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

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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.

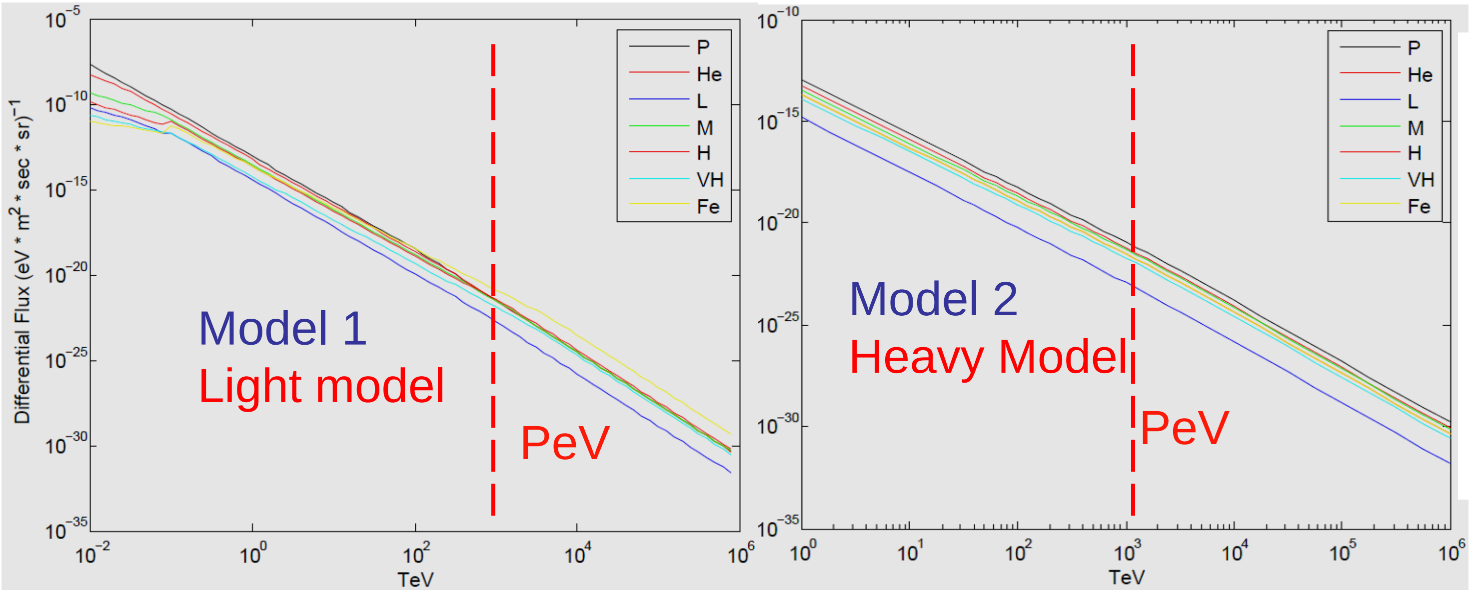

background
Gamma-ray
HERD
electron
He
proton
Dark matter particle

Science goals and requirements for HERD

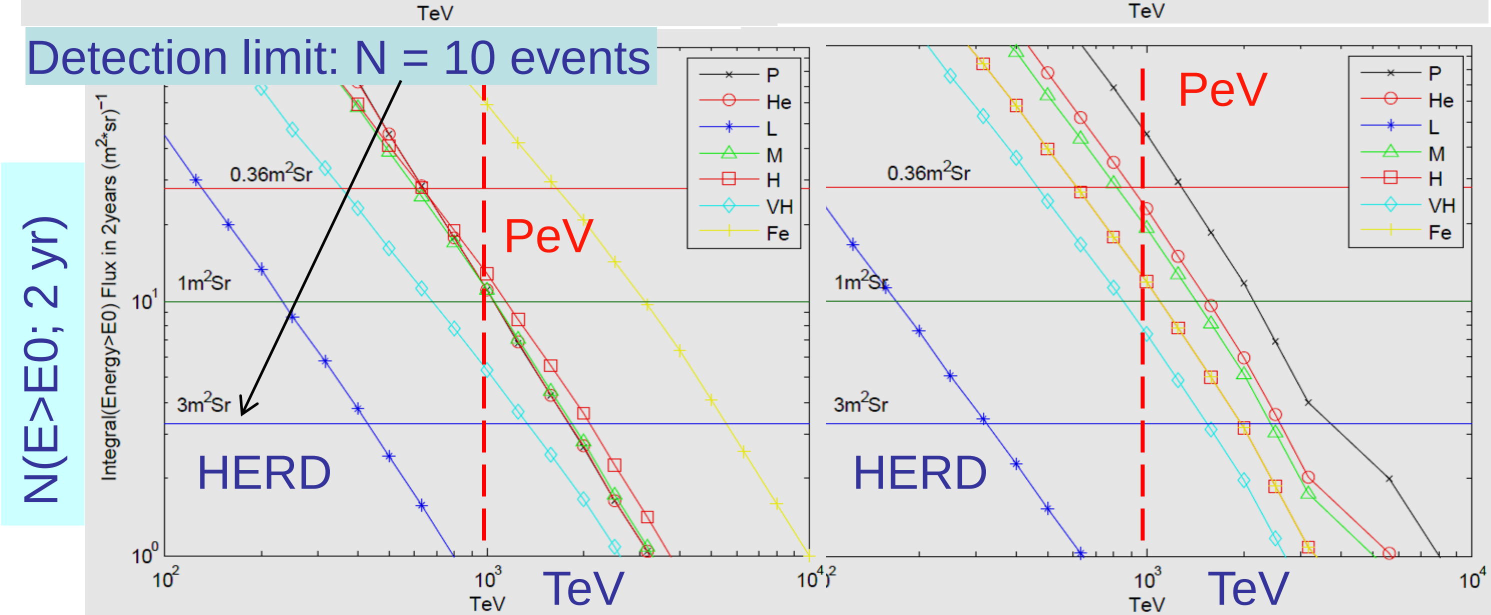
Science goals	Mission requirements
Dark matter search	R1: Better statistical measurements of e/γ between 100 GeV to 10 TeV
Origin of Galactic Cosmic rays	R2: Better spectral and composition measurements of CRs between 300 GeV to PeV with a large eff. geometrical factor

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

HERD Cosmic Ray Capability Requirement



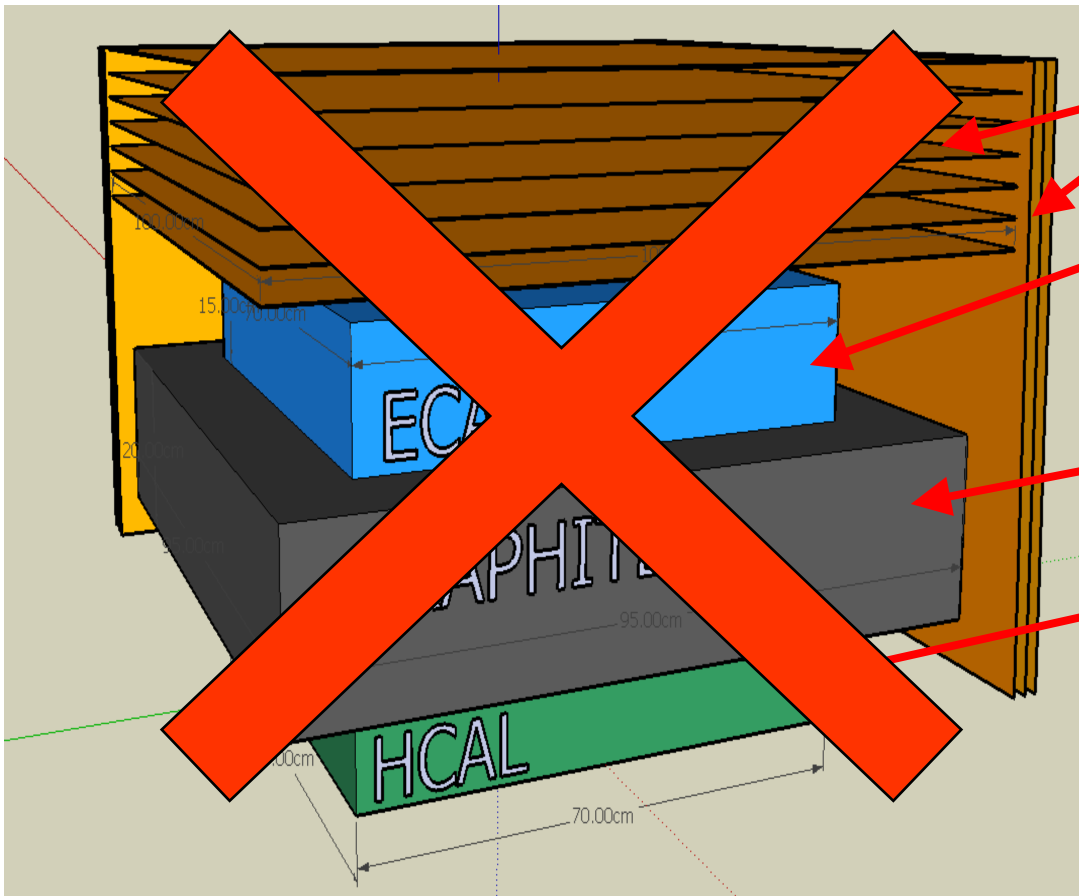
P (<A> ~ 1)
He (<A> ~ 4)
L (<A> ~ 8)
M (<A> ~ 14)
H (<A> ~ 25)
VH (<A> ~ 35)
Fe (<A> ~ 56)



