SIGN:
A Pressurized Noble Gas Approach to WIMP Detection

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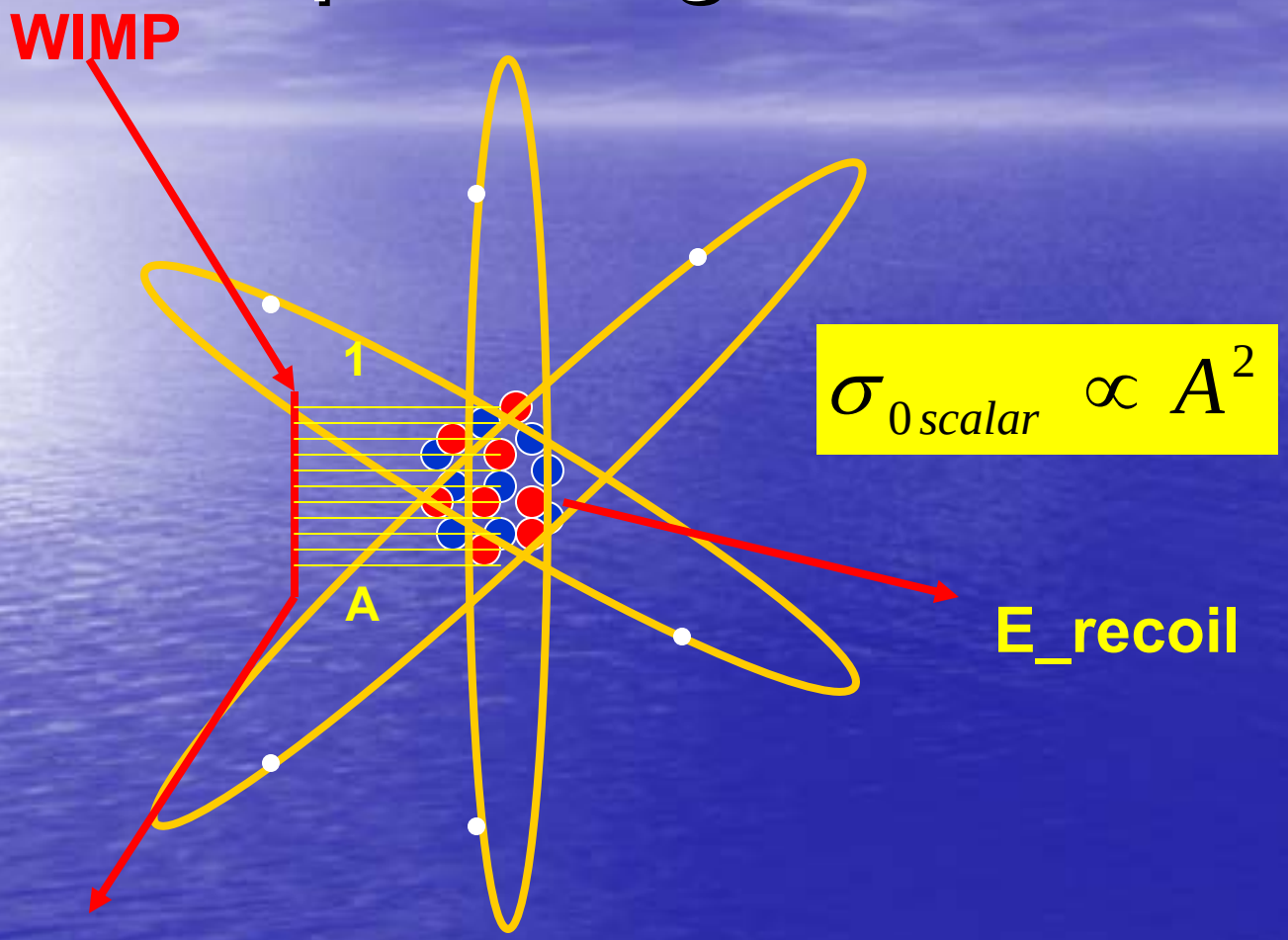
Dark Side of the Universe – U. Minnesota, 6/7/2007

Why Gaseous Nobles?

- **Original Motivation:**
  - Neon
    - Electron mobility → possible S2/S1 discrimination
      → fiducial well defined - TPC
- **Another Advantage:**
  - Room Temperature Operation !!!
    - Simpler purification
    - No leveling
    - No Cryo, etc ...
- **NEW!!**
  - S2/S1 Discrimination observed at WIMP Energy scale!

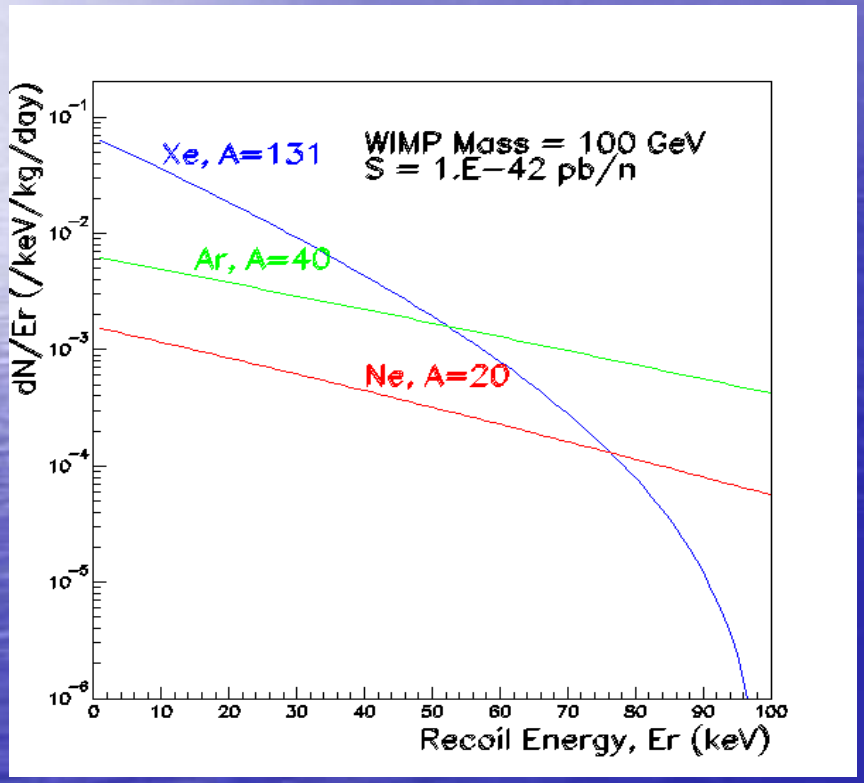
Multiple Target Motivation

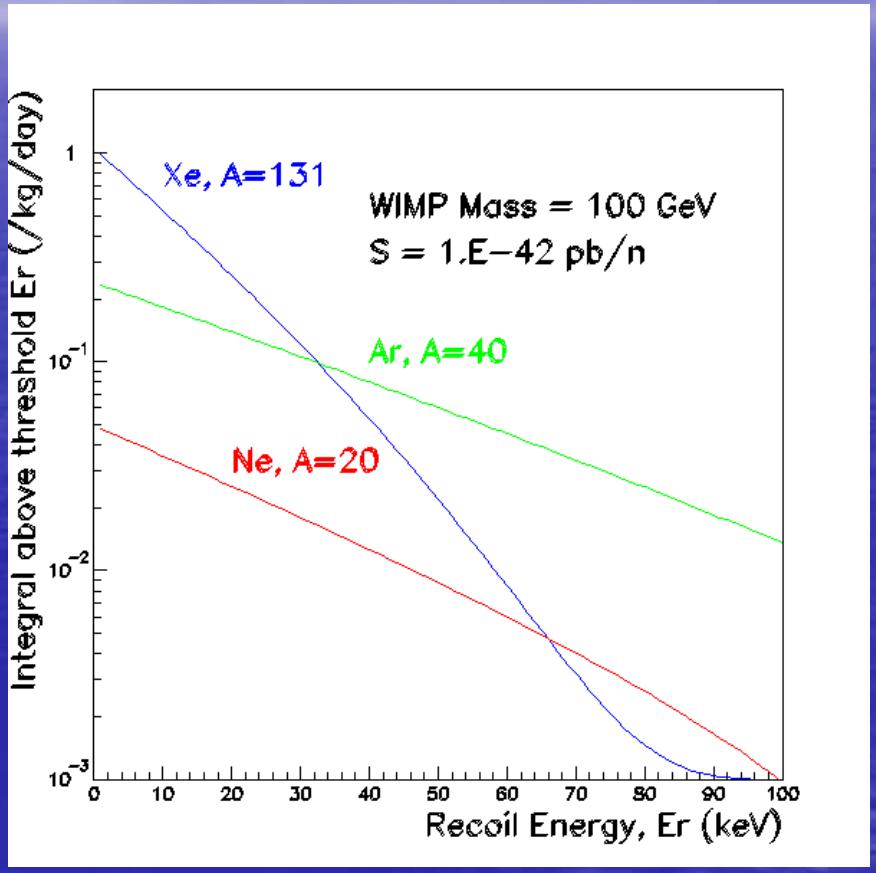


$$\sigma_{0\,scalar} \propto A^2$$

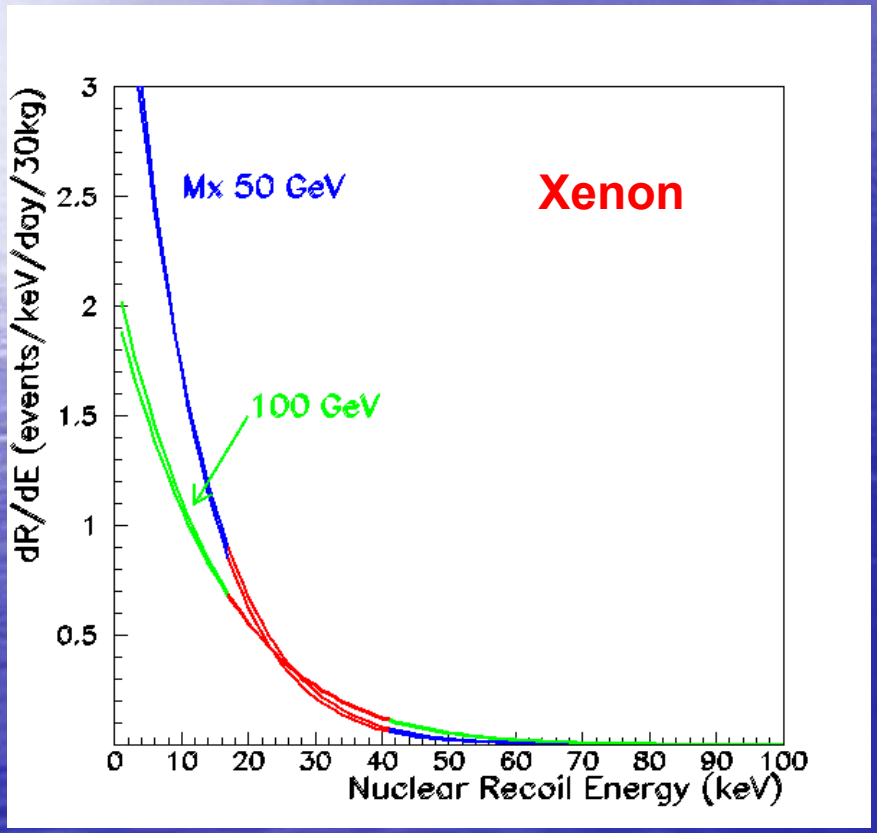
A^2 Dependence of Recoil Spectra

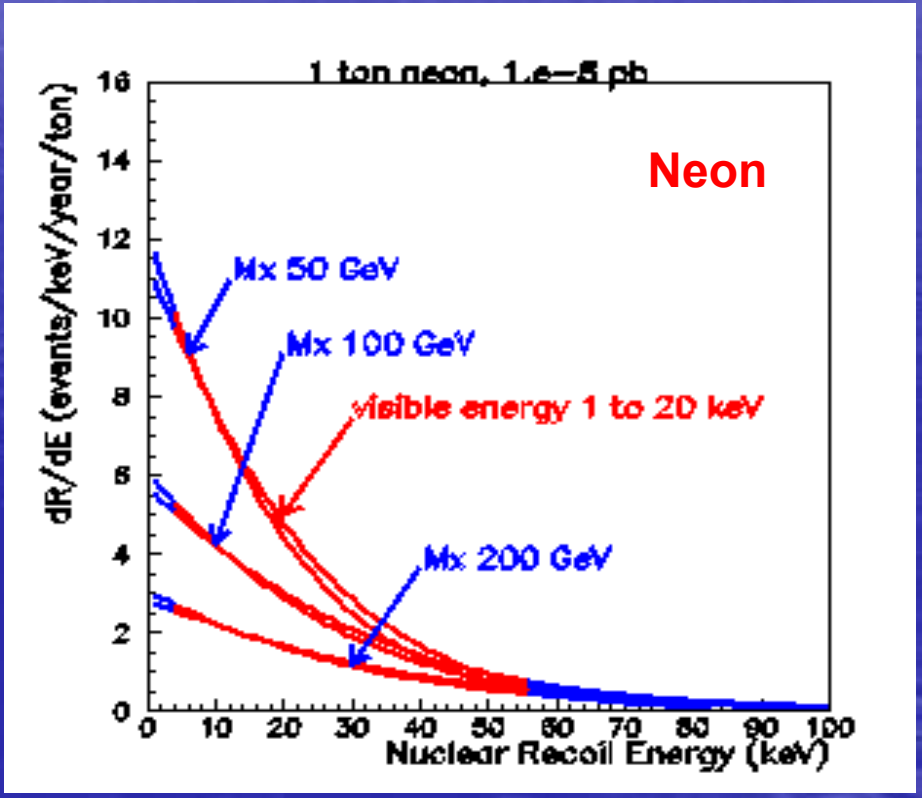
$$\frac{dR}{dE_R} = \frac{\sigma_0 \rho_0}{4 v_e m_x m_r^2} F^2(E_R) \left[erf\left(\frac{v_{\min} + v_e}{v_0} \right) - erf\left(\frac{v_{\min} - v_e}{v_0} \right) \right]$$



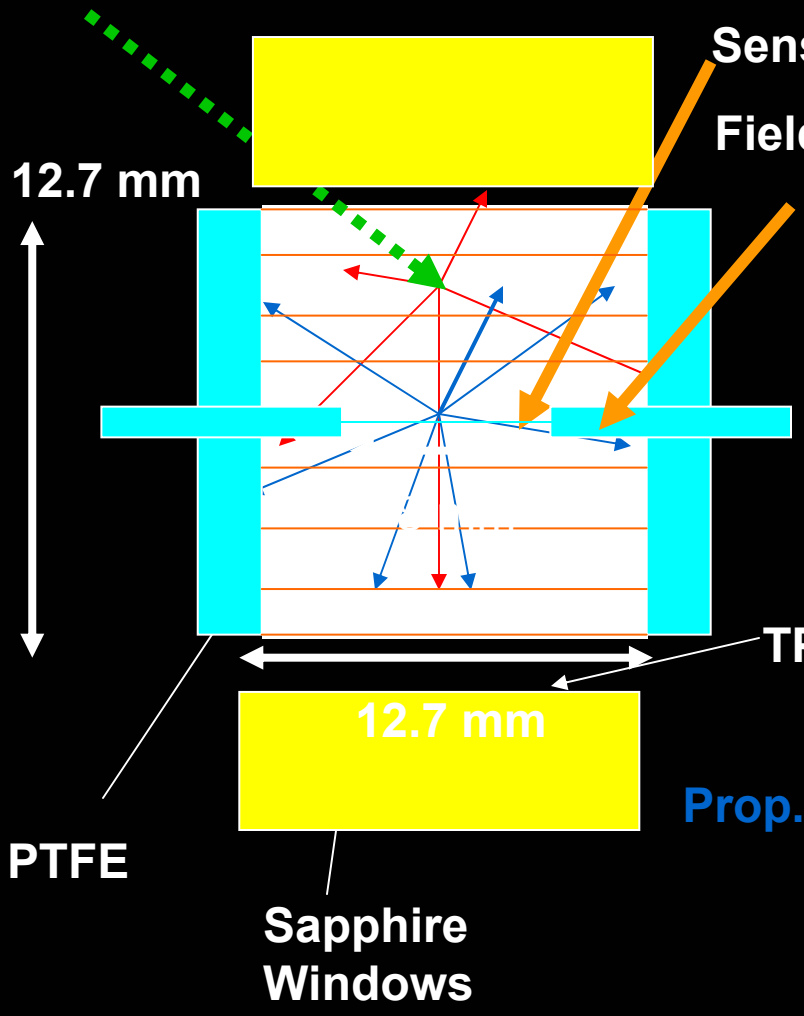


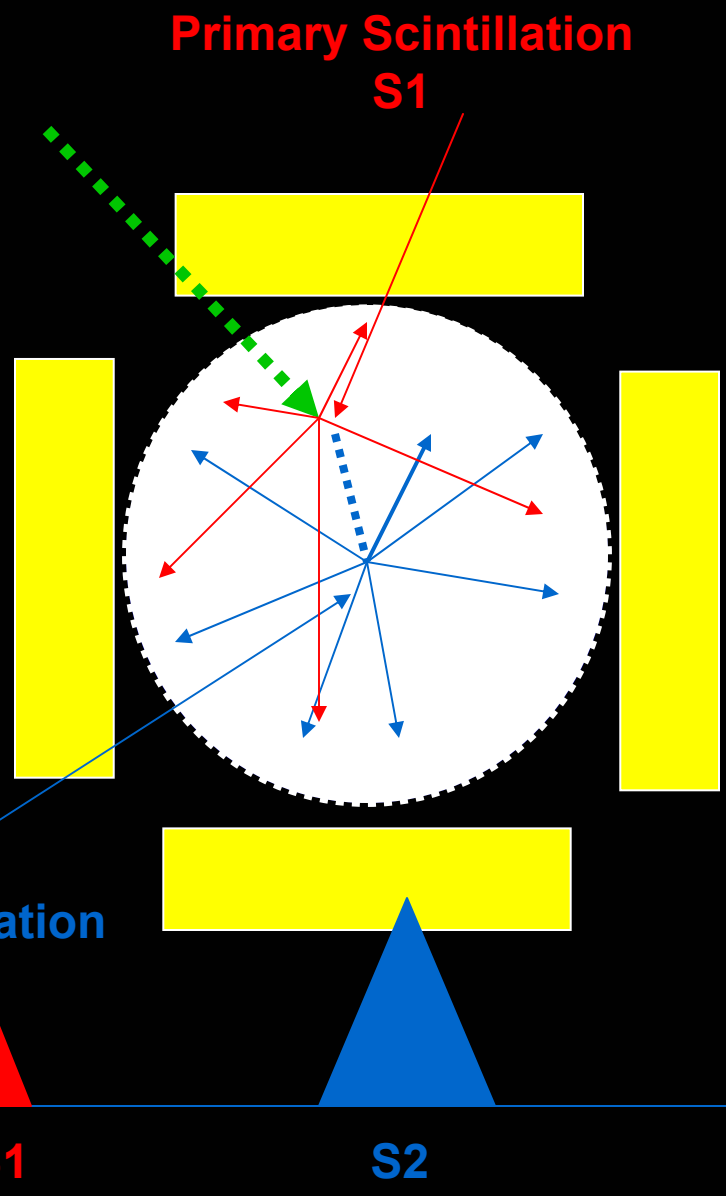
Mass / Halo <v> / # species ?



