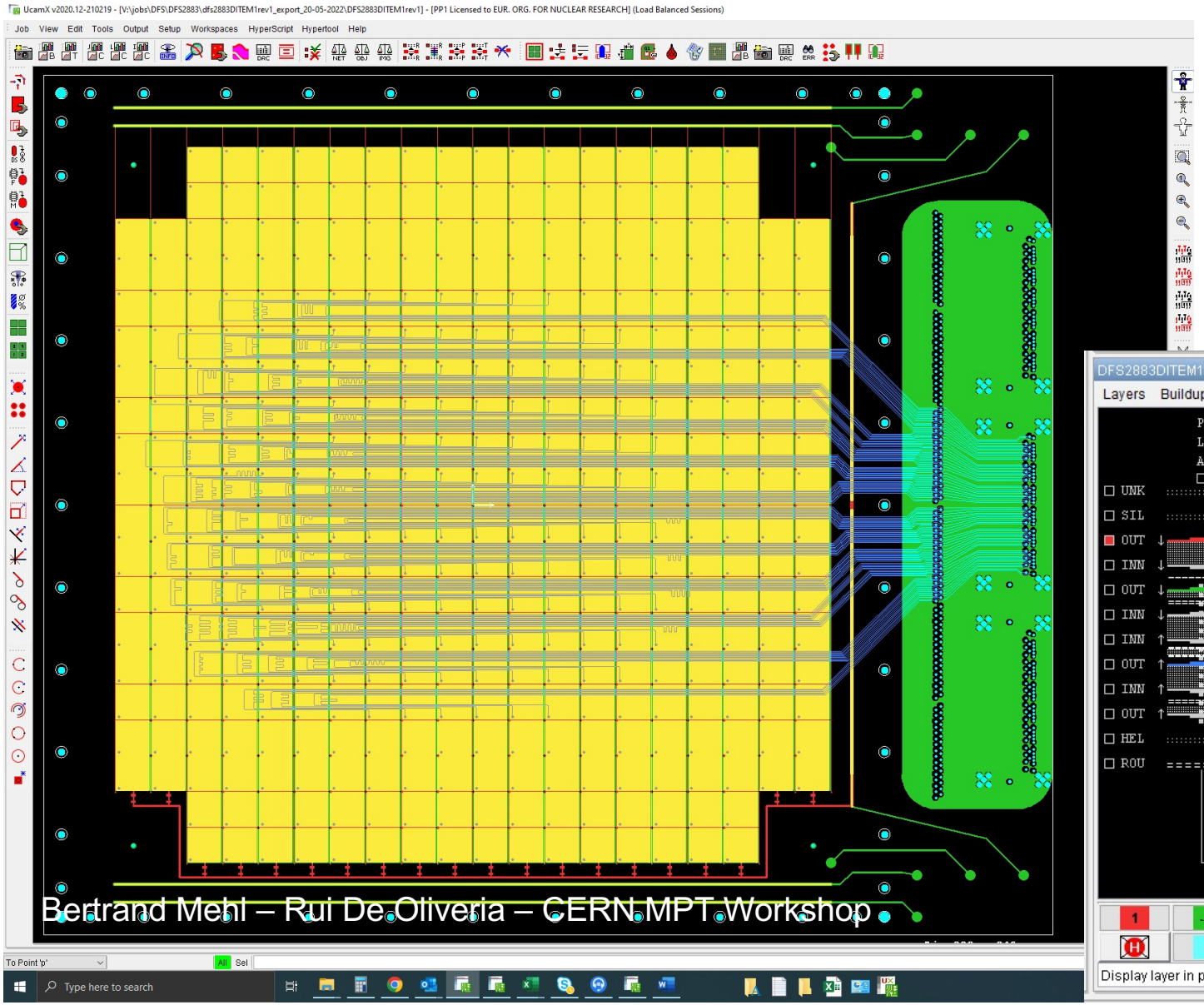
Totale: 21 ke

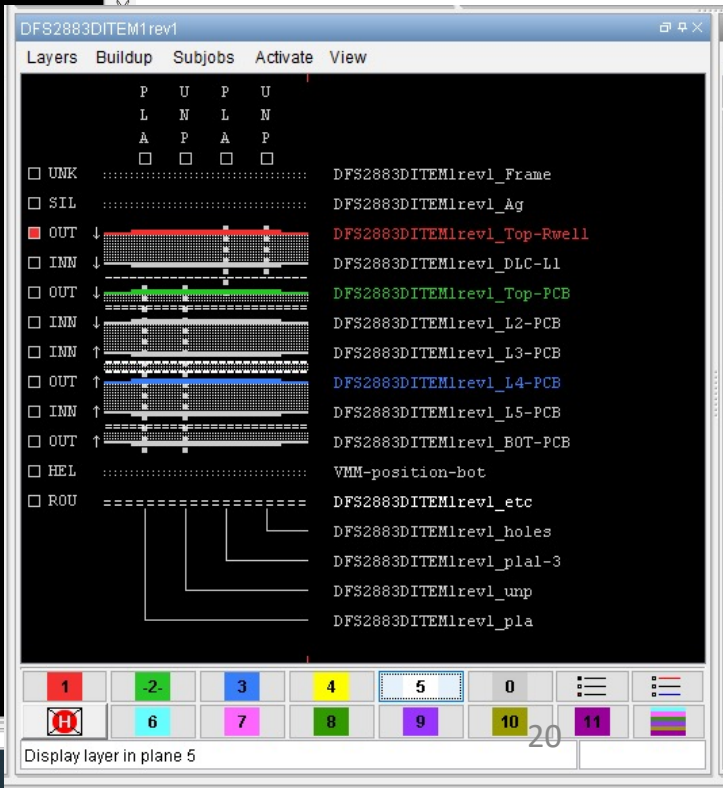
Backup

Assegnazioni 2022

Sigla Loc.	Capitolo	Riunione	Note Alla Richiesta	Rich.	Rich. SJ	Assegn.	Assegn. SJ	Assegn. Dot.	Commento Alla Assegnazione
BA	CON	Assegnazioni	10 Cavi samtec (8 + 2 spares, circa 100 euro/cavo)Â§	1.0	0.0	0.0	1.0		SJ alla presentazione di un piano organico per i prox 2/3 anni
		Assegnazioni	10 FATIC2 plug-in card (8 + 2 spares). 400 euro/plug-in cardÂ§	4.0	0.0	0.0			si auspica cofinanziamento GR5/RD51/LHCb
		Assegnazioni	Electronics concentrator cardÂ§	2.0	0.0	0.0	2.0		SJ alla presentazione di un piano organico per i prox 2/3 anni
		Assegnazioni	Prototipo calorimetro adronico a campionamento con MPGD: 2 Micromegas = 10 kEÂ§	10.0	0.0	0.0	10.0		SJ alla presentazione di un piano organico per i prox 2/3 anni
		Assegnazioni	20 stainless steel sheets (50x30x0.1 cm^3), 100 euros each (+23euros IVA) to build the passive layers of a (modular) calorimetric cell. This material will be also used in future to test other calorimetric-cell layout, using different MPGD technologies as active layers.Â§	2.0	0.0	0.0	2.0		SJ alla presentazione di un piano organico per i prox 2/3 anni