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

HERD old baseline design: March 2013

The detector is consisted of 4 parts:



Micro silicon strip tracker

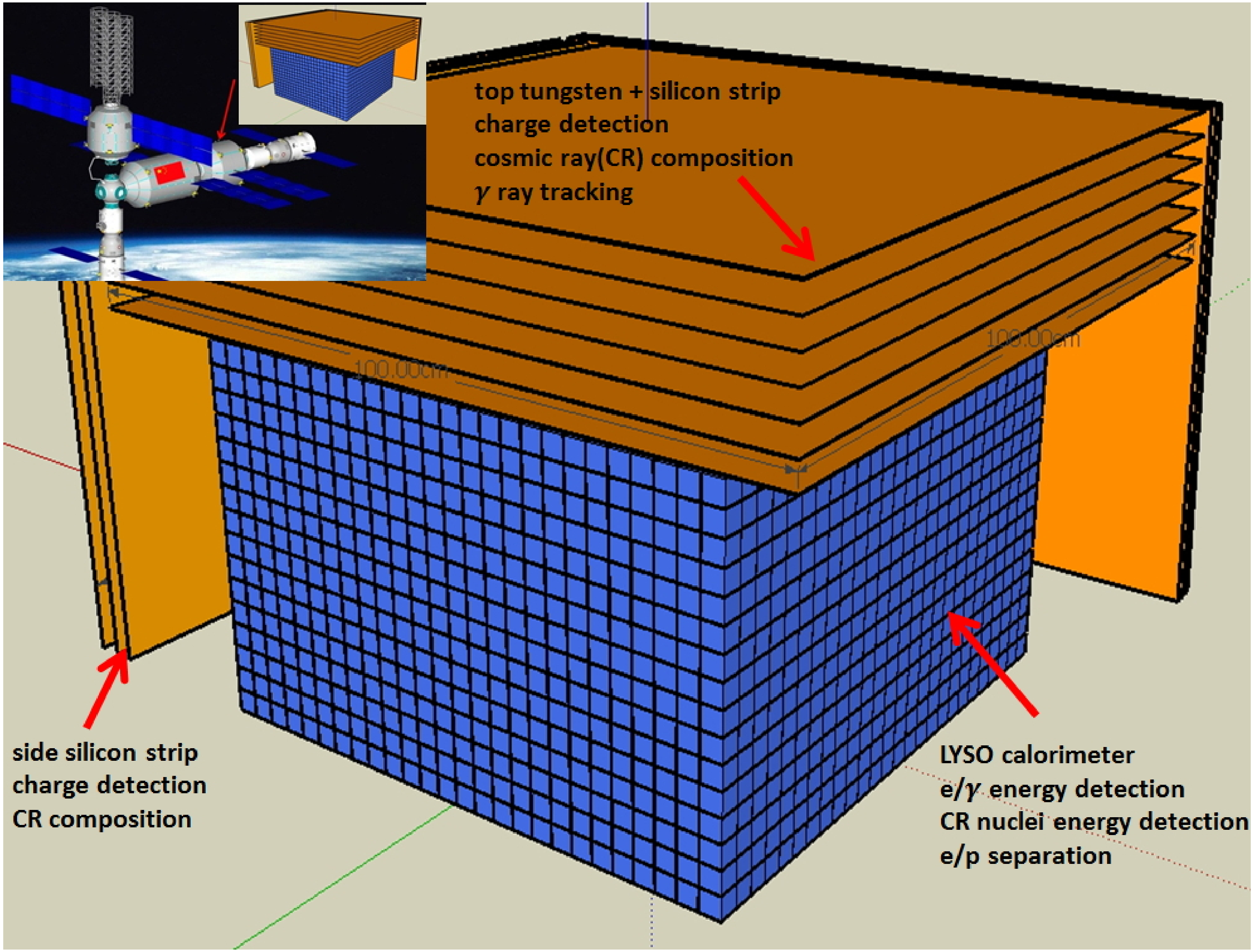
ECAL: Electromagnetic calorimeter

Graphite target

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

Only $1.2m^2sr$ for cosmic rays

HERD new baseline design: July 2013



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	~10K 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

Total detector weight: ~2000 kg

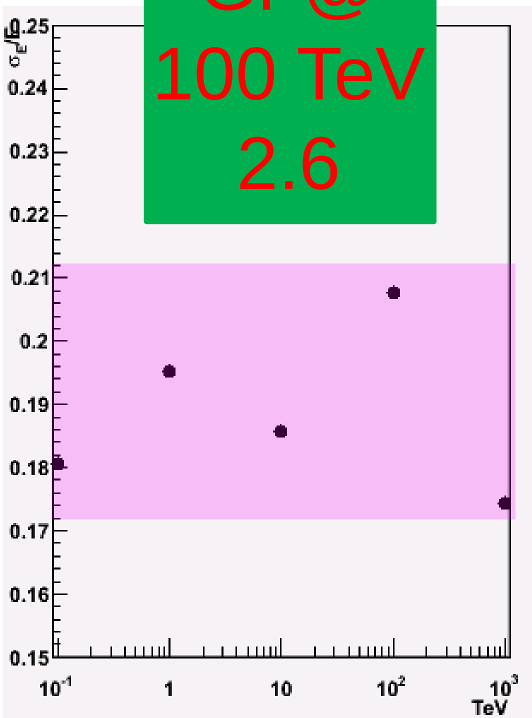
Why LYSO detectors?

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
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

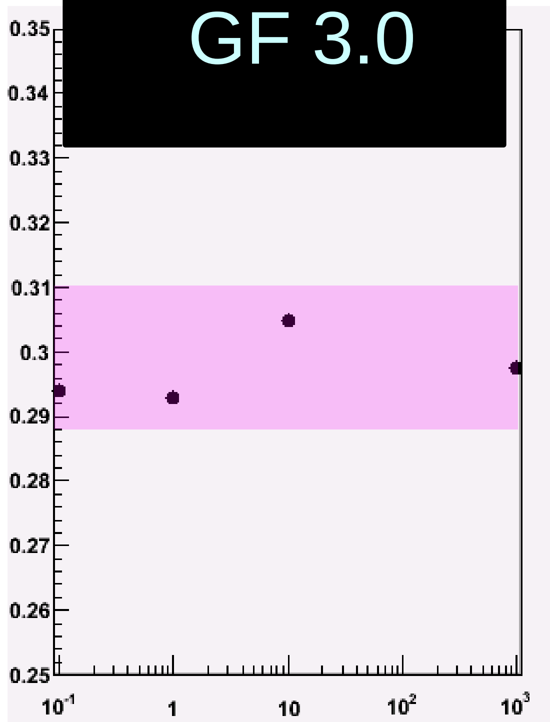
Proton energy resol. vs. detector thickness

GF@ 100 TeV 2.6



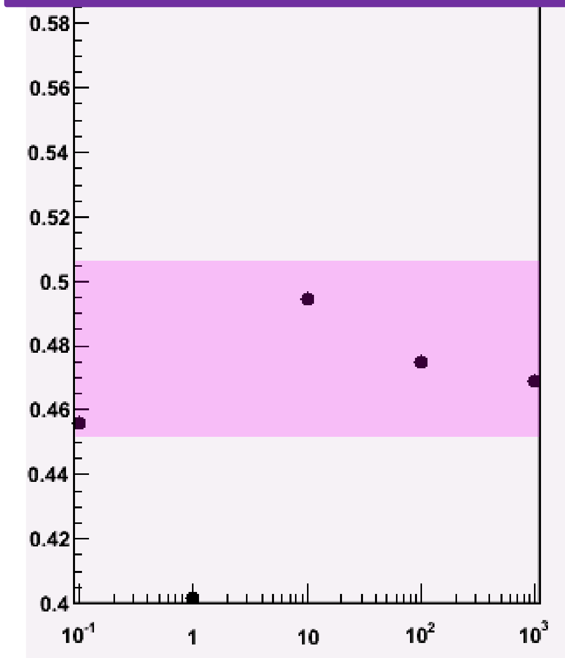
→63*63*63cm
3 nucl.inter.length,
20% resolution

