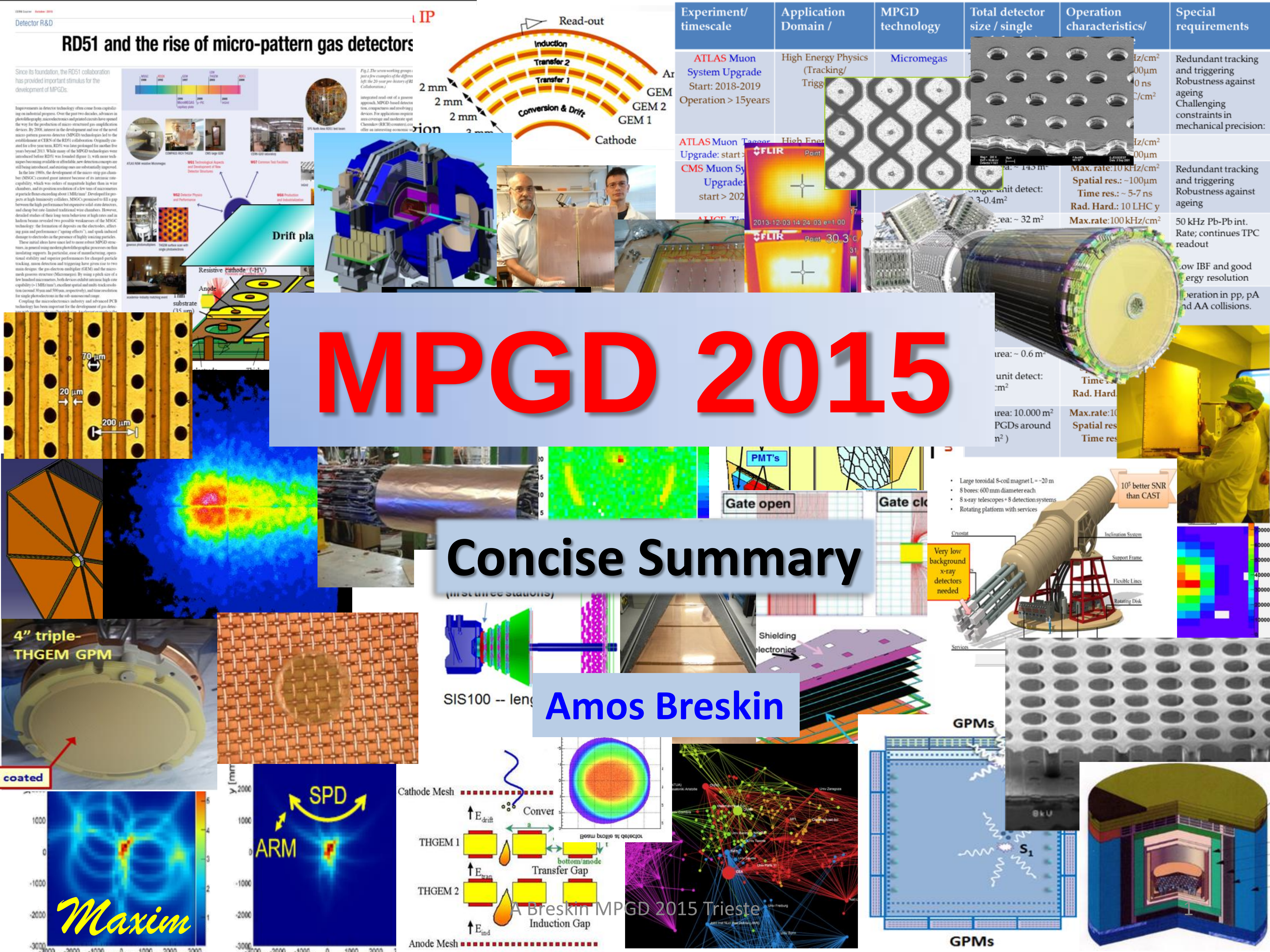
MPGD 2015

Concise Summary

Amos Breskin

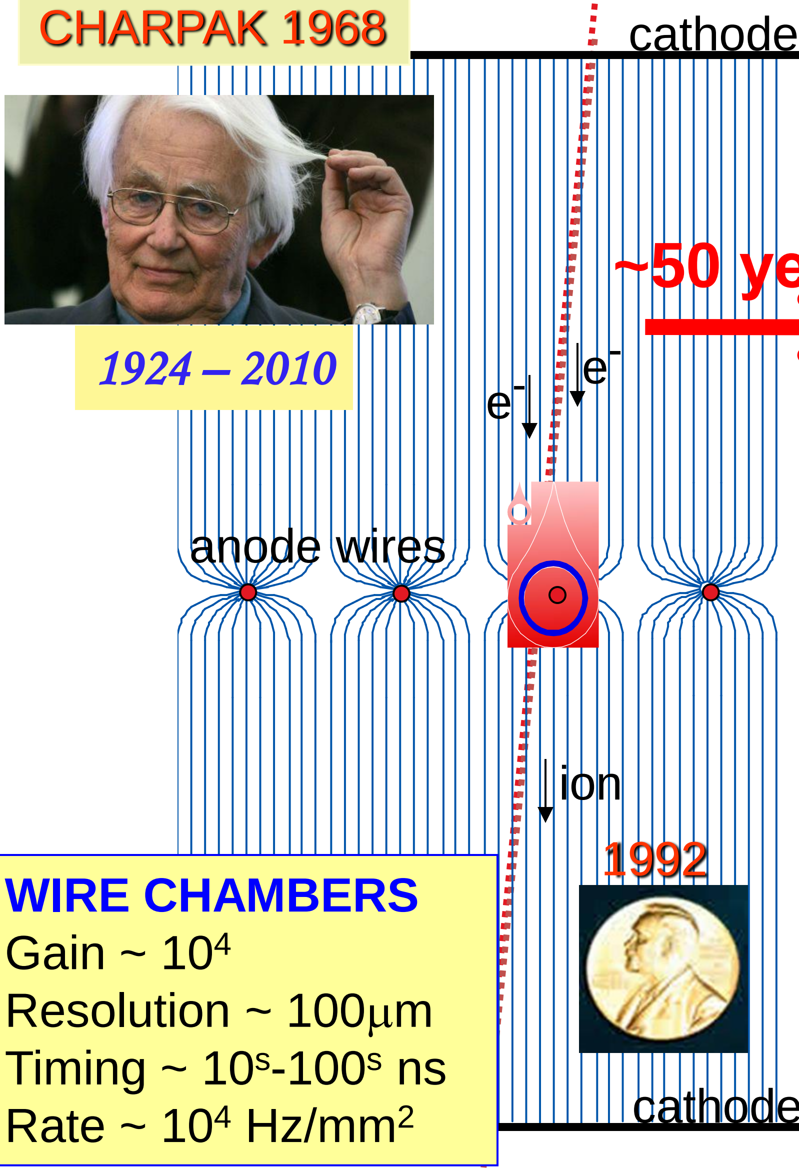


Grazie SILVIA & her local TEAM !
+ all committee members !

Grazie Silvia for devoted “service” as Chair of RD51 Collaboration Board!

OLD GOOD WIRE CHAMBERS - GAIN RESOLUTION

CHARPAK 1968



1924 – 2010

~50 years…

1992

WIRE CHAMBERS
Gain ~ 10^4
Resolution ~ 100μm
Timing ~ 10^s-100^s ns
Rate ~ 10^4 Hz/mm²

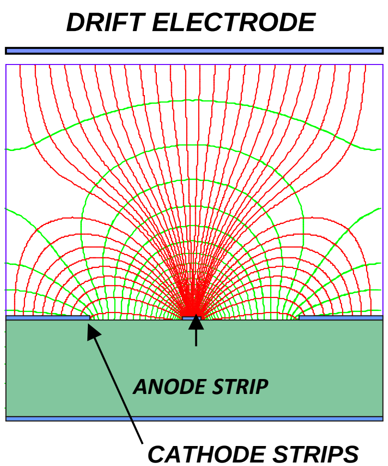
ATLAS 2015

ATLAS Thin-Gap Chambers (TGC):
Upgraded for sLHC "Small Wheel".
Status: 50μm resolution.

MPGD2015 covered these:

Oed 1988

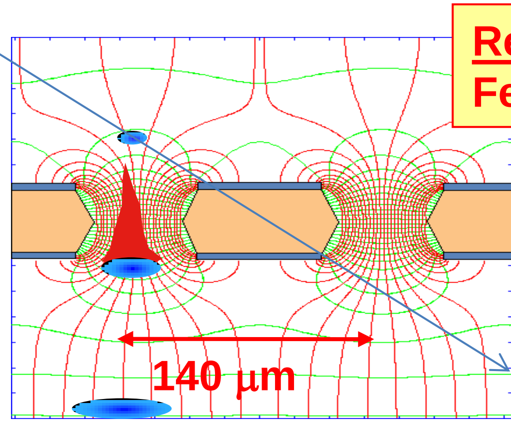
MICRO-STRIP CHAMBER MSGC



Drift + thin multiplication-strips on insulator

Sauli 1997

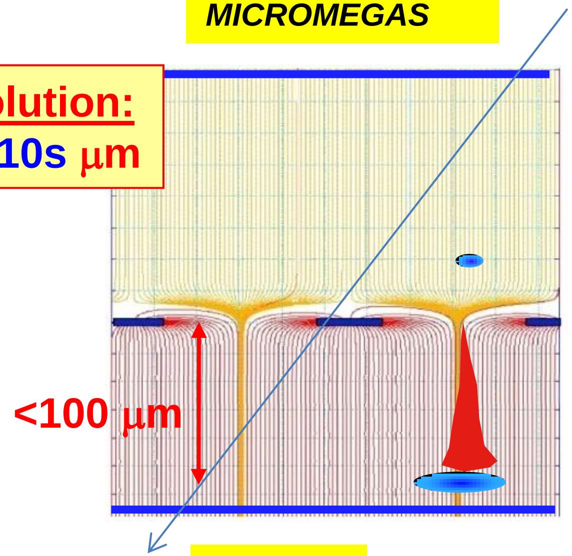
GAS ELECTRON MULTIPLIER (GEM)



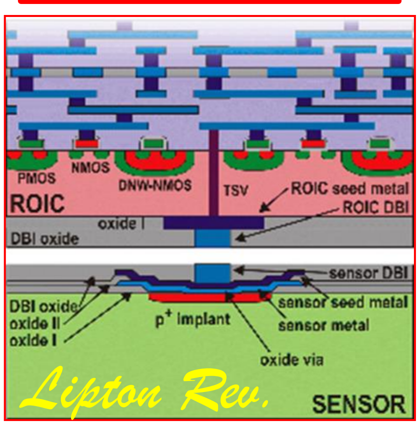
Giomataris 1998

MICROMEGAS

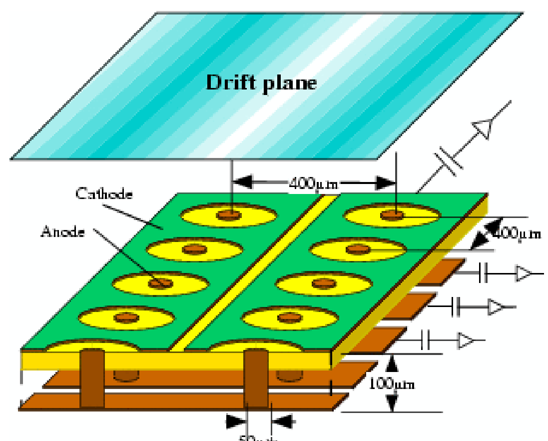
Resolution:
Few **10s** µm



COMPETITORS!!!

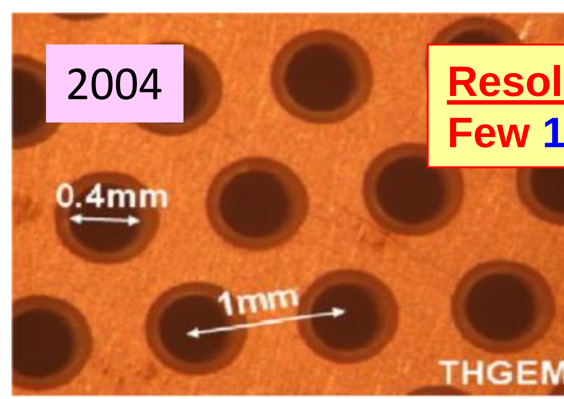


MICRO-PIXEL



THGEM (LEM)

2004



Resolution:
Few **100s** µm

Grazie CHEF RUI !

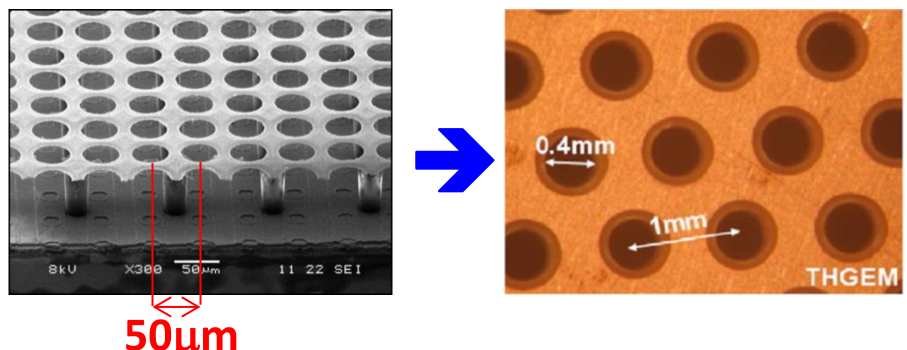
"cooking" for us a variety of "TASTY MPGD TOYS"

We tackled many detector "Problems"

- Discharge limits (dynamic range) → resistive electrodes
- Ion backflow blocking (TPC, RICH) → cascades, staggered holes, graphene coatings
- Photon feedback (noble gases) → cascades, staggered holes
- Resolutions: E, t, position (physical limits, readout)
- Rate capability (space charge, charge evacuation)
- Radiation hardness
- Radio-purity (rare-event searches)
- Purity (sealed detectors)
- Large-area detectors (production; industrialization)
- Readout electronics
- Physics simulations

Applications

- Tracking in HEP & Astro
- TPC
- Calorimetry (DHCAL)
- Single-photon (UV, visible) imaging (RICH)
- Neutron & x-ray imaging
- Noble Liquids (UV detectors, electron detectors)
- Nuclear Physics
- Homeland security
- Medical imaging
- etc



Position resolutions needed:
10s' microns - to - <u>centimeters</u>!

Ion Back-Flow (IBF)

- **BEWARE**: block ions with no (or minimal) electron losses.
- Application dependent
- **TPC**: IBF affects tracking; electron losses affect E-resolution!
- **RICH**: IBF affects photocathode lifetime; secondary effects; photoelectron losses – affect Ring imaging!

