DE LA RECHERCHE À L'INDUSTRIE

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sPHENIX

Irfu - CEA Saclay
Institut de recherche sur les lois fondamentales de l'Univers

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TPOT : TPC Outer Tracker

Micromegas for the sPHENIX experiment at RHIC

MPGD Conference 12/2022

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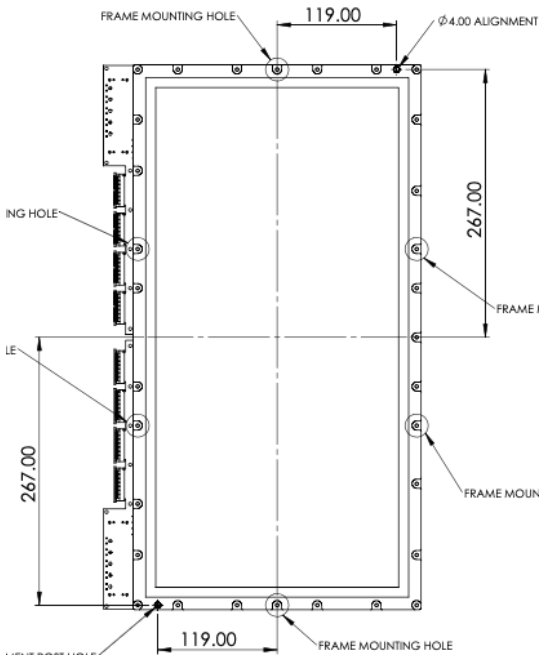
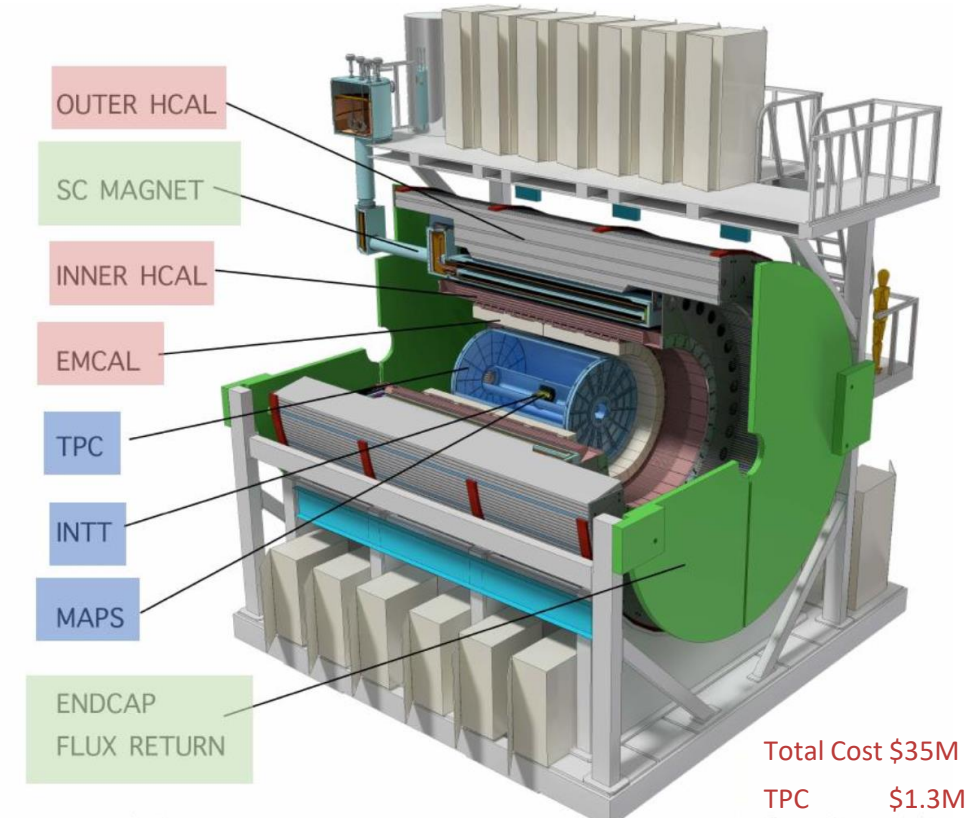
TPOT : MICROMEGAS FOR SPHENIX



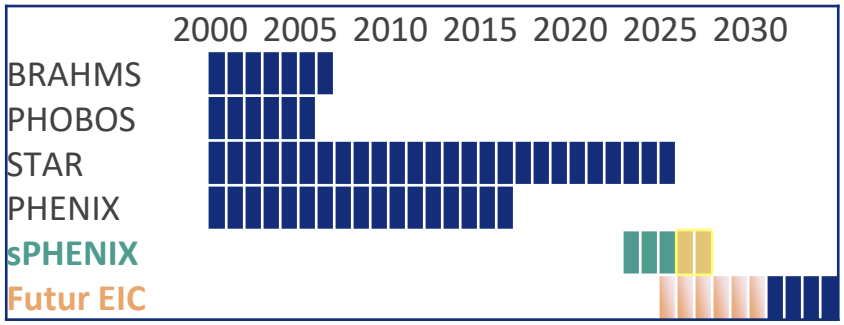
- Space Charge correction for the SPHENIX TPC
- First Prototype
- Green Light and start of production
- Production *Challenges*
- Characterization with cosmic rays
- Installation at BNL
- Status of the TPOT detector

THE sPHENIX DETECTOR AT RHIC



Year	Species	$\sqrt{s_{NN}}$ [GeV]	Cryo Weeks	Physics Weeks	Rec. Lum. $\lvert z\rvert$ <10 cm	Samp. Lum. $\lvert z\rvert$ <10 cm
2023	Au+Au	200	24 (28)	9 (13)	3.7 (5.7) nb^{-1}	4.5 (6.9) nb^{-1}
2024	$p^{\uparrow}p^{\uparrow}$	200	24 (28)	12 (16)	0.3 (0.4) pb^{-1} [5 kHz] 4.5 (6.2) pb^{-1} [10%-*str*]	45 (62) pb^{-1}
2024	$p^{\uparrow}$+Au	200	–	5	0.003 pb^{-1} [5 kHz] 0.01 pb^{-1} [10%-*str*]	0.11 pb^{-1}
2025	Au+Au	200	24 (28)	20.5 (24.5)	13 (15) nb^{-1}	21 (25) nb^{-1}

Data taking at RHIC



2016 Start of R&D
2019-2021 Construction
2022 Installation et commissioning
2023 - 25 Data taking

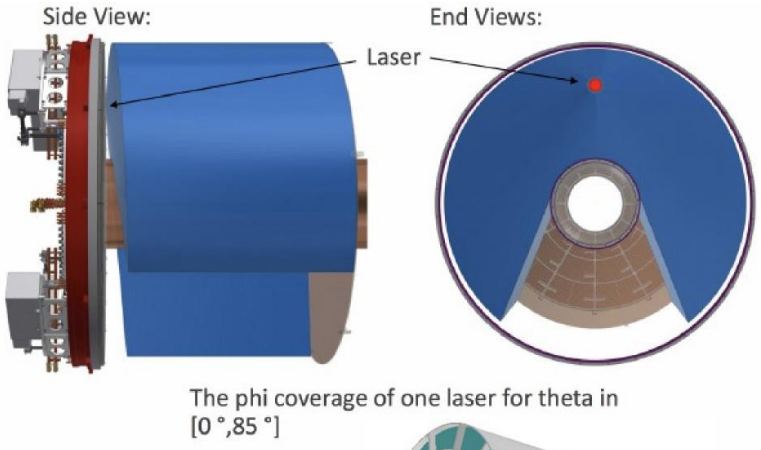
Heavy physics with central tracker based on TPC

- Operated in continuous mode without gating grid
- 1m drift in Ar:CF4 60-40
- 50kHz collision rate in Au-Au
- Read-out quadruple GEM (upgrade ALICE) 12 sectors with 3 detector layers

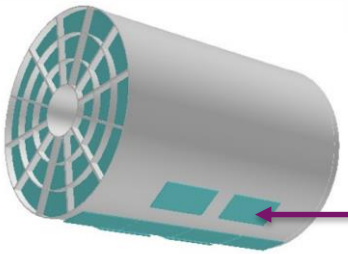
TOOLS TO RECONSTRUCT DISTORTIONS

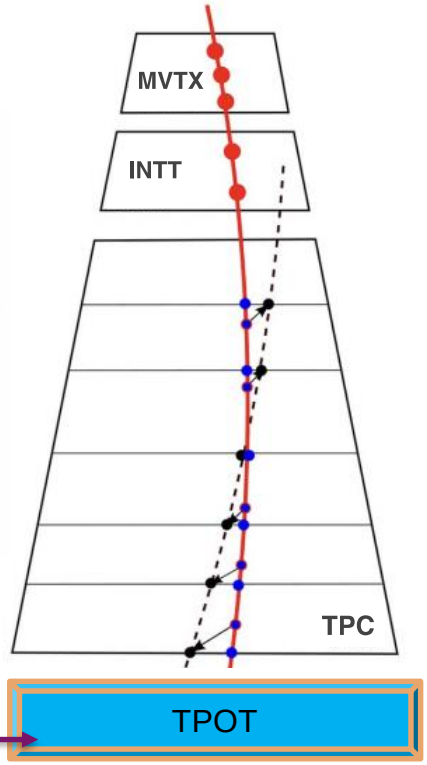
1. **Direct lasers** → static distortions O(cm) during commissioning
2. **Tracks** → time-dependant distortions induced by the beam O(mm)
3. **Diffuse laser system** (and analog current reading) → event-by-event fluctuations (<100µm)

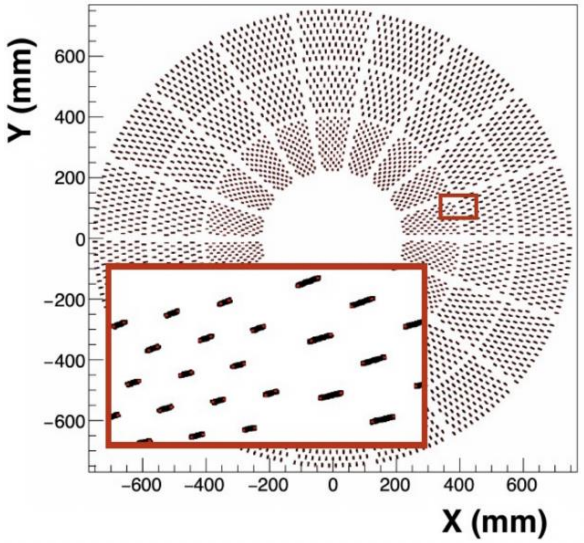
Need to use all **methods in cooperation**, to fully correct TPC distortions with the required precision of 100µm



Direct laser







Pads on the TPC central membrane

TPOT useful for the track extrapolation in the reconstruction of beam-induced distortions

2019

CHARACTERISTICS OF TPOT

Size :

- **Thin detectors** to fit between ECAL and TPC => *Micromegas amplification*
- Covers most of a TPC sector

Environment :

- **Magnetic field** (1.5T): gas mixture to lower Lorentz angle, thin drift gap => *Ar/Iso 95/05*
- **Heavy ions physics** => *resistive layer* (preliminary simulation shown 100spark/s without protection)

No access to detector :

- **Max reliability** with segmentation => *4 HV sectors per module*
- No risk in detector design => *1D micromegas*

Schedule :

- Compatible with fast production => *standard PCB, size* ***compatible with Saclay MPGD lab***
- Maximize production yield with no components on readout => *Independent HV boards*
- Compatible with DREAM electronics for cosmic rays and source characterization at Saclay

Sampa readout :

- Minimum work for DAQ integration => ***TPC FEE***
- FEE compatible => *256 strips per layer*

Performances :

- Efficiency above 90%
- Resolution of 200µm (Rphi) 300µm (Z)

=> Micromegas detector natural choice

Specifications Start of 2021

2019

TPOT : MICROMEGAS DESIGN CHOICES

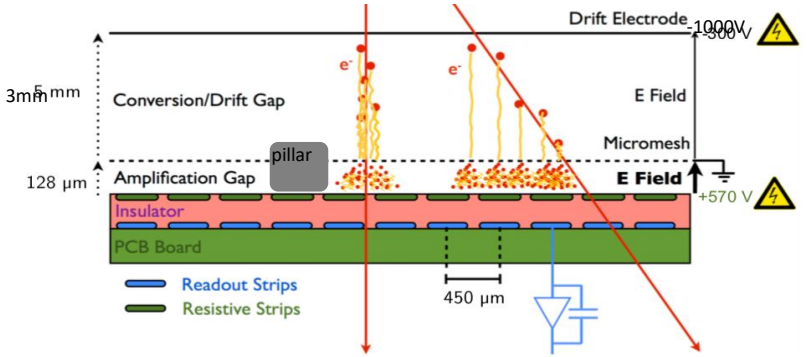
1 TPOT module is two 1D Micromegas layers (rΦ and Z)
- Design is simple
- 3mm drift
- No R&D on 2D resistive necessary

Resistive layer with strips
- Necessary with heavy ions environment
- Occupancy is high, strips limit cluster size
- Division in 4 HV sectors for reliability (no access after installation)

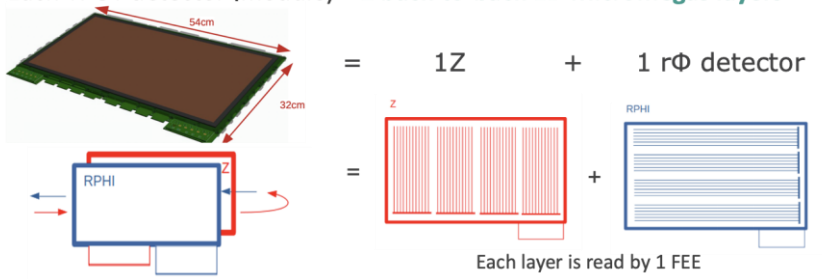
Reuse of TPC services
- **SAMPA FEE** + cooling

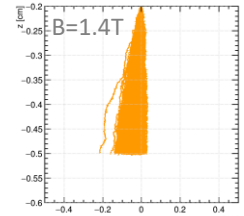
Z Pitch is 2mm, rΦ pitch is 1mm
- Each layer is read by 1 FEE
- Straight strips for simplicity and low capacitance

No soldering design
- Mec8 connectors on side of PCB (1.6mm thickness)
- HV card with FSI connectors
- Drift connections through springs in frame

