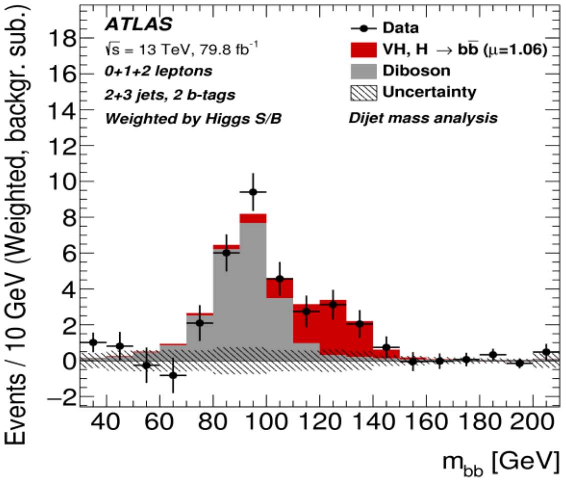
Charm quark, Higgs boson and Unknowns

A glimpse of Particle Physics in China

Prof. Lei Zhang

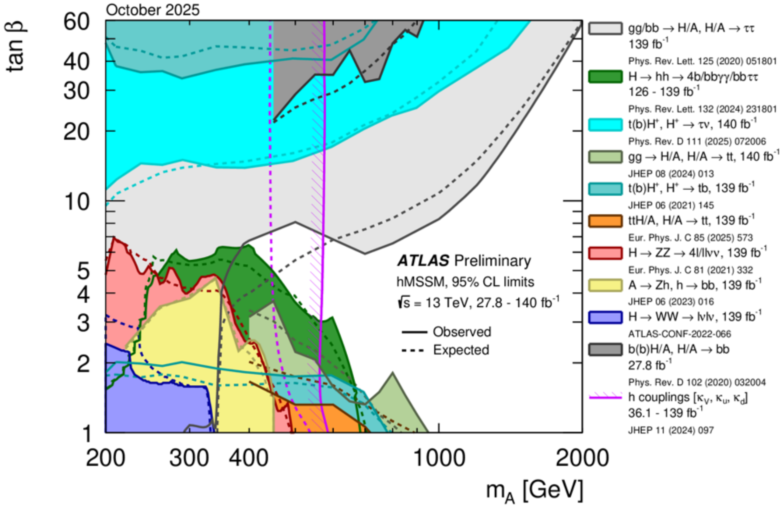
Nanjing University

2011-13, with Andy,
on SM H→bb



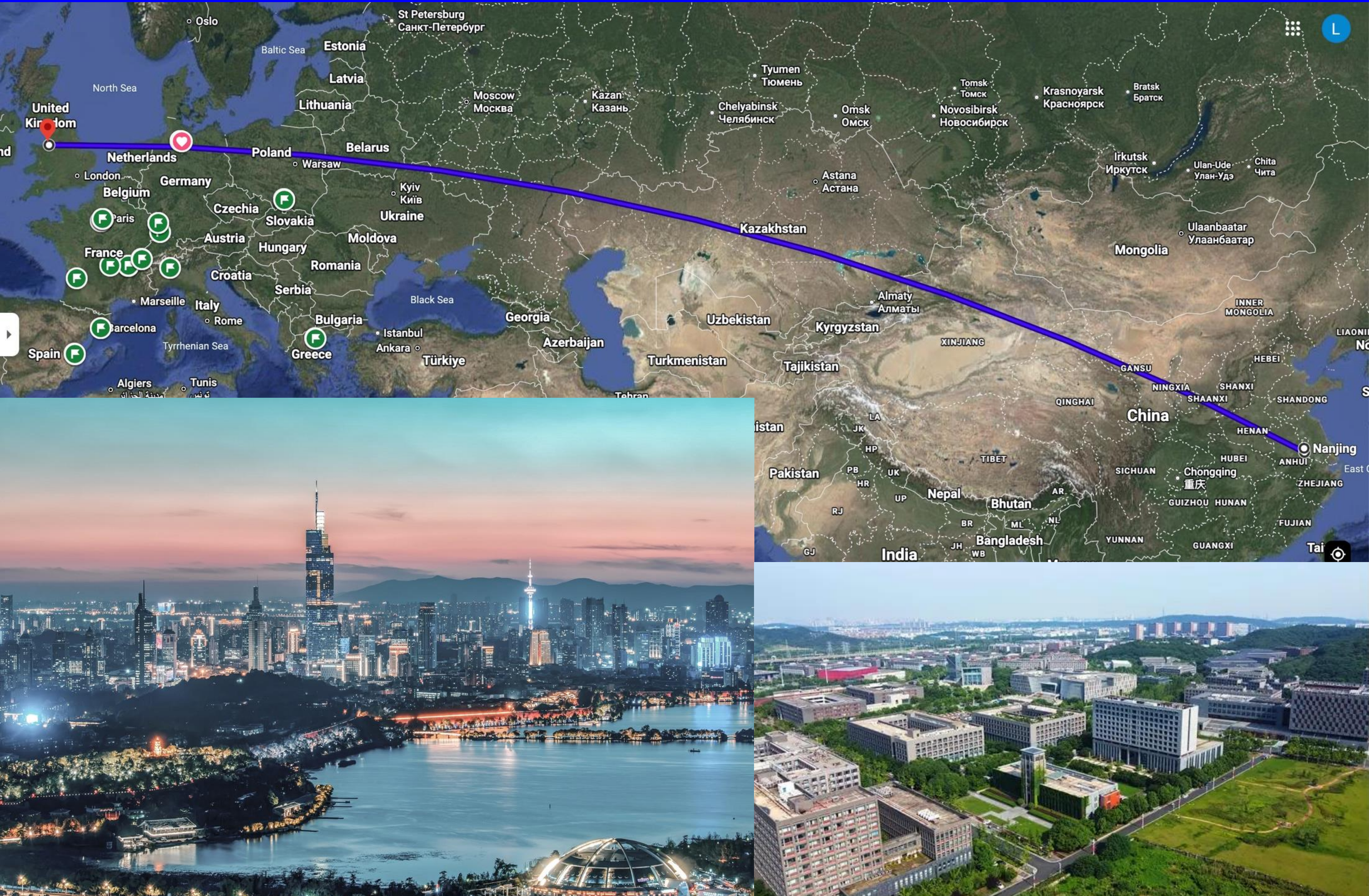
2014-15, with Carl
on BSM H→ZZ

2015-18, with Nikos
on BSM A/H $\rightarrow\tau\tau$



University of Liverpool, UK, July 2026

Nanjing (南京)


Oslo
St Petersburg
Санкт-Петербург
Baltic Sea
Estonia
North Sea
Latvia
Lithuania
United Kingdom
Netherlands
Poland
Warsaw
Belarus
London
Germany
Belgium
Czechia
Slovakia
Paris
Ukraine
Kyiv
Київ
Moldova
Austria
Hungary
France
Romania
Croatia
Serbia
Marseille
Italy
Rome
Bulgaria
Barcelona
Istanbul
Ankara
Spain
Tyrrhenian Sea
Greece
Türkiye
Algiers
Tunis
Black Sea
Georgia
Azerbaijan
Moscow
Москва
Kazan
Казань
Tyumen
Тюмень
Chelyabinsk
Челябинск
Omsk
Омск
Tomsk
Томск
Novosibirsk
Новосибирск
Krasnoyarsk
Красноярск
Bratsk
Братск
Irkutsk
Иркутск
Ulan-Ude
Улан-Удэ
Chita
Чита
Astana
Астана
Kazakhstan
Mongolia
Ulaanbaatar
Улаанбаатар
Almaty
Алматы
Uzbekistan
Kyrgyzstan
Turkmenistan
Tajikistan
Tehran
XINJIANG
INNER MONGOLIA
LIAONING
HEBEI
GANSU
NINGXIA
SHANXI
SHAANXI
SHANDONG
QINGHAI
China
HENAN
Nanjing
ANHUI
HUBEI
TIBET
Pakistan
SICHUAN
Chongqing
重庆
ZHEJIANG
Nepal
Bhutan
GUIZHOU
HUNAN
FUJIAN
Bangladesh
YUNNAN
GUANGXI
India
L

Outline

- BEPCII-BESIII experiment
  - and its recent upgrades
- LHC experiment, focus on ATLAS
  - Upgrade projects for HL-LHC
  - Proposed future Higgs factory: CEPC, FCC-ee
- Non-collider experiments: Neutrino and dark matter
  - Some proposal on fix target experiments
- Summary

Note: a broad range of nuclear physics (e.g. HIAF, CiADS) and astrophy facilities (e.g. LHAASO, FAST, AliCPT, Taiji, etc.) ongoing or planed in China, but not included in this talk.

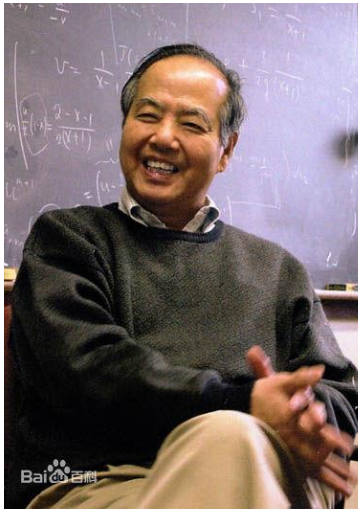
Beijing Electron-Positrion Collider (BEPC)

- Beginning of Particle physics in China
  - BEPC construction started in 1984, first collision in 1988

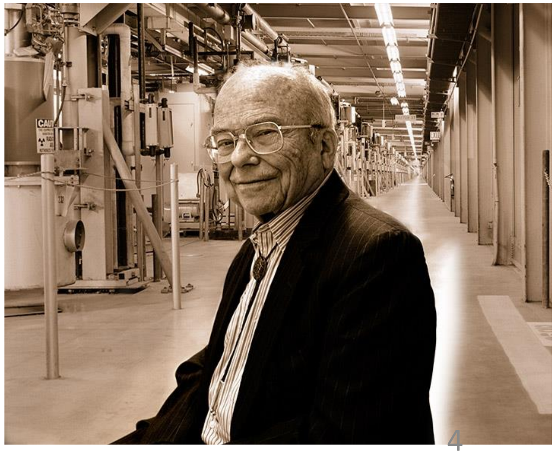
The first meeting of the Sino-US committee on HEP, 1979, China

Deng at ground breaking (Oct. 7, 1984)

Prof. T. D. Lee

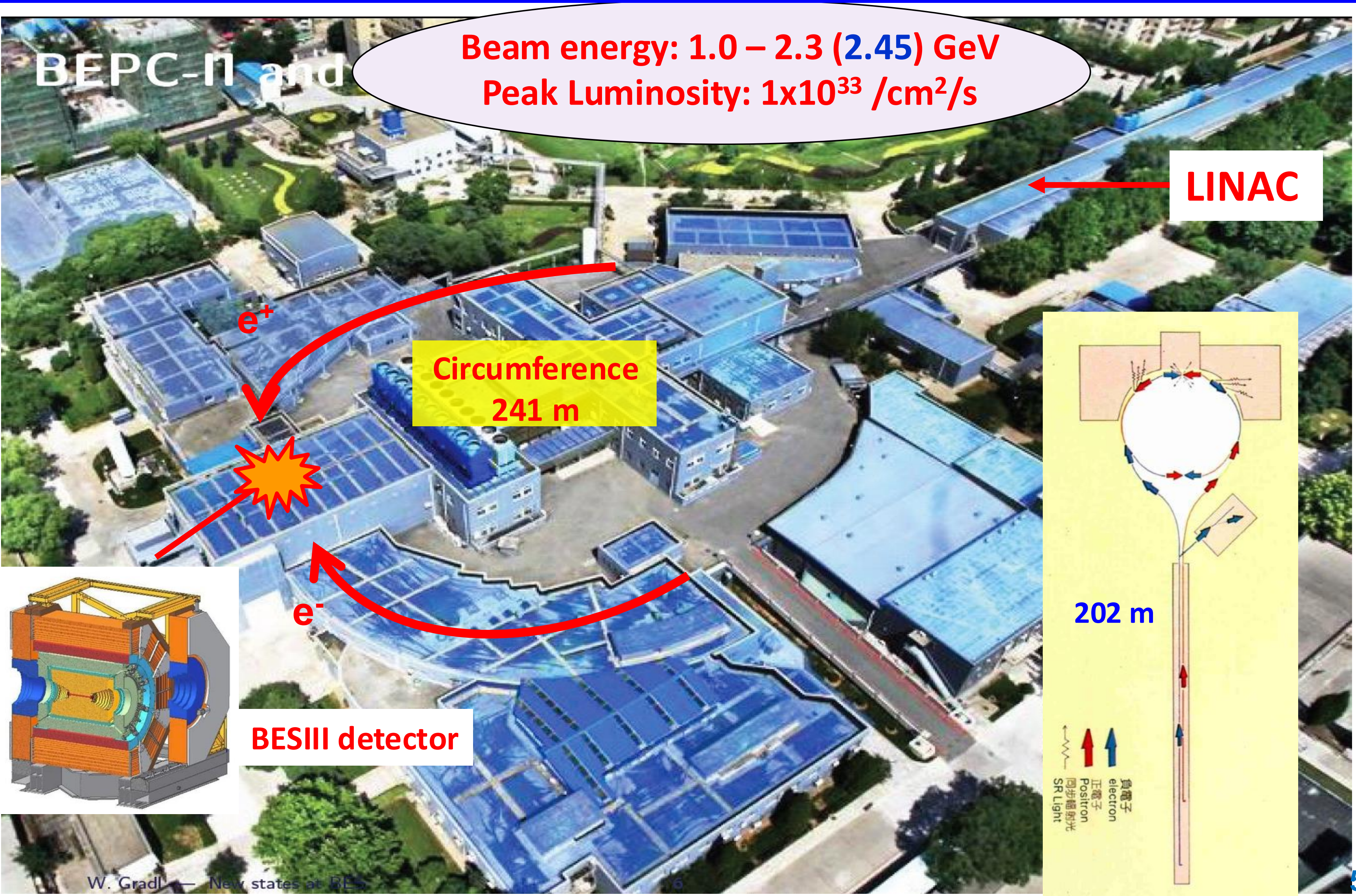


Prof. Panofsky, from SLAC



BEPCII: upgrade by 2009

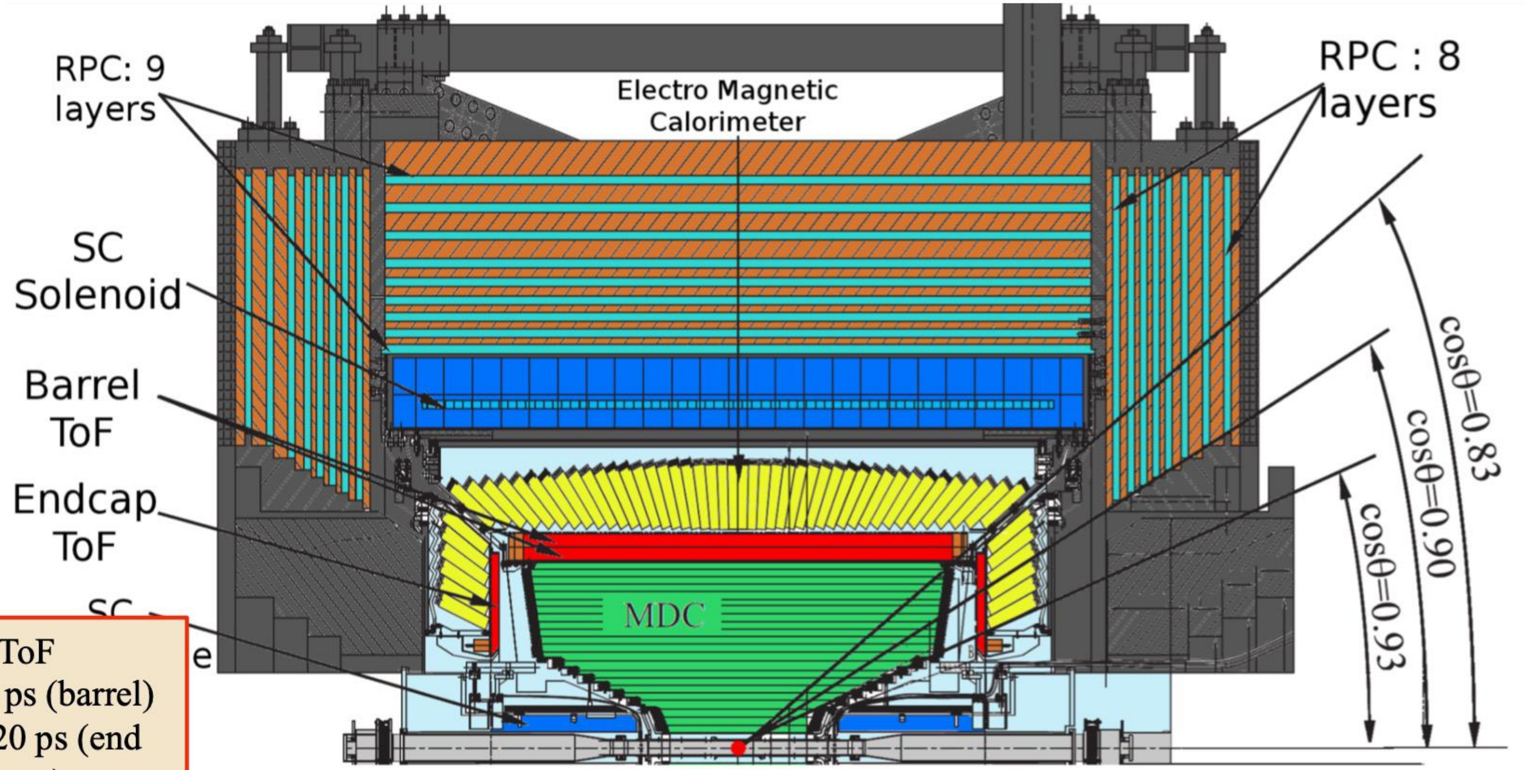
Beam energy: 1.0 – 2.3 (2.45) GeV
Peak Luminosity: 1x10^{33} /cm^2/s



BEPCII-BESIII experiment

BESIII moved in at Jun. 22rd 2008 for joint commissioning

BESIII detector



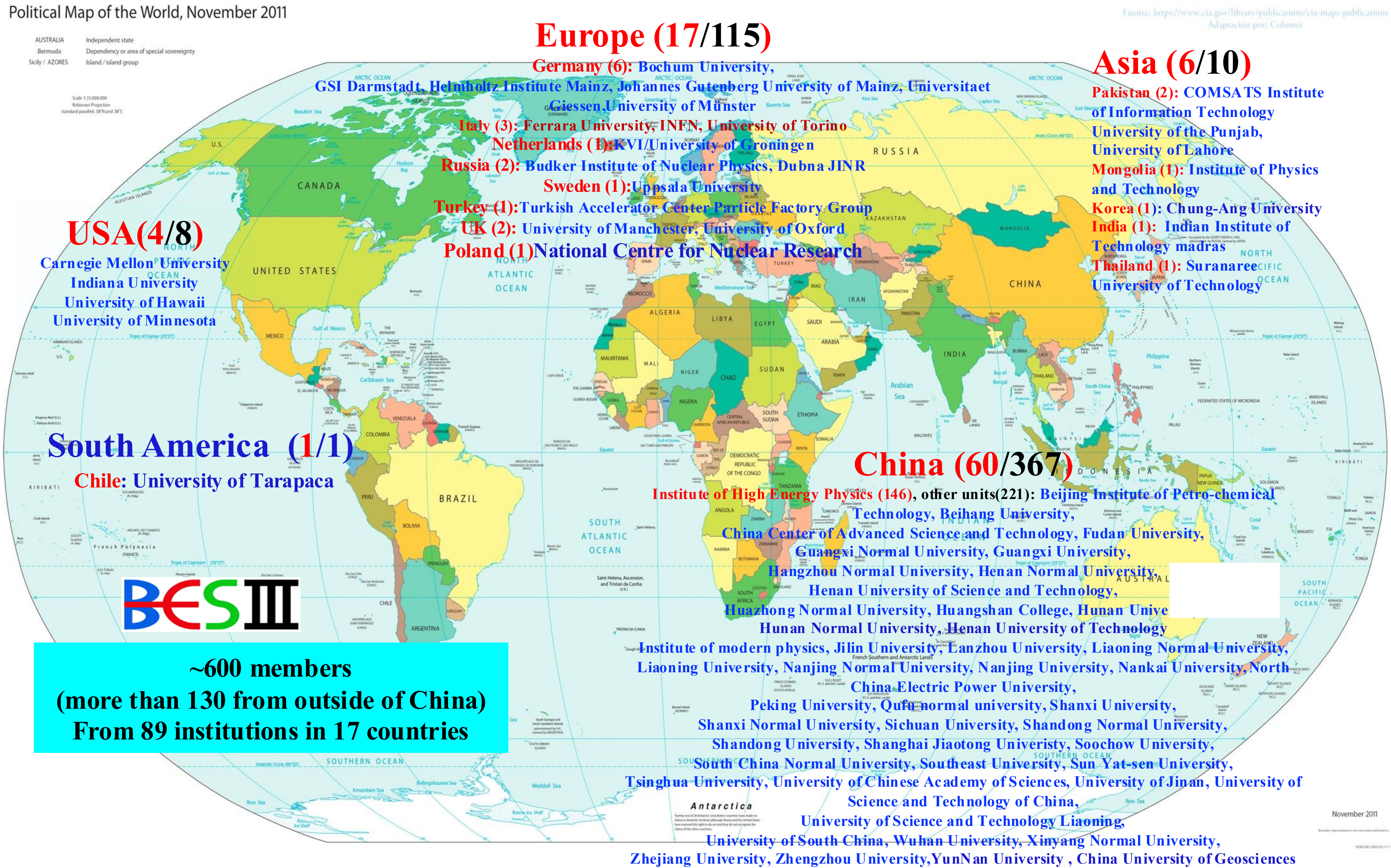
ToF
$\sigma_t \sim 90$ ps (barrel)
$\sigma_t \sim 120$ ps (end caps)

Drift Chamber
$\sigma_{r\phi} \sim 130$ μm (single wire)
$\sigma_{pt}/p_t \sim 0.5$ % @ 1 GeV

Electromagnetic CsI(Tl) Calorimeter
$\sigma_E/E < 2.5\%$ @ 1 GeV (barrel)
$\sigma_E/E < 5\%$ @ 1 GeV (end caps)
$\sigma_{xy} \sim (6 \text{ mm})/E^{1/2}$ @ 1 GeV

RPC Muon Detector
$\Delta\Omega/4\pi = 93\%$

BESIII Collaboration



Europe (17/115)

Germany (6): Bochum University, GSI Darmstadt, Helmholtz Institute Mainz, Johannes Gutenberg University of Mainz, Universitaet Giessen,University of Münster

Italy (3): Ferrara University, INFN, University of Torino

Netherlands (1):KVI/University of Groningen

Russia (2): Budker Institute of Nuclear Physics, Dubna JINR

Sweden (1): Uppsala University

Turkey (1): Turkish Accelerator Center Particle Factory Group

UK (2): University of Manchester, University of Oxford

Poland (1) National Centre for Nuclear Research

Asia (6/10)

Pakistan (2): COMSATS Institute of Information Technology University of the Punjab, University of Lahore

Mongolia (1): Institute of Physics and Technology

Korea (1): Chung-Ang University

India (1): Indian Institute of Technology madras

Thailand (1): Suranaree University of Technology

USA(4/8)

Carnegie Mellon University
Indiana University
University of Hawaii
University of Minnesota

South America (1/1)

Chile: University of Tarapaca

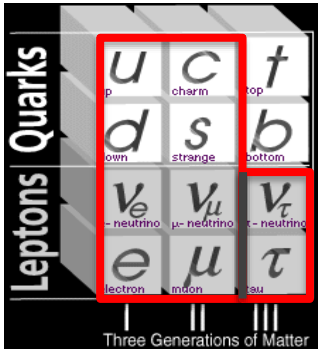
China (60/367)

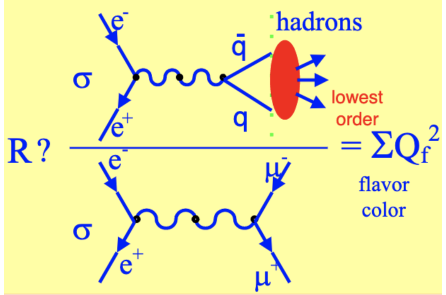
Institute of High Energy Physics (146), other units(221): Beijing Institute of Petro-chemical Technology, Beihang University, China Center of Advanced Science and Technology, Fudan University, Guangxi Normal University, Guangxi University, Hangzhou Normal University, Henan Normal University, Henan University of Science and Technology, Huazhong Normal University, Huangshan College, Hunan Unive

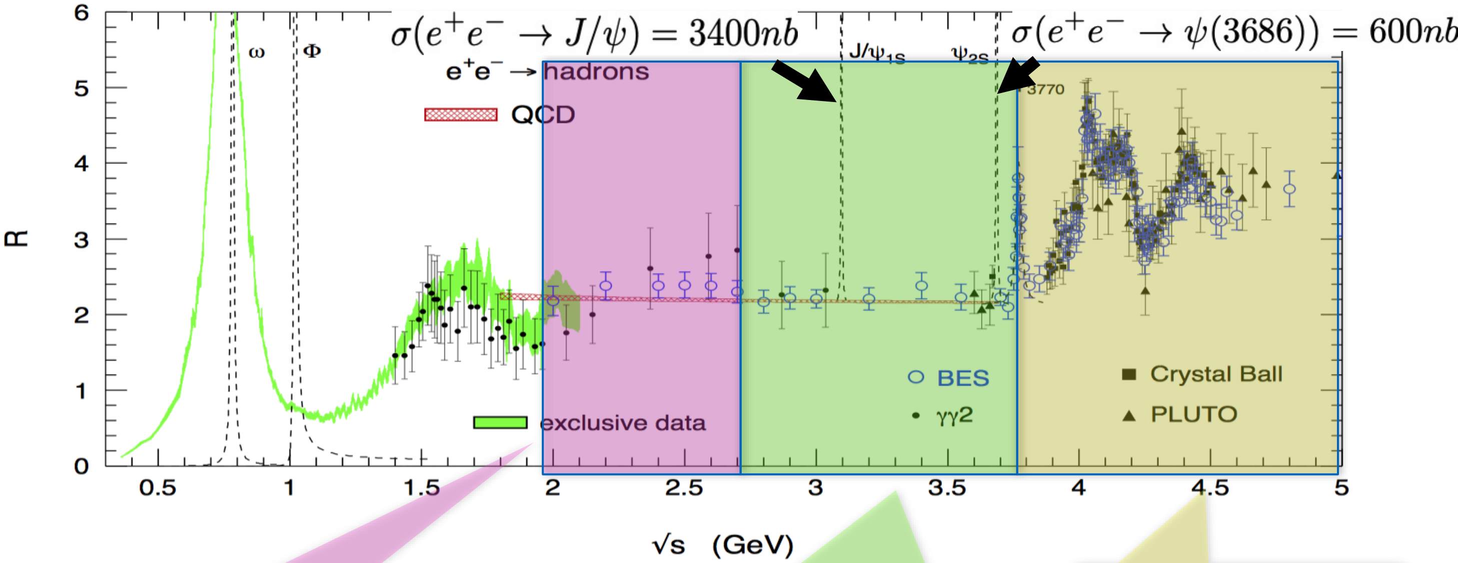
Hunan Normal University, Henan University of Technology Institute of modern physics, Jilin University, Lanzhou University, Liaoning Normal University, Liaoning University, Nanjing Normal University, Nanjing University, Nankai University, North China Electric Power University, Peking University, Qufu normal university, Shanxi University, Shanxi Normal University, Sichuan University, Shandong Normal University, Shandong University, Shanghai Jiaotong Univeristy, Soochow University, South China Normal University, Southeast University, Sun Yat-sen University, Tsinghua University, University of Chinese Academy of Sciences, University of Jinan, University of Science and Technology of China, University of Science and Technology Liaoning, University of South China, Wuhan University, Xinyang Normal University, Zhejiang University, Zhengzhou University,YunNan University , China University of Geosciences

~600 members
(more than 130 from outside of China)
From 89 institutions in 17 countries

Physics at Tau-Charm Energy Region







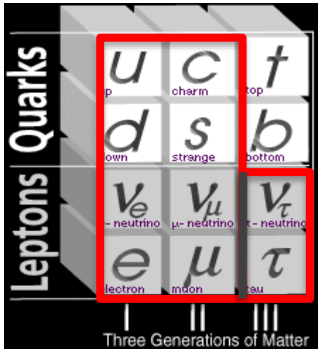
- Hadron form factors
- R values and QCD

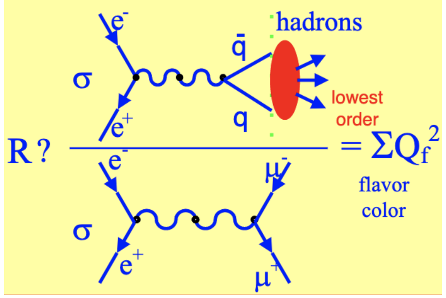
- Light hadron spectroscopy
- Gluonic and exotic states
- Physics with t lepton

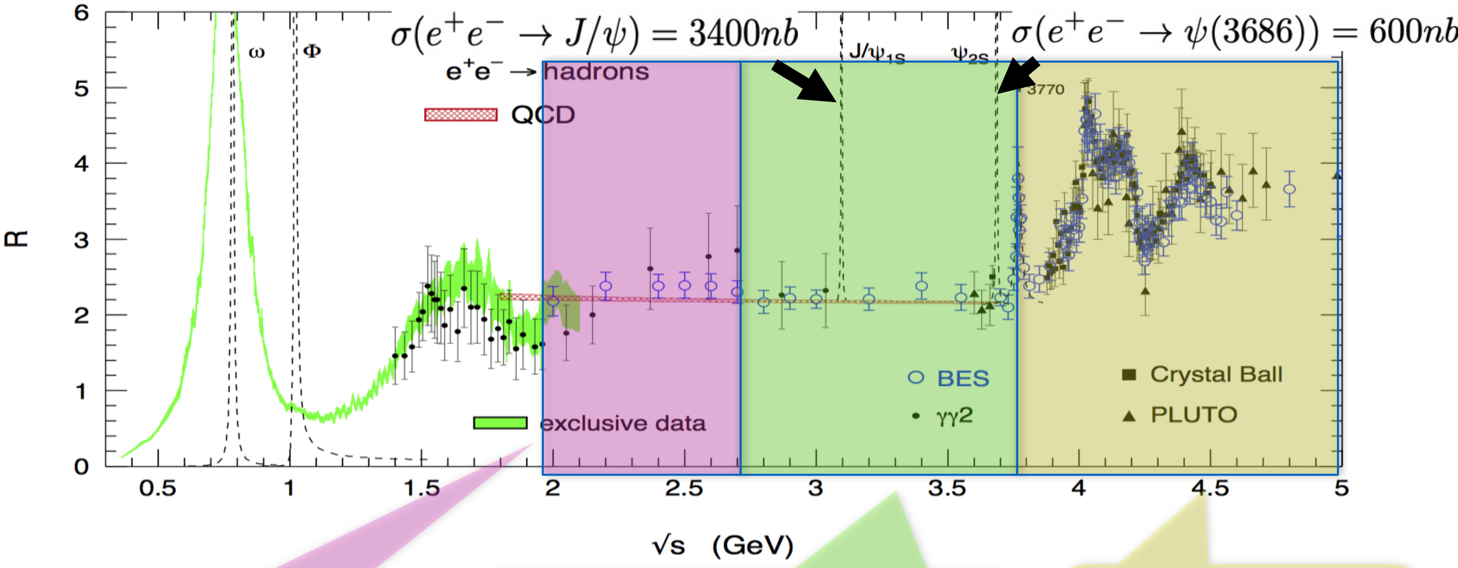
- XYZ particles
- Charm mesons
- Charm baryons

$$R \equiv \frac{\sigma^0(e^+e^- \to \text{hadrons})}{\sigma^0(e^+e^- \to \mu^+\mu^-)} \equiv \frac{\sigma^0_{\text{had}}}{\sigma^0_{\mu\mu}}$$

