Progress in Room-Temperature and Cryogenic Resistive THGEM-based detectors

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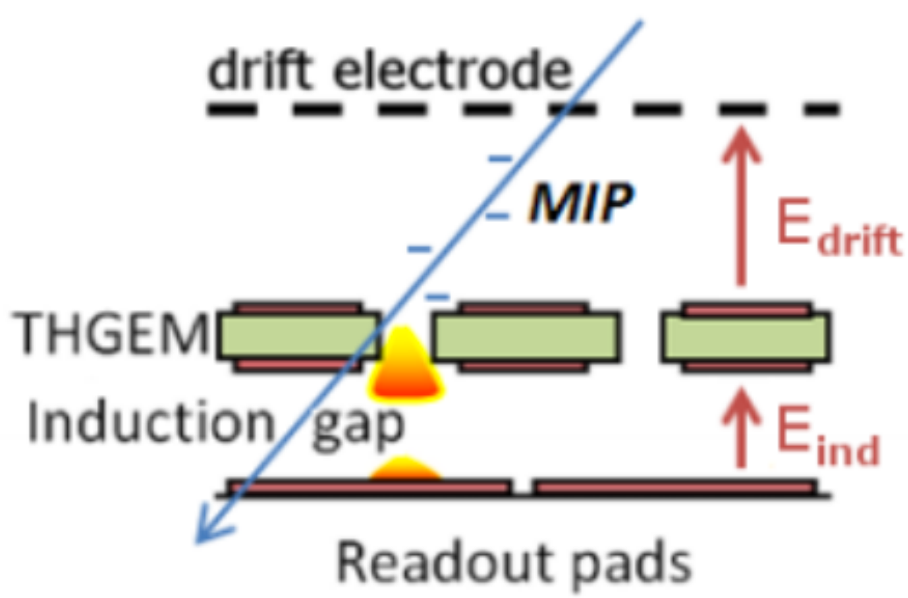
THGEM Thick Gaseous Electron Multiplier

A. Breskin et al. NIM A598 (2009) 107

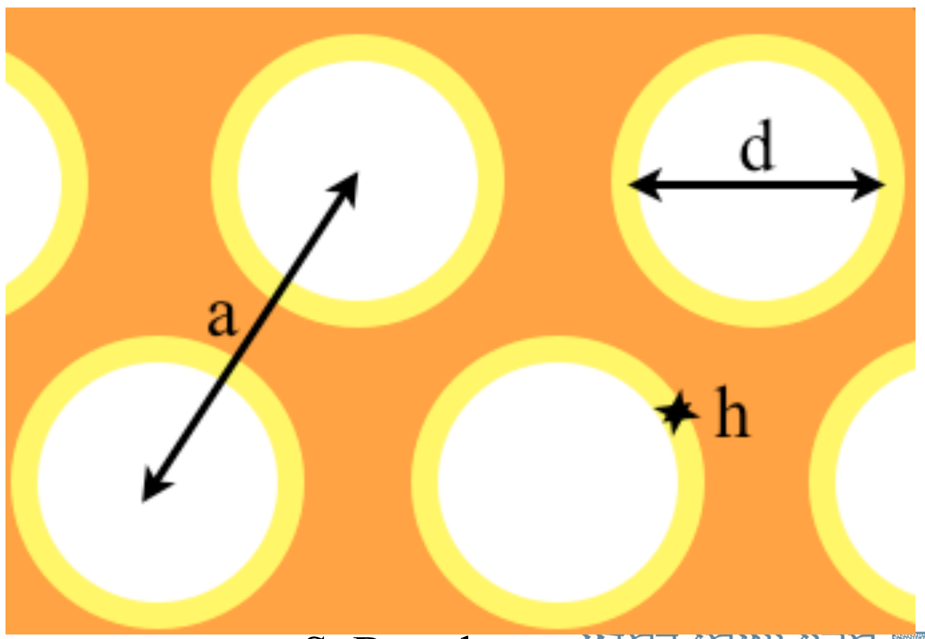
Operation principle

- Mechanically drilled FR4 plate Cu-clad on both sides
- Placed a few mm above the readout pads
- Voltage supplied to the electrodes
  - Creates a strong dipole field between the THGEM electrode - amplification region
  - Drift field focuses the primary ionization into the holes
  - Induction field pull the avalanche induced electrons to the anode



Typical geometry ×10 GEM

a ~ 1 mm, d ~ 0.5 mm, h ~ 0.1 mm



THGEM Thick Gaseous Electron Multiplier

Wish list

Random order

- Simple
- Robust
- Cost-effective
  - Production
  - Operation (etc. gas mixtures)
- Large-area
- Efficient
- Resolution: spatial, time, energy
- Broad dynamic range
- Discharge free
- Rate capabilities
- Industrially produced

Applications

Random order

- RICH devices
  M. Alexeev et al. 2012 JINST 7 C02014
- Cryogenic detectors for TPC in neutrino physics and rare-event searches
  M. Resnati et al. 2011 J. Phys.: Conf. Ser. 308 012016
  A. Bondar et al. 2011 JINST 6 P07008
- GPM for dark matter searches
  L. Arazi et al. Expected online publication in JINST: November 2015
- Medical imaging
  S. Duval et al. 2011 JINST 6 P04007
- Neutron/Gamma imaging in cargo inspection systems
  A. Breskin et al. 2012 JINST 7 C06008
  I. Israelashvili et al. 2015 JINST 10 P03030
- Thin sampling elements for DHCAL
  S. Bressler et al. 2013 JINST 8 P07017

- And more...

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Hard - common for all MPGDs

- Efficient
  - MIP detection - gain of 10^4
  - Single photon detection - gain of 10^5
- Background event depositing 10^2-10^3 primary electron $\Rightarrow$ reach the Ruether limit $\Rightarrow$ Discharge

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Solution I - cascade

- Split multiplication between several stages
  - The filed in each stage is lower
  - The charge is divided between several holes
- More expensive
- Not suitable for applications like DHCAL requiring thin elements

THGEM Thick Gaseous Electron Multiplier

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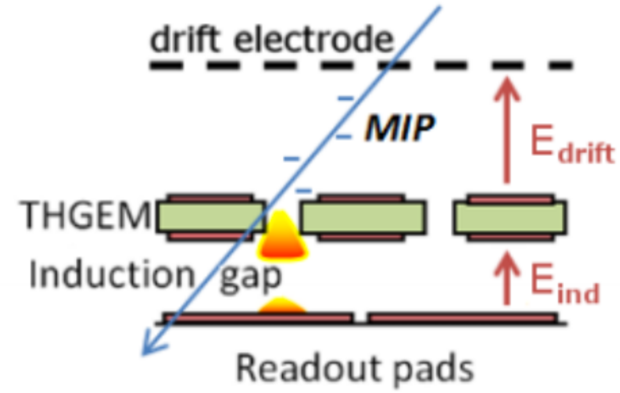
Solution II - Resistive configuration

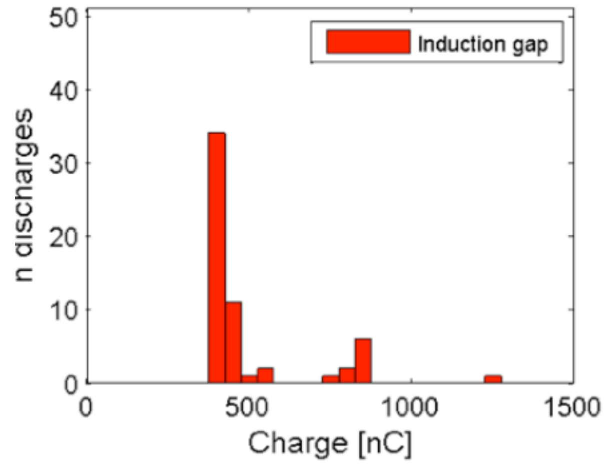
- Single stage
- Operated with cost-effective gas mixtures (Ar-based rather than Ne-based)
- Targeting discharge self-quenching mechanism
- Rate capabilities - 5% efficiency drop over 3 orders of incoming particle rates

THGEM Resistive configurations - background

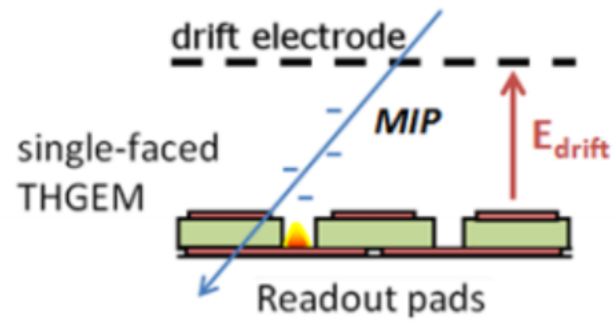
THGEM
- Cu-clad on both sides
- Operation with induction gap

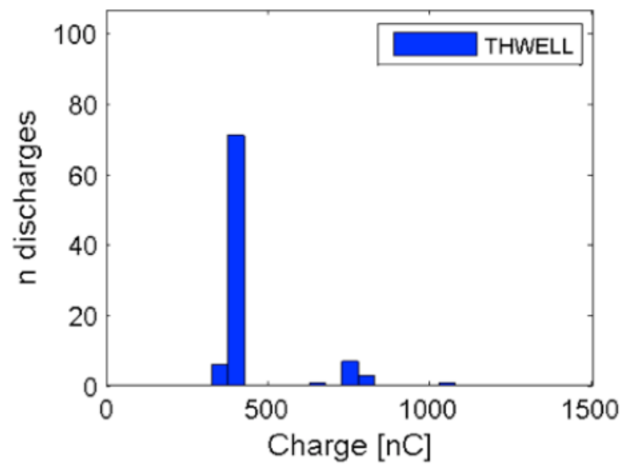


Discharge energy

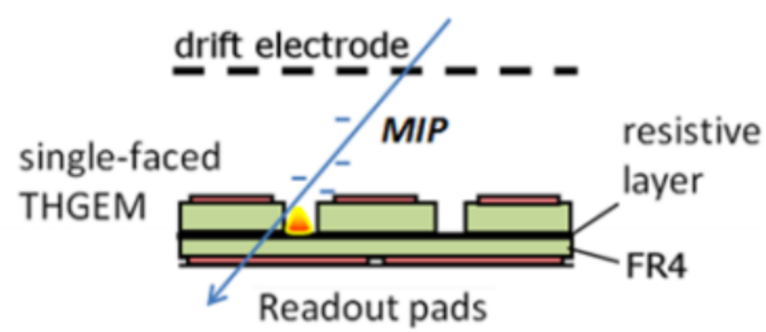


THick-WELL (THWELL)
- Cu-clad on one side
- Electrode coupled directly to the anode

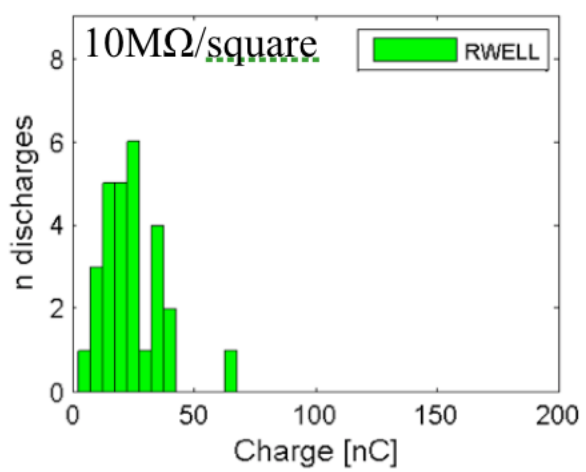




Resistive-WELL (RWELL)
- WELL coupled to the readout through resistive layer (10-20 MΩ)
- Readout separated from the readout by a thin insulating sheet
- Signal induced on the readout



