micro-TPC Fast Neutron Detectors
(for Commissioning Detector)

Sven Vahsen & Igal Jaegle

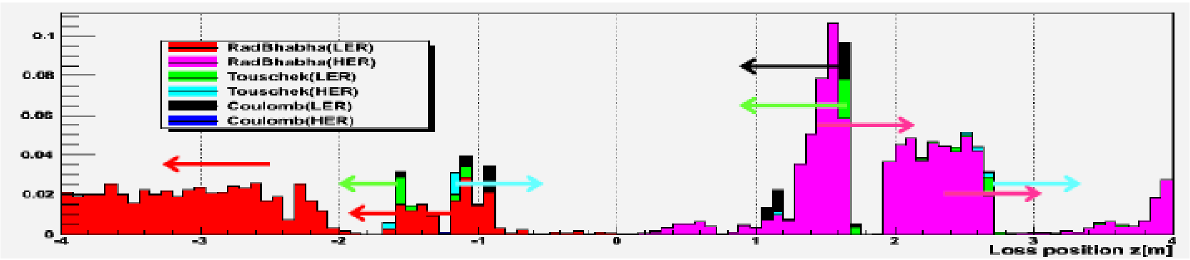
Outline

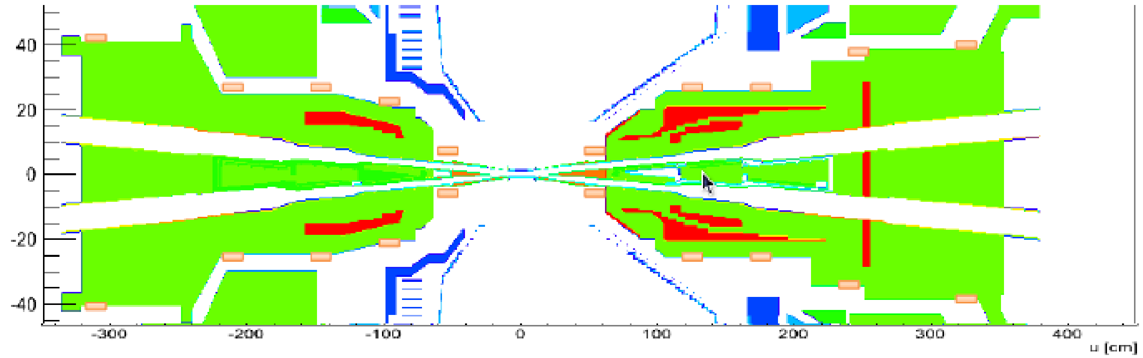
- Motivation / Objective
- Detector Principle of Operation
- Performance Requirement & KPPs
- Pre-Prototypes & their performance
- Final prototype specifications
- Schedule
- Conclusion

Motivation for TPCs

- Neutron Backgrounds
  - Caused problems already for Belle and Babar
  - Difficult both to predict & measure accurately
  - Will be critical for Belle-II operation and lifetime
    - KLM deadtime, ECL electronics lifetime, iTOP photocathode lifetime
- Idea: neutrons produced at specific loss-positions along the beam-line. Fast neutrons preserve directional information and can be directionally reconstructed. Use them to "image" loss spots.
- Directional detection motivation
  1. Can isolate component coming directly from beam lines (rather than re-scattered)
  2. Can measure neutron flux versus polar angle (beam line position) → validate/tune simulation

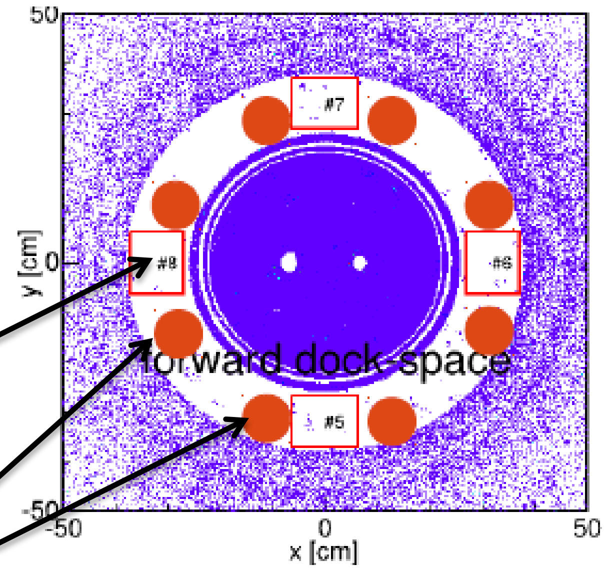
(Secondary motivation: TPCs could be used to monitor flux of MIPs / total ionizing dose as well)

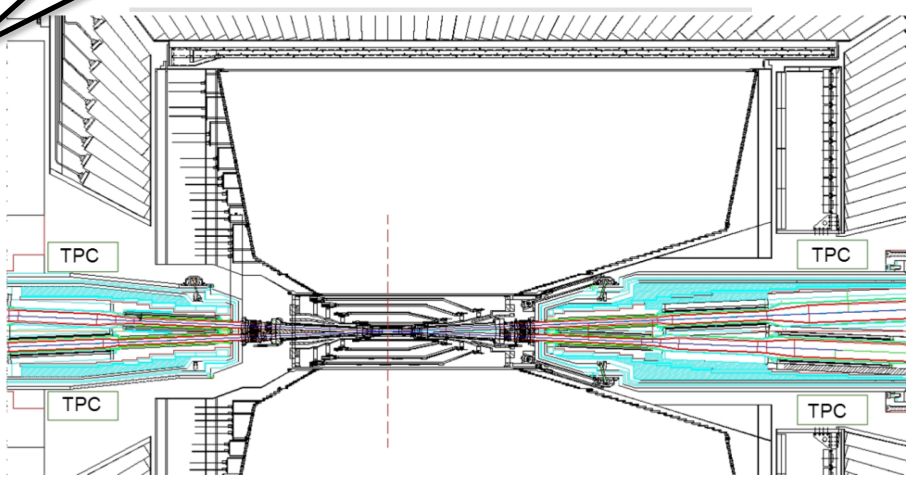




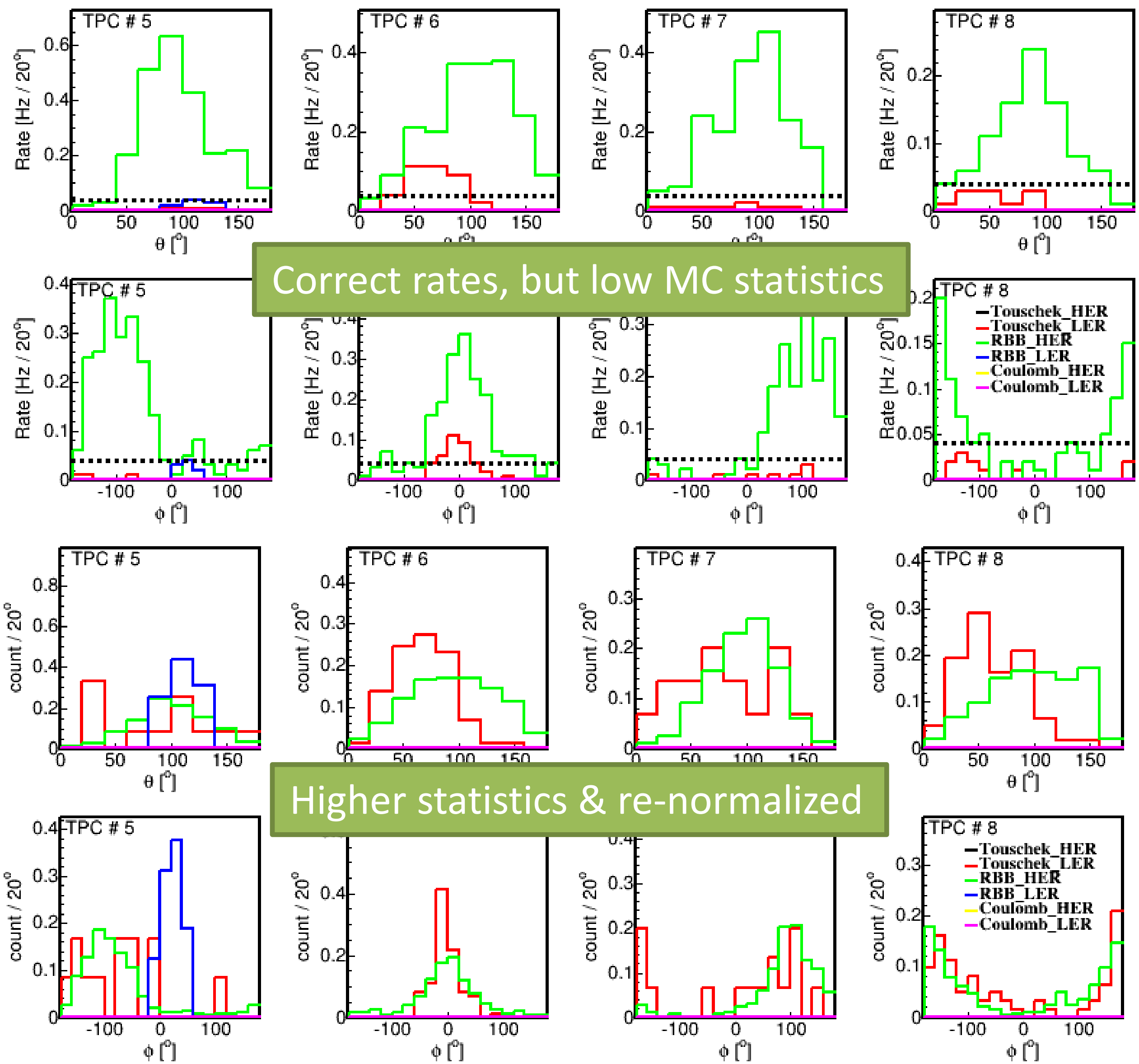
How TPCs will be used

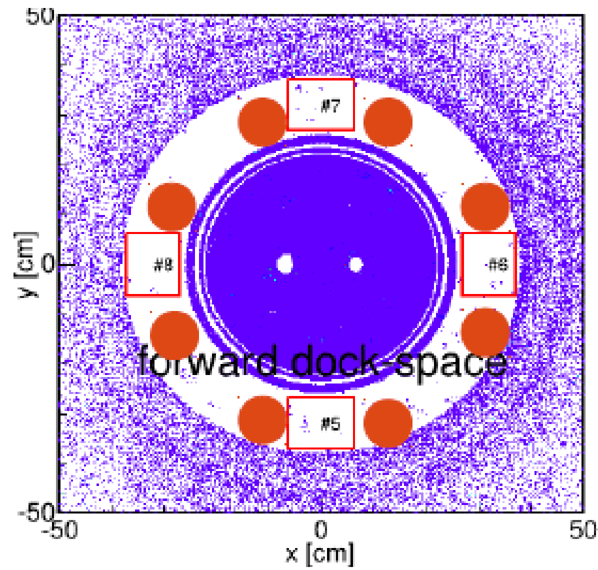
- Commissioning phase II: He-3 tubes and micro-TPCs in dock space
  - TPCs image direction of incoming fast neutrons, but detected rate is low
  - He-3 tubes measure rate of thermal neutrons, which is high





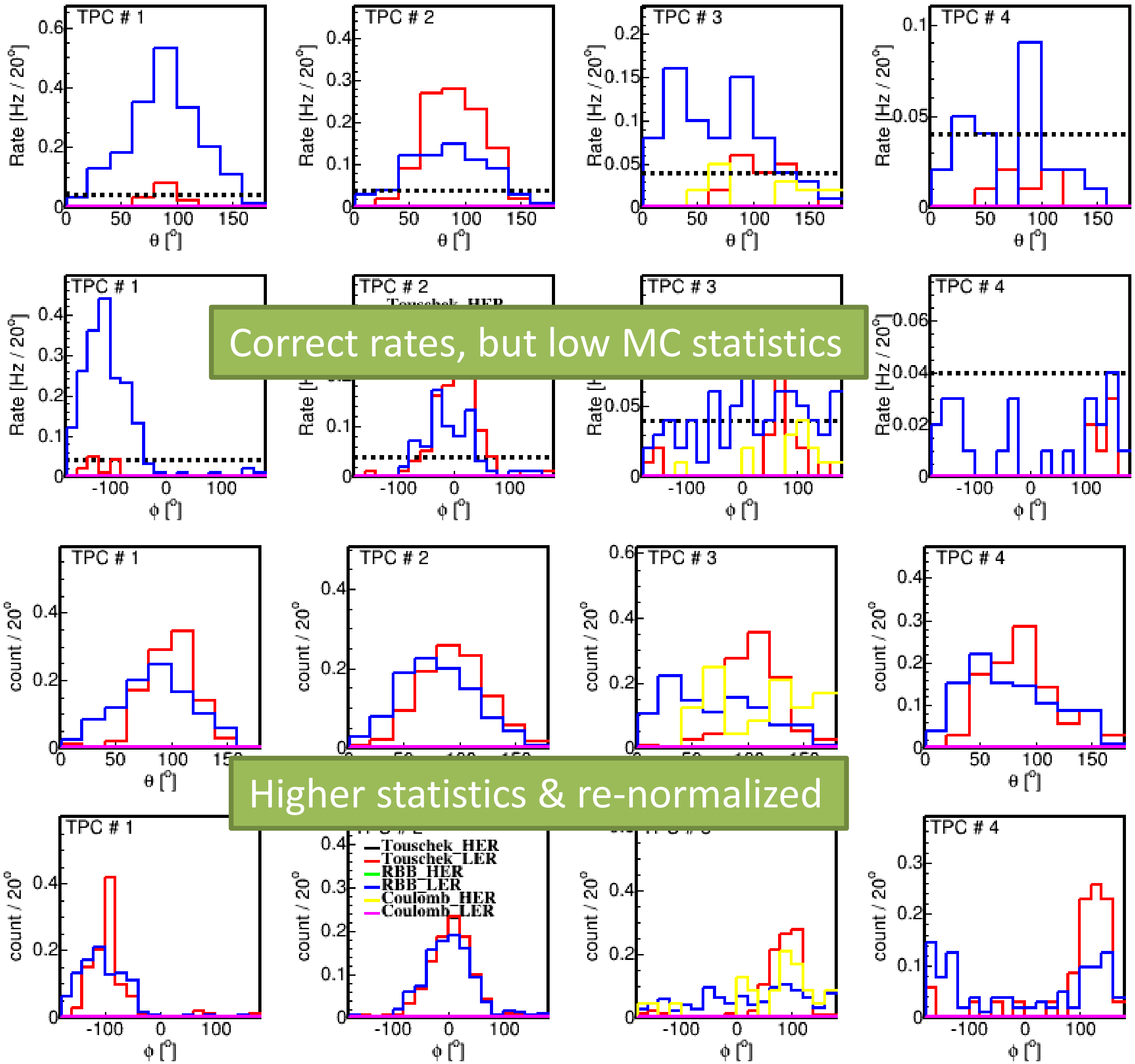
Recoil angle distribution in Forward TPCs





- nominal beams: RBB LER dominates
  → measure
- Run single beams
  - no RBB
  - measure Touchek
  - vacuum bump
    → measure Coulomb

Backward TPCs



Correct rates, but low MC statistics

Higher statistics & re-normalized

- nominal beams: RBB HER dominates
  → measure
- Run single beams
  - no RBB
  - measure Touchek
  - vacuum bump
    → measure Coulomb

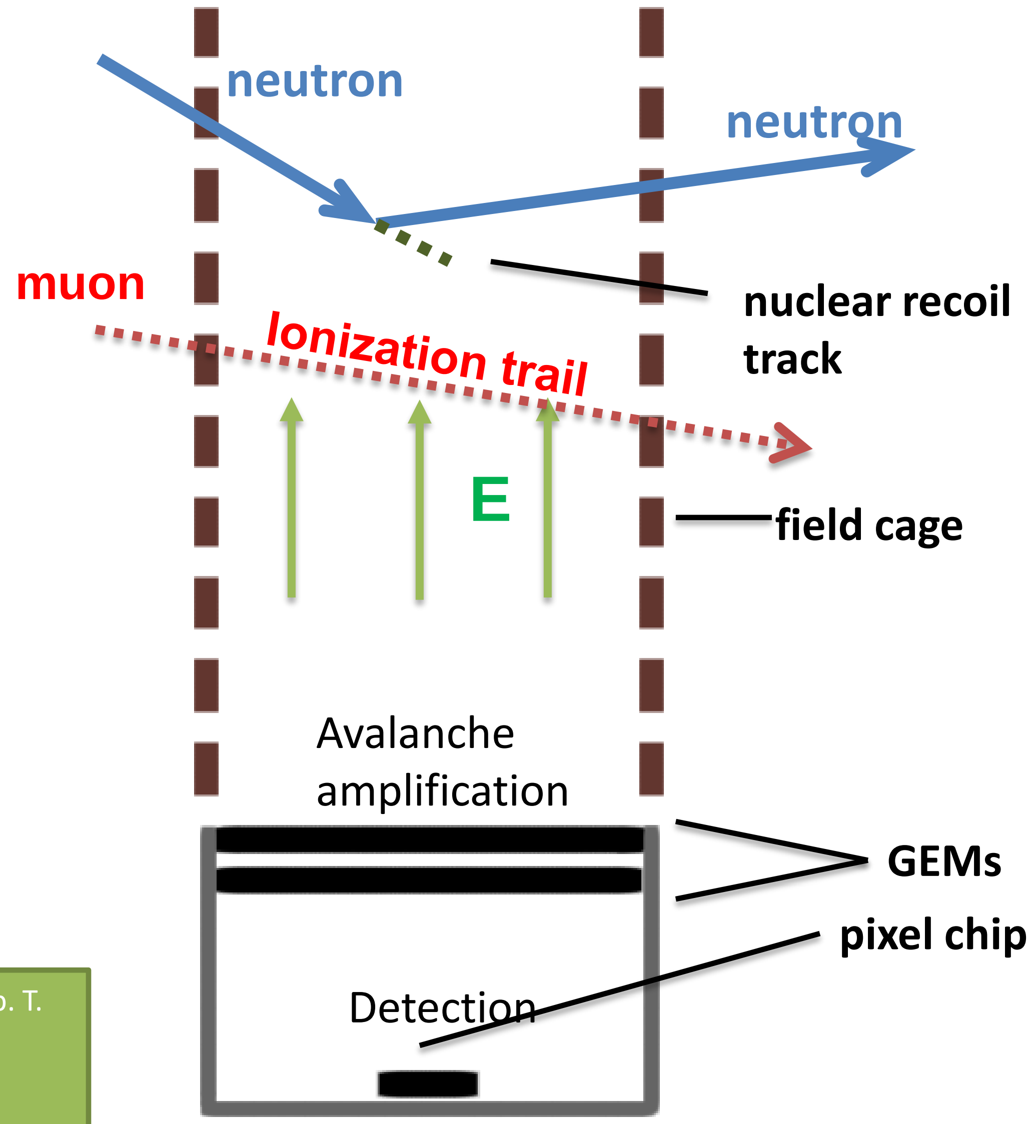
Performance Requirements

- Identification of fast neutrons & measurement of recoil direction (resolution $\leq 15^{\circ}$)
- 8 micro-TPCs: forward, backward, phi dependence
- Rigid, non-magnetic mechanical support with position accuracy ≤ 1 cm
- Position w.r.t. magnetic field axis < ~1 degree

Detector Principle of Operation

- Detect neutrons via **elastic** scattering in gas target, resulting in short (mm) nuclear recoils.
- **Reconstruct both energy and 3D-trajectory** of individual recoils by leveraging fast (40Mhz) and spatially precise (<100 µm) Pixel Electronics and GEMs

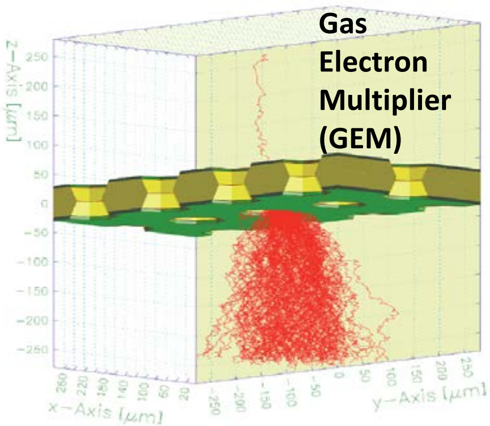
- Benefits
  - Directional sensitivity
  - Can ID recoiling particle
  - Easy to change target nucleus
- Drawback
  - low efficiency



Readout of TPC tracking chambers with GEMs and pixel chip. T. Kim, M. Freytsis, J. Button-Shafer, J. Kadyk, S.E. Vahsen, W.A. Wenzel (LBL, Berkeley), Nucl. Instr. and Meth. A 589 (2008) 173-184.

