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WEIZMANN INSTITUTE OF SCIENCE

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Israeli Centers of Research Excellence

Towards spark-free single stage large THGEM

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Outline

- Motivation
- The challenge
    - Discharges
    - Up-scaling
- Dealing with discharges
- Dealing with up-scaling
- Update from the TB - preliminary results
- Summary

Motivation

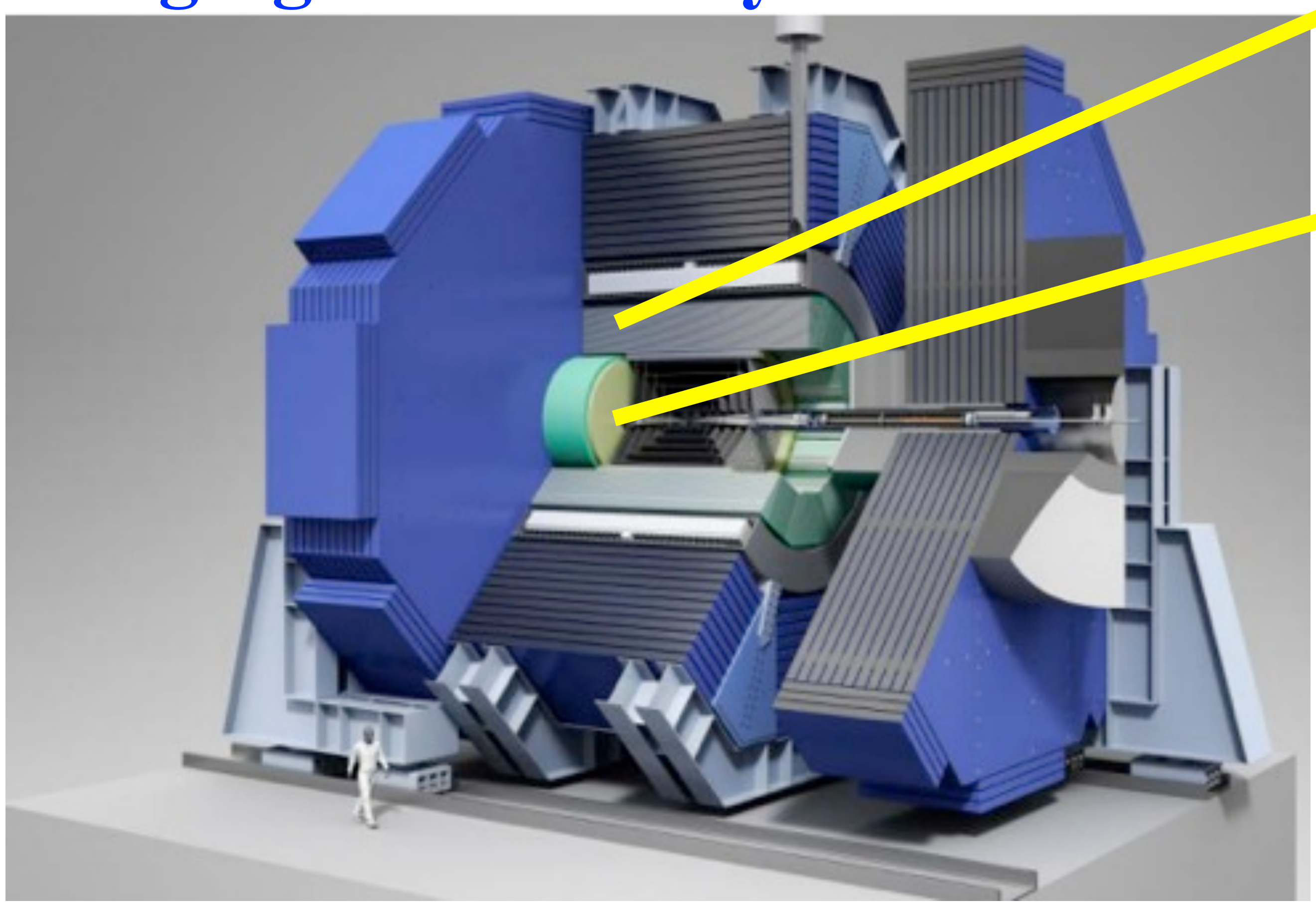
- Charged particle & photon detection
- Large area coverage @ reasonable cost
- Good spatial resolution
- Good time resolution
- High counting rate
- Low material budget
- Broad dynamic range

MPGD: Motivation

Particle physics - MIP detection

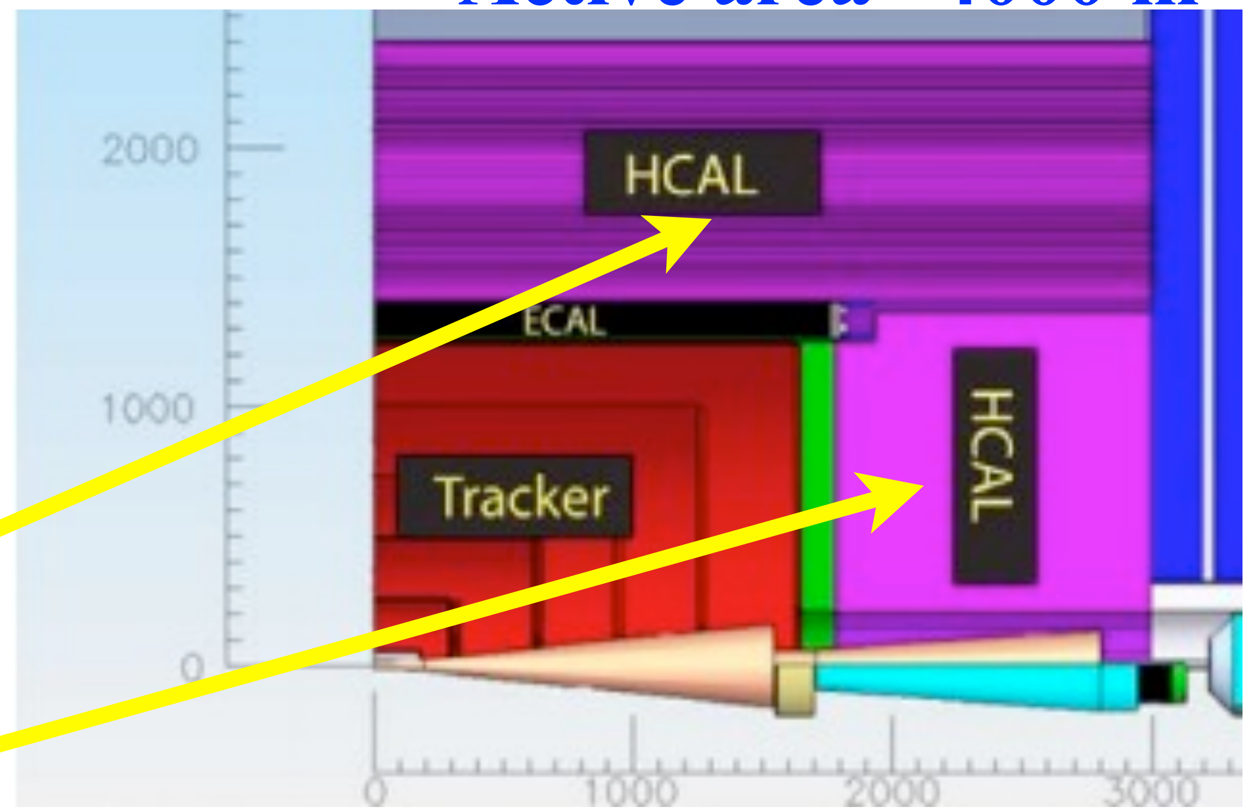
- Large area coverage @ reasonable cost
- Good spatial resolution
- Good time resolution
- Moderate counting rate
- Low material budget

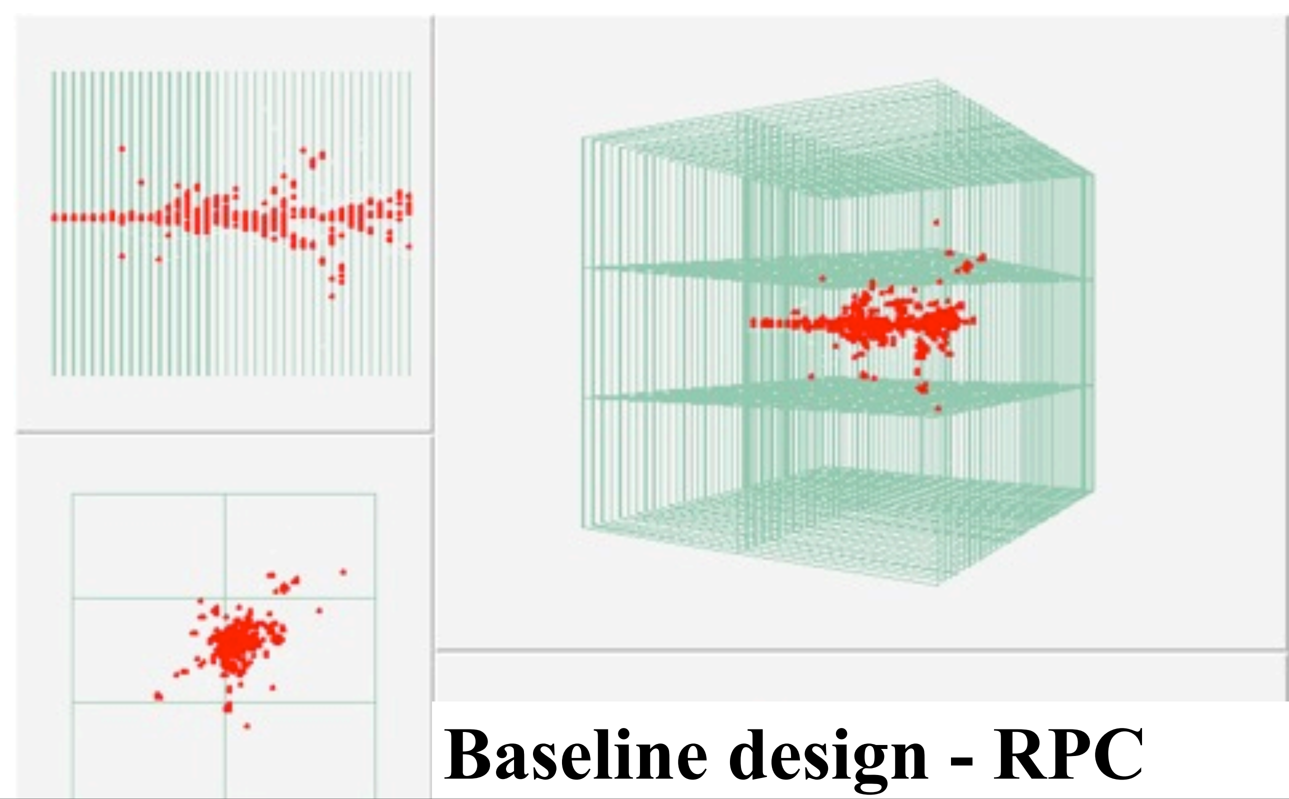
Imaging Calorimetry in SiD ILC



SiD Detailed Baseline Design

Active area~ 4000 m^2





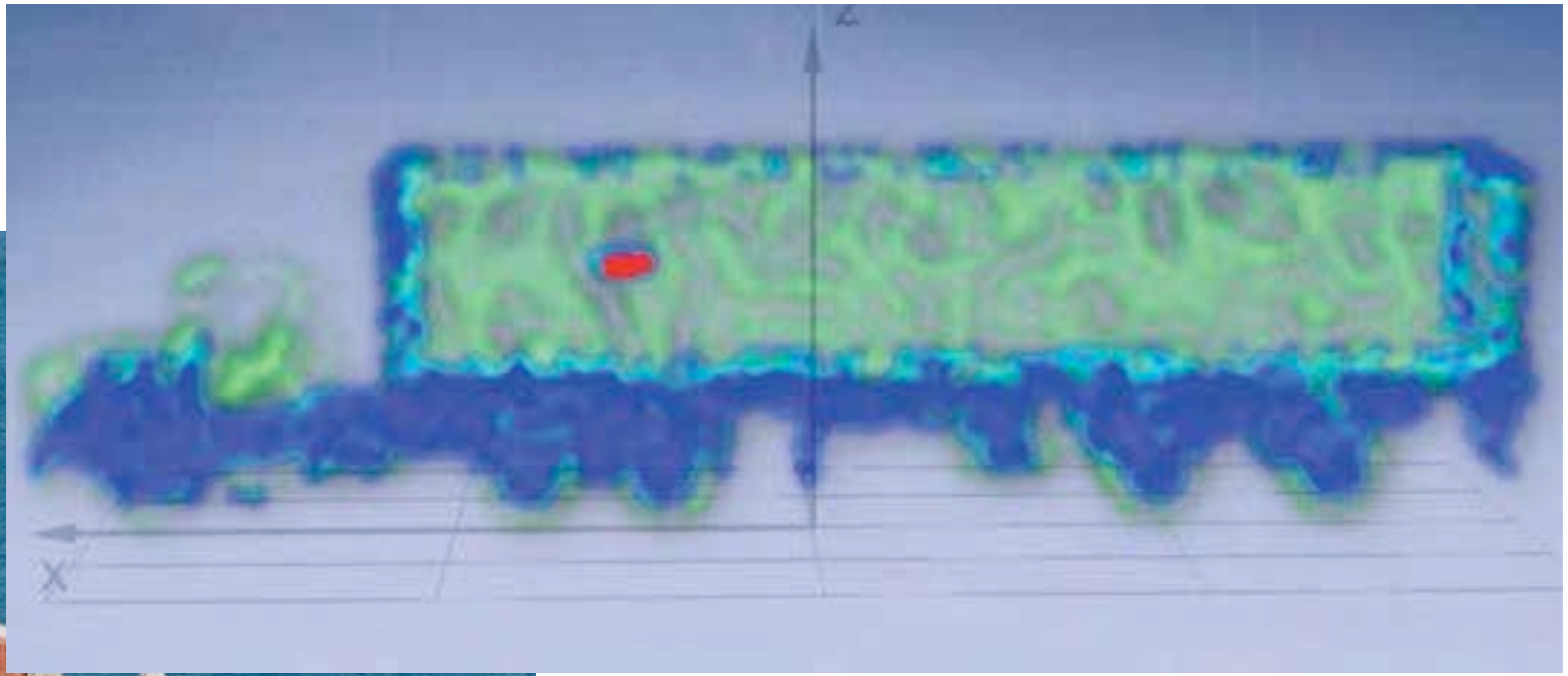
Baseline design - RPC

MPGD: Motivation

Inland security - μ detection

- Large area coverage @ reasonable cost
- Good spatial resolution
- Good time resolution
- Low counting rate
- Low material budget

Cargo scanning based on muon-tomography

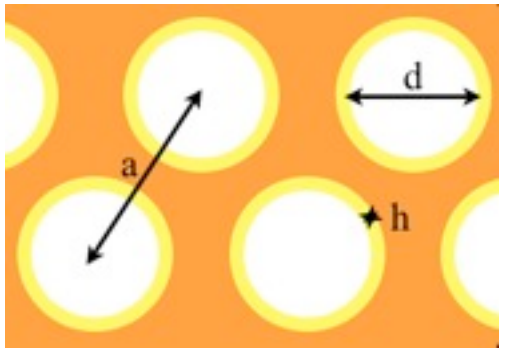


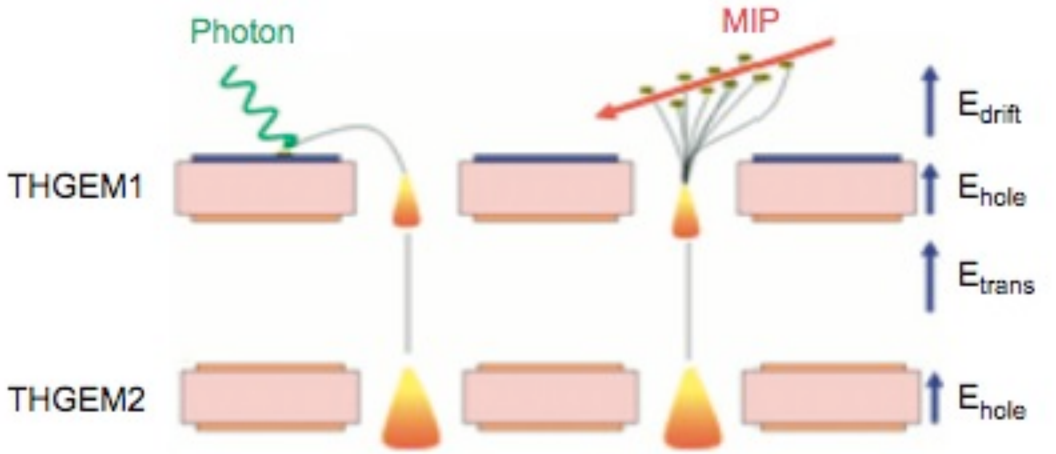
The THick-GEM: A typical PR slide

R. Chechik et al, NIM A535 (2004) 303
A. Breskin et al, NIM A623 (2010) 132

10 folds larger than GEM → **Robust**

- thickness t ≃ 0.4 - 3 mm
- a ≃ 0.5 - 1 mm
- d ≃ 0.2 - 0.5 mm
- h ≃ 0 - 0.1 mm



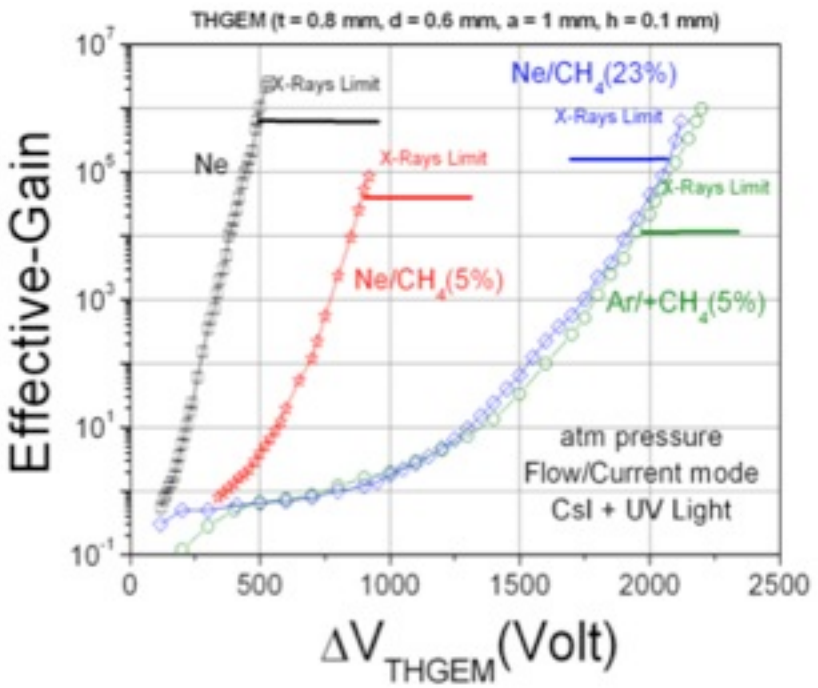


Simple

- Does not require sophisticated mechanical support (self supporting)
- Easy to operate

High gas gain

M. Cortesi et al., JINST 4 P08001 2009



Production

- **Industrially produced** in PCB technologies
  - Italy, Israel, China, ...
- **Large scale**
- **Economic**

Spatial resolution ~ 0.5 mm
Time resolution ~7 ns (double stage)

The challenge - Discharges & instabilities

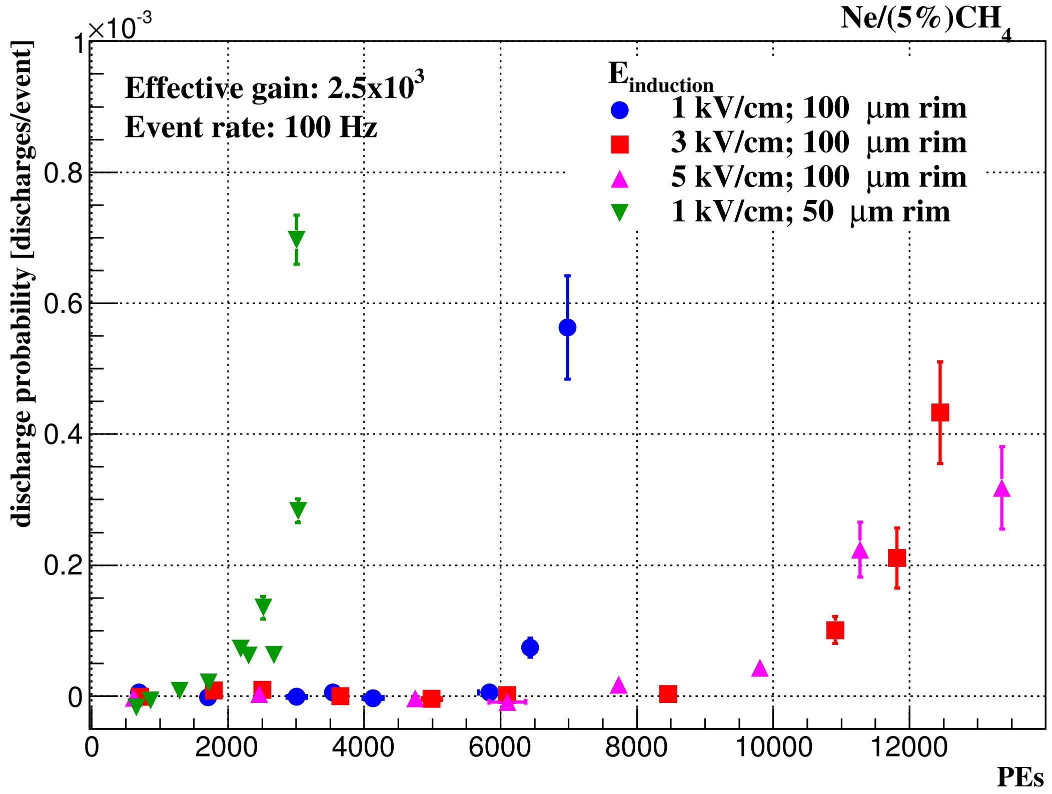
Overview

- No natural gain saturation mechanism
  - Gas gain increases with applied voltage
  - At fixed gain: total charge ∝ primary charge
- Breakdown at high charge density
  - May damage the detector
  - May damage the readout electronics
  - Dead time - efficiency loss

