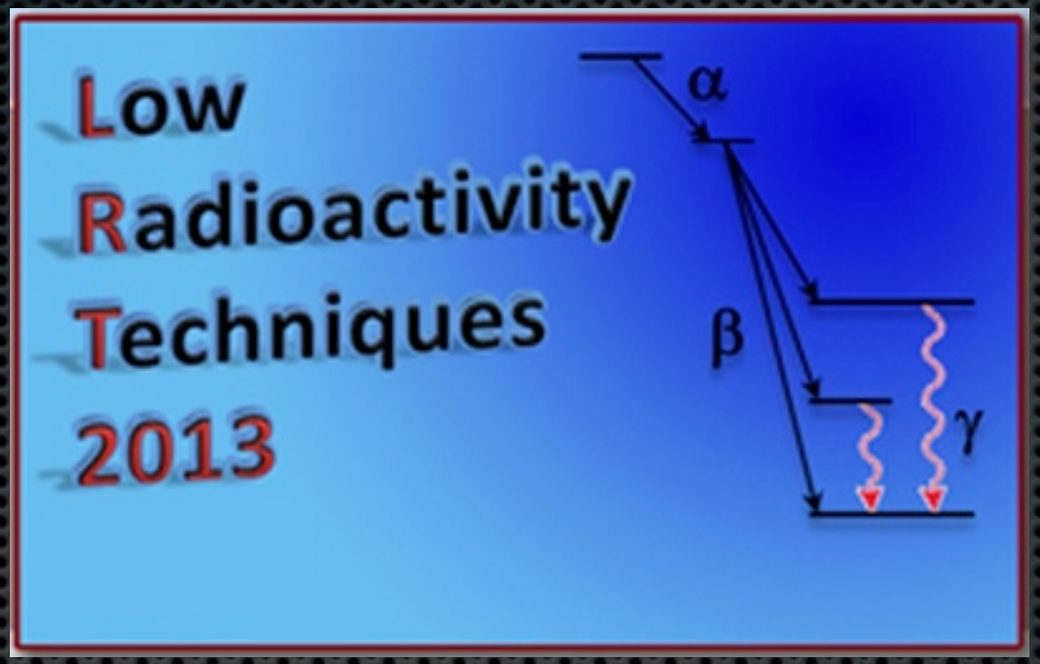
The Prototype BetaCage



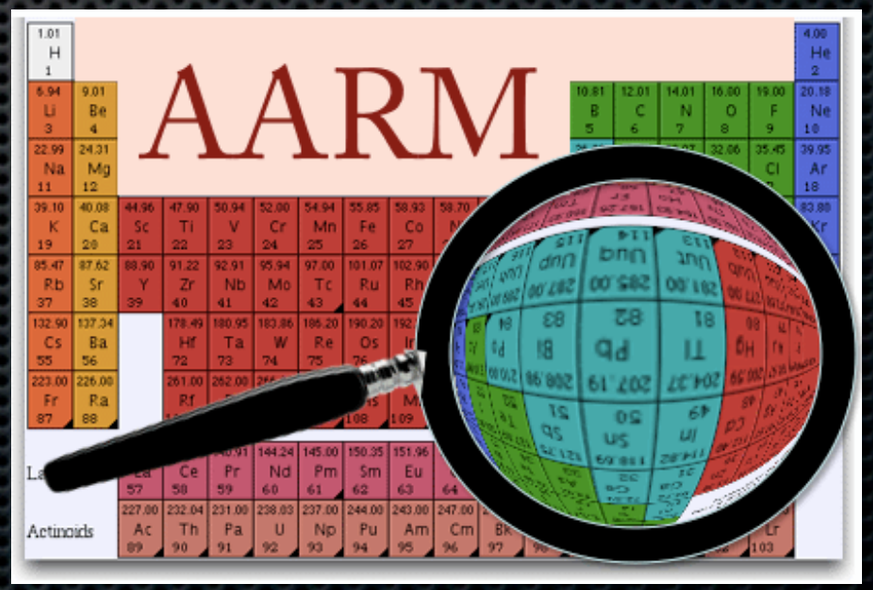
Robert H. Nelson
Caltech
2013.04.10

BetaCage Collaboration

Z. Ahmed, S. R. Golwala, R. H. Nelson*, A. Rider, A. Zahn

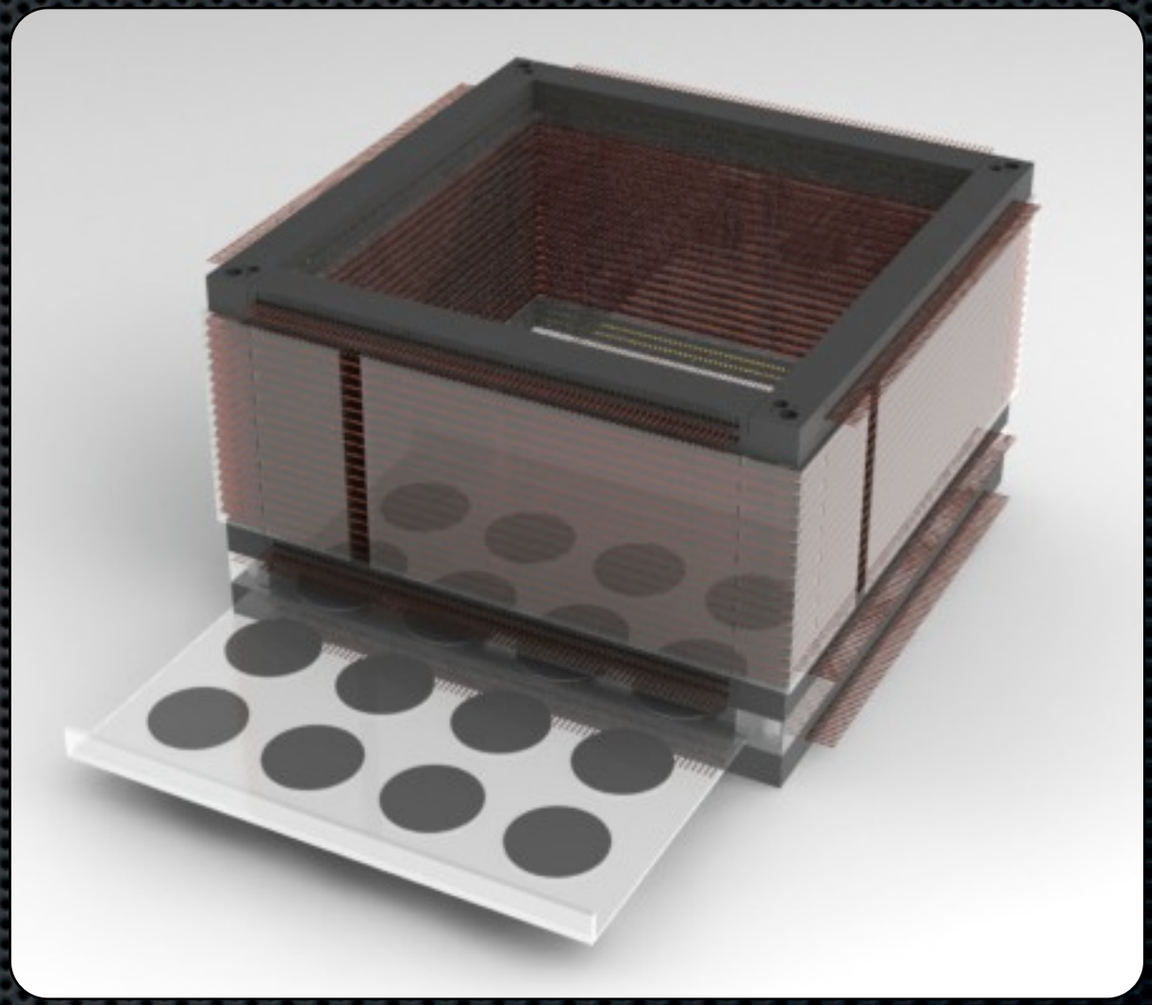
M. Bowles, R. Bunker, M. Kos, R. W. Schnee, B. Wang

D. Grant



Outline

- Design goals
- Prototype assembly and design
- MWPC data results
- Electronics
- Track reconstruction
- Gain mapping



