The DarkSide-10 Prototype Dark Matter Detector

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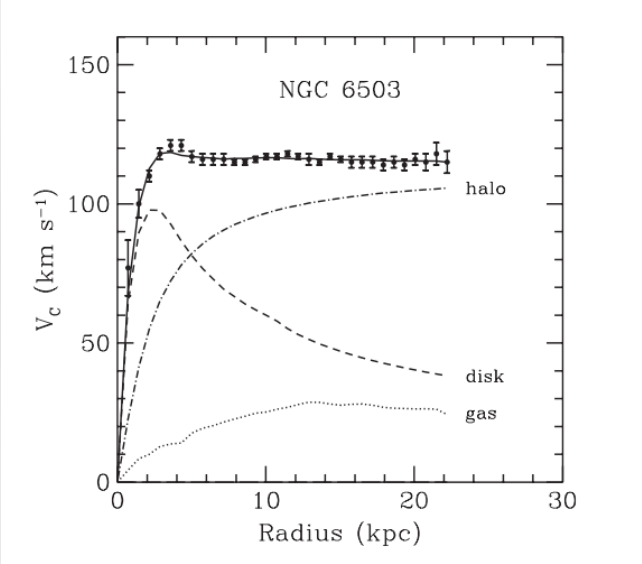
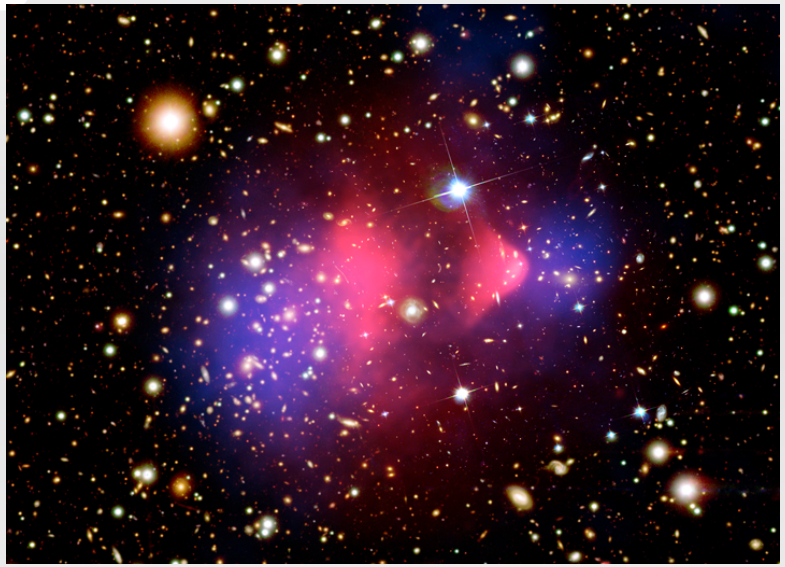
Outline

- What would a dark matter signal look like?
- Argon as a dark matter target
- The DarkSide-10 prototype two phase argon time projection chamber: construction and data analysis
- Next steps: DarkSide-50 and depleted argon

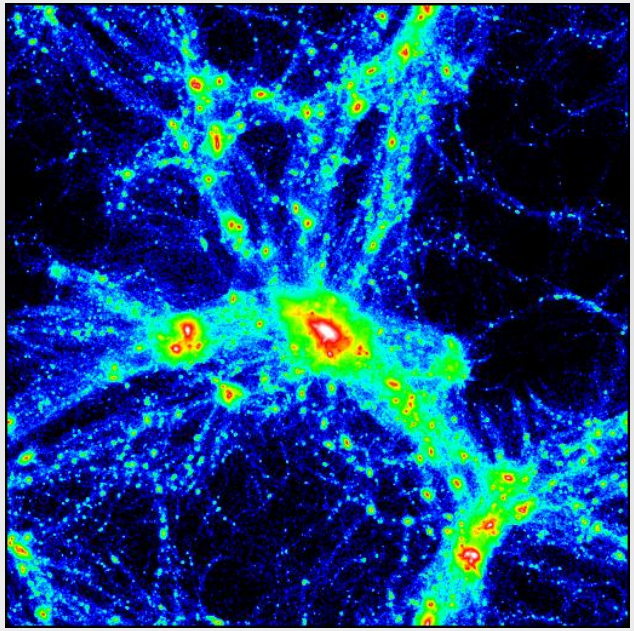
Evidence for dark matter: compelling at all scales



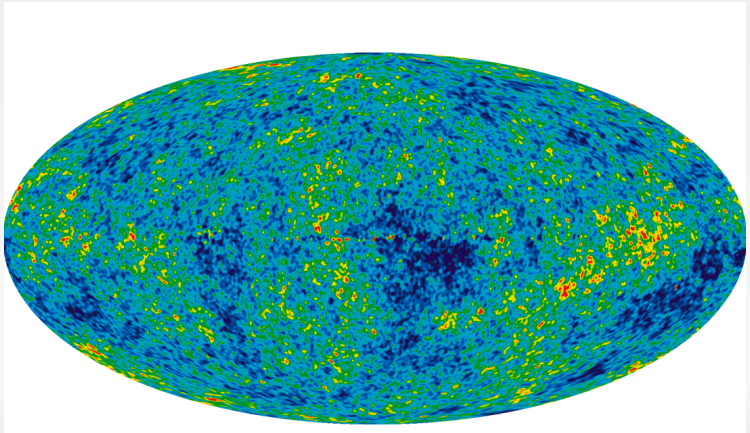
K.G. Begeman, A.H. Broeils, R.H. Sanders, MNRAS 249 (1991) 523



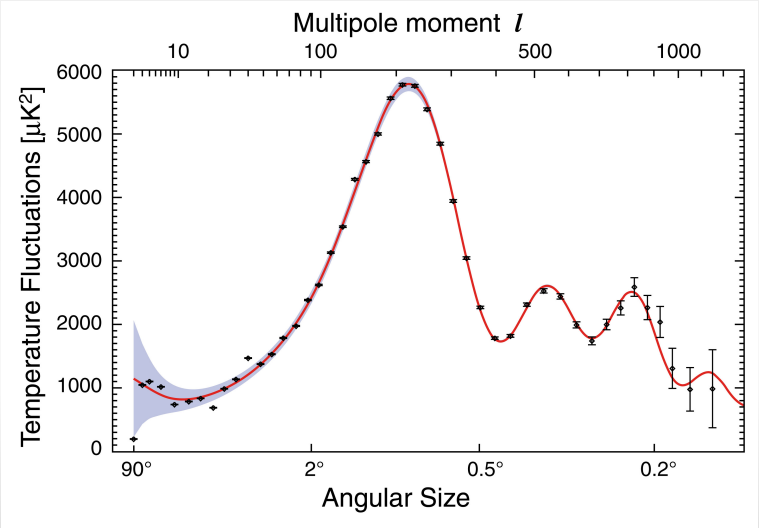
X-ray: NASA/CXC/CfA/M.Markevitch et al.; Optical: NASA/STScI; Magellan/U.Arizona/D.Clowe et al.; Lensing Map: NASA/STScI; ESO WFI; Magellan/U.Arizona/D.Clowe et al.



R. Cen, Princeton University.



NASA / WMAP Science Team



Other dark matter searches

- Direct Detection: observe interaction of dark matter particle with target material
  - CDMS, Xenon, DAMA, CoGeNT, LUX, DEAP/CLEAN, COUPP, ZEPLIN, WARP
- Indirect detection: Look for high energy products of dark matter annihilation in space
  - PAMELA, Fermi/GLAST, ATIC, EGRET, Milagro
- Colliders

DarkSide Collaboration

- Augustana College – SD, USA
- Black Hills State University – SD, USA
- Fermilab – Il, USA
- IHEP – Beijing, China
- INFN Laboratori Nazionali del Gran Sasso – Assergi, Italy
- INFN and Università degli Studi Genova, Italy
- INFN and Università degli Studi Milano, Italy
- INFN and Università degli Studi Napoli, Italy
- INFN and Università degli Studi Perugia, Italy
- Joint Institute for Nuclear Research – Dubna, RussiaPrinceton University, USA
- RRC Kurchatov Institute – Moscow, Russia
- St. Petersburg Nuclear Physics Institute – Gatchina, Russia
- Temple University – PA, USA
- University of California, Los Angeles, USA
- University of Houston, USA
- University of Notre Dame, USA
- University of Massachusetts at Amherst, USA
- University of Virginia, USA

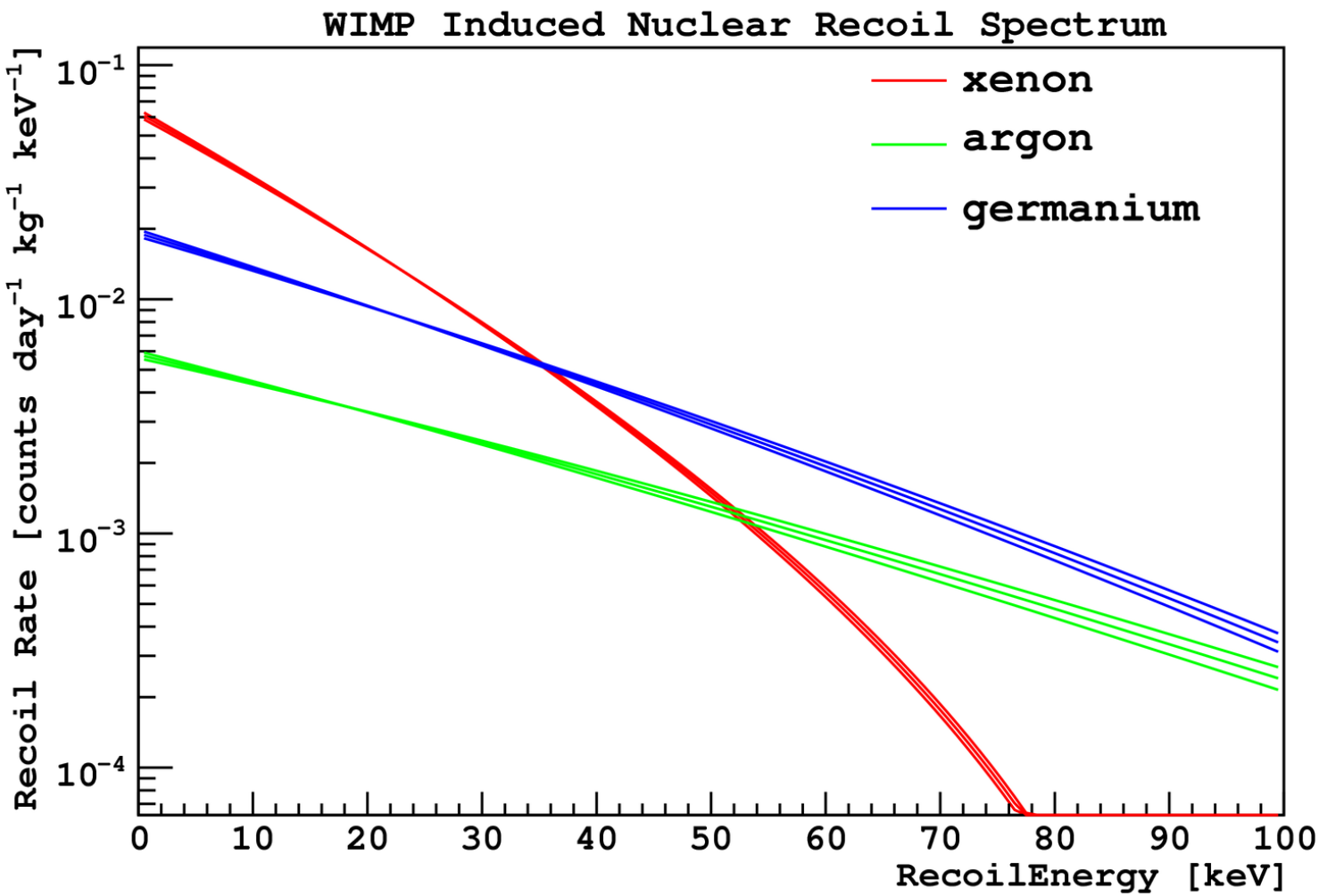
Expected WIMP Properties

- Often identified with neutralino, or lightest supersymmetric particle
- All predictions are somewhat model dependent; these are most common standards
- Predicted to collide with normal matter at ultra-weak scale, cross section $<10^{-40}$ cm^2
- Particle mass ~GeV-TeV
- Maxwellian velocity distribution with v_{avg}~230km/s; negligible net rotation
- Local density ~0.3 GeV/cm^3

Expected WIMP Detection Signal

- Low momentum transfer:
  - Observe elastic recoil of nucleus struck by WIMP, similar to neutron elastic scattering
  - Coherent scattering with whole nucleus, gives A^2 factor enhancement to cross section for spin-independent interactions
  - At higher momentum transfer, A^2 coherence factor reduced by nuclear form factor
- Low cross section: predict at best a few nuclear recoil signatures per ton of target per year

WIMP-induced Nuclear Recoil Spectra



100 GeV WIMP mass

Three lines for each nucleus are average, summer, and winter

Argon as a Dark Matter target

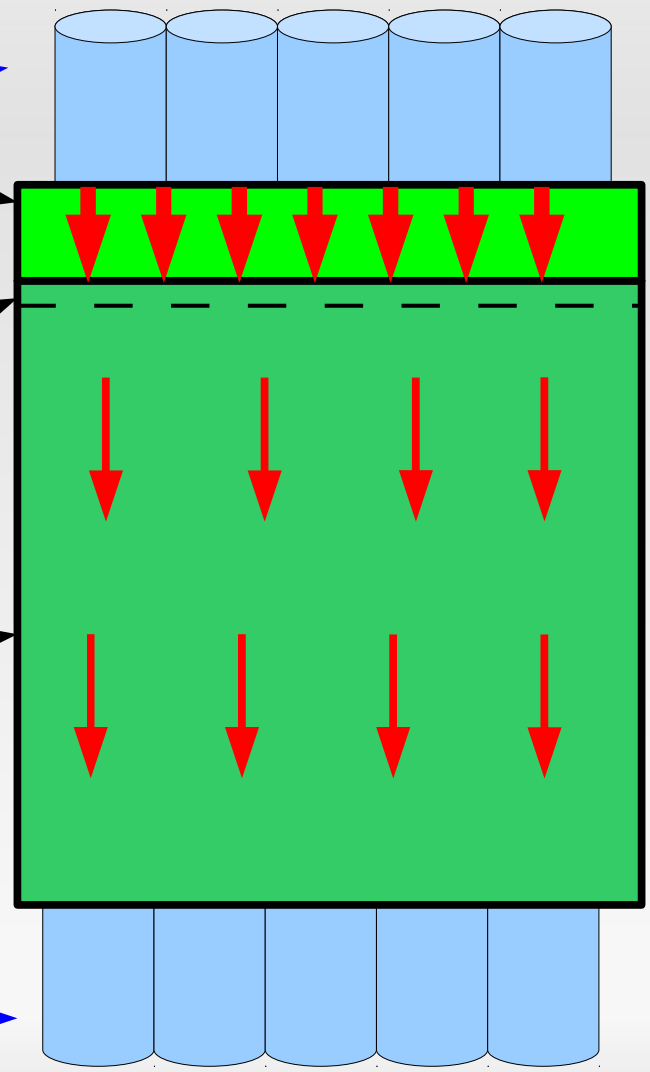
- WIMP signals are very low rate (few per year), low energy (<100-200 keV)
- Dominant background at this energy will be gammas emitted from radioactive contaminants in the detector and surrounding material
- Passive shielding can reduce this background, but not enough to observe WIMP signals
- ALL direct detection experiments must actively discriminate against backgrounds

Argon as a Dark Matter target

- In argon, energetic interactions produce both scintillation and ionization
- Both the scintillation time profile and the ratio of scintillation to ionization depend on the local ionization density of the interaction
- By measuring both of these parameters, we can distinguish nuclear recoils (high ionization density) from gammas (low ionization density)
- How do we measure these?

