FUTURE SPACE CHALLENGES

IFD 2015
INFN Workshop on Future Detectors

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Structure of the talk (I)

- From very low energy X ray photons (10^3 eV) up to the extremely high energy cosmic rays (10^{20} eV): an impossible task!
- Main focus of the talk:
  - Charged cosmic rays in the TeV→PeV region
    - Calorimeter
    - Magnetic spectrometer
- Some interesting jumps on different aspects:
  - The very low energy region (only for photons):
    - Measurement of the X ray polarization in the 1 keV:100 keV region
  - The case of anti-deuteron detection in the sub-GeV region:
    - Detection of characteristics X ray produced in the anti-deuteron slow down

Structure of the talk (II)

- The main focus will be on the detector's technological challenges, driven by the physics case
- Physics problems will be very shortly introduced

- Disclaimers, apologies and thanks:
  - This is my private point of view….
  - My sincere apologies for all the missing items not covered in the talks!!!!
  - Many thanks to all peoples that gave me detailed slides:
    - P. Papini, B. Bertucci, L. Baldini, M. Ricci, etc. etc.

THE LOW ENERGY FRONTIER

X ray polarization measurement in the 1 keV-100 keV region

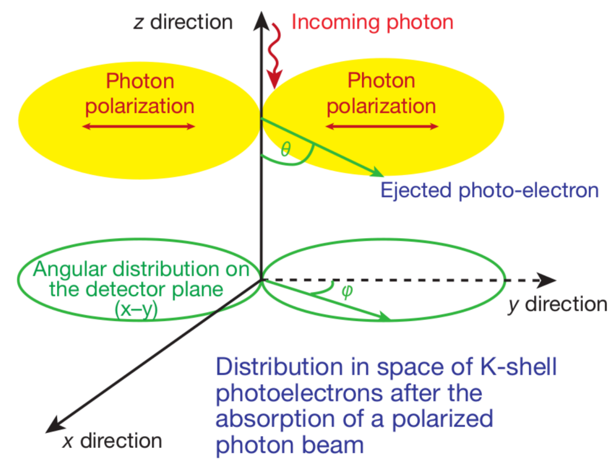
X-Ray polarimetry: great expectations...

- Spectroscopy, imaging and timing are routine techniques in X-ray astronomy.
  - Unlike polarimetry, they underwent continuous development over the last four decades.
- Polarimetry is potentially adding two parameters to the phase space:
  - (linear) polarization degree;
  - polarization angle (phase).
- Significant X-ray *linear* polarization expected in most classes of non-thermal X-ray sources:
  - Emission processes
    - Synchrotron radiation and Inverse Compton.
    - Acceleration phenomena (supernova remnants, pulsar wind nebulae, jets).
  - Geometry
    - Photon scattering in aspherical geometries (accretion disks, X-ray reflection nebulae).
    - Photon propagation in magnetized plasmas (accreting pulsars, magnetars).
  - Fundamental physics
    - Quantum electrodynamics (photon propagation in strong magnetic fields).
    - General relativity (photon propagation in strong gravitational fields)
    - Quantum gravity and Lorentz-invariance violation.

From L. Baldini

The challenging experimental technique

- Photoelectric effect is the dominant interaction process at a few keV
- The distribution of the direction of emission of a K-shell photoelectron is 100% modulated if the incident radiation is 100% linearly polarized:



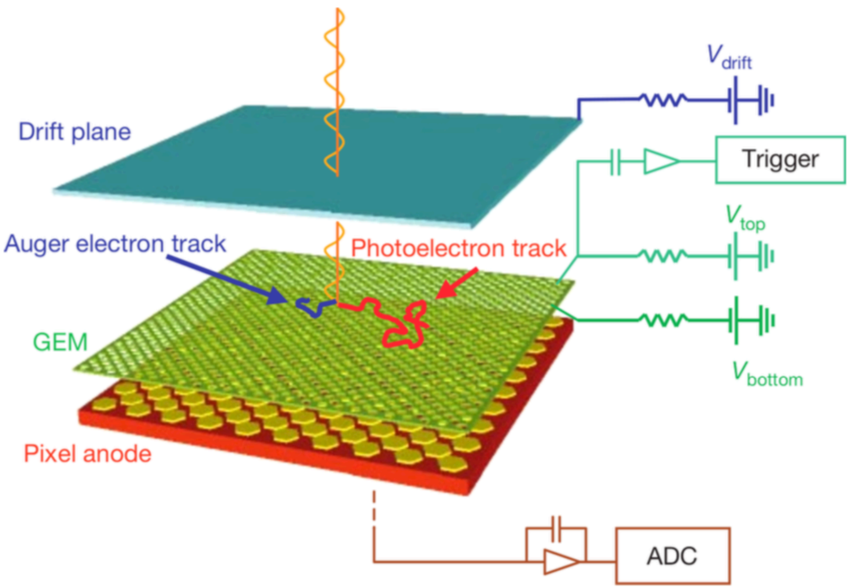
$$\frac{d\sigma_C^K}{d\Omega} \propto Z^5 E^{-\frac{7}{2}} \frac{\sin^2\theta\cos^2\phi}{(1+\beta\cos\theta)^4}$$

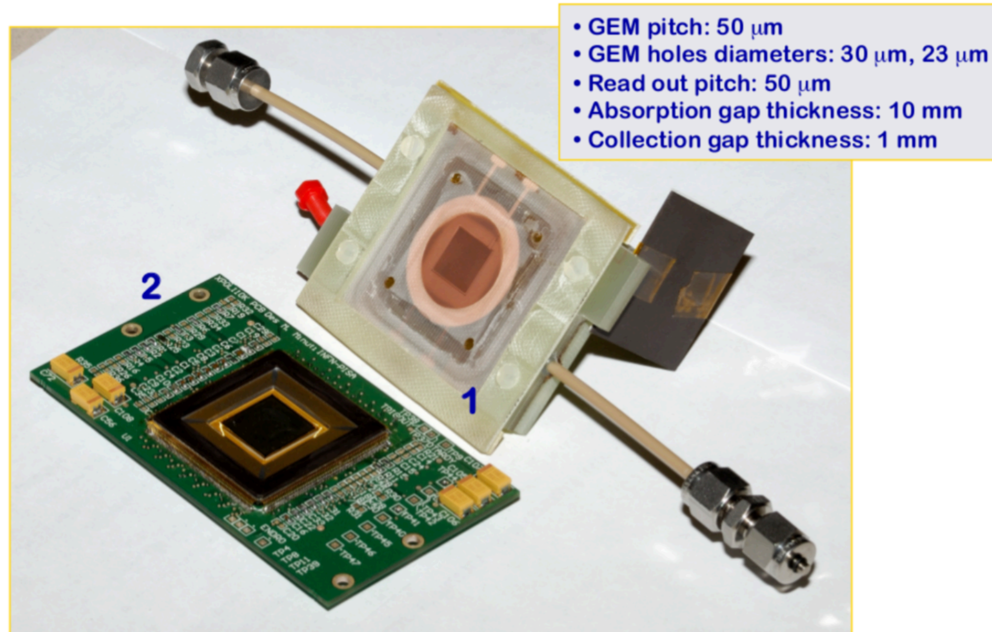
- e⁻ preferentially emitted orthogonal to the incident direction
- Technical challenges:
  - Small photoelectron range (typically less than 1 mm in gas).
  - Multiple Coulomb scattering.

Measurement of:
Energy
Polarization
Timing
in X-ray sources (black holes, compact objects) in the keV region allow to probe the fundamental physical law in extreme conditions (extreme gravity, extreme density, extreme magnetic fields)

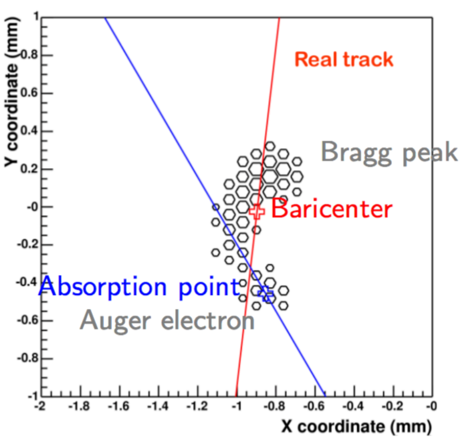
LOFT, XTP ,XIPE

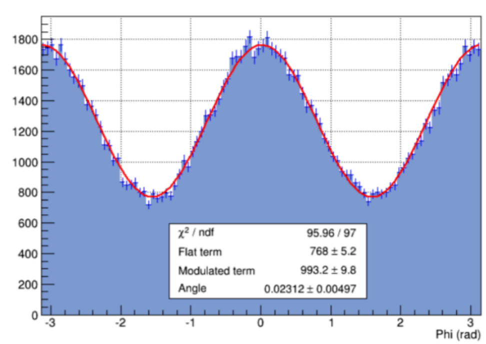
Gas pixel detector for XIPE mission

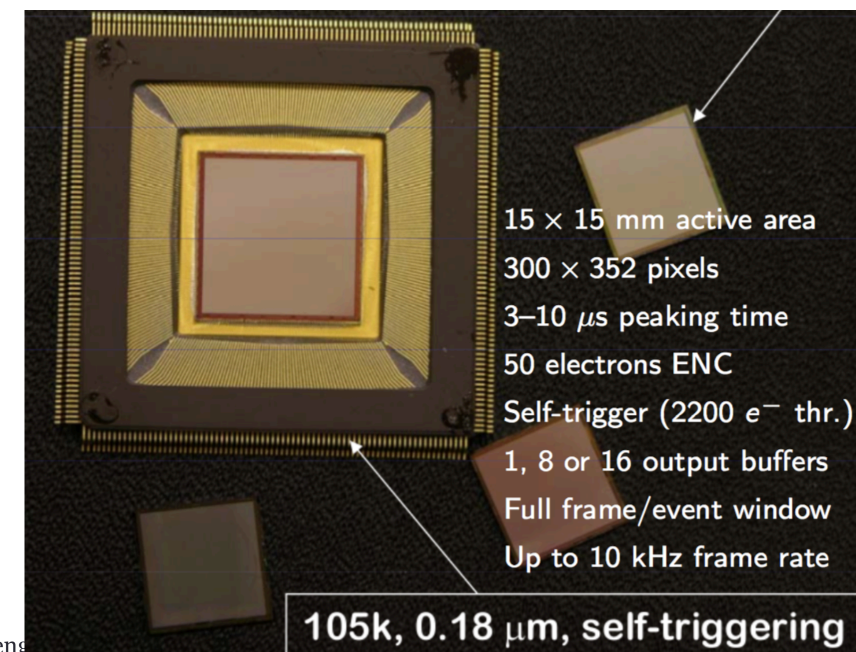




- Sensitive down to very low energy (~ 1 keV).
- Fully 2-dimensional (imaging).
- Highly azimuthally symmetric (no need of rotation to control systematics).







DARK MATTER SEARCH

The antideuteron detection as a dark matter smoking gun

Why Anti-deuterons ?

Unlike anti-protons, which are easy to produce as secondary particles, anti-deuteron secondaries are severely suppressed at low energies.

Primary Component (DM):

$\chi\,\chi \rightarrow e^{+}, \bar{p}, \bar{d}$

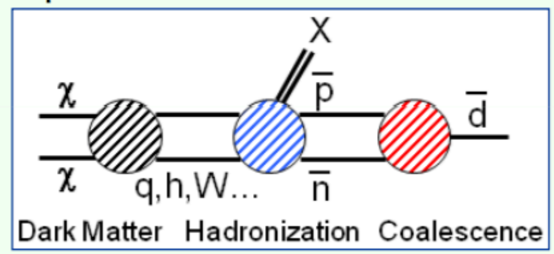
Secondary Component, includes:

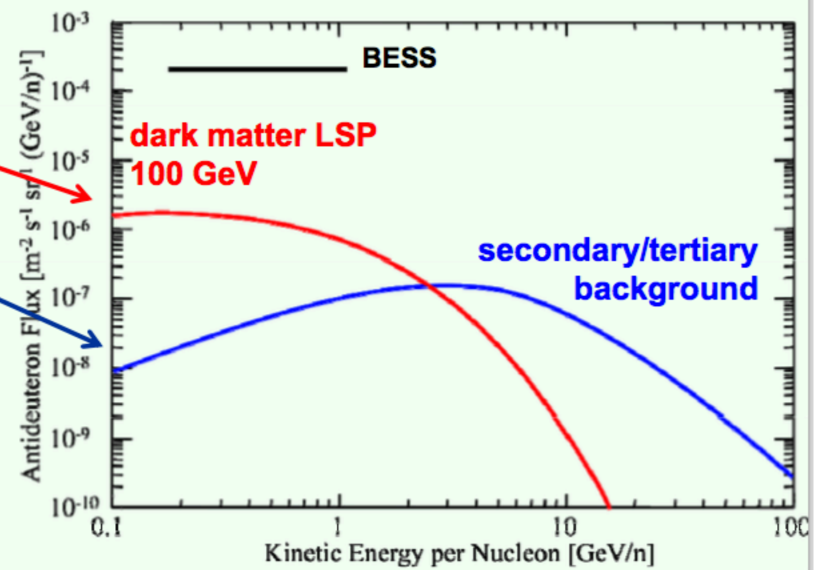
$p\,A \rightarrow \bar{d}\,X$ [via $p(\overline{pn})n$]

where A = p, He

1) Anti-deuterons provide extremely clean signature.
2) Detection of even a few events would be very interesting.
3) Low fluxes require a very sensitive detector.

DM production of $\bar{d}$



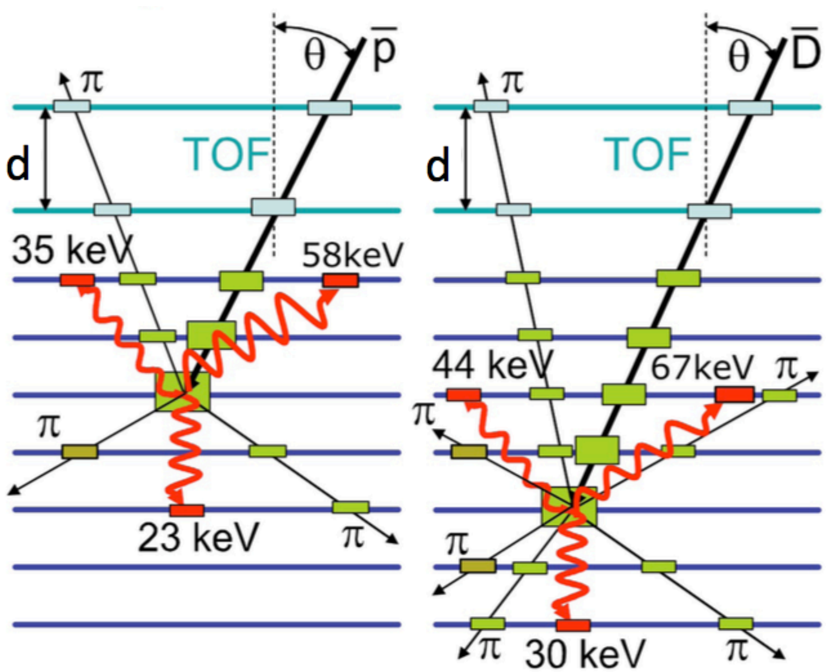


No dedicated anti-deuteron exists → GAPS

From R. A. Ong, Gaps Collaboration

The detection concept

- The antiparticle slows down by the dE/dX energy loss and stops in the target material
  - Formation of an exotic, excited atom
- The exotic atom de-excites with the emission of Auger electrons as well as atomic X-rays
  - Unique signature of the mass of the antiparticle
- The antiparticle is later on captured by the nucleus and annihilate
  - Annihilation products are another indication of the mass of the antiparticle

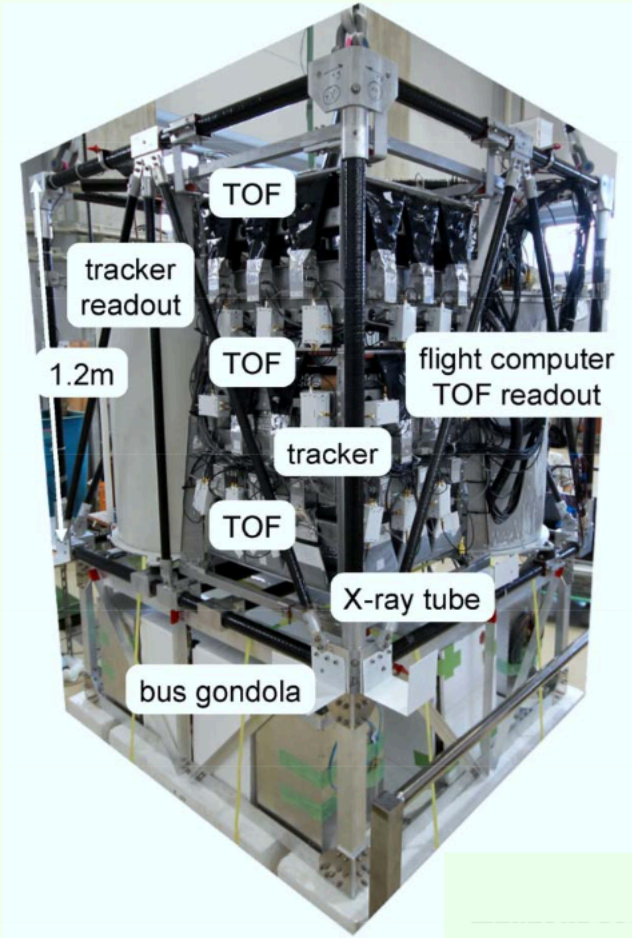


Low noise segmented Si(Li) detectors are used to reconstruct the event topology and identify the characteristics X-Ray

~8000 Si(Li) detectors will be used for the Long Duration GAPS balloon flight

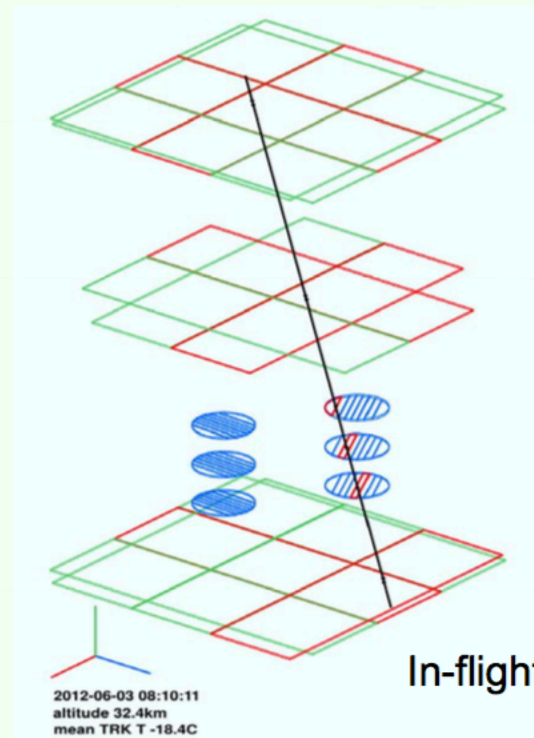
Efficient antiproton background rejection

Prototype GAPS Instrument



pGAPS Payload

GOALS:
- Demonstrate stable operations of detector components: Si(Li), TOF
- Si(Li) cooling: verify thermal model
- Measure incoherent backgrounds



In-flight event

A Long Duration Balloon flight is foreseen from Antarctica in 2020

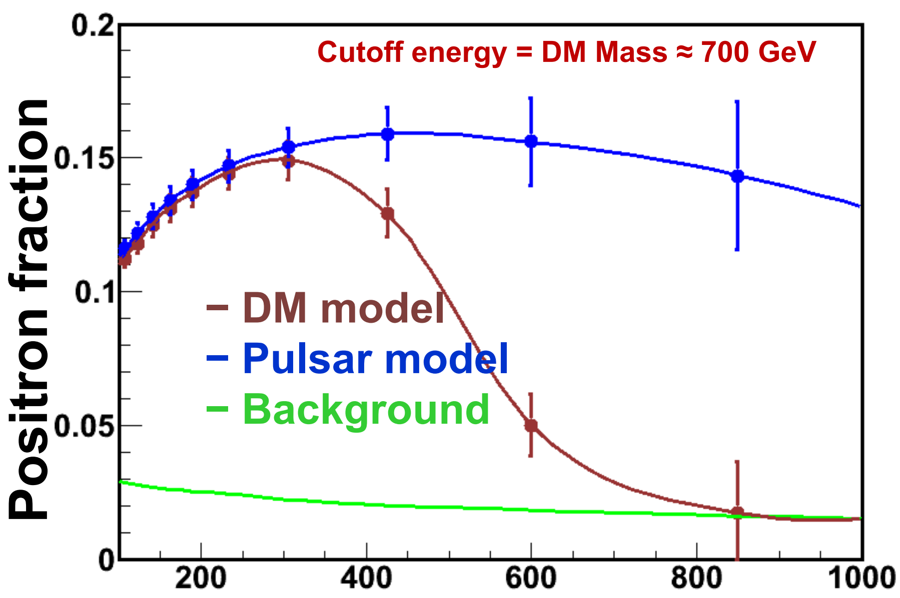
CHARGED COSMIC RAYS IN THE TEV-PEV ENERGY REGION

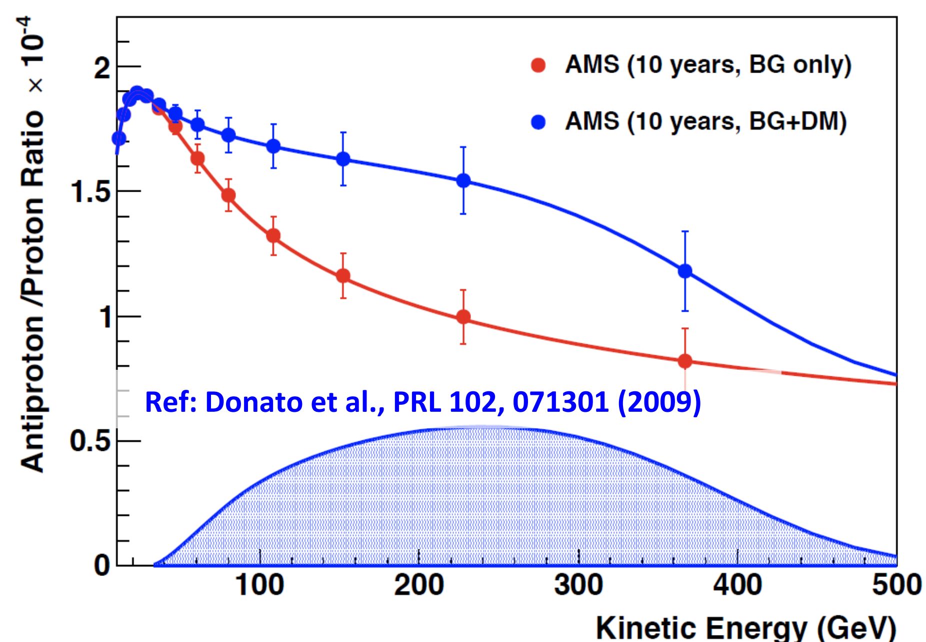
Some new ideas toward a novel optimized future detector