		Assegnazioni	4 Bosch profilates for the mechanical structure and support (180+40 euros IVA) of the calorimetric cell.Â§	1.0	0.0	0.0	1.0		SJ alla presentazione di un piano organico per i prox 2/3 anni
		Febbraio	prototipi 2 micromega	10.0	da sj 10.0	10.0	da sj 10.0		
		Febbraio	sblocco sj -m10 cavi samtec	1.0	da sj 1.0	1.0	da sj 1.0		
		Febbraio	sblocco sj - electronic concentrator card	2.0	da sj 2.0	2.0	da sj 2.0		
		Febbraio	sblocco sj - 4 barre profilato bosch	1.0	da sj 1.0	1.0	da sj 1.0		
		Febbraio	16 FATIC2 plug-in card (14 + 2 spares). 400 euro/plug-in card - richiesta complessiva schede di lettura	6.5	da sj 2.0	2.0	da sj 2.0		
		Totale CON		**40.5**	**-16.0**	**16.0**	**0.0**	**0.0**	
Totale BA				**40.5**	**-16.0**	**16.0**	**0.0**	**0.0**	

Design 20x20 Readout Board





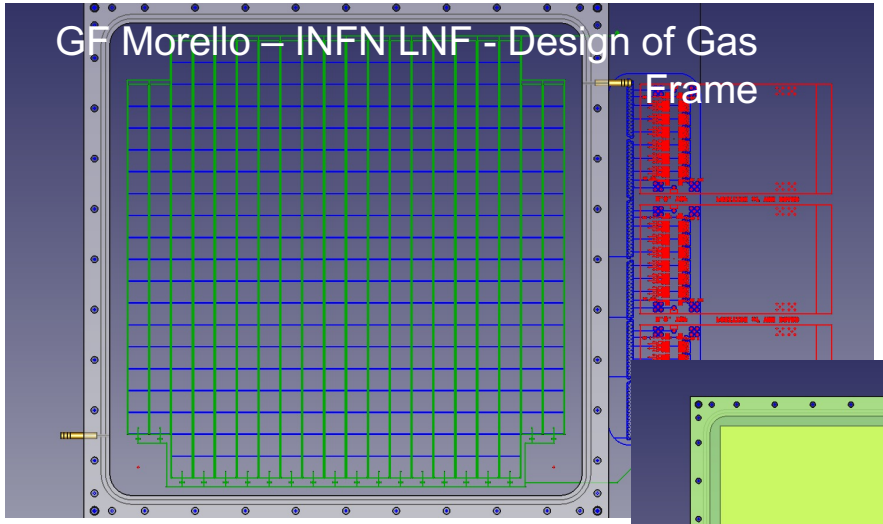
- Common RO board is 6-layer PCB
- 386 pixels – 3 HRS connectors
- Equalized Tracelength

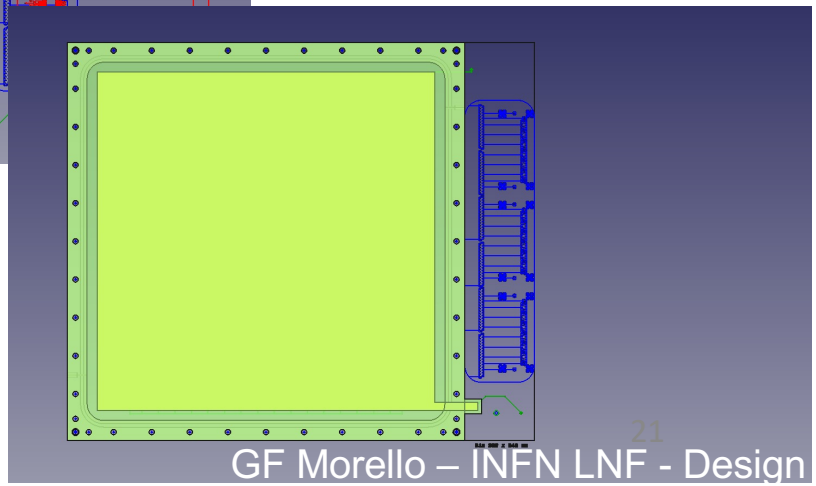
Design of Gas Frame and Cathode

- Design delivered by CERN MPT Workshop contains:
  - Common Readout board on which both uRWELL and uMegas can be constructed
  - Design for uRWELL construction
  - Design for uMegas construction
- Our side: design of Gas Frame and Cathode board that closes the detector

- Gas frame can be constructed at LNF workshop (Peek)

