HERD Science Operations System

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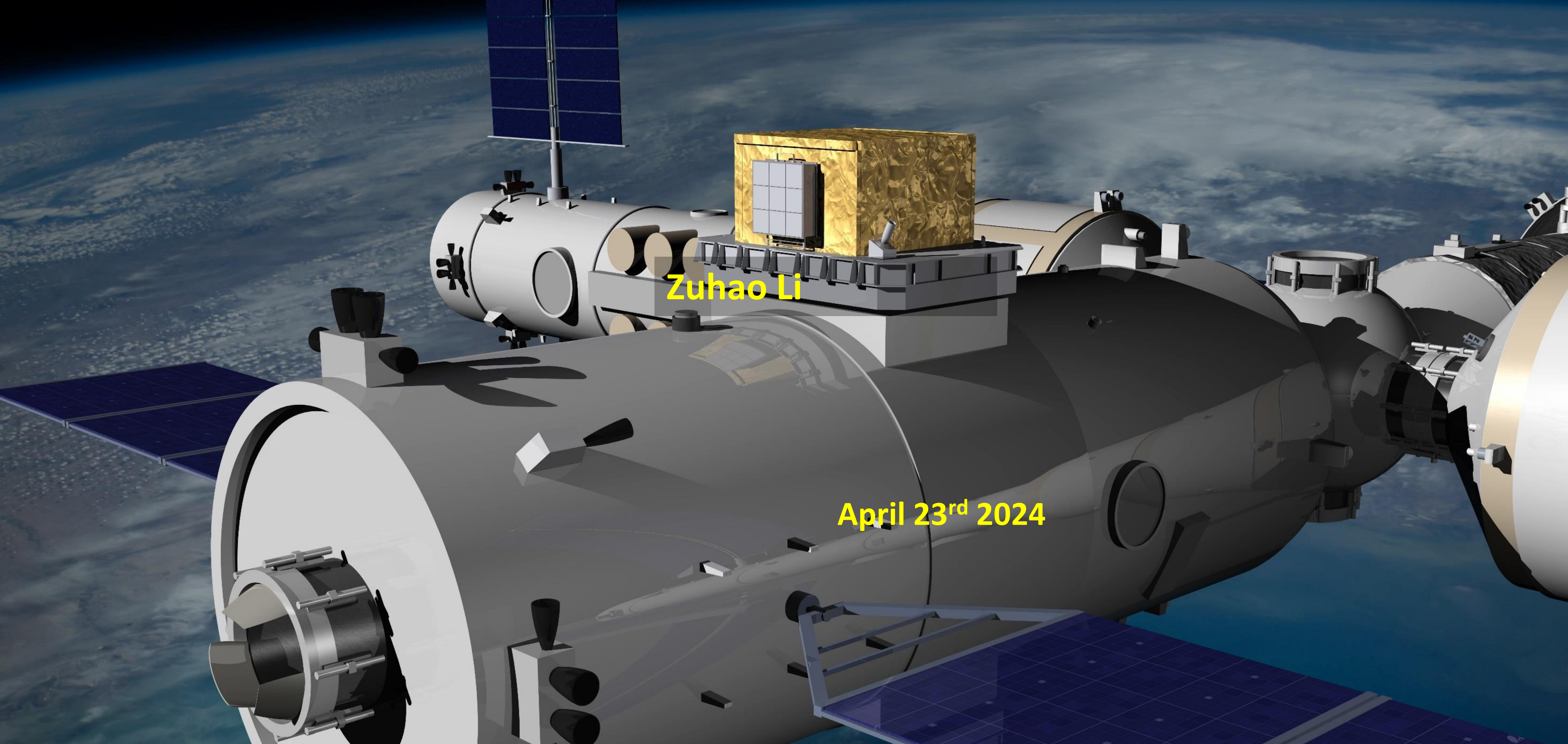
April 23rd 2024

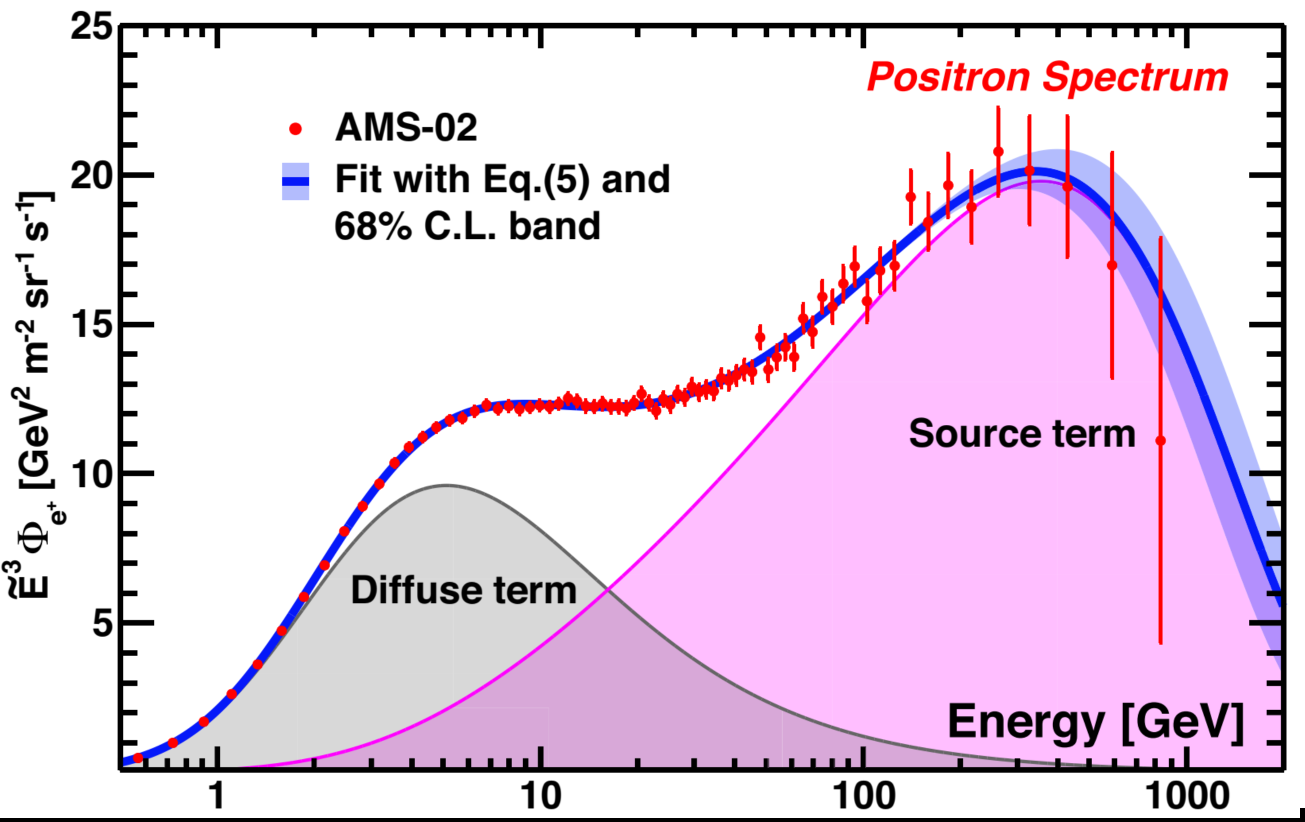


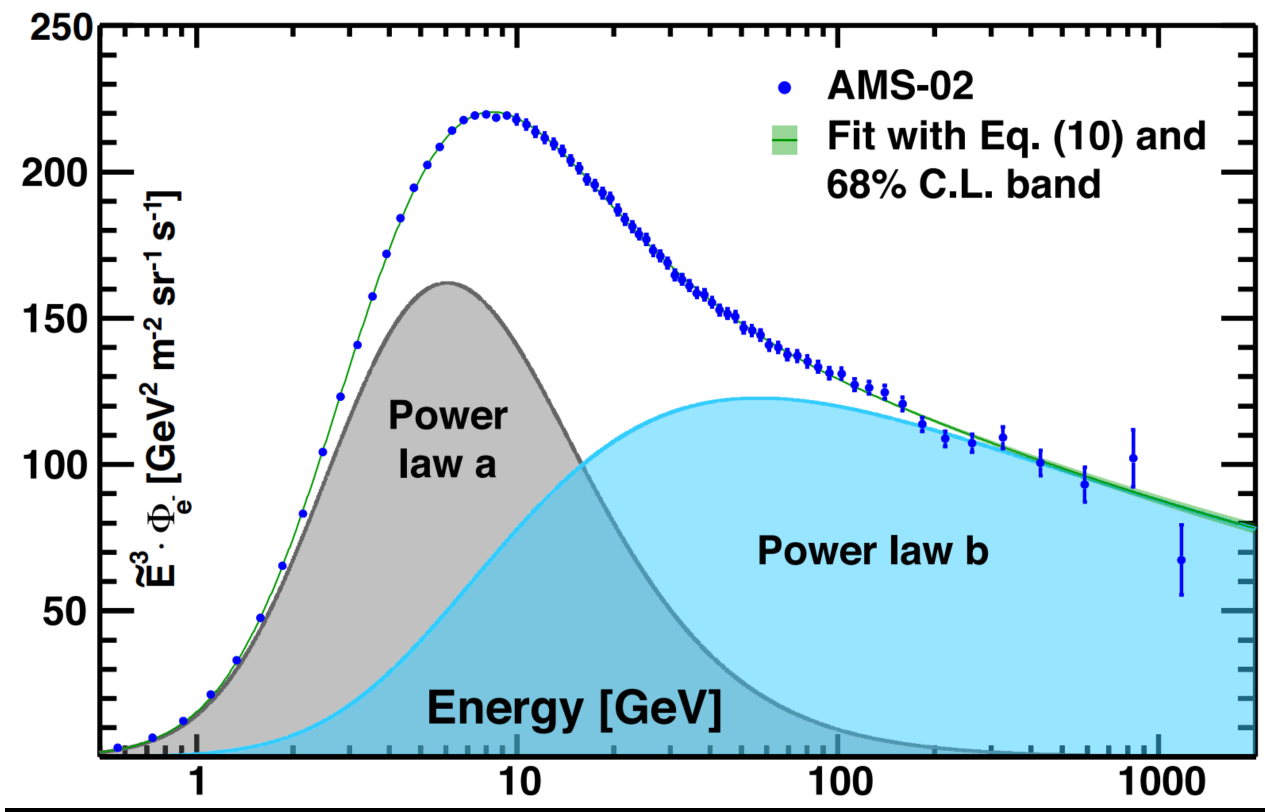
Science Goal of High Energy Radiation Detector HERD

HERD is a space particle astrophysics experiments, will run in the Chinese Space Station for more than ten years. HERD Adopting an innovative design with three-dimensional position resolution and five-sided sensitivity, core scientific capabilities will maintain significant lead ship for a long time.

Science Goal	Type	Contribution to Physics	Meathod
Precision measurement of cosmic ray electron flux and dark matter search	Core	Key contribution to solve one of the most important puzzle for astronomy and physics: dark matter	Precision flus measurement of high energy electron and gamma.
Origin, acceleration and propagation of cosmic rays	Core	Key contribution to the origin of cosmic rays	Measurement of cosmic ray nuclei up to Z=28 to the highest energy
High energy gramma rays all-sky survey and monitoring		Search and identify gamma ray source，understand the physics of extreme conditions in the universe; search for new physical signals	Wide energy range, High precision measurement of Gamma rays

