Recent Updates from the Dark Matter Time Projection Chamber (DMTPC) Collaboration

Cosmin Deaconu

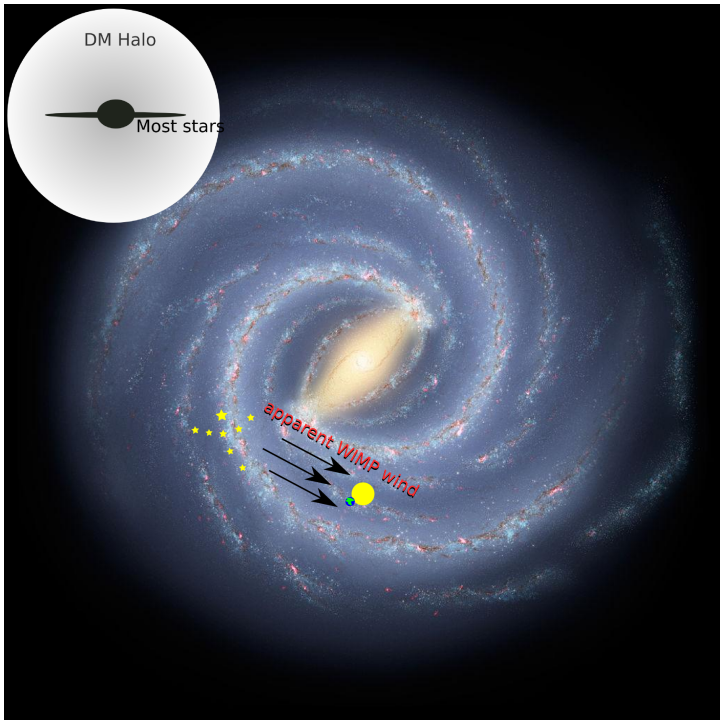
MIT/LNS

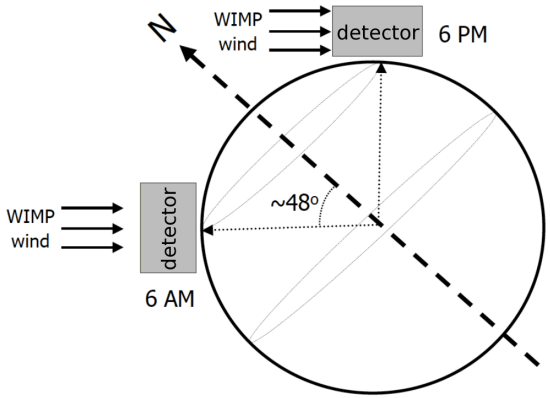
September 11, 2013

Outline

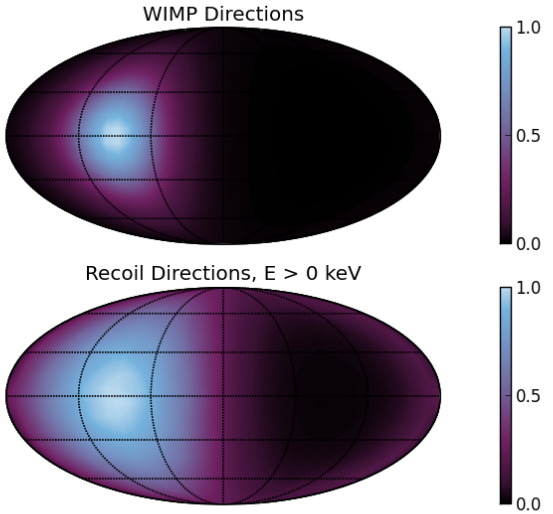
- Introduction
  - Directional Detection
  - The DMTPC Experiment
- Reconstruction Improvements
- Amplification Region Hardware R&D

Directional Dark Matter Detection



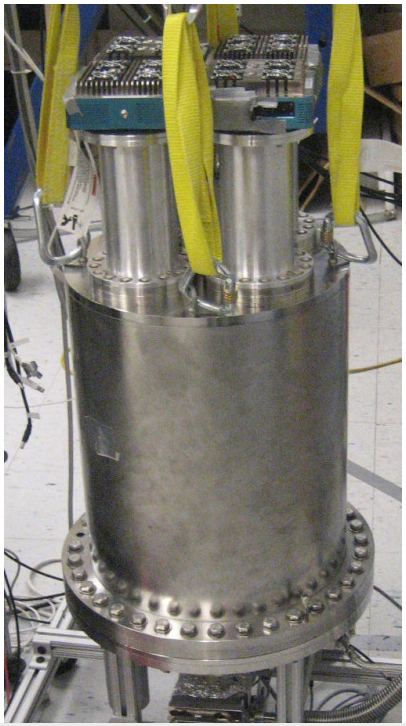


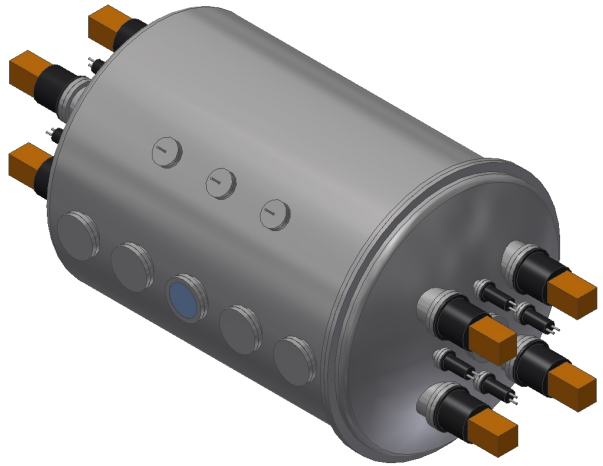
- WIMPs expected to have preferred direction in galactic coords
- Detector that can measure direction of low-E nuclear recoils can exploit this



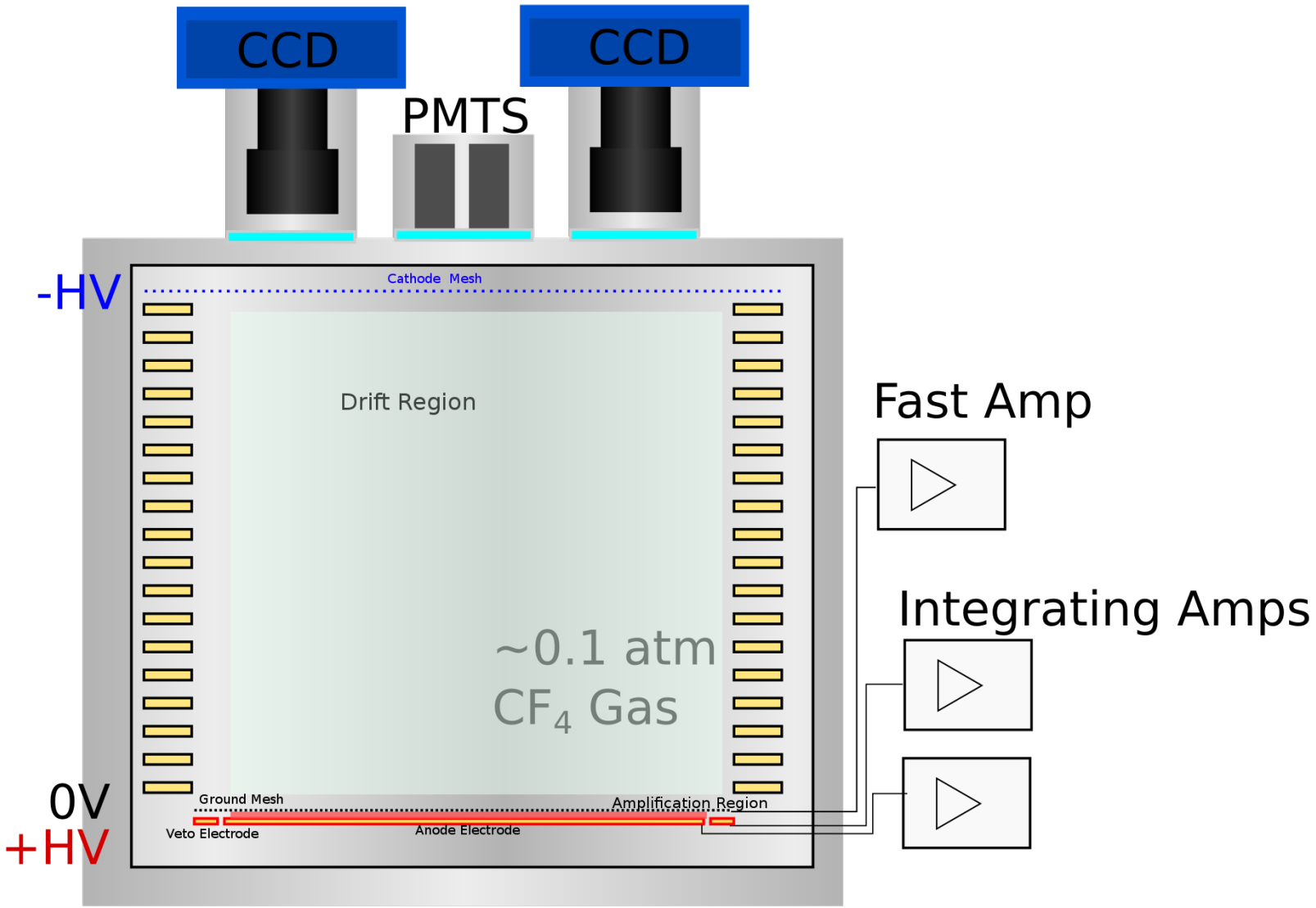
DMTPC Basics

- We look for nuclear recoils from WIMPs in low-pressure (≈50 Torr) CF_4 gas. Low-pressure allows macroscopic extent of particle tracks.
- Because of ^{19}F nuclear structure and small mass, DMTPC sensitive mostly to spin-dependent WIMP coupling.
- Detector is a TPC with CCD + charge + PMT readout
- In prototyping, (not discovery) stage. Goal is to come up with a m^3-scale detector that could be replicated for large target mass.

