The High Energy cosmic Radiation Detection (HERD) facility onboard China's Space Station

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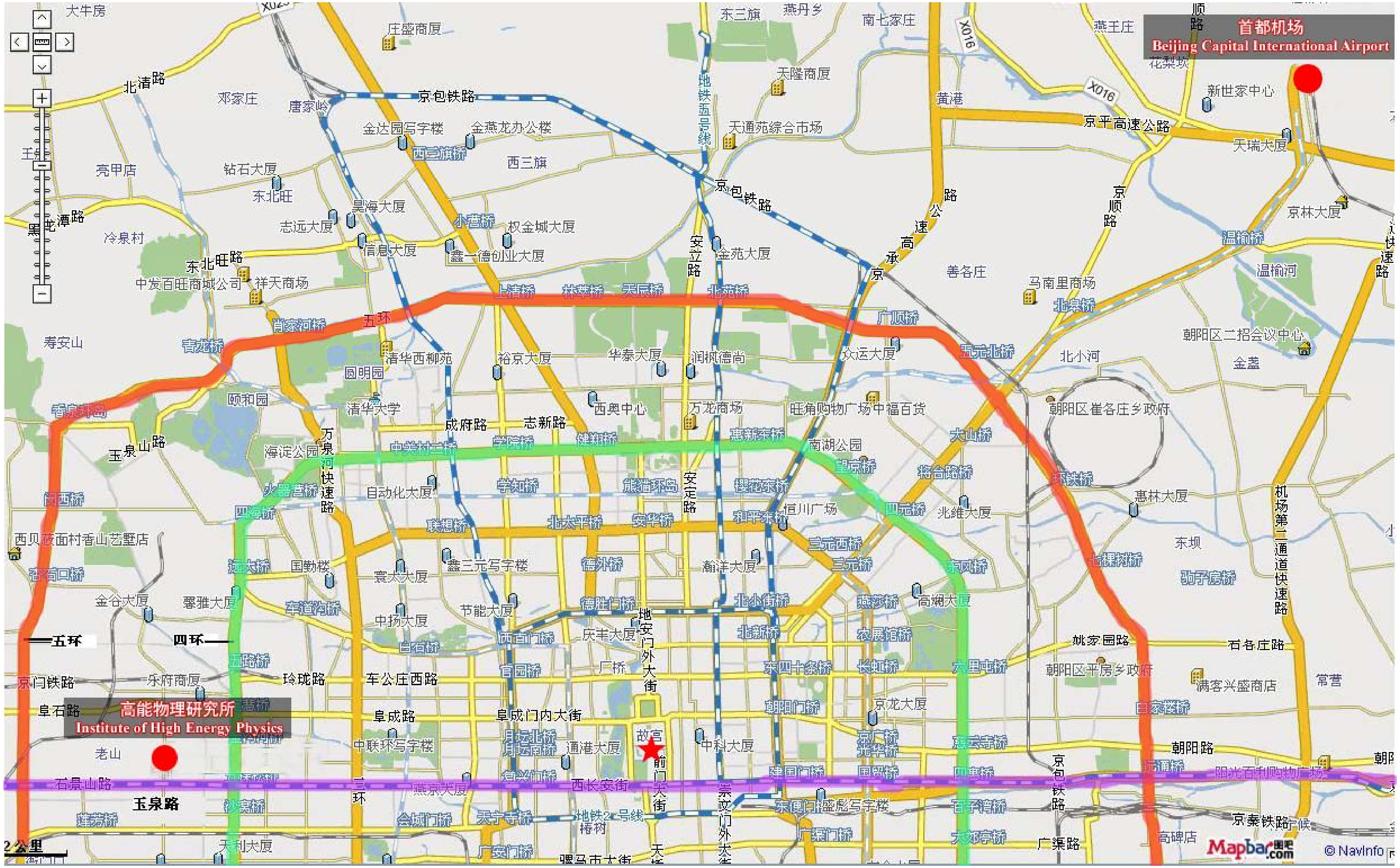
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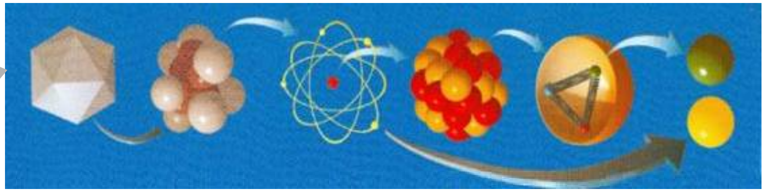
IHEP Campus Map

Research in IHEP: >1300 fulltime staff

Science goals

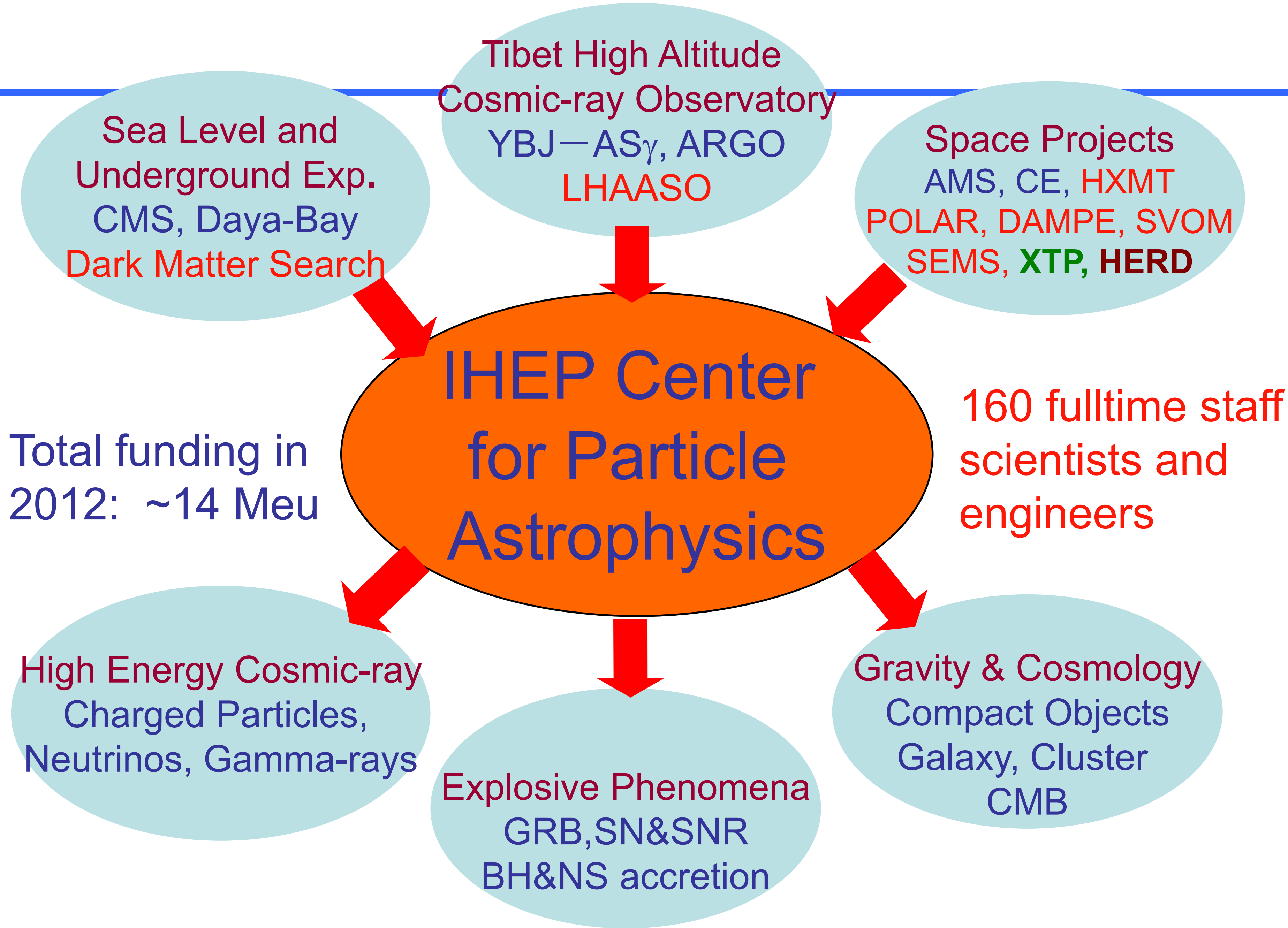


Fundamental structure of matter and evolution of the universe

Total funding in 2012: ~140 Meu

Multi-discipline Platform

Collider, Synchrotron, Underground lab, high-altitude cosmic ray observatory, space instruments


Tibet High Altitude
Cosmic-ray Observatory
YBJ—ASγ, ARGO
LHAASO
Sea Level and
Underground Exp.
CMS, Daya-Bay
Dark Matter Search
Space Projects
AMS, CE, HXMT
POLAR, DAMPE, SVOM
SEMS, XTP, HERD
IHEP Center
for Particle
Astrophysics
Total funding in
2012: ~14 Meu
160 fulltime staff
scientists and
engineers
High Energy Cosmic-ray
Charged Particles,
Neutrinos, Gamma-rays
Explosive Phenomena
GRB,SN&SNR
BH&NS accretion
Gravity & Cosmology
Compact Objects
Galaxy, Cluster
CMB

China's Space Station Program

- Three phases
  - 1st phase: so far 7 Chinese astronauts have been sent out and returned back successfully; many space science research has been done. Completed successfully.
  - 2nd phase: spacelab: docking of 3 spaceships with astronauts delivering and installing scientific instruments. 1st launch on Sept. 29, 2011.
  - 3rd phase: spacestation: several large experimental cabins with astronauts working onboard constantly. 1st launch ~2018.

International collaborations on space science research have been and will continue to be an important part.

Cosmic Lighthouse Program: China's Space Station

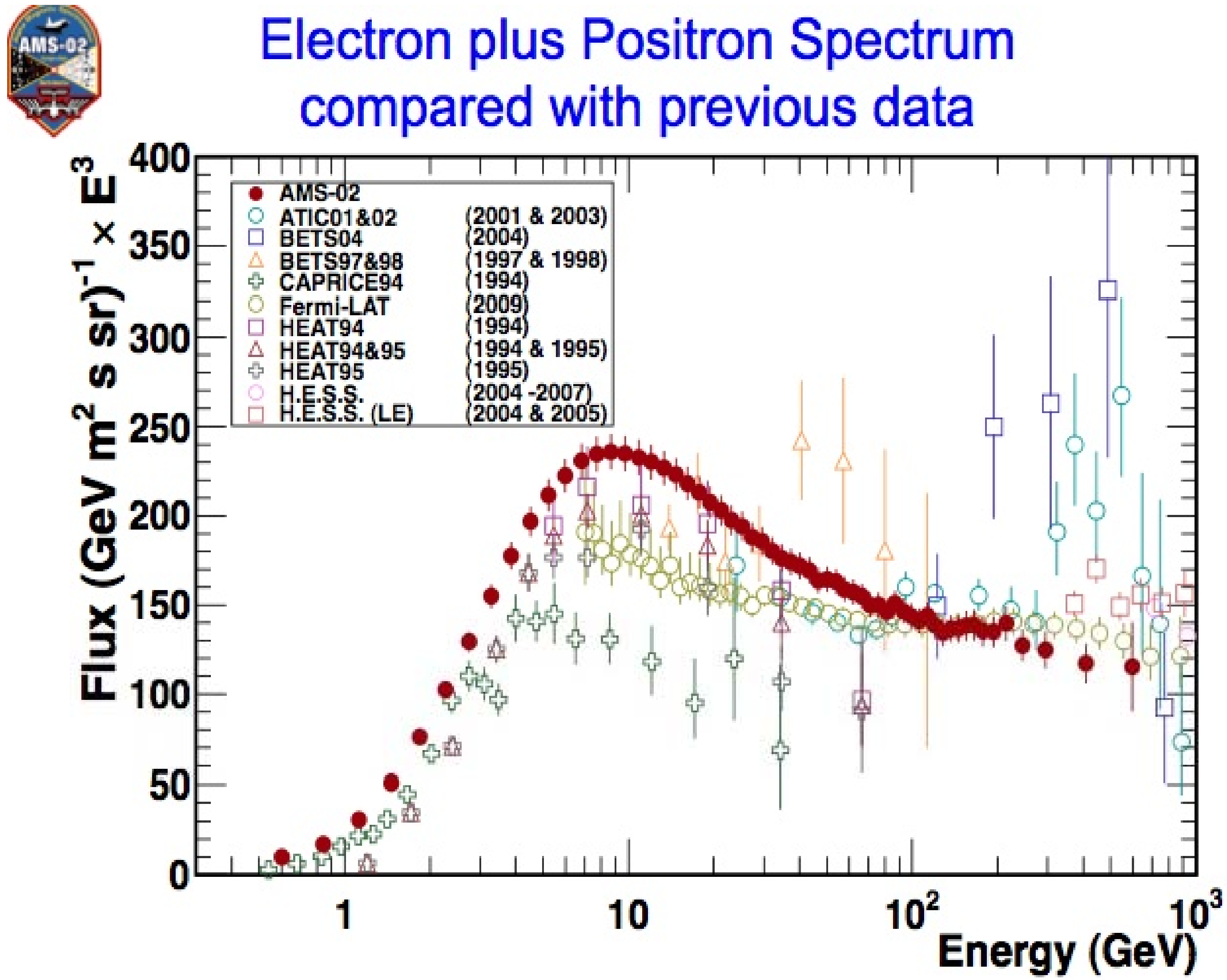
Candidate Projects	Main Science Topics
Large scale imaging and spectroscopic survey facility (**approved**)	Dark energy, dark matter distribution, large scale structure of the universe
HERD (**concept**)	Dark matter properties, cosmic ray composition, high energy electron and gamma-rays
Soft X-ray-UV all sky monitor (?)	X-ray binaries, supernovae, gamma-ray bursts, active galactic nuclei, tidal disruption of stars by supermassive black holes
X-ray polarimeter (?)	Black holes, neutron stars, accretion disks, supernova remnants
Galactic warm-hot gas spectroscopic mapper (?)	The Milky Way, interstellar medium, missing baryons in the Universe
High sensitivity solar high energy detector (?)	Solar flares, high energy particle acceleration mechanism, space weather
Infrared spectroscopic survey telescope (?)	Stars, galaxies, active galactic nuclei


background
Gamma-ray
HERD
electron
proton
He
Dark matter particle

AMS02

Weight 8,500 kg
Volume 64 m^3
Cost $1.5 billion (estimated)