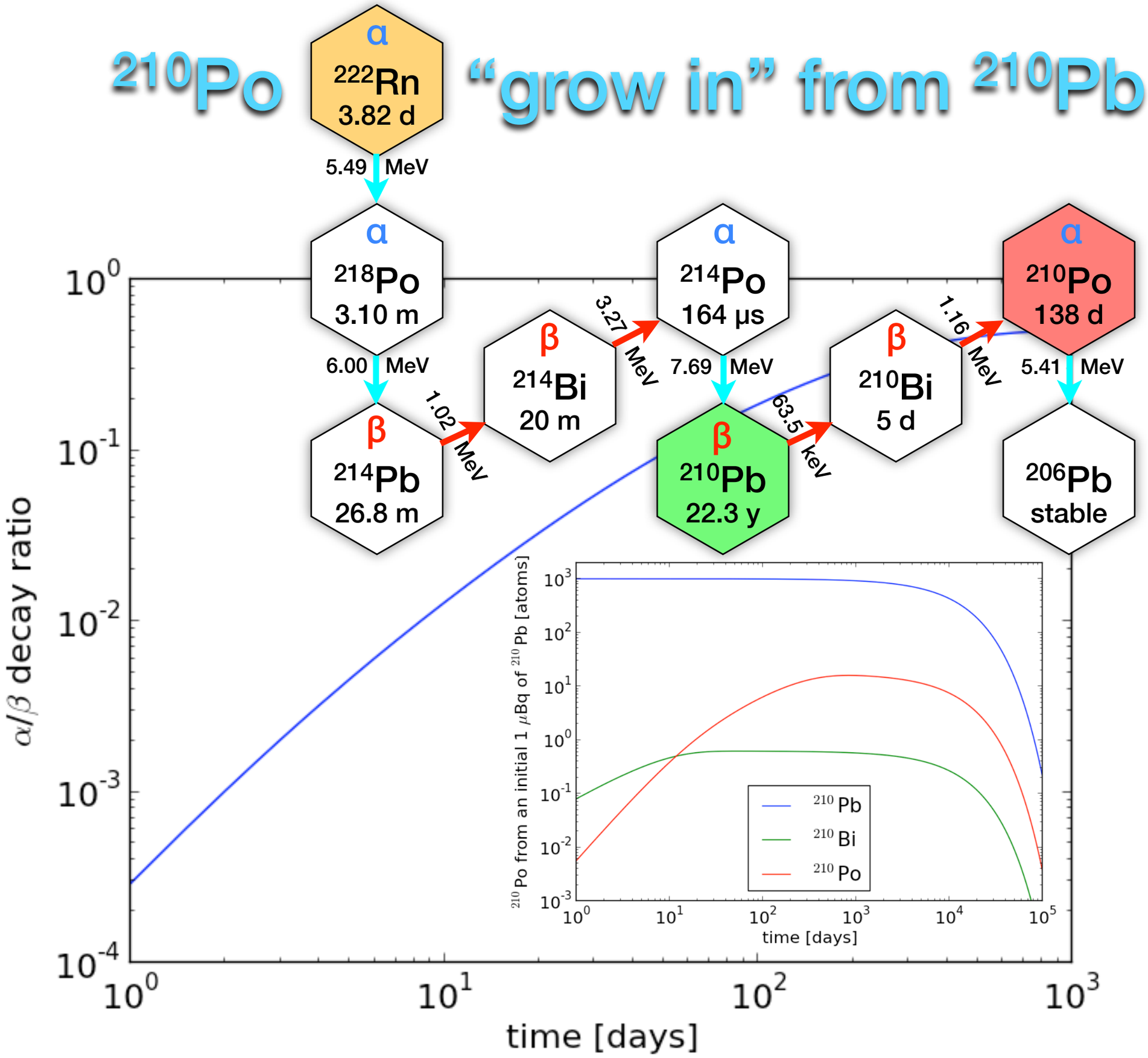
Need for a beta screener

Method	Long-lived Beta-Emitting or Electron-Capture Isotopes
ICP-MS (1 ppb)	^{40}K ^{48}Ca ^{50}V ^{87}Rb ^{92}Nb ^{98}Tc ^{113}Cd ^{115}In ^{123}Te ^{138}La ^{176}Lu ^{182}Hf ^{232}Th ^{235}U ^{238}U ^{236}Np ^{250}Cm
ICP-MS (1 ppt)	^{10}Be ^{36}Cl ^{60}Fe ^{79}Se ^{93}Zr ^{94}Nb ^{97}Tc ^{99}Tc ^{107}Pd ^{126}Sn ^{129}I ^{135}Cs ^{137}La ^{154}Eu ^{158}Tb ^{166m}Ho ^{208}Bi ^{208}Po ^{209}Po ^{252}Es
γ	^{40}K ^{50}V ^{60}Fe ^{60}Co ^{93}Zr ^{92}Nb ^{94}Nb ^{93}Mo ^{98}Tc ^{99}Tc ^{101}Rh ^{101m}Rh ^{102m}Rh ^{109}Cd ^{121m}Sn ^{126}Sn ^{125}Sb ^{129}I ^{134}Cs ^{137}Cs ^{133}Ba ^{138}La ^{145}Pm ^{146}Pm ^{150}Eu ^{152}Eu ^{154}Eu ^{155}Eu ^{157}Tb ^{158}Tb ^{166m}Ho ^{173}Lu ^{174}Lu ^{176}Lu ^{172}Hf ^{179}Ta ^{207}Bi ^{208}Bi ^{232}Th ^{235}U ^{238}U ^{236}Np ^{241}Pu
α	^{210}Pb ^{208}Po ^{209}Po ^{228}Ra ^{227}Ac ^{232}Th ^{235}U ^{238}U ^{236}Np ^{241}Pu ^{250}Cm ^{252}Es
β/ppt MS	^{10}Be ^{36}Cl ^{79}Se ^{97}Tc ^{107}Pd ^{135}Cs ^{137}La ^{154}Eu ^{209}Po
β only	^{3}H ^{14}C ^{32}Si ^{63}Ni ^{90}Sr ^{106}Ru ^{113m}Cd ^{147}Pm ^{151}Sm ^{171}Tm ^{194}Os ^{204}Tl

Thanks H. N. Nelson and I. Ruchlin

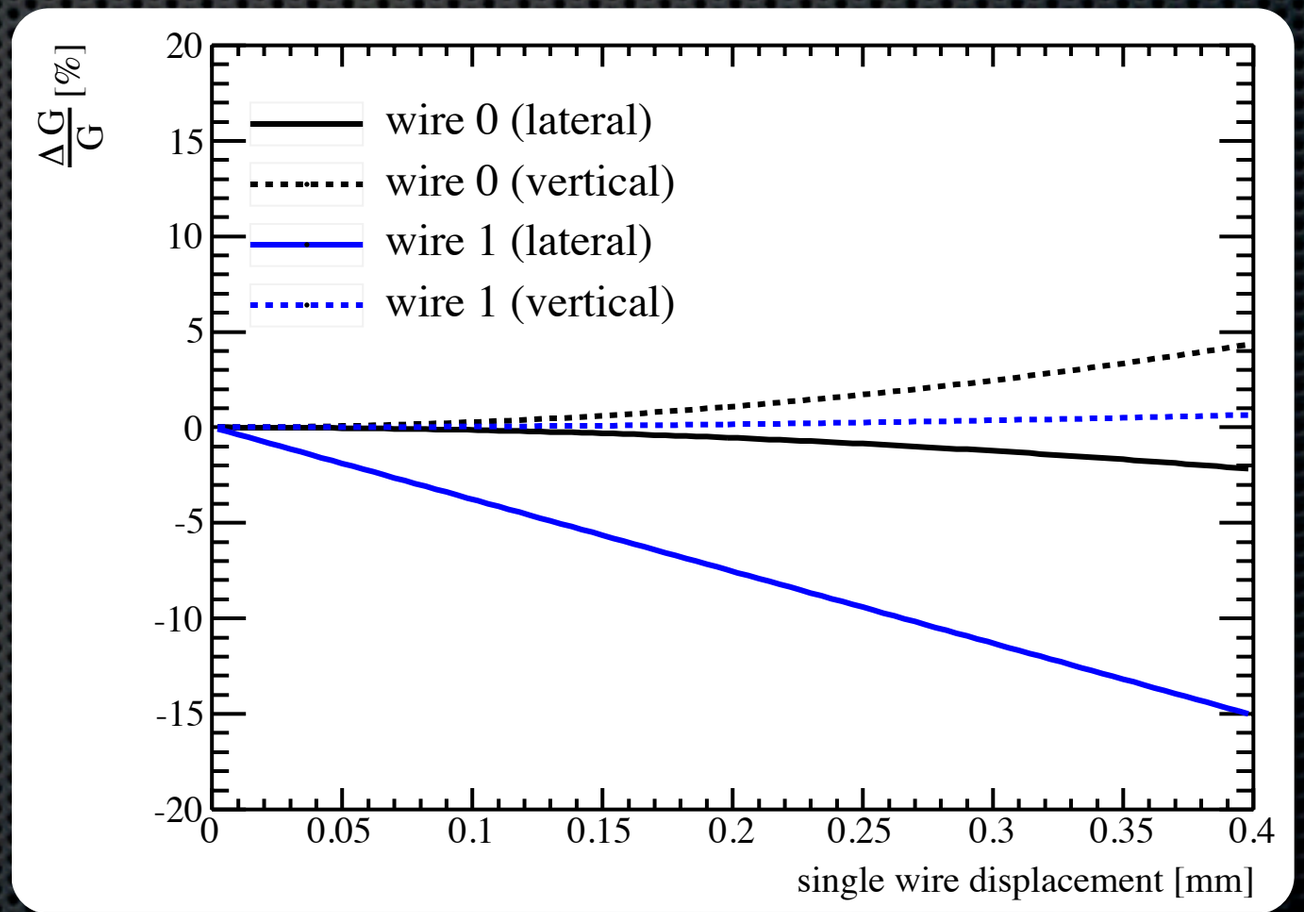
- There are 21 isotopes that can only be assayed using β-screening or extraordinary ICP-MS measurements.
- Some isotopes are currently measured by α-decays of their decay products.
- The sensitivity goals is 0.1 β/keV-m^2-day and 0.1 α/m^2-day (R. Bunker Poster).

^{210}Po "grow in" from ^{210}Pb

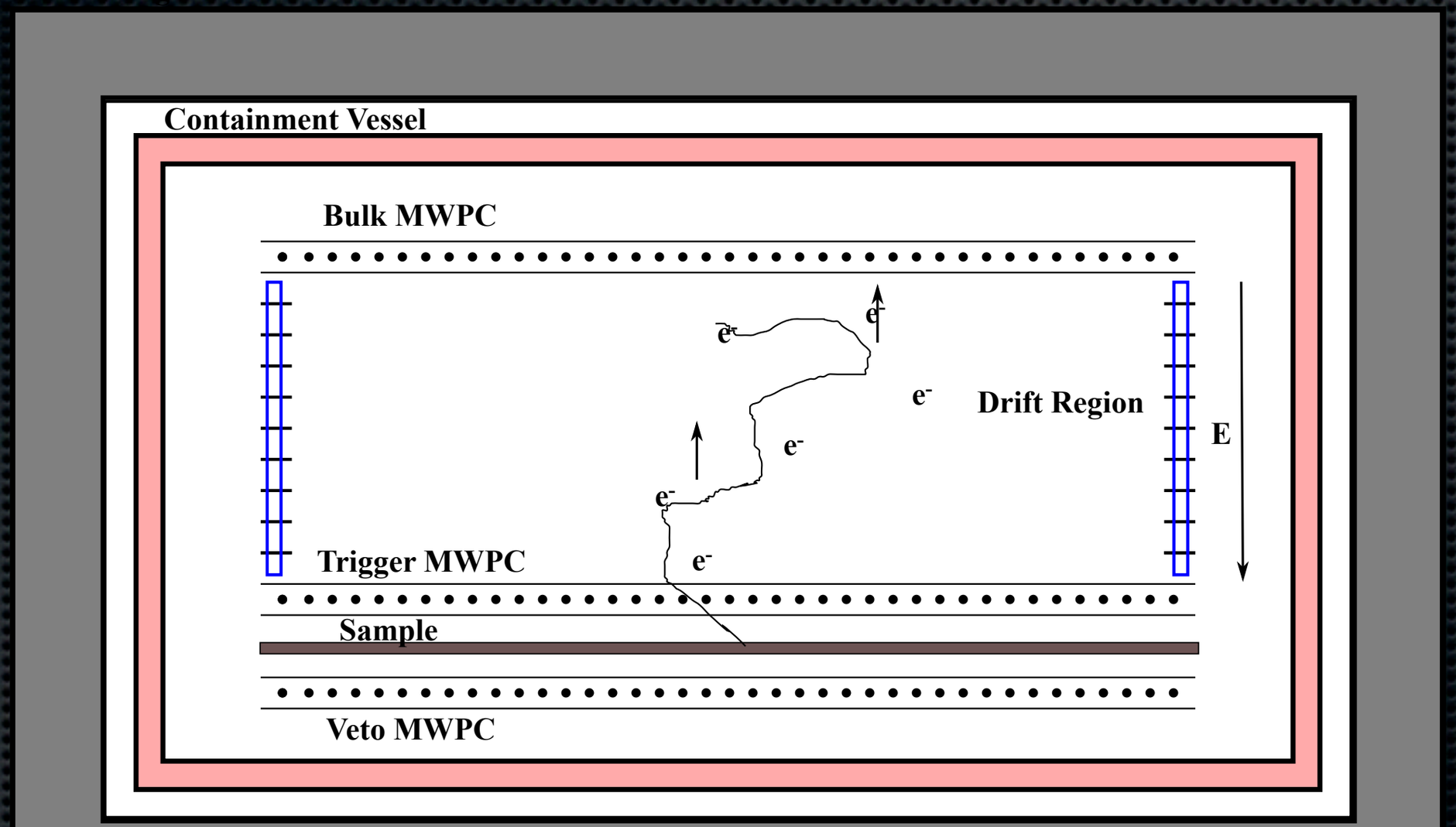


Mechcanical design considerations

- Gain variations: Goal < 5%
  - Anode wire variations:
    ΔD = 3% ⇒ ΔG/G = 10%
  - Frame displacement:
    Δz = 1 cm ⇒ ΔG/G = 0.2%
  - Single wire displacement:
    Δd = 25 μm ⇒ ΔG/G = 1.7%