GF 3.0



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

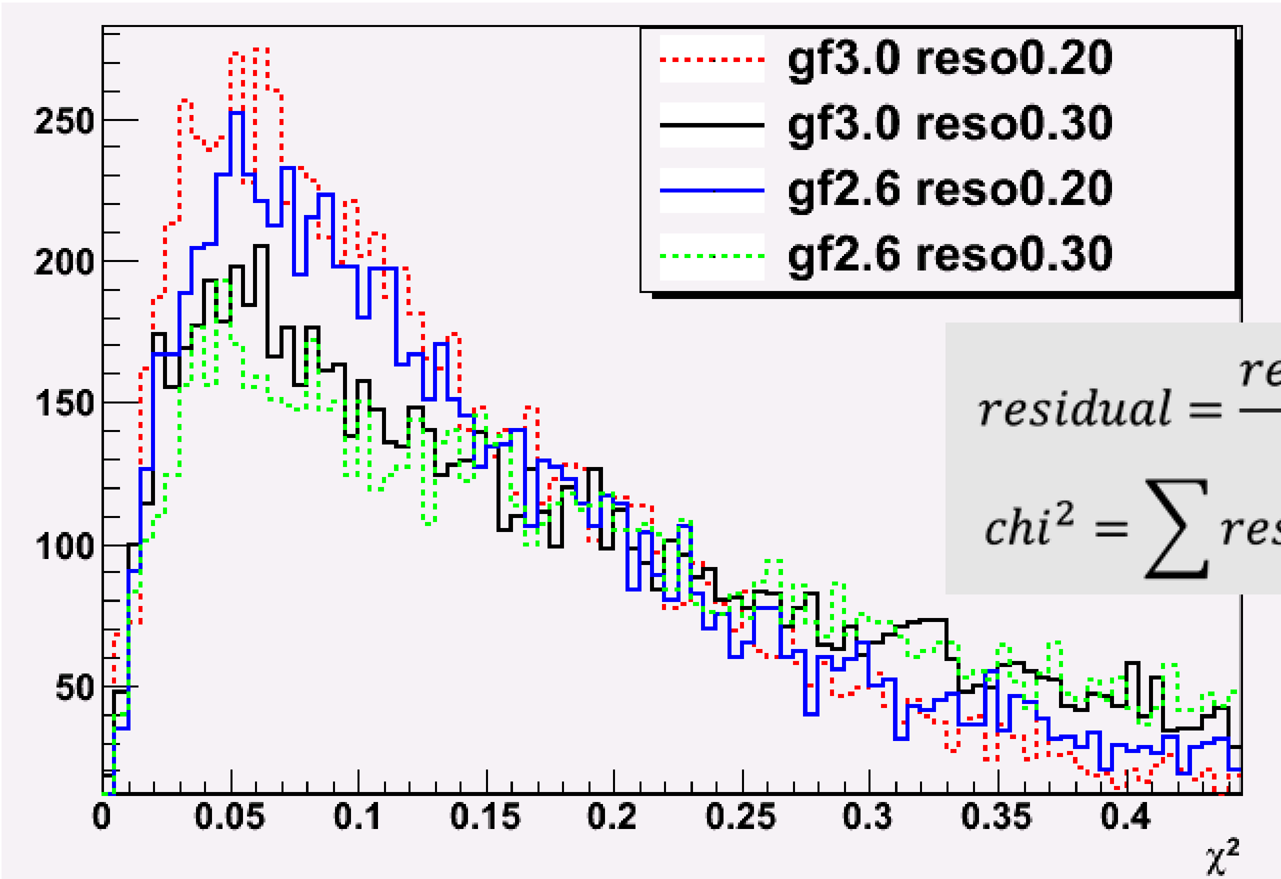
GF 2.0



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

Total detector weight: 2000 kg

HERD reconstruction vs. energy resol.

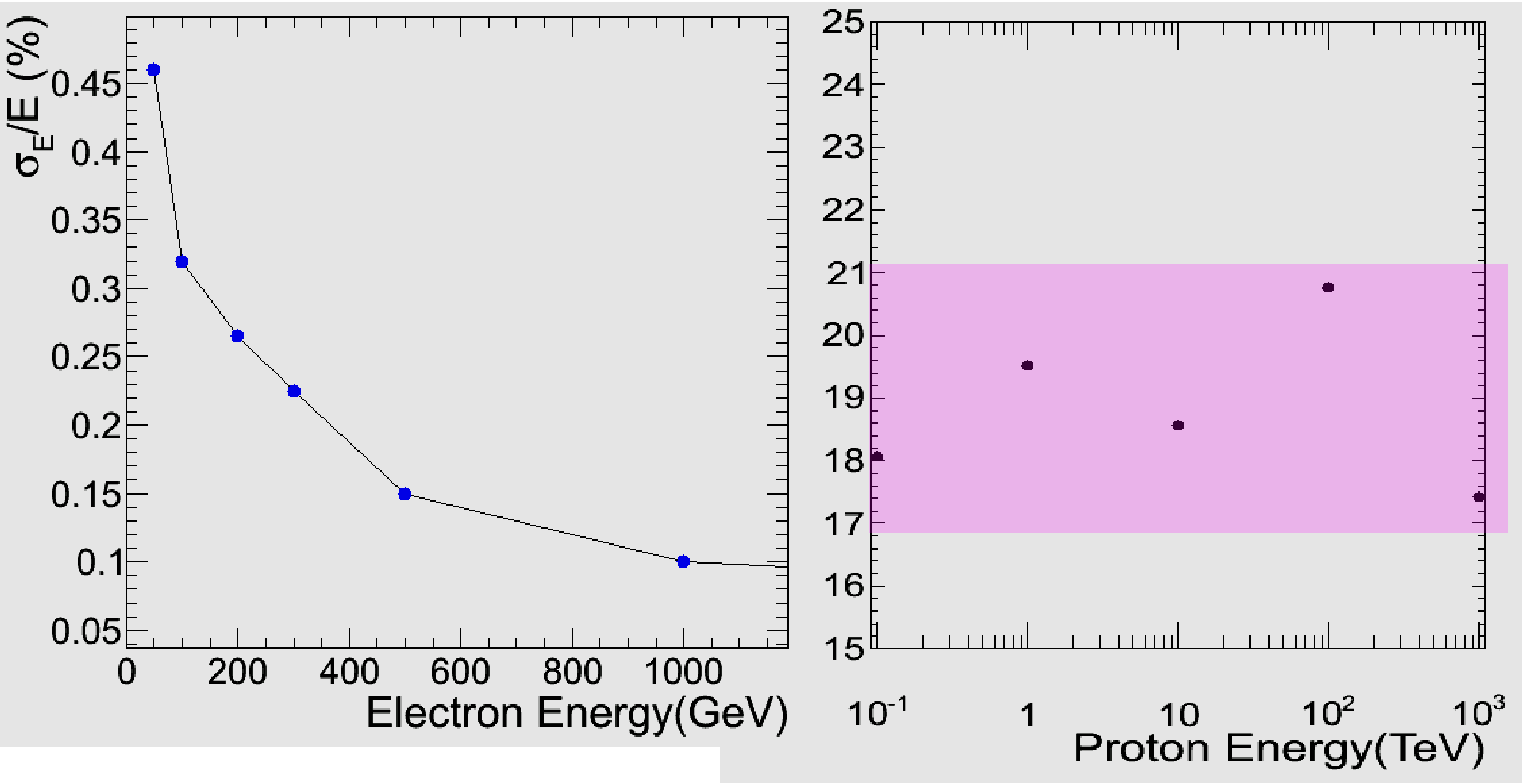


$$residual = \frac{reco - truth}{truth}$$

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

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

Simulation results: energy resolutions



Electron < 1%; Proton: ~20%

Essential for spectral features!

TMVA: Multi-Variable Analysis

Define 8 parameters for a shower in CALO

TMVA input :

Var1: $(\sum_{k=1}^{Nlayer}\sum_{i,j=max-2}^{max+2} E_{i,j,k})/E_{vis}$

Var2: $(\sum_{k=Nlayer-2}^{Nlayer} E_k)/E_{vis}$

Var3: $\ln(E_{vis})\sum_{k=1}^{5} E_k/E_{vis}$

Var4: $\frac{\sum_{k=1}^{Nlayer} E_{hit,k}/N_{hit,k}}{\sum_{k=1}^{Nlayer} E_{hit,k}/\sum_{k=1}^{Nlayer} N_{hit,k}}$