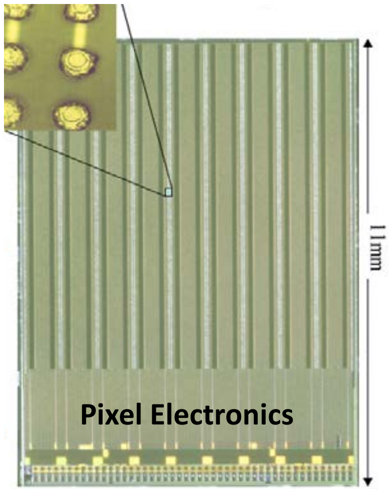
Charge Amplification and Detection

- Drift charge amplified with double layer of GEMS - gain ~20k
- Detected with pixel electronics - threshold ~2k e^-, noise ~ 100 e^-



+

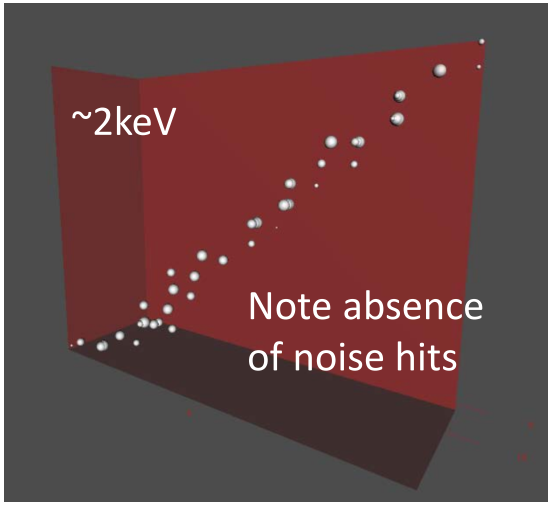
50 µm



- ATLAS FE-I3
- 50x400 µm pixels
- Sampling at 40 Mhz

=

Cosmic ray track (~7mm) detected with Hawaii prototype

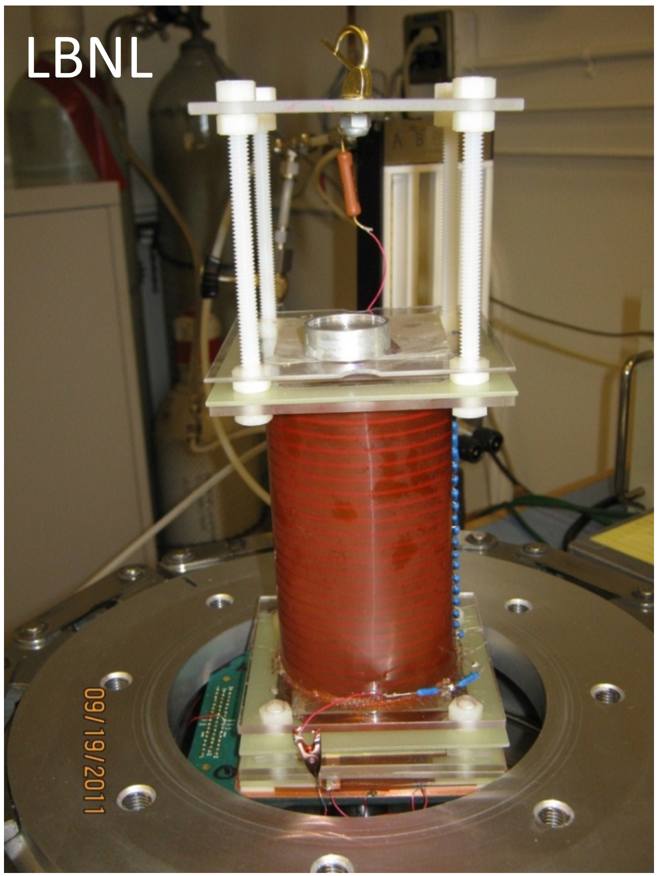


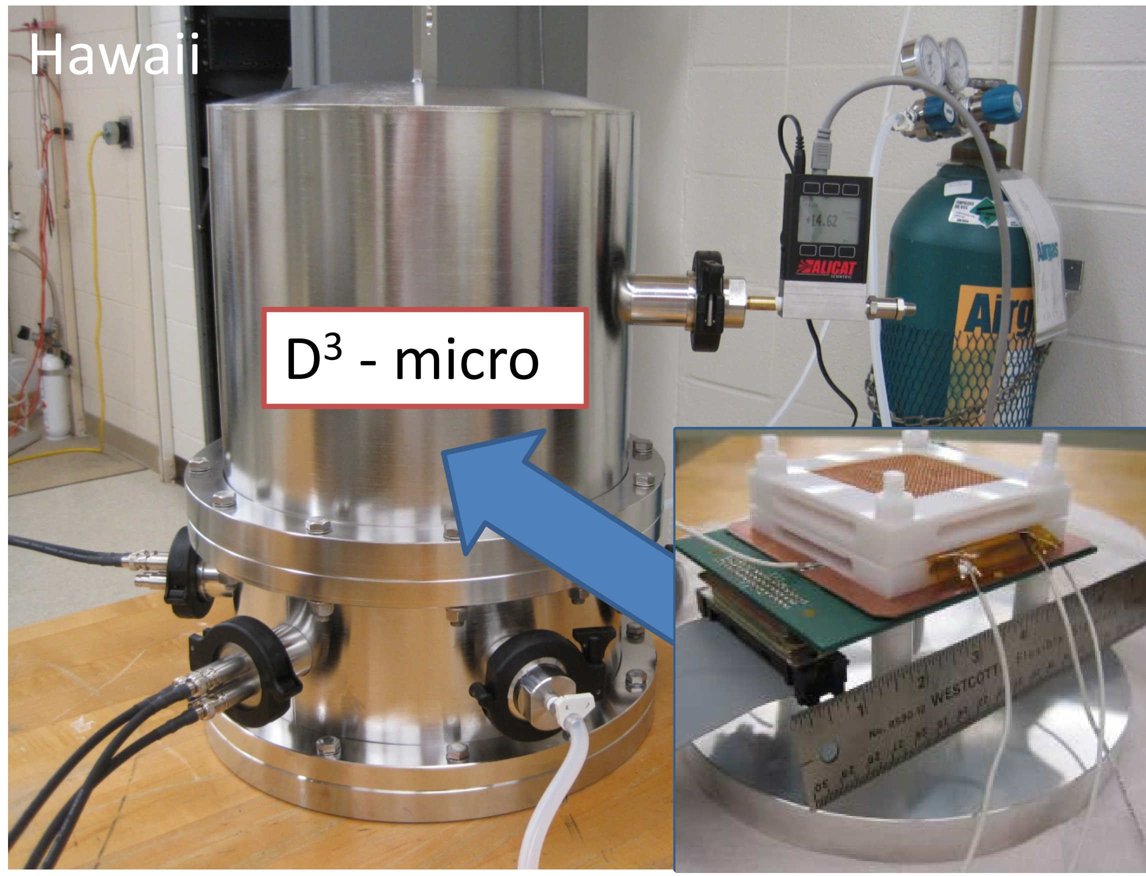
size of each bubble shows amount of ionization measured

Pre-prototypes

Belle II

- Several small (1-10 cm^3) prototypes built at LBNL and U. Hawaii
- First LBNL prototype 2007 (ILC tracking detector)
- New effort targeting directional DM / neutron detection since ~Fall 2010





Journal Publications & Conference Proceedings

- **S. Vahsen et al. "3-D Tracking of Nuclear Recoils in a Miniature Time Projection Chamber", in preparation, for publication in Nucl. Instrum. Meth. A (2013)**
- **S. Vahsen et al.," Tests of Gases in a Mini-TPC with Pixel Chip Readout", accepted for publication in Nucl. Instrum. Meth. A (2013)**
- I.S. Seong, K. Beamer, M.T. Hedges, I. Jaegle, M.D. Rosen, S.J. Ross, T.N. Thorpe, S.E. Vahsen, J. Yamaoka, "Time projection chambers with integrated pixels and their application to fast neutron detection and dark matter searches", Proceedings from the 13th Vienna Conference on Instrumentation, Nucl. Instrum. Meth. A (2013), in press
- S. Ross et al., "Charge-Focusing Readout of Time Projection Chambers", Proceedings from 2012 Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC), IEEE (2012) http://dx.doi.org/10.1109/NSSMIC.2012.6551412
- J. Yamaoka et al., "Application of Time Projection Chambers with GEMs and Pixels to WIMP Searches and Fast Neutron Detection", Proceedings of 2nd International Conference on Technology and Instrumentation in Particle Physics (TIPP 2011), to be published in Physics Elesvier Procedia (2011) http://arxiv.org/abs/arXiv:1206.2378
- S.E. Vahsen, H. Feng, M. Garcia-Sciveres, I. Jaegle, J. Kadyk, Y. Nguyen, M. Rosen, S. Ross, T. Thorpe, J. Yamaoka, "The Directional Dark Matter Detector (D^3)", EAS Publ. Ser. 53 (2012) http://dx.doi.org/10.1051/eas/1253006
- I. Jaegle, H. Feng, S. Ross, J. Yamaoka, S.E. Vahsen. "Simulation of the Directional Dark Matter Detector (D^3) and Directional Neutron Observer (DiNO)", EAS Publ. Ser. 53 (2012) 111-118 http://dx.doi.org/10.1051/eas/1253014
- S. Ahlen et al., "The case for a directional dark matter detector and the status of current experimental efforts" , International Journal of Modern Physics A, Volume: 25, Issue 1 (2010) doi:10.1142/S0217751X10048172
- T. Kim, M. Freytsis, J. Button-Shafer, J. Kadyk, S. E. Vahsen and W. A. Wenzel, "Readout Of TPC Tracking Chambers With GEMs And Pixel Chip," Nucl. Instrum. Meth. A 589, 173 (2008) doi:10.1016/j.nima.2008.02.049

3-D Tracking of Nuclear Recoils in a Miniature Time Projection Chamber

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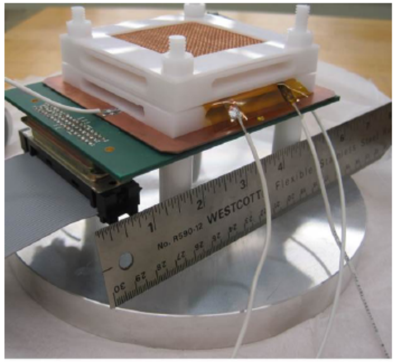
Abstract

The three-dimensional (3-D) reconstruction of nuclear recoils is of interest for both directional spectroscopy of fast neutrons and direction-sensitive searches for weakly interacting massive particles (WIMPs) that may constitute the Dark Matter of the universe. We have demonstrated this capability with the D^3/DiNO-Micro detector prototype - a miniature gas target Time Projection Chamber (TPC) where the drift charge is avalanche multiplied with a double layer of Gas Electron Multipliers (GEMs) and detected with the ATLAS FE-I3 Pixel Application Specific Integrated Circuit (ASIC). We report on detailed performance characterization of the detector with cosmic muons, low-energy x-rays, and alpha particles, using the gases Ar:CO_2 (70:30) and He:CO_2 (70:30) at atmospheric pressure. We discuss the implication of our results for future, larger directional neutron and direction Dark Matter detectors, and conclude by demonstrating the 3-D recontruction of neutron-induced He-recoils in He:CO_2 (70:30) gas.

Keywords: TPC, GEM, pixel, directional, neutron, dark matter

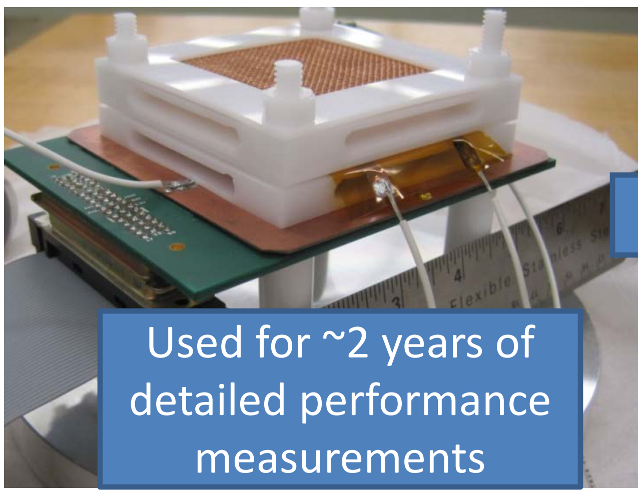
1. Introduction

Time Projection Chambers [1] with charge readout via micro-pattern gaseous detectors are the digital analog to bubble chambers: They can reconstruct ionization deposited in the detector in three dimensions, with great precision. A number of past studies [2] have demonstrated impressive performance in the context of reconstructing minimally ionizing primary particles. Our group is investigating [5][6][7] the application of such detectors to the detection of neutral particles, such as neutrons and potentially WIMPs, which are detected through nuclear recoils produced when they scatter with nuclei in the target gas. We report here on a series of measurements that characterize the low-level detector performance of a minature prototype detector, D^3/DiNO-micro (short of Directional Dark Matter Detector / Directional Neutron Observer), constructed at the University of Hawaii in 2010. In that detector the TPC drift charge is

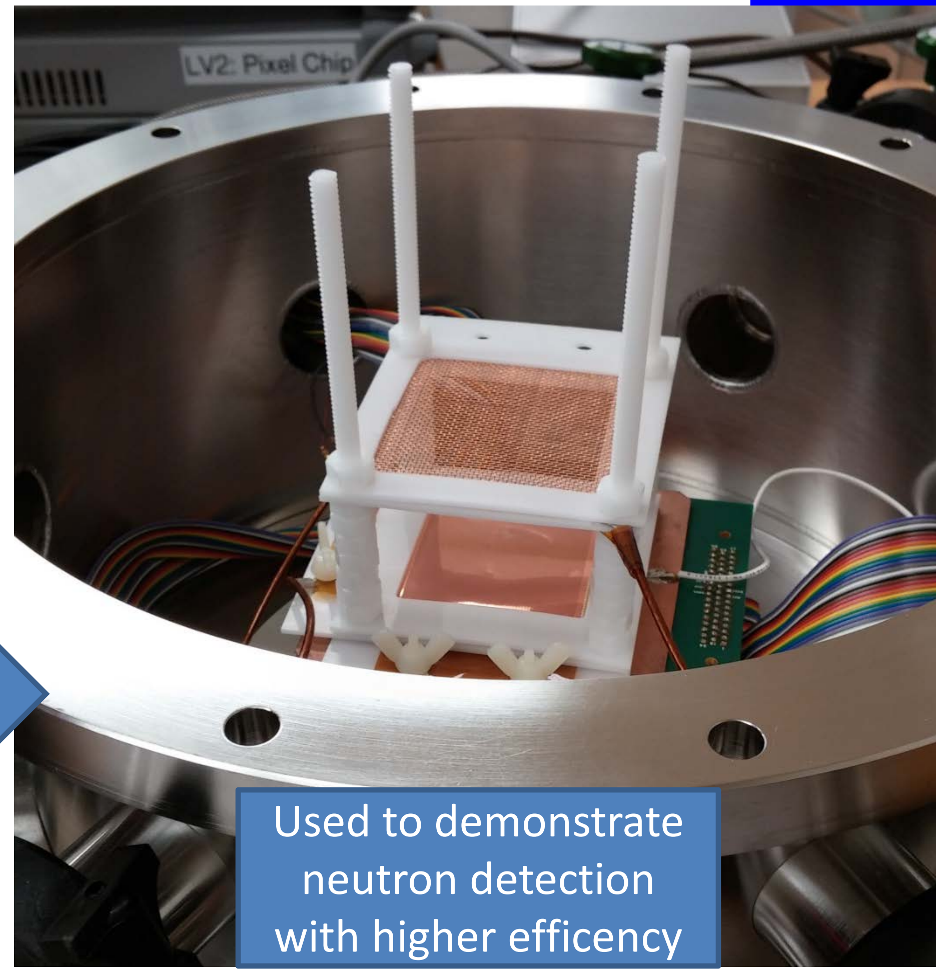


Small Modification → Large Improvement

- July 2013: Larger volume & less plastic
  - 5 x higher neutron detection efficiency
  - 10 x lower background rate



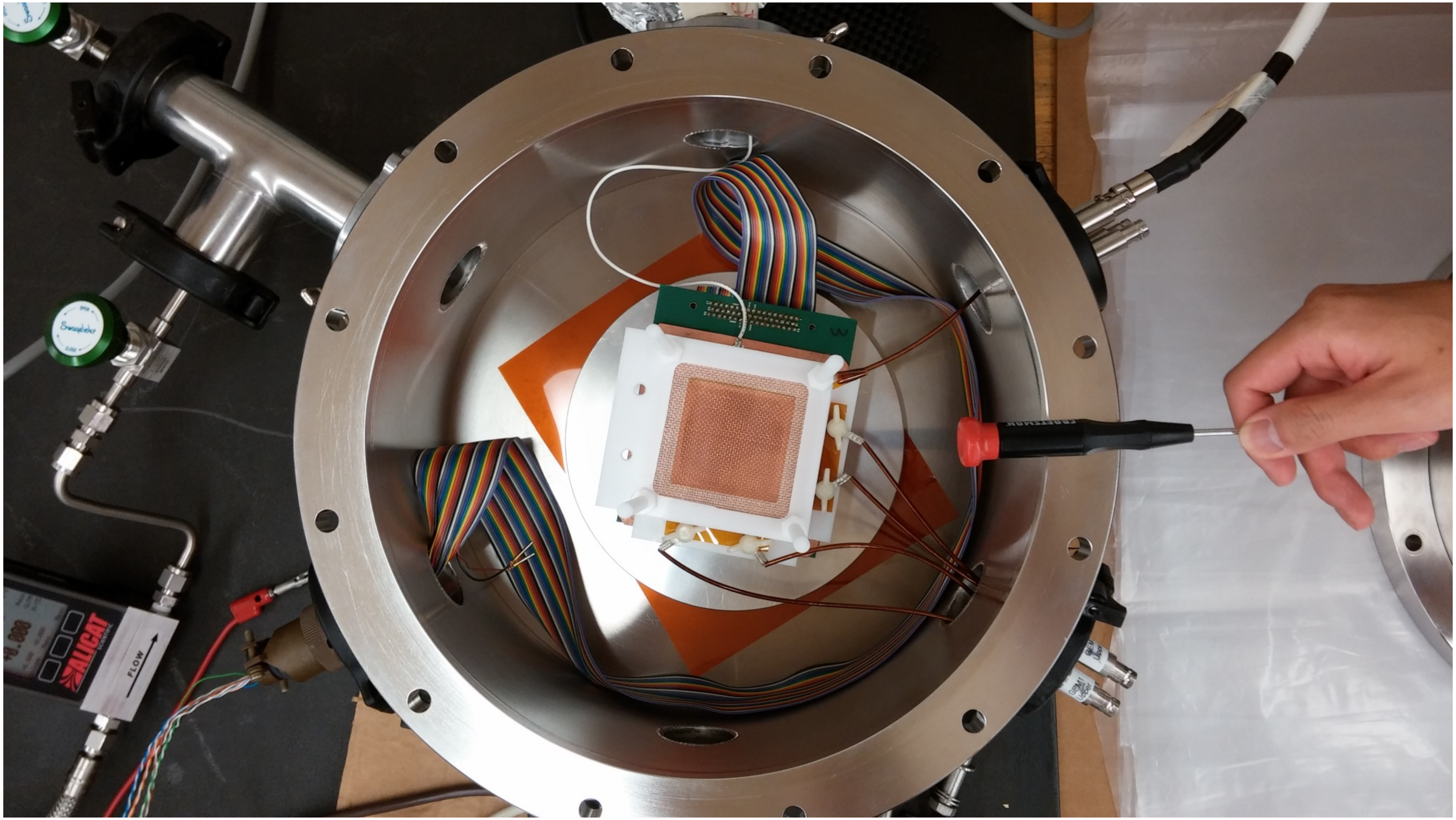
Used for ~2 years of detailed performance measurements



Used to demonstrate neutron detection with higher efficency

Performance of these detectors studied in great detail, well understood
Commissioning Detector TPCs : further scale-up in size to increase neutron detection efficiency

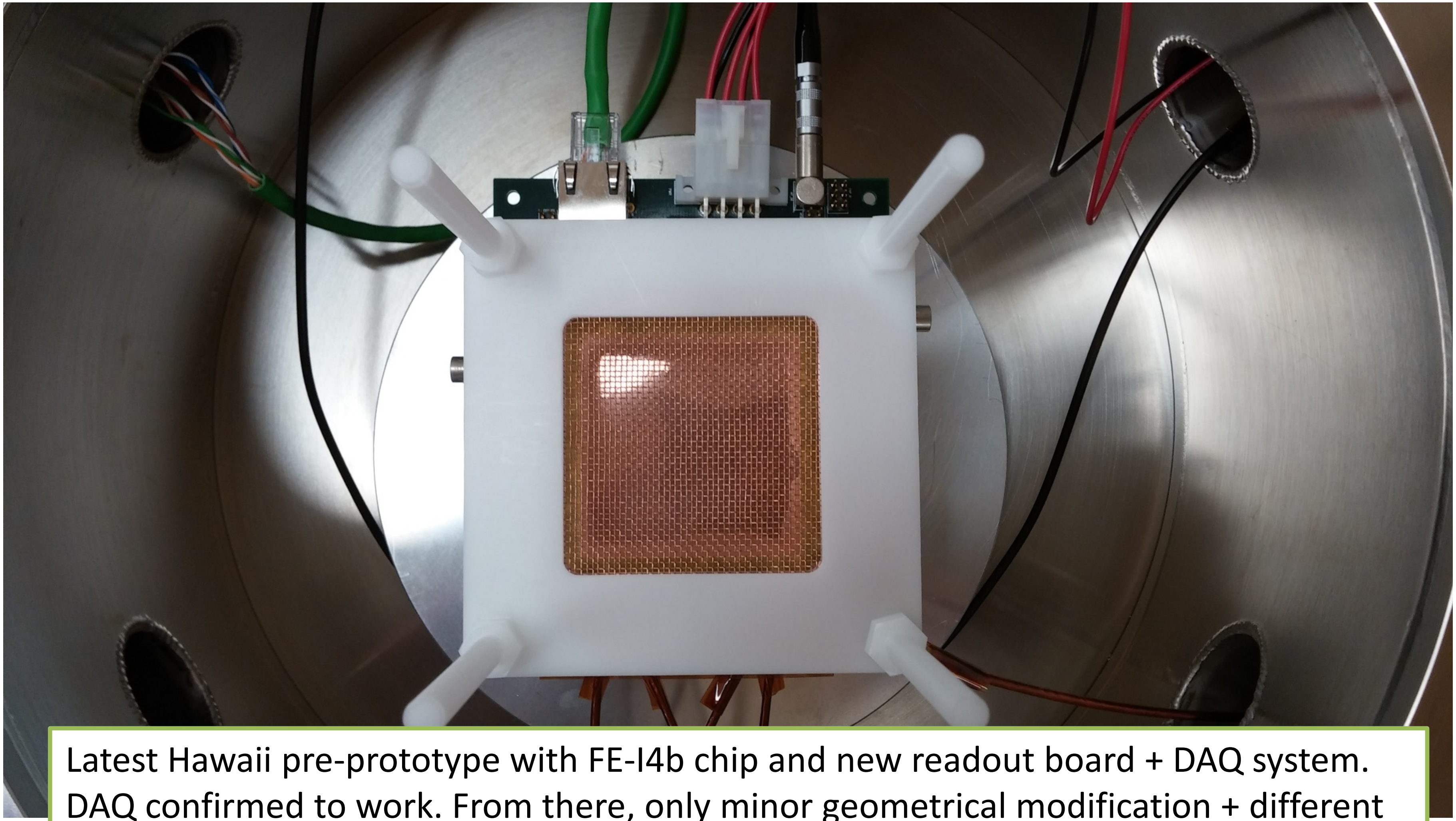
- ~4x longer drift still→ need electric field cage
- ~6x larger pixel chip (FE-I3→Fe-I4)



