

Scientific Programme

Field Theory and the Electro-Weak Standard Model

Rohit Choudhry (IISc, India)

Heavy-Ion Physics

Sourendu Gupta (IITR, India)

Higgs and Beyond the Standard Model

Koshi Hamaguchi (IIT, Tokyo, Japan)

Flavour Physics and CP Violation

Sung-J. Lee (KIST, Korea)

Cosmology

Viktor Rubakov (INR Moscow, Russia)

QCD

Peter Szendrői (ICRAN and U. Monash, Australia)

Particle Physics in Asia

Atsuto Suzuki (KEK, Japan)

Practical Statistics for Particle Physicists

Wolfgang Verkerke (Nikhef, the Netherlands)

Instrumentation and Detectors

Jos-Louis Wijnands (SOA, INSP/USAPP, France)

Neutrino Physics

Zhi Zhang (IHEP, China)

Particle Physics in Europe

Eric

Discussion Leaders

Abdusalam Azarov (CERN)

Andreas Blazek (CERN and KIT, Germany)

Cheng Wei Chang (National Central U., Taiwan)

Debajyoti Choudhury (I.I. Delhi, India)

Sudhar Vempati (IISc, India)

Jin-Woo Kim (CERN)

International Advisory Committee

Giuseppe Giacchino (INFN, Italy)

John G. Thompson (CERN, Switzerland)

Yoshinori Yamaguchi (KEK, Japan)

Yunfeng Zhou (IHEP, China)

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Yunfeng Zhou (IHEP, China)

Yunfeng Zhou (IHEP, China)

Yunfeng Zhou (IHEP, China)

# Particle Physics in Asia

Atsuto Suzuki



INTER-UNIVERSITY RESEARCH INSTITUTE CORPORATION  
HIGH ENERGY ACCELERATOR RESEARCH ORGANIZATION

# Outline

**1. Electron-Positron Colliders**

**2. Proton Accelerator Research Complex: J-PARC**

**3. Reactor Neutrino Oscillation Project**

**4. Underground Particle Physics Project**

**Double Beta-Decay Detection**  
**Dark Matter Search**  
**Gravitational Wave Detection**

**5. Astro-Particle Physics Project**

**6. Summary**

# 1. Electron-Positron Colliders



SuperKEKB/Belle II



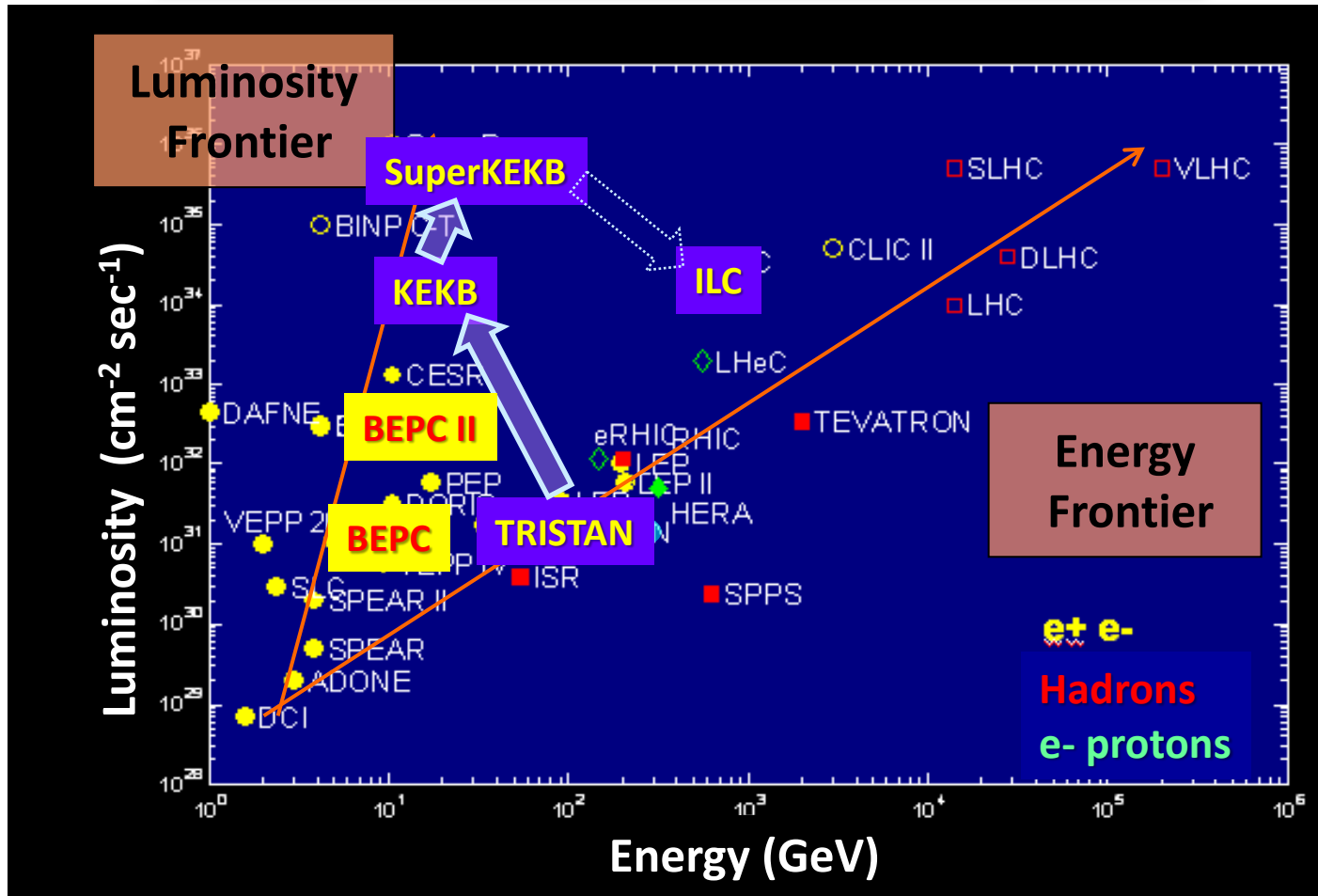
BEPCII/BESIII



ILC



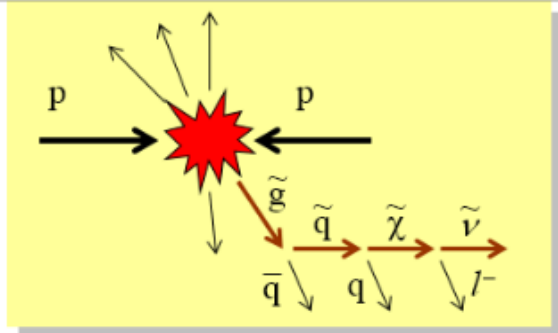
# Trend in High Energy Accelerators



# Discovery/Establish SM

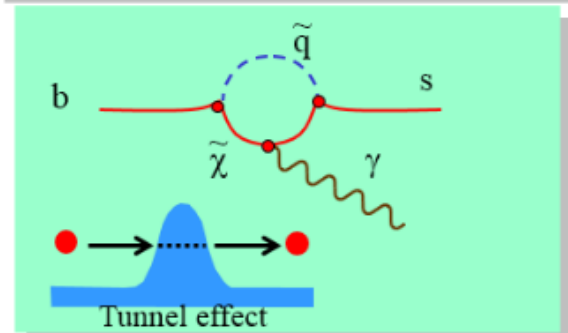
## Energy Frontier

### Direct Production by High Energy Coll.

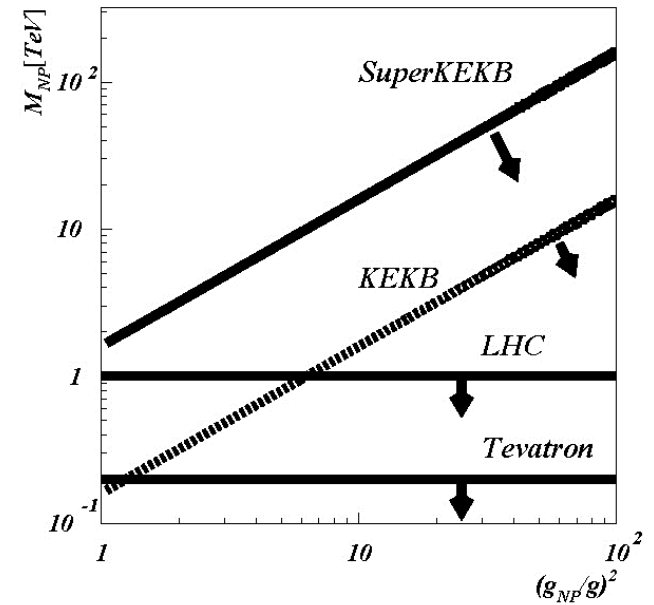


## Luminosity Frontier

### Virtual Production via Quantum Eff.



1974: J/ψ (c quark)	1964: CPV in K
1975: τ lepton	
1977: Υ (b quark)	
1983: W,Z	1987: B <sup>0</sup> -mixing
1995: t quark	2001: CPV in B
	2004: Direct CPV
	2007: D <sup>0</sup> -mixing
2012: Higgs	

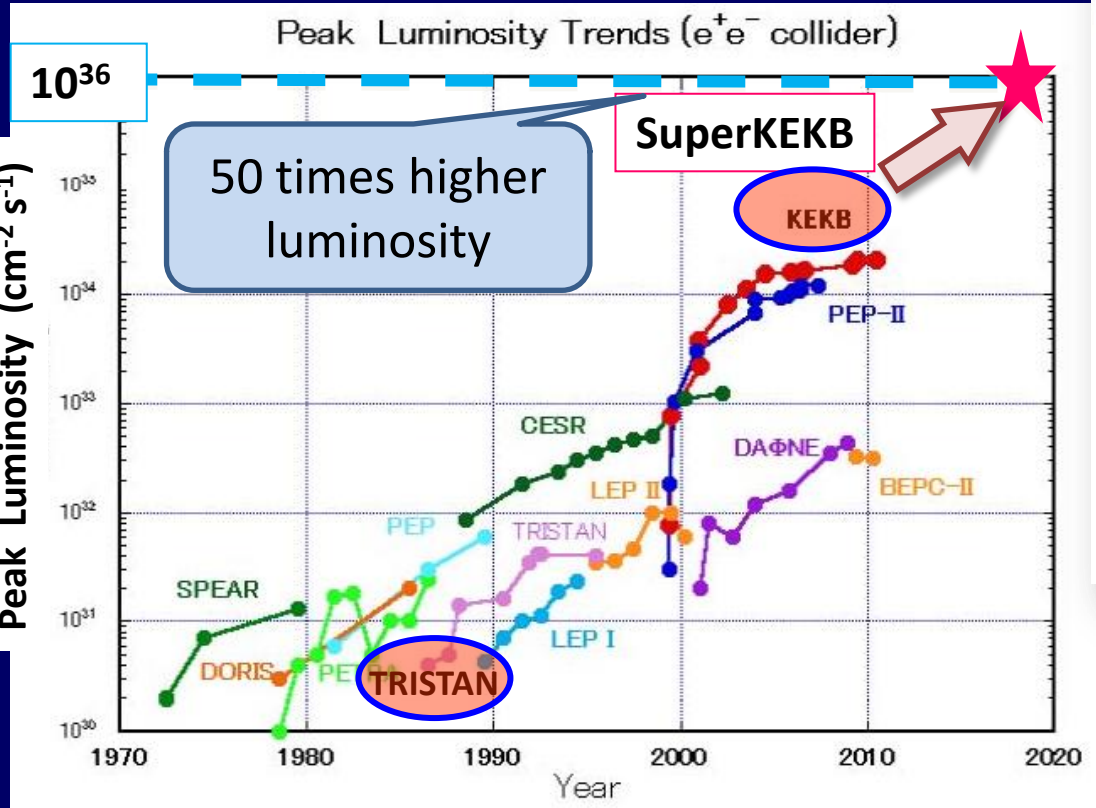
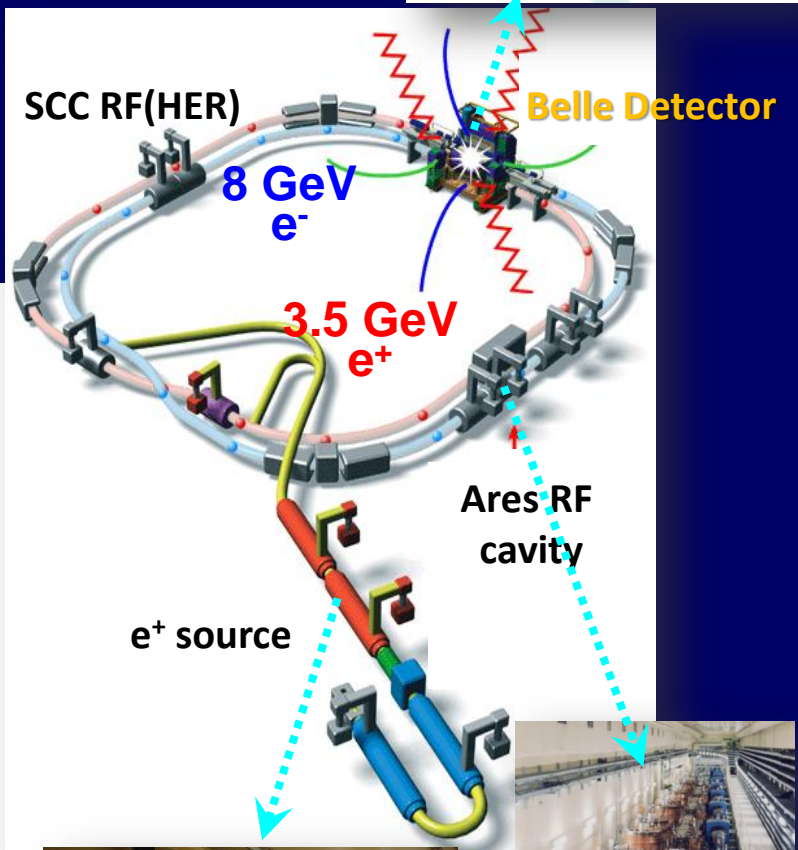
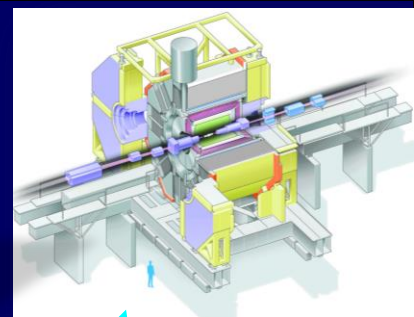


Higher Energy Scale can be searched (even if LHC finds no New Physics)



# KEK $e^- e^+$ Collider :

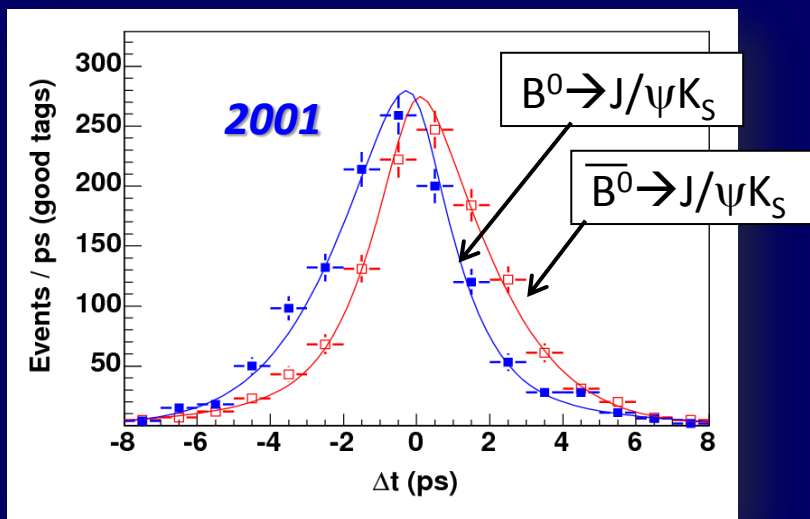
KEKB/Belle  $\rightarrow$   
SuperKEKB/Belle II



15 countries, ~400 collaborators

# KEKB/Belle Collaboration

## Discovery of CP-violation in the $B$ -meson system



Decay Time Difference

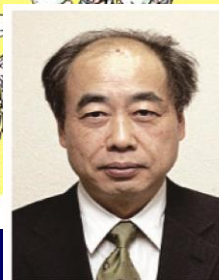
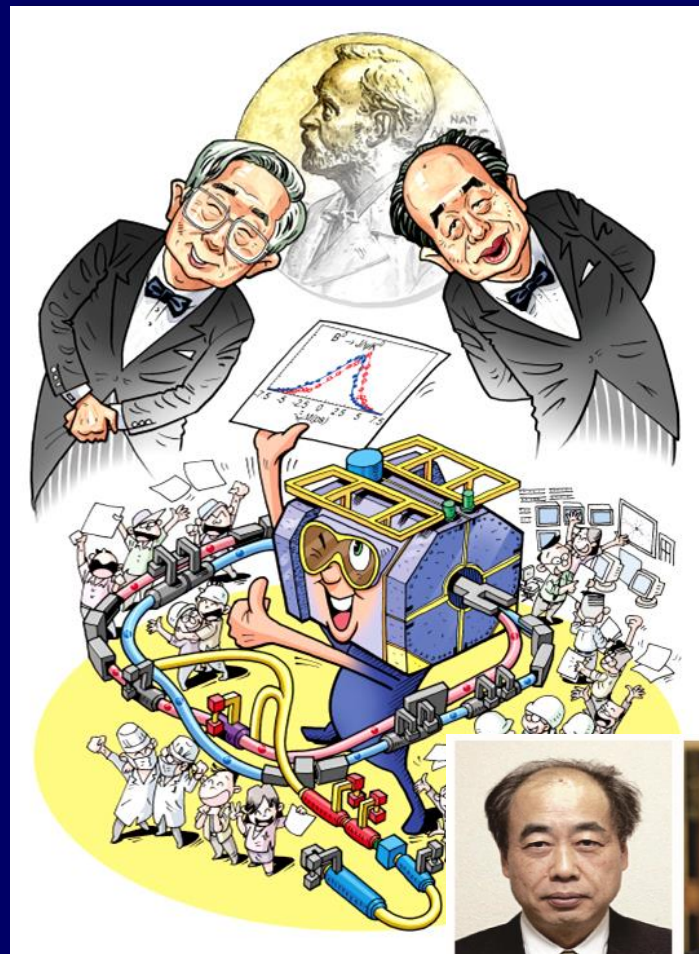


Photo: KEK

Photo: Kyoto University

Makoto Kobayashi

Toshihide Maskawa



The Nobel Prize in Physics 2008

# Major achievements at Belle

## Belle collaboration

15 countries ~400 collaborators

As of March 2010

# of papers : 315

# of citations: 13,309

(fb)<sup>-1</sup>

Integr. Evidence for B → τν

Evidence for D<sup>0</sup> mixing

Observation of direct CP violation in B → π<sup>+</sup>π<sup>-</sup>

Observation of b → dγ

Evidence for direct CP violation in B → K<sup>+</sup>π<sup>-</sup>

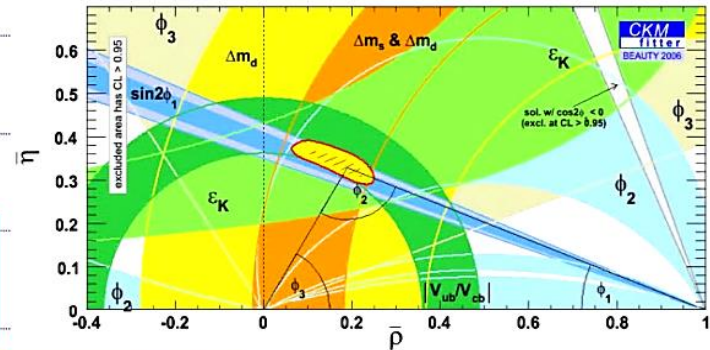
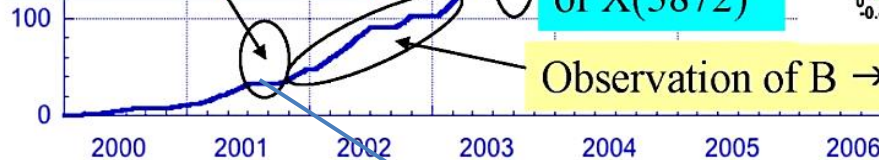
Decisive confirmation of Kobayashi-Maskawa theory

Measurements of CP violation in B → φKs, η'Ks etc.

Observation of CP violation in B meson system

Discovery of X(3872)

Observation of B → K<sup>(\*)</sup>ll

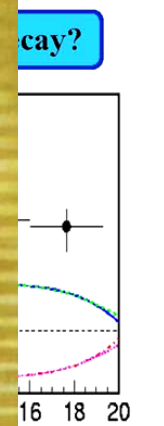
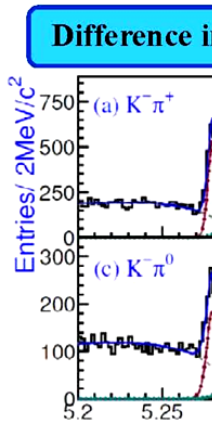
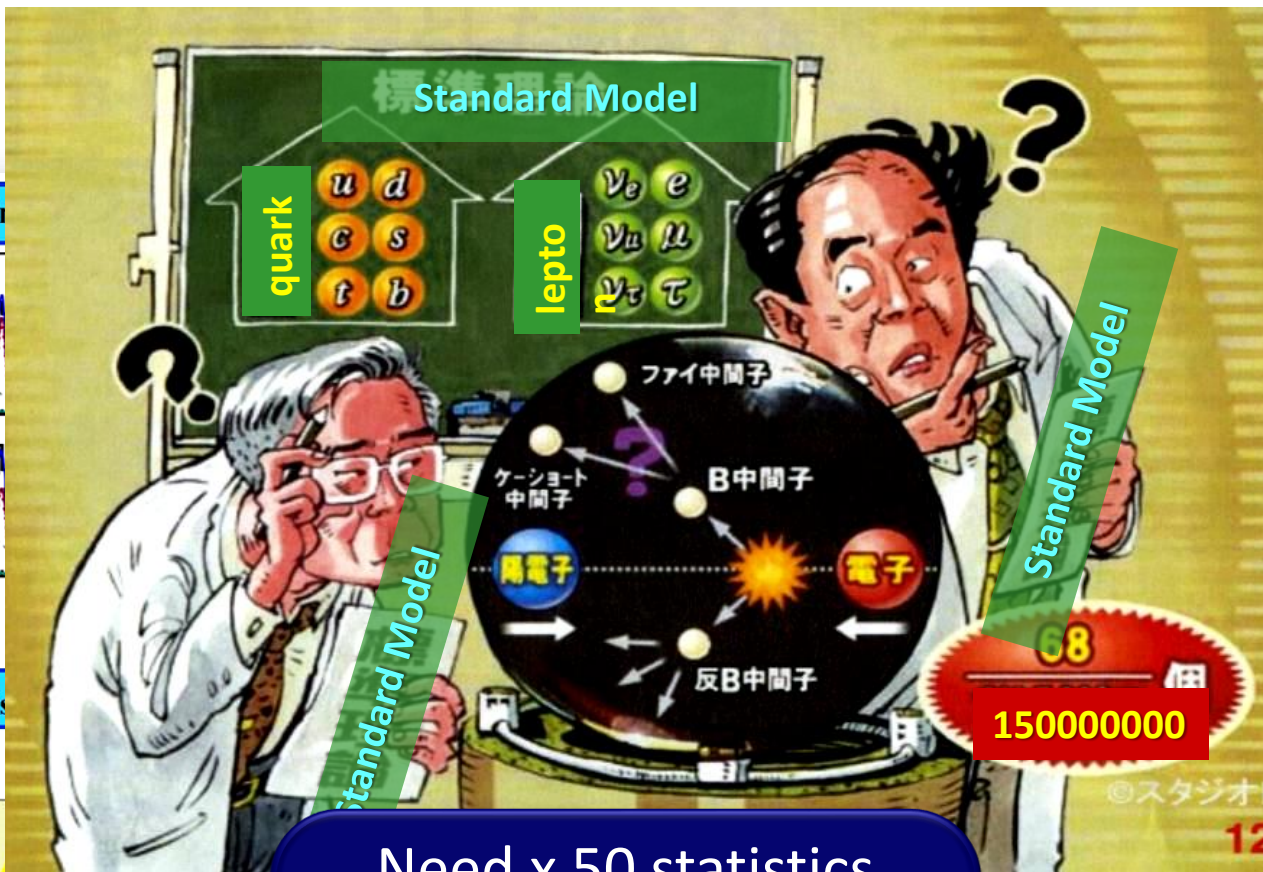


CPV: caused by a single phase of CKM matrix

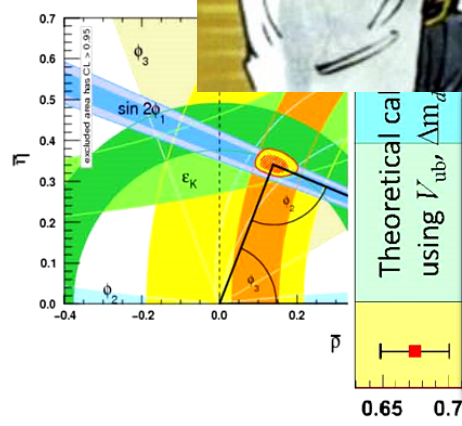




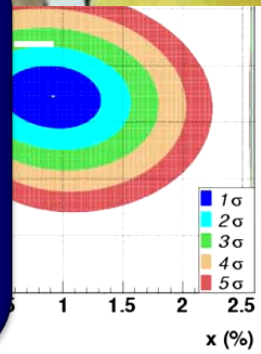
# Possible Hints for New Physics ?



Inconsi

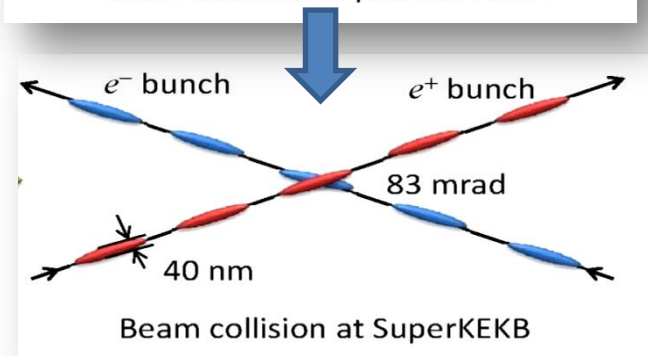
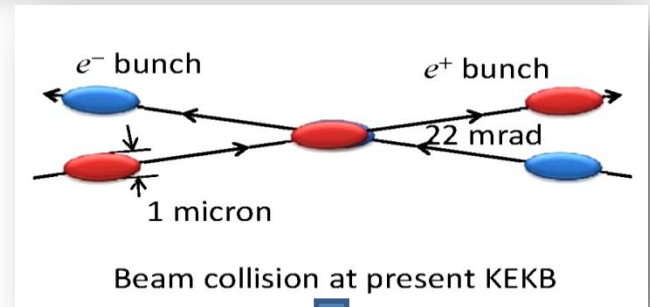


Need x 50 statistics  
to clarify new physics  
:  
Motivation of  
SuperKEKB/Belle II

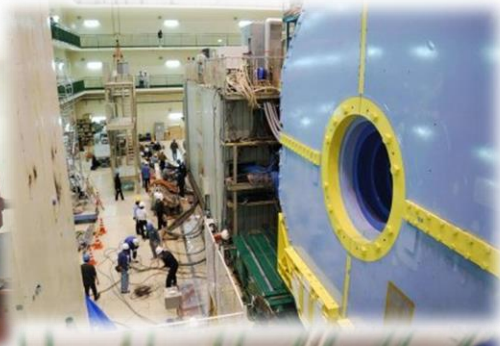
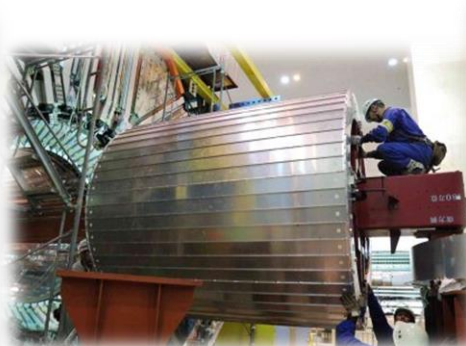


# KEKB to SuperKEKB : current status

- KEBB operation finished at 9:00 am June 30, 2010



# KEKB/Belle being disassembled



# SuperKEKB and Belle II

**Belle II**

$e^+$  4GeV 3.6 A

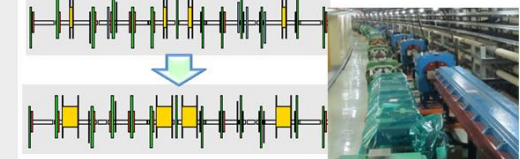
$e^-$  7GeV 2.6 A

**SuperKEKB**

Target:  $L = 8 \times 10^{35} / \text{cm}^2 / \text{s}$

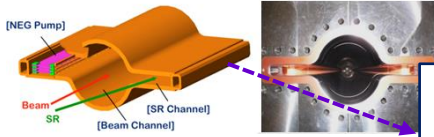
New superconducting / permanent final focusing quads near the IP  
New IR  
Colliding bunches

Replace short dipoles with longer ones (LFR)



Redesign the lattices of HER & LER to squeeze the emittance

TiN-coated beam pipe with antechambers  
Cu for wigglers and Al alloy for the rest



Damping ring

@1.1 GeV  
To inject low emittance positrons

Low emittance gun

Add / modify RF systems for higher beam current

Positron source  
New positron capture section

**Direct Winding by BNL:**  
Dipole corrector for QC2RP

**LER Arc Cell**

**HER Wiggler**

**100% : delivered from BINP**  
**87% : TiN coated/baked in KEK**  
**77% : installed**

**Damping Ring**

**LER Wiggler**



**BINP, KEK, Nara**  
**Taiwan, Hanyang, Perugia,**  
**Frascati, Roma3, Roma1,**  
**Napoli, ...**

# Belle II Detector Upgrade



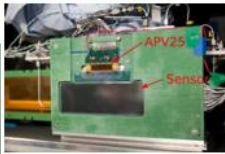
**CsI(Tl) EM calorimeter:**  
 waveform sampling  
 electronics, pure CsI  
 for end-caps

7.4 m

**RPC  $\mu$  &  $K_L$  counter:**  
 scintillator + Si-PM  
 for end-caps **ITEP, Virginia, KEK,**  
**Hawaii, Indiana,**  
**Wayne state, ...**

**MPI, Bonn, Heidelberg, Giessen,**  
**Goettingen, Karlsruhe, DESY,**  
**Valencia, Vienna, Charles,**  
**KEK, IPMU, U-Tokyo, Tohoku, TIFR,**  
**Melbourne, Kyunpook, Krakow,**  
**Pisa, Trieste**

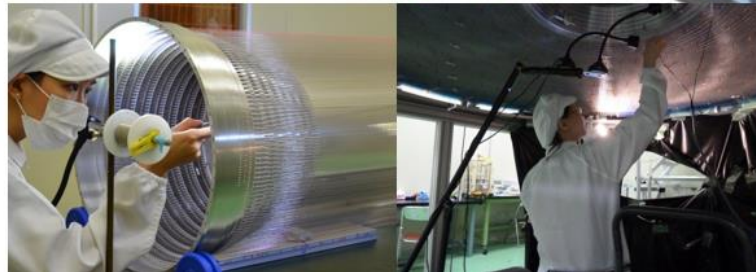
**4 layers DS Si Vertex  
 Detector →**  
**2 layers PXD (DEPFET)**  
**4 layers DSSD**



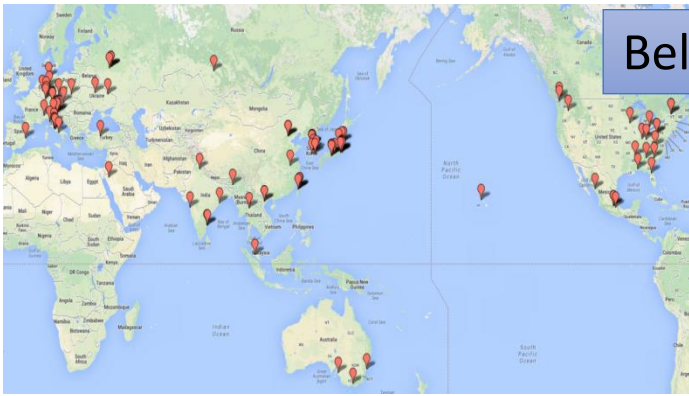
**Central Drift Chamber:**  
 smaller cell size,  
 long lever arm

**KEK, Taiwan, RCNP,**  
**Viet Nam, Malaya,**  
**Chiang Mai, ...**

**Nagoya, Toho, Chiba, Niigata,**  
**Hawaii, Cincinnati, PNNL, KEK,**  
**Tokyo metro, Ljubljana,**  
**PID system Torino, Padova, ...**  
**Time-of-Propagation counter**  
 (barrel),  
**prox. focusing Aerogel RICH**  
 (forward)