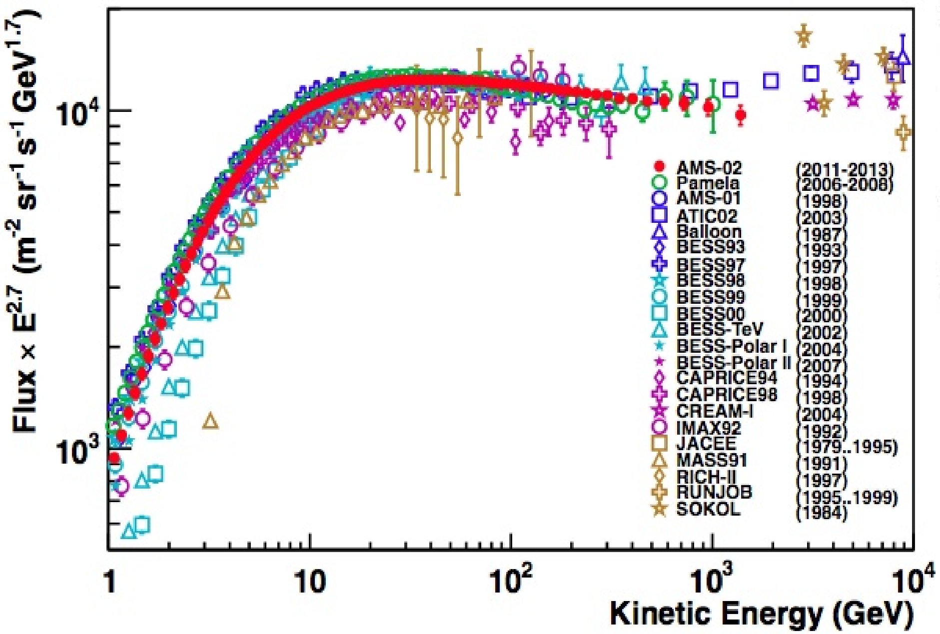
Recent AMS02 Results: electrons



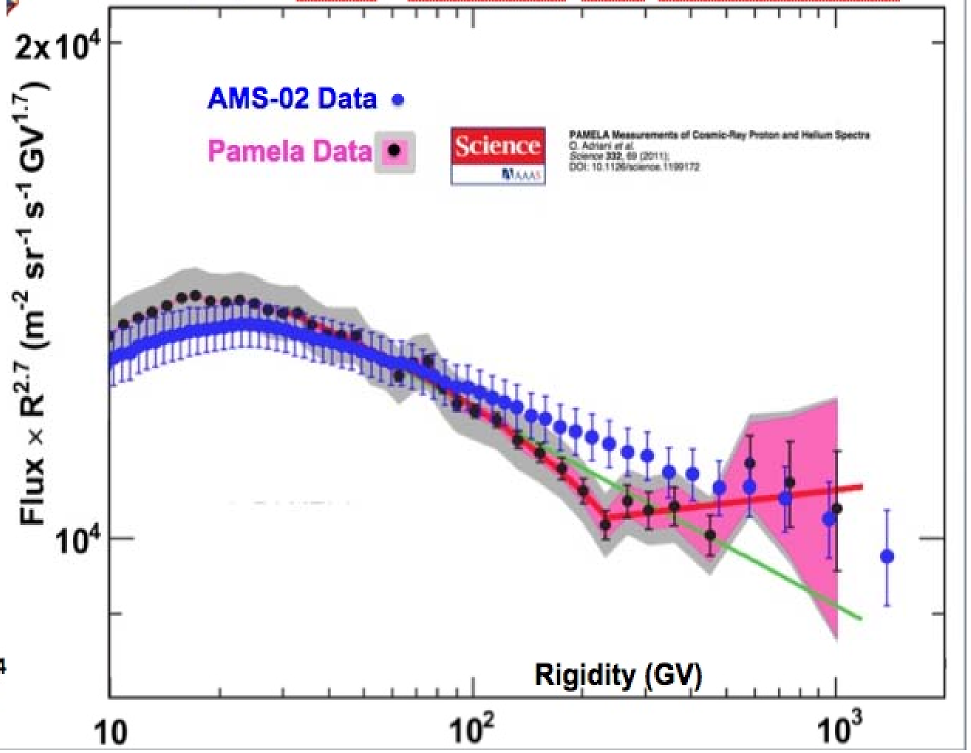
Recent AMS02 Results: protons

Proton flux

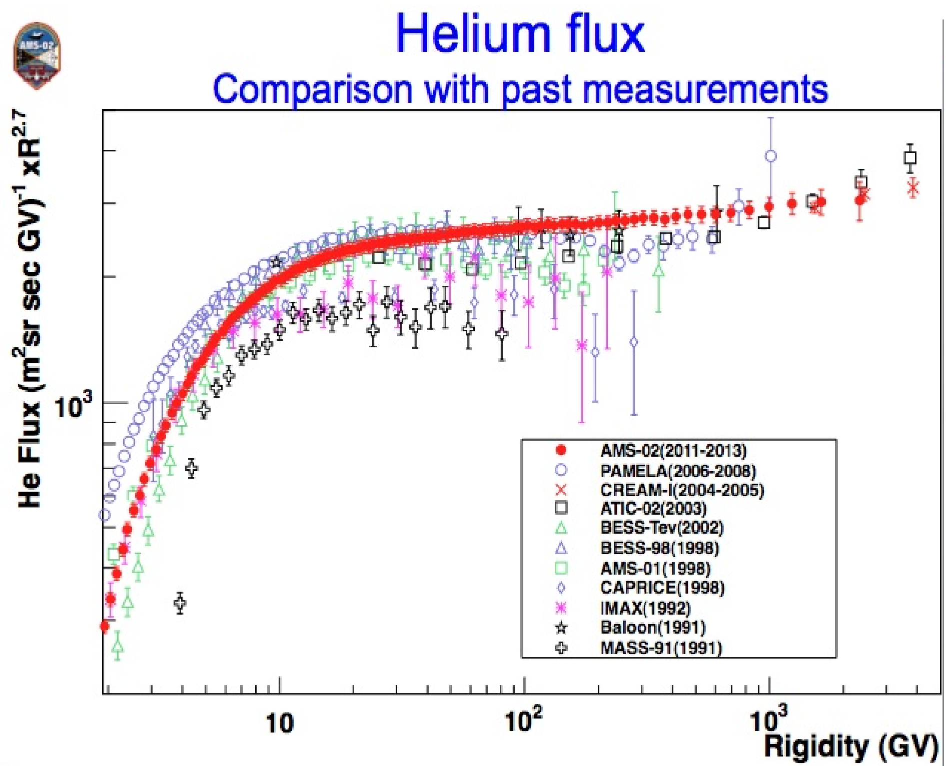
Comparison with past measurements

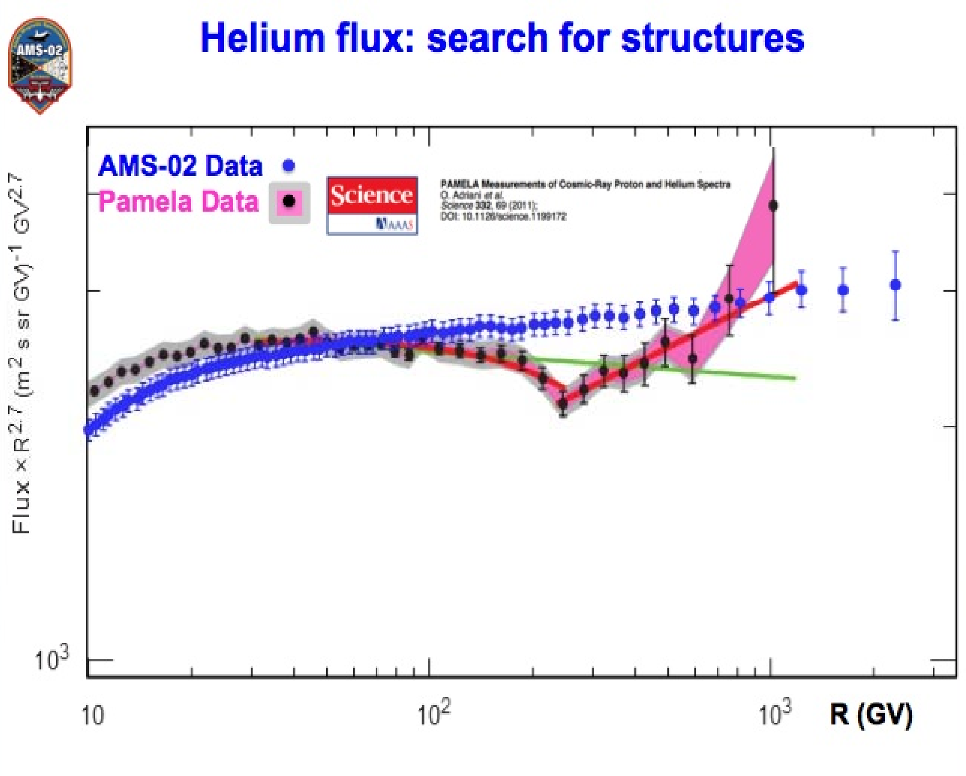


Proton flux: search for structures

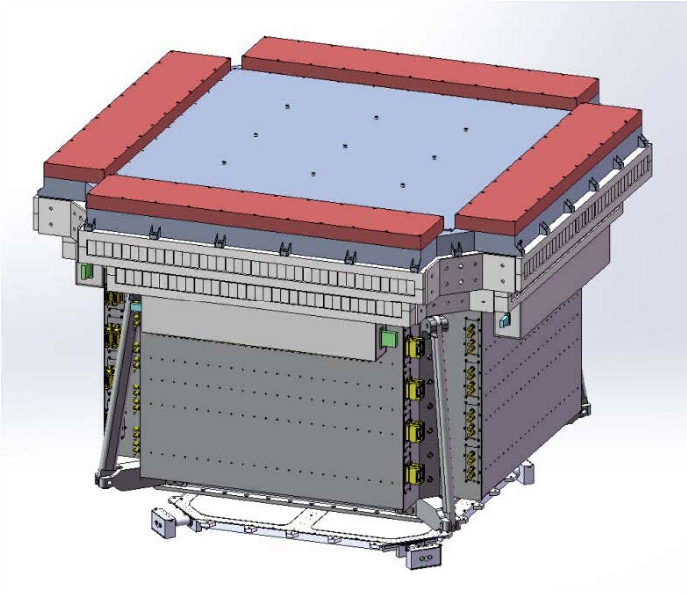


Recent AMS02 Results: Heliums





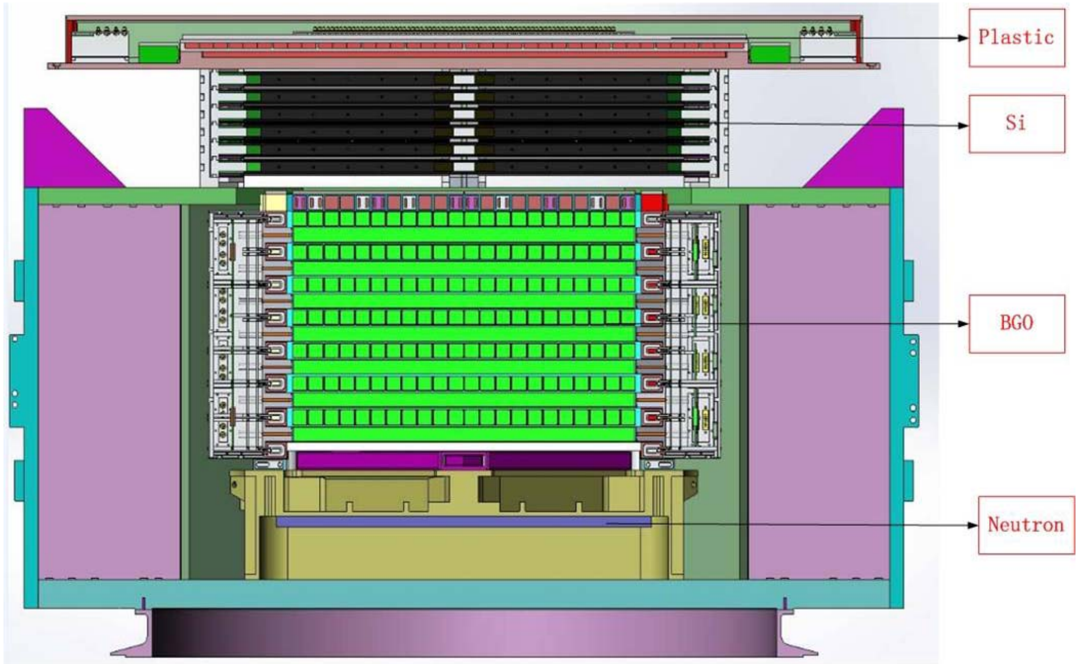
Beyond AMS: DAMPE



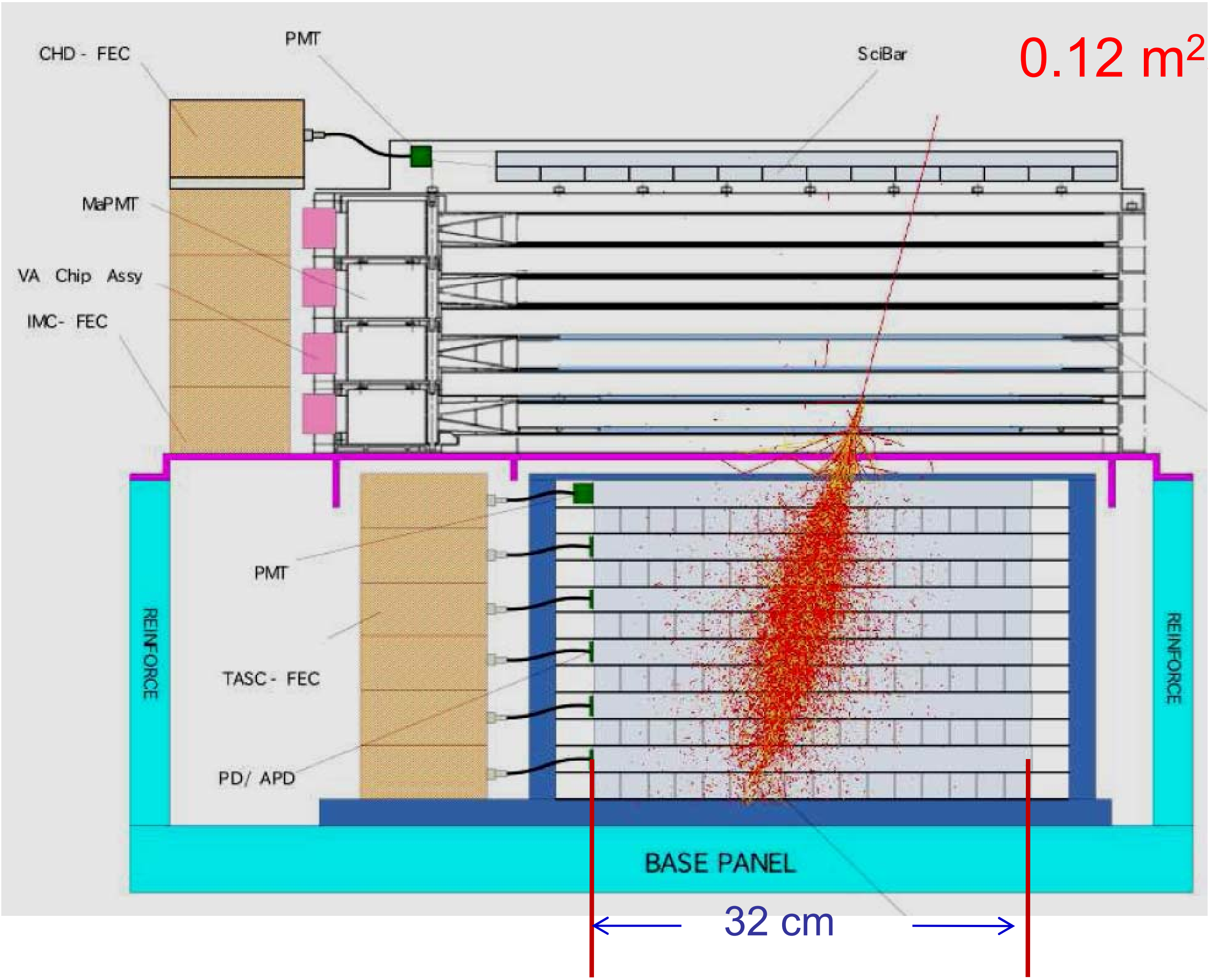
