An HTS Demonstrator Magnet for a Space Experiment (HDMS)

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Physics with space spectrometers

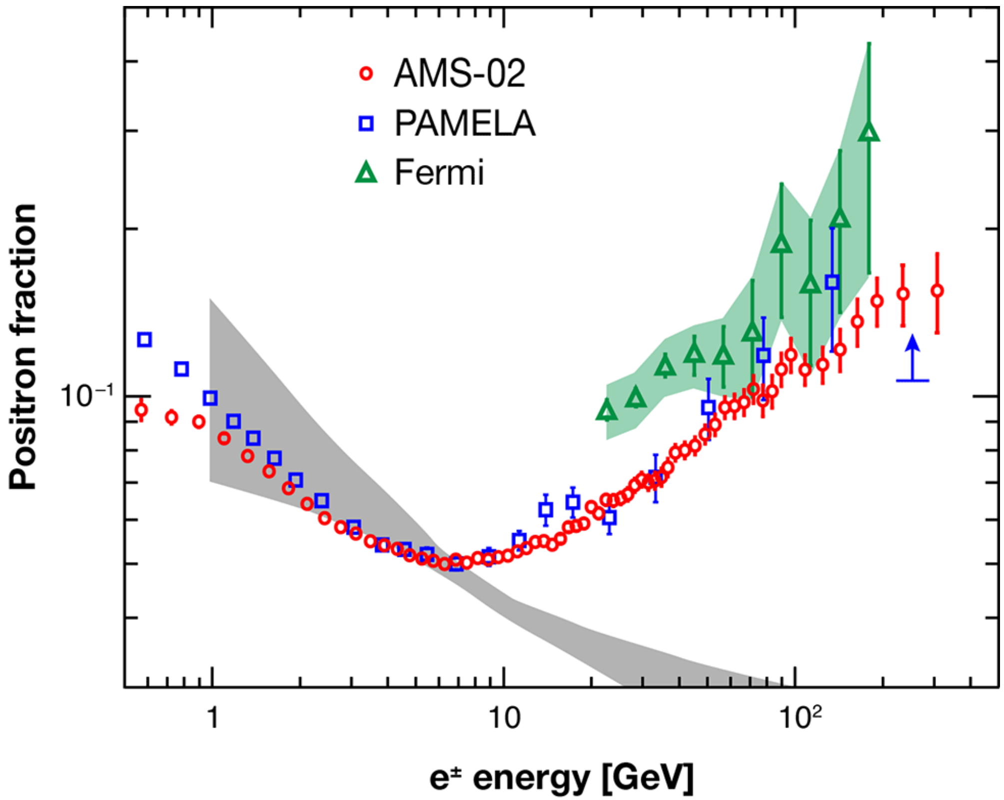
- Searching for dark matter has few "golden channels", among which signatures involving anti-matter.
- The AMS-02 experiment represents the status-of-the-art for what concerns magnetic spectrometers operated in space.
- It is operated on the ISS and has bending power as high as 0.8 T*m, obtained with a permanent magnet.

A Nb-Ti superconducting solution was initially explored, to get higher bending power and extend the dynamic range.

The project was abandoned after years of development, because of issues with the long-term cryogenics requirements.

