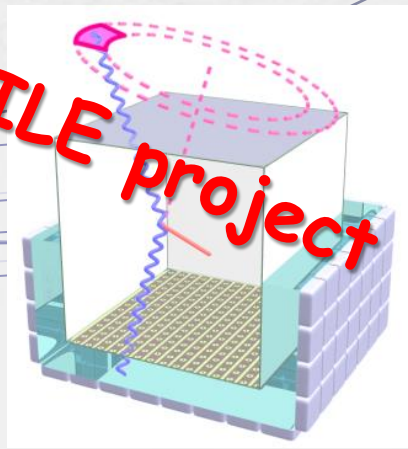
BN4-10

An Observational Key to SN Ia Progenitors: MeV All-Sky Survey

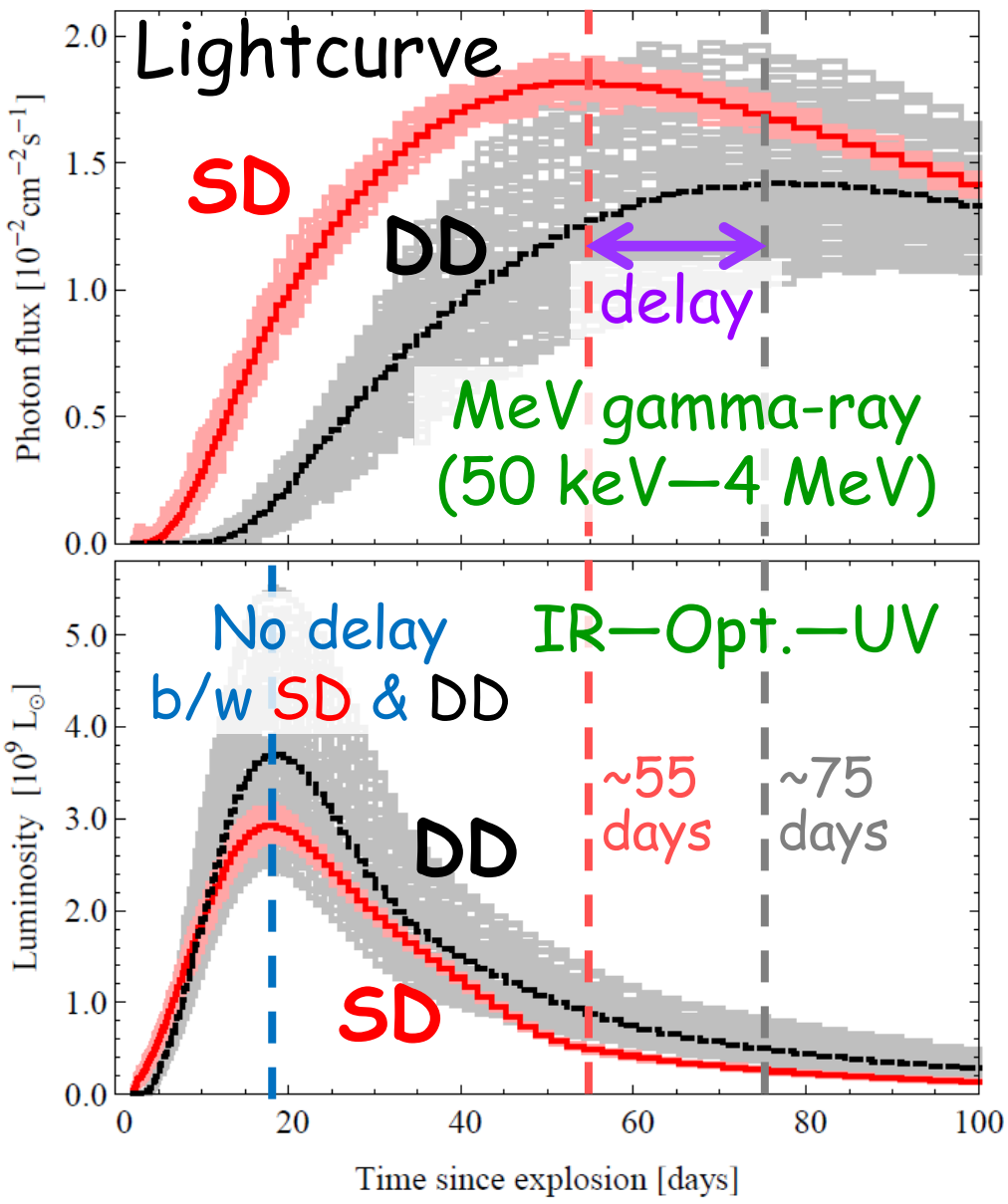
Yoshitaka Mizumura
(Kyoto Univ.)



T. Tanimori, A. Takada, S. Komura, T. Kishimoto,
T. Takemura, S. Miyamoto, Y. Nakamasu, K. Yoshikawa,
H. Kubo, T. Mizumoto, S. Sonoda, D. Tomono, J. D. Parker,
K. Nakamura, Y. Matsuoka, M. Oda, K. Miuchi, T. Sawano

A diagnostics of SN Ia progenitors

A. Summa, …, K. Maeda, et al., A&A 554, A67 (2013)



Delay of Lightcurves

- Optical: No delay
- MeV gamma-ray:
  - **SD** scenario: ~55 days
  - **DD** scenario: ~75 days

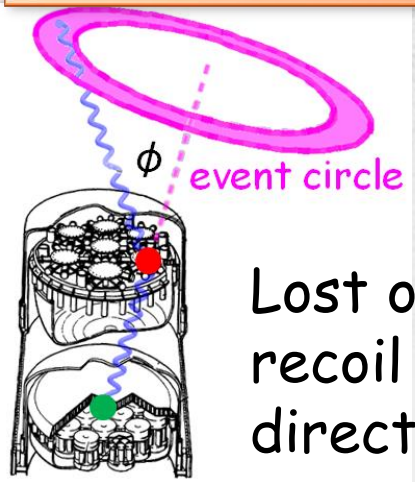
MeV gamma provides crucial hints for **SN Ia progenitors**

Requirements for telescope

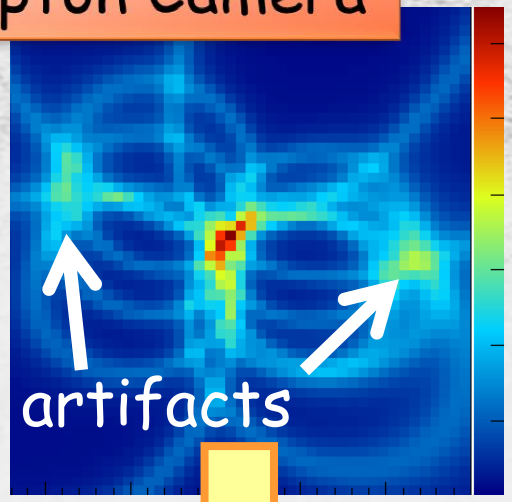
- Good Point Spread Function (PSF)
- Efficient BG rejection
- Wide Field of View (FoV)

Concepts of our MeV telescope: ETCC (Electron-Tracking Compton Camera)

Conventional Compton Camera

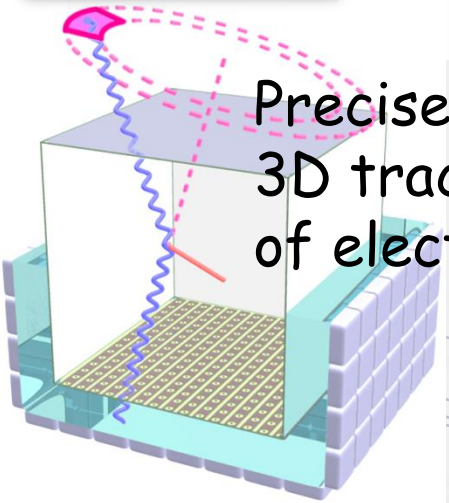


Lost of recoil e^- direction

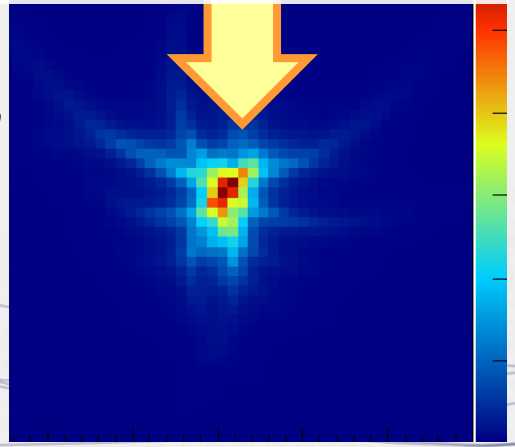


ETCC

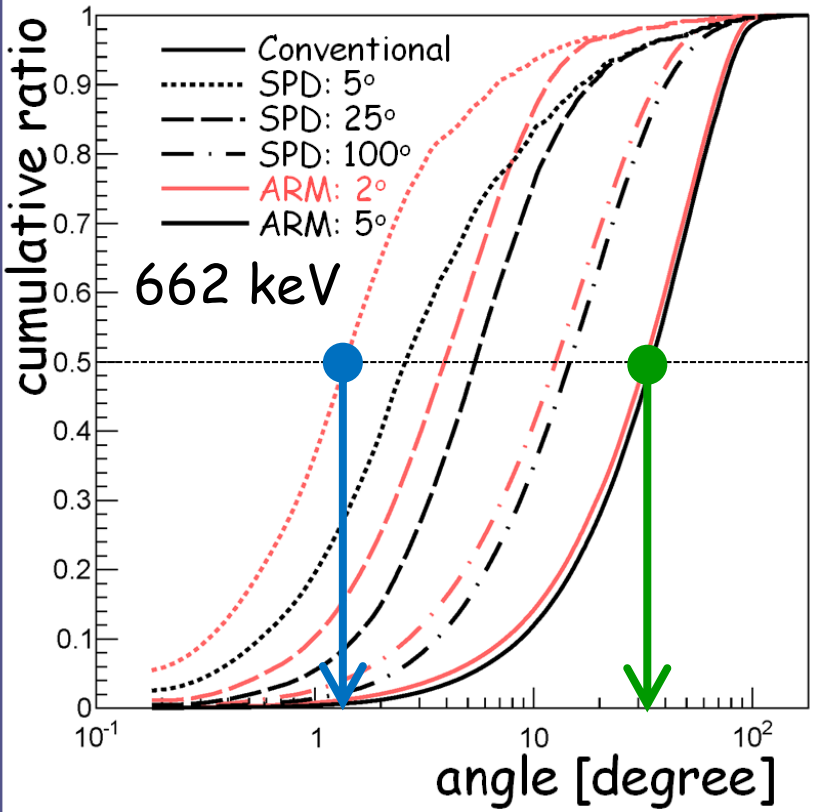
Significant Improvement of MeV imaging



Precise 3D tracking of electron



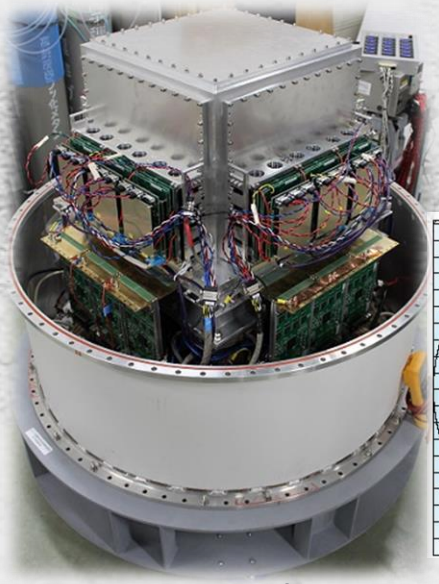
Point Spread Function (PSF)



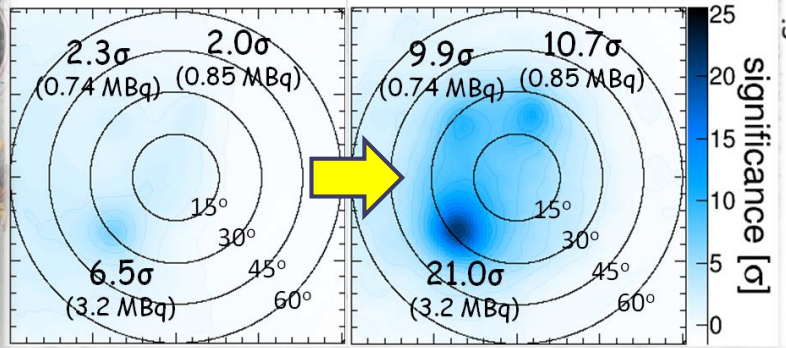
Half of all photons within

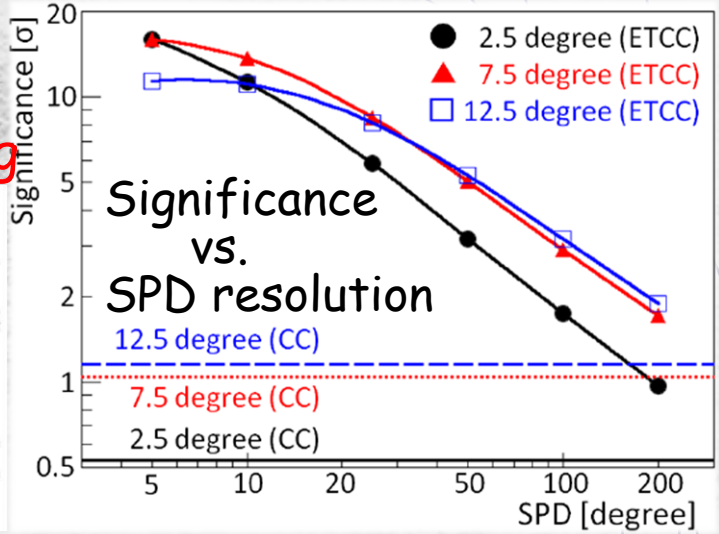
>30°: Conventional CC.

1-2°: ARM 2° + SPD 5°

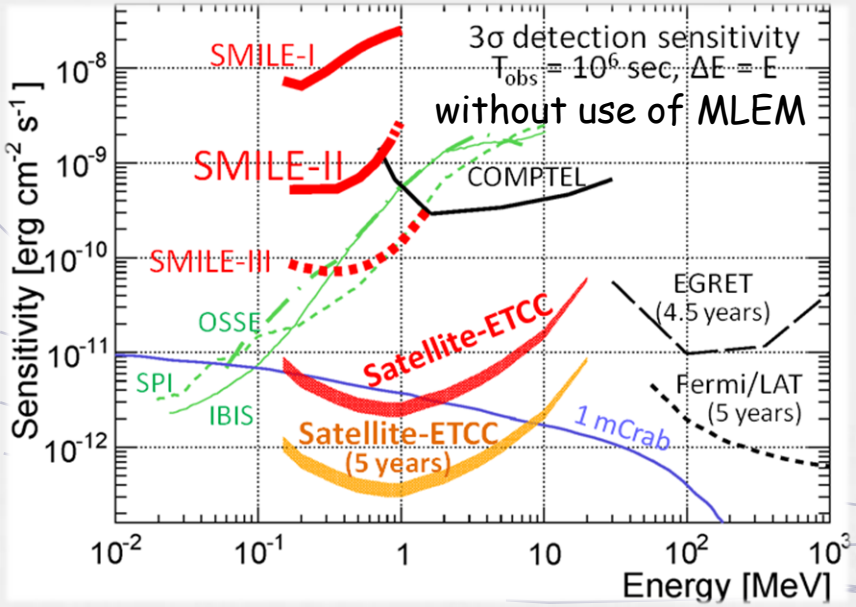


Compton imaging with
Conventional Electron-Tracking





Details of ETCC and its future prospects is accepted for publ. in ApJ (T. Tanimori+)



arXiv:1507.03850
Please check/read it!!

Well-defined PSF 2°, and
1 mCrab sensitivity in 10^6 sec

↓

Amassed lightcurve of
SNe Ia @ 60 Mpc is obtainable.