The detector is consisted of 4 parts:
Top scintillators
Si tracker (5 layers)
BGO calorimeter
Neutron detector

e: 0.3m^{2}sr@200GeV

p: 0.12 m^{2}sr@100TeV



Beyond AMS: CALET



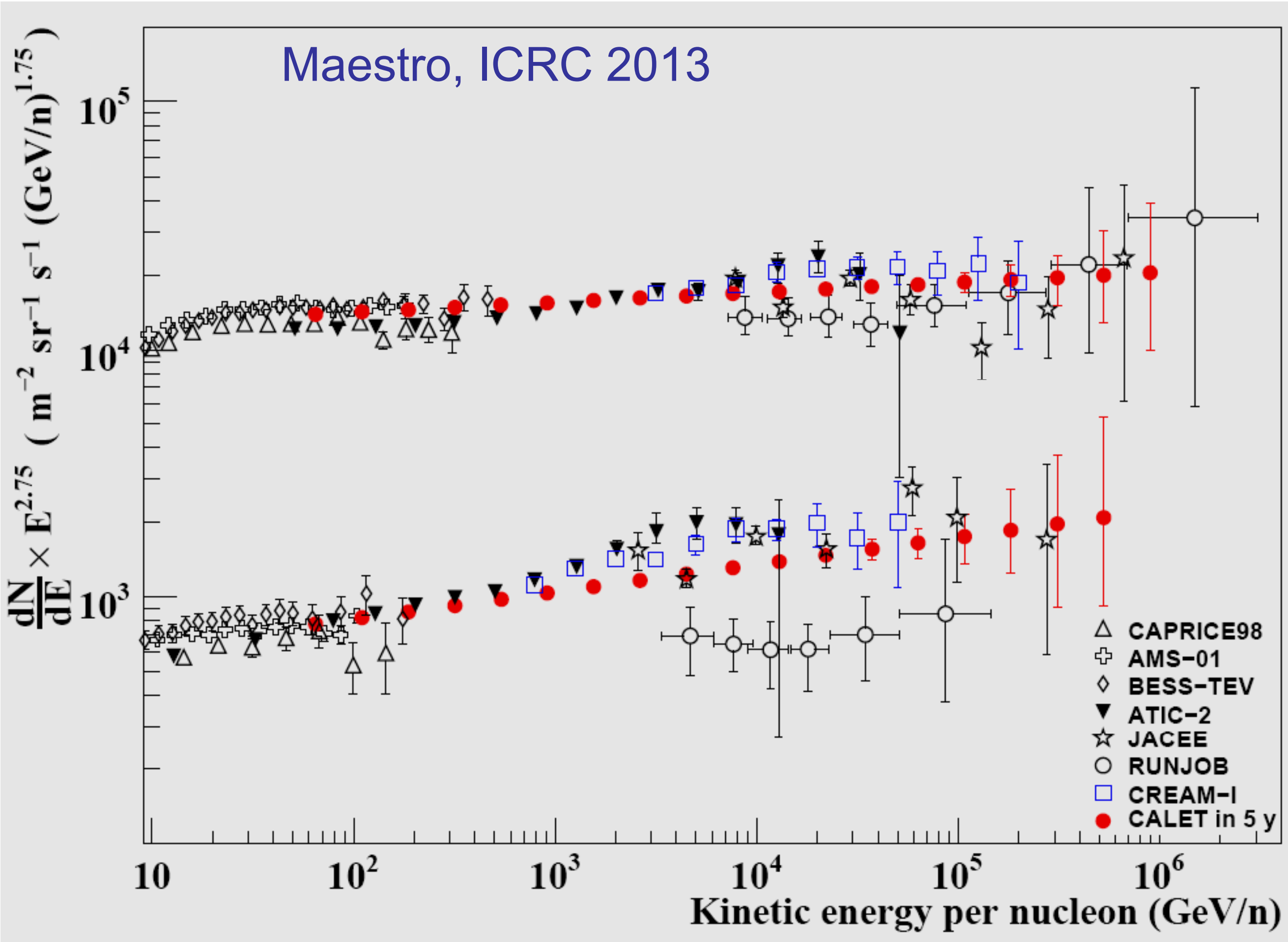
0.12 m^{2}sr@100TeV

Charge Detector

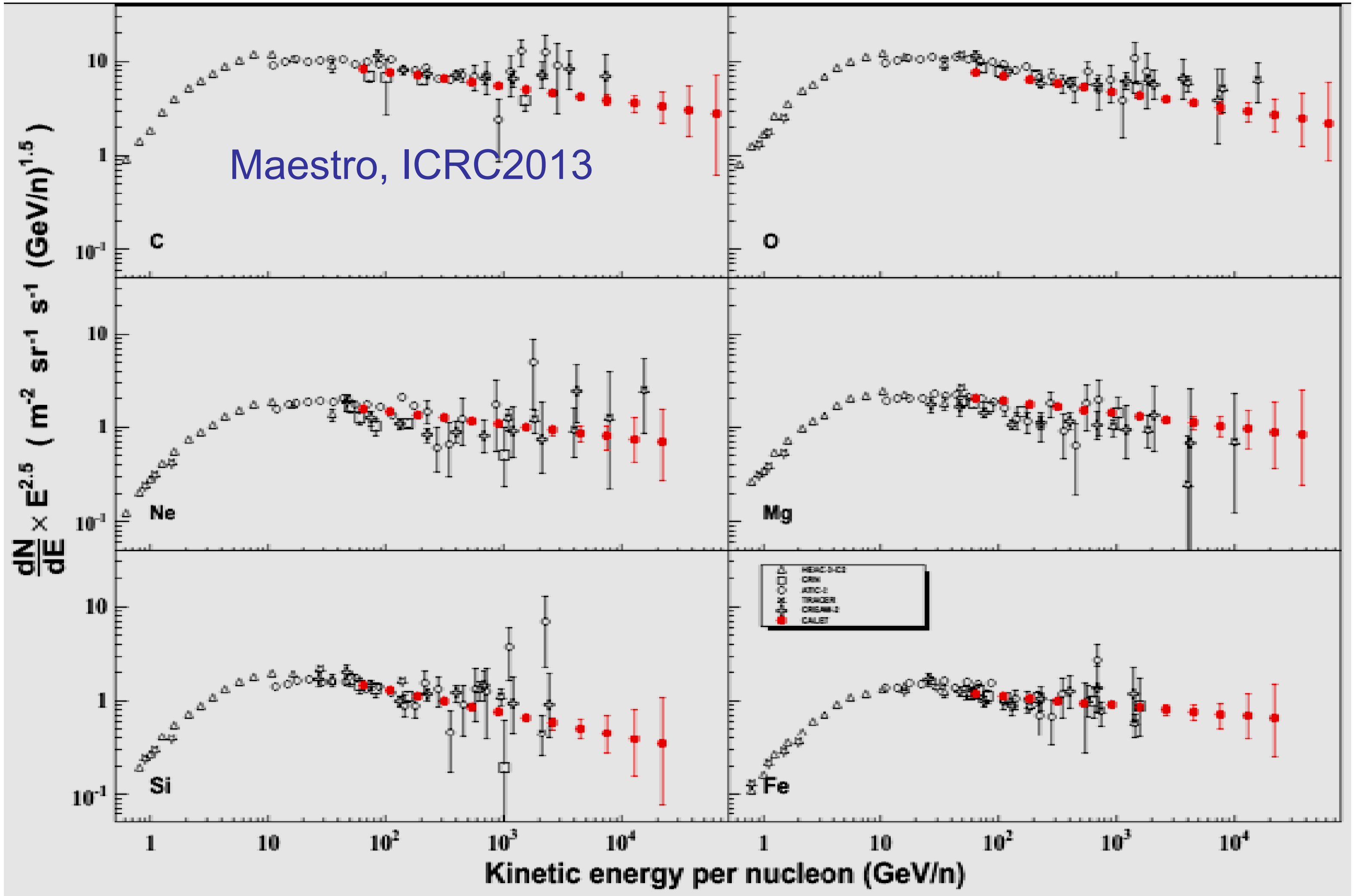
Imaging Calorimeter

Total Absorption Calorimeter

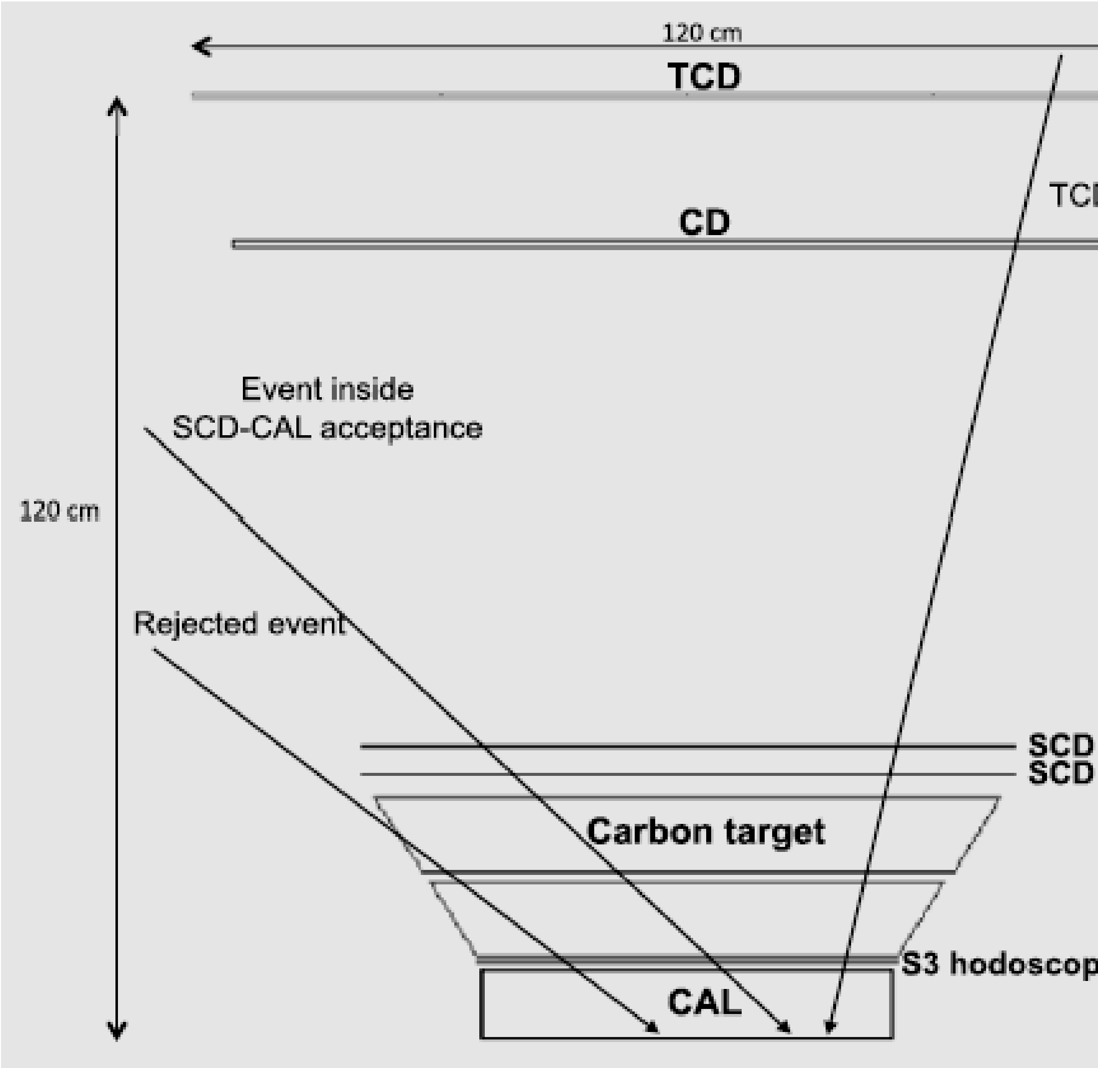
Expected CALET proton and He spectra after 5 years of observation



