Directional Dark Matter using LAr

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The case for a directional dark matter detector

- WIMPs are still excellent candidates for particle dark matter

  SUSY WIMPs with masses > 50 GeV - 100 TeV and cross sections: 10^{-45} - 10^{-49} cm^2

  ton to multi-ton scale experiments in preparation will probe the full space of parameters for a WIMP scattering down to the “neutrino floor”

- Observation of a few WIMP-like events might not be enough to claim discovery

  background discrimination

- A sidereal variation of WIMP wind from Cygnus i.e. a substantial anisotropy in nuclear recoils is expected

  no terrestrial background can mimic a sidereal directional modulation

Directionality might be key to the discovery!

Directionality of WIMPs

- WIMP halo → WIMP wind

  Solar system orbit (~230 km/s)

- Annual rate modulation

  Earth orbit (±30 km/s, few % effect)

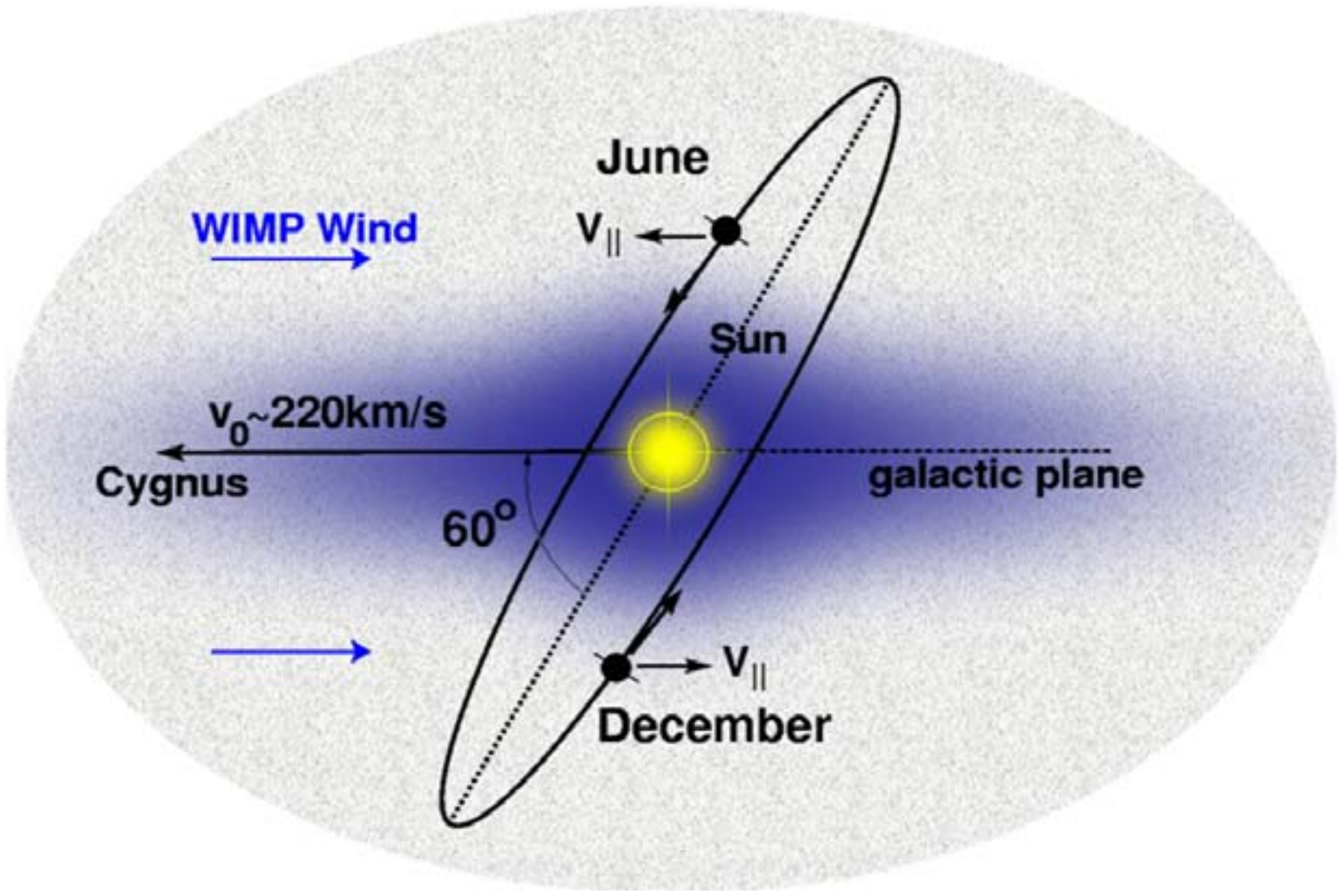
  Background signal may be also annually modulated

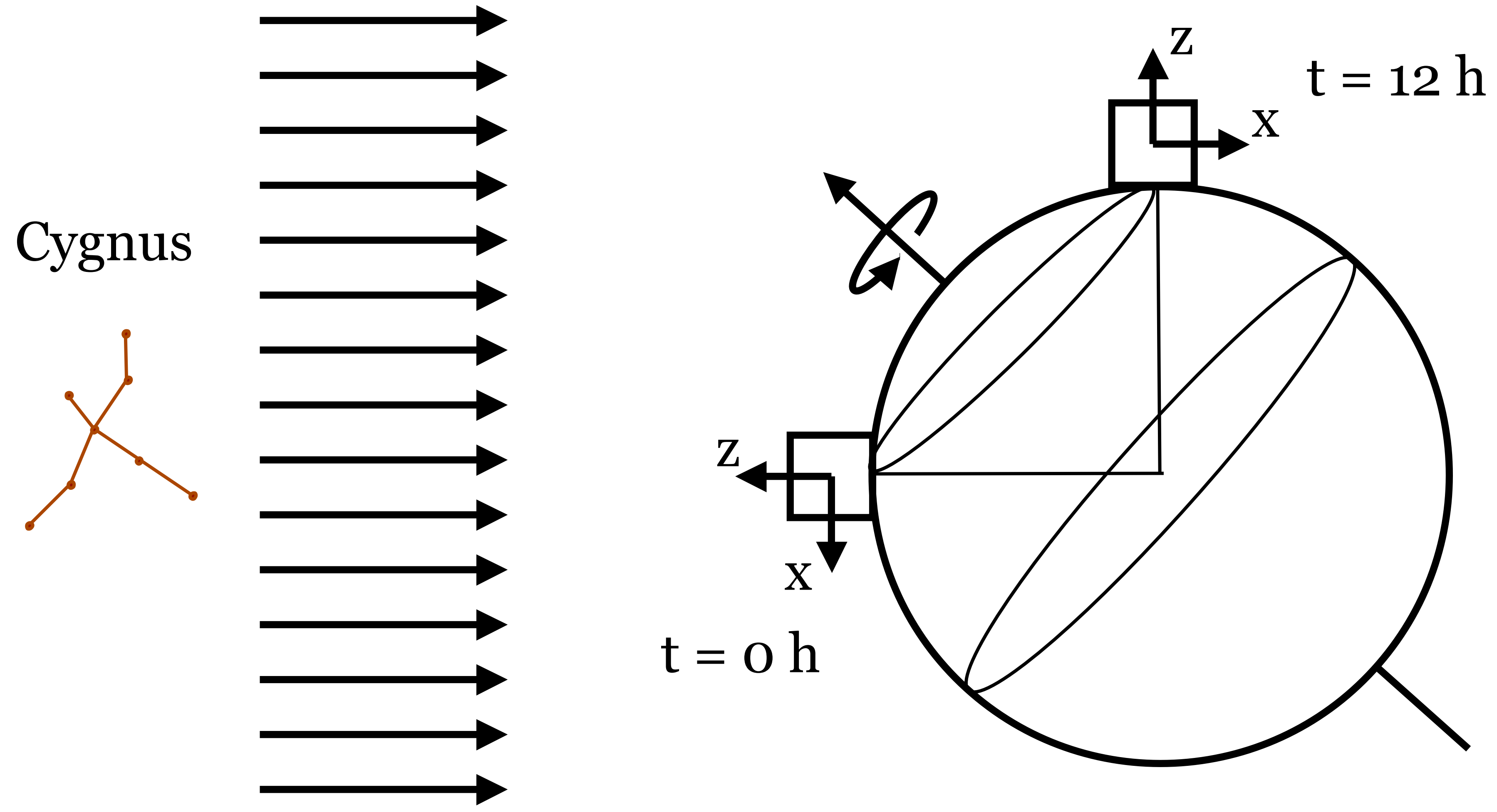
- Sidereal direction modulation

  Angle between WIMP wind & **E**

  Directionality signature (unique to WIMPs)

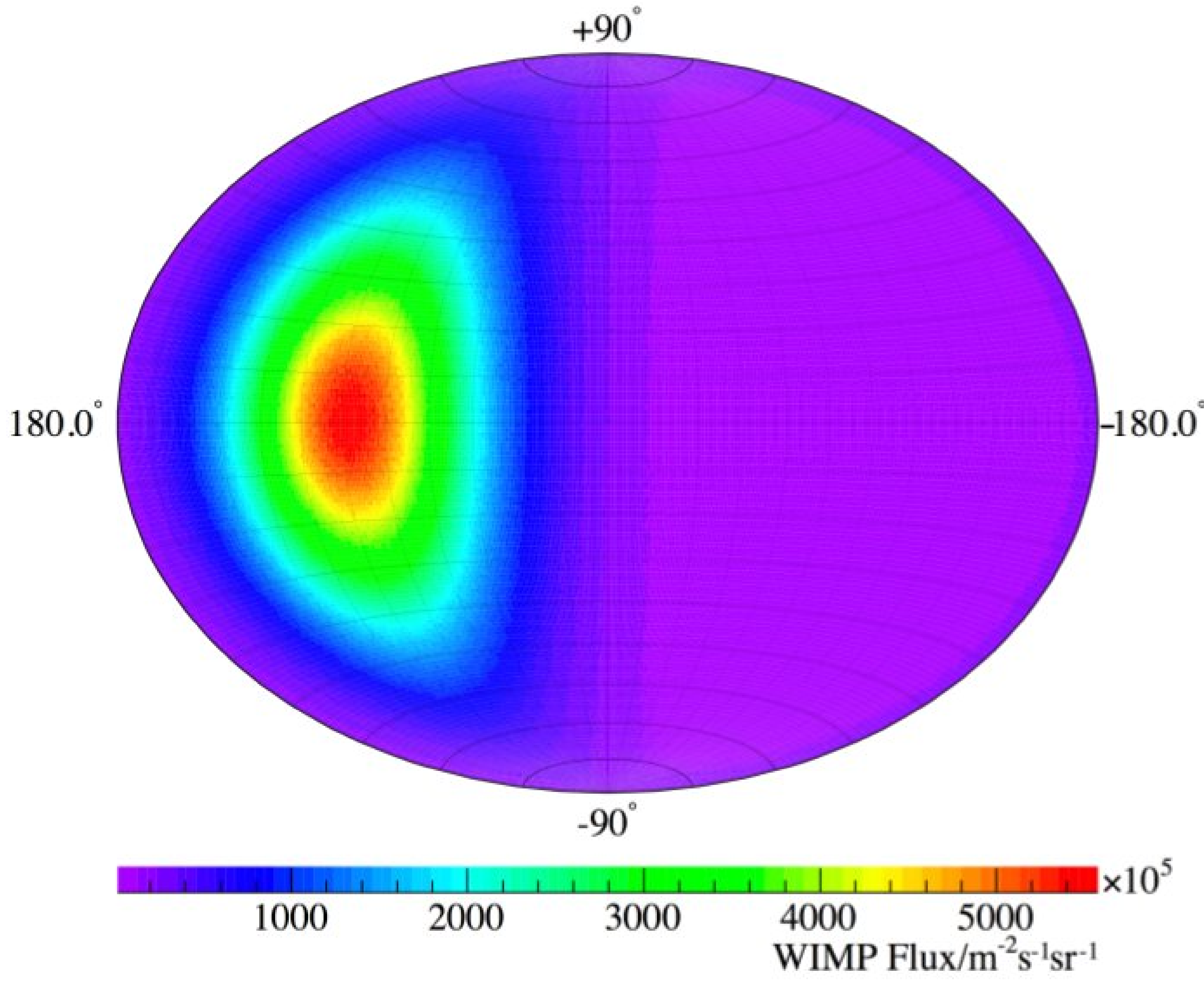
  O(10) rate variation between forward and backward directions (large effect)



