xy Position Reconstruction in DarkSide-50

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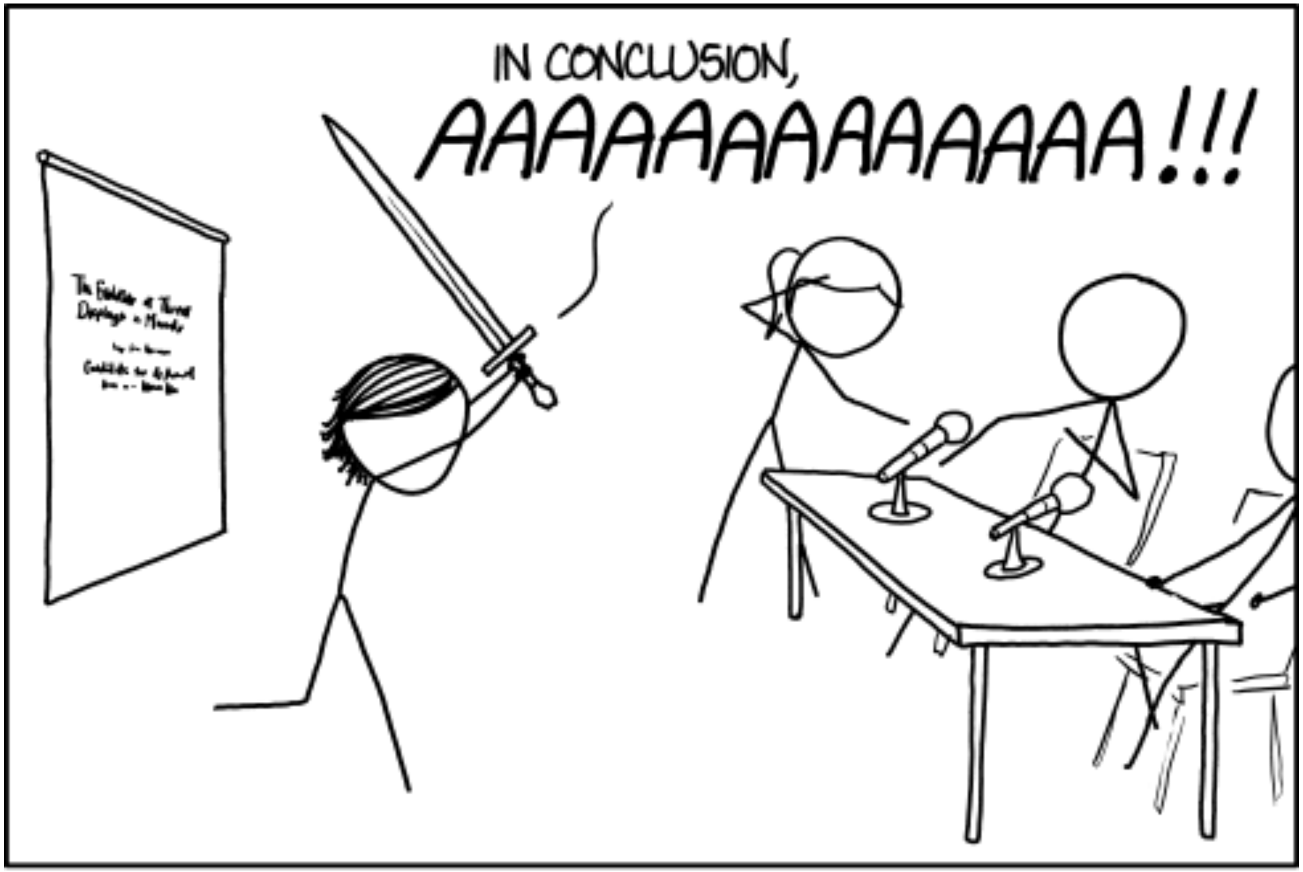
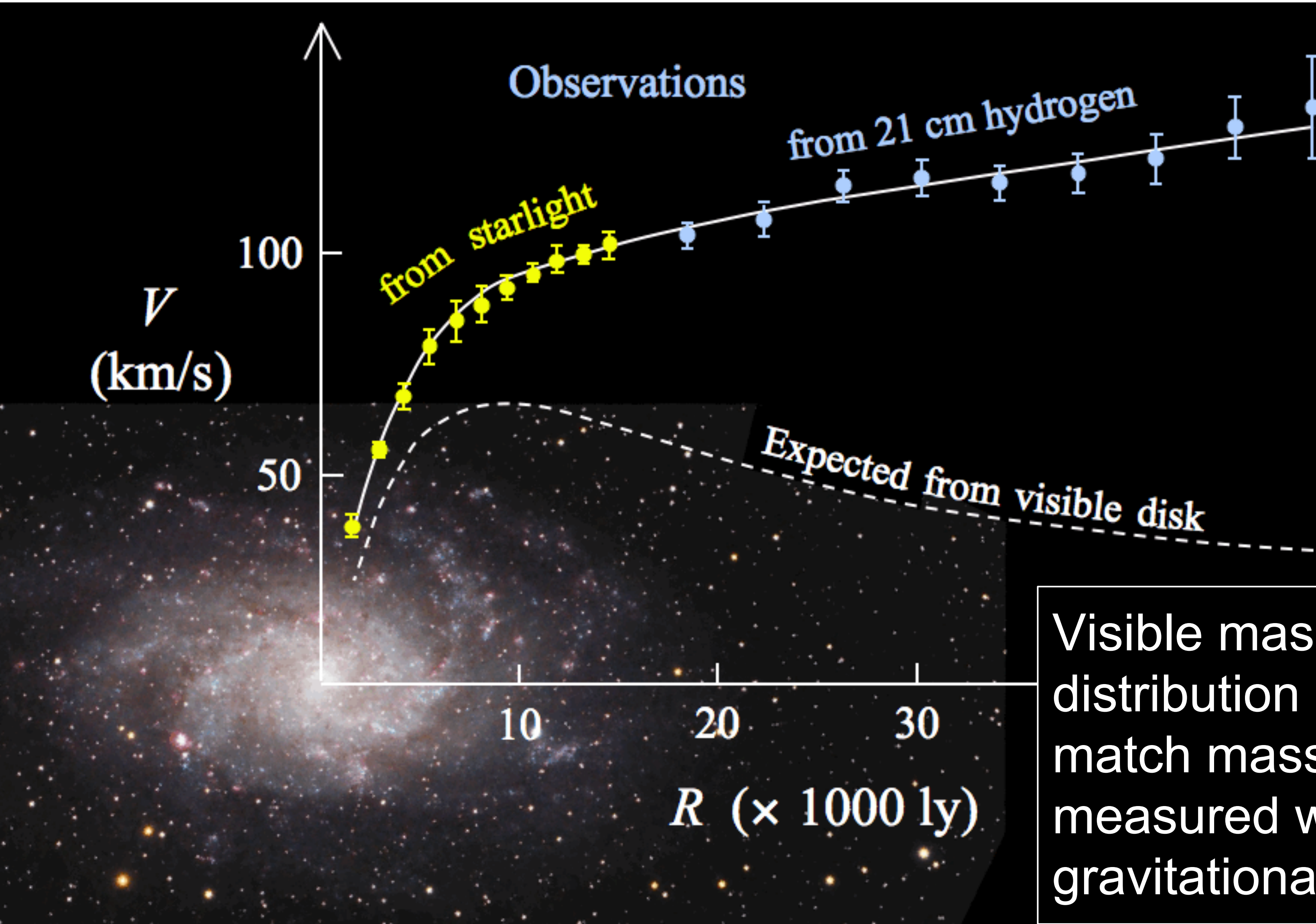


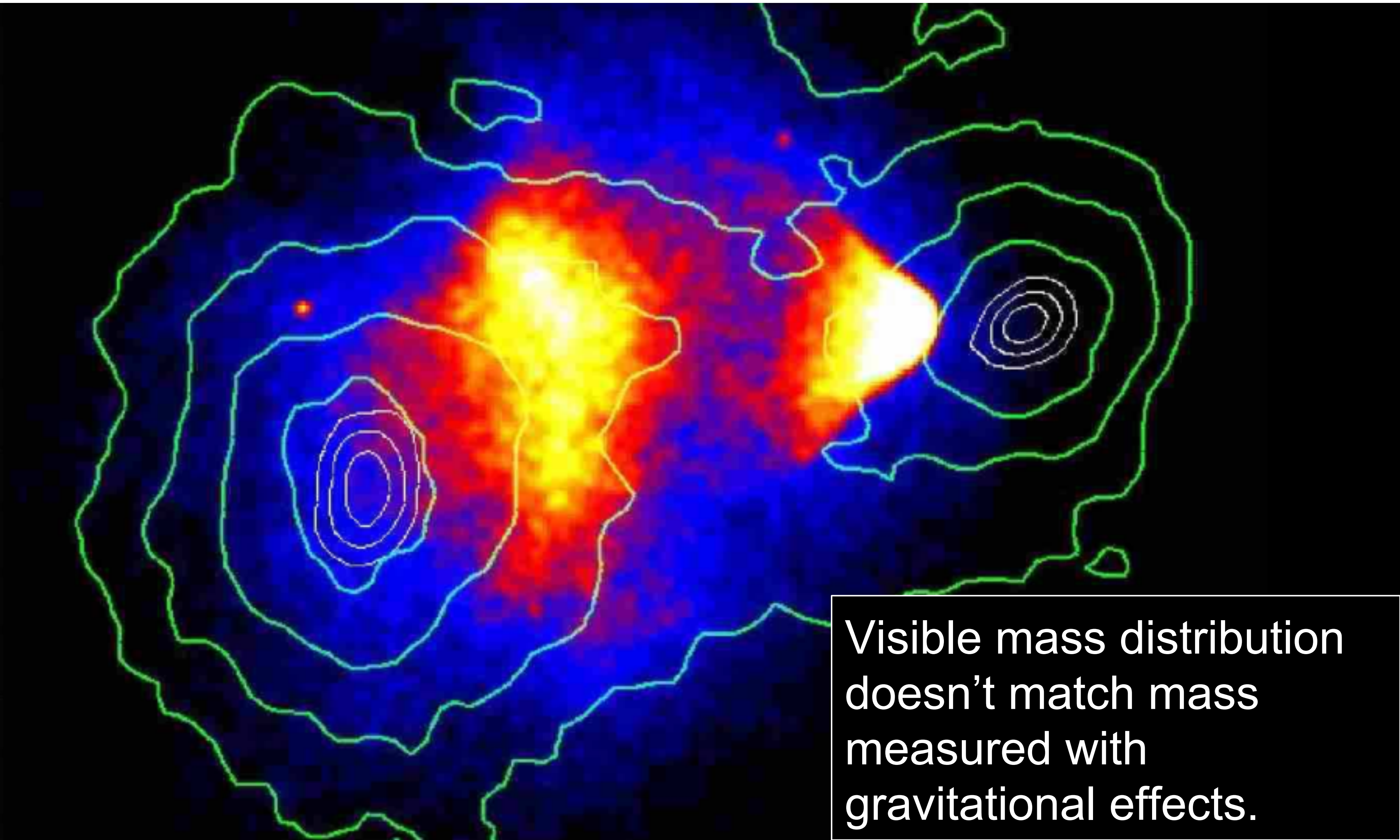
THE BEST THESIS DEFENSE IS A GOOD THESIS OFFENSE.

Gravitational Evidence for Dark Matter: galactic rotation curves



Visible mass distribution doesn't match mass measured with gravitational effects.

Gravitational Evidence for Dark Matter: Bullet Cluster



Visible mass distribution doesn't match mass measured with gravitational effects.