Expectation Conditions

SN Ia Explosions

- Spectra & Time evolutions:
  A. Summa+ (2013) models
  (Partially interpolated by Y. M)
- Explosion rate (<60 Mpc):
  ~2×10^{-5} [yr^{-1} Mpc^{-3}]

Distance [Mpc]	SN rate [yr^{-1}]	in 5 yrs [SNe]
15	0.28	1.4
20	0.67	3.4
40	5.4	27
60	18	90

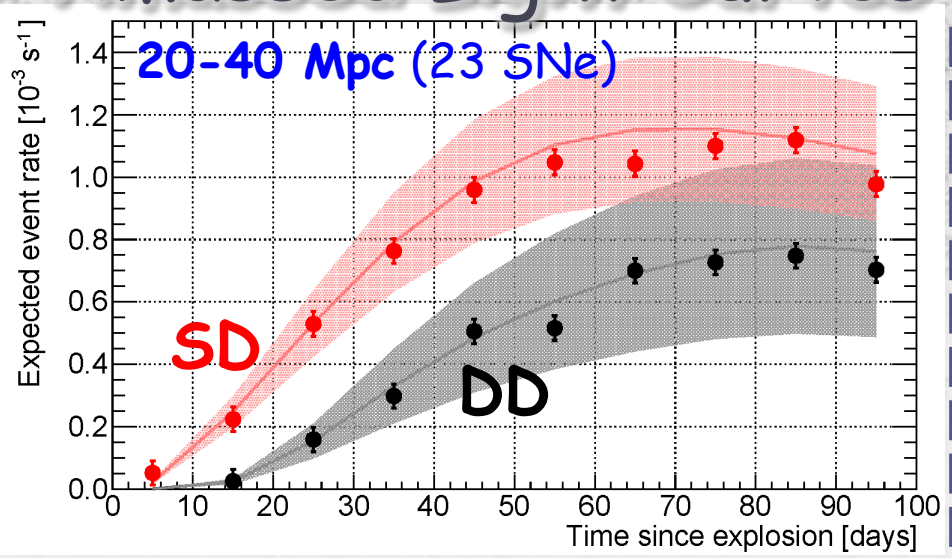
- Intrinsic flux ambiguity:
  - ^{56}Ni gen. 20% (SD & DD)
  - Viewing angle 30% (only DD)

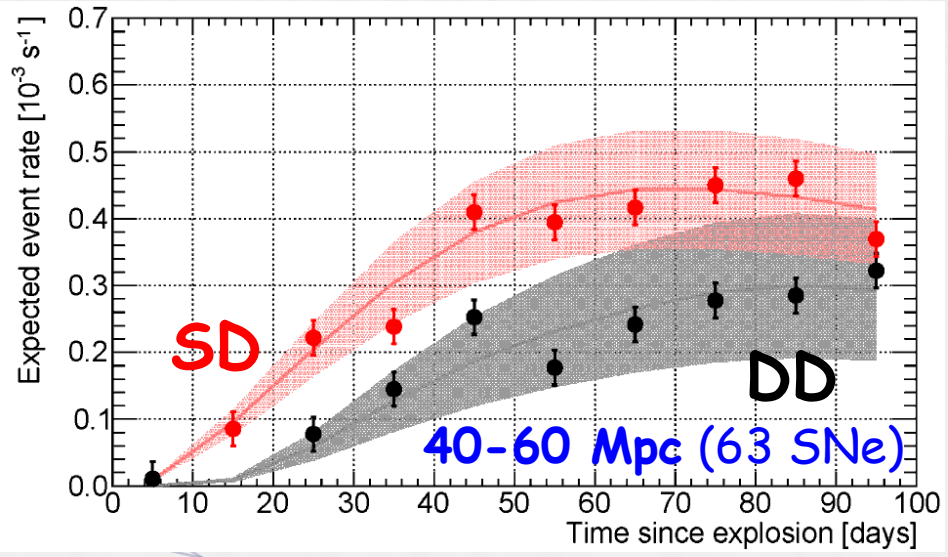
Instruments & Operation

- Instrument: Satellite-ETCC
  (4 x 50 cm-cubic ETCCs)
- Effective Area:
  240 cm^2 @ 1 MeV
- Point Spread Function:
  2^o @ 1 MeV
- Energy Resolution:
  $5 \times (E/(662\ keV))^{-0.5}$ [%]
- Field of View: 2π sr
- Livetime (incl. FoV): 33%
- BG spectrum:
  2 x (Observed CXB)
- Operation:
  5 years in a low-earth orbit

Distance, Flux ambiguity, photon statistics --> random numbers

Amassed Light Curves (Energy: 0.7—4.0 MeV)

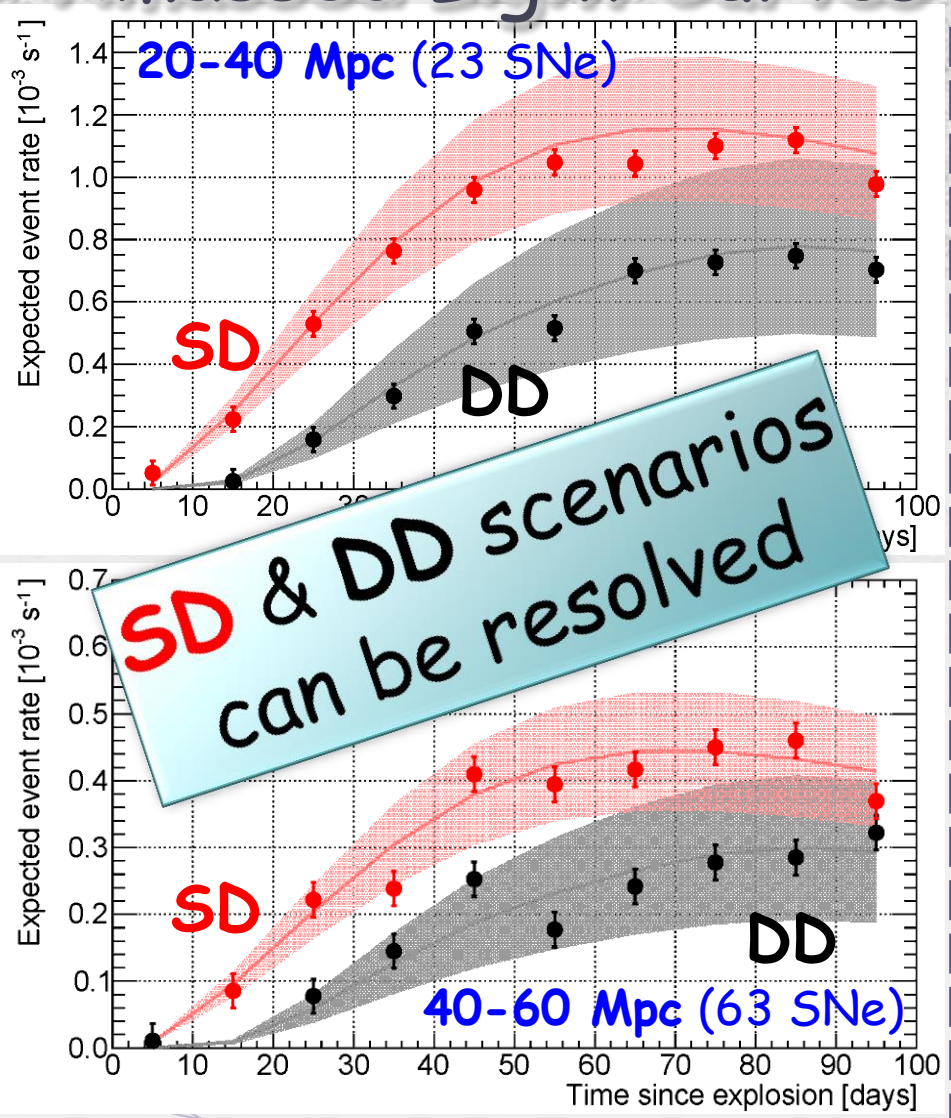




Cancel out of characteristics by large # of SNe is effective!!

--> All-Sky Survey

Amassed Light Curves (Energy: 0.7—4.0 MeV)

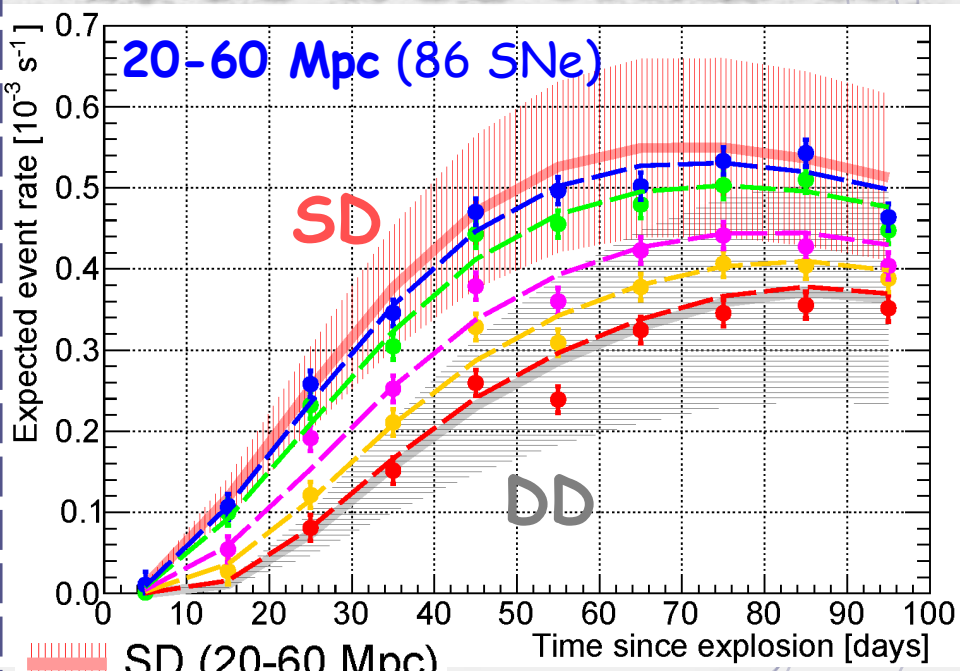


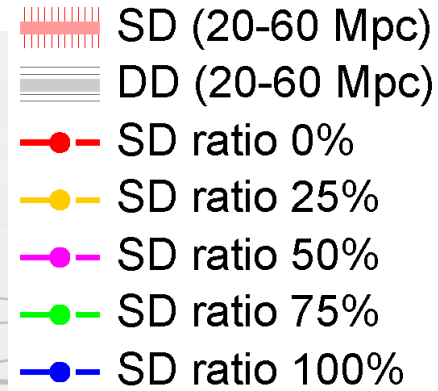
SD & DD scenarios can be resolved

Cancel out of characteristics by large # of SNe is effective!!

--> All-Sky Survey

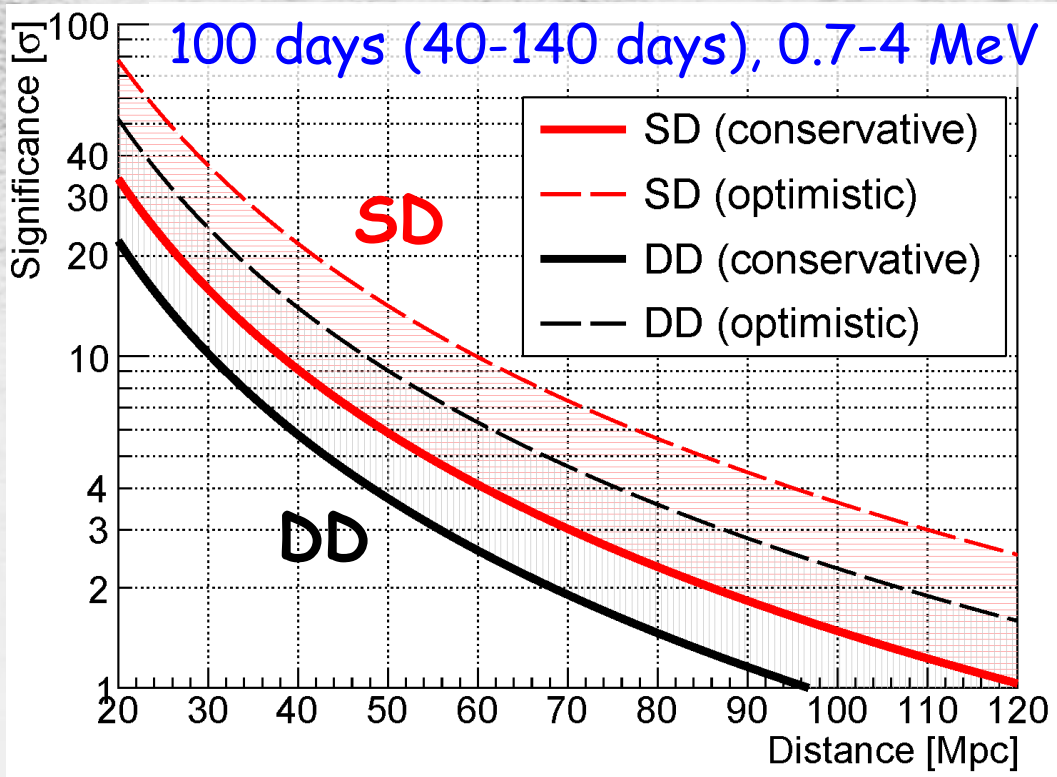
Challenge to measure co-existence ratio of SD & DD scenarios





It might be obtainable with an accuracy of ~20 %

Distance limit for detection



◆**Conservative model**
- BG: **2x**(Observed CXB)
- Operation: **survey mode**
  Livetime(incl. FoV): 33%

◆**Optimistic model**
- BG: **1x**(Observed CXB)
- Operation: **pointing mode**
  Livetime(incl. FoV): 100%

Significance [σ]	3	4	5
Conservative (SD, DD) [Mpc]	70, 55	60, 48	55, 45
Optimistic (SD, DD) [Mpc]	110, 85	95, 75	85, 65

SNe Ia with distances up to 100 Mpc

>400 SNe with optical coincidence during 5 years operation would be expected.

Summary

arXiv: 1507.03850

- **Satellite-ETCC** would reach **1 mCrab** sensitivity (with 2° PSF @ 1 MeV)
  - Amassed light curve (<60 Mpc) is obtainable
- Resolving of **SD** or **DD** scenarios is expected
  - MeV all-sky survey (Large # of SNe) is important to cancel out individual characteristics of SNe
- Co-existence ratio of **SD** & **DD** scenarios might be obtained with ~20% accuracy
- Distance limits in 100 days (3σ) are 70-110 Mpc and 55-85 Mpc for **SD** and **DD**, resp.
  - **>400 SNe** with optical coincidence would be expected during **5 years operation of Satellite-ETCC**, if we achieve detection-distance limit up to 100 Mpc

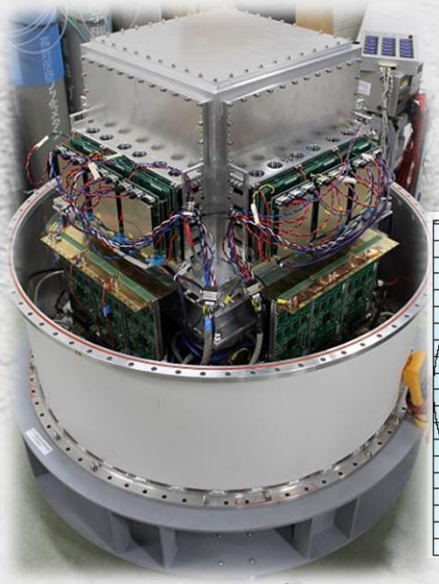
arXiv:
1507.03850

Thank you for your attention!!

