Prospects for the Future Indirect Dark Matter Search: an AMS03-like Experiment

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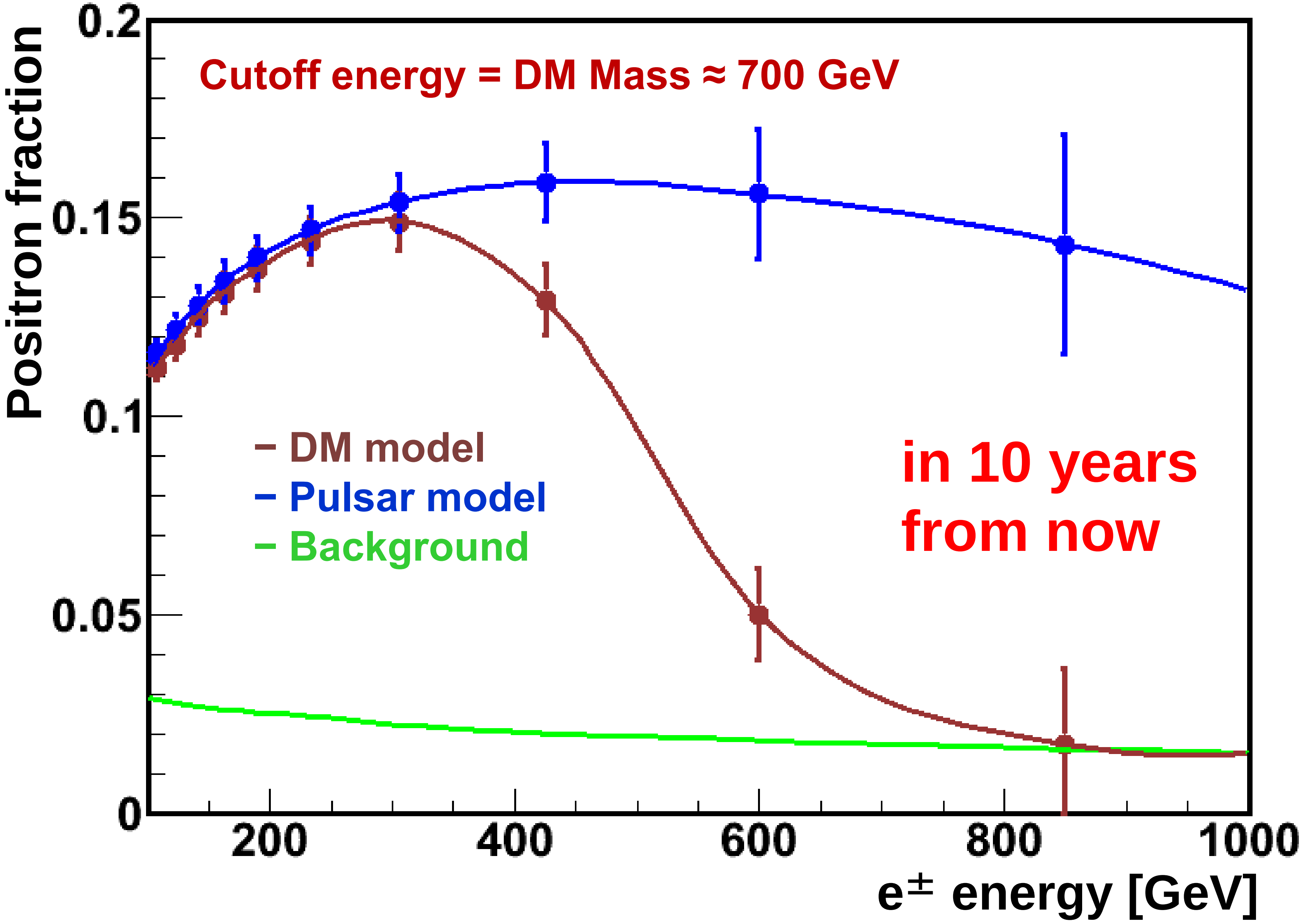
Open issues after AMS-02

- Dark matter:
  - Positrons at the 1-10 TeV scale
  - Antiprotons at the 1 TeV scale
  - Gamma Rays at 1-10 TeV scale
  - Antideuterons at the GeV scale with high sensitivity ($\Phi_{\bar{d}} \sim 10^{-8}$) or at the 100 GeV-1TeV scale with ultrahigh sensitivity ($\Phi_{\bar{d}} \sim 10^{-11}$)
  - Positrons Anisotropies in galactic coordinates with fine sensitivity ($\delta \sim 10^{-3}$)