JINST 8 (2013) C12012



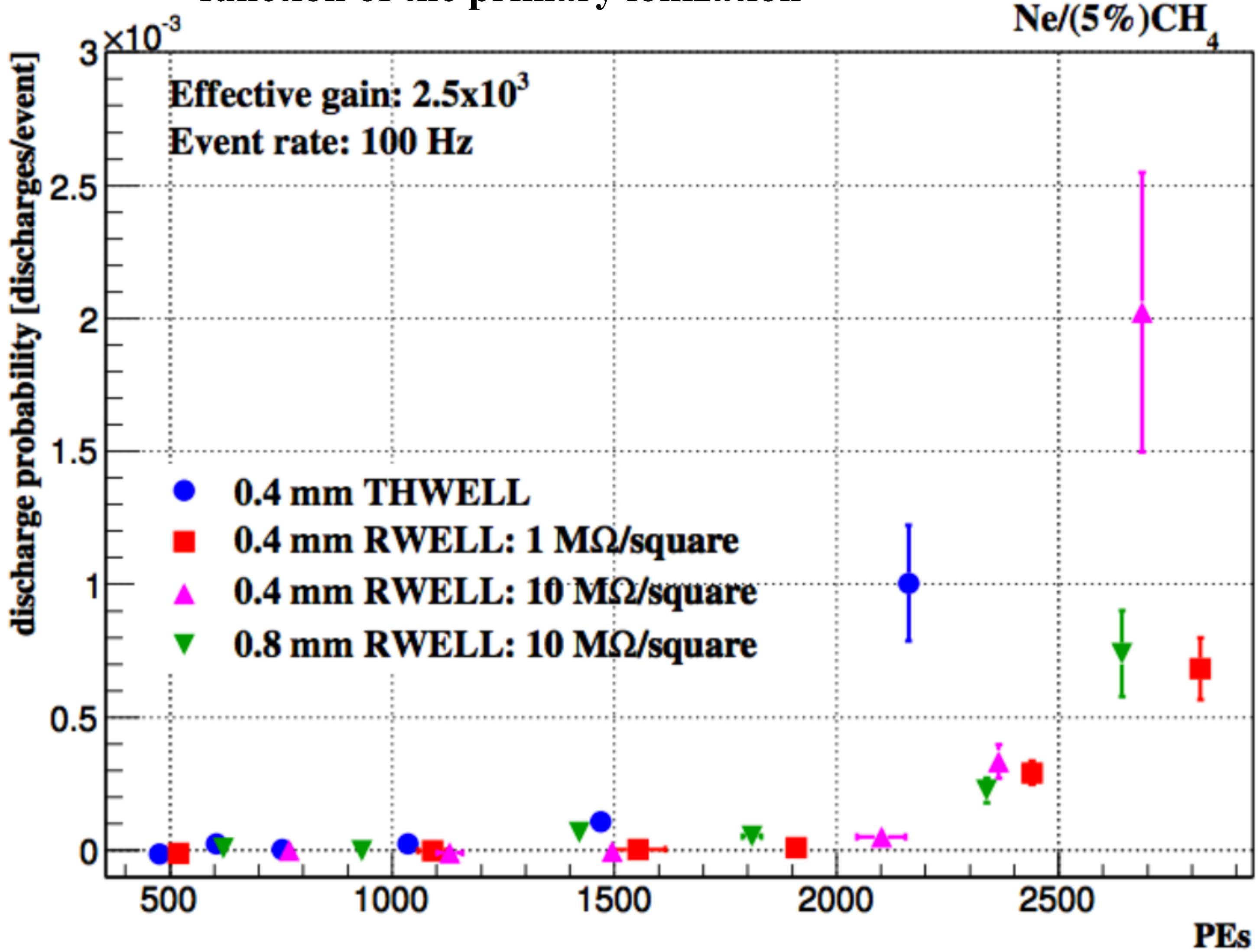
JINST 9 (2014) P04011

Resistive configurations

- Discharge energy is quenched
- Discharge probability does not change

JINST 9 2014 P03005

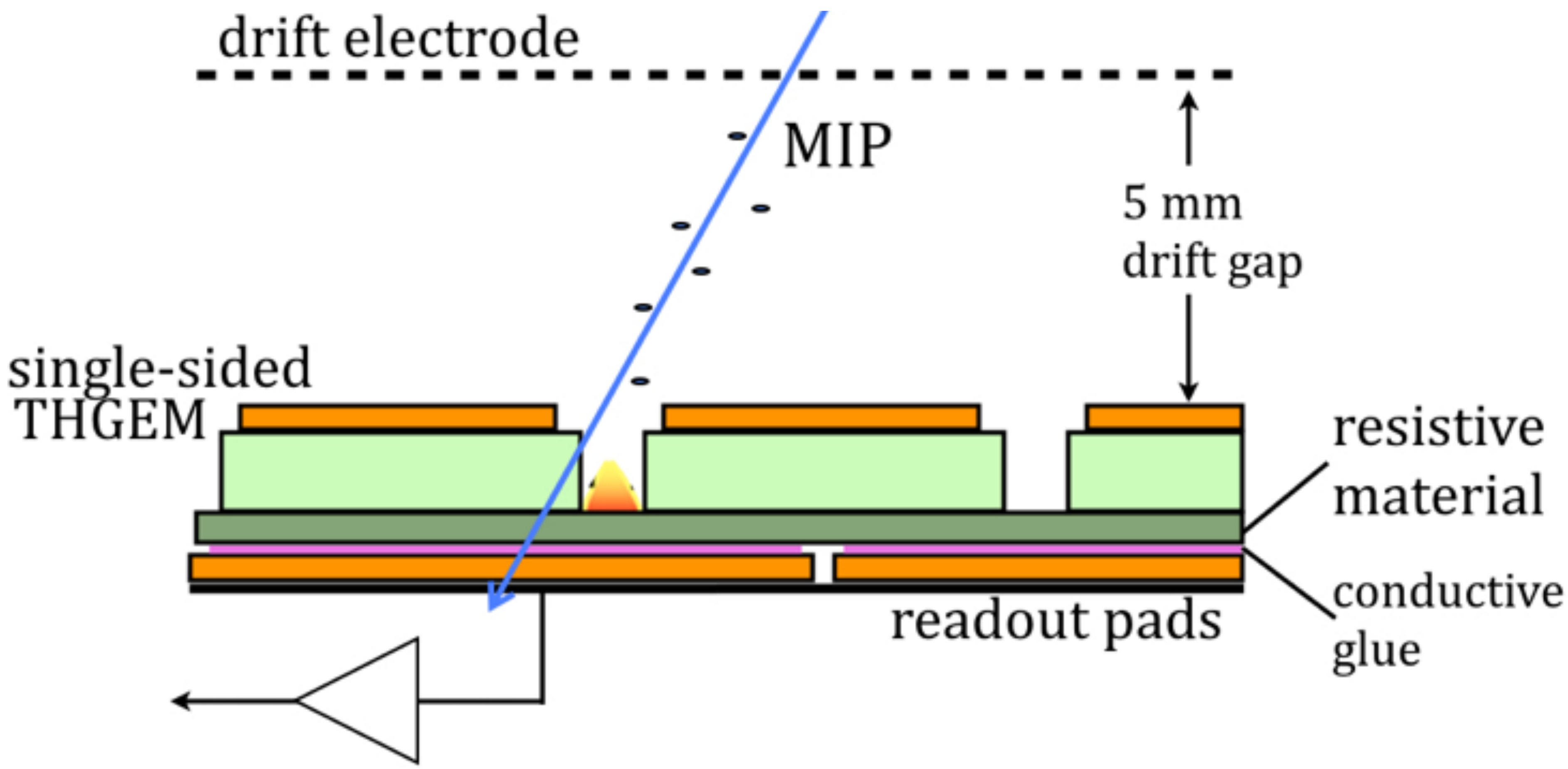
Discharge probability of THWELL and RWELL as a function of the primary ionization



RPWELL Resistive Plate WELL

JINST 8 (2013) P11004

- Single sided THick Gaseous Electron Multiplier (THGEM)
- Coupled to the readout anode through material of high bulk resistivity



Voltage supplied to the RPWELL electrode creates a strong field inside the holes - amplification region.

The signal is induced on the readout anode.

Discharge quenching is achieved by delaying the charges on the RP - local reduction of the field

RPWELL Resistive Plate WELL

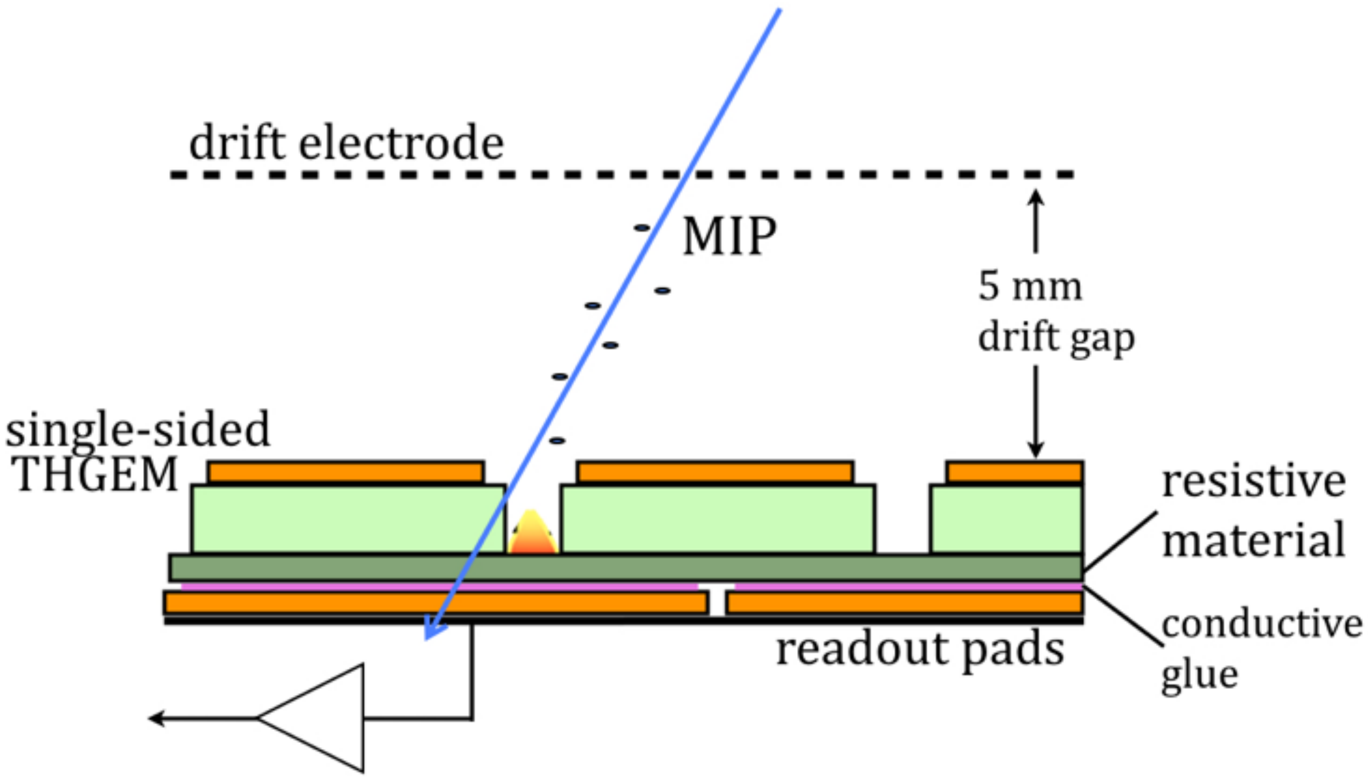
JINST 8 (2013) P11004

- Single sided THick Gaseous Electron Multiplier (THGEM)
- Coupled to the readout anode through material of high bulk resistivity

Main characteristics - room temperature

JINST 11 (2016) no. 01 P01005
NIM A845 (2017) 2620265
JINST 11 (2016) no. 09 P09013

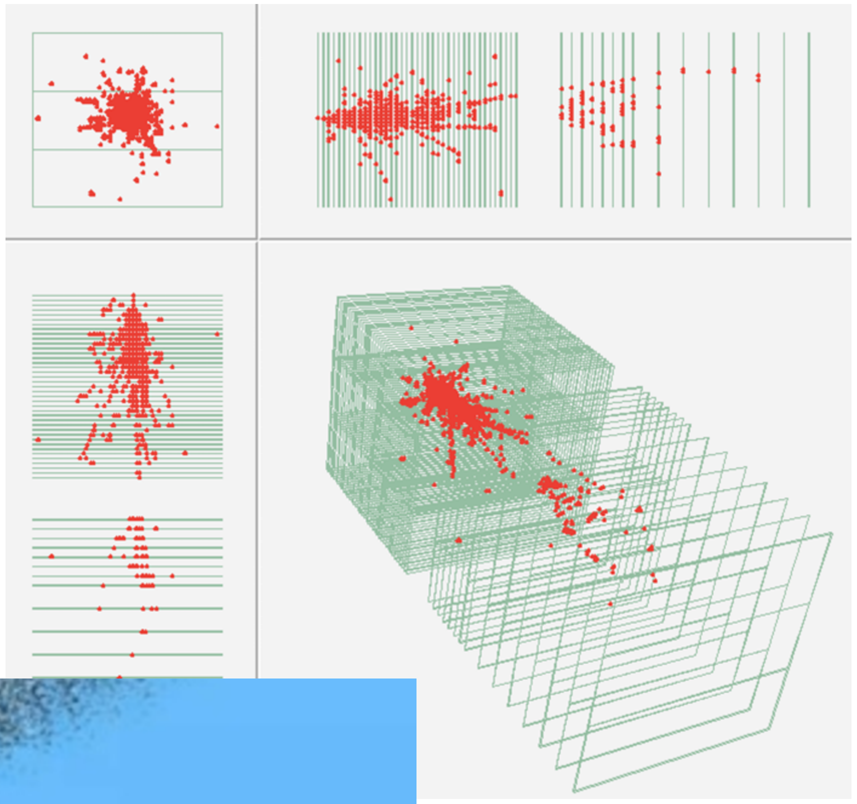
- High single-electron gain (**>10^5**) with single element
- High detection efficiency (MIP ~**99%**)
- Moderate gain loss under high rate of incoming particle fluxes
- **Discharge free operation**
  - With **Ne-** and **Ar-based** gas mixtures
  - At muon and high rate pion beams
  - Under broad dynamic range of primary ionization