Results of a space spectrometer: AMS-02

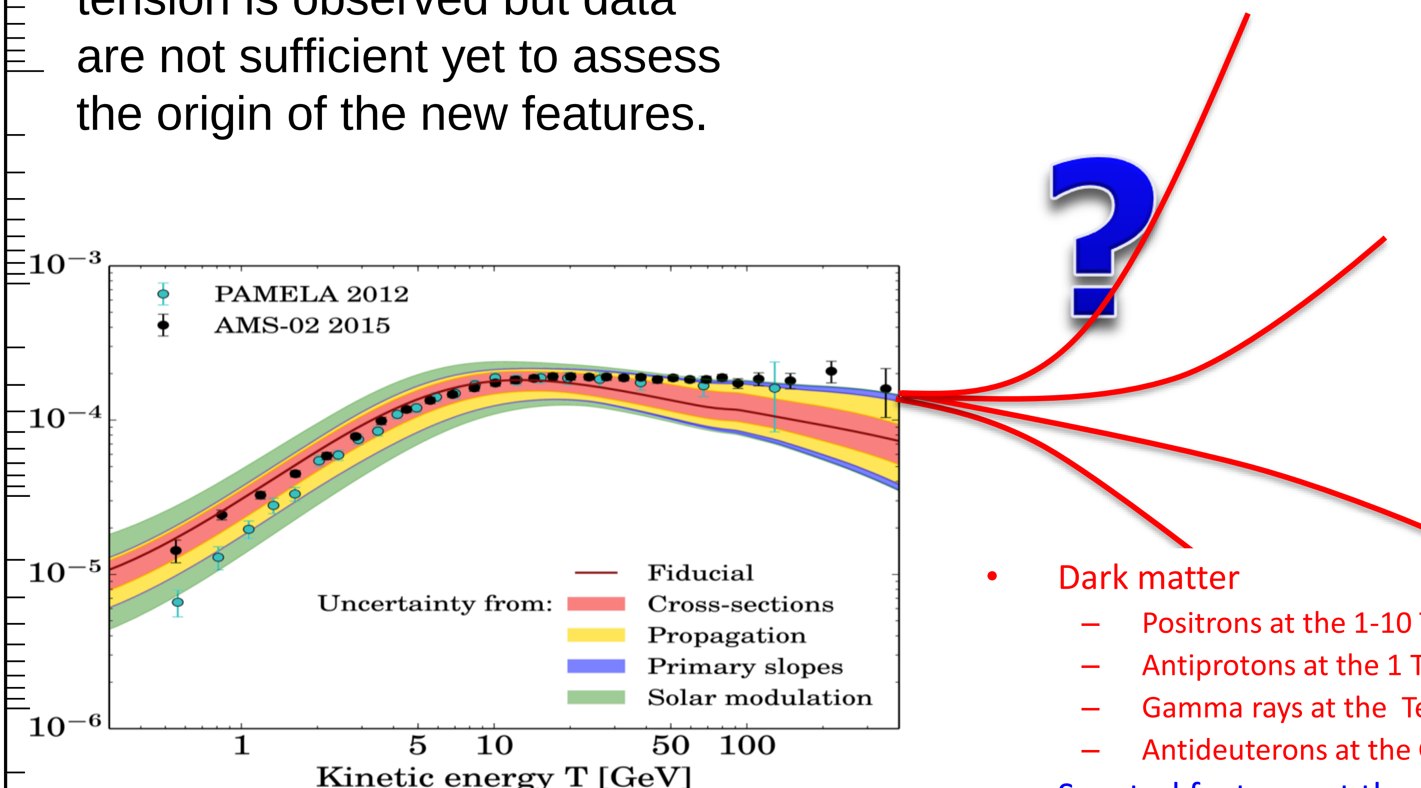
AMS-02 proved to be extremely sensitive in the sub-TeV region, confirming that from 10 GeV on the flux of positrons exceeds the secondary production, by up to one order of magnitude at 100 GeV.



Whether related to DM annihilation or due to unknown astrophysical reasons (e.g. nearby sources), the excess demands to be followed up above 1000 GeV, for which AMS-02 is too small and has not sufficient bending power.

Measurement range needed

Weaker evidence for antiprotons, where still some tension is observed but data are not sufficient yet to assess the origin of the new features.



Gaëlle Giesen et al., JCAP 2015 10.1088/1475-7516/2015/09/023

- Dark matter
  - Positrons at the 1-10 TeV scale
  - Antiprotons at the 1 TeV scale
  - Gamma rays at the TeV scale
  - Antideuterons at the GeV scale
- Spectral features at the “knee scale”
  - Protons at the PeV scale
  - Helia at the PeV scale
  - Ions at the 100 TeV scale

Scientific objective for a new space spectrometer

measure cosmic anti-matter up to rigidities as high as 30 TeV/e.