AMS-02 results: Flux of electrons and positrons





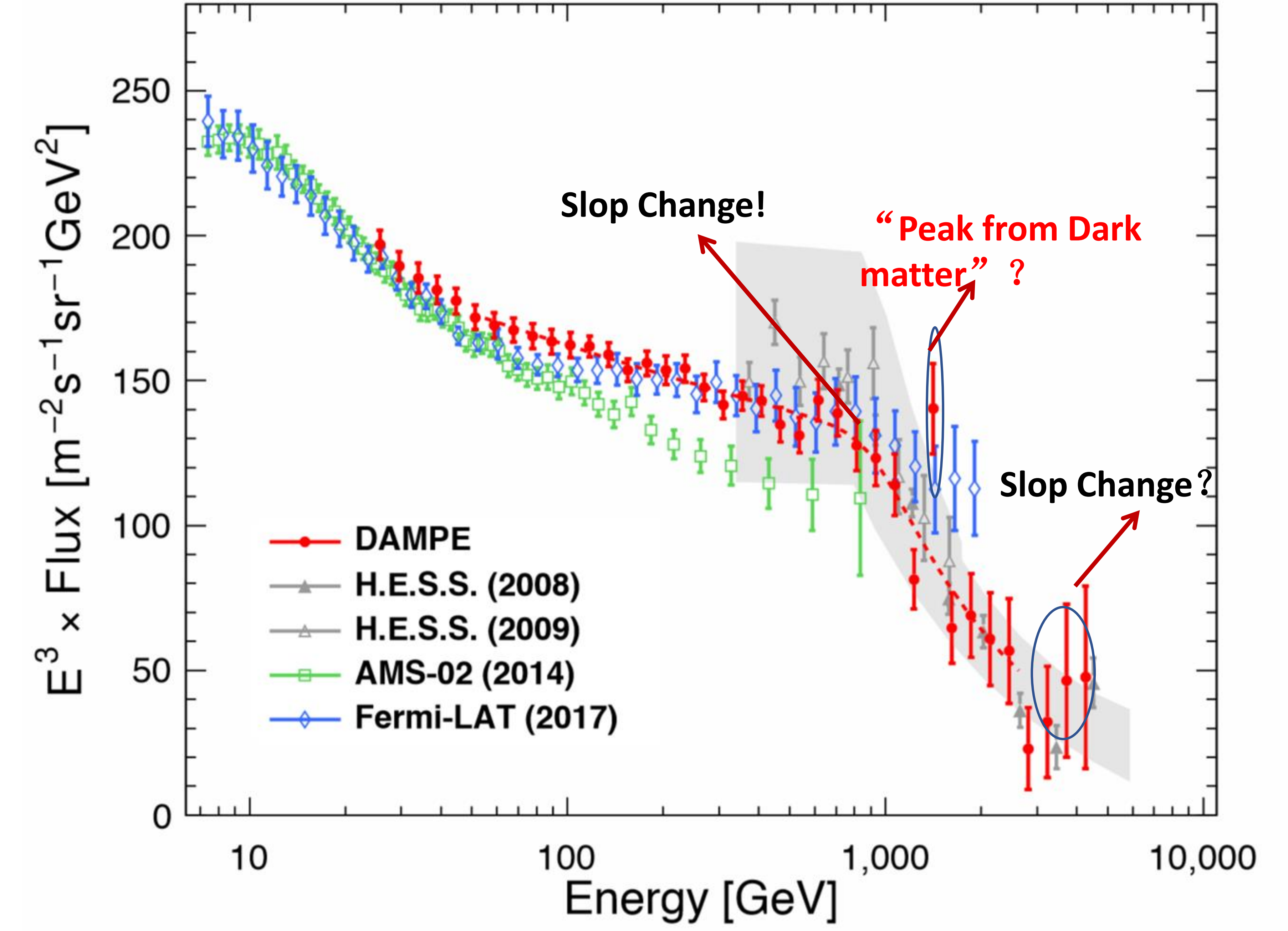
AMS-02 positron flux

Physics report, 2021

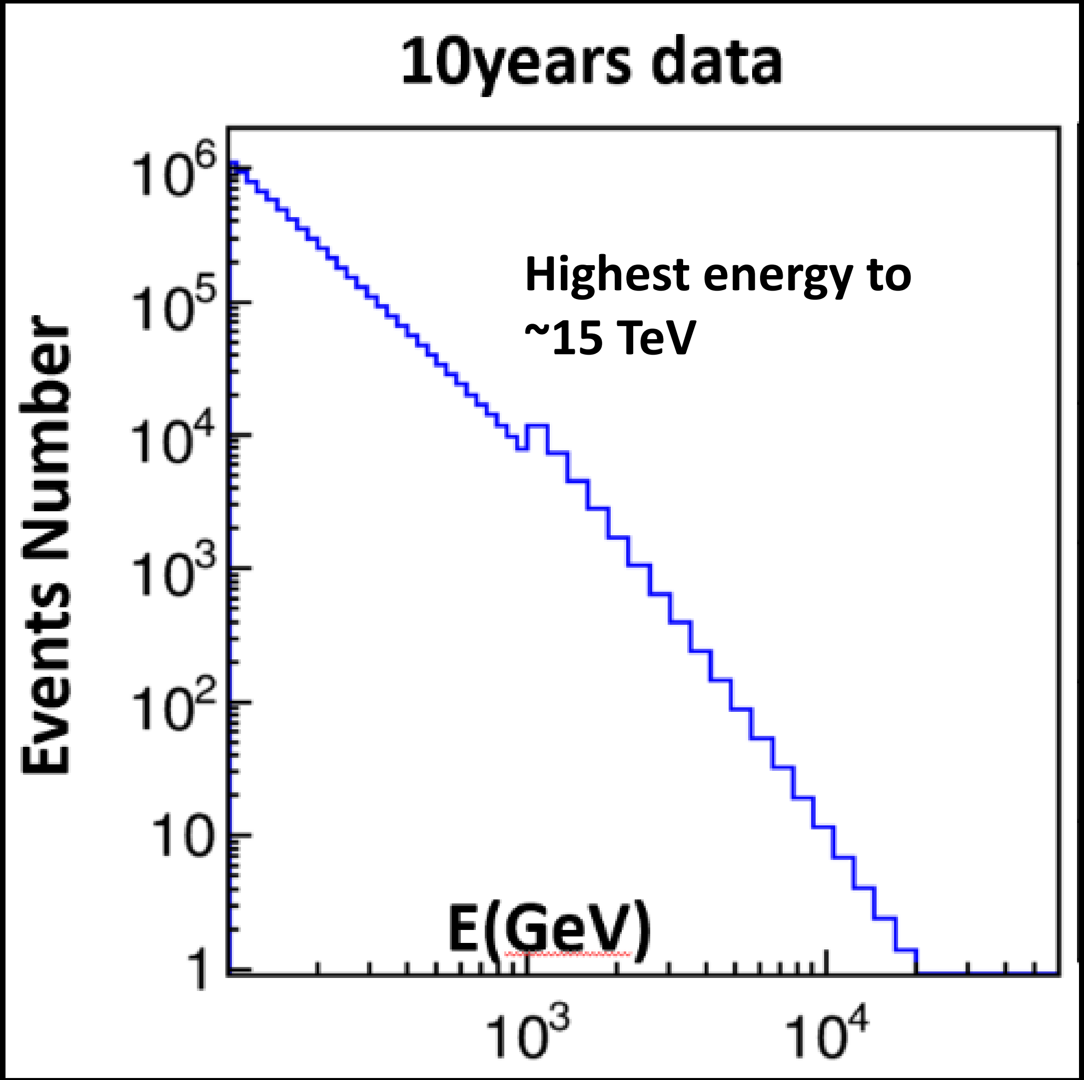
AMS-02 electron flux

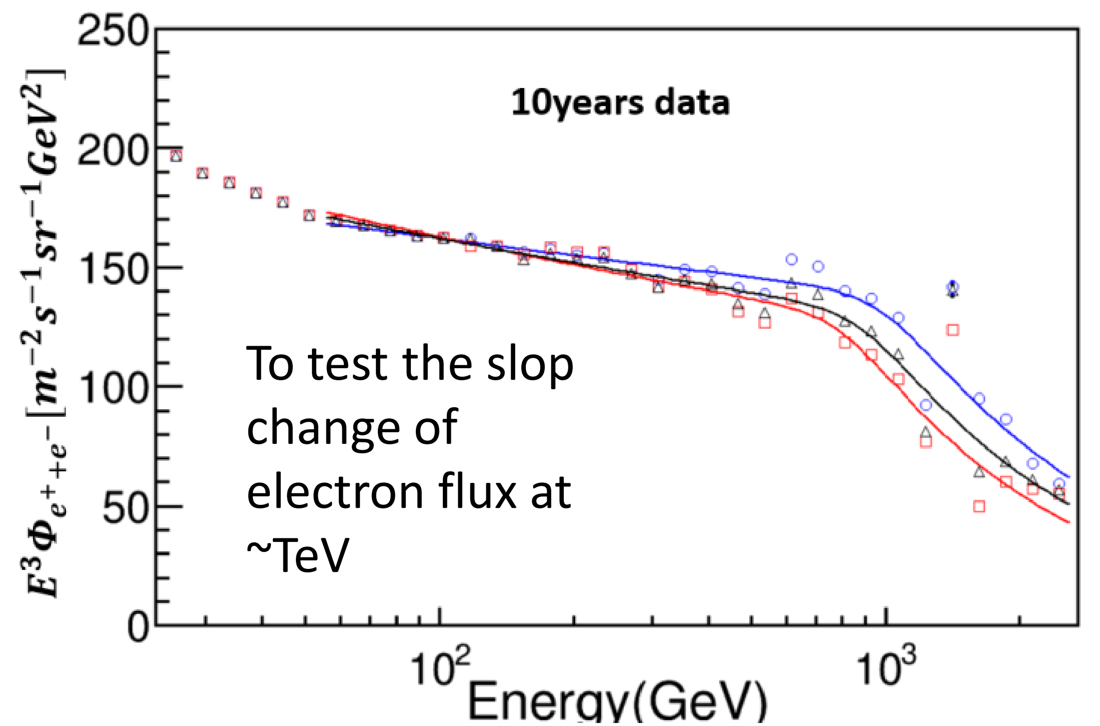
Largely improved precision and wide energy range of the measurements, but can not identify the existence of dark matter.

"DAMPE" results： Most precision high energy flux of cosmic ray electrons

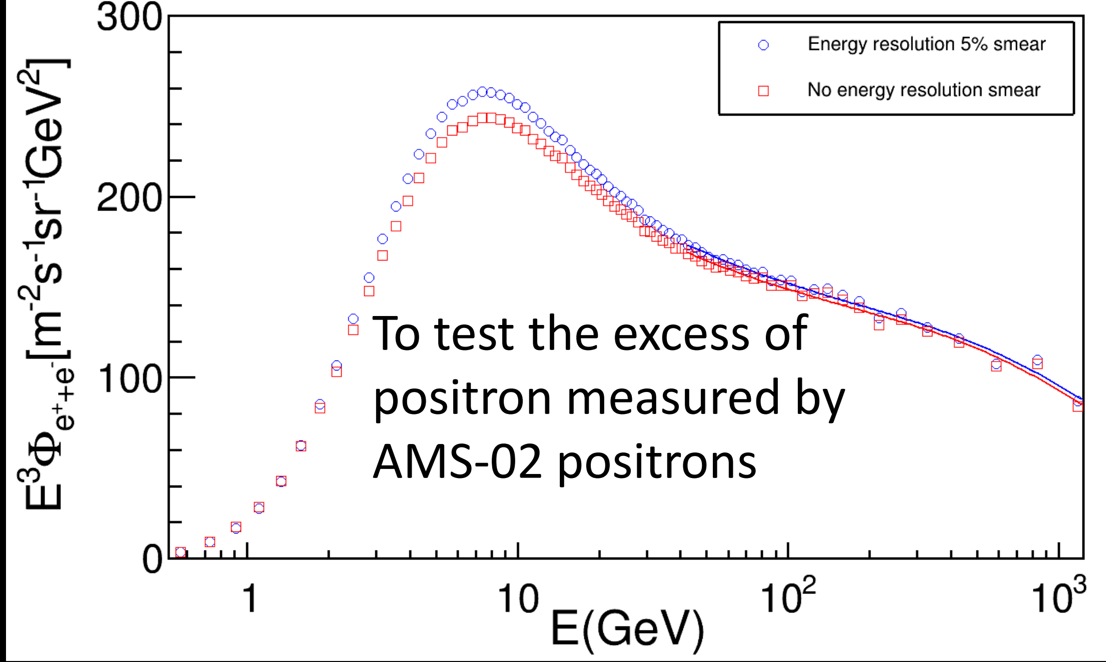


HERD will measure cosmic ray electrons to highest energy

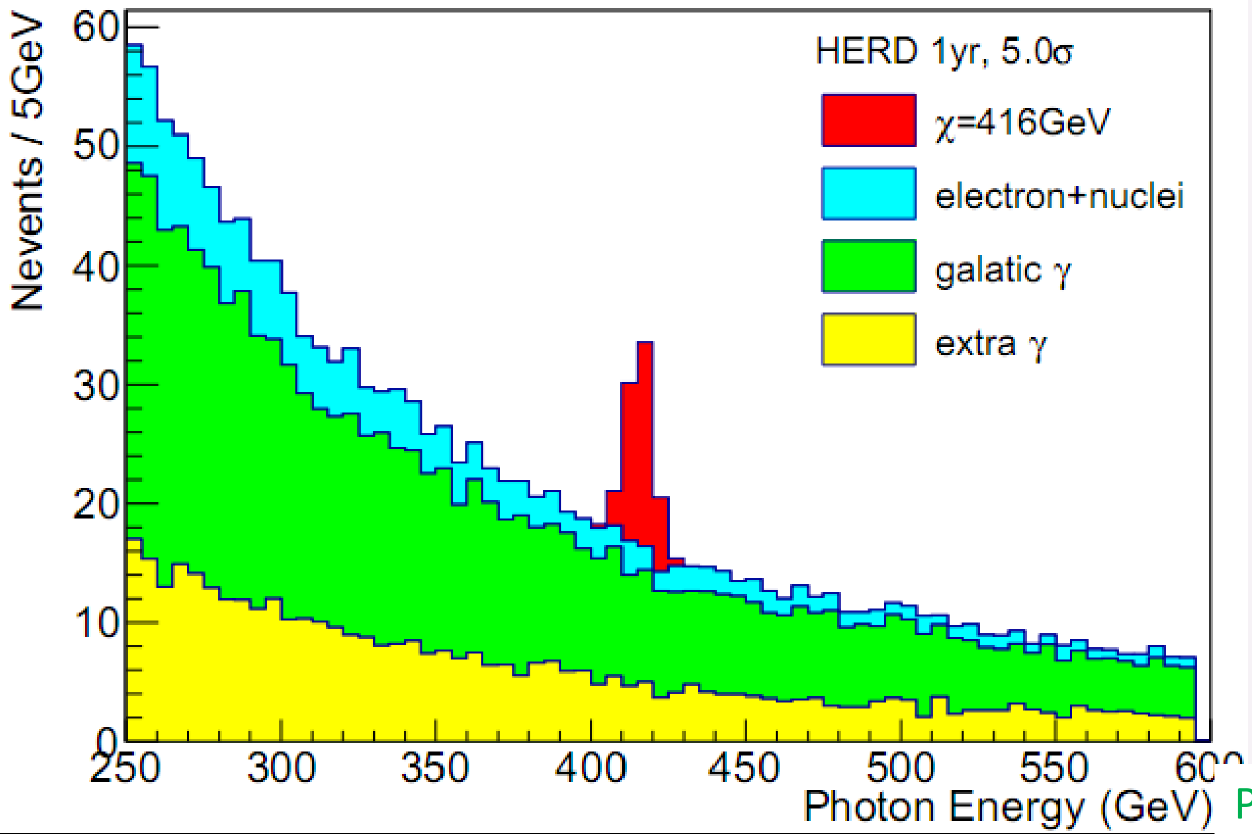


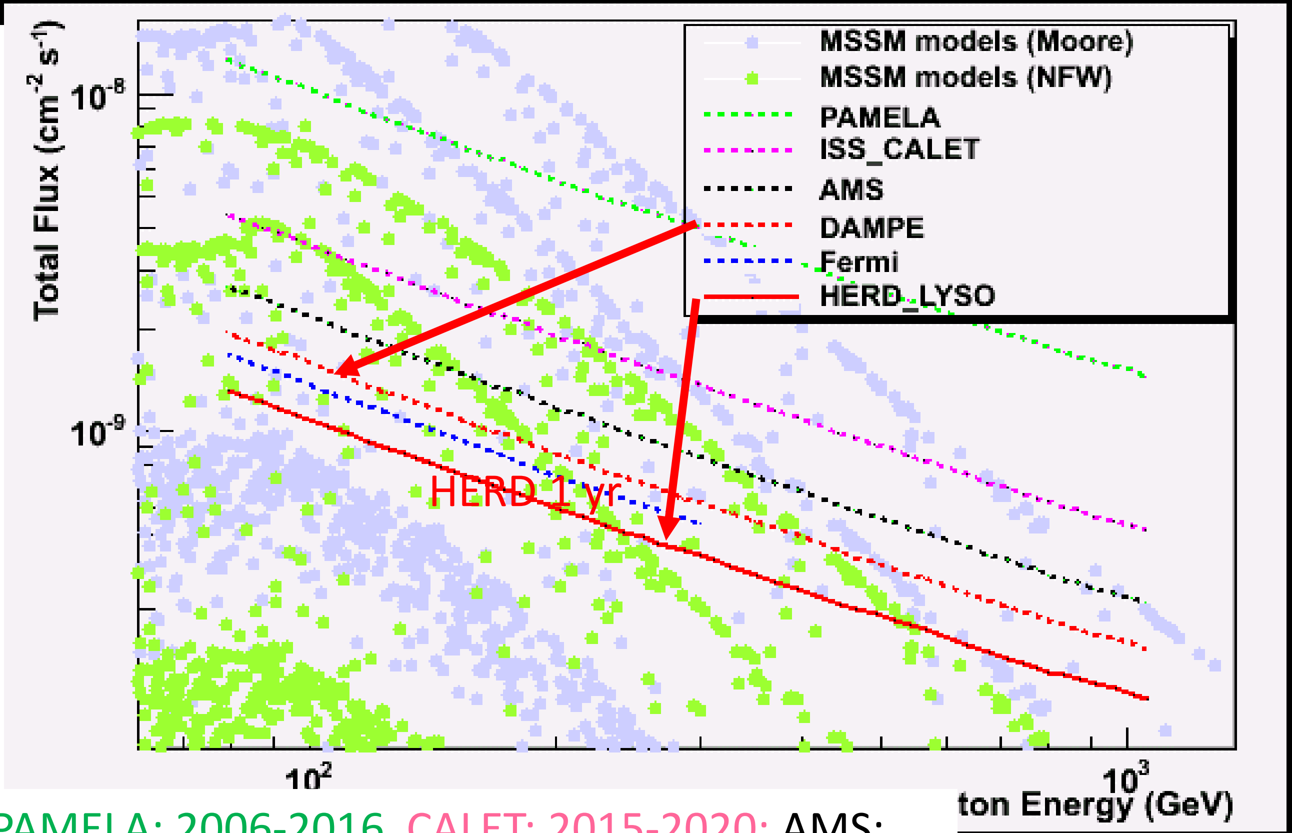


HERD Estimated Electron+Positron Flux 10year



HERD sensitivity to dark matter search through gamma ray “line spectrum” measurement

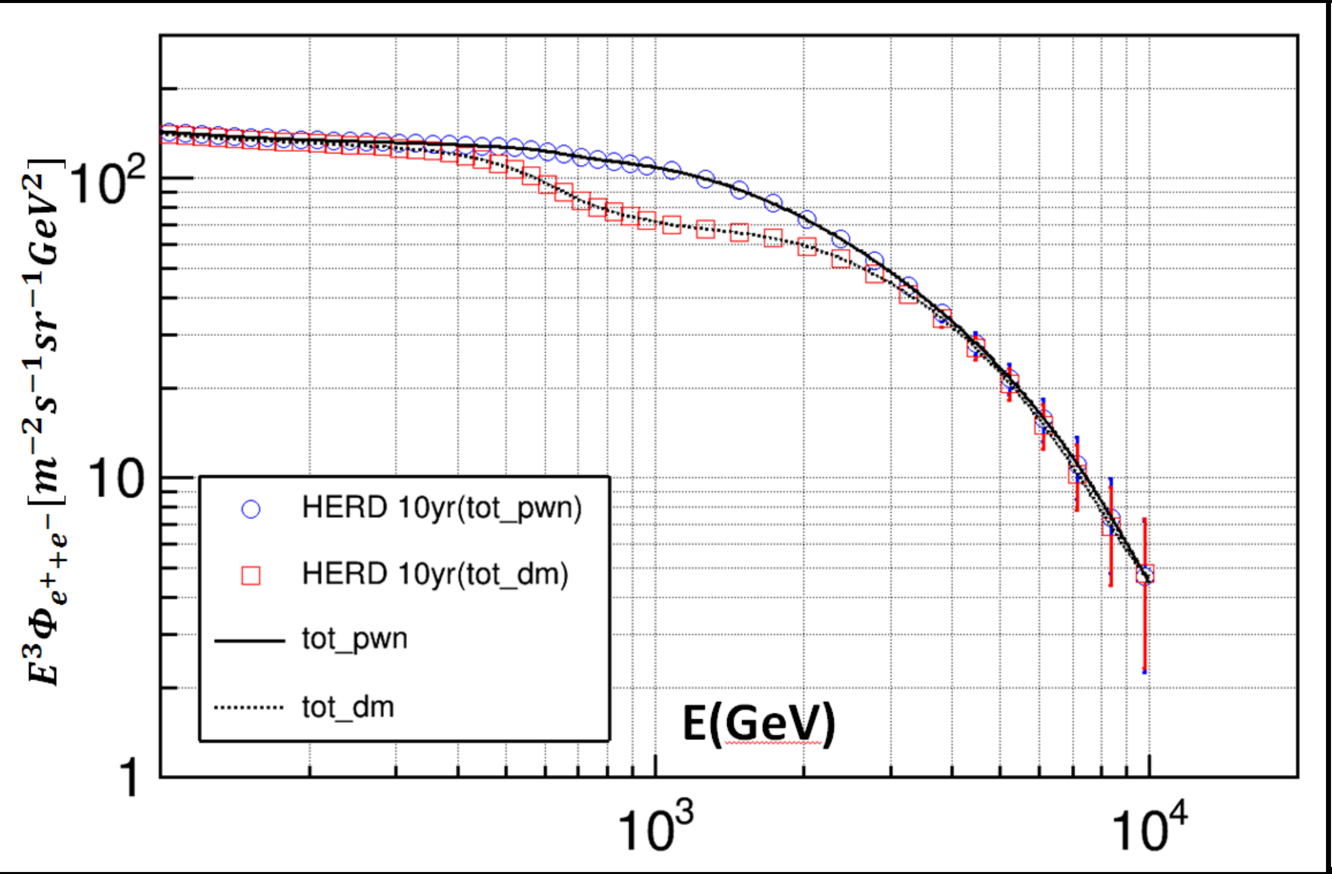


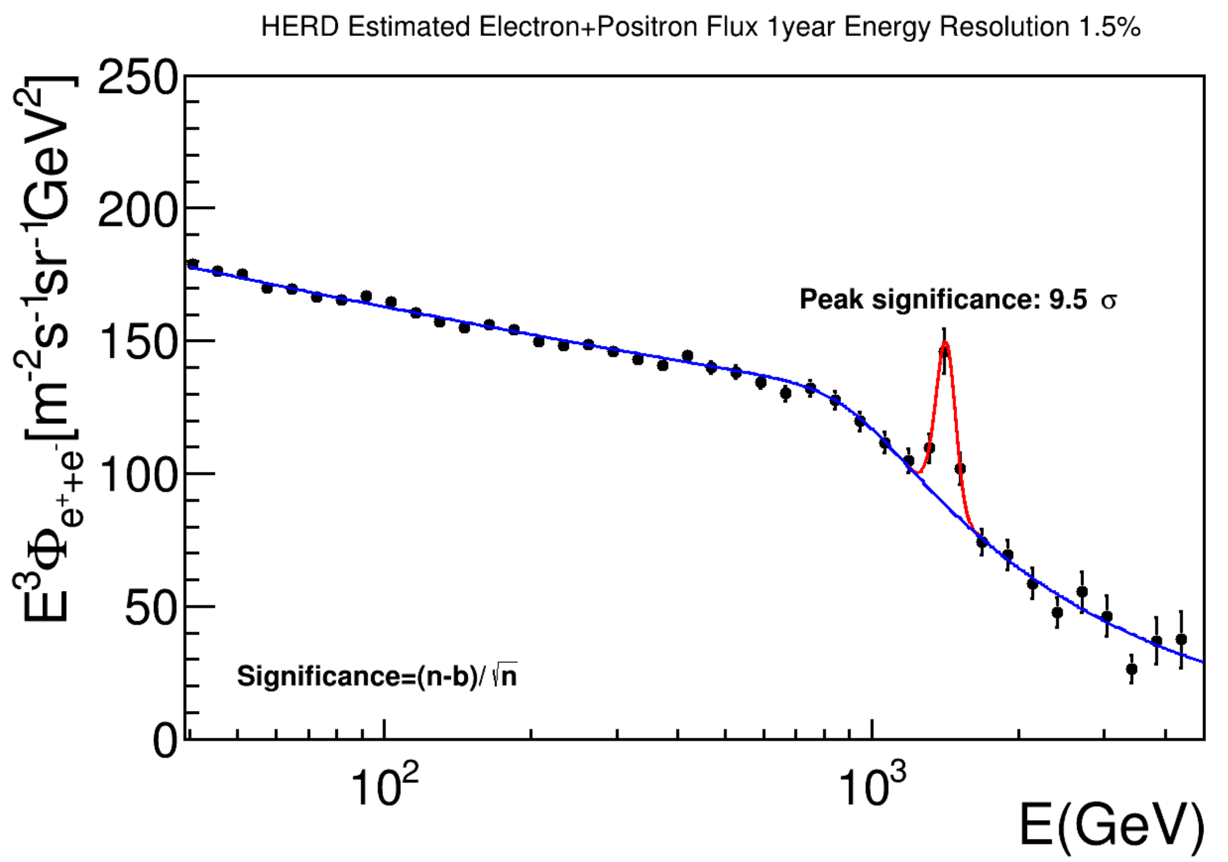


PAMELA: 2006-2016 CALET: 2015-2020; AMS: 2011-2024; DAMPE: 2015-2020; Fermi: 2008-2018; HERD: 2027-

HERD sensitivity to dark matter “line spectrum” with 1 years data is much better than 5 years data of all other experiments

