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Italiadomani
PIANO NAZIONALE DI RIPRESA E RESILIENZA

INFN

Development of a innovative electron-positron discrimination technique for space application:

the EPSI project

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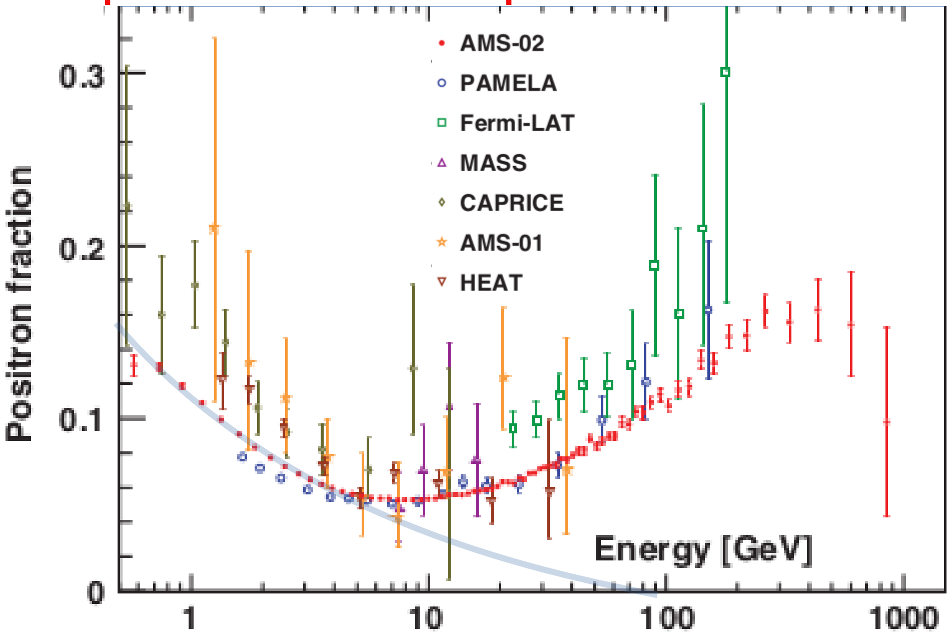
Motivation

Positron Fraction
(PAMELA, AMS-02, Fermi-LAT)
Spectrometric experiments

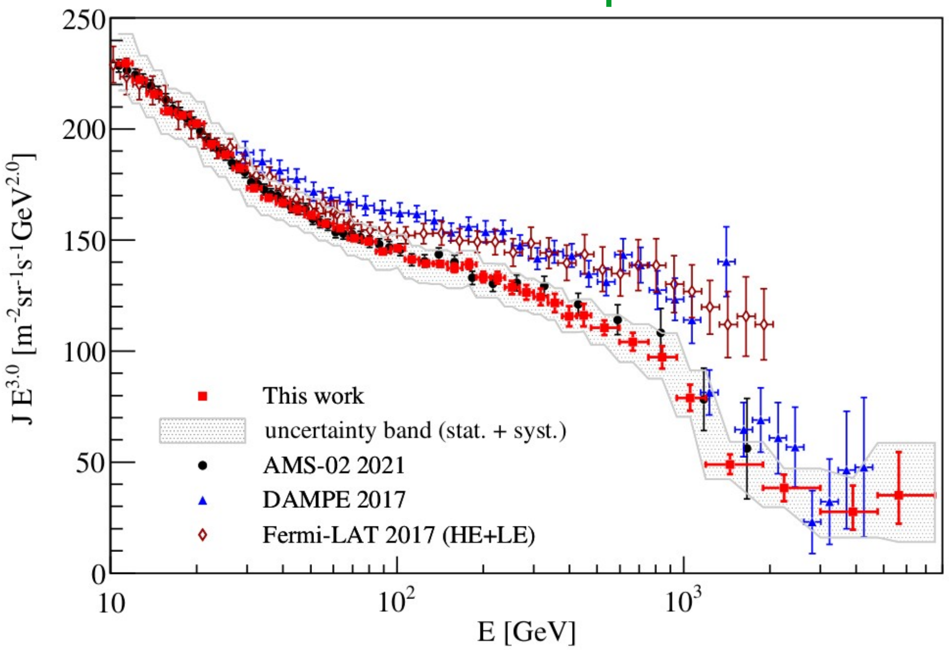


Positron excess with respect to pure secondary production may indicate the possible presence of a primary positron source (Pulsar/SNR/DM?): To better understand this excess, it is important to extend the current measurement above 1 TeV

Spectrometer-based experiments are ideal for this measurement but are limited in energy by technological issues, which may be overcame in the long term only by complex instruments like the ones proposed by ALADInO/AMS100 projects