# Belle II Collaboration



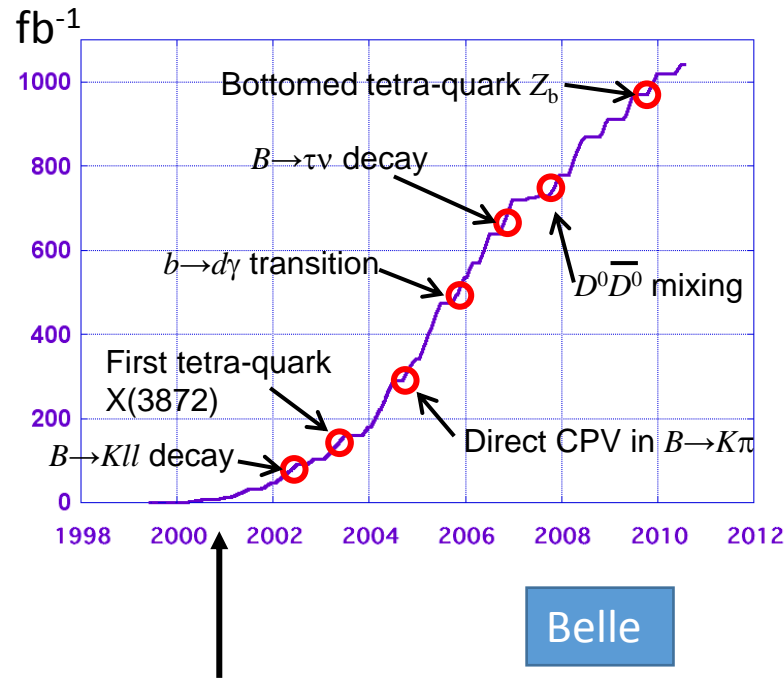
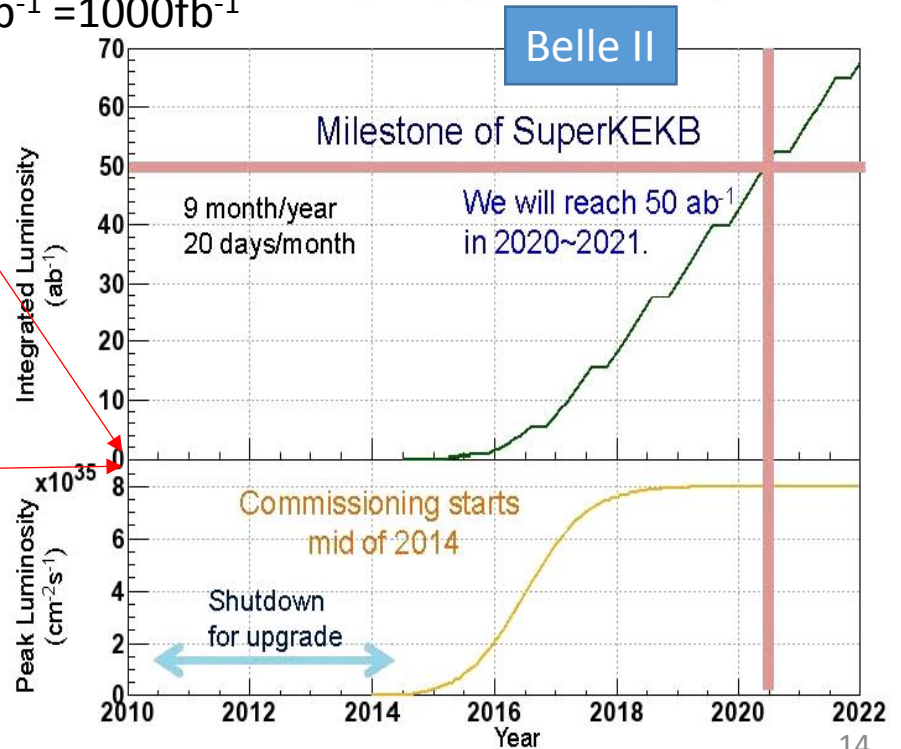
~600 collaborators from 97 institutions in 23 countries/regions



IIT-Bhubaneswar (2), IIT-Guwahati (5), IIT Madras (5), Inst. Math. & Sci. (1), Panjab U (3), TIFR (6)

## Luminosity upgrade projection

$ab^{-1} = 1000fb^{-1}$



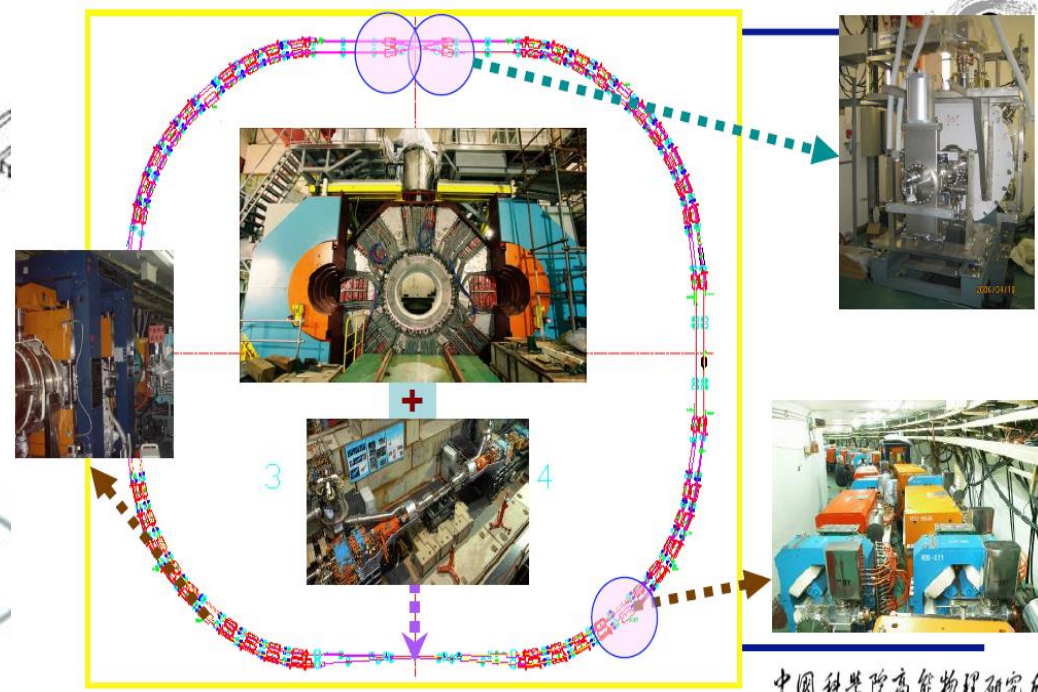
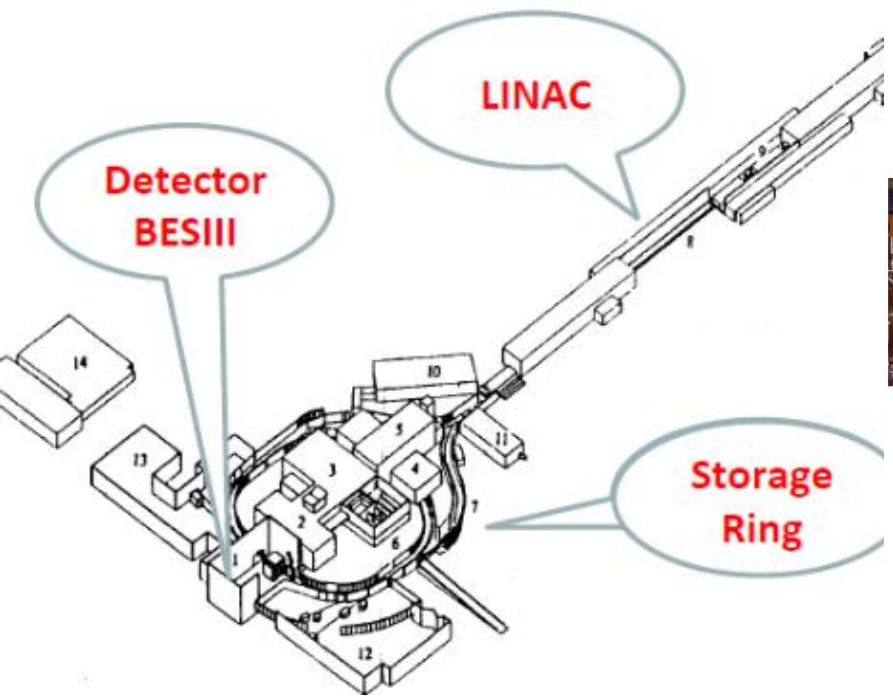
Discovery of CP violation in B decays



# BEPC & BEPCII



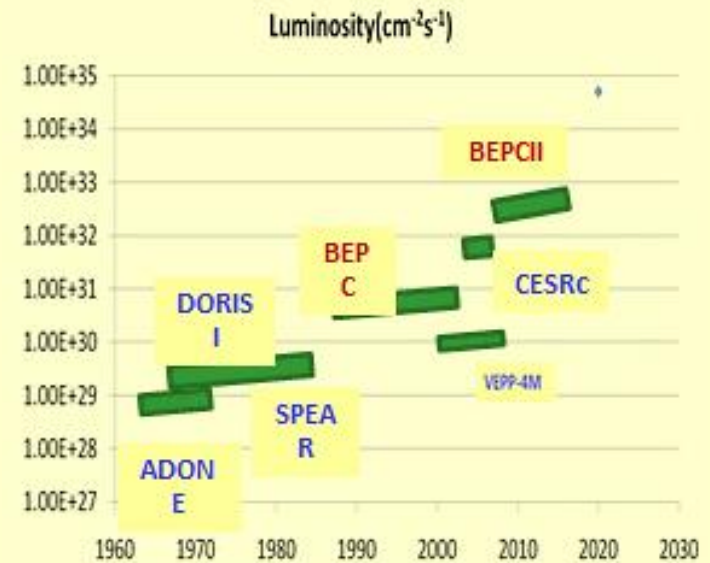
- From BEPC to BEPCII
  - a double-ring factory-like machine
  - deliver beams



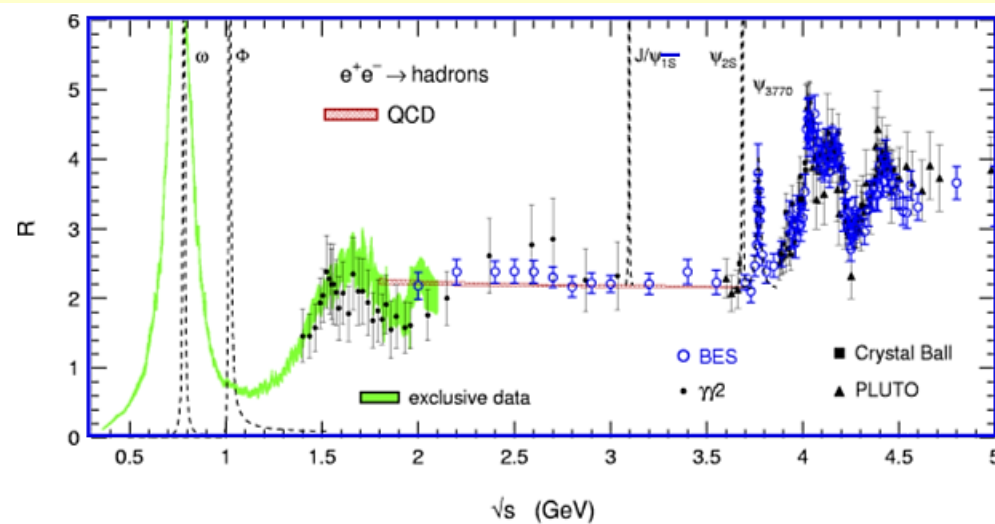
中国科学院高能物理研究所  
Institute of High Energy Physics

# BEPCII/BESIII: Operational since 2009

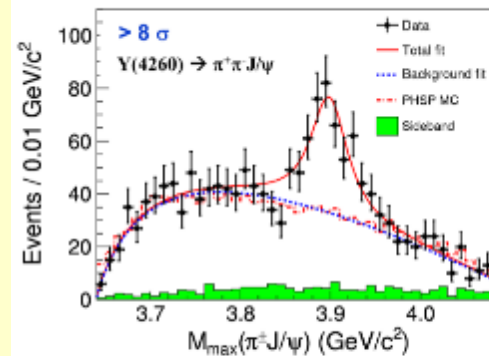
A high lumi.  $e^+e^-$  collider at the  $\tau$ -c energy region



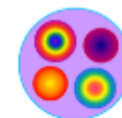
	Previous Data set	BESIII Near future
J/psi	BESII 58M	2009: 200M, 2012: 1 B
Psi'	CLEO: 28 M	2009: 100M, 2012: 0.4 B
Psi''	CLEO: 0.8/fb	2010: 0.9/fb, 2011: 2.6/fb
$\psi(4040)/\psi(4160)$ & scan	CLEO: 0.6/fb @ $\psi(4160)$	2011: 0.4/fb @ $\psi(4040)$ 2013: 0.5/fb (4260), 0.5/fb (4360)
R scan & Tau	BESII	2013: 1.5/fb (4260)



## BESIII observed a charged Charmonium state $Z_c(3900)$



- Close to  $M(DD^*)$
- Couples to  $c\bar{c}$
- Has electric charge
- At least 4-quarks
- What is its nature?



arXiv:1303.5949

BESIII will continue for the next 8-10 years

- S-wave Breit-Wigner with efficiency correction
- Mass =  $(3899.0 \pm 3.6 \pm 4.9)$  MeV
- Width =  $(46 \pm 10 \pm 20)$  MeV
- Fraction =  $(21.5 \pm 3.3 \pm 7.5)\%$

By collecting a lot of data, we may understand the nature of  $Y(4260)$ ,  $Z_c$  and probably, many XYZ particles with the help of LQCD





# BESIII Collaboration

326 members, 48 Institutes, 10 Countries



**274 members, 29 Institutes**



**5 members, 1 Institutes**



**8 members, 3 Institutes**



**4 members, 1 Institutes**



**9 members, 2 Institutes**



**11 members, 4 Institutes**



**3 members, 1 Institutes**



**1 members, 1 Institutes**



**1 members, 1 Institutes**

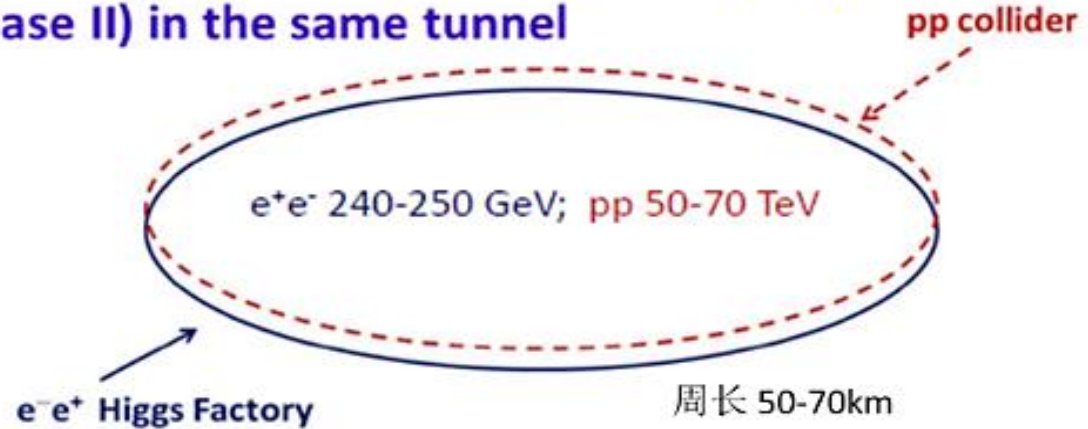


**10 members, 6 Institutes**

# Future



- Super tau-charm factory
  - B factory
  - Z factory
  - Higgs factory → upgradable to pp(AA, ep,eA)
- Circular Higgs factory (phase I) + super pp collider (phase II) in the same tunnel

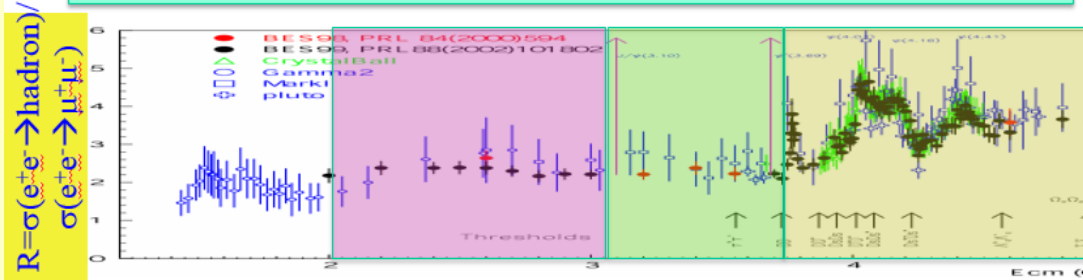


- Energy frontier
  - LHC: ~ 1% participation
  - ILC: hopefully (5-10)% participation if any

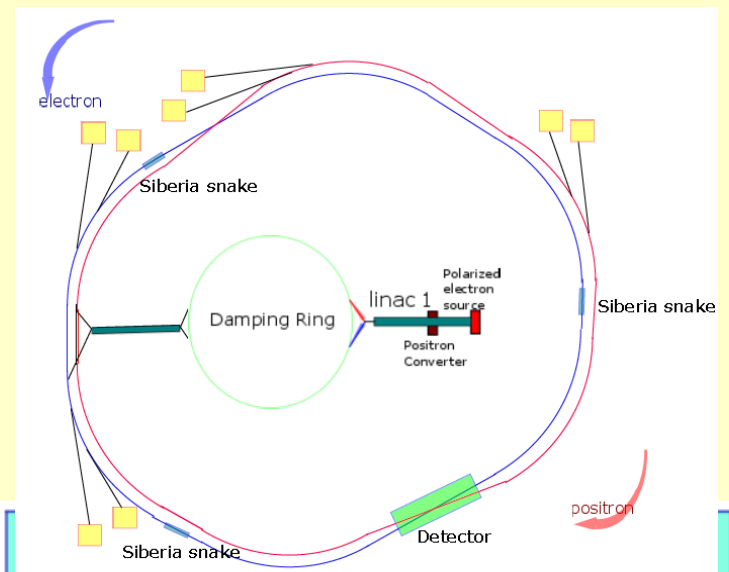
# Super tau/charm Factories

- BINP: VEPP → STCF; from early time
- INFN: DAΦNE → [SuperB → STCF (2013)]
- China: BEPC I/II → STCF (recently)

- $\tau$  production/decay properties (at  $\sim$ threshold)  
Beam polarization has important role
- $D^0, D^+, D_s^+$  decays: rare & precise measurements  
 $\sim$ threshold:  $D_{(s)}\bar{D}_{(s)}$  production in  $1^{--}$  state
- Charmonium(-like) resonance  
hadron spectroscopy & physics



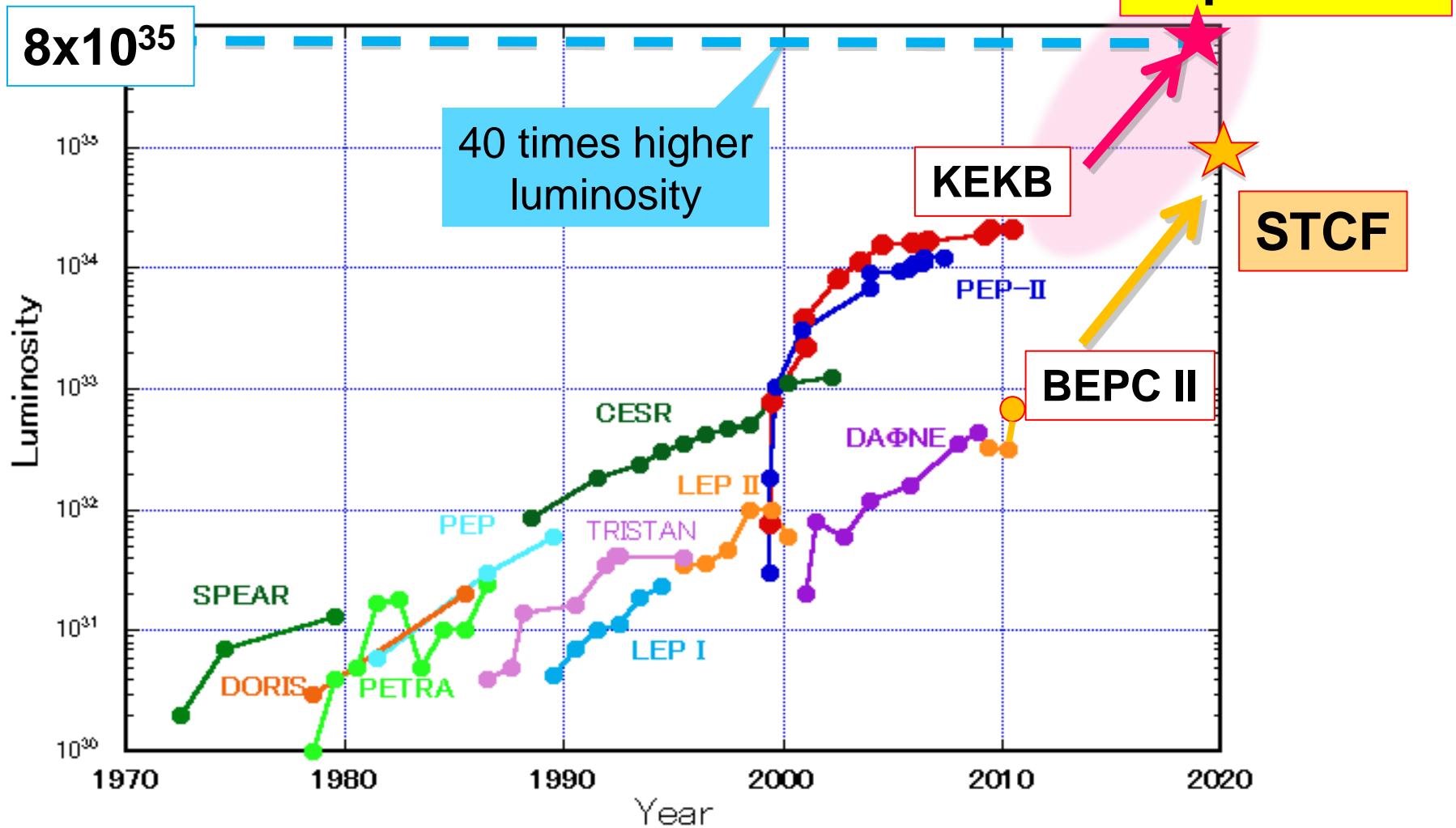
## STCF: Machine Parameters



Beam Energy, GeV	1.0-3.5
Circumference, m	992.8
Number of bunches	540
Bunch Current, mA	5
Beam Current, A	2.7
Emittance Horiz, nm	10
Emittance Vert, nm	0.05
Bunch length, mm	10
beta x (IP), cm	100
beta y (IP), cm	0.1
RF frequency, MHz	500.06
Luminosity, $\text{cm}^{-2}\text{s}^{-1}$	$1.05 \times 10^{35}$

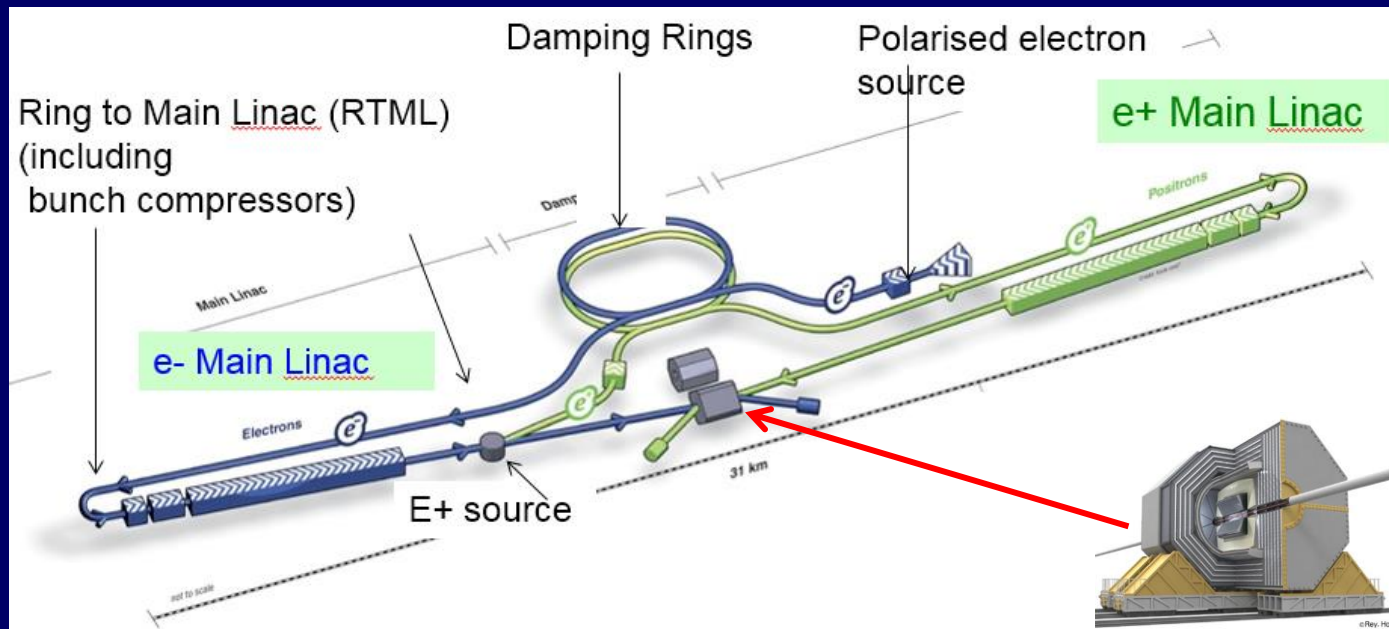
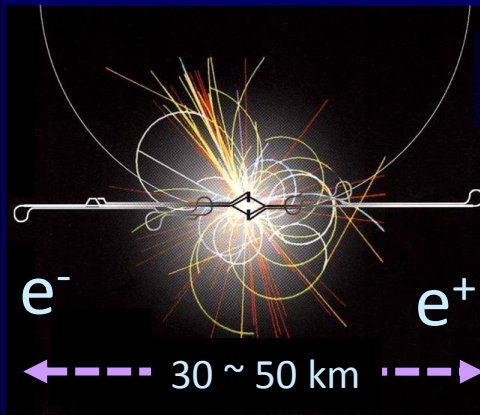
# Super Flavor machines

Peak Luminosity Trends ( $e^+e^-$  collider)



# ILC : Next Energy Frontier Project

## International Linear Collider

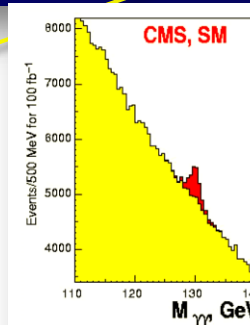
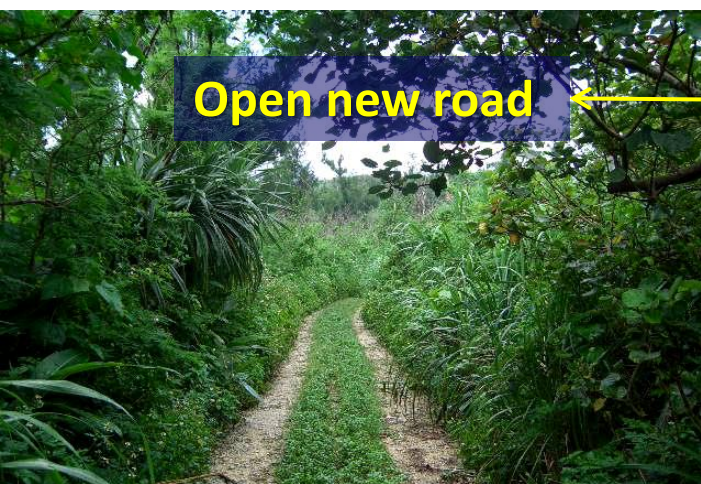
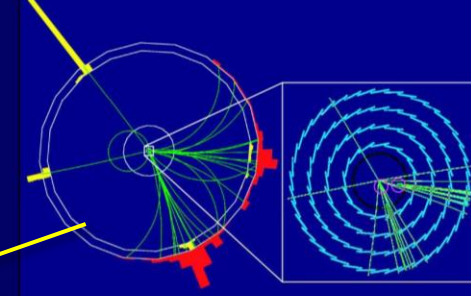
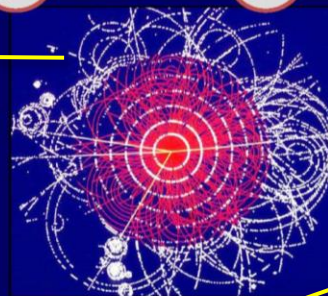
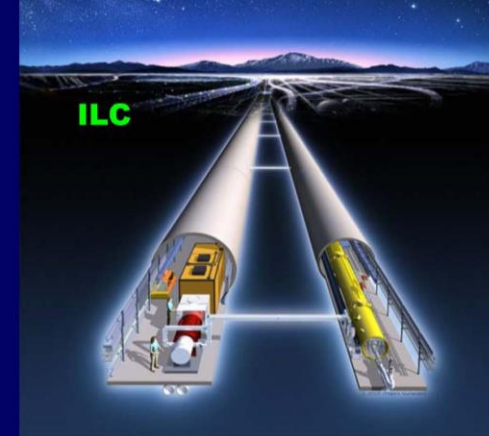
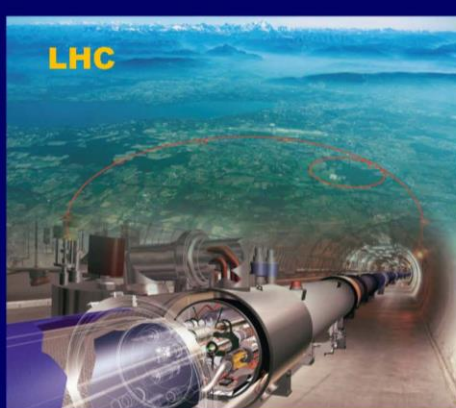


# Why the ILC ?

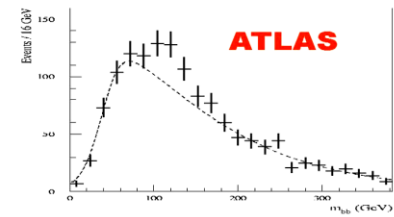
Proton First, Electron Next !