Physics at Tau-Charm Energy Region





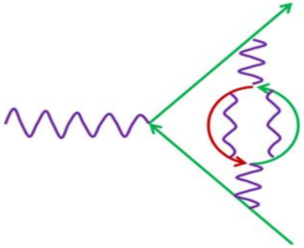


- Hadron form factors
- R values and QCD

- Light hadron spectroscopy
- Gluonic and exotic states
- Physics with t lepton

- XYZ particles
- Charm mesons
- Charm baryons

$$R \equiv \frac{\sigma^0(e^+e^- \to \text{hadrons})}{\sigma^0(e^+e^- \to \mu^+\mu^-)} \equiv \frac{\sigma^0_{\text{had}}}{\sigma^0_{\mu\mu}}$$

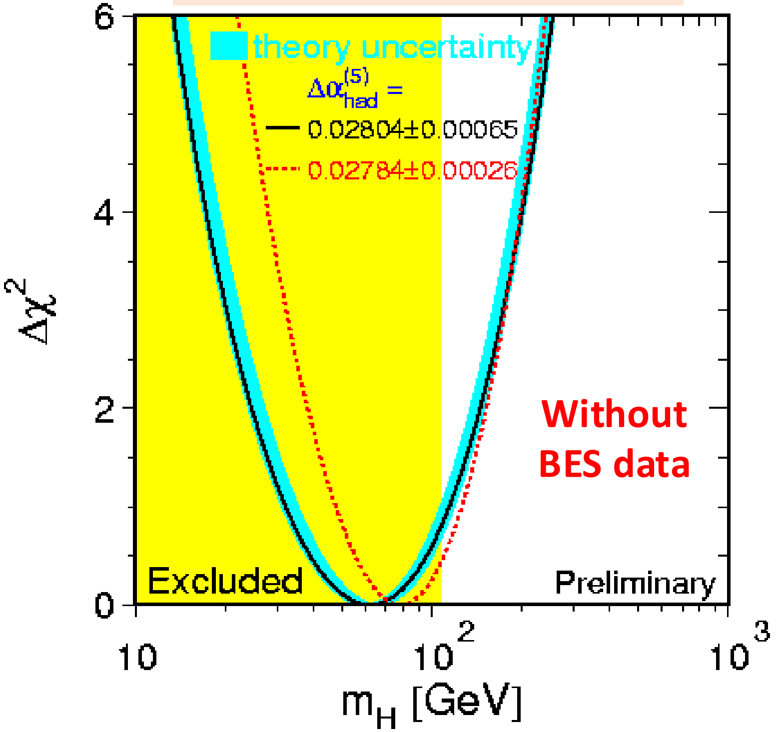


- Important input for determining the Hadronic Vacuum Polarization (HVP) of running coupling constant (m^2_Z)

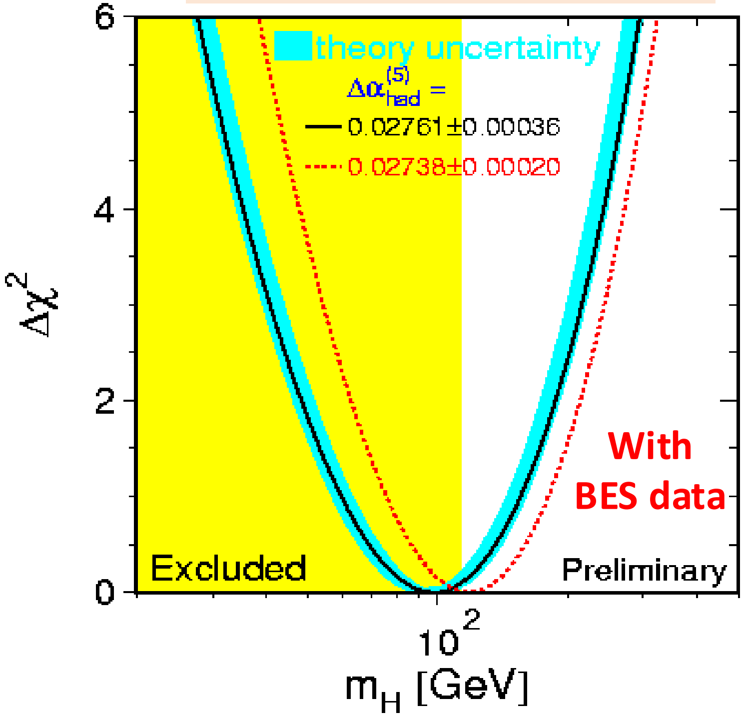
Impact to Global Fit for Higgs boson

- BESII reduced $\alpha(M_Z^2)$ uncertainty which is crucial for Higgs boson mass prediction in the EW global fit around 2000

$m_H = 62^{+53}_{-30}$ GeV



$m_H = 98^{+58}_{-38}$ GeV



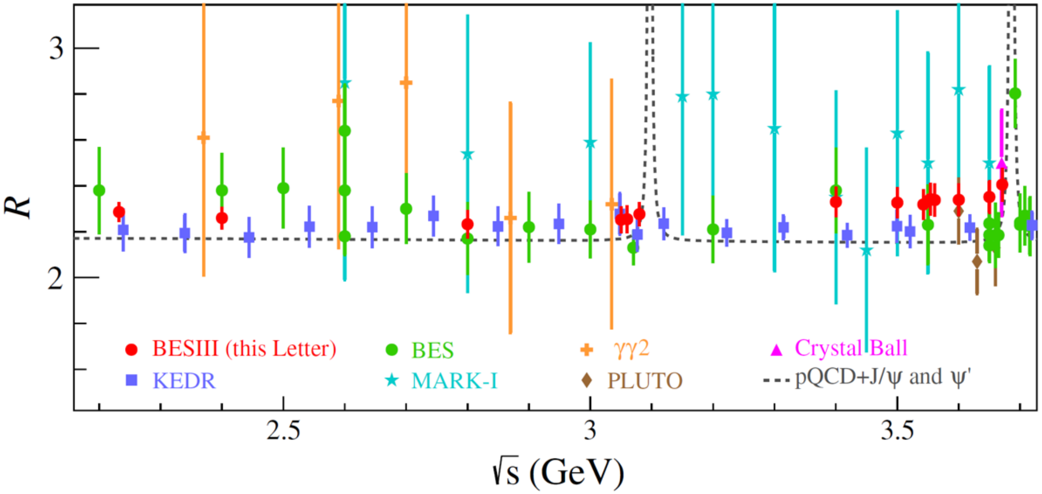
"without this result, we could have excluded the SM Higgs",

Bolek Pietrzyk at ICHEP Osaka 2000,

Latest results: R-Value

- Continue provide the best precision between 2.2-3.7 GeV

PRL 128 (2022) 062004

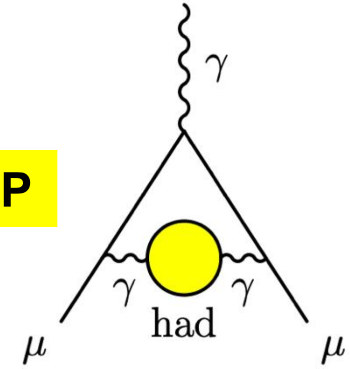


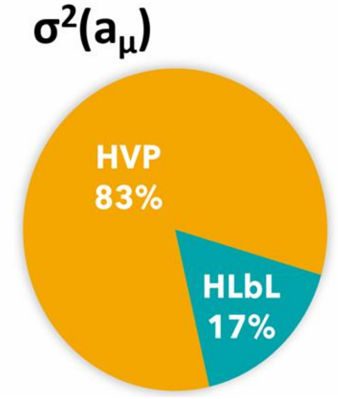
- Muon g-2: hadronic vacuum polarization (HVP)
  - Dominant uncertainty (>80%)

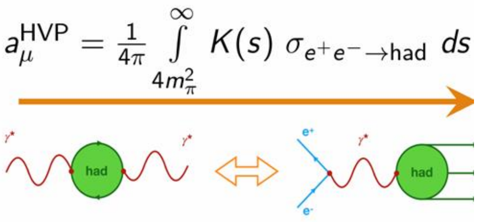
$$a_\mu^{SM} = a_\mu^{QED} + a_\mu^{Weak} + a_\mu^{Had.}$$

Extracted from ee→hadrons

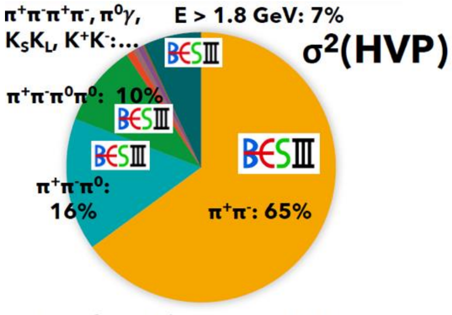
HVP







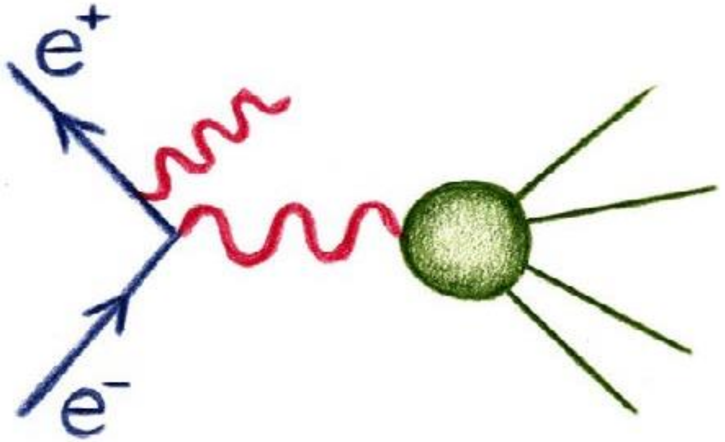
$$a_\mu^{HVP} = \frac{1}{4\pi}\int_{4m_\pi^2}^{\infty} K(s)\,\sigma_{e^+e^-\to\mathrm{had}}\,ds$$



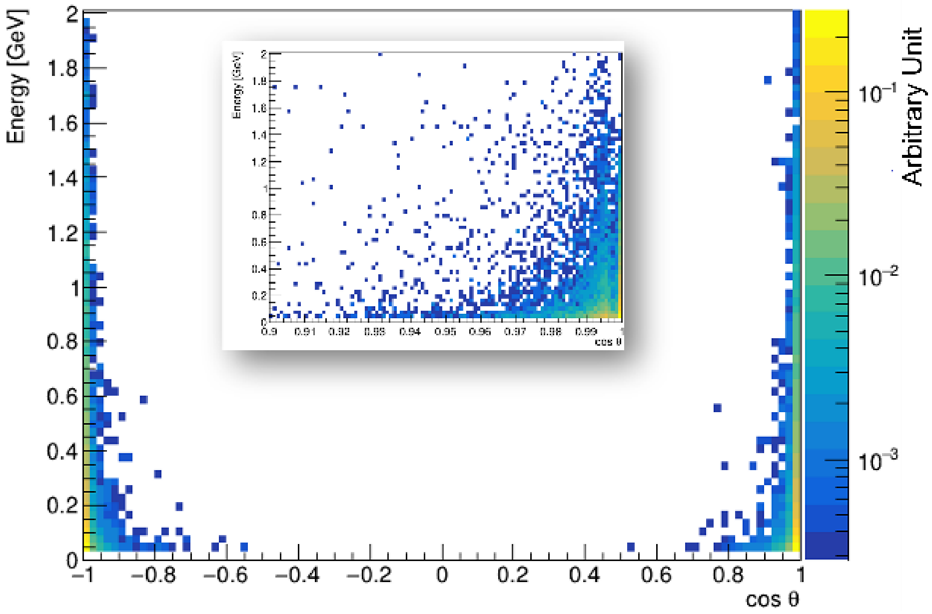
[Data from: Phys.Rep 887 (2020) 1-166]

ISR return

- Initial State Radiation (ISR) return
  - $e^+e^-\to\gamma^{ISR}e^+e^-\to\gamma^{ISR}\,X$ lower the effective collision energy
- ISR photon mostly in forward region (|cosθ|>0.99)
  - EMC (|cosθ| <0.93) only detect large angle ISR photon, very low efficiency
- Dedicated detector planed to measure ISR photon

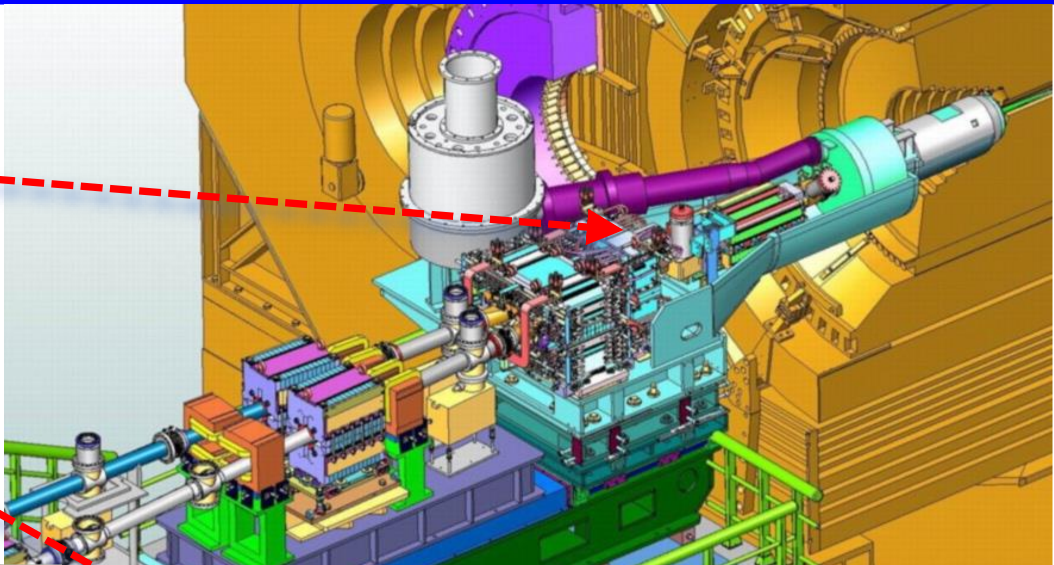


A forward detector will significantly boost ISR physics

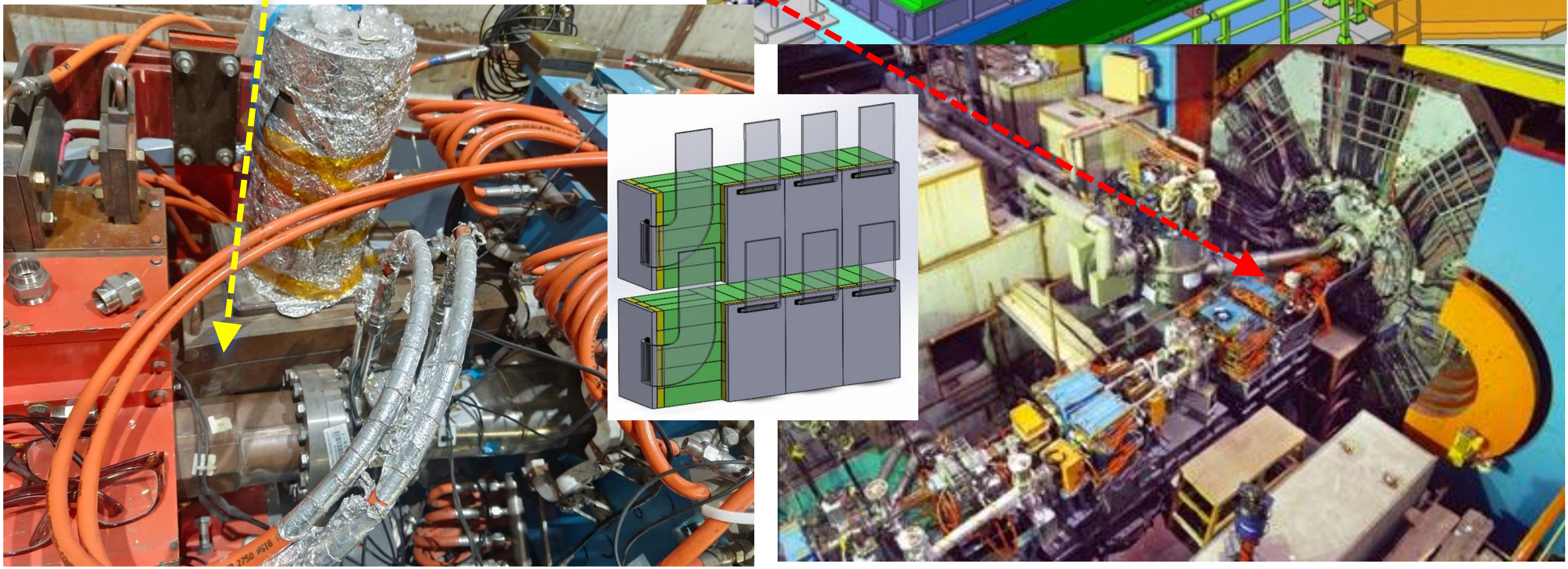


Zero Degree Calorimeter (ZDC)

- 3.3m <z<3.5 m,
  θ=0 in CMS frame

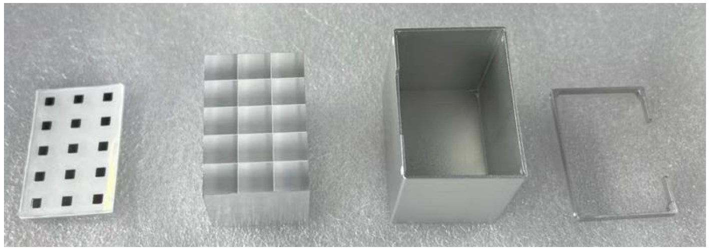


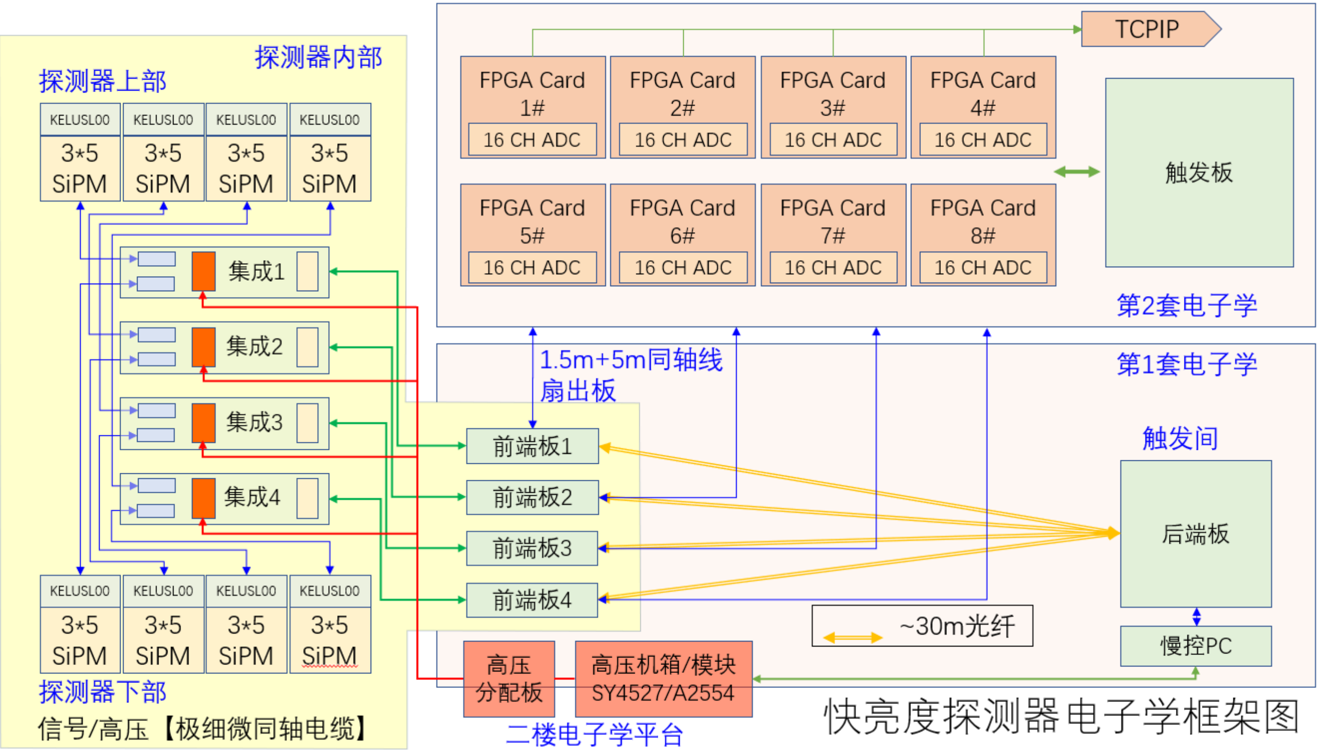
Copper window of
out-going beampipe



Zero Degree Calorimeter (ZDC)

- Detector: LYSO+SiPM array
  - 240 ch, full waveform readout





探测器内部

探测器上部

KELUSL00 KELUSL00 KELUSL00 KELUSL00

3*5 SiPM 3*5 SiPM 3*5 SiPM 3*5 SiPM

集成1

集成2

集成3

集成4

KELUSL00 KELUSL00 KELUSL00 KELUSL00

3*5 SiPM 3*5 SiPM 3*5 SiPM 3*5 SiPM

探测器下部

信号/高压【极细微同轴电缆】

TCPIP

FPGA Card 1# 16 CH ADC

FPGA Card 2# 16 CH ADC

FPGA Card 3# 16 CH ADC

FPGA Card 4# 16 CH ADC

FPGA Card 5# 16 CH ADC

FPGA Card 6# 16 CH ADC

FPGA Card 7# 16 CH ADC

FPGA Card 8# 16 CH ADC

触发板

第2套电子学

1.5m+5m同轴线

扇出板

第1套电子学

前端板1

前端板2

前端板3

前端板4

触发间

后端板

~30m光纤

慢控PC

高压分配板

高压机箱/模块 SY4527/A2554

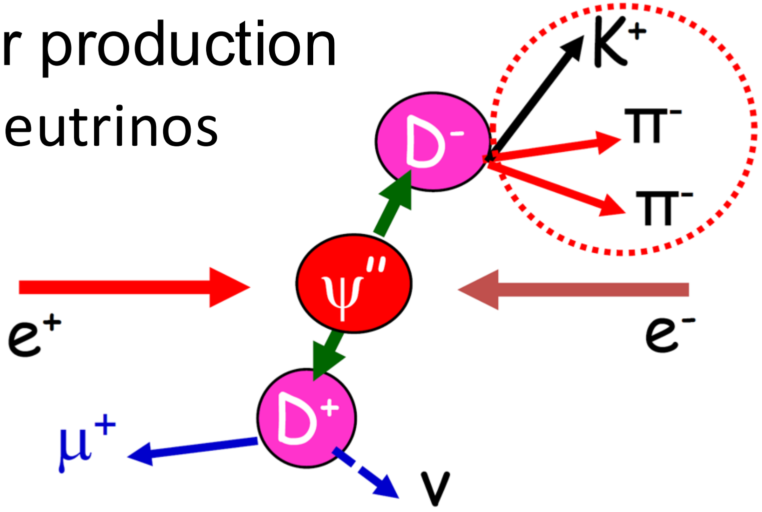
二楼电子学平台

快亮度探测器电子学框架图

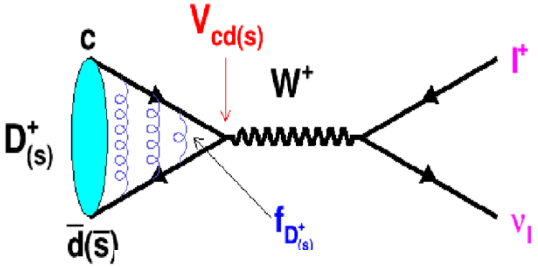
Crate：50cm * 60cm * 120cm

Flavor physics at Charm quark

- Correlation constraint of charm pair production
  - Advantage on those channel with neutrinos
  - Precise measurements

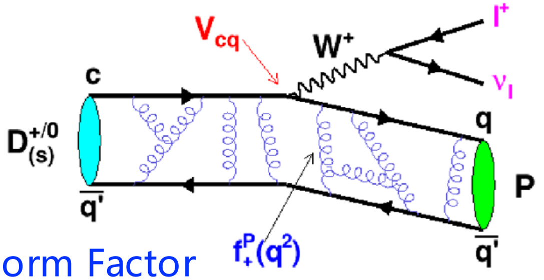


Leptonic decay



Decay constant

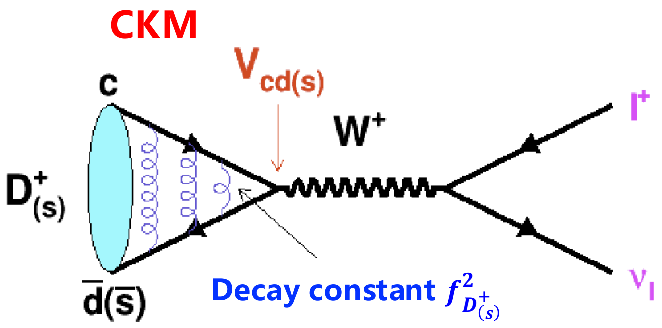
Semileptonic decay



Form Factor

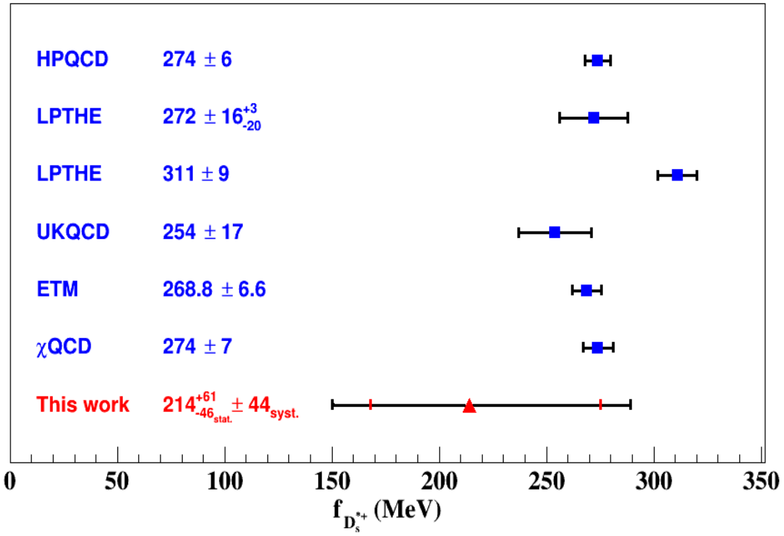
- Strong interaction: Hadron structure, non-pert. QCD, etc.
- Weak interaction: CKM matrix, lepton universality, BSM

Flavor physics at Charm quark



$$\Gamma(D^+_{(s)} \to \ell^+\nu_\ell) = \frac{G_F^2 f^2_{D^+_{(s)}}}{8\pi}|V_{cd(s)}|^2 m_\ell^2 m_{D^+_{(s)}}\left(1-\frac{m_\ell^2}{m^2_{D^+_{(s)}}}\right)^2$$

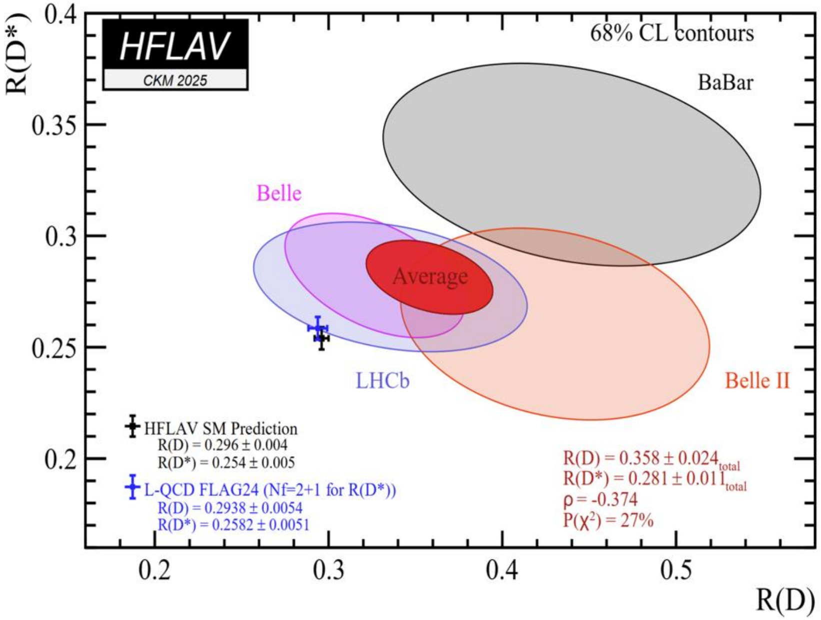
Leptonic decay



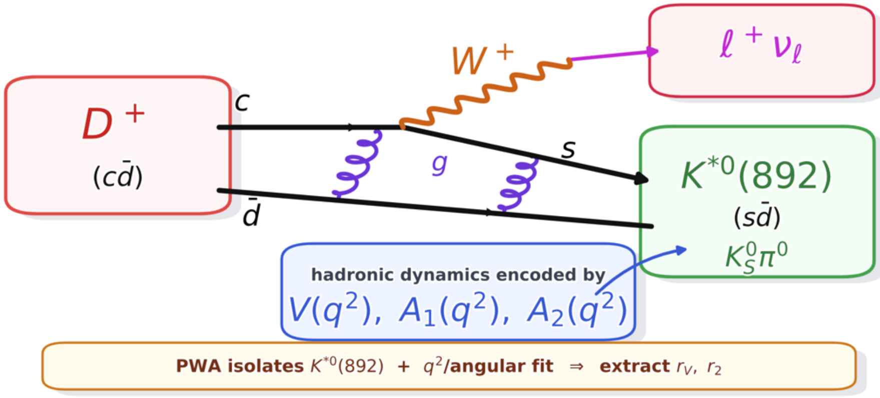
- $D_s^* \to e\nu_e$: first study excited D_s^* weak decay and measure the decay constant: $f_{D_s^*}$ test LQCD prediction

PRL 131, 141802 (2023)