Upscaling

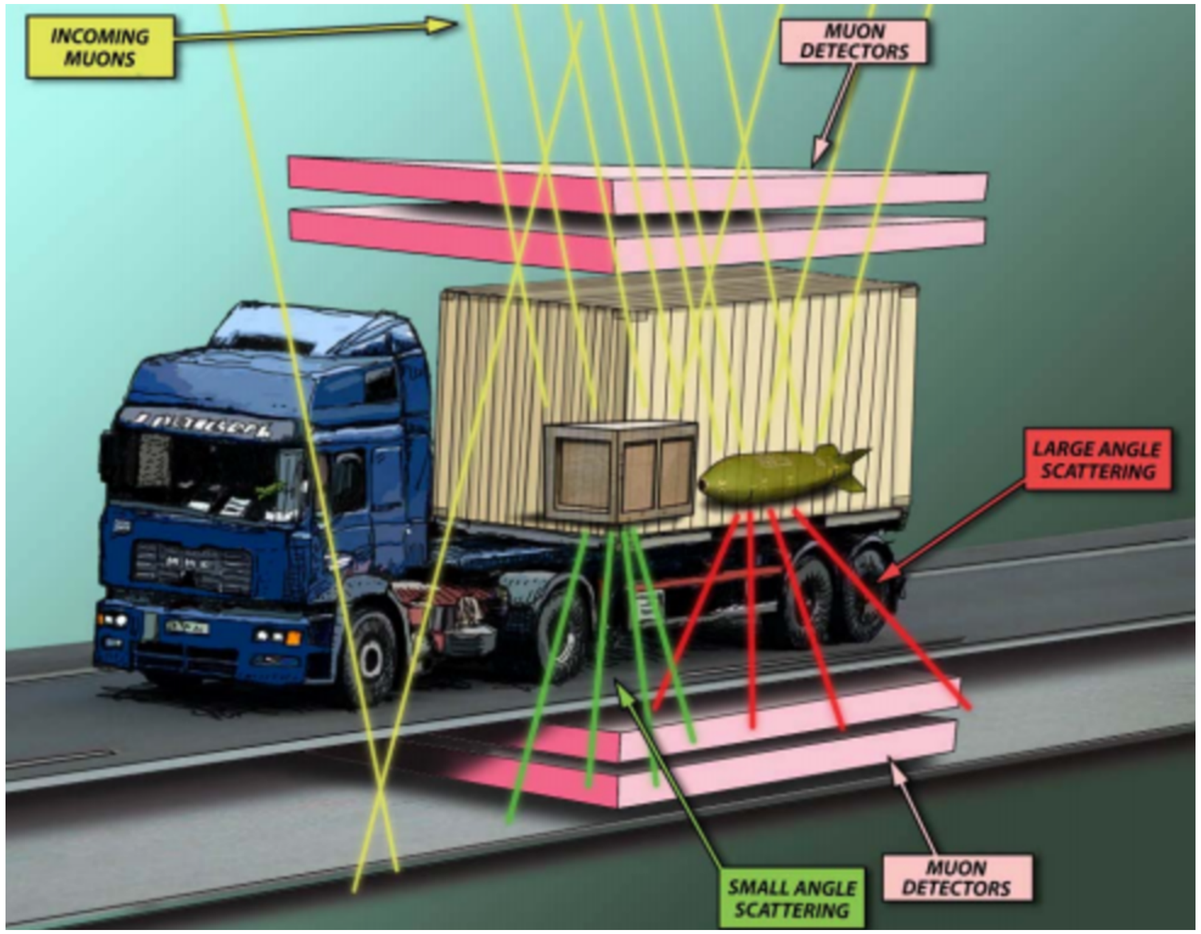
Moving to 50×50 cm^2

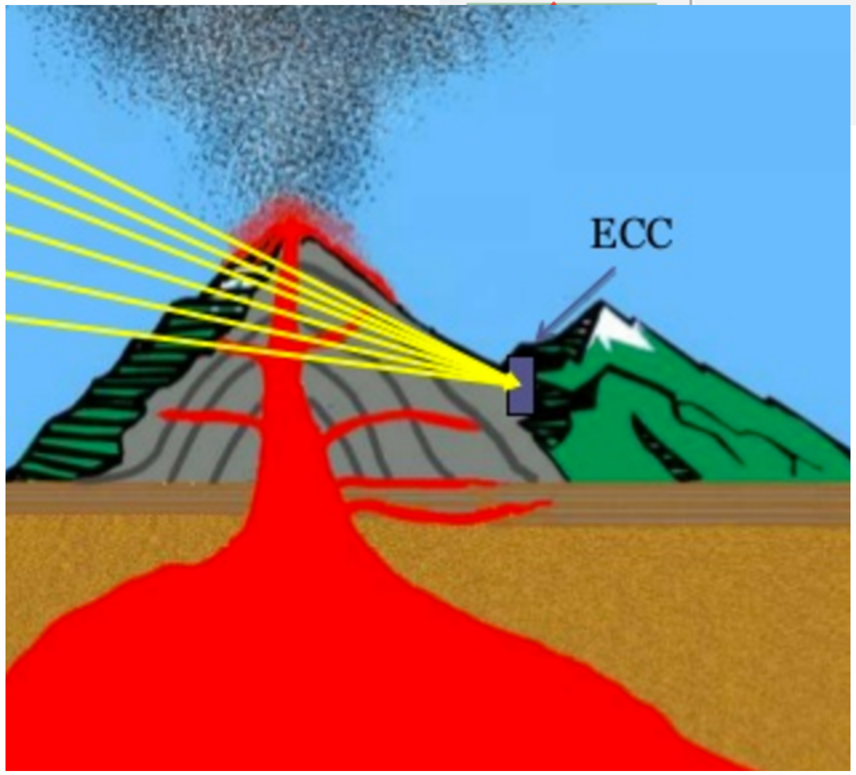
3×3 cm^2 $\Rightarrow$ 10×10 cm^2 $\Rightarrow$ 30×30 cm^2 $\Rightarrow$ 50×50 cm^2



Motivation

- Applications requiring cost-effective large area detectors
  with moderate spatial resolution
  - (Semi) Digital Hadronic Calorimeter - (S)DHCAL
  - Muon tomography for homeland security
  - Volcanology and more





RPWELL Results in the context of a (s)DHCAL

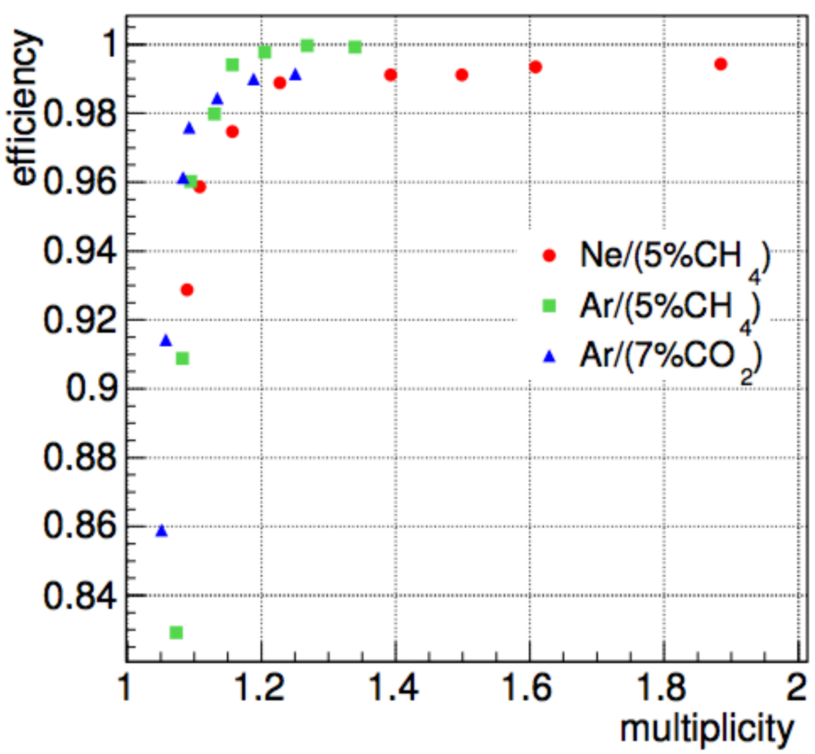
- 10×10 and 30×30 cm^2 prototypes
- 1×1 cm^2 pad readout
- 0.4 mm thick Semitron resistive plate
- 5 mm drift gap
- $Ne/CH_4(5\%)$, $Ar/CO_2(7\%)$, $Ar/CH_4(5\%)$
- Muon and high rate pion beams
- APV25/SRS readout

Discharge free operation also under high pion flux

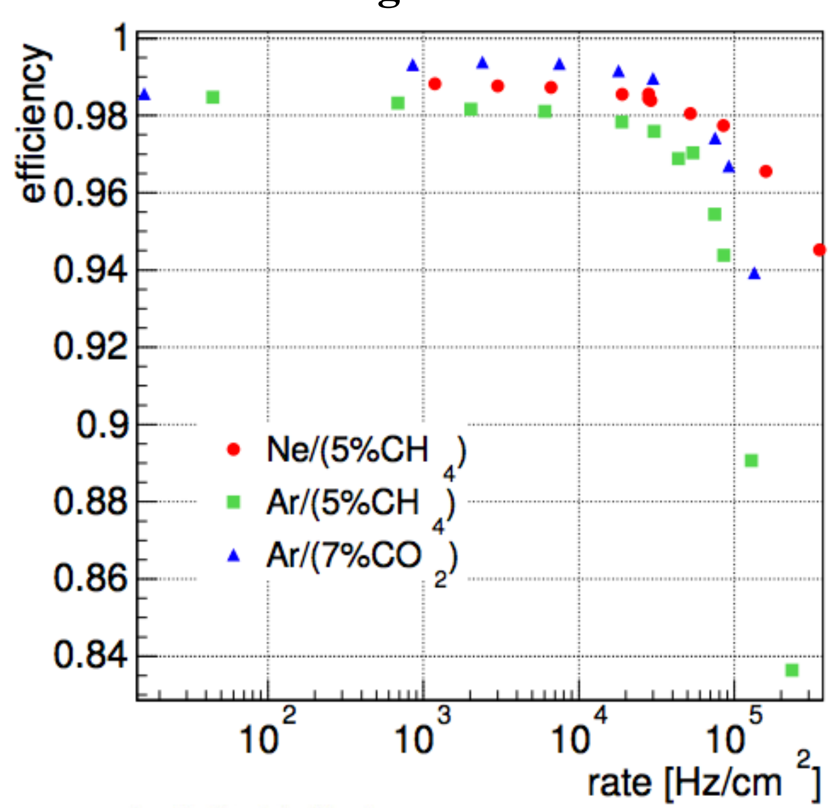
NIM A845 (2017) 2620265

JINST 11 (2016) no. 09 P09013

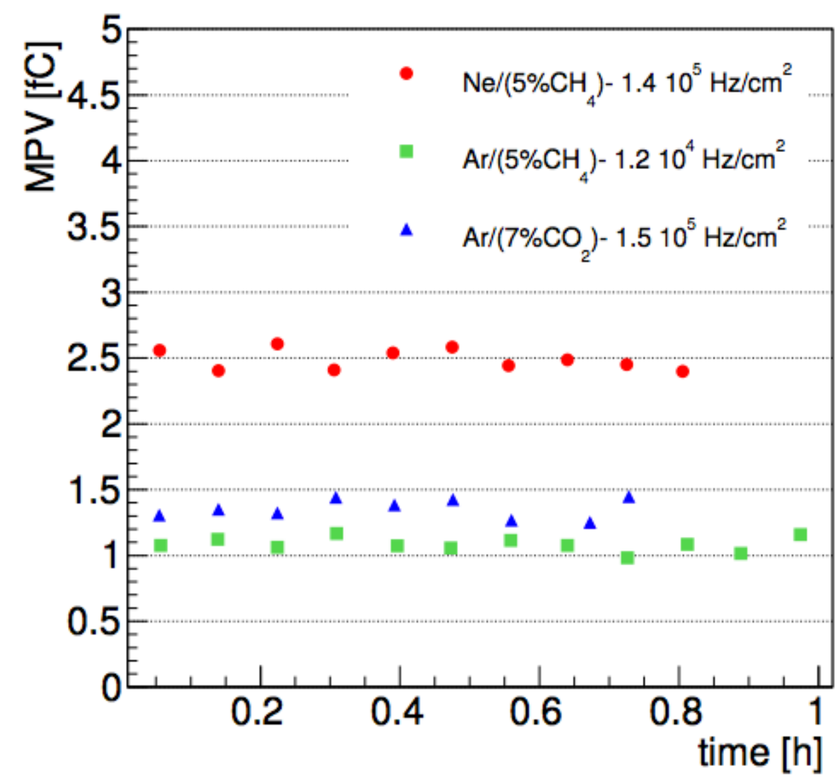
High detection efficiency at low pad multiplicity



High detection efficiency over 3 order of magnitude in rate



Stable gain over time



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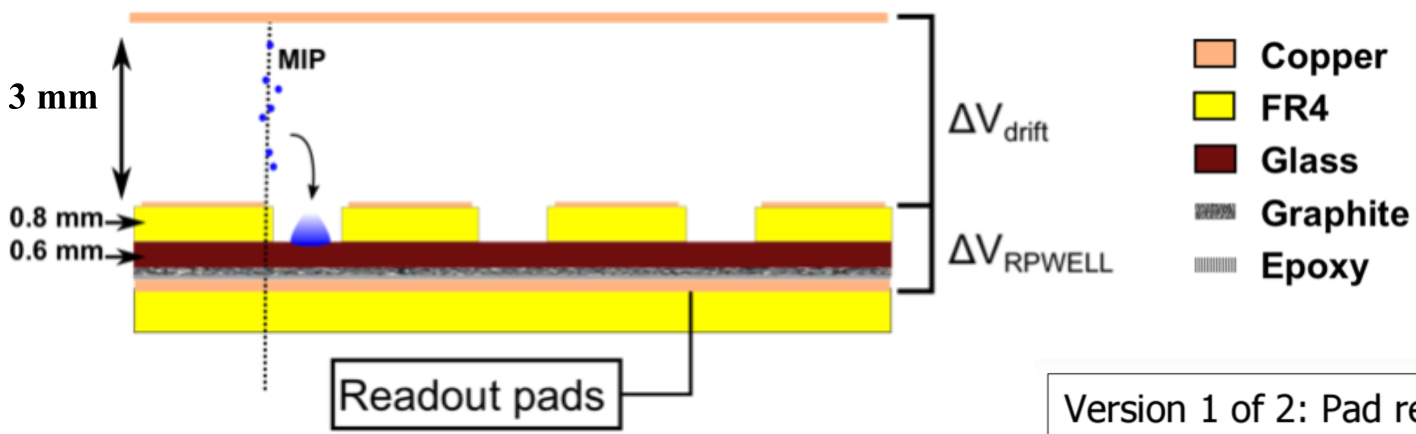
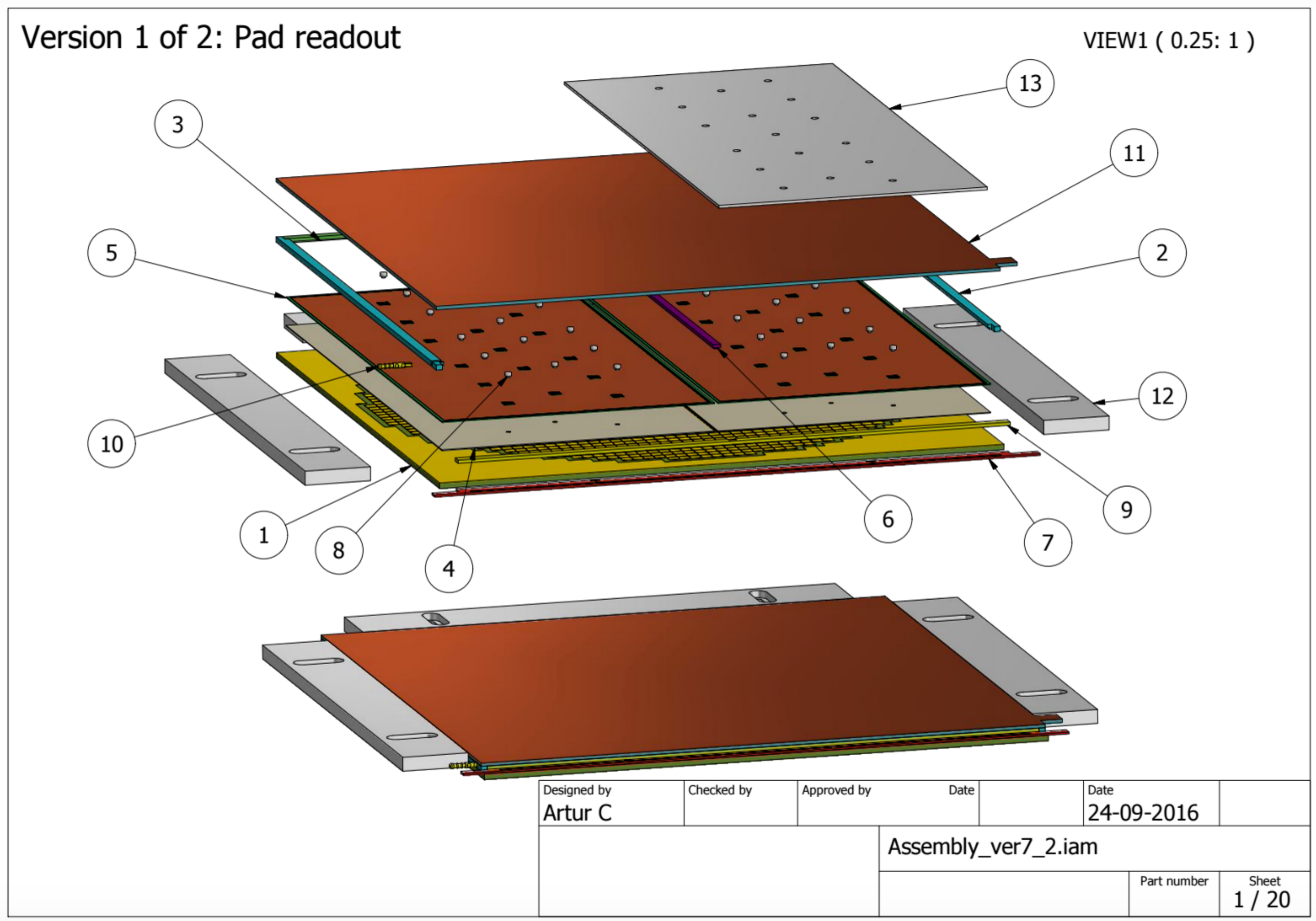
Design



