Discussion On Future Facilities For High Energy Physics In China

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Outline

• High energy physics after the discovery of Higgs boson
• Discussions led by HEPAC on future facilities of high energy physics
  - Z Factory
  - HIEPA (High Intense Electron Positron Accelerator)
  - CEPC + SppC
    - Circular Electron Positron Collider (Higgs Factory)
    - Super Proton Proton Collider (100 TeV)
  - EIC (Electron Ion Collider)
• Non accelerator particle physics
• Summary
SM Is Complete After The Discovery Of Higgs

- Precision and property
  - Mass, width and spin parity
  - Prod. modes and cross sections
  - Decay modes
  - Couplings

- Search for
  - 2 HDM
  - MSSM, NMSSM
  - Doubly charged Higgs

- Higgs as tools for discovery
  - DM (invisible Higgs)
  - Hidden sectors
  - BSM with H in the final states (ZH, WH, HH)

- New physics beyond SM
  - Dark matter
  - Antimatter
  - SUSY
TeV Data Agree With The SM

Standard Model Production Cross Section Measurements

ATLAS Preliminary
Run 1 $\sqrt{s} = 7, 8$ TeV

LHC pp $\sqrt{s} = 7$ TeV
Theory
Data 4.5 – 4.7 fb$^{-1}$

LHC pp $\sqrt{s} = 8$ TeV
Theory
Data 20.3 fb$^{-1}$

$\sigma$ [pb]
CEPC + SppC

Circular $e^+e^-$ Collider: $E_{cm} \approx 240 \text{GeV}, L \sim 2 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$

- $2 \times 10^5$ Higgs, $10^{11} Z$ per year
- Use Higgs particle as discovery tool $\rightarrow$ precision measurement

$pp$ collider: $E_{cm} \approx 50$-100 TeV; ep option

- Potential for discovery

In the same tunnel
Super proton-proton Collider

New particle discovery machine, much higher production cross section for the new particles beyond the SM
One Of The Candidate Site: Qing Huang Dao

300 km away from Beijing
World Wide Effort

International Workshop on Future High Energy Circular Colliders
Dec. 16-17, 2013, IHEP, Beijing

Future Circular Collider Study Kick-off Meeting
12-15 February 2014, University of Geneva, Switzerland

IHEP-KEK Annual Meeting

55th ICFA Advanced Beam Dynamics Workshop on High Luminosity Circular e+e- Colliders
- Higgs Factory

Topics
- Parameters
- Optics
- Interaction region and machine-detector interface
- Synchrotron radiation and shielding
- Superconducting RF
- Injection and extraction
- Beam stability and beam instabilities
- Polarization
- Instrumentation and control

October 9-12, 2014
Hotel Wanda Realm
Beijing, China

SLAC 100 TeV Workshop
Ideal Timeline

- **CEPC (2021 – 2035)**
  - 2015 – 2020: Feasibility, R&D and design
  - 2021 – 2027: Construction
  - 2028 – 2035: Commissioning

- **SppC (2035 – 2055)**
  - 2014 – 2030: Feasibility + R&D
  - 2030 – 2035: Design
  - 2035 – 2042: Construction
  - 2042 – 2055: Commissioning

Too aggressive to believe?
High Intensity Electron Positron Accelerator (HIEPA)

Collaborative Innovation Center for Particle Physics and Interaction

University of Science and Technology of China
Institute of High Energy Physics, CAS
Institute of Theoretical Physics, CAS
Tsinghua University
University of Chinese Academy of Sciences
Shangdong University
Shanghai Jiaotong University
Peking University
Nanjing University
Nankai University
Wuhan University
Hua Zhong Normal University
What Is HIEPA?

- Providing peak luminosity about $1 \times 10^{35}$ cm$^{-2}$s$^{-1}$ at 4 GeV for physics at tau charm sector, covering $E_{cm} = 2-7$ GeV.

- Being a $3^{rd}/4^{th}$ generation SRF (synchrotron radiation facility).