⋮

Standard Strategy of HEP

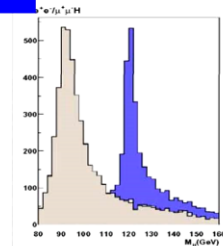
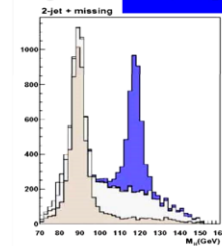
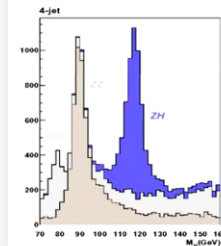


LHC



## Higgs Particle Study

ILC





# ILC Time Line



## 1980' ~ Basic Study

2005 2006 2007 2008 2009 2010 2011 2012 2013

2004



ILC-GDE

LCC

Ref. Design (RDR)

Tech. Design : TDP1



TDR

TDP 2

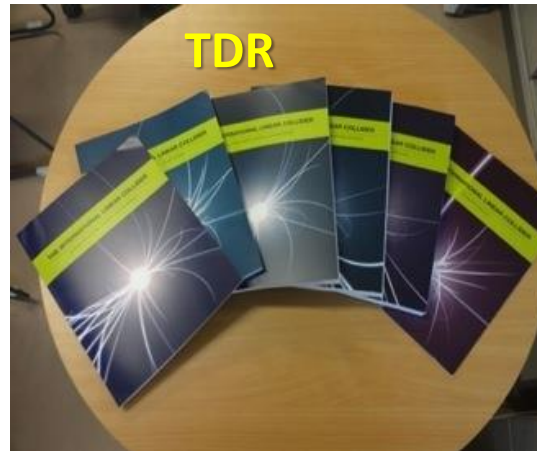
completion



International Technology Recommendations Panel Meeting  
August 11 - 13, 2004, Wuzhiky of Korea



COLLIDER TECHNOLOGY CHEP CONFERENCE 2004 BEIJING



TDR



2013.6.12



2012.12.15

Selection of SC Technology

# ILC - A GLOBAL PROJECT

**TTF/FLASH** (DESY) ~1 GeV  
ILC-like beam ILC RF unit



DESY#



INFN#Frasca\*#



**DAΦNE** (INFN Frascati)  
kicker development  
electron cloud

**STF** (KEK) operation/construction  
ILC-like Cryomodule test: S1-Gloabal  
SRF beam acceleration : QB, STF2



KEK,#apan#



**ATF#&#ATF2#**(KEK)  
ultra-low emittance  
Final Focus optics, nano-beam  
**KEKB** electron-cloud



**CesrTA** (Cornell)  
electron cloud  
low emittance

Cornell#

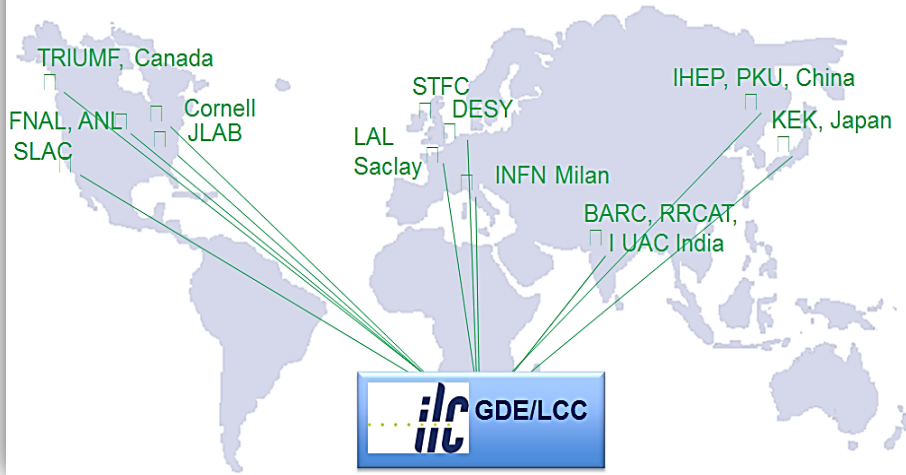
FNAL#



**NML/ASTA#facility**  
ILC RF unit test  
Full-CM Test,  
SRF beam acceleration, soon

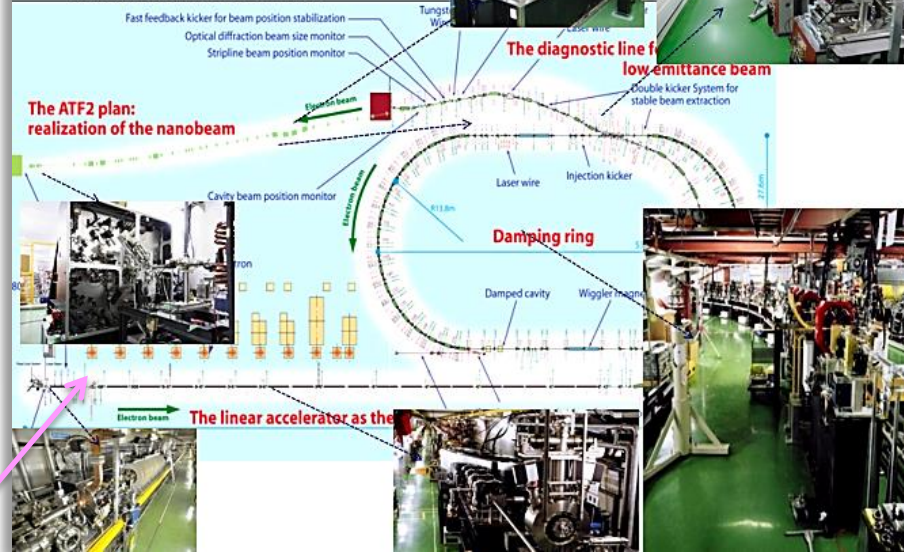


# ILC R&D: Global Collaboration



## ATF: Accelerator Test Facility for ILC

- Generate Low Emittance Beams
- Handle Nano-Size Beams



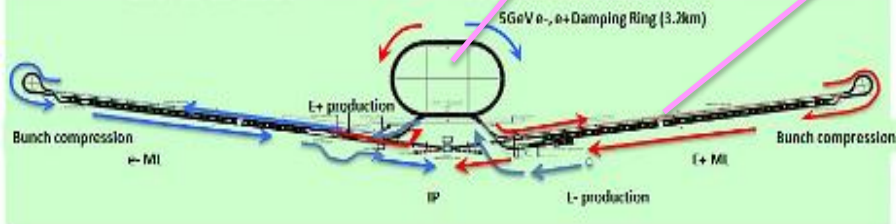
## Requirements from Physics Exp.

### Basic requirements:

- Luminosity :  $\int L dt = 500 \text{ fb}^{-1}$  in 4 years
- $E_{cm}$  : 200 – 500 GeV and the ability to scan
- E stability and precision: < 0.1%
- Electron polarization: > 80%

### Extension capability:

- Energy upgrade: 500 → 1.000 GeV



## S1-Global hosted at KEK: Global cooperation to demonstrate SCRF system



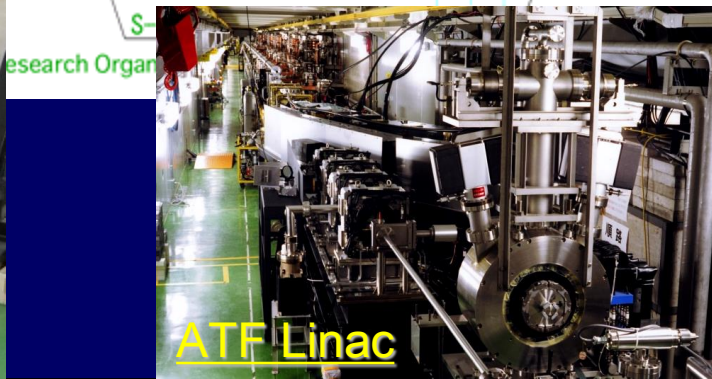
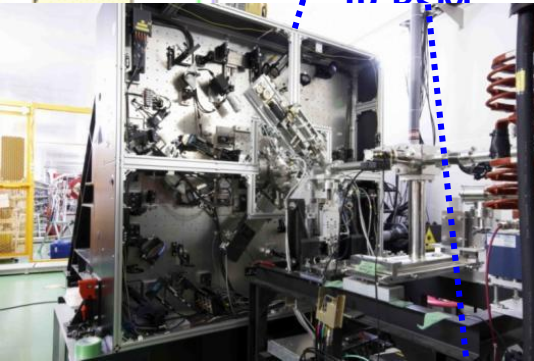
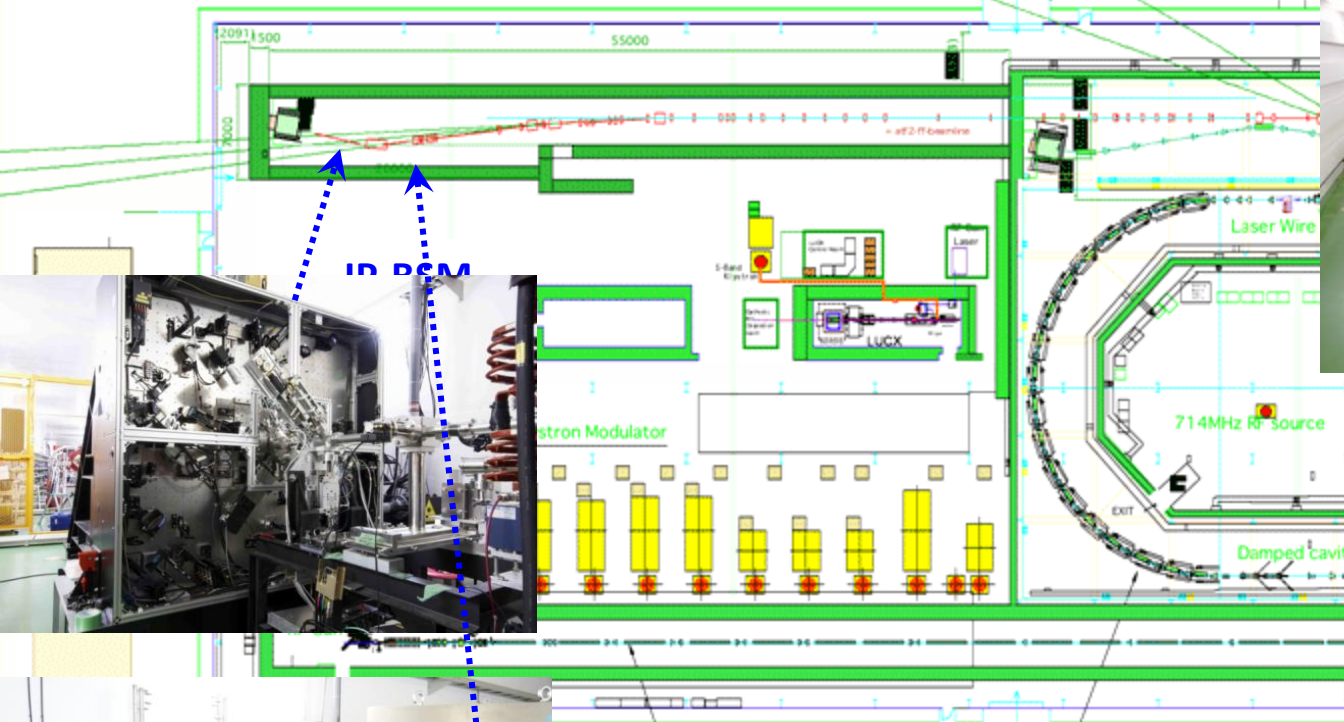
Successful global cooperation hosted by KEK with variety of cavity design

# ATF : Accelerator Test Facility

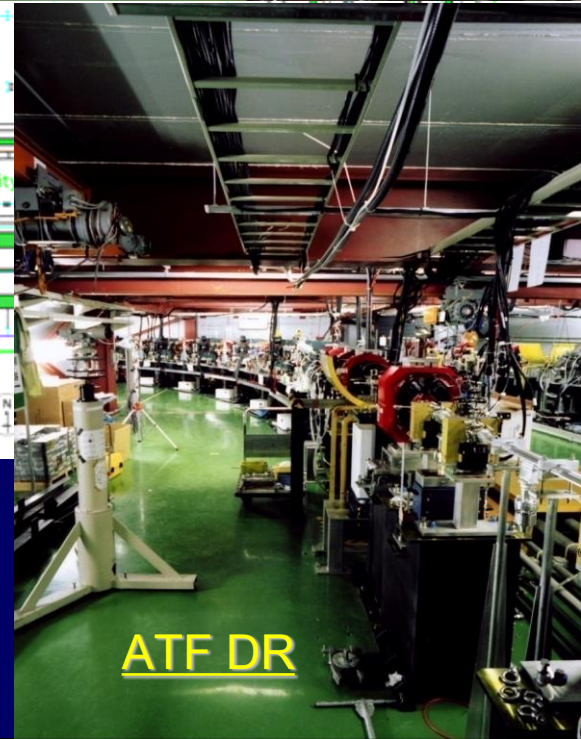
- Generate Low Emittance Beams
- Handle Nano-Size Beams

**ATF2: Realization of the nanobeam  
(beam commissioning : October 2008)**

**Diagnostic line for  
the extracted low emittance beam**



**ATF Linac**



**ATF DR**

# Recent progress of KEK-ATF

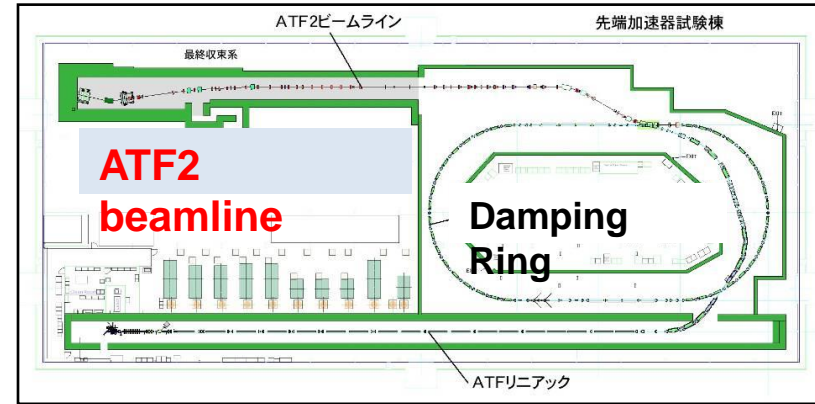
## ATF2: Final focus Test beamline

Goal-1: Develop final focus system for ILC

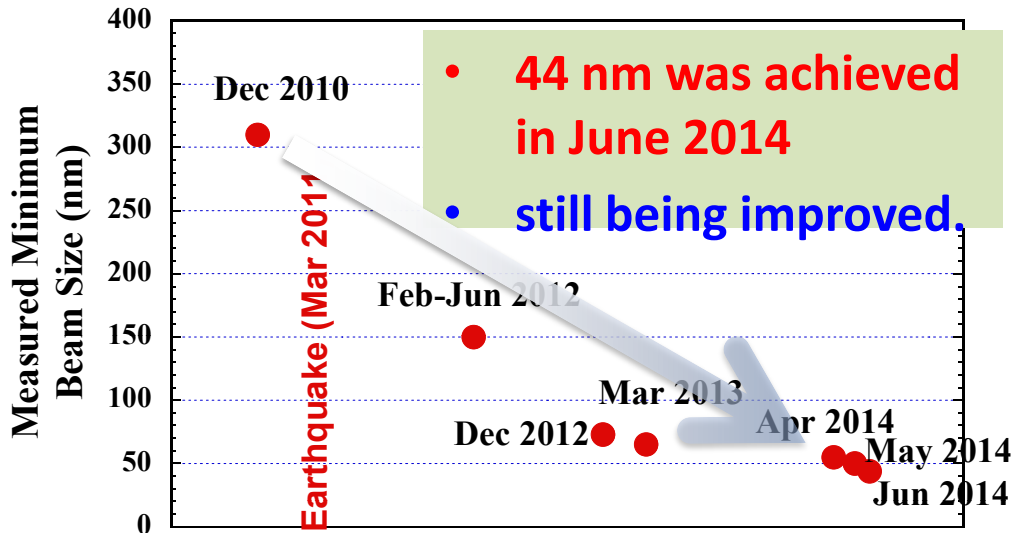
→ 37 nm vertical beam size at IP

Goal-2: Develop beam position stabilization in a few nm

→ Study of Intra-train feedback has been started.



## History of measured minimum beam size



Presented by K.Kubo at IPAC2014

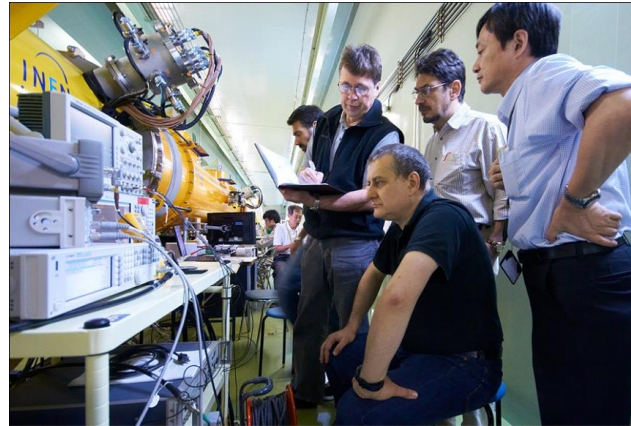
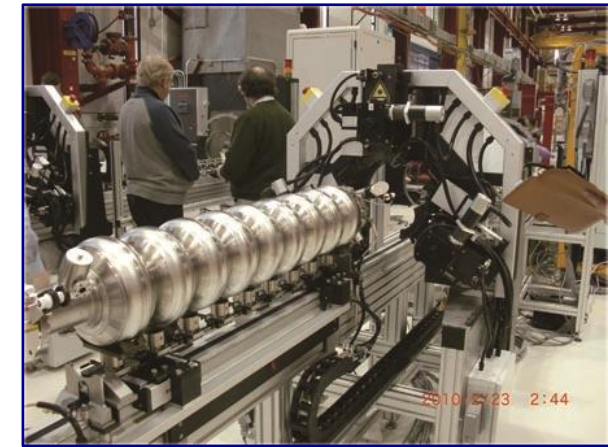
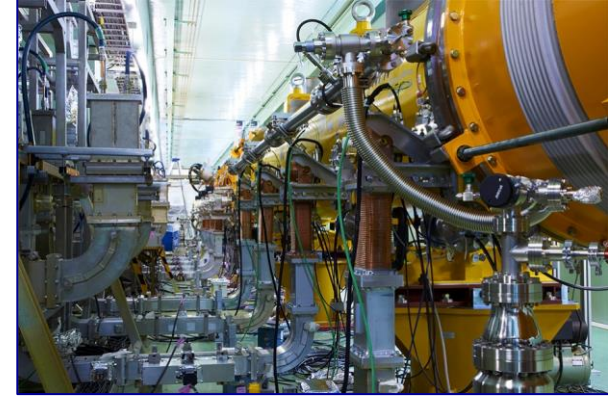
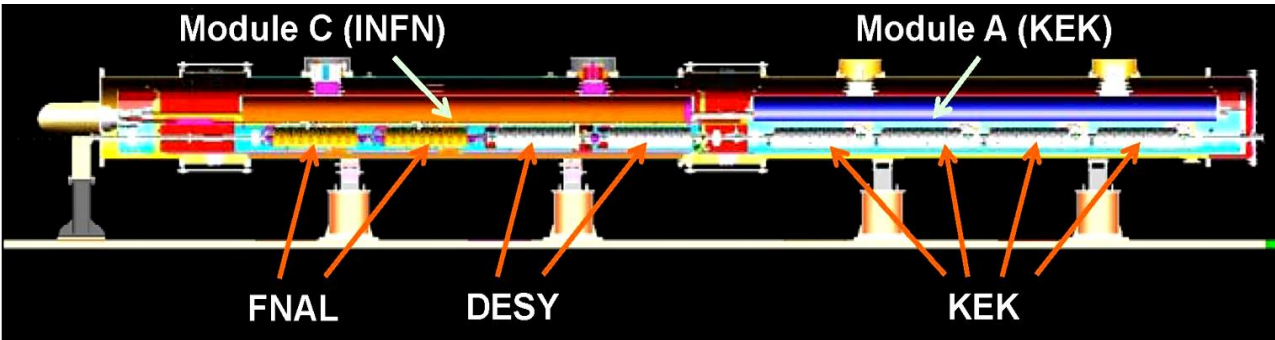
	FY2014	FY2015	FY2016	FY2017	FY2018
Goal-1	Achievement of the 37 nm beam size and establishment of the final focus system				
	Study of the Wake field mitigation				
	KEK-CERN collaboration: beam studies toward 20 nm				
Goal-2	Studies of the beam position stabilization in a few nanometers				
	Grand Motion Studies (with beam feedback)				
	Other R&Ds (High intensity Comptons, Beam monitors, Fast Kicker,...)				

# Superconducting Test Facility (STF)

## The first step of ILC

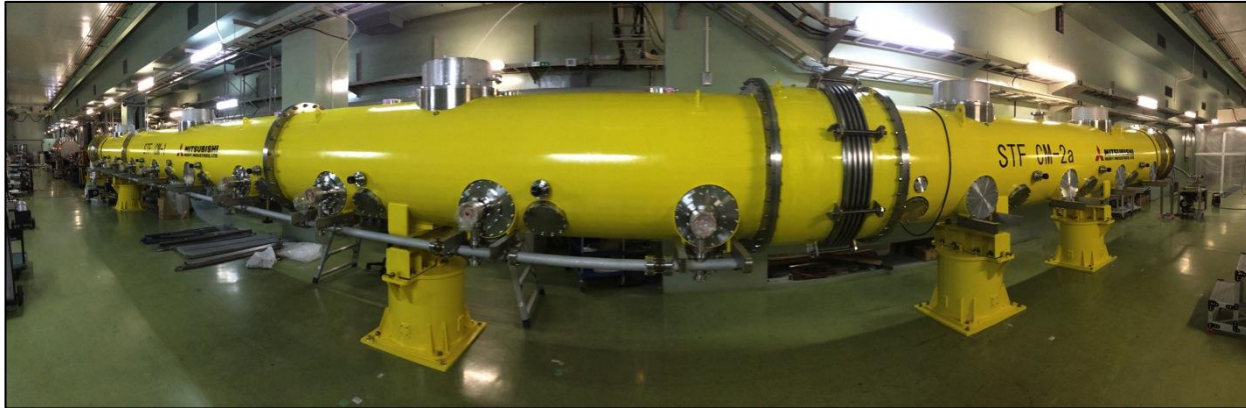
2009 ~ 2011.2.25

S1-Global



**Plug compatibility of SCRF system was successfully demonstrated by international collaboration.**

# ILC STF Accelerator under construction



**CM-1 cavities: Average Gradient 36MV/m before installation**

*STF Accelerator parameters*

*Beam Energy : 418MeV*

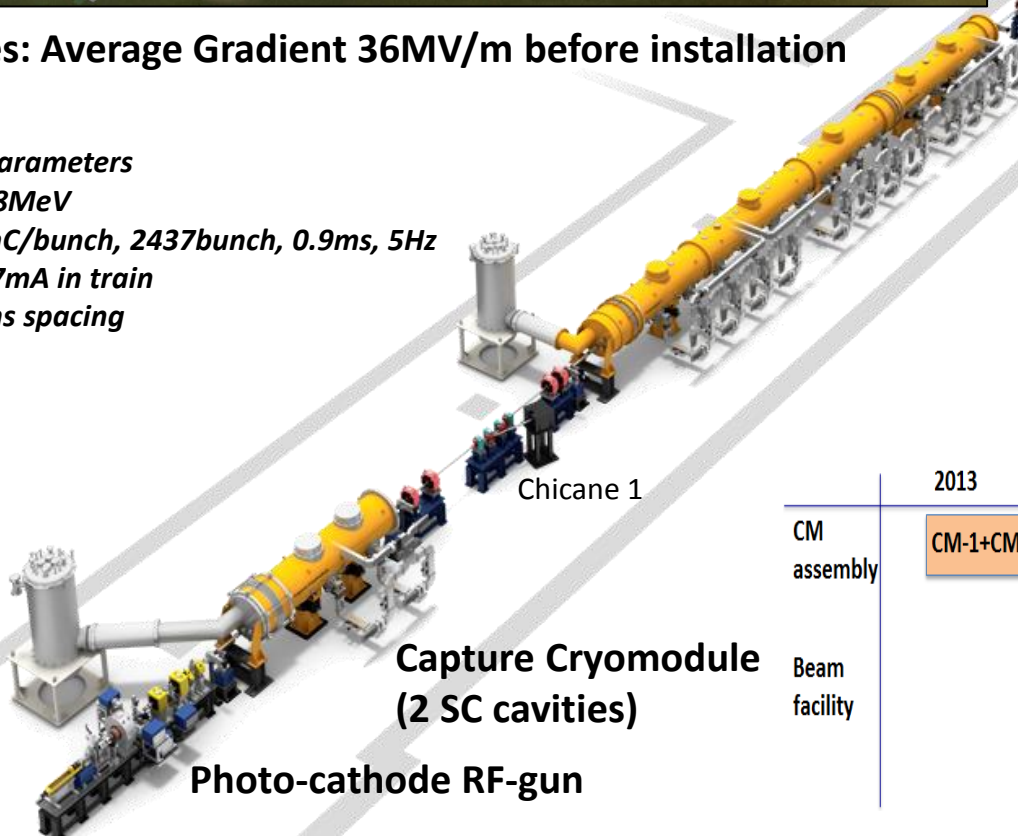
*Beam Charge : 2nC/bunch, 2437bunch, 0.9ms, 5Hz*

*Beam current: 5.7mA in train*

*Bunch train: 369ns spacing*



**ILC-type Cryomodule (CM-1)  
(8 SC cavities + SC-quad/BPM)  
+  
half-size Cryomodule (CM-2a)  
(4 SC cavities)**



Plan of STF Start-up schedule

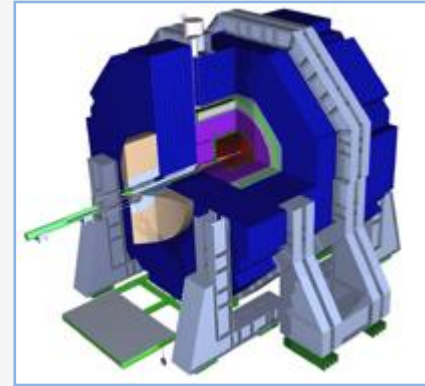
	2013	2014	2015	2016
CM assembly	CM-1+CM-2a assembly			
Beam facility		Cool-down test	Beam-line Installation	Beam commissioning

## 2 Detector Concepts: **Detailed Baseline Design**

ILD



SiD



- **Large R** with TPC tracker

- 32 countries,
- 151 institutions,
- ~700 members

– **B=3.5T**, TPC+Si trackers, ECal (R=1.8m)

- **High B** with Si strip tracker

- 18 countries,
- 77 institutions,
- ~240 members

– **B=5T**, Si only tracker, Ecal(R=1.27m)

- **Basic requirements:**

- $E_{cm}$  :
- Luminosity :
- E stability and precision:

**200 – 500 GeV, and the ability to scan**

$\int L dt = 500 \text{ fb}^{-1}$  in 4 years

< 0.1%

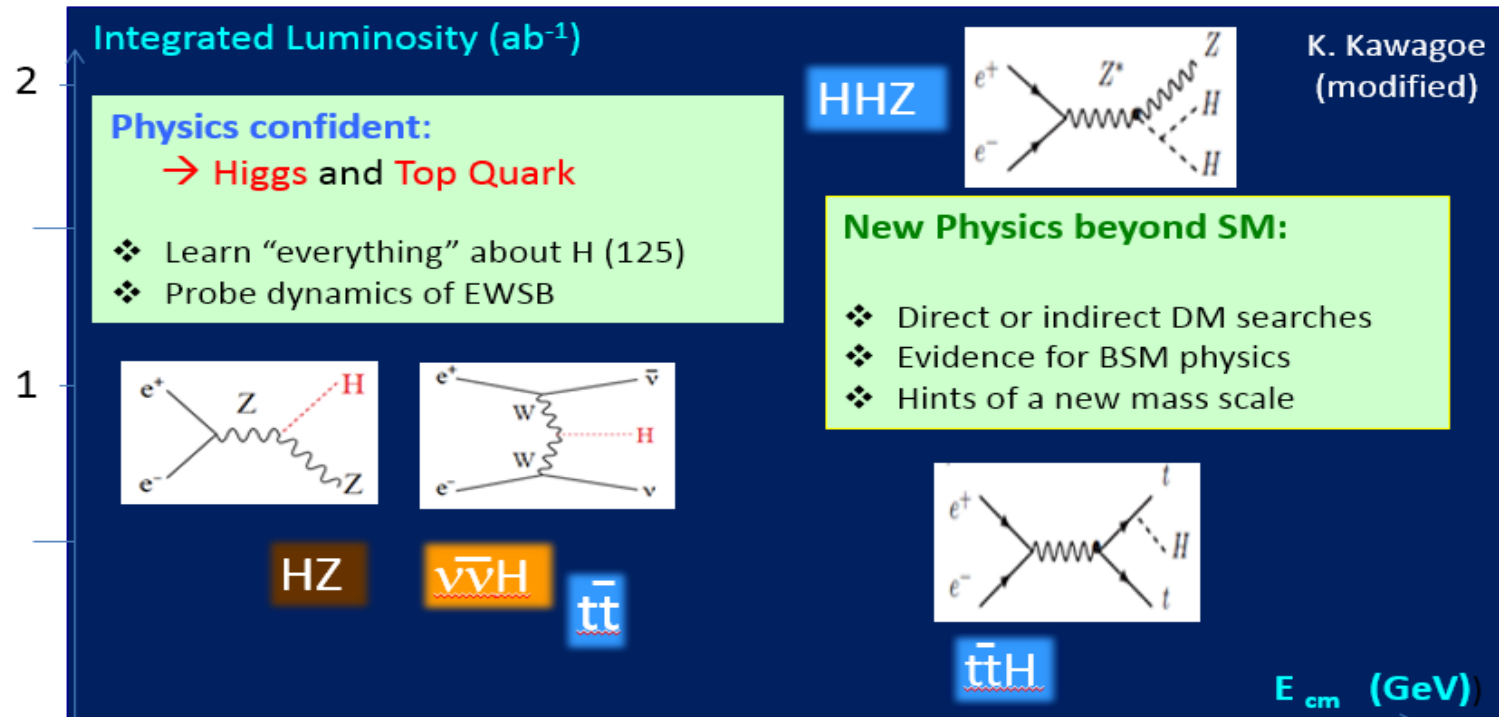
- **Extend-ability:**

- Energy upgrade:

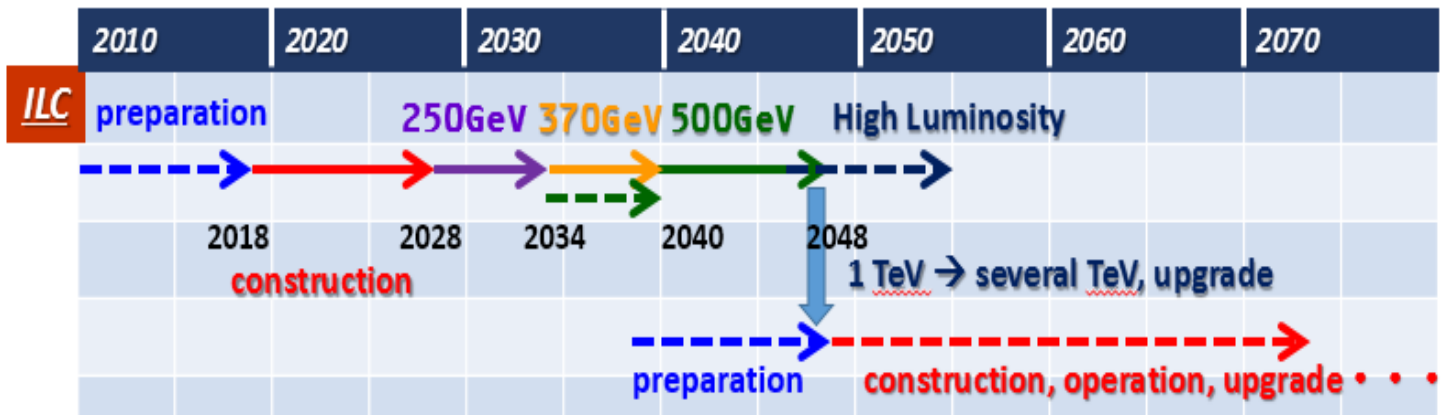
**500  $\rightarrow$  1,000 GeV**

# Important Energies in ILC

❖ Discovery of a **125 GeV Higgs** has reinforced the importance of the ILC



K. Kawagoe (modified)



# Messages from World HEP Communities

8 March 2013

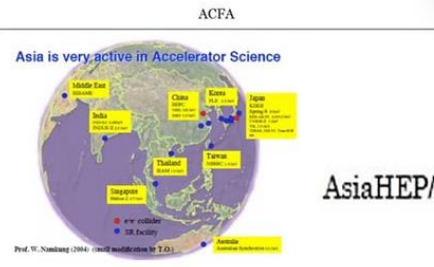
ORGANISATION EUROPEENNE POUR LA RECHERCHE NUCLEAIRE  
**CERN** EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

There is a strong scientific case for an electron-positron collider, complementary to the LHC. . . . . The TDR of the ILC has been completed, with large European participation. The initiative from the Japanese particle physics community to host the ILC in Japan is most welcome, and European groups are eager to participate. *Europe looks forward to a proposal from Japan to discuss a possible participation.*

There is a strong scientific case for an electron-positron collider, complementary to the LHC, that can study the properties of the Higgs boson and other particles with unprecedented precision and whose energy can be upgraded. The Technical Design Report of the International Linear Collider (ILC) has been completed, with large European participation. The initiative from the Japanese particle physics community to host the ILC in Japan is most welcome, and European groups are eager to participate. *Europe looks forward to a proposal from Japan to discuss a possible participation.*



- Home
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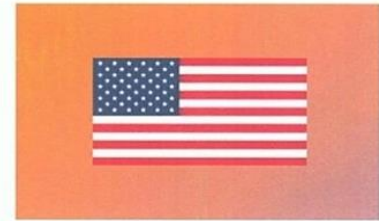
## AsiaHEP/ACFA Statement on the ILC (draft)

**AsiaHEP/ACFA welcomes the proposal by the Japanese HEP community for the ILC to be hosted in Japan. AsiaHEP/ACFA looks forward to a proposal from the Japanese Government to initiate the ILC project.**

**In China, the community has reached a consensus during the so called Fragrant Hill meeting in June 2013, that ILC should be strongly supported and that requests to funding agencies should be started soon.**

## HEPAP Facilities Subpanel: Report on Energy Frontier Facilities

S. Dawson, BNL  
 March 11, 2013



## US Participation in Japanese Hosted ILC

- Science drives the need for e<sup>+</sup>e<sup>-</sup> collider
  - ILC addresses absolutely central physics questions and is complementary to the LHC
  - Japanese hosted ILC could be under construction before 2024
- Parameters of a potential US contribution are not known and depend on international agreements
  - The US has made substantial contributions to detector and accelerator development through the global effort
  - Should an agreement be reached, the US particle physics community would be eager to participate in both the accelerator and detector construction

We need an agreement at diplomatic levels

S. Dawson

22



# ILC Site Candidate Location in Japan: Kitakami Area

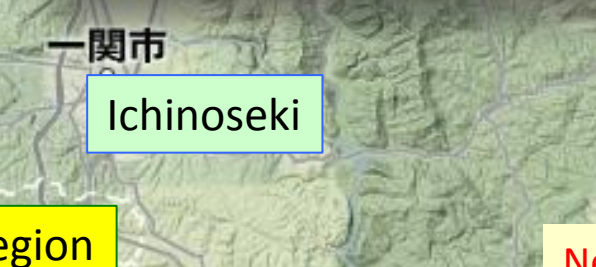
「世界でただ1つの未来の加速器」を楽しいマンガで紹介!

