Directional Dark Matter Detection with DMTPC

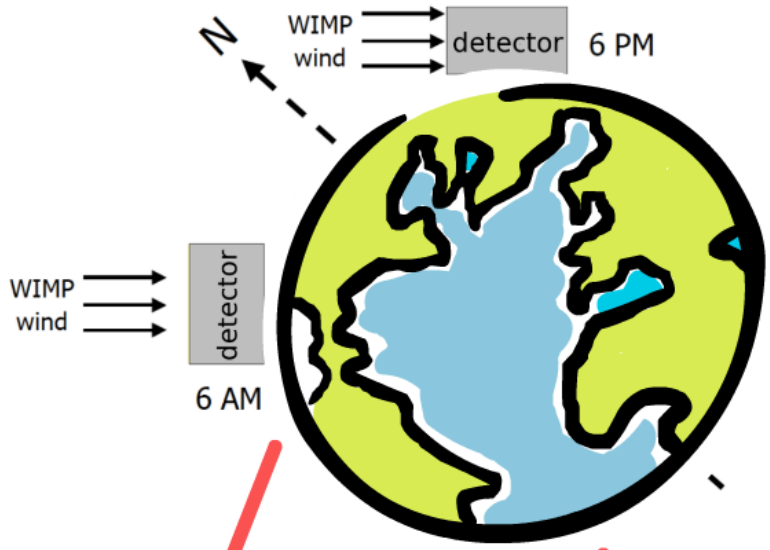
Michael Leyton

(on behalf of the DMTPC collaboration)

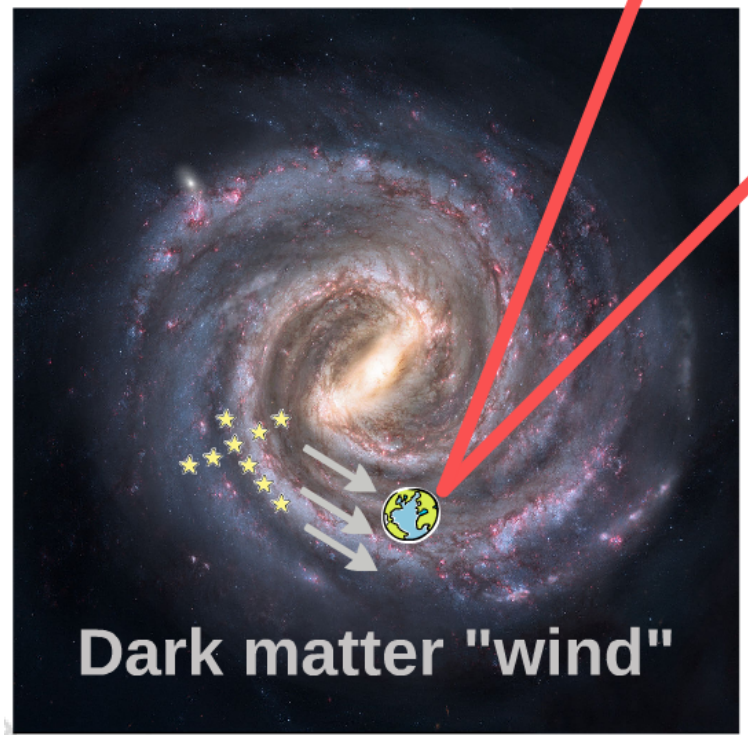
7 September 2015

14th International Conference on TAUP - Torino, Italy

WIMPs have a preferred direction in galactic coordinates



Sidereal modulation in direction ~10x annual modulation



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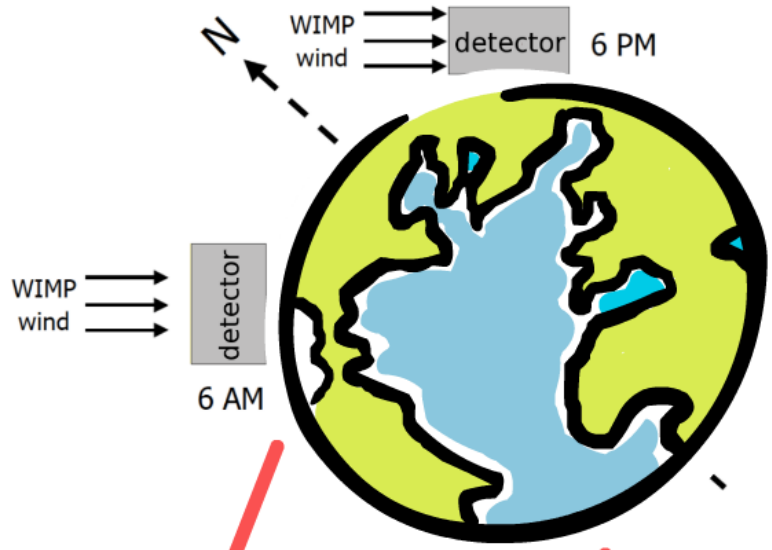
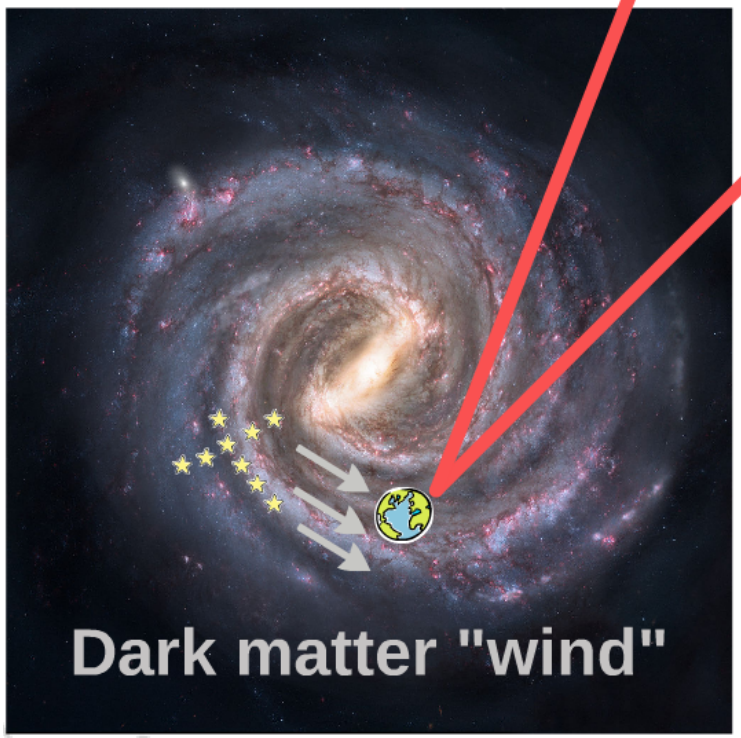
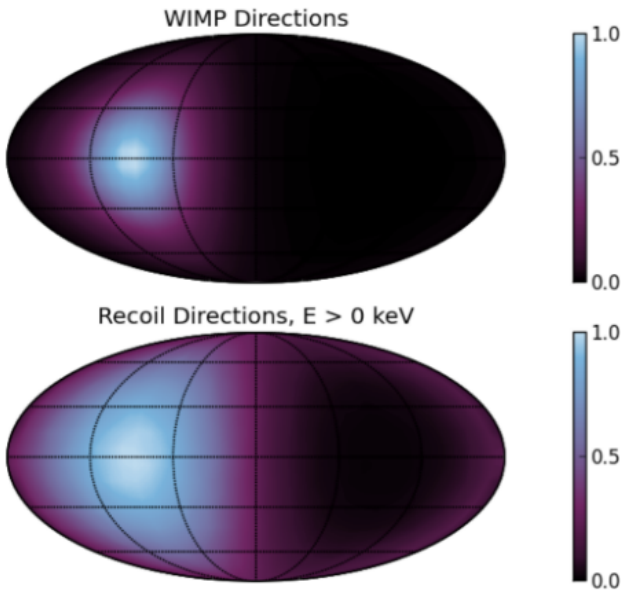
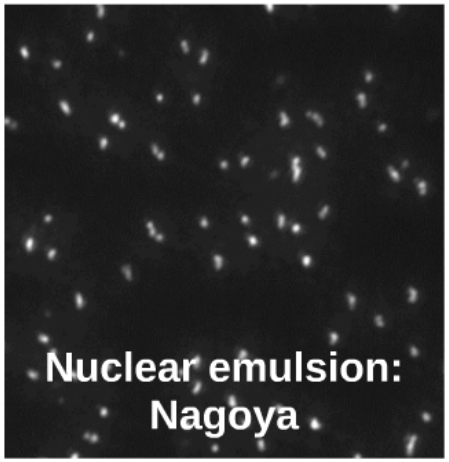
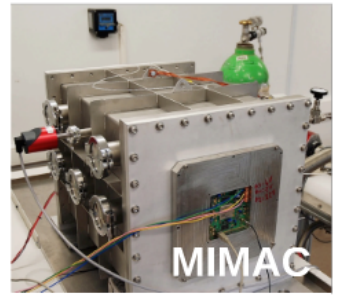