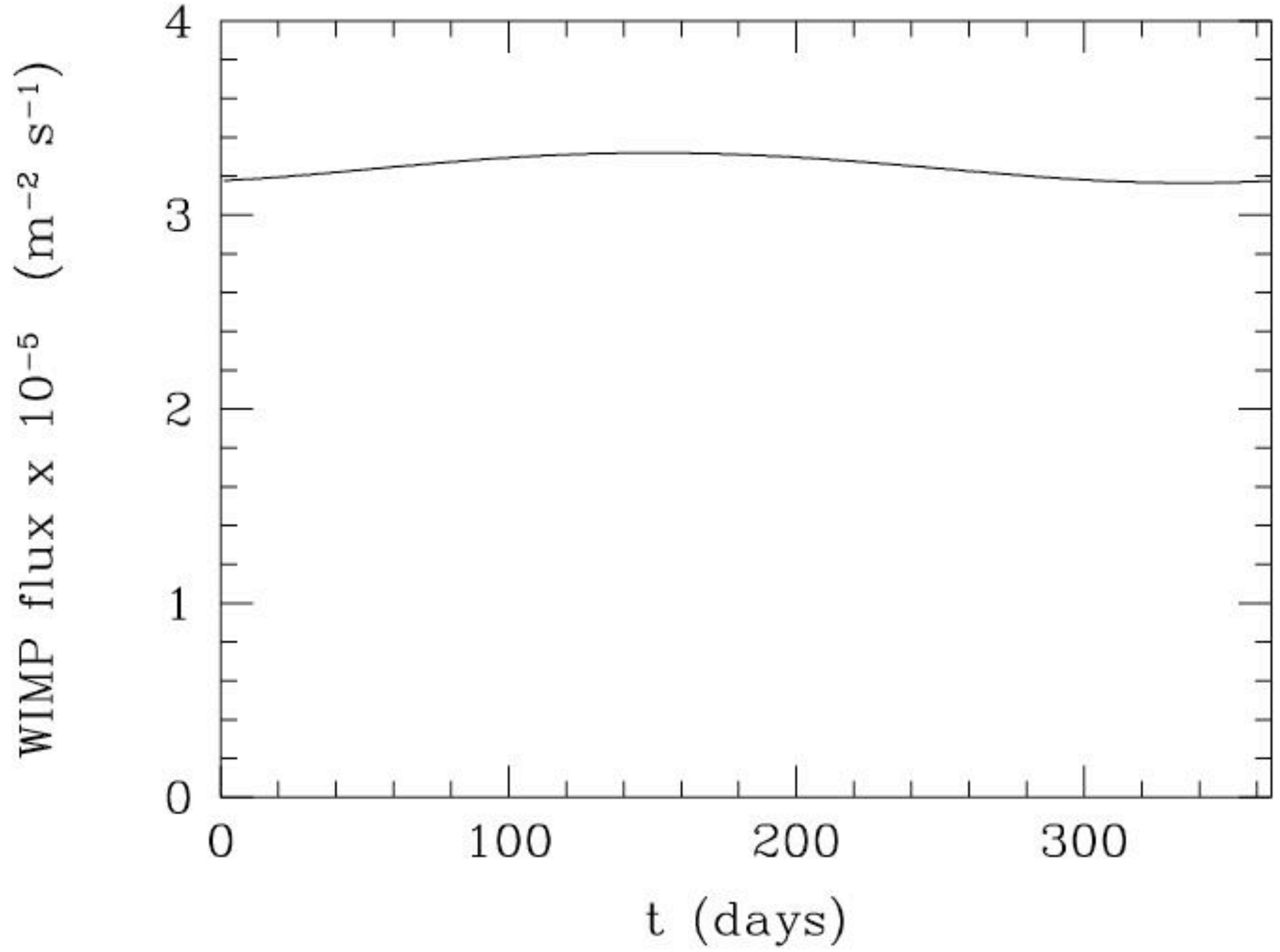


Directional Dependence vs Annual Modulation

Directional signal



Annual modulation signal



Hard for a background to mimic the directional signal.

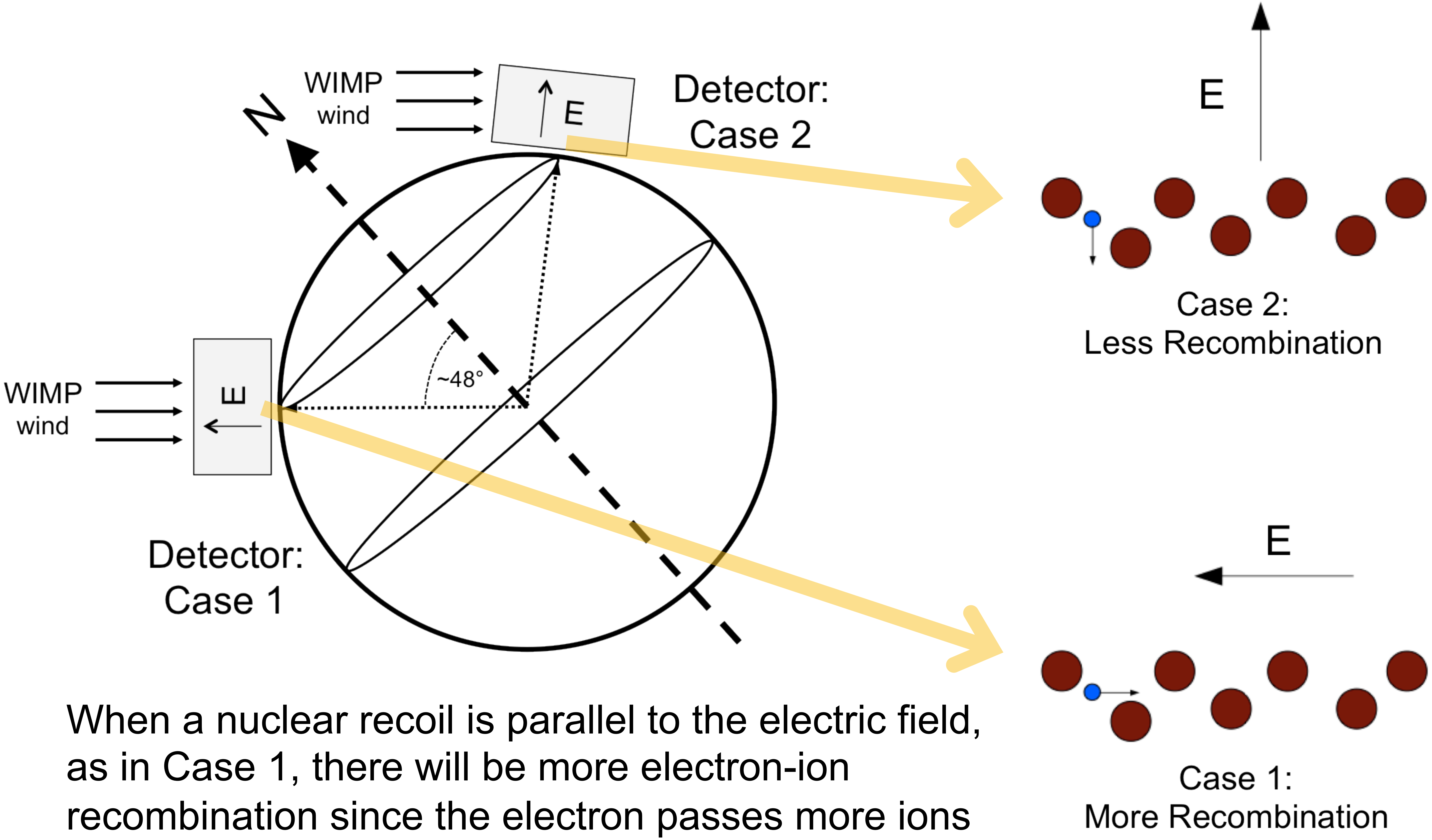
(anisotropic backgrounds in lab are isotropic in Galactic rest-frame)

A WIMP directional signal could (in principle) be detected with of order 10 events

[Copi, Heo & Krauss; Copi & Krauss; Lehner & Spooner et al.]

Towards WIMP Astronomy

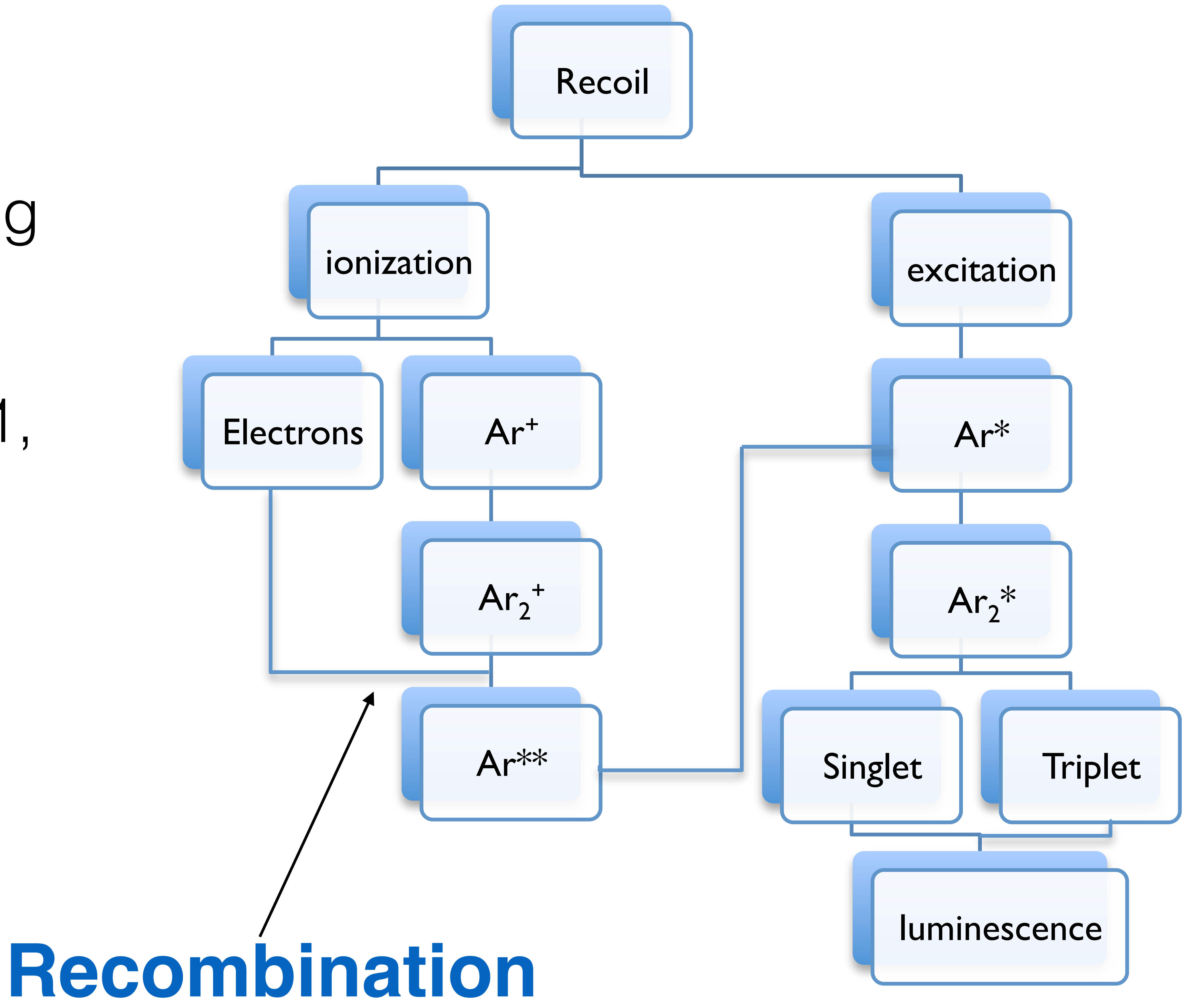
DM & columnar recombination



When a nuclear recoil is parallel to the electric field, as in Case 1, there will be more electron-ion recombination since the electron passes more ions as it drifts through the chamber.