Dark Matter Candidates

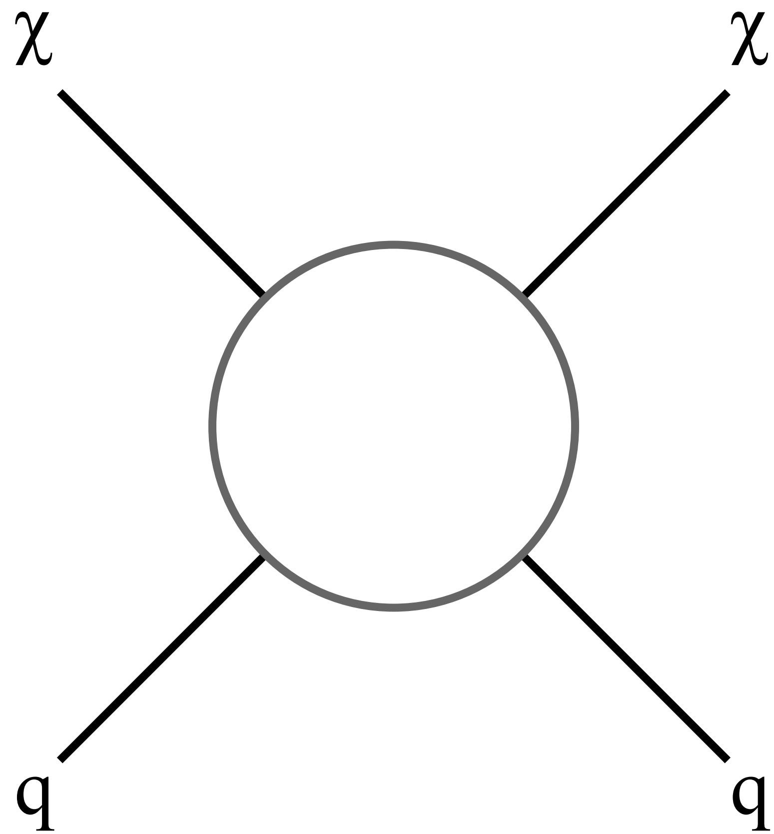
WIMP Dark Matter

Weakly

Interacting

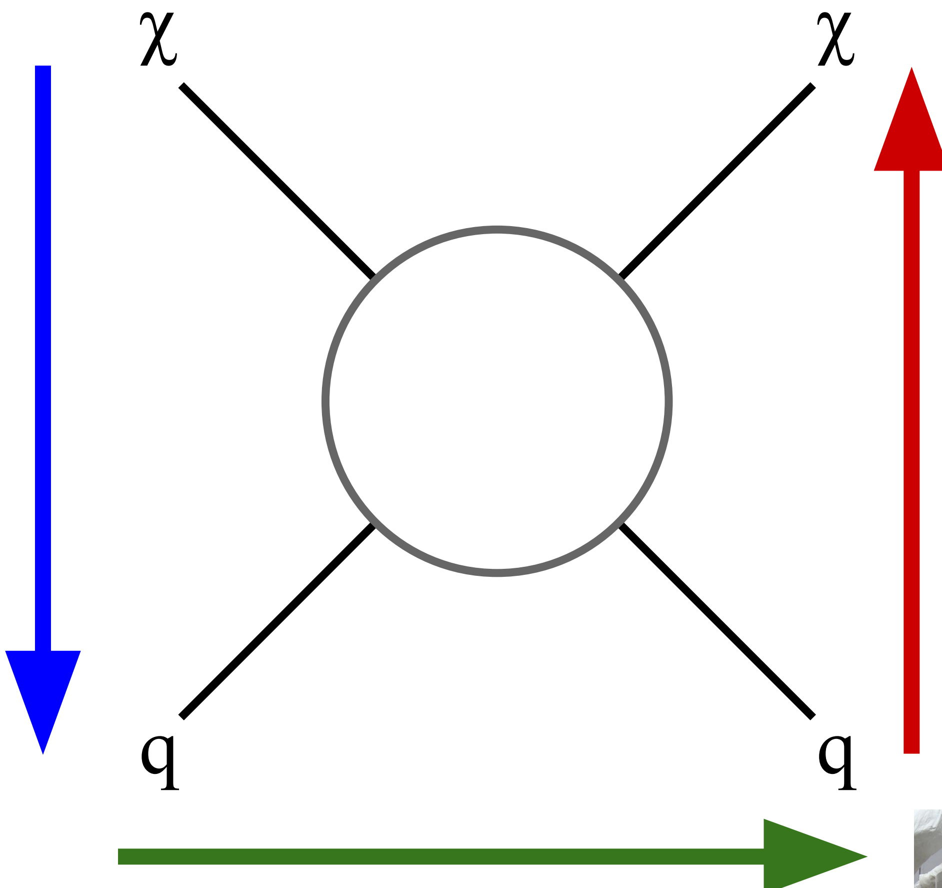
Massive

Particle



Direct Detection

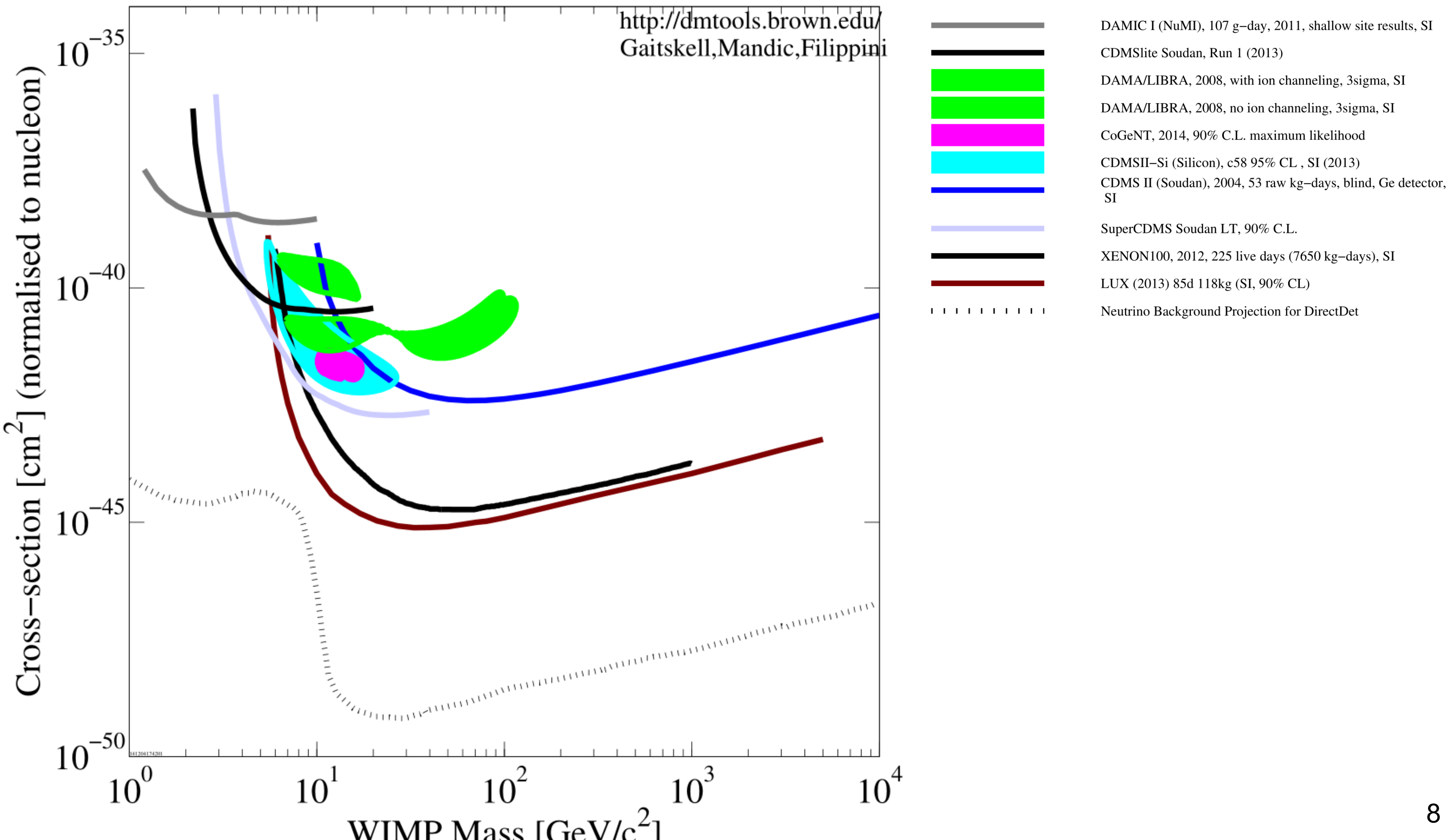
Annihilation



Collider

Direct Detection

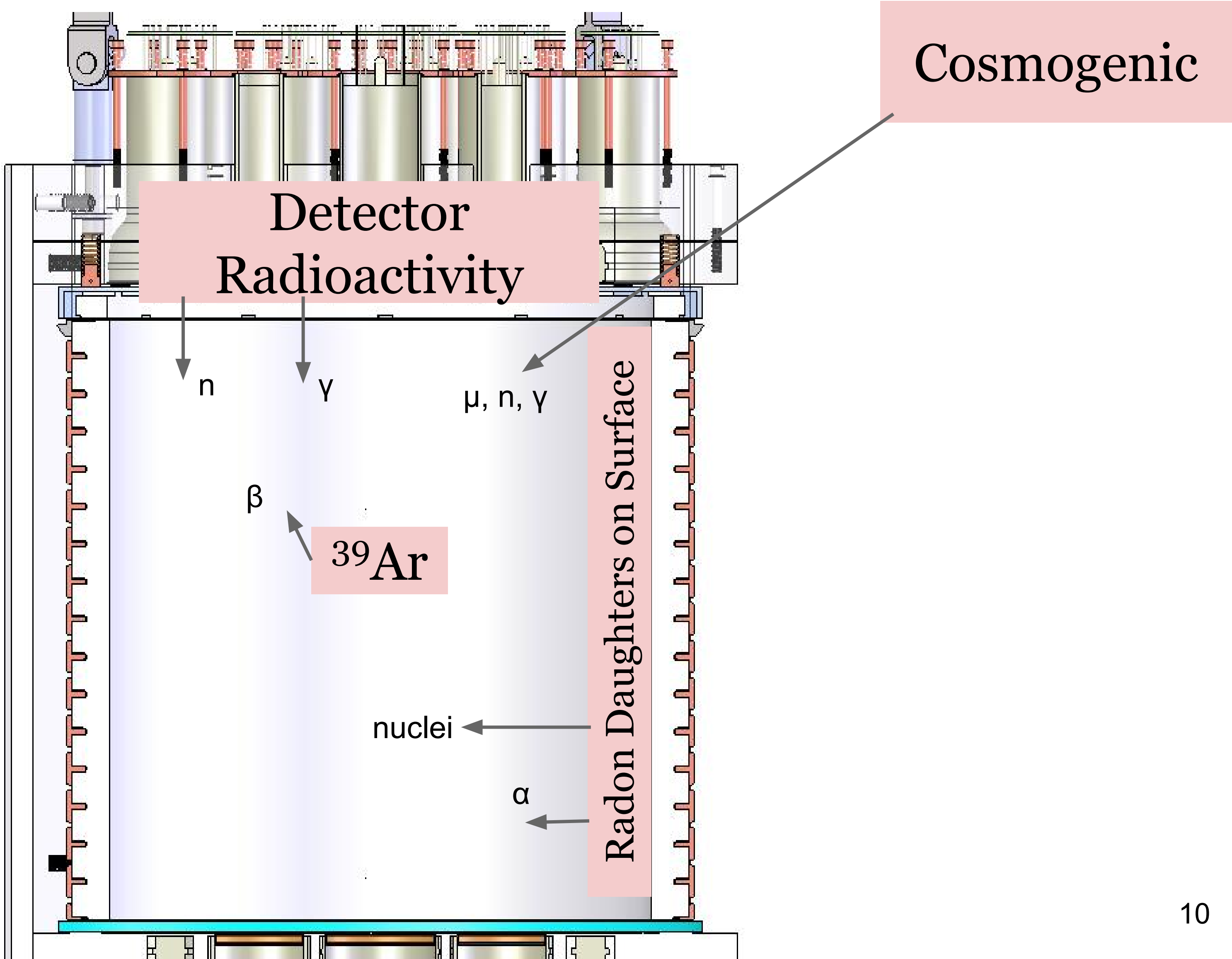
Field Results So Far



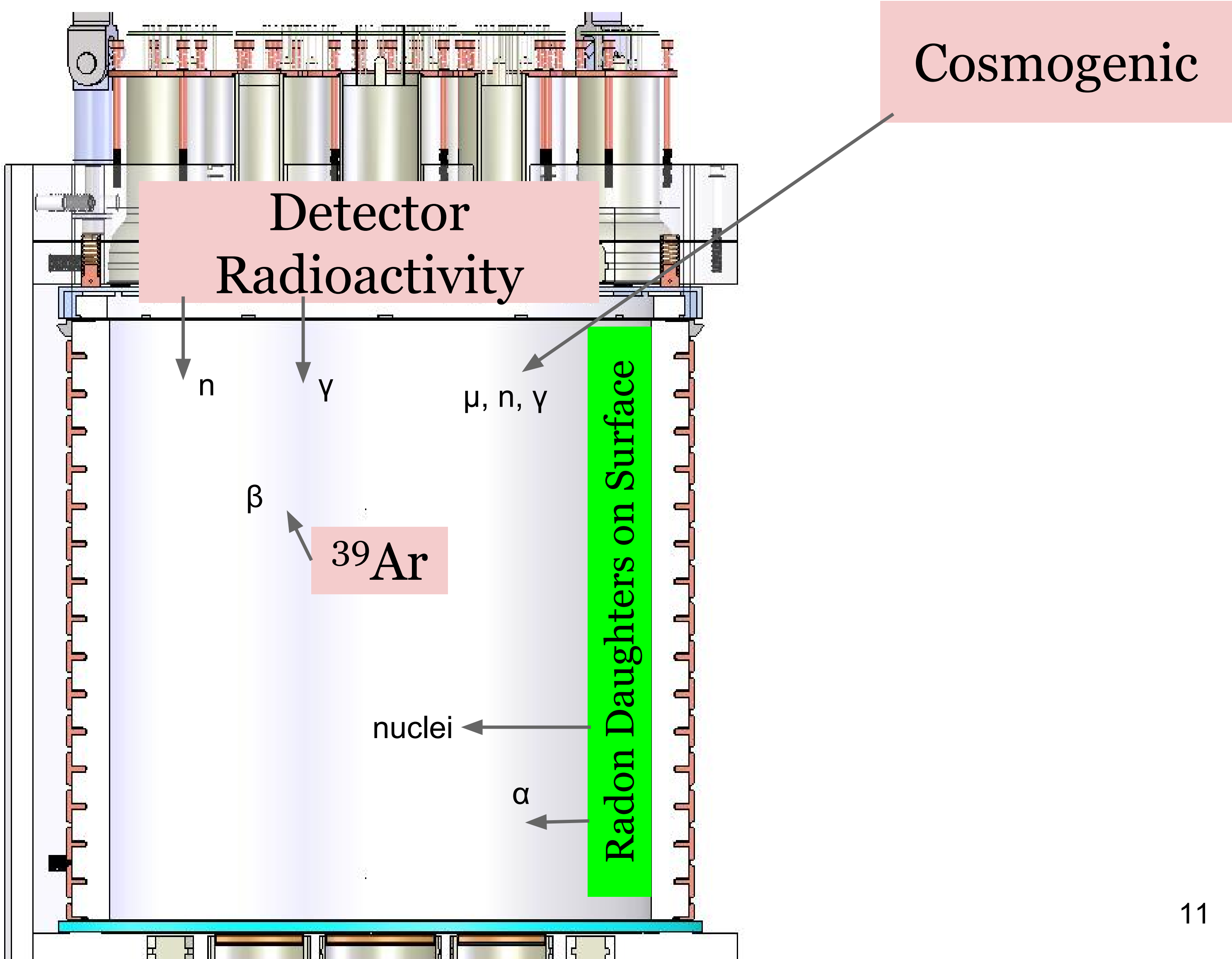
DarkSide-50

- Three nested detectors
- Inner detector: 50 kg liquid argon time projection chamber (TPC)
- 4 m diameter organic scintillator neutron detector
- 850 ton water cosmic muon detector
- Built extremely radiation-clean
- Underground argon program
- Designed for significant background-free exposure

Backgrounds: The Fundamental Challenge

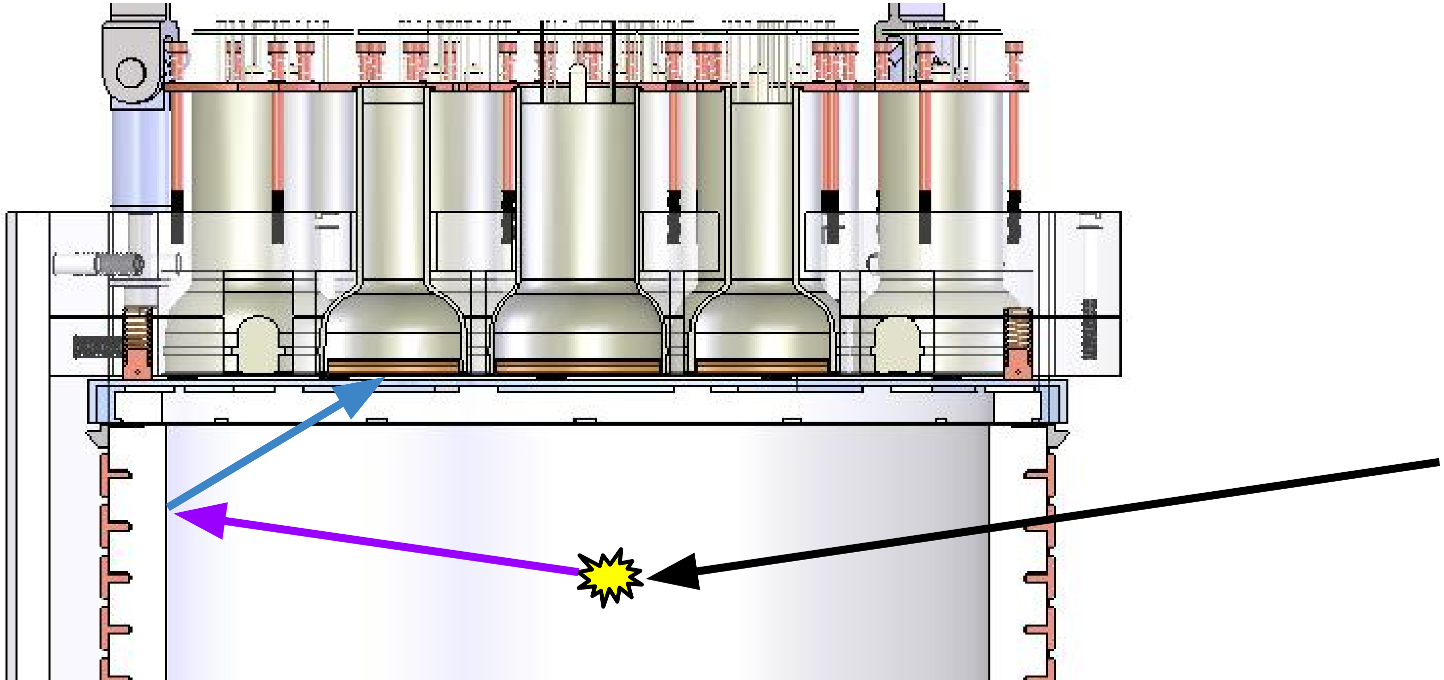


Backgrounds: The Fundamental Challenge



Signals: Scintillation

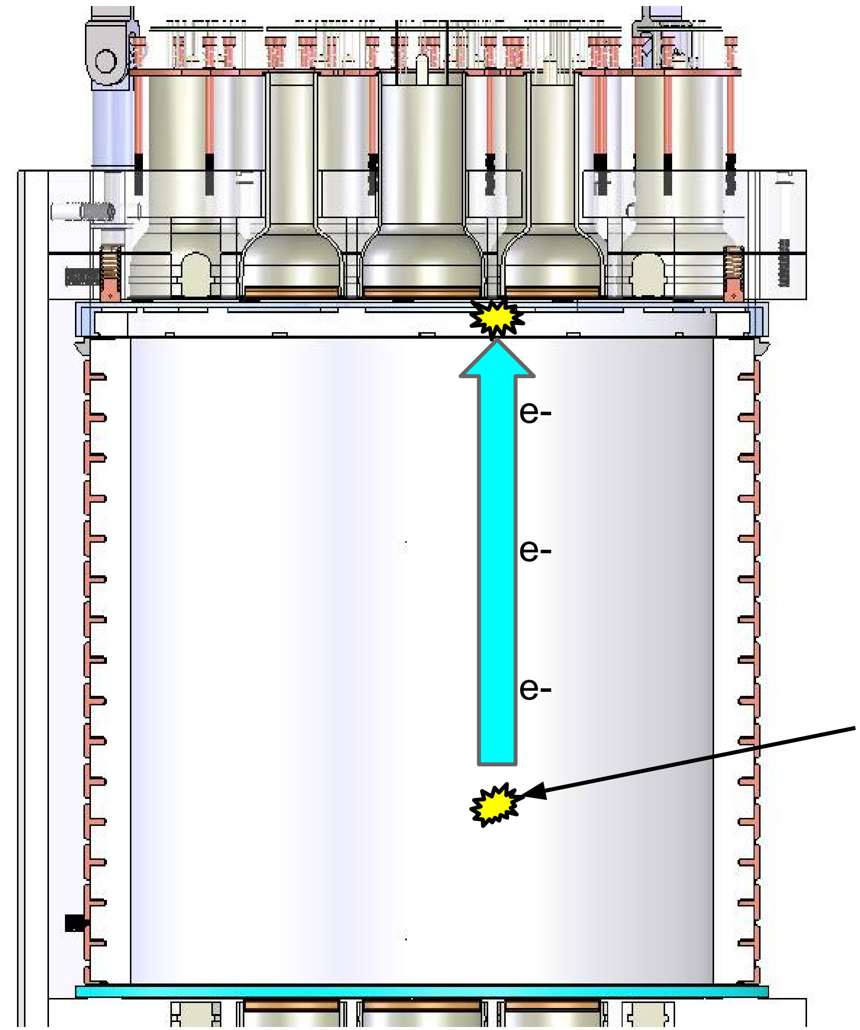
- Scintillation at 128 nm
- Shift wavelength to visible with tetraphenyl butadiene (TPB)
- Observe with photomultiplier tubes



Signals: Ionization

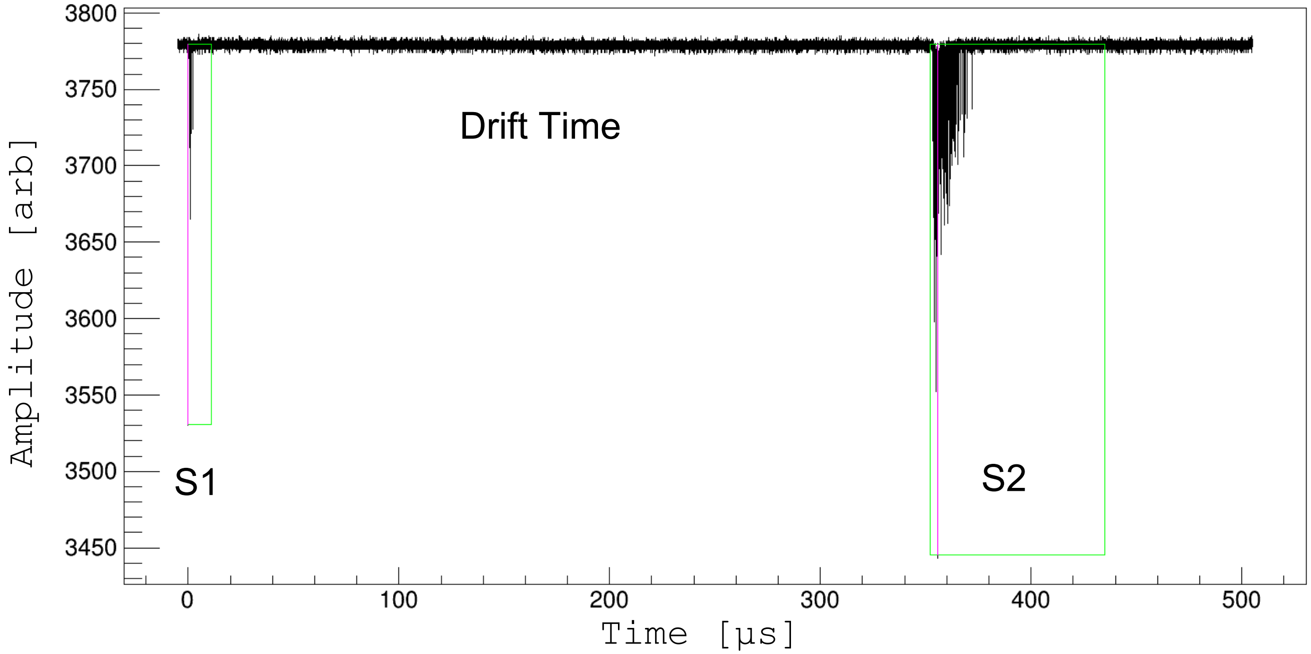
- Ionization produces free electrons
- Electric field pulls electrons to gas gap at top
- Electrons in gas release secondary light signal
- Time projection: time between signals indicates position of original event on vertical axis