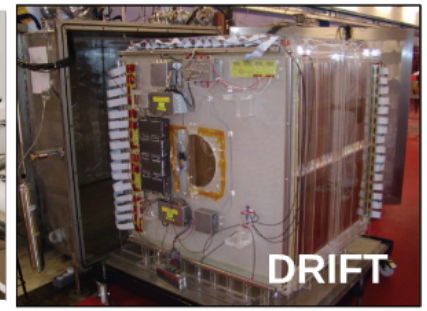


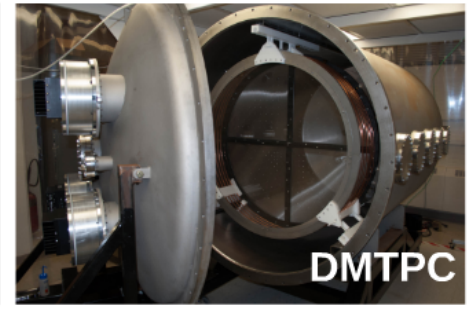


A correlated signal would be **unambiguous proof**

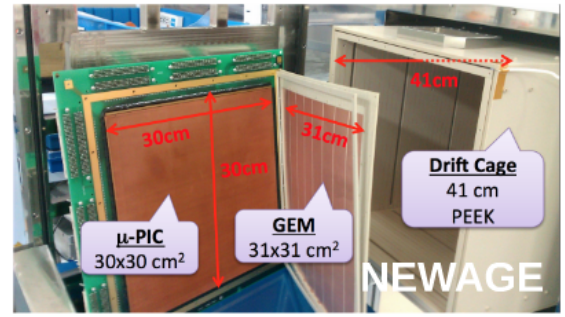








Gas-based detectors / TPCs



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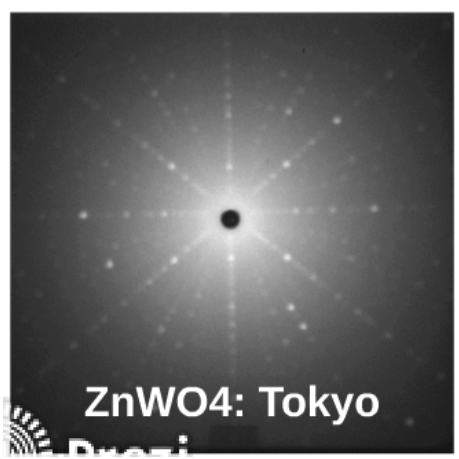
Directional community

http://arxiv.org/abs/0911.0323



Not pictured: NITEC,
columnar recombination ...

DMTPC

DARK MATTER TIME PROJECTION CHAMBER

Canary

C. Deaconu, Ph.D. thesis (2015):
- 30 torr pressure
- Triple-mesh amplification region

4-shooter

J. Battat et al., *Nucl. Instrum. Meth. A* **755** (2014) 6-19:
- Multi-camera readout
- Low-background materials;
- Event discrimination with charge readout

10-L

S. Ahlen et al., arXiv: 1006.2928 (2010):
- Deployed underground
- Dark matter limit

DMTPC

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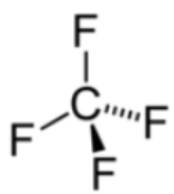
m^3

