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

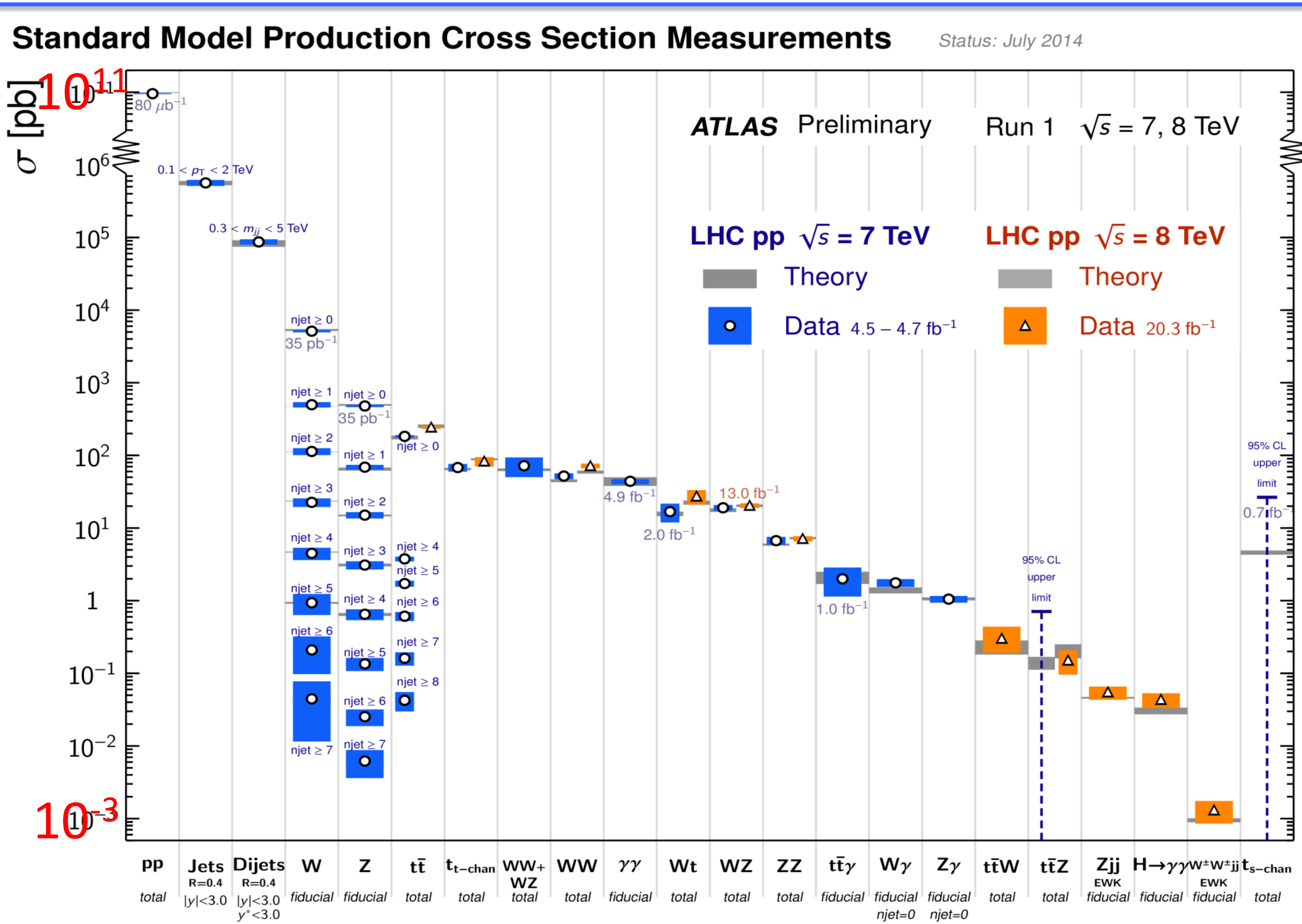
Search for
- 2 HDM
- MSSM, NMSSM
- Doubly charged Higgs

H

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



ATLAS Exotic Searches

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: ICHEP 2014

ATLAS Preliminary

$\sqrt{s}$ = 7, 8 TeV

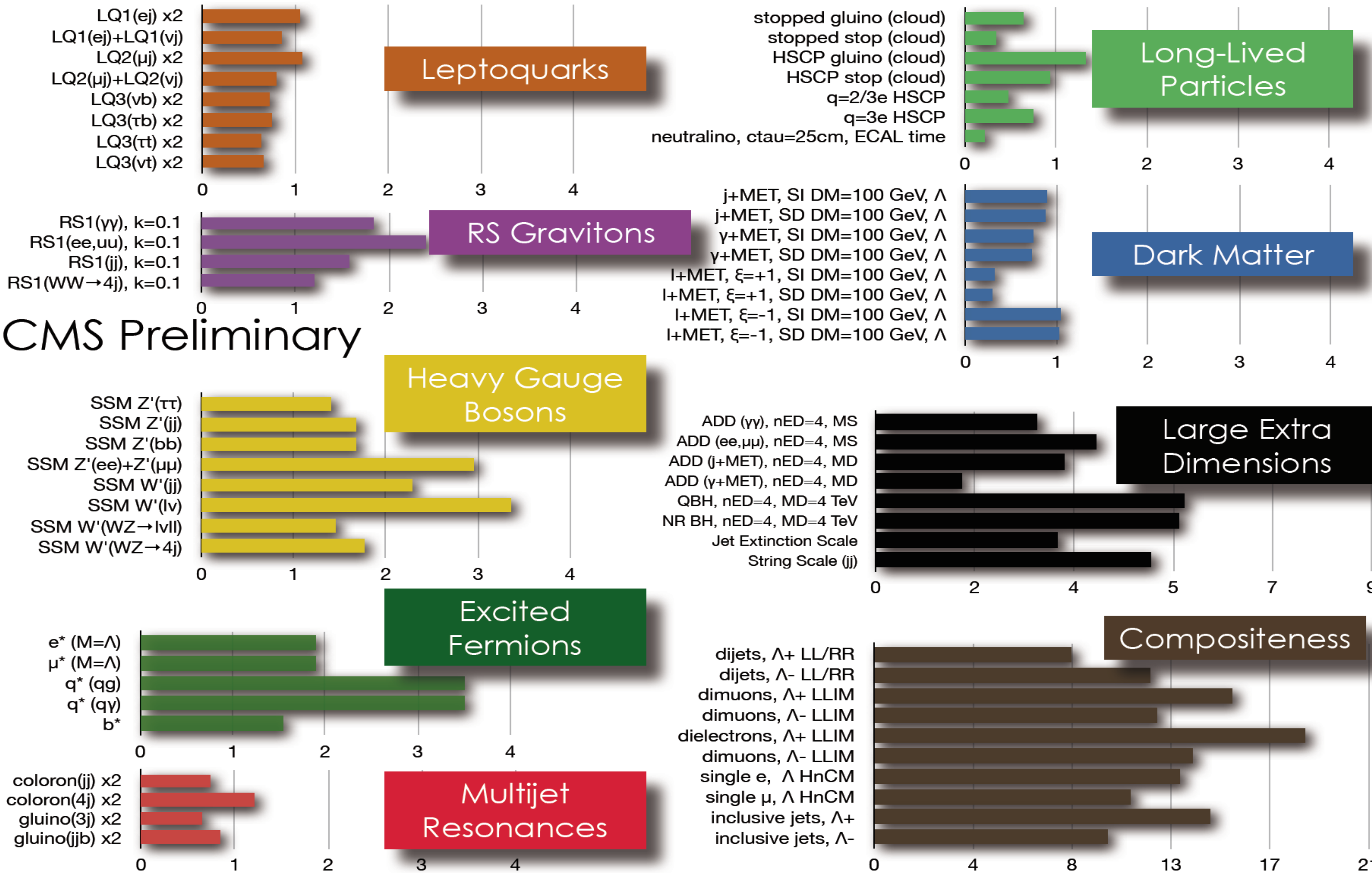
	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\,dt[fb^{-1}]$	Mass limit		Reference
Inclusive Searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	$\tilde{q}, \tilde{g}$ 1.7 TeV	$m(\tilde{q})=m(\tilde{g})$	1405.7875
	MSUGRA/CMSSM	1 e,μ	3-6 jets	Yes	20.3	$\tilde{g}$ 1.2 TeV	any $m(\tilde{q})$	ATLAS-CONF-2013-062
	MSUGRA/CMSSM	0	7-10 jets	Yes	20.3	$\tilde{g}$ 1.1 TeV	any $m(\tilde{q})$	1308.1841
	$\tilde{q}\tilde{q}, \tilde{q}\rightarrow q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{q}$ 850 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, m(1st gen. $\tilde{q}$)=m(2nd gen. $\tilde{q}$)	1405.7875
	$\tilde{g}\tilde{g}, \tilde{g}\rightarrow q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$ 1.33 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	1405.7875
	$\tilde{g}\tilde{g}, \tilde{g}\rightarrow qq\tilde{\chi}_1^{\pm}\rightarrow qqW^{\pm}\tilde{\chi}_1^0$	1 e,μ	3-6 jets	Yes	20.3	$\tilde{g}$ 1.18 TeV	$m(\tilde{\chi}_1^0)$<200 GeV, $m(\tilde{\chi}^{\pm})$=0.5($m(\tilde{\chi}_1^0)$+$m(\tilde{g})$)	ATLAS-CONF-2013-062
	$\tilde{g}\tilde{g}, \tilde{g}\rightarrow qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	2 e,μ	0-3 jets	-	20.3	$\tilde{g}$ 1.12 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-089
	GMSB ($\tilde{\ell}$ NLSP)	2 e,μ	2-4 jets	Yes	4.7	$\tilde{g}$ 1.24 TeV	tanβ<15	1208.4688
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	20.3	$\tilde{g}$ 1.6 TeV	tanβ >20	1407.0603
	GGM (bino NLSP)	2 γ	-	Yes	20.3	$\tilde{g}$ 1.28 TeV	$m(\tilde{\chi}_1^0)$>50 GeV	ATLAS-CONF-2014-001
	GGM (wino NLSP)	1 $e,\mu + \gamma$	-	Yes	4.8	$\tilde{g}$ 619 GeV	$m(\tilde{\chi}_1^0)$>50 GeV	ATLAS-CONF-2012-144
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	4.8	$\tilde{g}$ 900 GeV	$m(\tilde{\chi}_1^0)$>220 GeV	1211.1167
	GGM (higgsino NLSP)	2 e,μ (Z)	0-3 jets	Yes	5.8	$\tilde{g}$ 690 GeV	m(NLSP)>200 GeV	ATLAS-CONF-2012-152
	Gravitino LSP	0	mono-jet	Yes	10.5	$F^{1/2}$ scale 645 GeV	$m(\tilde{G})>10^{-4}$ eV	ATLAS-CONF-2012-147
3rd gen. $\tilde{g}$ med.	$\tilde{g}\rightarrow b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	20.1	$\tilde{g}$ 1.25 TeV	$m(\tilde{\chi}_1^0)$<400 GeV	1407.0600
	$\tilde{g}\rightarrow t\bar{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3	$\tilde{g}$ 1.1 TeV	$m(\tilde{\chi}_1^0)$ <350 GeV	1308.1841
	$\tilde{g}\rightarrow t\bar{t}\tilde{\chi}_1^0$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$ 1.34 TeV	$m(\tilde{\chi}_1^0)$<400 GeV	1407.0600
	$\tilde{g}\rightarrow b\bar{t}\tilde{\chi}_1^+$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$ 1.3 TeV	$m(\tilde{\chi}_1^0)$<300 GeV	1407.0600
3rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\rightarrow b\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$\tilde{b}_1$ 100-620 GeV	$m(\tilde{\chi}_1^0)$<90 GeV	1308.2631
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\rightarrow t\tilde{\chi}_1^{\pm}$	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{b}_1$ 275-440 GeV	$m(\tilde{\chi}_1^{\pm})$=2 $m(\tilde{\chi}_1^0)$	1404.2500
	$\tilde{t}_1\tilde{t}_1$ (light), $\tilde{t}_1\rightarrow b\tilde{\chi}_1^{\pm}$	1-2 e,μ	1-2 b	Yes	4.7	$\tilde{t}_1$ 110-167 GeV	$m(\tilde{\chi}_1^0)$=55 GeV	1208.4305, 1209.2102
	$\tilde{t}_1\tilde{t}_1$ (light), $\tilde{t}_1\rightarrow Wb\tilde{\chi}_1^0$	2 e,μ	0-2 jets	Yes	20.3	$\tilde{t}_1$ 130-210 GeV	$m(\tilde{\chi}_1^0)$ =$m(\tilde{t}_1)$-$m(W)$-50 GeV, $m(\tilde{t}_1)$<<$m(\tilde{\chi}_1^{\pm})$	1403.4853
	$\tilde{t}_1\tilde{t}_1$ (medium), $\tilde{t}_1\rightarrow t\tilde{\chi}_1^0$	2 e,μ	2 jets	Yes	20.3	$\tilde{t}_1$ 215-530 GeV	$m(\tilde{\chi}_1^0)$=1 GeV	1403.4853
	$\tilde{t}_1\tilde{t}_1$ (medium), $\tilde{t}_1\rightarrow b\tilde{\chi}_1^{\pm}$	0	2 b	Yes	20.1	$\tilde{t}_1$ 150-580 GeV	$m(\tilde{\chi}_1^0)$<200 GeV, $m(\tilde{\chi}_1^{\pm})$-$m(\tilde{\chi}_1^0)$=5 GeV	1308.2631
	$\tilde{t}_1\tilde{t}_1$ (heavy), $\tilde{t}_1\rightarrow t\tilde{\chi}_1^0$	1 e,μ	1 b	Yes	20	$\tilde{t}_1$ 210-640 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	1407.0583
	$\tilde{t}_1\tilde{t}_1$ (heavy), $\tilde{t}_1\rightarrow t\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$\tilde{t}_1$ 260-640 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	1406.1122
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\rightarrow c\tilde{\chi}_1^0$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$ 90-240 GeV	$m(\tilde{t}_1)$-$m(\tilde{\chi}_1^0)$<85 GeV	1407.0608
	$\tilde{t}_1\tilde{t}_1$ (natural GMSB)	2 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$ 150-580 GeV	$m(\tilde{\chi}_1^0)$>150 GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\rightarrow\tilde{t}_1 + Z$	3 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_2$ 290-600 GeV	$m(\tilde{\chi}_1^0)$<200 GeV	1403.5222
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell}\rightarrow\ell\tilde{\chi}_1^0$	2 e,μ	0	Yes	20.3	$\tilde{\ell}$ 90-325 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\rightarrow\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e,μ	0	Yes	20.3	$\tilde{\chi}_1^{\pm}$ 140-465 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\ell},\tilde{\nu})$=0.5($m(\tilde{\chi}_1^{\pm})$+$m(\tilde{\chi}_1^0)$)	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\rightarrow\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$ 100-350 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\tau},\tilde{\nu})$=0.5($m(\tilde{\chi}_1^{\pm})$+$m(\tilde{\chi}_1^0)$)	1407.0350
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\rightarrow\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu), \ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e,μ	0	Yes	20.3	$\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$ 700 GeV	$m(\tilde{\chi}_1^{\pm})$=$m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell},\tilde{\nu})$=0.5($m(\tilde{\chi}_1^{\pm})$+$m(\tilde{\chi}_1^0)$)	1402.7029
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\rightarrow W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$	2-3 e,μ	0	Yes	20.3	$\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$ 420 GeV	$m(\tilde{\chi}_1^{\pm})$=$m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, sleptons decoupled	1403.5294, 1402.7029
	$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0\rightarrow W\tilde{\chi}_1^0 h\tilde{\chi}_1^0$	1 e,μ	2 b	Yes	20.3	$\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^0$ 285 GeV	$m(\tilde{\chi}_1^{\pm})$=$m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, sleptons decoupled	ATLAS-CONF-2013-093
	$\tilde{\chi}_2^0\tilde{\chi}_3^0, \tilde{\chi}_{2,3}^0\rightarrow\tilde{\ell}_R\ell$	4 e,μ	0	Yes	20.3	$\tilde{\chi}_{2,3}^0$ 620 GeV	$m(\tilde{\chi}_2^0)$=$m(\tilde{\chi}_3^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell},\tilde{\nu})$=0.5($m(\tilde{\chi}_2^0)$+$m(\tilde{\chi}_1^0)$)	1405.5086
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^{\pm}$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}_1^{\pm}$ 270 GeV	$m(\tilde{\chi}_1^{\pm})$-$m(\tilde{\chi}_1^0)$=160 MeV, $\tau(\tilde{\chi}_1^{\pm})$=0.2 ns	ATLAS-CONF-2013-069
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$ 832 GeV	$m(\tilde{\chi}_1^0)$=100 GeV, 10 μs<$\tau(\tilde{g})$<1000 s	1310.6584
	GMSB, stable $\tilde{\tau}, \tilde{\chi}_1^0\rightarrow\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	15.9	$\tilde{\chi}_1^0$ 475 GeV	10<tanβ<50	ATLAS-CONF-2013-058
	GMSB, $\tilde{\chi}_1^0\rightarrow\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	4.7	$\tilde{\chi}_1^0$ 230 GeV	0.4<$\tau(\tilde{\chi}_1^0)$<2 ns	1304.6310
	$\tilde{q}\tilde{q}, \tilde{\chi}_1^0\rightarrow qq\mu$ (RPV)	1 μ, displ. vtx	-	-	20.3	$\tilde{q}$ 1.0 TeV	1.5 <$c\tau$<156 mm, BR(μ)=1, $m(\tilde{\chi}_1^0)$=108 GeV	ATLAS-CONF-2013-092
RPV	LFV $pp\rightarrow\tilde{\nu}_\tau + X, \tilde{\nu}_\tau\rightarrow e + \mu$	2 e,μ	-	-	4.6	$\tilde{\nu}_\tau$ 1.61 TeV	λ'_{311}=0.10, λ_{132}=0.05	1212.1272
	LFV $pp\rightarrow\tilde{\nu}_\tau + X, \tilde{\nu}_\tau\rightarrow e(\mu) + \tau$	1 $e,\mu + \tau$	-	-	4.6	$\tilde{\nu}_\tau$ 1.1 TeV	λ'_{311}=0.10, $\lambda_{1(2)33}$=0.05	1212.1272
	Bilinear RPV CMSSM	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{q}, \tilde{g}$ 1.35 TeV	$m(\tilde{q})$=$m(\tilde{g})$, $c\tau_{LSP}$<1 mm	1404.2500
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\rightarrow W\tilde{\chi}_1^0, \tilde{\chi}_1^0\rightarrow ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e,μ	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$ 750 GeV	$m(\tilde{\chi}_1^0)$>0.2×$m(\tilde{\chi}_1^{\pm})$, $\lambda_{121}\neq0$	1405.5086
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\rightarrow W\tilde{\chi}_1^0, \tilde{\chi}_1^0\rightarrow\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 $e,\mu + \tau$	-	Yes	20.3	$\tilde{\chi}_1^{\pm}$ 450 GeV	$m(\tilde{\chi}_1^0)$>0.2×$m(\tilde{\chi}_1^{\pm})$, $\lambda_{133}\neq0$	1405.5086
	$\tilde{g}\rightarrow qqq$	0	6-7 jets	-	20.3	$\tilde{g}$ 916 GeV	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2013-091
	$\tilde{g}\rightarrow\tilde{t}_1 t, \tilde{t}_1\rightarrow bs$	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{g}$ 850 GeV		1404.250
Other	Scalar gluon pair, sgluon$\rightarrow q\bar{q}$	0	4 jets	-	4.6	sgluon 100-287 GeV	incl. limit from 1110.2693	1210.4826
	Scalar gluon pair, sgluon$\rightarrow t\bar{t}$	2 e,μ (SS)	2 b	Yes	14.3	sgluon 350-800 GeV		ATLAS-CONF-2013-051
	WIMP interaction (D5, Dirac χ)	0	mono-jet	Yes	10.5	M* scale 704 GeV	$m(\chi)$<80 GeV, limit of<687 GeV for D8	ATLAS-CONF-2012-147