Flavor physics at Charm quark



$$R_{D^{(*)}} = \frac{\mathcal{B}(B\rightarrow D^{(*)}\tau\nu_\tau)}{\mathcal{B}(B\rightarrow D^{(*)}l\nu_l)} \qquad (l = e, \mu)$$

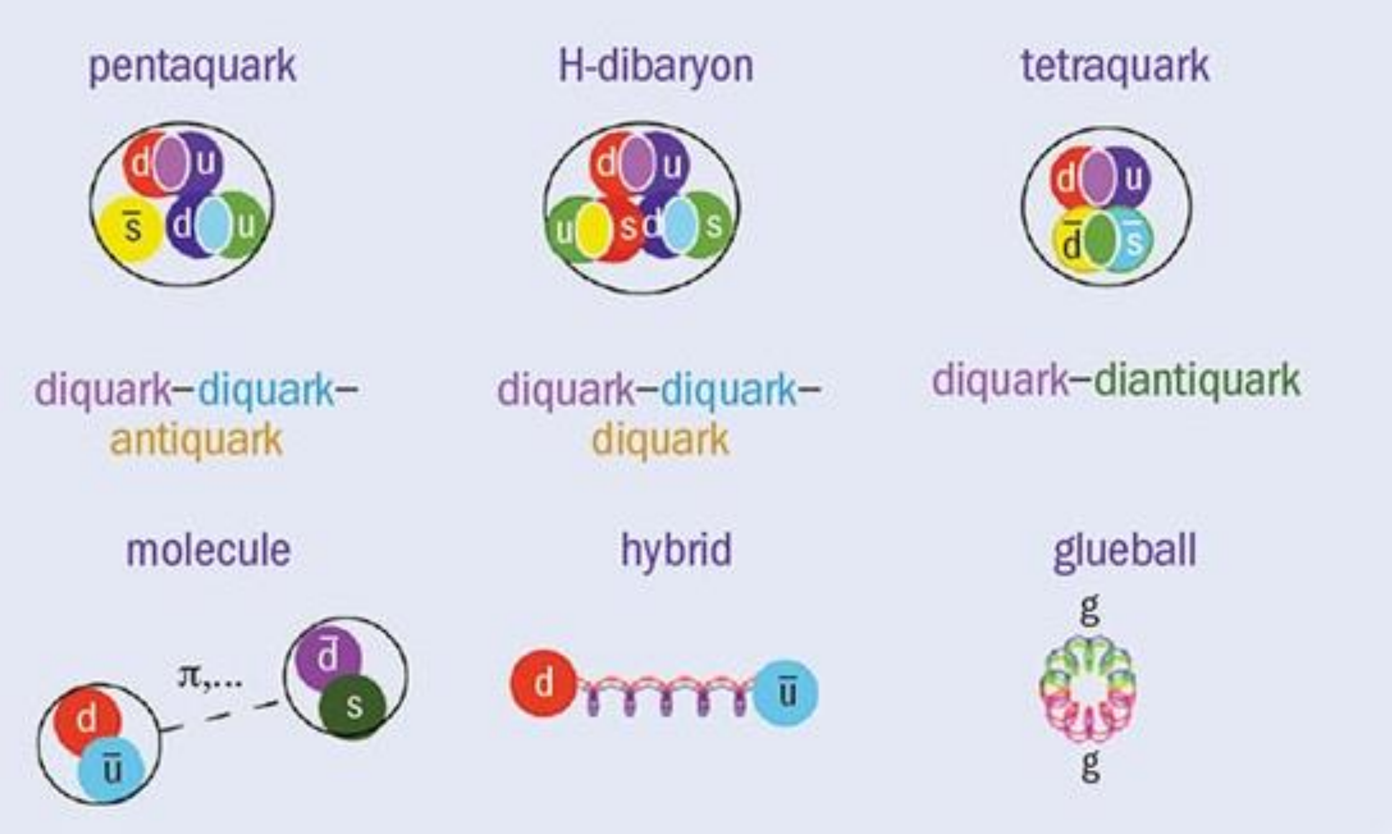


PRL 135, 171801 (2025)

- $D^+ \rightarrow K^* l^+ \nu_l$ similar to $B \rightarrow D^{(*)} l^+ \nu_l$
    - Test: $\mathcal{R}_{\mu/e} = 0.94 \pm 0.02$, Important for testing Lepton Flavor Universality

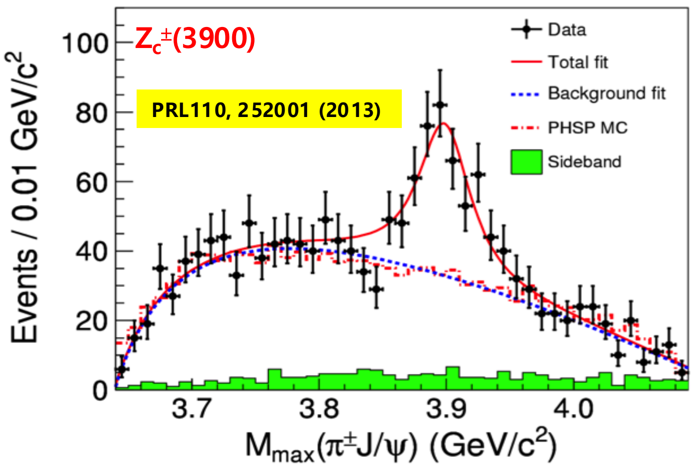
Exotic Hadron States

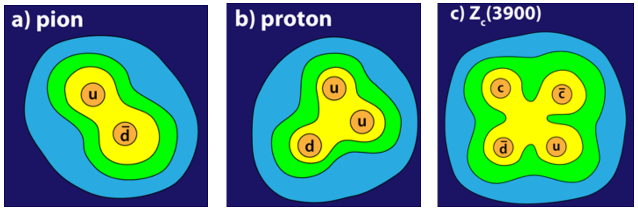
- Quark Model (in text book), great prediction power
  - Not only the hadrons with different quark composition but also the excitation spectrum for charm and bottom
- Exotic hadron states predicted more than 50 years ago



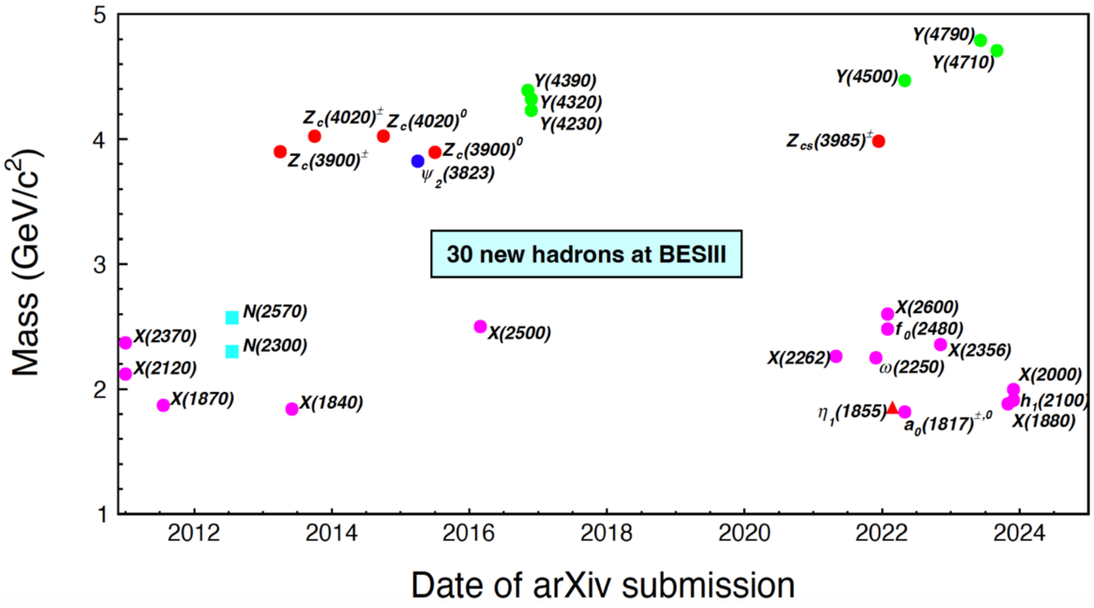
Exotic Hadron States

- BESIII discovered tetra-quark state $Z_c^{\pm}(3900)$ at 2013
  - More exotic states found, e.g. $Z_c^0(3900)$, $Z_c^0(4020)$, $Z_{cs}(3985)$, etc.



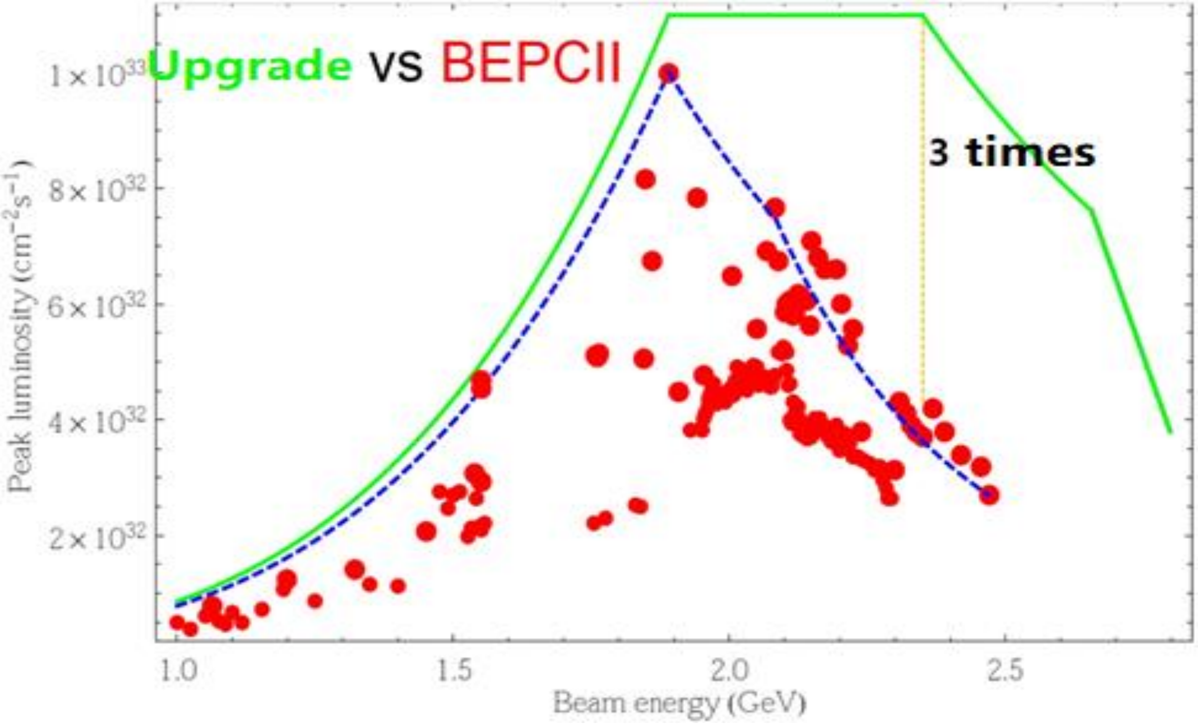


30 New Hadrons Discovered

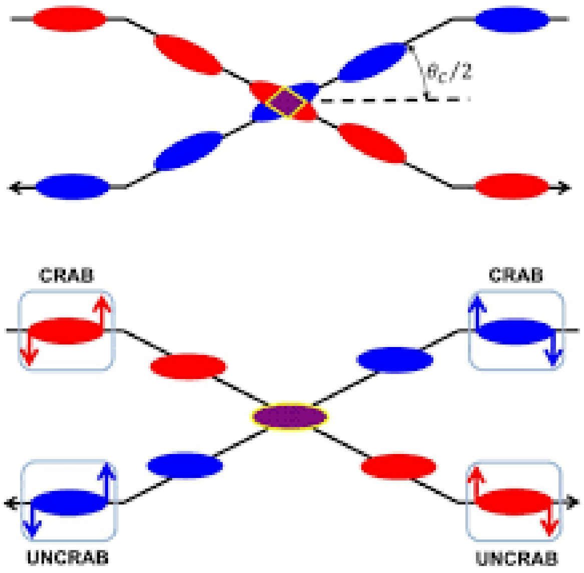


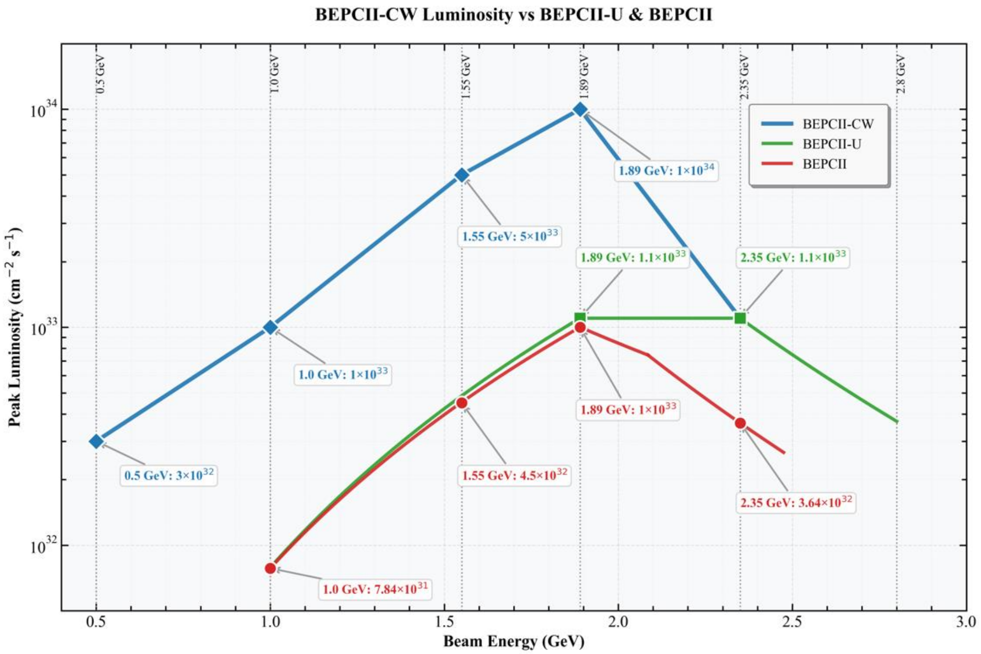
BEPCII upgrades in 2024-2025

- Upgrade on BEPCII → PEPCII-U
  - Increase luminosity at sqrt(s)>4GeV, energy up to 5.6 GeV
- Potential physics: XYZ states, charmed baryons, etc.



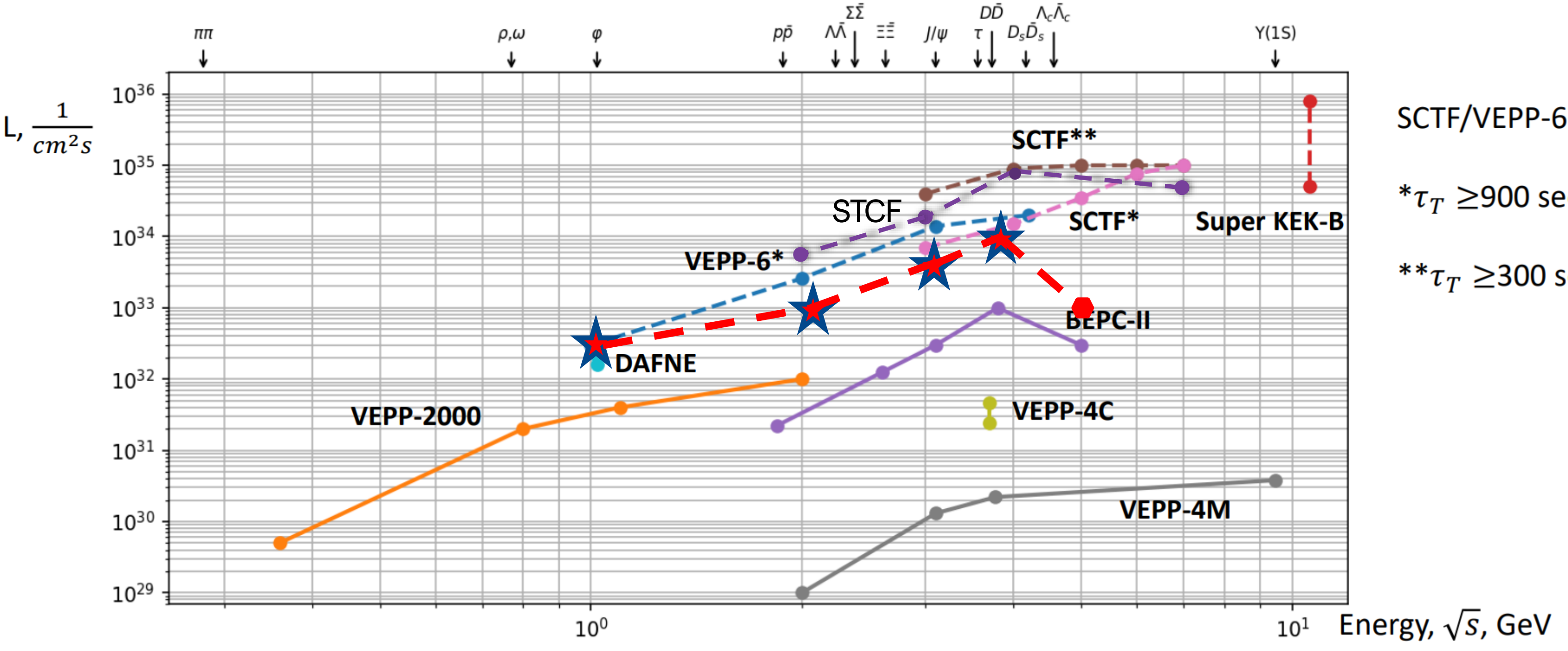
Recent proposal: Crab Waist at BEPCII





- Luminosity may increase by ×10 below 1.89GeV
  - Charm physics: 0.1 B $D\bar{D}$ pair → 1 B $D\bar{D}$ pair
- Operation below 1GeV is enabled for low energy scan:
  - Nucleon Form Factors, Strange Hadron Physics (e.g. Λ, Σ, Ξ), R-Scan, etc.

e+e- colliders at a glance



SCTF/VEPP-6:

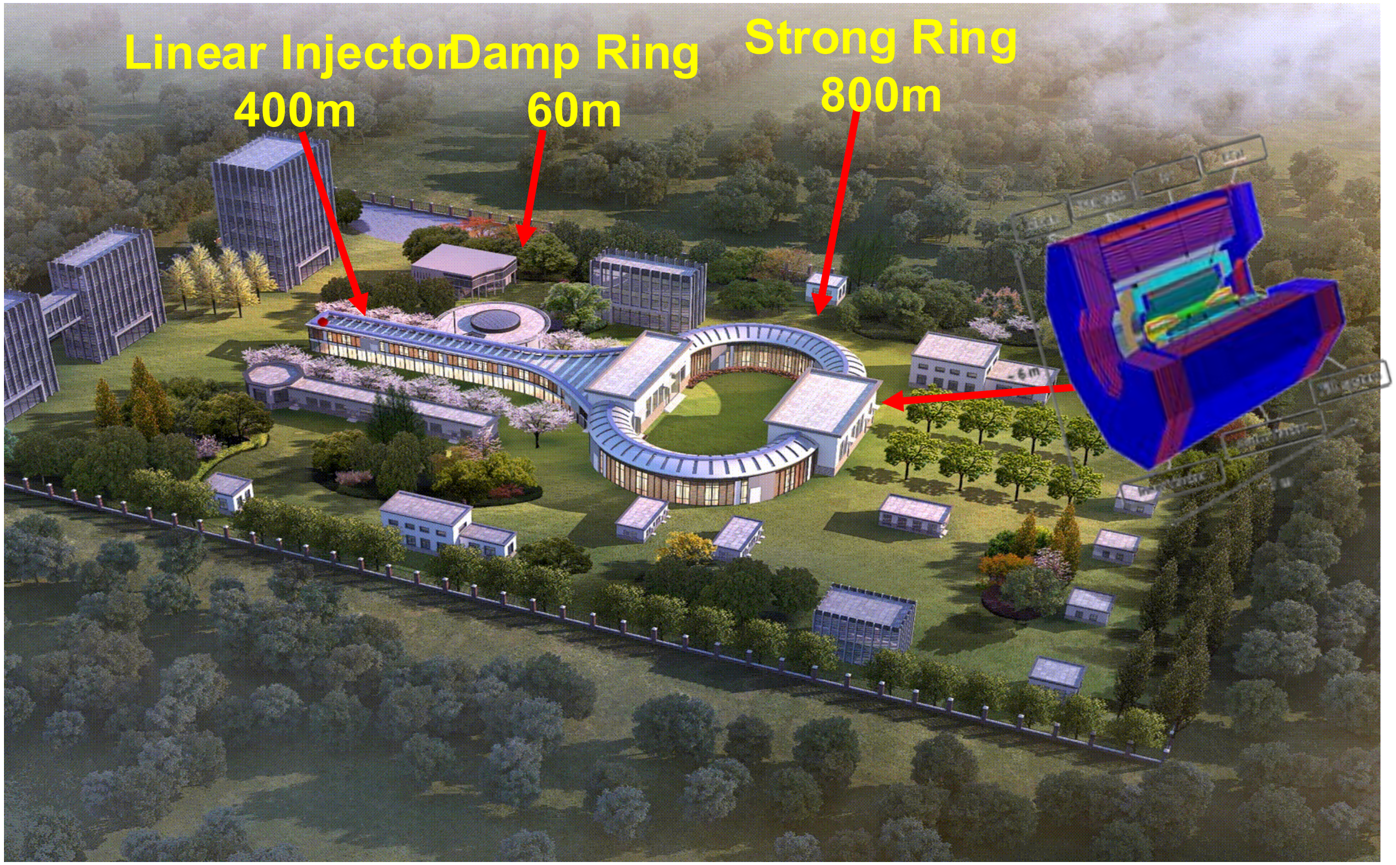
*$\tau_T \geq$900 sec

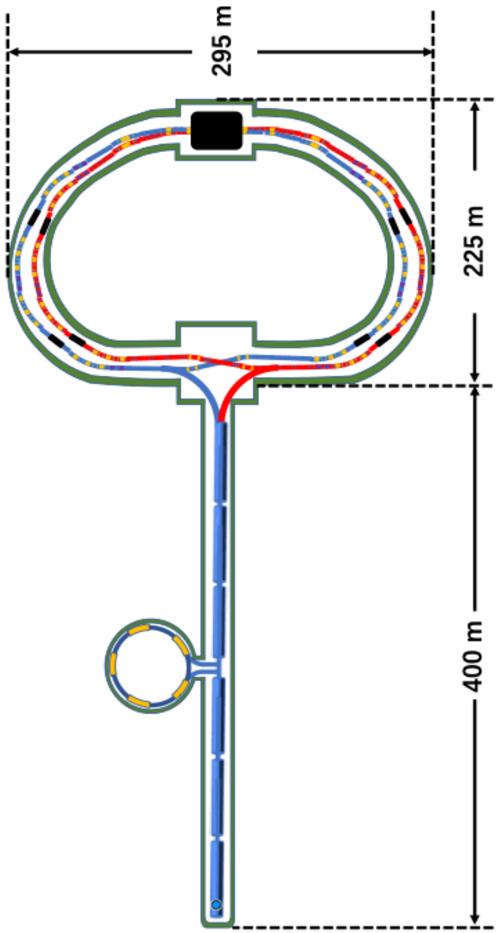
**$\tau_T \geq$300 sec

Ref: Ivan Logashenko @FTCF2025（November 24, 2025）

Super τ-Charm Facility (STCF)

- E_{cm}= 2-7GeV, peaking Luminosity =5×10^{34} cm^{-2} s^{-1} @ 4GeV
  - Potential for upgrade to increase L and realize polarized beam



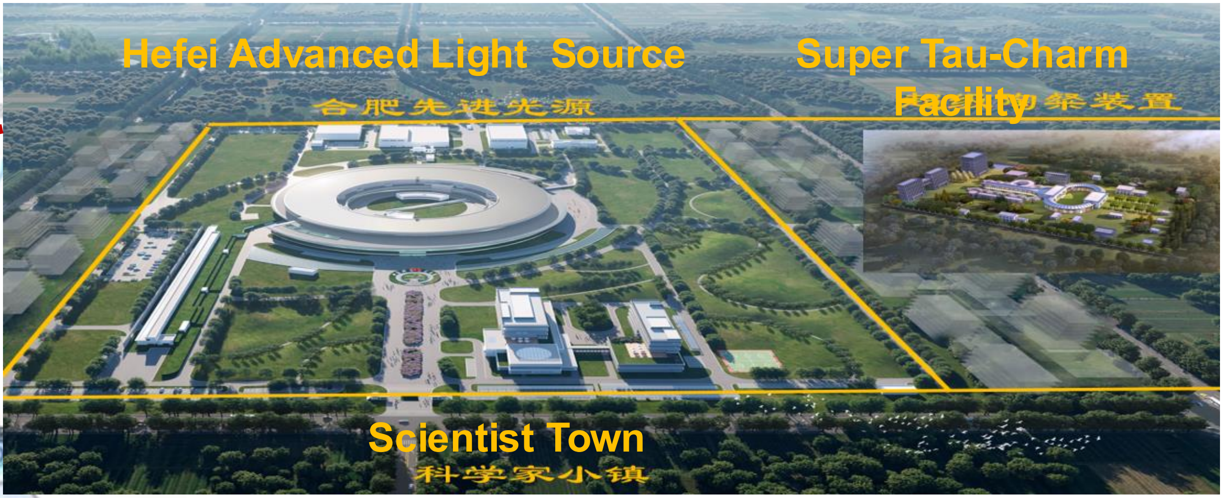


STCF: Site - Hefei

Hefei: near Nanjing and Shanghai

STCF: Site - Hefei

A very attractive Science City, has one of three comprehensive national science centers for 'Mega-science' facilities

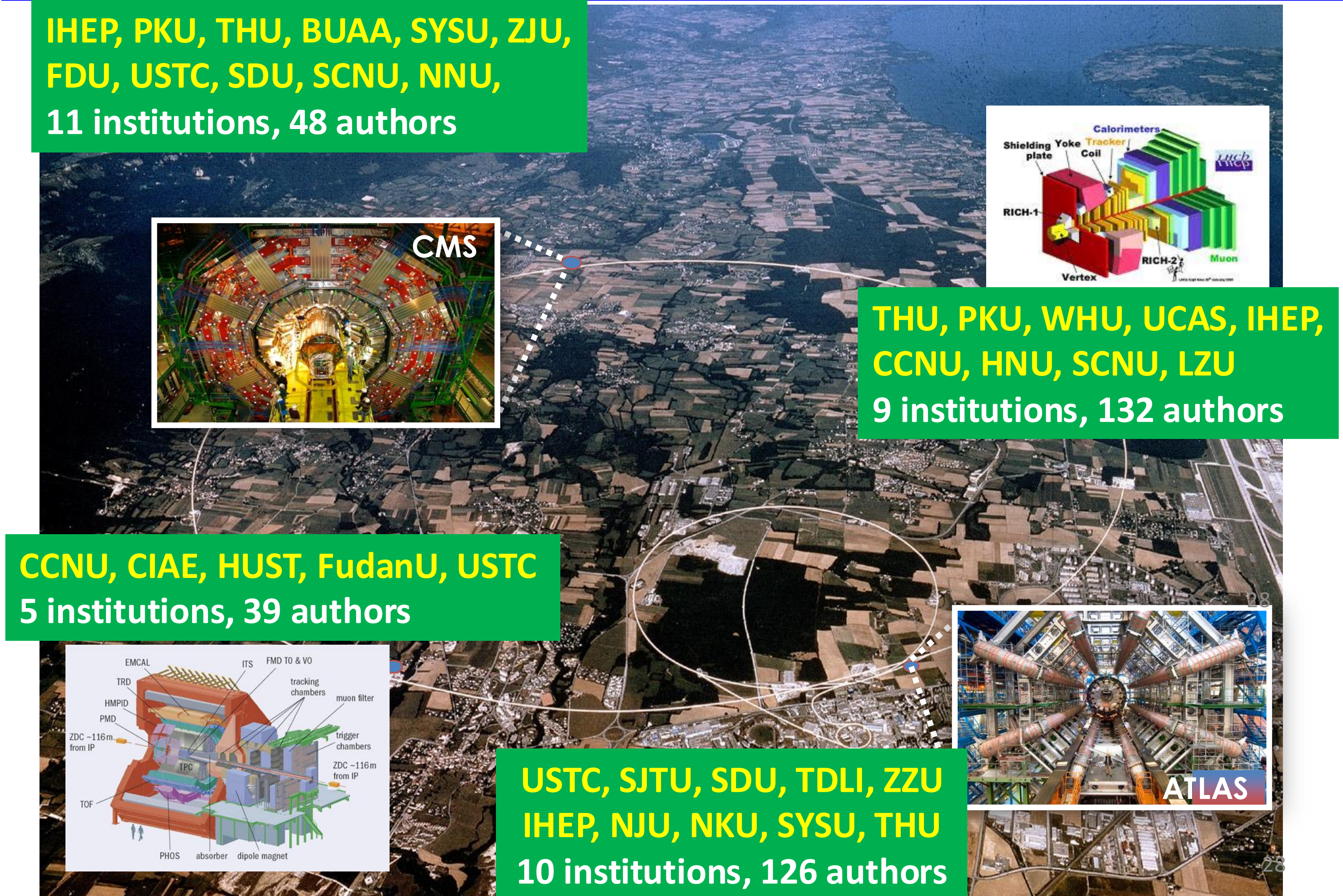


- **6 big facilities** for science and technologies (17155 acres).
- Ecological green space and modern agricultural (11815 acres)
- **HALF (4th generation light source)** was **approved** by central government, and just began **construction**
- **STCF** site is **preliminarily decided** by local government in Apr. 2023, **geological exploration** and **engineering design** is ongoing

Energy frontier in China

- LHC Physics community in China rather large and growing
- Deeply involved in all LHC key physics programs
  - Higgs property measurement, EW precision measurement, Flavor physics, BSM new physics searches, heavy ion physics, etc.