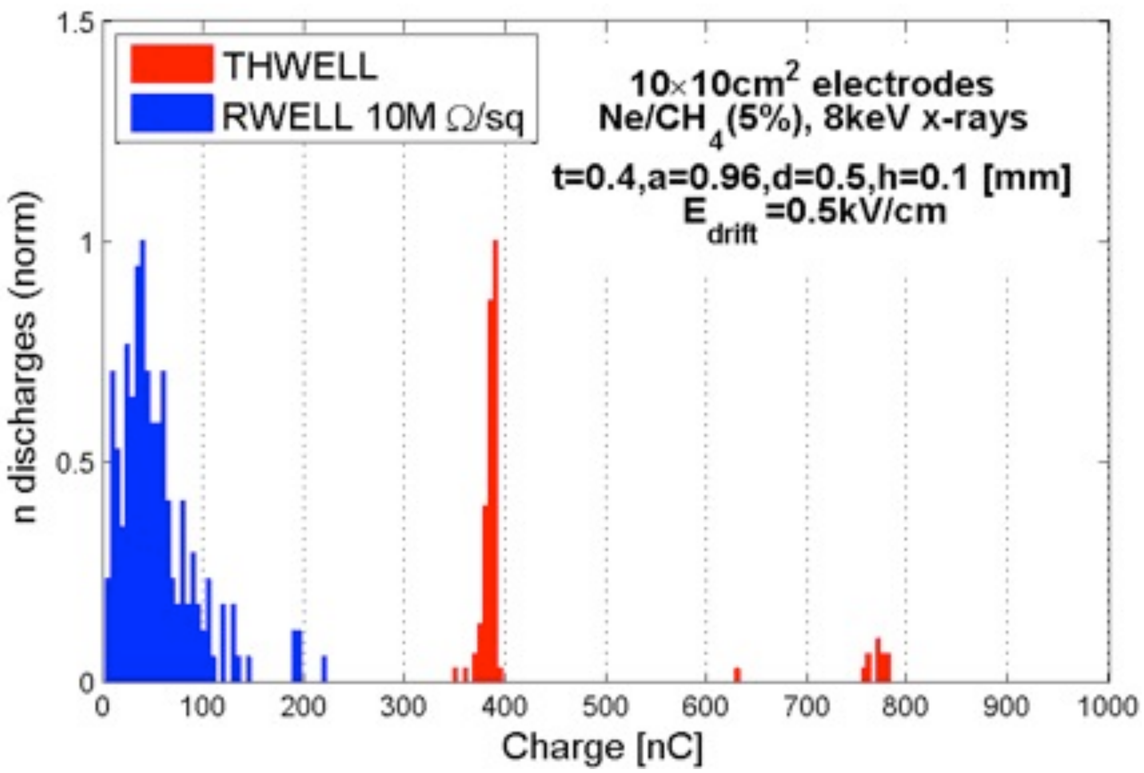
Solutions

- Cascade detectors
  - Lower gain in each stage
  - Less charge in each detector cell
- Protection: resistive anodes
- Low noise electronics
  - lower operation gain

Discharge probability Vs. primary charge (THGEM)



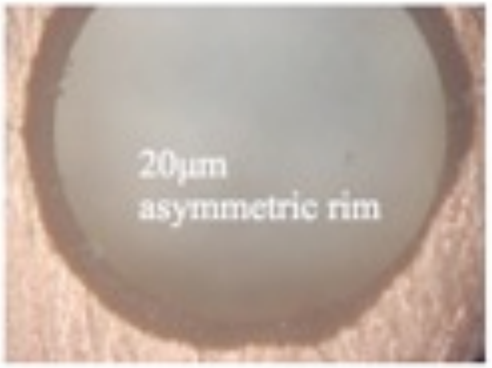
Energy quenching (THGEM)



The Challenge: Up-scaling

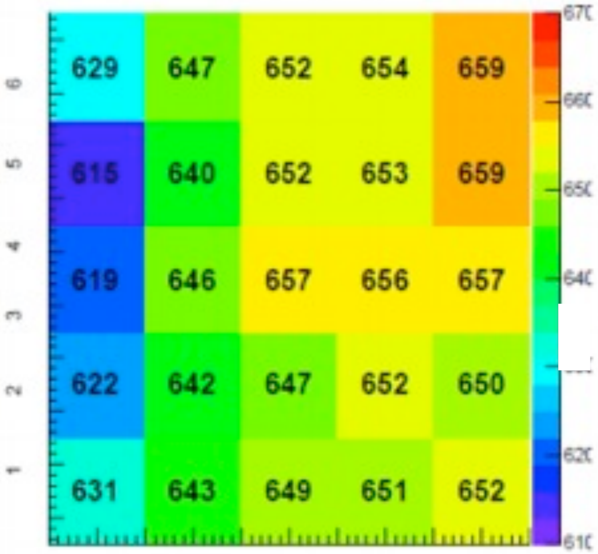
Technicalities: large MPGDs
- Drill millions of THGEM holes

THGEM holes



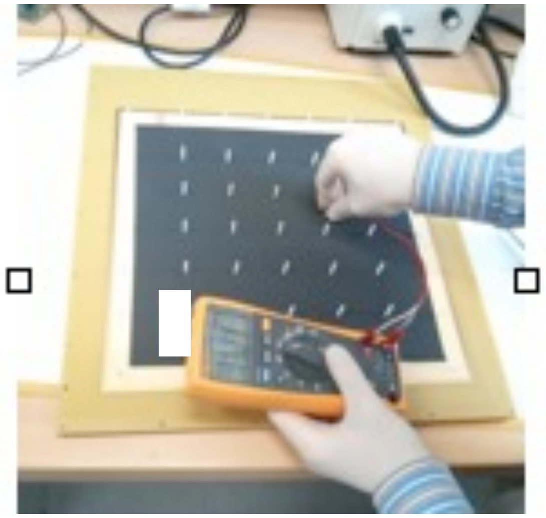
Uniform response: gain, discharge rate
- Uniform gaps
- Uniform element thickness
- Uniform cells quality
- Uniform resistivity values

Thickness



M. Alexeev et. al, JINST 9 C03046 2014

Resistivity



Capacitance
- More noise
- Energetic discharges

Power distribution
- Many high voltage channels
- Cross talk effects

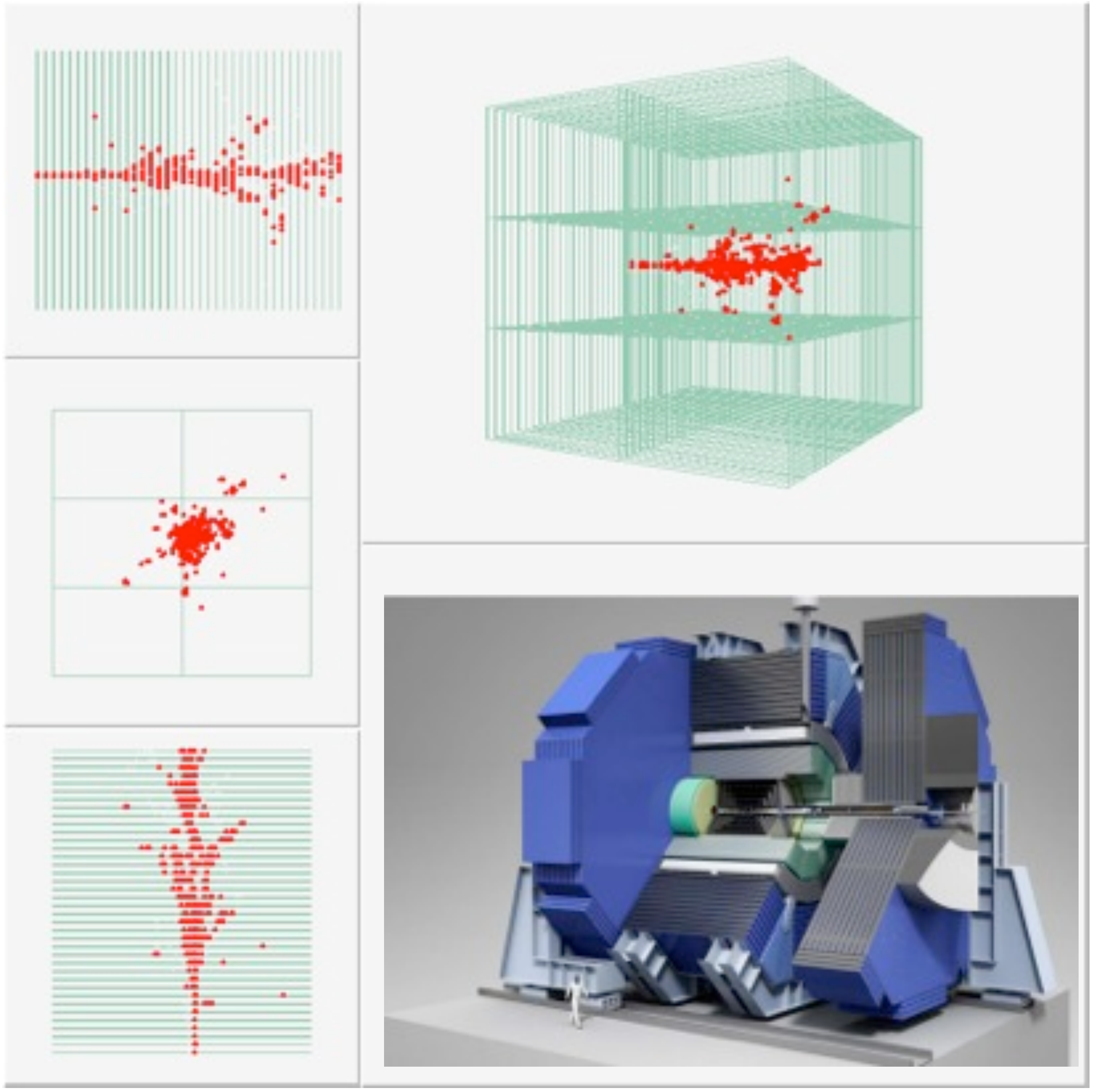
Reproducibility

Industrialization

The Challenge: Application specific

The exact configuration should match the application
Non application specific studies can only hint at the right direction

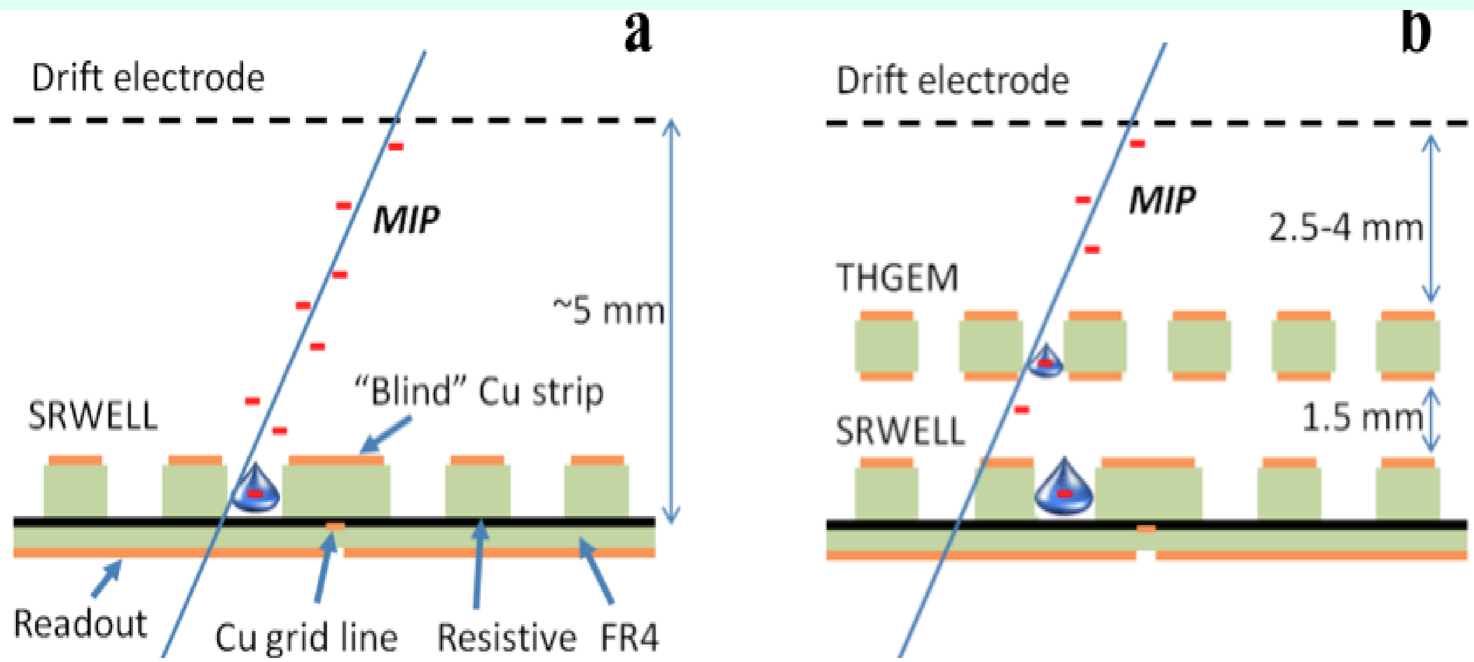
Dimensions	(4000-5000 m^2, **thickness < 8 mm inc. readout electronics**)
Detection efficiency	(>98%)
Coverage (dead area)	( )
Spatial resolution	(1 cm^2)
Time resolution	(insignificant)
Energy resolution	((S)DHACL)
Rate capabilities	(1 kHz/cm^2)
Complexity	(millions channels)
Safety	( )
Aging effects	( )
Cost	(**single-stage - must!**)

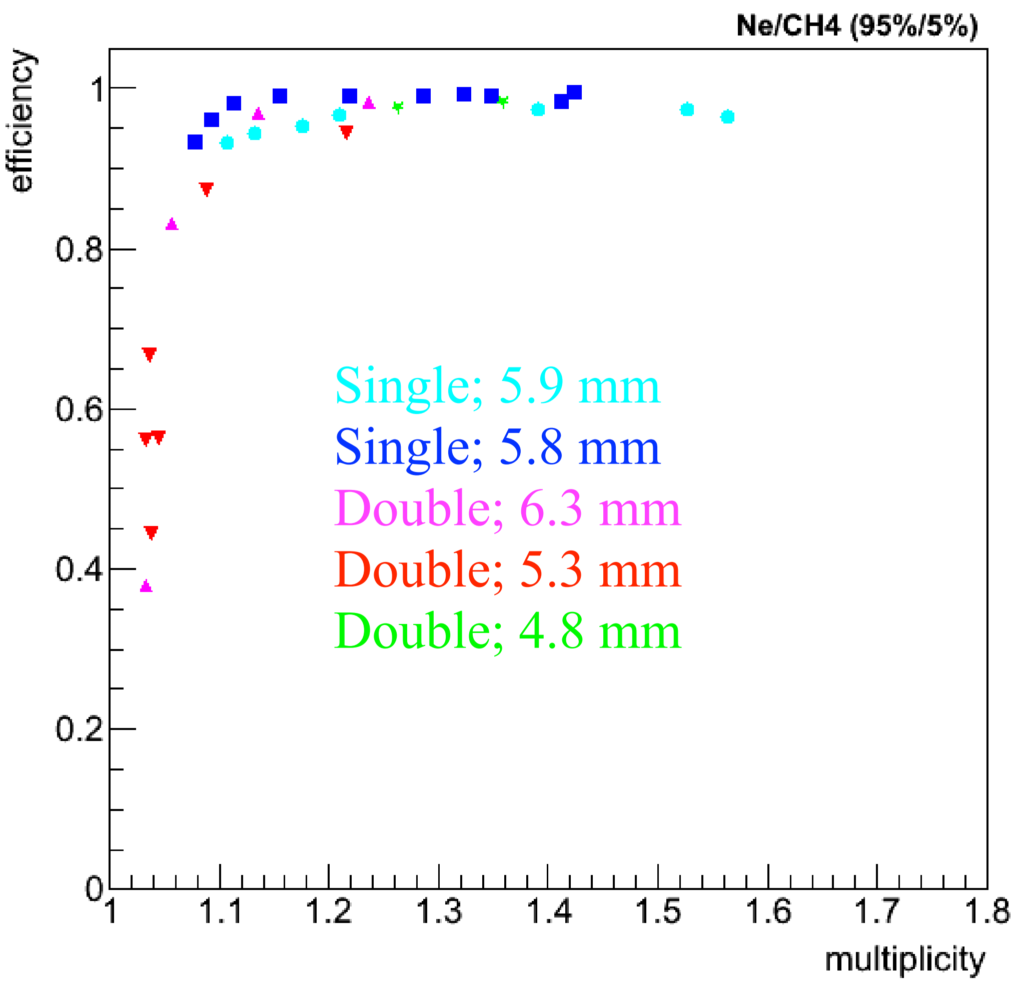


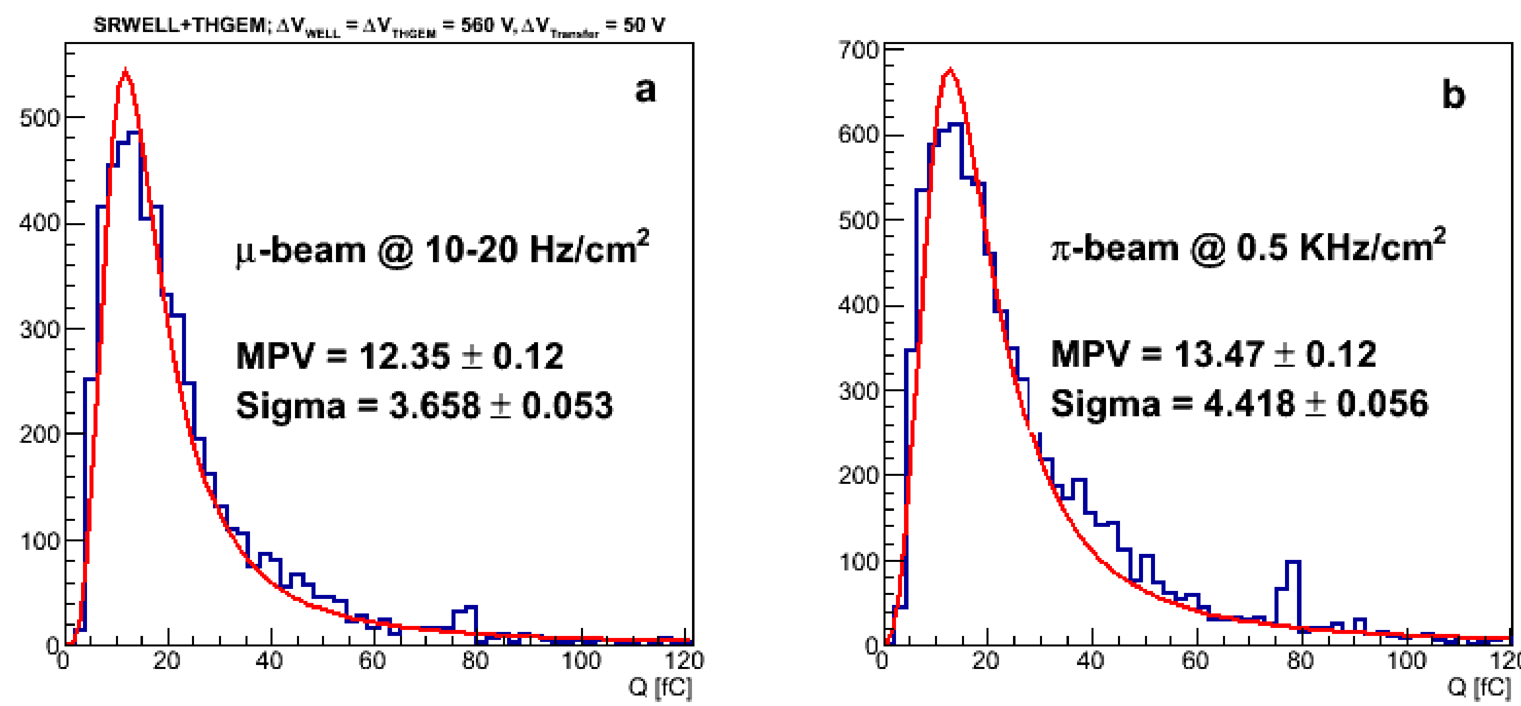
Test beam results - SRWELL for (S)DHCAL

Beam test evaluation: SRS/APV readout

- 4.8 - 6.3 mm thick single- and double-stage configurations
- Gains 1000-8000
- Detection efficiency > 95% @ pad multiplicity ≲ 1.2







