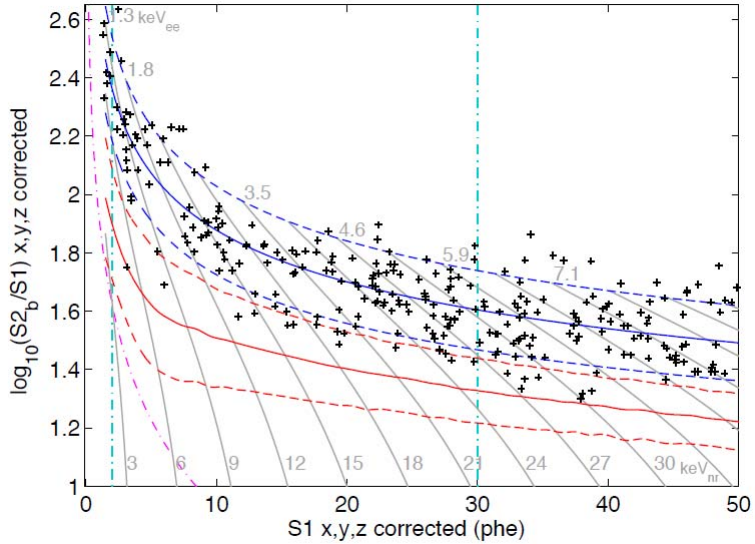
Directions in Direct Dark-Matter Directionality Detection

Azriel Goldschmidt, LBNL
"the Art of Experiment" Symposium
Berkeley, May 2014

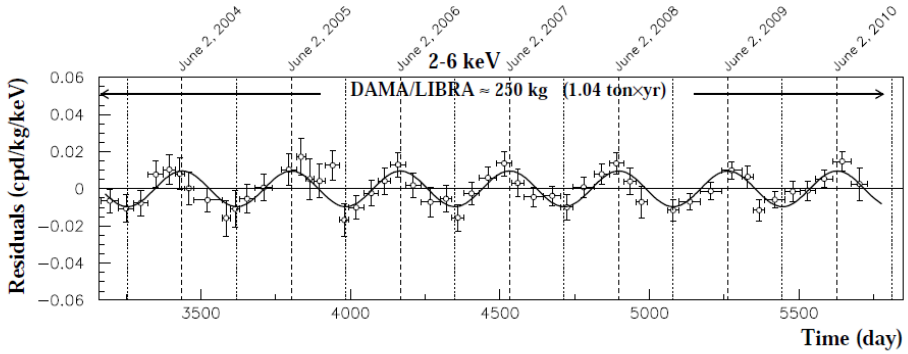
Direct WIMP-like DM search: status

Counting experiments: search for low energy nuclear recoils



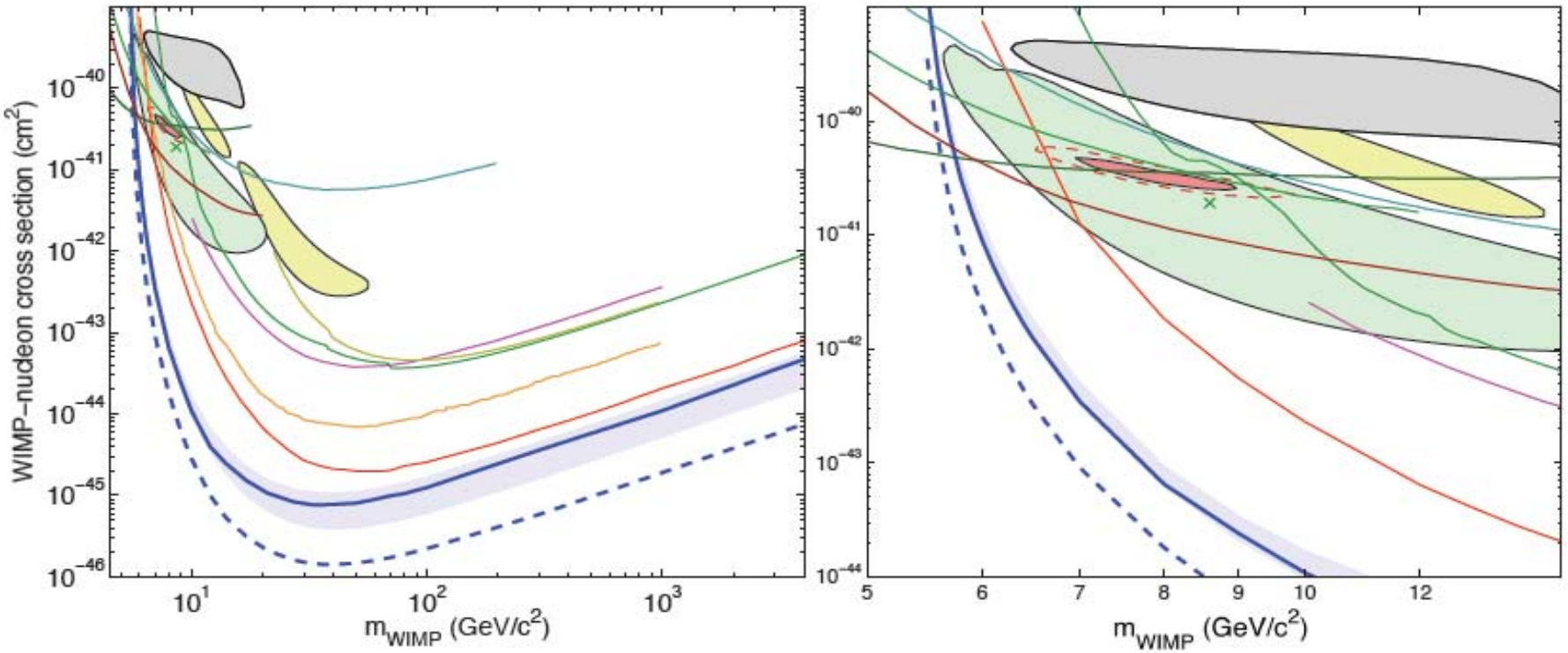
LUX result:350 kg of Xenon, 10,000 kg-days

Annual modulation: rate above threshold changes with Earth's velocity in the galaxy (230 km/sec ± 30 km/sec)



DAMA/LIBRA result:250 kg of NaI, 370,000 kg-days

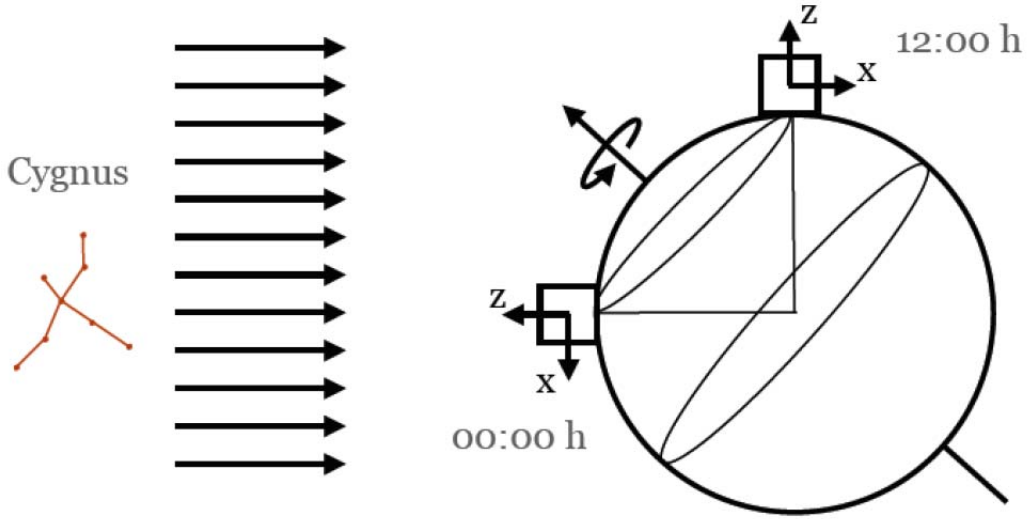
Direct WIMP-like DM search: status



From LUX 2013-2014 paper

A preferred direction

From galaxy rotation (and thus Sun & Earth) in a non co-rotating Dark Matter halo



$$\frac{dR}{dRd\cos\psi} \approx \frac{1}{2}\frac{R_0}{E_0 r}\exp\left[-\left(\frac{v_{\mathrm{E}}\cos\psi - v_{\mathrm{min}}}{v_0}\right)^2\right]$$