## 宇宙をつくる加速器 [国際リニアコライダー] がやってくる!?

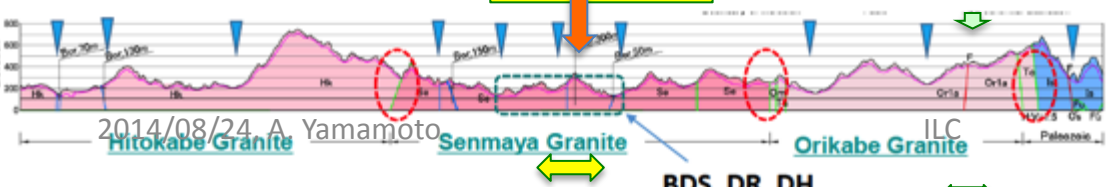
企画 大学共同利用機関法人 高エネルギー加速器研究機構  
監修 村山 清 (リコファルニアスパーケイ教授、東北大学リニア加速器研究センター長、国際リニアコライダー・コンソーシアム(国際リニアコライダー))  
制作 うるのクリエイティブ事務所



Community  
Local Government



IP Region



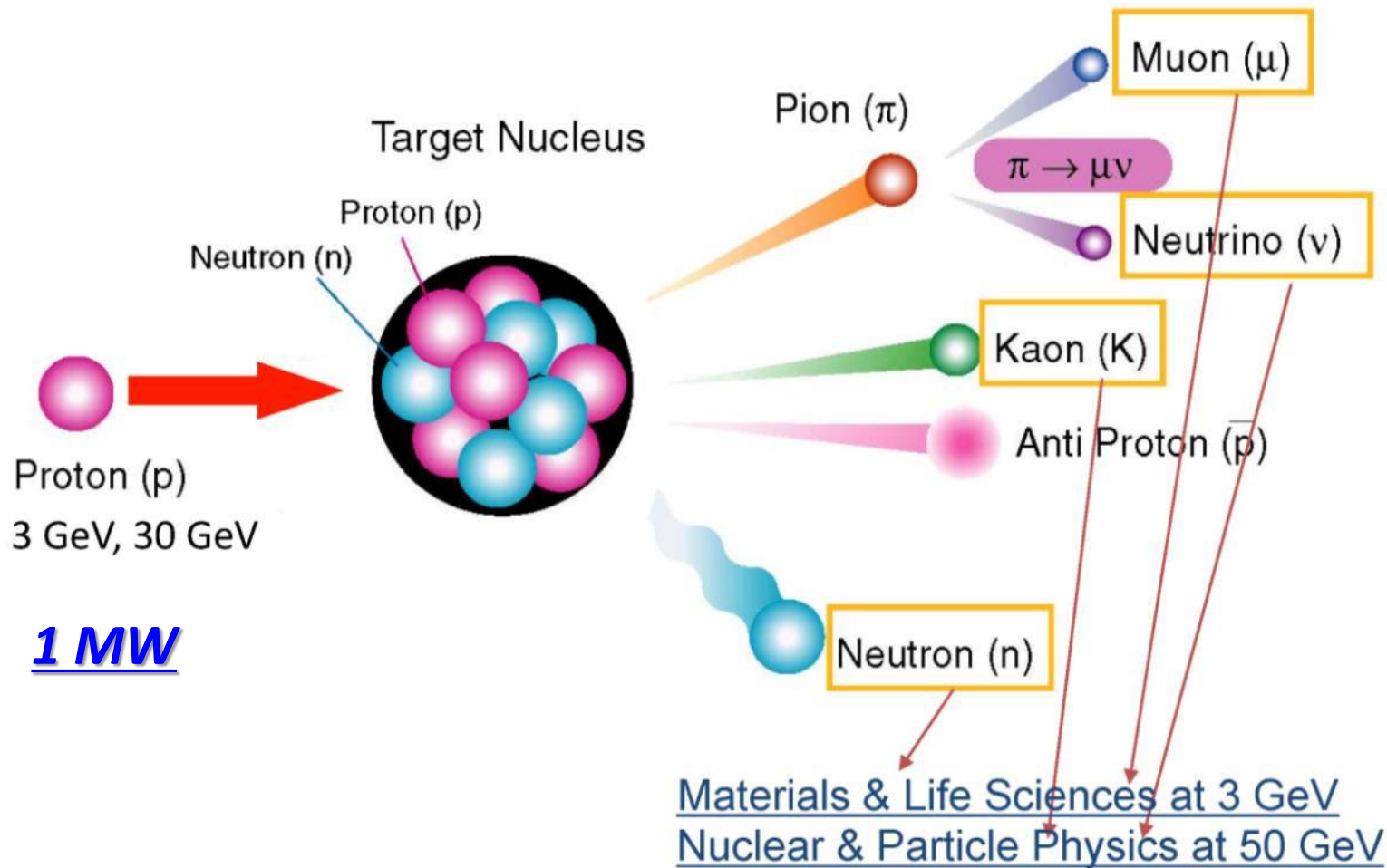
Need to finalize:

- IP / Linac orientation and length
- Access points and IR infrastructure
- Conventional Facilities and Siting (CFS)
- ...

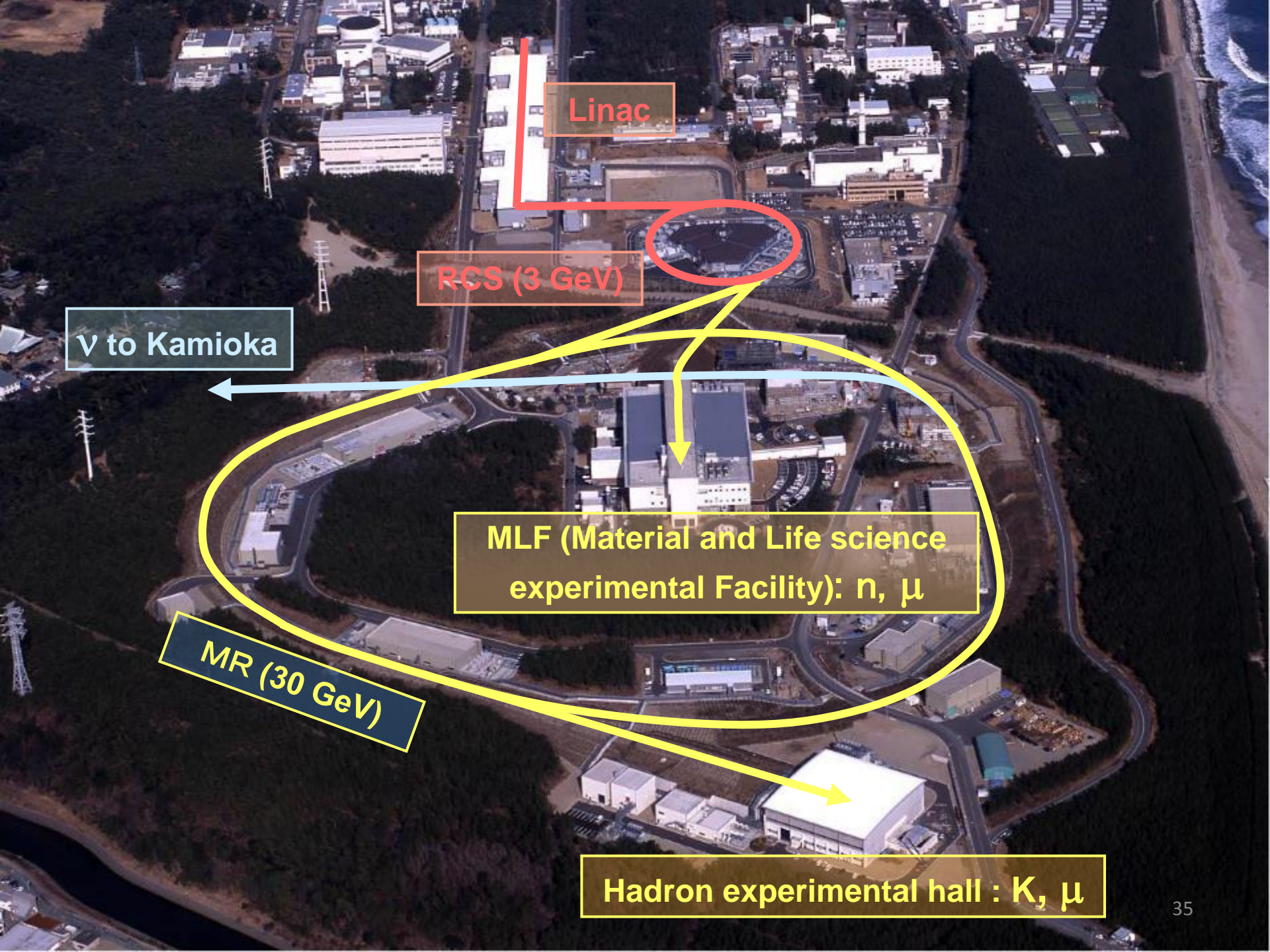
## 2. Proton Accelerator Research Complex: J-PARC

Joint Project between KEK and JAEA

J-PARC = Japan Proton Accelerator Research Complex



Luminosity Frontier Accelerator



Linac

RCS (3 GeV)

$\nu$  to Kamioka

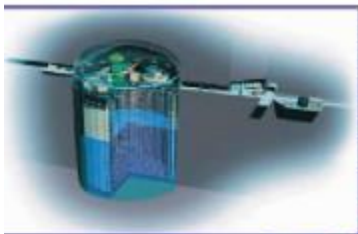
MLF (Material and Life science  
experimental Facility):  $n, \mu$

MR (30 GeV)

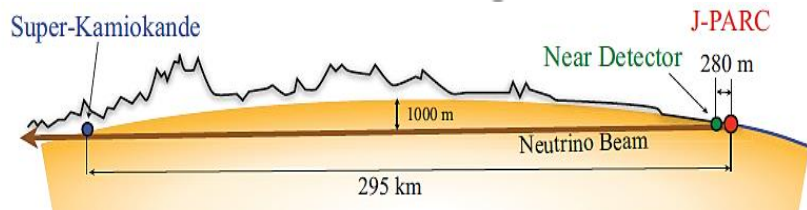
Hadron experimental hall :  $K, \mu$

# T2K Experiment

# Long-Baseline Neutrino Experiment



Super-Kamiokande  
(ICRR, Univ. Tokyo)



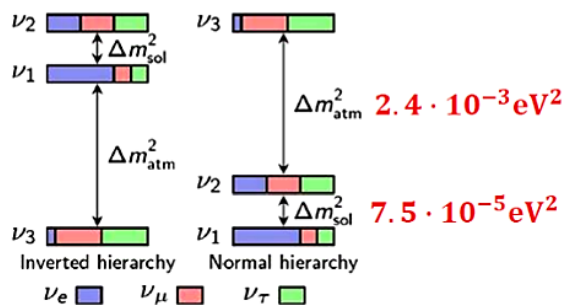
J-PARC Main Ring  
(KEK-JAEA, Tokai)



## Neutrino Oscillation

In a 3- $\nu$  framework

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu1} & U_{\mu2} & U_{\mu3} \\ U_{\tau1} & U_{\tau2} & U_{\tau3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$



$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13} \\ 0 & e^{-i\delta} & 0 \\ -s_{13} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} e^{i\rho} & 0 & 0 \\ 0 & e^{i\sigma} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$\theta_{23} \sim 45^\circ$   
Atmospheric  
Accelerator

$\theta_{13} \sim 9^\circ$   
Reactor  
Accelerator

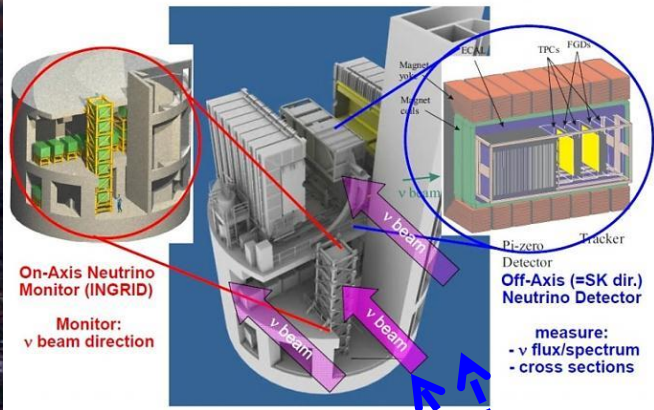
$\theta_{12} \sim 34^\circ$   
Solar  
Reactor

$0\nu\beta\beta$

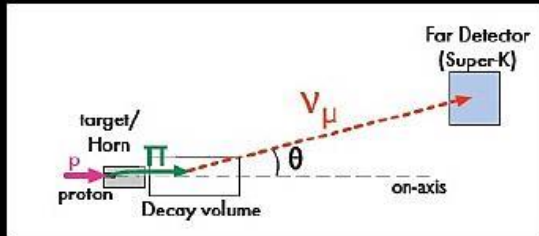
## Accelerator Based Neutrino Experiments

Status of Experiments	US-based	Japan-based	Europe-based
Recently Completed	MINOS MiniBooNE		ICARUS OPERA
Currently Running	ArgoNeuT MINERvA NOvA, MINOS+	T2K	
Approved	MicroBooNE LBNE/LBNF (CD1)		
Proposed		Hyper-Kamiokande	LBNO

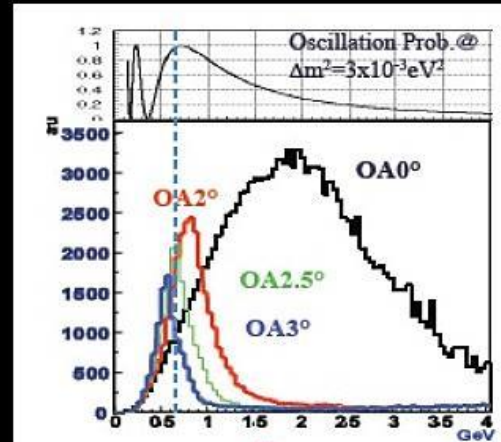
# Near Detector (ND280)



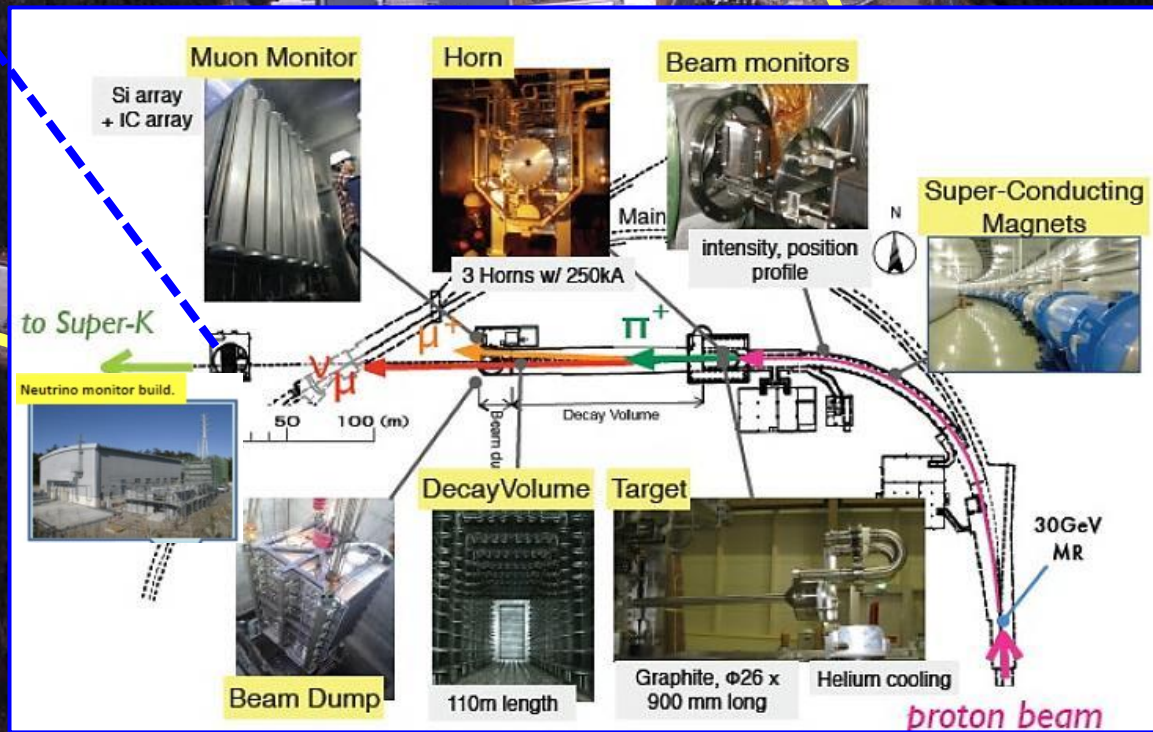
# Off-axis beam: intense & narrow-band beam



Beam energy @ oscillation  
max:  $E_\nu \sim 0.6 \text{ GeV}$



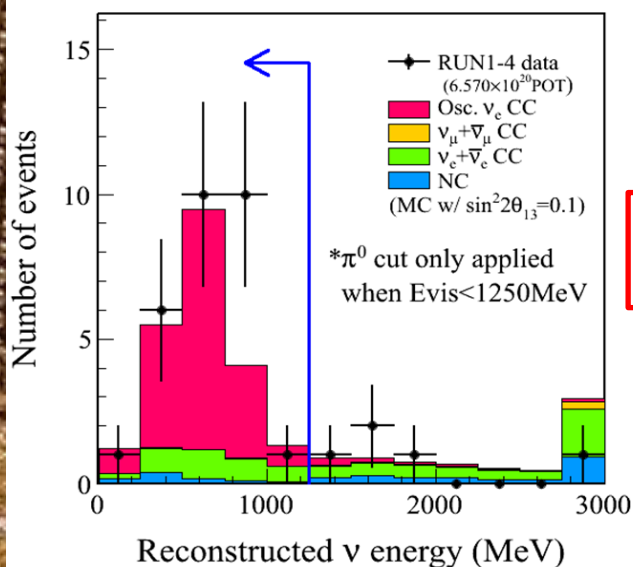
Neutrino Beams  
(to Kamioka)



# $\nu_\mu \rightarrow \nu_e$ Result from T2K



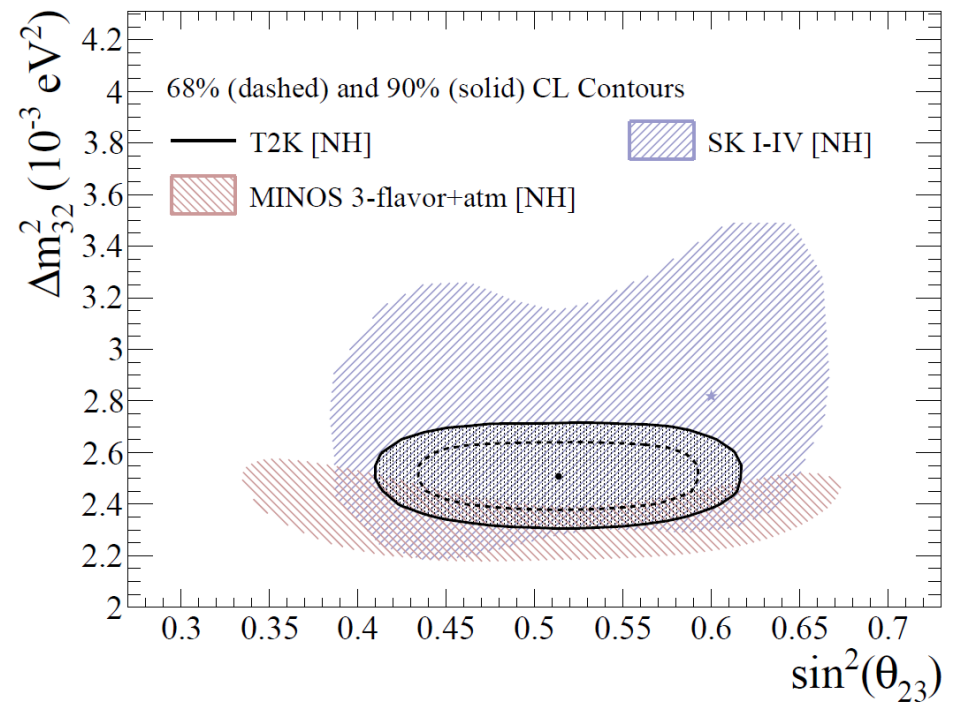
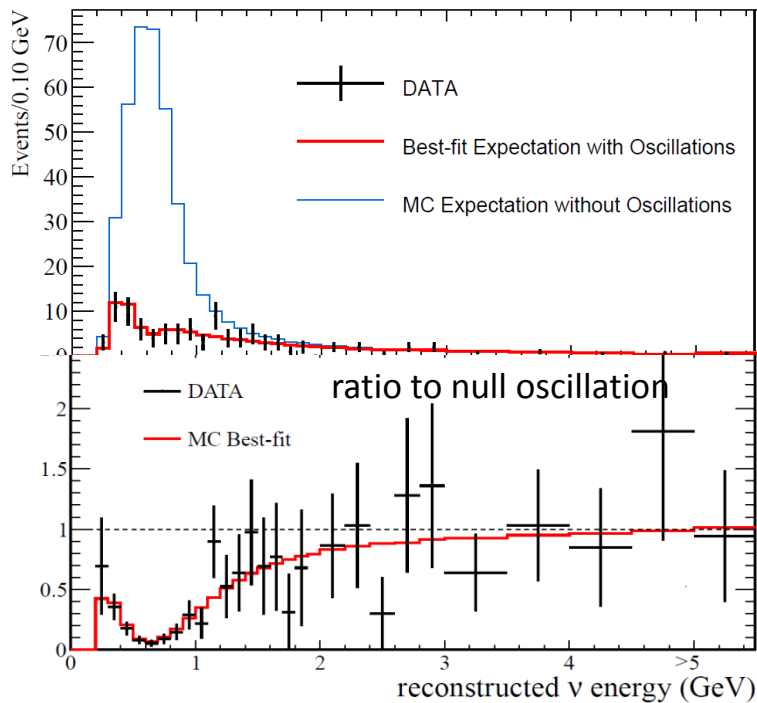
- Stable operation at  $\sim 230\text{kW}$  achieved
- $7.39 \times 10^{20}$  POT by June
  - $> 1.2 \times 10^{14}$  ppp ( $1.5 \times 10^{13} \times 8\text{b}$ ) is the *world record* of extracted protons per pulse for synchrotrons
  - first anti- $\nu$  running in 2014
  - Data :  $6.57 \times 10^{20}$  POT by 2013



- 28  $\nu_e$  candidate events were observed while background expectation is 4.9
- Observation of  $\nu_e$  appearance with  $7.3\sigma$  significance
- Slightly larger than  $\delta_{\text{CP}}=0$  expectation  $\rightarrow$  constraint on  $\delta_{\text{CP}}$

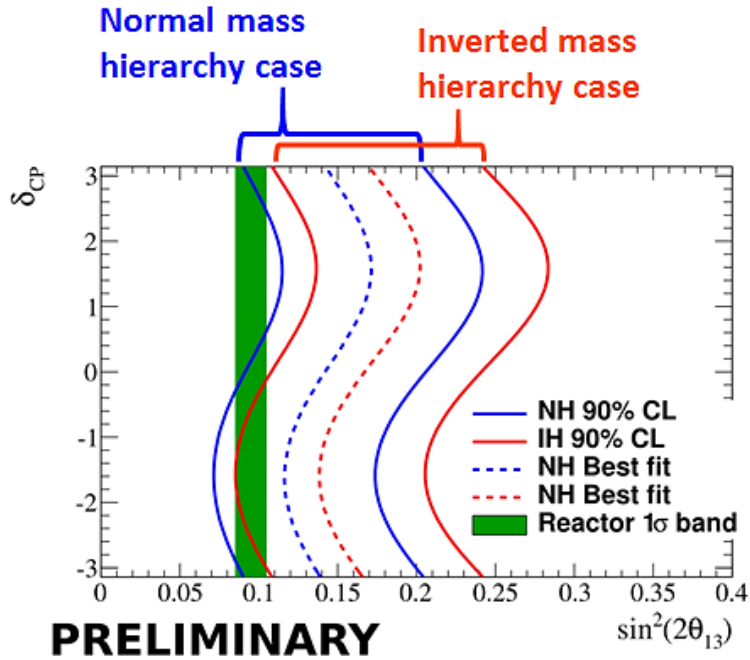
**Definite confirmation of  
ELECTRON NEUTRINO APPEARANCE!!**

# $\nu_\mu$ disappearance measurement



T2K favors maximal mixing of  $\theta_{23}$

# Constraint on $\delta_{CP}$ using $\nu_e$ appearance and $\nu_\mu$ disappearance samples and reactor measurements

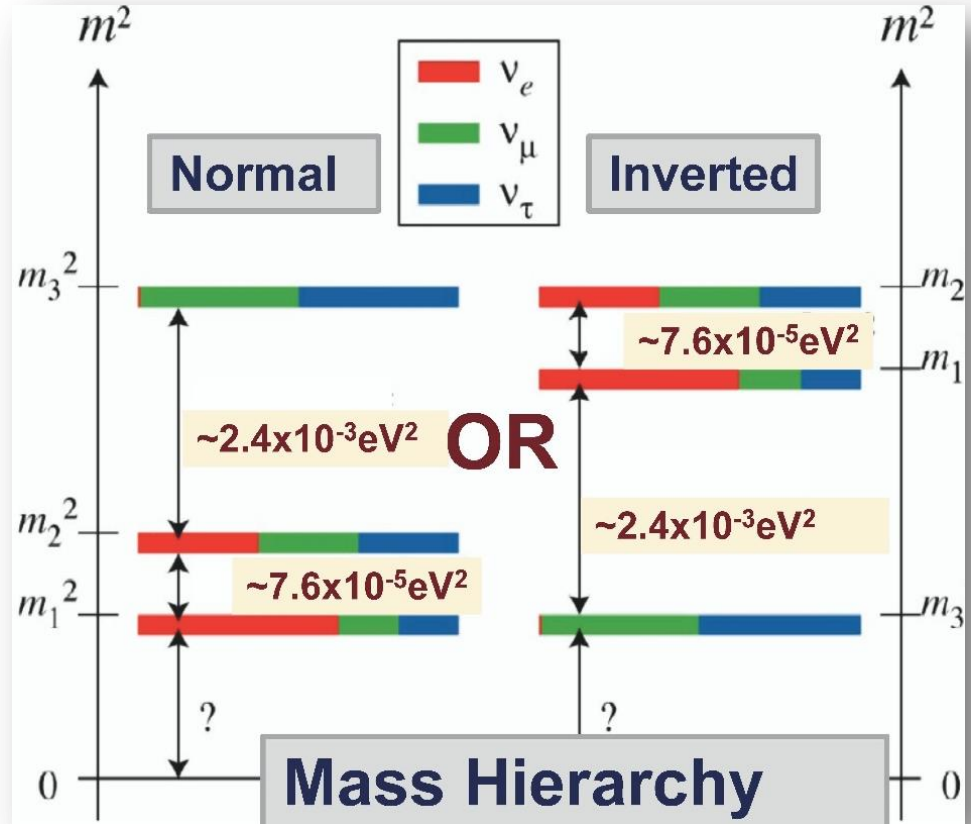


**PRELIMINARY**

Reactor value from PDG2013  
 $\sin^2(2\theta_{13}) = 0.095 \pm 0.01$

(%)	NH	IH	Sum
$\sin^2\theta_{23} \leq 0.5$	18	8	26
$\sin^2\theta_{23} > 0.5$	50	24	74
Sum	68	32	

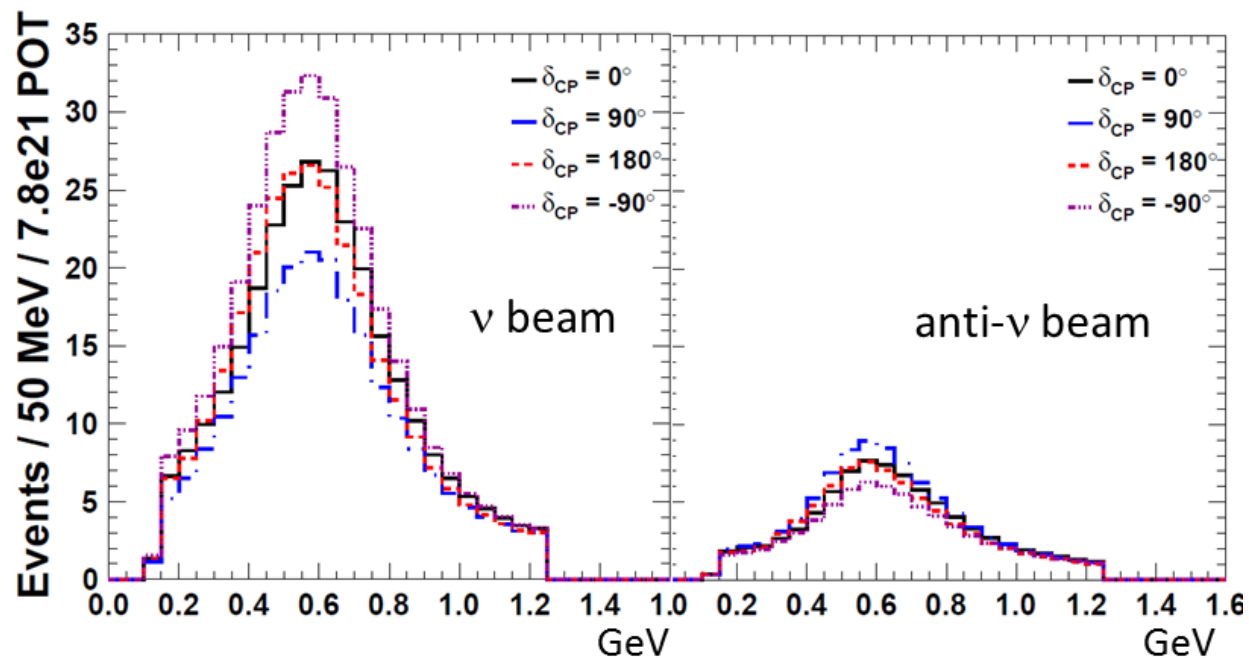
**PRELIMINARY**





- Measure  $\nu_e$  app. for both  $\nu_\mu$  and  $\bar{\nu}_\mu$  beam
- Take asymmetry

$$A_{CP} \equiv \frac{P(\nu_\mu \rightarrow \nu_e) - P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)}{P(\nu_\mu \rightarrow \nu_e) + P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)} \approx \frac{\Delta m_{12}^2 L}{E} \cdot \frac{\sin 2\theta_{12}}{\sin \theta_{13}} \cdot \sin \delta$$



# Sensitivity to CPV

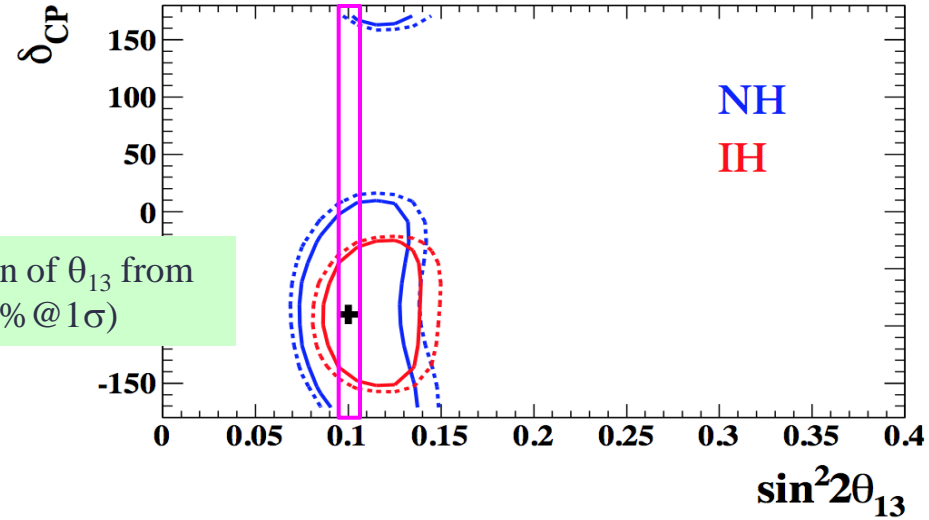
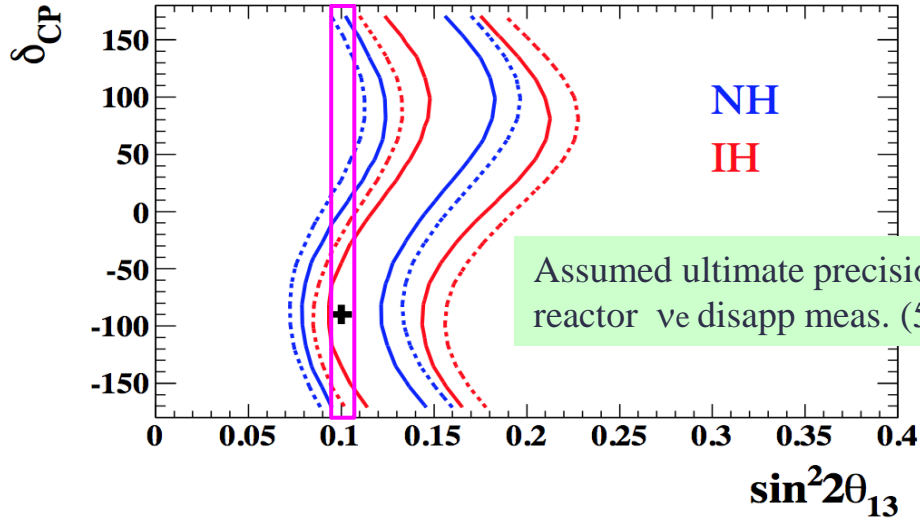
T2K expected results

100%  $\nu$

Solid: stat only

Dashed: T2K current syst

50%  $\nu$  50%  $\bar{\nu}$





## The T2K Collaboration



~ 500 members, 59 Institutes, 12 countries

### Canada

TRIUMF  
U. Alberta  
U. B. Columbia  
U. Regina  
U. Toronto  
U. Victoria  
U. Winnipeg  
York U.

