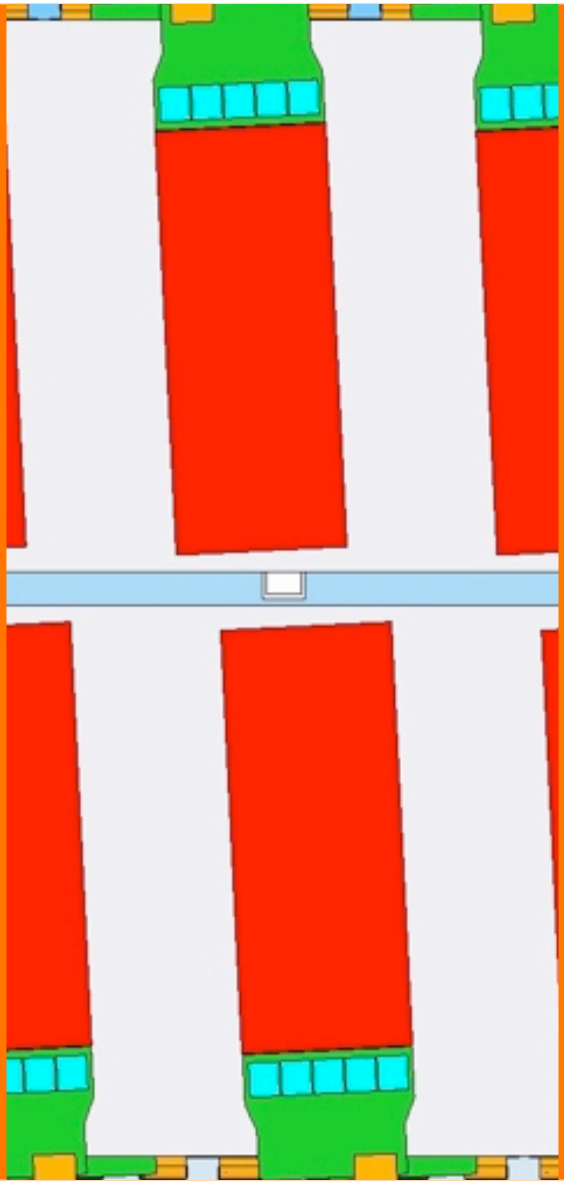
HPS Tracking and Vertexing System



Tim Nelson - SLAC

Boson 2010, JLab

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The Elevator Pitch

Sensitivity relies upon abilities to *precisely*...

- determine invariant mass of A′ decay products (estimate momentum vectors)
- distinguish A′ decay vertexes as non-prompt (extrapolate tracks to origin)

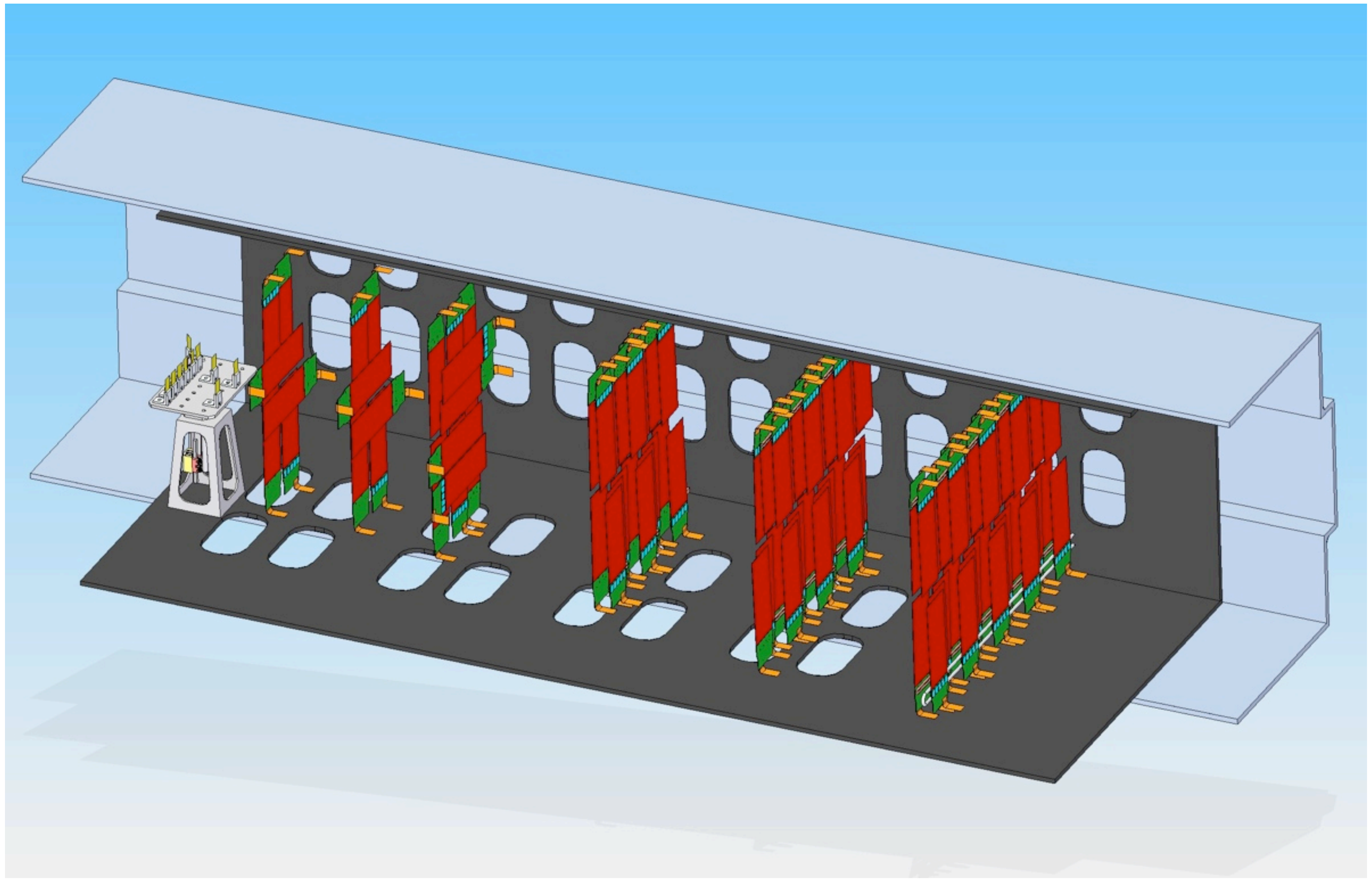
Placement of a tracking and vertexing system immediately downstream from a target and inside an analyzing magnet provides both measurements with high acceptance from a single, relatively compact detector.

Challenges

- At relevant beam energies and interesting A′ masses, decay products tend to be electrons with momenta order a few GeV. Multiple scattering...
  - dominates both mass and vertexing measurement errors
  - leads to pattern recognition mistakes in dense environments
- Proximity to target means primary beam must pass through apparatus.
  - scattered beam sweeps out a “dead zone” of extreme occupancy and radiation, compounded by beam-gas interactions
  - puts low-mass acceptance in opposition to longevity and tracking purity
- Long-lived A′ signal very small: vertexing must be exceedingly pure to eliminate fakes.
- Most attractive if can be done quickly and at minimal cost.