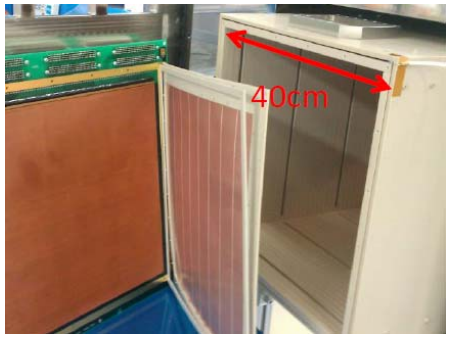
Sidereal-day modulation quickly goes out of phase with the day-night cycle

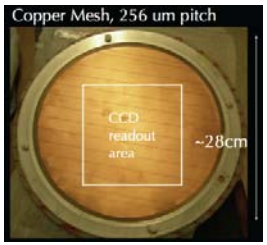
Approaches to directionality detection (1): Low pressure tracking

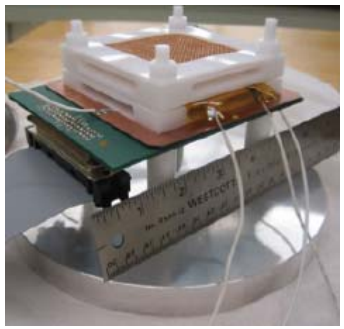
Low pressure O(100 Torr) gas TPCs:

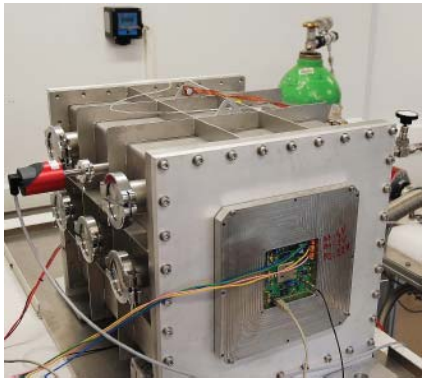
DRIFT(CS_2+CF_4), NEWAGE (CF_4), MIMAC(CF_4+CHF_3), DMTPC(CF_4), D^3(CF_4+)

- Tracks O(mm) lengths
- Large (or very large) volumes required
- Control of diffusion
- Large area with O(mm) or better resolution
- 3D fiducialization important(t0)



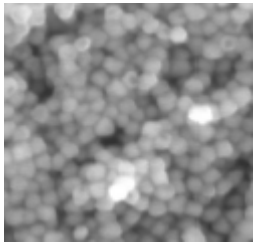


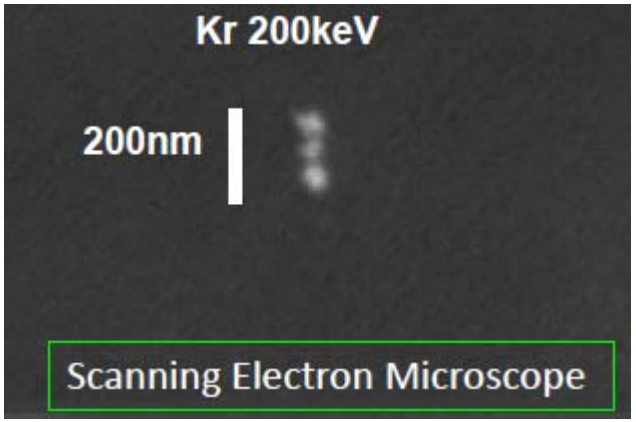


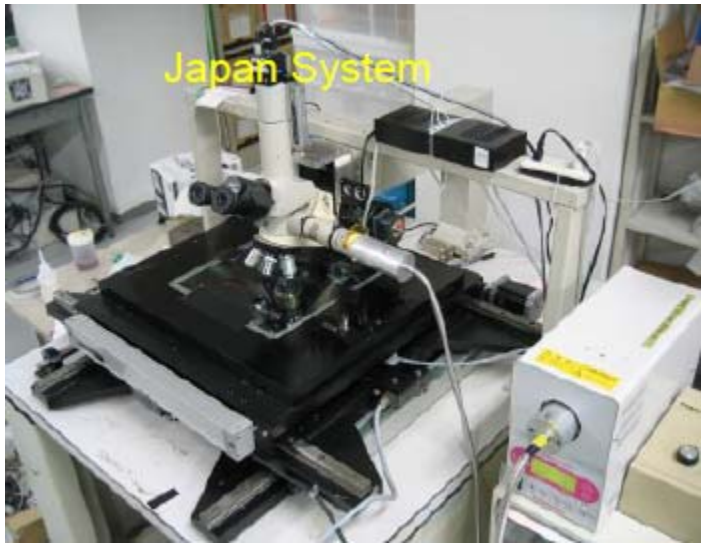


Approaches to directionality detection (2): Nuclear Emulsions

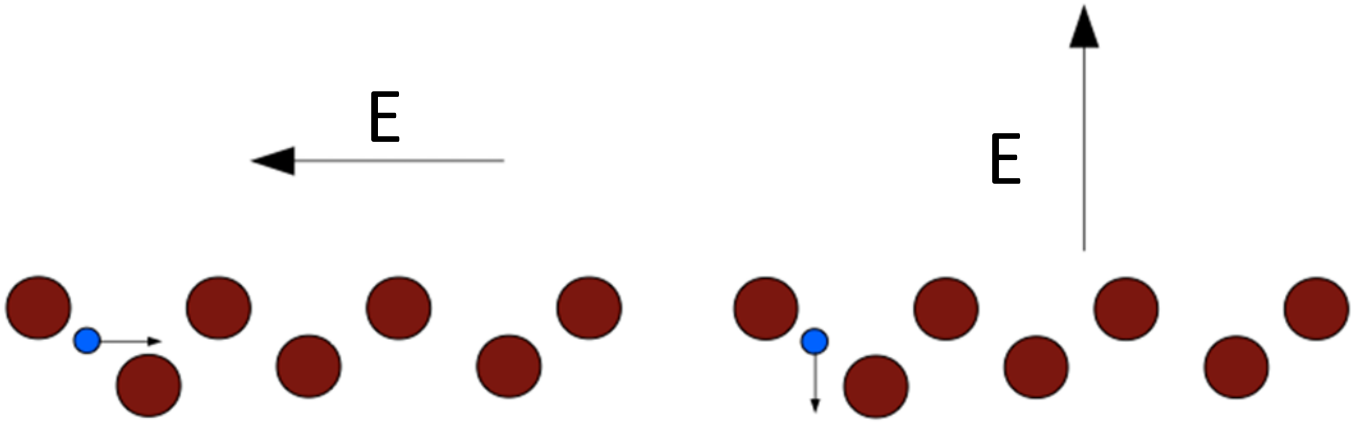
- Tracks O(100 nm) lengths
- Automated scanning required
- Masses 1-10 kg possible
- Integrate over time pointing to Cygnus direction





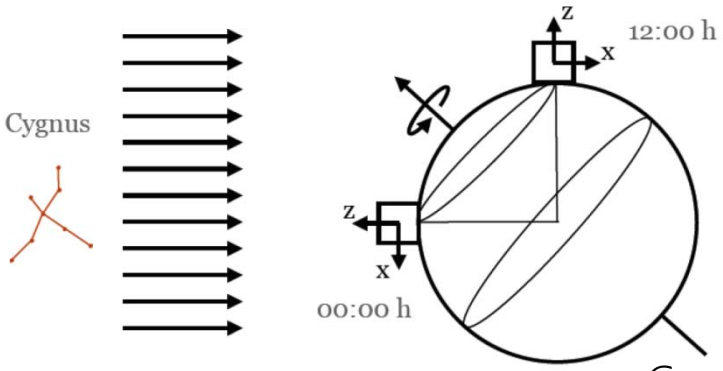


Approaches to directionality detection (3): Columnar recombination and Inferring direction without track image



Case 1:
More Recombination

Case 2:
Less Recombination



Concept by Dave Nygren, LBNL

Molecular additive to xenon: trimethylamine (TMA)

- Enhance intrinsic columnar recombination signal by:
  - Reduction in electron diffusion
  - Transferring xenon excitations to TMA ionizations through Penning
- Enhance measured columnar recombination signal:
  - Increase ten-fold light collection efficiency (with less PMTs): TMA recombination light at ~300 nm converted in WLS bars