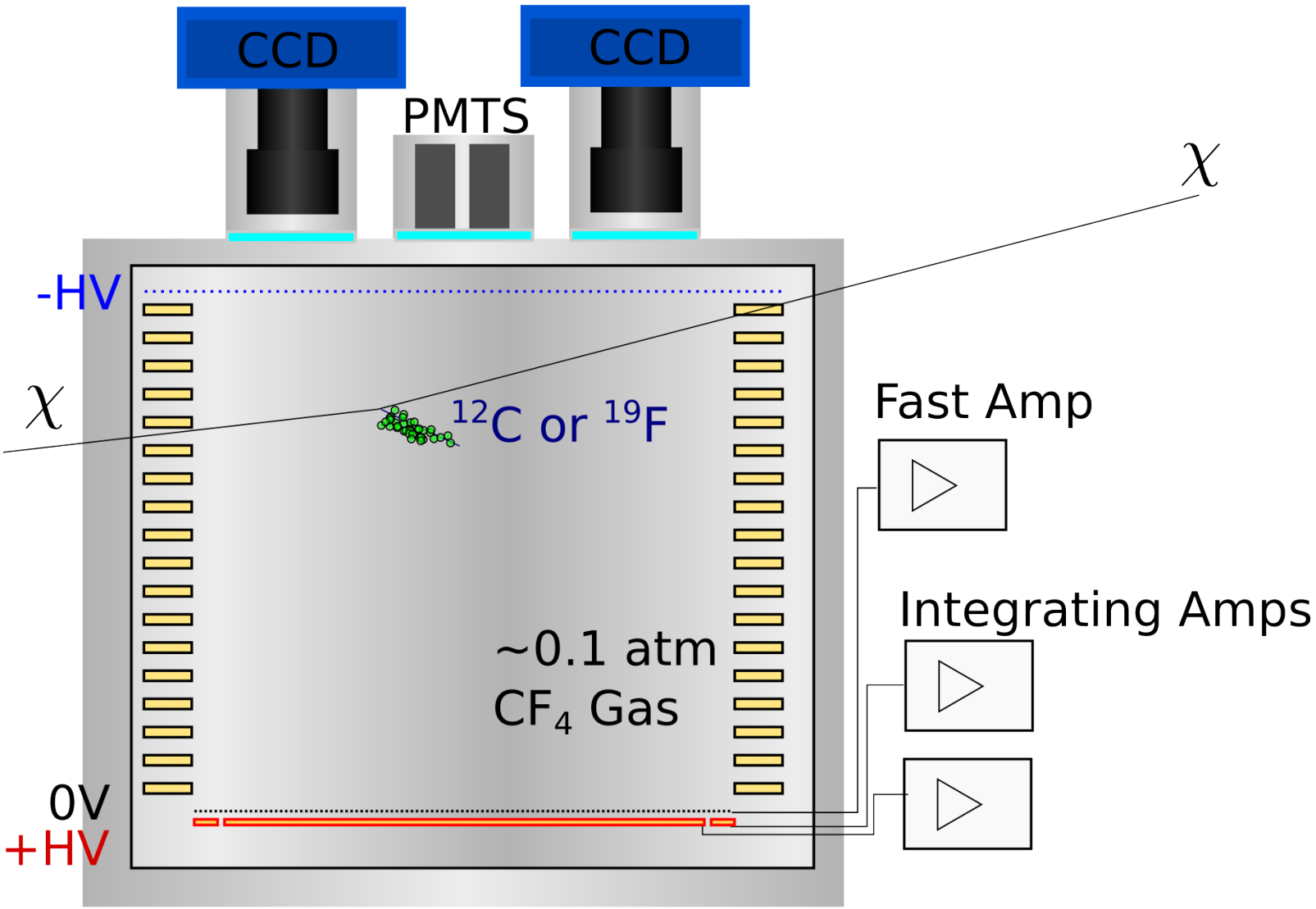




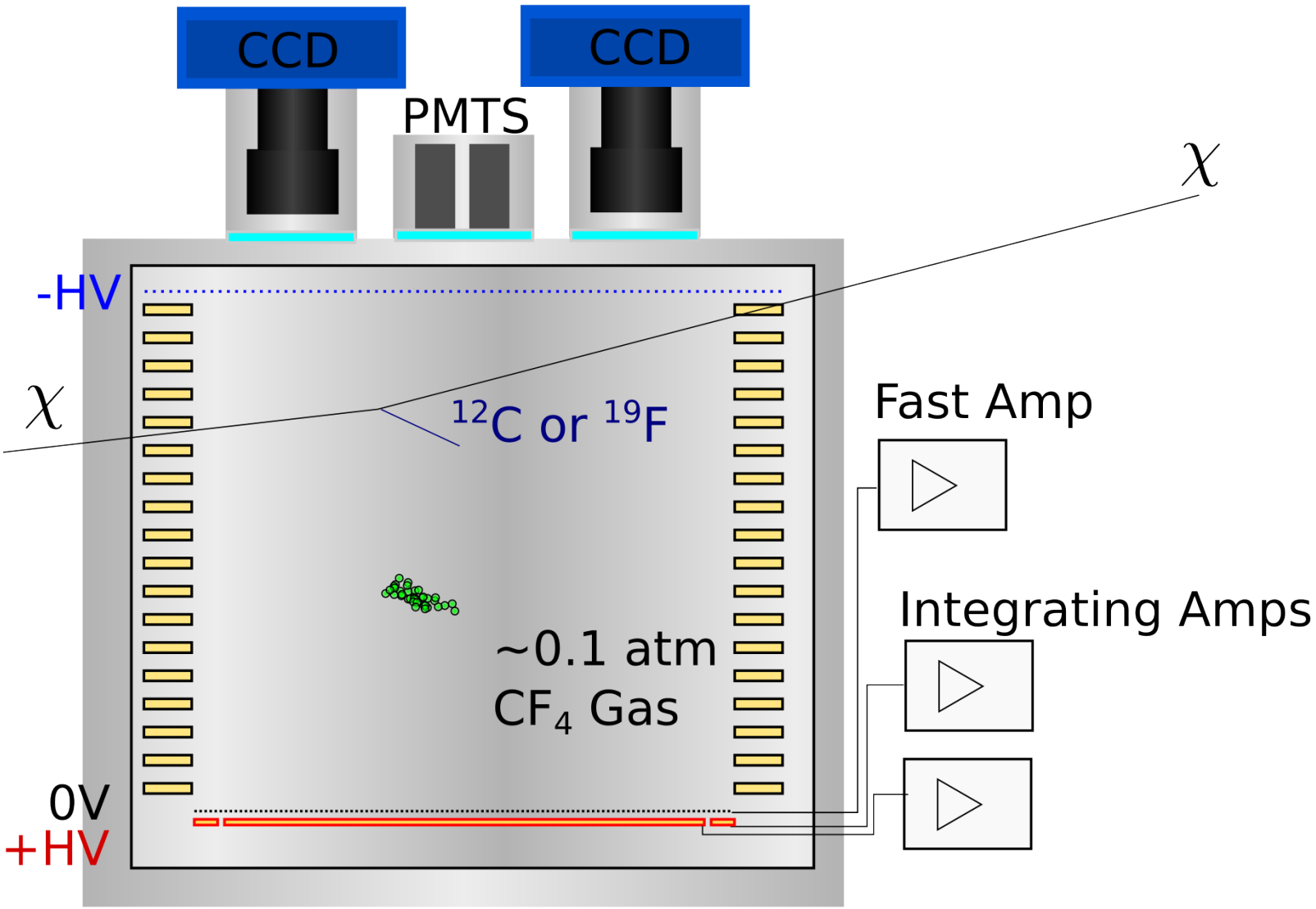
Detector concept



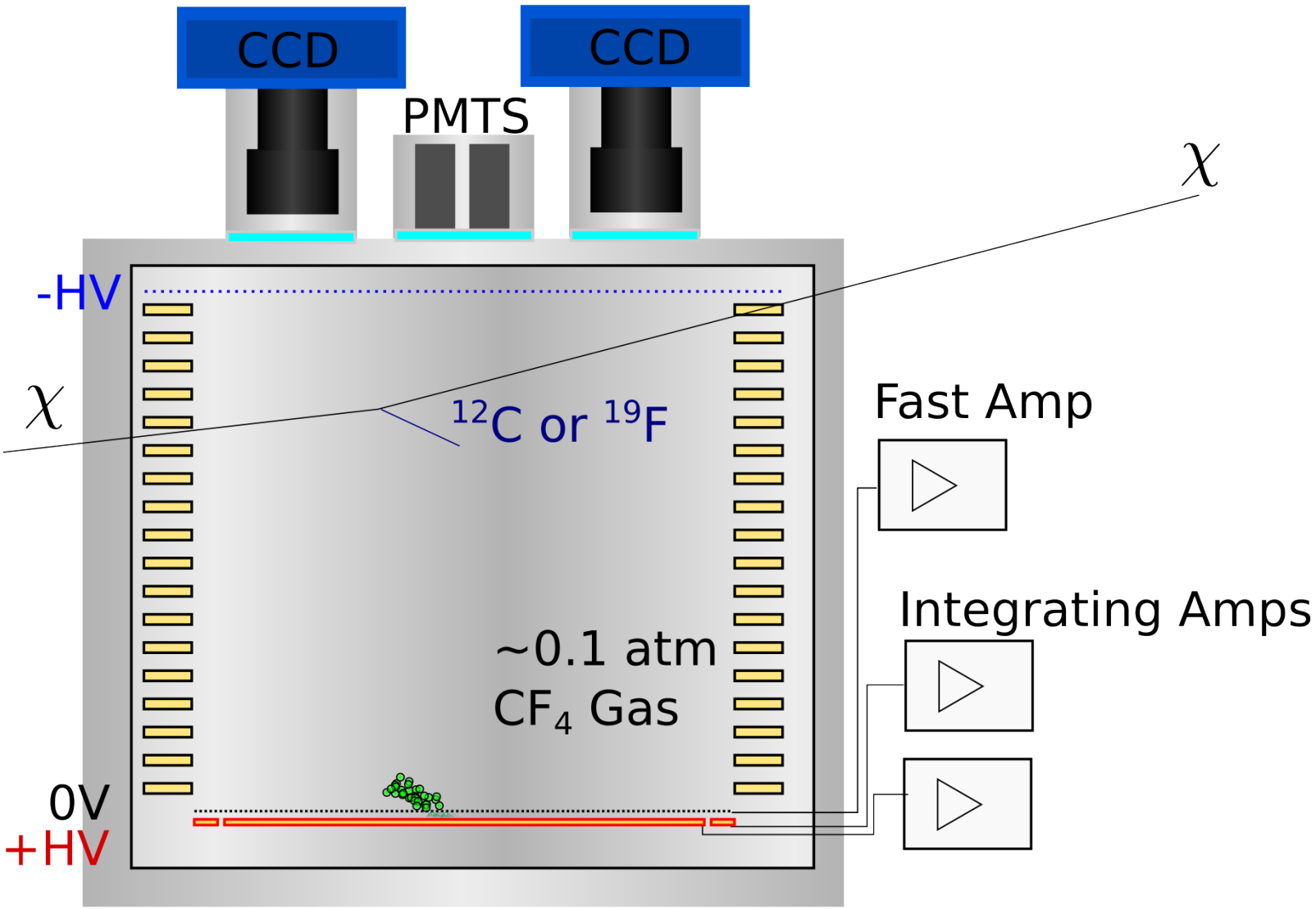
Detector concept



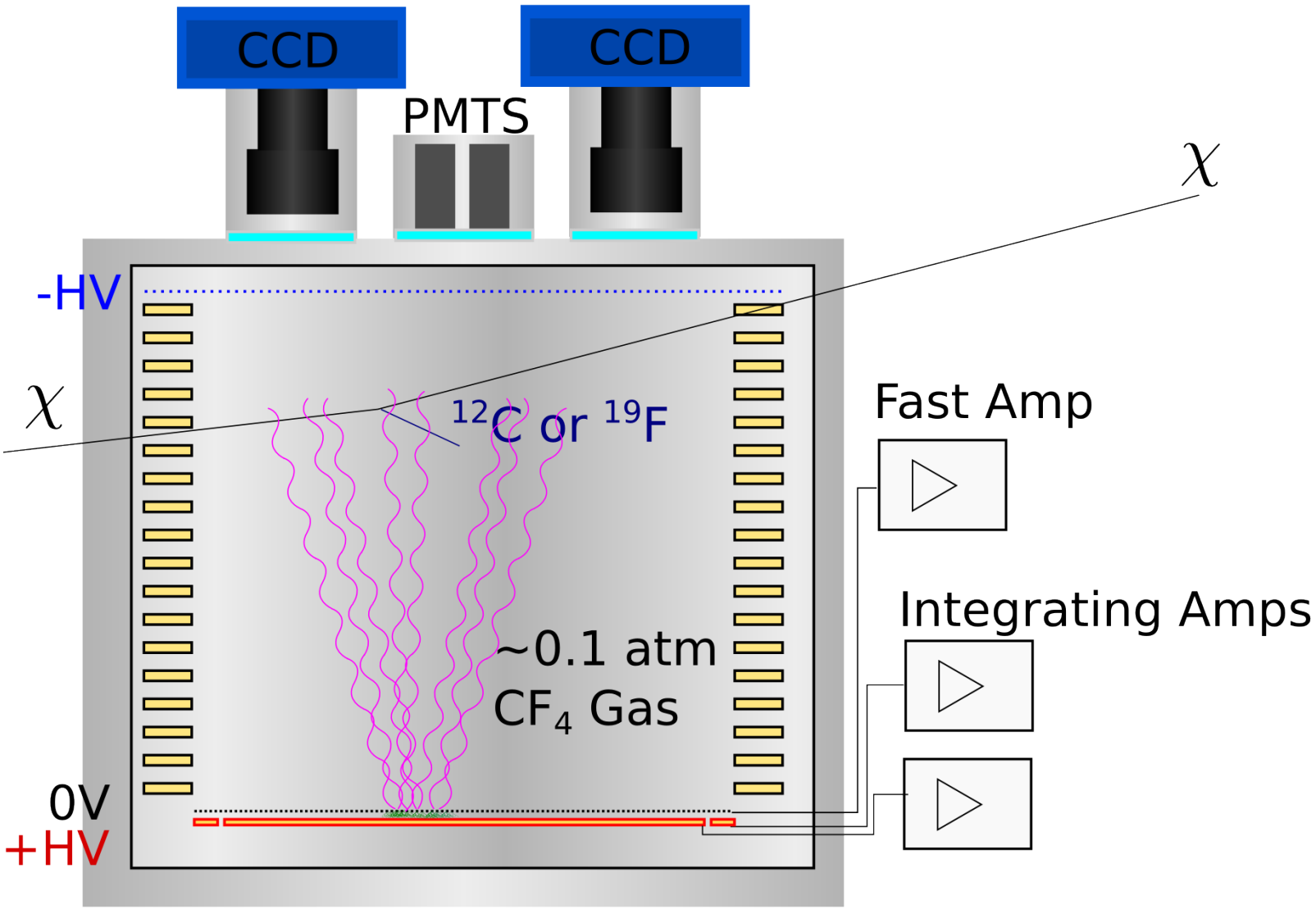
Detector concept



Detector concept



Detector concept



Detector Readouts

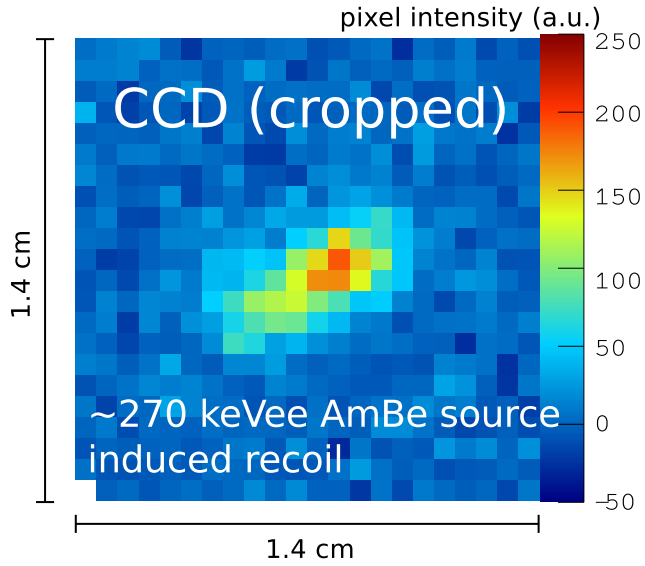
CCDs Take 2-Dimensional image of projected track scintillation profile. Currently use Alta U6 binned 4x4.