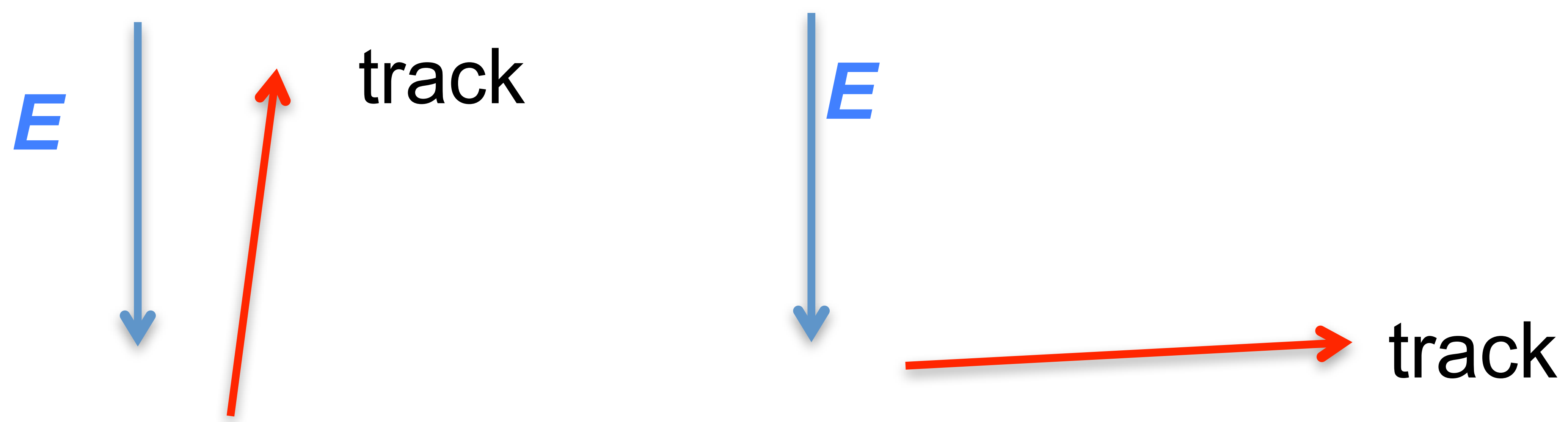
Nuclear recoils in LAr

- Energy ≠ S1: energy deposited into 3 channels (“heat” prominent for NR, reducing their S1 & S2)
- Excitation and recombination lead to the S1, while escaping ionization electrons lead to the S2
- Divisions at each stage are functions of particle type, electric field, and dE/dx or energy



Directional sensing for nuclear recoils?

Columnar Recombination may display a sensitivity to the angle between nuclear recoil direction and drift field ***E*** in a LAr TPC



Substantial CR: more light, less charge

CR small: less light, more charge

"Columnarity" is given by the aspect ratio between the nuclear recoil track range and the Onsager radius $r_O = e^2/\varepsilon KT$

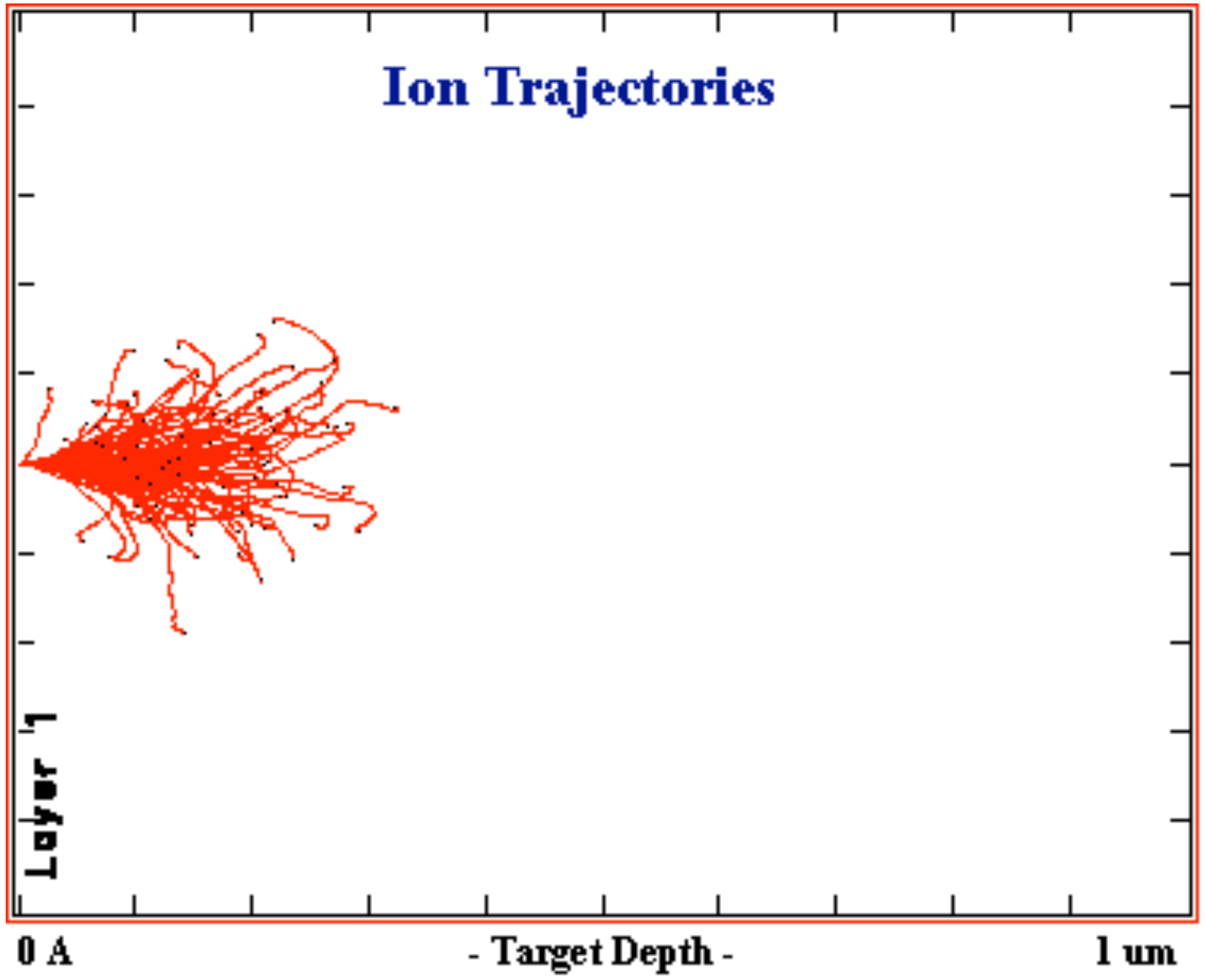
(the distance between a positive ion and a free electron for which the potential energy is balanced by the electron kinetic energy KT)

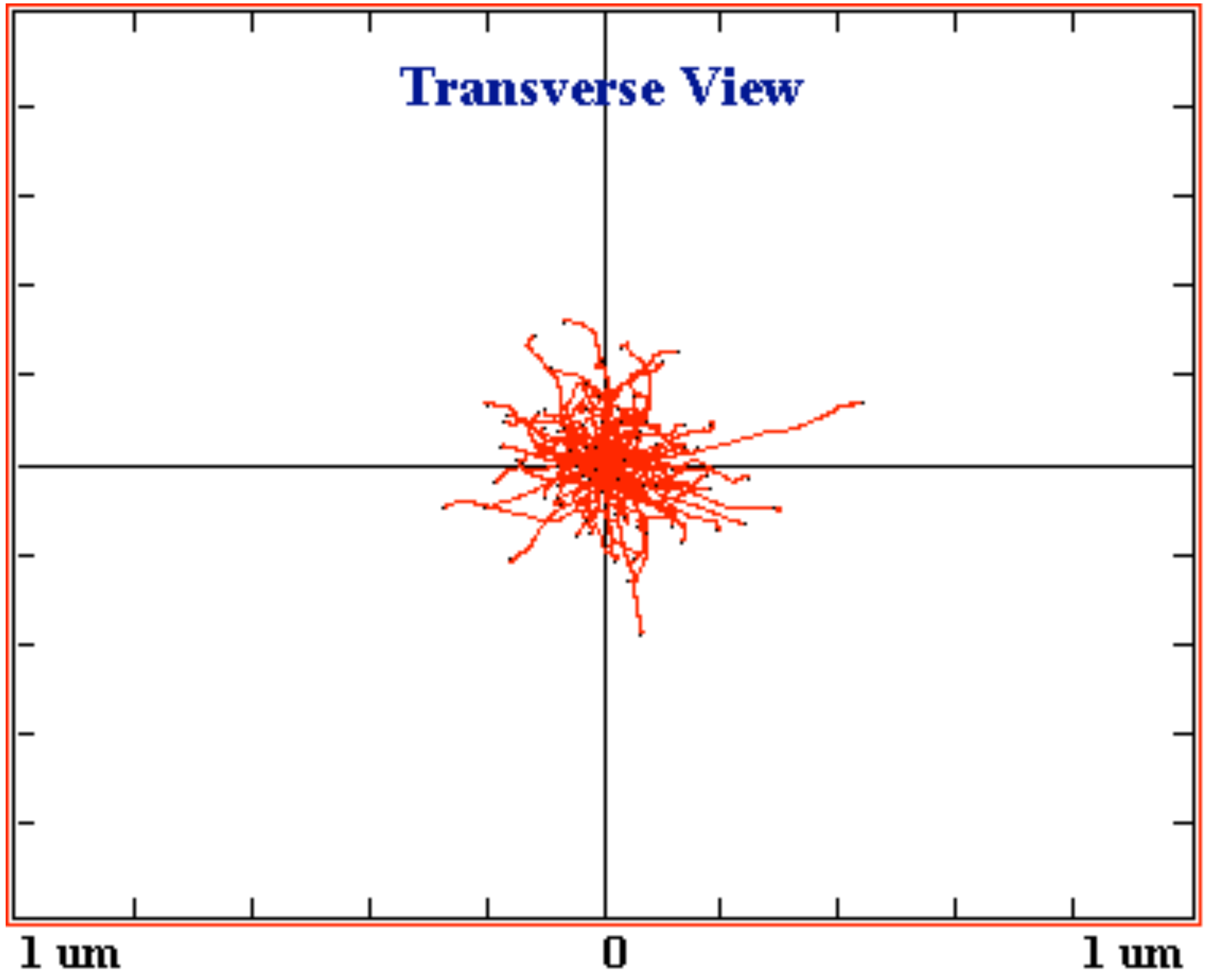
LAr:

$r_O \simeq 80$ nm

range of NR $\simeq$140nm @ 60 keV

Do nuclear recoils retain directionality?