Expected CALET measurement of more abundant heavy nuclei



Beyond AMS: CREAM



0.2 m^2Sr
@100 TeV
for proton
On ISS

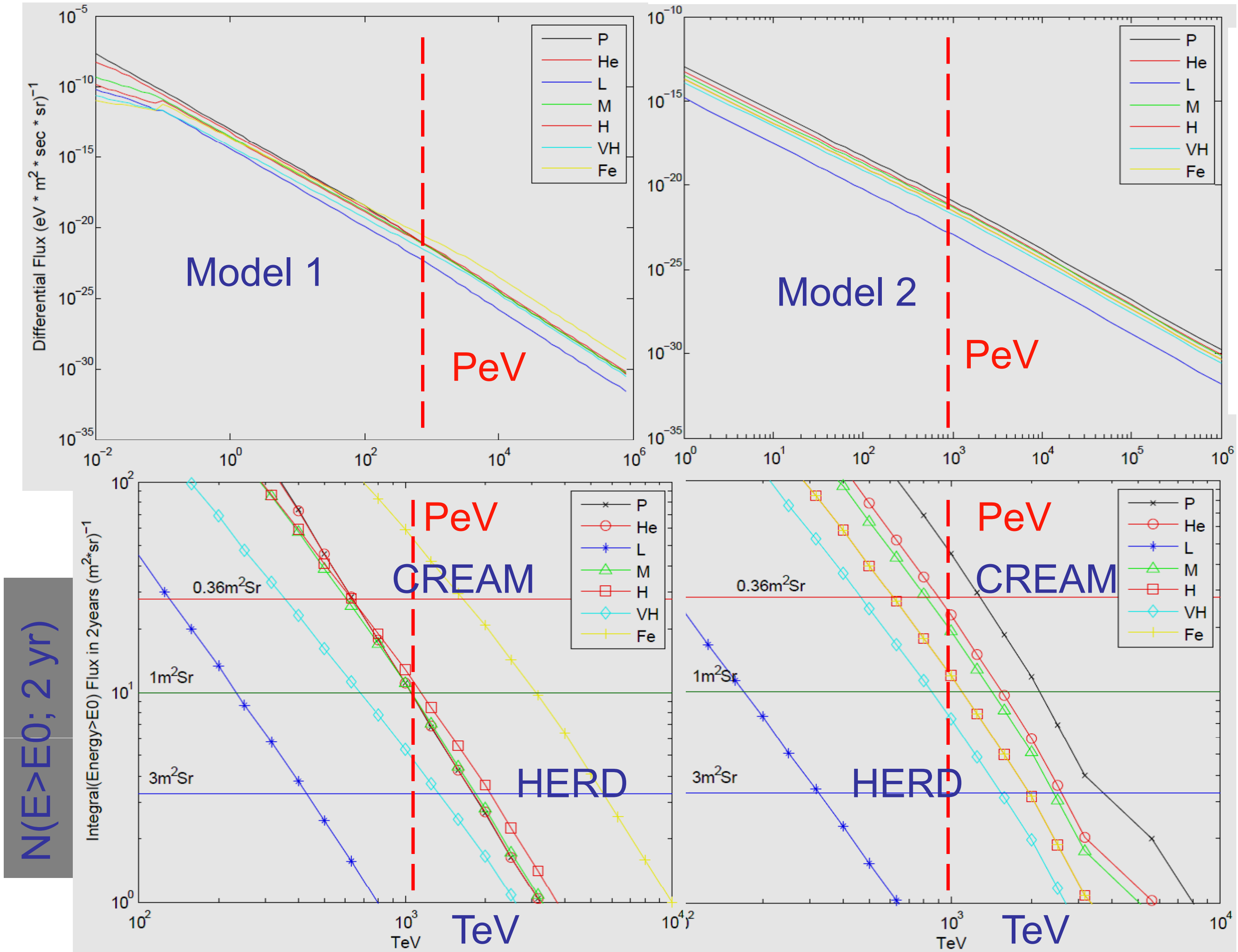
Science goals and requirements for HERD

Science goals	Mission requirements
Dark matter search	R1: Better statistical measurements of e/γ between 100 GeV to 10 TeV
Origin of Galactic Cosmic rays	R2: Better spectral and composition measurements of CRs between 300 GeV to PeV* with a large geometrical factor

Secondary science: monitoring of GRBs, microquasars, Blazars and other transients.

*Complimentary to key LHAASO science

HERD Cosmic Ray Capability Requirement

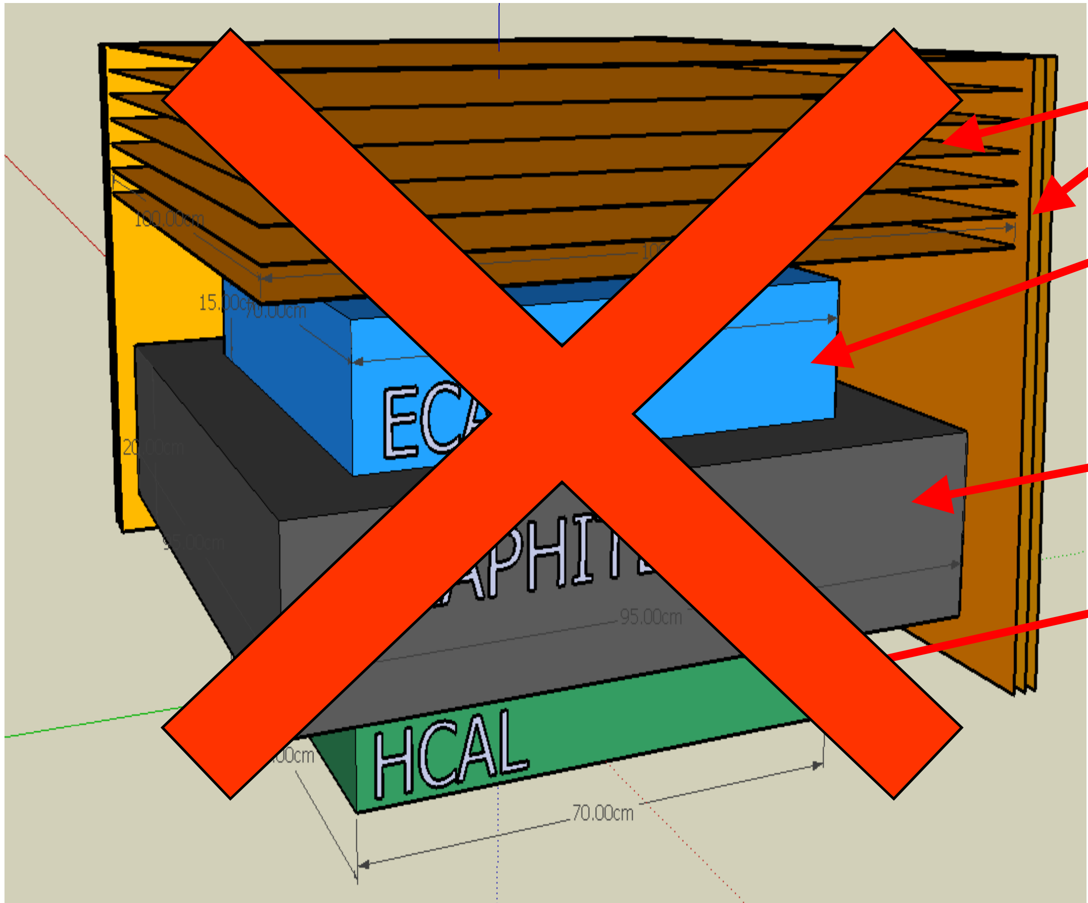


P (<A> ~ 1)
He (<A> ~ 4)
L (<A> ~ 8)
M (<A> ~ 14)
H (<A> ~ 25)
VH (<A> ~ 35)
Fe (<A> ~ 56)

Except for L, up to PeV spectra feasible with **GF~2-3 in ~years: discriminate between models.**

Old Baseline design of HERD

The detector is consisted of 4 parts:



Micro silicon strip tracker

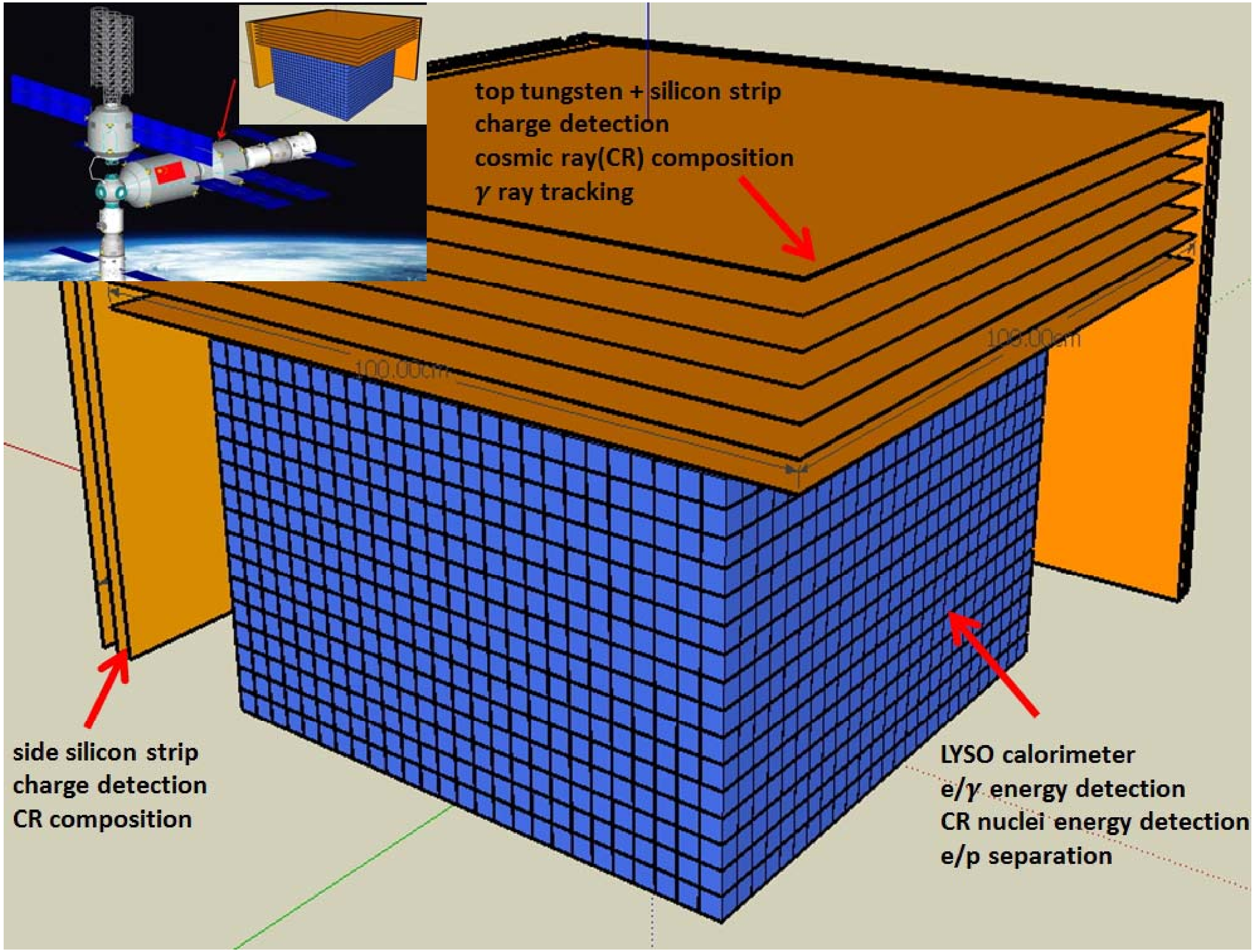
ECAL: Electromagnetic calorimeter

Graphite target

HCAL: Hadronic calorimeter: 3D-CsI stack with ICCD readout

Only 1.2m^{2}sr for cosmic rays

New Baseline design of HERD



Characteristics of all components

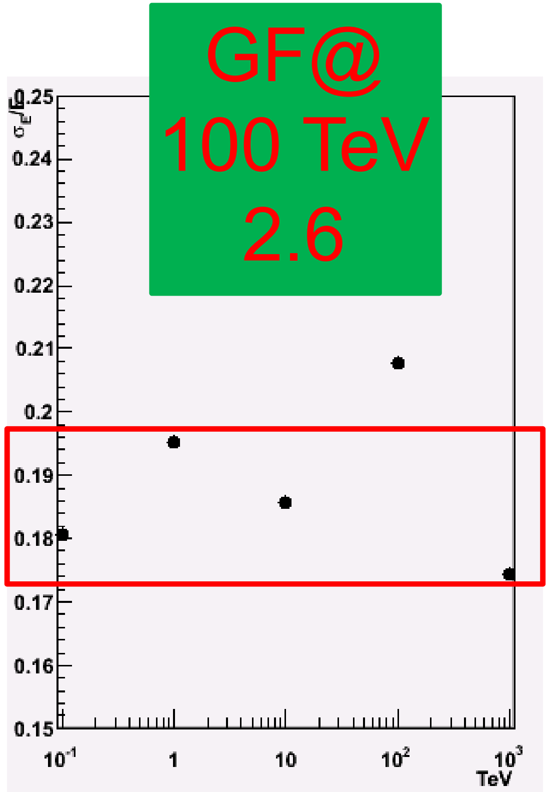
	type	size	X0,λ	unit	main functions
tracker (top)	Si strips	70 cm × 70 cm	2 X0	7 x-y (W foils)	Charge Early shower Tracks
tracker 4 sides	Si strips	65 cm × 50 cm	--	3 x-y	Nucleon Track Charge
CALO	LYSO cubes	63 cm × 63 cm × 63 cm	55 X0 3 λ	3 cm × 3 cm × 3 cm	e/γ energy nucleon energy e/p separation

