Massive Argon Space Telescope (MAST): heavy time projection chamber as a next-generation space gamma-ray observatory

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The presentation is based on our paper

Timur Dzhatdoev, Egor Podlesnyi (2019). *Massive Argon Space Telescope (MAST): a concept of heavy time projection chamber for gamma-ray astronomy in the 100 MeV – 1 TeV energy range*, Astropart. Phys., 112, 1–7

https://arxiv.org/abs/1902.01491
https://doi.org/10.1016/j.astropartphys.2019.04.004

The earliest papers on the topic of time projection chambers:

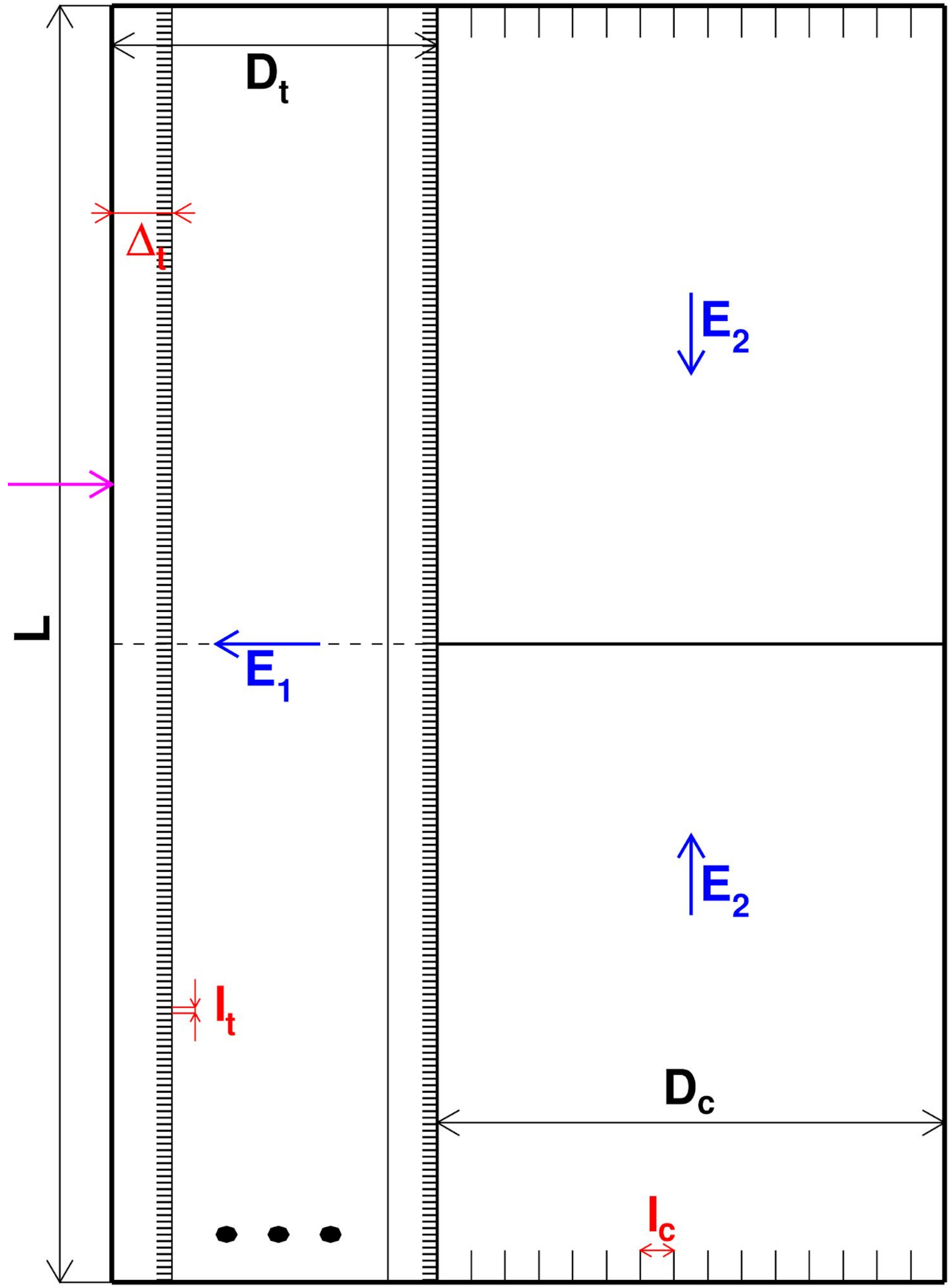
- Two-phase time projection chamber (TPC): Dolgoshein et al. (1970)
- General discussion of the TPC concept: Nygren (1974)
- Liquid Argon TPC: Rubbia (1977)

The state of the art: ICARUS T 600 (600 t of liquid argon): Rubbia et al. (2011) and see also the talk by Luca Grandi about application of TPC in the dark matter search

Projects of argon gamma-ray space telescopes

1. **AdEPT** (Advanced Energetic Pair Telescope) - polarimetry in the energy range 5-200 MeV (gas) (S. D. Hunter et al., Astropart. Phys. 59 (2014) 18–28)
2. **HARPO** (Hermetic ARgon Polarimeter) - polarimetry in the energy range 3-100 MeV (gas) (P. Gros et al., Astropart. Phys. 97 (2018) 10–18)
3. Theoretical investigation of the application of noble gases for gamma-ray astronomy was carried out by D. Bernard, NIM A 701 (2013) 225–230

Unlike these projects the **MAST** instrument is aimed at the high energy range (100 MeV - 1 TeV) although it does not provide measurements of polarisation.



$$
\begin{aligned}
M &= 36\,\mathrm{t} \\
L &= 400\,\mathrm{cm} \\
D_c &= 110\,\mathrm{cm} \\
D_t &= 50\,\mathrm{cm} \\
\Delta_t &= 1\,\mathrm{cm} \\
\mathrm{l}_t &= 0.1\,\mathrm{mm} \\
\mathrm{l}_c &= 1\,\mathrm{mm} \\
E_t &= 3\,\mathrm{kV}/\mathrm{cm} \\
E_c &= 500\,\mathrm{V}/\mathrm{cm}
\end{aligned}
$$

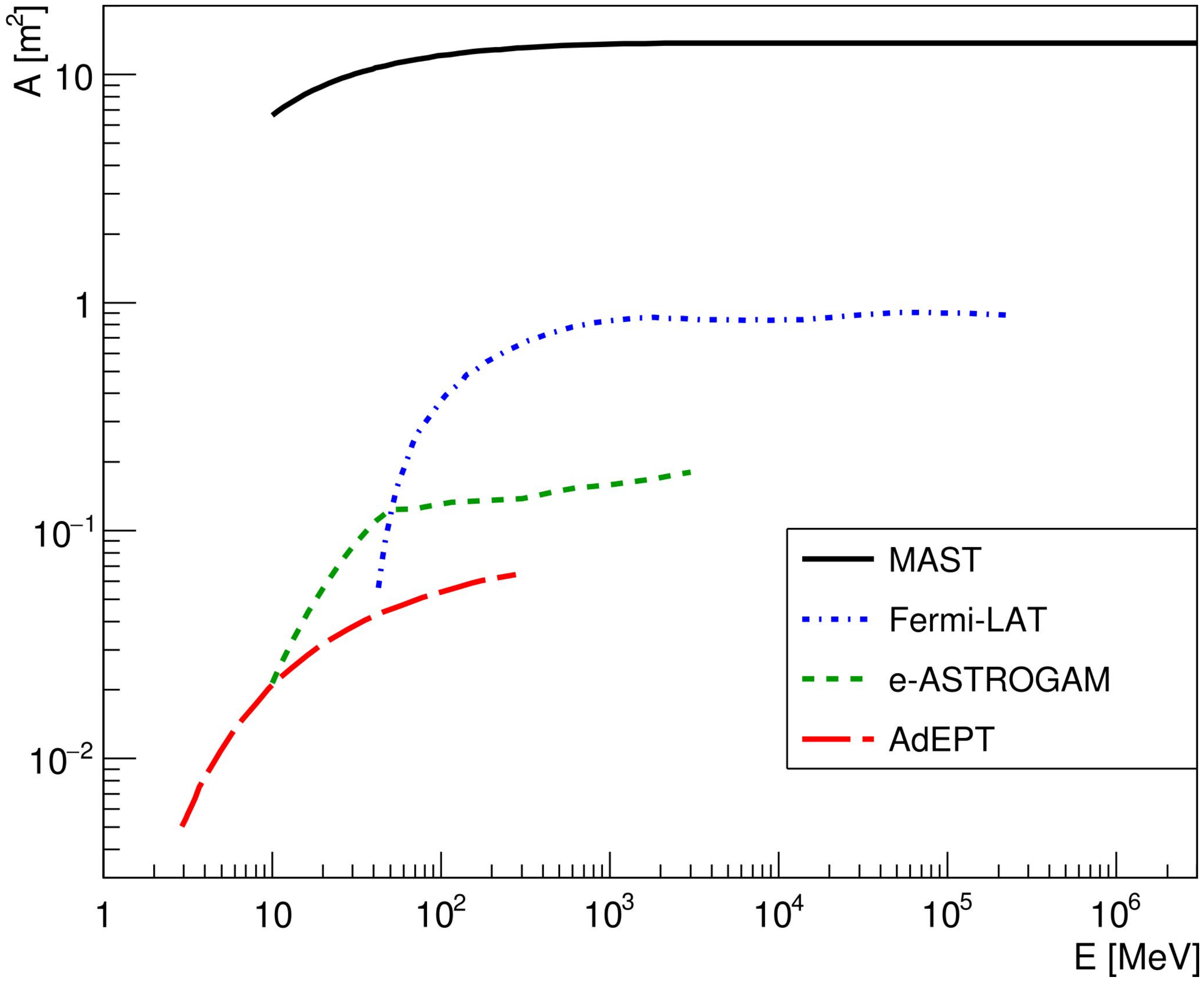
MAST is supposed to be launched by a rocket such as *Falcon Heavy*

