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

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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**

Center for Particle Astrophysics

141 students, postdocs and visiting scholars

155 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

Evidence of Dark Matter

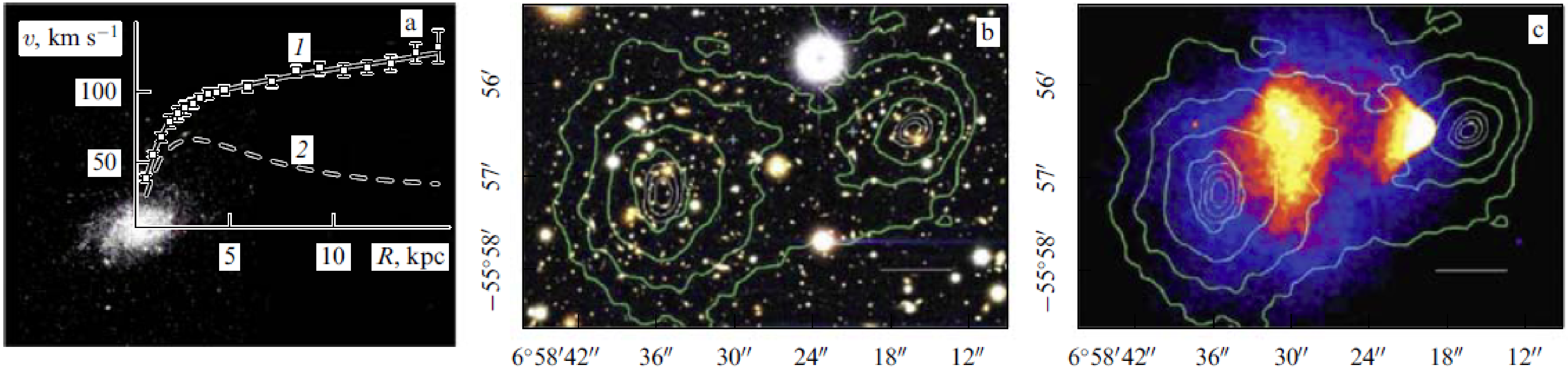


Figure 2. (a) Rotation curves for the M33 galaxy [4]: *1*, the observed curve, *2*, theoretical curve of the glowing galactic disk. (b) Optical and (c) X-ray images of cluster 1E0657-558 obtained with the Hubble and Chandra telescopes, respectively. The curves show mass density contours reconstructed by gravitational lensing [5]. Horizontal axes are the inclination angles, vertical axes are the ascention angles.

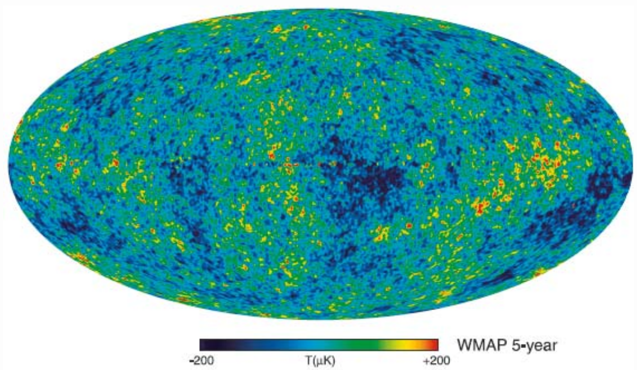


Figure 12. The foreground-reduced Internal Linear Combination (ILC) map based on the five year *WMAP* data.

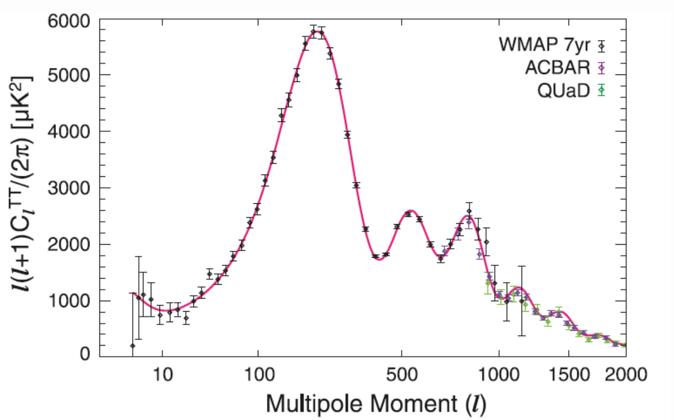
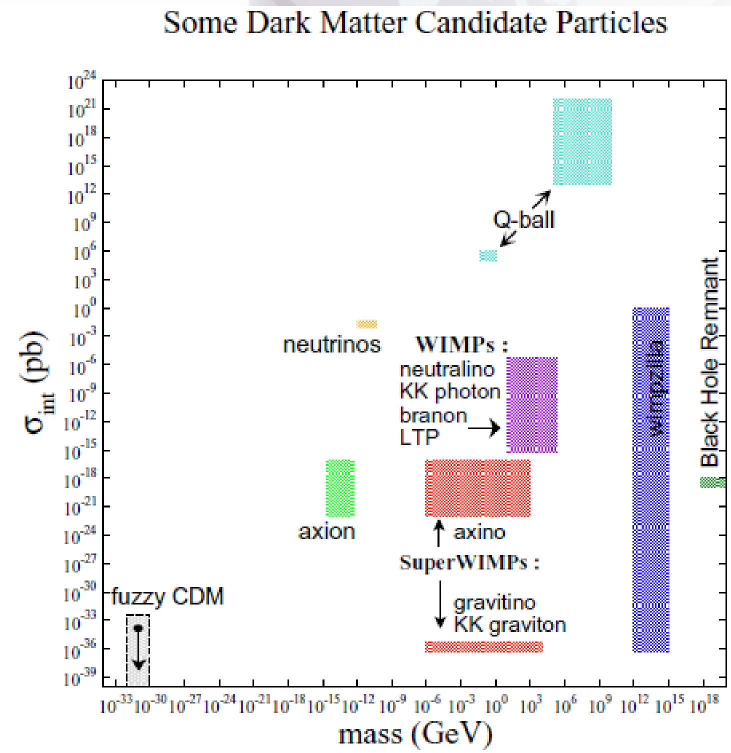


FIG. 7.— The *WMAP* 7-year temperature power spectrum (Larson et al. 2010), along with the temperature power spectra from the ACBAR (Reichardt et al. 2009) and QUaD (Brown et al. 2009) experiments. We show the ACBAR and QUaD data only at $l \geq 690$, where the errors in the *WMAP* power spectrum are dominated by noise. We do not use the power spectrum at $l > 2000$ because of a potential contribution from the SZ effect and point sources. The solid line shows the best-fitting 6-parameter flat ΛCDM model to the *WMAP* data alone (see the 3rd column of Table 1 for the maximum likelihood parameters).

Candidates for DM particles

- Neutrinos
  - Standard model neutrinos
  - Sterile neutrinos
  - Heavy and very heavy neutrinos
- WIMPs
  - Supersymmetric particles, e.g. neutralino
  - Kaluza-Klein states
- SWIMPs. E.g. axions
- Magnetic monopoles
- Mirror particles
- Exotic baryonic candidates
  - MAssive Compact Halo Objects (MACHO), Stragelets and nuclearities, Technibaryons, CHAMPs, Superheavy X-particles, Supersymmetric Q-balls, crypto-baryonic DM



Baer & Tata 2009

Detection methods of WIMPs

- **Directly.** Via elastic scattering on detector nuclei in the lab.

Difficulty:
Scattering cross section $<10^{-6}$ pb;
Small Energy of recoil nuclei ~10-100 keV;
High background;

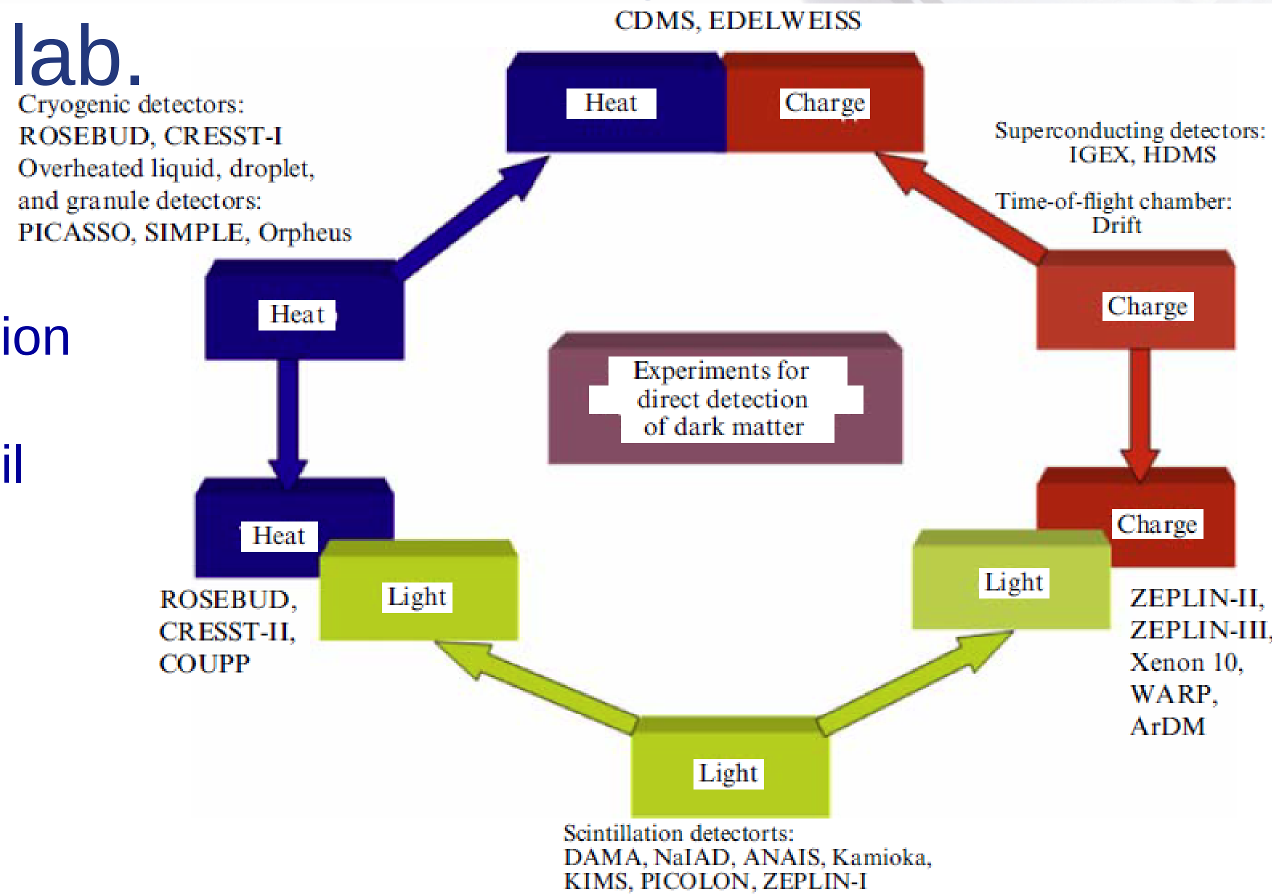


Figure 10. Principal detection methods and experiments designed to search for WIMPs.