$\sqrt{s}$ = 7 TeV full data | $\sqrt{s}$ = 8 TeV partial data | $\sqrt{s}$ = 8 TeV full data

10^{-1} 1 **Mass scale [TeV]**

*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

CMS Exotic Searches



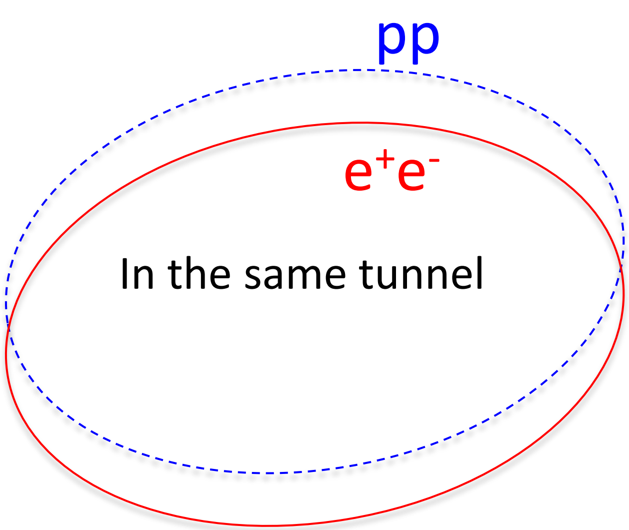
CEPC + SppC

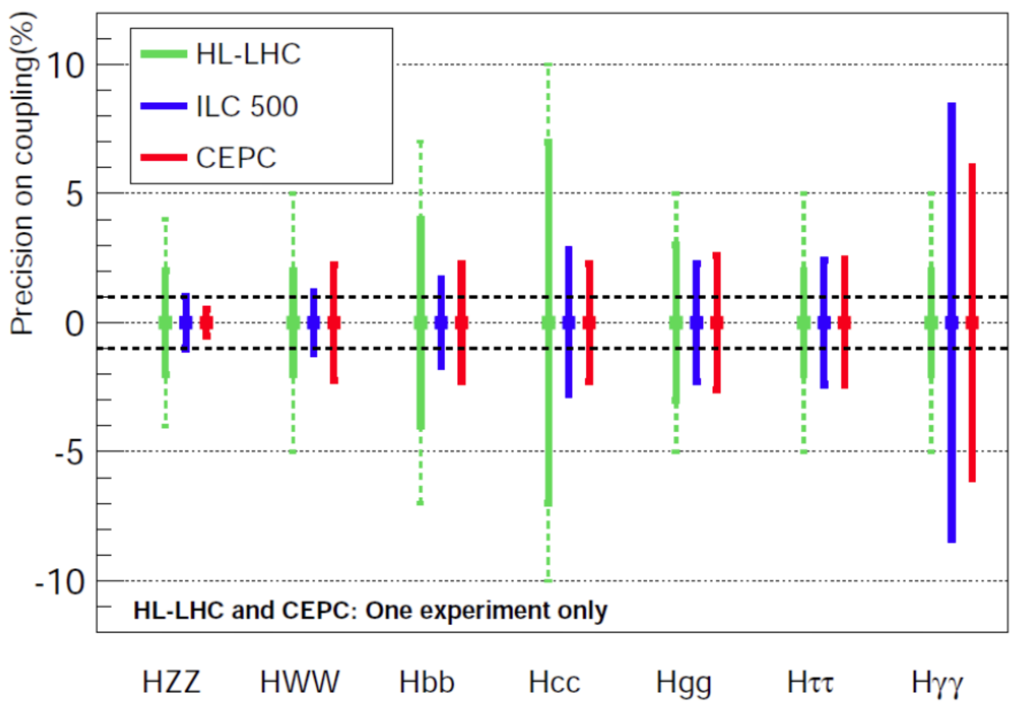
Circular e^+e^- Collider: $E_{cm} \approx 240$GeV, L ~2×10^{34} $cm^{-2}s^{-1}$

- **$2x10^5$ Higgs, 10^{11} Z per year**
- **Use Higgs particle as discovery tool → precision measurement**

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

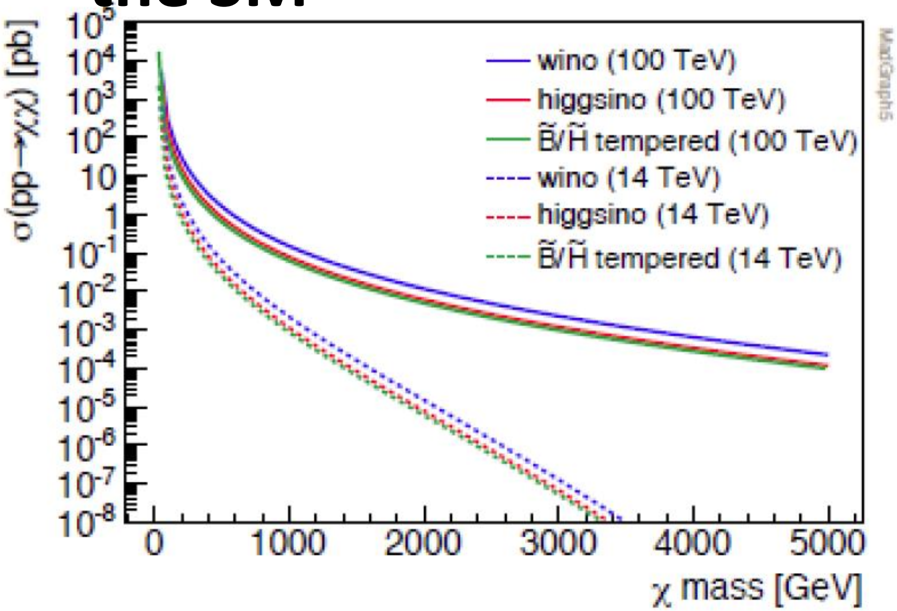
- **Potential for discovery**

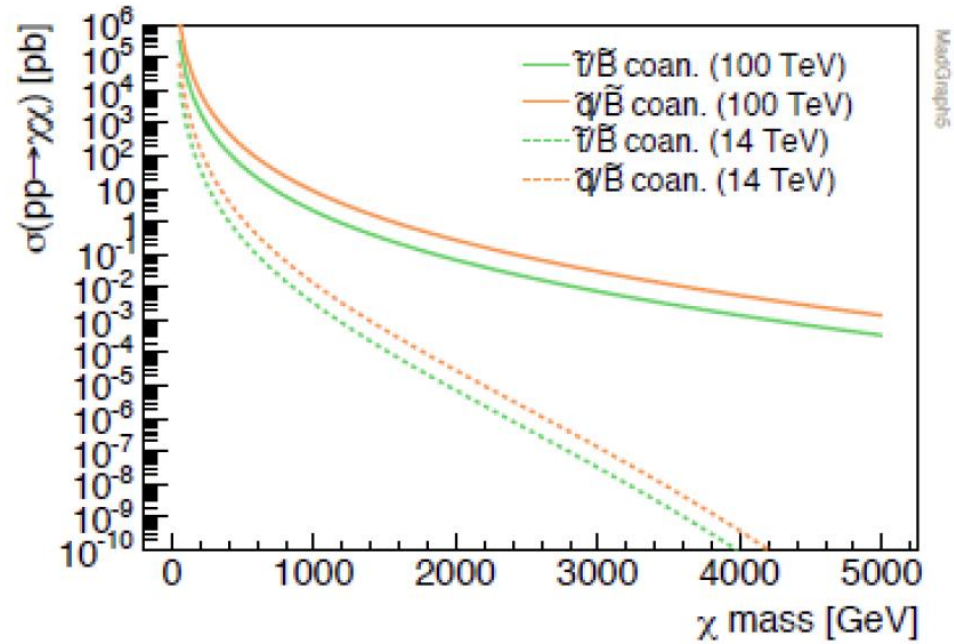




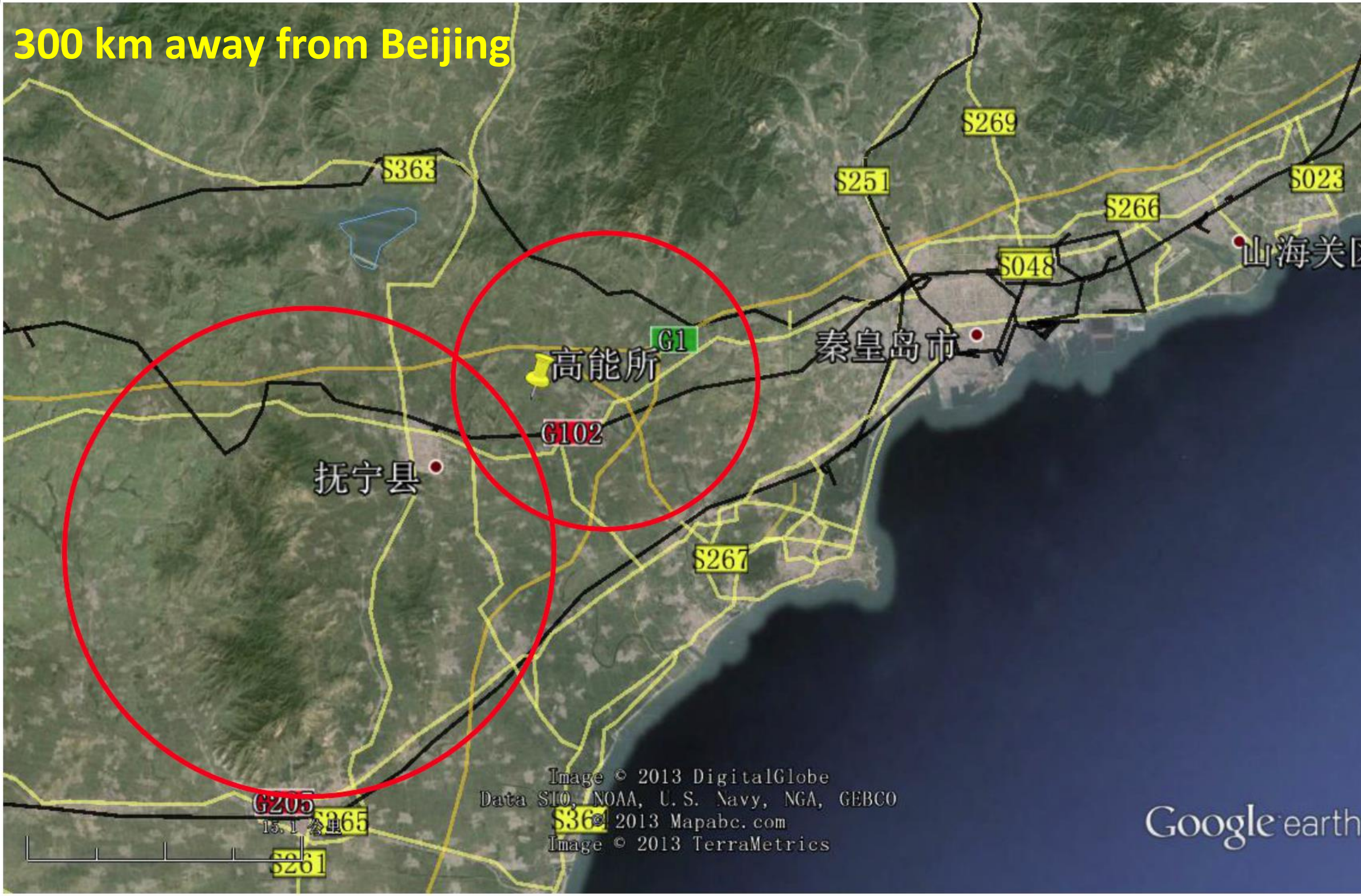
Super proton-proton Collider

New particle discovery machine, much higher production cross section for the new particles beyond the SM