1: Measurements requiring the identification of the charge sign

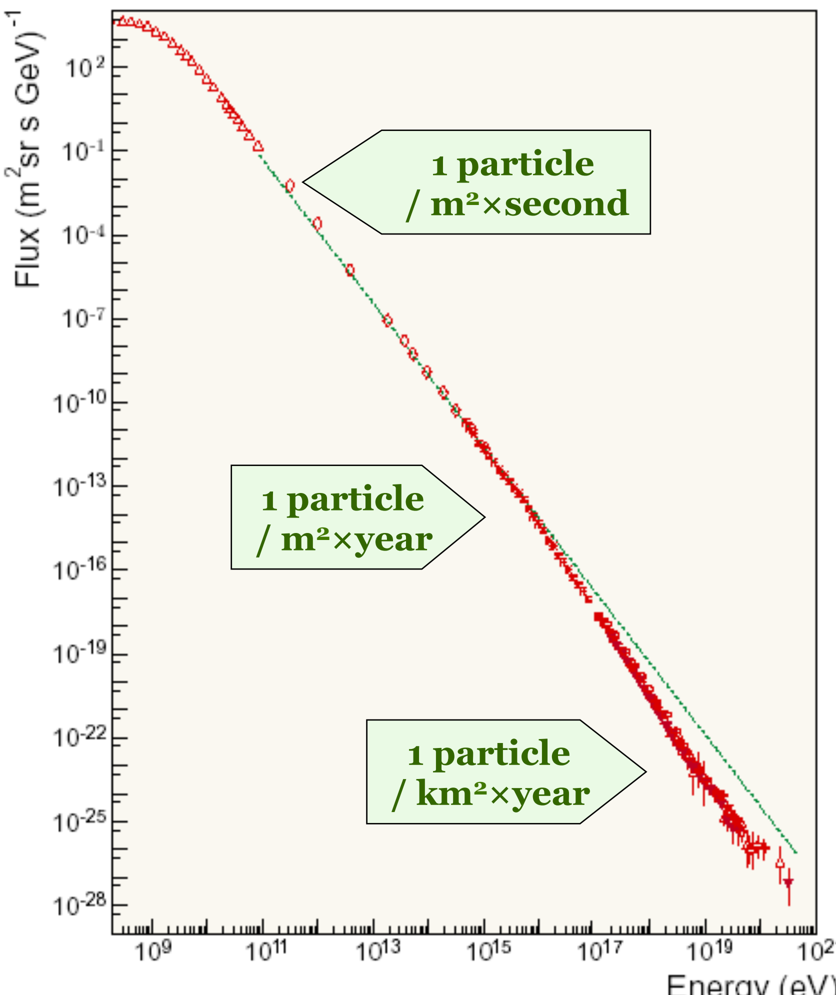
- Antiprotons, Positrons
- Magnetic spectrometers are necessary
  - Pamela/AMS/(Fermi)
- Current limits:
  - Positrons: up to 500 GeV
  - Antiprotons: up to 350 GeV

Expected AMS-02 reach in 10 more years





2: Measurements NOT requiring the identification of the charge sign



High energy nuclei

- **"Knee" structure around ~ PeV**
  - Upper energy of galactic accelerators (?)
  - Energy-dependent composition
- **Structures in the GeV – TeV region recently discovered for p and He**
  - Composition at the knee may differ substantially from that at TeV
- **Spectral measurements in the knee region up to now are only indirect**
  - Ground-based atmospheric shower detectors
  - High uncertainties

A direct spectral measurement in the PeV region requires great acceptance (many m^{2}sr), good charge measurement and good energy resolution for hadrons (much better than 40%)

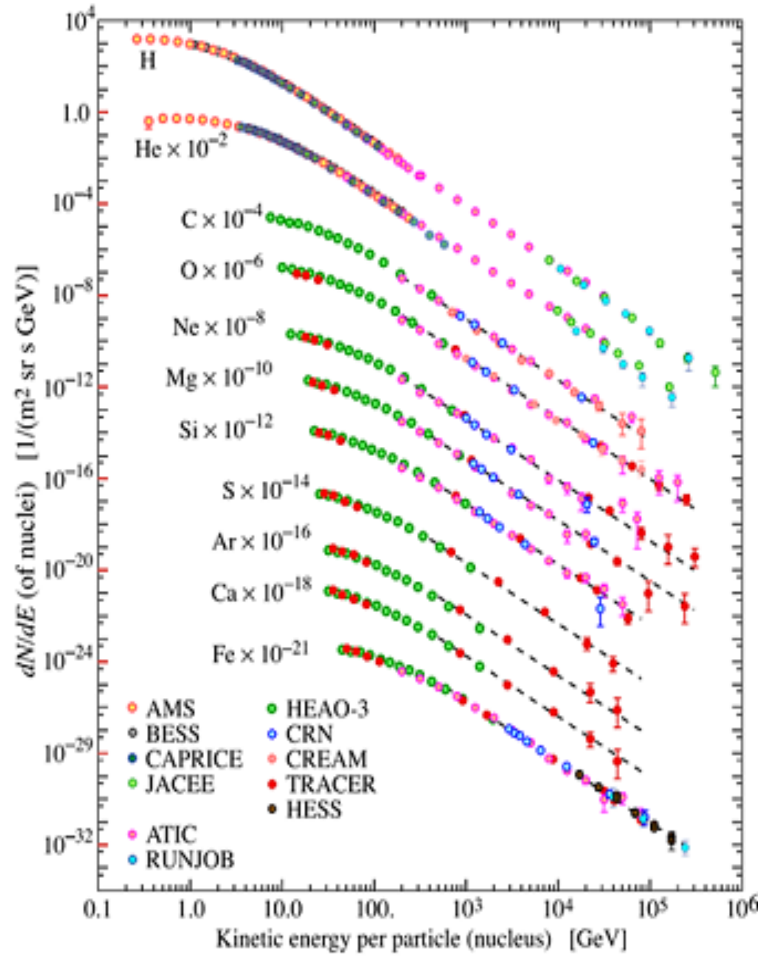
High energy Electrons+Positrons

- **Currently available measurements show some degree of disagreement in the 100 GeV – 1 TeV region**
- **Cutoff in the TeV region?**

Direct measurements require excellent energy resolution (~%), a high e/p rejection power (> 10^5) and large acceptance above 1 TeV

2: Measurements NOT requiring the identification of the charge sign

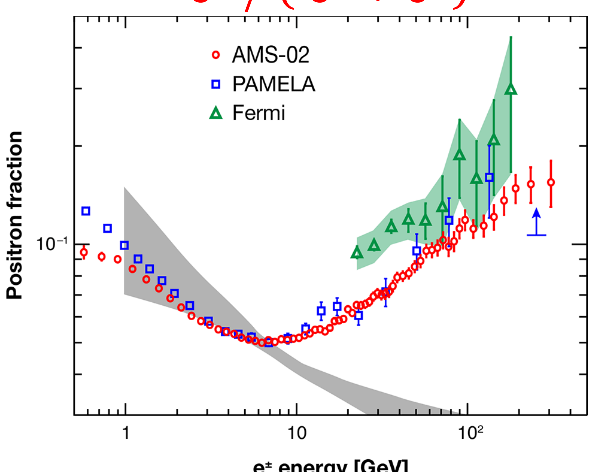
- Spectral features and chemical composition at the knee scale
  - Protons at the PeV scale
  - Helium Nuclei at the PV scale
  - Heavier Ions at the 100 TeV/PeV scale
- Up to now no measurements in orbit for E>few TeV
- Near future
  - Calet (recently installed on ISS)
  - Dampe (December 2015 on Chinese Satellite)
  - ISS-Cream (~2016 on ISS)
- Medium future
  - Herd on Chinese Space Station (>2022?)



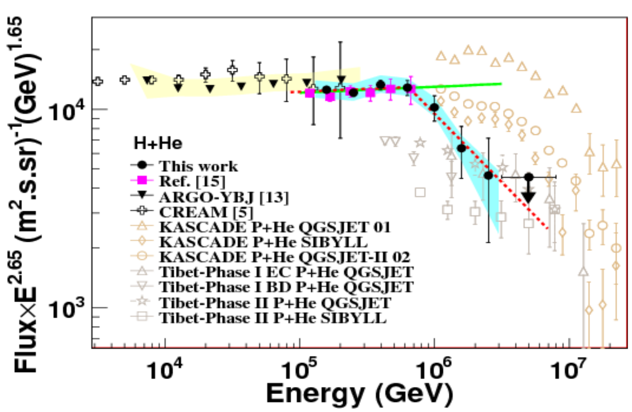
A new, very challenging approach (the astroparticle physicist dream?!)

- Combine the 2 techniques in a single experiment:
  - A very large acceptance calorimeter (few m² sr)
  - An extremely performing spectrometer, with MDR>10 TV
- Direct measurements above the knee (>1 PeV)
- Antimatter component detection above TeV

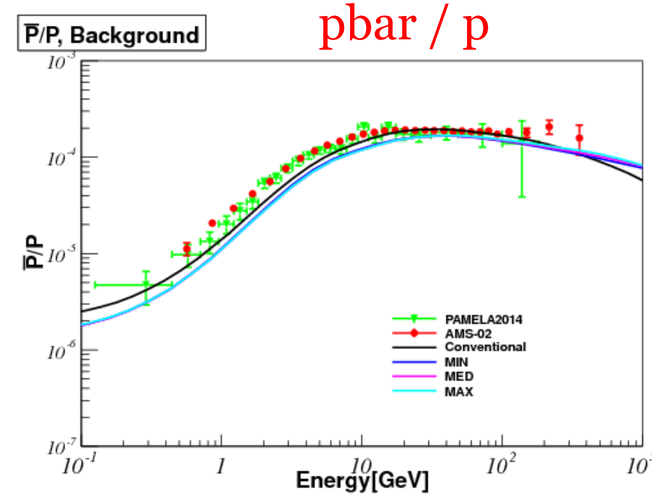
$e^+ / (e^+ + e^-)$



The knee”



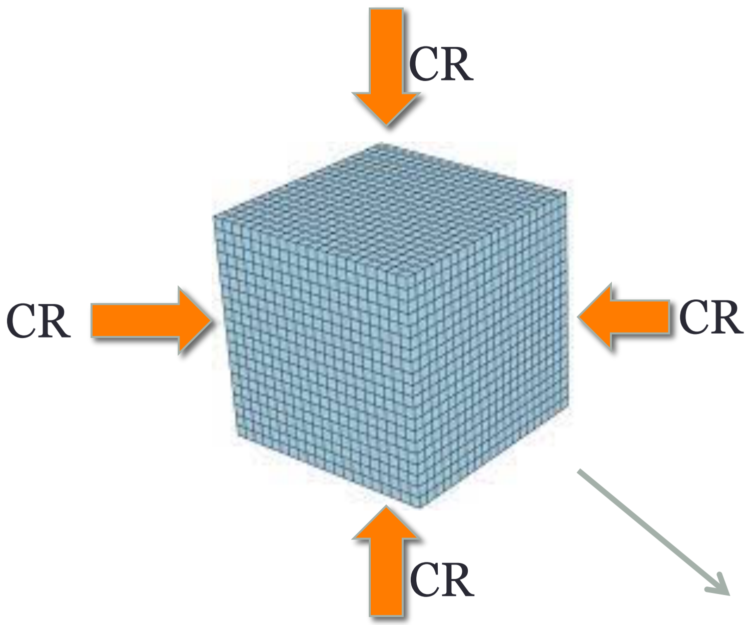
pbar / p



CaloCube (INFN CSN5)

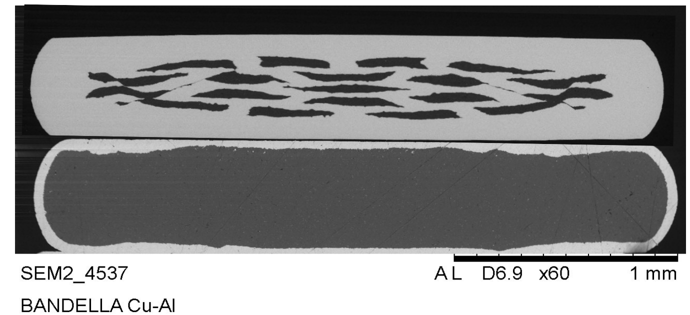
- Exploit the CR isotropy to maximize the effective geometrical factor, by using all the surface of the detector (aiming to reach $\Omega = 4\pi$)

- The calorimeter should be highly isotropic and homogeneous



SR2S (INFN and UE)

- R&D of high temperature superconducting magnets (MgB_2) for space applications (T $\approx$ 10÷20 °K)



Materials percentages:

titanium: 40%

alluminium: 50%

MgB_2: 10%

Quite small density: ≈ 3.4 g/cm^3

A novel idea for a next generation cosmic ray experiment in space

Assumption for the next slides:
2000 kg for the calorimeter
2000 kg for the magnetic material

Work and slides by Paolo Papini, thanks!

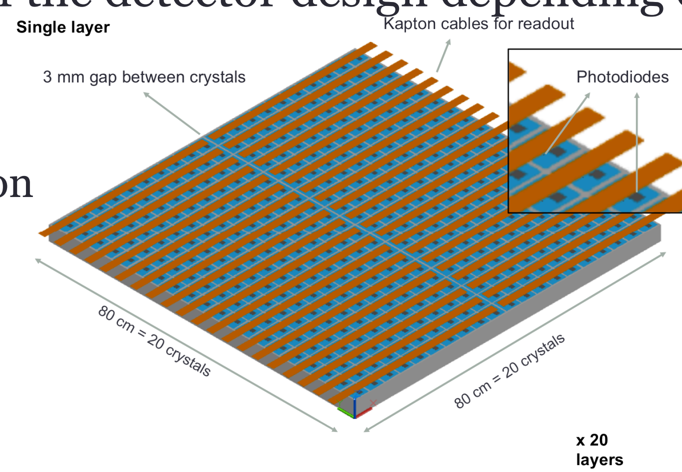
THE CALORIMETRIC PART

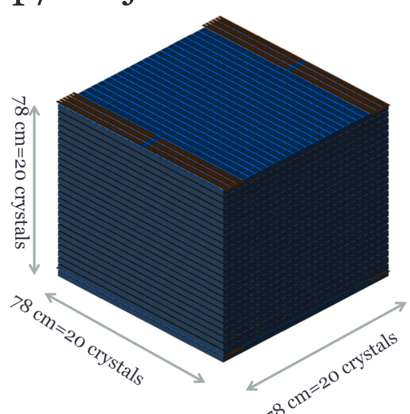
An interesting evolution of the CaloCube project!

Not many details reported here, have a look to the Calocube results presented elsewhere

The basic ideas of the CaloCube project

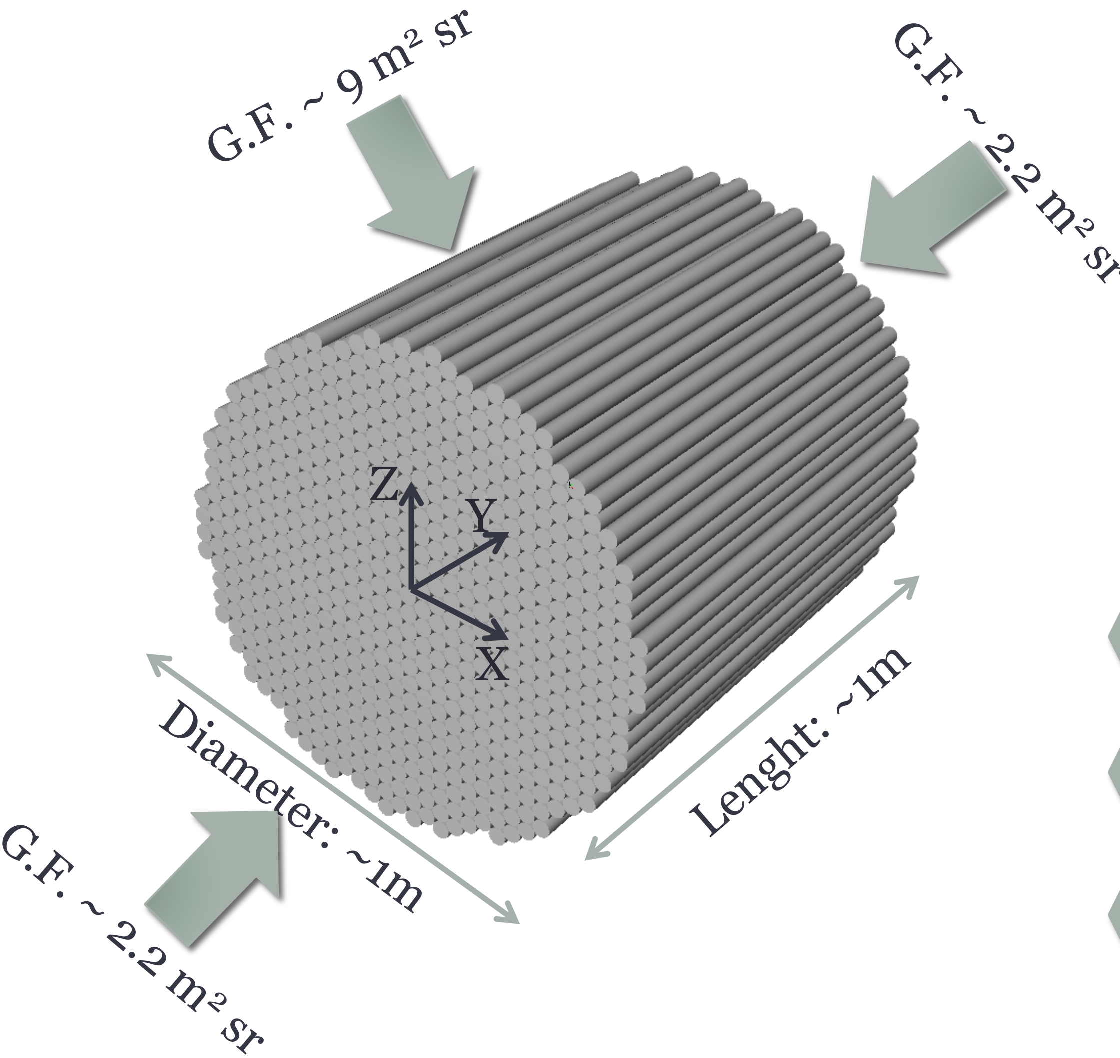
- **An homogeneus, deep, isotropic calorimeter**
  - can accept events from all sides → ~GF * 6
  - segmentation in every direction gives e/p rejection power by means of topological shower analysis
  - small size (~Molière radius) scintillating crystals for homogeneity
  - gaps between crystals increase GF and can be used for signal readout
    - small degradation of energy resolution
  - modularity allows for easy resizing of the detector design depending on the available mass&power
  - dual/multiple readout
    - Improve the hadronic energy resolution
    - Improve the p/e rejection

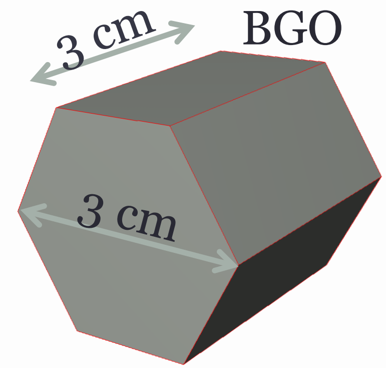




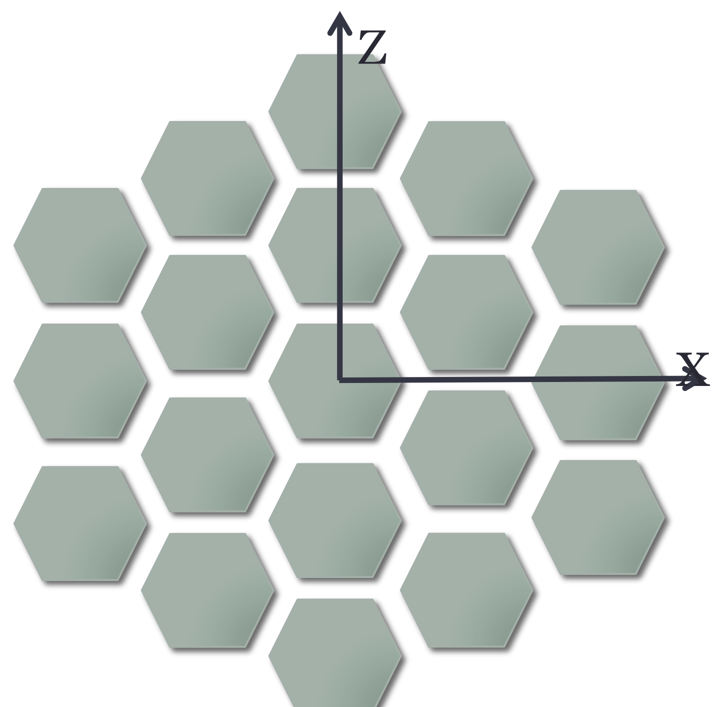
A Cylindrical shape calorimeter with 3D hexagonal tesselation

