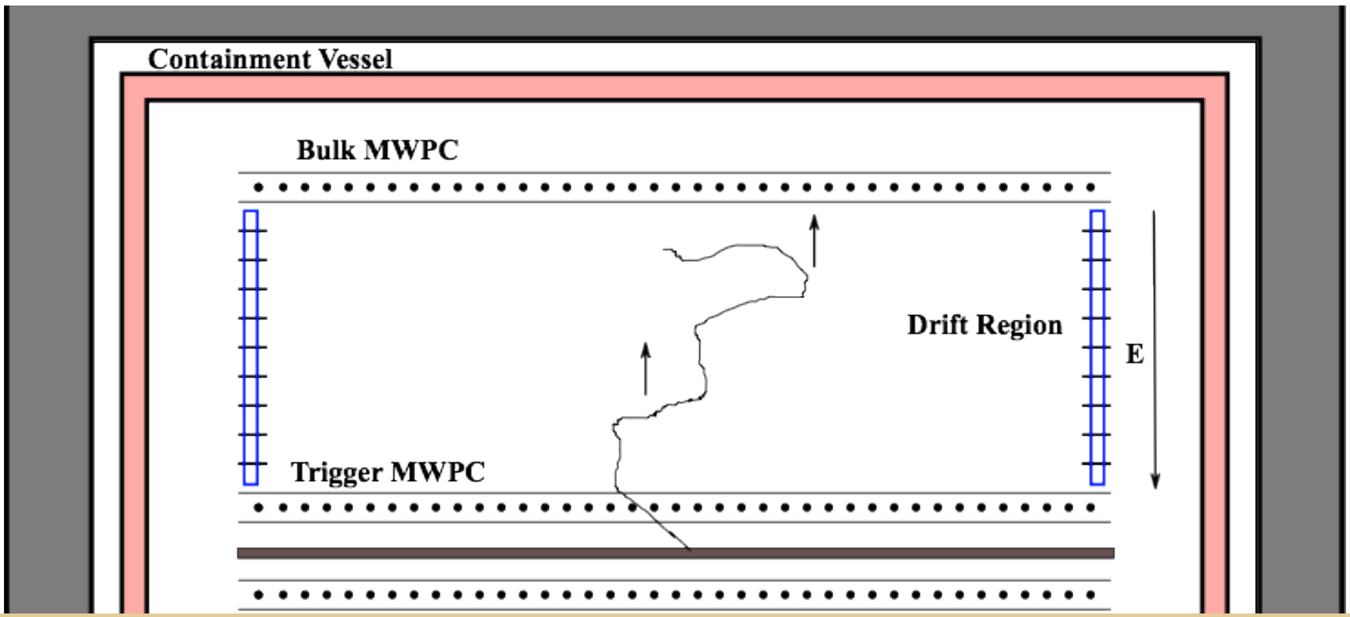
The BetaCage: An ultra-sensitive screener for surface contamination



Richard Schnee
South Dakota School of Mines and Technology

JINST 9 P01009 http://dx.doi.org/10.1088/1748-0221/9/01/P01009,
LRT 2013 Proceedings p.132-5; p116-9, 128-131

BetaCage Collaboration

SOUTH DAKOTA SCHOOL OF MINES & TECHNOLOGY
R. Bunker,
R. W. Schnee,
J. Ziadat

CALIFORNIA INSTITUTE OF TECHNOLOGY 1891
Z. Ahmed,
S. R. Golwala,
R. H. Nelson,
A. Rider, A. Zahn

SYRACUSE UNIVERSITY FOUNDED AD 1870 SUOS CULTORES SCIENTIA CORONAT
M.A. Bowles,
D. Jardin,
B. Wang
(Ph. D. 2014)

UNIVERSITY OF ALBERTA QUAECUMQUE VERA
D. Grant

For pending NSF MRI proposal, adding

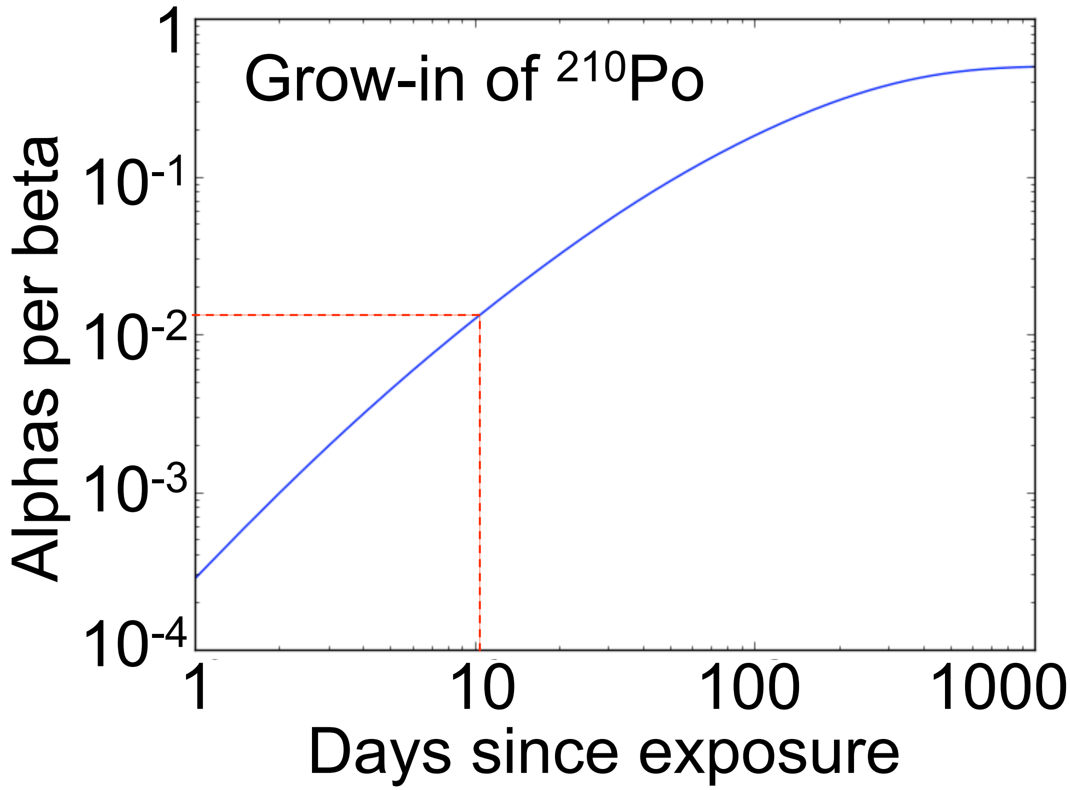
Co-PIs J. Cooley (SMU), J. Heise (SURF), K. Keeter (BHSU), K. Lesko (LBNL),

