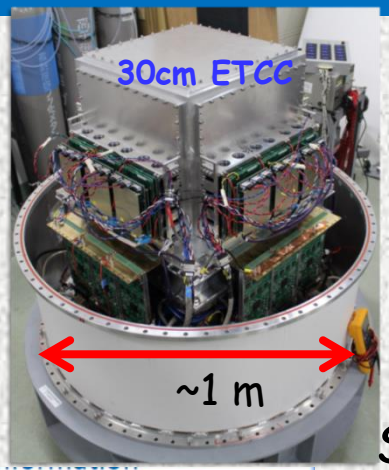
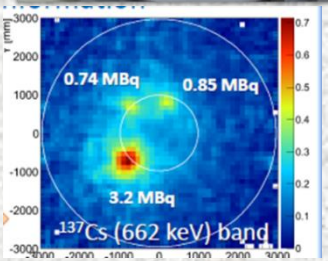
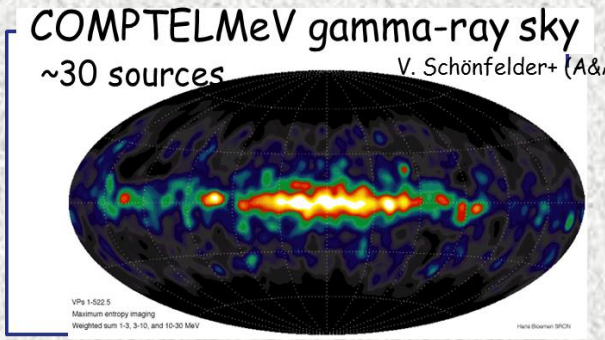
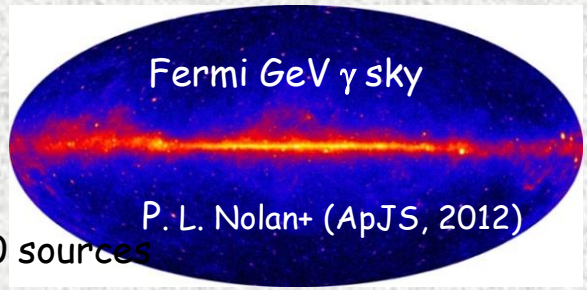
Deep sky survey of MeV gamma rays due to advanced Electron Tracking Compton Camera (ETCC) with balloon experiment



SMILE-II

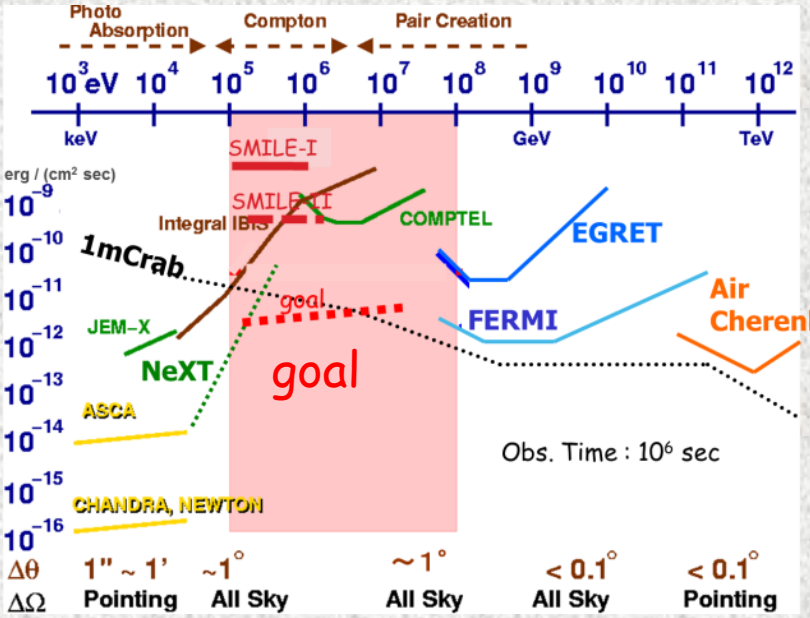






CONTENS

1. Problem of MeV g observation
2. How to challenge by ETCC
3. Improvement of Point Spread Function
4. Future plan & Summary



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How to reach 1mCrab

Target in Next generation MeV gamma Observatory

1mCrab =10^{-12} erg $cm^{-2}s^{-1}$ @ 10^6s (100 times better than COMPTEL)

- Assumption; Most of Background except for celestial emission would be removed
- Main Background -> Extragalactic diffuse gammas,
- Detection Area at least ~2x 100 cm^2 (from satellite size 1x1m^2 Max. Detection efficiency several %)

  & Point Spread Function (PSF) radius= 1-2°
- If PSF radius 30° -> Detection Area ~$10^5$$cm^2$ is needed!

Feasibility:

Eff. Area ~200cm^2 @1MeV Possible!

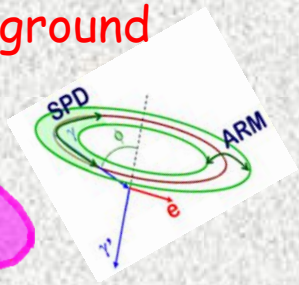
(50cm-cube CF_4 3atm 110cm^2@1MeV for Compton Scattering)

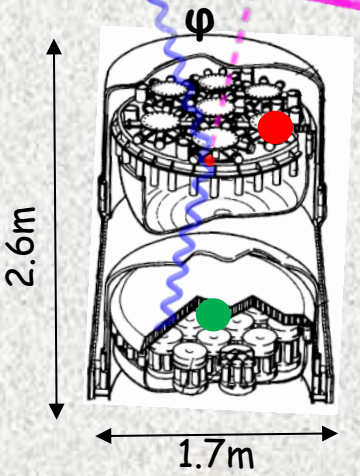
However, PSF in Compton Camera is very ambiguous !

Difficulty of MeV gamma-ray Observation

Two big problems in MeV

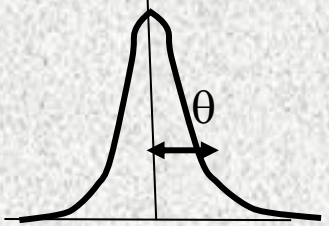
1. Huge Background





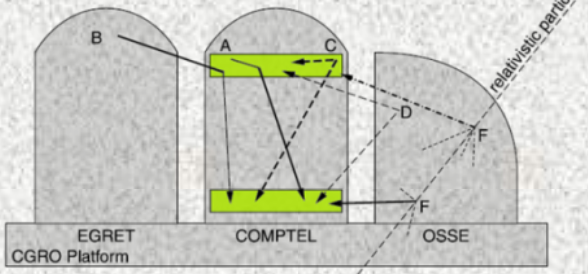
event circle

PSF(θ) = 1/2 of flux



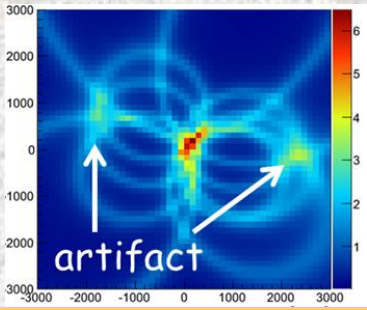
Effective Area~13cm^2@1MeV

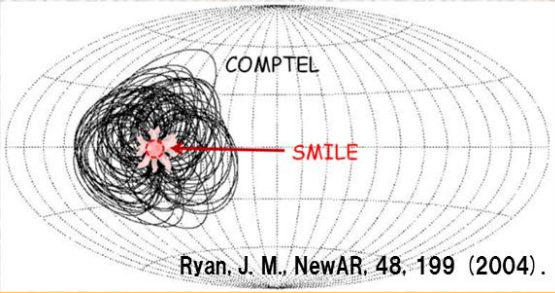
V. Schönfelder+ (ApJS, 1993)