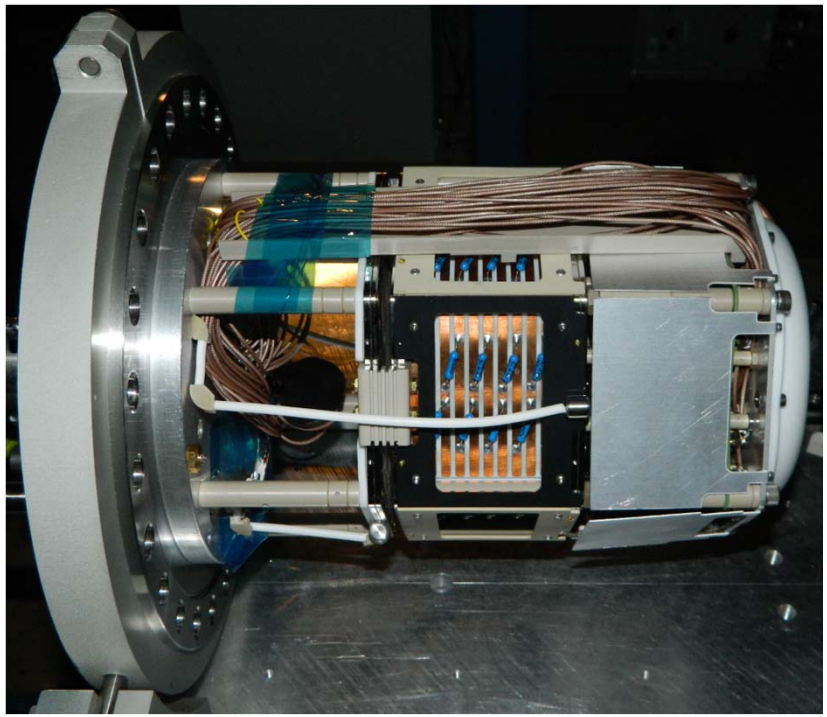
Concept by Dave Nygren, LBNL

R&D menu to explore concept

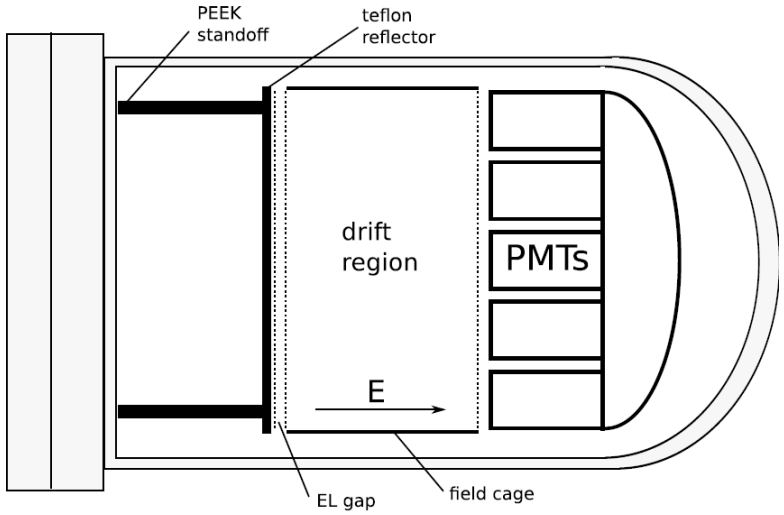
- Nuclear recoils yields in pure high pressure xenon (LBNL)
- Xe + TMA: S1, Electroluminescence, Recombination, Penning transfer (LBNL)
- Xe + TMA: Columnar recombination in 2-10 mm long alpha-particle tracks (Zaragoza)
- Simulation of micro-physics of columnar recombination (LBNL)
- Angular (Field-Recoil) dependence of yields for nuclear recoils using high-energy pion beam (FNAL)