Weight~2000 kg
N. crystals: 15925

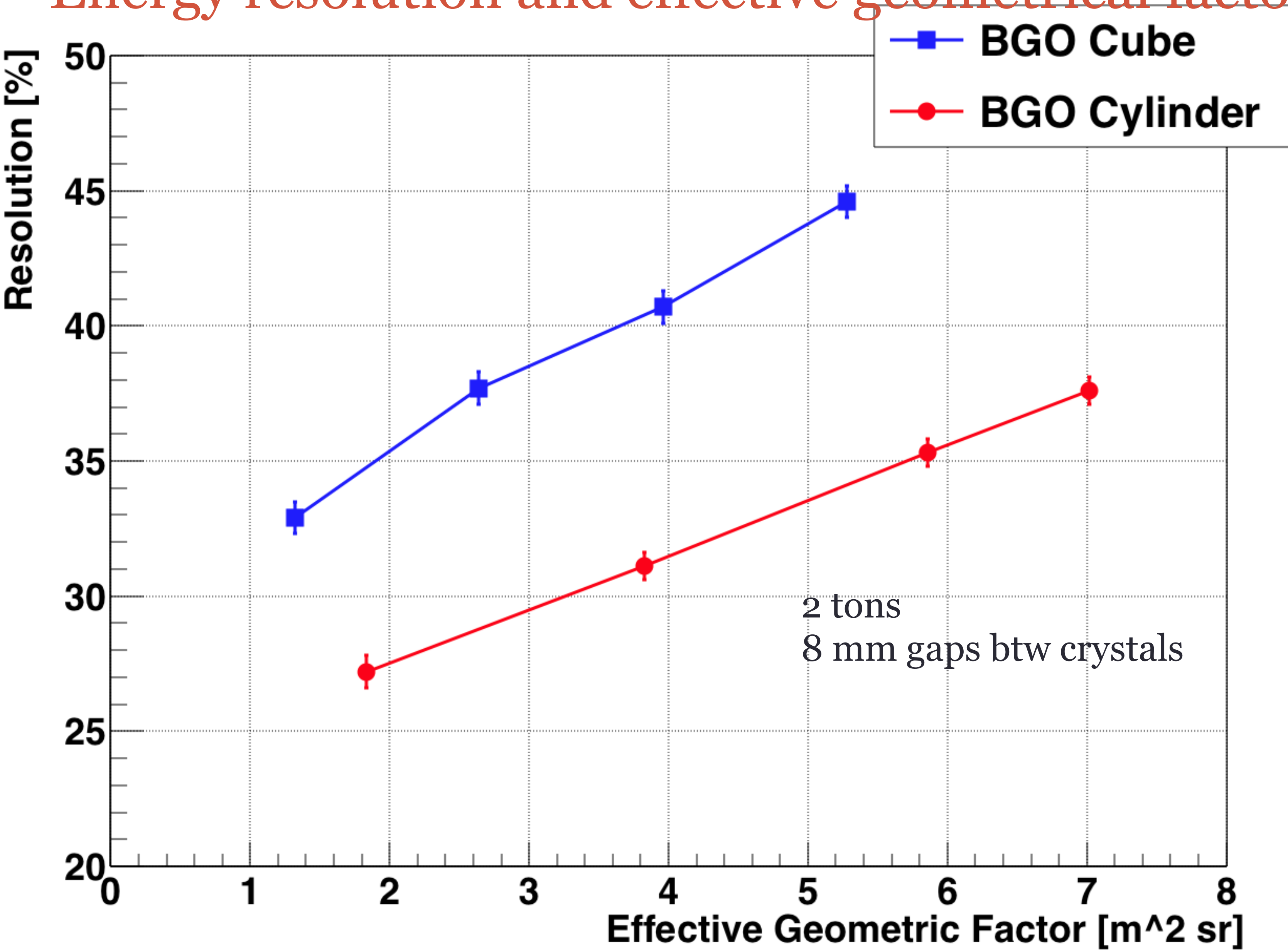




Basic crystal: hexagonal base prisma



1 TeV protons
Energy resolution and effective geometrical factor



Expected number of high energy charged cosmic rays events with a GF_{eff}=10 m² sr

Some assumptions:

- 10 years exposure
- e/p rejection factor ~ 10^5

Protons and Helium (Polygonato model)												
Effective GF (m² sr)	σ(E)/E	E>0.1 PeV		E>0.5 PeV		E>1 PeV		E>2 PeV		E>4 PeV	
		p	He	p	He	p	He	p	He	p	He
~10.0	35%	20.10^3	19.10^3	$1.1.10^3$	$1.3.10^3$	$3.0.10^2$	$3.7.10^2$	70	110	12	25

Electrons (no nearby sources)					
Effective GF (m² sr)	σ(E)/E	E>0.5 TeV	E>1 TeV	E>2 TeV	E>4 TeV
10	~1%	550.10^3	105.10^3	15.10^3	18.10^2

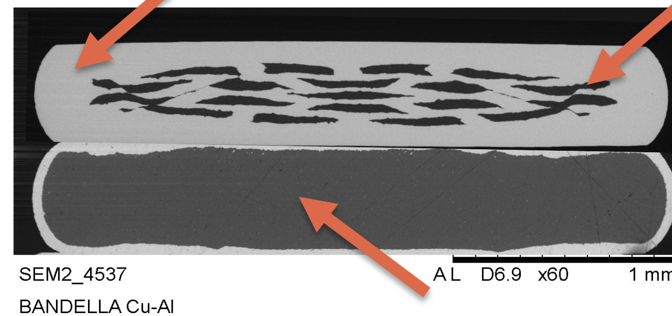
THE MAGNETIC SPECTROMETER

Disclaimers: these are mainly ‘ideas’ that should be carefully cross checked by Superconducting Magnets experts! Estimates probably quite conservatives?!

Columbus cable for SPACE applications (SR2S project)

TITANIUM cladding

19 MgB_2 filaments



ALUMINUM tape laminated

Materials densities:

titanium: ρ= 4.5 g/cm^3

alluminium: ρ= 2.7 g/cm^3

MgB_2: ρ= 2.55 g/cm^3

Materials percentages:

titanium: 40%

alluminium: 50%

MgB_2: 10%

Materials weights per component (per meter):

titanium: 5.4g

alluminium: 4.0g

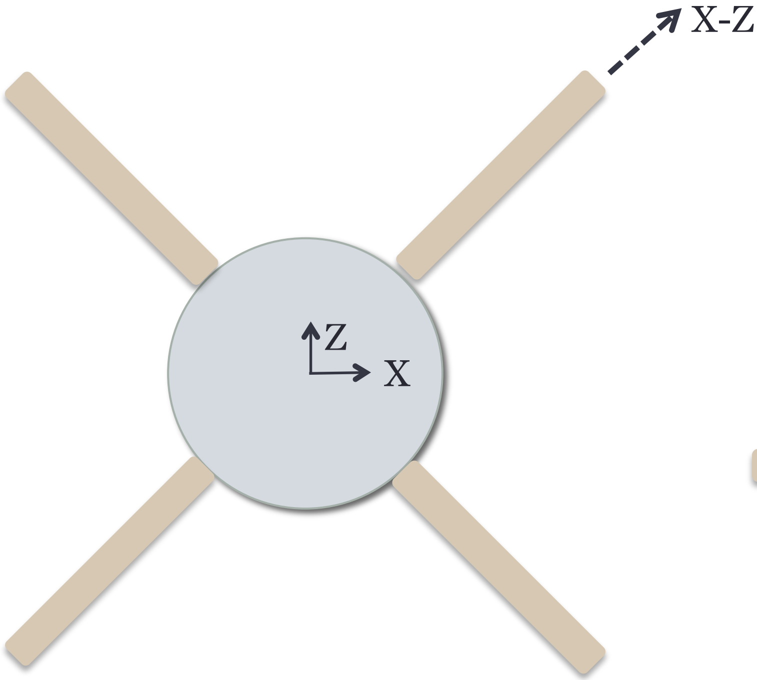
MgB_2: 0.77g

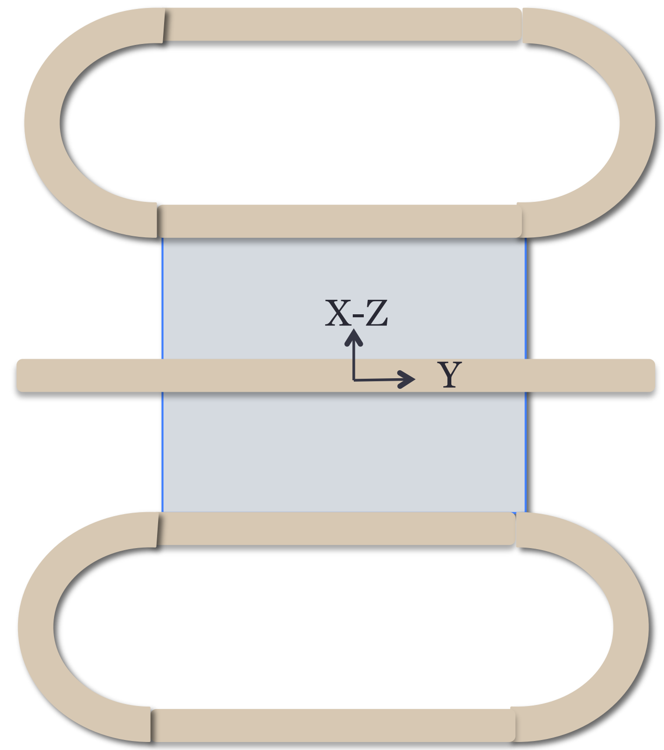
Global weight per 1m of MgB_2 SPACE app. cable: 10.2 grams

Cryogen free SC magnet, T>10K

Equivalent Mass Density = 3.4 g/cm^3

Toroidal magnetic configuration





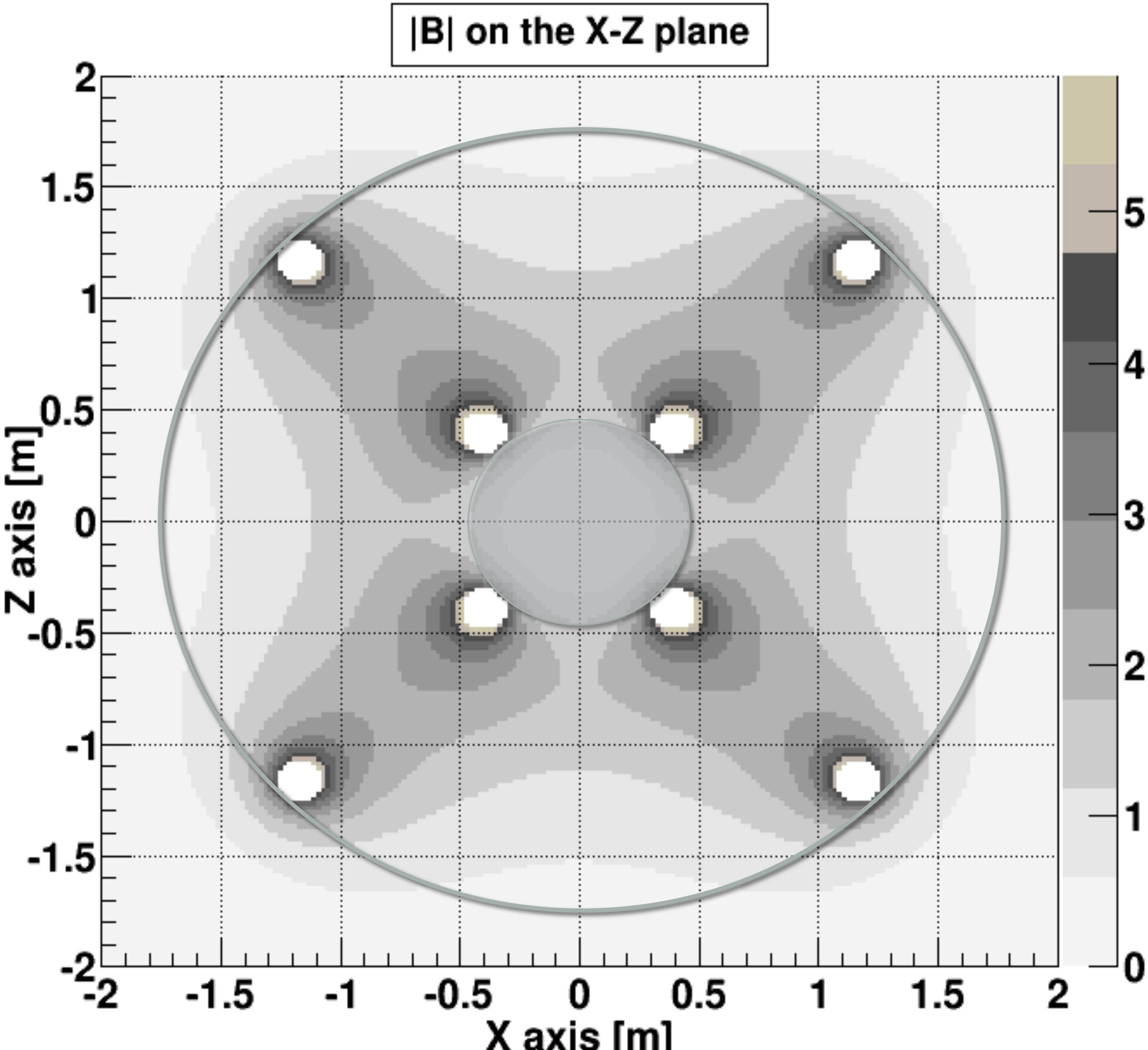
The magnetic system should be optimized taking into account the relationship btw maximum current density and maximum B field

Calorimeter diameter: 93.35 cm
Calorimeter length: 96.8 cm
External diameter: 350 cm
Weight of the magnetic material: 2000 kg
Current density: 83.6 A/mm^2
Number of coils: 4

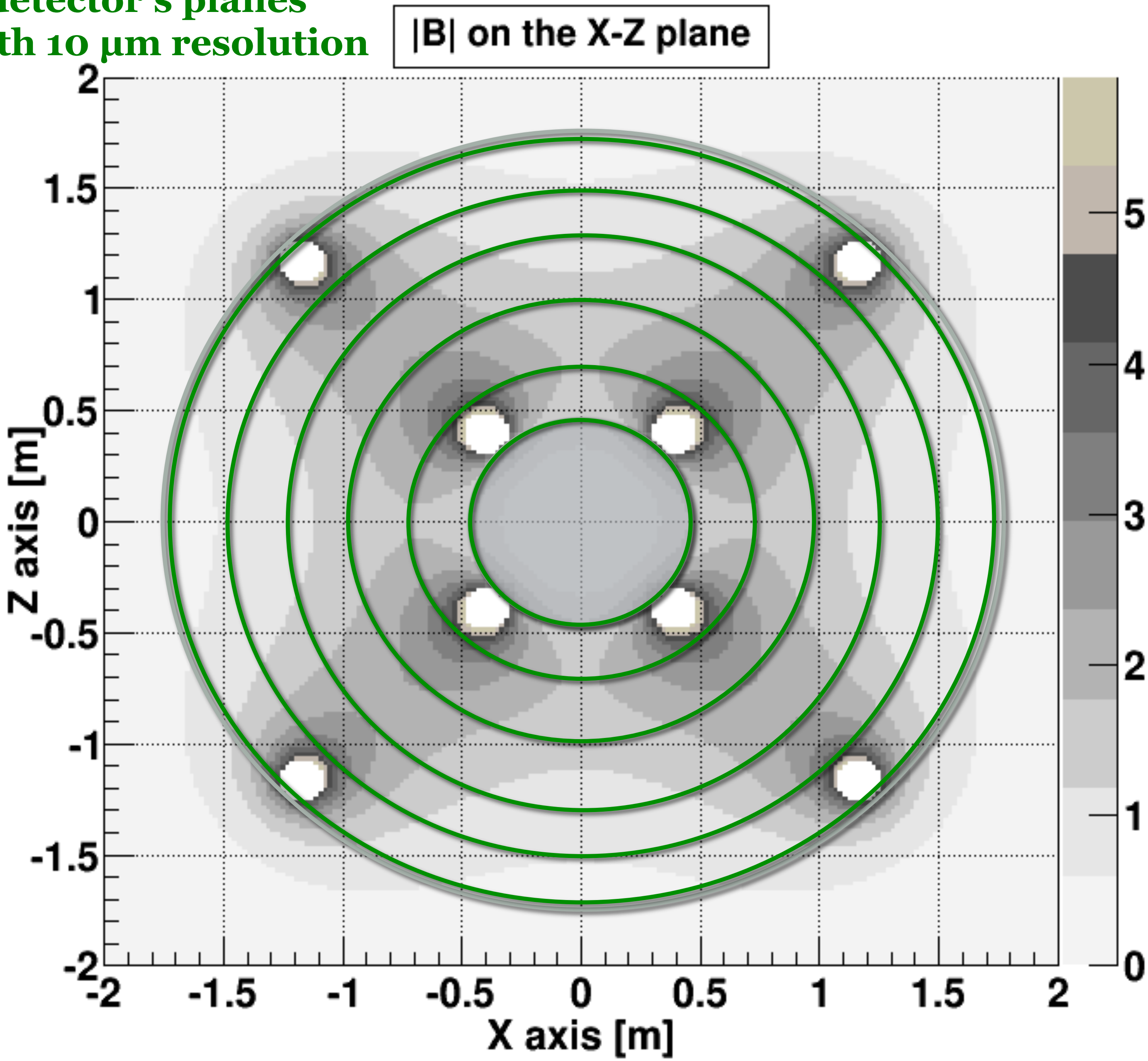
Coils diameter: 18.65 cm
Maximum field: 6.9 T

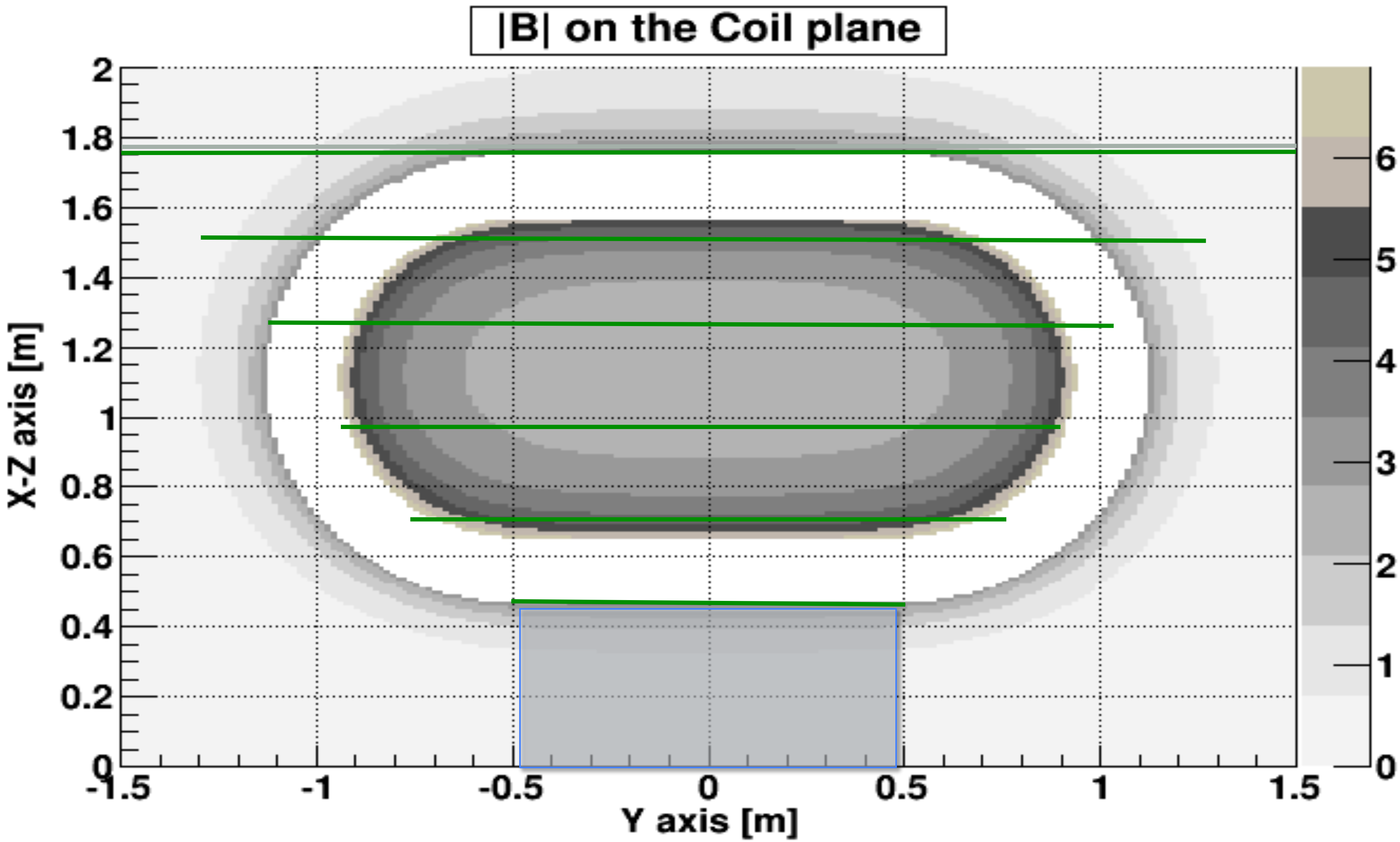
Advantages of the toroidal configuration:

- Null Magnetic Moment
- Compensation coils not necessary

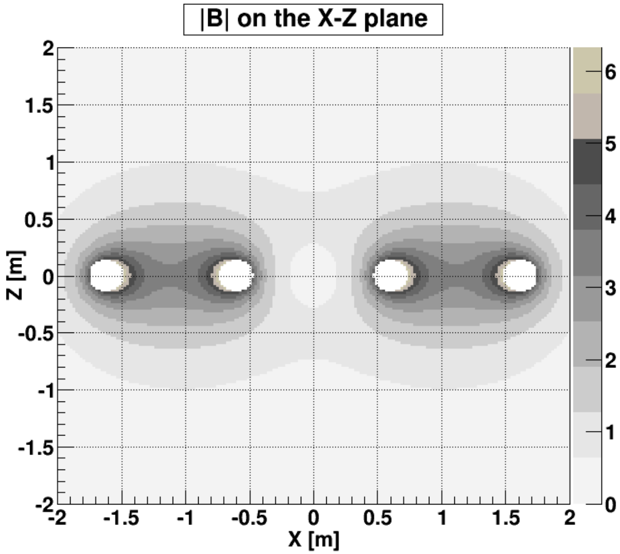

|B| on the X-Z plane
Z axis [m]
X axis [m]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
5
4
3
2
1
0

6 detector's planes with 10 μm resolution

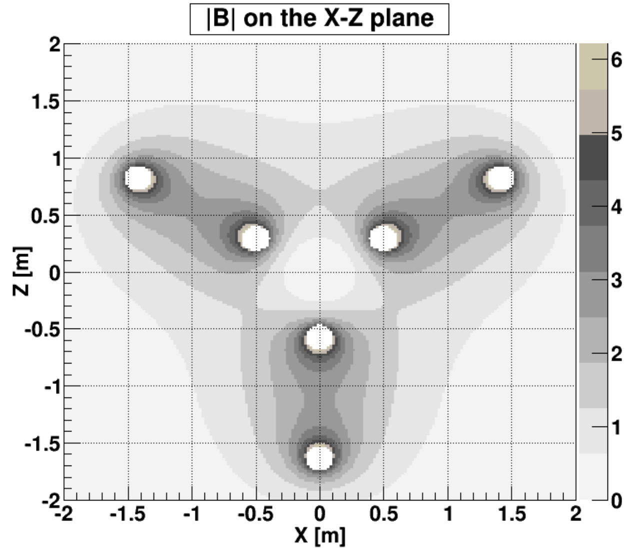




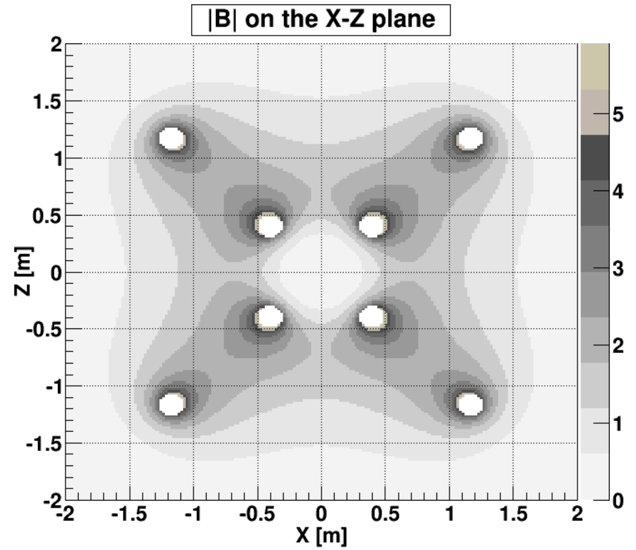
|B| on the Coil plane
X-Z axis [m]
Y axis [m]
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-1.5
-1
-0.5
0
0.5
1
1.5
6
5
4
3
2
1
0



2 spire

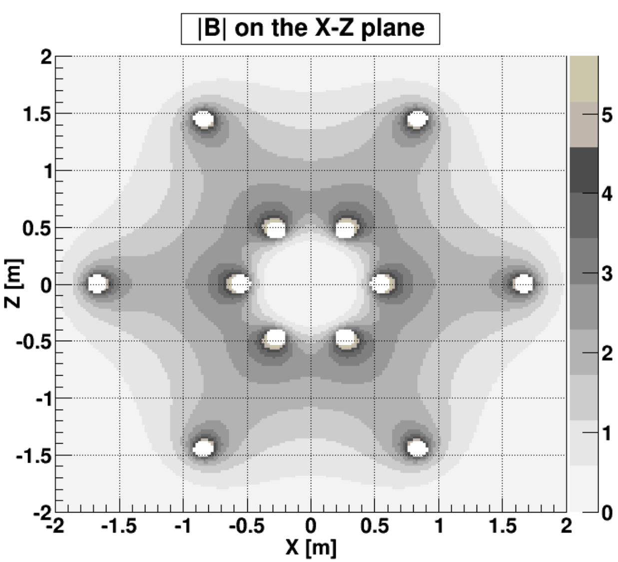


3 spire

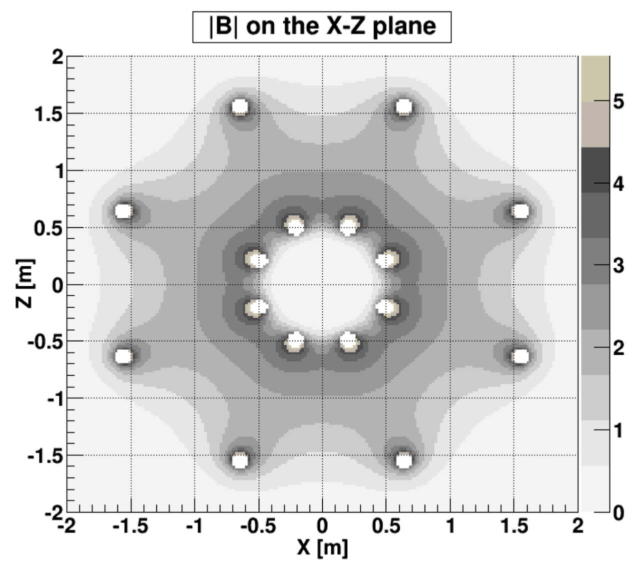


4 spire

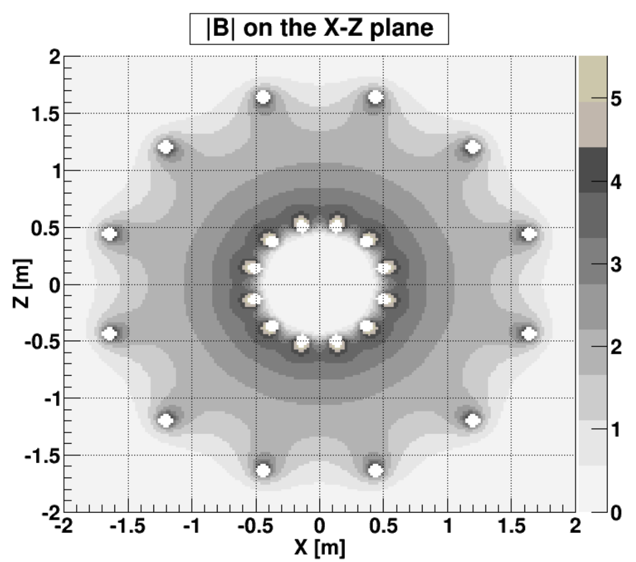
The number of coils can be optimized



6 spire

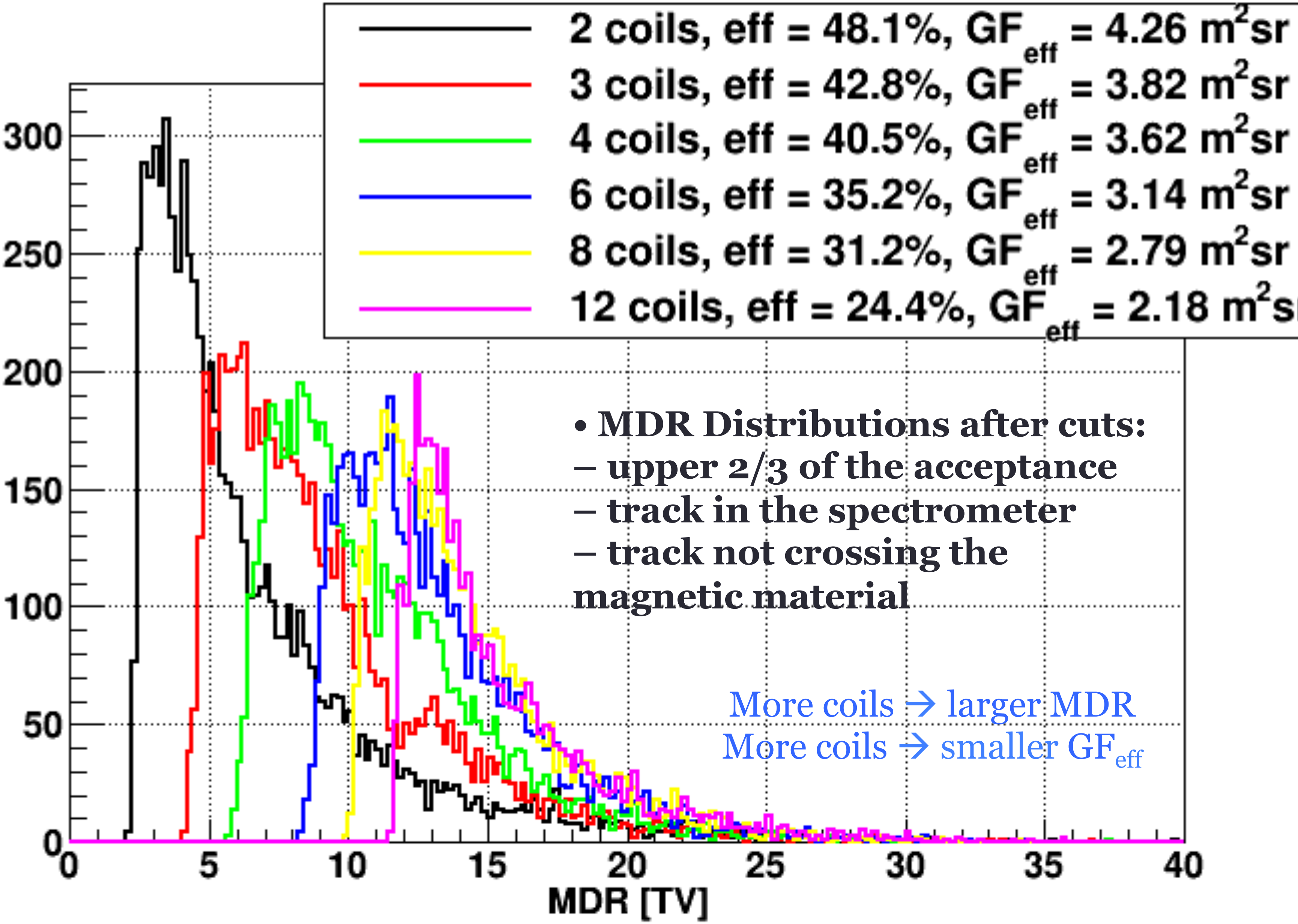


8 spire



12 spire

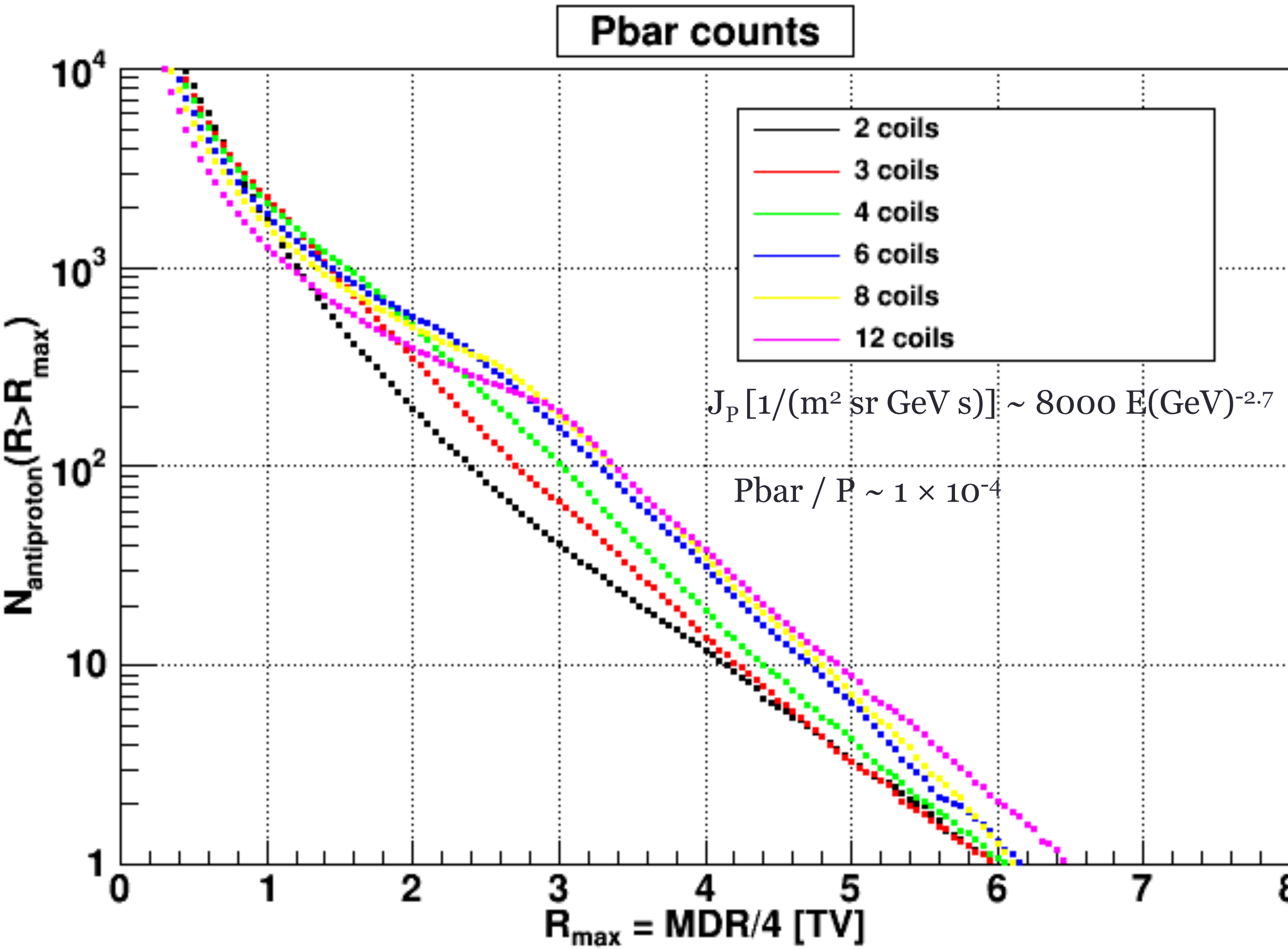
MDR: a way to estimate the performance in the antimatter detection



- **MDR Distributions after cuts:**
  - **upper 2/3 of the acceptance**
  - **track in the spectrometer**
  - **track not crossing the magnetic material**

More coils → larger MDR
More coils → smaller GF$_{eff}$

Expected antiprotons with rigidity>MDR/4 (to reject spillover events) for different magnetic configurations in 5 years



C

In summary.....

- Calorimetric part: ~ 2000 kg
- Magnetic system: ~ 2000 kg
- Tracking system: < 100 m^2 with 10 μm spatial resolution
- Maximum Detectable Rigidity ~ 20 TV

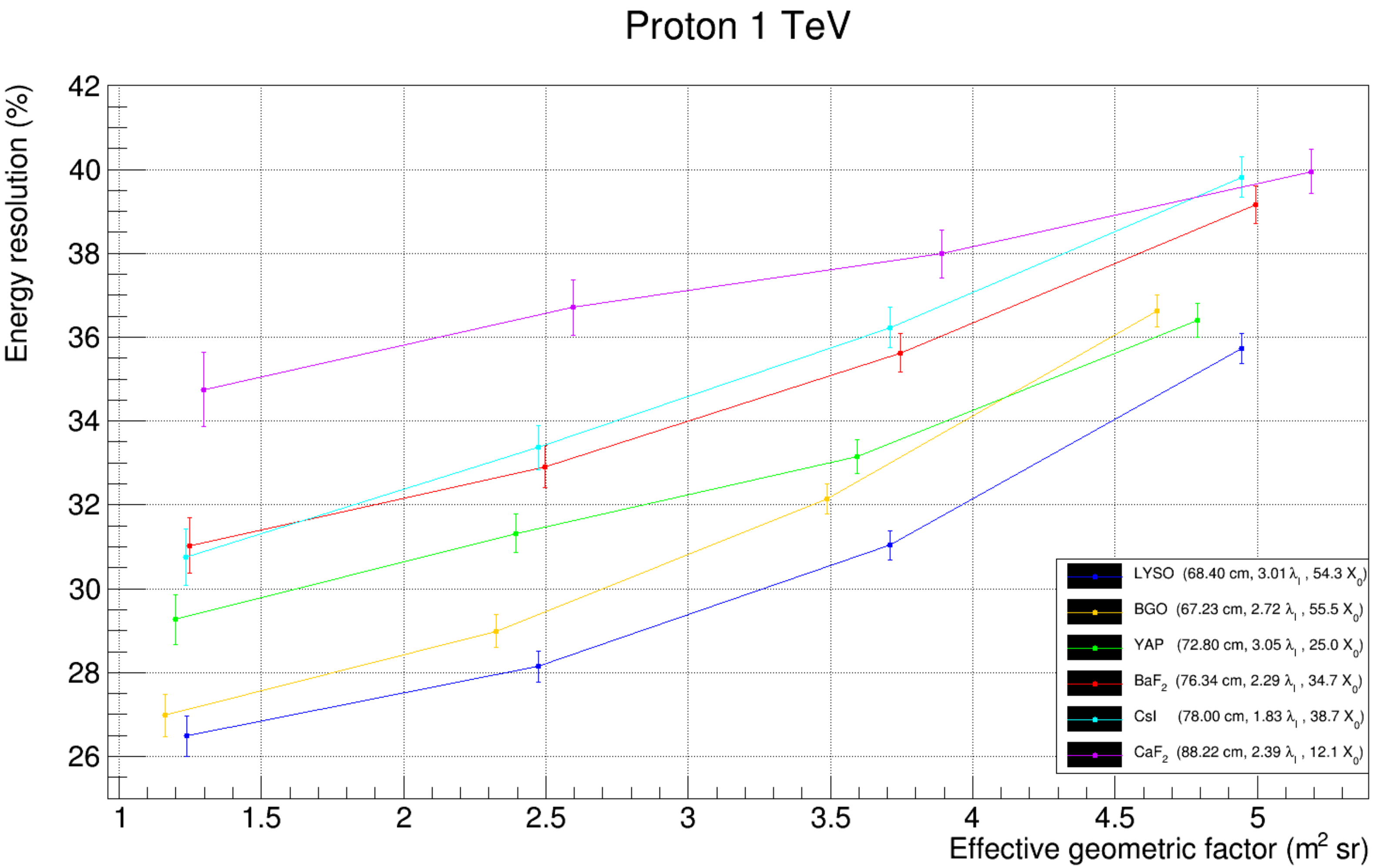
- With this giant, but not impossible, system, in 10 years of data taking we can reach:
  - The knee region for direct CR measurement
    - Few hundreds p and He events above 10^{15} eV
  - The multi TeV region for charged antiparticles
    - ~4000 really measurable antiprotons above 1 TeV
    - ~20 really measurable antiprotons above 5 TeV
  - The multi TeV region for electrons and positrons separately

Conclusions

- I didn't have time to cover all the interesting CR from space related aspects
- Most important skipped items (Sorry! ☹):
  - R&D for Gamma ray detectors (in the sub MeV-GeV range)
    - Key points:
      - Very large area silicon only detectors (~ 100 m^2)
      - Very low noise and very low energy threshold to reach the Compton Region, important for the MeV range
  - R&D for the Extreme energy region (in the style of EUSO, $>10^{18}$ eV)
    - Detection from space of fluorescence light induced by atmospheric showers
    - Key points:
      - Very performing UV optical system
      - Very efficient light detection system (large R&D effort on cooled arrays of UV sensitive SiPM)
  - Low energy X-ray detectors, with focus on the polarization measurement (XIPE, LOFT, XTP)
  - Sub-GeV Antideuteron detection with clear X-ray annihilation signature (GAPS)
  - Multi purpose calorimeter+magnetic spectrometer to investigate both:
    - Multi TeV range antiparticles
    - Nuclei measurement in the knee region (>PeV energies)
  - Space experiments are always very difficult and challenging, but also very exciting!