HERD dark matter search from annihilation

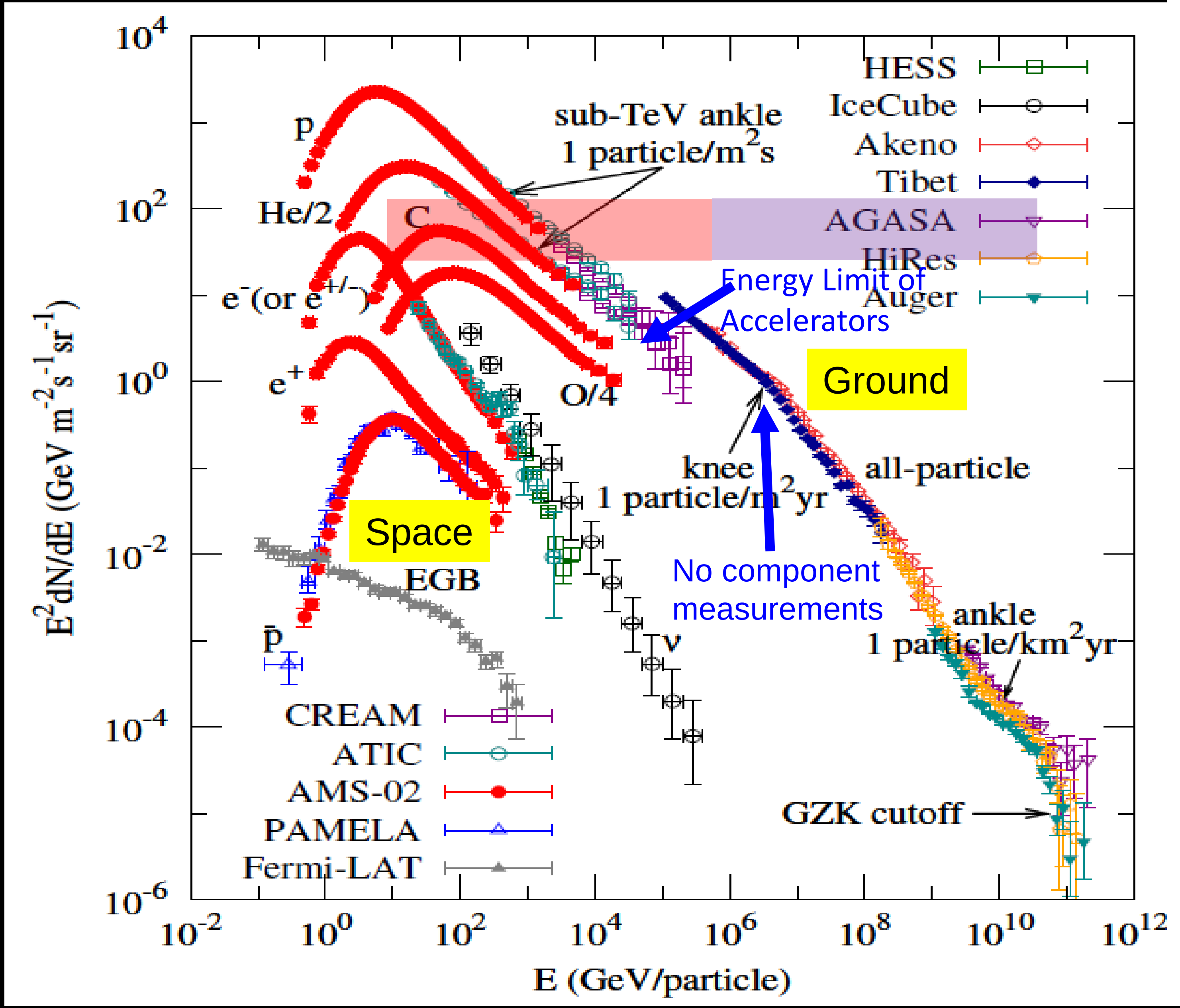


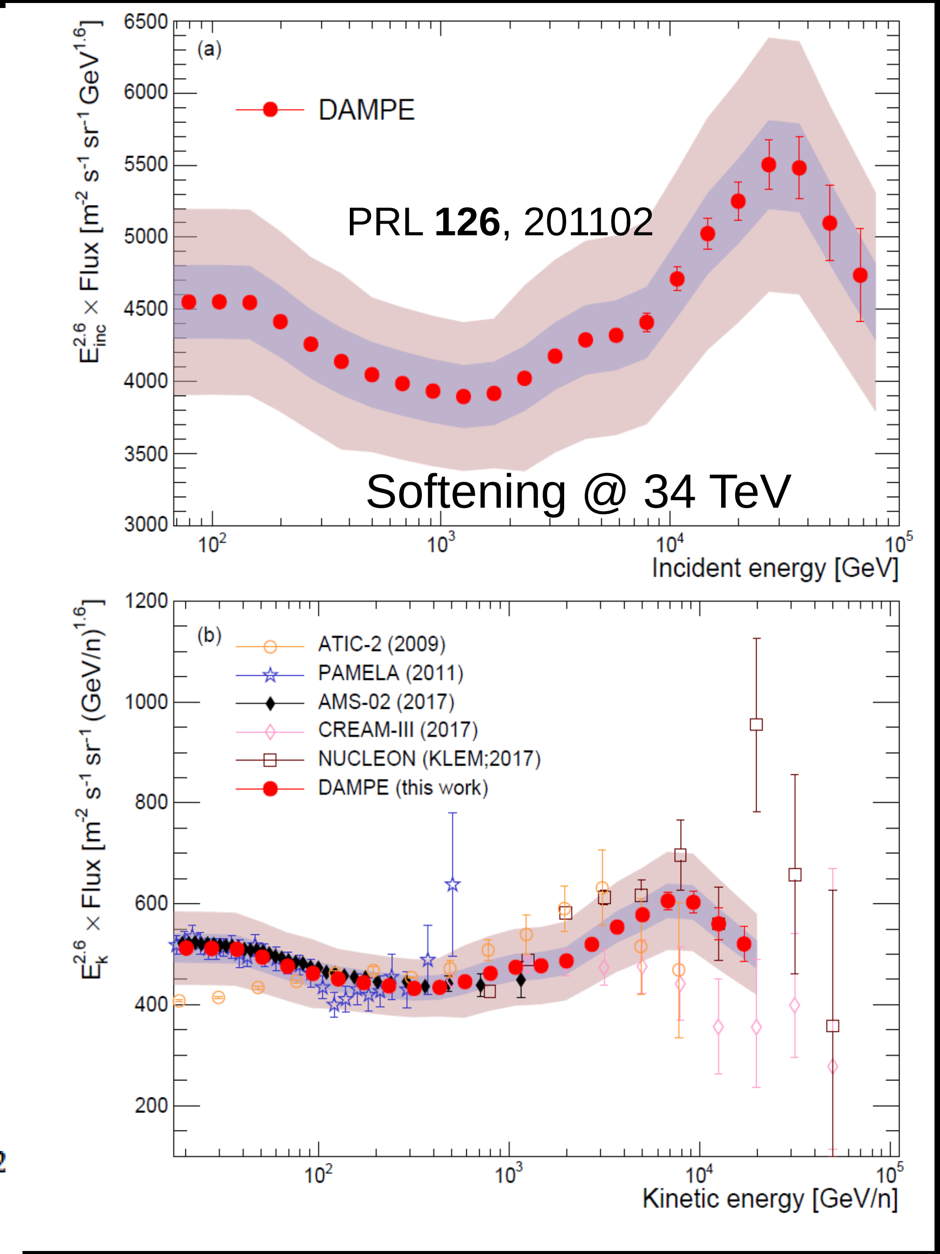


Identify dark matter model and pulsar model

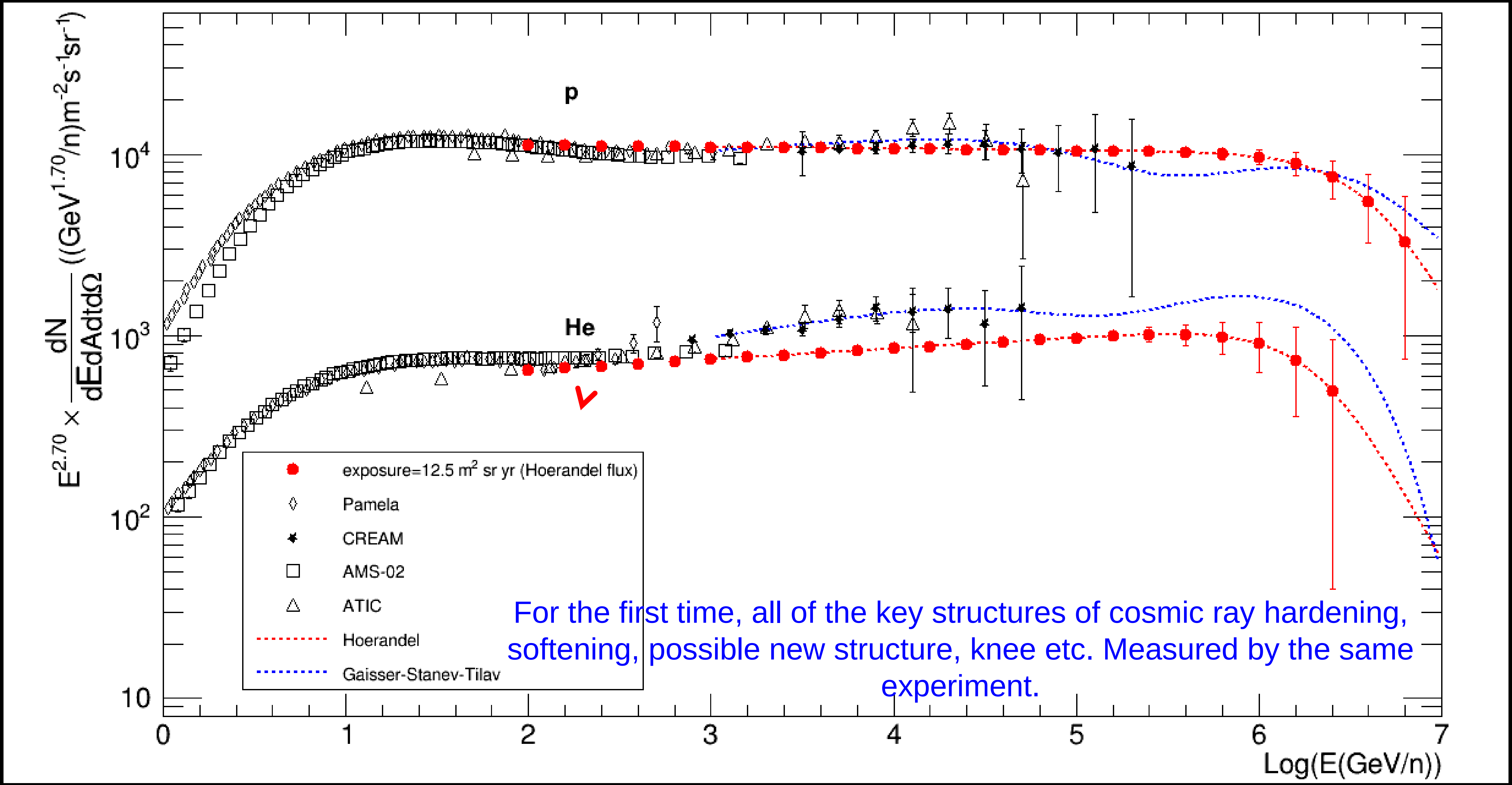
Test of DAMPE "peak"

Origin of Cosmic rays





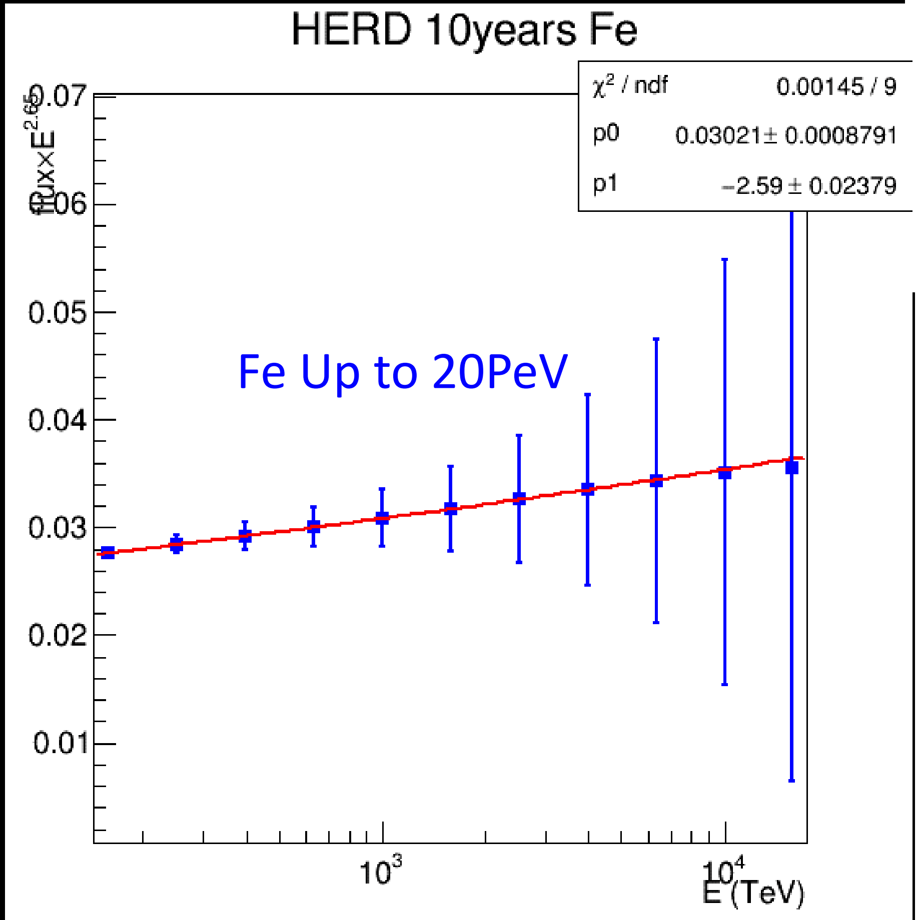
HERD Proton and Helium flux measurement with 5 yeas data (Hoerandal fluxes)

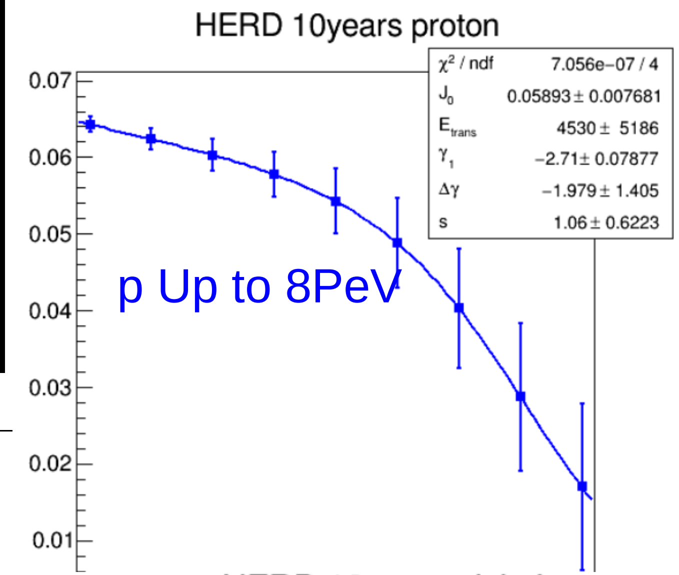


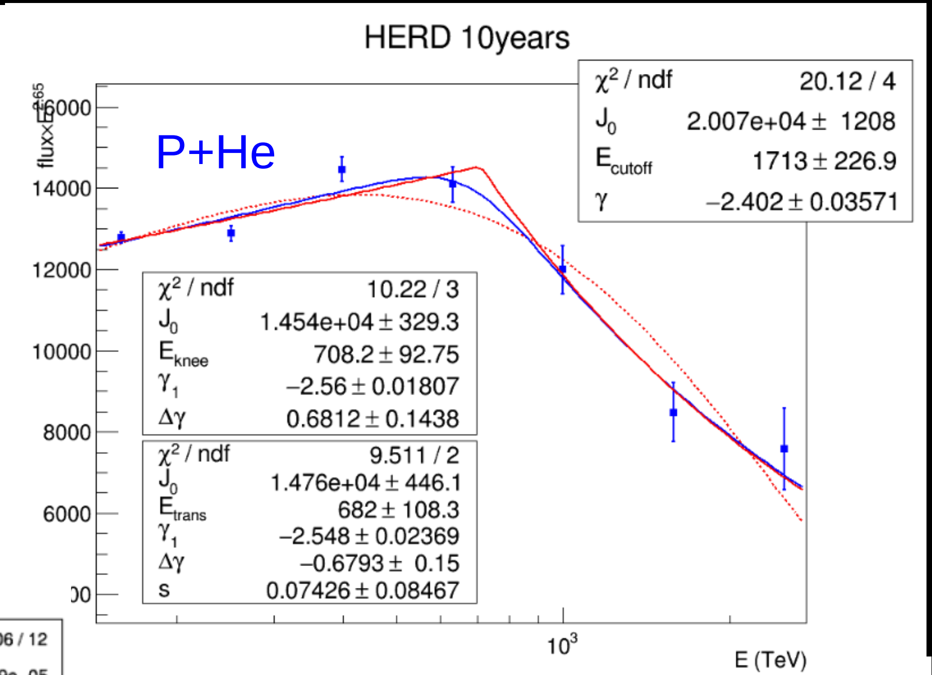
For the first time, all of the key structures of cosmic ray hardening, softening, possible new structure, knee etc. Measured by the same experiment.