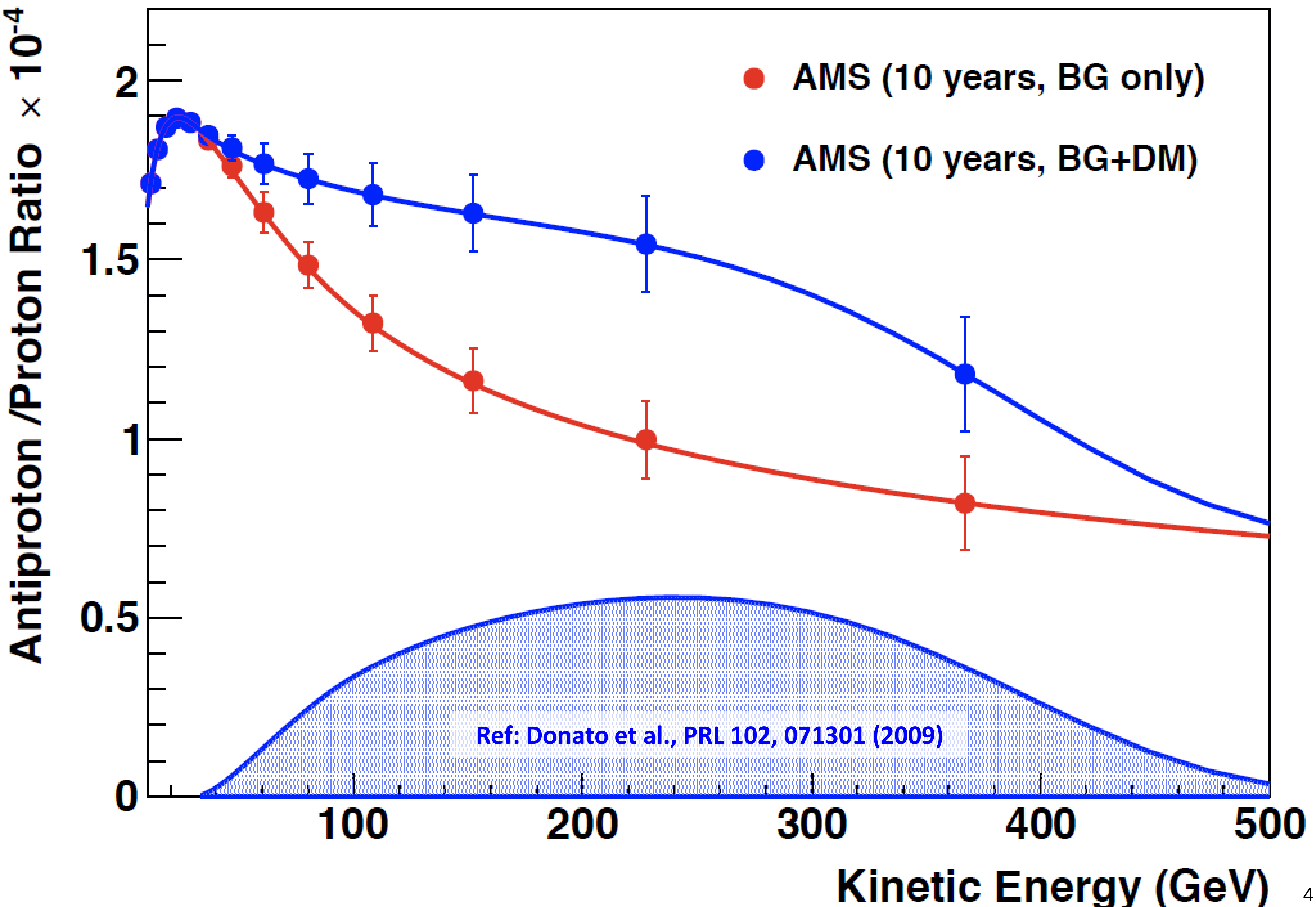
- CR Spectral features at the knee scale:
  - ✓ Protons at the PeV scale
  - ✓ Helia at the PV scale
  - ✓ Ions at the 100 TV scale
  - ✓ Spectral Breaks

Expected AMS-02 reach in 10 more years



What will the Positron Fraction look like at higher energies?

Expected AMS-02 reach in 10 more years



AMS-02 : expected rates and detection tools/limitations

	ELECTRON AND POSITRON PHYSICS @ AMS-02					EXCLUDED	EXCLUDED	EXCLUDED
eV	10^8	10^9	10^10	10^11	10^12	10^13	10^14	10^15
Scale	100MeV	GV			TV			PV
N Integral (1/y)	0,1-1 GeV	1-10 GeV	10-100 GeV	100-1000 GeV	>1.000 GeV	>10.000 GeV	>100.000 GeV	>1.000.000 GeV
e-	4,99E+08	3,11E+07	1,56E+06	9,33E+03	7,78E+01	7,78E-01	7,78E-03	7,78E-05
e+	4,99E+07	3,11E+06	2,33E+05	1,40E+03	1,17E+01	1,17E-01	1,17E-03	1,17E-05
Detectors	Tracker, TOF, TRD, ECAL	Tracker, TOF, TRD, ECAL	Tracker, TRD, ECAL	Tracker, TRD, ECAL	Tracker,TRD, ECAL			
Variables	R, beta, gamma, energy	R, beta, gamma, energy	R, gamma, energy	R, gamma, energy	R, gamma, energy	R, Energy, Synchroton Radiation	R, Energy, Synchroton Radiation	R, Energy, Synchroton Radiation
Physics	Van Allen, solar, subcutoff	solar, geomagnetic, galactic	DM, galactic, asymmetries	DM, galactic, asymmetries	DM, galactic	DM, galactic, moon shadow, sun shadow	DM, galactic	DM, extragalactic, knee
Tools	acceptance vs R, live time, efficiency, MC, inner tracker, alignement, TOF calibration, TRD calibration, backtracing (near Earth)	acceptance vs R, live time, efficiency, MC, inner tracker, alignement, TOF calibration, TRD calibration, backtracing (near Earth)	acceptance vs R, live time, efficiency, MC, inner tracker, alignement, TOF calibration, TRD calibration, backtracing (near Earth)	acceptance vs R, live time, efficiency, MC, inner/outer tracker, TRD, alignement, backtracing (Earth-Moon, Earth- Sun)	acceptance vs R, live time, efficiency, MC, outer tracker, alignement, SRD calibration, ECAL calibration, backtracing Earth-Moon, Earth-Sun	acceptance vs R, live time, efficiency, MC, outer tracker, alignement, SRD calibration, ECAL calibration, backtracing Earth-Moon, Earth-Sun	acceptance vs R, live time, efficiency, MC, outer tracker, alignement, SRD calibration, ECAL calibration, backtracing Earth-Moon, Earth-Sun	acceptance vs R, live time, efficiency, MC, outer tracker, alignement, SRD calibration, ECAL calibration, backtracing Earth-Moon, Earth-Sun
Background e-	-	-	-	p	p	p	p	p
Background e+	p	p	p	p	p	p	p	p
Limitations	multiple, scattering, acceptance,AMS 02 magnetic field		-	TRD loses, ECAL must be in acceptance	momentum resolution runs out, TRD loses, ECAL must be in accceptance	no statistics	no statistics	no statistics