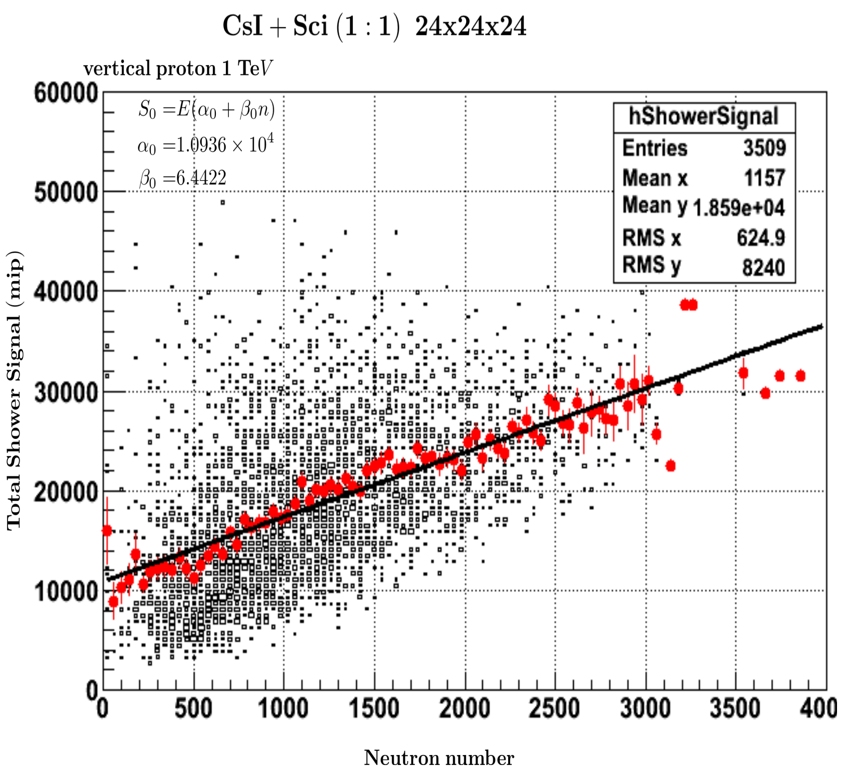
BACKUPS

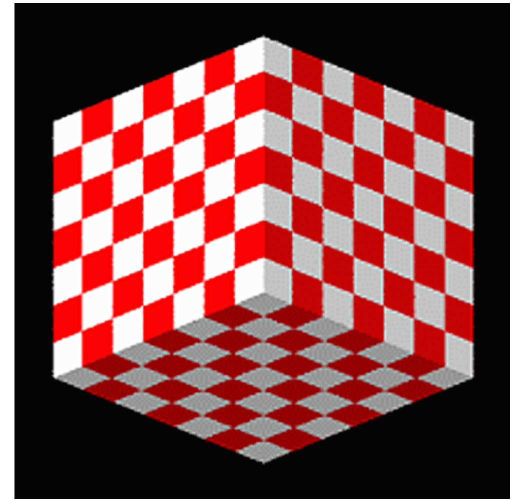
Effective geometrical factor for a 2 tons cubic calorimeter

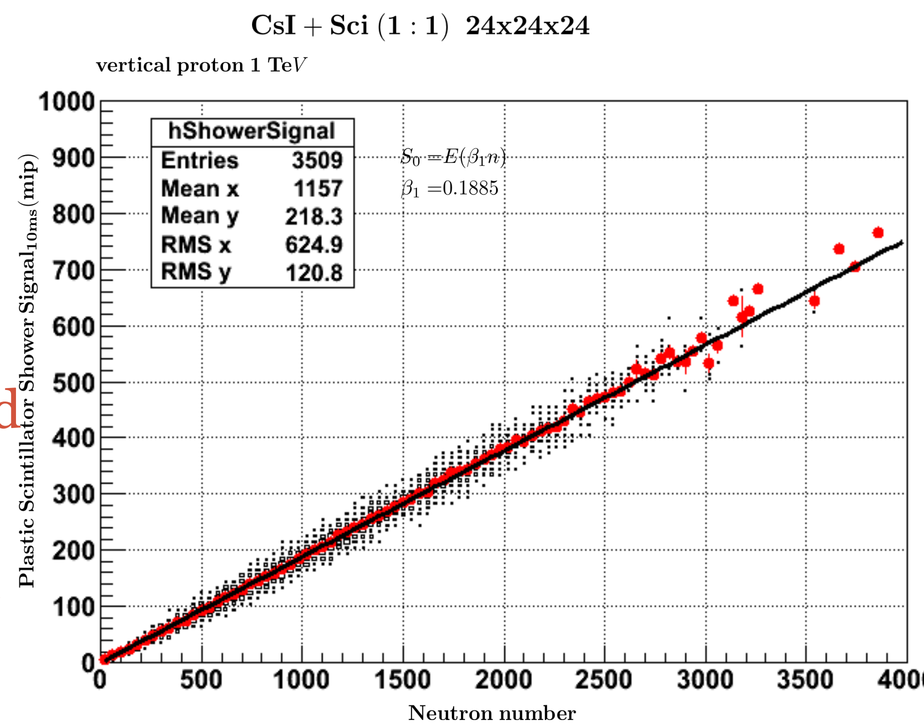


We can obtain different GF by applying different selection criteria

The Dual Readout option





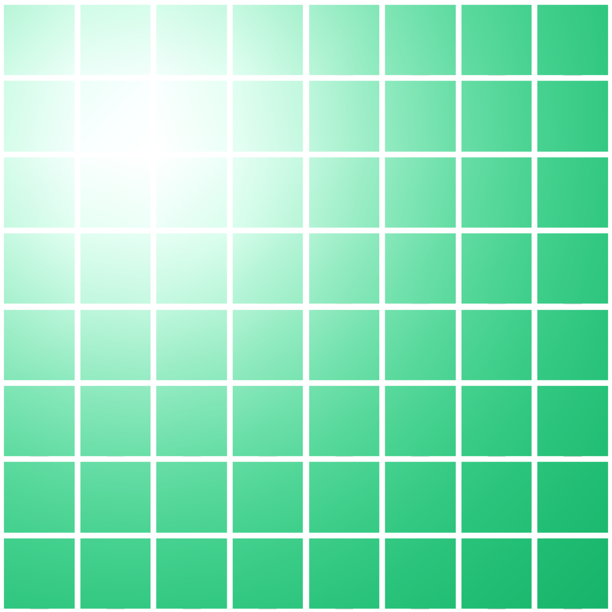


The number of neutrons N_n is correlated to the energy release

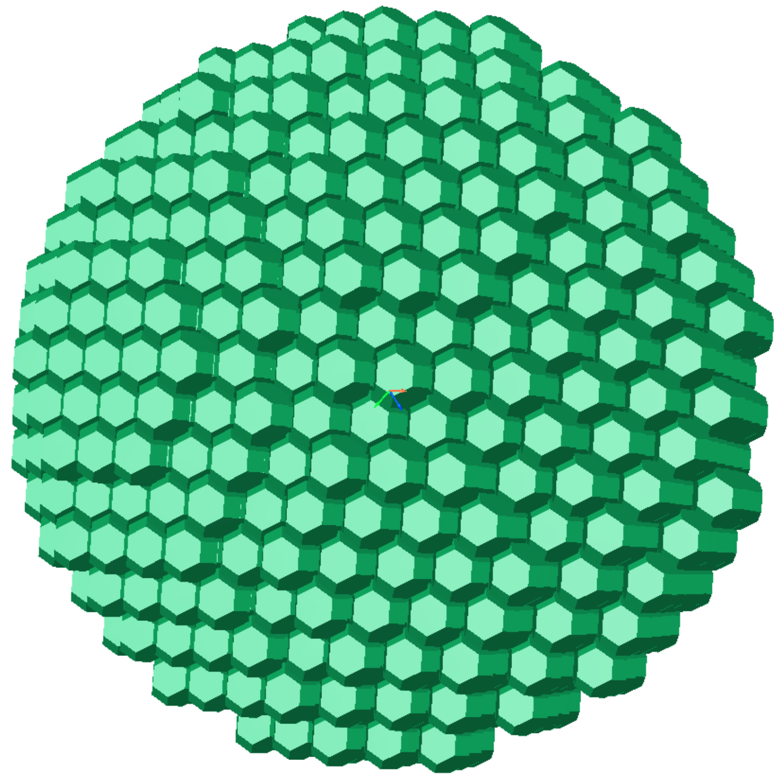
And delayed signal in plastic scintillator is a good tool to estimate N_n!

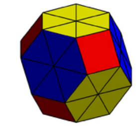
A more exotic solution

Cubic configuration with small size cubic crystal
Simpler from the mechanical point of view



Spherical configuration with small crystals with truncated octahedron shape
More complex from the mechanical point of view



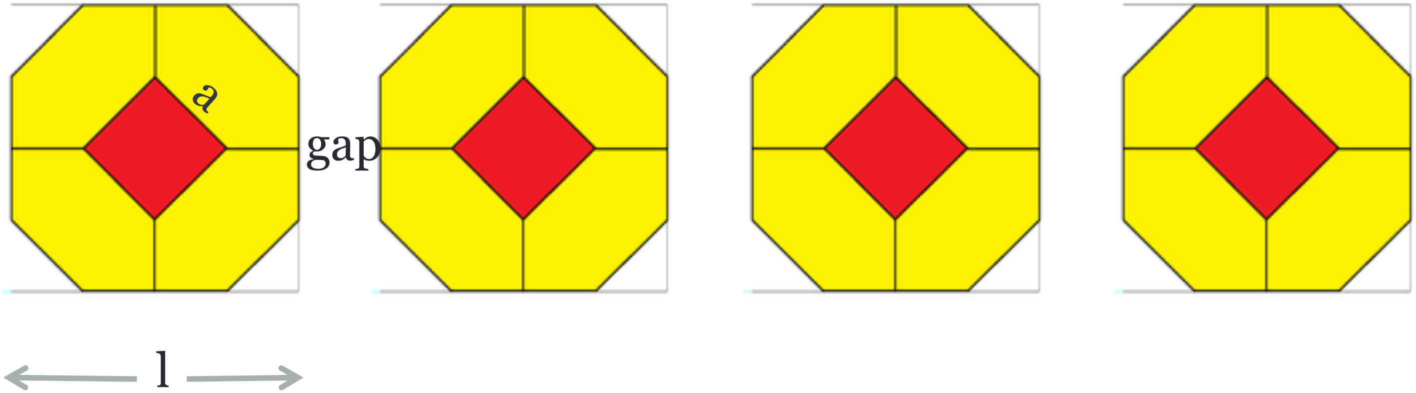


Basic ideas:

- Reduce as much as possible the leakages by avoiding possible escape planes
- Spherical geometry to increase the acceptance (maximize the surface, and hence the GF, once the weight is fixed)

Optimization criteria:

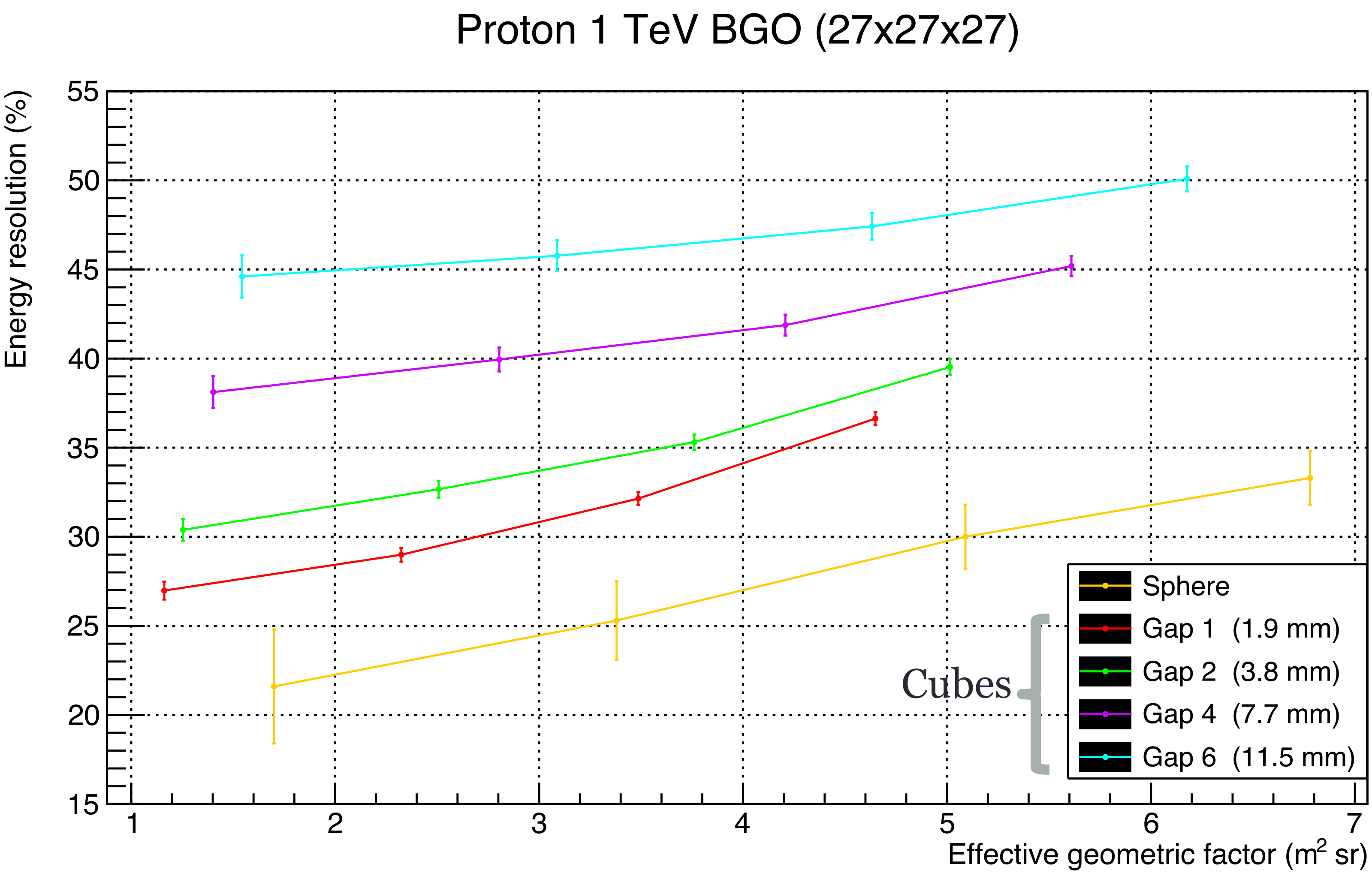
- Crystals dimensions
- Gap btw crystals to increase the acceptance



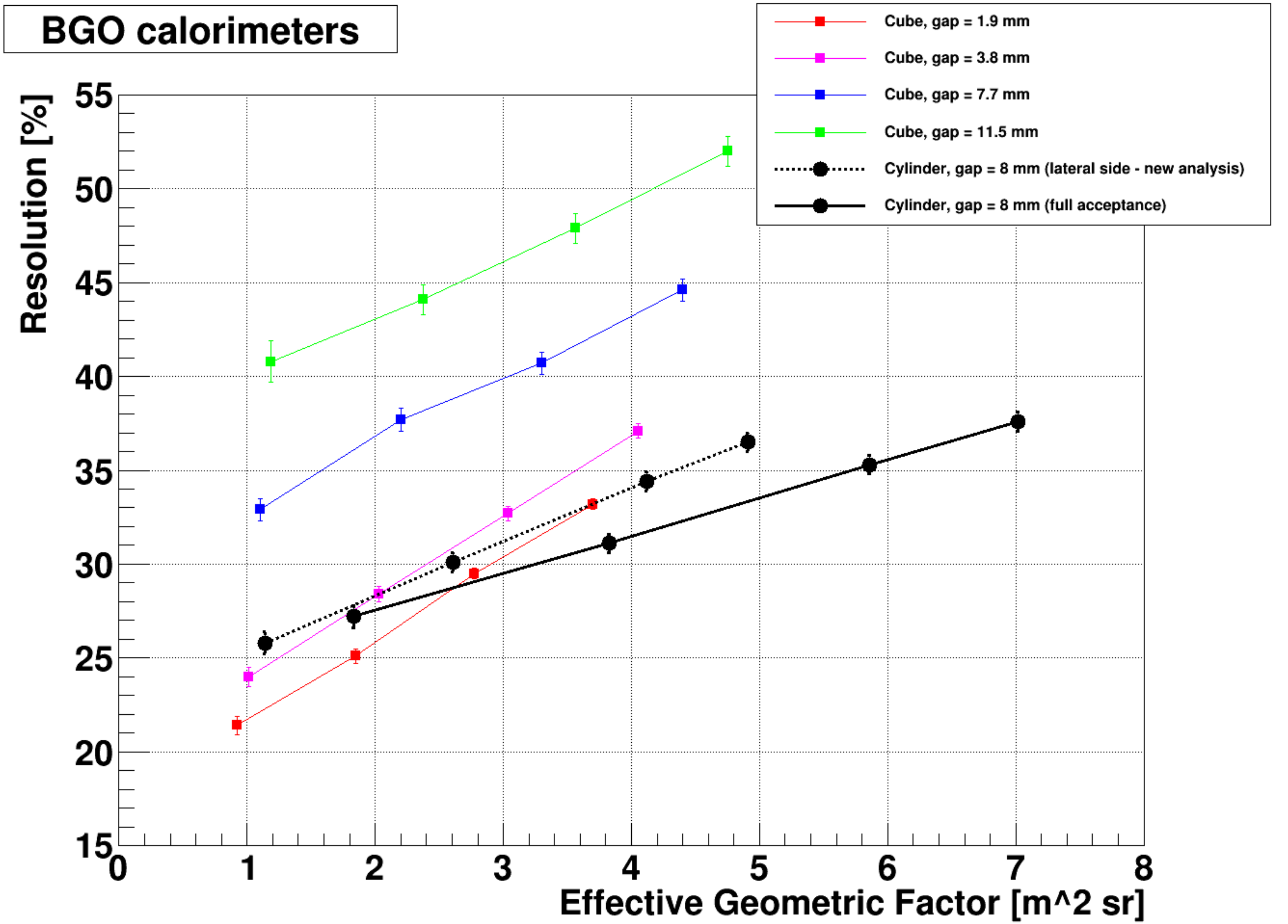
Size of the red square	a = *1.2 cm*	Single crystal
Size of the yellow cubic envelope	$l = \sqrt{2} \times 2 \times a = 3.4$ cm	
Gap	gap = *0.8 cm*	
Volume	$V = 8 \times \sqrt{2} \times a^3 = 19.55\ cm^3$	
Weight	W = *139.4 g*	

Number of crystals along the diameter	*25*	
Total number of crystals	*14361*	Spherical calorimetric
External Diameter	*103.6 cm*	
Total weight	*2002 kg*	
Depth on the diameter	$3.75\ \lambda_I$	
Geometrical factor	$10.6\ m^2\ sr$	

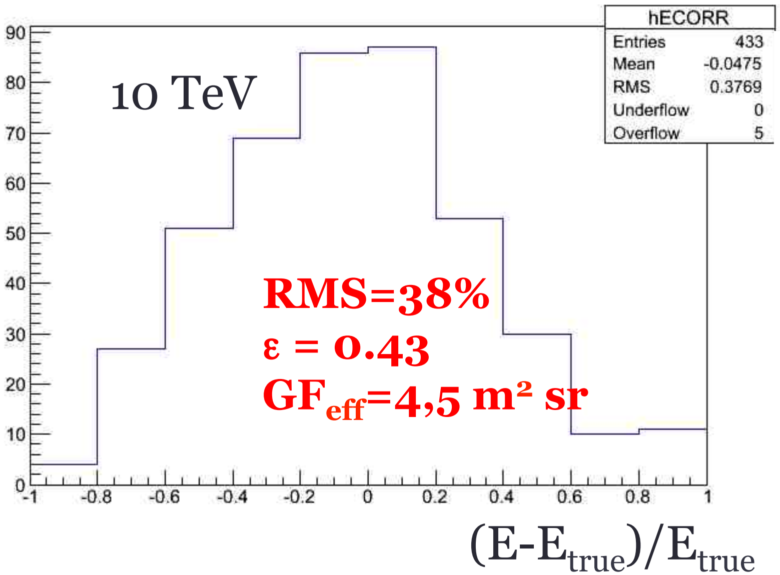
The Spherical Calorimeter

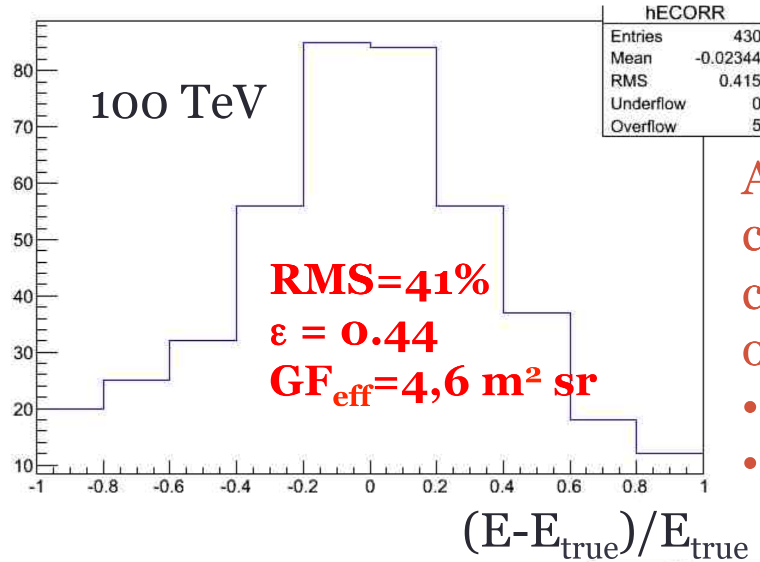


Ho definito gli assi dello sciame in analogia col momento di inerzia in meccanica.
Si determina quindi l'asse dello sciame senza riferimenti geometrici esterni.