Please visit to the SMILE project web page

(**S**ub-**M**eV gamma-ray **I**maging **L**oaded-on-balloon **E**xperiment)

http://www-cr.scphys.kyoto-u.ac.jp/research/MeV-gamma/index_e.html



Compton imaging with
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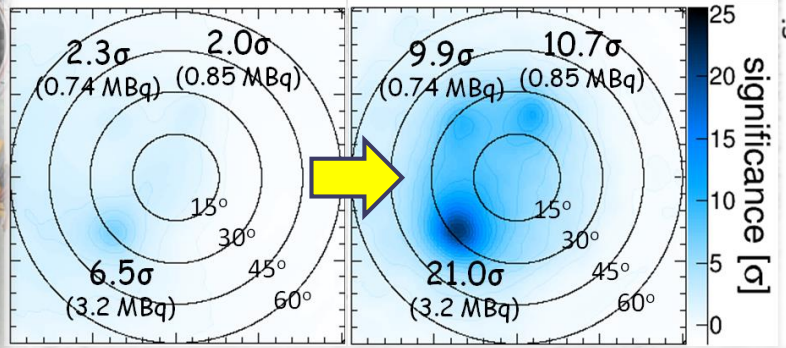

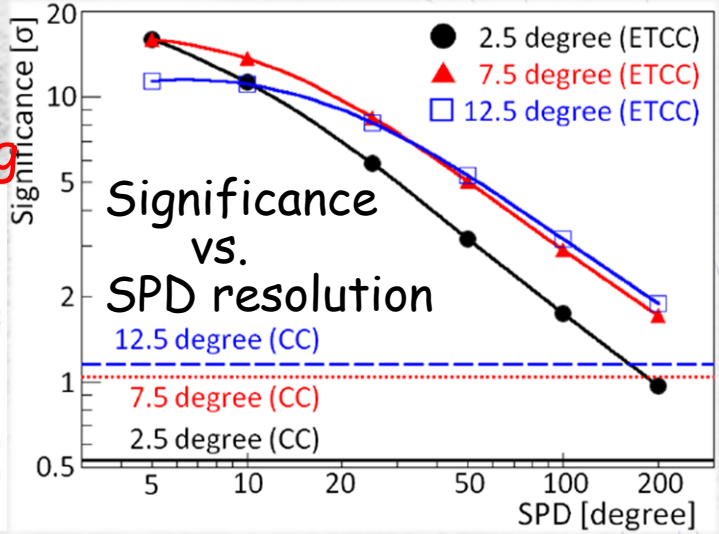

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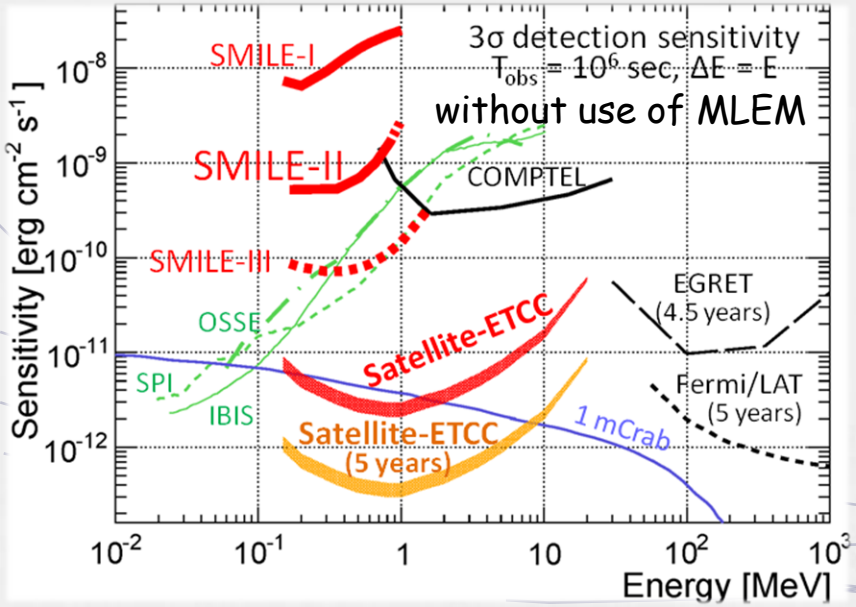

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Well-defined PSF 2°, and

1 mCrab sensitivity in 10^6 sec

↓

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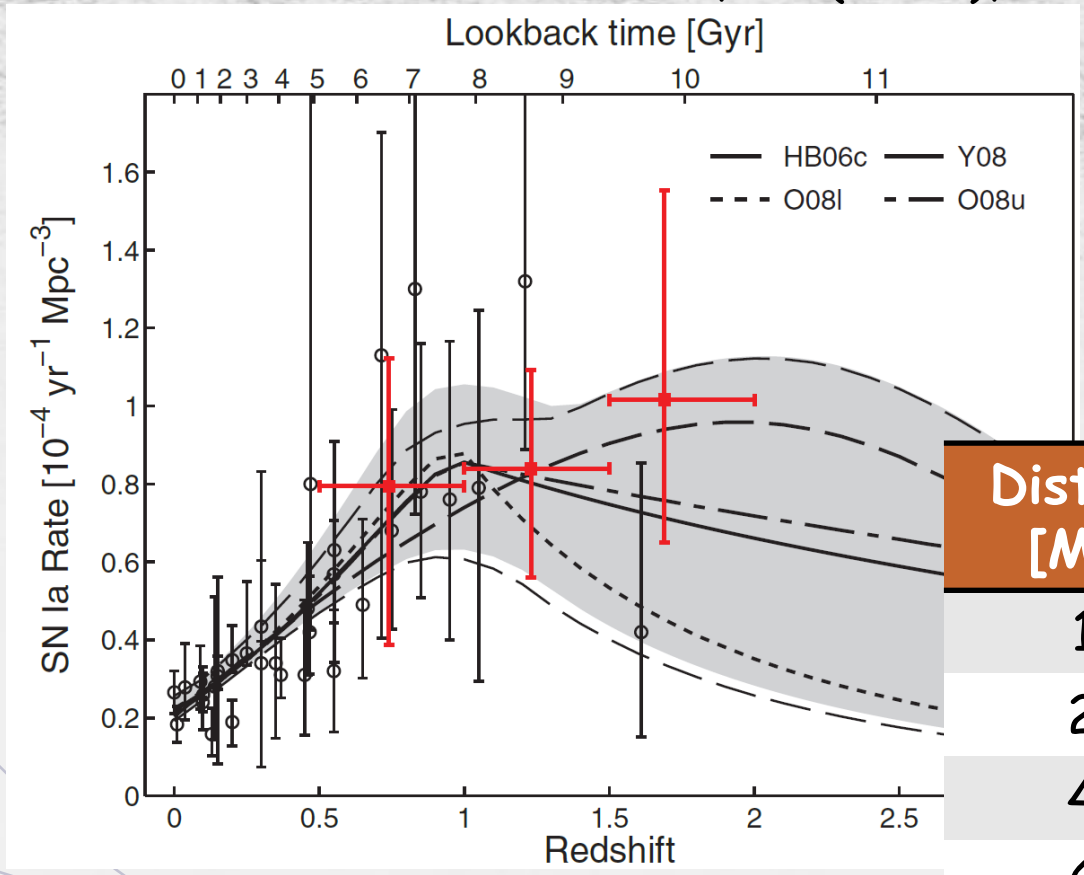
Supplemental Slides

Assumed explosion rate of SN Ia

D. Maoz, and F. Mannucci,
Publ. Astron. Soc. Australia, 29 (2013), 447



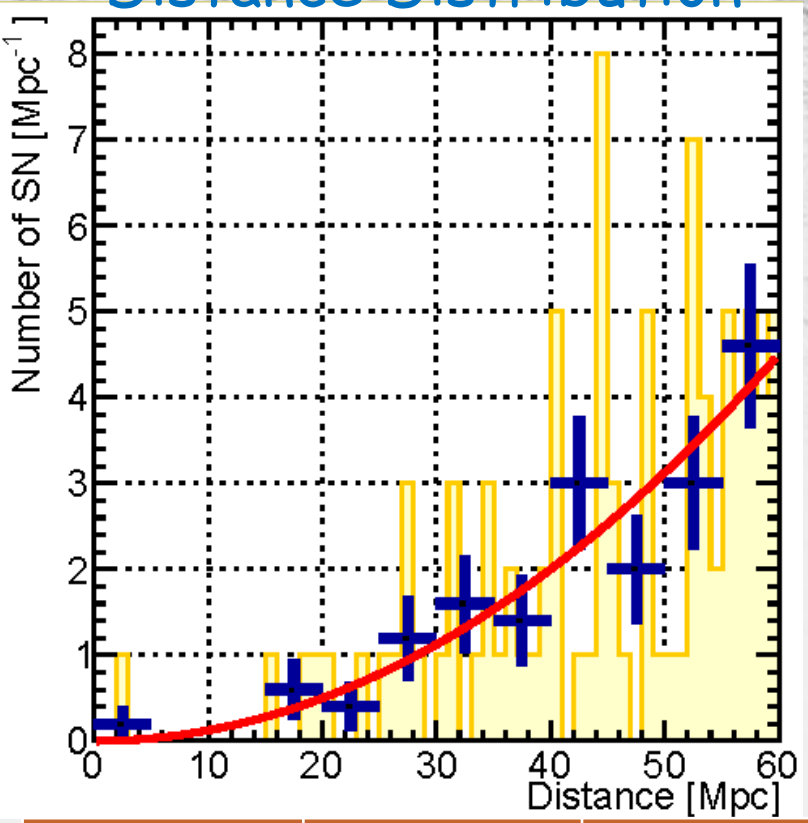
SN Ia rate
(@ nearby universe)
~2×10^{-5} [yr^{-1} Mpc^{-3}]

Distance [Mpc]	SN Ia rate [SNe yr^{-1}]	in 5 yrs [SNe]
15	0.28	1.4
20	0.67	3.4
40	5.4	27
60	18	90

During **5 years** operation of a satellite,
explosions of **90 SNe (<60 Mpc)** are expected.

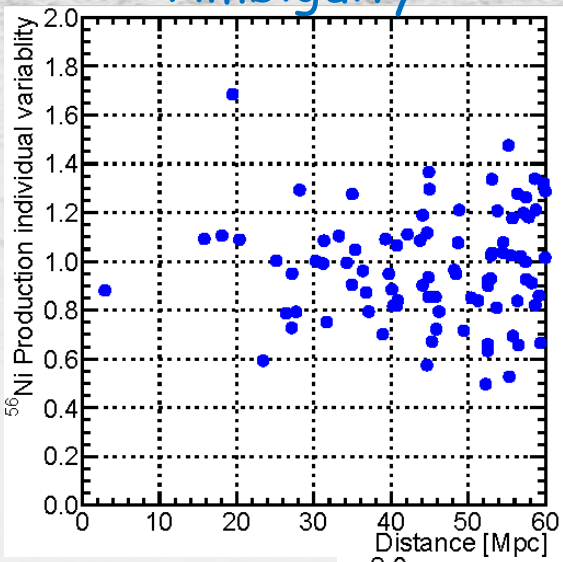
Generated SNe Ia by Random Numbers

Distance Distribution

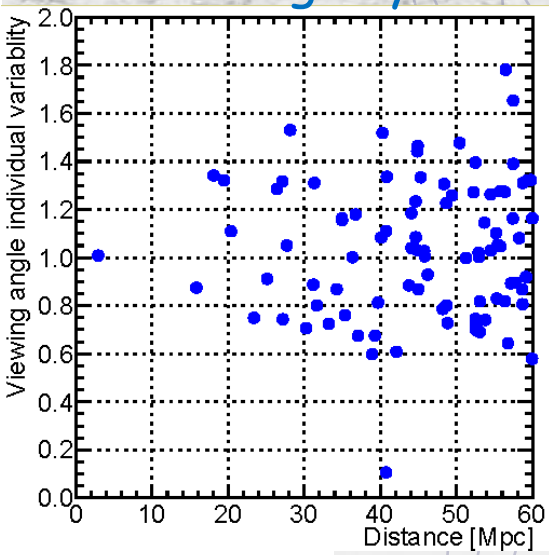


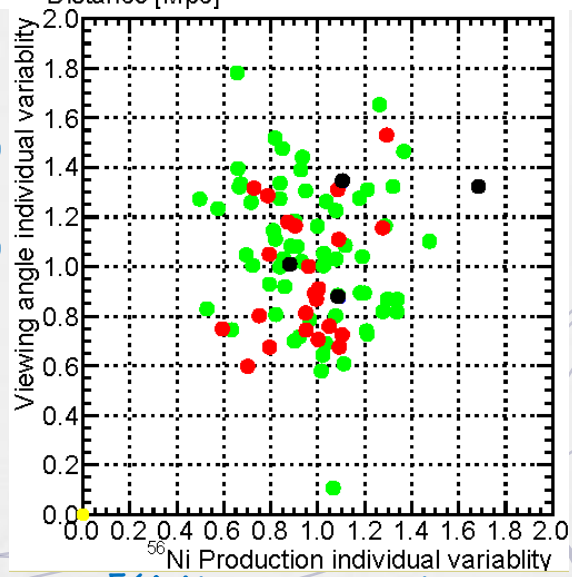
Distance [Mpc]	# of SNe	Mean Distance [Mpc]
0-20	4	14.0
20-40	23	31.9
40-60	63	51.3
0-60	90	44.7