- Reserving the potential for FEL (free electron laser) study with the long LINAC.
HIEPA Machine Layout

$E_{cm} = 2 \text{ - } 7 \text{ GeV}; \quad L = 1 \times 10^{35} \text{ cm}^{-2}\text{s}^{-1} \text{ at } 4 \text{ GeV}$

- For tau-charm physics
- 3\textsuperscript{rd} or 4\textsuperscript{th} generation SRF

$\sim 1000 \text{ m double ring}$
Physics at $\tau$-c Energy Region

- Nucleon form factors
- $\Upsilon(2175)$ resonance
- Multiquark states with $s$ quark, $Z$s
- MLLA/LPHD and QCD sum rule predictions

- Light hadron spectroscopy
- Gluonic and exotic states
- Process of LFV and CPV e.g. $\tau \rightarrow \mu \gamma$
- Rare and forbidden decays
- Physics with $\tau$ lepton

- $\text{XYZ}$ particles
- Physics with D mesons
- $f_D$ and $f_{D_s}$
- $D_0$-$\bar{D}_0$ mixing
- Charm baryons

$R = \sigma(e^+ e^- \rightarrow \text{hadrons})/\sigma(e^+ e^- \rightarrow \mu^+ \mu^-)$

- Precision $\Delta \alpha_{\text{QED}}$, $a_\mu$, charm quark mass extraction.
- Hadron form factor(nucleon, $\Lambda$, $\pi$).
Key science question: is there any new forms of hadron exist?

**Standard hadrons**

**Exotic hadrons**

- Exotic hadrons: made of quarks and possibly gluon, but do not have the same quark content as ordinary hadrons. They are not predicted by the simple quark model.

- After several decades’ effort, XYZ particles, such as X(3872), Y(4260) and Zc(3900) discovered by Belle, Babar and BESIII experiments.

- To reach conclusive evidence of an exotic hadron, an e^+e^- collider in the τ-c sector, which is able to provide much higher statistical data and cover broader energy range is essential.
Z_c(3900) Observed at BESIII and Belle

Belle with ISR: PRL110, 252002
967 fb\(^{-1}\) in 10 years running time

BESIII at 4.260 GeV: PRL110, 252001
0.525 fb\(^{-1}\) in one month running time

- \(M = 3894.5 \pm 6.6 \pm 4.5\) MeV
- \(\Gamma = 63 \pm 24 \pm 26\) MeV
- 159 \(\pm 49\) events
- \(>5.2\sigma\)

- \(M = 3899.0 \pm 3.6 \pm 4.9\) MeV
- \(\Gamma = 46 \pm 10 \pm 20\) MeV
- 307 \(\pm 48\) events
- \(>8\sigma\)
Nucleon Electromagnetic Form Factors (NEFFs)

• **Key science question**: why do quarks form colourless hadrons with only two stable configurations, proton and neutron?

• NEFFs are among the most basic observables of the nucleon, and intimately related to its internal structure.

• Nucleons are the building blocks of almost all-ordinary matter in the universe. The challenge of understanding the nucleon's structure and dynamics has occupied a central place in particle physics.

• The fundamental understanding of the NEFFs and HEFF (hadron form factor) in terms of QCD is one of the outstanding problems in particle physics.
Nucleon Electromagnetic Form Factors (NEFFs)

Space-like: FF real

Time-like: FF complex

Only 2 measurements, but results are contradict
Measurement of Proton FFs at HIEPA

Example @ 2.23 GeV

<table>
<thead>
<tr>
<th>Nsig</th>
<th>$\frac{\delta R_{EM}}{R_{EM}}$</th>
<th>$\frac{\delta \sigma}{\sigma}$</th>
<th>Luminosity (pb$^{-1}$)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$3881 \pm 62$</td>
<td>9.5%</td>
<td>1.6%</td>
<td>16.630</td>
<td>BESIII expected</td>
</tr>
<tr>
<td>$156253 \pm 395$</td>
<td>1.5%</td>
<td>0.25%</td>
<td>669.533</td>
<td>HIEPA reach 1</td>
</tr>
<tr>
<td>$389898 \pm 624$</td>
<td>0.96%</td>
<td>0.16%</td>
<td>1670.69</td>
<td>HIEPA reach 2</td>
</tr>
</tbody>
</table>

HIEPA reach 1

$c_0 = 1.082 \pm 0.015$

frac2 = 156253 ± 395

HIEPA reach 2

$c_0 = 1.0763 \pm 0.0096$

frac2 = 389898 ± 624
New Physics

• The discovery of the Higgs particle completes the list of the particles in the SM.