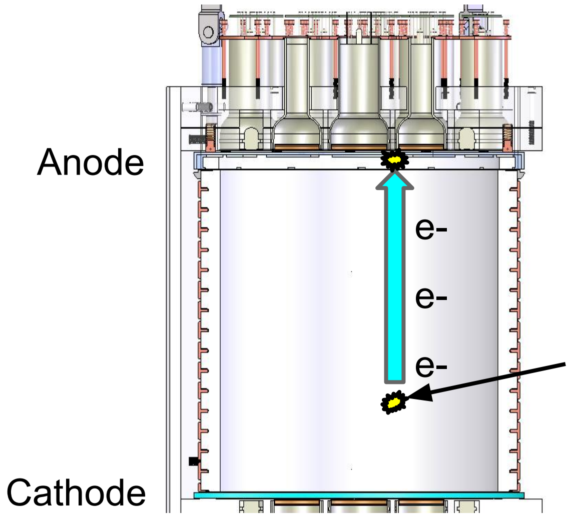
Anode



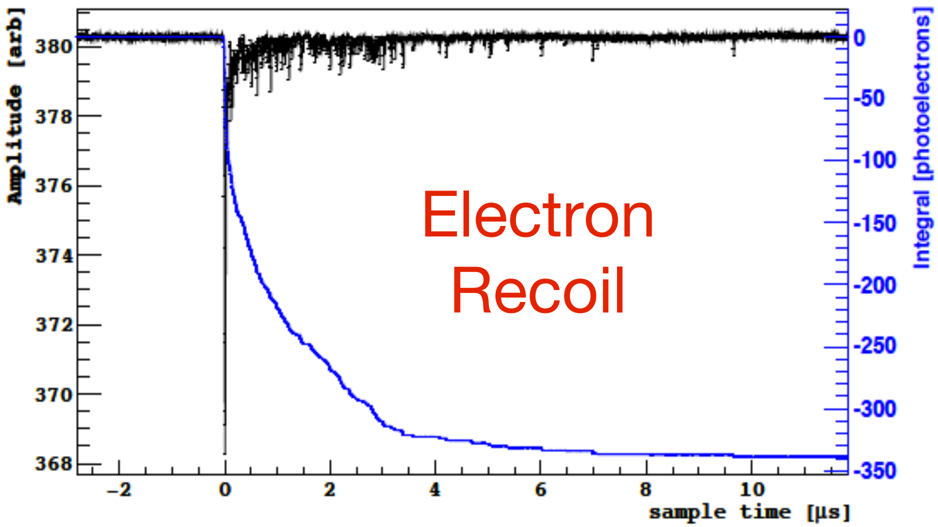
Cathode

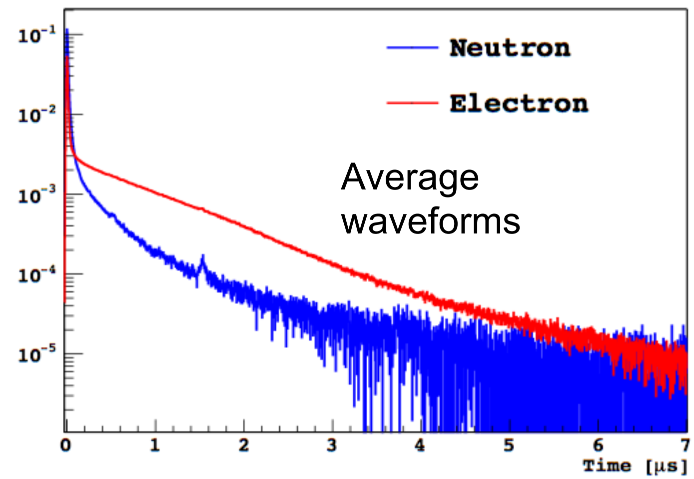
Signals: Ionization

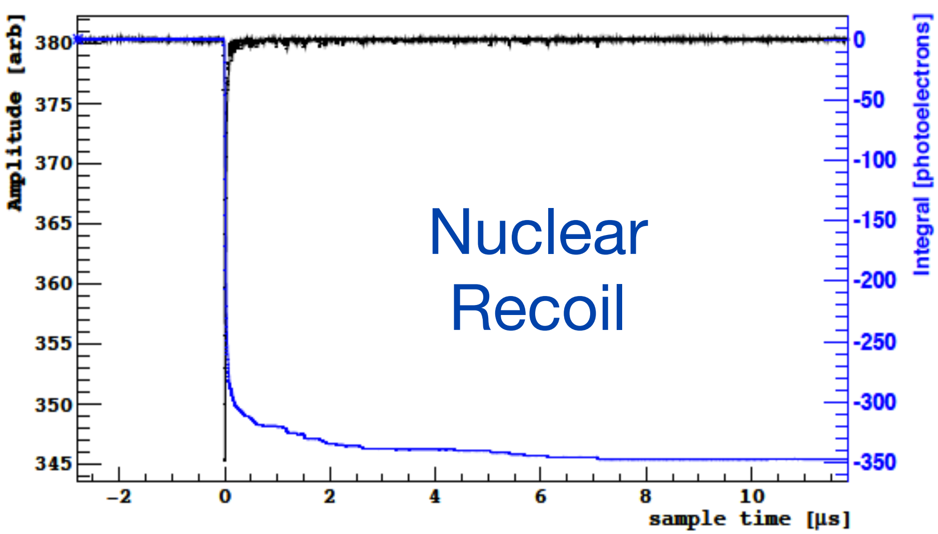




Background Rejection: Pulse Shape Discrimination







WIMPs (and neutrons) cause nuclear recoils

Beta/gamma backgrounds cause electron recoils

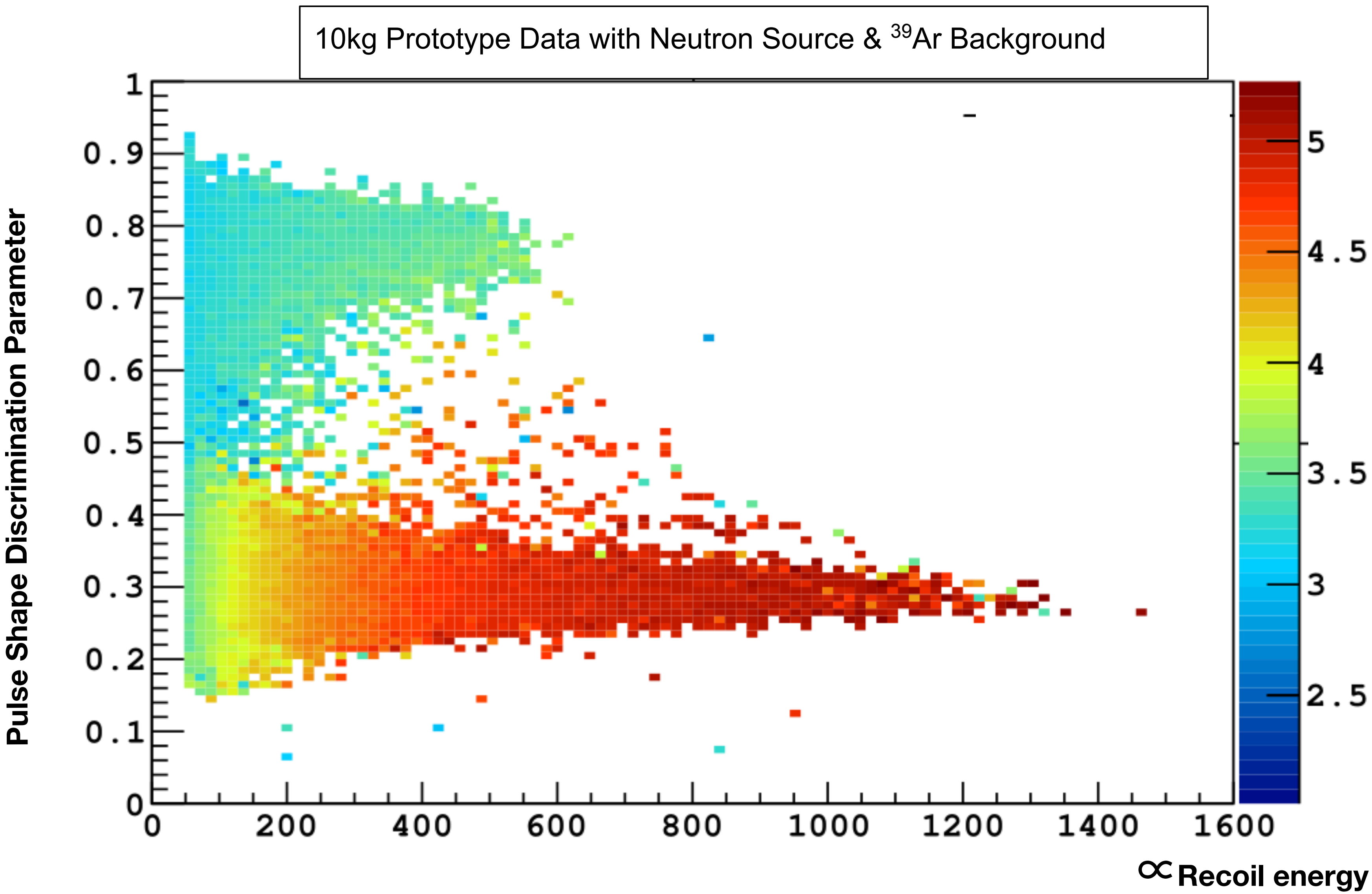
Different recoils preferentially excite different states of argon, with different decay times

Replaces S2/S1 or Light/Charge

10^6 - 10^8 power

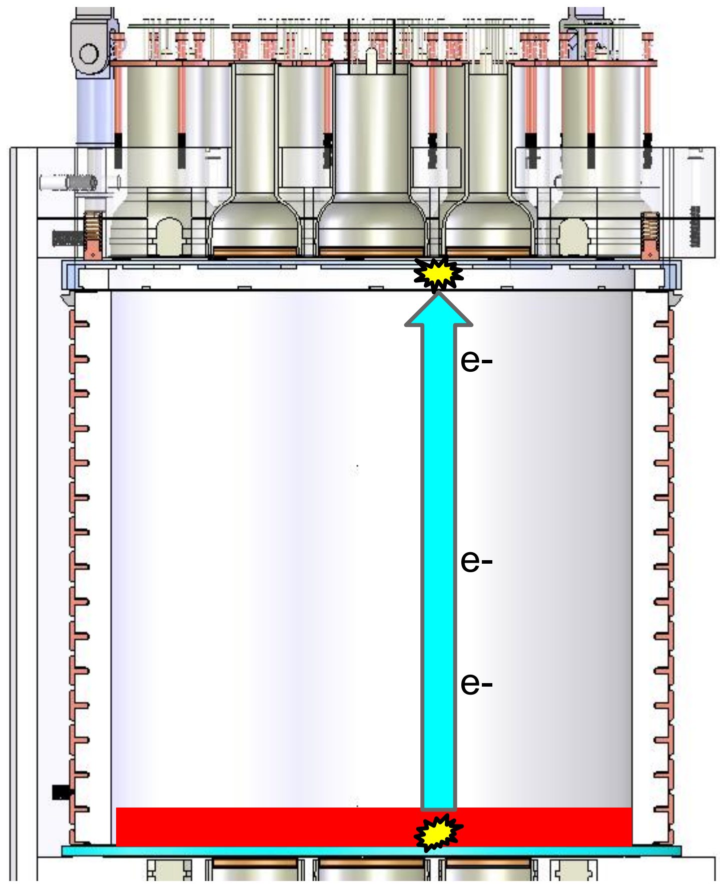
Thanks: M. Wada

Background Rejection: Pulse Shape Discrimination



Time Projection Chamber Background Rejection

Exclude surface background



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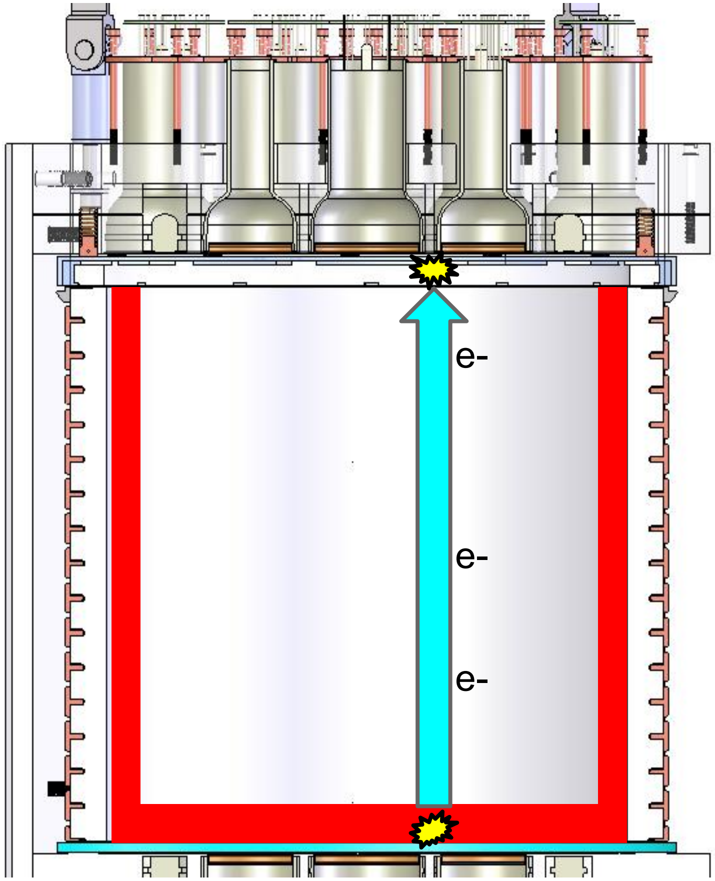
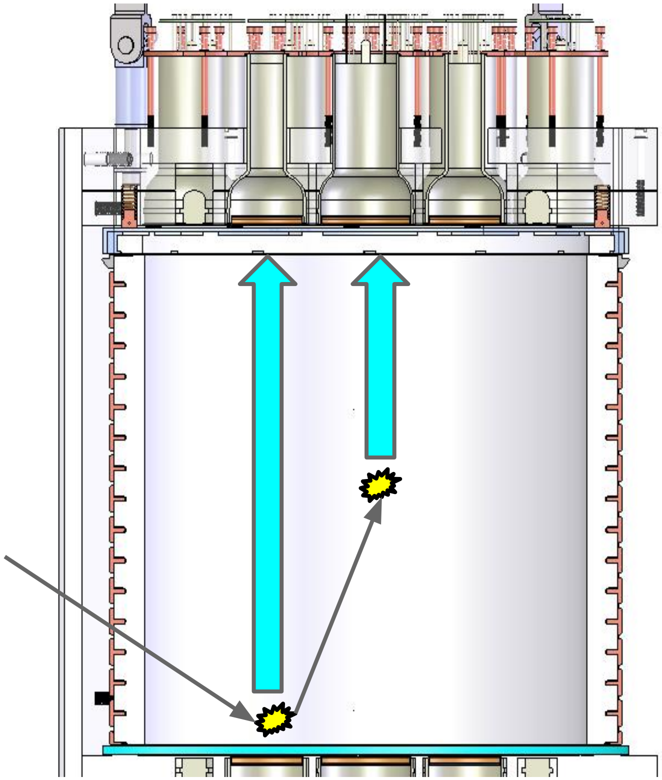


Time Projection Chamber Background Rejection

Exclude multiple scatters



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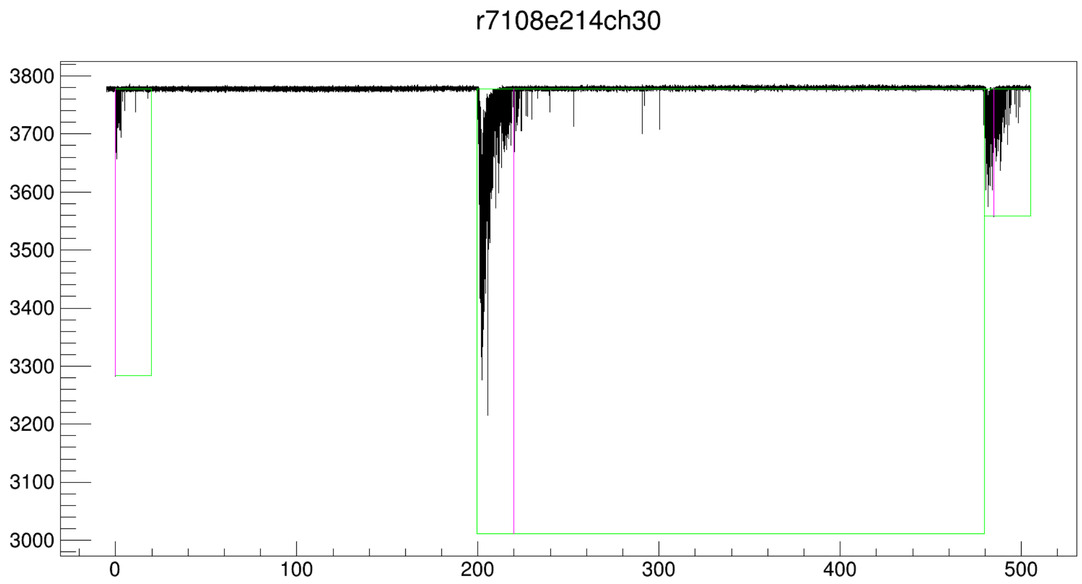
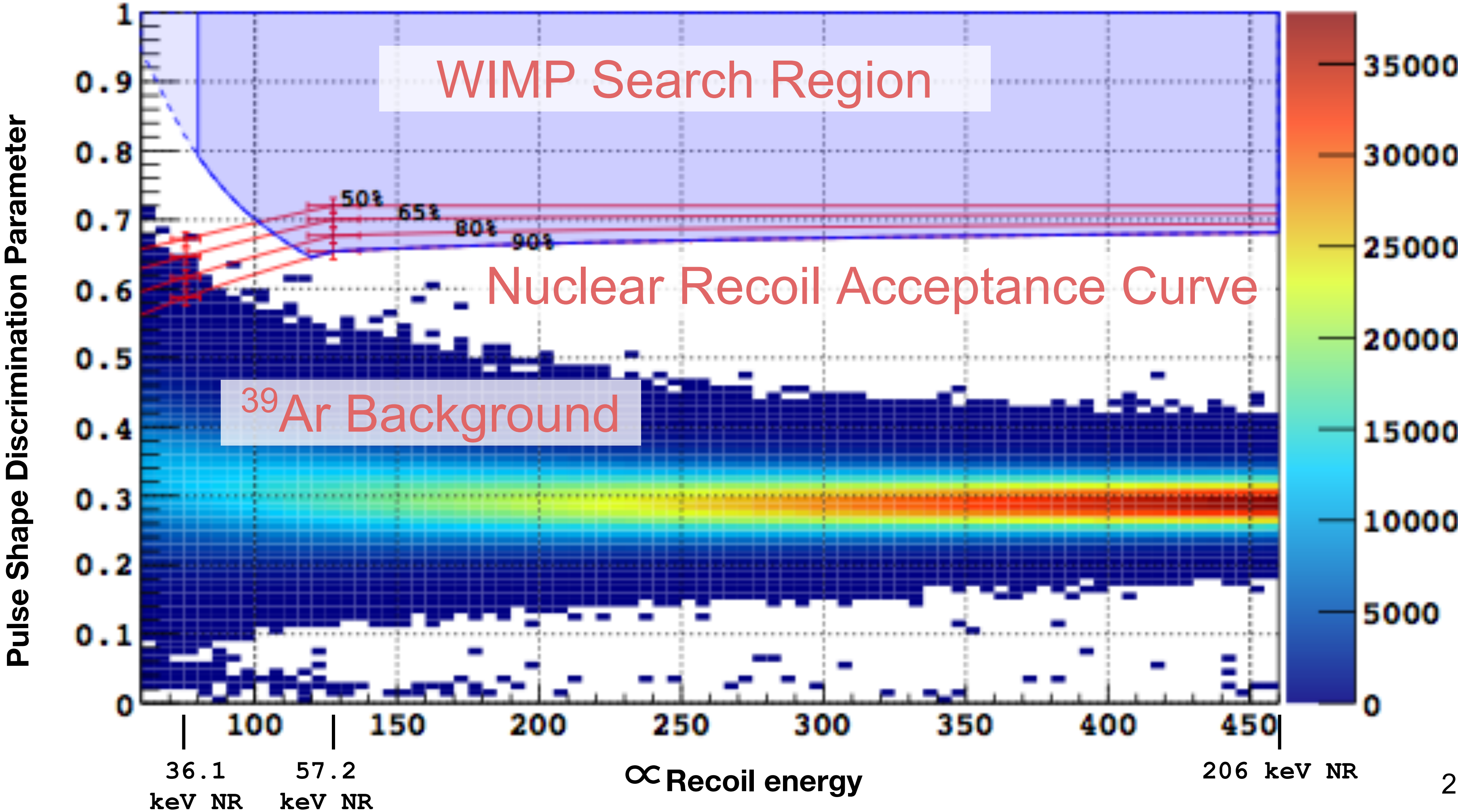