TESSARROTTO MPGD2015

COMPASS RICH

<u>MWPCs</u>

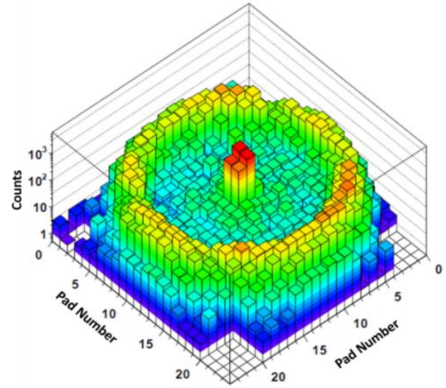
$G \approx 10^{4}$

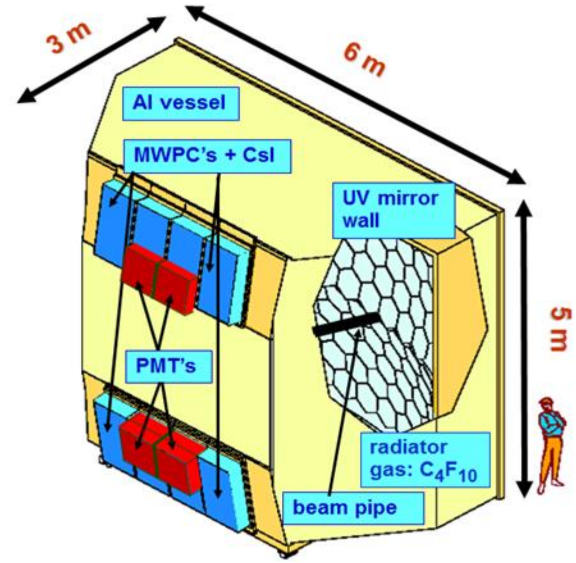
$IBF \approx 50\%$

Signal -> Ions -> $\approx 100\ ns$

Long recovery time

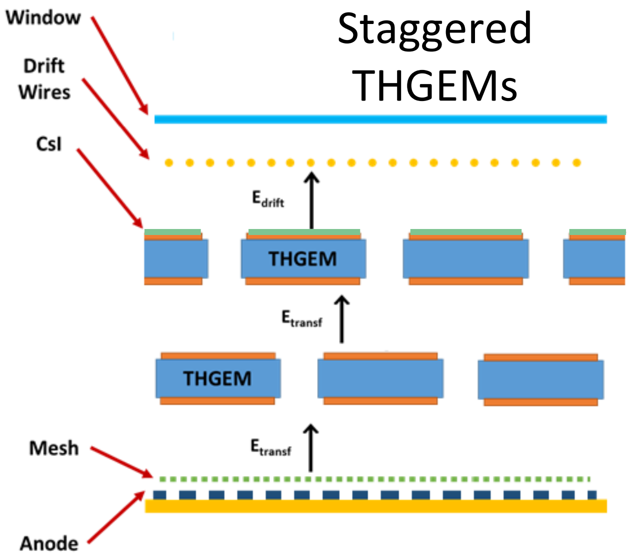
photon feedback

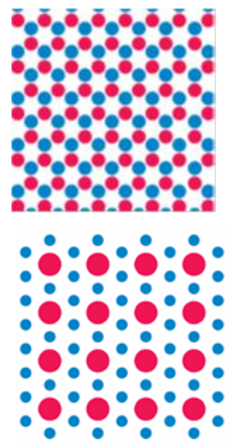




hybrid: 2 THGEMs + 1 Bulk Micromegas

Staggered THGEMs

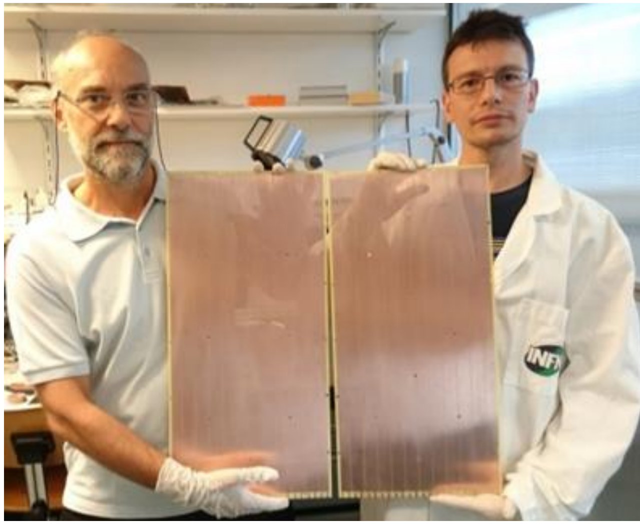


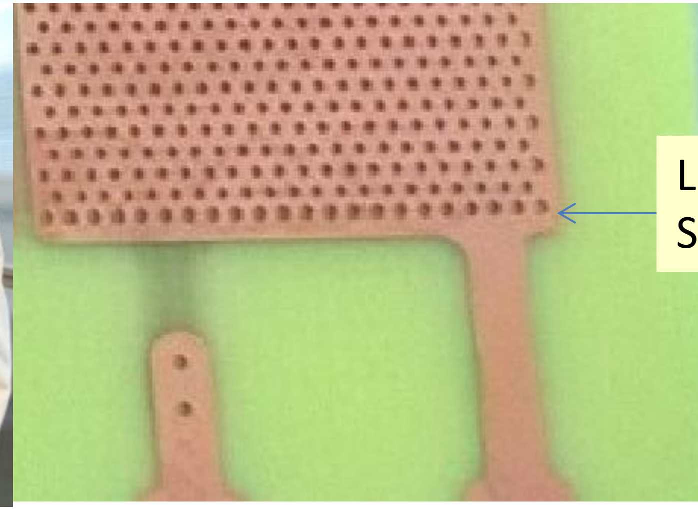


- High photoelectron extraction efficiency;
- Signals → Electrons drift → $\sigma \approx 10\ ns$;
- Cascade → $G \approx 10^5$ - 10^6
- IBF $< 5\%$;
- Stability: time & high rates

Double THGEM: t = 0.4 mm; p = 0.8 mm; h = 0.4 mm

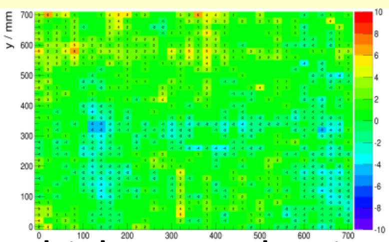
COMPASS RICH: ready to go!





Larger holes @ edge
Solve edge sparking

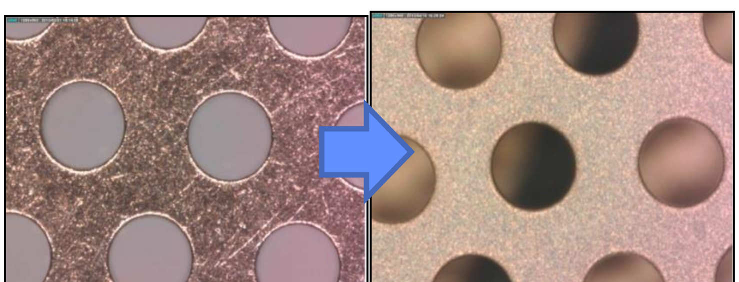
THGEM + MM: 2 x 300 x 600 mm^2



Thickness selection

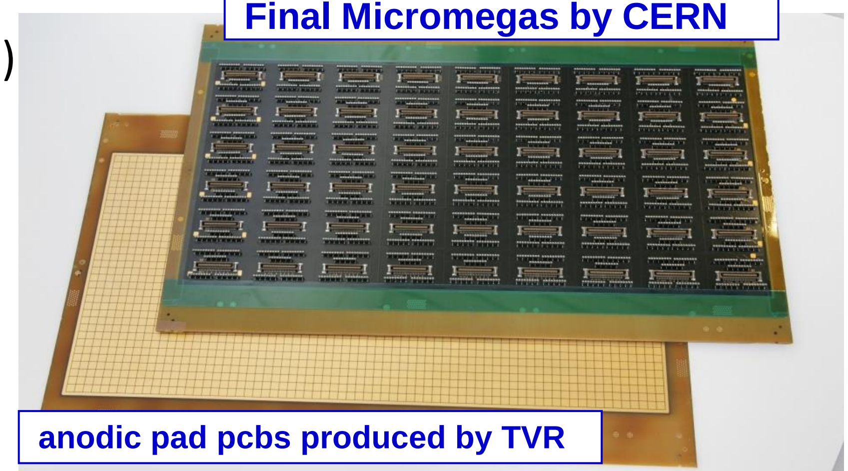
7 years - meticulous R&D

Control of HV f (T, p)



Surface polishing & cleaning

Final Micromegas by CERN

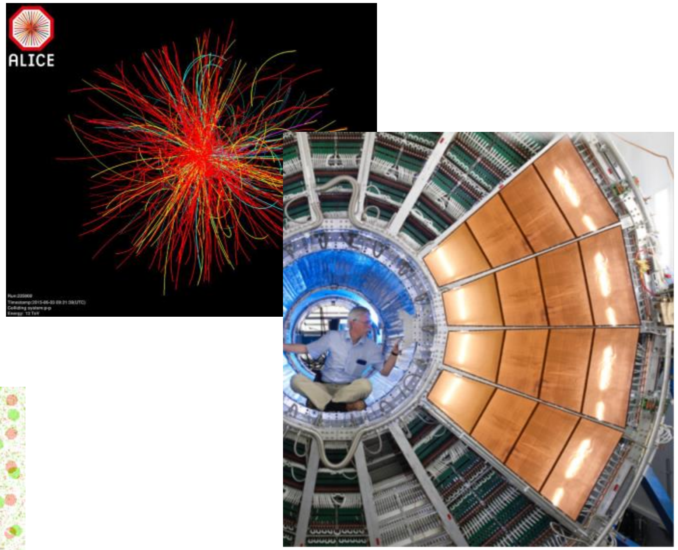


anodic pad pcbs produced by TVR

LIPPMAN ELBA2015
MATHIS MPGD2015

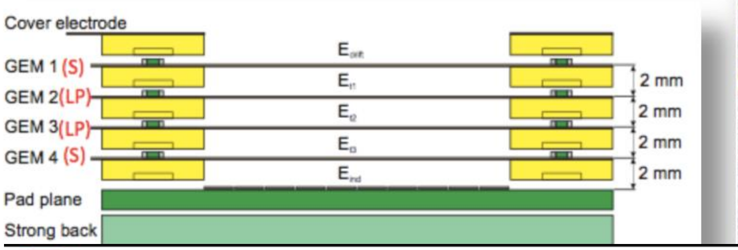
ALICE TPC UPGRADE: 100 x higher rates!

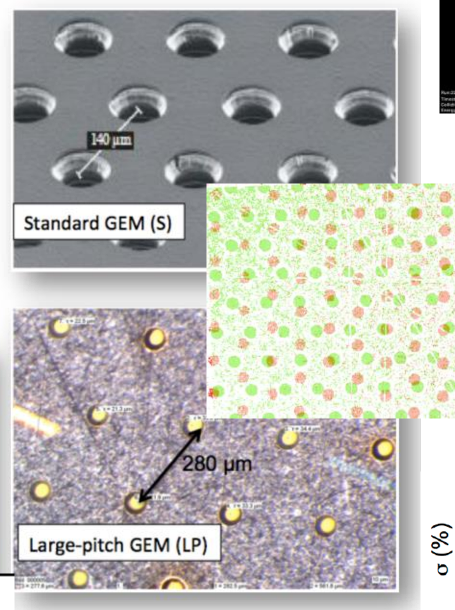
20,000 part./event



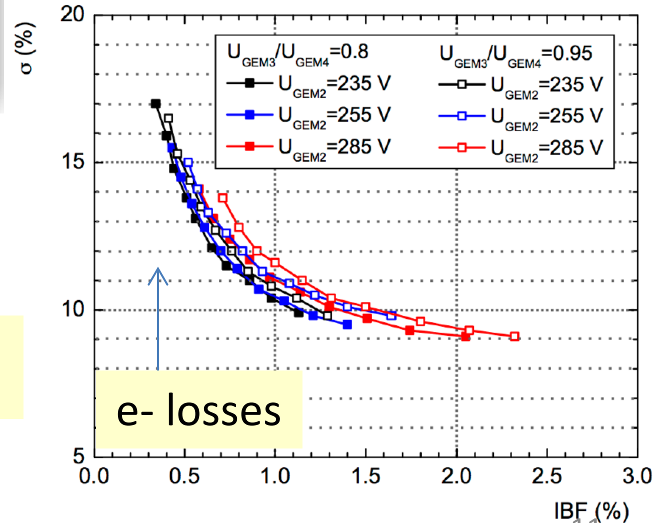
IBF optimized configuration (2)

- Satisfactory performance could not be achieved with 3 GEM stack
- Best results in terms of IBF and energy resolution:
  - 4 GEM stack
  - S-LP-LP-S configuration
  - S: standard GEM foils
  - LP: large hole pitch foils
  - Optimized V settings: V_{GEM}, E_T (transfer fields)





Trade-off: IBF vs E-resolution: 0.6@11-12% σ/E ^{55}Fe



OROC PROTOTYPE

ALICE

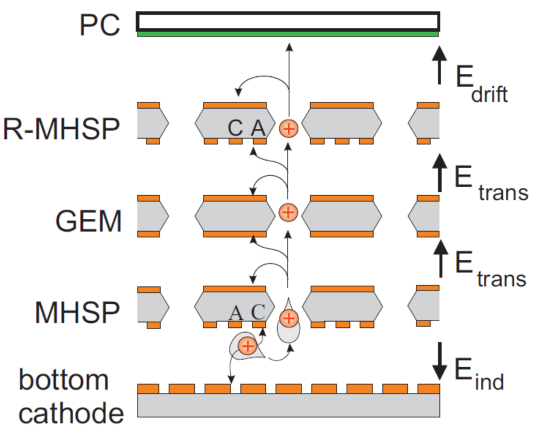
- Validate production methods with large size detector
  - Active GEM area = 0.6817 m²
  - ✓ GEM production & framing
  - ✓ Detector assembly
  - ✓ QA protocols
- ✓ Milestone for the project

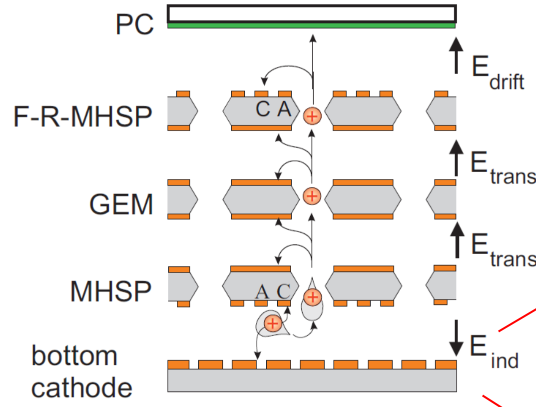
Discharge probability: ~6 10^{-12} discharges/incoming charged hadron

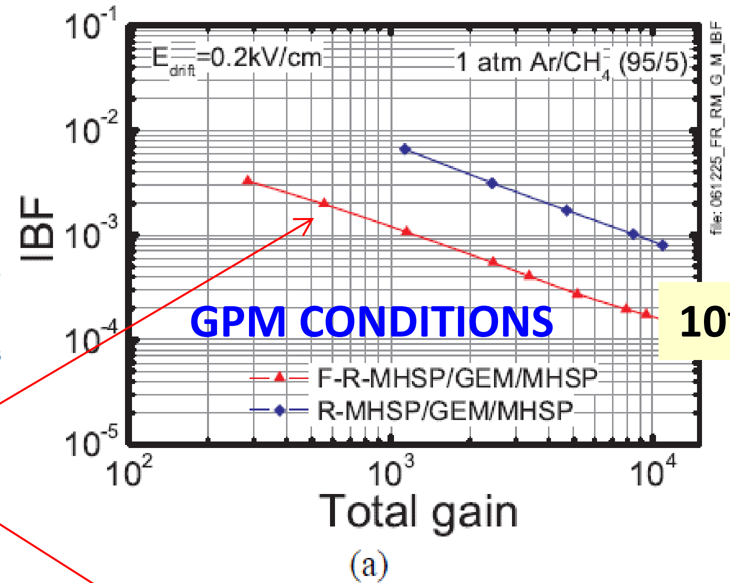
DEISTING

IBF blocking solutions

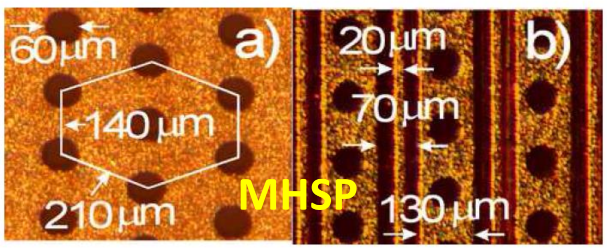
LYASHENKO 2007 JINST 2 P08004



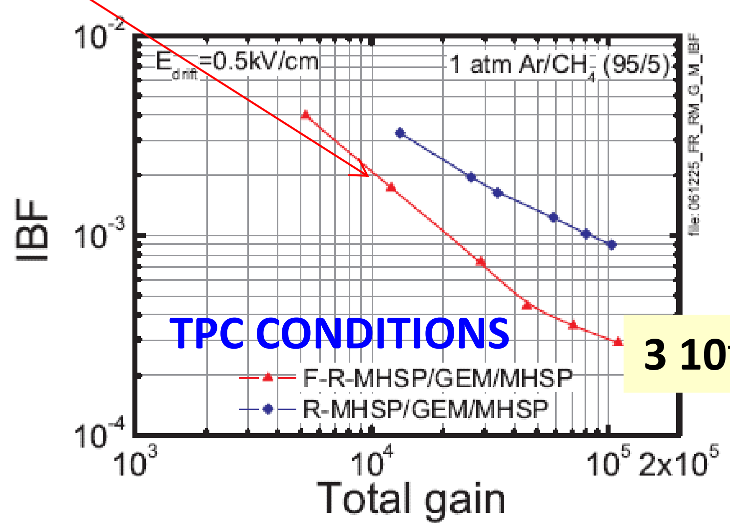




MHSP: Micro-Hole & Strip Plate
R-MHSP: Reveresed-bias MHSP
F-R-MHSP: Flipped Reversed-bias MHSP



→ "COBRA"

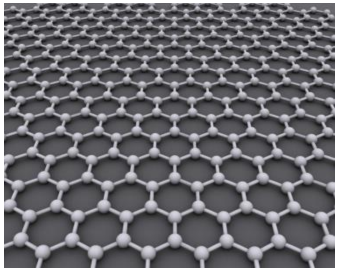


Cascaded GEM: ~1-3 10^{-2}
ALICE Various-pitch cascaded GEM: 6 10^{-3}
COMPASS 2-THGEM staggered + MM 5 10^{-2}
F-R-MHSP/GEM/MHSP: IBF~1-3 10^{-4}

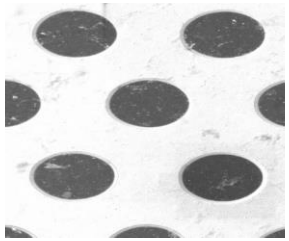
100% electron collection!!!!