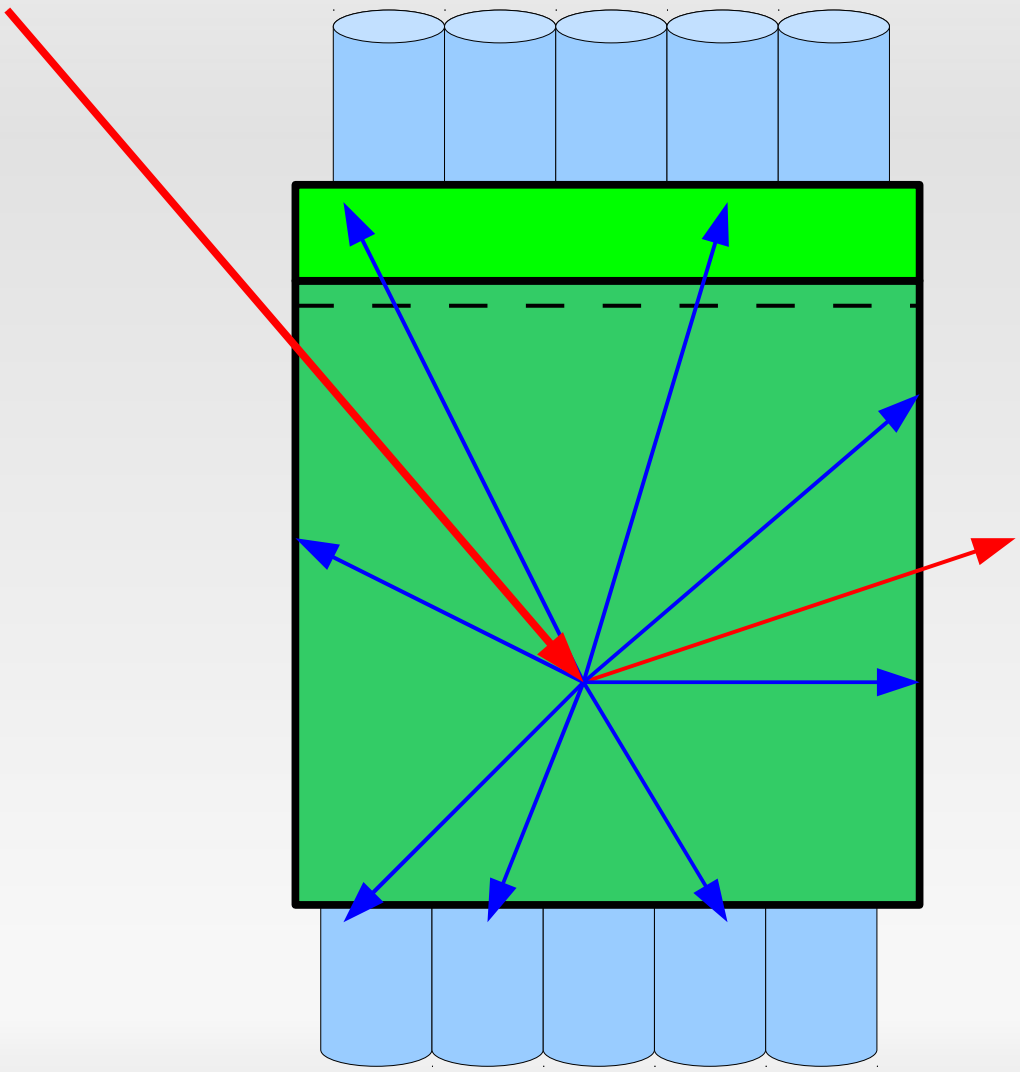
Dual-Phase Argon Time Projection Chamber

- Gaseous argon volume with multiplication field ~3-6 kV/cm
- Grid plane allows for discontinuity in field
- Liquid argon active volume with drift field ~1 kV/cm
- Photodetectors



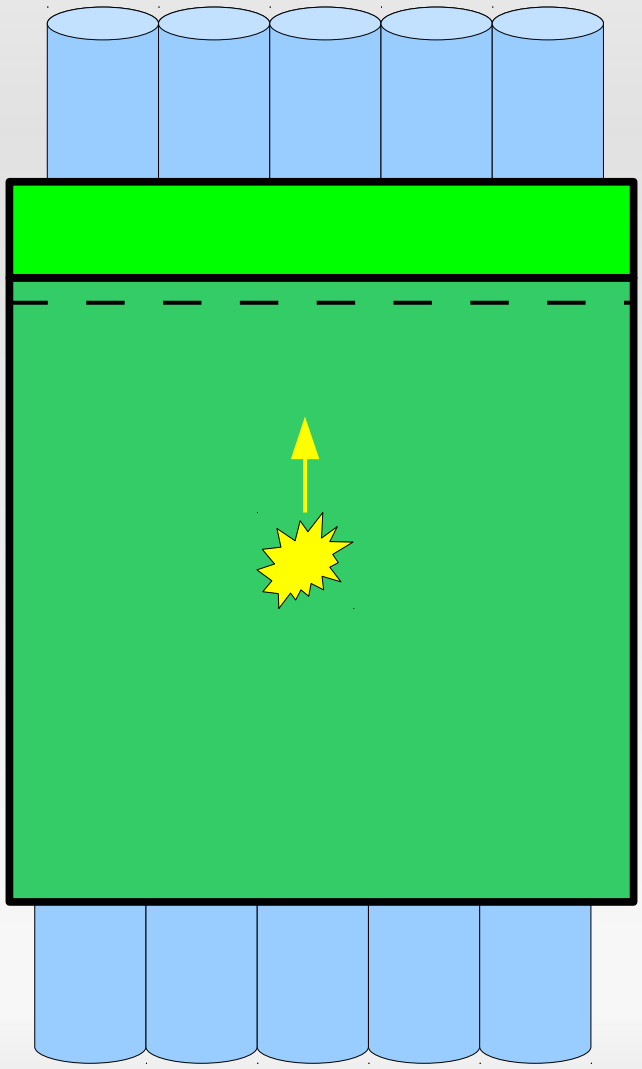
Dual-Phase Argon Time Projection Chamber

- An energetic particle (WIMP, gamma, etc) interacts in the liquid volume
- Prompt scintillation light (S1) is emitted from the point of interaction
- Gives time and energy of the event



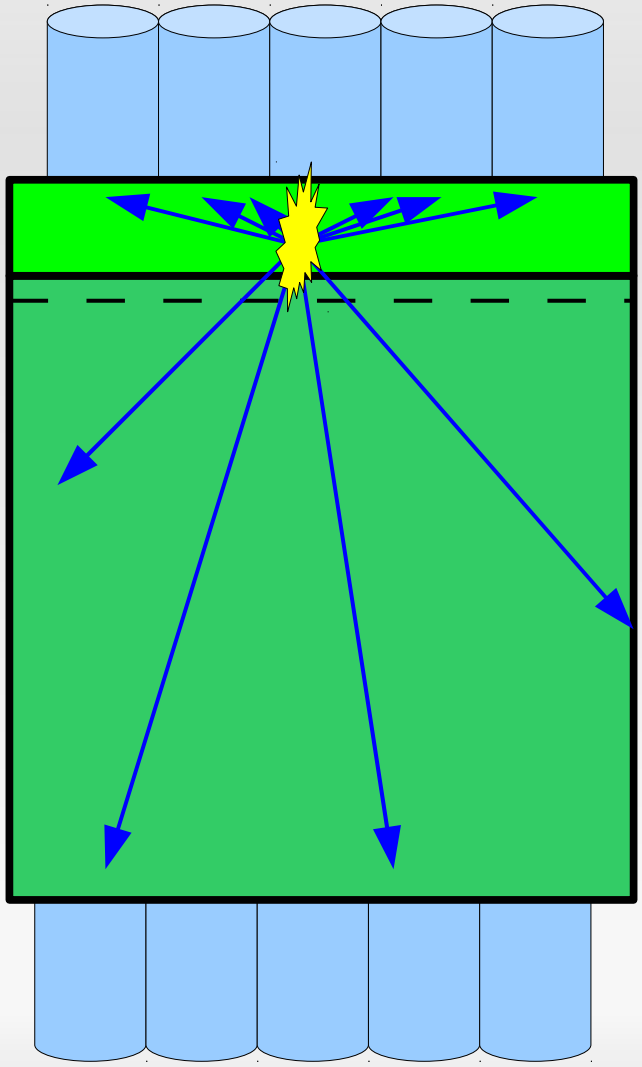
Dual-Phase Argon Time Projection Chamber

- Interaction also produces free electrons from ionization
- Electric field causes them to drift upward at ~1mm/microsec

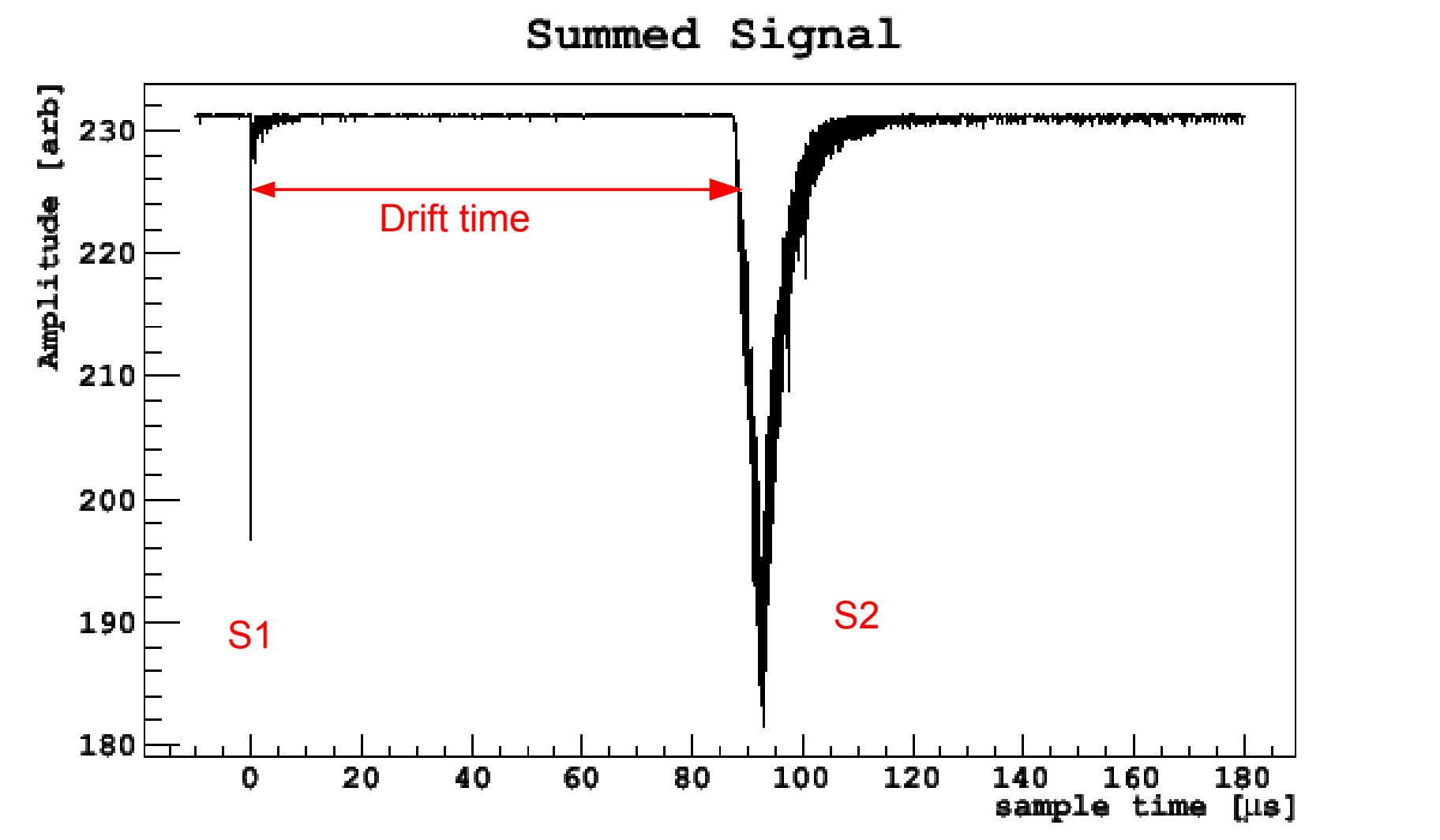


Dual-Phase Argon Time Projection Chamber

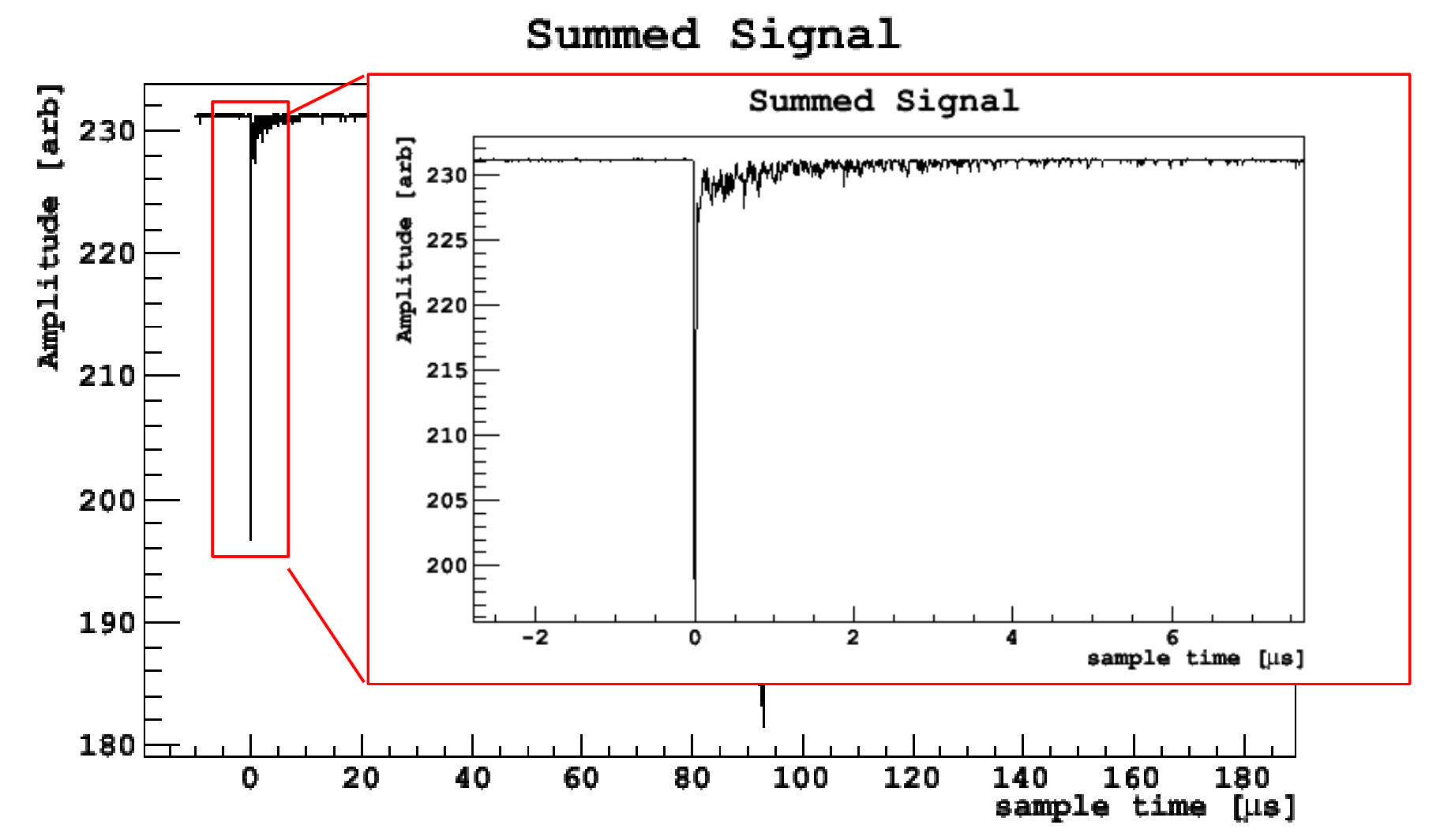
- High electric field in the gas region gives electrons energy to excite secondary scintillation (S2)
- Size of S2 gives amount of ionization
- Light collection ratio in PMTs gives x-y position
- Time between S1 and S2 gives z position