Challenges ⇒ Design Principles

- Mass and vertex resolution
  - low-mass construction
- Occupancies and radiation
  - fast, robust sensors / readout
  - movability / replaceability
  - operation in vacuum
- Acceptance/Purity
  - optimized sensor layout
- Schedule/Budget Sensitivity
  - reuse and recycle components and techniques

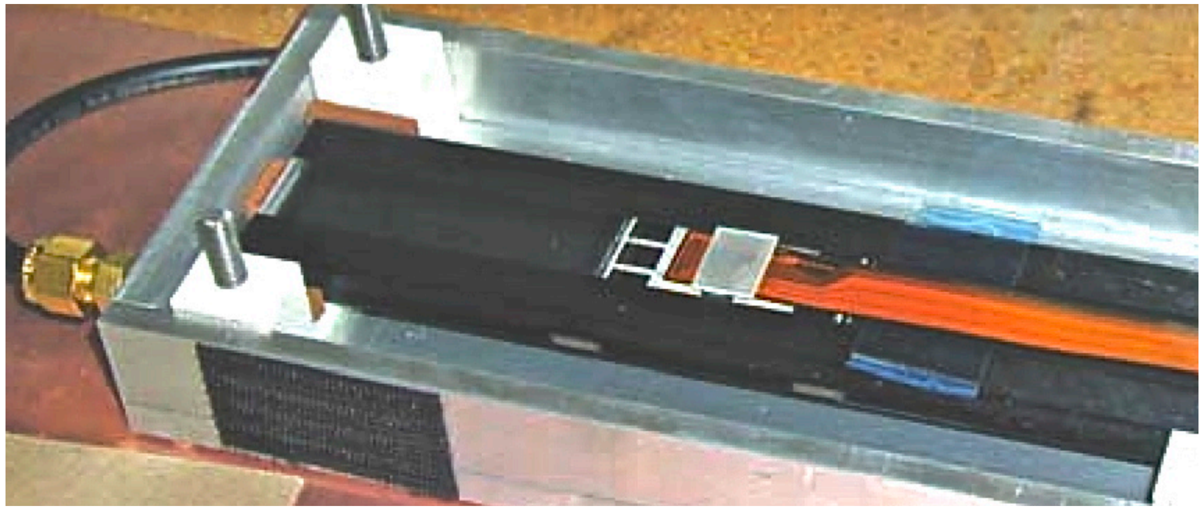


It’s *easier* being green!

- silicon sensors
- readout ASICs
- hybrids
- support and cooling
- vacuum chamber

Silicon Sensors

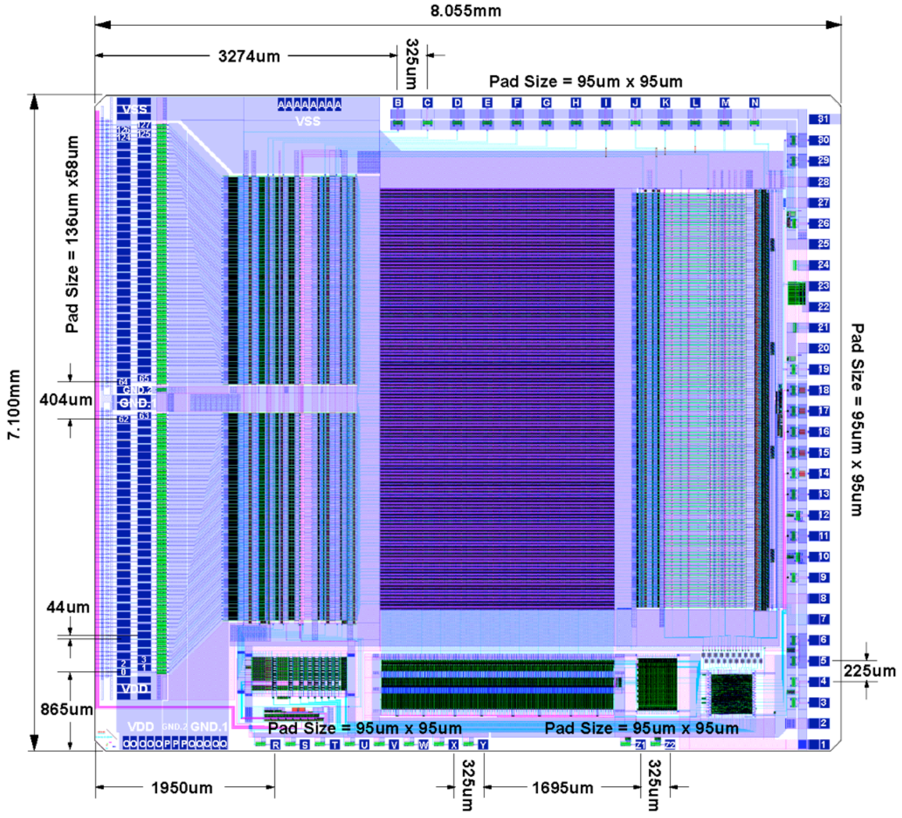
- pixels too massive, costly:
  microstrips are the simple, lightweight solution
- Production Tevatron RunIIb sensors
  - Radiation tolerant:
    many capable of 1000V bias
  - Fine readout granularity
  - Readily available in sufficient quantity



Cut Dimensions (L×W)	100 mm × 40.34mm
Active Area (L×W)	98.33 mm × 38.34mm
Readout (Sense) Pitch	$60\mu m$ ($30\mu m$)
# Readout (Sense) Strips	639 (1277)
Depletion Voltage	$40V < V_{dep} < 300V$
Breakdown Voltage	>350V
Total Detector Current at 350V bias	$<16\ \mu A$
Bias Resistor Value (both ends of strips)	$0.8 \pm 0.3\ M\Omega$
AC Coupling Capacitance	>12 pF/cm
Total Interstrip Capacitance	<1.2 pF/cm
Defective Channels	<1%

Readout Electronics: APV25

- Silicon readout for high rate environment: ***LHC***
- APV25 (CMS) is best of these for us.
  - Low noise: S/N ≈ 34 with our sensors
  - Radiation tolerant
  - Chips, DAQ infrastructure, knowledge; all widely available
  - ***Flexible in operation...***



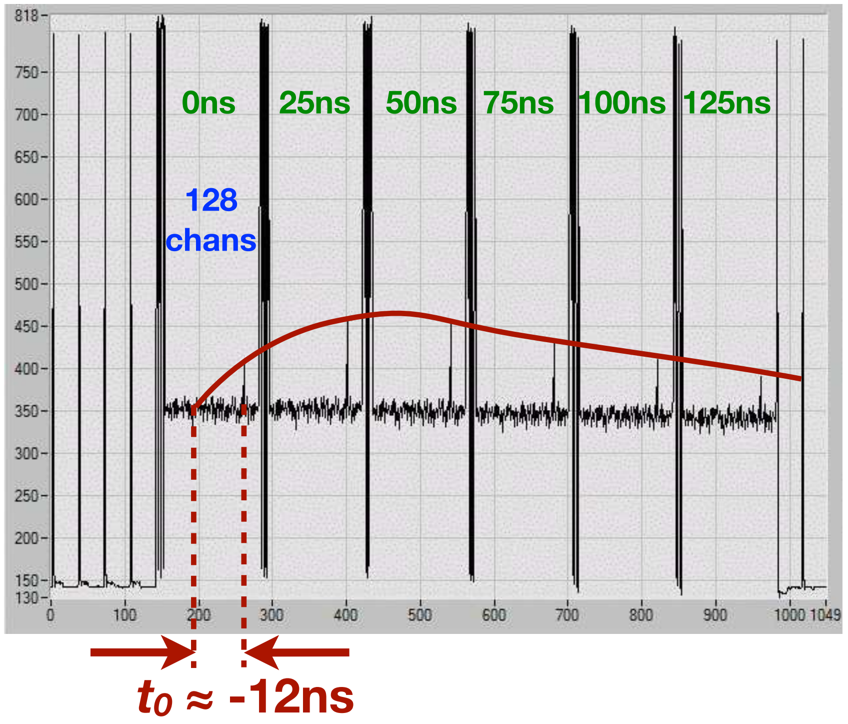
# Readout Channels	128
Input Pitch	44 μm
Shaping Time	50ns nominal (35ns min.)
Output Format	multiplexed analog
Noise Performance (multi-peak mode)	270+36×C(pF) e^- ENC
Power Consumption	345 mW
Communication Protocol	I^{2}C