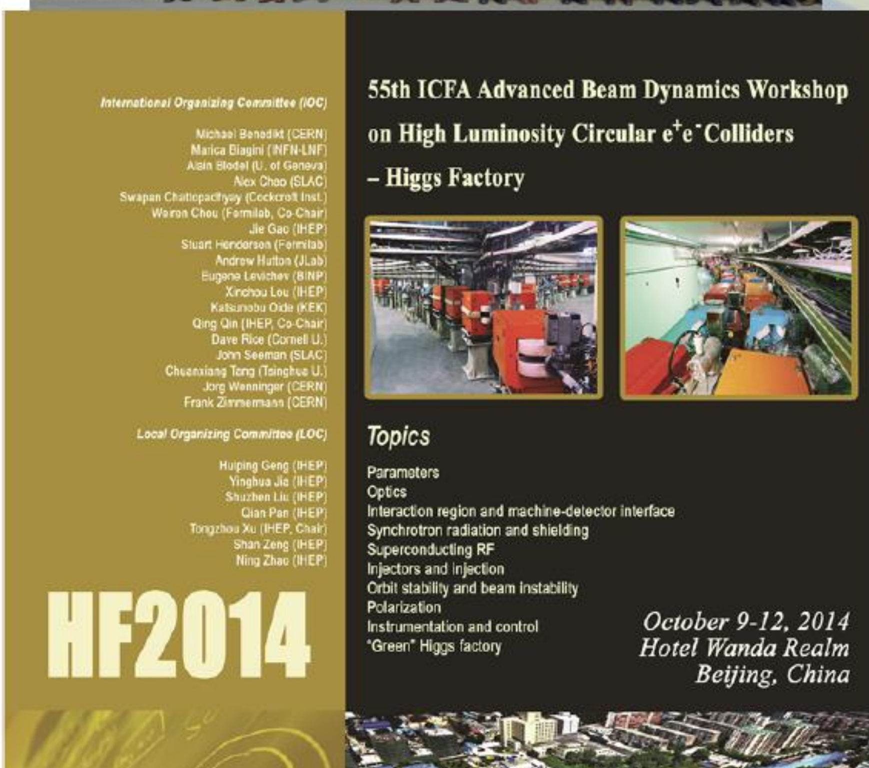




One Of The Candidate Site: Qing Huang Dao



World Wide Effort



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

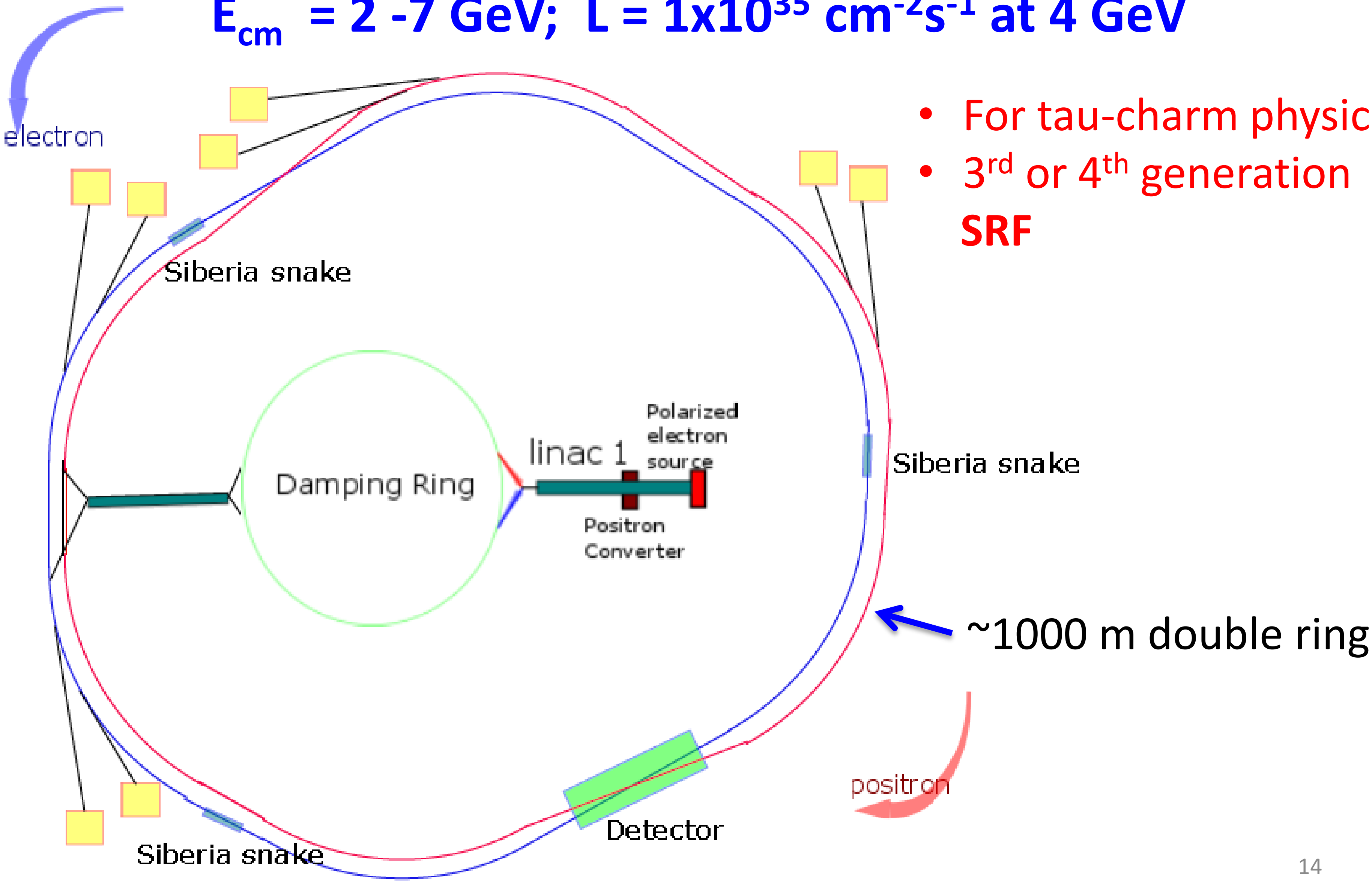
What Is HIEPA ?

- **Providing peak luminosity about 1x10^{35} $cm^{-2}s^{-1}$ at 4 GeV for physics at tau charm sector, covering E_{cm} = 2-7 GeV.**
- **Being a 3rd/4th generation SRF (synchrotron radiation facility).**
- **Reserving the potential for FEL(free electron laser) study with the long LINAC.**

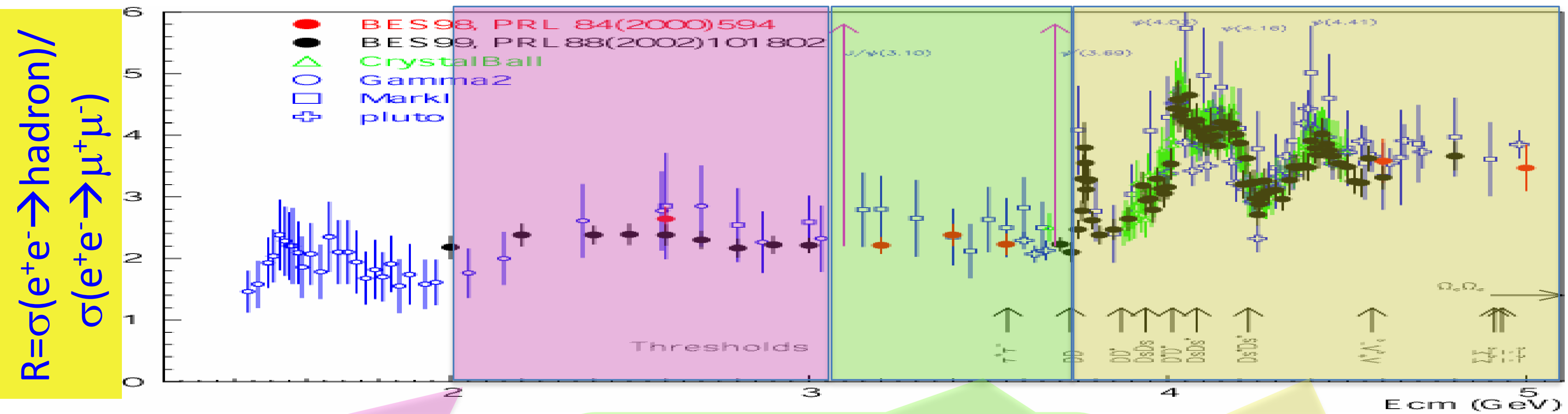
HIEPA Machine Layout

E_{cm} = 2 -7 GeV; L = 1×10^{35} $cm^{-2}s^{-1}$ at 4 GeV

- For tau-charm physics
- 3rd or 4th generation **SRF**



Physics at τ-c Energy Region



- Nucleon form factors
- Y(2175) resonance
- Mutltiquark states with s quark, Zs
- 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 τ lepton

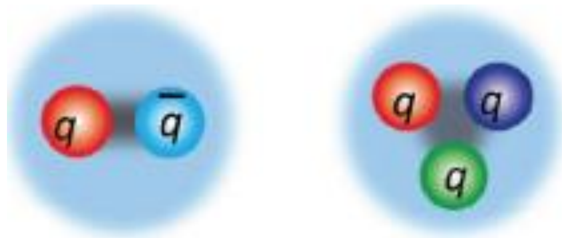
- XYZ particles
- Physics with D mesons
- f_D and f_{Ds}
- D_0-$\bar{D}_0$ mixing
- Charm baryons

R scan

- **Precision $\Delta\alpha_{QED}$, a_μ, charm quark mass extraction.**
- **Hadron form factor(nucleon, Λ, π).**

Key science question: is there any new forms of hadron exist ?

Standard hadrons

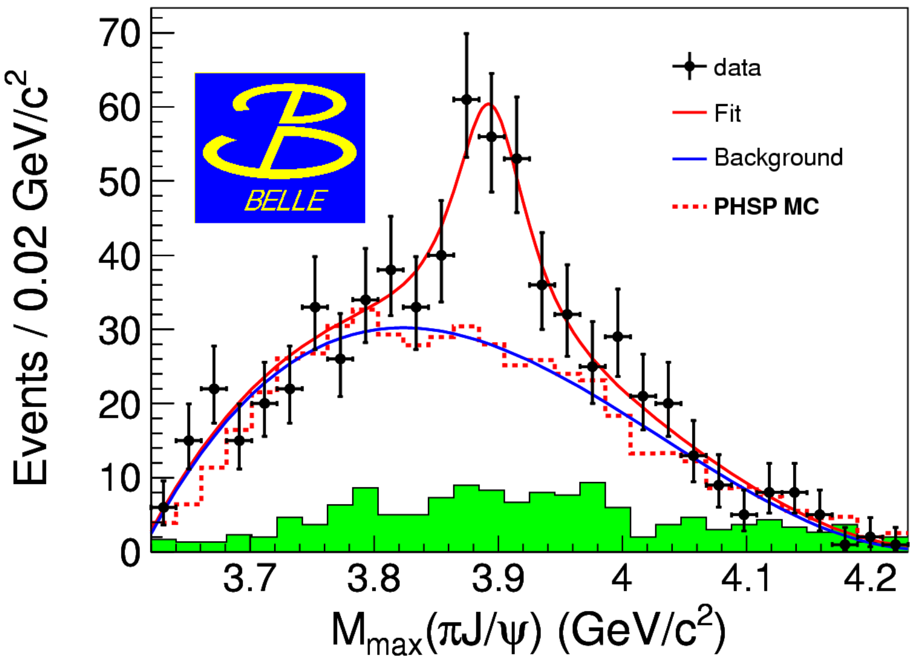


Exotic hadrons

- **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.**

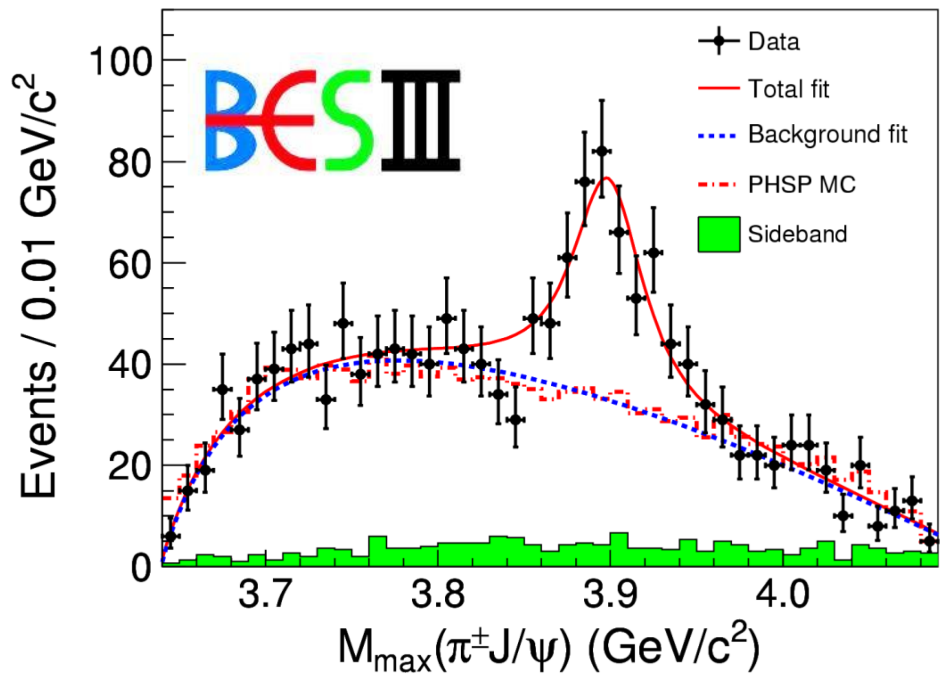
$Z_c(3900)$ Observed at BESIII and Belle

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



- M = 3894.5±6.6±4.5 MeV
- Γ = 63±24±26 MeV
- 159 ± 49 events
- >5.2σ

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



- M = 3899.0±3.6±4.9 MeV
- Γ = 46±10±20 MeV
- 307 ± 48 events
- >8σ

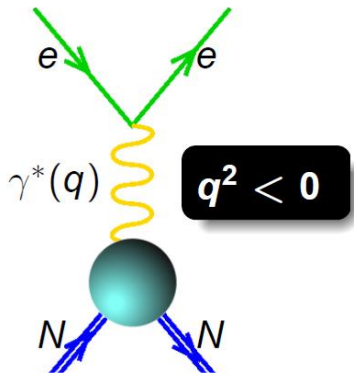
Nucleon Electromagnetic Form Factors (NEFFs)

- Key science question: why do quarks forms 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.