RESNATI

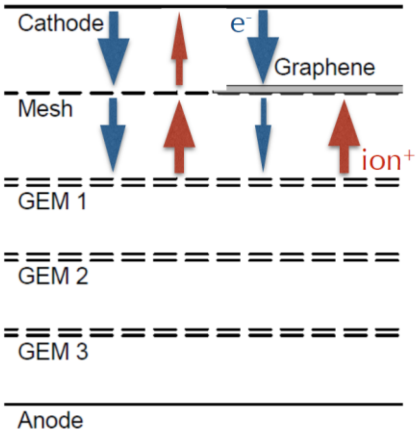
ION BLOCKING w GRAPHENE ON GEM

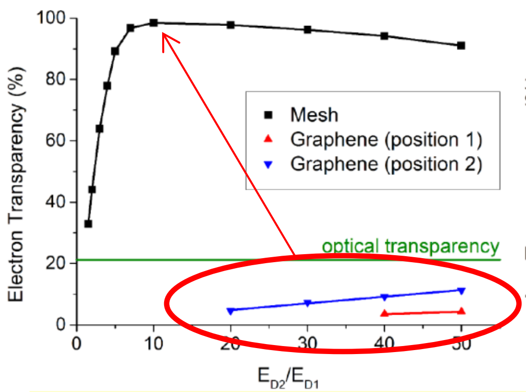


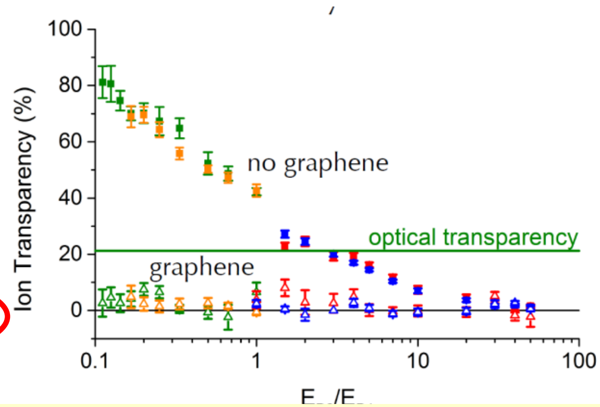
Graphene on “GEM”

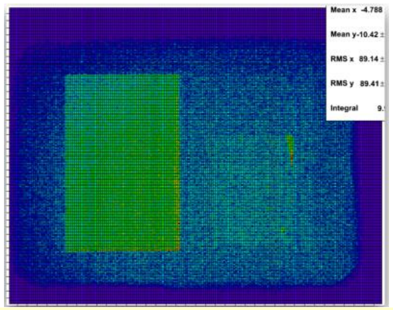


Graphene: opaque to ions and
UNDER SOME CONDITIONS:
transparent to electrons





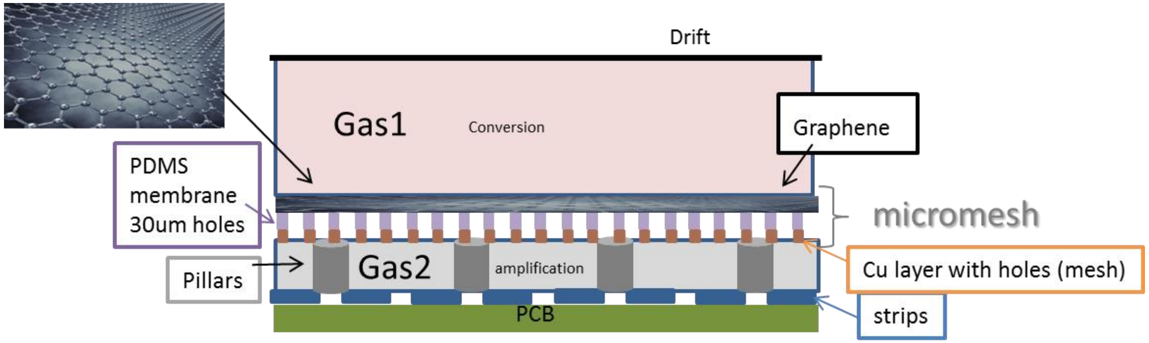




Coating GEM w GRAPHENE: need to increase e- Energy > 10kV/cm. Did not succeed to transmit e- via 3-layer Graphene. Literature: yet unclear (to our community) “directions”
➔ **consult with surface chemists!**

GRAPHENE:
2-GASES MM detector

GERALIS



The "rush" for Resistive Electrodes

- Important in high hadronic backgrounds, DHCAL, Nucl. Phys experiments, etc.
- Protects electronics/electrodes & avoids "dead-time"
- Trade-off between dynamic range (spark damping by HIPs) and counting rate/efficiency (avalanche-charge evacuation).
- Concepts: application dependent

Presently:

Resistive film coatings on GEM, THGEM, μ-PIC, InGrid, pads, strips….

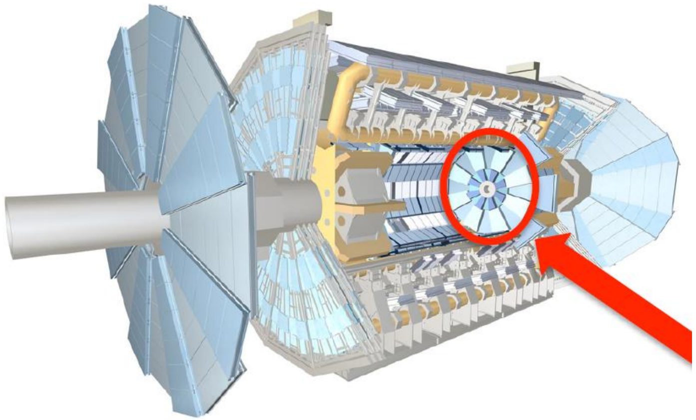
Buried resistors

Resistive sheets (on RPC, RPWELL)

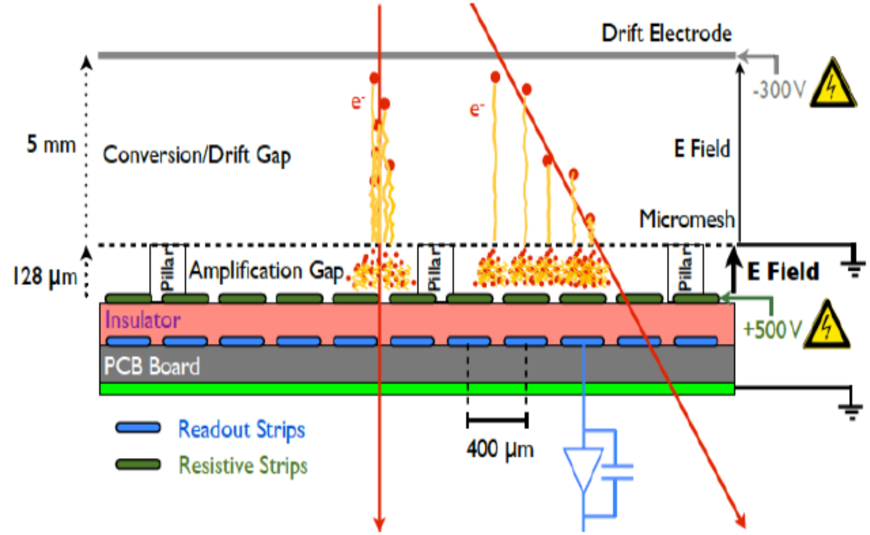
This activity requires further systematic exp./modeling studies!

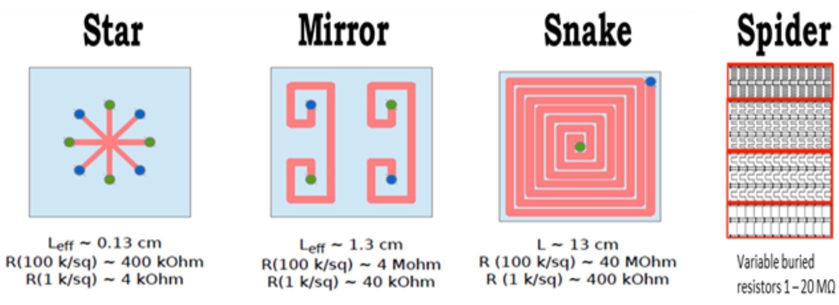
Atlas resistive Micromegas

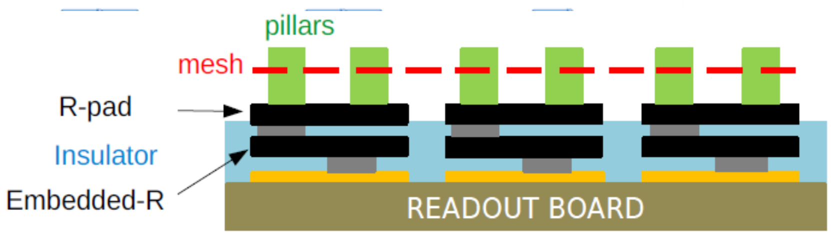
BORTFELDT



Floating mesh technique + resistive strips



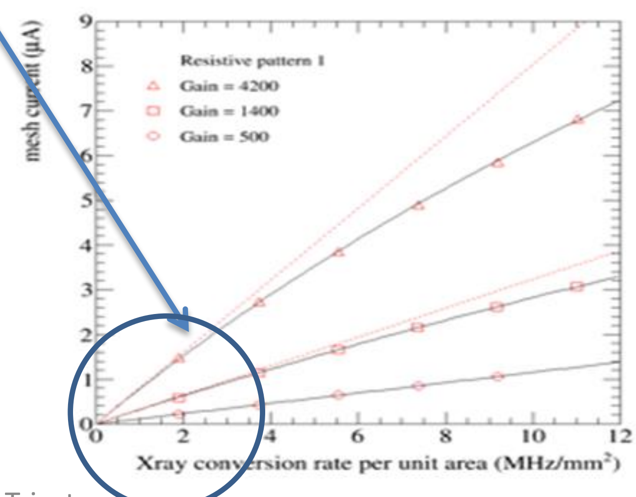




RC-constant controlled with embedded R-pattern

GERALIS MPGD2015 & CHEFDEVILLE ELBA2015

Method of "vertical evacuation" proposed by **Rui de Oliveira**.
Tune (reduce) resistivity & charge evacuation time but suppress discharges.
Keep linearity!



COMPASS hybrid pixilated high-rate MM almost went for "buried Rs"….

Neyret

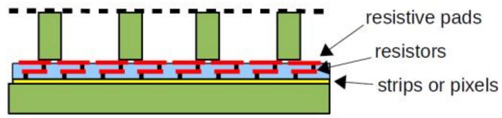
Pixilated MM for very small angles

STUDIES:

Resistive Micromegas

Other resistive schemes not fully adapted for pixels

***Buried resistors** scheme proposed in 2010 by R. de Oliveira et al.*

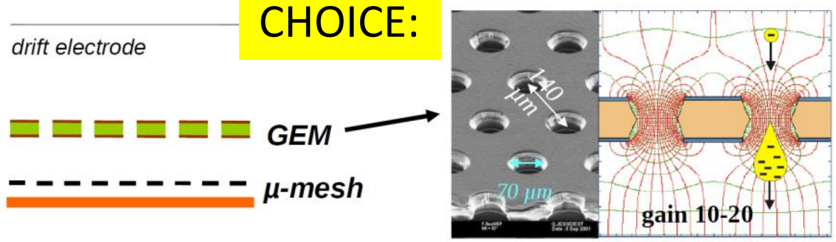


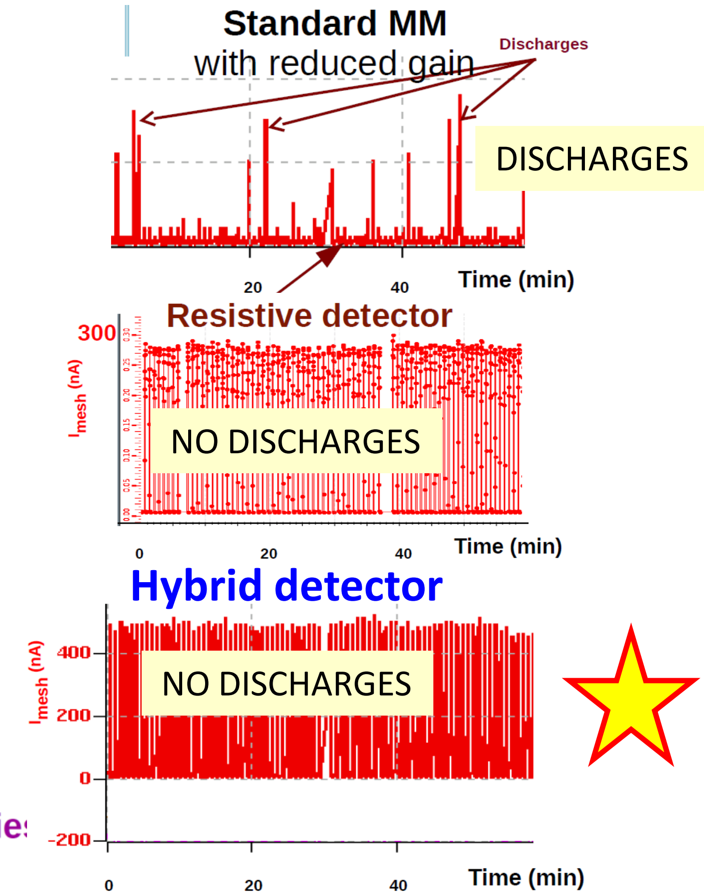
Hybrid Micromegas with 1 GEM foil

Preamplification with a GEM foil (gain 10-20)

Micromegas stage at lower gain → fewer discharge

CHOICE:





Buried resistor MM boards promising but further studies required

- *Complicated structure, R&D necessary for serial production of such boards*
- *Good efficiency and spatial resolution, but bad time resolution, origin not understood*

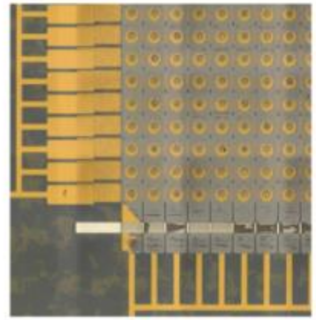
SHOULD ONE RECONSIDER RESISTIVE COATING?

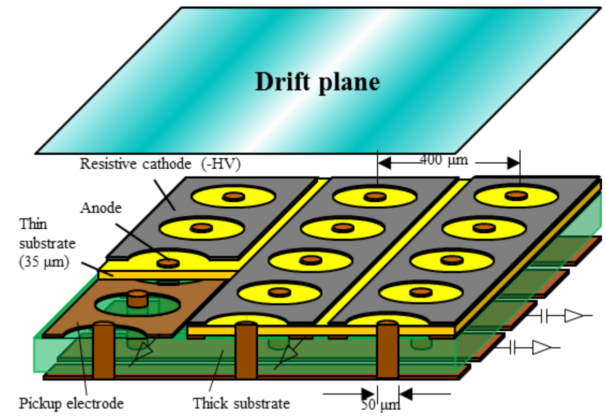
OCHI – KUBEC 014

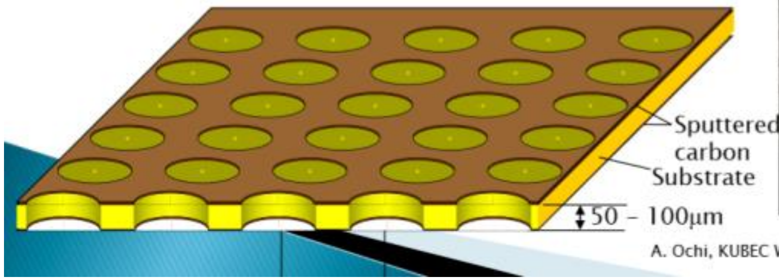
YAMANE

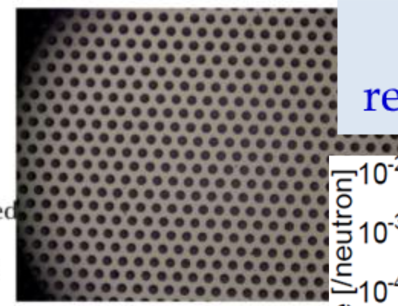
Other MPGD development using carbon sputtering

- Resistive μ-PIC
  - New version using carbon sputtering is being tested
- Resistive GEM
  - The resistive electrodes are made by very thin (50 – 300nm) material
    - It will improve the signal gain
  - We have just made it, and it is being tested now.
    - (Scienergy + Raytech)