Motivation

Electron+Positron Flux
(CALET, DAMPE,… HERD)
Calorimetric experiments

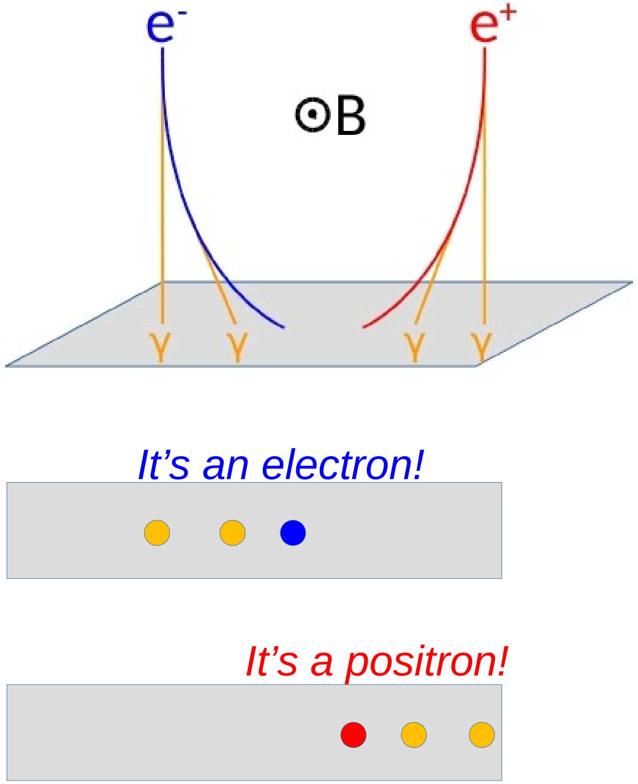


Calorimeter-based experiments are ideal for the extension of the current measurements to higher energies, hence present (CALET, DAMPE) and near-future (HERD) experiments will be based on a large calorimetric instrument

However, calorimeter-based experiments can*not* intrinsically distinguish electrons from positrons: the electron+positron flux can be measured, but the information that we can get on the positron excess is very indirect and uncertain.

Goal Develop a electron-positron discrimination technique that can be employed in a calorimeter-based experiment

Basic Idea



Since cosmic-ray experiments typically operate in Low Earth Orbits (LEO), we can exploit the particle bending due to the **geomagnetic field**

Knowing the structure of the geomagnetic field in a given point of the orbit, the simultaneous detection of the electron/positron and the emitted **synchrotron photons** is enough to univocally identify the charge sign of the detected particle.

Is it a new idea?

Originally proposed in 1972!

THE POSSIBILITY OF REGISTERING PRIMARY COSMIC ELECTRONS BY MEANS OF SYNCHROTRON RADIATION IN THE GEOMAGNETIC FIELD

O.F. Prilutskii
Moscow Engineering Physics Institute
Submitted 22 August 1972
ZhETF Pis. Red. 16, No. 8, 452 - 454 (20 October 1972)

Further development Stephens and Balasubrahmanyan
Journal of Geophysical Research: Space Physics 88.A10 (1983): 7811-7822

Several R&D and projects

This list may be incomplete!

AMS Hofer and Pohl *NIM A 416(1):59–63, 1998*

SRD Hofer, Kräber and Viertel *Nuclear Physics B 134:202-207, 2004*

CREST Yagi et al. *International Cosmic Ray Conference 2005, 3:425-428, 2005*

Sonya Galper, et al. *Journal of Physics: Conference Series, 798(1):012176, 2017*

NO!

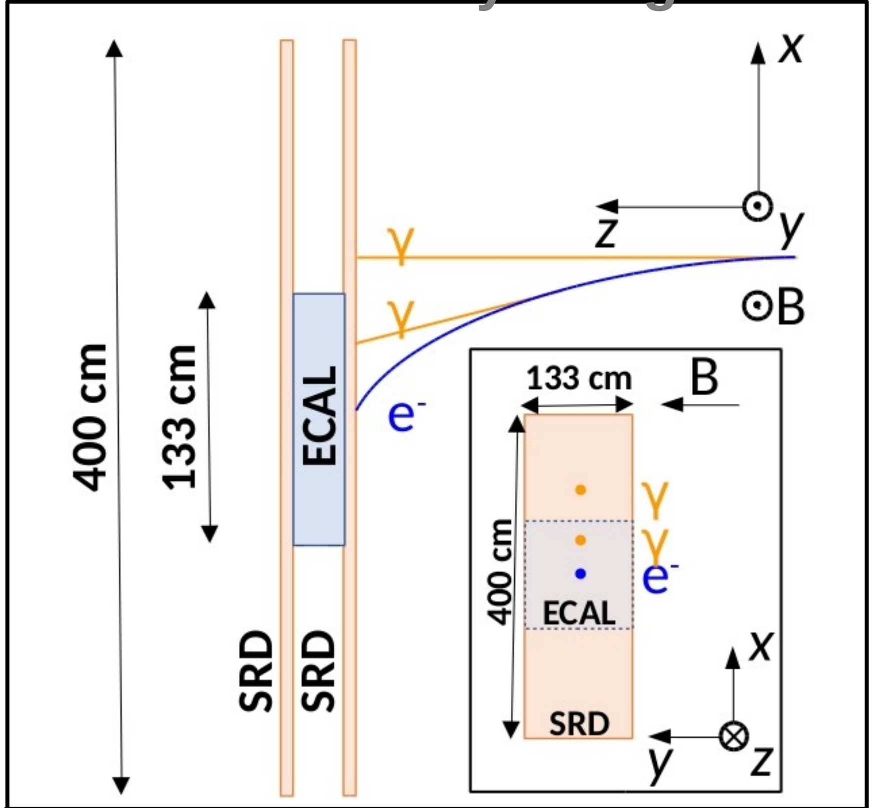
So what is new?