Typical Event



Typical Event



Fast (singlet) lifetime ~7 ns
Slow (triplet) lifetime ~ 1.5 μs

Ratio between singlet/triplet excittation depends on ionization density

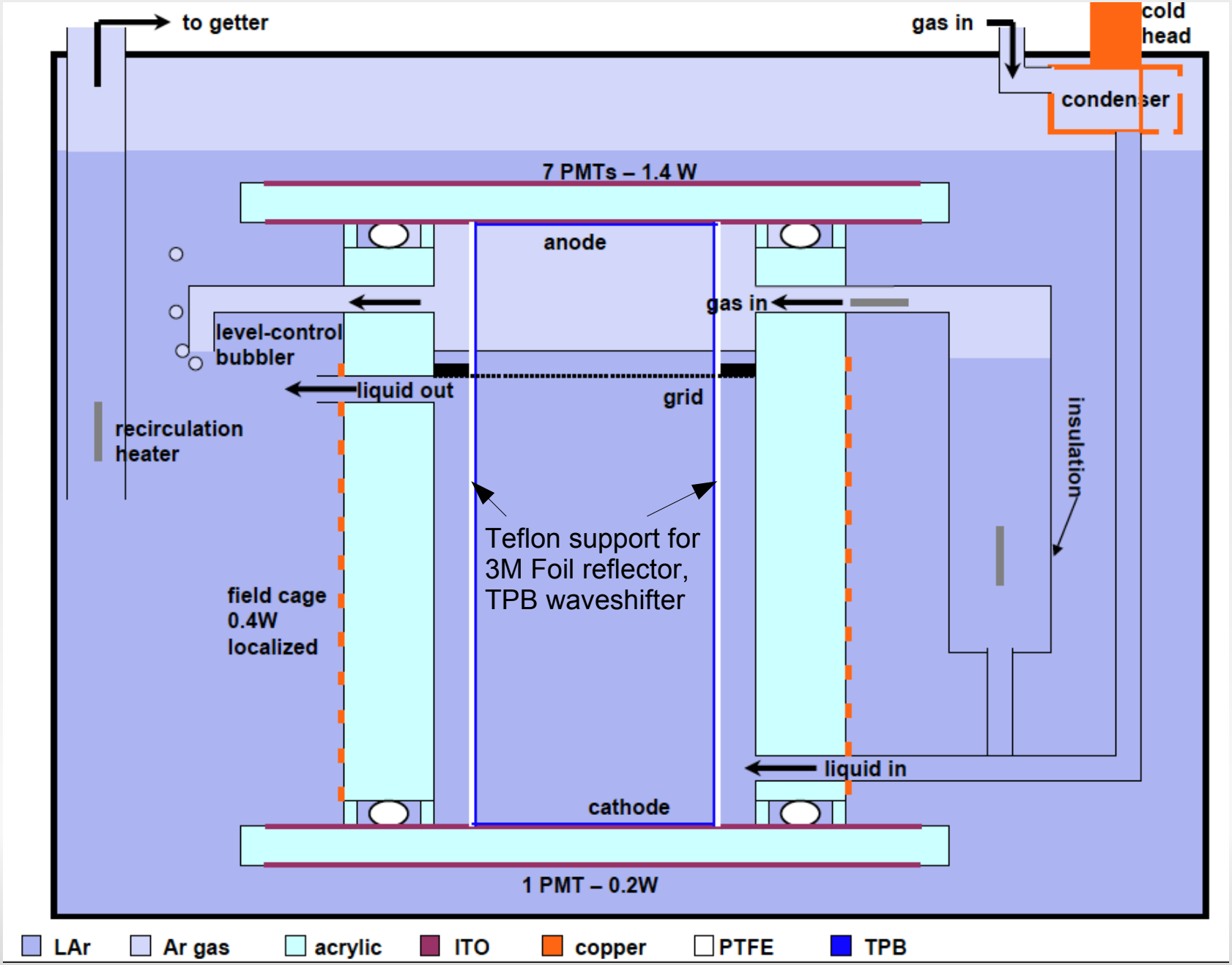
Requirements for a TPC

- To reduce background, we use pulse shape discrimination (PSD) and the scintillation to ionization ratio (S2/S1). To measure these parameters effecively, the TPC needs:
  - High chemical purity of argon
  - High light collection efficiency
  - Uniform electric fields
  - Stable temperature, pressure, and liquid level
  - Low radioactive contamination of entire detector

DarkSide-10 Goals

- Demonstrate operational capability
  - High light yield (optical collection, purity)
  - Long electron lifetime (purity)
  - TPC with position-independent multiplication (uniform fields, static state)
- Testbed for next generation
  - HV feedthroughs
  - TPB waveshifter evaporation
  - Transparent conductive windows
  - High QE, low background, cryogenic-capable PMTs

DarkSide-10 Design Concept



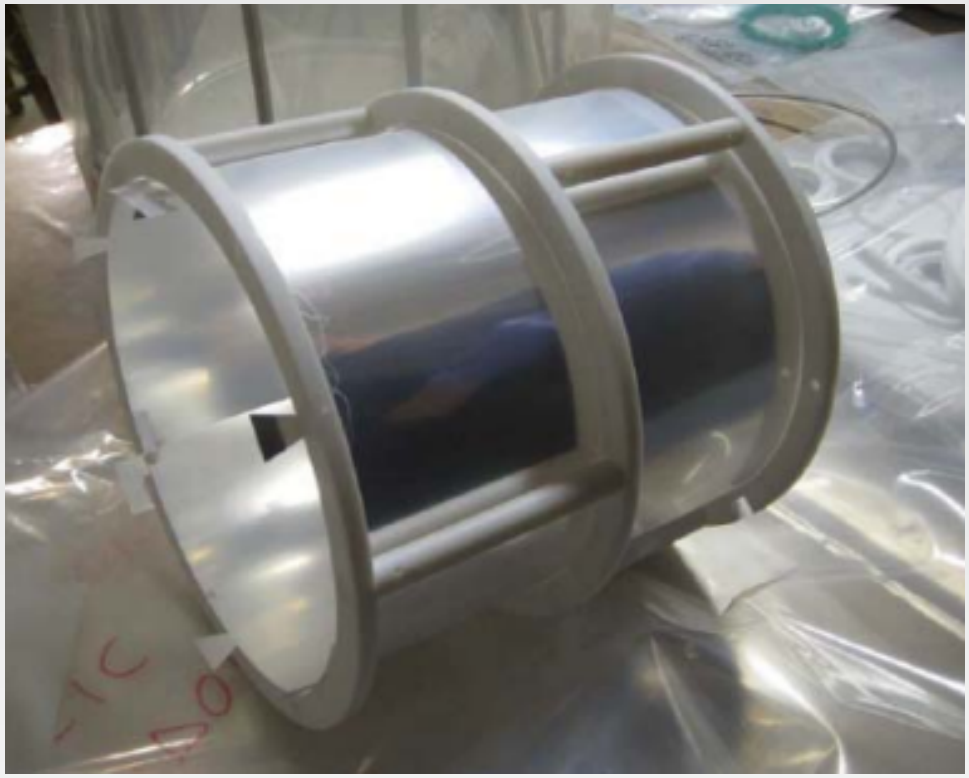
DarkSide-10

- 7x Hamamatsu R11065 3” PMTs on top
- 10 kg Lar active volume in sealed acrylic vessel
- 1x Hamamatsu R5912-02 8” PMT on bottom

DarkSide-10 Acrylic Vessel, Clamping structure

DarkSide-10 Reflector, Waveshifter

Vikuiti 3M reflective foil, PTFE support structure

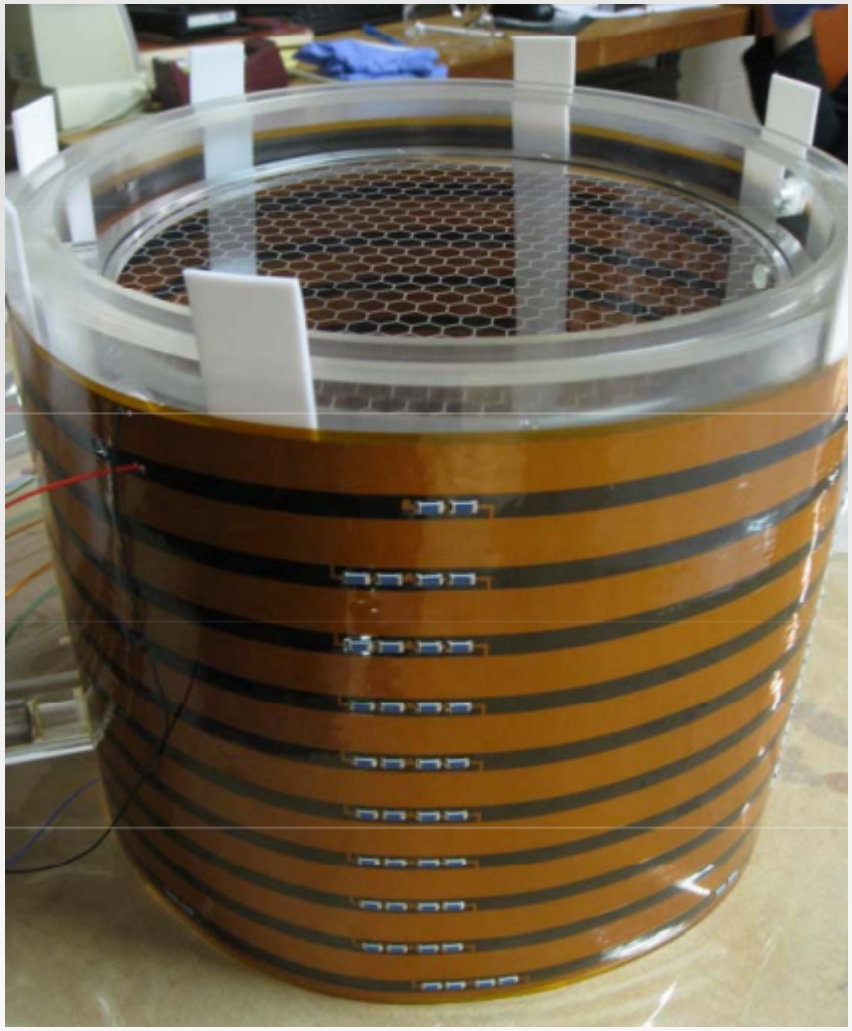


Inner surface (including top and bottom windows) evaporated with ~200 micrograms/cm^2 TPB waveshifter