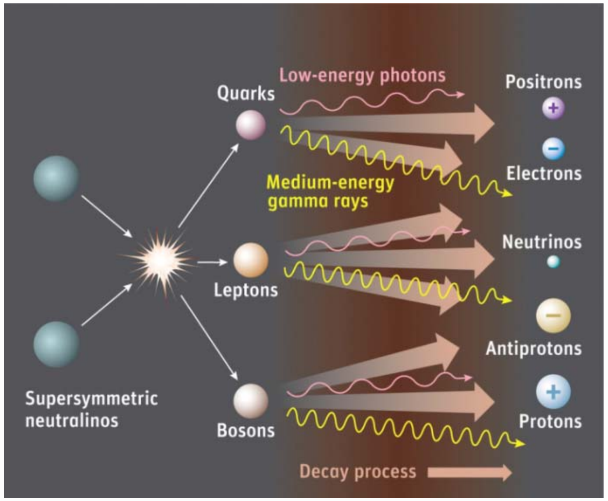
Ryabov 2008

- **Collider**

Detection methods of WIMPs

- **Indirectly.** Via annihilation products e.g. gamma-rays, positrons, anti-protons, neutrinos.

  The typical energy of these final states is about a tenth of the dark matter particle mass, so we can search indirectly for dark matter by looking for an excess of photons, antimatter or neutrinos in astrophysical data at energies between 1 GeV and 10 TeV. (*Bertone 2010*)



Annihilation place	particles	mission
Center of sun	neutrino	AMANDA, ICECUBE
Galactic center	photon	FERMI, HESS
Halo	positron	AMS, PAMELA, HEAT

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.

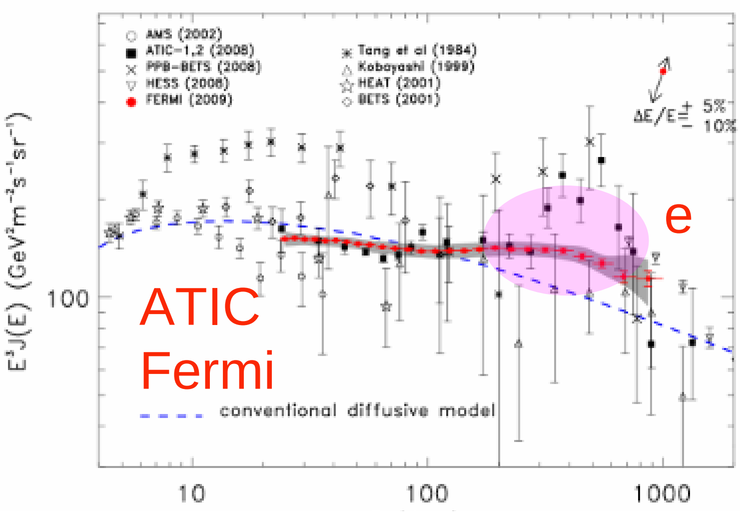
International collaborations on space science research have been and will continue to be an important part.

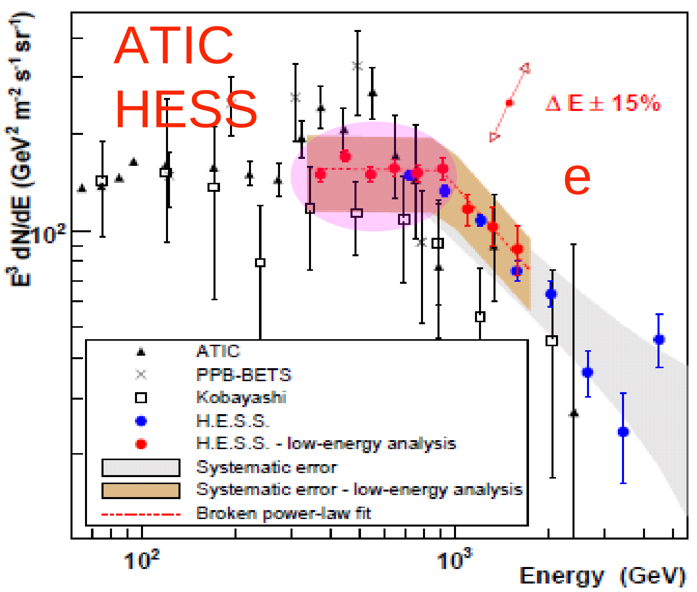
Cosmic Lighthouse Program onboard China's Space Station

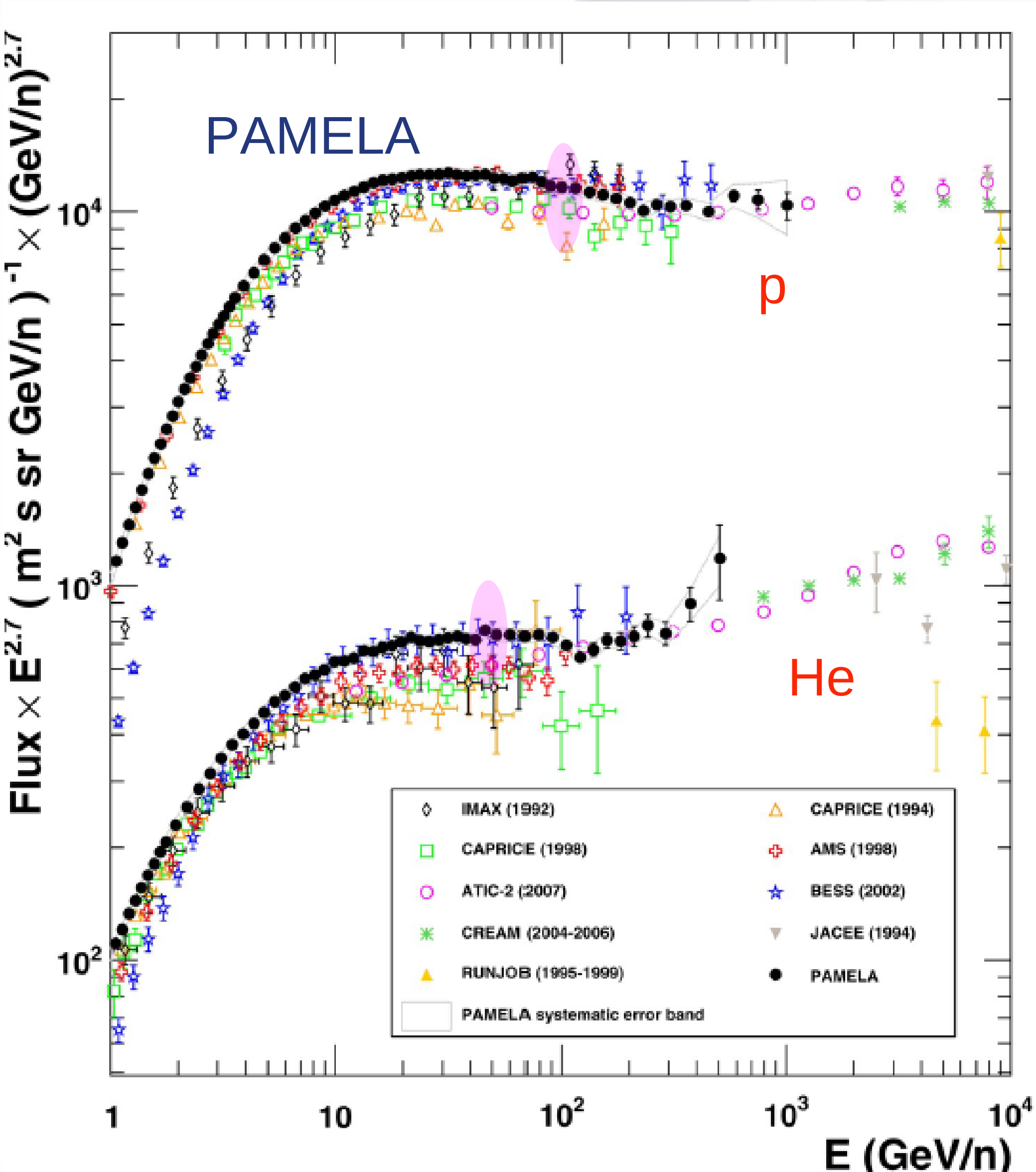
Candidate Projects	Main Science Topics
Large scale imaging and spectroscopic survey facility (**OK**)	Dark energy, dark matter distribution, large scale structure of the universe
HERD (**OK**)	Dark matter properties, cosmic ray composition, high energy electron and gamma-rays
Soft X-ray-UV all sky monitor (?)	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