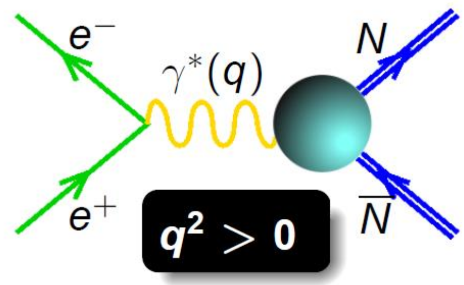
Nucleon Electromagnetic Form Factors(NEFFs)

$eN \to eN$

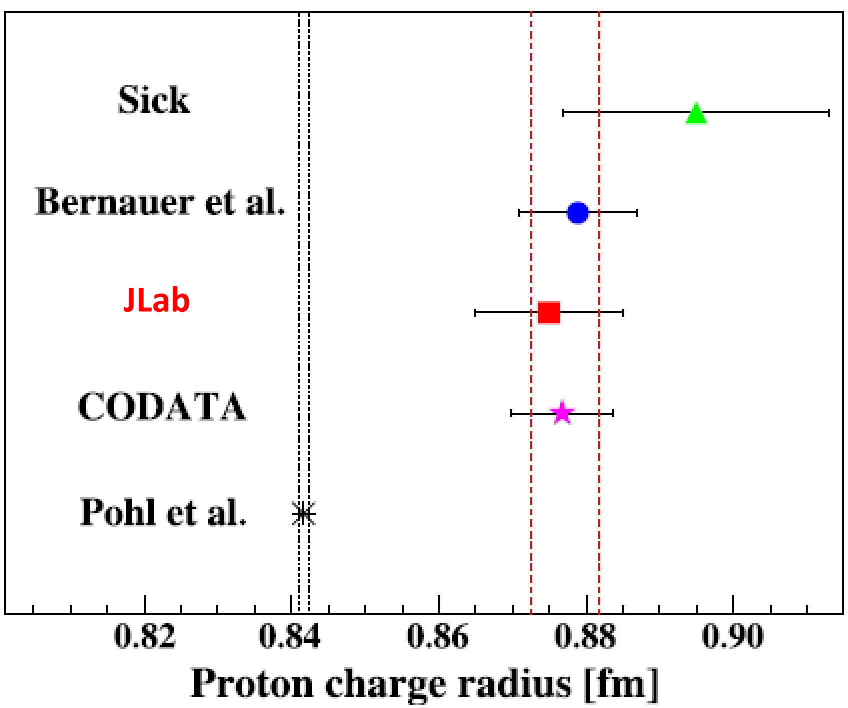
Space-like:
FF real

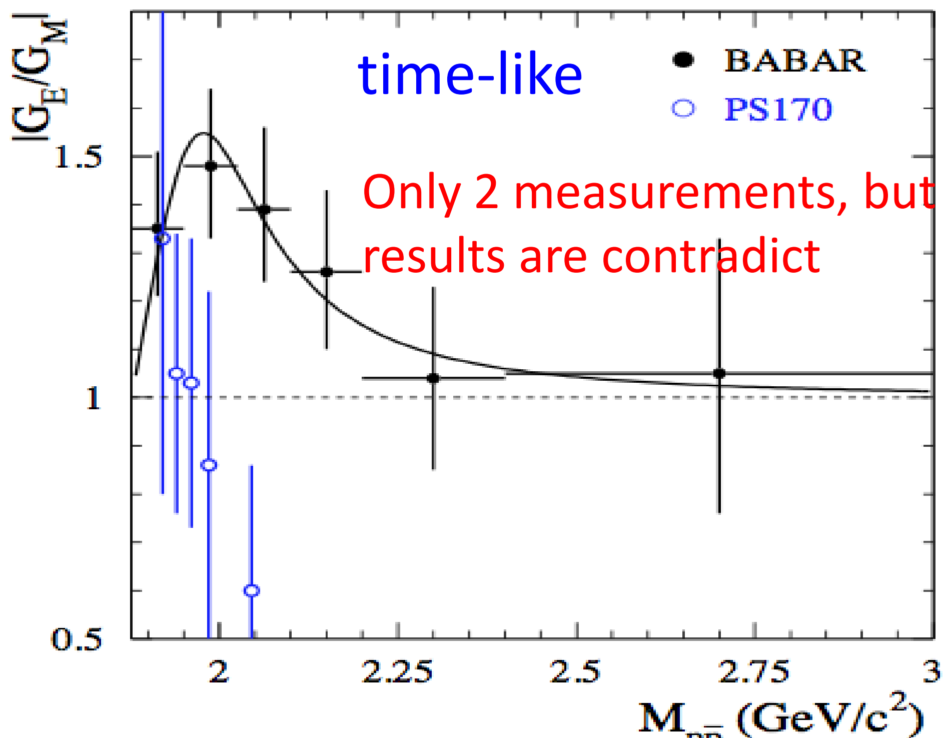


$e^+e^- \leftrightarrow N\bar{N}$, $\Lambda\bar{\Lambda}$



Time-like:
FF complex

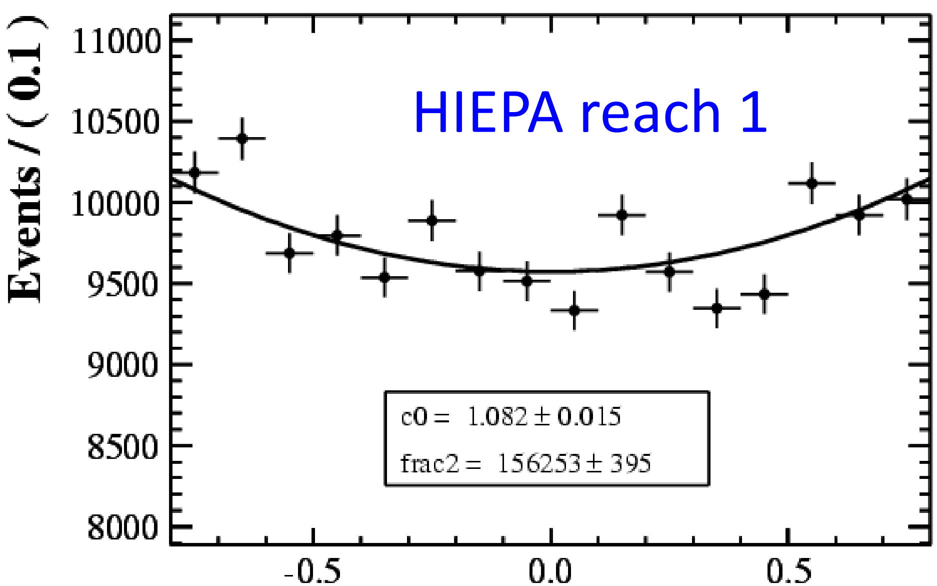


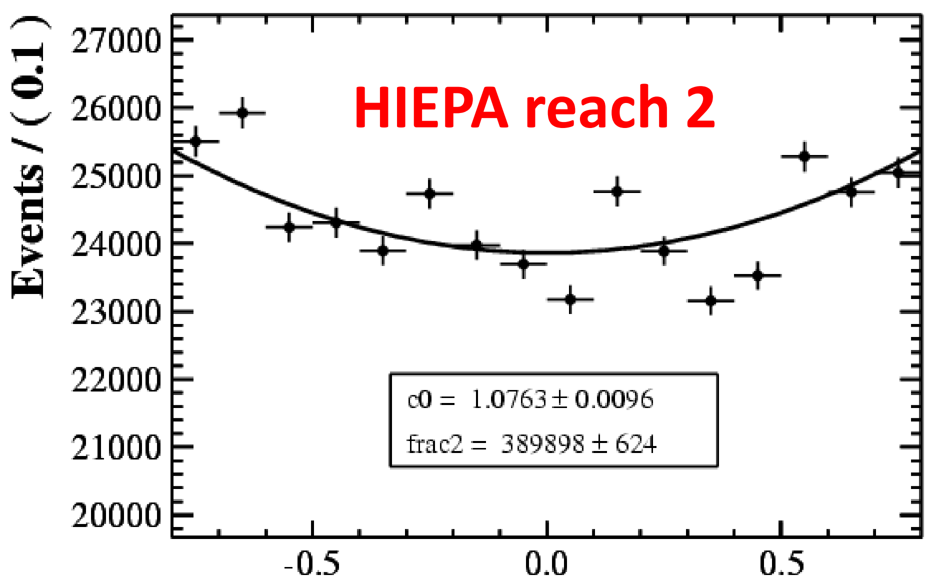


Measurement of Proton FFs at HIEPA

Example @ 2.23 GeV

Nsig	$\delta R_{EM}/R_{EM}$	$\delta\sigma/\sigma$	Luminosity (pb^{-1})	Comment
3881±62	9.5%	1.6%	16.630	BESIII expected
156253±395	1.5%	0.25%	669.533	HIEPA reach 1
389898±624	0.96%	0.16%	1670.69	HIEPA reach 2





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.

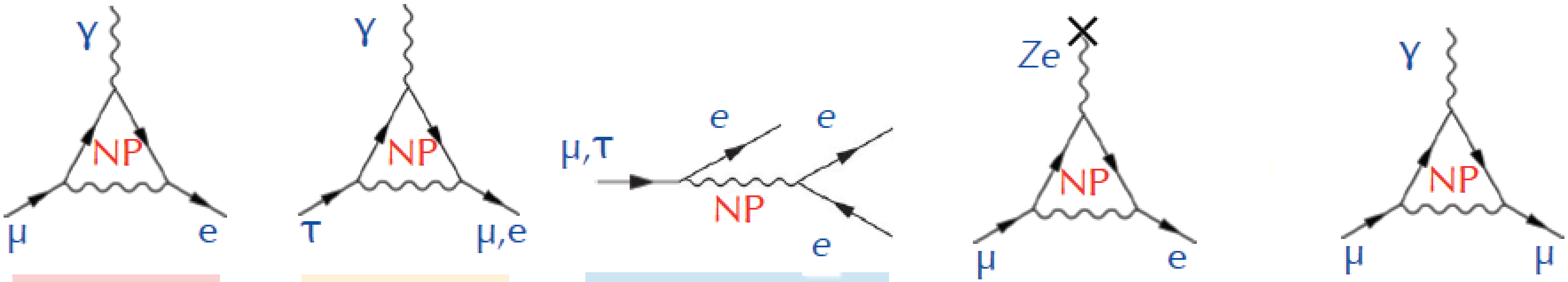
- No evidence of new physics been found at high energy frontier, it is important to search for new physics both directly and indirectly in the precision frontier.

Lepton Flavour Violating (LFV)

CLFV processes sensitive to New Physics (NP)

through lepton-lepton coupling $y_{ij}\bar{\ell}_i F^{\mu\nu}\ell_j\sigma_{\mu\nu}$

PSI　　　　　　　　　　　　　　　　　　　　Mu2e



$\mu \to e\gamma$ | $\tau \to \mu\gamma$, $\tau \to e\gamma$ | $\mu \to eee$ | $\mu^- \mathcal{N} \to e^- \mathcal{N}$ | $(g-2)_\mu$

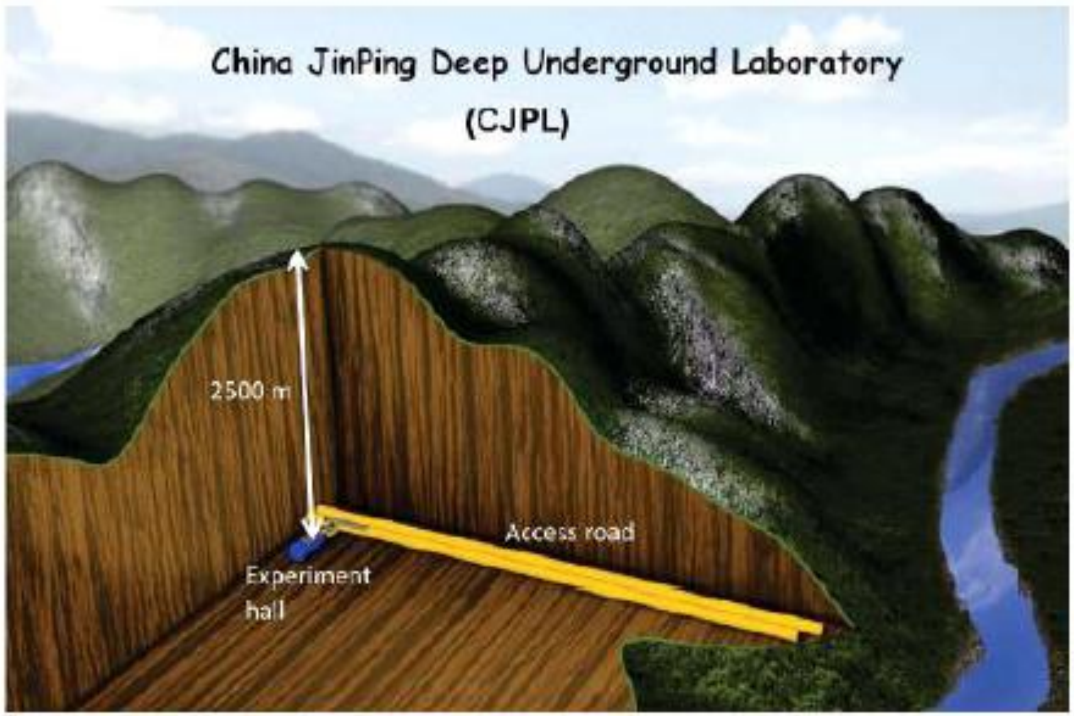
μ, τ anomalous decays

μ → e conversion

Anomalous magnetic moment

HIEPA Timeline

China Jinping Underground Laboratory

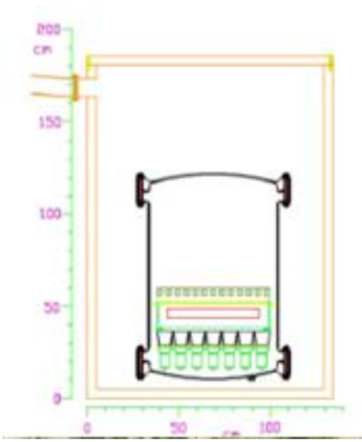


2400 m overburden of marble

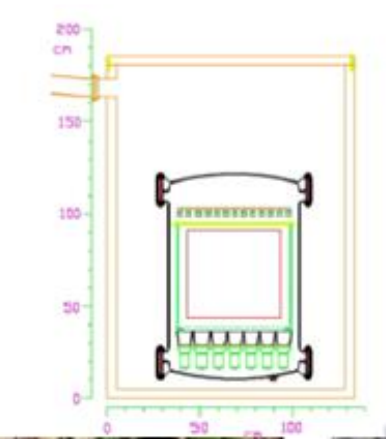
The deepest in the world

- 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}Xe

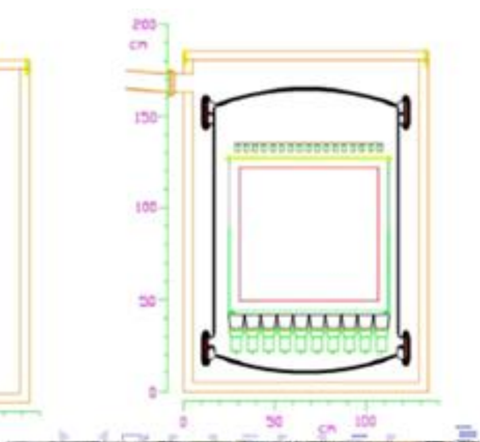
Phase I:125 kg



Phase II: 500kg



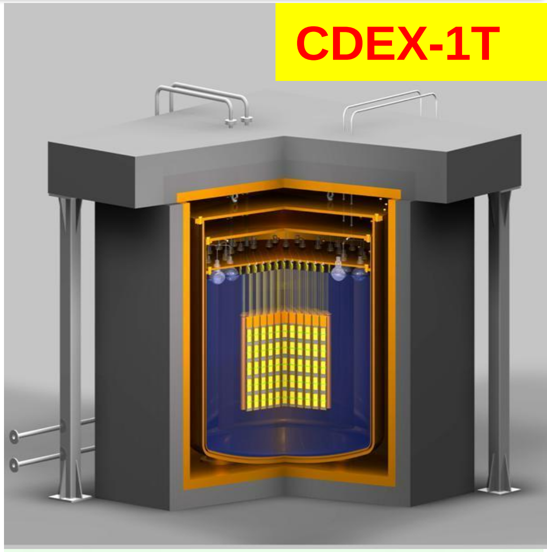
Phase III: 1.5 ton?