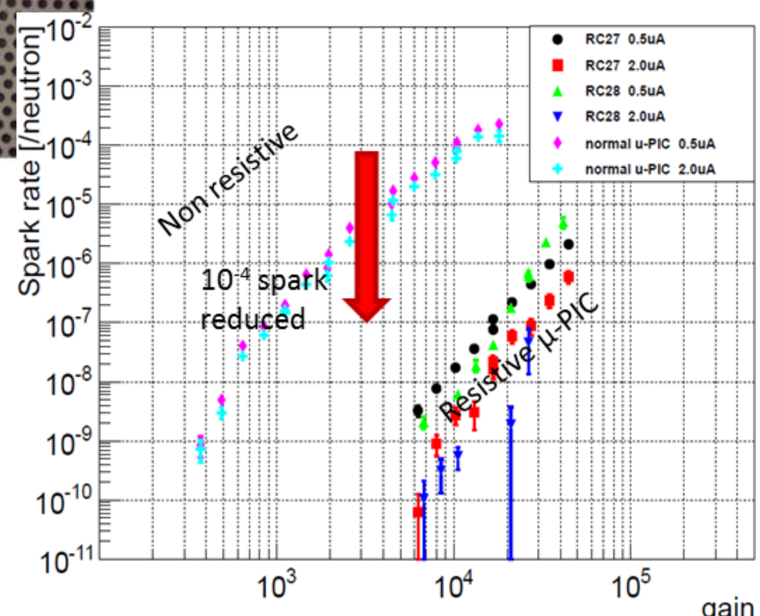


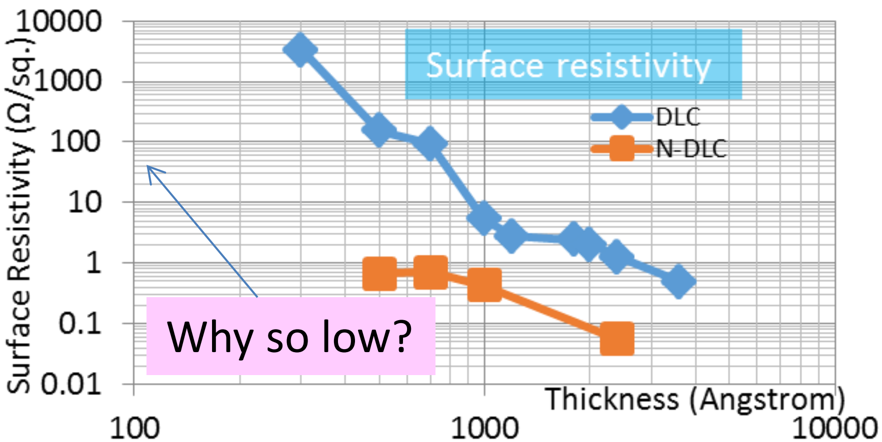




A. Ochi, KUBEC Workshop 2014/8/29

Spark rate reduction using resistive μ-PIC for fast neutron

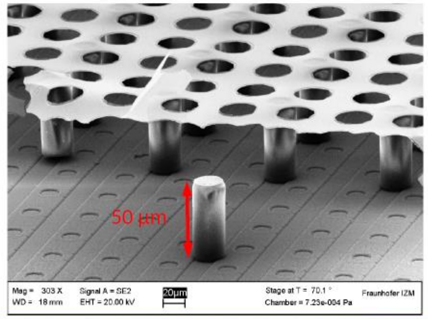




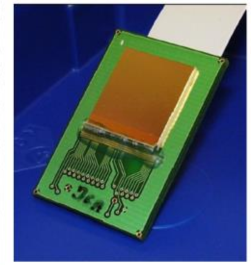
InGrid TPC for ILC-ILD

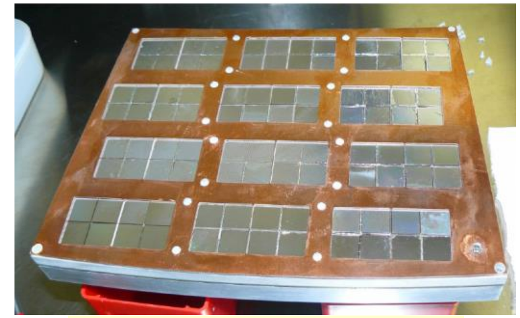
Kaminski

Resistive coating to “save chips”.
Chips die…
But: probably fabrication defects



Timepix





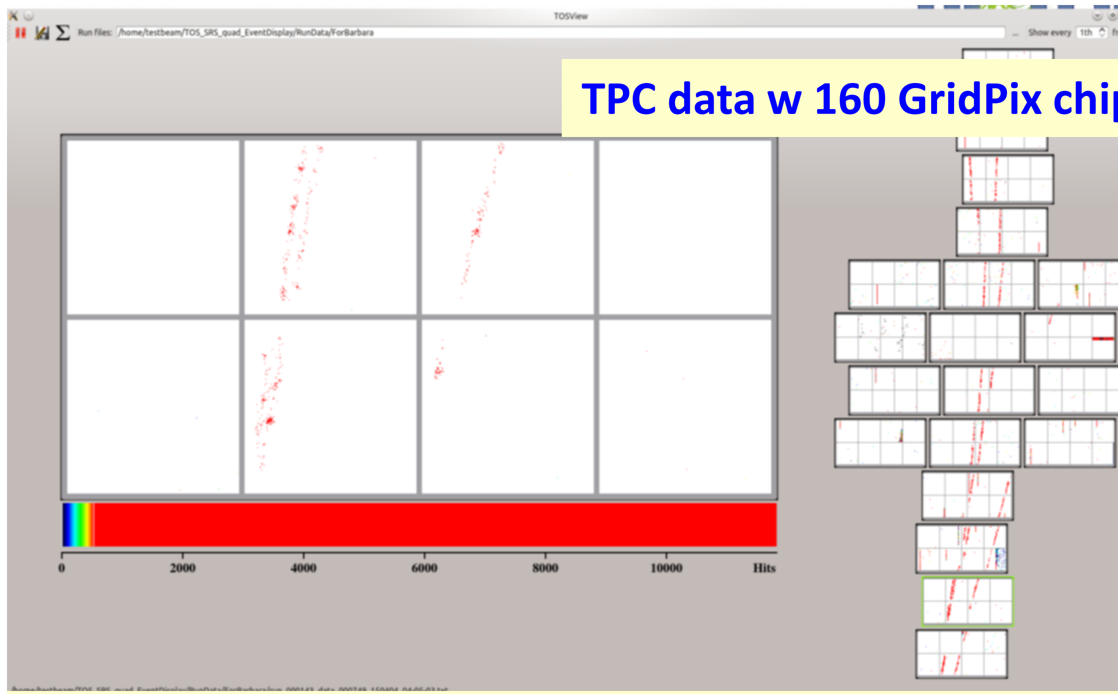
8 GridPix modules

GridPix Advantages:

- Lower occupancy
  → better track finding
- Identification and removal of δ-rays and kink removal
- Improved dE/dx, because of primary e^- counting
- Pad plane and readout electronics fully integrated

To readout the TPC with GridPixes:
~100-120 chips/module
240 module/endcap (10 m²)
→50000-60000 GridPixes

TPC data w 160 GridPix chips

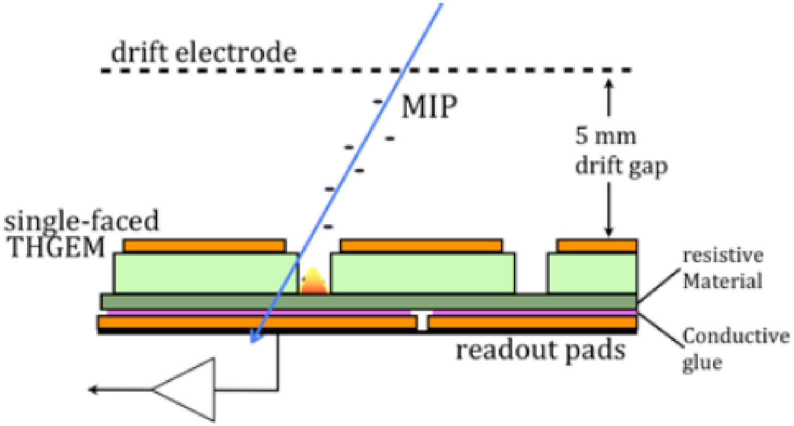


dE/dx resolution compatible with ILD-ILC requests
Localization resolution: not yet confirmed OK for ILD-ILC

RPWELL for DHCAL (WIS/Coimbra/Aveiro)

BRESSLER

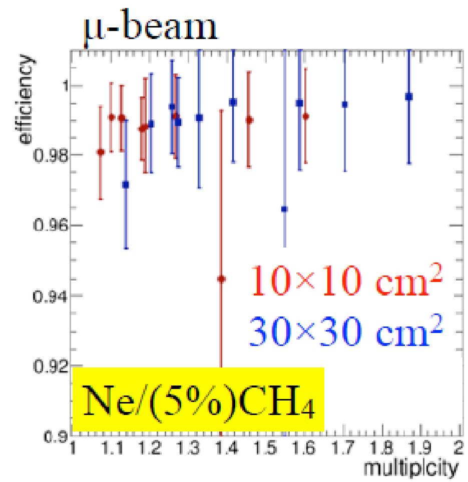
Resistive Plate Well (RPWELL)

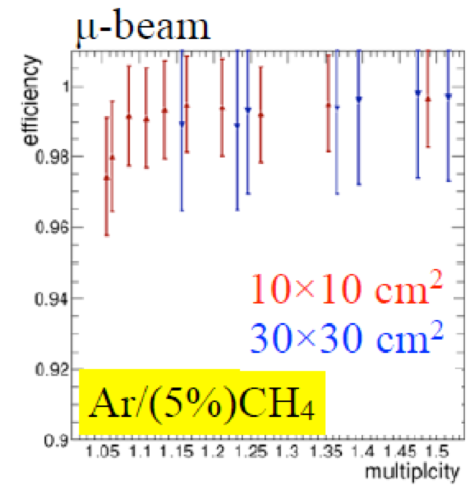


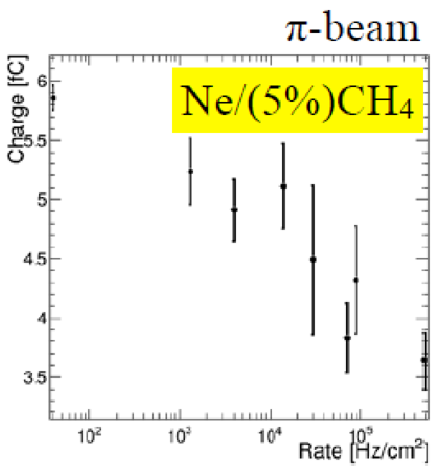
Performance

High (>98%) detection efficiency at low (<1.2) pad multiplicity

- Ne & Ar based gas mixtures
- Small (10x10 cm^2) & medium (30x30 cm^2) protos







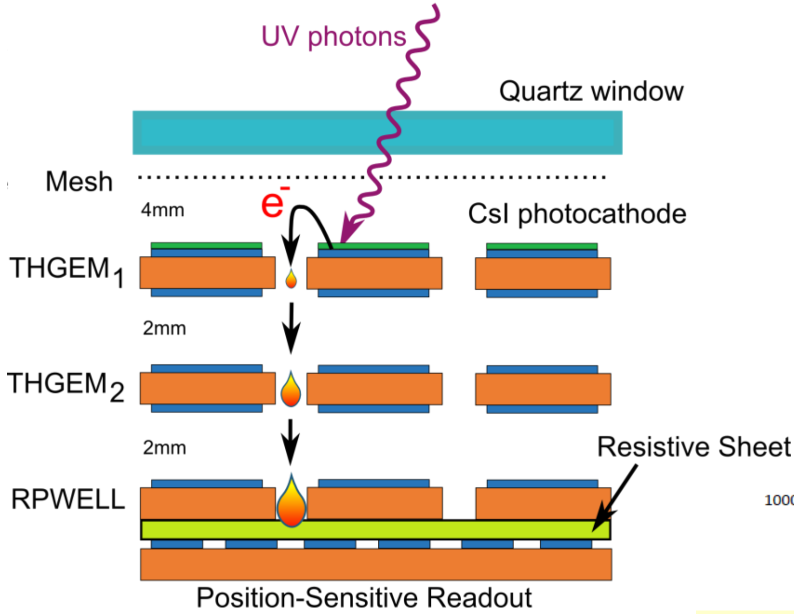
Rate capabilities

- ~30% gain drop from 10^2 to 10^5 H_z/cm^2
- <5% efficiency loss that could be restored with higher gain

Discharge-free single-stage THGEM-based RPWELL detector

- Also with high rate (~5×10^5 H_z/cm^2) π-beam

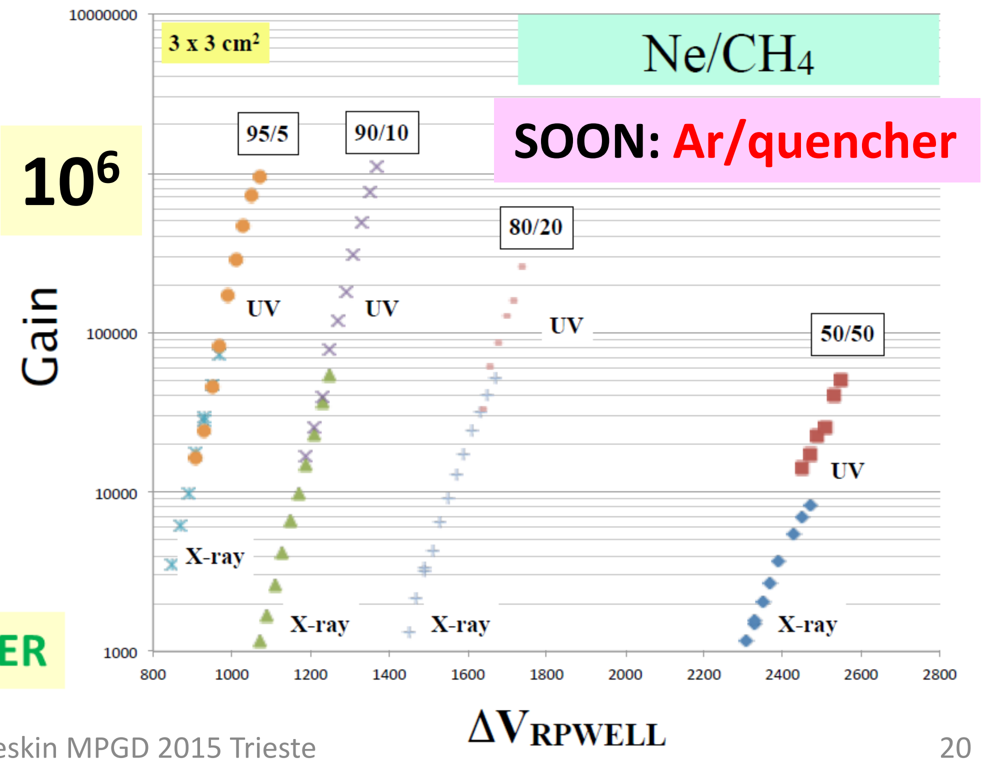
RPWELL a potential photon detector?