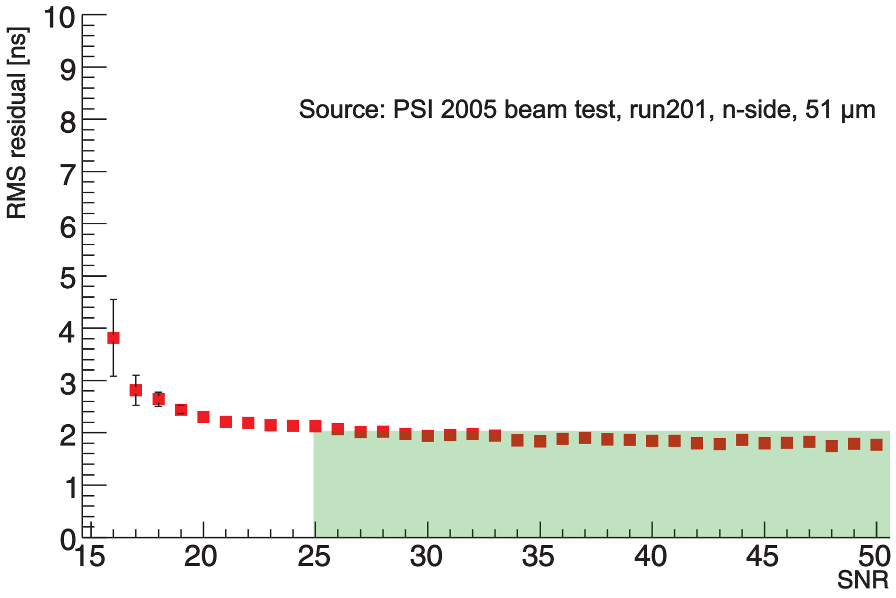
Timing Information

Multi-peak readout offers major reduction in background occupancy:

- Sample shaper output every 25ns in multiples of three snapshots: pioneered for Belle II.
- Fit to shaping curve determines hit time with RMS of ~2 ns or better for S/N > 25.
- 6-sample readout helps at high occupancy: de-convolute two hits in same shaping window
- For simulation studies, simply assume a 3-pulse time window for hits (2-sigma).

➡ Fitting tracks in both space *and* time will further assist pattern recognition and track selection.

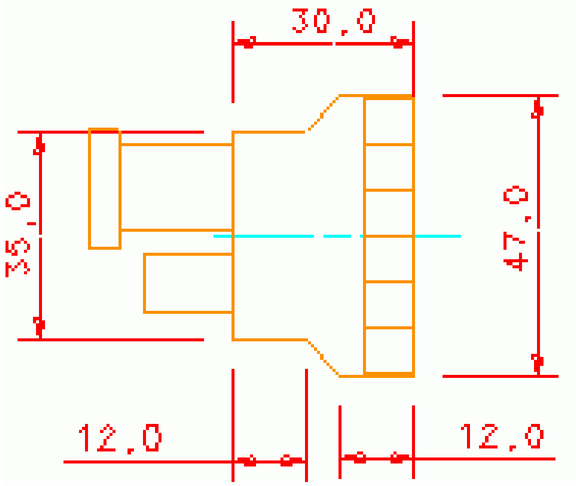


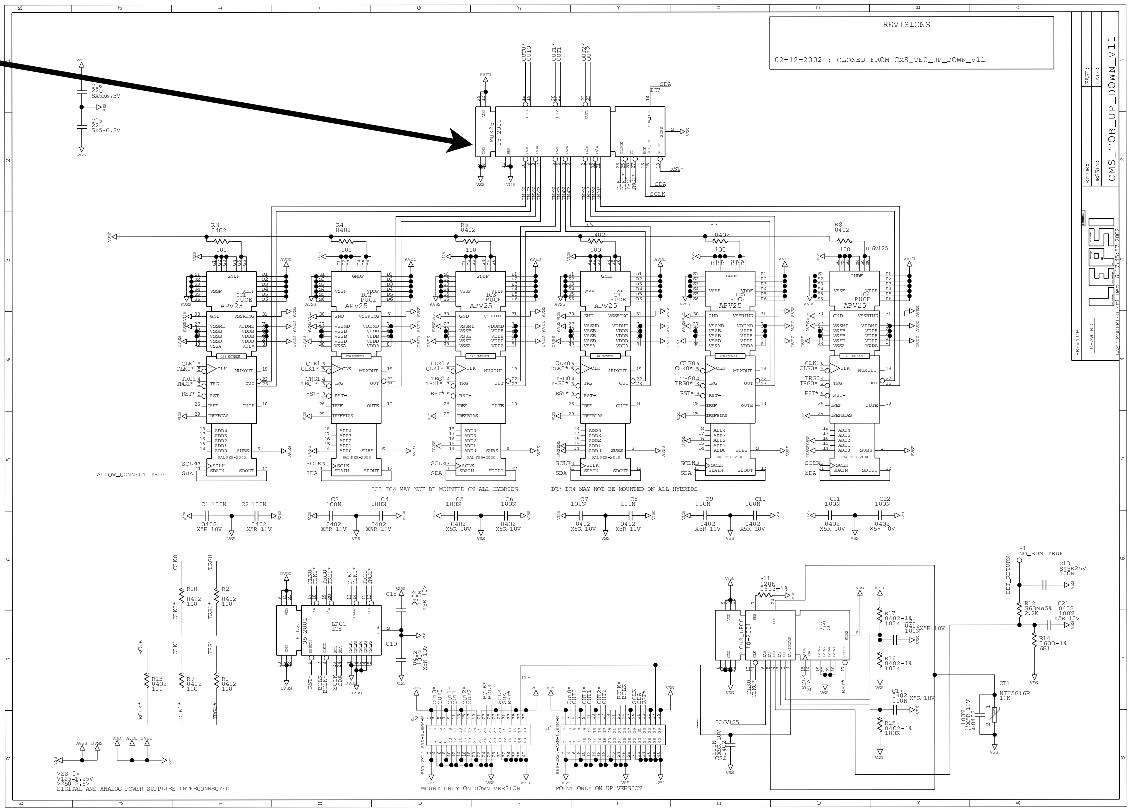


Source: PSI 2005 beam test, run201, n-side, 51 μm

Hybrids

- Need something simple and compact: similar to CMS TIB hybrid, *but*...
  - 5 chips instead of 6 to match sensors
  - analog driver instead of APVMUX
  - *probably* no need for pitch adapter
  - *probably* no need for ceramics
- Starting from CMS schematics, should be fairly simple
- Require prototype soon: critical path.