Developed

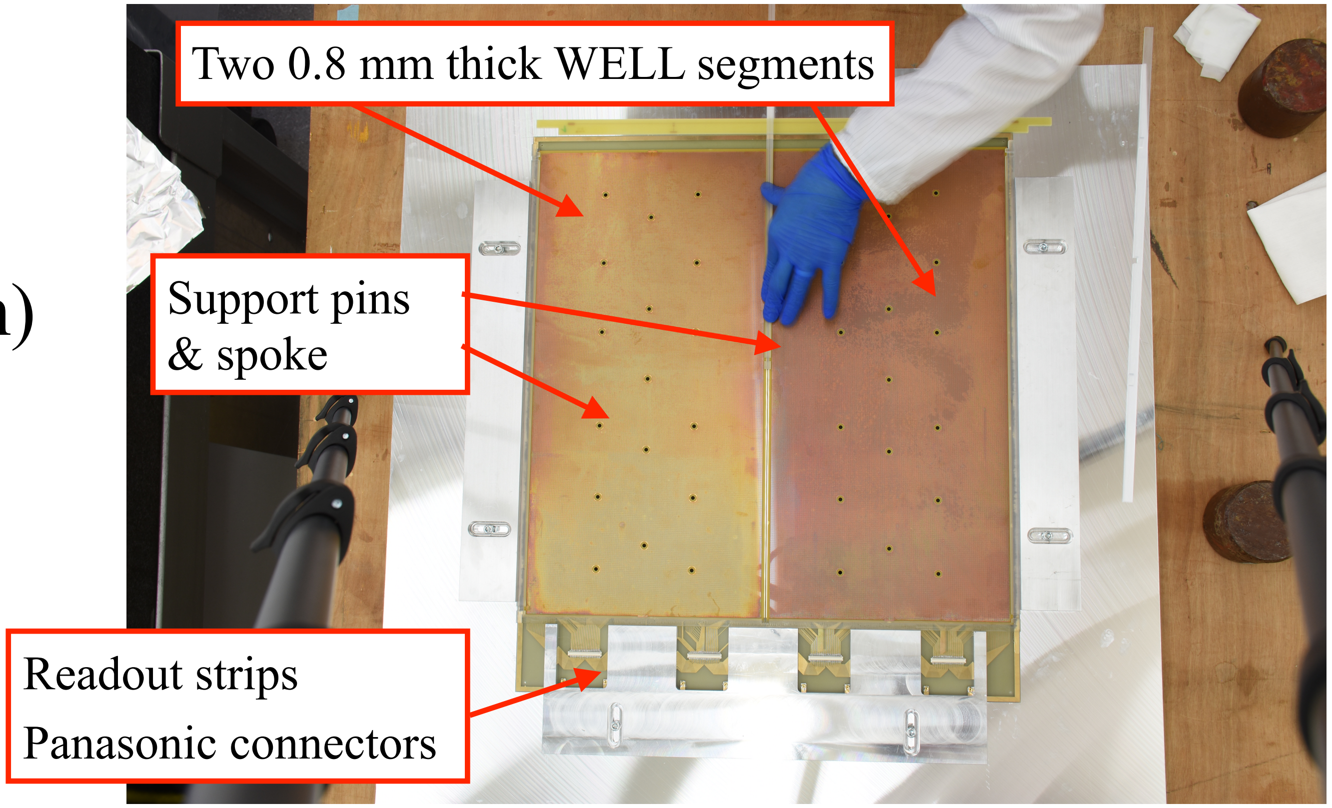
- Assembly protocol
- Tooling
- Testing protocol

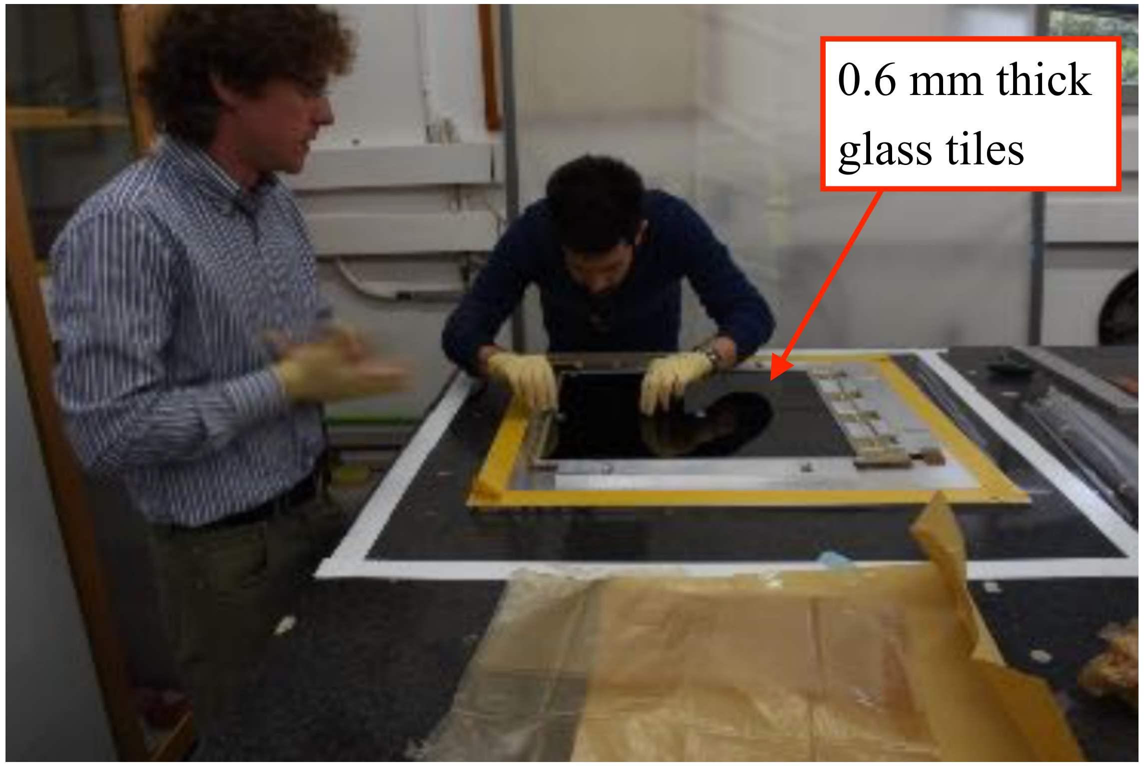


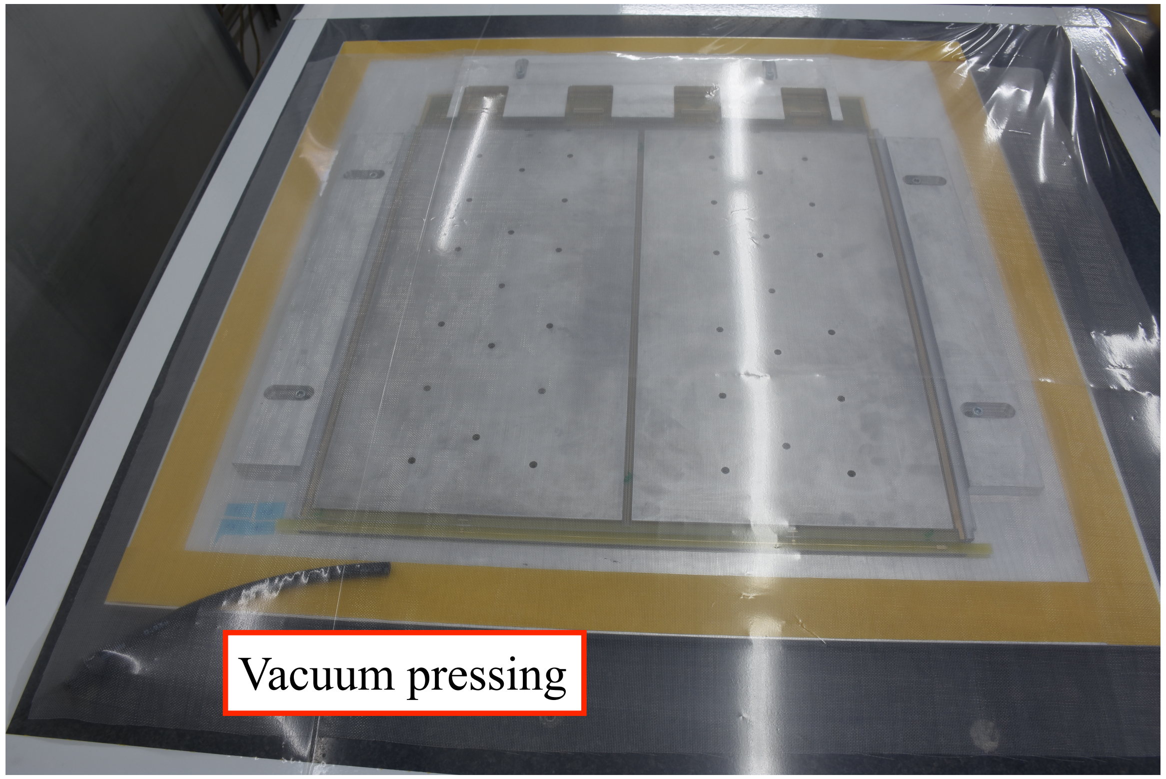
Upscaling — Moving to 50×50 cm^2

Assembly

- Strip readout (1 & 1.5 mm pitch)
- Silicate glass Resistive Plate (10^9 Ωcm)
  [J.-b. Wang et al., NIM A621 151]
- Anode to glass coupling through graphite-epoxy layer (~MΩ)
- Gluing under vacuum