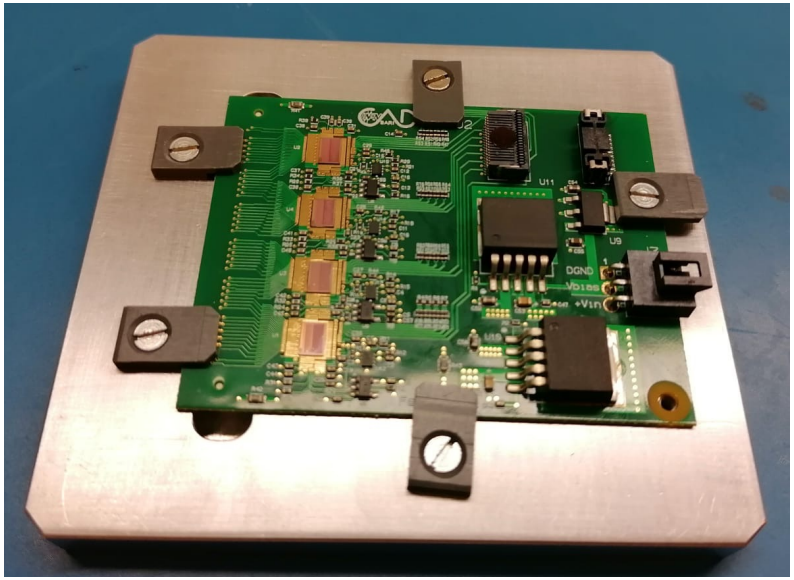
- Cathode board designed. Need to ask offer from ELTOS and place order

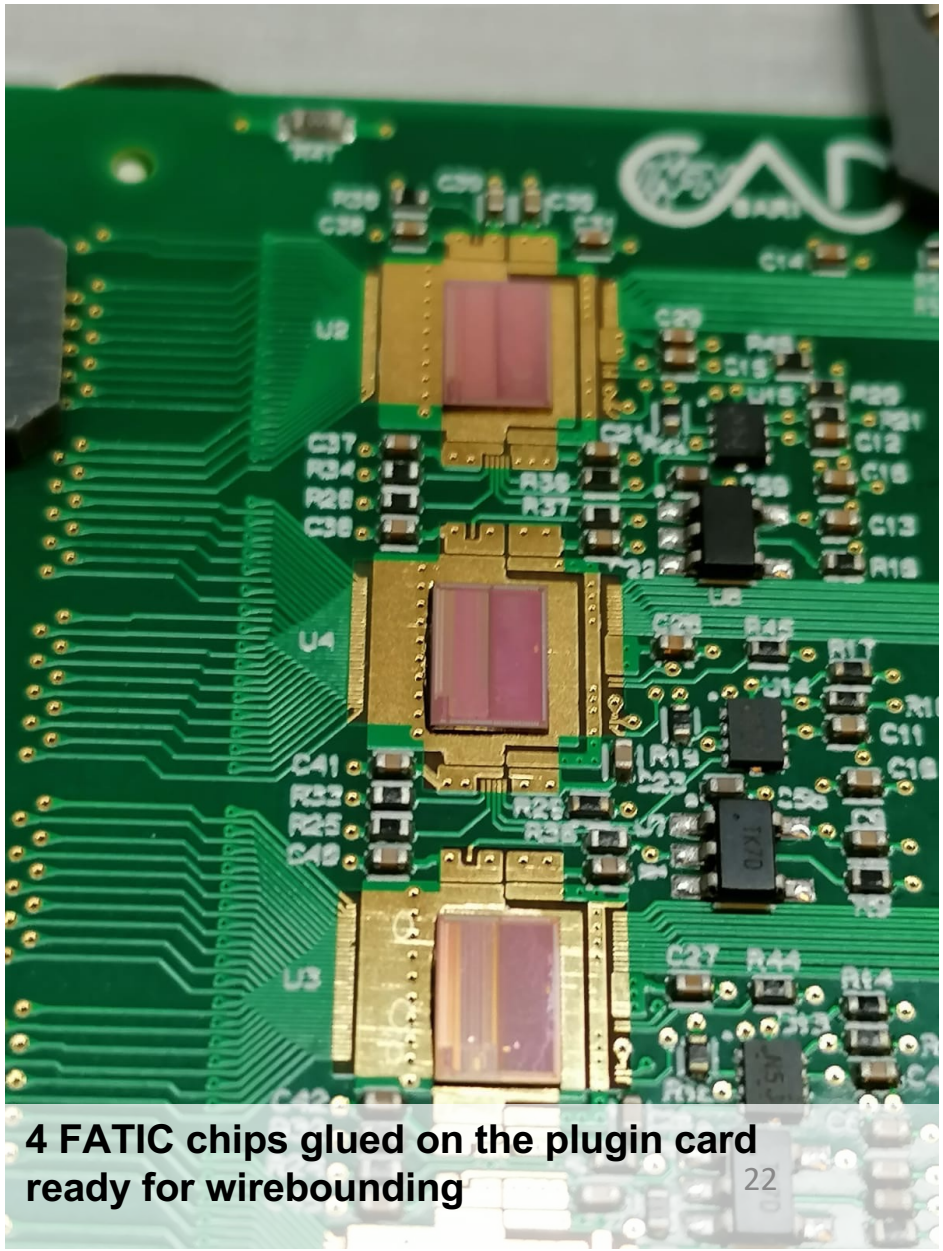




Front-End Electronics: Plugin-Card

- Plugin card with HRS connector processes signals from 128 channels
- 4 FATIC2 asics (32 channels each)
- Plugin-card board designed in 2021
- Order in Febr'22 – PCB produced and components mounted Jun'22
- Currently: chip glueing and wirebounding on 1 card (demonstrator)
- In total 18 cards were produced