Most of past projects use a *calorimeter* mainly for instrument trigger and background-rejection, whereas the electron energy is reconstructed mainly (or only) using synchrotron photons

The **AMS** project use ECAL to reconstruct electron energy but in a spectrometer-based geometry

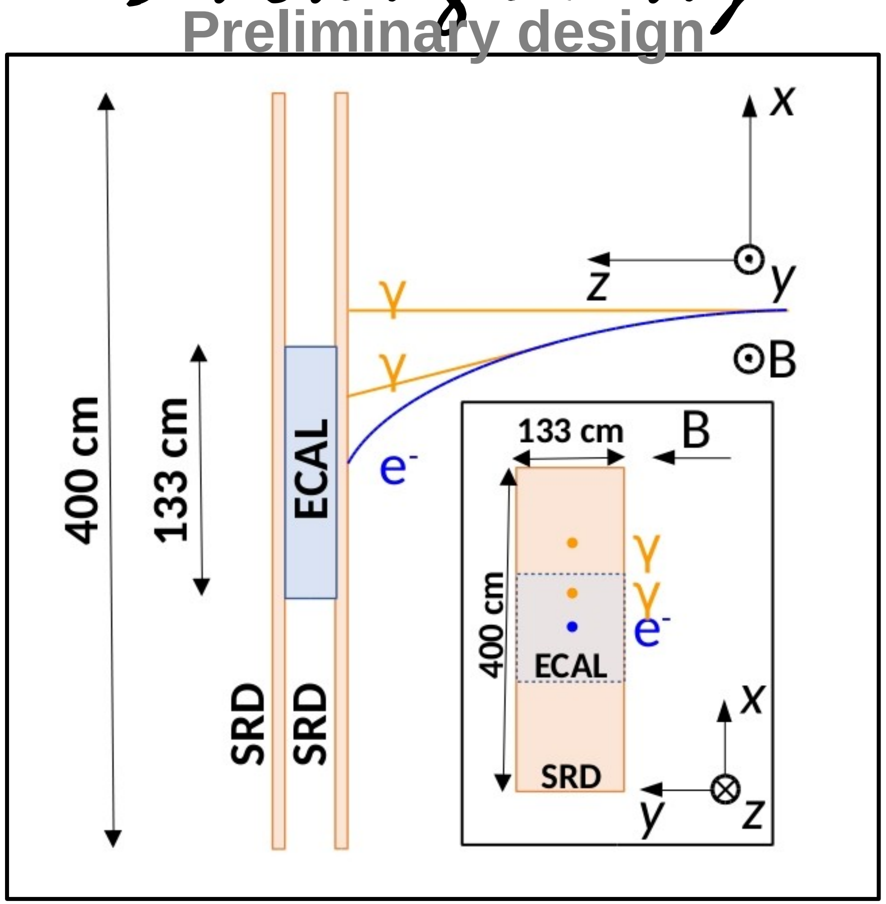
The ***EPSI*** project aims to use synchrotron photons just for *electron/positron discrimination* and exploit the advantages of a large ECAL in terms of resolution and acceptance with a novel design

Preliminary design



This is just a starting point to study the detection process, without considering a specific geometry of a future instrument

Detector geometry



ECAL
Electromagnetic CALorimeter

Main Purposes
- Energy reconstruction
- Track reconstruction
- E/H discrimination
- Instrument trigger

Possible implementation
- Fine granularity
- CsI+PD single cell
- 1.33x1.33x0.25 m^3
- Assuming 2 tons

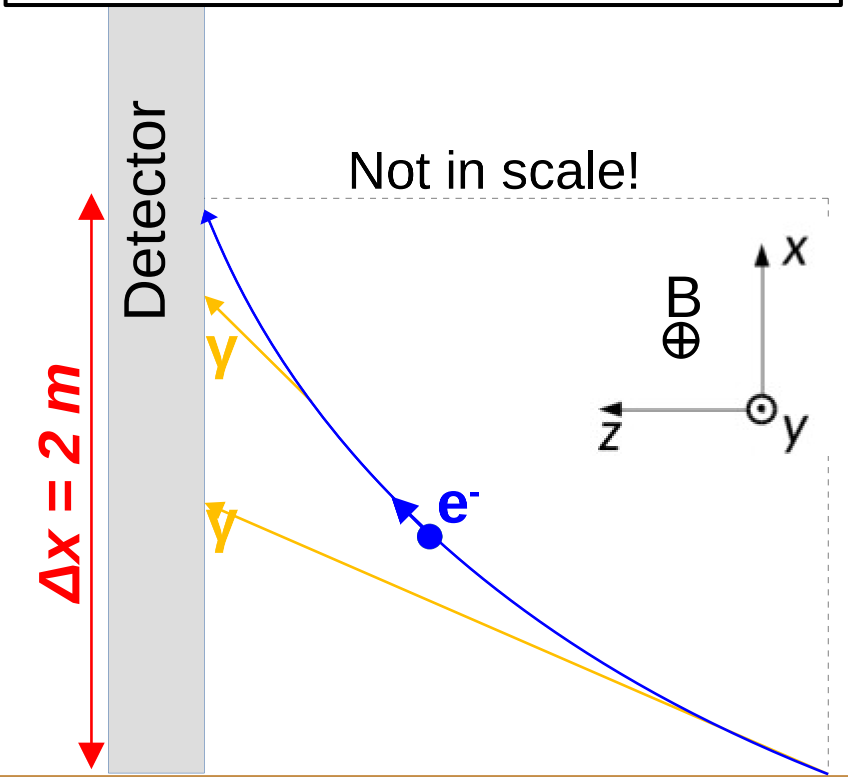
SRD
Synchrotron Radiation Detector

Main Purposes
- Synchrotron photons
- Point reconstruction
- Energy reconstruction for e^-/e^+ discrimination