AMS-02 : expected rates and detection tools/limitations

	PROTON and HELIUM PHYSICS @ AMS-02							
						EXCLUDED	EXCLUDED	EXCLUDED
eV	**10^8**	**10^9**	**10^10**	**10^11**	**10^12**	**10^13**	**10^14**	**10^15**
Scale	**100MeV**	**GV**			**TV**			**PV**
N Integral (1/y)	**0,1-1 GeV**	**1-10 GeV**	**10-100 GeV**	**100-1000 GeV**	**>1.000 GeV**	**>10.000 GeV**	**>100.000 GeV**	**>1.000.000 GeV**
p	3,00E+09	5,98E+09	1,19E+09	2,38E+07	4,32E+05	8,61E+03	1,72E+02	3,43E+00
He	1,08E+08	1,08E+09	2,15E+08	4,28E+06	7,77E+04	1,55E+03	3,09E+01	6,17E-01
Detectors	Tracker, TOF, RICH	Tracker, (RICH)	Tracker	Tracker	Tracker	TRD +ECAL ?		
Variables	R, beta	R	R	R	R, gamma	gamma		
Physics	Van Allen, solar, subcutoff	solar, geomagnetic, galactic	galactic	galactic	galactic, moon shadow, sun shadow	galactic, moon shadow, sun shadow	galactic	extragalactic, knee
Tools	acceptance vs R, live time, efficiency, MC, inner tracker, alignement, TOF calibration, RICH calibration, backtracing(near Earth)	acceptance vs R, live time, efficiency, MC, inner tracker, alignement, , RICH calibration, backtracing (near Earth)	acceptance vs R, live time, efficiency, MC, inner tracker, alignement, TOF calibration, RICH calibration, backtracing near Earth)	acceptance vs R, live time, efficiency, MC, inner/outer tracker, alignement, backtracing Earth-Moon, Earth- Sun)	acceptance vs R, live time, efficiency, MC, outer tracker, alignement, , ECAL calibration, backtracing Earth-Moon, Earth-Sun	acceptance vs R, live time, efficiency, MC, outer tracker, alignement, TRD calibration, ECAL calibration, backtracing Earth-Moon, Earth- Sun)	acceptance vs R, live time, efficiency, MC, outer tracker, alignement, TRD calibration, ECAL calibration, backtracing Earth-Moon, Earth- Sun)	
Background p	-	-	-	-	e-	e-	e-	
Background He	He3/He4	He3/He4	He3/He4	He3/He4	-	-	-	
Limitations	multiple, scattering, acceptance,AMS 02 magnetic field	-	-	different tracker acceptances, alignement	momentum resolution runs out, TRD comes in ?, if ECAL is used loss of factor 10 acceptance	only TRD has limited gamma resolution, if ECAL is used we lose a factor 50	only TRD has limited gamma resolution, if ECAL is used we lose a factor 50	no statistics

How to reach the 10 TeV scale ?

- **Exposure : increase by a factor O(100) for e+:**

  From 0.05 to 5 m^2 sr Acceptance

- **Detector : capable to deal with 10 TeV particles**
  - **Tracker + Magnet → MDR > 20 TV**
  - **ECAL → ECAL+HCAL**

Modular assembly in space or full detector assembly on the ground?

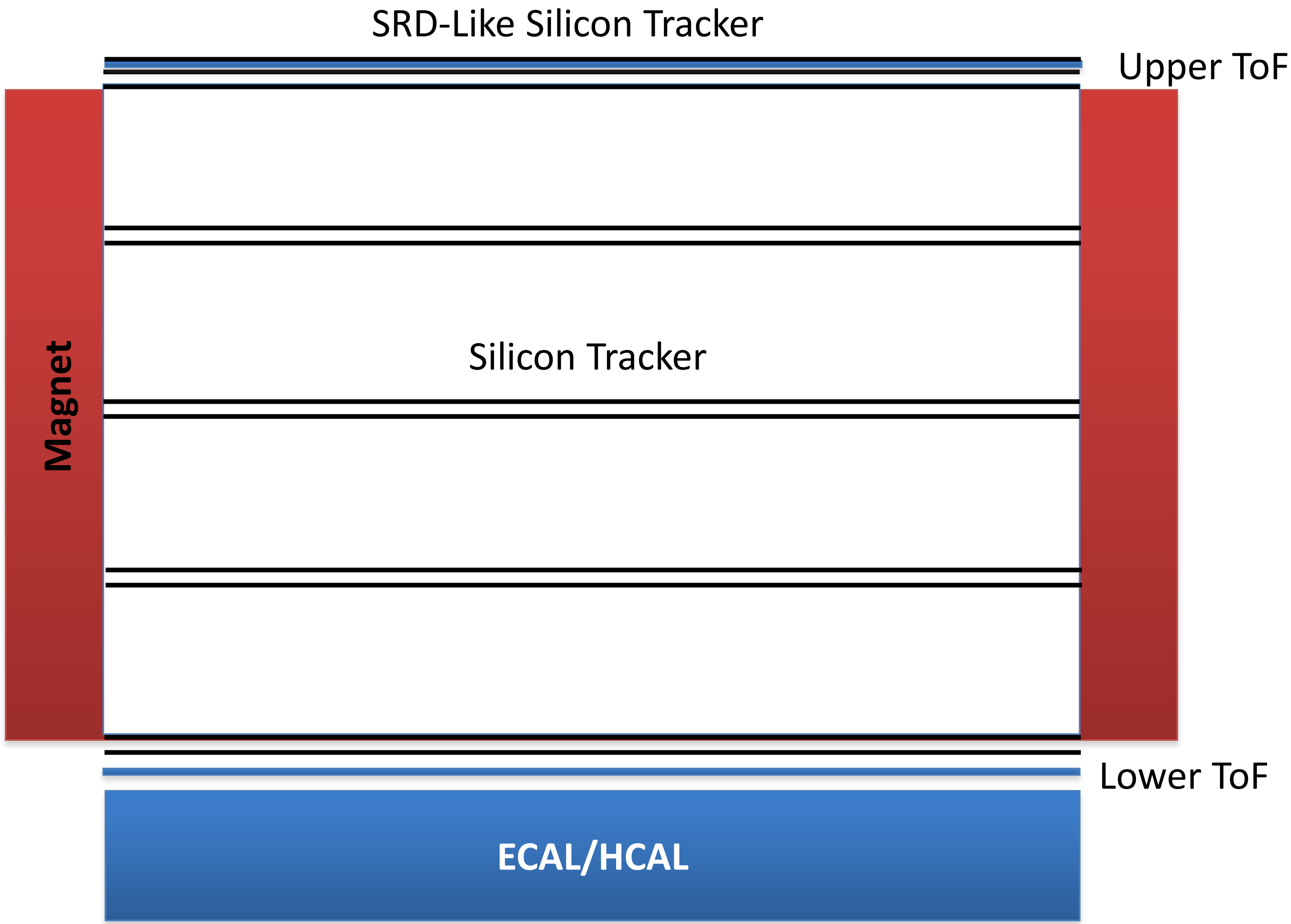
AMS-03 : expected rates and detection tools/limitations