INSTRUMENTED AREA

- The particle flux decreases by 99% every time we increase tenfold the energy. Keeping the experiment lifetime fixed this translates to instrument areas as large as 10-30 X AMS: ***30-90 square meters.***

$$Q = \bar{B}[\mathrm{T}]\, L[\mathrm{m}]\ \frac{d[\mathrm{m}]}{\sigma_p[\mathrm{m}]}$$

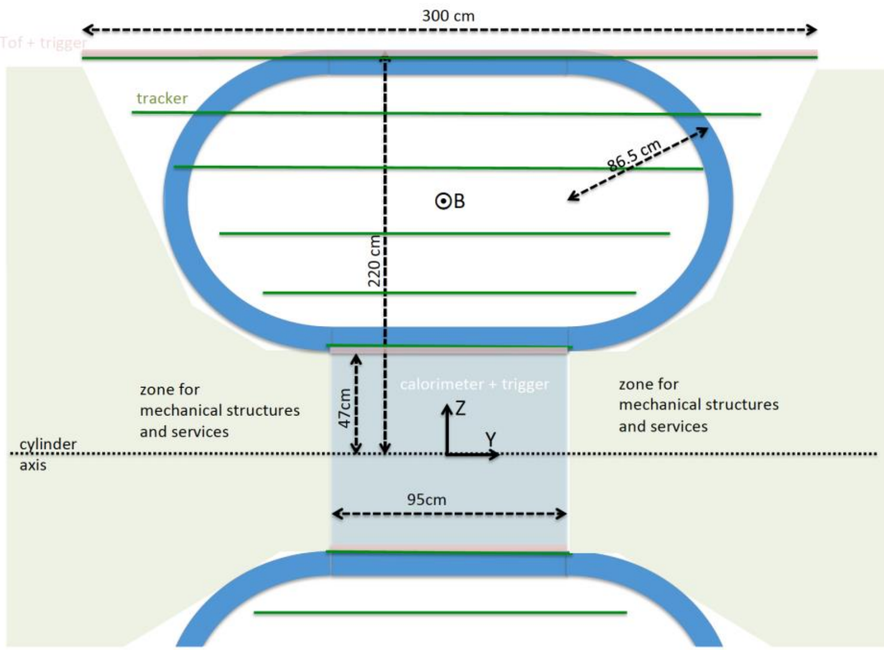
BENDING POWER

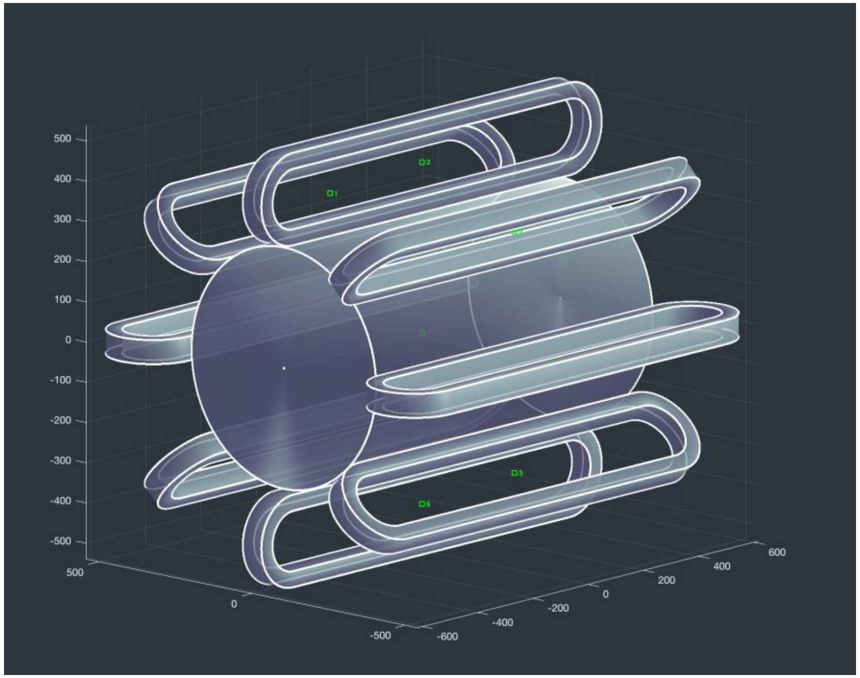
- The maximum detectable rigidity (MDR or Q) of a magnetic spectrometer is proportional to BL*L/s. The bending power BL and the lever-arm-to-sagitta ratio are the only handles to act upon to increase the MDR by a factor of 60. Keeping fixed the detector size and assuming the sagitta resolution can be improved by a factor of 10, it remains to increase BL by a factor of 6: ***up to 5 T*m.***

