Applications of the μ-PIC

1. Neutron Detector
2. Double Beta
3. Dark Matter

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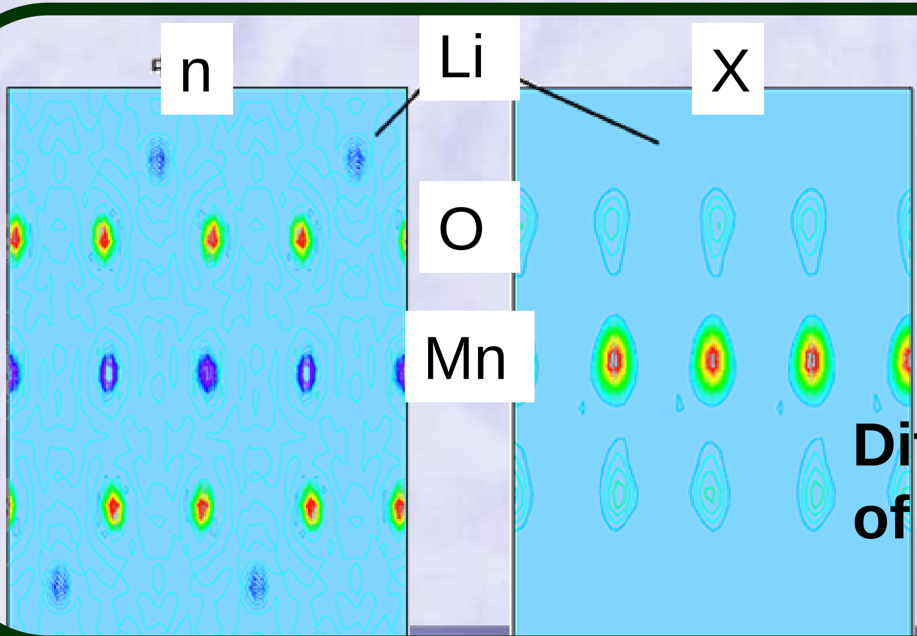
Neutron Imaging Detector with μ -PIC

1. Neutron Science

- **Comparison with the X-ray science**
  - charge 0 ⇒ penetrating power : large
  - sensitive to small-Z materials (H, Li, O) ⇒ industry, protein structure…
  - spin ½ ⇒ magnetic properties
  - TOF (time-of-flight) method (next slide)

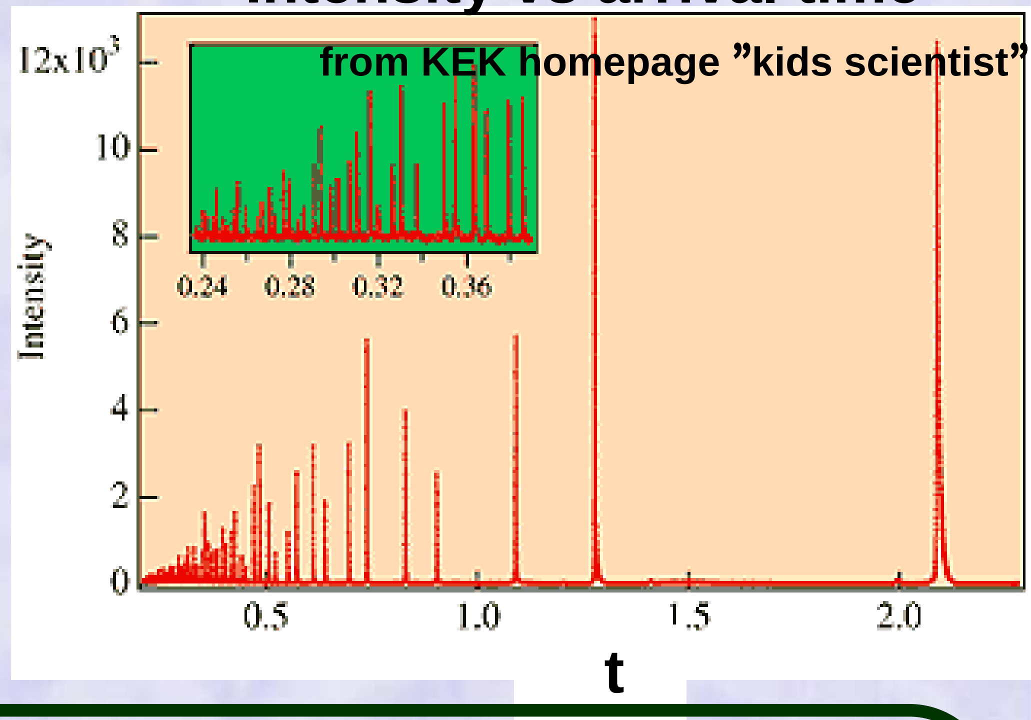


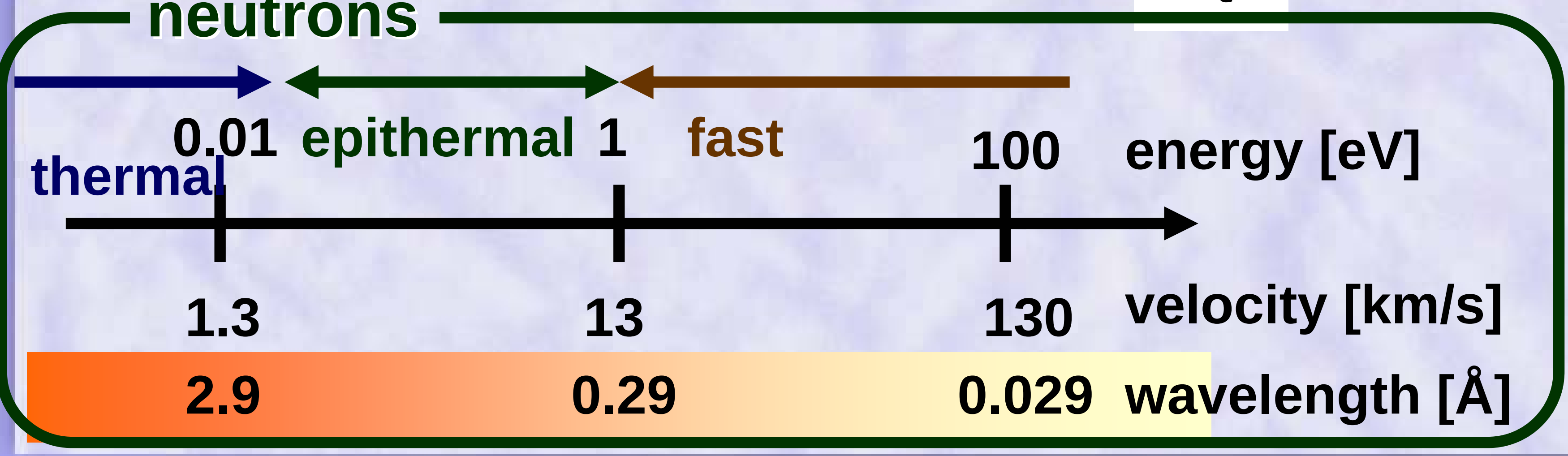
Diffraction images of a Li-ion battery

from KEK homepage ”kids scientist”

- **TOF method**
  - pulsed beam
  - arrival time ⇒ wavelength
  - time resolution: ~μs is required

Intensity vs arrival time

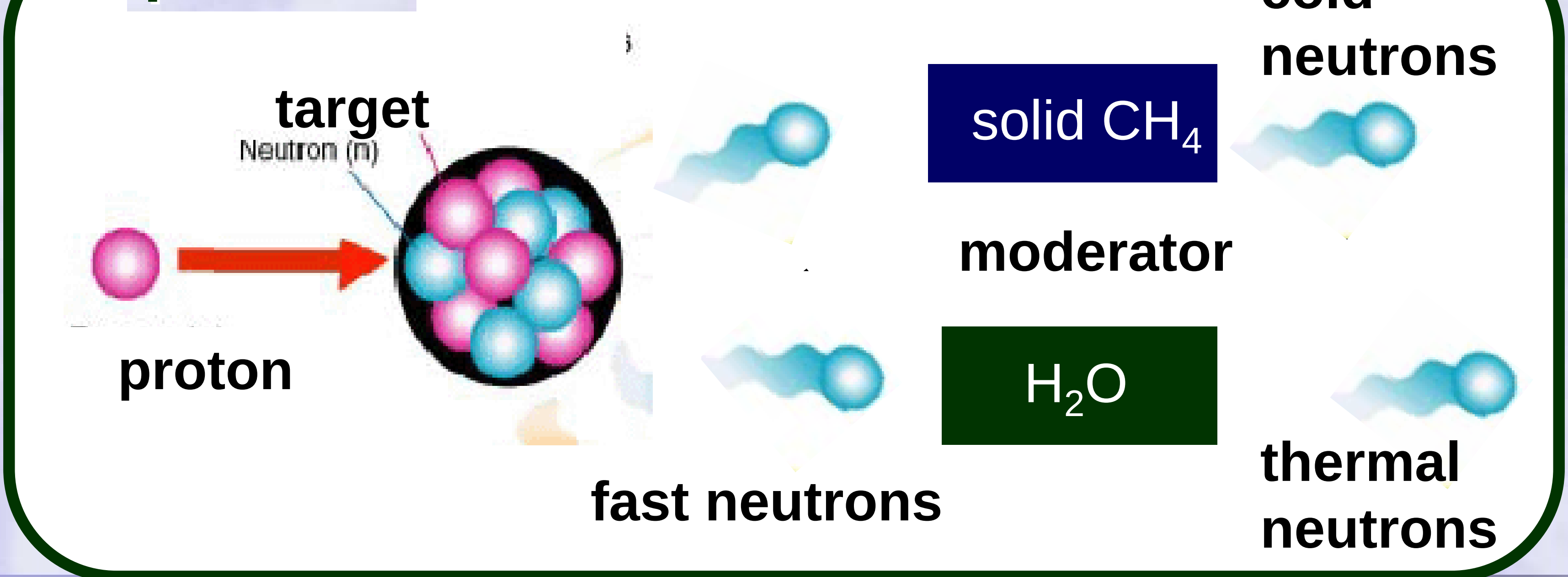




2.Neutron Source

- **Proton Synchrotron ⇒ Spallation**
  - KEK : 500MeV (3kW) proton + Ta target
    ⇒ 10^{12} n/pulse × 20Hz
  - J-PARC (2006~) : 3GeV (1MW) proton + Hg target
    ⇒ 25Hz 23 beam lines
  - European Spallation Source, Spallation Neutron Source

process



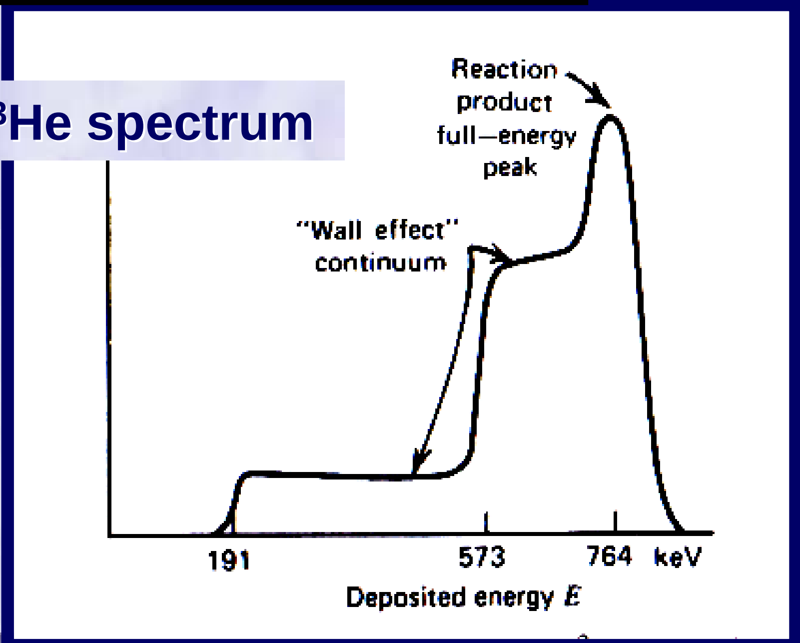
3. Neutron Detectors

- **neutron capture reactions**

reaction	Q value [MeV]	σ [barn]
$^{3}He + n \rightarrow p + {}^{3}H$	0.764	5330
$^{6}Li + n \rightarrow \alpha + {}^{3}H$	4.78	940
$^{10}B + n \rightarrow \alpha + {}^{7}Li$	2.31	3840
$^{157}Gd + n \rightarrow {}^{158}Gd + \gamma s$		26000