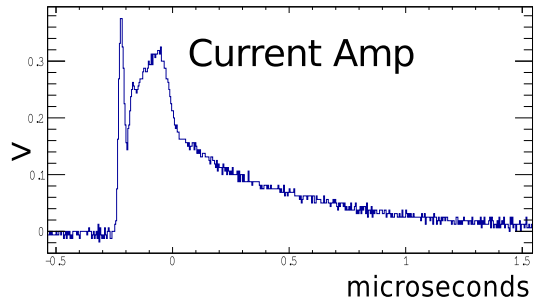
Anode Integrating Amp Charge-Sensitive Integrating Amp (CR-113) measures total charge induced on anode.

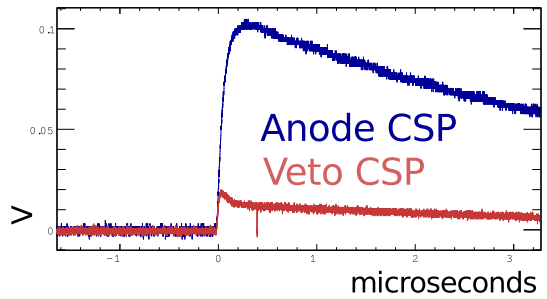
Veto Integrating Amp Charge-Sensitive Integrating Amp (CR-112) measures total charge induced on outer veto region (and cross-talk proportional to distance from center).

Fast Amp Current-Sensitive Amp (Route2Electronics) measures current between the ground mesh and anode.