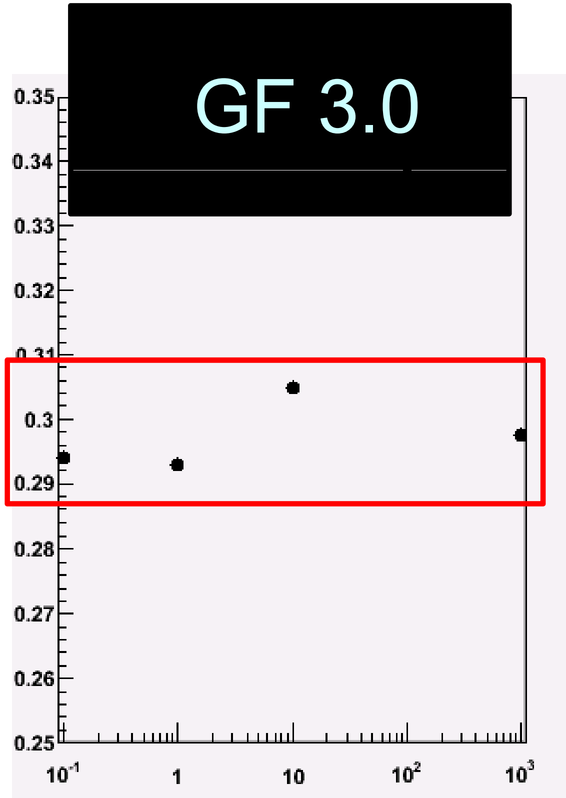
Why LYSO detectors?

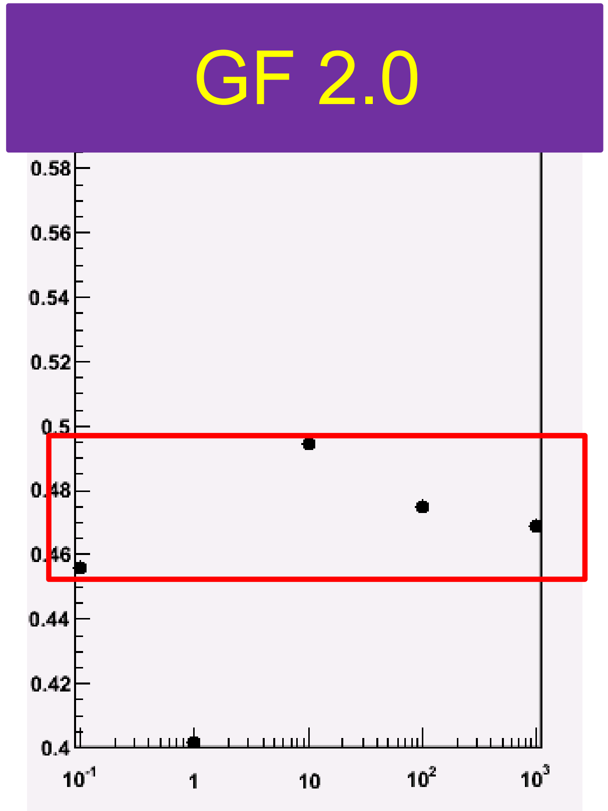
Crystal	CsI(Na)	BGO	PWO	LYSO
Density (g/cm3)	4.51	7.13	8.3	7.4
1 X0 (cm)	1.86	1.12	0.89	1.14
Rm (cm)	3.57	2.23	2.00	2.07
1 λ (cm)	39.3	22.8	20.7	20.9
Decay time (ns)	690	300	30	40
Light yield (%)	88	21	0.3	85

crystal + wls fiber

Proton energy resol. vs. detector thickness







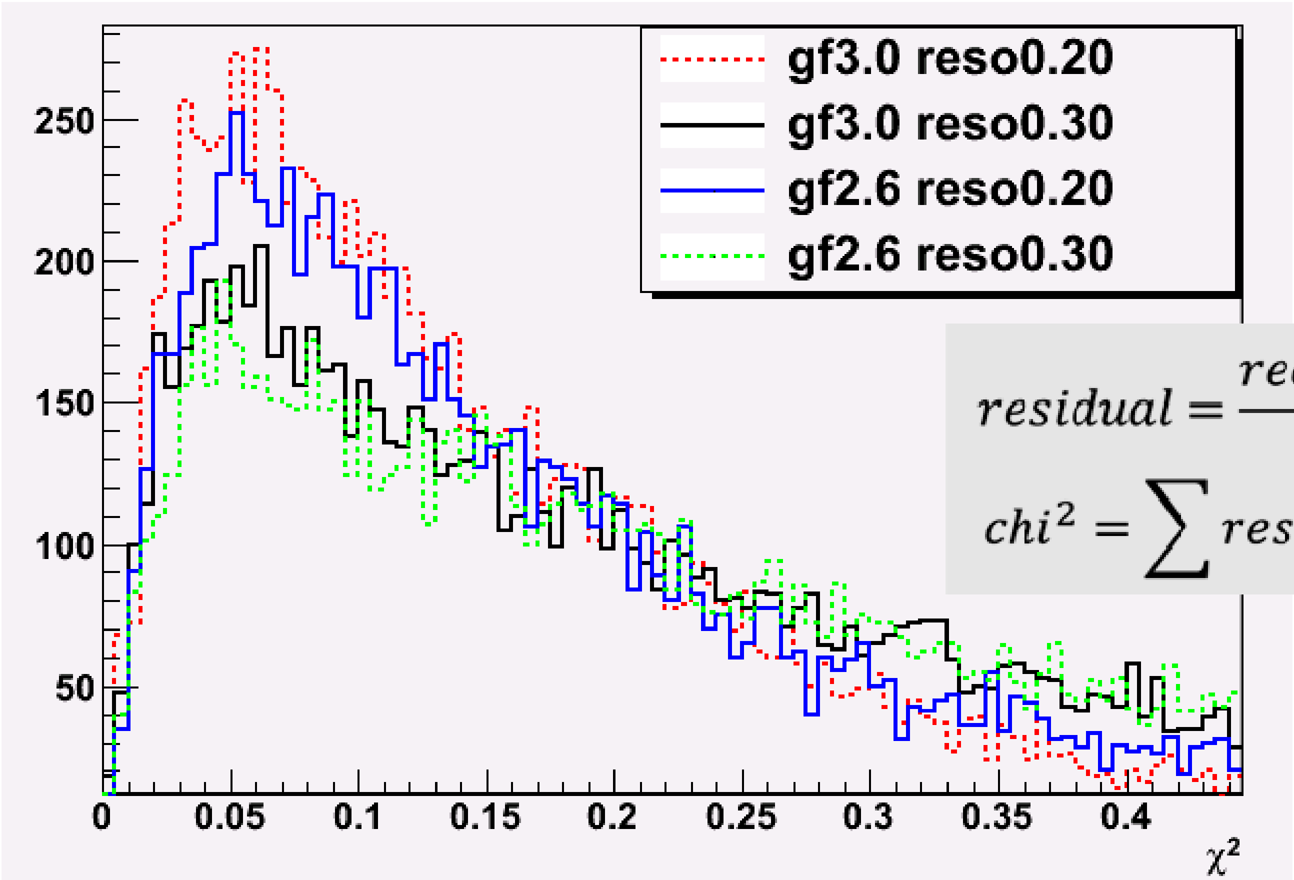
➔63*63*63cm
3 nucl.inter.length,
20% resolution

➔77*77*42cm
2 nucl.inter.length,
30% resolution

➔90*90*31cm
1.5 nucl.inter.length,
50% resolution

Total detector weight: 2000 kg

HERD reconstruction vs. energy resol.

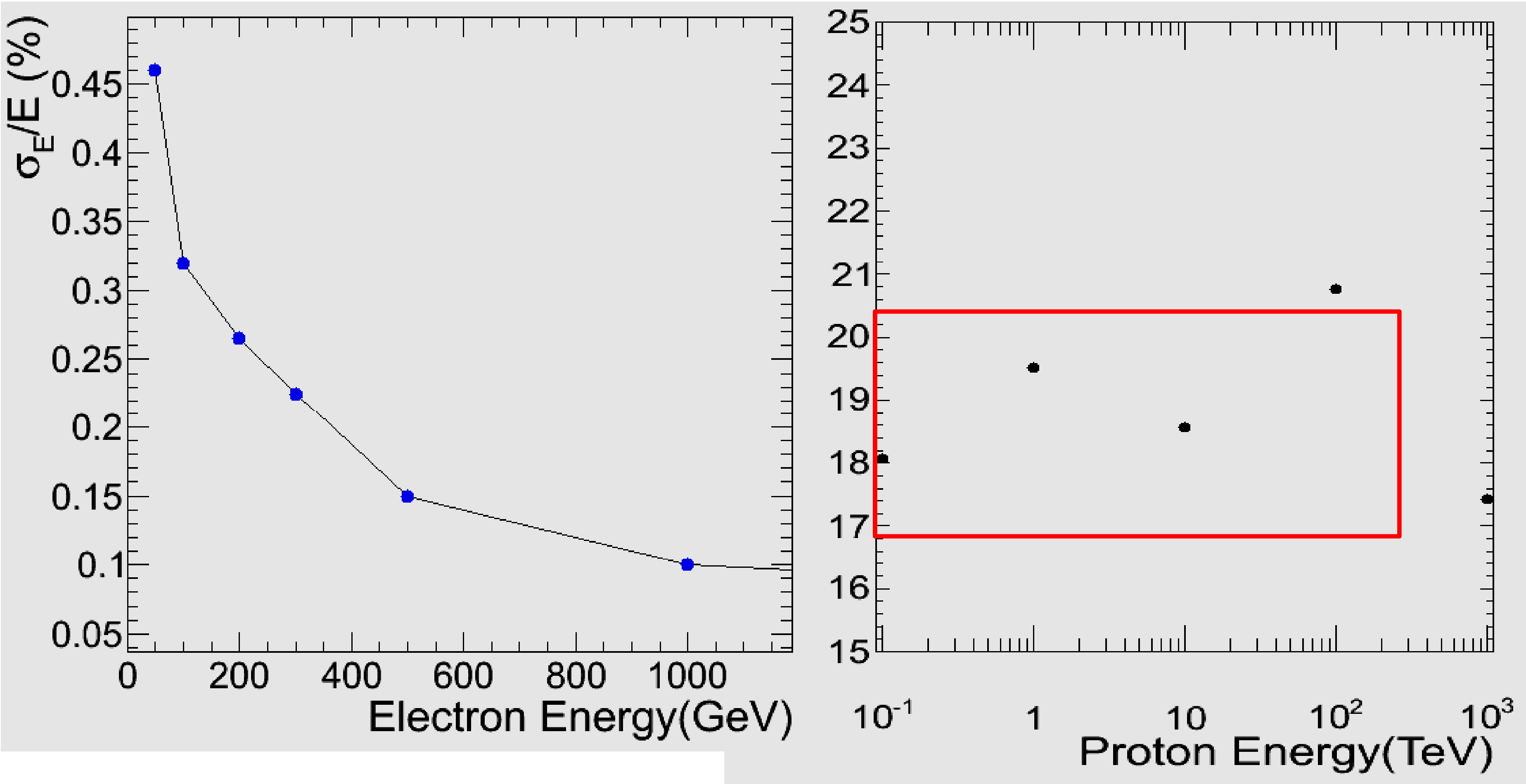


$$residual = \frac{reco - truth}{truth}$$

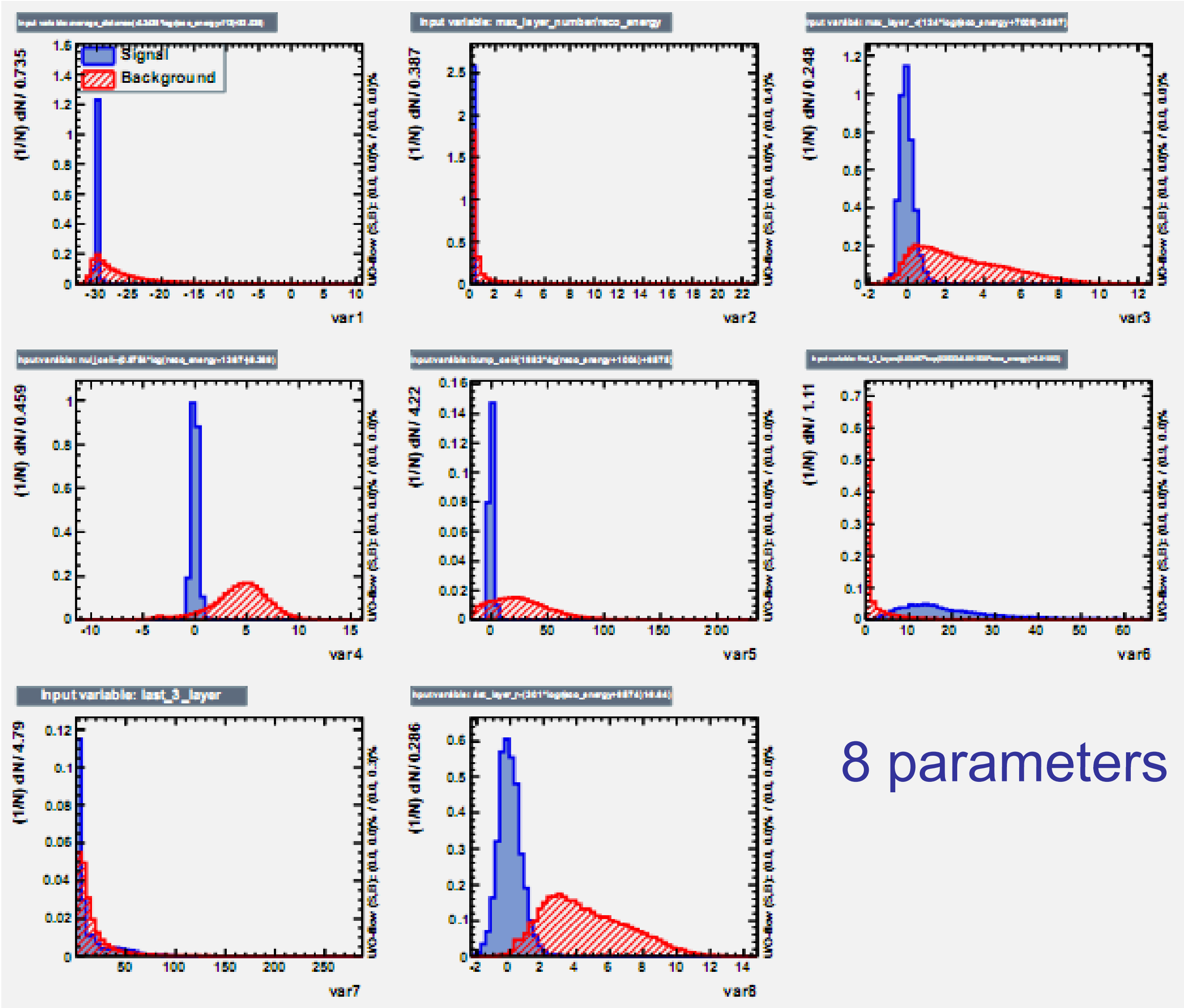
$$chi^2 = \sum residual^2$$

Under the weight limitation of 2 tons, resolution is more important for spectral reconstruction, based on the current design.