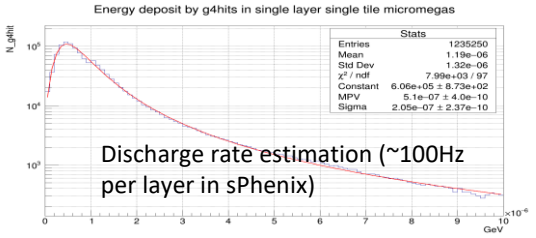


Each TPOT detector (module) = **2 back-to-back 1D Micromegas layers**





Lorentz Angle simulation



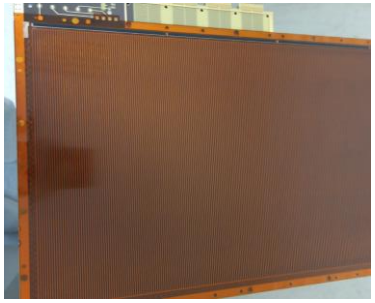
Discharge rate estimation (~100Hz per layer in sPhenix)

Specifications 06/2021

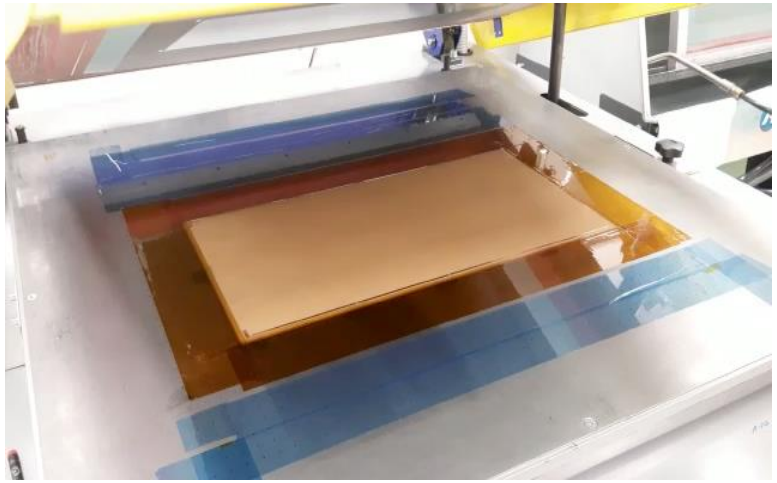
2019

First Prototype

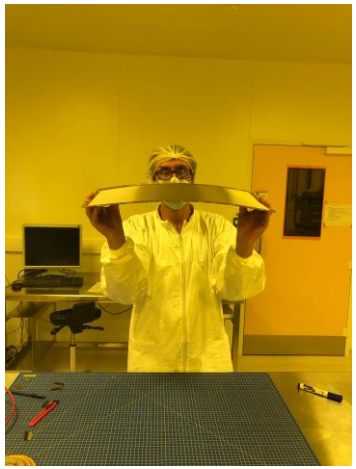
PCB at Saclay



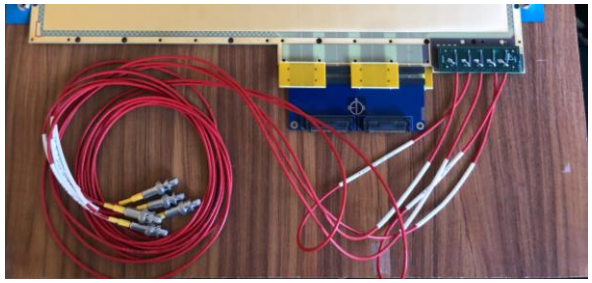
Resistive foil pressed on PCB

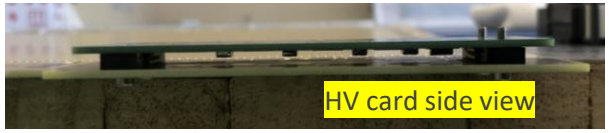


Printing resistive strips at Saclay

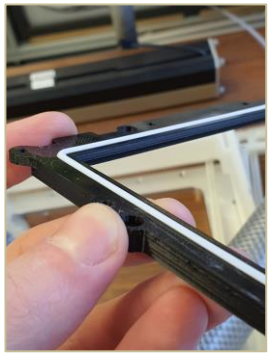


First test process





HV card with HV filter on FSI contact connector

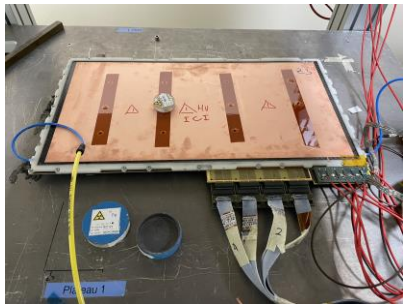


3D printed frame

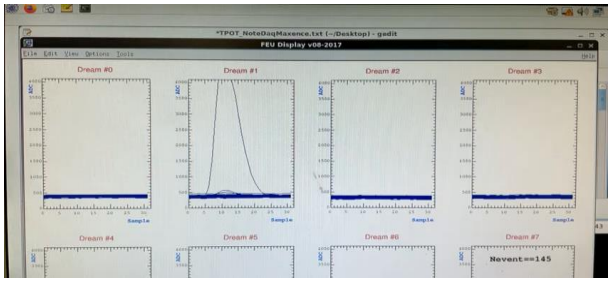
Frist carbon drift

Frist carbon drift + happy Cyril

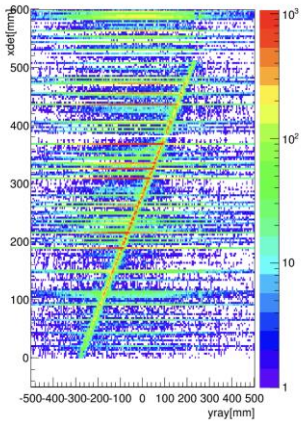
PROTOTYPE RESULTS

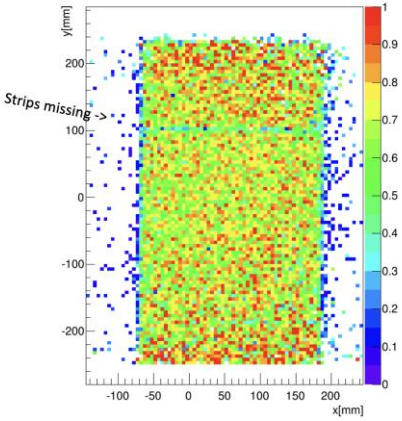


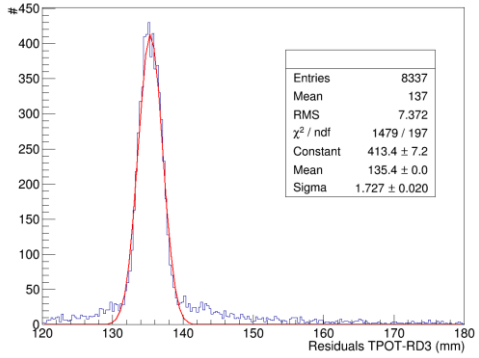
Test with 55Fe

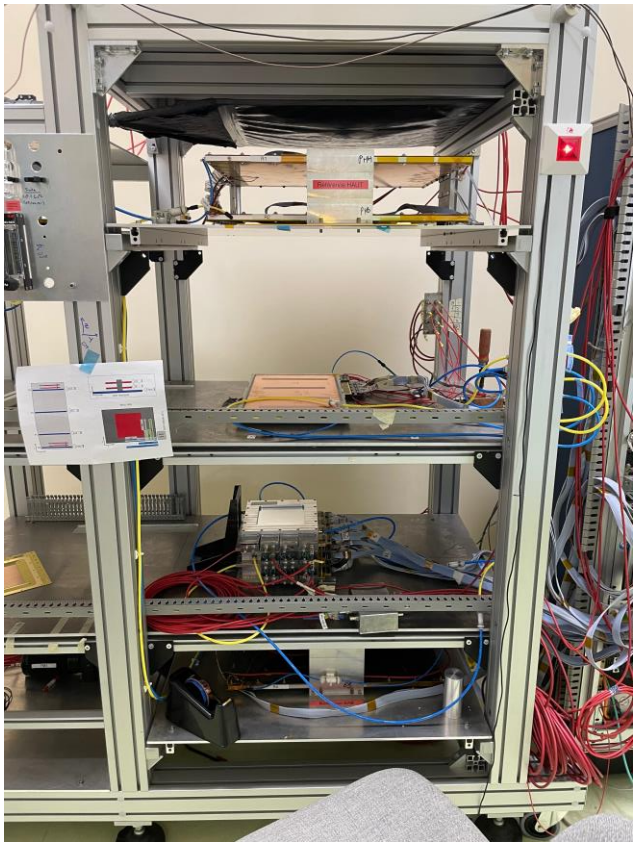


First cosmic rays signals with DREAM on TPOT









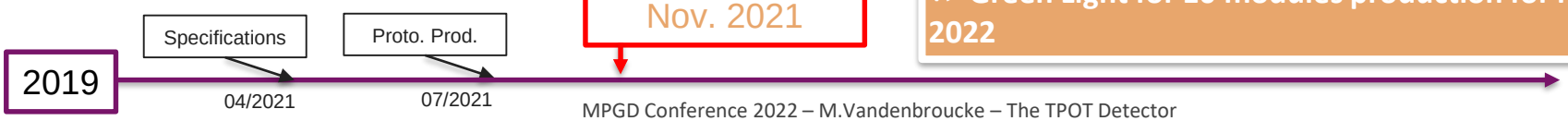
Test with cosmic rays

Performances of prototype

- Efficiency 80% (??)
- Resolution ~1 mm (??) with cluster size 1.2
- But only Z layer (2mm)

Prototype tests Nov. 2021

+> Detector performances are not critical for TPOT
+> Green Light for 10 modules production for mid 2022



GREEN LIGHT TO PRODUCTION

End of 2021 : Go for 10 modules production for June 2022

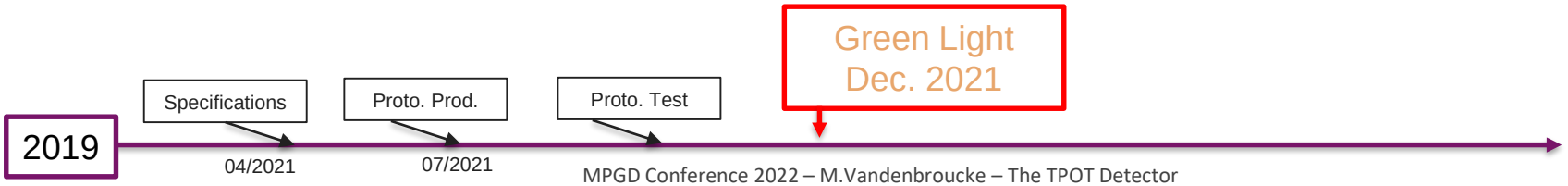
- Great news we have a contract and we'll go into sPHENIX if we deliver
- Few modifications on the readout side but design mostly final
- 3mm drift made in carbon works great
- **But :** RPHI layer not tested, Sampa not tested with mm, contracts take time

+> Supply chain issue and PCB production

- Prices went x5 in a few months
- Delivery time went from 2 weeks to months

+> And also :

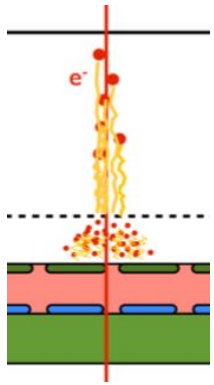
- Performance of prototype are not ok
- Production Engineer leaves for another project
- Production yield is very low (detectors are not stable)
- Delivery date set for June …

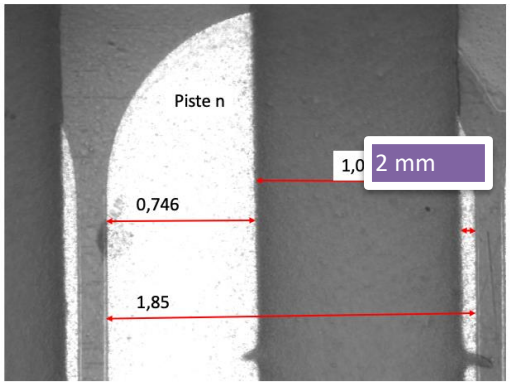


Z (2mm) Resolution issue

TPOT Z prototypes (10/2021) :

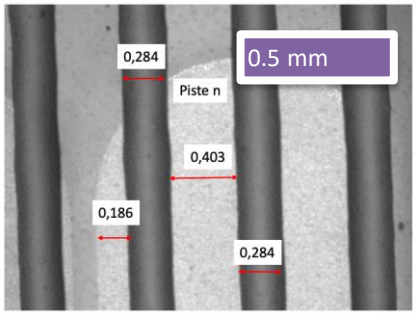
- Copper strip of 2mm with resistive strips of 2mm pitch 1mm wide
- Reconstructed position of the resistive strip and not the particle
- Readout design also done with zigzag and ordered

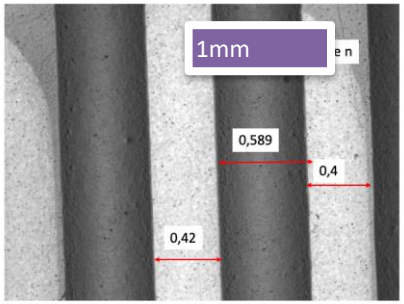


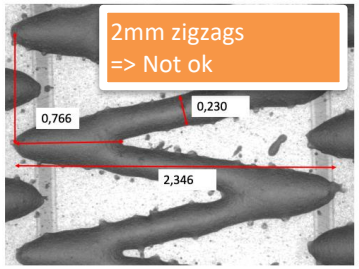


+> Prototype to test resistive layer :

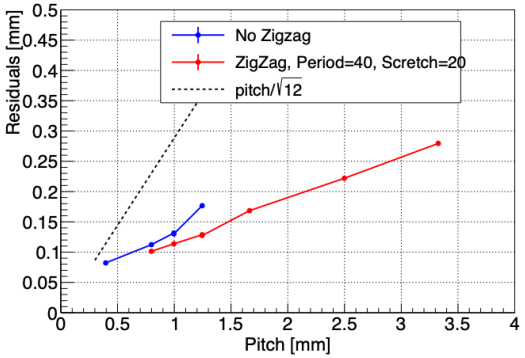
- Efficiency OK 98%
- Zigzag strips too high in resistivity
- Resolution pitch dependent : ~**650um** for 0.5mm res. pitch