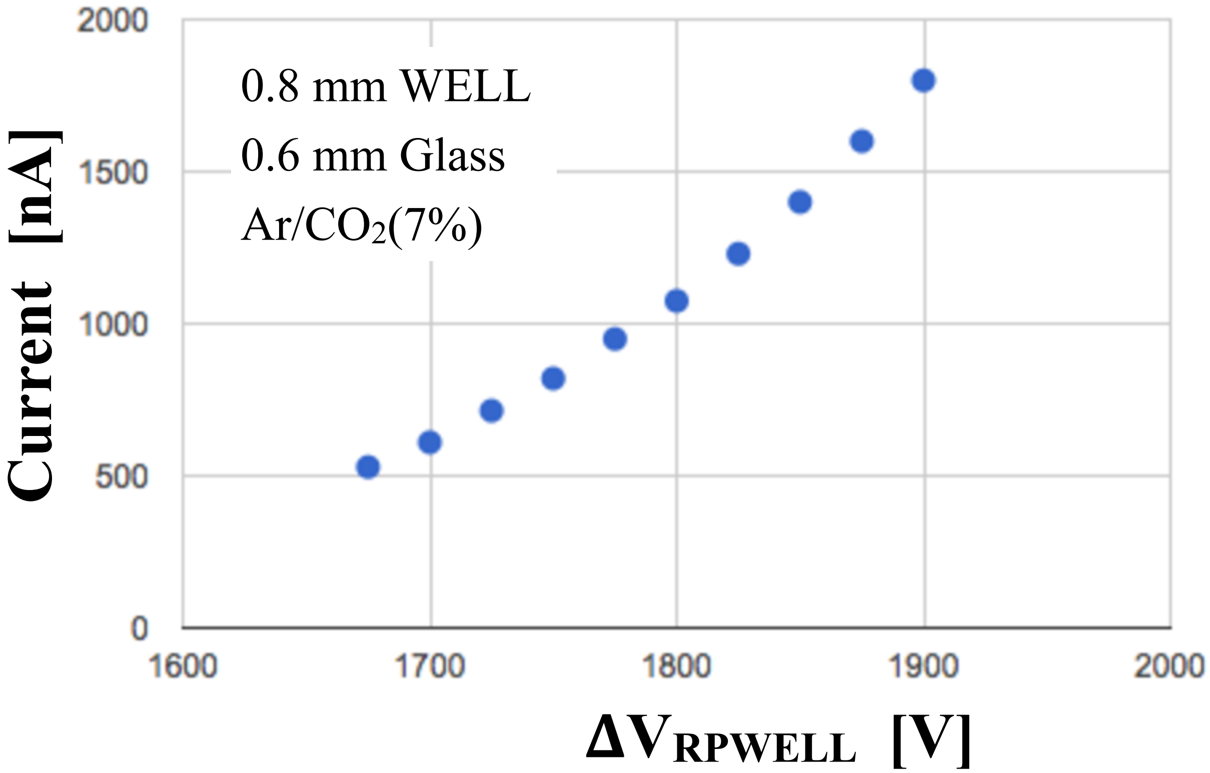
Upscaling

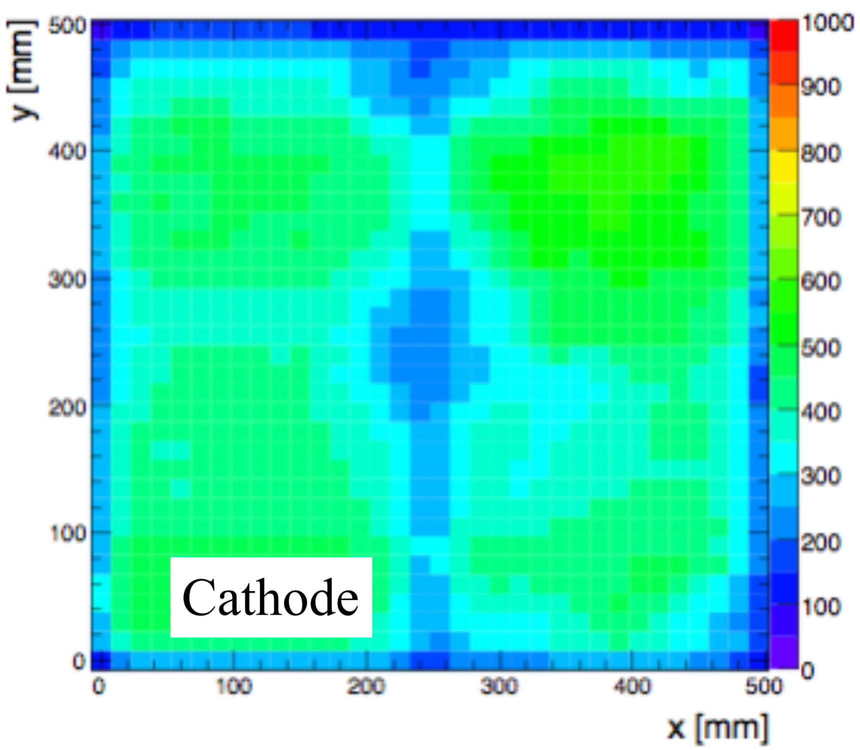
Moving to 50×50 cm^2

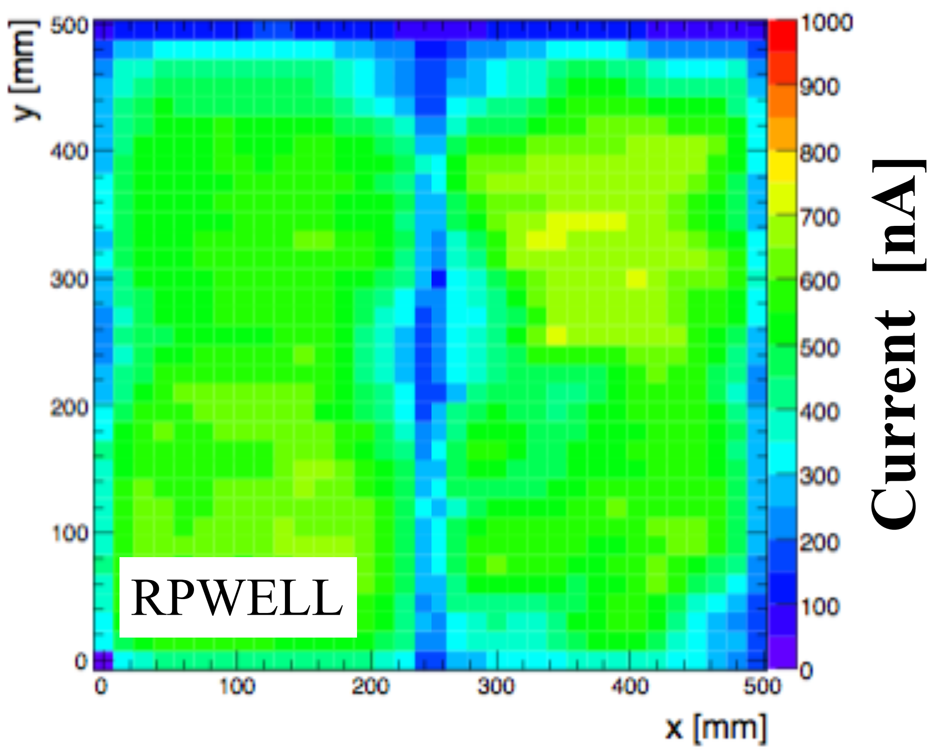
3×3 cm^2 ⇒ 10×10 cm^2 ⇒ 30×30 cm^2 ⇒ 50×50 cm^2

Performance

- Studies conducted with X-Y scanner
  - Developed for the ATLAS sTGC
- Ag-target x-ray tube ⇒ 22 KeV photons
  - Penetrating the 3 mm FR4 cover (cathode)
- High intensity (~400 KH$_z$/mm^2)
- HV current monitoring synchronized with the source position







Ar/CO$_2$(7%)
ΔV_{RPWELL} = 1800 V
Flux ~ 400 kH$_z$/mm^2
30 sec/point

- **Stable operation**
- **Some non-uniformities**
  - under study

Upscaling — Moving to 50×50 cm^2

Next steps

- In the lab
  - Investigate & solve the non-uniformities (correlated with the glass tiles)
- In-beam evaluation (soon)
  - Detection efficiency
  - Uniformity
  - Discharge probability
  - Position resolution
  - Energy resolution
  - …

(S)DHCAL

- Project shared with LAPP and Democritus
- Build prototype
  - With Pad readout
  - With the MICROROC chip
  - Design and assembly procedure identical to the one used
- Test in the lab and in the beam
- .
- .
- Incorporate within a stack of ~20 sampling elements; MICROMEGAS and RPWELL

Motivation

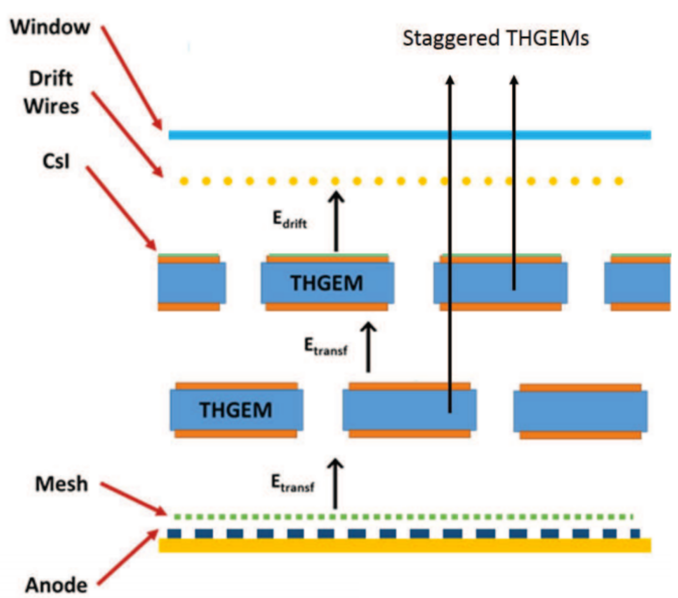
- Applications requiring large coverage of UV detection
- In room temperature and cryogenic temperatures
- Possibly with low ion back flow

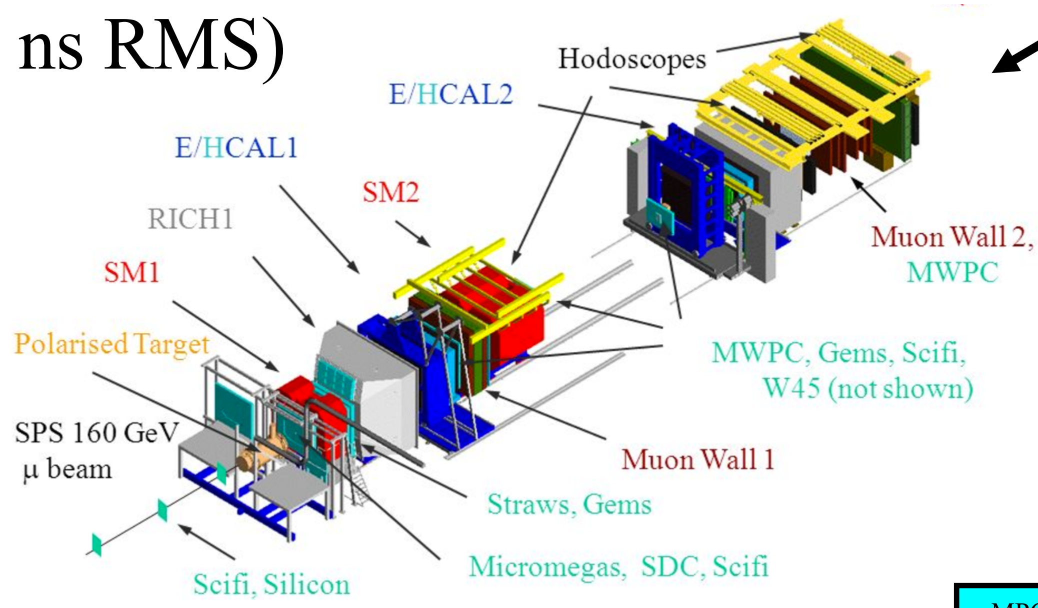
Example

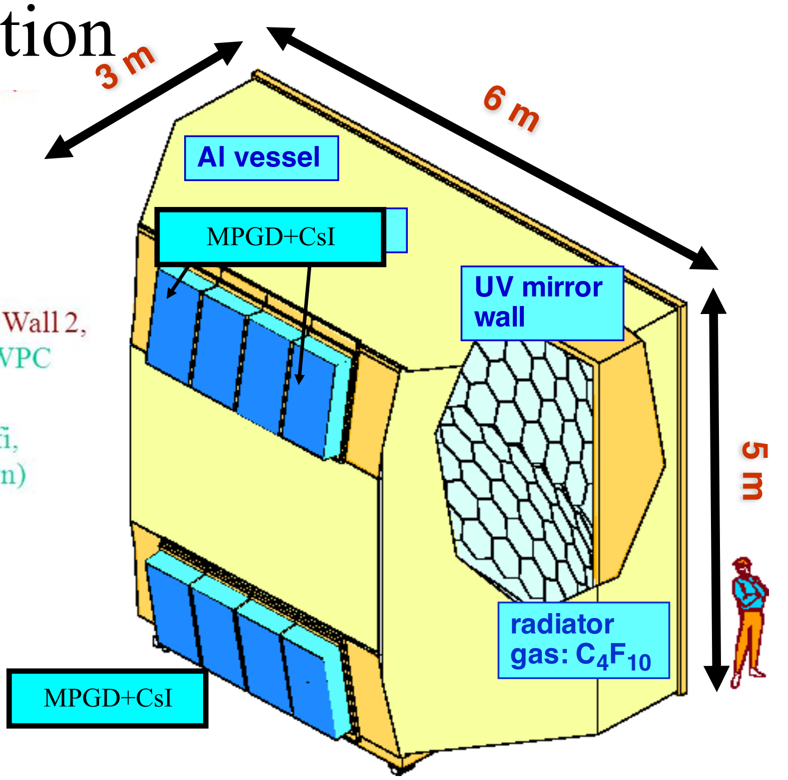
- RICH detectors (COMPASS 1 upgrade)
- Phoenix Hadron Blind Detector
- Cryogenic Gaseous Photon Multipliers (GPM) for
  - Multi-ton dark matter experiment
  - Multi-ton neutrino detectors
  - Homeland security, etc

UV detection — COMPASS RICH-I detector

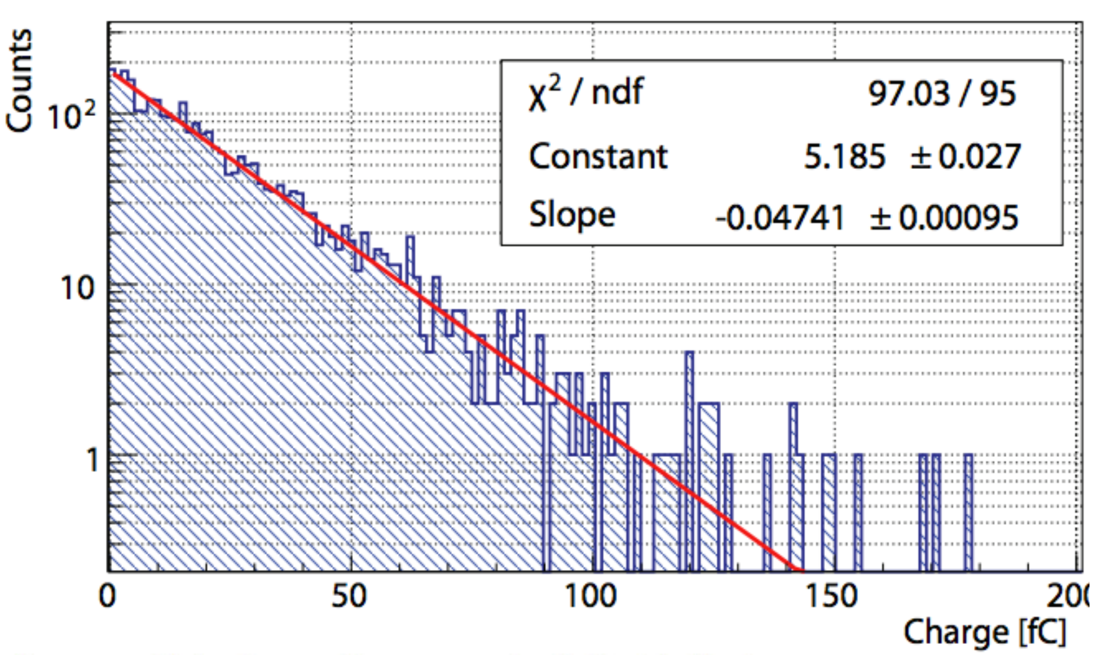
- Hybrid detector: two-stage THGEM+MICROMEGAS
- Operation gain ~10^5 Exponential single-photon distribution
- Good time resolution (7 ns RMS)
- Experiment ongoing