Simulation results: energy resolutions

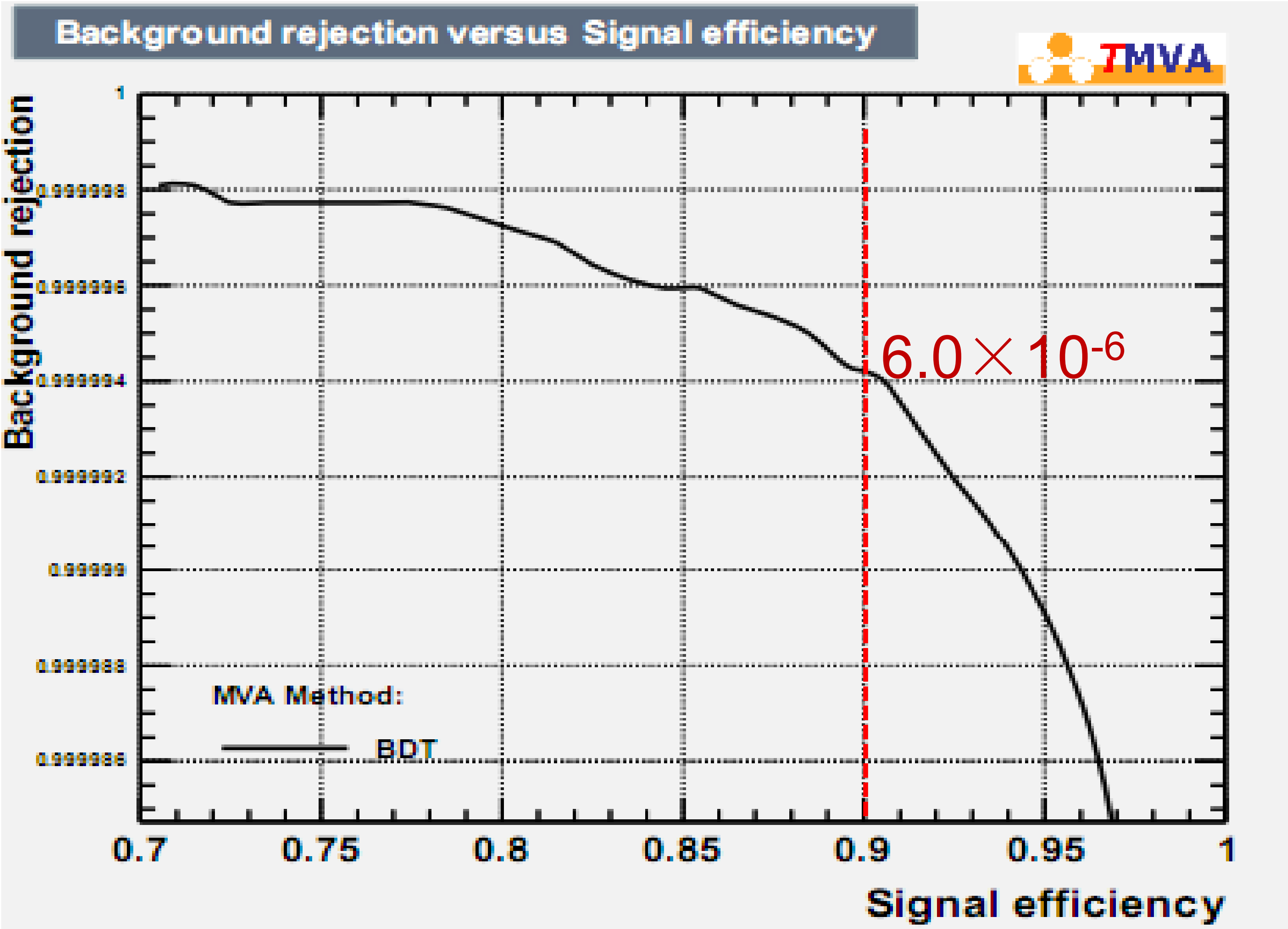


e/p separation (TMVA)

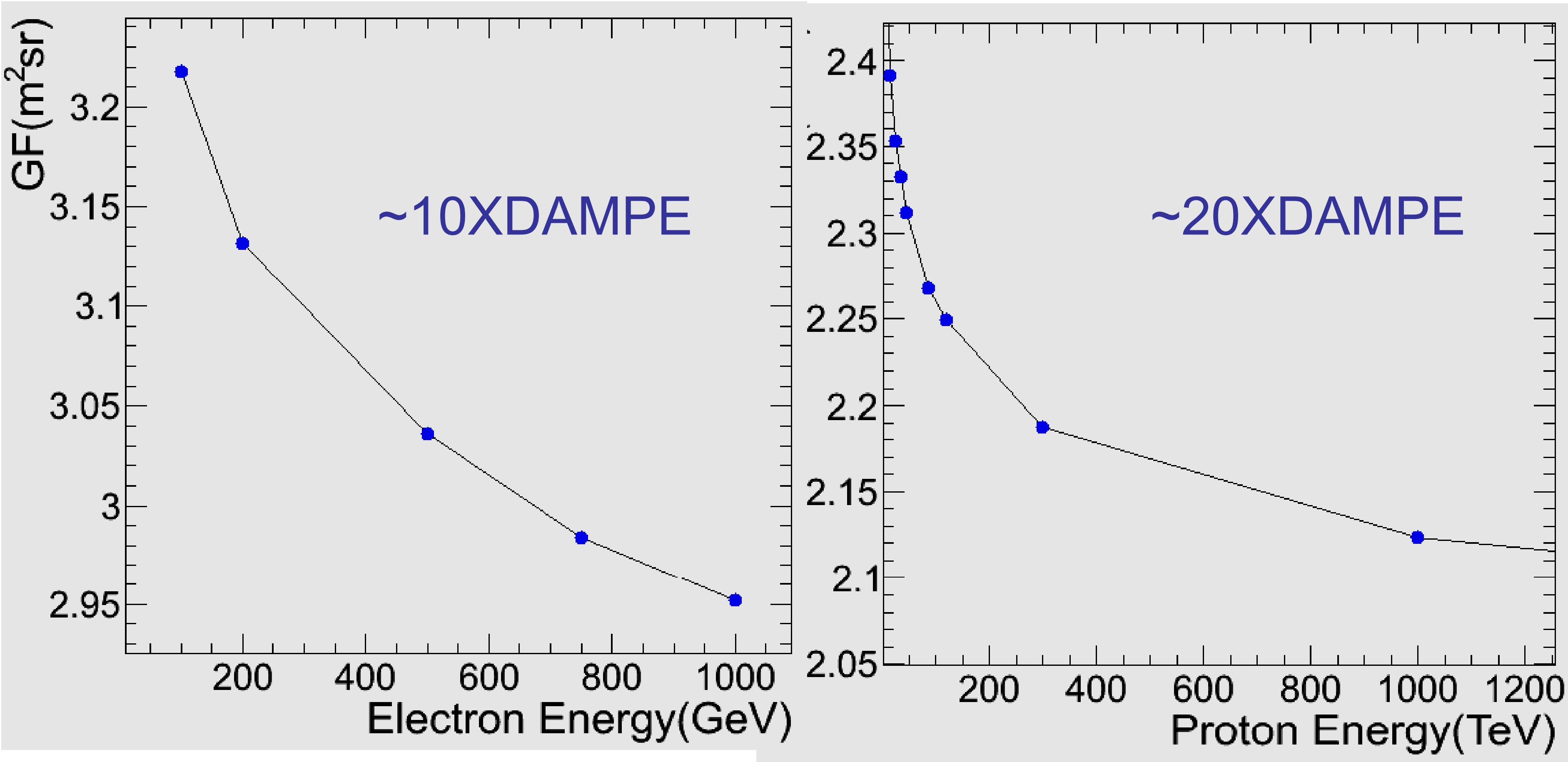


8 parameters

e/p separation (TMVA)



HERD Geometrical Factor



Expected performance of HERD

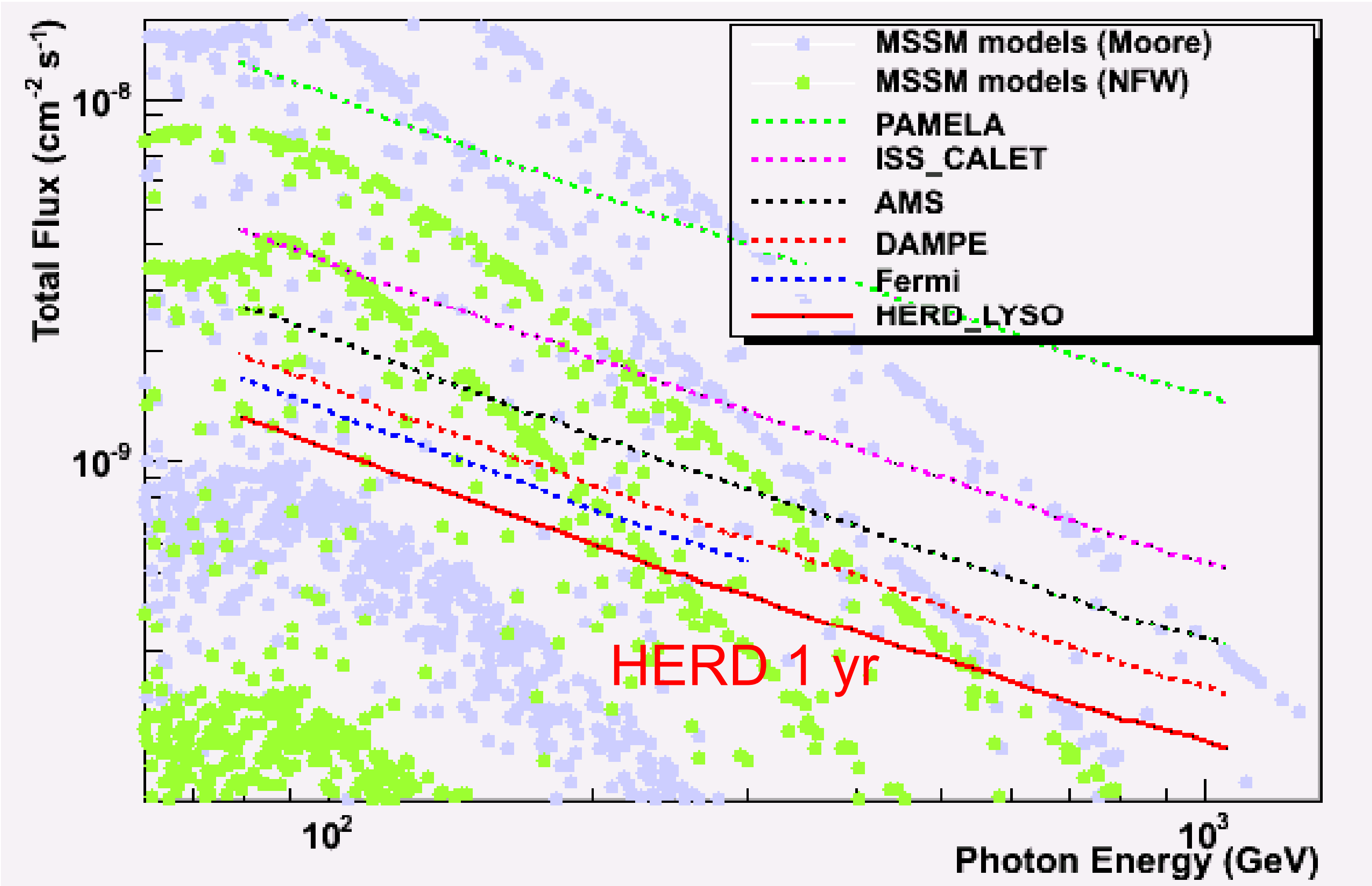
γ (electron) energy range	tens of GeV-10TeV
nucleon energy range	up to PeV
γ angular resol. (silicon)	0.1^{o}
nucleon charge resol. (silicon)	0.1-0.15 c.u
γ (electron) energy resolution	1%@200GeV
proton energy resolution	20%
e/p separation power	10^{-6}
electron geometrical factor	3.1 m^2sr@200 GeV
proton geometrical factor	2.3 m^2sr@100 TeV

performance comparison

	X0(λ)	ΔE/E for e	e/p sep.	e GF m^2sr@ 200GeV	p GF m^2sr@ 100TeV
HERD (2020)	55(3)	1%	10^{-6}	3.1	2.3
Fermi (2008)	10	12%	10^{-3}	0.9	--
AMS02 (2011)	17	2%	10^{-6}	0.12	--
DAMPE (2015)	31	1%	10^{-4}	0.3	--
ISS-CREAM (2015)	20(1.5)	--	--	--	0.2