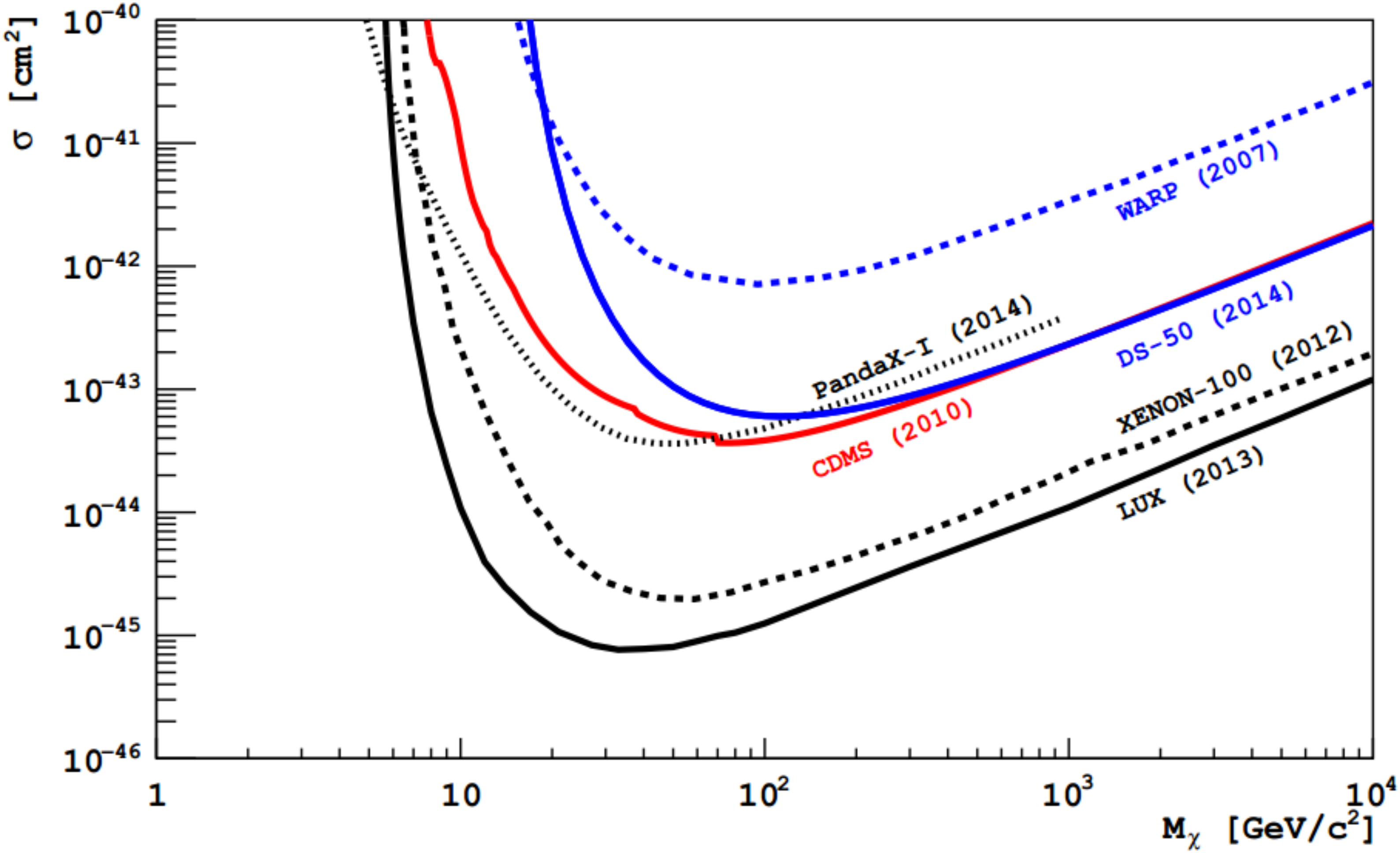
First Physics Result

Demonstrates even a ton-scale detector will be ^{39}Ar-background free (with underground argon)



First Physics Result

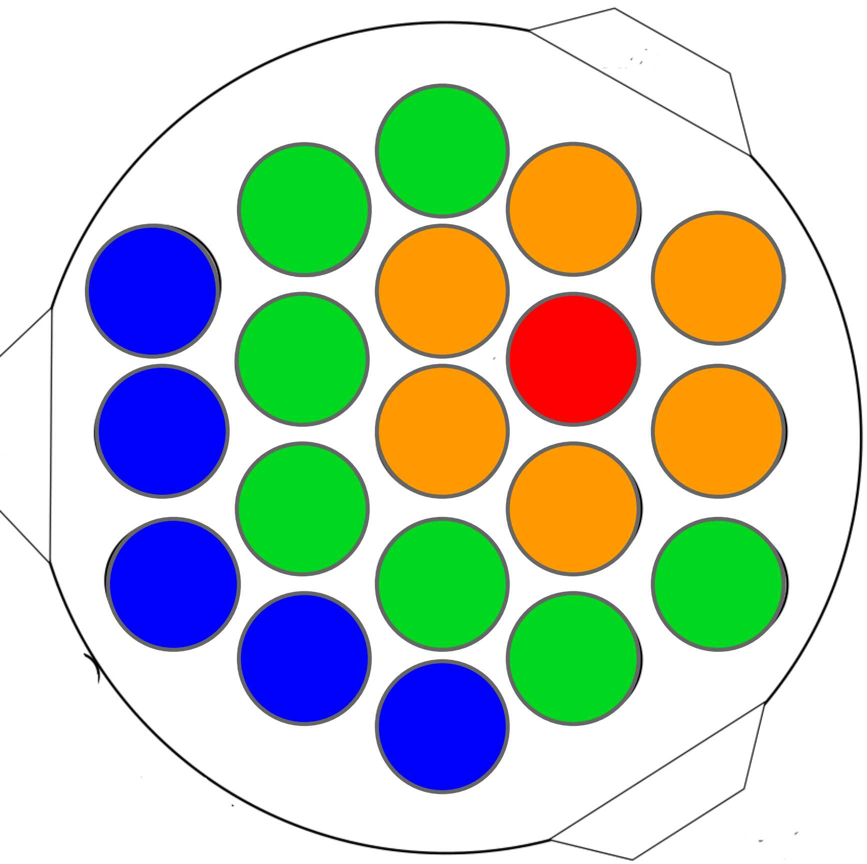
Most sensitive search with an argon target

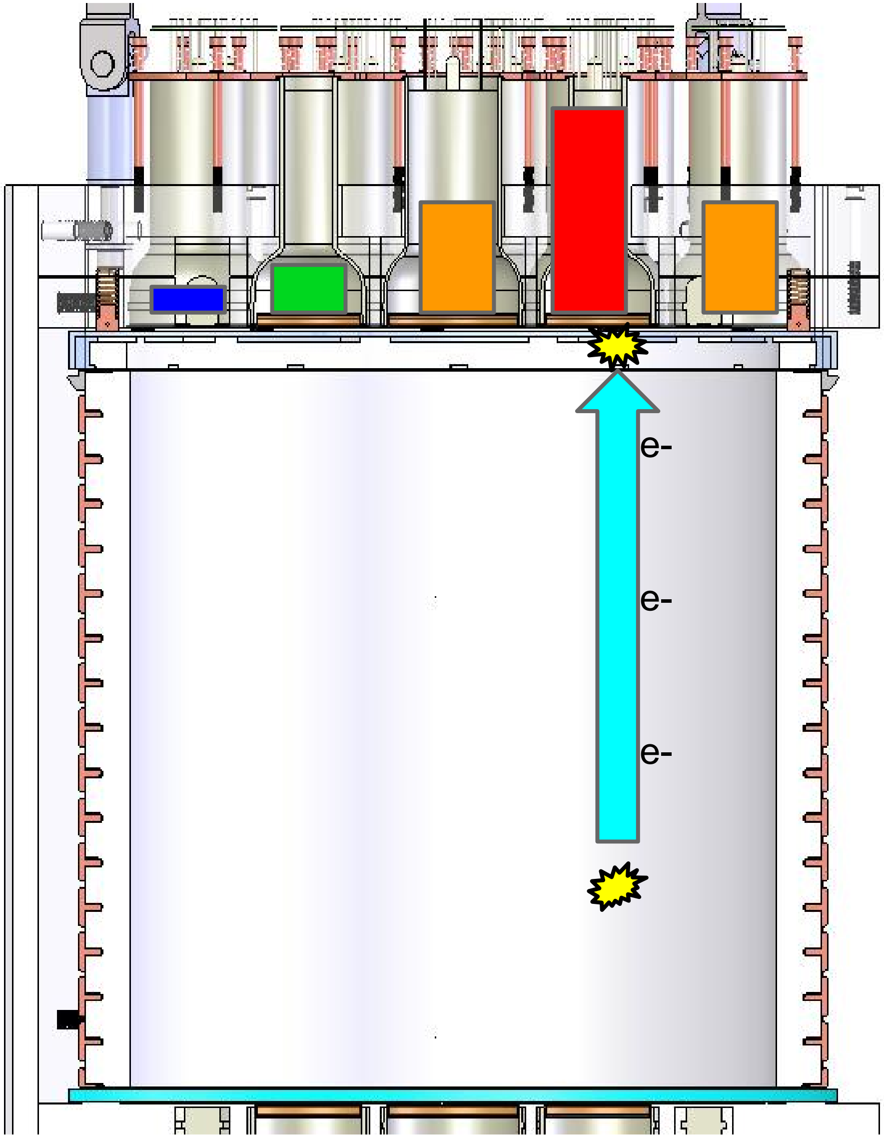


XY Reconstruction Introduction

- Time projection chamber gives Z of event
- Can we get XY?
  - Cut surface backgrounds
  - Understand detector features better
- Electron drift “S2” is very close to top PMTs
- Distribution of S2 light should be very correlated with position

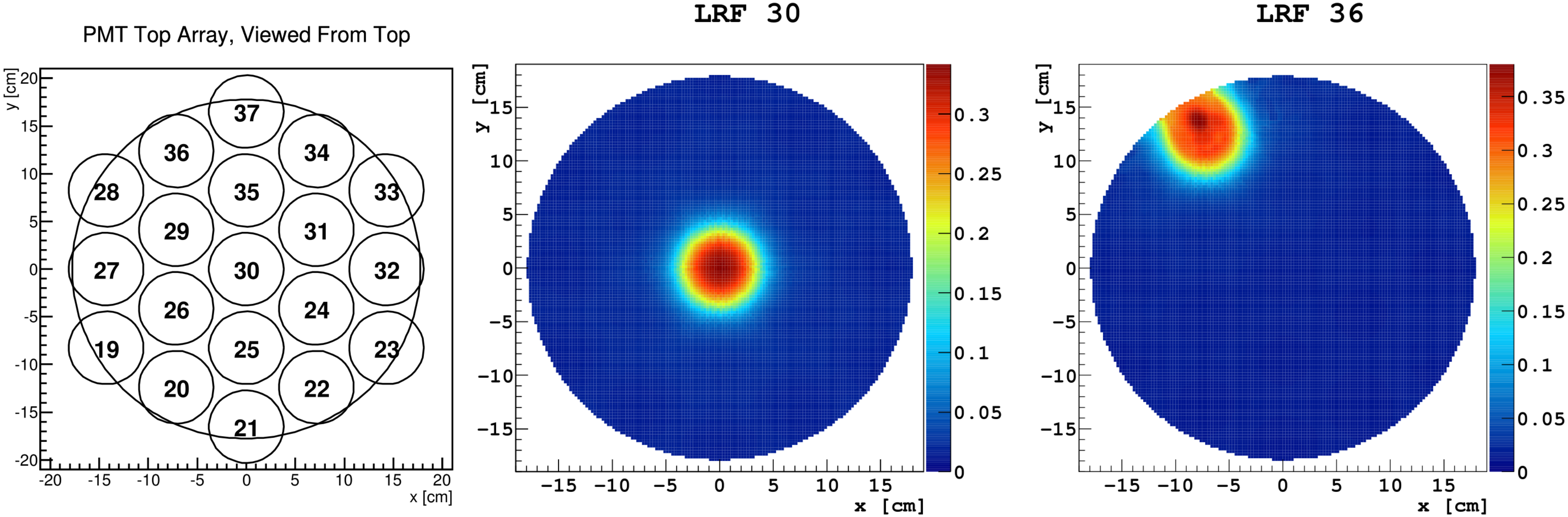
XY Reconstruction Introduction





Light Response Functions

- "Light Response Function": For a given PMT, how does light depend on event position?
- If we know the LRFs, we can find the position of any event by finding the position that matches the event's light distribution



Weighted Least Squares

Compare S2 measurement of event

Event 3285					
PMT	0	1	...	36	37
S2	48	65	..	1740	562

against a model of S2 *fraction* by location

At x = -7 cm, y = 12 cm					
PMT	0	1	...	36	37
S2	0.01	0.012	..	0.36	0.1

Does this event match this location?

Weighted Least Squares

S2 Measurement

Model (LRF)

Total S2

$$\chi^2 = \sum_i^{\mathrm{PMTs}} \frac{1}{\sigma_{M_i}^2} \left(M_i - L_i\,(x, y)\, M_{\mathrm{tot}} \right)^2$$

Variance of $M_i - L_i M_{\mathrm{tot}}$

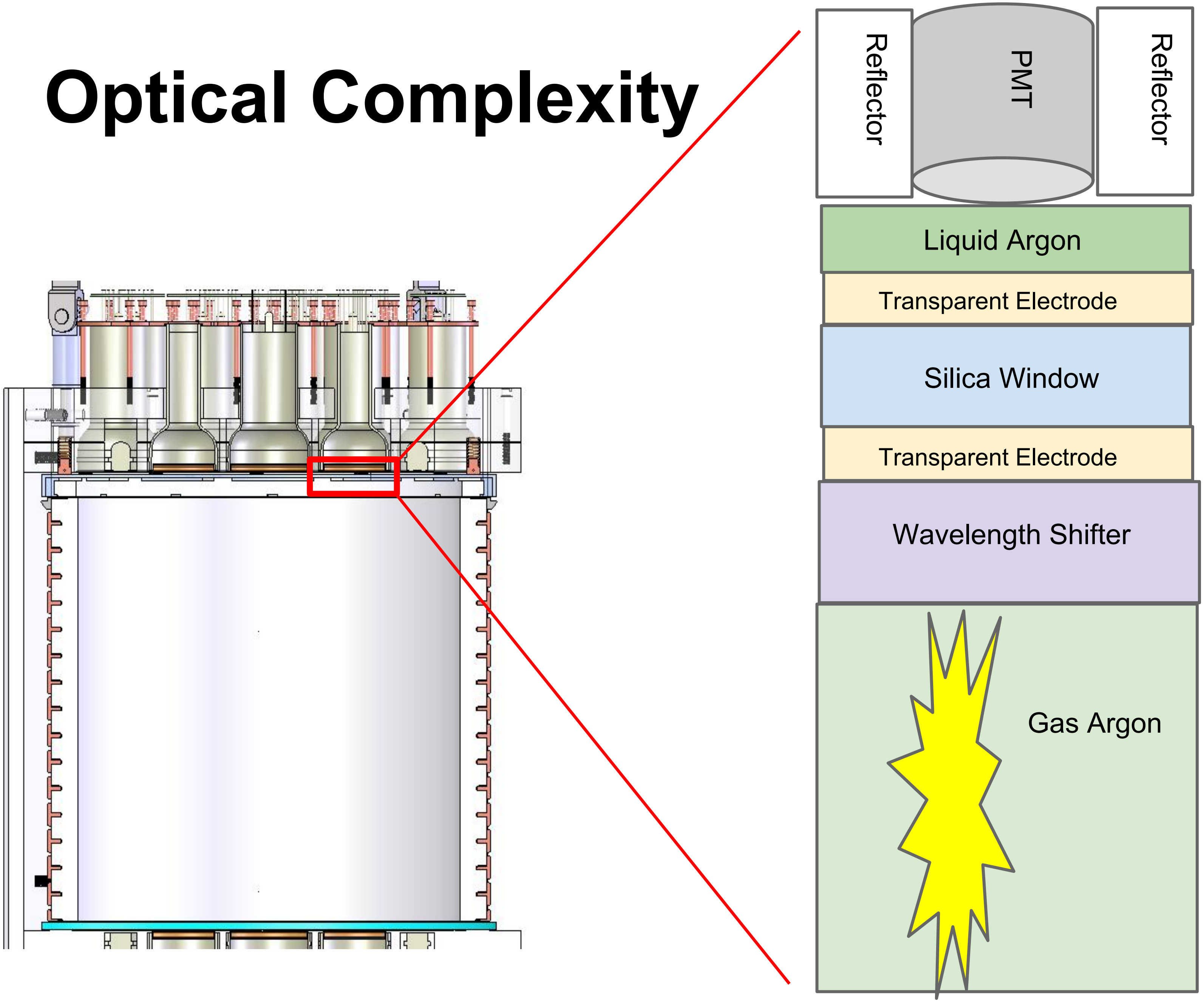
Estimated by M_i

Simulation-derived LRFs

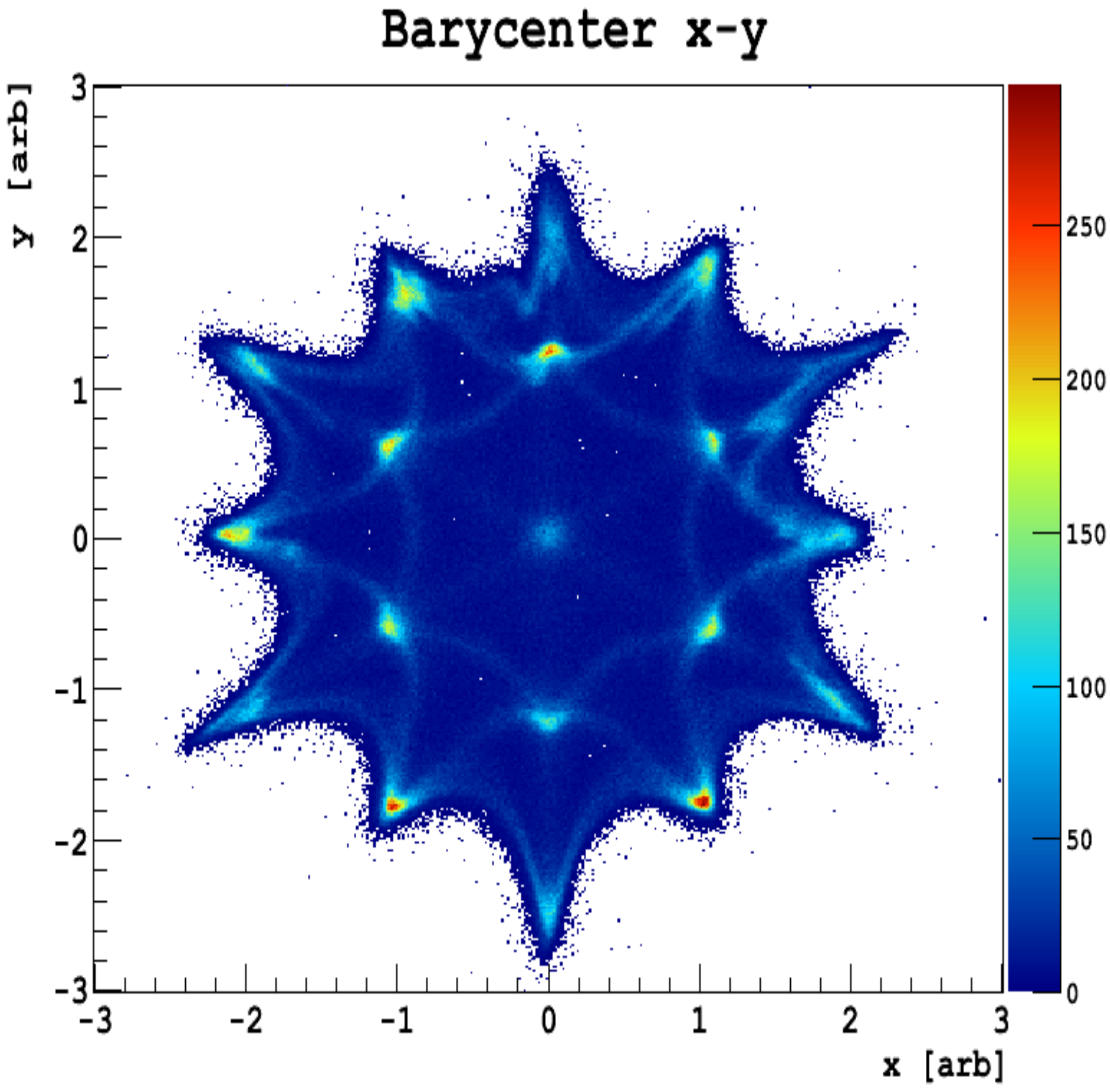
- Montecarlo simulation can produce LRFs, by simulating events at each position
- But, DS-50 optics are complex, hard to get right
  - Wavelength shifter (WLS) adds a step
  - WLS might not be uniform
  - Many optical layers between light and PMT