R. van Dijk (Ph.D thesis, 1996)

2. Unclear Imaging



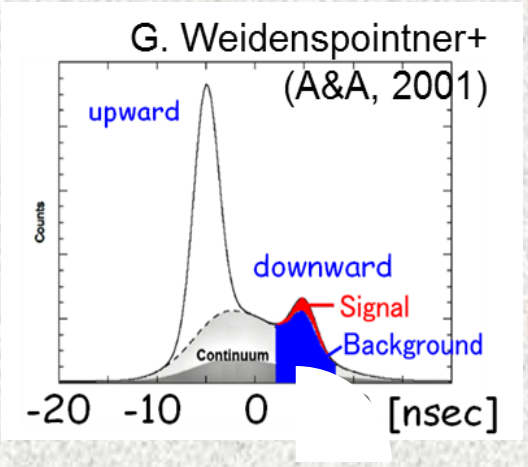


If no BG, several$\times$10cm^2 => a few mCrab@10^{6}sec

Approach

1.Good angular res.(ARM) = good Energy resolution

2 Intro, of new parameters of TOF, SPD, dE/dx



How to Remove BG

1. Good Point Spread Function (PSF) θ 1~2^o .
2. New parameters
3. Light material (low Z & small amount)

Optimization Algorithm for Compton Imaging

Maximum likelihood Expectation Maximization (MLEM)

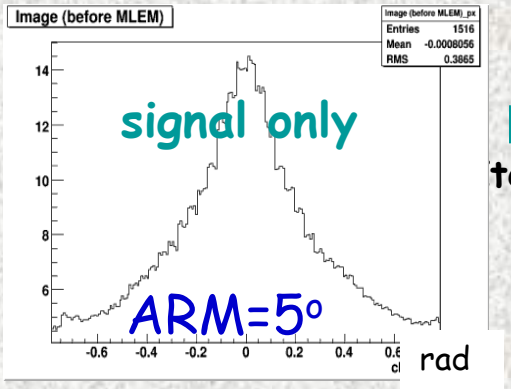
MLEM; optimize the known functions of signal and background such as detector acceptance or random noise to "best available" values.

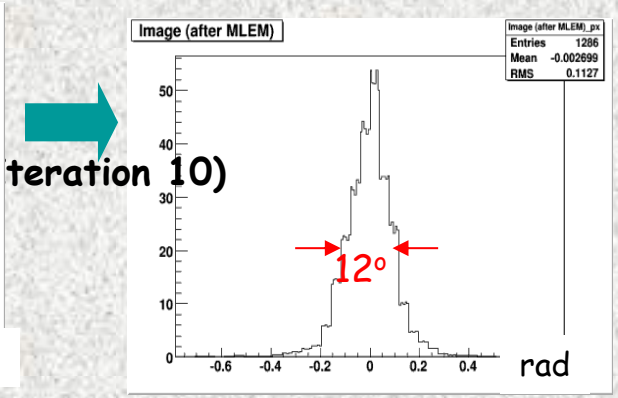
Know functions: Signal -> ARM resolution, and BG -> flat distribution

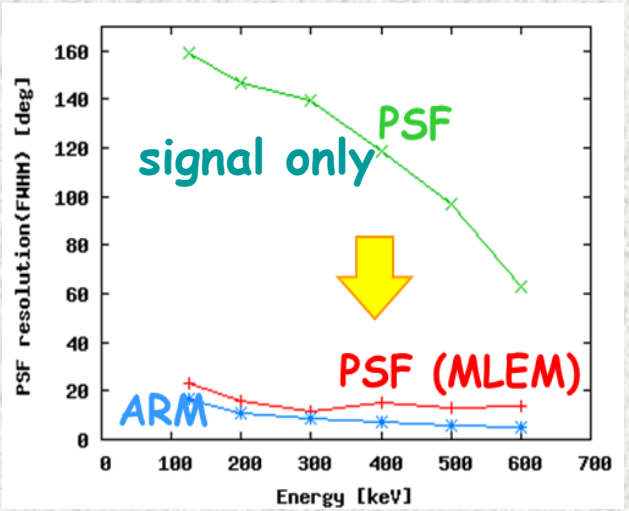
If we knew BG and detector response well, and statistics of signal is similar to that of BG, MELM would be functioned well,

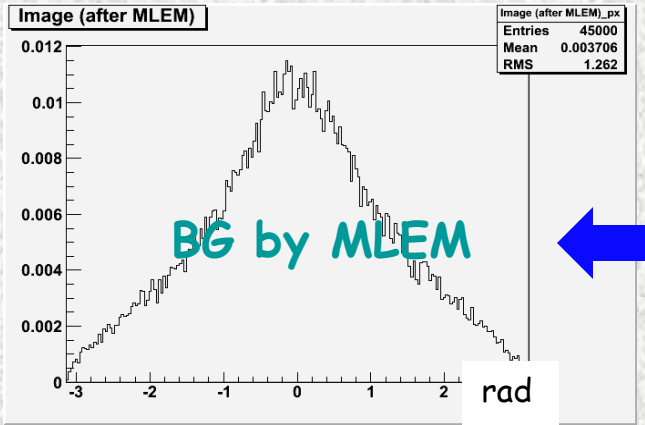
but quantitative accuracy seems unclear in any case.

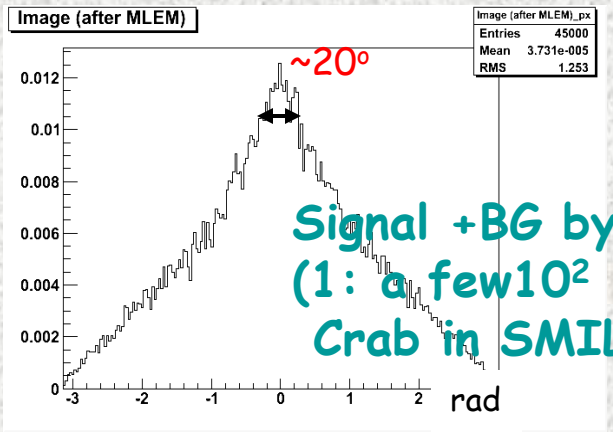
Simulation for Conventional Compton





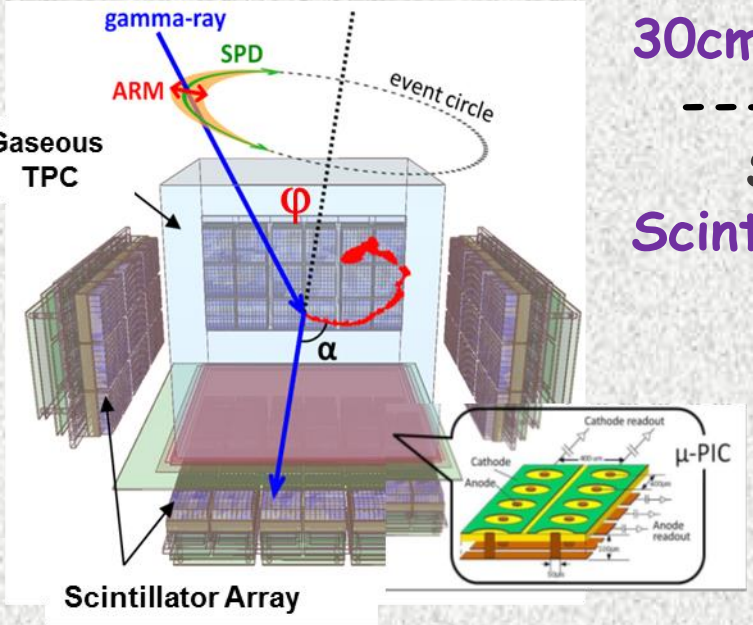






Signal +BG by MLEM
(1: a few10^2 for 2π sr : Crab in SMILE-II)