with contributions from

L. Corwin (SDSM&T), P. Cushman (UMinn), J. Orrell (PNNL),
H. Nelson (UCSB), B. Cabrera (Stanford)

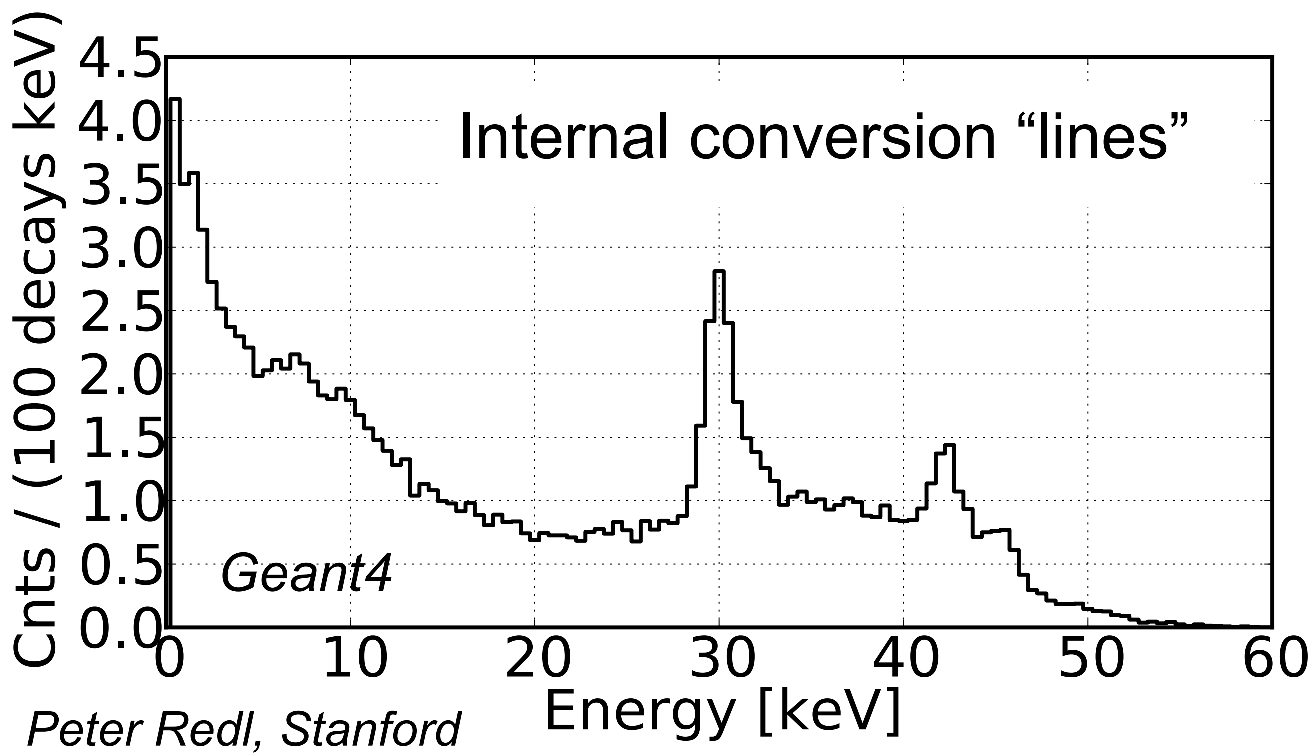
Need for Alpha/Beta Surface Screener

- Much better sensitivity to a large number of α- or β-emitting isotopes than HPGe γ detectors or ICP-MS
  - 12 β-emitting isotopes can be probed only by their β emission
    - Includes ^{3}H and ^{14}C, plus several others useful for radio isotope dating
  - 9 can be probed only by β emission or ppt ICP-MS
  - 6 only by their β or α emission
- Very useful for Rn daughters ^{210}Pb, ^{210}Po!
  - Efficiency ~ 1 vs. <5% branching fraction, efficiency for HPGe detection of 46 keV line
  - Can screen for ^{210}Pb betas promptly, without having to wait for grow-in of ^{210}Po alphas



^{210}Pb Spectrum Signature

- Often detect electron from internal conversion plus little or nothing else
  - ~half of particles go back into sample

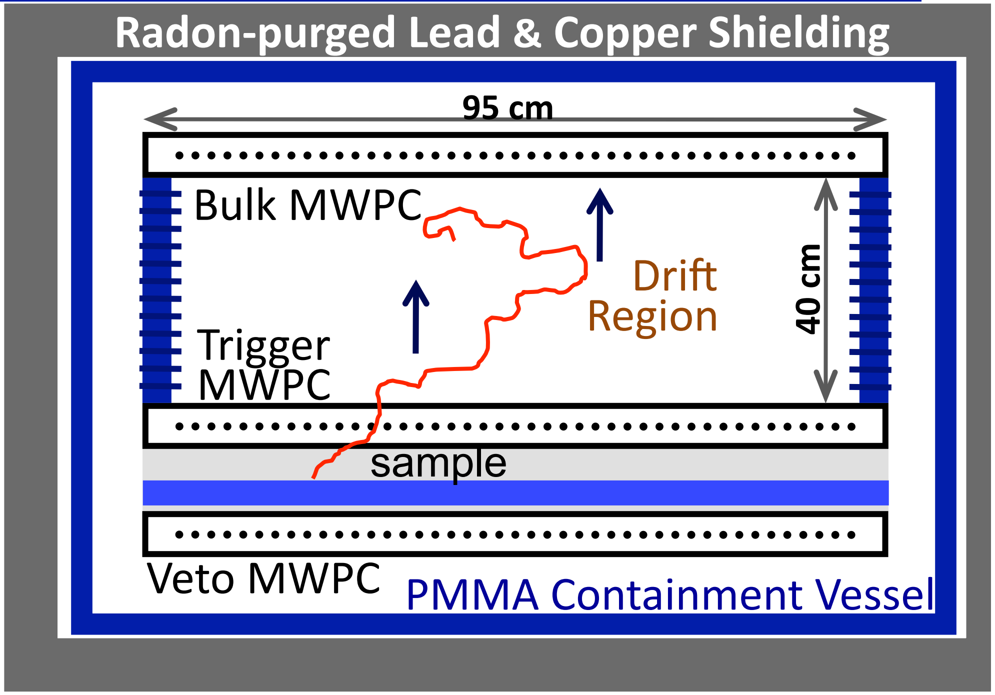


Peter Redl, Stanford

- 10% of decays give broad peak at 30 keV (L shell)
- Best sensitivity by comparing full ^{210}Pb energy region to spectrum without sample, but signature provides smoking gun.

BetaCage Design Principles

- Ultraclean, shielded, gas time projection chamber
  - 0.45 m^2 area, detection efficiency ~1 maximize signal
  - 40 cm Ne (1 atm) contains 200 keV electrons and all α's
  - Wires and gas provide minimum surface area and mass for background emissions & scattering

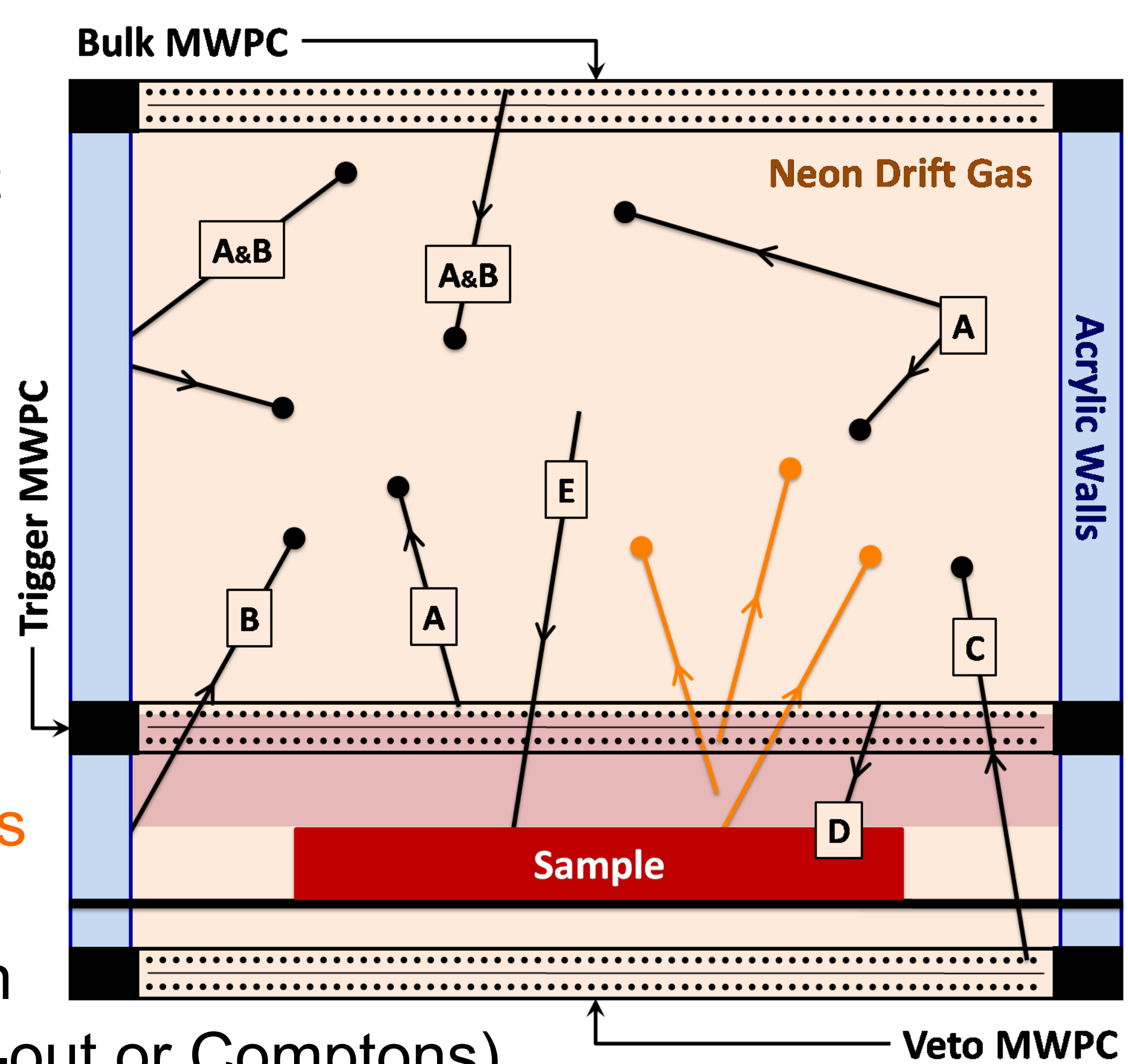


- Reject background interactions in bulk of gas by creating narrow (5 mm) "trigger region" near samples
  - Most gamma interactions in gas don't cause trigger
- Crossed grids for ~mm xy position information, tracking
  - Identify contamination position, reject backgrounds not from sample
- Expect ~100x more sensitive than existing instruments
  - 0.1 β/keV-m^2-day and 0.1 α/m^2-day