  - **Gd : γ-ray background**
- **BF_3 , ^{3}He gas counter**
  - **imaging : no**
  - **wall effect**
  - **high pressure**

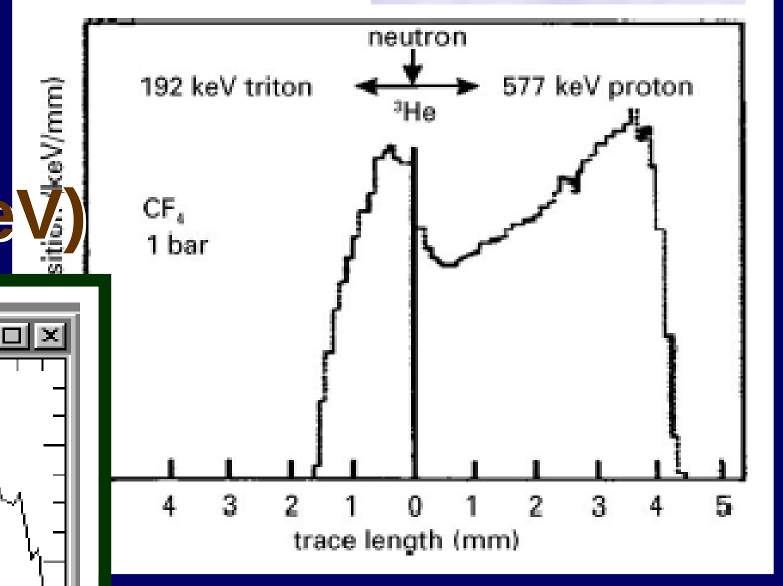
^{3}He spectrum



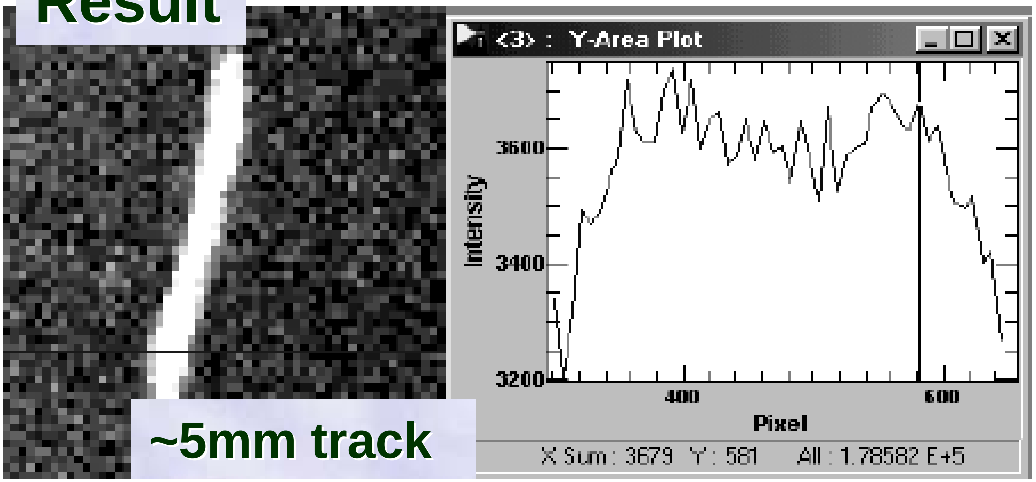
neutron PSD (position sensitive detectors)

- GEM + CCD NIM A478(2002)357
- ^3He(1atm) + CF_4(0.4atm)
- ^3He + n
  → p (573keV) + ^3H (191keV)

Calculation



Result



~5mm track

- Problems
  - high rate
  - large area
  - position resolution

with μ - PIC !

4. μ-PIC for a Neutron PSD

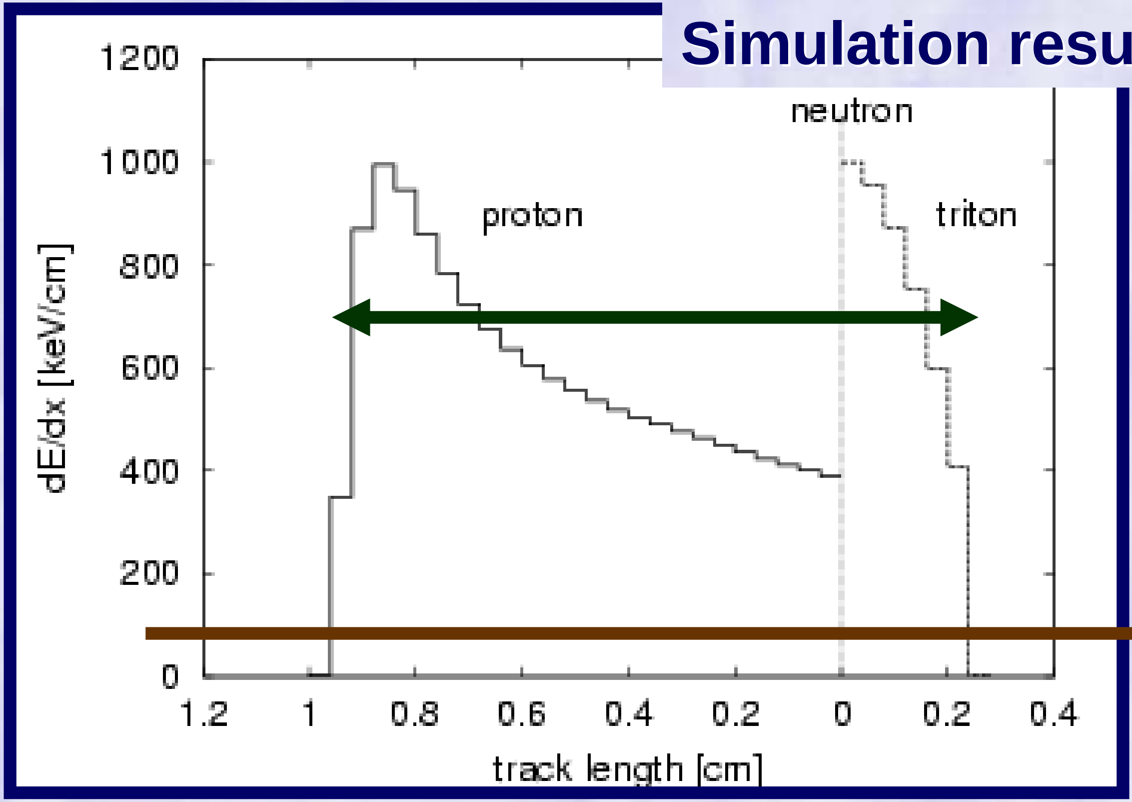
"Performance of a micro-TPC for a time-resolved neutron PSD" K. Miuchi et. al. submitted for NIM A

- Paper contents
  - Simulation
  - Proton (several hundred keV) tracking
  - Background γ-ray discrimination
- Merit of the μ-PIC based detector
  - high rate operation
  - large area
  - Background γ-ray discrimination
  - TPC ⇒ depth information

Simulation study

- $^3He + n \rightarrow p\ (573keV) + {}^3H\ (191keV)$
- $Ar+C_2H_6(10\%)+{}^3He(0.1\%)$ 1atm
- n capture efficiency ~0.1% (10cm gas depth)

Simulation result



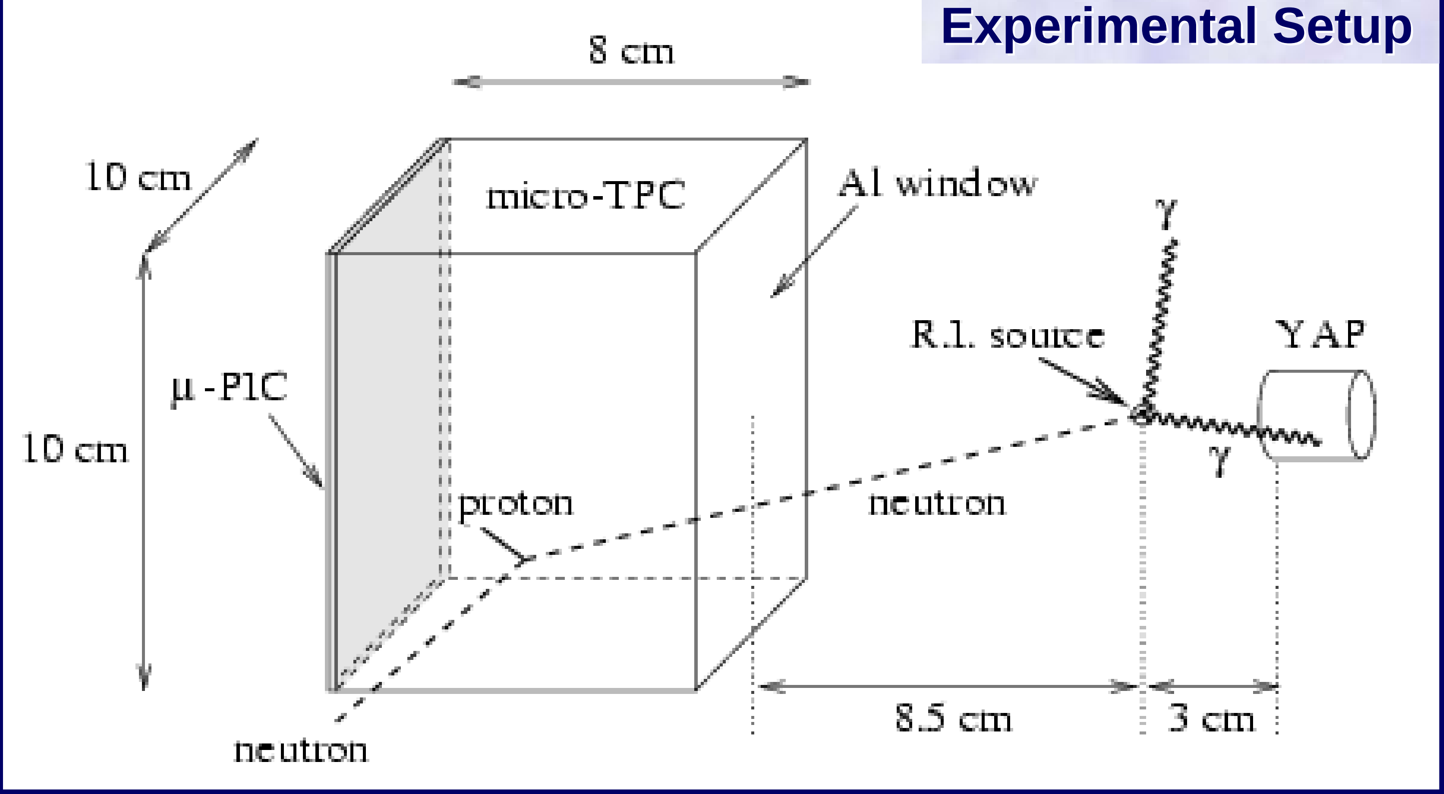
- track length: 1~1.5cm
- μ-PIC threshold : 50keV/cm

detectable? Let's see.