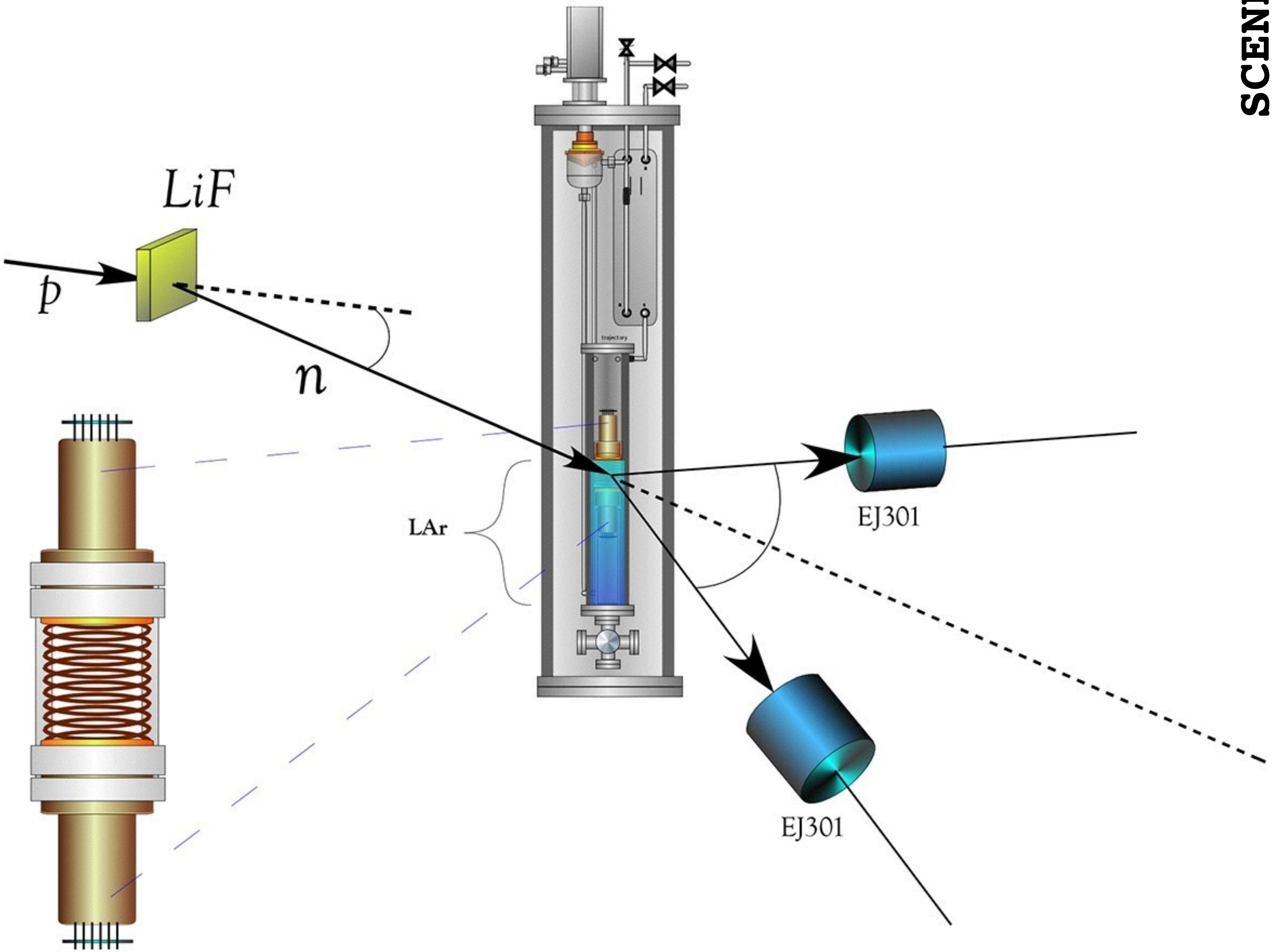
Tracks for Argon ions entering a liquid Argon target with a 60 keV recoil energy
(superposition of 100 tracks of Argon ions originating in the same position and with a momentum whose initial direction is horizontal - SRIM simulation from C. Galbiati and F. Calaprice, WARP internal report, 2005)

A measurement campaign to verify the directional sensitivity of LAr detectors

SCENE concept

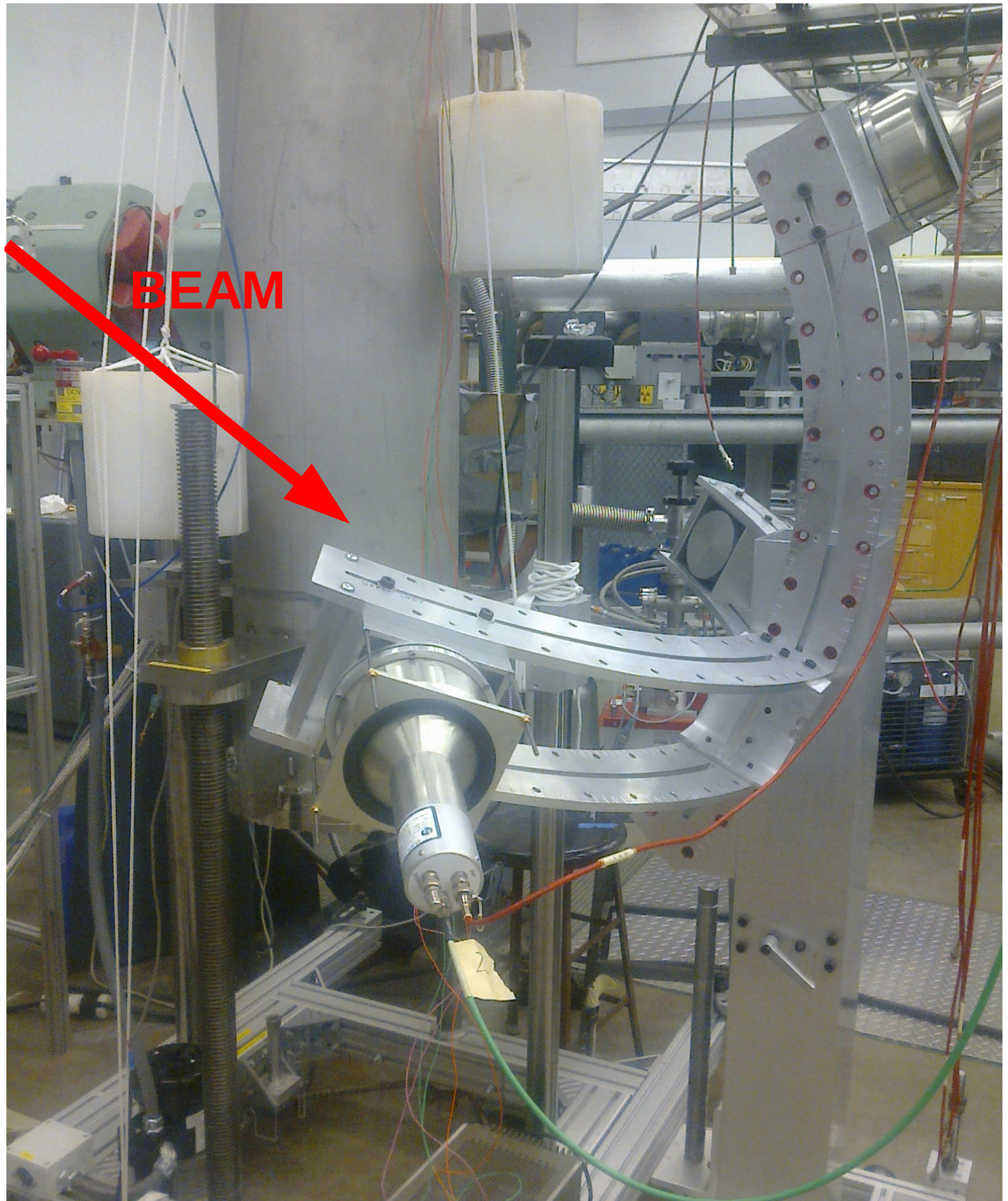
protons on thin LiF target to generate low energy, pulsed, monochromatic neutron beam

TOF between pulse proton beam, LAr TPC, liquid scintillator detectors for detection of scattered neutrons

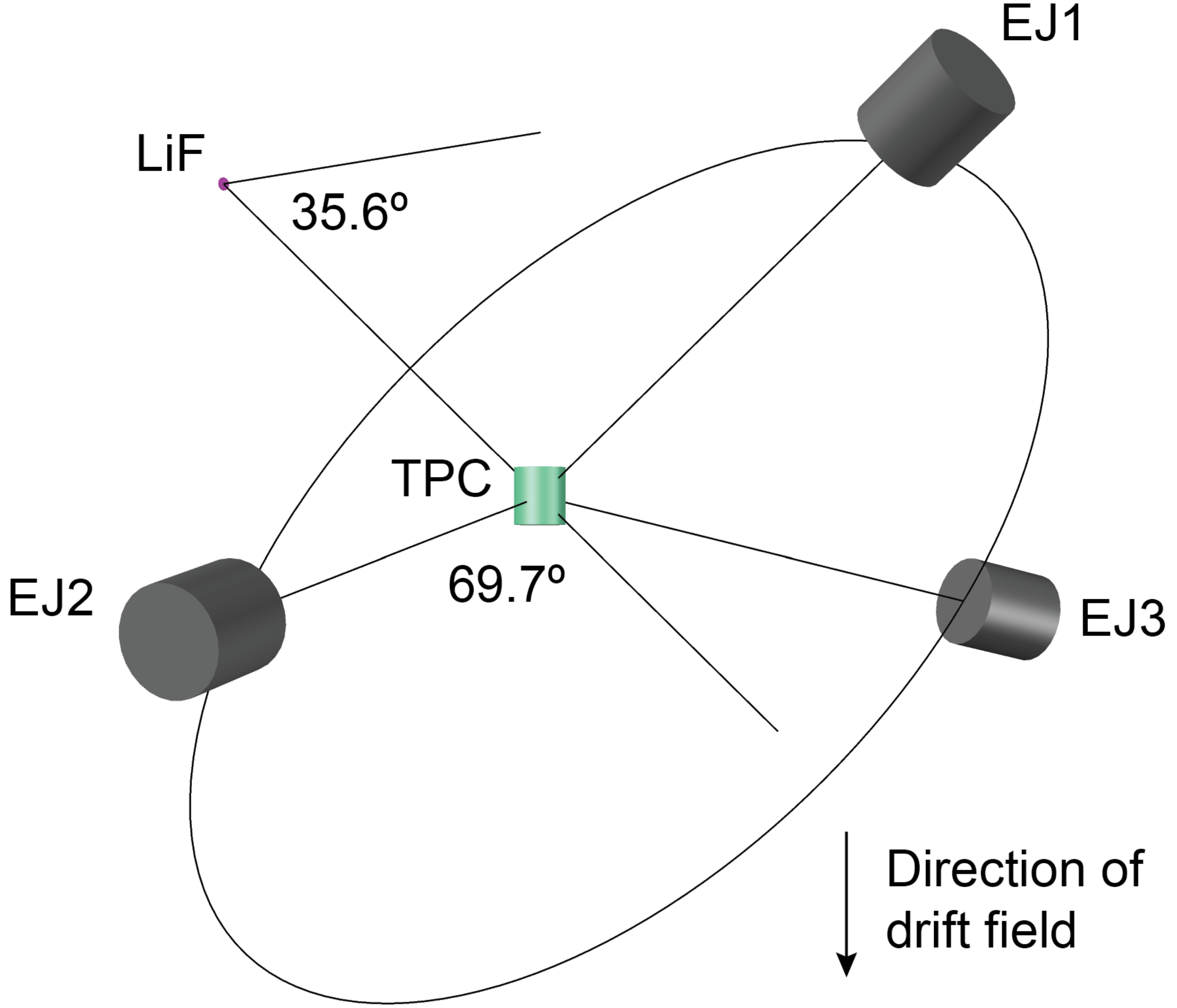


Directionality in SCENE

Accelerated protons on thin LiF target generate low energy, pulsed, monochromatic neutron beam