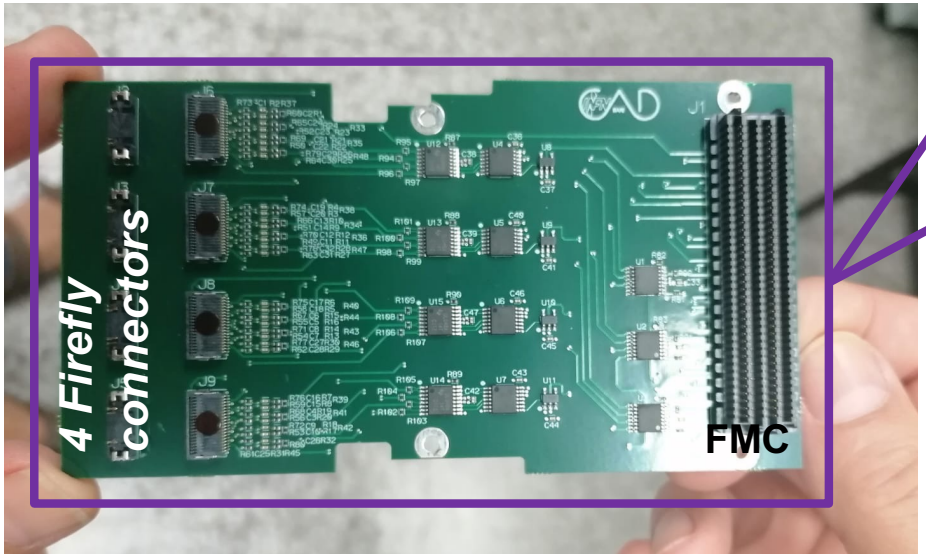


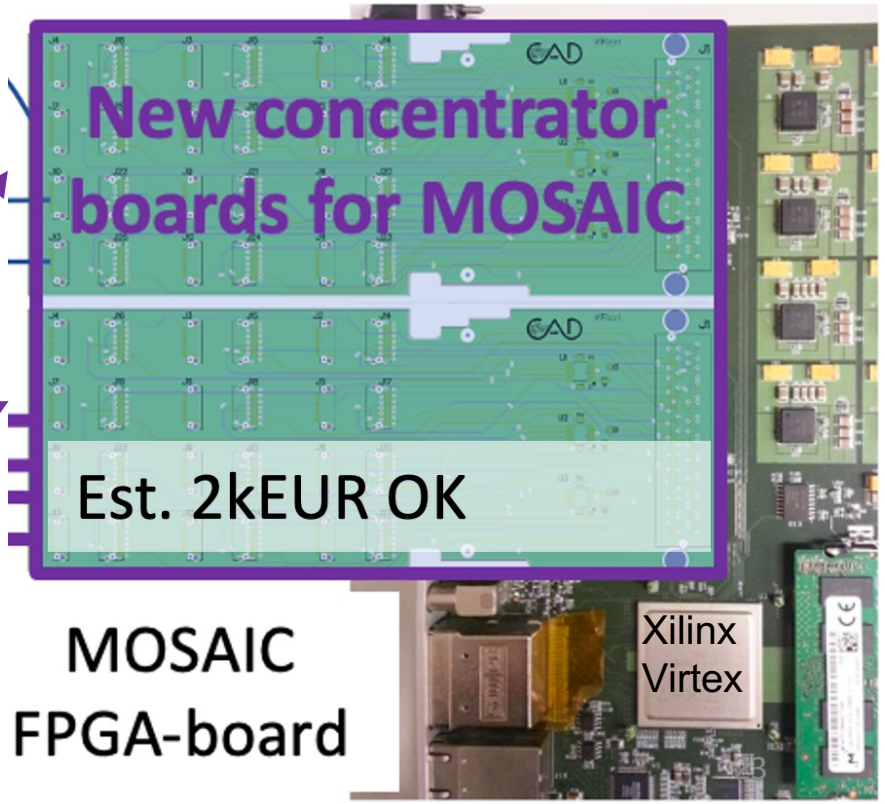
4 FATIC chips glued on the plugin card ready for wirebounding

Front-End Electronics: Back-End

- Each plugin card sends data from 4 FATIC asics to the concentrator board through a SAMTEC Fire-Fly Cable
- Each Concentrator board receives signals from 4 plugin-cards (16 asics)
- Each Mosaic can mount 2 Concentrator boards (32 asics) on FMC
- Concentrator boards designed in 2021
- Order in Feb'22 – PCB produced and components mounted Jun'22

In total 4 cards were produced
We have 2 MOSAIC boards available
They will work in Master-Slave config





MOSAIC Firmware & Software

- *Activity to start ~now*
- **Soon we will have first plugin-card ready**
  - To be connected to concentrator board & MOSAIC
  - FW to be written to communicate to FATICs
  - Tests to be performed – F.Licciulli & G.De Robertis
- **DAQ Software to be developed** – *A.Pellecchia*
  - Read several plugin-cards together
  - Features to be developed:
    - Start / Stop Run
    - Acquire date upon trigger externo; (busy logic?)
    - Write Data
    - S-curves FATIC
    - Monitor Running conditions (errors)
    - … ?
- *A lot of work to be done on this front before we are ready to go to testbeam !!!*

Common Project RD51

Request for Project Funding from the RD51 Common Fund

- Date: *31.07.21*-

Title of project: *Development of Resistive MPGD Calorimeter with timing measurement*

Contact person: *Piet Verwilligen,*
INFN sez. Bari, via E. Orabona 4, I-70125 Bari, Italy
+39 345 74 70 642,
piet.verwilligen@ba.infn.it

RD51 Institutes:
1. *INFN sez. Bari, contact person: piet.verwilligen@ba.infn.it*
2. *INFN sez. Roma III, contact person: mauro.iodice@roma3.infn.it*
3. *INFN LNF Frascati, contact person: giovanni.bencivenni@lnf.infn.it*
4. *INFN sez. Napoli, contact person: massimo.dellapietra@na.infn.it*

Request to RD51: *30 kCHF*
Total project cost: *105 kCHF*

Abstract:

Gaseous calorimetry is dead… long live Gaseous Calorimetry![1] The hadron calorimeter of the Aleph experiment [1], equipped with plastic streamer tubes, was the most performant calorimeter system of the LEP experiments, thanks to the implementation of Particle-Flow in the reconstruction software [2]. At future lepton colliders the most promising strategy to obtain the 3-4% jet energy resolution is to design the collider experiment for Particle-Flow Analysis (PFA) reconstruction by excellent tracking and track separation in a large volume embedded in a 4T magnetic field, combined with a high granularity "imaging" calorimeter. Improved time resolution will play an important role in the future to reduce the confusion in track to calorimeter deposit association. In the last decade resistive Micromegas were developed and tested for calorimetry at ILC [3] and for tracking in high-rate environments [4] at LHC, while new resistive detectors like the uRWELL [5] were developed. Building upon this experience we aim to make a comparative study of various resistive MPGDs for hadron calorimetry, studying the readout granularity, occupancy, cluster size and timing properties to make a synthesis of their performance.

[1] freely inspired by "*Le roi est mort, vive le roi!*

- **Unifies experience of:**
- INFN Na & RM3 >> Resistive MM
- INFN LNF >> uRWELL, GEM
- INFN Ba >> GEM,FTM

8 pages proposal funded for 2 years

Interesting discussion with RD51

Proposal triggered interest and Weissman Institute (ATLAS TGC) will collaborate

2021 Common Project

Approved!

After long review process in MB, those two proposals are approved from this year for two years

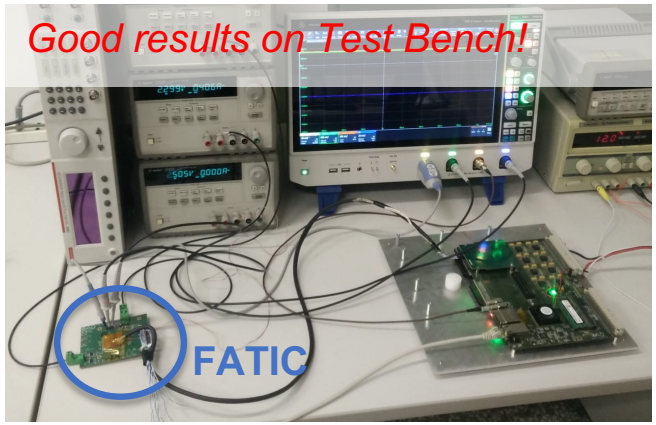
- Piet Verwillligen with 4 institutes
  - Development for Resistive MPGD Calorimeter with timing measurement
- Pawel Majewski with 3 institutes
  - Comprehensive studies of the glass, ceramic- and Kapton-THGEMs in high- and low-pressure TPCs

FATIC plugin card

Past example:
Example 4 boards: 1464 EUR => 366EUR/board

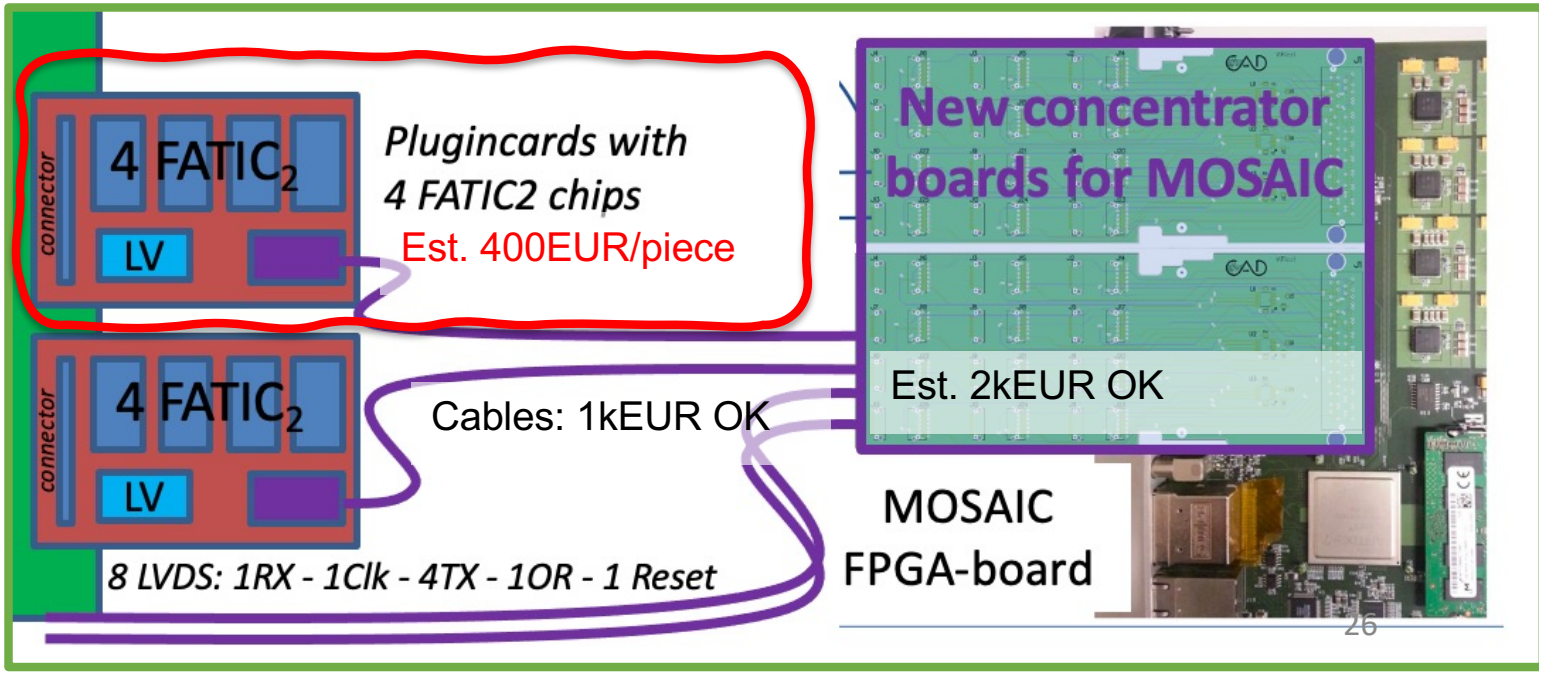
Mosaic Adaptors: PCB	500
Mosaic Adaptors: Components	339
Mosaic Adaptors: Mounting	625