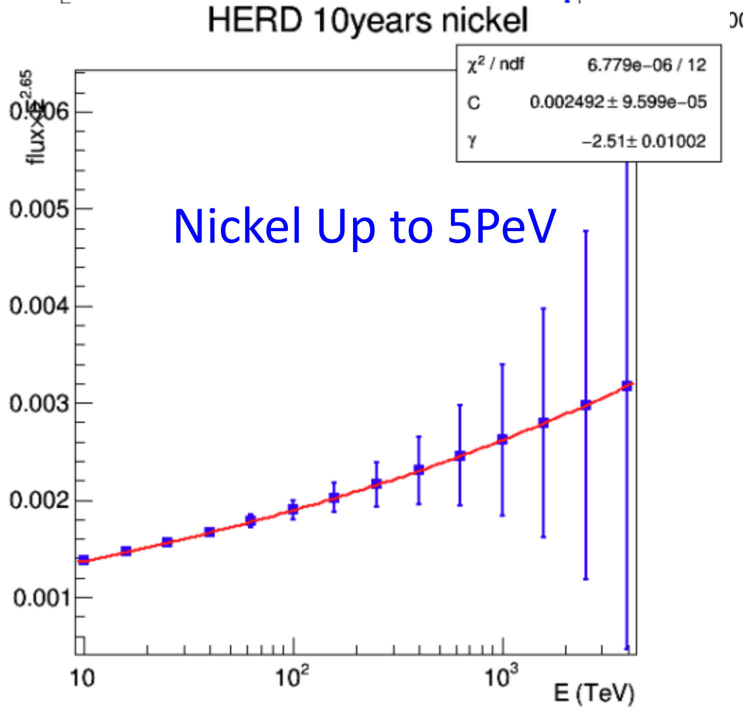
Direct measurement of Cosmic ray Nuclei to the highest energy

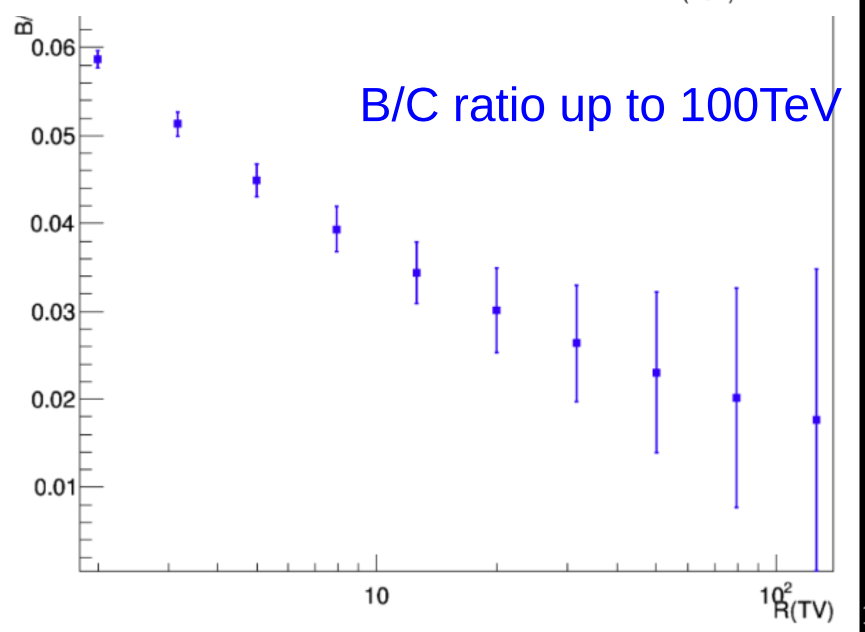
- For the first time, direct measurement of cosmic rays to the “knee”
- Measure Nuclei up to Z=28



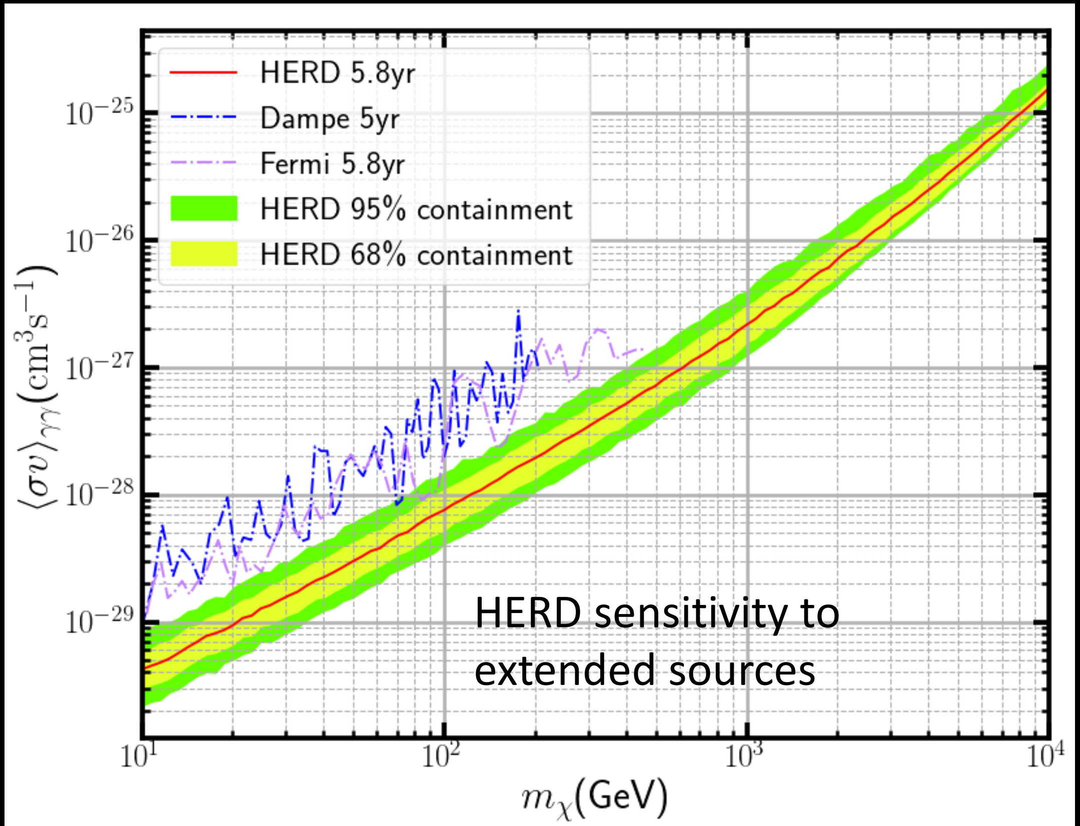








Do extreme astro sources produce high energy cosmic rays?



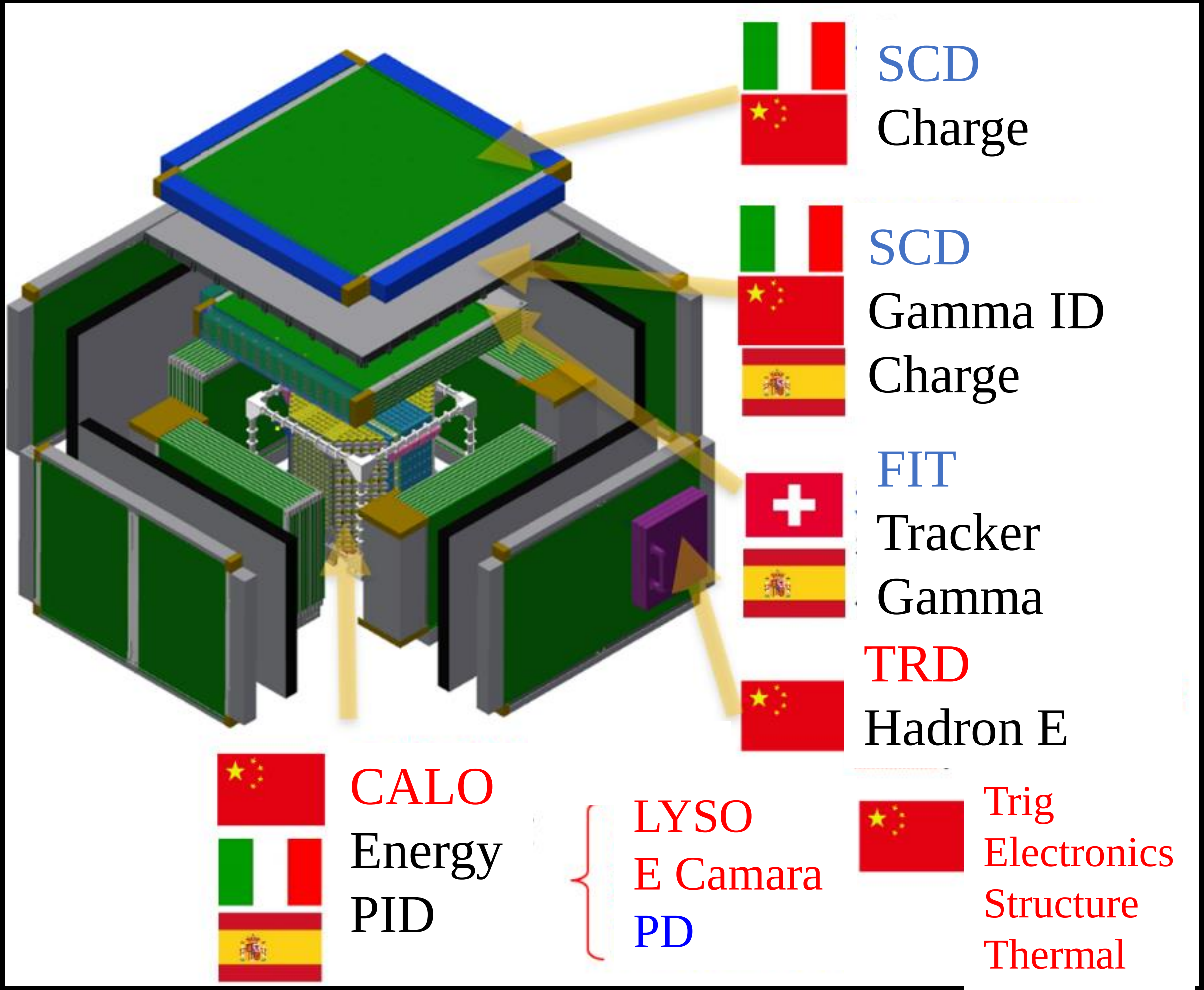
Ice Cube and Fermi LAT announced jointly that supermassive black holes are the sources of high energy cosmic rays in July 12th 2018!

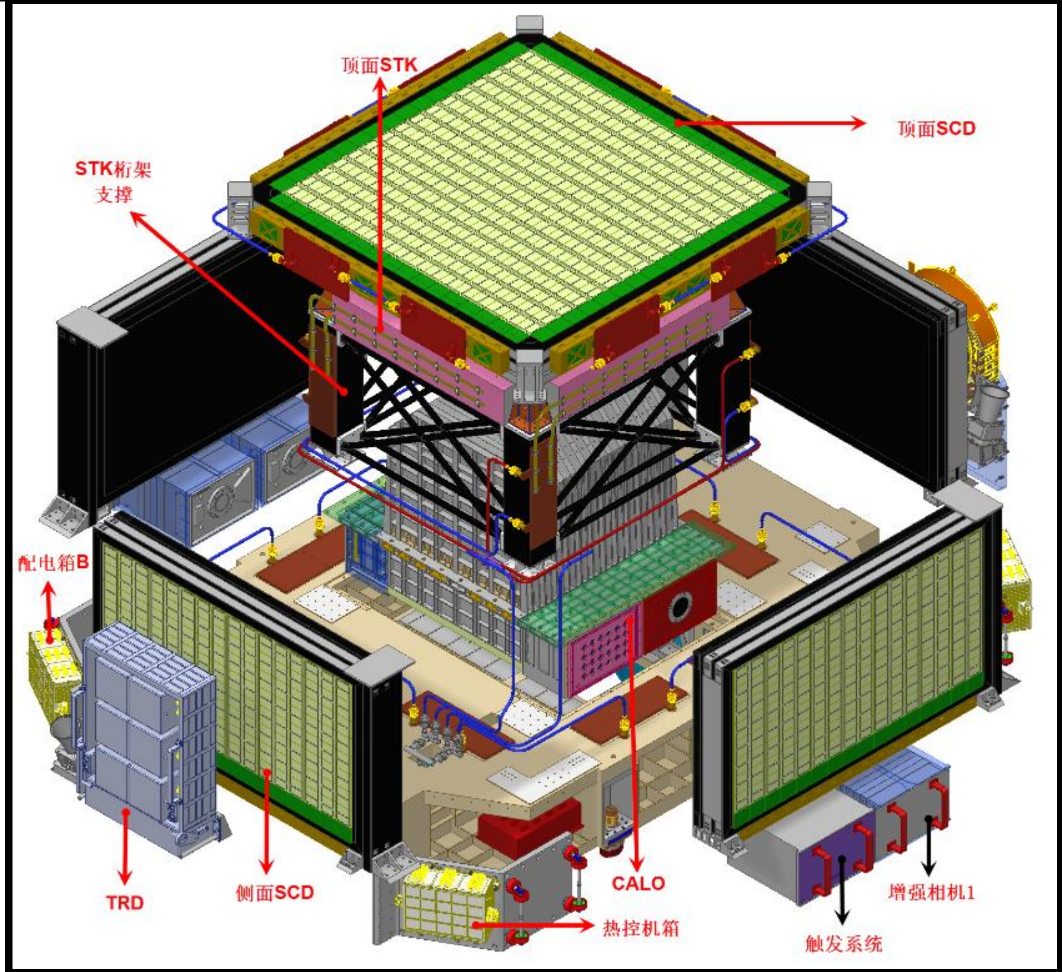
Only 1 case, not 5 Sigma Significance! Further joint sky survey by High energy neutrino and cosmic rays is needed in future.

HERD will be the largest field of view gamma ray observatory

HERD Detector

- HERD Detector consist of 3D CALO（7500 LYSO Crystal， 30K WS Fiber， 15k PD）、FIT（1.3M Sc Fiber， 230K SiPM）、PSD（700 PS Unit， 8k SiPM）， SCD（500k Channel Silicon Strip ）and TRD(800 channel gas detector





5 Side FIT
↓
1 side STK

Comparison of Main Feature of Space Experiments

Experiment (Starting Time)	Energy Range(e/γ)	Energy Range(p)	ResolutionE(e/γ)	Resolution E(p)	e/p Sepration	ACC (m^2sr)	ACC p m^2sr
FERMI (2008)	1GeV-300GeV	30GeV-10TeV	10%	40%	10^3	0.9	<0.28
ISS-AMS02 (2011)	1GeV-1TeV	1GeV-1.8TeV	2%	-	10^6	0.12	0.12
ISS-CALET (2015)	1GeV-10TeV	50GeV-10TeV	2%	35%	10^5	0.12	--
DAMEPE (2015)	5GeV-10TeV	40GeV-100TeV	≤1.5%	25-35%	$3*10^4$	0.3	0.04
China-SS-HERD (~2027)	10GeV-100TeV 0.5GeV-100TeV(γ)	30GeV-PeV	1%	20%	10^6	>3 (10X DAMPE)	>2 (50X DAMPE)

HERD is a next generation space particle physics detector

More than 10 times for ACC and Energy Range.

HERD detector development plan： 2027 Launch

- Phase B： 2023.01~2023.06
- EM, STM and QM： 2023.07~2025.12
- FM： 2025.01~2027.03

HERD Scientific Data Platform

- SDP： Scientific Data Platform
- Receive data from detector and also engineering data, support data processing, scientific research and international collaboration of grid computing etc.

Simulation, Reconstruction

Study of Dark matter search, Cosmic ray origin

Data transfer, open sharing etc.