### France

CEA Saclay  
IPN Lyon  
LLR E. Poly.  
LPNHE Paris

### Germany

Aachen U.

### Italy

INFN, U. Bari  
INFN, U. Napoli  
INFN, U. Padova  
INFN, U. Roma

### Japan

ICRR Kamioka  
ICRR RCCN  
KEK  
Kobe U.  
Kyoto U.  
Miyagi U. Edu.  
Osaka City U.  
U. Tokyo

### Poland

IFJ PAN, Cracow  
NCBJ, Warsaw  
U. Silesia, Katowice  
U. Warsaw  
Warsaw U. T.  
Wroclaw U.

### Russia

INR

### S. Korea

Chonnam N. U.  
Dongshin U.  
Seoul N. U.

### Spain

IFAE, Barcelona  
IFIC, Valencia

### Switzerland

ETH Zurich  
U. Bern  
U. Geneva

### United Kingdom

Imperial C. London  
Lancaster U.  
Oxford U.  
Queen Mary U. L.  
STFC/Daresbury  
STFC/RAL  
U. Liverpool

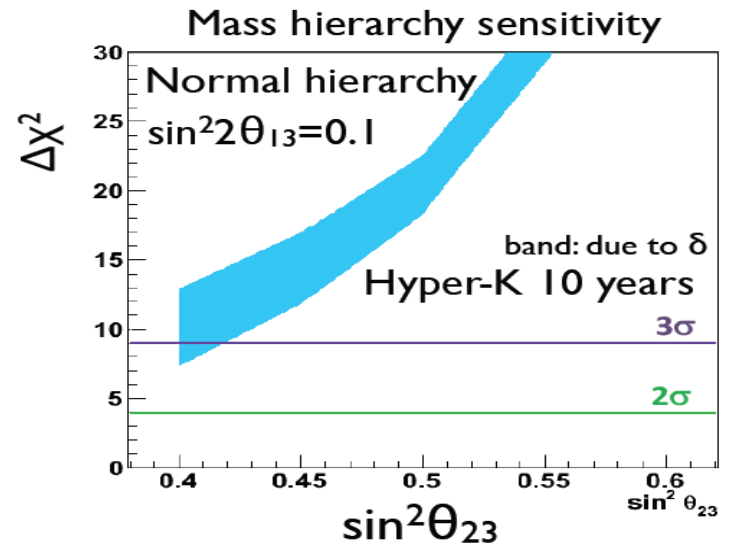
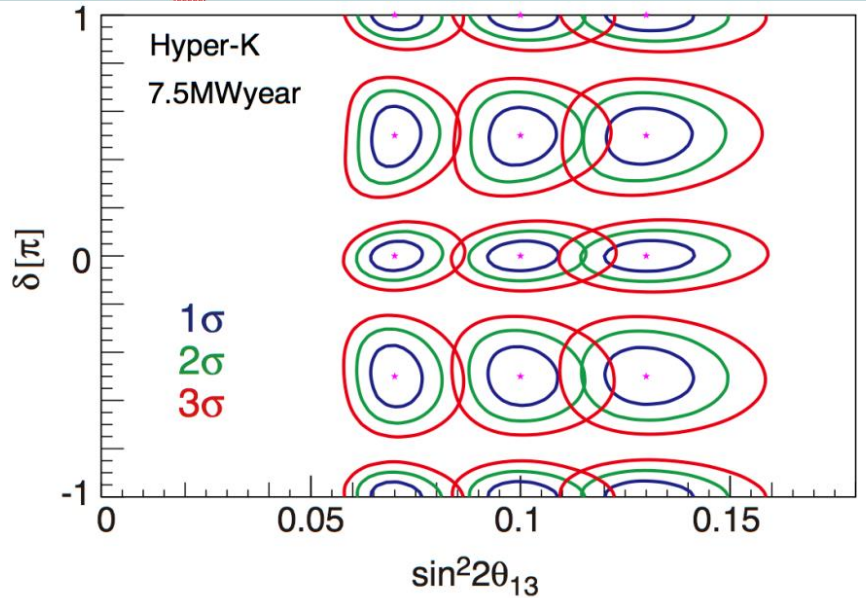
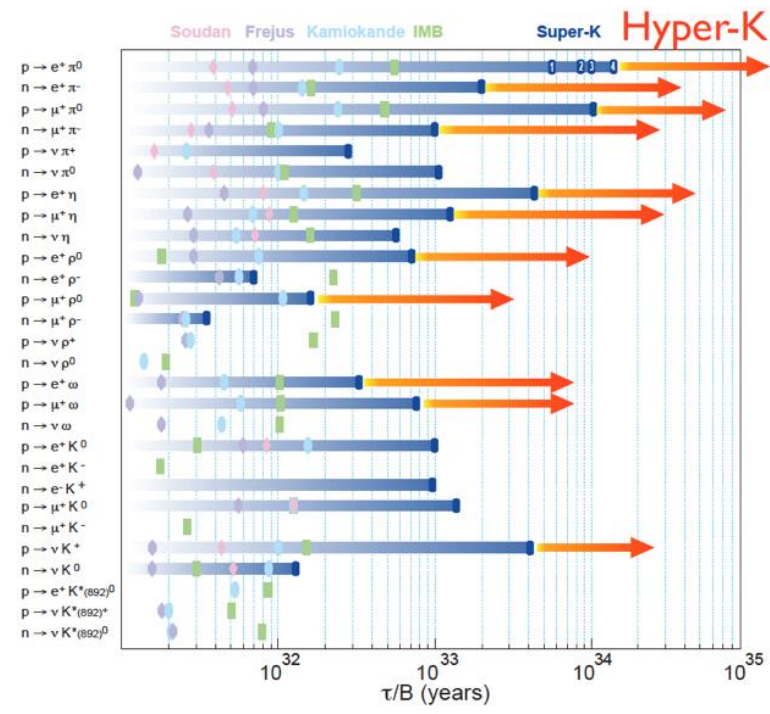
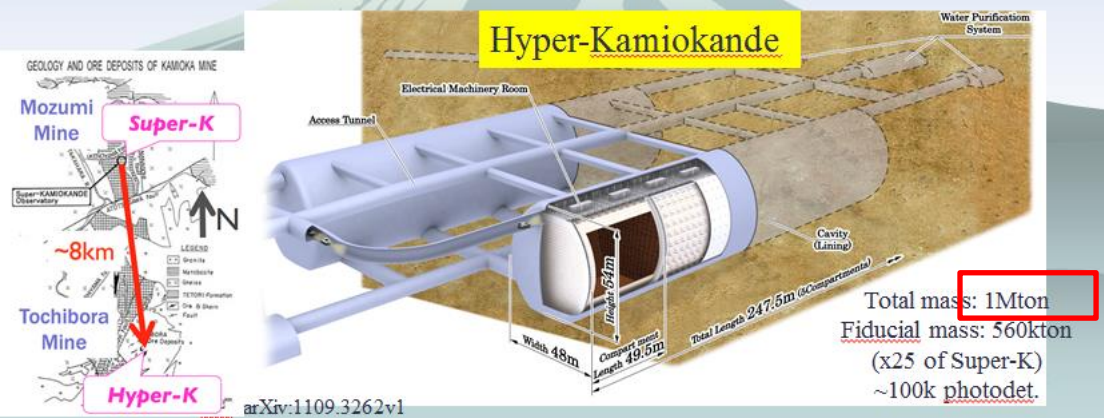
U. Sheffield  
U. Warwick

### USA

Boston U.  
Colorado S. U.  
Duke U.  
Louisiana S. U.  
Stony Brook U.  
U. C. Irvine  
U. Colorado  
U. Pittsburgh  
U. Rochester  
U. Washington

# The next generation LBL experiment w/ HK

- ~1MW (or higher) J-PARC MR + T2K beamline
- New huge detector: 1Mt Water Ch. Hyper-Kamiokande @ Kamioka
- Physics goals: CPV (w/ J-PARC  $\nu$  beam), Mass hierarchy w/ Atm  $\nu$ , proton decay, etc, find something unexpected!
- Communities support HK at high priority
  - HEP: One of two highest priority large projects (other is ILC)
  - Cosmic: endorses HK at high priority
  - HK project plan is submitted to the master plan for large scale projects in SCJ



Whole allowed parameter space is covered by atm $\nu$  only study

# Current Status of Neutrino Oscillation Parameter Measurements

- Remarkable progress!
- All mixing angles are now known
  - $\theta_{12} = 33.9^\circ \pm 1.0^\circ$
  - $\theta_{13} = 8.7^\circ \pm 0.4^\circ$
  - $\theta_{23} = 45^\circ \pm 6^\circ$  (90% C.L.)  
 → largest uncertainty

All three angles are non-zero and relatively large

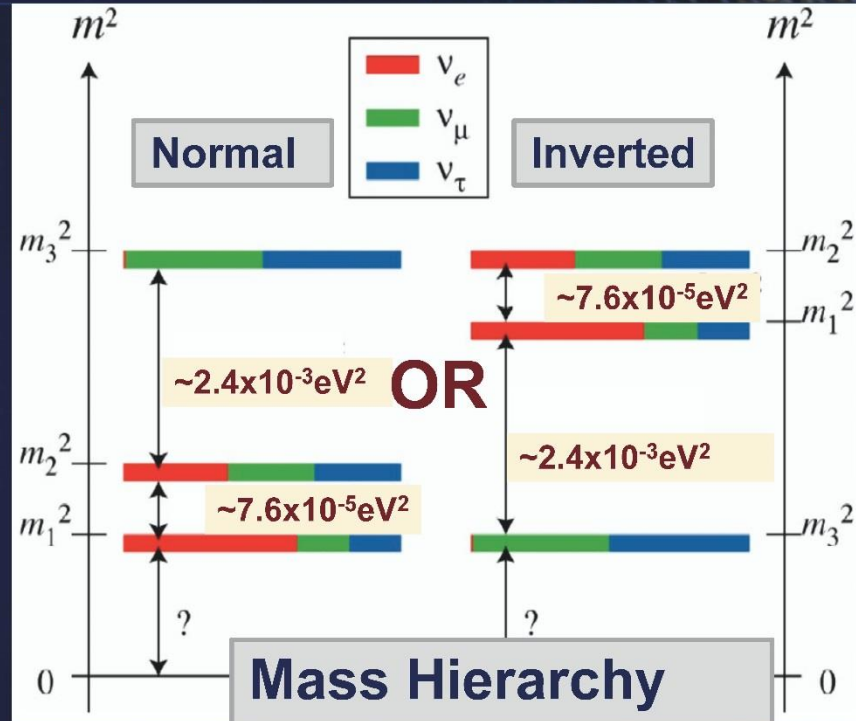
→ allows exploration of CPV in the lepton sector

$P(\nu_\mu \rightarrow \nu_e)$

$\propto$  leading term + ...

+ term( $\sin\theta_{12} \sin\theta_{23} \sin\theta_{13} \sin\delta_{CP}$ )

*Why is nature so kind to us?*

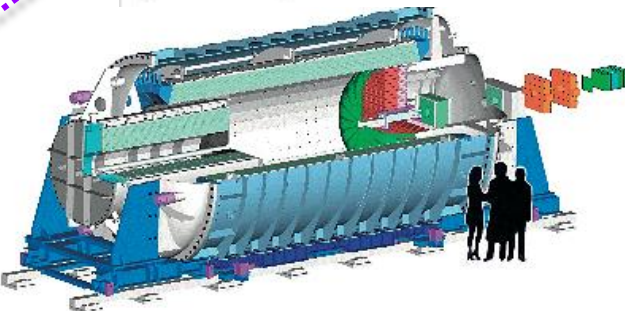
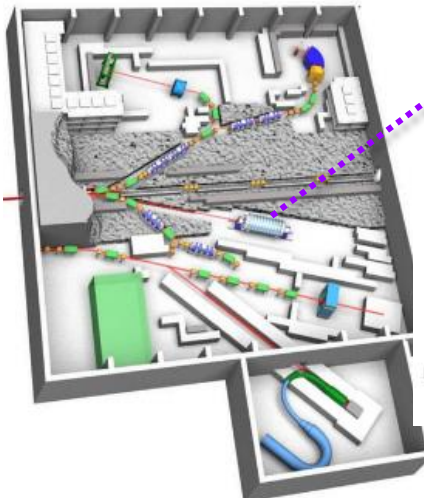


Critical for the  $\nu$ -less double- $\beta$  decay searches that would determine the Majorana-nature of  $\nu$

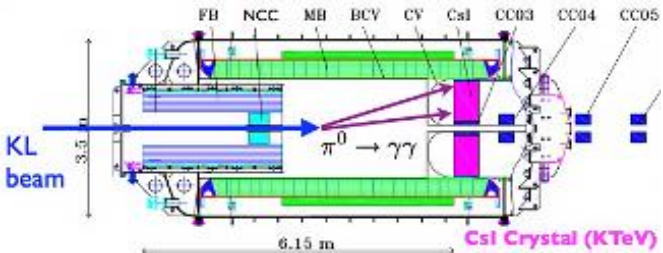


# J-PARC Hadron Facility

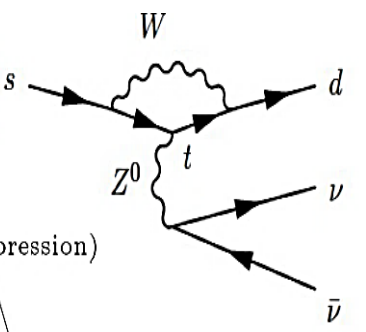
**KOTO** Rare Kaon Decay  
 $K_L^0 \rightarrow \pi^0 \nu \bar{\nu}$



Cheju 2 Chonbuk 1 Kyungpook 2 Pusan 3 Soul 2	KEK 7 Kyoto 9 Osaka 11 Saga 6 Yamagata 2	JINR 4	Nat. Taiwan 5	Arizona State 2 Chicago 5 Michigan State 4

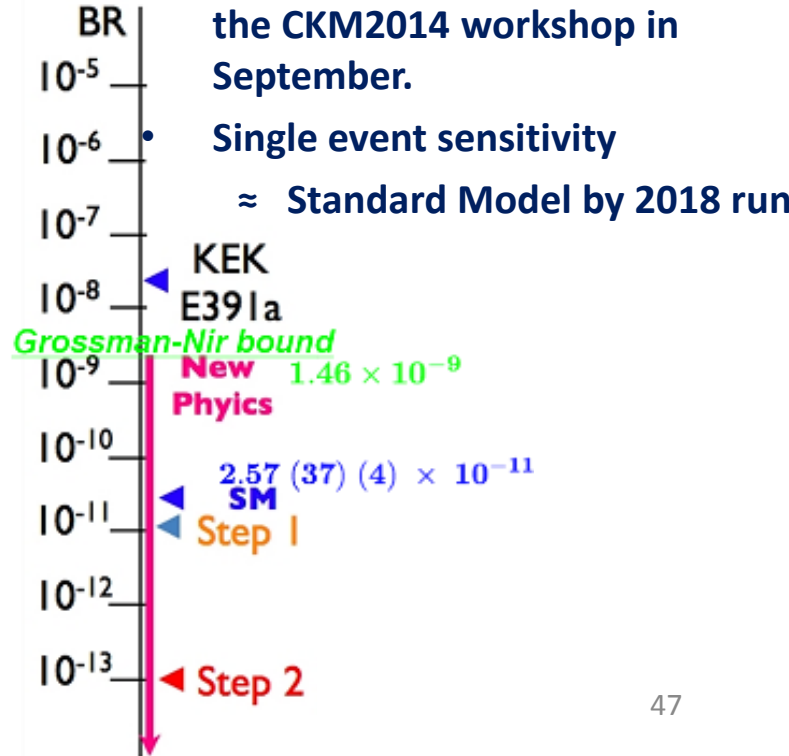


- Rare FCNC process  $Br(SM) = (2.4 \pm 0.4) \times 10^{-11}$ 
  - GIM suppression for u, c (Only t contribution for this decay)
  - Hierarchical structure of CKM for t quark
- Small theoretical uncertainty ( $\sim 2\%$ ) ( $\lambda^5$  suppression)
  - Short distance (W, Z, t)
  - Ke3 hadron matrix element from data
- Direct CP violation



Sensitive to new physics which break flavor structure and add new CP-violation

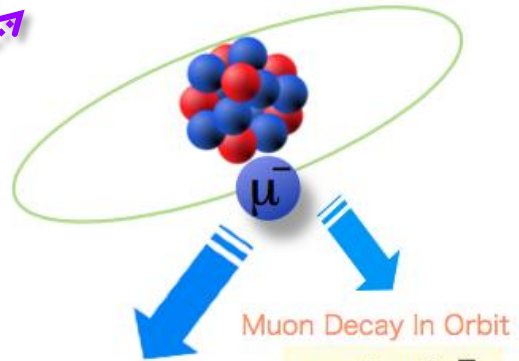
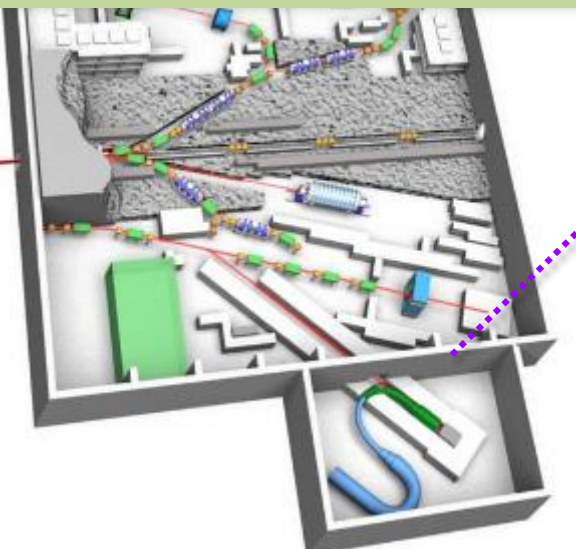
- Started running in 2013, first results (preliminary) reported at the CKM2014 workshop in September.
- Single event sensitivity  $\approx$  Standard Model by 2018 run.



## COMET: COherent Muon to Electron Transition

$\mu$ -e conversion

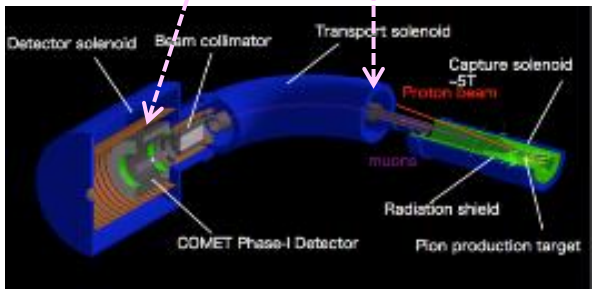
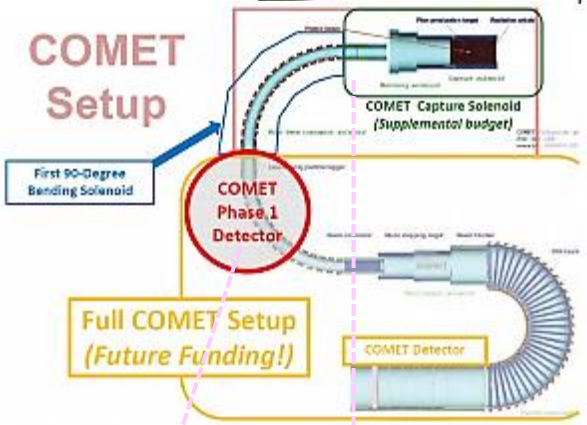
$$\mu^- + (A, Z) \rightarrow e^- + (A, Z)$$



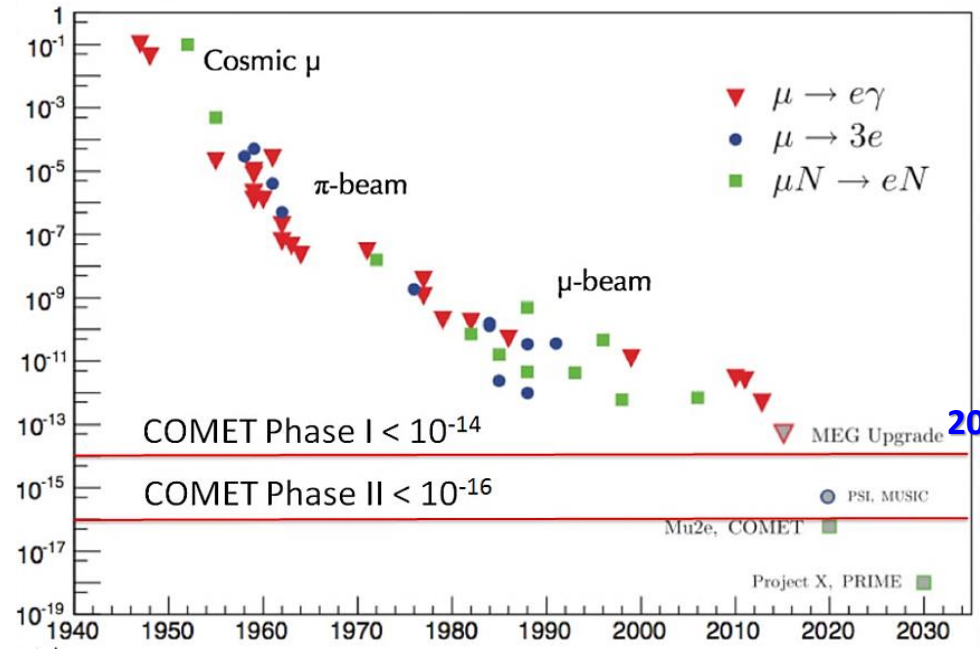
### Lepton Flavour Violation

- Forbidden in SM
  - Muon number +1  $\rightarrow$  0
  - Electron number 0  $\rightarrow$  +1
- **Stunning Evidence BSM once observed (No SM background)**

### COMET Setup



90% C.L. Upper Limit



2016-2017

2021



# COMET Collaboration & Schedule

- 160 researchers from 32 institutes in 13 countries + 1 international institute

## Major contributions from Asian countries

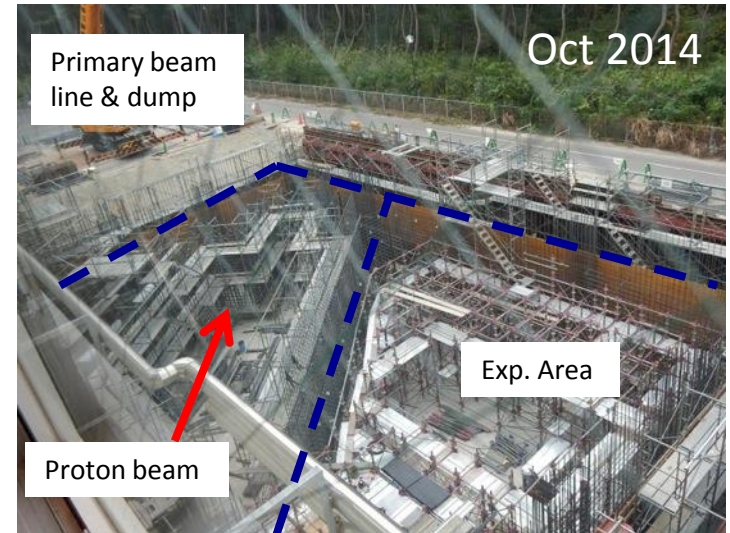


Japan – (host) Facility, Detector & Analysis,  
 China – Tracker Electronics & Physics analysis  
 India – Beam monitor, Vietnam – Analysis,  
 Malaysia - Analysis

... and of course many from other countries !



- Facility construction



- Phase-I Schedule

JFY	2013	2014	2015	2016	2017
Exp Hall	[Progress bar]				
Magnet	[Progress bar]				
Beam		[Progress bar]	[Progress bar]	[Progress bar]	
Detector		[Progress bar]			

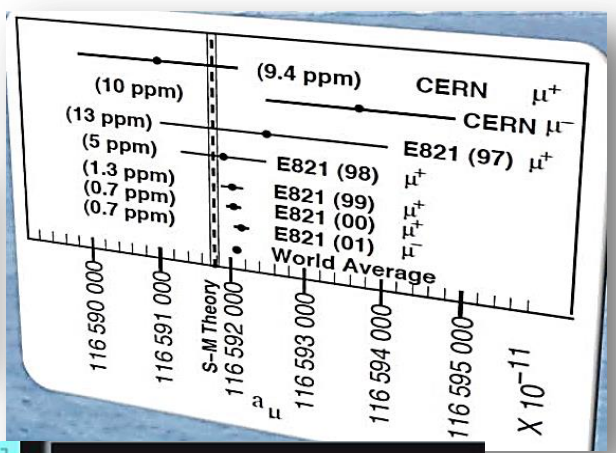
Engineering Run

Physics Run

Phase II around ~2020

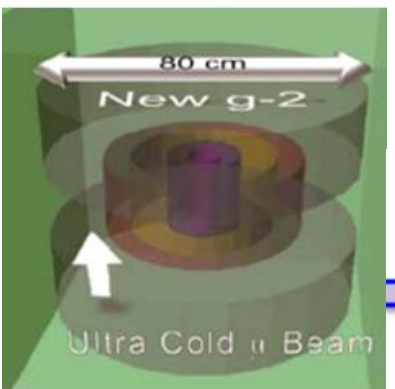
## Anomalous MDM

- 3.4 sigma deviation from the SM
- SM prediction OK?
- New Physics?

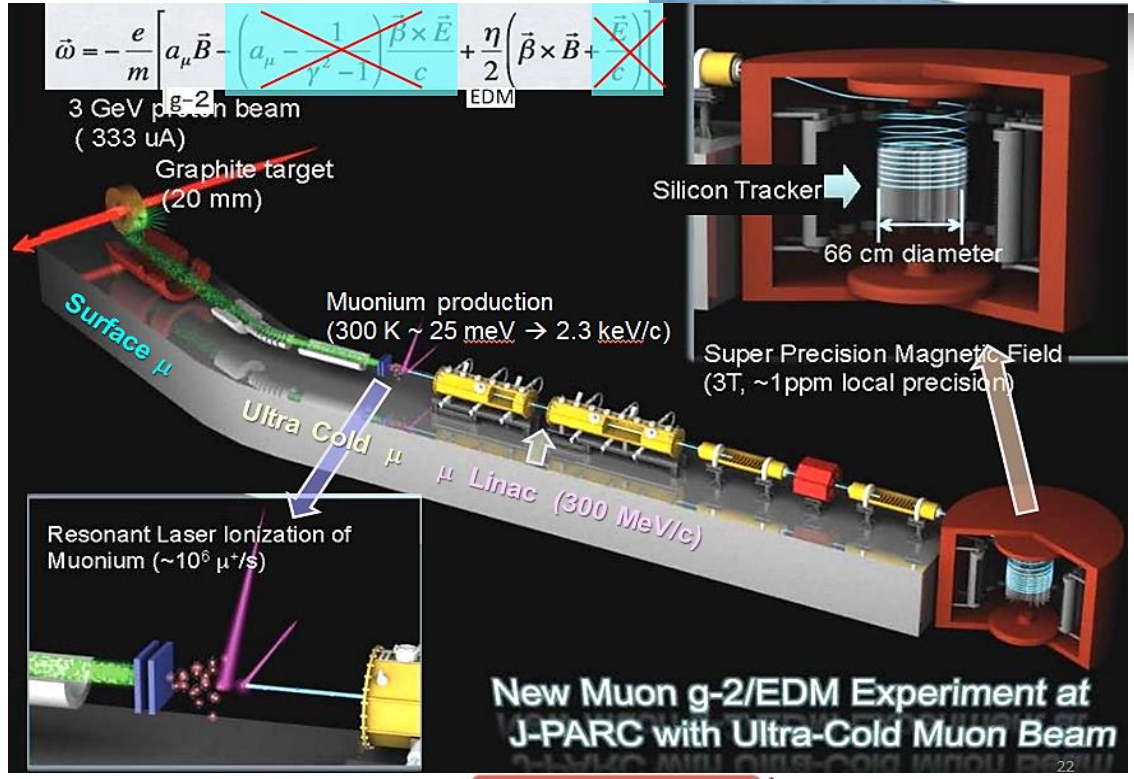


**Improve Precision by 5 (0.1 ppm)**

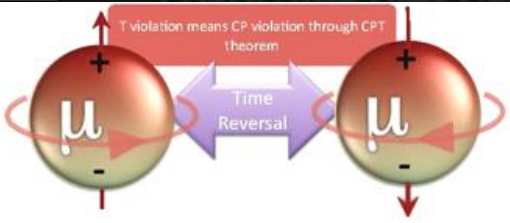
Muon g-2@J-PARC



**Improve Precision by 100**

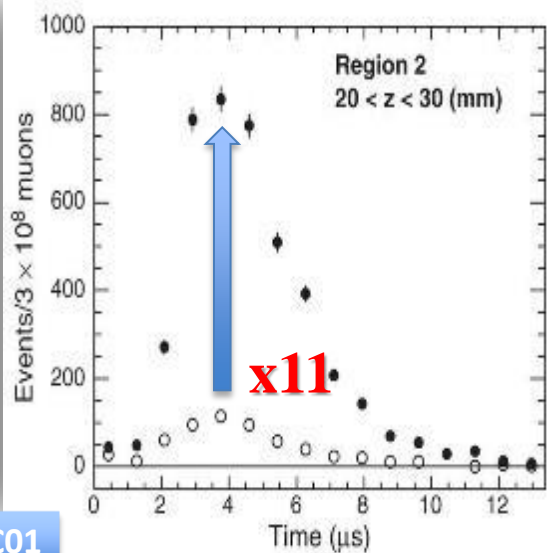


**New Muon g-2/EDM Experiment at J-PARC with Ultra-Cold Muon Beam**



# • Muonium production is improved by > 10 !

Laser-drilled aerogel produces more muonium!