• Physics beyond the SM due to phenomena that cannot be explained within the SM framework:
  - SM does not explain gravity
  - SM does not supply any fundamental particles that are good dark matter candidates, nor be able to explain dark energy
  - No mechanism in the SM sufficient to explain asymmetry of matter and anti-matter.

• No evidence of new physics been found at high energy frontier, it is important to search for new physics both directly and indirectly in the precision frontier.
Lepton Flavour Violating (LFV)

**CLFV processes** sensitive to New Physics (NP) through lepton-lepton coupling

\[ y_{ij} \ell_i F_{\mu \nu} \ell_j \sigma_{\mu \nu} \]

**PSI**
- \( \mu \rightarrow e\gamma \)
- \( \tau \rightarrow \mu\gamma \)
- \( \tau \rightarrow e\gamma \)
- \( \mu \rightarrow eee \)

**Mu2e**
- \( \mu^- \bar{N} \rightarrow e^- \bar{N} \)
- \( (g - 2)_\mu \)

\( \mu, \tau \) anomalous decays

\( \mu \rightarrow e \) conversion

Anomalous magnetic moment
# HIEPA Timeline

<table>
<thead>
<tr>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
</tr>
</tbody>
</table>

- **Kick-off collaboration forming**
- **Workshops**
  - Feasibility study
  - Review
- **CDR, R&D → TDR?**
China Jinping Underground Laboratory

2400 m overburden of marble
The deepest in the world
• PandaX = Particle AND Astrophysical Xenon Detector

• Objective: using dual-phase XENON technology to perform direct search for dark matter and neutrinoless double beta decay of $^{136}\text{Xe}$

Phase I: 125 kg
Phase II: 500 kg
Phase III: 1.5 ton?

Mar 2014: started physics run (125 kg active target)
• **CDEX-1**: Development of HPGe detector.

• **CDEX-10**: HPGe array detector system and its passive/active shielding systems.

• **CDEX-10X**: Fabrication of HPGe detector and Germanium crystal growth by our group.

• **CDEX-1T**: Multi-purpose experiment for dark matter and double beta decay.
CDEX-1 Physical Results

- The first dark matter physical result from China!
- The lowest energy threshold of PCGe!
- 10 times improved sensitivity!
- The best sensitivity by PCGe!
- Excludes the region favored by CoGeNT with same technology!

W. Zhao et al., Phys. Rev. D 88, 052004 (2013);

DArk Matter Particle Explore (DAMPE)

- 4 sub-detectors to measure $\text{e}^+/-, \gamma$ and ion
- Energy: $5\text{GeV} \sim 10\text{TeV}$
- Resolution: $1.5\% @ 800\text{GeV}$
- $\text{p, e}$ separation: $< 1\%$
- Altitude 500 km
- Inclination $97.4065^\circ$
- Period 90 minutes
- Sun-synchronous orbit
Detector and Collaboration

Plastic Scintillator (IMP)
Silicon strip (Geneva U./IHEP)
EMCAL (BGO) (USTC)
Neutron detector (PMO)
Timeline

• Dec. 2011, approved for construction;
• Oct. 2012, prototype beam test;
• Currently: various tests for engineering model (thermal, vacuum, magnetic, gravity, beam...); flight model under construction;
• Scheduled launch: 2015.
Main Array:
6300 scintillator detectors every 15 m &
1220 μ–detectors every 30 m

Water Cherenkov Detector
90,000 m²

Central Array
24 Wide field View Cherenkov telescopes:
precision measurement of CR spectrum
542 burst detectors:
identification of primary CR species

LHAASO
Prospects and Status

- LHAASO observatory
  - Unique at 10 TeV $\gamma$ monitoring with highest sensitivity
  - Window for discovering the hadronic origins of cosmic rays
  - Provides crucial CR data in the region of knees