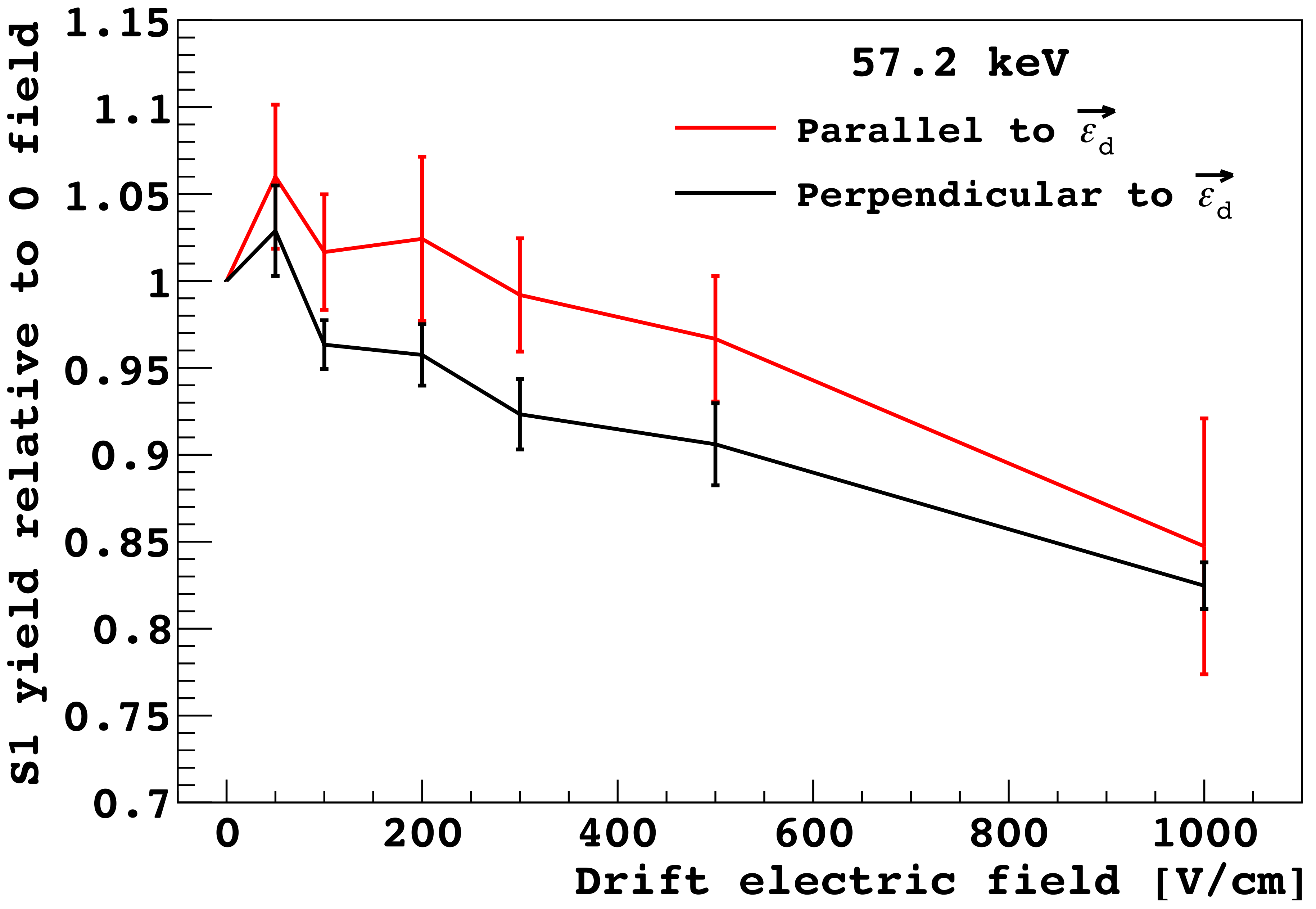
Goniometer mount for the neutron detectors. Data simultaneously accumulated at a given neutron scattering polar angle but with recoils tagged as parallel or perpendicular to the drift field.



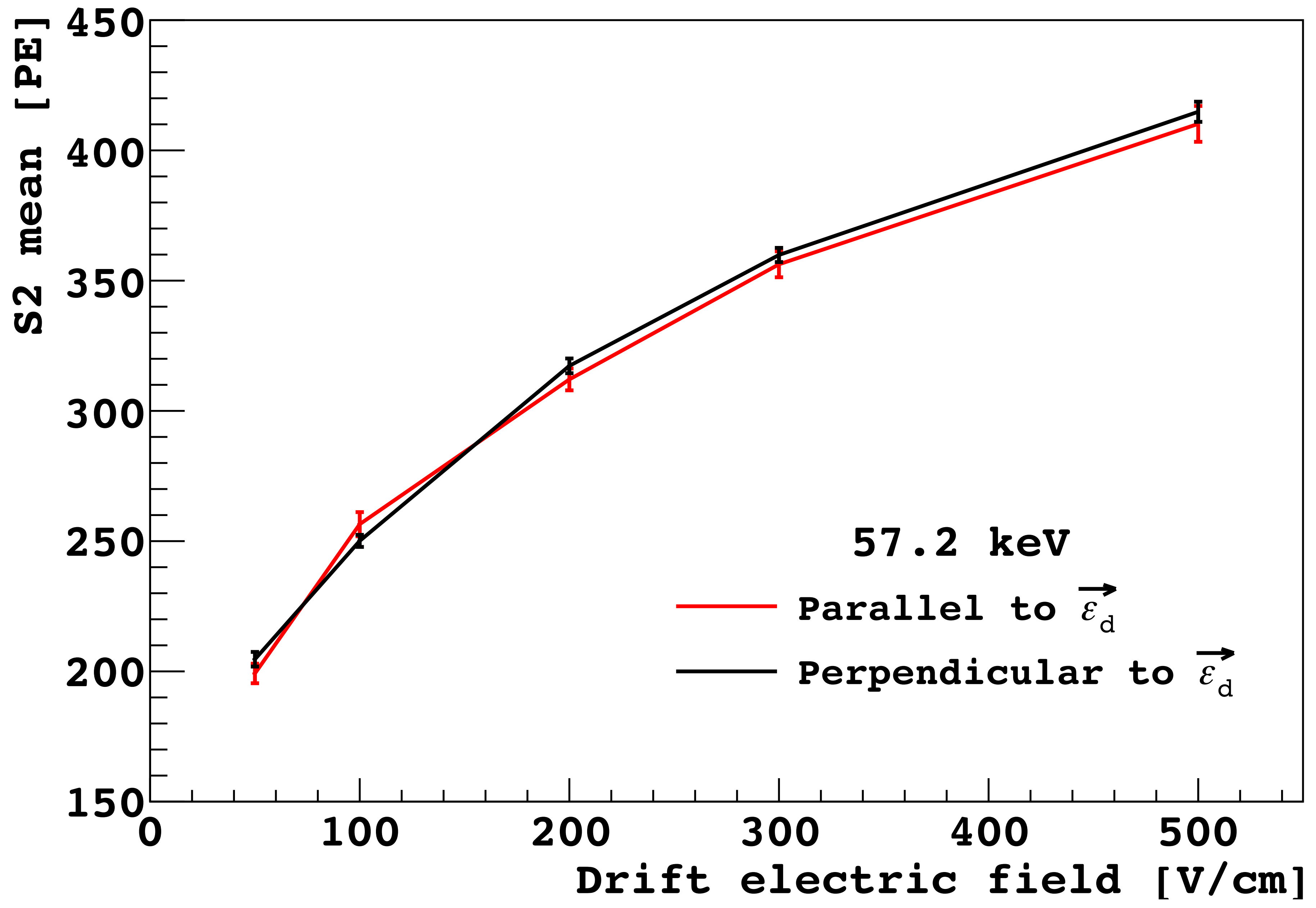
Initial momentum of nuclear recoil tagged by EJ1 is parallel to field
EJ2 & 3 is perpendicular to field

Angular dependence from SCENE

Scintillation



Ionization



Hint for anisotropy of 57.2 keV nuclear recoils

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further investigation with more precise measurements and higher energies

Can we improve the sensitivity?

- Optimize the TARGET (less undesired gammas produced) - ??
- More statistics (more beam time)
- More efficient neutron detectors - ??
- A new TPC

  Photosensor performance (fatigue, resolution)

  Light Yield

  Optimized design: drift length might be enlarged to reduce S1-S2 overlap

SCENE@UNINA

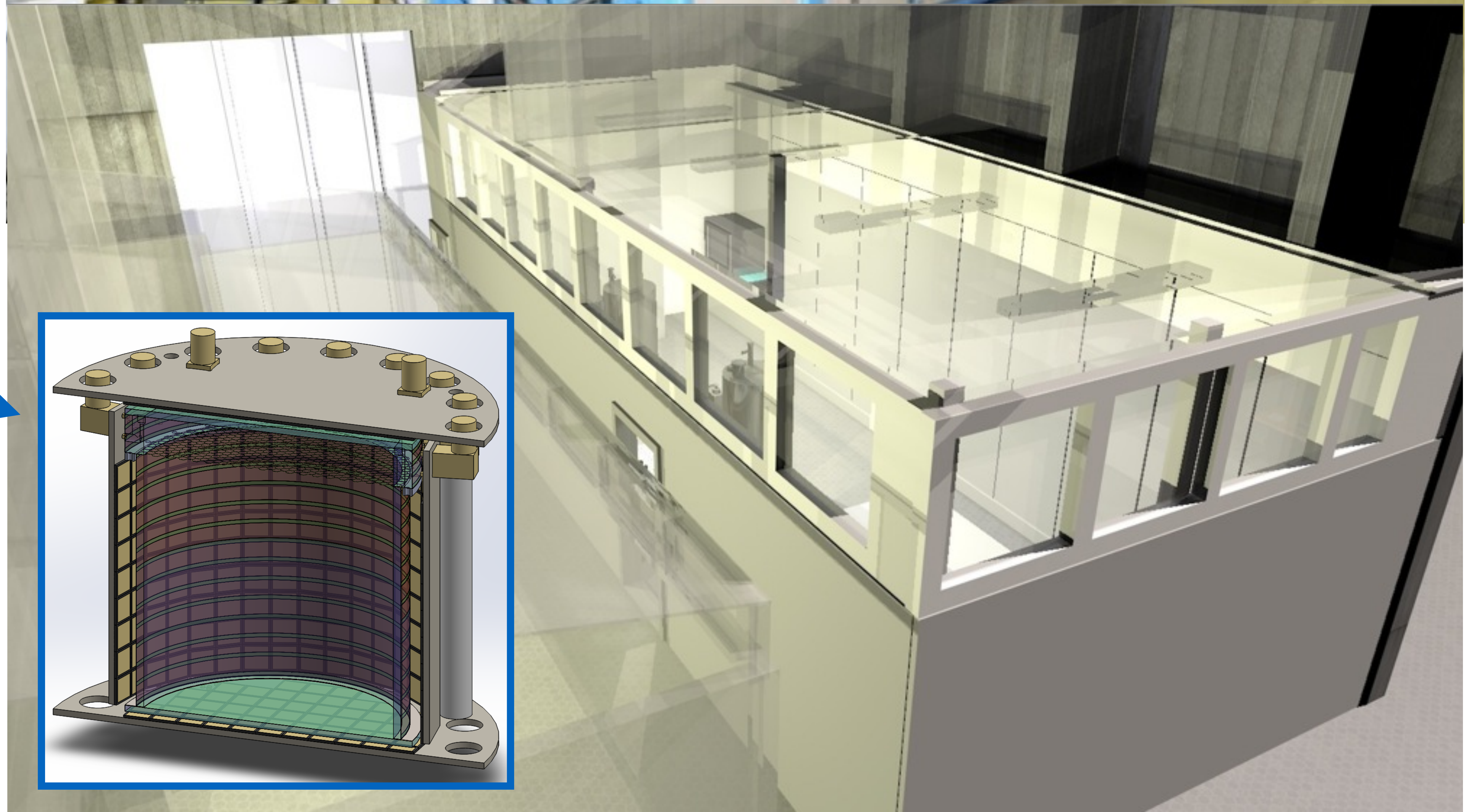
- Pulsed neutron beam at the TTT-3 Tandem accelerator
- Cryolab