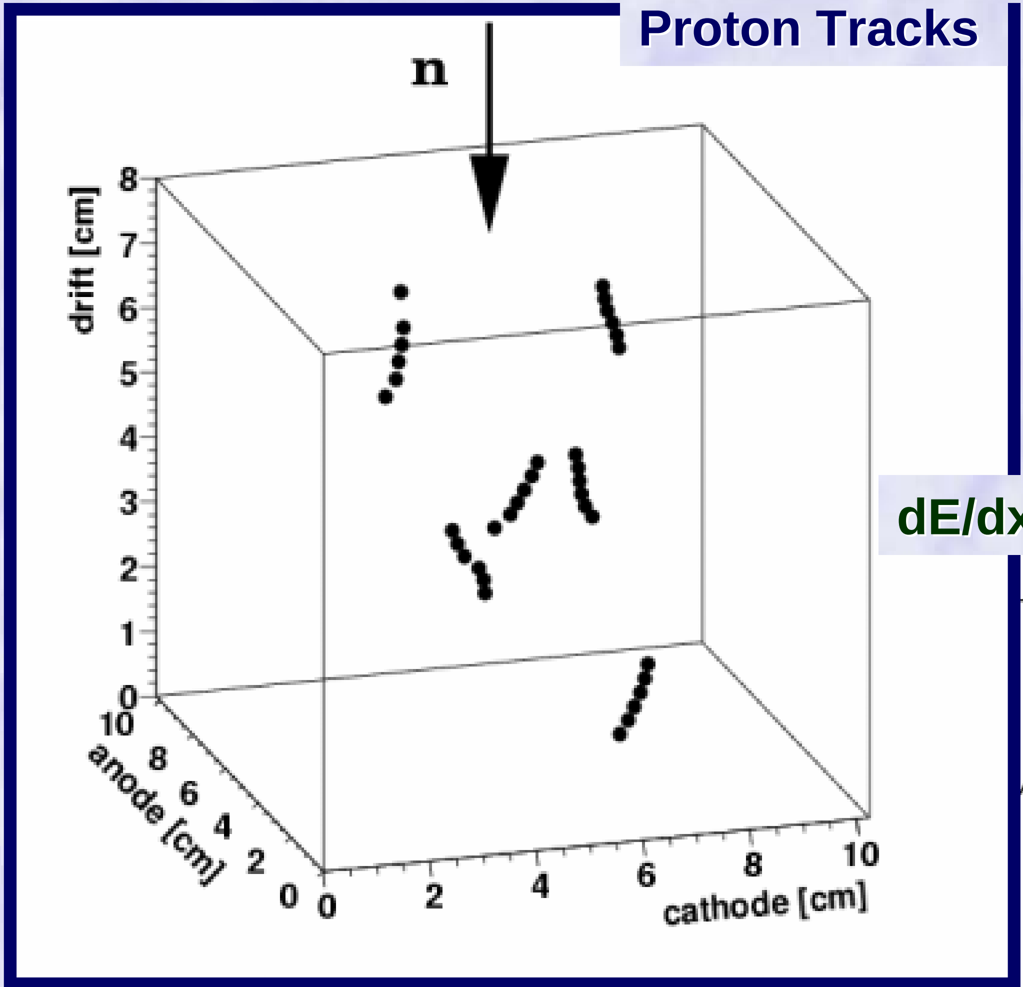
Proton tracking experiment

- Ar + C_2H_6 (10%) at 1atm
- R. I. source : ^{252}Cf (3.8 n + 9.7 γ)
- n(500keV~1MeV) - proton scattering
- Trigger (t=0 for the TPC) : YAP

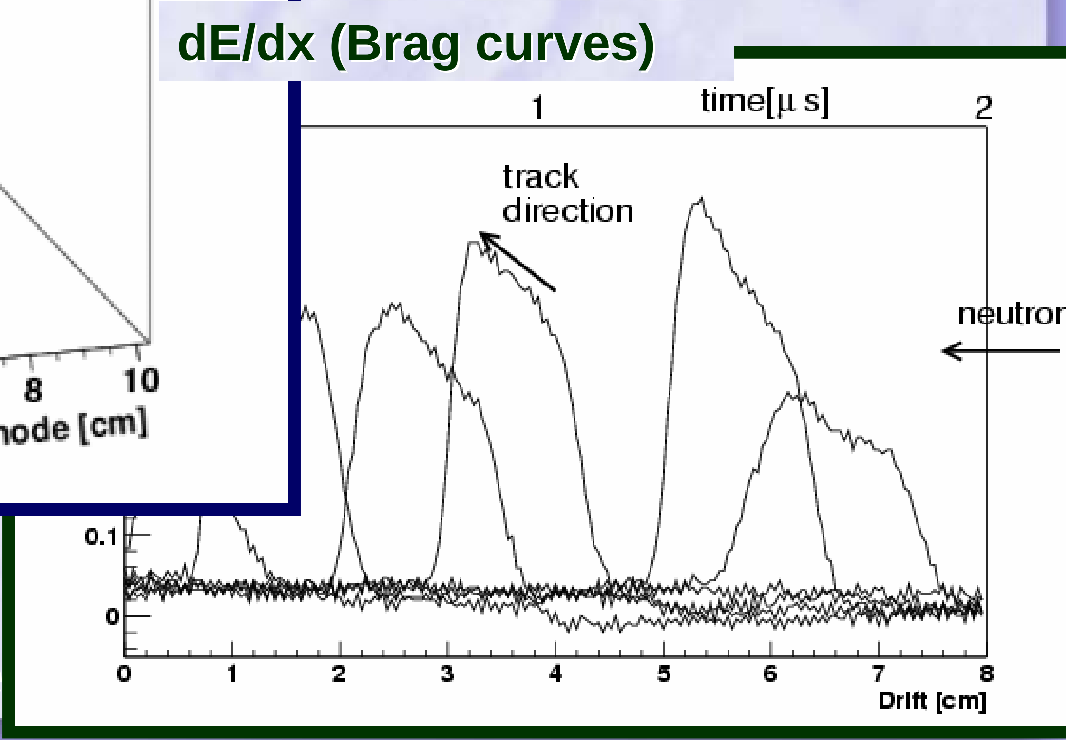
Experimental Setup



Proton tracking results



- Tracking : OK
  proton (0.5~1MeV)