Field-shaping components

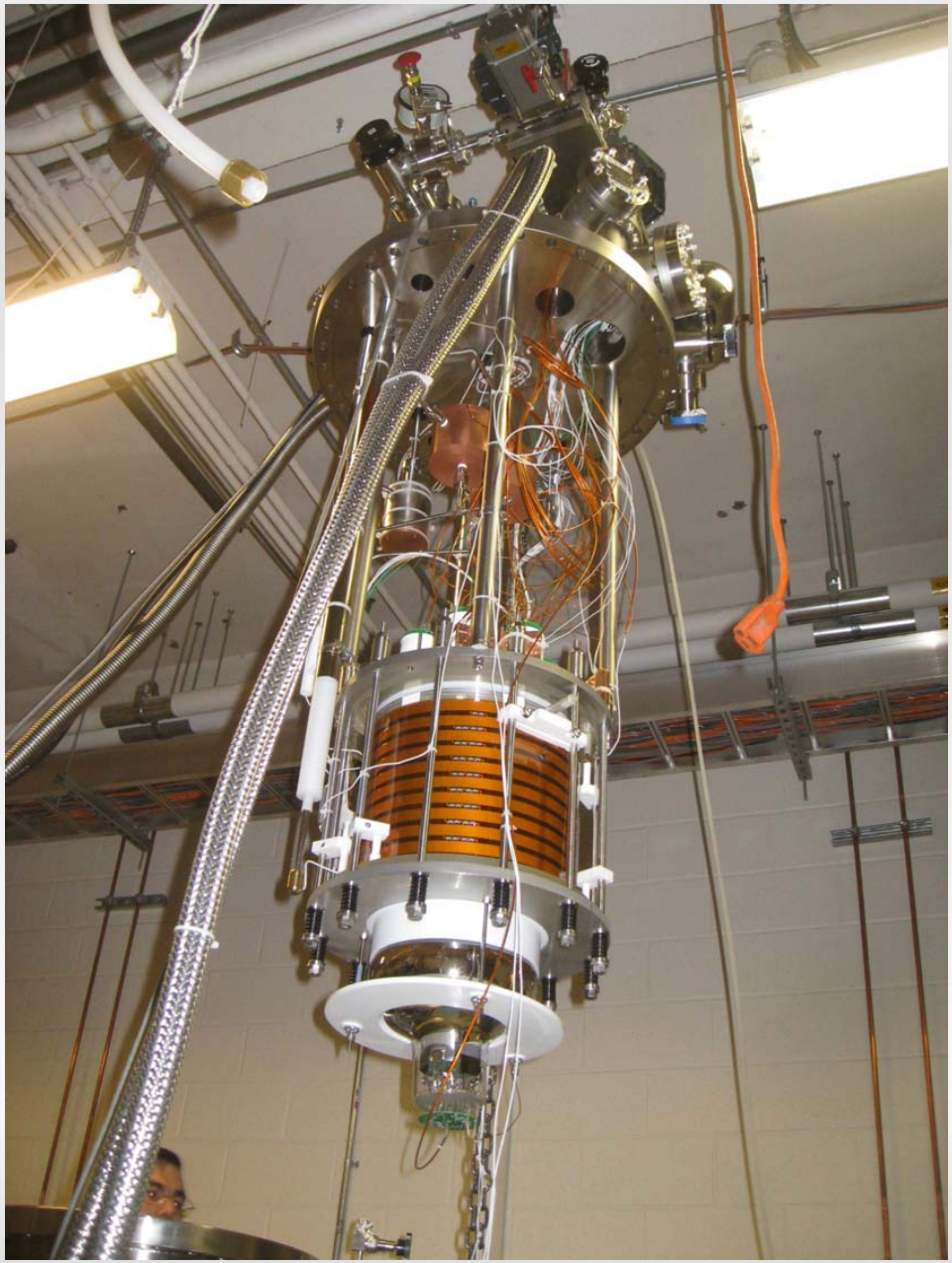
ITO Evaporated onto acrylic window

Etched stainless steel grid

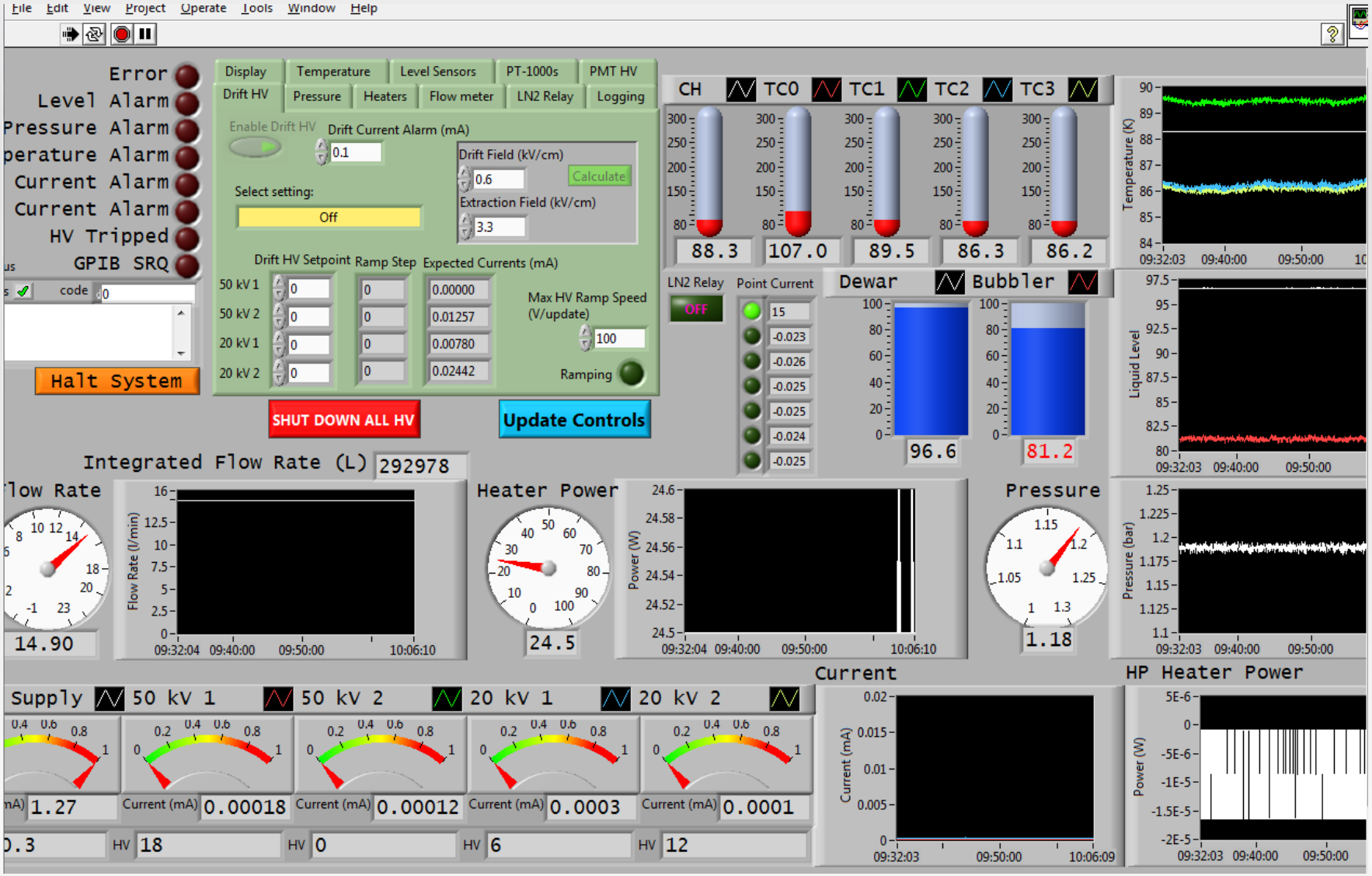


Kapton flex PCB field cage

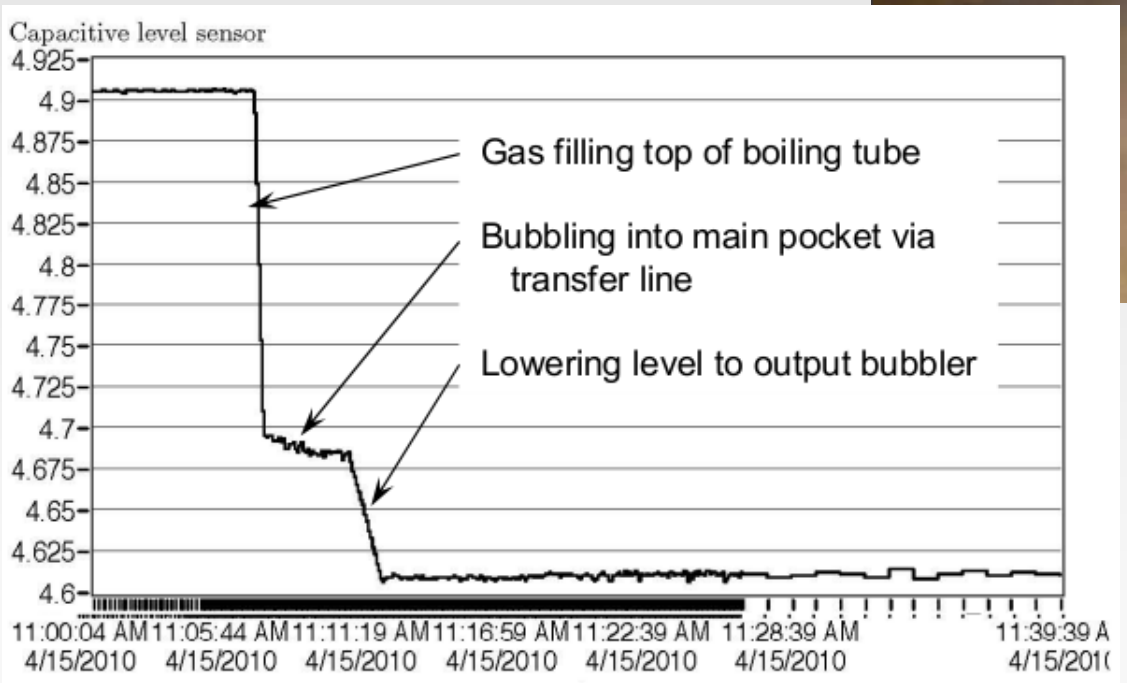
DarkSide-10
Inner Detector Fully Assembled