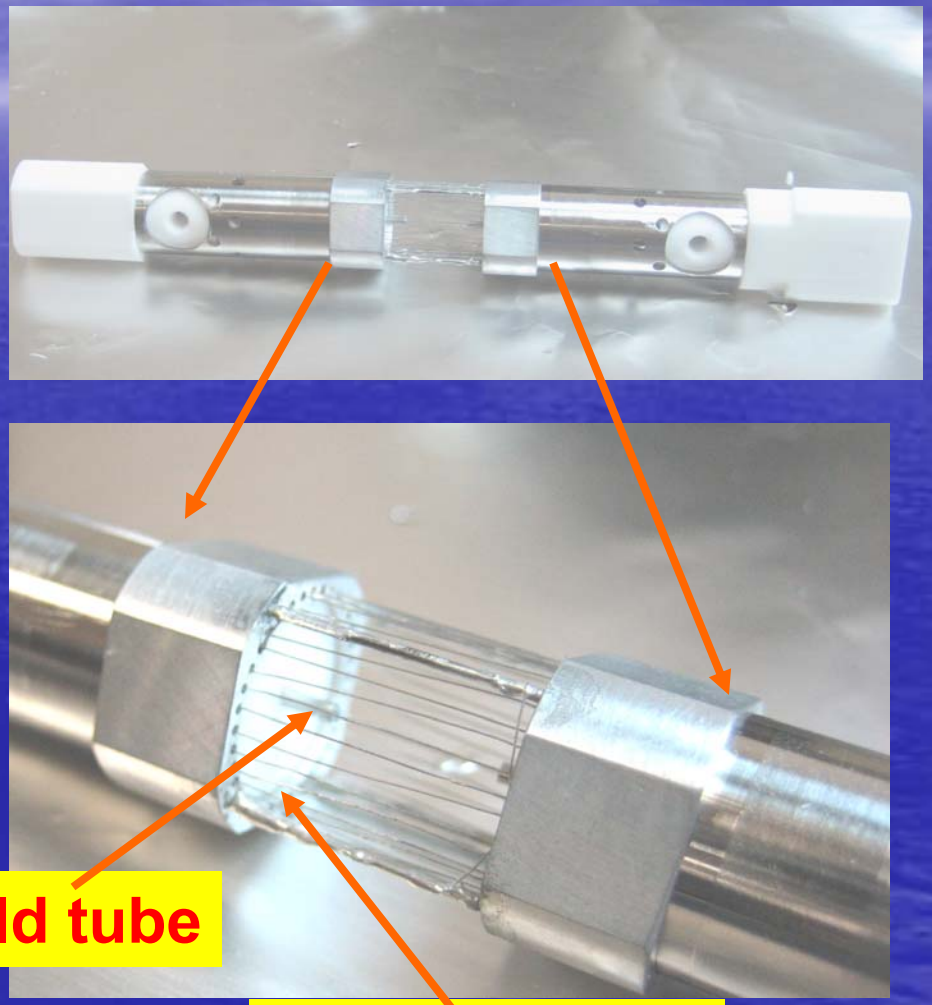


Pressurized noble gas Test Cell



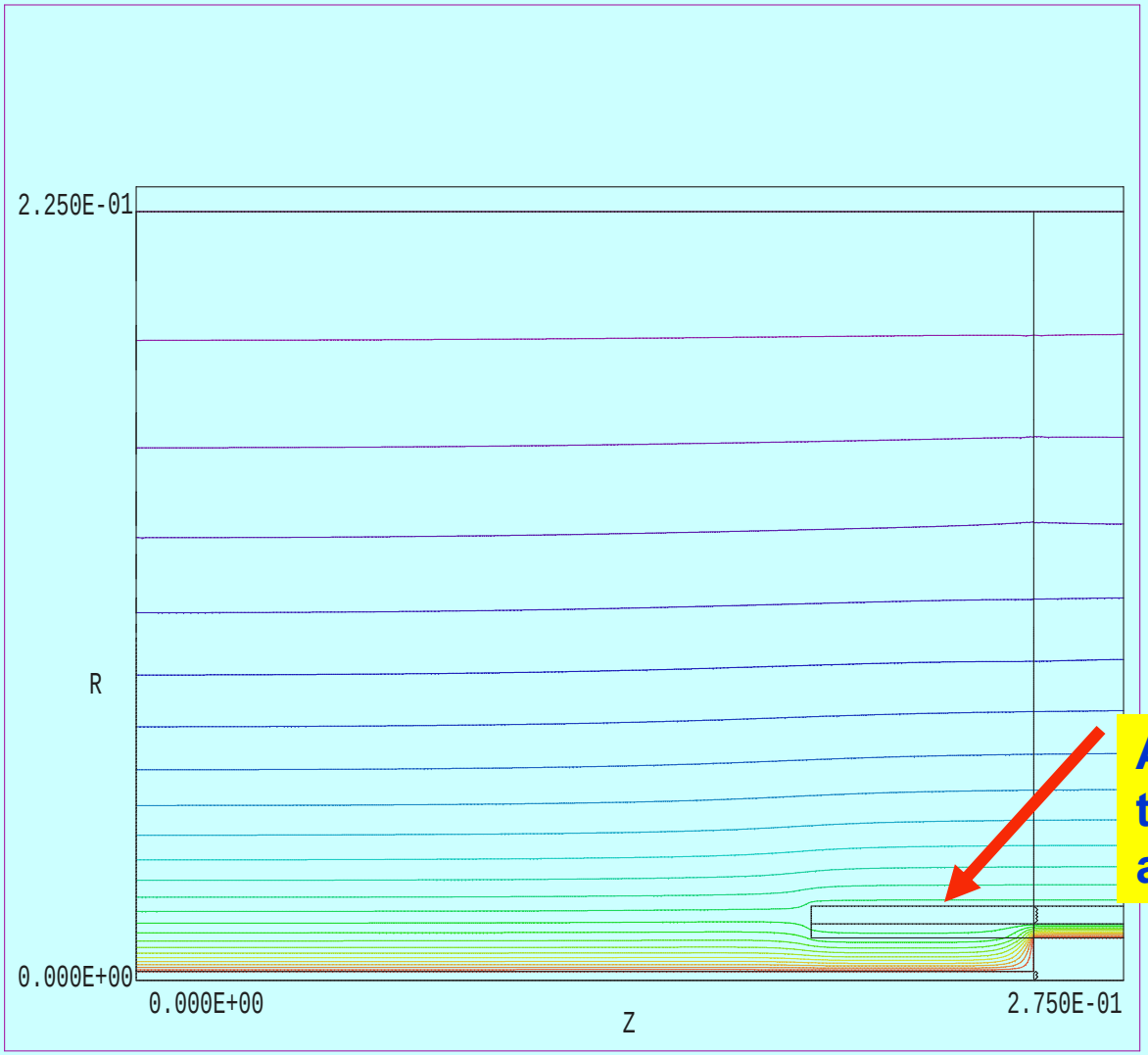


4-PMT - 100 atm Test Cell



Sapphire Windows

Field Tuning



File prefix: tetrav2.EOU
Plot type: Contour
Quantity: Potential (V)

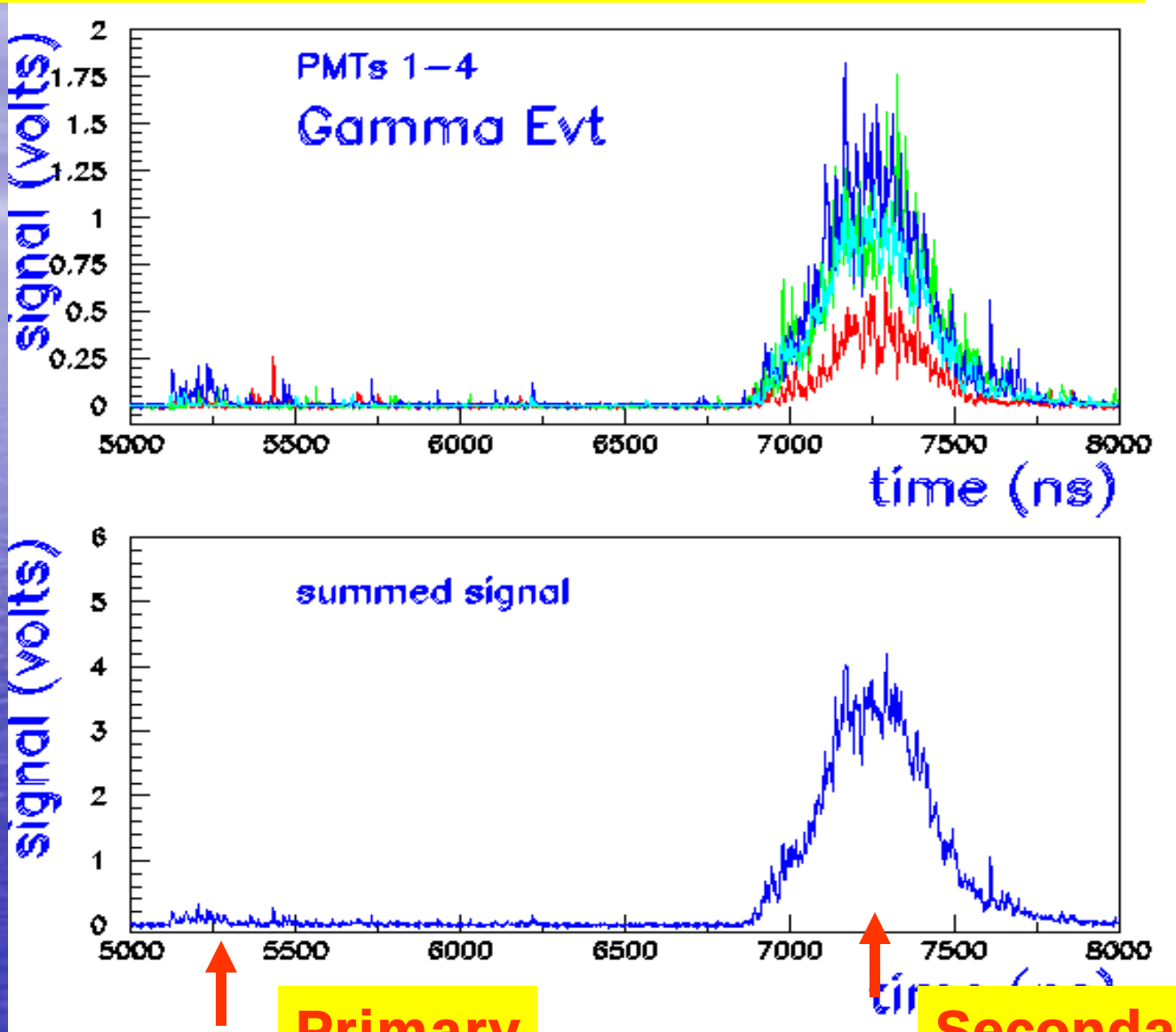
Minimum value: 0.000E+00
Maximum value: 4.198E+03

	3.498E+02
	6.997E+02
	1.049E+03
	1.399E+03
	1.749E+03
	2.099E+03
	2.449E+03
	2.799E+03
	3.148E+03
	3.498E+03
	3.848E+03
	4.198E+03

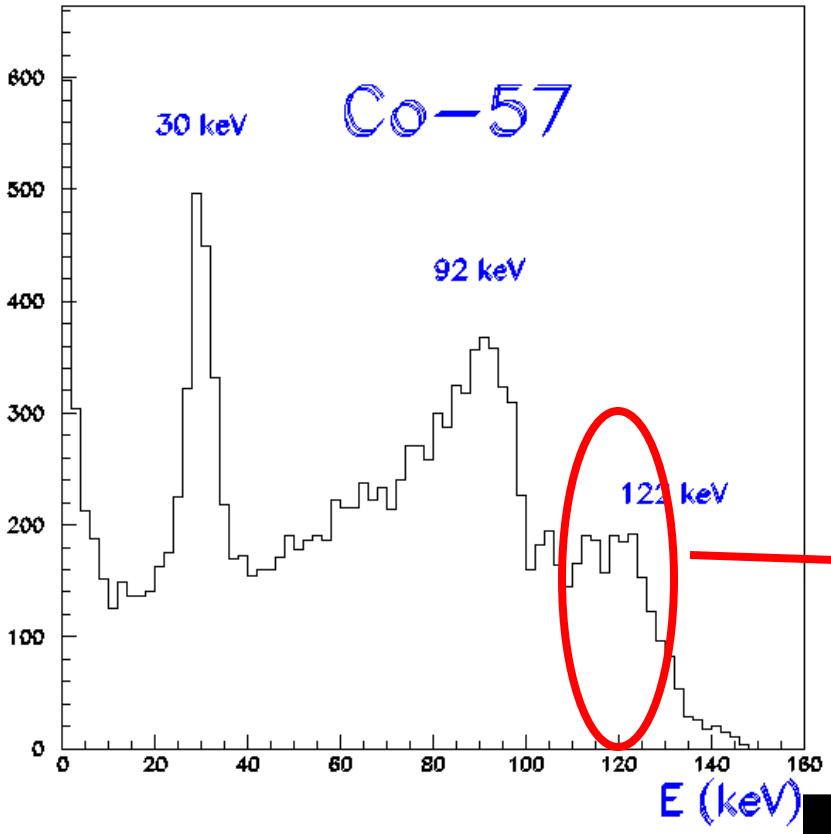
Adjust field tube potential to optimize E-field uniformity along sense wire

Current view window

Event Waveform (Ne-Xe (0.5%))

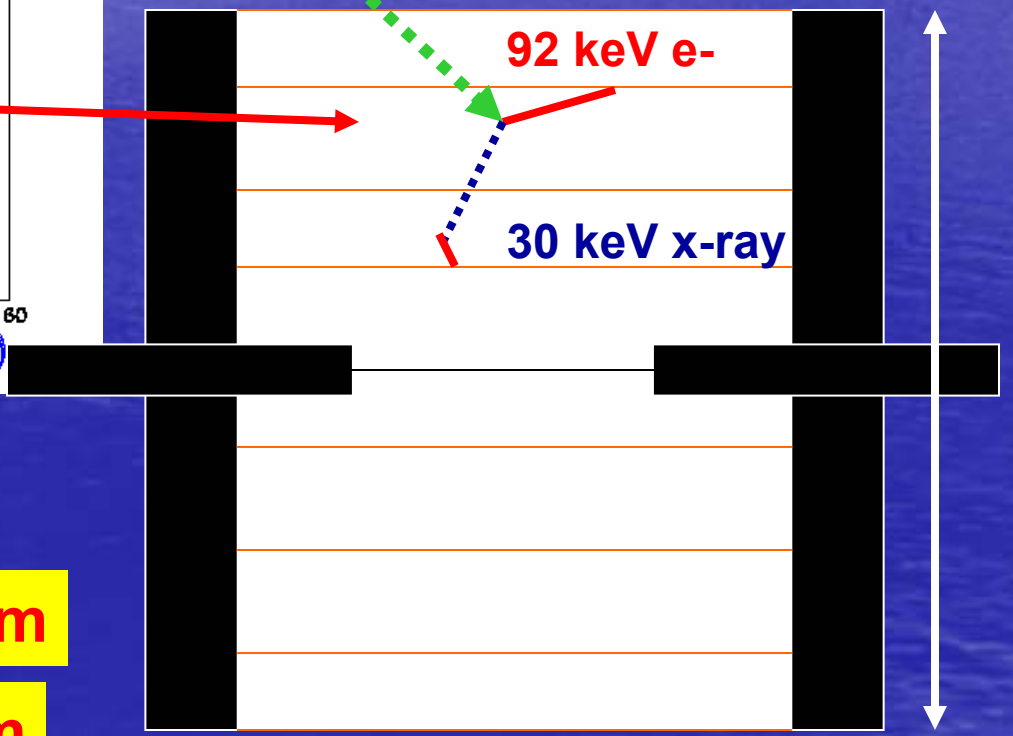


Calibration



Xe gas: 20 atm

122 keV Gamma (+ some 136)