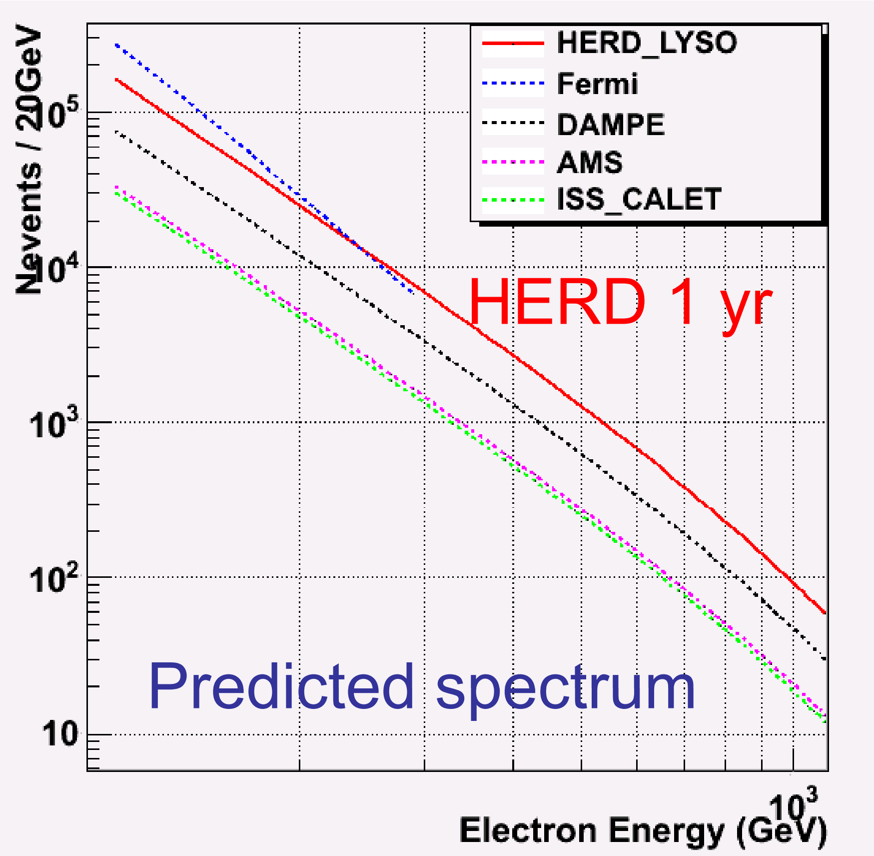
HERD can improve by at least 10X for electrons and 20X for cosmic rays over previous missions: this is necessary since it will operate much later.

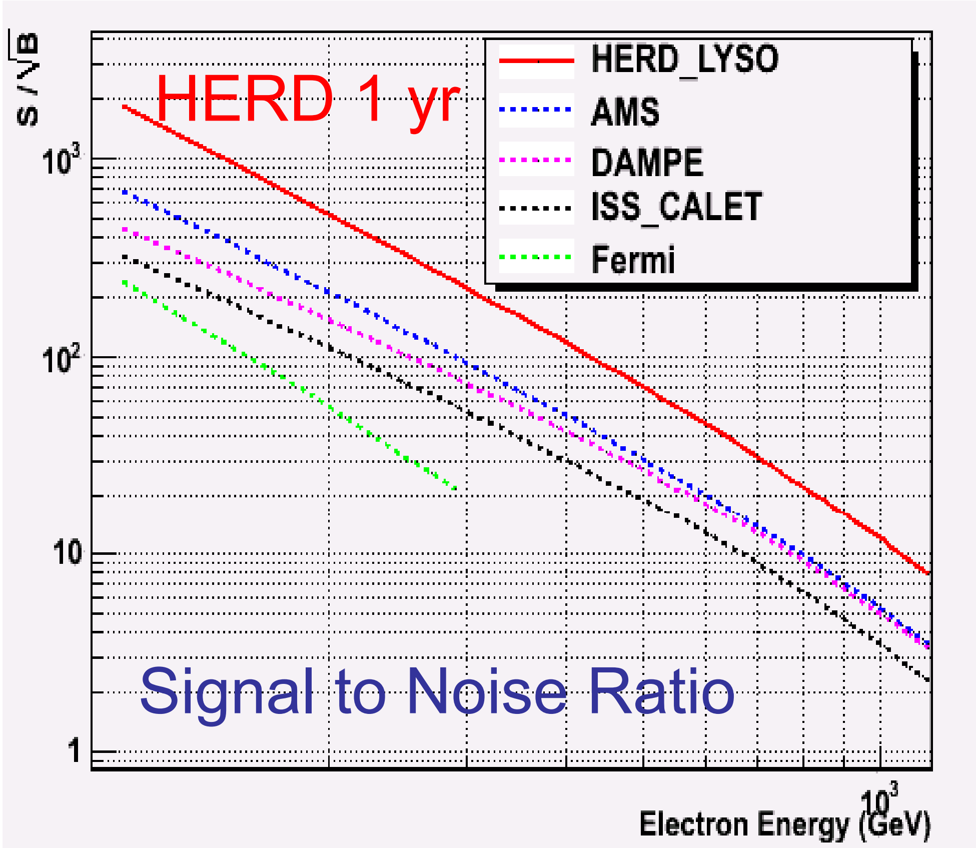
HERD sensitivity to gamma-ray line



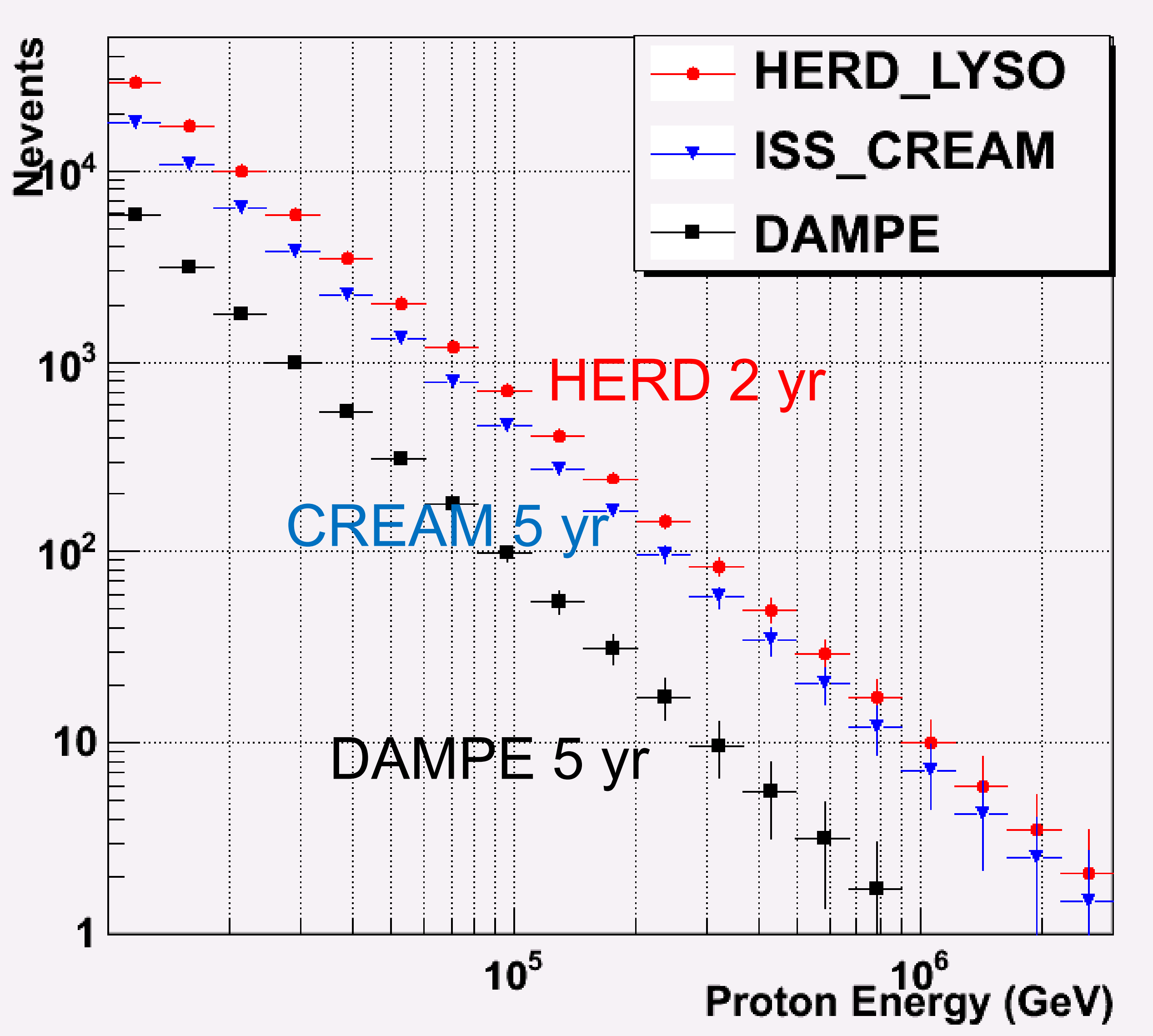
PAMELA: 2006-2016 CALET: 2015-2020; AMS: 2011-2021;
DAMPE: 2015-2020; Fermi: 2008-2018; HERD: 2020-2021

HERD electron detection capability: 2021





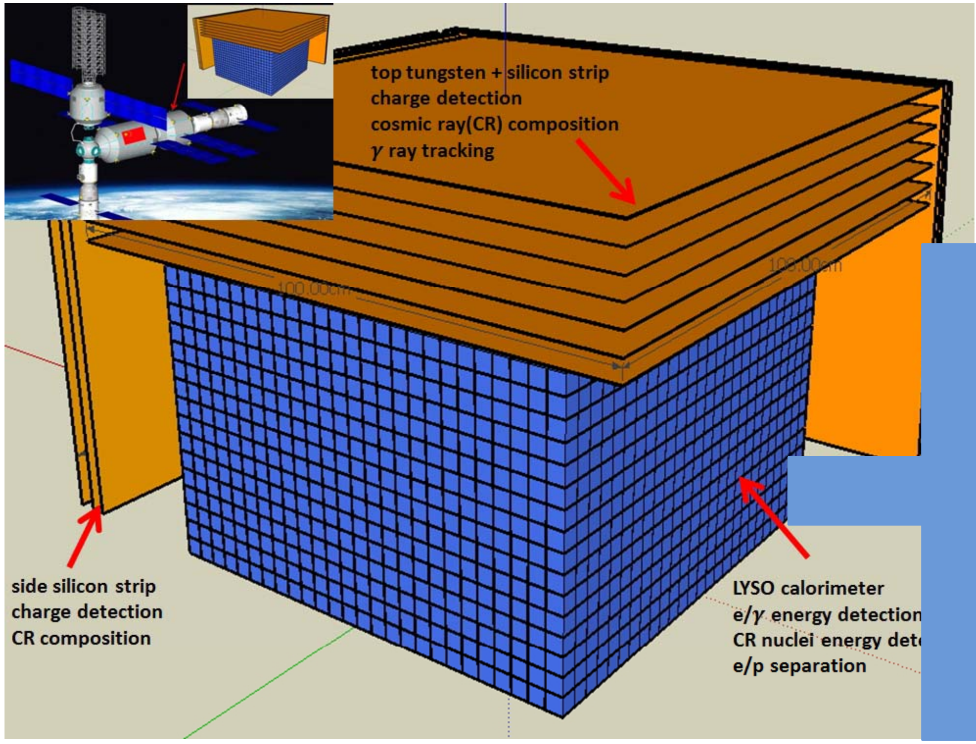
HERD proton (nucleon) detection capability



HERD：
2020-2022
CREAM：
2015-2020
DAMPE：
2015-2020

But CREAM is planned to operate only for several months on ISS.