^{56}Ni generation Ambiguity



Viewing angle Ambiguity

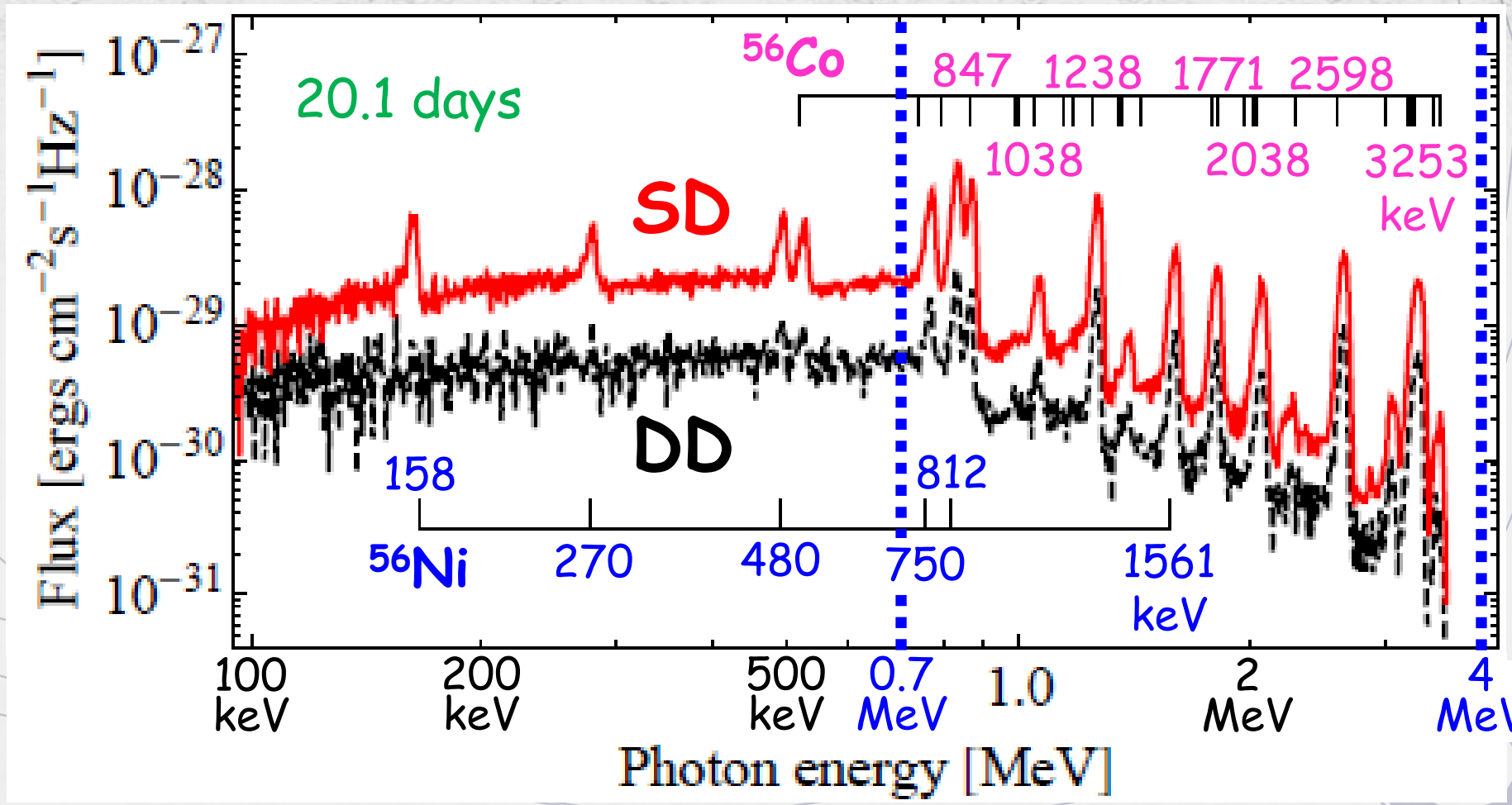




Spectral Lines in MeV gamma-ray band

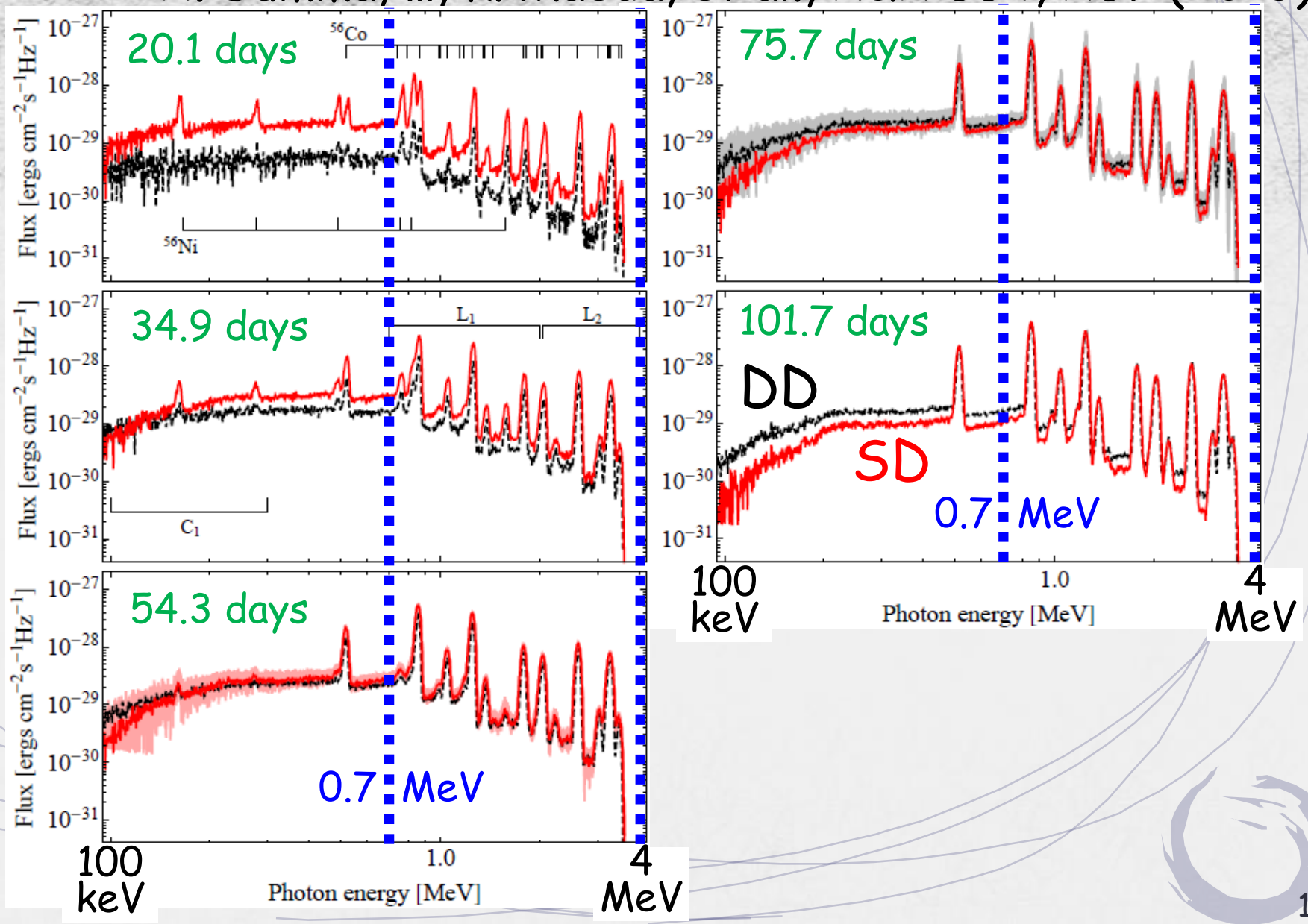
A. Summa, …, K. Maeda, et al., A&A 554, A67 (2013)

^{56}Ni (6.1 days) --> **^{56}Co** (77.2 days) --> ^{56}Fe

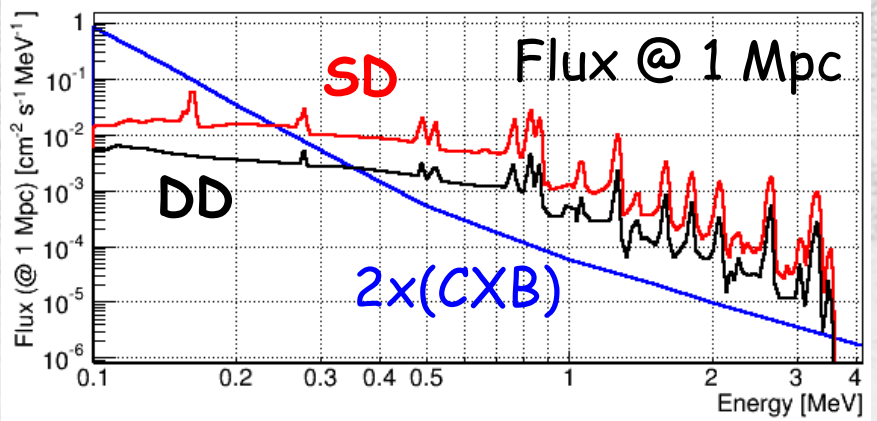


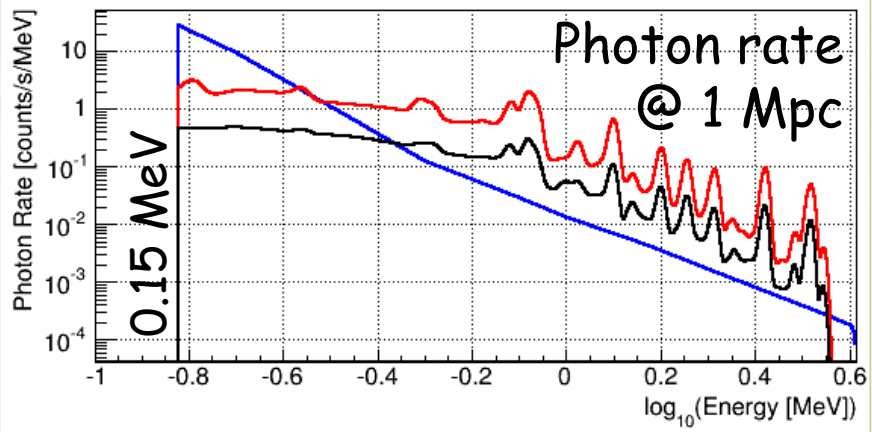
Time Evolution of MeV-band Spectra

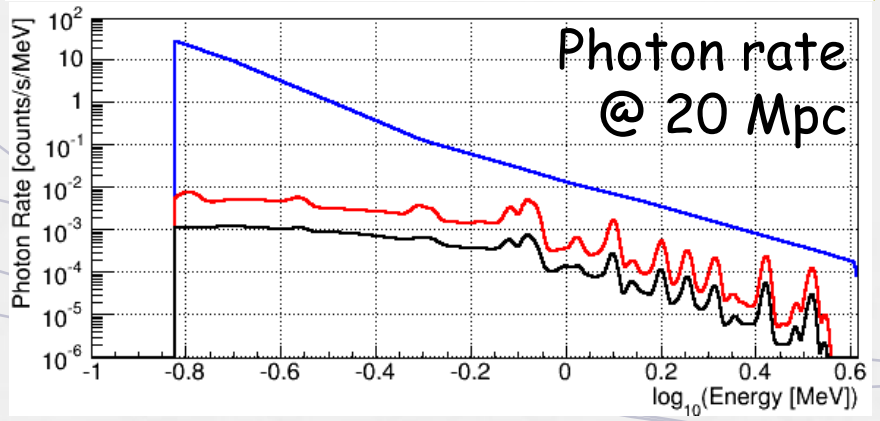
A. Summa, …, K. Maeda, et al., A&A 554, A67 (2013)



Conversion of SN Ia Spectra



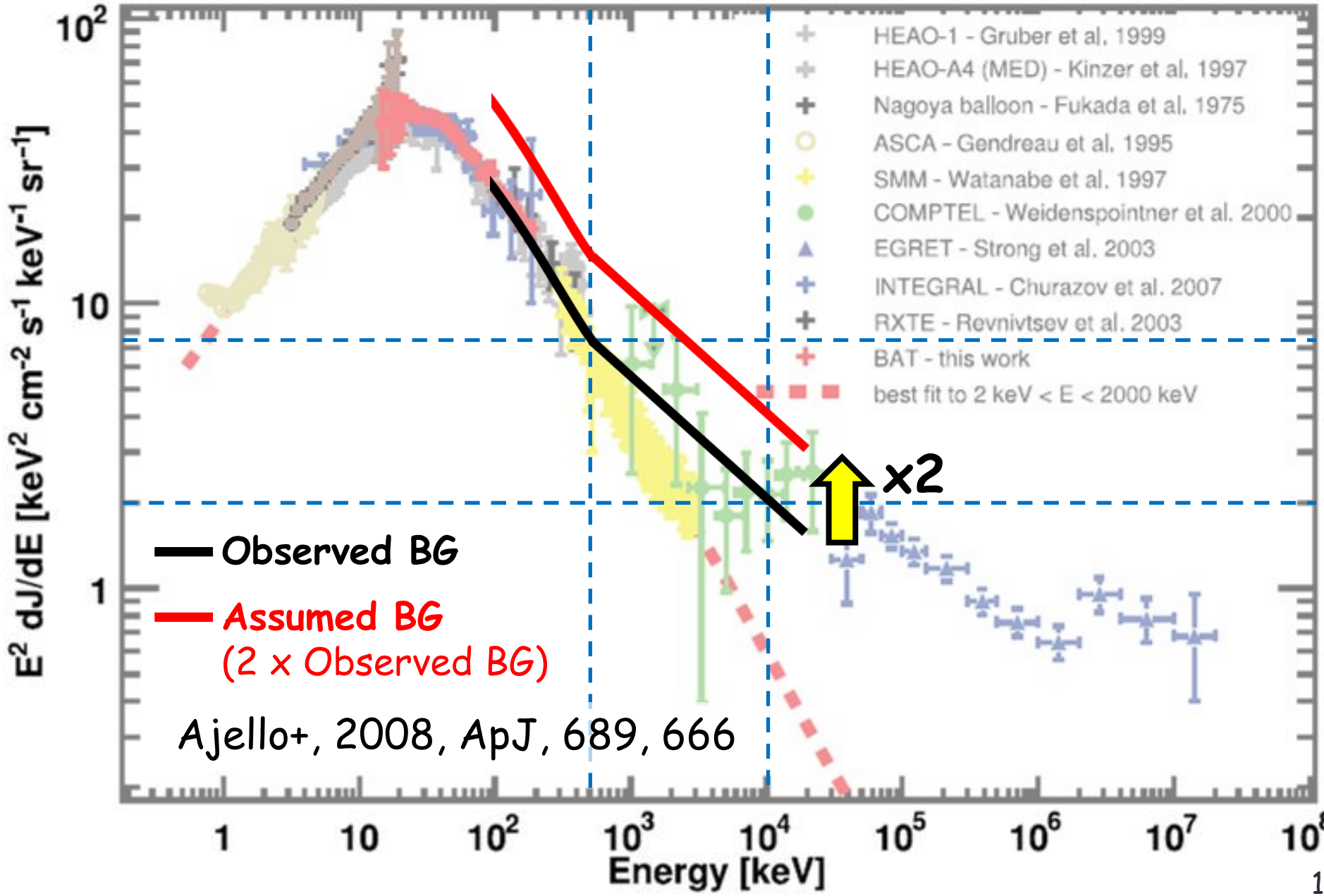




- Energy resolution
- Effective area
- Point Spread Function

- Rate scaling by distance

Assumed BG gamma-ray spectrum



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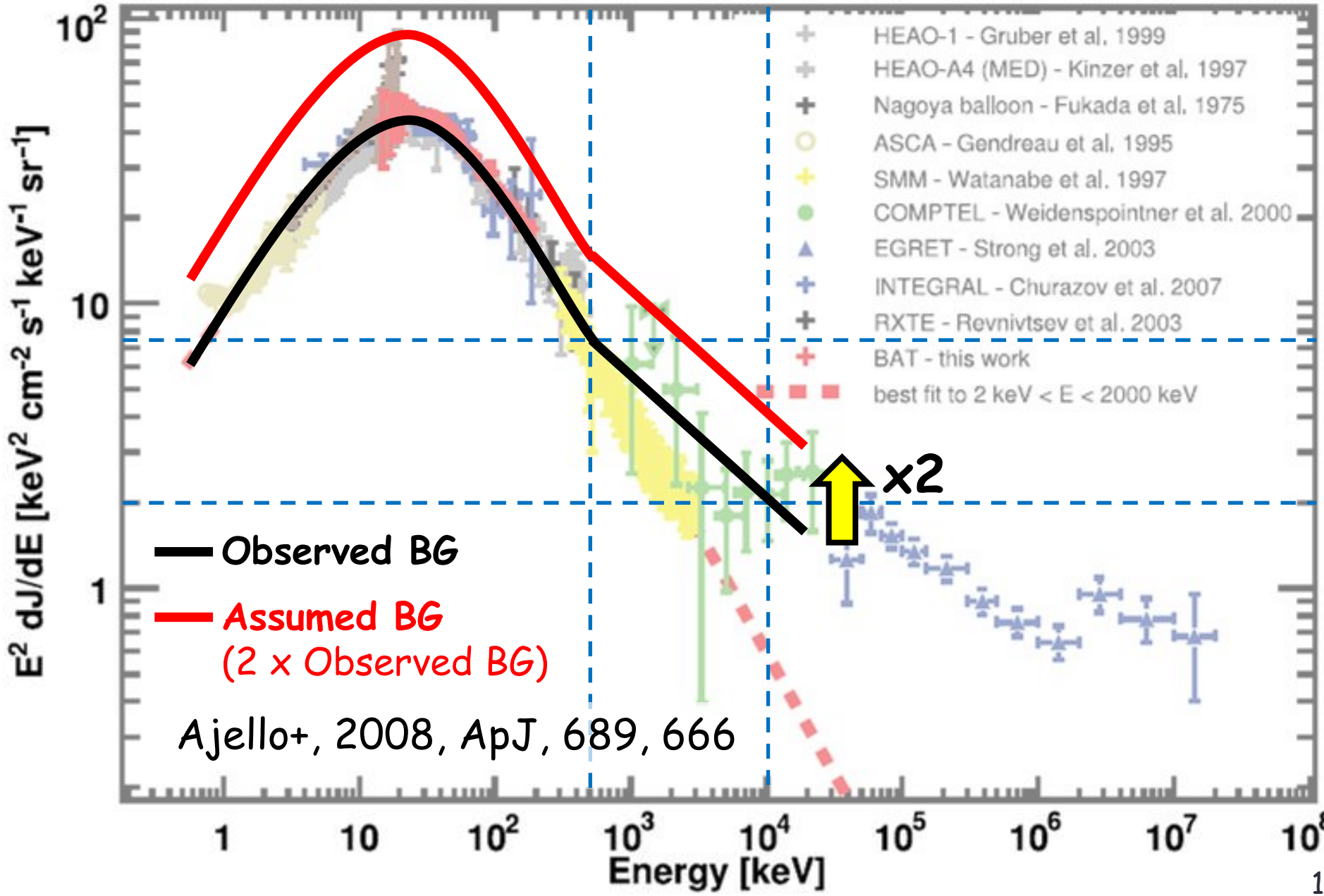
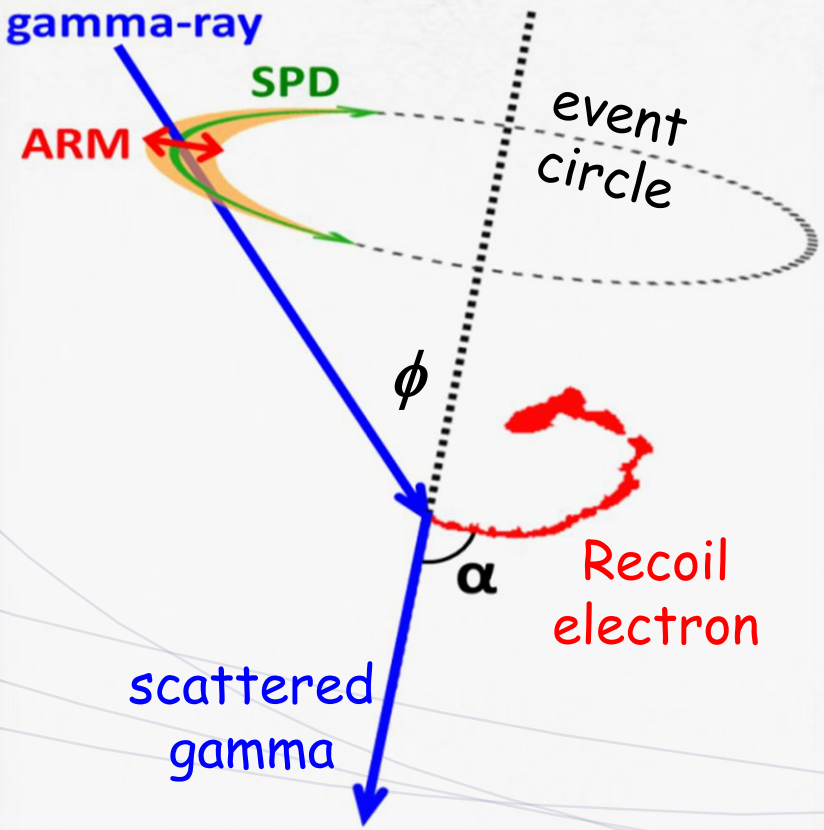
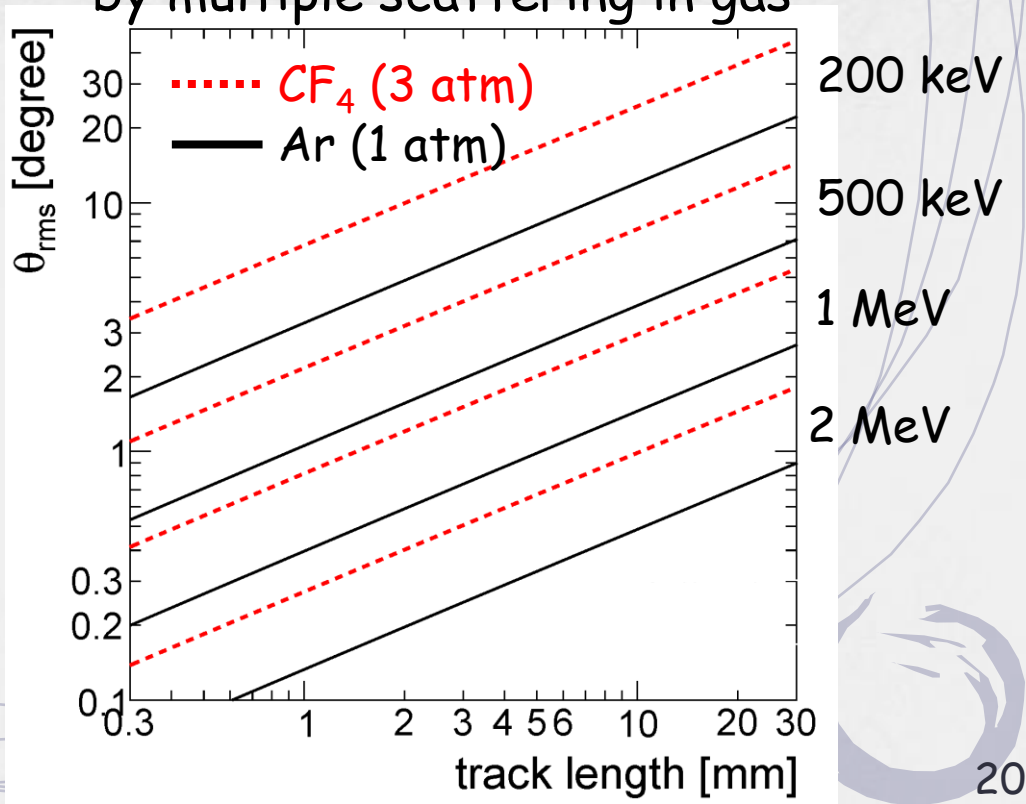