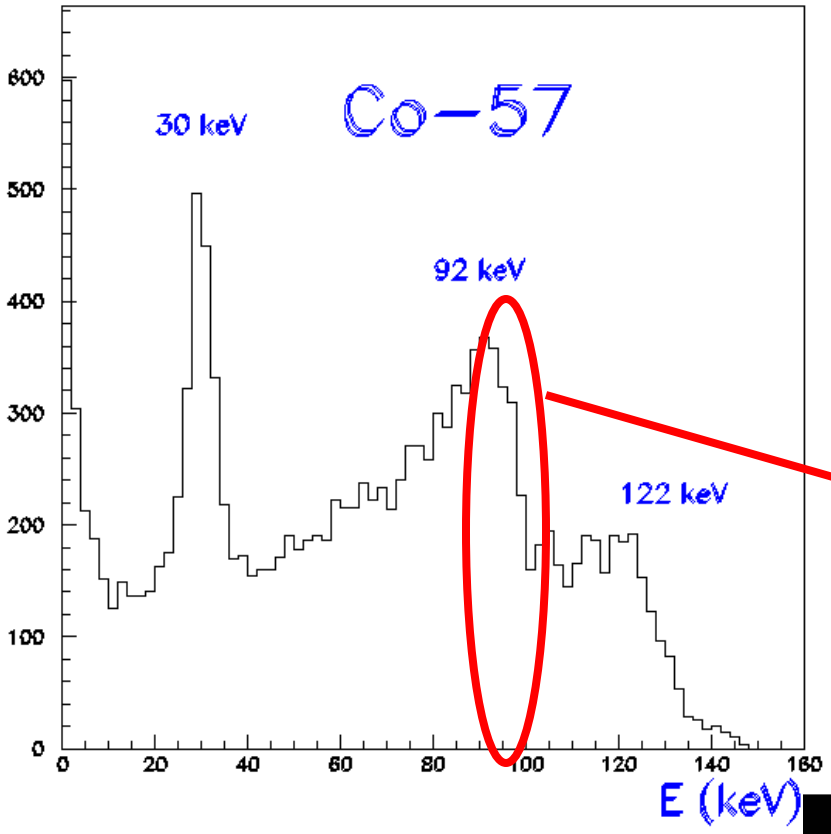


Range 92 keV e- ~ 2 mm

Range 30 keV x-ray ~ 1 cm

Range 30 keV e- ~ 0.2 mm

Calibration



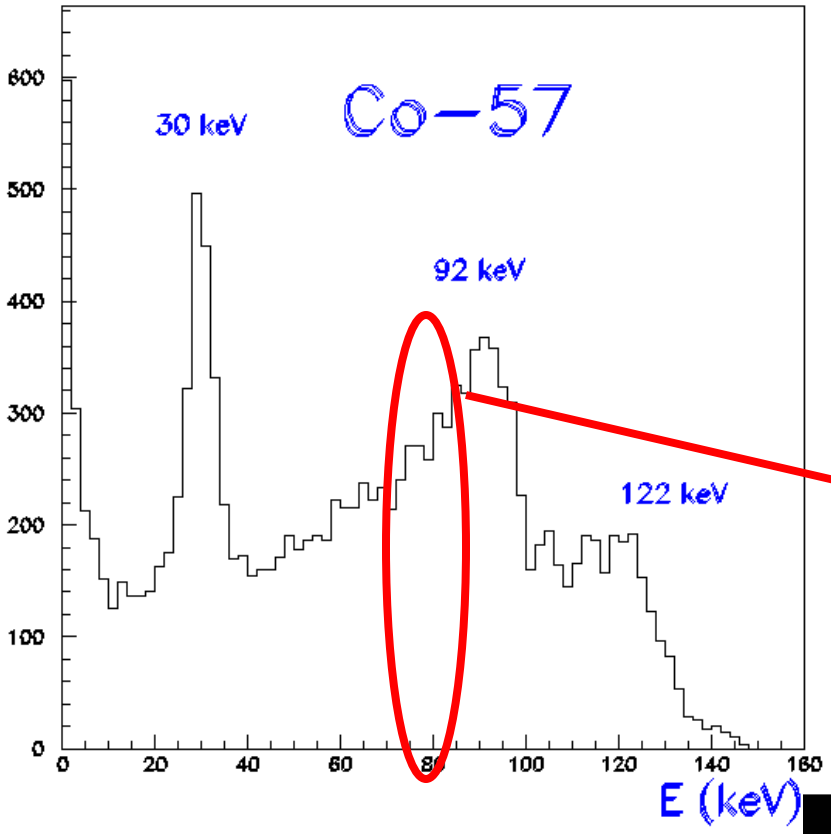
122 keV Gamma

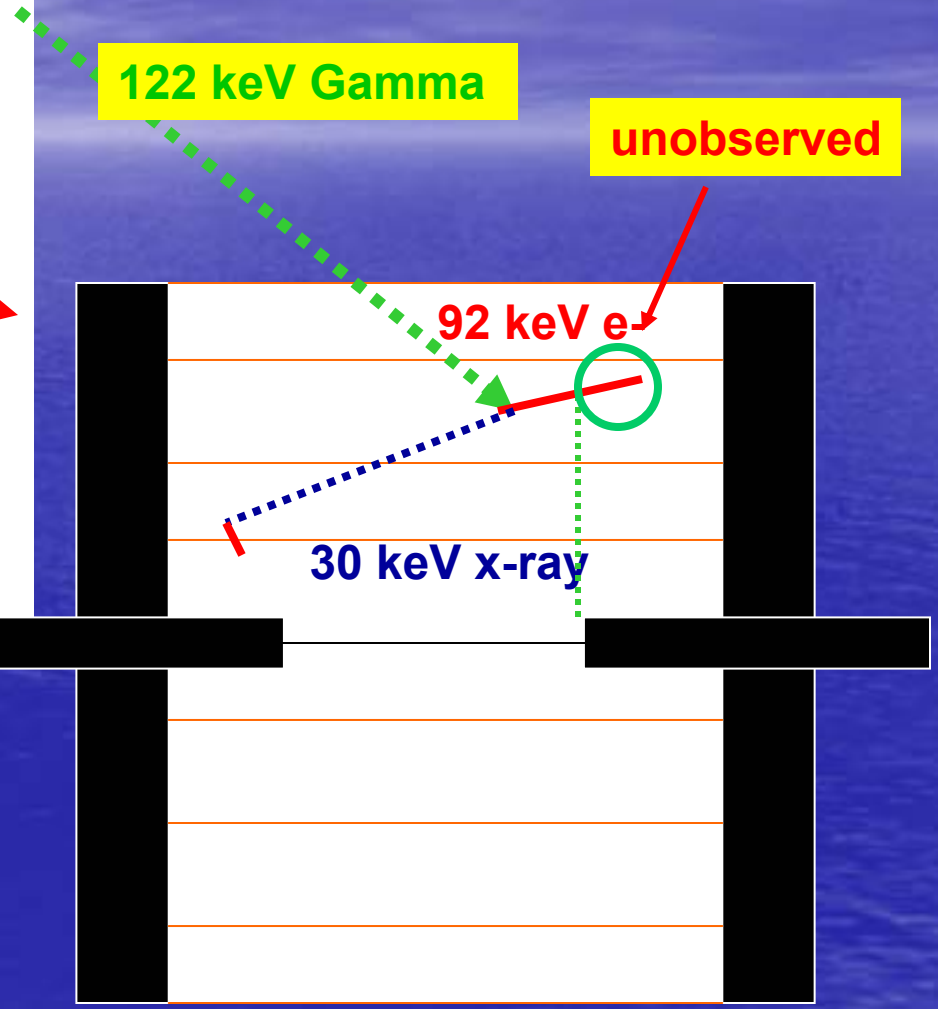
92 keV e-

30 keV x-ray

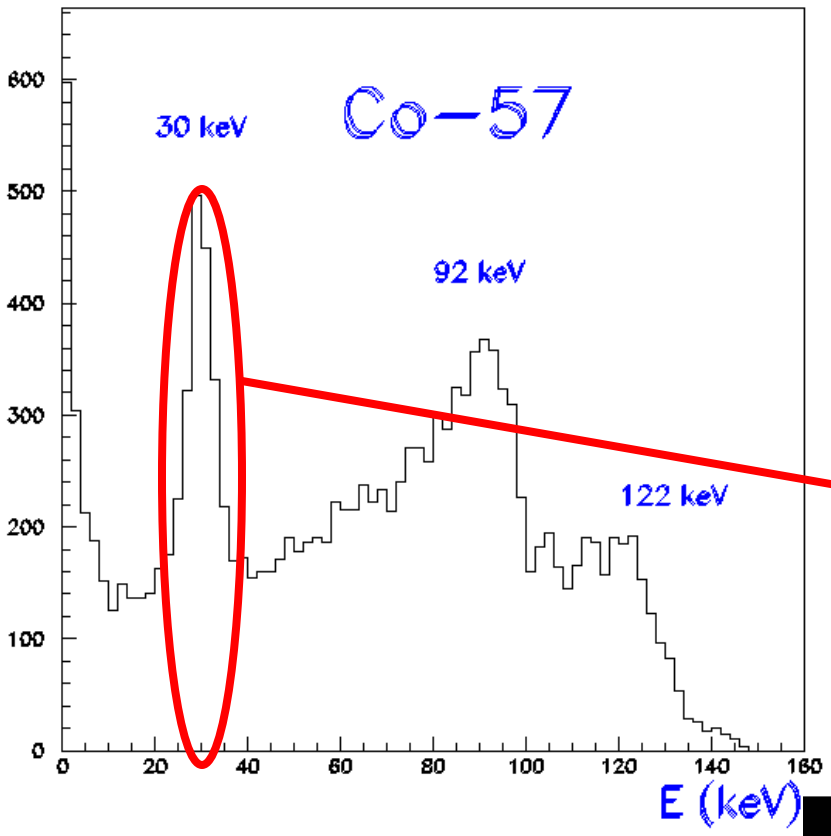
unobserved

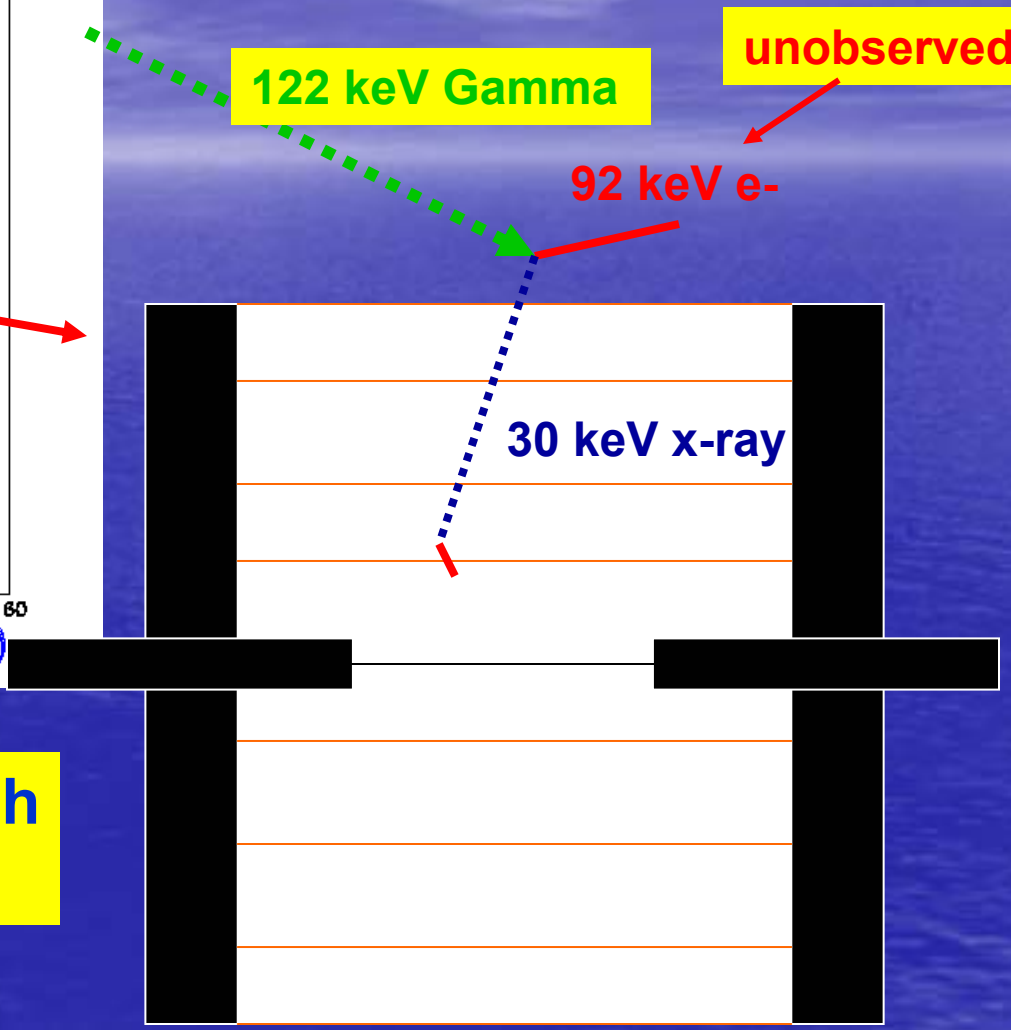
Calibration





Calibration





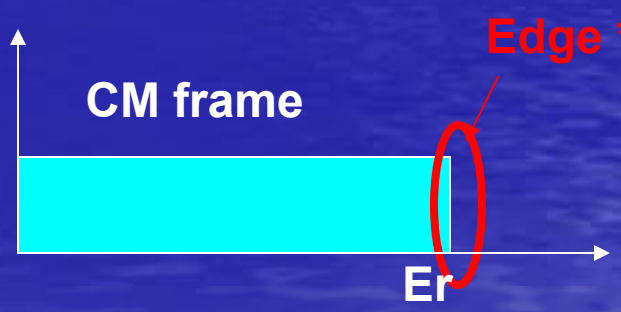
Leff ~ 4.5% if Ws=76ev/ph
Qgain ~ 1.2 p.e./e- (here)

Neutron Scattering w/ Mono-Energetic Neutrons

$\Theta \rightarrow \pi$

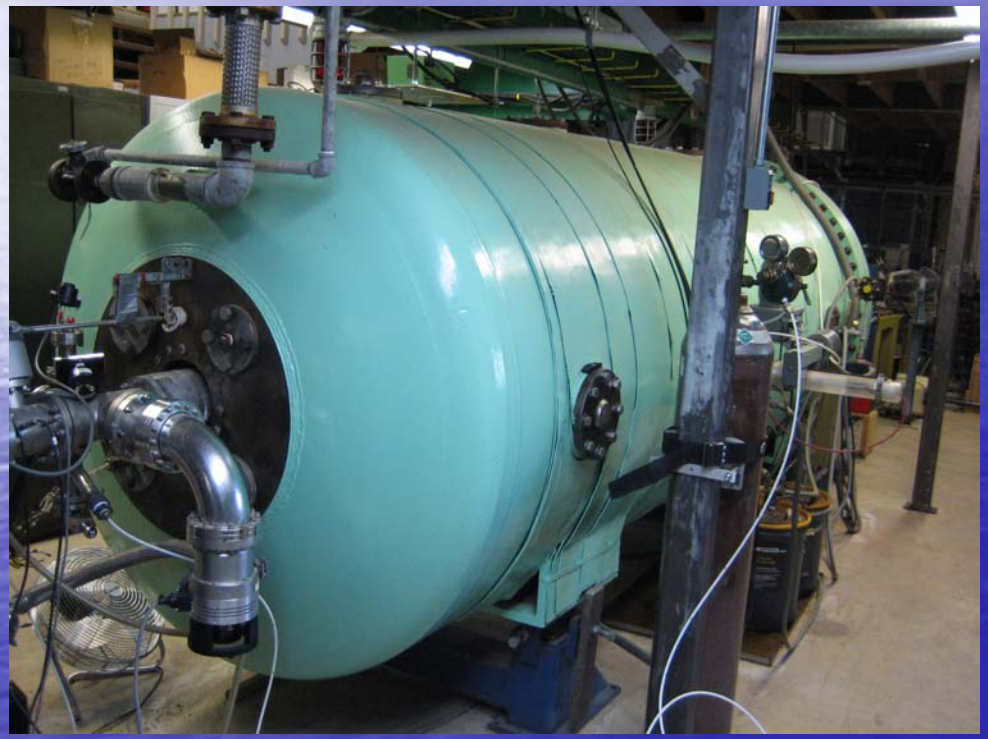
$Er \rightarrow Ermax = (4\ m\ M/(m+M)^2)\ En$

S – Wave →

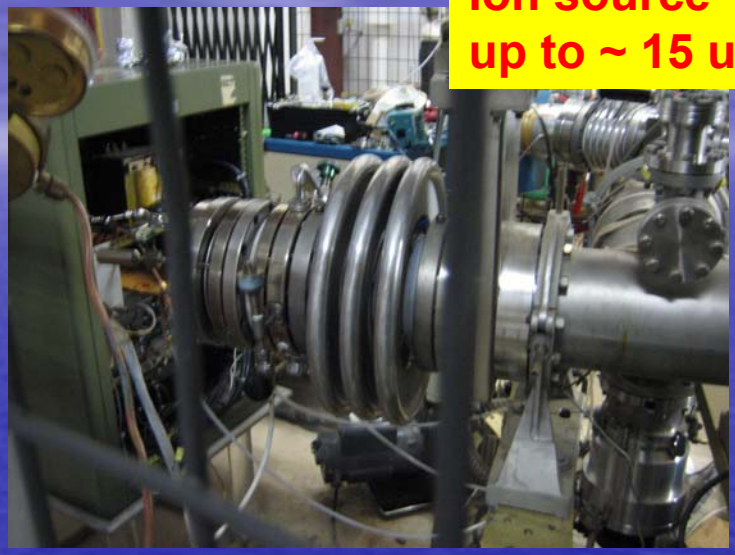


4-MeV Proton Accelerator at TAMU

Tandem van de Graaff



Duoplasmatron Ion source up to ~ 15 uA



Monochromatic neutrons up to 2 MeV using ^{7}(Li(p,n)^{7}Be reactions.