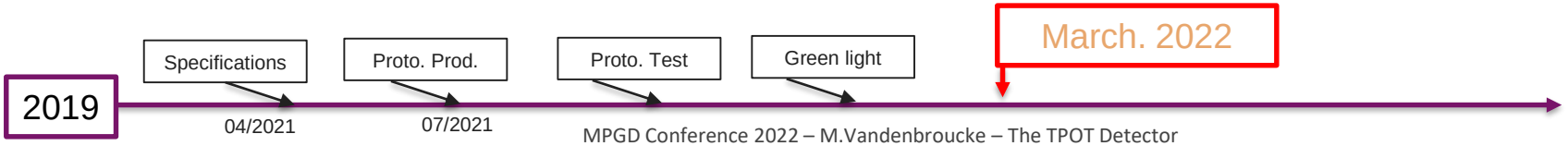




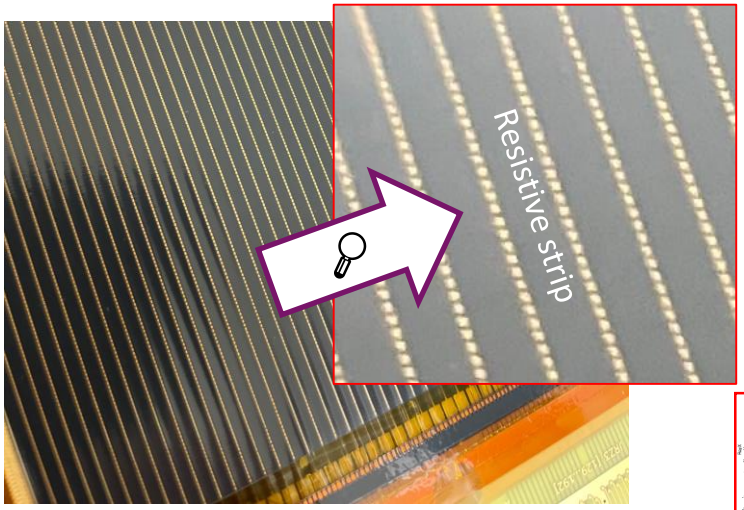
Prototype with 3 different resistive zone



ZZ R&D from LDRD program “Zigzag”



Z (2mm) : Zigzags to the rescue



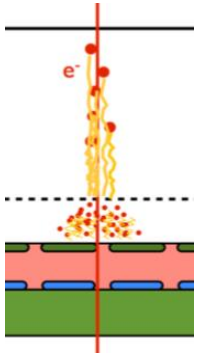
Large resistive strips over zigzag strips

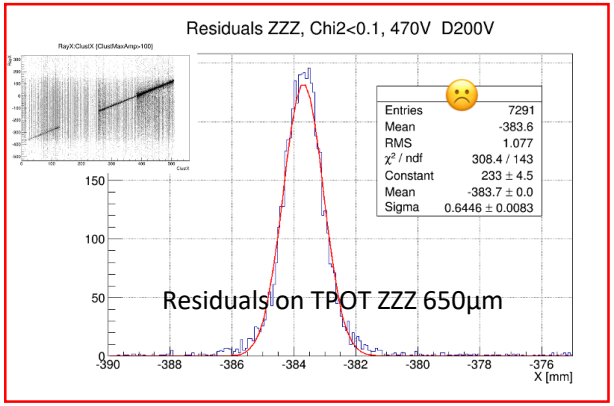
02/2022 : New TPOT Z Zigzag (ZZZ)

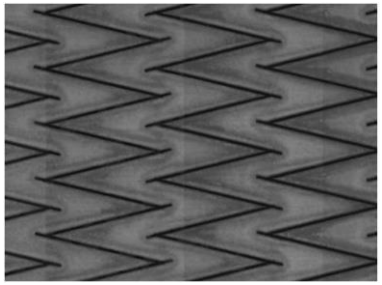
- Zigzag from LDRD program

⇒ **Efficiency OK 98%**

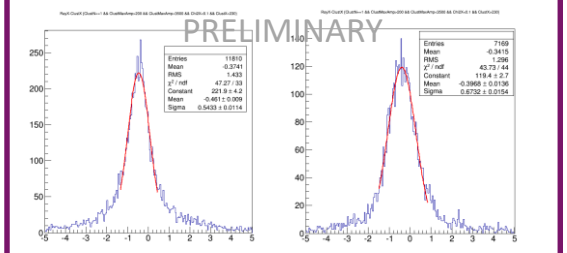
⇒ **Resolution ~650µm**





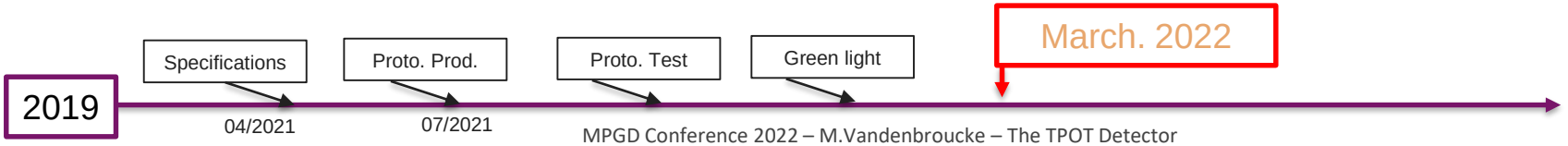


ZZ strips



TPOT ZZZ and double pitch resistive
=> 2mm:620µm, **0.5mm:470µm**

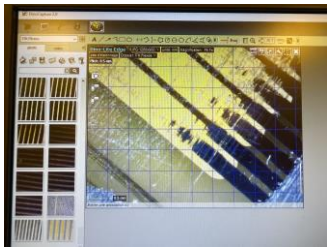
=> 470um resolution is good enough for the TPOT project since integration time can compensate resolution
=> Noise level are ok with SAMPA

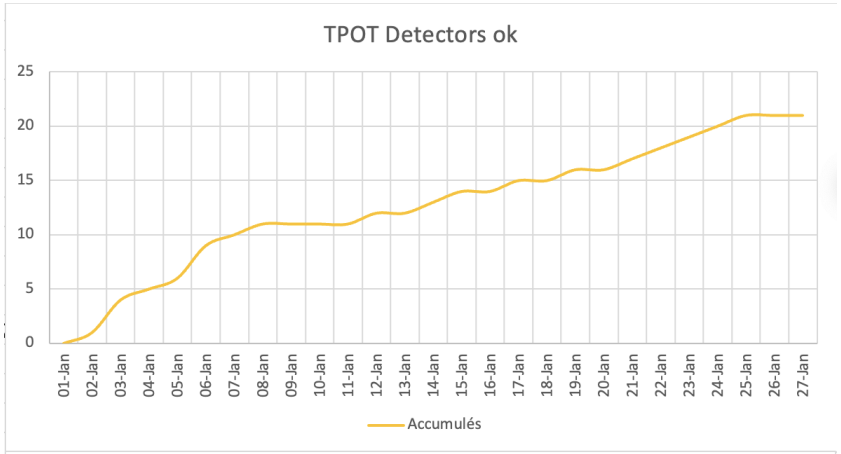


PROCESS PRODUCTION - YIELD

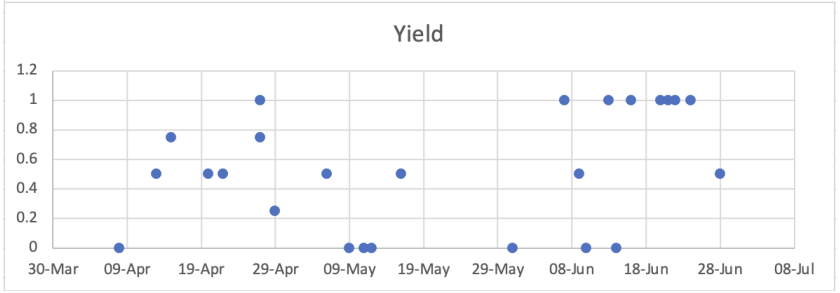
Improvement to fix the poor yield :

- Systematic long HV test
- Debulking
- Resistive layer removal
- Pressing on good press at CERN (thx Rui !)
- Missing pillars on design fixed during production

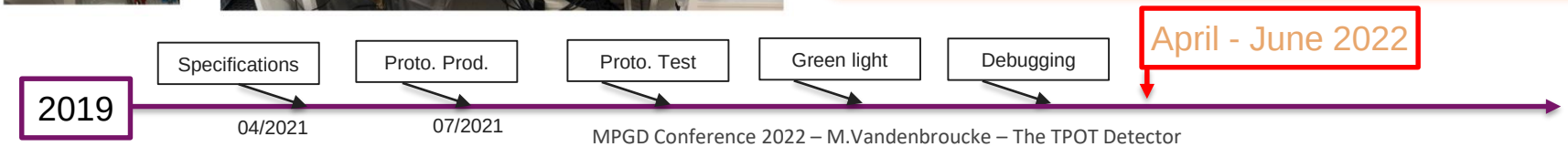




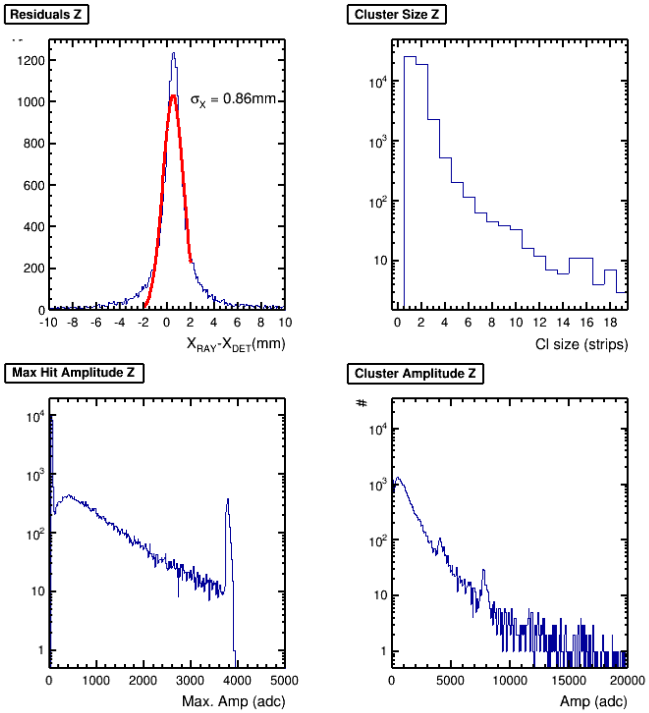
HV station with 48 HV channels + monitoring developed for NSW



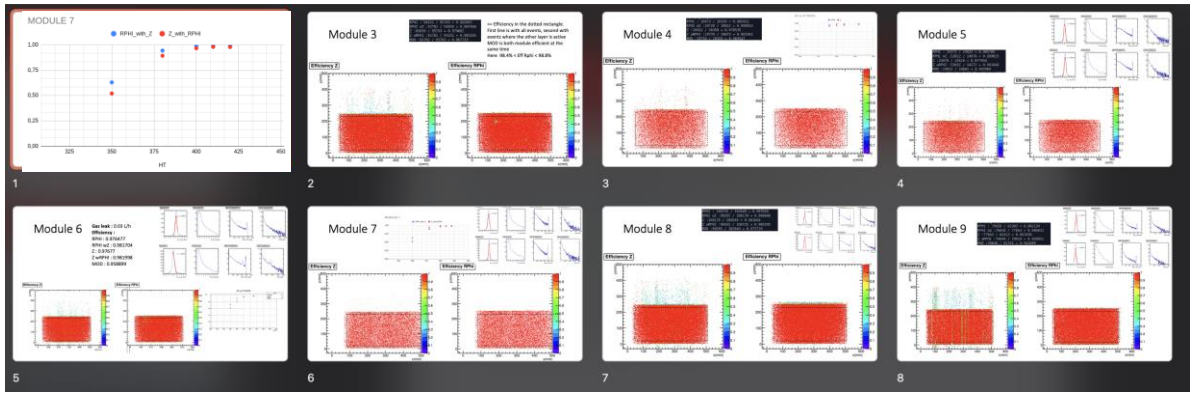
+> at the end we had ~90% success on the first try



PRODUCTION MODULE QC WITH COSMIC RAYS



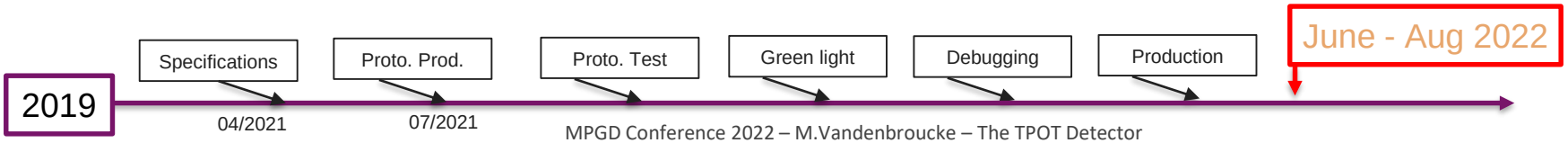
Module 7 monitoring plots



Module	1	2	3	4	5	6	7	8	9
RPHI eff		98 %	98 %	99 %	99 %	98 %	99 %	99 %	99 %
Z eff		98 %	98 %	98 %	99 %	98 %	98 %	98 %	98 %
Module eff		97 %	97 %	97 %	97 %	96 %	97 %	97 %	97 %
Gas leak	0.03L/h (detection limit of the setup)								

Operating points for testing:
Ar/iC4H10 95/5
Drift HV: -200V
Amplification HV: +420V