Two angular resolutions (ARM & SPD)

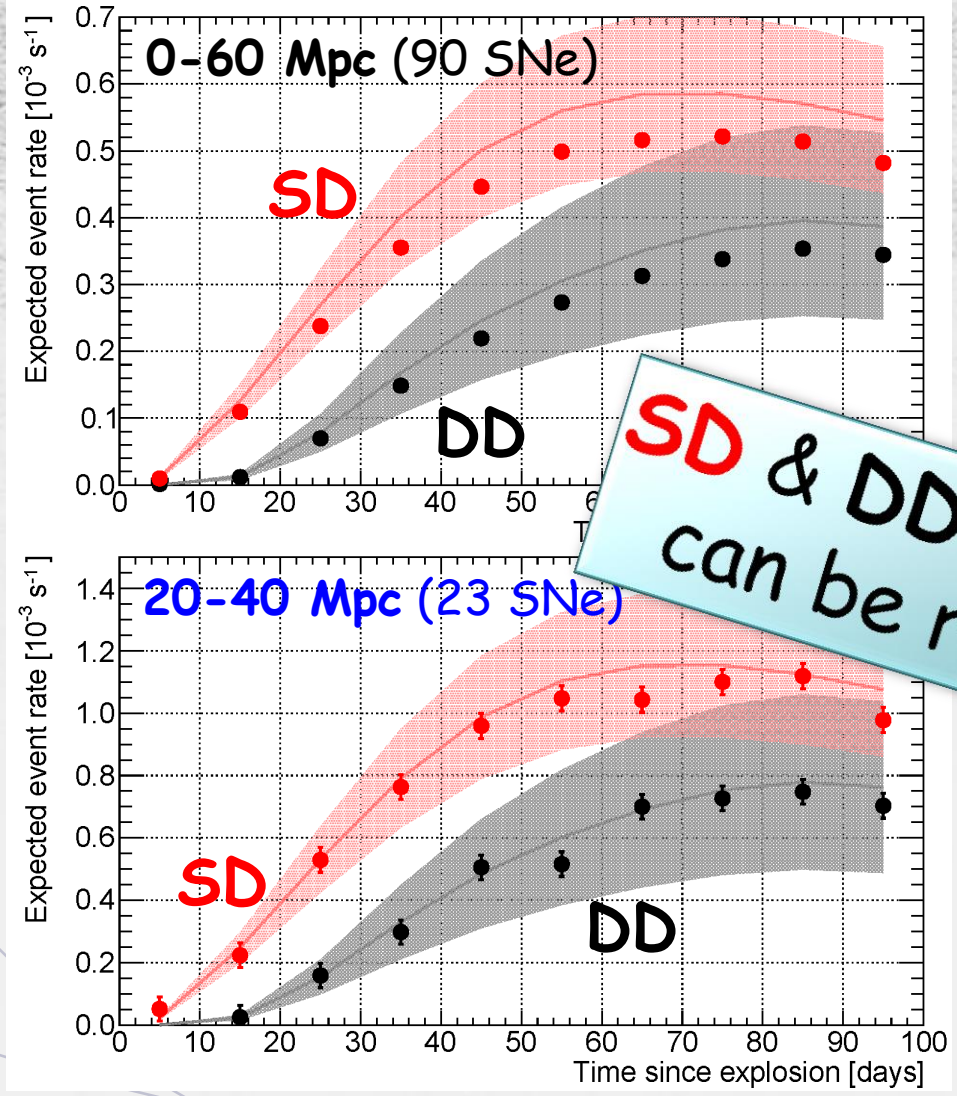
- **ARM** (**A**ngular **R**esolution **M**easure)
  Resolution of Compton scattering angle ϕ
- **SPD** (**S**catter **P**lane **D**eviation)
  Resolution of direction of Compton scattering plane
  --> Requires direction of recoil electron

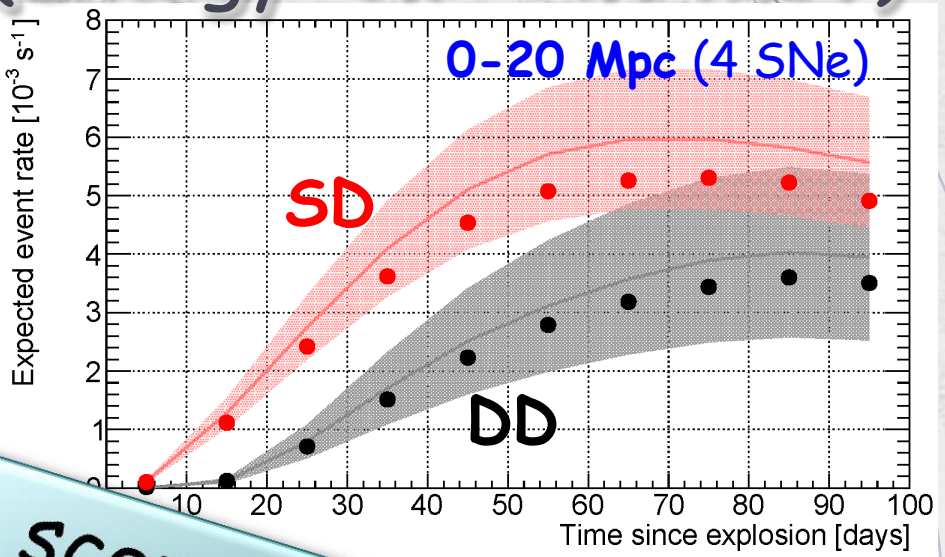


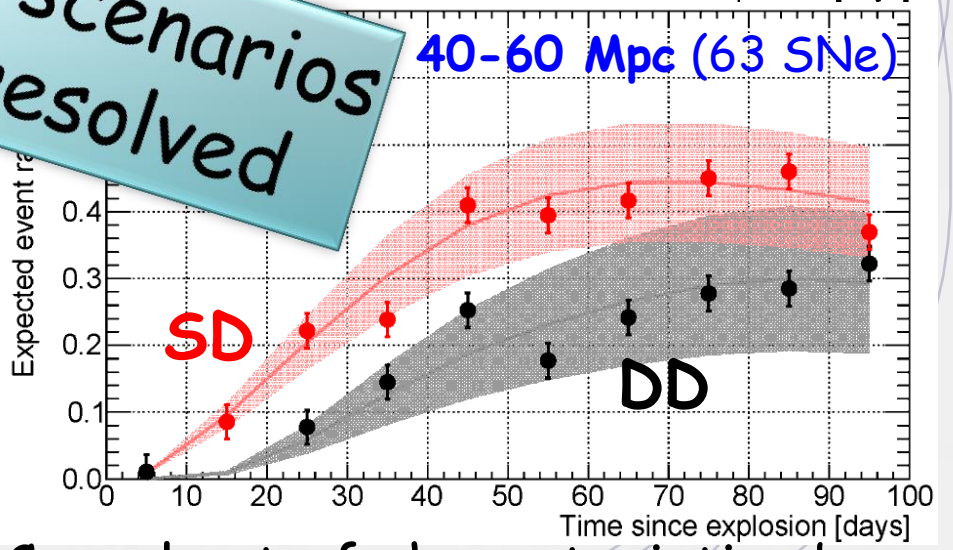
θ_{rms} of electron direction by multiple scattering in gas



Amassed Light Curves (Energy: 0.7—4.0 MeV)







SD & DD scenarios can be resolved

Ambiguities of near SNe Ia have significant weight.

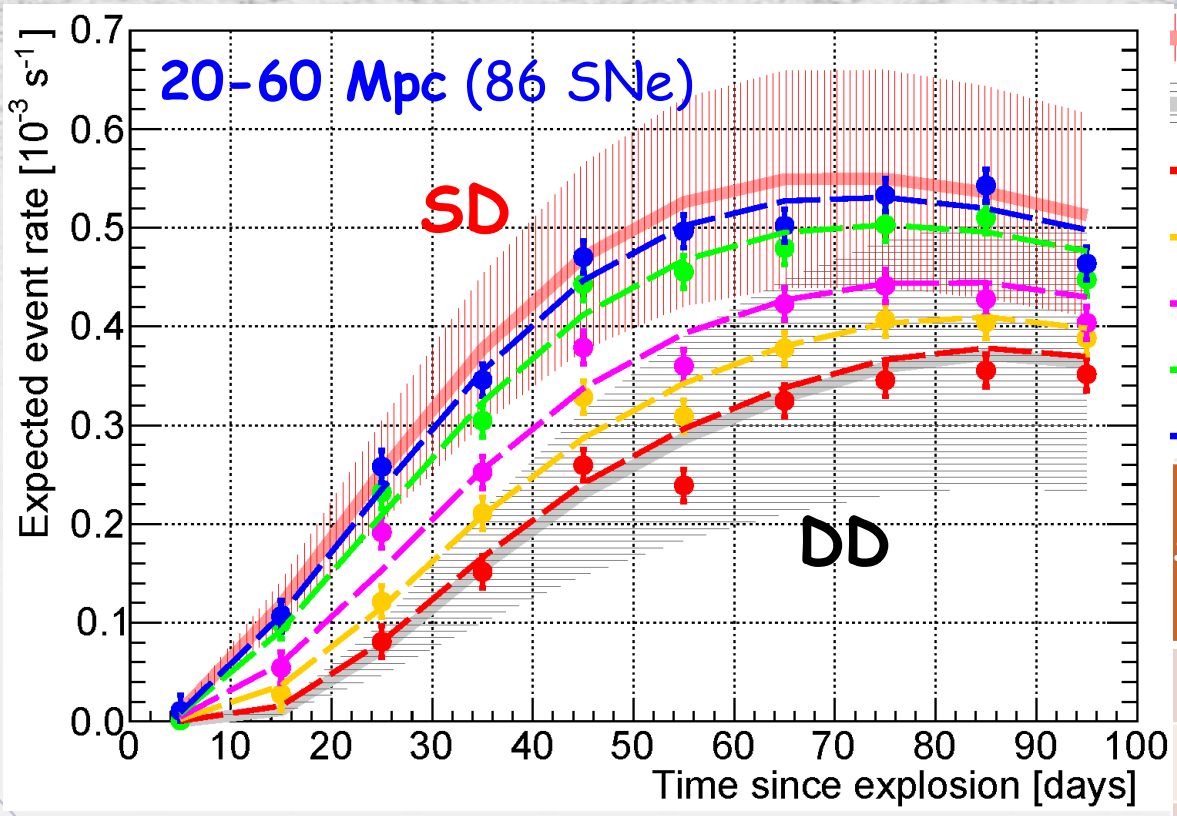
Cancel out of characteristics by large numbers of SNe is effective!!

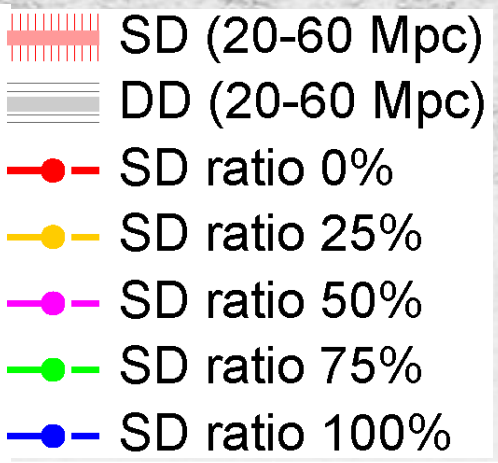
--> All-Sky Survey

(all light curves are scaled to a mean distance of SNe in each distance bin.)

Challenging work

Can we measure co-existence ratio of SD & DD scenarios?



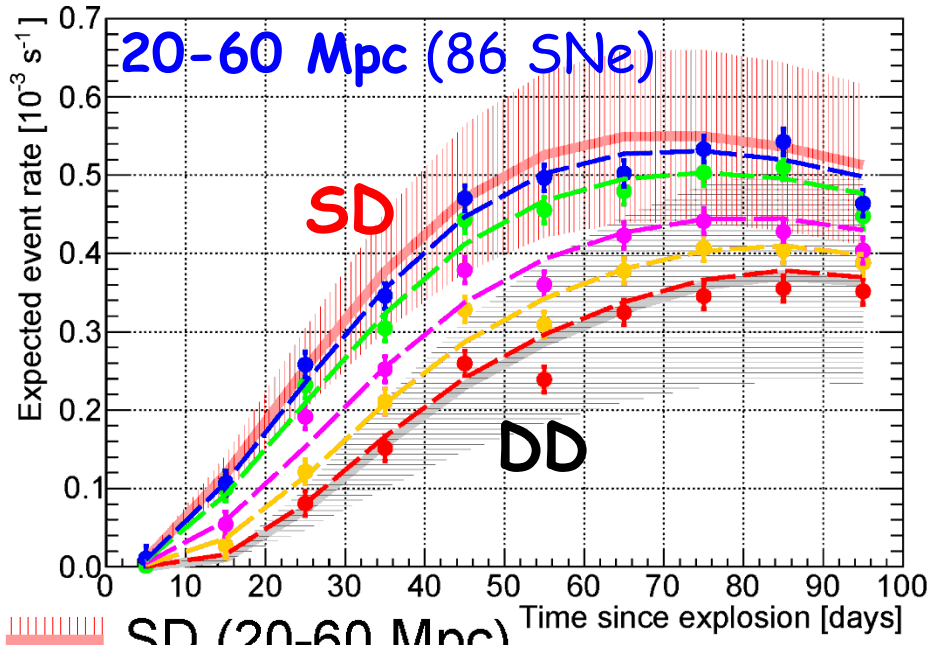


Generated # of SD, DD [SNe]	Generated SD ratio [%]	Best fitted SD ratio [%]
0, 86	0.0	4 ± 11
20, 66	23.3	23 ± 3
42, 44	48.8	44 ± 3
64, 22	74.4	76 ± 3
86, 0	100	90 ± 3

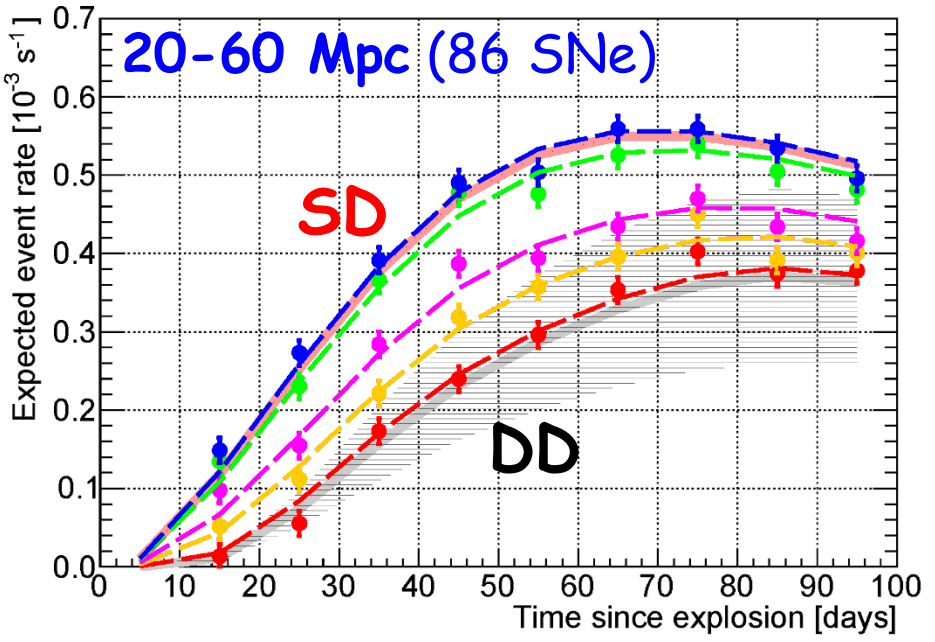
Satellite-ETCC might be able to obtain co-existence ratio with an accuracy of ~20%.