Data receiving

Data Processing

Scientific Research

Grid Computing

User Management

Network Equipment

Safety Certification

Computing Cluster

Information Services

Data Storage

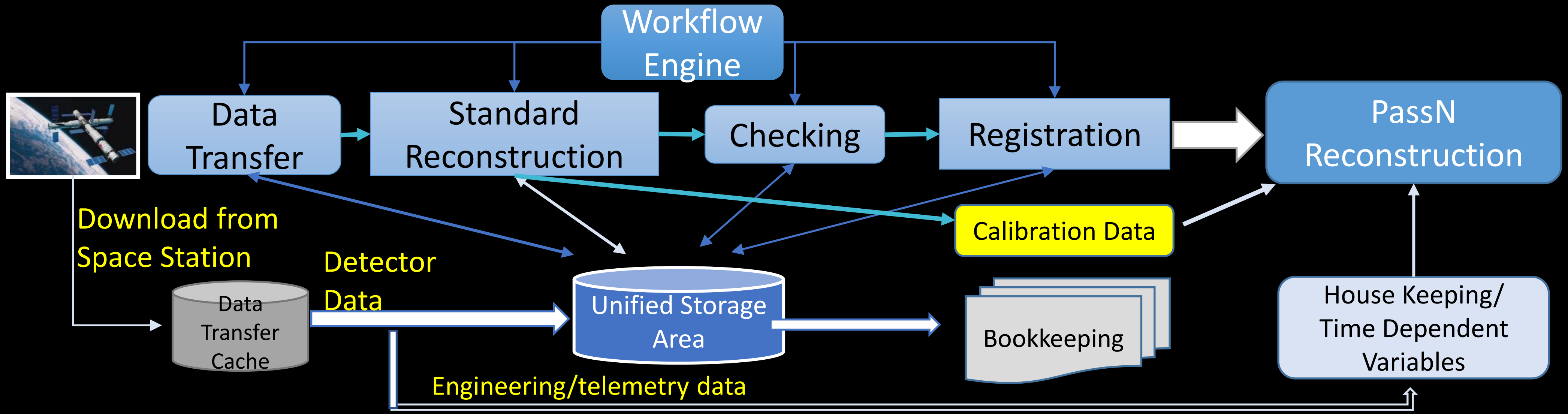
Distributed Computing

Tape Backup

Scientific Data Platform

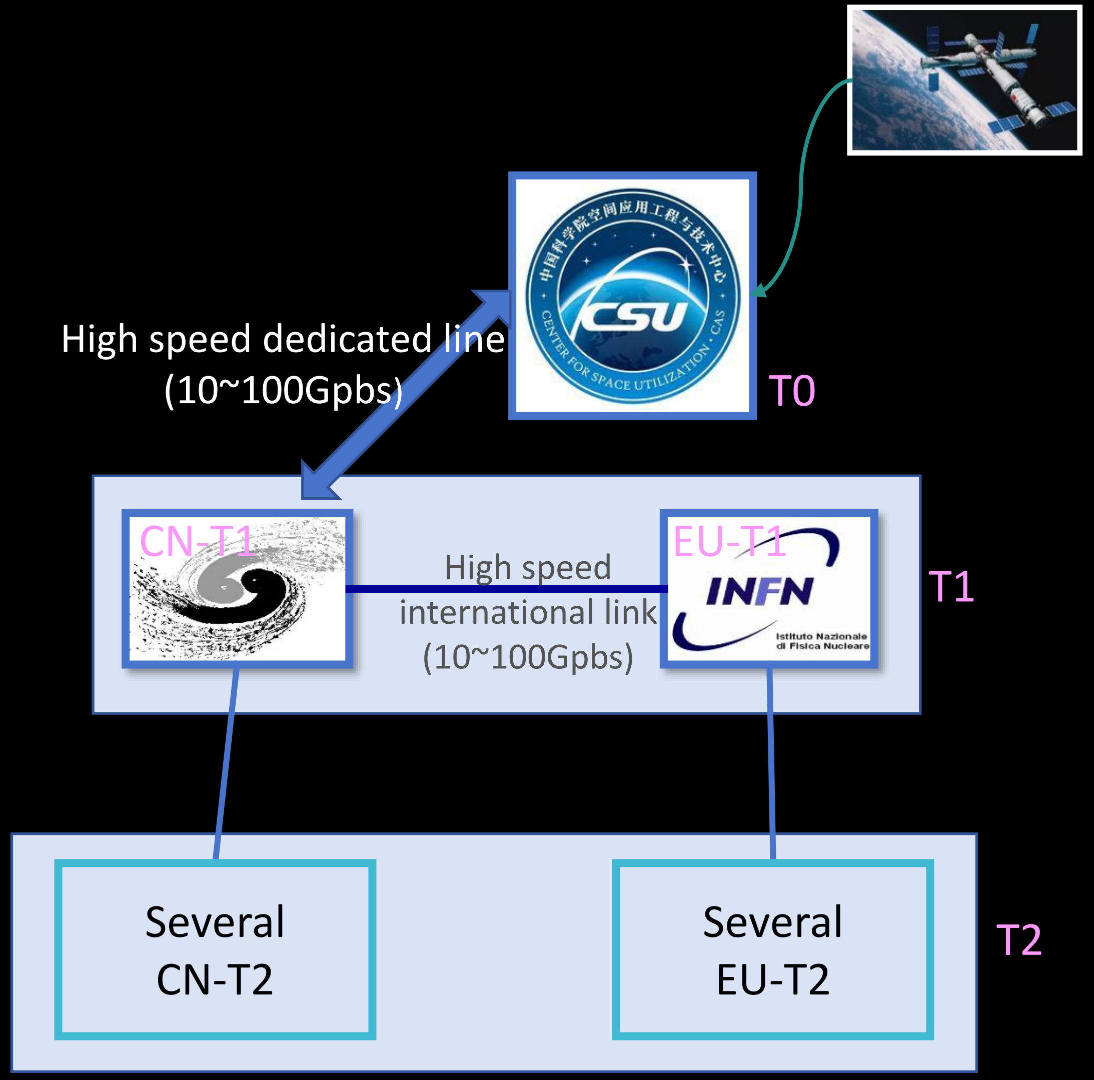
Data Processing Flow

- 1. Download data from Space Station, save to Data Transfer Cache
- 2. Move data to Unified Storage Area, Trigger different data processing procedure according to data type (engineering, telemetry and detector data)
- 3. Standard reconstruction， (Download again if problem with integrity)
- 4. For detector data, after checking, obtain a persistent identifier in the global storage system, and save to metadata management system (bookkeeping)
- 5. Data from Standard reconstruction is used to monitoring, calibration etc.
- 6. After calibration, data used for data analysis is generated by PassN Reconstruction
  - Normally once/6 months； N in “PassN” means major change of software version, all of the data need to be reconstructed.



International Grid Computing Platform

- Sharing of data and resources based on grid computing technology
- Set T0 at CSU
  - Data reconstruction, simulation etc.
  - Data saving of all type, Tape backup
- Set T1 in CN and EU, IHEP and INFN）
  - Saving all type of data, Enable data and resource sharing
  - Synchronize data with T0, distribute data to T2
  - INFN site set by EU
- Institute and Universities in Asia and EU set several T2
  - Data simulation, data analysis
  - Accessing grid data and contributing resources
- Several T3 setup in the other Institute/Universities
  - Accessing grid data
  - Computing resource not shared



Estimation of Computing and Storage

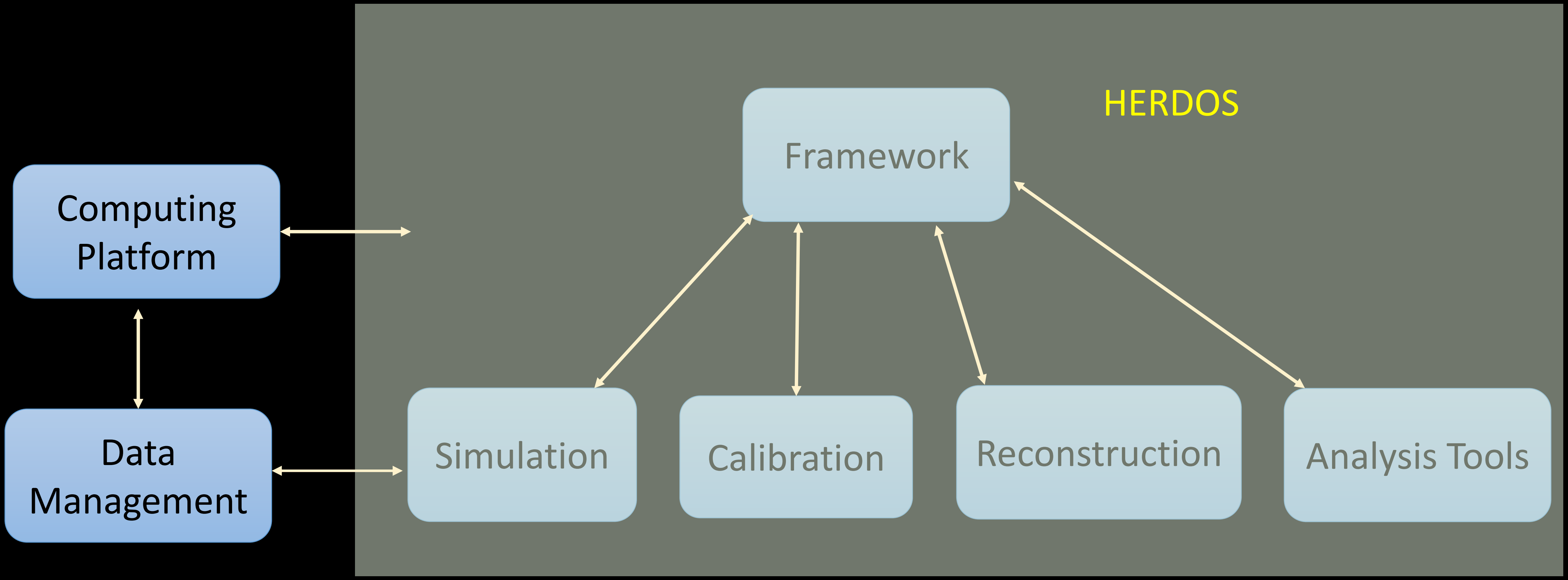
Data type	Data size （PB）			Computing （CPU Core）		
	5 years	10 years	Site	5 year	10 year	Site
Flight Data	2	6	T0, T1	-	-	T0
Standard Reconstruction	2.5	7.5	T0, T1	200	400	T0
Data transmission control system	1	2	T0	300	600	T0
PassN reconstruction	5 （2 version）	15 （2 version）	T0, T1	1000	3000	T0
Simulation data	5	15	T0, T1	4000	8000	T0
Analysis Data	2	4	T1	2000	4000	T1
Summary	15.5+16.5	45.5+47.5		7500	16000	

Note： 1) If keep all version of PassN data (N=6)， PassN data 15PB for 5 years， 70PB for 10 years (more if N>6)

2) T0 provide dual tape library backups, one for offline, one for online access

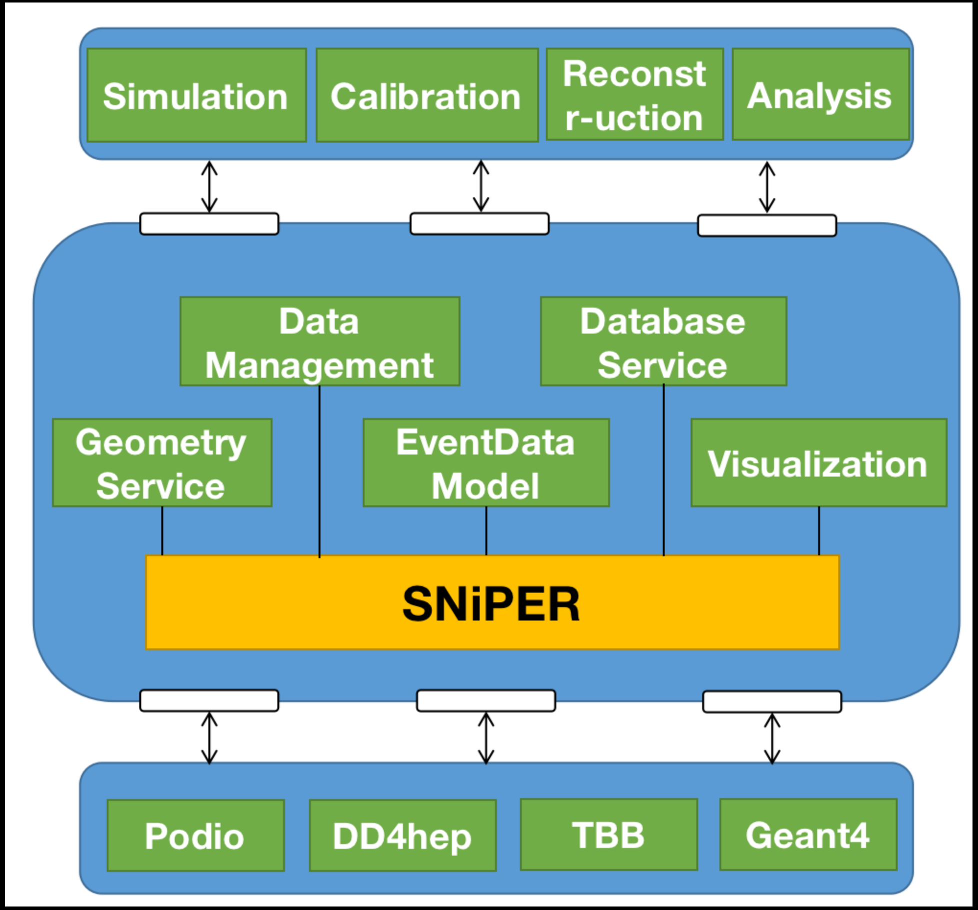
3) T1 keep all data on disk, therefore have same storage resources as T0 for online access to the Grid

HERD Science Operation System



Overview of HERDOS

- HERDOS (HERD Offline Software) is developed for the HERD offline data processing tasks based on SNiPER
  - Simulation, calibration, reconstruction and data analysis
- HERDOS is also partially based on Key4hep
  - Common software stack for future HEP experiments
  - A few state-of-the-art software and toolkits in the HEP community are adopted
- Technical advantages of HERDOS:
  - **Good support for concurrent detector simulation**
  - **Consistent and flexible detector description for all applications**
  - **Lightweighted design, yet complete in every part**
  - **Good machine learning inference support**

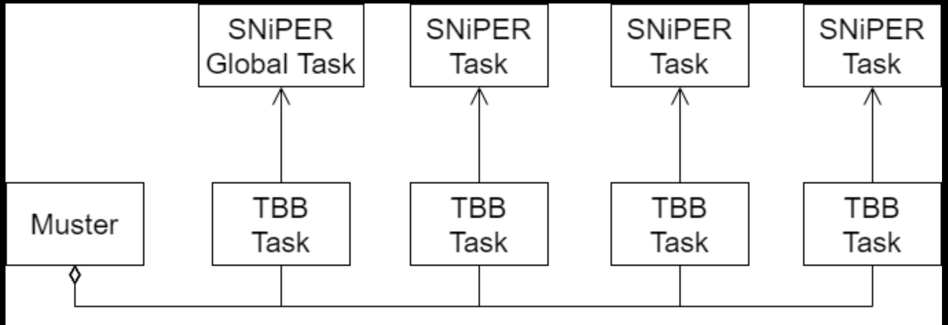


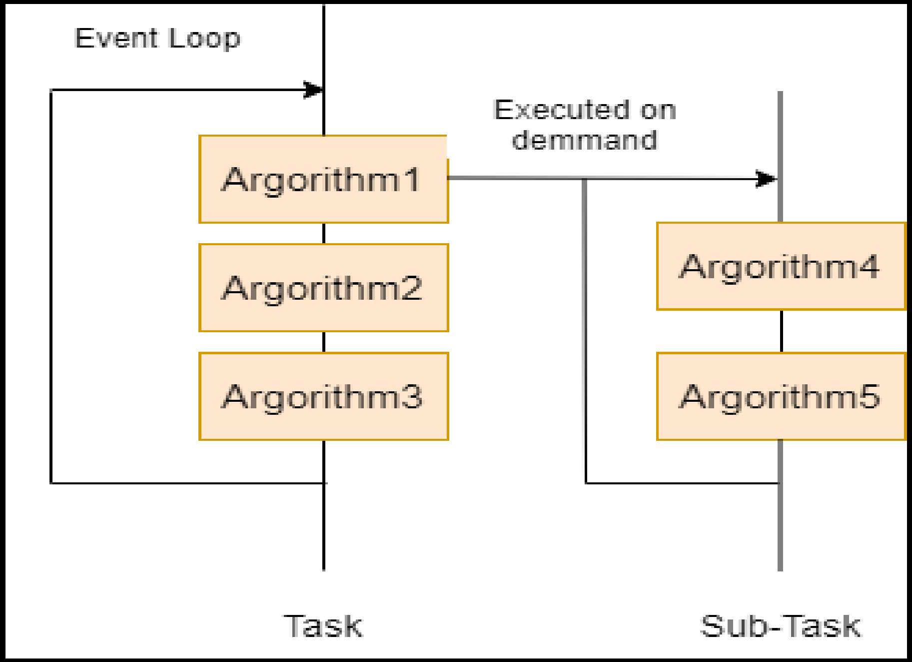
Documentation: https://herd.ihep.ac.cn/internal/herdos/manual/index.html

The Underlying Framework

Documentation:
https://herd.ihep.ac.cn/internal/herdos/manual/sniper/index.html

- Software for non-collider experiments (Sniper)
  - Designed and developed for non-collider experiments (since 2012)
  - Maintained by **10+ developers from IHEP, SDU, SYSU etc.**
  - Adopted as underlying framework for JUNO, LHAASO, nEXO etc.
- Key features of SNiPER
  - Light-weighted, with minimal dependencies of external libraries
  - High cohesion and low coupling design
  - Flexible user interface based on Python binding
  - Support building flexible data processing procedure (sequential/ concurrent/ branching/ jumping)
  - Flexible multi-threading support

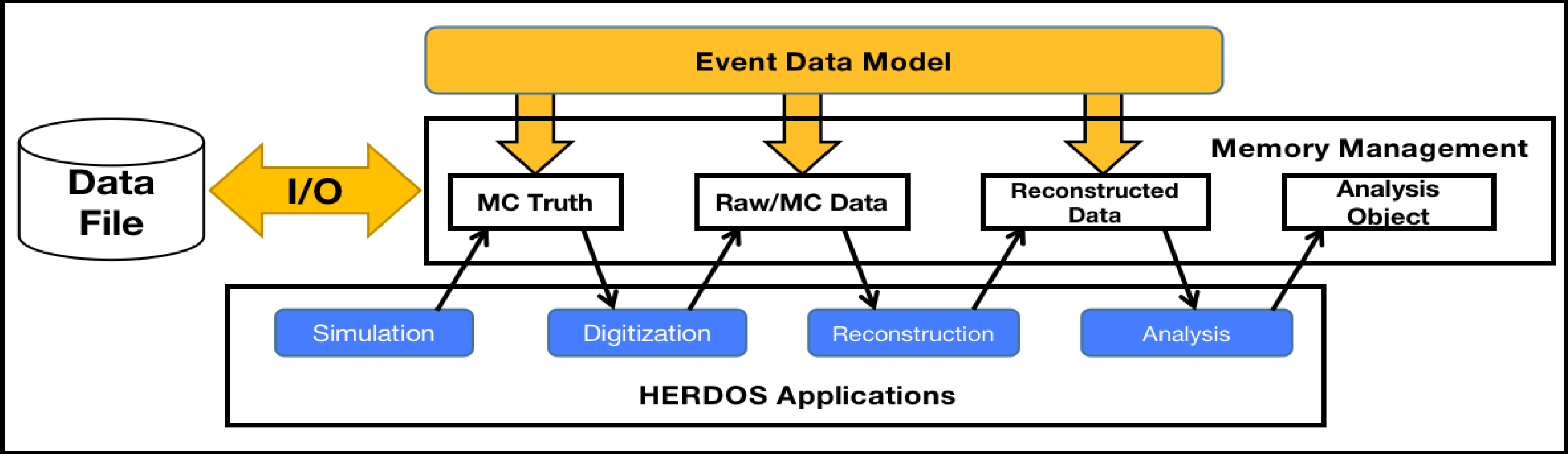




reference: J. H. Zou et al J. Phys.: Conf. Ser. 664 (2015) 072053
J. H. Zou et al EPJ Web Conf. 214 (2019) 05026