+> Shipping to BNL in two batches in August 2022

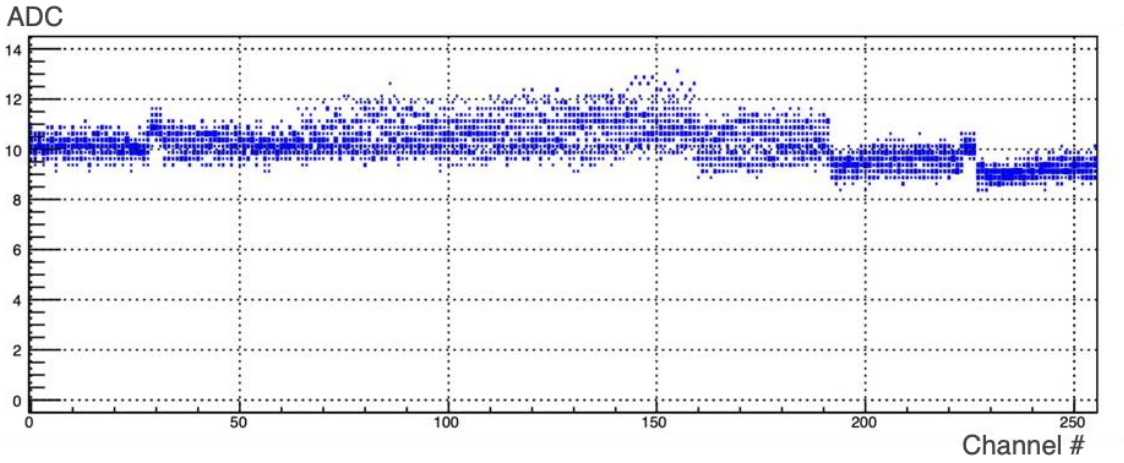


First measurements at BNL with SAMPA

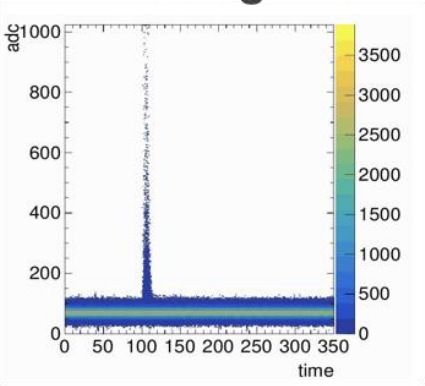
Assembled boards

1 FEE per detector (2/module)
512 channels per module

Noise measurements



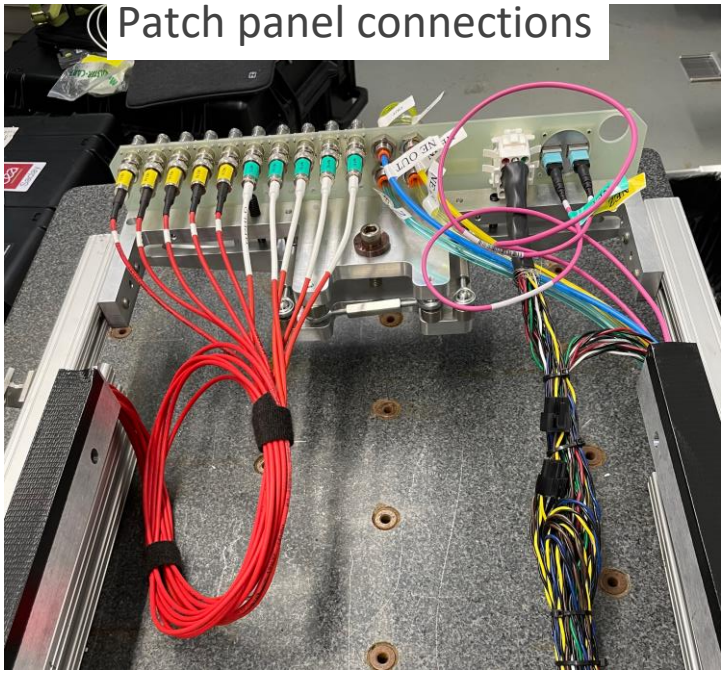
First signals

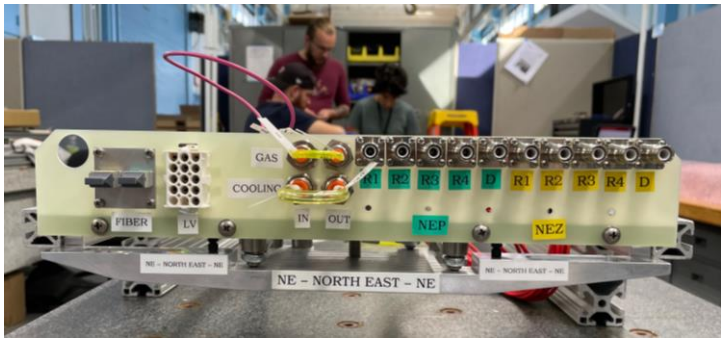


TPOT team at BNL[X]

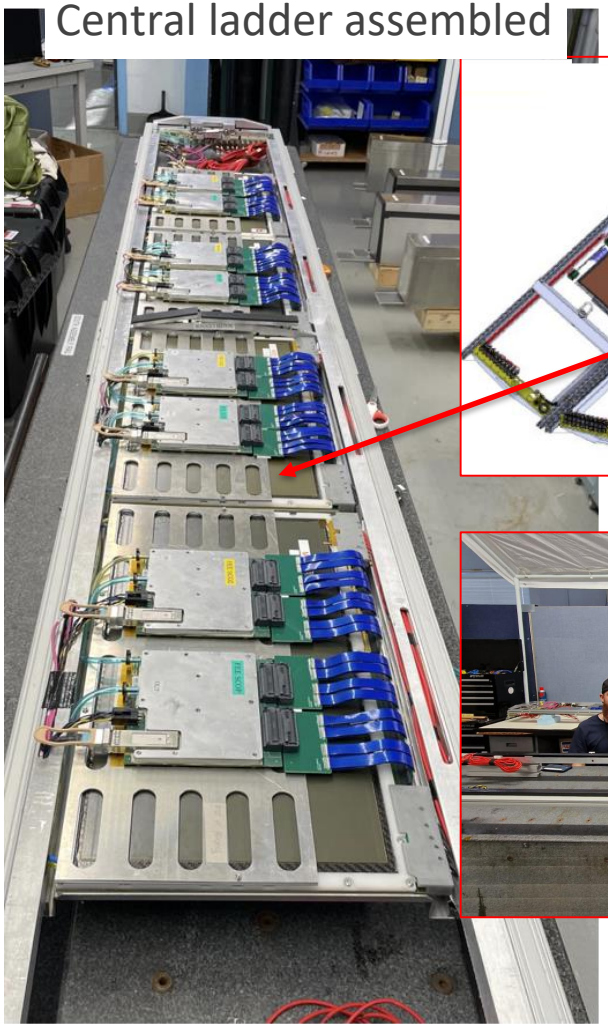
INSTALLATION ON LADDER – CABLING

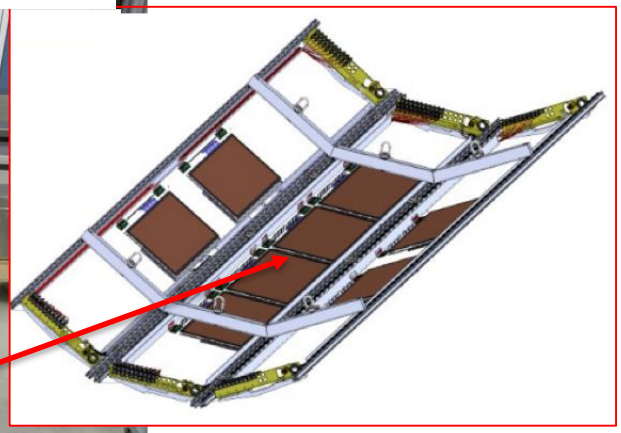
Patch panel connections





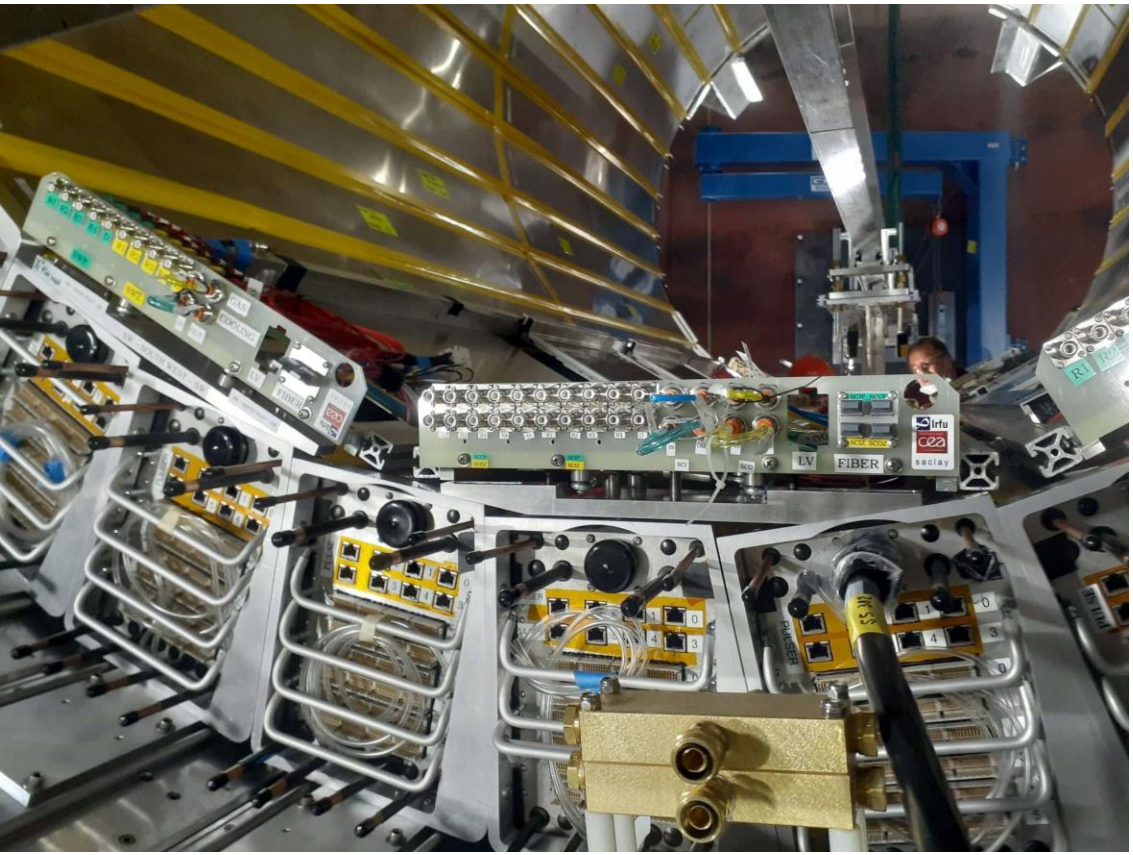
Central ladder assembled





2019 → Specifications (04/2021) → Proto. Prod. (07/2021) → Proto. Test → Green light → Debugging → Production → shipping (08/2022) → Oct. 2022

OUTLOOK



The TPC Outer Tracker :

- Give a reference point outside of the TPC
- 8 Micromegas modules to cover 3 sectors
- 3 ladders (2-4-2)

Micromegas detectors :

- Design, production, and test at Saclay
- PCB from the industry, Kapton base from CERN
- 3.5 months of production with debug

Many challenges :

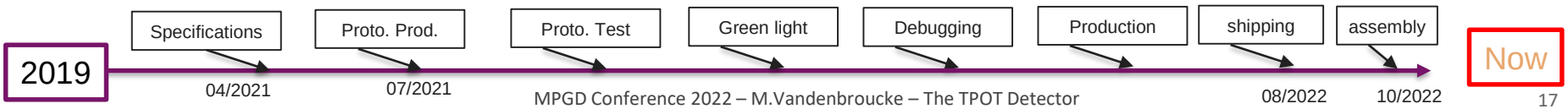
- Supply chain crises
- Covid still around
- Understanding the resistive layer
- Understanding the cooking procedure to make a bulk
- Test with DREAM but SAMPA used

Now :

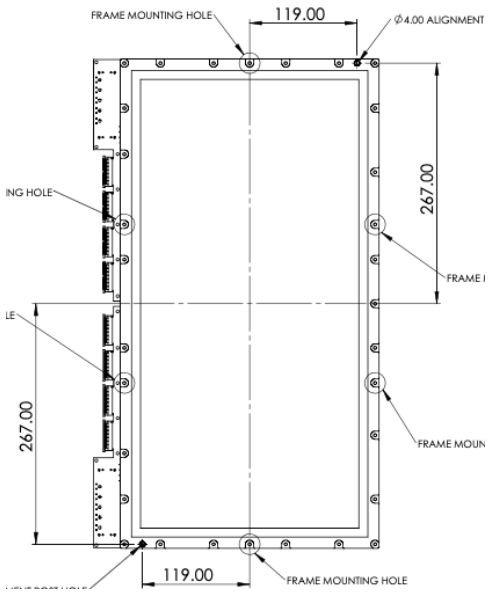
- Installed in sPHENIX since 9/12
- Cabling and test before TPC installation
- Data taking before the summer

Next : Micromegas EIC

- R&D for good 2D resistive Micromegas
- High R full resistive layer
- Different 2D readout
- Test beam at MAMI in June



TPOT : MICROMEGAS POUR SPHENIX

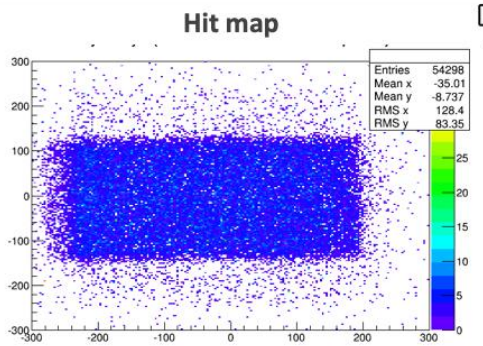


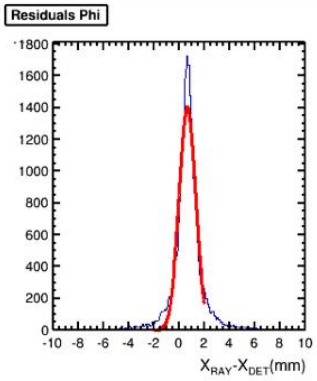
SPARES

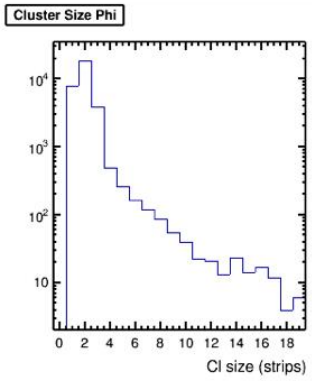
TPOT TESTS AND VALIDATION

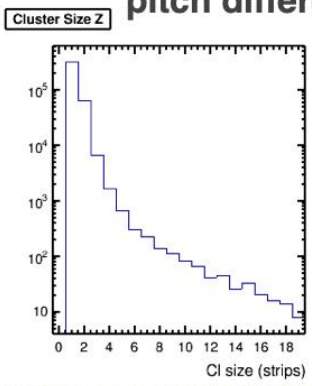
Detector performances with cosmic test bench @ Saclay using DREAM electronics