Electron Tracking Compton Camera (ETCC) in SMILE-II



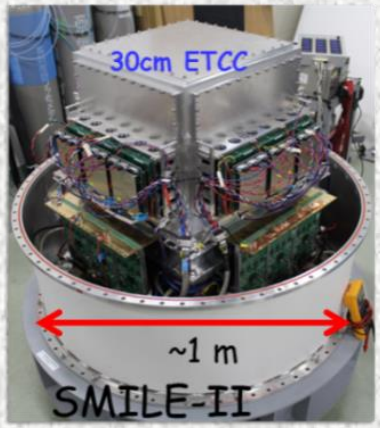
30cm-cubic Gaseous Time Projection Chamber

--- tracking of recoil electron ---

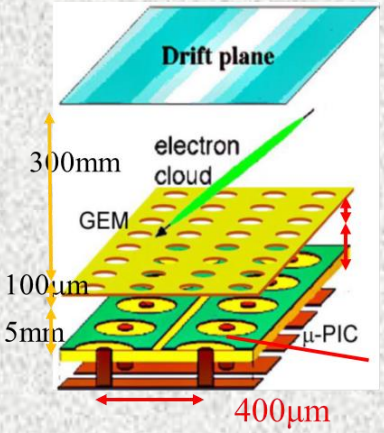
SPD + dE/dX+α angle

Scintillator Array for scattered γ

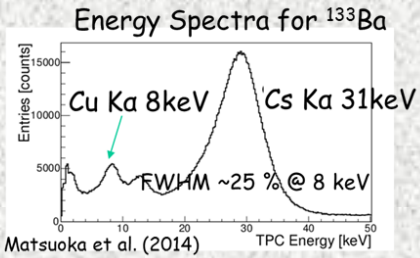
- SPD -> good PSF without MLEM
- Reliable reconstruction of Compton Event
- Efficient BG Rejection by new parameters
  - dE/dx : particle identification
  - α angle: ->accidental event cut

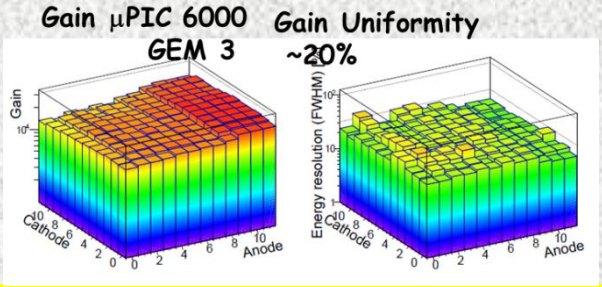


30cm cubic
ETCC in Astro
Eff. Area of 1-20cm²

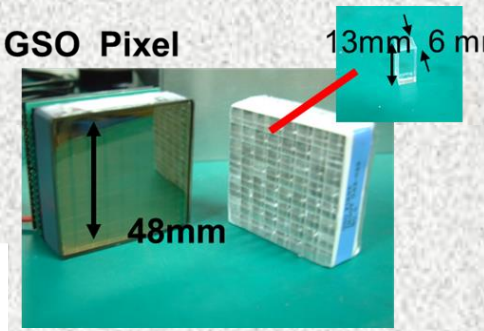


30x30cm μPIC



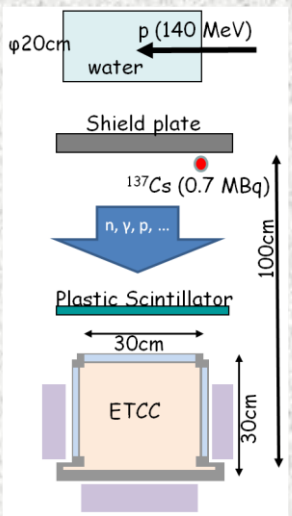


72 PSAs 11%@ 662 keV

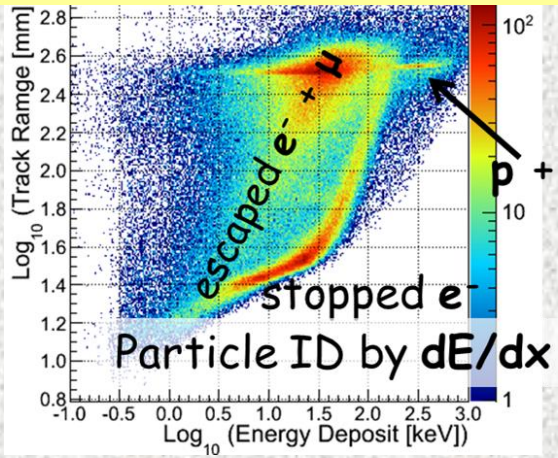


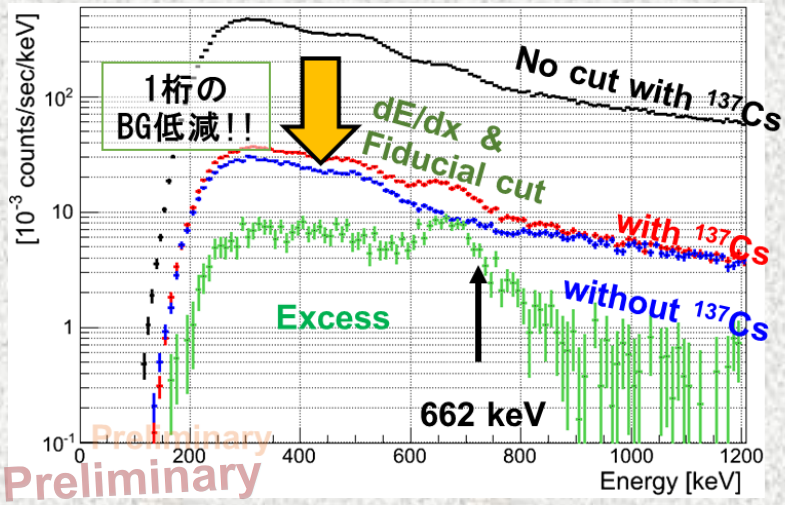
Final GOAL 100 times better sensitivity than COMPTEL <(1mCrab)