Brief scientific background: DM & CR

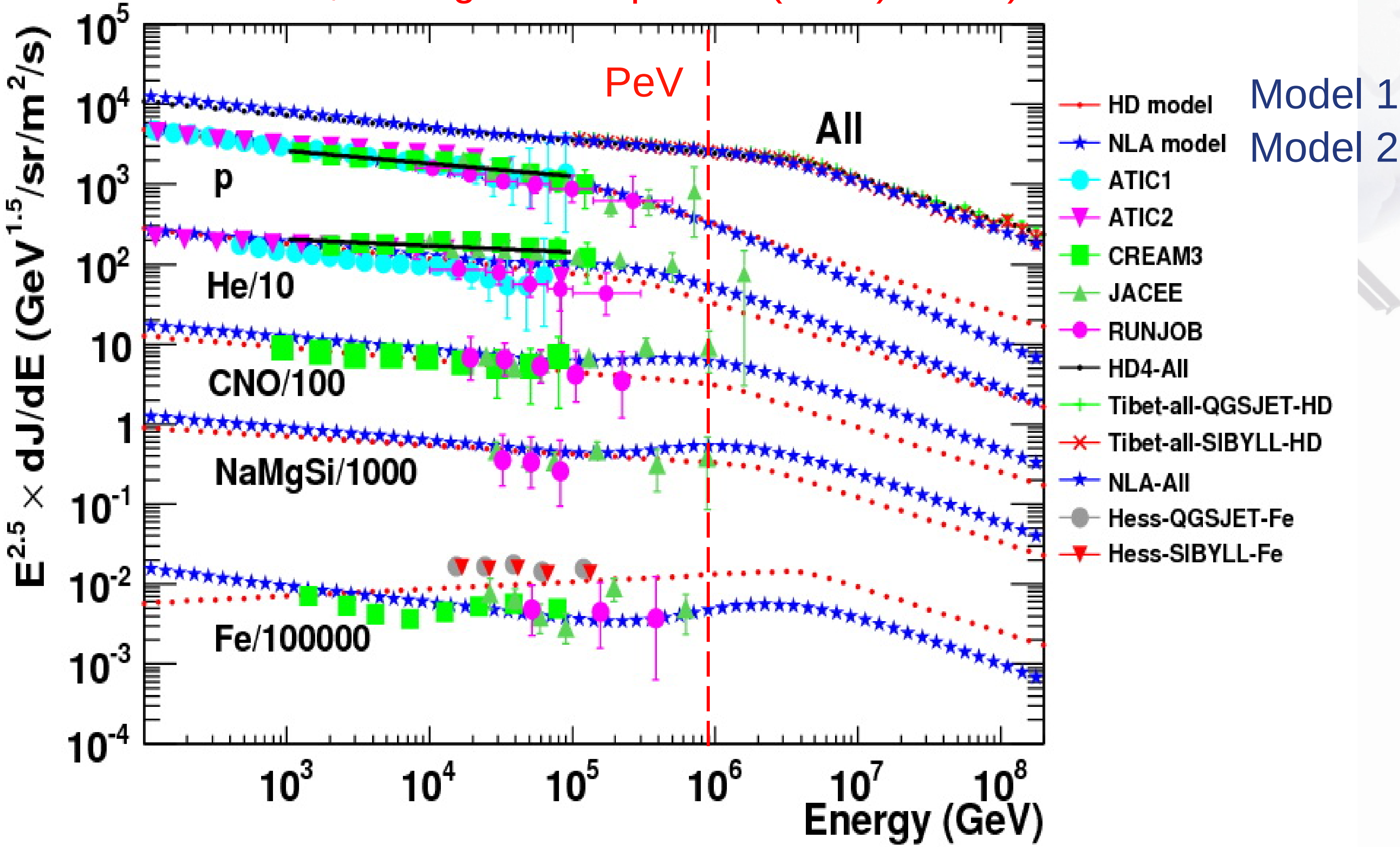




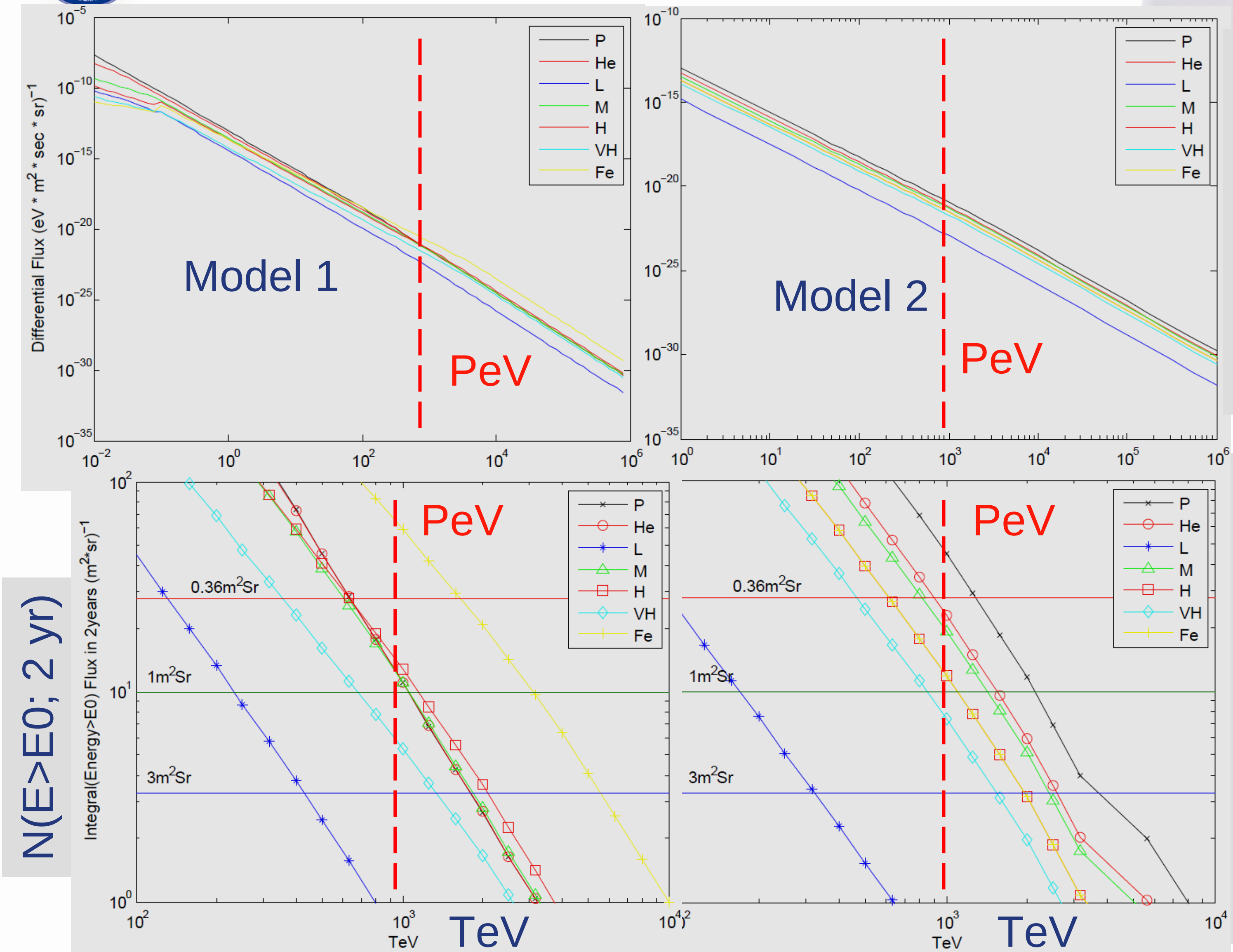


CR composition models around the "Knee"

Shibata, Huang et al. ApJ 716 (2010) 1076)



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.

Requirements for HERD

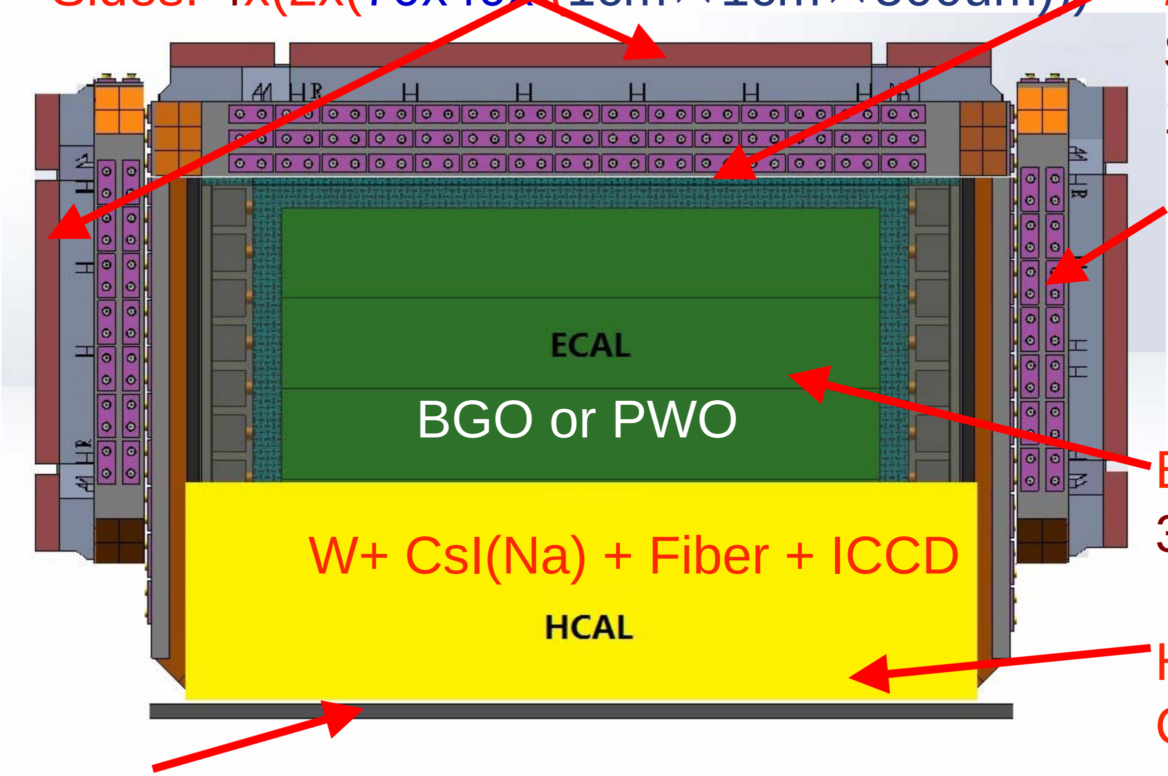
Science goals	Mission requirements
Dark matter search	R1: Better energy (& direction) measurements of e/ γ between 100 MeV to 10 TeV
Origin of Galactic Cosmic rays	R2: Better composition (& specrtal) measurements of CRs between 100 GeV to PeV with a large geometrical factor

Secondary science (VHE γ -ray astronomy): monitoring of GRBs, microquasars, Blazars and other transients.

Baseline Design: ~2 T, ~2 KW

Charge detector: Si+PIN.
Top: 2x(70x70x(1cm×1cm×500um));
Sides: 4x(2x(70x40x (1cm×1cm×500um)))

Shower Tracker:
W: $4X_{0;}$ 10x3.5mm +
2x17.5mm + 2x35mm
Scin. Fibers:
14x(2x(700x($1x1x700mm^3$)))



Nucleon Tracker: scin. fibers
400x($1x1x700mm^3$)+
700x($1x1x400mm^3$)

ECAL: $16X_0=0.7X_{NIL}$
3x(2x($25x25x700mm^3$))

HCAL: W: 20x3.5mm ($0.8X_{NIL}$)
CsI: 20x(2.5cmx2.5cmx0.2cm)

Neutron detector: B-doped plastic scintillator for delayed signals. Enhanced e/p discrimination. (TBD)

Main features

Performance	FOV	detectors
Good e/γ direction: R1	center	Shower Tracker + ECAL
e/γ discrimination: R1	center	Si-PIN + Shower Tracker
CR charge measurement up to z=26: R2	5-sides	Si-PIN + Shower Tracker
e/γ energy < 1 PeV: R1	center	ECAL + HCAL
CR spectrum < 1 PeV: R2	5-sides	HCAL+ Nucleon Tracker +ECAL + Shower Tracker
e/p discrimination: R1	center	HCAL+ECAL+ Neutron

Both requirements are satisfied. Almost every detector is used for both requirements; each function is performed with at least two detectors → performance & redundancy.

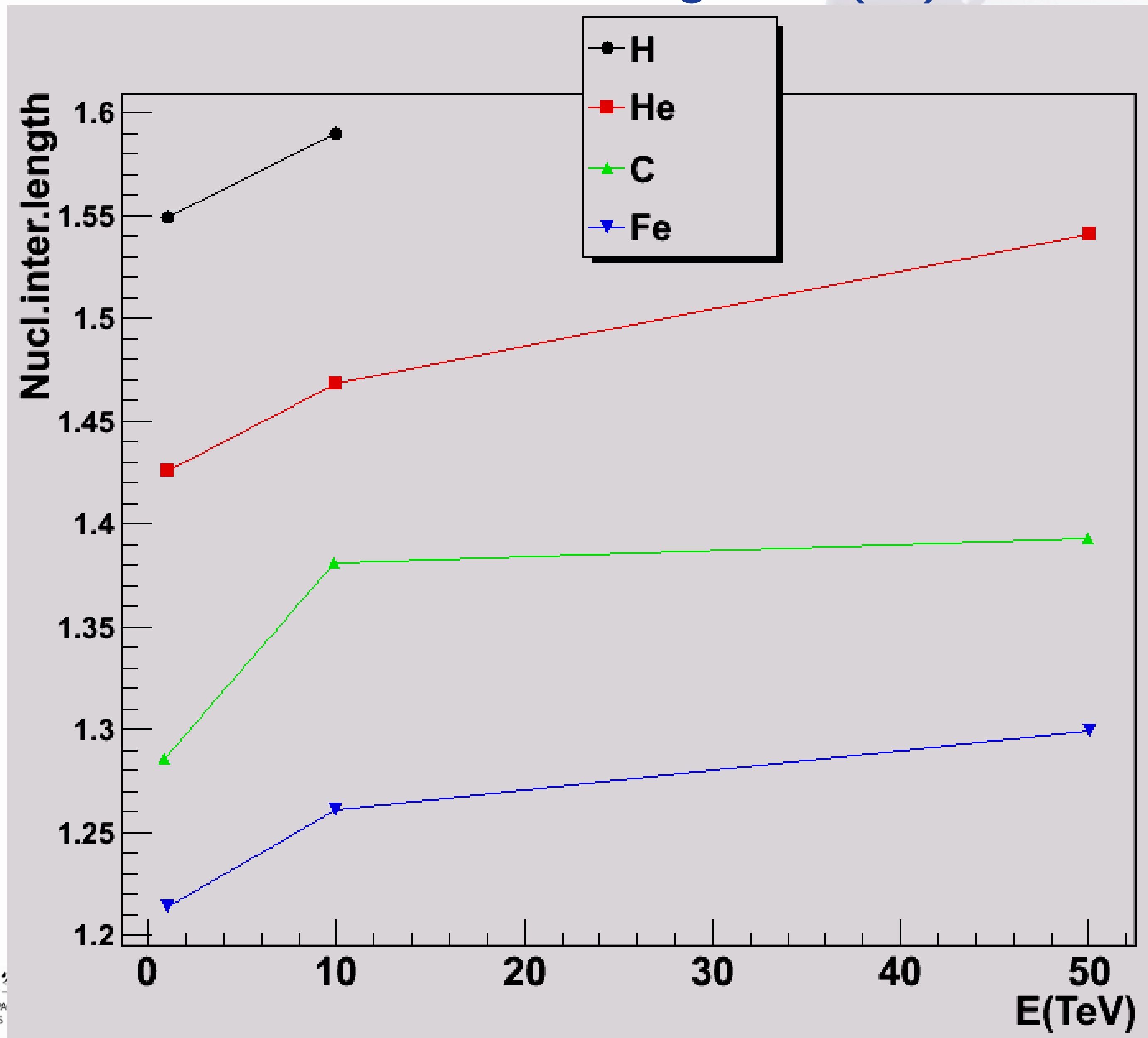
Comparisons with other missions

	HERD	DAMPE	AMS	PAMELA	FERMI	CALET
e/γ Energy Res. @100GeV	1%	1.5%	3%	5%	10%	2%
e/γ Ang. Res. @100GeV	0.3^{o}	0.8^{o}	0.3^{o}	1.0^{o}	0.1^{o}	0.3^{o}
Geometrical Factor m^2.sr	1-2	0.3	0.1	0.02	1.0	0.1
e/p discrimination	$5x10^6$	10^5	10^6	10^4	10^3	10^5
Energy range (GeV)	0.1-10^6	5-10^4	0.1-10^3	0.1-300	0.02-300	5-$5x10^3$