Excellent Background Rejection

arXiv:1404.5803

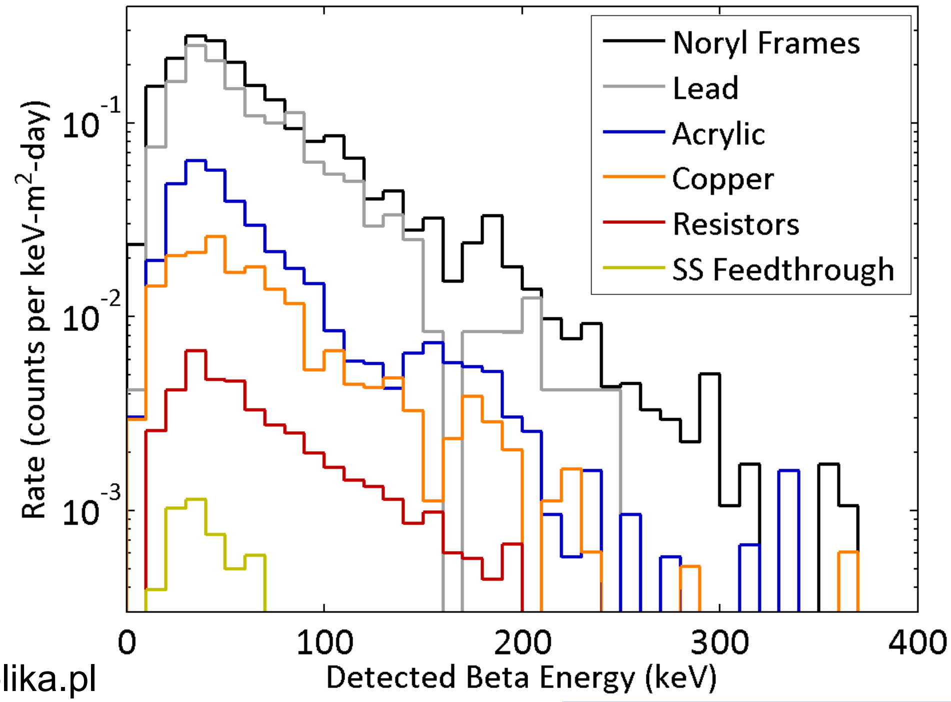
- Can reject all black tracks due to
  - A. Too little energy in trigger region
  - B. Lack of containment in fiducial region
  - C. Too much energy in veto MWPC
  - D. Too little energy in bulk MWPC
  - E. Uniform *dE*/*dx*, even at end of track



- Poor rejection only for decays / scatters in gas or wires just above sample, or in sample itself (plate-out or Comptons)

Expected Photon Backgrounds

mBq/kg	^{238}U	^{232}Th	^{40}K
Resistors [a]	8	0.46	0.34
Noryl [b]	<3	<1	5
Lead [c]	3,000 ^{210}Pb		
Acrylic [d]	<0.12	<0.04	<1.5
Copper [e]	0.08	0.012	0.04
Stainless Steel [d,f]	<1	<10	<4



arXiv:1404.5803

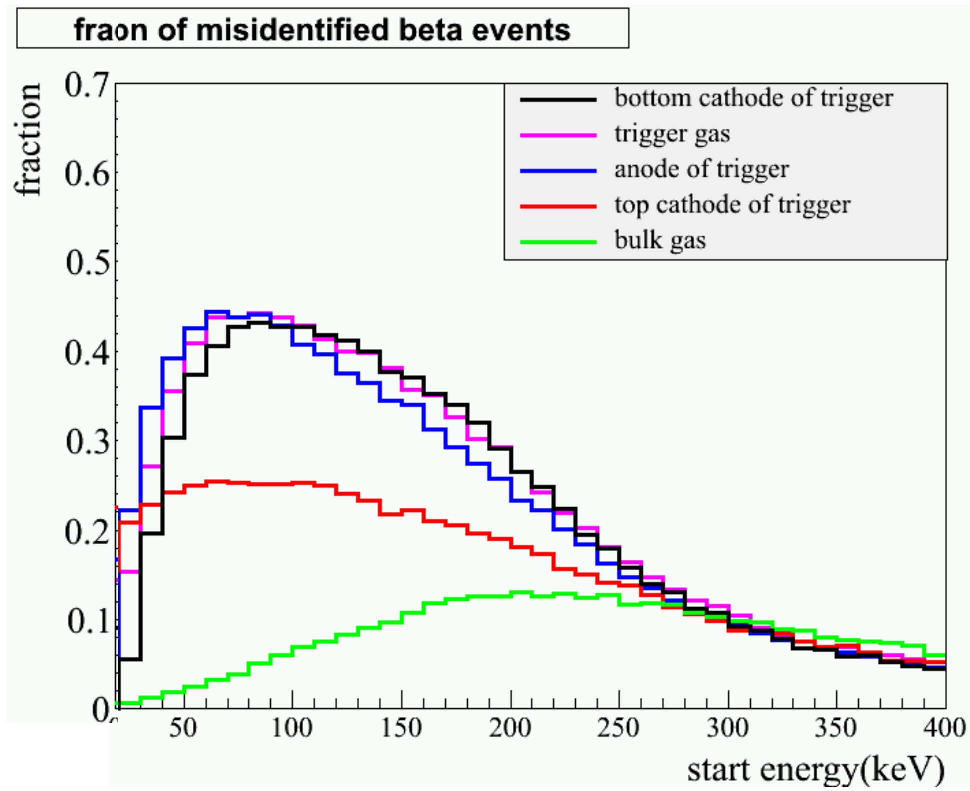
[a] S. Cebrian (NEXT/LSC), LRT 2013.
[b] U/Th→UMN Gopher HPGe & Caltech ICP-MS; K→UC Davis NAA
[c] PLOMBUM low-activity lead, www.plombum.republika.pl
[d] radiopurity.org
[e] E. Aprile et al., Phys. Rev. D83 (2011) 082001

[f] SS feedthrough contributes negligibly to beta background

- Full background simulation using measured or limited radiopurity of components indicates gammas from lead shielding should dominate, total background for betas 0.25 keV^{-1} m^{-2} day^{-1}

Background from Radon Daughters

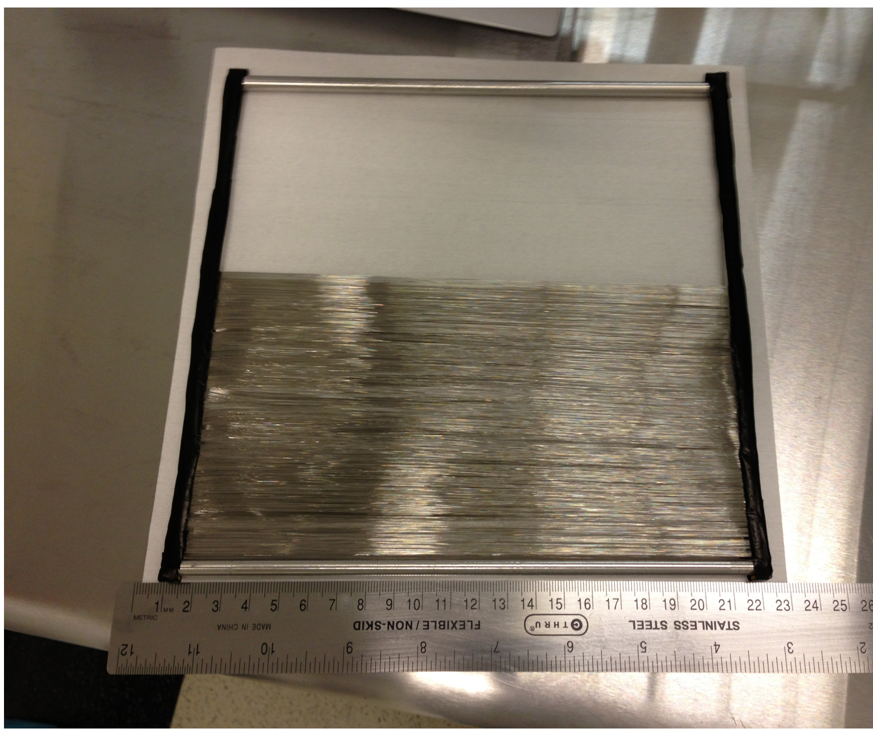
- Radon daughters on wires of trigger grid (and in gas) provide dangerous background
  - Beta emitters elsewhere may be vetoed with very high efficiency.
  - Helped by wire surface area only 15% of total sample area
  - Also veto most events from wires due to not enough energy deposited in trigger region