Possible implementation
- Fine granularity
- Crystal+SiPM single cell
- 2 opposite single layers
- Surface of 4x1.33 m^2

Detector requirements

Let us consider a 1 TeV electron, perpendicular to a 0.4 G field, impinging at detector center



The average number of photons reaching the detector is

$<N> = 4.51$

having a critical energy of synchrotron emission of

$\varepsilon_C = 26.78\ keV$

$<N> \propto \sqrt{E}$

$\varepsilon_C \propto E^2$

$E_{electron}$	<N>	ε_c [keV]
500 GeV	3.19	6.69
1 TeV	4.51	26.78
10 TeV	14.28	2677.60

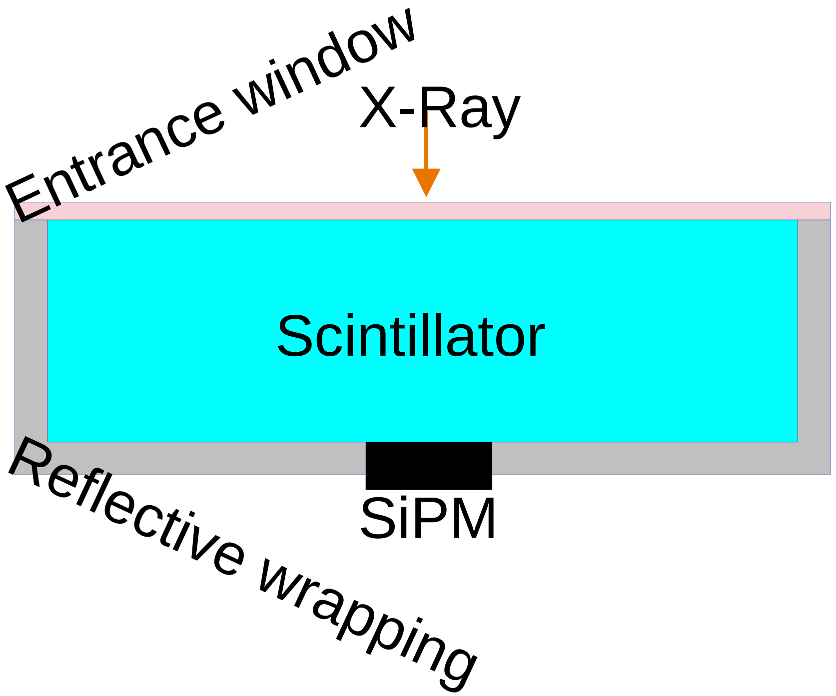
Since at least two synchrotron photons are necessary to identify the charge sign, a **high detection efficiency** in the **soft X-ray region** is necessary, while keeping the *cost* limited in order to scale the device to a large area

Detector development

Scintillator size of about 2cm x 2cm x 2.5mm

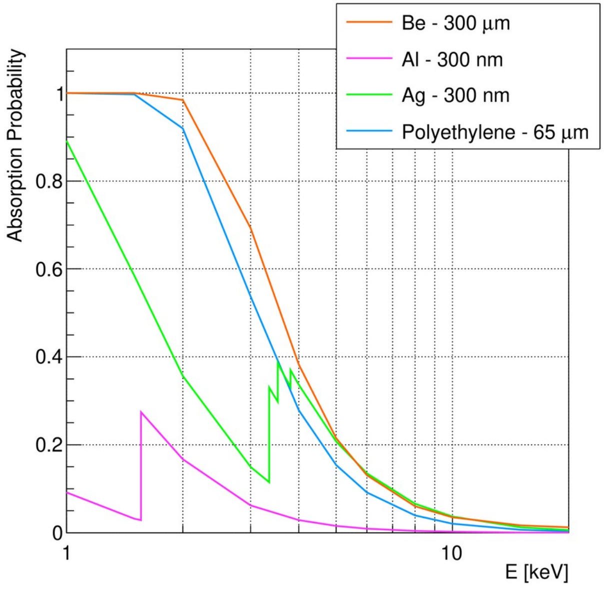
*Need of high __light-yield__ and possibly fast **crystals***

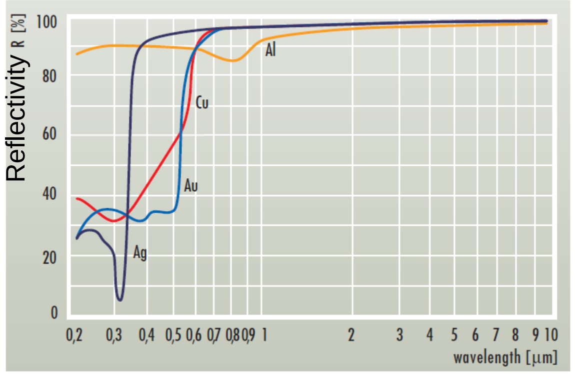
	Light Yield [γ/MeV]	Decay Time [ns]
CsI(Tl)	54000	900
GAGG(Ce)	60000	<150