- **FATIC chip:**
  - 32channels; 1 CSA + Timing & Energy branch; 100ps on ~1.5fC: *timing for small signals!*
  - can be used for any type of Micro-Pattern Gaseous Detector
- **64 FATIC chip available @ INFN Bari**
  - Chip development financed in Gr5 2018-2021 (3y) 30kEUR
  - Activity in Gr5: Design – Production & Test on bench
  - Not foreseen to test on detector due to time-scale project
- **64 chips can be mounted on 16 Plugin-Cards (128 channels each)**
  - Project requires 6 chambers x 3 connectors = 18 plugin cards
  - We can read 5 detectors 20x20 + 1 detector 10x10 (only inner channels)
- **Interest from LHCb to test this chip for the uRWELL upgrade**
  - We share the resources @ INFN Ba for design & test
  - Common order, but each experiment pays for the number of cards needed



Cost Estimate based on past plugin cards made

- 4-layer PCB
- Mounting of Fire-Fly and Hirose connectors
- Price does not include wire-bounding asic (will be done @ INFN)



Altre attività LEMMA TB preparation

International MUON Collider Collaboration

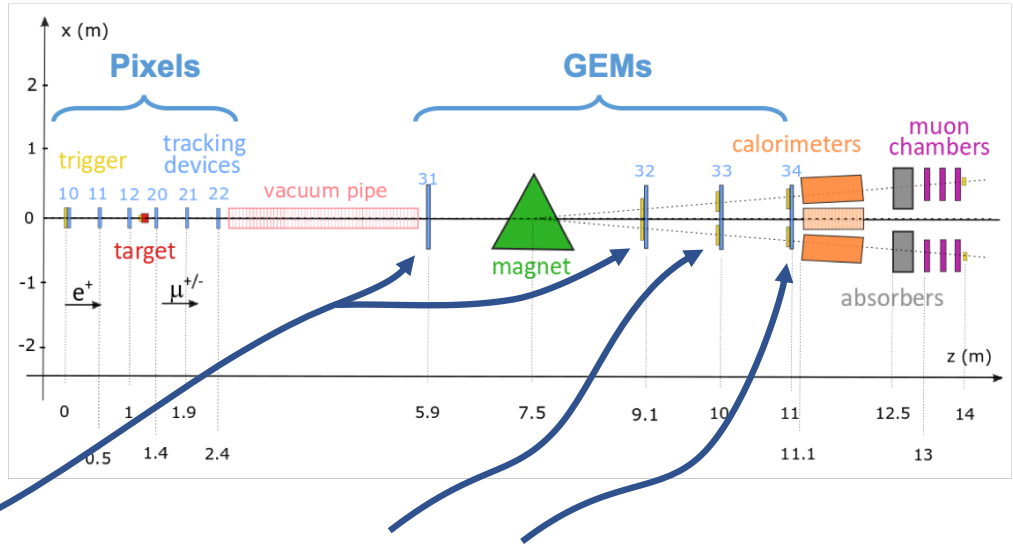
INFN

Preparation for LEMMA-TB: Outlook

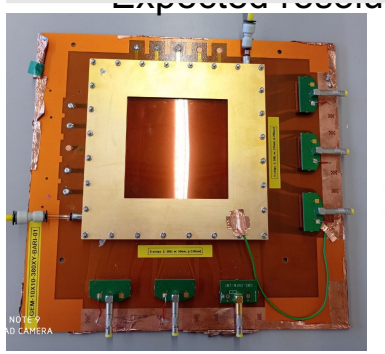
LEMMA Test Beam (2023)

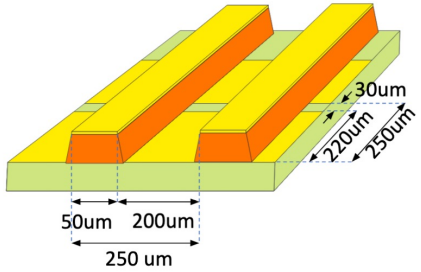
Goal: measuring the **$e^+e^- \rightarrow \mu^+\mu^-$ cross section** and **muon beam emittance** at μ production threshold

Bari participation: muon spectrometer with high-resolution triple-GEM detector



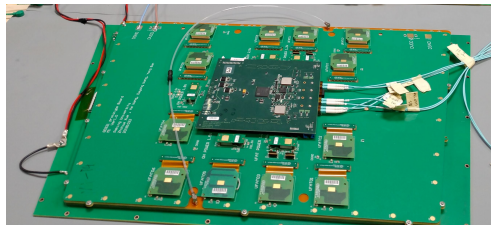
Strict requirement on **telescope space resolution:** 4x triple-GEMs(10x10 cm^2)
Expected resolution 75 μm





Tracking chamber readout strips

In muon arms **CMS Phase-2 triple-GEMs** (GE2/1 station): large-area detector, 380-500 μm space resolution