DarkSide-10 Slow Control

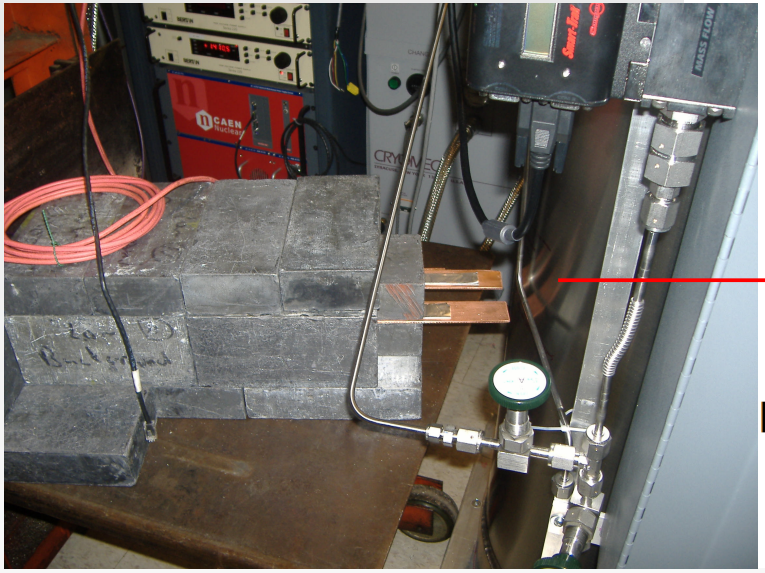


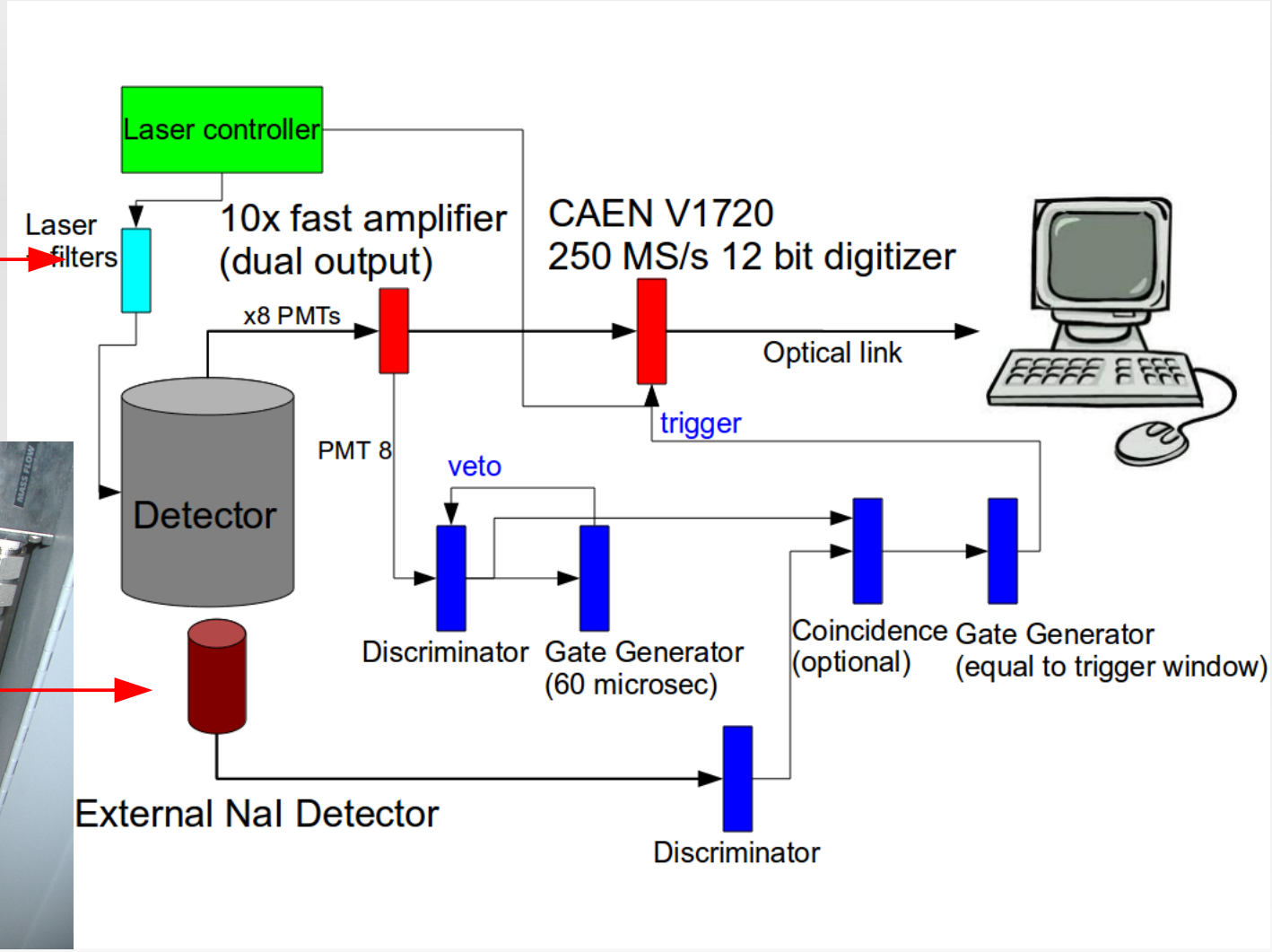
DarkSide-10
Gas Pocket Creation



Level stable to ~0.5 mm

DarkSide-10 Data Acquisition

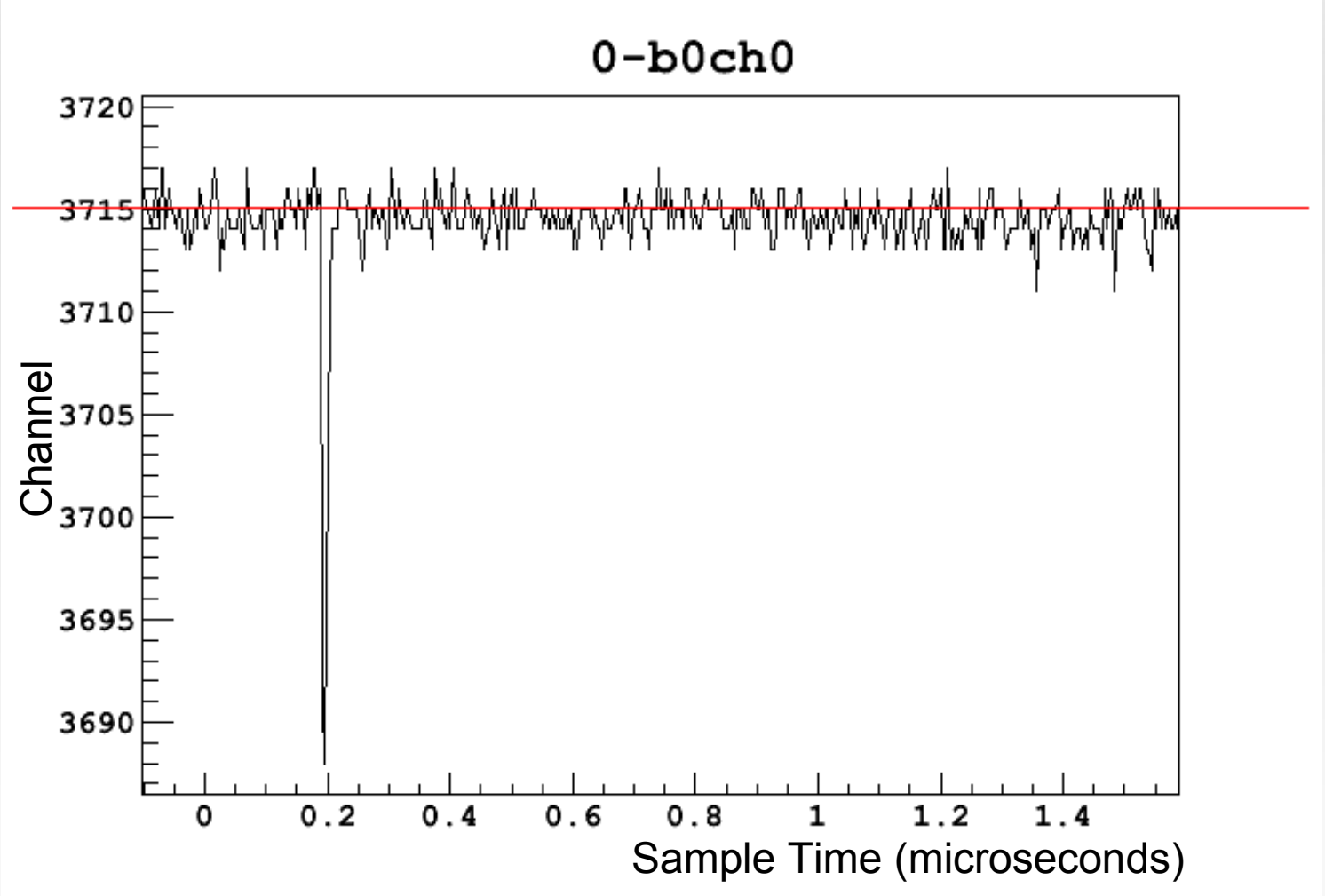




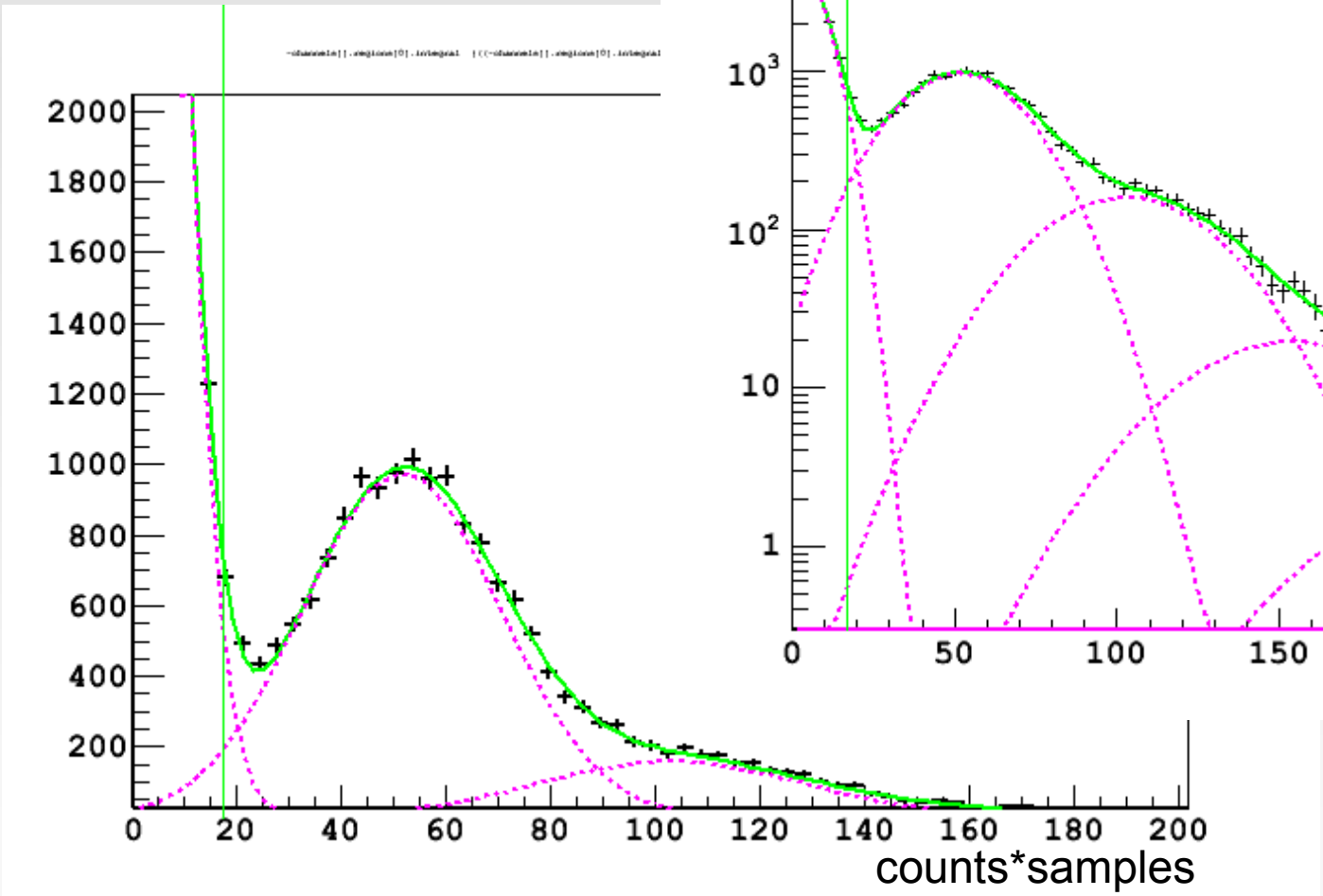
DarkSide-10 Trigger

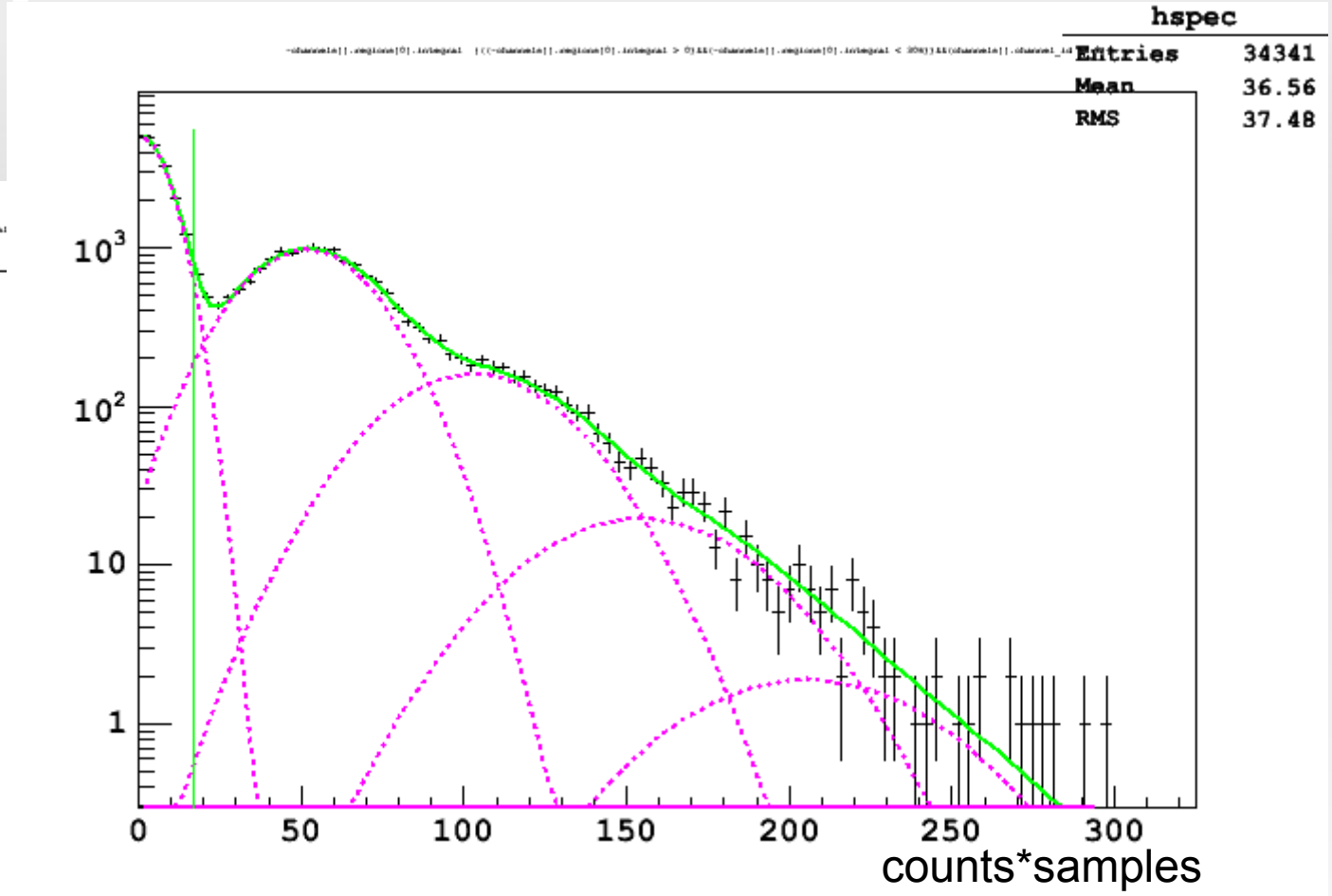
- Three main trigger modes
- Laser:
  - Generated by sync out of pulsed laser source
  - Used to calibrate single photoelectron response
- Regular:
  - Generated by discriminator on signal from 8” PMT at ~10 photoelectrons
- Coincidence:
  - Coincidence between regular trigger and external commercial NaI detector
  - Used with Na22 and AmBe sources to reduce background
  - Sources can be collimated vertically

DarkSide-10 Analysis: Typical Laser Event



DarkSide-10 Analysis: Photomultiplier Calibration



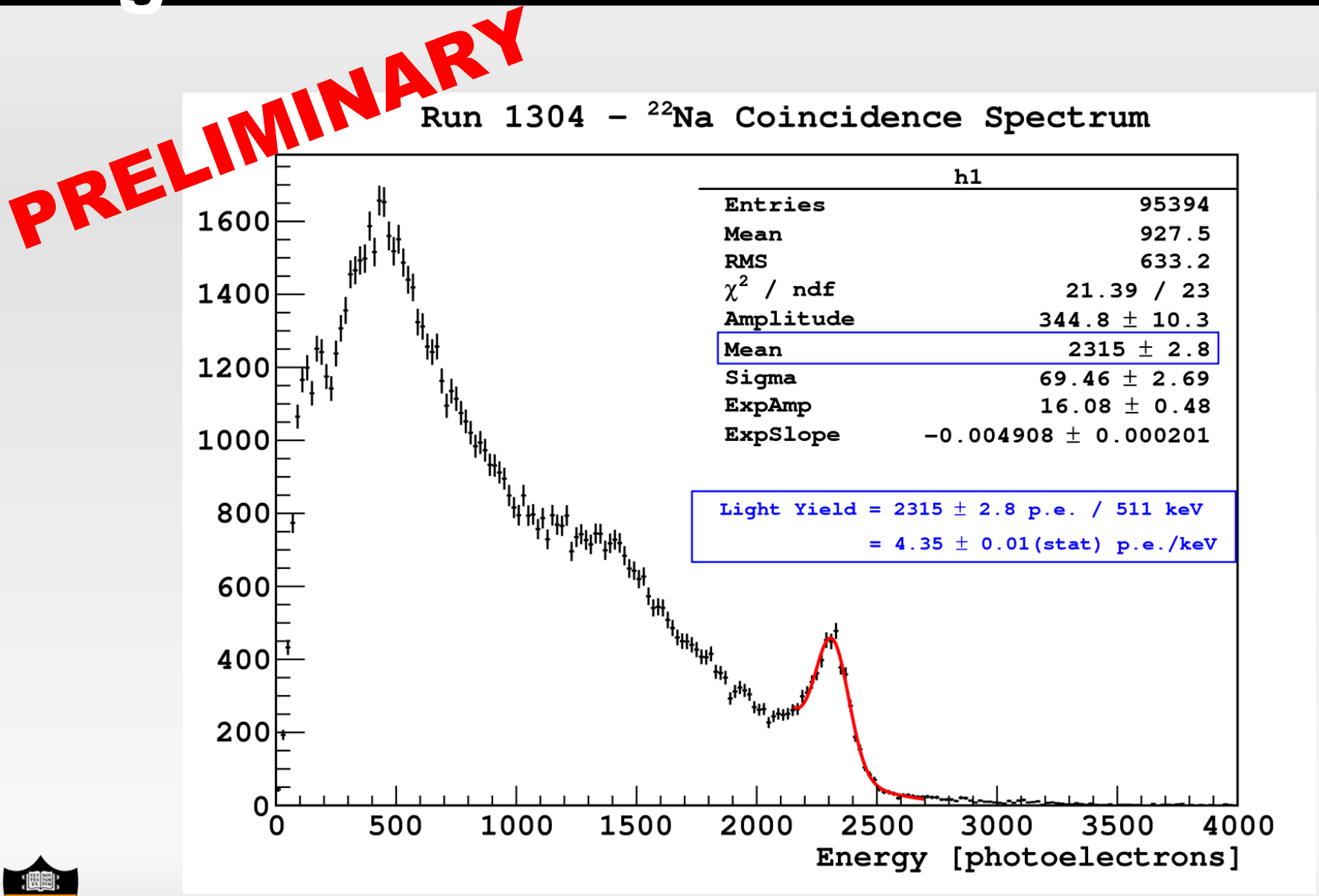


Single photoelectron spectrum from laser

Analysis event selection

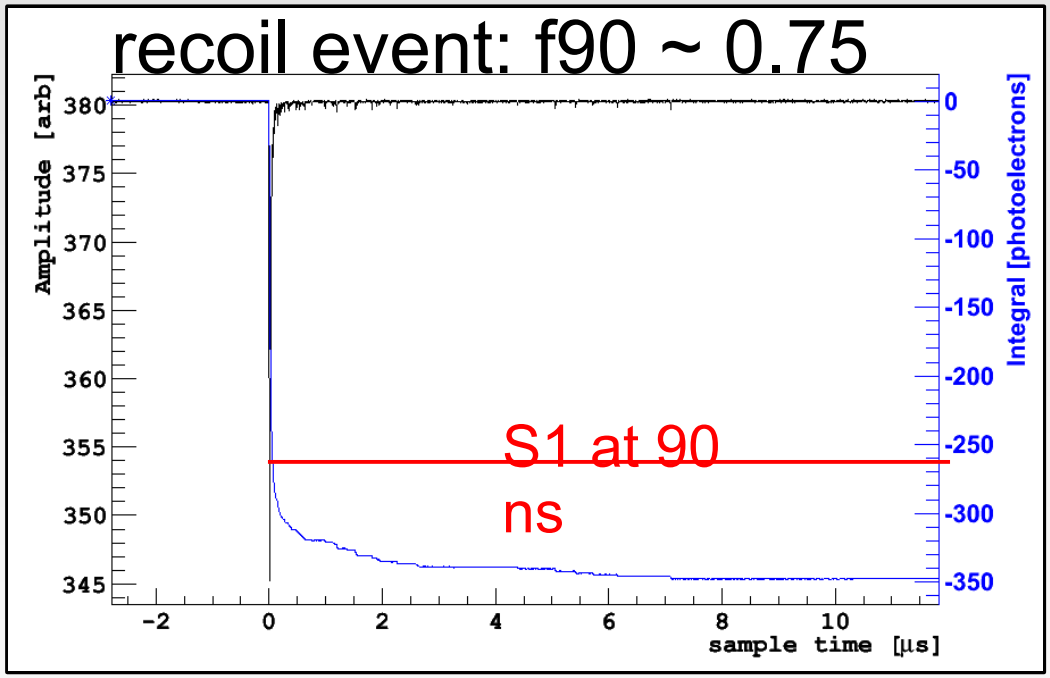
- Single-sited events: exactly one S1 and one S2
- S1 must start within 100 ns of trigger
- S1 > 50 p.e., S2 > 10 p.e.
- Well separated: drift time > 20 μs
- Well resolved: S2 must start > 30 μs before end of acquisition window
- Signal stays within 2V range of digitizer