Chinese Participation to LHC



IHEP, PKU, THU, BUAA, SYSU, ZJU,
FDU, USTC, SDU, SCNU, NNU,
11 institutions, 48 authors

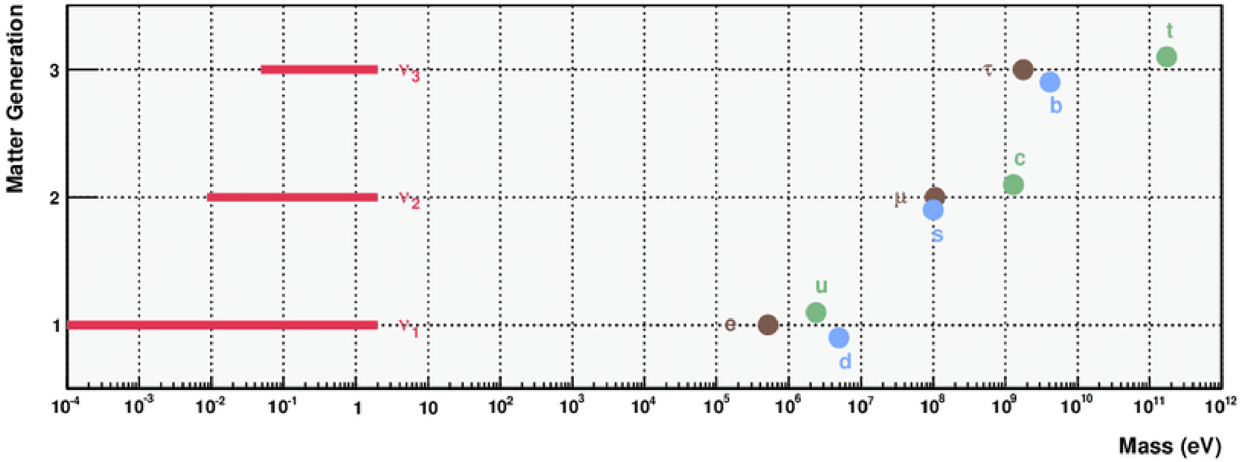
THU, PKU, WHU, UCAS, IHEP,
CCNU, HNU, SCNU, LZU
9 institutions, 132 authors

CCNU, CIAE, HUST, FudanU, USTC
5 institutions, 39 authors

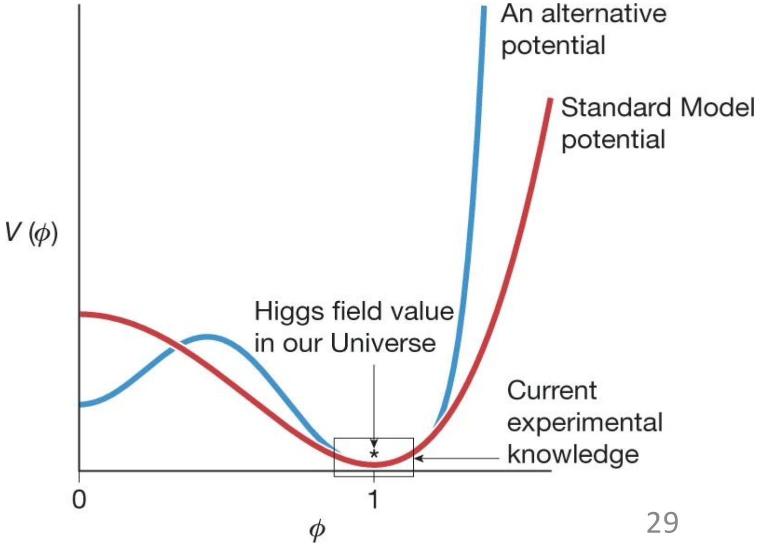
USTC, SJTU, SDU, TDLI, ZZU
IHEP, NJU, NKU, SYSU, THU
10 institutions, 126 authors

Post Higgs discovery

- Mass of fermions, e.g. quark, lepton, via Higgs Yukawa coupling
  - with huge hierarchy and many free parameters



- Nature of EW Symmetry breaking
  - Higgs Self-coupling to probe the Higgs potential
  - First order or Second order?



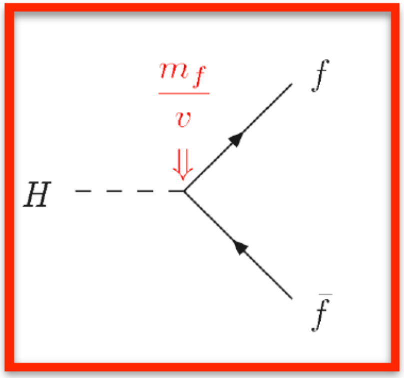
Higgs-Yukawa coupling

- Fermion mass from Higgs to fermion Yukawa coupling

$$\mathcal{L}^{(4)}_{SM} = -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} + \bar{\psi} i \not{D} \psi$$

$$\boxed{+(y_{ij}\bar{\psi}^i_L \phi \psi^j_R + \mathrm{h.c.})}$$

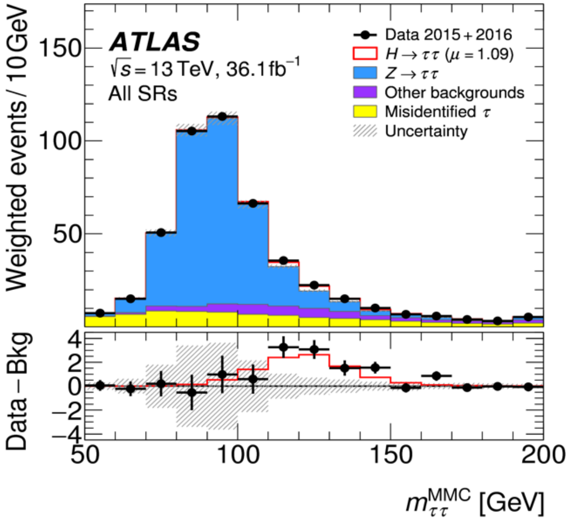
$$+|D_\mu \phi|^2 - V(\phi)$$



- $H \to \tau\tau$: established Higgs to Lepton Yukawa coupling, precisely test the lepton mass generation mechanism
    - Heavy, strong coupling to Higgs sector
    - Spin information can be probed via the decay product
    - Clean: no irreducible background via strong interaction

Evolution of $H\to\tau\tau$ measurement

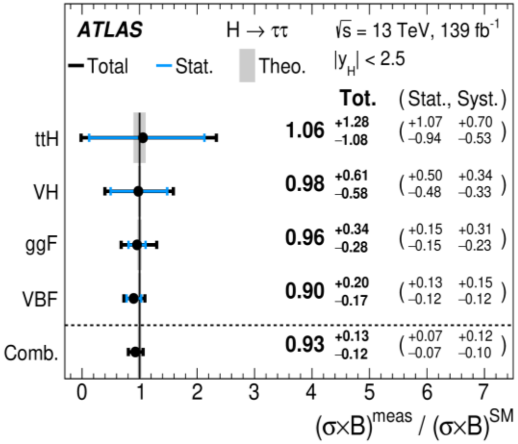
Discovery



- 6.4 σ significance

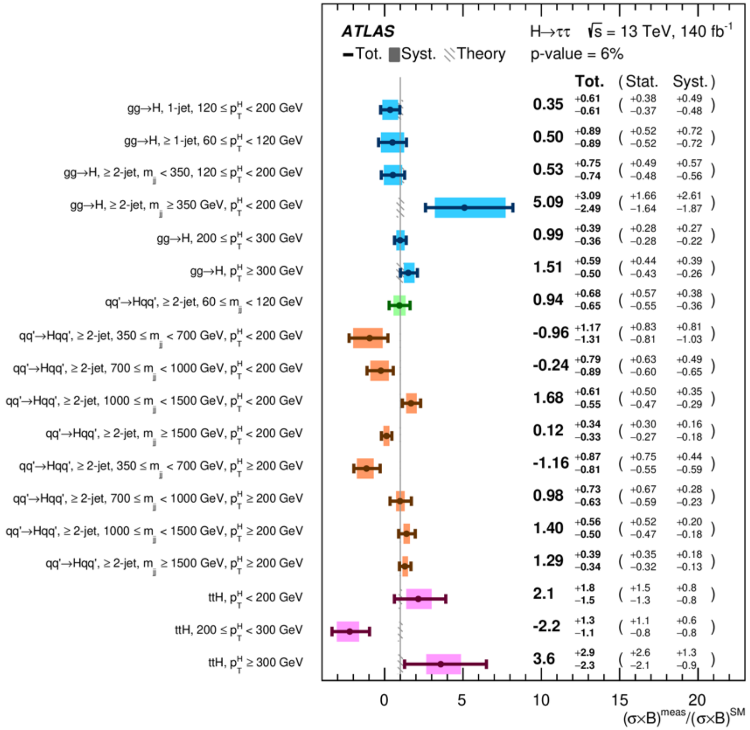
Phys. Rev. D 99 (2019) 072001

Production mode



JHEP 08 (2022) 175

Differential Cross Section



JHEP 03 (2025) 010

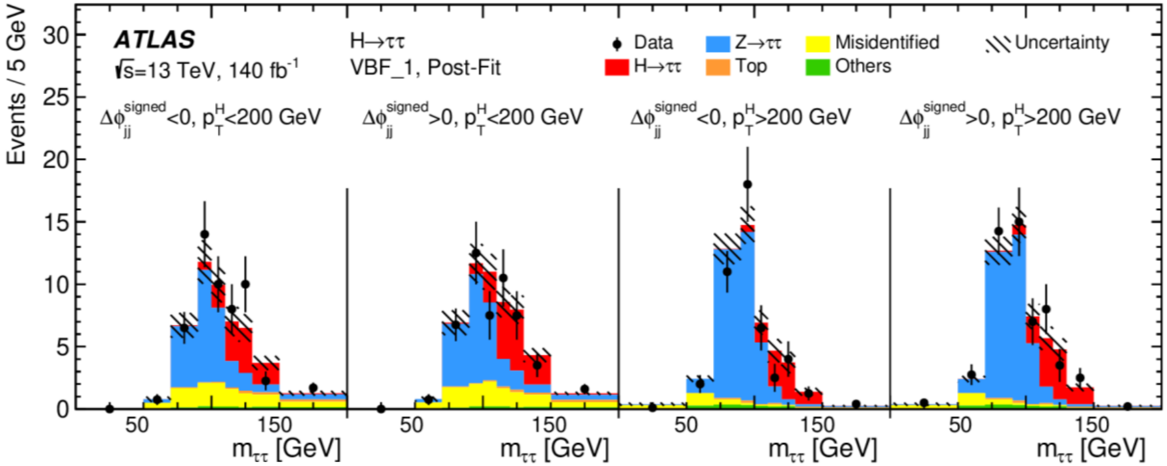
2015

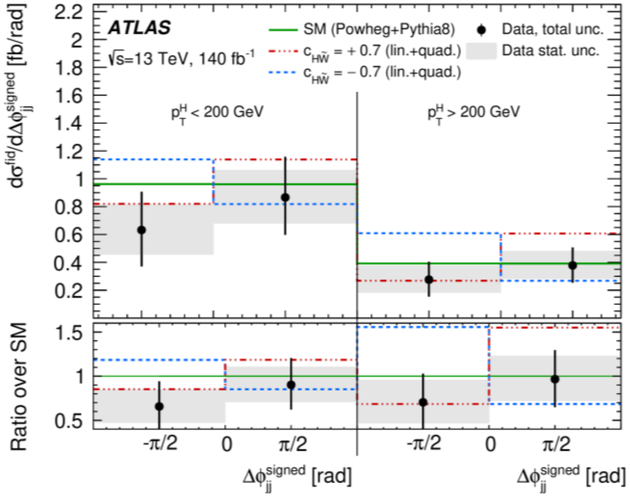
2025

$H\to\tau\tau$ differential cross section

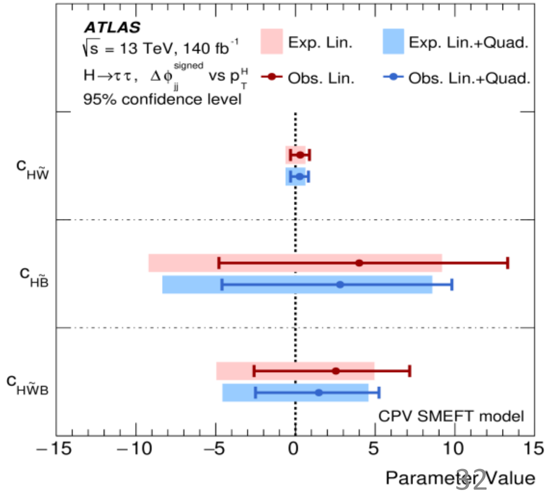
- Measurement in a dedicated phase space of VBF
  - Unfolding several variables, e.g. $p_T(H)$ and $\Delta\phi_{jj}$

JHEP 03 (2025) 010

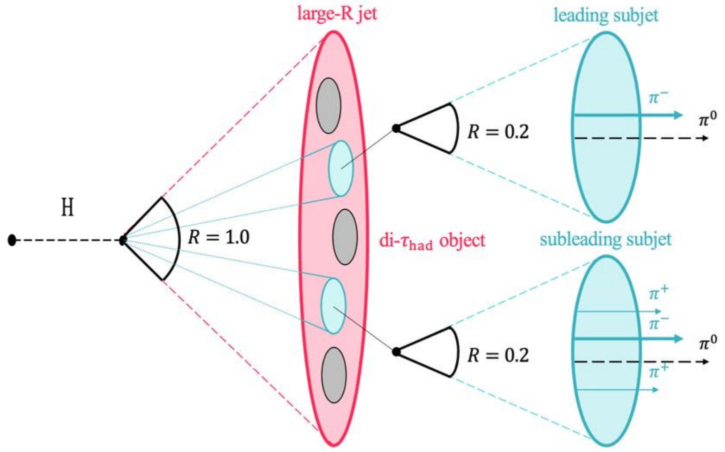


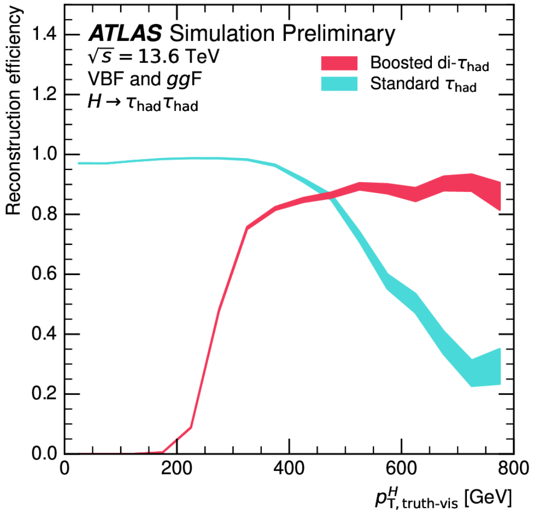


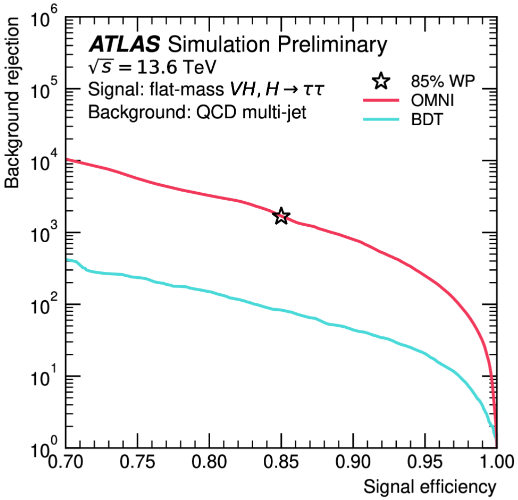
Constraints on CP-odd EFT operators



Boosted $H\rightarrow\tau\tau$ reconstruction



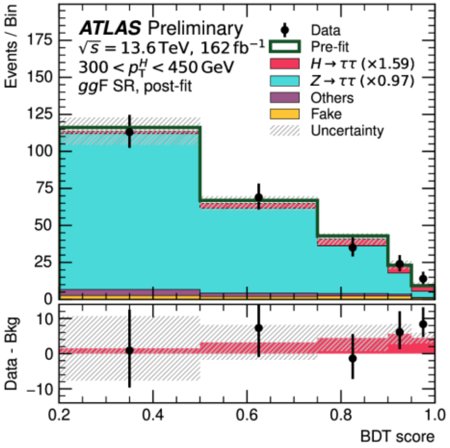


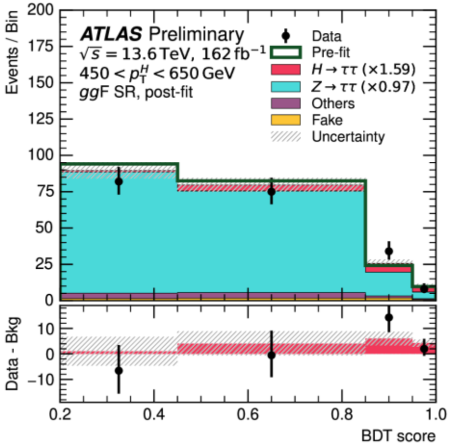


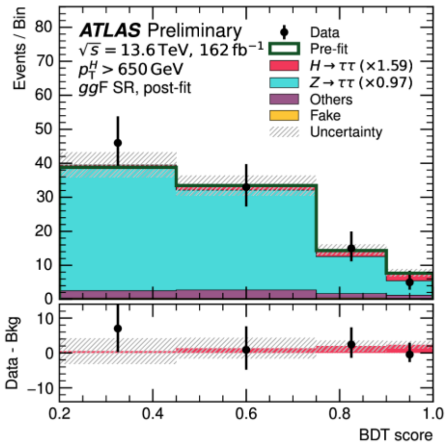
- Di-tau reconstruction seeded by large-R jet and developed in JHEP 11 (2020) 163 for $HH \rightarrow bb\tau\tau$
  - Re-cluster to small jets (R=0.2), associate tracks to these subjets
  - The two leading subjets considered to contain the tau decay
- Use the improved di-τ ID to perform the first cross-section measurement of boosted Higgs in di-τ final state in ATLAS

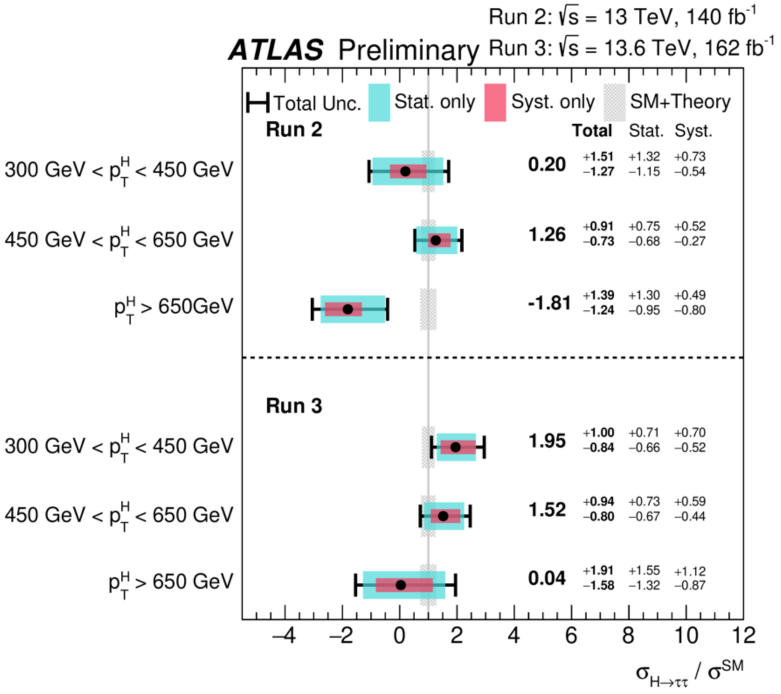
Recent results: boosted $H \rightarrow \tau\tau$

- $p_T(H) > 300$GeV with obs. (exp.) significance of 3.8 (3.3) σ
  - Differential cross-section in three $p_T(H)$ bins inclusive prod. modes
  - SM compatibility: 33% (56%) for Run2 (Run3)





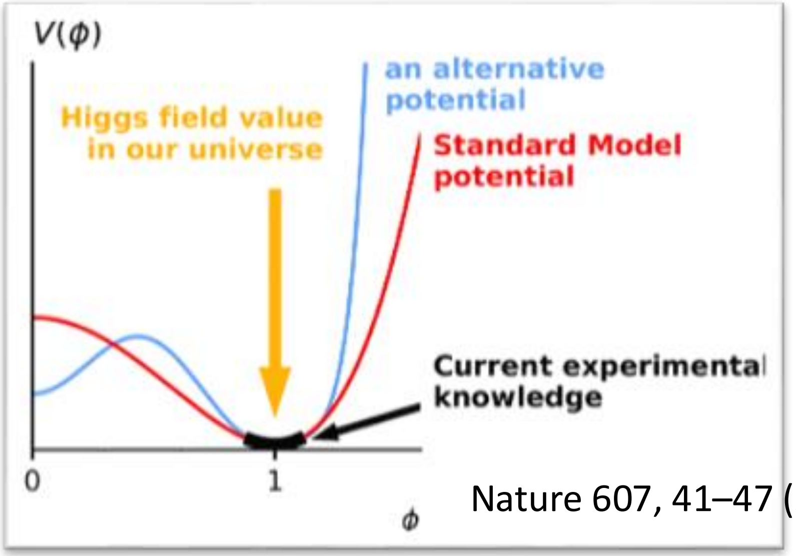




ATLAS-CONF-2026-005

Nature of EW symmetry breaking

- Higgs potential → thermal history of EW symmetry breaking



Nature 607, 41–47 (2022)

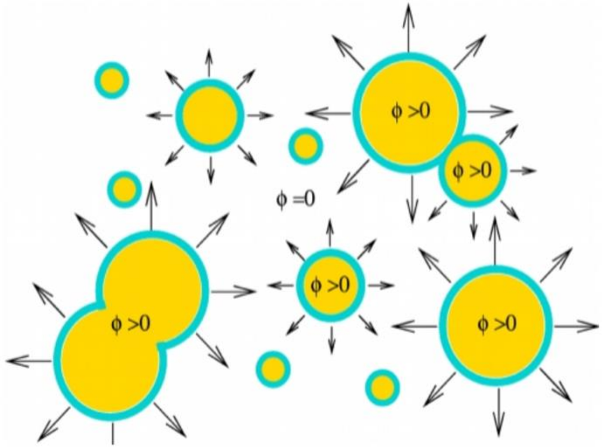
- SM assumed simplest form

$$V(\phi) = -\mu^2\phi^2 + \lambda\phi^4$$

- Alternative ones

$$V'(\phi) = V + \sum_i \frac{c_i^{(6)}}{\Lambda^2}\mathcal{O}_i^{(6)} + \sum_i \frac{c_i^{(8)}}{\Lambda^4}\mathcal{O}_i^{(8)} + \cdots$$

1st order or **2nd order** Phase Transition?



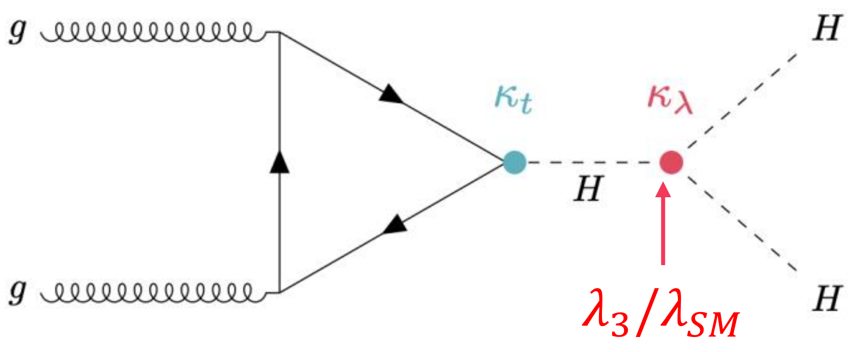
- Important for Baryongensis:
  - First order phase transition, depart from thermal equilibrium
  - Preserve matter-antimatter asymmetry

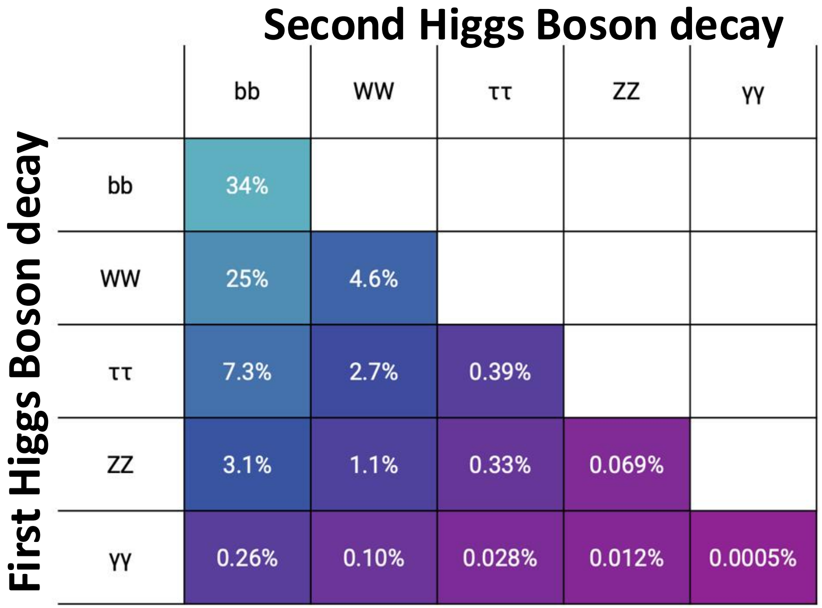
Higgs self-coupling

- Expand Higgs potential about the minimum

$$V(H) = \frac{1}{2} m_H^2 H^2 + \lambda_3 v H^3 + \frac{1}{4}\lambda_4 H^4 + O(H^5) \qquad \lambda_3 = \lambda_4 = \lambda_{SM} = \frac{m_H^2}{2v^2} \qquad \lambda_i = 0 \text{ for } i \geq 5$$

- Di-Higgs production: a direct probe of Higgs potential
  - Main production: ggH, $\sigma_{hh} \simeq 31 fb$ at 13TeV





Second Higgs Boson decay

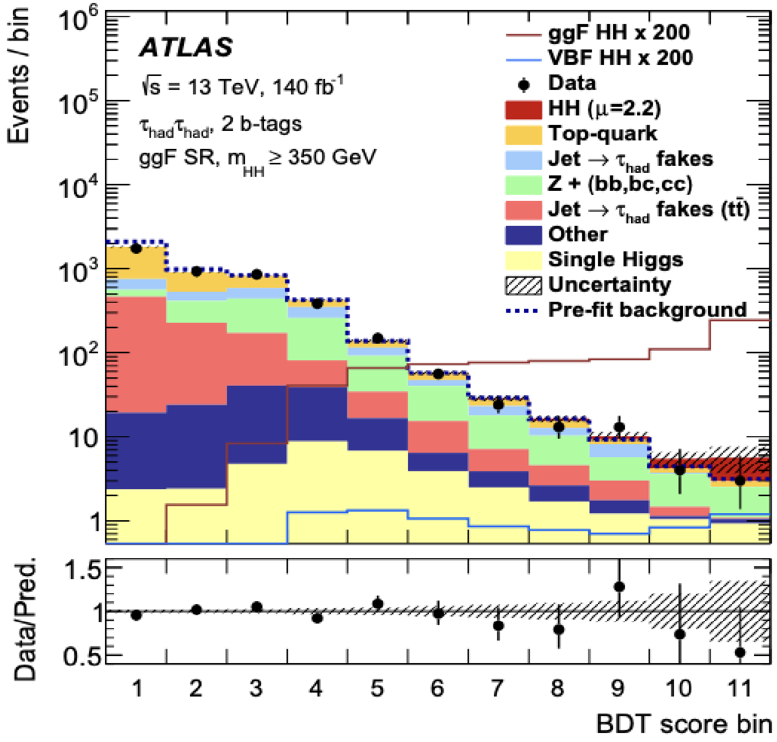
First Higgs Boson decay

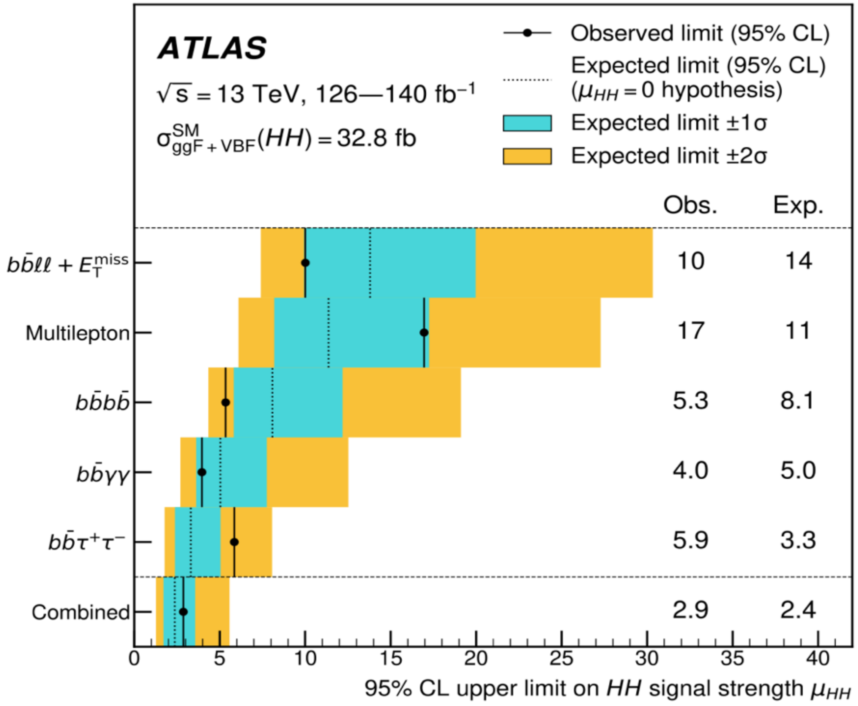
	bb	WW	ττ	ZZ	γγ
bb	34%				
WW	25%	4.6%			
ττ	7.3%	2.7%	0.39%		
ZZ	3.1%	1.1%	0.33%	0.069%	
γγ	0.26%	0.10%	0.028%	0.012%	0.0005%

- Major analysis channels: bbbb, bb$\tau\tau$, bb$\gamma\gamma$, bbll+MET, Multi-lepton

Di-Higgs production

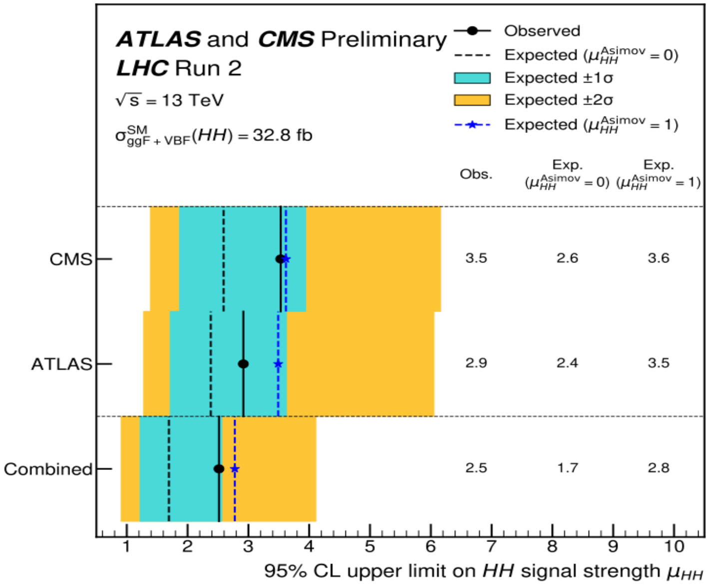
- HH→bb$\tau\tau$ channel, as an example
  - Br (HH→bb$\tau\tau$)≈7.3%, the best sensitivity to SM HH
- Combine ATLAS Run-2 HH analyses: $\mu_{HH} < 2.9\ (2.4\ exp.)$ at 95% CL

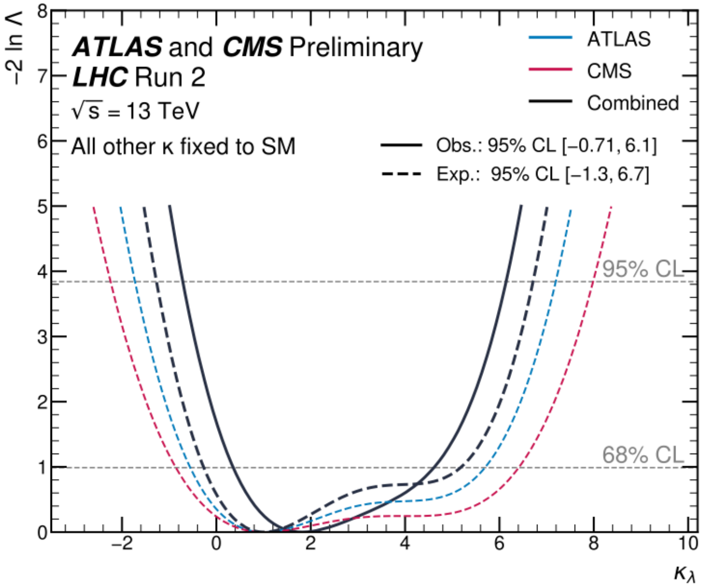




First LHC HH Combination

- Combine with CMS, to achieve the best sensitivity
  - ~30% improvement w.r.t. single experiment



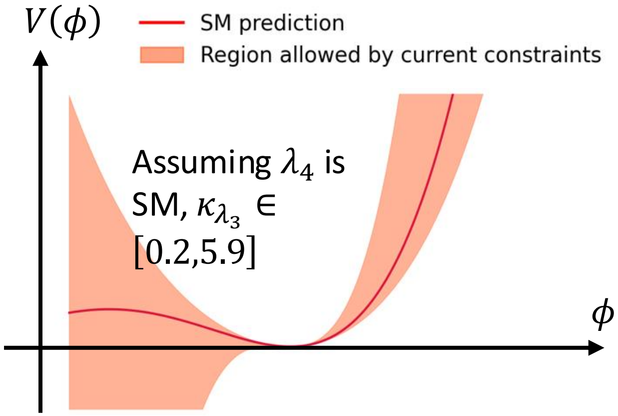


More exciting results with Run 3 data coming soon.