S. Bressler et. al, JINST 8 P07017 2013

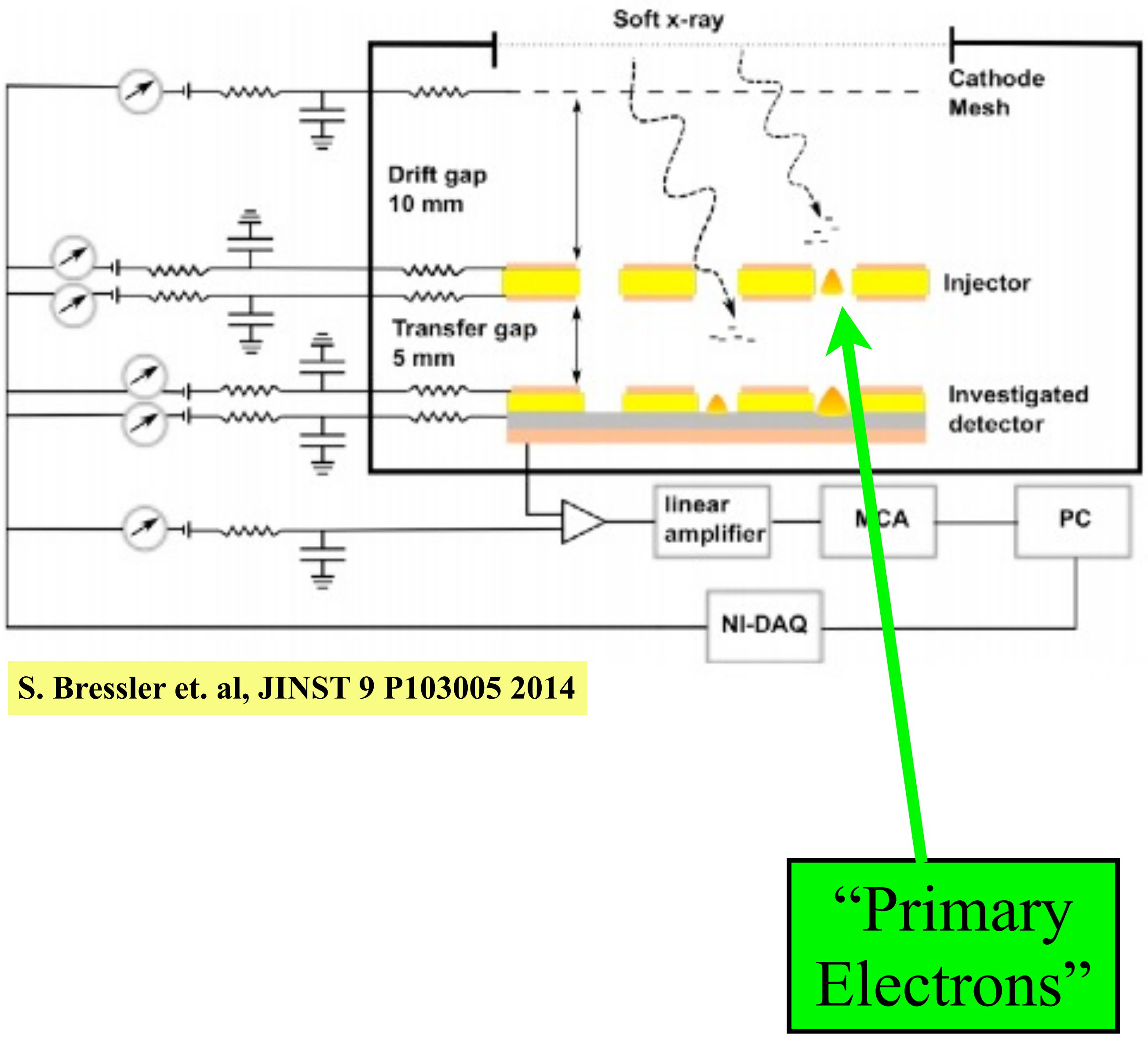
<u>But</u> with single stage configurations discharge probability ~10^{-6}

Dealing with discharges

Response to Highly Ionizing Particles (HIPs)

- Mimic Highly Ionizing Particles in the lab
- Measure the discharge probability as a function of the number of primary electrons

- The *injector* method:
  - Use additional multiplication stage far from the detector
  - Multiply the electron from the x-ray conversion prior to the detector
  - Characterized the injector gain precisely



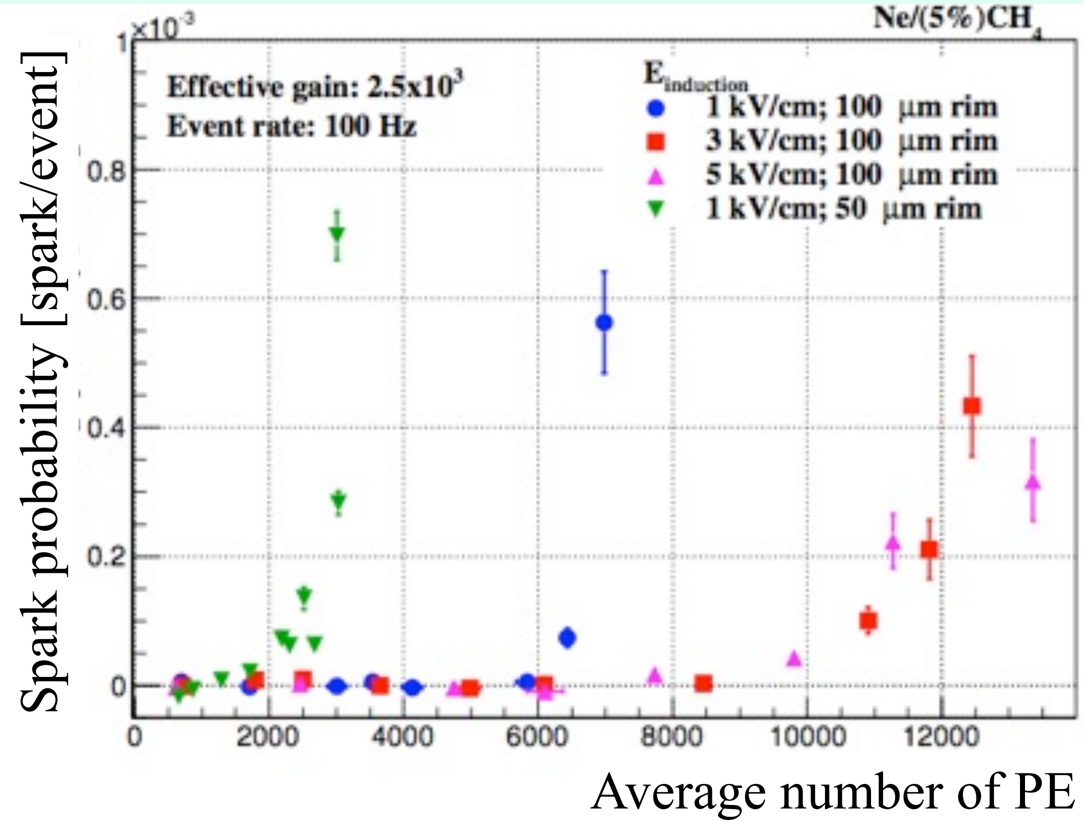
S. Bressler et. al, JINST 9 P103005 2014

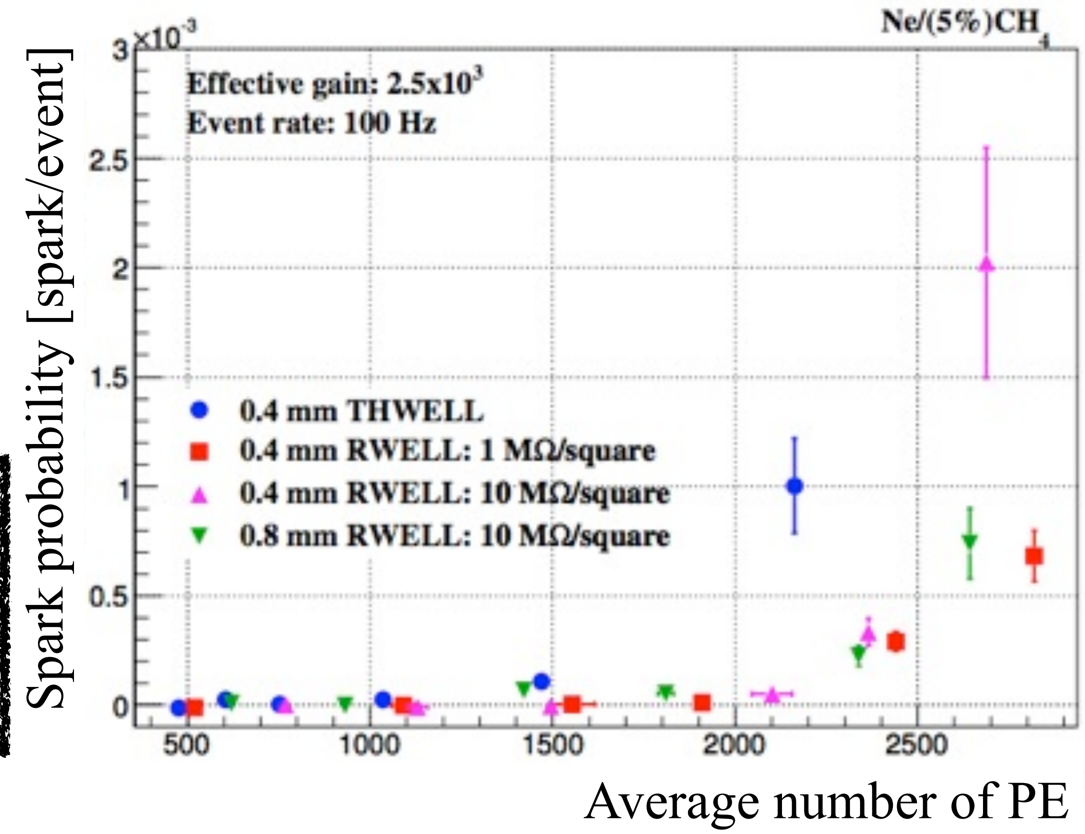
Response to HIPs

- The dynamic range of the detector is studied in conditions more similar to those in the experiment
  - Fixed gain (here ~ 5000)
  - Different ionization conditions

- Detectors with larger rims are more stable
- Multiplication in the induction gap results in more stable configuration
- WELL configurations are less stable than standard configurations

Decided:
Focus on configurations with 1 mm induction gap
Multiply also in the induction gap (G_{ind}~10)

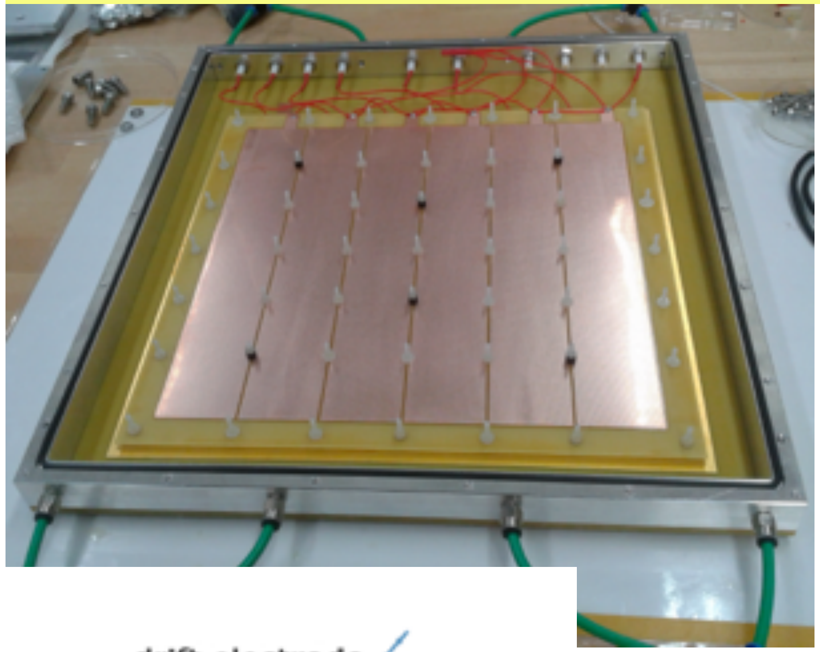


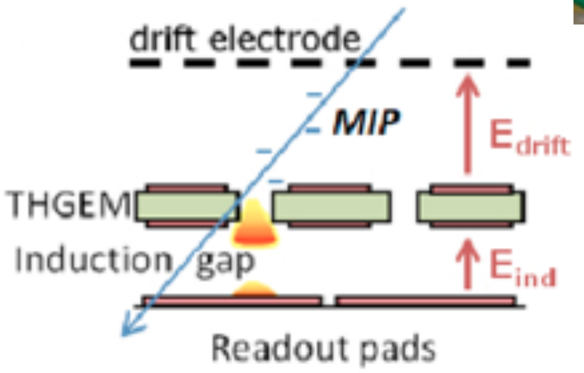


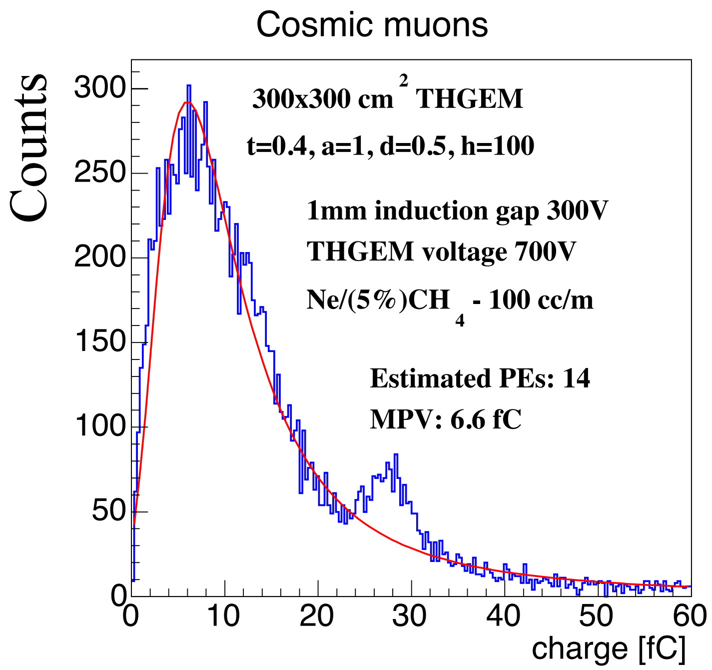
S. Bressler et. al, JINST 9 P103005 2014

30 x 30 cm^2 proto. with 1 mm induction gap

Structure similar to the one developed by Trieste; M Alexeev et. al, JINST 7 C02014 2012

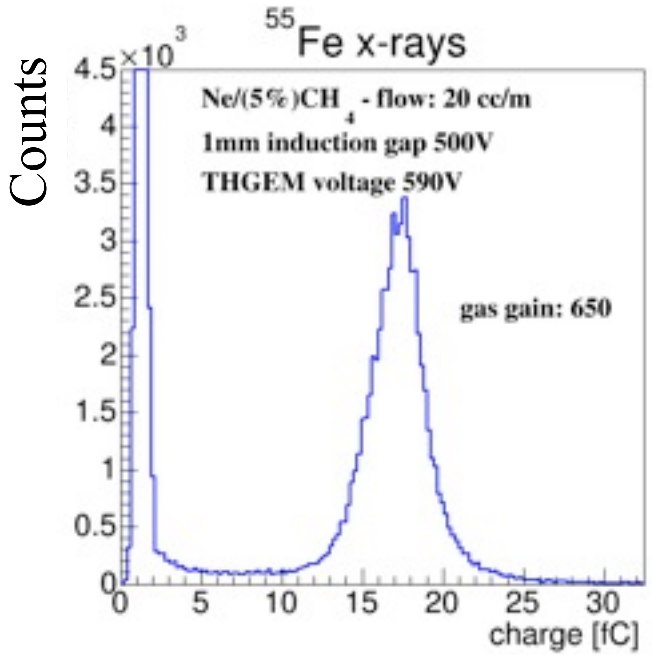


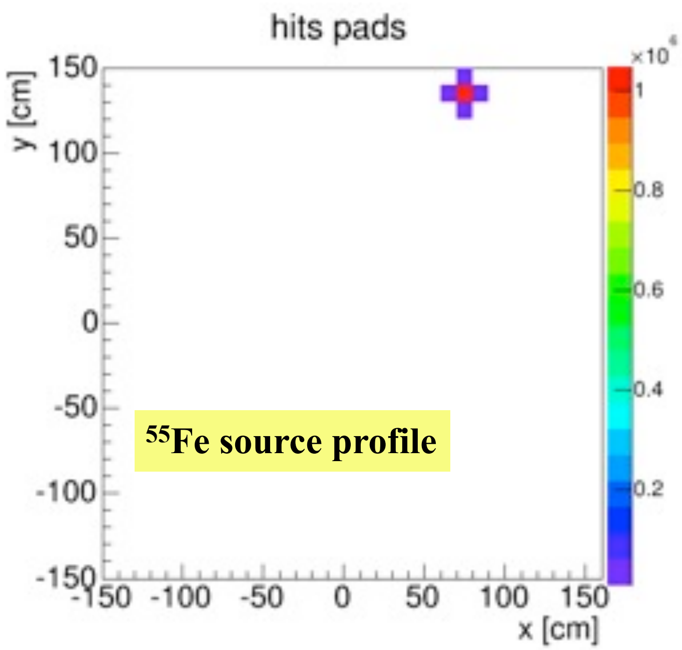




In the lab

- Good S/B with ^{55}Fe and cosmic muons
- High eff (>95%)
- Low multiplicity
- But also constant and uniform discharge rate
  - 20 / hour / strip





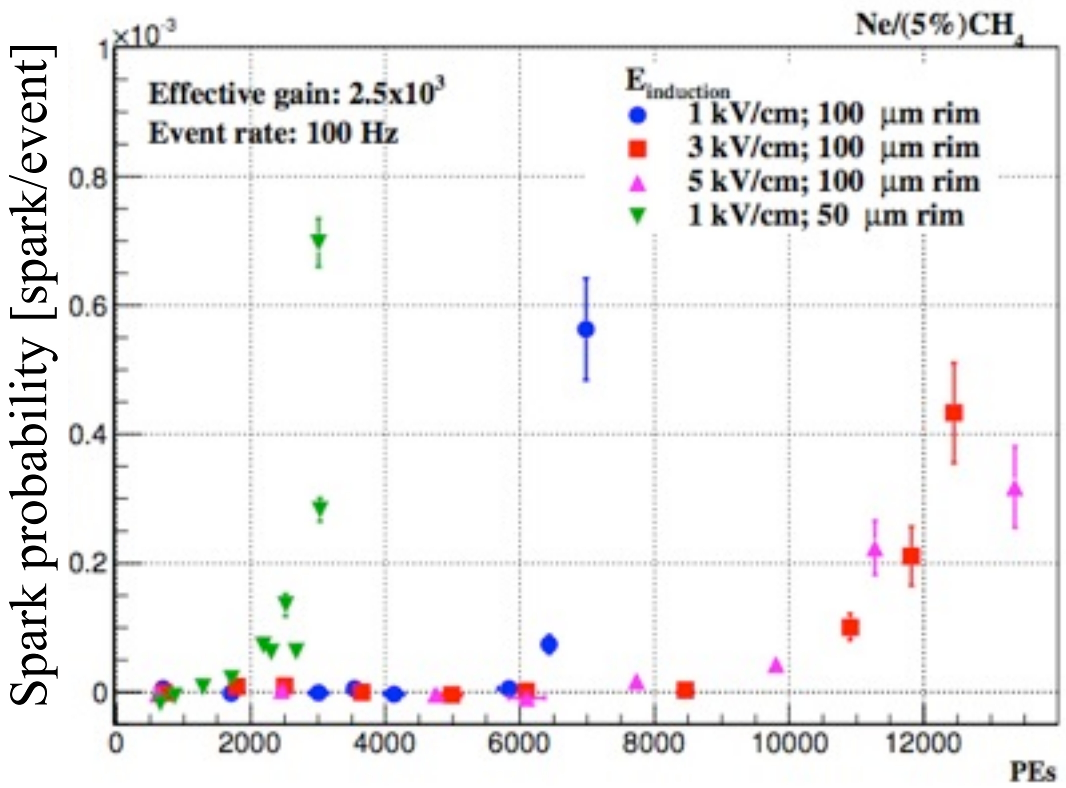
Operation mode

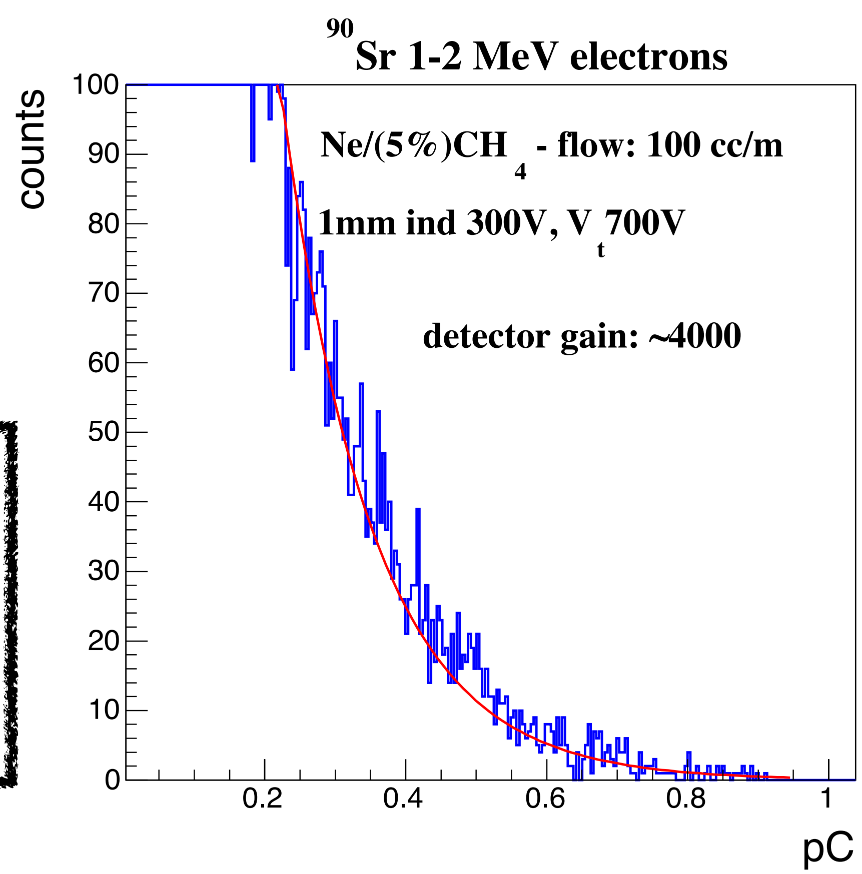
- With multiplication in the induction field
- E_{ind} = 3 kV/cm
- G_{ind} ~ 10