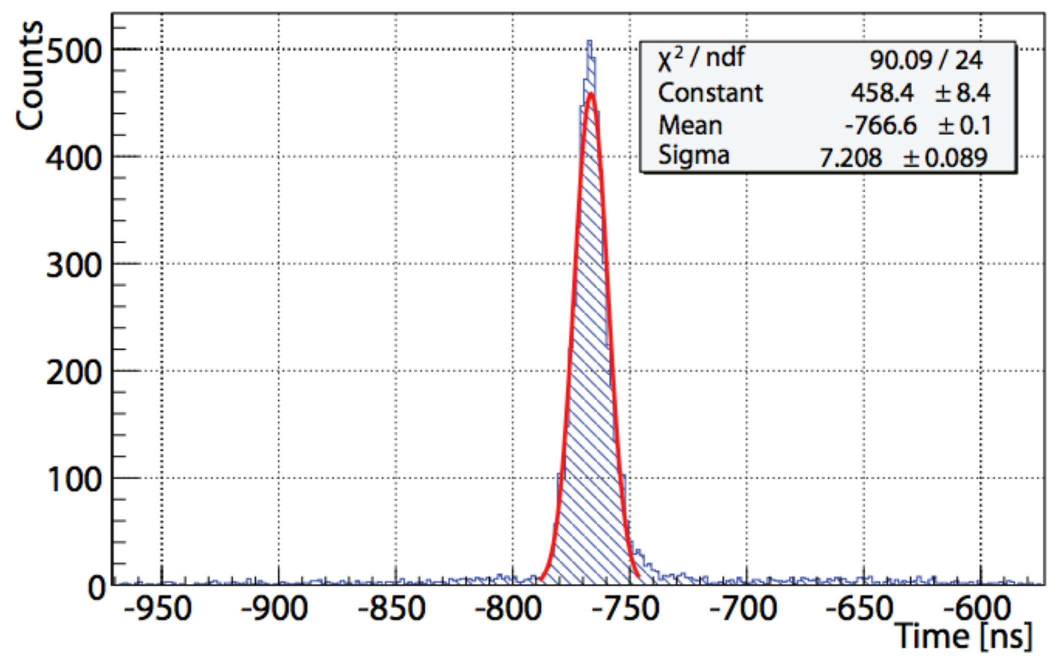






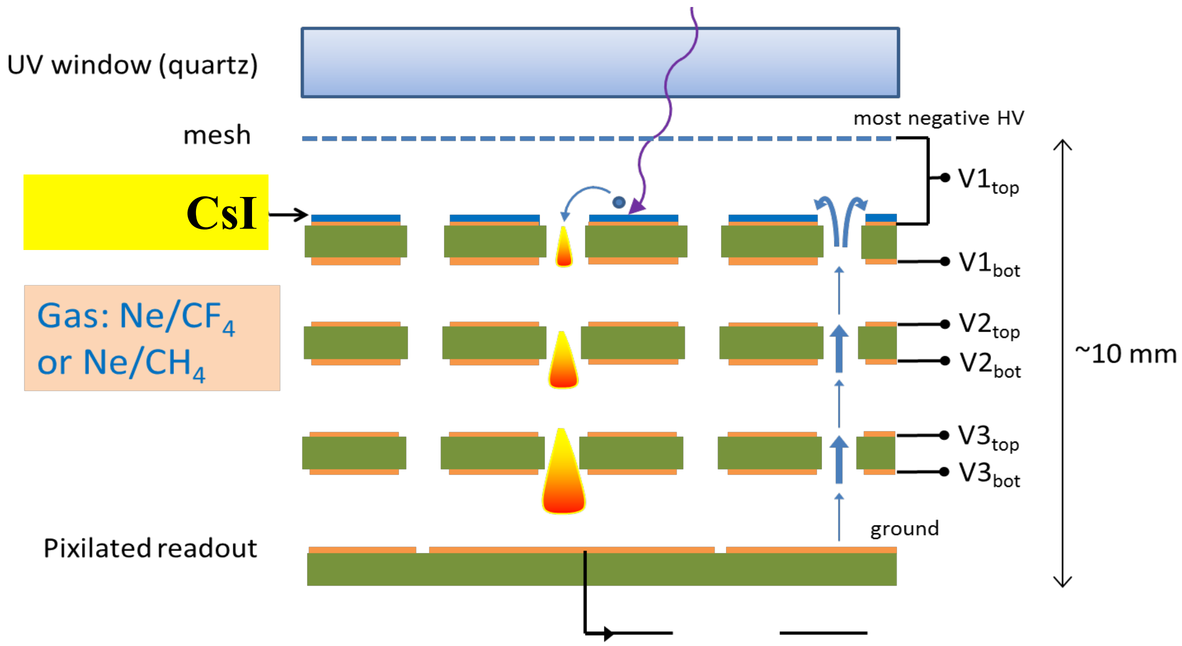
DOI: 10.1109/NSSMIC.2015.7581949



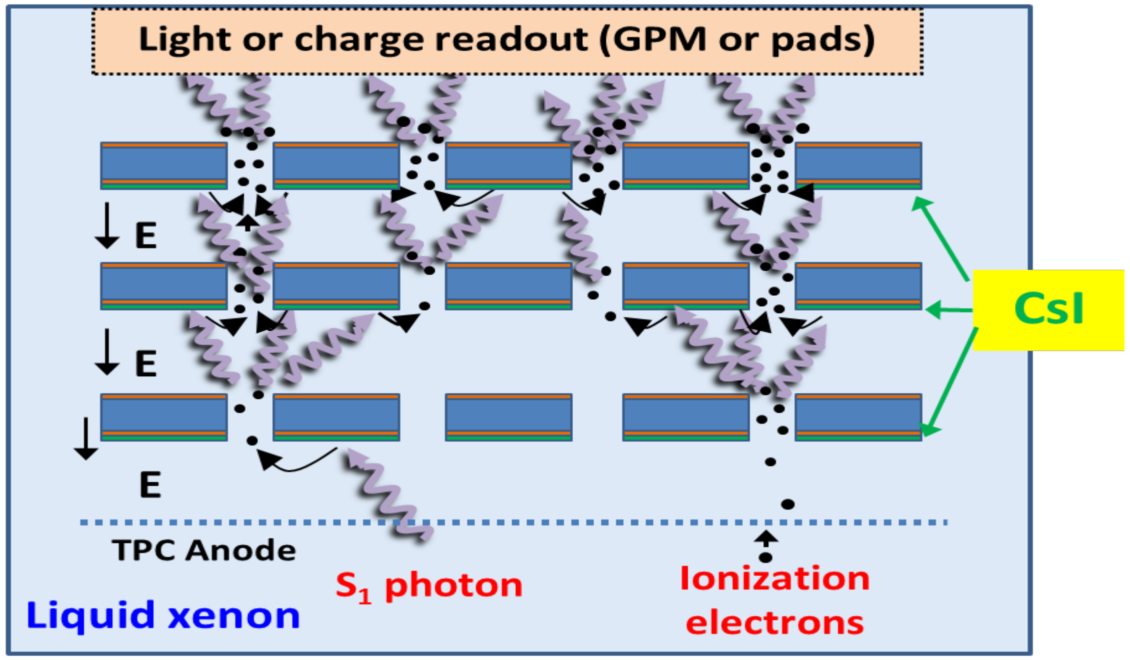


GPM Gaseous Photon Multiplier

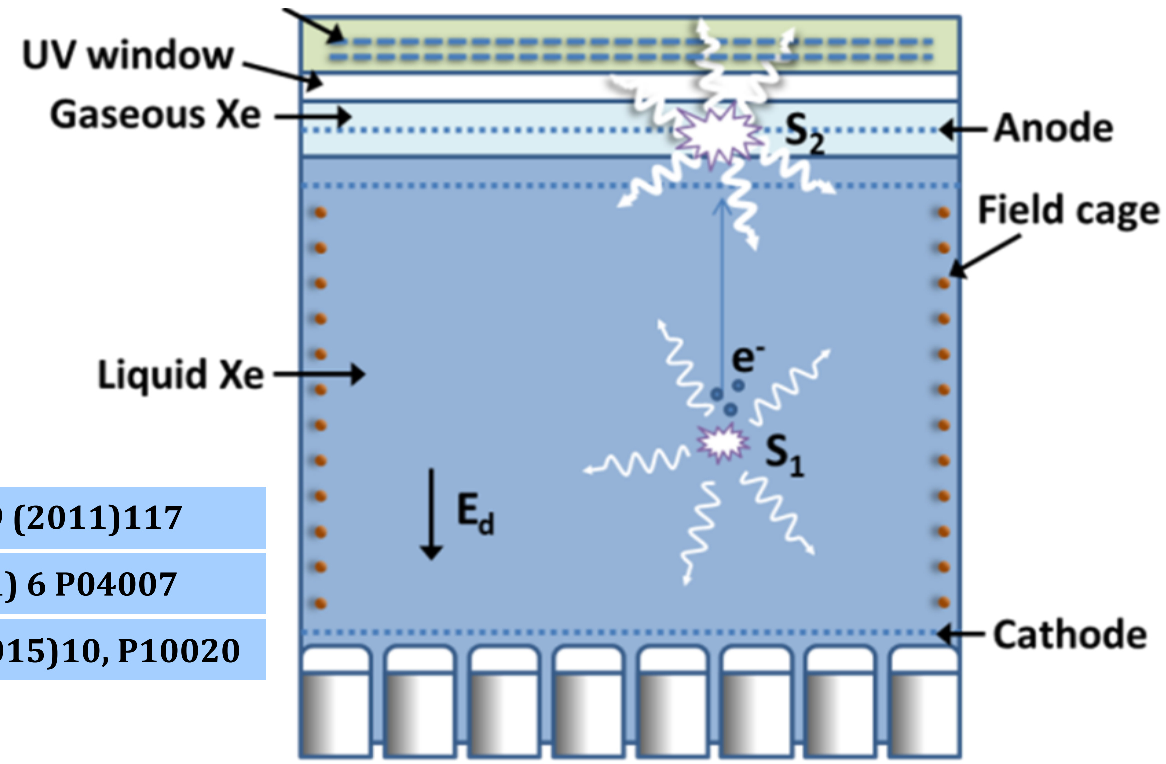
Charge-based amplifications



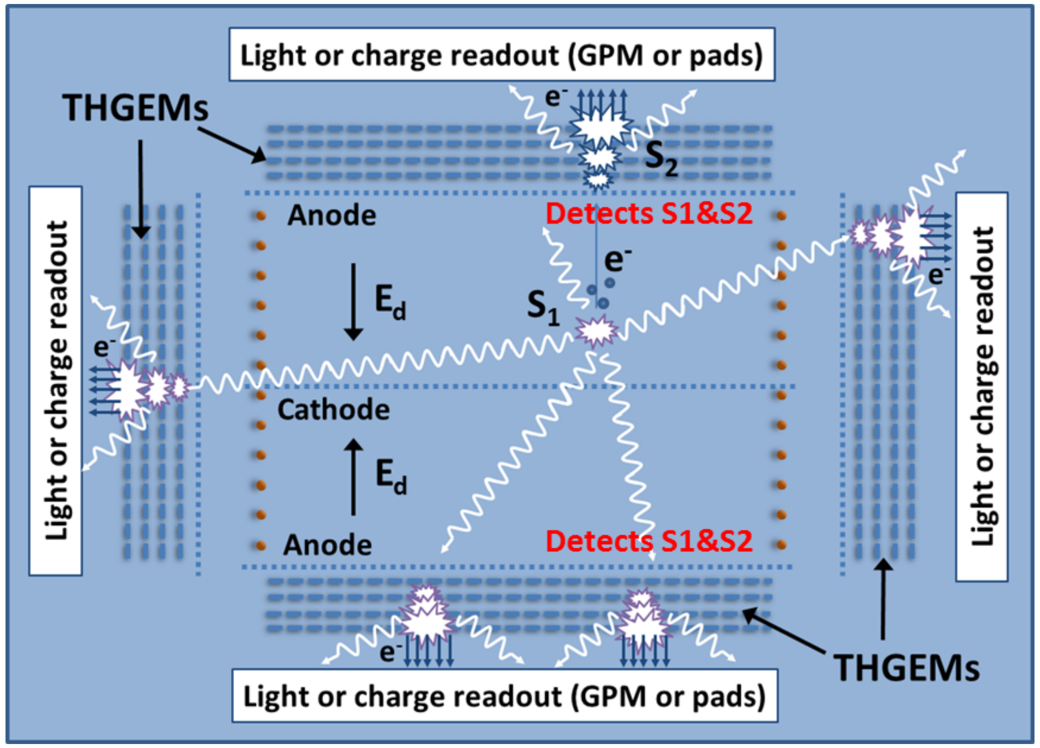
Light&Charge amplifications



Dual phase TPC



4π all Liquid TPC



Breskin, NIM A639 (2011)117
Duval, JINST (2011) 6 P04007
Arazi, JINST 10 (2015)10, P10020