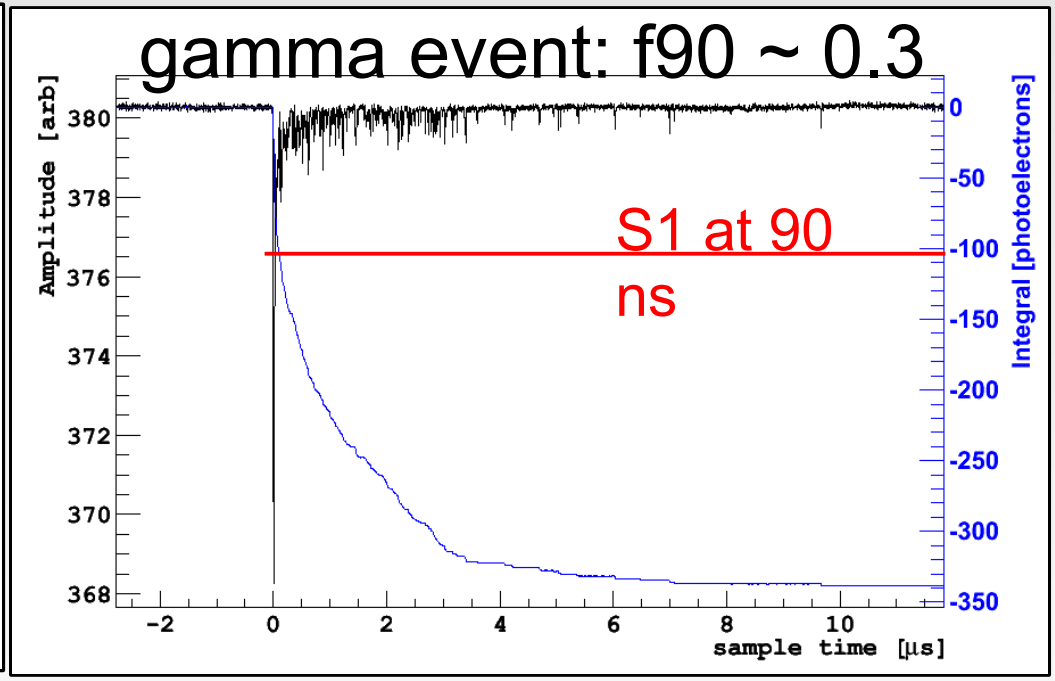
DarkSide-10 Analysis: Light Yield



DarkSide-10 Analysis: Pulse Shape Discrimination

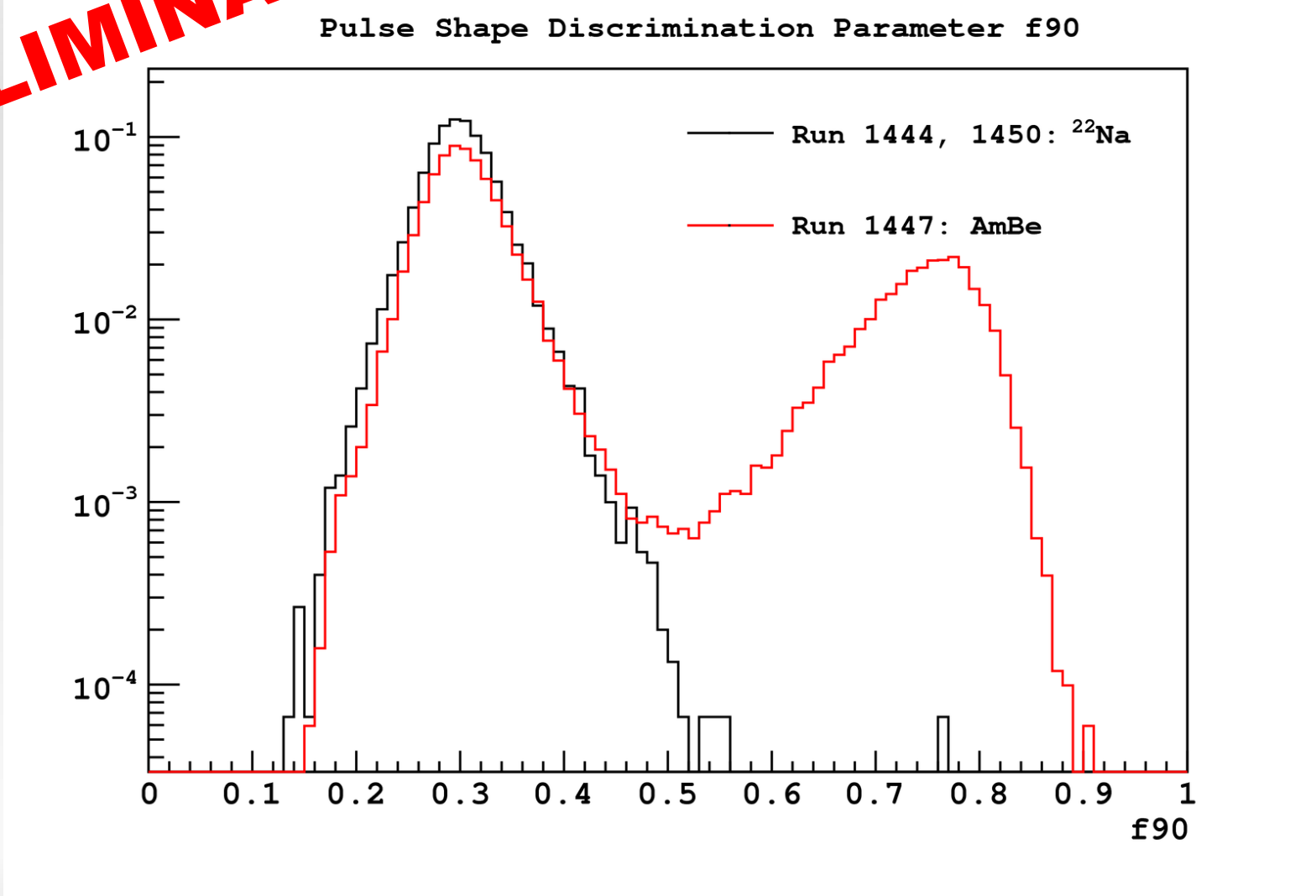
- f90: the fraction of S1 light that arrives within the first 90 ns



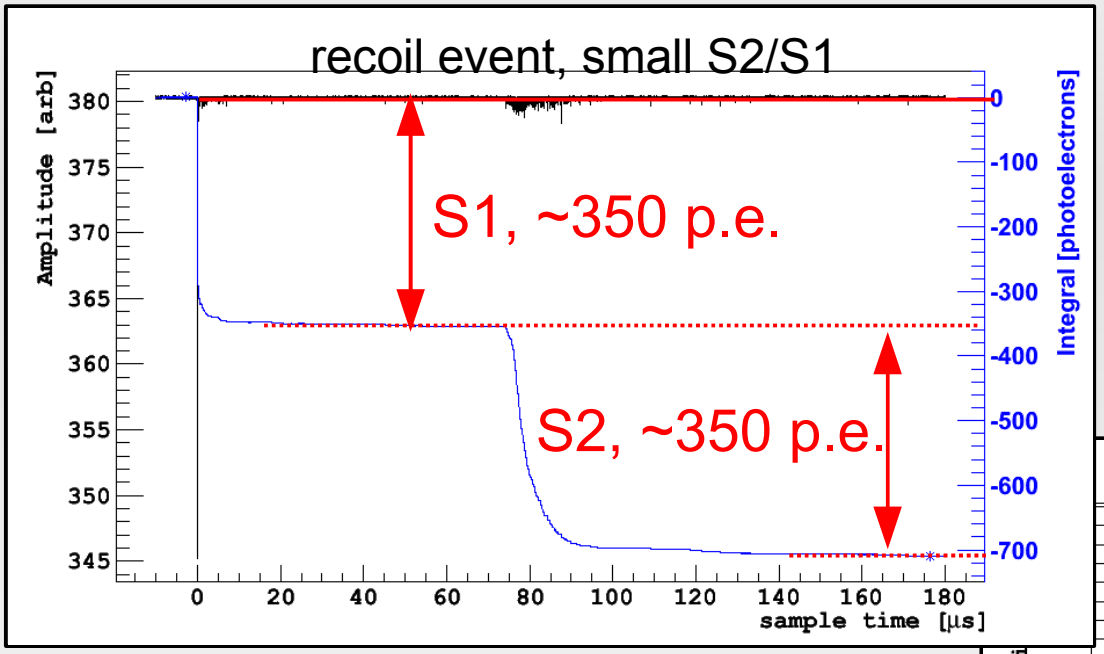


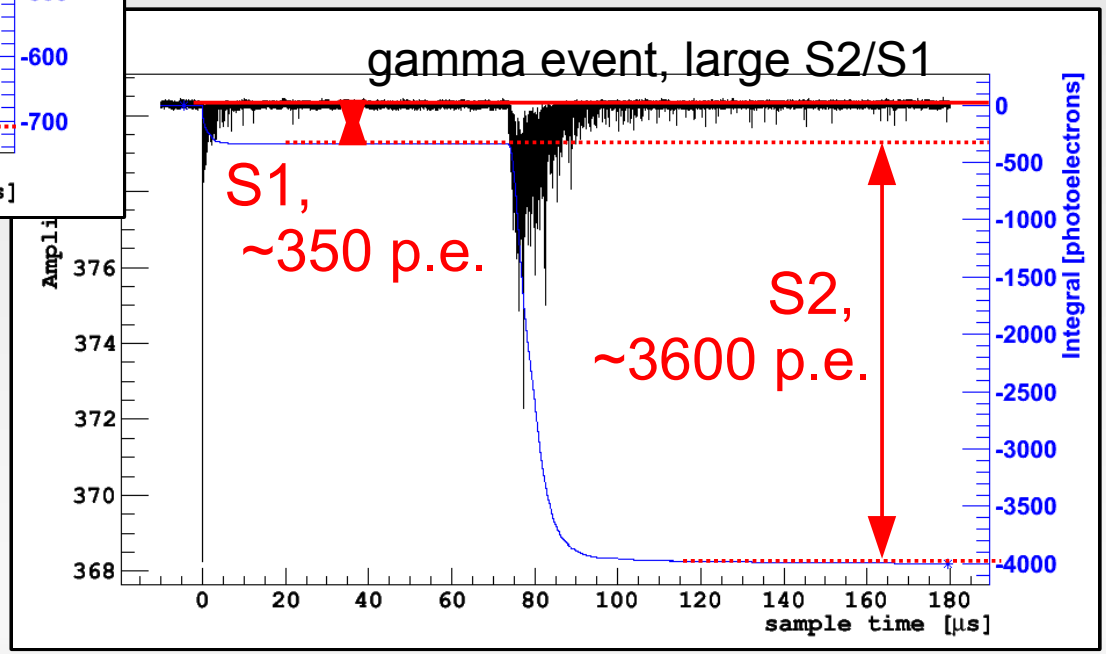
DarkSide-10 Analysis: Pulse Shape Discrimination

PRELIMINARY



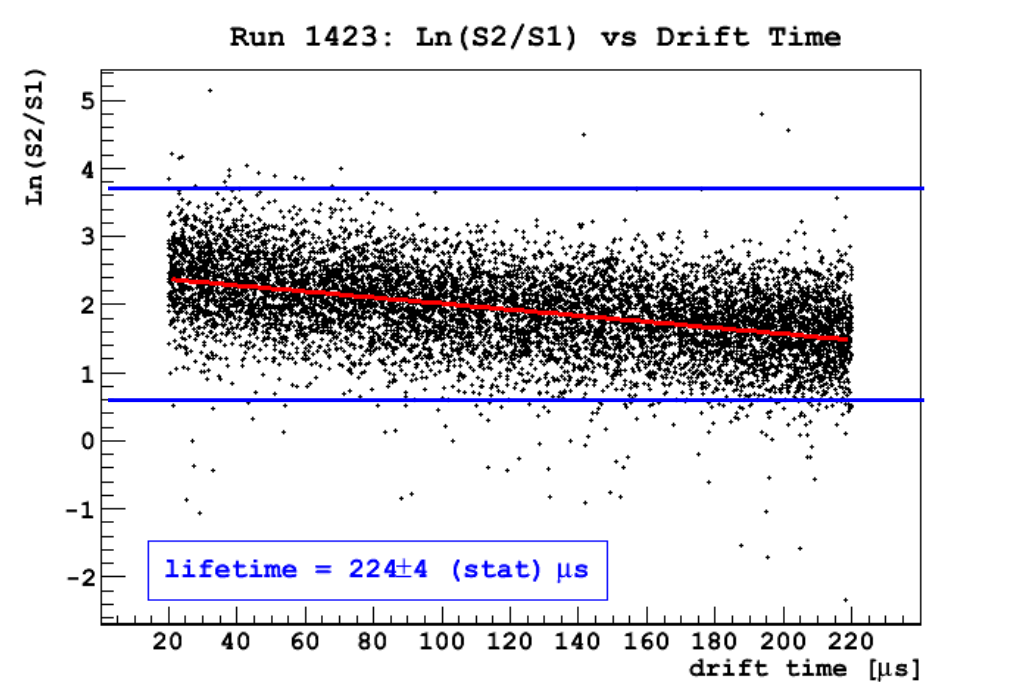
DarkSide-10 Analysis: Scintillation/Ionization Ratio