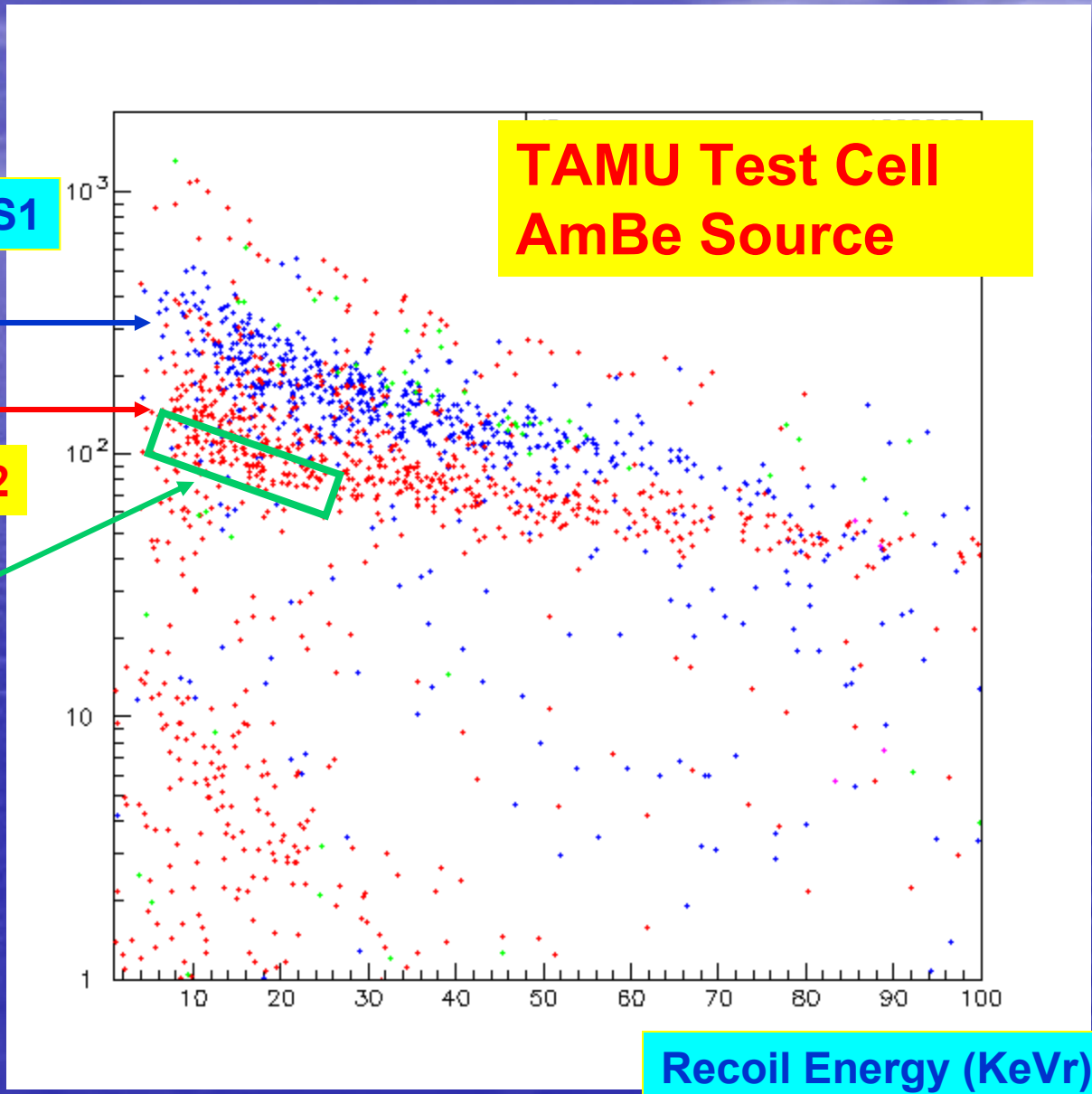
Achieved >1 uA on target ➔ >5E6 n/sr/s

Results

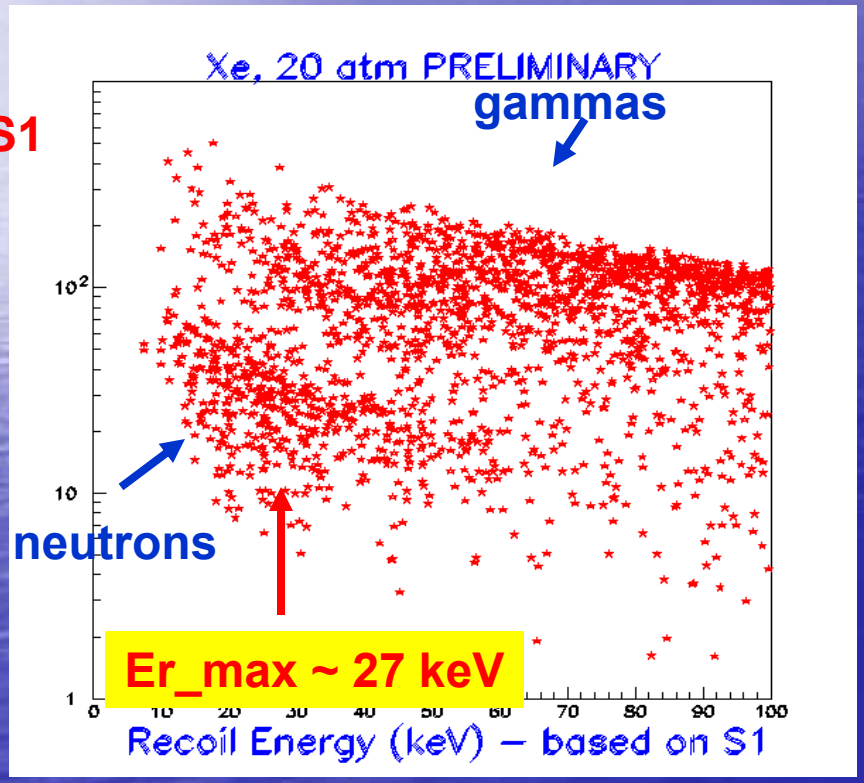
Xe @ 20 atm

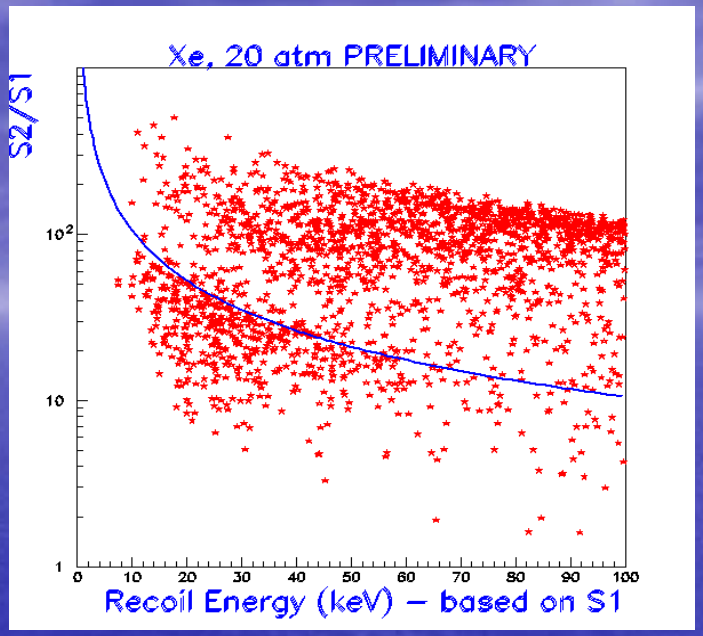
~ 300 psi

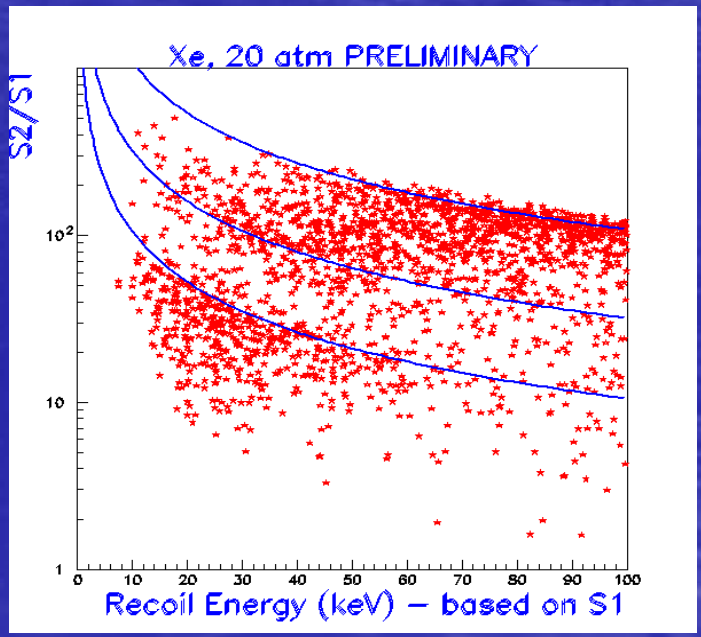
Digression: Two-Phase Xenon Discrimination



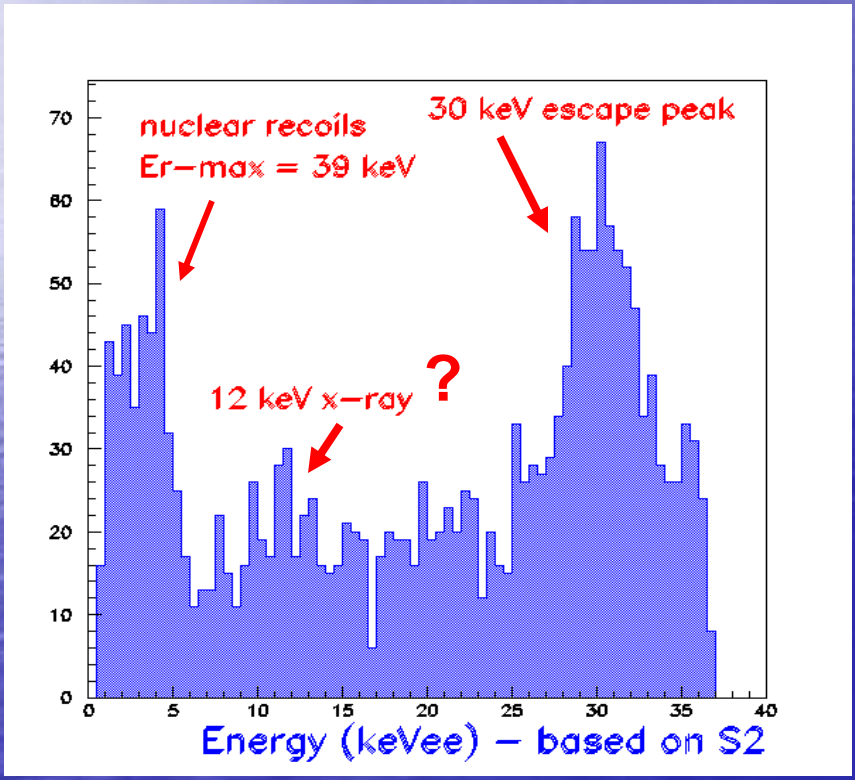
Xe – 20 atm
Nuclear Recoils

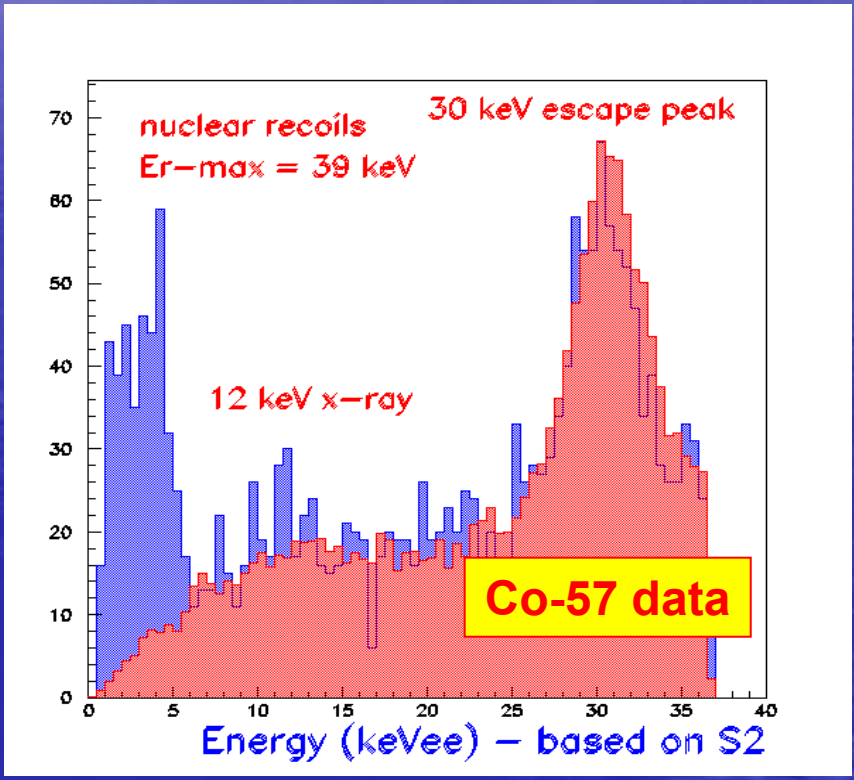




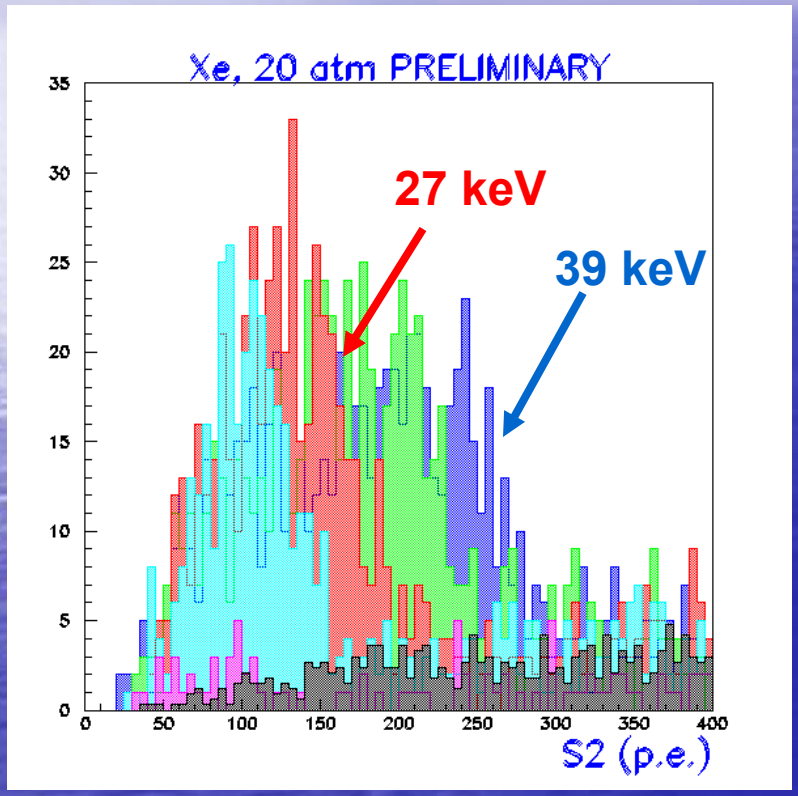


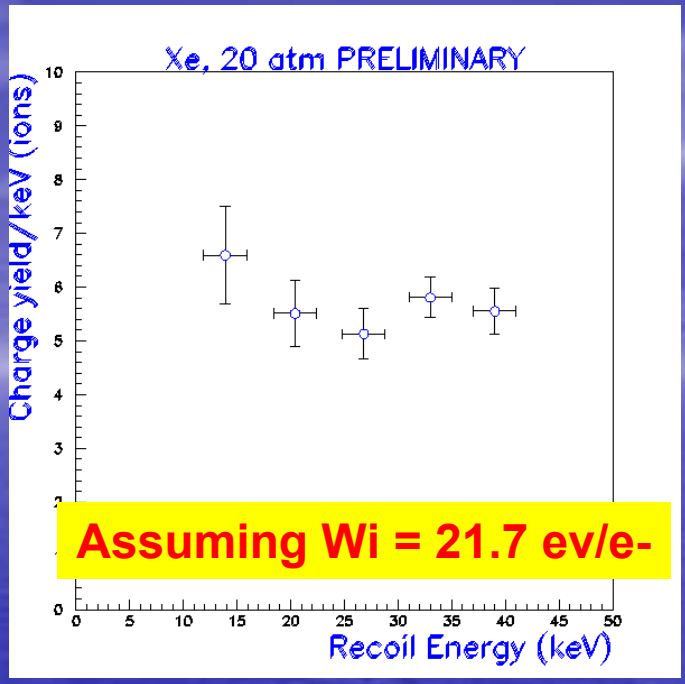
S2 Spectra

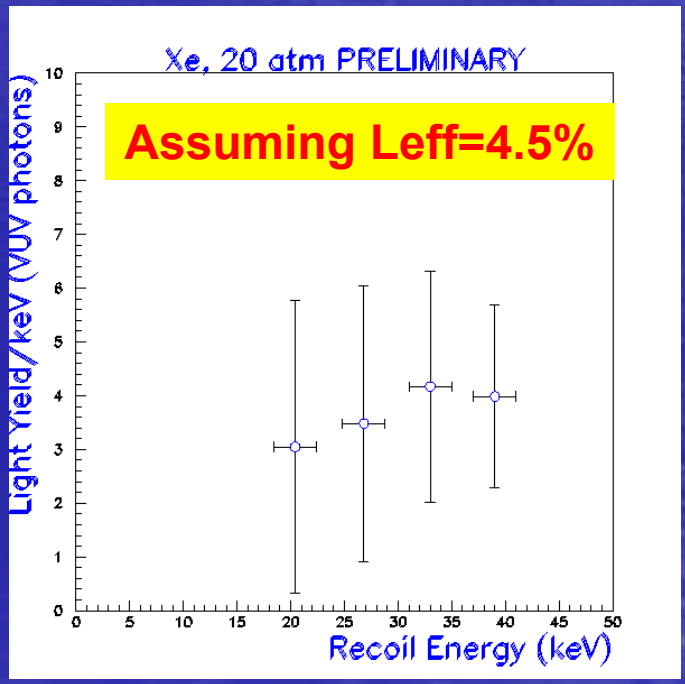

nuclear recoils
Er−max = 39 keV
30 keV escape peak
12 keV x−ray
?
Energy (keVee) – based on S2


nuclear recoils
Er−max = 39 keV
30 keV escape peak
12 keV x−ray
Co-57 data
Energy (keVee) – based on S2

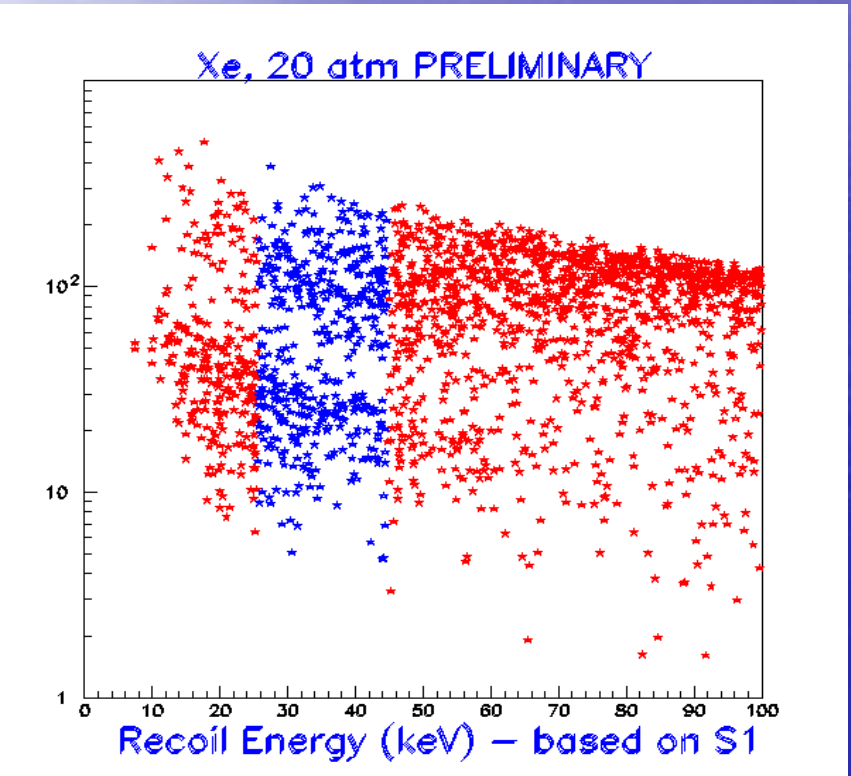
Xe – 20 atm
NR Q & L yields

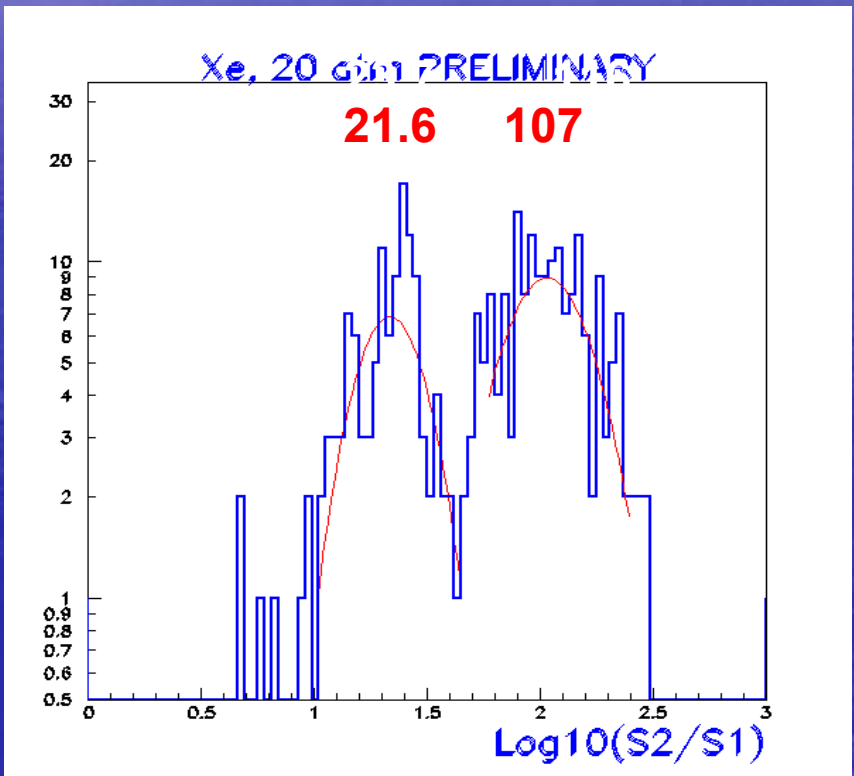






Xe – S2/S1 Discrimination





Centroid Separation > X4 ?