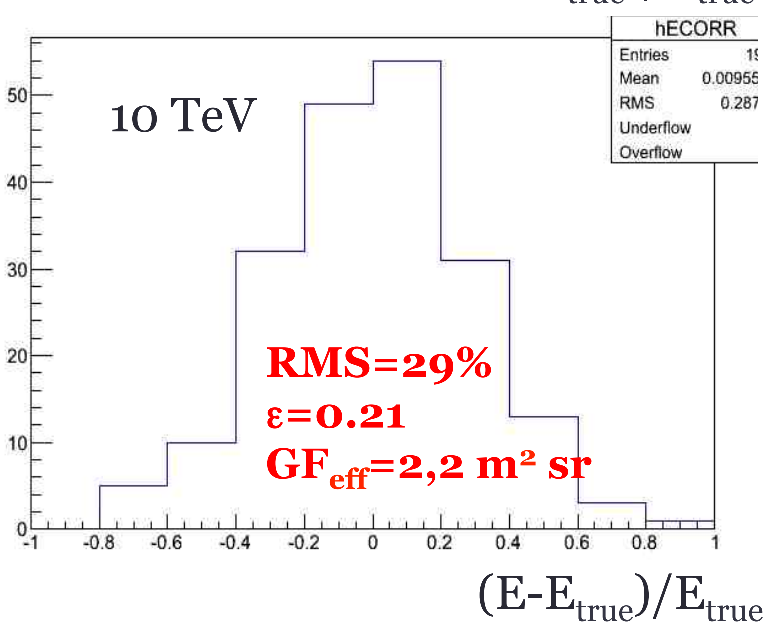
Protons: energy resolution

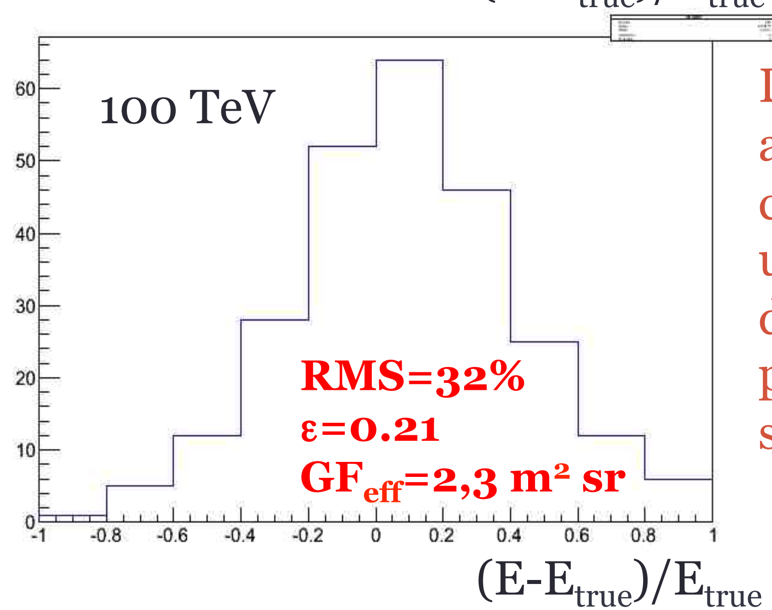




Analysis criteria can be changed to optimize:

- Acceptance
- Energy resolution

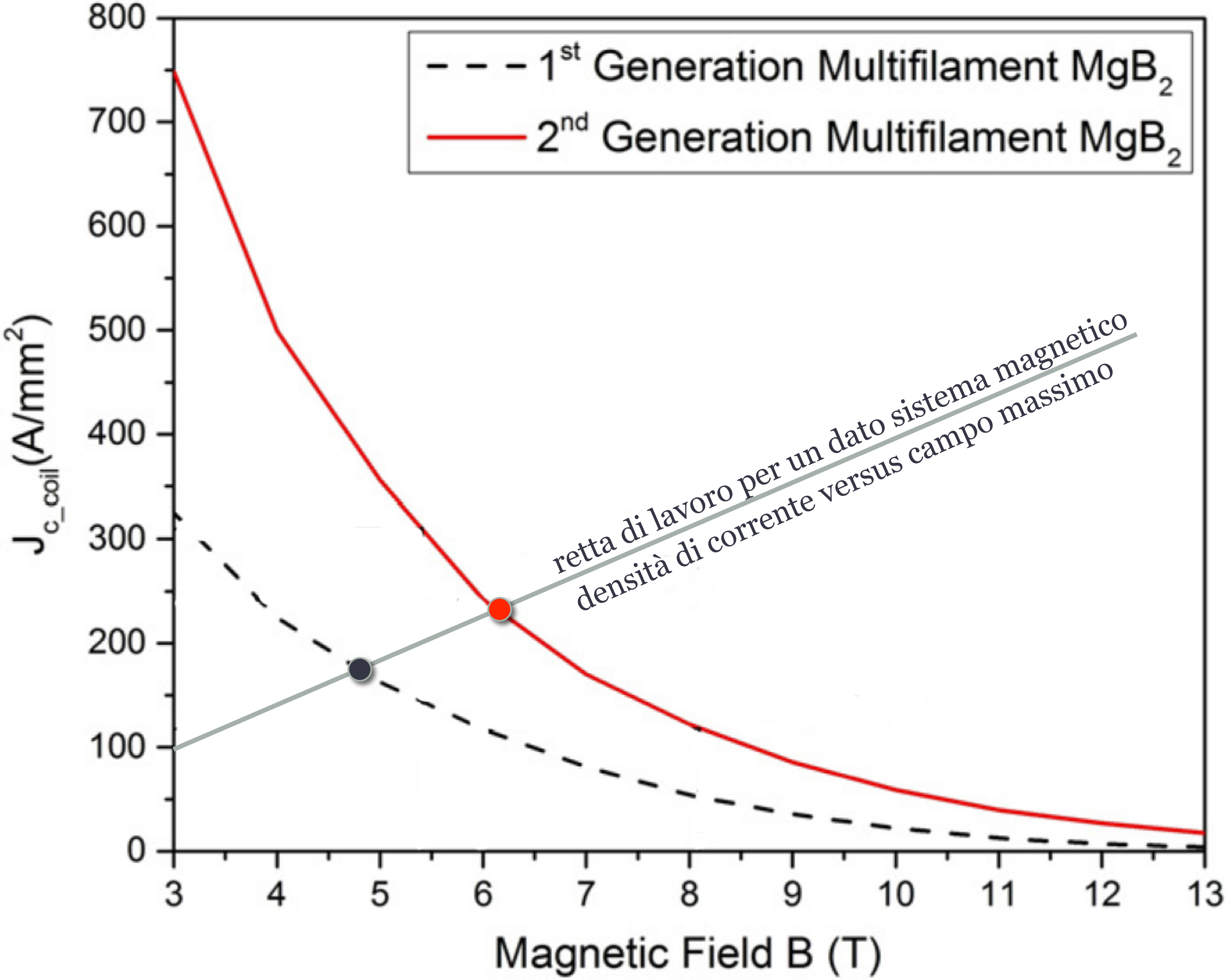




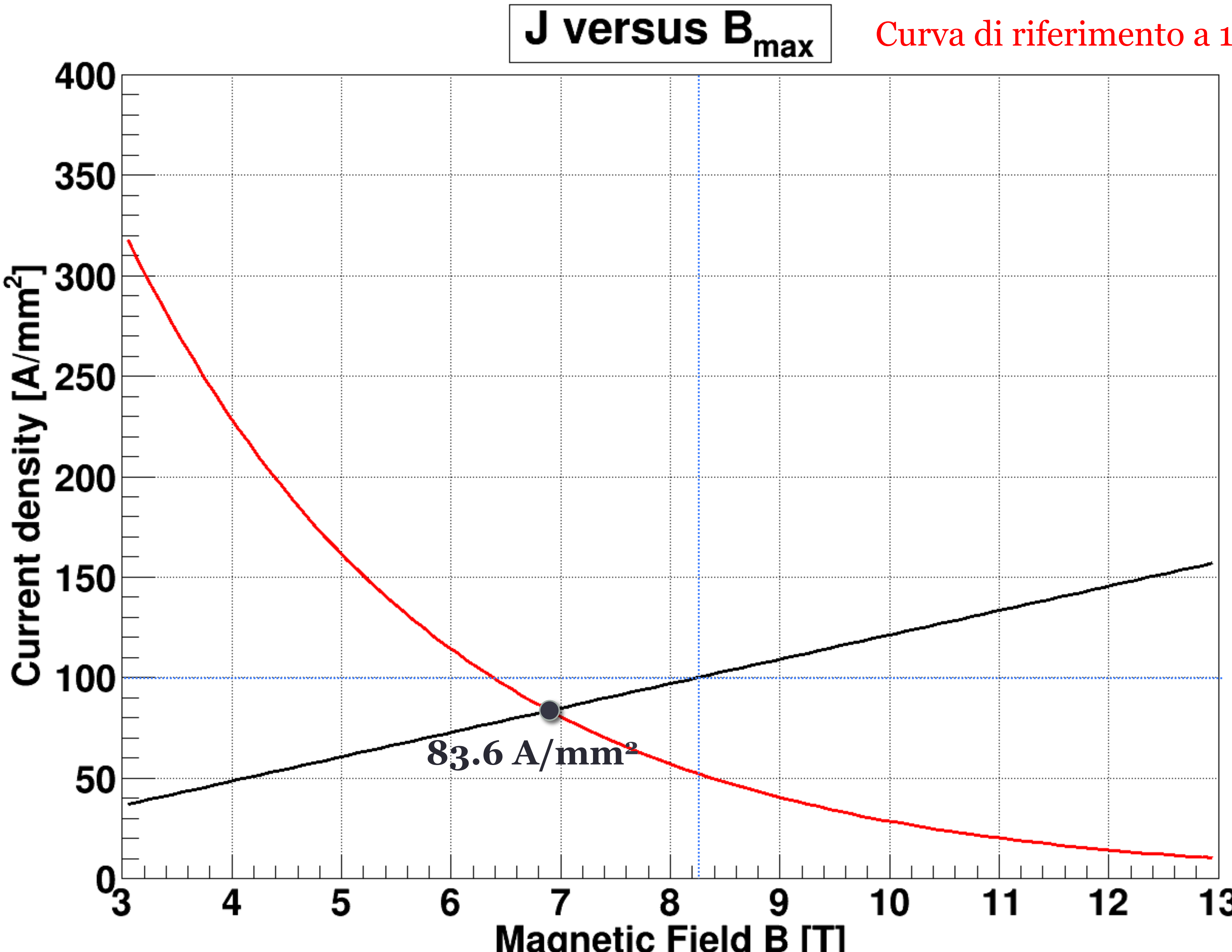
Different analysis criteria can be used for different portions of the spectrum

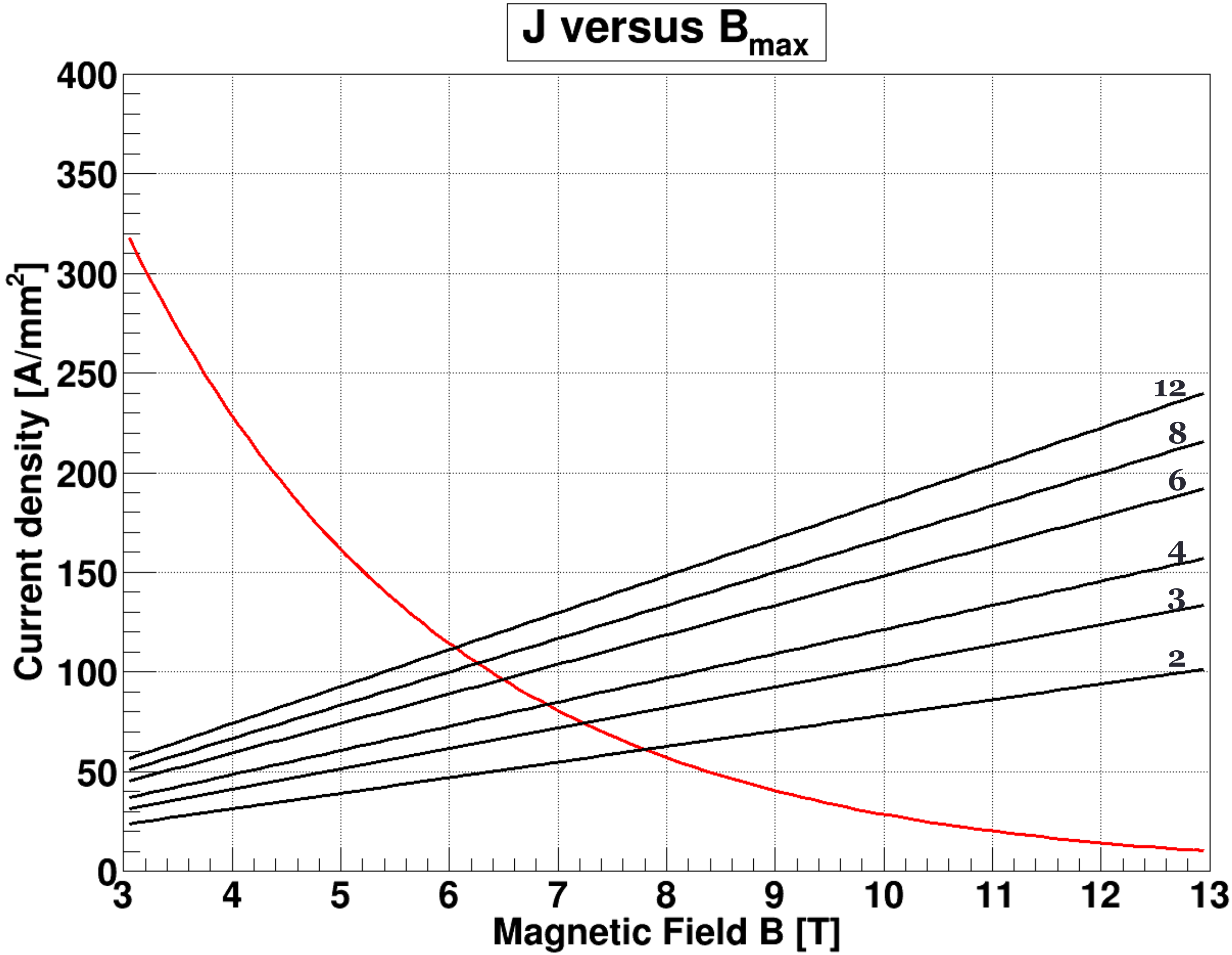
		Density (g/cm3)	λ (cm)	X_0 (cm)	λ/X_0	R_M (cm)	Cube side (cm) @ 2t	Total n.int.lengths @ 2t	Total n.rad.lengths @ 2t	W.L. max. emission (nm)	D.time (ns)	L.Y. (%) @300K	Price (EUR/cm^3)	S	C	n	Notes
Li-glass		2,5	?	?	?	?	93	?	?	?	?	?		✓	?	✓	
CaF2:Eu		3,18	34	3,1	11	3,7	86	2,5	28	435	940	50		✓			
LGB:Ce	Li6GdB3O9	3,5	?	?	?	?	?	?	?	390	200	26		✓	?	✓	
NaI:Tl		3,67	43	2,6	17	4,1	82	1,9	32	410	230	100		✓			
LiI:Eu		4,08	45	2,6	18	4,4	79	1,7	31	470	1400	30		✓		✓	
YSO:Ce	Y2SiO5	4,5	27	3,0	9	2,9	76	2,8	25	420	35	26		✓	?		
CsI		4,5	40	1,9	21	3,6	76	1,9	41	310	10	5	8	✓	T		
CsI:Na		4,5	40	1,9	21	3,6	76	1,9	41	420	630	88	6,5	✓	T		
CsI:Tl		4,5	40	1,9	21	3,6	76	1,9	41	550	1250	165	6	✓	✓		prototype 4,5 EUR/cm3
YAG:Ce	Y3Al5O12	4,57	25	3,5	7	2,8	76	3,0	22	550	70	40	94	✓	T		
YAG:Yb	Y3Al5O12	4,57	25	3,5	7	2,8	76	3,0	22	335	20	9	?	✓	T		
BaF2		4,89	31	2,0	15	3,1	74	2,4	37	300	630	36	11	✓	T		good UV properties
YAP:Yb	YAlO3	5,5	22	2,7	8	2,4	71	3,3	26	362				✓	T		
YAP:Ce	YAlO3	5,5	22	2,7	8	2,4	71	3,3	26	370	27	47	170	✓			
GSO:Ce	Gd2SiO5	6,7	22	1,4	16	2,2	67	3,0	48	440	56	24		✓	?		
LuAG:Yb	Lu3Al5O12	6,73	21	1,5	14	2,2	67	3,3	46	346			?	✓	?		
LuAG:Ce	Lu3Al5O12	6,73	21	1,5	14	2,2	67	3,3	46	535	70	20	290	✓	?		
BSO	Bi4Si3O12	6,8	22	1,1	20	2,2	67	3,0	60	480	100	6		✓	✓		
BGO	Bi4Ge3O12	7,13	23	1,1	20	2,2	65	2,9	58	480	300	21		✓	✓		
NBWO	NaBi(WO4)2	7,5	?	?	?	?	64	?	?	0	0	0			✓		
LYSO:Ce	Lu2Y2Ce2x(SiO4)O	7,4	21	1,1	19	2,1	65	3,1	59	402	40	85		✓			
LSO:Ce	Lu2Ce2x(SiO4)O	7,4	21	1,1	19	2,1	65	3,1	59	402	40	85		✓			
PbF2		7,7	?	0,9	?	2,2	64	?	69	0	0	0			✓		
CWO	CdWO4	7,9	19	1,1	18	2,0	63	3,3	58	470	14500	39		✓			
PWO	PbWO4	8,3	21	0,9	23	2,0	62	3,0	70	425	5	0,3		✓			

Curve di riferimento a 10 K

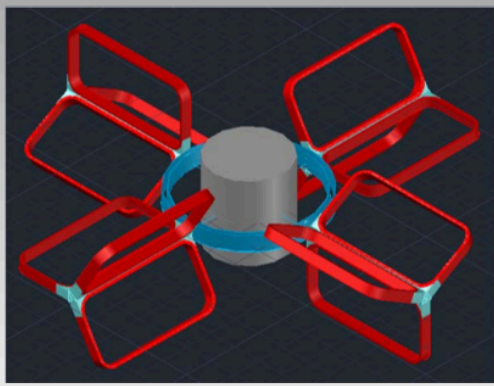


Curva di riferimento a 10 K



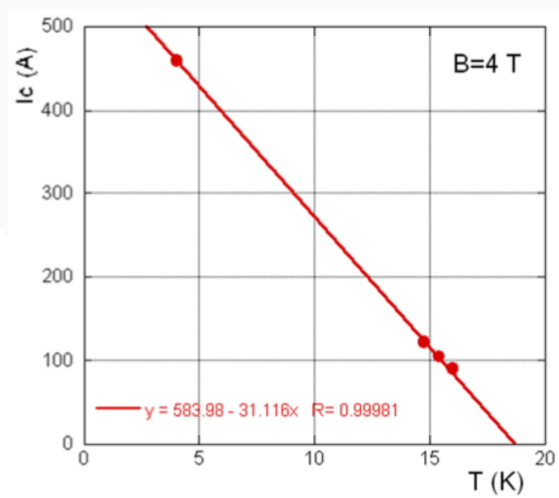

J versus B_{max}
Current density [A/mm^2]
Magnetic Field B [T]
0
50
100
150
200
250
300
350
400
3
4
5
6
7
8
9
10
11
12
13
12
8
6
4
3
2

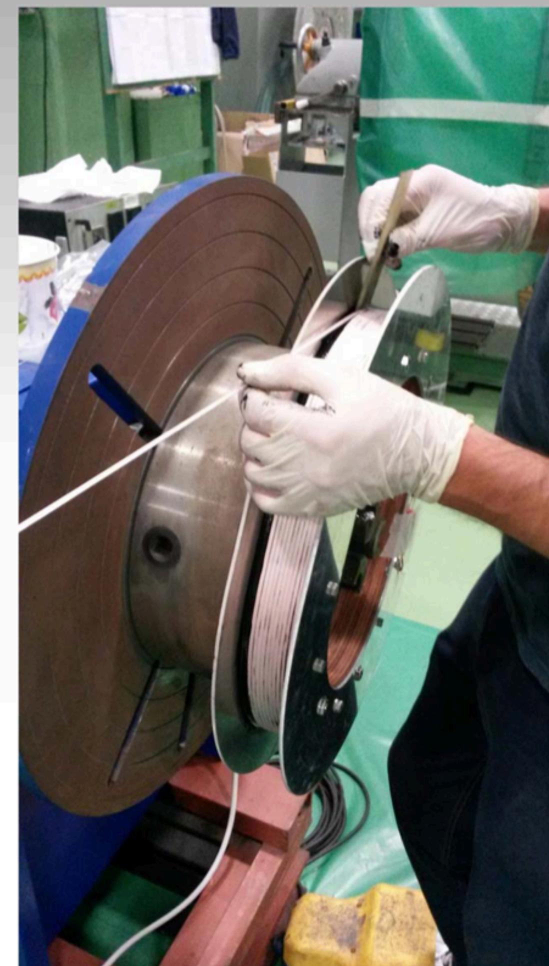
SR2S Space Radiation Superconducting Shield



Magneti leggeri operanti a 10 K

Conduttore basato su MgB_2 in matrice di titanio





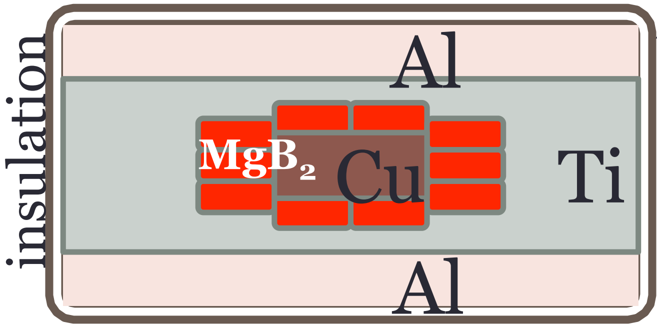
R&D on High Temperature Superconductors

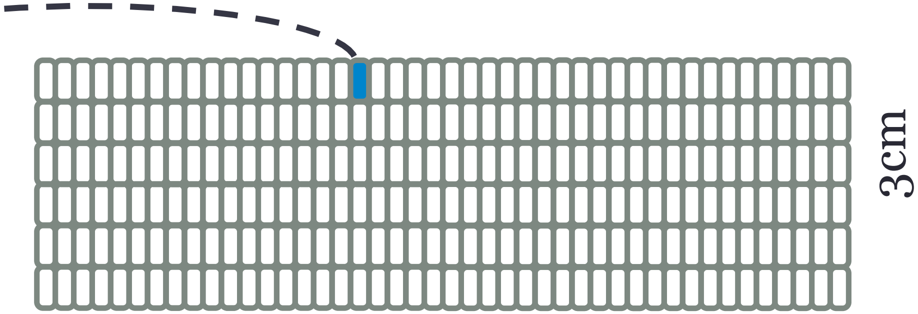
Superconducting Compound	T_c in Kelvin	Hc_2 at 4.2 K in Tesla	ξ (nm)	Mass Density (g/cm³)
Nb-Ti	9	10	5	6.0
Nb_3Sn	18	28	5	7.8
MgB_2	39	up to 70	5	2.5
YBCO-123	90	> 50	<< 1	5.4
BSCCO-2223	108	> 50	<< 1	6.3

SRS2 FP7 program is developing a **MgB2 –Ti cable** which could match the needs of such a spectrometer

Magnet operation temperature 10K, cryogenics based on recirculating fluid → **no endurance limit**