*Need of a large-area and high __photodetection efficiency__ **SiPM***

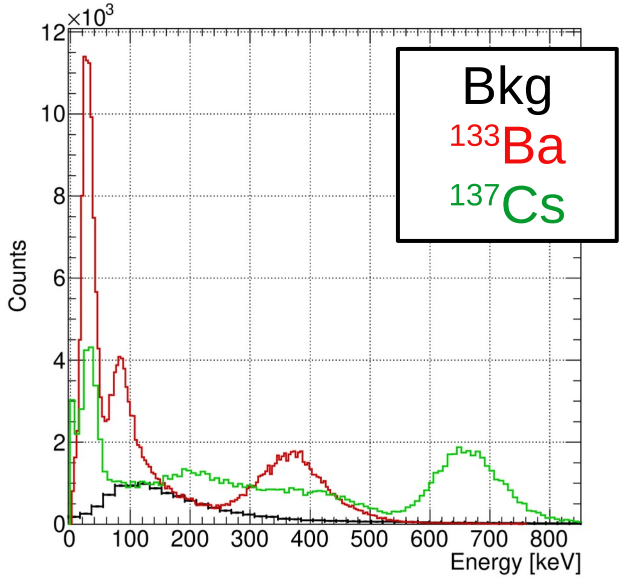
*Need of high __reflectivity__ and low __X-absorption__ **coating***





First tests

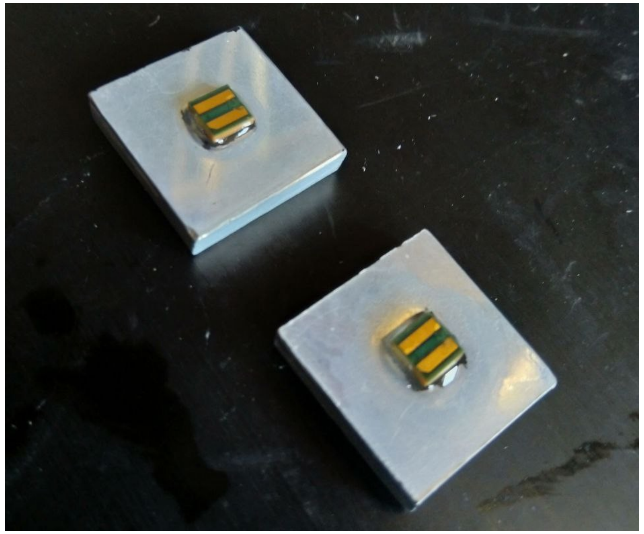
We have performed a first test with what we had in laboratory (3.6cm x 3.6cm x 1.8 mm CsI:Tl wrapped in Vikuiti ESR coupled to a simple 4mm x 4 mm SiPM)



Very thin entrance window can be obtained by Al and/or Ag deposition obtained using a **sputtering machine**

We are currently testing different solutions for wrapping/deposition by studying optical properties

CsI:Tl crystals covered by 300 nm Al deposit



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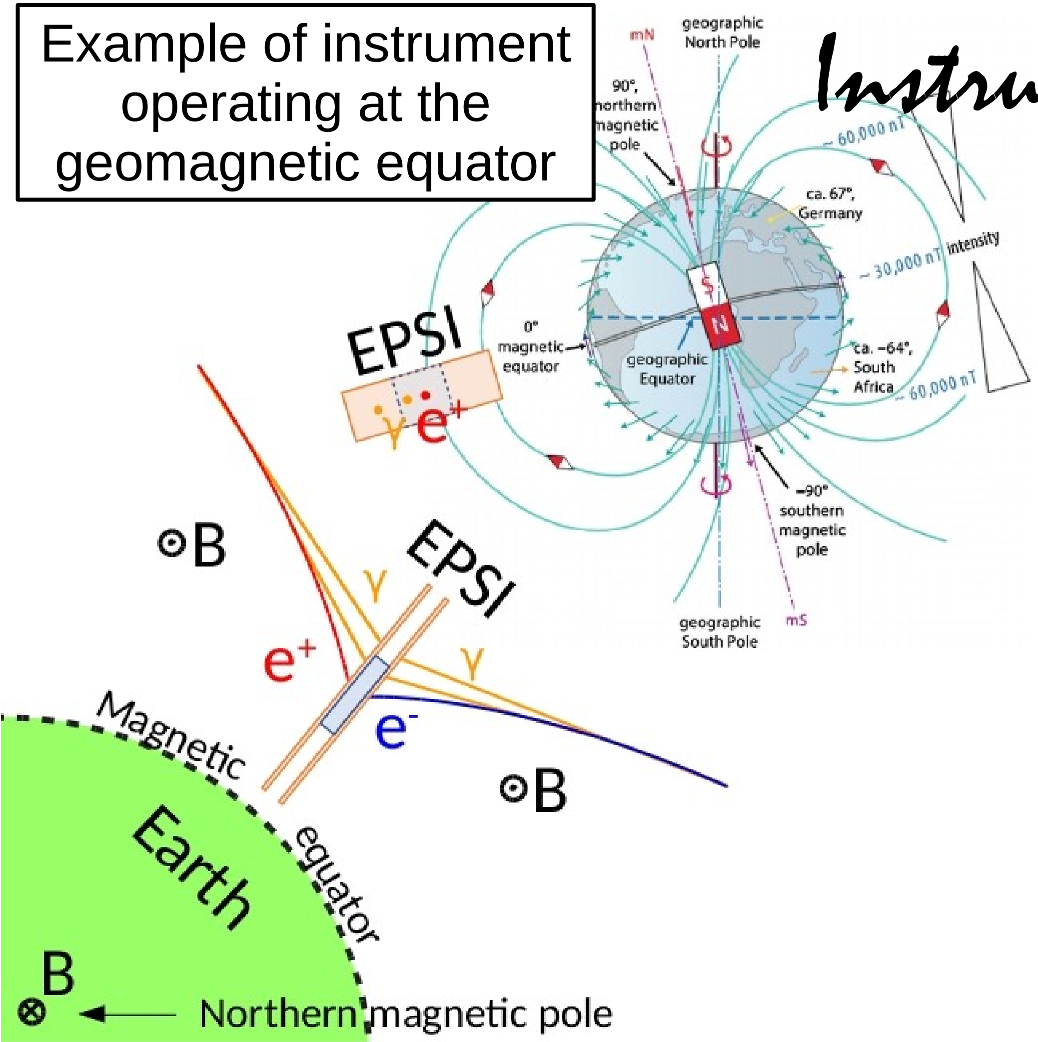
Instrument optimization