- We can’t stake everything on MC being right

Optical Complexity



Optical Complexity: Asymmetry

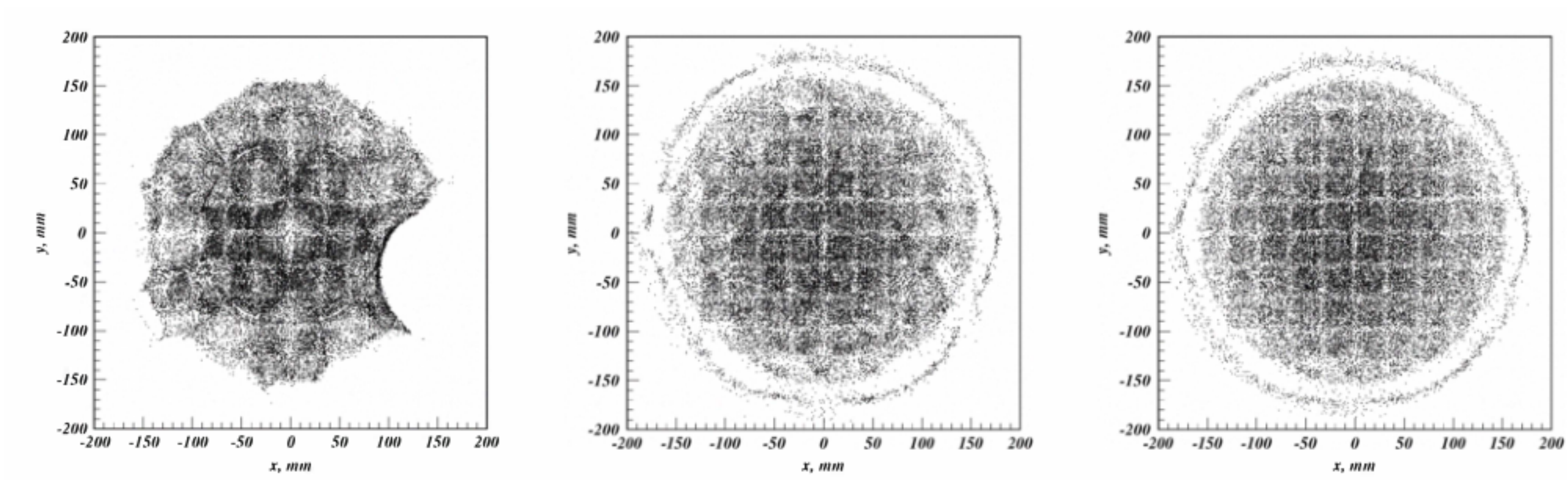


Data-derived LRFs

- We can build LRFs from data: just look at average light distribution of data events at each location
- ...assuming we already knew the position of the data events
- Rather circular!
- But we do know one thing about the data: argon-39 is uniformly distributed
- Can we use this?

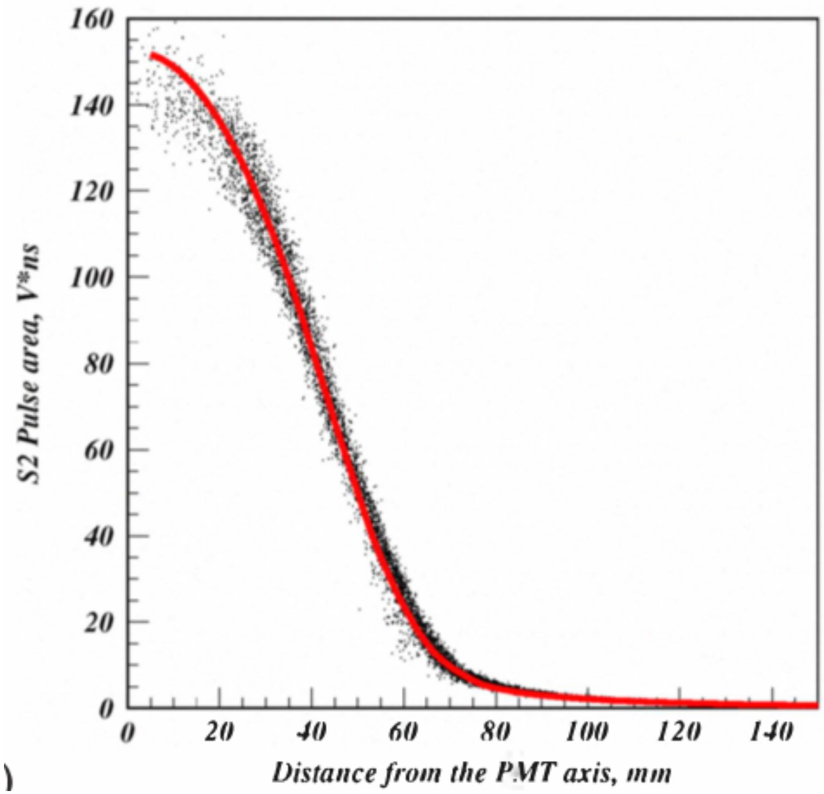
Prior Work: Solovov et al.

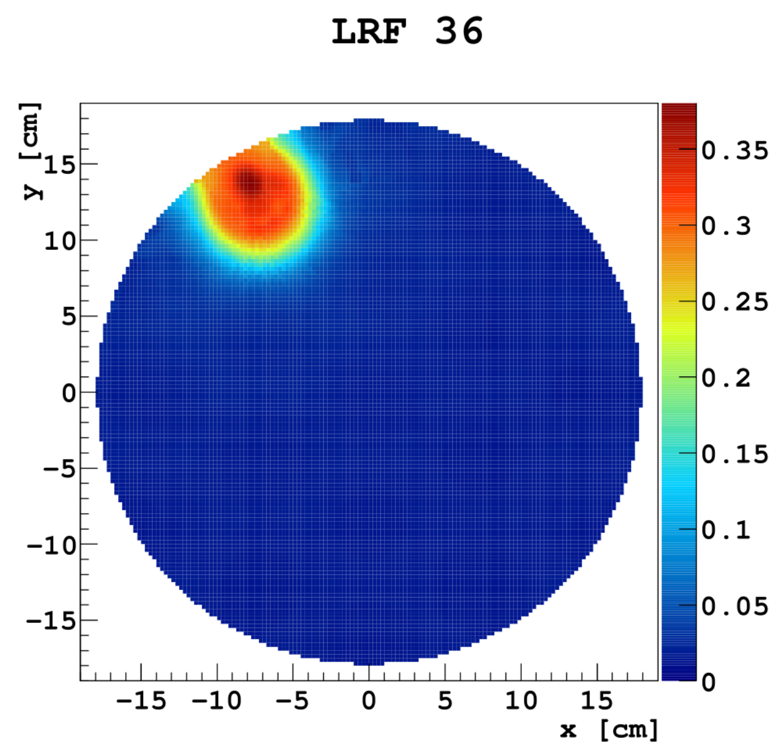
1. Start from simulated LRFs
2. Reconstruct data using LRFs
3. Make data LRFs from reconstructed data. Use strong assumption about data to constrain LRFs.
4. Repeat 2 & 3 until assumption is satisfied



Extending to 2D

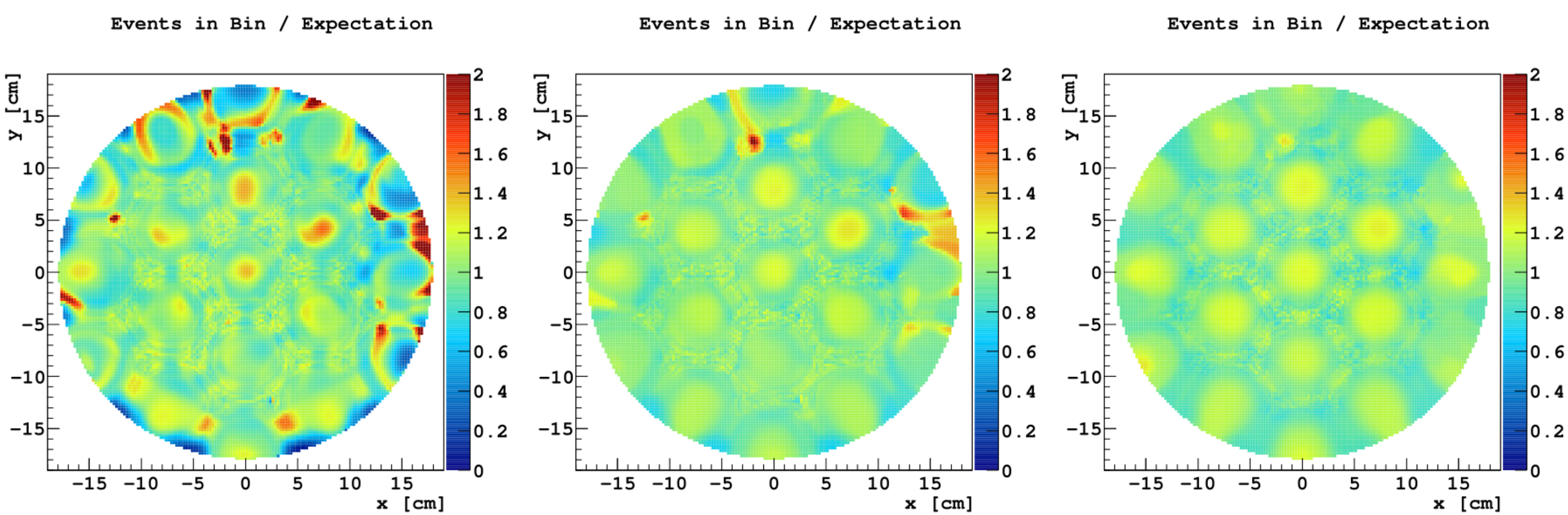
- Radial symmetry assumption of Solovov et al. does not hold in DS-50
- Have to make LRFs 2D functions





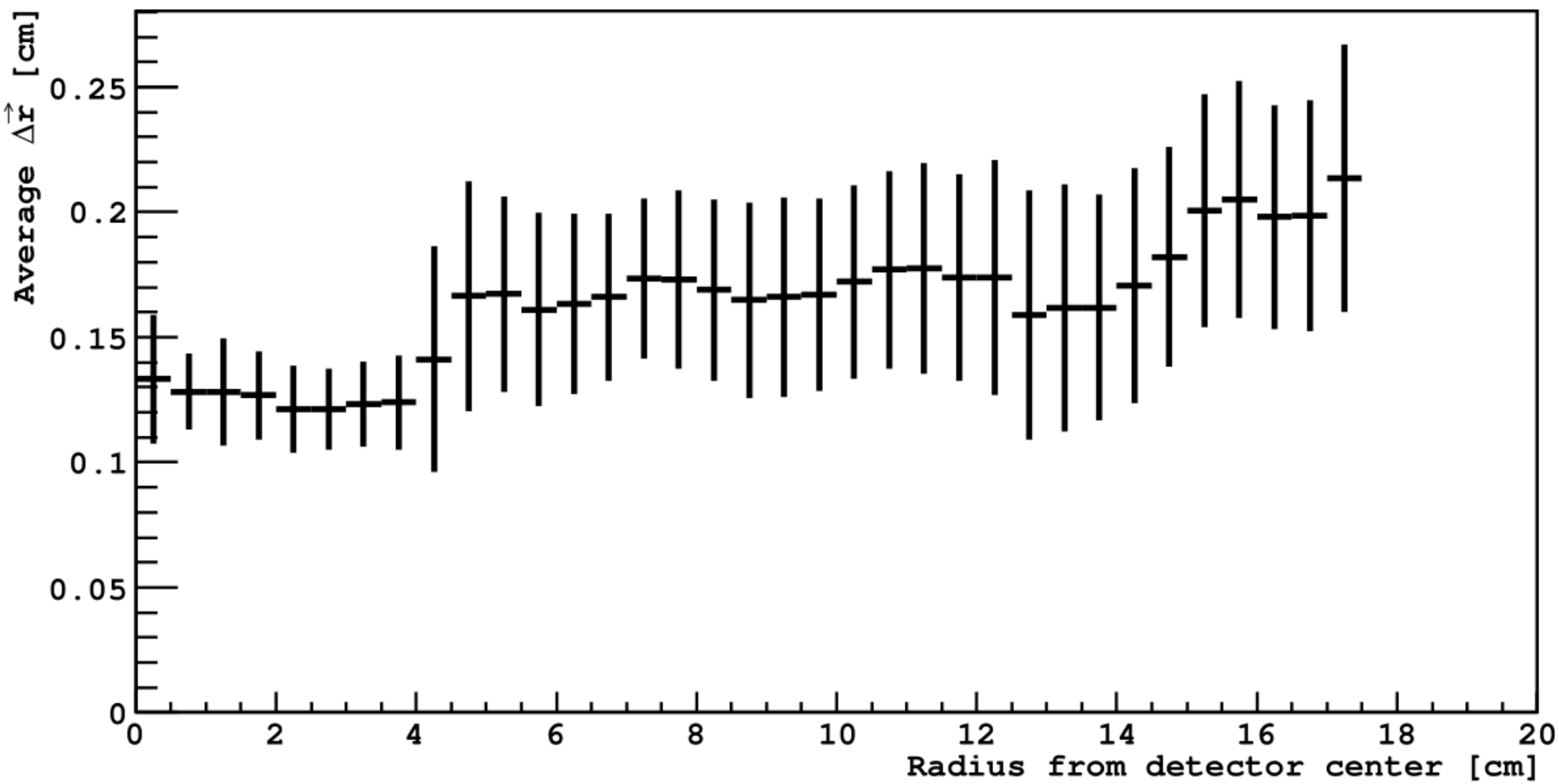
Uniformity Pressure

- Assumption still required, or solution-finding will diverge
- Uniformity of ^{39}Ar is a weaker assumption than symmetry, produces only partial convergence



Results

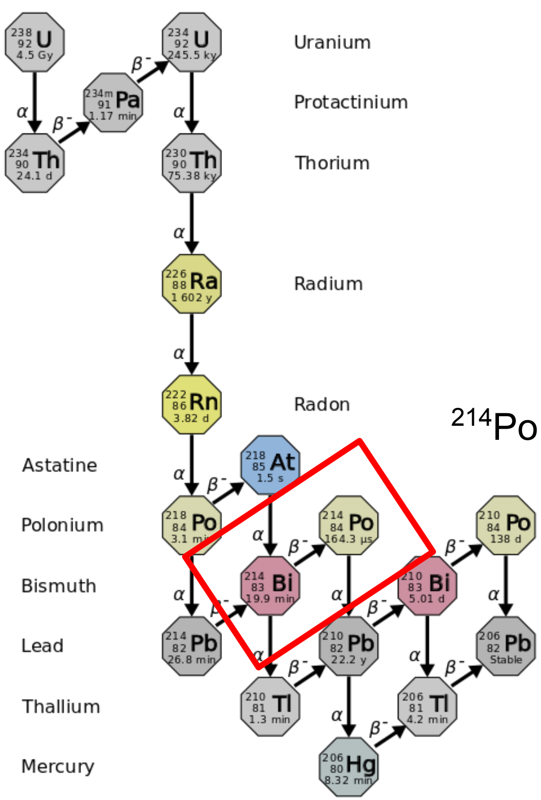
Montecarlo testing best seen performance:



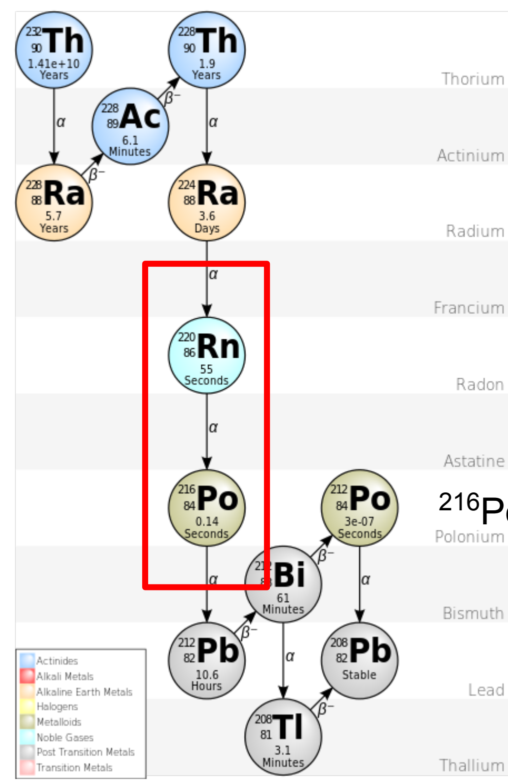
...but some locations with ~8mm error

Results: Coincident Decays

“Bi-Po” events in data: two decays at same position. Similarly, RnPos.



^{214}Po 164μs h.l.



^{216}Po 0.14s h.l.