Commissioning detector: lack of space

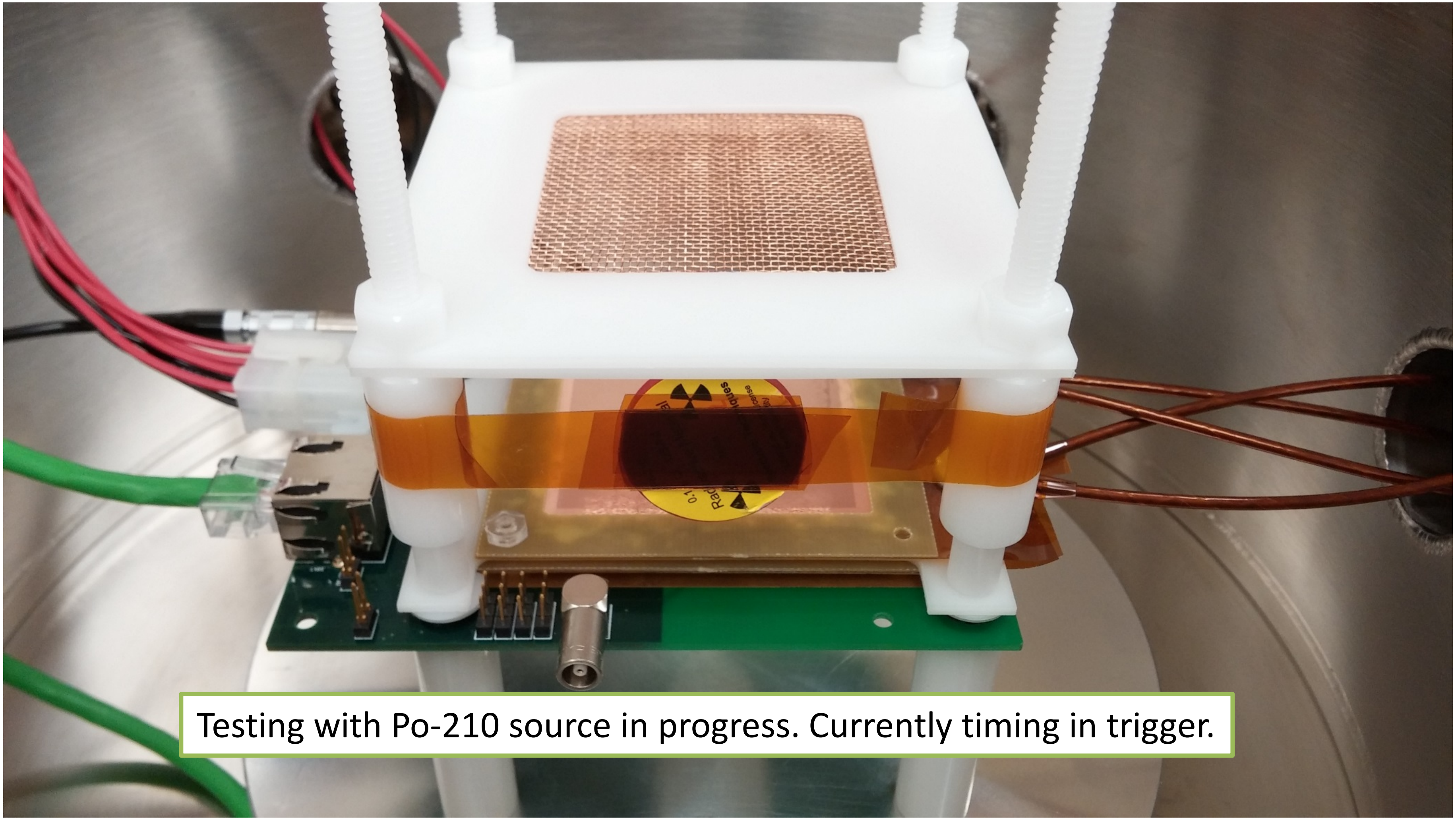
→ need smallest possible vacuum vessel that fits around detector

Pre-prototypes



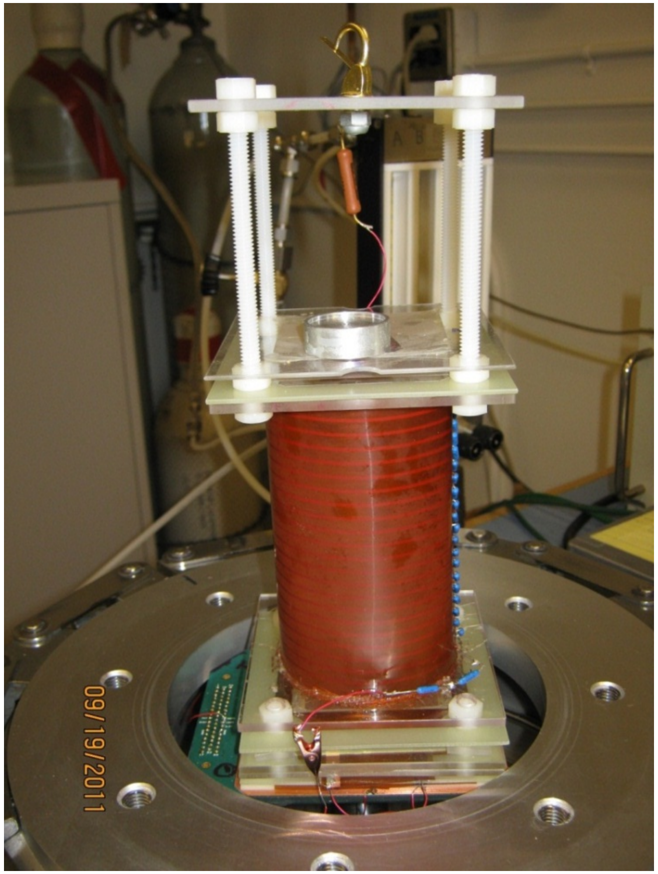
Latest Hawaii pre-prototype with FE-I4b chip and new readout board + DAQ system. DAQ confirmed to work. From there, only minor geometrical modification + different connectors for DAQ in BEAST TPCs

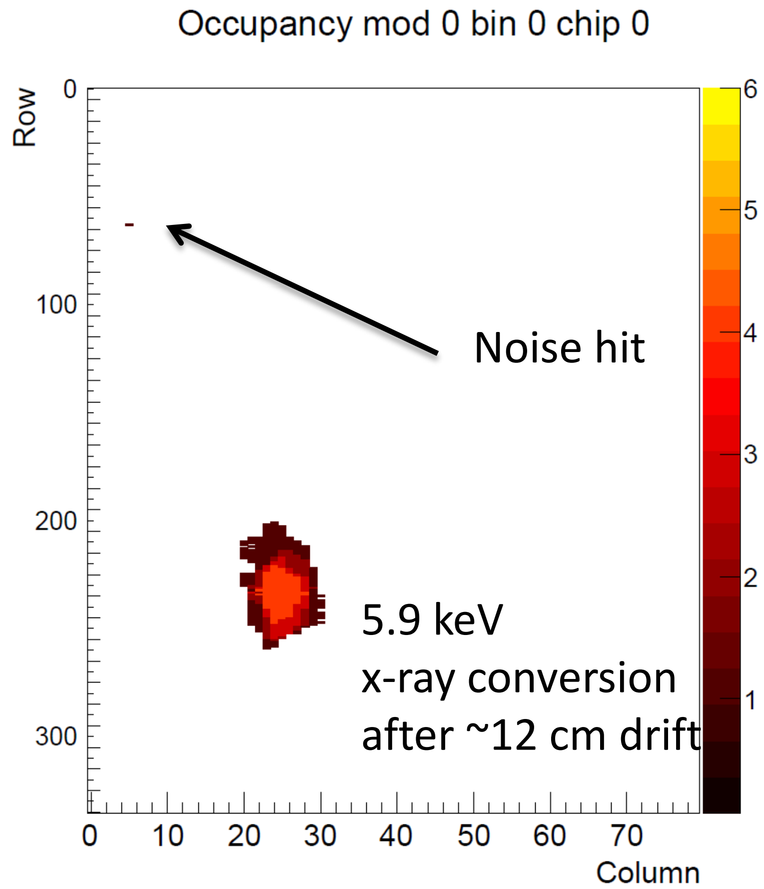
→ **final** board also already produced, but not tested yet.



Testing with Po-210 source in progress. Currently timing in trigger.

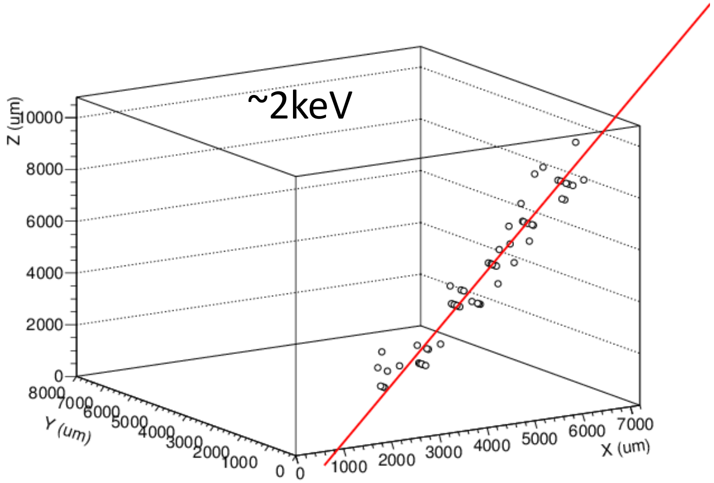
LBNL test with FE-I4a



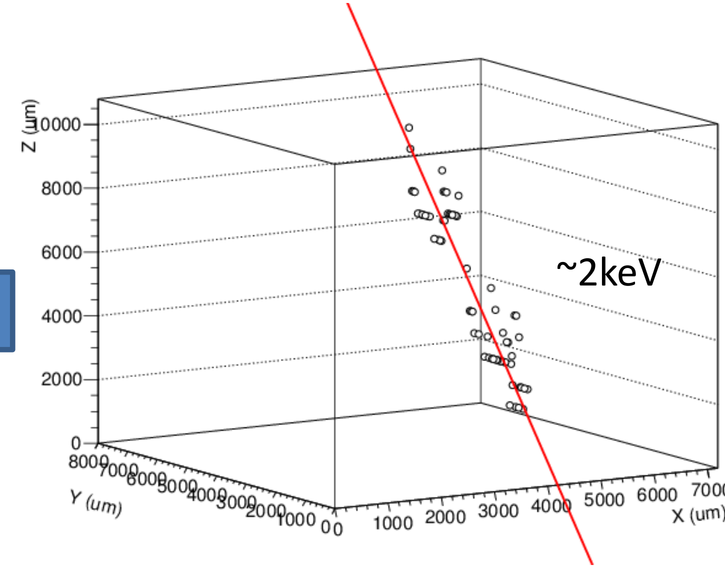


FE-I4a, 12cm field cage. This happens to be *very* close to final BEAST TPC design. Works beautifully.

Point Resolution w/ Cosmic Muons

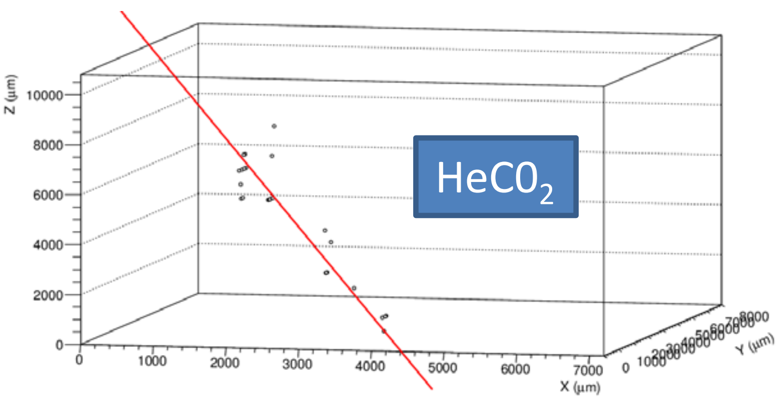


ArC0$_2$



<1 keV track ?

detector threshold ~ 25 eV ?

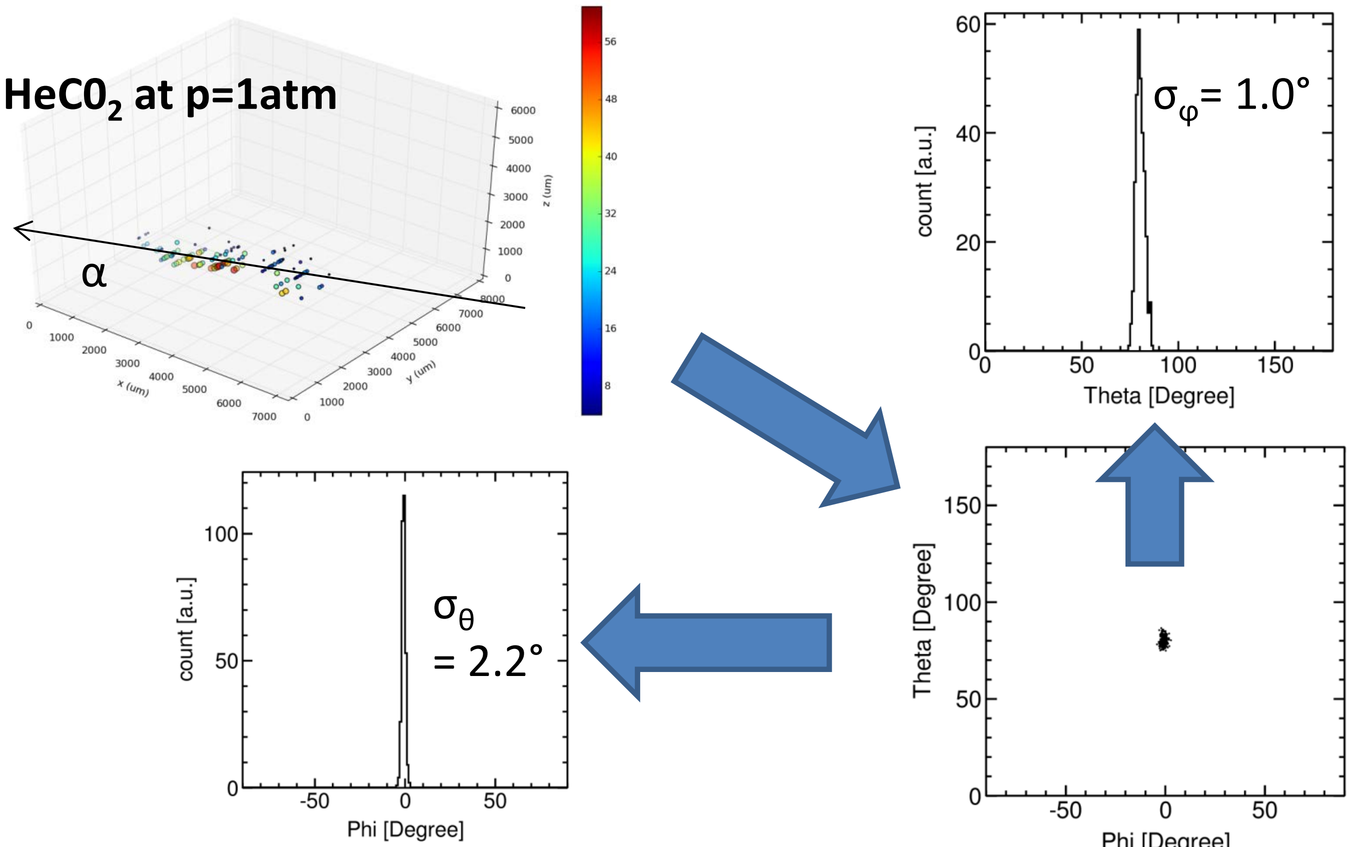


- > 10k cosmic events recorded
- ArC0$_2$ gas: excellent for cosmic ray measurements, calibration, comparisons
- HeC0$_2$ gas: better for neutron detection
- Use such events to measure detector point resolution & diffusion (~ 200 μm)
- Alpha particles: slightly worse

- Point roughly resolution consistent with simulation
- Expect angular resolution on nuclear recoils ~1°

Angular and Energy Resolution, nuclear recoils

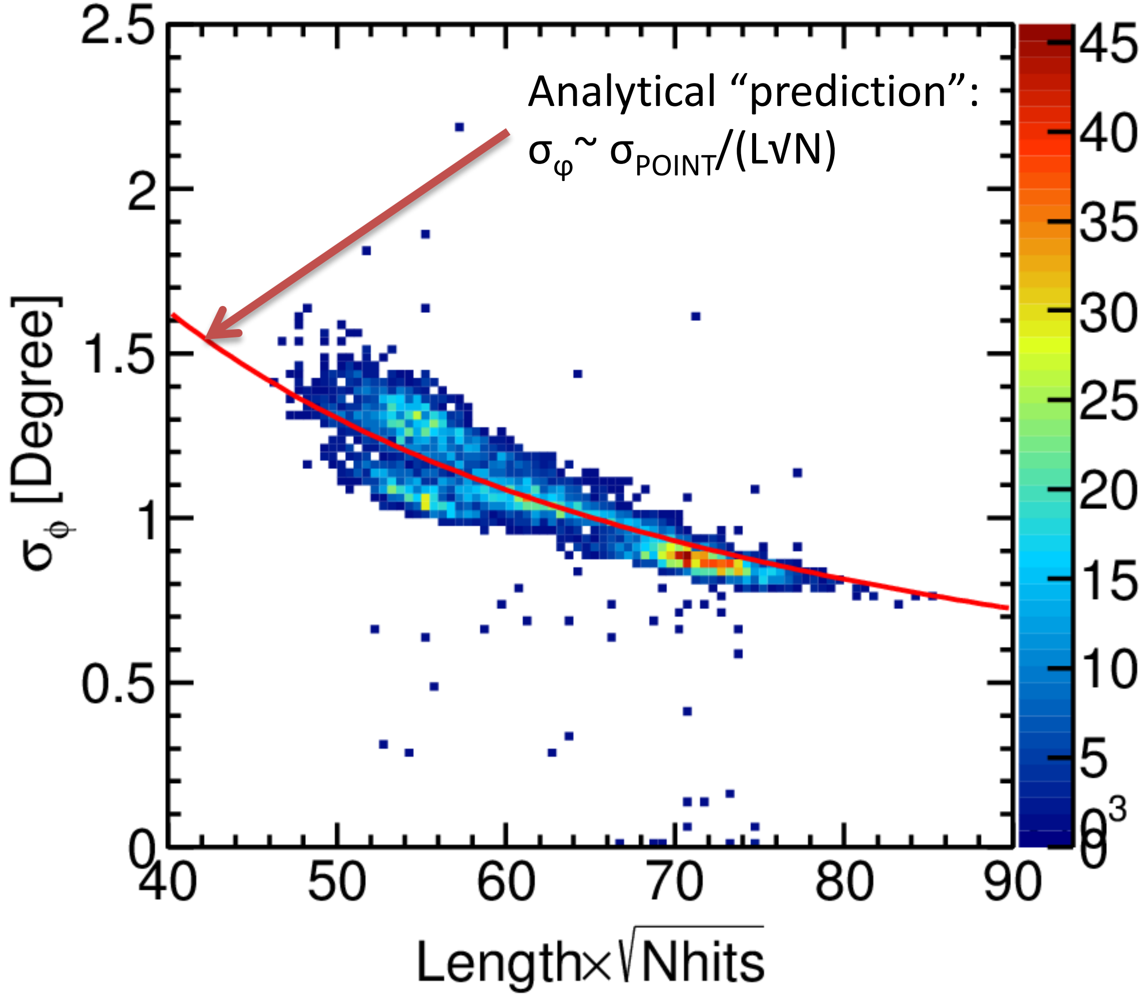
Po-210 α-source inside vacuum vessel. How well can we locate it?



$$\sigma_{angle} = \sqrt{\sigma^2_{detector} + \sigma^2_{straggling} + \sigma^2_{\cancel{source}\ cone} + \sigma^2_{source\ size}}$$

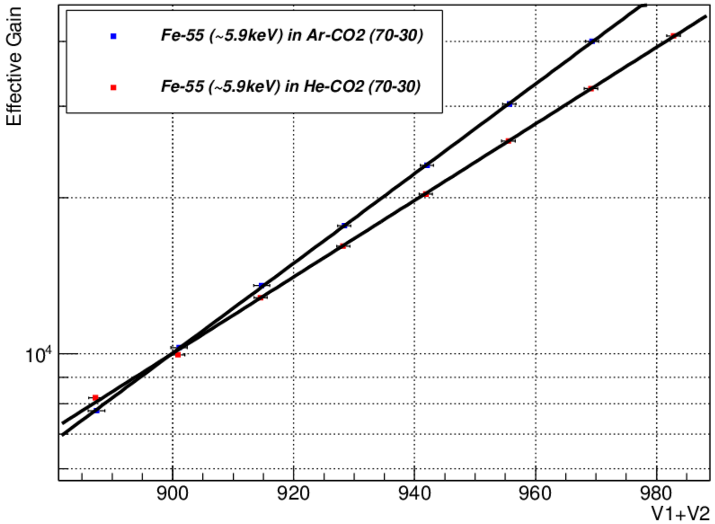
- Selected events clearly point back to a single source
- No BG after good-track selection
- consistent with $\sigma_{\phi,\theta\ \mathrm{detector}} \sim 1^\circ$