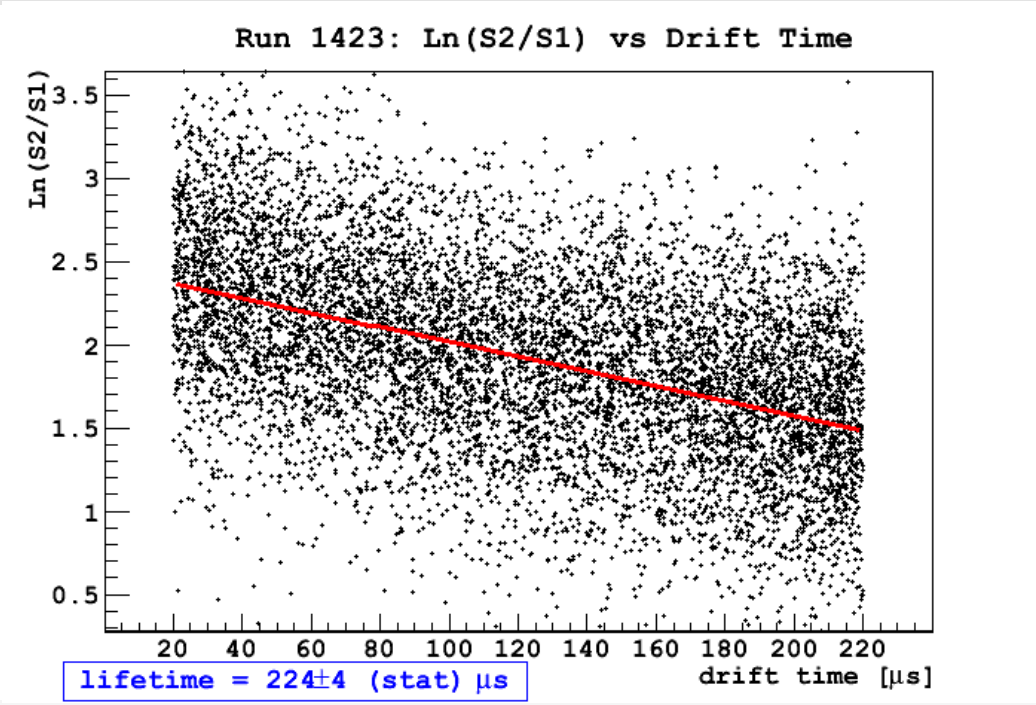




DarkSide-10 Analysis: Electron Lifetime

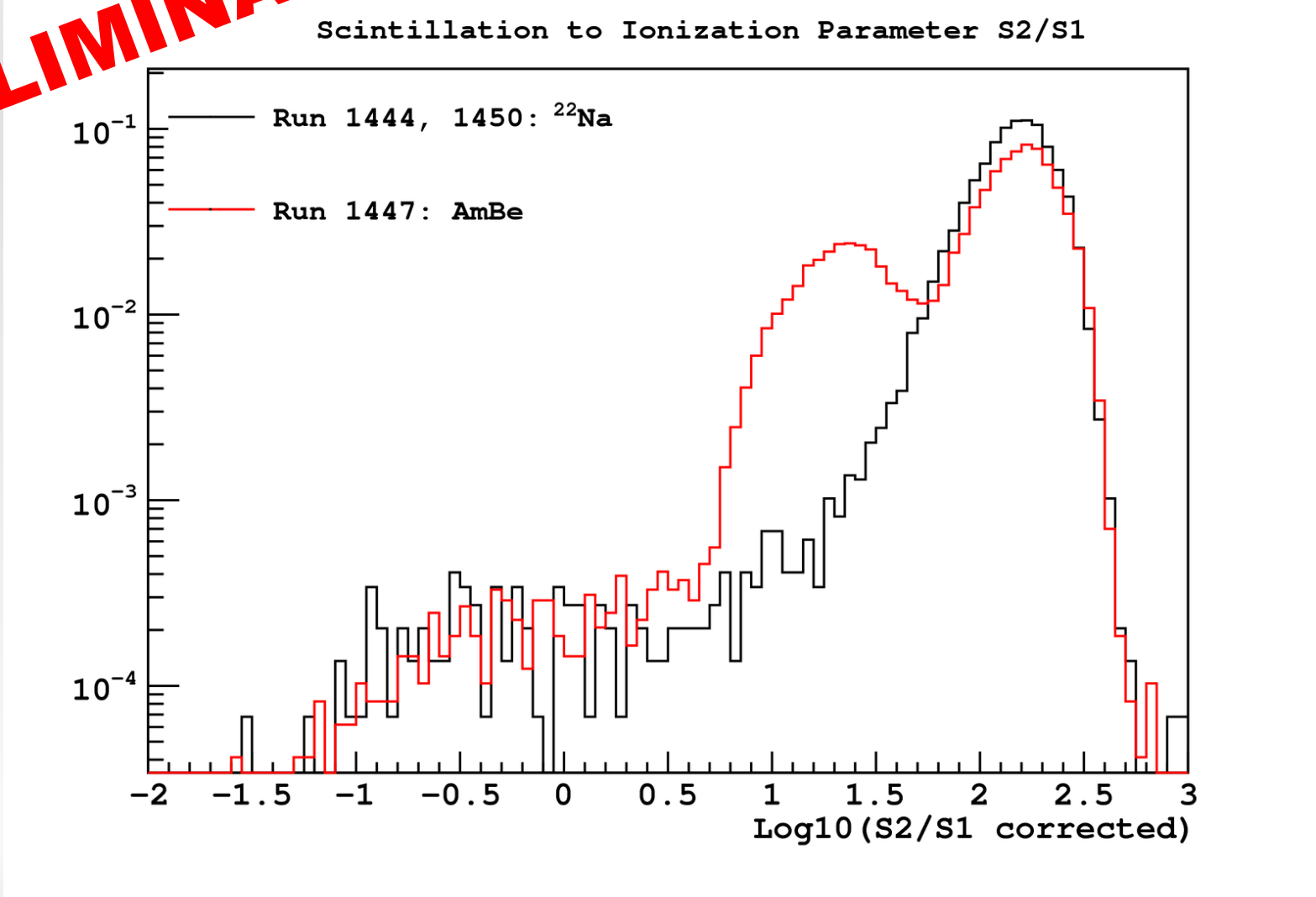
PRELIMINARY



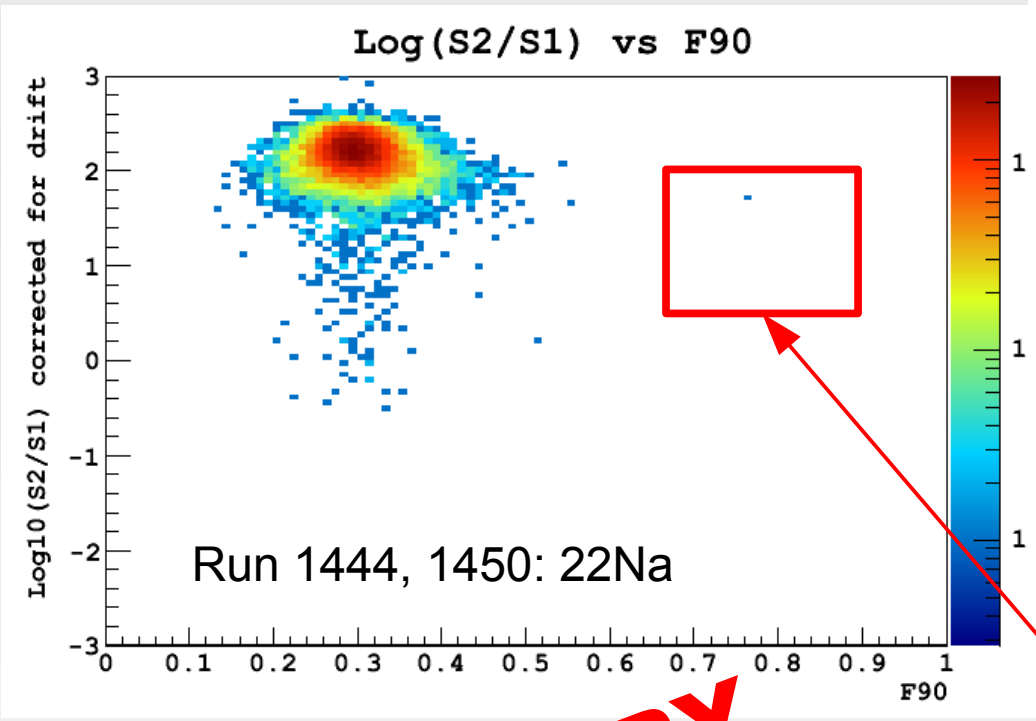


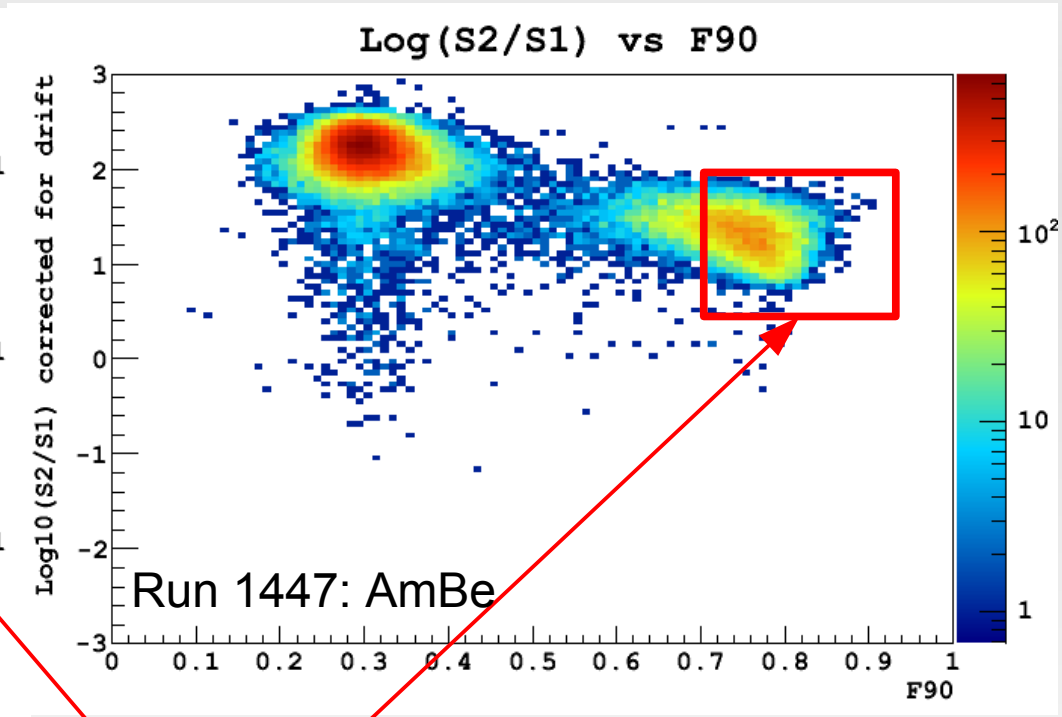
DarkSide-10 Analysis: Scintillation/Ionization Ratio

PRELIMINARY



DarkSide-10 Analysis: Combined Background Rejection



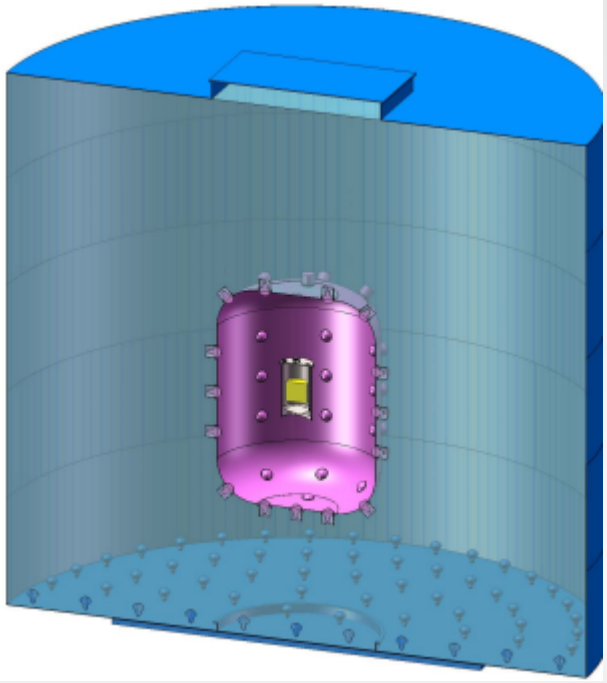


PRELIMINARY

Example nuclear recoil acceptance bounds

Moving forward: DarkSide-50

- To be constructed at the Laboratori Nazionali del Gran Sasso (LNGS) in the Borexino CTF water tank
- Major upgrades:
  - Water + borated scintillator shielding and active veto
  - Larger target mass
  - Quartz vessel, very thin ITO
  - New high-crystallinity PTFE reflector
  - Low radioactivity materials and construction
  - Depleted argon
- Expected to reach sensitivity of 10^{-45} cm^2 in three years data collection



Why do we need depleted argon?

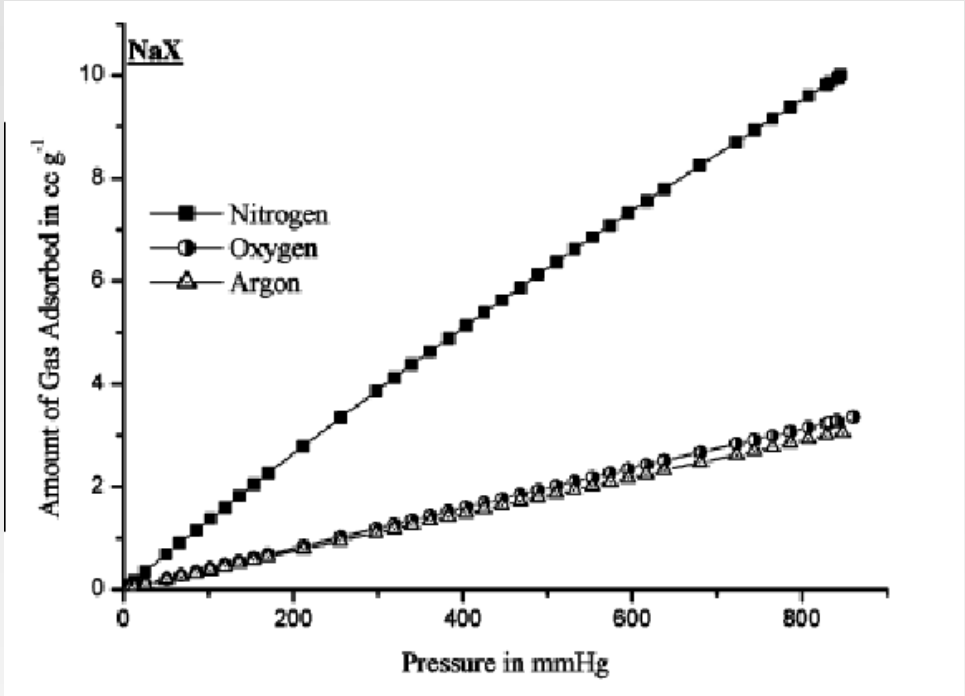
- "Natural" argon derived from the atmosphere contains ^{39}Ar, a radioactive isotope which undergoes beta decay with Q=565 keV and a half-life of 269 years, at a level of 1 Bq/kg.
- This would be the dominant source of background in a ton-scale detector, even with rejection techniques
- Even if it can be rejected, pileup becomes a serious issue