30 x 30 cm^2 proto. discharge study

Possible origins:

- FR4 radioactivity
  - Hard to assess ?
- High Cosmic Landau tail
  - Expecting increase increase in discharge probability at 12000 PE
- Stress test with ^{90}Sr & injector
  - Reach ~10000 PE at relatively low rate
  - No increase in discharge probability





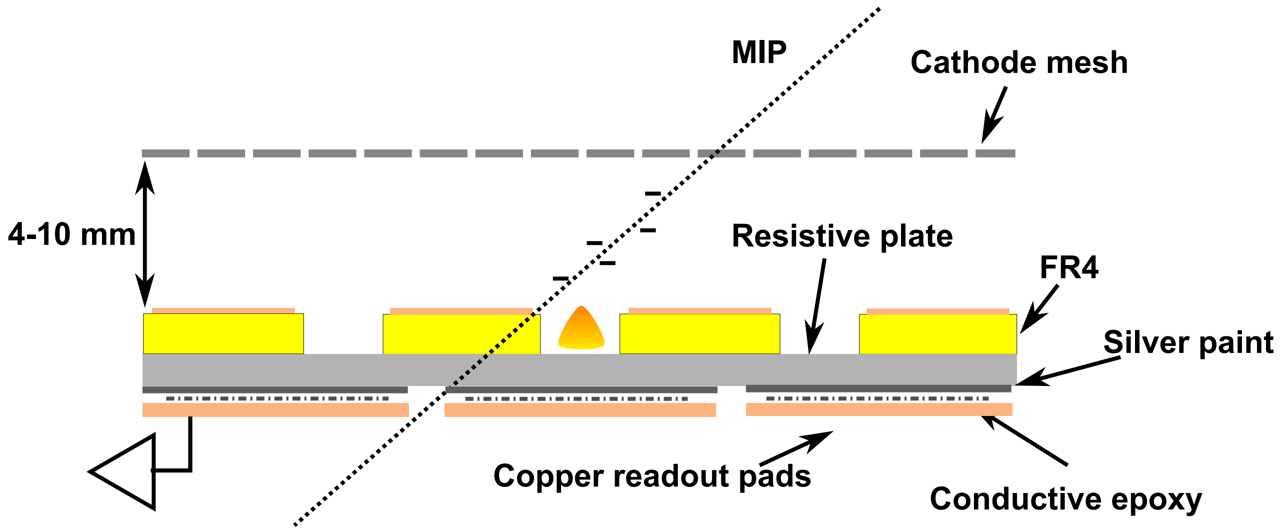
Decided:
Evaluate in the beam

- Possible outcome - single stage configurations with induction gap are simply not good enough...

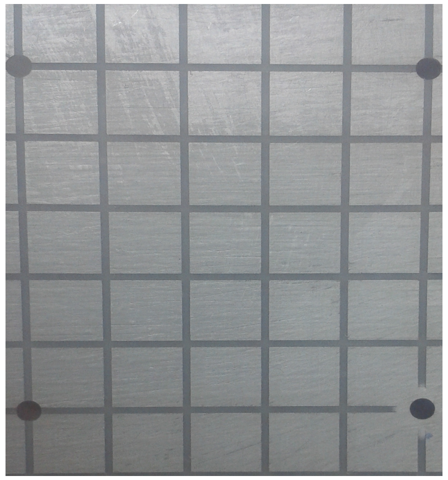
The RPWELL

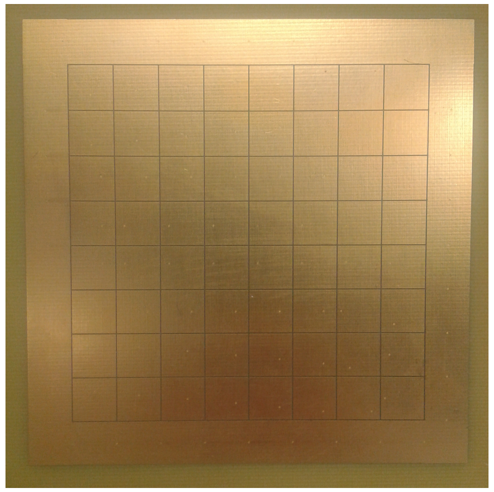
Resistive ***P***late ***WELL***:

- WELL coupled to materials with large bulk resistivity
- The charge is induced on the readout pads
- The avalanche charge flows through the plate to the anode (doesn't propagate sideways)
  - Less cross talk ? (under study)



A. Rubin et. al, JINST 8 P11004 2013





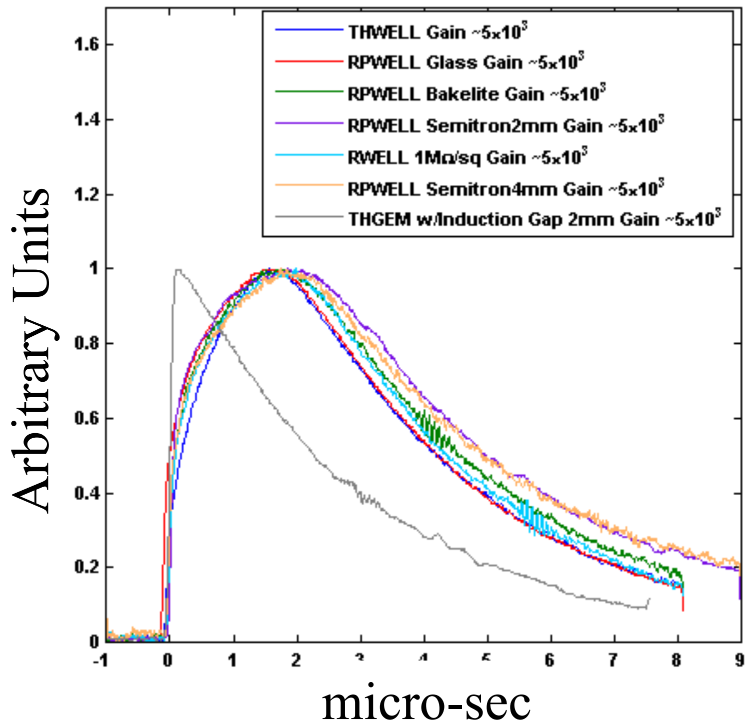
Tested materials

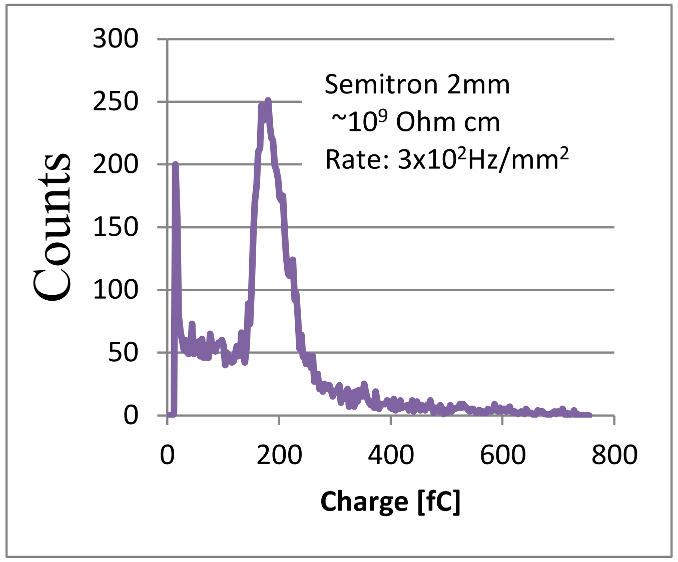
Material	Dimensions [mm]	Bulk resistivity [Ωcm]
VERTEC 400 glass	36×31×0.4	8×10^{12}
HPL Bakelite	29×29×2	2×10^{10}
Semitron ESD 225	30×30×2	2×10^{9}
Semitron ESD 225	30×30×4	3×10^{9}

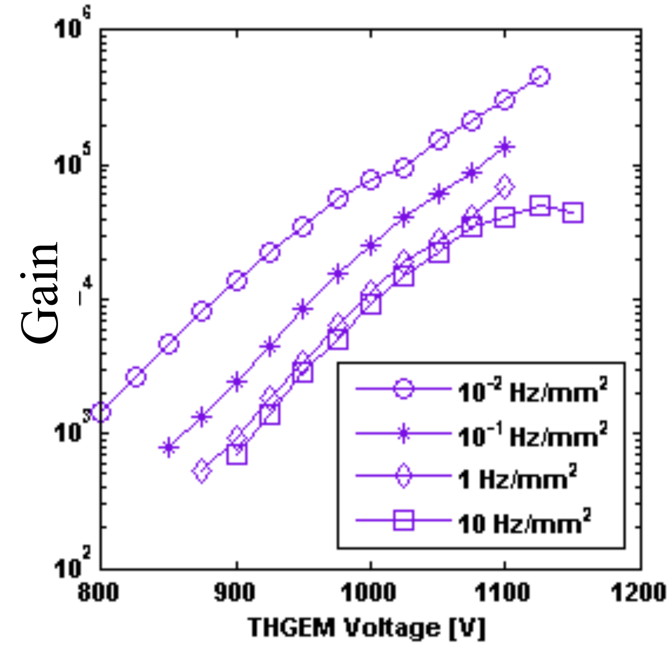
Focus on thin Semitron ESD 225 layers

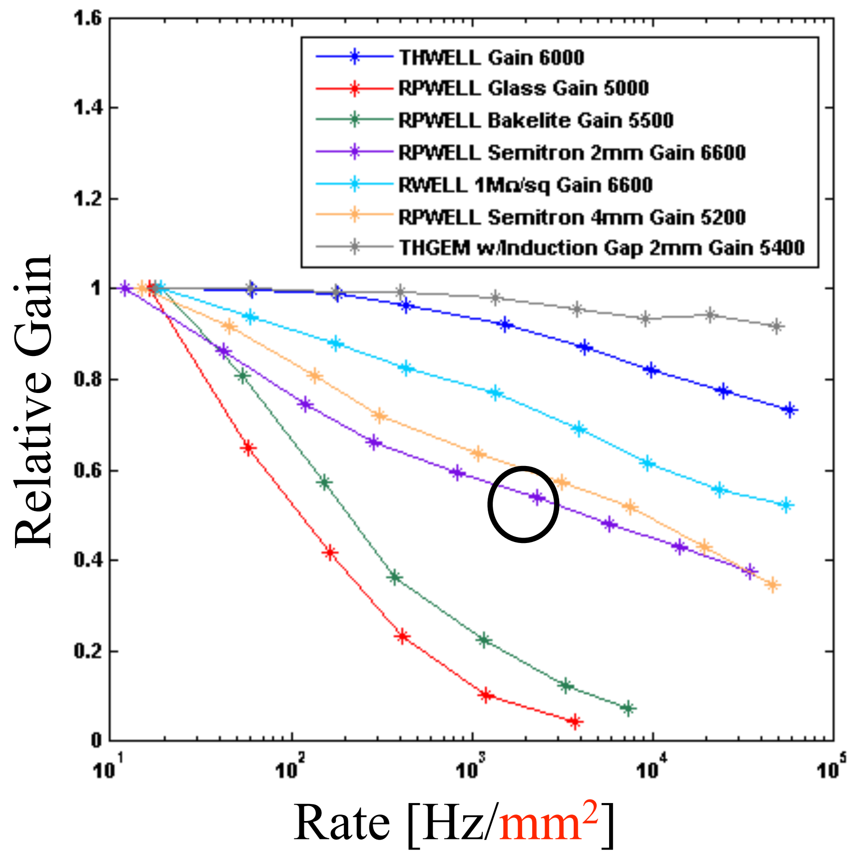
A. Rubin et. al, JINST 8 P11004 2013

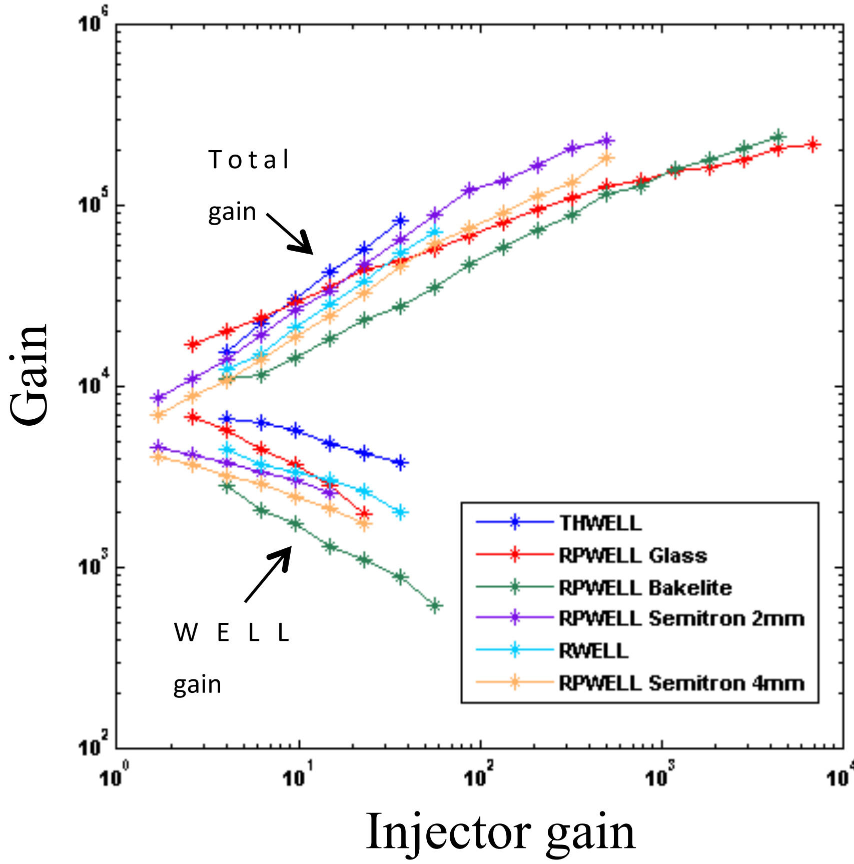
RPWELL 10^9 Ωcm - 2 mm layer







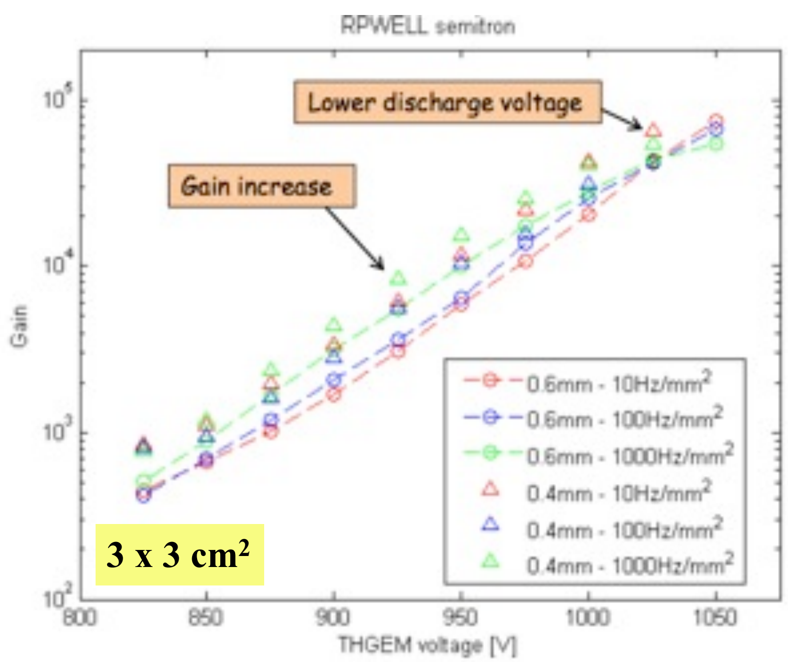




- Same pulse shape as standard well
- ~20% Energy resolution
- Gain saturation at high irradiation rate
- < 50% gain drop over 4 orders of rate magnitudes
- **No discharges at high rate of HIPs**