New calorimeter readout technique



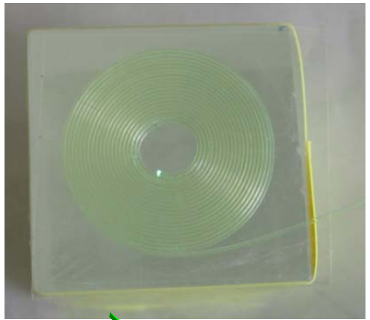
Direct Coupling

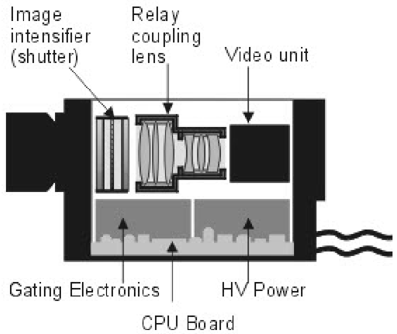
PD, APD, SiPM:
Complicated system,
high power consumption

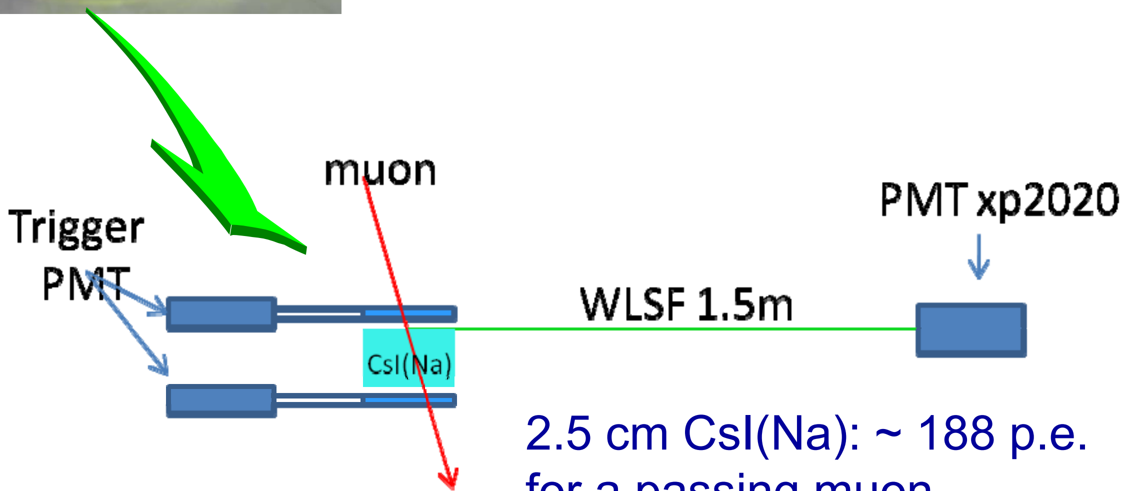
MAPMT, SiPM: high power consumption
CCD: No single photon detection
EMCCD, EBCCD: no ns gate control
ICCD: no above problems, but premature

Wavelength shifter fiber readout

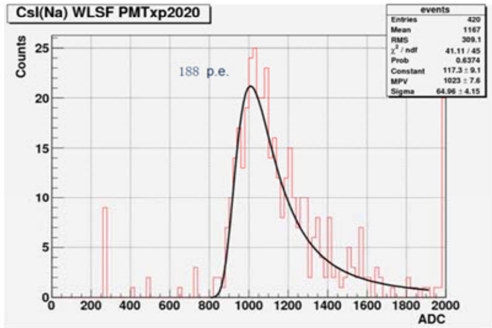
An example





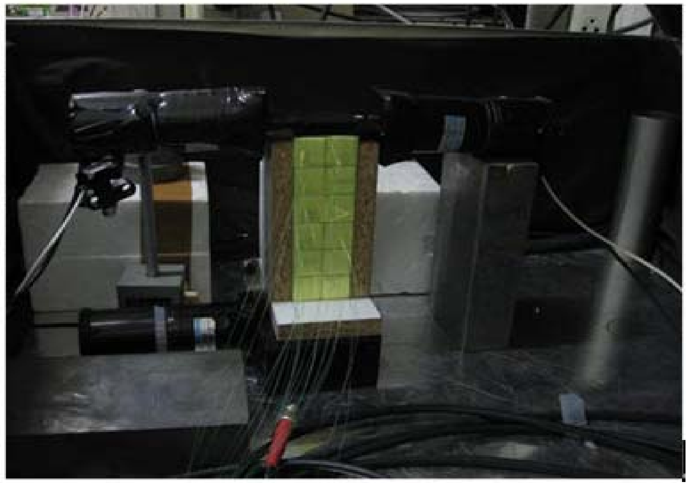


2.5 cm CsI(Na): ~ 188 p.e.
for a passing muon

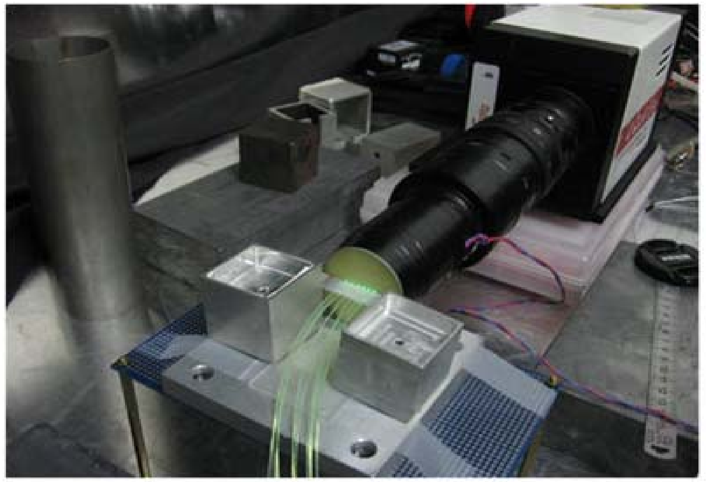


Sun, X. L. and et al. (2011). "A Digital Calorimeter for Dark Matter Search in Space." Journal of Physics: Conference Series **293(1): 012038.**

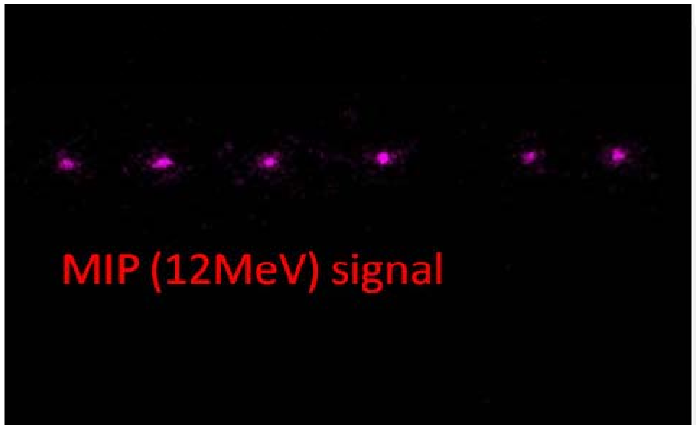
Test set-up and results

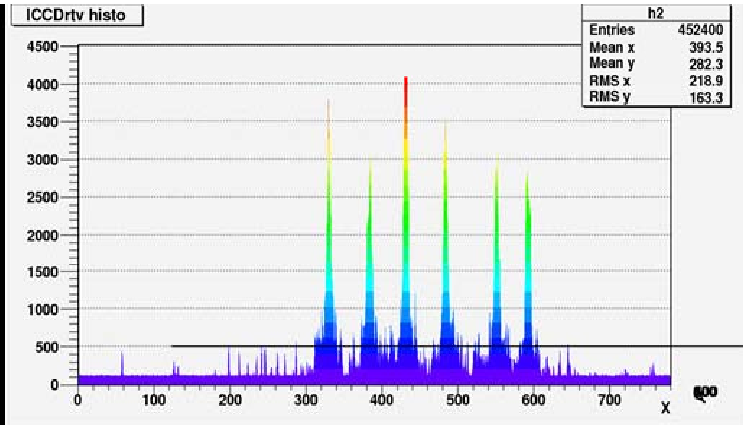


2×2×6 granular CsI with fibers sandwiched between two detectors



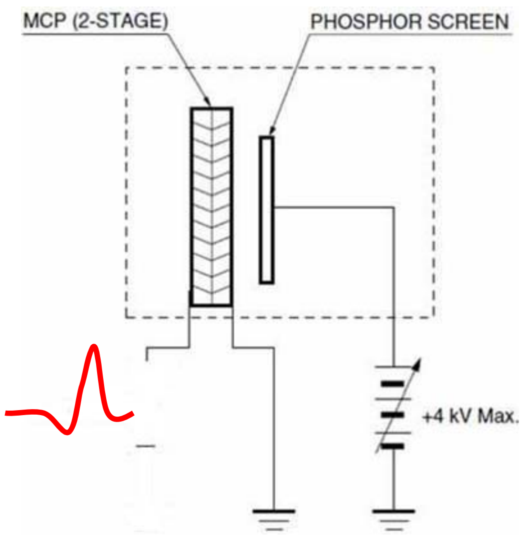
Taper +Imaging Intensifier + ICCD





ICCD image of typical muon events

Concept of ICCD readout system



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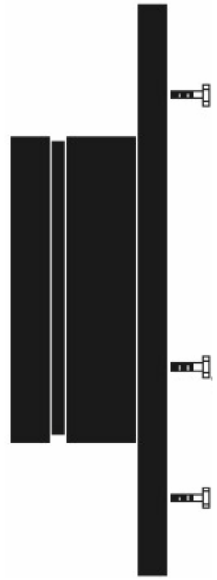

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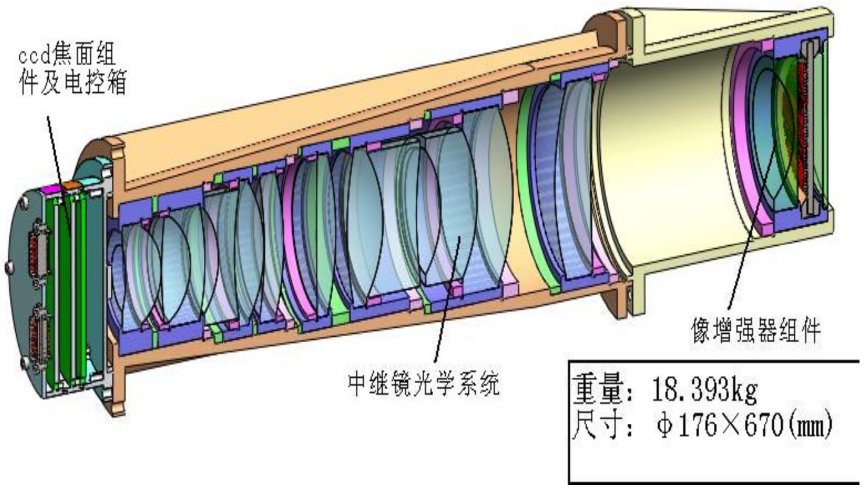
Cathode Triggered Intensifier

Optical Coupler

High frame rate and large format CCD

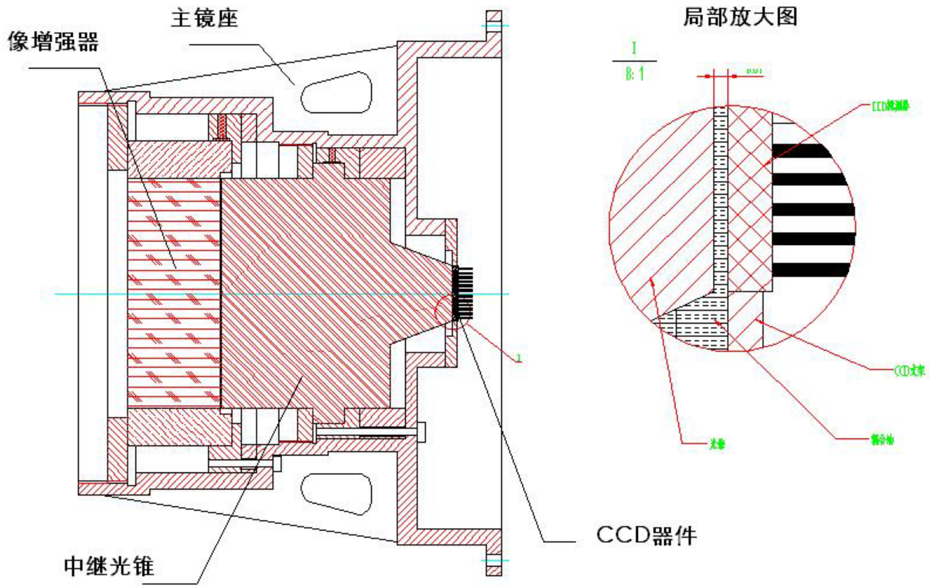
Two types of coupling

Relay mirrors



Single unit: weight of 18.393 kg,
size， size of φ176×670(mm)。

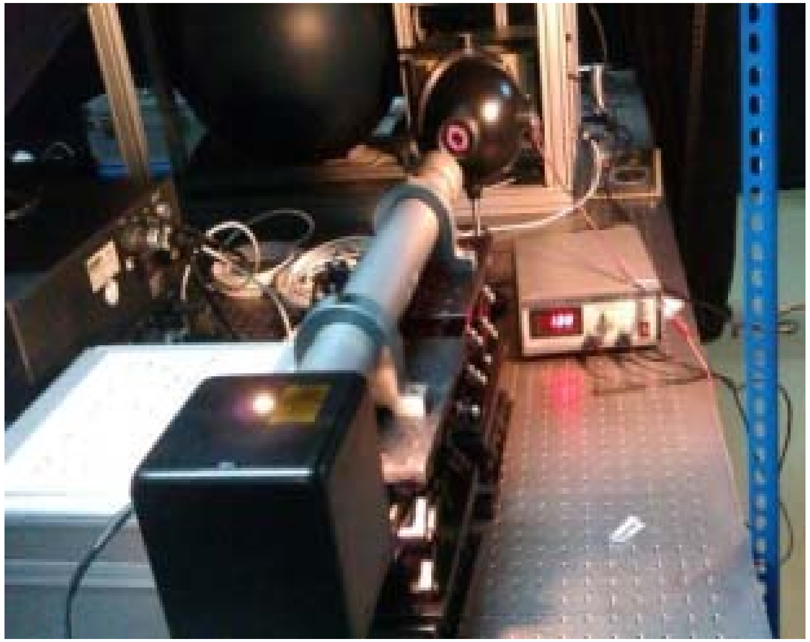
Taper



Technology development funded by XIOPM, CAS and NSFC.

Looking for collaborators in Italy.

ICCD readout R&D



Current status of HERD

- The mission concept (science goals with requirements) has been selected, not in competition with other missions.
- The design concept has been reviewed on Feb. 29, 2012, together with all other proposals in all fields.
- Technical review for mission selection may happen anytime.
- Launch in 2018-2020.

1st HERD workshop, Oct.17-18, 2012, IHEP, Beijing

Roberto Battiston et al. participated via video-con.

The HERD Team

- Current Chinese member institutions
  - Institute of High Energy Physics, China
  - Purple Mountain Observatory, China
  - Xi'an Institute of Optical and Precision Mechanics, China
  - University of Science and Technology of China
- Current international member institutions (tentative)
  - University of Geneva, Switzerland
  - Università di Pisa and INFN, Italy
  - IAPS/INAF, Italy
  - University of Florence and INFN Firenze, Italy
  - University of Perugia/Trento and INFN, Italy
  - University of Bari and INFN, Italy
  - KTH, Sweden

Possible contributions from INFN?

- Mission concept and design of HERD detectors
- Silicon trackers: similar to Italian contribution to DAMPE
- CALO: joint development
- Additional detectors for complementarities/redundancies
- Anything else is also welcome!