Mar 2014: started physics run (125 kg active target)

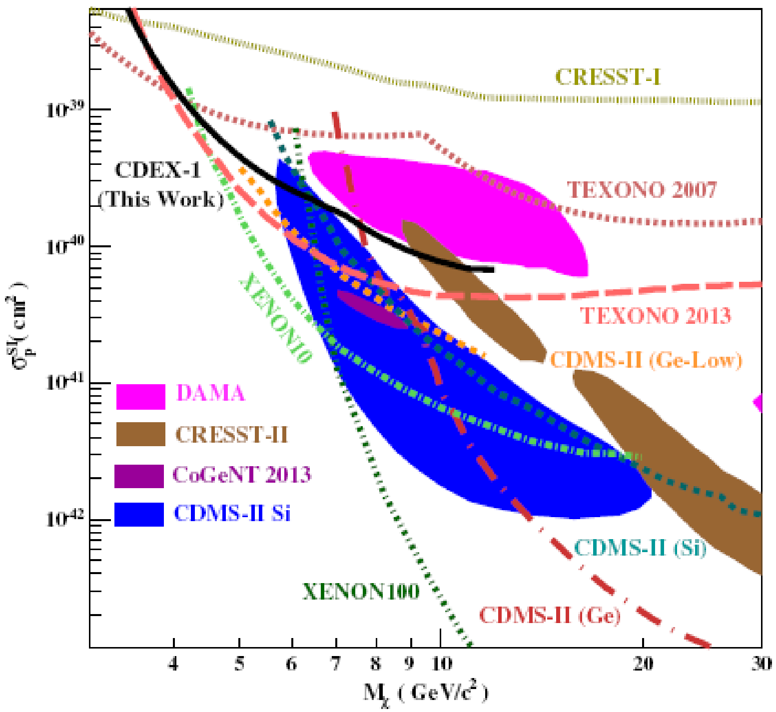
CDEX

- **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**



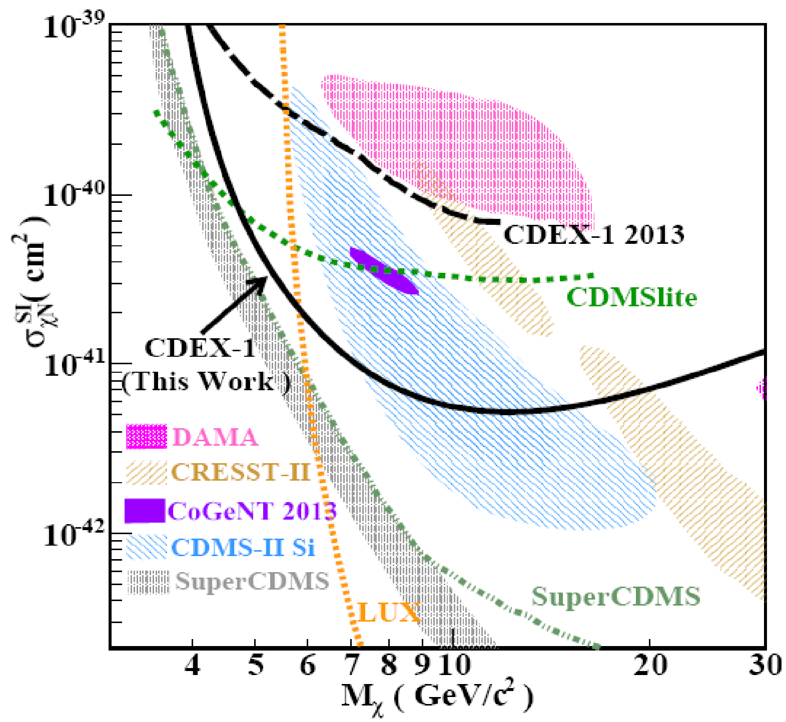
CDEX-1 Physical Results

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



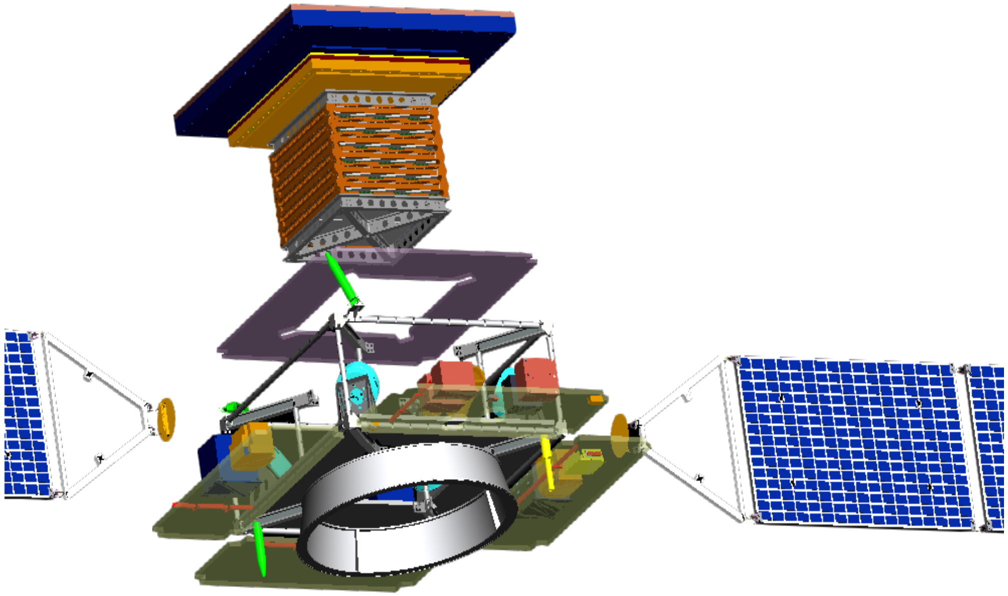
- ✓ The first dark matter physical result from China!
- ✓ The lowest energy threshold of PCGe!

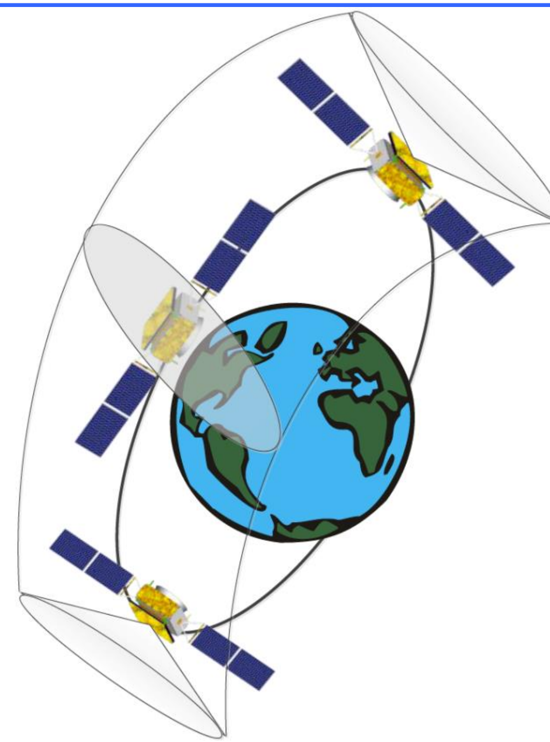
Q.Yue et al., arXiv:1404.4946. (2014)



- ✓ 10 times improved sensitivity!
- ✓ The best sensitivity by PCGe!
- ✓ Excludes the region favored by CoGeNT with same technology!

DArk Matter Particle Explore (DAMPE)

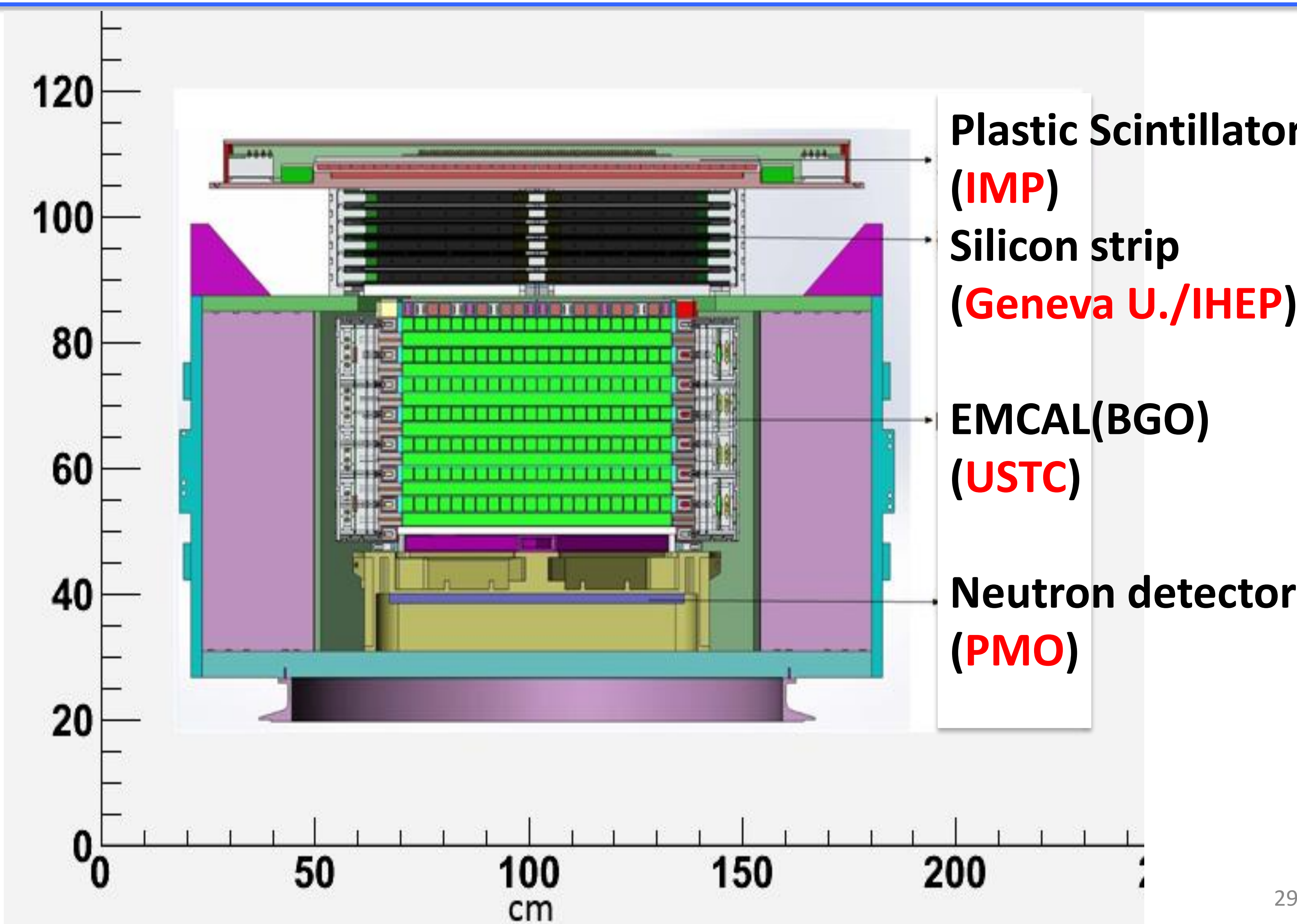




- 4 sub-detectors to measure $e^{+/-}$, γ and ion
- Energy: 5GeV~10TeV
- Resolution: 1.5%@800GeV
- p, e separation: < 1%

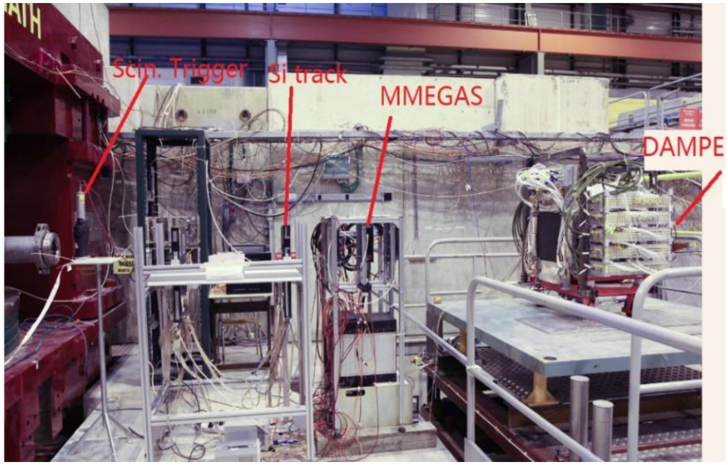
- Altitude 500 km
- Inclination 97.4065°
- Period 90 minutes
- Sun-synchronous orbit

Detector and Collaboration



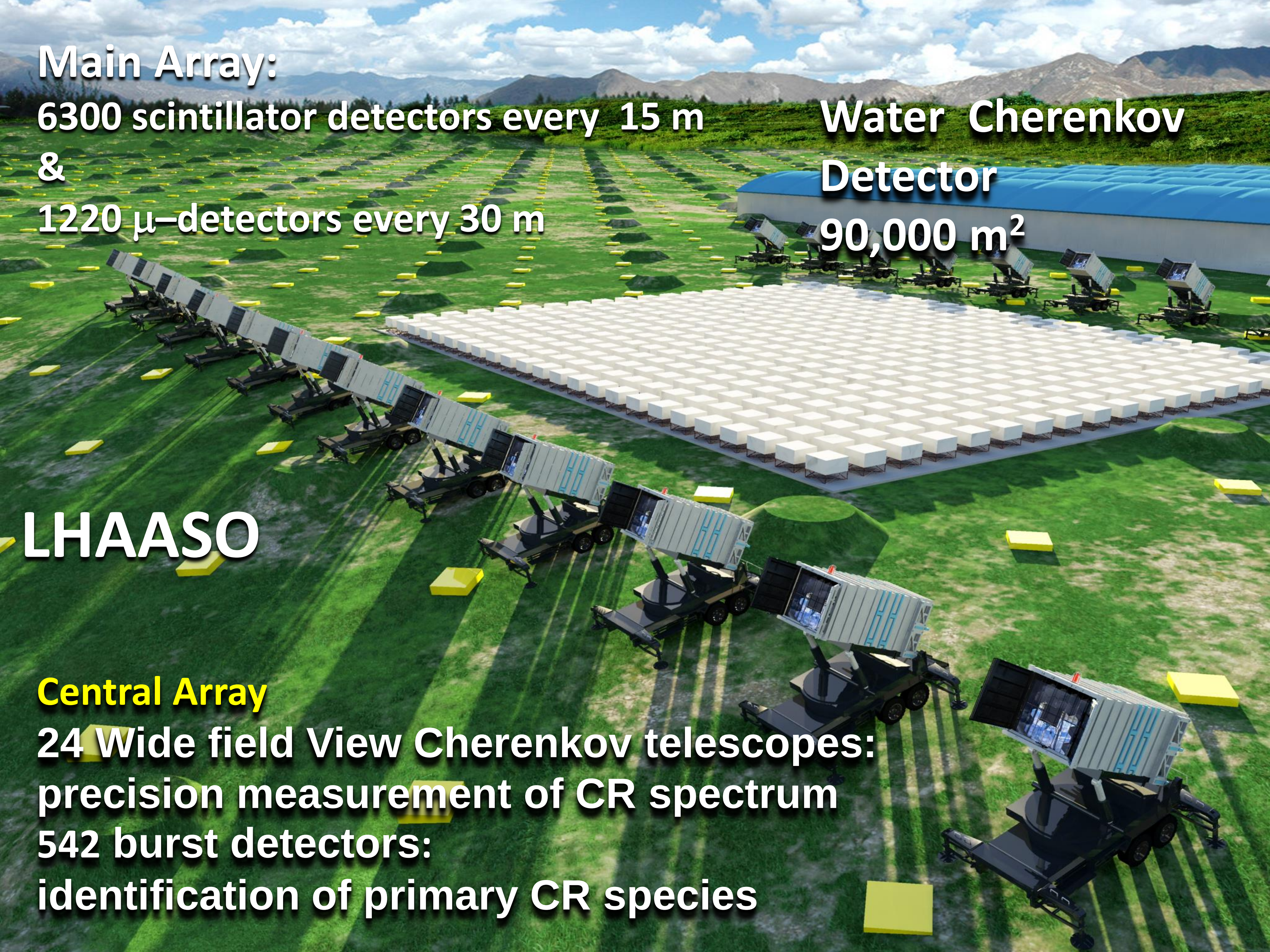
Timeline

- 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.