- Direction : known
  from the Brag curve

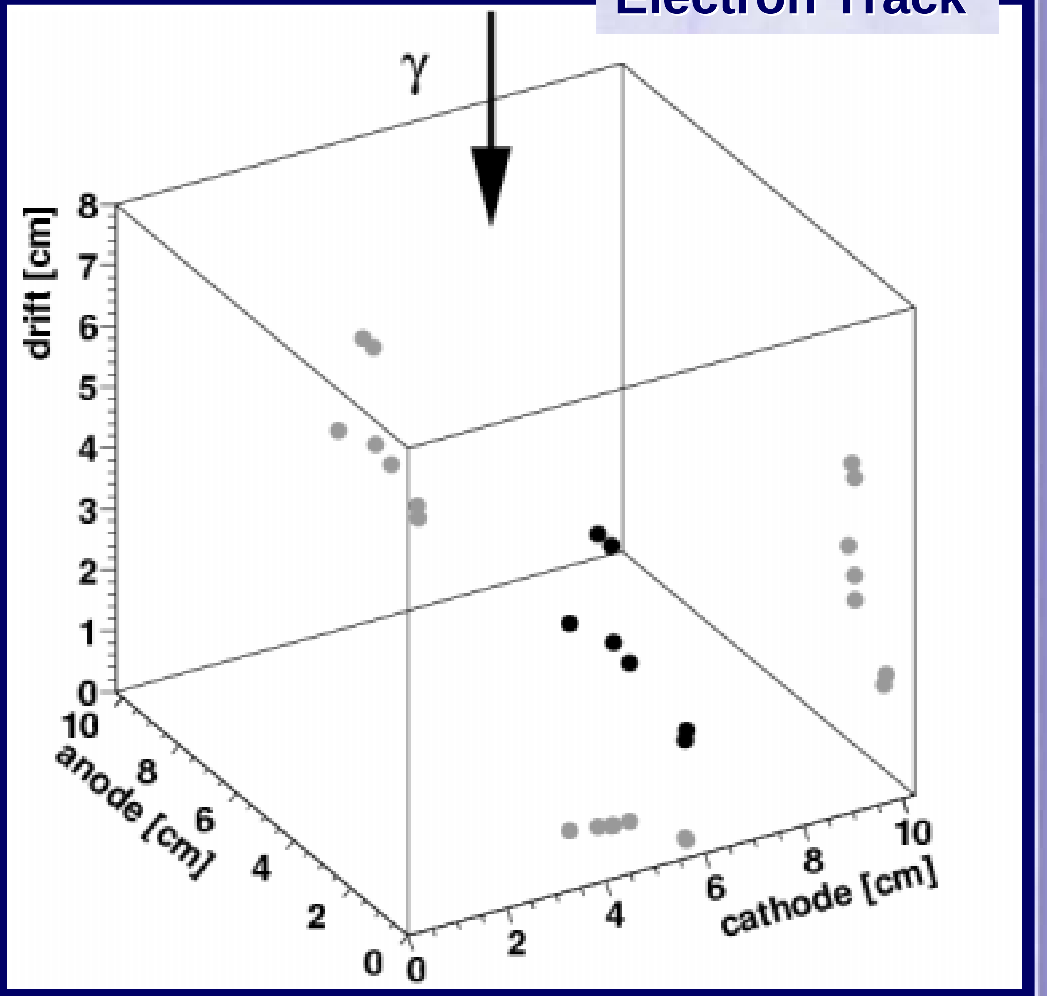
γ - ray events

- γ -ray source ^{22}Na
- 511keV γ -rays (back-to-back)
- Same setup

- dE/dx
- fitting with linear lines

γ - ray discrimination

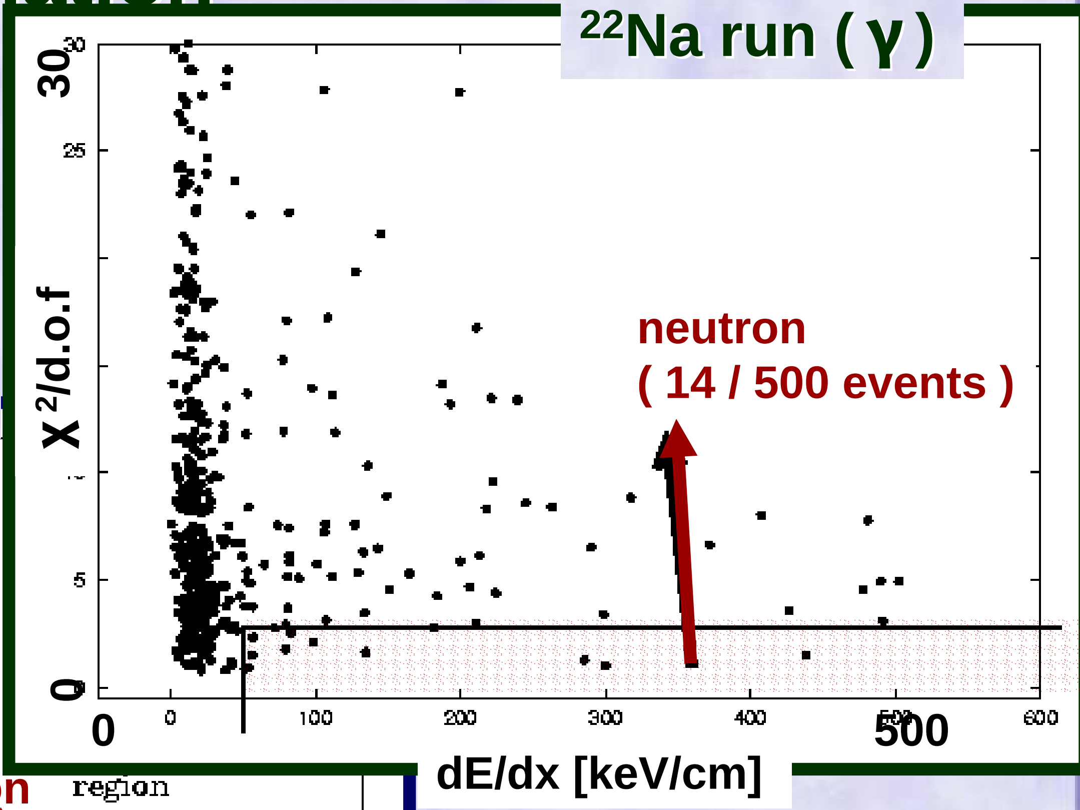
Electron Track

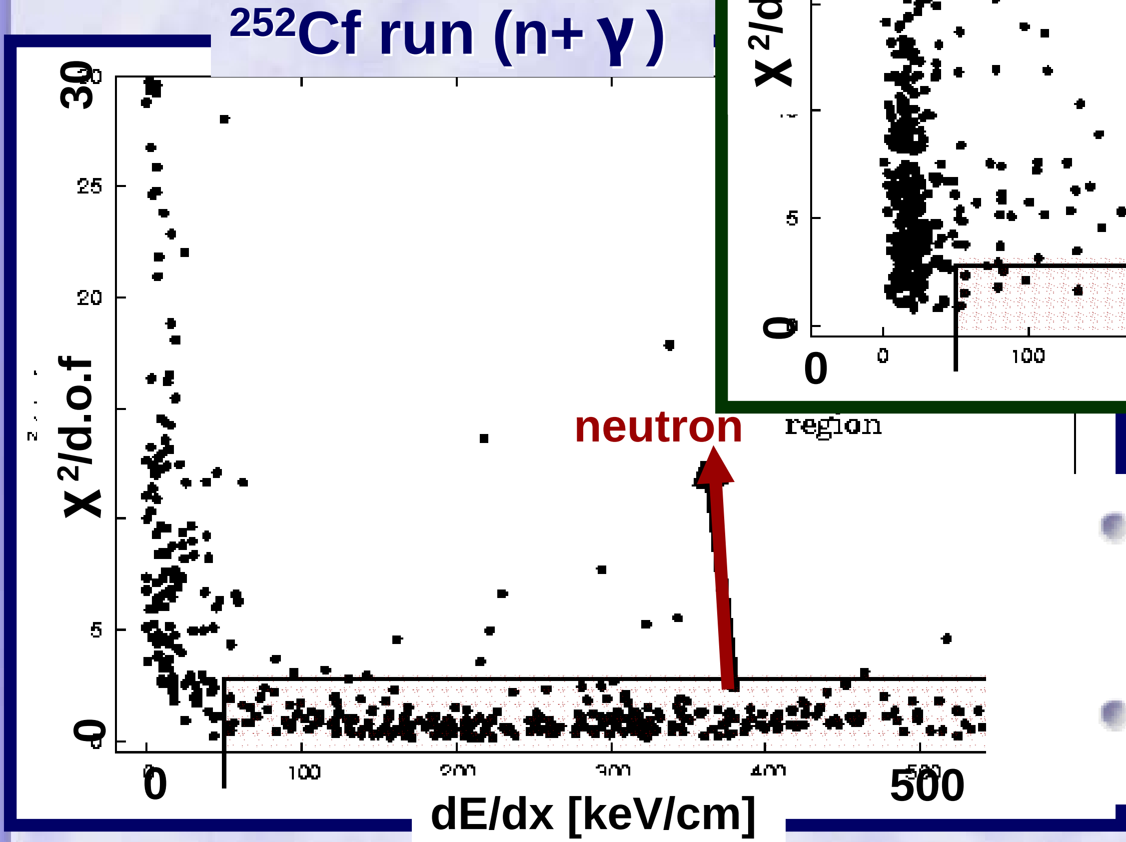


γ - ray discrimination

- χ^2 vs dE/dx plot
  - large dE/dx
  - straight

neutron





- >95% γ -rays were discriminated
- n efficiency ~1

5. Future Works

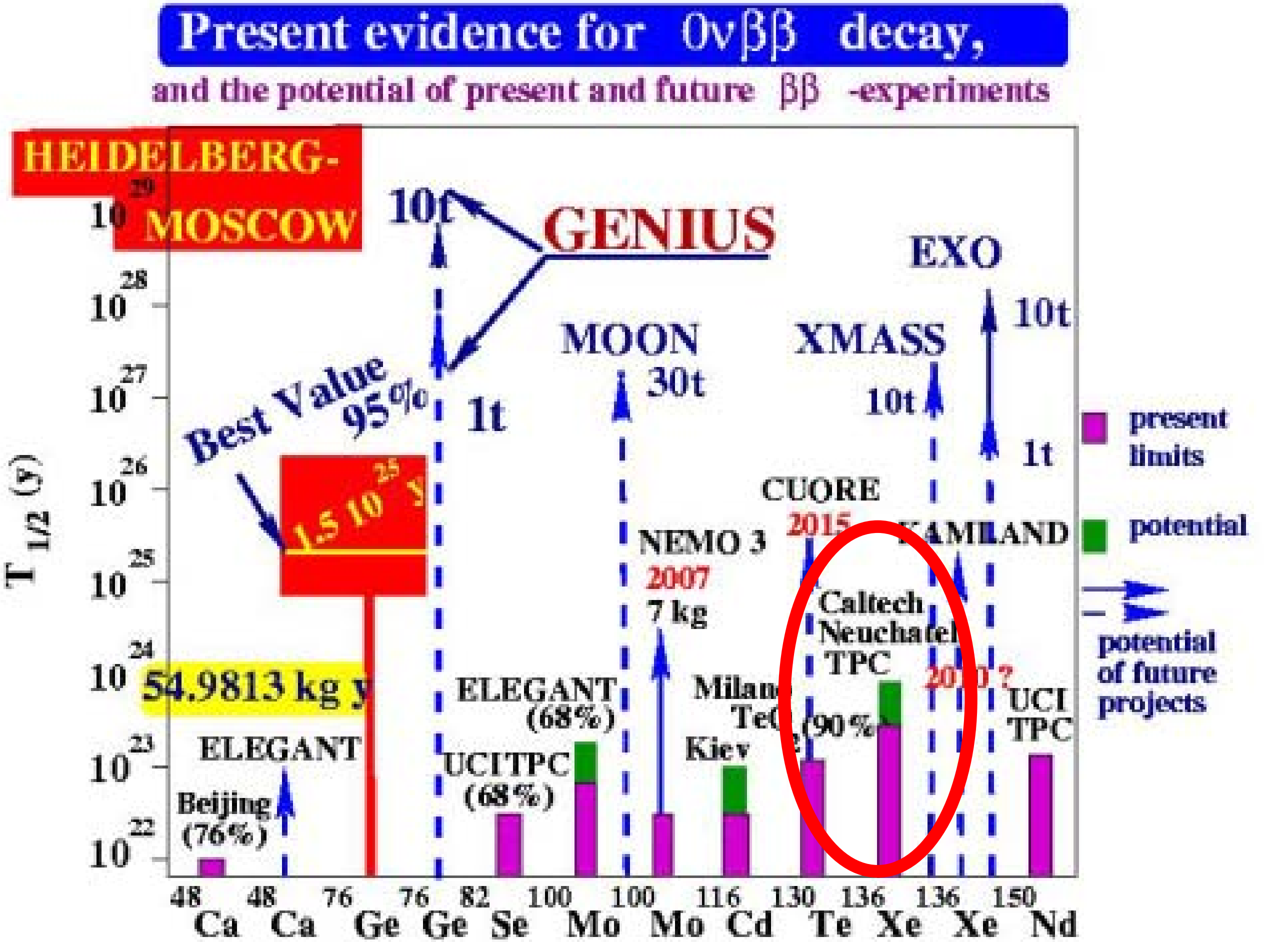
- Scintillating micro-TPC
  - for self-triggering
  - with PMT?
- Measurement with ^{3}He

5. Conclusions

- **Neutron PSD requirements**
  - high-rate operation
  - large area
  - γ-ray discrimination
- **Neutron PSD with μ-PIC**
  - tracking, proton/triton distinguishable
  - γ-ray discrimination: >95%
  - spatial resolution: sub-millimeter (simulation)

β β with micro-TPC

1. ^{136}Xe experiment



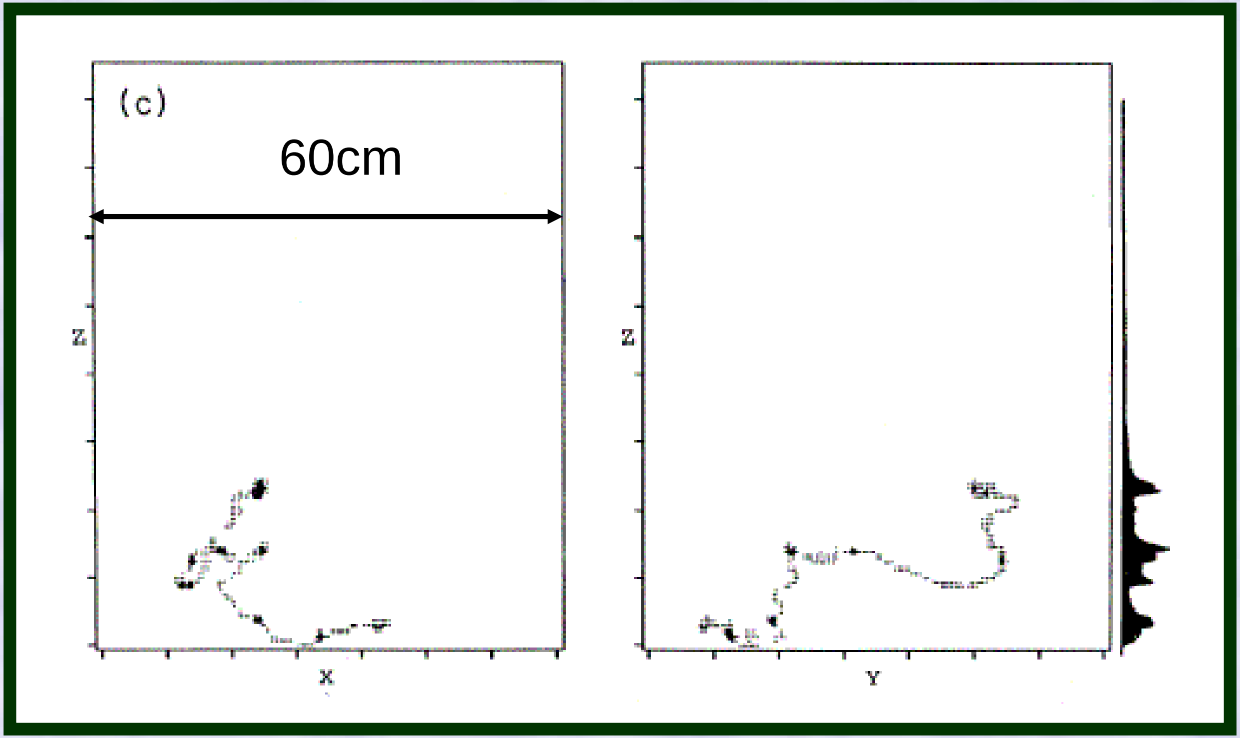
H.V. Klapdor-Kleingrothaus et al. Mod.Phys.Lett.A16(2001)2409-2420

H.V. Klapdor-Kleingrothaus "60 Years of Double Beta Decay", World Scientific (2001)