R&D @ Weizmann

- RT & noble-liquid T
- RPWELL vs nTHGEMs+RPWELL
- Gases
- stability

10^6

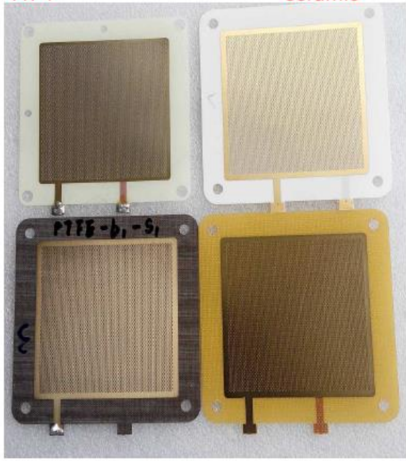


BRESSLER

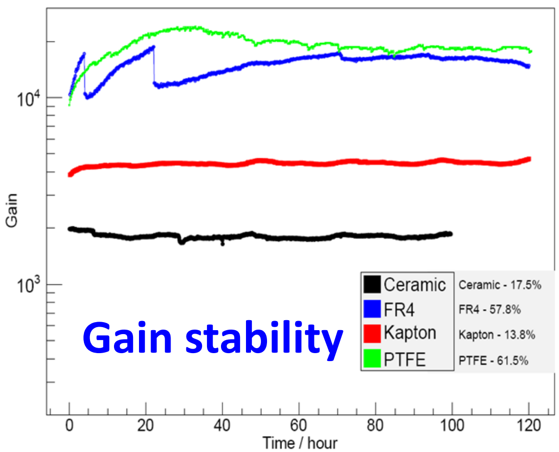
Yuguang Xie

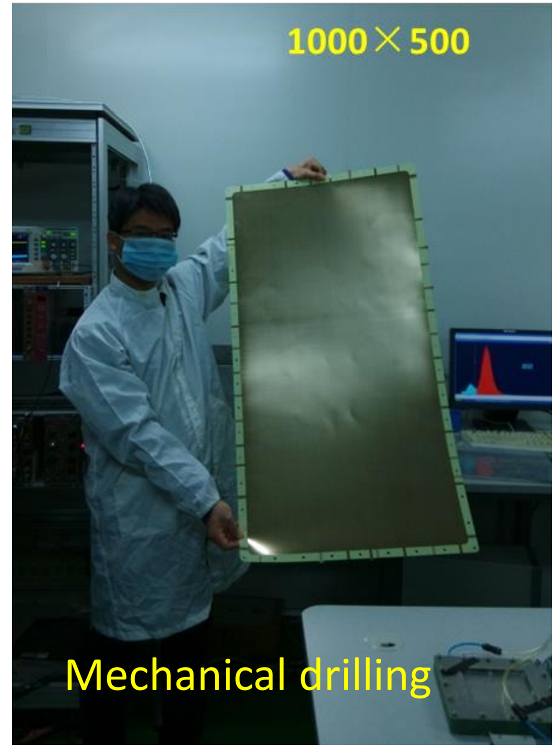
THGEM materials & production in China

FR-4 Ceramic

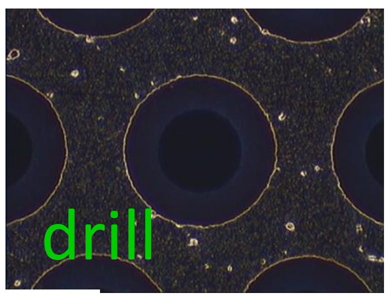


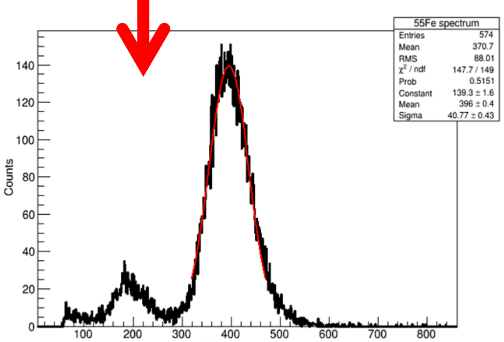
PTFE (Teflon) Kapton(PI)





Unclear results of radio-purity

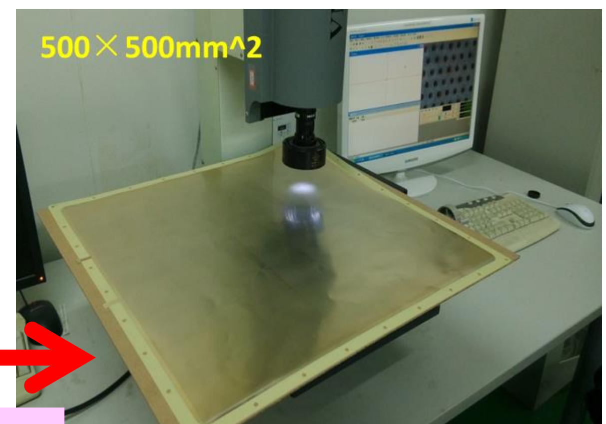




24%@gain=4×10^3

Laser etching 10 x faster!!!

So far tested only small sizes. Made large

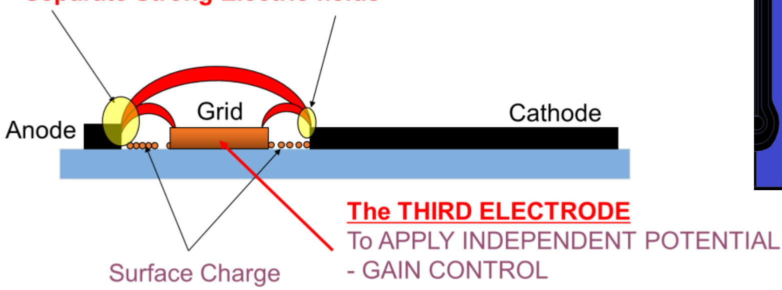


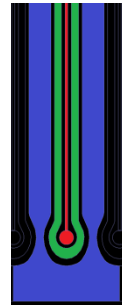
Many ongoing applications!

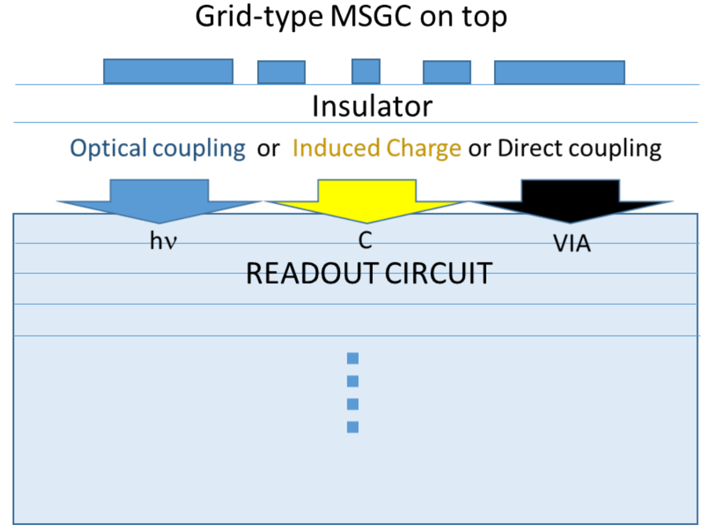
Transparent (LCD) Single-grid-MSGC

TAKAHASHI

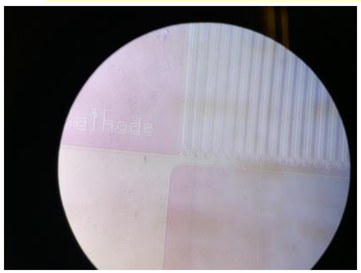
MSGC with Grid→ no-discharge

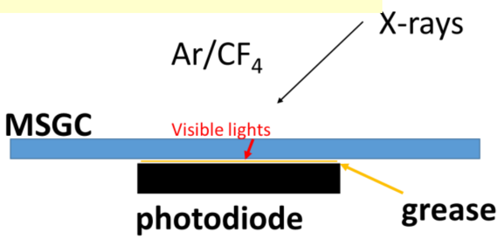


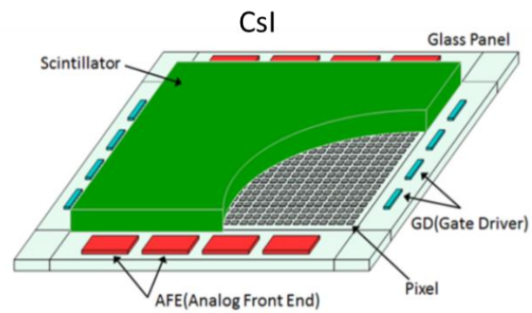




OPTICAL READOUT OF AVALANCHE





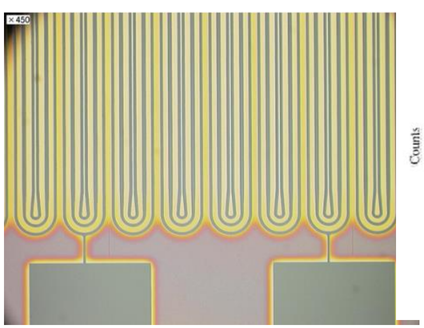


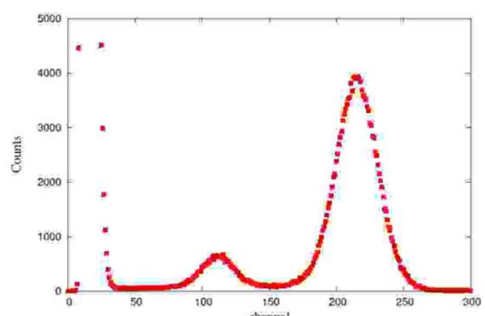
MSGC on transparent IZO layer

(80μm pitch)

The number of grid = 2

Active Pixel Sensor photodiode readout

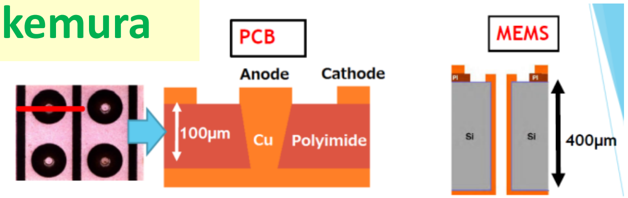


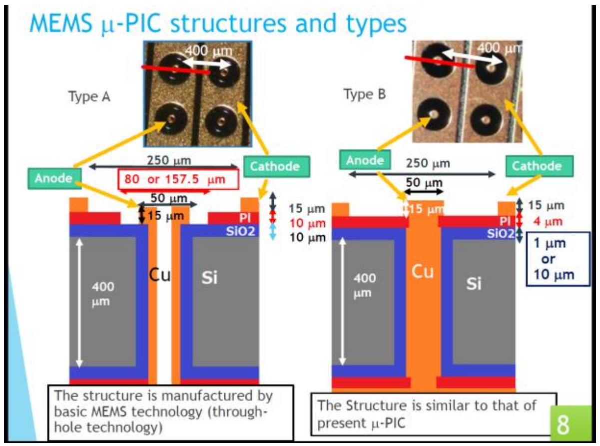


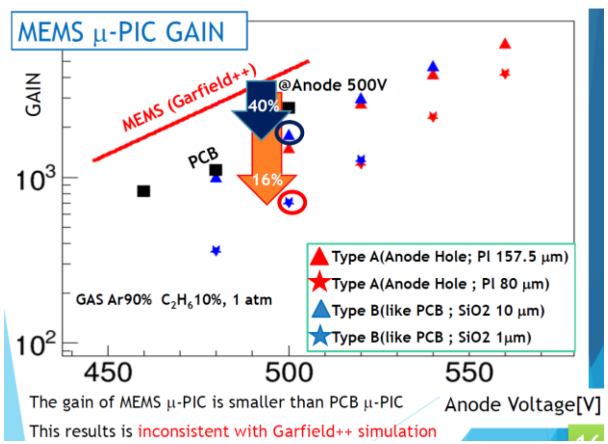
MANY MORE IDEAS SHOWN!!!!

μ-PIC based on MEMS

Takemura





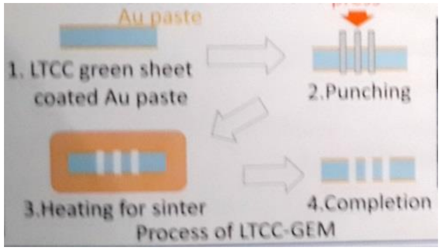


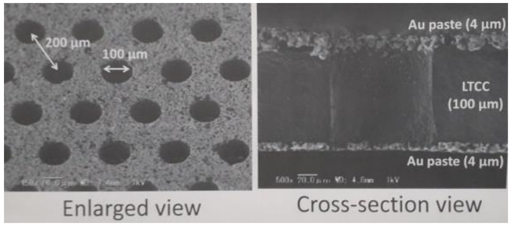
Simulated gain of MEMS μ-PIC expected > PCB one.
It is lower than expected.
Probably due to the Si (not dielectric)

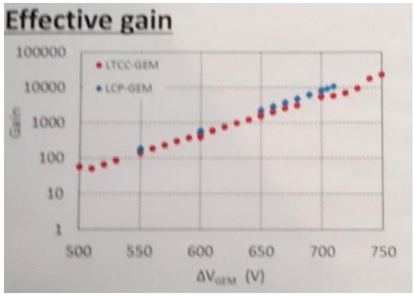
GEM of fine CERAMIC - LTCC

POSTER: KOMIYA

LTCC: low T co-fired ceramic





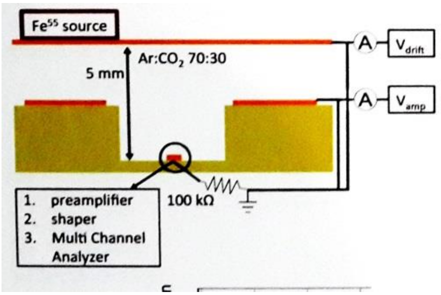


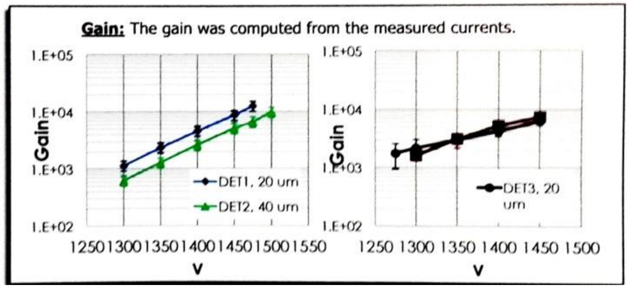
Parameters of test GEMs

	LTCC- GEM	LCP-GEM
Pitch	200 μm	140 μm
Diameter	100 μm	70 μm
Thickness	100 μm	100 μm
electrode	Au paste (4 μm)	Cu (8 μm)
Size	15 x 15 mm^2	30 x 30 mm^2
Process	Punching	Laser etching

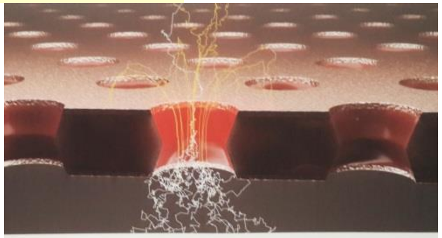
THICK-GROOVE for cosmic tomography

LENGO





HILDEN **Hole size dependence on GEM performence**



A simulation of a single electron avalanche in a GEM-foil

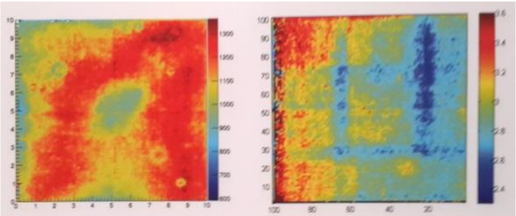
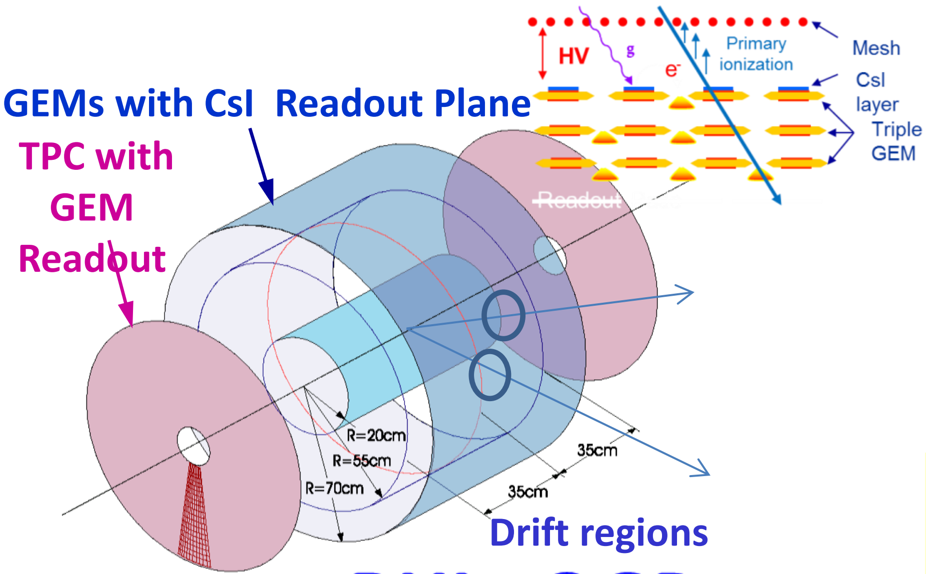


Figure 2: The gain map of a double GEM-detector (left) used to measure the gain of a third foil (right)

Woody

TPC-RICH for sPHENIX & IEC



RHI - QGP

- TPC provides momentum measurement and particle id through dE/dx. Use ionization in gas volume to measure track trajectory.
- Use Cherenkov light produced in the *same* gas volume to identify electrons

  ⇒ **HBD concept**

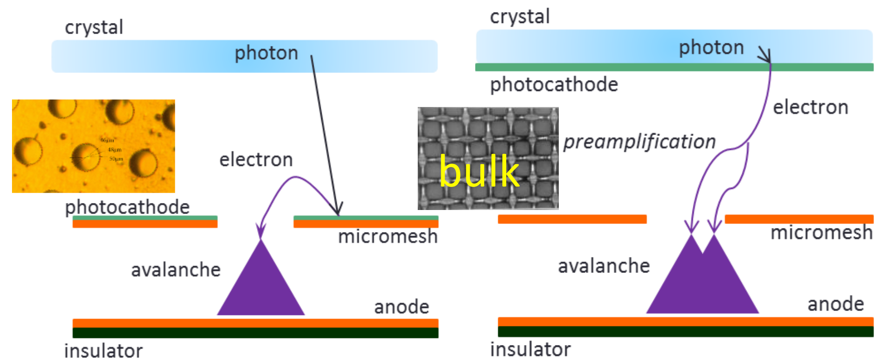
  Acts as a threshold counter

HBD: CF_4 or Ar/CF_4 – radiator & TPC gas

Papaevangelou

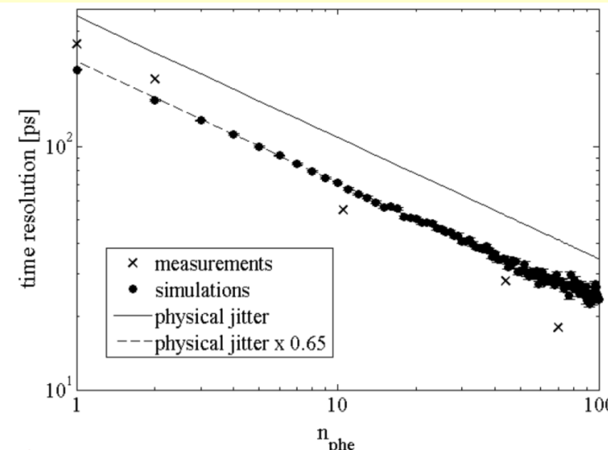
Fast –timing MM

MM photomultiplier + Cerenkov-radiator



Goals: Single electron time jitter ~100 ps

Many photoelectrons ➔ ~ 10 ps.