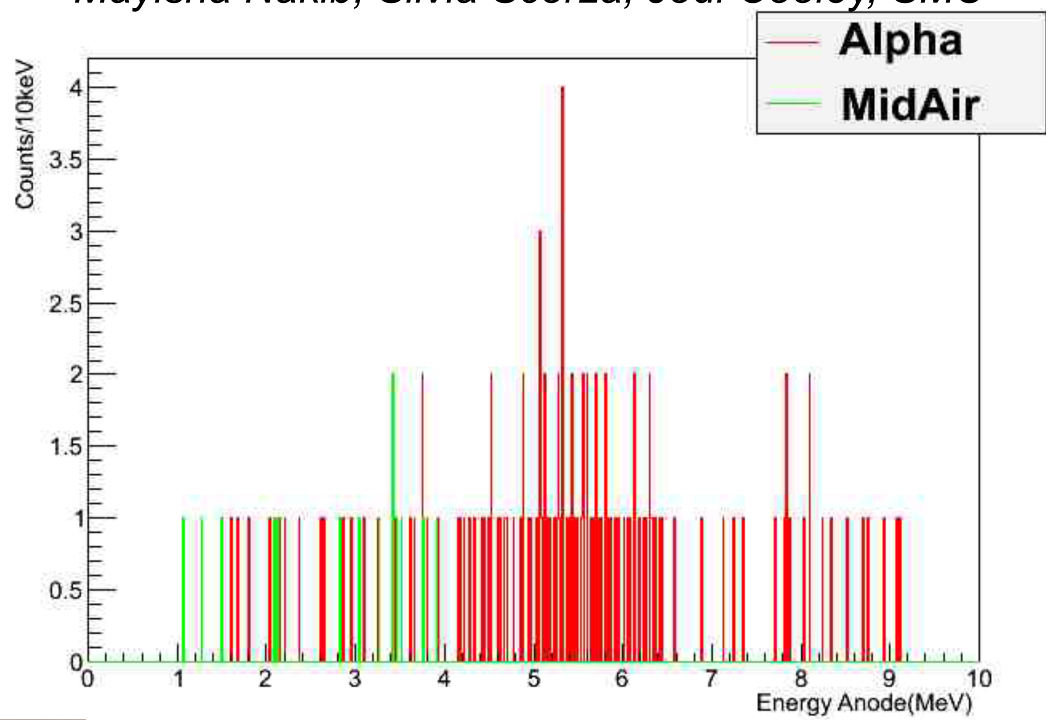
- Consider three sources:
  - Background from clean wire from manufacturer
  - Background introduced during detector assembly
  - Plate-out from emanation of radon during lifetime of detector

Background from Plate-out onto Wire

- Measure 0.07 ± 0.02 ^{210}Po alphas / (cm^2 day) with SMU XIA Ultra-Lo 1800 on new but uncleaned wire.
  - Results in 22 betas / (m^2 day) in BetaCage after data selection cuts , < half of photon-induced background.
  - Cleaning steps under consideration (see e.g. arXiv:1404.5843).



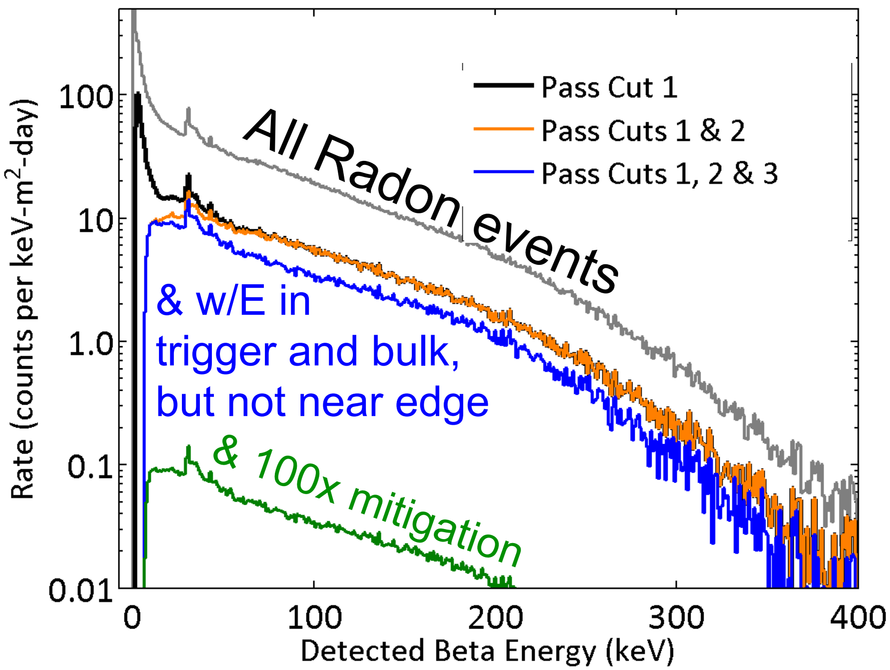
Mayisha Nakib, Silvia Scorza, Jodi Cooley, SMU

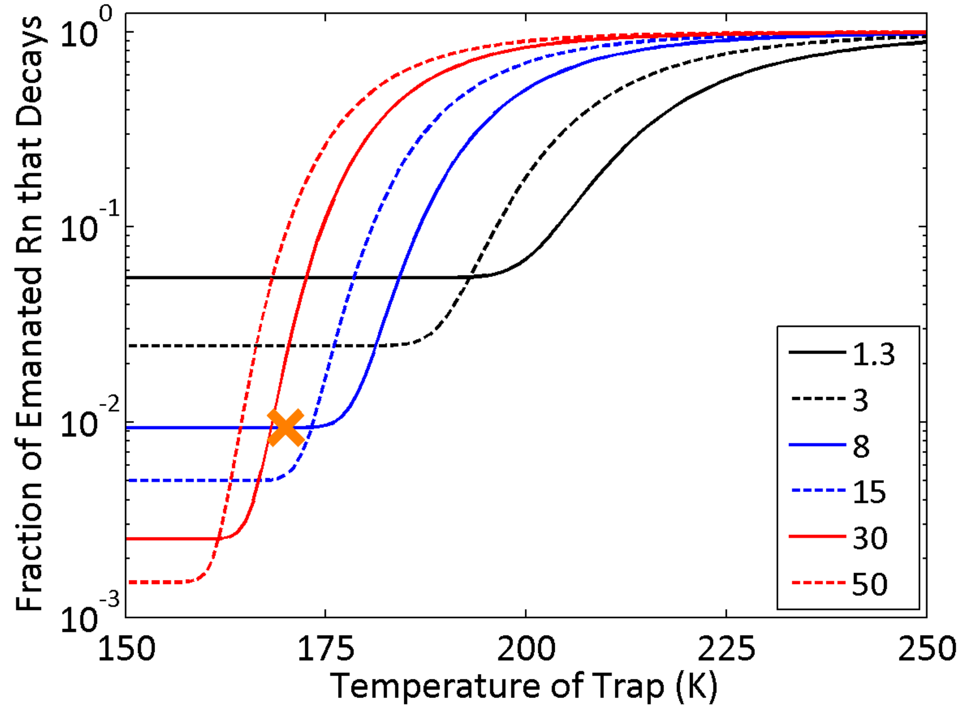


Background from Plate-out onto Wire

- Measure 0.07 ± 0.02 ^{210}Po alphas / (cm^2 day) with SMU XIA Ultra-Lo 1800 on new but uncleaned wire.
  - Results in 22 betas / (m^2 day) in BetaCage after data selection cuts , < half of photon-induced background.
  - Cleaning steps under consideration (see e.g. arXiv:1404.5843).
- Exposed wire sample to high-radon (100 Bq/m^3) lab environment for expected assembly exposure time, measured upper limit <0.3 ^{210}Po alphas / (cm^2 day) in commercial alpha counter.
  - Translates to < 2 ^{210}Pb decays / (cm^2 day) due to not waiting for full grow-in
  - Implies contribution is negligible (<2 betas / (m^2 day) in BetaCage) if assembly occurs in low-radon lab with <0.3 Bq/m^3.
  - Already achieved this low activity in our low-radon cleanroom:
    - See Ray Bunker talk and Joseph Street poster