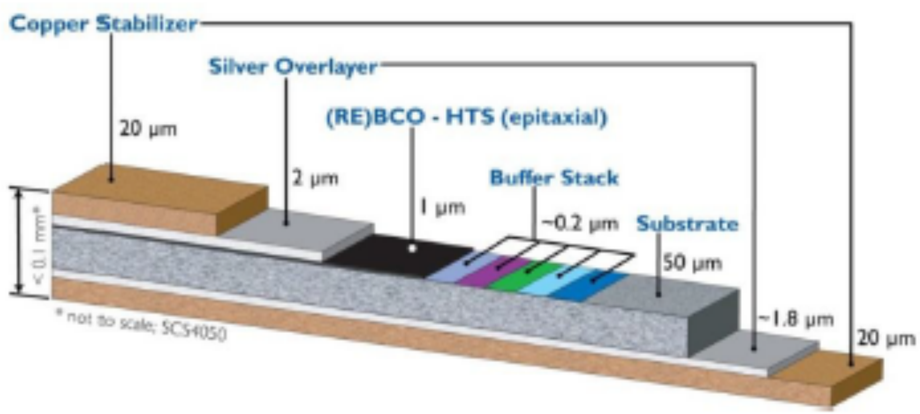
MgB_2 @ ≥10K [δ=600A/mm², d=3.64g/cm³]





Cross section: 2.5x5mm²

YBCO @ 40K [δ=870/mm² (for Rad protection in space - project), d>6.4g/cm³]



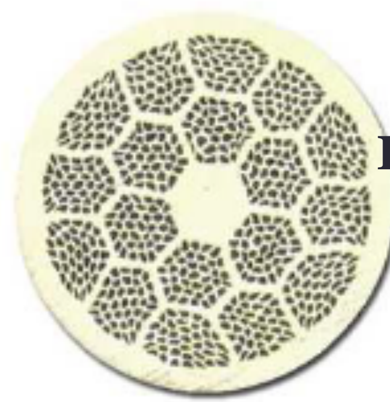


Figure 3 Example YBCO tape (graphic provided courtesy of SuperPower Inc.), left; and example BSSCO multifilament round wire in Ag stabilizer (graphic provided courtesy of Oxford Instruments), right

European Seventh Framework Program

Space Radiation Superconductive Shield (SR2S)

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V. Calvelli, INFN-Genova, Italy
S. Farinon, INFN-Genova, Italy
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M. Sorbi, INFN-Milan, Italy
G. Laurenti, INFN-Bologna, Italy
M. Guerzoni, INFN-Bologna, Italy
P. Rapagnani, INFN-Roma1. Italy
B. Spataro, INFN-Frascati, Italy
P. Fazilleau, CEA, France
B. Baudoy, CEA, France
L. Quettier, CEA, France
A. Ballarino, CERN. Switzerland
C. Gargiulo, CERN, Switzerland
L. Rossi, CERN, Switzerland
V.I. Datskov, CERN, Switzerland
D. Schinzel, CERN, Switzerland
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R. Piccardo, Columbus Superconductors, Italy
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E. Monchieri, CGS, Italy
F. Zurla, CGS, Italy
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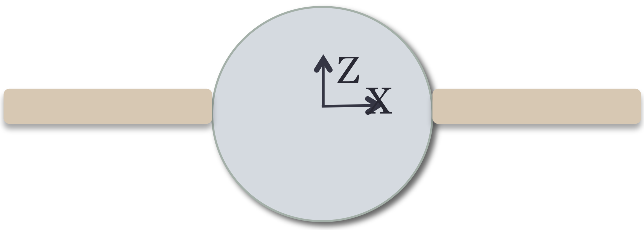
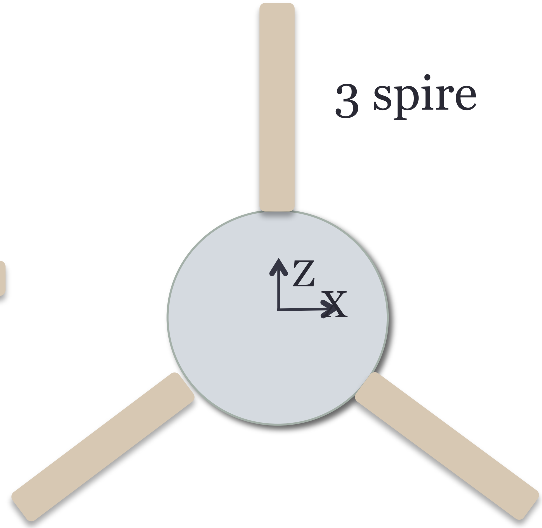
M. Giraudo, Thales Alenia Space, Italy
R. Destefanis, Thales Alenia Space, Italy
C. Lobascio, Thales Alenia Space, Italy
E. Gaia, Thales Alenia Space, Italy

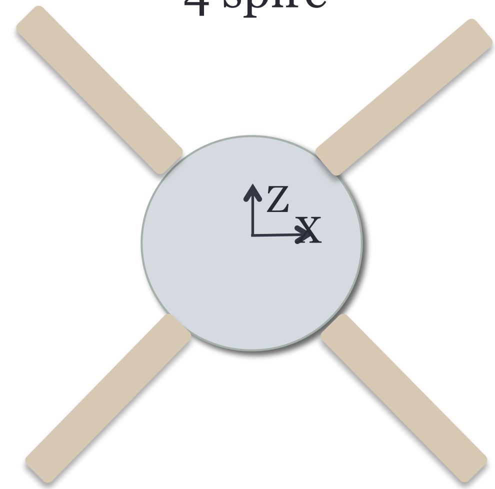
2 spire



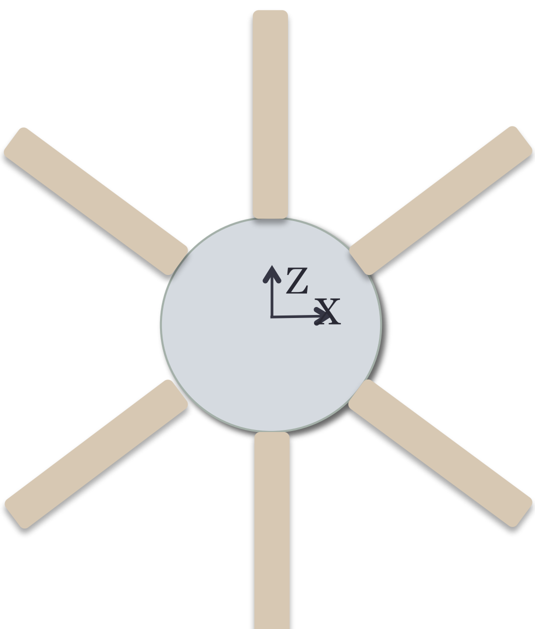
3 spire



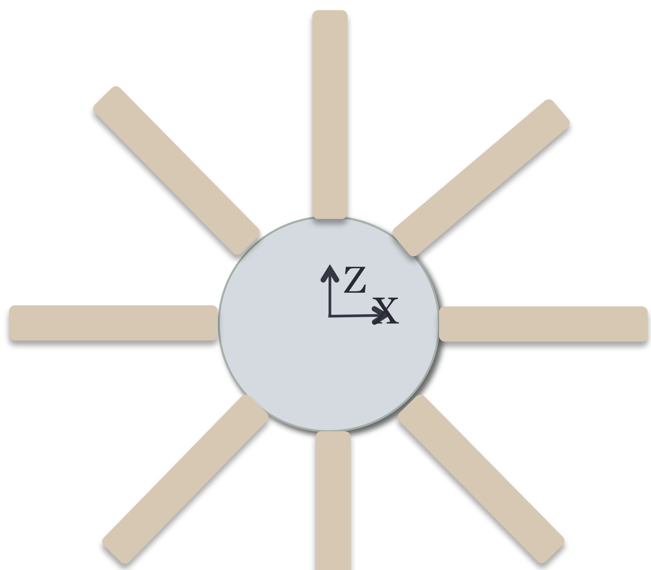
4 spire



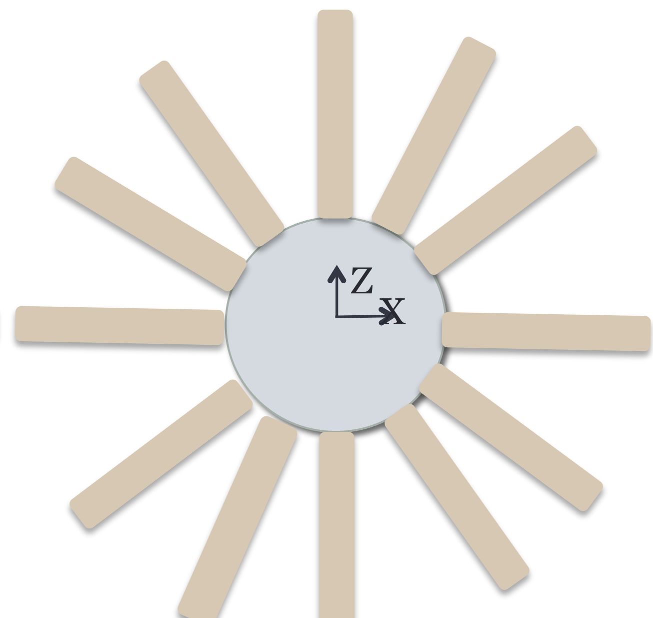
6 spire



8 spire



12 spire



Valutazione MDR
(in attesa di una simulazione puntuale)

- Per ogni configurazione magnetica ho generato 15000 eventi isotropi sull'accettanza cilindrica del calorimetro

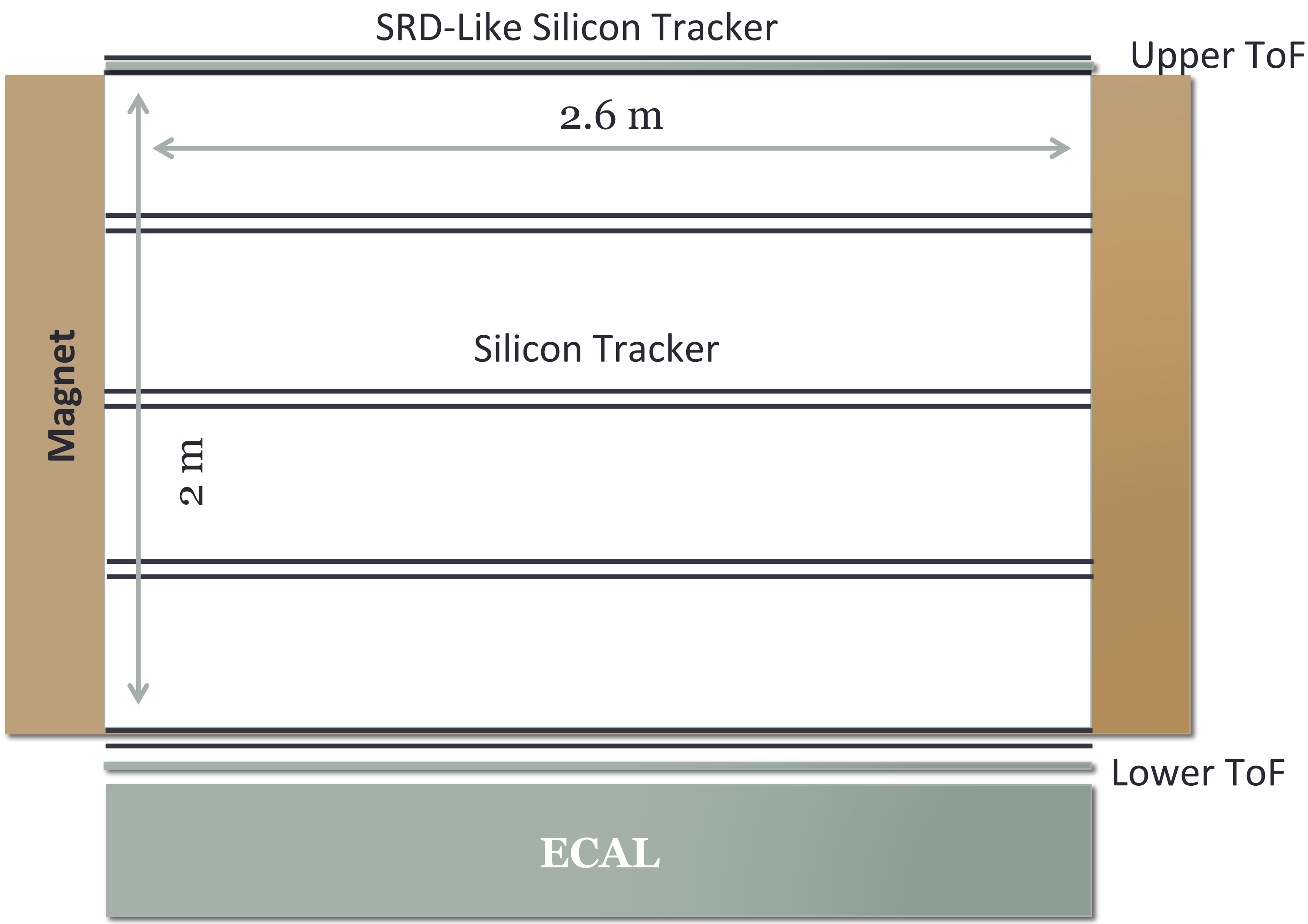
- Spettrometro fatto da 6 piani con risoluzione 10 μm (lunghezza del piano esterno 3 m

$$\frac{\Delta p}{p} = \frac{\Delta x}{0.3 < B_\perp > L^2}\sqrt{\frac{720}{N+4}} \times R$$

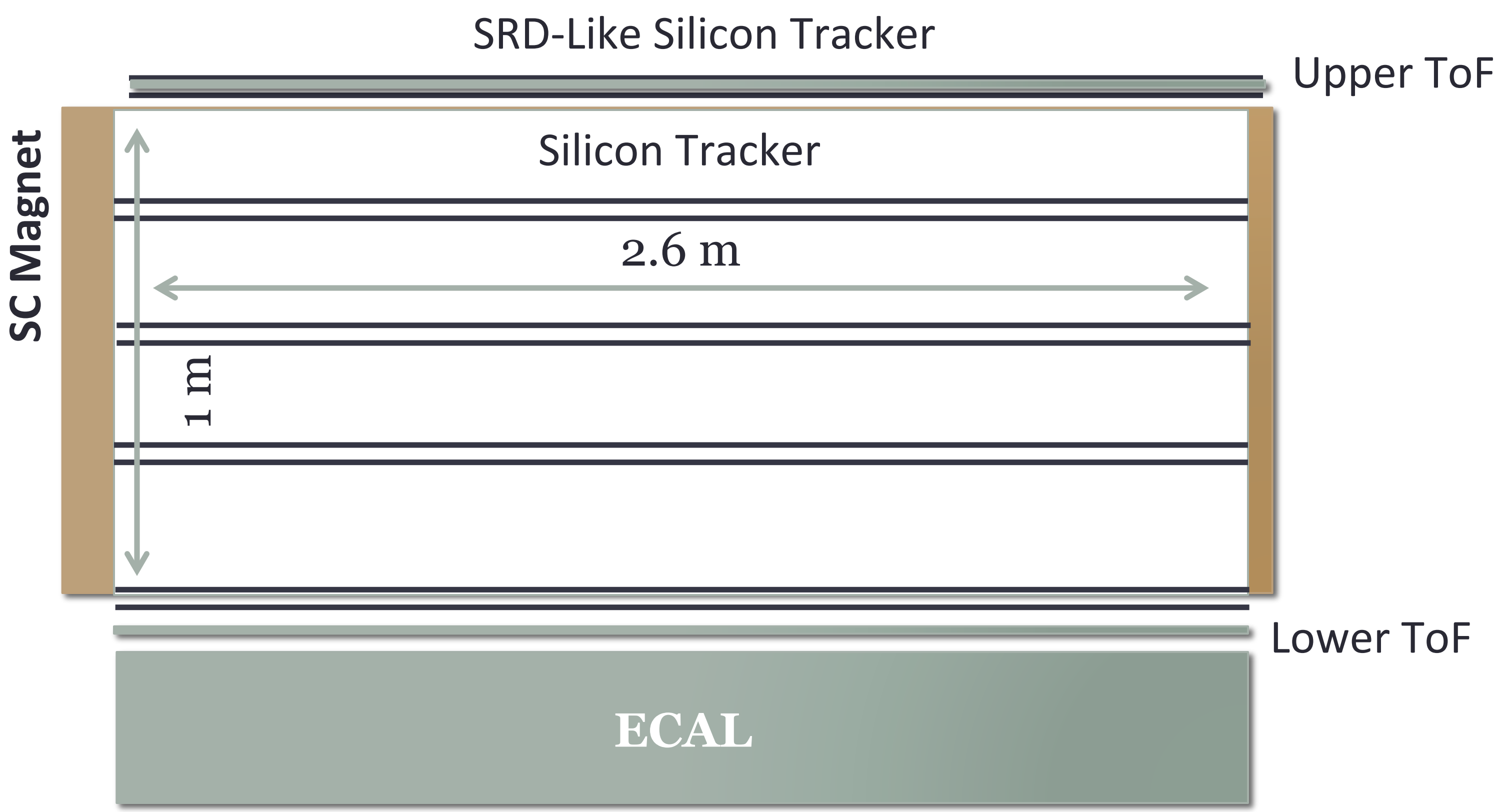
- Distribuzione MDR dopo i seguenti tagli:

  – 2/3 superiore dell'accettanza
  – La traccia passa per lo spettrometro
  – La traccia non passa per il sistema magnetico

IMPROVED AMS-Permanent Magnet

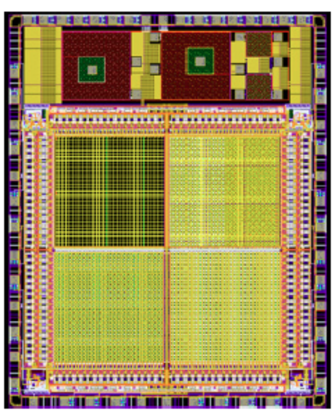


IMPROVED-AMS- Super Conducting Magnet



How to get to micron tracking accuracy

- 1) AMS experience show us that through suitable cooling micron level stability can be achieved over O(1) m^3 using stiff CR as alignement tool
- 2) Space seems to be the right place to implement O(1) um resolution tracking which is considered for LHC upgrades and has been developed for at least 10 years → CMOS monolithic pixel sensors



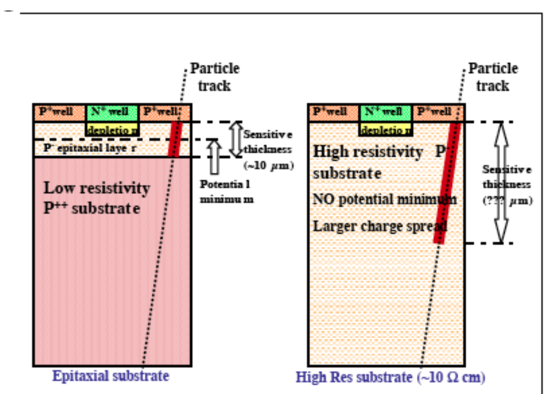


Fig. 1. Cross section of silicon wafers used for the fabrication of CMOS monolithic pixel sensors. On the left, the structure of epitaxial type wafer is shown. On the right the non-epitaxial, high resistivity wafer is presented.

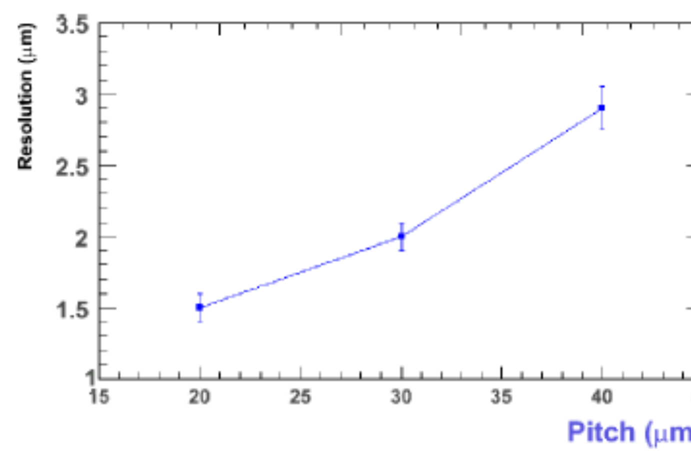


Fig. 8. Spatial resolution for minimum ionizing particles as a function of pixel pitch, measured with Mimosa9 prototype.