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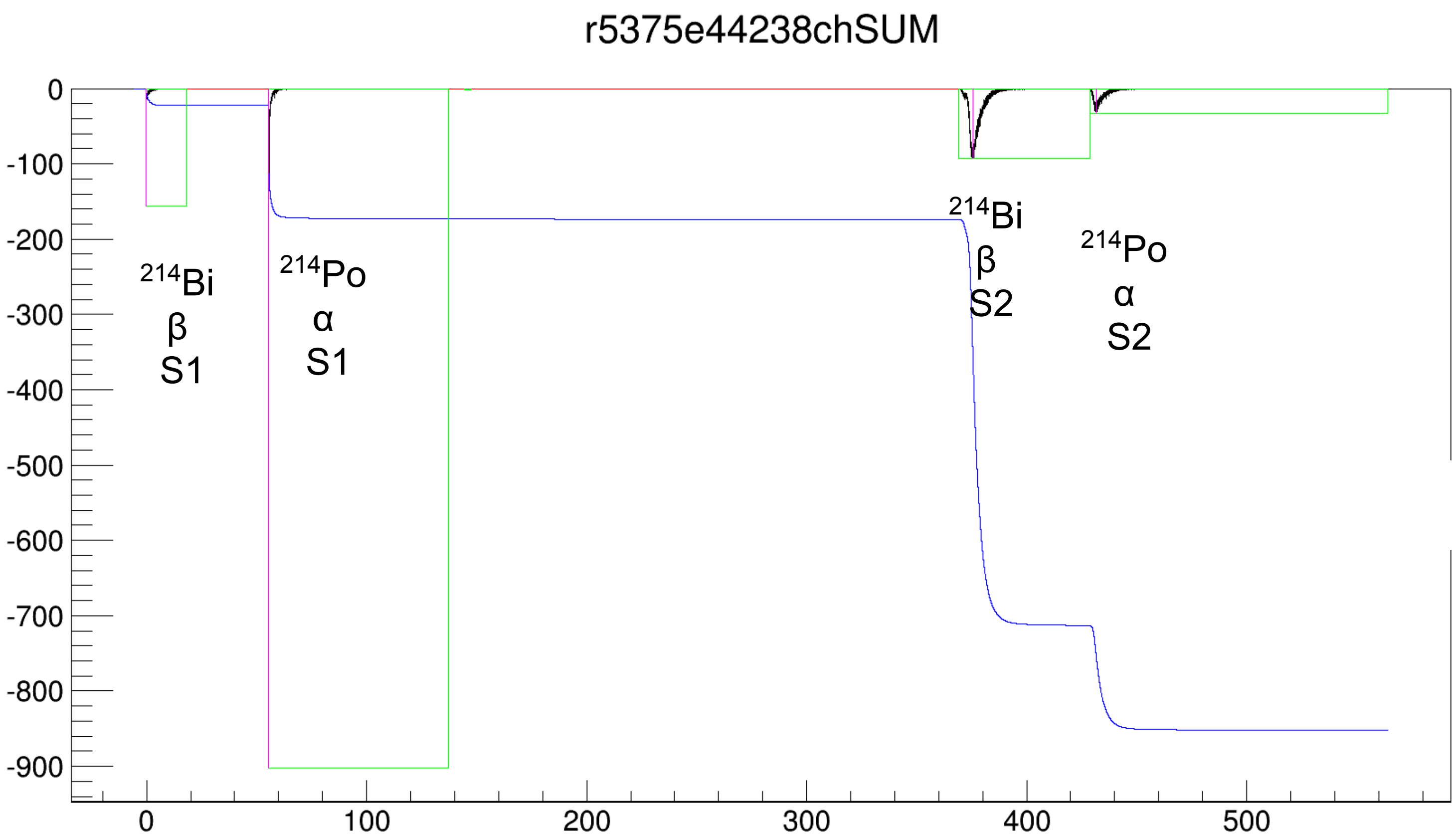
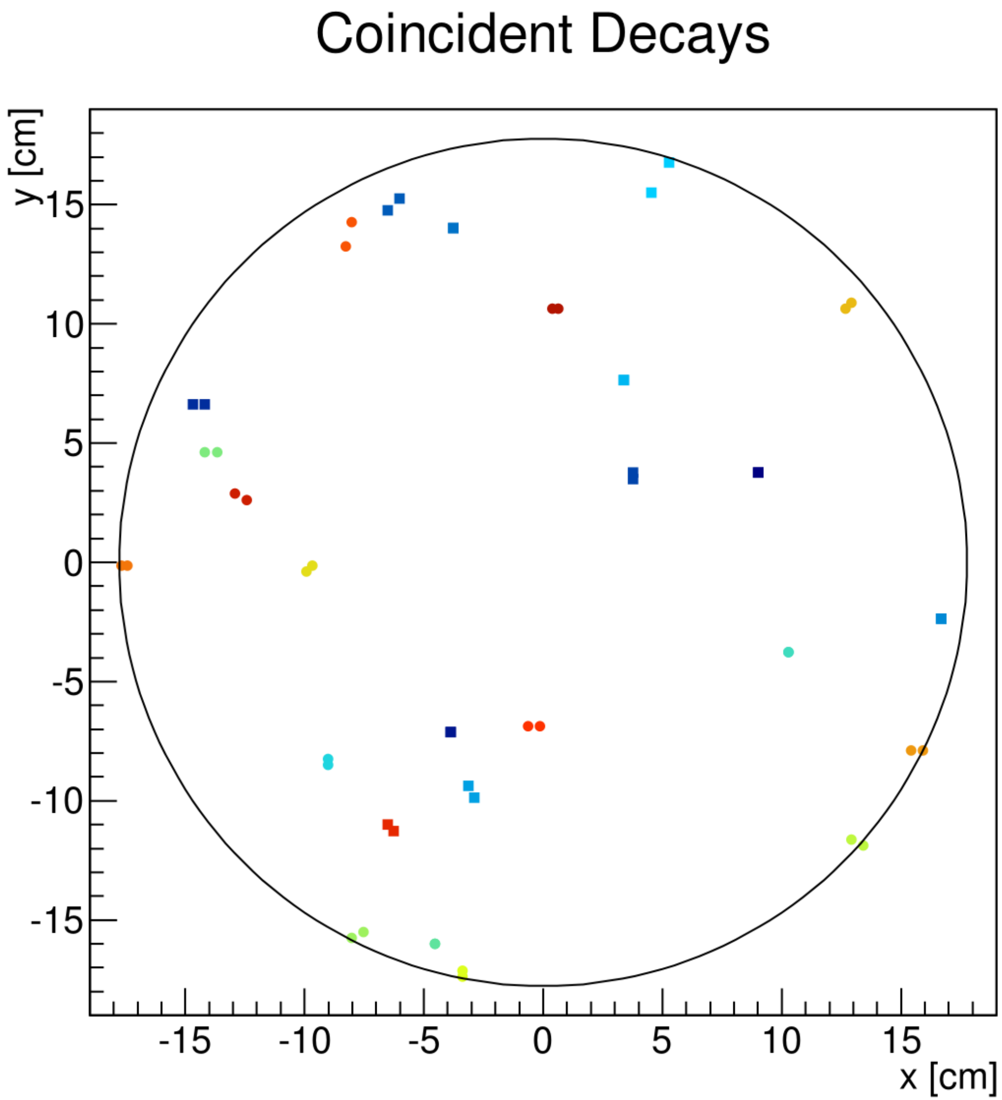
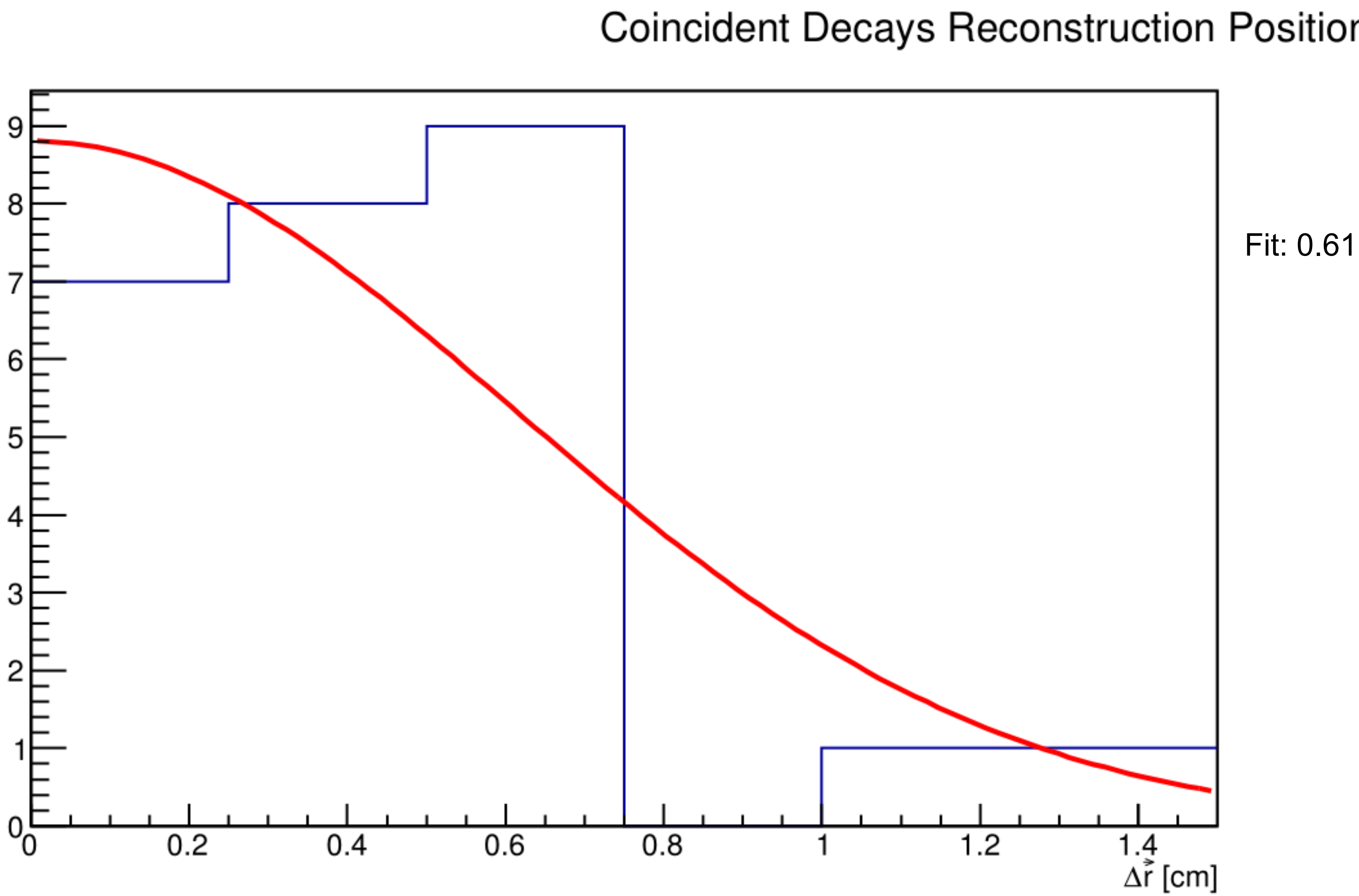


Coincident Decays



Coincident Decays



Fit: 0.61 ± 0.09 cm

Surface background cut

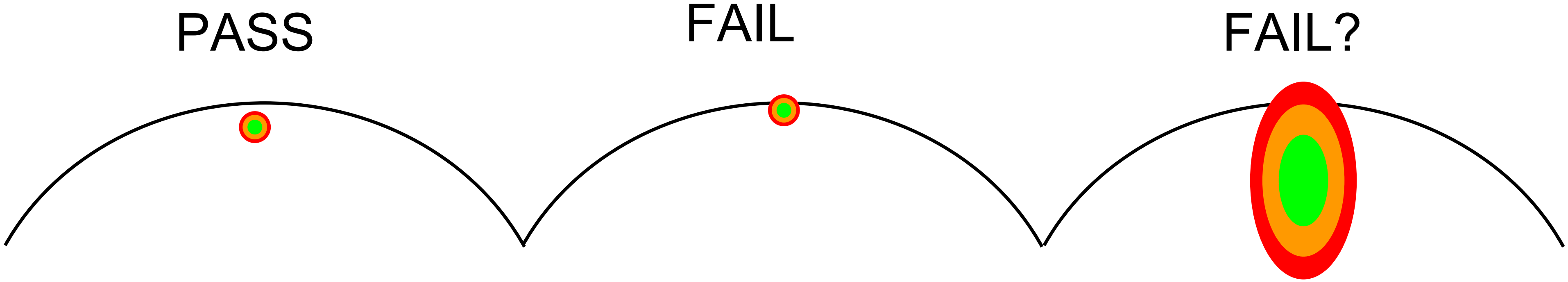
Surface backgrounds don’t travel far

An event definitely 5 mm from the edge should PASS

An event that is probably right at the edge should FAIL

An event fit best at 5 cm from the edge, but fits OK right at the edge, should probably FAIL

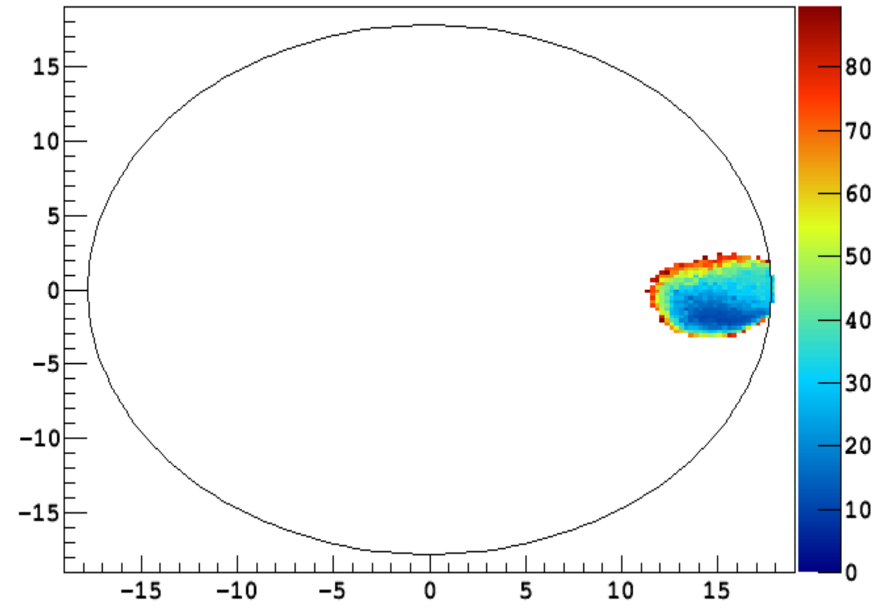
NOT cutting a specific radius



Procedure

For each event, calculate χ^2 of every possible position (on grid)

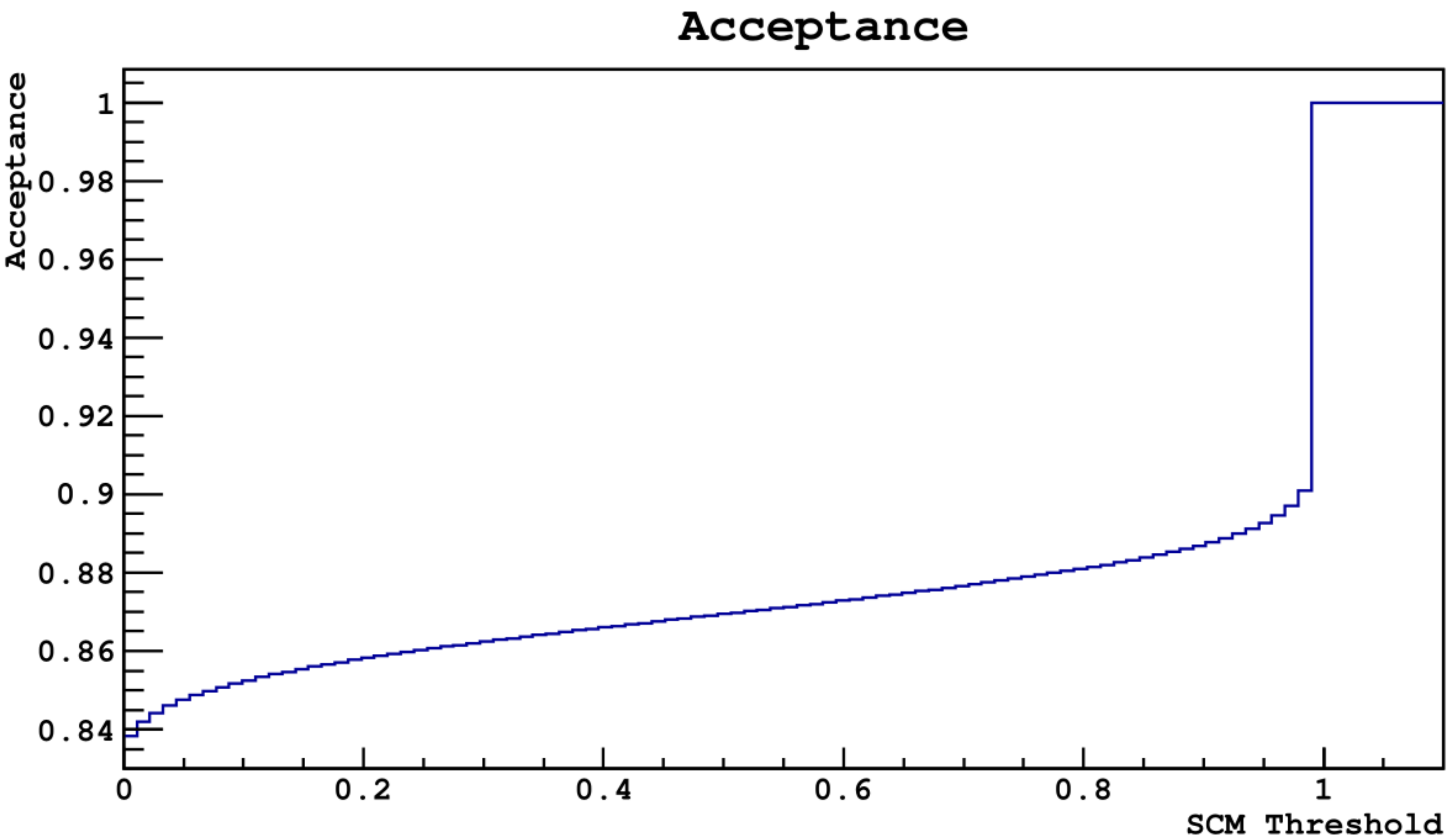
Find best χ^2 overall, and best in edge



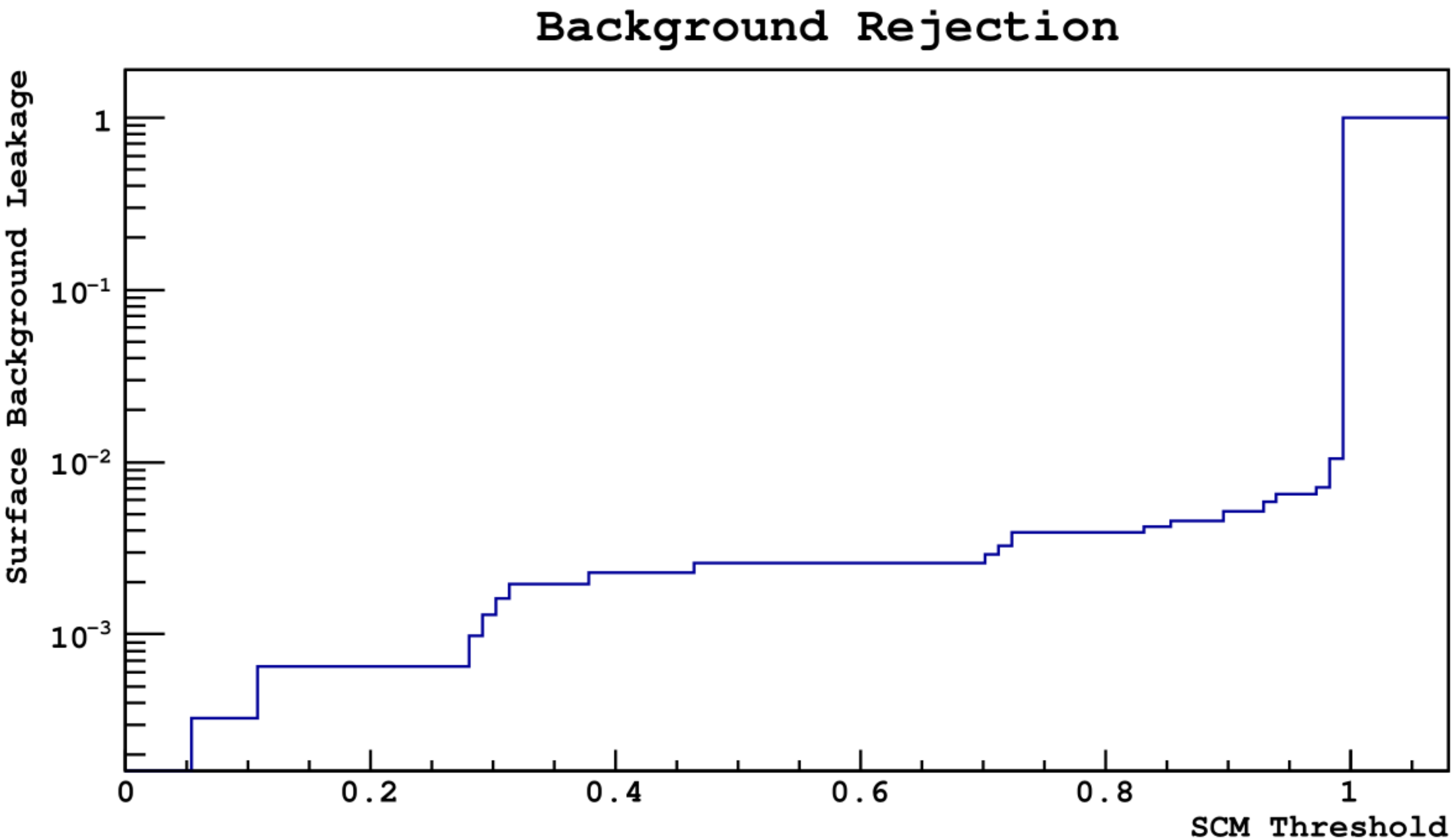
Surface Cut Metric = $P(\chi^2_{edge} - \chi^2_{best})$