PMTs Measure light output over time for track. Not discussed here



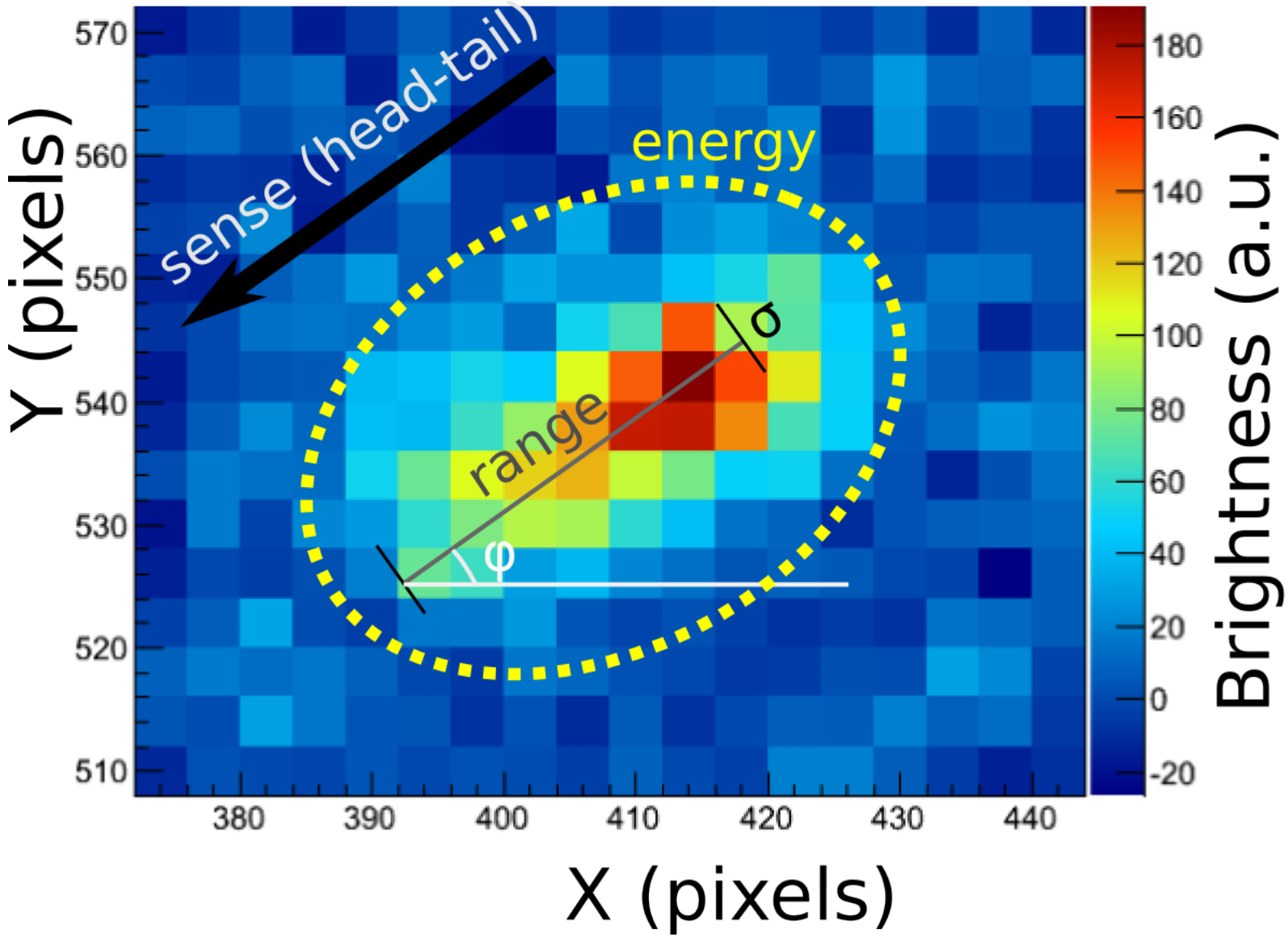




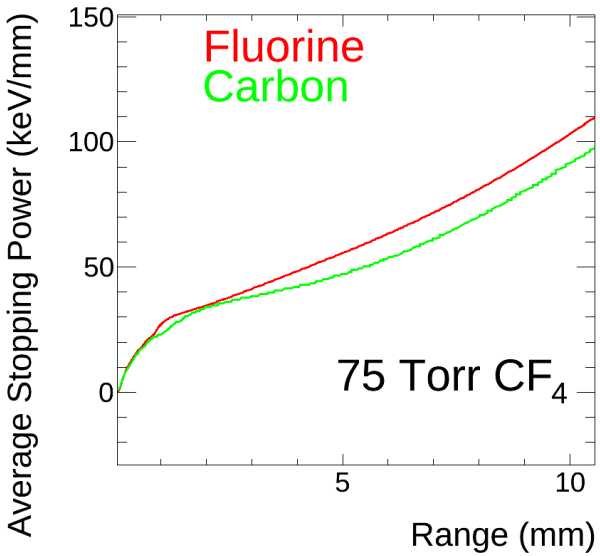
Outline

- Introduction
  - Directional Detection
  - The DMTPC Experiment
- Reconstruction Improvements
- Amplification Region Hardware R&D

CCD Track Parameters

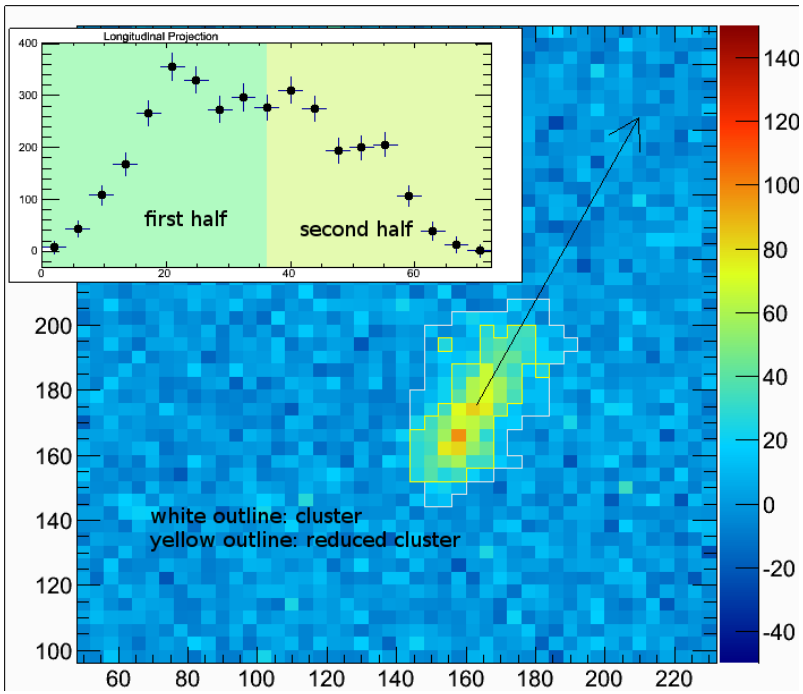


Head-Tail



- A nuclear recoil in the energy range of interest (well below Bragg peak) will lose more energy towards the front of the track
- However, diffusion and spatial resolution "blur" the track, making reconstruction of sense difficult in practice
- "Head-tail" fraction is fraction of tracks with correct sense (i.e. pointing in the correct hemisphere)

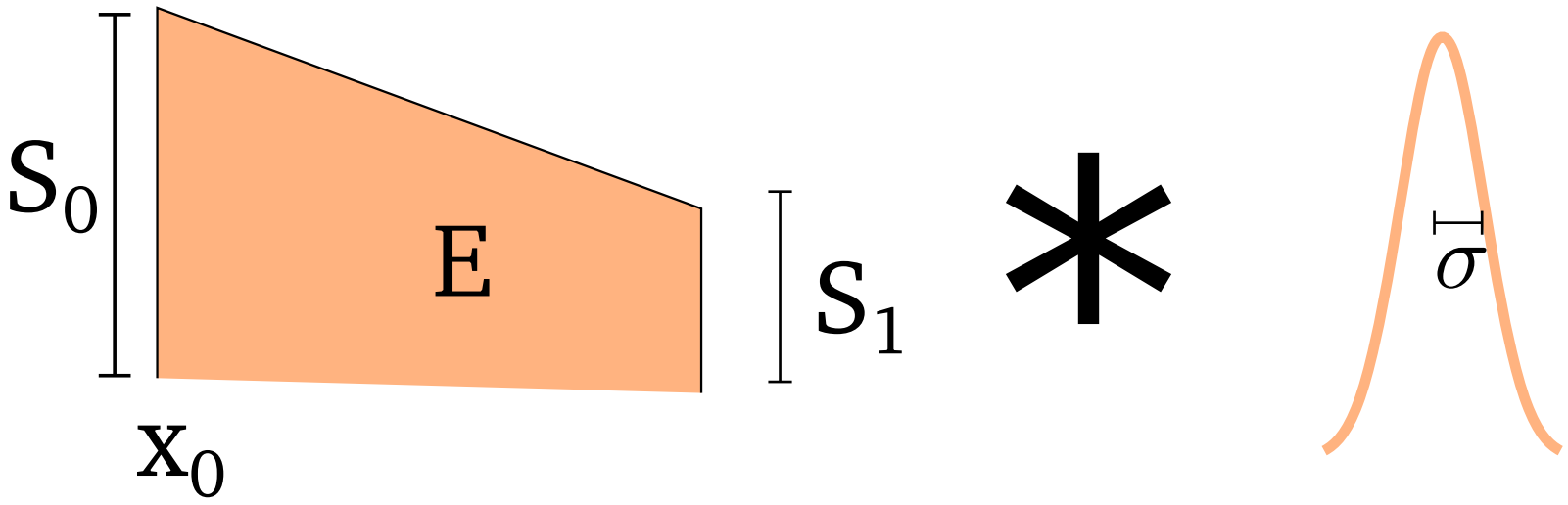
Parameter Reconstruction (old method)



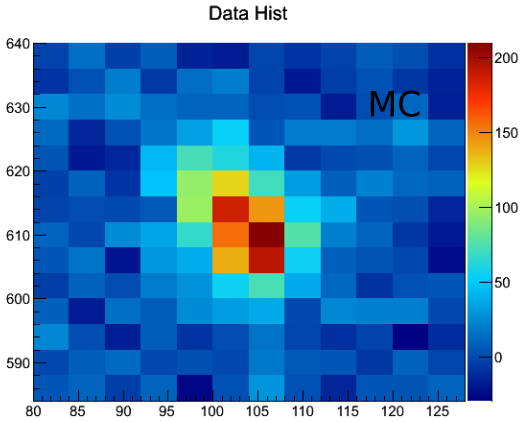
- To estimate axis, find axis that maximizes moments of pixels in cluster
- To get vector direction, pick half of track that has more energy
- Energy from sum of intensities
- Range from maximal separation in reduced cluster
- All of these methods rely on picking the pixels in the track correctly, which is difficult to do

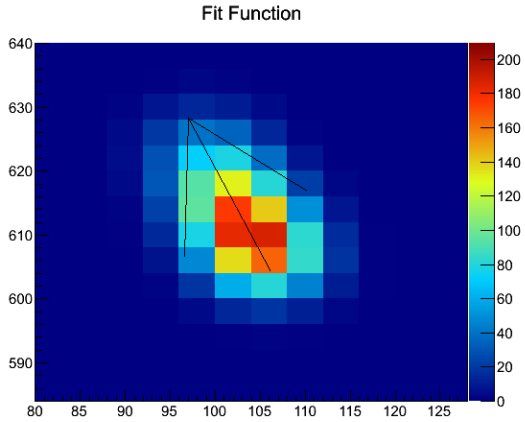
Model-based Fitting

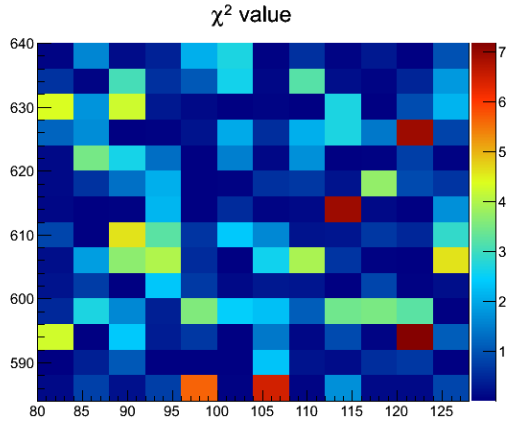
- Improve reconstruction of CCD parameters by fitting image near track to simple dE/dX model convolved with "diffusion"