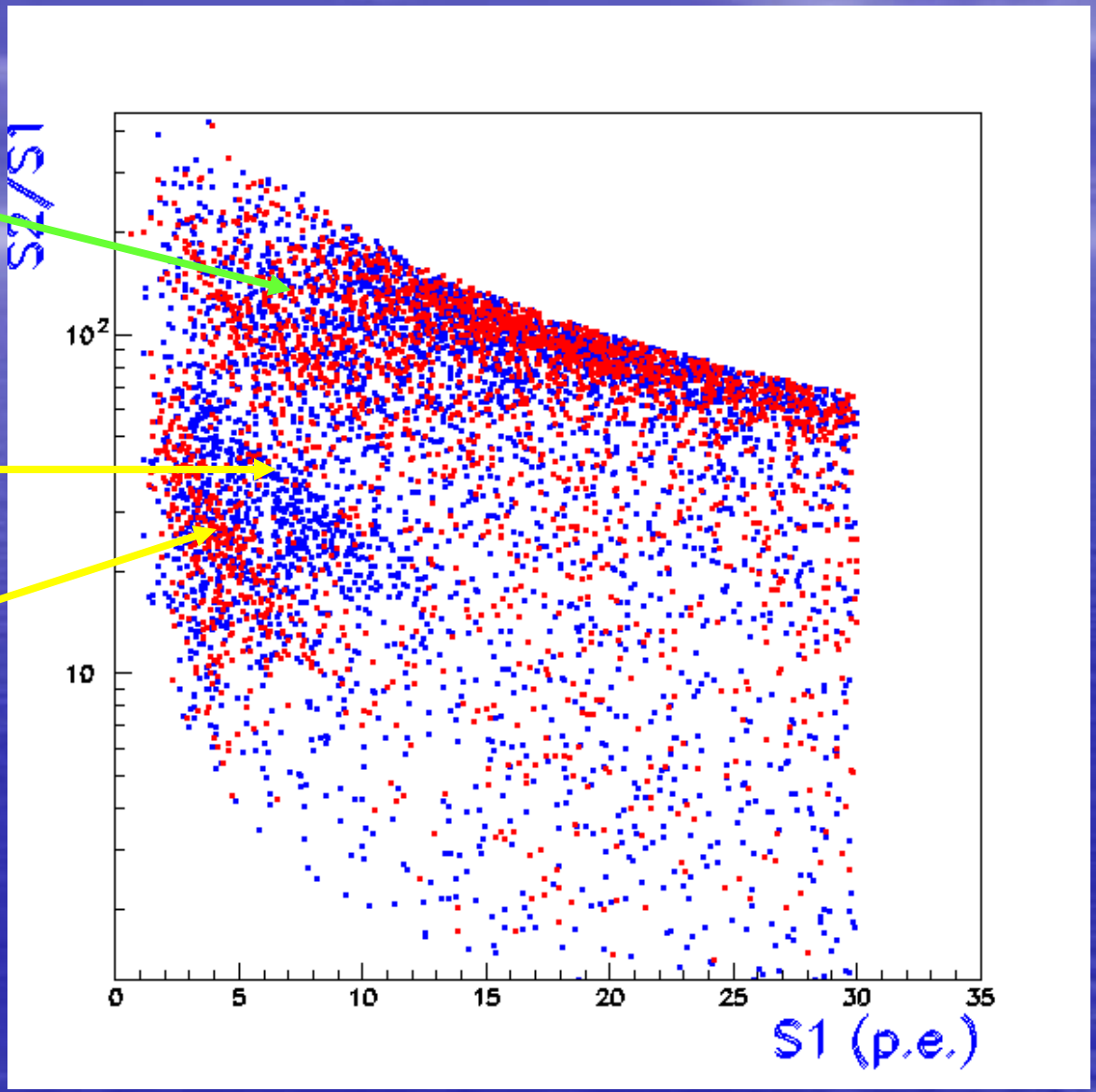
20 atm Xe

Electron Recoils

Nuclear Recoils

Er edge 39 keV

Er edge 20 keV

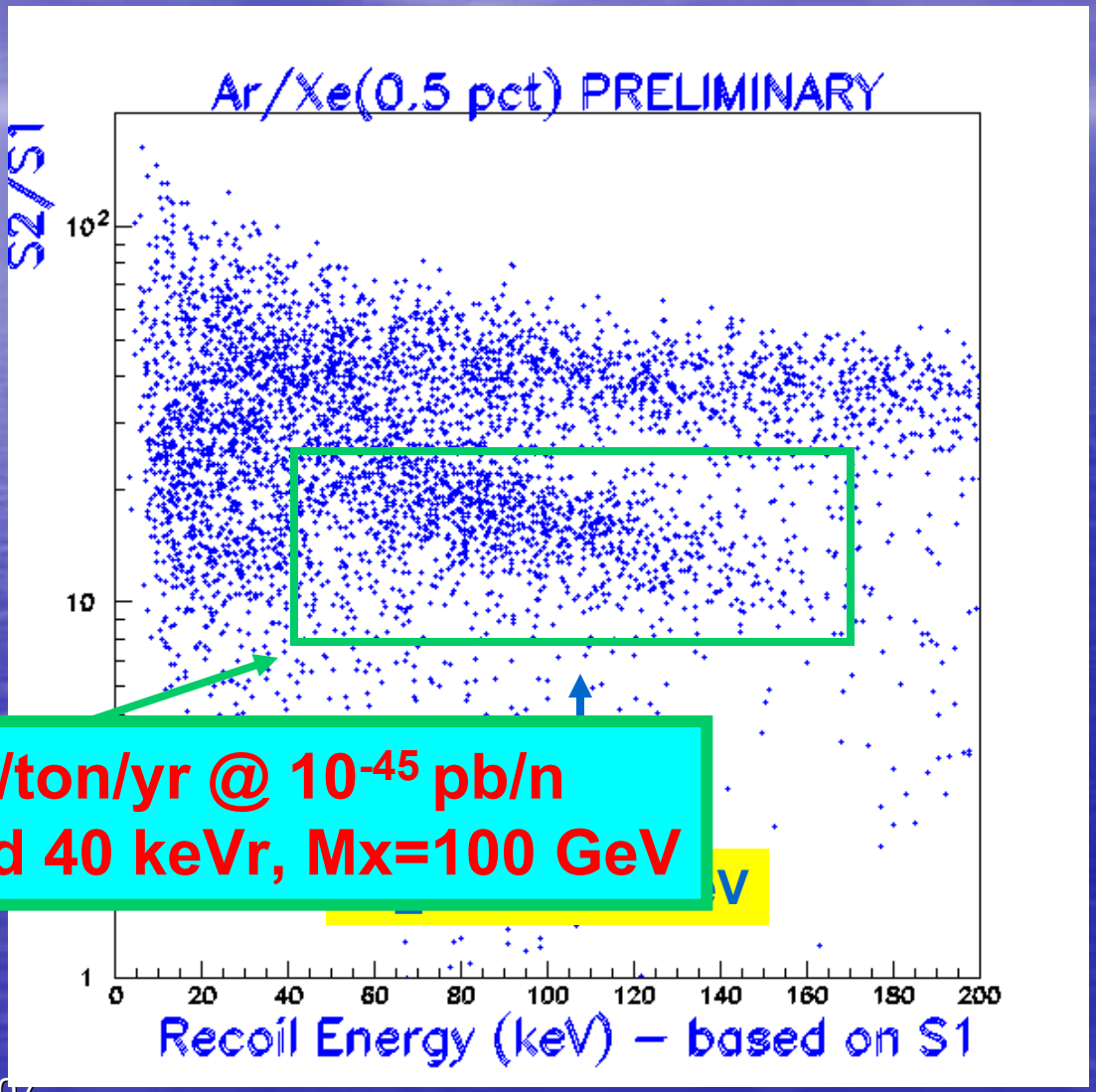


Results

ArXe(0.5%) @ 50 atm

~ 750 psi

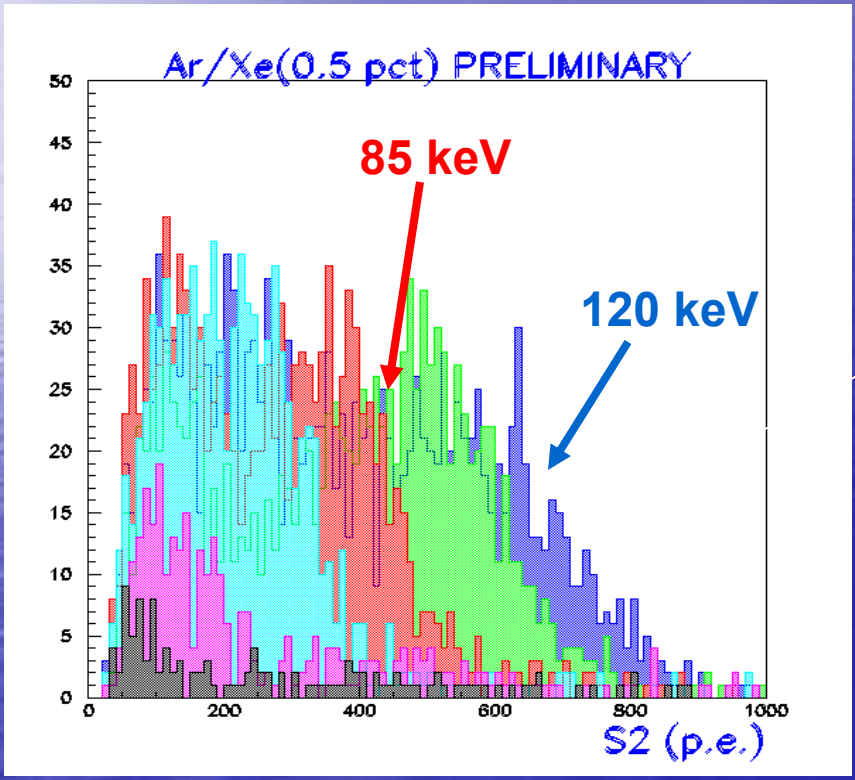
ArXe(0.5%) – 50 atm
NR Response

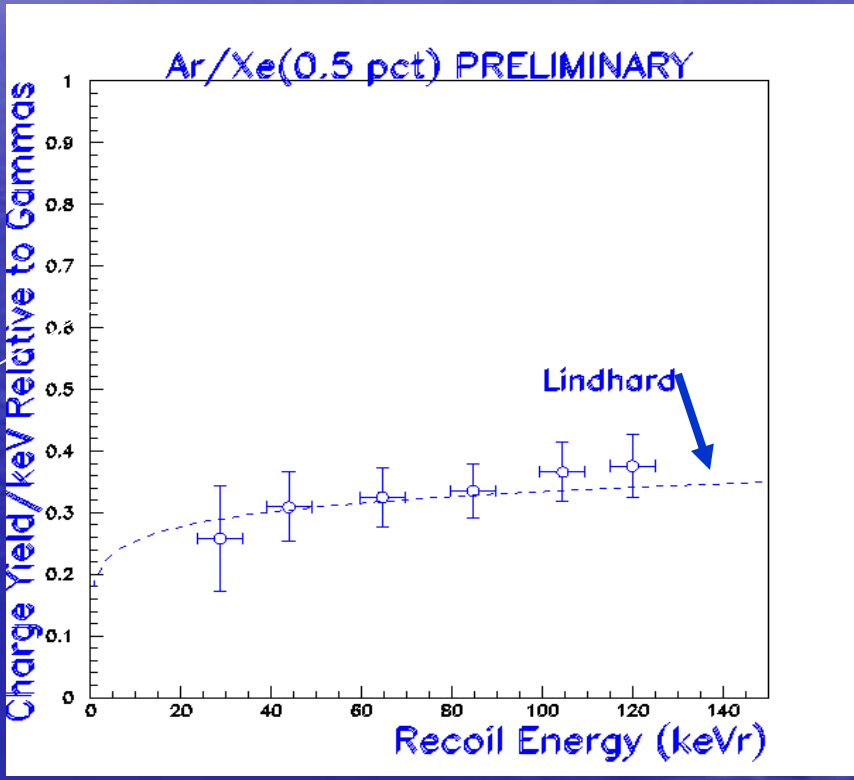


~ 15 events/ton/yr @ 10^{-45} pb/n
Er threshold 40 keVr, Mx=100 GeV

Ar Xe(0.5%) – Charge Yield

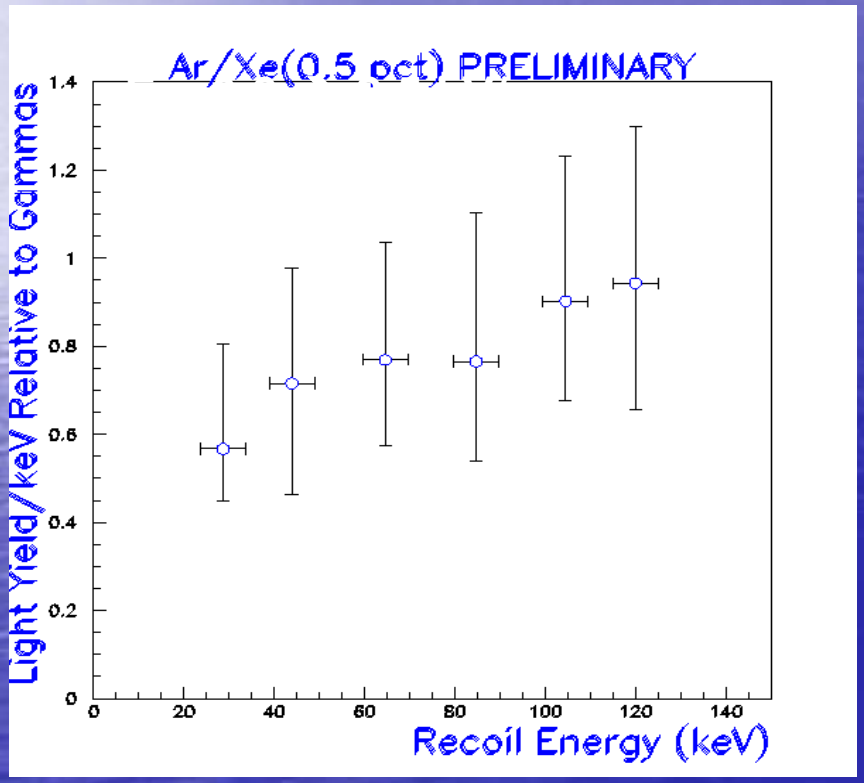
Key! (Penning effect…)

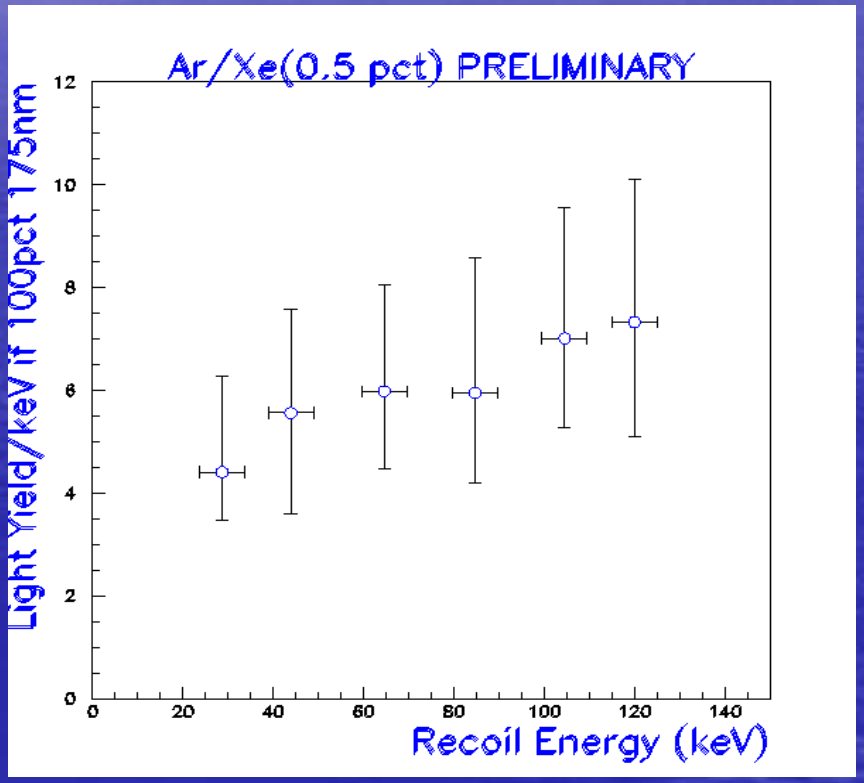




ArXe(0.5%) – Light Yield

Key!