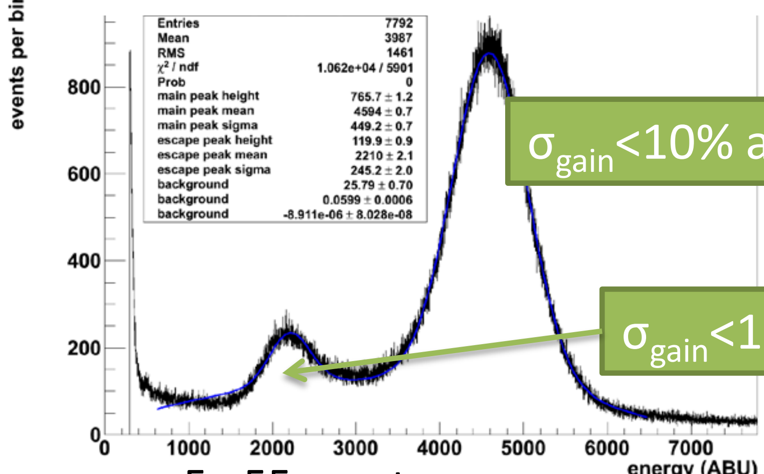
Angular resolution versus "track size"



The above allows us to extrapolate our results to other energies and gas pressures

GEM Gain Measurement w/ x-rays





σ_{gain}<10% at 5.9 keV

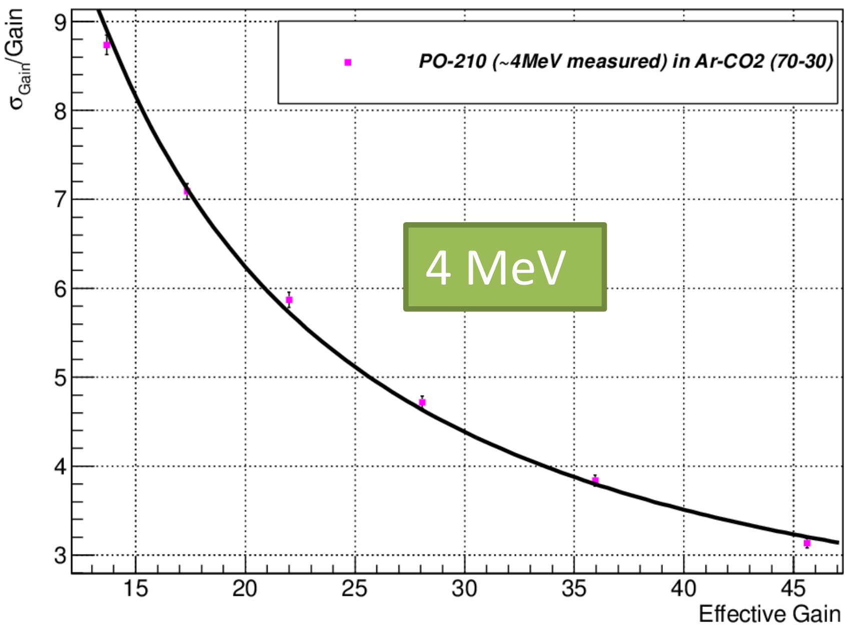
σ_{gain}<11% at 3 keV

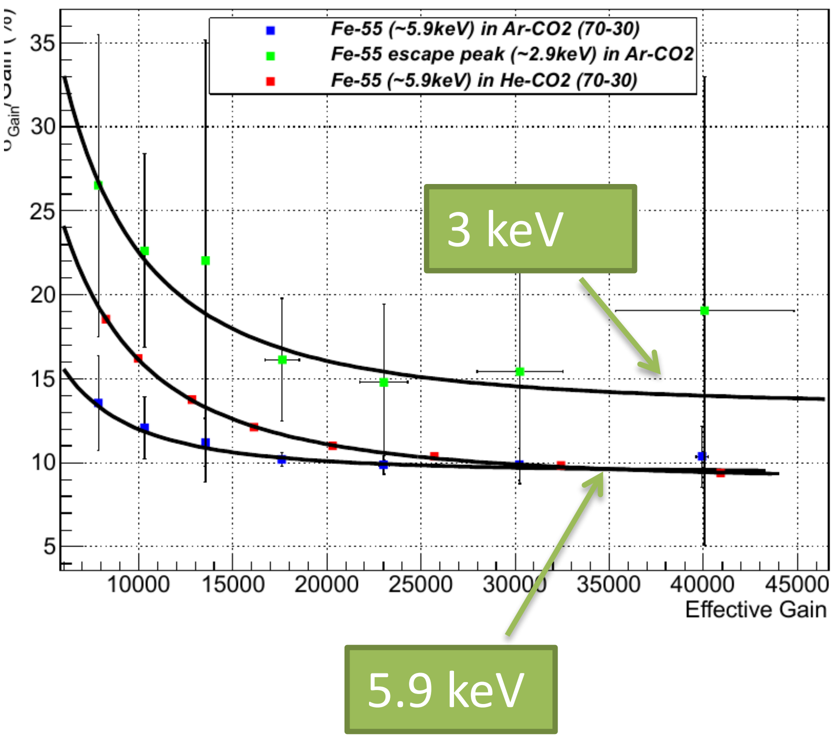
Fe-55 spectrum

- Have run with high (10^4), gain without sparking for weeks at a time
- We have operated with the same pixel chip for *two years* – worries about susceptibility to sparking unfounded

- Sufficient gain to achieve single-electron sensitivity if needed (→ threshold ~ 25 eV!)
- For neutron detection, run at *low* gain (easier), essentially blind to cosmics and MIPS

Gain Resolution versus Gain





Gain resolution better than expected/simulated at all energies

Gain Resolution Versus Energy

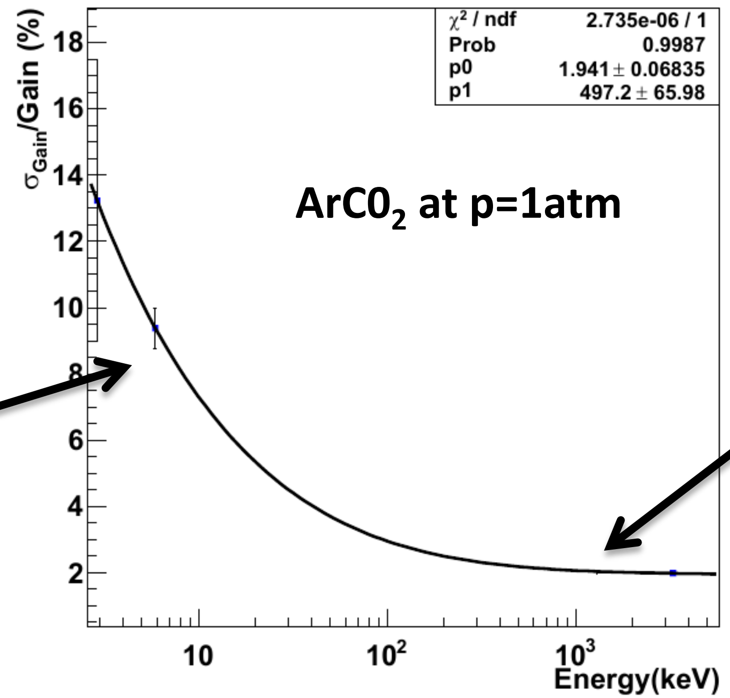
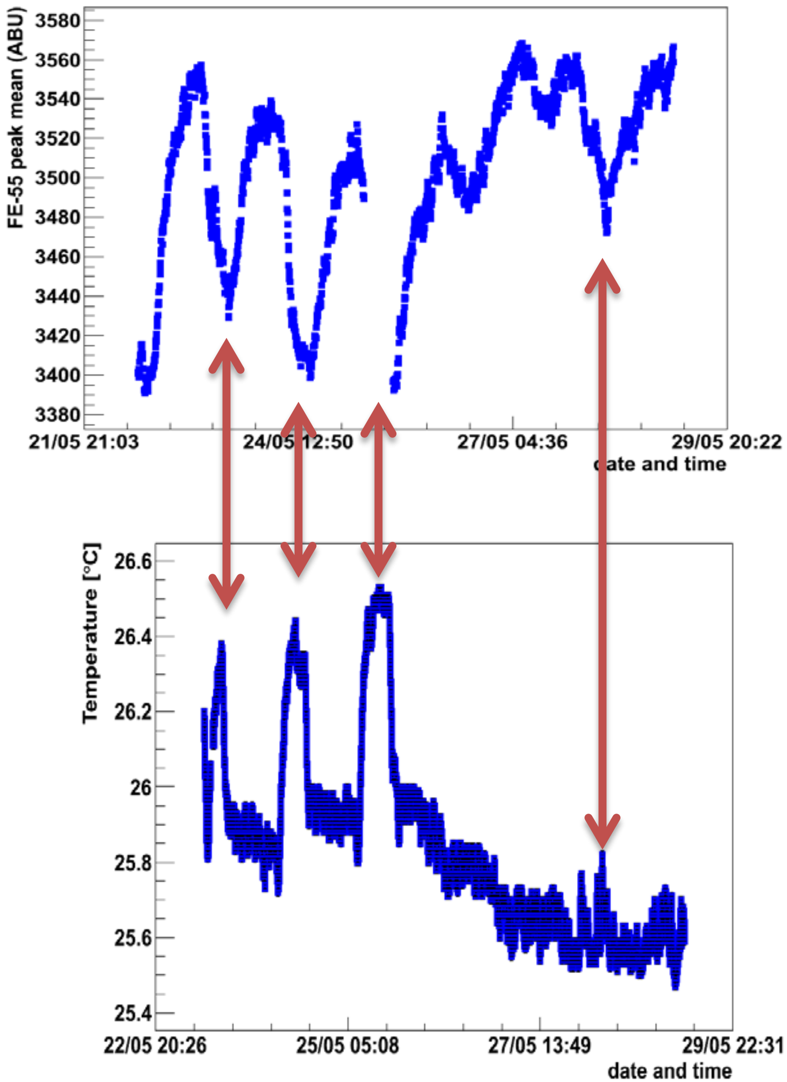


Figure 7: Asymptotic (high-gain) gain resolution versus primary ionization energy. See text for discussion.

- Good gain resolution for MeV-scale signals, adequate even for few-keV signals!

→ Expect to achieve good head-tail identification, perhaps even in keV range

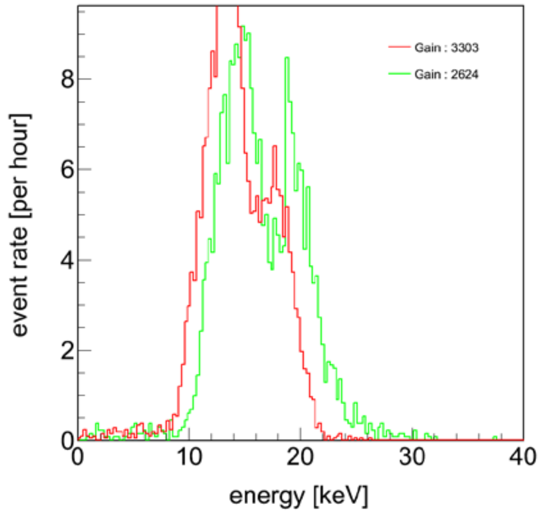
Gain Stability

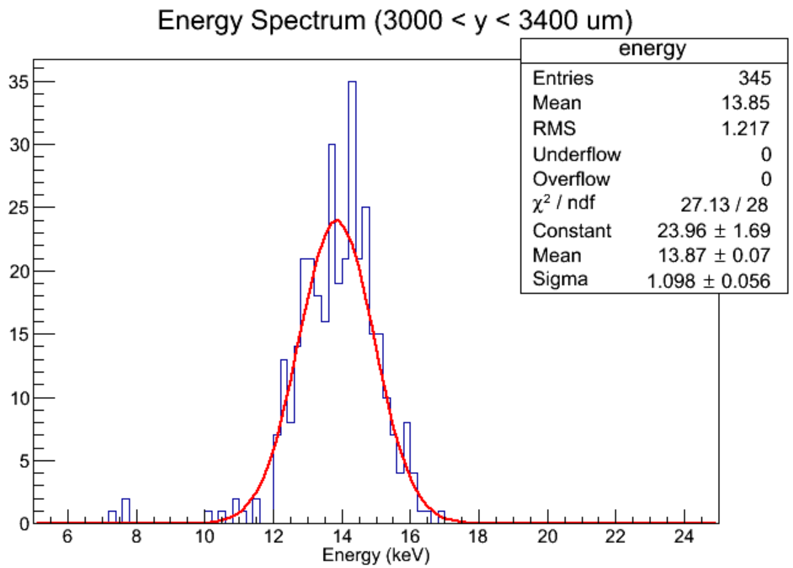


- Measured gain continuously for 5 days, to test for possible gain degradation due to decreasing gas purity
- Not observed (=good!)
- Instead observed +/- 2% gain variation tightly correlated with lab temperature; guessing this is due to NIM electronics

Excellent stability without flowing gas
→ simplifies operations at KEK

Energy Resolution - Surprises

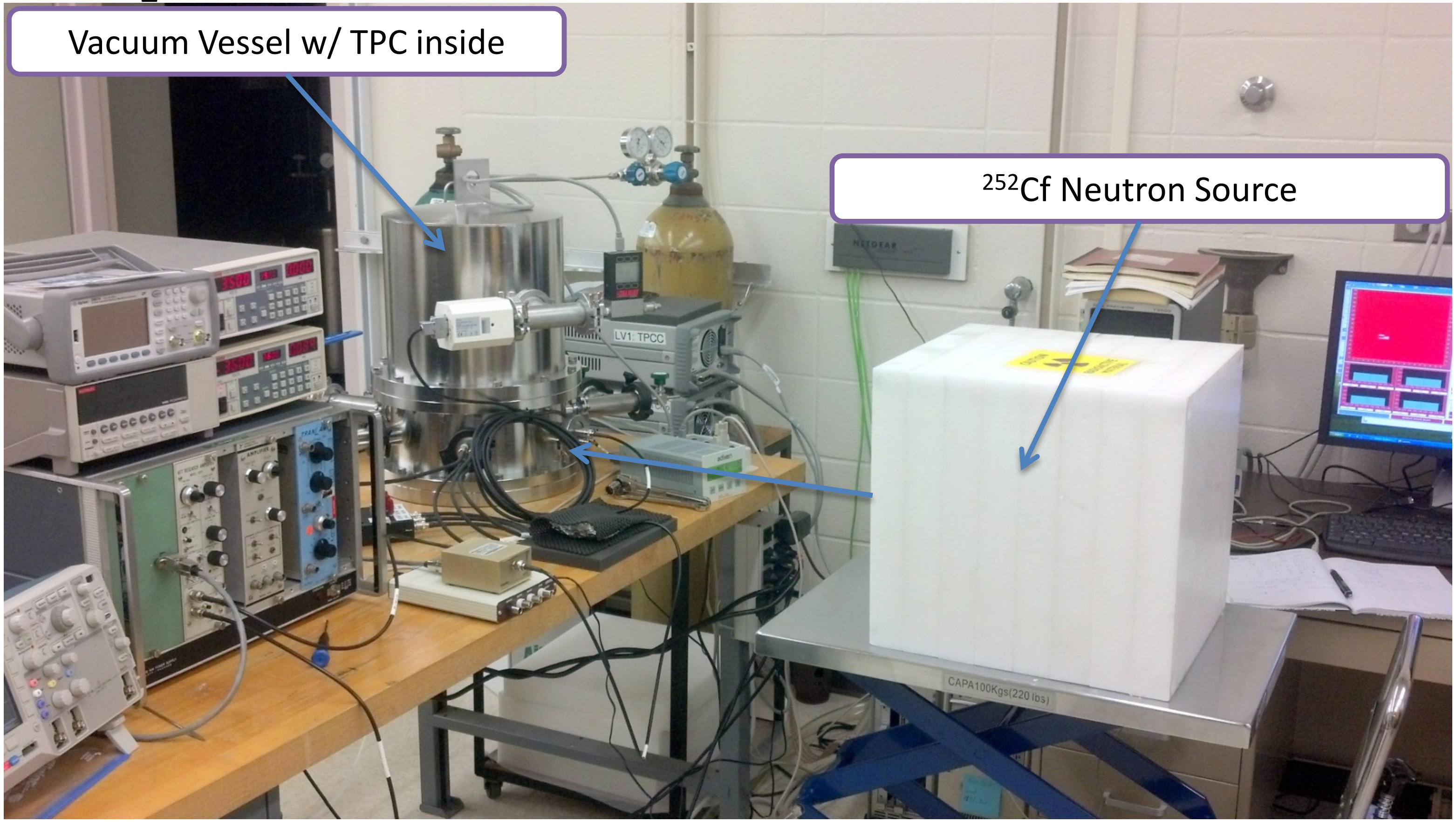




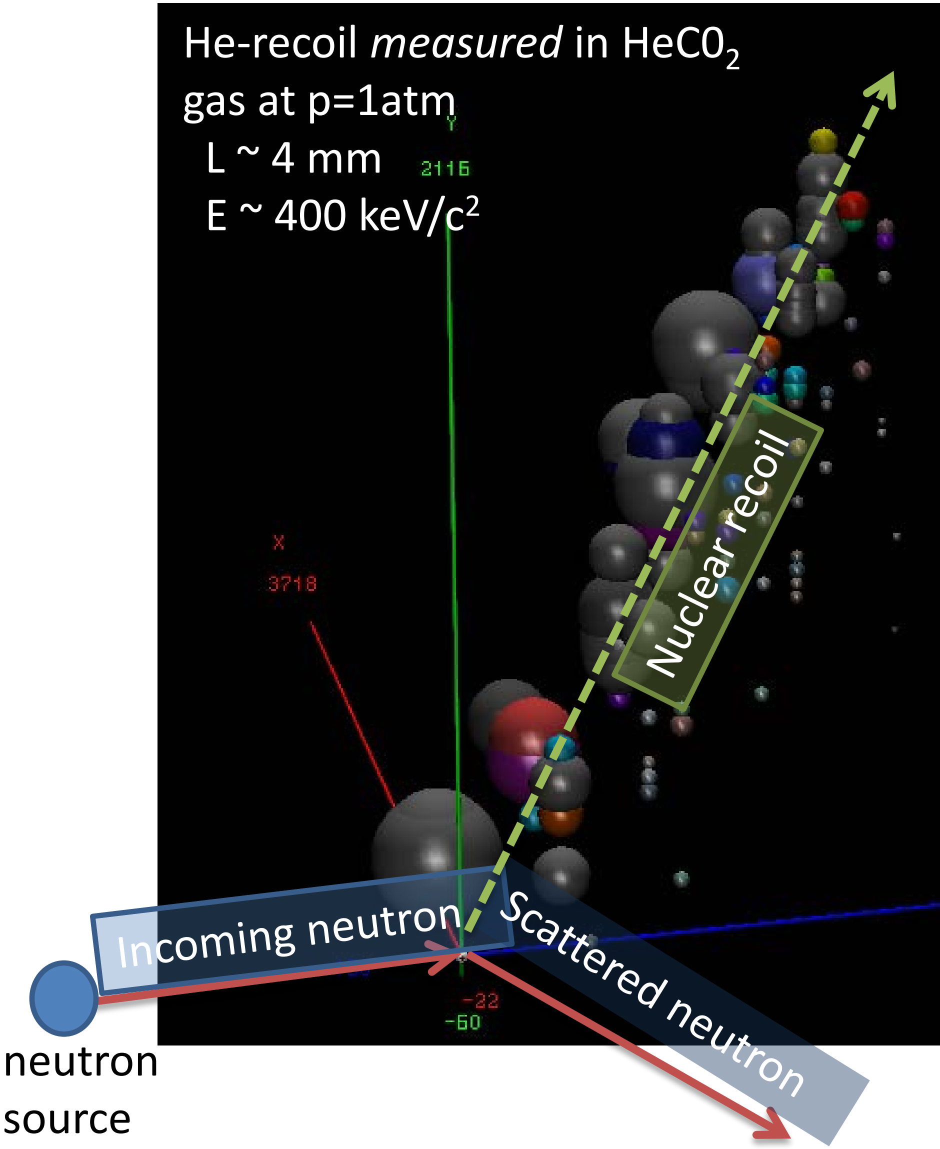
- Energy resolution significantly worse than gain resolution when measured over entire pixel chip area
- Surprising, as both GEM gain and pixel chip calibration measured independently to be uniform (<4%) and stable in time (<2%)
- If we restrict only to small region of chip, energy resolution improves to 7-8%
- **need position dependent calibration to reach <=4% energy resolution at pixel chip**
- **Aim to do so: improves particle ID and measurement of neutron spectra**
- **There is a long story here - ask me for more details if interested**