  Ar recirculation and purification

  Clean Room facilities
- GAP-TPC: LAr TPC with high performance G-APD readout

  explore scintillation and ionization in LAr with low energy NR

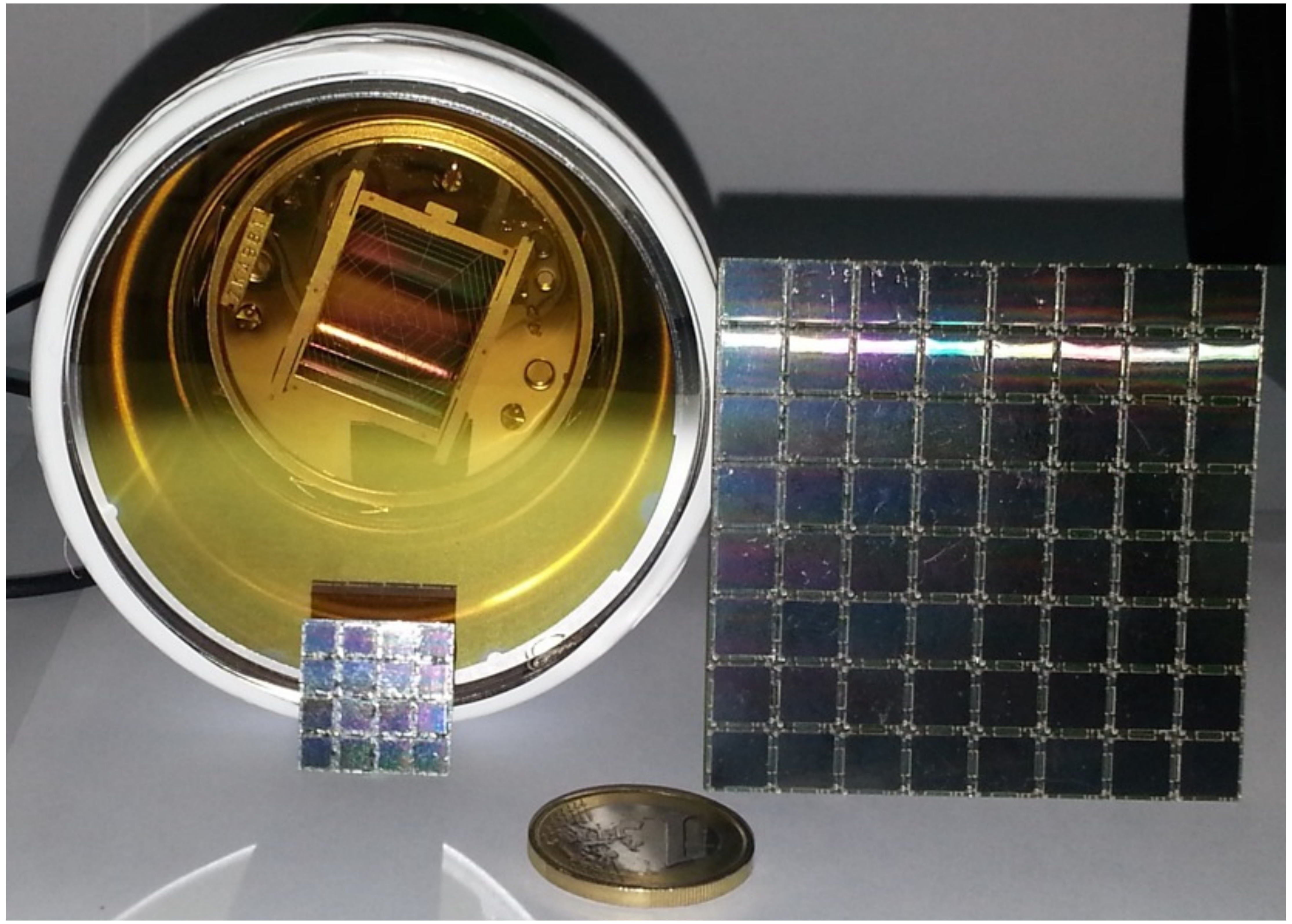
  assess CR as a function of angle between track and field



GAP-TPC

Geiger mode-Avalanche Photodiode TPC

Large area G-APD arrays instead of 3'' Hamamatsu R11065 PMTs

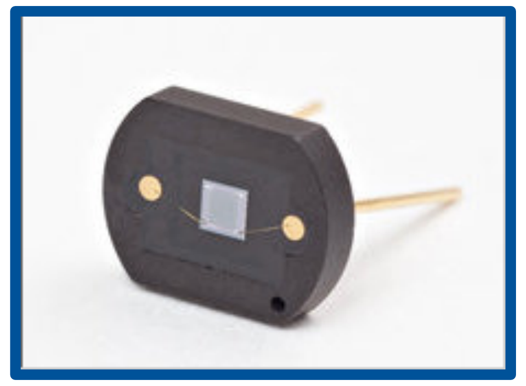


- Current commercial solutions (SensL, Hamamatsu, Advansid, etc.)
- Sensitive area equivalent to 3'' PMT
- Cheap, robust, compact
- No fatigue but higher dark rate
- Very high resolution to SPE (few %)

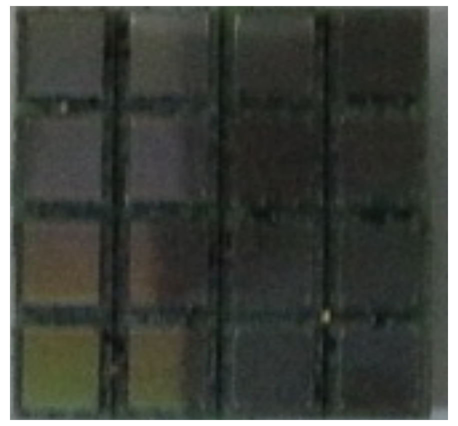
R&D: our strategy

SiPM arrays of different sizes + cryogenic read-out electronics to substitute Hamamatsu 3'' PMTs

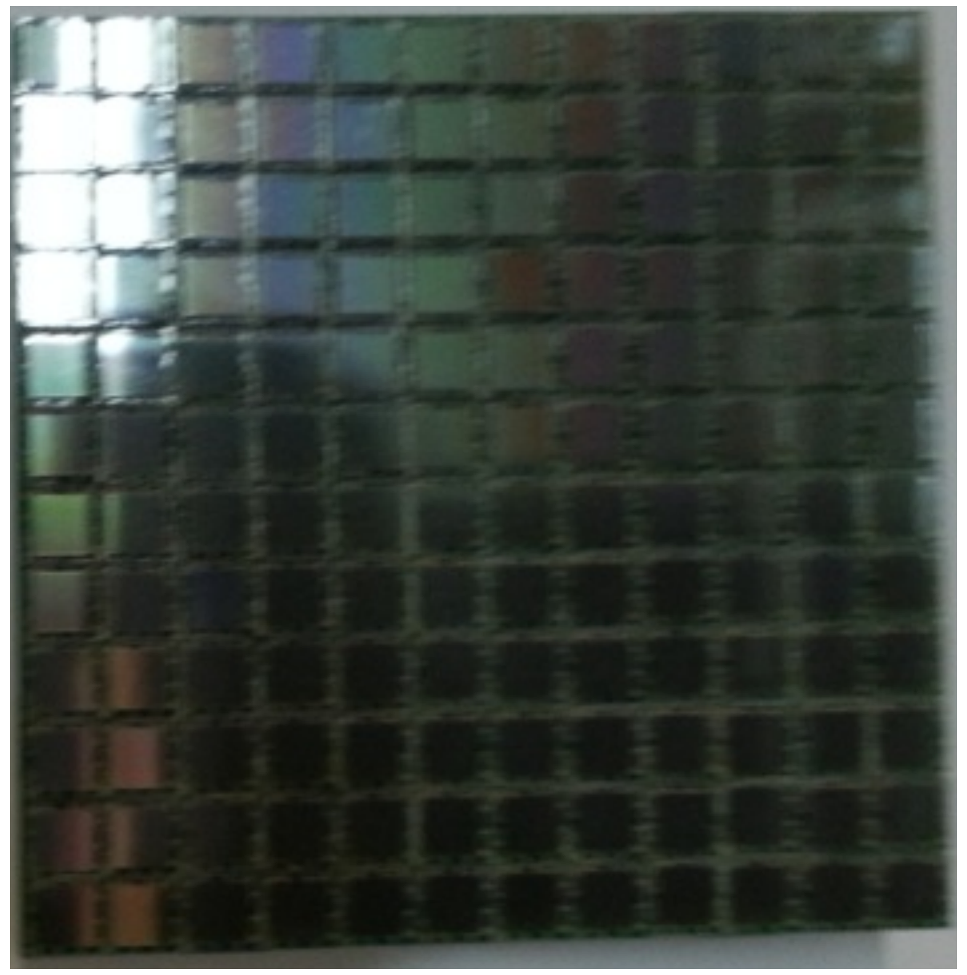
FBK involved in specific development through R&D agreement



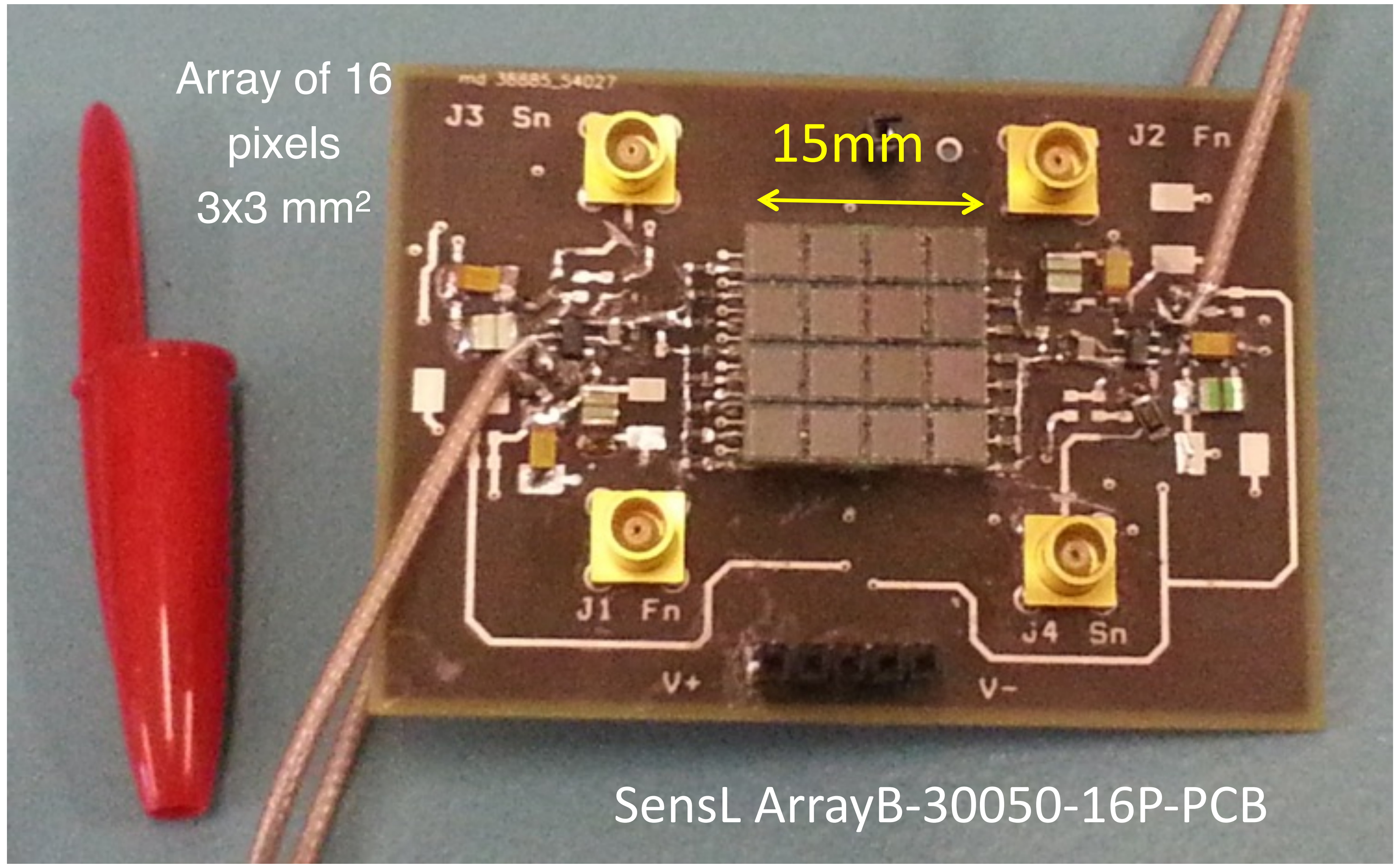
50 μm microcells
(2668 μcells)
3x3 mm^2 pixel
47% PDE
$6 \cdot 10^6$ gain