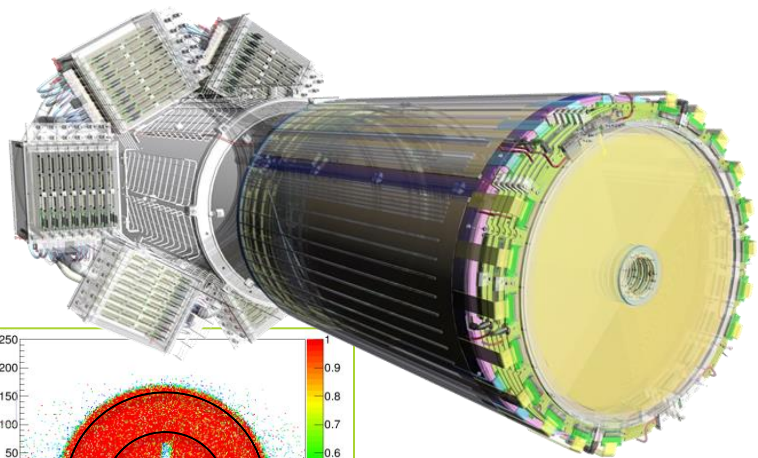
180 ps for <N>=1.26 p.e. with bulk MM in **semi-transparent** & sealed mode + **preamplification**

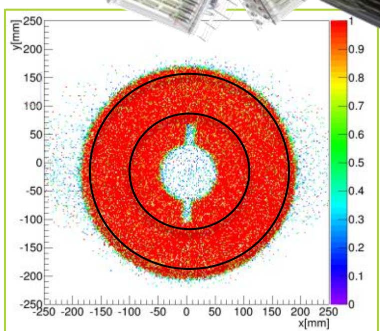
Replace C-radiator by Secondary e- emitter?

ELEGANT "GUNs"! ➔ impressive achievements!

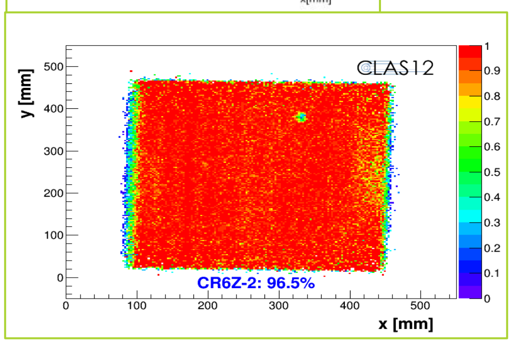
MM Vertex Tracker for CLAS12

VANDENBROUCKE

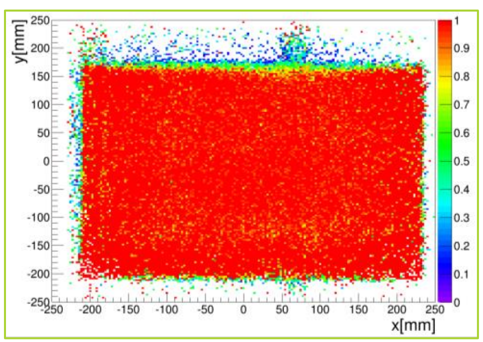




efficiency >98%



Z Barrel Efficiency Map

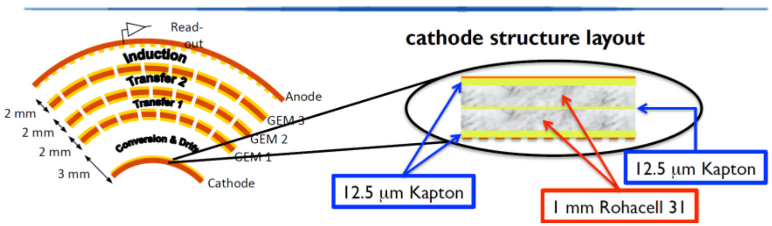


C Barrel Efficiency Map
(with 6.5μA on res. strips)

Cylindrical GEM for BESIII Experiment @ e+e- collider Beijing

Cibinetto

Rohacell technique for mechanical structure

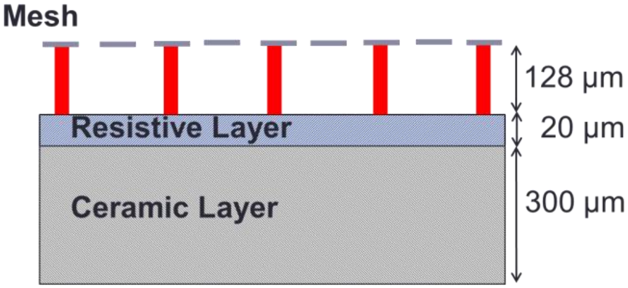


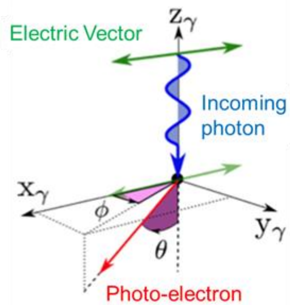
Test beam results of planar chambers
Commissioning expected 2018

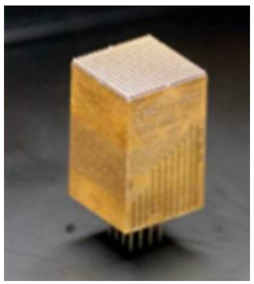
CALIST-MM: X-ray polarimetry

Serrano

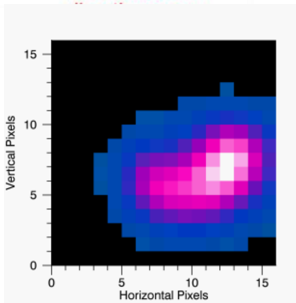
Piggyback Micromegas







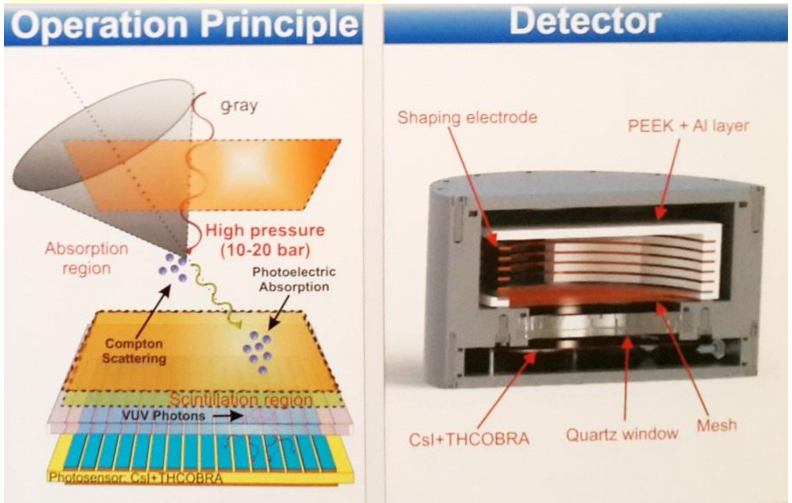
CALIST
- 10 x 10 x 20,7 mm³ (Compact)
- 16x16 pixels : 8 ASICs of 32 channels
- Pixel Ø = 500 µm ; Pixel Pitch = 580 µm
- Consumption = 850 µW/channel (218 mW in total)
- Low Noise (ENC = 50 e⁻ rms)

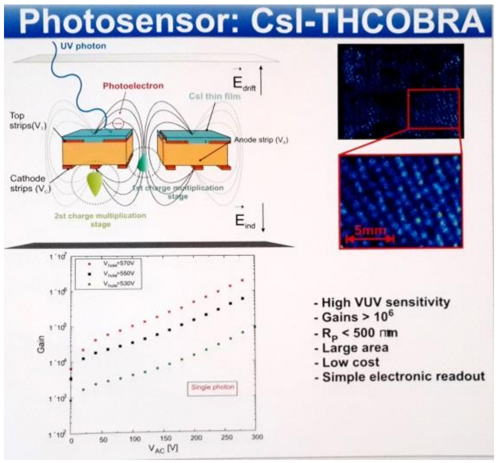


$He-CO_2$

Ab-initio: Gaseous Compton Camera

POSTER: VELOSO

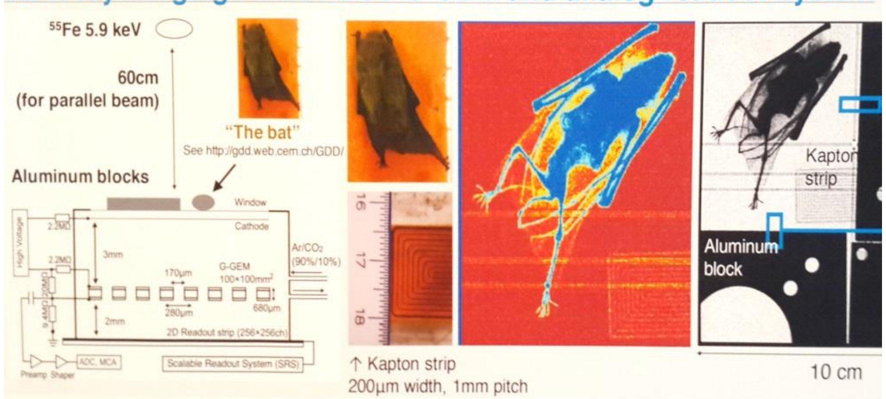


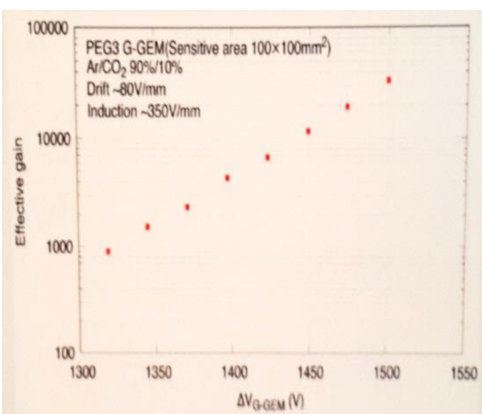


POSTER MITSUYA

The Glass GEM

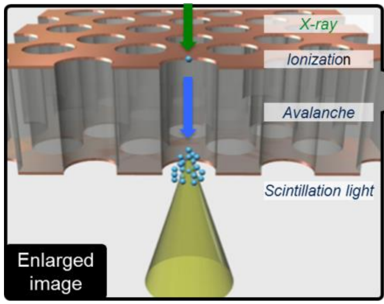
4.3 X-ray imaging with PEG3C G-GEM and analog readout system

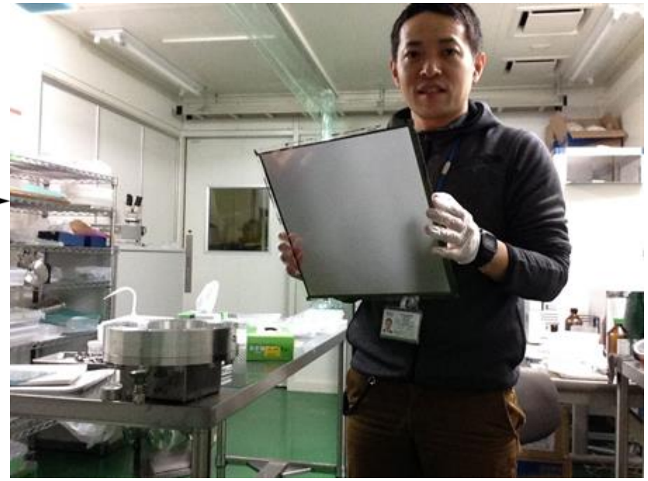


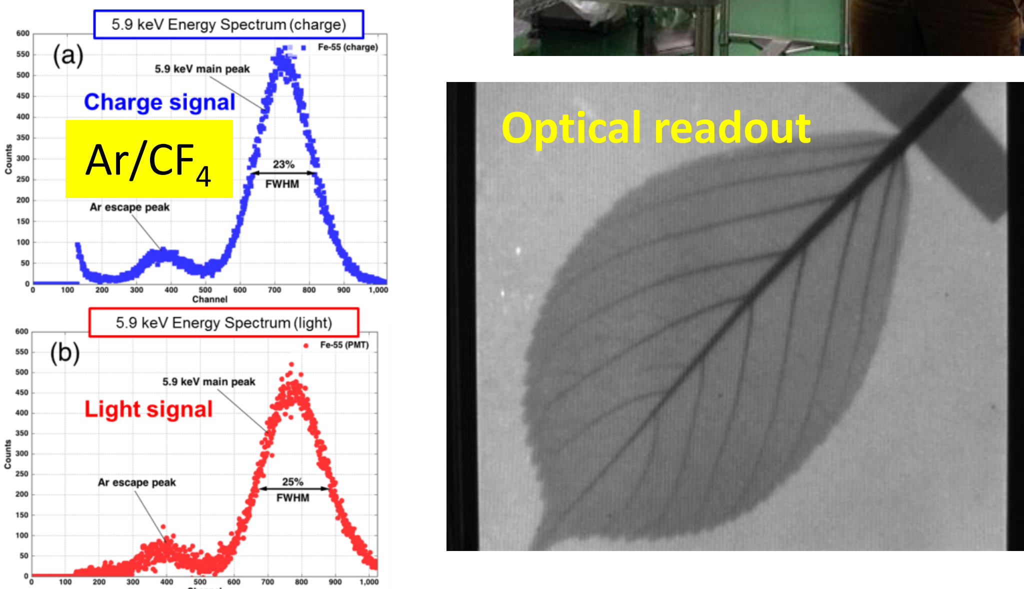


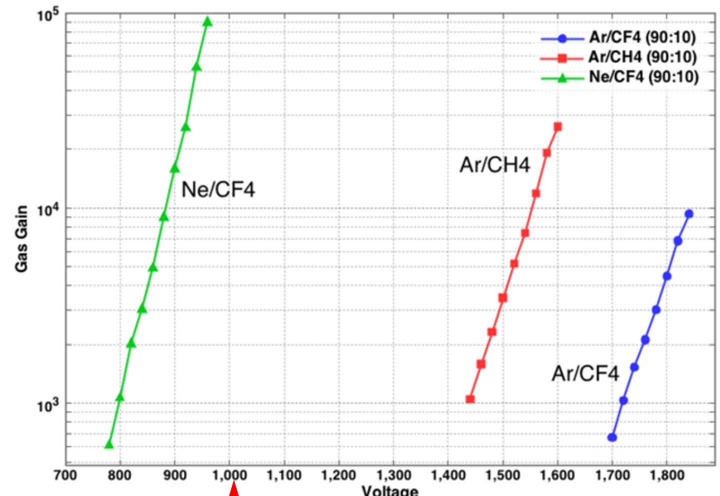
Scintillating Glass-GEM imager

Fujiwara





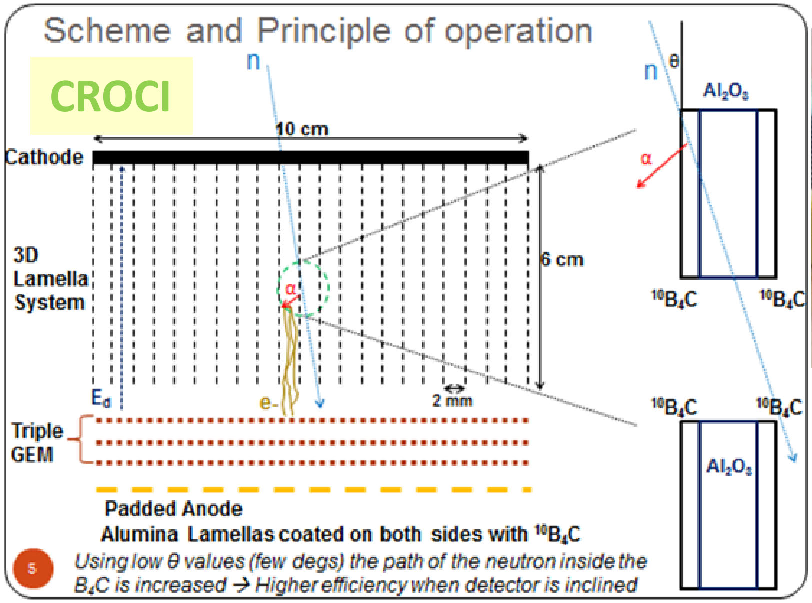


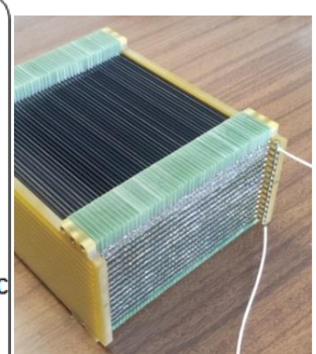


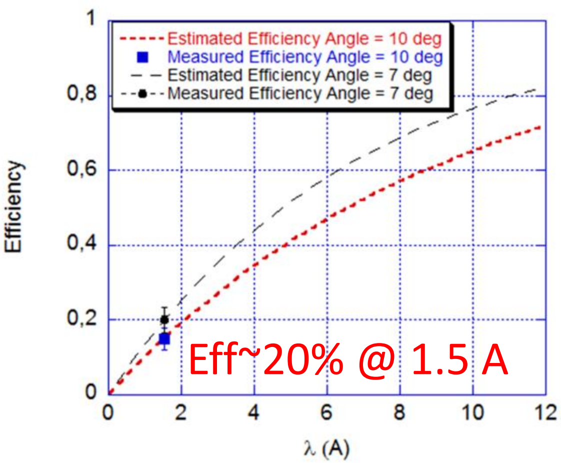
Imaged n, gamma, ions…showed tomography….