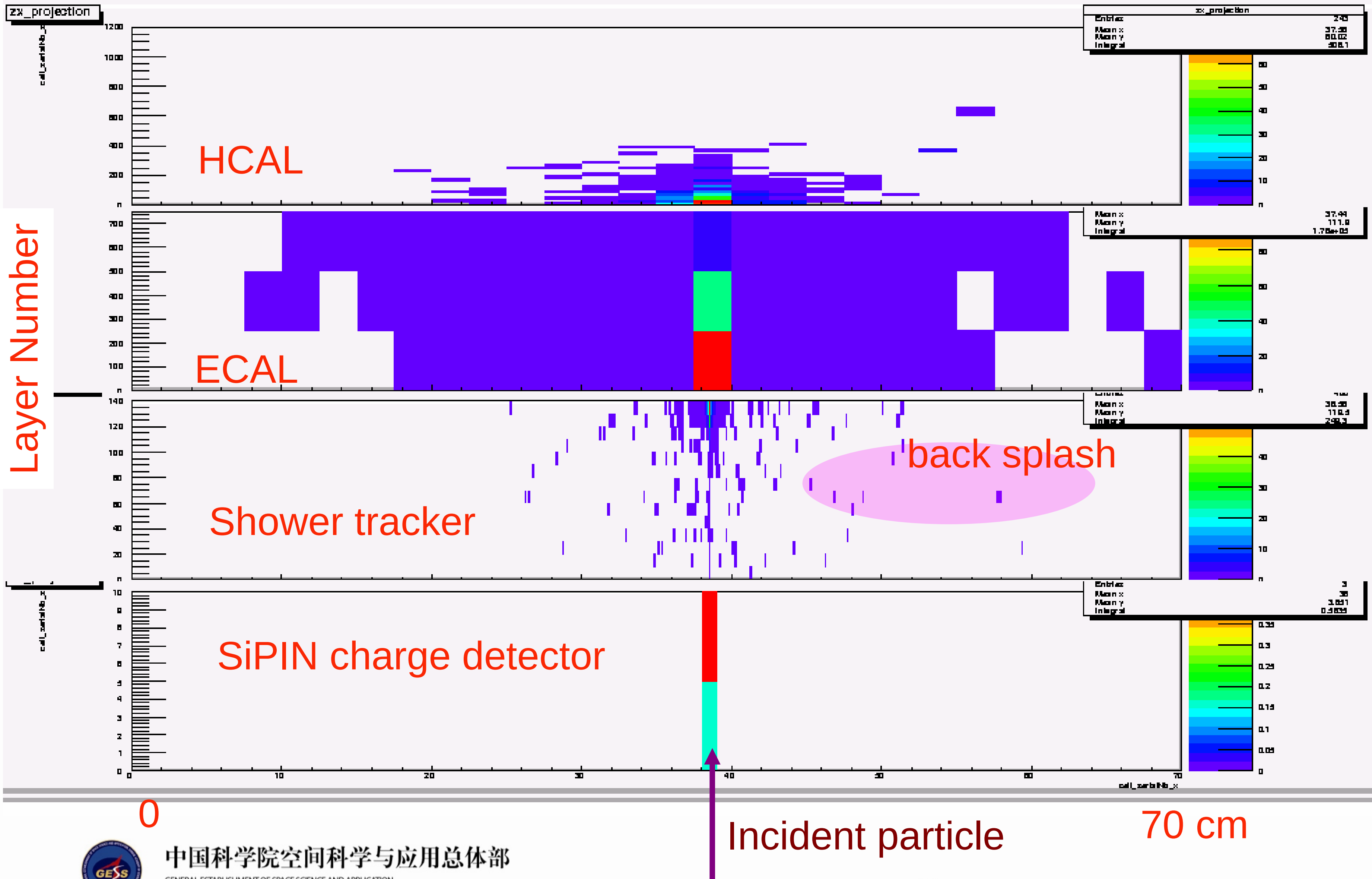
HERD is advantageous in terms of energy resolution (e/γ), geometrical factor (CR) and energy range (e/γ & CR).

Fluka based MC: Tungsten (W)

Shower max as the minimum detector thickness



Event display: 200 GeV electron



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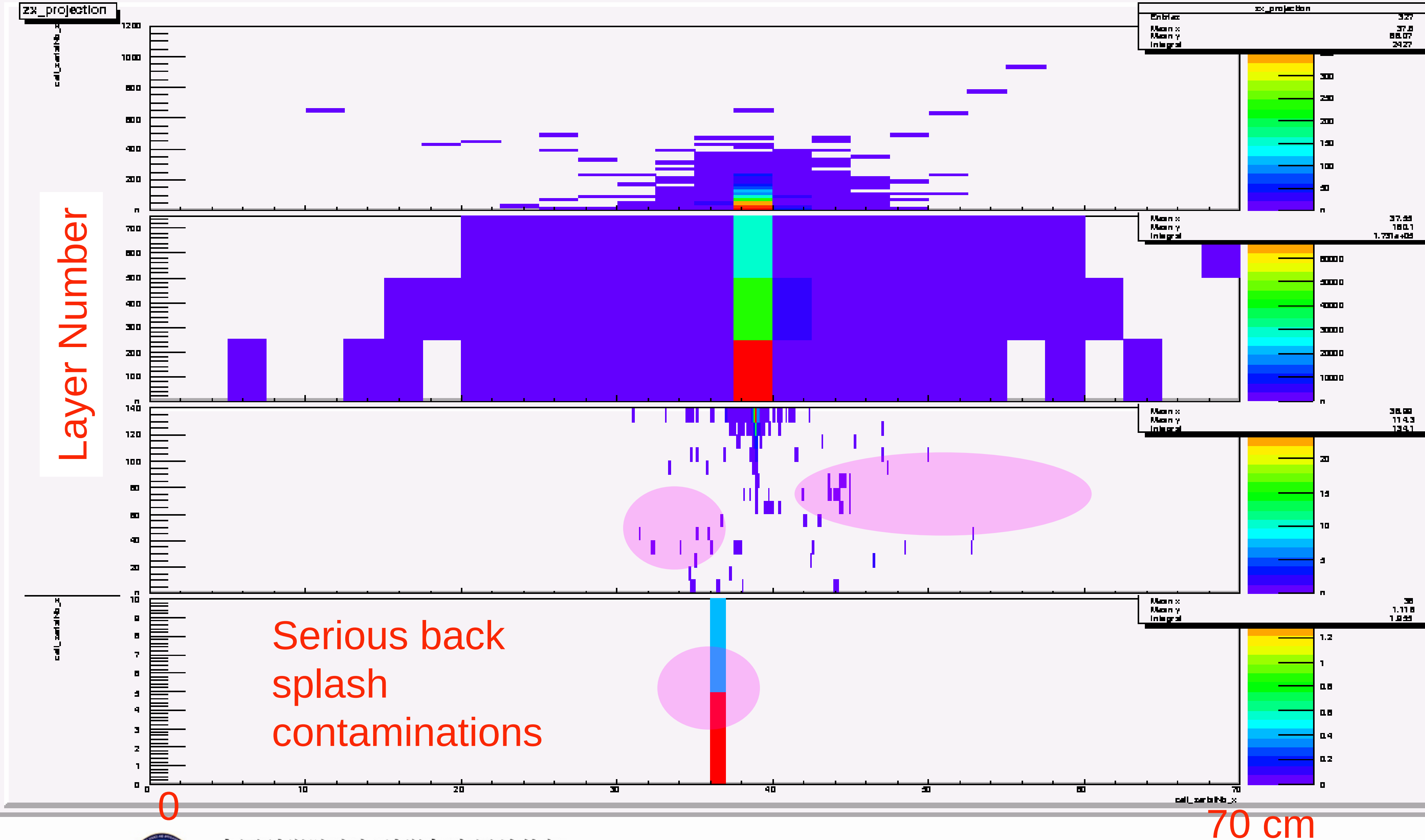
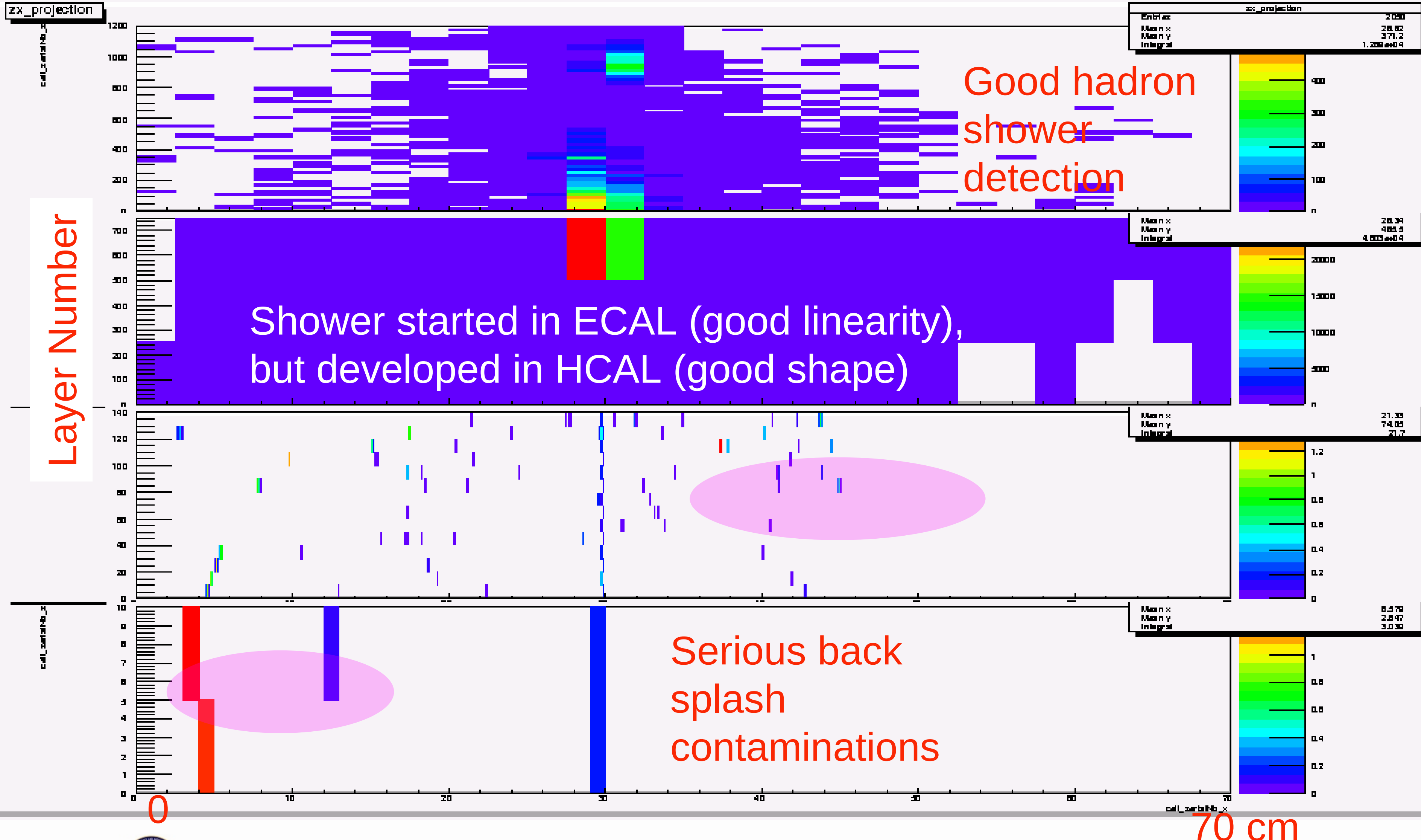
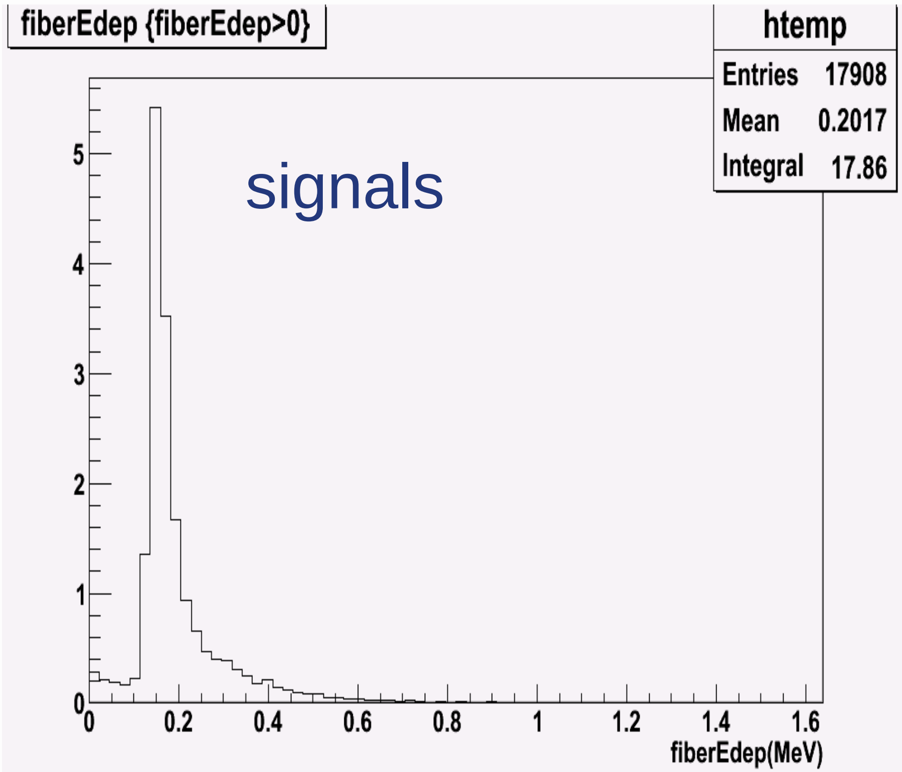
200 GeV gamma