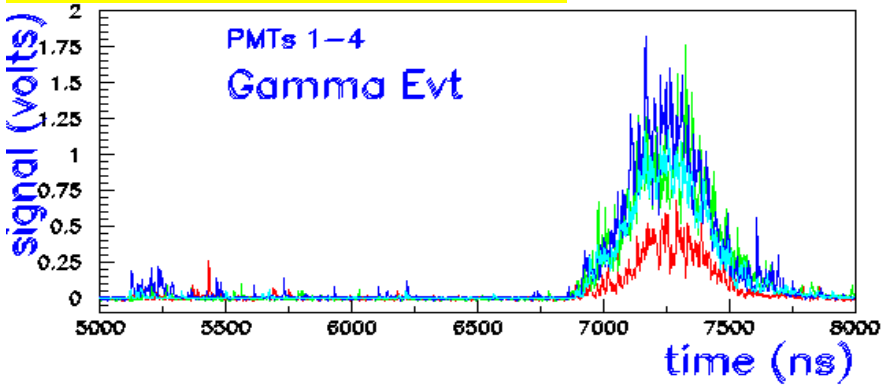
Results

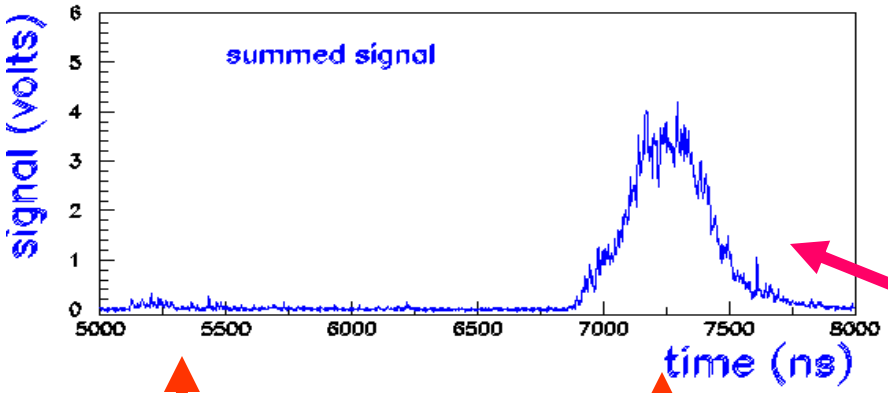
NeXe(0.5%) @ 100 atm

1600 psi

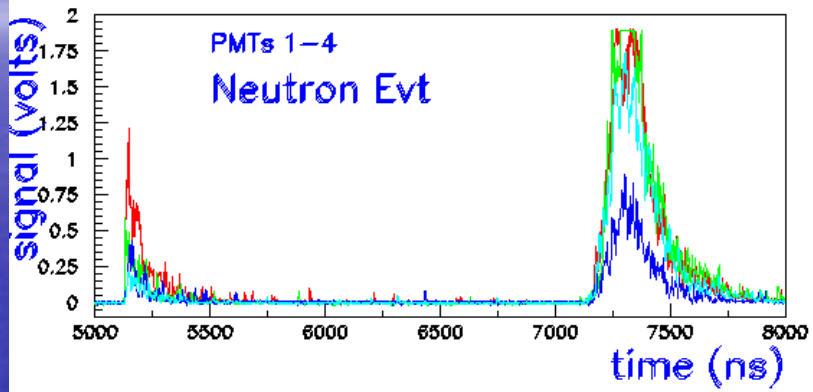
Event Waveforms (Ne-Xe example)

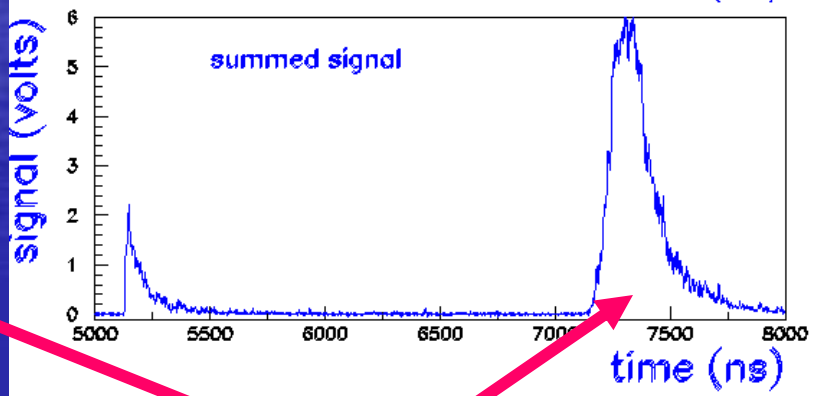
Gamma Event





Neutron Event





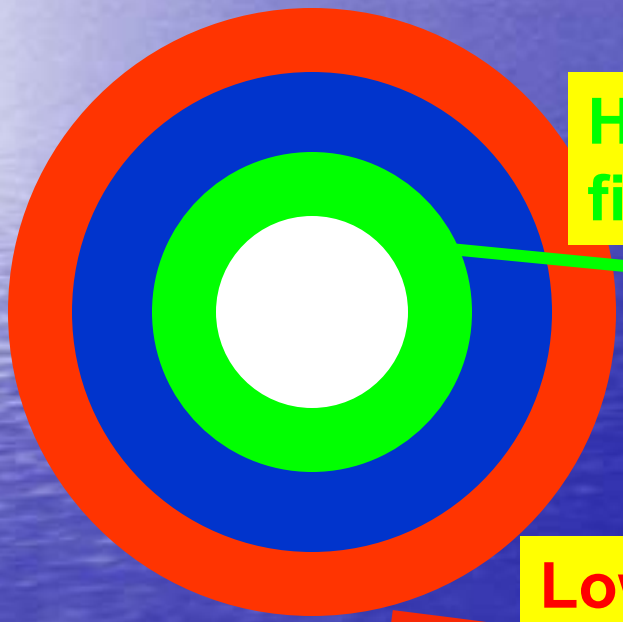
Primary (S1)

Secondary (S2)

Areas Same
i.e. ionization same

Nuclear Recoil Discrimination: S2 vs S1

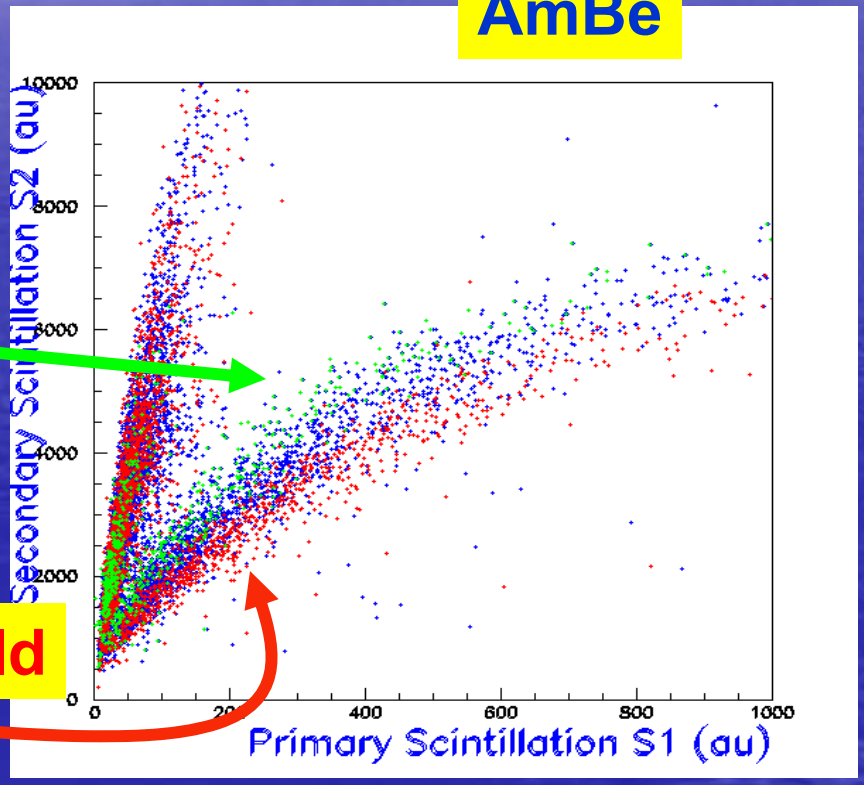
Drift regions



Higher field

Lower field

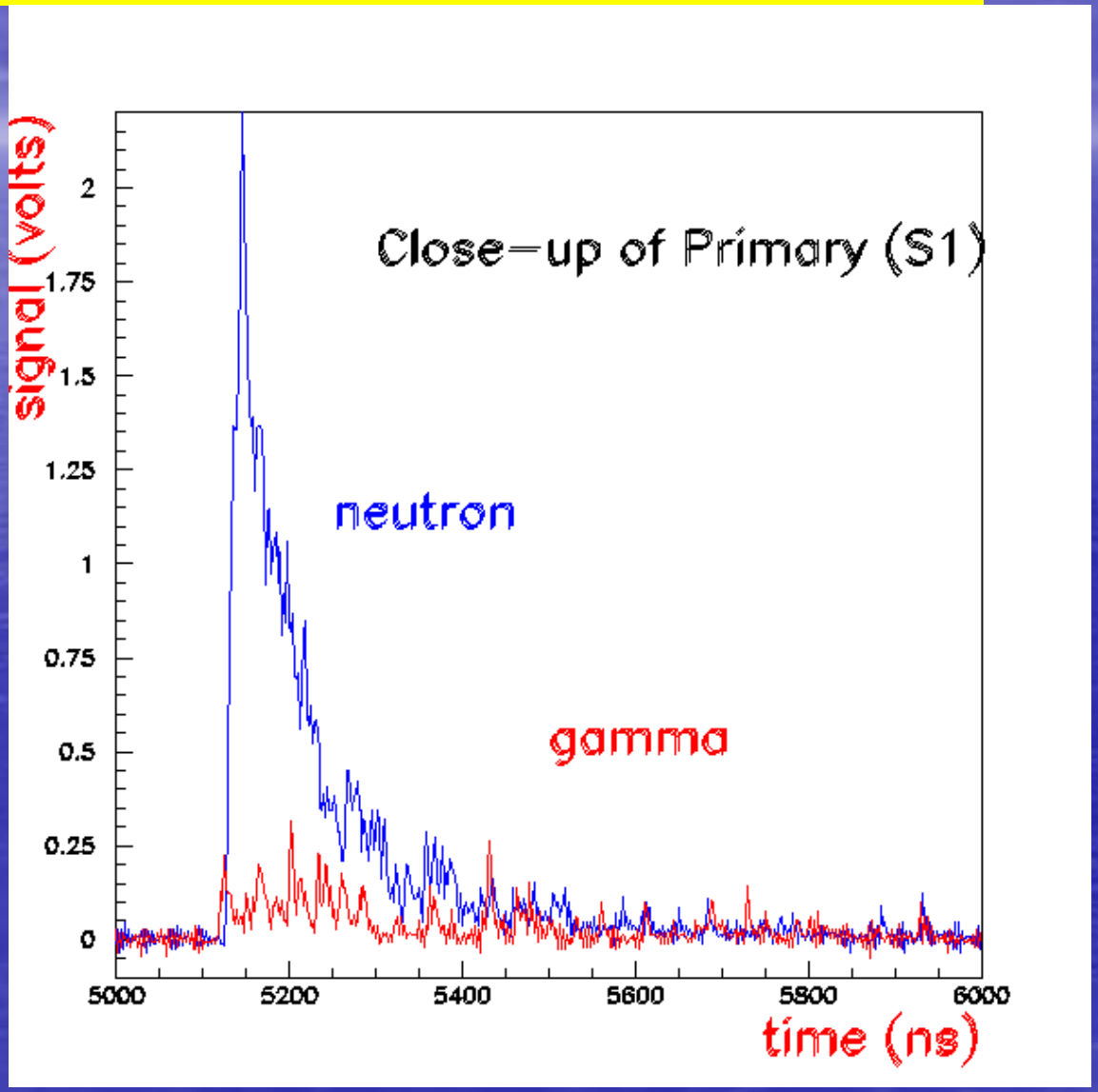
AmBe



➔S2/S1 field (and density) dependent for nuclear recoils

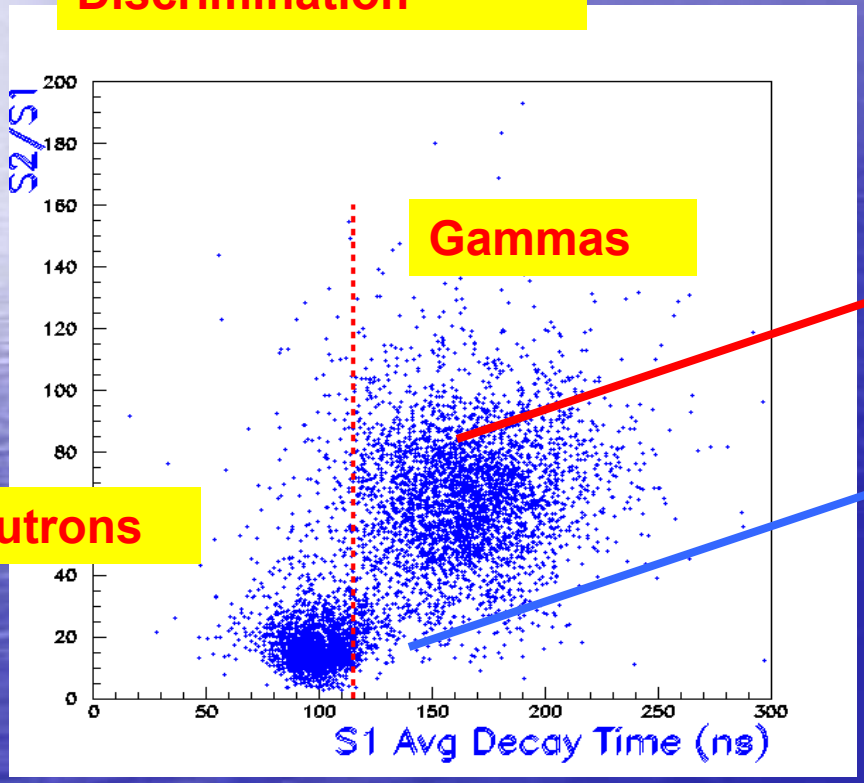
➔Gammas unaffected (Emin ~ 600 v/cm here)

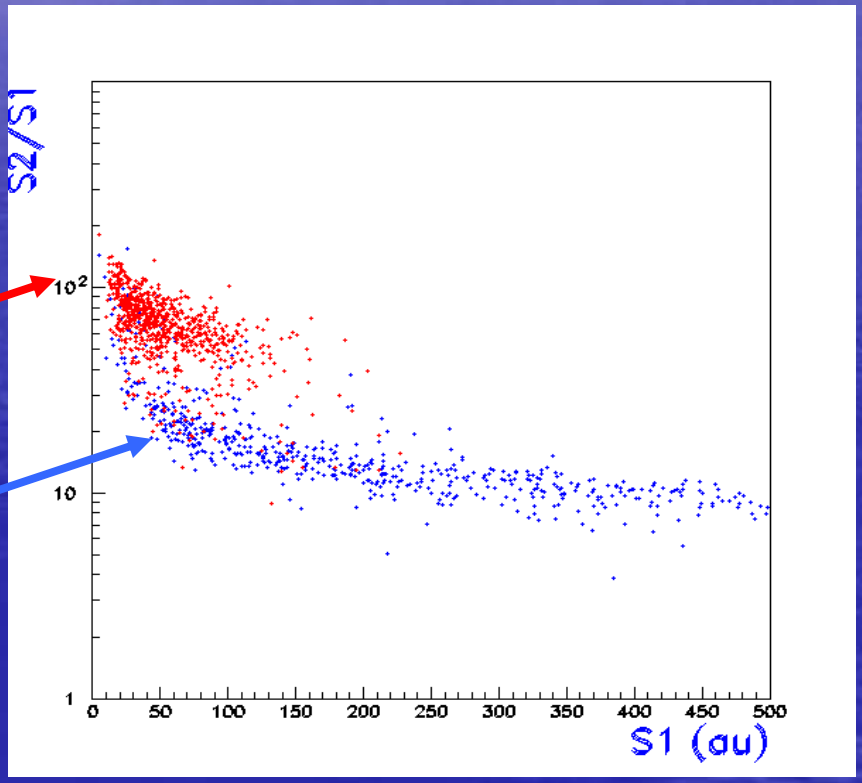
Primary Pulse Shape Discrimination



S2/S1 AND Primary Shape Discrimination!