These requirements can be met only with dedicated efforts in matter of large-scale superconducting magnet applications for space.

Concept for a new space spectrometer

- The toroidal configuration exploits the magnetized volume best.
- This allows to develop effective areas as large as 10 m^2 with volumes as low 1.5 m^3.





Current proposals focus on increasing the lever arm to gain a factor of 10 on Q (3 on BL and 3 on d/σ)

To gain a factor of 100 on Q, you need a factor of 10 on BL and a factor of 10 on d/σ

Detectors

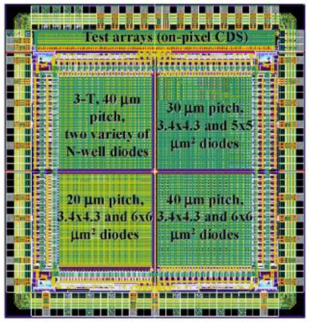


Fig. 3. Layout of Mimosa9: the overall dimension of this prototype is 4.1 × 4.3 mm².

R&D STAR vertex detector @ BNL

From Dulinski et al., "Optimization of Tracking Performance of CMOS Monolithic Active Pixel Sensors", IEEE 54, 1 (2007) – R&D for the STAR experiment

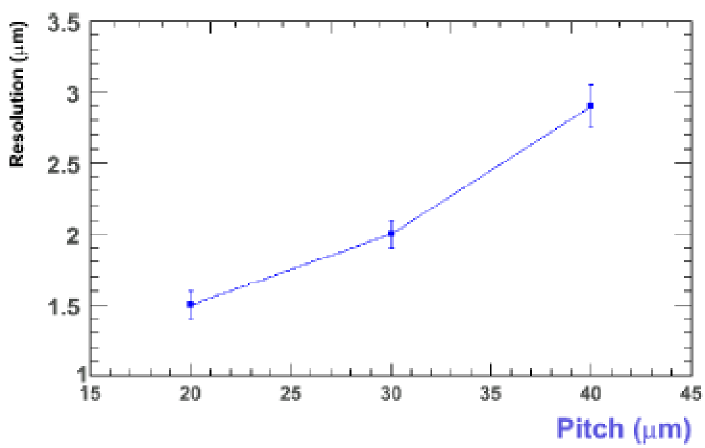
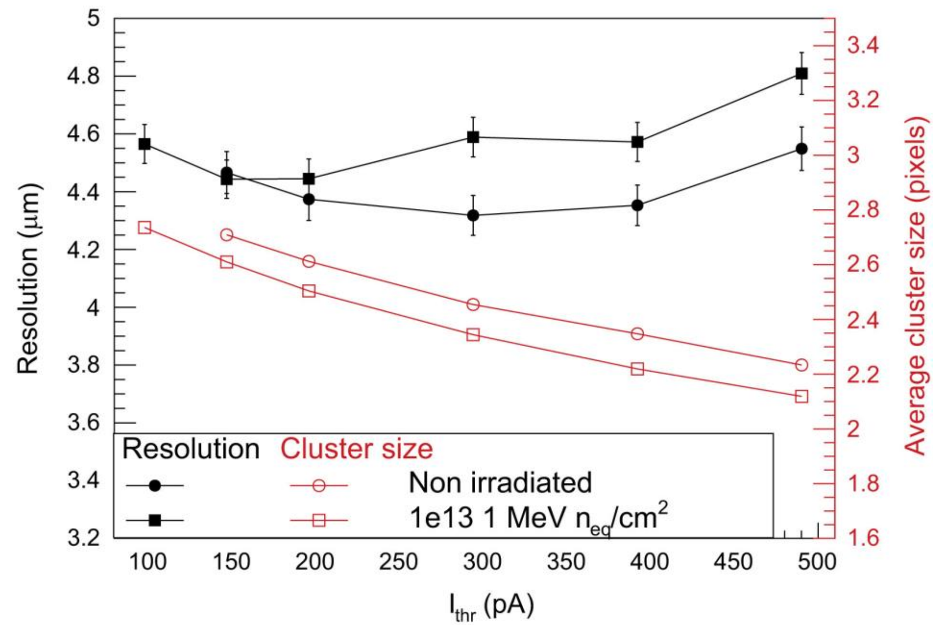