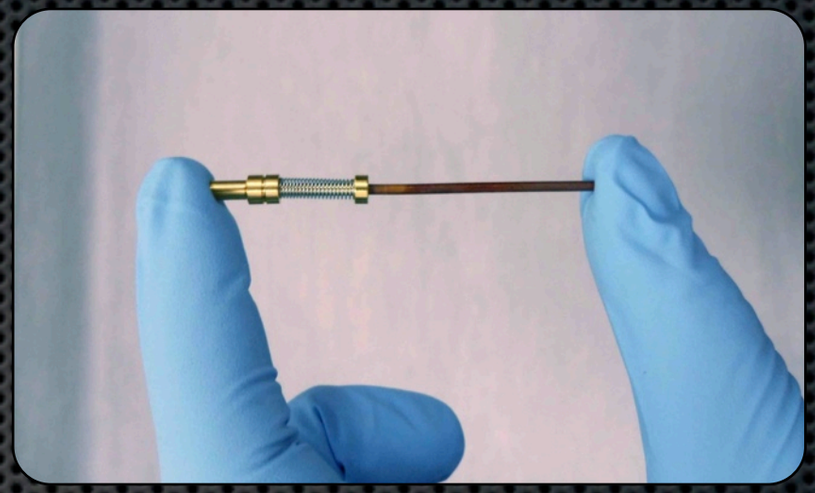


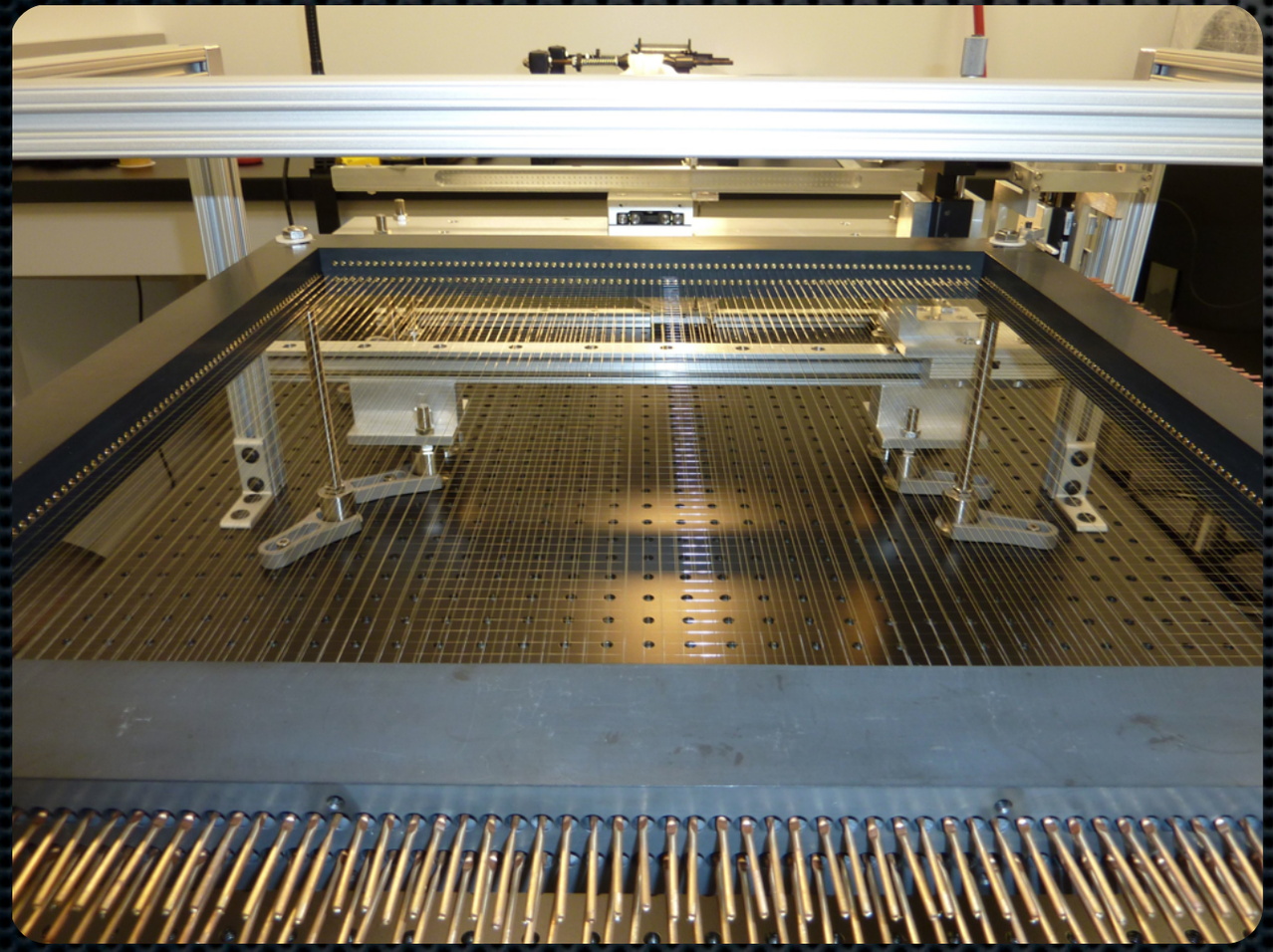
BetaCage concept

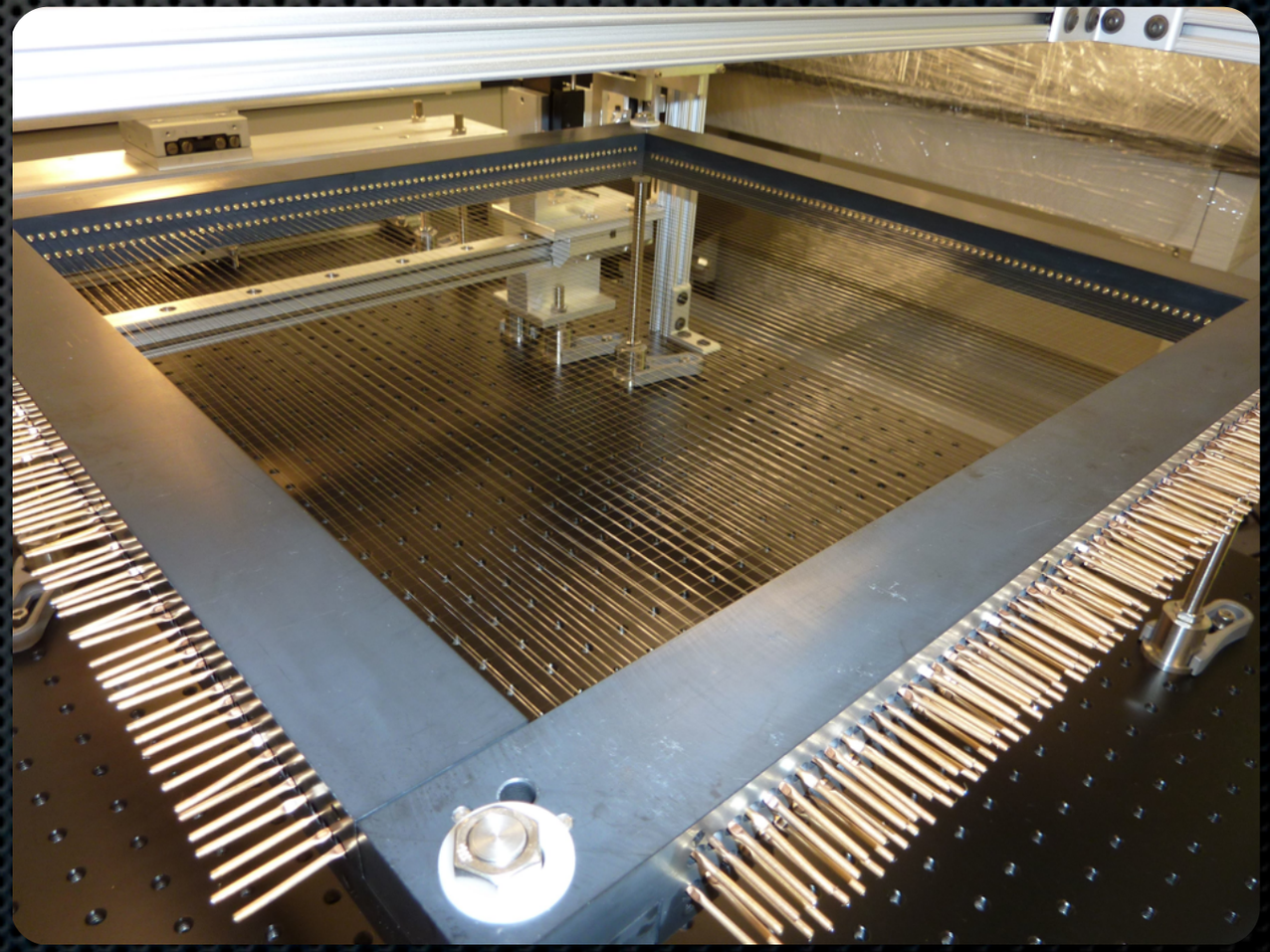


Fully-strung MWPC frame

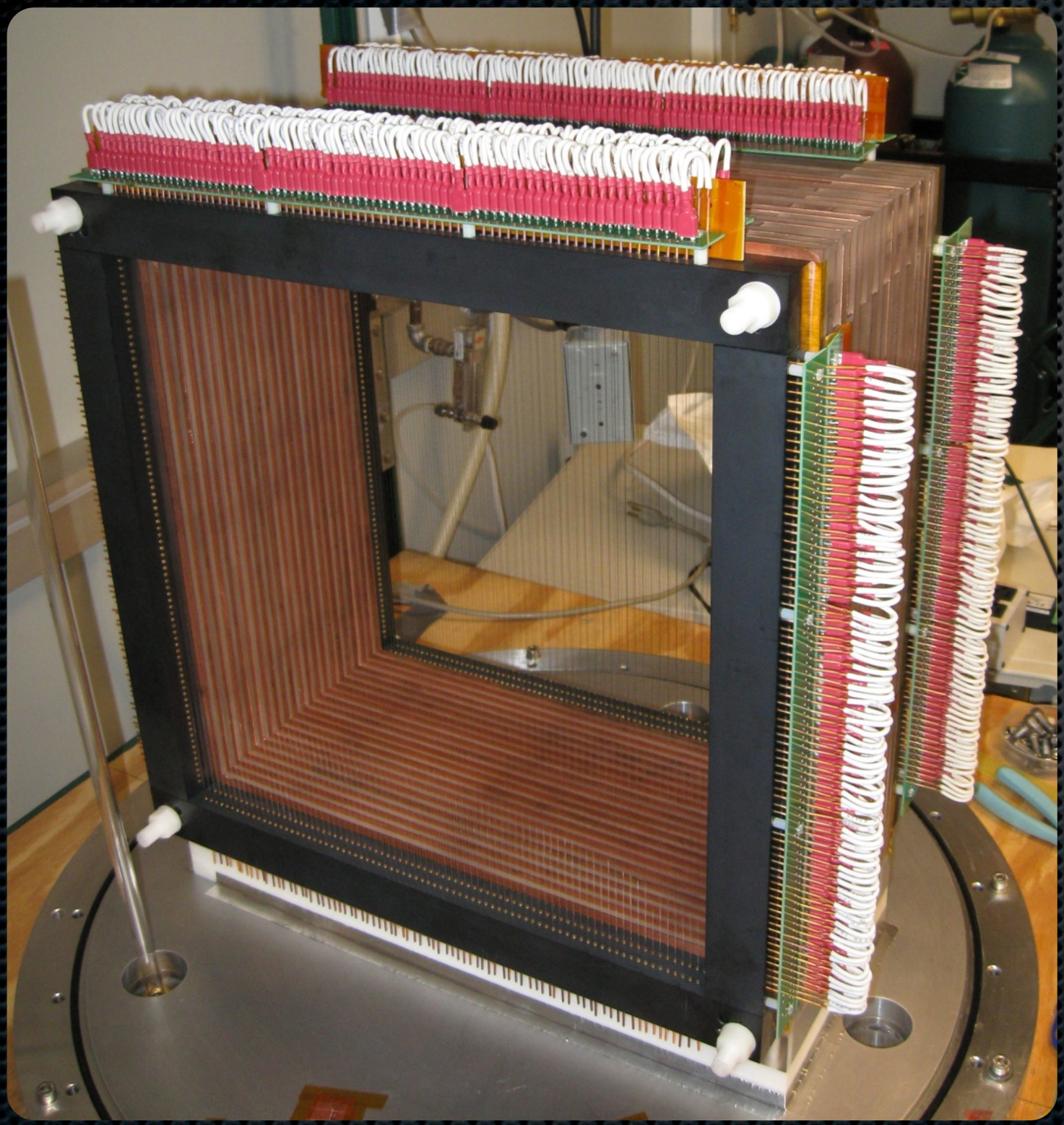
- MWPC comprised of 2 cathode layers and a crossed anode layer: 5 mm pitch, 5 mm plane spacing
- Spring-loaded feedthrus.
- MWPC-frame assembly occurred in a class 1000 cleanroom.
- Wires were strung using a custom stringing jig. Roughly 6 minutes per wire.