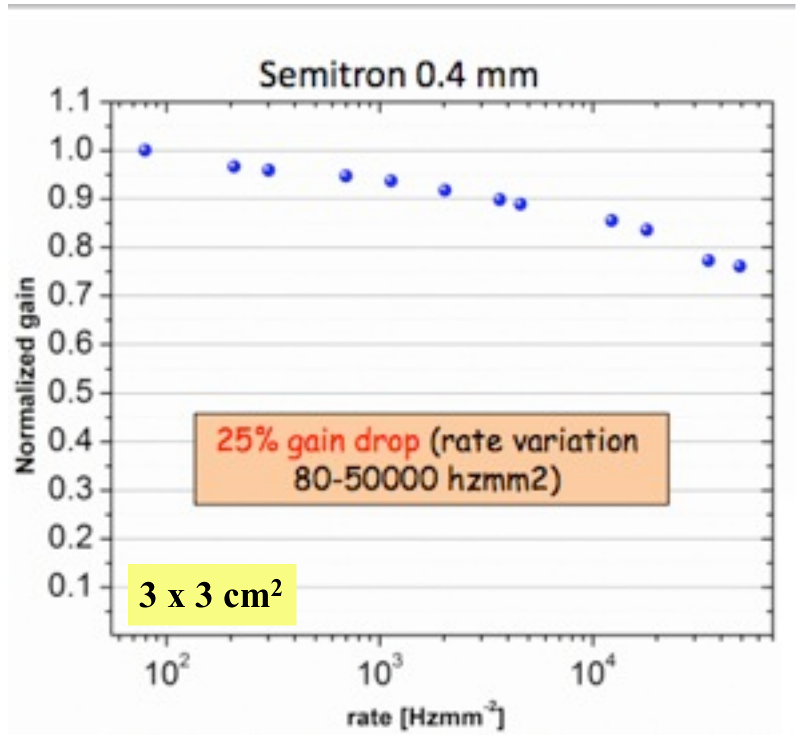
Focus on thin Semitron ESD 225 layers

Improved performance with thinner (0.4 & 0.6 mm) layers - **R~#10^8 Ωcm**



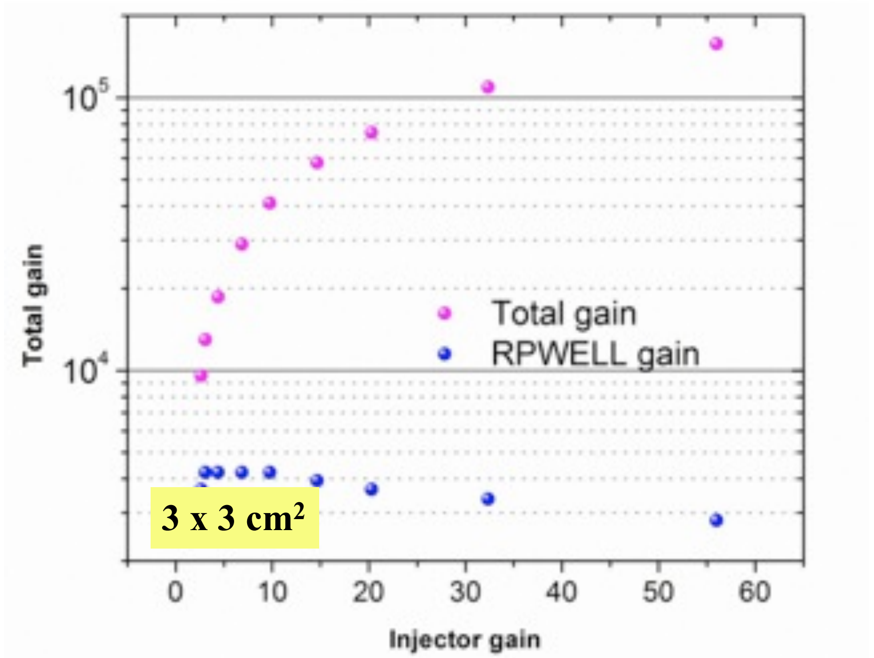
Higher gain for the same voltage

- Smaller anode-cathode gap



Gain drops slower with rate

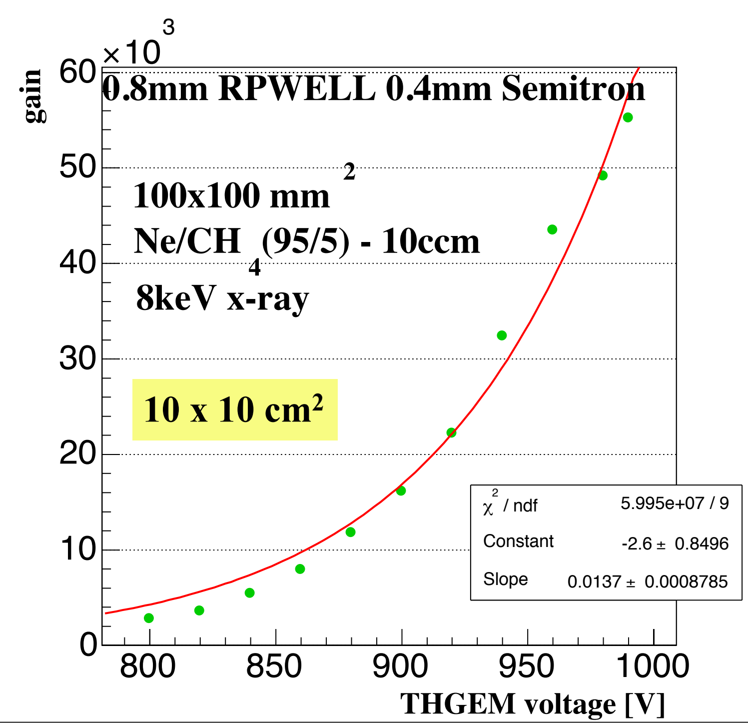
- Lower resistivity

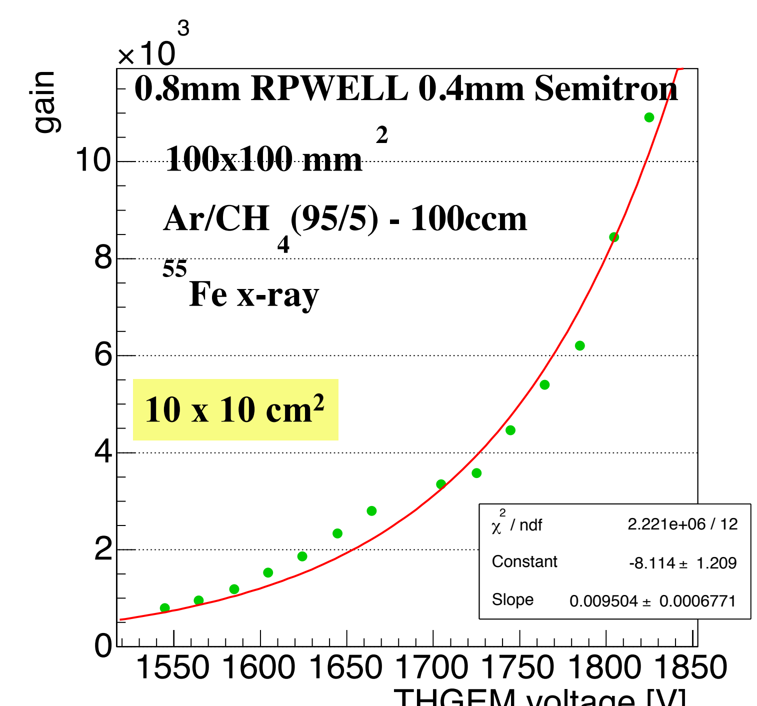


Stable with HIPs

- Observe gain saturation

Decided:
Build 10 x 10 cm² proto. with 0.4 mm Semitron layer
Test in the lab
Test in the beam

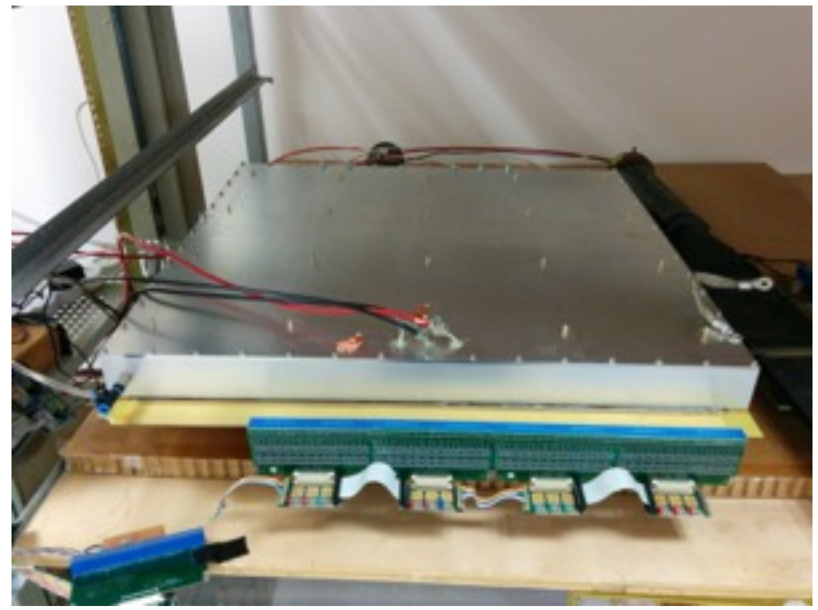




Up-scaling & Industrialization

Up-scaling & Industrialization

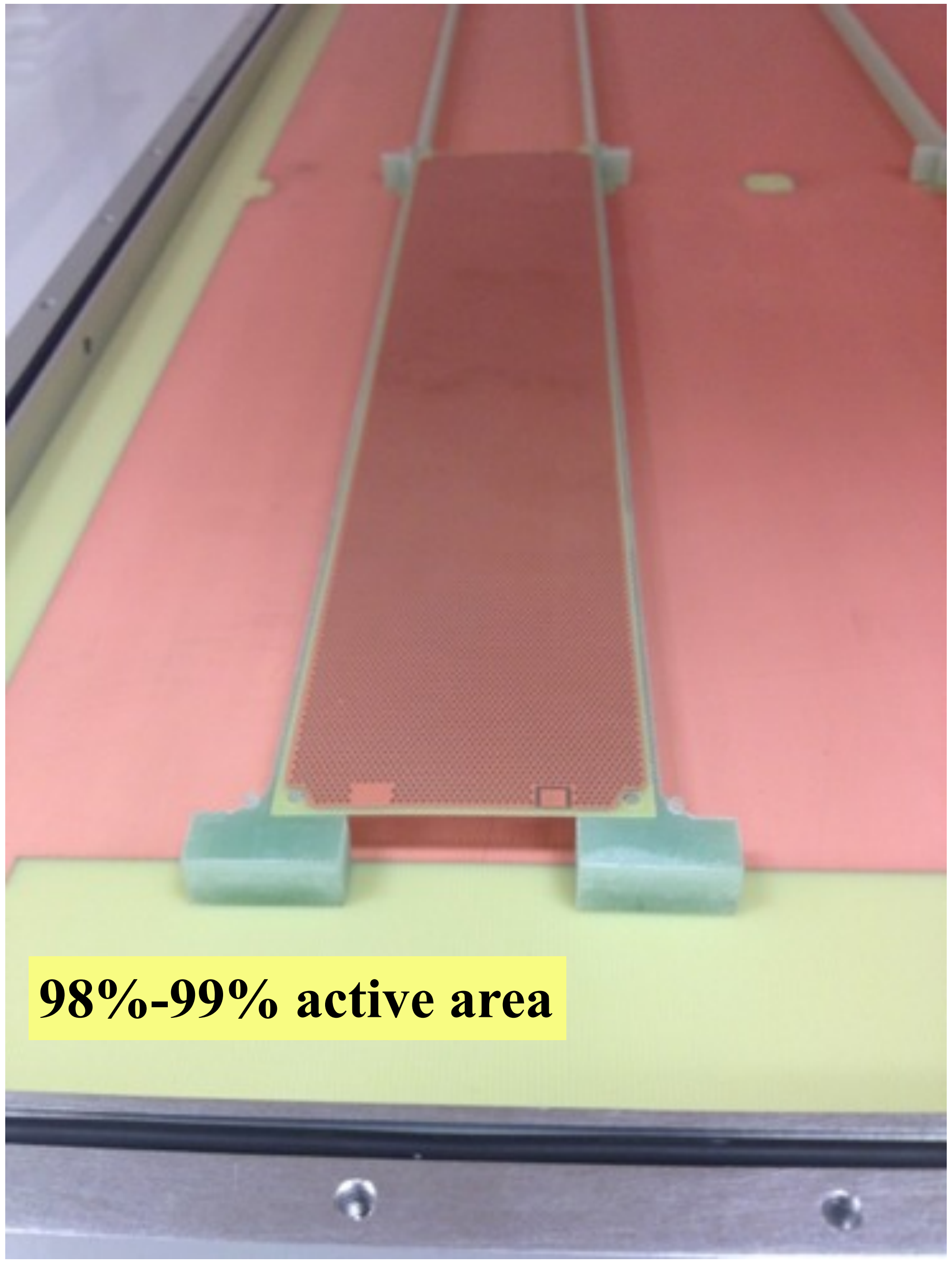
- Starting from the end: prototype 0 is ready



- First 50 x 60 cm^2 detector prototype produced by Lingacom - an Israeli company
  - Including all components
  - Operated in Ar
- Lingacom next step: produce 4-6 such units
- ~1/4 of a single system prototype
- Several hundreds of such systems are expected to be sold ...
- Still a long way to go

Up-scaling & Industrialization

- Looking inside: for now a configuration with induction gap
  - RPWELL is much easier to produce



- The large area is built a a mosaic of small electrode
  - Only good electrodes are selected
    - Based on electrical properties / Thickness uniformity / etc.
  - No post treatment of electrodes is needed (reduce the production cost)
  - Defected electrode can be replaced also at a later stage

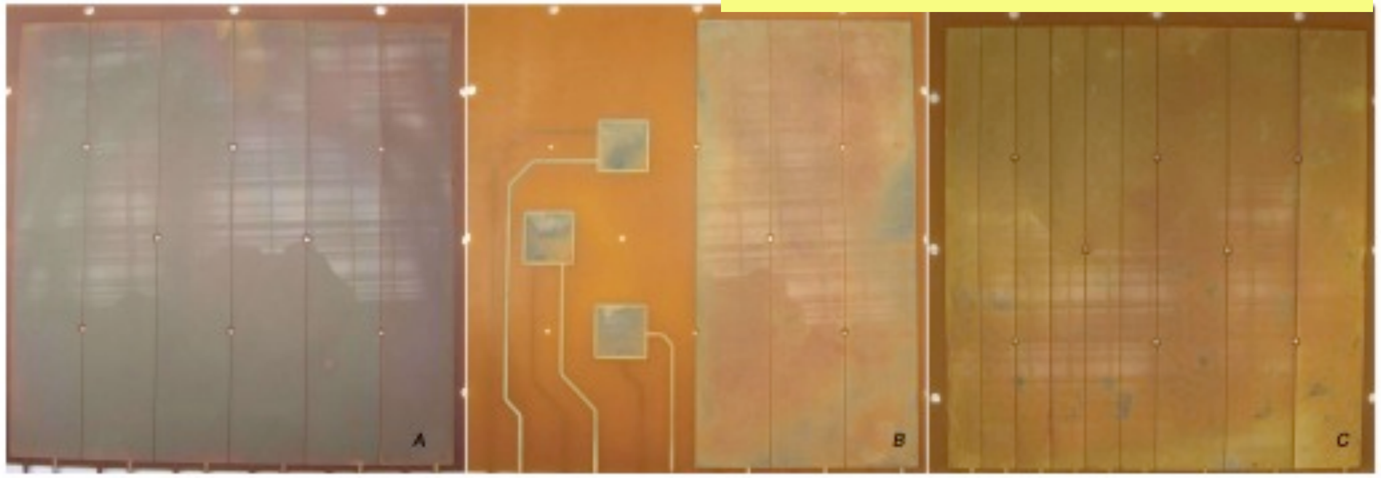
- The electrodes are supported by a 'so-called' snake structures
  - Improves gas circulation along the full volume

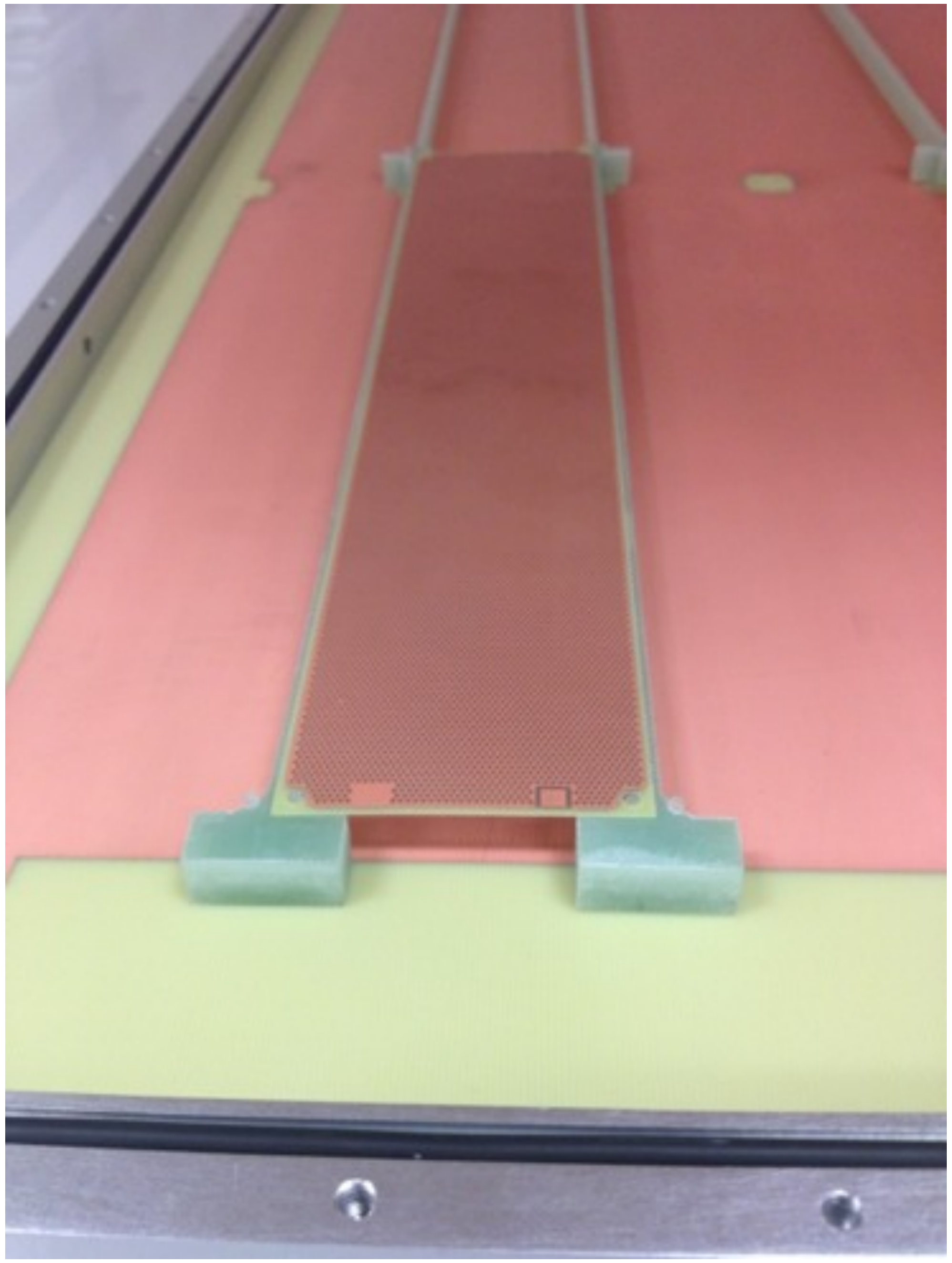
- Power is supplied to each strip
  - Electrodes are connected using small 'jumpers'

Up-scaling & Industrialization

- Many remaining questions

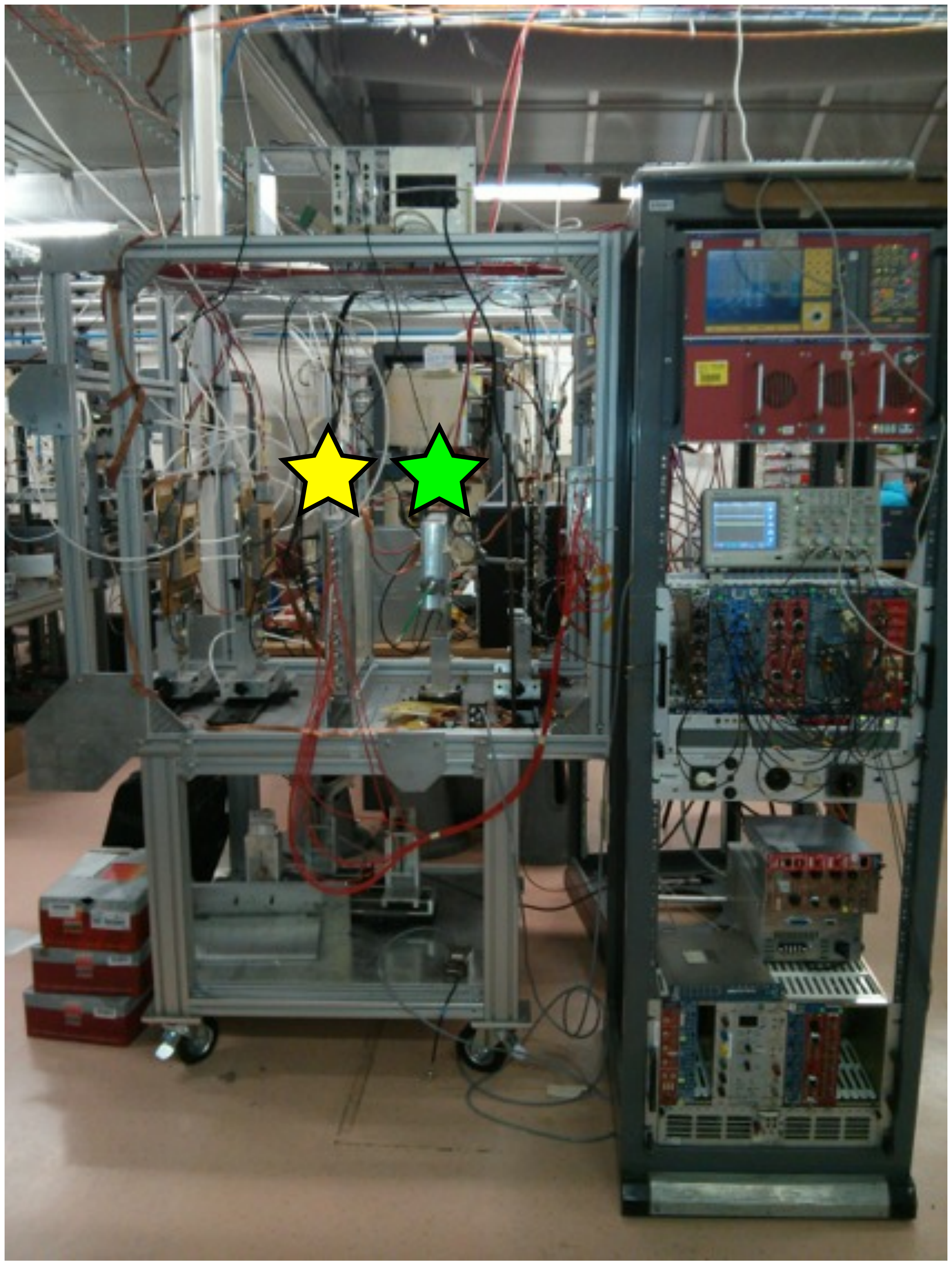
M. Alexeev et. al, JINST 9 C03046 2014





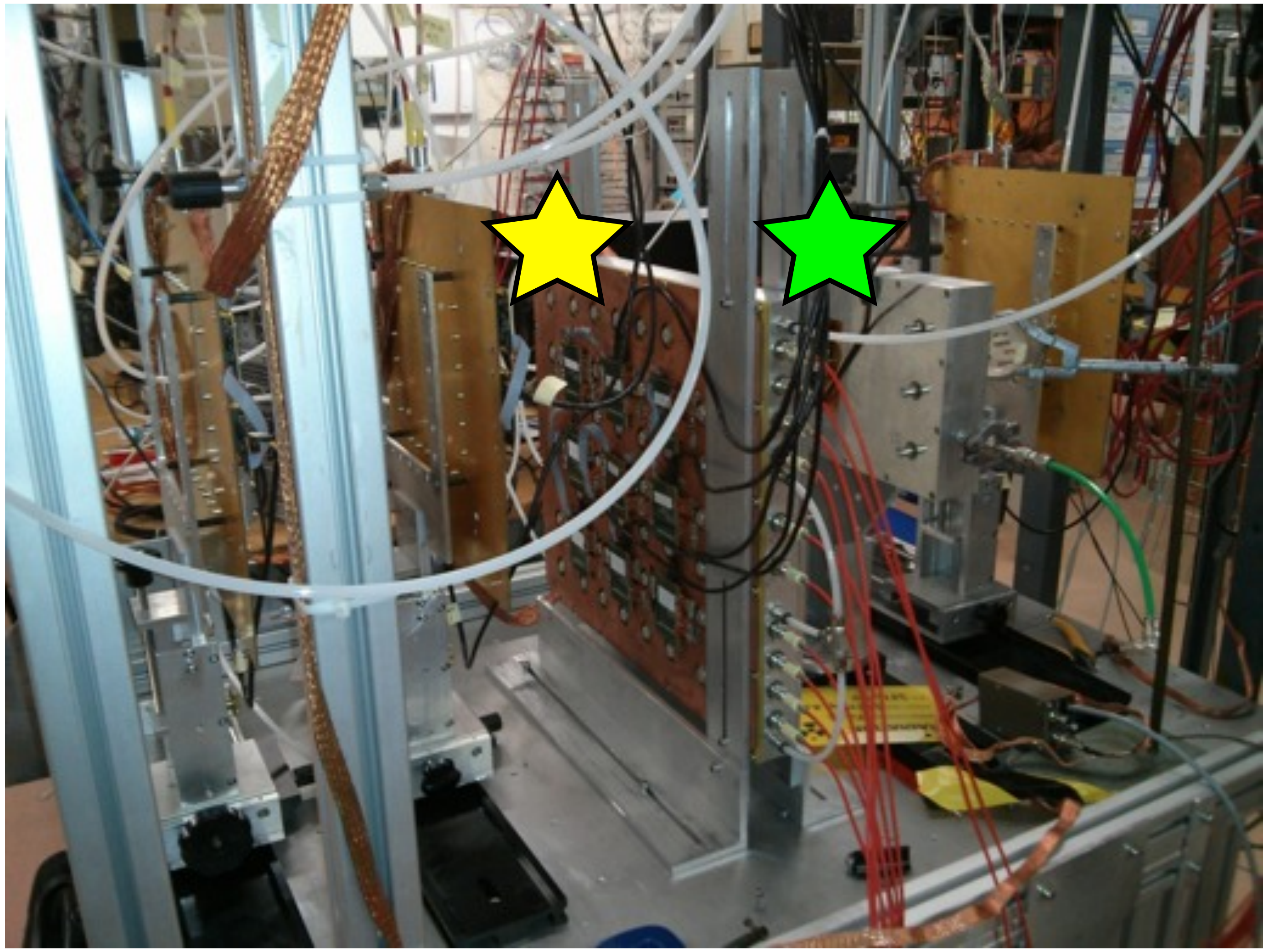
- Trieste have shown that small area electrodes are stable (or at least stabler than large area electrodes)
  - What fraction of electrodes can be used ?
- Performance is not yet estimated
  - Efficiency: need > 99 %
  - Resolution
- Uniformity
- Snake structure is a bit expensive to produce