The most important components of the performance of a gamma-ray space telescope

1. Effective area
2. Angular resolution
3. Energy resolution
4. Differential sensitivity

Effective area

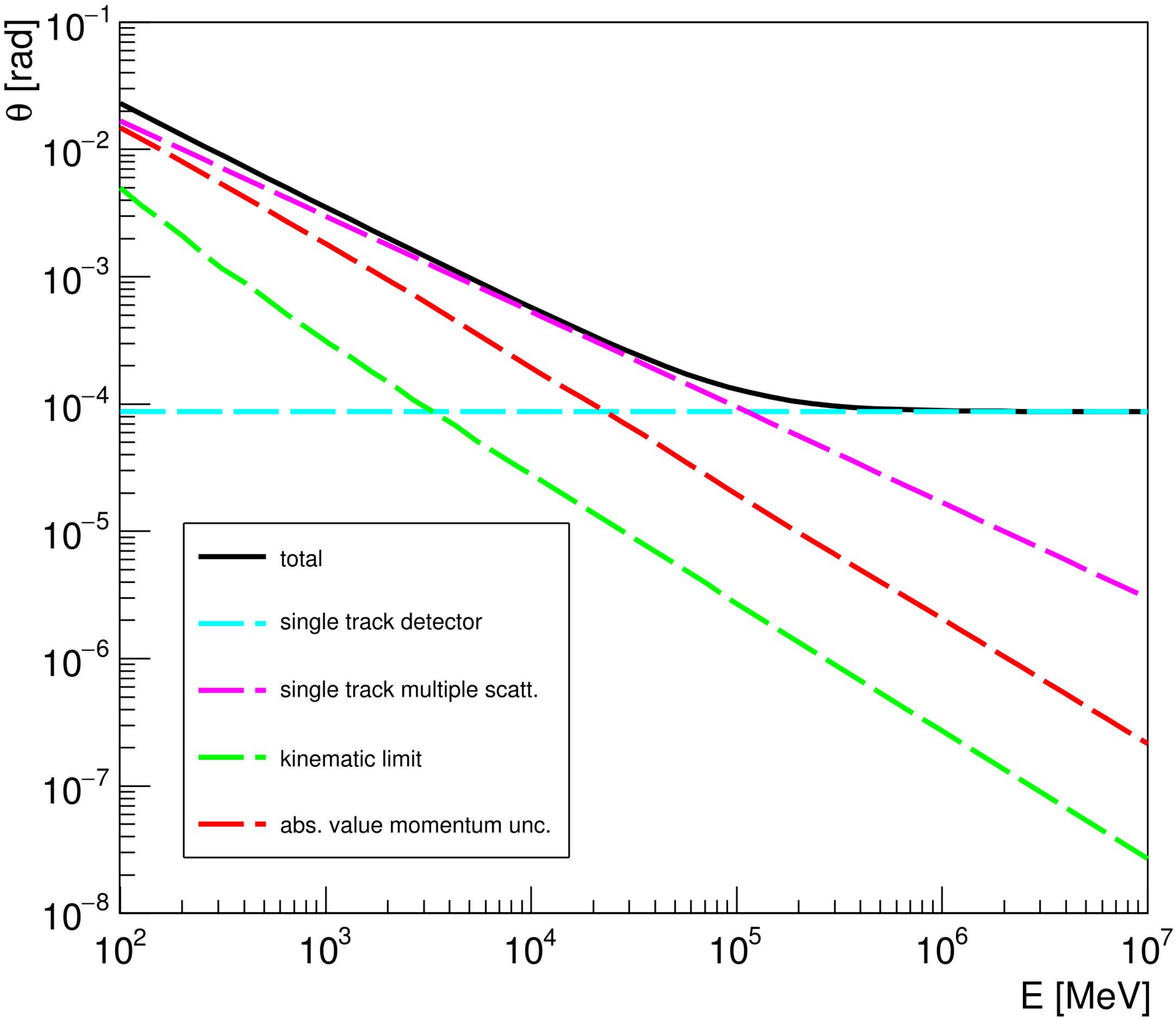
$$A(E) = L^2 \left[1 - exp(-\sigma_p(E) n(D_t - X_0))\right]$$



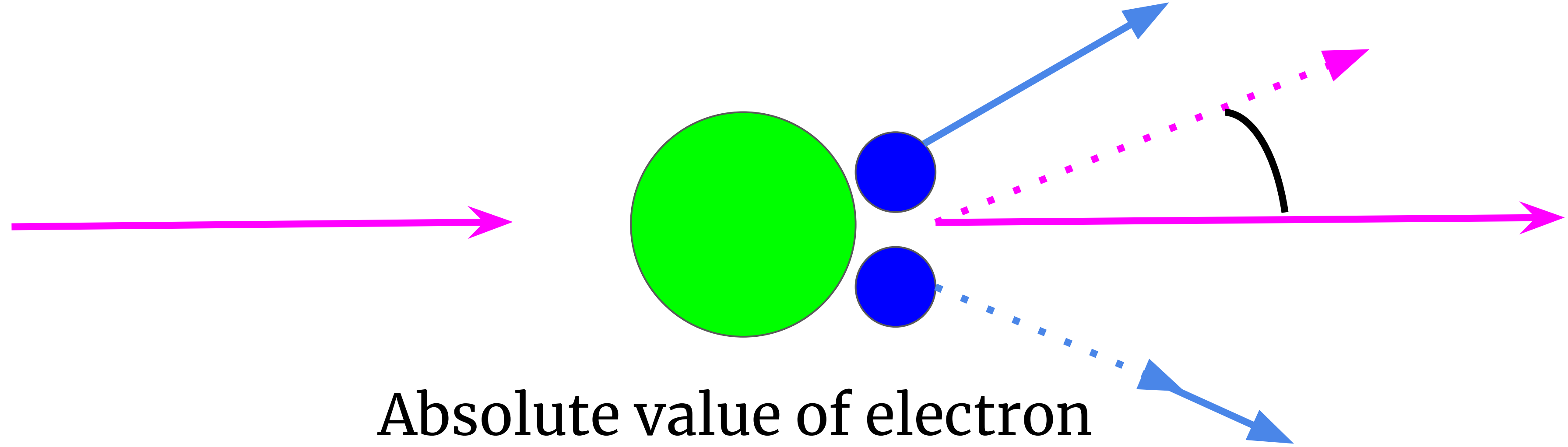
Effective area

Angular resolution

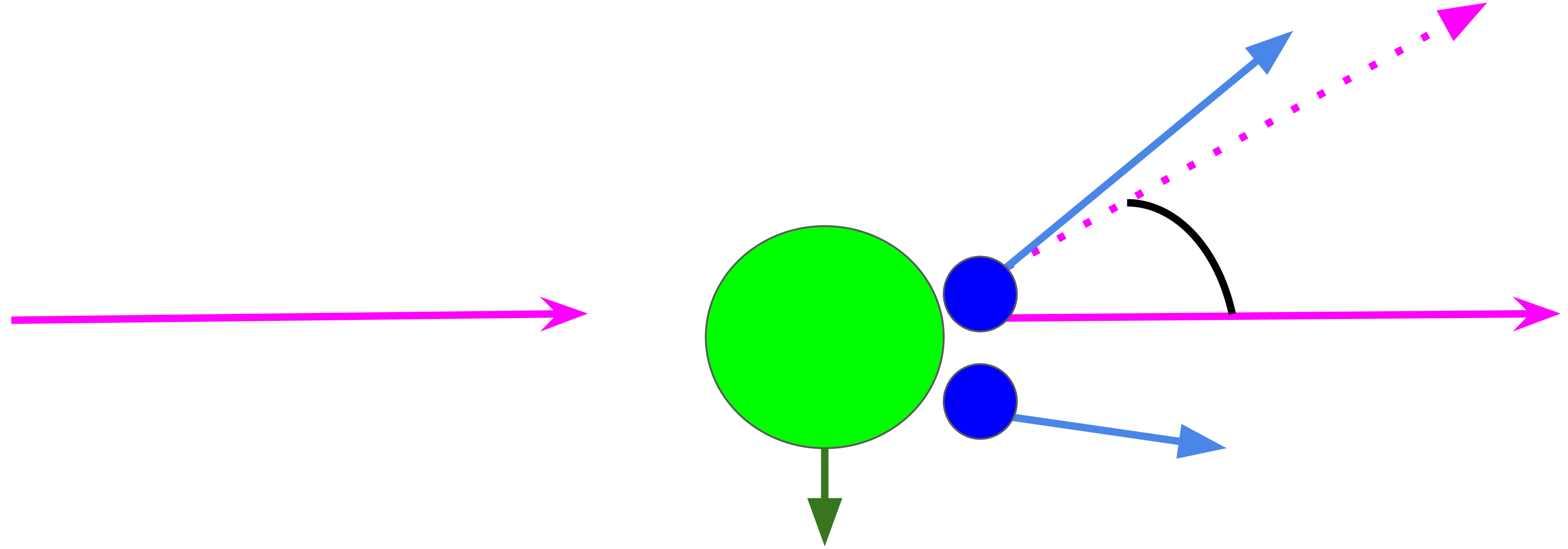
$$\sigma_\theta = \sqrt{\sum_{i=1}^{4} \sigma_{\theta i}^2}$$