Event Data Model

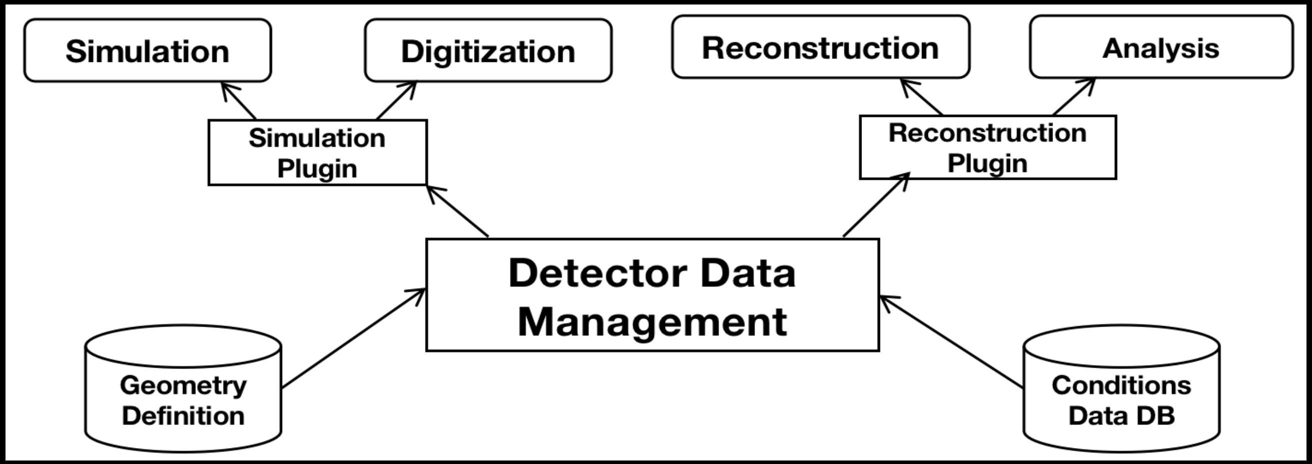
- Event data model is implemented based on podio and provides rich features:
  - Flexible event data-definition, such as automatic code generation based on yaml
  - Flexible relationships between MCParticles, hits, readouts, tracks, clusters
  - Provide backward and forward compatibility of data files
  - Provide automatic memory management and data I/O
  - Guarantee thread-safety

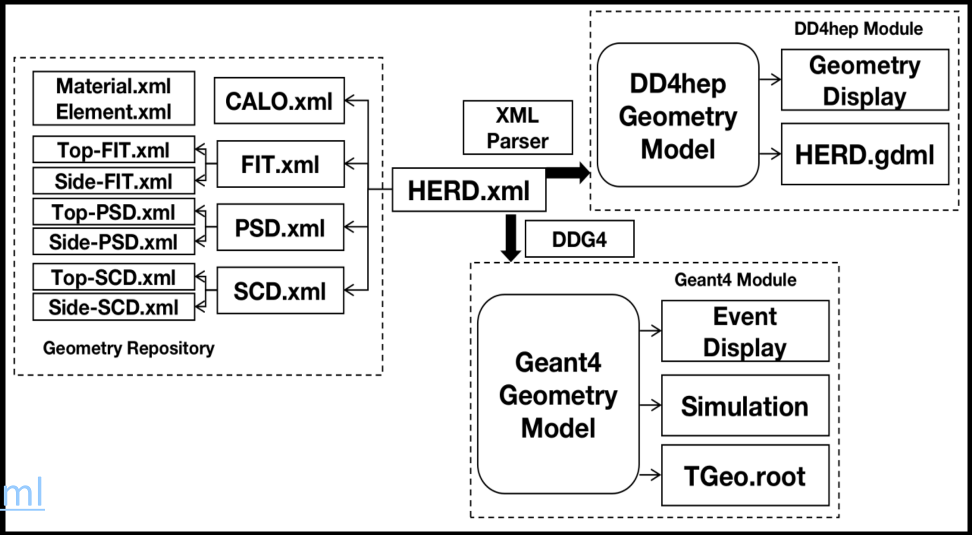


Documentation: https://herd.ihep.ac.cn/internal/herdos/manual/edm/index.html

Detector Description Management

- A powerful and unified detector description system is designed for all applications
  - Provide simple method for **geometry description definition**
  - Provide **consistent detector description for all applications** (simulation, digitization, reconstruction, ...)
  - Provide **multiple geometry version support**
  - Provide interface to **conditions data** from space station
  - Provide rich functionalities for application software (geometry format conversion, coordinates conversion, calculating volume position, dimention, track-length etc.)

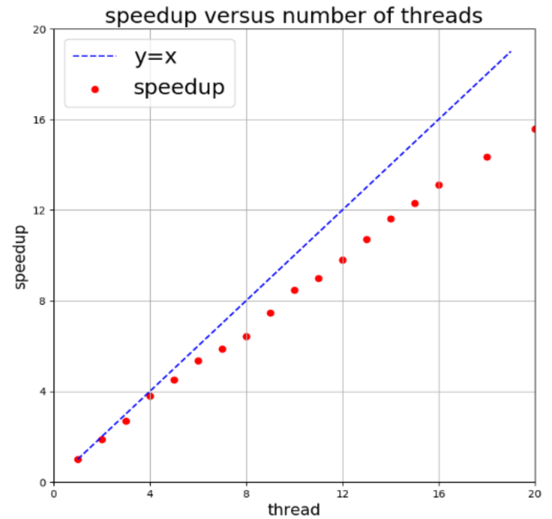


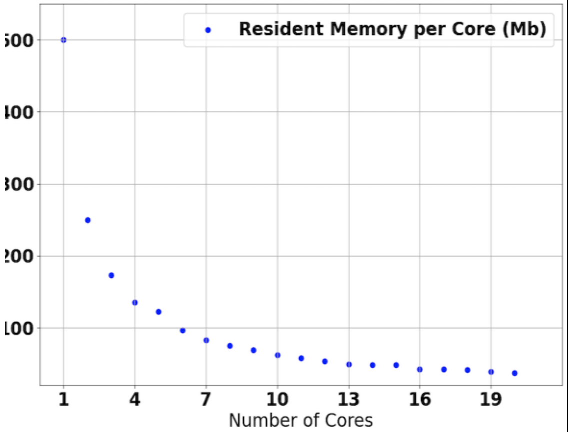


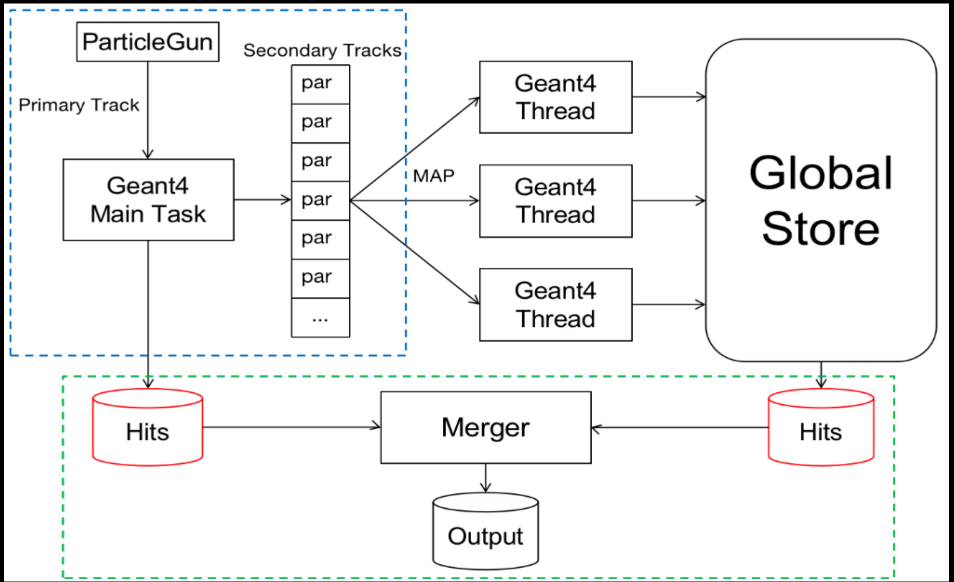
Documentation: https://herd.ihep.ac.cn/internal/herdos/manual/geometry/index.html

Concurrent Detector Simulation

- To efficiently simulate high energy level heavy nucleons, concurrent detector simulation software is being developed
  - Both **event-level** and **track-level** concurrent simulation
    - Event-level: simulate multiple events concurrently
    - Track-level: simulate one event within multiple threads
  - **Greatly speed up the simulation of PeV level heavy nucleons, which cost dozens of hours without parallel support**
  - **Reduce overall memory consumption by sharing objects across multiple threads**
  - **Preliminary performance tests show promising scalability**



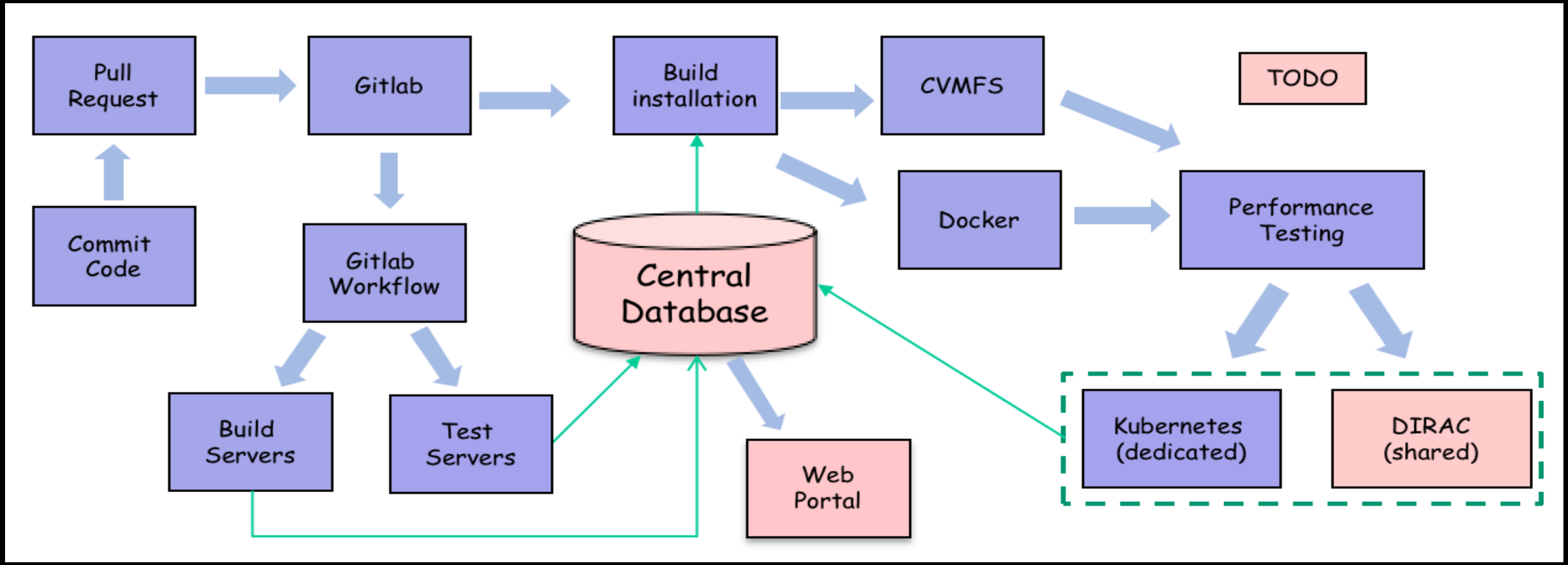


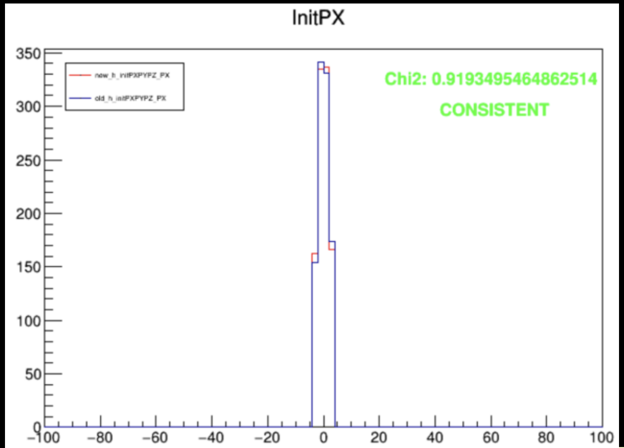


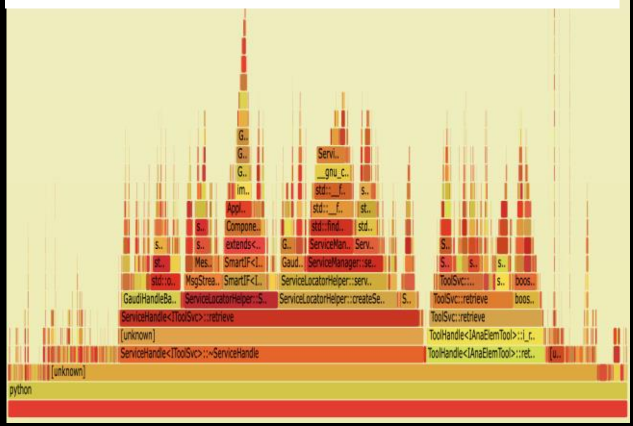
Under development: https://code.ihep.ac.cn/herdos/offline/-/tree/MT

Automated Software Validation

- An automated software validation is being developed to build complete software validation
  - Support building unit test, integrated test, performance profiling and physics validation
  - Integrated with Gitlab CI/CD for automated validation
  - Support building test matrix across multiple OS, CPU arch. etc.
  - Test cases from all sub-systems are being enriched







[Under development: https://code.ihep.ac.cn/herdos/offline/-/tree/3-CI-deploy](https://code.ihep.ac.cn/herdos/offline/-/tree/3-CI-deploy)

HERDOS User Interface

- High level Python module is developed as HERDOS user interface
  - Handle the creation of Sniper components
  - Encapsule common configurations and expose properties to command line interface
  - Provide detailed helper message
  - **Users can quickly get started without much knowledge of Python and HERDOS**

```
-bash-4.2$ python simulation.py -h
**************************************************
Welcome to SNiPER 2.1.0
Running @ lxslc713.ihep.ac.cn on Wed Feb 21 12:11:12 2024
**************************************************
usage: simulation.py [-h] [--loglevel {Test,Debug,Info,Warn,Error,Fatal}] [--dryrun] [--evtmax EVTMAX] [--user-output USER_OUTPUT] [--EnableUserOutput]
                     [--DisableUserOutput] [--profiling] [--no-profiling] [--profiling-detail] [--no-profiling-detail] [--seed SEED]
                     [--seed-status-file SEED_STATUS_FILE] [--seed-status-vector SEED_STATUS_VECTOR [SEED_STATUS_VECTOR ...]]
                     [--geometry-compact-file GEOMETRY_COMPACT_FILE] [--enable-base-box] [--disable-base-box] [--sim-random-seed SIM_RANDOM_SEED]
                     [--g4-run-mac G4_RUN_MAC [G4_RUN_MAC ...]] [--g4-commands G4_COMMANDS [G4_COMMANDS ...]] [--g4-vis-mac G4_VIS_MAC]
                     [--enable-space-lab] [--disable-space-lab] [--run-id RUN_ID]
                     [--solar-panel-param SOLAR_PANEL_PARAM SOLAR_PANEL_PARAM SOLAR_PANEL_PARAM SOLAR_PANEL_PARAM SOLAR_PANEL_PARAM SOLAR_PANEL_PARAM SOLAR_PANEL_PARAM SOLAR_PANEL
PARAM]
                     [--physics-list {FTFP,QGSP,CRMC,ADPM}] [--gps-energy GPS_ENERGY [GPS_ENERGY ...]] [--gps-energy-kn GPS_ENERGY_KN]
                     [--gps-particle GPS_PARTICLE] [--input INPUT [INPUT ...]] [--output OUTPUT] [--output-colls OUTPUT_COLLS [OUTPUT_COLLS ...]]
                     [--transfer-colls TRANSFER_COLLS [TRANSFER_COLLS ...]] [--transfer-colls-exclude TRANSFER_COLLS_EXCLUDE [TRANSFER_COLLS_EXCLUDE ...]]
                     [--transfer-all]

optional arguments:
  -h, --help            show this help message and exit
  --loglevel {Test,Debug,Info,Warn,Error,Fatal}
                        Log level of the job
  --dryrun              only show the job, without running
  --evtmax EVTMAX       number of events to be processed
  --user-output USER_OUTPUT
                        output user data file name
  --EnableUserOutput    Enable User Output
  --DisableUserOutput   Disable User Output
  --profiling           enable profiling
  --no-profiling        disable profiling
  --profiling-detail    enable saving profiling details
  --no-profiling-detail
                        disable saving profiling details
  --seed SEED           common random seed (for both CLHEP and ROOT engines)
```

```python
#!/usr/bin/env python
#-*- coding: utf-8 -*-
# Author: Teng LI <tengli@sdu.edu.cn>

from HERDOSModule import *
from GeometrySvc import GeometryModule
from RandomSvc import RandomModule

app = HERDOSApplication()

# Random engine
app.registerModule(RandomModule())

# Geometry
app.registerModule(GeometryModule())

# Detector simulation
app.registerModule(DetectorSimulation())

# Data management
app.registerModule(DataManagement())

app.run()
```

Documentation: https://code.ihep.ac.cn/herdos/offline/-/blob/28-UIOptimize/Framework/UI/README.md

Software Installation and Distribution

- **Automated software installation toolkit for HERDOS is developed**
  - Support **one-click installation** of HERDOS (including HERDOS app and various external libraries)
  - Support **multiple platforms** (amd64/arm64, el7/el9, etc.)
  - Automated patching of external libraries
  - Easy-switching of external software versions
- HERDOS is **distributed via CVMFS**
  - Available under /cvmfs/herd.ihep.ac.cn mount point
  - Multiple platforms (amd64/arm64, el7/el9, etc.) now included
- HERDOS **container is available**
  - For sites without access to CVMFS, or using un-supported OS