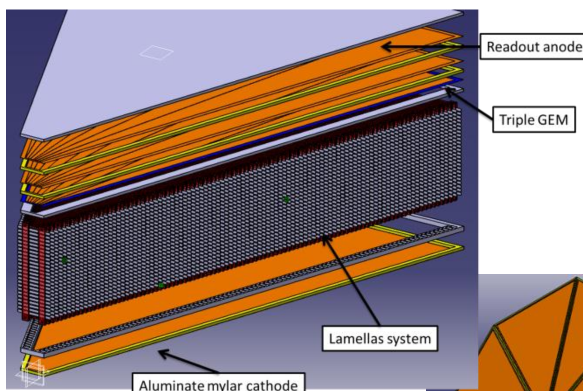
MAIN INTEREST: SEALED DETECTORS

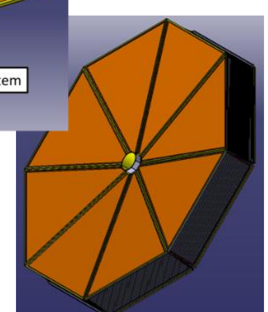
Boron Array Neutron Detector









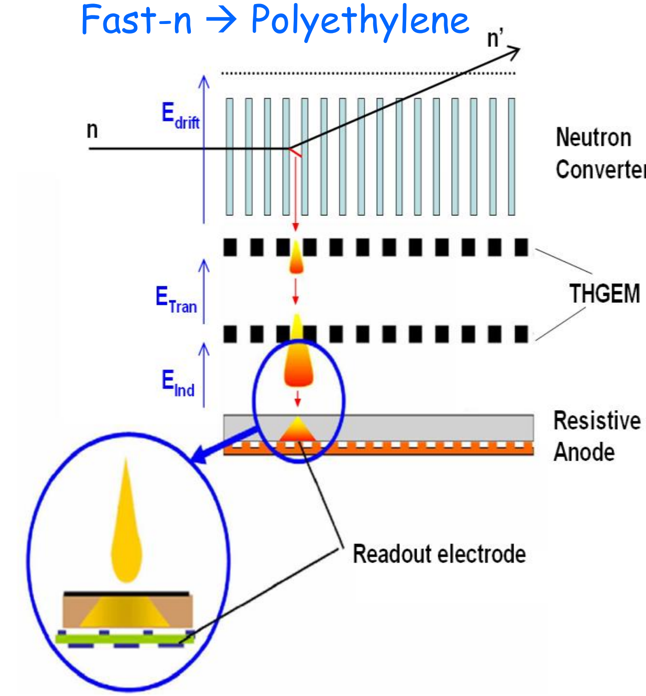


Many applications foreseen

Competitors…

Neutron multi-foil Detector

Thermal-n → B/Gd
Fast-n → Polyethylene



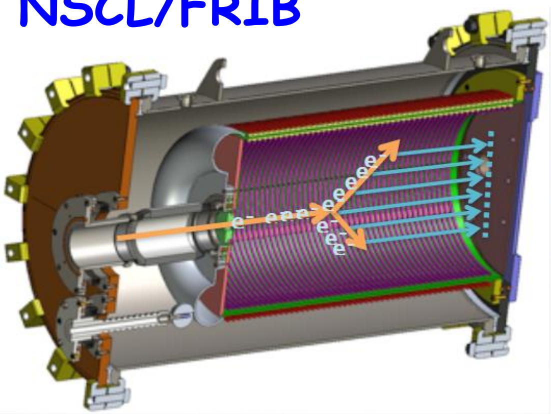
Cortesi et al. 2012 JINST 7 C02056

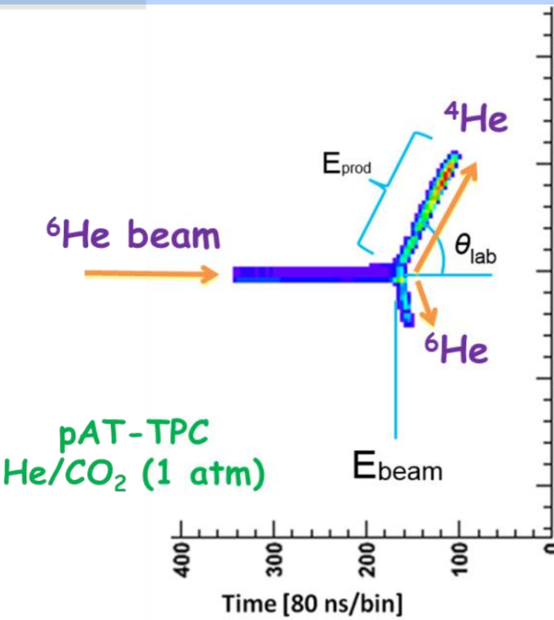
CORTESI

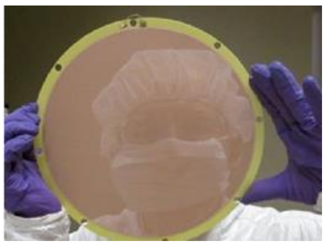
AT-TPC applications with RIBs

GOAL: THGEM as pre-amplification stage ➔ High Gain @ low-P pure noble gas

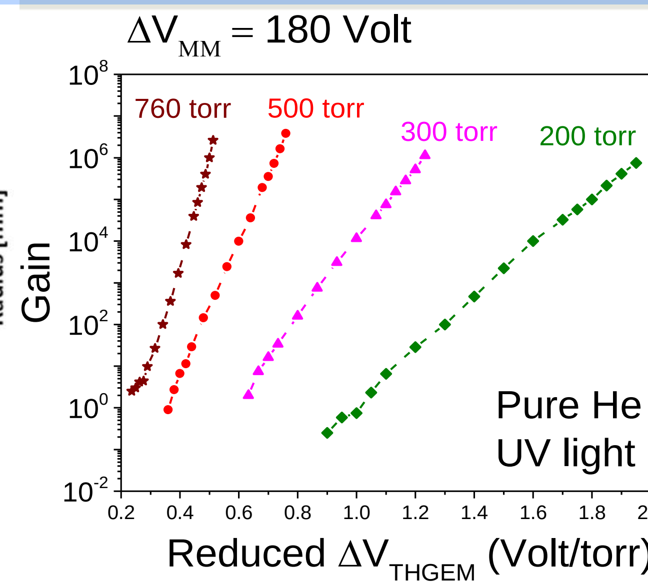
NSCL/FRIB

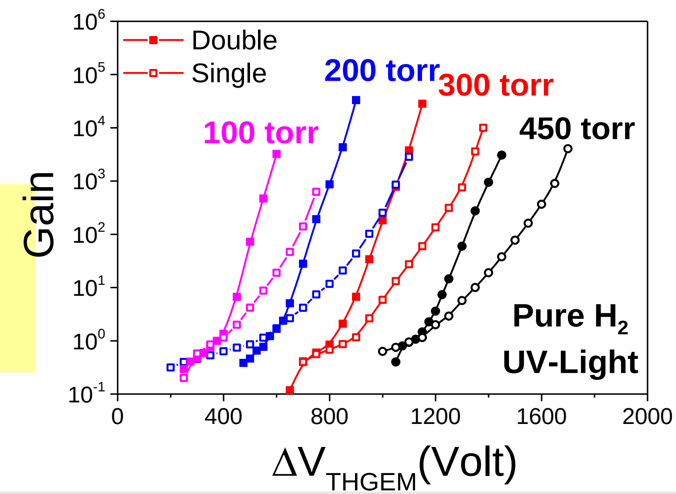






Position-sensitive endcap detector: Micromegas + THGEM





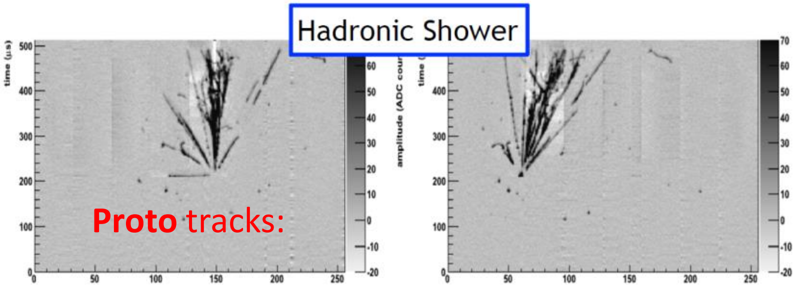
High-gain operation in **low-pressure H_2, D_2 & He** with THGEM due to:
- -) Avalanche confinement in holes ➔ reduced photo-secondary effects
- -) Impurities (mostly N_2) act as quencher ➔ High effective gain
- -) Extended thickness of the avalanche volume

Cortesi et al. 2015 JINST 10 P09020
Cortesi et al. 2015 JINST 10 P02012

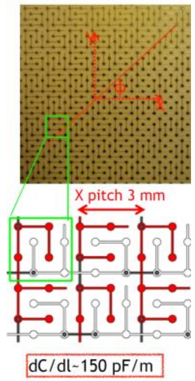
WU

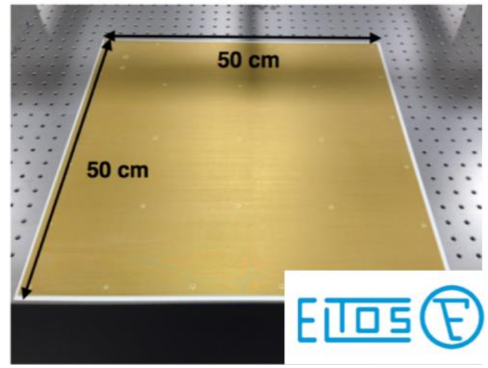
Double-phase LAr LEM TPC

Large-area coverage of dual-phase LAr readout with single-element LEM (THGEM) TPCs.
Goal: Neutrino oscillation experiments: WA105 (on ground) and future (underground) DUNE.



high ionization density in LAr➔ need low gain

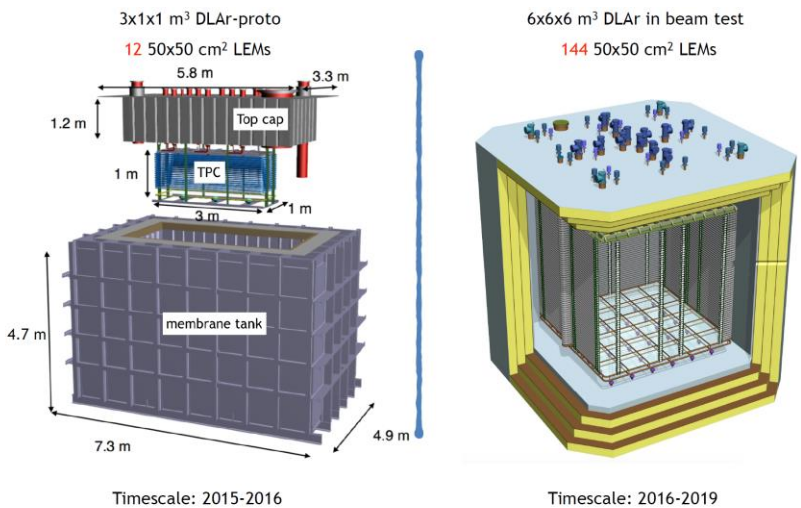




ptimised values
- 40 µm rim
- 1 mm FR4 thickness
- 500 µm diameter hole
- 800 µm hole pitch and hexagonal layout

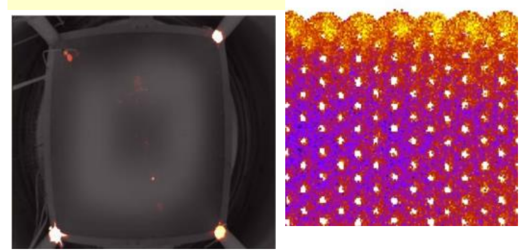
DC: 5nA/LEM(50x50)
Stable gain ~20 (fine)

"demonstrators"



12 & 144 50x50cm² LEMs

DUNE: ~3000 LEMs (50x50)

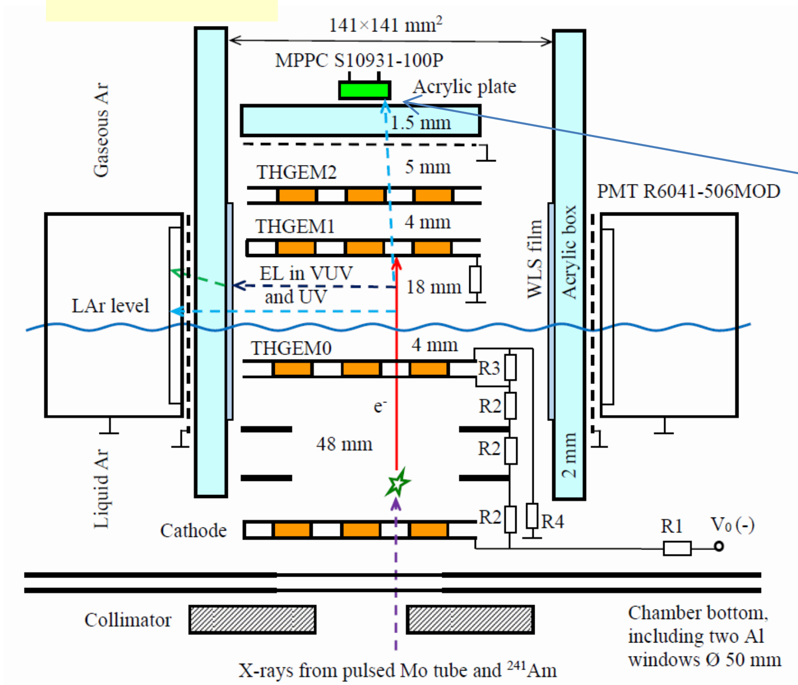


~3500V; spark on edges
(use COMPASS RICH solution?)
Charging up of rims: gain stabilizes. OK