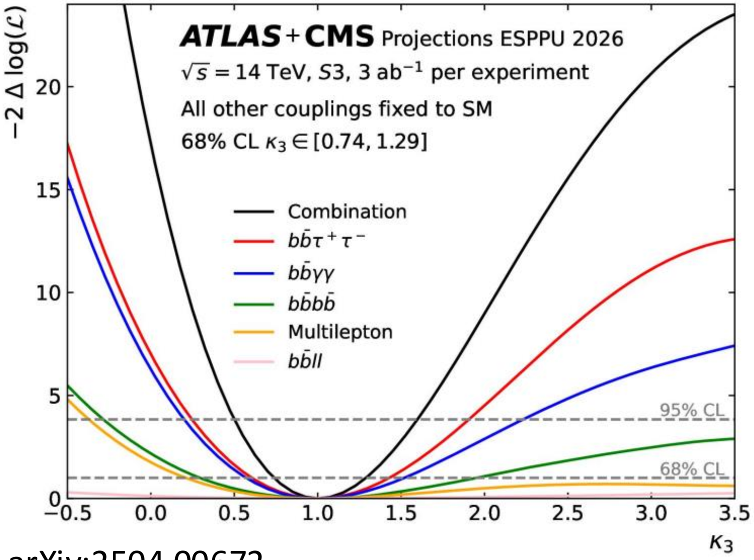
Stay tuned!

HL-LHC Projection

- Current precision not sufficient to determine the nature of EWSB
- HL-LHC: expected $\boldsymbol{\kappa}_\lambda$ precision better than 30%

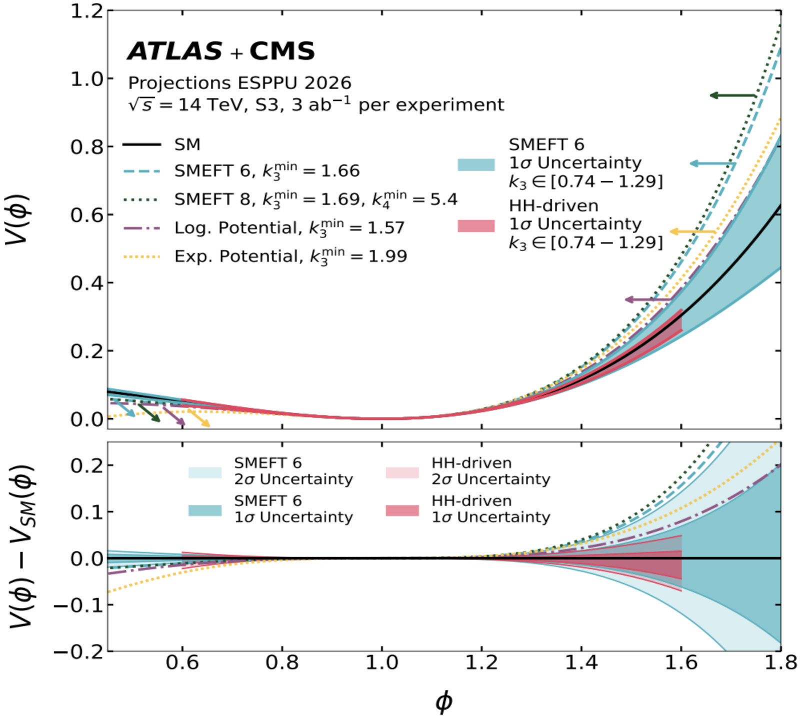


Assuming λ_4 is SM, $\kappa_{\lambda_3} \in [0.2,5.9]$

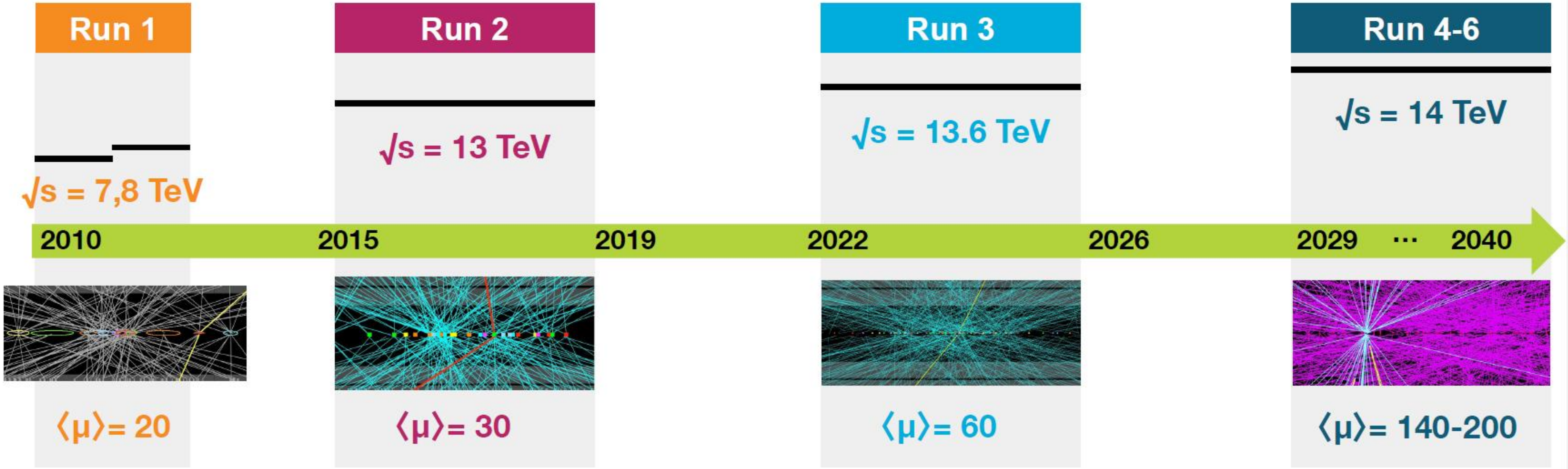


arXiv:2504.00672

Exclude several the Higgs potential shapes for first order EW Phase Transition



HL-LHC overview

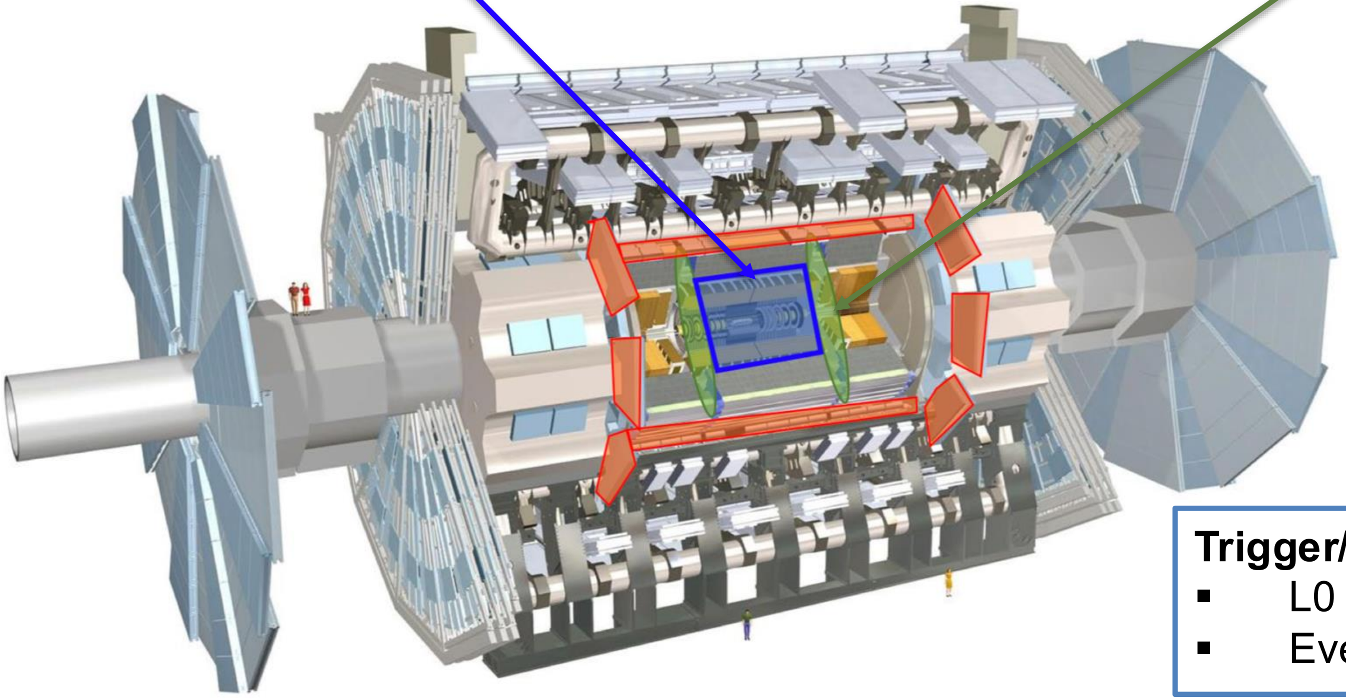


Elizabeth Brost
Higgs@10 Symposium

- Instantaneous luminosity: 5–7.5 times higher
  - Pile up and beam induced background increases linearly
  - Much larger radiation to detectors
  - Larger data sample: big challenges for computing and data storage
- Require improvements for experiments in all areas
  - Detectors, Electronics & Trigger, Software and computing

ATLAS phase-II upgrade

- Major upgrades to achieve physics goals of HL-LHC
- Tracks measurement to find vertex in Z-direction



Fully silicon inner tracker (ITK)

- Coverage up to |η| = 4.0, less material, finer segmentation

High Granularity Timing Detector (HGTD)

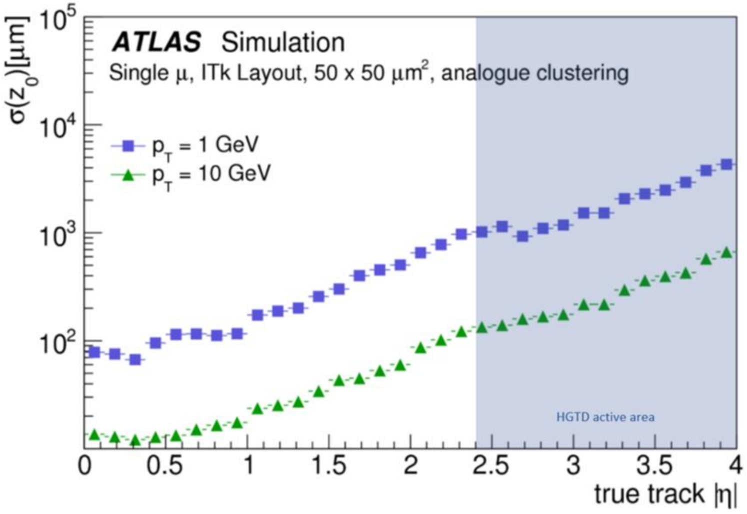
- 30 ps timing resolution with LGAD
- Coverage: 2.4 < |η| < 4.0, suppress pile-up and measure bunch-by-bunch luminosity

Trigger/Data Acquisition

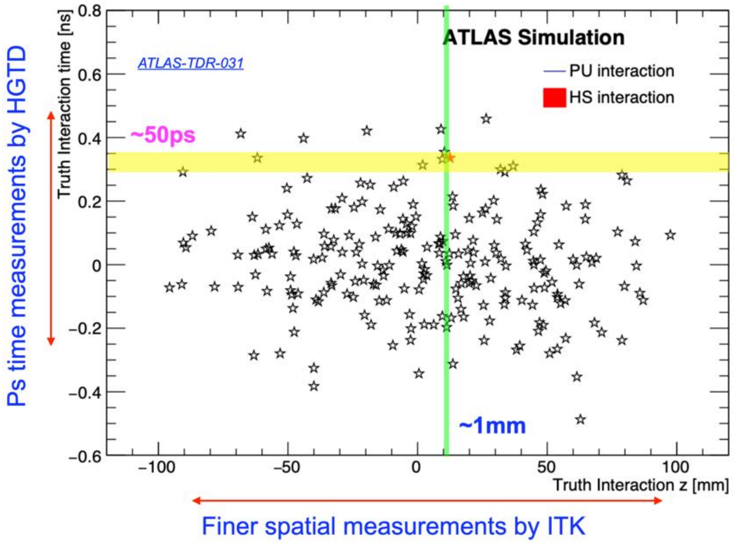
- L0 rate: 1 MHz
- Event Filter: O(10) kHz

Motivation of HGTD

- New Inner Tracker (ITk) in at $2.4 <|\eta| \leq 4$
  - Poor resolution of associating tracks to primary vertex
- High Granularity Timing Detector (HGTD)
  - Placed in front of endcap calorimeter $(2.4<|\eta|<4)$
  - Timing resolution of 30-50 ps/track, additional ~x6 pileup rejection
  - Up to a fluence $2.5\text{x}10^{15}$ n_{eq}/cm^2

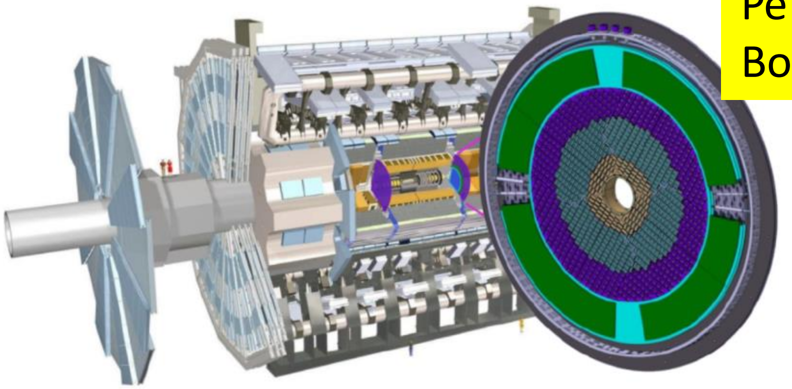


Vertices have time spread of ~180 ps

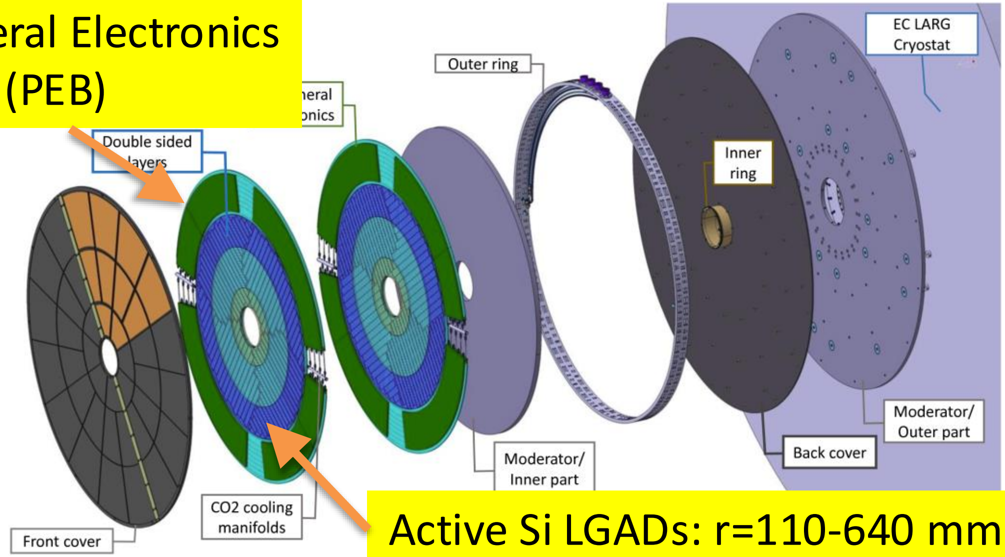


Overview of HGTD

- Installed in front of endcap calorimeter
  - Two double sided layers, mounted at cooling disks (-30℃)

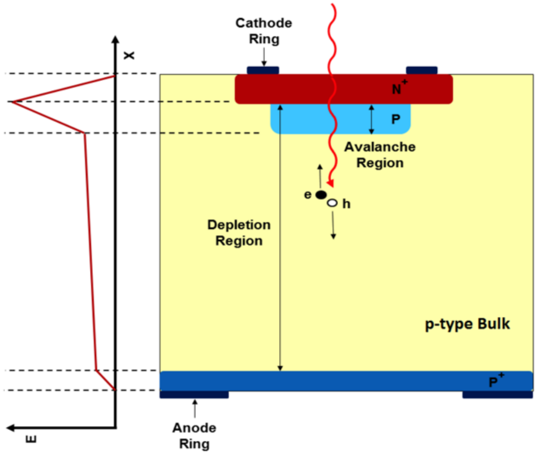


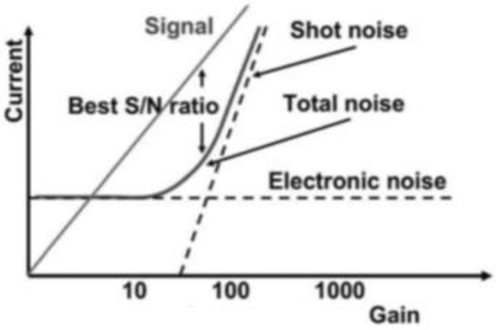
Peripheral Electronics Boards (PEB)



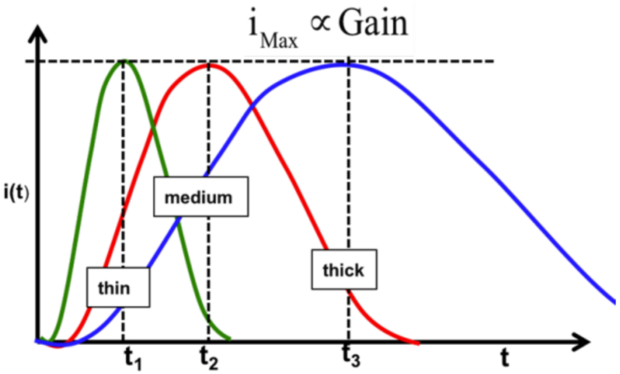
Active Si LGADs: r=110-640 mm

- LGAD Sensor



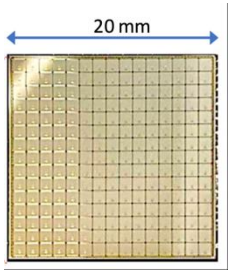


NIM A765 (2014) 12

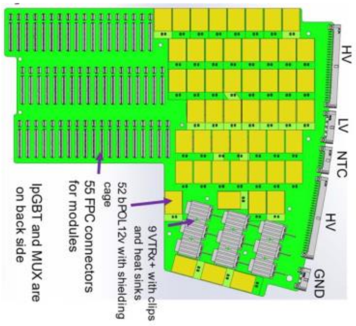


A closer look at HGTD

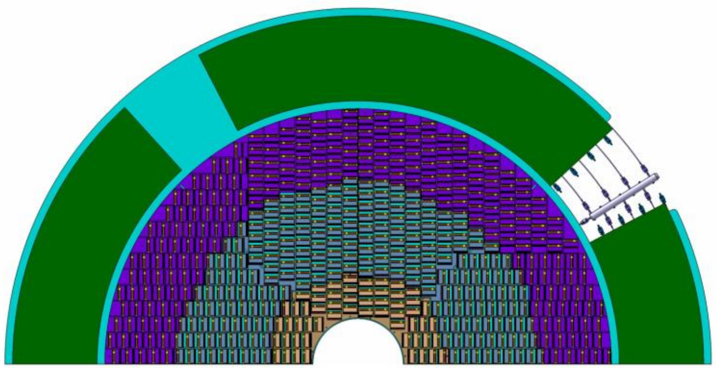
1. Detector module



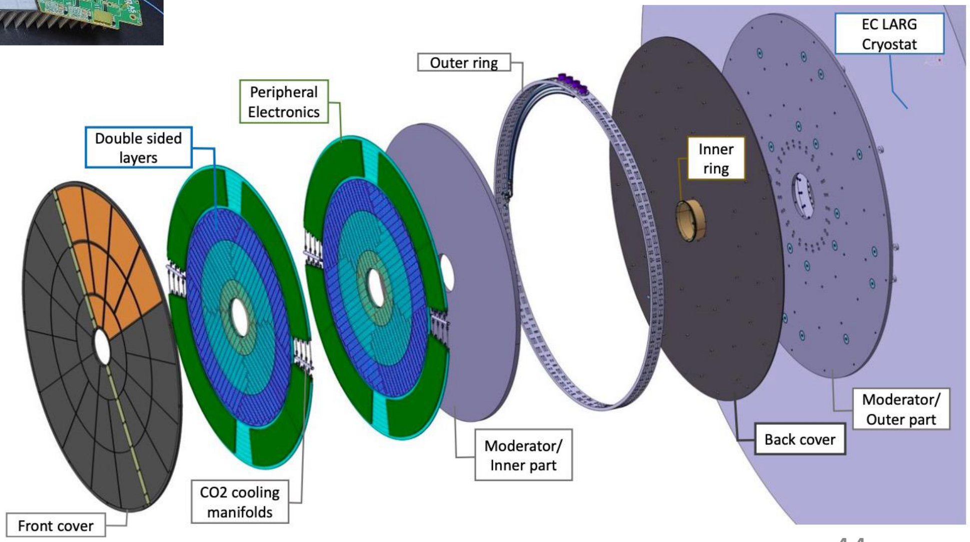
2. Flex to Peripheral Electronics



3. Half Wheel

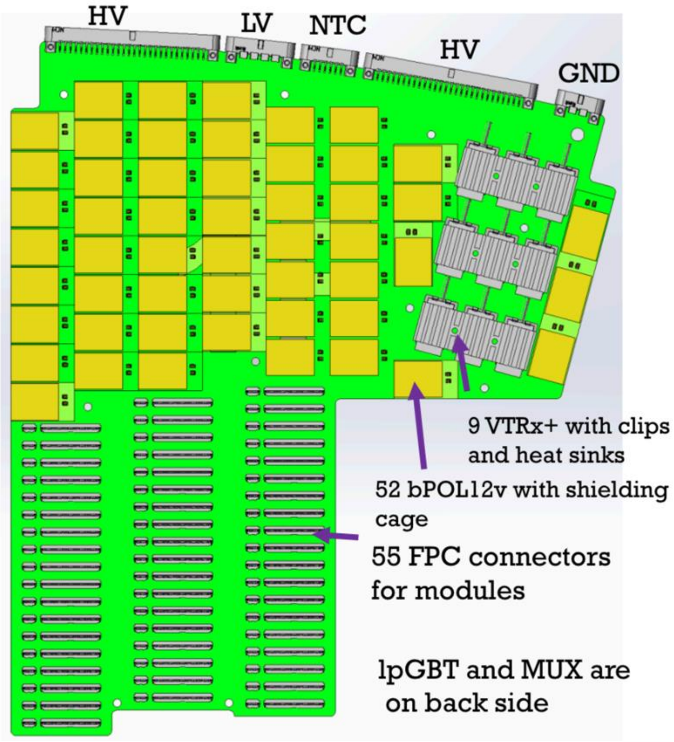


4. Detector Vessel



PEB 1F and final proto-type

- 1F board is the most complex one
  - 22 layer PCB, connects 54 modules
  - 9 timing and 3 lumi lpGBTs, 9 MUX, 9 VTRX+, 52 bPOL12V

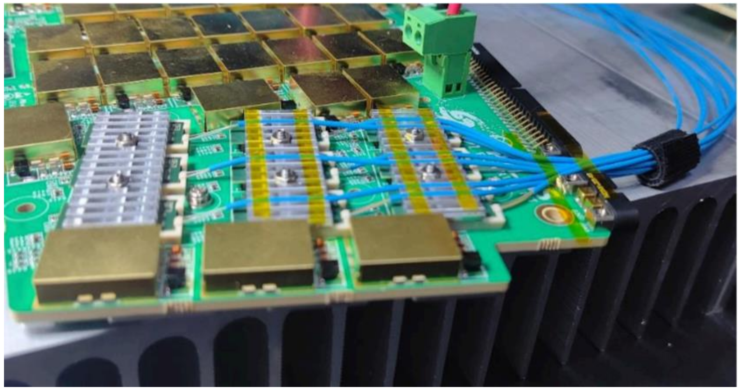


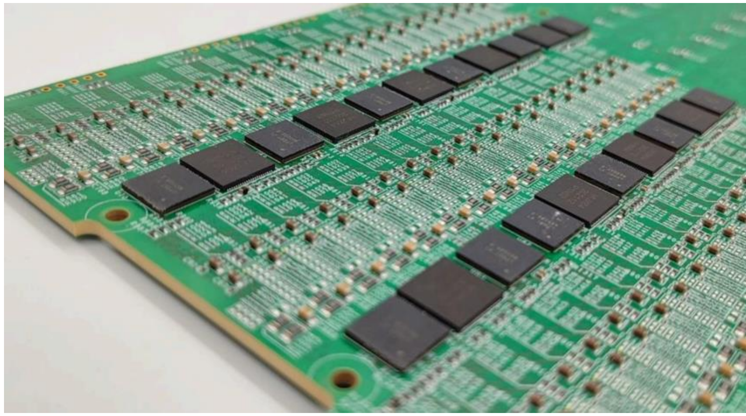
9 VTRx+ with clips and heat sinks

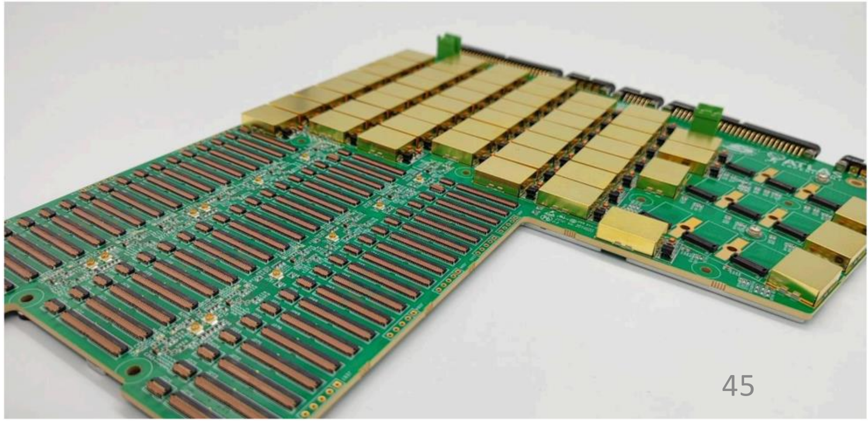
52 bPOL12v with shielding cage

55 FPC connectors for modules

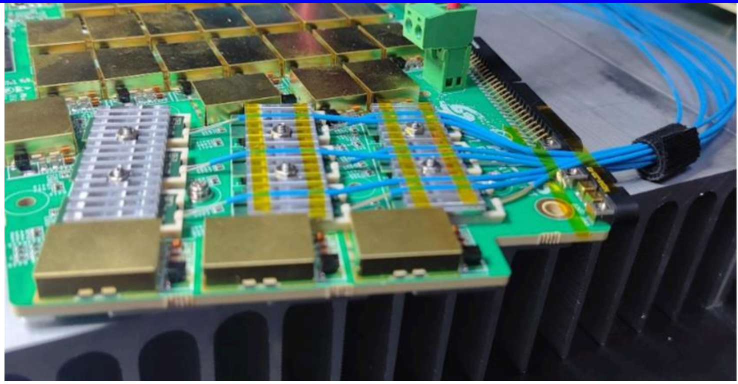
lpGBT and MUX are on back side





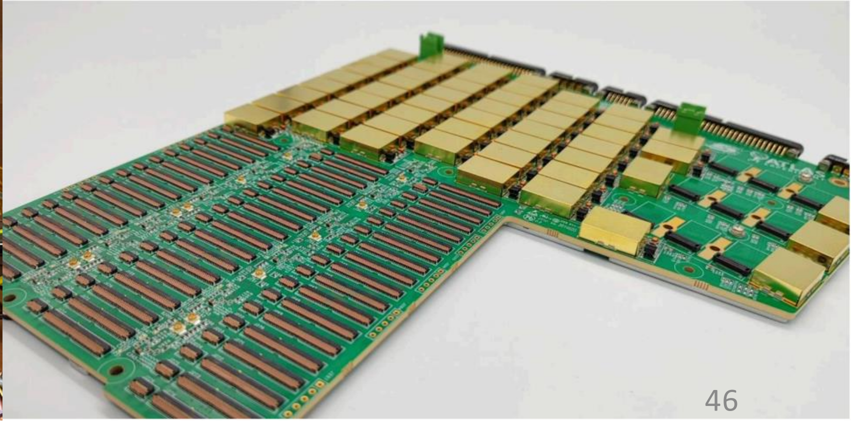


PEB 1F and final proto-type



- 1F board is the most complex one
  - 22 layer PCB, connects 54 modules
  - 9 timing and 3 lumi lpGBTs, 9 MUX, 9 VTRX+, 52 bPOL12V

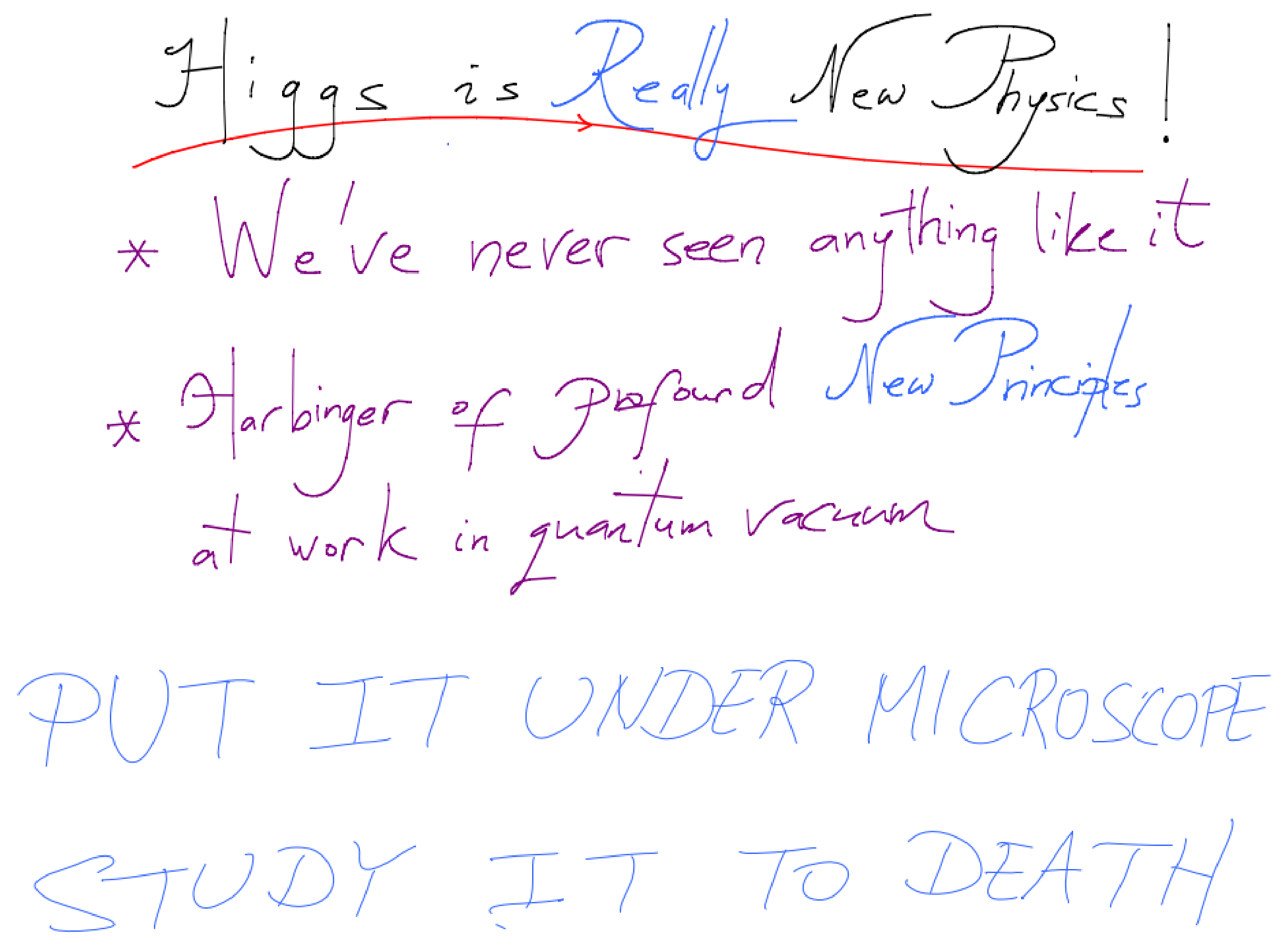
- Full system level tests
  - Integration & testing of LV&HV supplies and interlock system
  - Development of DAQ SW and detector control system



HGTD in China

- China team is making key contributions to HGTD
  - 100% LGAD sensor (66% from CERN tendering)
  - 44% detector assembly
  - 100% front-end electronics board (NJU+ IHEP)
  - Others: ~33% flex tail, 50% ASIC test, >16% HV systems, …

Future Particle Physics: Higgs factory



Higgs is Really New Physics!