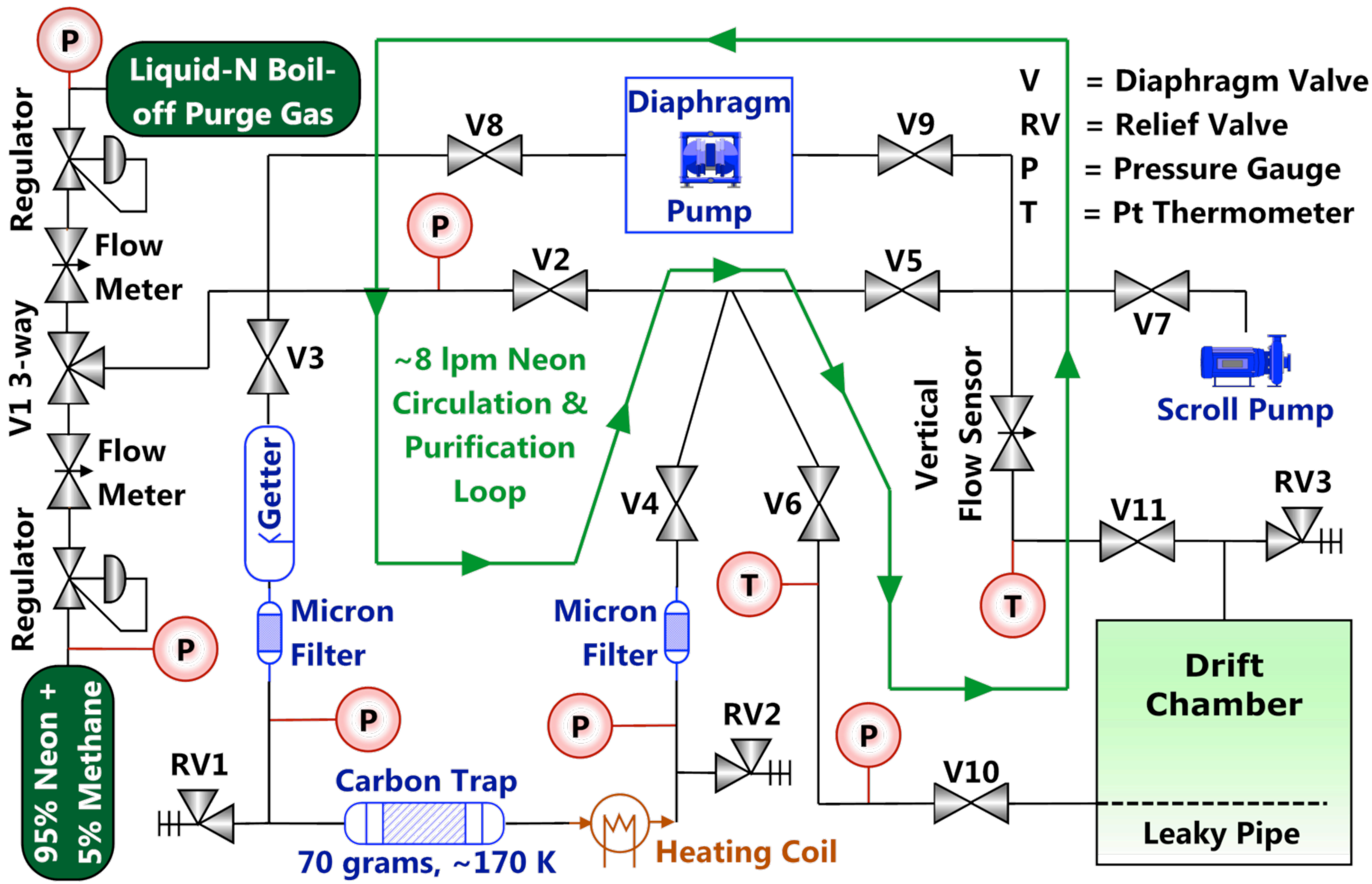
Expected Radon Emanation Background



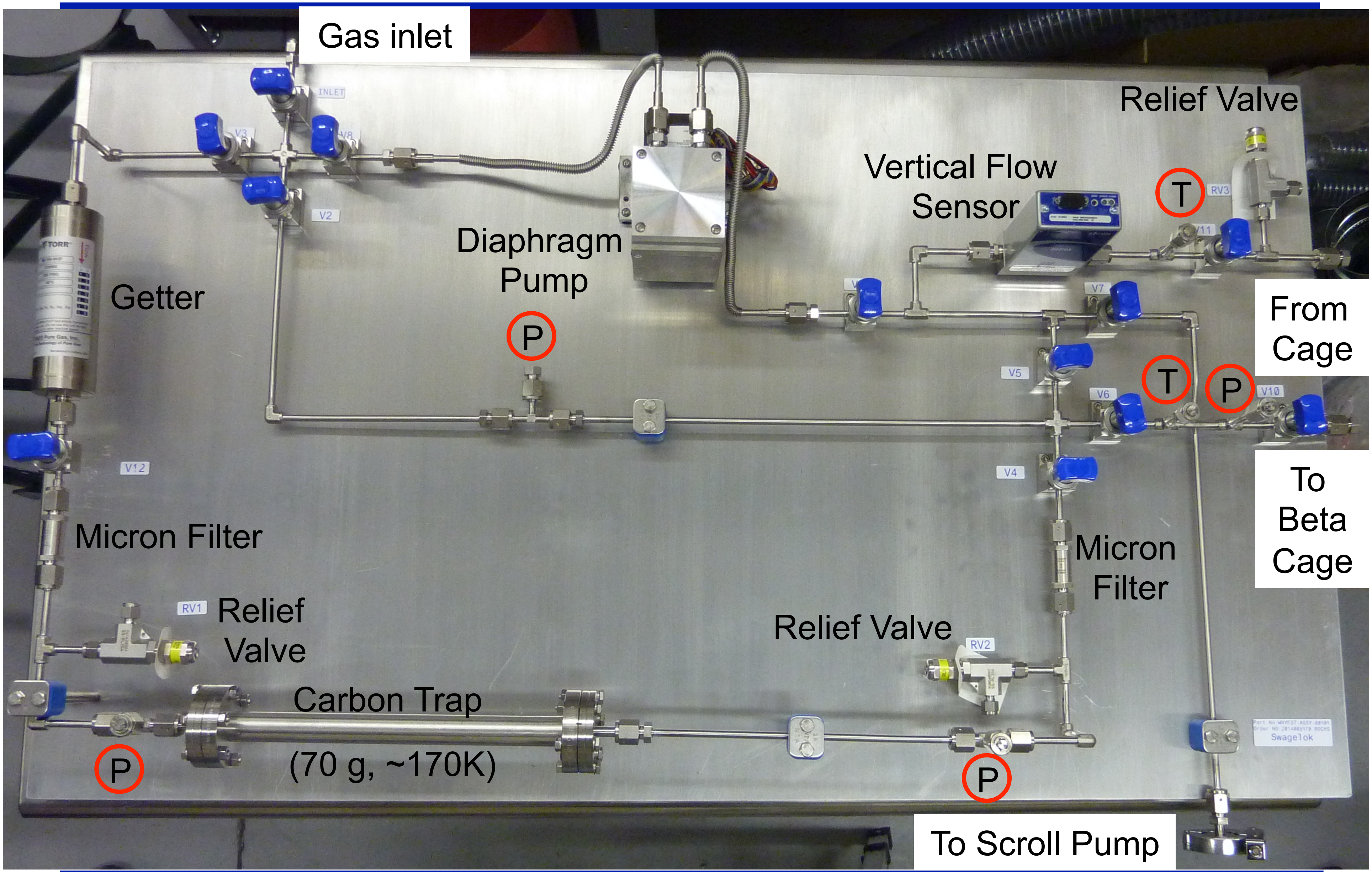


- Detector provides rejection of >80% of events from radon daughters following emanation during detector operation
  - But expected background would still dominate without mitigation for conservatively estimated emanation rates (10,000/day total).
  - 100x improvement, enough to make background subdominant, achievable with 8 lpm flow rate through cooled carbon trap