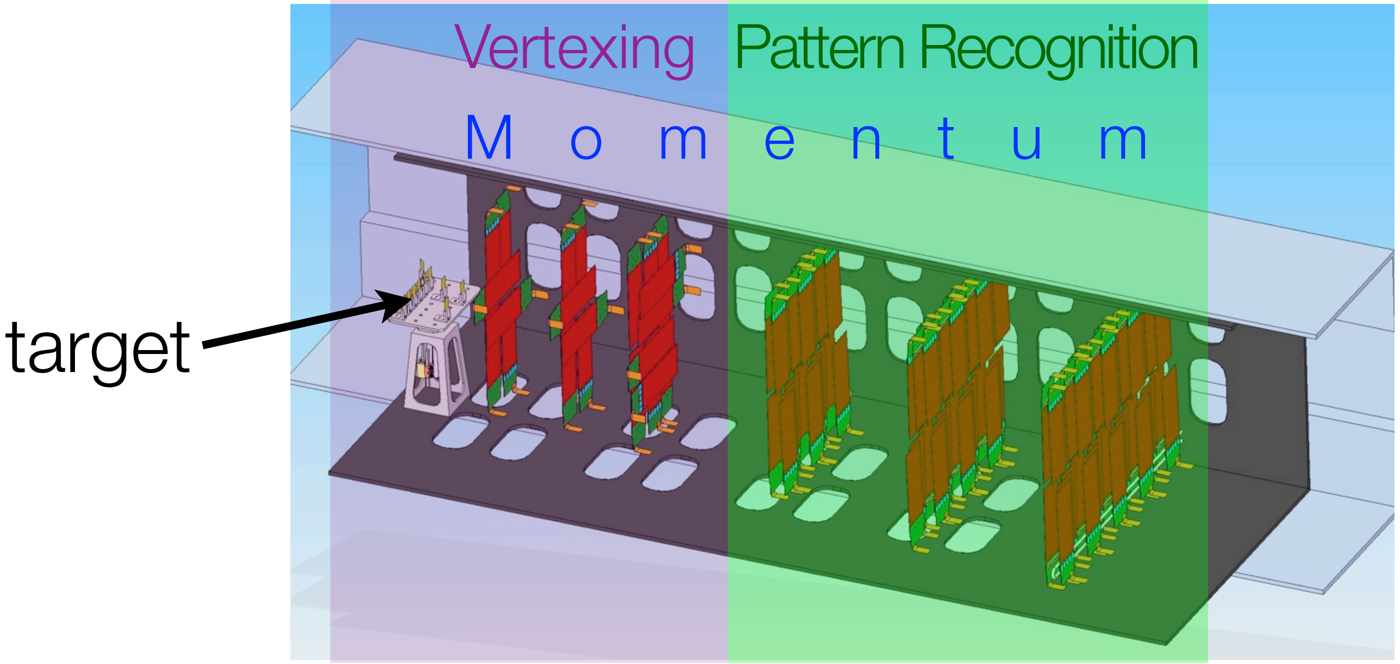




Detector Layout

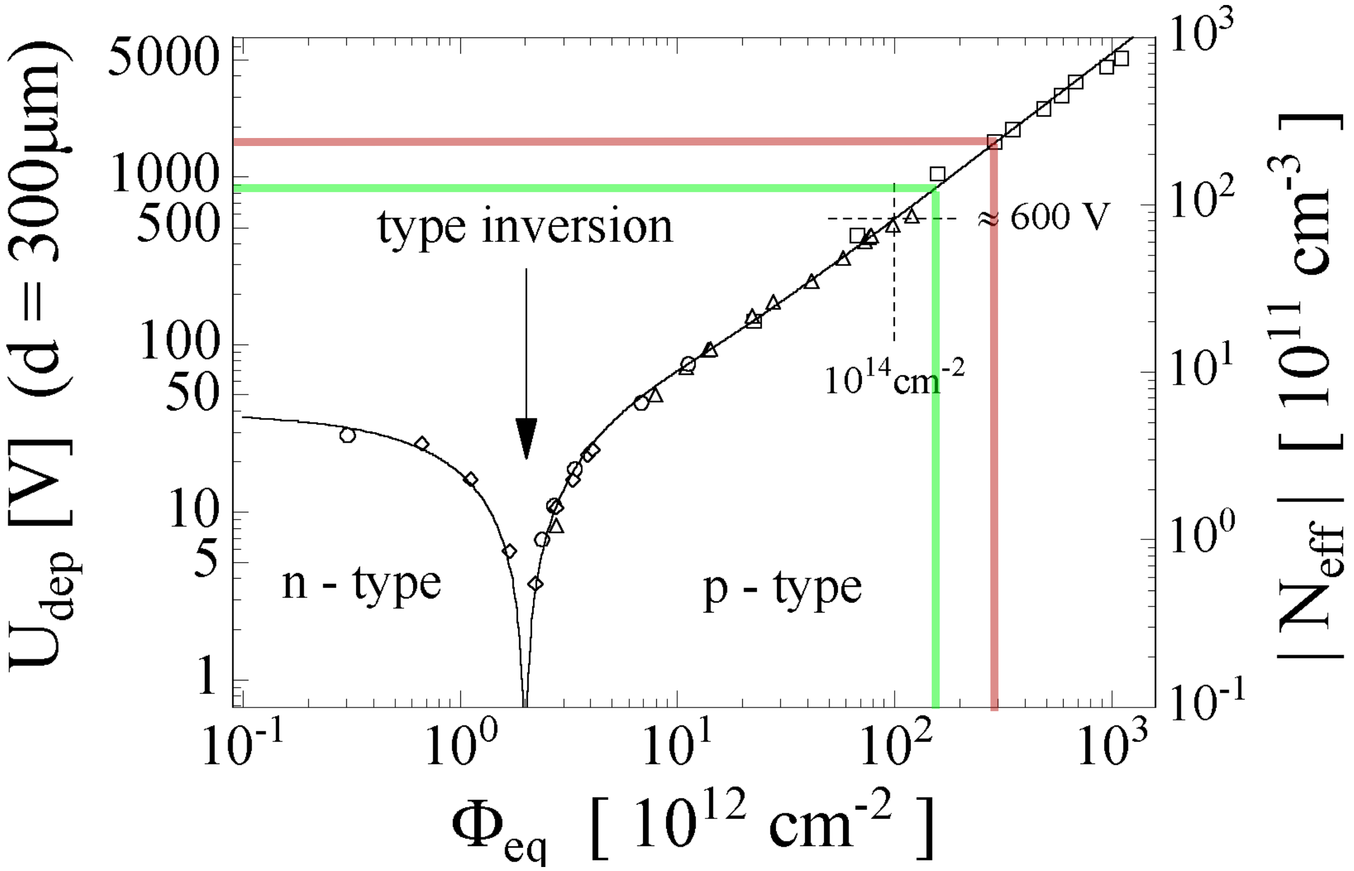
- Layers 1-3: vertexing
- Layers 4-6: pattern recognition with adequate pointing into Layer 2.
- Bend plane measurement in all layers: momentum
- 106 sensors/hybrids
- 530 APV25 chips
- 67840 channels

	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 6
z position, from target (cm)	10	20	30	50	70	90
Stereo Angle	90 deg.	90 deg.	90 deg.	50 mrad	50 mrad	50 mrad
Bend Plane Resolution (μm)	≈ 6.5	≈ 6.5	≈ 6.5	≈ 6.5	≈ 6.5	≈ 6.5
Stereo Resolution (μm)	≈ 6.5	≈ 6.5	≈ 6.5	≈ 130	≈ 130	≈ 130
# Bend Plane Sensors	4	4	6	10	14	18
# Stereo Sensors	2	2	4	10	14	18
Dead Zone (mm)	±1.5	±3.0	±4.5	±7.5	±10.5	±13.5
Power Consumption (W)	10.5	10.5	17.5	35	49	63