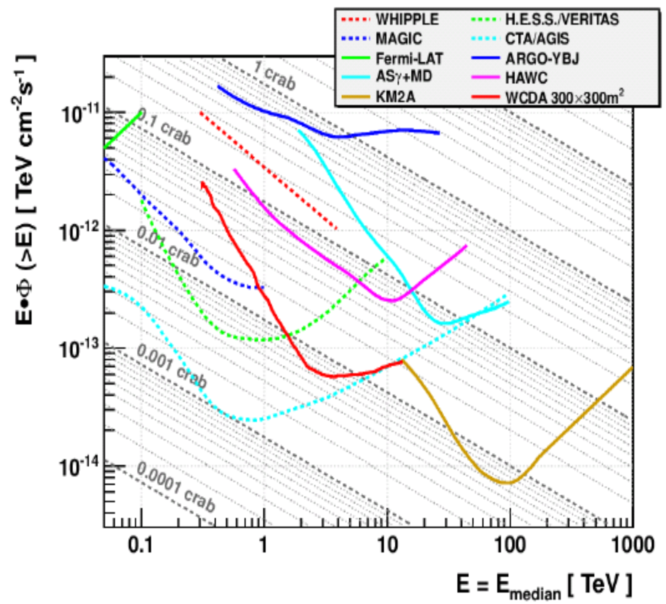
Prototype beam test


Engineering model magnetic test

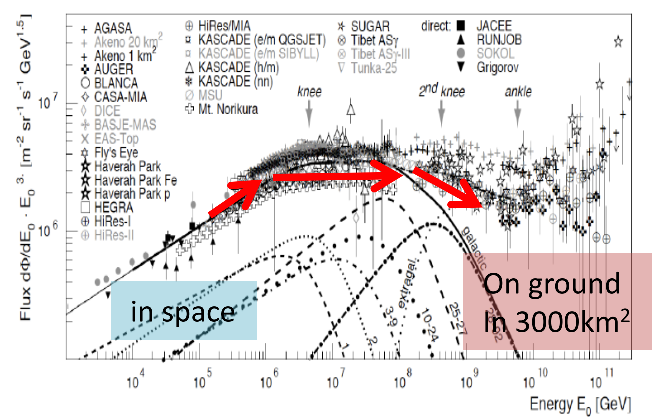

Main Array:
6300 scintillator detectors every 15 m
&
1220 μ–detectors every 30 m
Water Cherenkov
Detector
90,000 m²
LHAASO
Central Array
24 Wide field View Cherenkov telescopes:
precision measurement of CR spectrum
542 burst detectors:
identification of primary CR species

Prospects and Status

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

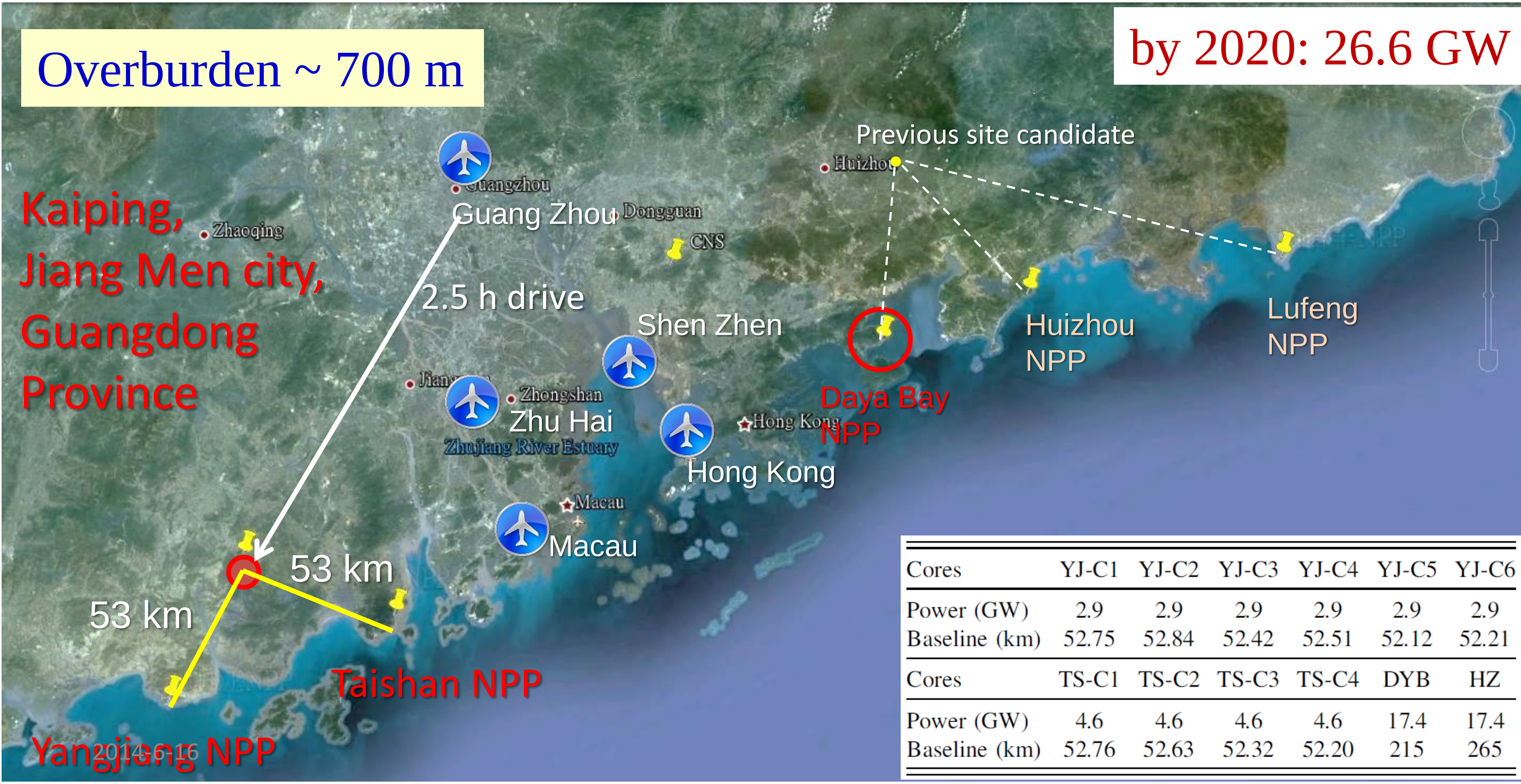


- **Agreement with Sichuan province for site is scheduled to be signed next month. This will pave the road to start the construction of LHAASO next year**



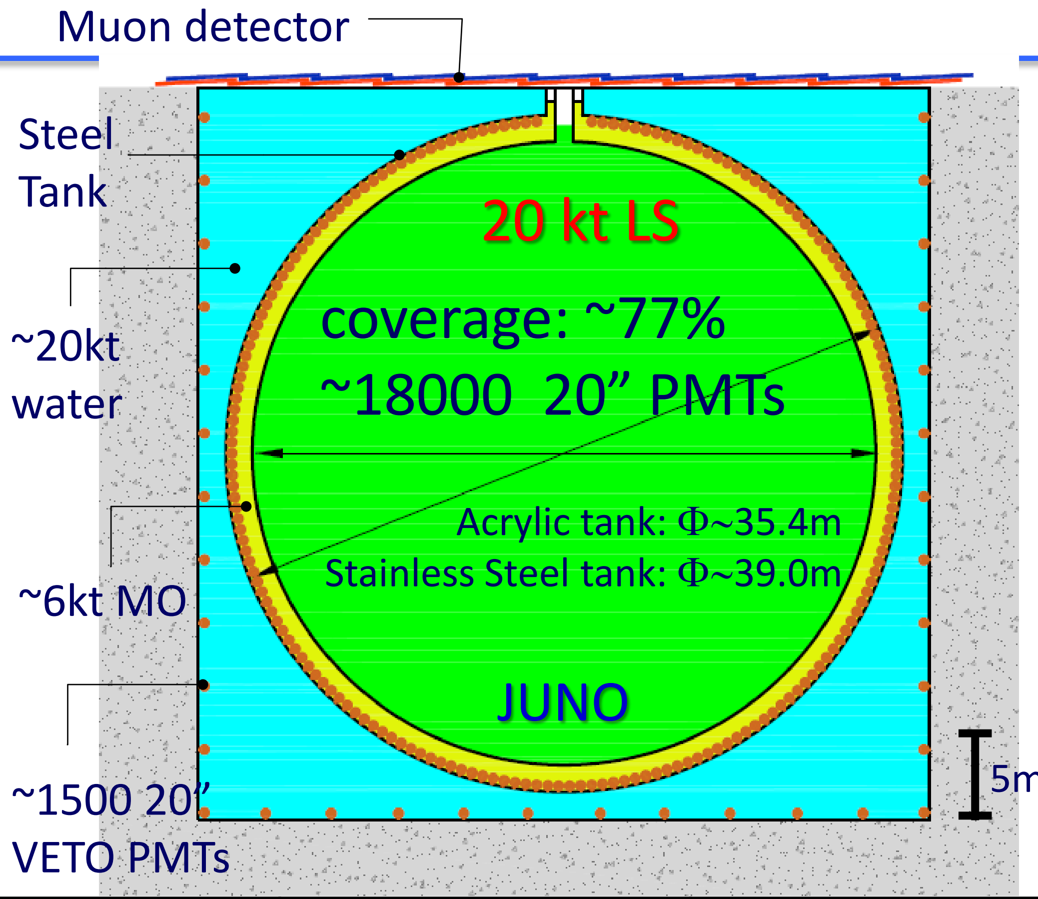
JUNO

NPP	Daya Bay	Huizhou	Lufeng	Yangjiang	Taishan
Status	Operational	Planned	Planned	Under construction	Under construction
Power	17.4 GW	17.4 GW	17.4 GW	17.4 GW	18.4 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

JUNO Detector



	KamLAND	BOREXINO	JUNO
LS mass	1 kt	0.5 kt	20 kt
Energy Resolution	6%/	5%/	3%/
Light yield	250 p.e./MeV	511 p.e./MeV	1200 p.e./MeV

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……

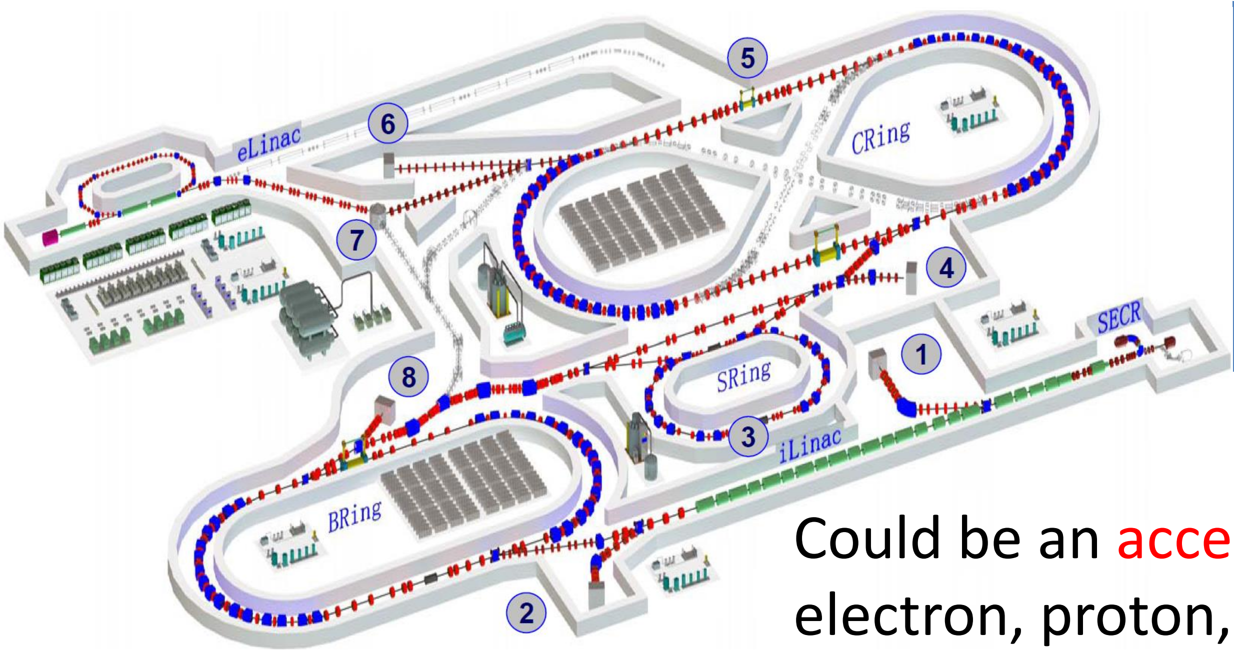
Facilities for Particle Physics in China

Heavy Ion Accelerator Facility (HIAF)

中科院：詹文龙

Oct. 18. 2013

- (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

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 Λ_{NP} ?**
- **Which symmetry keeps M_H away from Λ_{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

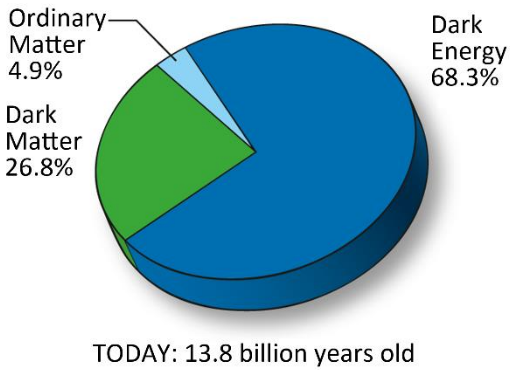
Precision Higgs physics is on the HEP agenda for the next 2-3 decades
- for a deep understanding of the SM
- for an accurate comparison with experiments
- for an access to BSM

Open Question About Higgs

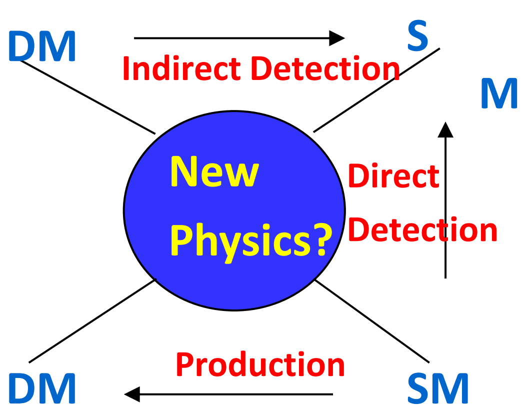
Is it

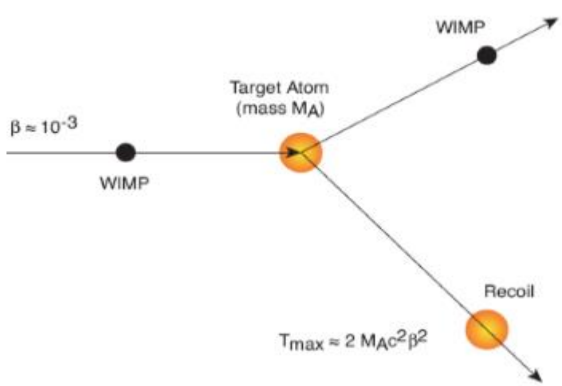
- the SM Higgs?
- an elementary/composite particle?
- unique/solitary?
- eternal/temporary?
- natural?
- the first supersymmetric particle ever observed?
- really “responsible” for the masses of all the elementary particles?
- mainly produced by top quarks or by new heavy vector-like quarks?
- a portal to a hidden world?
- at the origin of the matter-antimatter asymmetry?
- Has it driven the inflationary expansion of the Universe?