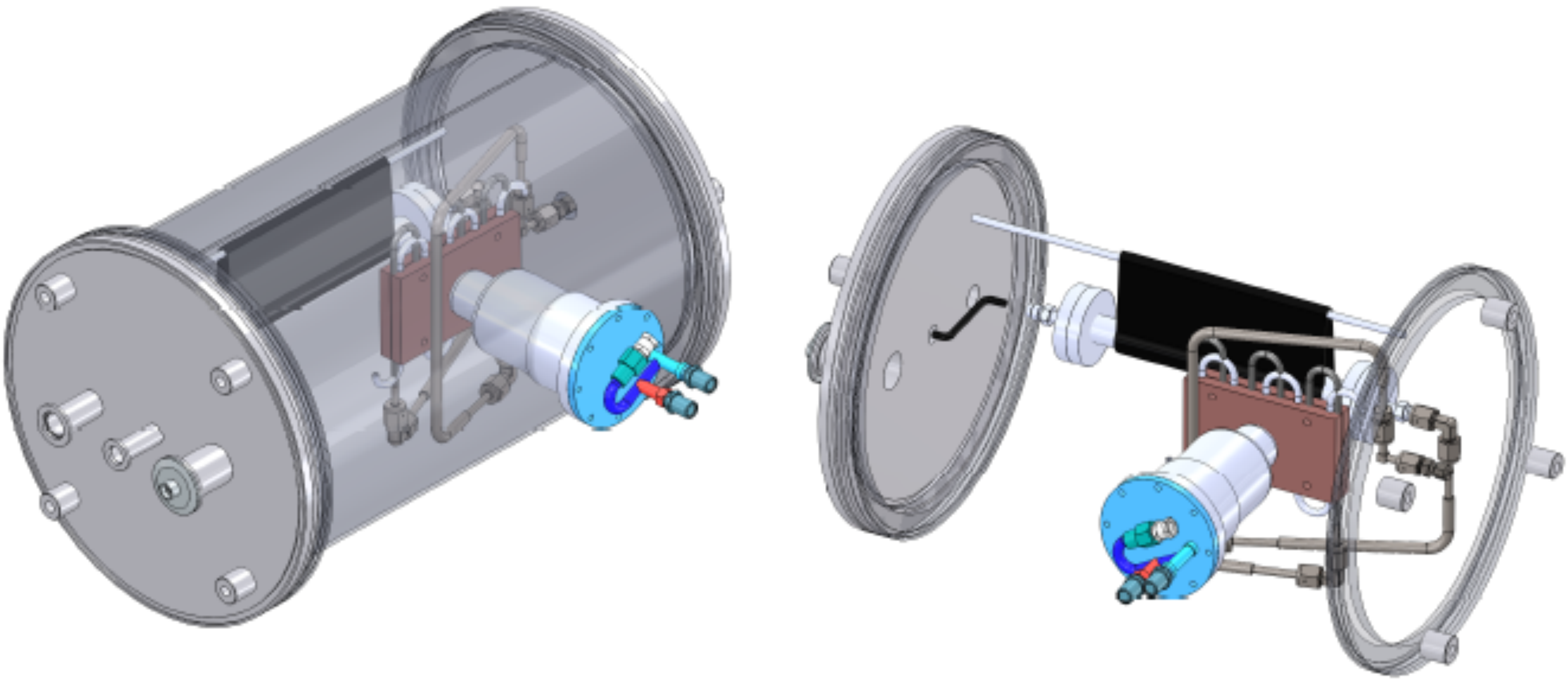
Gas Panel with Radon Trap



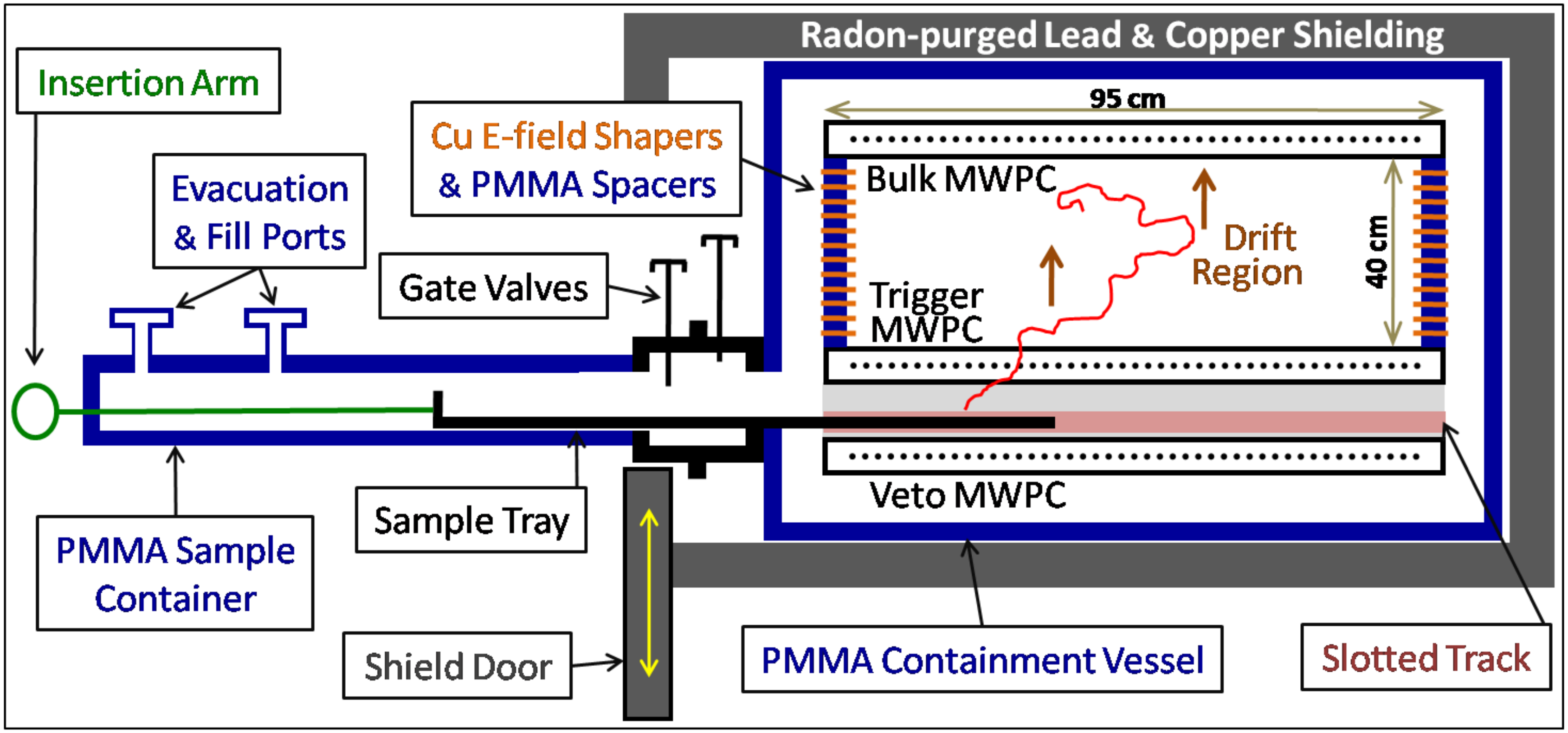
Gas Panel with Radon Trap



Gas Panel with Radon Trap



Minimize Rn Ingress with Sample Load/Lock



Minimize Rn Ingress with Sample Load/Lock

Transfer valve / insert MONOVAT — VAT Series 02/03

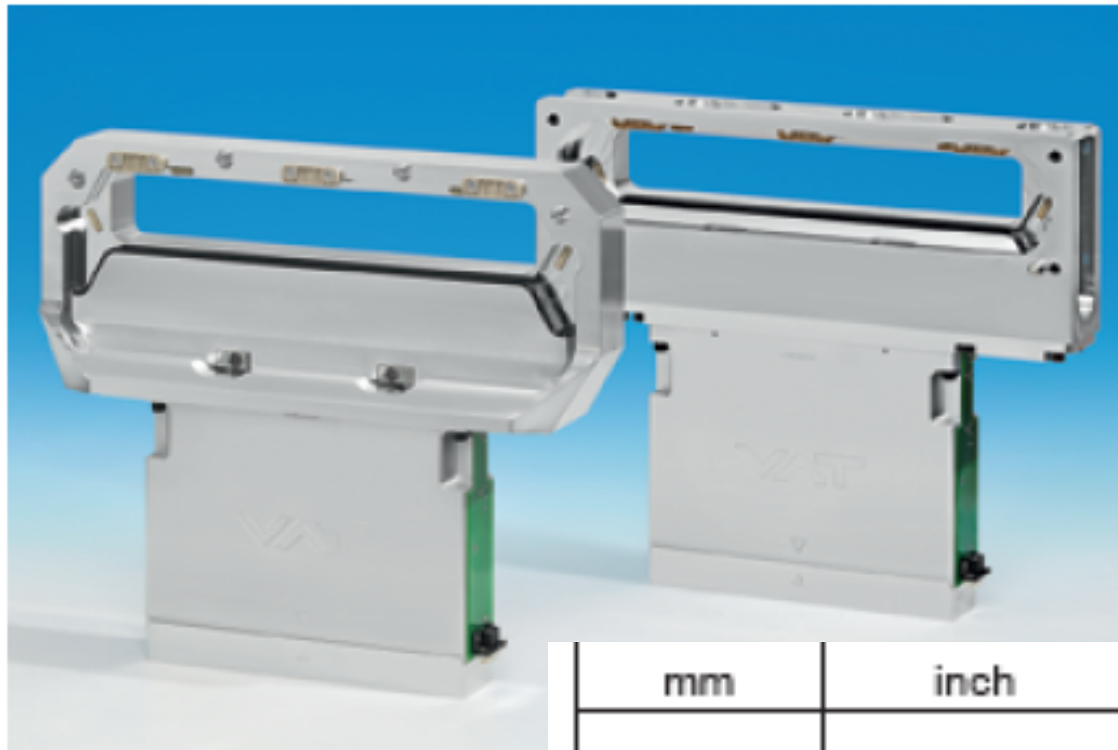
For SEMI applications handling
200, 300 and 450 mm wafers

For load lock / process module isolation