Light and charge yield of nuclear recoils in high pressure (10-15 atm) xenon

- text

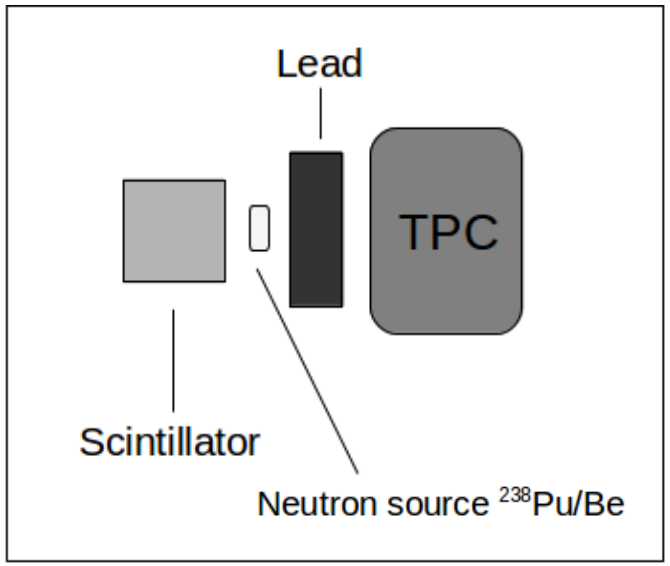


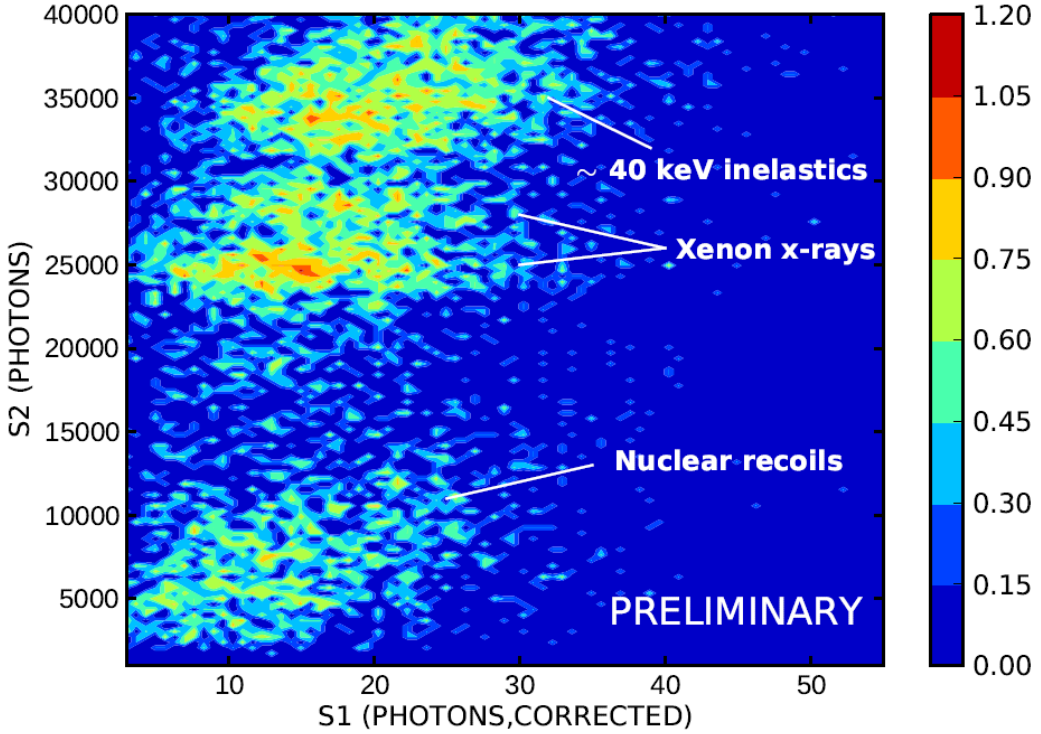
8 cm

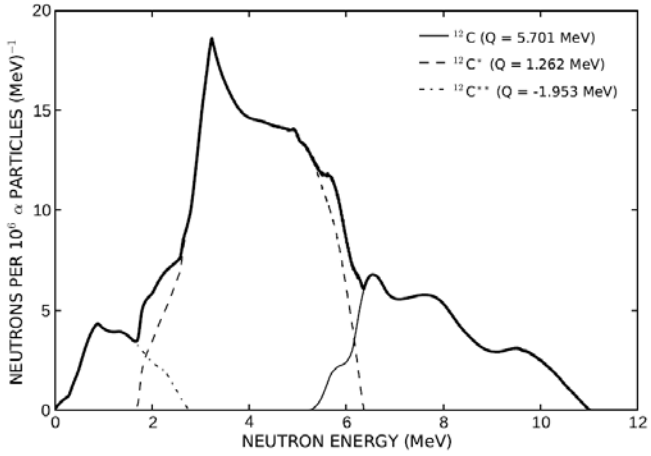


Joshua Renner, LBNL

Light and charge yield of nuclear recoils in high pressure (10-15 atm) xenon







Joshua Renner, LBNL

Light and charge yield in high pressure xenon

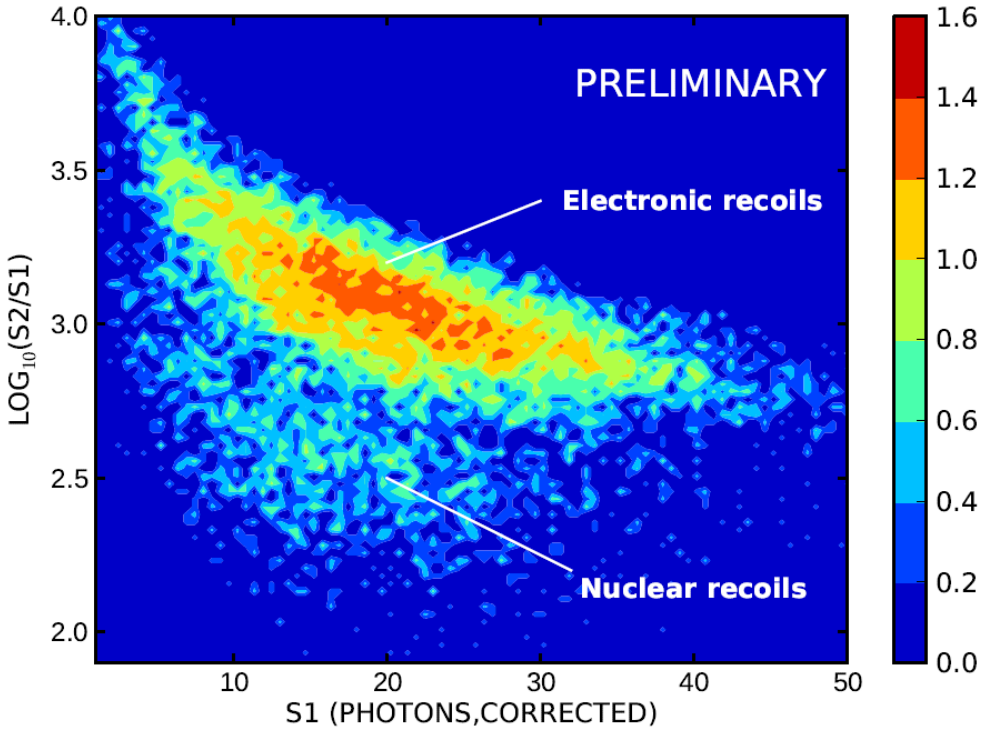


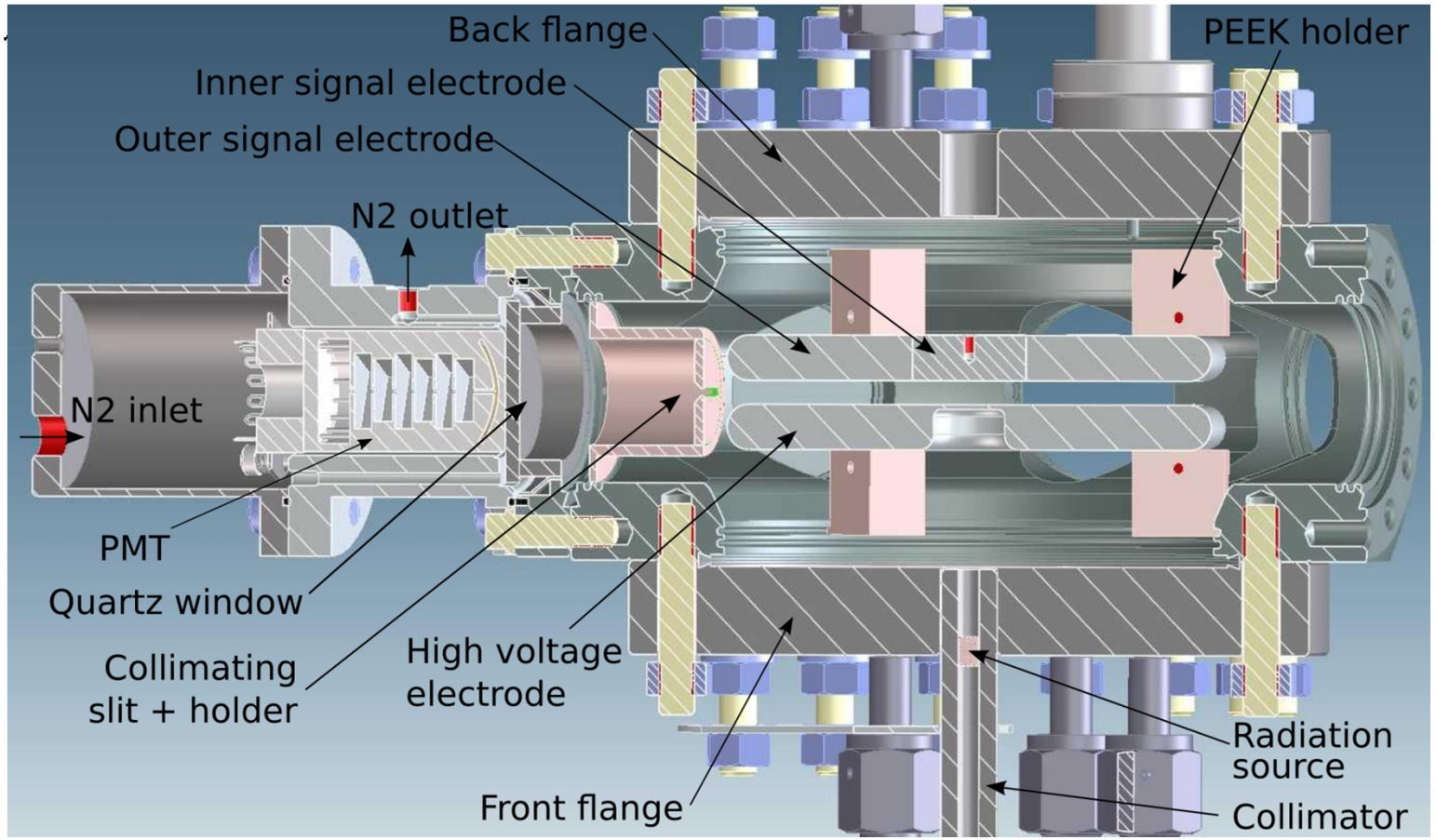
Table for 80 keV NRs	HPXe (14 Atm, 370 V/cm)	LXe (370 V/cm) –NEST-
NR S1 yield (photons/keV)	9.5	12.4
NR S2 yield (electrons/keV)	6.4	2.5
$(S2/S1)_{e^-}/(S2/S1)_{NR}$	3	5

*Currently exploring lower drift field values

PRELIMINARY

Joshua Renner, LBNL

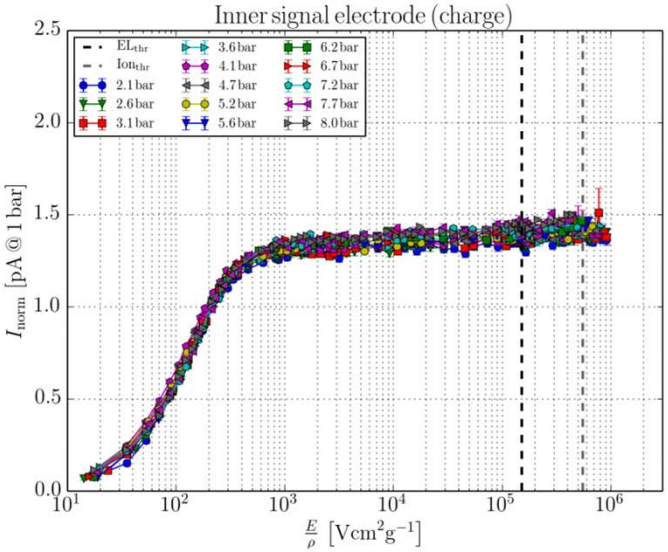
Xe+TMA: S1, Electroluminescence, Recombination, Penning transfer