Test in intense BG environment by Proton Beam



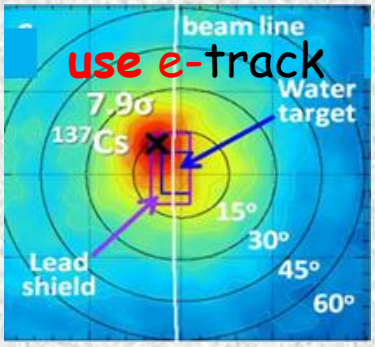
1. Power of dE/dx of a track

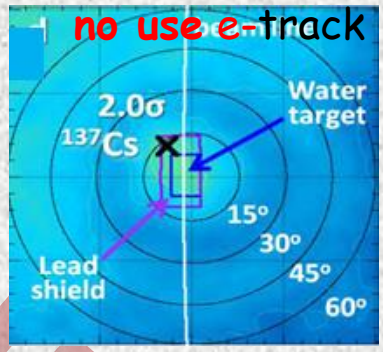


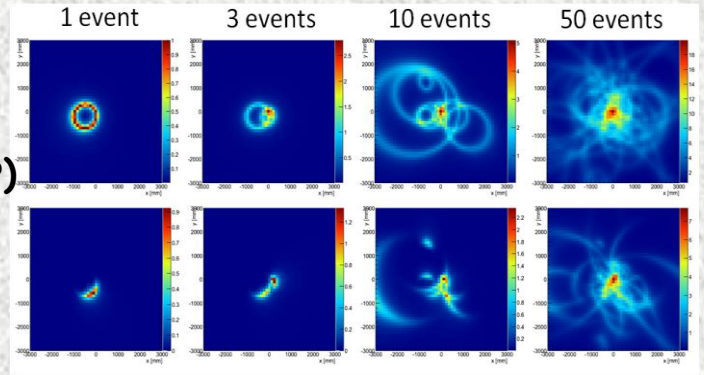


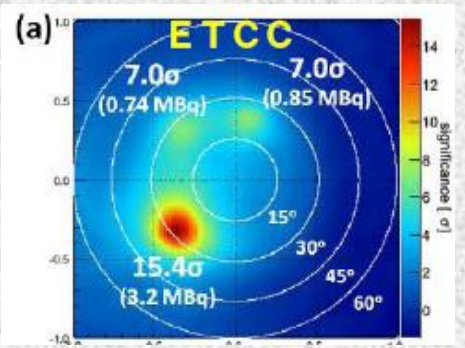
Intense Radiation (x4 of balloon altitude) with keeping an efficiency

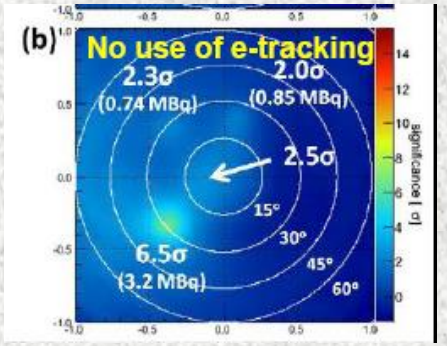
2. Power of Electron Tracking











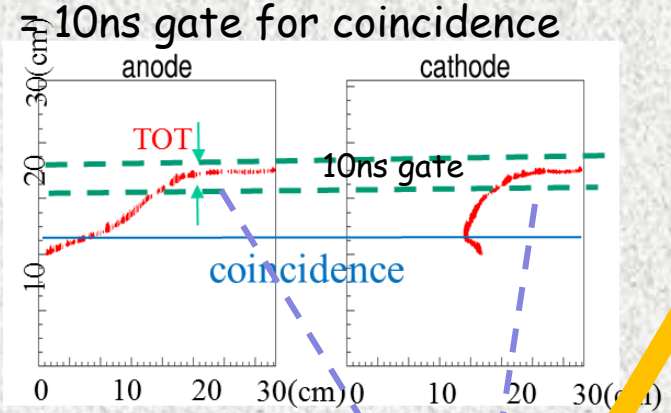
Improvement of Sensitivity

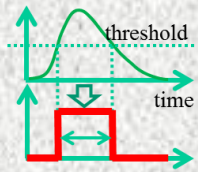
dE/dx ~ x 3

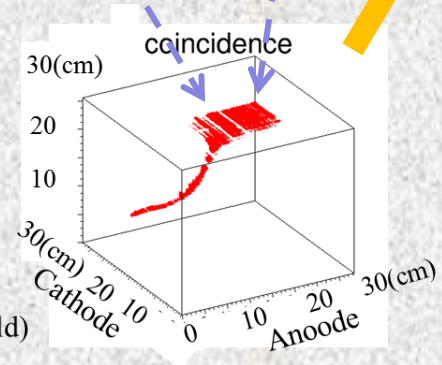
SPD x3~4 Total x 5~10

x10 sensitivity = x 100 Efficiency

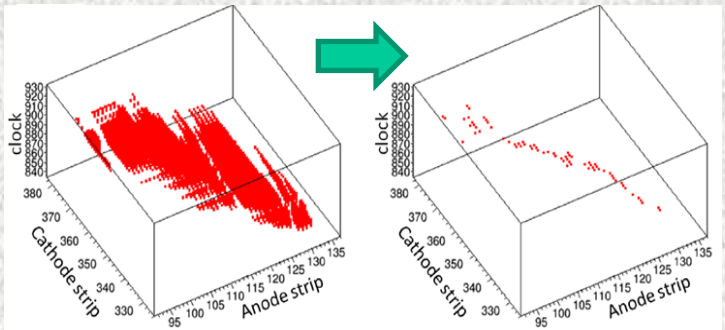
3D tracking in TPC and problem

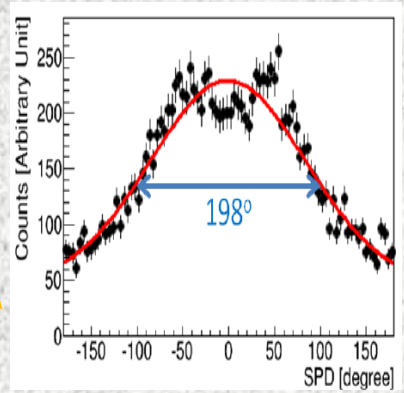


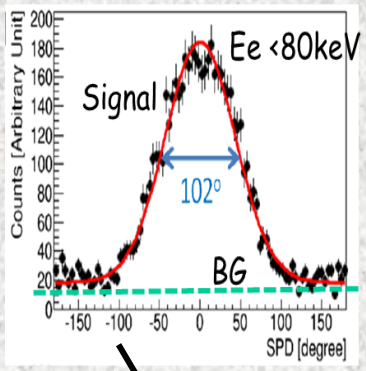


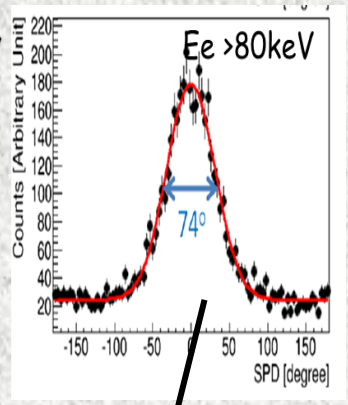


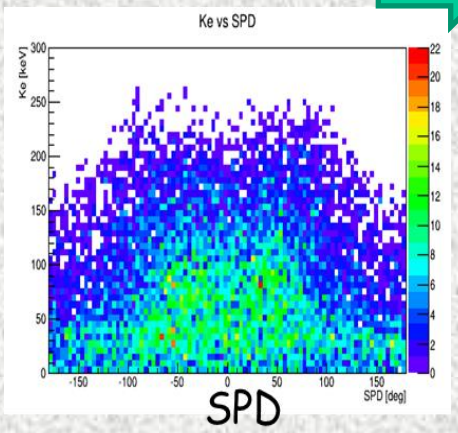
1ns gate by time walk correction using TOT