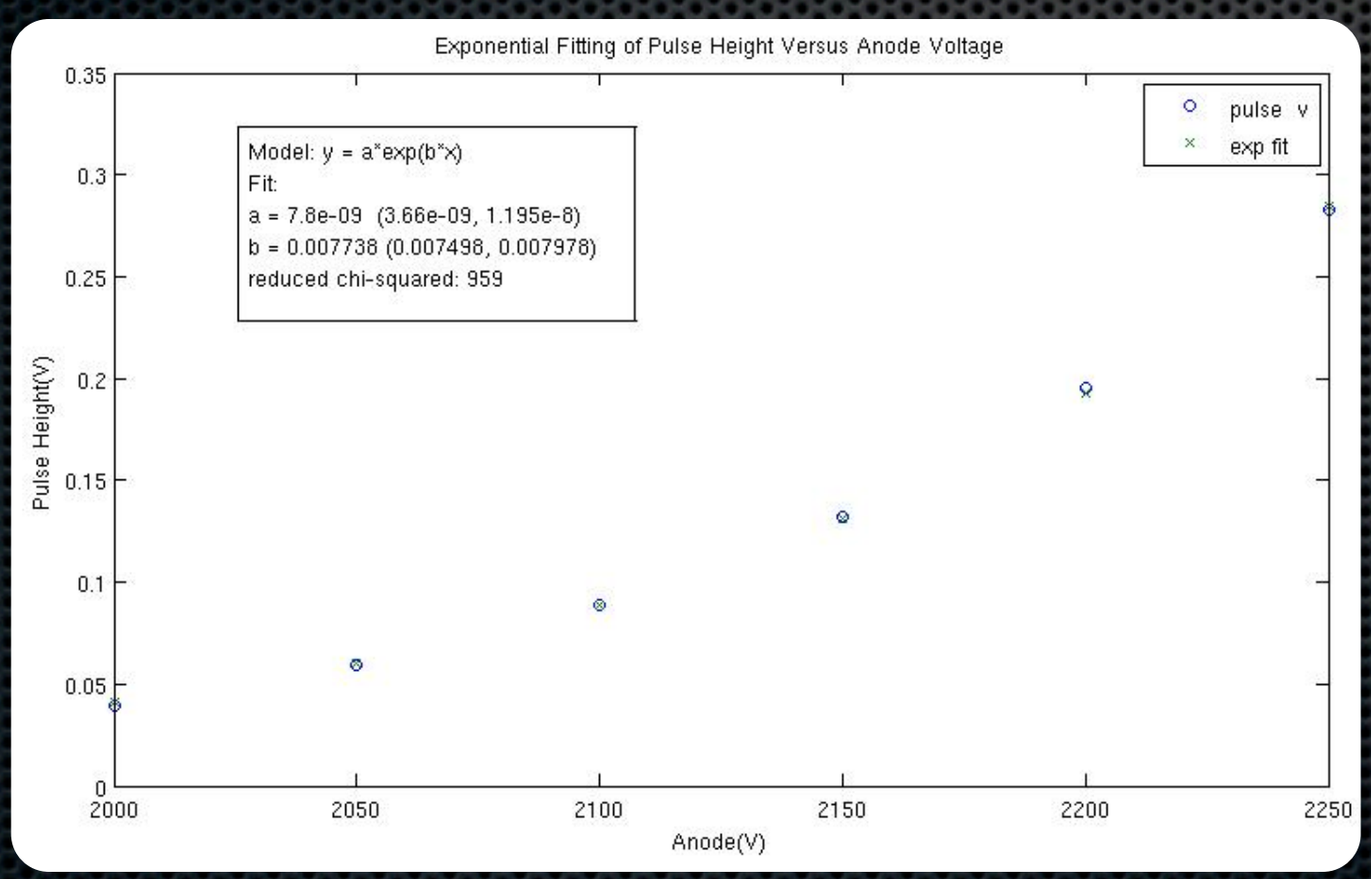
Assembled BetaCage prototype

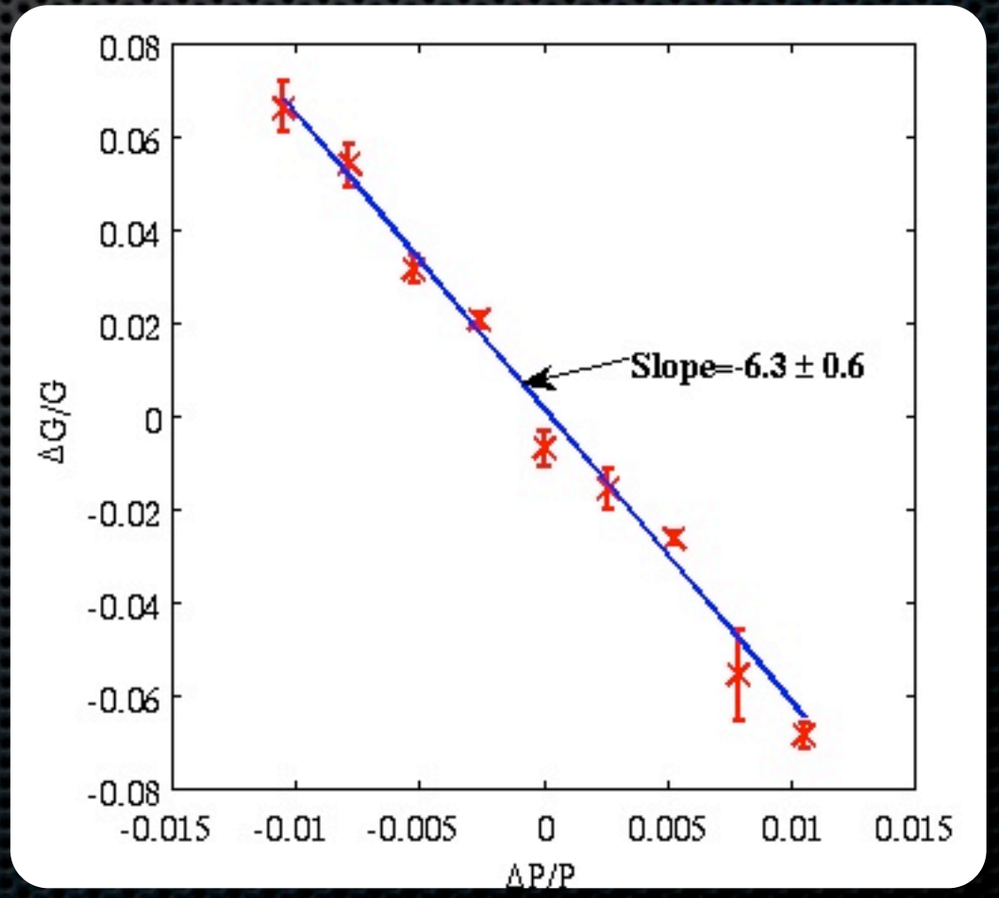


- 2 40x40-cm^2 MWPCs (3 layers of 79 wires each) sandwiching a 20-cm field-cage.
- Standing on end to fit in our bell jar.
- Prototype only uses 2 MWPCS.
  - A trigger MWPC
  - An imaging “bulk” MWPC
- P10 gas at STP; eventually switch to neon/methane.
- Anode planes at ~2 kV relative to their cathode planes. 50 V/cm drift field.