Set threshold in (0,1)

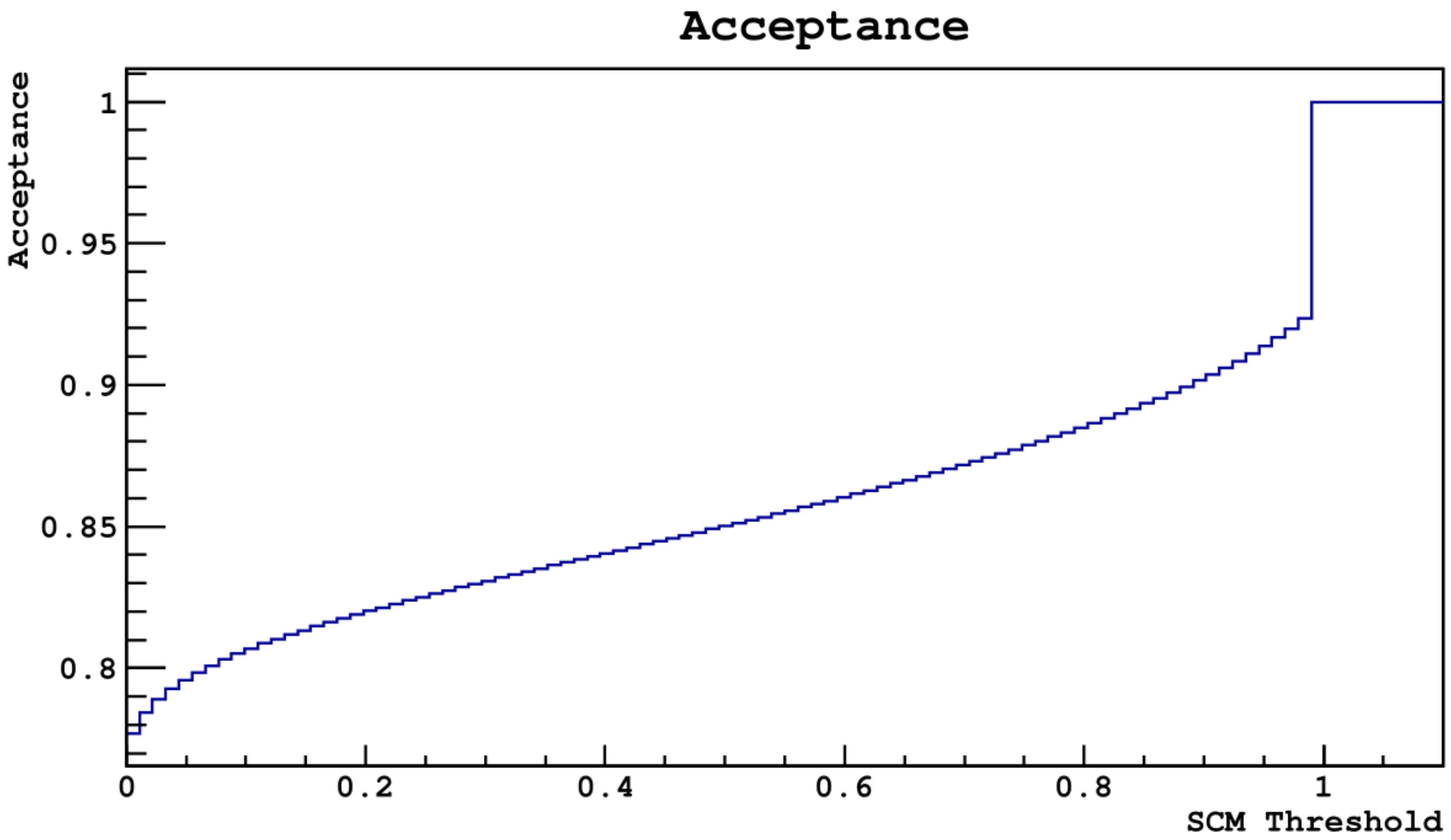
Surface Cut MC Acceptance



Surface Cut MC Background Rejection



Surface Cut Data Acceptance



Surface Cut Data Background Rejection: Method

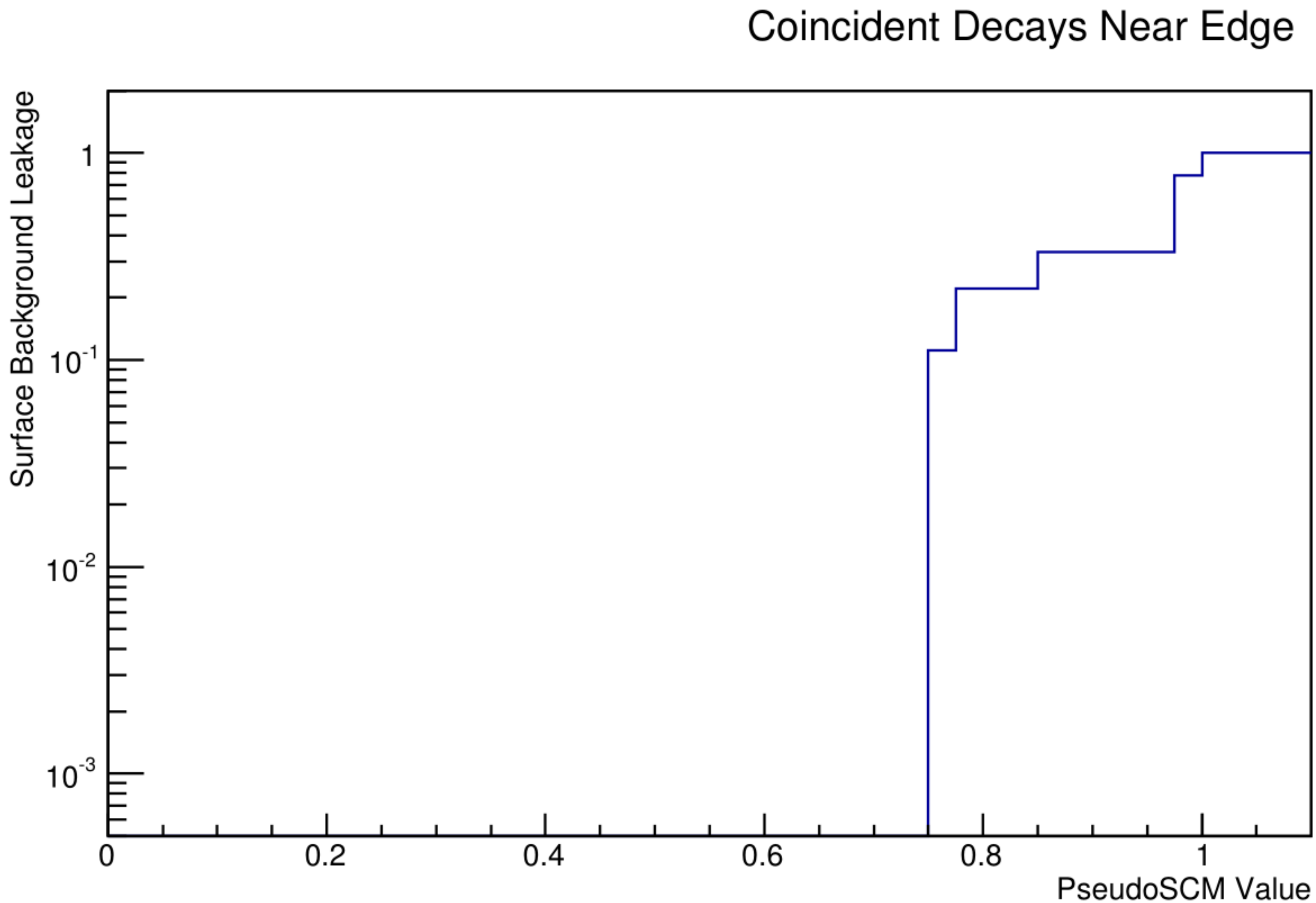
No events known for sure to be at the edge!

...but coincident decays can be close to the edge.

Pretend one decay is an “edge” position, and evaluate the other decay with the Surface Cut Metric.

Does it fit well at the “edge”?

Surface Cut Data
"Background Rejection"



Repairing Flaws

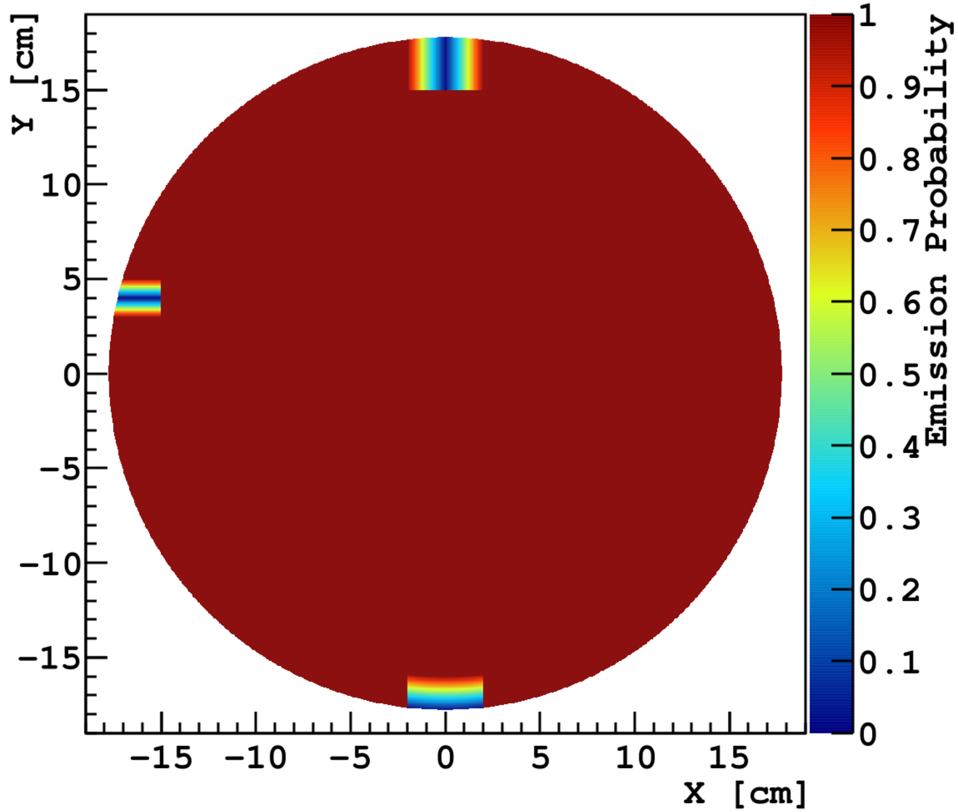
Testing the assumption that the iterative process can “repair” differences between the simulation and data

Start with normal simulated LRFs, then iterate using “flawed” simulated events.

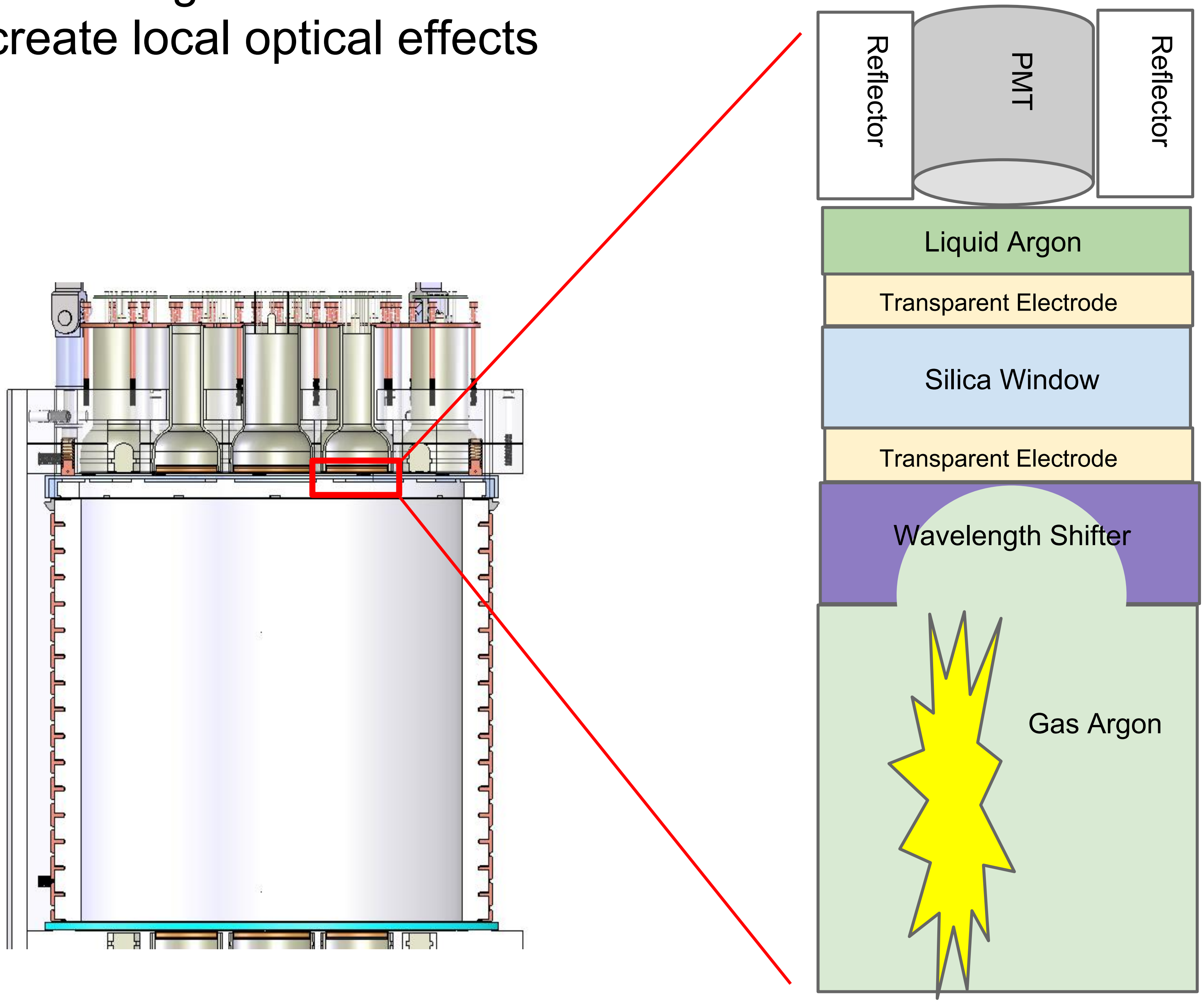
“Flawed” Simulation

Reduce wavelength shifting efficiency in spots

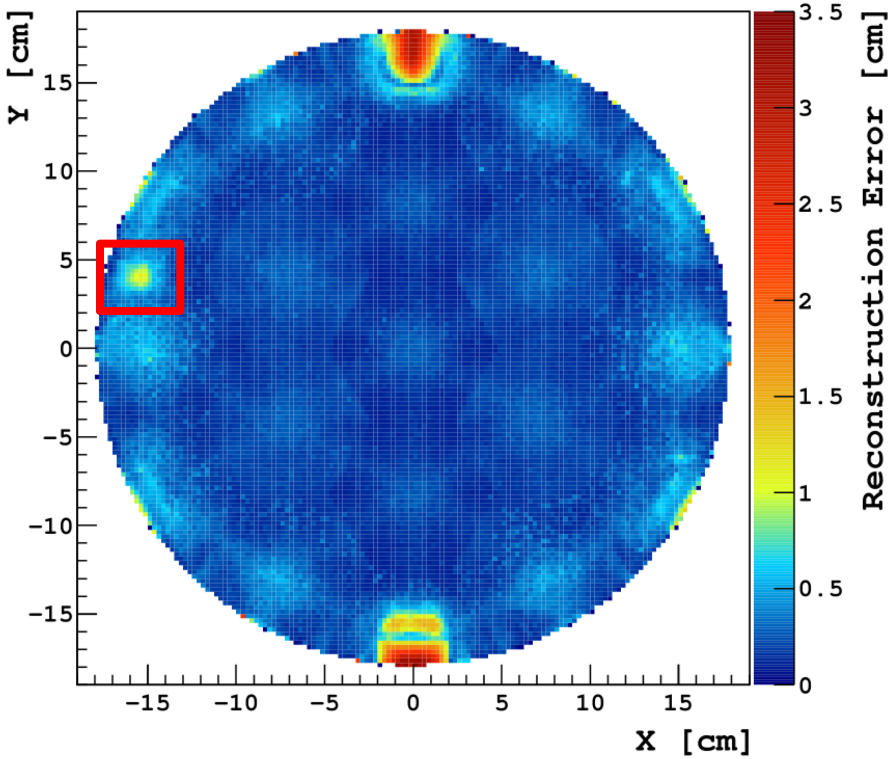
Mimics possibility wavelength shifter is damaged