- We've never seen anything like it
- Harbinger of Profound New Principles at work in quantum vacuum

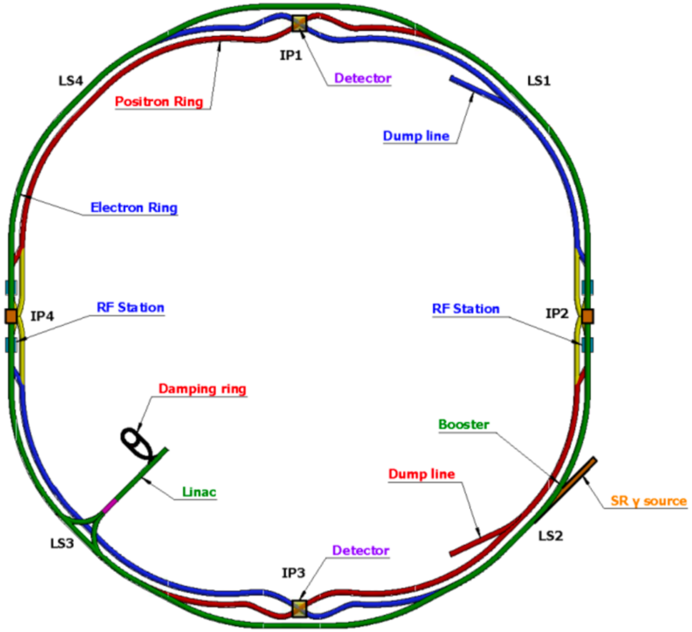
PUT IT UNDER MICROSCOPE

STUDY IT TO DEATH

Nima Arkani-Hamed

Circular Electron Position Collider (CEPC)

- e^+e^- collider producing Higgs/W/Z bosons and top quarks
  - Potential upgrade to **Super pp Collider (SppC)** of $\sqrt{s}$ ~ 100 TeV
  - Similar version in Europe: FCC-ee/hh
- Proposed in 2012, CDRs released in 2018
- **TDR released: accelerator (2023), ref. detector (2025)**



2018

IHEP-CEPC-DR-2018-01
IHEP-AC-2018-01

CEPC
Conceptual Design Report
Volume I - Accelerator

The CEPC Study Group
August 2018

IHEP-CEPC-DR-2018-02
IHEP-EP-2018-01
IHEP-TH-2018-01

CEPC
Conceptual Design Report
Volume II - Physics & Detector

The CEPC Study Group
October 2018

2023

IHEP-CEPC-DR-2023-01
IHEP-AC-2023-01

CEPC
Technical Design Report
Accelerator

The CEPC Study Group
December 2023

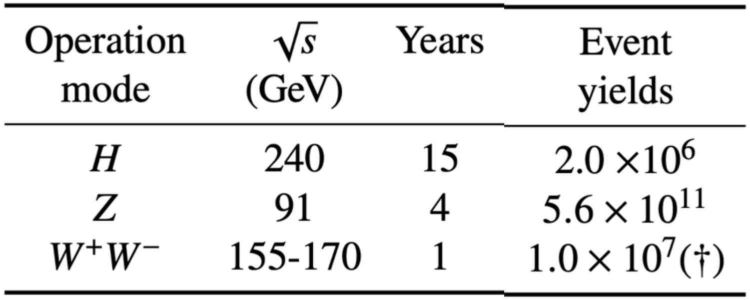
http://cepc.ihep.ac.cn

2025

IHEP-CEPC-DR-2025-01
IHEP-EP-2025-01

CEPC Reference Detector
Technical Design Report

The CEPC Study Group
October, 2025



Operation mode	$\sqrt{s}$ (GeV)	Years	Event yields
H	240	15	2.0×10^6
Z	91	4	5.6×10^{11}
W^+W^-	155-170	1	$1.0 \times 10^7 (\dagger)$

Extensive R&D progress on acclerator

Jie Gao’s talk in CEPC2026 at Lisbon

CEPC Accelerator TDR Completed in 2023

✓ **Specification Met**

✓ **Prototype Manufactured**

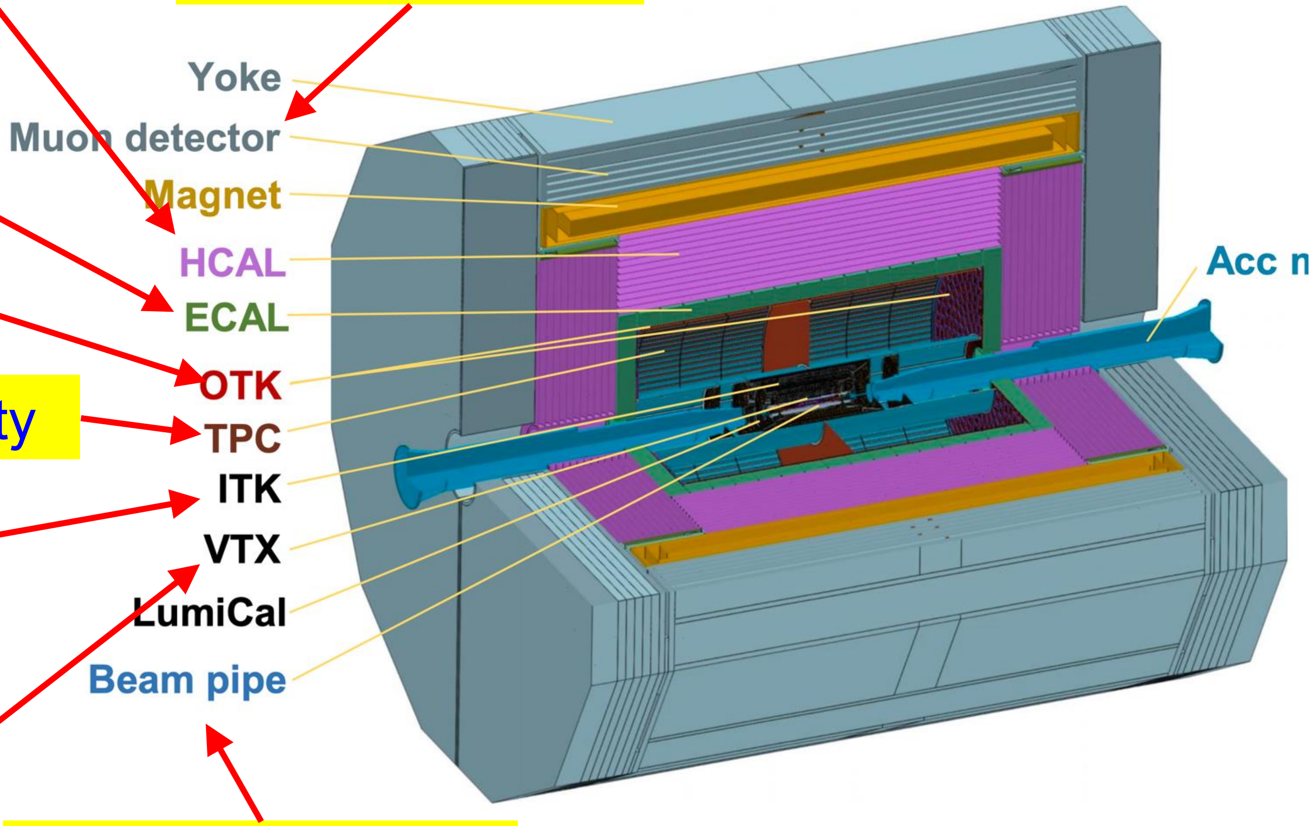
Accelerator	Fraction
✓ Magnets	27.3%
✓ Vacuum	18.3%
√ RF power source	9.1%
✓ Mechanics	7.6%
✓ Magnet power supplies	7.0%
✓ SC RF	7.1%
✓ Cryogenics	6.5%
✓ Linac and sources	5.5%
✓ Instrumentation	5.3%
✓ Control	2.4%
✓ Survey and alignment	2.4%
✓ Radiation protection	1.0%
✓ SC magnets	0.4%
✓ Damping ring	0.2%

IHEP HEPS (4th generation light source at IHEP) 6 GeV, 36 nm·rad, has been completed in Oct. 2025

CEPC Accelerator TDR was published in Radiation Detection Technology and Methods (RDTM) on June 3, 2024:
DOI: 10.1007/s41605-024-00463-y https://doi.org/10.1007/s41605-024-00463-y

Reference Detector: AGORA

- AGORA: Advanced Glass Optimized Research Apparatus



Glass scintillator, SiPM + Fe

Plastic scintillator bars, SiPM

4D transverse crystal bars

AC-LGAD→TOF

TPC with high granularity

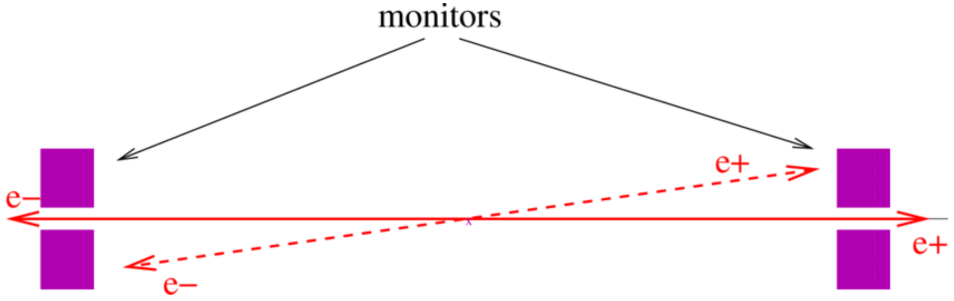
Si Pixels: CMOS MAPS 55-nm

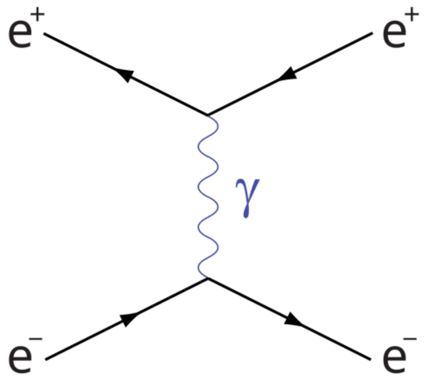
Si Pixels: CMOS MAPS+stitching

Beryllium, ϕ 20 mm

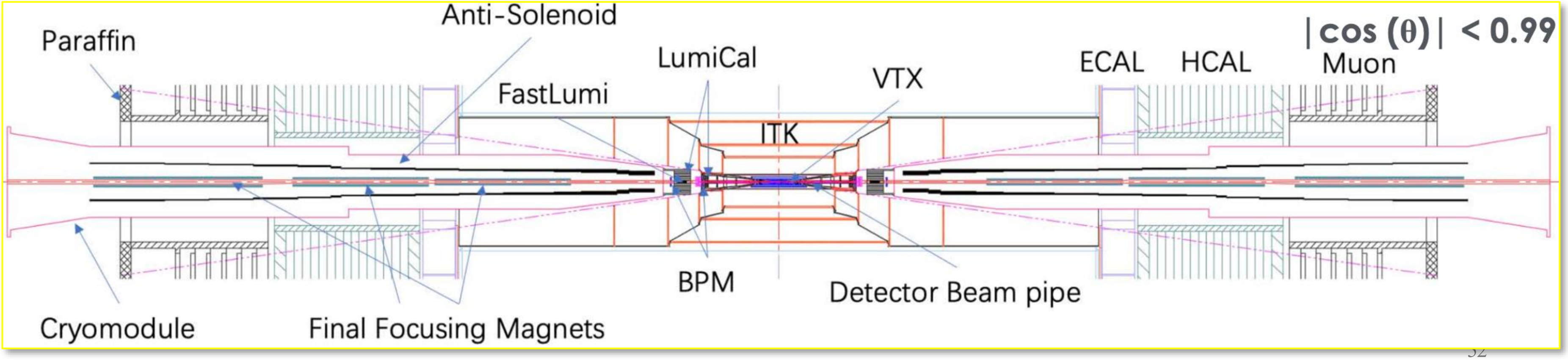
Luminosity measurement and LumiCal

- Small-angle Bhabha scattering (SABS) events
  - Peaked in the forward region, at <100 mRad



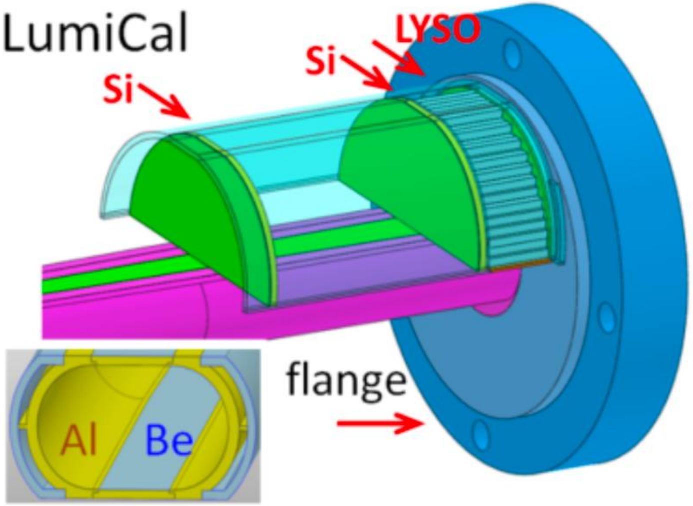


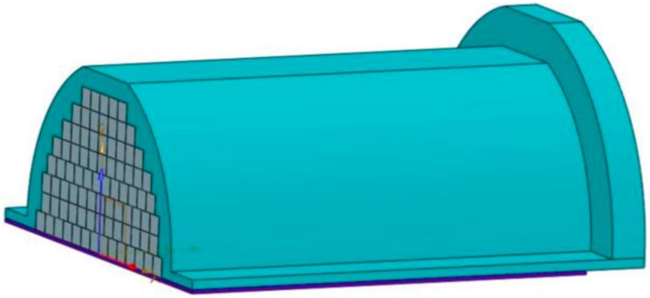
- Two detectors on each side of Interaction Point
  - Low-mass beampipe window: Be 1mm thick, traversing @22 mRad, traversing L= 45 mm, = 0.13 X_0 (Be)



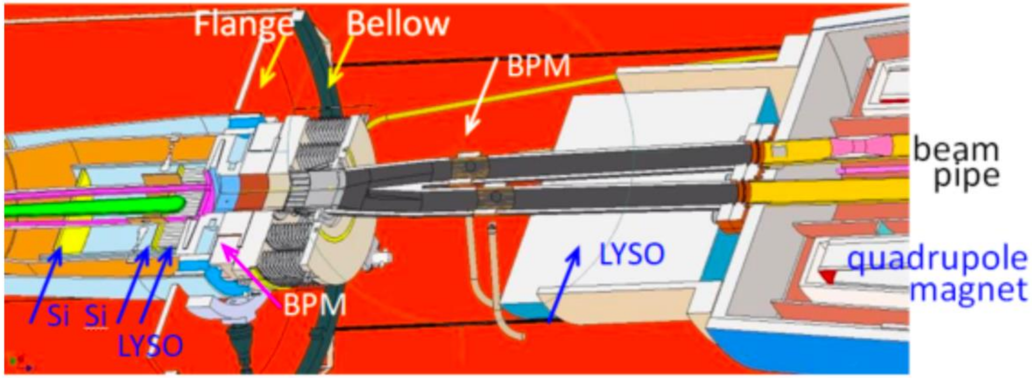
CEPC LumiCal design

- Before flange: $\mathrm{z} = 560{\sim}700\ \mathrm{mm}$: 2 Si-tracker and 2 X_0 LYSO (23 mm)
- After Bellow: $\mathrm{z}= 900{\sim}1100\ \mathrm{mm}$: 13$X_0$ LYSO (150 mm)

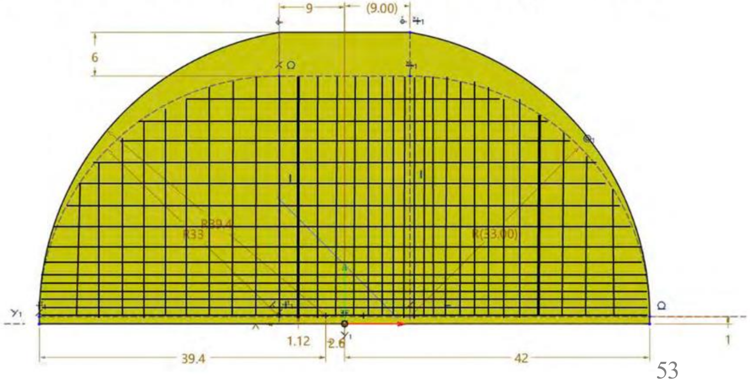




- Two layer AC-LGAD trackers
  - 2D readout of electron hits



Si-wafer surface plan with sample of segmentation



Non-accelerator Experiments

Neutrino Experiments

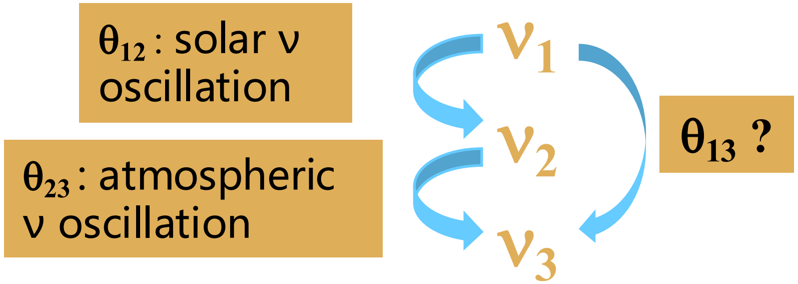
NPP: Nuclear Power Plant

TAO: Taishan Neutrino Observatory

JUNO location driven by reactor neutrino physics goals

Daya Bay Experiment (Sino-US): θ_{13}

- Daya Bay discovered the third oscillation mode in 2012
  - Measured θ_{13} precisely : $\sin^2 2\theta_{13} = 0.092 \pm 0.016 \pm 0.005$



θ_{12} : solar ν oscillation

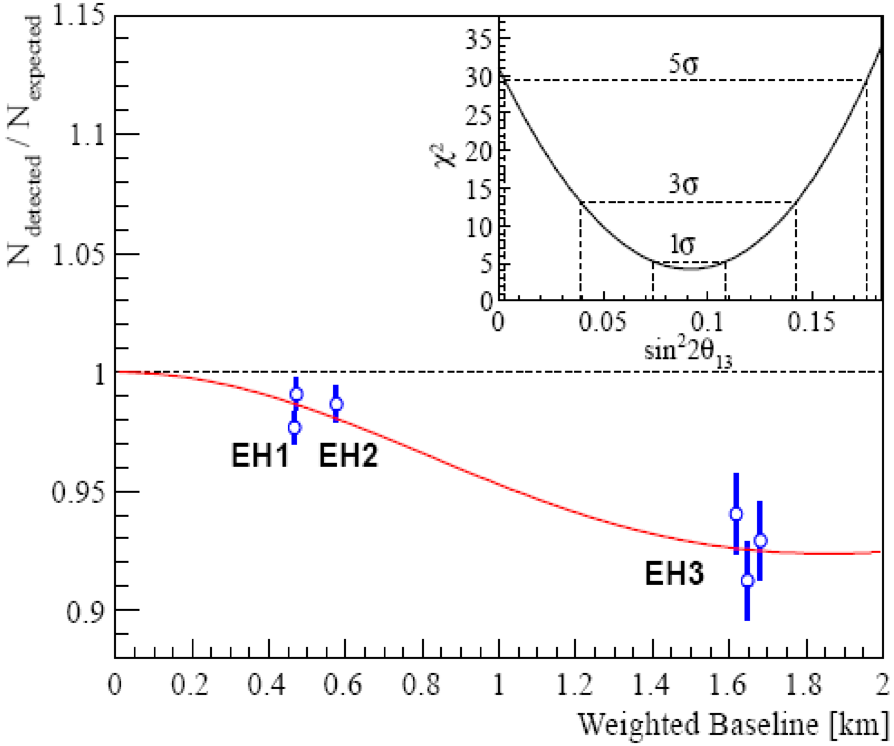
θ_{23} : atmospheric ν oscillation

ν_1

ν_2

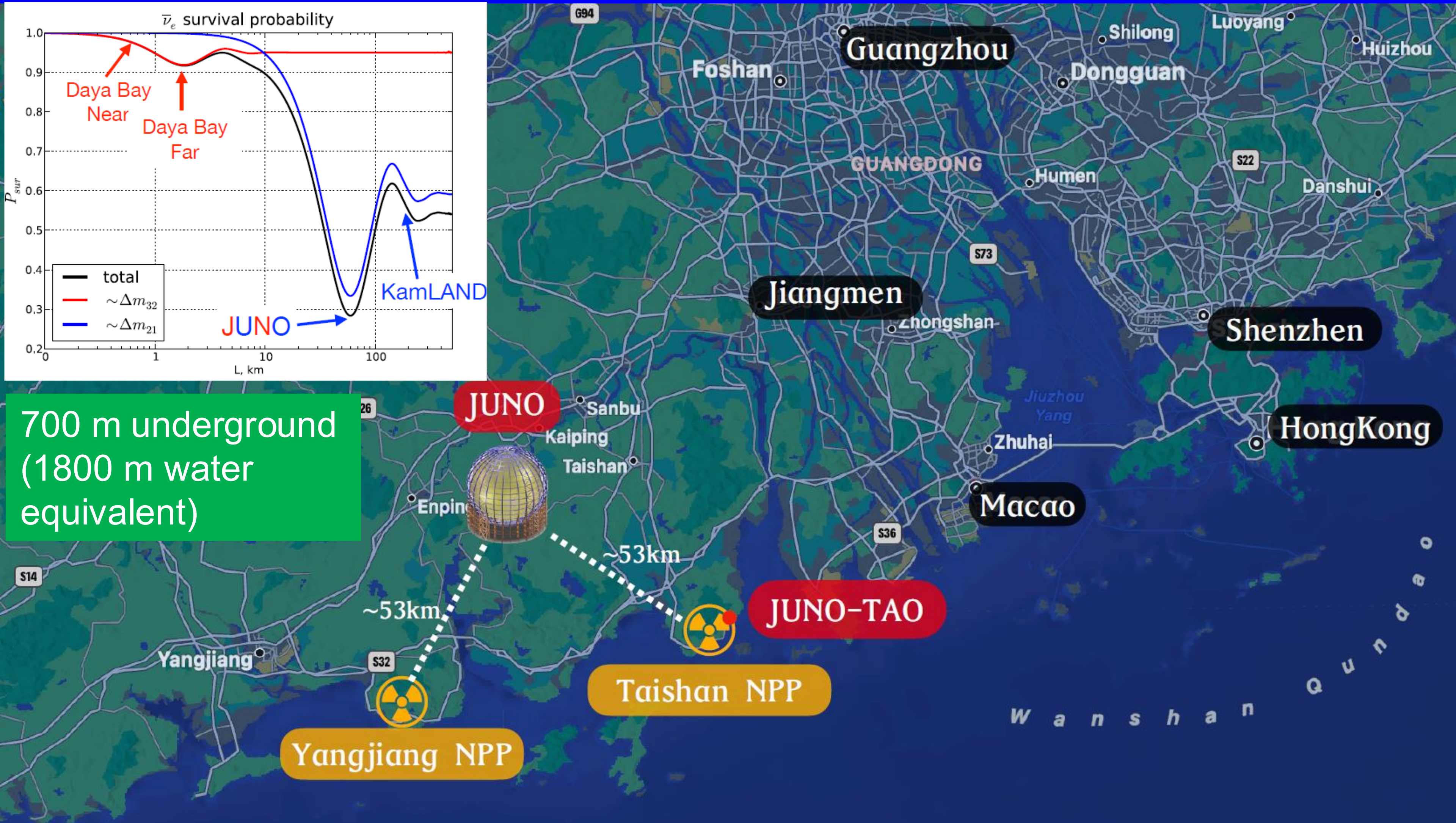
ν_3

θ_{13} ?