Caltech-Neuchatel experiment

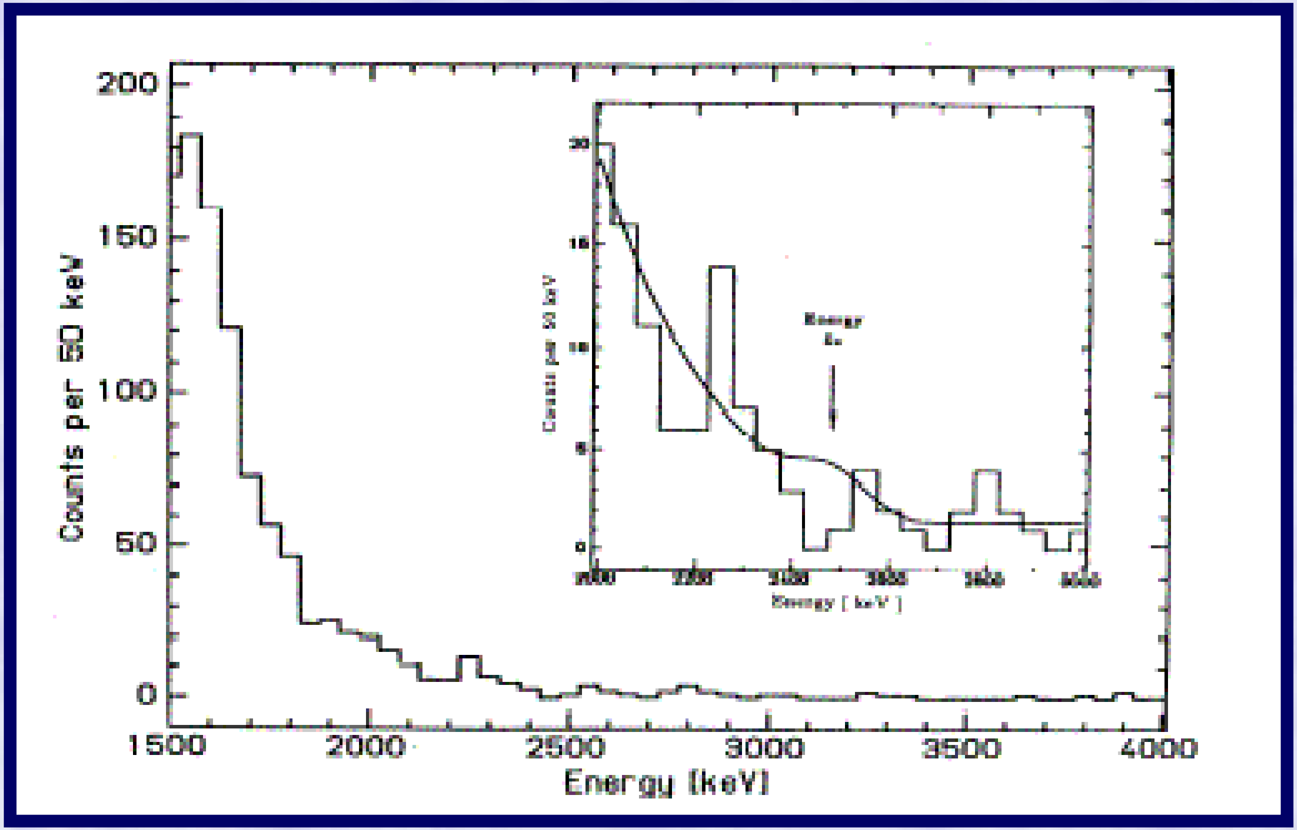
Phys. Rev. D 48 3 (1993) 1009

- Xe TPC (5atm 180 liters)
- ^{136}Xe enriched (62.5%)
- search for “double-ends tracks”



Results of the Caltech exp.

Spectrum of the two electron events



$T_{1/2}(0\nu) > 3.4\times10^{23}$yr

2. ββ exp. with μ-PIC

- **Merit?**
  - if scintillating TPC is realized
    ⇒ t=0 determination ⇒ absolute z values

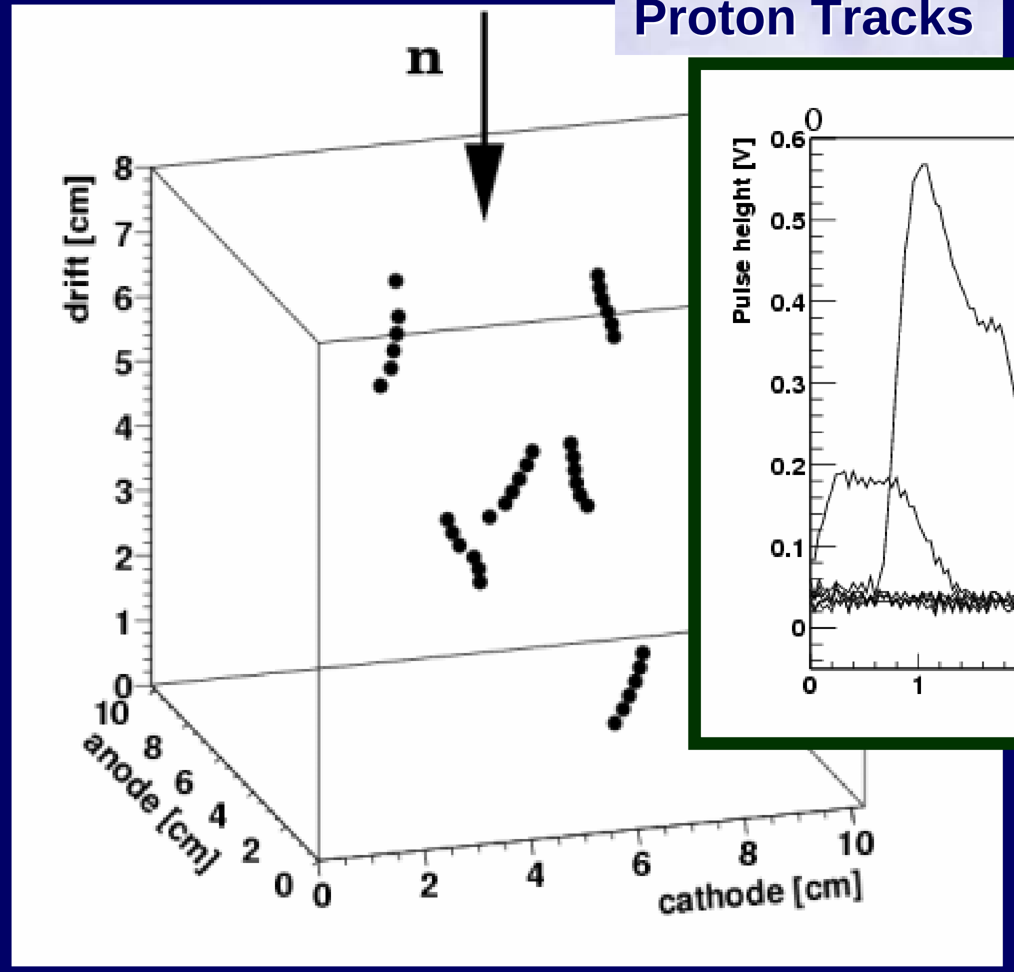
WIMP-Wind Measurement with Micro-TPC

all results are preliminary

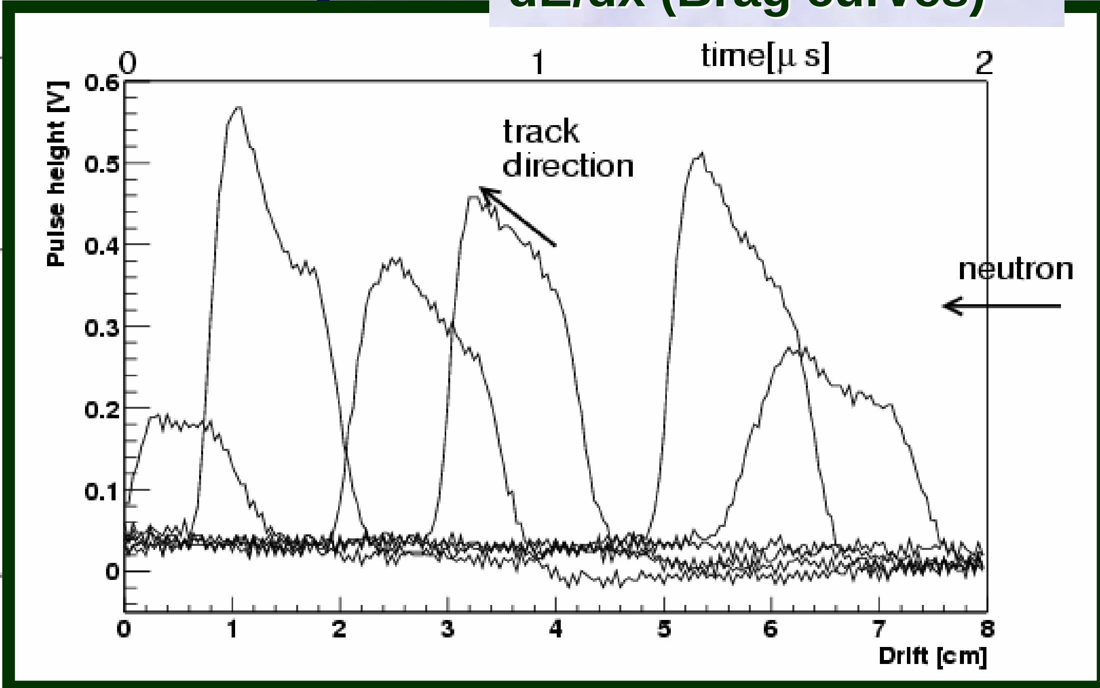
1. Performance of the μ-PIC

- **Tracking performance**
  - length >5mm (several points, direction)

Proton Tracks



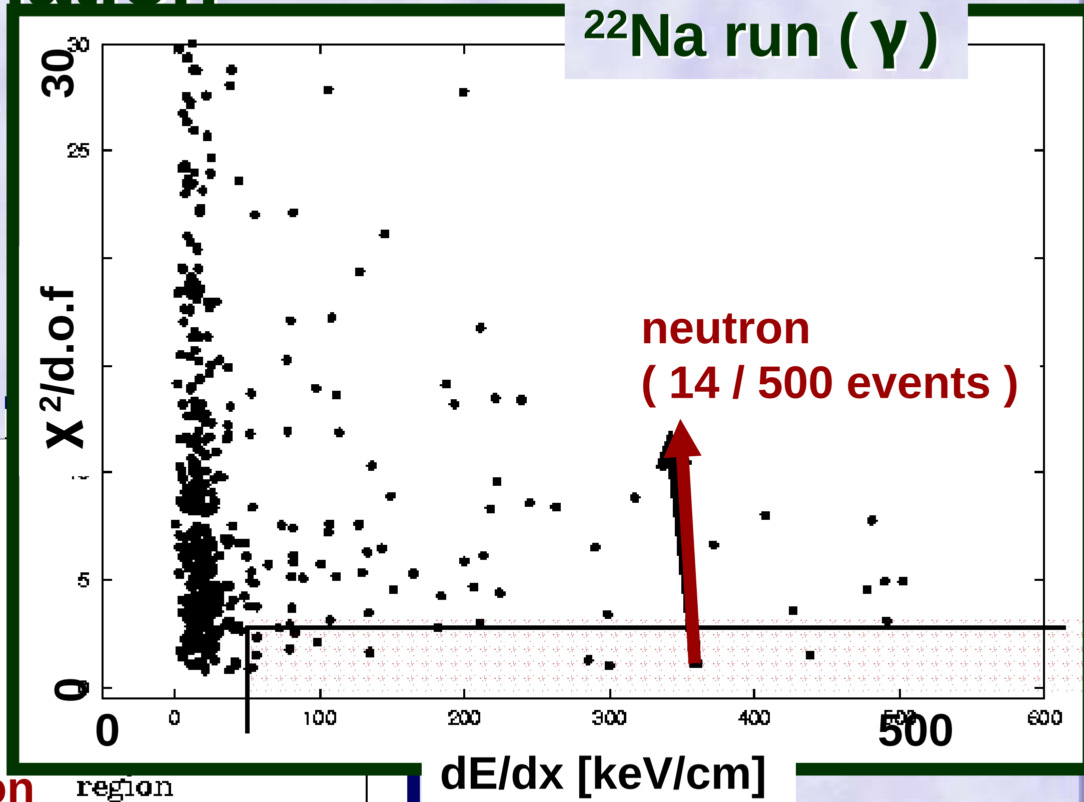
dE/dx (Brag curves)