	ELECTRON AND POSITRON PHYSICS @ AMS-03							
					ACCESSIBLE		EXCLUDED	EXCLUDED
eV	**10^8**	**10^9**	**10^10**	**10^11**	**10^12**	**10^13**	**10^14**	**10^15**
Scale	**100MeV**	**GV**			**TV**			**PV**
N Integral (1/y)	**0,1-1 GeV**	**1-10 GeV**	**10-100 GeV**	**100-1000 GeV**	**>1.000 GeV**	**>10.000 GeV**	**>100.000 GeV**	**>1.000.000 GeV**
e-	4,99E+10	3,11E+09	1,56E+08	9,33E+05	7,78E+03	7,78E+01	7,78E-01	7,78E-03
e+	2,50E+09	1,56E+08	1,56E+07	1,40E+05	1,17E+03	1,17E+01	1,17E-01	1,17E-03
Detectors	tracker, TOF, TRD, ECAL	tracker, TOF, TRD, ECAL	Tracker, TRD, ECAL	Tracker, TRD, ECAL	Tracker,SRD,ECAL	Tracker,SRD,ECAL		
Variables	R, beta, gamma, energy	R, beta, gamma, energy	R, gamma, energy	R, gamma, energy	R,Energy, Syncrotron Radiation	R, Energy, Synchroton Radiation		
Physics	Van Allen, solar, subcutoff	solar, geomagnetic, galactic	DM, galactic, asymmetries	DM, galactic, asymmetries	DM, galactic	DM, galactic, moon shadow, sun shadow	DM, galactic	DM, extragalactic, knee
Tools	acceptance vs R, live time, efficiency, MC, inner tracker, alignement, TOF calibration, TRD calibration, backtracing (near Earth)	acceptance vs R, live time, efficiency, MC, inner tracker, alignement, TOF calibration, TRD calibration, backtracing (near Earth)	acceptance vs R, live time, efficiency, MC, inner tracker, alignement, TOF calibration, TRD calibration, backtracing (near Earth)	acceptance vs R, live time, efficiency, MC, inner/outer tracker, TRD, alignement, backtracing (Earth-Moon, Earth- Sun)	acceptance vs R, live time, efficiency, MC, outer tracker, alignement, SRD calibration, ECAL calibration, backtracing Earth-Moon, Earth-Sun	acceptance vs R, live time, efficiency, MC, tracker, alignement, SRD calibration, ECAL calibration, backtracing Earth-Moon, Earth-Sun		
Background e-	-	-	-	p	p	p	p	p
Background e+	p	p	p	p	p	p	p	p
Limitations	multiple, scattering, acceptance,AMS 02 magnetic field		-		SRD Acceptance, MDR Tracker, ECAL must be in accceptance	SRD acceptance, MDR Tracker, ECAL must be in accceptance	no statistics	no statistics

AMS-03 : expected rates and detection tools/limitations

	PROTON and HELIUM PHYSICS @ AMS-03					ACCESSIBLE	ACCESSIBLE	ACCESSIBLE
eV	**10^8**	**10^9**	**10^10**	**10^11**	**10^12**	**10^13**	**10^14**	**10^15**
Scale	**100MeV**	**GV**			**TV**			**PV**
N Integral (1/y)	**0,1-1 GeV**	**1-10 GeV**	**10-100 GeV**	**100-1000 GeV**	**>1.000 GeV**	**>10.000 GeV**	**>100.000 GeV**	**>1.000.000 GeV**
p	4,99E+10	9,96E+10	1,99E+10	3,97E+08	7,19E+06	1,44E+05	2,86E+03	5,71E+01
He	1,80E+09	1,79E+10	3,58E+09	7,14E+07	1,29E+06	2,58E+04	5,15E+02	1,03E+01
Detectors	Tracker, TOF, RICH	Tracker, (RICH)	Tracker	Tracker	Tracker	Tracker+ HCAL	Tracker+ HCAL	Tracker+ HCAL
Variables	R, beta	R	R	R	R	R, Energy	Energy	Energy
Physics	Van Allen, solar, subcutoff	solar, geomagnetic, galactic	galactic	galactic	galactic, moon shadow, sun shadow	galactic, moon shadow, sun shadow	galactic	extragalactic, knee
Tools	acceptance vs R, live time, efficiency, MC, inner tracker, alignement, TOF calibration, RICH calibration, backtracing(near Earth)	acceptance vs R, live time, efficiency, MC, inner tracker, alignement, , RICH calibration, backtracing (near Earth)	acceptance vs R, live time, efficiency, MC, inner tracker, alignement, TOF calibration, RICH calibration, backtracing near Earth)	acceptance vs R, live time, efficiency, MC, inner/outer tracker, alignement, backtracing Earth-Moon, Earth- Sun)	acceptance vs R, live time, efficiency, MC, outer tracker, alignement, , ECAL calibration, backtracing Earth-Moon, Earth-Sun	acceptance vs R, live time, efficiency, MC, tracker, alignement, HCAL calibration, backtracing Earth-Moon, Earth- Sun	acceptance vs R, live time, efficiency, MC, tracker, alignement, HCAL calibration, backtracing Earth-Moon, Earth- Sun	HCAL calibration, backtracing Earth-Moon, Earth- Sun
Background p	-	-	-	-				
Background He	He3/He4	He3/He4	He3/He4	He3/He4	-	-	-	
Limitations	multiple, scattering, acceptance,AMS 02 magnetic field	-	-	different tracker acceptances, alignement	MDR	MDR+ HCAL	HCAL	HCAL