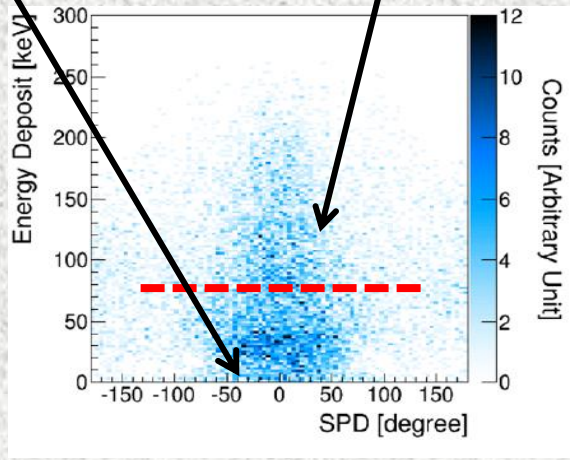


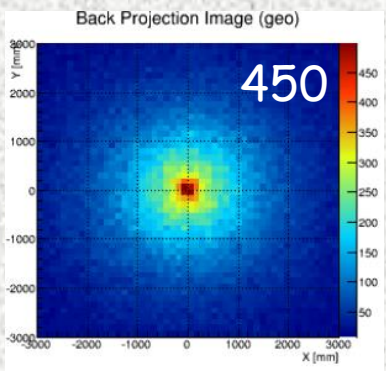


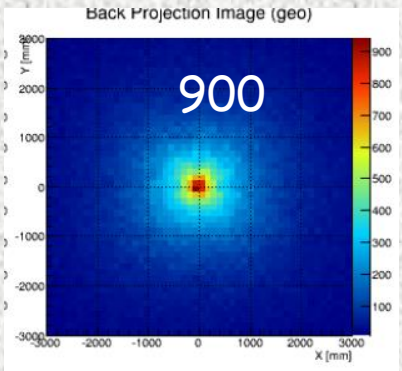












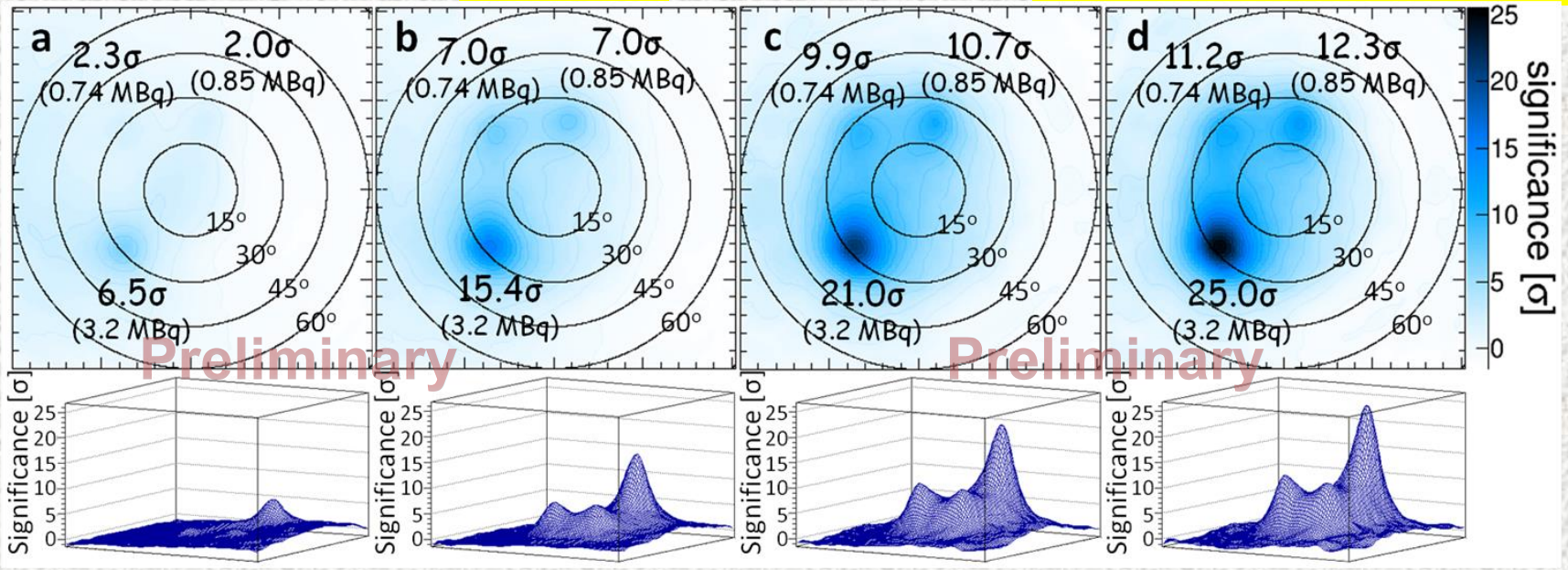
Improvement of Sensitivity

no use of SPD

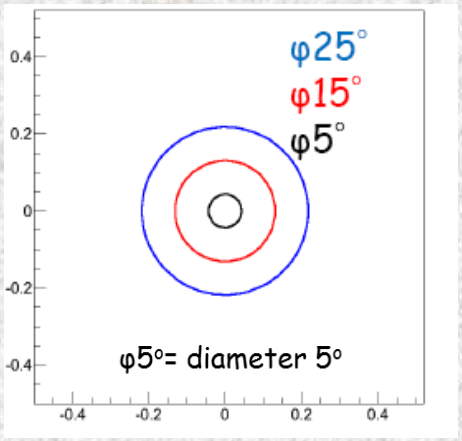
SPD ~200°

SPD ~100°

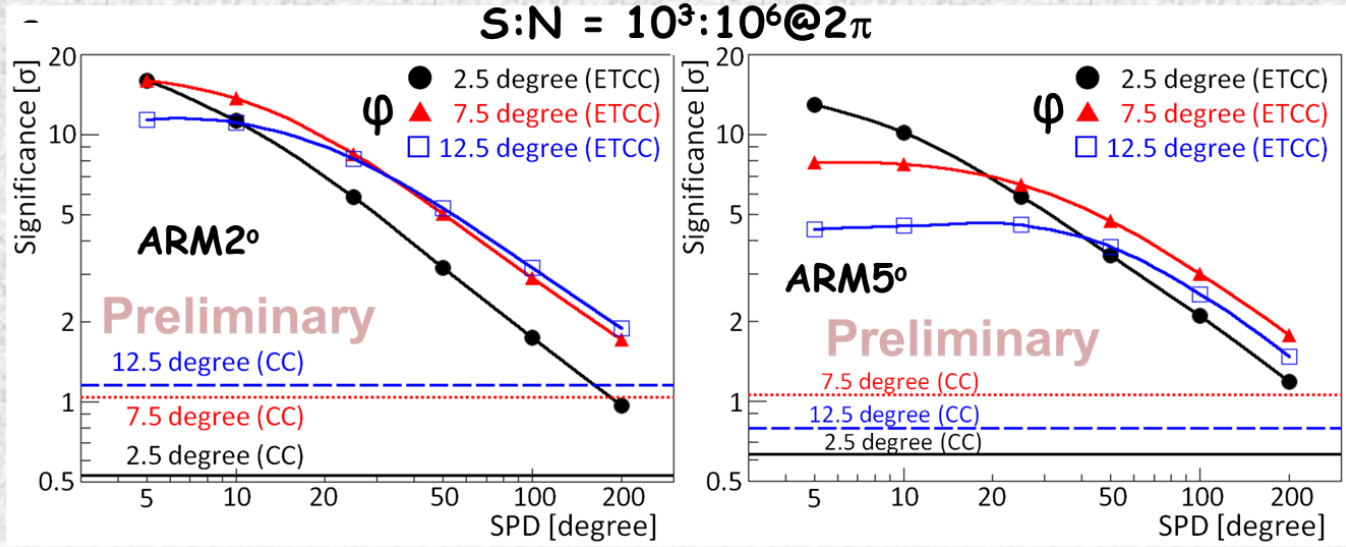
SPD 90° <80keV, SPD 45° >80keV



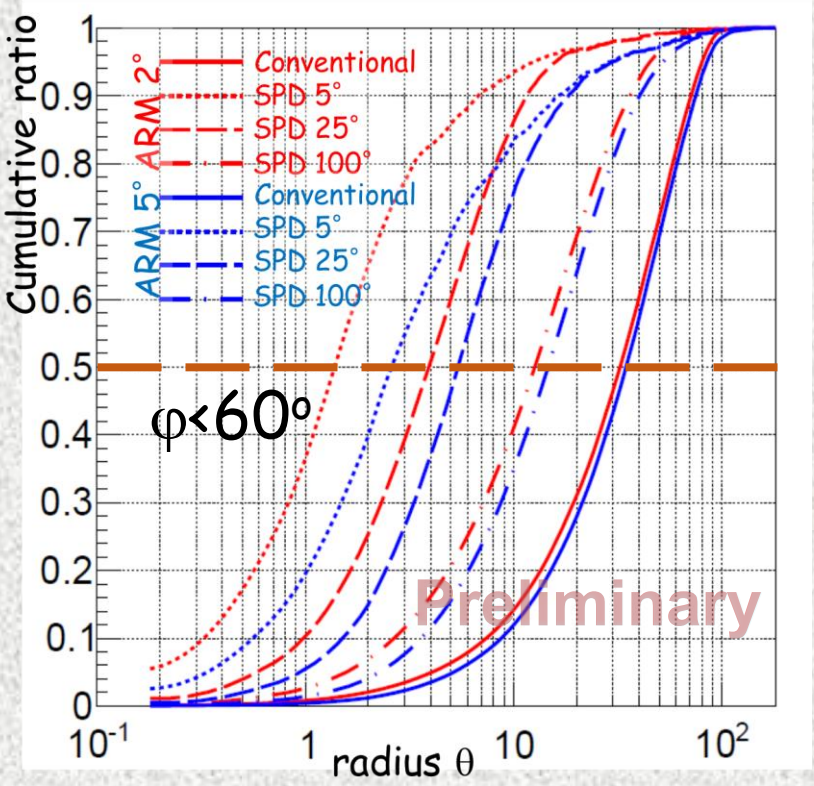
Simulation for better SPD



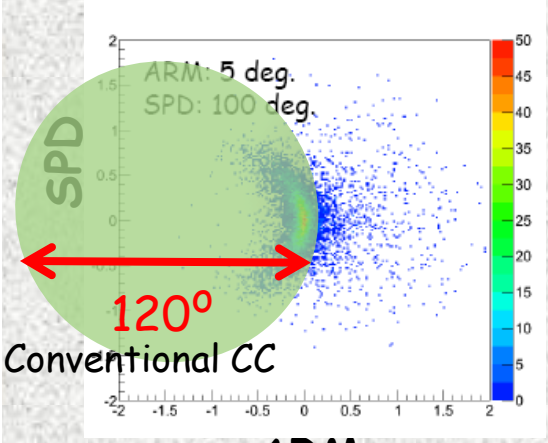