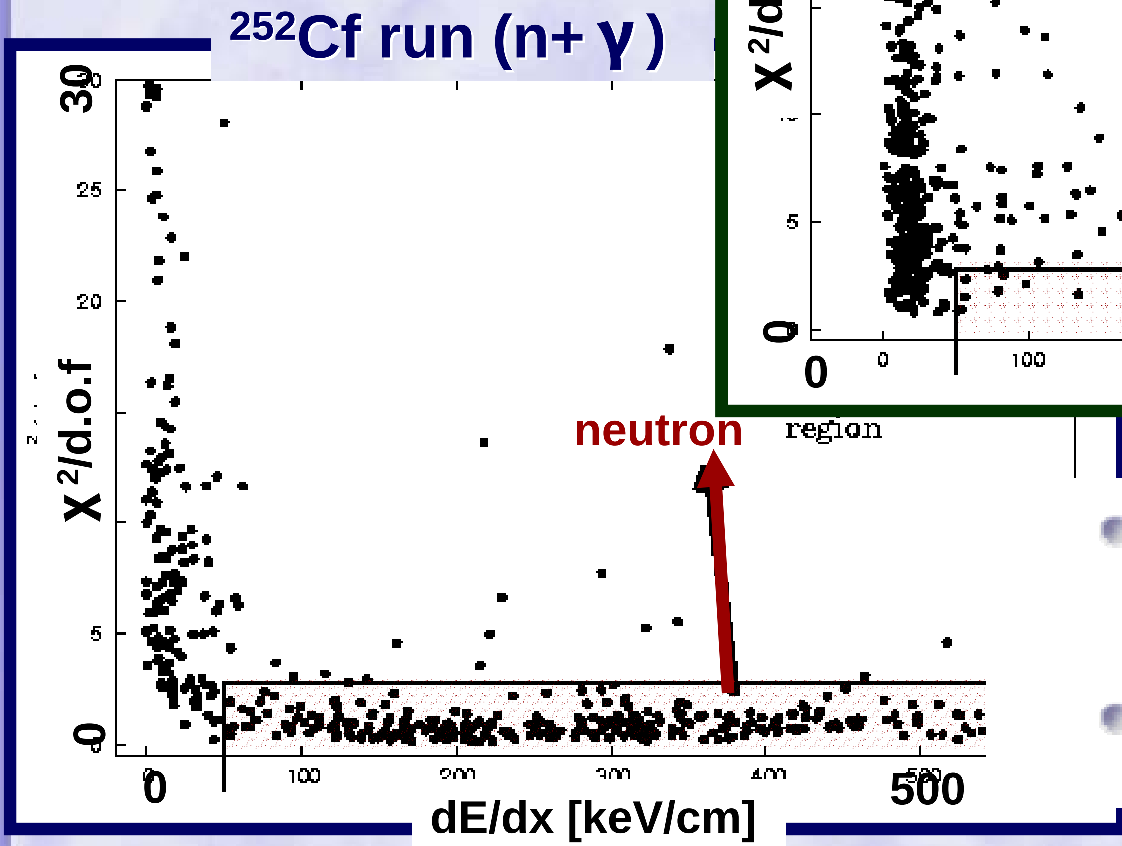


γ - ray discrimination

- χ^2 vs dE/dx plot
  - large dE/dx
  - straight

  (neutron)



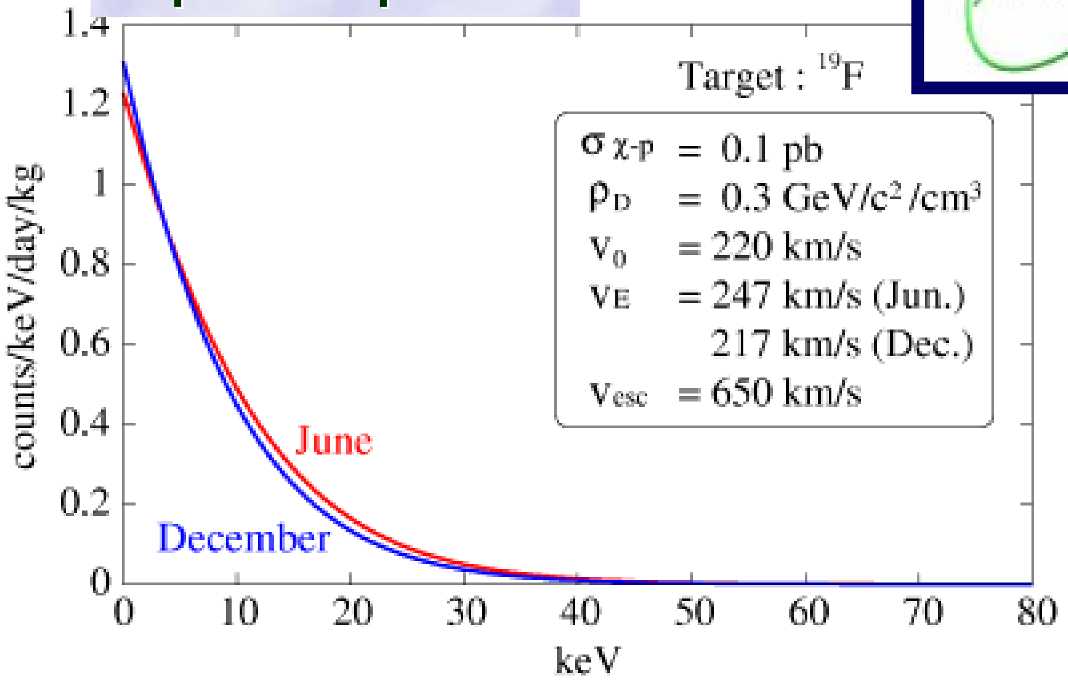


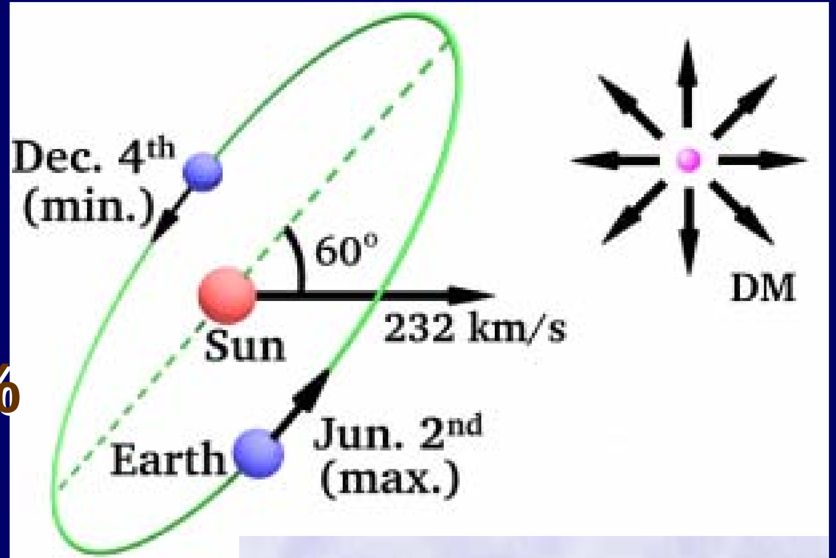
- >95% γ -rays were discriminated
- n efficiency ~1

2. WIMP direct detection

- **WIMP-nucleus elastic scattering**
- **Annual modulation**
  - **rate difference : a few%**

Expected spectra

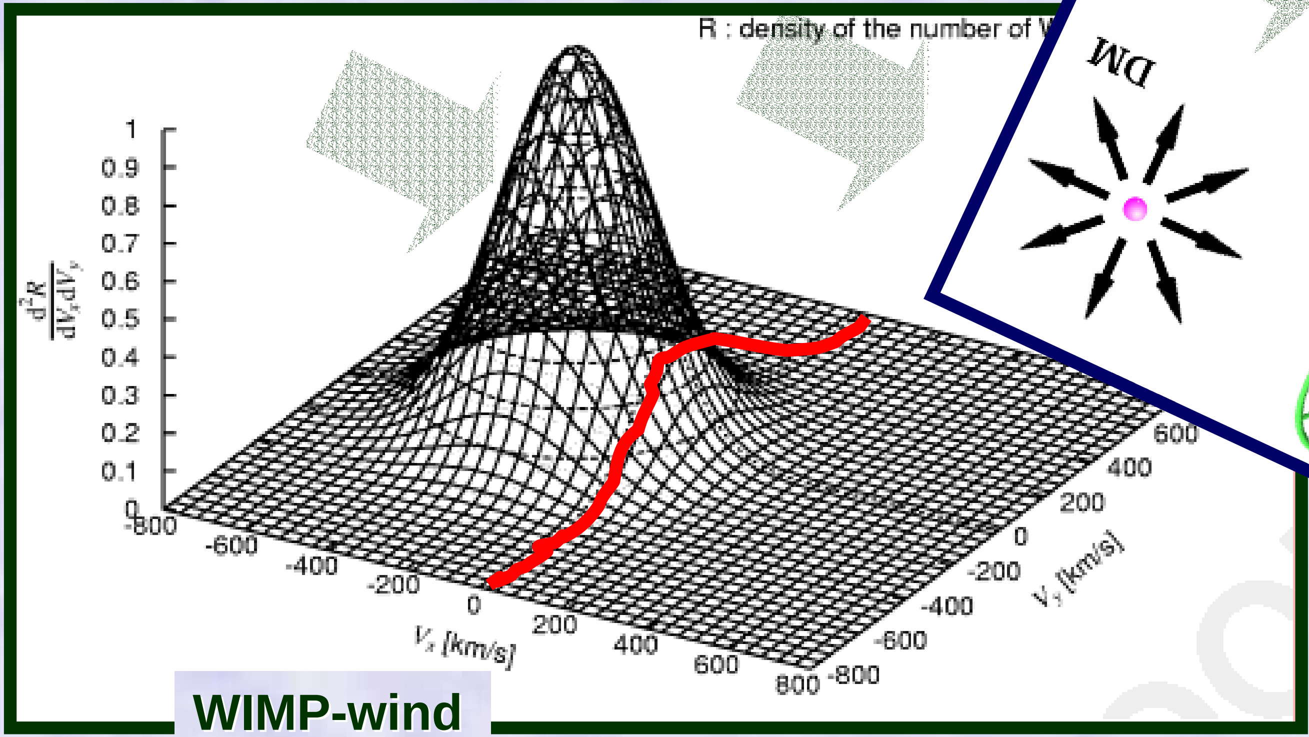


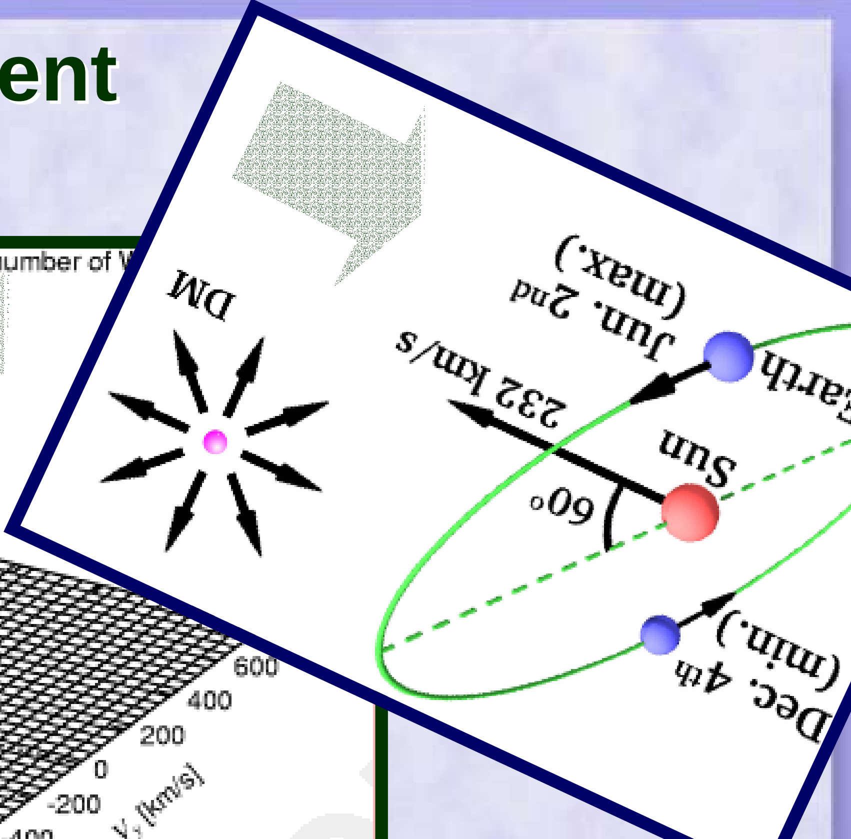


Movement of the Earth

Very hard to see…

WIMP wind measurement





WIMP-wind

Y. Shimizu et.al NIM A 496(2003)347

- WIMP-wind ⇒ nucleus-recoil asymmetry

3. WIMP-wind measurement with μ-PIC

- Merit
  - recoil direction
  - γ-ray discrimination
  - fine pitch (400μm) ⇔ DRIFT(2mm)
  - dedicated electronics (100MHz near future)
- Demerit
  - low mass (gas detector)
- Strategy
  - quantity oriented (track >1mm)
  - quality oriented (track >5mm)