Motivation



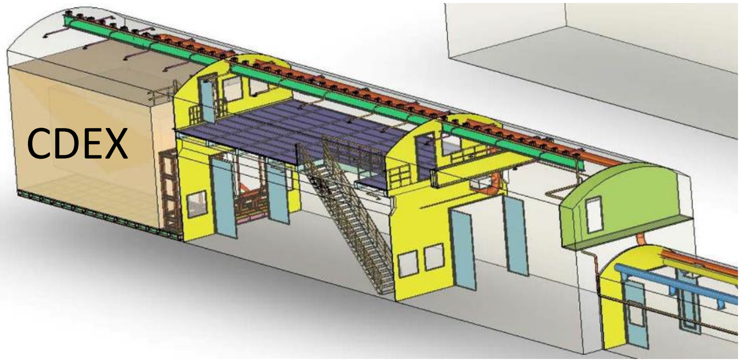
- Nature of dark matter unknown.
- WIMPs -- well motivated candidate.
- Three strategies to detect.





CDEX target:

Direct detection of low mass cold dark matter with ton-scale PCGe array with ultra-low energy threshold (<300eVee) .

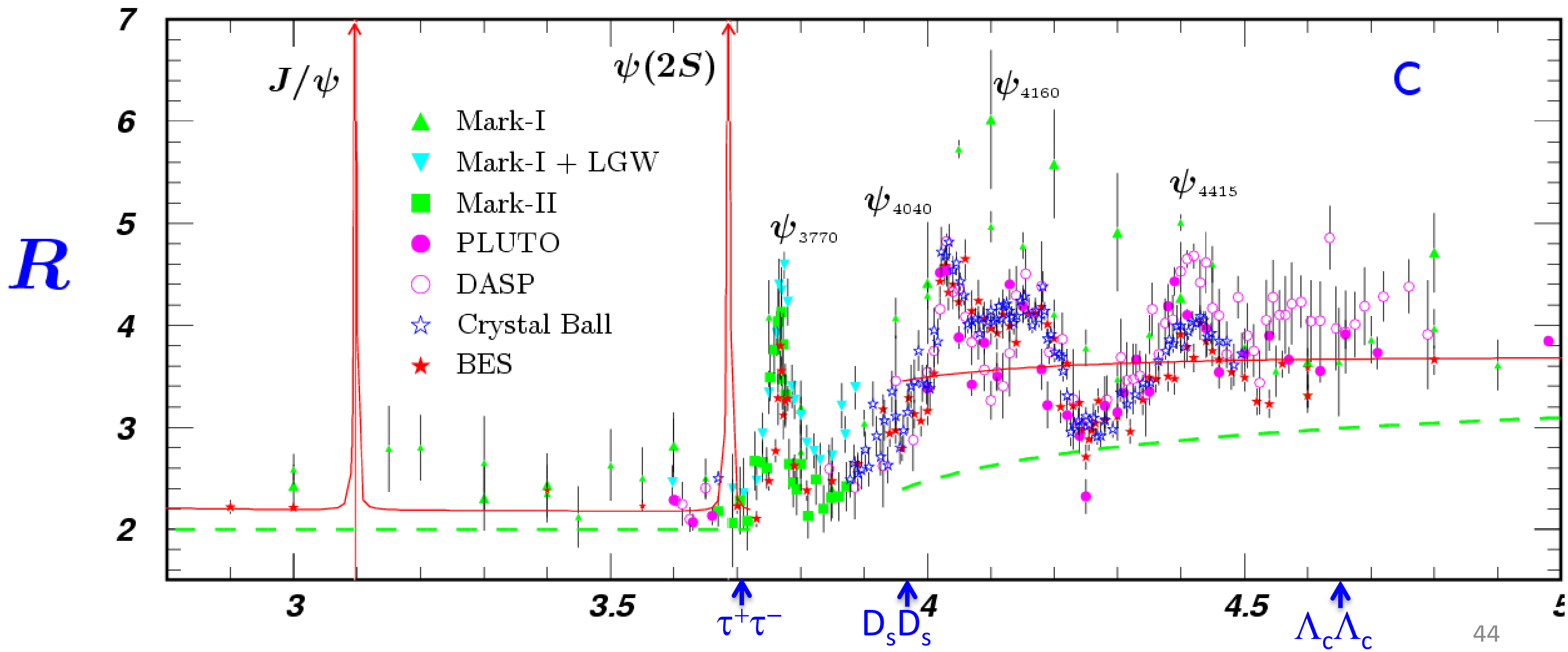


Forthcoming Discoveries in Particle Physics

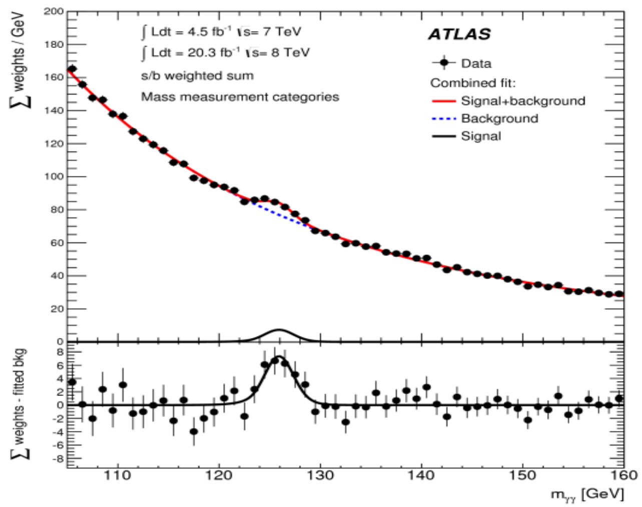
Topic	Crucial measurement	Significance
WIMP	Existence	Dark Mater
Higgs boson	M ~125 GeV	Confirm spontaneous symmetry breaking in gauge theory
Super-symmetric particles	Existence, M > 1 TeV	Hope of understanding gravity
Technicolour particles	Existence, M > TeV?	Dynamic symmetry breaking, Composite Higgs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

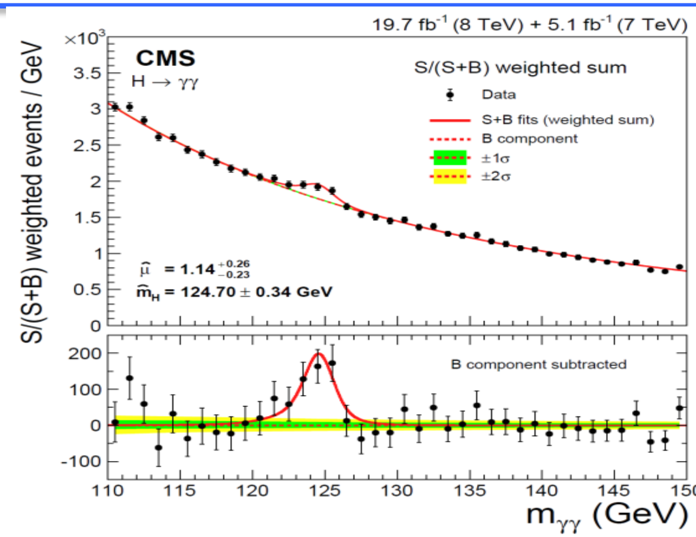
Features of the τ-c Energy Region

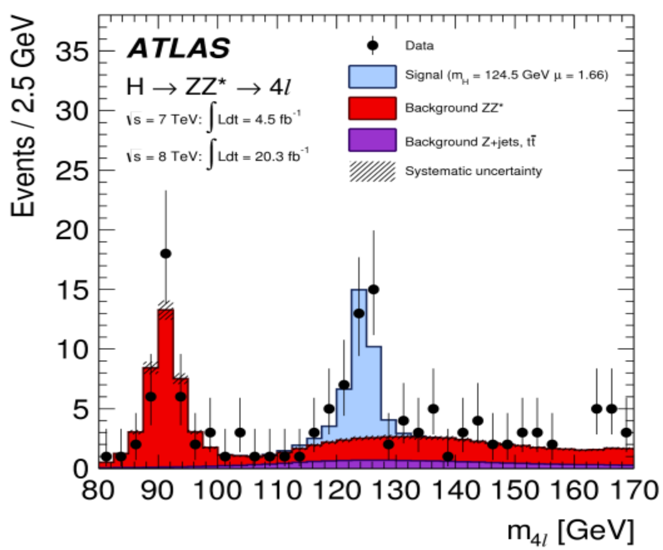
- Rich of resonances, charmonium and charmed mesons.
- Threshold characteristics (pairs of τ, D, D_s, charmed baryons…).
- Transition between smooth and resonances, perturbative and non-perturbative QCD.
- Mass location of the exotic hadrons, gluonic matter and hybrid.

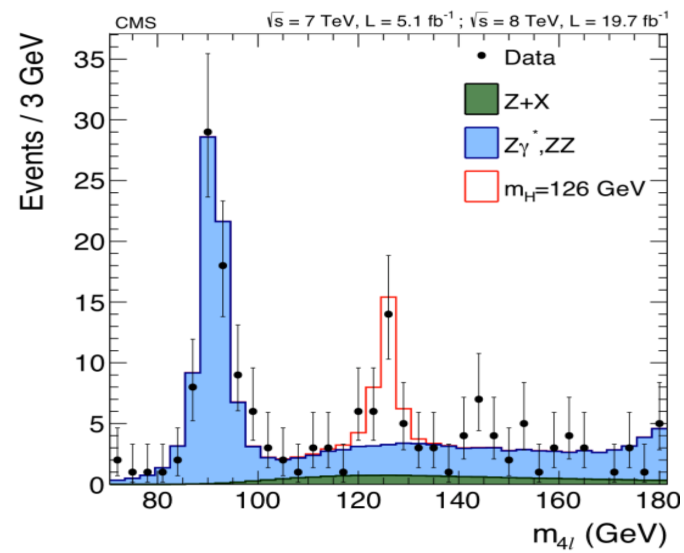


H(125): Favor SM Scalar Boson









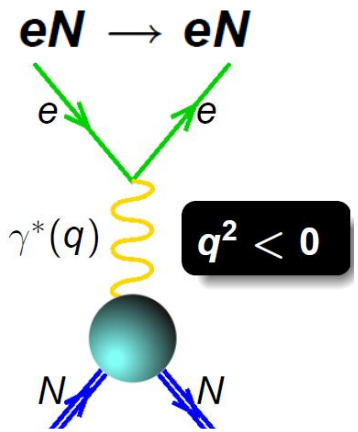
$M_H = (125.36 \pm 0.37 \pm 0.18)$ GeV

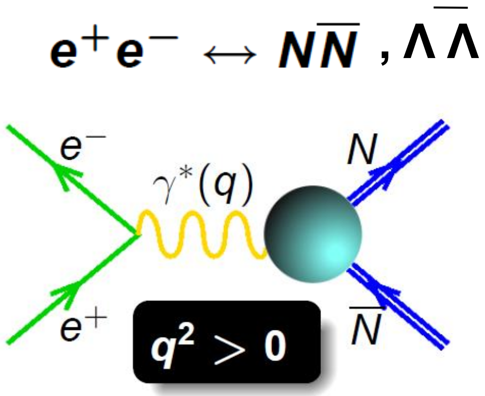
$M_H = (125.03\ ^{+0.26+0.13}_{-0.27-0.15})$ GeV

Nucleon Electromagnetic Form Factors(NEFFs)

Spatial distributions of electric charge and current inside the nucleon

Space-like:
FF real





Time-like:
FF complex

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

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

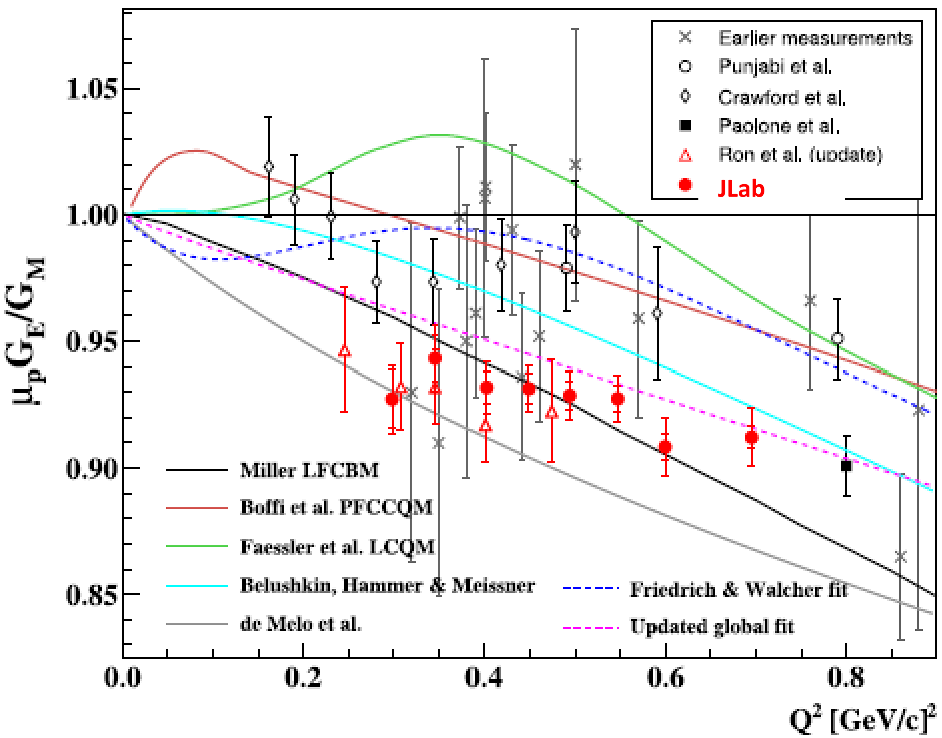
Dirac	**Pauli**
$F_1^p(q^2=0)=1$	$F_2^p(q^2)=1$
$F_1^n(q^2=0)=0$	$F_2^n(q^2)=1$

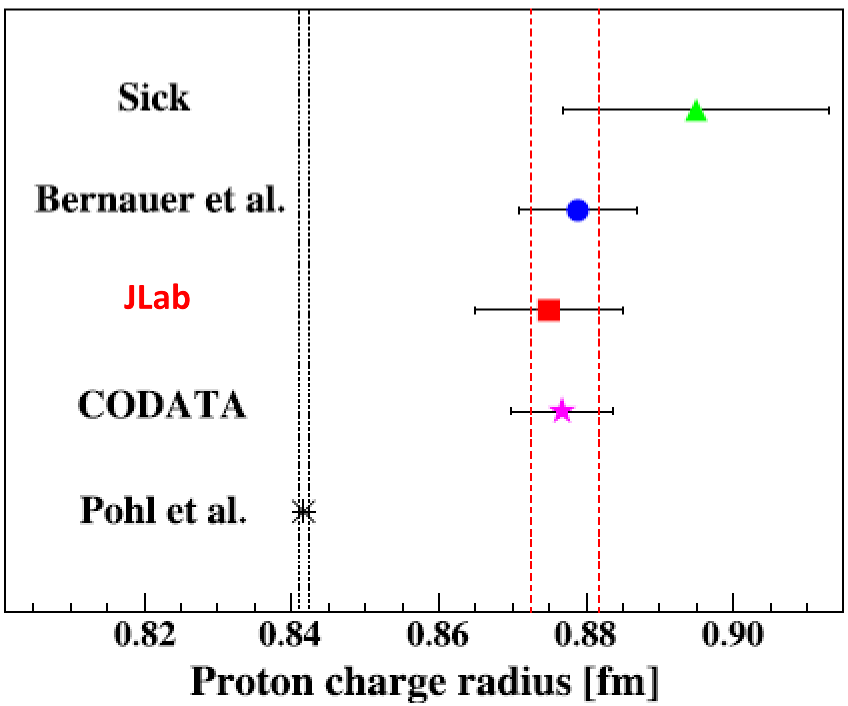
Sachs

$$G_E = F_1 + \frac{\kappa q^2}{4M^2}F_2 \qquad G_M = F_1 + \kappa F_2 \qquad G_E(4M_p^2) = G_M(4M_p^2)$$

The Measurement of Proton FF(Space-like)

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 ~1%, based on which the proton electronic and magnetic radii could be extracted.