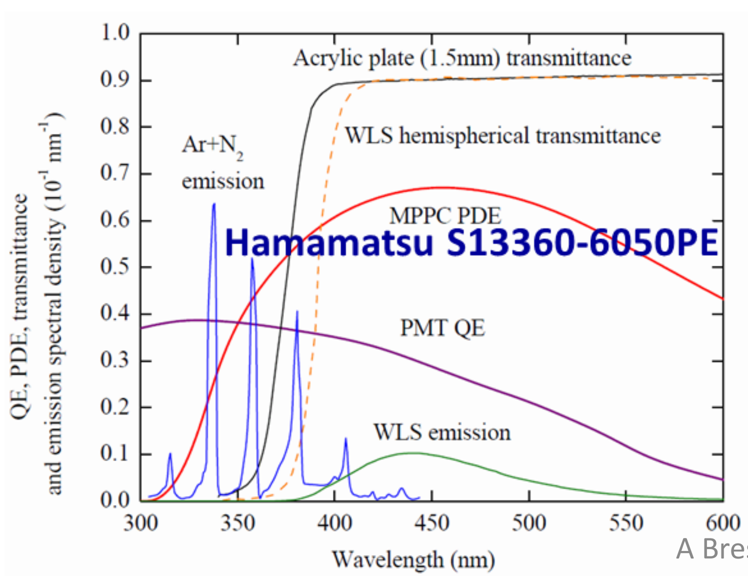
Ongoing R&D on RESISTIVE WELL concepts

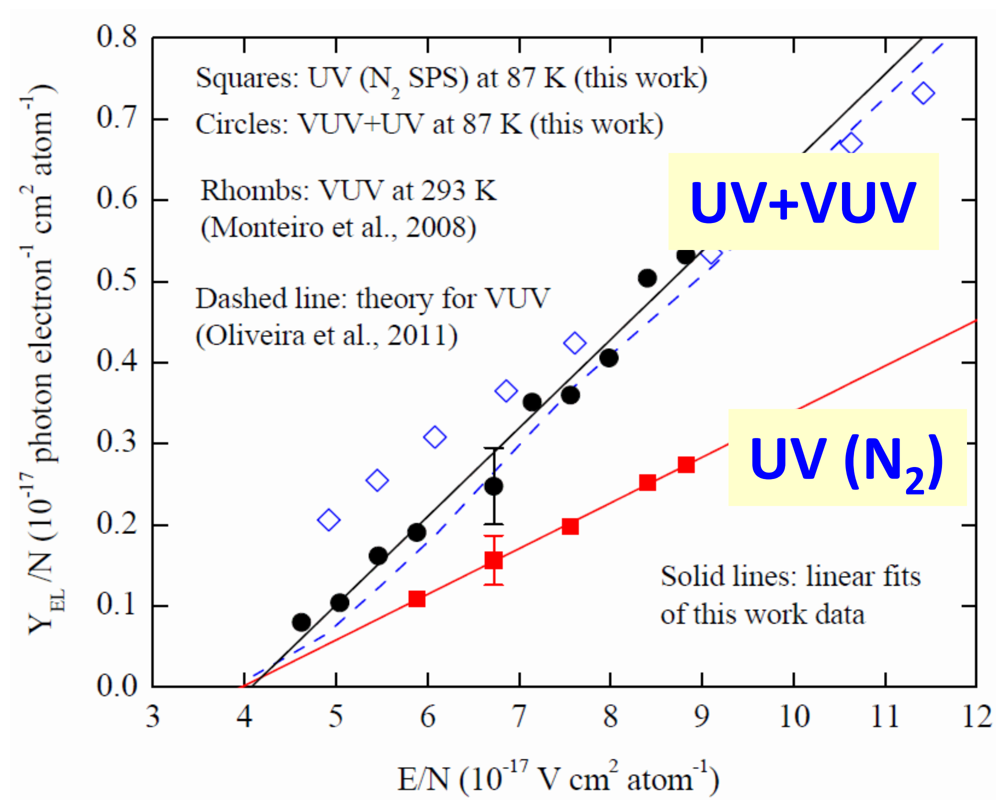
Proportional Electroluminescence in two-phase Ar

SOKOLOV



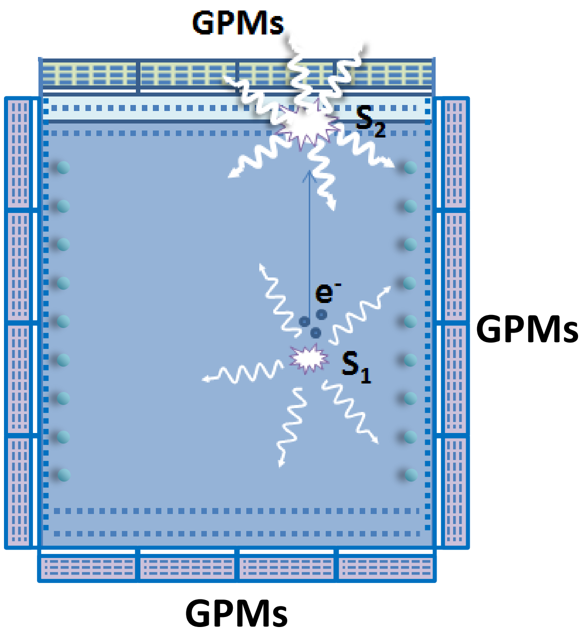
Small additives of N2 ➔
UV photo-yield ~ VUV one!
➔ Simpler photo-detectors
(e.g. SiPM)



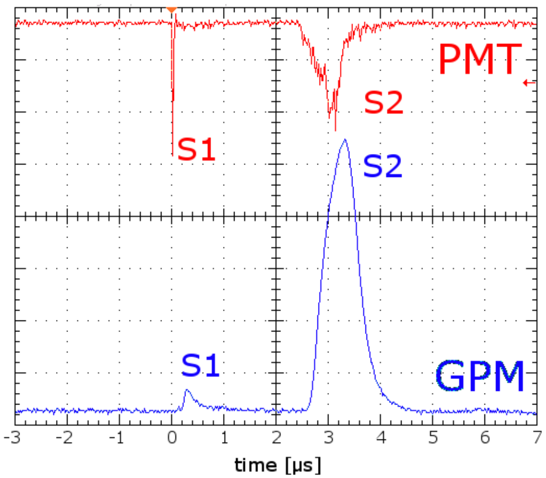


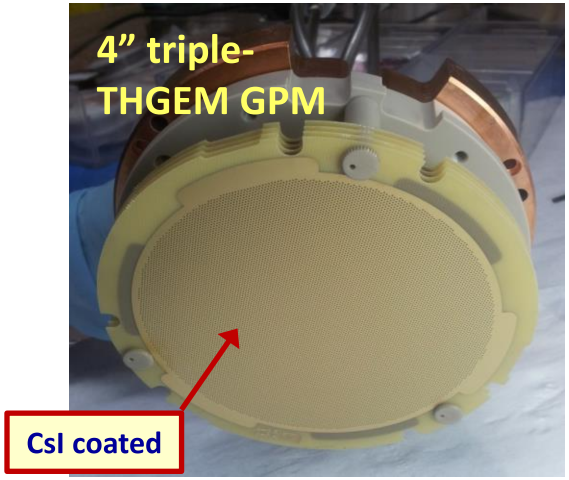
Buzulutskov et al. arXiv:1509.00664v1

Gaseous Photo-Multipliers (GPMs) for future dark matter searches



- WIS R&D on **GPMs** for future multi-ton LXe TPCs for dark matter searches (within DARWIN)
- Aim for **4π coverage** – not practical with PMTs (cost, bulkiness) or SiPMs (dark count rate)
- Successful demonstration of 4" cryogenic **triple-THGEM GPM** with reflective CsI coupled to dual phase LXe TPC: (arXiv:1509.02354)
  - Stable gain ~ 10^5
  - Large dynamic range: 1 – $O(10^3)$ photoelectrons
  - 1 ns timing (~ 200 PEs)
  - Expected PDE ~15% after optimization





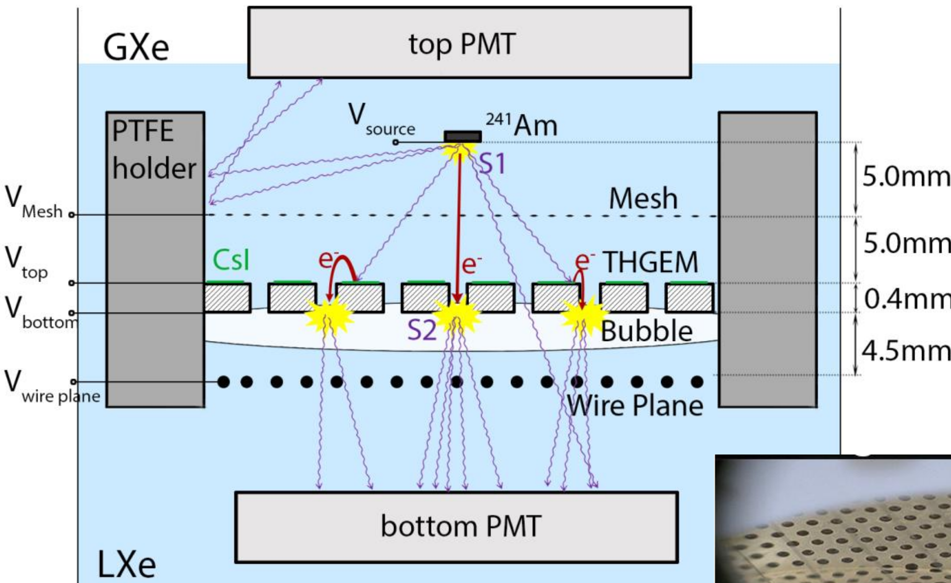
- Also: on-going R&D on **n/γ imaging** with pixilated readout (arXiv:1501.00150)

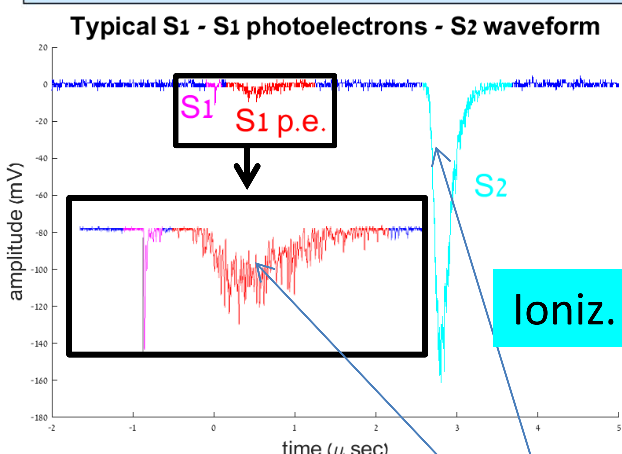
ERDAL

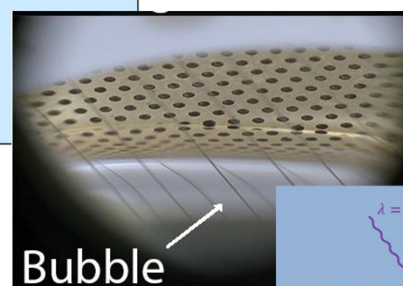
Bubble-assisted electroluminescence in Lxe: A "local dual-phase" noble-liquid detector

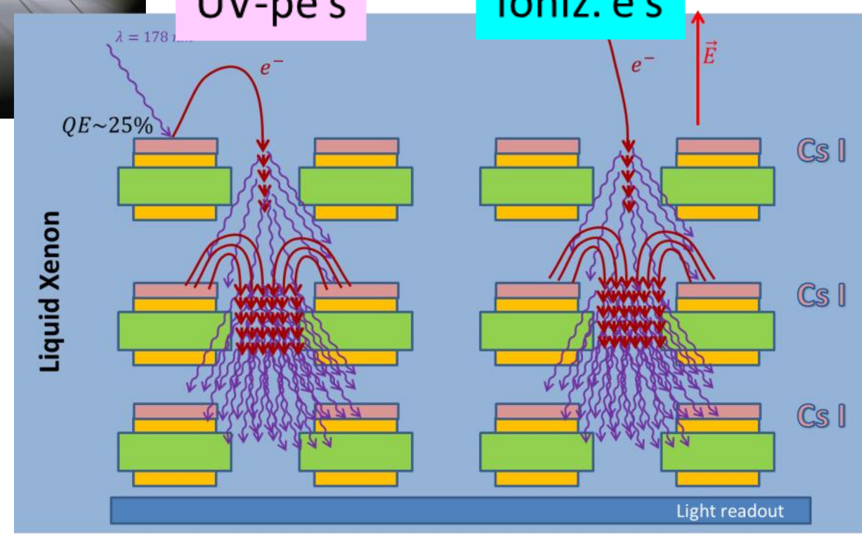
TOWARDS LARGE-SCALE NOBLE-LIQ DETs

Energy resolution 5MeV alphas: $\sigma/E=7.5\%$
Time resolution: $\sigma=10ns$
Bubble (under THGEM, GEM) stable for days
CsI on THGEM: high pe extraction









UV-pe's

Ioniz. e's

Ioniz. e's

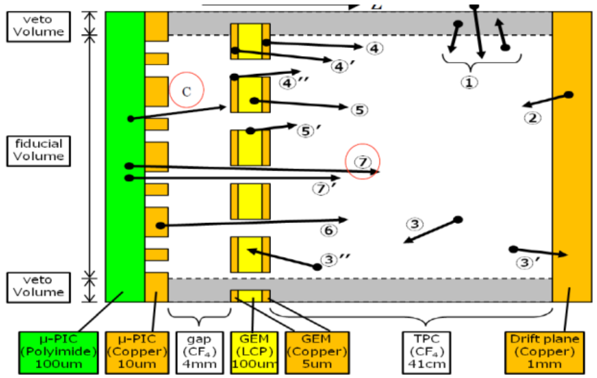
UV-pe's

EL in bubble

Breskin, *J. Phys. Conf. Ser.* 460(2013) 012020

Negative-Ion TPC using μ-PIC for Directional DM search

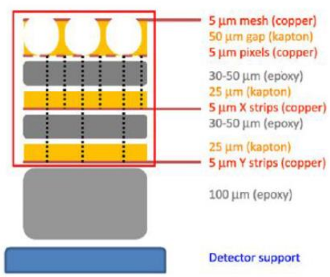
TOMONORI



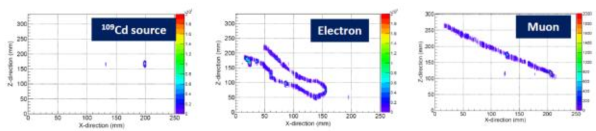
- Principle invented by the DRIFT DM collab.
- Event-induced Neg ions drift towards ab end cap multiplier
- At the high-field neg-ions ➔ electrons➔mltiplication
- Advantage: low diffusion
- Problem: need special gas DRIFT: CS_2
- Low-pressure➔ expansion of the recoil track.

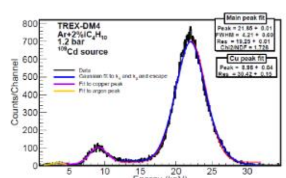
NEWAGE detector: R&D on other gases: SF6 spin-dependent DM) and mixtures
CS2: best; gain > 1000 at 38Torr (CS2: 300; very high V needed)

Micro-bulk MM x-ray detector for axions & WIMPs: CAST & IAXO



Two bulk Micromegas have been characterized in Ar + 2% iC_4H_{10} up to 10 bar.

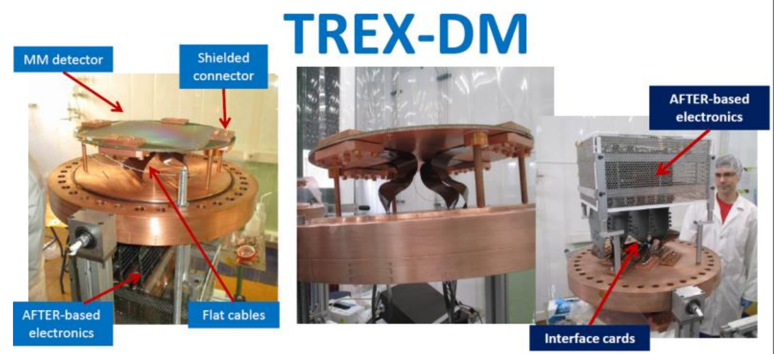




CAST: very good results
IAXO: underway

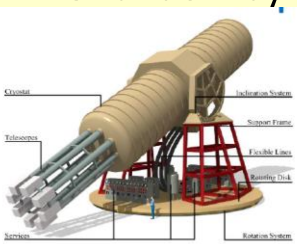
FINE TOPOLOGY!

. GARZA



- 20 x 20 cm² bulk MM detectors. 432x432 strips, 0.6 mm pitch, 128 μm gap.

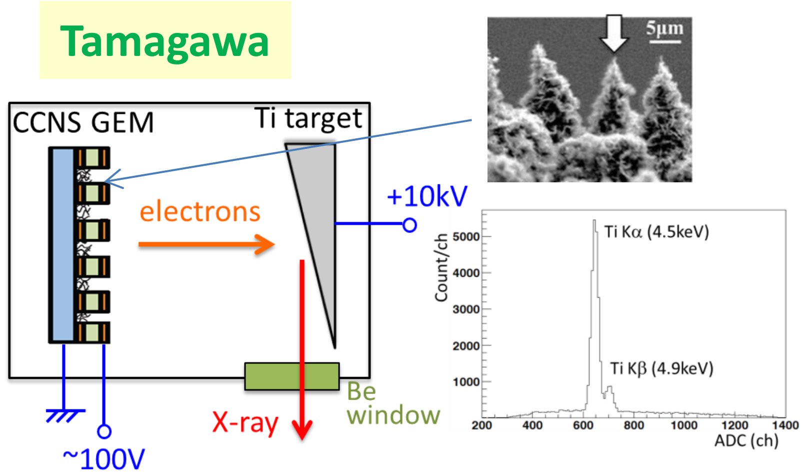
High sensitivity: LIGHT WIMPs



EXOTICS….

GEM X-ray generator…

Tamagawa



I love it!

Continue inventing MPGD-based gadgets!

Gas-avalanche Detectors:
A fascinating, ever-growing field
With many multidisciplinary applications -
far beyond Particle Physics!
Many Science & Technology topics
Attractive & Exciting field for the younger generation!

- Being surrounded by talented young fellows is beneficial!
- Some of us can go fishing …
- Others can …

Some of the concepts discussed can be found below

Thank you & good continuation!