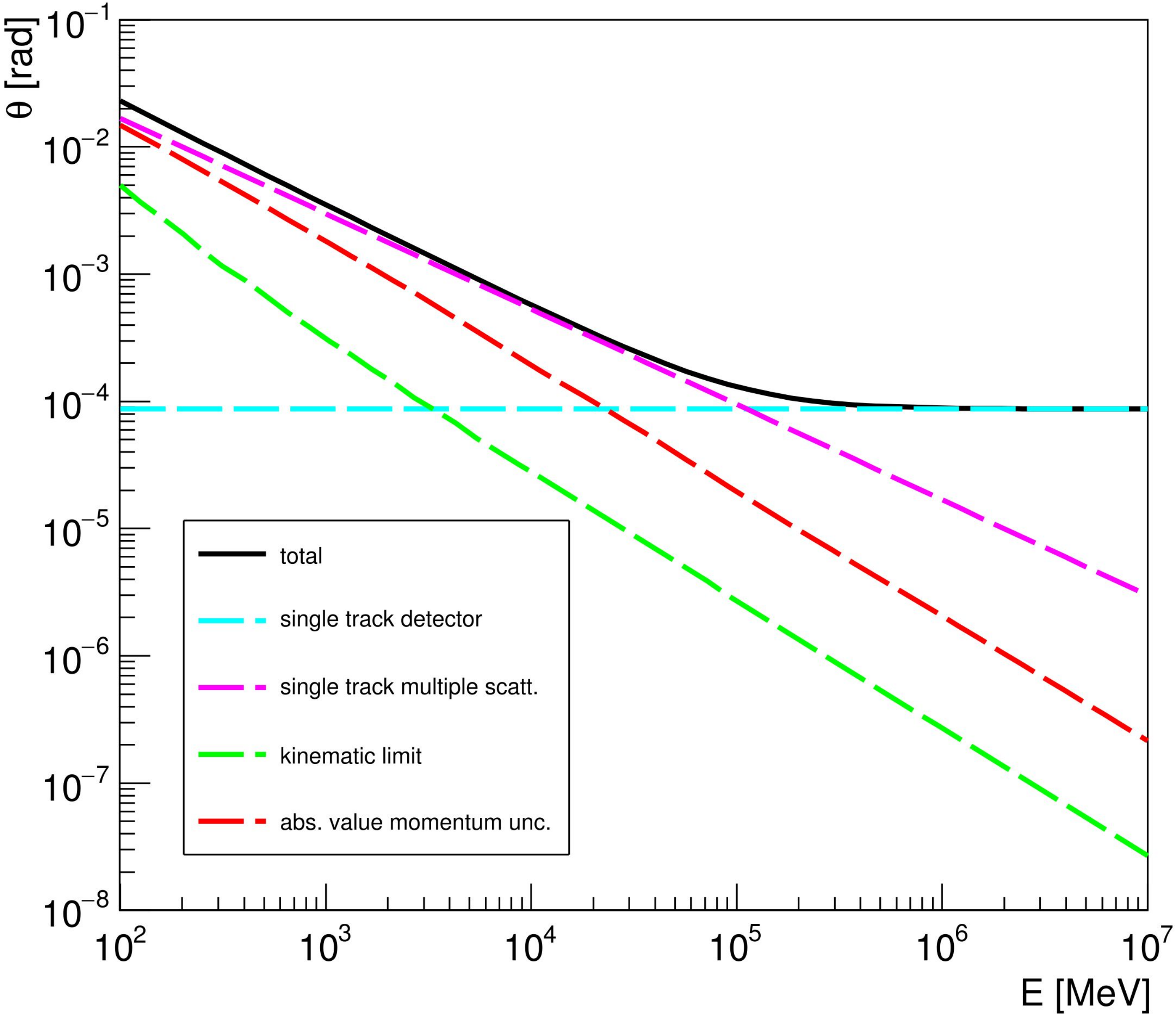
Components of the MAST angular resolution



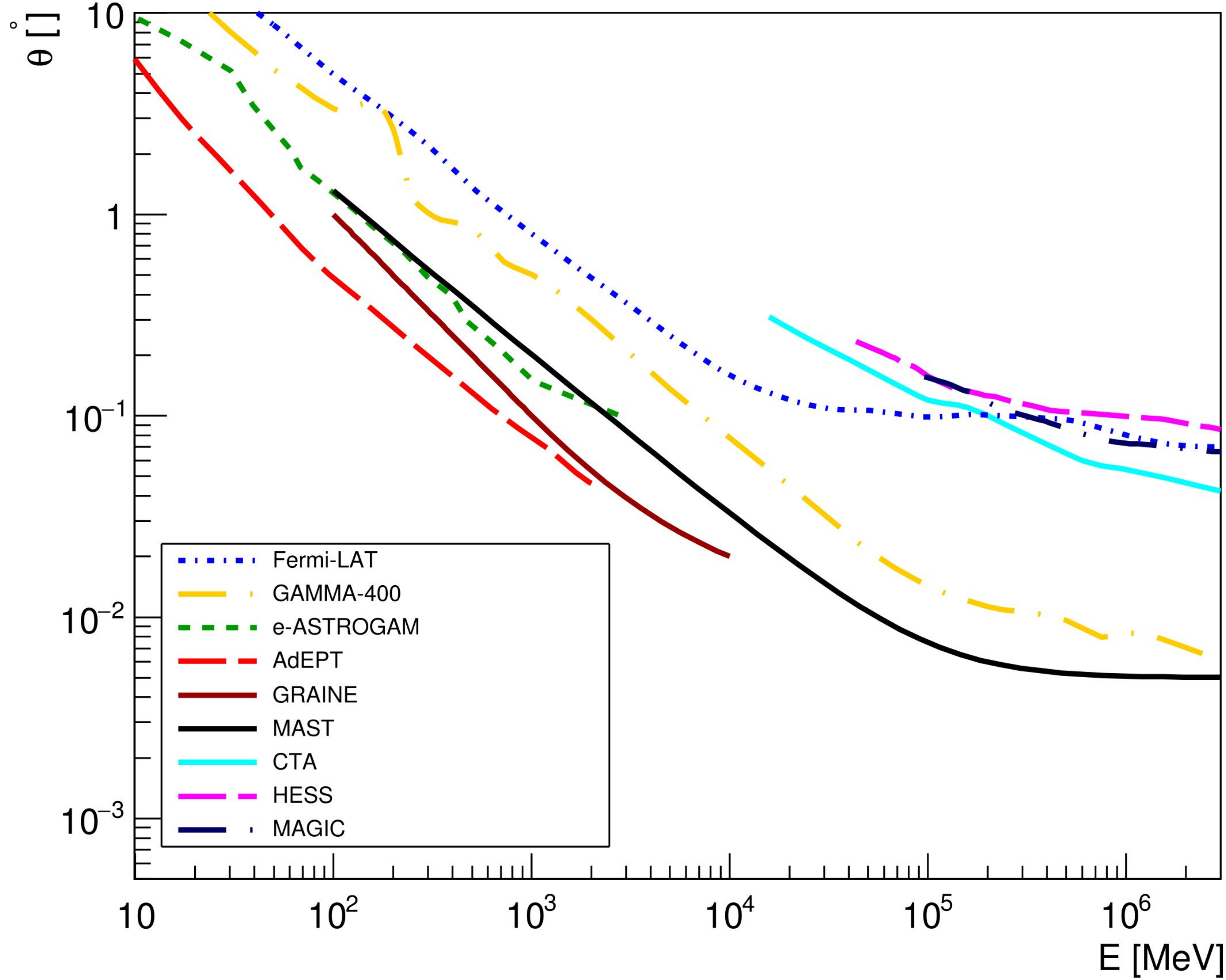
Absolute value of electron momentum uncertainty