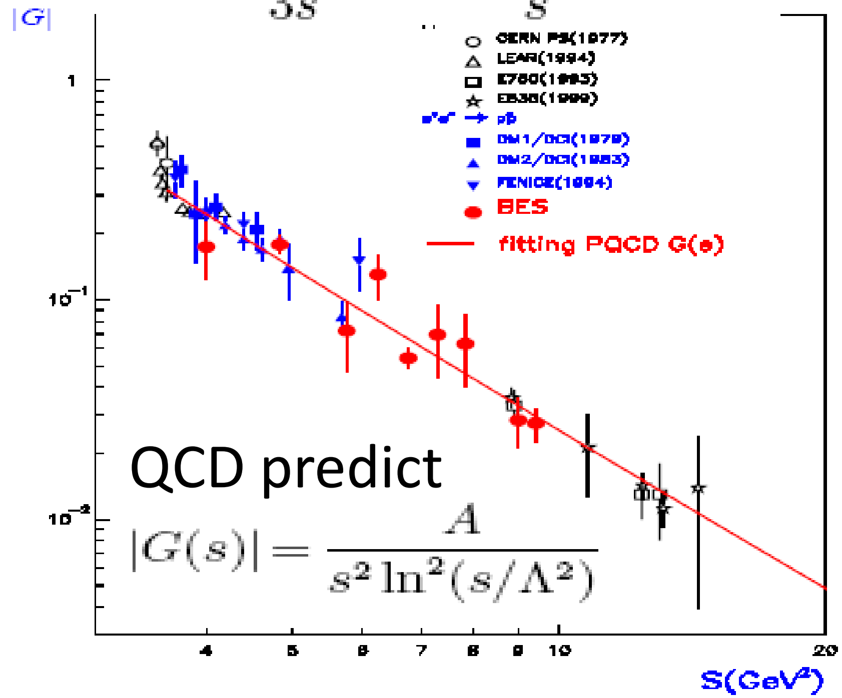




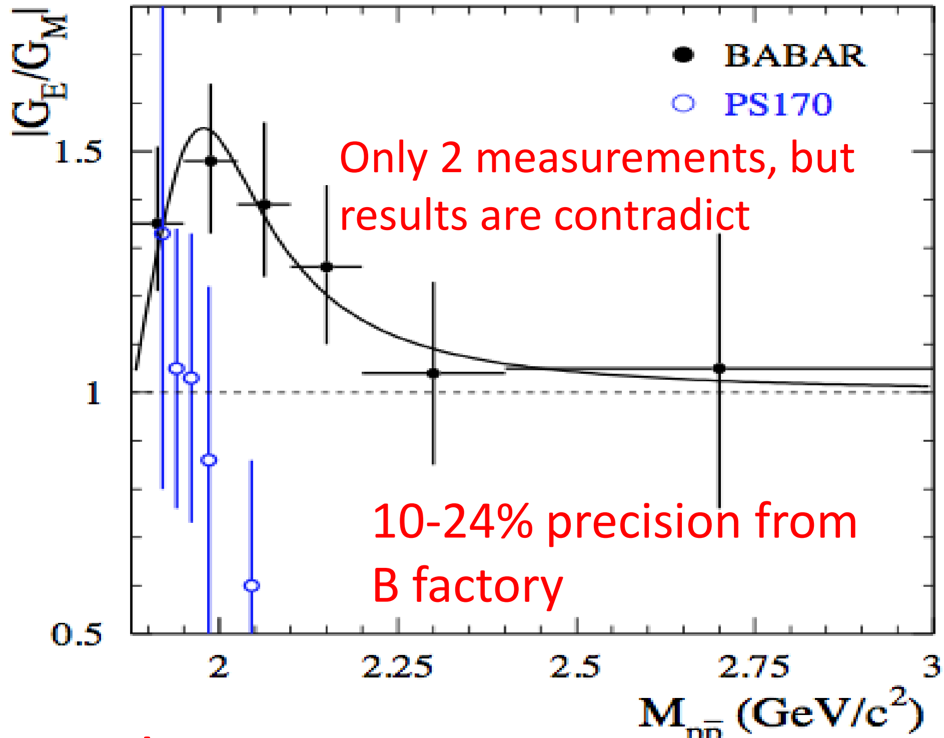
Proton Form Factor: $|G_E|/|G_M|$

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

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

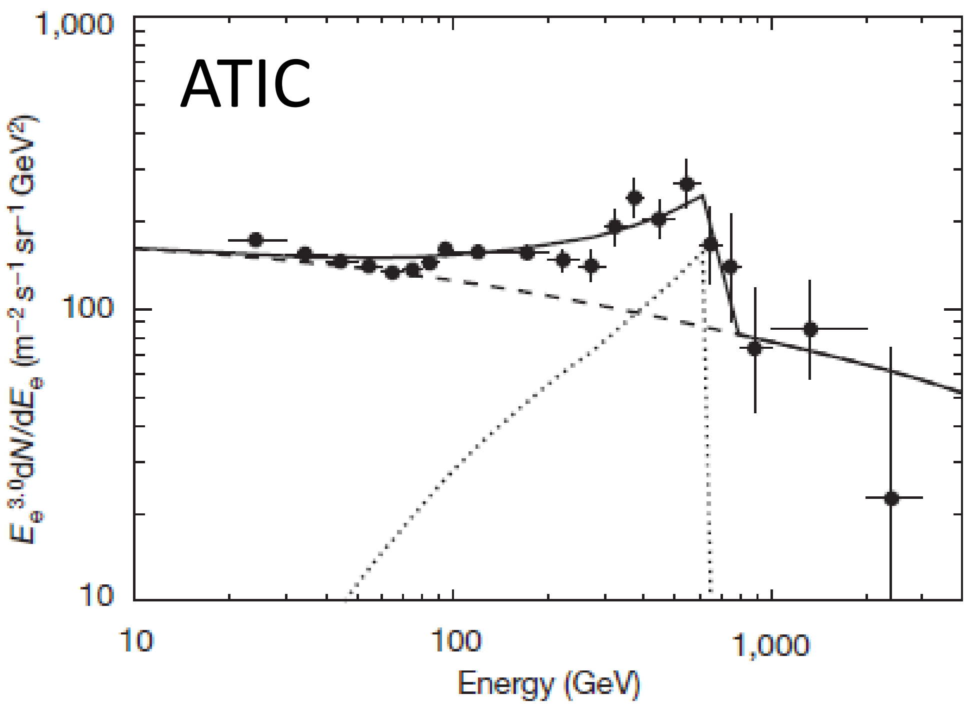


time-like

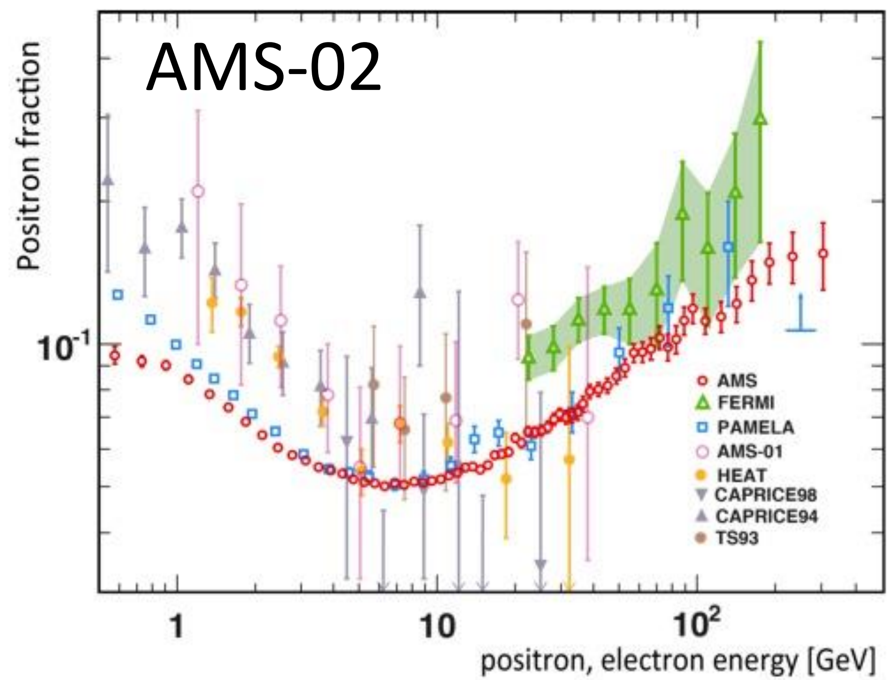


Complete picture of the nucleon structure requires space-like and time-like measurements!

Motivation



ATIC
1,000
100
10
10
100
1,000
Energy (GeV)
$E_e^{3.0}dN/dE_e$ (m^{-2}s^{-1}sr^{-1}GeV^2)

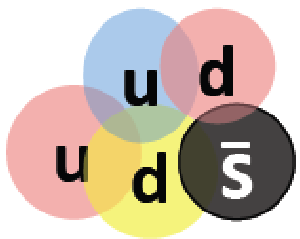


AMS-02
Positron fraction
10^{-1}
1
10
10^2
positron, electron energy [GeV]
AMS
FERMI
PAMELA
AMS-01
HEAT
CAPRICE98
CAPRICE94
TS93

Exotic Hadrons

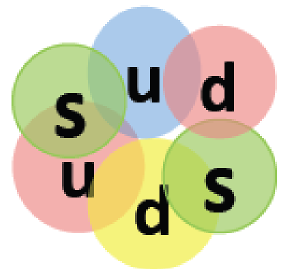
(possible combination of quark and glue)

Pentaquark



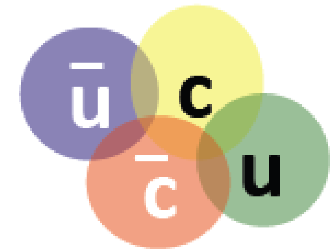
S=+1 Baryon

H-diBaryon



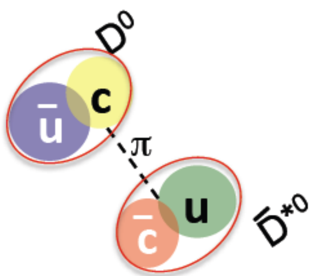
Tightly bound 6-quark state

Tentraquark



Tightly bound diquark-diantiquark

Meson molecule

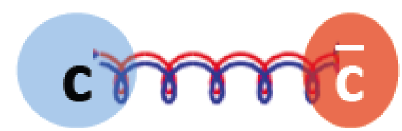


Loosely bound meson-antimeson

Glueball

Color-single multi-glue bound state

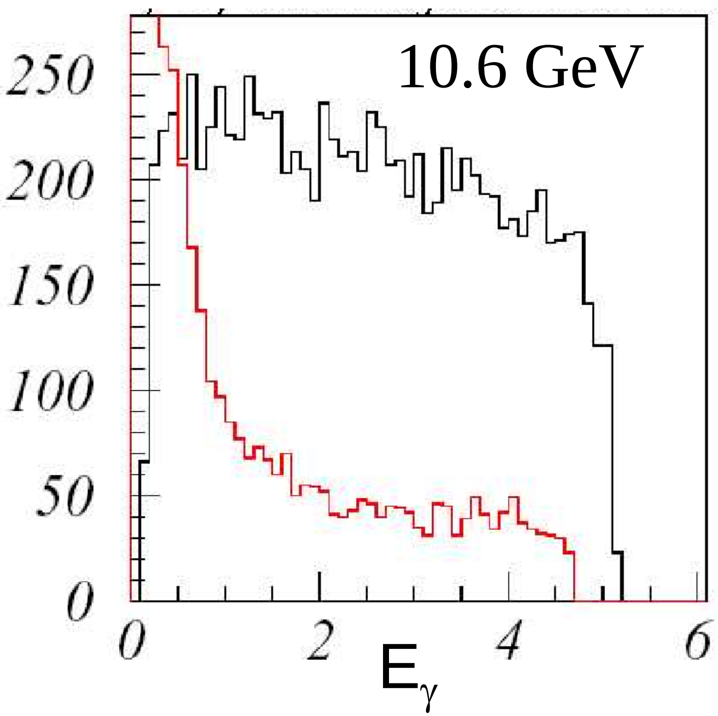
Hybrid

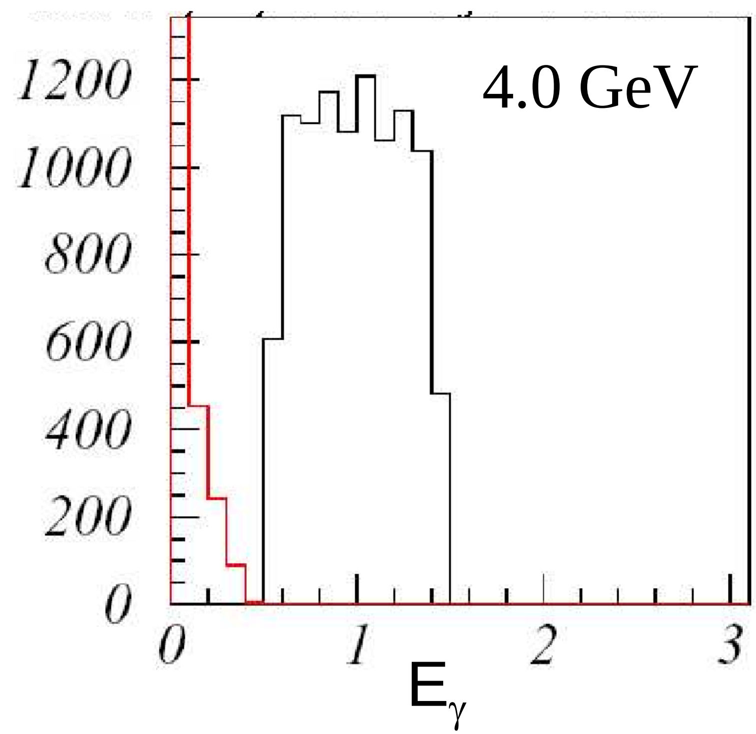


$q\bar{q}$ glue hybrid

$\tau \to \mu\gamma$

- The process $e^+e^- \to \tau^+\tau^-\gamma$, dominant background source at Υ(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) ≤ UL(SuperBelle@Y in 12-15 yrs).





DArk Matter Particle Explorer (DAMPE)