Single GE2/1 detector module equipped with final front-end electronics

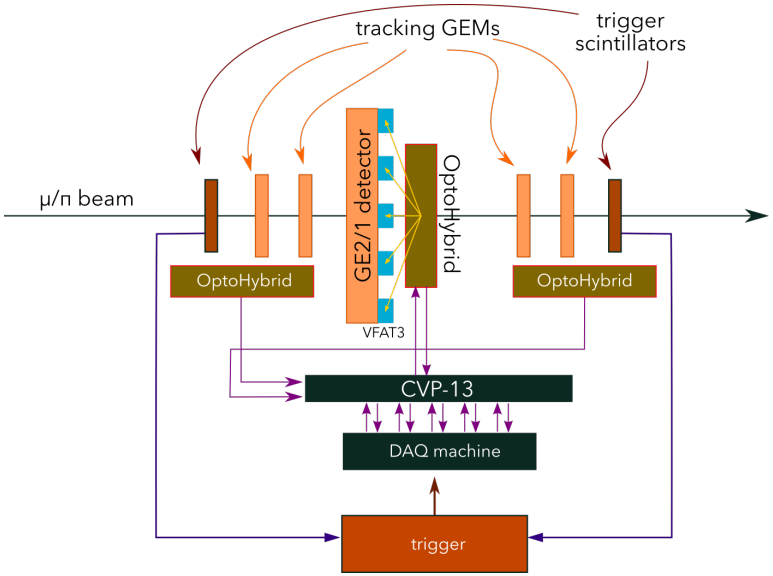
Activities for LEMMA preparation:

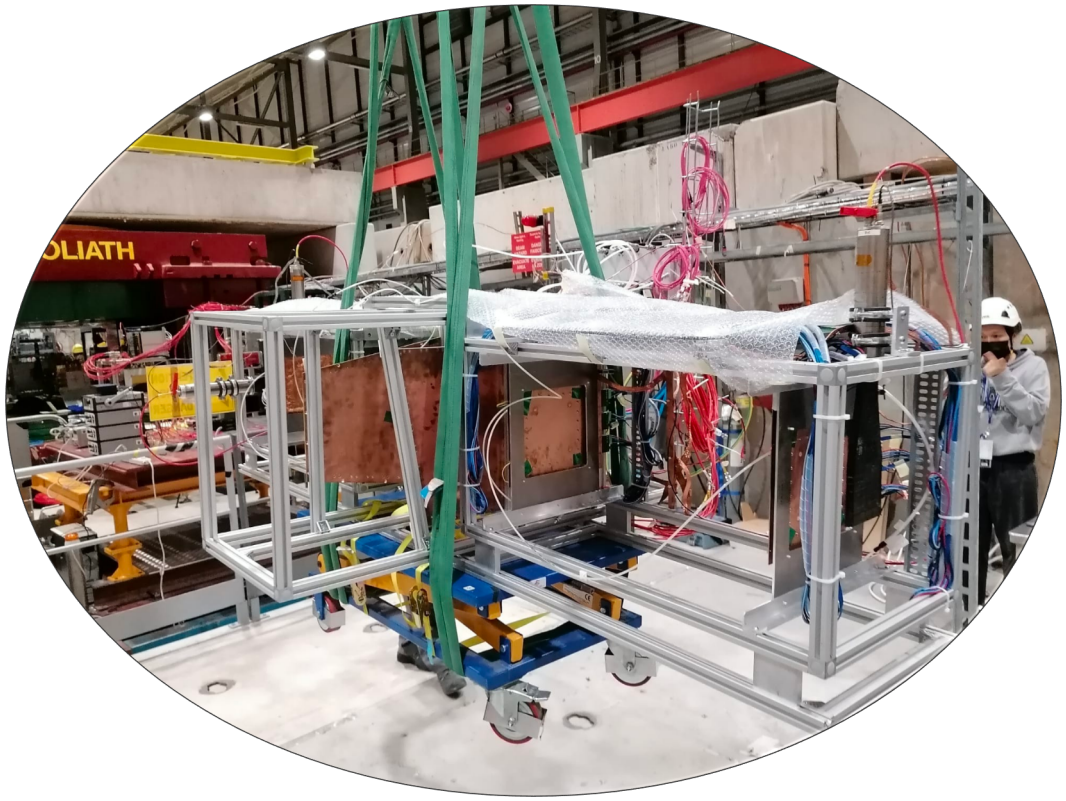
- Tracker **design, production, test**
- GE2/1 **electronics integration**
- Overall **DAQ** development and integration
- 2021 Test beam for **performance measurement → next slide**

Test Beam for LEMMA preparation

Test beam at CERN NA (held in Fall 2021)

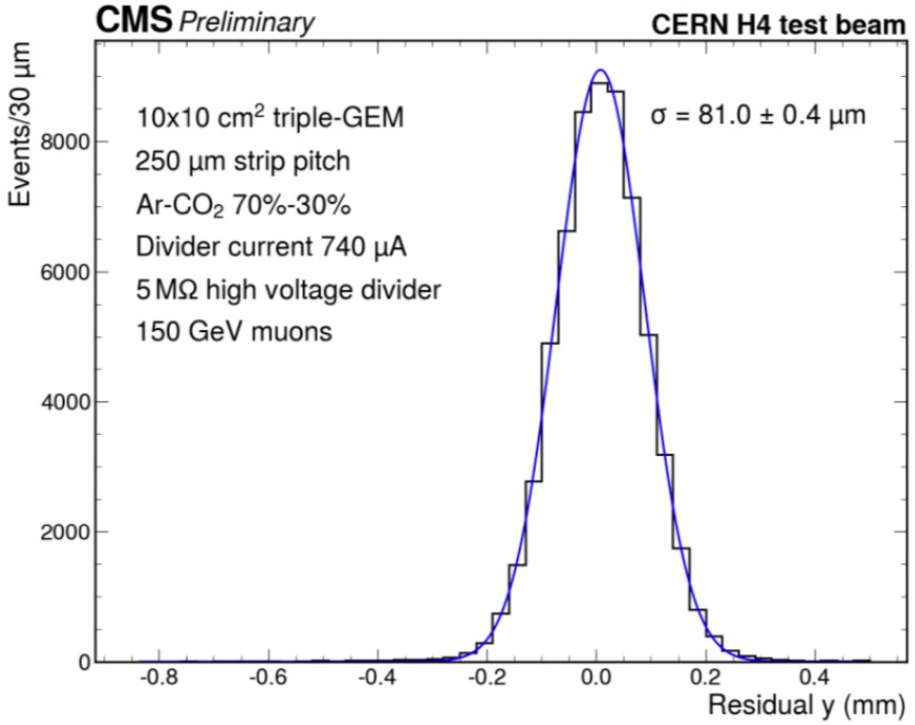
Goal: test of **integration and performance** of **LEMMA GEM detectors** under muon and pion beam irradiation