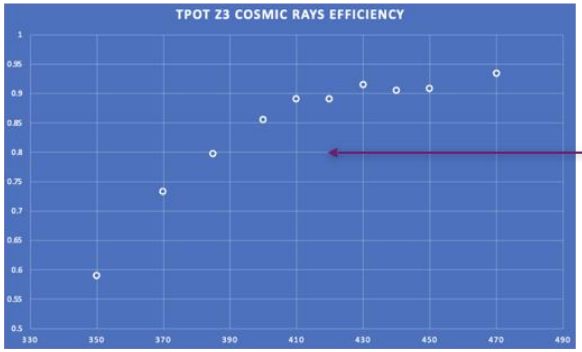
zigzag pattern compensates the pitch difference



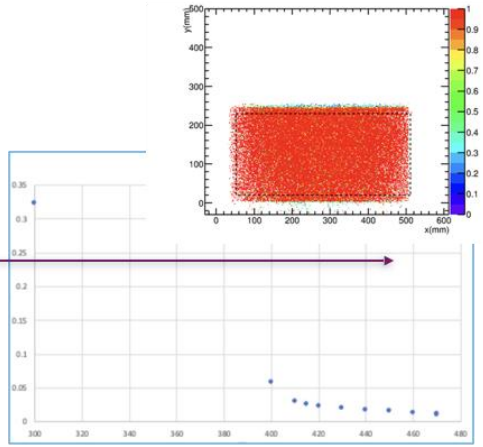




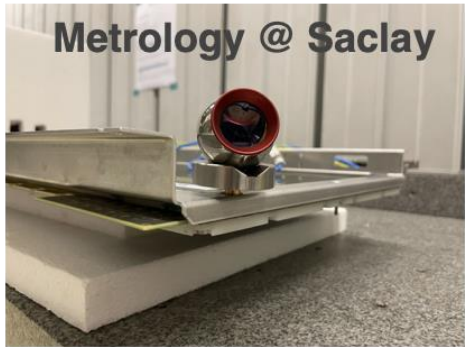




Efficiency plateau with cosmic rays

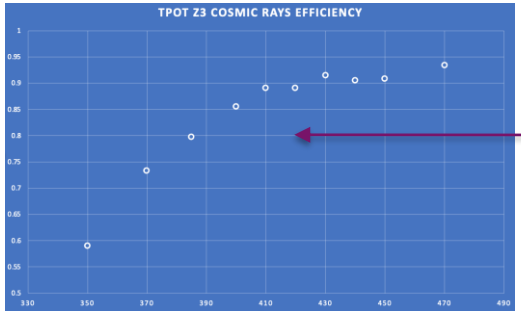


Efficiency curve with ^{55}Fe

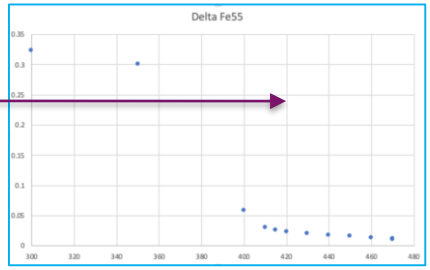


X

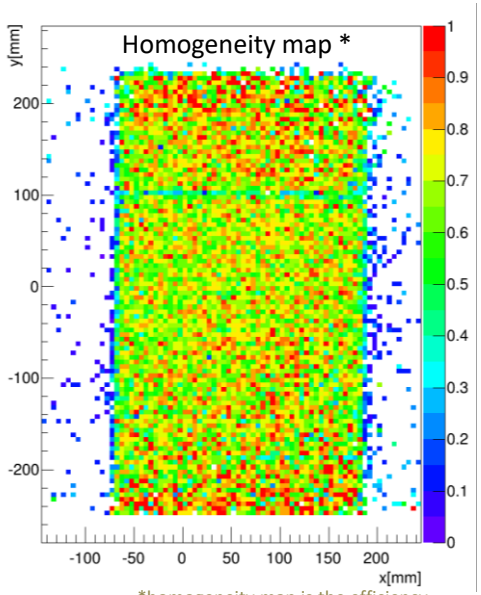
1) **Tests HT au labo bulk**
   - Micromegas à 900V dans l'air
   - Continuité avec dérive
2) **Étanchéité Gaz**
   - Test dérive sur plexiglas (sous 0.1L/h de fuite)
   - Layer puis module assemblé (sous 0.2L/h de fuite)
3) **Test Gain avec source Fe55 (Lecture par DREAM)**
4) **Test Cosmique (DREAM avec paramètres type SAMPA)**
   - Plateau d'efficacité
   - Résolution spatiale
5) **Métrologie avant envoi**
   - Mesure de la position des inserts venant accueillir les billes pour mét



Efficiency plateau with cosmic rays



Efficiency curve with ^{55}Fe



*homogeneity map is the efficiency map with very drastic cuts on track quality to see the details of the detectors

THANKS ALL FOLKS !

Historique TPOT à l'Irfu

2019

- R&D on Ion Back Flow correction for the sPhenix TPC
  - TPC readout with Micromegas + GEM
  - External tracker for validation
- ➢ TPC readout "Alice" with GEMs
- ➢ Meeting at CERN in July 2019 with ALICE IBF team
  - ➢ Task Force started to study IBF effects

2020

- Task Force simulation effort shows that would efficiently correctly TPC distortions
- Cost and Schedule meeting in December 2020 to decide the future of an external tracker
- ➢ External tracking point is seriously considered by the sPhenix community
- ➢ Prototype contract of 39k$ from BNL is awarded to IRFU to start design

2021

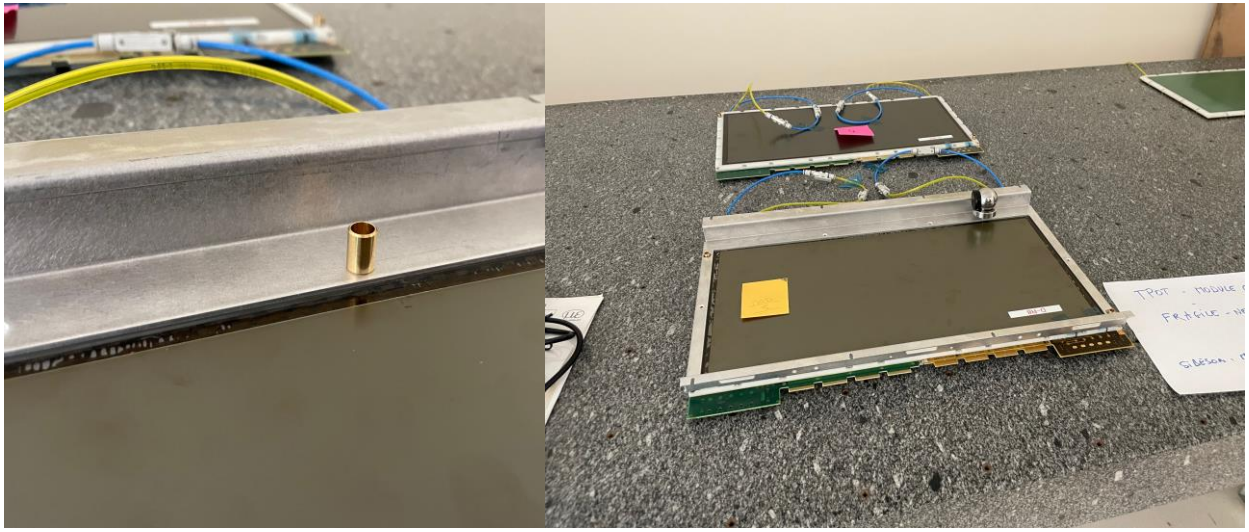
- Prototype contract is signed 23/03/2021 and detector design starts at Saclay
- June 2021 review of scientific merit in front of BNL NPP PAC
- ➢ PAC recommends that sPHENIX accepts the TPOT proposal and BNL to monitor plan for possible installation
- Cost and Schedule meeting in September 2021
- ➢ TPOT is descoped to 8 modules to be installed before the TPC
- ➢ Installation after run 2 is too risky
- ➢ Manpower for mechanical design and integration will help TPOT team
- ➢ Contract for hardware construction of 10 modules is awarded to IRFU in November
- First prototypes have produced at IRFU in October 2021 and tested
- Design and order of pre-serie end of 2021

2022

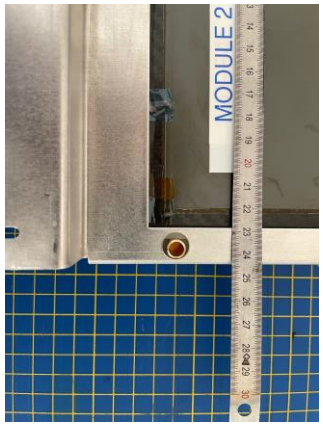
- Prototype TPOT Z send to BNL in January 2021
- Project review at BNL with DOE January 2021
- ➢ Design (detector and mechanical structure) is validated by BNL/DOE
- Pre-serie detector produced in February 2021
- Contract is signed between IRFU and BNL for 10 modules in February
- All orders for serie detector are placed in early March 2021
- Project review at IRFU 22/03/2022

ADDATIONAL POINT ON TRAY

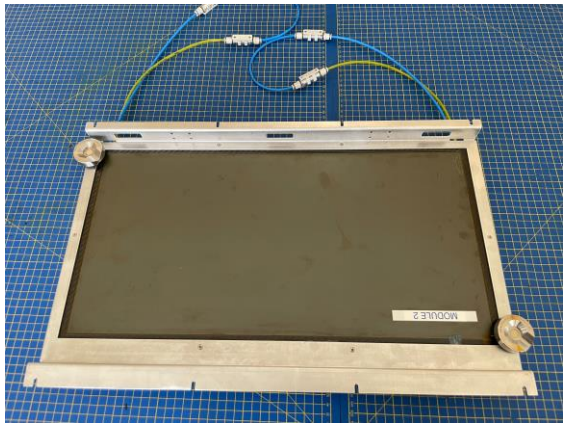
With only 2 space points, not possible to reconstruct plane => new point on tray by glueing pin



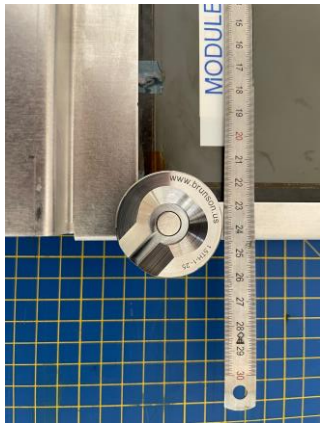
METROLOGY – OPTICAL + 3D



Drill bush on detector

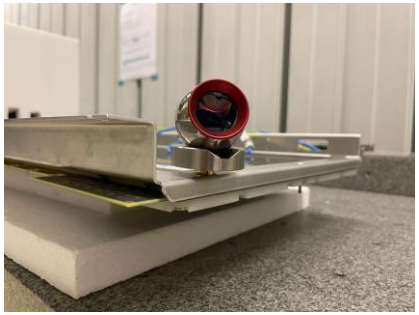


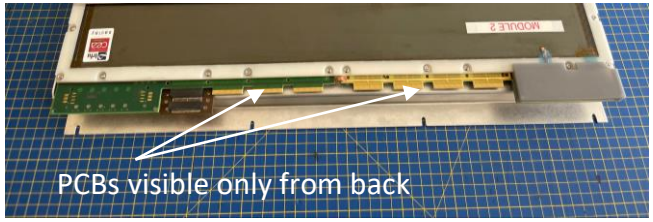
Detector + the 2 target



Target on detector

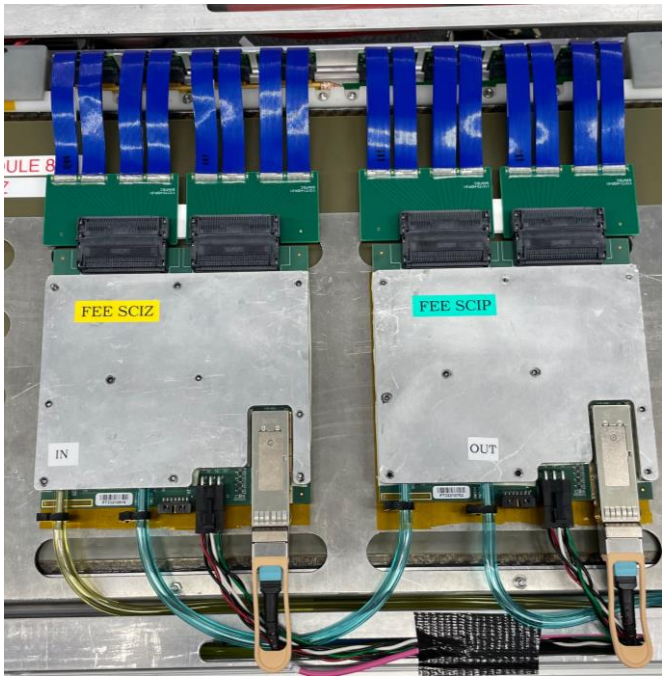
- We need to measure the 2 readout PCB positions wrt the 2 targets





INSTALLATION ON LADDER – COOLING

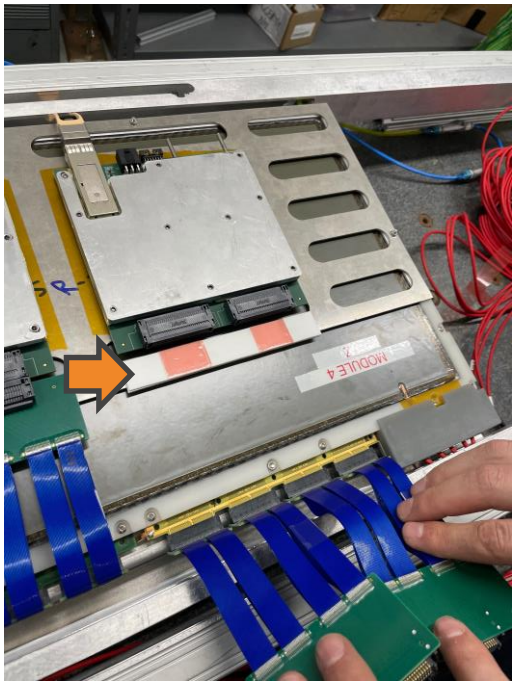
Tube connection + lock installation :