DMTPC

+HV

DARK MATTER TIME PROJECTION CHAMBER

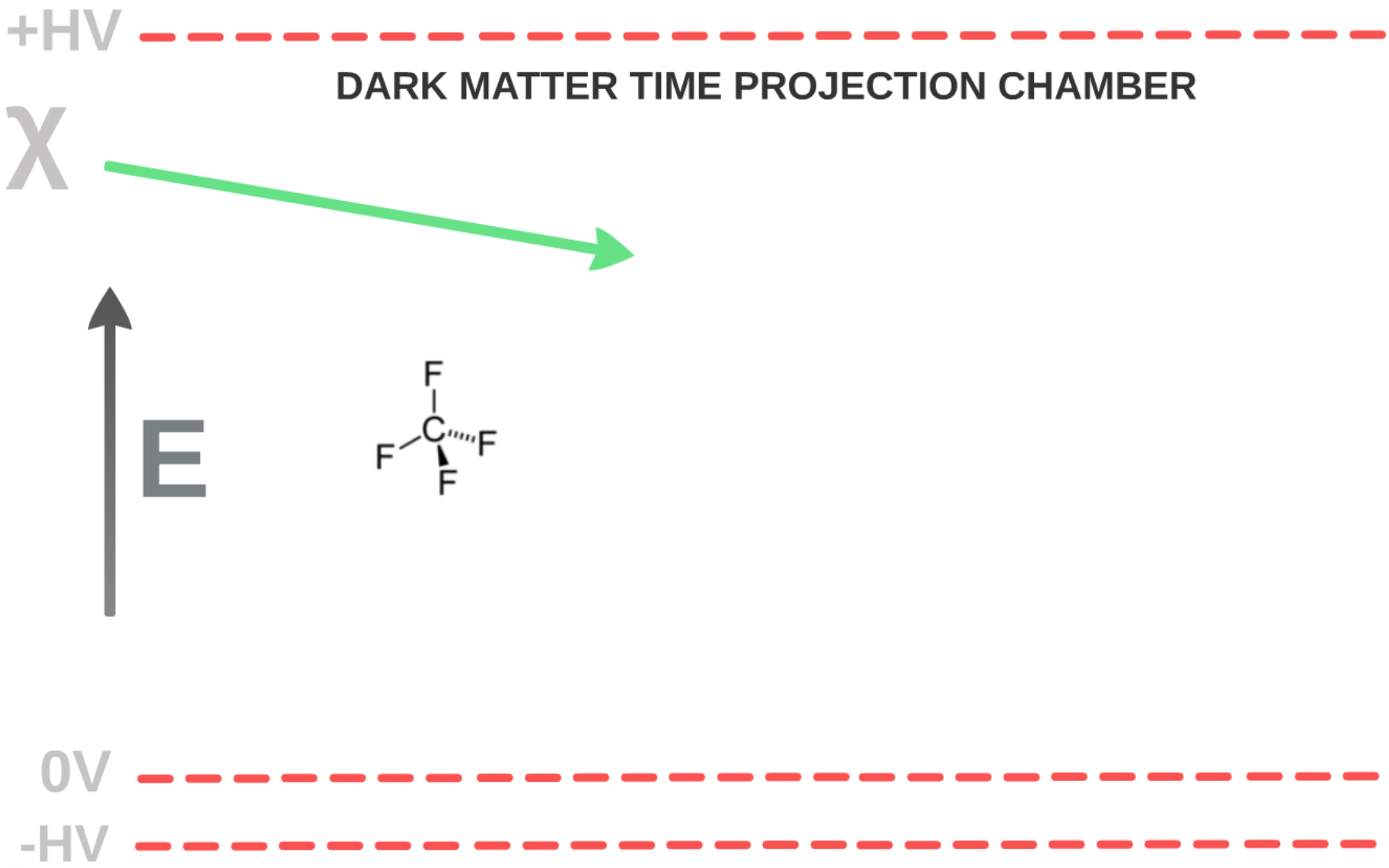
E



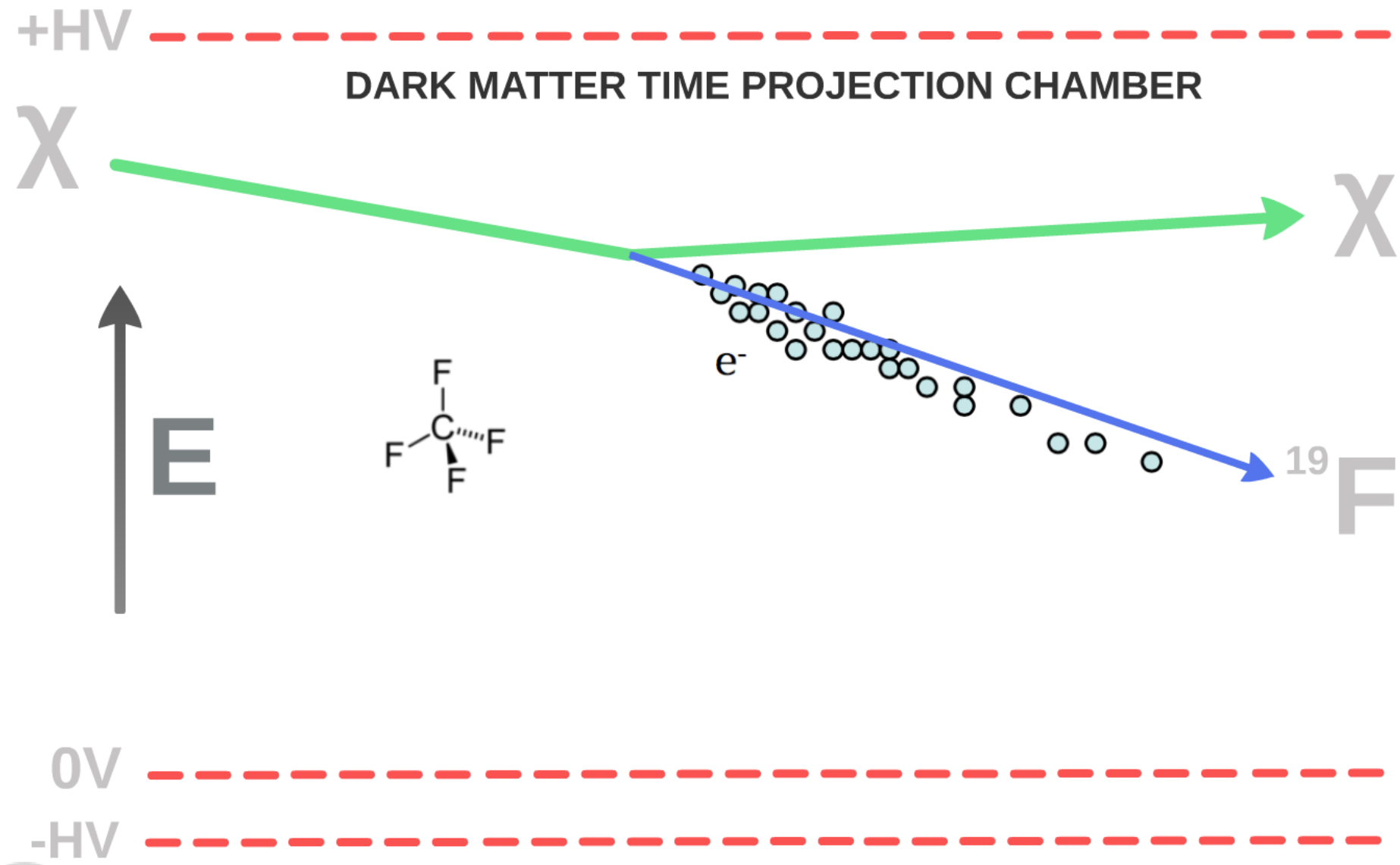
0V

-HV

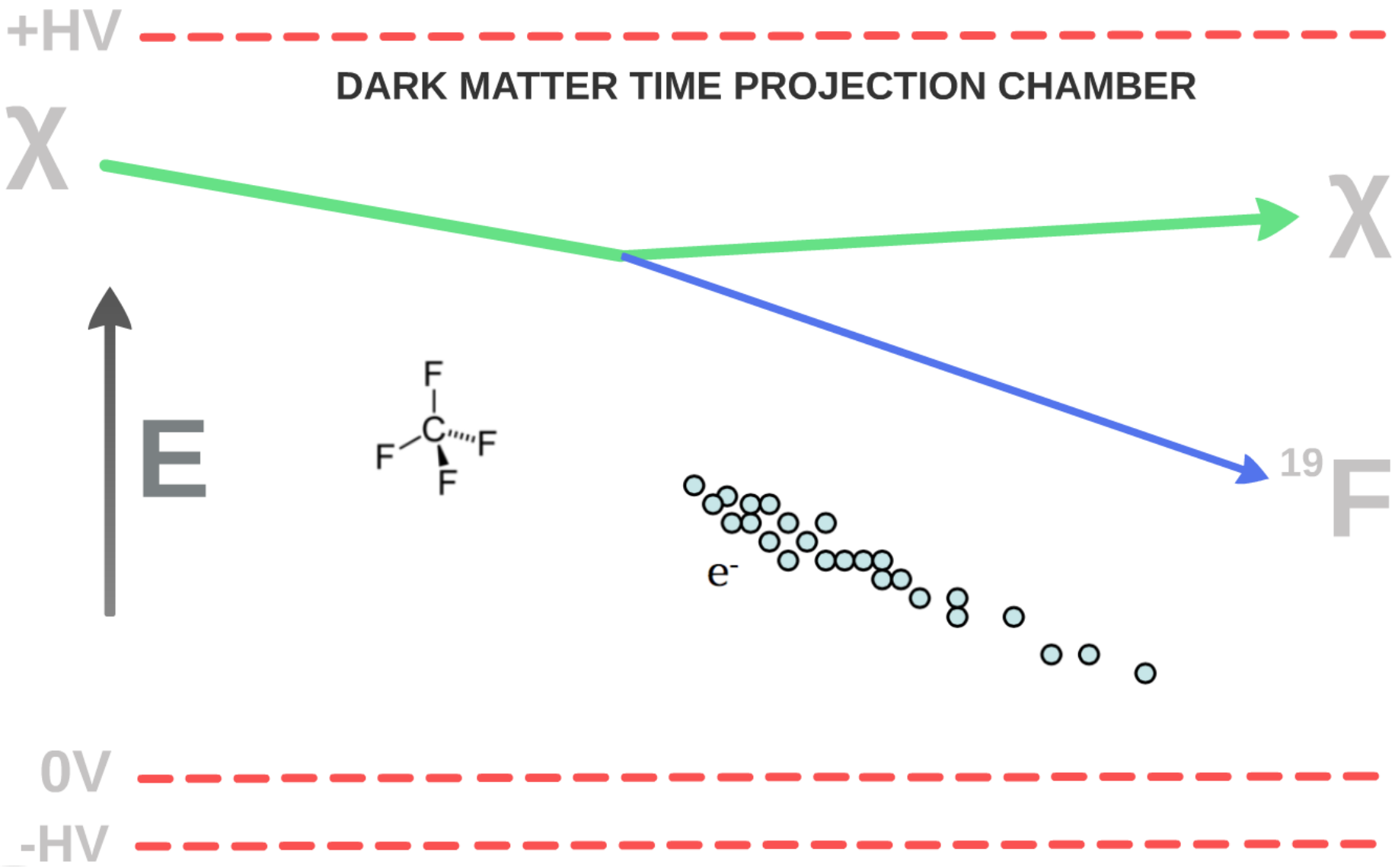
DMTPC



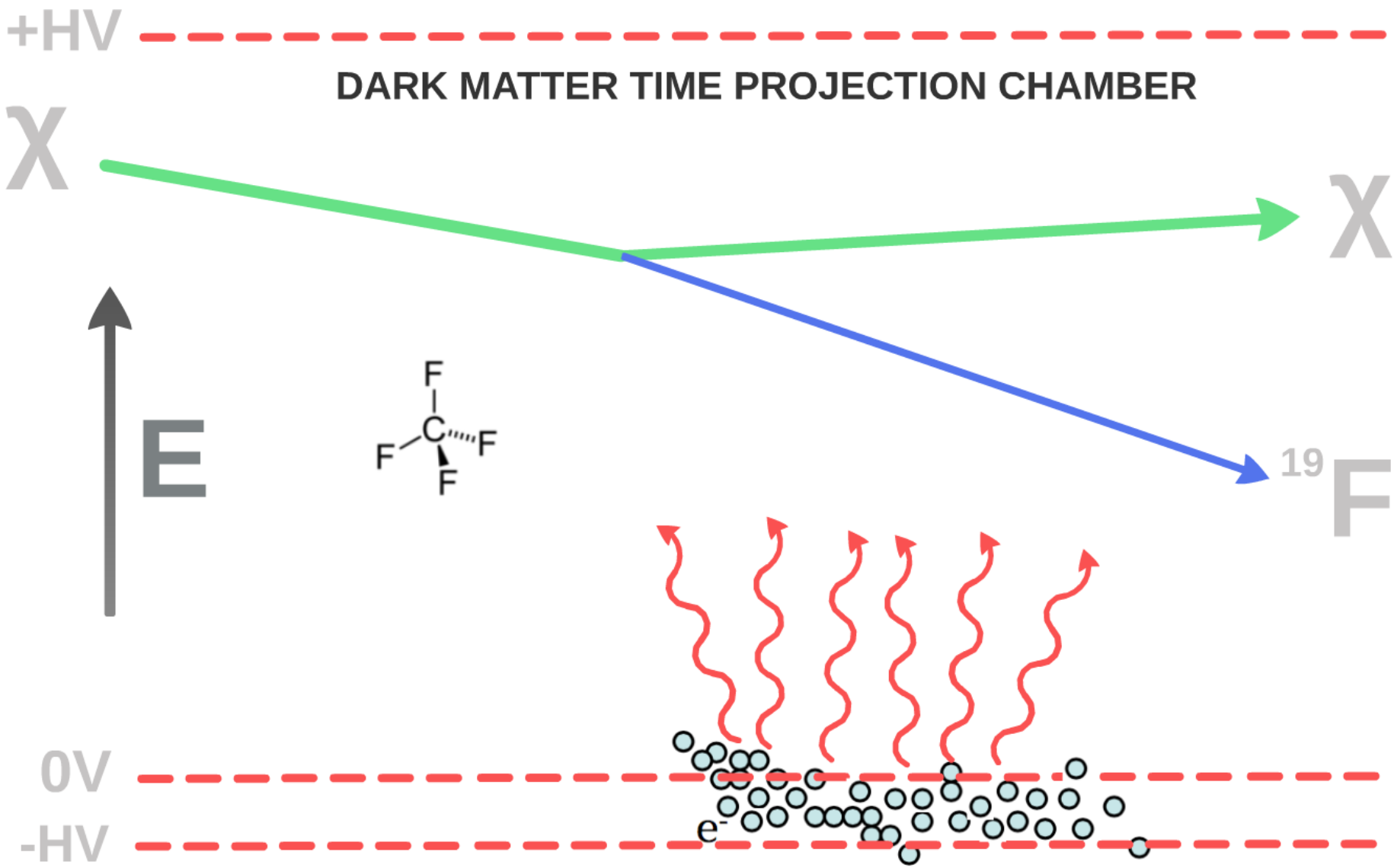
DMTPC

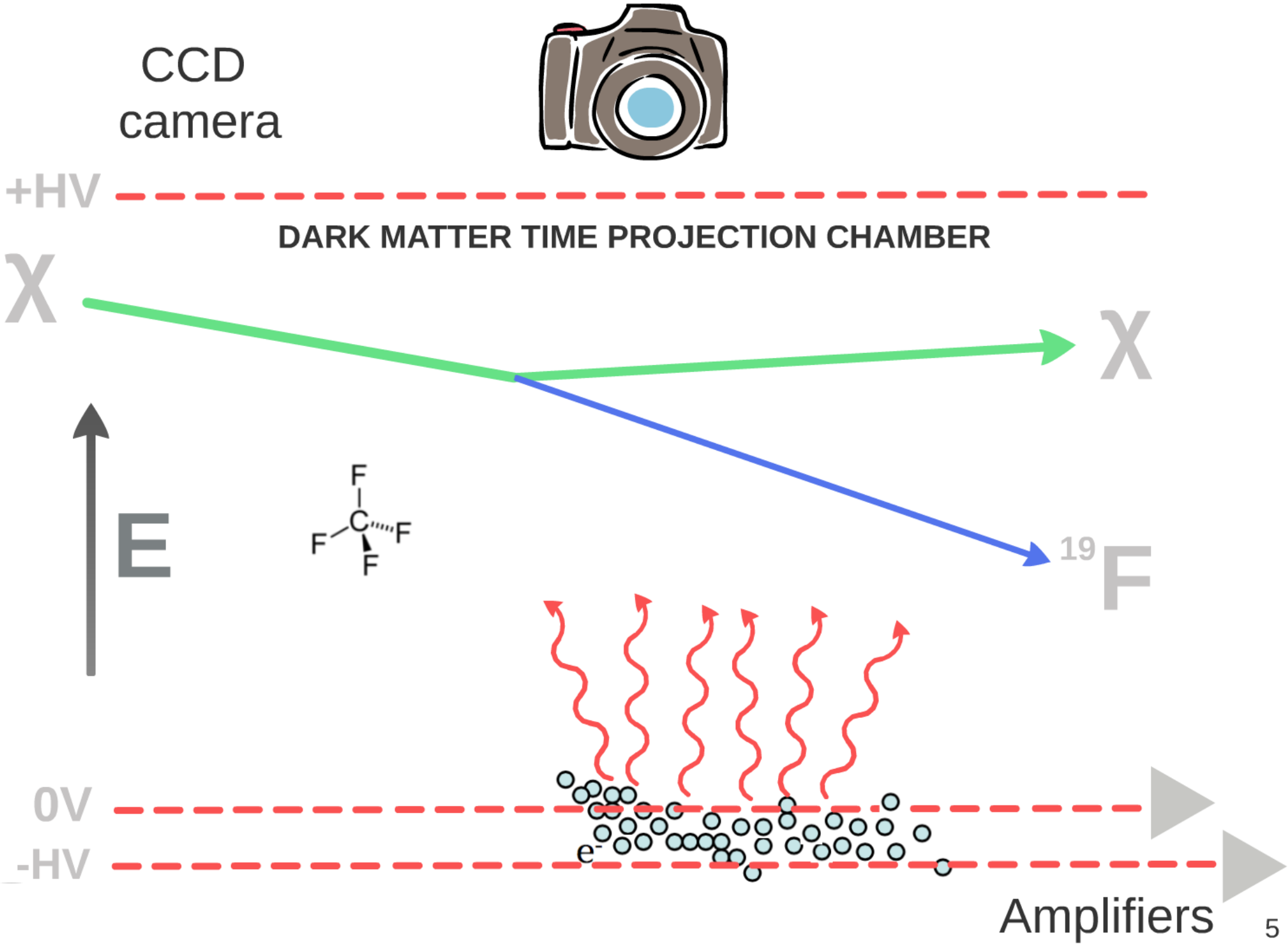


DMTPC



DMTPC

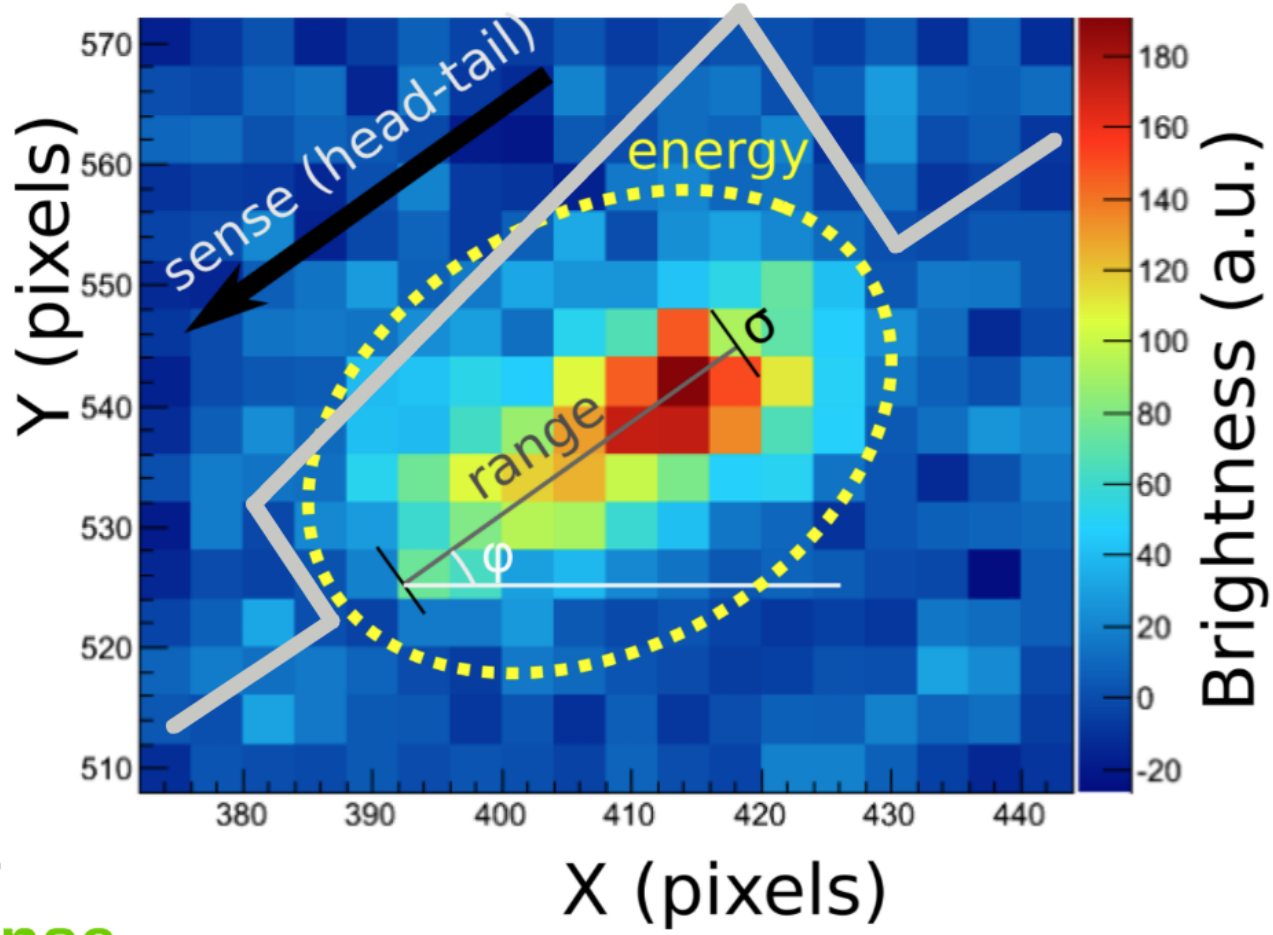