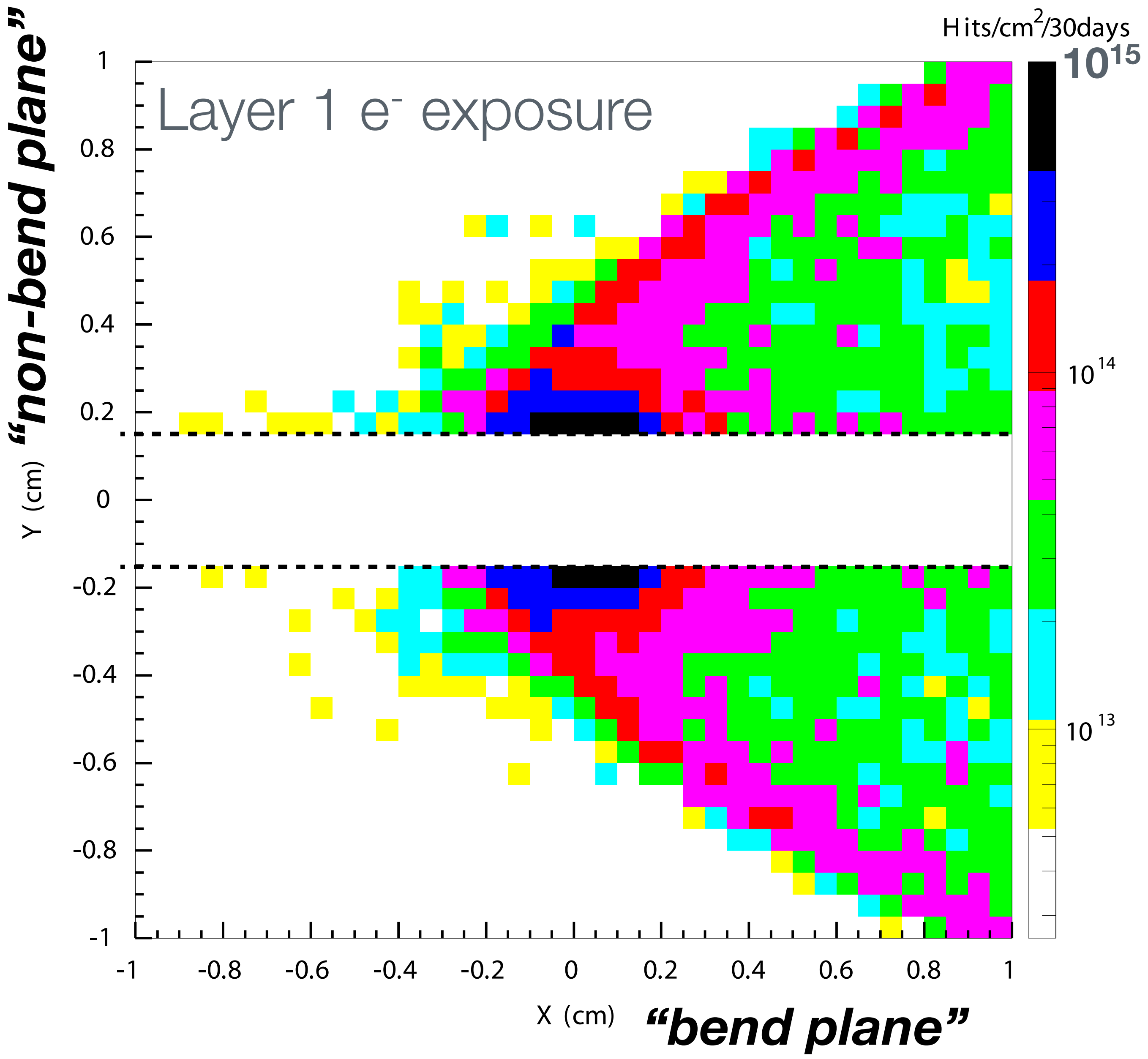
Dead Zone: radiation limit

- At V_{bias} = 1000V, sensors fully depleted up to $\Phi_{eq} > 1\times10^{14}$ cm^{-2} (1 MeV neutron equivalent dose)
- Electron damage is 1/30 that of 1MeV neutrons: full depletion up to at least 3×10^{15} e$^-$/cm^2
- After that, a “soft landing,” with lost signal degrading timing and resolution beyond ~6×10^{15} e$^-$/cm^2



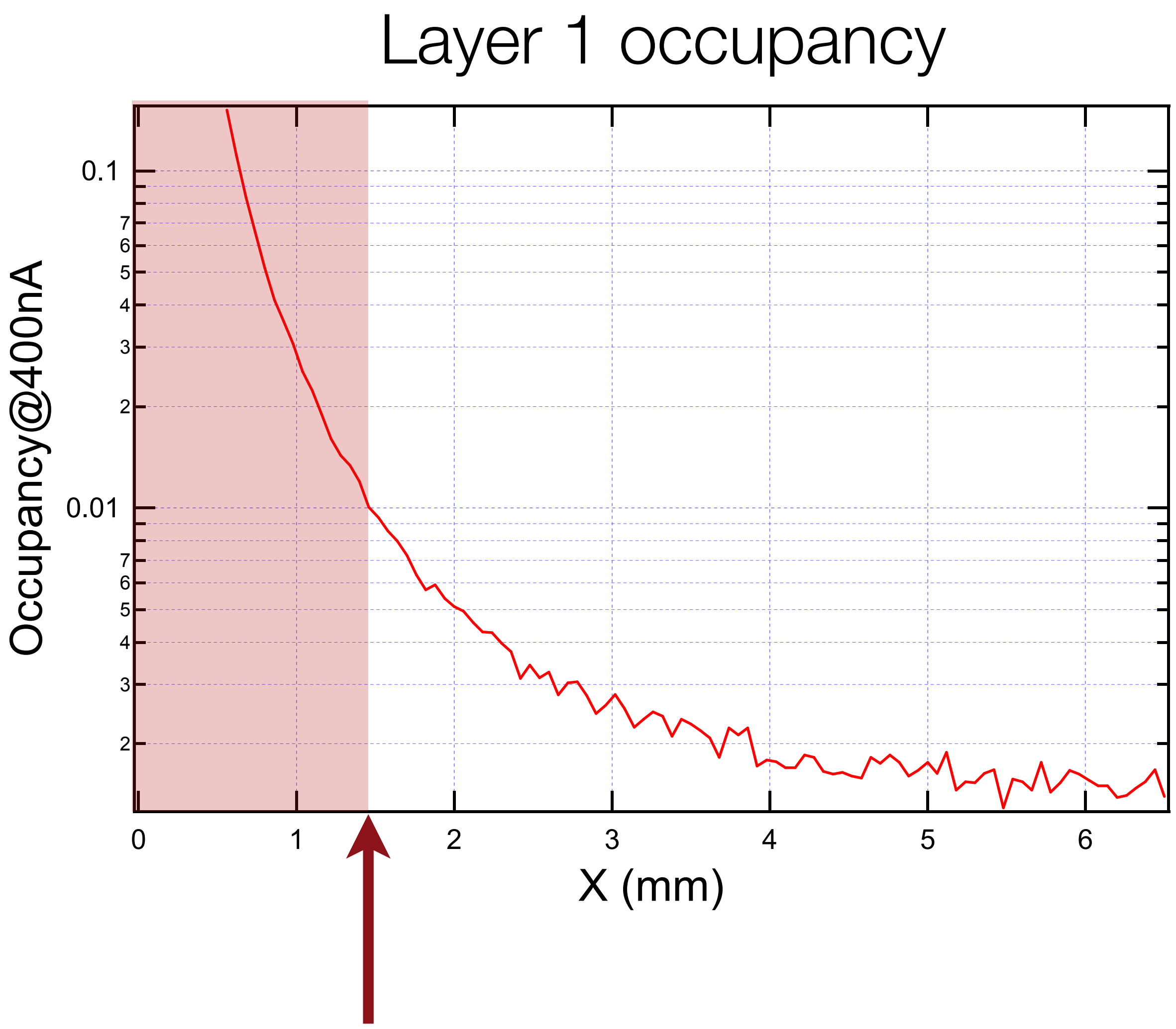
Dead Zone: radiation limit

- Would like entire detector to remain fully depleted for 3 months $\Rightarrow 1\times10^{15}$ e$^-$/cm^2 /month
- In first layer, that requires a dead zone in the region y < ±1.5mm
- With z_{L1} = 10cm ⇒ 15 mrad dead zone for entire tracker