Demonstration of Directional Neutron Detection

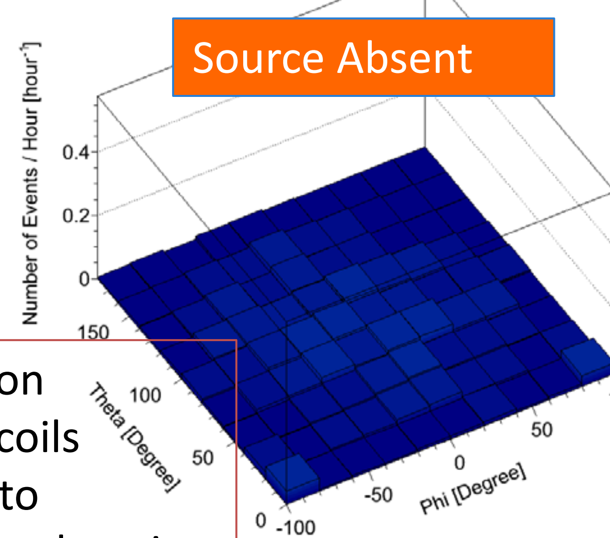
- ^{252}Cf Neutron Source
- $HeCO_2$ (70:30) gas at atmospheric pressure

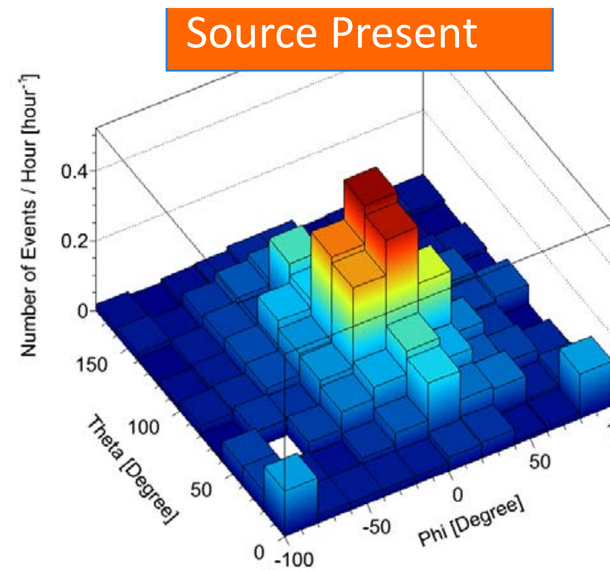


Directional Neutron Detection



Mean direction of nuclear recoils corresponds to neutron source location

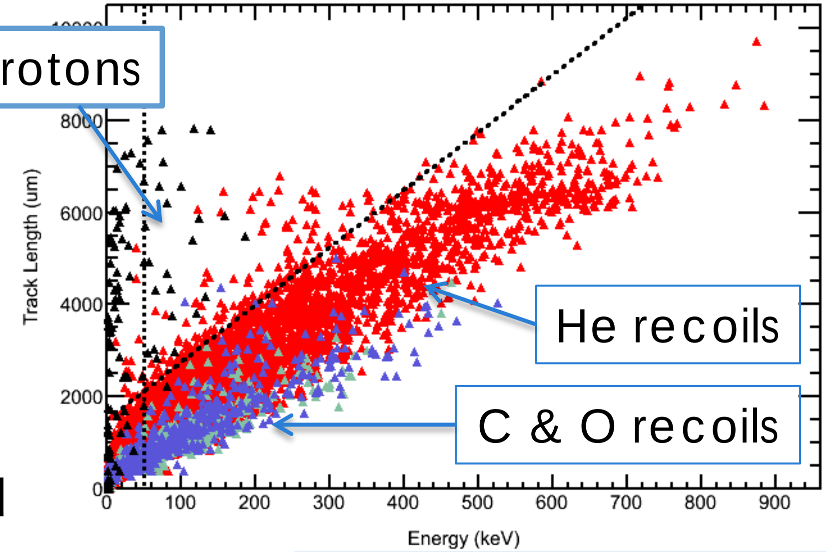




Clear excess & peaks in expected direction!

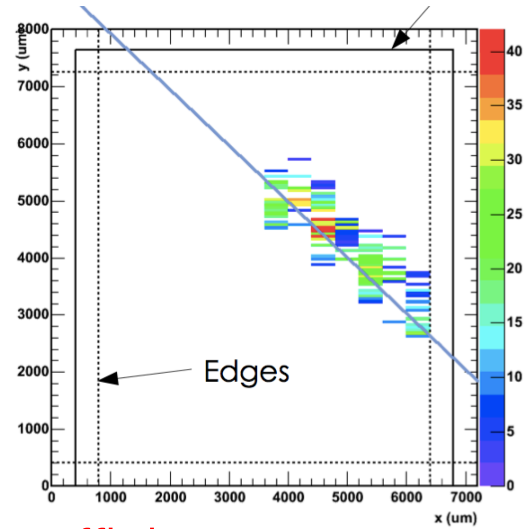
Event Selection & Particle ID

MC simulation



- Protons are produced by interaction between neutron and plastic parts in supporting structure
- ➔Select nuclear recoils: Particle ID cut based on MC
- Remove backgrounds caused by radio-activity and select events containing full information
- ➔Define edges as veto area

Event Display on Pixel Chip



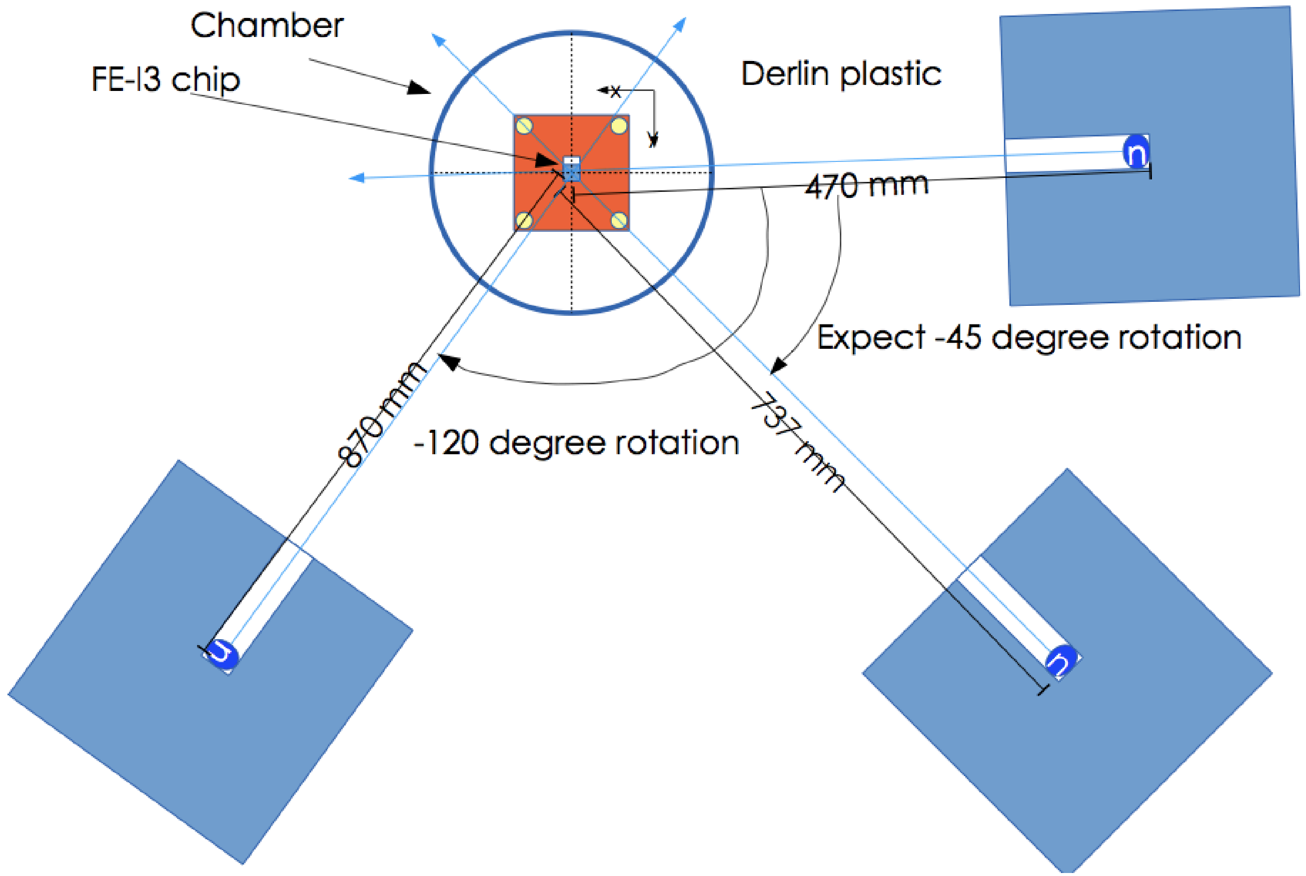
Summary table signal to background ratio

	Source Absent	Source Present	Signal/Background
Total Events	2.79 hour^{-1}	10.50 hour^{-1}	2.76
Particle ID	0.58	2.93	4.05
No hit on Edges	0.02	0.52	22.95

Edge cut is very powerful, but it's inefficient for current small FE-I3 chip

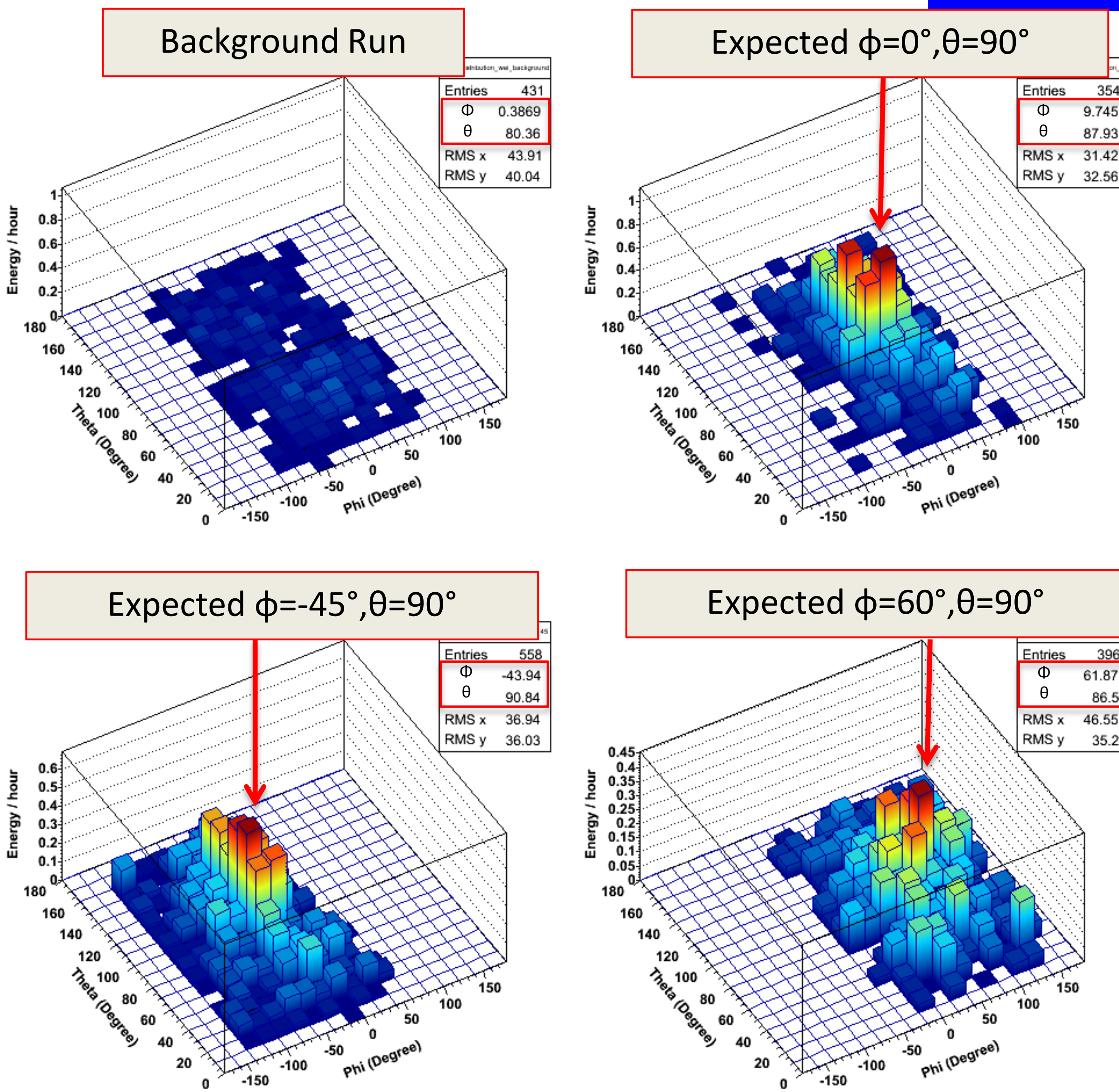
➔With larger pixel chip, edge cut will be much more efficient

Measurements with Different Source Location



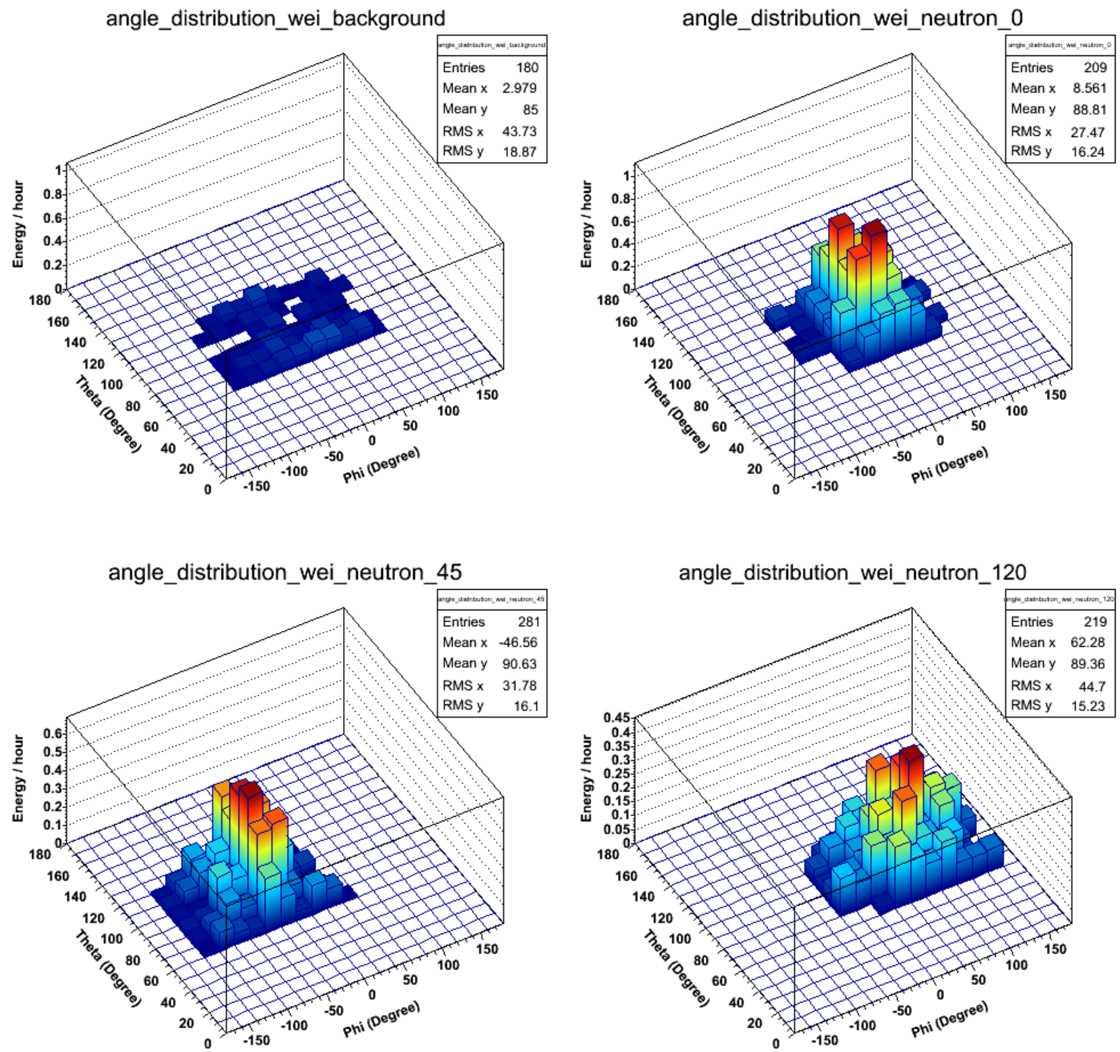
Directional Neutron Detection

- Applied Particle ID cut and rejected events which contain more than 50% hits in the edge area.
- Recoil angle distribution peak points correctly back to neutron source location



Directional Neutron Detection II

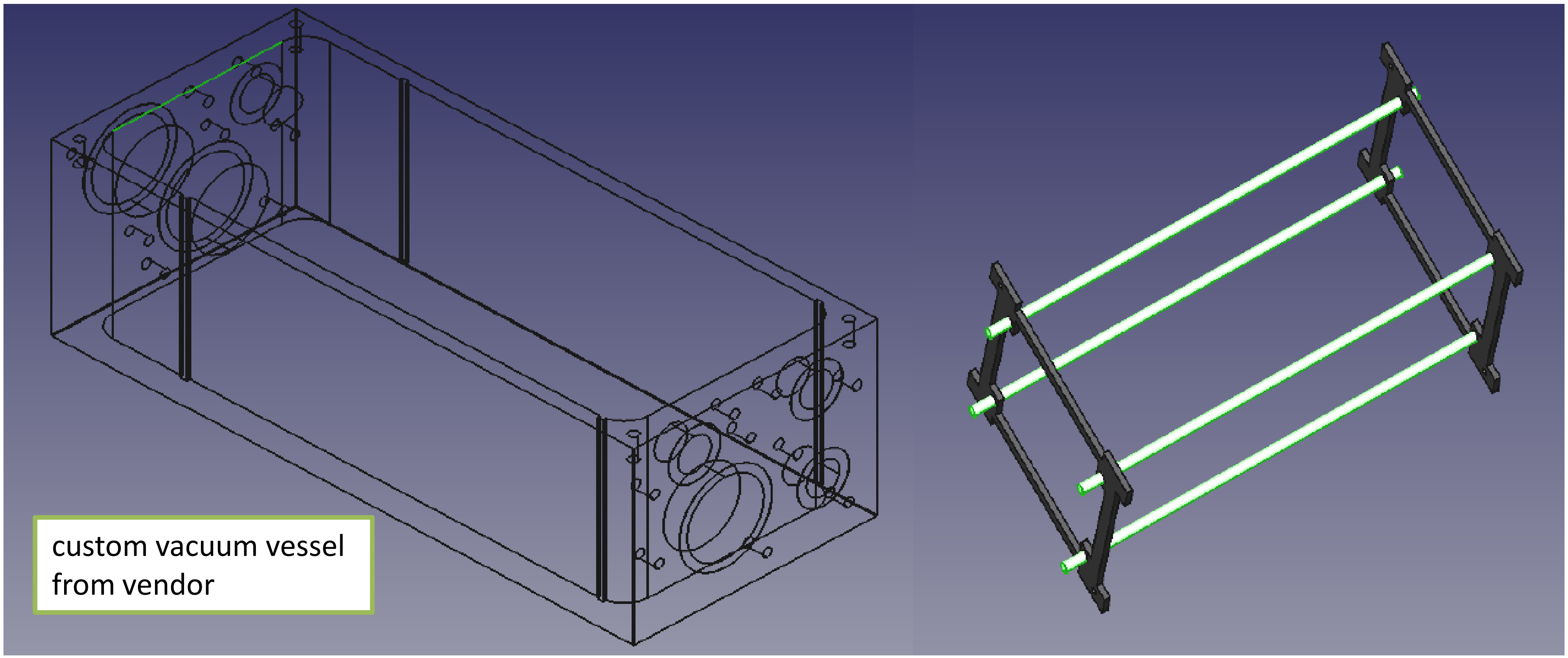
- Since neutron source is always at same theta, cut on theta → S/B improves to 30-40
- Same idea will be used at SuperKEK (cut on phi to select only those neutrons coming directly from beamline)



Final TPC Prototype

Structure mounted between two support plates that slide in the vessel

- vessel
- support plates

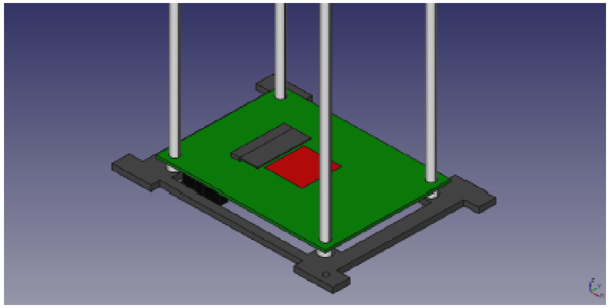


- structure different layers slip on four rods
- distance between each layers are fixed by spacers

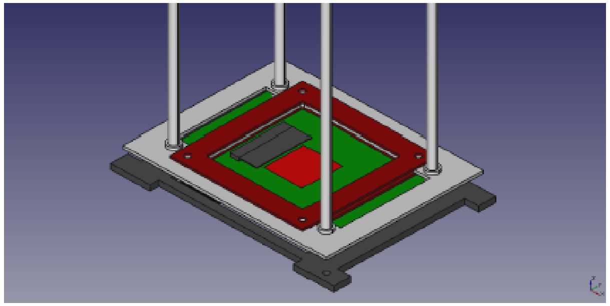
Final TPC Prototype

- 2.2 mm collection gap between chip and bottom GEM foil
- 2.8 mm transfer gap between GEM foils
- GEMs attached to a Delrin plate spacer by 4 Delrin screws
- 0.6 mm between top GEM foil and cathode