Target gas

- WIMP mass
  ~ target mass
- Spin-dependent：
  large spin factor
- Spin-independent :
  large atomic number

Isotope	%	λ *J(J+1)*
^{19}F	100	0.647
^{23}Na	100	0.041
^{73}Ge	7.8	0.065
^{129}Xe	26.4	0.124

Spin factors

WIMP mass	Light (50GeV)	Heavy (100GeV)
SPIN-DEPENDEMT	CF_4	Xe
SPIN-INDEPENDENT	Ar	Xe

Gas pressure, target mass

- threshold： 40keV
- track ： 5mm

➡ pressure

gas	Pressure [Torr]	Density [g/m³]	dE/dx [keV/cm]
CF_4	20	90	85
Ar	20	47	85
Xe	5	38	120

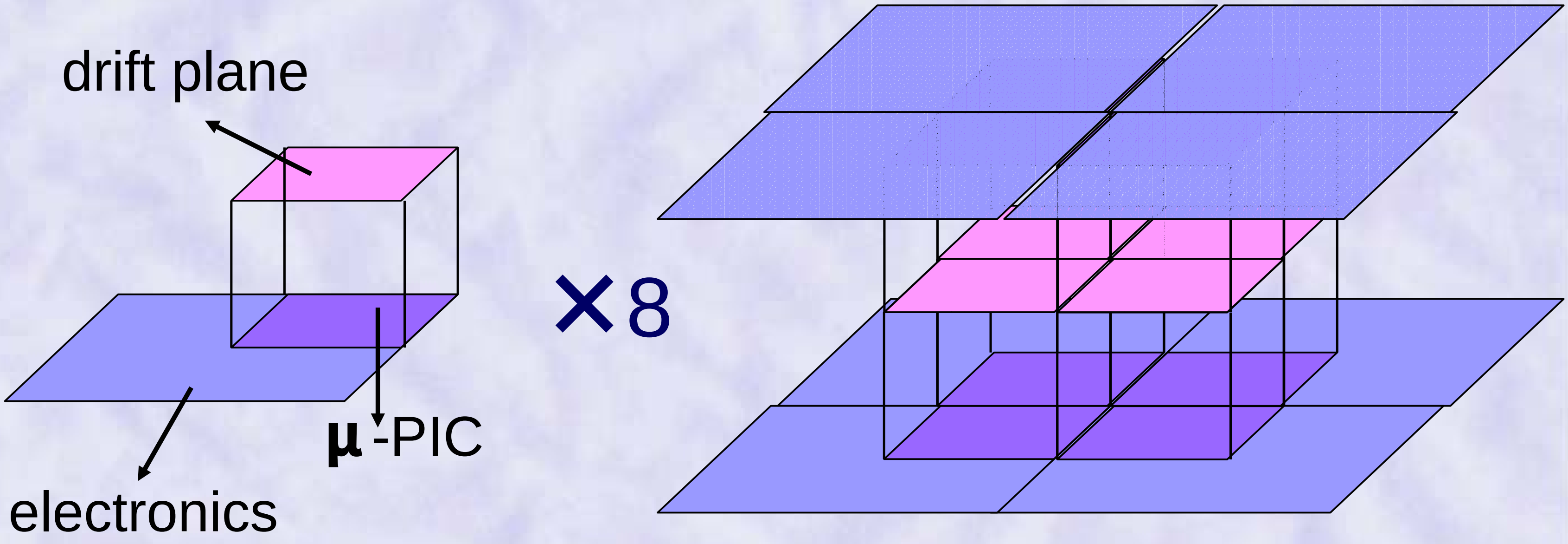
~ 10×1m³ detector

OK

(μ - PIC threshold : 50keV/cm)

Scaling-up

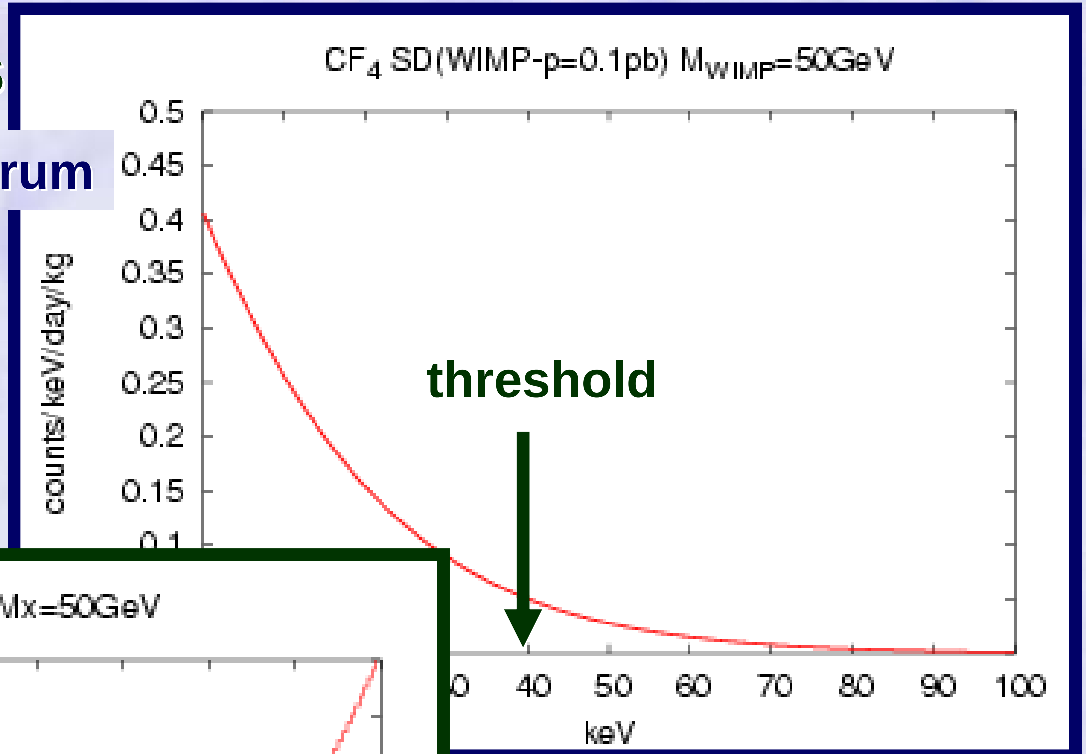
- prototype : 30×30×30cm^3
  ×8 = 60×60×60cm^3
- large area μ- PIC : 50×50×50cm^3
  ×8=1m^3
- 1m^3×n