PTEP 2014 (2014) 091C01

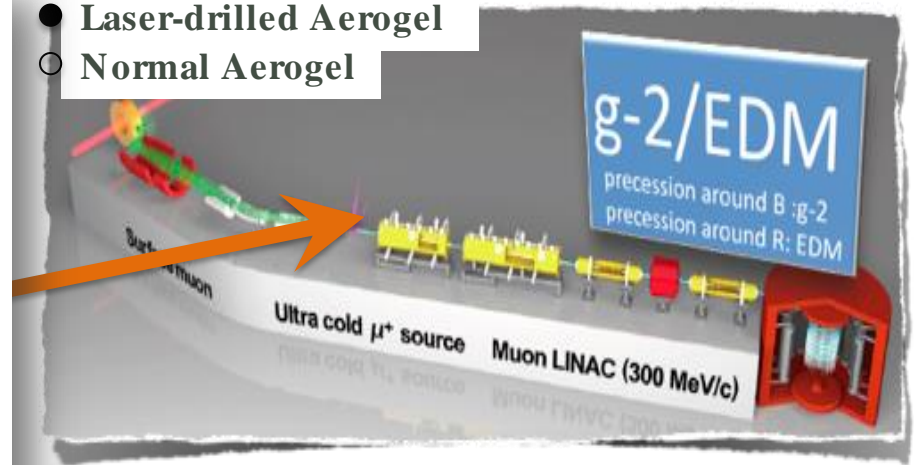
98 members from 21 institutes in 8 countries

## Collaboration

- 98 members (...still evolving)
- 21 Institutions
- Academy of Science, BNL, BINP, CRNS-APC, UC Riverside, Charles U., KEK, Korea U, NIRS, UNM, Osaka U., PMCU, RCNP, STFC RAL, RIKEN, Rikkyo U., SUNYSB, CRC Tohoku, U. Tokyo, TITech, TRIUMF, U. Victoria
- 8 countries
- Canada, China, Czech, France, Japan, Korea, Russia, UK, USA (alphabetic order)



- Laser-drilled Aerogel
- Normal Aerogel



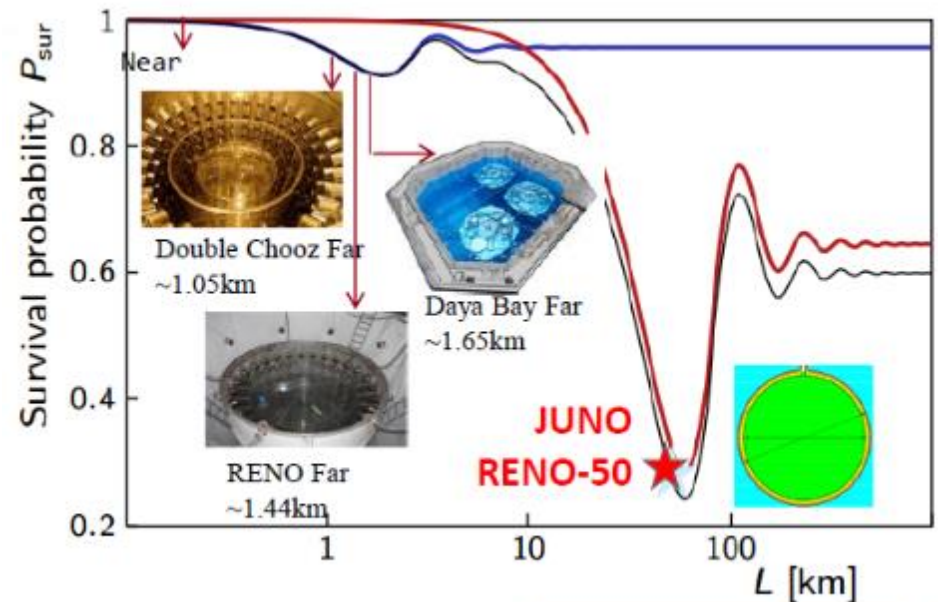
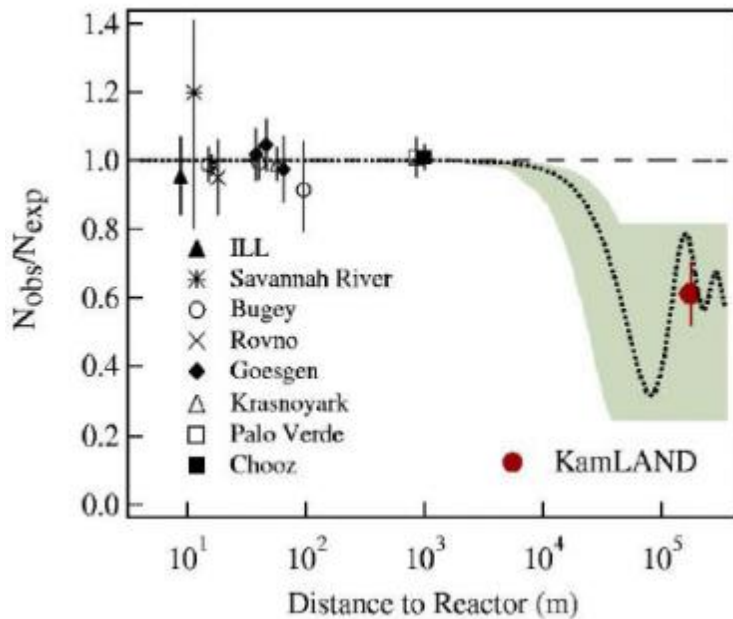
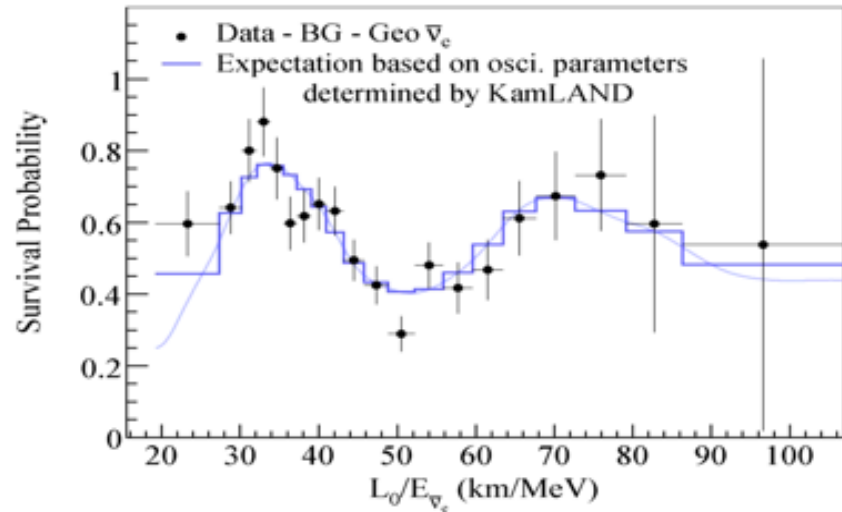
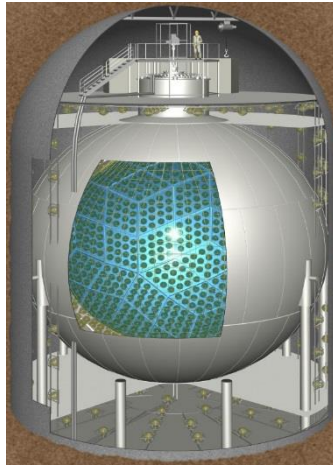
## Intended Schedule

	2013	2014	2015	2016	2017	2018
Muon Source	R&D	Design			Construction	
Muon LINAC	R&D	Design			Construction	
Ultra-Precision Magnet	R&D	Design			Construction	
Detector	R&D	Design			Construction	

Experiment

# 3. Reactor Neutrino Oscillation Studies

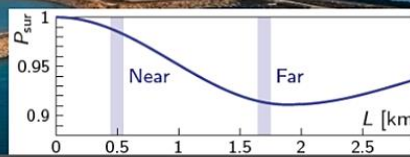
## Discovery of First Reactor Antineutrino Oscillations (2003) : KamLAND



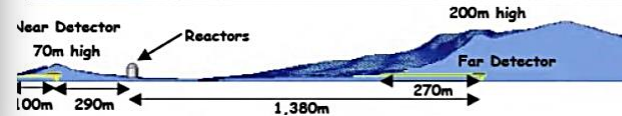
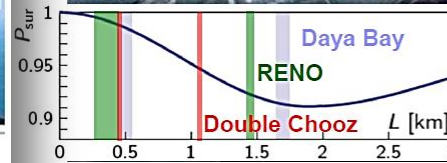
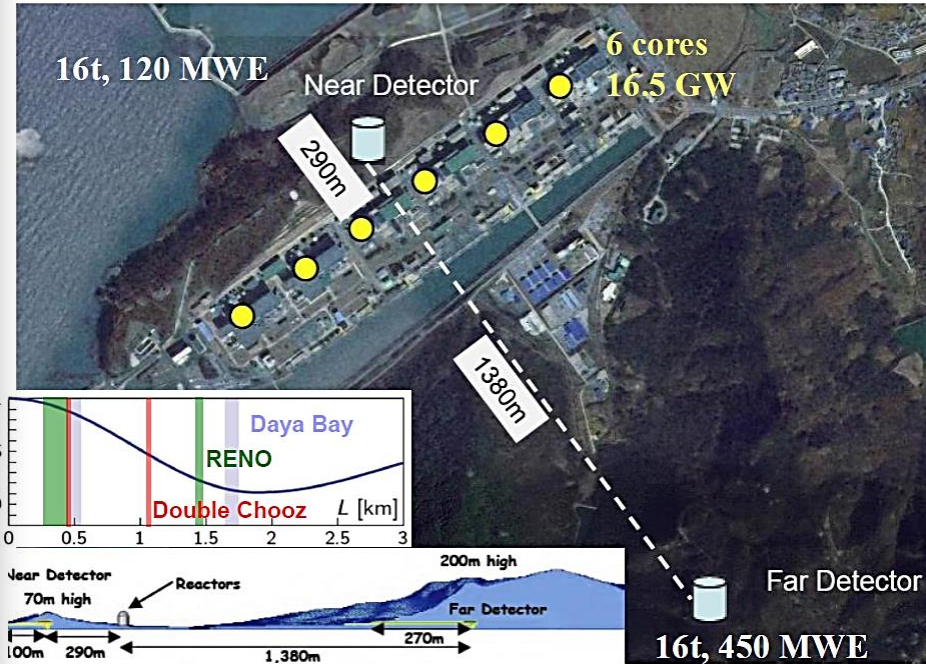
# 2<sup>nd</sup> Generation Reactor Neutrino Oscillation Projects in Asia

## The Daya Bay Experiment

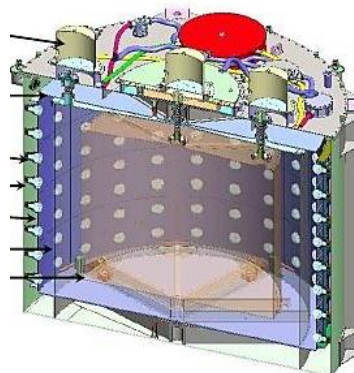
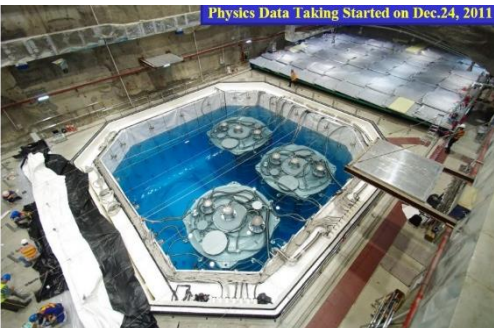
- 6 reactor cores, 17.4 GW<sub>th</sub>
- Relative measurement
  - 2 near sites, 1 far site
- Multiple detector modules
- Good cosmic shielding
  - 250 m.w.e @ near sites
  - 860 m.w.e @ far site
- **Redundancy**



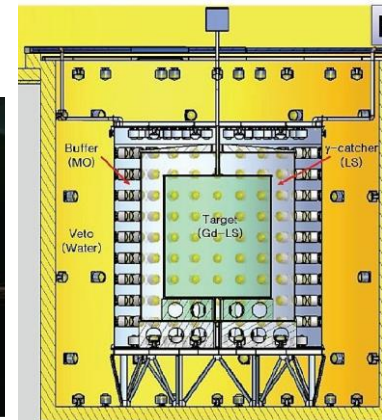
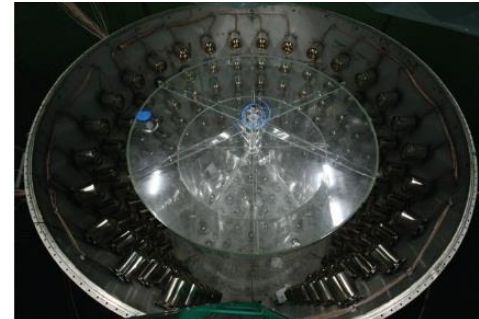
## RENO



## 20 ton Gd-loaded LS



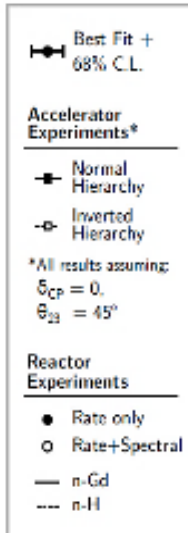
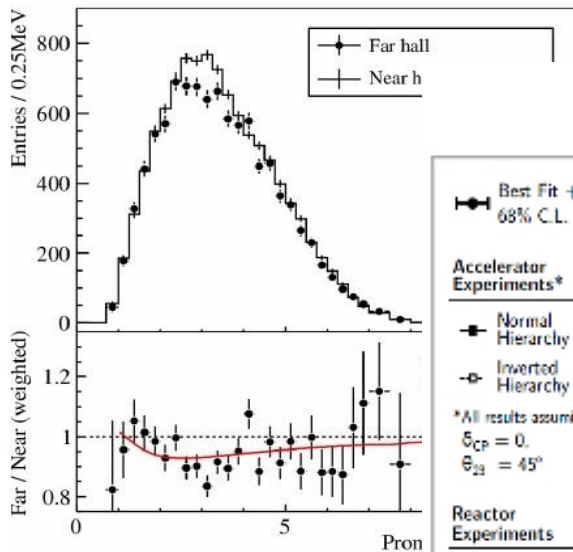
## 16.5 ton Gd-loaded LS



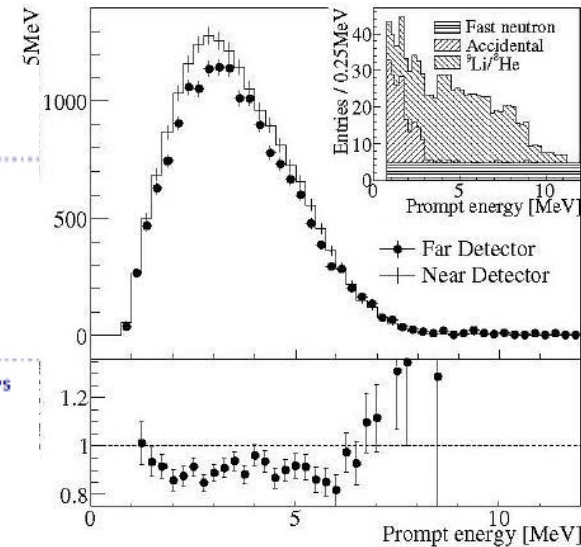
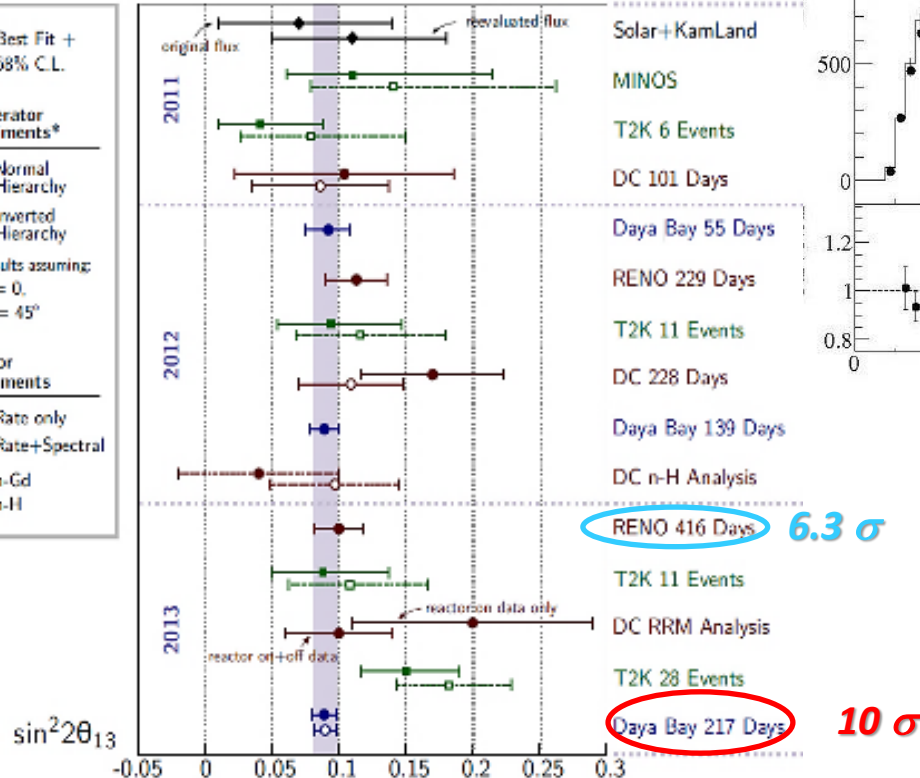
$$R = 0.940 \pm 0.011 (\text{stat}) \pm 0.004 (\text{syst})$$

$$\sin^2 2\theta_{13} = 0.092 \pm 0.016 (\text{stat}) \pm 0.005 (\text{syst})$$

$$R = \frac{\Phi_{\text{observed}}^{\text{Far}}}{\Phi_{\text{expected}}^{\text{Far}}} = 0.920 \pm 0.009 (\text{stat}) \pm 0.014 (\text{syst})$$



## Global Comparison of $\theta_{13}$ Measurements

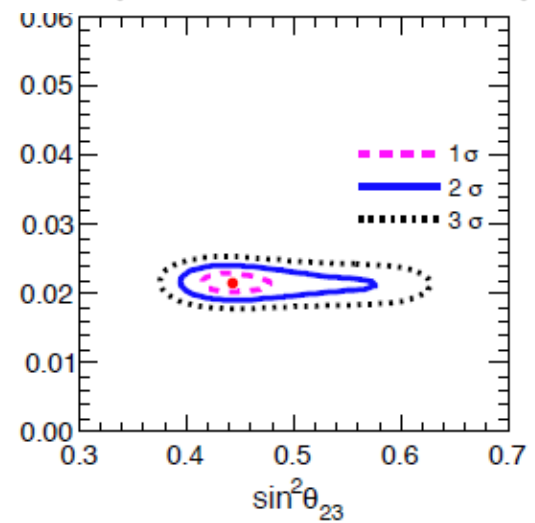
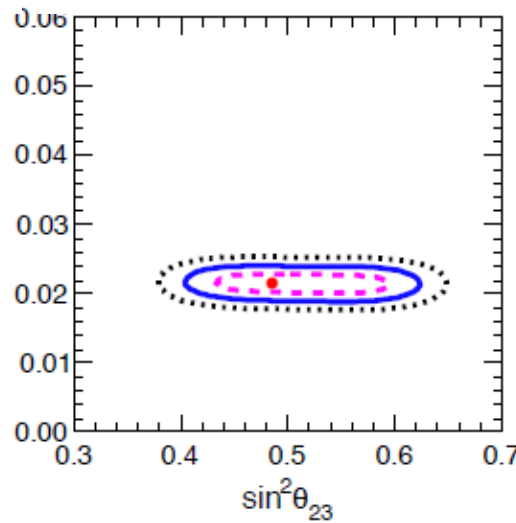
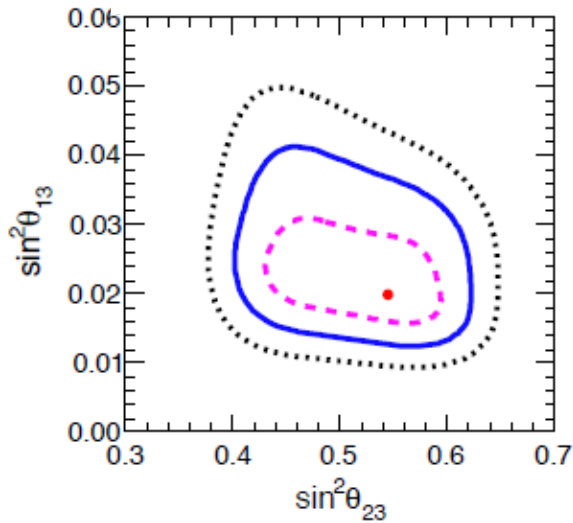


# $\theta_{13}$ vs. $\theta_{23}$

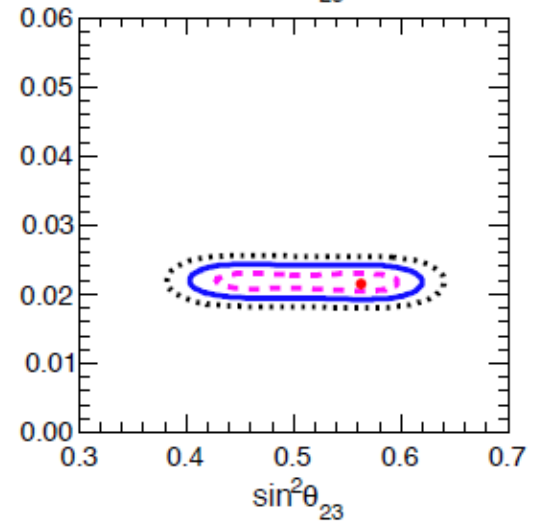
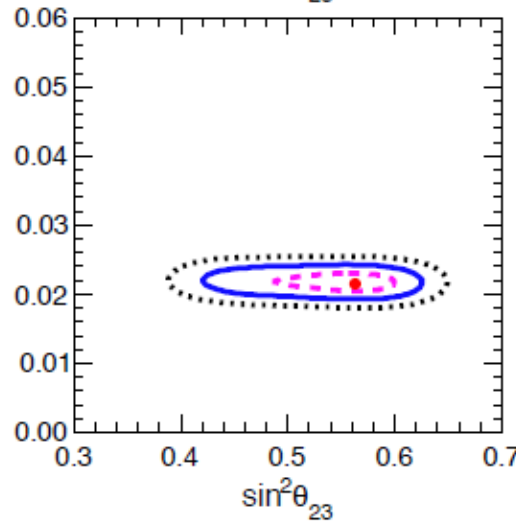
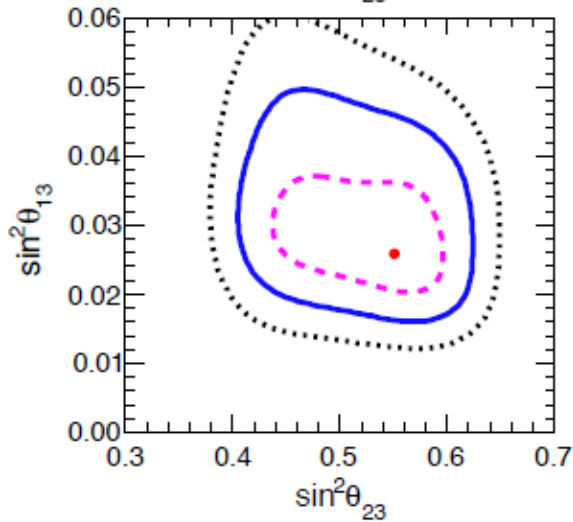
Long Baseline Accelerator  
+ Solar Neutrino  
+ KamLAND

Long Baseline Accelerator  
+ Solar Neutrino  
+ KamLAND  
+ Short Baseline Reactor

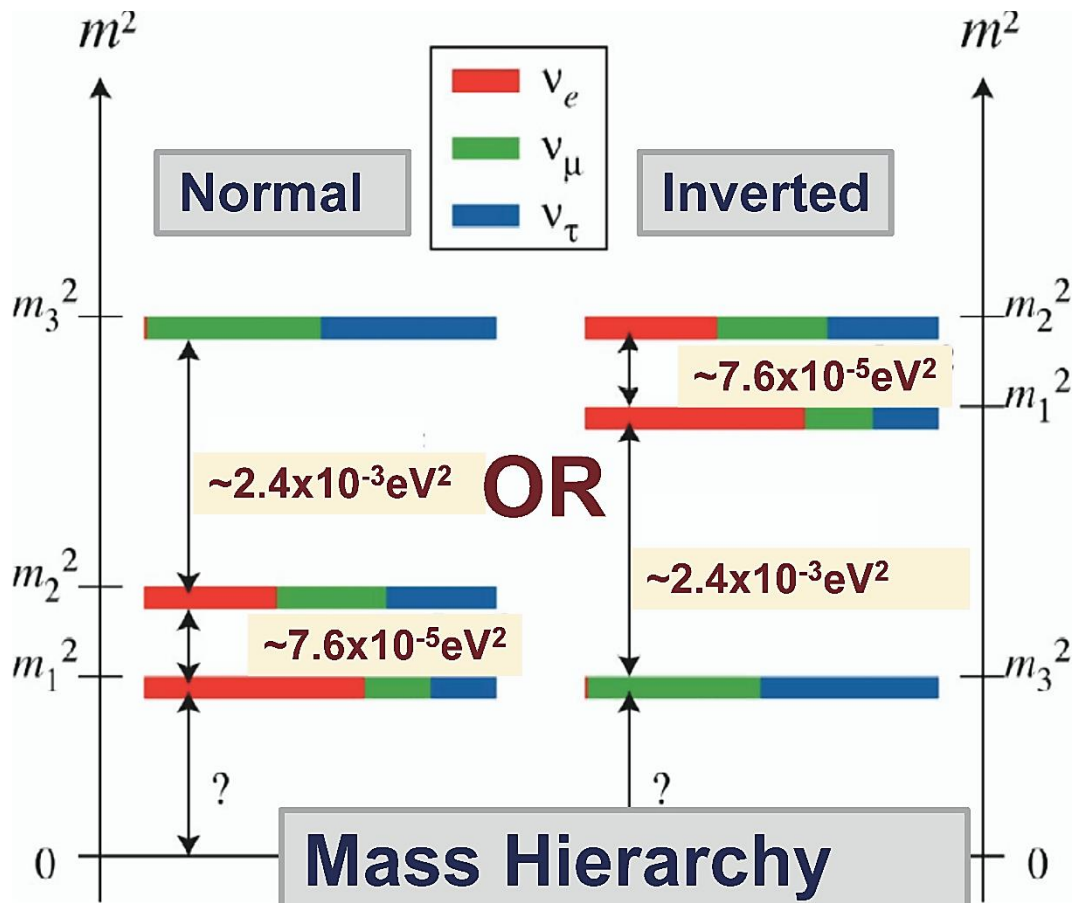
Long Baseline Accelerator  
+ Solar Neutrino  
+ KamLAND  
+ Short Baseline Reactor  
+ SuperKamiokande Atmospheric  $\nu$



Normal Hierarchy



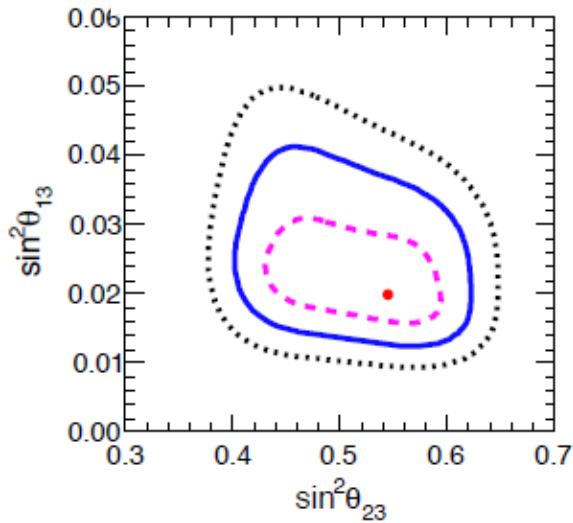
Inverted Hierarchy



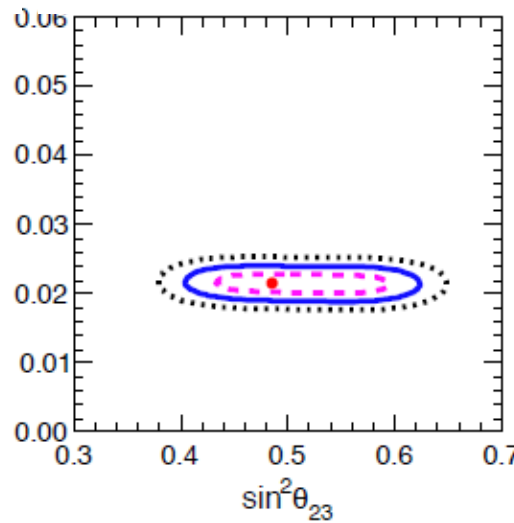


# $\theta_{13}$ VS. $\theta_{23}$

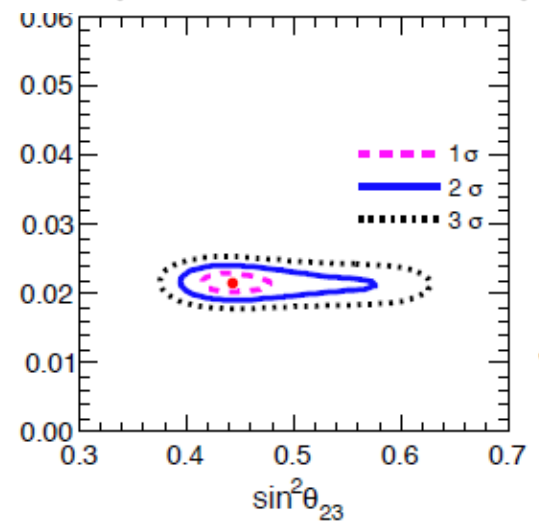
Long Baseline Accelerator  
+ Solar Neutrino  
+ KamLAND



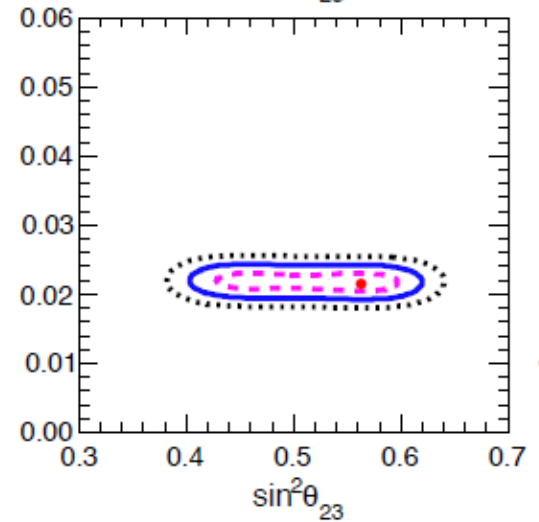
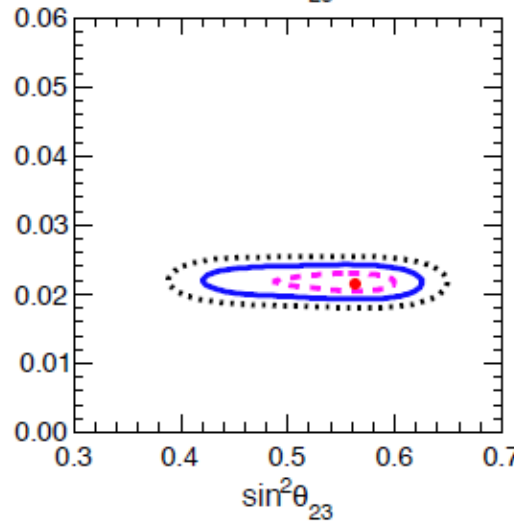
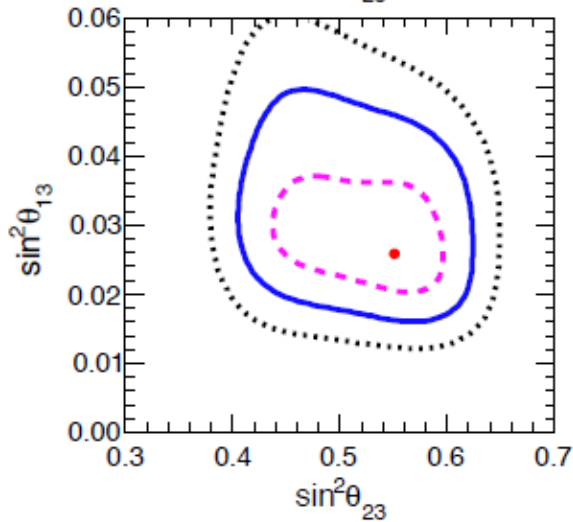
Long Baseline Accelerator  
+ Solar Neutrino  
+ KamLAND  
+ Short Baseline Reactor



Long Baseline Accelerator  
+ Solar Neutrino  
+ KamLAND  
+ Short Baseline Reactor  
+ SuperKamiokande Atmospheric  $\nu$



Normal Hierarchy



Inverted Hierarchy

Political Map of the World, June 1999



~250 Collaborators



## RENO Collaboration

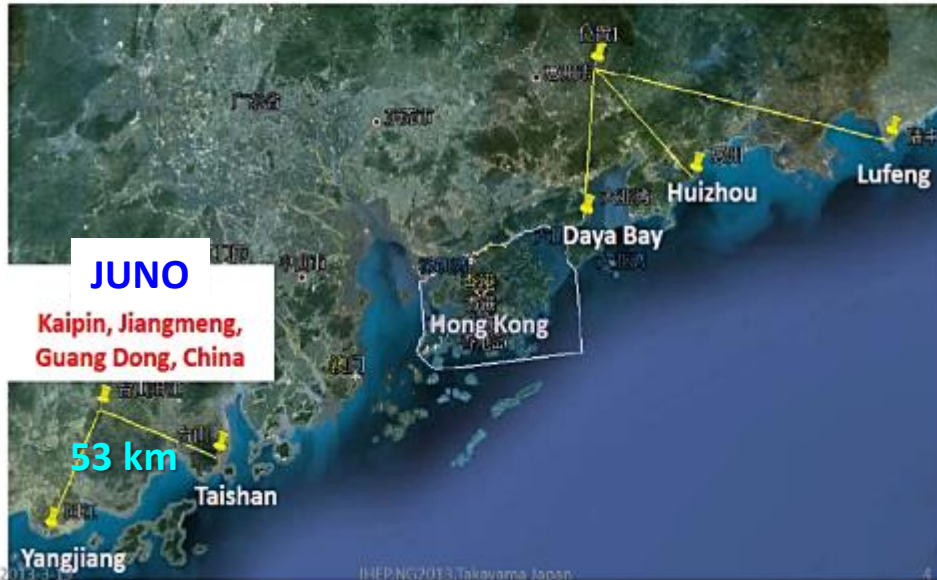


### 12 Institutions and 40 physicists

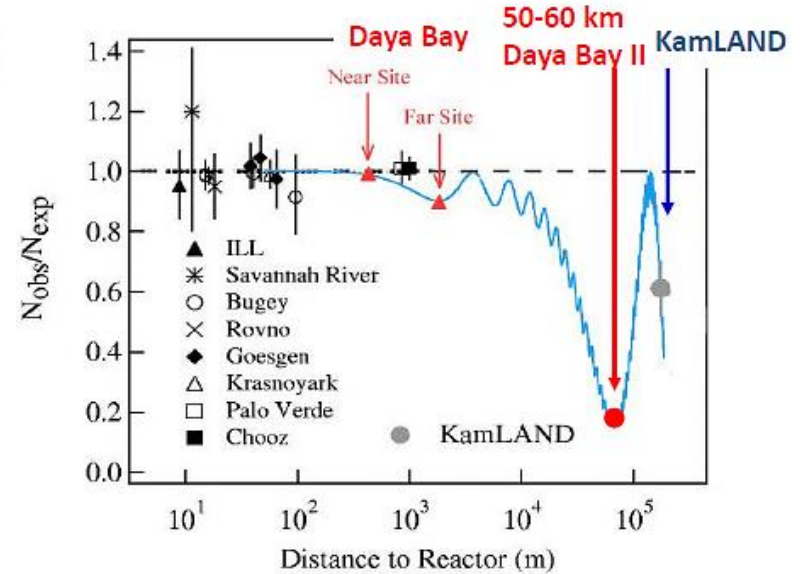
- Chonbuk National University
- Chonnam National University
- Chung-Ang University
- Dongshin University
- Gyeongsang National University
- Kyungpook National University
- Pusan National University
- Sejong University
- Seokyeong University
- Seoul National University
- Seoyeong University
- Sungkyunkwan University

# Daya Bay II: Jiangmen Underground Neutrino Observatory (JUNO)

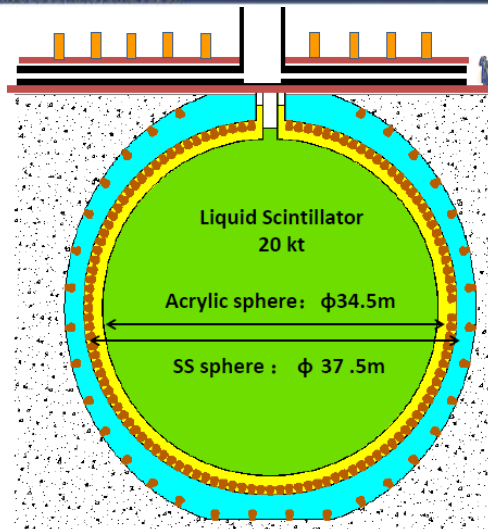
	Daya Bay	Huizhou	Lufeng	Yangjiang	Taishan
Status	Operational	Planned	Planned	Under construction	Under construction
Power	17.4 GW	17.4 GW	17.4 GW	17.4 GW (~2017)	18.4 GW (~2014,?)