S:N = 10^3:10^6@2π

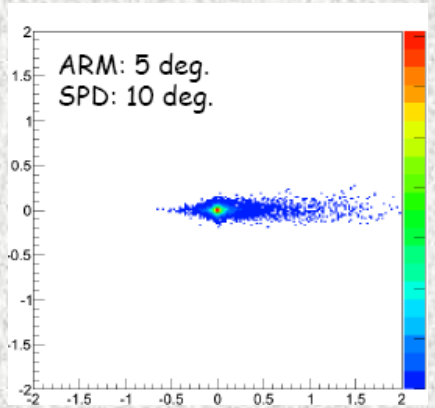


Point Spread Function in CC



Spread on SPD-ARM plane





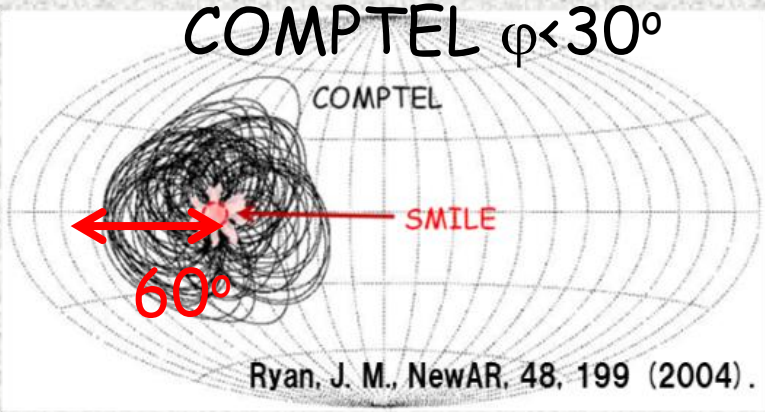
PSF(θ) = ½ gammas in the radius of θ

Conventional CC PSF(35°)

SPD 50° ARM 5° PSF(7°)

SPD 25° ARM 5° PSF(5°)

SPD 5° ARM 2° PSF(1.2°)



PSF of CC/ PSF (1.2o) of ETCFC ~30 times significance

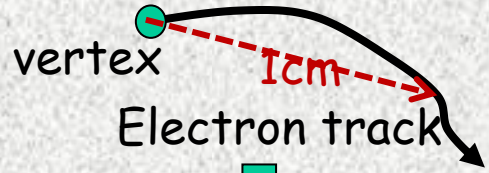
PSF (<2°) is inevitable to reach 1mCrab sensitivity @10^6s & a few 100cm^2