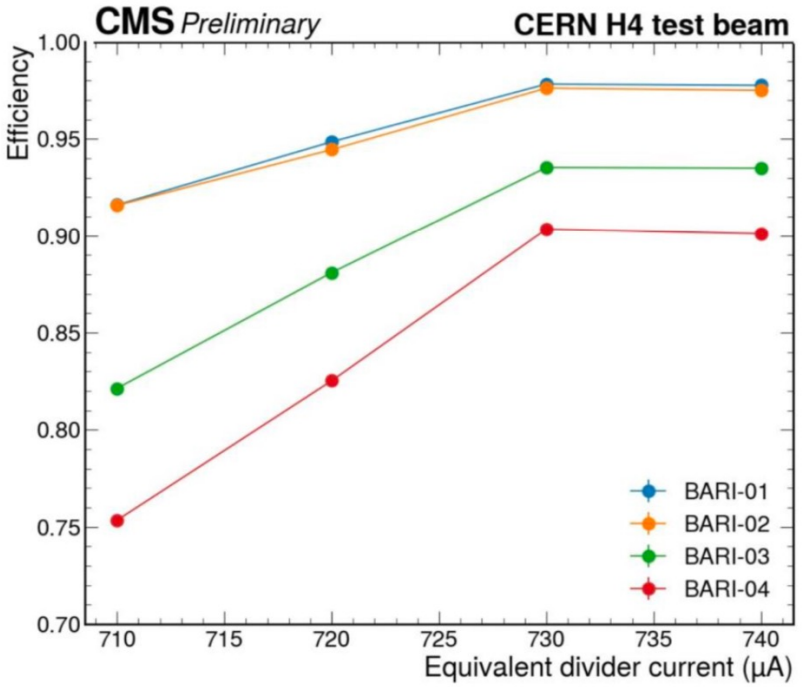




Outcome: detectors successfully tested and operated with final **CMS electronics (VFAT3 chips + OptoHybrid) and DAQ** + **custom compact back-end** based on commercial FPGA (CVP-13)

Results – tracking GEMs



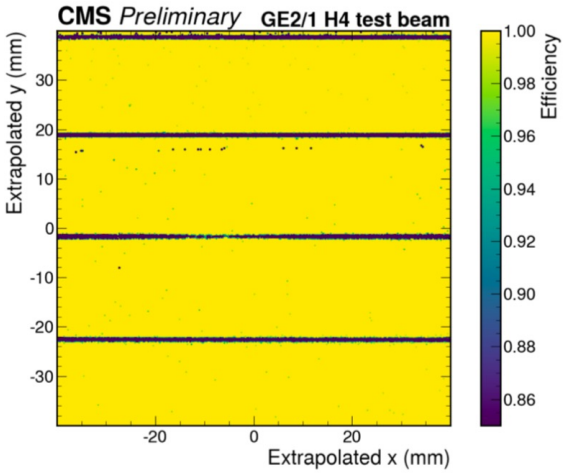


Average space resolution of **81 µm** extracted from residual distribution

1.Efficiency to muons between 90% and 100% for BARI-01 and BARI-02 operated at effective gas gain of 105

2.Lower efficiency for BARI-03 and BARI-04 operated at a lower effective gain

Results: GE2/1

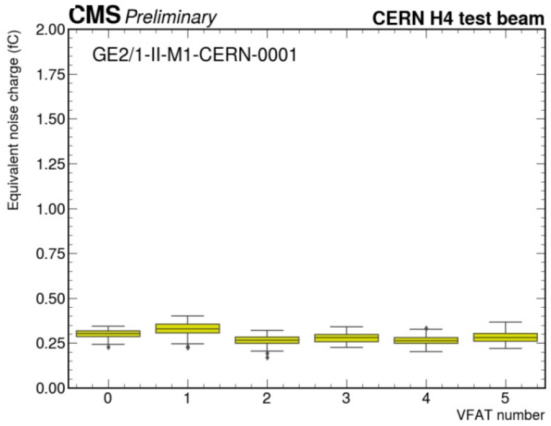


Efficiency map

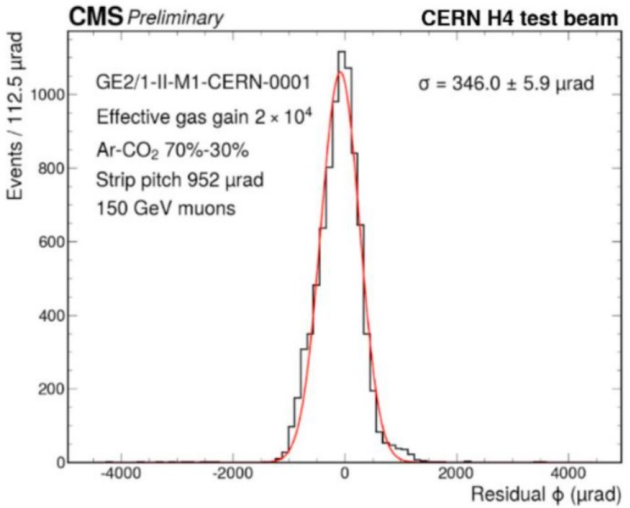
Excellent local efficiency to 150 GeV muons reachable thanks to lower electronic noise at a gain of 2×10^4. Average efficiency limited to 98% by **sectorization dead areas**.

Noise level of front-end electronics attached to GE2/1 detector: the **shielding** provided by the GEB and the several **grounding pins** of the VFAT3 plugin cards allow to keep the **noise below 0.5 fC**

Noise level per VFAT



Residual distribution



346 ± 5.9 µrad space resolution in angular coordinate