Tests in the beam - happening now

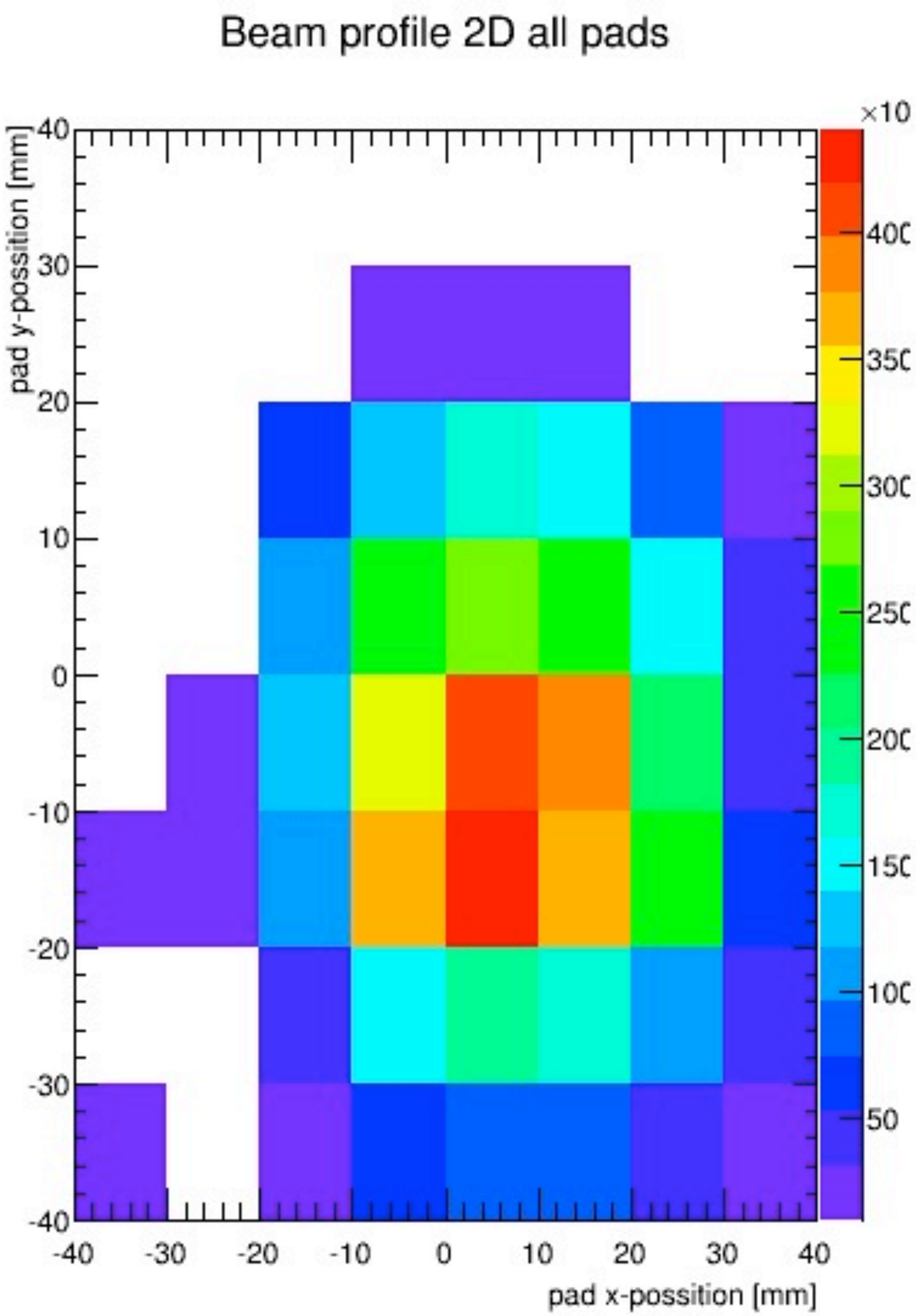


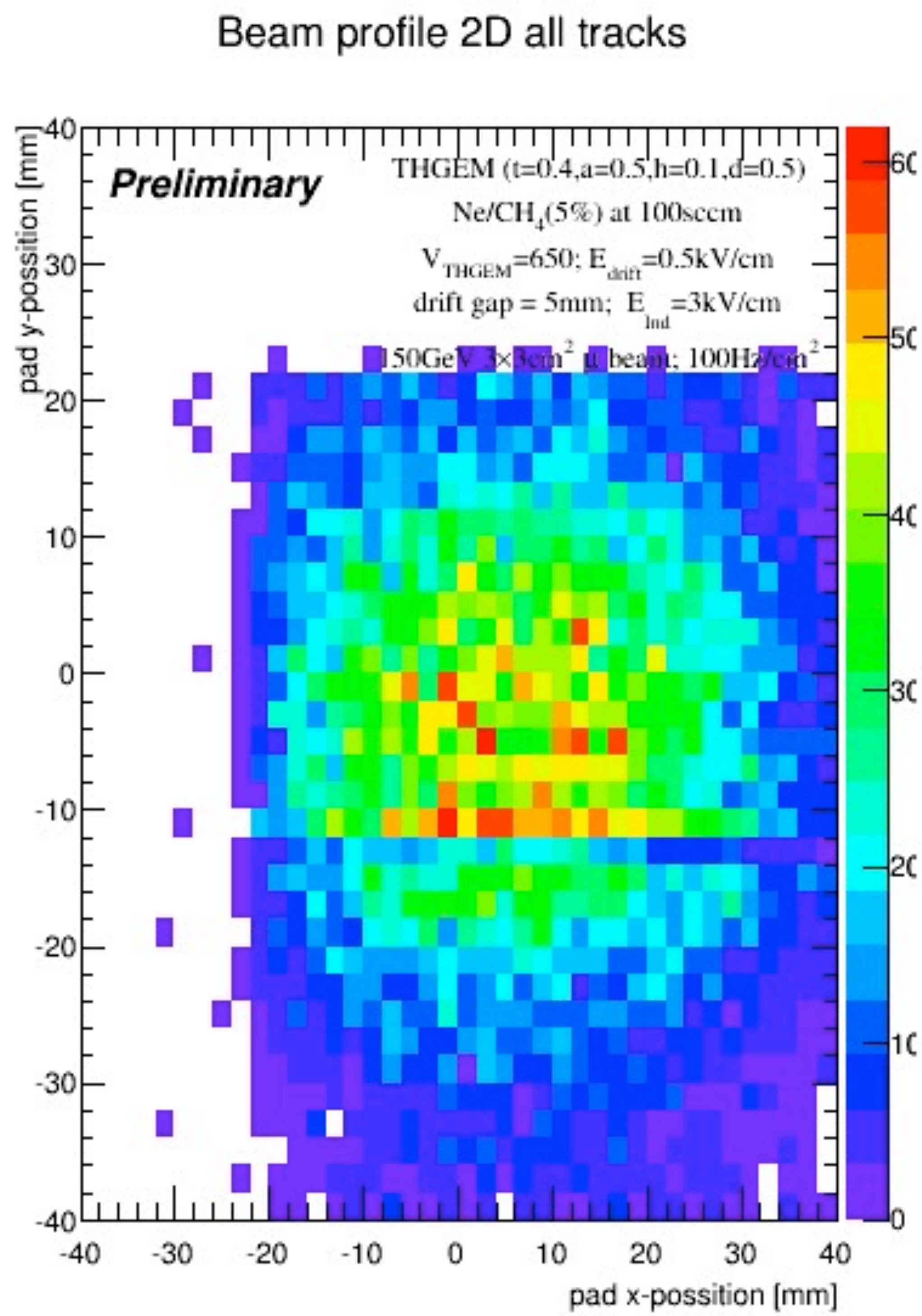
2 detectors setup + telescope installed in SPS/H4 beam area:

- 30 x 30 cm^2 configuration with induction gap
- 10 x 10 cm^2 RPWELL 0.4 mm Semitron layer

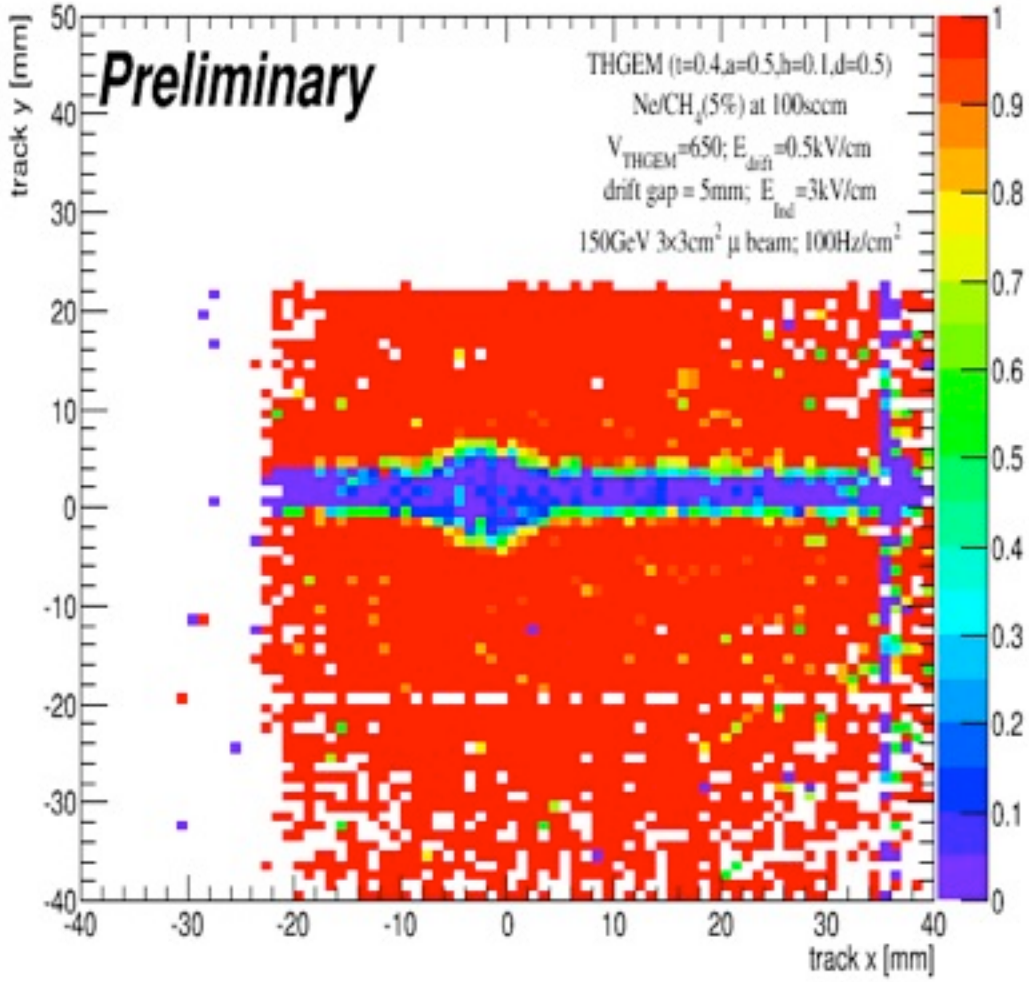


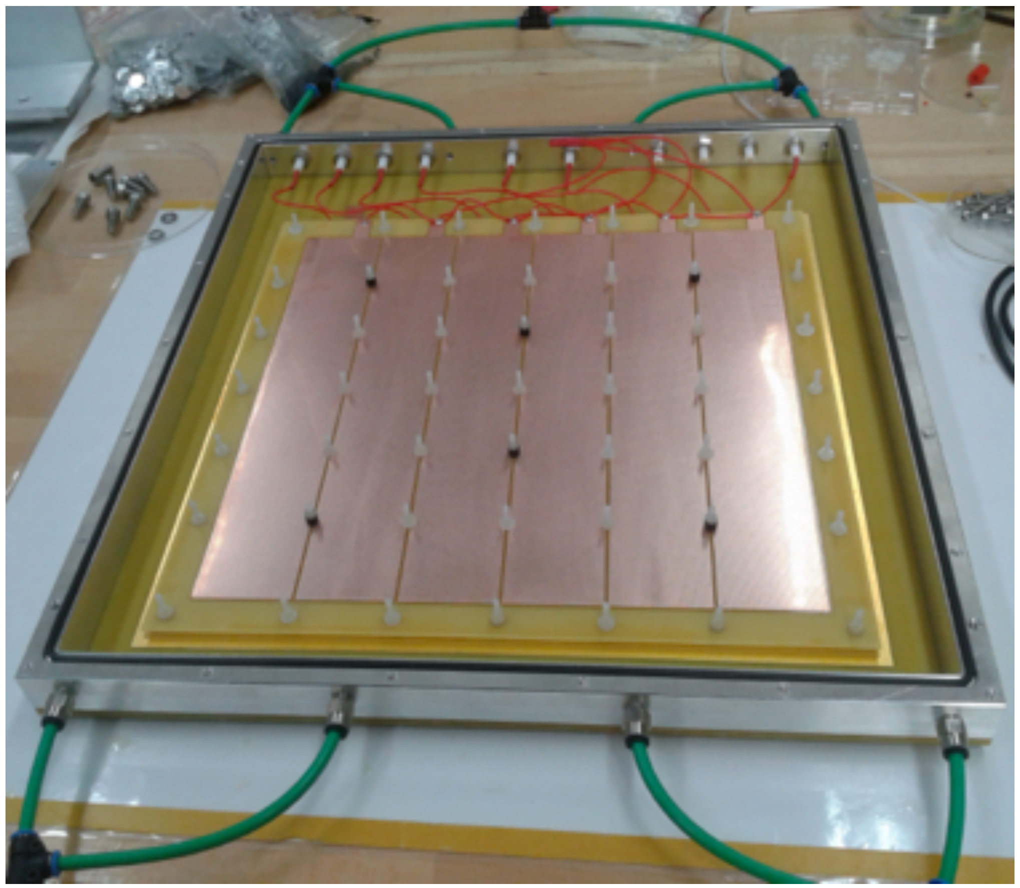
Test Beam results - 30 x 30 cm^2 + induction





Test Beam results - 30 x 30 cm^2 + induction



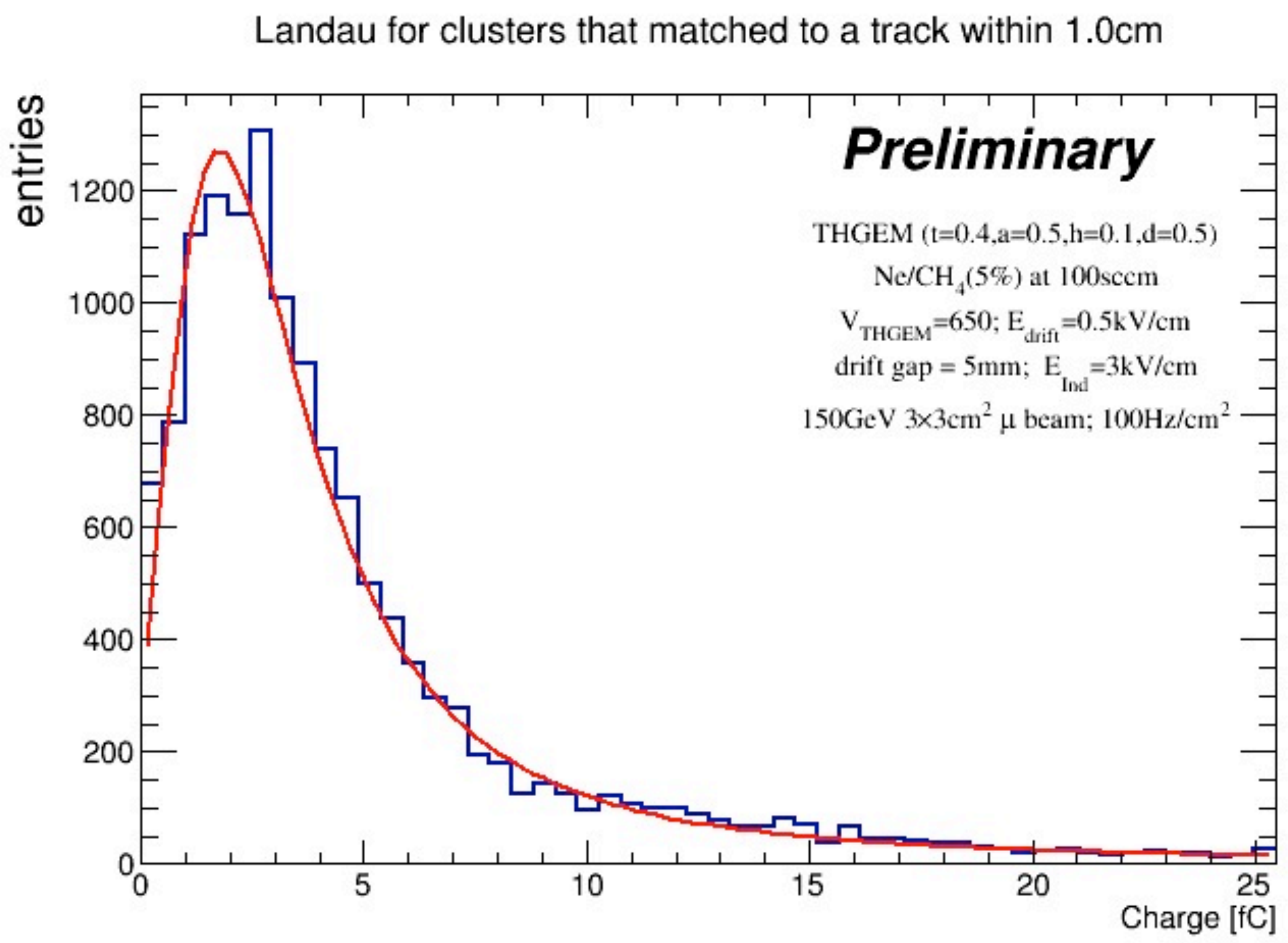


Efficiency > 95% over all of the active area
Inactive area (due to support structure) are easily identified

Test Beam results - 30 x 30 cm^2 + induction

Discharge analysis is on going

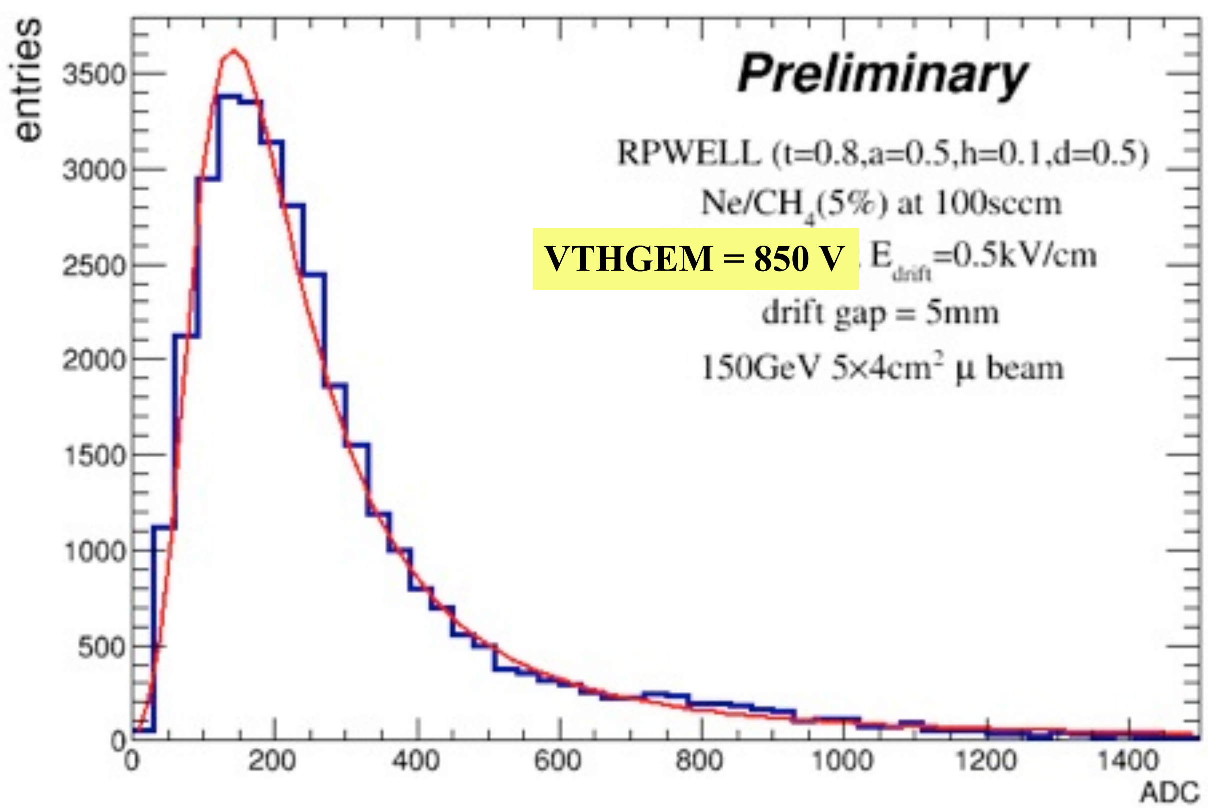
Comparing number of HIP events (PE>12000) to number of discharges