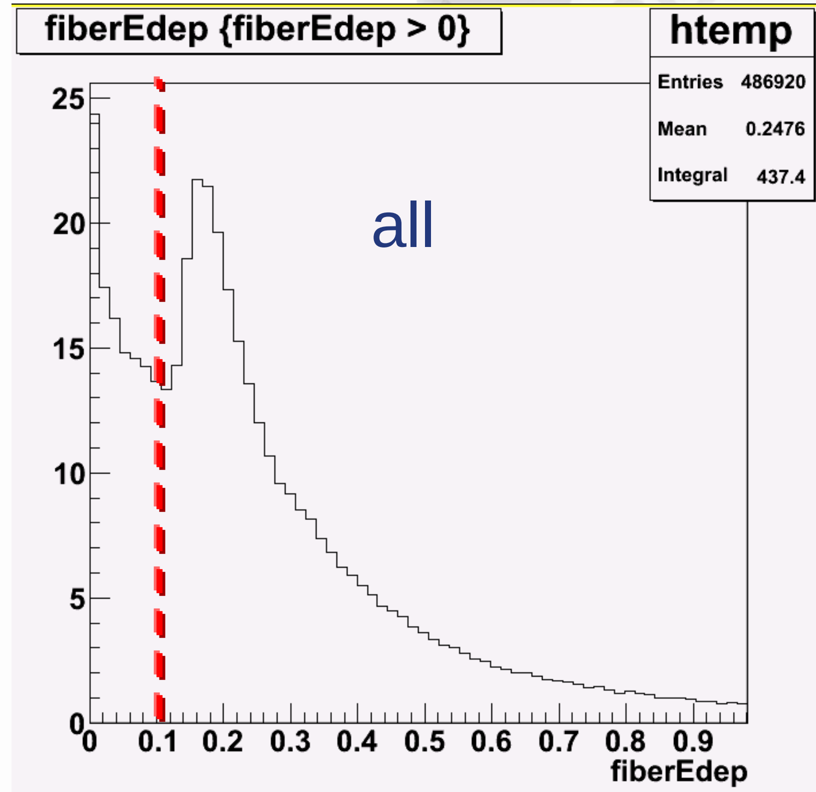


200 GeV proton



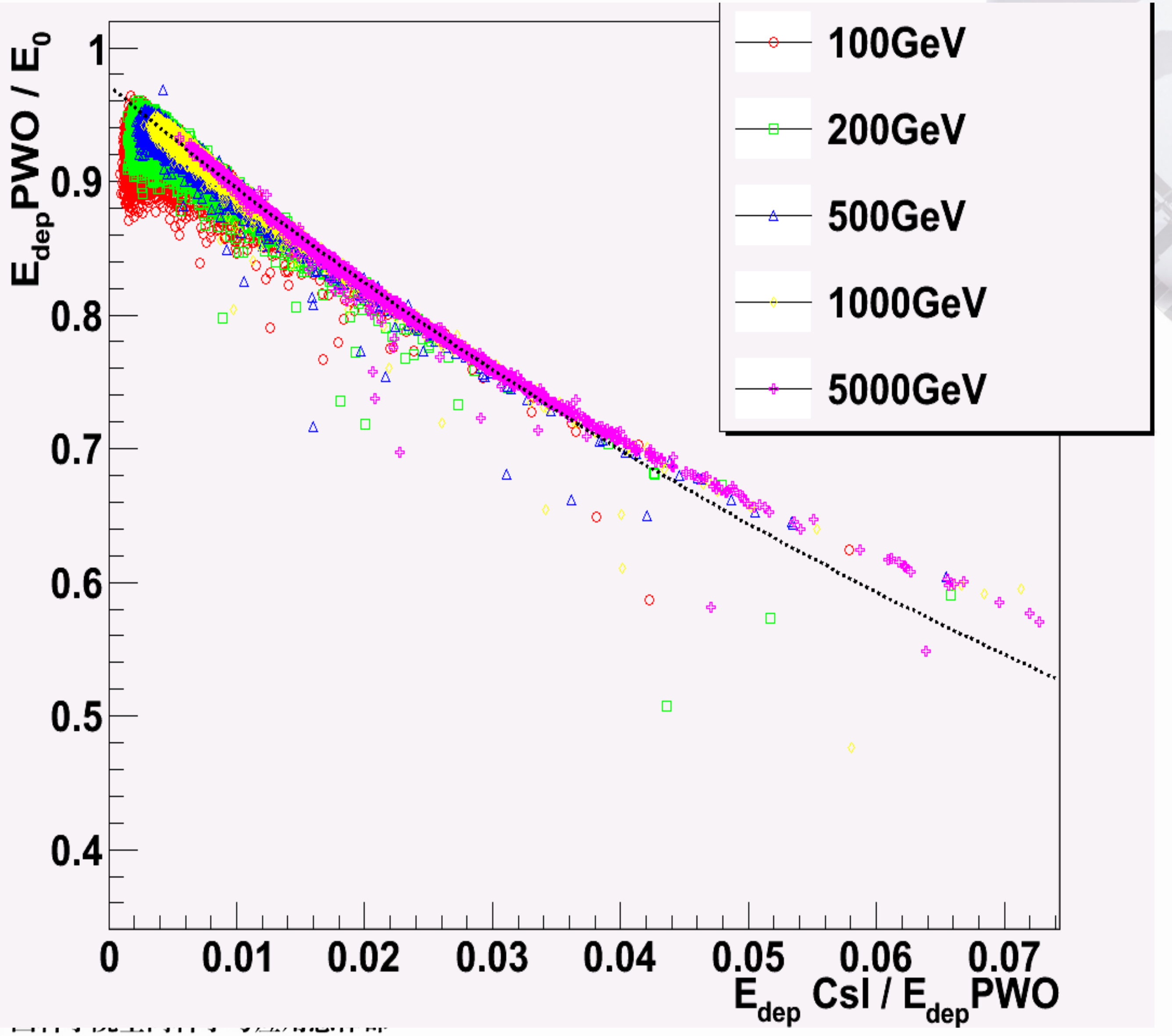
Back-splash rejection



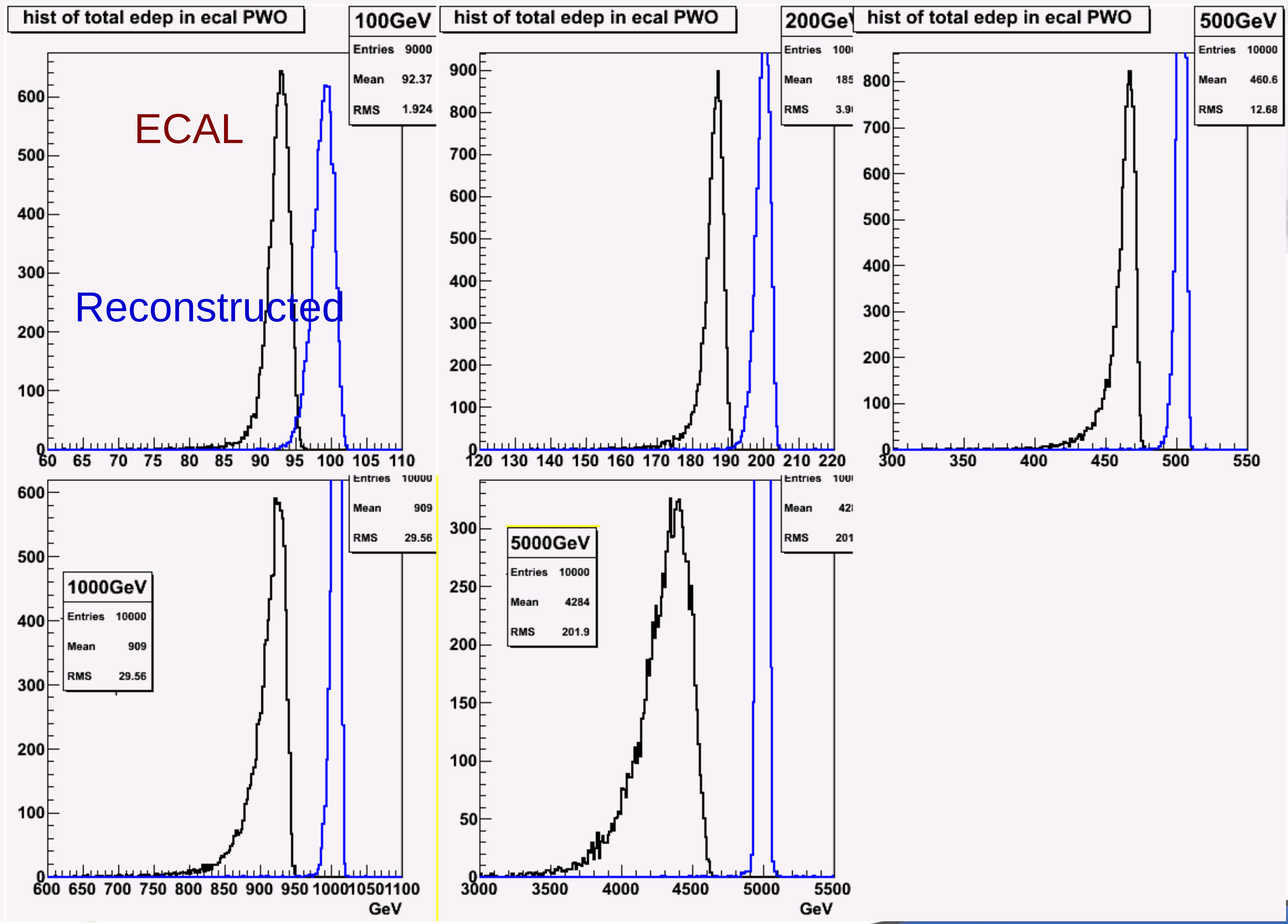


Threshold > 100 keV: 20% back-splash rejected and 5% signal loss

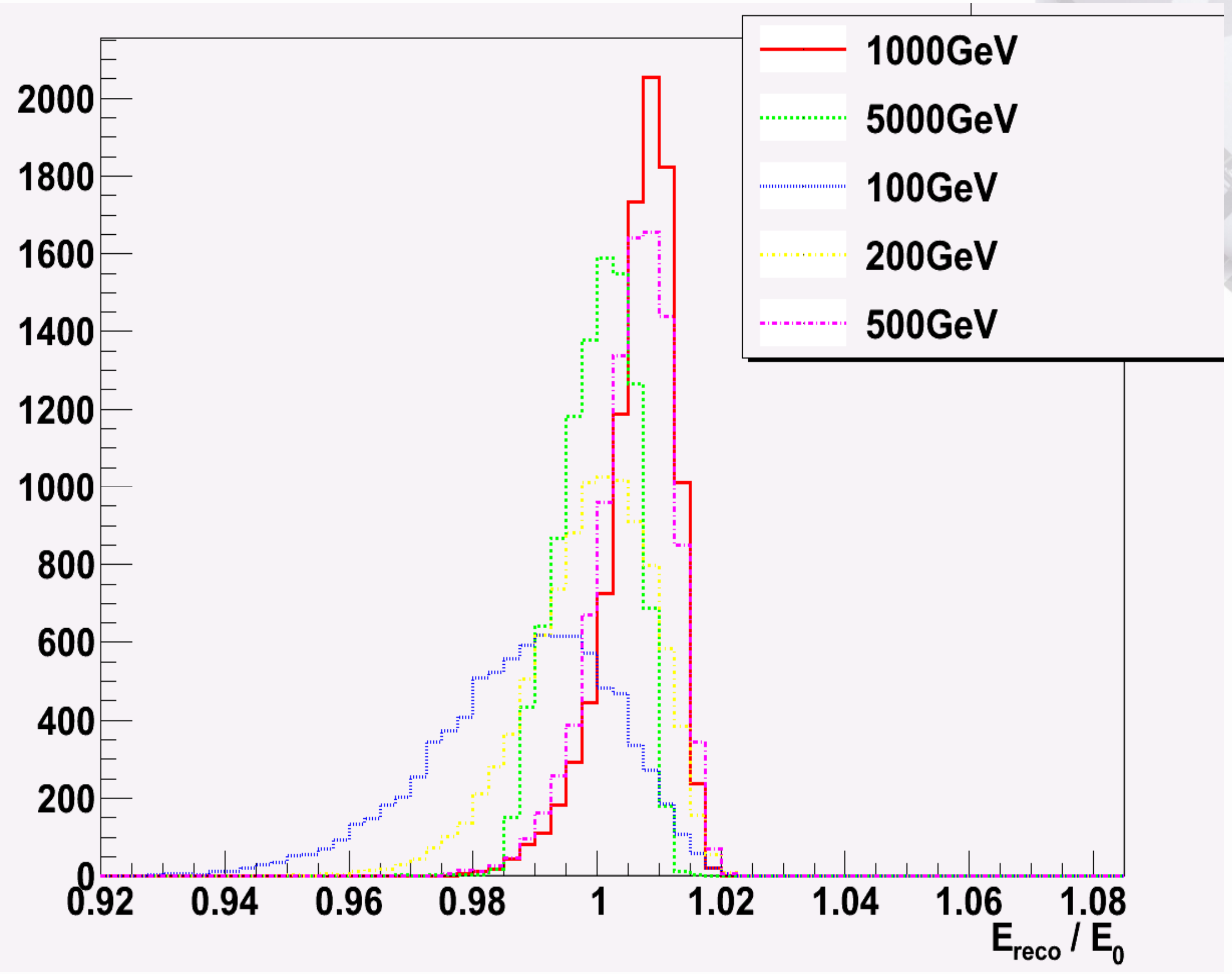
e/ γ energy reconstruction



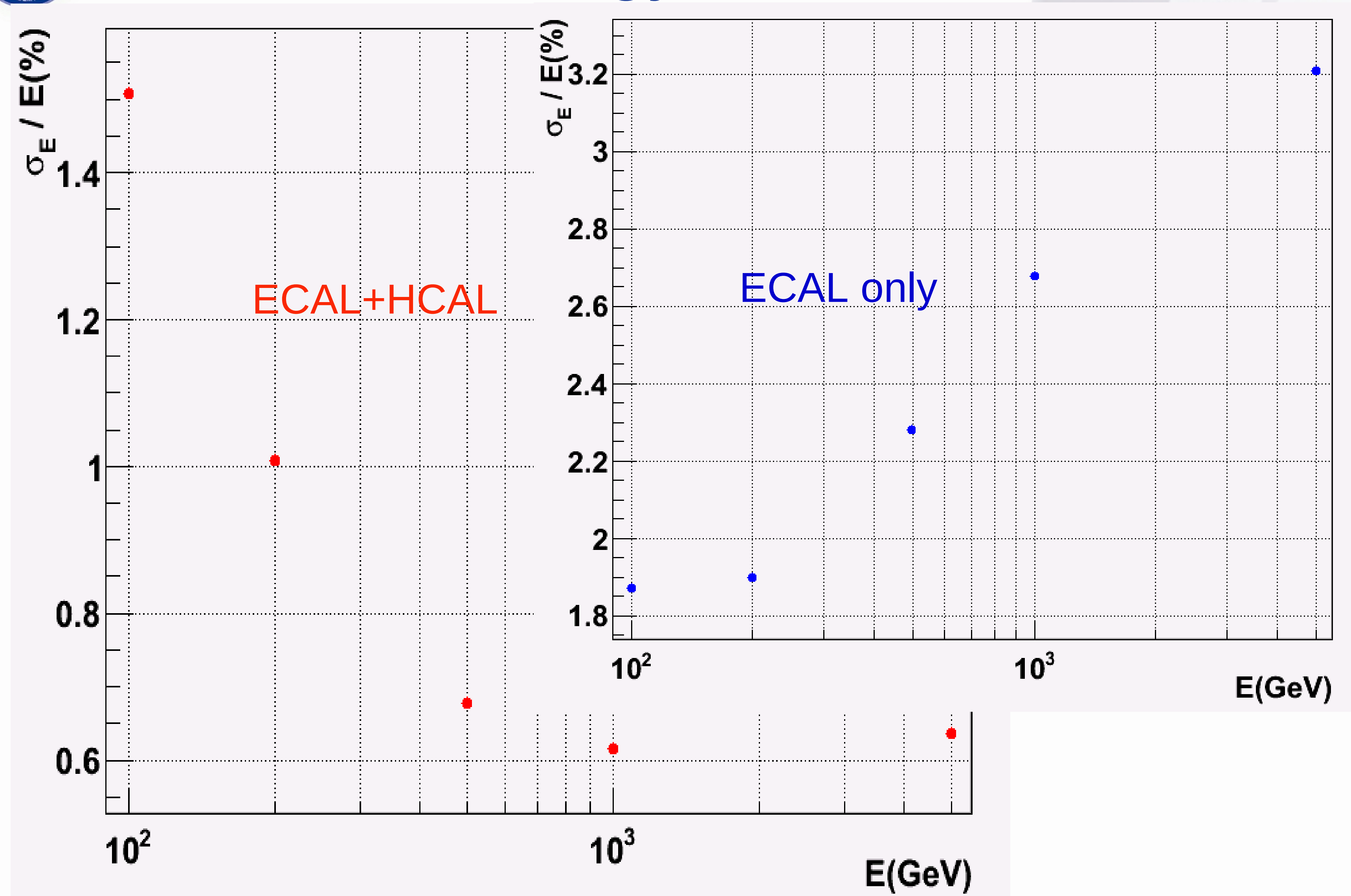
e/ γ energy reconstruction



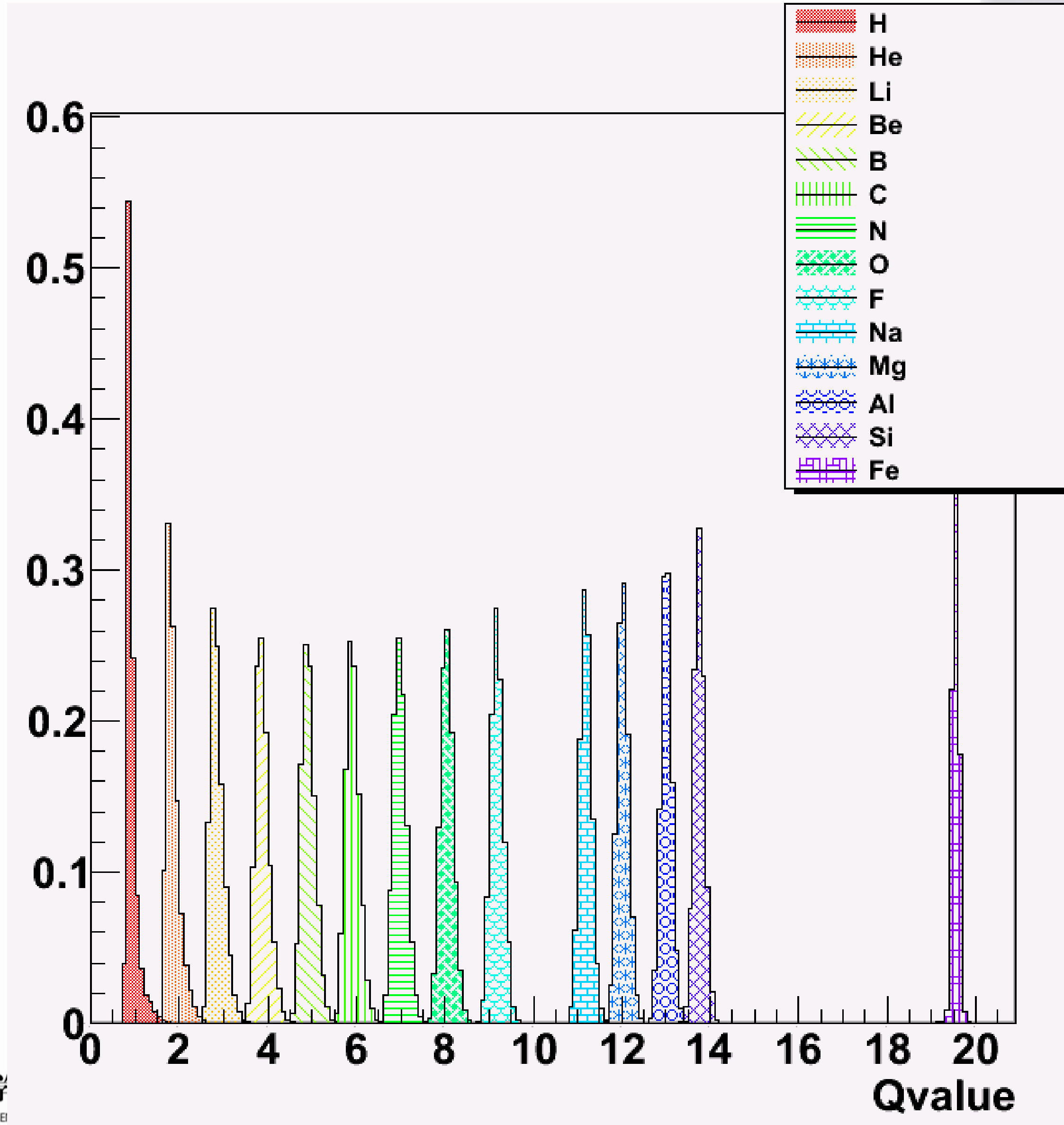
e/ γ energy reconstruction