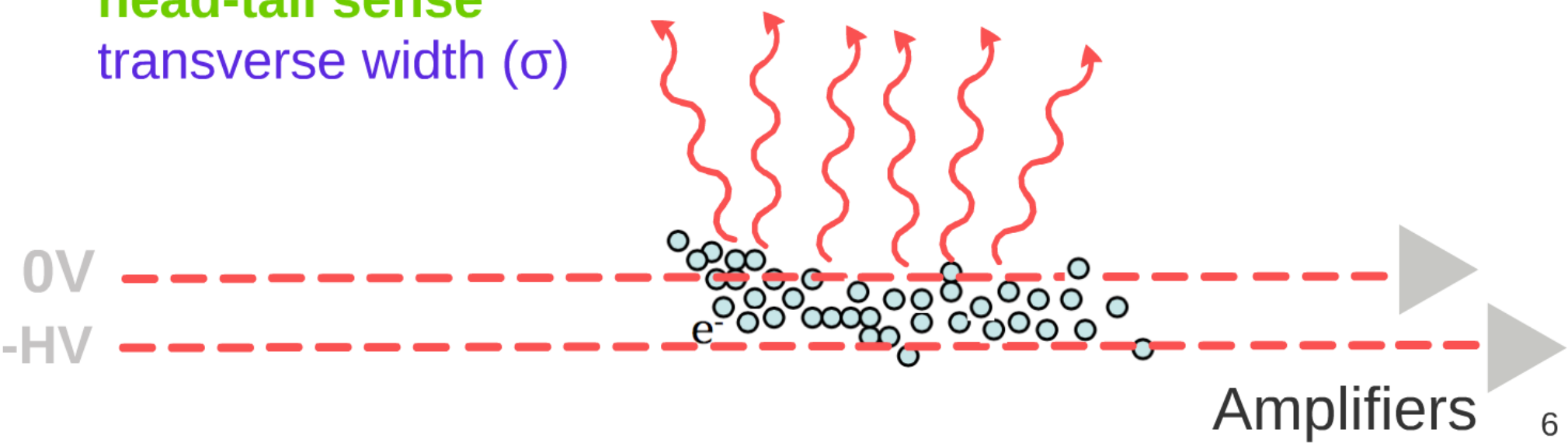

CCD
camera
+HV
DARK MATTER TIME PROJECTION CHAMBER
χ
χ
E
F
C
F
F
F
19
F
0V
-HV
e-
Amplifiers

CCD camera

Measure:

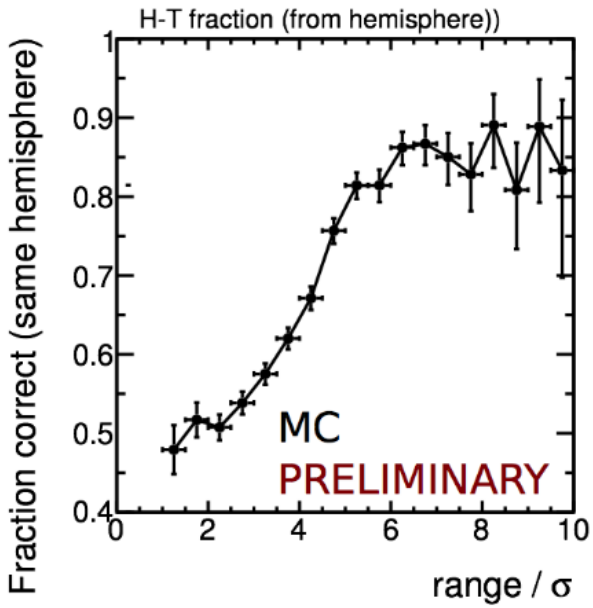
- energy
- range
- axis
- **axial angle**
- dE/dx profile
- **head-tail sense**
- transverse width (σ)