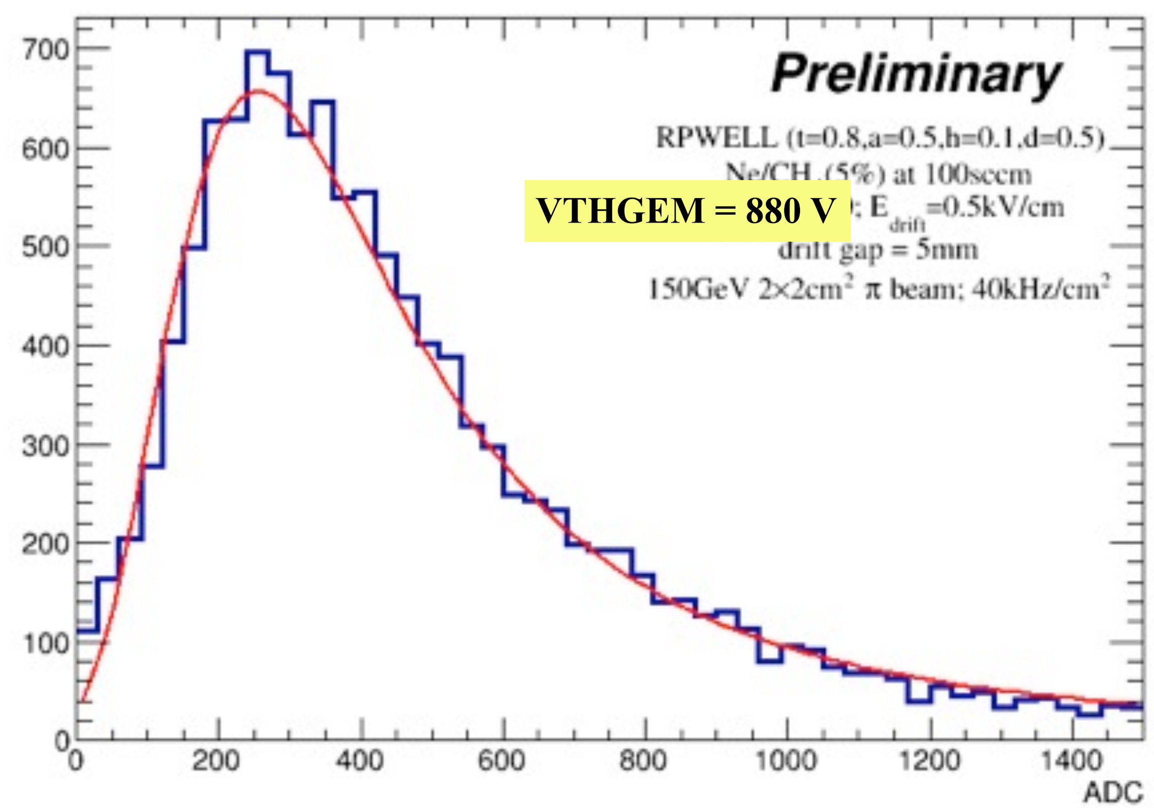


Test Beam results - 10 x 10 cm² RPWELL

Clear Landau distribution

Excellent signal to noise separation in low and high rate beams

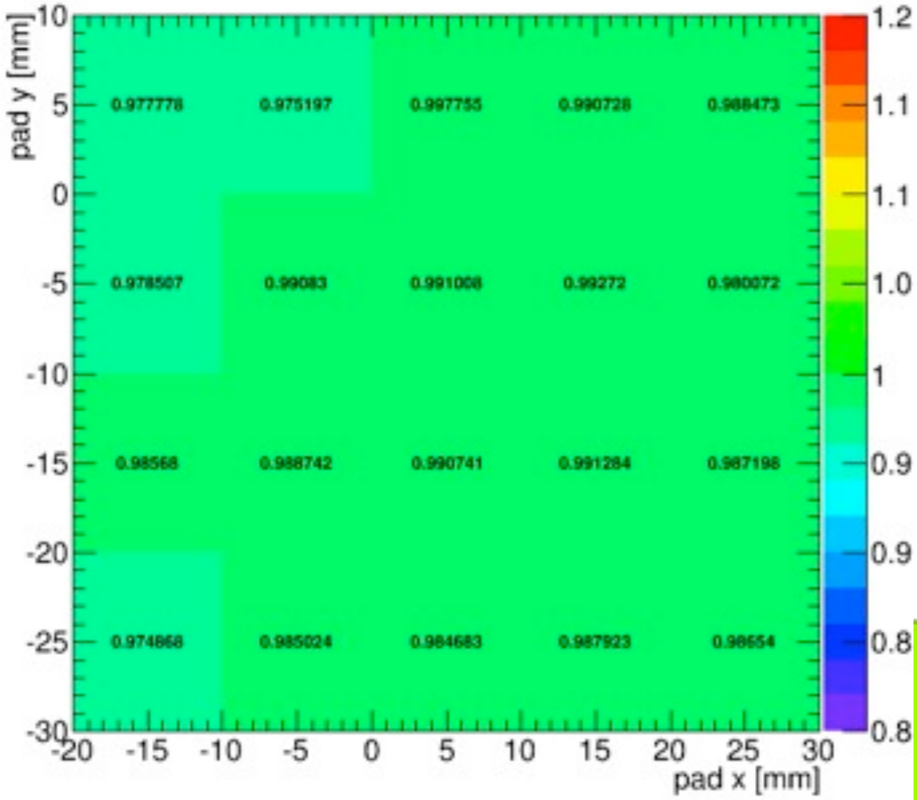


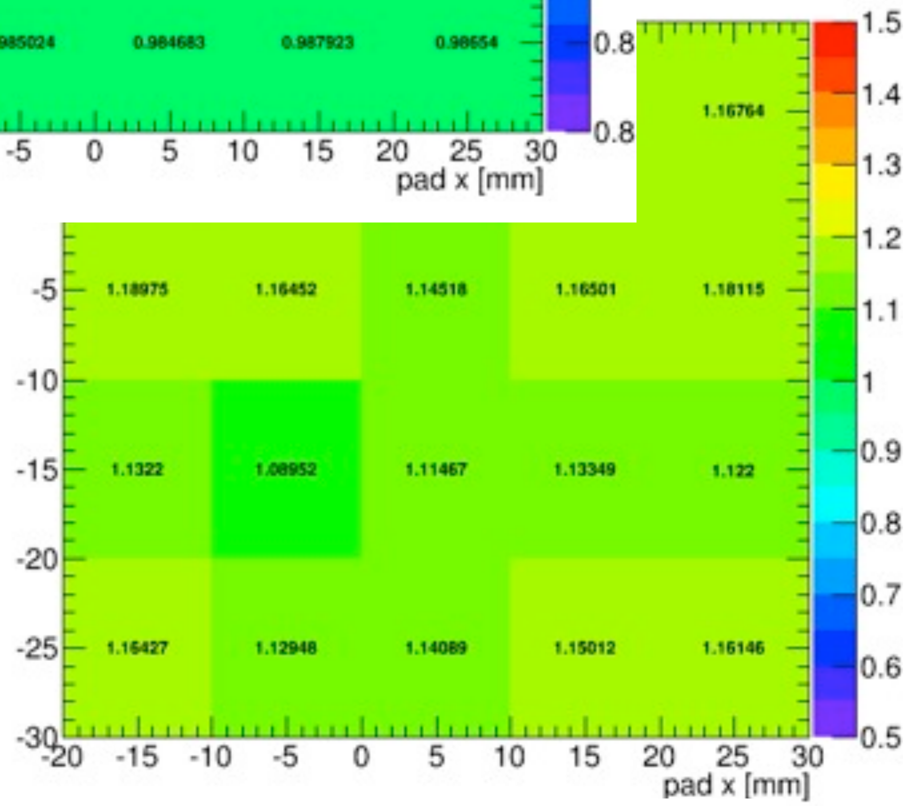


200 ADC counts ~ Q = 4 fC ~ Effective gain = 3000

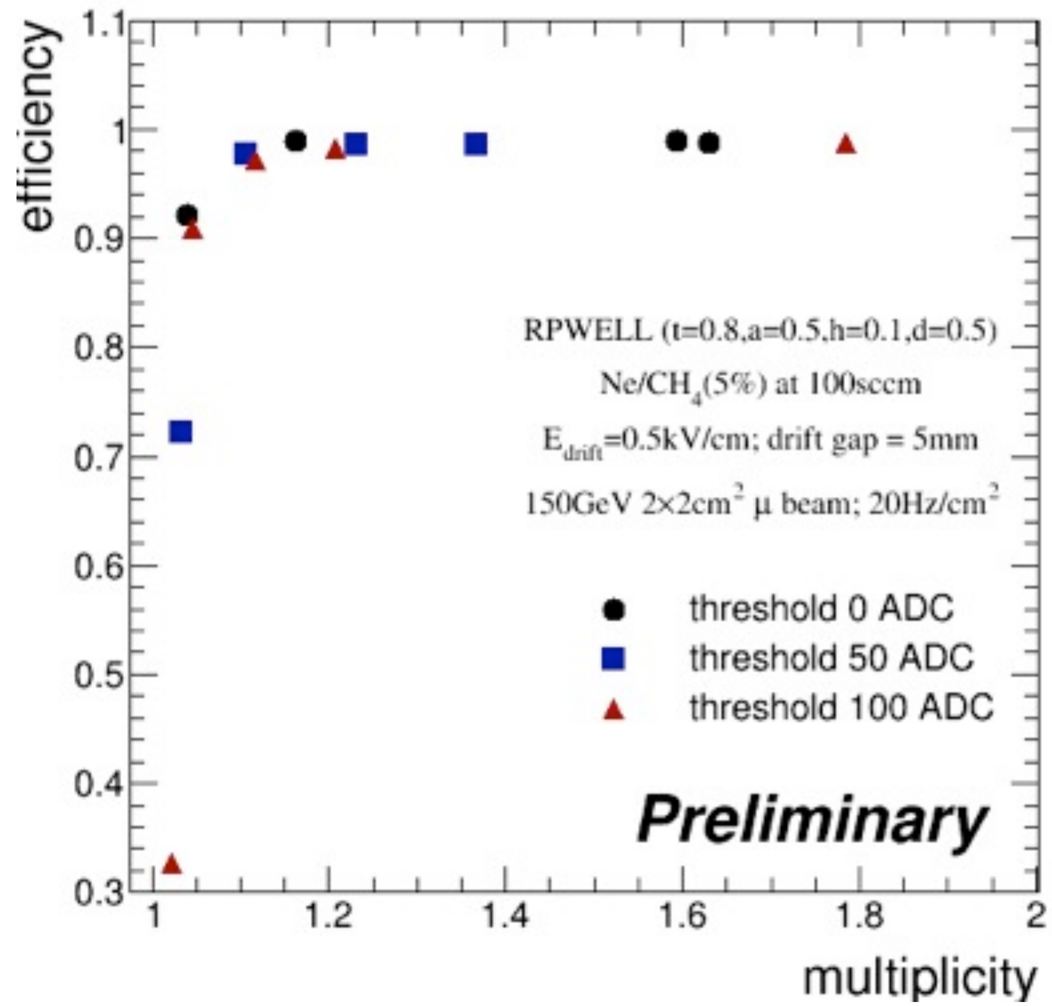
Test Beam results - 10 x 10 cm^2 RPWELL

Pad efficiency





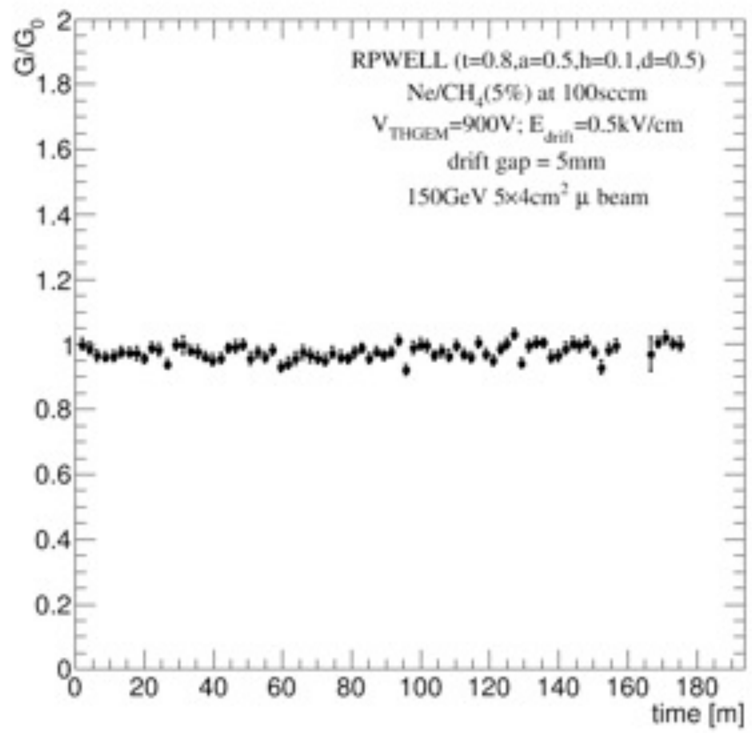
Average pad multiplicity

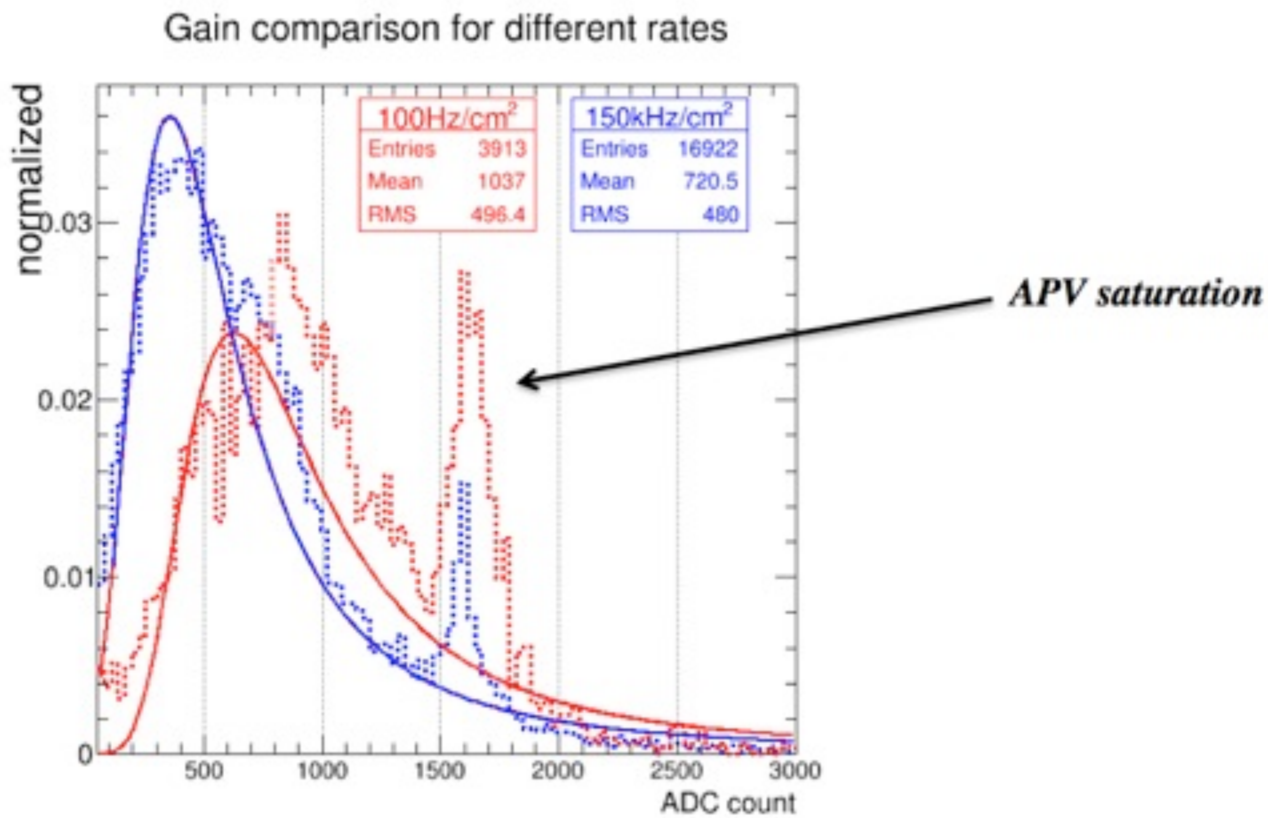


High efficiency (>98%) at reasonably low multiplicity (1.1) - **preliminary!**

Uniform response

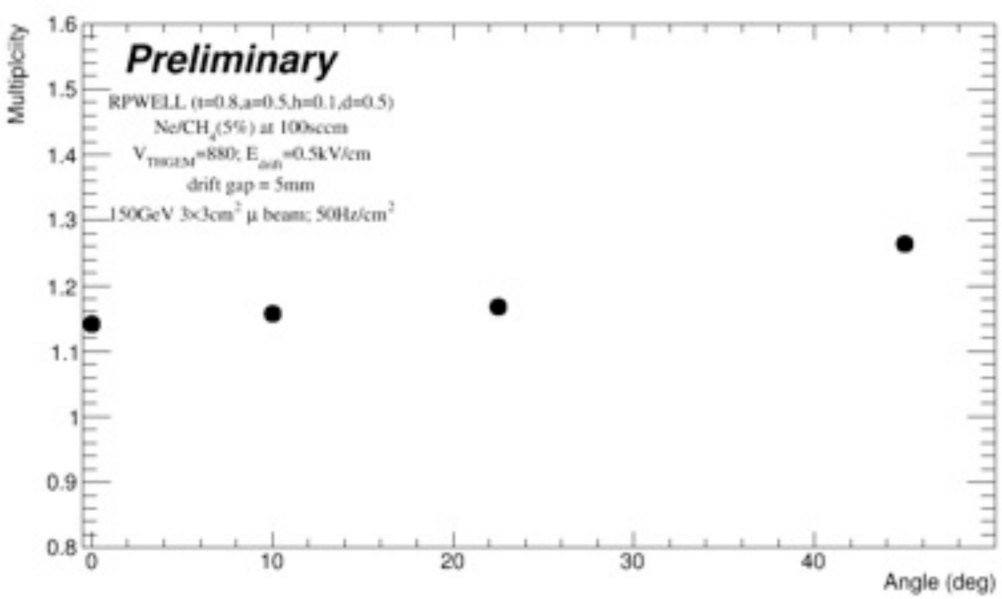
Test Beam results - 10 x 10 cm^2 RPWELL





10% variation in gain over time - **preliminary!**
Gain drop of order 30-40% over 4 orders of magnitude of rate - **preliminary!**

~10% increase in multiplicity for particle incoming angle of 45 degrees - **preliminary!**