e/ γ energy resolution



Charge reconstruction: with SiPIN



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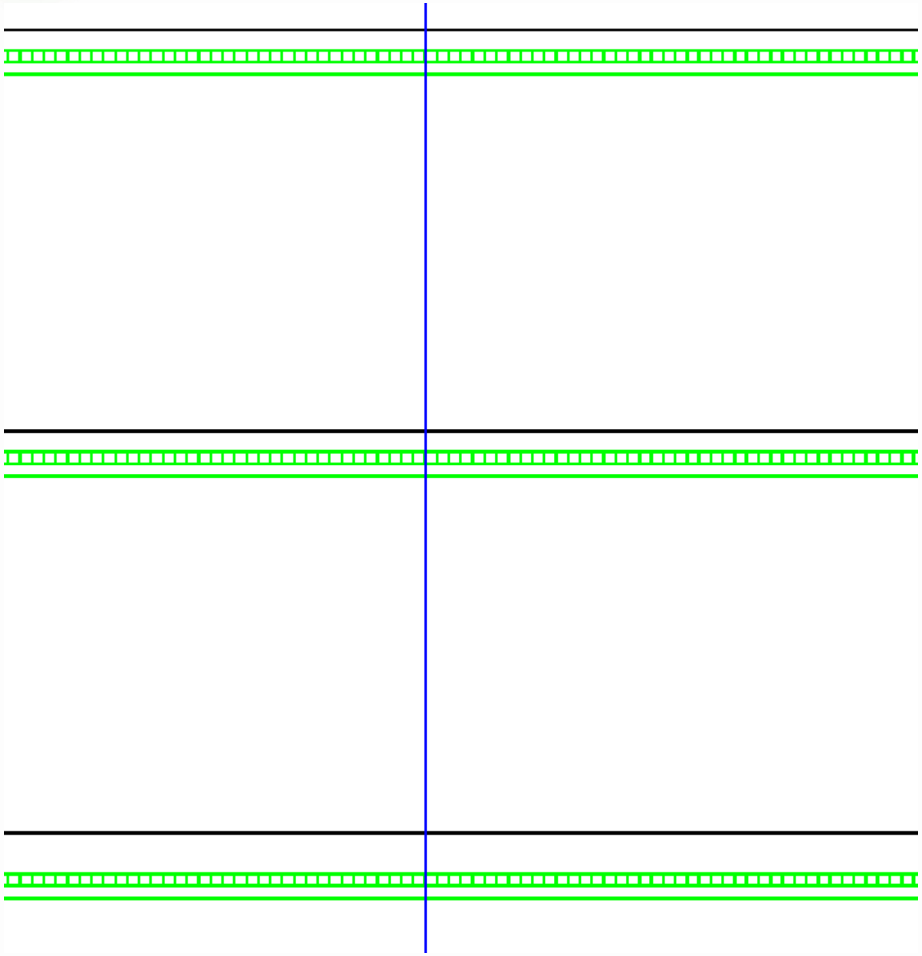
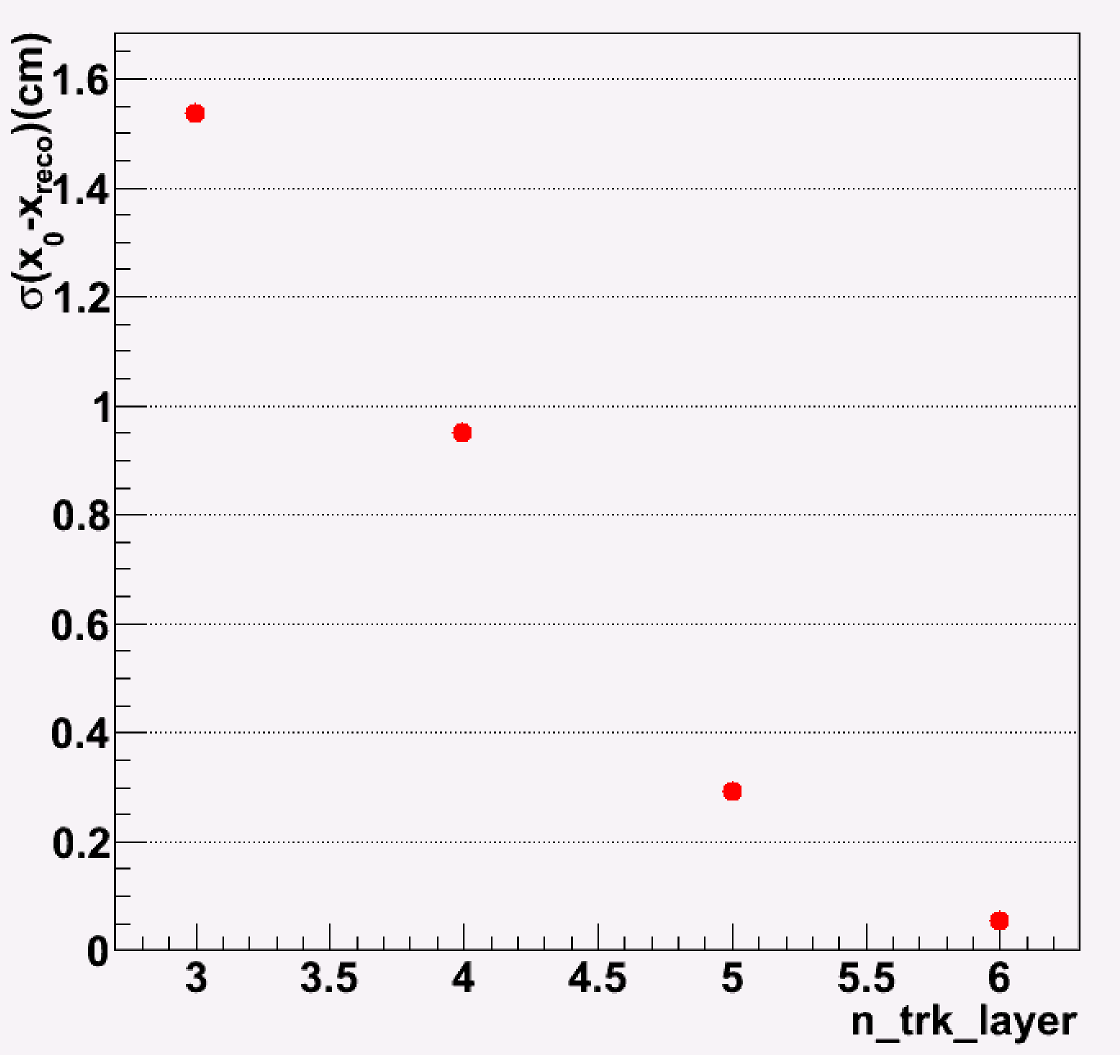
Tracking optimization



– Top tracker
- Scintillation Fibers (1 mm×1 mm) XY
- W：6×0.175 cm
  1×0.35 cm
- Separation: 3 cm
- Readout channels: 700×2×7 = 9800

Single track position vs no. of layers



Additional constraints：

$\Delta \chi^2 < 1e\text{-}5$