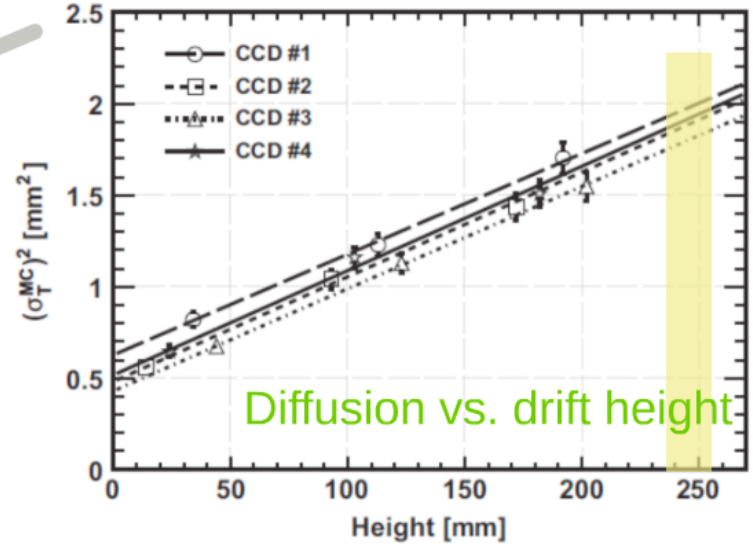


Diffusion vs. directional sensitivity

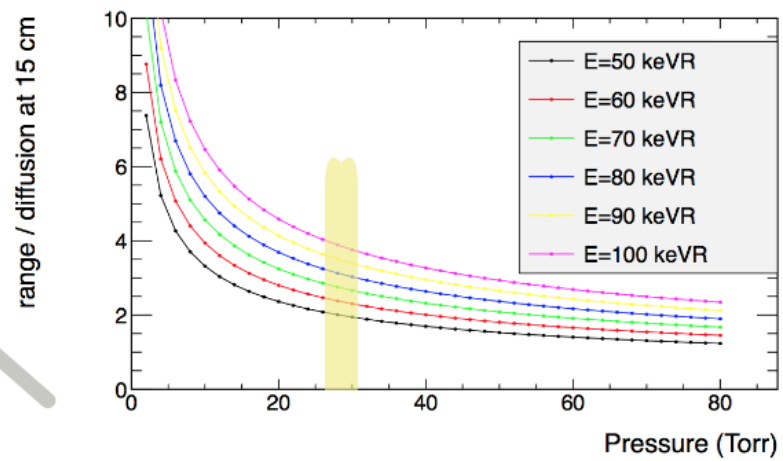
To improve directional sensitivity at low E, need to



Key parameter for directional sensitivity



constrain drift height:
z < 25 cm

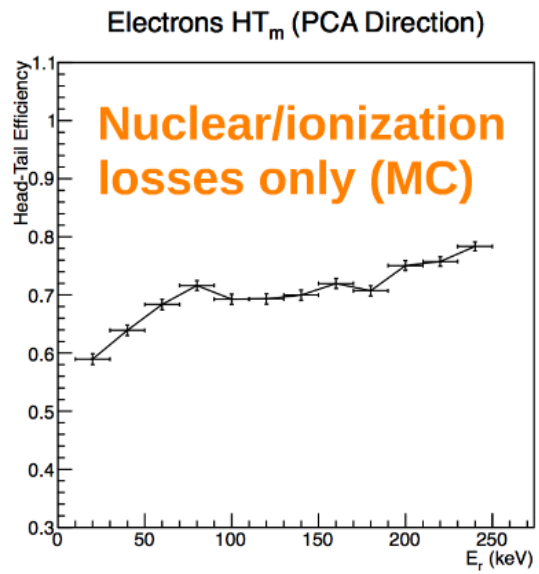


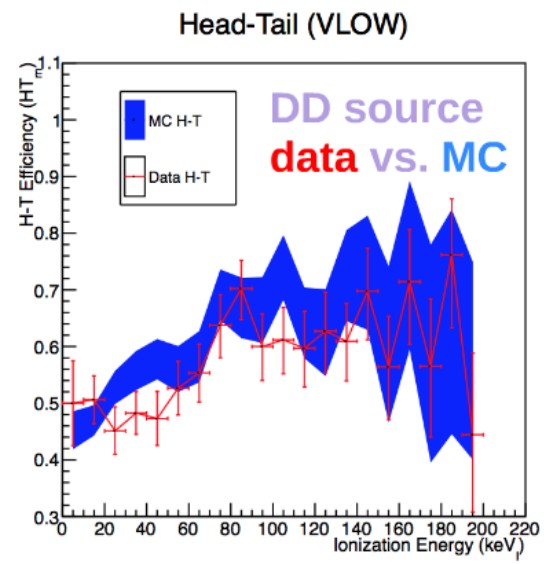
go to lower pressure:
P ~ 30 torr

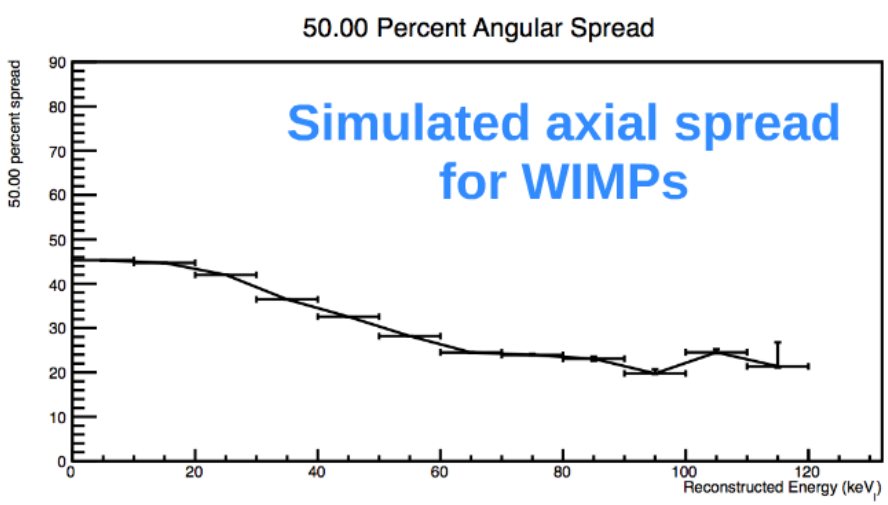
What is the ability of a m^3 DMTPC detector to distinguish a WIMP source from an isotropic background?

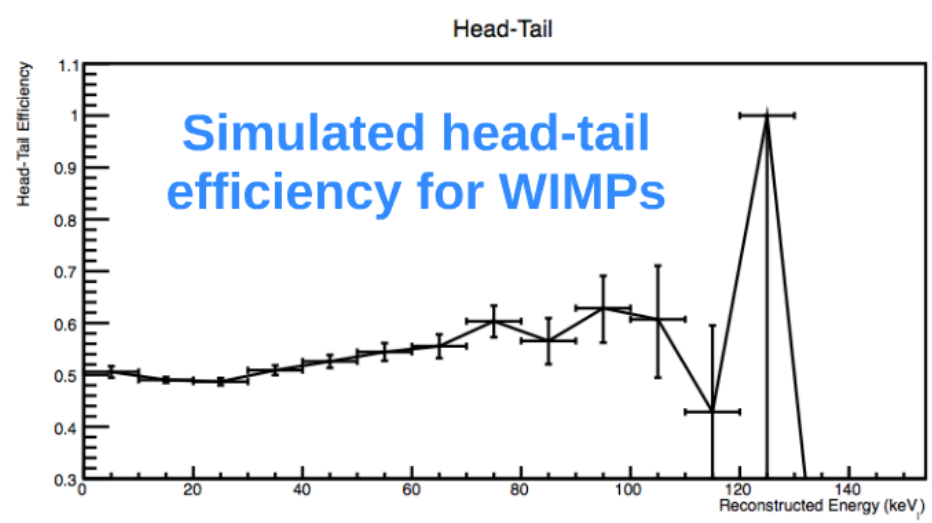
Assuming:

- 30 torr pressure
- 100K gas gain
- Drift height < 25 cm







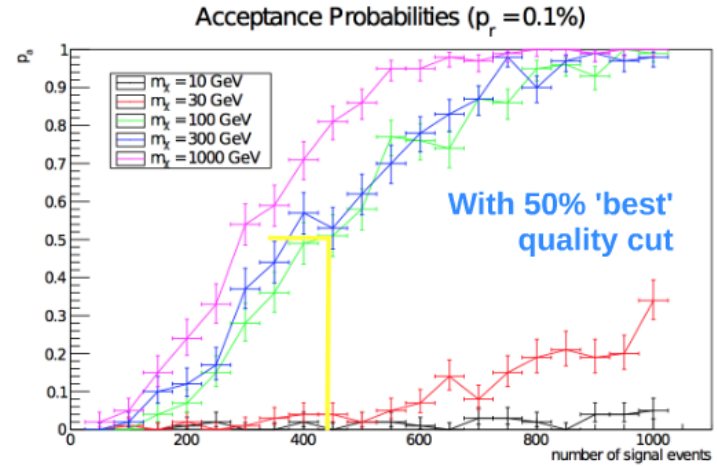


Projected m^3 directional sensitivity

Take simulated response and run many fake experiments with *n* signal events

Compute head-tail and axial spread in each energy bin

Calculate *p* of obtaining value in each bin from isotropic distribution and combine to build an overall χ2 statistic