Dead Zone: occupancy limits

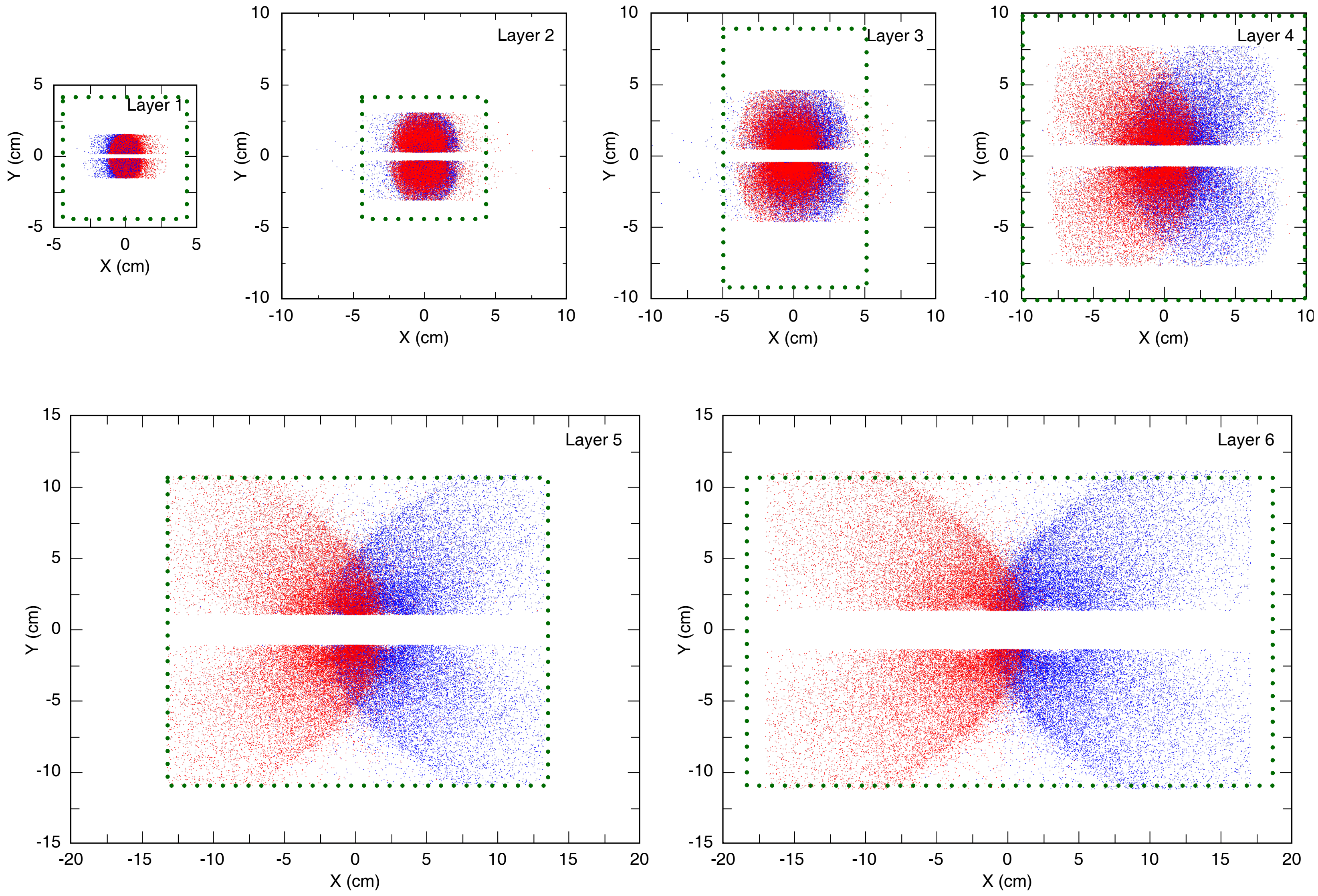
- For pattern recognition, want 3-pulse occupancy < 1%
  - Results in dead zone < 14 mrad
- Triple-coincidences?
  - For smallest APV25 shaping time rate of triple coincidences is acceptable.
- Unanimous: 15 mrad dead zone.



Acceptance

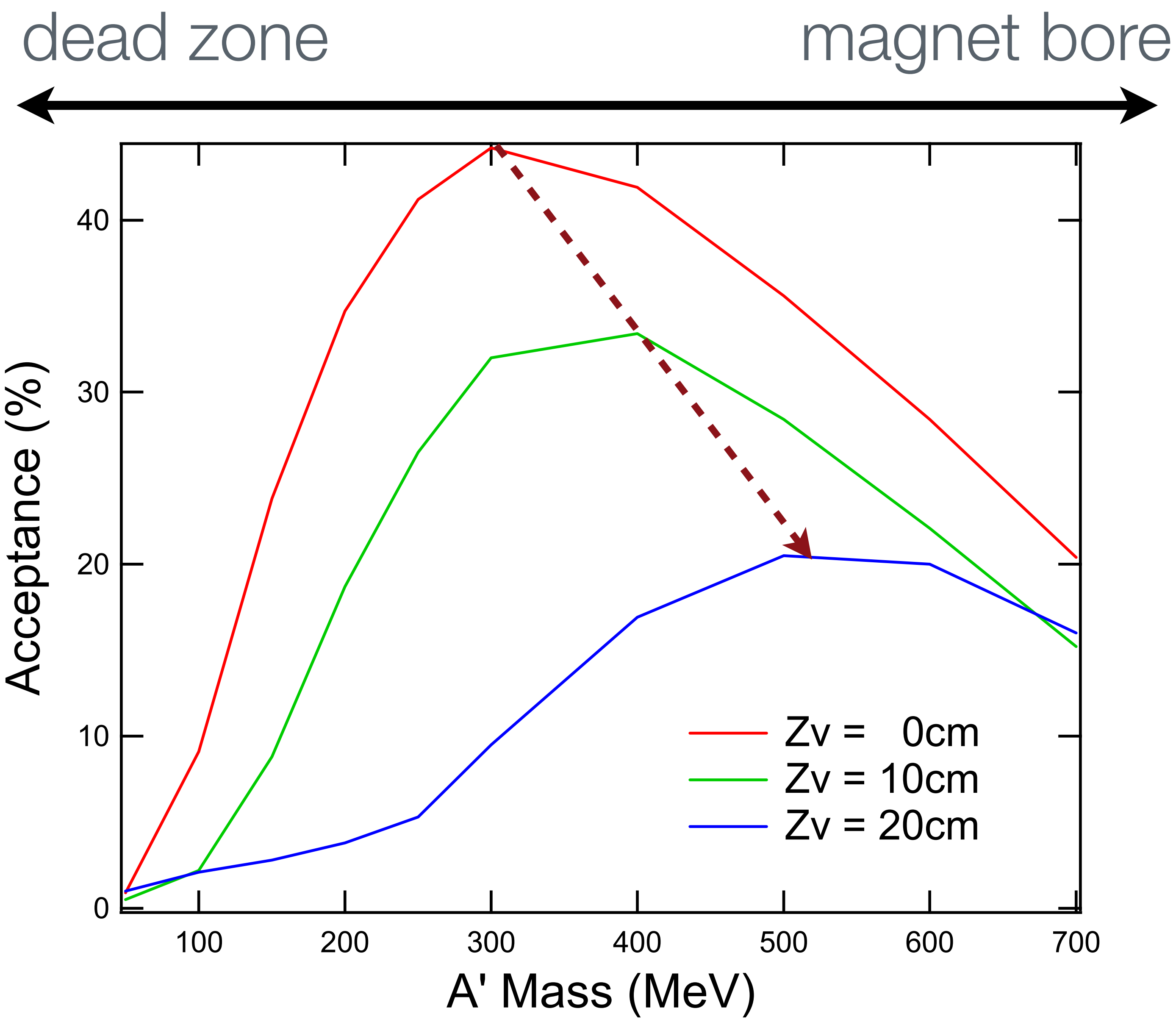
$m_{A'}$ = 300 MeV/c^2, particles with hits in L5

- At smaller masses, dead-zone limits acceptance
- At larger masses, losses due to limited coverage in layers 5 and 6 become important.