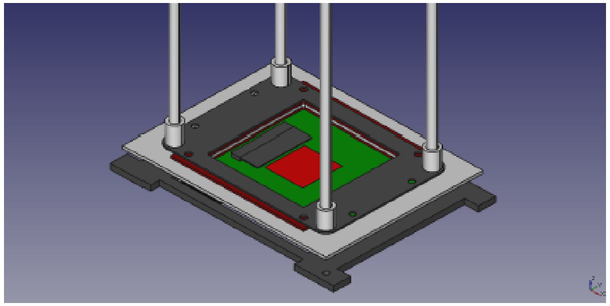
- FE-I4B board



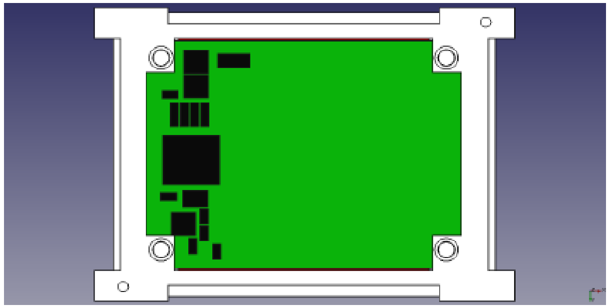
- FE-I4B board+GEMs



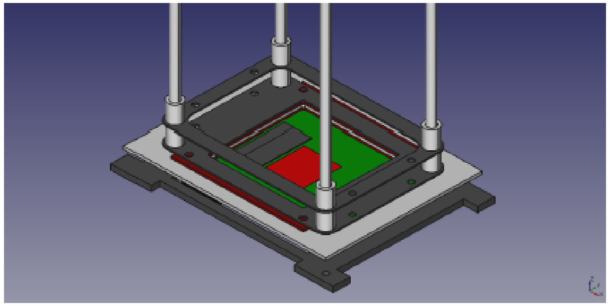
- FE-I4B board+GEMs+cathode



- FE-I4B board / bottom view



- FE-I4B board+GEMs+cathode+first ring



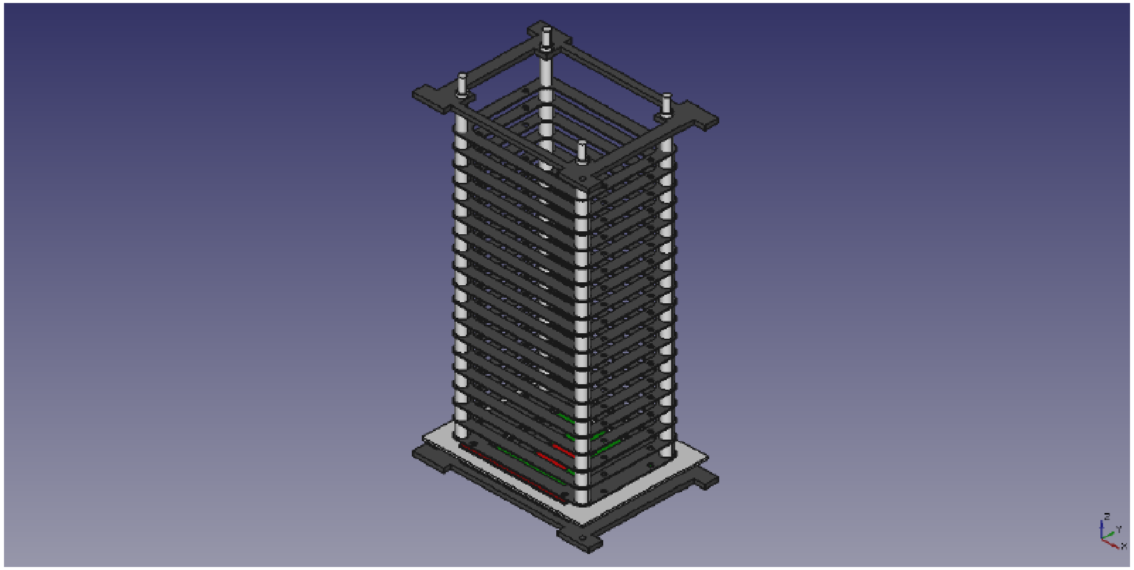
- 7 mm/10 mm gap between each rings
- electronic and gas choice fix operating drift velocity and electric field

Final TPC Prototype

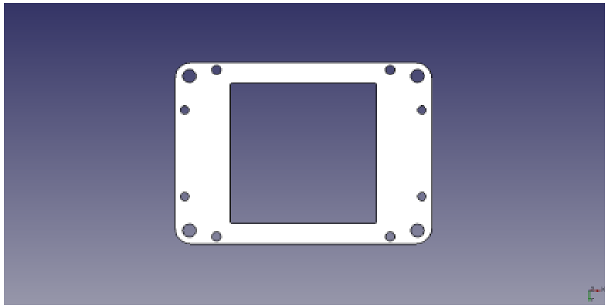
FC encircles sensitive volume and produced the electric field, it is composed of:

- an anode plane, field-shaping rectangular rings and a cathode
- connected to a resistor chain creating a linearly degrading potential

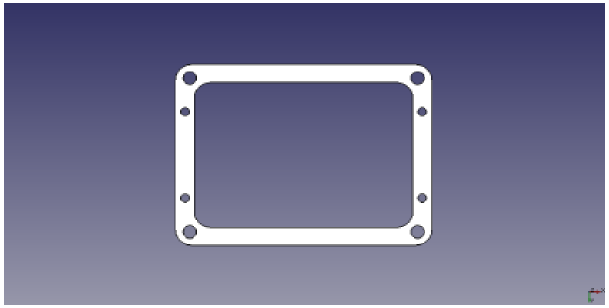
- full structure
  - ★ 7 mm/10 mm gap between each rectangular rings
  - ★ 18 cm drift gap
  - ★ rings are 1 cm from the vessel wall



- cathode



- rectangular ring

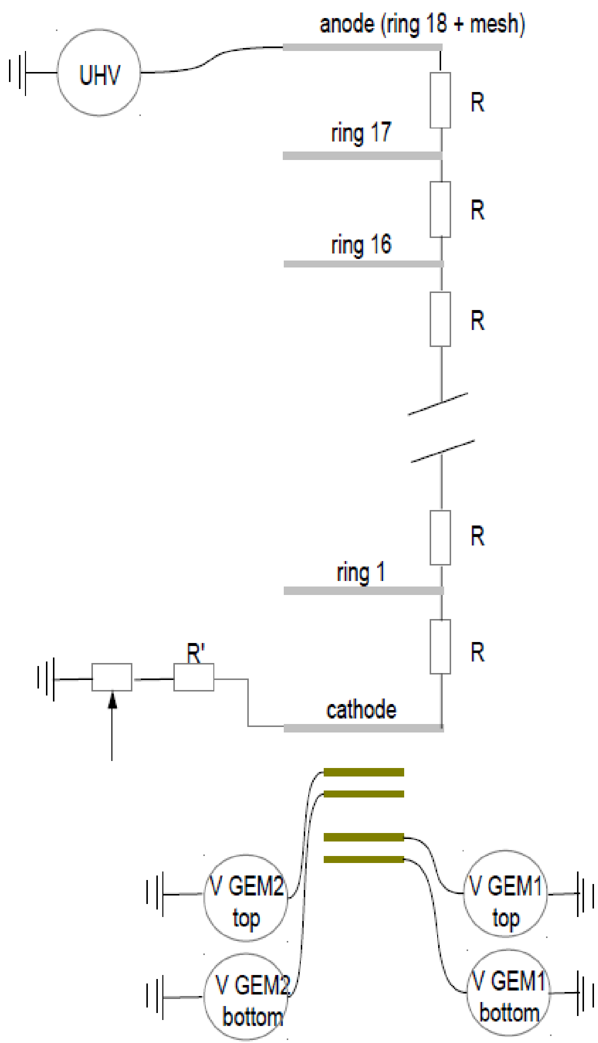


- anode: rectangular ring at which is glued a mesh

v_{drift} [μm/ns]	D_t [$\mu m/\sqrt{cm}$]	E [kV/cm]	V_{anode} [kV]
10	124.3	0.53	$9.54+V_{GEM_2^{top}}$

Final TPC Prototype

- circuit diagram



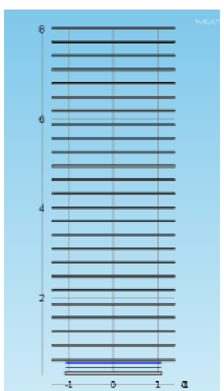
- $R = 4\ M\Omega \pm 0.1\ \% => R^{total} = 64\ M\Omega$
- GEM HV range between 900 V and 2000 V
- $V^{max}_{anode} = 11.54$ kV
- $I = 132.5\ \mu A$
- $R' = 7.075\ M\Omega$
- $V_{cathode} = V_{GEM_2^{top}} + 530$ V/cm x 0.6 mm

Radial displacement (Δr) / Field Cage

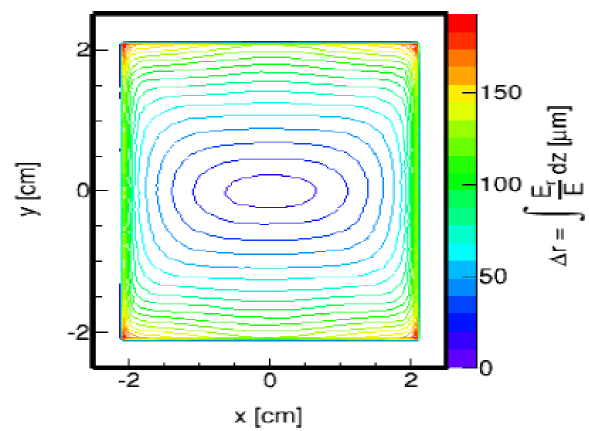
Electric field should be as uniform as possible to minimize distortions of the reconstructed tracks

- $\Delta r(x,y) = \int_{z=0}^{z_{max}/2} \frac{E_r(x,y,z)}{E(x,y,z)} dz$ with
  - z drift distance
  - E_r radial field
  - E field
- Finite Element Method (FEM) used to study the uniformity (in COMSOL)

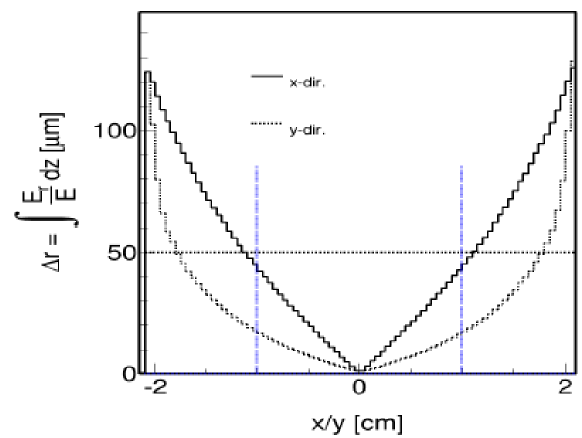
- field cage in COMSOL



- Δr vs. x vs. y



- Δr for x=0 and y=0, blue dashed lines represent one chip



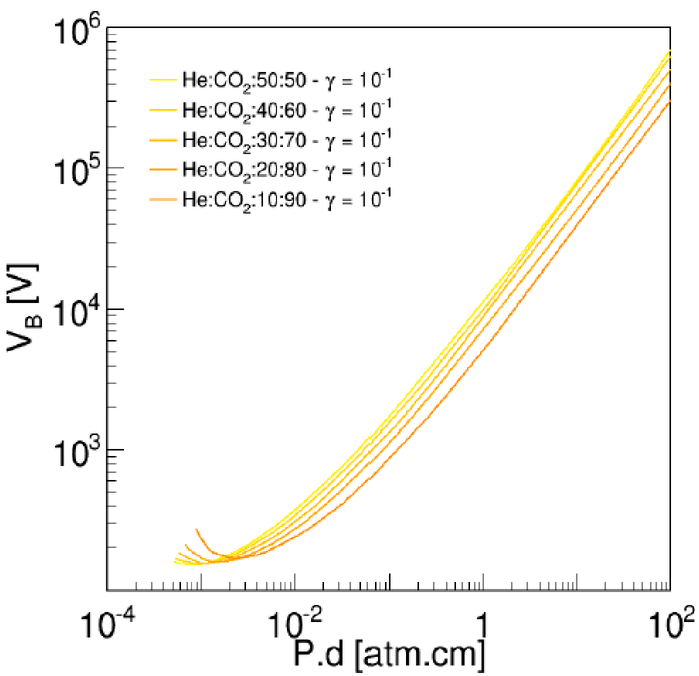
- point resolution in $r\phi < 125\ \mu m$ in the 18 cm drift gap
- point resolution in $z < 250\ \mu m$ in the 18 cm drift gap

Breakdown voltage / Field cage

2 vessels ordered with interior wall coated with parylene C

- 1^{st} vessel with 1 mil parylene C coating => dielectric resistivity ~ 5.3 kV
- 2^{nd} vessel with 3 mil parylene C coating => dielectric resistivity ~ 15 kV
- for comparison, Kapton dielectric resistivity is 20 kV/mm
- in $He:CO_2$:70:30, $V_B = 8$ kV for P.d = 1 atm.cm

▸ breakdown voltage vs. P.d

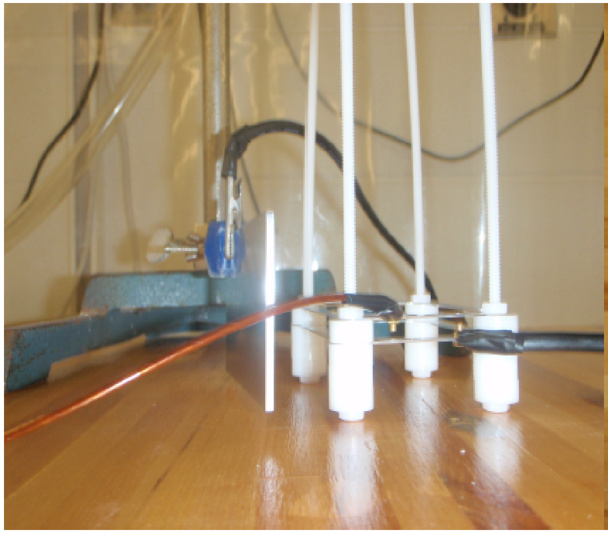


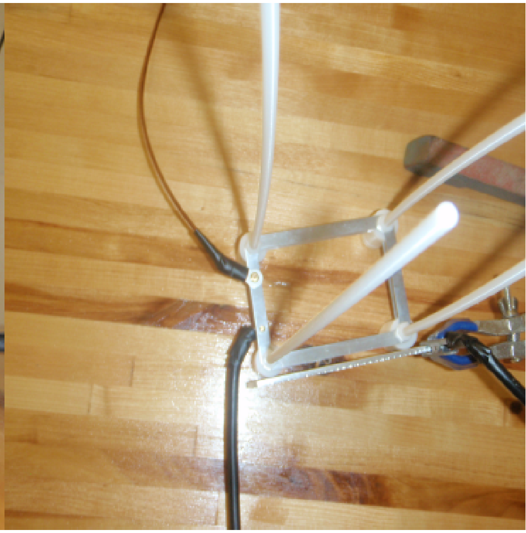
▸ High Voltage (HV) test in air

CNC fabricated rectangular rings

★ 2 rings: one at ground - second at HV

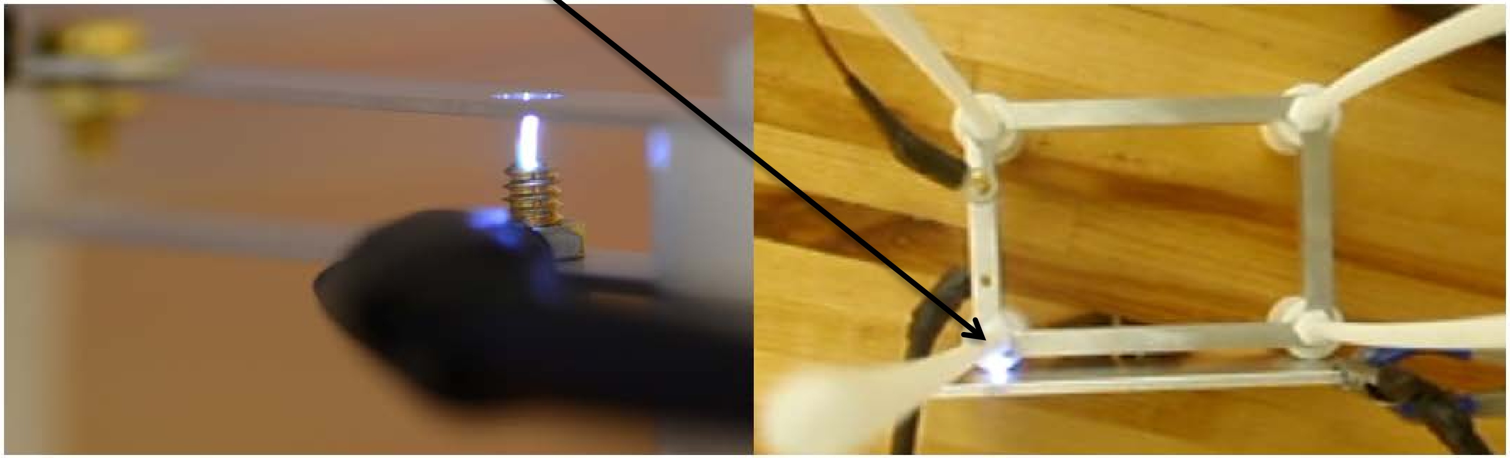
★ aluminum plate at ground to simulate the wall





Final TPC Prototype

- sparks at screw at 6.8 kV $\sim$ 20 % higher than the expected value
- sparks where radius starts at 4.8 kV $\sim$ 40 % lower than the expected value

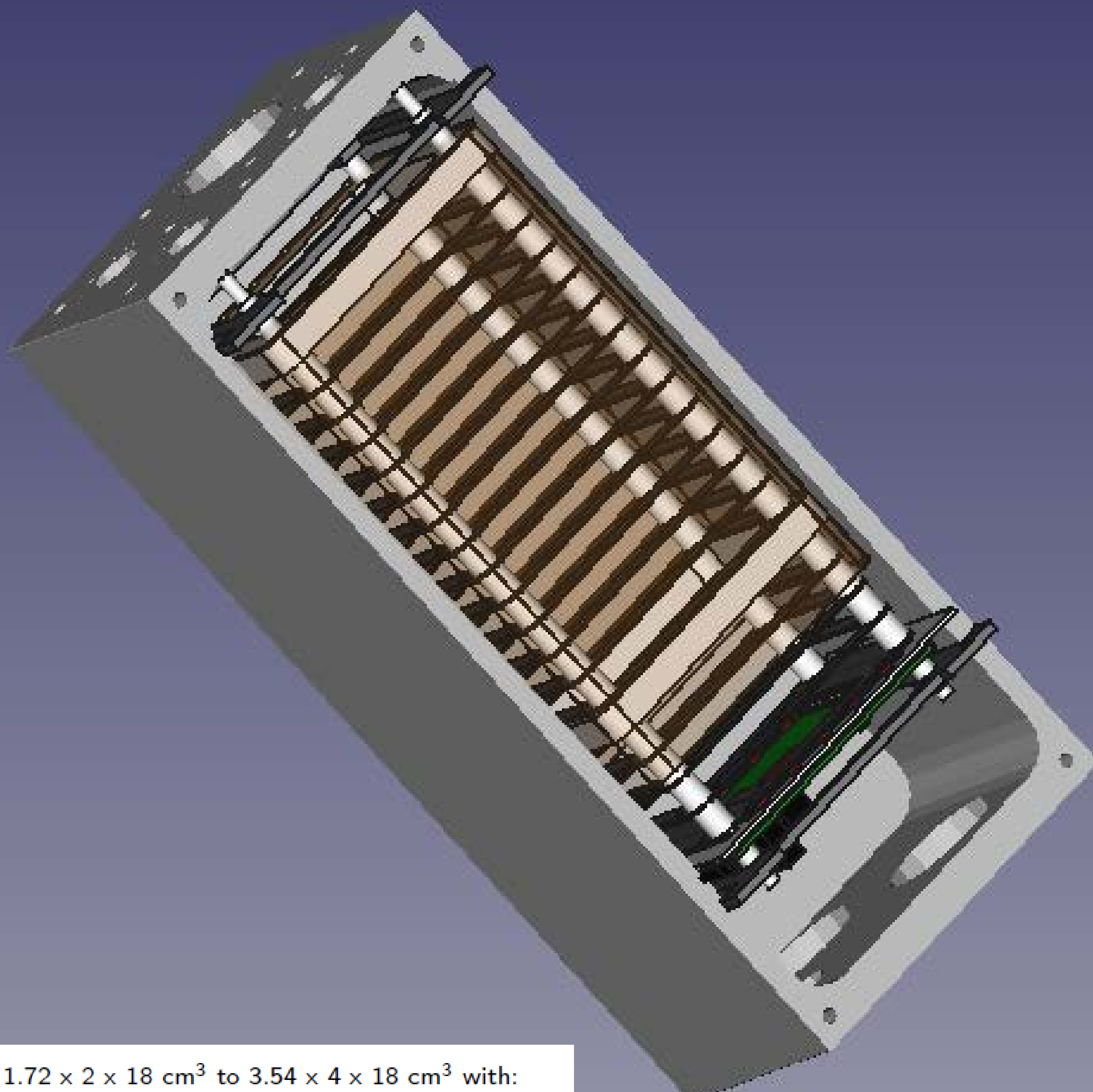


- add one layer of Kapton tape (0.0035" ie $\sim$ 1.8 kV dielectric resistivity) at screw and wall
- sparks where radius starts at 6.8 kV $\sim$ 5 % lower than the expected value (4.8+1.8 kV)