AMS-03-Permanent Magnet



PRELIMINARY DESIGN (26-10-2013) _(A) with Permanent Magnet_

ToF + Tracker + Ecal/HCAL + Syncrotron Radiation Detector-like

SRD-like: 2D X-ray detector to be installed on the top of the magnet on a space station (ISS or future Chinese Station)

Magnet: (A) Permanent: Inner radius 130 cm, Height 200 cm, B-field 0.20 Tesla
Weight: ~13 Tons , MDR 22 TV,
Acceptance 6 times AMS-02-Magnet

ECAL: Radius 130 cm, tungsten absorber, scintillating fibers with SiPM readout,
Thickness 32 cm, 37 Radiation Length,
Weight ~15 Tons, Acceptance 50 times AMS-02 ECAL

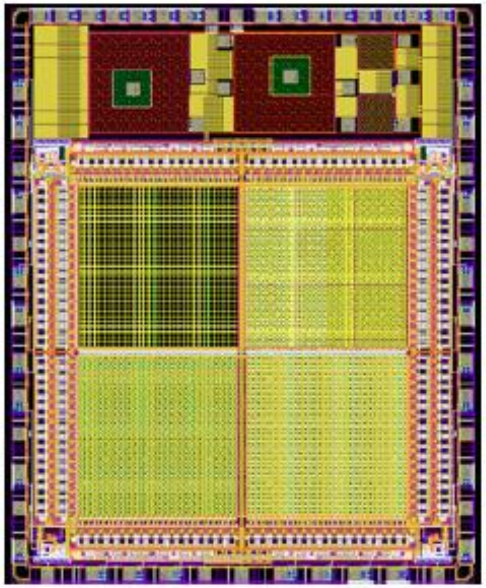
Hadronic energy resolution of the ECAL : to be calculated, expected 30-40% @ TV scale

Tracker: 5 carbon fiber disks in a carbon fiber support structure with a top and bottom silicon layer on each disk.
Single Point resolution < 0.002 mm. Technology : CMOS camera arrays being developed for LHC during the last 10 years (record resolution 600 nanometers)

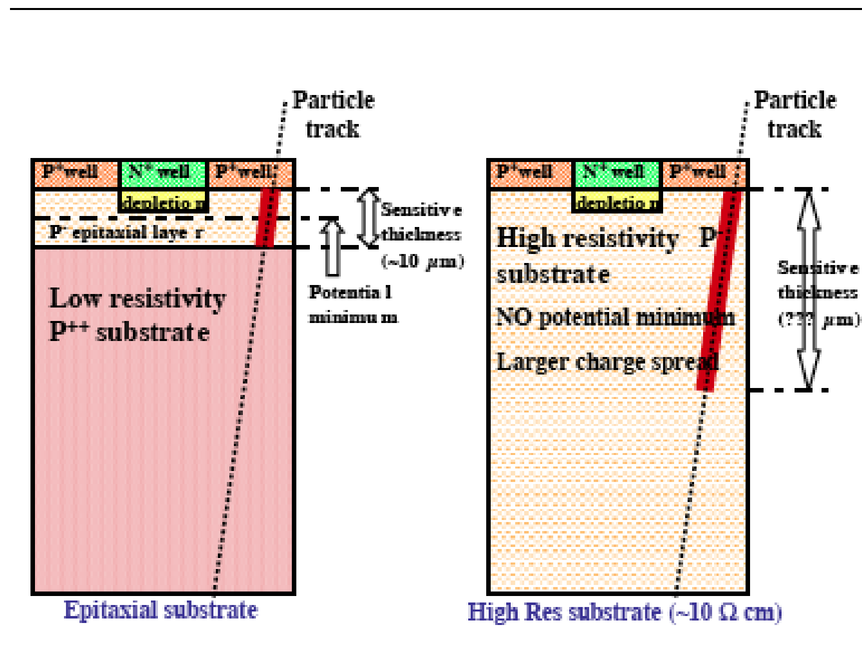
Expected Acceptance: ~5 m^2 sr
MDR: 22 TV
Mass: ~ 30 tons