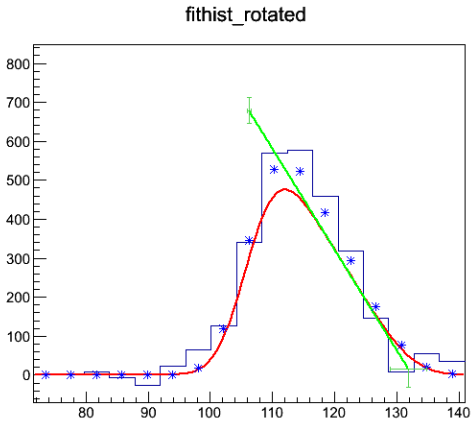


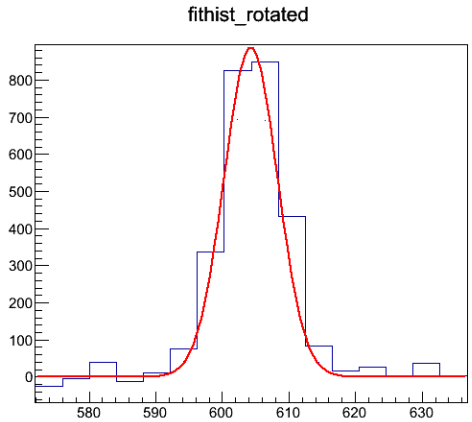
Fitting Example











$$\chi^2/ndof = 1.4$$

$$s_0 = 769.8^{+38.8}_{-35.5}$$

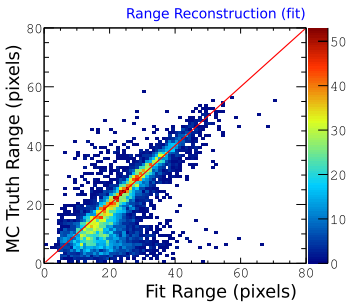
$$\Delta s = -752.49^{-118.85}_{+39.03}$$

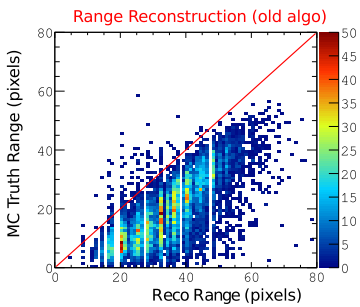
$$\phi = 1.94 \pm 0.035$$

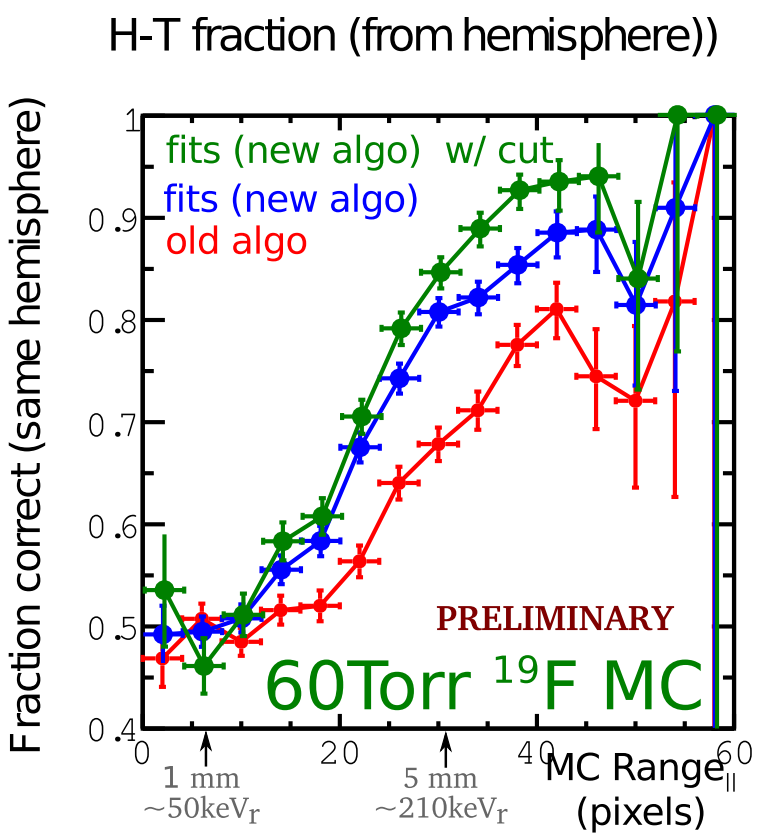
$$\sigma = 4.0 \pm 0.15$$

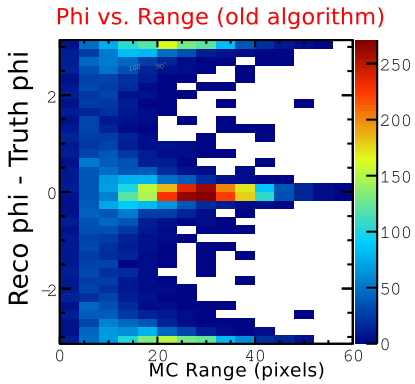
Fitting Improvements

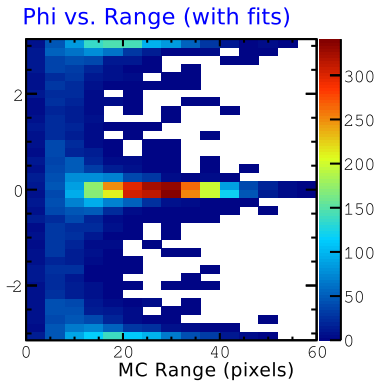
- Better range and energy reconstruction than with cluster-based algorithms.
- Fitting improves the fraction of tracks with correctly-reconstructed sense, and also provides a lot of ways to make cuts.