Fig. 8. Spatial resolution for minimum ionizing particles as a function of pixel pitch, measured with Mimosa9 prototype.



From M. Mager, "ALPIDE, the Monolithic Active Pixel Sensor for the ALICE ITS upgrade" **(NIMA, 2015)**

R&D ALICE inner tracker @ CERN

Current microstrip resolution in AMS-02 is 10 um

A new space spectrometer

EUCAS 2017

Project HDMS: HTS Demonstrator Magnet for Space

- Ambitious project to demonstrate technical feasibility for using high field HTS magnets technologies under development for particle accelerators in aerospace applications for science
- Target mission (design driver): high resolution astro-particle spectrometer in space
- Possible secondary applications:
  - active astronauts radiation shielding, high power electric propulsion, medical analysis (NMR), compact radioisotopes production
- Project framework:
  - implementation of a bilateral collaboration agreement between CERN and ASI
  - granted CERN Knowledge Transfer Fund for Aerospace Application project
- Project status: approved by CERN and ASI, expected to start before end 2017

Strong synergy with EuCARD2/ARIES and the CERN HTS program for High Field HTS magnets

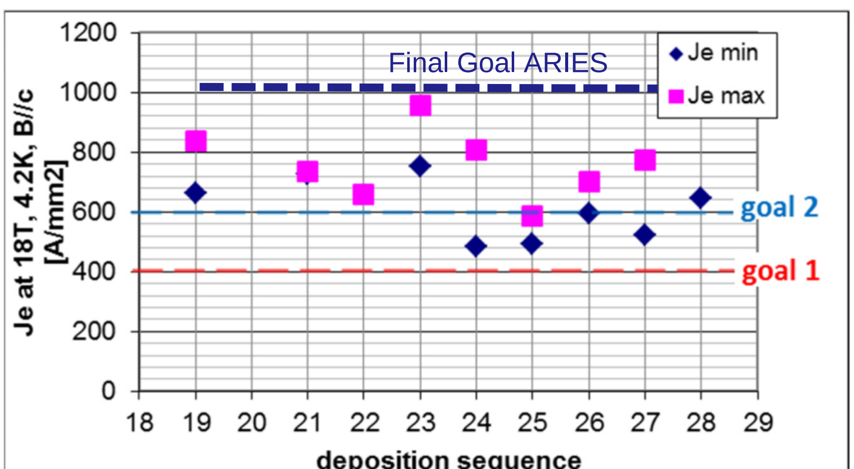
Base for the application: EuCARD2 Conductor

EuCARD-2 is co-funded by the partners and the European Commission under Capacities 7th Framework Programme, Grant Agreement 312453