- Agreement with Sichuan province for site is scheduled to be signed next month. This will pave the road to start the construction of LHAASO next year
## JUNO

<table>
<thead>
<tr>
<th>NPP</th>
<th>Daya Bay</th>
<th>Huizhou</th>
<th>Lufeng</th>
<th>Yangjiang</th>
<th>Taishan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status</td>
<td>Operational</td>
<td>Planned</td>
<td>Planned</td>
<td>Under construction</td>
<td>Under construction</td>
</tr>
<tr>
<td>Power</td>
<td>17.4 GW</td>
<td>17.4 GW</td>
<td>17.4 GW</td>
<td>17.4 GW</td>
<td>18.4 GW</td>
</tr>
</tbody>
</table>

**Overburden ~ 700 m**

Kaiping, Jiang Men city, Guangdong Province

**by 2020: 26.6 GW**

Cores: YJ-C1, YJ-C2, YJ-C3, YJ-C4, YJ-C5, YJ-C6

- Power (GW): 2.9, 2.9, 2.9, 2.9, 2.9, 2.9
- Baseline (km): 52.75, 52.84, 52.42, 52.51, 52.12, 52.21

Cores: TS-C1, TS-C2, TS-C3, TS-C4, DYB, HZ

- Power (GW): 4.6, 4.6, 4.6, 4.6, 17.4, 17.4
- Baseline (km): 52.76, 52.63, 52.32, 52.20, 215, 265

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<table>
<thead>
<tr>
<th>Cities</th>
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<tbody>
<tr>
<td>Hong Kong</td>
</tr>
<tr>
<td>Shen Zhen</td>
</tr>
<tr>
<td>Zhu Hai</td>
</tr>
<tr>
<td>Lufeng NPP</td>
</tr>
<tr>
<td>Taishan NPP</td>
</tr>
<tr>
<td>Yangjiang NPP</td>
</tr>
</tbody>
</table>

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Distance: 53 km

2.5 h drive

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2014-6-16
JUNO Detector

Muon detector

Steel Tank

~20kt water

~6kt MO

~1500 20" VETO PMTs

20 kt LS

coverage: ~77%

~18000 20” PMTs

Acrylic tank: \( \Phi \sim 35.4 \text{m} \)

Stainless Steel tank: \( \Phi \sim 39.0 \text{m} \)

JUNO

<table>
<thead>
<tr>
<th></th>
<th>KamLAND</th>
<th>BOREXINO</th>
<th>JUNO</th>
</tr>
</thead>
<tbody>
<tr>
<td>LS mass</td>
<td>1 kt</td>
<td>0.5 kt</td>
<td>20 kt</td>
</tr>
<tr>
<td>Energy Resolution</td>
<td>6%/</td>
<td>5%/</td>
<td>3%/</td>
</tr>
<tr>
<td>Light yield</td>
<td>250 p.e./MeV</td>
<td>511 p.e./MeV</td>
<td>1200 p.e./MeV</td>
</tr>
</tbody>
</table>
Summary

• China is at a **critical** time to define the future projects for particle physics.

• HEPAC is helping lay the roadmap for particle physics of China. The projects with accelerator for high energy physics under discussion are **CEPC+SppC, Z Factory, HIEPA** and **EIC** (bring high energy and nuclear physics together)

• CJPL has the potential to be built to a world first class deep underground lab for tackling the key science question of our century.

• Particle/nuclear physics are **global science**, our opinion should be globalized when planning our future projects.
My Comments to CEPC+SppC

A Higgs factory (e^+e^- collider) and a super hadron collider (~ 100 TeV pp, ep, eA) will be the project of the high energy physics of the world → Global big science

• Probing the key science questions
• World wide advanced technology
• Center of the high energy physics of the world

I believe China dream will become true, hope that CEPE+SppC dream could be part of the China dream.