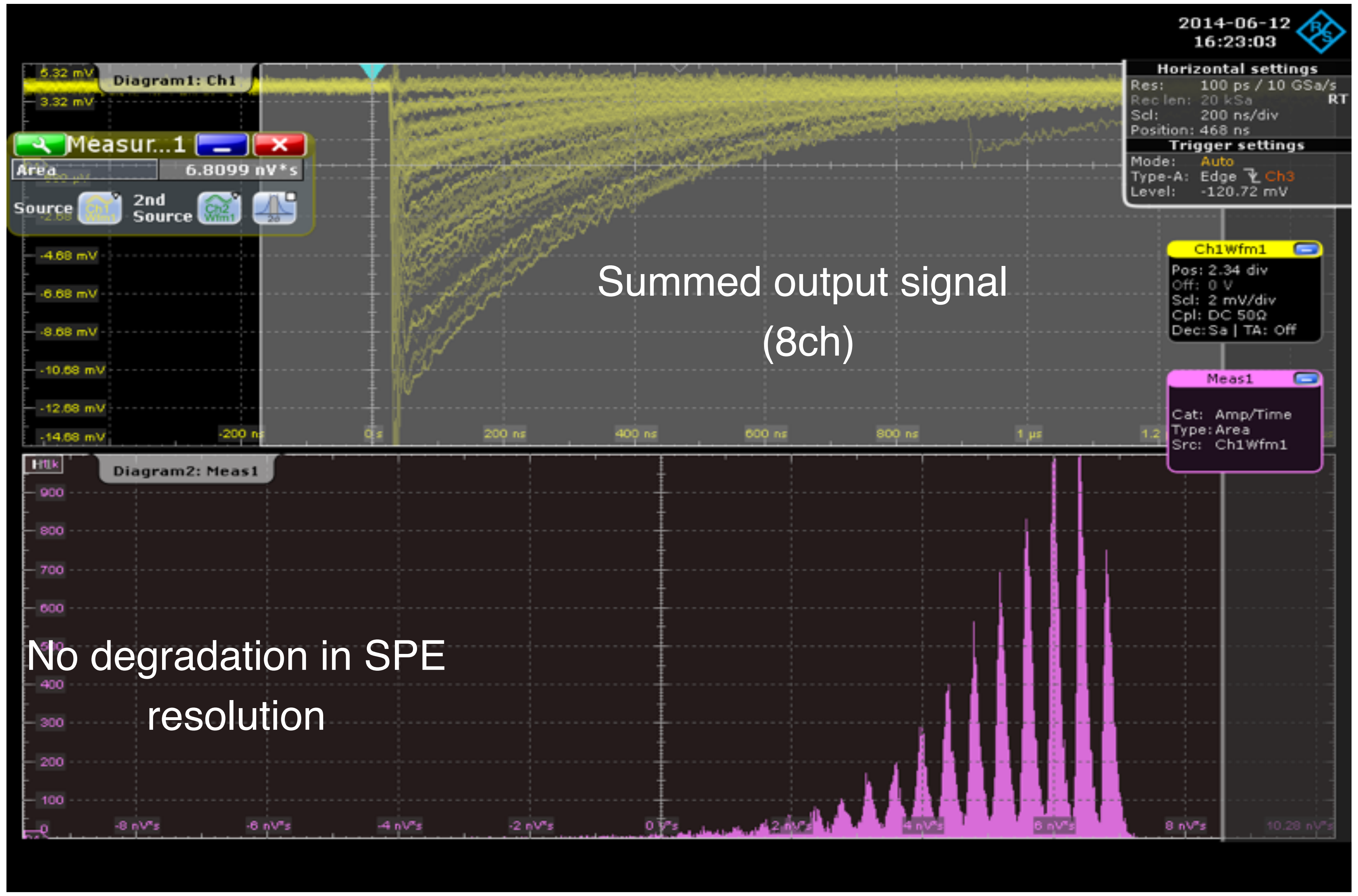


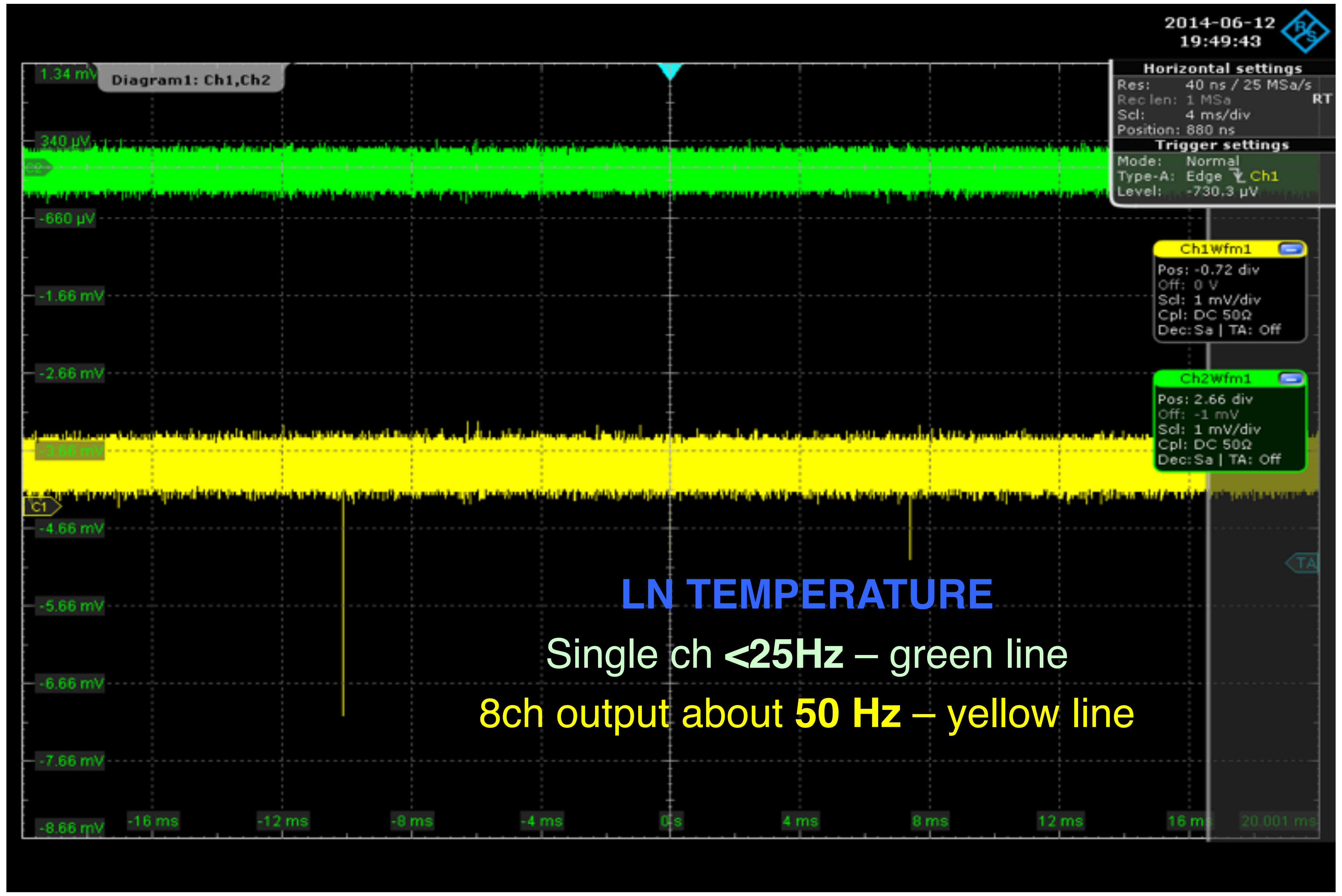
Array of 4x4 3x3 mm^2 pixels
2.74 cm^2



Array of 12x12 3x3 mm^2 pixels
25.2 cm^2







Dark Rate of 8ch negligible at LN temperature

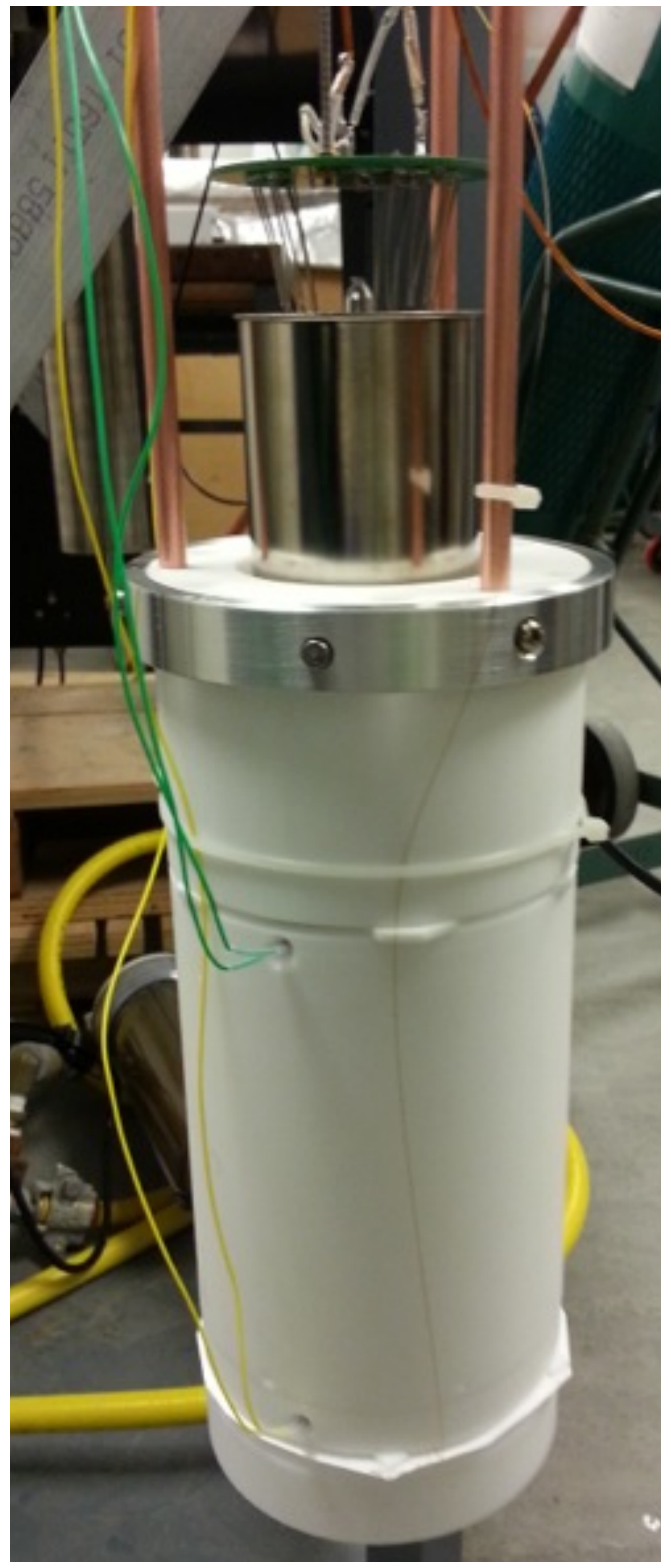
VERY GOOD NEWS

Huge dynamics (16x2700 µcells) limited by FE dynamics and not by photosensor (important feature for LAr-S2 large signals)

ROBUSTNESS: The array survived many cooling cycles

R&D current status: GAP-TPC

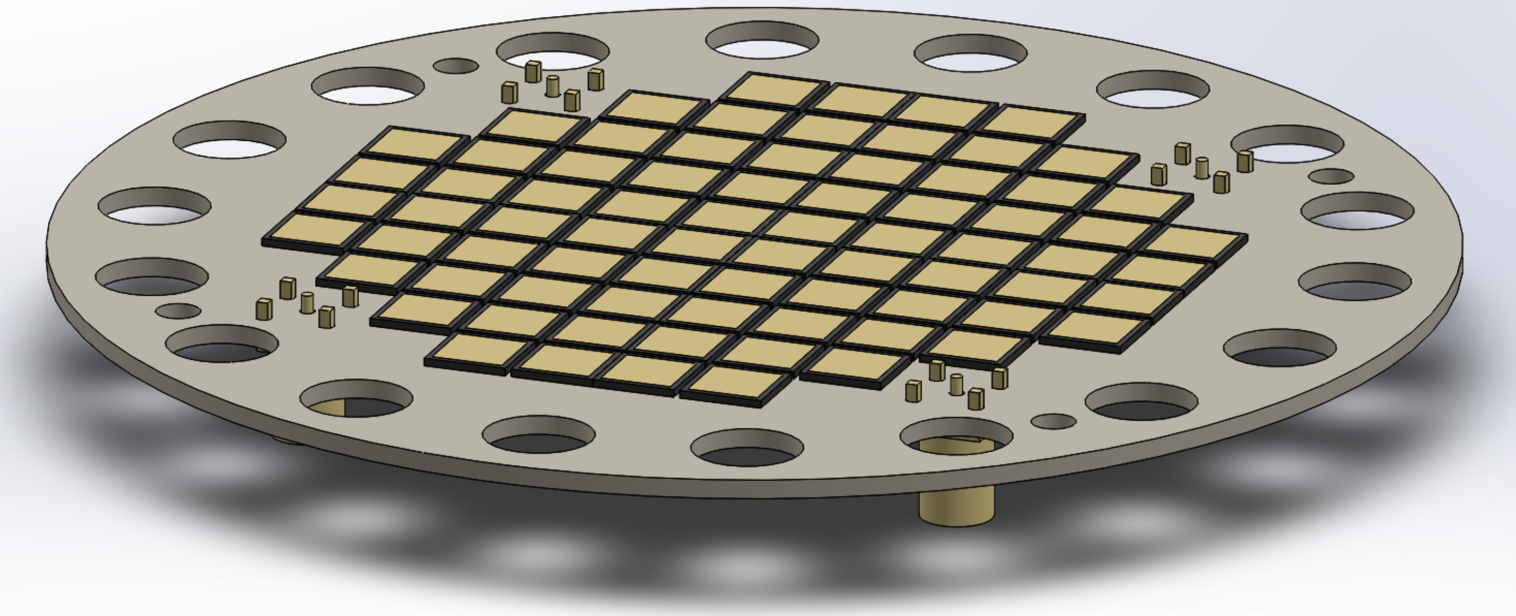
- Design readout board for the large array of 8x8 or 12x12 pixels (3 inches)
- Test in LN
- Upgrade existing LAr detector
- Compare the performance of Hamamatsu R11065 PMTs vs SiPM arrays (LY, SPE resolution, nuclear/electron recoil separation)