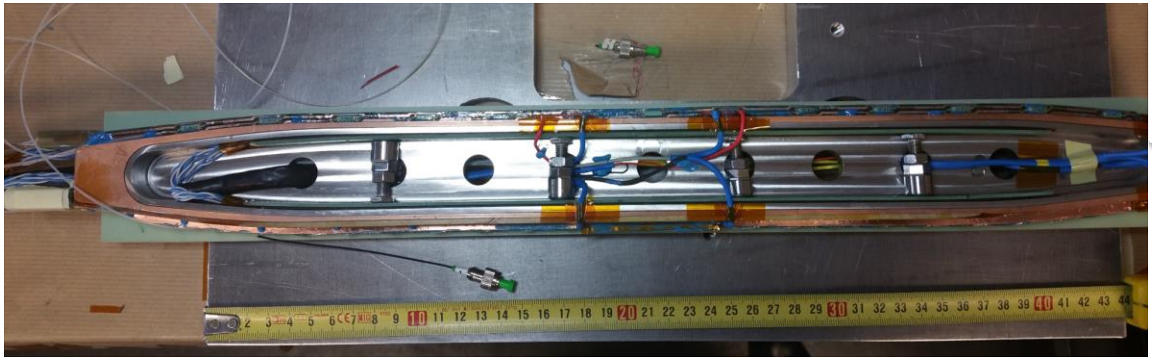
CAPACITIES

HTS: YBCO/REBCO coated conductor

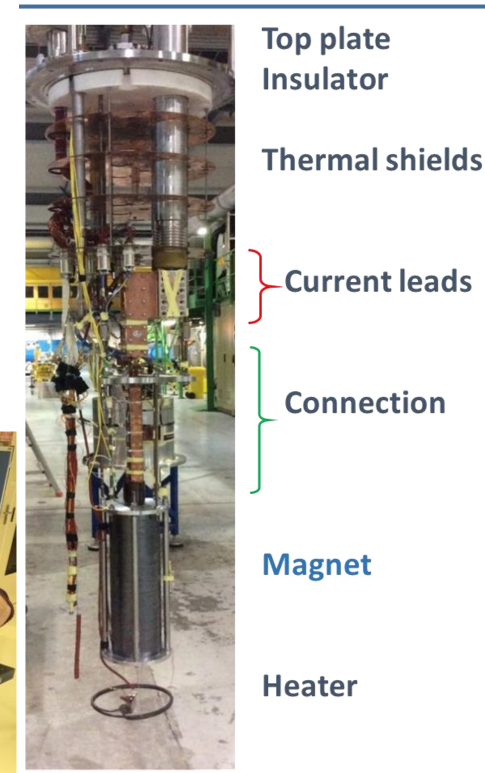
Eucard2 – WP10
Future Magnets for post-LHC colliders



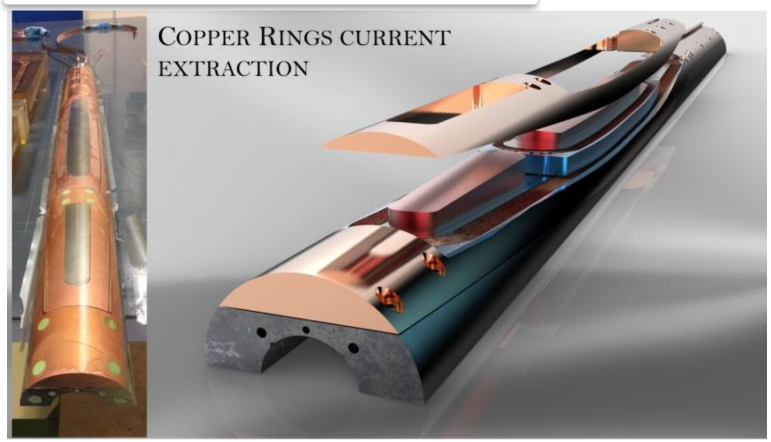
Base for the application:
EuCARD2 dipole wound with roebel cable