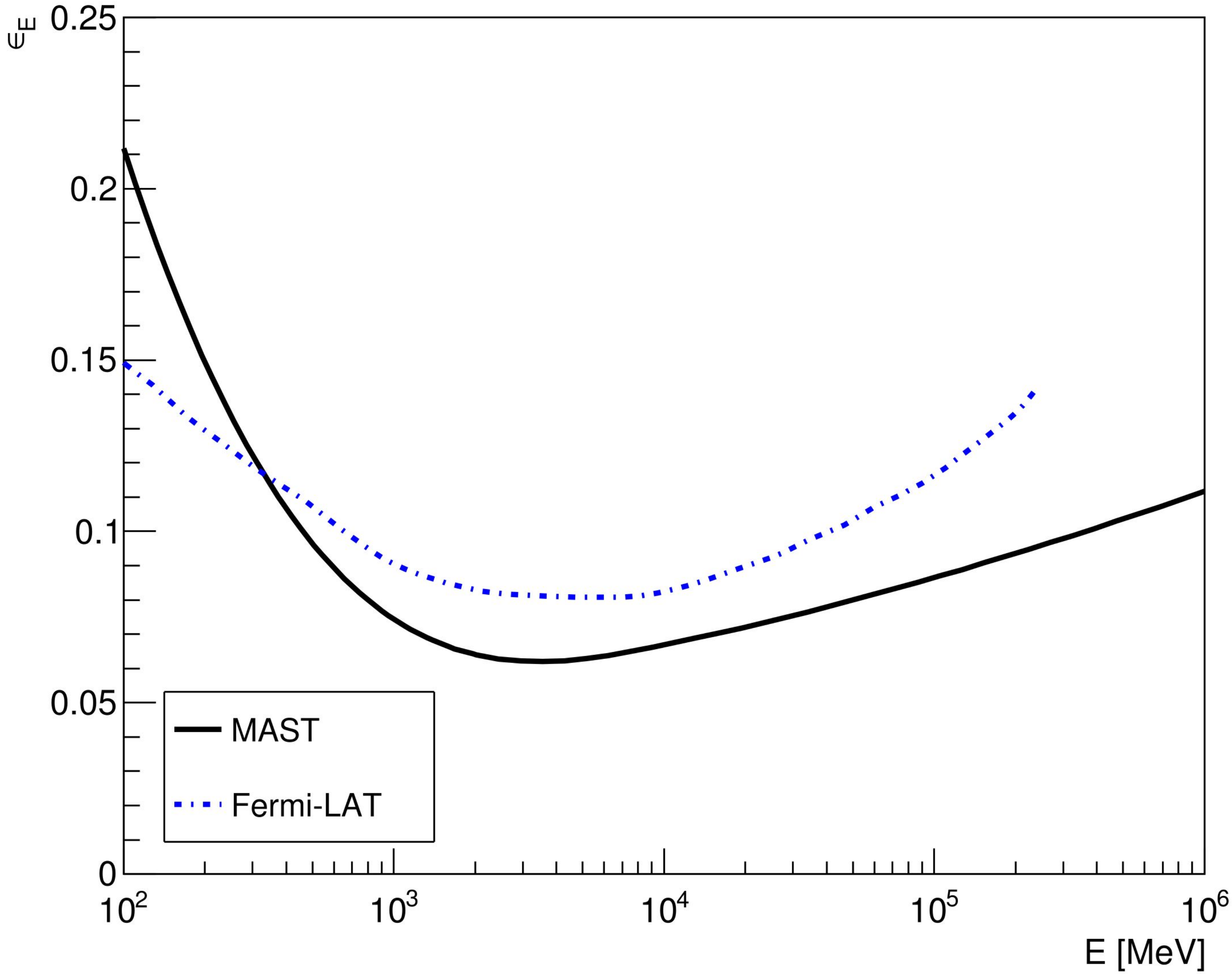
Kinematic limit
(unknown momentum of the recoil nucleus)



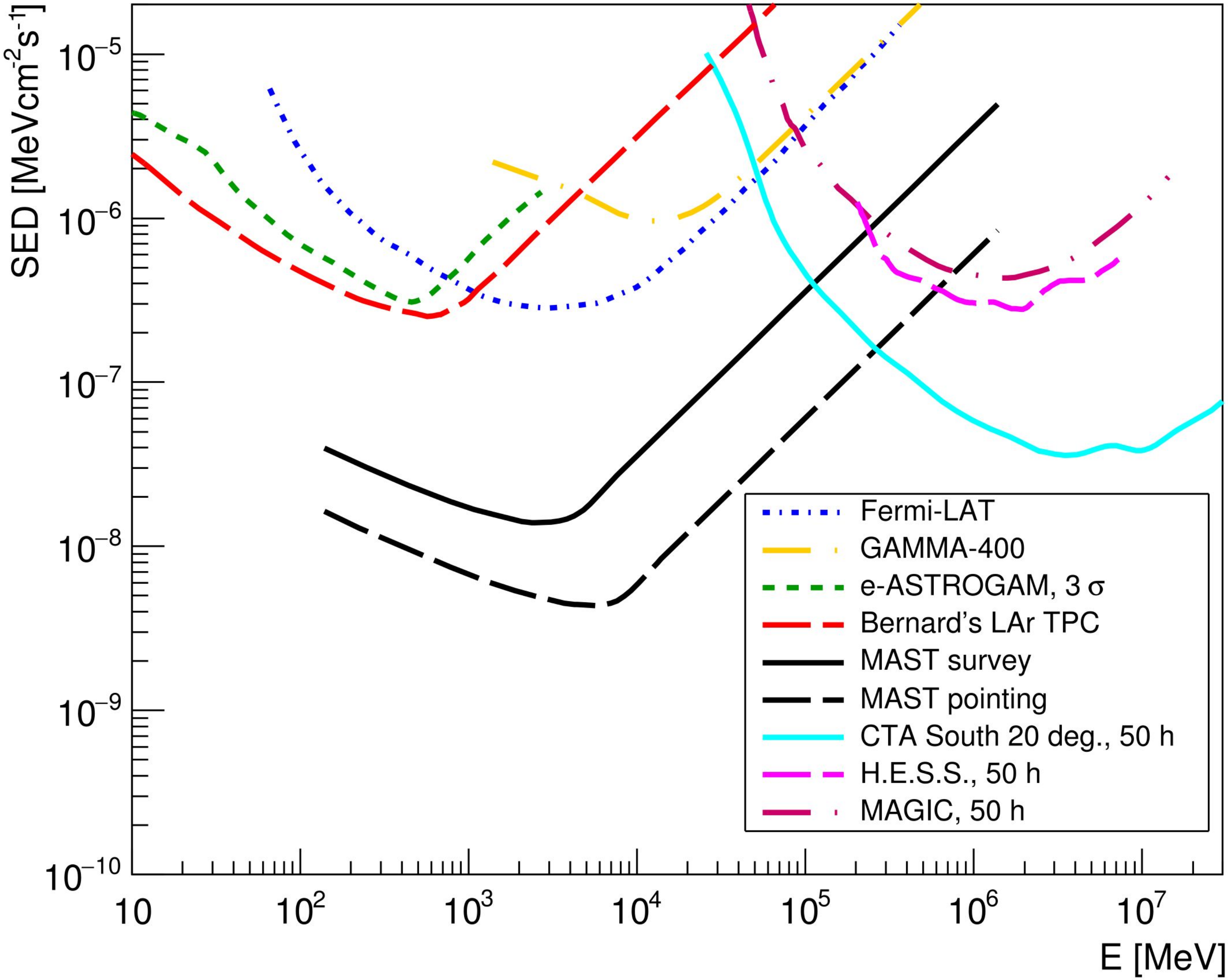
Components of the MAST angular resolution



The MAST angular resolution in comparison with other instruments



Energy resolution



Differential sensitivity

Conclusions

- The MAST instrument would have:
  1. one order of magnitude greater effective area than Fermi-LAT has
  2. 3-10 times better angular resolution than Fermi-LAT has
  3. more than one order of magnitude better differential sensitivity than Fermi-LAT has
  4. energy resolution similar to Fermi-LAT's one

- The project would provide an effective connection between ground based and space based gamma-ray observations.

- Thanks to its performance the MAST instrument will be able to:

1. Discover plenty of new faint gamma-ray sources
2. Measure the extragalactic gamma-ray background (EGRB) with high precision
3. Improve constraints on annihilation (decay) processes of dark matter (or discover these processes)
4. Investigate objects associated with IceCube astrophysical neutrinos and sources of gravitational waves (GW) registered by LIGO, VIRGO, etc.
5. Reduce uncertainty of parameters of the Extragalactic Magnetic Field (EGMF)

Thank you for your attention!

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Additional slides

$$\sigma_{\theta 1} = \frac{2\sigma_d}{x}\sqrt{\frac{3}{N+3}}$$

uncertainty due to the finite size of the readout layers

$$\sigma_{\theta 2} = \frac{(2\sigma_d)^{1/4} l_t^{1/8}}{X_0^{3/8}} \left(\frac{p_0}{p}\right)^{3/4}$$

uncertainty due to the multiple scattering of electrons

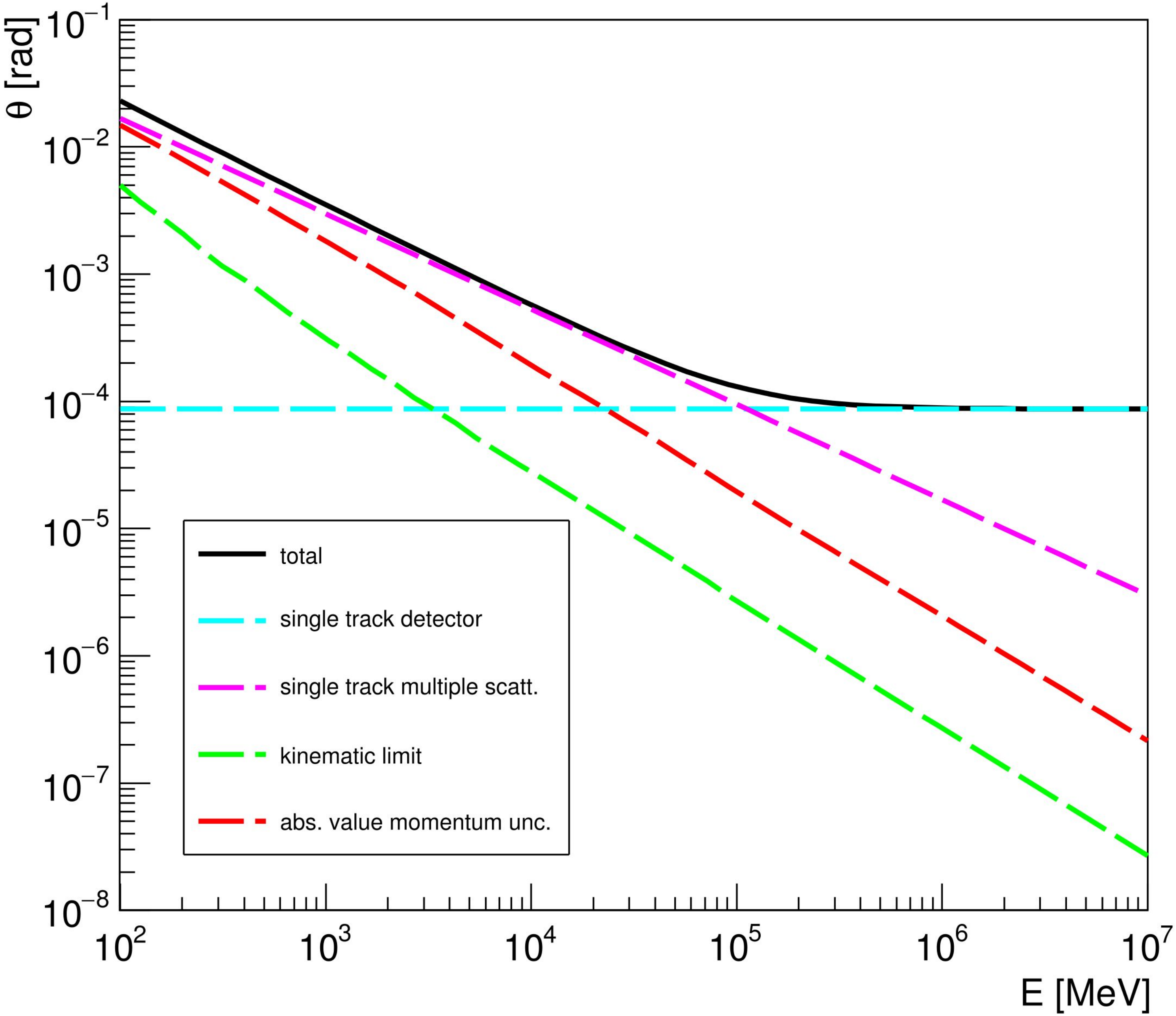
$$\sigma_d = \sqrt{\frac{l_t^2}{12} + \frac{K_D \Delta_t}{v_d}}$$