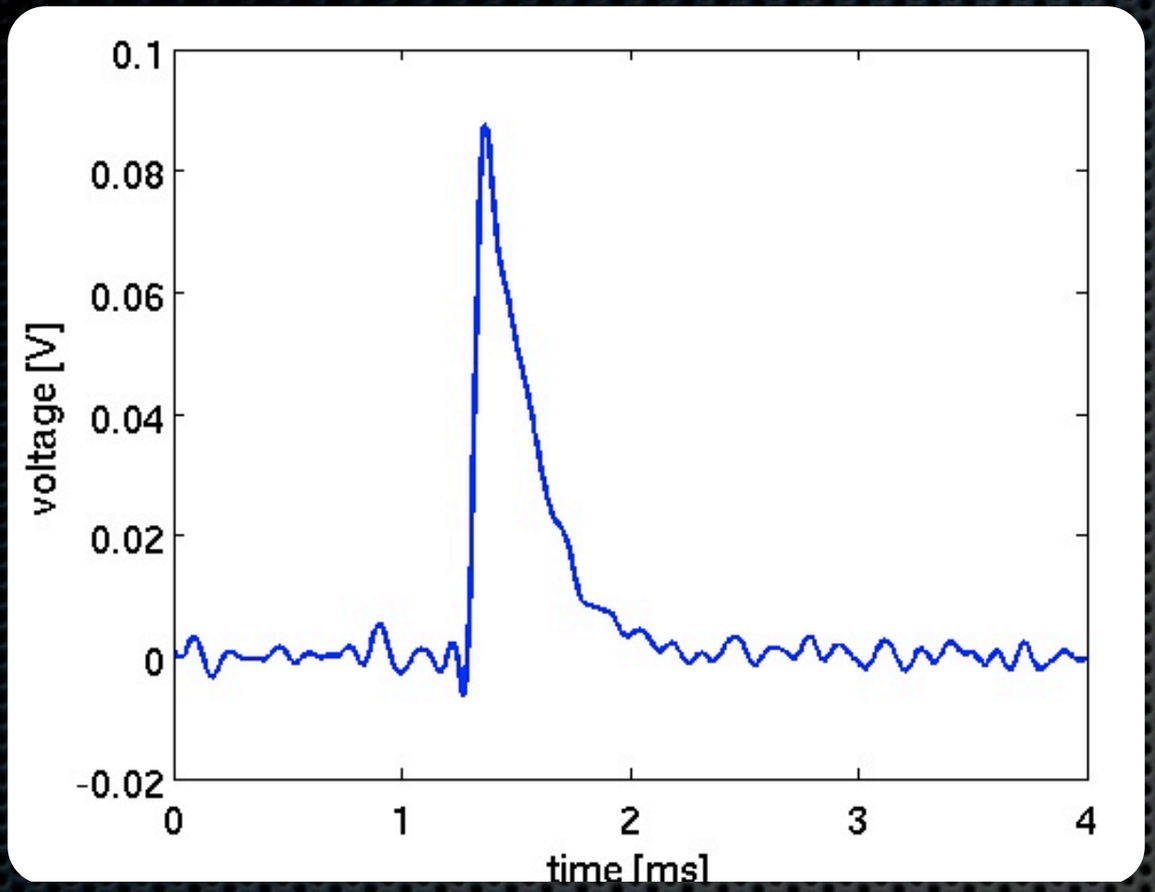
Stability of the MWPCs

- Stability to voltage variations and pressure variations have been studied and found to be consistent with the Diethorn formalism.



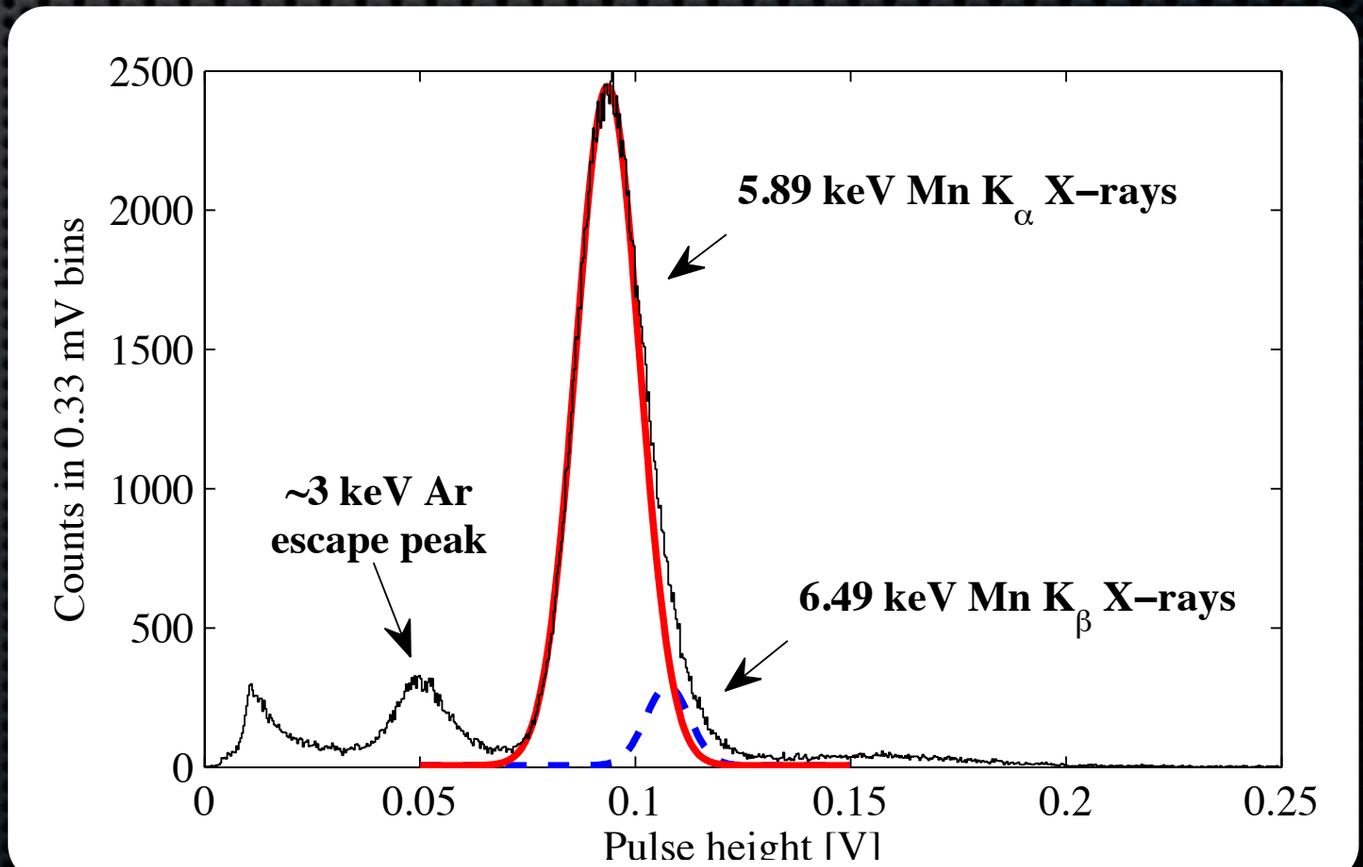


Single MWPC ^{55}Fe-source spectrum

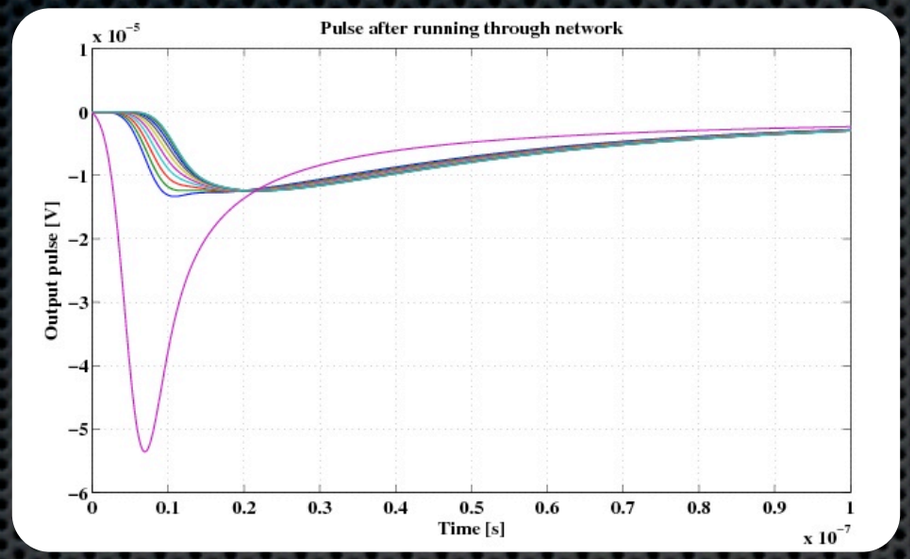


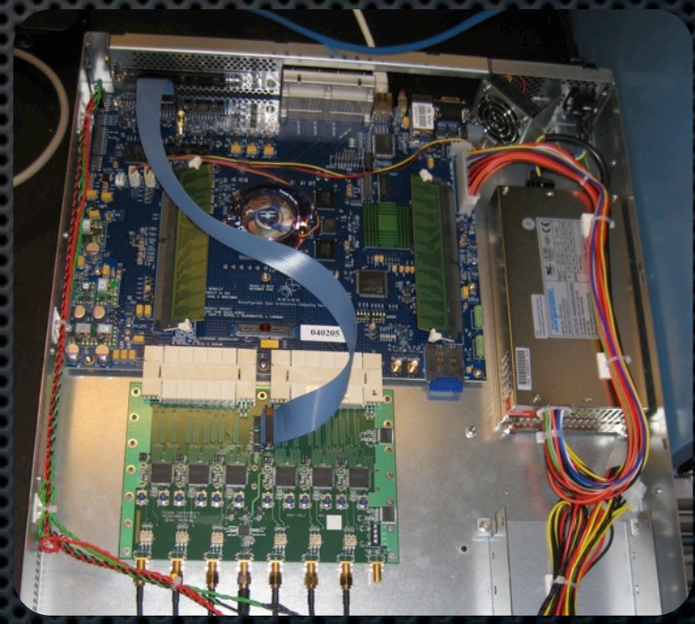
- Typical pulse through the cremat from an ^{55}Fe x-ray source.
- G ~ 2x10^4; P10 at STP
- Anode 2100 V; Cathode 100V

- Data collected from ^{55}Fe source x-rays collimated into the central 3-wire channel. Read into a charge integrating amplifier and a slow digitizer.
- 18% energy resolution at 5.9 keV (Fano limit is 13%).