How to get to micron tracking accuracy

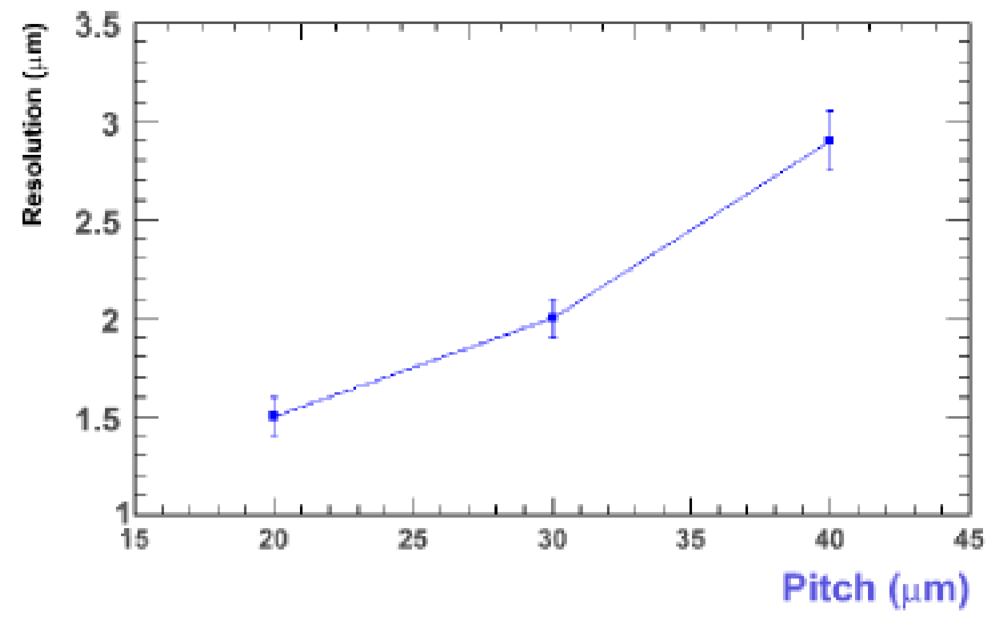
- 1) AMS experience show us that through suitable cooling micron level stability can be achieved over O(1) m^3 using stiff CR as alignament tool
- 2) Space seems to be the right place to implement O(1) μm resolution tracking, which is considered for LHC upgrades and has been developed for at least 10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



Layout of a Successor2 prototype, showing four arrays of 32x32 pixels. The arrays described in this work are located in the bottom part: the 3 transistor standard structures are on the left while the self-biased diodes are on the right. Two upper arrays contain a novel PhotoFET charge sensing element, not discussed in this work. On top of the device, large test structures for the study of irradiation effects through C-V and I-V measurements are included



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.

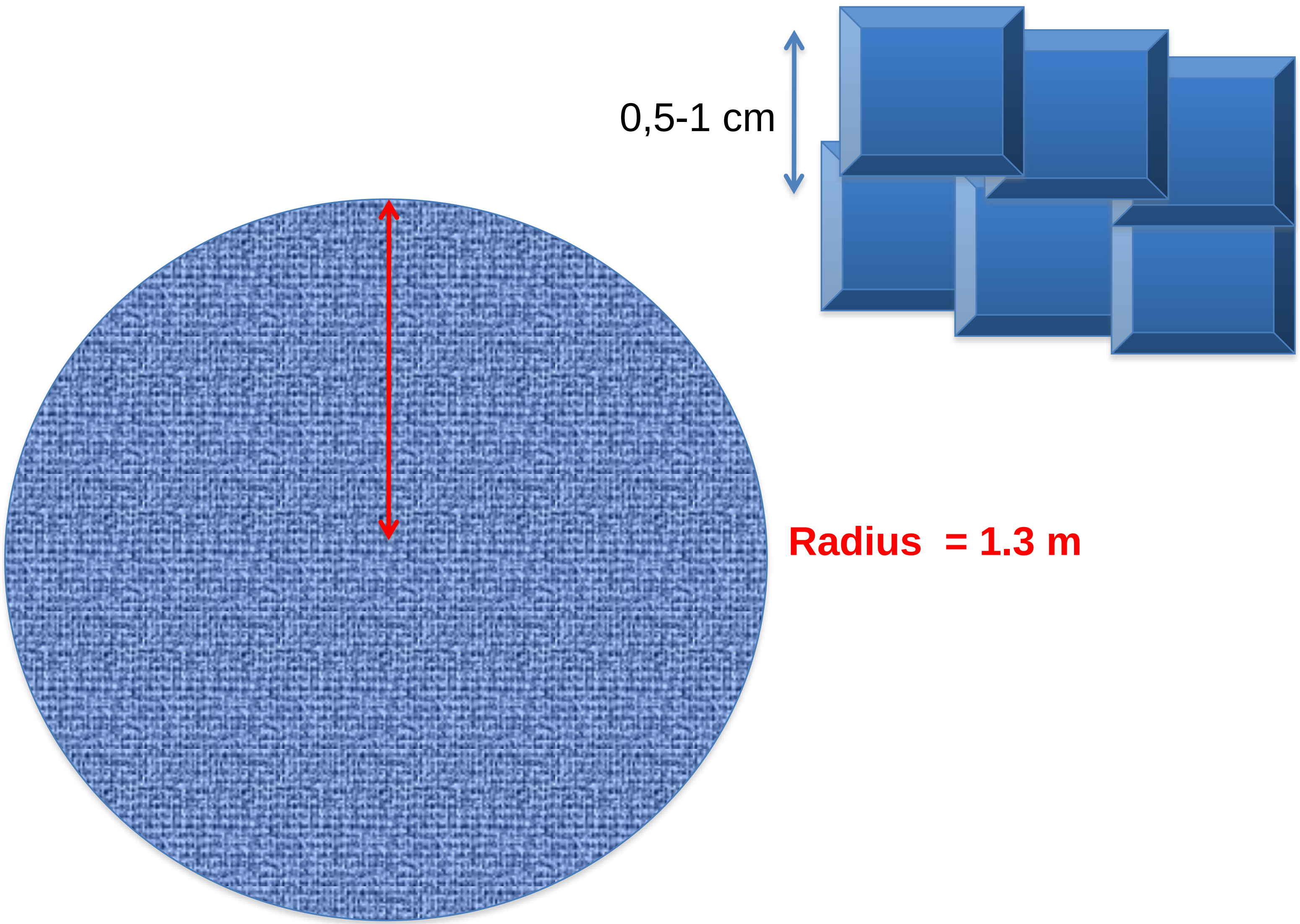


Spatial resolution for minimum ionizing particles as a function of pixel pitch, measured with Mimosa9 prototype.