minimal space distance to separate two different tracks

$$N = \frac{x}{3\sigma_d}$$

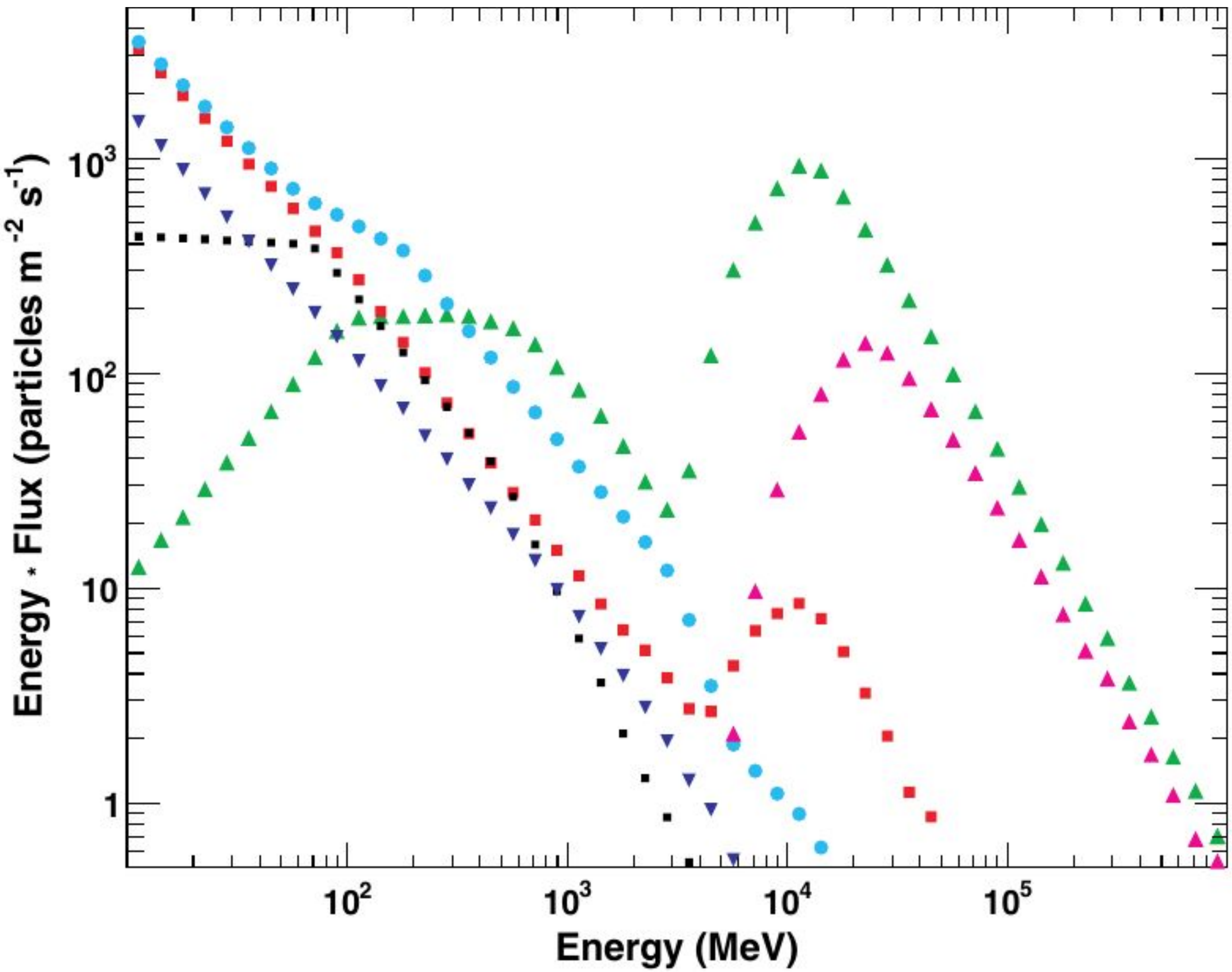
number of samplings

D. Bernard, NIM A 701 (2013) 225–230



Components of the MAST angular resolution

Background



protons - green

He - purple

electrons - red

positrons - light blue

Earth albedo neutrons - black

Earth albedo gamma-rays - dark blue

Atwood et al. (Fermi-LAT) Astrophysical Journal, 697:1071–1102, 2009

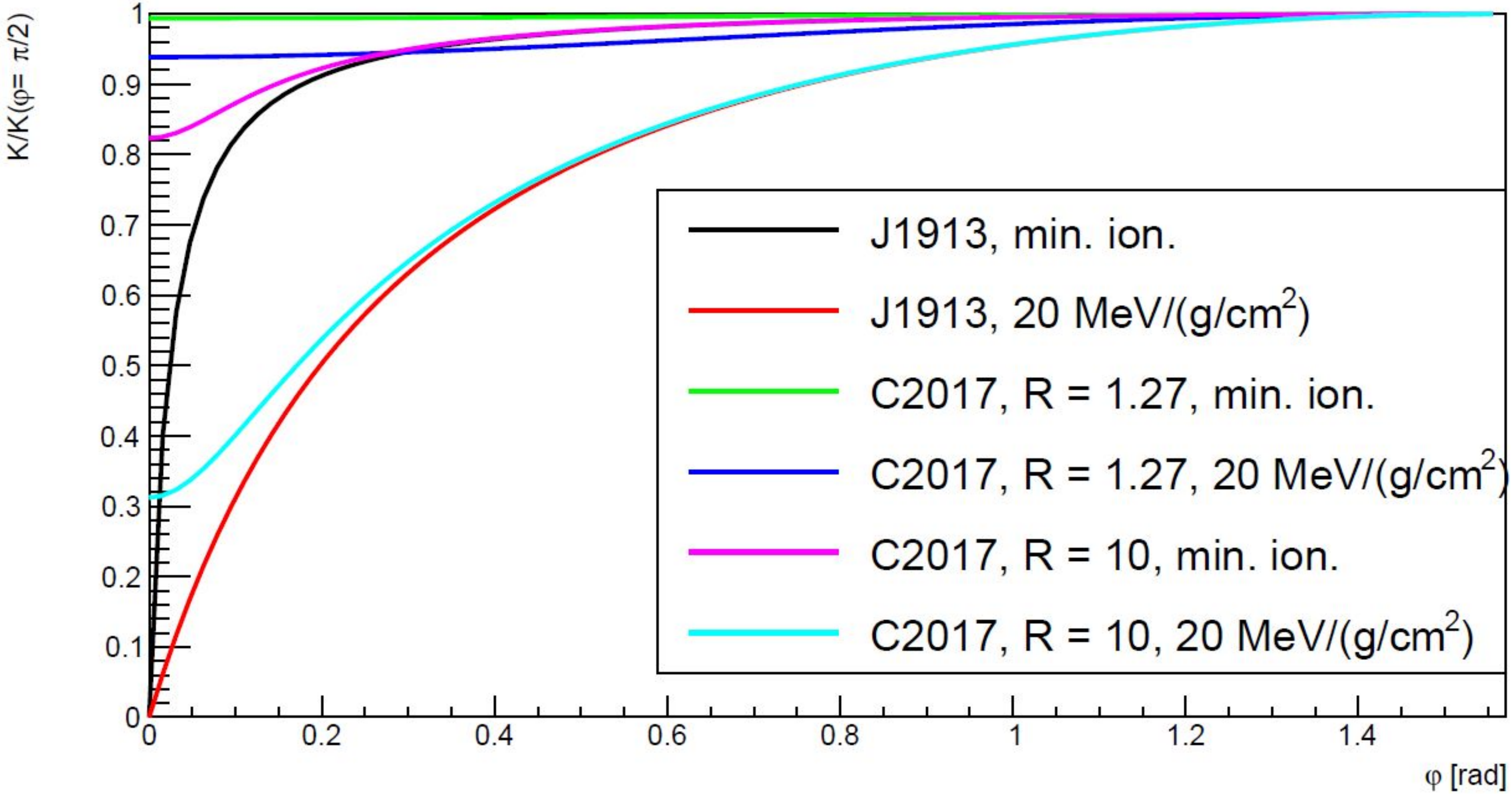
Background signals

The ACD (anti-coincidence detector) could be similar to the Fermi-LAT one (plastic scintillator, inefficiency $\delta = 3\times10^{-4}$ (Moiseev et al., 2007))