- add 10 layers of Kapton tape, no sparks at 8 kV

Spark Test Conclusion: all OK

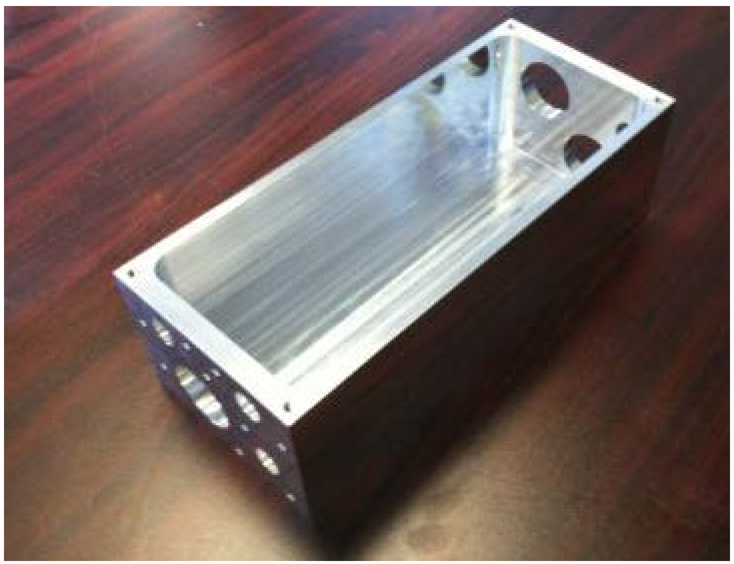
- Sparking starts <=40% below analytically expected threshold voltage, i.e. no large effect from surface roughness / edges
- Can test each field cage ring to ensure similar behavior
- 3 mil Parylene should be sufficient to avoid sparks to vessel wall & reduces outgasing (gas purity), but it is somewhat costly
- Kapton is inexpensive, add it for additional safety factor



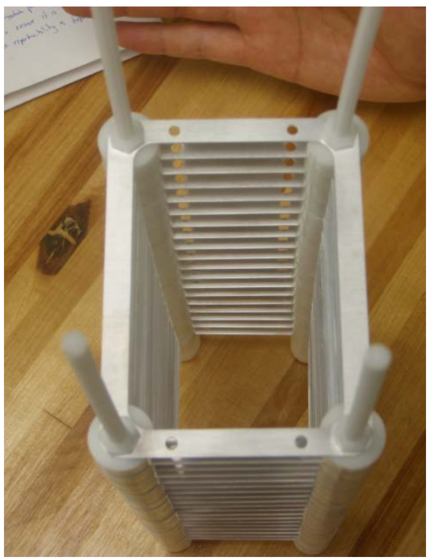
- sensitive volume between 1.72 x 2 x 18 cm^3 to 3.54 x 4 x 18 cm^3 with:
  - point resolution in $r\phi < 125\ \mu m$ in the 18 cm drift gap
  - point resolution in $z < 250\ \mu m$ in the 18 cm drift gap

Final TPC Prototype

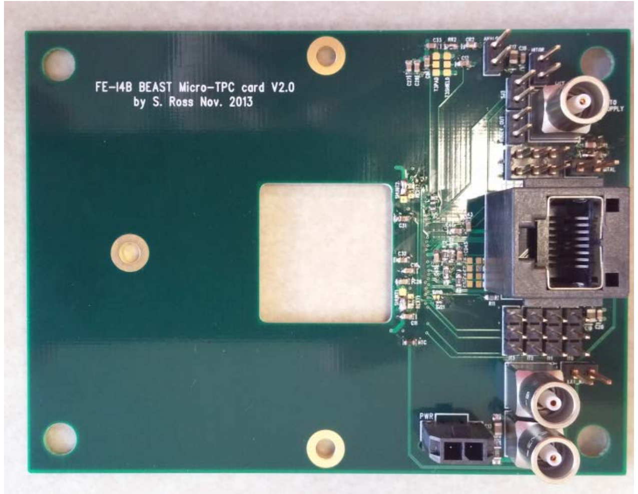
- Design finalized
- Two final prototypes are in production



Vacuum vessel



Field cage assembly



Final DAQ board

Other Considerations

- Issues not presented, but in backup slides
  - vessel material selection, activation
  - sensitivity to magnetic field axis / miss-alignment
  - gamma-ray rejection
  - TPC services, cabling (LV, HV, Gas system, DAQ)
  - position-dependent energy scale calibration

Conclusion

- Pre-prototype TPCs met all performance requirements
- Directional neutron detection with $HeC0_2$ gas demonstrated
- Final prototype designed, in production / assembly
  - Main changes from pre-prototype:
    - Fe-I3 → FE-I4b + new DAQ board
    - 5 cm drift w/ mesh → 18 cm drift w/ field cage

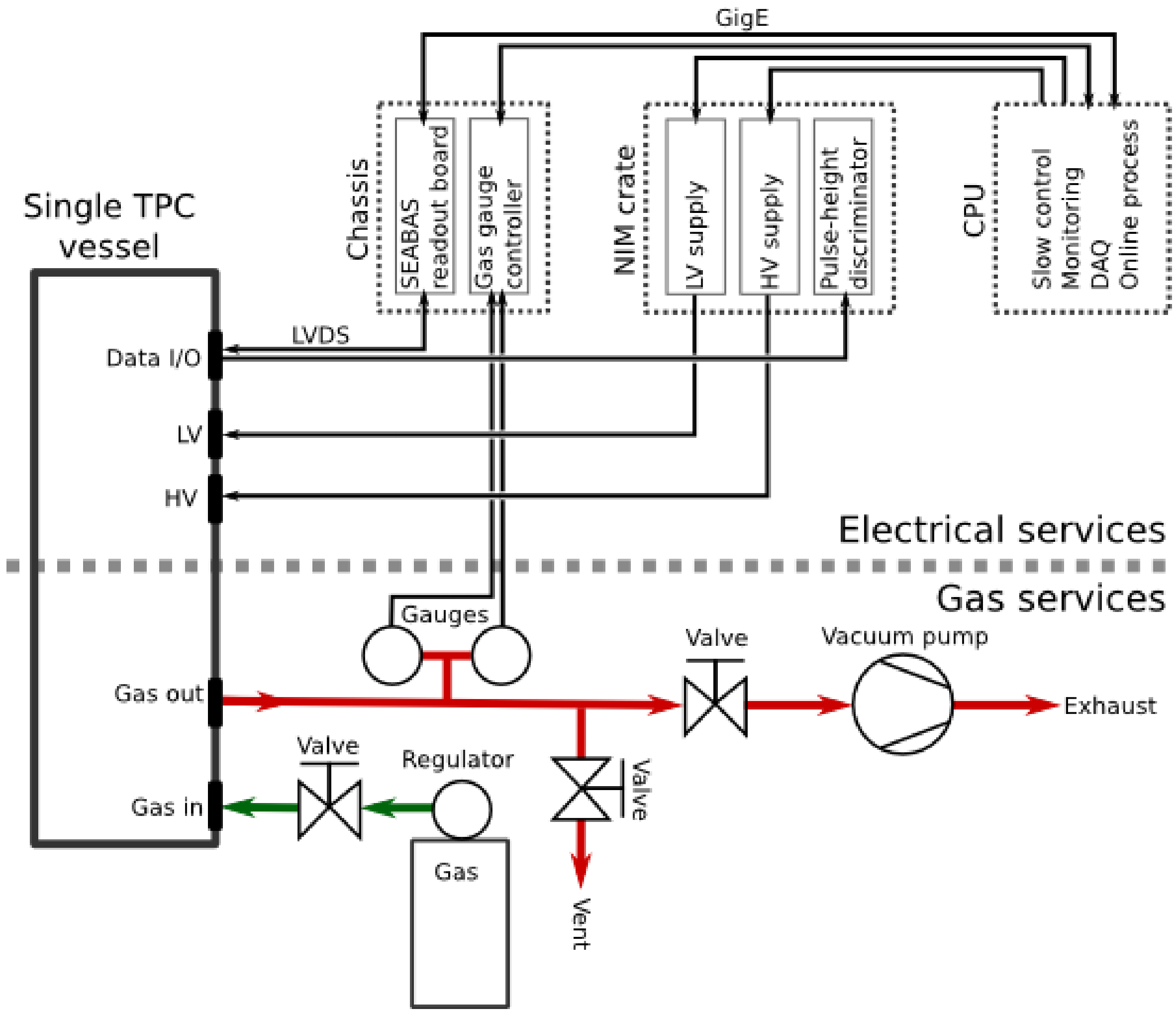
  →We've demonstrated operation of FE-I4b with near-final DAQ board

  →LBNL detector has demonstrated FE-I4a + 12 cm drift

  →We've built a mock field cage and studied sparking
- All ingredients and new features tested or demonstrated
- Detailed prototype testing with sources over holidays
- Final confirmation with neutron beam test in March

BACKUP SLIDES

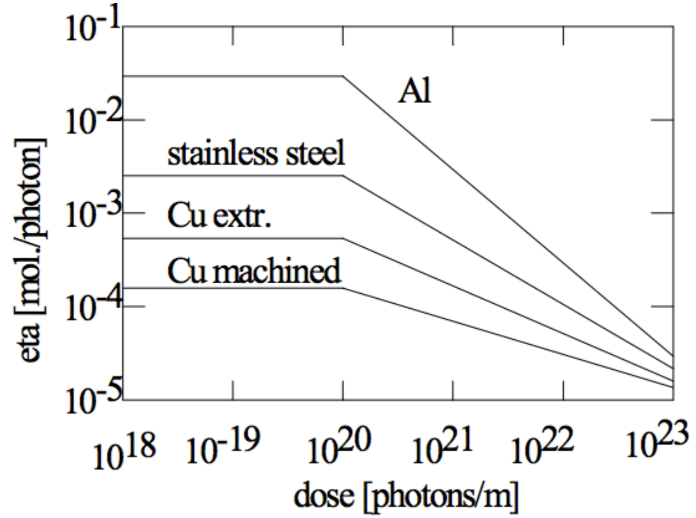
TPC services in phase II



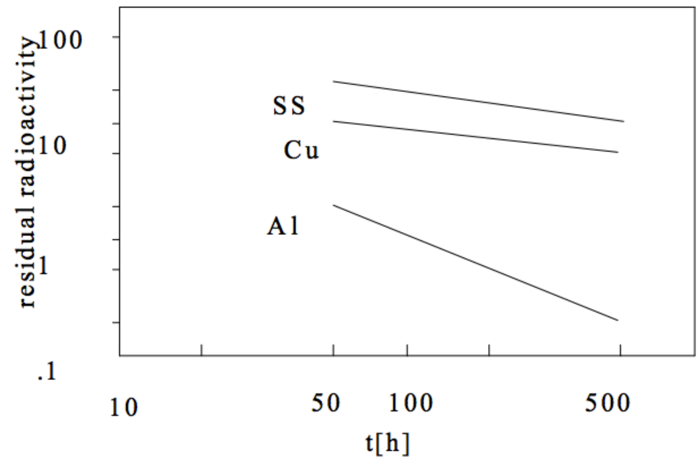
Choosing the vessel material

- Two best candidates: Aluminum 6063 or Stainless 316
- Considerations:
  - Magnetic permeability
    - Minimize distortions of magnetic field in vessel
    - Need permeability as close to vacuum [1.0] as possible
    - Al 6063: 1.000022
    - SS 316: 1.004, but cold-working can create pockets up to 7.0
    - With annealing SS 316 may be acceptable—**Al 6063 is ideal**
  - Desorption
    - SS 316 better than Al 6063 by ~order of magnitude in photon-stimulated desorption due to thick oxide layer on Al
    - With a parylene coating [needed for electromagnetic insulation], **both are identical**
  - Activation [more details next slide]
    - SS 316 activates much more readily
    - Residual activity in Al 6063 decays much more readily than in SS 316
    - **Al 6063 is ideal**
- Choice:
  - **Aluminum 6063**

Photon-stimulated desorption

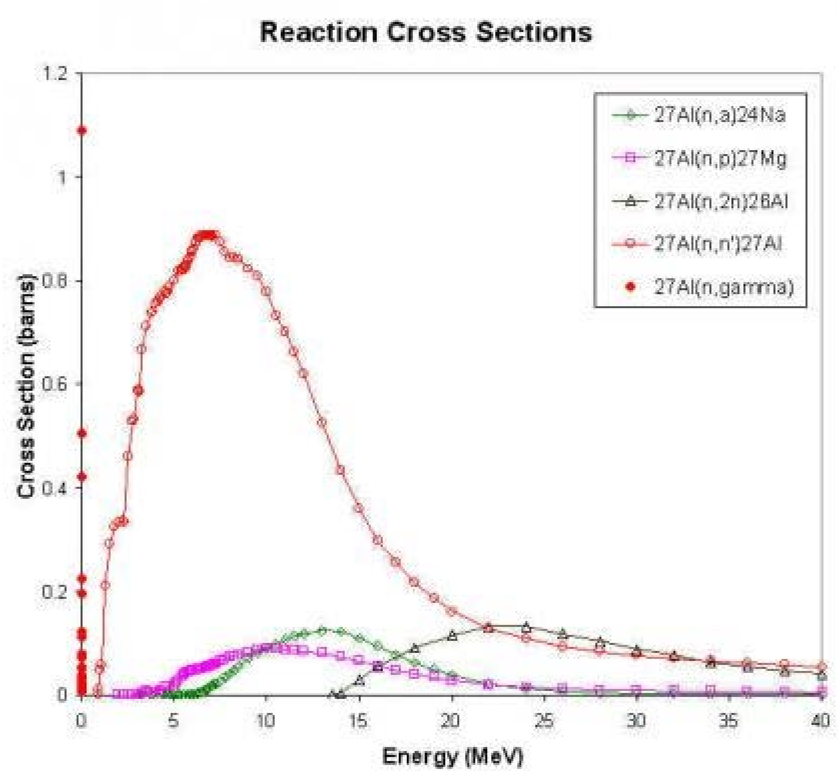


Residual activity



Activation

- Aluminum activation modes:
  - Large cross-section (12b) for thermal neutron capture $^{27}Al + n = {}^{28}Al$ with secondary β and γ
  - Several processes with cross-sections < 1b [right] with α, *n*, *p*, β and γ.



http://www.geneseo.edu/nuclear/aluminum-activation-results

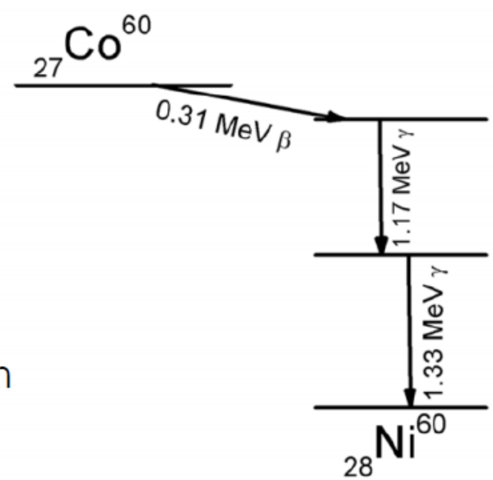
- Considerations:
  - Secondary backgrounds
    - β, γ and *p* easily removed offline with dE/dx selections
    - α from the field cage need to be minimized
    - Fast neutrons should be minimized
    - Cross-sections of processes that lead to *n* and α secondaries have integrated cross-sections less than 1b.
    - **Expected background rate for these processes is 2-3 orders of magnitude below the neutron flux from outside the vessel**
  - Safe handling of vessel after beam is turned off
    - Only major activation mode (neutron capture) produces ^{28}Al, which has a half-life of 2.2 minutes
    - Operation protocol will include ~15 minute cool-down period after beam shutoff

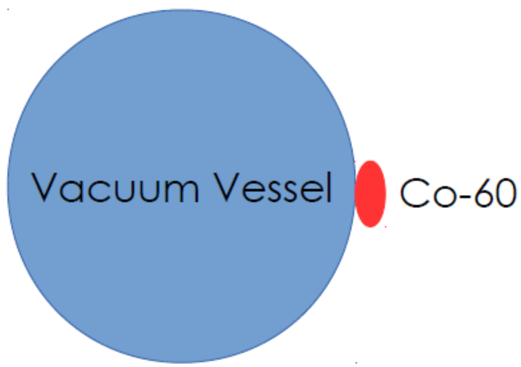
Co-60 Gamma Source Run

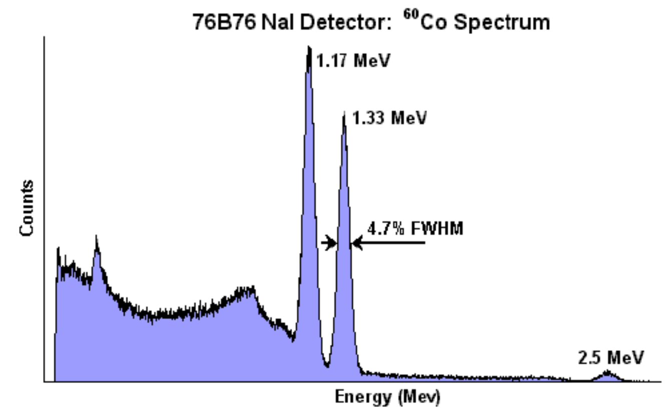
University of Hawaii
ILSOO SEONG

Co-60

- 1 μCi, born Sep. 2009
- $T_{1/2}$ = 5.2714 year
- Current activity : 0.578 μCi
- Vacuum wall thickness : 3.175 mm
  -> 0.51 μCi (assume as iron)
- Distance from wall to center of chip : 127.5 mm
  -> 0.293 μCi in air



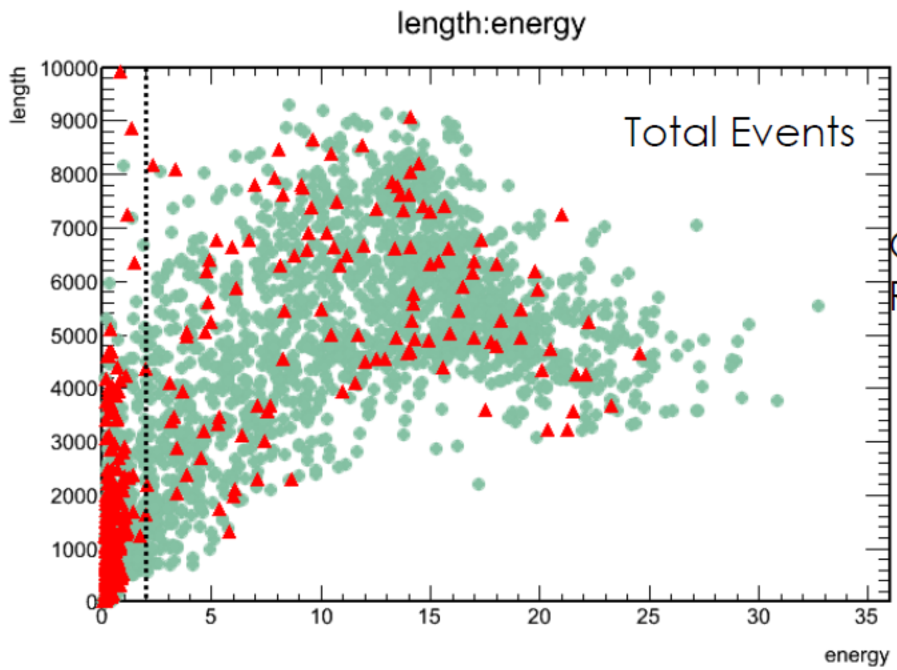




From somewhere on web

Event Rate

	background	neutron (0 degree)	gamma source
Total Number of Events	3735	1886	2088
Total Event Rate (hour^{-1})	2.79	10.50	14.76
Single Hit Events (hour^{-1})	0.92	2.57	8.30
Saturated Events (hour^{-1})	0.40	0.93	0.25
Loose Cut (hour^{-1})	0.32	1.97	0.20
Final Cut (hour^{-1})	0.02	0.52	0.01



Green dot : background
Red Tri. : gamma

Plan : measure gamma energy from our neutron source

Monte Carlo simulation study of magnetic field impact

Igal Jaegle

University of Hawai'i at Mānoa

for the Belle2 Collaboration

Technical Review

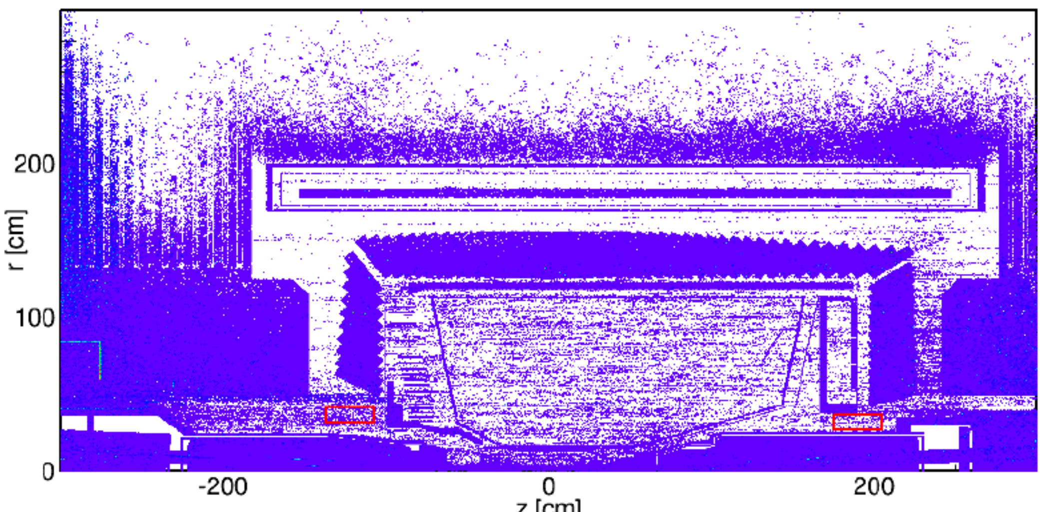
Table of contents

Introduction

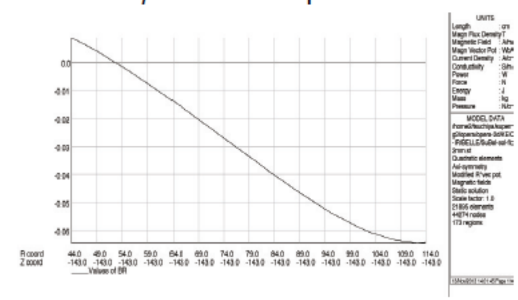
During phase 2 and phase 3, the micro-TPCs will be located inside a super-conducting solenoid that provides a 1.5 T magnetic field.