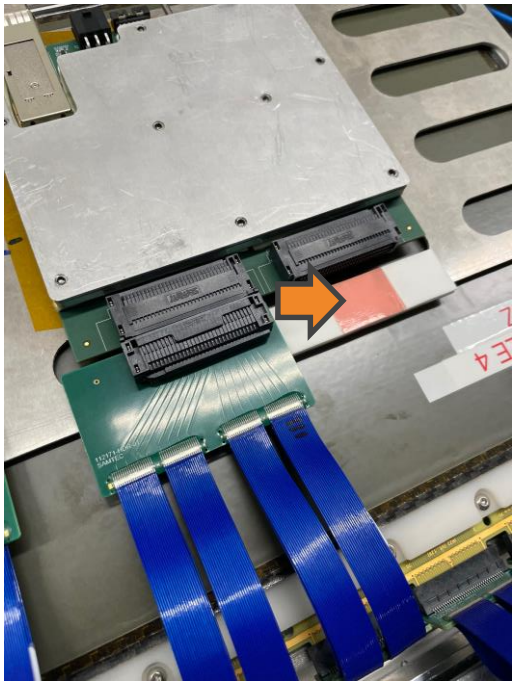


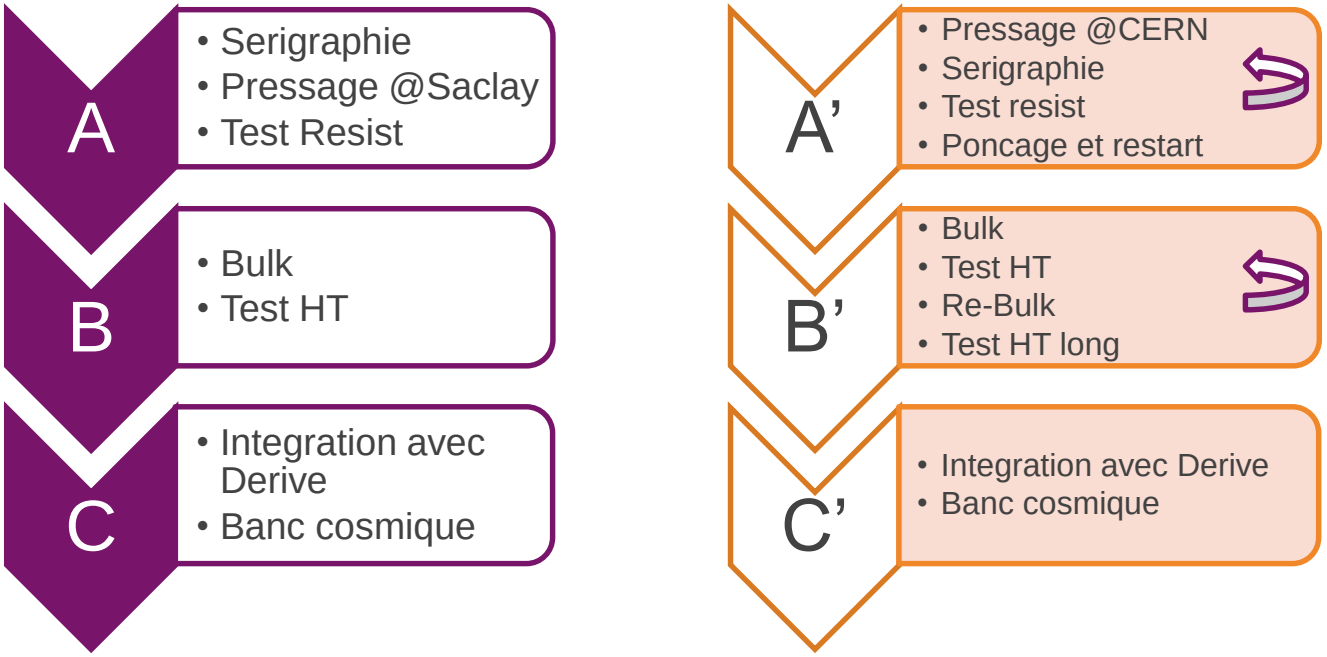
DETECTOR PREPARATION

Support for the transition card :

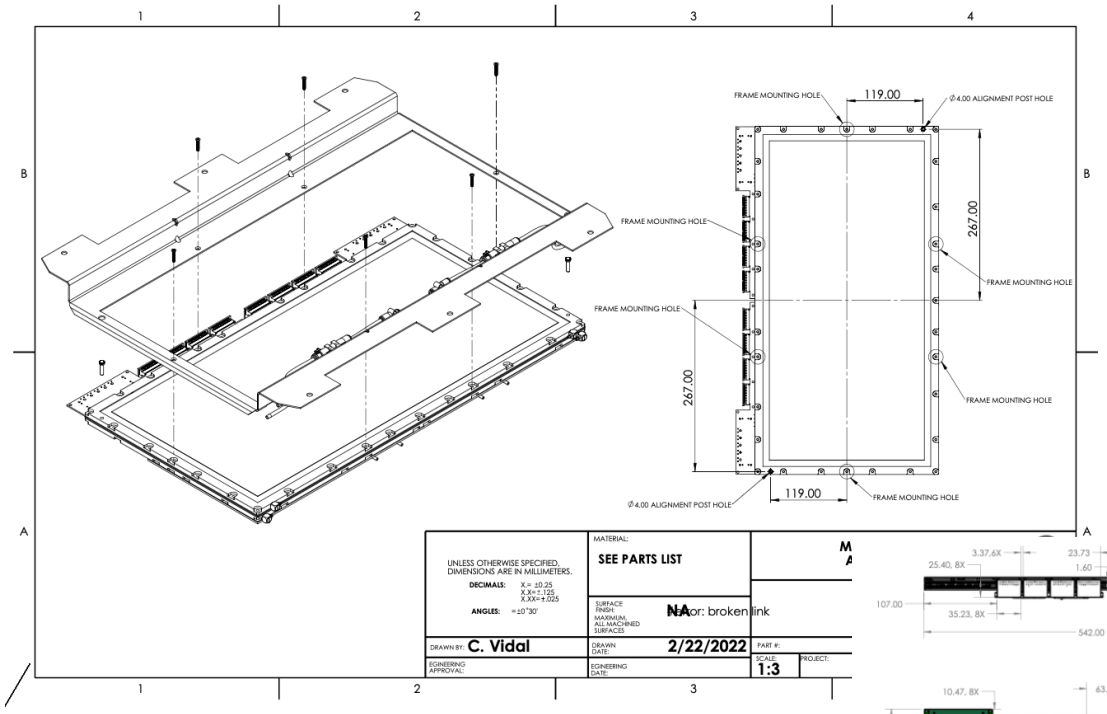
Added a double taped 4mm shim to support and secure the SEAM connector plugged. To unplugged, first lift the transition card to un-glue it.

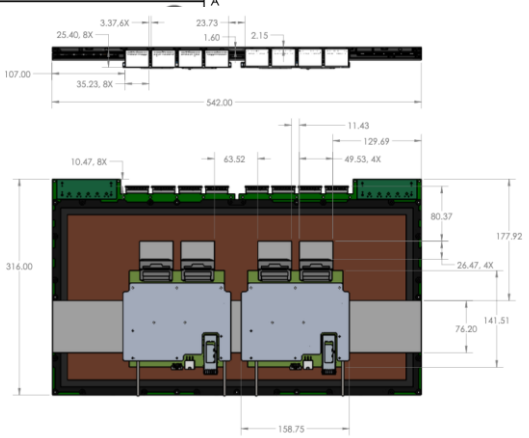






+ Changement masque plots
+ Procedures Ecrites
+ Test HT long

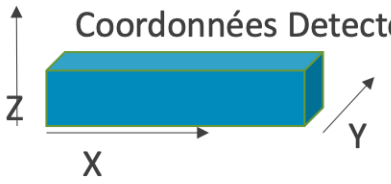

1
2
3
4
B
A
FRAME MOUNTING HOLE
119.00
Ø4.00 ALIGNMENT POST HOLE
267.00
FRAME MOUNTING HOLE
FRAME MOUNTING HOLE
267.00
FRAME MOUNTING HOLE
Ø4.00 ALIGNMENT POST HOLE
119.00
FRAME MOUNTING HOLE
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN MILLIMETERS.
DECIMALS: X = ±0.25 X.X = ±.125 X.XX = ±.025
ANGLES: = ±0°30'
MATERIAL:
SEE PARTS LIST
SURFACE FINISH: MAXIMUM ALL MACHINED SURFACES
NA
DRAWN BY: C. Vidal
DRAWN DATE: 2/22/2022
PART #:
SCALE: 1:3
PROJECT:
ENGINEERING APPROVAL:
ENGINEERING DATE:

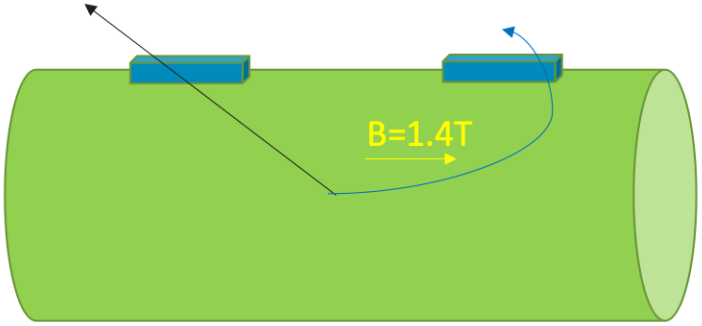

3.37.6X
23.73
25.40, 8X
1.60
2.15
107.00
35.23, 8X
542.00
11.43
129.69
10.47, 8X
63.52
49.53, 4X
80.37
177.92
316.00
26.47, 4X
141.51
76.20
158.75

Quel Gaz pour Outer tracker ?

Angle de Lorentz

$$\tan(\theta_L) = \omega\tau = \frac{v_D B}{E}$$

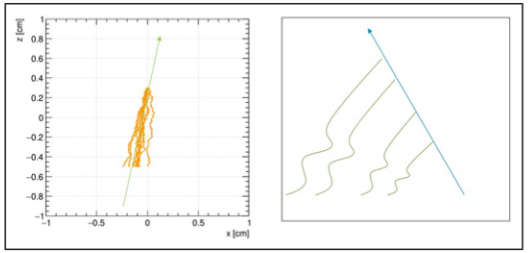




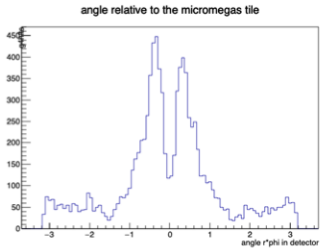
Donc B selon Xdet
=> Lorentz angle selon Ydet

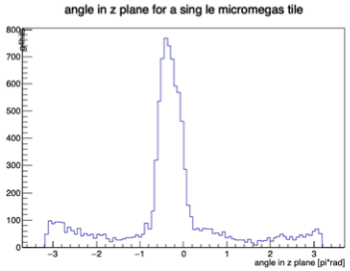
Angle R_Phi = ZY
=~ polarité de la particule

Angle Z = ZX
=~ coté de la TPC



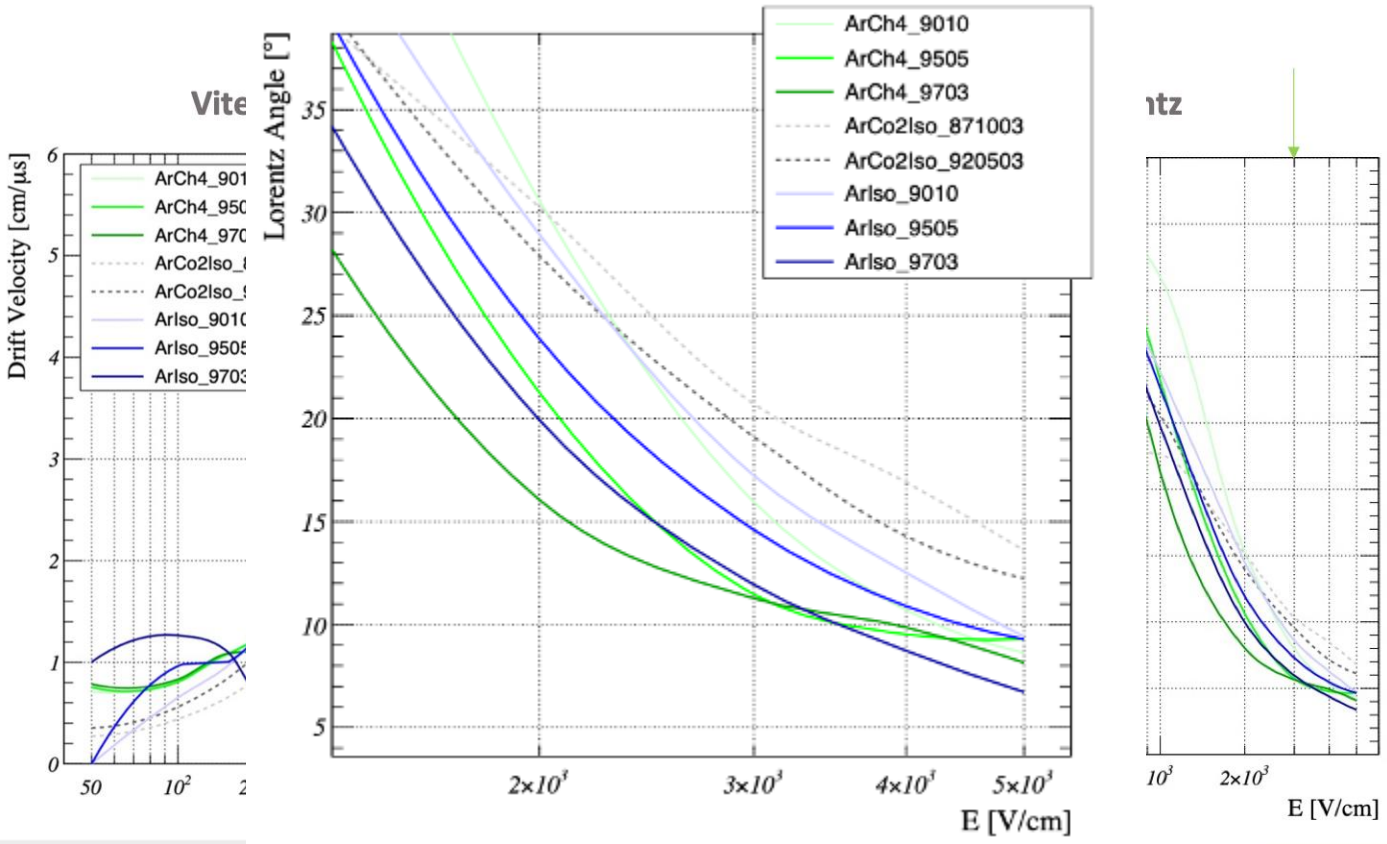
Effect of Lorentz angle along Y





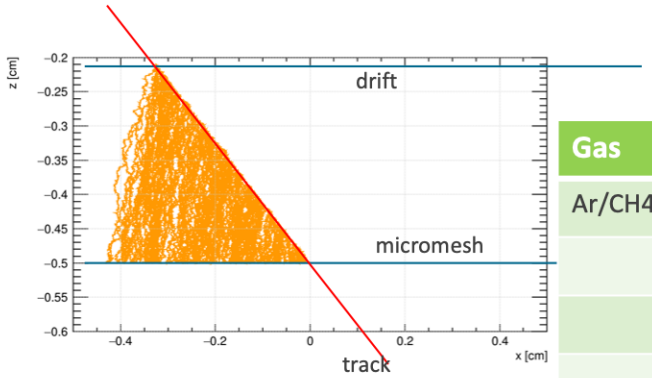
=> On cherche un gaz qui a une Vitesse de derive basse a haut champ electrique .