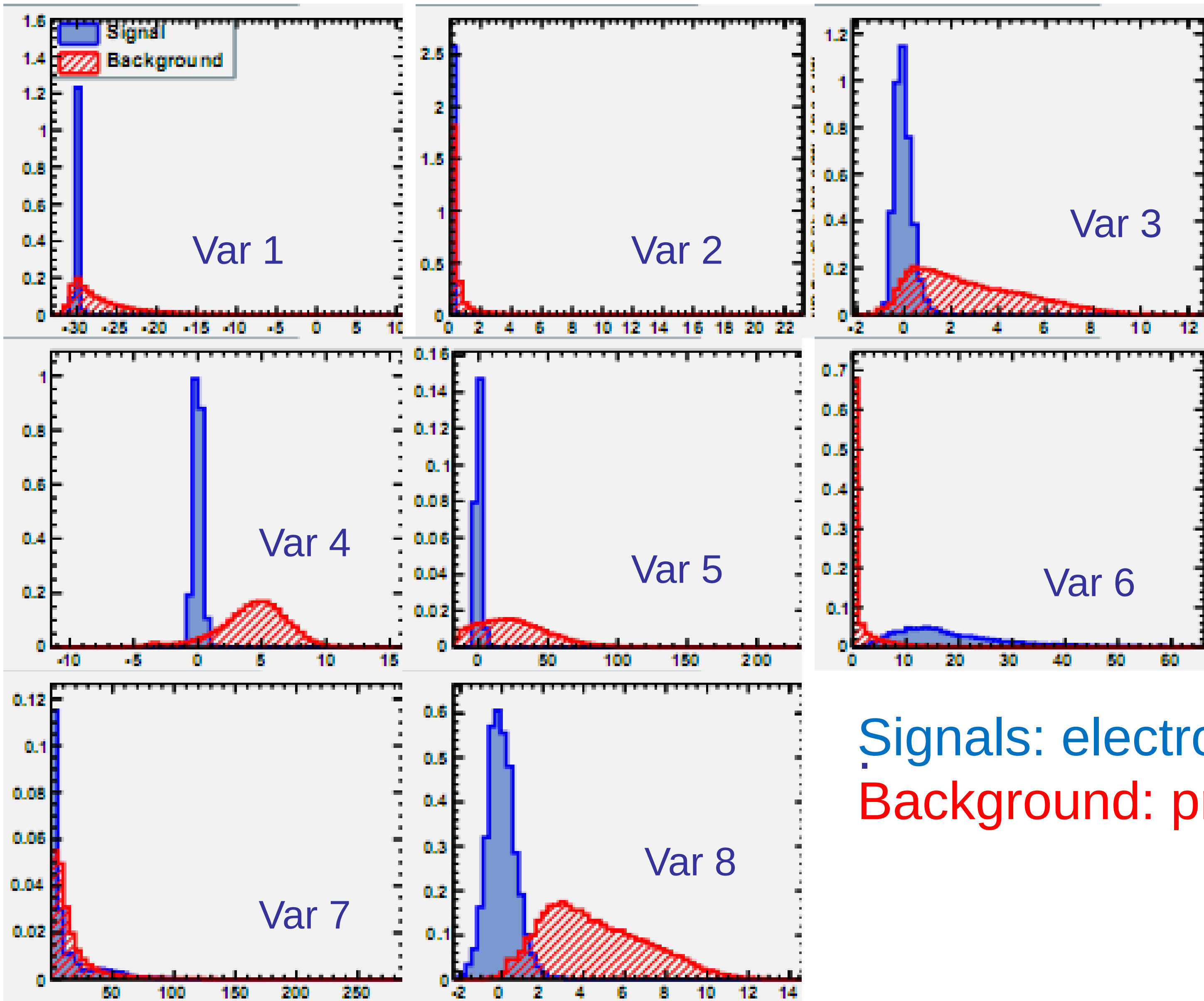
Var5: $\frac{a-1}{b} - \ln(E_{dep})$

Var6: $\sum_{k=1}^{Nlayer} \frac{E_{bump,k}|X_{bump,k}-X_{c,k}|}{E_{hit,k}}$

Var7: $(\sum_{k=1}^{Nlayer}\sum_{i,j}\frac{E_{i,j,k}|X_{i,j,k}-X_{c,k}|}{E_{vis}}$