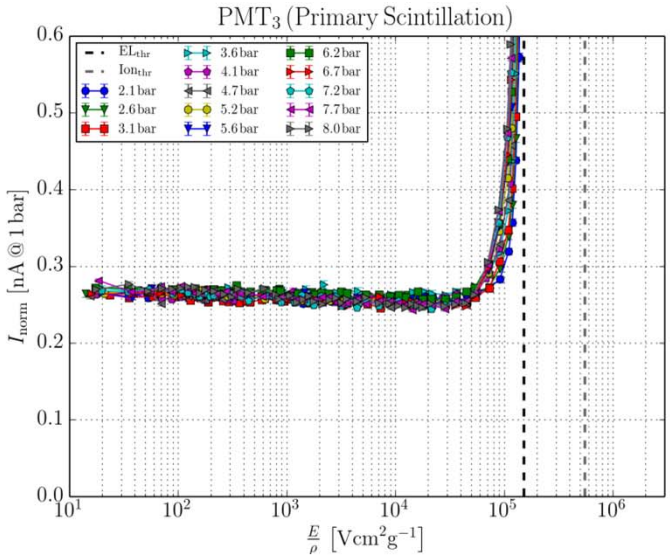
- 

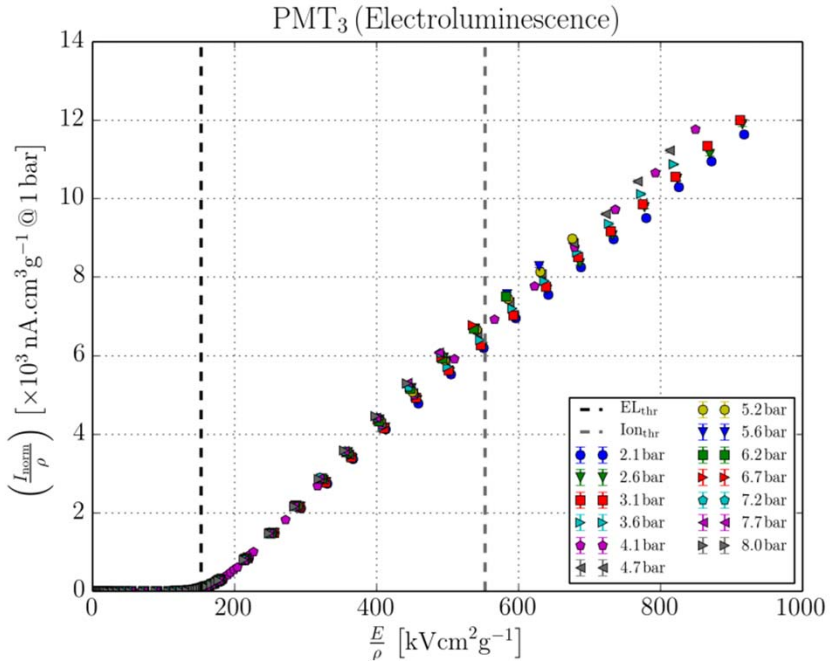
DC measurement of current on PMTs and electrode to ionization from 60 keV gammas

Carlos Oliveira & Tom Miller, LBNL

Pure xenon benchmark



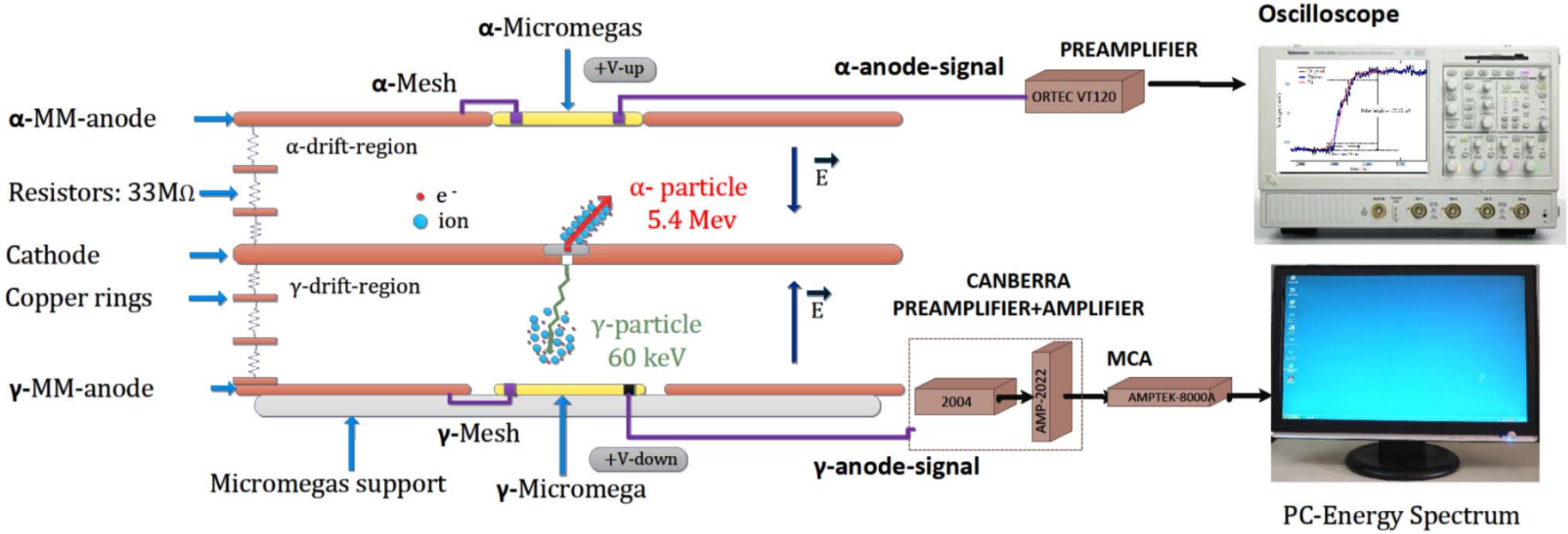




Very good agreement with expectation.
Recently started Xe+TMA campaign

Carlos Oliveira, LBNL

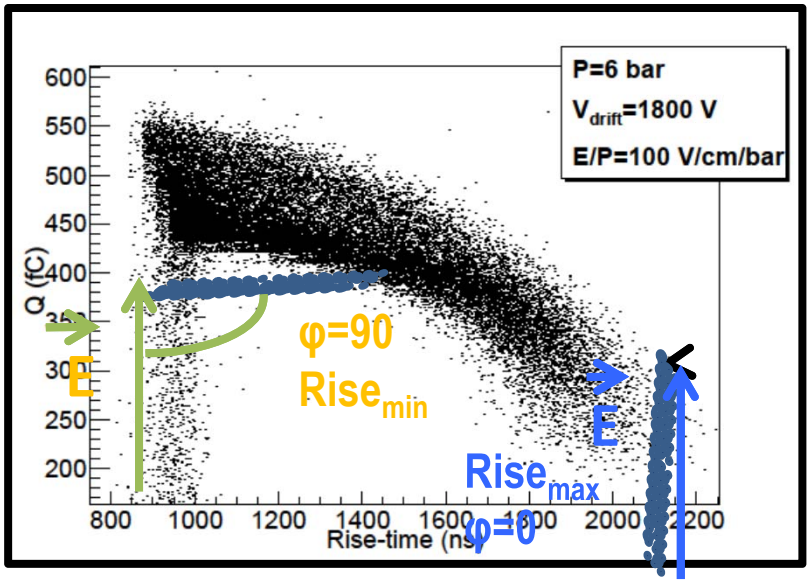
Xe+TMA Columnar Recombination: α-particles



α-anode-signal: Pulse shape Analysis
Pulse-heigth vs rise-time
Measurements: Scanning drift field
-From 3 to 10 bar