**Budget : almost approved (300 M\$ ?)**



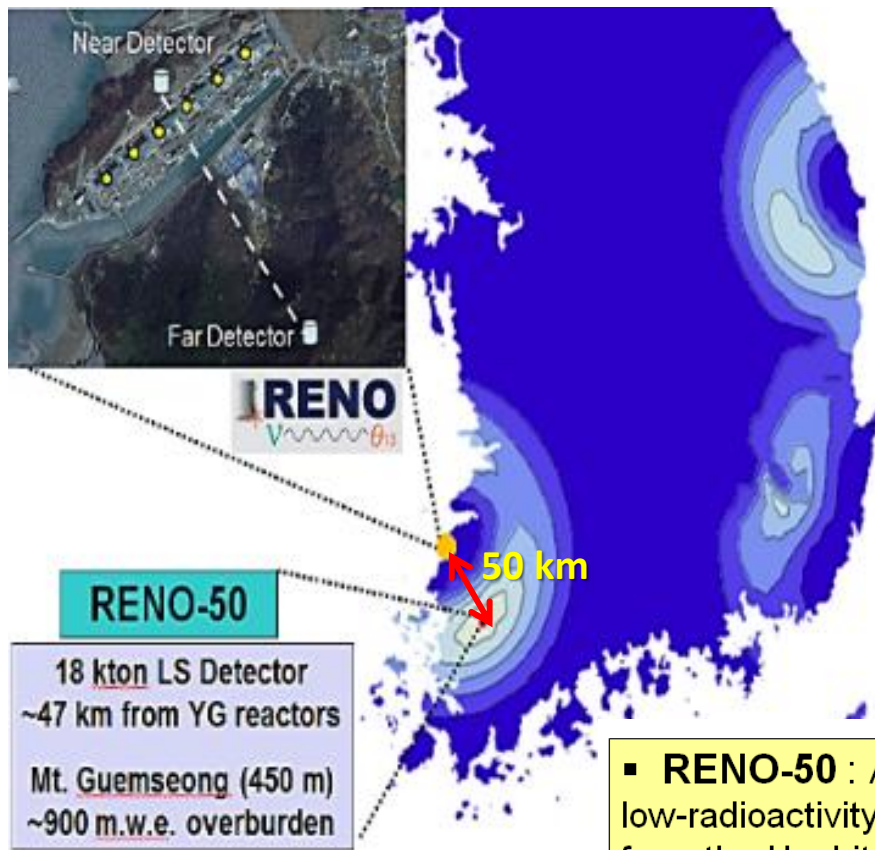
- Extremely difficult to build both the stainless steel tank and the acrylic tank
- Options:
  - No steel tank, only acrylic tank
  - Steel tank +
    - Acrylic box/wall
    - Balloon
    - nothing



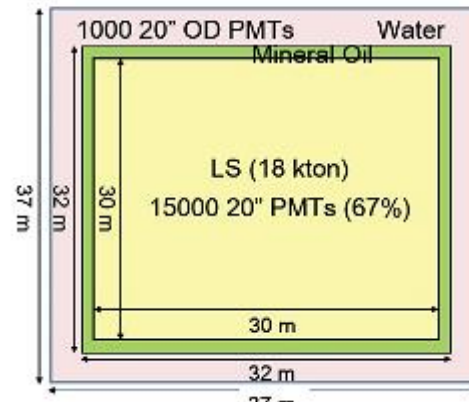
- 20 kton LS detector
- 2-3 % energy resolution
- Rich physics possibilities
  - Mass hierarchy
  - Precision measurement of 3 mixing parameters
  - Supernova neutrino
  - Geoneutrino
  - Sterile neutrino
  - Atmospheric neutrinos
  - Exotic searches

**Data taking: ~ 2020**

# Next RENO: RENO-50



## Conceptual Design of RENO-50



▪ **RENO-50** : An underground detector consisting of 18 kton ultra-low-radioactivity liquid scintillator & 15,000 20" PMTs, at 50 km away from the Hanbit(Yonggwang) nuclear power plant

▪ **Goals** : - Determination of neutrino mass hierarchy  
- High-precision measurement of  $\theta_{12}$ ,  $\Delta m^2_{21}$  and  $\Delta m^2_{31}$   
- Study neutrinos from reactors, the Sun, the Earth, Supernova, and any possible stellar objects

▪ **Budget** : \$ 100M for 6 year construction  
(Civil engineering: \$ 15M, Detector: \$ 85M)

▪ **Schedule** : 2014 ~ 2019 : Facility and detector construction  
2019 ~ : Operation and experiment

R&D Budget : approved

# Current Status of Neutrino Oscillation Parameter Measurements

Remarkable progress!

Neutrino physics learns from nothing ! (Late 1980's)

Neutrino physics learns from evidence ! (Now)

→ largest uncertainty

All three angles are non-zero and relatively large

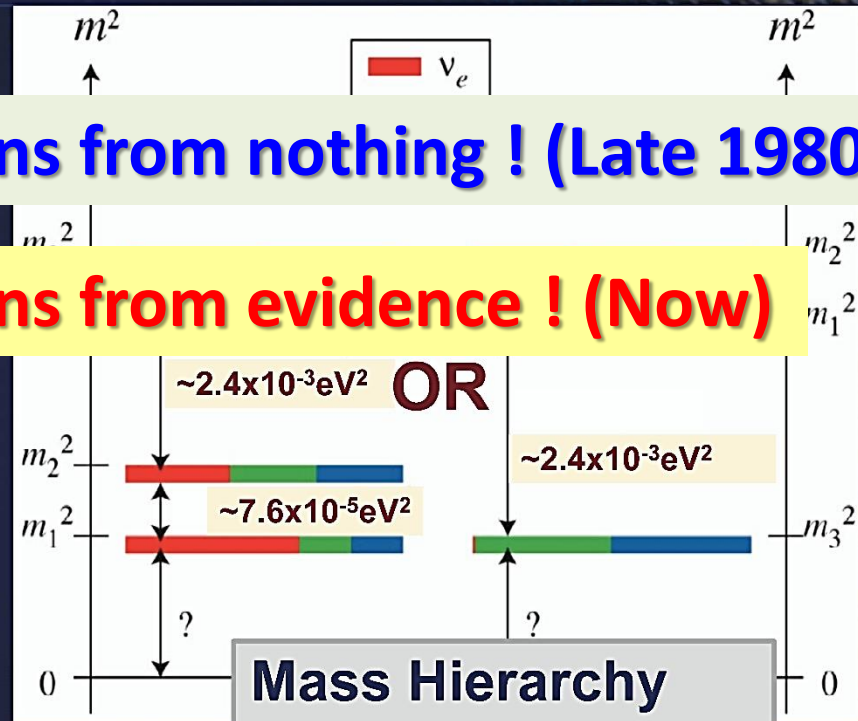
→ allows exploration of CPV in the lepton sector

$$P(\nu_\mu \rightarrow \nu_e)$$

$\propto$  leading term + ...

$$+ \text{term}(\sin\theta_{12} \sin\theta_{23} \sin\theta_{13} \sin\delta_{CP})$$

*Why is nature so kind to us?*



Critical for the  $\nu$ -less double- $\beta$  decay searches that would determine the Majorana-nature of  $\nu$



# 4. Underground Particle Physics Projects

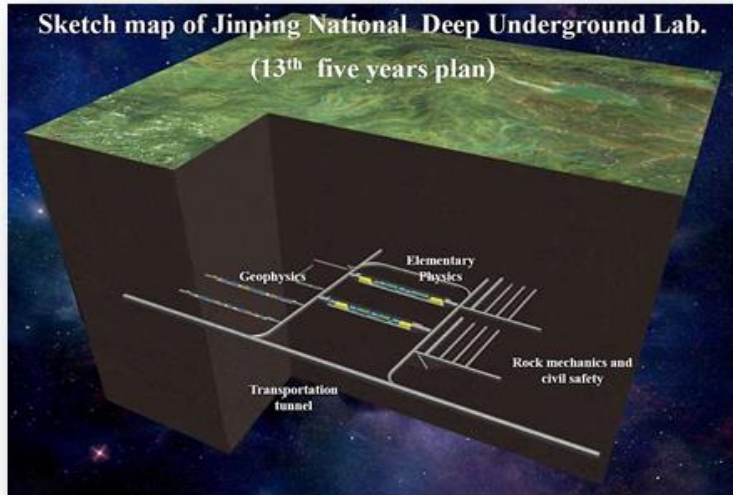
Japan

## Kamioka Underground Facility



# China

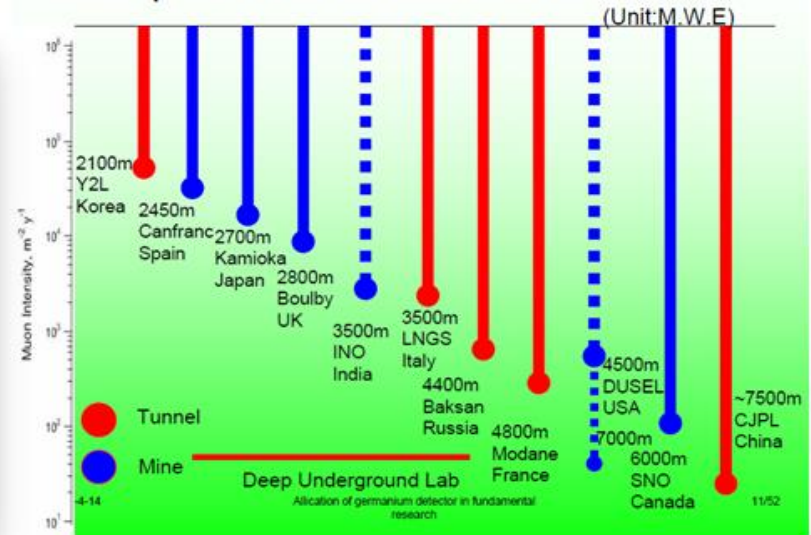
## Jinping underground lab. of Tsinghua Univ. (2500m rock overburden)



The main hall of CJPL in June 2010



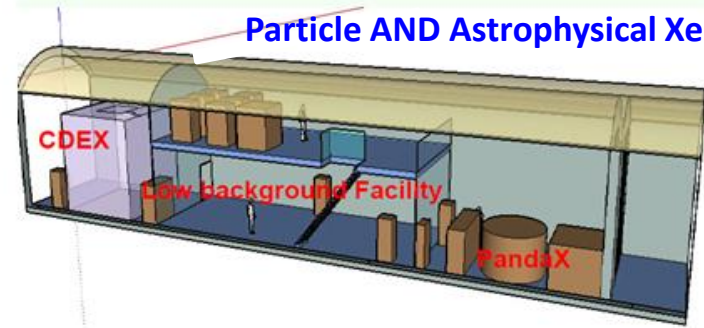
## Comparison of main ULs in the world



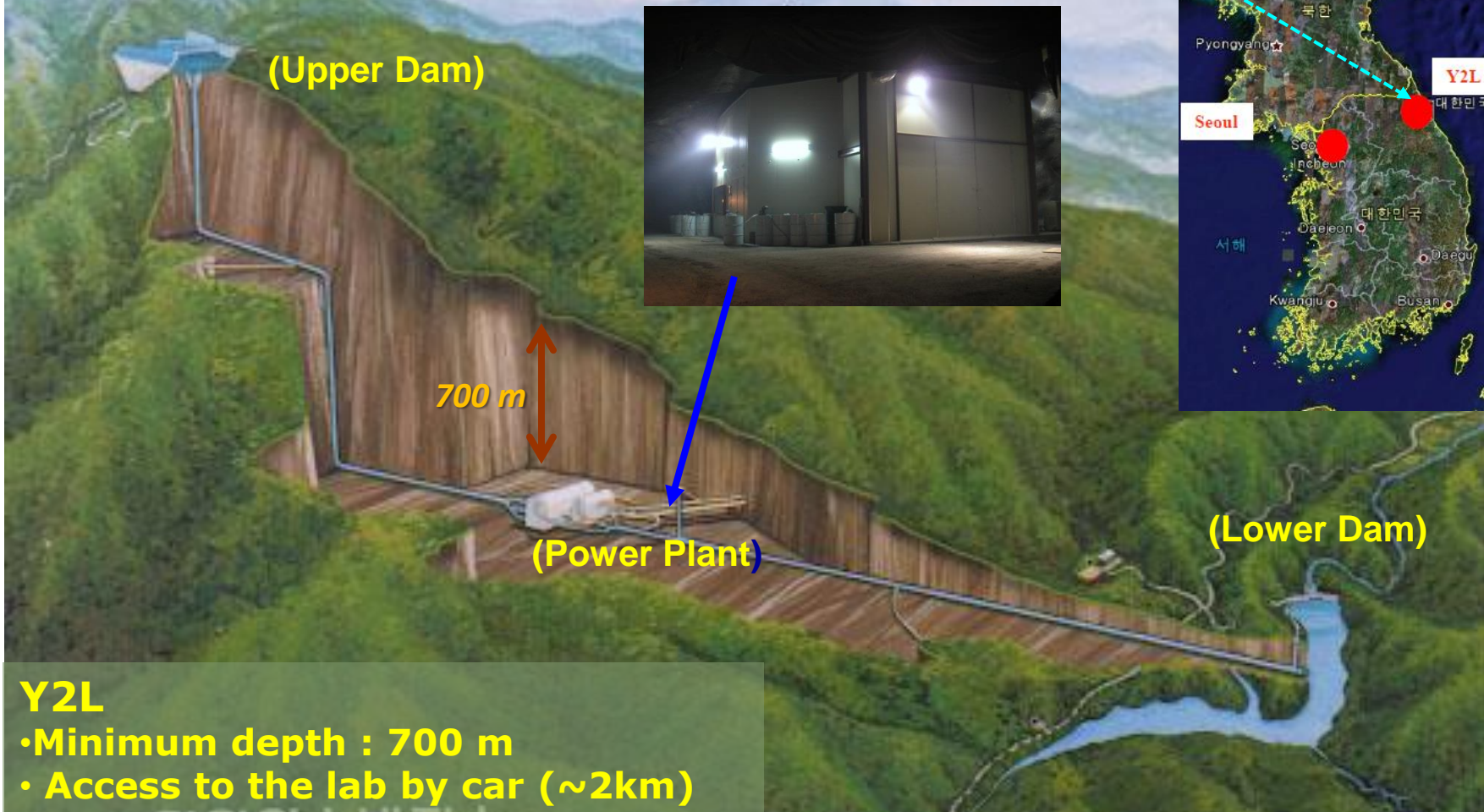
## Internal space use

PandaX :

Particle AND Astrophysical Xenon TPC



## YangYang Underground Laboratory(Y2L)



### Y2L

- Minimum depth : 700 m
- Access to the lab by car (~2km)

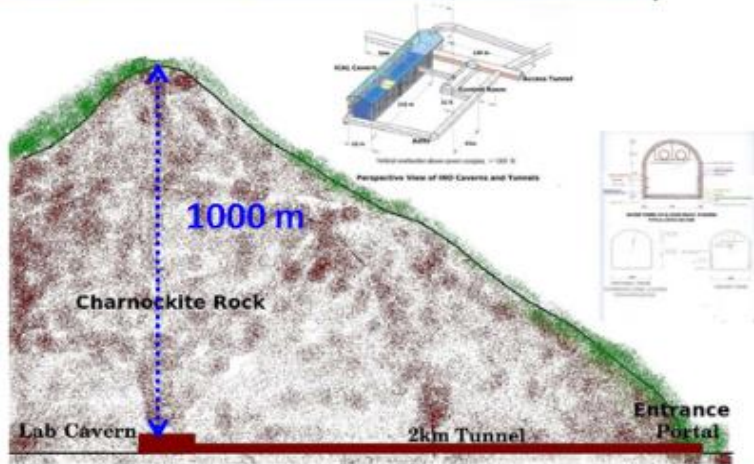
### Experiments:

- KIMS: Korea Invisible Mass Search in operation
- AMoRE: Advanced Mo based Rare process Experiment in preparation

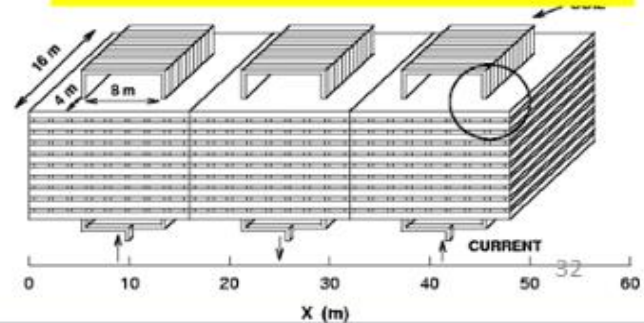




# INO : India-based Neutrino Observatory

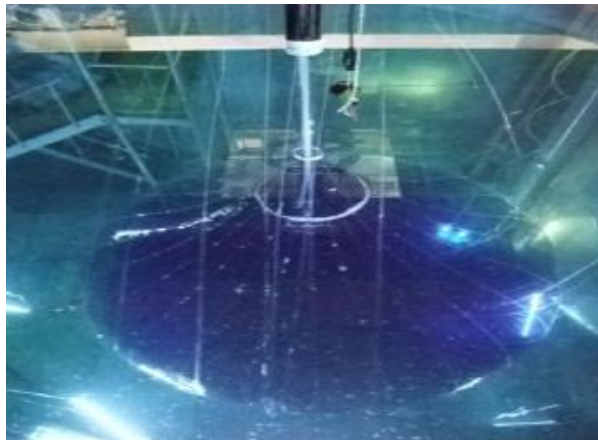
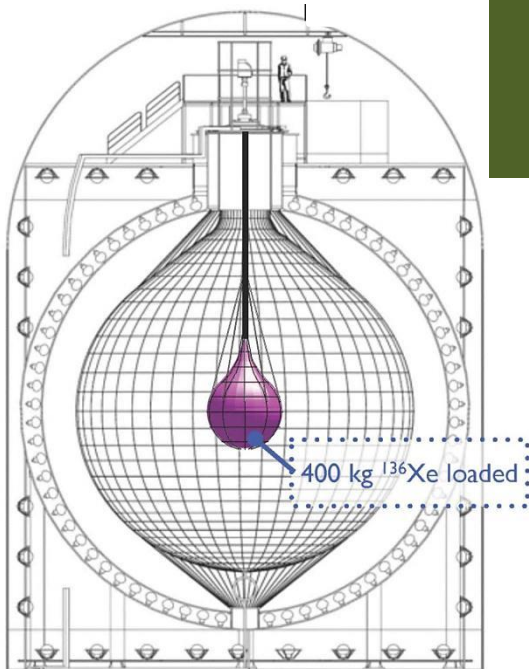


50 kton magnetized iron module(s) with 30,000 channel RPC



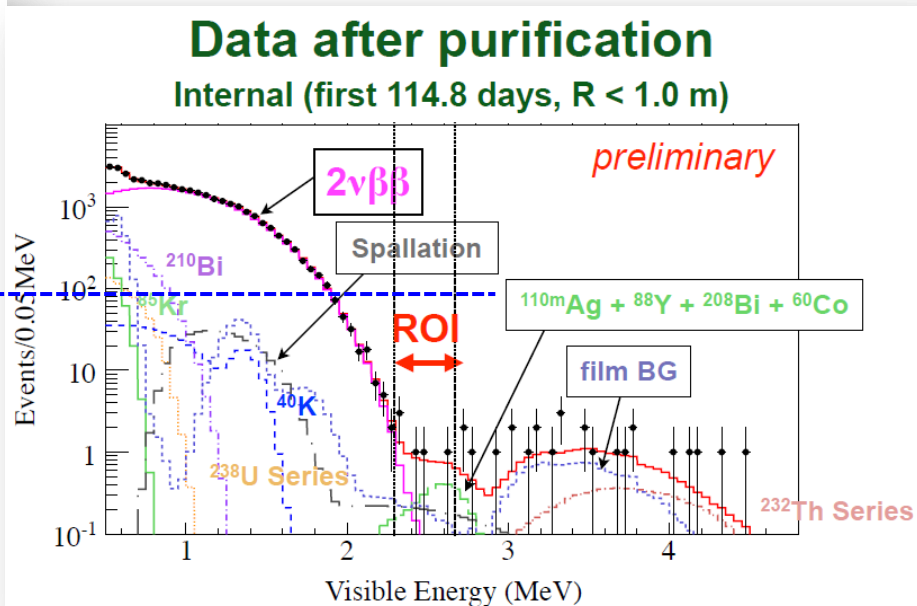
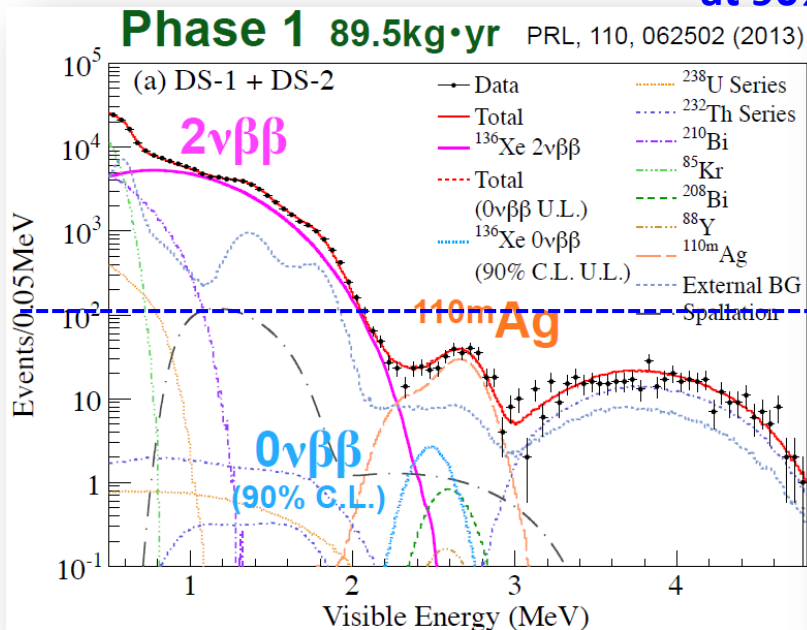
# KamLAND-Zen

## $\beta\beta$ -Decay Search

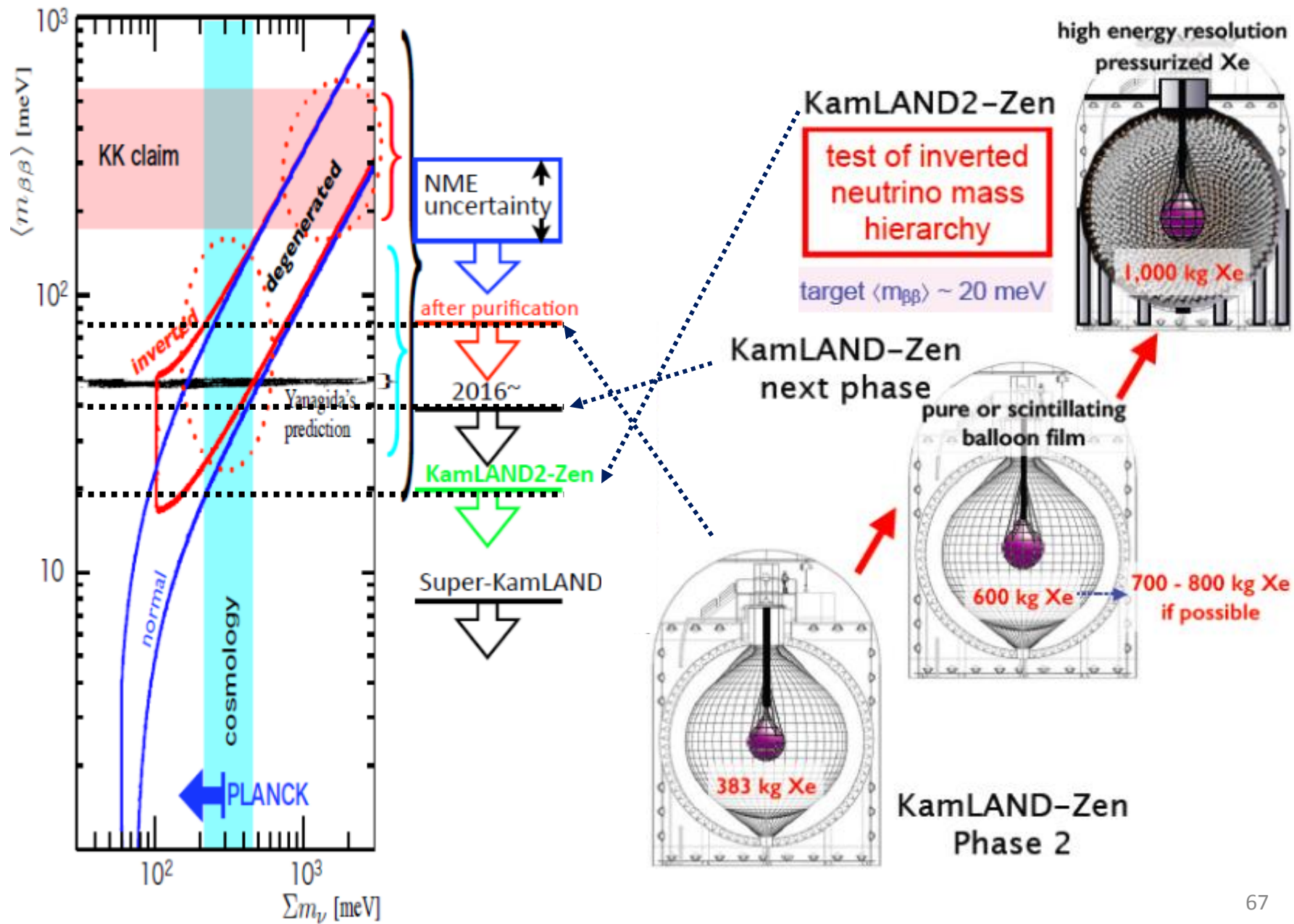


$\langle m_\nu \rangle < 140\text{-}280$  meV  
at 90% C.L.

Data-taking: Oct. 2011 – June 2012



# Prospects



# AMoRE – $0\nu\beta\beta$ experiment

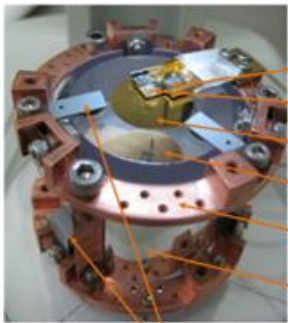
- Detector : 200 kg of  $^{40}\text{Ca}^{100}\text{MoO}_4$  scintillating bolometer.
- Reach “zero background” for 3 years data.
- $\langle m_{ee} \rangle \sim 30\text{-}50 \text{ meV}$
- AMoRE-10kg (2016-2017)  $\rightarrow$  200kg (2019-2022)



Russia, Ukraine, Germany

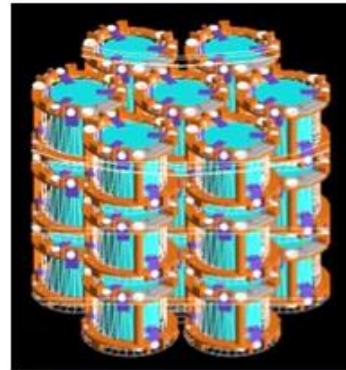


200kg  $\text{CaMoO}_4$



- Current sensing SQUID
- Meander type MMC sensor
- $\text{Ø}2\text{cm} \times 200\text{nm}$  gold thermalization pad
- $\text{Ø}4 \times 4\text{cm}^3$   $\text{CaMoO}_4$
- Copper sample holder
- VM2000 foil

Teflon coated phosphor-bronze springs

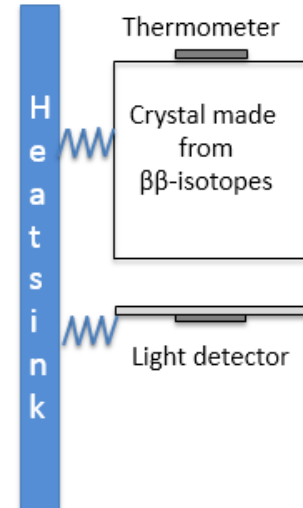
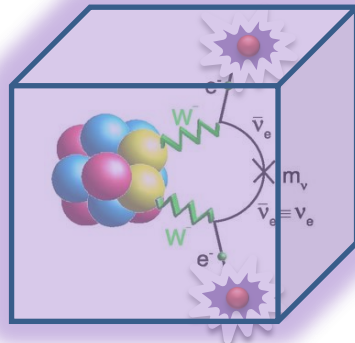


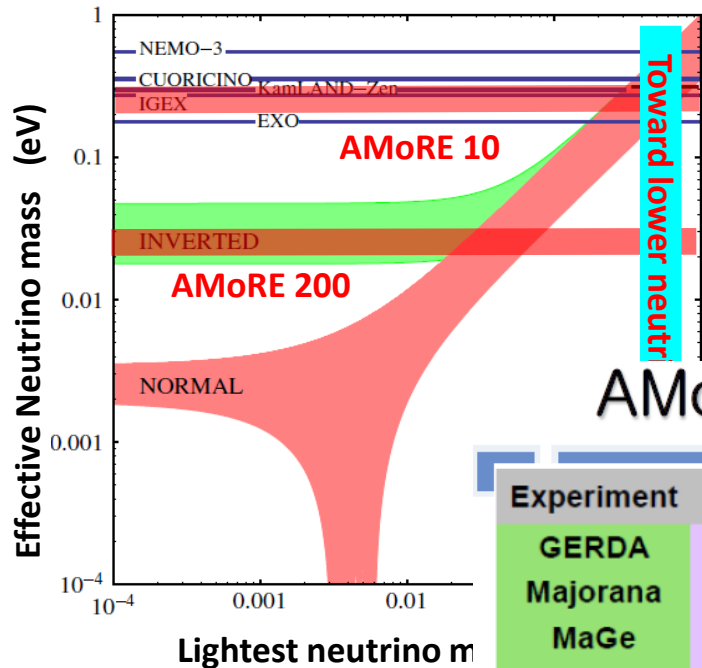
AMoRE-200

2<sup>nd</sup> phase  
200 kg  
setup

**$\text{CaMoO}_4$  Bolometer**  
4cm(D) $\times$ 4cm(L), 211g  
Energy resolution  
10 keV(2013)  $\rightarrow$  5 keV  
(2015)

1<sup>st</sup> phase  
10 kg setup  
AMoRE-10

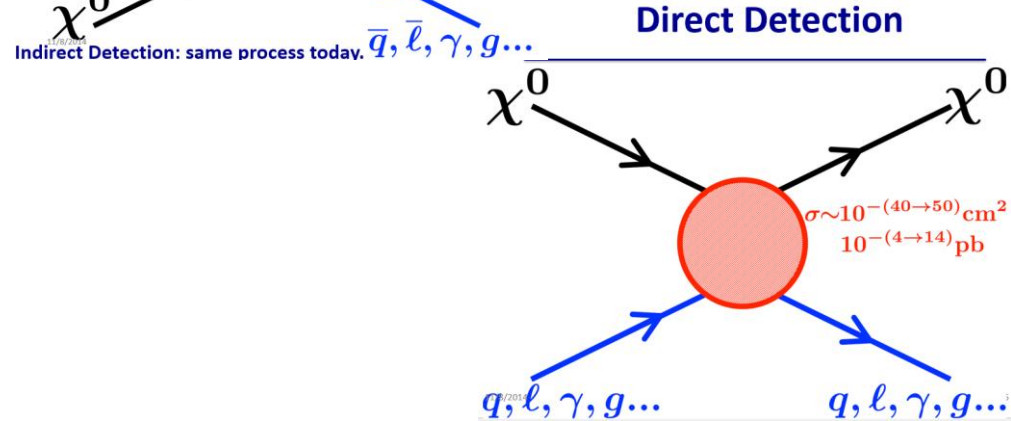
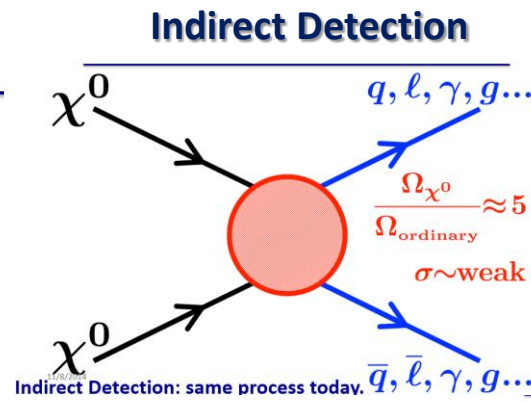




AMoRE has one of best sensitive exps.