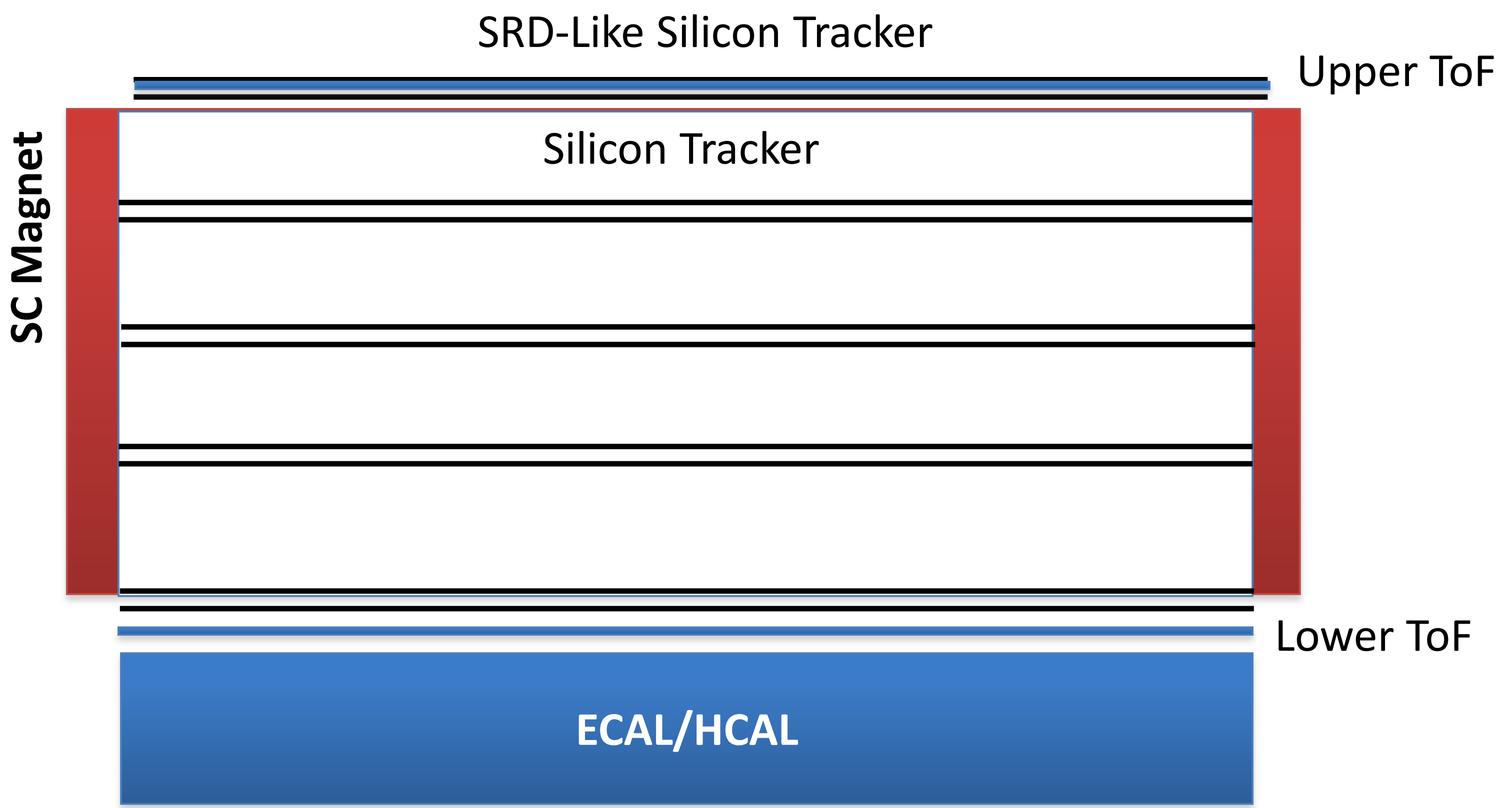
. Intrinsic resolution measurements for APS devices

Sensor	Telescope Method	Sigma of the Fit	Telescope on-a-chip	Telescope on-a-chip with $\sigma_{predicted}$ subtraction
	$[\mu m]$		$[\mu m]$	$[\mu m]$
RAPS03 (small phot.)	1.400 ± 0.260	1.870 ± 0.500	1.560 ± 0.100	n.a.
RAPS03 (large phot.)	n.a.	1.780 ± 0.920	1.100 ± 0.240	n.a.
MT9V011	n.a.	0.851 ± 0.185	0.694 ± 0.478	0.580 ± 0.230
MT9T031	n.a.	0.739 ± 0.150	0.493 ± 0.280	0.375 ± 0.158
MT9T012	n.a.	0.323 ± 0.081	0.287 ± 0.216	0.297 ± 0.053
MT9T013	n.a.	0.280 ± 0.103	0.240 ± 0.122	0.166 ± 0.037
MT9J003	n.a.	0.311 ± 0.073	0.137 ± 0.087	0.090 ± 0.027

Micron accuracy, tiles tracker



AMS-03-Superconductive Magnet



PRELIMINARY DESIGN (25-10-2013) <u>(B) with SC magnet</u>

ToF + Tracker + Ecal/HCAL + SRD-Like

SRD-like: 2D X-ray detector to be installed on the top of the magnet on the space station

Magnet: (B) MgB_2 double helix (perfect dipole): Inner radius 130 cm, Height 100 cm,
B-field 1 Tesla
Weight: << 1 Ton , MDR 56 TV,
Acceptance 6 times AMS-02-Magnet

ECAL: Radius 130cm, tungsten absorber, scintillating fibers with SiPM readout,
Thickness 32 cm, 37 Radiation Length,
Weight ~15 Tons, Acceptance 75 times AMS-02 ECAL

Hadronic energy resolution of the ECAL : to be calculated, expected 30-40% @ TV scale

Tracker: 5 carbon fiber disks in a carbon fiber support structure with a top and bottom silicon layer on each disk.
Single Point resolution < 0.002 mm. Technology : CMOS camera arrays being developed for LHC during the last 10 years (record resolution 600 nanometers)

<u>Expected Acceptance</u>: 9 m^2 sr
<u>MDR</u>: 56 TV
<u>Mass</u>: ~ 15÷18 tons

European Seventh Framework Program

Space Radiation Superconductive Shield (SR2S)