Acceptance

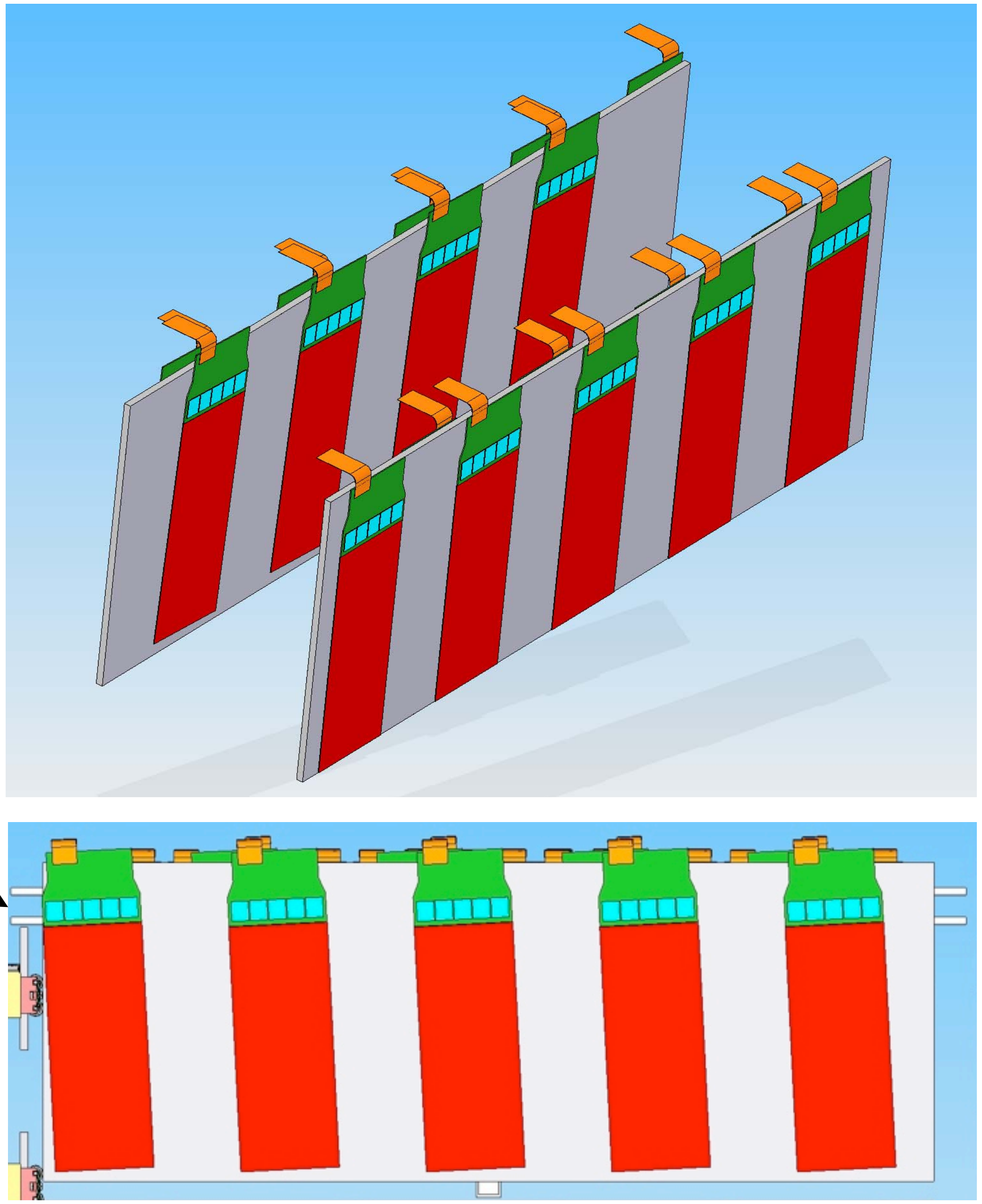
- At smaller masses, dead-zone limits acceptance
- At larger masses, losses due to limited coverage in layers 5 and 6 become important.
- Solid angle of dead zone increases with increasing z-vertex position



Sensor Modules

Simple, well-understood construction:

- silicon for each single view on alternating sides of carbon-fiber skinned, rohacell foam sheet: each “layer” is a pair of modules on either side of dead zone.
- cooling tubes only under hybrids, water-glycol at -5°C.
- passivated pyrolytic graphite sheet under sensors isolates HV and increases lateral thermal conductivity



Material Budget

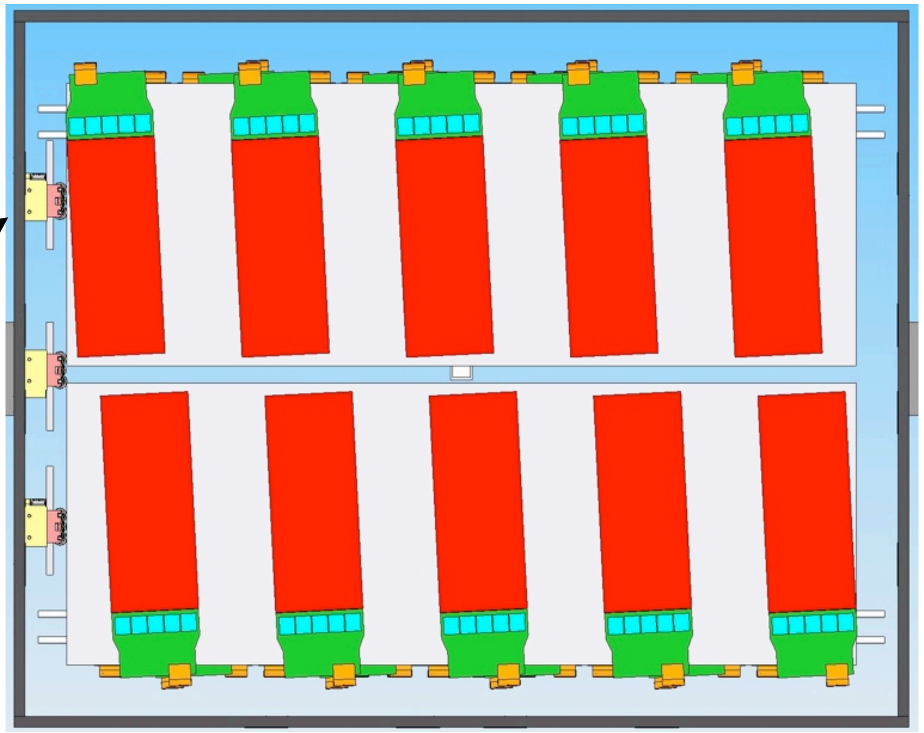
- Approx 1.0% X_0 / layer, including overlaps
- dominated by silicon itself

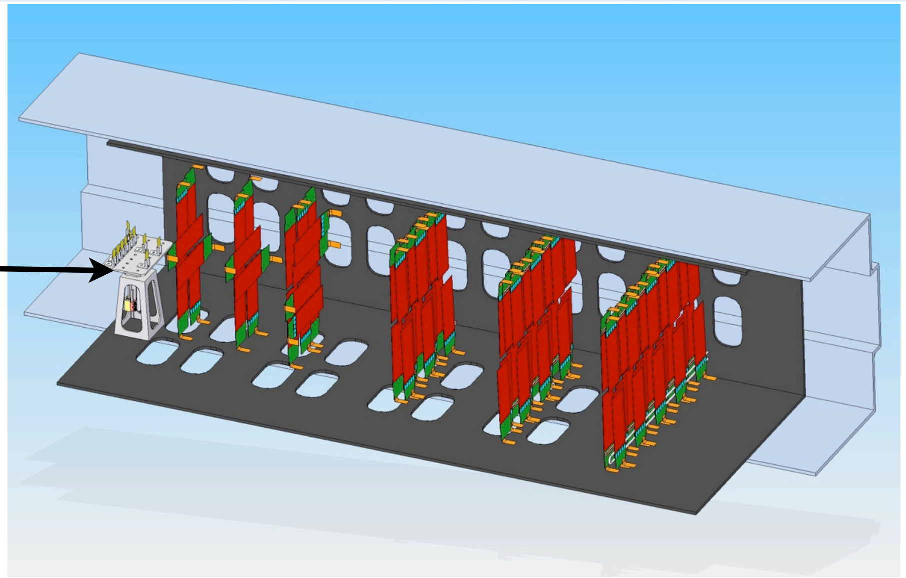
per measurement plane

	Radiation Length (mm)	Thickness (mm)	Coverage/ Unit Acceptance	Scattering Material (% X_0)
Silicon	**93.6**	**0.320**	**1.2**	**0.410**
Rohacell Foam	13800	3.0	0.5	0.011
Carbon Fiber	242	0.150	0.5	0.031
PGS Passivation	256	0.101	1.25	0.049
Epoxy	290	0.050	0.5	0.009
Total	-	-	-	**0.510**