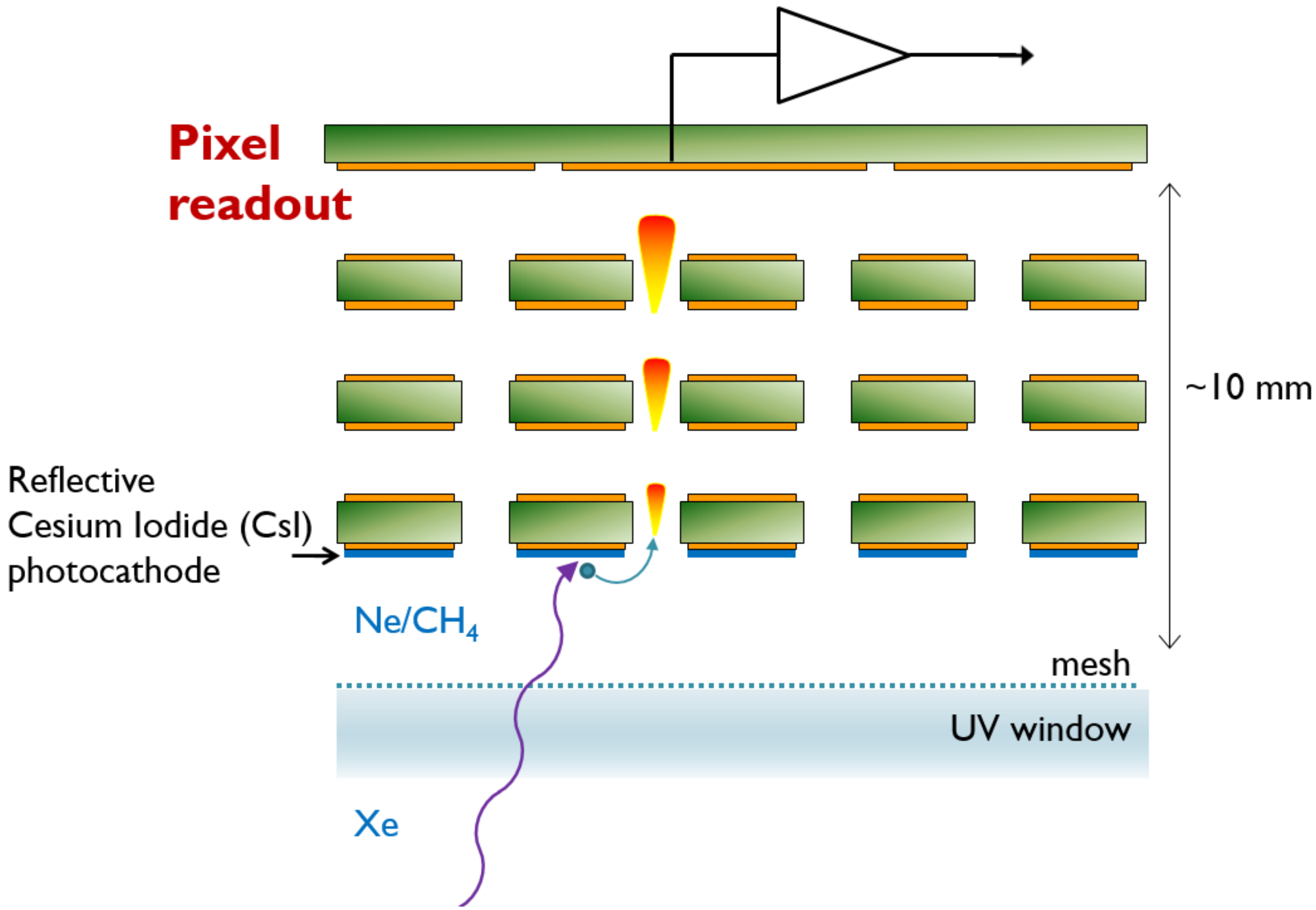
GPM Gaseous Photon Multiplier

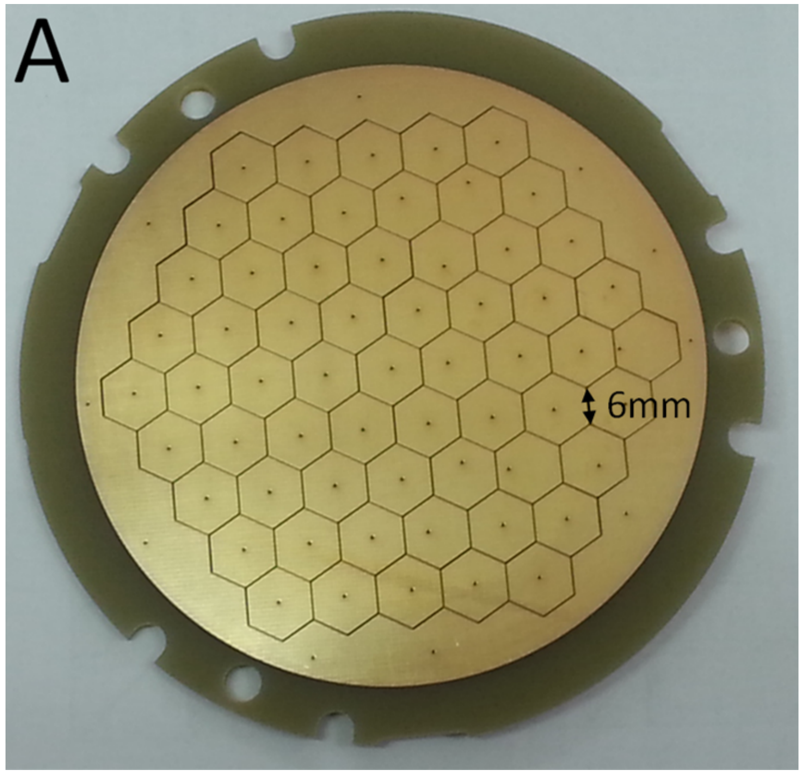
Cascade structure

- To reduce discharge rate
- Possibility to reduce Ion Back Flow

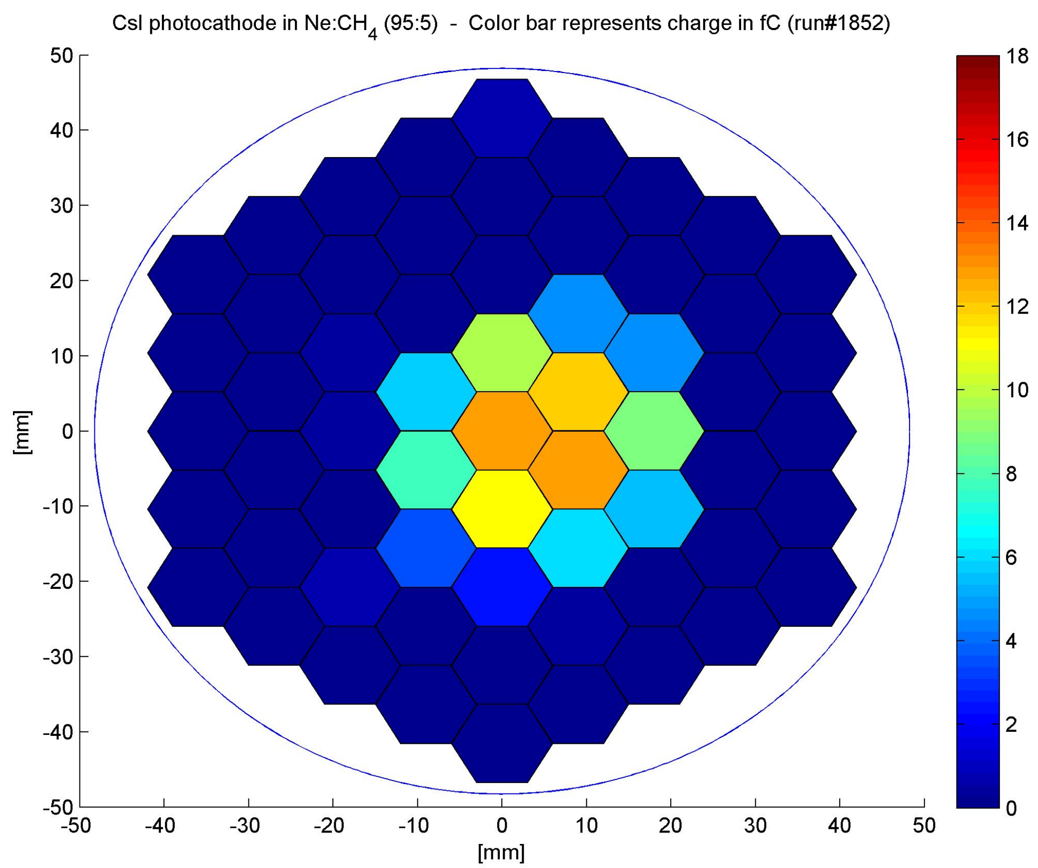
Imaging capabilities

- Pixelated readout
- Low noise

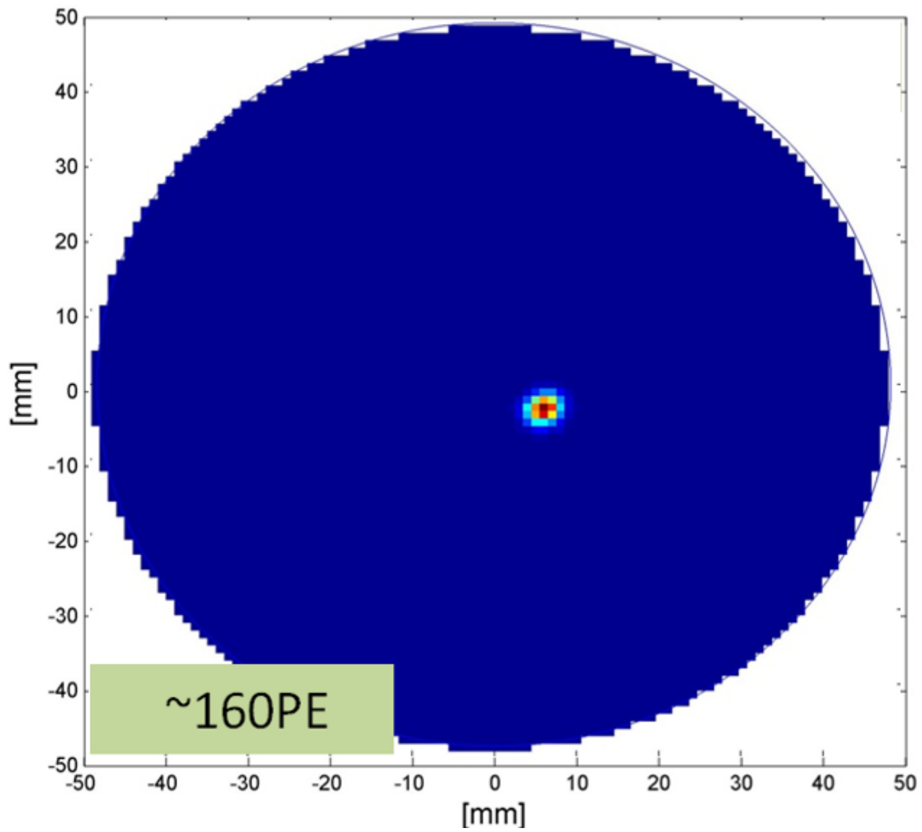




Imaging at Room Temperature

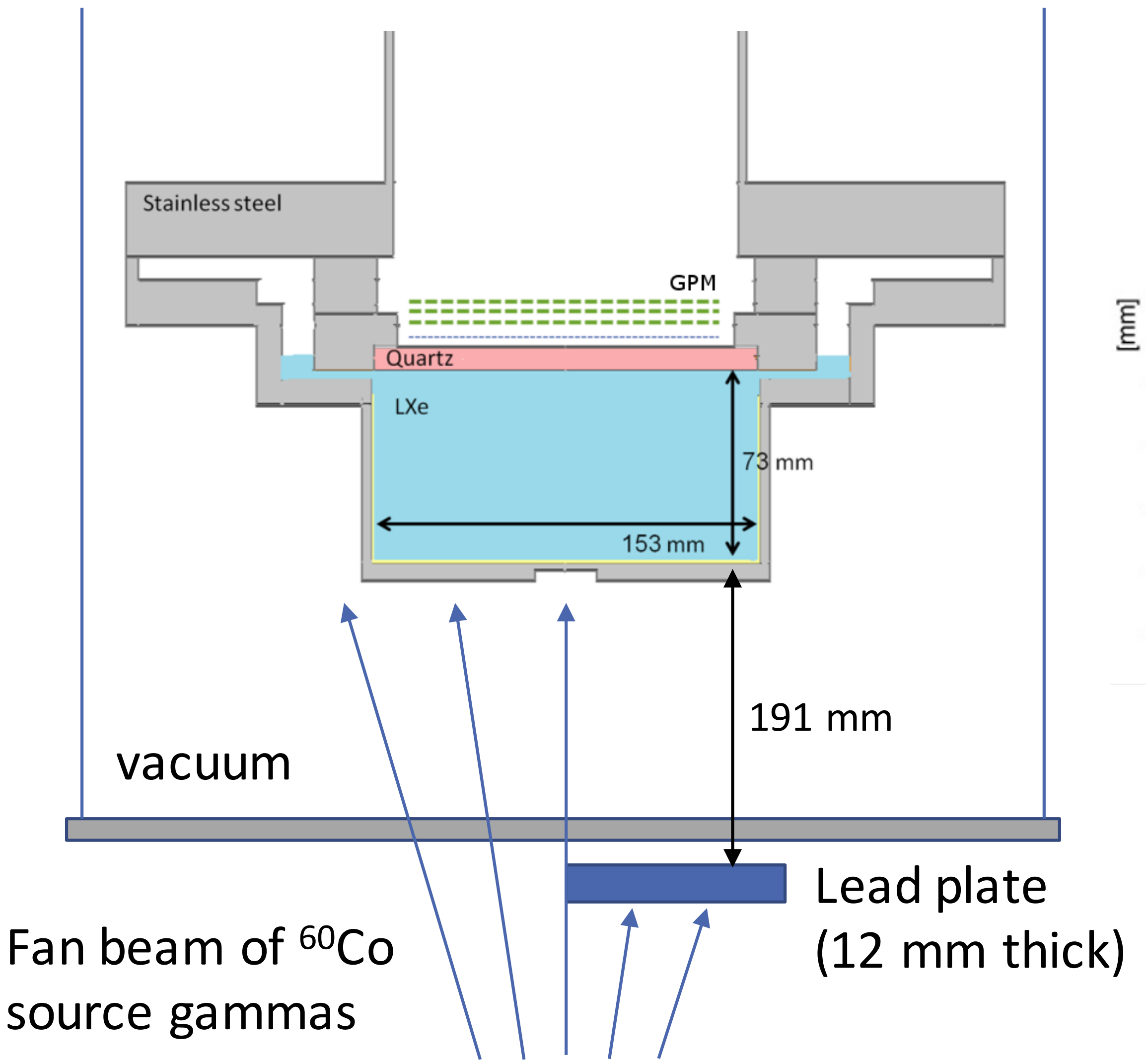


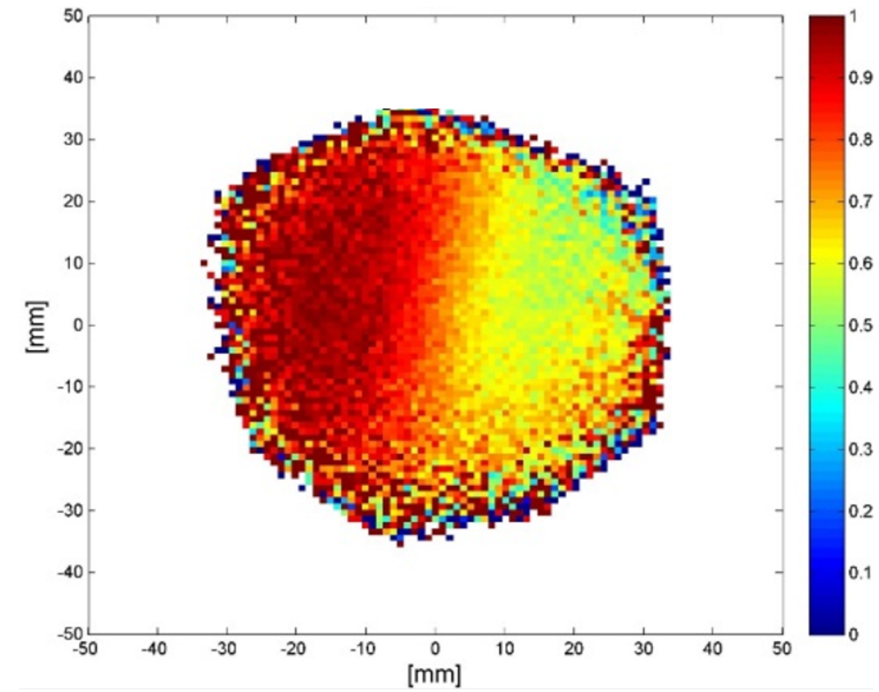
Single event image (H2 lamp); Center of gravity (COG) calculated for each event