SPD resolution in TPC with μPIC

Present 800μm pitch

Linear Fitting

Between vertex to 1cm

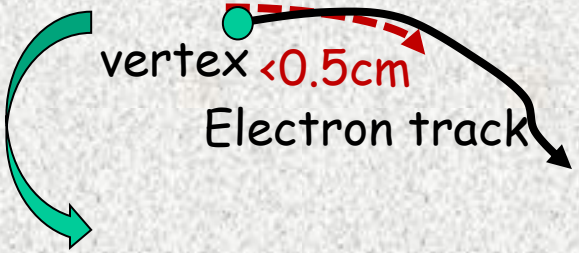


1 year later 400μm pitch

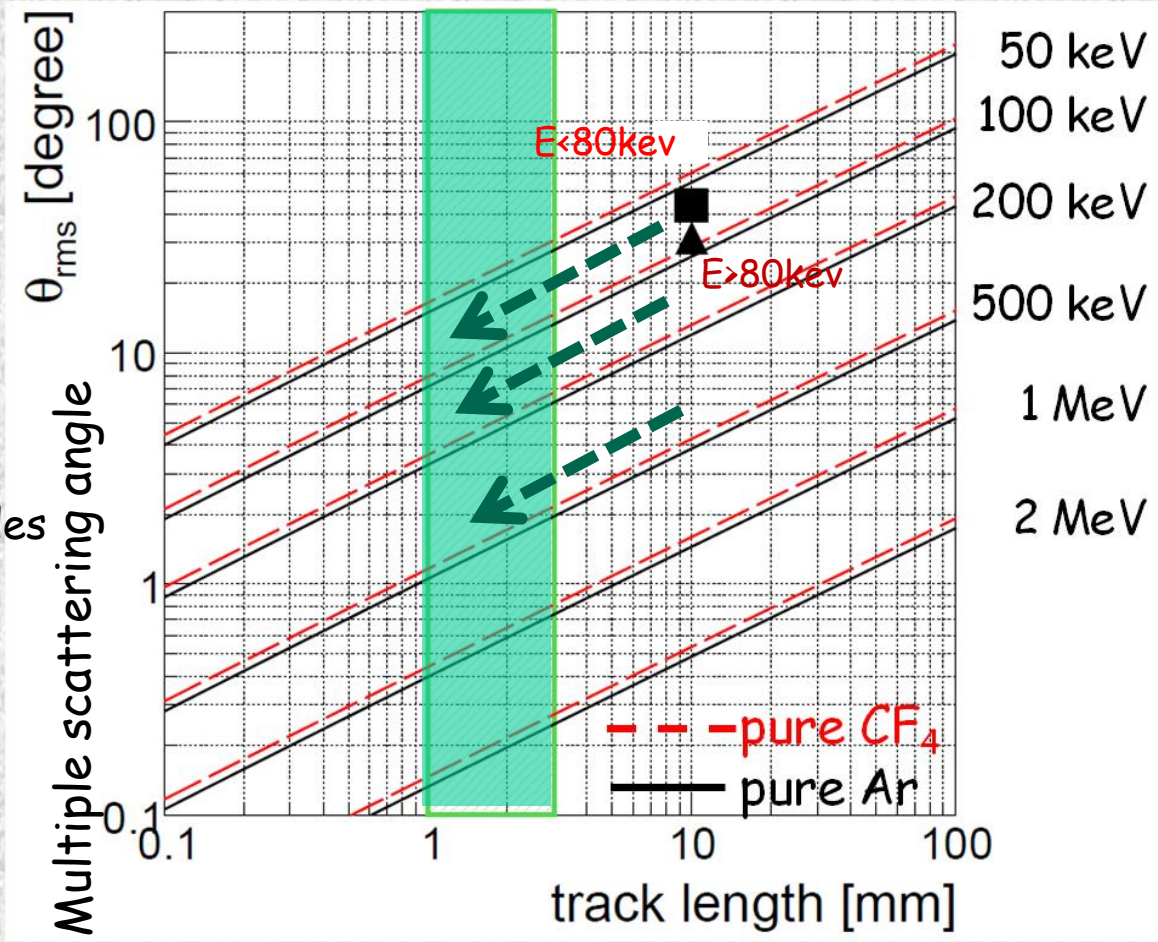
U,V,X electrodes

Spline Fitting

Between vertex to 0.5cm



Scattering Angle @ a few mm



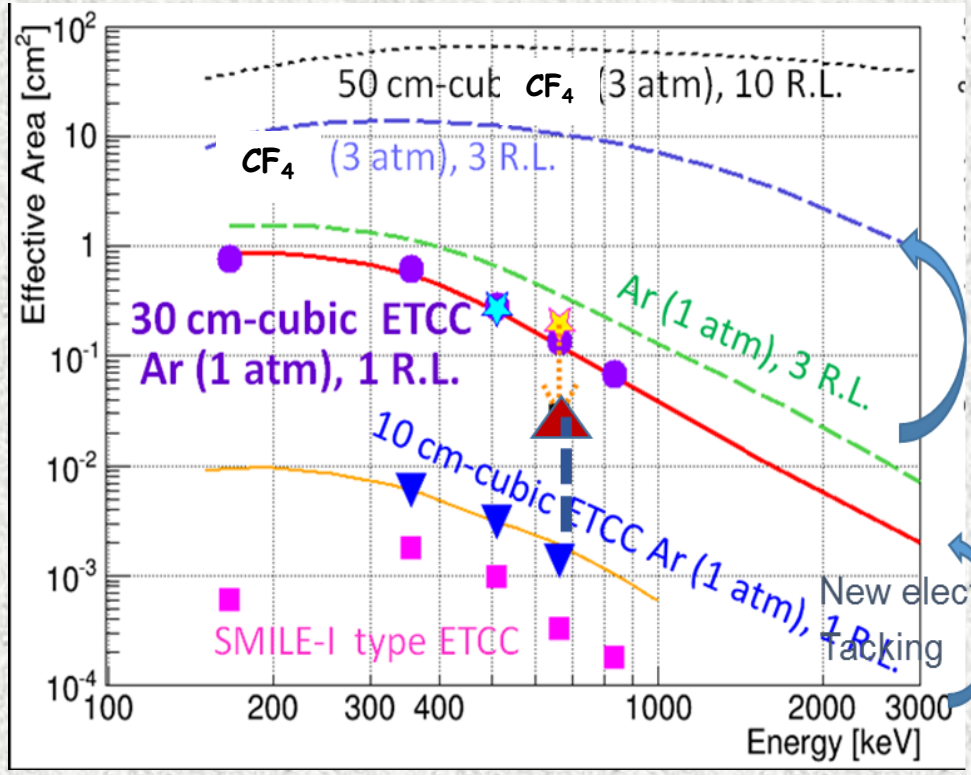
SPD resolution

500keV Gamma Ee ~150keV SPD: 15° - 5°

>1MeV Gamma Ee ~300keV SPD: 10° - 2°

PSF(θ =1.2°) SPD 5° ARM 2° PSF(θ) θ -> 1°~2° possible

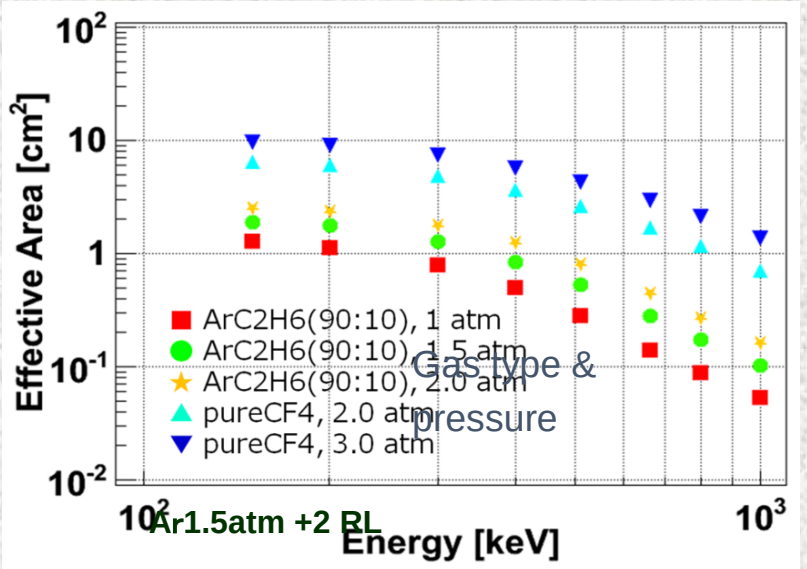
Efficiency & Effective Area



Current Effective Area ~1 cm²
(Requirement > 0.5 cm²)

Compton electrons in TPC
→ ~100% detection!!