Trigger condition: $(S_{ACD}=0)\&(E_{dep}>30\ \mathrm{MeV})$
Expected rates:

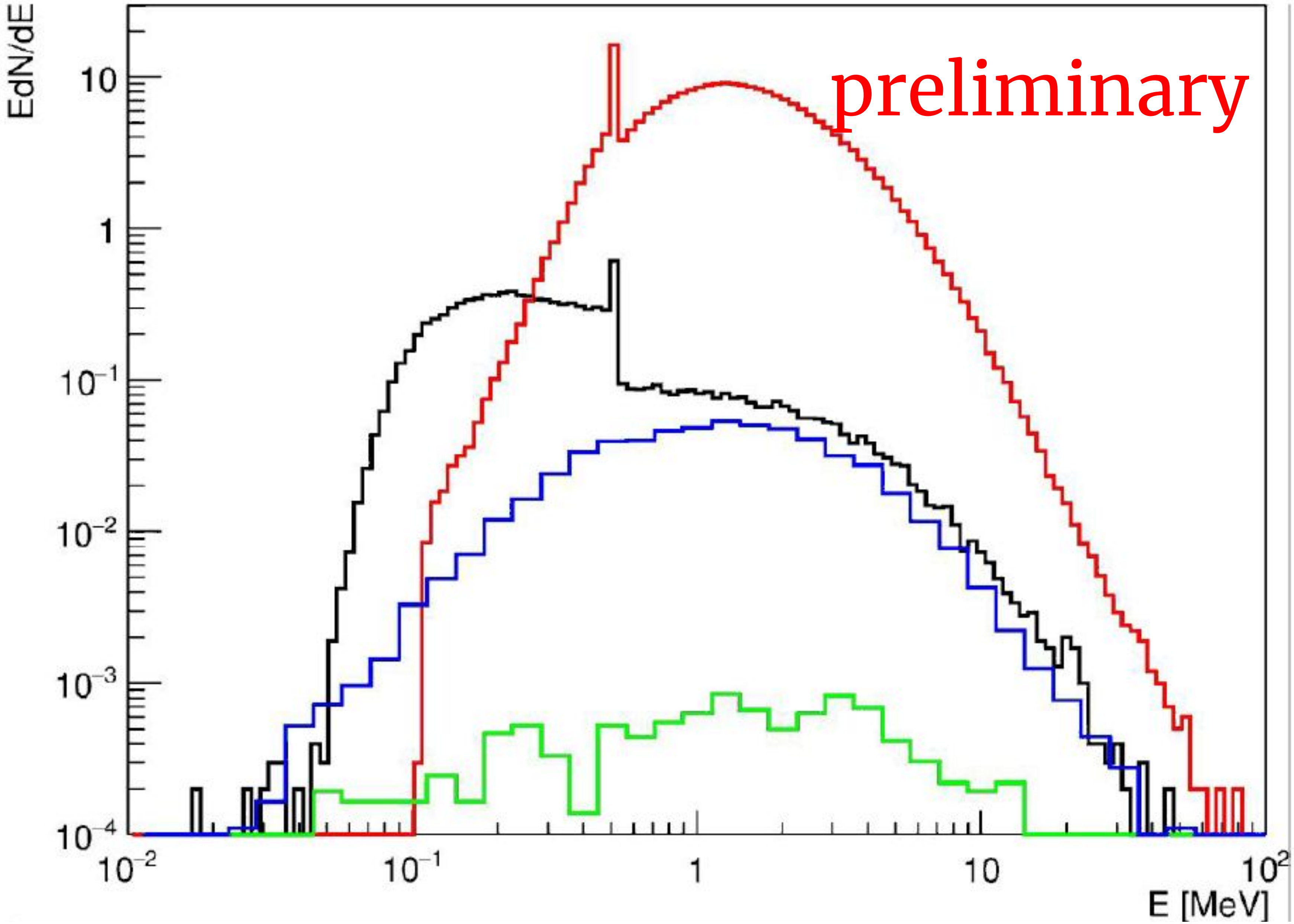
- Charged particles - 30 Hz
- Background gamma-rays - <500 Hz
- Neutrons - 500 Hz

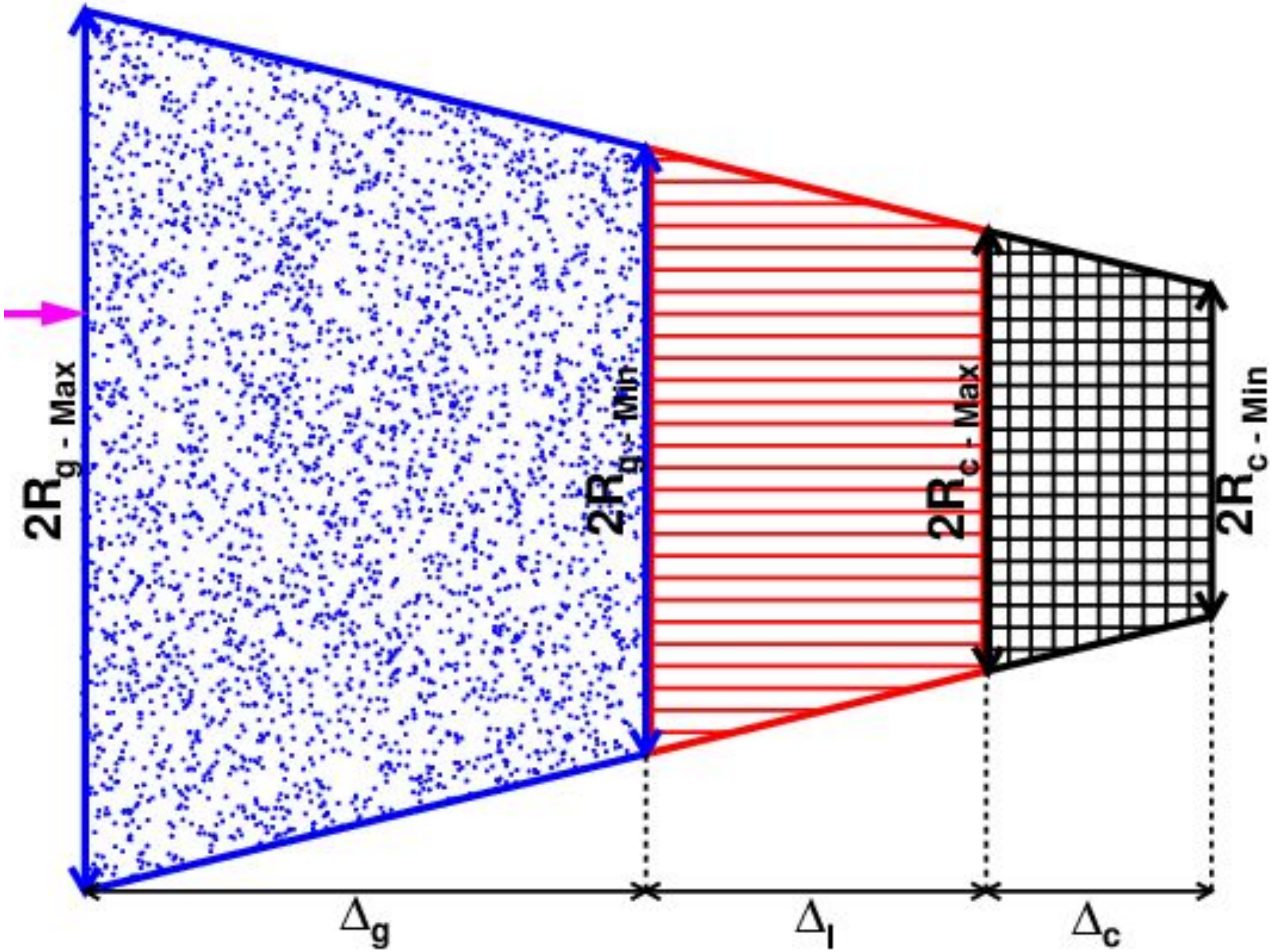
Total background rate is comparable with the downlink frequency of Fermi-LAT