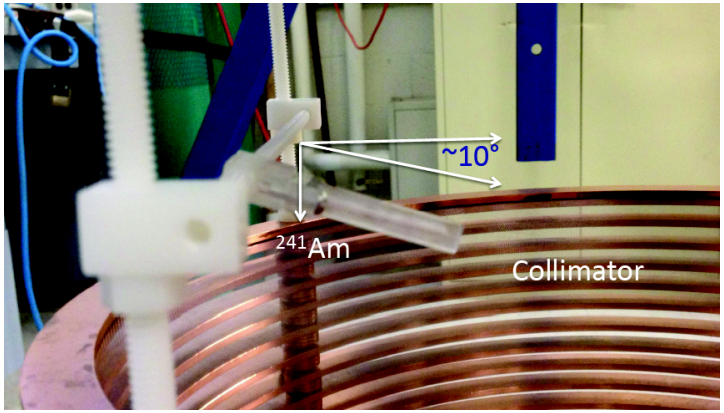


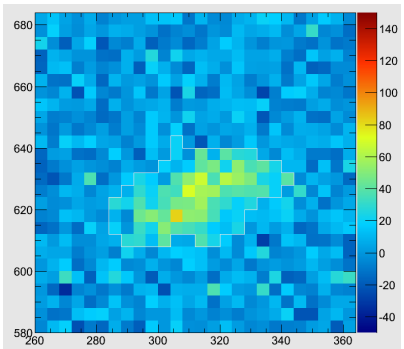


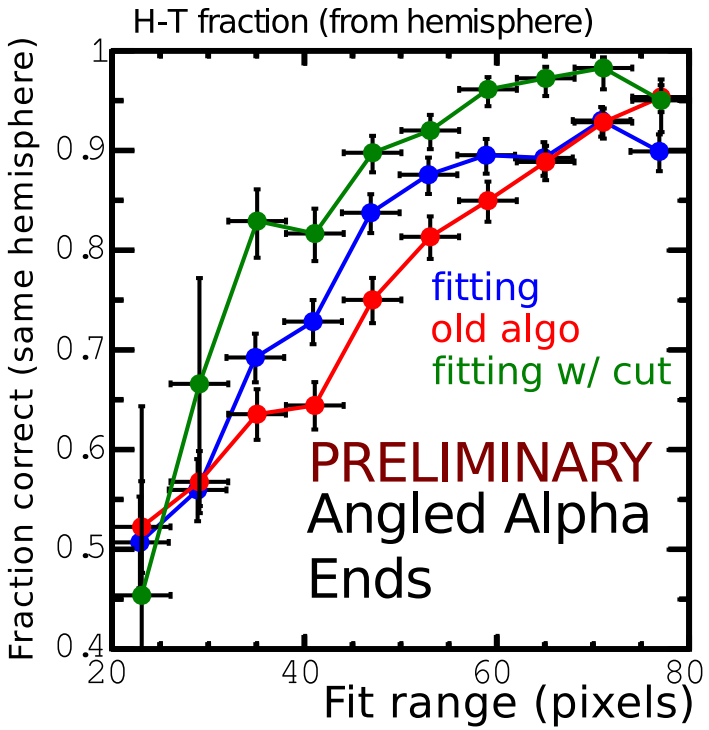


Angled Alpha Study Comparison

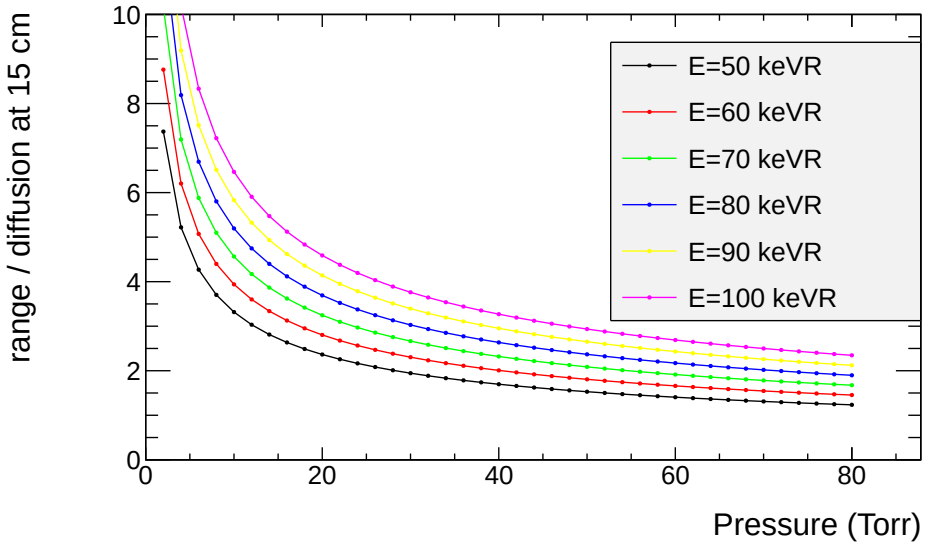
- Use ^{241}Am alpha source placed so only last few hundred keV enter detector.
- Because all events are near cathode, maximal diffusion.
- Smaller dE/dX than nuclear recoils, similar to recoils at lower pressure.

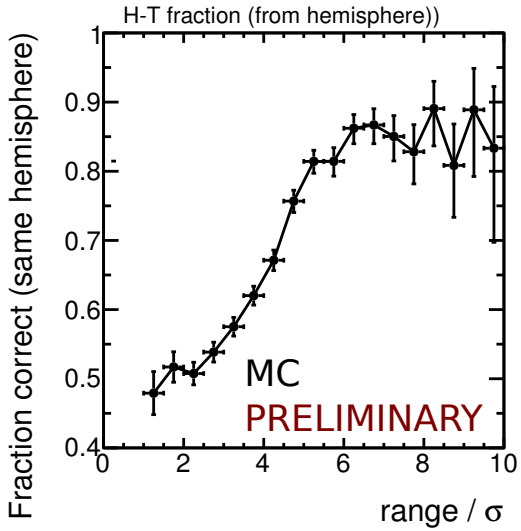






Detector parameter optimization





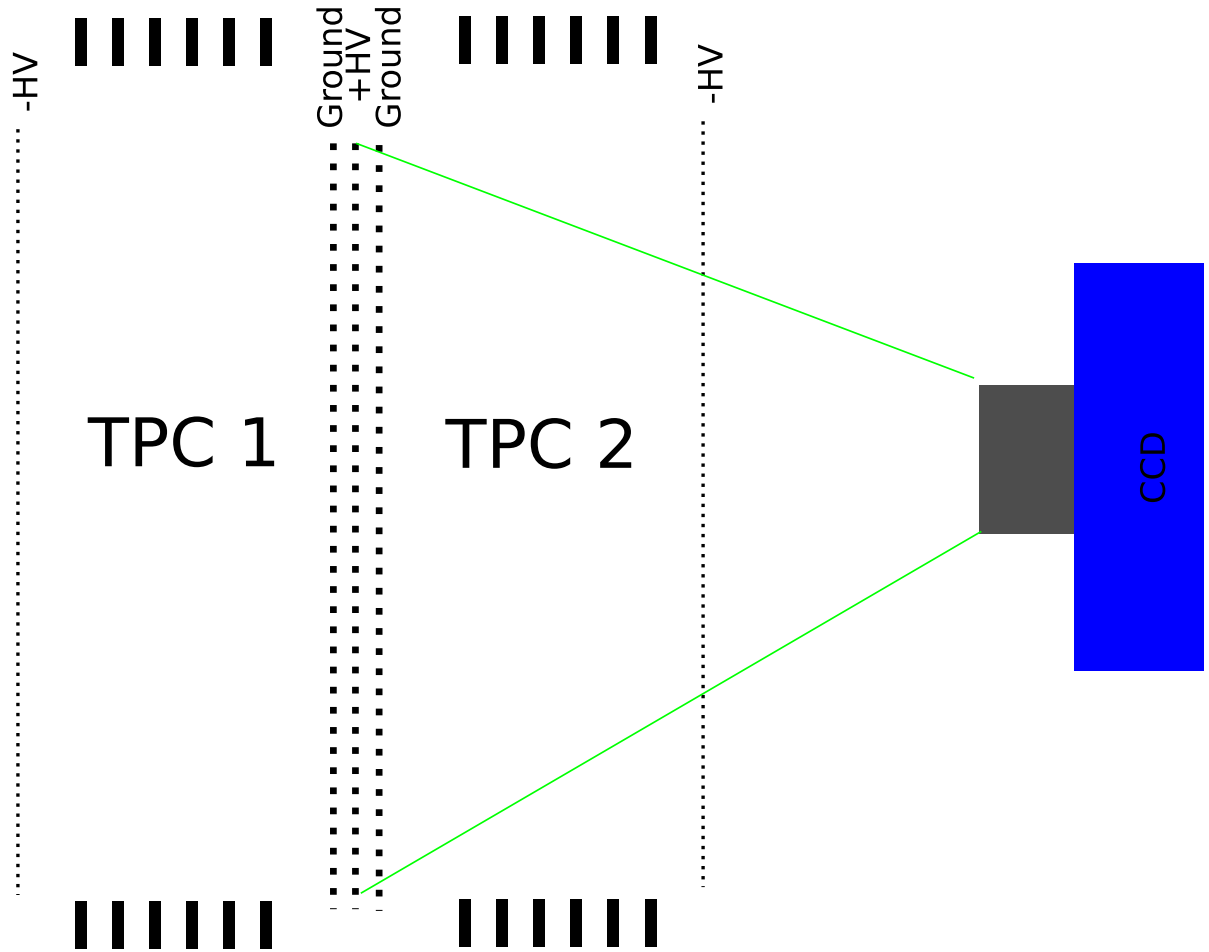
- MC studies show that key parameter for directionality is ratio of track projected length to transverse width (from diffusion).
- Suggests that going to lower pressure is necessary for lower sense-sensitivity threshold.
- Current production amplification regions don't work at high gain below 60T due to mechanical issues, which we are working on.

Outline

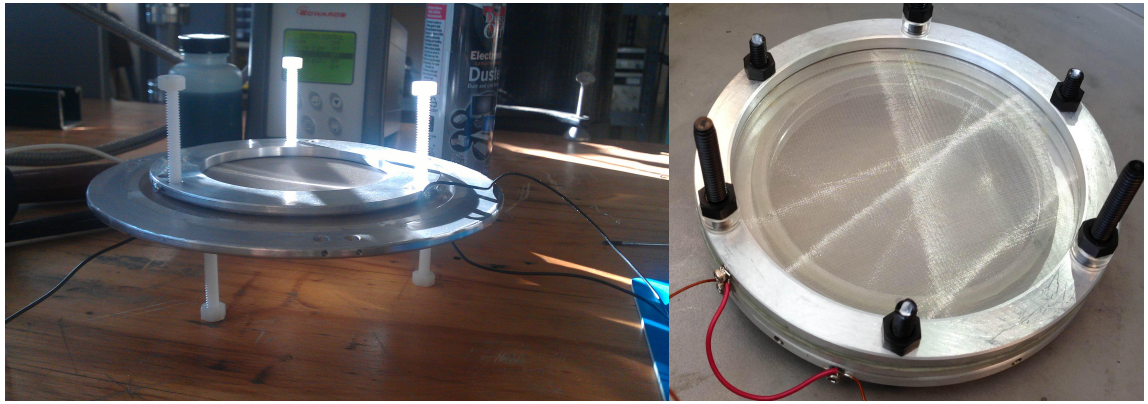
- Introduction
  - Directional Detection
  - The DMTPC Experiment
- Reconstruction improvements
- Amplification Region Hardware R&D

New Amplification Design: Triple Mesh

- Allows imaging of two TPC's with one camera (good cameras and lenses are expensive).



Current Prototypes



- Small prototypes in test chamber demonstrate concept works with charge $+^{55}$Fe. CCD tests forthcoming.
- Alternative double-stage amplification setup (similar to work Loomba has done with DRIFT) greatly increases gas gain (preliminary: $>$500,000 at 30 Torr).
- For nuclear recoils, cannot operate at such high gain due to Raether Limit, which limits the total number of electrons in an avalanche to around 10^8 before sparking.
- But lowering pressure $\rightarrow$ less density $\rightarrow$ can raise gain and keep SNR approximately constant with longer tracks.

Near Future

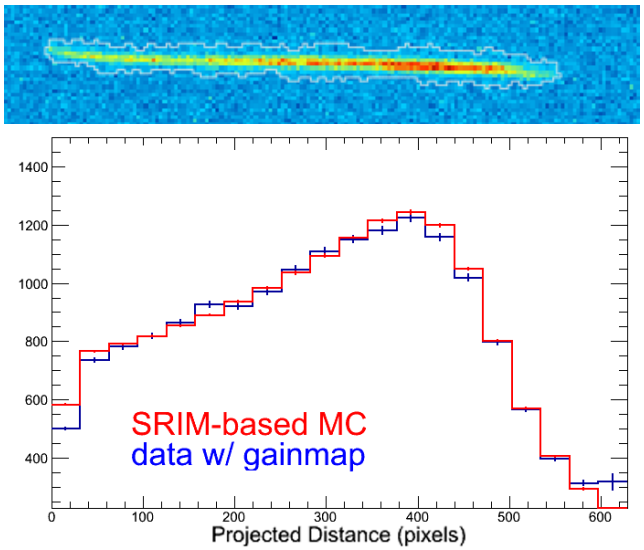
- Underground results from WIPP for older prototype
- Neutron calibration results from new prototype
- We've been slow about writing papers, but are getting around to writing a bunch right now.