PRL 108 (2012) 171803

Current: JUNO experiment



700 m underground (1800 m water equivalent)

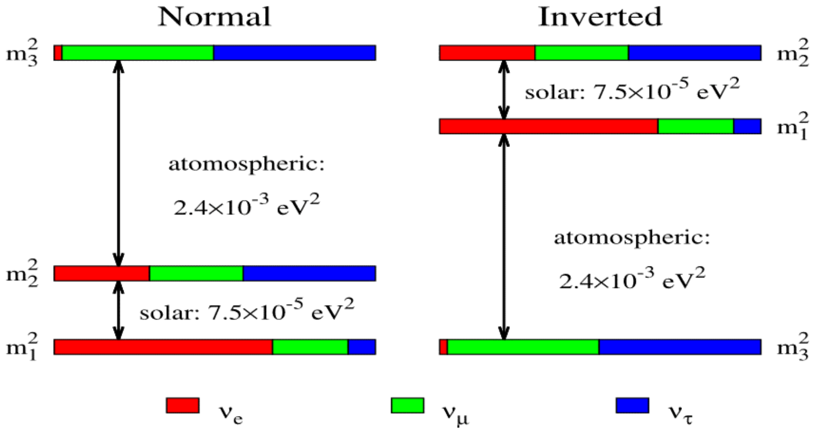
NPP: Nuclear Power Plant

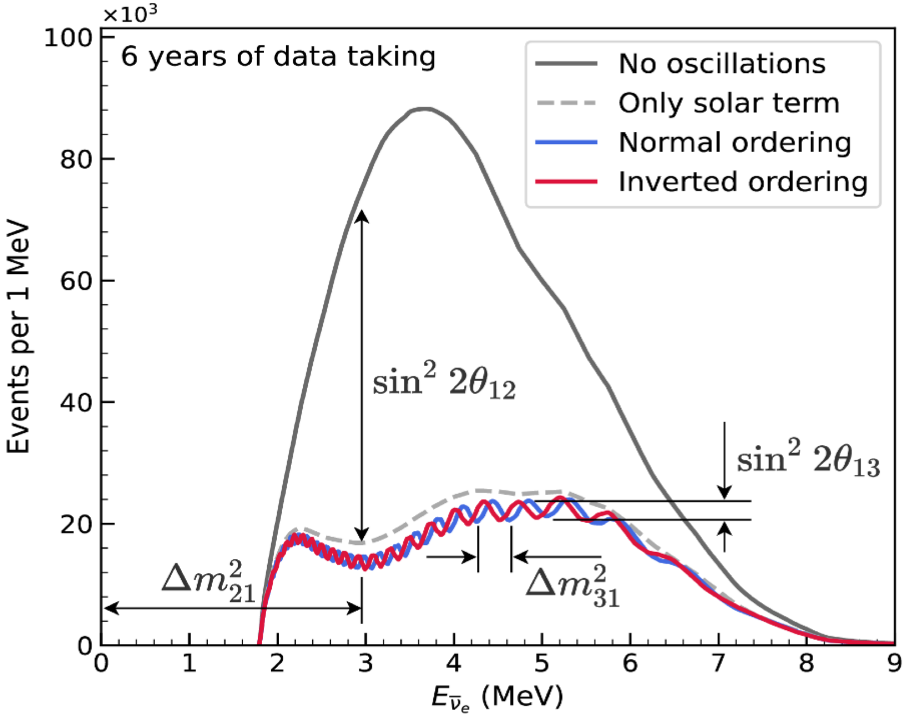
TAO: Taishan Neutrino Observatory

JUNO location driven by reactor neutrino physics goals

Neutrino Mass Order

$m_3 > m_{1,2}$ or $m_3 < m_{1,2}$





- Neutrino mass order determined by:
    - Modulation of two oscillation driven by ($\theta_{12}, \Delta m^2{}_{21}$) and ($\theta_{13}$, $\Delta m^2{}_{31}$)

JUNO collaboration

Liverpool
Warwick

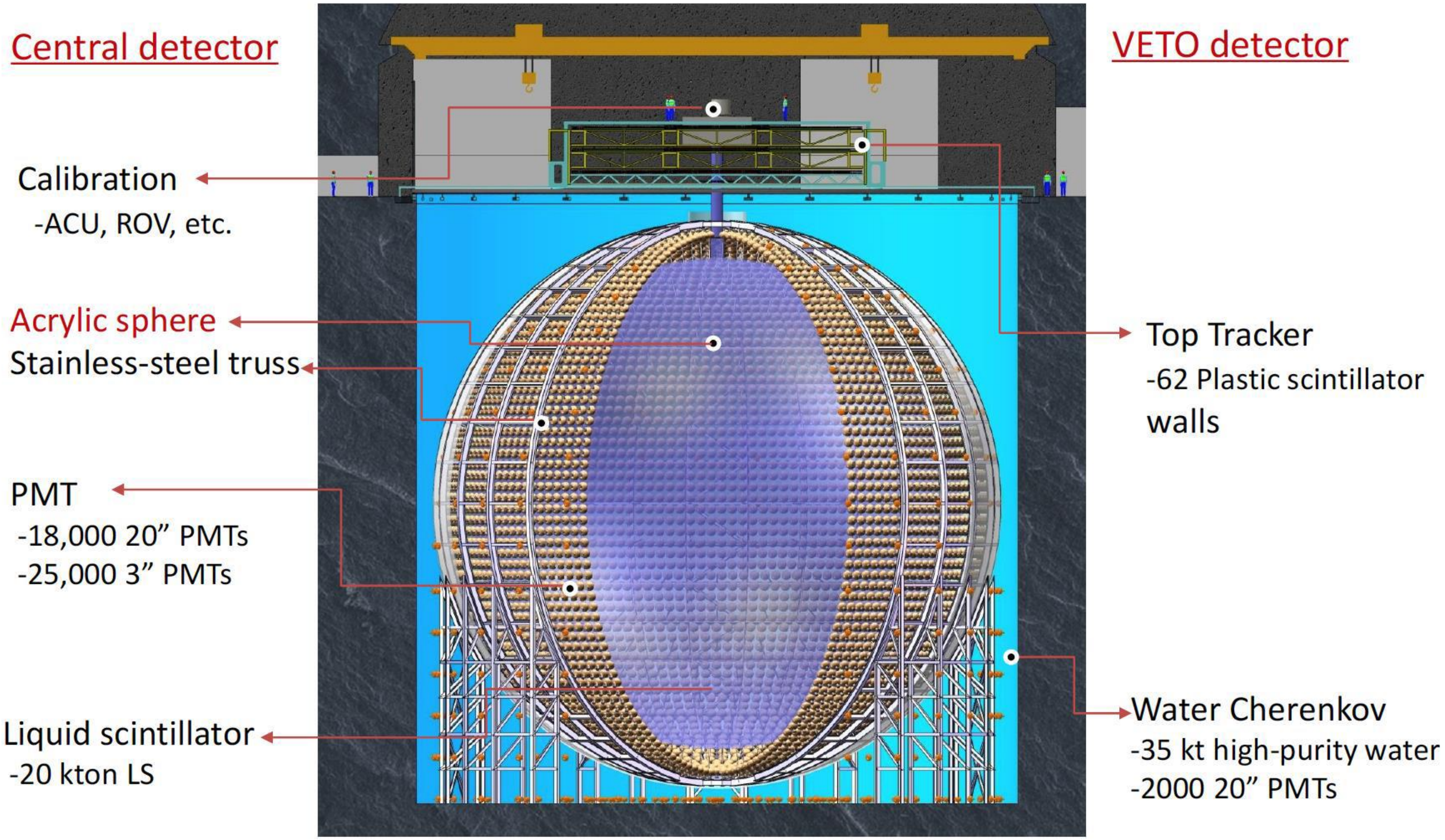
Collaboration established in 2014
77 institutions, ~600 collaborators

JUNO location driven by reactor neutrino physics goals

JUNO detector

- **Central detector:** 20 kTon of active mass of liquid scintillator (sphere of ~35 m in diameter), energy resolution (3% at 1 MeV)
- **Light detection:** 18k 20'' PMTs and 25k 3'' PMTs (two independent systems, coverage >75%)

PMTs and electronics will be under water



Central detector

Calibration
-ACU, ROV, etc.

Acrylic sphere

Stainless-steel truss

PMT
-18,000 20'' PMTs
-25,000 3'' PMTs

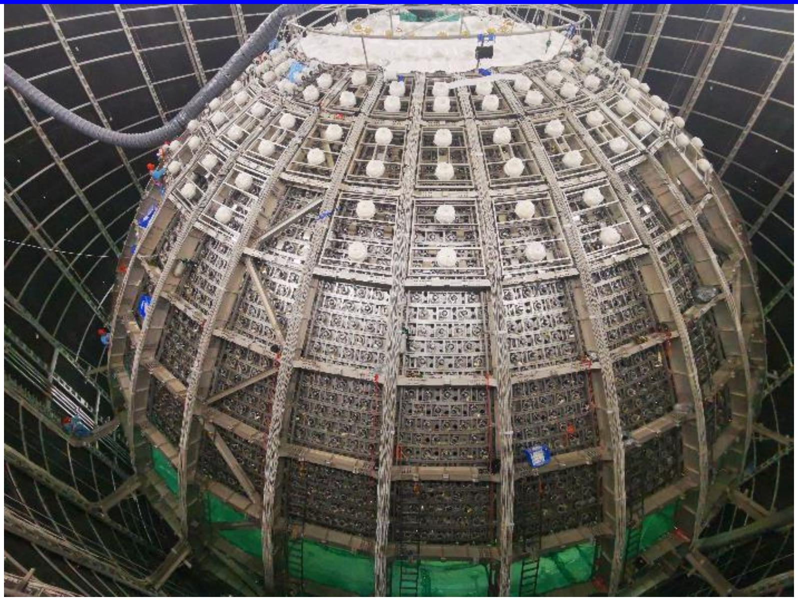
Liquid scintillator
-20 kton LS

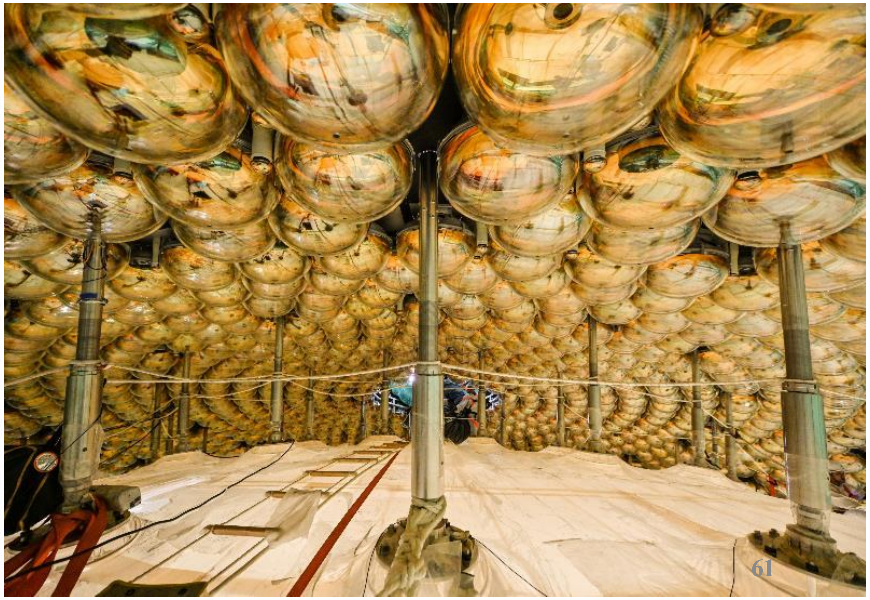
VETO detector

Top Tracker
-62 Plastic scintillator walls

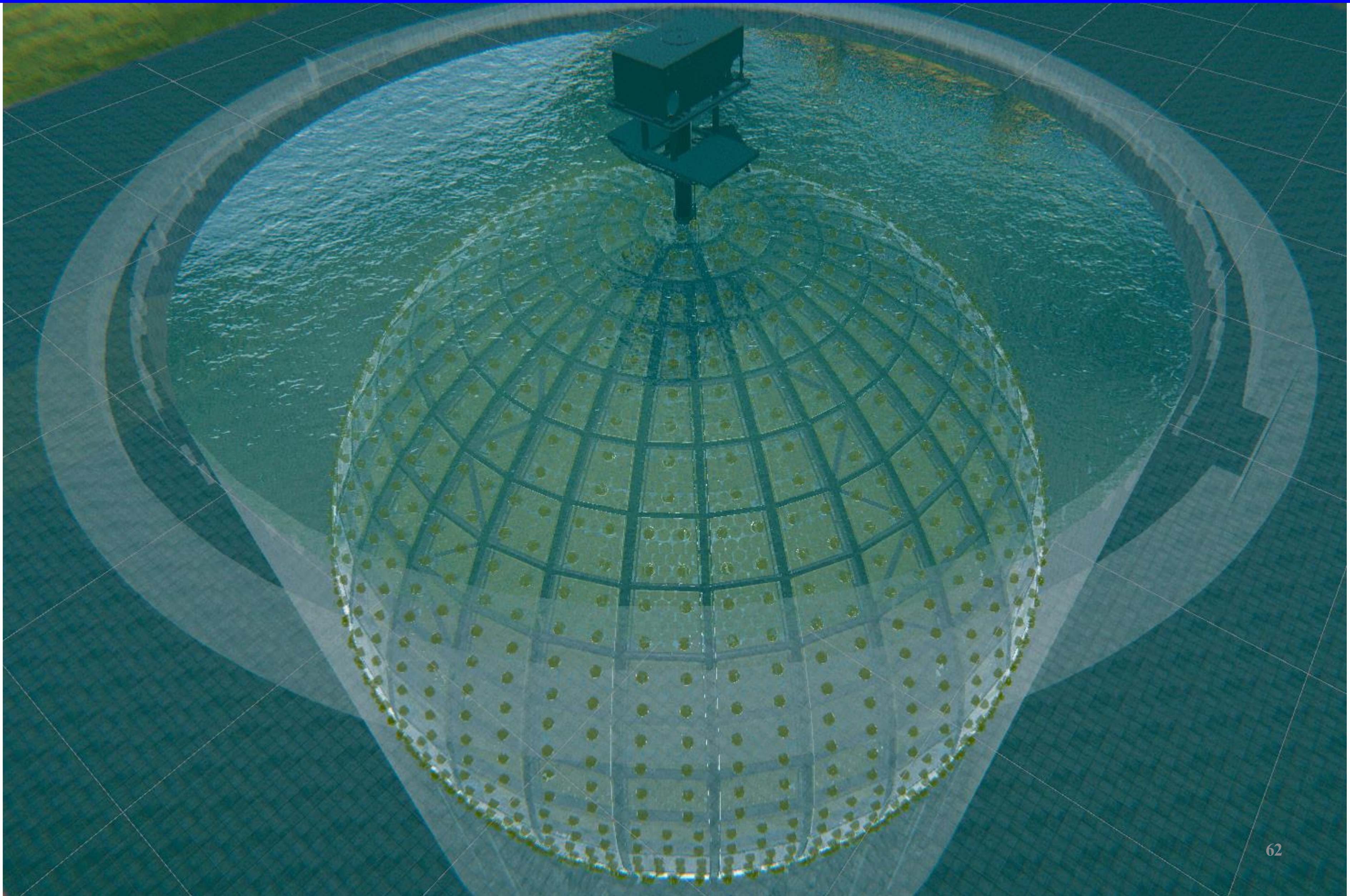
Water Cherenkov
-35 kt high-purity water
-2000 20'' PMTs

Some photos during the construction



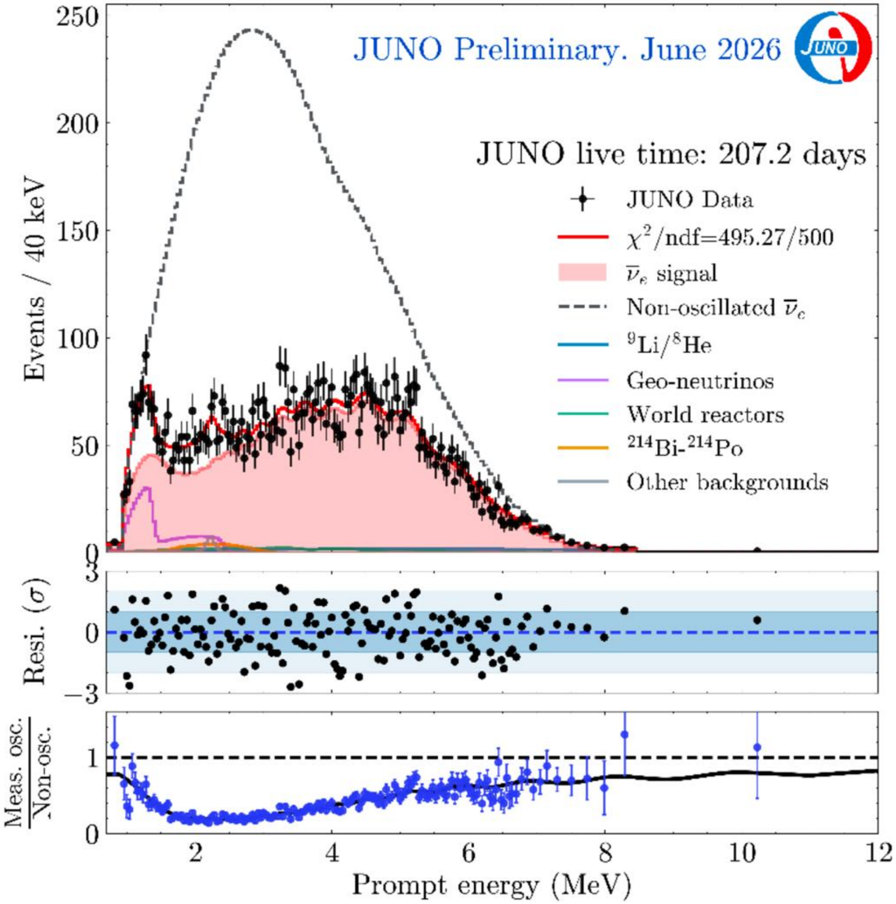


JUNO detector (illustrative)

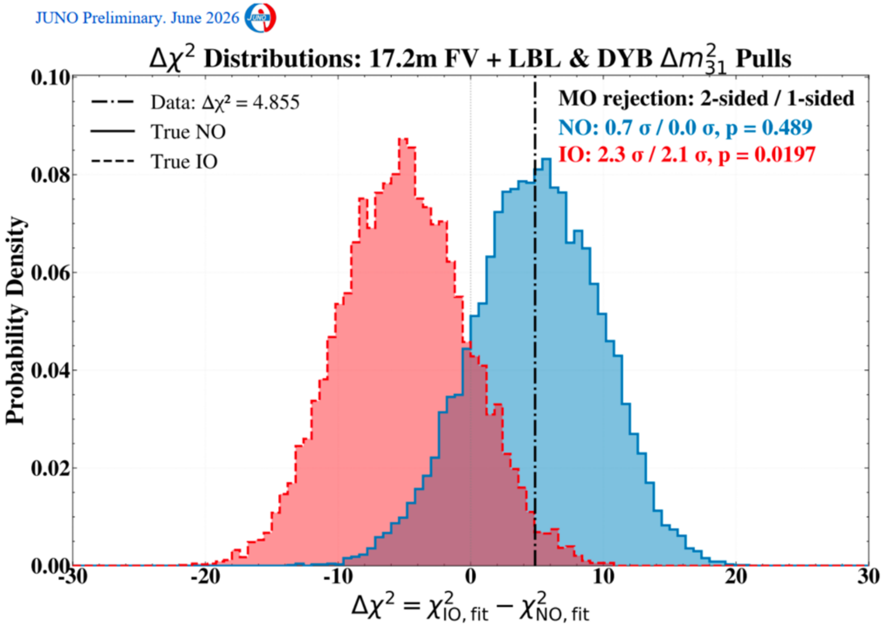


Recent results reported at Neutrino2026

- Data taking period for this analysis: 2025.08.30-2026.05.18



- Normal Ordering favored at 2.3σ
  - Combining with LBL and DYB



JUNO Physics Overview

Prog. Part. Nucl. Phys. 123, 103927 (2022)

IBD: inverse beta decay
NMO: neutrino mass ordering
CCSN: core-collapse supernova
DSNB: Diffused Supernova Neutrino Background

Neutrino oscillation & properties

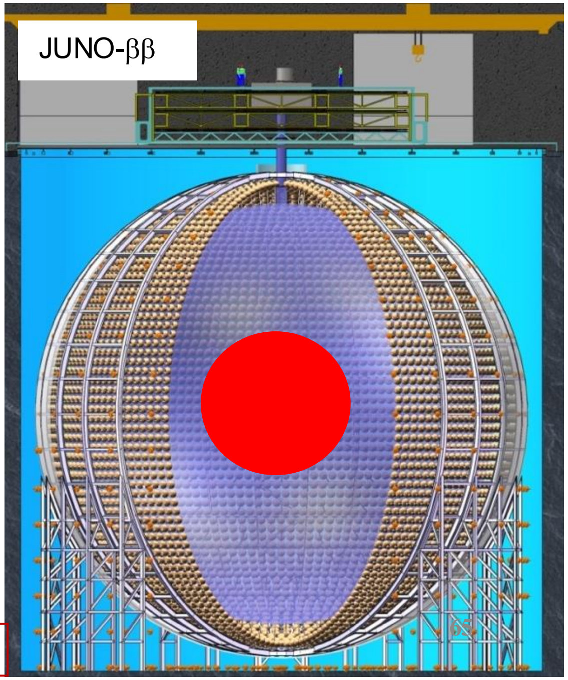
+ New physics
Neutrinos as a probe

- Energy resolution 2.95% @ 1MeV w/ full simulation
- NMO: 3σ (reactor only)@ ~6 yrs
- Supernova ν: ~7300 of all-flavor neutrinos @ 10 kpc
- DSNB: 3σ in 3 yrs (2205.08830)
- Solar ν: ^{7}Be, pep, CNO (2303.03910) and ^{8}B flux (2210.08437)
- Geo ν: ~400 per year, 5% precision in 10 yrs
- Nucleon Decays: $p \rightarrow \nu K + 9.6\times10^{33}$ yrs (90% C.L.) in 10 yrs (2212.08502), neutron invisible decay (ongoing)

Future of neutrino phyiscs

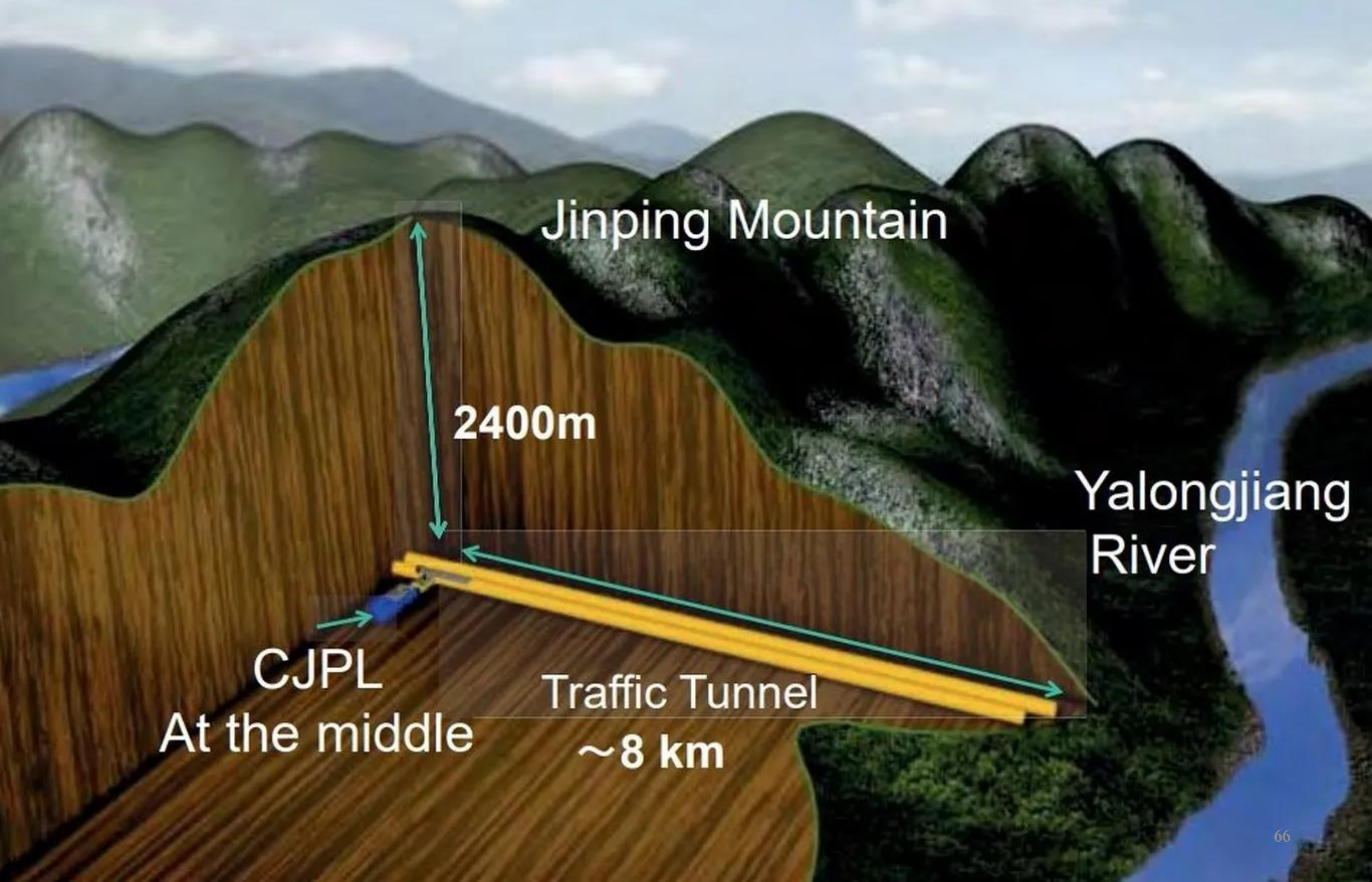
- After ten years, neutrino oscillation will be clarified:
  - Nova+T2K+JUNO+ORCA+DUNE for the NMO
  - DUNE+T2HK/HyperK for the CP phase
- Key question in neutrino sector:
  - Majorana? Does neutrino less double β decay exist?
- JUNO upgrade ~2030, to be the 0νββ decay experiment

	Isotope	Mass(t)	$<m_{\beta\beta}>$,meV
SNO+	^{130}Te	8	19-46
KamLAND2-Zen	^{136}Xe	1	~20
NEXT-HD	^{136}Xe	1	14-40
nEXO	^{136}Xe	5	7-22
Darwin/Panda-nT	^{136}Xe	3-5	7-22
LEGEND-1000	^{76}Ge	1	10-40
AMoRE-II	^{100}Mo	0.1	12-22
CUPID	^{100}Mo	0.24	12-20
CUPID-1T	^{100}Mo	1	4-7
JUNO-ββ	^{136}Xe	50	4-10
	^{130}Te	100	3-14



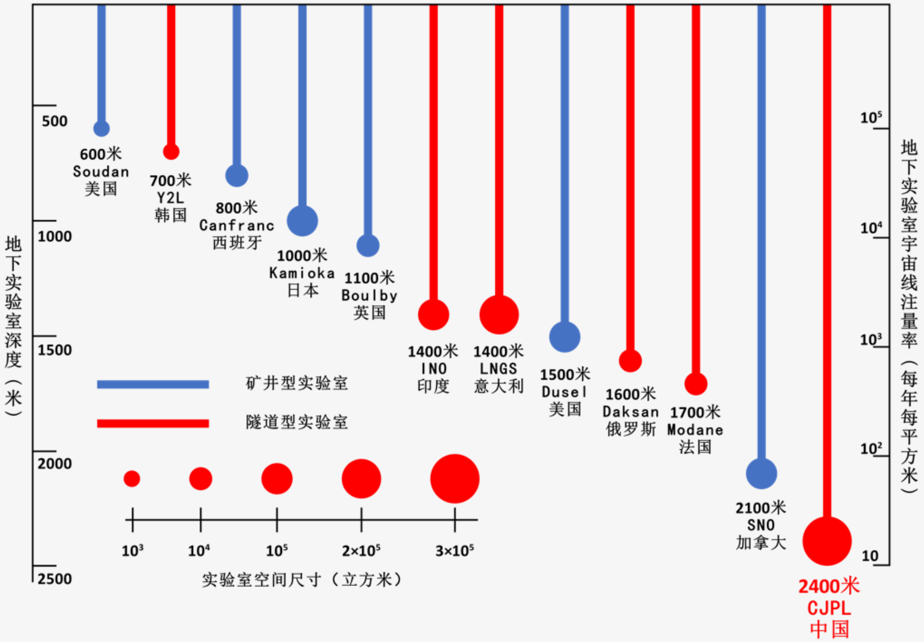
Zhao et al., CPC 41（2017）5

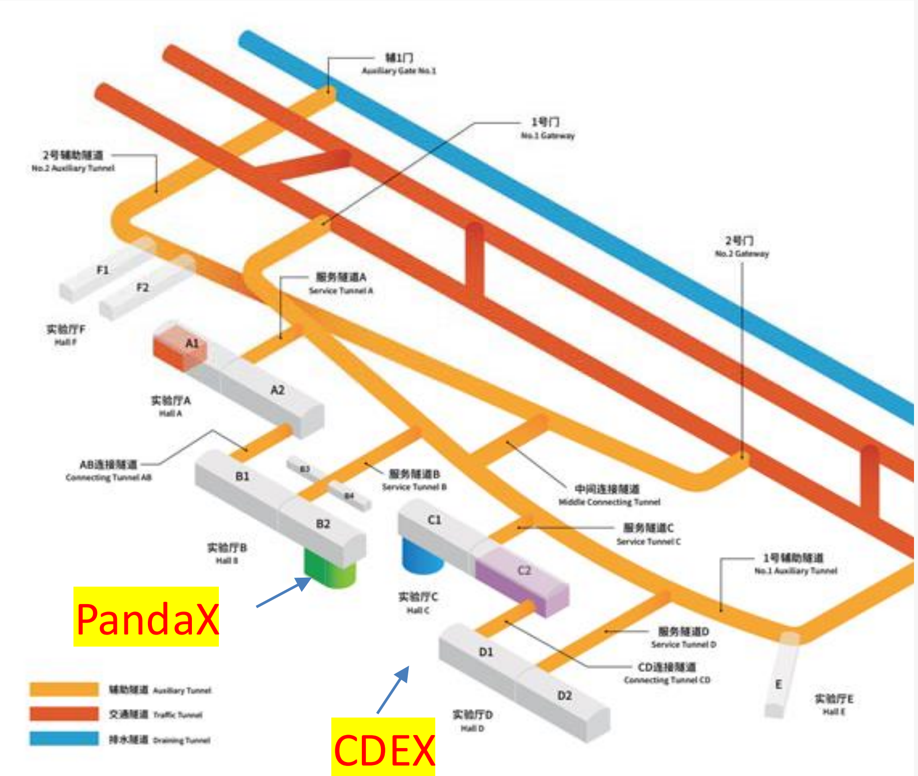
China JingPing underground Laboratory (CJPL)



China JingPing underground Laboratory (CJPL)

- **Deepest**
  - – 6800 m.w.e. ; <0.2 μ/m^2/day
- **Horizontal access**
  - – 9 km long tunnel
- **8 new experimental halls**
  - – (L: 65m H: 14m W: 14m)





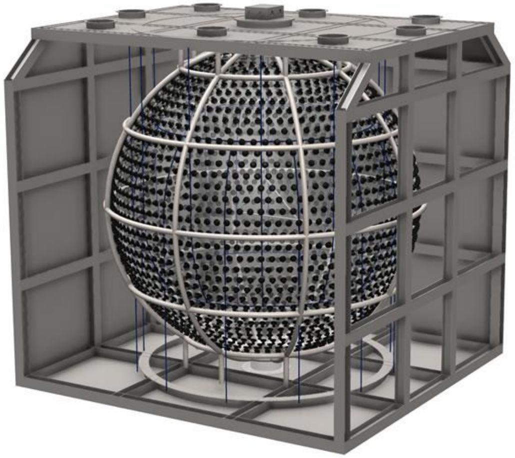
China JingPing underground Laboratory (CJPL)

China Dark Matter Experiment (CDEX)

Particle and Astrophysical Xenon Experiments（PandaX）

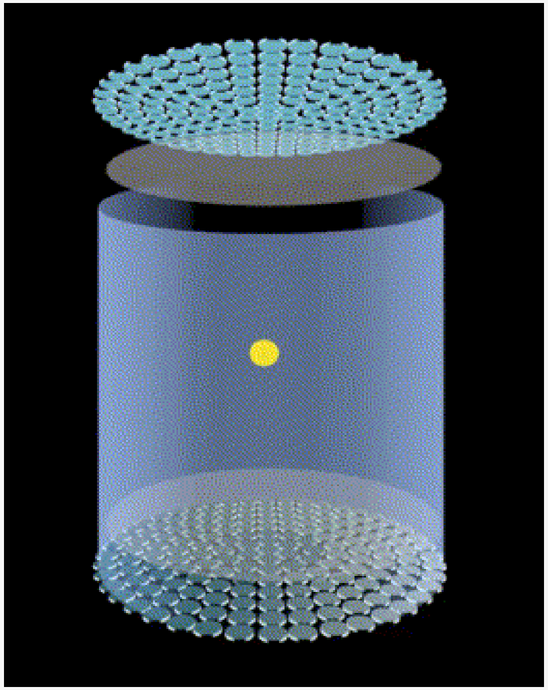
Jinping Underground Experiment for Nuclear Astrophysics (JUNA)

Jinping Neutrino Experiment (JNE)



Dark Matter experiments in CJPL

- Direct detection technologies
  - High mass: liquid noble gas (Xenon, Argon, etc.)
  - Low mass: Ge, Si, Bolometer, etc.