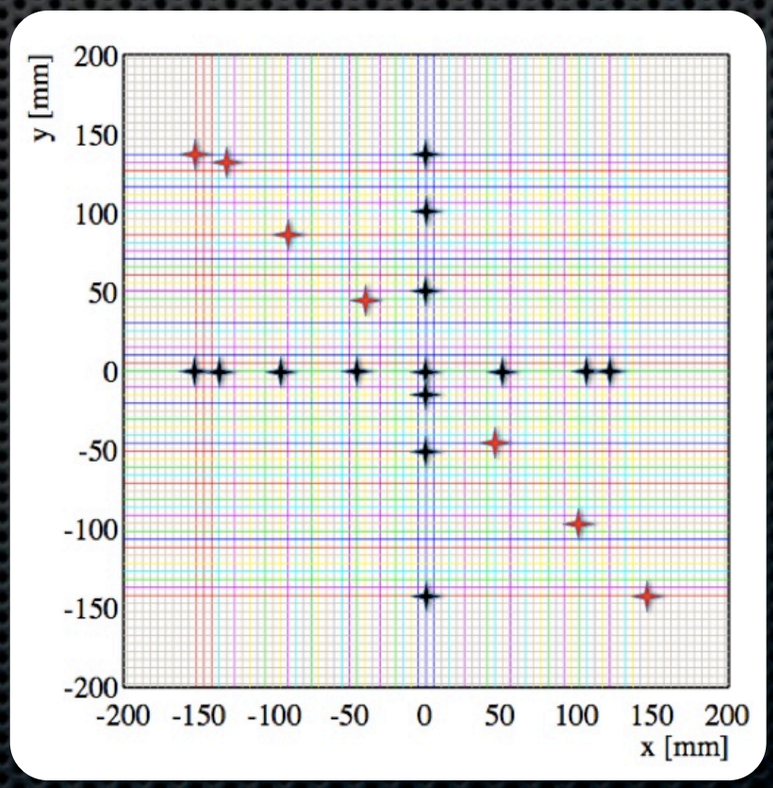


Current and future work

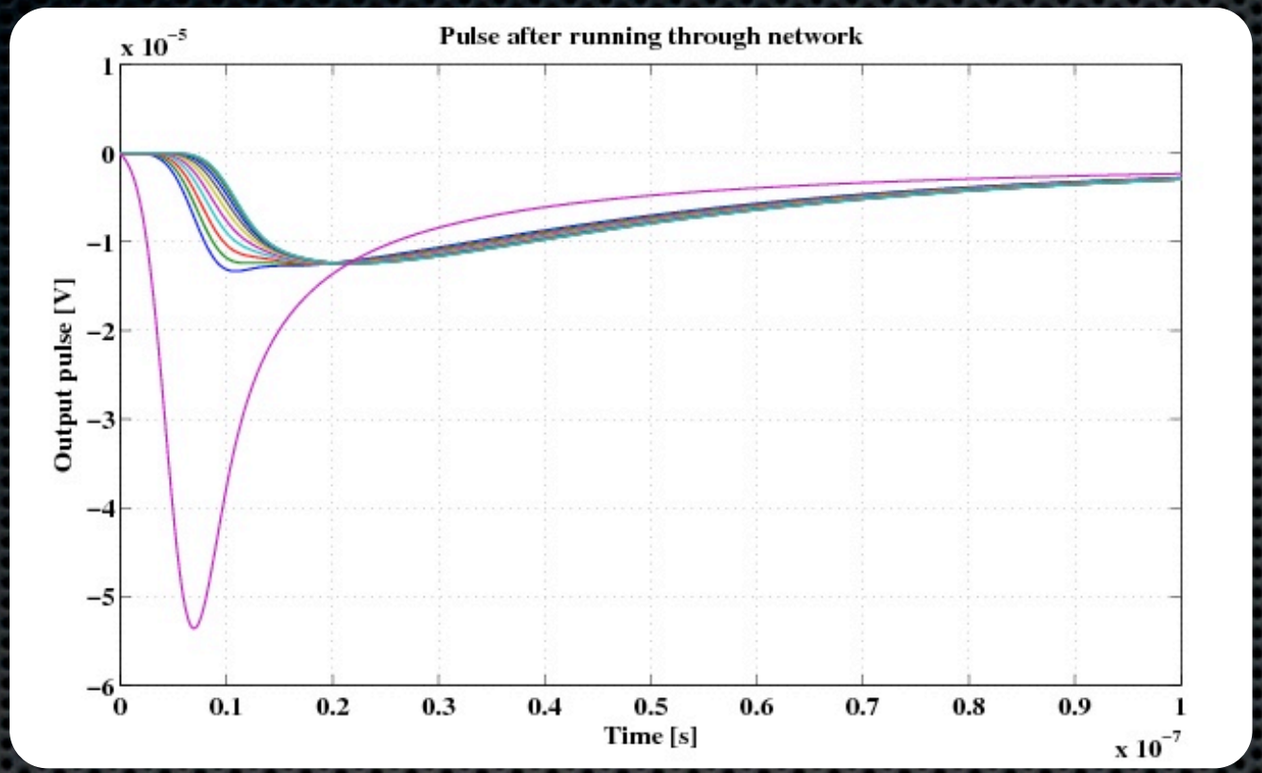


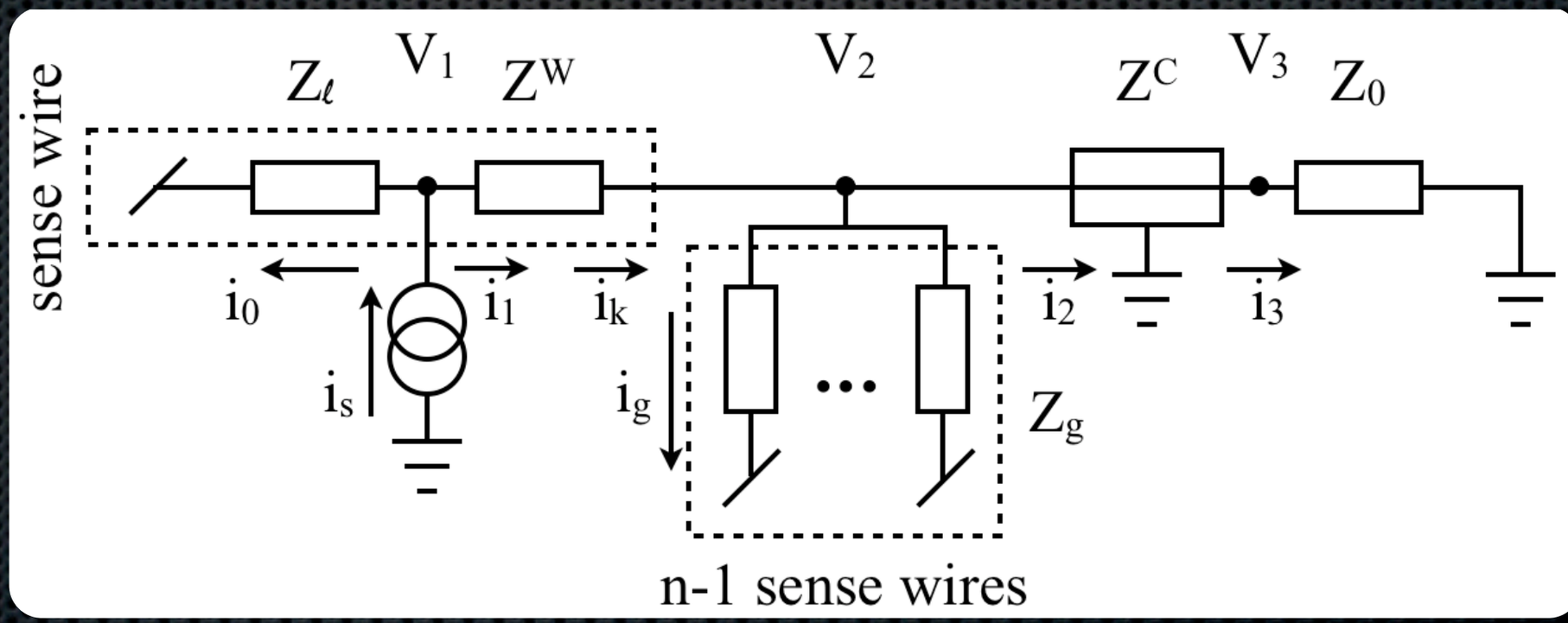


- Pulse digitization
- Track reconstruction
- Position-dependent gain measurement
- Alpha screening