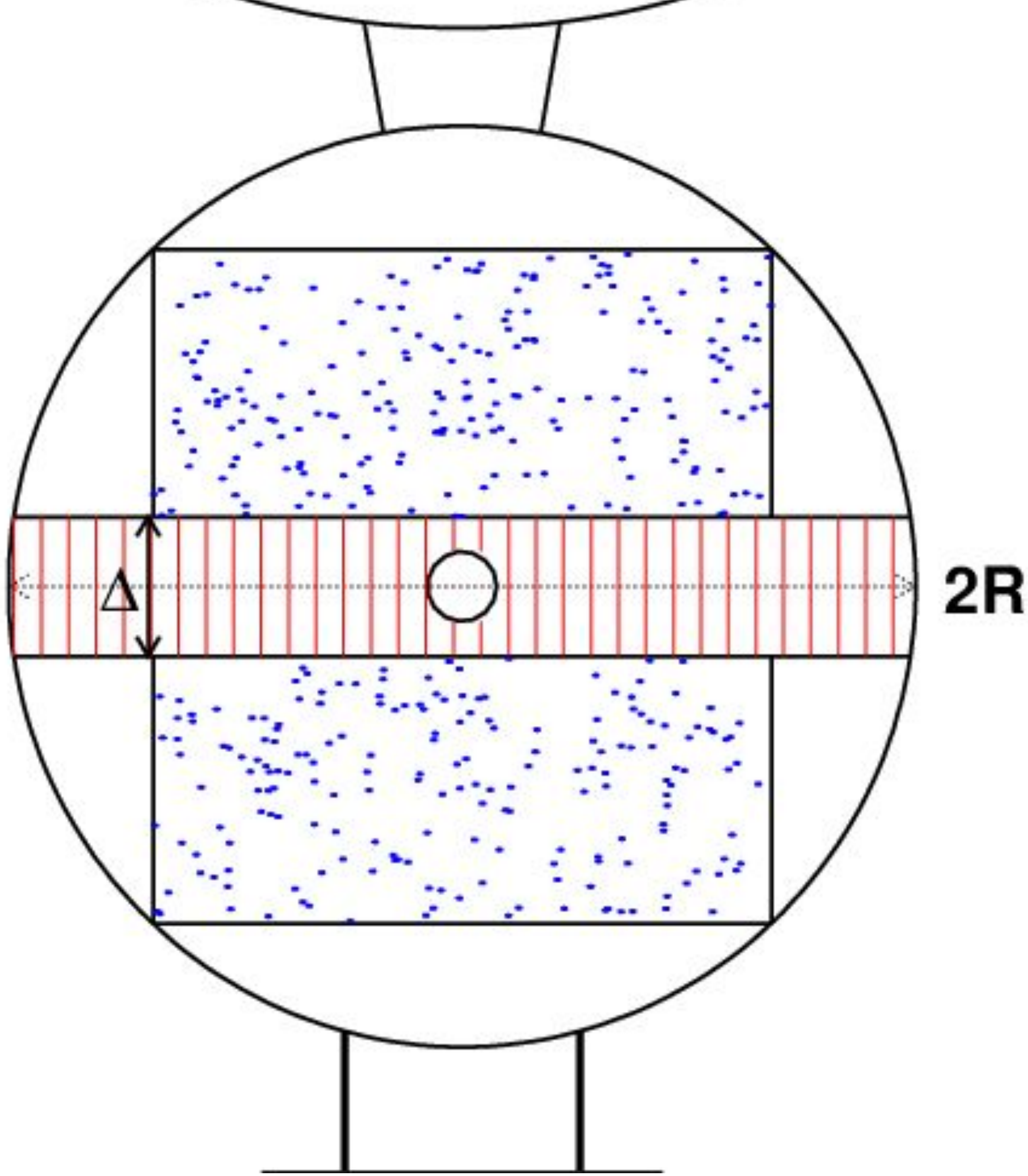
Survival probability

The flux of “backsplash” (“reverse current”) for Argon (γ-rays: black; $e^{+}+e^{-}$: green) and Tungsten (γ-rays: red; $e^{+}+e^{-}$: blue)