Example of instrument operating at the geomagnetic equator



Optimize the **design** of the space instrument in terms of geometric factor, charge-sign reconstruction, energy/track resolution, background rejection

Carefully estimate **background** sources due to:
- Sun X-rays
- Astrophysical X-rays
- Low energy charged cosmic rays
- Backscattering from calorimeter

Study the best **orbit** both in terms of maximize the *bending effect* of the geomagnetic field and of minimizing the impact of *X-rays from the Sun*

Summary

EPSI is an R&D, financed by PRIN 2022 funds, which aims to investigate a novel e^-/e^+ discrimination technique at high energies for future calorimeter-based experiments

This technique requires to develop a *synchrotron radiation detector* with high efficiency in the soft X-ray region, which must be enough cheap to be scaled to a large area

We are optimizing the properties of the detector starting with a scintillator crystal, covered by a thin reflective deposition and coupled to a large-area SiPM

In parallel, we are optimizing the geometry of a space instrument completely dedicated to the extension of the measurement of electron and positron fluxes at high energies

Using simulation, we are optimizing the geometry and the orbit of the instrument in terms of acceptance, resolution, charge discrimination and background suppression

BACK UP

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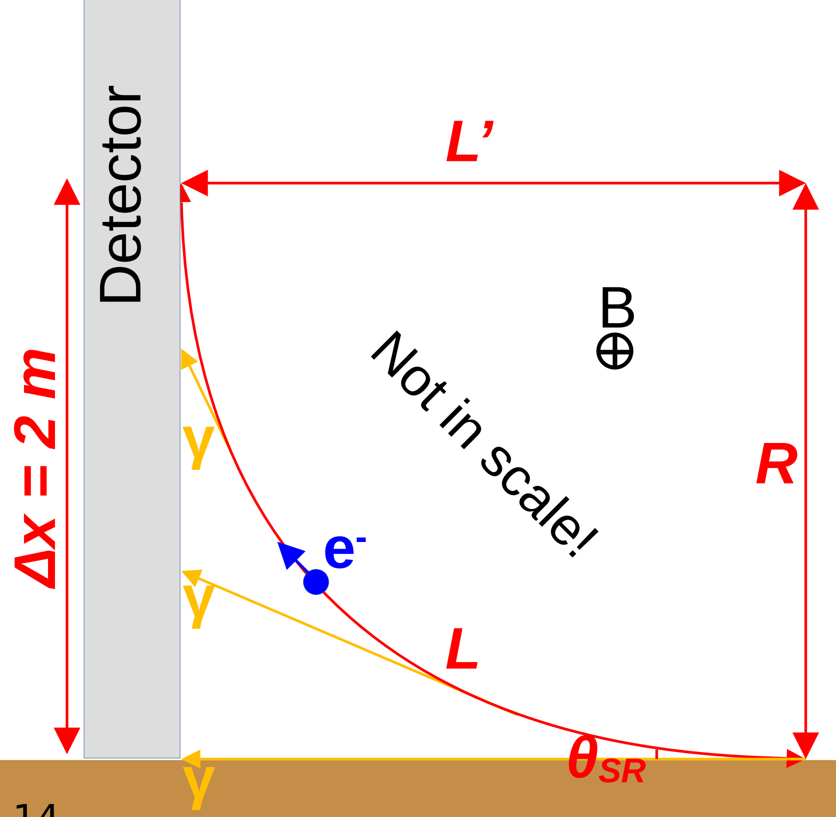
Some computations (I)

Let us consider a 1 TeV electron, perpendicular to a 0.4 G field, impinging at detector center



Curvature radius

$$R[m] = \frac{p[GeV]}{0.3\ B[T]} \sim 83 \times 10^3\ km$$

...since $R << \Delta x$:

$$L' \sim L$$

$$\theta \sim L/R \sim 0.22\ mrad$$

...assuming $\Delta x = 2$ m:

Effective track length

$$L \sim \sqrt{2\,R\,\Delta x} \sim 18.3\ km$$

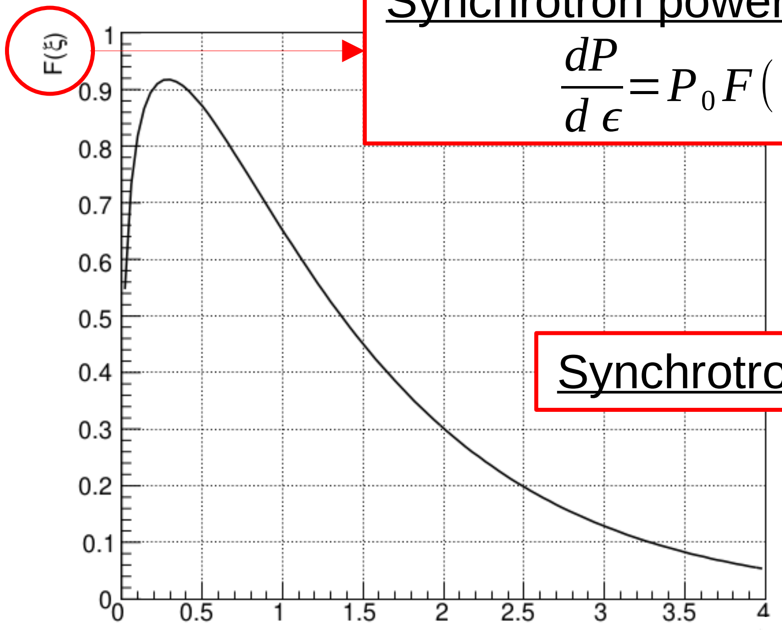
RMS Emission angle

$$< \theta^2_{SR} >^{1/2} = \frac{1}{\gamma} = \frac{m}{E} \sim 0.51\ \mu rad$$

Let us consider a 1 TeV electron, perpendicular to a 0.4 G field, impinging at detector center

Some computations (II)

Considering a 1 TeV electron in B = 0.4 G field



$\xi = \epsilon / \epsilon_c$

Synchrotron power spectrum

$$\frac{dP}{d\epsilon} = P_0 F(\xi)$$

Synchrotron photon energy

Average number of γ reaching the detector

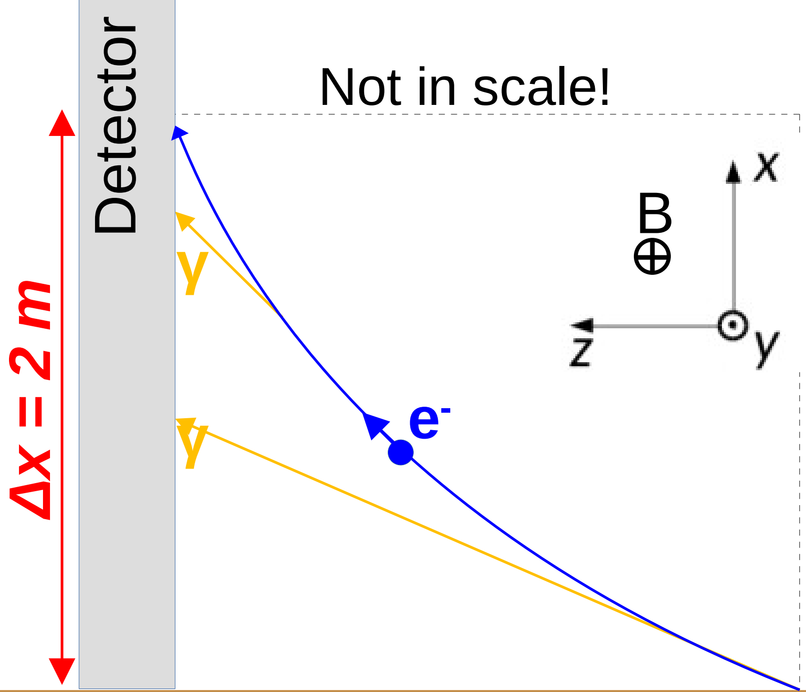
$$< N > = < \frac{dN}{dl} > L = \frac{5\sqrt{3}}{6} \alpha\gamma \sqrt{\frac{2\,\Delta x}{R}} = 4.51$$

Critical energy of synchrotron emission

$$\epsilon_c = \frac{3}{2}\hbar c \frac{\gamma^3}{R} = \frac{3}{2}\frac{\hbar e B}{m^3 c^4} E^2 = 26.78\ keV$$

Detection cell size

Let us consider a 1 TeV electron, perpendicular to a 0.4 G field, impinging at detector center