Linear fit iterations < 10,000

Expect photon converted in the first few layers of the tracker, and the more hit layers the better resolution

0.5 mm position resolution → ~0.4 deg

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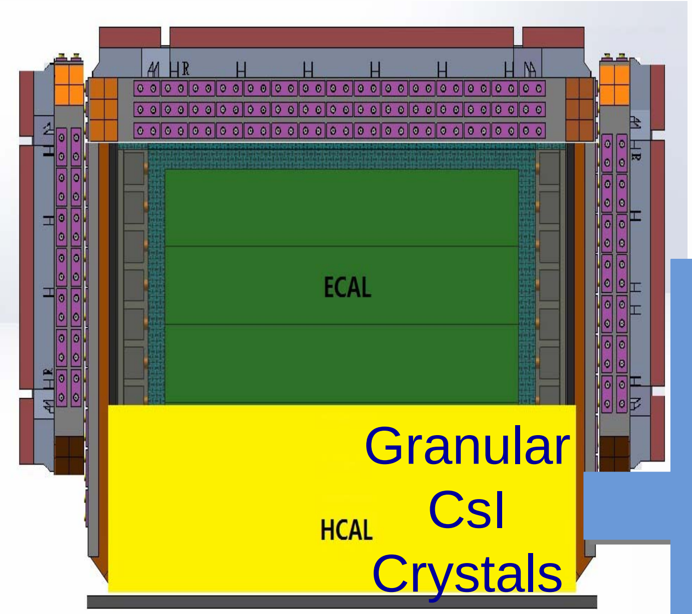
CsI light transmission and collection



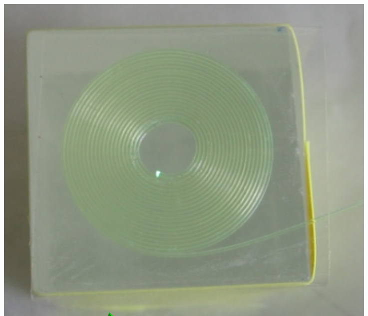
Direct Coupling

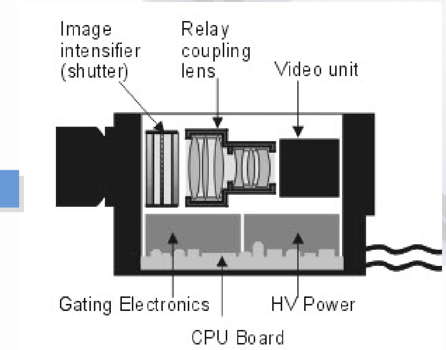
PD, APD, SiPM: Complicated system, high power consumption