- precisely in the forward and backward dock-spaces
- magnetic field homogeneity affected by the evolving radiation shielding design around beam pipes

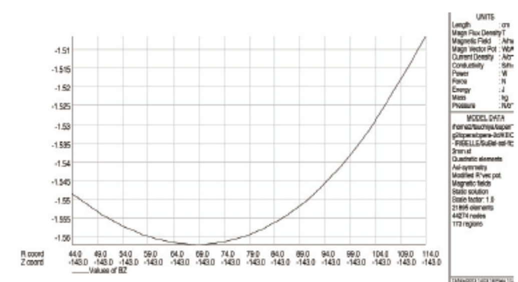
- "phase 2/3" top view - TPCs located in dock-spaces



- B_r at ARICH position



- B_z at ARICH position

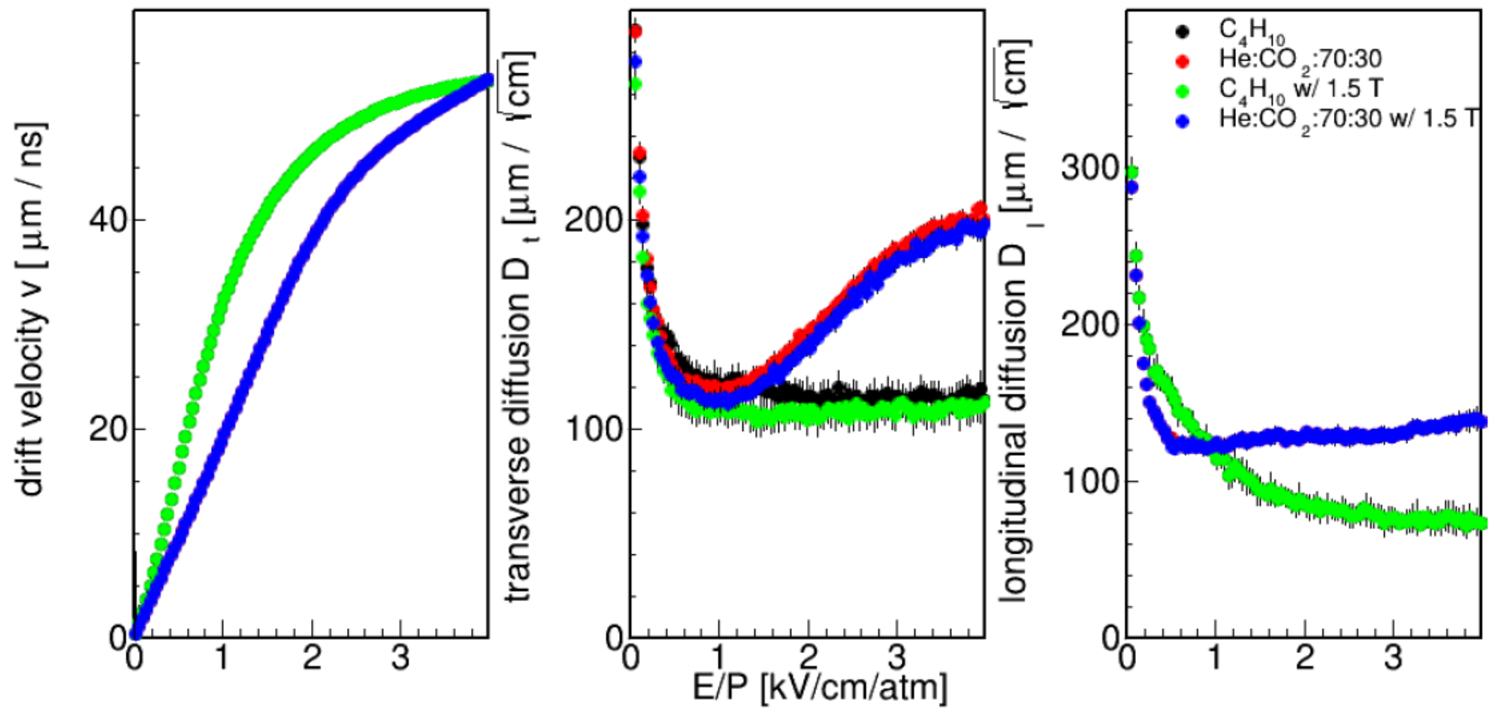


- 8 TPC chambers 10.5 x 13.5 x 30 cm^3
- optimal condition: E || B (530 kV/cm || 1.5 T)
- B_r/B_z in dock-spaces estimated to be less than 1 %

Magnetic field effect on gas properties

Calculated by MAGBOLTZ

- gas parameters

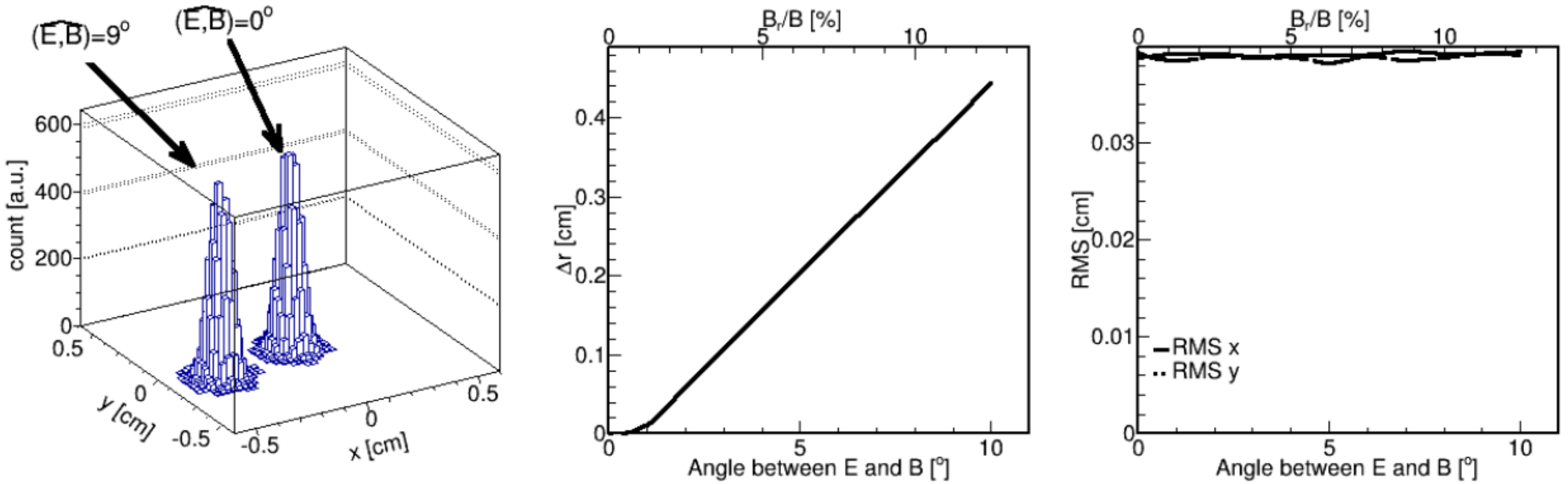


- B-field has negligible effect on gas properties (for gases with small drift velocity)
- we want E || B
- if not E || B => diffusion and drift velocity more complex form that will affect drift charge path to the amplification stage

Magnetic field impact on drift charge

Calculated by MAGBOLTZ and GARFIELD++

- impact on drift charge path (for an extreme case)
- Δr vs. B_r/B_z
- diffusion RMS vs. B_r/B_z



- radial displacement (Δr) calculated for a drift distance of 10 cm and (x=0,y=0)
- diffusion not affected
- for $B_r/B_z < 1$ %, $\Delta r < 100\ \mu m$
- same effect if E not perfectly aligned

Conclusion

Magnetic field effect on gas properties has been estimated:

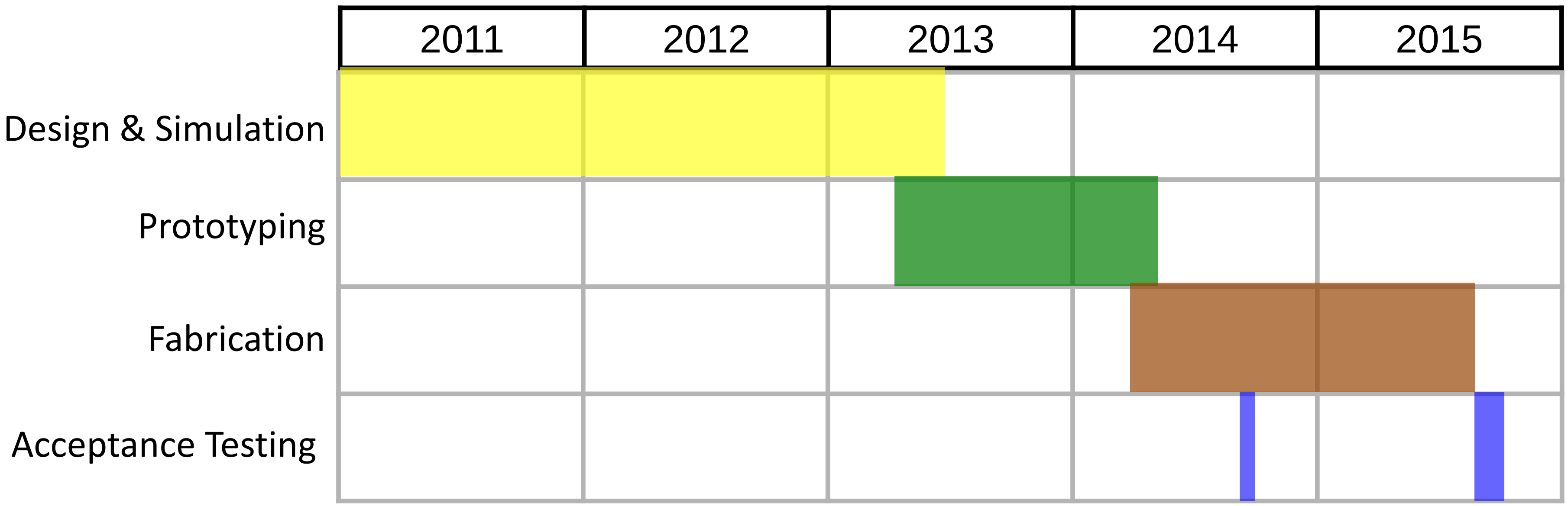
- negligible effect on diffusion if E || B or not parallel

Magnetic field non-homogeneity impact has also been estimated on drift charge path to the amplification stage:

- if $B_r/B_z < 1\ \%$ impact is negligible

Schedule

- Key drivers/constraints
  - Deliver PIN diodes, two prototype TPCs, mechanical structure, DAQ to support SuperKEKB turn-on in Jan 2015 (phase I)
  - Deliver 8 final TPCs for measurements starting Feb 2016 (phase II)



Schedule shows calendar years.

Key Personnel

- TPC Lead: S. Vahsen (faculty)
- TPC mechanical: I. Jaegle (postdoc)
- TPC DAQ + DAQ integration: P. Lewis (postdoc)
- Supported by experienced mechanical engineer (Rosen), four graduate students, two machine shop staff, undergraduates
- Wirebonding & electronics support from LBNL

Team at U. Hawaii

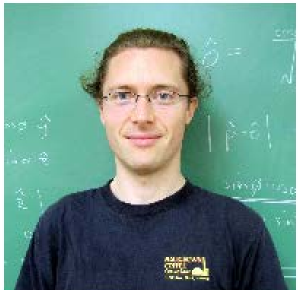
Igal Jaegle
Postdoc

Jared Yamaoka
Postdoc

Marc Rosen
Mechanical Engineer

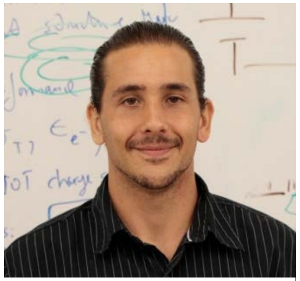
Michael Hedges
Graduate Student

Steven Ross
Graduate Student



Thomas Thorpe
Graduate Student

Ilsoo Seong
Graduate Student

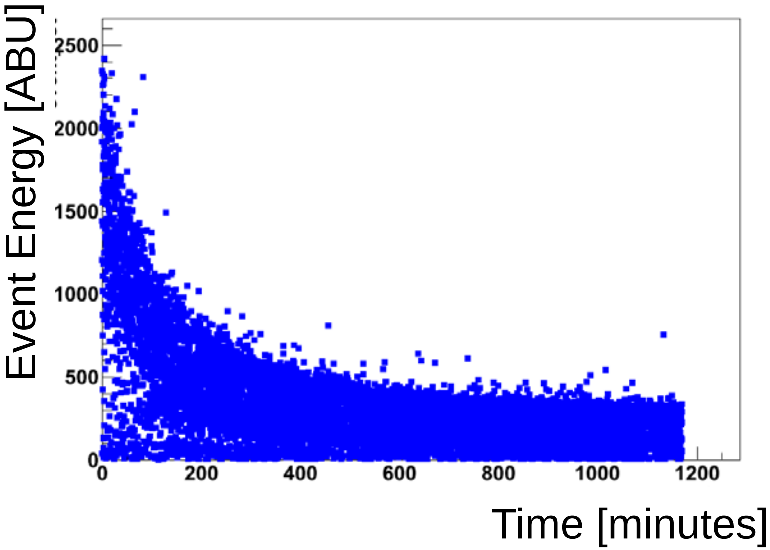


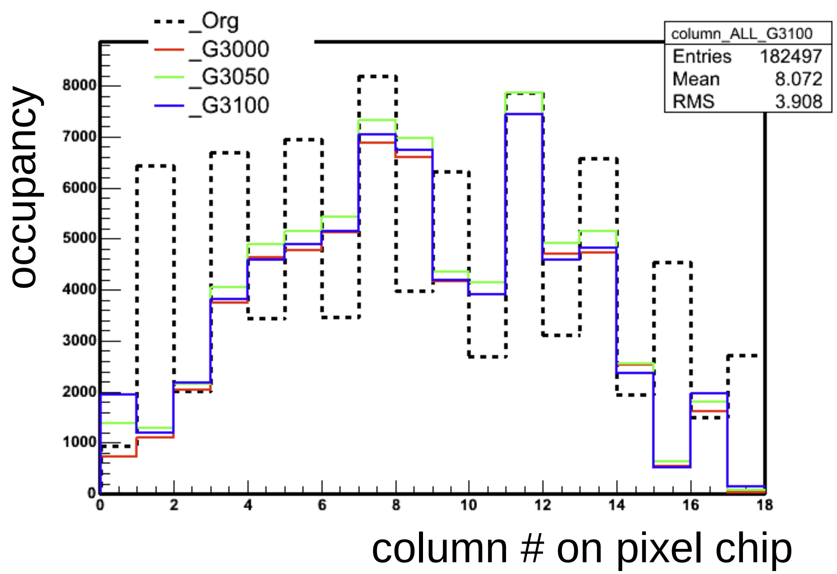
Kamaluoawaiku Beamer
Undergraduate Student
(+5 others!)

Sven E. Vahsen

UNIVERSITY of HAWAI'I
MĀNOA

Energy VS Time and Position





- …More detailed investigation revealed: even though GEM gain and pixel calibration are stable & uniform, effective gain is time and position dependent
- Hypothesis: charge-up of pixel chip surface distorting E-fields and affecting ***charge collection efficiency***
- *Supporting evidence:*
  - *Higher gain → faster gain reduction*
  - *Gain recovers when E-field turned off*

Studying Time /Position Dependence I

rectangular aluminum pads deposited on top of chip, grounded during operation

ATLAS FE-I3

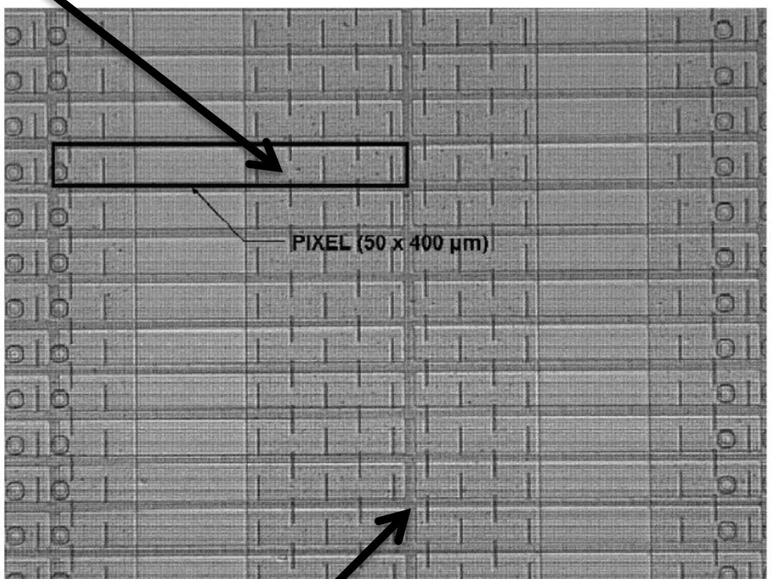
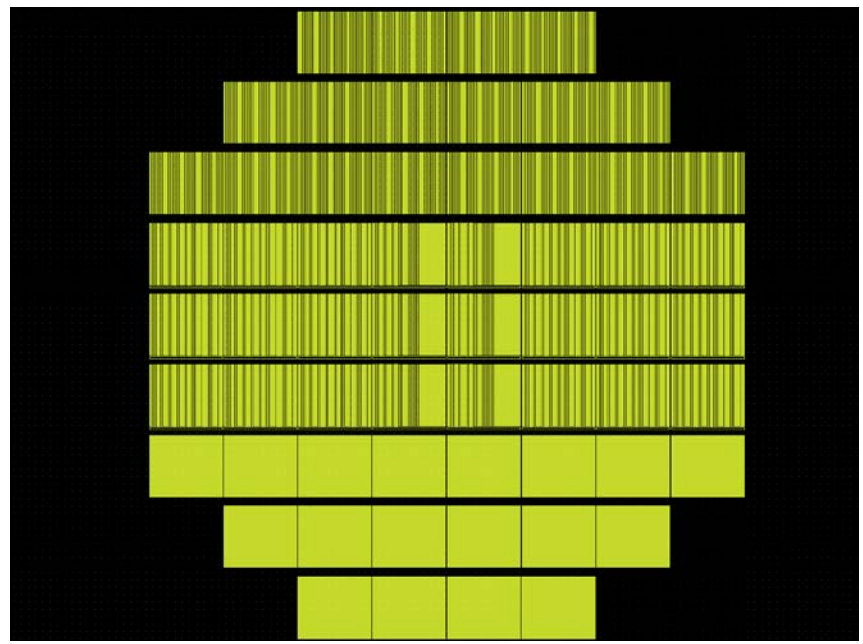


Fig. 6. Microphotograph of the surface of the ATLAS FEI3 chip after deposition of gold. One of the 50 x 400-micron cells is outlined. The entire chip, containing 2880 pixel cells, is 7.2 mm by 10.8 mm in surface dimensions and is 700 microns in thickness.

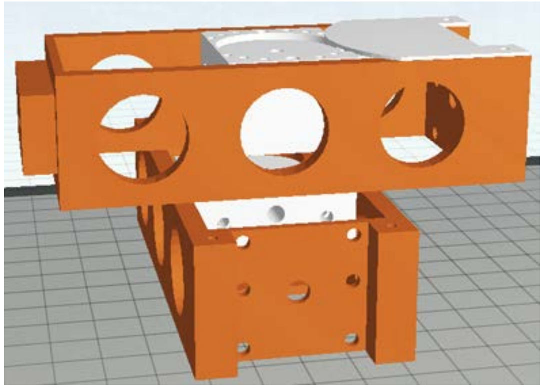
FE-I4: depositing a variety of metal pad shapes to study effect on effective gain (see backup slides)

ATLAS FE-I4 Wafer

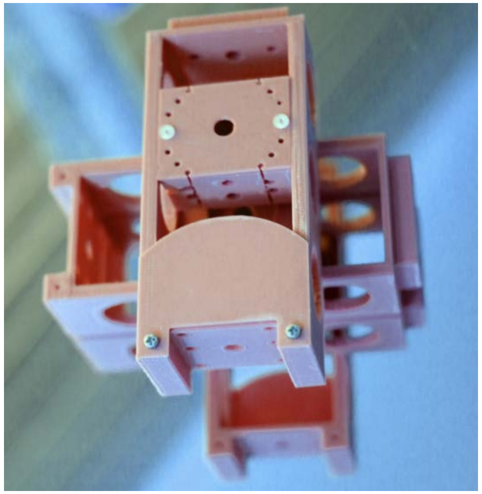


SiOxide between pad is insulating. Charging up at high gains & rates?
→ may explain both position and time-dependence

Studying Time /Position Dependence II

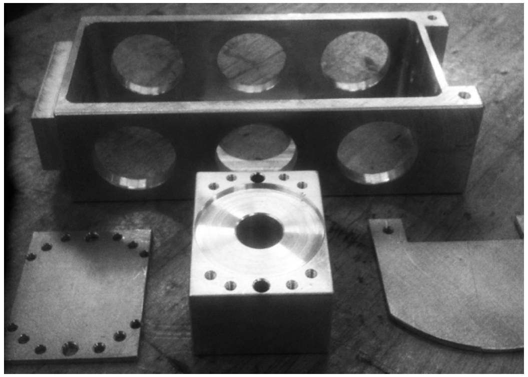


CAD design



3D-printed model

- Undergrad student designed 2D-motion stage for scanning collimated Fe-55 calibration source across chip
- Will allow us to measure position and time dependence of energy scale versus metal pad shape



machined, final aluminum parts