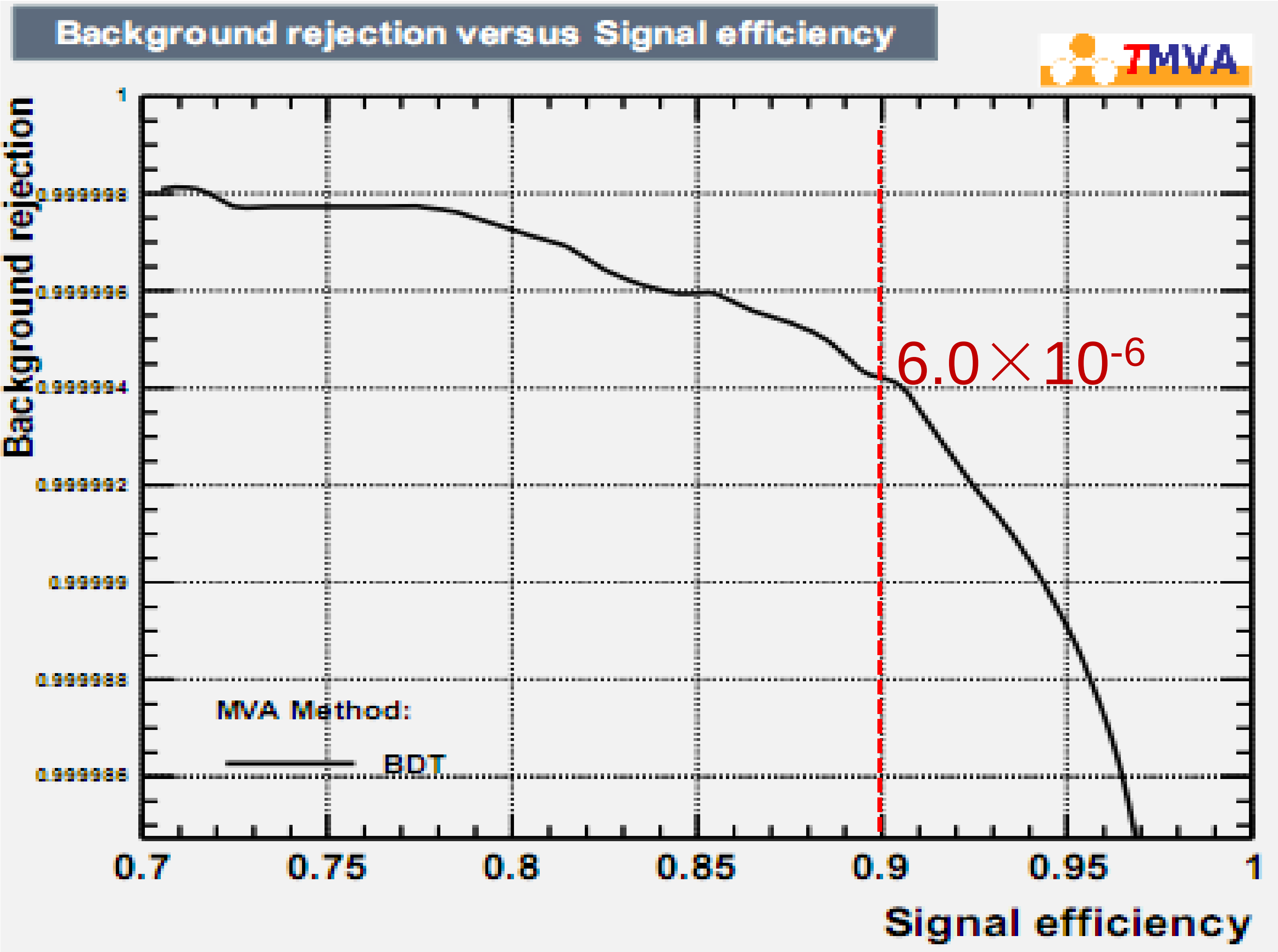
Var8: $\frac{E_{fit}-E_{vis}}{E_{vis}}$

Distributions of the 8 parameters

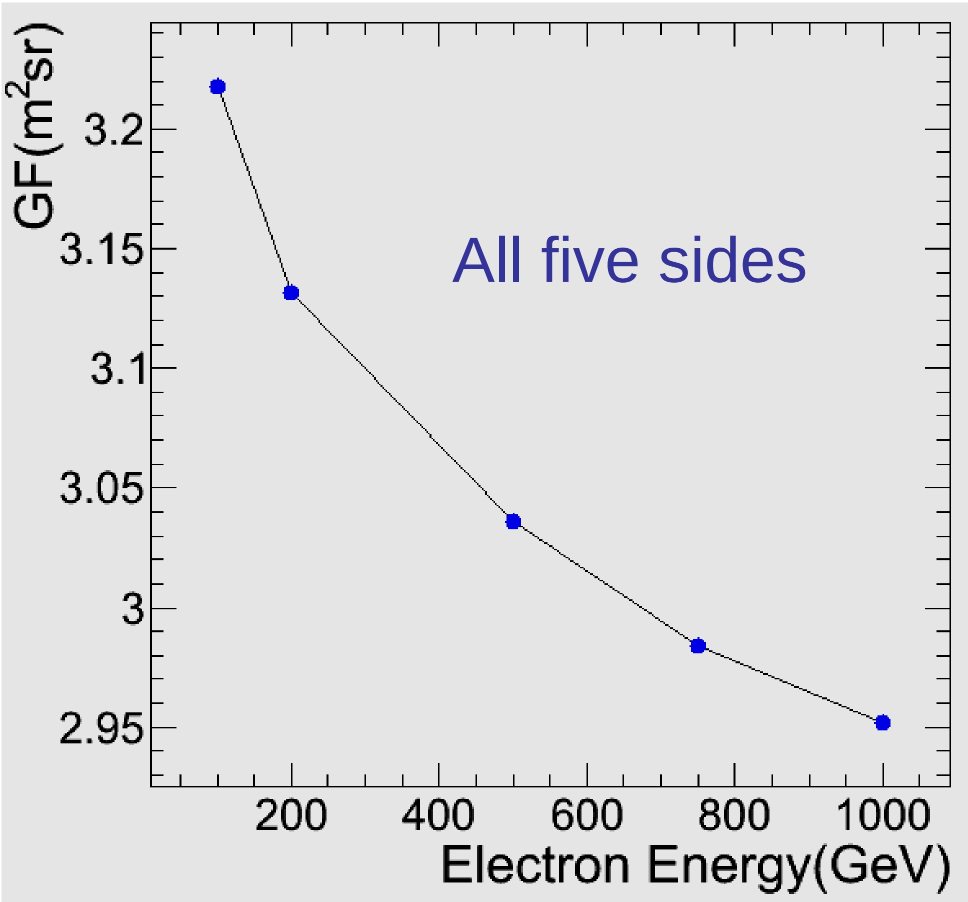


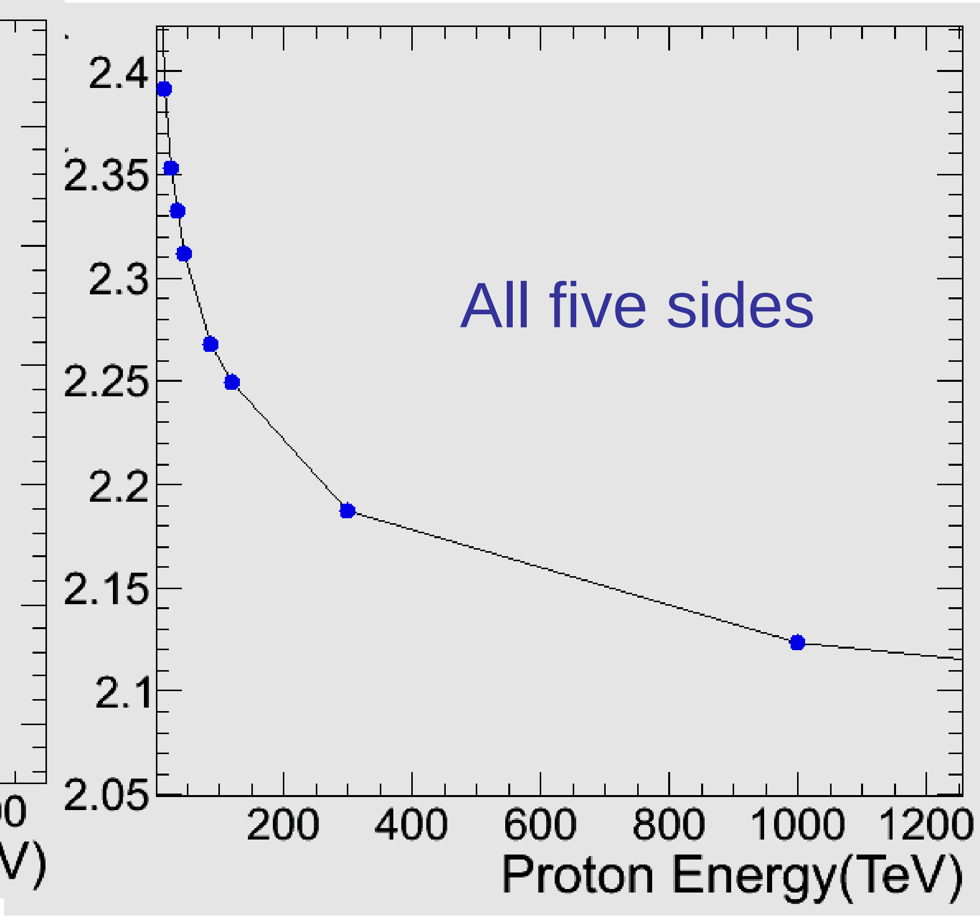
Signals: electrons
Background: protons

e/p separation (TMVA)



HERD Eff. Geometrical Factor



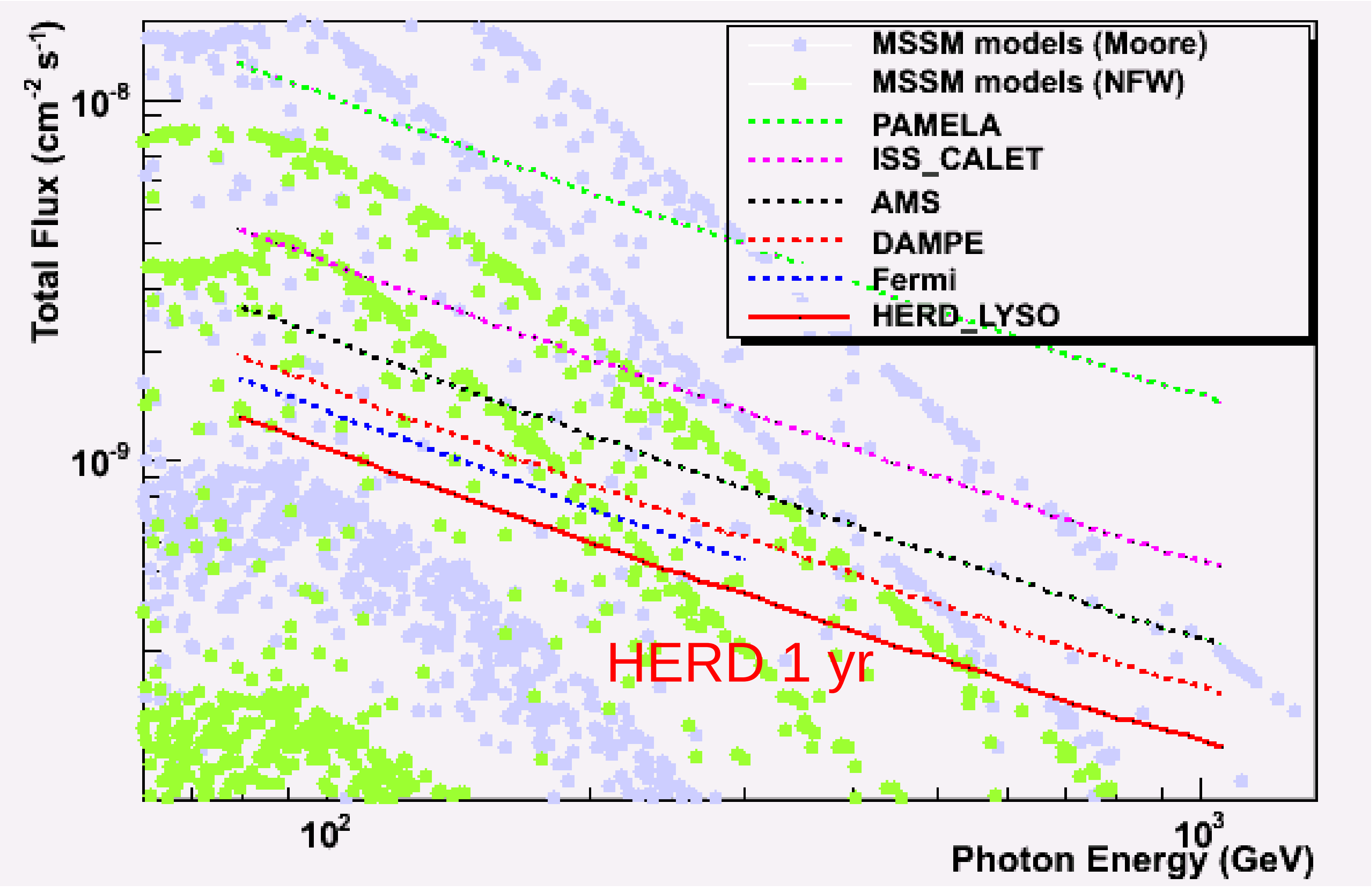


Si-strips are not considered: here only CALO is used for event selection and energy reconstruction.

Expected performance of HERD

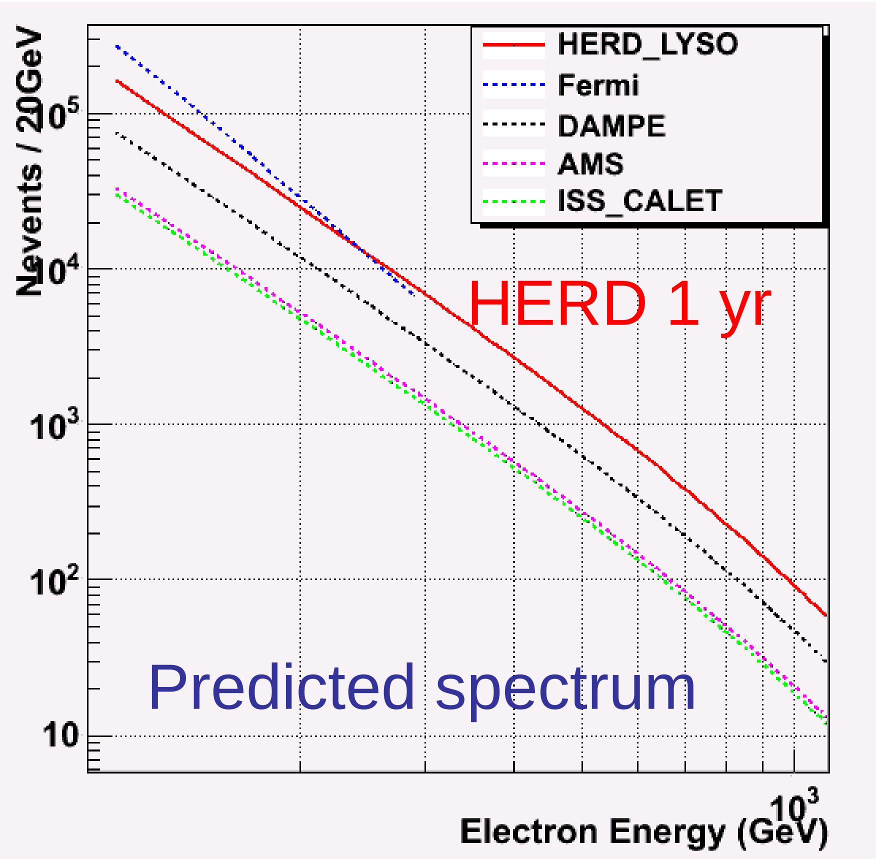
γ/e energy range (CALO)	tens of GeV-10TeV
nucleon energy range (CALO)	up to PeV
γ/e angular resol. (top Si-strips)	0.1^{o}
nucleon charge resol. (all Si-strips)	0.1-0.15 c.u
γ/e energy resolution (CALO)	<1%@200GeV
proton energy resolution (CALO)	20%
e/p separation power (CALO)	$<10^{-5}$
electron eff. geometrical factor (CALO)	3.1 m^2sr@200 GeV
proton eff. geometrical factor (CALO)	2.3 m^2sr@100 TeV