Support Box

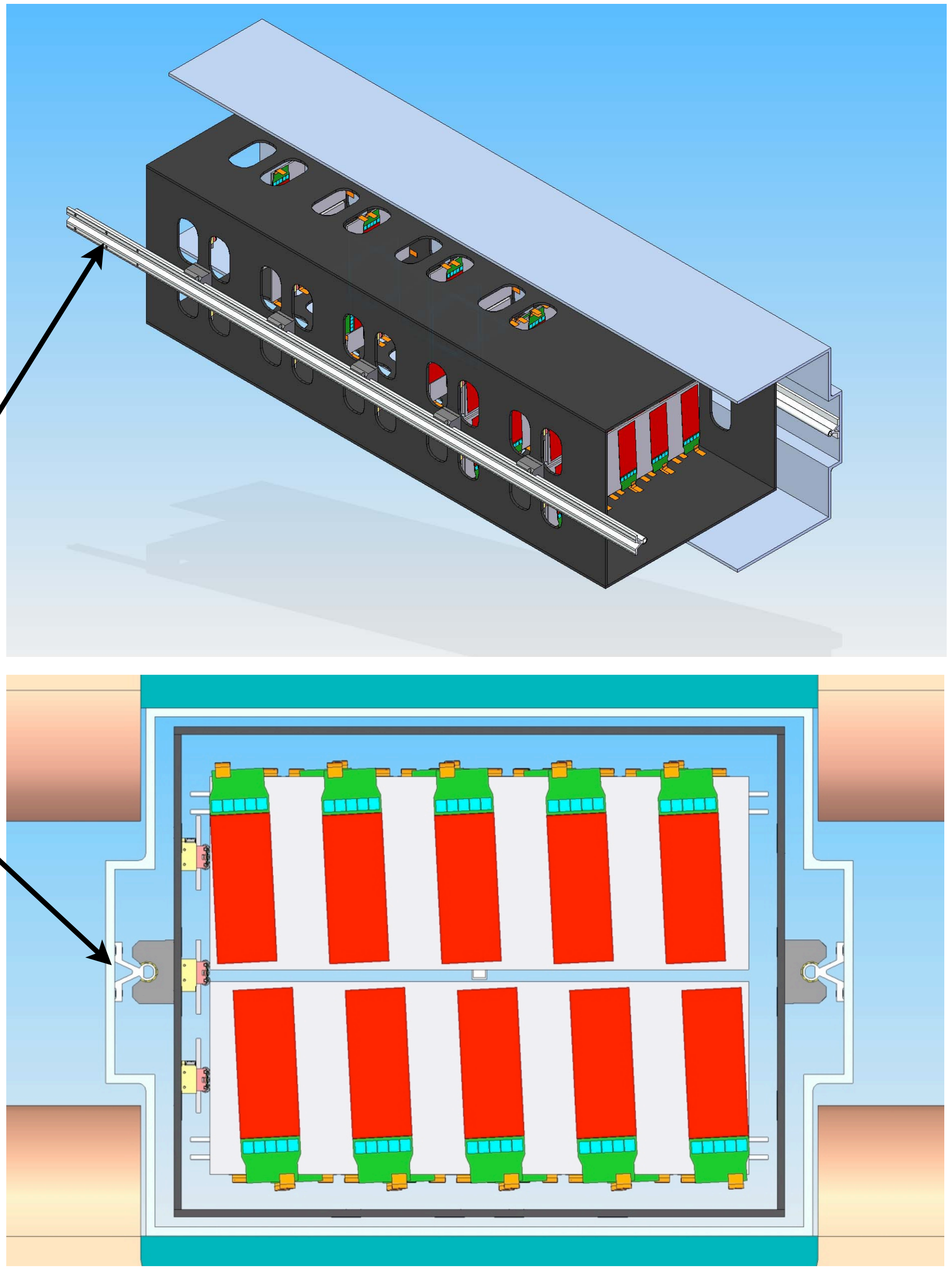
- modules kinematically mounted with pair of piezo motors for vertical adjustment in situ
- extension cables and cooling lines from hybrids and modules to patch panel on vacuum chamber pre-installed on support box
- also supports target stand, including similar motion control system for target selection





Vacuum Chamber

- vacuum chamber permanently captured inside magnet bore
- Patch panel for cooling and cable connections at front face.
- linear rail system with carriages on support box for insertion and extraction of tracker
- custom multi-layer insulation (MLI) blanket eliminates radiative heating: ~5W/module.
- Ensuring negligible heat load on silicon necessitates vacuum of 10^{-4} Torr or better.



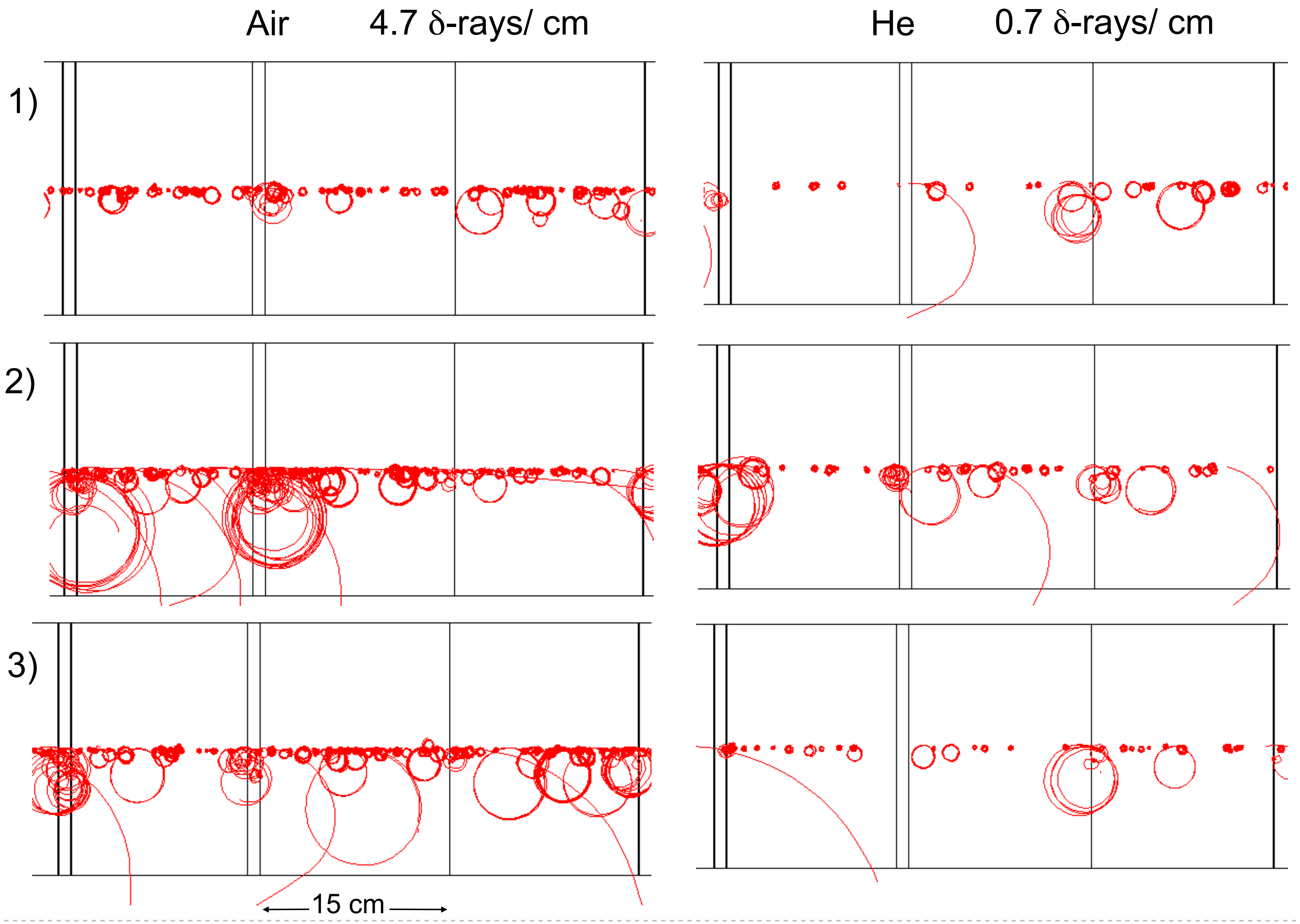
Summary

- A relatively small and simple tracker is all we require (see Matt's talk after lunch for review of performance.)
- Most expensive and complicated components, sensors and readout ASICs, are well developed and readily available free or at reasonable cost.
- Some unusual requirements (operation in vacuum, movable planes) will require careful attention.
- Time pressure is the biggest challenge. Important to get started as soon as possible, avoid unnecessary distractions and development by keeping things simple wherever possible.

Backup Slides

Why Vacuum?

δ-ray background in 25 ns



Upgrade?

Thin silicon in Layers 1 and 2?

- Reduces material budget by 0.15% X_0 / plane: 30% of total.
- S/N still ~22: timing resolution degrades by only ~10%.
- Cost: $37.5k for silicon per copy
- Should be possible to use same hybrids, partially populated, with a pitch adapter
- Additional risk for parts not in hand. Risk in working with Micron, but minimal for such a small production of single-sided sensors.

Cabling and Cooling Plant