The <u>dispersion of synchrotron photon emission angle</u> is

$\sigma_\theta = 0.51\ \mu rad$

which translates into a <u>position dispersion at detector</u> of

$\sigma_y < L * \sigma_\theta = 9.3\ mm$

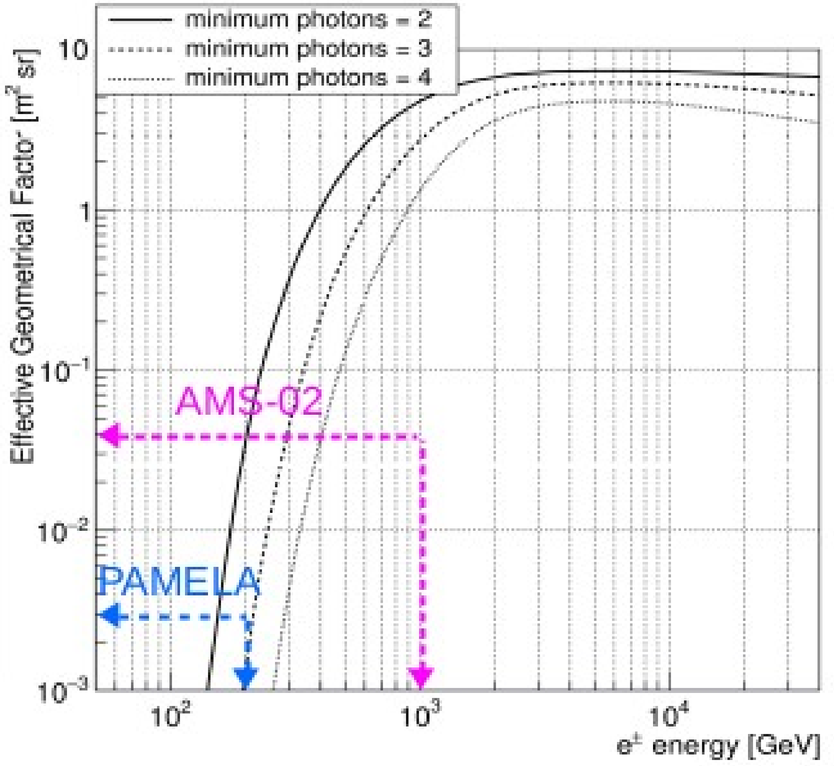
Synchrotron photons can be separated by astrophysical background since they lie on the electron bending plane: for this separation, it is enough a segmentation such that each detection channel have a size of about 1 x 1 cm^2

Assuming a SRD with 100% detection efficiency in the range 1-100 keV

Considering Earth shadow and generic direction

Only SRD selection is applied

Effective geometric factor



$\langle N \rangle \propto \sqrt{E}$

$\varepsilon_C \propto E^2$

$E_{electron}$	<N>	ε_c [keV]
500 GeV	3.19	6.69
1 TeV	4.51	26.78
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- The detection technique works well above 1 TeV
- The detection technique is limited below 100 GeV

Below a few hundreds of GeV we can use the back-tracing technique used by Fermi for charge-sign discrimination

Protons and Nuclei

Synchrotron radiation generated by protons and nuclei cannot be detected since

$$\langle N \rangle \propto \sqrt{E} * Z^{5/2}/M$$
$$\varepsilon_C \propto E^2 * Z/M^3$$

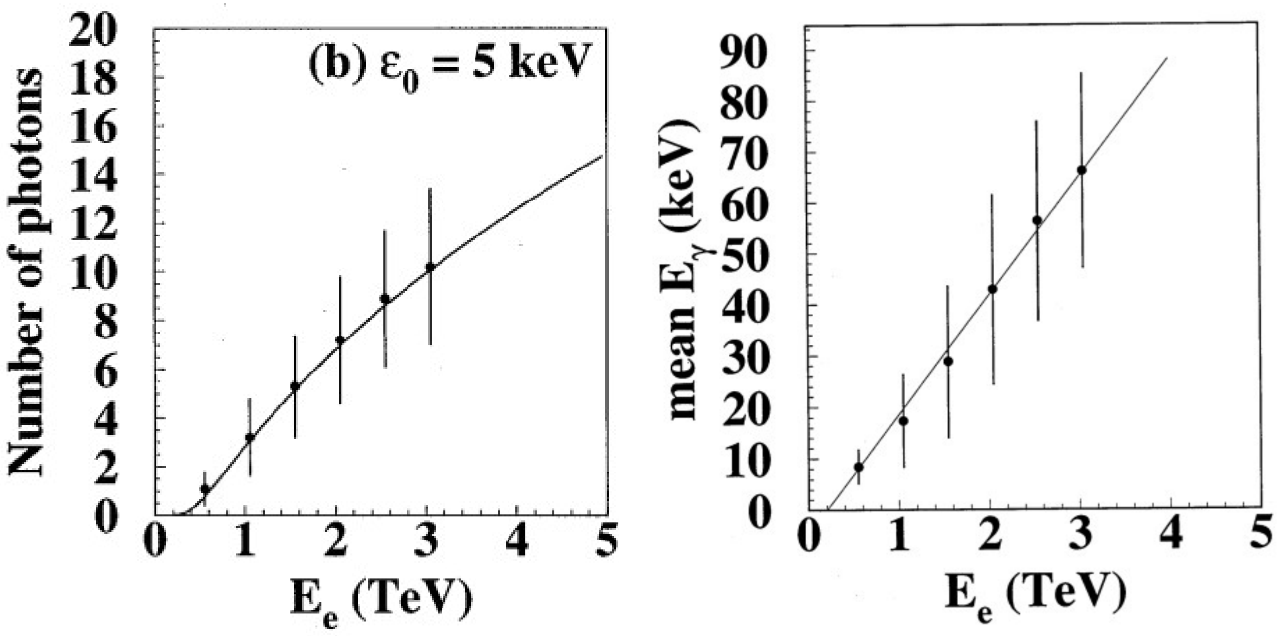
For example, a 1 PeV proton has $\langle N \rangle = 0.05$ and $\varepsilon_C = 4.4\ eV$, below detection limit

CON: We cannot separate nuclei from antinuclei

PRO: We can increase proton rejection factor

Calibration of the energy scale

From *H. Hofer, M. Pohl/Nucl. Instr. and Meth. in Phys. Res. A 416 (1998) 59–63*



The number and mean energy of synchrotron photons depend on the electron energy, thus it can be used to get an independent measurement of the electron energy

This is useful to check the absolute energy scale calibration of the calorimeter, which is crucial for calorimeter-based experiments like CALET, DAMPE, Fermi-LAT