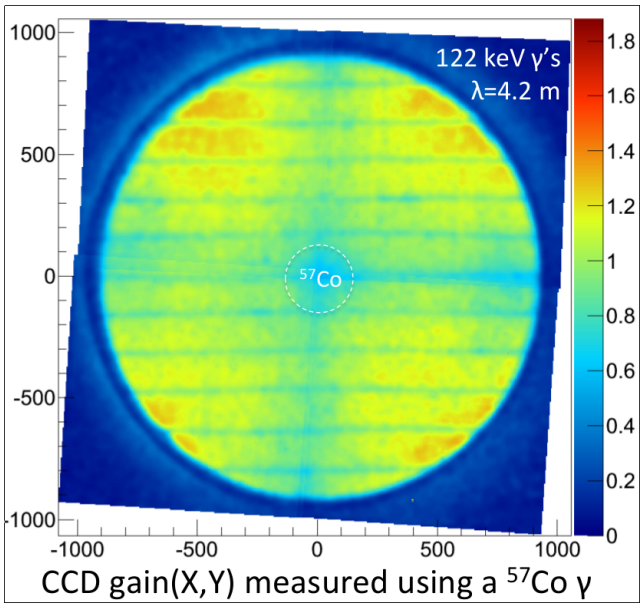
Thank you!

Questions?

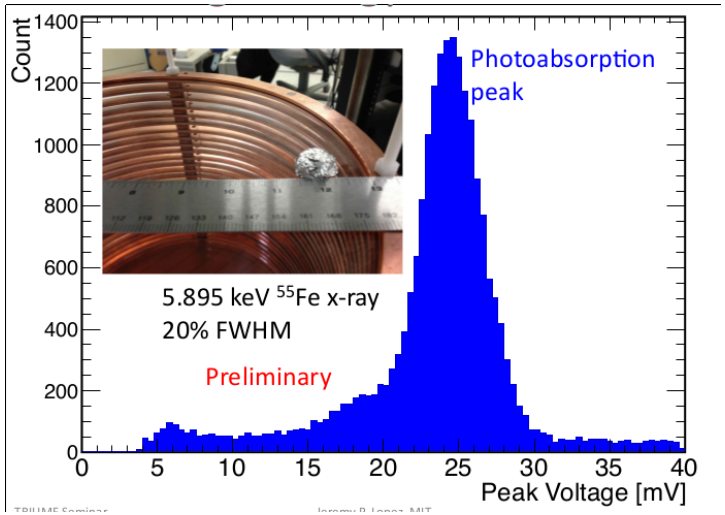
Backup Slides

Energy Calibration

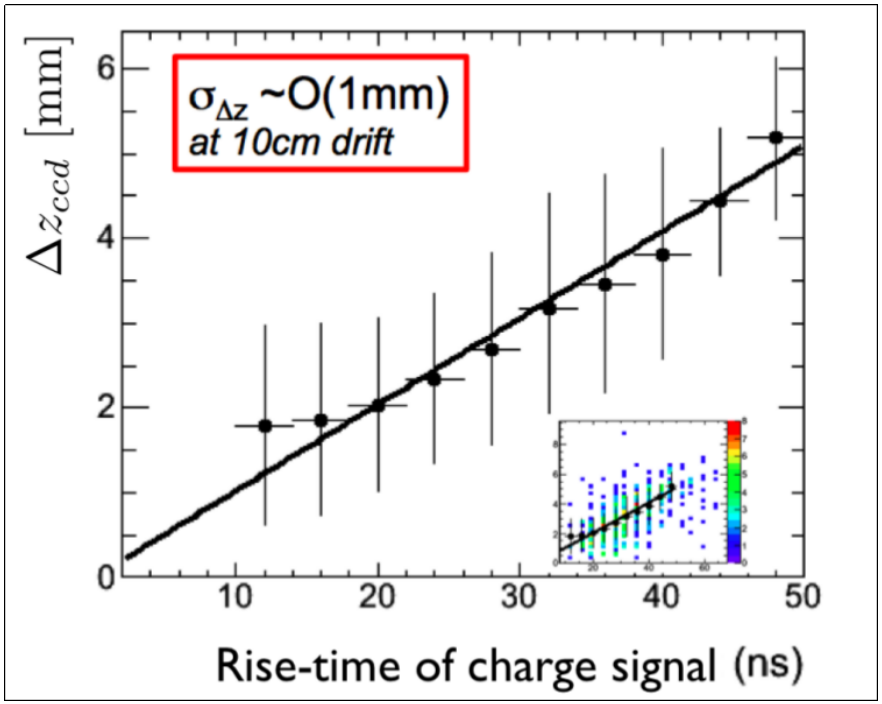


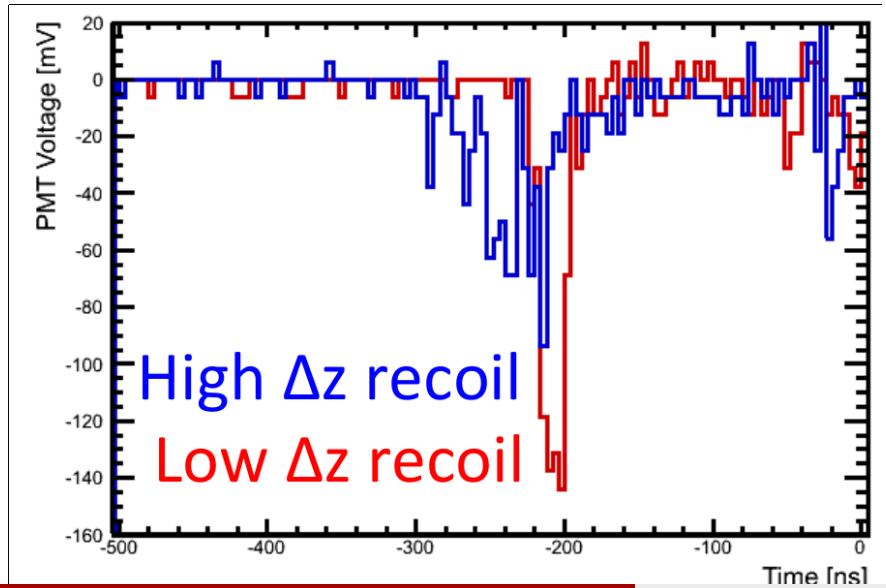


- For CCD, use projection of α track from $^{241}\mathrm{Am}$ source and compare averaged dE/dX to SRIM prediction.
- For charge, use $^{55}\mathrm{Fe}$ source.
- Use $^{57}\mathrm{Co}$ to calibrate for spatial gain variation



Out of plane (Vertical) Angle

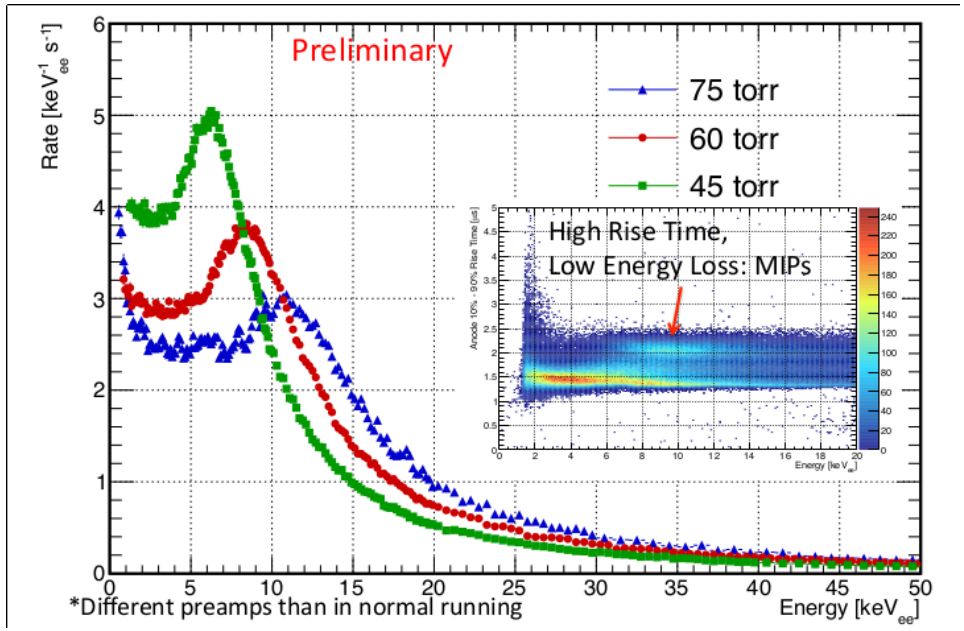




- Rise time of fast pulse correlated with ΔZ
- PMT width also correlated.
- Track fit can also be used to estimate angle (based on Energy / projected range relation and maximum dE/dX achieved)