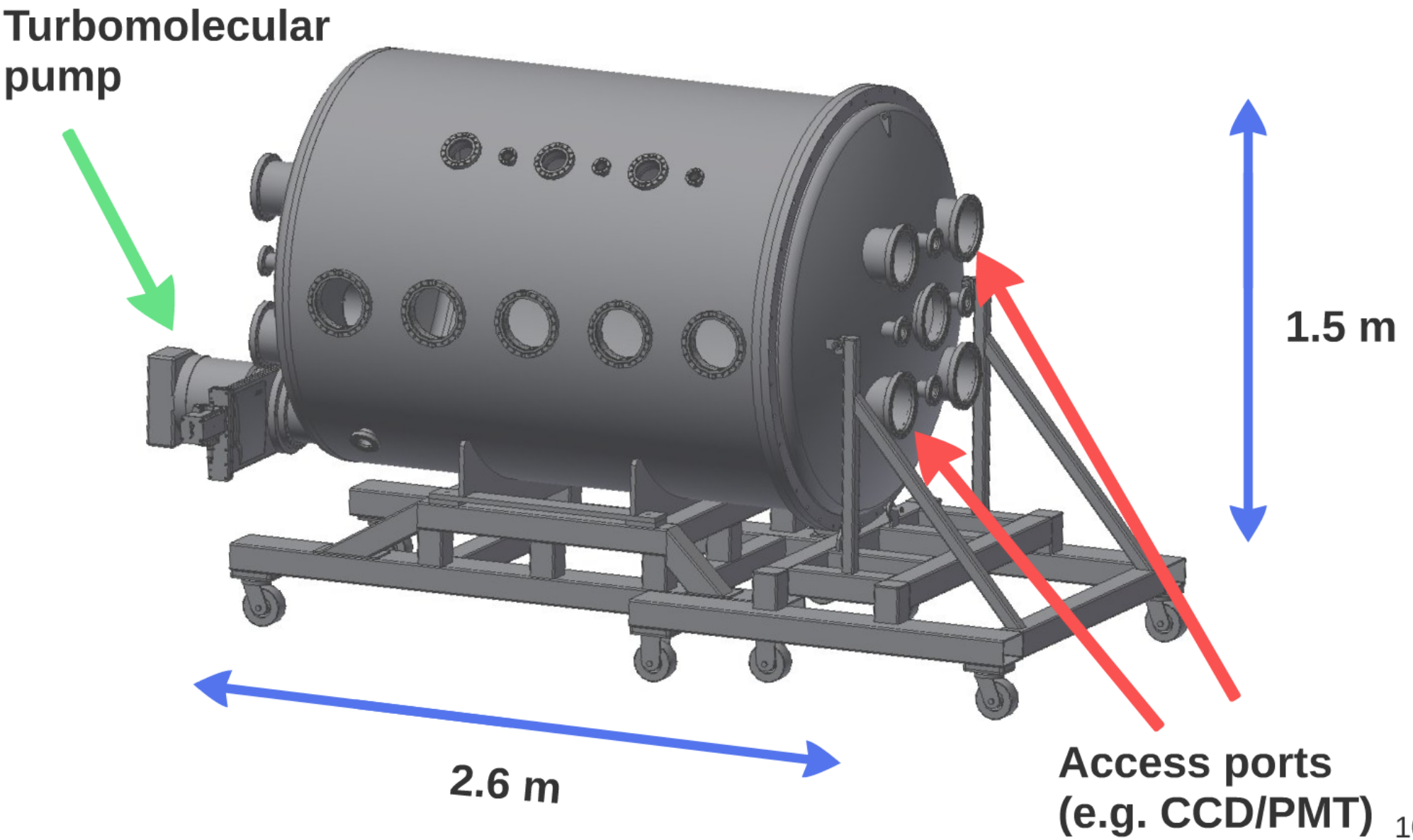


Probability of rejecting isotropy to the given significance level with *n* signal events

Assuming target mass at 30 torr and 100 (1000) GeV WIMP, with σ = 1 fb, it would take **500 (300) m^3-years** to acquire 450 events necessary to reject isotropy half of the time at 0.1% significance

This is equivalent to only 4.3 (2.6) Excalibur-years

m^3



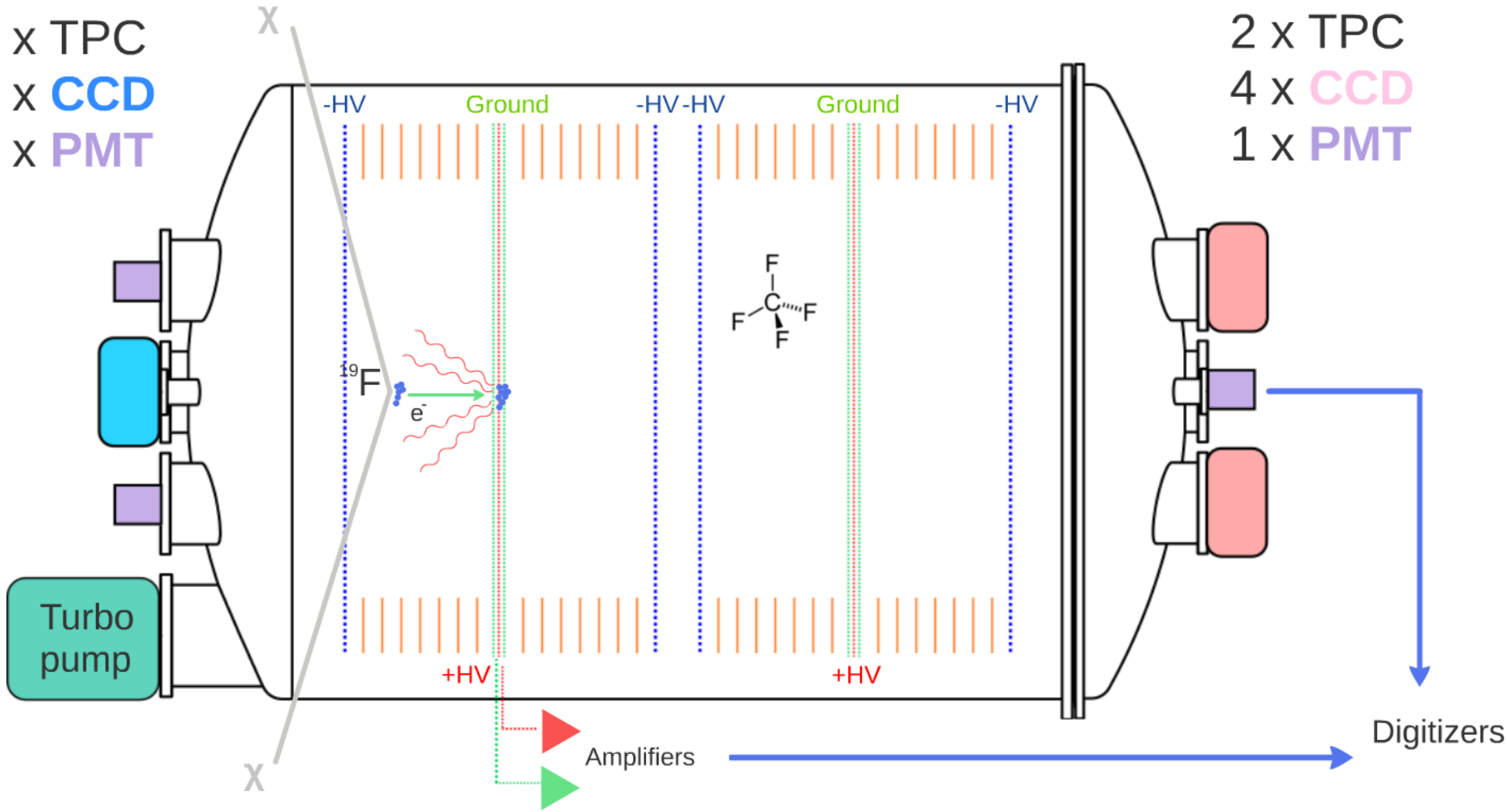
m^3

1-shooter side:

2 x TPC
1 x **CCD**
4 x **PMT**

4-shooter side:

2 x TPC
4 x **CCD**
1 x **PMT**



Charge readout for E measurement,
background subtraction and trigger

4 x FLI ProLine 9000

Front-illuminated Kodak sensor
3056 x 3056 pixels
12 µm pixel size
0.2 ¢/channel

up to 8 MHz readout speed
Read noise: 9 e- RMS @ 1 MHz
< 0.01 e-/pixel/sec @ -40 C