THE HIGH ENERGY FRONTIER

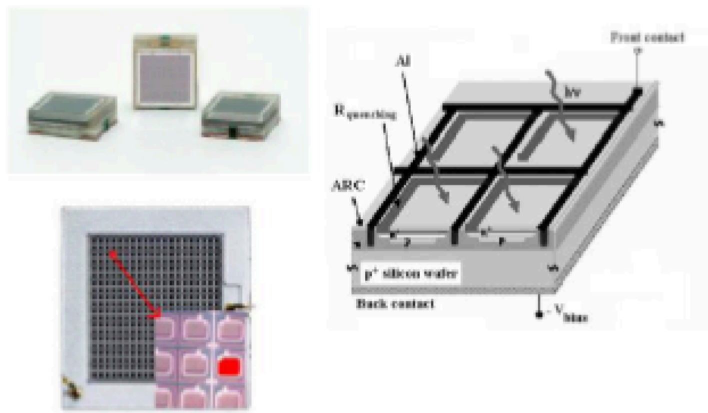
Detection of atmospheric showers from space in the above 10^{18} eV region

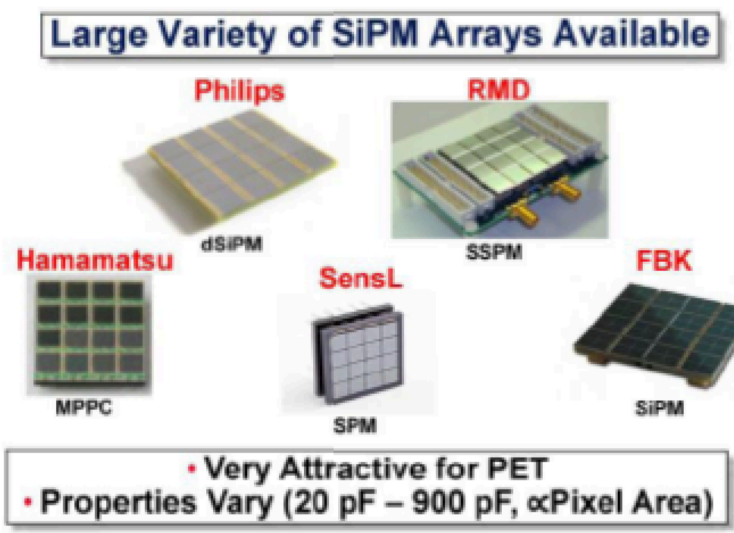
JEM-EUSO R&D ON SILICON PHOTOPULTIPLIERS (SIPM) FOR SPACE APPLICATIONS

Issues:

- **large sensitive area (to avoid dead space and light cones)**
- **sensitivity to fluorescence light (UV-range)**
- **Fast readout (specific ASIC, digital SiPM, monolithic SiPM/ASIC readout)**
- **characteristics and calibration (single photon efficiency)**

SiPM





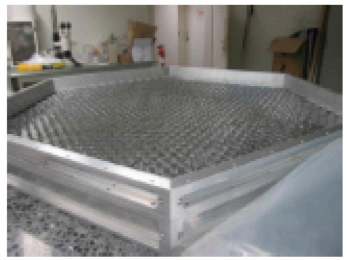
- **fast development**
- **good PDE** (but PMT still better [Razmik])

Still improvements needed

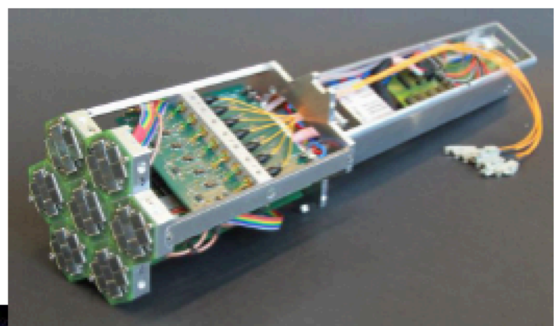
- PDE (=QE?)
- crosstalk
- dark current
- fast readout
- large areas
- operation temperature
- wavelength range
- cost reduction
- .....

Conclusion:
Will be the future!
Need close cooperation between companies and experiments

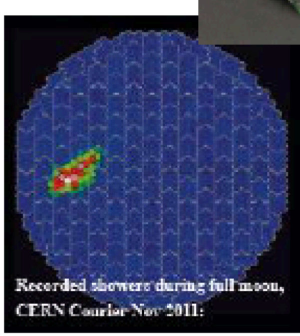
Examples: CTA - SiPM



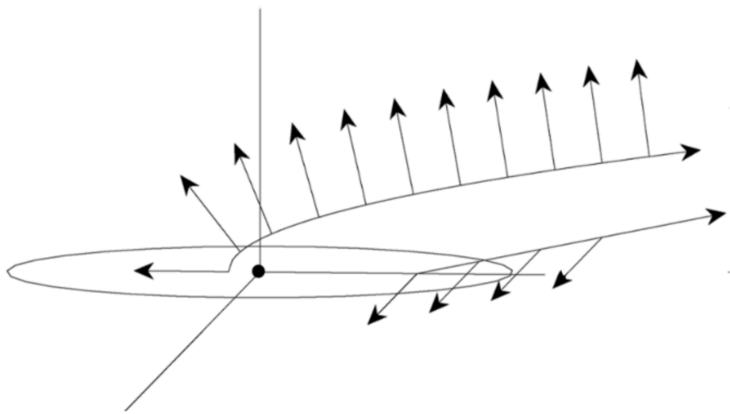
- **SST prototype with SiPM = ASTRI**
- **Already existing: FACT**
- **MAGIC started to replace**

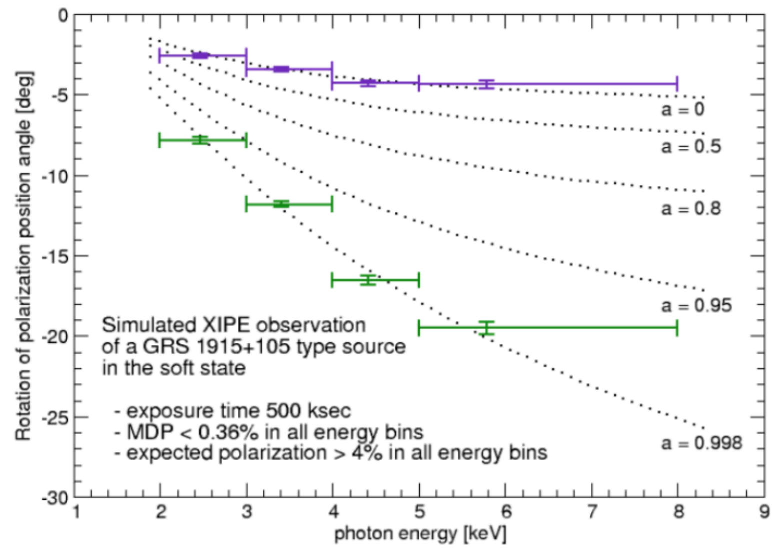


SiPM are particularly fit
for gamma-ray astronomy,
• Operation during Moonlight
~ 30% larger duty cycle
• No evidence of ageing
• Lightweight and robust cameras
• Excellent single PE sensitivity
• High PDE at ~ 40%

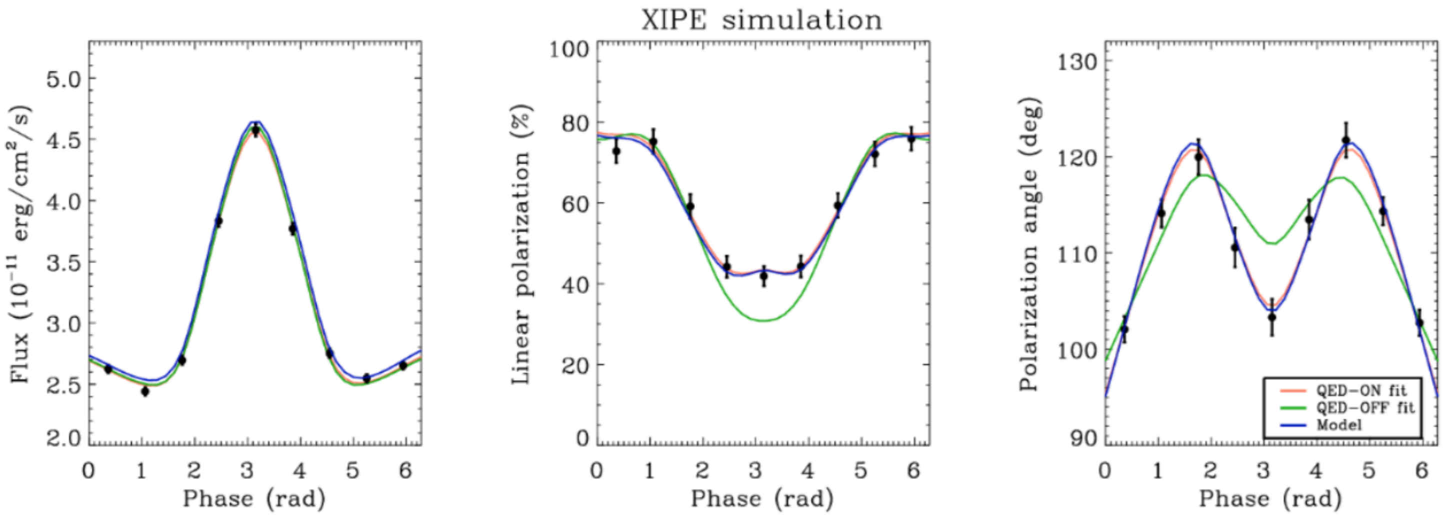


Conclusion:
Imaging Cherenkov Telescopes first large-scale application of SiPM





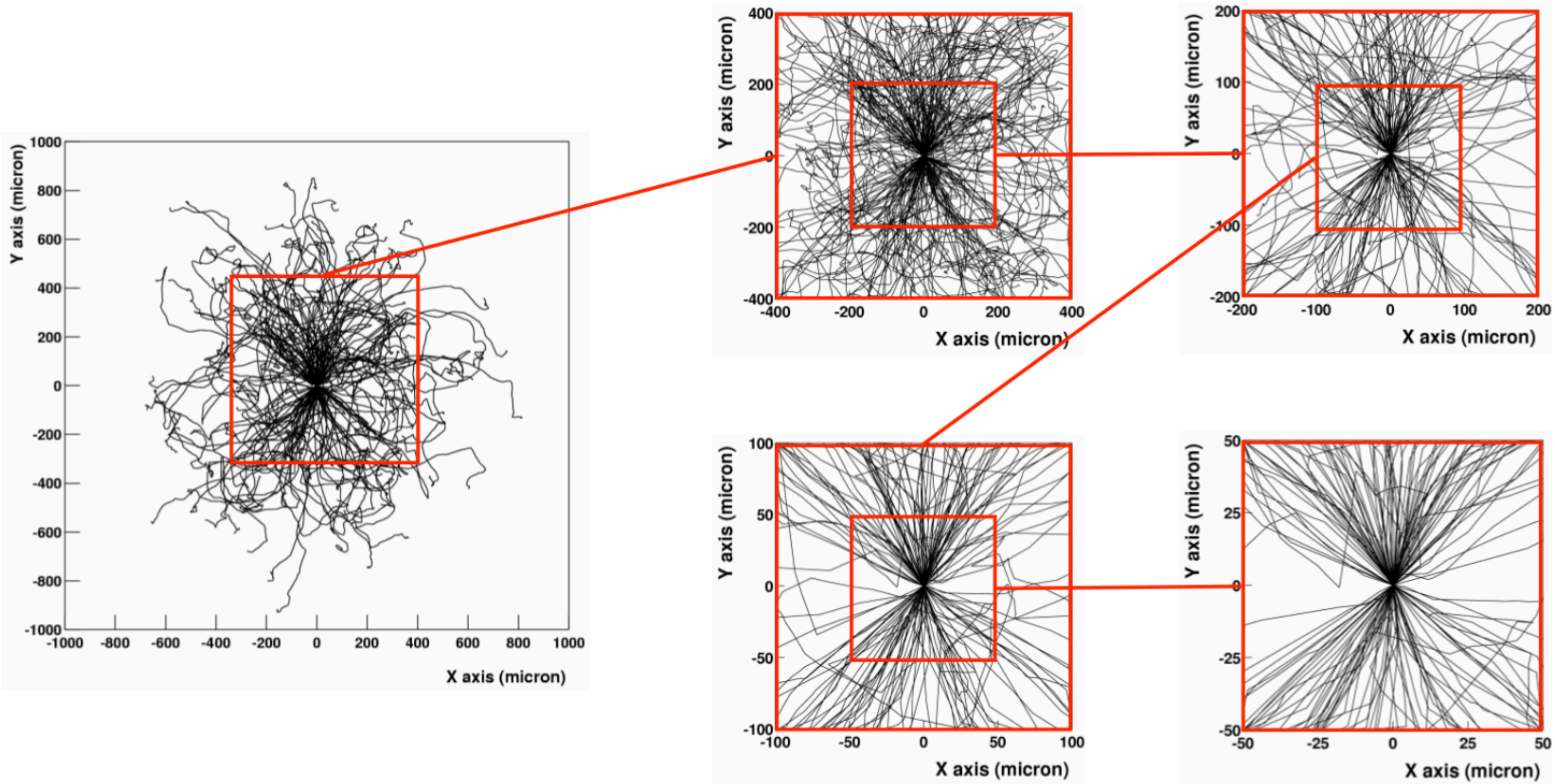
- When BH binaries are in high state, the dominant component in the 2–10 keV energy band is from the thermal emission from the accretion disk.
- The proximity of the BH causes a rotation of the polarization angle of the radiation emitted from the disk.
  - As the temperature of the disk decreases with the radius, the polarization of the rotation angle increases with energy.
- XIPE: measure polarization degree (to $\pm 0.5\%$) and angle (to $\pm 1^\circ$) for the μQSO GRS 1915+105 in 500 ks.



- X-ray polarimetry is a privileged probe to test genuine QED effects.
- Vacuum polarization induced by strong magnetic field.
  - Predicted by Heisenberg and Euler in 1936.
  - In a strong magnetic fields (such as those in magnetars) the vacuum dielectric and magnetic permeability tensor depend on the magnetic field intensity.
  - Photon propagation is influenced, and the polarization angle and degree are modified.
- Tiny effect on the intensity, measurable effect on the polarization degree and angle.
- XIPE: polarization sensitivity to better than 10% in 10 phase bins for 1RXS J1708 in 250 ks.

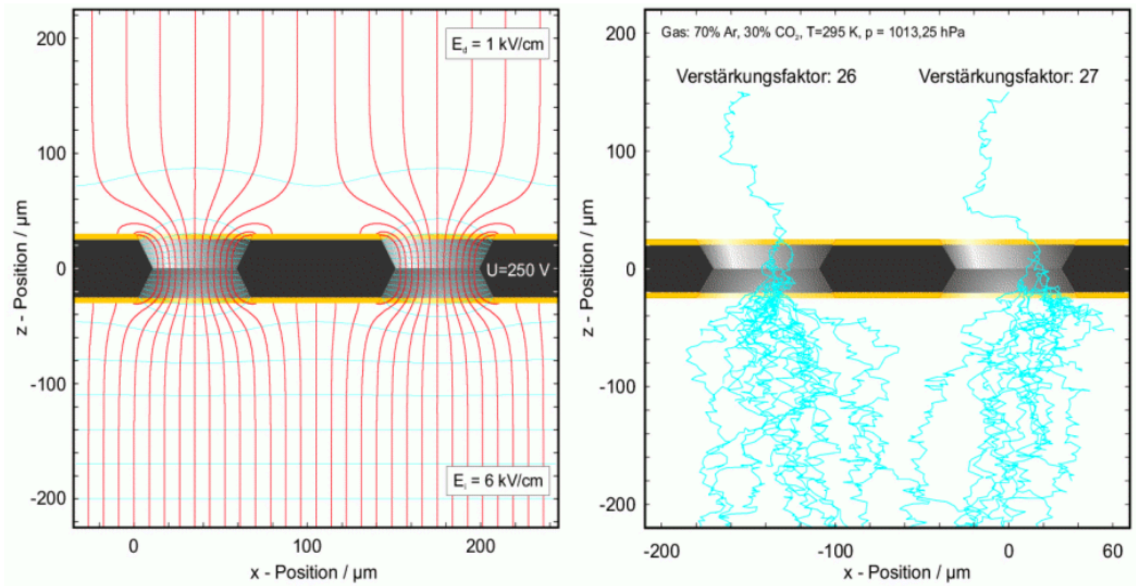
Basics of photoelectric effect in gas

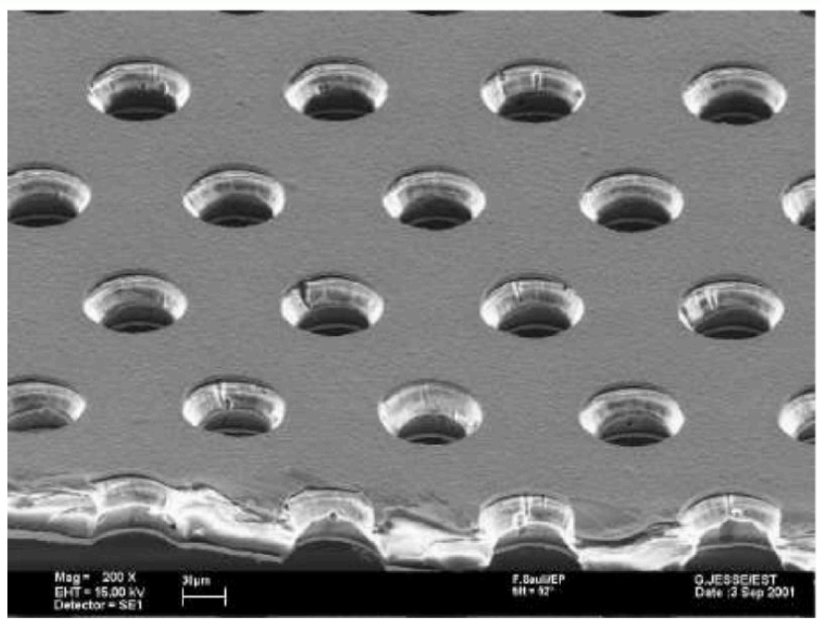
5.4 keV simulated electrons in Ne/DME 80/20



- Most of the directional information in the initial part of the track.
  - Need to identify the absorption point and deweight the pixels corresponding to the last part of the track.

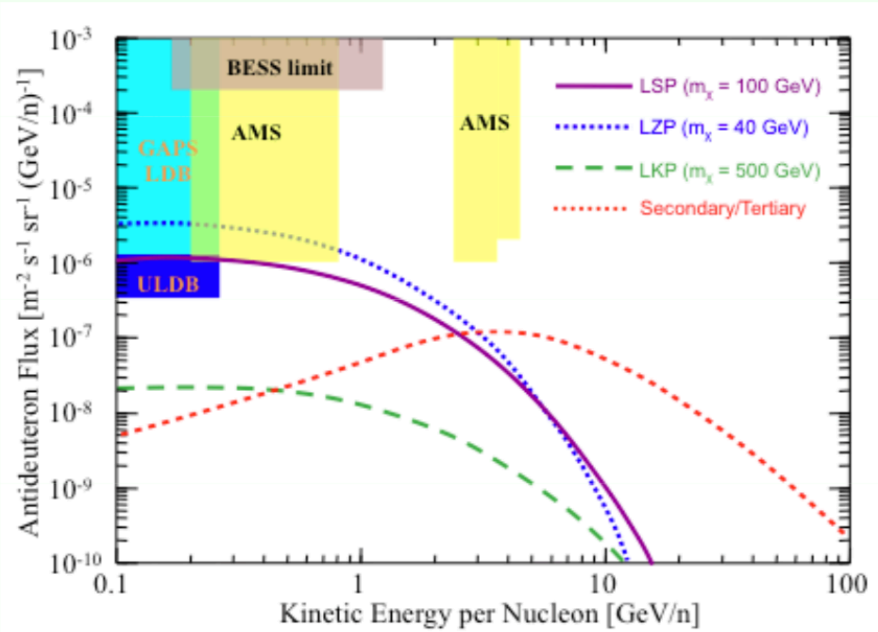
The gas electron multiplier (GEM)



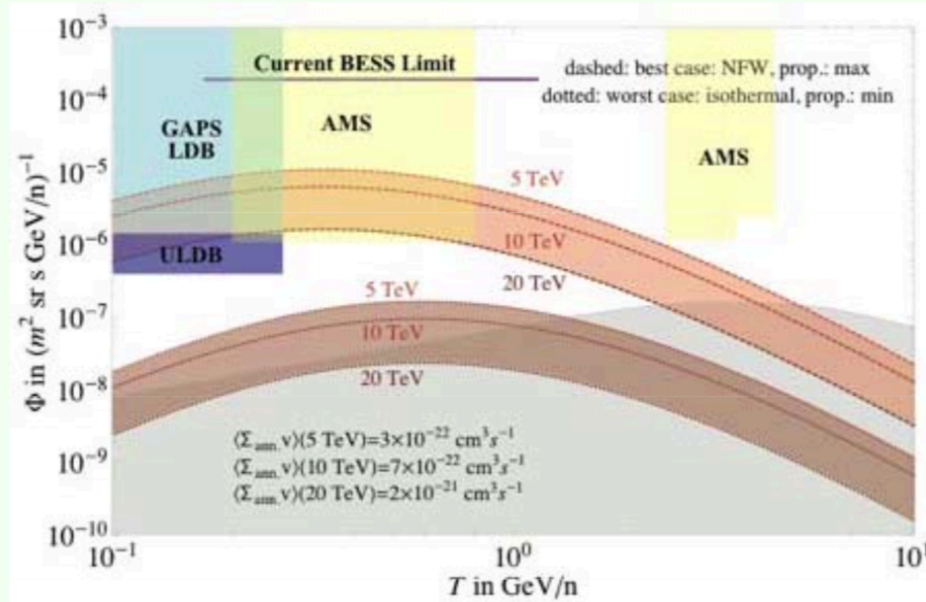


Unique DM Reach

LSP, LZP, LKP models (Baer & Profumo, 2005)



Massive Neutralinos
DM models (Brauninger & Cirelli, 2009)
Sensitivities & bkgnd (Hailey et al., 2013)



DM Reach & Complementarity

- DM Detection can be well above bkgnds.
- New expts provide ~3 orders of magnitude improvement over BESS limits.
- Compementarity:
  Anti-deuterons vs other indirect/direct
  GAPS and AMS

Uncertainties

Significant uncertainties exist:

- Signal: propagation, production
- Bkgnd: production in Galactic disk

3.2. Atomic X-ray

As discussed above, the stopped antiparticles can form exotic atoms and emit atomic X-rays during the de-excitation. The energies of the atomic X-rays are uniquely determined by the components of the exotic atom as seen below.

$$E_X = (zZ)^2 \frac{M^*}{m_e^*} R_H \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right) \tag{A}$$

Here, z and Z are the charge of the antiparticle and target atom, M^* and m_e^* are the reduced masses of an antiparticle in the exotic atom and an electron in the target atom, R_H is the Rydberg constant and n_i and n_f are the initial and final principal quantum number. The antideuteronic exotic atom formed with the Si target can emit 30 keV, 44 keV and 67 keV atomic X-rays, while 23 keV, 35 keV and 58 keV X-rays can be emitted for antiprotonic exotic atoms formed with the Si target. The X-ray yield, defined as the probability to emit atomic X-rays per exotic atom, for each atomic X-ray was estimated as $\sim 80\%$ with the simple cascade model as discussed in [21]. Note that in addition to the antiparticles,