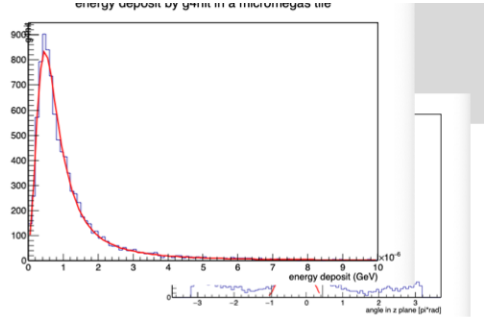
Choix du Gaz


Vite
Drift Velocity [cm/µs]
ArCh4_901
ArCh4_950
ArCh4_970
ArCo2Iso_
ArCo2Iso_
ArIso_9010
ArIso_9505
ArIso_9703
50
10²
Lorentz Angle [°]
ArCh4_9010
ArCh4_9505
ArCh4_9703
ArCo2Iso_871003
ArCo2Iso_920503
ArIso_9010
ArIso_9505
ArIso_9703
35
30
25
20
15
10
5
2×10³
3×10³
4×10³
5×10³
E [V/cm]
ıtz
10³
2×10³
E [V/cm]

Results

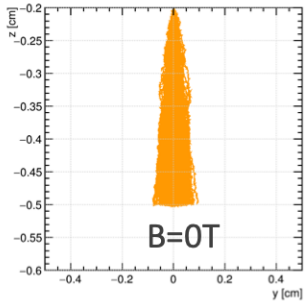
Distribution depuis les simu sphenix + fit pour MC:

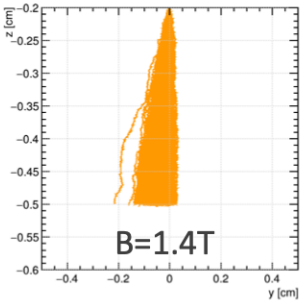


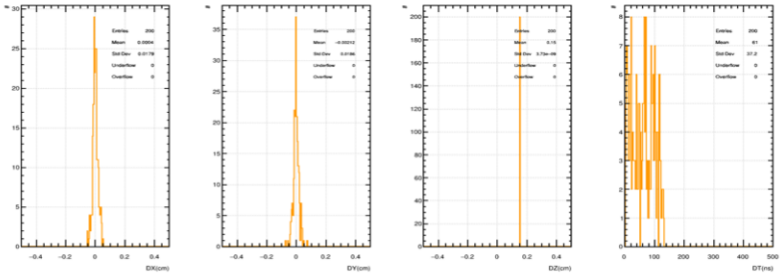


Gas	Condition		Std Dev (µm)
Ar/CH4 90/10	B=1.4T, E=1kV	X/Y	400/300
	1mm drift	X/Y	300/300
	Angle = 90deg	X/Y	200/300
	B=0T	X/Y	400/300
	B=OT Angle=90	X/Y	180/180
Ar/Iso 90/10		X/Y	8320/2550

⇒ With right gas, B effect small, dominated by angle
⇒ ~400/300um diffusion at readout level



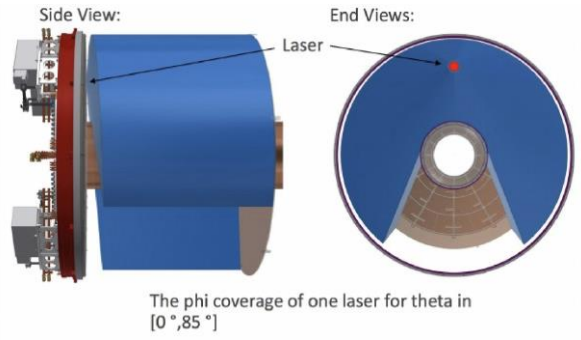




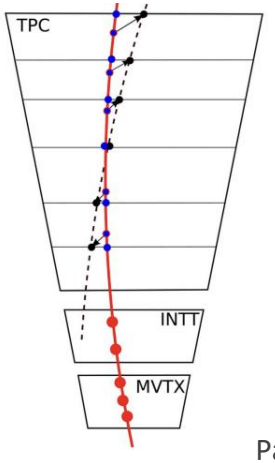
OUTILS DE RECONSTRUCTION DES DISTORTIONS

1. **Lasers directs pour reconstruire les distorsions statiques O(cm) lors du commissioning**
2. **Traces pour reconstruire les distorsions spatio-temporelles induites par le faisceau O(mm)**
3. **Lasers diffus (et courants digitaux) pour monitorer les fluctuations événement par événement (<100µm)**

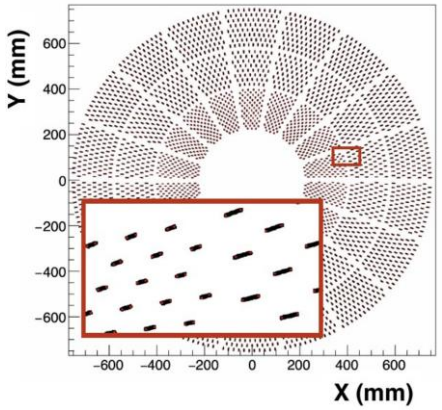
Nécessité d'utiliser toutes les méthodes en coopération, pour complètement corriger les distortions dans TPC avec la précision requise de 100µm



Trajectoires des lasers directs



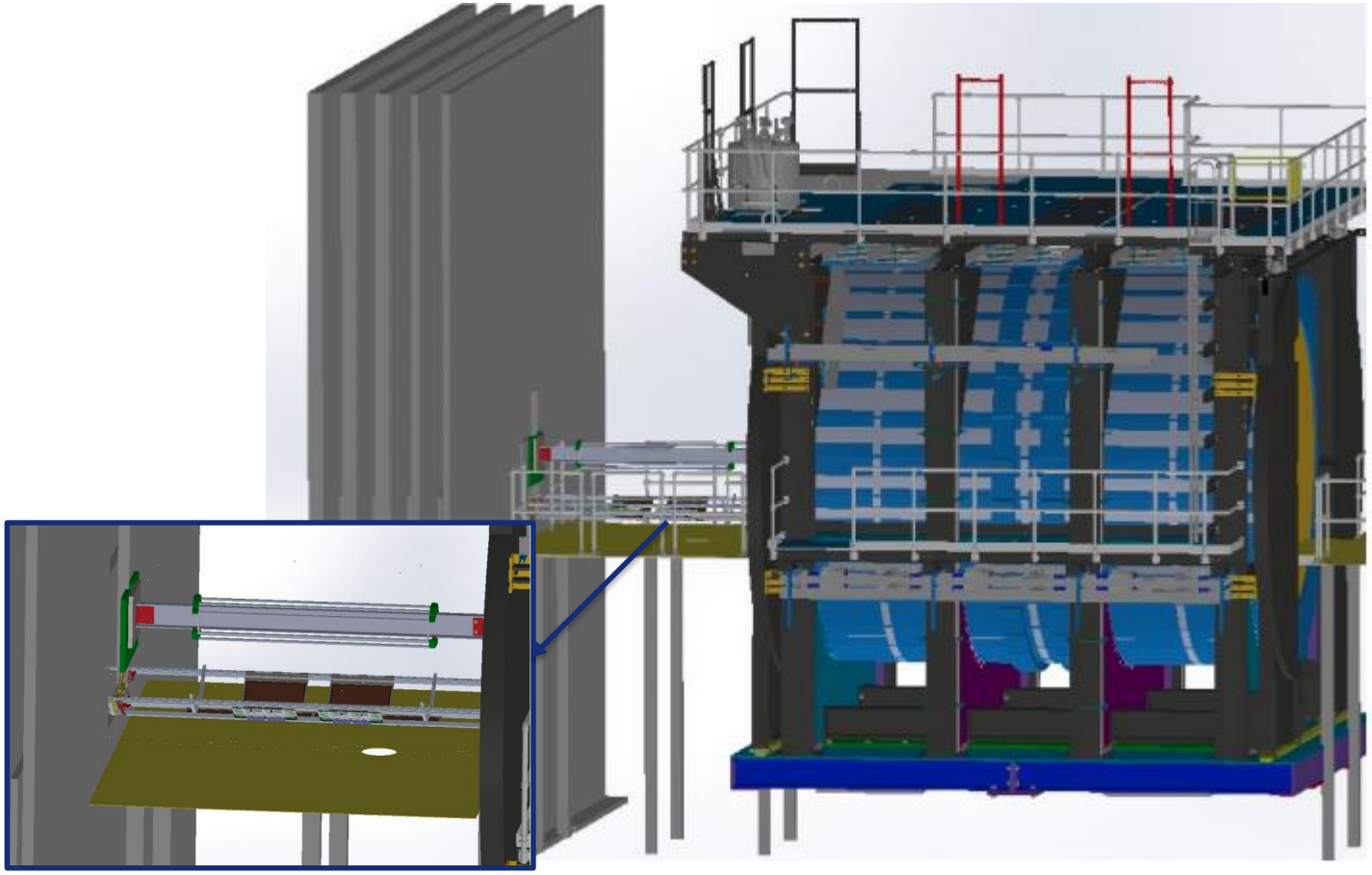
Extrapolation des traces jusqu'à la TPC



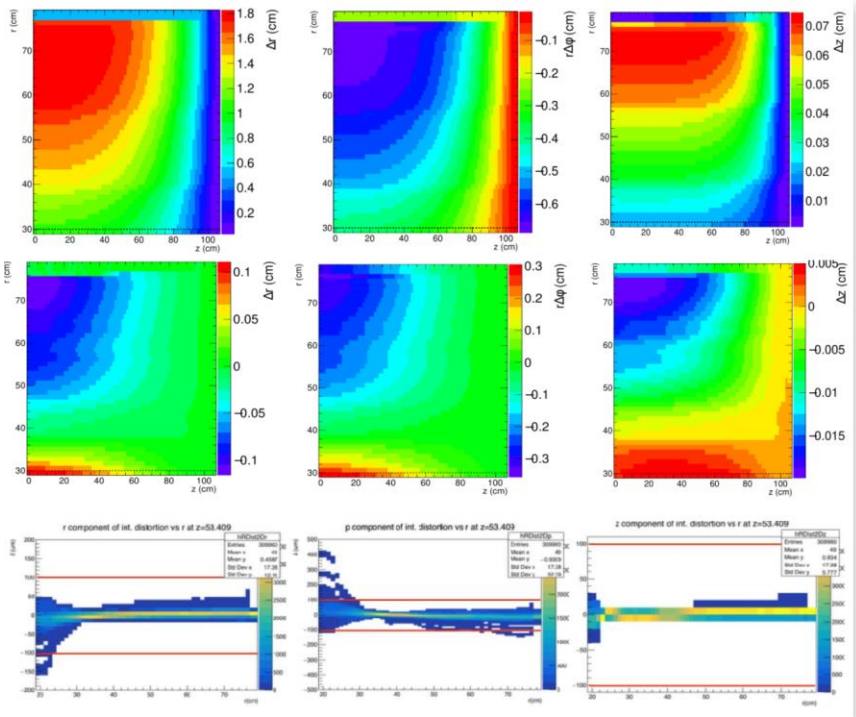
Pads métalliques de la membrane centrale

TPOT pertinent pour l'utilisation des traces dans la reconstruction des distorsions induites par le faisceau

[BACK-UP] INSERTION SPHENIX



[BACK-UP] MAGNITUDE DES DISTORTIONS



Static distortions due to E and B fields
inhomogeneities and misalignment
Are present also without beam
Measured during commissioning
Time scale: 1y data taking
Length scale: O(1cm)

Beam-induced distortions due to ions
(primary << IBF)
Vary slowly with beam intensity/conditions
Time scale: 1/2h
Length scale: O(1mm)

Event-by-event, due to particle
multiplicity fluctuations
Time scale: O(10ms)
Length scale: < 100µm