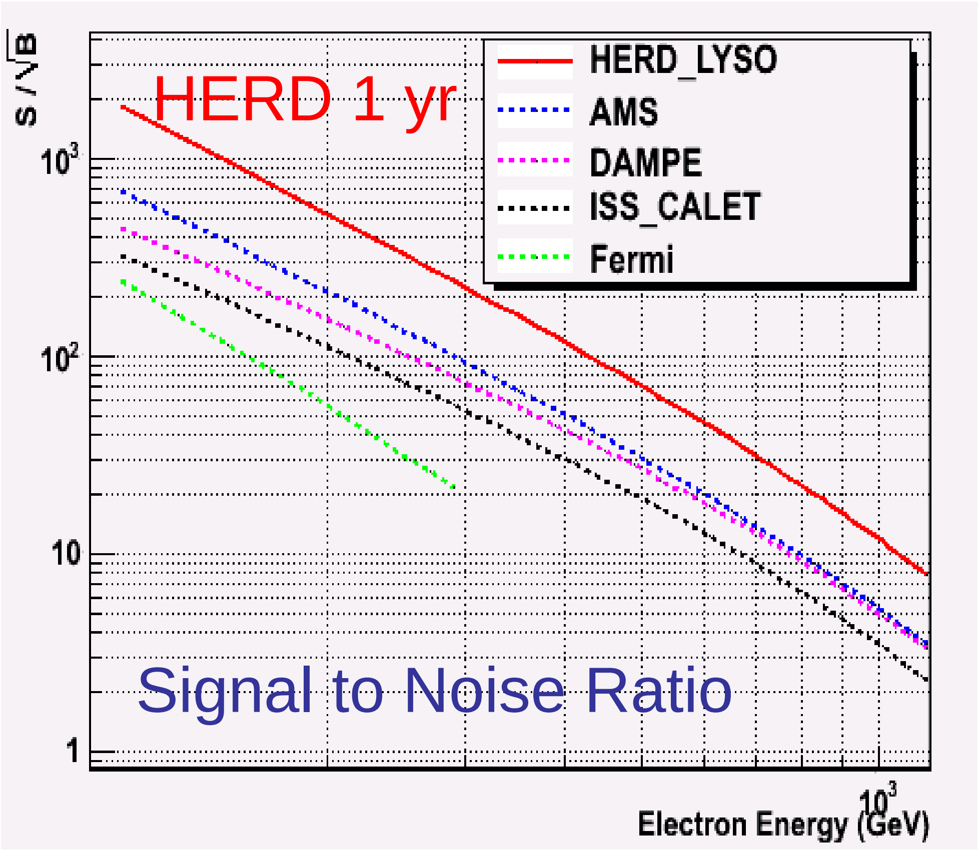
HERD sensitivity to gamma-ray line



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

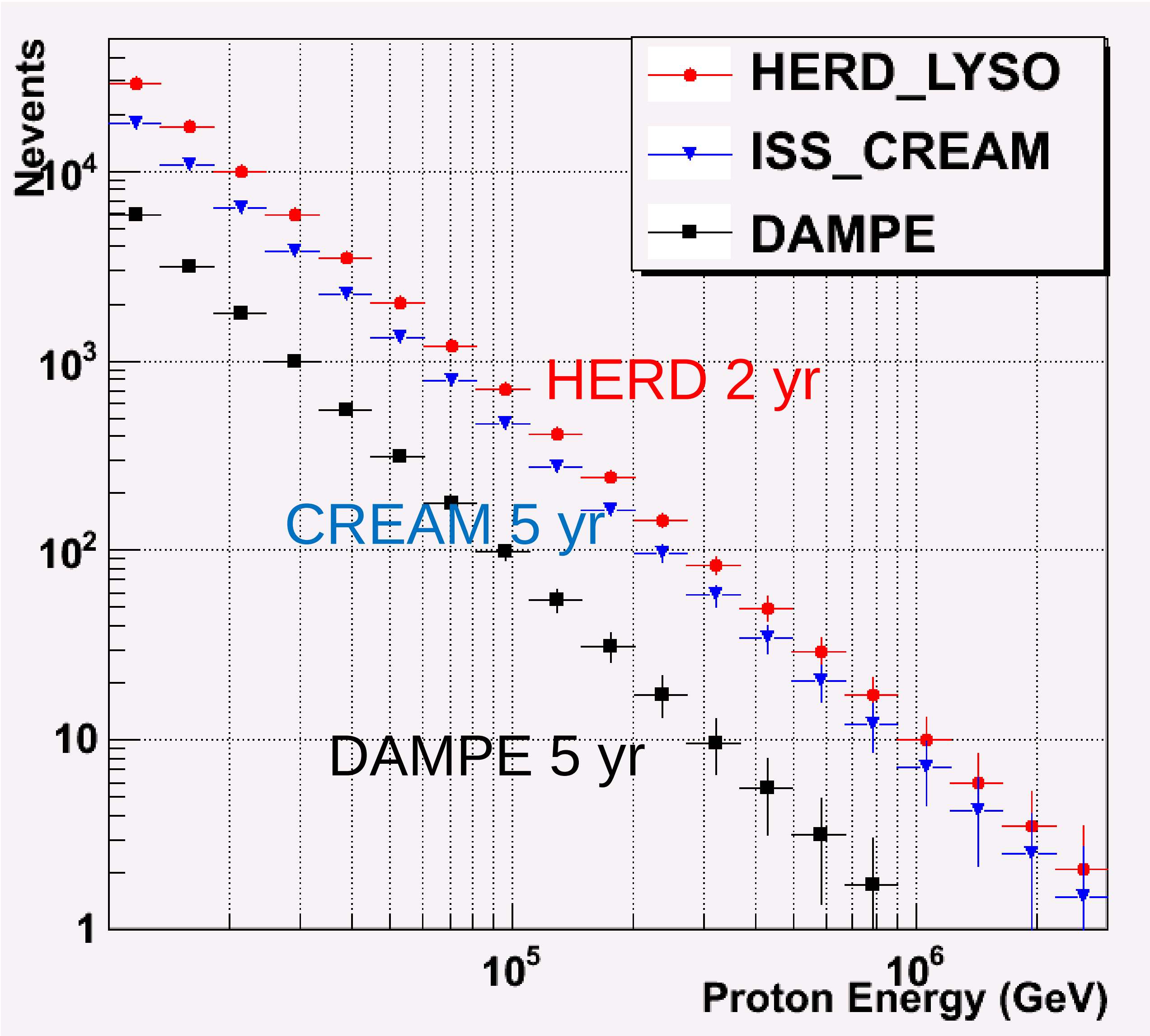
HERD electron detection capability: 2021





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

HERD proton (nucleon) detection capability



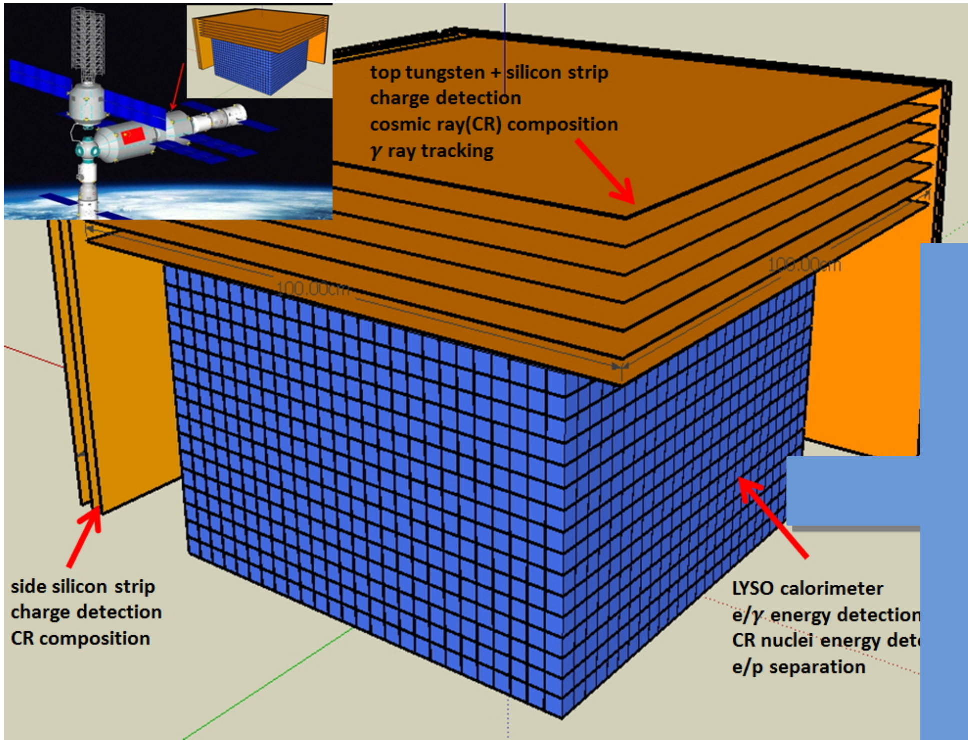
HERD：2020-2022

CREAM：2015-2020

DAMPE：2015-2020

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

New calorimeter readout technique: ICCD



Direct Coupling

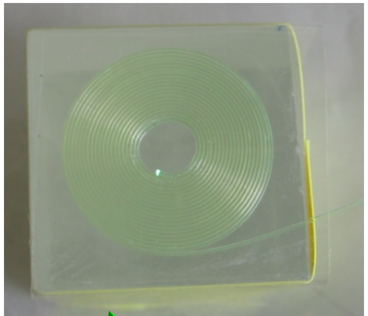
PD, APD, SiPM: Complicated system, high power consumption