FM0.4 sub-size coil
Successful test : 12 kA



FM2 magnet for 3-5 T
under construction

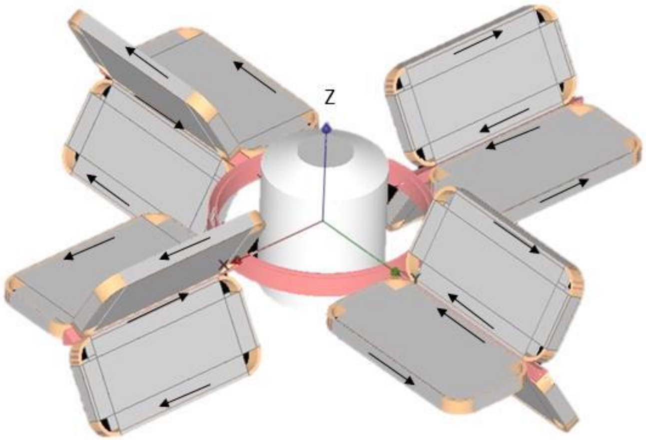


Potential secondary application: magnetic shielding for spaceships (FP7-SR2S)

ASI, INFN, CERN, CEA and other Institutions

Coil based on MgB2 technology: results have not been very successful

SR2S
Space Radiation
Superconducting Shield



Magnet design mostly based on flat coils arranged in toroidal shape – 3-5 T

HTS Demonstrator Magnet for Space

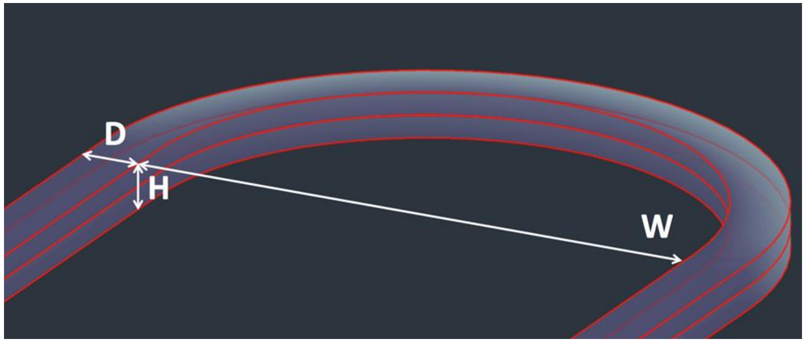
Technical objectives:

- Design a compact dipole field demonstrator, racetrack-type and based on CERN Accelerator Technology under development future colliders
- Develop the conductor suitable for a space magnet, based on the HTS tape developed for CERN in EuCARD2/ARIES
- Manufacture a small race track demonstrator (300 mm < L < 1000 mm) to test conductor and most of magnet technologies
- Test of demonstrator in a wide temperature range, 4 K < T_{op} < 80 K.

Conceptual Pre-design

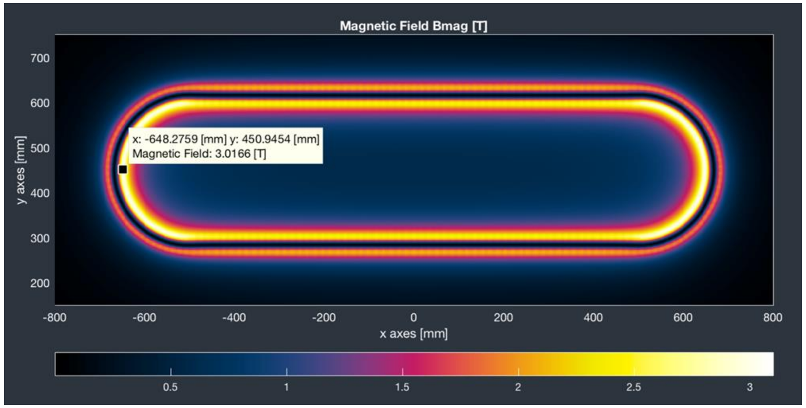
Operation at 10 K – 10 T (same as 20 K – 5 T)

Parameter	Symbol	Value	Unit
Critical current density (field orthogonal)	J_c	14	kA/mm^2
Maximum engineering current density (tape)	$J_{c,en}$	355	A/mm^2
Maximum engineering current in the coil	$I = J_{c,en} \times D \times H$	256	kA