Big questions: are we ready for the projects? → Expertise, key technologies, education system, sustainable financial support to high energy physics community……
Heavy Ion Accelerator Facility (HIAF)

- (BR+SR+CR): high quality & intensity pulsed RIBs, β beam
  - high accuracy RIA, astrophysics, application...
- (BR+SR+CR): high power compressed U beam
  - HED...
- (BR+SR+CR+ER): polarized e & p beams
  - EIC
  - U+U, RIB+RIB...
  - Merging Experiments...

10’s MW Spallation Target
Integrate with HIAF:
Power In Flight and
ISOL for RIB & β Beam

Could be an accelerator complex in China
electron, proton, heavy ion
Neutrino beam

中科院: 詹文龙
Oct. 18. 2013
A. Pich

Status & Outlook

- The SM appears to be the right theory at the EW scale
- The H(125) behaves as the SM scalar boson
- The CKM mechanism works very well
- Neutrinos do have (tiny) masses. Lepton flavour is violated
- Different flavour structure for quarks & leptons
- **New physics needed** to explain many pending questions:
  Flavour, CP, baryogenesis, dark matter, cosmology...

- How far is the Scale of New-Physics $\Lambda_{NP}$?
- Which symmetry keeps $M_H$ away from $\Lambda_{NP}$?
  Supersymmetry, scale/conformal symmetry...
- Which kind of New Physics?
Conclusions

“Where is everybody? What is the scale of new physics?”

Proton decay: $>10^{15}$ GeV
Flavor violations: $>10^8$ GeV
CP violation (EDMs): $10^4$ GeV

New physics should be around the TeV scale
to stabilize the Higgs potential (aka hierarchy problem).
That makes the Higgs a very special character

Precision Higgs physics is on the HEP agenda for the next 2-3 decades
- for a deep understanding of the SM
- for an accurate comparison with experiments
- for an access to BSM
Is it
- the SM Higgs?
- an elementary/composite particle?
- unique/solitary?
- eternal/temporary?
- natural?
- the first supersymmetric particle ever observed?
- really “responsible” for the masses of all the elementary particles?
- mainly produced by top quarks or by new heavy vector-like quarks?
- a portal to a hidden world?
- at the origin of the matter-antimatter asymmetry?
- Has it driven the inflationary expansion of the Universe?
Motivation

- Nature of dark matter unknown.
- WIMPs -- well motivated candidate.
- Three strategies to detect.

New Physics?

DM

Indirect Detection

S

Direct Detection

M

Production

SM

CDEX target:
Direct detection of low mass cold dark matter with ton-scale PCGe array with ultra-low energy threshold (<300eVee).
## Forthcoming Discoveries in Particle Physics

<table>
<thead>
<tr>
<th>Topic</th>
<th>Crucial measurement</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>WIMP</td>
<td>Existence</td>
<td>Dark Mater</td>
</tr>
<tr>
<td><strong>Higgs boson</strong></td>
<td>M (~125) GeV</td>
<td>Confirm spontaneous symmetry breaking in gauge theory</td>
</tr>
<tr>
<td>Super-symmetric particles</td>
<td>Existence, M &gt; 1 TeV</td>
<td>Hope of understanding gravity</td>
</tr>
<tr>
<td>Technicolour particles</td>
<td>Existence, M &gt; TeV?</td>
<td>Dynamic symmetry breaking, Composite Higgs</td>
</tr>
<tr>
<td>Gravitational waves (Gravitons)</td>
<td>Existence</td>
<td>Support general relativity</td>
</tr>
<tr>
<td>Magnetic monopole</td>
<td>Existence, mass, electric charge</td>
<td>Electric and magnetic charge symmetry predicted by Dirac. Structure of gauge field configuration</td>
</tr>
<tr>
<td>Free quarks</td>
<td>Existence, fractional charge</td>
<td>Would confuse all current prejudice</td>
</tr>
<tr>
<td>Neutrino mass and oscillation</td>
<td>M &lt; 1 eV</td>
<td>Structure of GUTs. Eventual fate of the universe</td>
</tr>
<tr>
<td><strong>Exotic hadron Glueball</strong></td>
<td>M_g = 1-2 GeV, M_{exotic, c} (~4) GeV</td>
<td>Understand QCD</td>
</tr>
</tbody>
</table>
Features of the $\tau$-c Energy Region