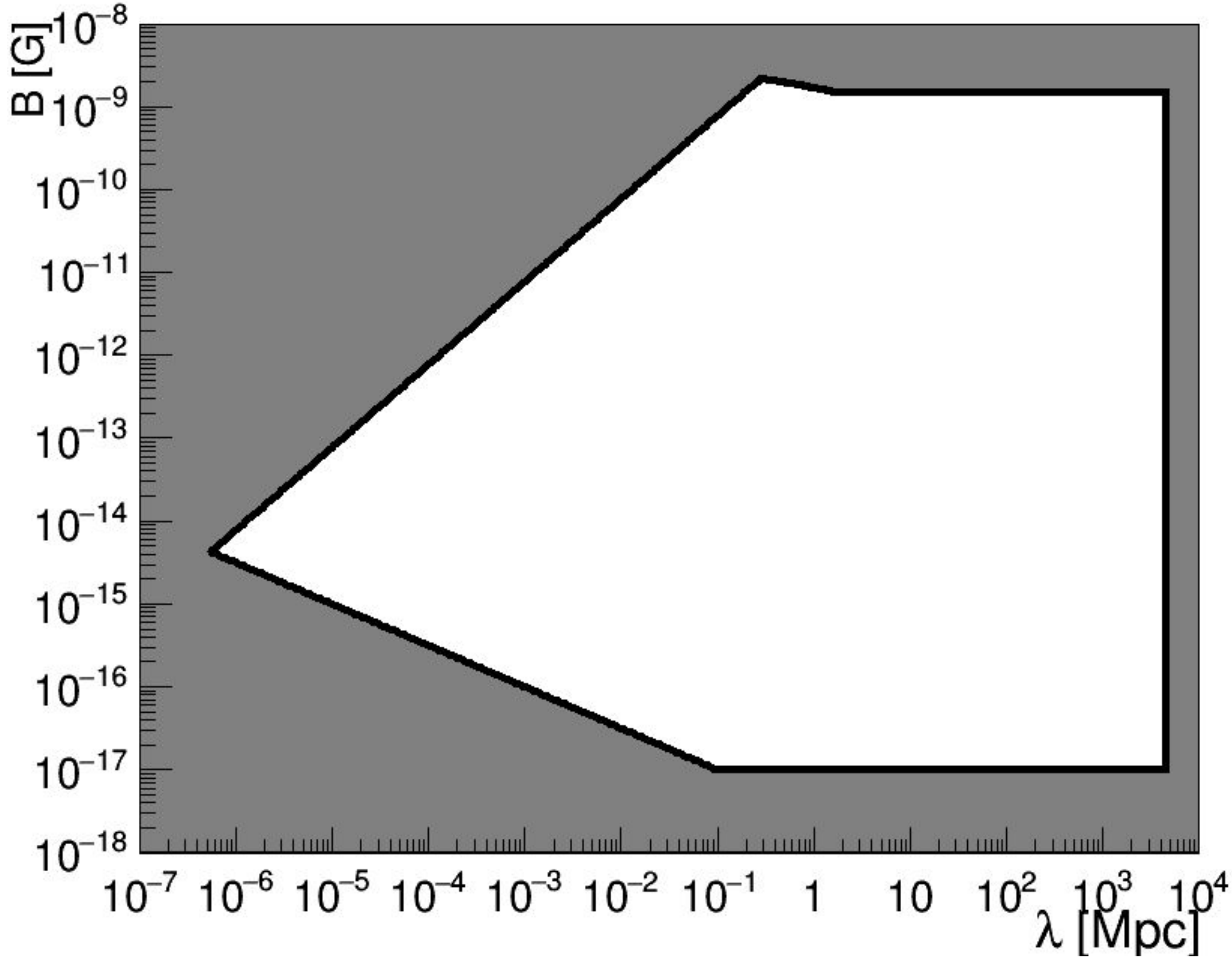




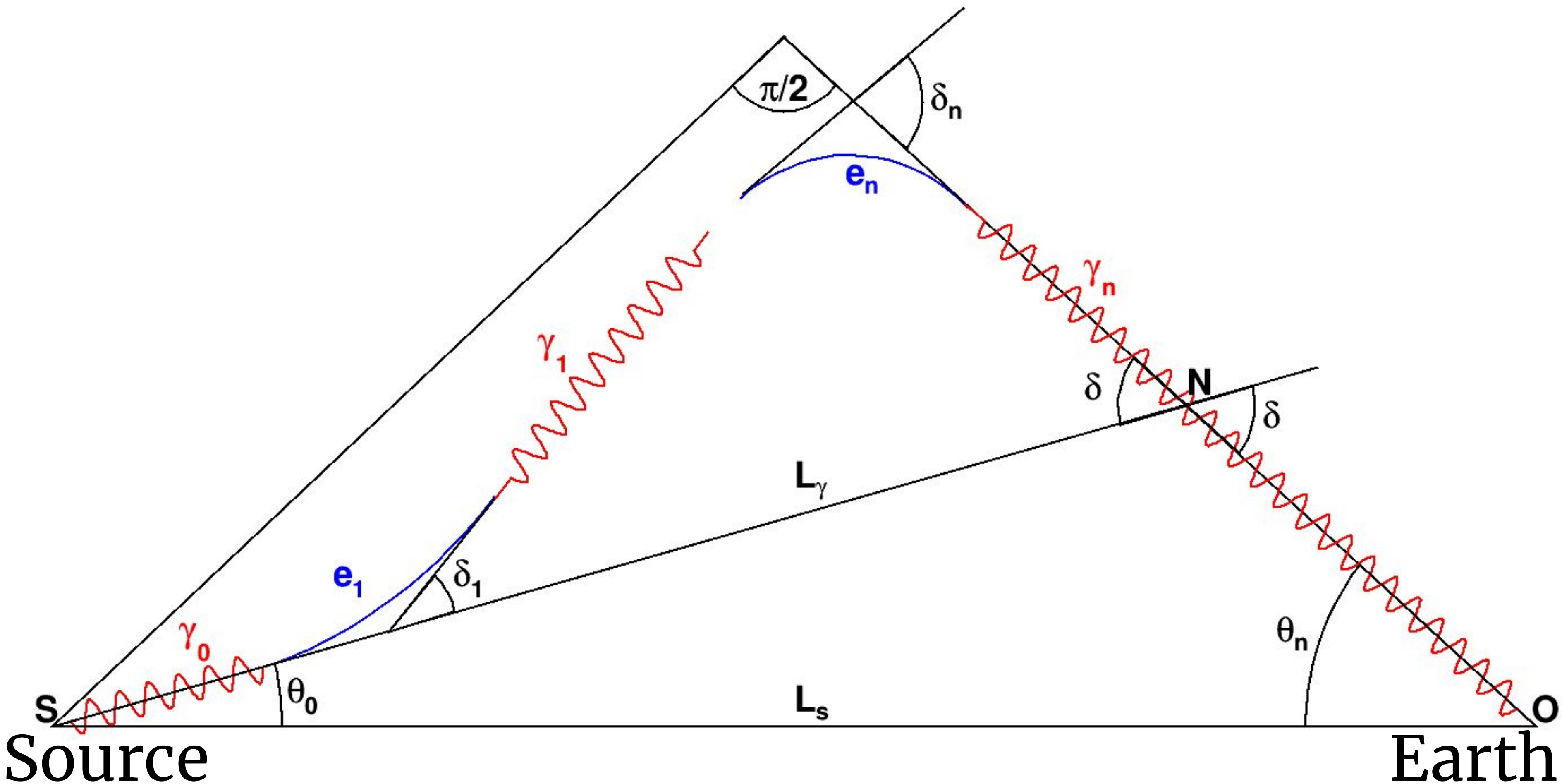
Scheme of Non La



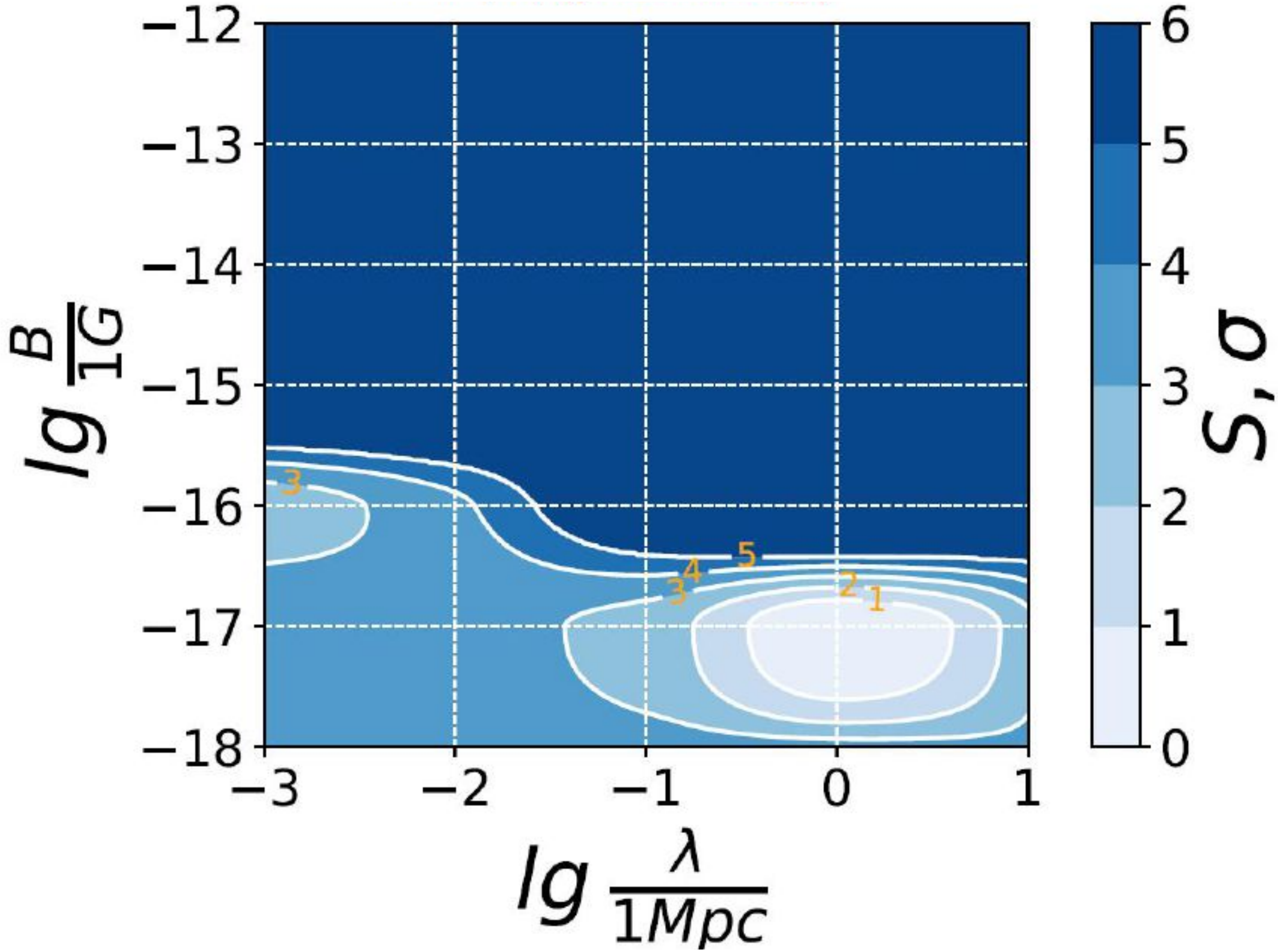
Scheme of TACT (Thin Argon Conversion Telescope)



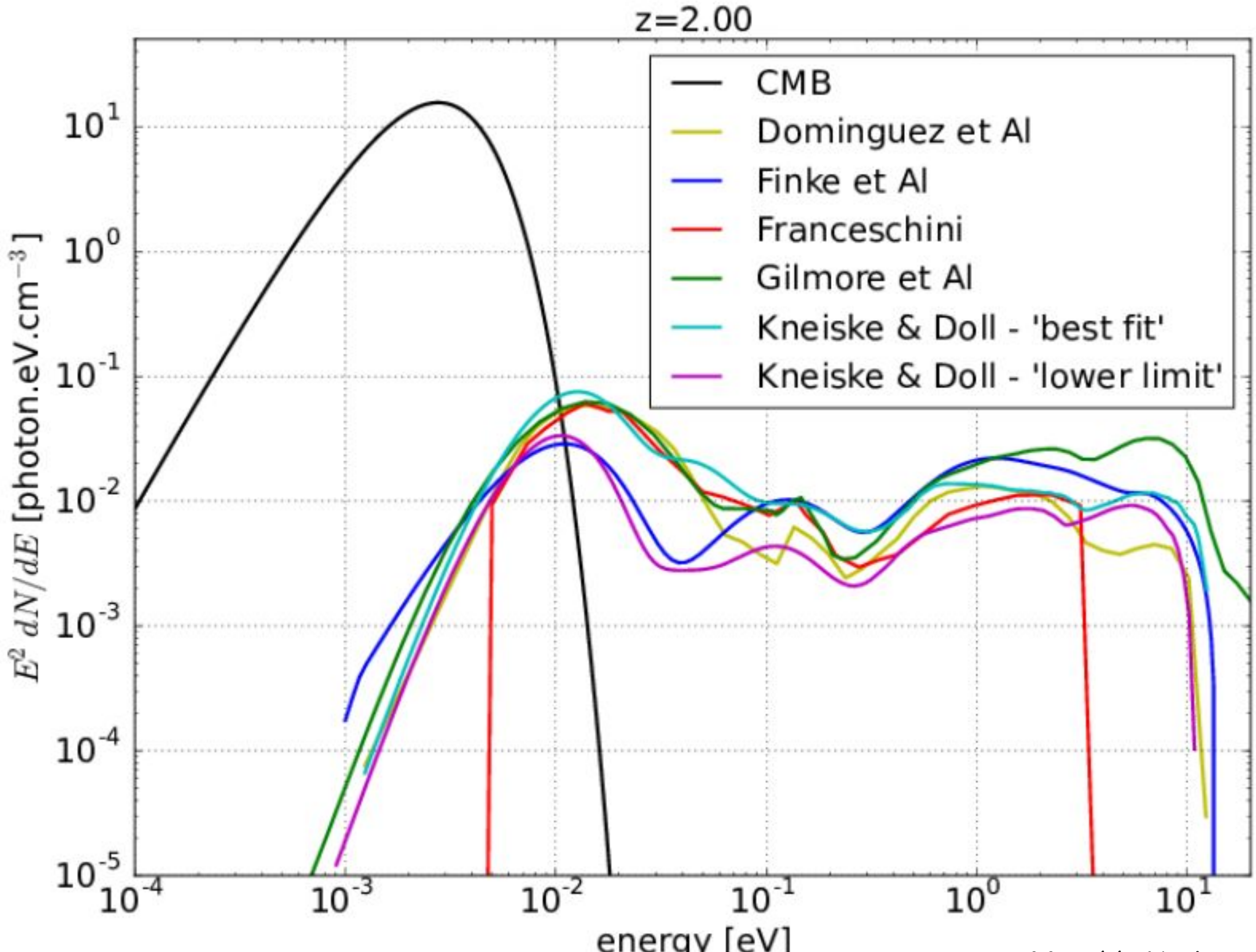
Contemporary constraints on the parameters of the EGMF



Scheme of the extragalactic electromagnetic cascade



Sensitivity to the parameters of the extragalactic magnetic field (EGMF) for 1ES 0347-121 (spectrum + ang. distribution, 3 years in survey mode, Monte-Carlo true field is 10 aG, 1 Mpc) (preliminary)



EBL & CMB

Monthly Notices of the Royal Astronomical Society, Volume 466, Issue 3, 21 April 2017, Pages 3472–3487