Virtually particle and vibration-free

>5 million cycles between maintenance

Very easy maintenance
thanks to self-adjusting plate



Body material

aluminum or stainless steel

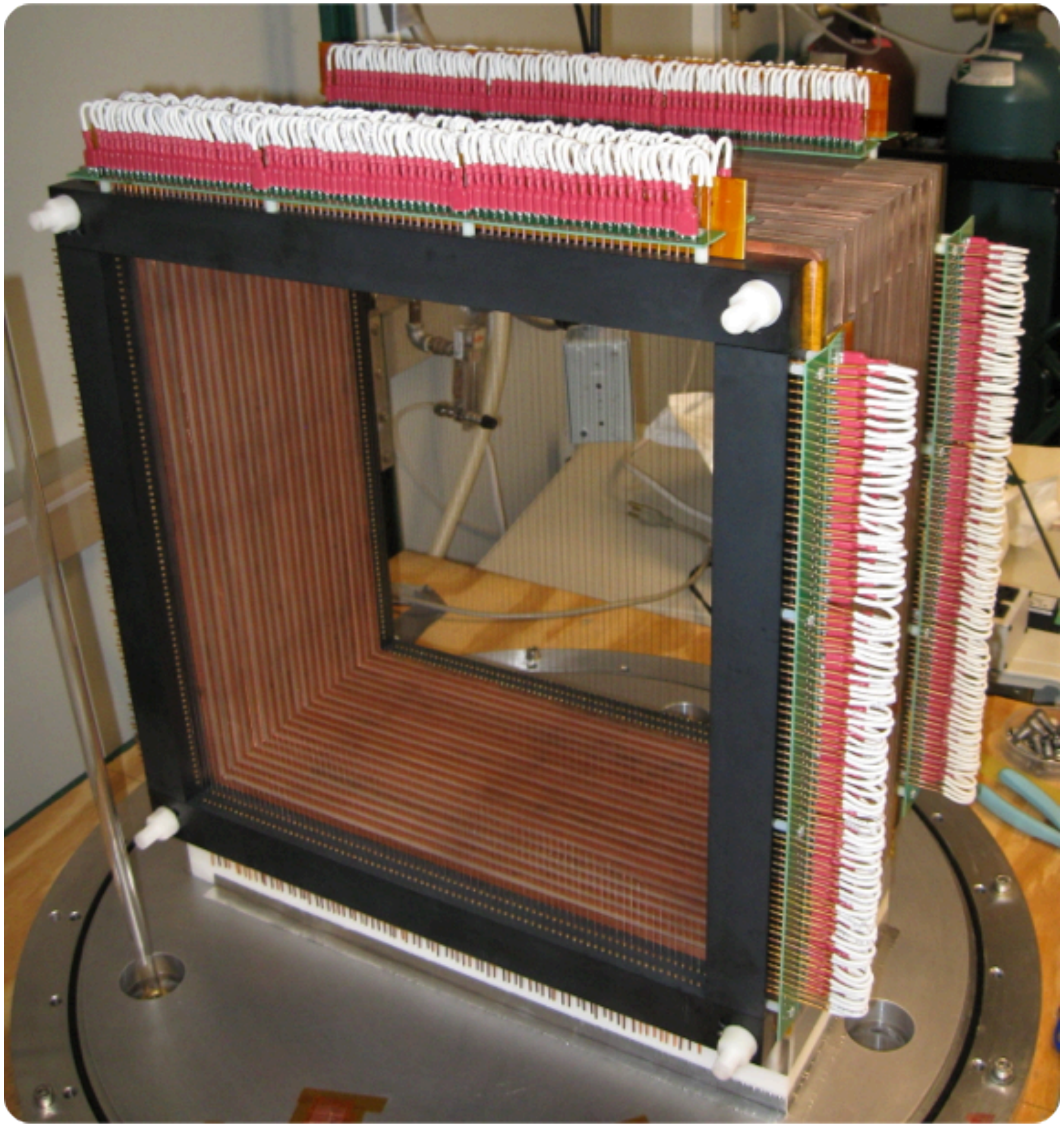
Valve
Series 022

double acting
pneumatic actuator
with position indicator

Maximum sample size
49 x 78 x 5.5 cm

mm	inch
32 x 222	1.26 x 8.74
46 x 236	1.81 x 9.29
50 x 336	1.97 x 13.23
56 x 496	2.20 x 19.53