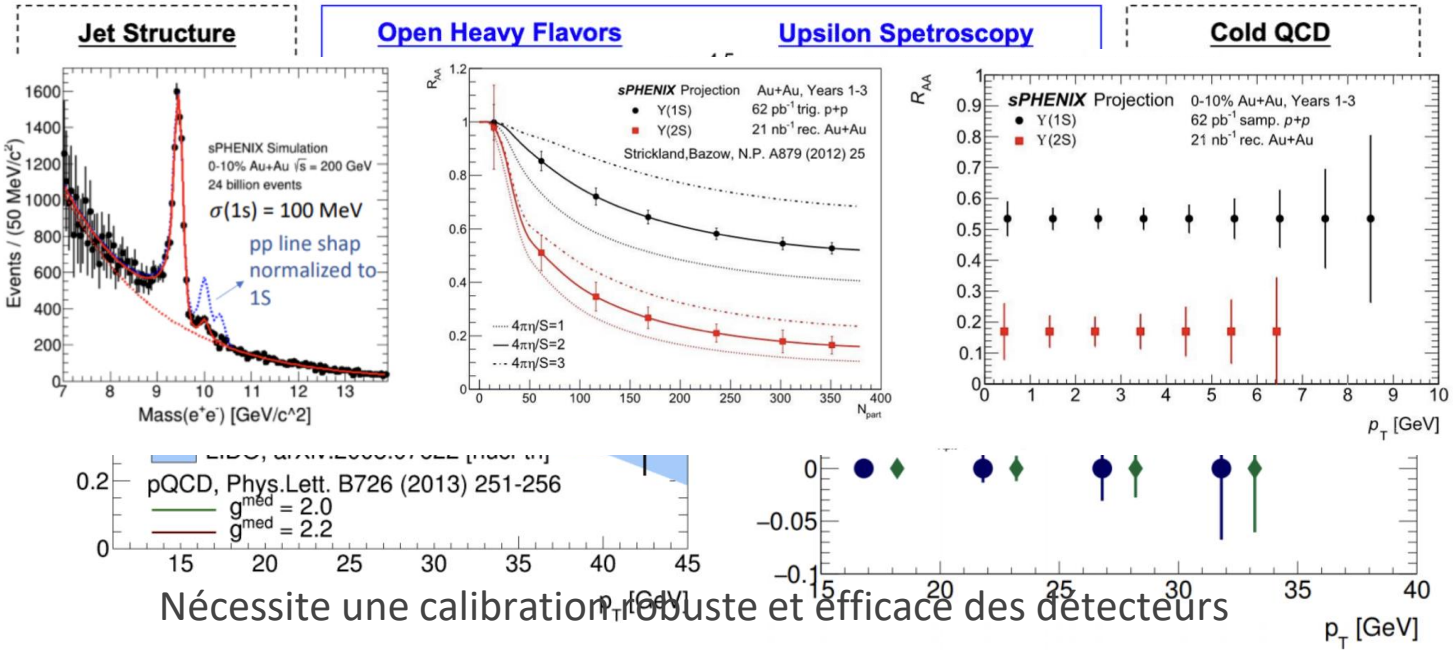
12

Magnitudes des distortions attendues :

- jusqu'à 3mm selon Φ
- jusqu'à 1.2 mm selon r
- jusqu'à 200 µm selon z

PROGRAMME DE PHYSIQUE sPHENIX

- Étude des propriétés microscopiques de la matière déconfinée avec des sondes dures
- Programme de QCD froide : portail vers l'EIC



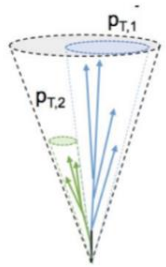
Nécessite une calibration robuste et efficace des détecteurs

en particulier de la TPC

PROGRAMME DE PHYSIQUE sPHENIX

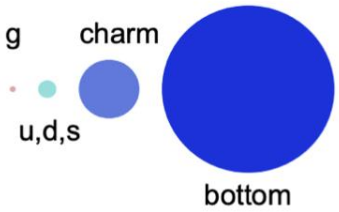
- Étude des propriétés microscopiques de la matière déconfinée avec des sondes dures
- Programme de QCD froide : portail vers l'EIC

Jet Structure



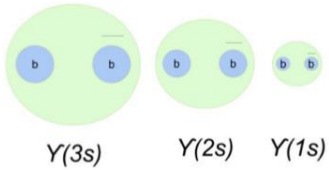
Vary momentum & angular scale of probe

Open Heavy Flavors



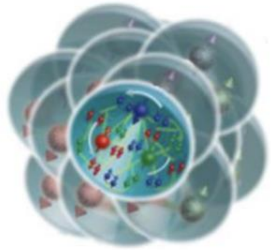
Vary mass & momentum of probe

Upsilon Spetroscopy



Vary size of probe

Cold QCD



Vary temperature of QCD matter

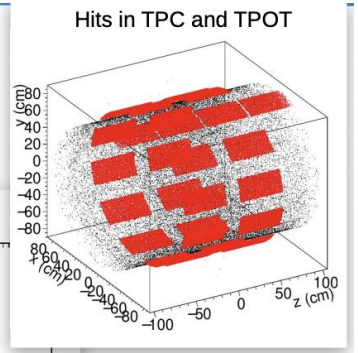
→ **TRACKING**

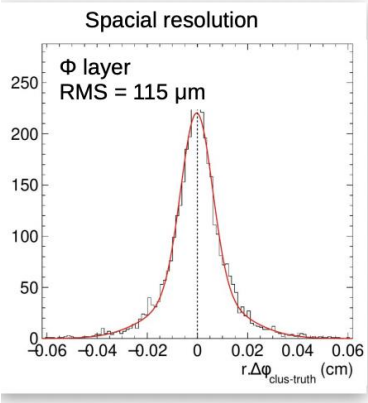
Nécessite une calibration robuste et efficace des détecteurs

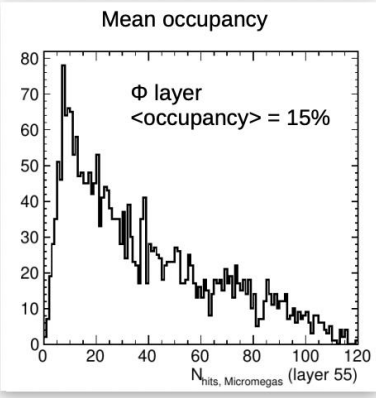
en particulier de la TPC

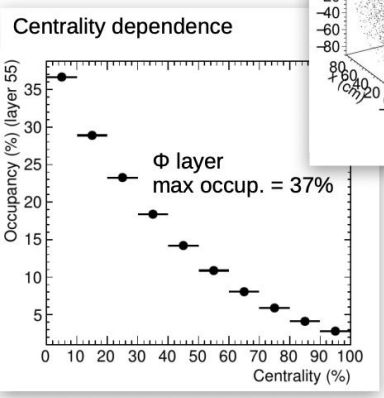
[BACK-UP] Occupancy TPOT

- Realistic description of the bare detector in sPHENIX GEANT4 simulation
- Complete integration in sPHENIX tracking
- First algorithm in place to estimate and correct for time-averaged distortions



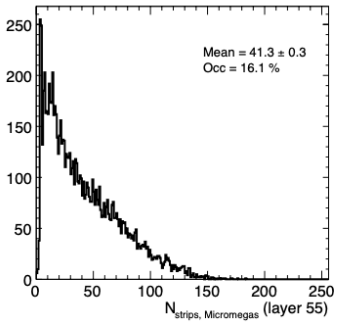


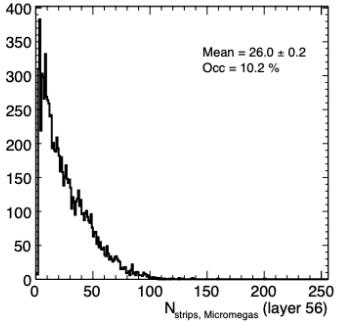


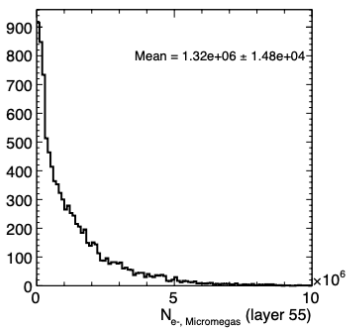


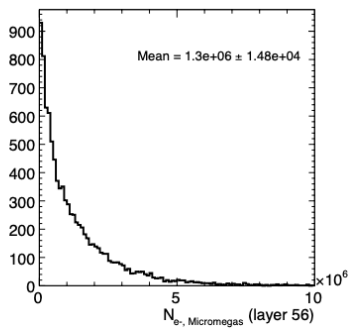
- RMS = 115μm probably too optimistic expect rather 200μm in Φ and 300μm in z
- High occupancy should not be a problem for the detector nor FEE, tracking can handle it

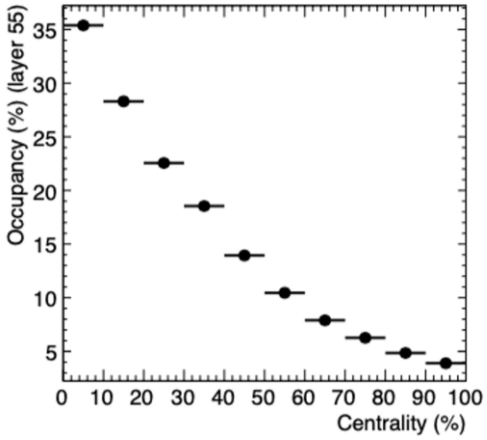
TAUX D'OCCUPATION

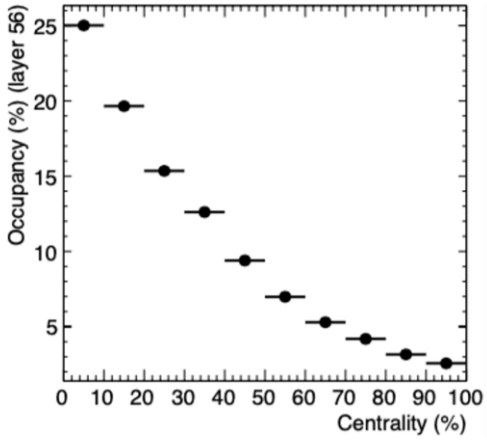






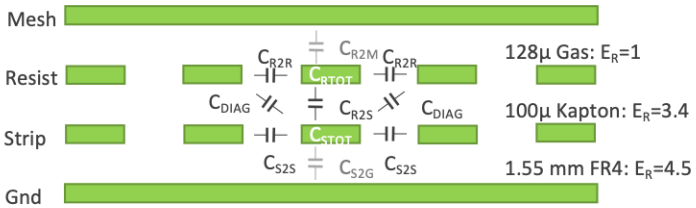


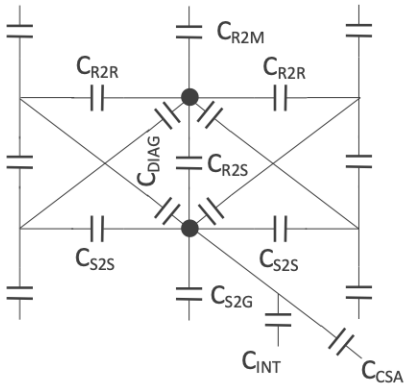




Capacitance Simulation : Detector modeling

- Cadence signal integrity tools are used to extract
  - → Strip capacitances and inter-strip cross-coupling
  - → Under validation with measurements
- Includes readout strip to connector lines





- Assess charge collection and cross-talk
  - → Includes relevant details of Sampa's VFE

Pitch mm	Len cm	Wid mm	Q_{CSA}/Q_{TOT}	X-talk %	C_{ENC} pF
1 mm STR	50 cm	0.875	0.60	7.2	146
1 mm ZZ	206	0,243	0.41	20.8	306
2 mm STR	25 cm	1.875	0.69	3.51	90
2 mm ZZ	202	0,248	0.42	20.8	299

- Straight strips are advantageous compared to a particular ZZ topology studied

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TPC / TPOT READOUT

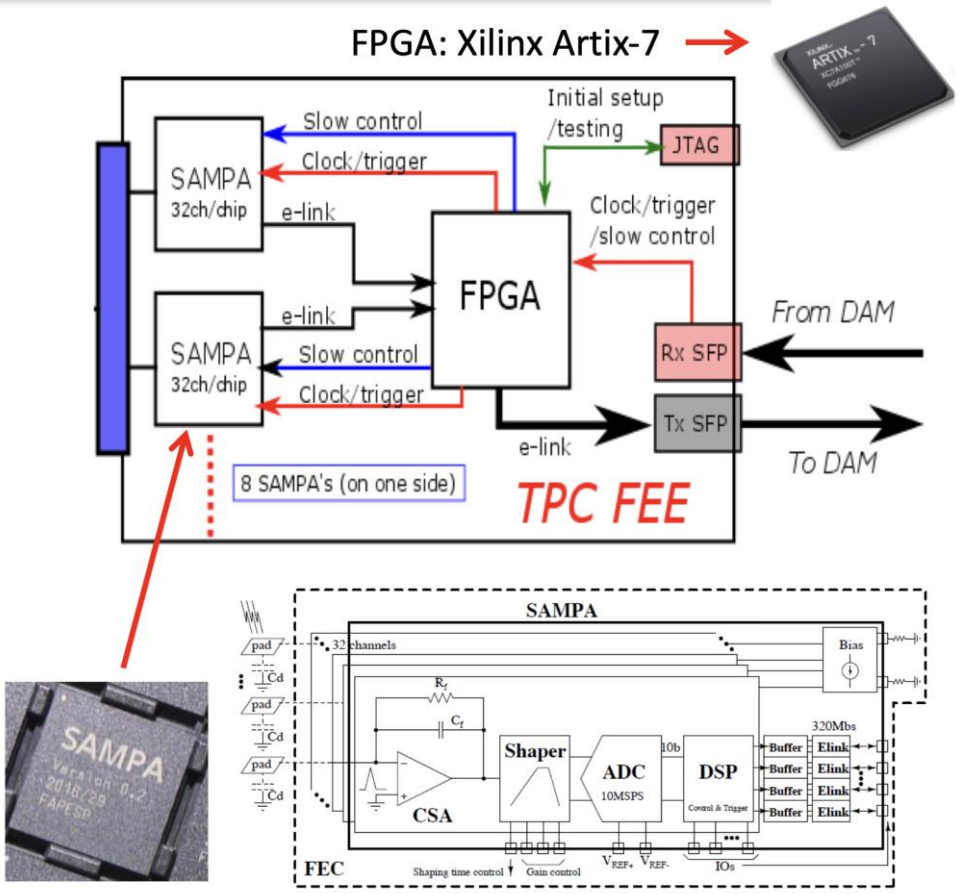

Figure 6.4: Schematic of the SAMPA ASIC for the GEM TPC readout, showing the main building blocks.