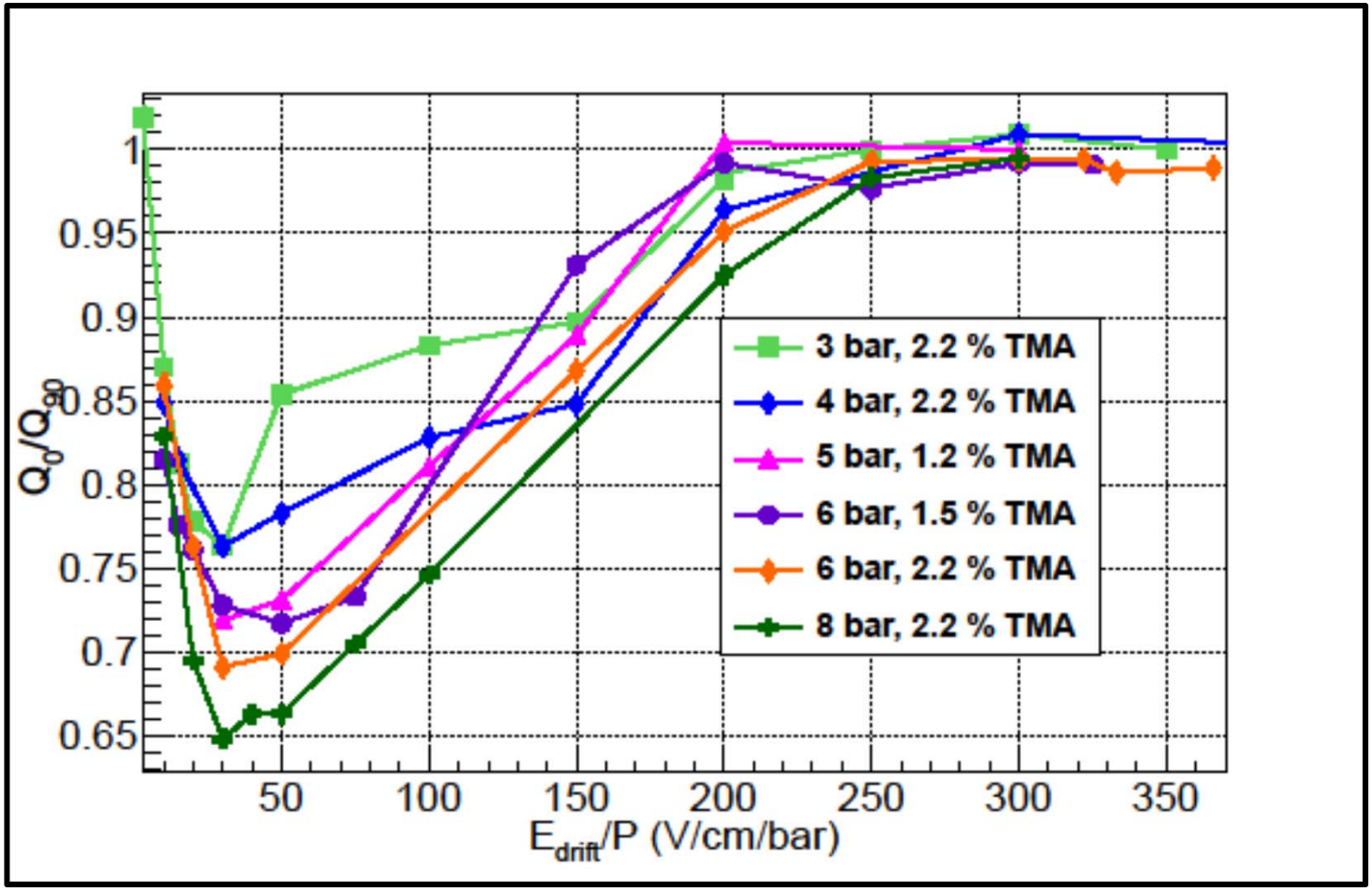
Results

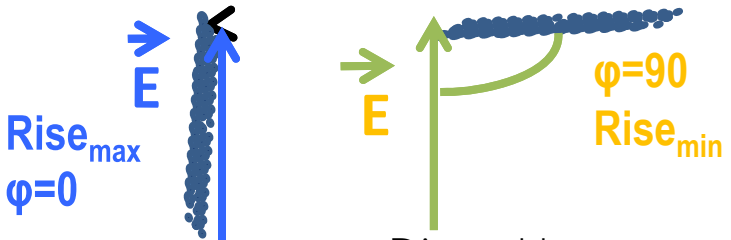
Charge vs rise-time
Charge depends on rise-time
Compatible with columnar recombination