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W.J. Burger, Università di Perugia, INFN, Italy
F. Ambroglini, INFN-Perugia, Italy
R. Musenich, INFN-Genova, Italy
V. Calvelli, INFN-Genova, Italy
S. Farinon, INFN-Genova, Italy
P. Spillantini, INFN-Firenze, Italy
G. Volpini, INFN-Milan, Italy
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
G. Grasso, Columbus Superconductors, Italy
S. Brisigotti, Columbus Superconductors, Italy
D. Nardelli, Columbus Superconductors, Italy
V. Cubeda, Columbus Superconductors, Italy
M. Tropeano, Columbus Superconductors, Italy
R. Piccardo, Columbus Superconductors, Italy
F. Maillard, CGS, Italy
E. Monchieri, CGS, Italy
F. Zurla, CGS, Italy
G. Ober, CGS, Italy
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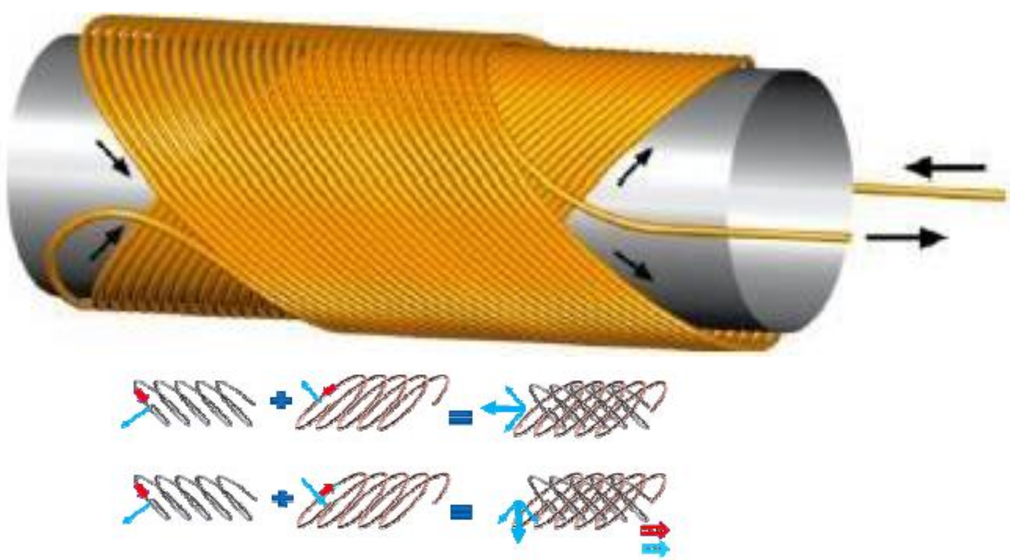
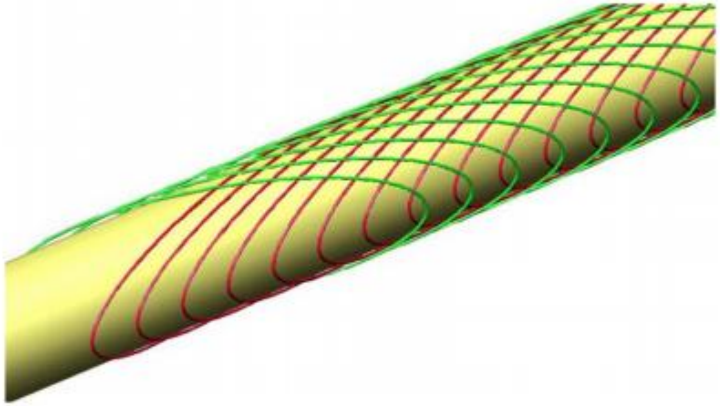
M. Giraudo, Thales Alenia Space, Italy
R. Destefanis, Thales Alenia Space, Italy
C. Lobascio, Thales Alenia Space, Italy
E. Gaia, Thales Alenia Space, Italy

R&D on HTS

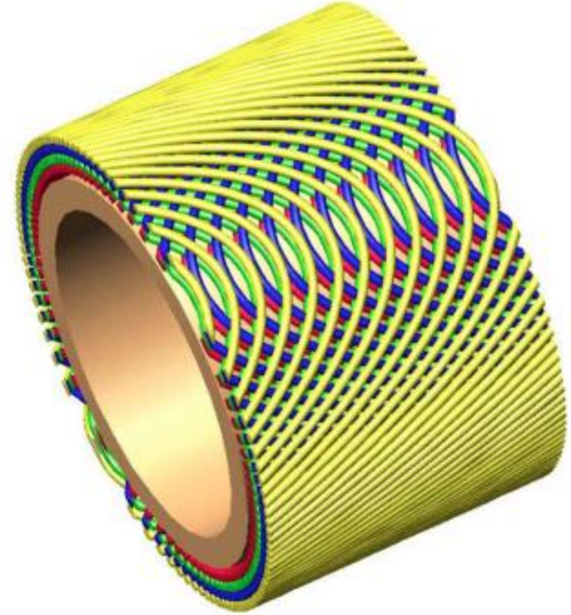
Superconducting Compound	T_c in Kelvin	Hc_2 at 4.2 K in Tesla	ξ (nm)	Mass Density (g/cm³)
Nb-Ti	9	10	5	6.0
Nb_3Sn	18	28	5	7.8
MgB_2	39	up to 70	5	2.5
YBCO-123	90	> 50	<< 1	5.4
BSCCO-2223	108	> 50	<< 1	6.3

- **SRS2 FP7 (***Framework Programme for Research and Technological Development)* is developing a **MgB_2 –Ti cable** which could match the needs of AMS-03
- Magnet operation temperature 10K, cryogenics based on recirculating fluid → **no endurance limit**





Conceptual view of pure dipole windings.



Center cut of the 4 layer "cos-theta" dipole.

Actual cross section of the dipole tested.