- Rich of resonances, charmonium and charmed mesons.
- Threshold characteristics (pairs of $\tau$, D, D$_s$, charmed baryons...).
- Transition between smooth and resonances, perturbative and non-perturbative QCD.
- Mass location of the exotic hadrons, gluonic matter and hybrid.
$M_H = (125.36 \pm 0.37 \pm 0.18) \text{ GeV}$

$M_H = (125.03^{+0.26+0.13}_{-0.27-0.15}) \text{ GeV}$
Nucleon Electromagnetic Form Factors (NEFFs)

Spatial distributions of electric charge and current inside the nucleon

Vector current, two form factors \((F_1\) and \(F_2\))

\[
\Gamma_\mu = e\bar{u}(p')[F_1(q^2)\gamma_\mu + \frac{\kappa}{2M_N}F_2(q^2)i\sigma_\mu\nu q^\nu]u(p)e^{iq\cdot x}
\]

**Dirac**

\[
\begin{align*}
F_1^p(q^2 = 0) &= 1 \\
F_1^m(q^2 = 0) &= 0
\end{align*}
\]

**Pauli**

\[
\begin{align*}
F_2^p(q^2) &= 1 \\
F_2^m(q^2) &= 1
\end{align*}
\]

**Sachs**

\[
G_E = F_1 + \frac{\kappa q^2}{4M^2}F_2 \\
G_M = F_1 + \kappa F_2
\]

\(G_E(4M_P^2) = G_M(4M_P^2)\)
There have been many measurements of the proton form factors in the space-like region. At Jlab, the proton factor ratio was measured precisely with an uncertainty of \(\sim 1\%\), based on which the proton electronic and magnetic radii could be extracted.
Proton Form Factor: $|G_E|/|G_M|$

\[
\sigma_{e^+e^-\rightarrow NN} = \frac{4\pi\alpha^2\beta}{3s} C_N(s) \left[ |G_M^N(q^2)|^2 + \frac{2M_N^2}{s} |G_E^N(q^2)|^2 \right]
\]

\[
\sigma_0 = \frac{4\pi\alpha^2\beta}{3s} \left(1 + \frac{2M_N^2}{s}\right)|G(s)|^2
\]

Only 2 measurements, but results are contradict

QCD predict

\[
|G(s)| = \frac{A}{s^2 \ln^2(s/\Lambda^2)}
\]

Complete picture of the nucleon structure requires space-like and time-like measurements!
Motivation

ATIC

AMS-02
# Exotic Hadrons

*(possible combination of quark and glue)*

<table>
<thead>
<tr>
<th><strong>Pentaquark</strong></th>
<th><strong>H-diBaryon</strong></th>
<th><strong>Tentraquark</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Pentaquark" /></td>
<td><img src="image" alt="H-diBaryon" /></td>
<td><img src="image" alt="Tentraquark" /></td>
</tr>
<tr>
<td>S=+1 Baryon</td>
<td>Tightly bound 6-quark state</td>
<td>Tightly bound diquark-diantiquark</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Meson molecule</strong></th>
<th><strong>Glueball</strong></th>
<th><strong>Hybrid</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Meson molecule" /></td>
<td><img src="image" alt="Glueball" /></td>
<td><img src="image" alt="Hybrid" /></td>
</tr>
<tr>
<td>Loosely bound meson-antimeson</td>
<td>Color-single multi-glue bound state</td>
<td>qq glue hybrid</td>
</tr>
</tbody>
</table>
\( \tau \rightarrow \mu \gamma \)

- The process \( e^+e^- \rightarrow \tau^+\tau^-\gamma \), dominant background source at \( \Upsilon(4S) \), does not contribute below \( 2E \approx 4m_\tau/\sqrt{3} \approx 4.1 \) GeV.
- The favorable kinematical condition and the use of polarization can allow an UL(STCF in 1-2 years) \( \leq \) UL(SuperBelle@Y in 12-15 yrs).
DARK Matter Particle Explorer (DAMPE)