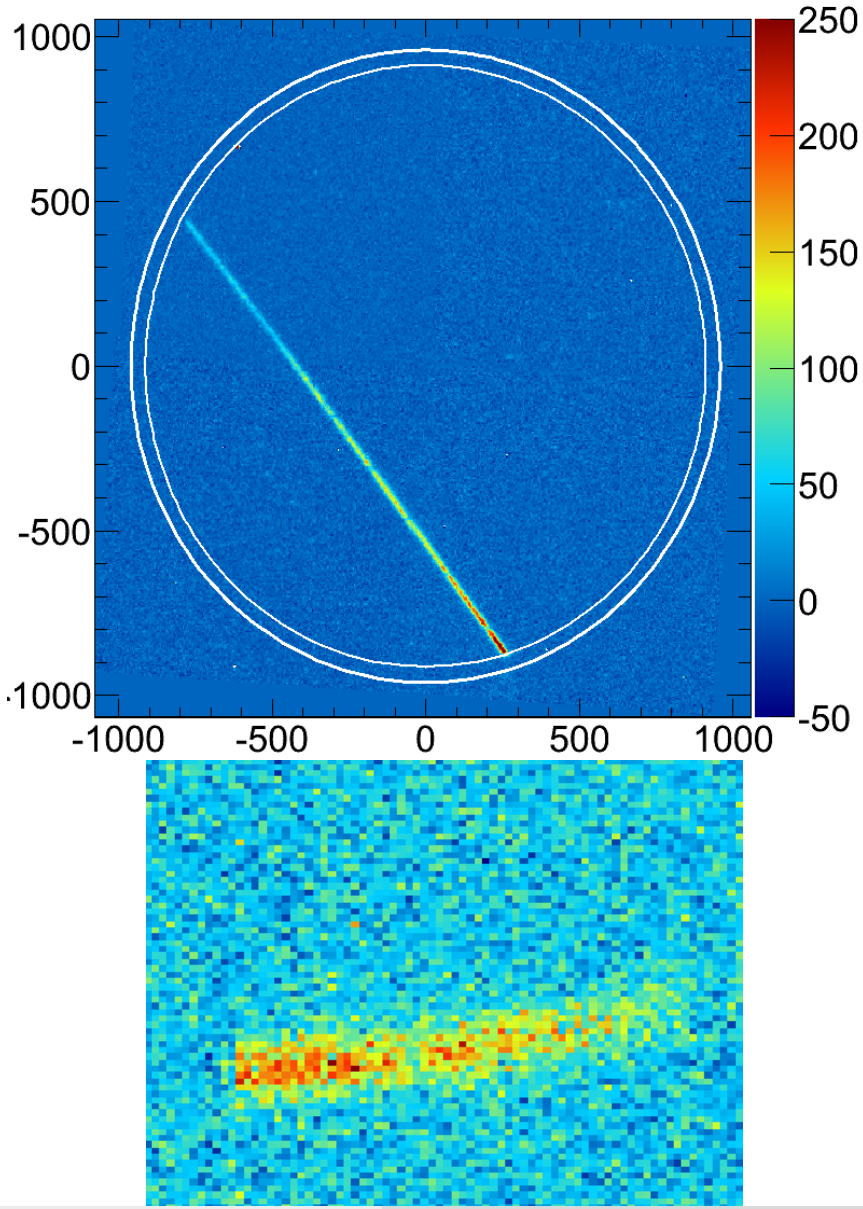
Backgrounds - MIPs

- Charge channels easily detect ionization from minimially ionizing particles passing through the detector
- If vertical track, CCD may detect as well.
- Tracks have very long pulse rise time and can be vetoed by paddles.

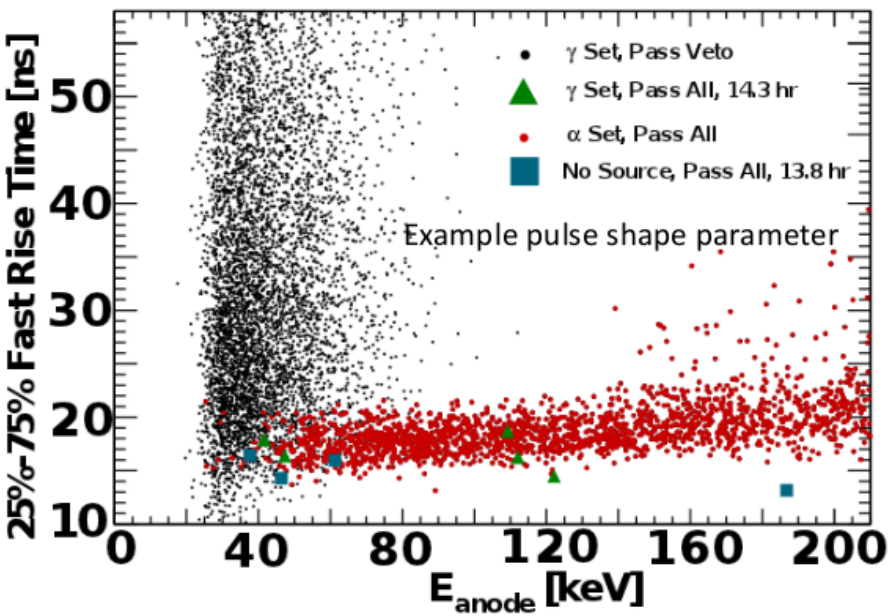


Backgrounds - α

- From internal radiation in the detector
- Most come from rings and are easily identified
- Dangerous αs come from tracks which are cutoff by the CCD readout process
- A shutter can be used to mitigate this, or we can look for a hard ege

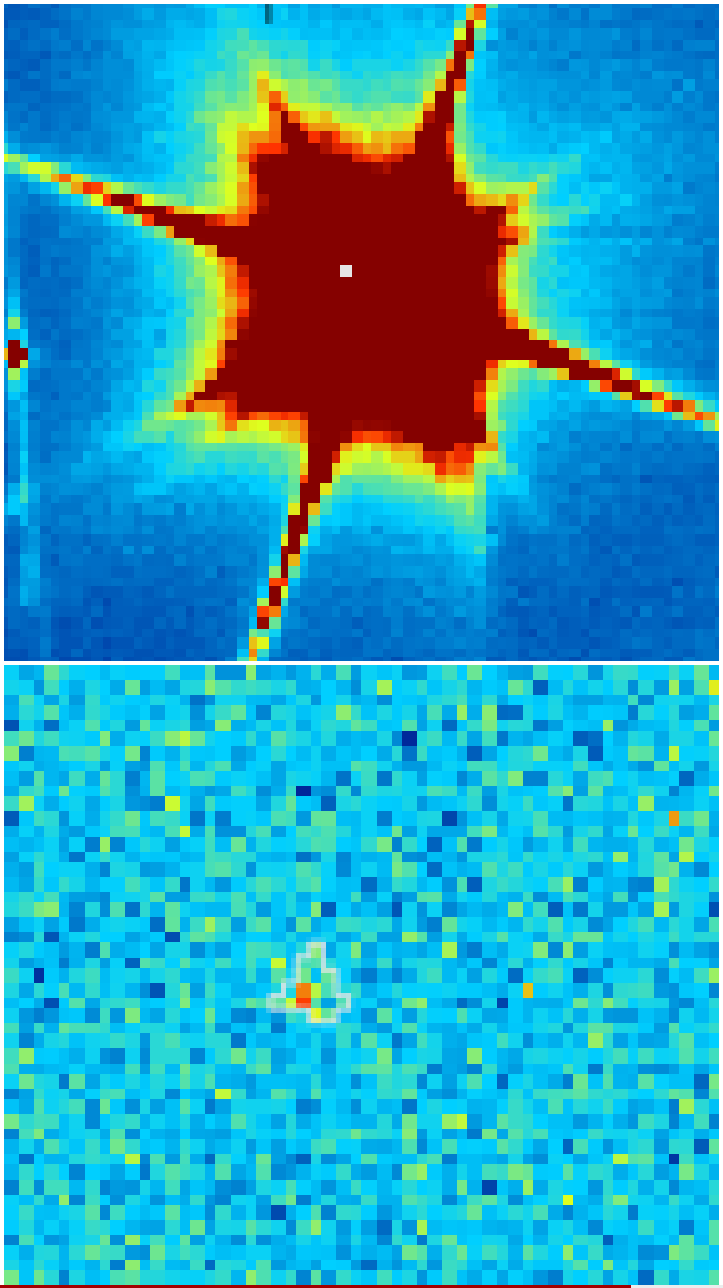


Backgrounds - γ



- From internal radiation
- CCD mostly blind due to low dE/dX
- Charge channels see many of these, but veto and topology of fast amplifier pulse can be used to remove $> 99.9\%$ of these.

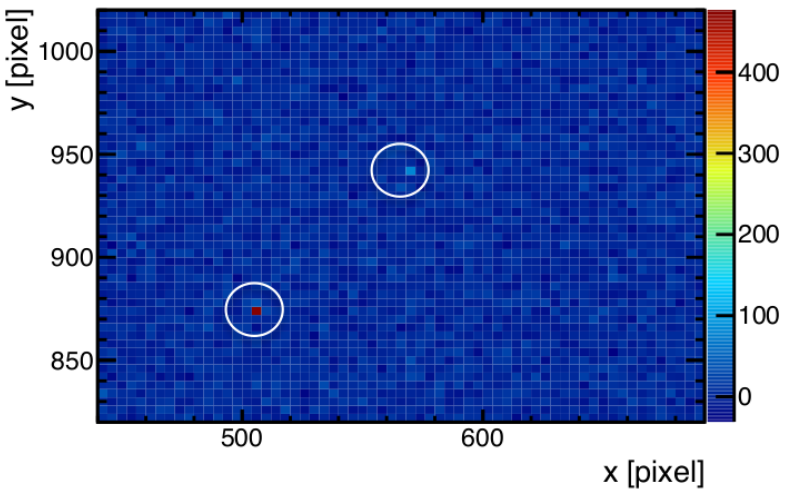
Backgrounds - RBIs



- With front illuminated CCD's (such as ours), exposure to large amounts of infrared light (from e.g. sparks) leads to charge being stored in an interface trap.
- This manifests itself as a slowly-fading after image
- Can be removed by use of spacial correlation and removing areas that saturate during sparks.

Backgrounds - Hot Pixels and CCD Interactions

- Hot pixels are generally removed by subtracting averaged background frames. However, since they turn on and off, a partially subtracted hot pixel combined with fluctuations can look like a track to our algorithms.
- Direct interactions between e.g. cosmic rays and the CCD also produce tracks.
- This class of backgrounds can be studied by taking images with the CCD turned off. A multivariate algorithm is then applied on cluster parameters to optimally distinguish between CCD-only events and nuclear recoils.



Track Recognition

- For the CCD, we must determine which pixels make up a track before performing further analysis.
- Current algorithm works by low-pass filtering the image, applying a threshold (based on image noise) to select a "seed" for a cluster, then adding additional pixels around using a sliding threshold.
- Requirements are made on morphological compactness and number of pixels
- Because of spacers in the amplification region, there are dead spots in the image. Clusters must be merged across, otherwise one long α appears as many shorter tracks. Merging is done by checking if tracks are directly across spacers and by checking if track combinations form lines.