Getting depleted argon

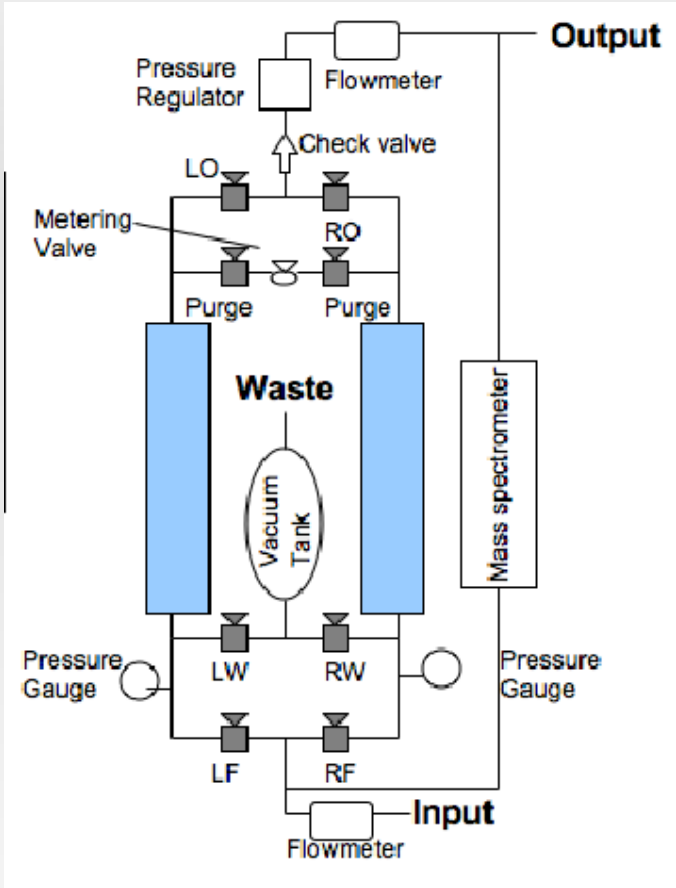
- ^{39}Ar is made by (n,2n) interactions on ^{40}Ar from high energy cosmic rays in the upper atmosphere
- ^{40}Ar, the main stable isotope, is created in the beta decay of ^{40}K
- ^{40}Ar in underground wells, shielded from cosmic rays, can have very little ^{39}Ar
- BUT (n,p) reactions on ^{39}K can produce ^{39}Ar, so sites must be tested

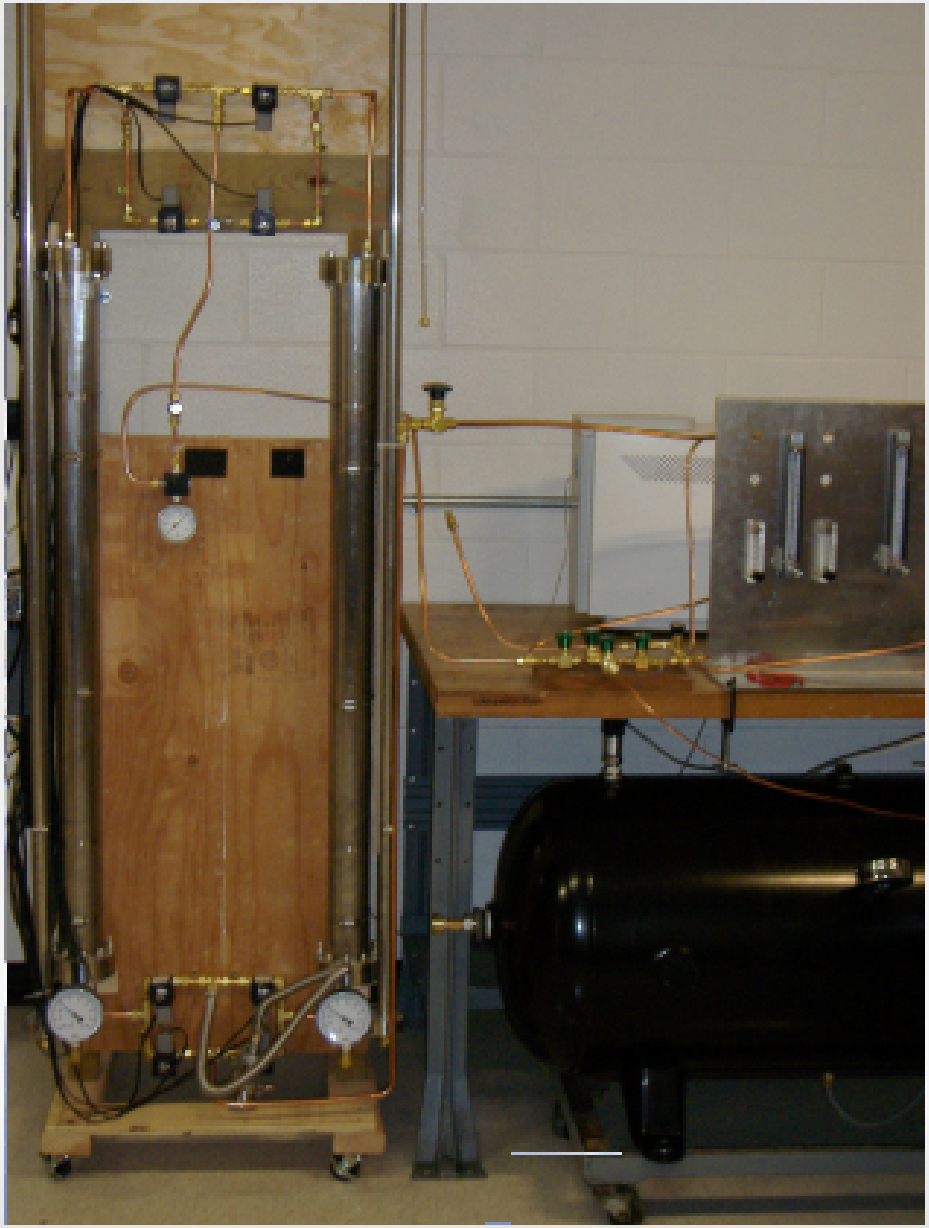
Stage 1: Pressure Swing Adsorption

- Modification of technology used in oxygen generators
- Exploits different saturation points of gases on adsorbents
- Concentrates few ppm levels of Ar from gas wells to a few %

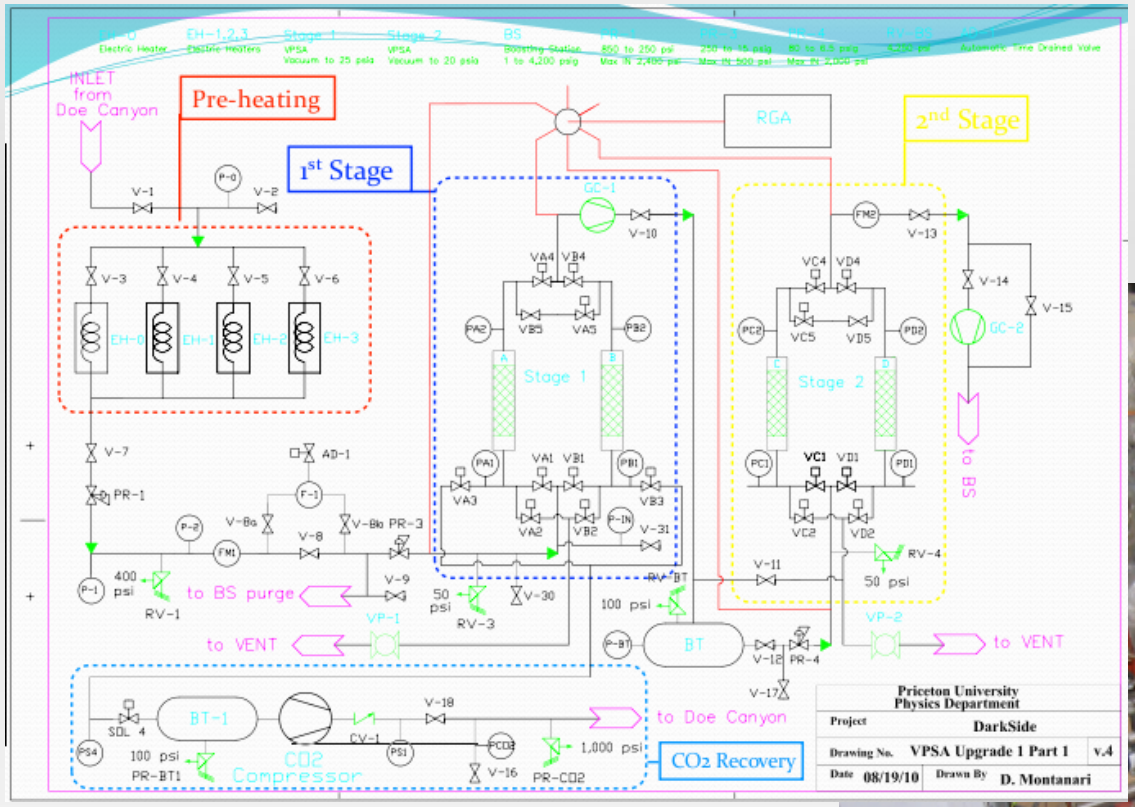


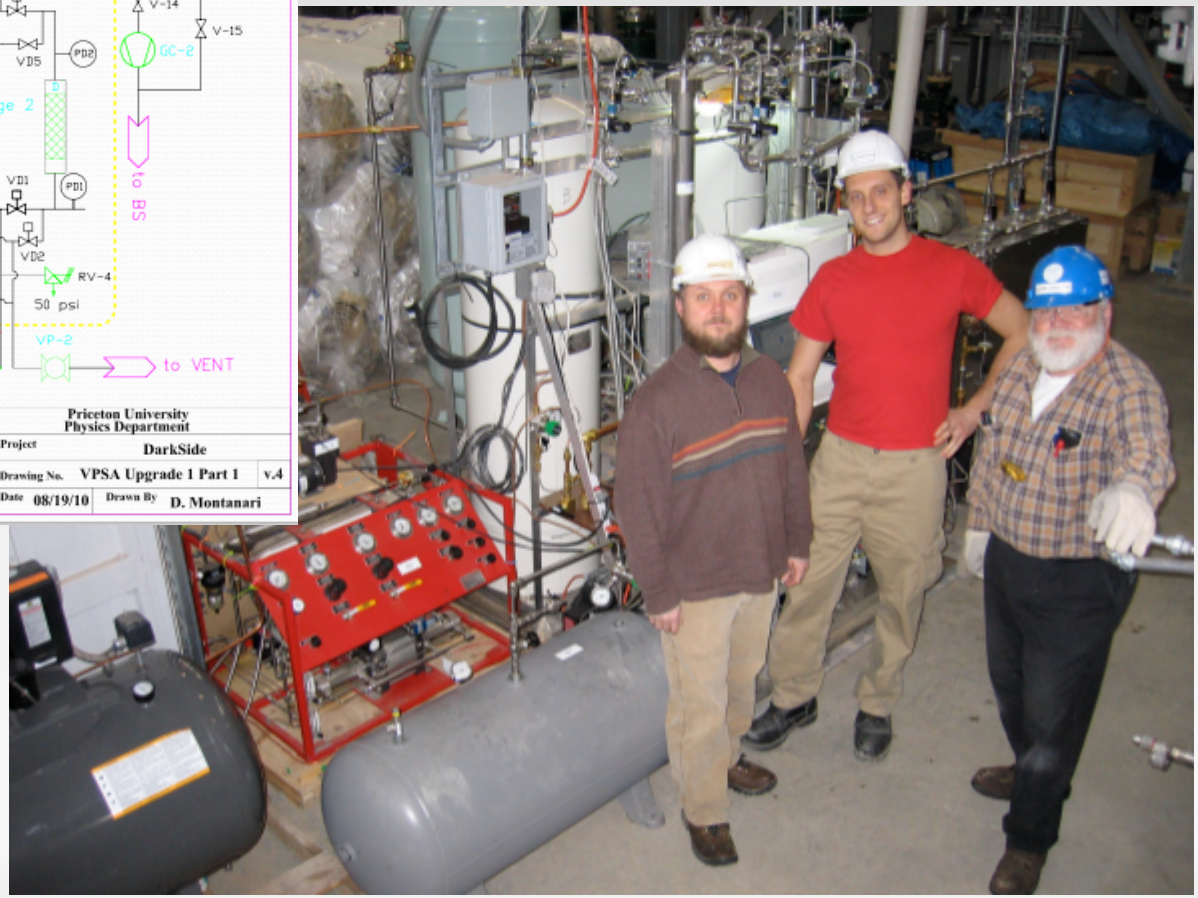
PSA Prototype





Operational PSA





Thanks to David Montanari

Getting depleted argon: PSA status

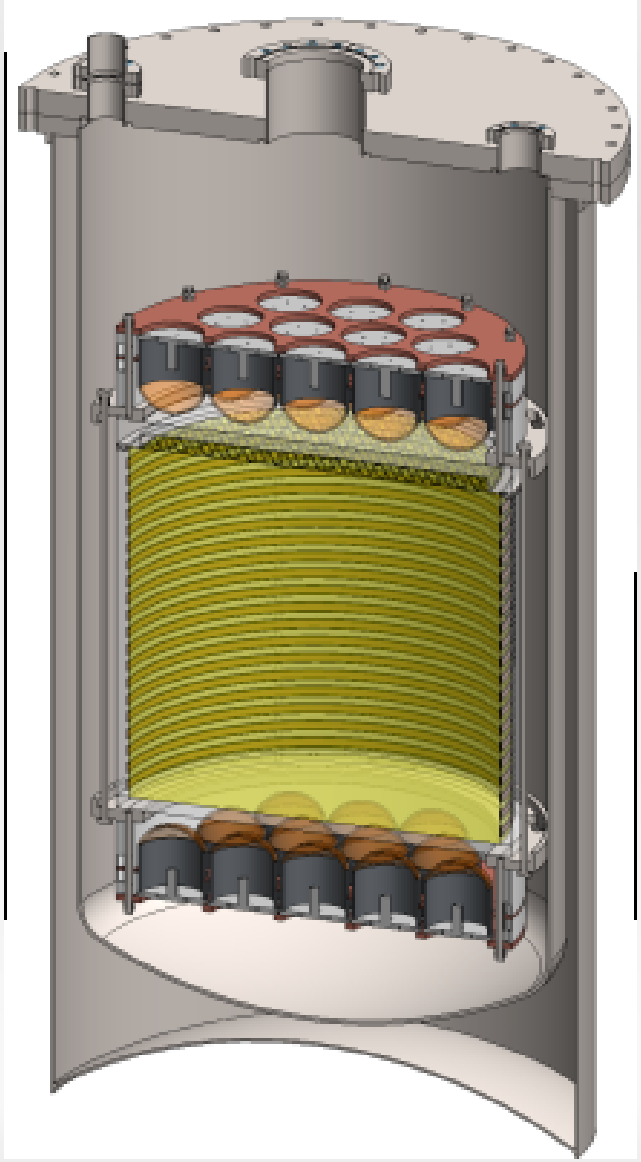
- Currently the plant produces output with 3-4% Ar, at 0.7-0.8 kg Ar per day
- ~45 kg total produced
- Remainder of gas is ~72% He and 24% N_2
- Output has been measured to have a factor of >25 reduction of ^{39}Ar compared to atmospheric sources
- A more sensitive measurement is coming soon from a dedicated detector constructed at Princeton

Stage 2: Cryogenic distillation

- Need 99.9999999% (”nine nines”) purity Ar for detectors
- First batches purified through chemical/charcoal getters
- Cryogenic distillation is industry standard
- Plant constructed at FNAL (in PAB)
- Status: commissioned, preparing for first run

DarkSide-50 Status

- Planning and design stage
- Estimate finish construction of ID by end of 2011
- Start acquiring data summer 2012
- Very exciting time!



Thank You