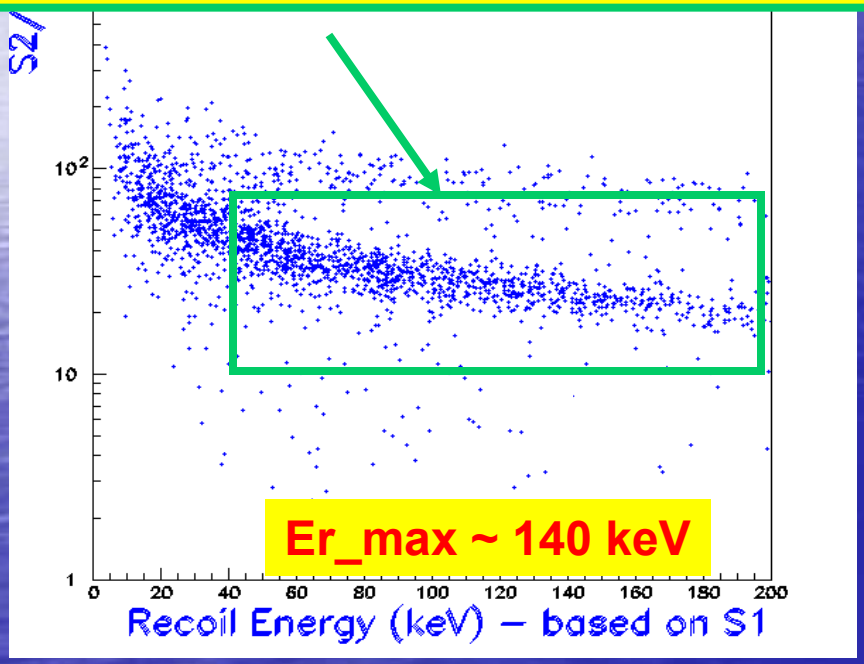
Primary Pulse Shape Discrimination

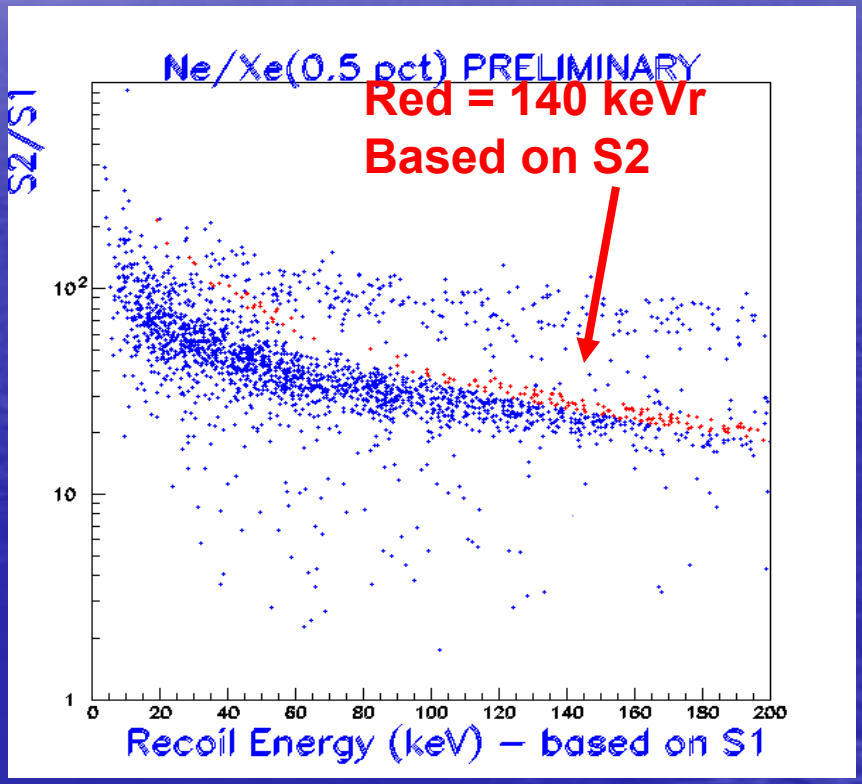




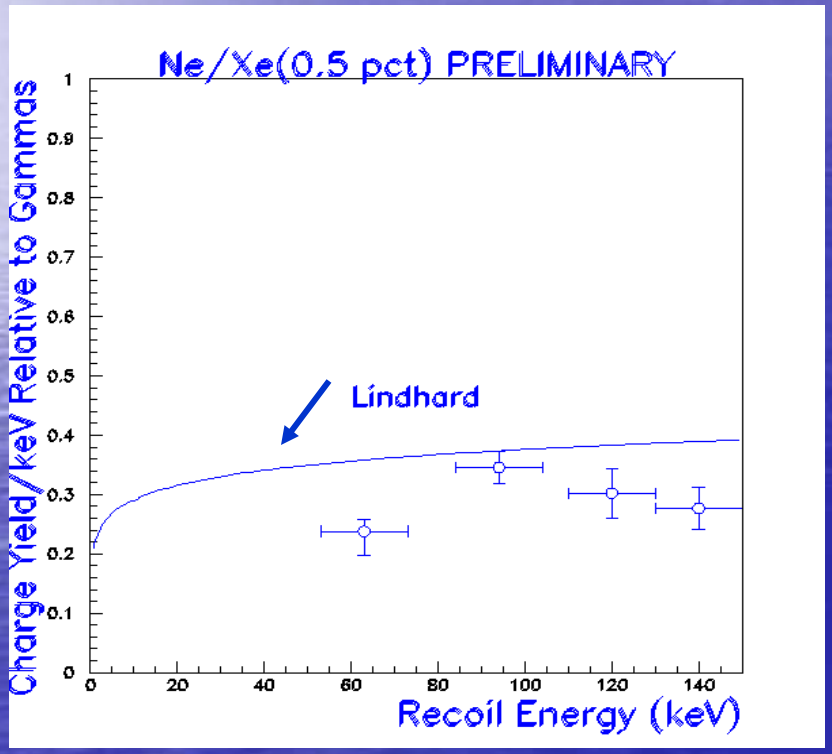
NeXe(0.5%) – 100 atm
NR Response

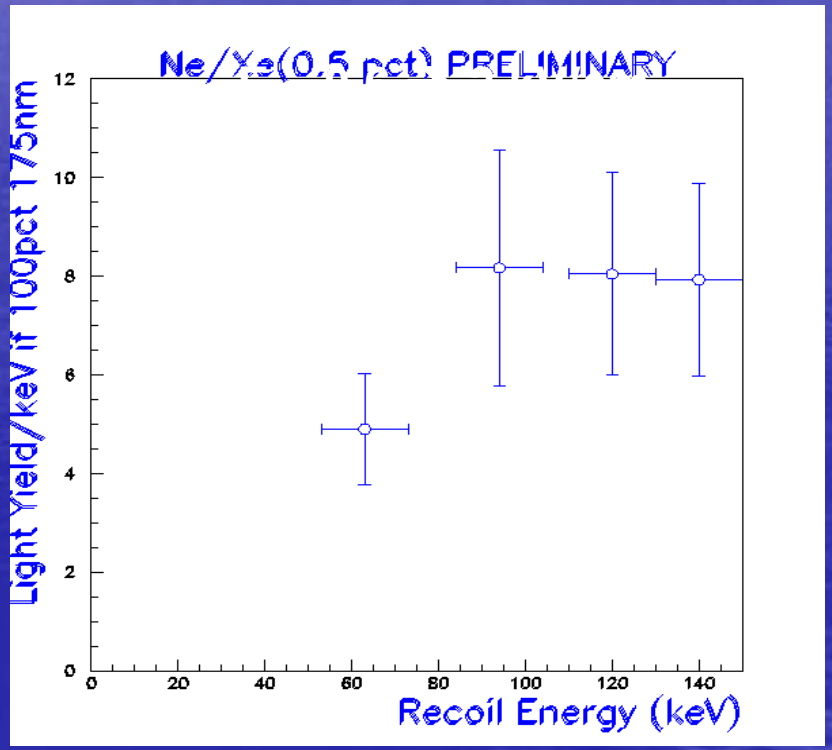
~ 1.8 evts/ton/yr @ 10^{-45} pb/n
@ Er >= 40 keV Mx=100 GeV





NeXe(0.5%) – Q&L Yield

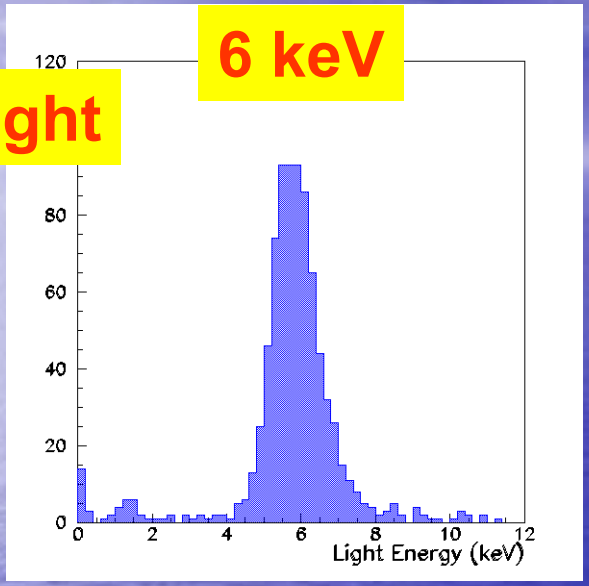




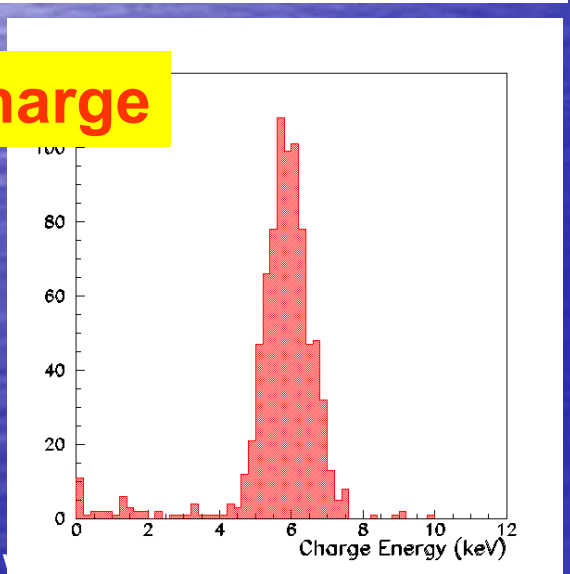
^{55}Fe 6 keV gamma in Ne-Xe(0.5%)