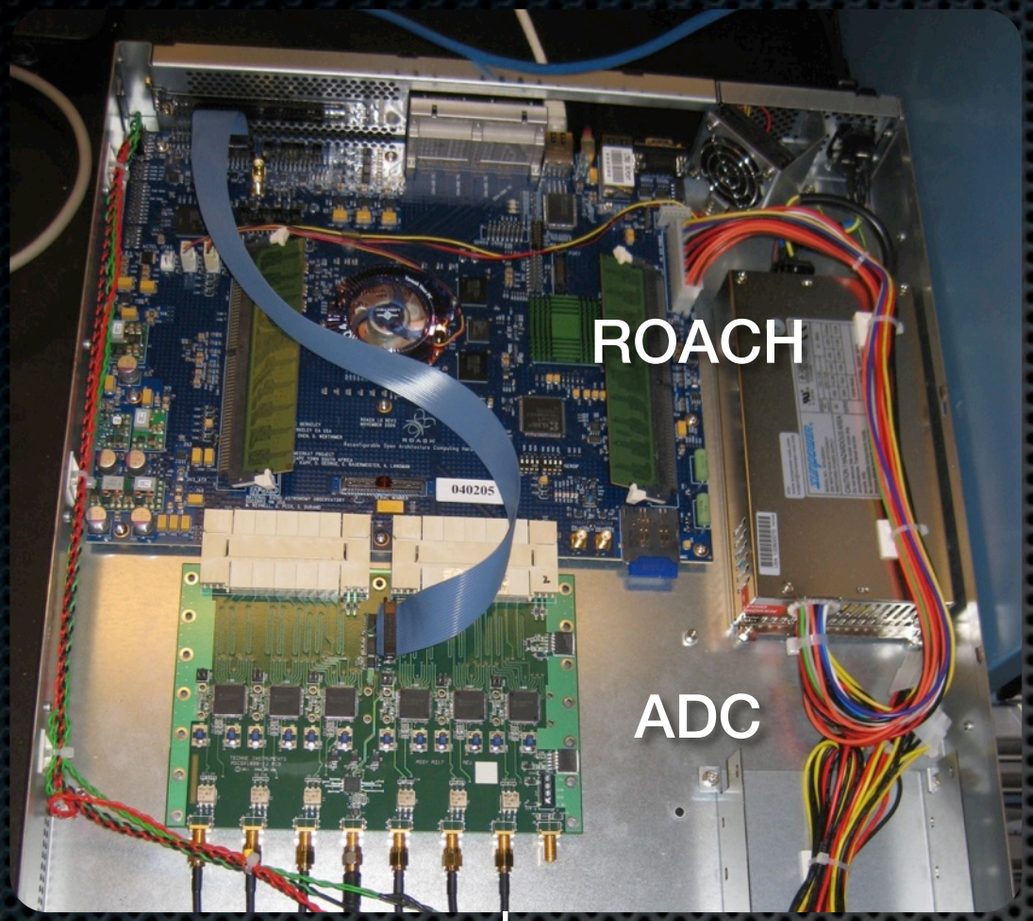


Expected pulse shapes

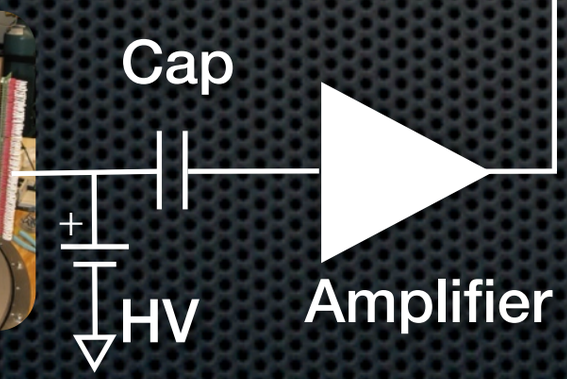




BetaCage Electronics



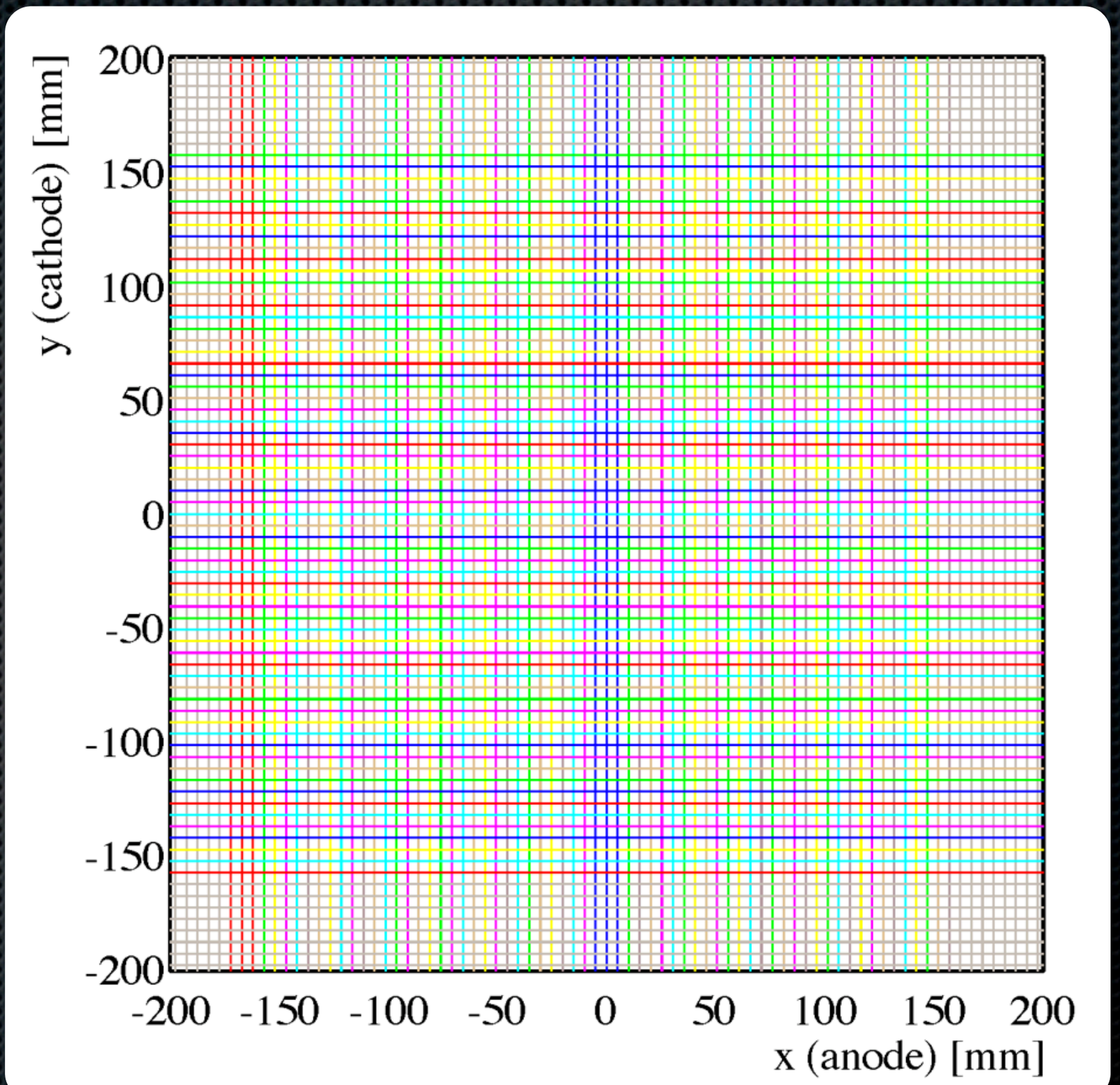
Prototype



- FPGA-based open-source ROACH hardware.
  - ROACH handles DAQ and triggering.
  - Can also perform signal filtering.
  - Coded in python, maybe a midas module in the future.
- Custom 12-bit 1 GS/s 6-channel ADCs clocked at 760 MS/s for pulse-shape readout.
- Custom 26dB 0.05-6 GHz amplifiers (500 MHz Nyquist rolloff).

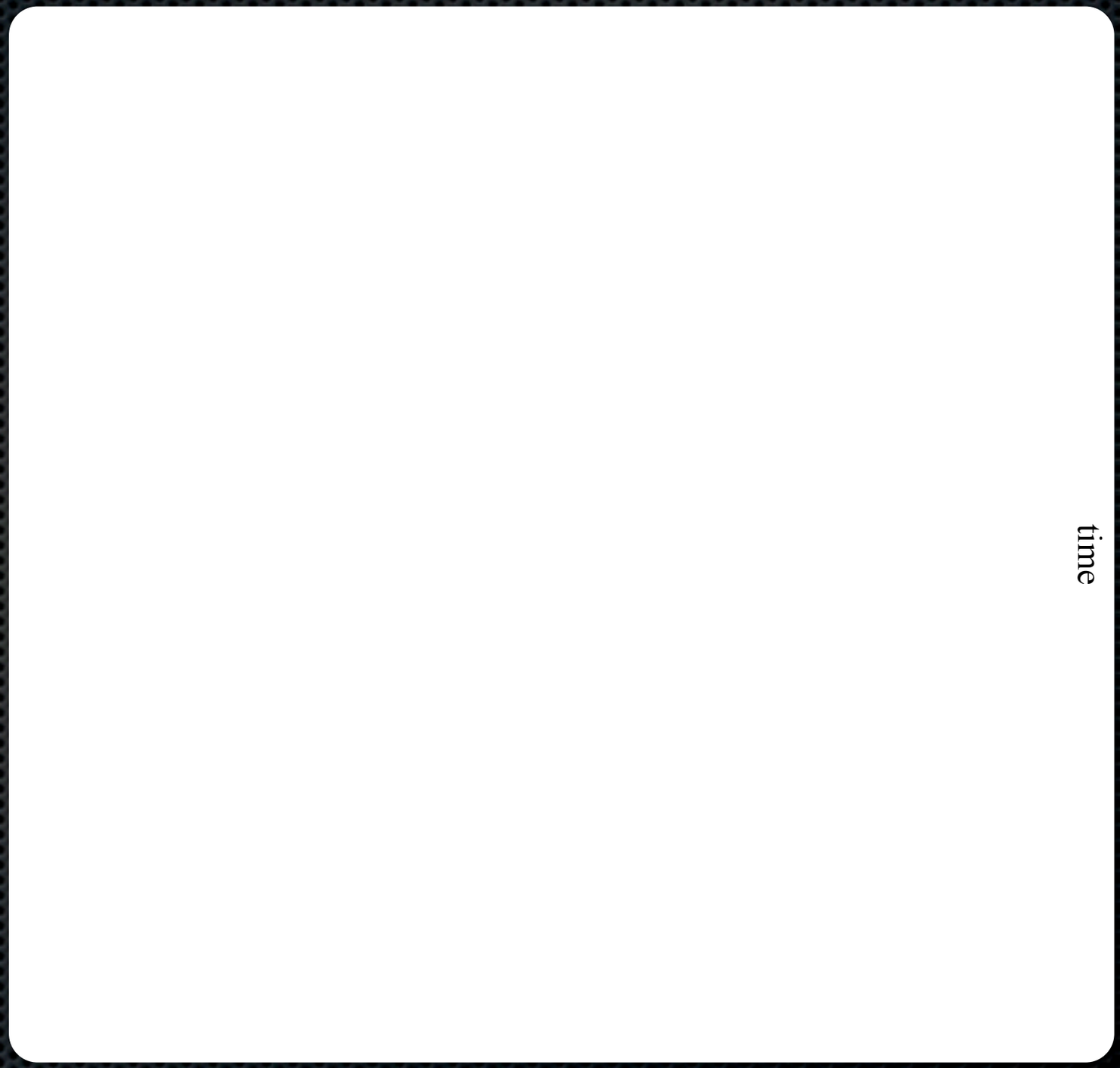
Bulk MWPC channelization (future)

- Pseudo-random ganging pattern:
  - 9 anode channels
  - 8 cathode channels
- Different colors represent different gangs.
- 2 3-wire test channels for diagnostics.
- Custom PCBs at the MWPC does the ganging.
- Hits in time localize the track in x and y.