1 x Spectral 1100S

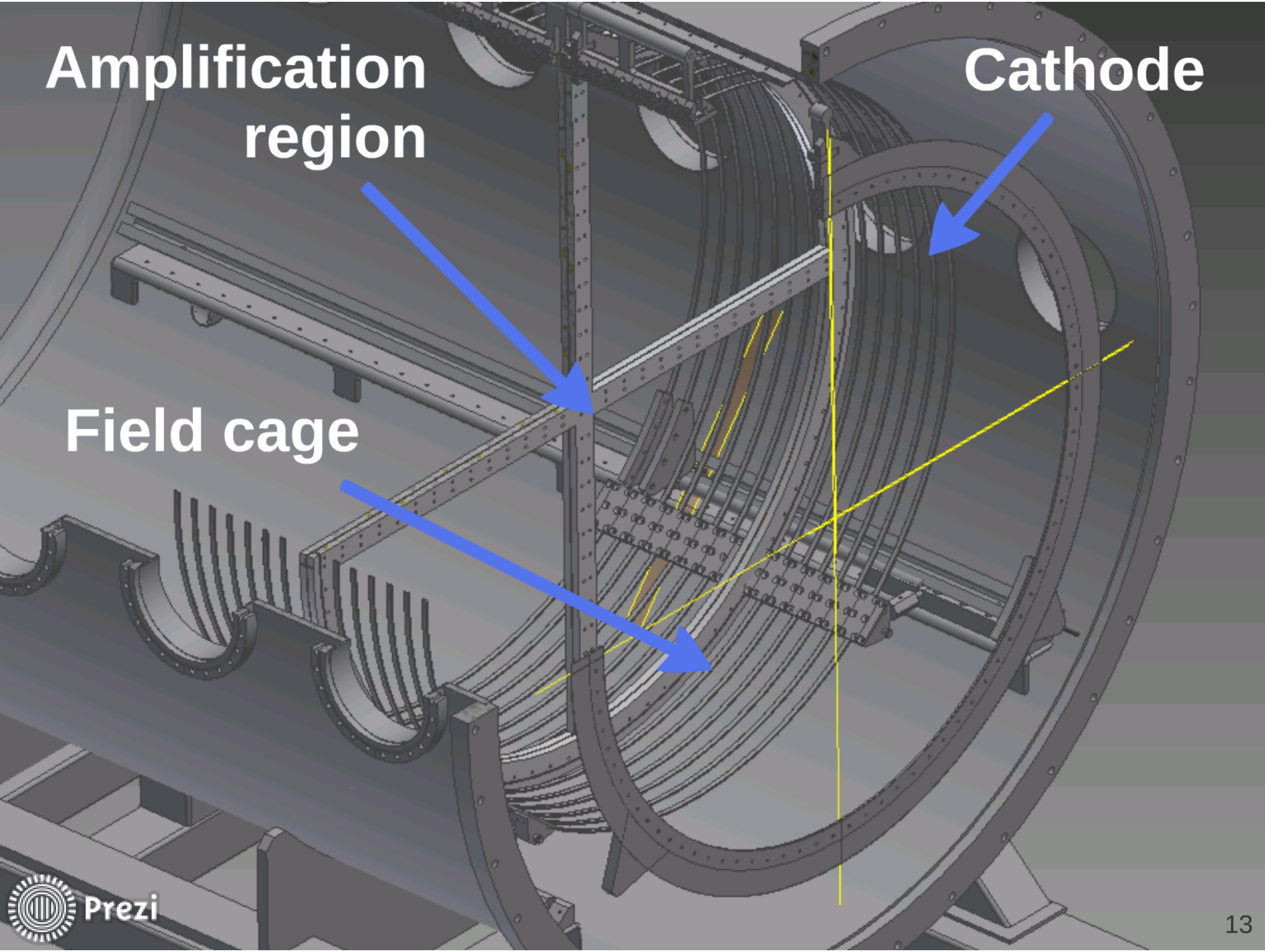
Back-illuminated Fairchild sensor
4096 x 4096 pixels
15 µm pixel size
0.5 ¢/channel

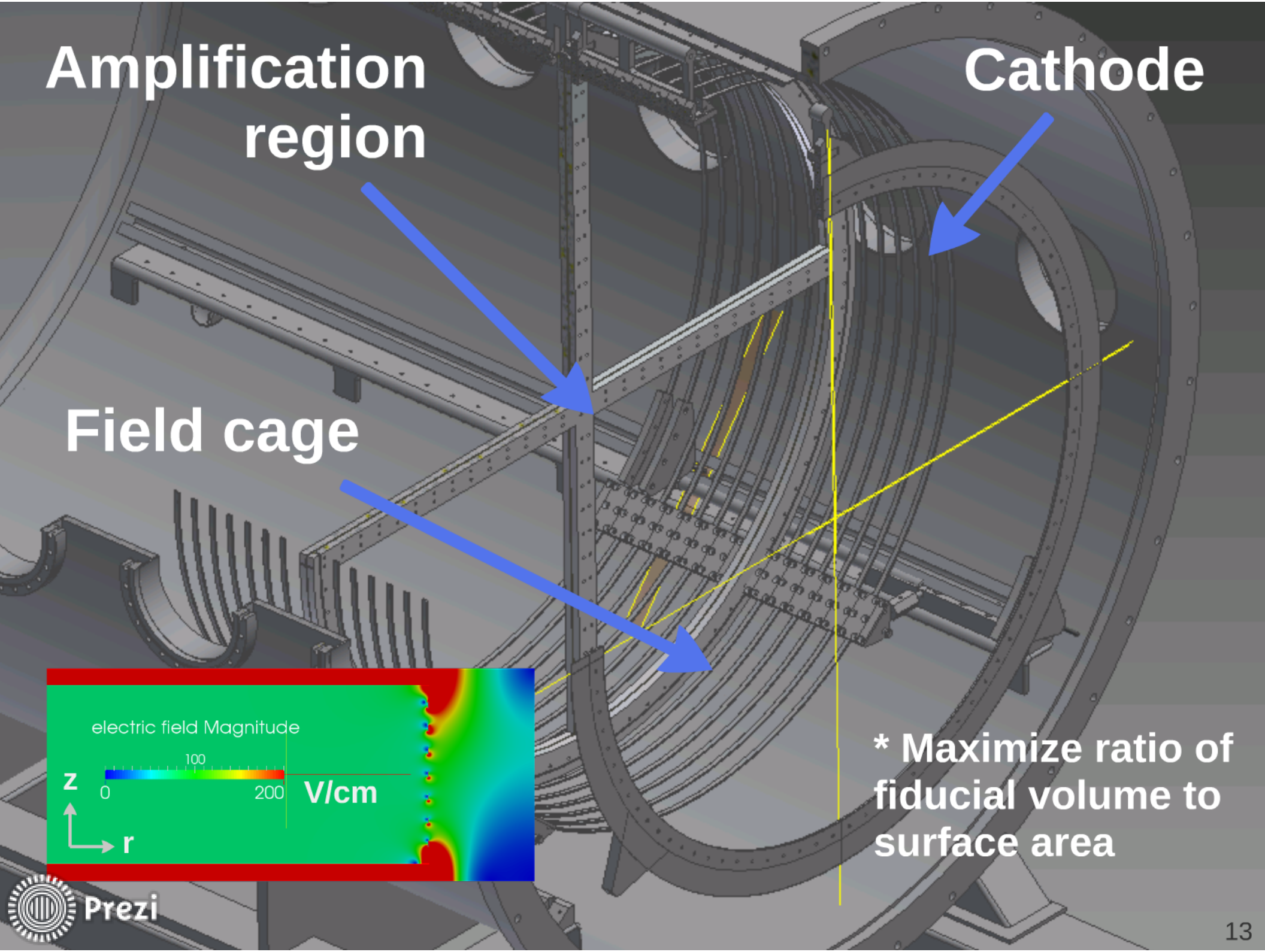
up to 8 MHz readout speed
Read noise: 7 e- RMS @ 1 MHz
< 1 e-/pixel/sec

5 x Hamamatsu R1408

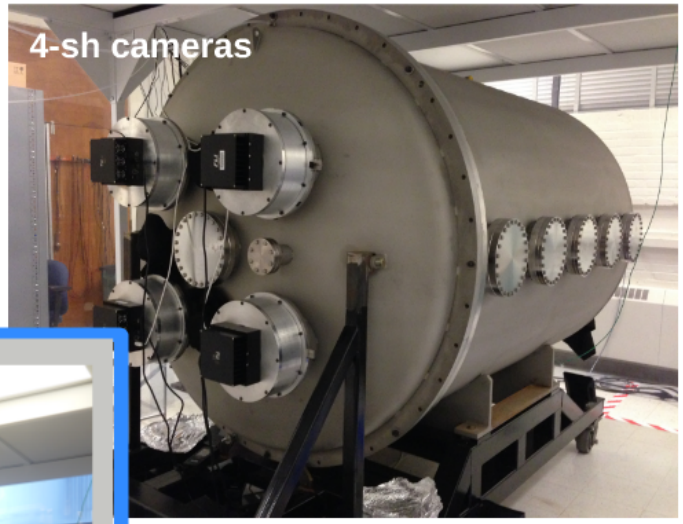
14-bit
250 MHz bandwidth
Little to no dead time