Simulated Effective Area



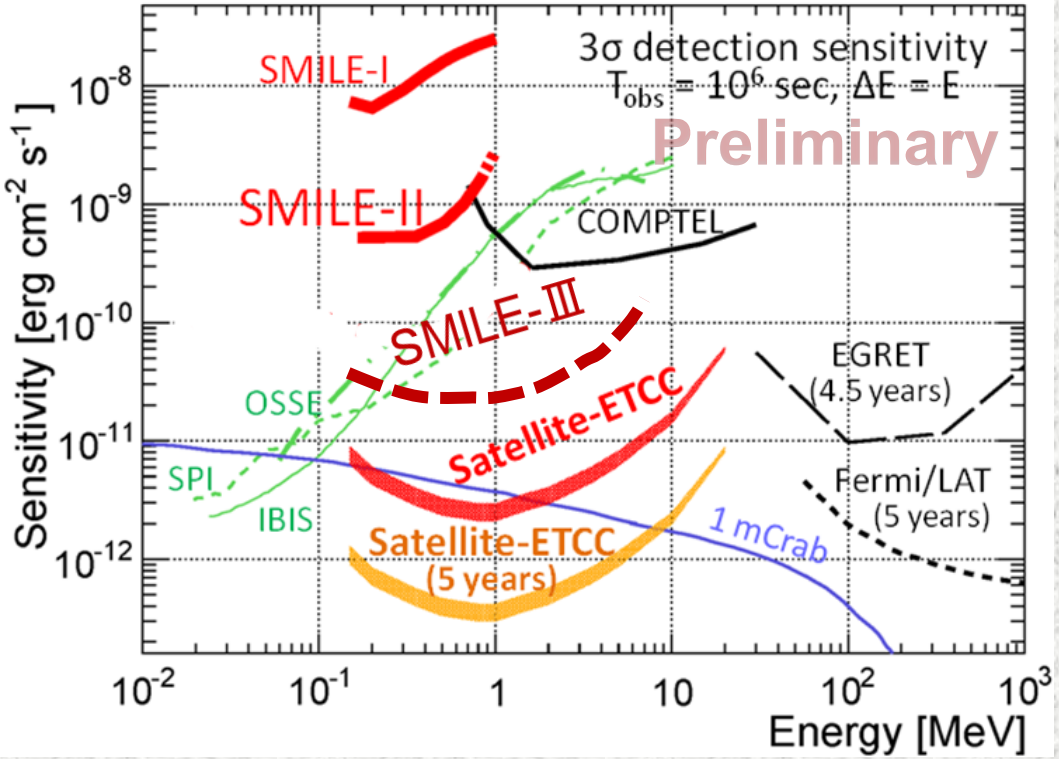
Further Improvements

CF_4 gas + 3 atm. ⇒ ~10 cm²
+ double scintillator ⇒ ~15 cm²

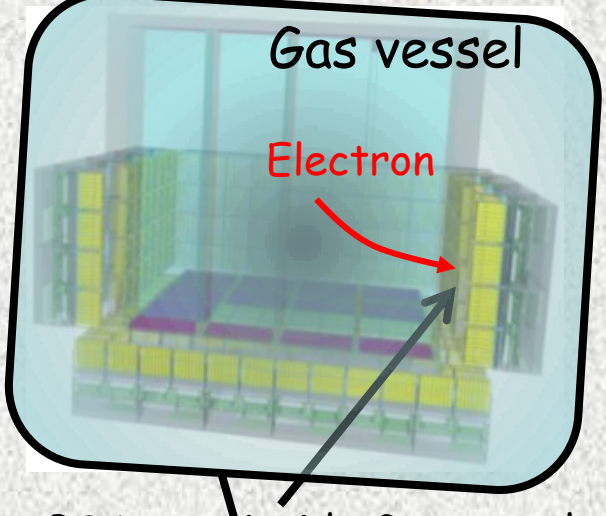
Similar effective area to COMPTEL
But ~6 sr FoV, Low background, Clear Imaging in SMILE

Future Sensitivities by ETCC

Sensitivities are calculated simply from effective.area and PSF with no use of MELM



SMILE-Satellite 4x50cm-ETCC



PSAs set inside Gas vessel to catch high-energy recoil electron escaping the drift region

■ SMILE-II (in USA)

- ◆ Collaboration with Goddard
- ◆ 30cmETCC with 1~4cm^2
- ◆ Detection Crab ,CygX-1 at >5σ
- ◆ Polarization

■ SMILE-Ⅲ (Polar region)

- ➢ 40cm-cubic ETCC x2
  ->> ~40cm^2 X2 = ~80cm^2
- ➢ Deep Survey for galactic plane

Summary

- ETCC provides a well-defined PSF which reveals the way to reach 1mCrab sensitivity without assuming the use of Optimization Algorithm.(essential for a good PSF of 1~4°)
- Future balloon Plan MILE-II for Crab & SMILE-III (Eff.Area ~100 cm²) with >1/10 of COMTEL sensitivity.

Example of New Astronomy by ETCC

Detection of Gamma Ray Burst of First Stars (Population III)
Long duration weak GRB with $10^{4\text{-}5}$s

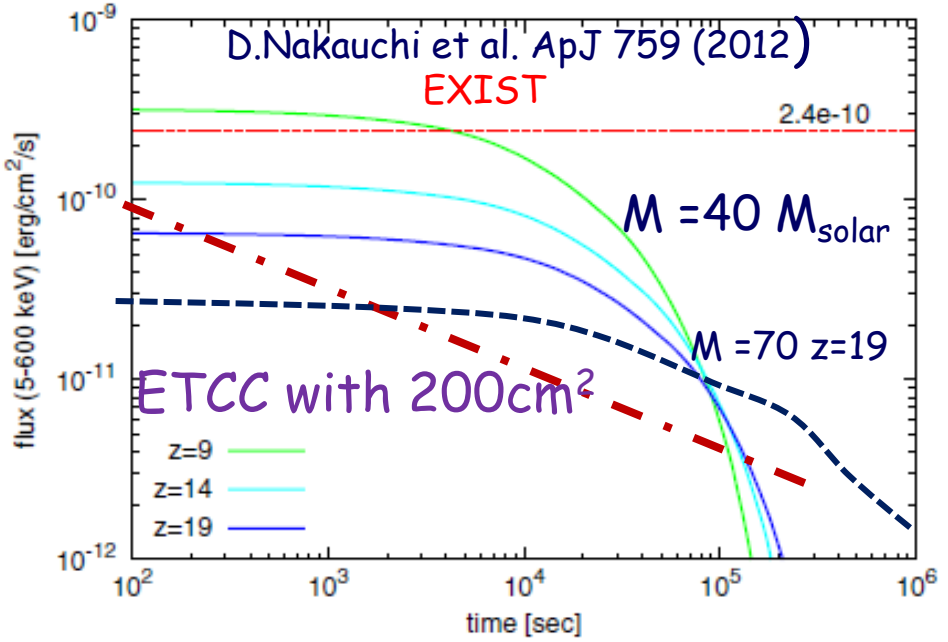


Figure 3. Same as Figure 2 but for the *EXIST* case. *EXIST* will have the limited energy range of 5–600 keV. The red dashed line represents the *EXIST* sensitivity $f_{sen} \sim 2.4 \times 10^{-10}$ erg cm^{-2} s^{-1} (5–600 keV, 5σ) in the longest exposure timescale at the on-board process ($\Delta t \sim 512$ s; Hong et al. 2009).