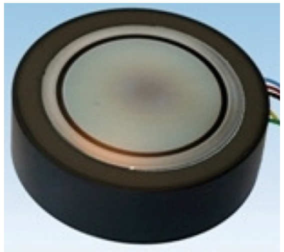
MAPMT, SiPM: high power consumption
CCD: No single photon detection
EMCCD, EBCCD: no ns gate control
ICCD: no above problems, but premature

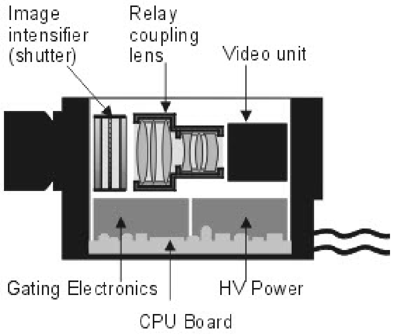
Wavelength shifter fiber readout

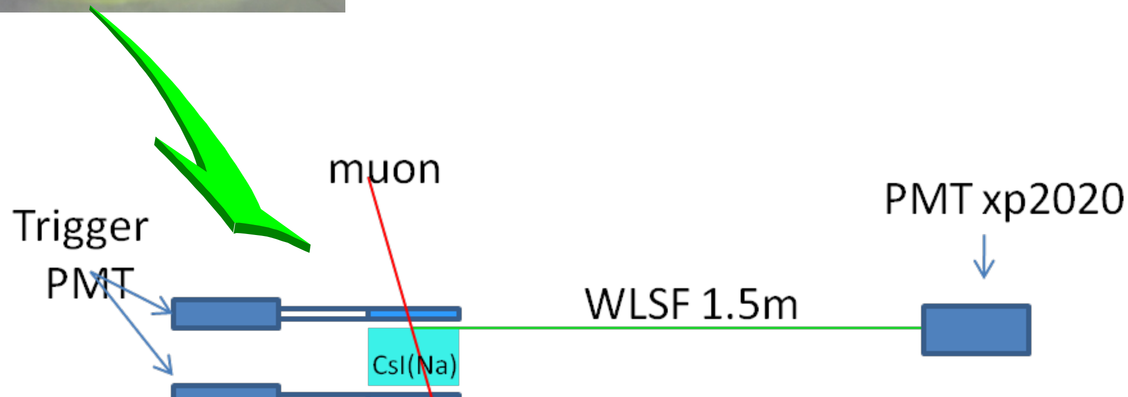
Only ONE CCD chip needed!

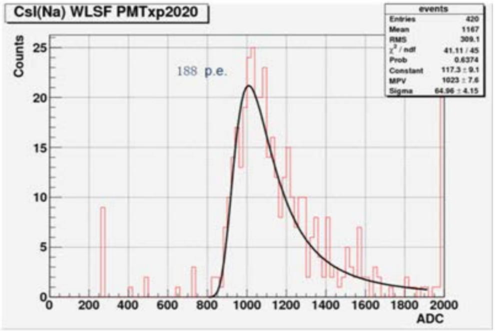
An example







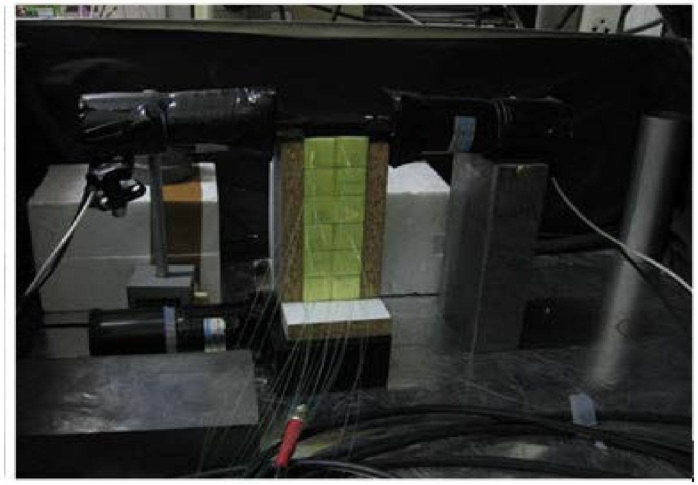




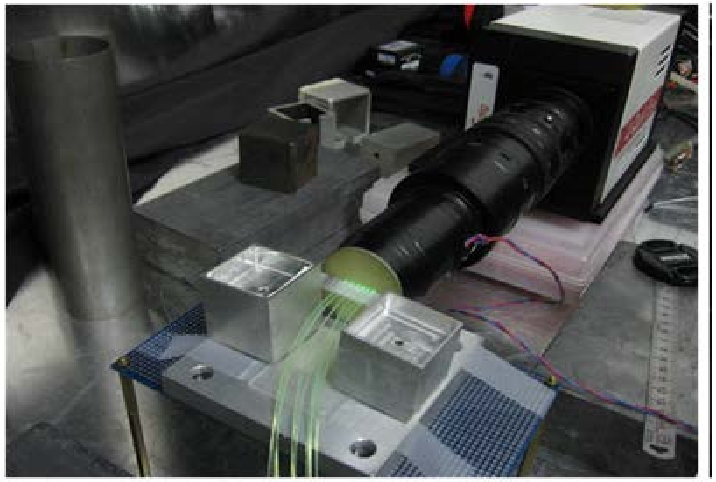
2.5 cm CsI(Na): ~ 188 p.e.
for a passing muon

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

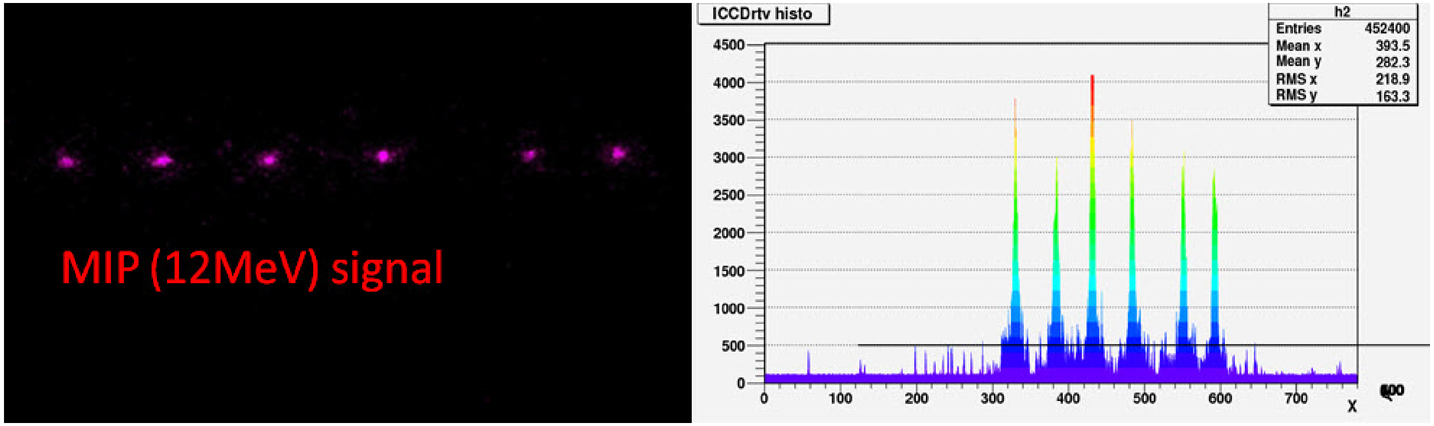
Test set-up and results



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

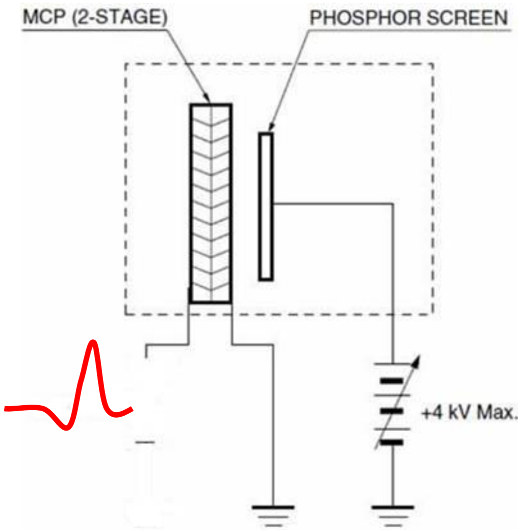


Taper +Imaging Intensifier + ICCD



ICCD image of typical muon events

Concept of space ICCD readout system



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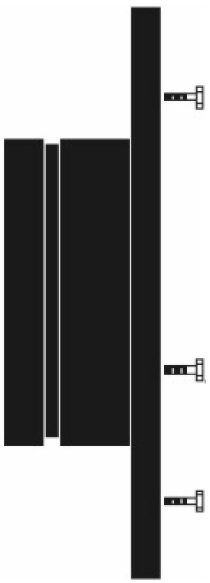