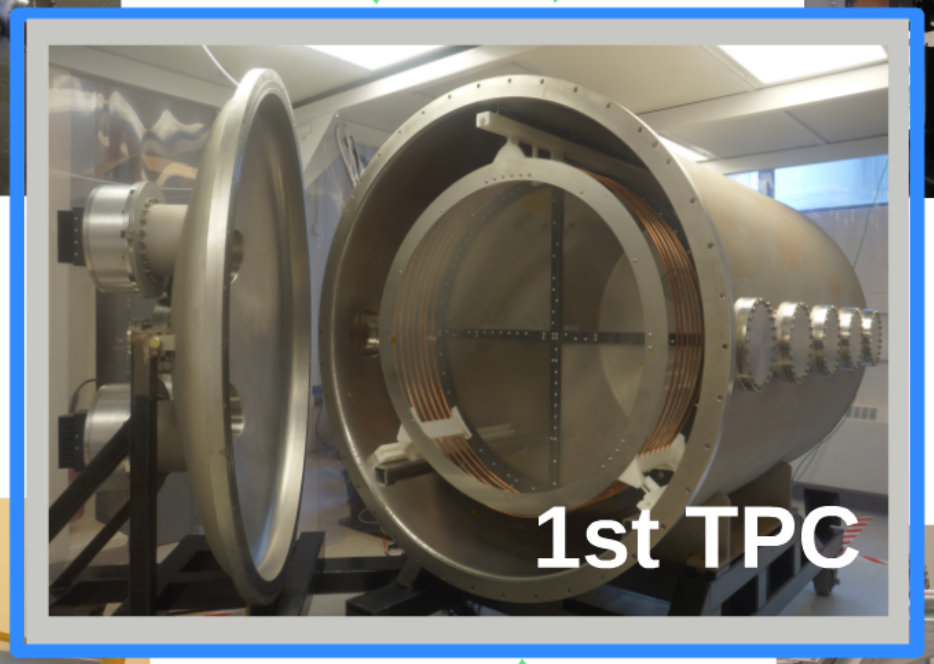
2 x CAEN N6730 WFD

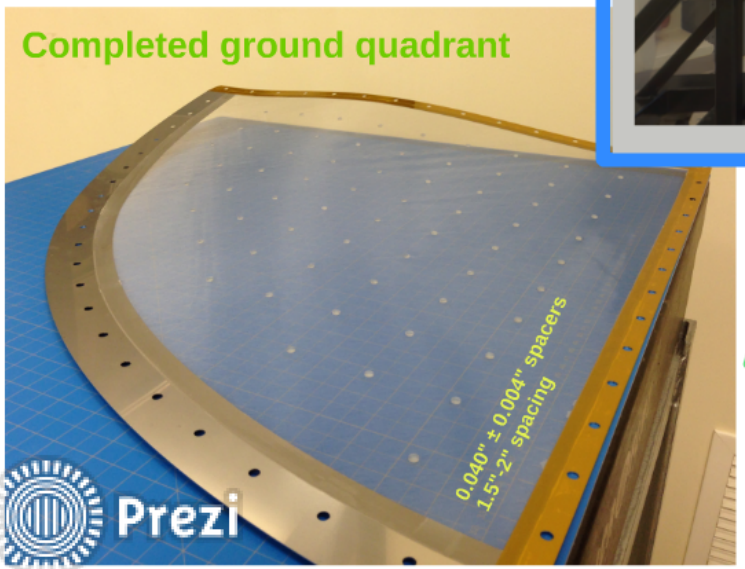

Amplification region
Cathode
Field cage
Prezi

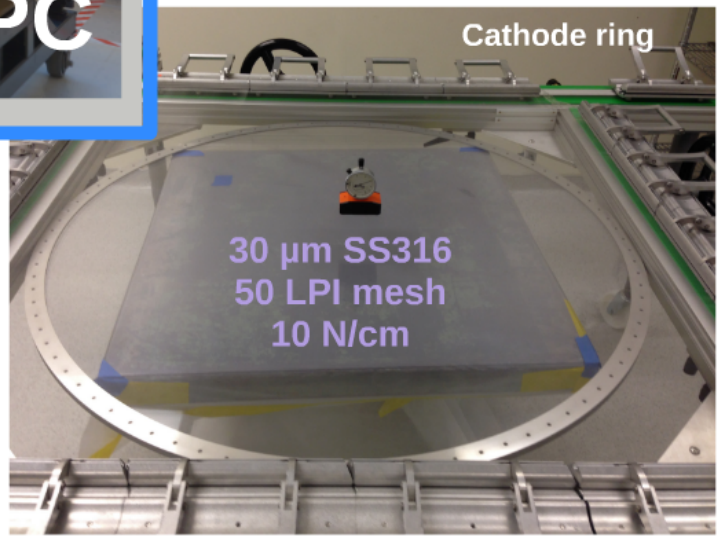

Amplification region
Cathode
Field cage
electric field Magnitude
100
0
200
V/cm
z
r
* Maximize ratio of fiducial volume to surface area
Prezi

Assembly and Integration

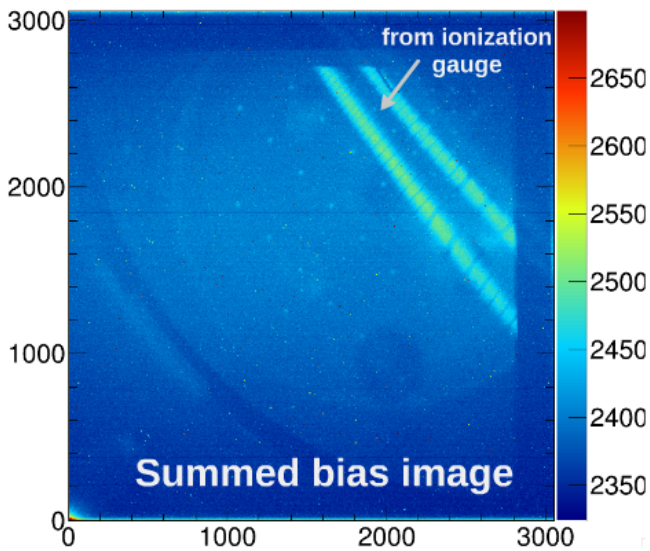


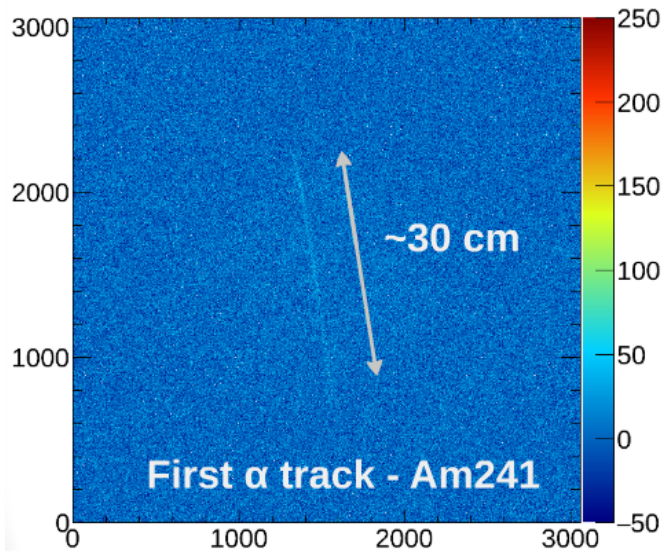


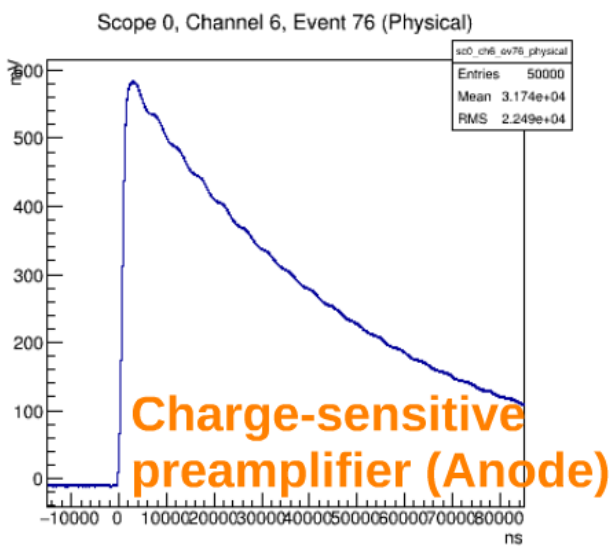




A first look at the data!





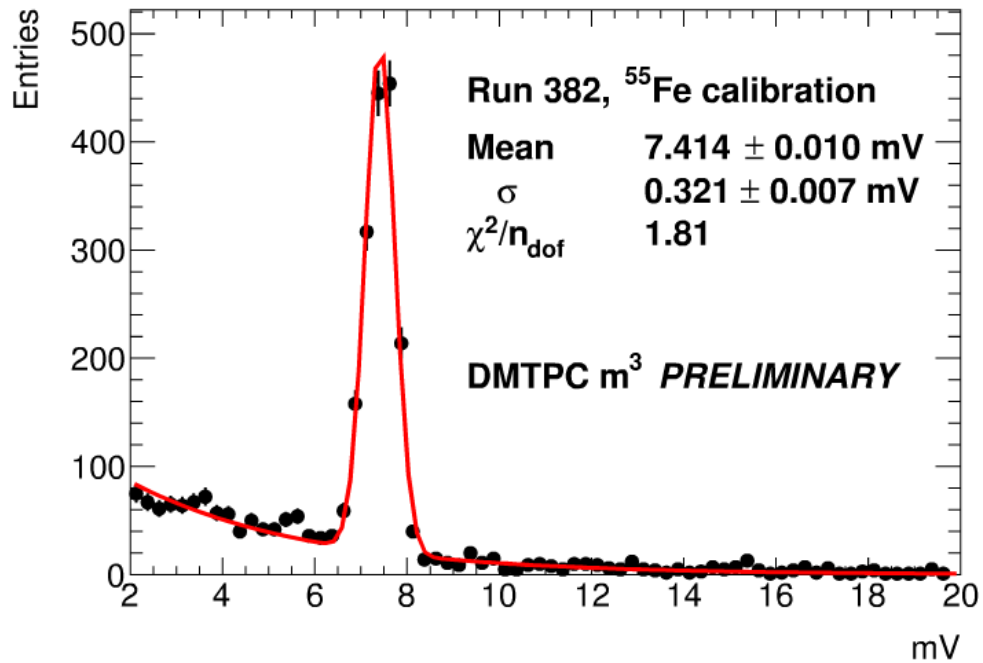


Gain calibration

Measured gas gain (multiplication) using Fe-55 source and amplitude of anode signal

$$G \sim \frac{(V_{out} / \text{Amplifier gain})}{(5.9 \text{ keV} / W)}$$

W for CF_4 = 33.8 ± 0.4 eV



For anode at 690 V:

Gas gain = 82,000 ± 6000

Summary

Full detector model, validated with data, now available for DMTPC

Developed directional sensitivity metric incorporating head-tail and axial measurements

300 (500) m^3-years necessary for 3σ detection of 1 fb 1000 (100) GeV WIMPs

1 (out of 4) TPC's installed into m^3 chamber

Demonstrated proof-of-principle at m^3 scale using **modular, scalable design**

Next steps:

Complete fabrication and continue commissioning studies

Study directionality performance of detector at the surface

Deploy at SNOLAB in 2016

Directional detectors are on the verge of learning how to solve scale-up problem!

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