Power consumption - Joints

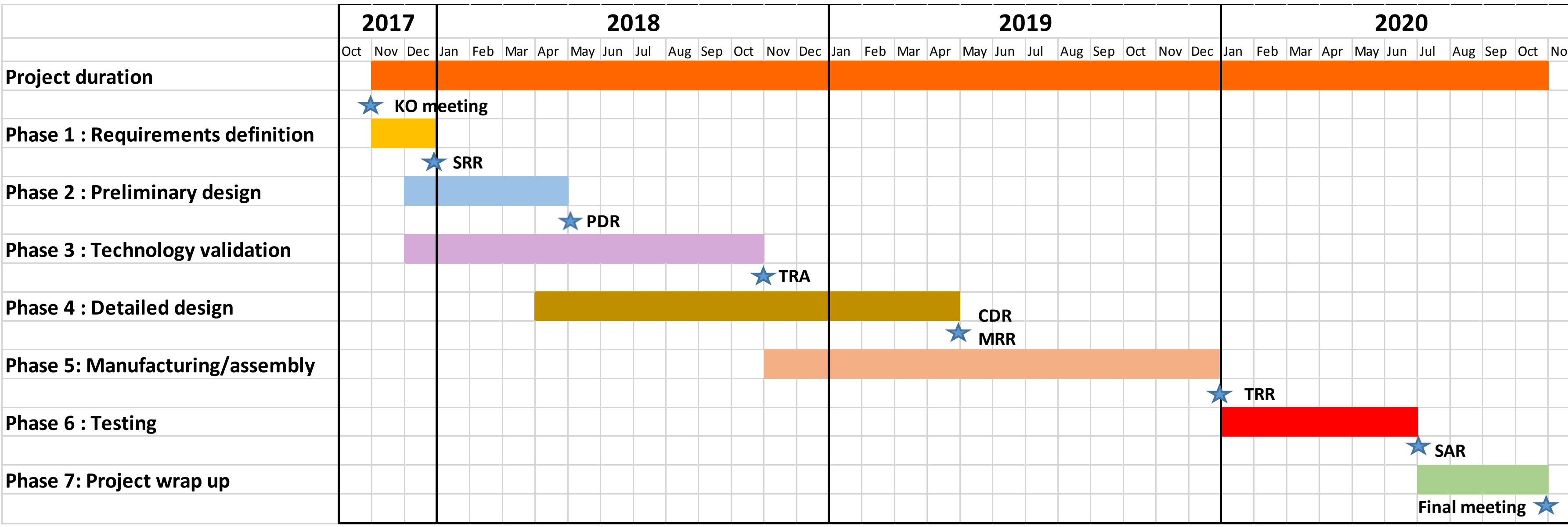
Parameter	Symbol	Value	Unit
Maximum tape length	f	90	m
Number of tapes per pancake	$N_t = F/f/N_p$	7	
Joint resistance	R_j	30	nΩ
Pancake resistance	$R_p = R_j \times N_t$	210	nΩ
Coil resistance	$R_c = N_p \times R_p$	420	nΩ
Maximum power consumption at 5 K -20 T	$P = R_c \times I^2$	0.143	W
Maximum cryo power needed at 5 K – 20 T (COP 300)	P_{cryo}	2.7	kW
Max power consumption at 10 K -10 T (same as 20K-5T)	$P = R_c \times I^2$	0.170	W
Maximum cryo power needed at 20 K – 5 T (COP 150)	P_{cryo}	0.396	kW



Expected magnetic field intensity at $J_{c,en}$=330 A/mm^2.
No background field considered.

HDMS

Collaborative program between ASI and CERN , based on 7 milestones with a 3 year duration



Start of project: October 2017,

End 2017: Recruitment of a fellow

Conclusions

- HTS Demonstrator Magnet for Space project is launched
- Will apply accelerator HTS magnet technology for a space spectrometer magnet
- Necessary step for the next step space spectrometer to look at high energy antimatter in space

- Good example how different fields can advance together

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