Documentation: https://herd.ihep.ac.cn/internal/herdos/manual/installation/installation.html

Status and Plan of Framework

DONE

TO DO

- Underlying framework
  - Most basic functionalities are developed
  - New Sniper-MT (track-level) under development and testing
  - Improvements to be made based on feedbacks
- Event Data Management
  - Most basic functionalities are developed
  - Further optimization on concurrent event data management system is needed
  - Event data management system in Python to be implemented
- Detector description Management
  - For simulation, digitization and reconstruction, most basic functionalities are developed
  - Further development of more advanced GeometrySvc based on further requirements
  - Integration with conditions data to be implemented

Status and Plan of Framework

DONE

TO DO

- Detector Simulation
  - Serial detector simulation is implemented
  - Event-level parallelled detector simulation is implemented and tested
  - Further development and test of sub-event-level parallelled detector simulation
- Detector and event visualization
  - Basic UI, detector and event visualization are implemented
  - Further optimization and improvement are needed, especially for performance and UI, multi-clients need to be implemented
- Software Validation
  - Toolkit for building test cases are developed
  - Full stack software validation needs to be established
- Software installation and distribution
  - Most basic functionalities are developed and tested
- Analysis based on RDataframe to be developed

Simulation

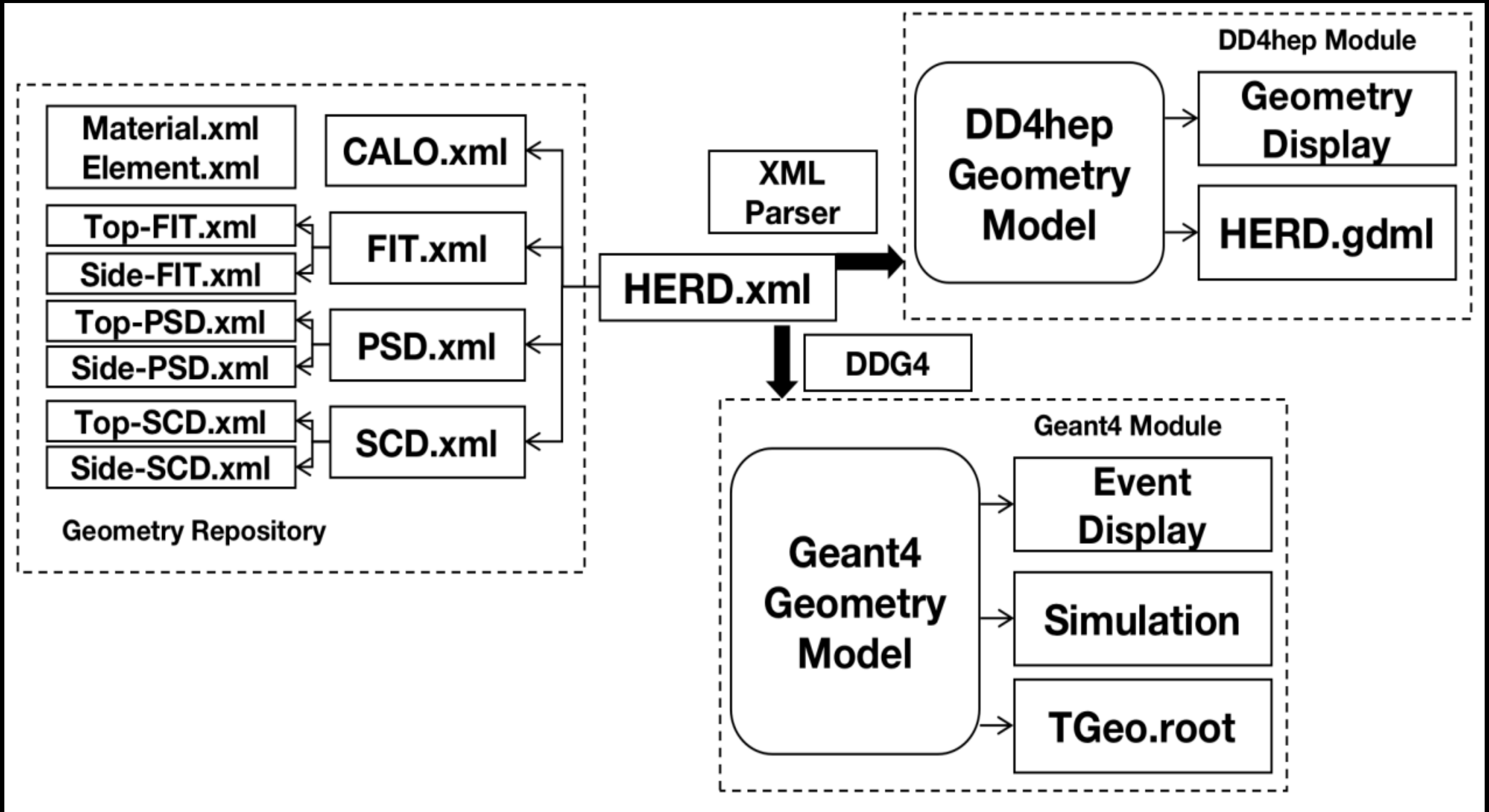
- The simulation using Monte Carlo method, based on precision description of the detector, physics interaction models, obtain accurate detector response
- Important for performance evaluate at the detector design stage, and obtain detector acceptance, efficiency, and other important parameters for the data analysis.
  - Detector geometry description
  - Physics interaction models
  - Digitization
  - Manage mass simulation production

Detector geometry description

- The simulation using Monte Carlo method, based on precision description of the detector, physics interaction models, obtain accurate detector response
- Important for performance evaluate at the detector design stage, and obtain detector acceptance, efficiency, and other important parameters for the data analysis.
  - Detector geometry description
  - Physics interaction models
  - Digitization
  - Event Data Model and Information Saving
  - Manage mass simulation production

Detector Geometry Description

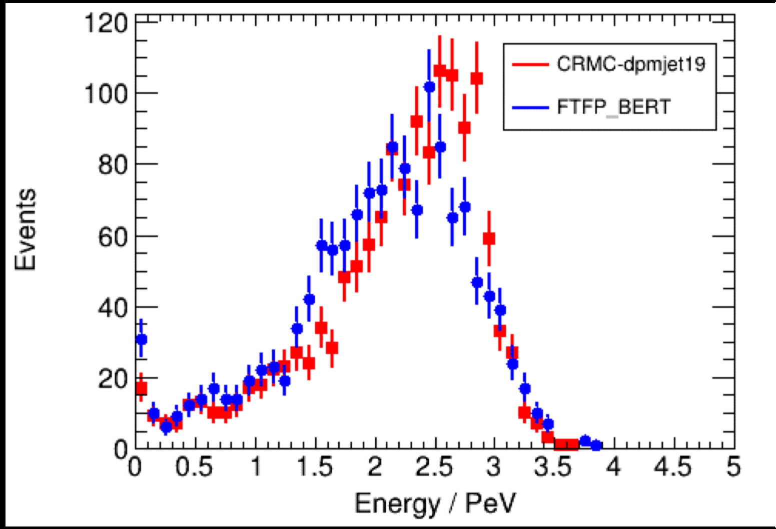
- **Define unified coordinate system** and **cell ID definition rules**
- **Multiple geometry version including different Beam Test geometry (3 types for 2023 BT) based on DD4hep**

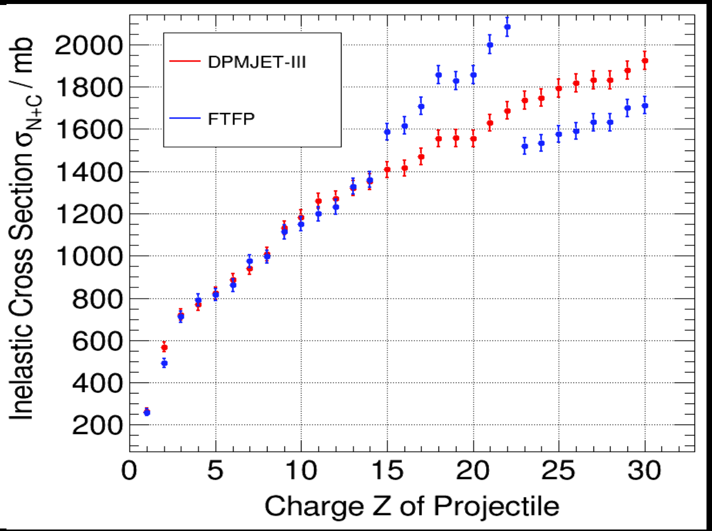


Documentation: https://herd.ihep.ac.cn/internal/herdos/manual/geometry/index.html

Physics Interaction Models

- To support up to PeV Cosmic Ray measurements of HERD,
  - Energy limit of 100TeV in Geant4 extended
  - Understanding the cross-sections of various interaction models beyond 100TeV
  - Support more hadronic models, e.g. DPMJET, by integration of CRMC package
  - Evaluating the difference of models in the simulation results, e.g. energy in CALO, fragmentation fraction, etc.





see https://herd.ihep.ac.cn/internal/herdos/manual/detsimulation/index.html for details

Digitization

- The process of the hits in sensitive cell from Geant4 simulation is converted into the final electronic readout, including
  - effects occurs during the conversion of energy deposits into readout signal, e.g. optical photons, or electron-hole pairs
  - as well as effects in the readout device and electronics
- The conversion parameters at each step rely on separate or overall testing of components of the detector.
  - Parameters obtained in form of center value and distribution width from beam test or flight data
  - Combined with the estimation of statistical errors by Poisson sampling in the digitization process
  - With possible fine-tuning based on real data, obtain digitized results accurately consistent with the real status of the detector

- **Digitization of all subdetectors, except CALO PD, are implemented, parameters are being tuned according to data from test bench and Beam test, and also future flight data.**

see https://herd.ihep.ac.cn/internal/herdos/manual/detsimulation/index.html#digitization for details

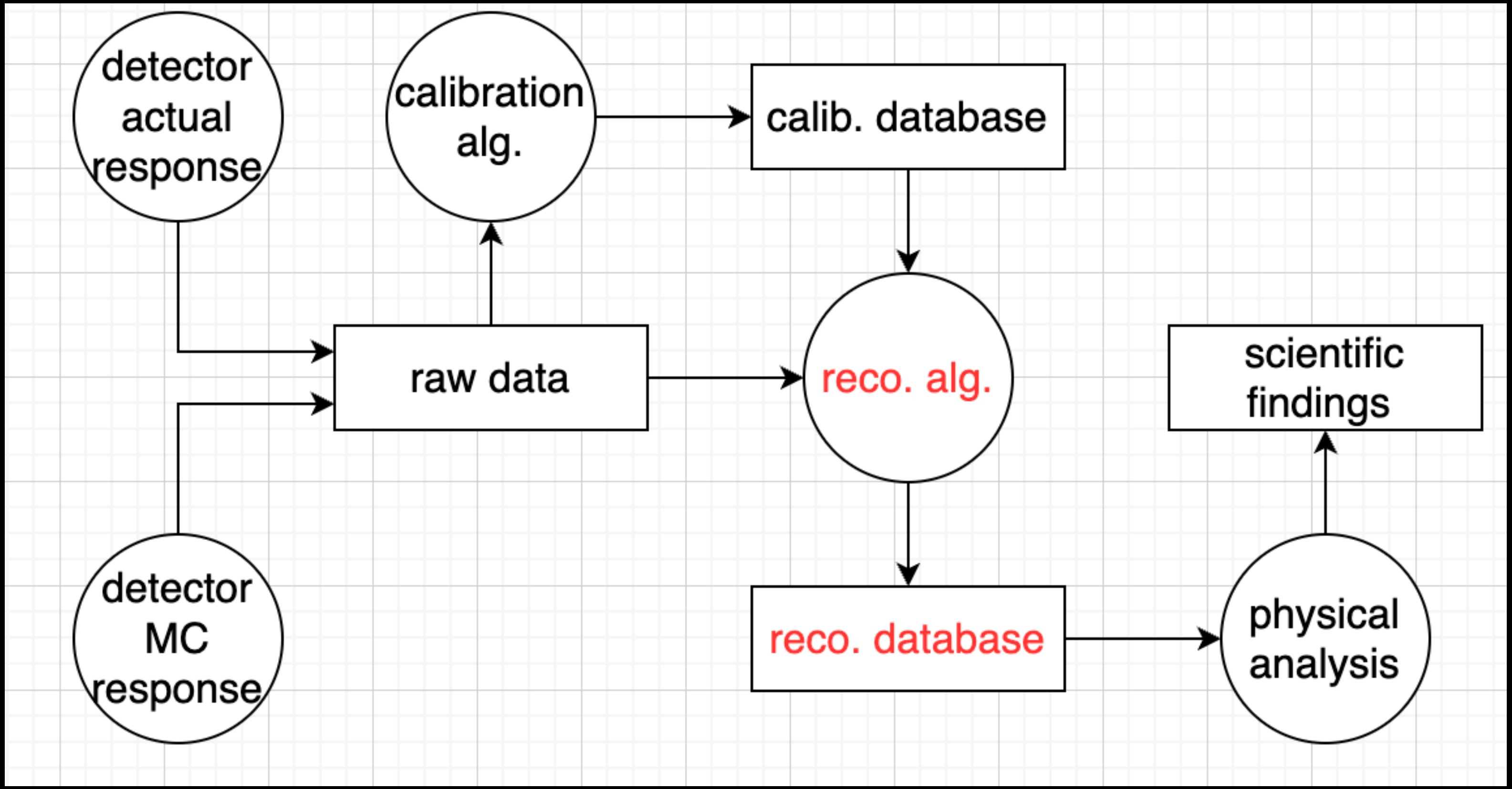
Event Data Model

- Record energy, time and position information for all sensitive units for digitization process
- Record particle position, direction in each detector, and information of important secondary particle for algorithm development and debug. (Optional, can be turned off by change the running parameters. https://herd.ihep.ac.cn/internal/herdos/manual/detsimulation/index.html#saving-of-information

- **Information after digitization: all information contained in flight data, and some particular mediate information for debug**

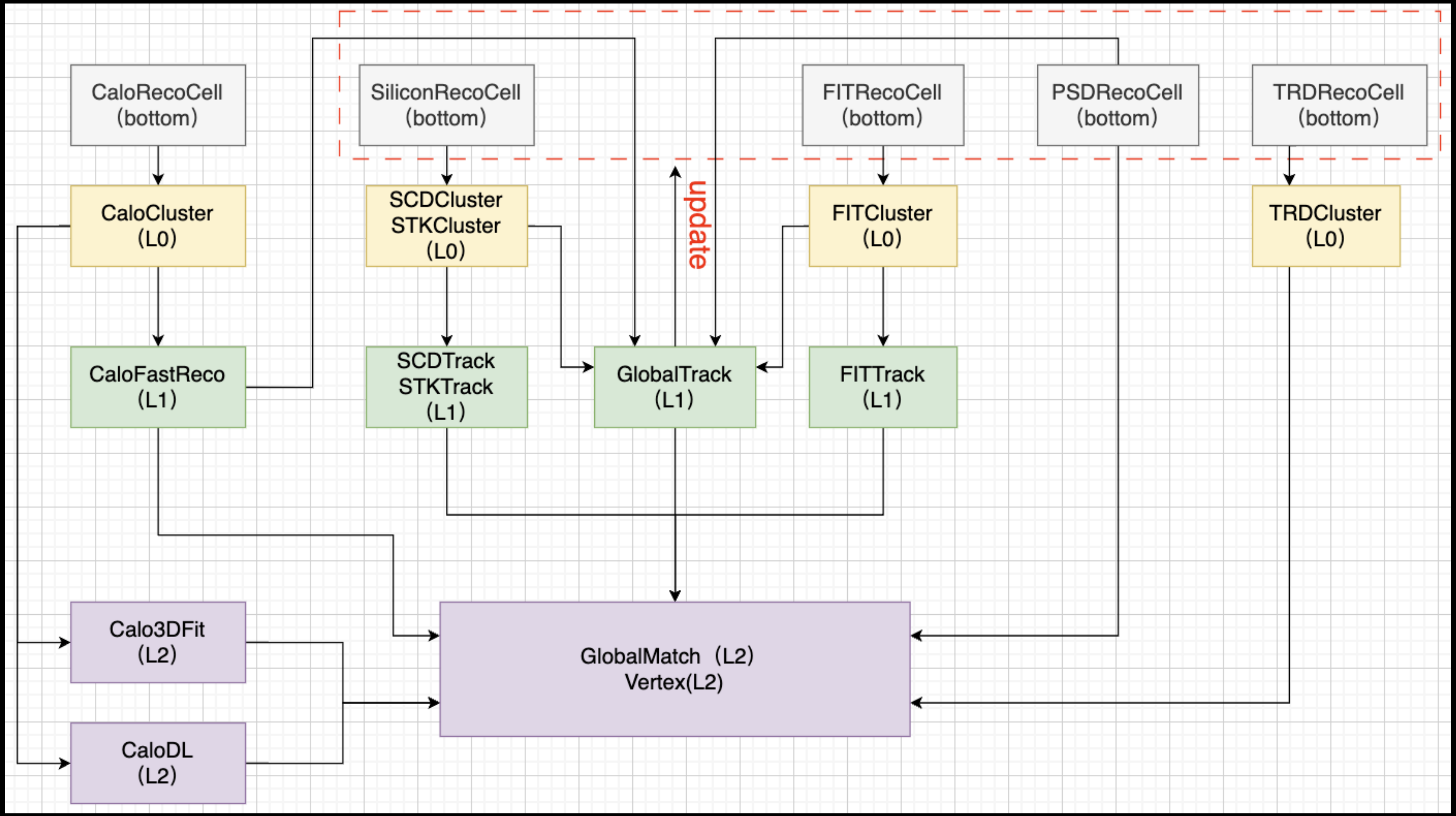
Reconstruction overview

- reconstruction: convert the raw electrical signal data (raw data) recorded by detectors into physical quantities
- documentation for stable version is available at https://herd.ihep.ac.cn/internal/herdos/manual/reconstruction/index.html
  - latest developping version can be requested on demand



Four level definition in reconstruction

Bottom level: ADC (gray) to Edep
L0: Edep to clusters
L1: primary reconstruction to form track feature(charge, direction) and fast calo info(energy, pid), and updating/iterating with bottom level objects
L2: high level reconstruction with advanced algorithms