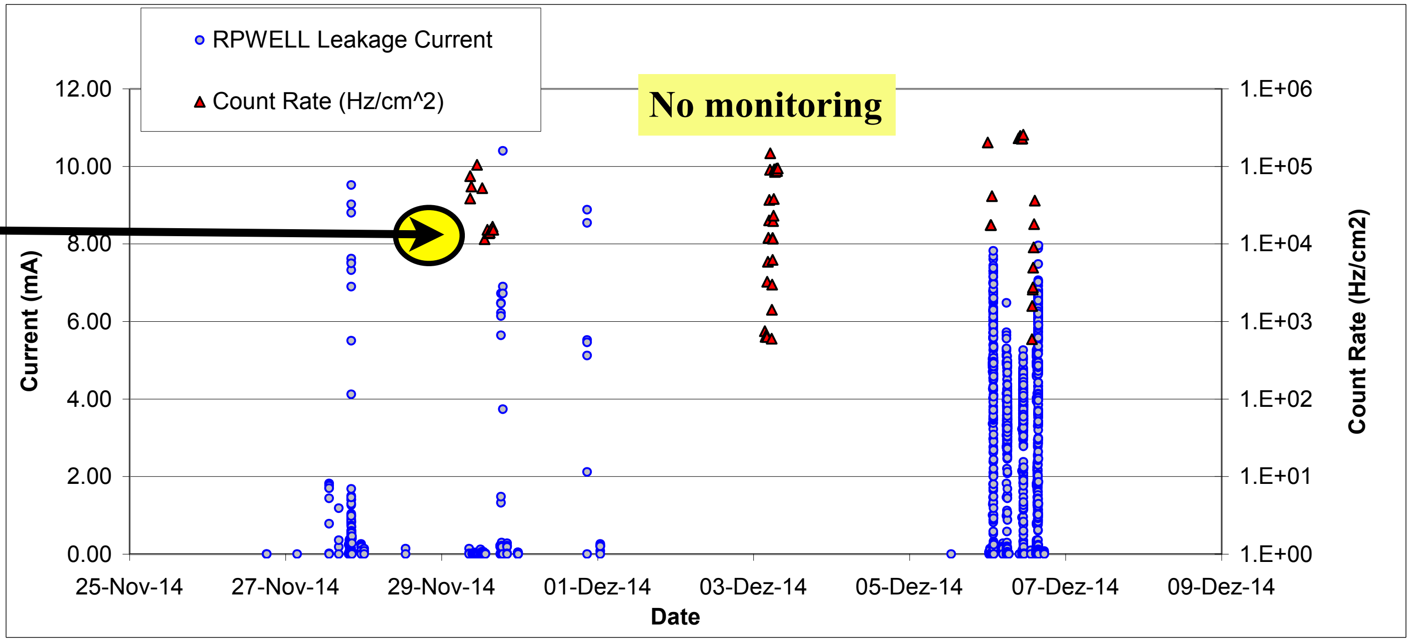
Test Beam results - 10 x 10 cm^2 RPWELL

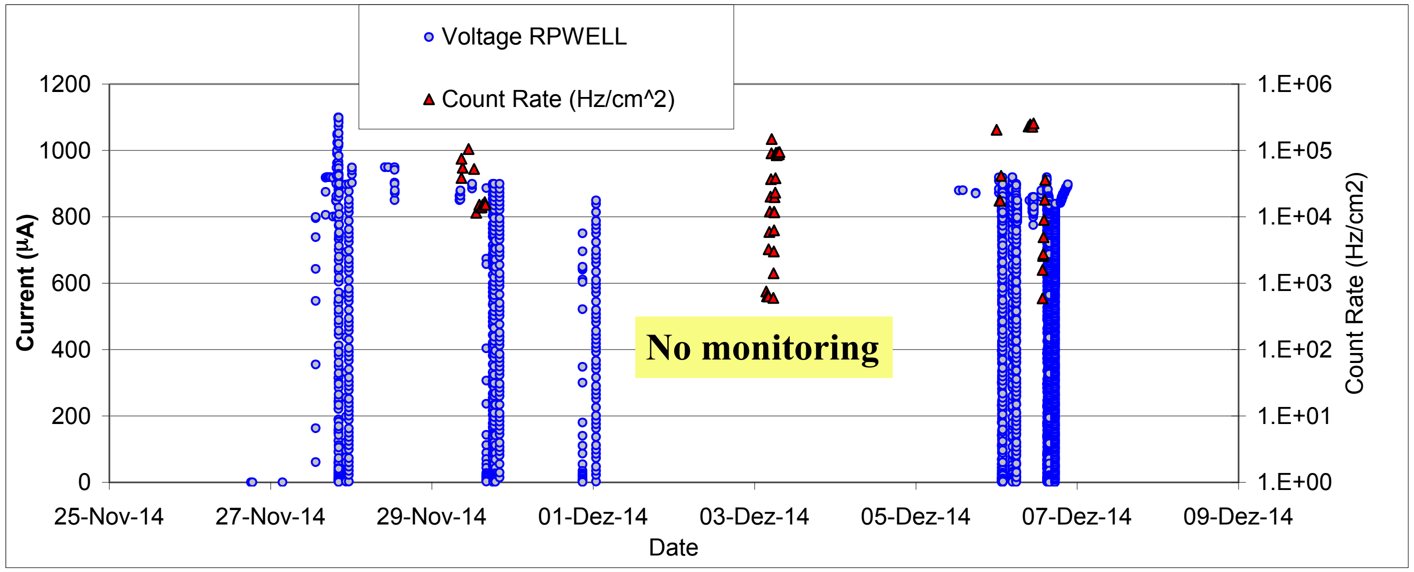
Discharge free*!! Discharge prob < 10^{-10} (first approximation - **Preliminary**)

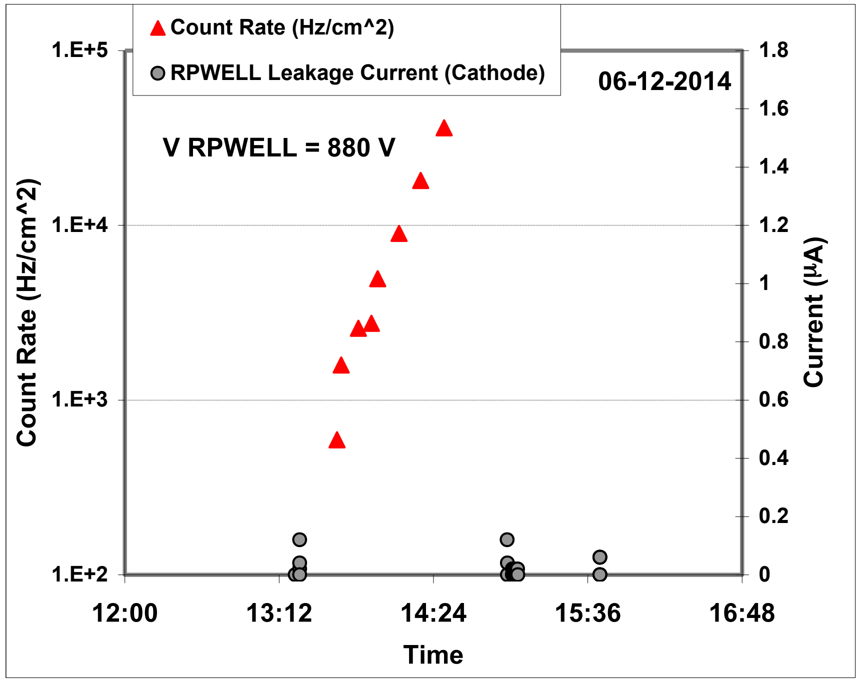
Long Pi run. No current activity

Trips - long term high current - occur rarely

- At very high rates and high gains (at the same time)
- Recovery takes time
- Cause has to be understood







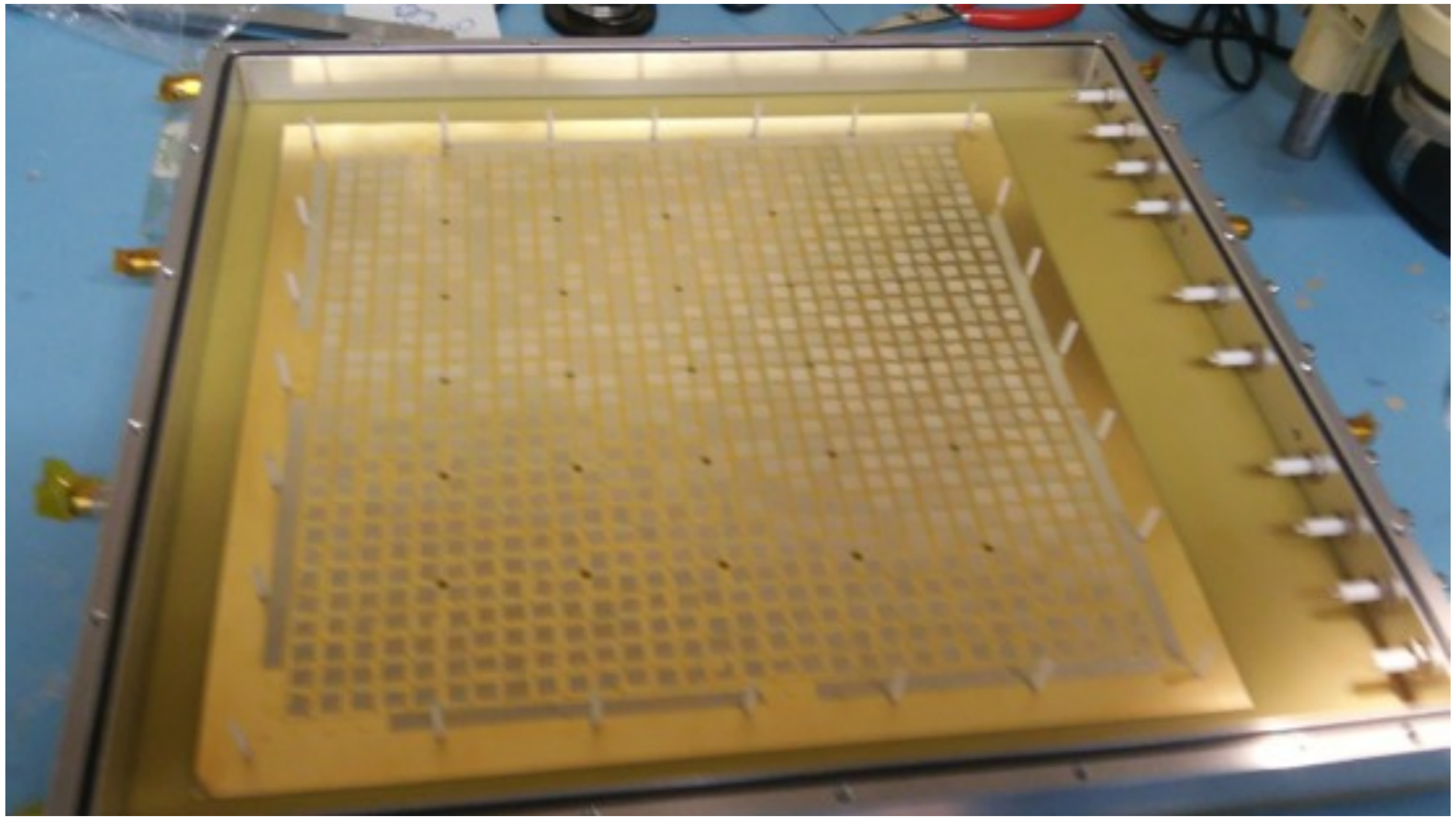
Analysis is on going

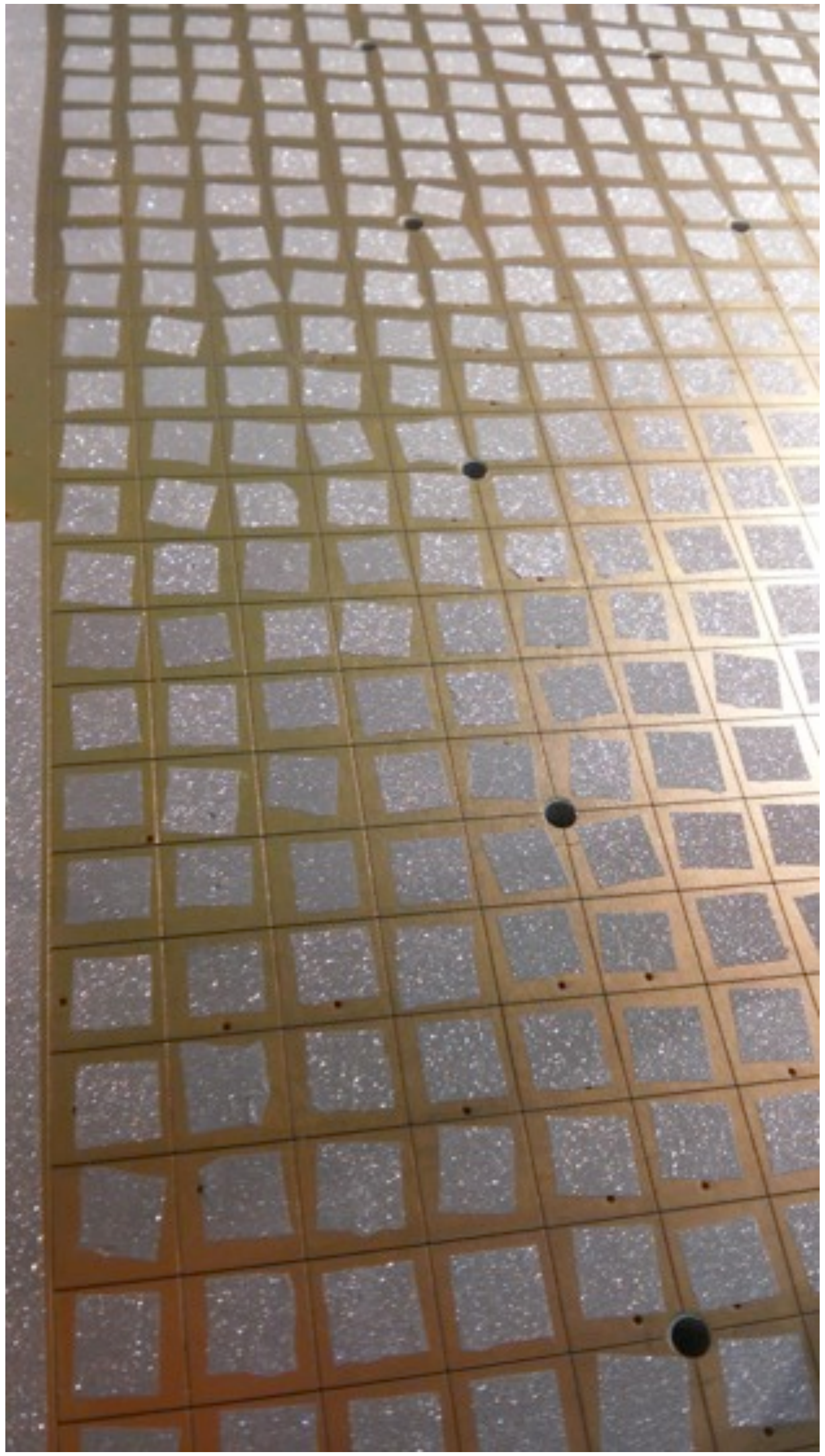
Test Beam: The remaining days

Two RPWELL 0.4 mm Semitron configurations:

- 10 x 10 cm^2 - 0.8 mm electrode; 3 mm drift
  - Operation in Ne/CH4 and maybe also Ar/Co2
- 30 x 30 cm2 - 0.4 mm electrode; 5 mm drift
  - Electrode of bad quality (not intentionally)

30 x 30 cm^2





Summary

- Single-stage THGEM based structure are suitable for applications that require *low cost* large area detection at moderate spatial resolution

- The most recent RPWELL is very promising
  - Discharge free at high gains
  - Excellent S/B separation
  - Moderate rate dependence
- Trips have to be understood

- Up scaling & Industrialization are in progress
- We are now producing our own “mosaic” detector
  - Can support an RPWELL
  - Can couple of ILC dedicated electronics

We are in the right way towards discharge-free single-stage THGEM detector

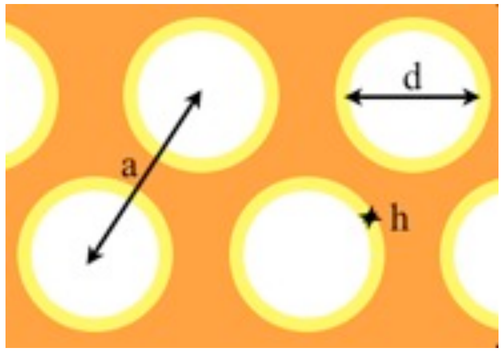
But we also still have a lot to understand

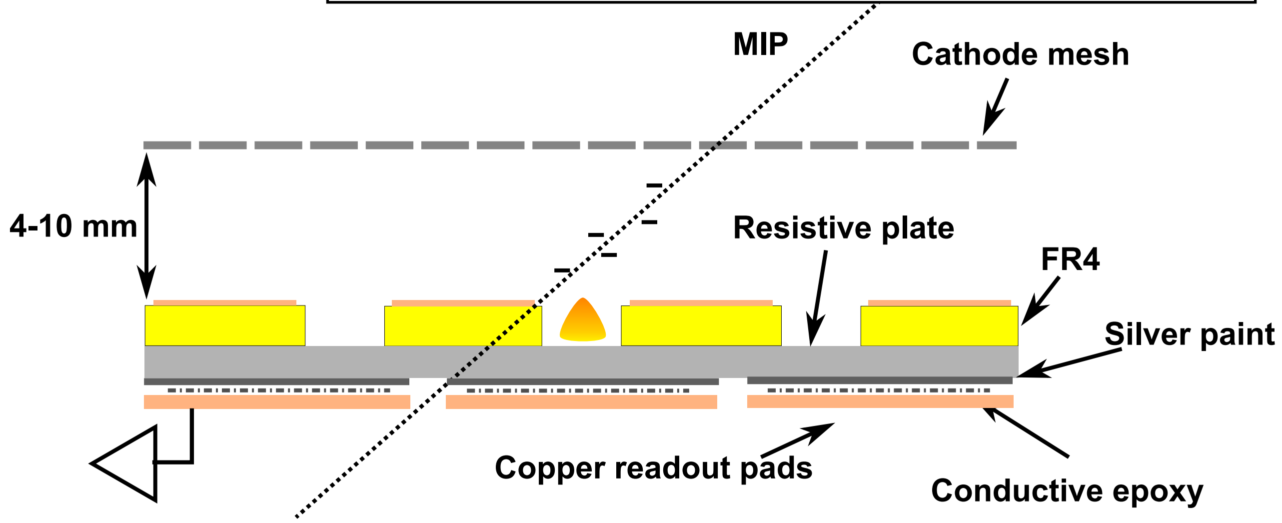
The THick-GEM - New PR slide ?

R. Chechik et al, NIM A535 (2004) 303
A. Breskin et al, NIM A623 (2010) 132

10 folds larger than GEM → **Robust**

- thickness t ≃ 0.4 - 3 mm
- a ≃ 0.5 - 1 mm
- d ≃ 0.2 - 0.5 mm
- h ≃ 0 - 0.1 mm





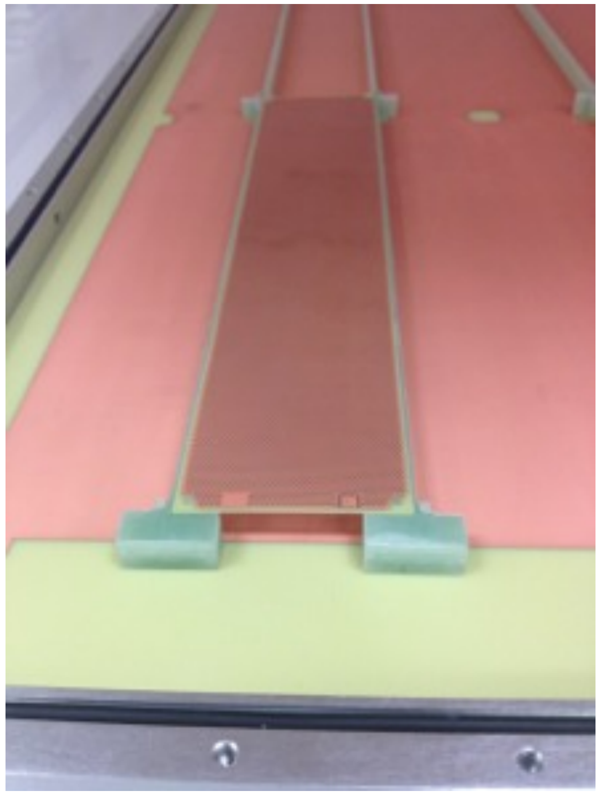
A. Rubin et. al, JINST 8 P11004 2013

Simple

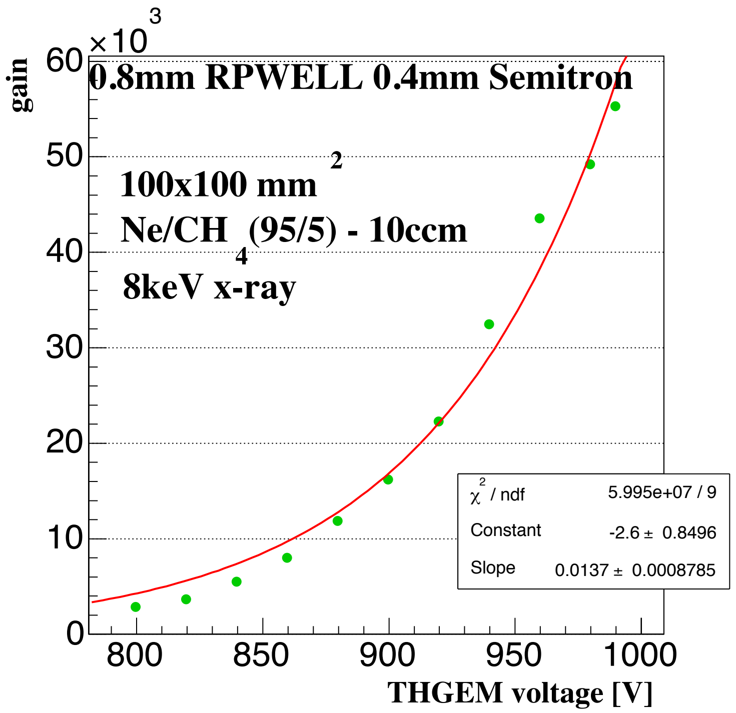
- Does not require sophisticated mechanical support (self supporting)
- Easy to operate

Production

- **Industrially produced** in PCB technologies
  - Italy, Israel, China, ...
- **Large scale**
- **Economic**



High gas gain



Backup