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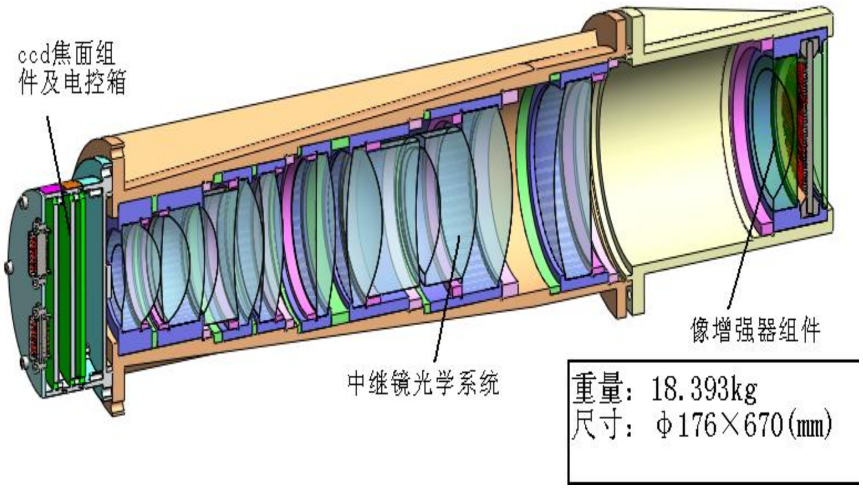
Cathode Triggered Intensifier

Optical Coupler

High frame rate and large format CCD

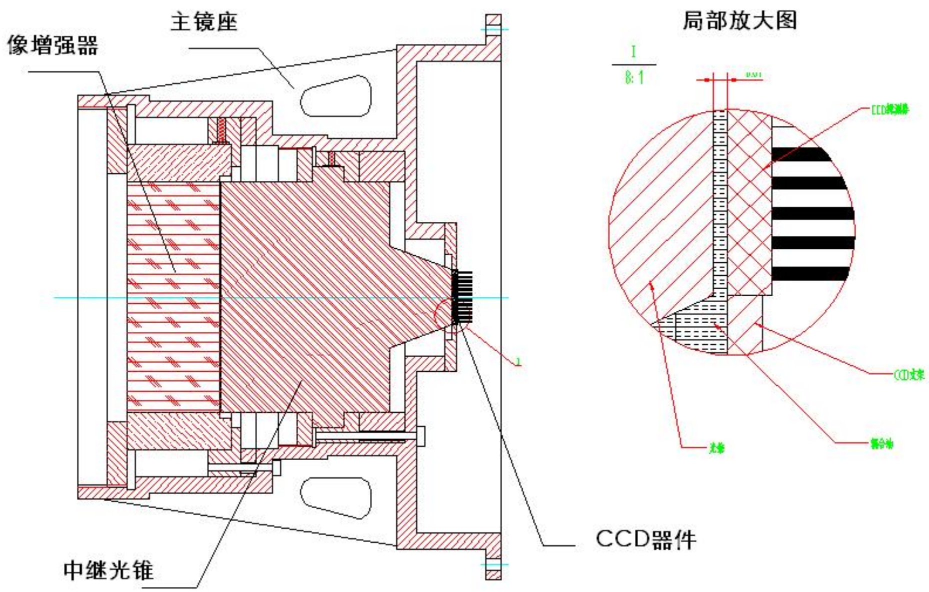
Two types of coupling designs

Relay mirrors



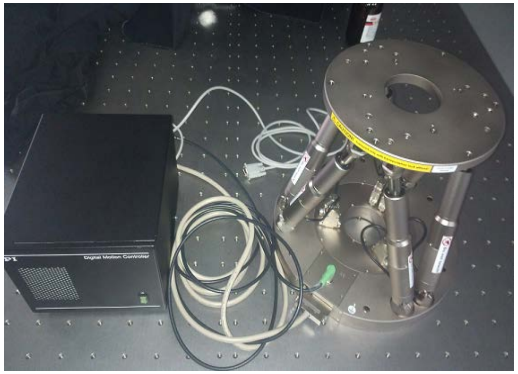
Single unit: weight of 18.393 kg, size， size of φ176×670(mm)。

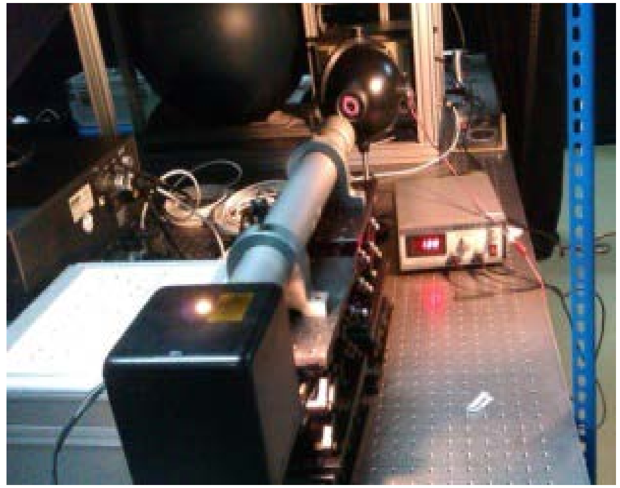
Taper

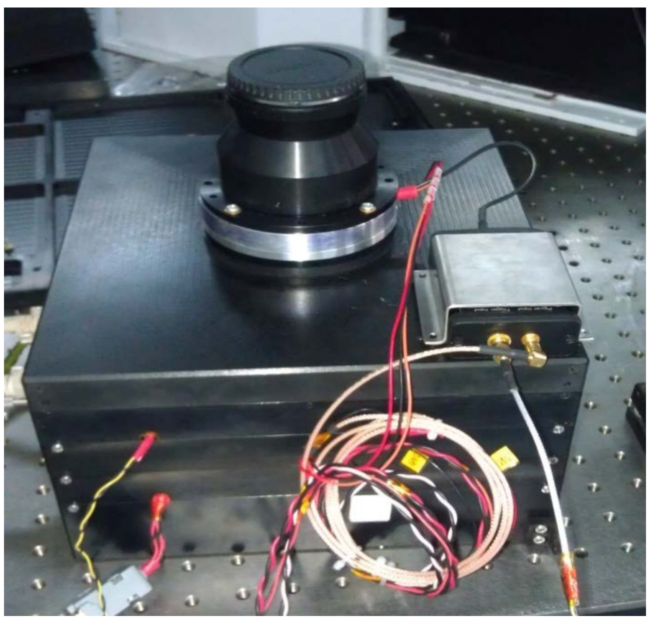


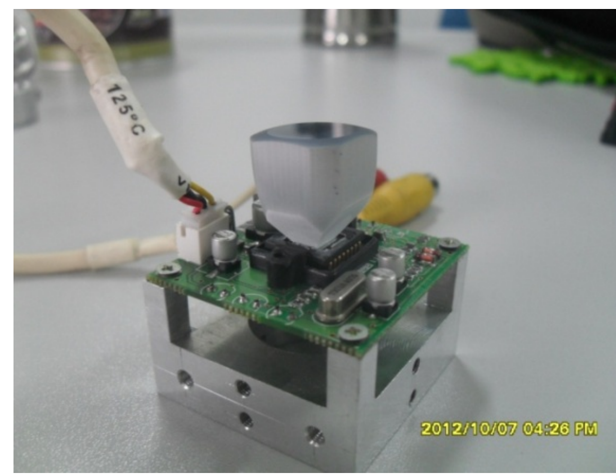
Technology development funded by XIOPM, CAS and NSFC.

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 final mission selection may happen anytime.
- Launch in 2018-2020.

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

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

2nd HERD workshop, Dec.1-4, 2013, IHEP, Beijing

List of further contacts

- Scientific objectives: Prof. Shuang-Nan Zhang (zhangsn@ihep.ac.cn), PI of HERD
- Monte-Carlo simulations: Dr. Ming Xu (mingxu@ihep.ac.cn)
- Scintillator-fiber coupling: Dr. Zhigang Wang (wangzhg@ihep.ac.cn)
- ICCD readout: IHEP Dr. Tianwei Bao (baotw@ihep.ac.cn), XIOPM Dr. Le Wang (joy@opt.ac.cn)
- Payload system, mechanical support, platform interface and all others: Dr. Yongwei Dong (dongyw@ihep.ac.cn)