Assembled BetaCage prototype

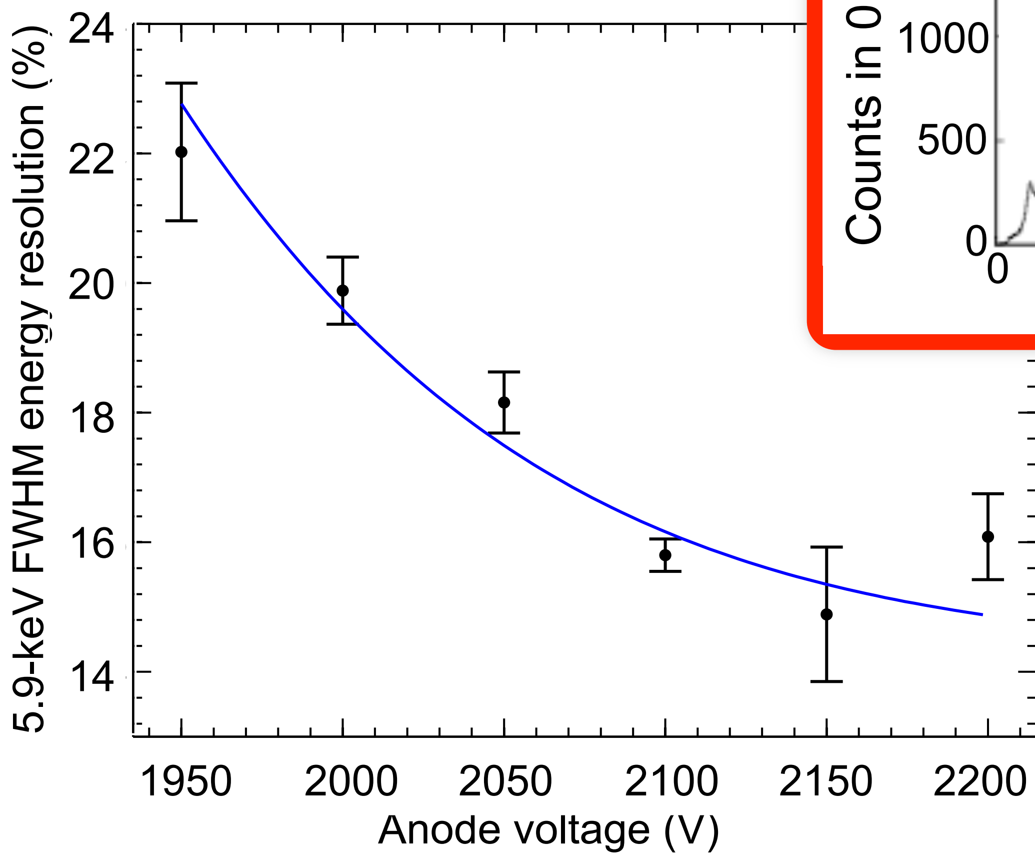


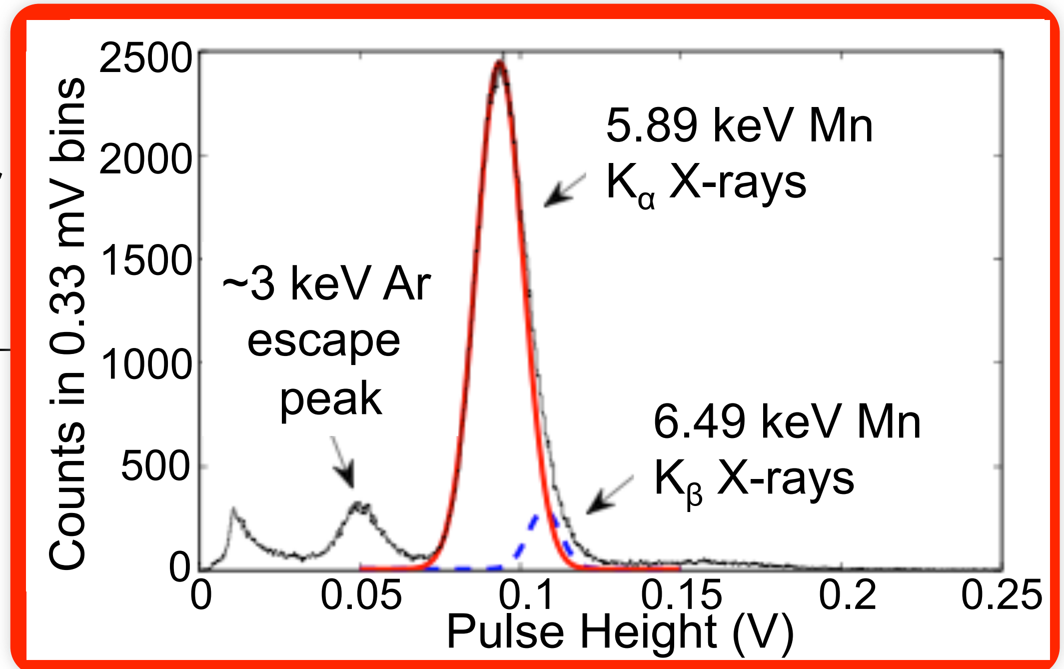
- 2 40x40-cm^2 MWPCs (3 layers of 79 wires each) sandwiching a 20-cm field-cage.
- Standing on end to fit in our bell jar.
- Prototype only uses 2 MWPCS.
  - A trigger MWPC
  - An imaging “bulk” MWPC
- P10 gas at STP; eventually switch to neon/methane.
- Anode planes at ~2 kV relative to their cathode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

JINST 9 P01009, 2014

Energy Resolution Nearly Ideal

Data collected from ^{55}Fe source x-rays. Read into a charge integrating amplifier and a slow digitizer.



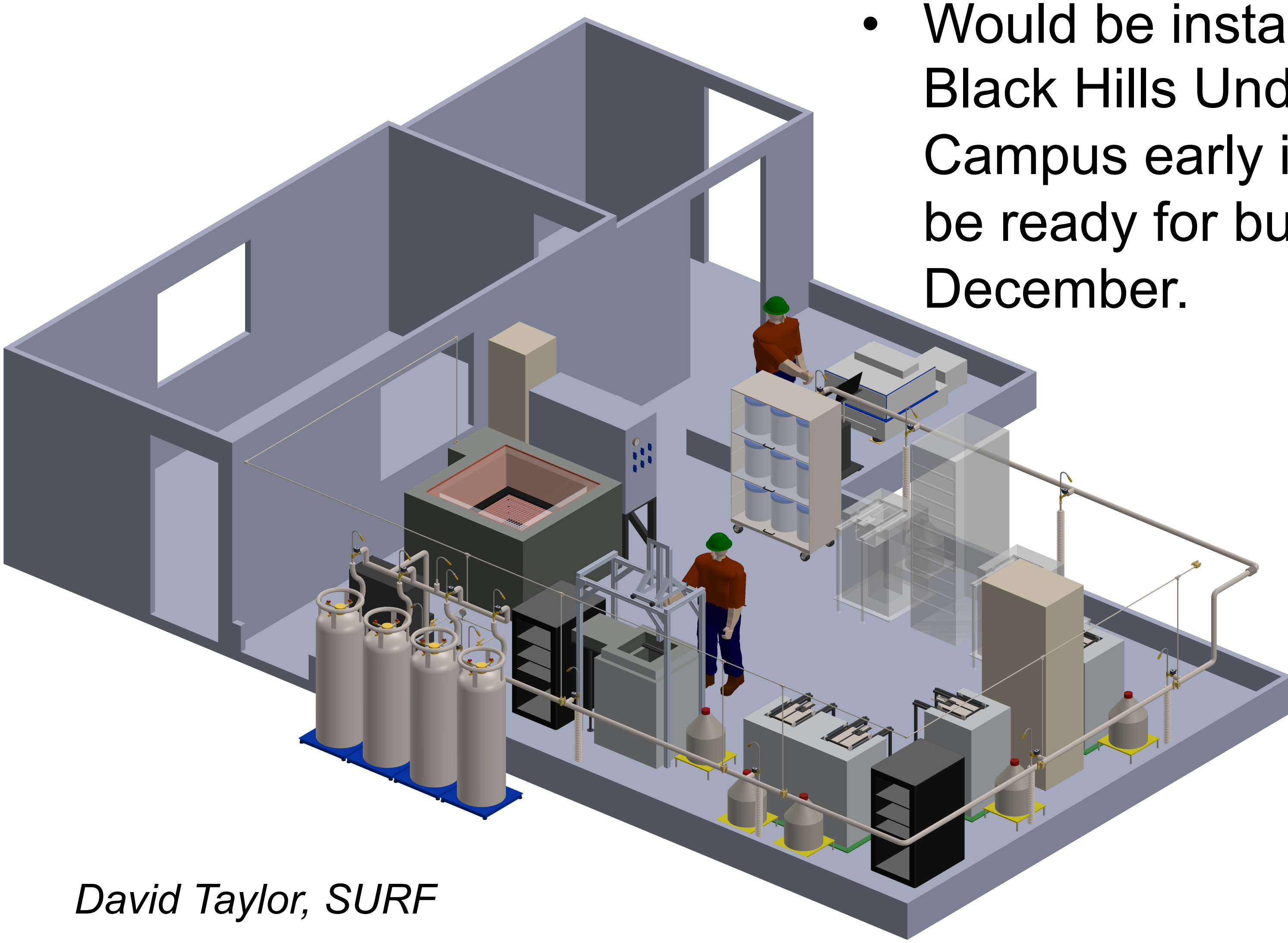


- At 5.9 keV, intrinsic resolution ~16% (vs. "ideal" ~14%)
  - < 8% due to gain non-uniformity

JINST 9 P01009, 2014

Pending Funding, First Assay End of 2017

- Proposal to NSF MRI (January 2015) is pending.
  - Would be installed in Black Hills Underground Campus early in 2017 and be ready for business by December.



David Taylor, SURF

Summary

- BetaCage should provide outstanding sensitivity to alphas and betas on surfaces
  - Combines high signal acceptance with excellent background rejection
  - Expected sensitivity is 0.1 β/keV-m^2-day and 0.1 α/m^2-day
  - Should have transformative impact on surface screening
- Design has progressed to high level of maturity
  - Detailed simulations of all important backgrounds done
  - Assays of noryl plastic for frames and stainless steel wires both show acceptable radiopurity; other materials achievable based on literature
  - Will minimize backgrounds from radon during assembly and operation
- Prototype MWPC shows excellent resolution and stability using radiopure materials.