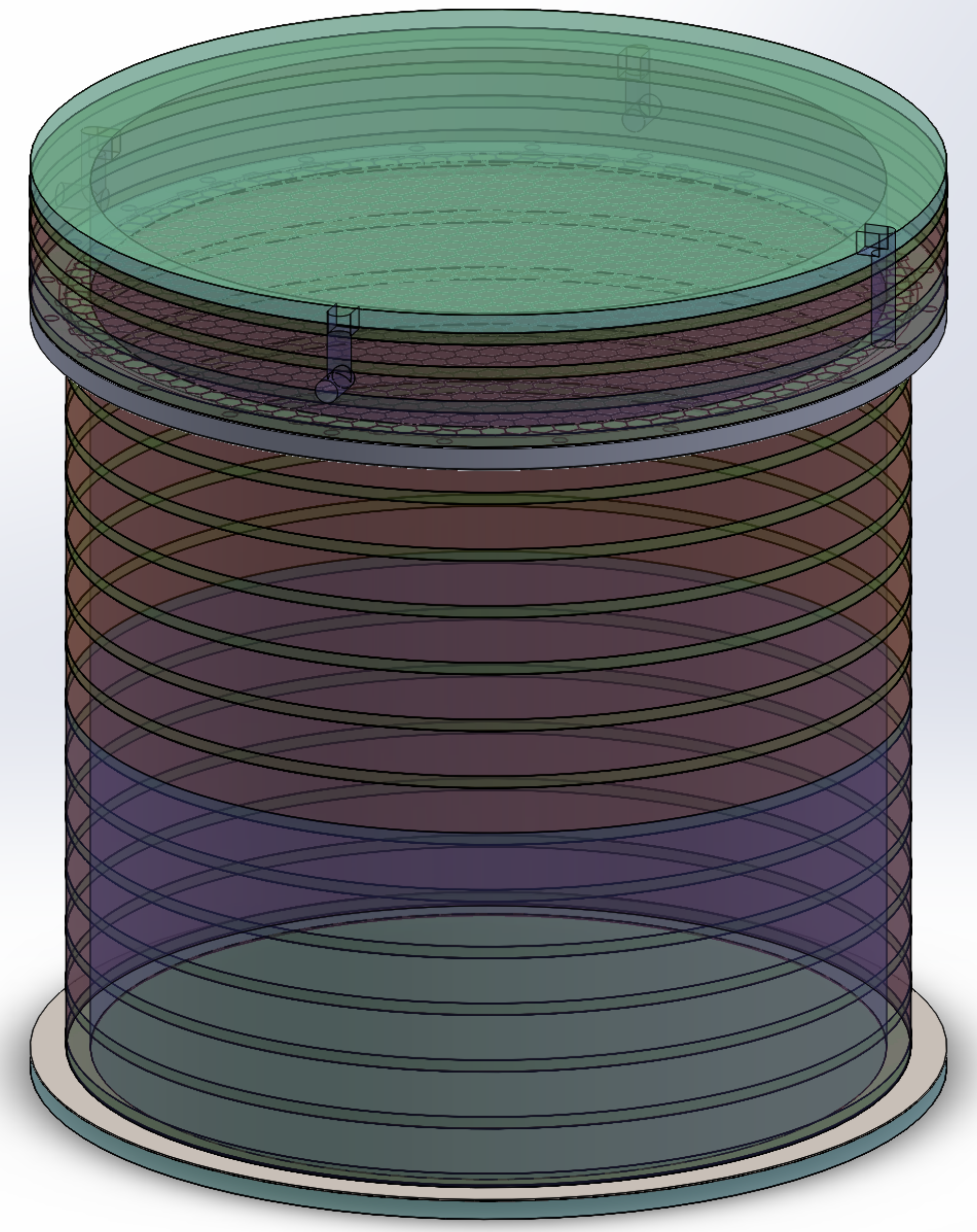


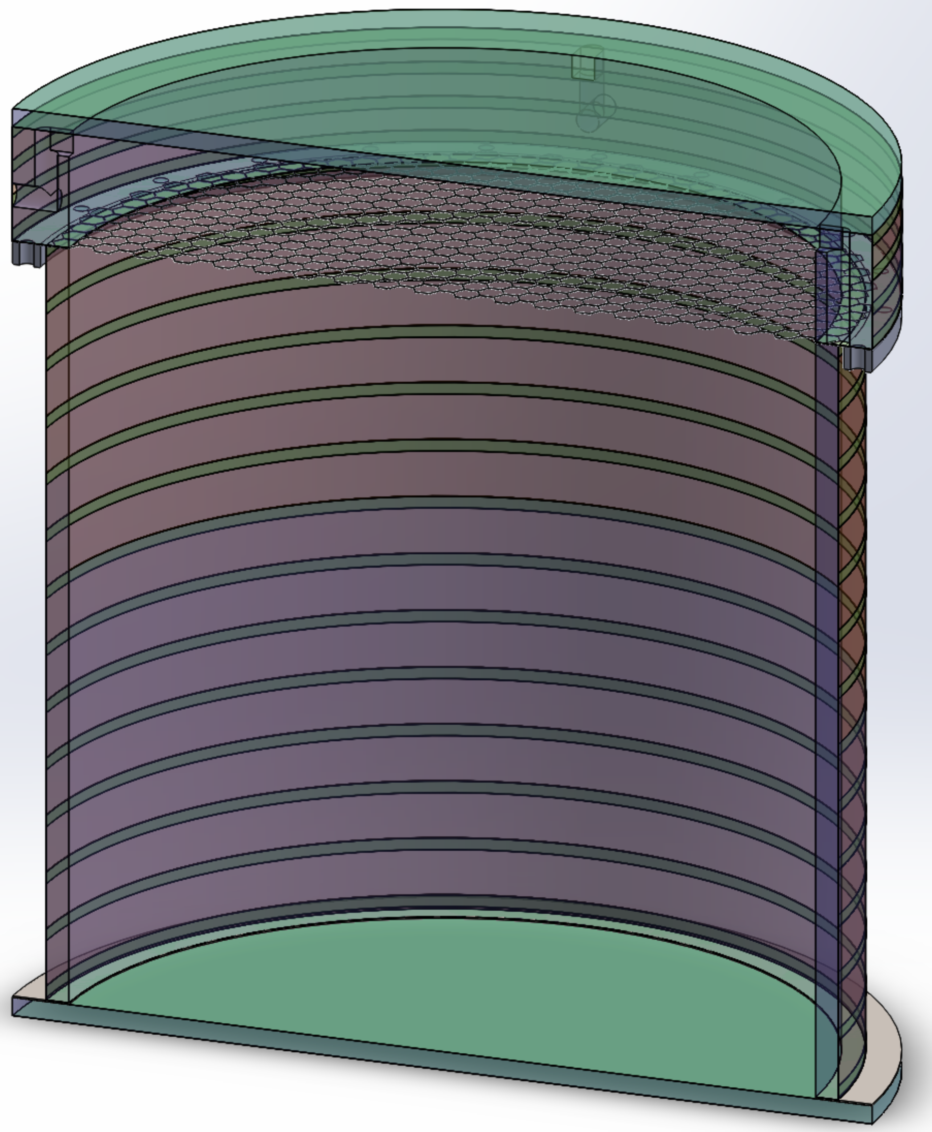
GAP-TPC: LAr TPC with high performance G-APD readout

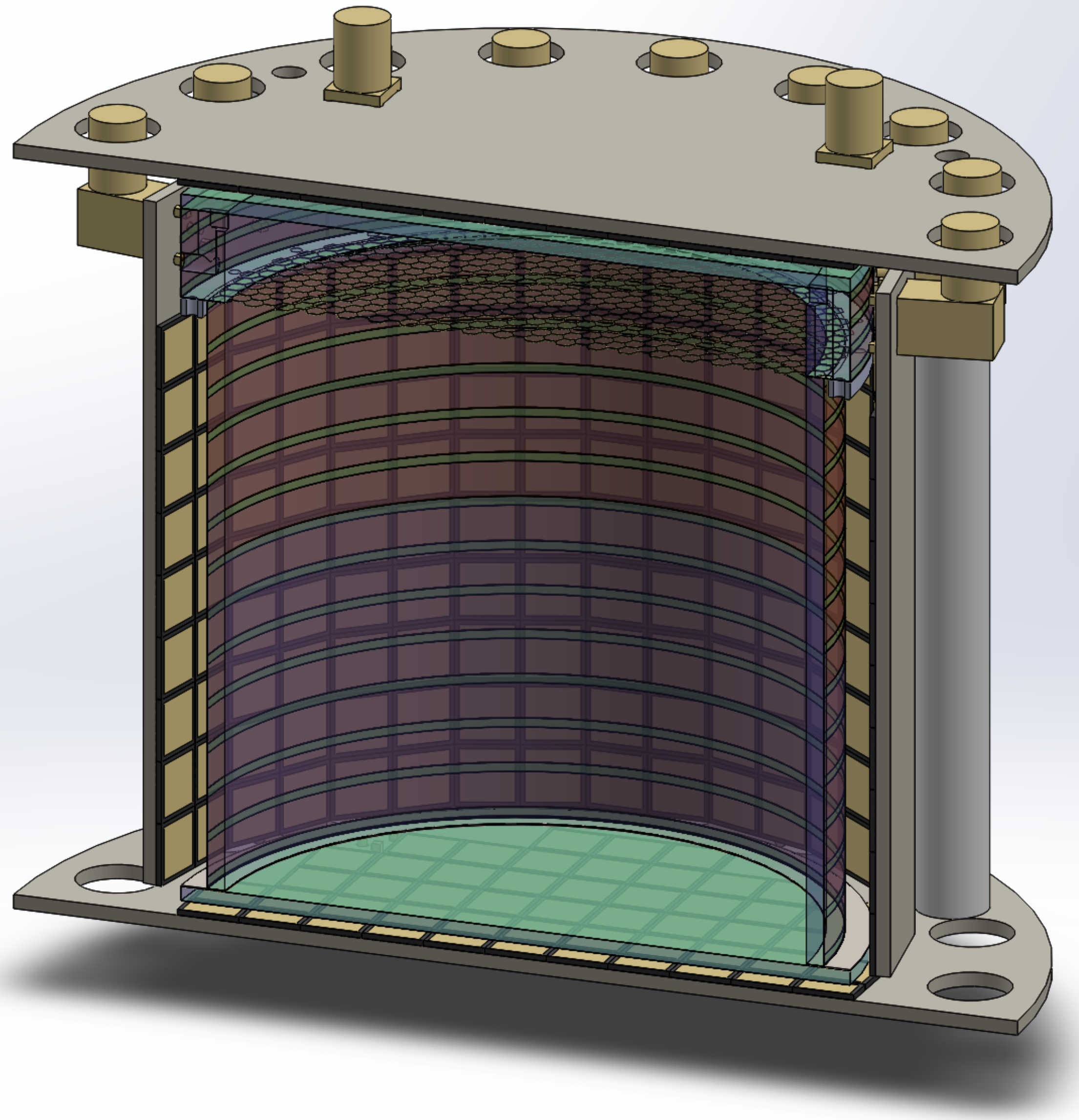
will allow a measurement campaign towards Directional Dark Matter using LAr

R&D next step: enhance LY
4pi SiPM readout









Participating groups:
UNINA & INFN-NA, INFN-LNGS, INFN-RM1, APC-IN2P3,
Princeton, Temple, UCLA