Can we resolve co-existence ratio of SD & DD scenarios?

With 20% ambiguity of ^{56}Ni



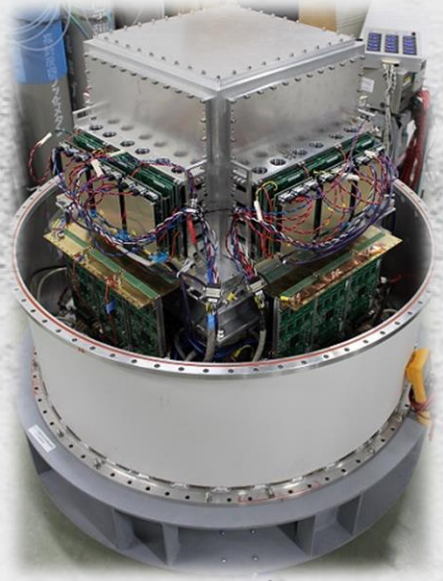
Without ambiguity of ^{56}Ni gens.

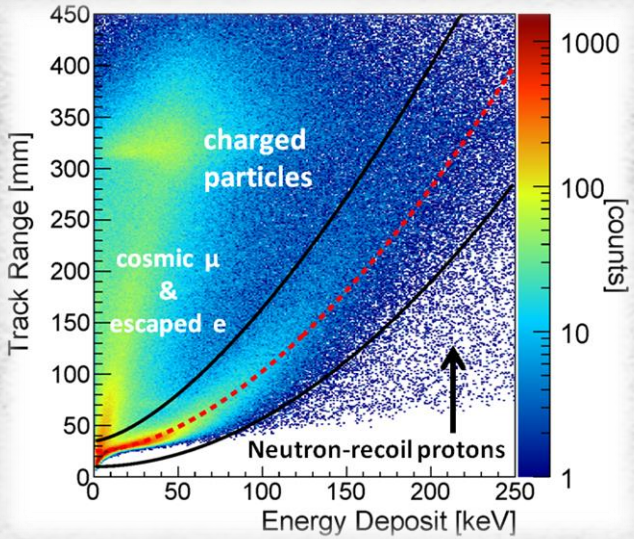


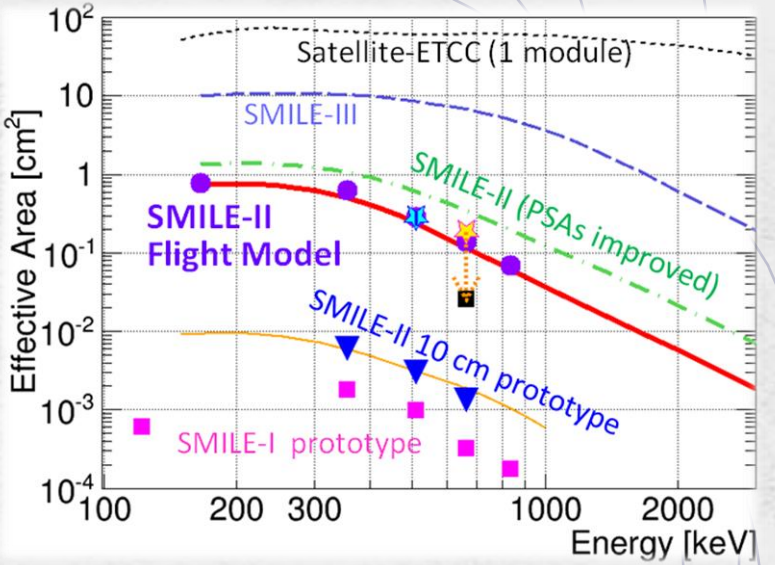
SD (20-60 Mpc)
DD (20-60 Mpc)
SD ratio 0%
SD ratio 25%
SD ratio 50%
SD ratio 75%
SD ratio 100%

Mass of generated ^{56}Ni can be estimated from observations of IR/optical band.

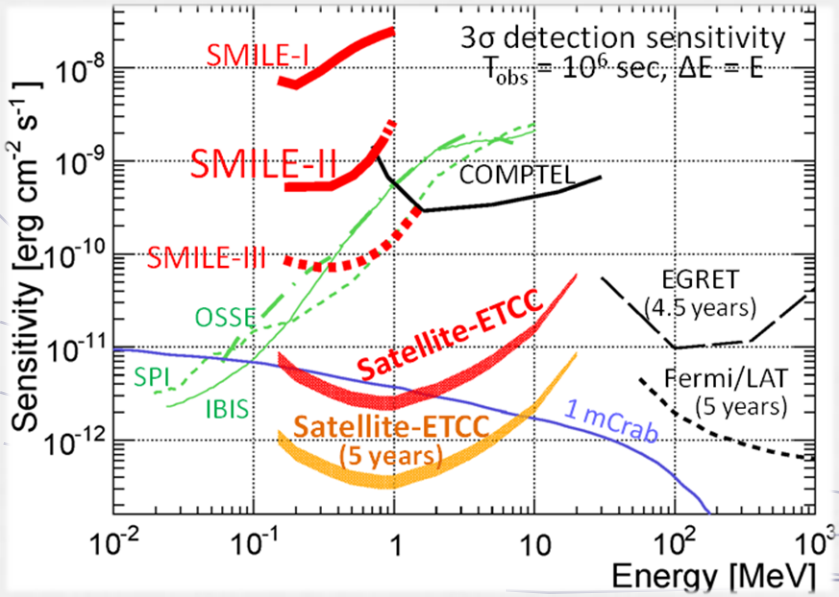
--> We can correct its ambiguities, if there is sufficient IR/optical data







Details of ETCC and its future prospects is submitted to ApJ (T. Tanimori+)



Please look forward to it!!

Satellite-ETCC would reach
2° PSF @ 1 MeV and
1 mCrab sensitivity in 10^6 sec

↓

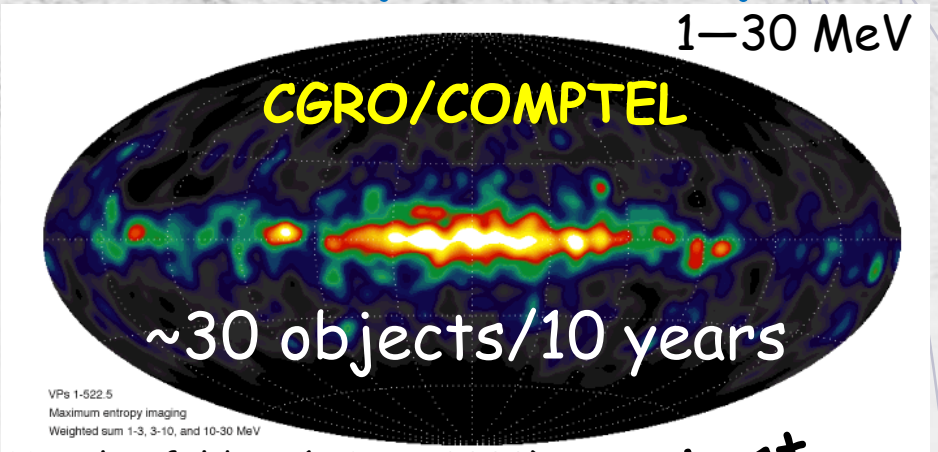
Amassed lightcurve of
SNe Ia @ 60 Mpc is obtainable

Sub-MeV/MeV gamma-ray astronomy

Treasure box of Interesting Science

- Nucleosynthesis
  SNR, Galactic plane
- Particle acceleration
  Relativistic Space Jet
- Strong gravitational potential
  Blackhole, accretion disk
- Evolution of the Universe
  Most-distant GRB
- Others
  Solar flare, Gamma-ray pulsar

All-sky MeV map



V. Schönfelder+ (A&AS, 2000)

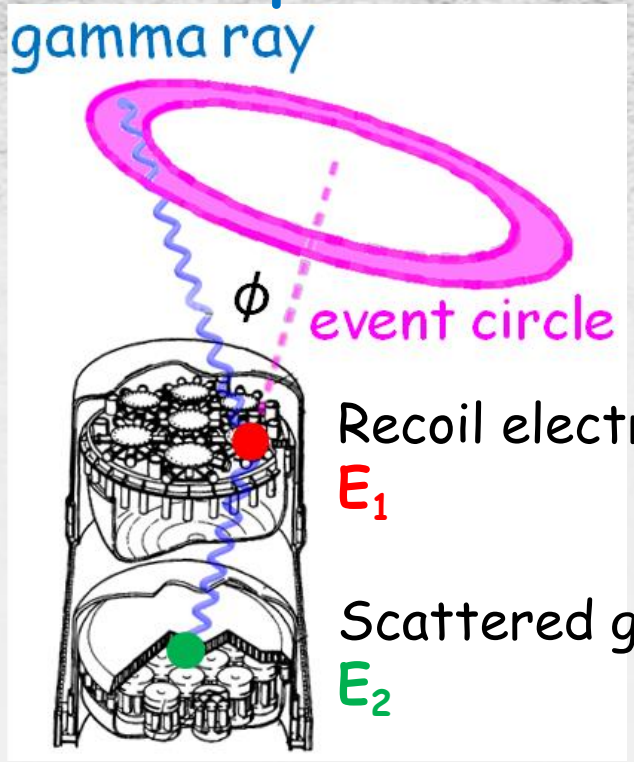
Unrevealed last wide window for Astronomy

Requirements for the next generation telescopes

- Large Field of View
- High quality image
- Wide-band detection

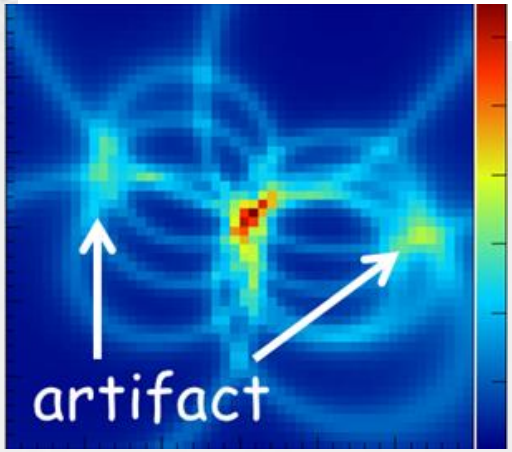
Difficulty of MeV gamma-ray imaging

Compton scattering dominates in MeV cross section



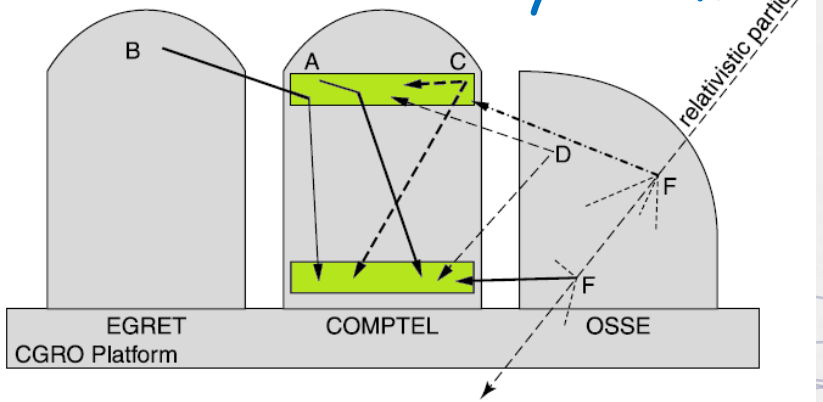
Principle of Compton Imager

$$\cos\phi = 1 - m_e c^2 \left(\frac{1}{E_2} - \frac{1}{E_1 + E_2} \right)$$



Unclearness
&
Artifacts

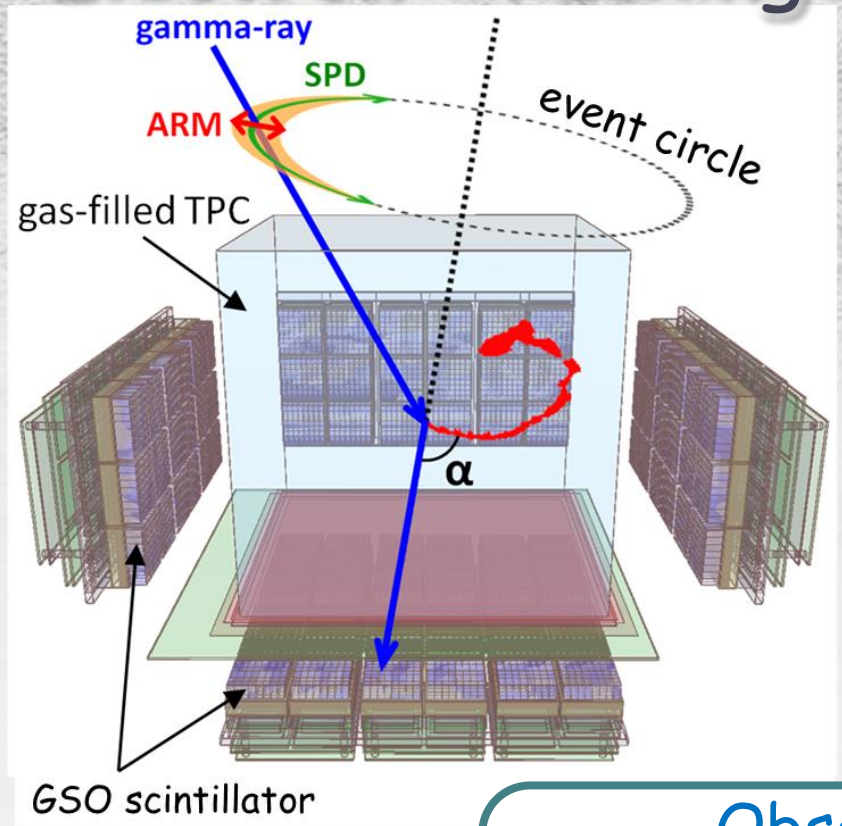
Radioactivation by cosmic rays -> Huge background in space

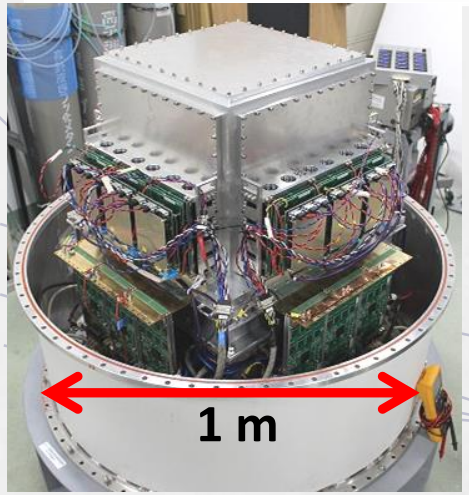


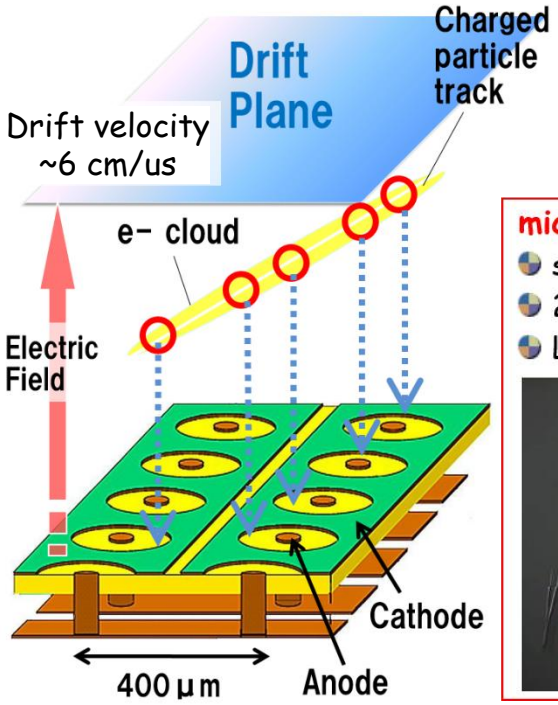
- Improvement of imaging
- Background suppression

are two big tasks in MeV

Electron-Tracking Compton Camera (ETCC)