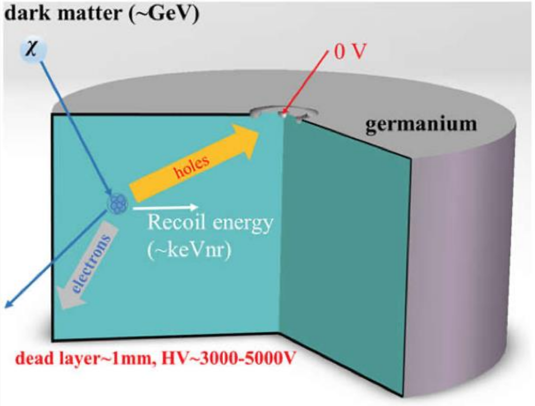


PandaX-4T

- Dual-phase xenon TPC
  - Scintillation light (S1) and ionized electrons (S2)
  - Precise energy and 3D-positon reconstruction

CDEX-10, -50 (on-going)

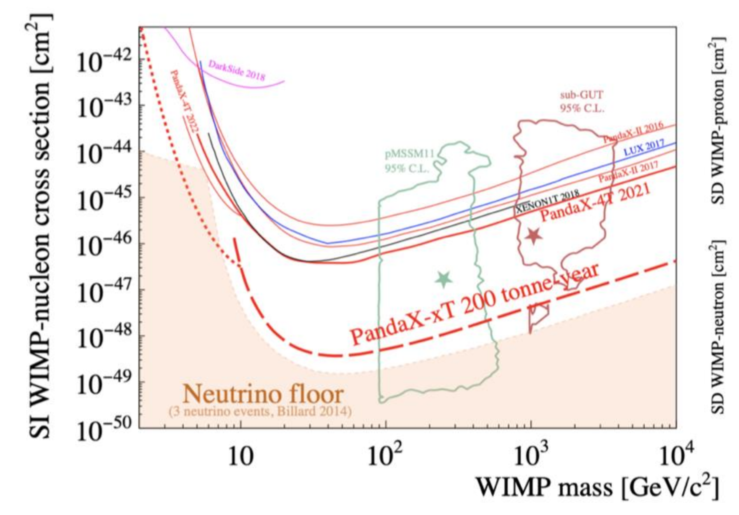
- Point-contact Germanium detector
- Low threshold: sensitive to light mass DM

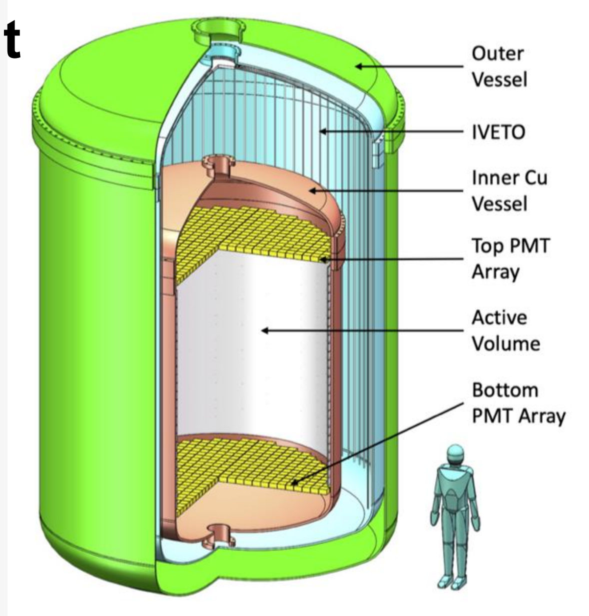


Future plan

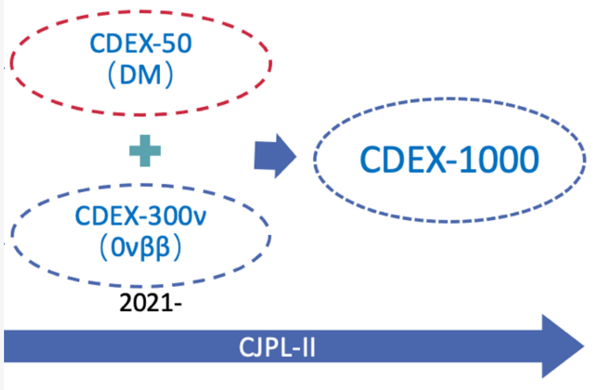
- **PandaX-xT: “ultimate” liquid xenon experiment**

Towards the neutrino floor





- **From CDEX-50 to CDEX-1000**
  - CDEX-50: 50kg, SI sensitivity reaching 10^{-44} cm^2



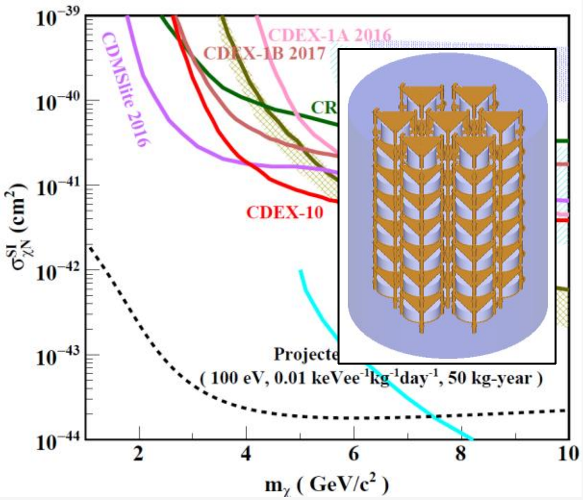
CDEX-50 (DM)

CDEX-300ν (0νββ)

2021-

CDEX-1000

CJPL-II

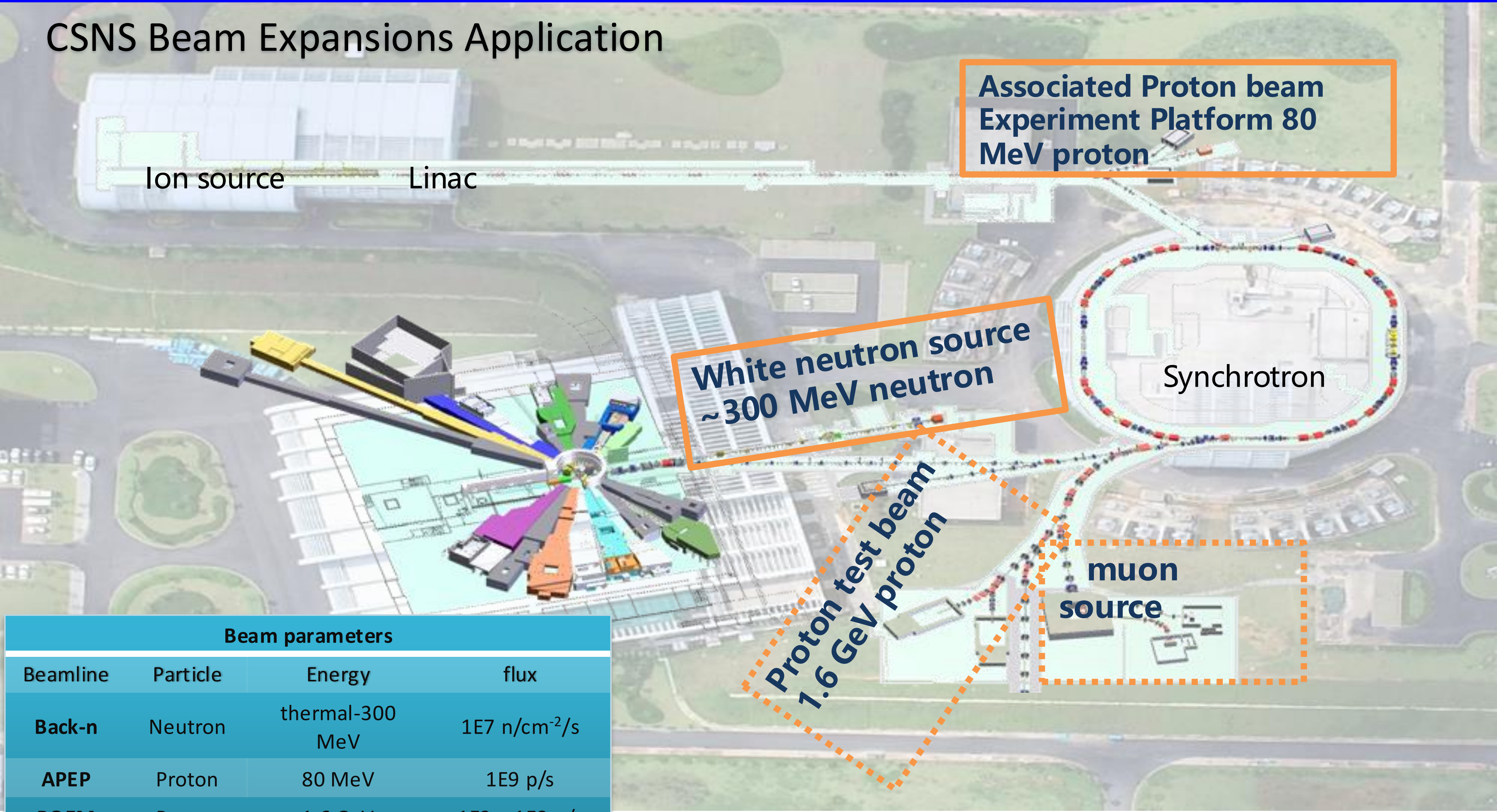


Accelerated based: Non-collider experiments

- Dongguan in Guangzhou Province (near Hongkong)
  - – Like ISIS and Diamond Light Source near RAL

Accelerated based: Non-collider experiments

CSNS Beam Expansions Application



Beam parameters			
Beamline	Particle	Energy	flux
Back-n	Neutron	thermal-300 MeV	1E7 n/cm^{-2}/s
APEP	Proton	80 MeV	1E9 p/s
POEM	Proton	1.6 GeV	1E3 – 1E8 p/s
MELODY	Muon	4 MeV	1E5 muon/pulse

- Similar muon experiments proposed in the nearby city Huizhou

Accelerated based: Non-collider experiments

- HIAF: High-Intensity Heavy Ion Accelerator Facility
- CiADS: China-initiative Accelerator-Driven Subcritical system
  - the world’s first megawatt-level ADS research facility
- The construction of both facilities should be completed by next year

Summary and Reflection

- Major particle physics facilities in China reviewed, as well as newly planed facilities or upgrades
    - From hadron physics to energy frontier physics, as well as neutrino physics and dark matter search
- Particle physics progresses in China wouldn’t happen without the support and participation from all over the world
    - Collaboration and new proposals are welcome!

Summary and Reflection

- Major particle physics facilities in China reviewed, as well as newly planed facilities or upgrades
  - From hadron physics to energy frontier physics, as well as neutrino physics and dark matter search
- Particle physics progresses in China wouldn’t happen without the support and participation from all over the world
  - Collaboration and new proposals are welcome!

Thank You!

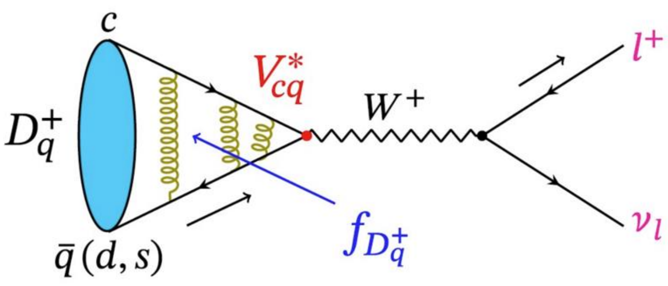
Thank You!

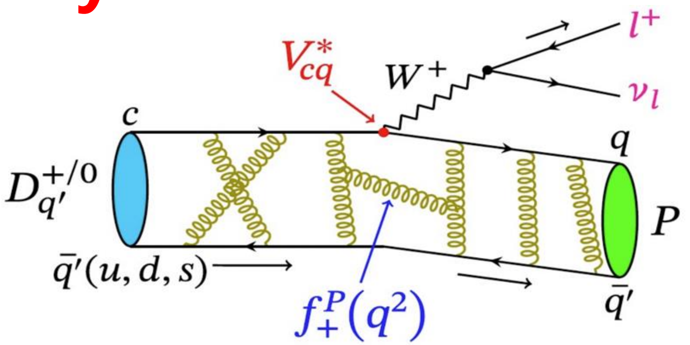
The end

Backup

Flavor physics at Charm quark

Leptonic and semileptonic decay





Decay constant $f^2_{D^+_{(s)}}$ (LQCD)

Decay rate

CKM matrix element

$$\boxed{\Gamma\left(D^+_{(s)} \to l^+\upsilon\right)} = \frac{G_F^2 \boxed{f^2_{D^+_{(s)}}}}{8\pi} \boxed{\left|V_{cd(s)}\right|^2} m_l^2 m_{D^+_{(s)}} \left(1 - \frac{m_l^2}{m^2_{D^+_{(s)}}}\right)^2$$

CKM matrix element

Form Factor (LQCD)

Decay rate

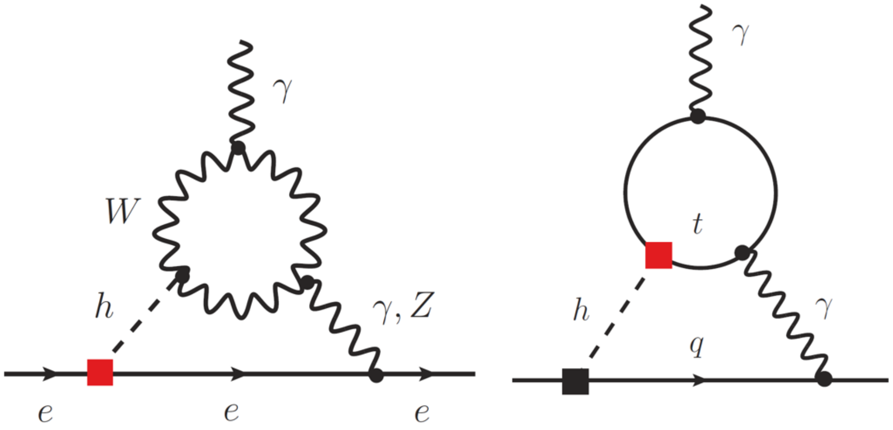
$$\boxed{\frac{d\Gamma(D^{+/0}_{(s)} \to K(\pi)l^+\upsilon)}{dq^2}} = \frac{G_F^2 \boxed{\left|V_{cd(s)}\right|}^2 p^3_{K(\pi)}}{24\pi^3} \boxed{|f_+(q^2)|^2}$$

- Strong interactions
  - Gluon exchanges between quarks, parameterized as “decay constant” and “form factor”
- Weak interactions
  - Leptonic(Semileptonic) decay with quark-antiquark annihilation(charm quark trainsition), extracting the CKM matrix

Indirect constraint

- Low energy experiments, e.g. electron EDM, can constrain the Higgs CP indirectly

$$\mathcal{L} \supset -\frac{y_f}{\sqrt{2}}\left(\kappa_f \bar{f} f + i\tilde{\kappa}_f \bar{f}\gamma_5 f\right) h$$



ACME collaboration:

eEDM<1.1×10^{-29} e·cm

⇩

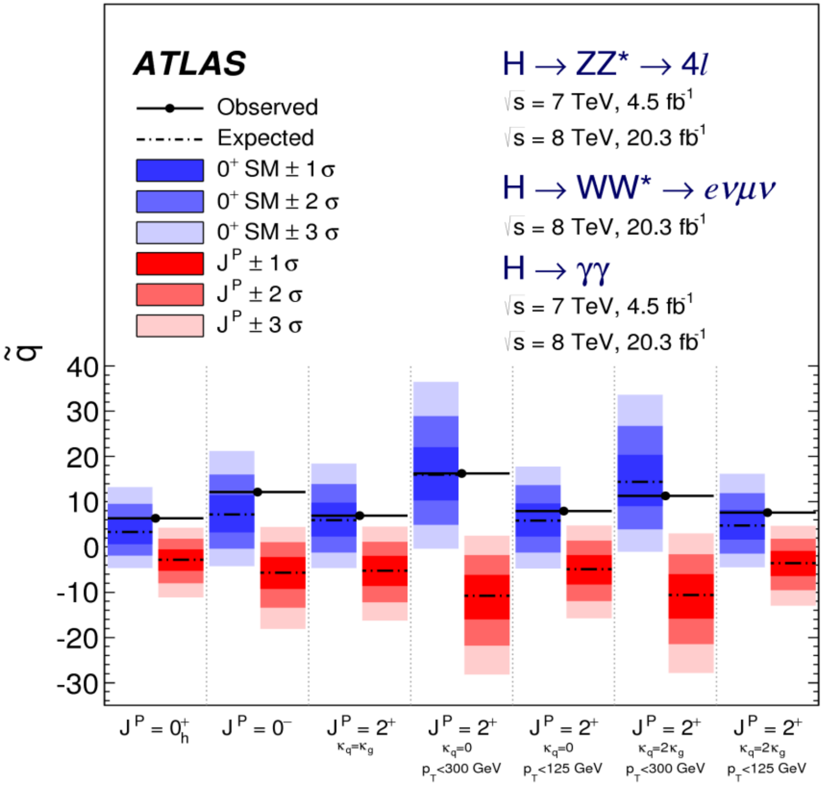
$$|\tilde{\kappa}_e| \lesssim 1.7 \times 10^{-2}$$
$$|\tilde{\kappa}_t| \lesssim 1.0 \times 10^{-2}$$

- But, very model dependent
  - Gauge-dependent contributions, UV-divergent diagrams, etc.

From J. Brod at Higgs 2020

Higgs boson open the door

- Higgs boson is found very SM-like, e.g. CP-even scalar
  - $J^P=0^+$ compared with alternative spin-model
  - Mixing between CP-even and CP-odd, which could lead to CP violation, is still allowed



Tau decay mode classification

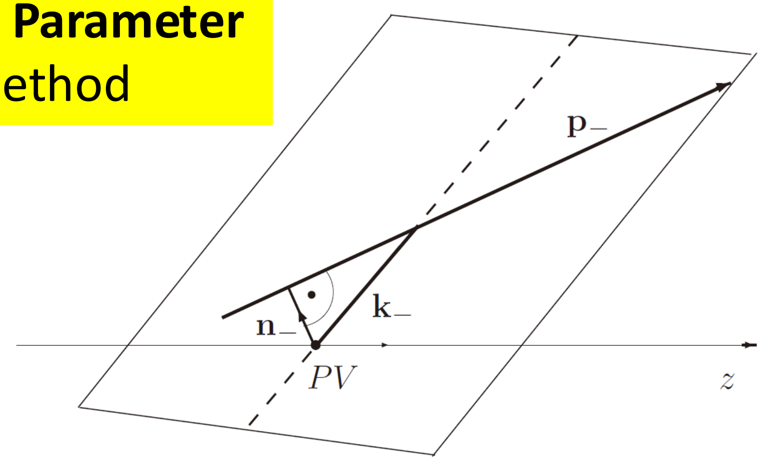
- Methods to build τ decay plane

Decay mode	Branching fraction
$\ell^{\pm}\bar{\nu}\nu$	35.2%
$h^{\pm}\nu\ (\pi^{\pm}\nu)$	11.5% (10.8%)
$h^{\pm}\pi^{0}\nu\ (\pi^{\pm}\pi^{0}\nu)$	25.9% (25.5%)
$h^{\pm} \geq 2\pi^{0}\nu\ (\pi^{\pm}2\pi^{0}\nu)$	10.8% (9.3%)
$3h^{\pm}\nu\ (3\pi^{\pm}\nu)$	9.8% (9.0%)

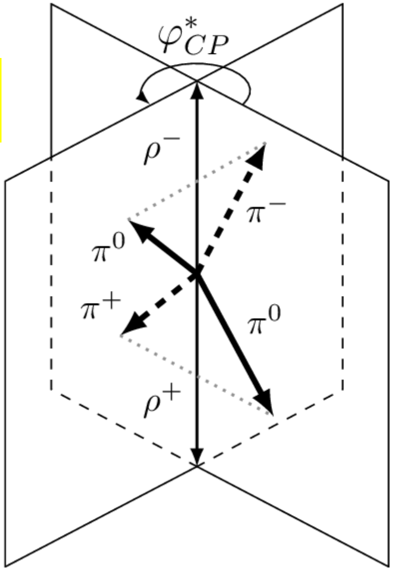
Impact Parameter (IP) method

Rho method

Impact Parameter method

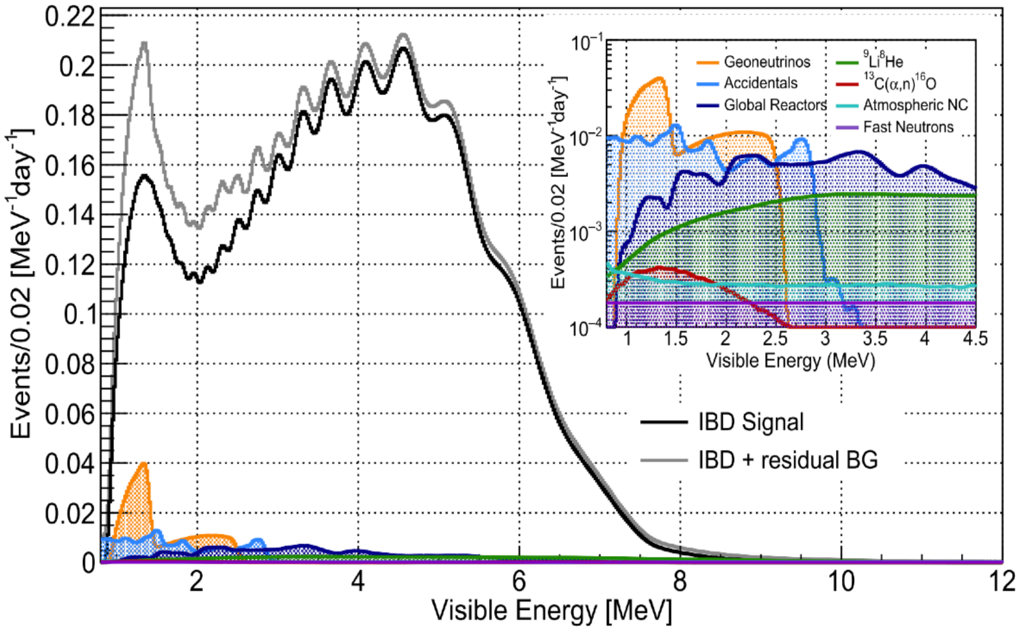


Rho method



Reactor Neutrino Oscillation

- Sources: 8 reactor cores from 2 NPP with total 26.6 GW_{th}
- Oscillation: $\bar{\upsilon}_e$ disappearance, ~53km baseline, vacuum driven
- Detection: IBD $\bar{\upsilon}_e + \mathrm{p} \rightarrow \mathrm{e}^+ + \mathrm{n}$ (prompt-delay coincidence)
  - Reactor IBD rate: ~47/day and Background rate: ~4/day

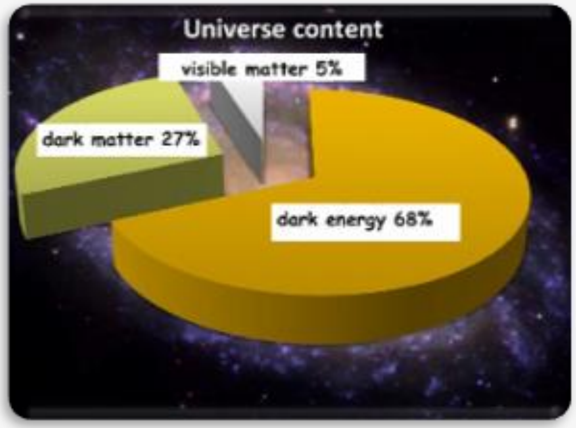


- ν mass ordering: 3σ (reactor only)@ ~6 yrs, atmospheric voscillation being improved
- ν oscillation parameters: precision of $\sin^2\theta_{12}$, $\Delta m^2{}_{12}$, $|\Delta m^2{}_{31}|$ < 0.5%in 6 yrs, unprecedented precision (2204.13249)

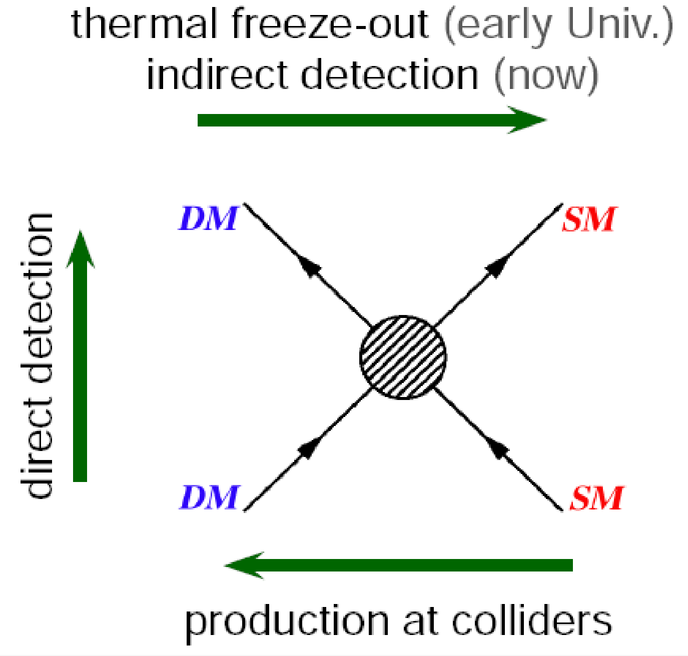
CPC 46 (2022) 12, 123001

Dark Matter

- Strong evidences for the existence of dark matter
- The nature of dark matter is unknown

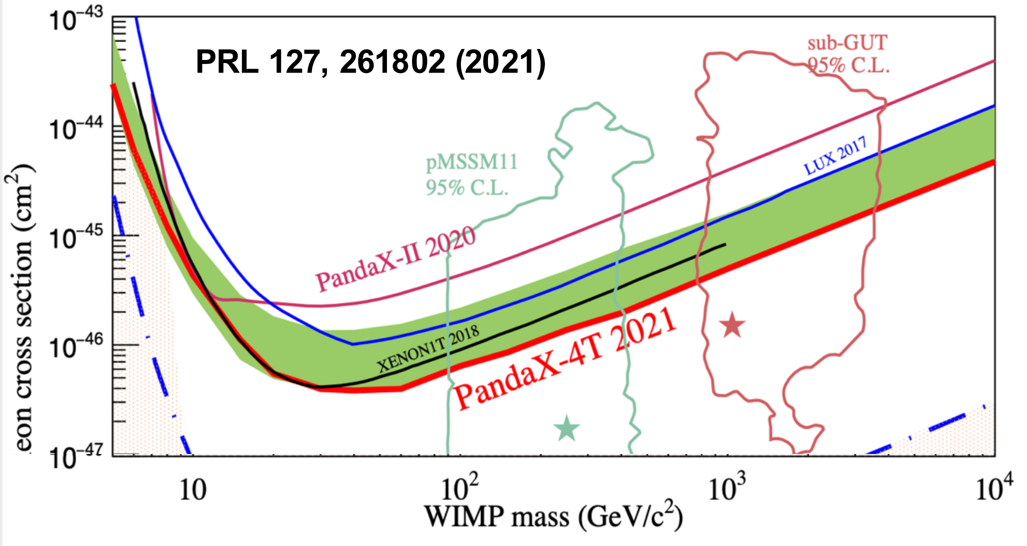


- Dark Matter Searches
  - Direct detection, indirect detection, collider search
- CJPL excellent for direct detection
  - Solar system in the dark matter halo
  - Detection of incoming dark matter scattering off target atom

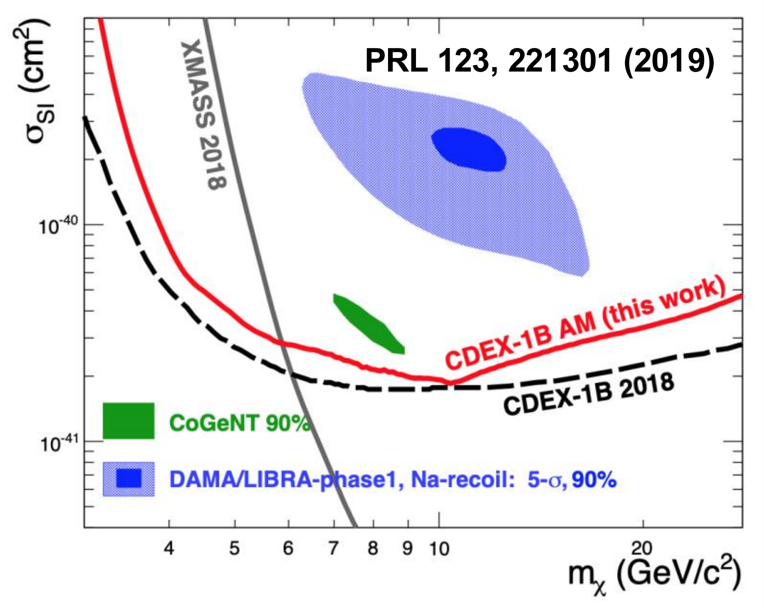


Dark Matter searches results (selected)

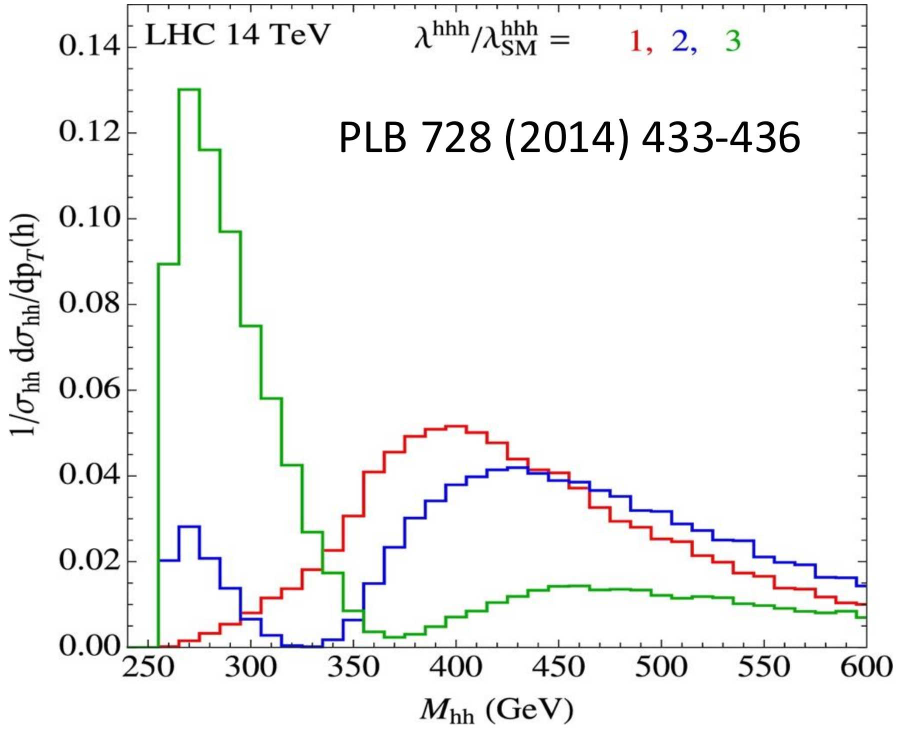
- **PandaX-4T**
  - 3.7-tonne LXe
  - Approaching the “low E” neutrino floor



- **CDEX-1B**
  - 4.2 years: 1107.5 kg-day exposure
  - Search for annual modulation signal of spin-independent(SI) WIMP-nucleon interaction



HH search in future



PLB 728 (2014) 433-436

ATL-PHYS-PUB-2022-053