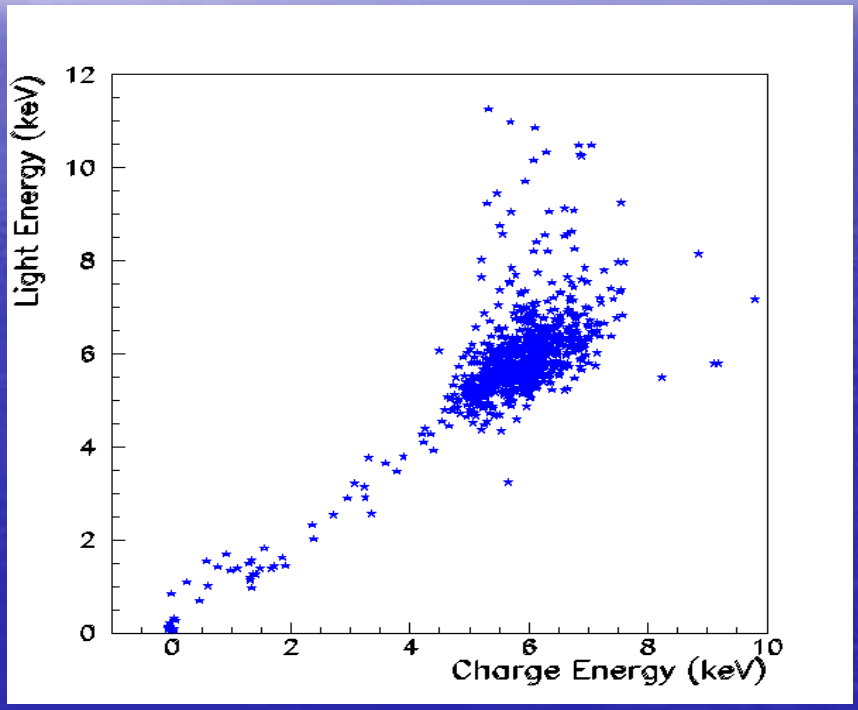
Light

6 keV



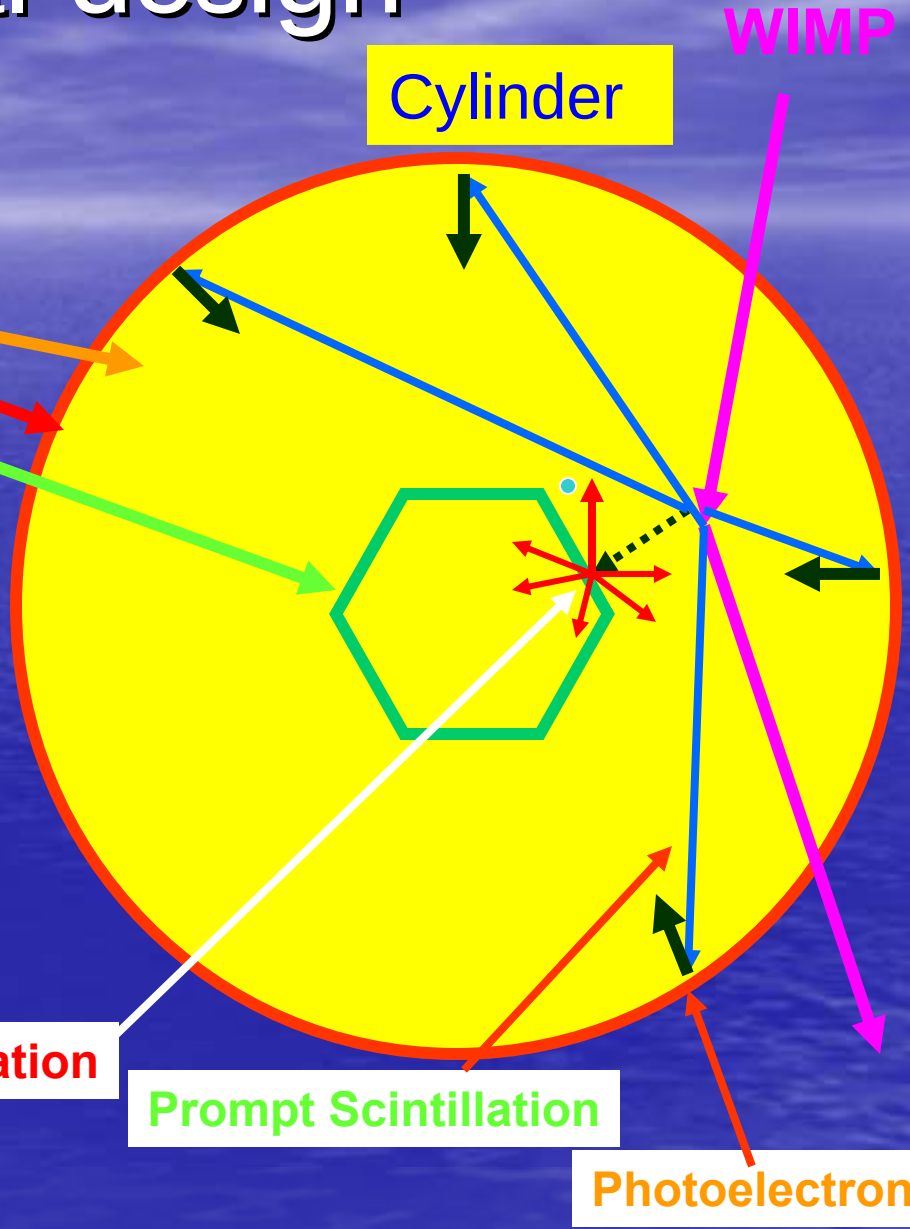
Charge



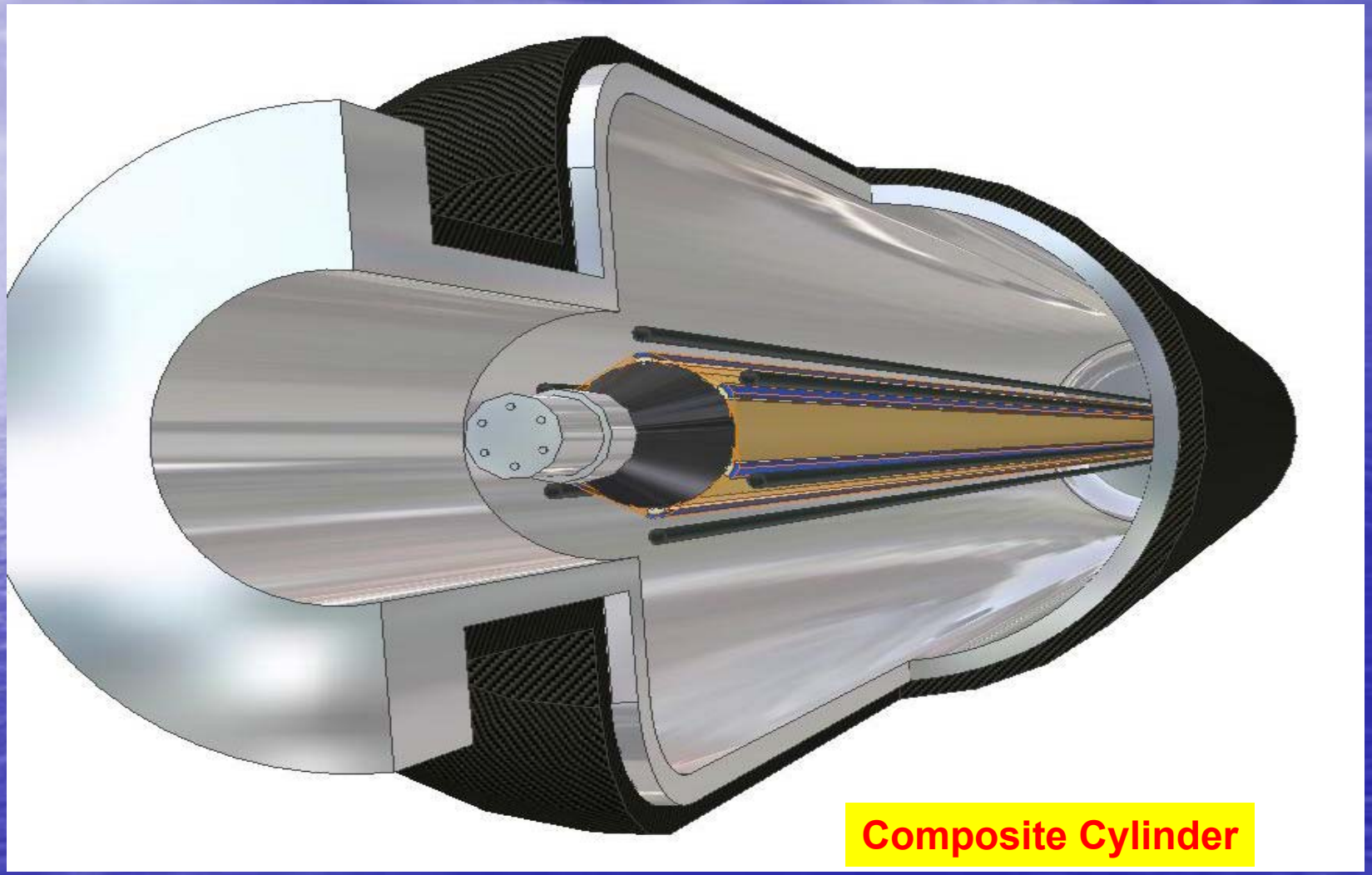


SIGN conceptual design

- Gas
- CsI Photocathode
- Light gain structure using WLS fibers



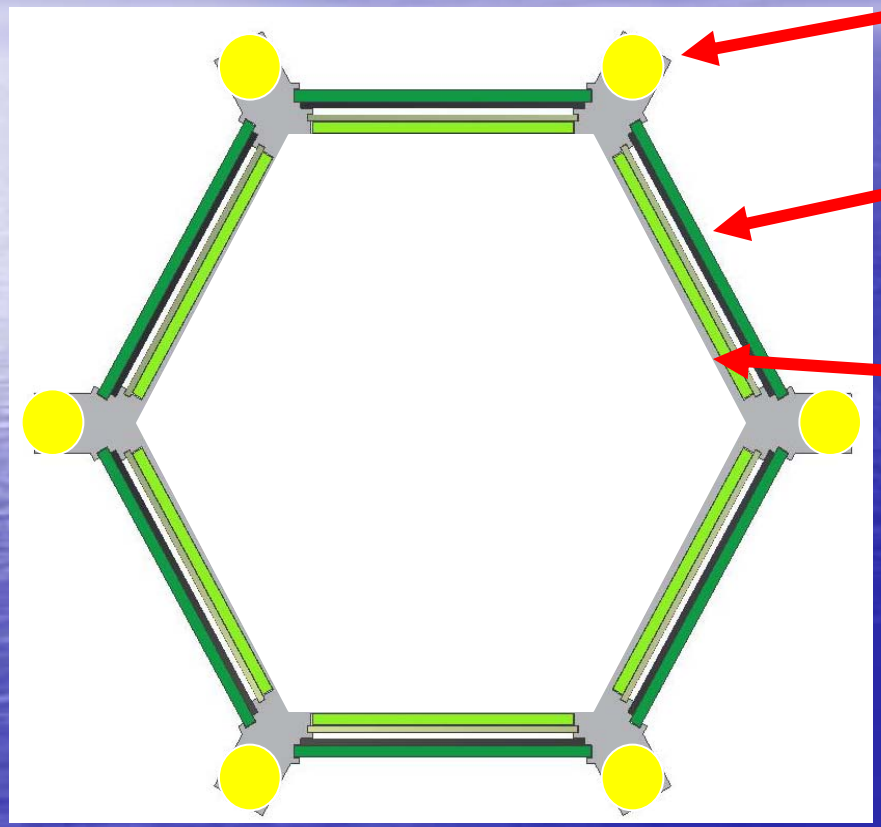
Detector Concept



Composite Vessels

- Carbon, Kevlar wound
- Some rated > 10000 psi !
- Used on mass transit (Methane))
- Used for Hydrogen fuel cells
- On jets, spacecraft
- DOT certified !

Hub Structure – one example

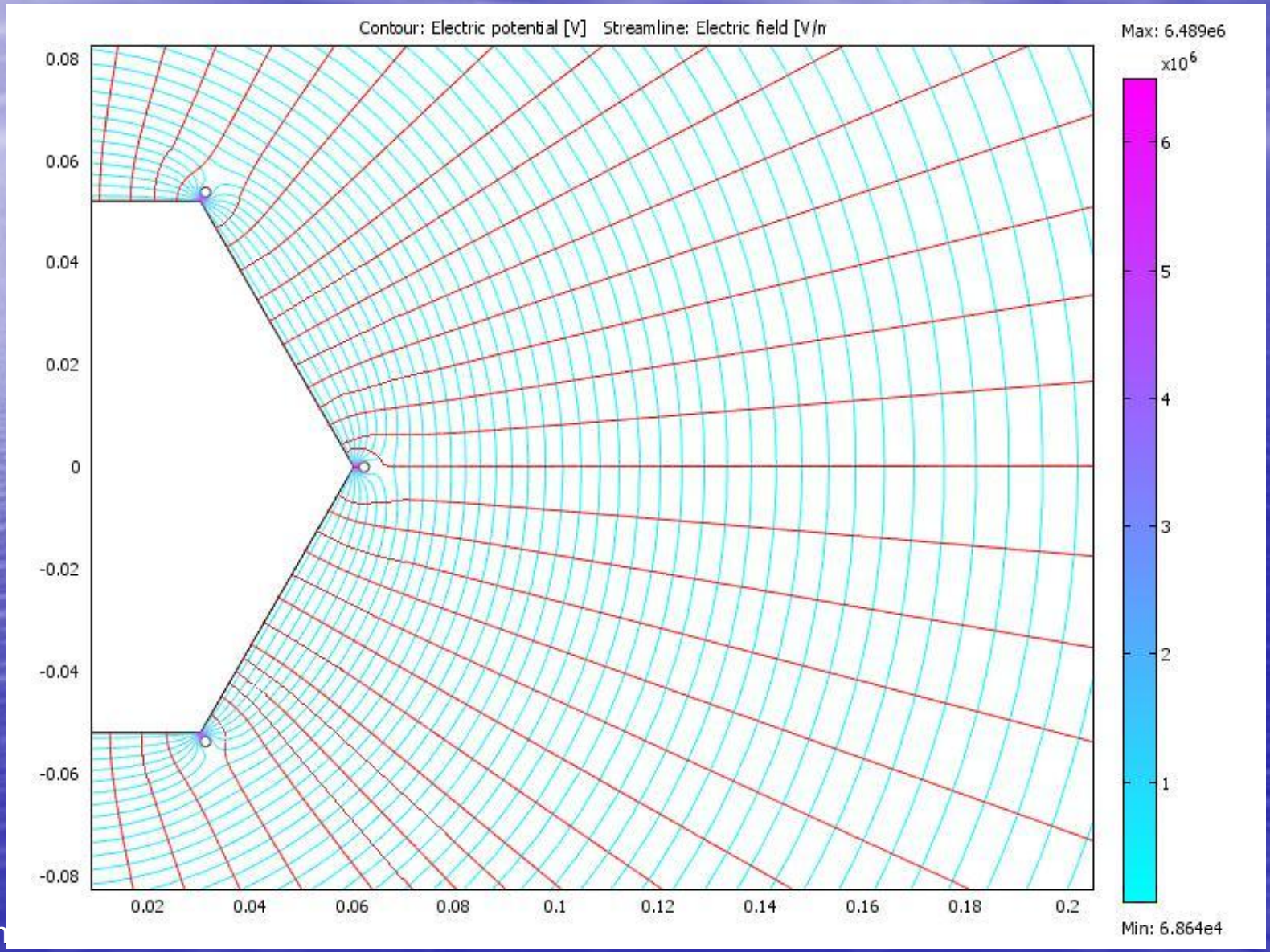


Field Shaping Electrodes

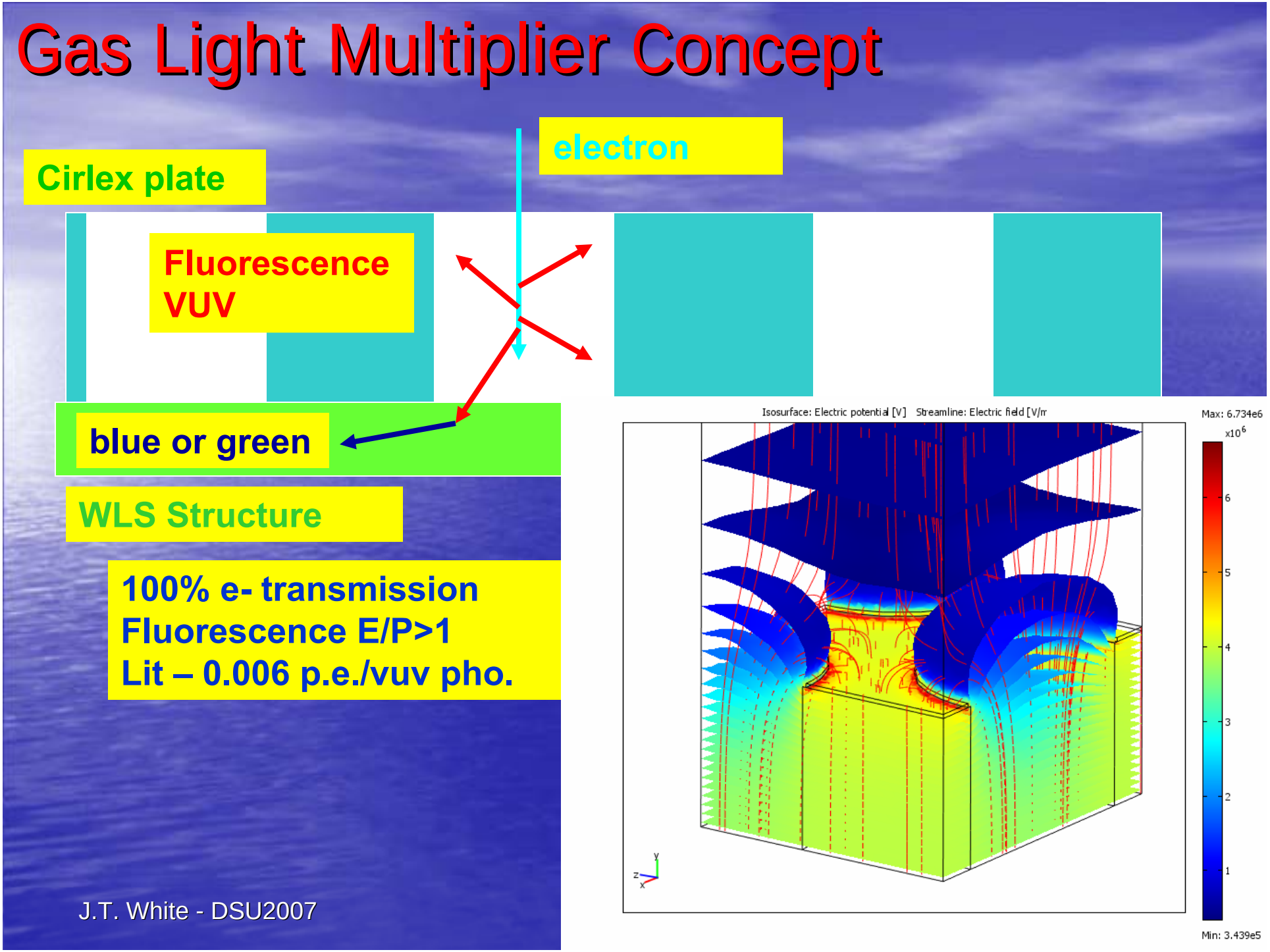
Proportional light gain structure

WLS Structure

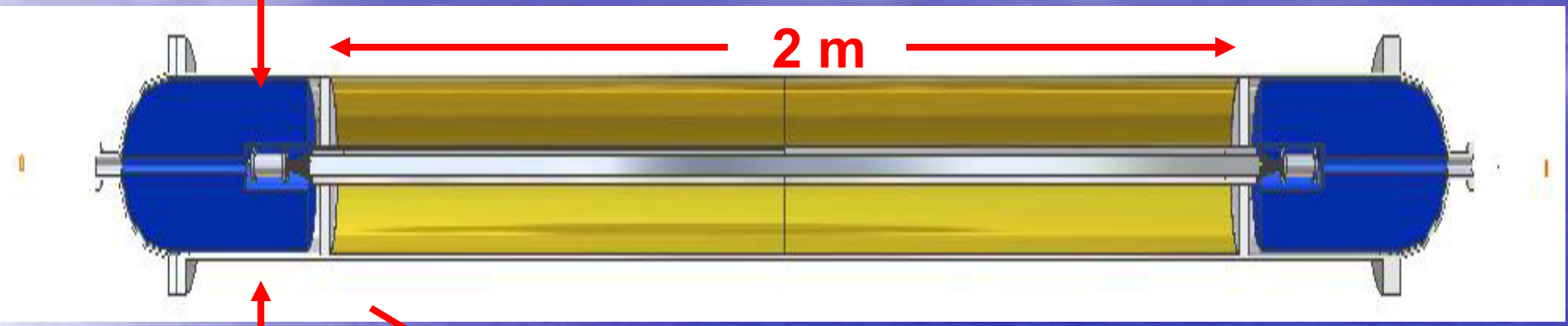
Electron Drift Flow



Gas Light Multiplier Concept



20 kg 20 atm Xe Prototype

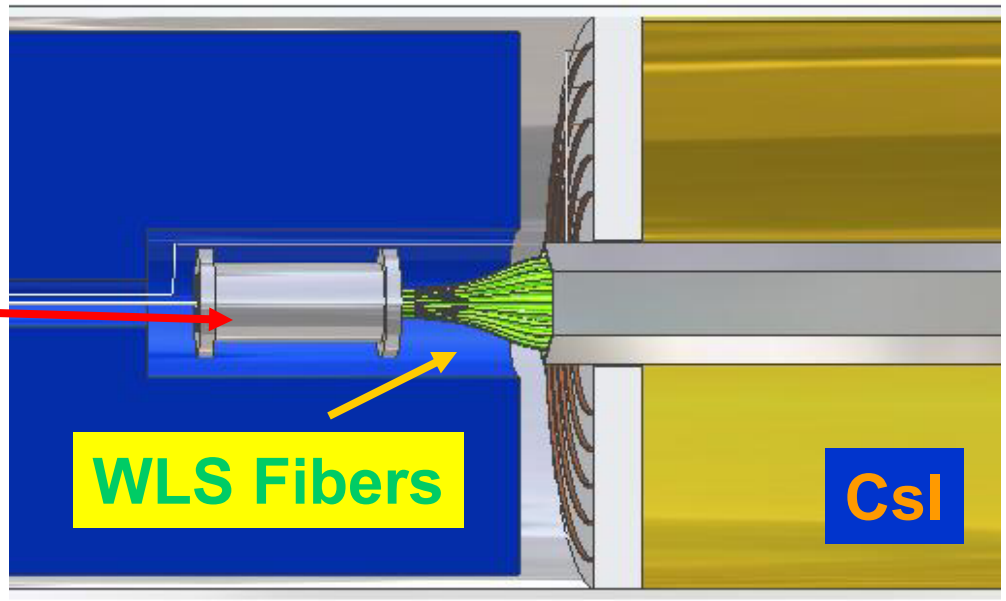


0.4 m

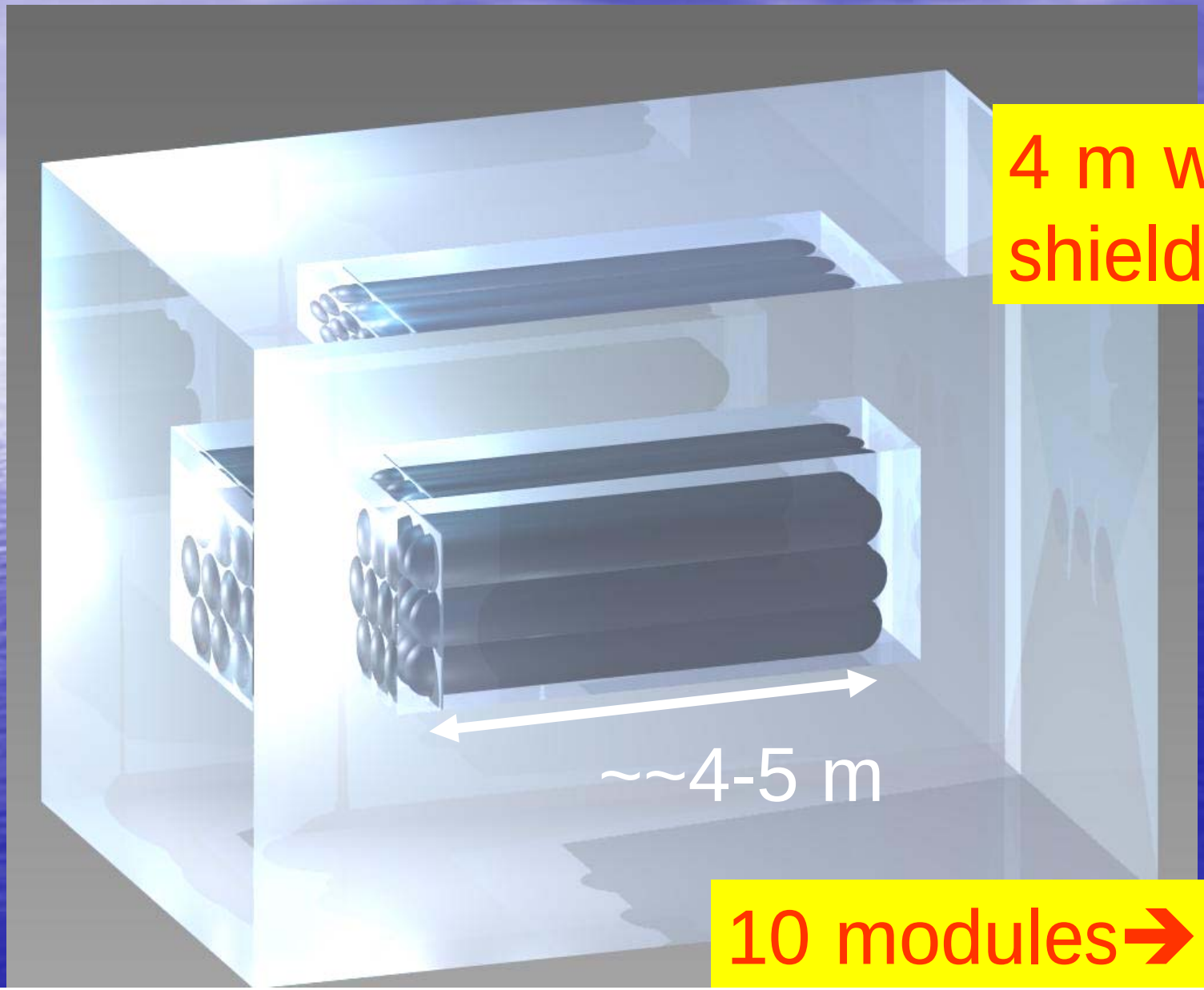
Shielding

PMT

SS Tube
~0.25 inch wall



Shielding



4 m water shield

10 modules➔ 1 ton

Plans – Phased Program

- 20 kg Xe proto-experiment @ 20 atm
  - SS vessel
  - Water shield
  - Only 300 psi
- Future – Neon @ 200 atm
  - WIMP Mass = ????
  - Halo velocity dispersion = ????
  - Number of “species” = ????