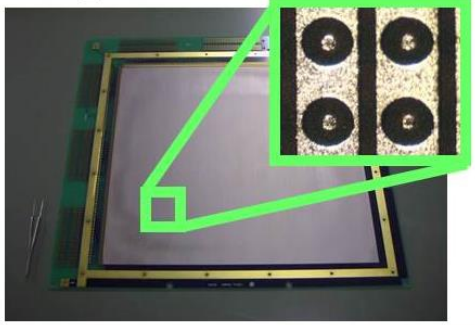




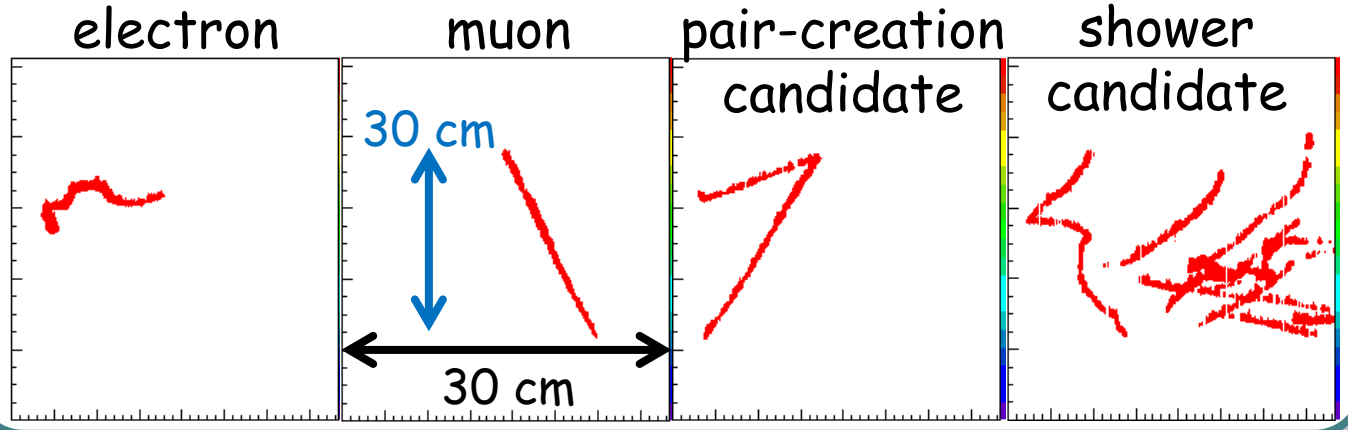


Ray-Tracer (Gas TPC)

micro PIxel Chamber(μ-PIC)
- sliced proportional chambers
- 2D readout (400 μm pitch)
- Large detection area : $(30cm)^2$



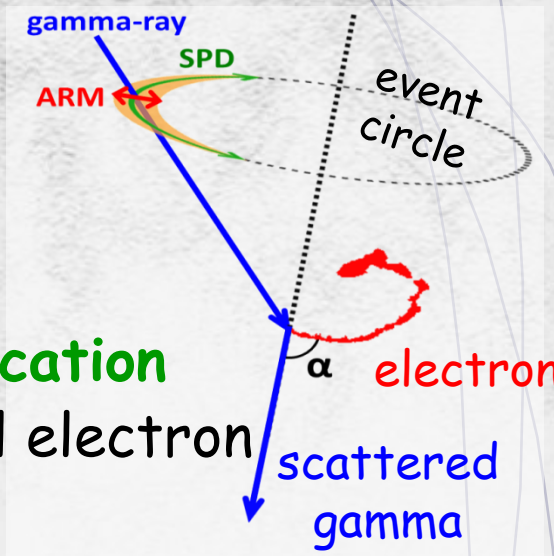
Observed typical tracks in TPC



Effectiveness of Ray-Tracing information

Three additional parameters

1. **SPD**, Direction of scattering plane
   - -> Event by event arrival direction
2. **dE/dx**, Energy deposit rate of particle
   - -> Background rejection by particle identification
3. **α**, Angle between scattered gamma and recoil electron
   - -> Background rejection by kinematics test



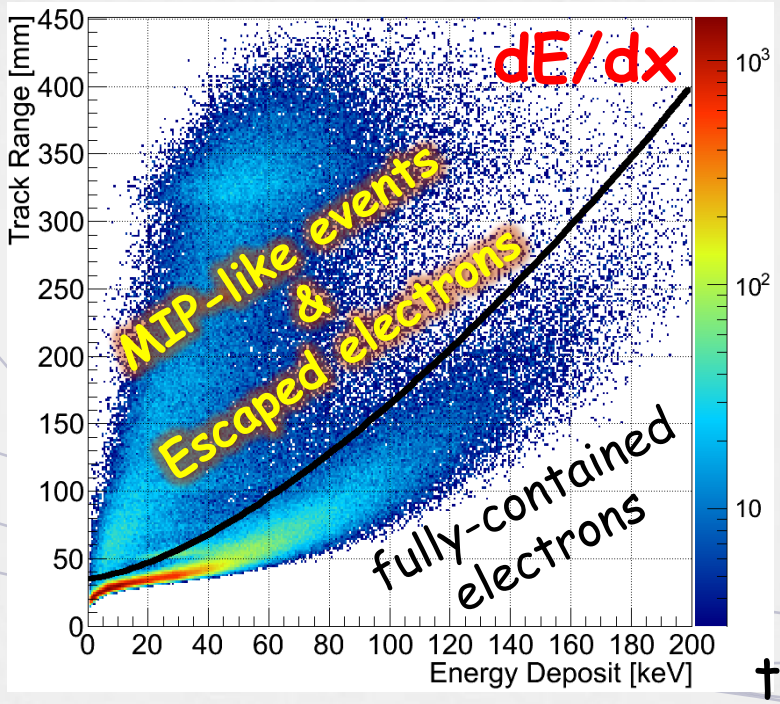
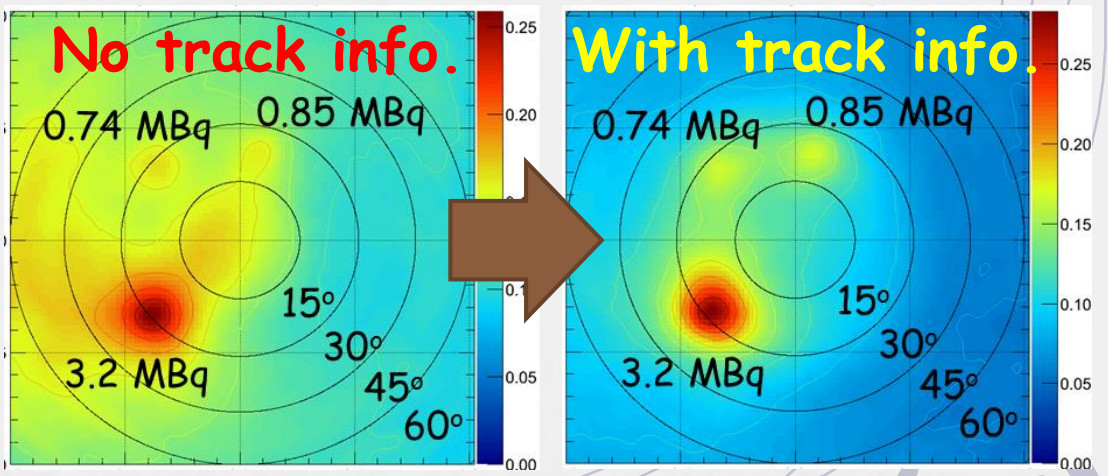


Image of three ^{137}Cs (662 keV) sources with/without ray tracing info.



Ray-Tracing info. enables us to detect the sources by **factor ~3 in significance**

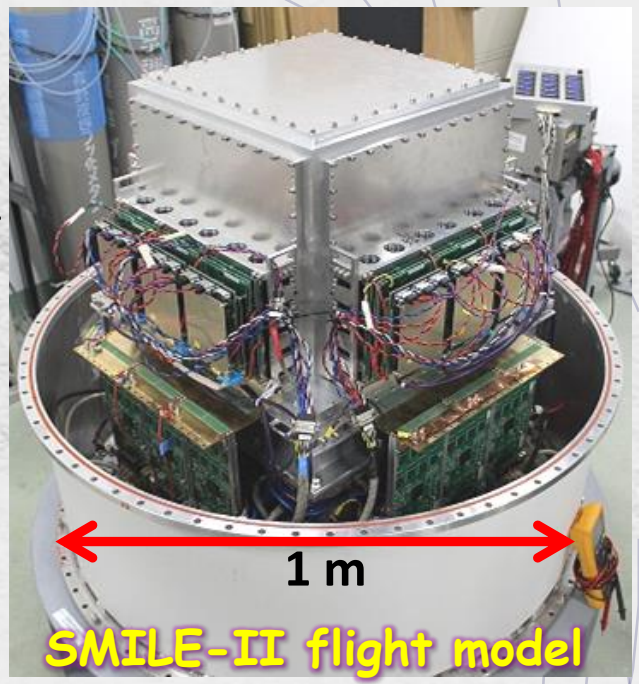
ETCC for 2nd balloon exp. (SMILE-II)

Sub-**M**eV gamma-ray **I**maging
Loaded-on-balloon **E**xperiment

Aim: **Confirmation as a sub-MeV telescope**

-> Imaging of Crab/Cyg X-1

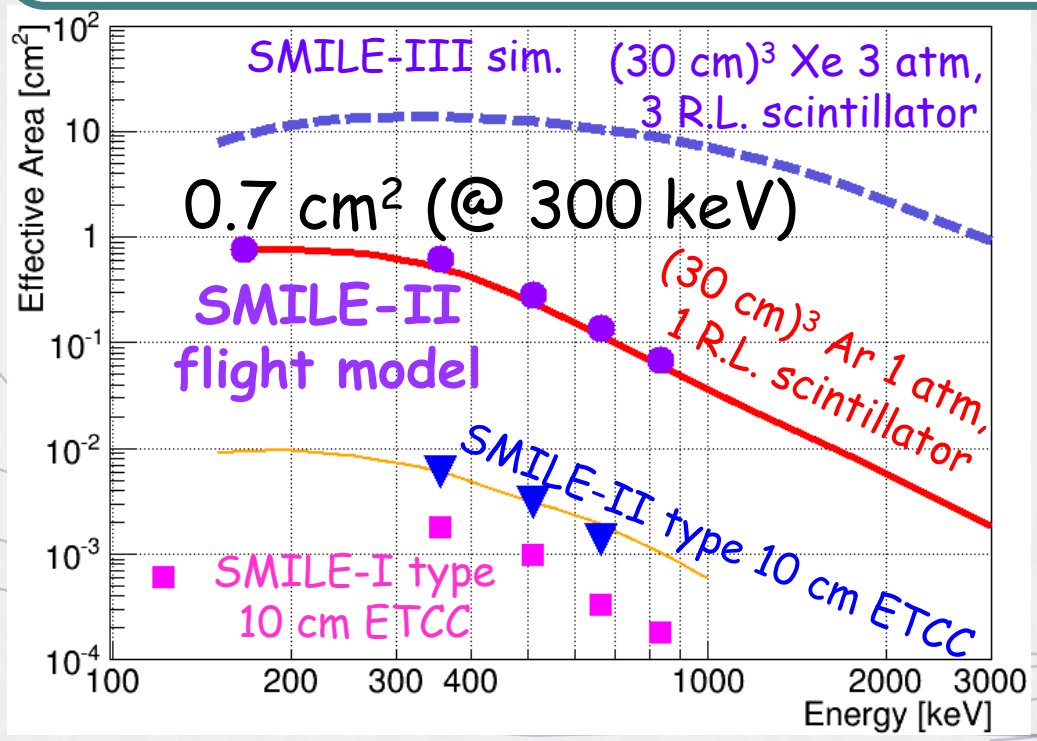
(>3σ detection, ~40 km, one-day flight)

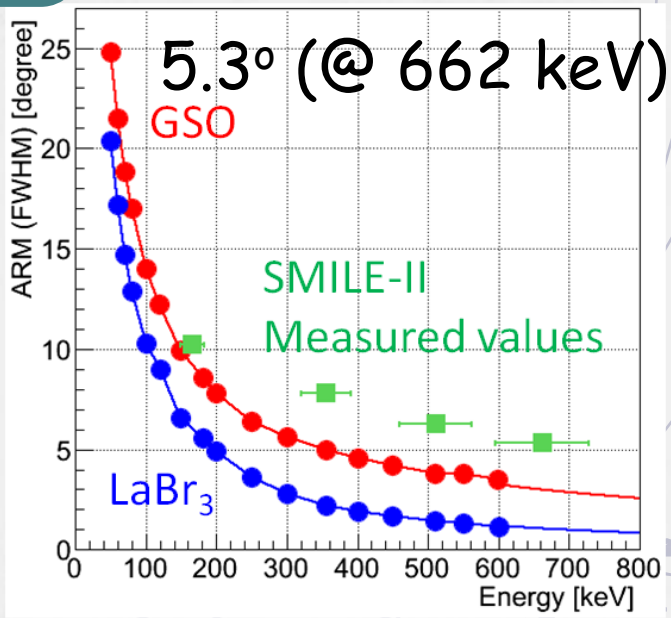


Required Performances

Effective area: >0.5 cm² (@300 keV)

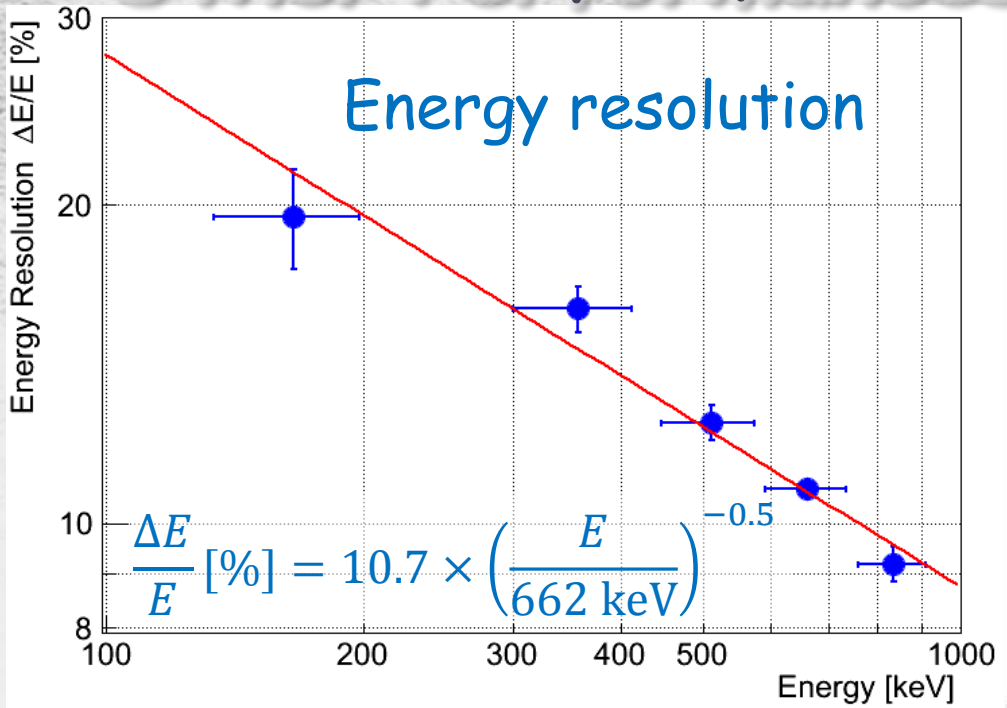
Angular resolution: <10° (@600 keV)

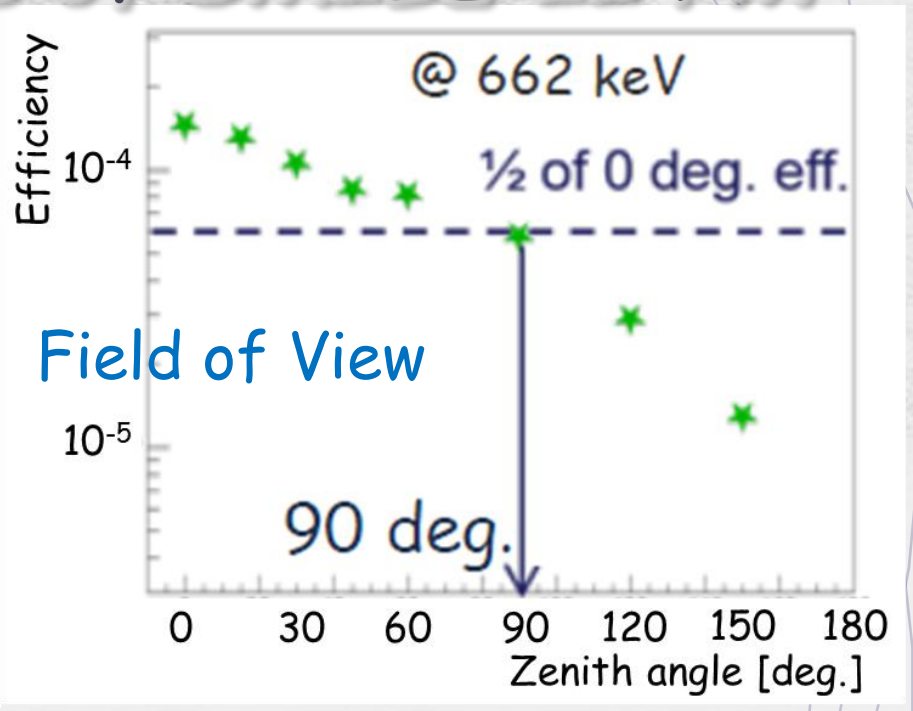




fullfil the requirements!!