Diana Herrera and Diego Gonzalez, U. of Zaragoza

Xe+TMA Columnar Recombination: α-particles



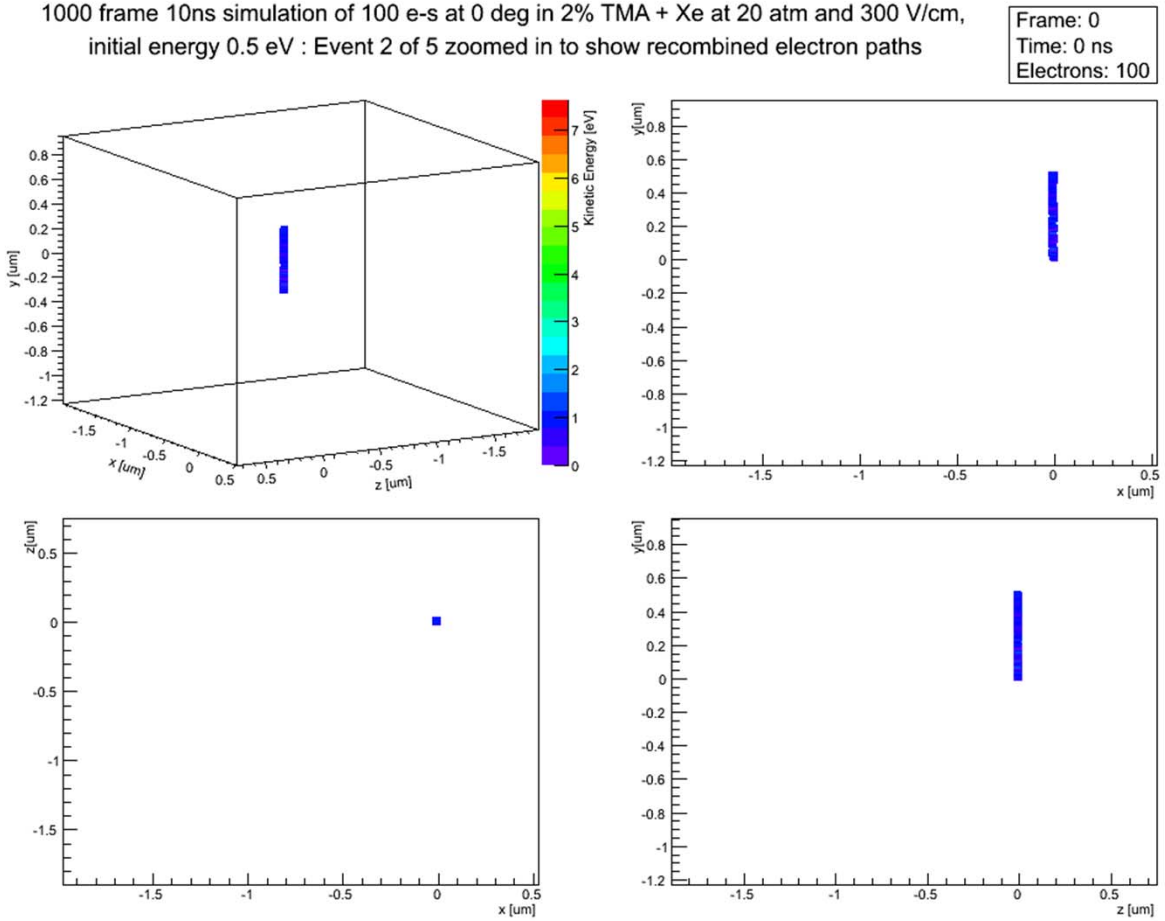


Diana Herrera and Diego Gonzalez, U. of Zaragoza

Recombination simulation

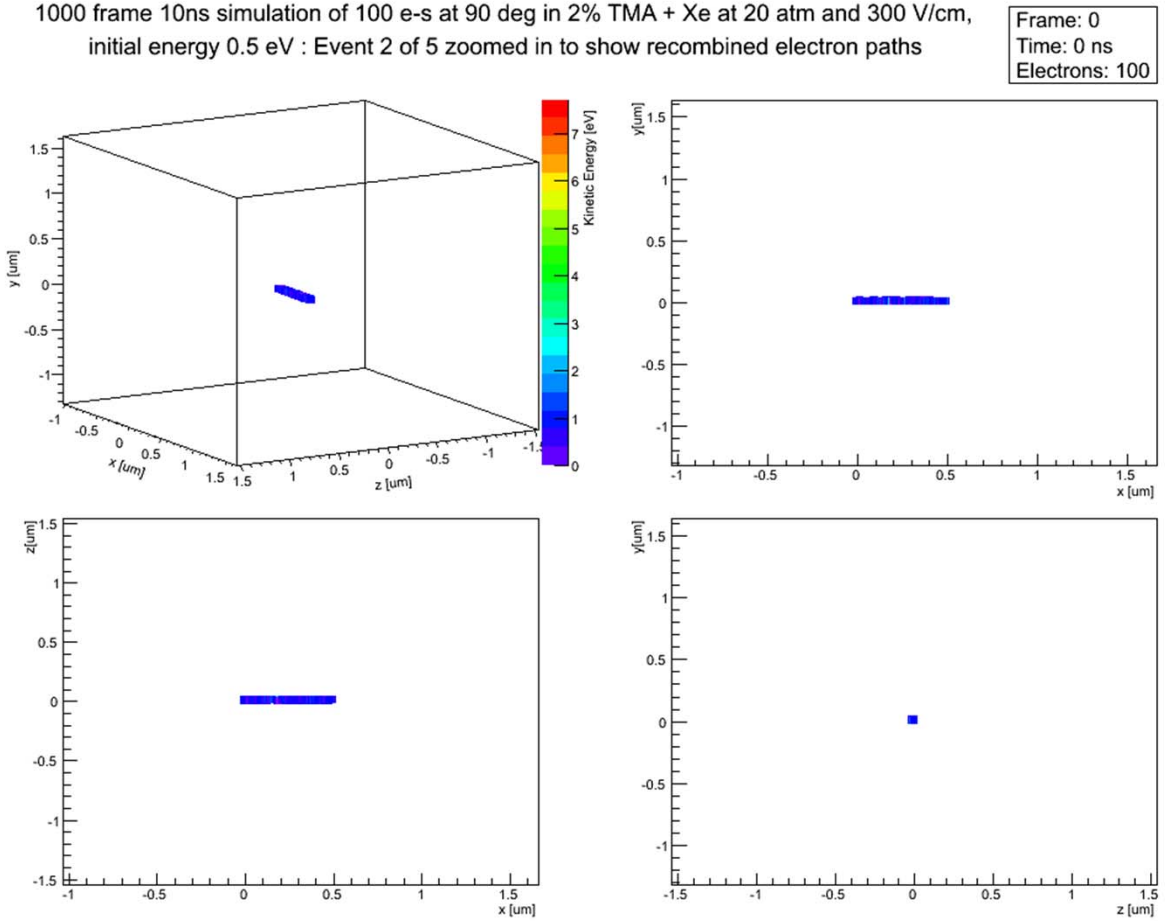
- Garfield++ with Magboltz cross sections for Xe and TMA
- Electrostatic interactions between all charges (ions and electrons)
- Define energy spectrum of ionization electrons
- Simplified nuclear recoil ionization tracks (equidistant ions at expected linear density)
- Recombination condition (negative total energy of electron)
- Use large Carver cluster (NERSC) of computers

Xe + 2% TMA: Field and Track Parallel Simulation



Megan Long, LBNL

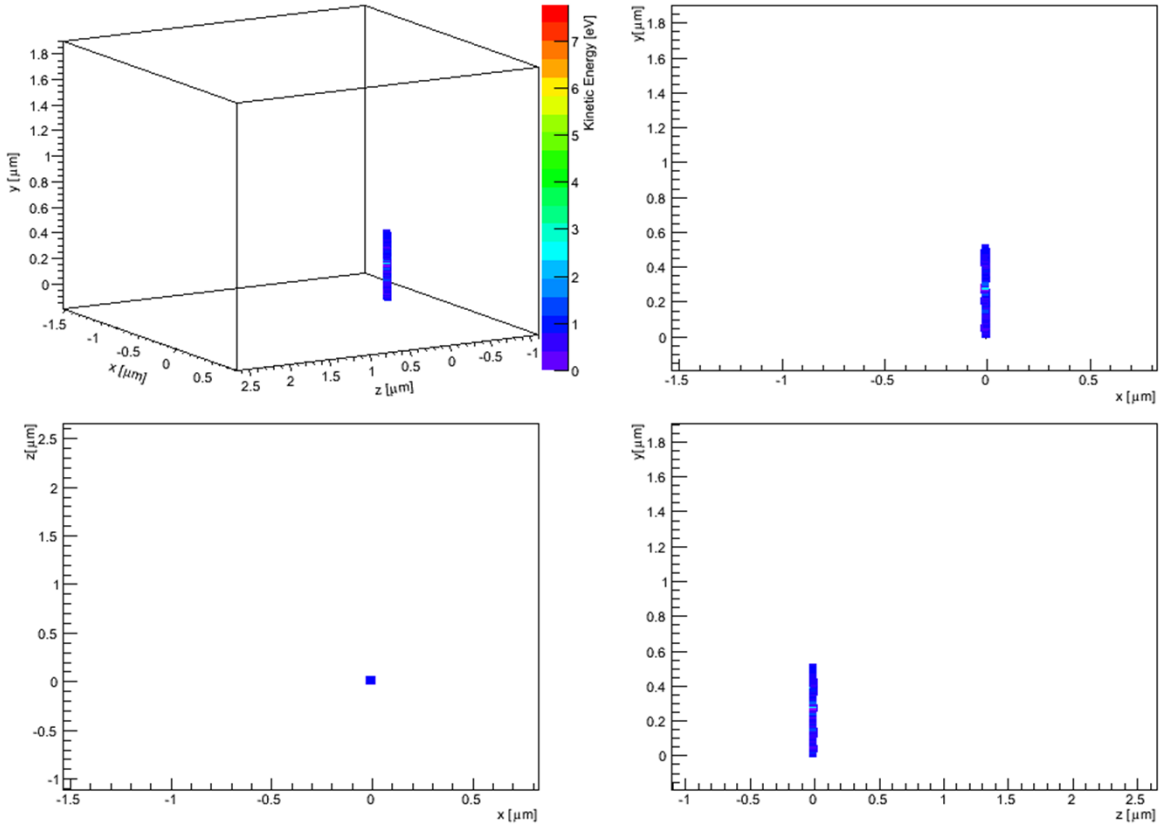
Xe + 2% TMA: Field and Track Perpendicular Simulation