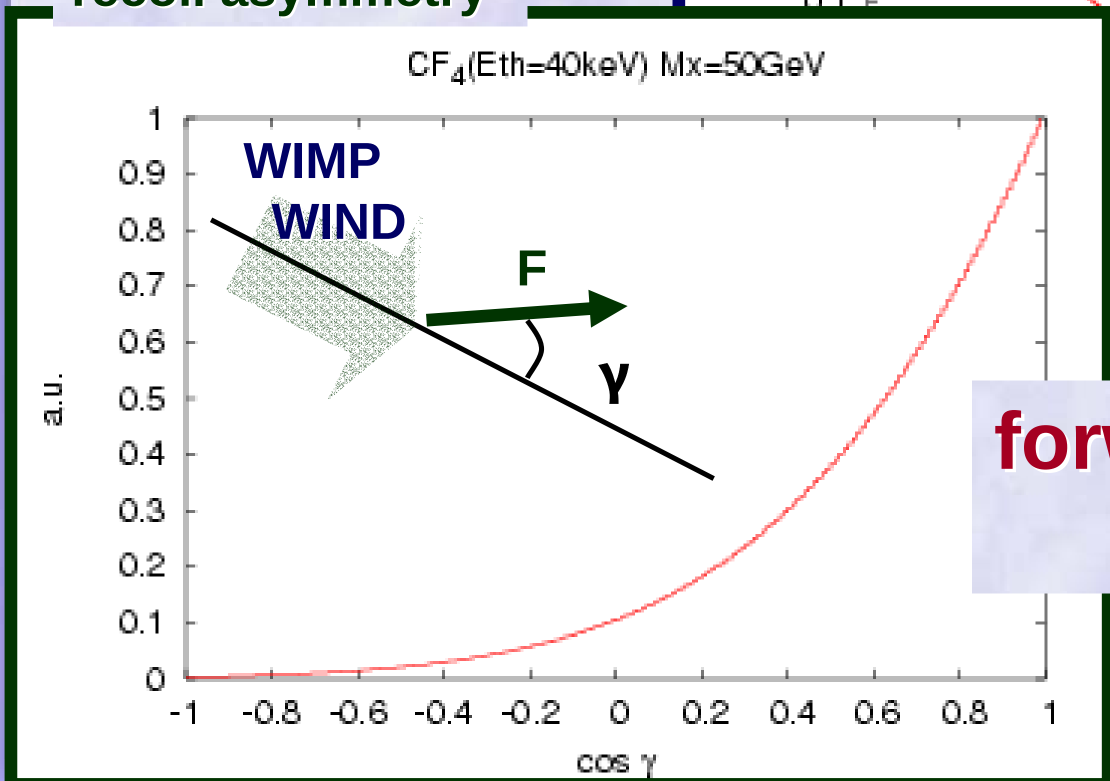
Expected Signals

- gas: CF_4
- WIMP-p 0.1pb

spectrum



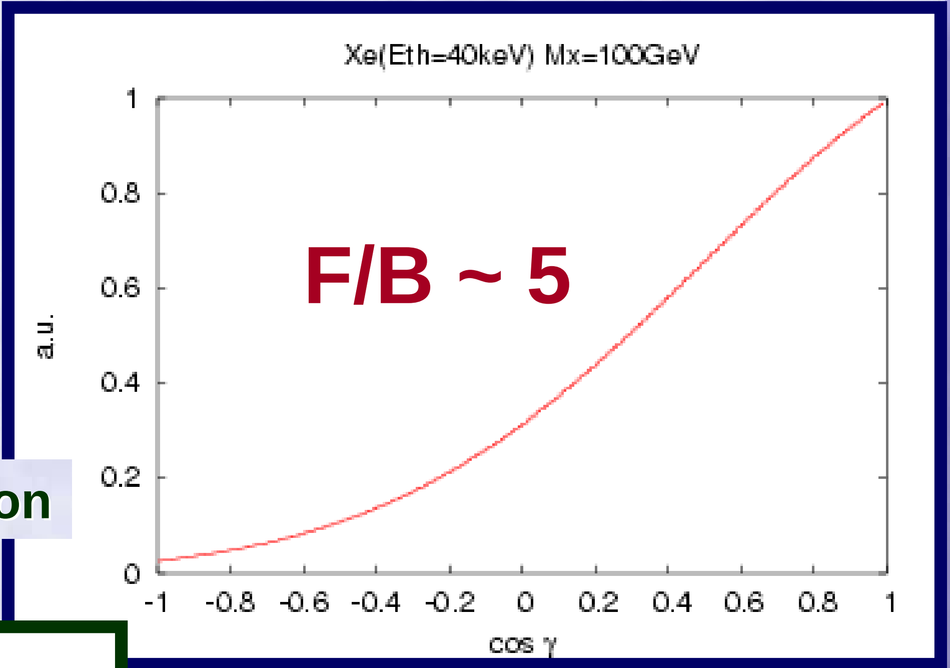
recoil asymmetry



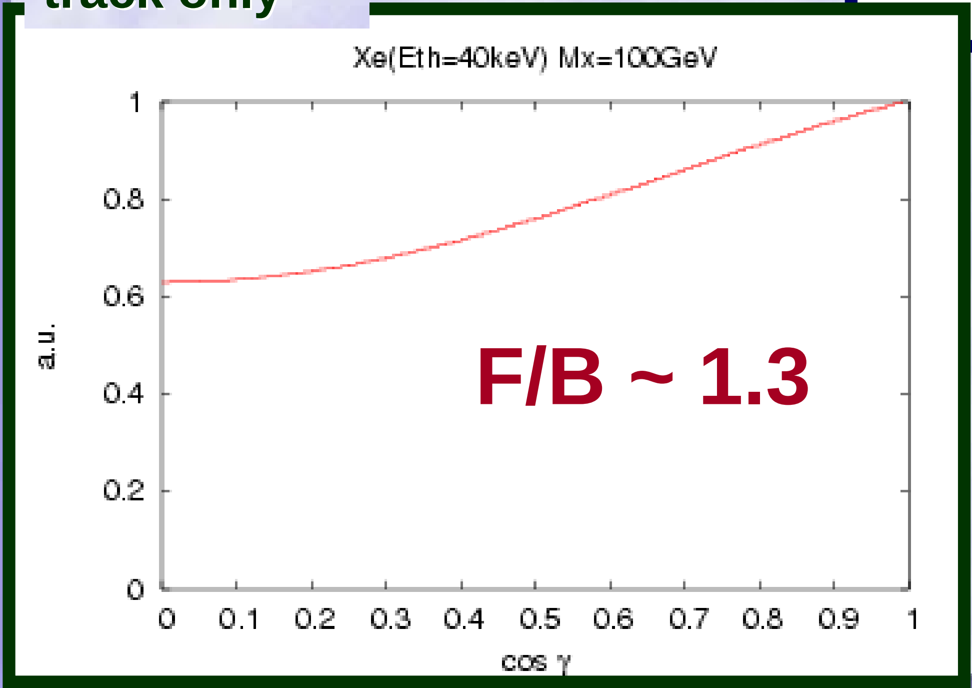
forward/backward >10

- **track direction is important**

track+direction



track only

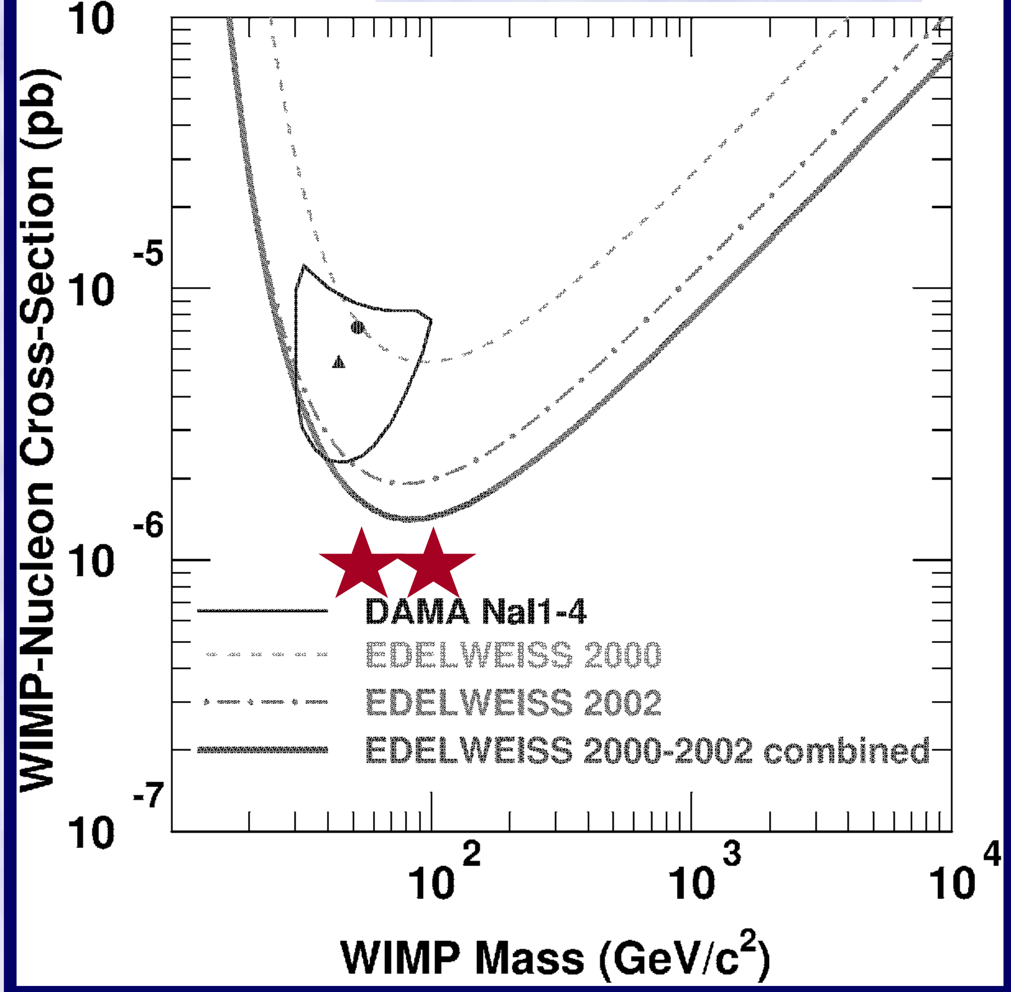


Expected rate

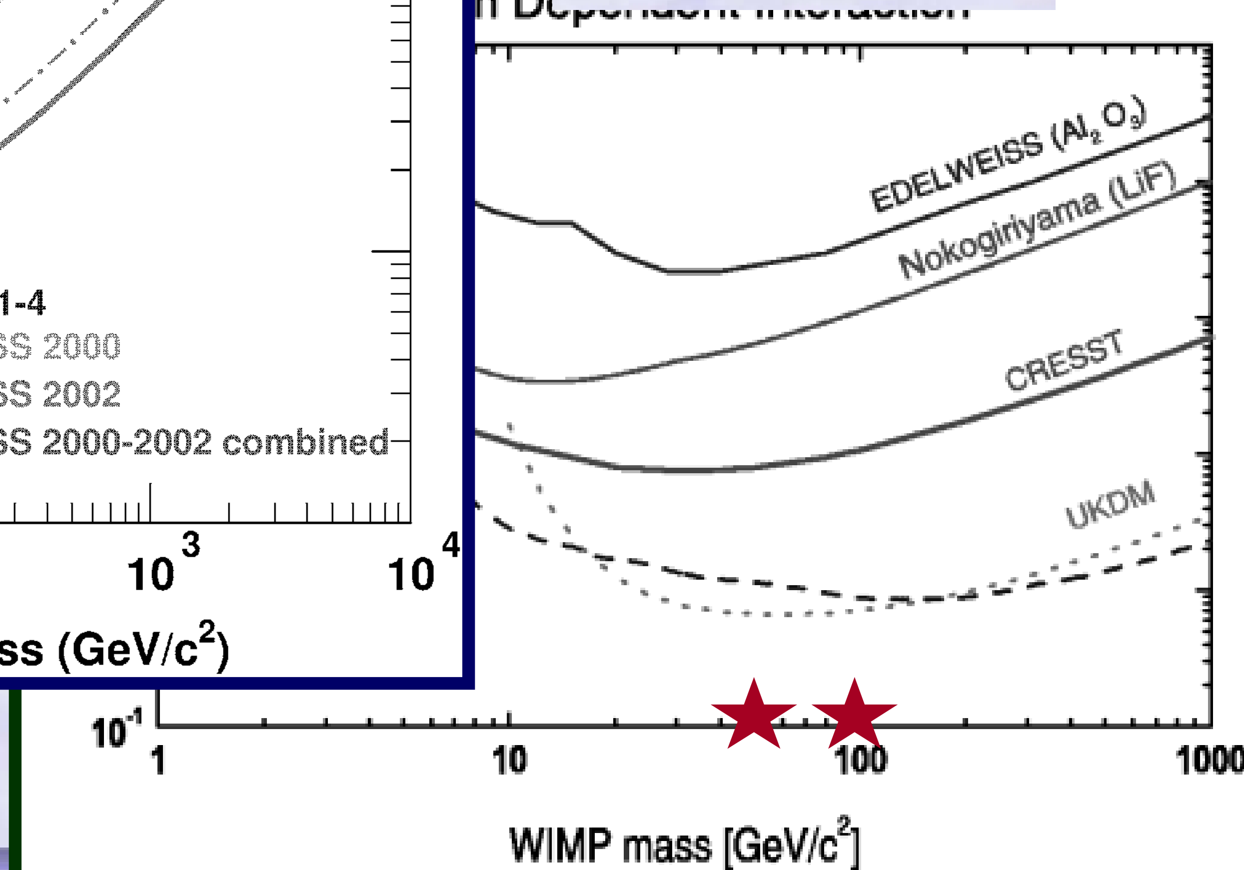
- threshold: 40keV
- WIMP mass: 50 GeV for F, Ar
  100GeV for Xe
- WIMP-p cross section : 0.1 pb for SD
  10^{-6} pb for SI

gas	pressure [torr]	density [g/m^3]	rate [cpd/kg]	Event (10m^3 × 1yr)
CF_4	20	90	0.21	260
Ar	20	47	0.034	4.1
Xe(SD)	5	10	0.011	1.4
Xe (SI)	5	38	0.079	9.6

SPIN-INDEPENDENT



SPIN-DEPENDENT



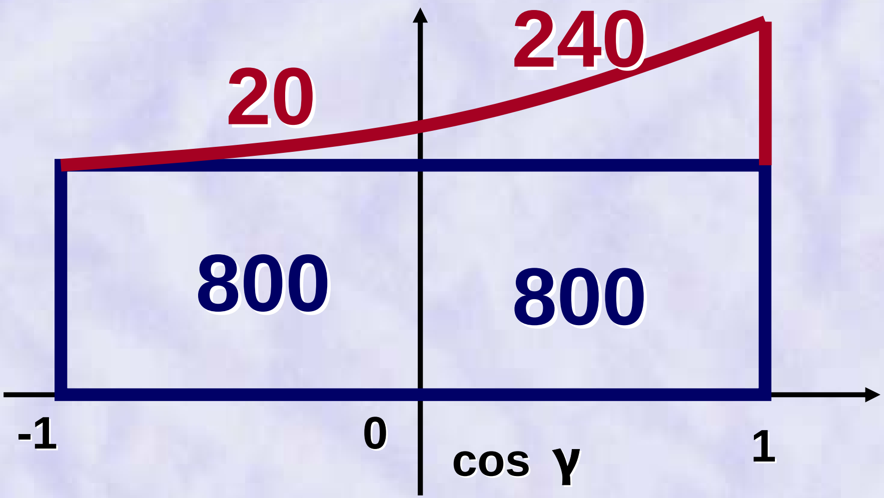
Detection Confidence Level

- Background: fast neutron $2 \times 10^{-5} cm^{-2} s^{-1}$

  $\Rightarrow$ 0.1cpd/kg/keV for CF_4 (no shield)

  $\Rightarrow$ 1600 BG events / $10m^3 \times 1yr$

- WIMP : 260 events



820 1040

more than 5σ asymmetry

S/N calculation

- threshold: 40keV
- WIMP mass: 50 GeV for F, Ar
  100GeV for Xe
- WIMP-p cross section : 0.1 pb for SD
  10^{-6} pb for SI

gas	Event ($30m^3$ × 3yr)	F/B ratio	Modulation (σ)	n BG ×1/100
CF_4	2340	14	20σ	40σ
Ar	37	11	0.4σ	3σ
Xe(SD)	13	5	0.1σ	1σ
Xe (SI)	86	5	0.4σ	5σ

4. Future works

- Event rate study (Ar, Xe)
  - gas pressure, track length, threshold
- Gas study
  - CF_4 properties
- Background study
  - γ -ray discrimination
- Energy Calibration
  - track length v.s. energy

5. Conclusions

- **WIMP-wind measurement**
  - **idea : NOT NEW**
  - **μ-PIC fine pitch**
- **μ-PIC**
  - **sensitive to SD and SI, light and heavy**
  - **factor 10 forward/backward asymmetry**
  - **CF_4 5σ detection possibility**
  - **precise studies to do**