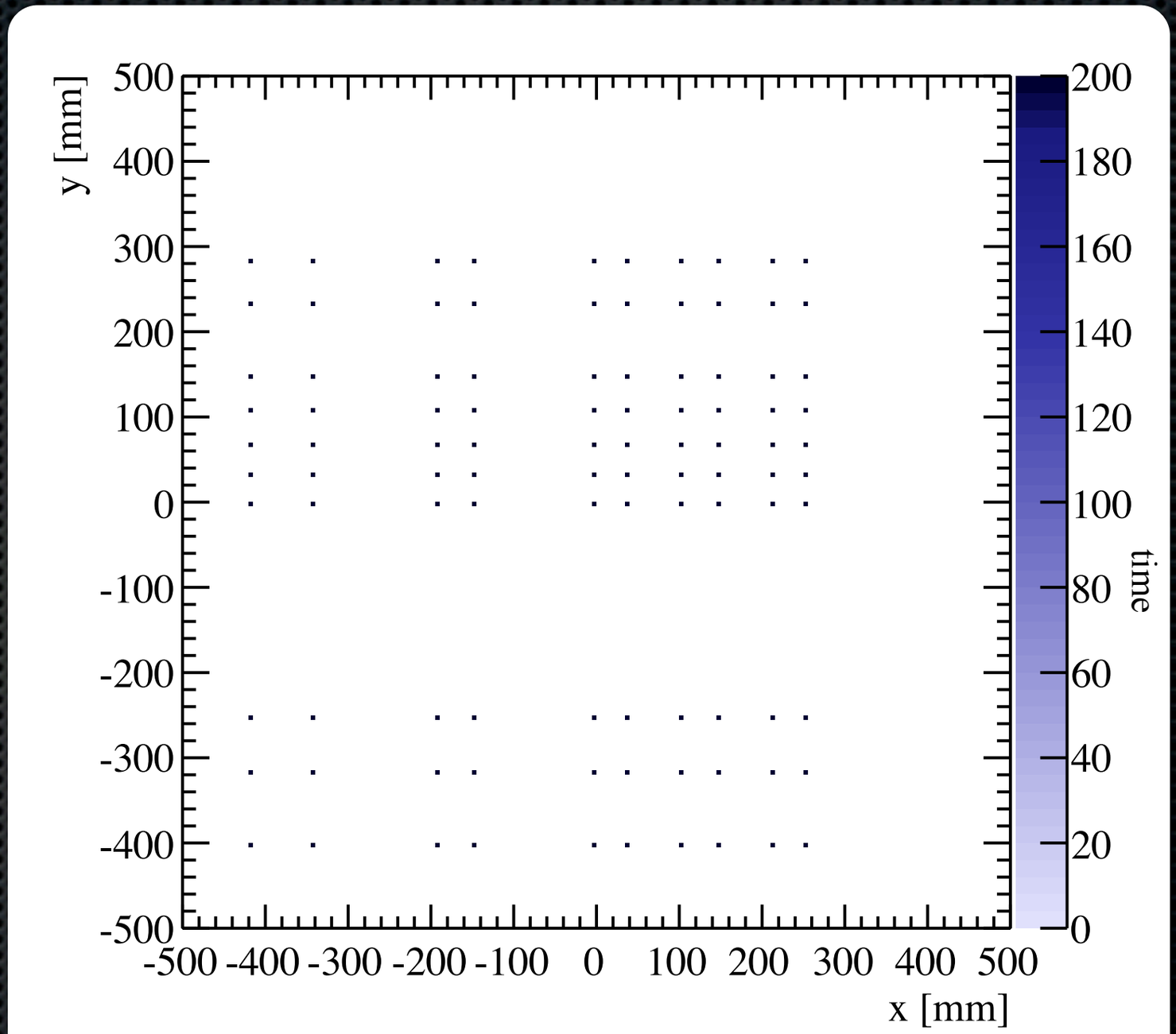
Random-pattern track reconstruction

- Localization of a track is performed by consecutive hits in time.
- Depending on the wire ganging scheme, each single hit has N_{xwires} x N_{ywires} number of possible locations.
- After a couple of hits, most tracks can unambiguously be located. Lost tracks are a hit to the efficiency.



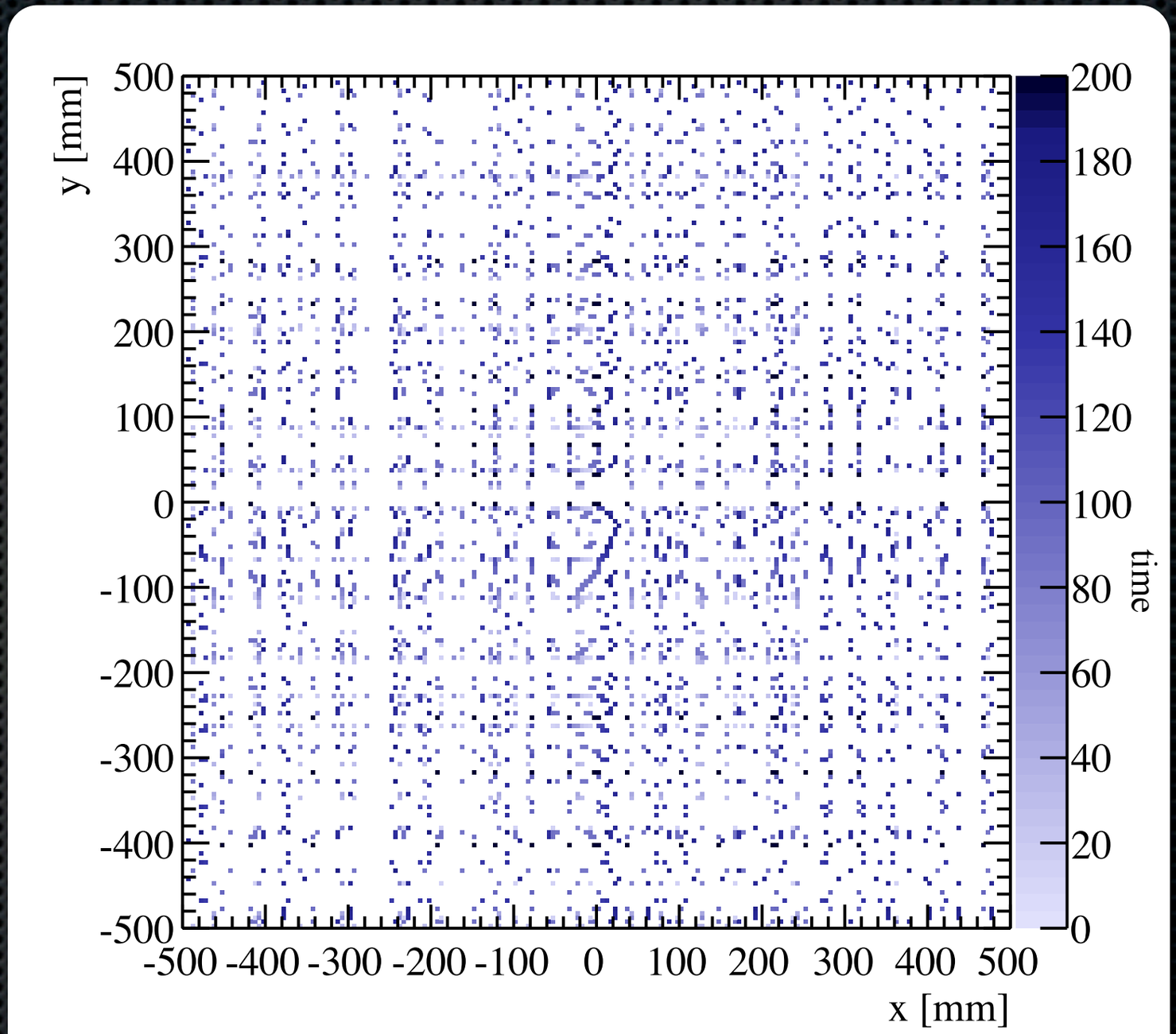
Random-pattern track reconstruction

- Localization of a track is performed by consecutive hits in time.
- Depending on the wire ganging scheme, each single hit has N_{xwires} x N_{ywires} number of possible locations.
- After a couple of hits, most tracks can unambiguously be located. Lost tracks are a hit to the efficiency.

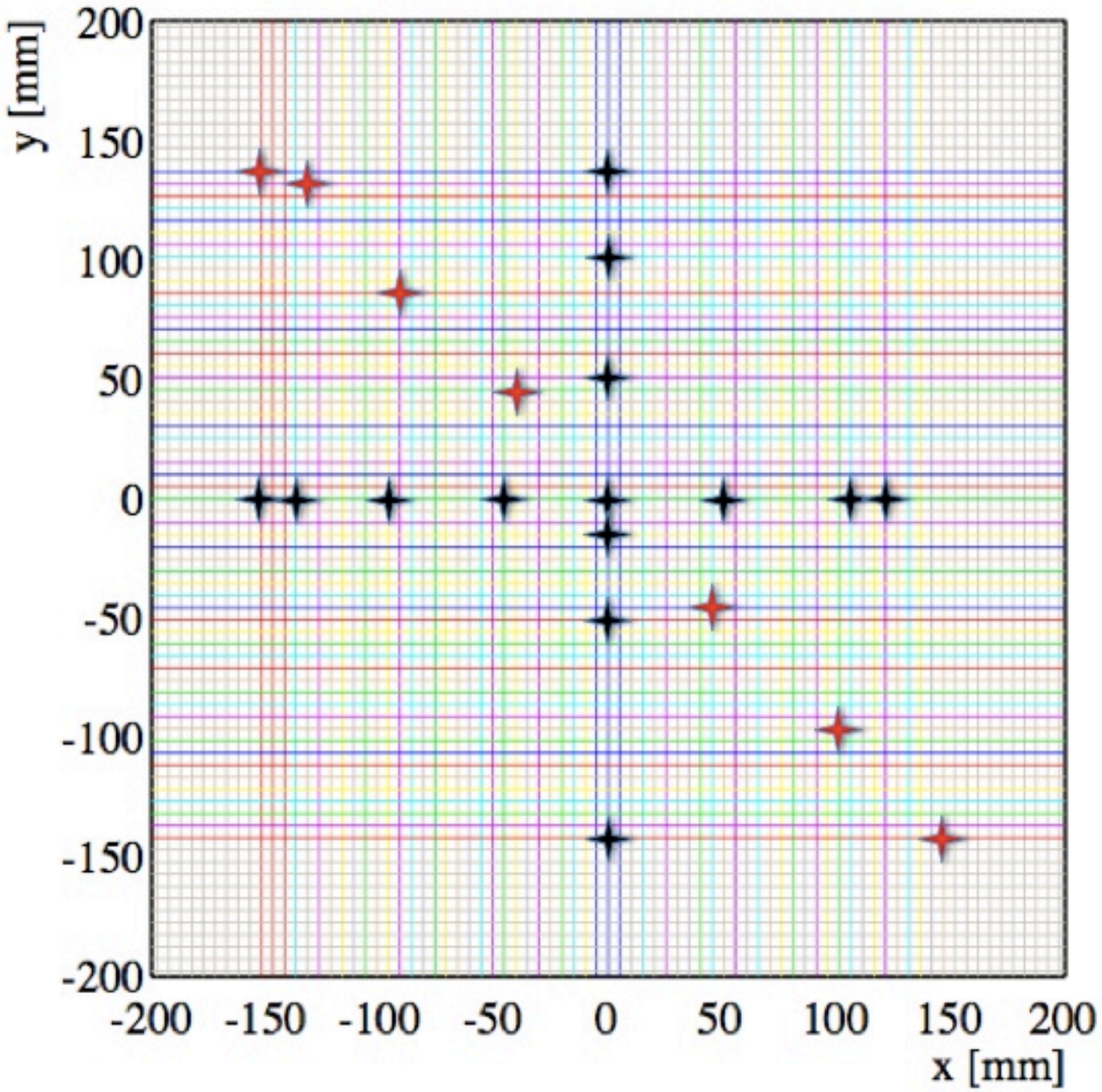


Random-pattern track reconstruction

- Localization of a track is performed by consecutive hits in time.
- Depending on the wire ganging scheme, each single hit has N_{xwires} x N_{ywires} number of possible locations.
- After a couple of hits, most tracks can unambiguously be located. Lost tracks are a hit to the efficiency.



Proposed gain map to study position



- Currently collecting data moving the ^{55}Fe source around to measure the position dependance.

Summary

- A prototype BetaCage has been built and is currently being commissioned at Caltech.
- Studies of gain/gas/position dependent properties are currently underway.
- Am FPGA-based DAQ system is currently being prototyped and commissioned.
- Preparations for alpha counting are underway.
- Track reconstruction will be tested as soon as we have multi-channel data.
- Preparations for the full BetaCage are making excellent progress, see R. Bunker's poster!