Megan Long, LBNL

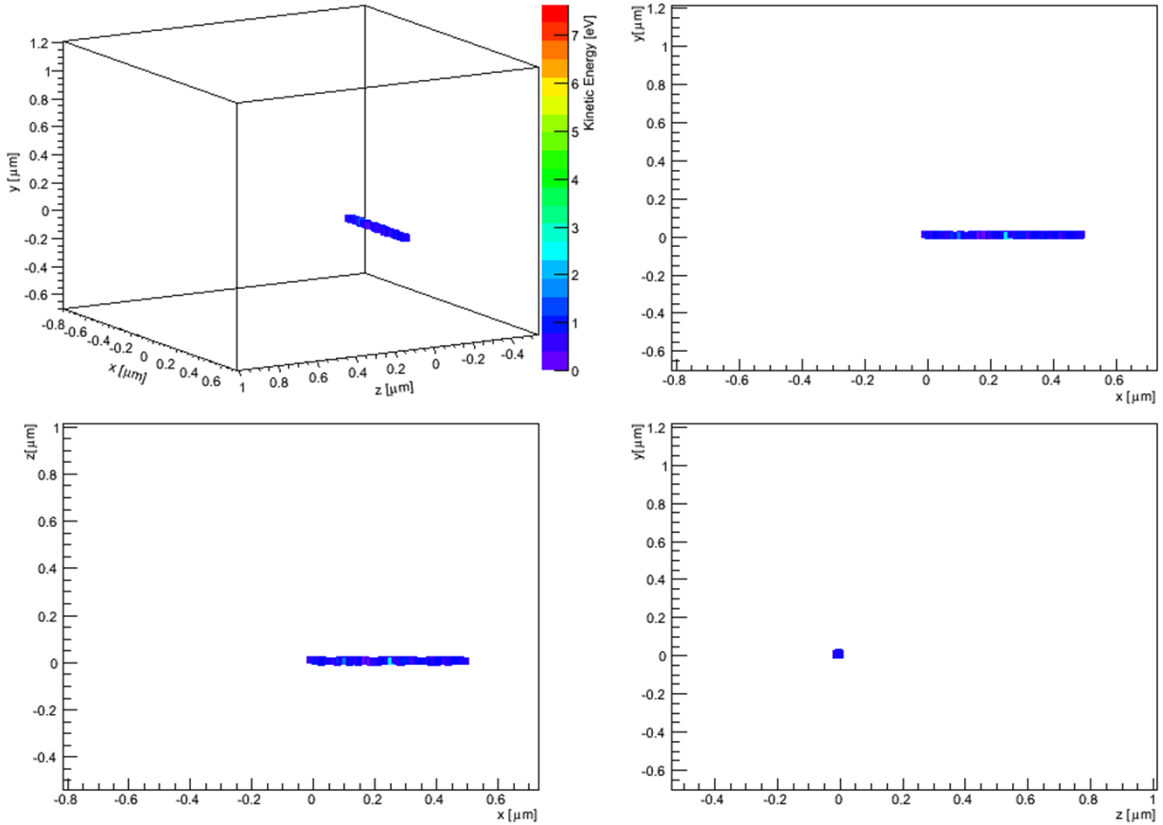
10 frame 0.02 ns simulation of 100 e⁻s at 0° w.r.t. the electric field of 1000 V/cm along -ŷ
2% TMA + 98% Xe at 20 atm with initial electron energy of 0.5 eV
Event 2. Black crosses represent non-recombined ions.

Frame: 0
Time: 0 ns
Electrons: 100

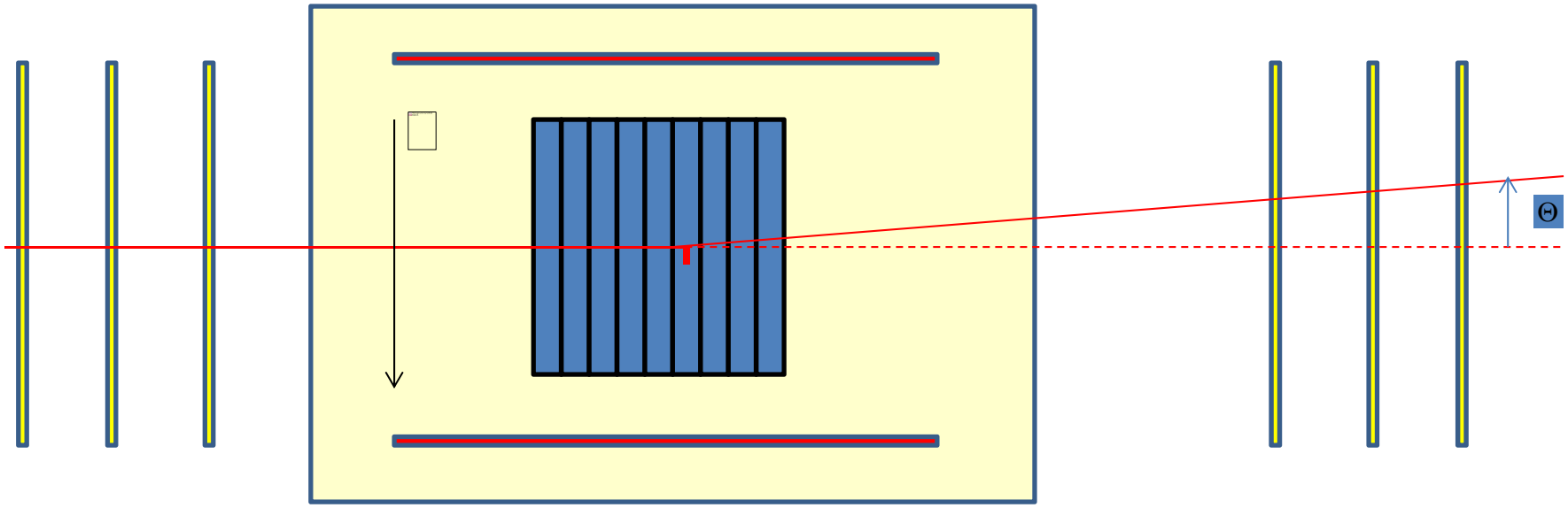


10 frame 0.02 ns simulation of 100 e⁻s at 90° w.r.t. the electric field of 1000 V/cm along -ŷ
2% TMA + 98% Xe at 20 atm with initial electron energy of 0.5 eV
Event 2. Black crosses represent non-recombined ions.

Frame: 0
Time: 0 ns
Electrons: 100



Plan for direct test at FNAL using high-energy pion beam



$$p_{rec} = p_T = E_b \Theta$$

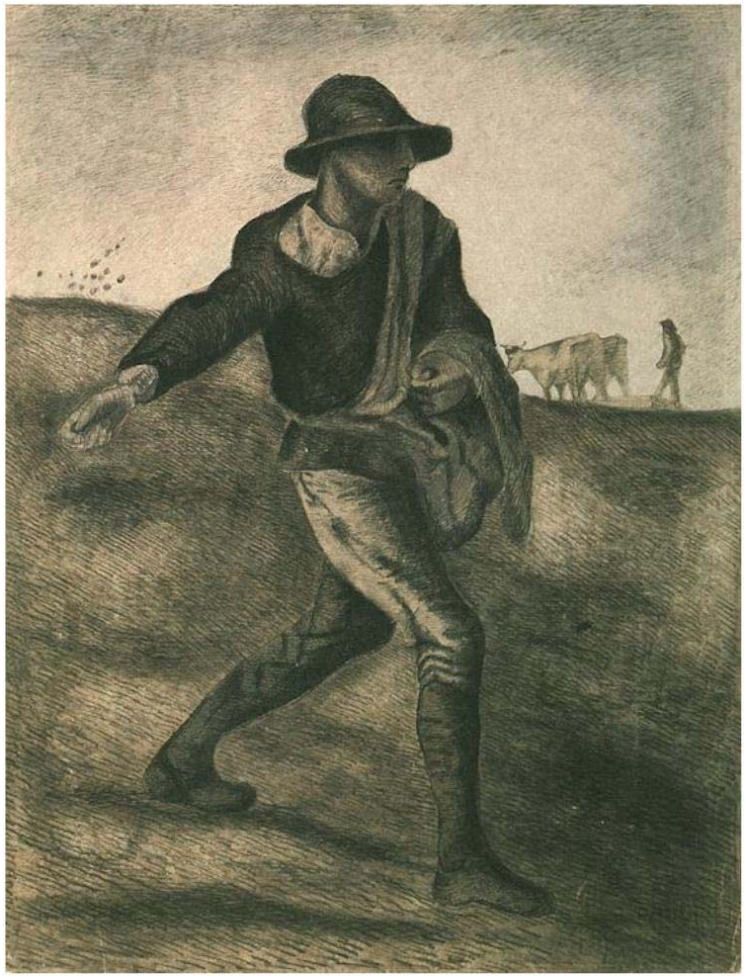
$$E_{rec} = \frac{(E_b \Theta)^2}{2M_{rec}}$$

Adam Para, FNAL

Conclusions

- New concept by Dave Nygren for DM directionality measurement using columnar recombination
- Multiple R&D efforts to test idea:
  - Nuclear recoils in pure xenon characterized
  - Xe+TMA charge and light yields soon to be measured (for EL, S1, Penning and recombination)
  - Columnar recombination observed in Xe+TMA for alpha-particle tracks
  - Microphysics simulations of recombination in ideal nuclear recoil tracks: no sign of yet directionality in the range investigated.
  - Plan for direct measurement of directionality signal in nuclear recoils with high energy pion beam

Thanks Dave
for teaching us the power of ideas-based physics and
for being for me personally the role model
of scientific integrity, diligence, creativity and courage



"The Sower" by Vincent Van Gogh