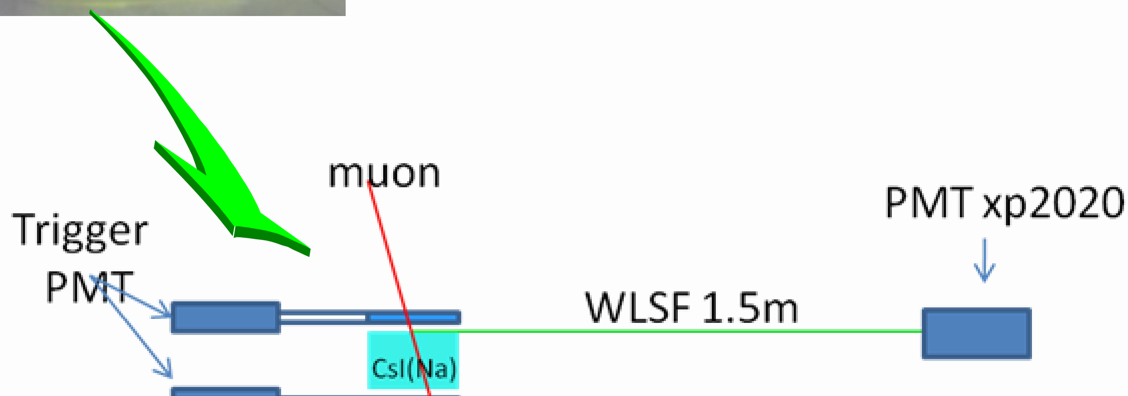
MAPMT, SiPM: high power consumption
CCD: No single photon detection
EMCCD, EBCCD: no ns gate control
ICCD: no above problems, but premature

Wavelength
Shifter
Fiber

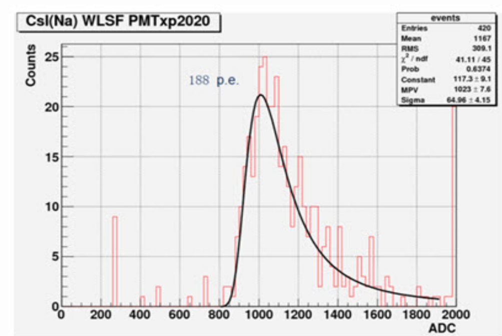
An example



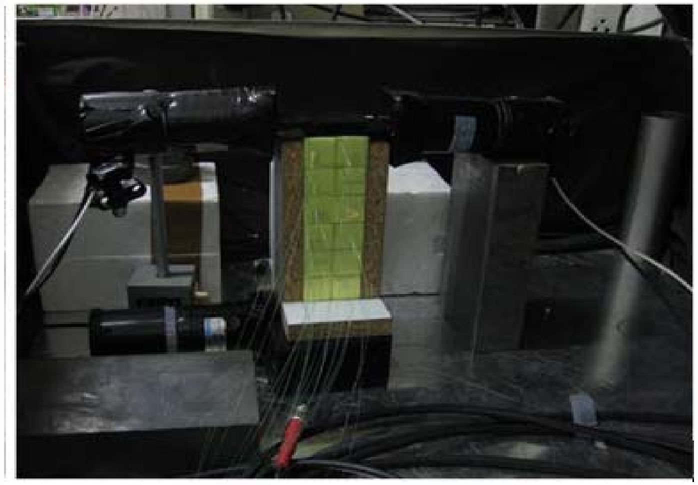




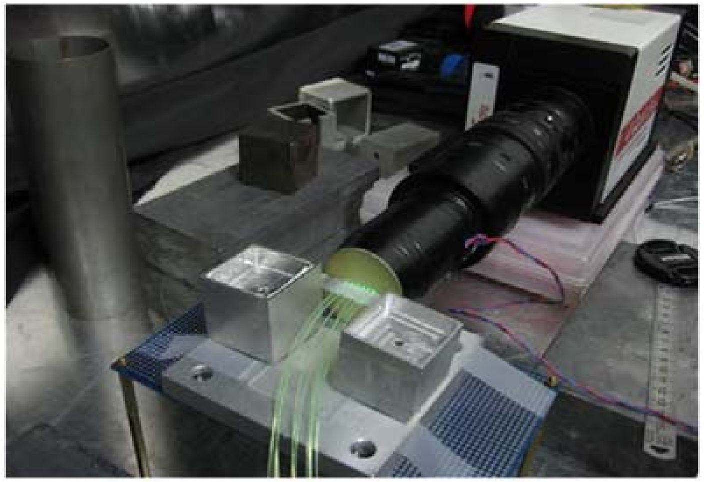
2.5 cm CsI(Na): ~ 188 p.e.
for a passing muon



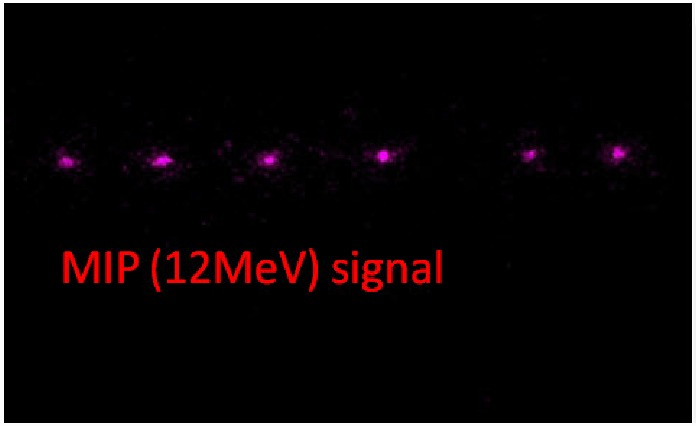
Test set-up and results

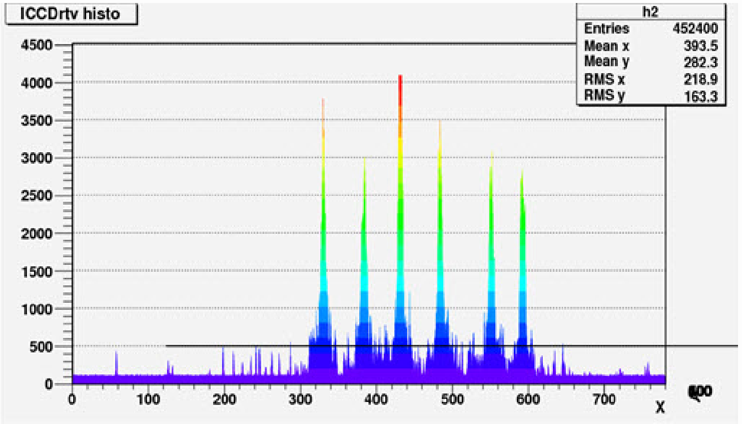


2×2×6 granular CsI with fibers sandwiched between two detectors



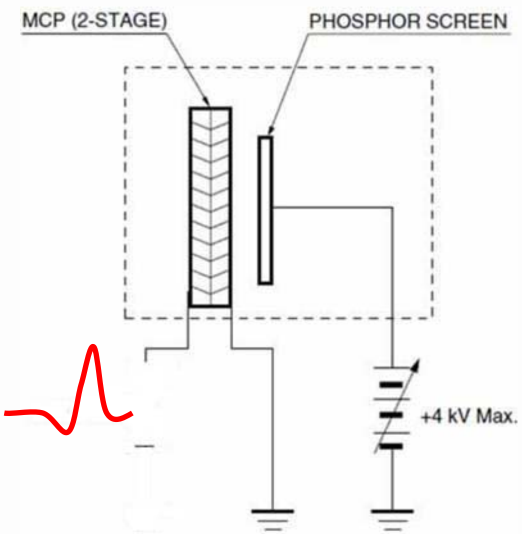
Taper +Imaging Intensifier + ICCD





ICCD image of typical muon events

Concept of ICCD readout system



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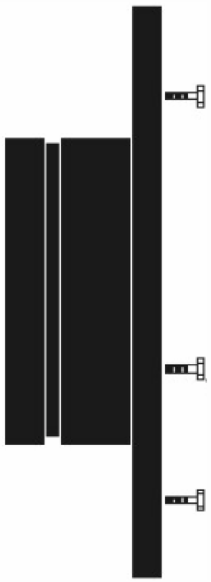

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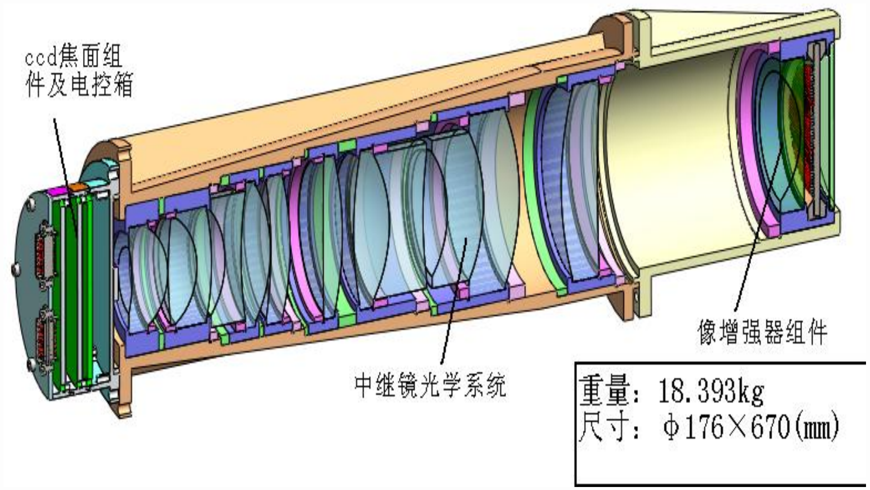
Cathode Triggered Intensifier

Optical Coupler

High frame rate and large format CCD

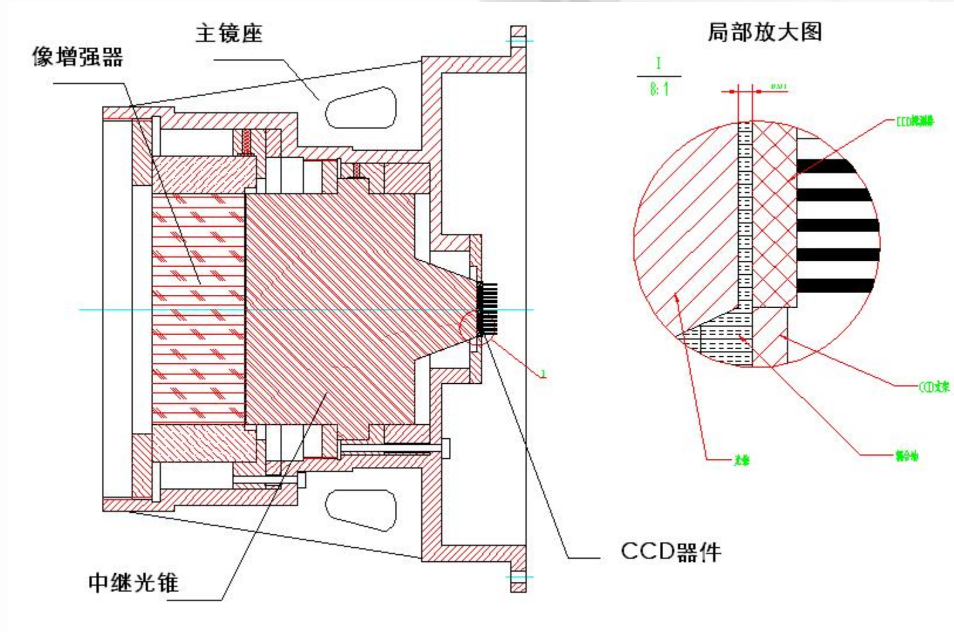
Two types of coupling

Relay mirrors



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

Taper



The HERD Team

- Current member institutions (more wanted!)
  - 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
- Interested institutions (more wanted!)
  - University of Geneva, Switzerland
  - Università di Pisa, Italy
  - IAPS/INAF, Italy
  - University of Florence and INFN Firenze, Italy
  - University of Perugia, Italy
  - KTH, Sweden

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.
  - A top ranked mission concept at this stage.
  - However simulations on the concept just started, much more needs to be done to have a real design.
- Technical review for mission selection may happen anytime.
- Launch in 2018-2020.