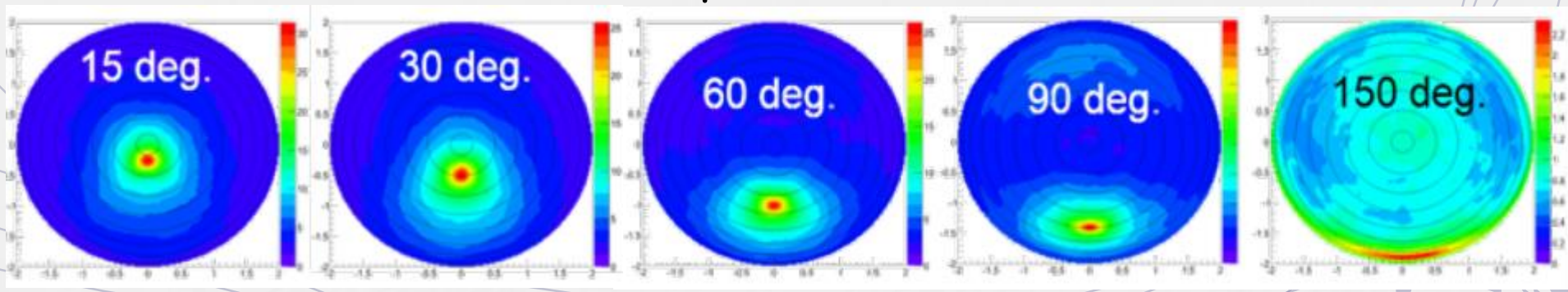
Other Performances of SMILE-II FM





Imaging check for large zenith angles

^{137}Cs (662 keV, 0.7 MBq) at 2 m distance from ETCC

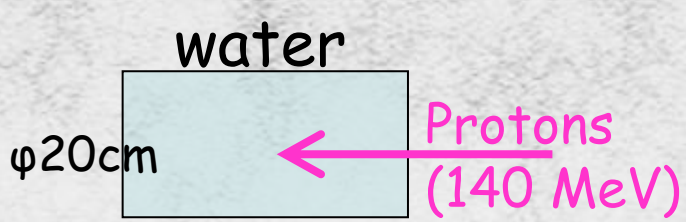


SMILE-II flight model ETCC has large FoV ~2π str

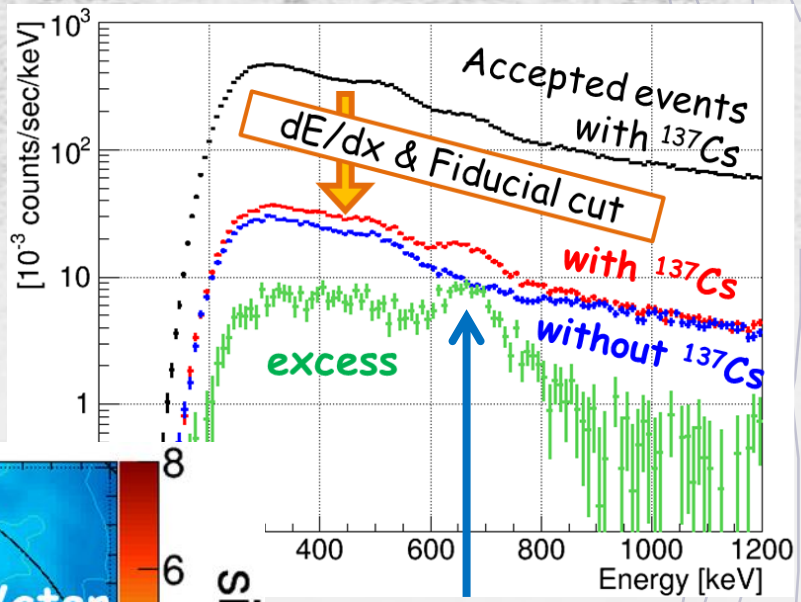
ETCC in intense radiation field

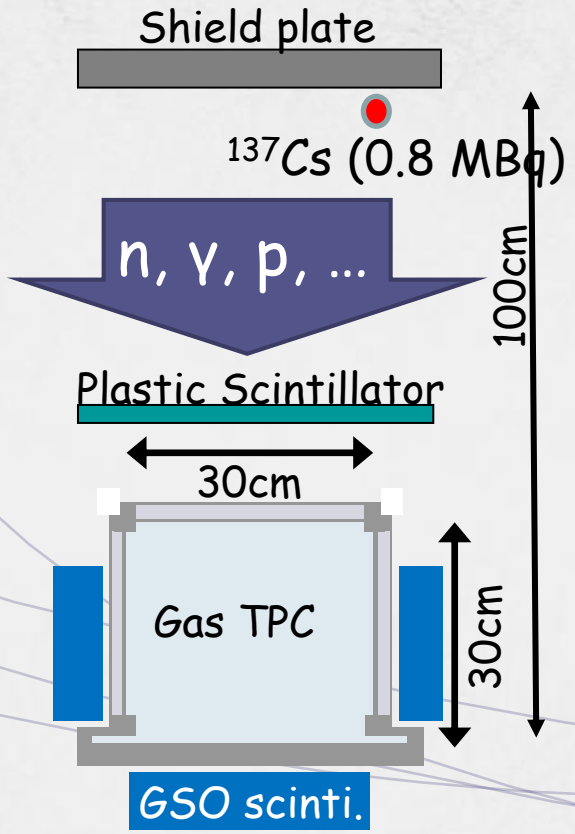
Balloon/Satellite altitude has intense background radiation

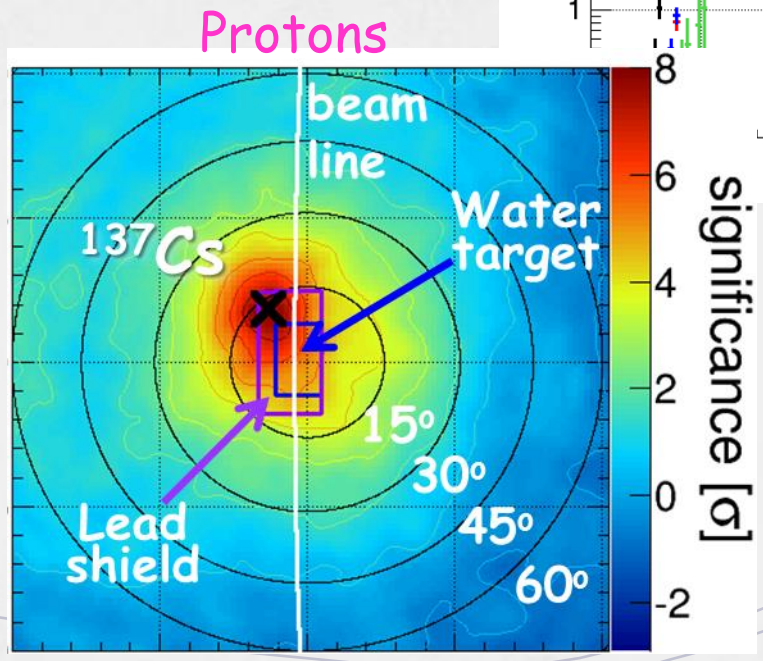
-> Can ETCC image a gamma-ray source in such field?



We generate factor ~5 more intense field than expected BG



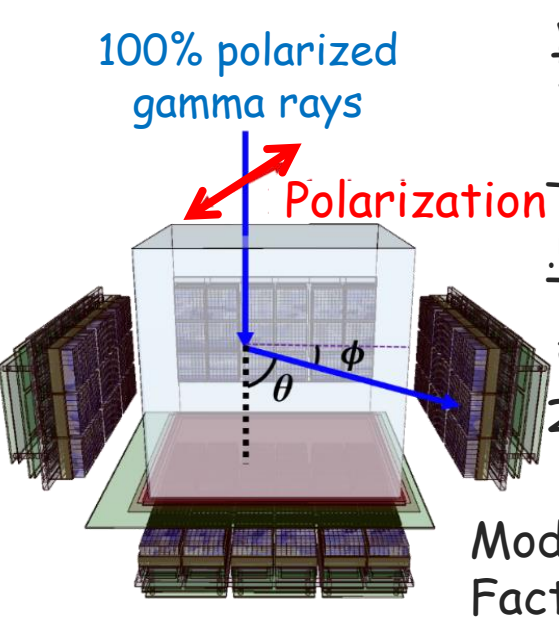


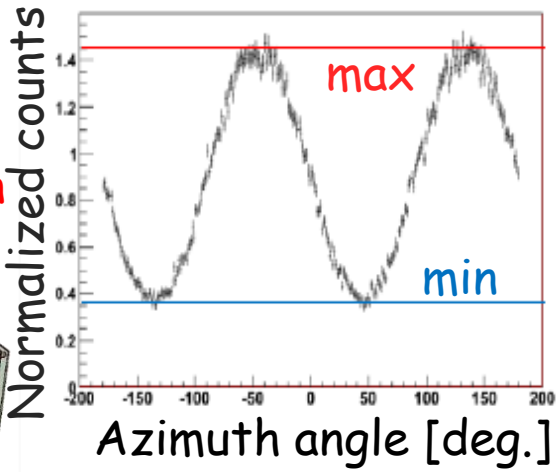


ETCC has imaging capability in intense BG

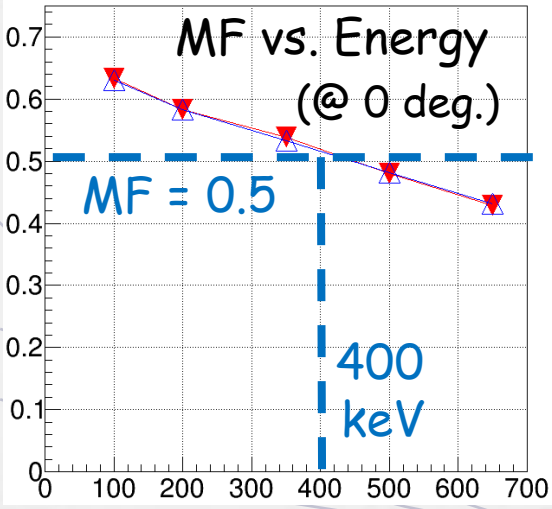
ETCC as a gamma-ray polarimeter

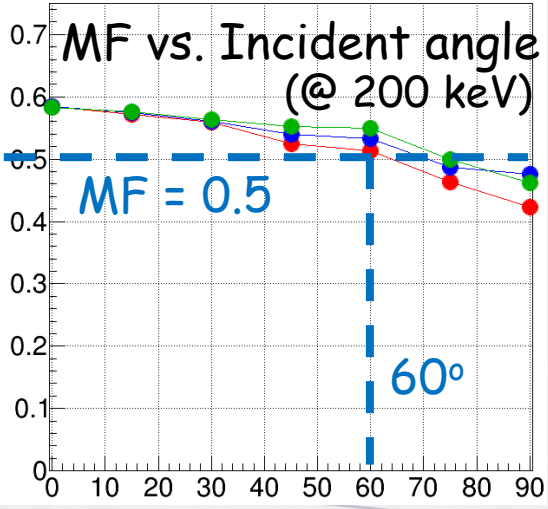
Simulation



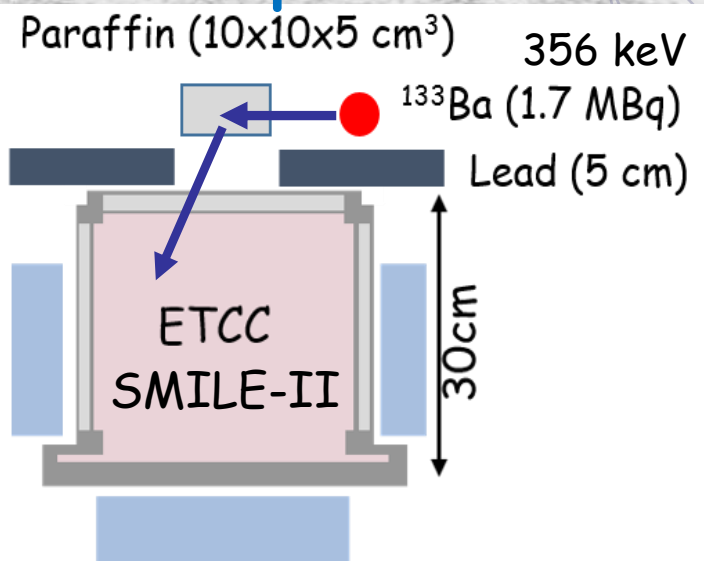


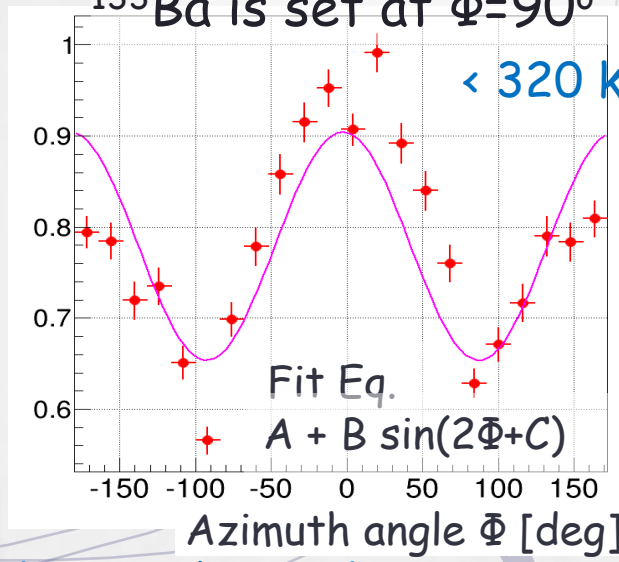
$$\text{Modulation Factor (MF)} = \frac{max - min}{max + min}$$





Experiment





ETCC has large MF which can detect low S/N polarization

Summary of Current ETCC (SMILE-II)

- Electron-tracking info. brings big benefits for Compton imager
  - High quality/contrast imaging (**SPD**)
  - Efficient background rejection (**dE/dx**, **α**)
- SMILE-II ETCC fulfills the requirement performances
  - Effective area: **0.7 cm^2** (@ 300 keV)
  - Angular resolution: **5.3 deg.** (@ 662 keV, ARM FWHM)
  - Energy resolution: **10.7% x $(E/662\ keV)^{-0.5}$**
  - Wide Field of View: **~2π str** (@662 keV)
- Imaging capability in intense radiation field
- As a background-suppressed imaging polarimeter
  - Modulation Factor: **>0.5** (E < 400 keV, Zenith angle < 60°)

SMILE-II ETCC can detect Crab (>3σ, several hours)

Negotiation with NASA/GSFC for balloon flight(s) @ fort sumner is ongoing