2D histogram of COGs of events comprising 160 PEs

GPM Imaging at Cryogenic Temperature

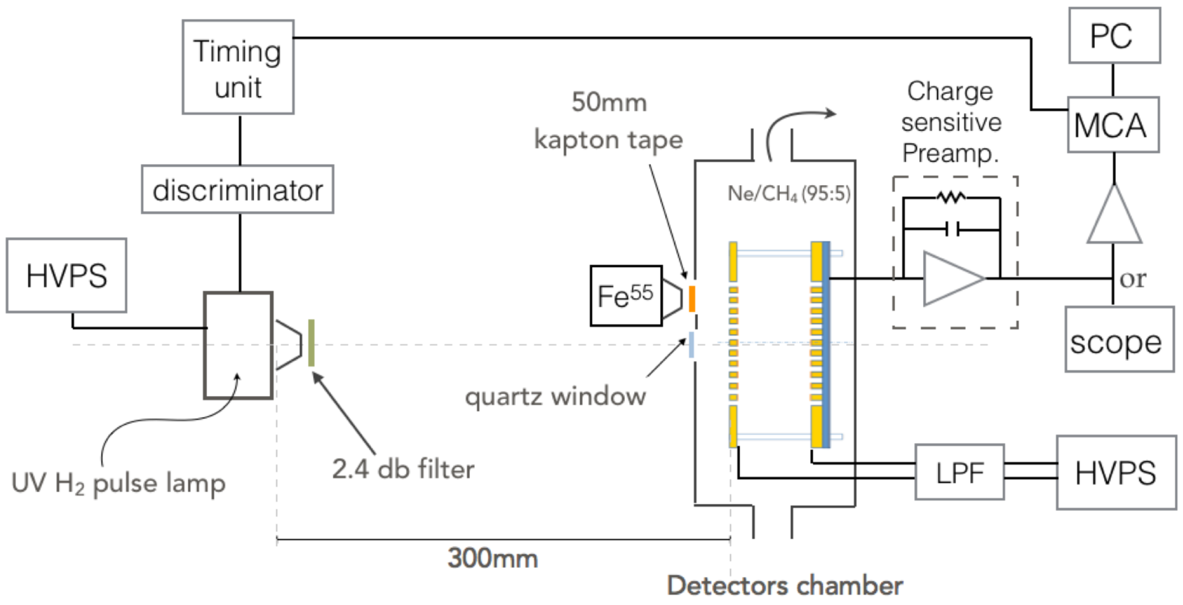


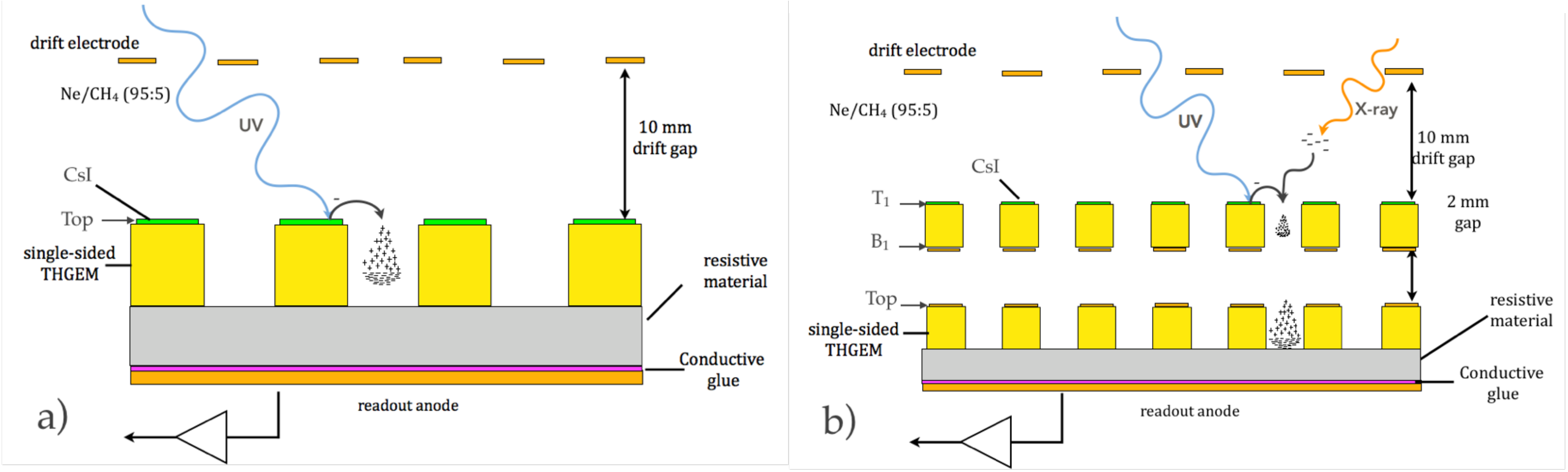


UV detection with RPWELL

Objective

- Characterize single-stage and double-stage RPWELL-based configurations as UV detectors
- Achieve high gain and high detection efficiency under stable operation
    - Expose to events with higher primary charge (dynamic range)

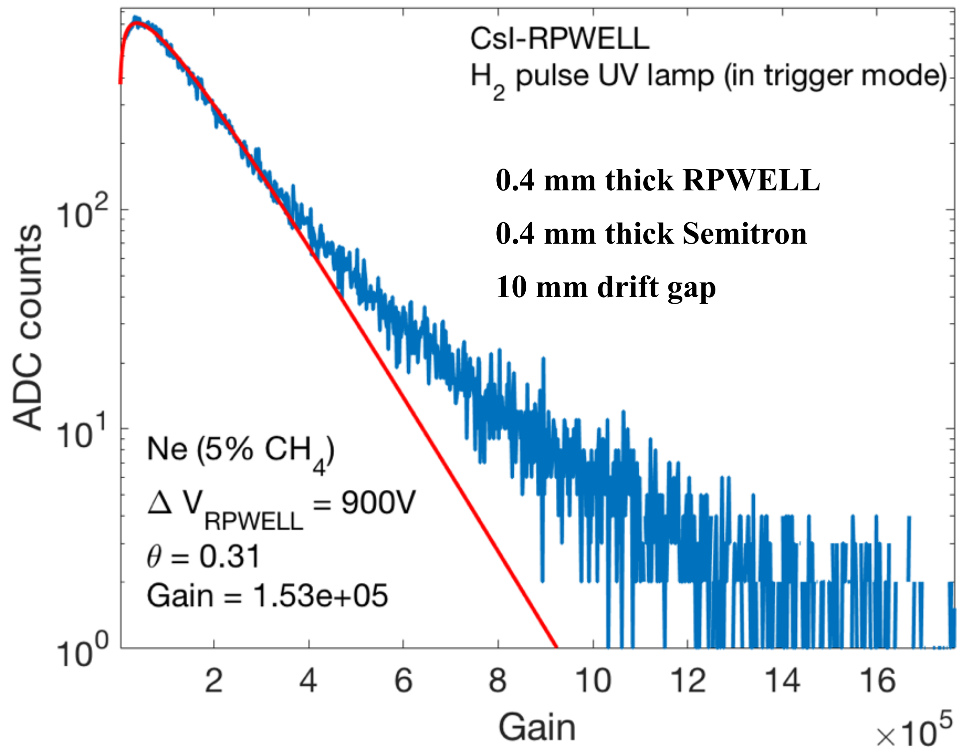


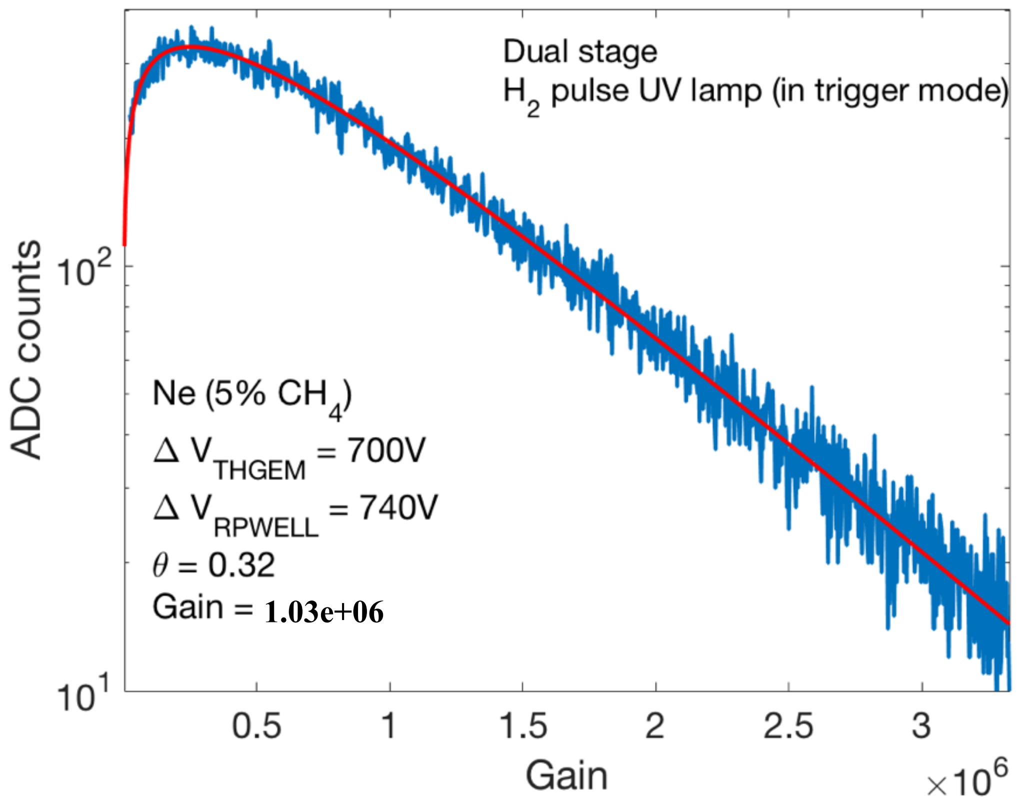


UV detection with RPWELL

Results

- Polya pulse-height distribution observed with both configurations





0.4 mm thick RPWELL
0.4 mm thick THGEM
0.4 mm thick Semitron
10 mm drift gap (no field)
2 mm transfer gap

A Polya Vs. Exponential

- Higher detection efficiency for equal average gain, noise and threshold

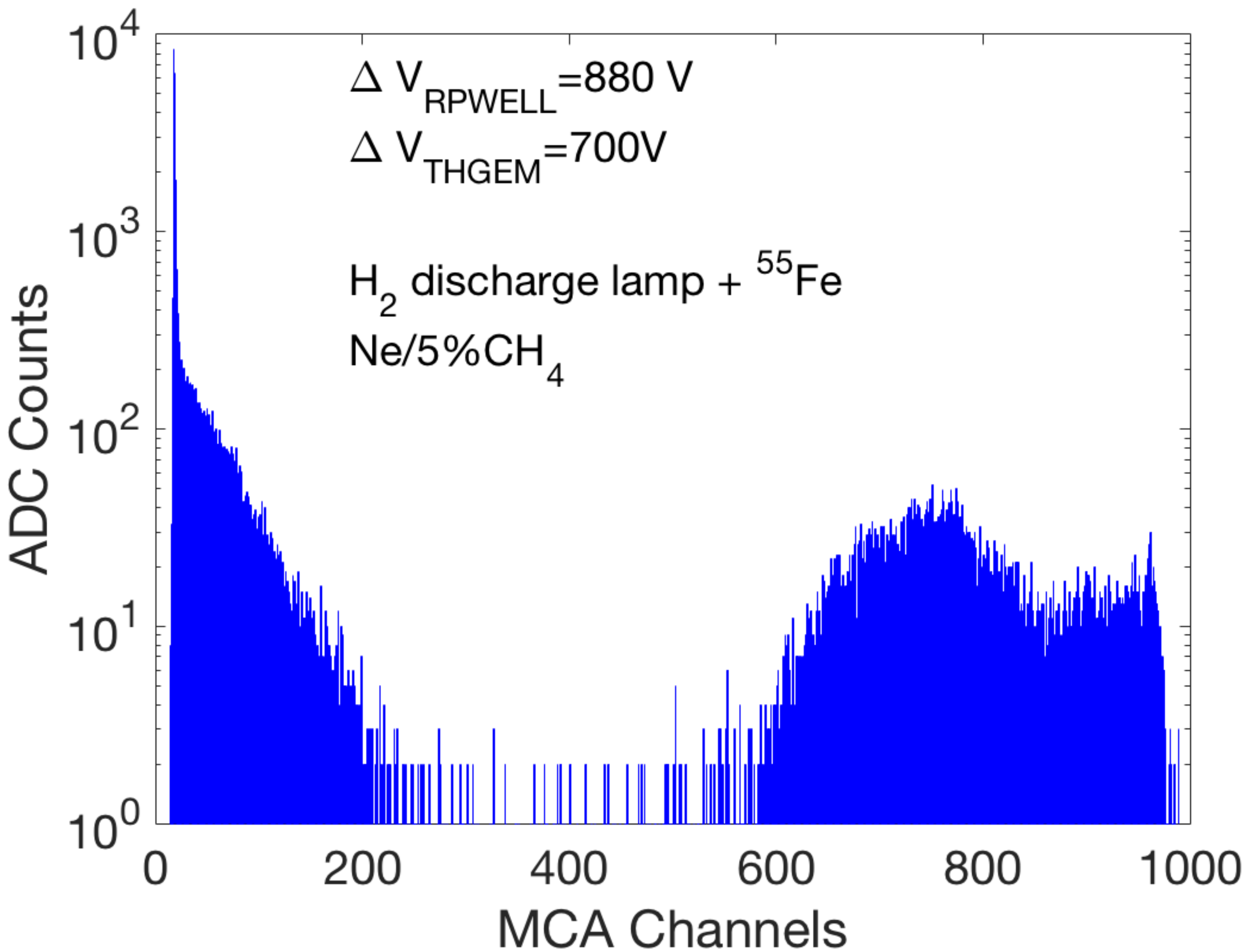
UV detection with RPWELL

Results

- Polya pulse-height distribution observed with both configurations
- Dual stage detector - stable UV detection while exposed to 6 KeV x-rays background under a gain of ~10^7

Conclusions

- Dual-stage RPWELL based detector is an excellent candidate UV detector
- Rate dependence: under study



Summary - The RPWELL

- Stable and efficient operation with single element (broad dynamic range)
  - Reduce the need for cascade configurations
  - Economic
  - Thin
  - Simple

- Upscaling is easy - 50 × 50 cm^2 detector has been assembled and tested in the lab
  - Beam tests foreseen in July
  - Prototype sampling-element for (S)DHCAL foreseen end of the year

- Promising candidate for room-temperature UV imaging (e.g. in RICH)
  - Stable operation at room temperature with UV under 6 KeV x-rays background
- Under advanced study: Operation in Cryogenic temperatures:
  - Search for adequate resistive materials
  - Operation in Ne mixtures for reading light in noble-gas TPCs
  - Operation in vapor phase of noble gases