Reconstruction algorithms and status: 5 released

bottom level	1	CALOCameraBottomReco	convert cameral pixel gray scale to edep	developing, v1 will be released 2024/08
	2	CALOPDBottomReco	convert PD adc to edep	will start in 2025
	3	CALOPMTBottomReco	convert trigger PMT adc to edep	will start in 2025
	4	FITBottomReco	convert SiPM adc to edep	will start in 2025
	5	PSDBottomReco	convert SiPM adc to edep	developing, v1 will be released 2024/08
	6	SCD/STKBottomReco	convert strip adc to edep	developing, v1 will be released 2024/08
	7	TRDBottomReco	conver strip adc to edep	developing, v1 will be released 2024/08
L0			cell hits into clusters	developing, v1 will be released 2024/12
	2	FITClustering	channel hits into clusters	v1 released, based on Sim. data
	3	SCDClustering	strip hits into cluster	v1 released, based on Sim. data, TB validation
	4	STKClustering	strip hits into cluster	will start in 2024/10
	5	TRDClustering	strip hits into cluster	developing, v1 will be released 2024/12
L1	1	CALOFast	fast/raw, shower axis, energy, pid	developing, v1 will be released 2025/06
	2	FITLocalTracking	local tracks based on FIT clusters	v1 released, based on Sim. data
	3	SCDLocalTracking	local tracks based on SCD clusters	v1 released, based on Sim. data, TB validation
	4	STKLocalTracking	local tracks based on STK clusters	will start in 2025
	5	GlobalTracking	combied trajectory by intergrating shower axis, FIT/SCD clusters, PSD hits	v1 released, based on Sim. data
	6	TrackUpdating	iterations of making corrections to clusters	will start in 2025
	7	PSD/FIT/STK/SCD chargeZ	hit/cluster equivalent Q, as to be iterated in tracking	developing, v1 will be released 2024/12
L2	1	CALO3DFit	precice shower axis, energy, pid based on Fitting	developing, v1 will be released 2026
	2	CALOML	precice shower axis, energy, pid based on Machine Learning	developing, v1 will be released 2026
	3	TrackML	advanced track finding based on Machine Learning	developing, v1 will be released 2026
	4	GlobalMatch	combine information and form partcile info.	developing, v1 will be released 2025
	5	Vertex	fragmentation/conversion vertex finding	developing, v1 will be released 2025

Calibration

Task List	Task Content	Method
Payload parameter acquisition	Retrieve various physical parameters for each sub-payload, including the density and dimensions of all LYSO crystals, geometric structure parameters, inconsistencies in the positions of various detectors, temperature coefficients for each detector, and ionization effects of silicon photodiodes (PD)	Ground testing for each sub-payload
CALO	CALO MIP Calibration	Before payload launch, calibration is performed using cosmic muons and particle beam tests. After the payload is in orbit, calibration is carried out by selecting proton MIP events
	CALO Cross Calibration	Beam test on the ground and selecting showered events for calibration in orbit.
	Geomagnetic cut-off rigidity Calibration	Calibration in orbit by measuring the cutoff of the cosmic ray electron energy spectrum below 20 GeV

Calibration

IsCMOS Calibration	**This involves the inconsistency in gain positions, response linearity at different positions, crosstalk measurements at different positions, fluorescence screen luminescence attenuation curves at different positions and light intensities, as well as cross-calibration of sCMOS at high and low gains.**	**Using a fast calibration system composed of an LED array illuminating a WLSF bundle to calibrate the IsCMOS before and after payload launch**
PSD	PSD MIP Calibration	Cosmic ray muon or beam tests are conducted at ground, and proton MIP events are selected for calibration in orbit.
	PSD charge response	Tests using ion beam are conducted at ground, and proton and ion MIP events are selected for calibration in orbit.
SCD	SCD MIP Calibration	Cosmic ray muon or beam tests are conducted at ground, and proton MIP events are selected for calibration in orbit.
	SCD charge response	Tests using ion beam are conducted at ground, and proton and ion MIP events are selected for calibration in orbit.
	SCD charge sharing parameters	Tests using ion beam are conducted at ground.

Calibration

STK	**STK MIP Calibration**	**The same as SCD MIP calibration, Cosmic ray muon or beam tests are conducted at ground, and proton MIP events are selected for calibration in orbit.**
TRD	Relationship between TR response and Lorentz factor	Using 0.5GeV~ 5GeV electron beam for calibration at ground, and using LEE trigger to select low energy electron for calibration in orbit.
	TeV energy calibration	Using TR response curve to calibrate 0.5~2.5TeV proton
	TRD gain calibration	Using built-in radioactive sources for calibration
	TRD electron drift distance	Using built-in radioactive sources for calibration
Pedestal for sub-system (excluding IsCMOS)	Pedestal subtraction	Using dummy triggers without physical events to obtain pedestal.

Calibration

Alignment	**Measure the relative positions between internal modules within each subpayload and between subpayloads**	**Validate algorithms through cosmic ray muons or other charged particle beams on the ground, and accumulate charged particle trajectories for correction in orbit.**
Calibration database api	Provide an interface for data processing and payload calibration data	Design and implement the interface between data processing software and calibration database.

Payload Parameters

Detector	Parameter	Precision
CALO	Material definition, density, geometric parameters of LYSO	Density 0.01g/cm^3， position 0.1mm
	Material definition, density, geometric parameters of supporting structure of LYSO array.	Density 0.01g/cm^3， position 0.1mm
	Positional un-uniformity of LYSO light output.	Position 1mm， Photon counts 0.1%
	Temperature effect of LYSO and WLSF	Temperature 0.1deg， Photon counts 0.1%
	Attenuation length of WLSF	0.1cm
	Temperature effect of LEDs of fast calibration system	Density 0.1deg， Photon counts 0.1%
SCD/STK	Material definition, density, geometric parameters of Silicon detector	Density 0.01g/cm^3， position 0.1mm

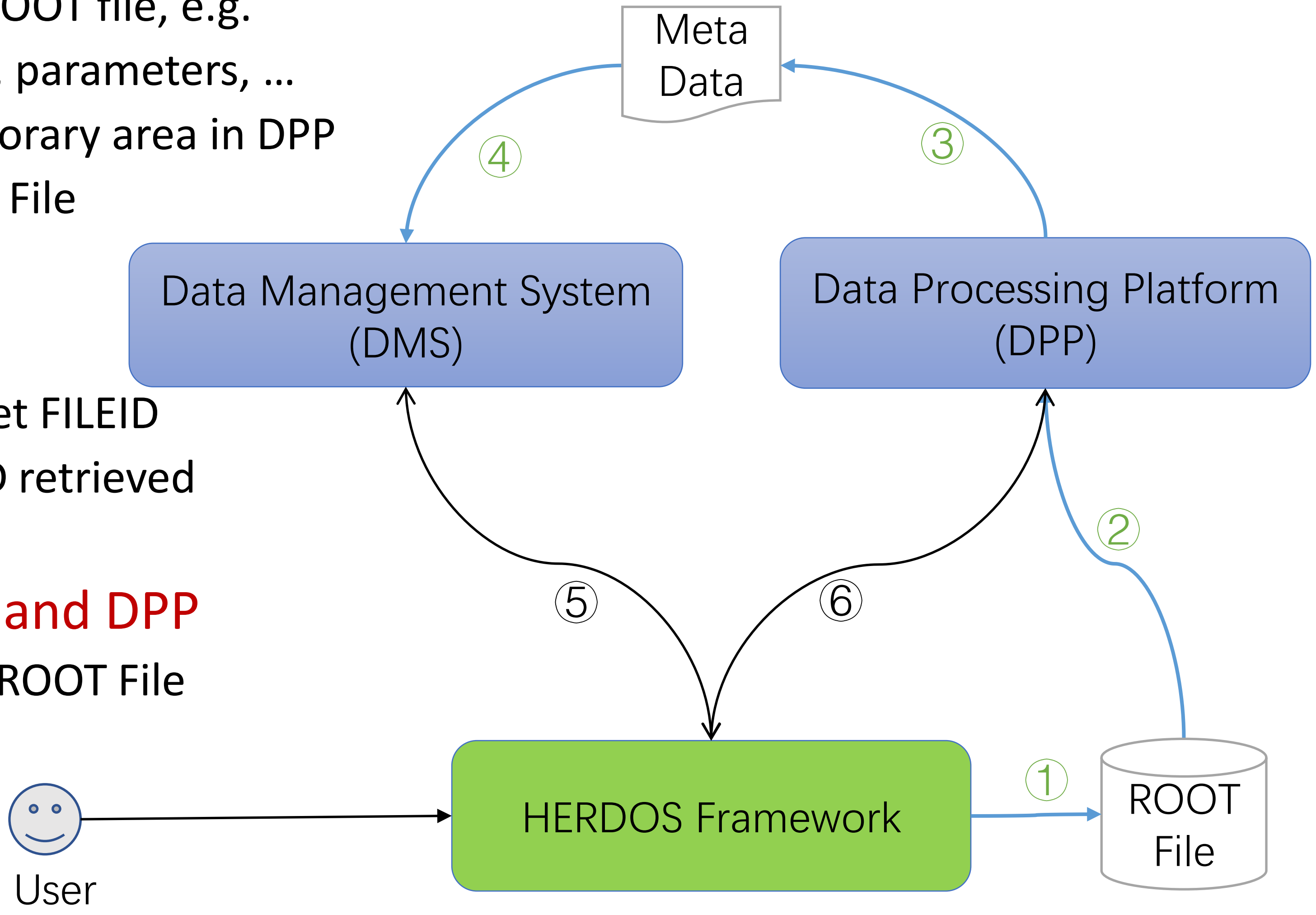
PSD	Material definition, density, geometric parameters of PS	Density 0.01g/cm^3， position 0.1mm
	Material definition, density, geometric parameters of supporting structure of PSD	Density 0.01g/cm^3， position 0.1mm
	Positional un-uniformity of PSD output.	Position 1mm， Photon counts 0.1%
	Temperature effect of PS	Temperature 0.1deg， Photon counts 0.1%
	Temperature effect of PSD-SiPM	Temperature 0.1deg， Photon counts 0.1%
FIT	Material definition, density, geometric parameters of fibers	Density 0.01g/cm^3， position 0.1mm
	Material definition, density, geometric parameters of supporting structure of FIT	Density 0.01g/cm^3， position 0.1mm
	Temperature effect of FIT	Temperature 0.1deg， Photon counts 0.1%
	Temperature effect of FIT-SiPM	Temperature 0.1deg， Photon counts 0.1%
TRD	Material definition, density, geometric parameters of TRD sensitive material	Density 0.01g/cm^3， position 0.1mm
	Material definition, density, geometric parameters of supporting structure of TRD	Density 0.01g/cm^3， position 0.1mm
	Positional and angle un-uniformity of TRD output.	Position 0.1mm， Angle 0.1deg， Photon counts 0.1%

Analysis Tools

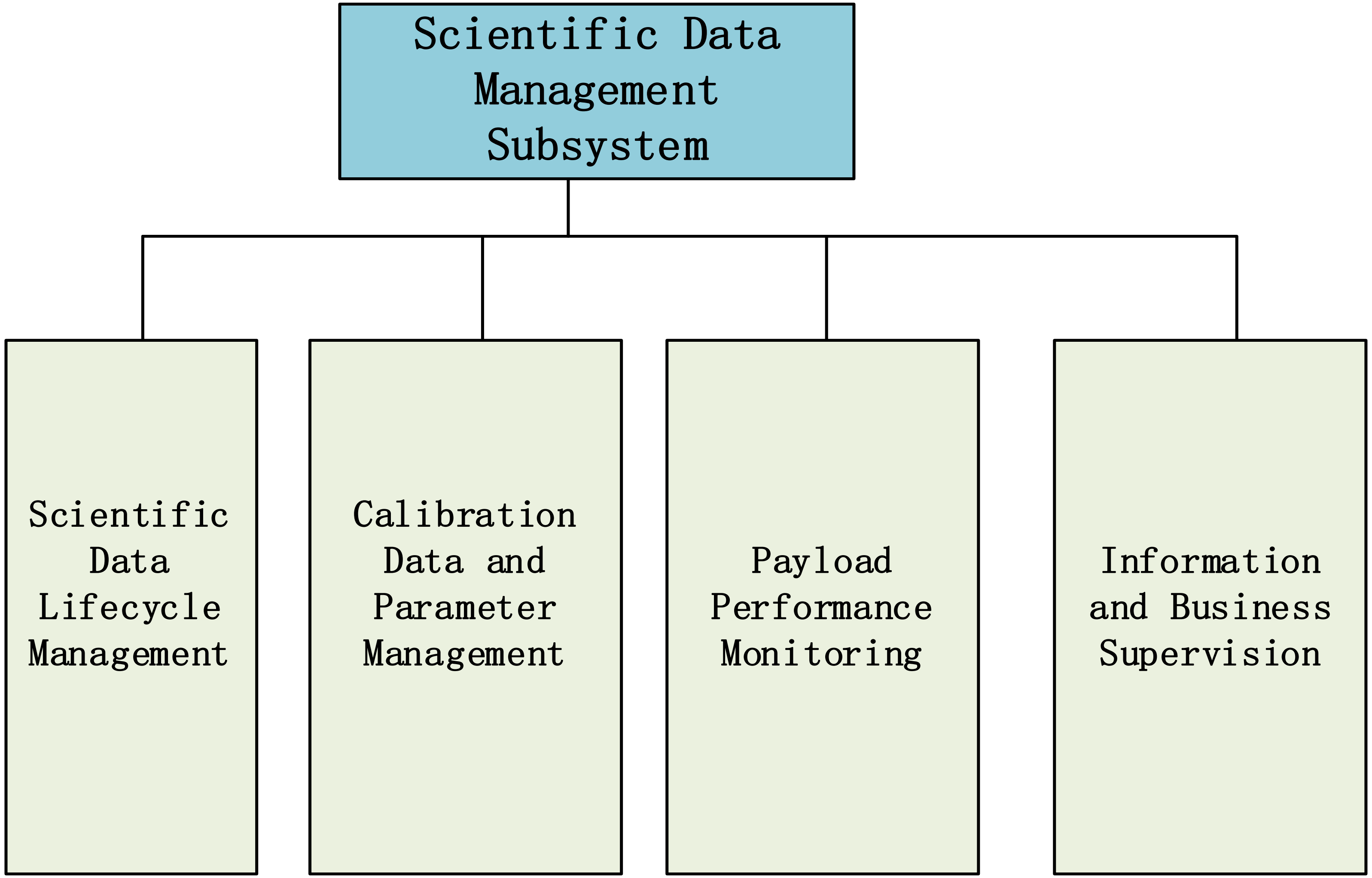
- Particle Identification
  - e/p discrimination
  - Gamma identification
  - Nuclear comprehensive identification
- Flux analysis tools
  - Acceptance
  - Trigger efficiency
  - Back-tracing and cutoff rigidity
  - Exposure time
  - Coordinate system transformation
  - Template fitting
  - Energy unfolding
  - Background above instrument

Framework adopts to the computing infrastructure

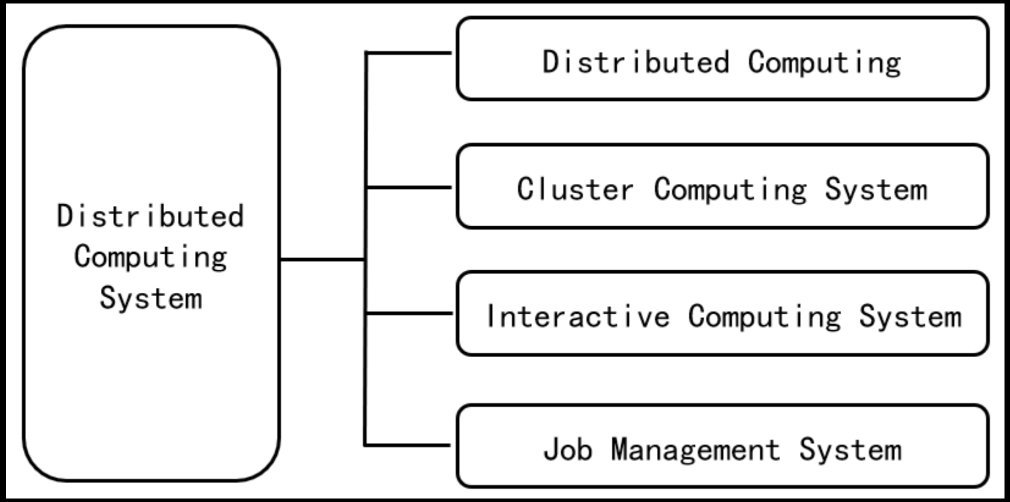
- Metadata registration in the DMS
  - ① Framework write metadata into ROOT file, e.g. site, node, OS, arch, version, user, parameters, …
  - ② ROOT File is moved into the temporary area in DPP
  - ③ Metadata is extracted from ROOT File
  - ④ Metadata is written into DMS
- Metadata query and data access
  - ⑤ Query metadata from DMS and get FILEID
  - ⑥ Read data from DPP using FILEDID retrieved from DMS
- Customized interfaces to the DMS and DPP
  - Metadata information in the output ROOT File
  - Metadata query from the DMS
  - Direct data access to the DPP Storage area



Scientific Data Management



Data Processing Platform



Distributed Computing

Scientific Data Storage and Access

High-performance data transmission

User management and authentication authorization

Conclusion and future plan

- HERDOS is based on Sniper which is **developed and maintained by 10+ faculties** and students from IHEP, SDU and SYSU etc. for non-collider experiments.
- Powerful detector description management system is designed for all applications based on DD4HEP, providing **consistent detector description for all applications** with **multiple versions support.**
- **Concurrent detector simulation for event-level is implemented**, track-level is being developed.
- Multiple Physics Interaction Models, from **geant4-build-in and CRMC** package has been applied, tuning will be applied according to Beam test and flight data.
- **Digitization of all subdetectors, except CALO PD, have been implemented**, parameters are being tuned according to data from test bench, test Beam and also future flight data.
- Four levels of more than 20 reconstruction algorithms are designed, and are being developed in parallelly by more than 15 people. 5 verified by simulation data only have been released, most will be released in August 2024 verified by simulation and BT data.
- More than 10 people are working on computer platform and data managements for HERD based on HERDOS, Automatic work flows of simulation, database for calibration data etc. have been designed and tested.

International Collaboration is very important, any effort is more than welcome!