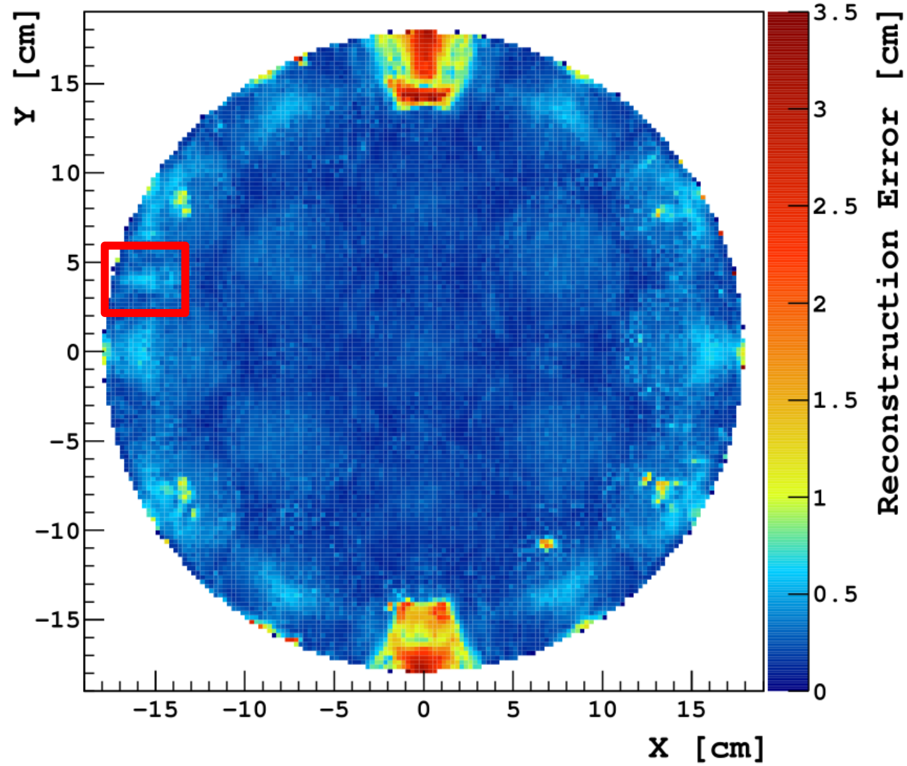


Wavelength shifter defects create local optical effects



Iteration Fixes Some Flaws





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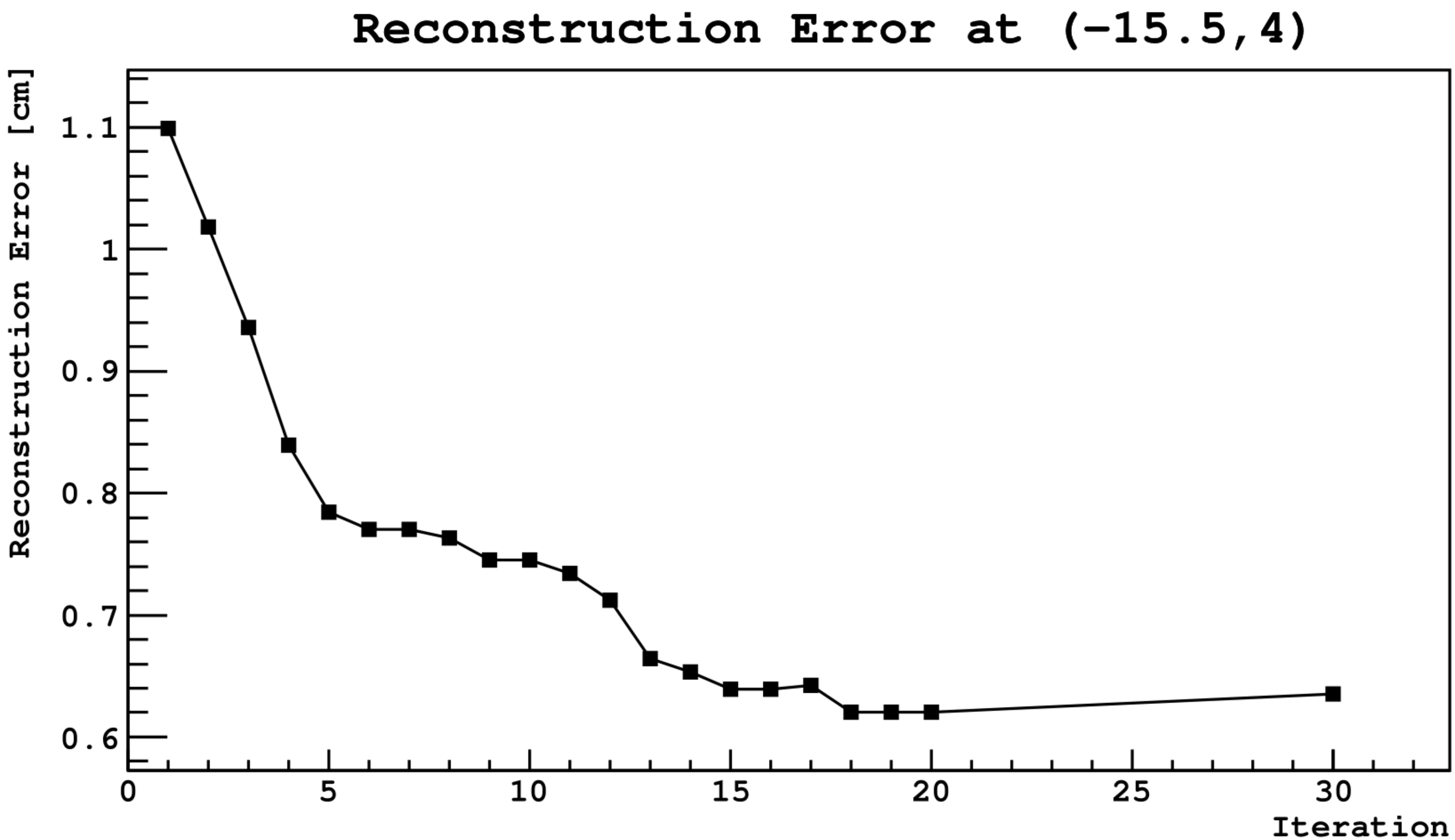
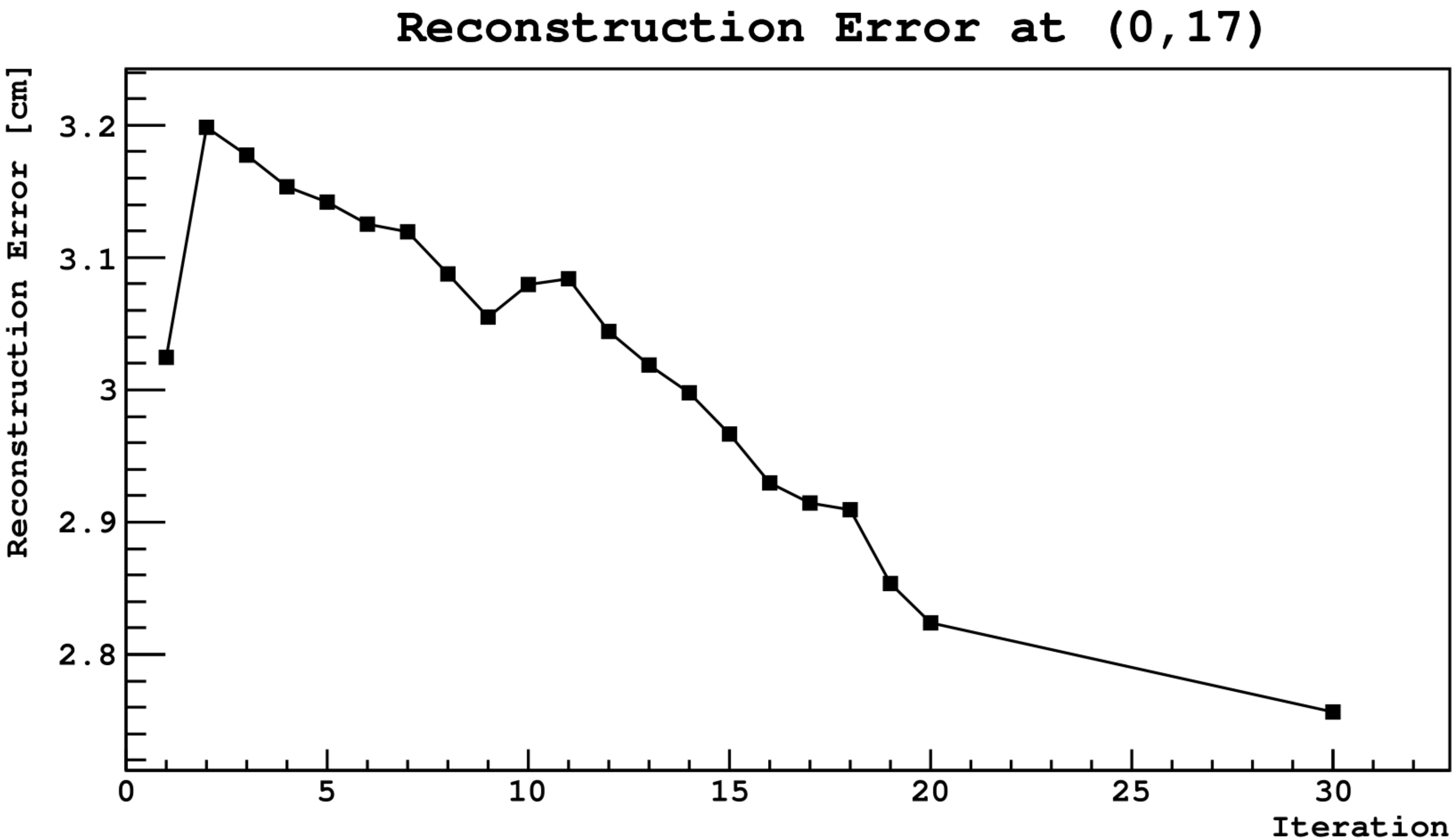
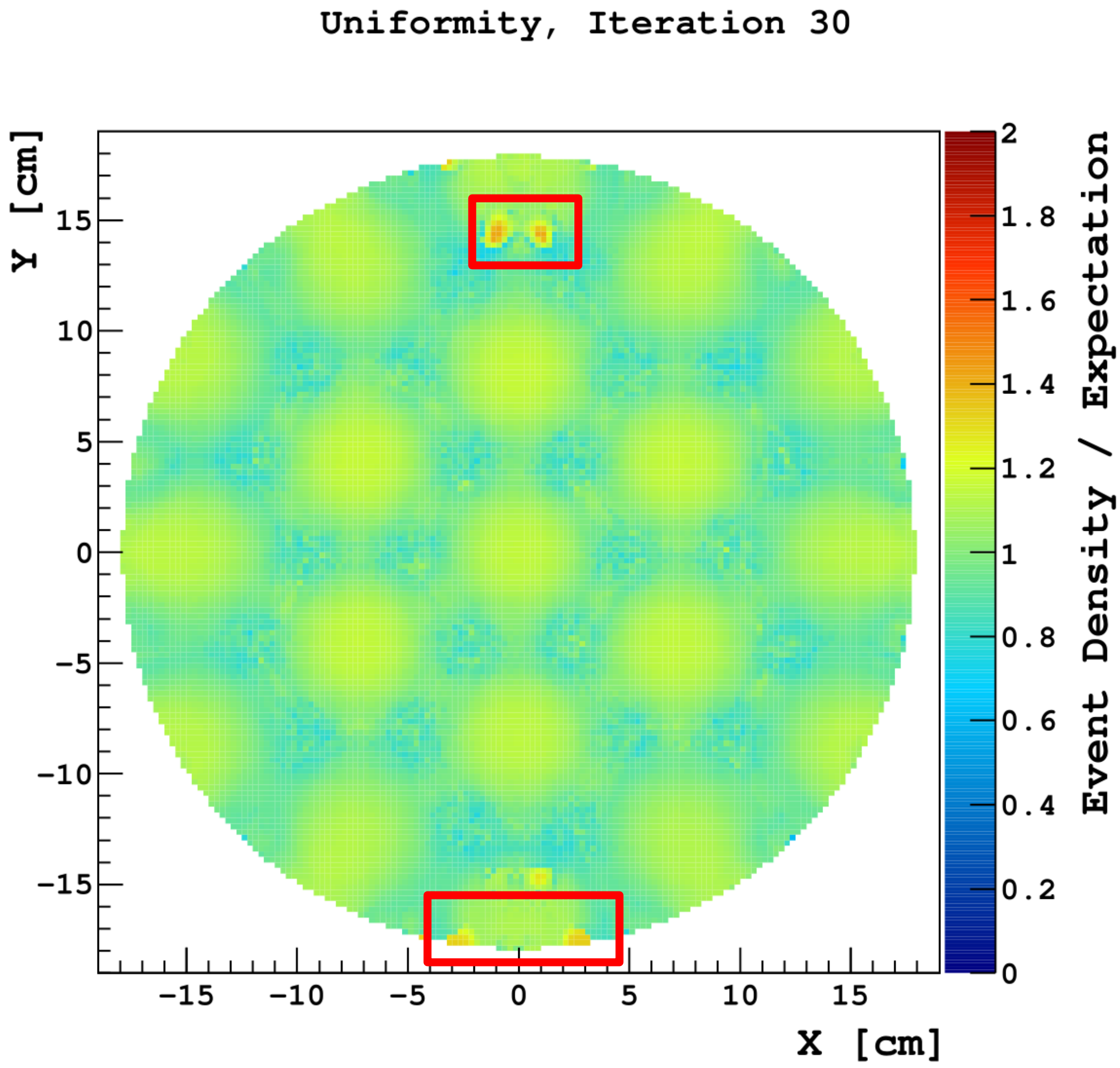


...But Not All Are Fixed Quickly



Uniformity Warns of Unfixed Flaws



Conclusions

The DarkSide experiment has performed a background free WIMP search and is preparing for a more sensitive search.

Iterated LRFs can precisely determine position, even using weaker constraints such as uniformity.

Argon-39 background events are a boon in the early stages of detector development.

Thank you!

Thanks: Peter Meyers, Masayuki Wada, Andrew Watson, Chris Stanford
and all my colleagues, collaborators, and co-conspirators here at Princeton.

BACKUP

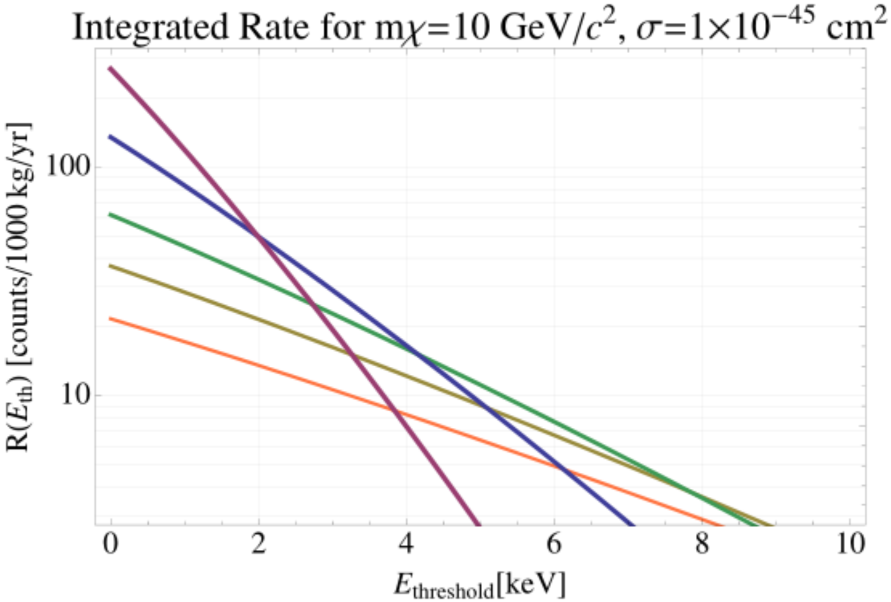
Liquid Argon as a Target

Weak, coherent interaction between WIMP and argon nucleus

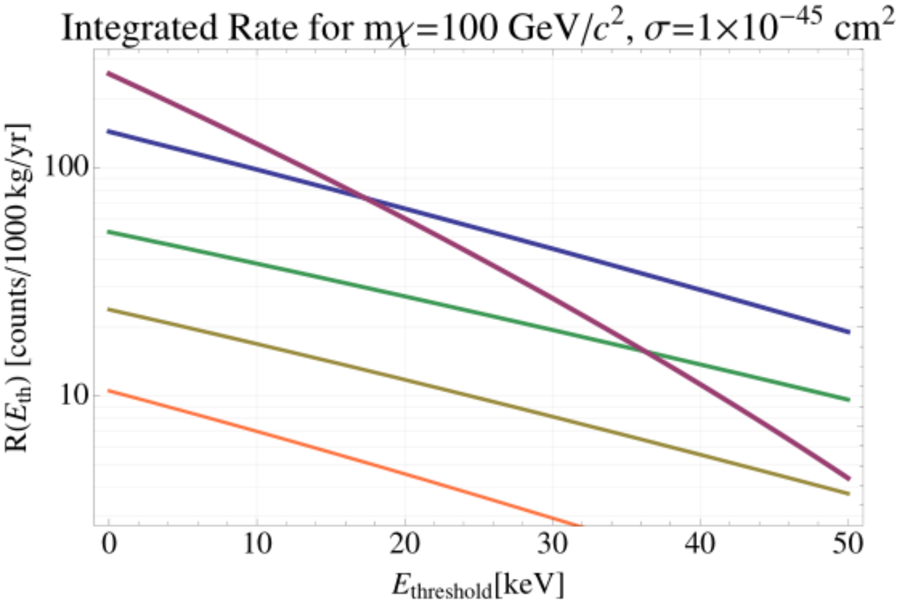
Nuclear mass improves cross section

Nuclear and WIMP masses determines energy distribution

Argon needs high threshold, strongest for high mass WIMPS



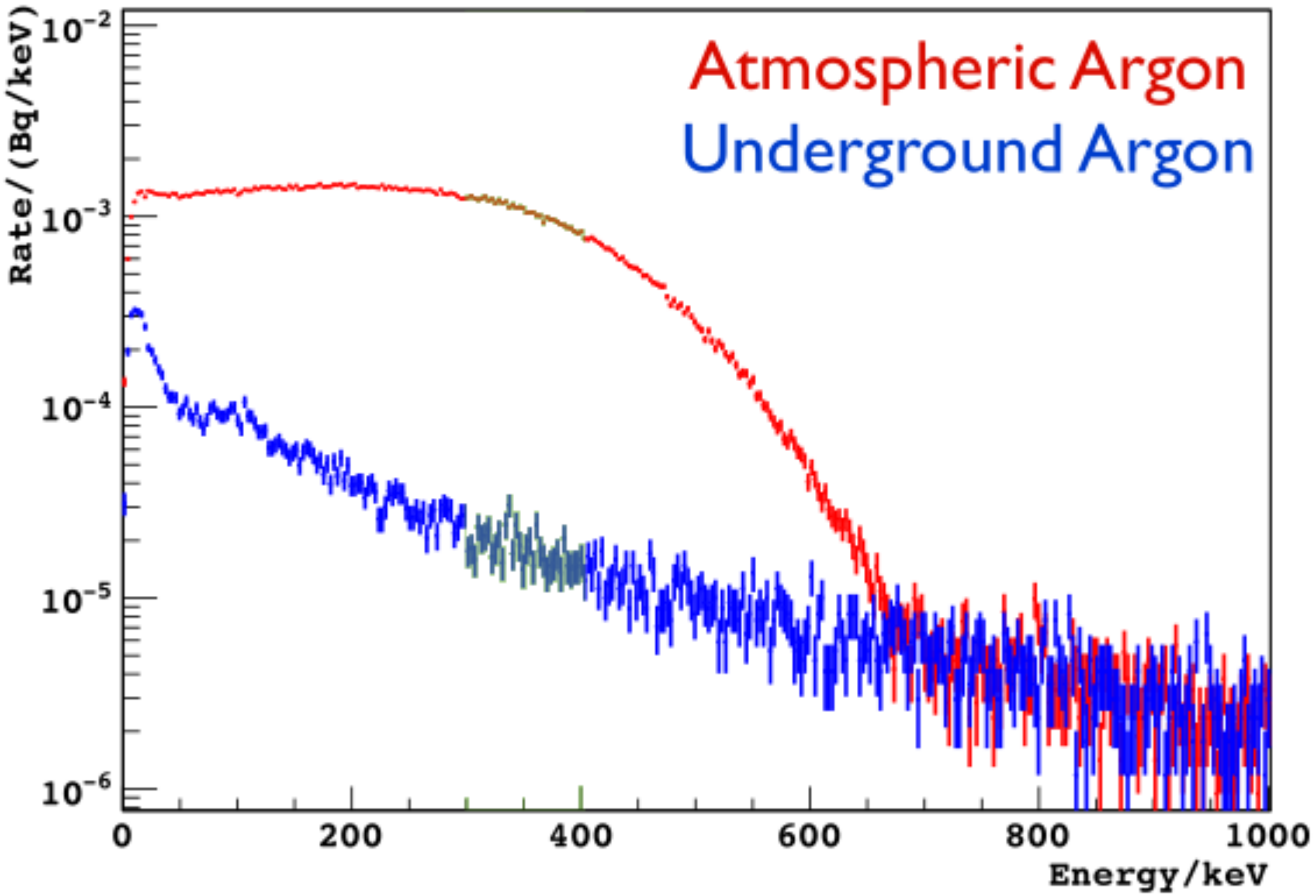
arXiv:1310.8327v2 [hep-ex]



Xe Ge Ar Si Ne

Underground Argon

Mined from a CO_2 plant
Shielded from cosmic rays, so 150x less ^{39}Ar



arXiv:1204.6011