Experiment	$\beta\beta$ candidate	Q-value[keV]	Enrichm.	$N_{\beta\beta} \times 10^{26}$	Start [y]	$\langle m_{ee} \rangle$ [meV]@5y
GERDA	$^{76}\text{Ge}$	2039	yes	3.2	2013	73-203
Majorana	$^{76}\text{Ge}$	2039	yes	2.4	2014	106-295
MaGe	$^{76}\text{Ge}$	2039	yes	68	2020	43-120
CUORE	$^{130}\text{Te}$	2527.5	no	9.6	2014	40-94
Lucifer	$^{82}\text{Se}$	2995	yes	1.3	2014	35-94
AMore	$^{100}\text{Mo}$	3034	yes	3	?	27-63
SNO+	$^{150}\text{Nd}$	3370	no	1.8	2014	172-180
Kamland-Zen	$^{136}\text{Xe}$	2476	yes	4	2013-2015	25
Candles	$^{48}\text{Ca}$	4270	no	0.04	2011	500
Candles-enr	$^{48}\text{Ca}$	4270	yes	1	?	IH
Exo-200	$^{136}\text{Xe}$	2476	yes	2.3	2011	87-221 @2y
Exo-Full	$^{136}\text{Xe}$	2476	yes	20	?	16-40
Next-100	$^{136}\text{Xe}$	2476	yes	4	2015	90 @6y
Next-1t	$^{136}\text{Xe}$	2476	yes	30	?	38 @(3+3)y
COBRA	$^{116}\text{Cd}$	2809	yes	nd	?	50
SuperNemo	$^{82}\text{Se}$	2995	yes	7.3	2014	40-105
Moon	$^{82}\text{Se}/^{100}\text{Mo}$	2995/3134	yes	30	?	IH
DCBA	$^{150}\text{Nd}$	3370	yes	10	?	30

# Dark Matter Searches



## Dark matter searches

## Indirect Detection

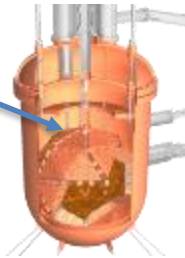
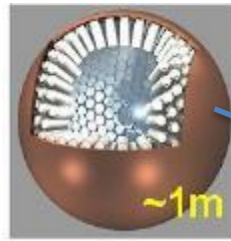
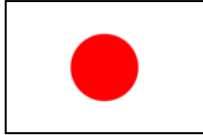
Fermi  $\gamma$   
 VERITAS  
 Super-K  $\nu$   
 IceCube Lab  
 IceCube Array: 86 strings, 80 sensors each, 5,300 optical sensors  
 DeepCore: a string optimized for low energies  
 Eiffel Tower: 324 meters  
 ICECUBE  
 PAMELA  $e^-, e^+, p, \bar{p}$   
 AMS

From Matthew Wood. SLAC



# XMASS

Single phase liq. Xe detector  
Dark Matter Search



**High Scalability**

**Phase I: FV100kg (856kg total) is on-going:  
Plan → 1ton (FV) → 10 ton (FV)**

XMASS-I: restarted in November, 2013 with a reduced background level

**Latest result from XMASS:  
Bosonic Super-WIMPS search**

**Phys. Rev. Lett. 113, 121301(2014)**

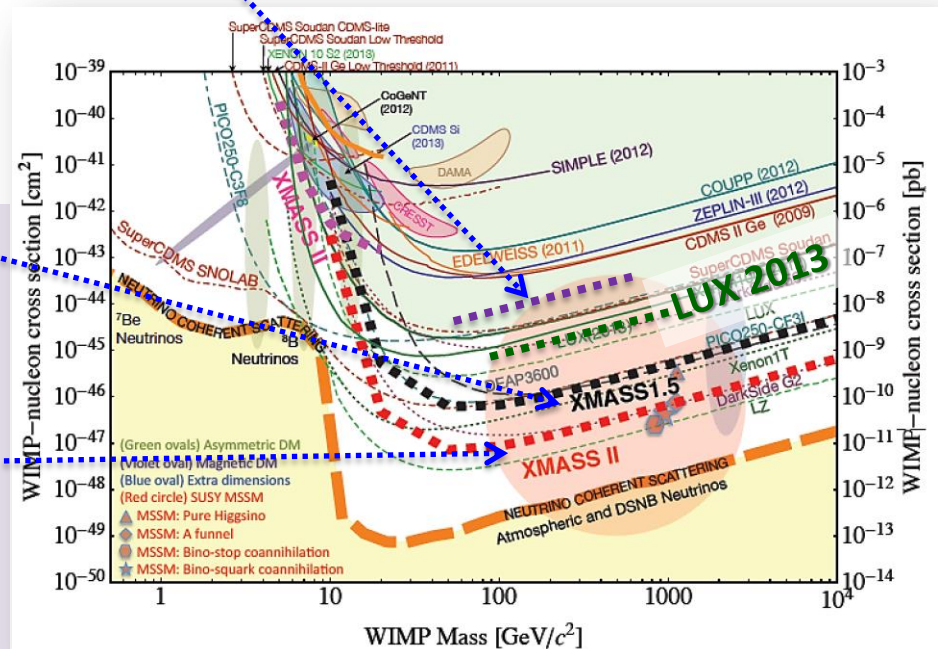
## Future

**XMASS1.5: (5 ton total, 1 ton fiducial mass)**

- sensitivity  $\sigma_{SI} < 10^{-46}$  cm<sup>2</sup> (at  $m_\chi \sim 100$  GeV)
- Operation in 2017: close to XENON1T at high mass

**XMASS-II: (24 ton total, 10 ton fiducial mass)**

- sensitivity  $\sigma_{SI} < 10^{-47}$  cm<sup>2</sup> (at  $m_\chi \sim 100$  GeV)
- Operation in 2019 < ? : close to LZ at high mass
- Double Beta decay and pp-<sup>7</sup>Be solar neutrinos



# KIMS+ Projects



## I. KIMS-CsI : Upgrade of CsI(Tl) crystal detector

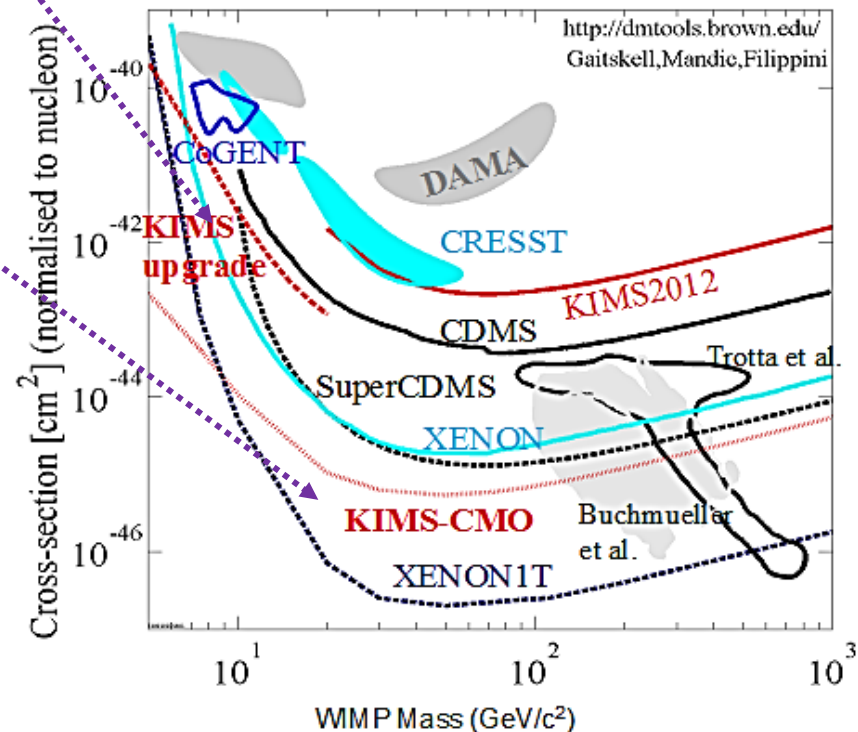
- Lower threshold  $\sim 1.5\text{keV}$ ,  $<1\text{dru}$ ,  $\text{counts}/(\text{keV kg day})$ .
- This will help to clear issues about the modulation signals of DAMA.

## II. KIMS-NaI : new NaI(Tl) detector

- Duplicate DAMA experiment with ultra-low background NaI(Tl) crystals.
- 200kg run in 2015-2016

## III. KIMS-CMO

- $^{\text{nat}}\text{Ca}^{\text{nat}}\text{MoO}_4$  crystals  $\sim 200$  kg year.
- High sensitivity in low mass WIMP.
- 2019-2022







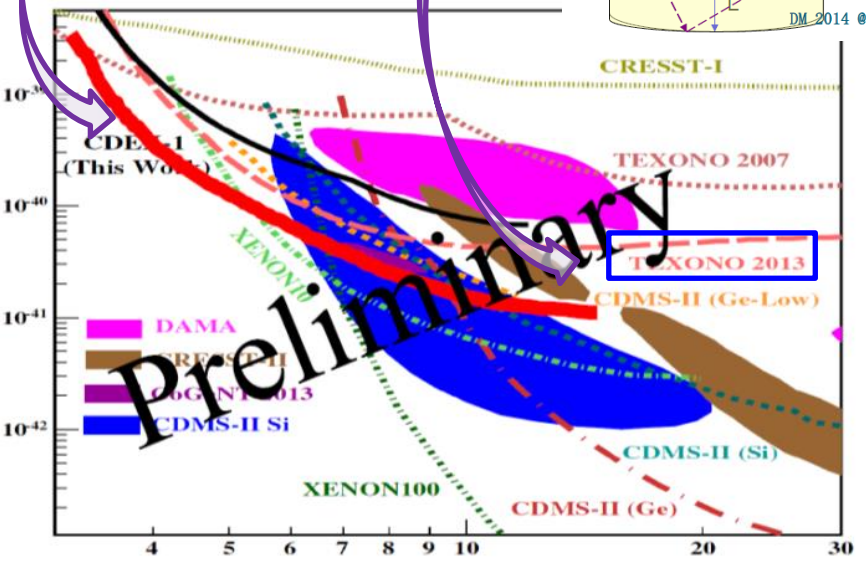
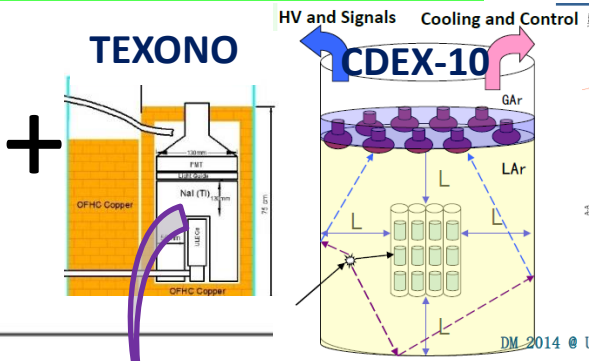
# PandaX goal

- PandaX: Particle AND Astrophysical Xenon TPC
- Build a state-of-art large-size xenon dual-phase TPC detector working at the lowest background possible
  - Used for both dark matter search and
  - 136Xe double beta decay search
- Two important features:
  - Emphasize light collection efficiency so as to enhance the sensitivity to low-mass WIMPs (stage 1)
  - Accommodate a ton-scale experiment (stage 2)

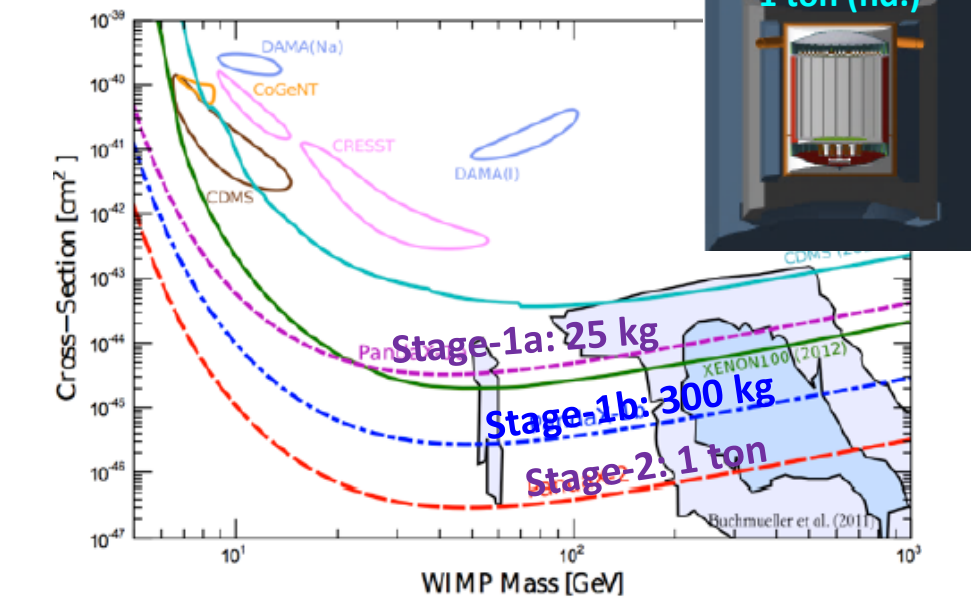
# China Dark matter EXperiment (CDEX)-

- Direct detection of cold dark matter with **Ton-scale PCGe** array with ultra-low energy threshold ( $<300\text{eV}$ ).
- Located at CJPL!

- 2005, Start 1kg-scale detector. **CDEX-1**
- 2011, 10kg-scale detector. **CDEX-10**
- 2015, 1T-scale PCGe array detector

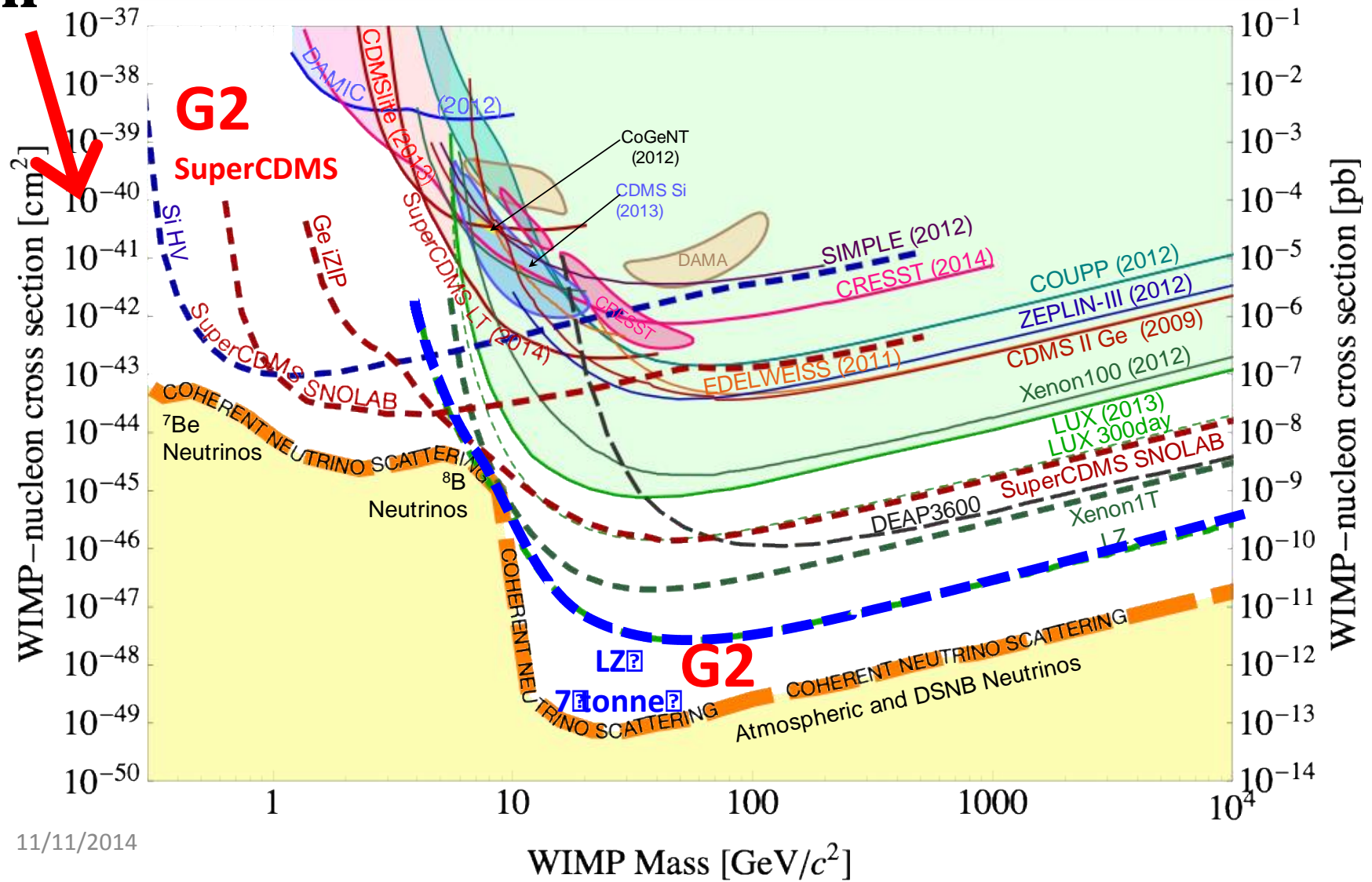


# 2014: under commissioning



$10^{-40}$   
 $\text{cm}^2$

# The Near Term Future

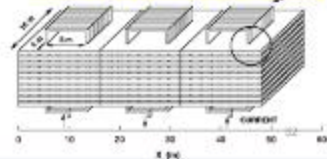
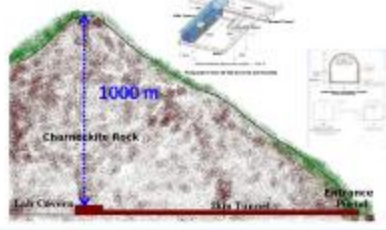




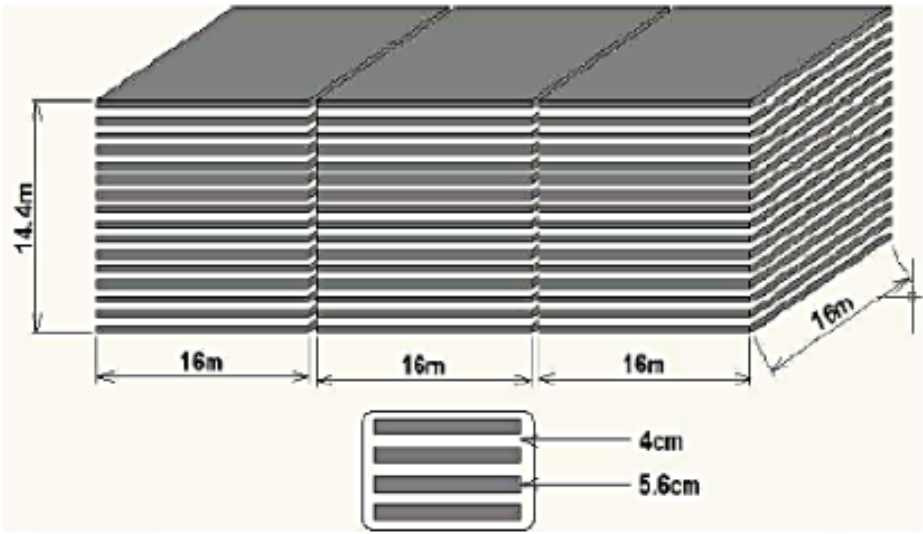
# INO : India-based Neutrino Observatory



50 kton magnetized iron module(s) with 30,000 channel RPC

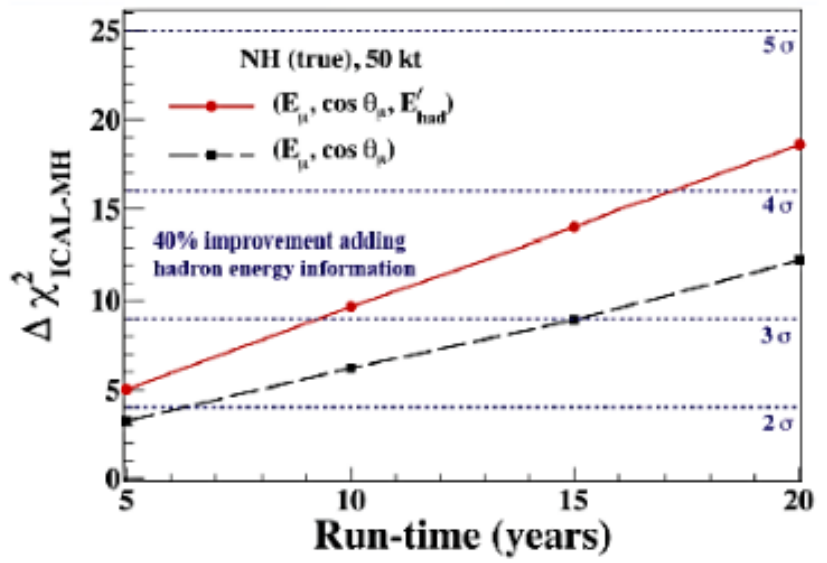


## INO ~2020- 50kton Iron Calorimeter

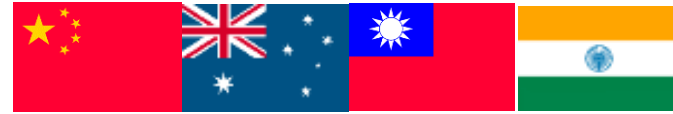


## PHYSICS WITH ATMOSPHERIC NEUTRINOS

- \* Reconfirm neutrino oscillations from distortion in  $L/E$
- \* Measure  $|\Delta m^2_{31}|$  and  $\sin^2 2\theta_{23}$
- \* Determine the neutrino mass hierarchy
- \* Determine the deviation of  $\theta_{23}$  from  $45^\circ$  and its octant
- \* Other (new) physics (sterile neutrinos, NSI, CPTV, LIV, Long range forces....)
- \* Very high energy neutrinos and muons



# KAGRA

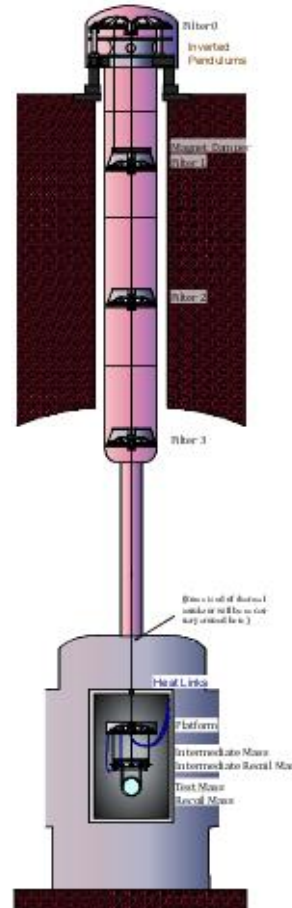


Japan (162), Korea (17), China (8),  
Australia (5), Taiwan (4), India (1), USA  
(14), Italy (13), Germany (1), France (1),  
Netherland (1), UK (1), Russia (1) : 229

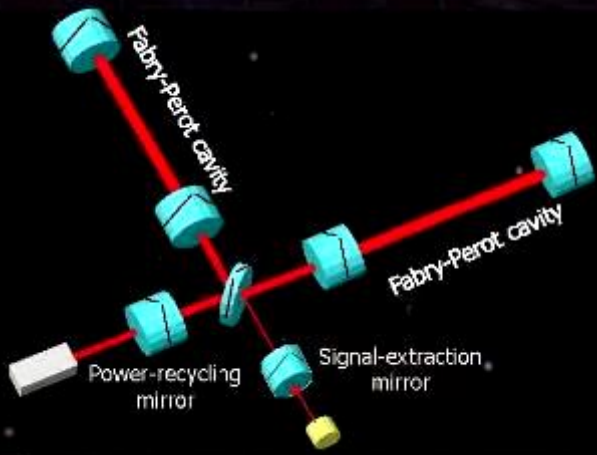
Excavation completed in March,  
2014



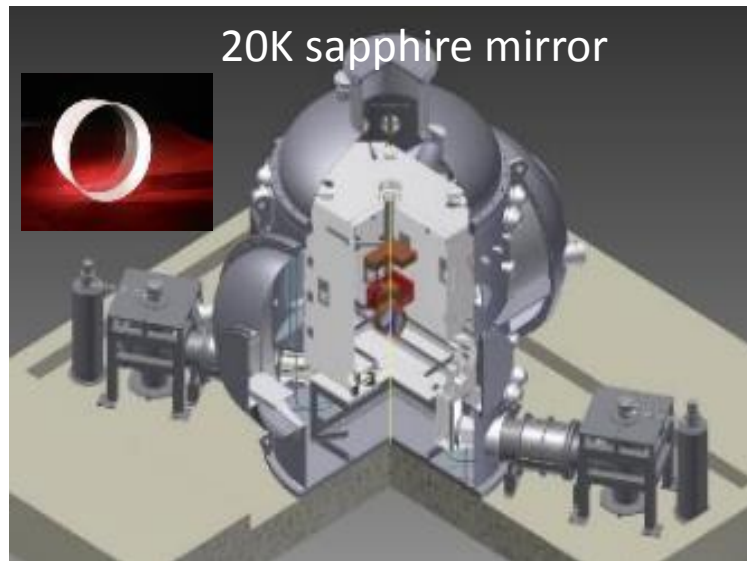
Double floors  
SAS system



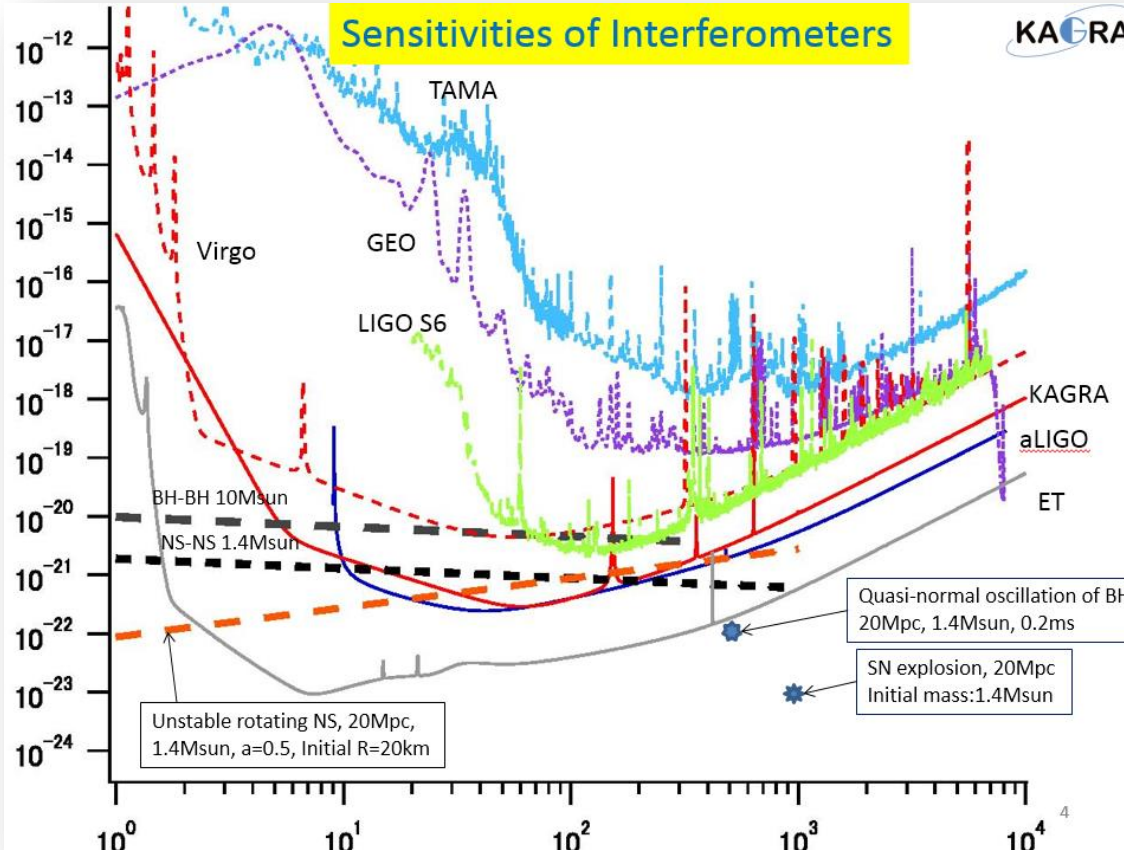
Optical configuration  
Fabry-Perot Michelson  
interferometer with RSE  
(Resonant-Sideband Extraction)



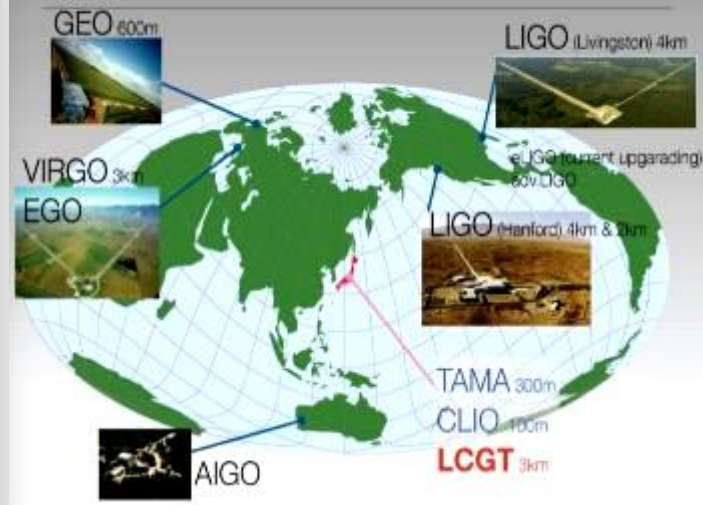
20K sapphire mirror



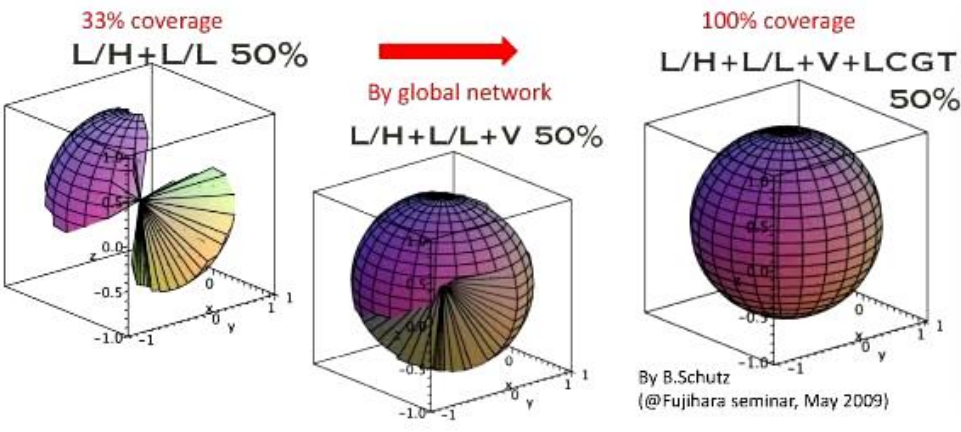
# Sensitivities of Interferometers



# World Wide Network of GW Observatories



LCGT and LIGO/H-LIGO/L-Virgo can cover almost 100% of the sky.



09 10 11 12 13 14 15 16 17 18 19





## LIGO

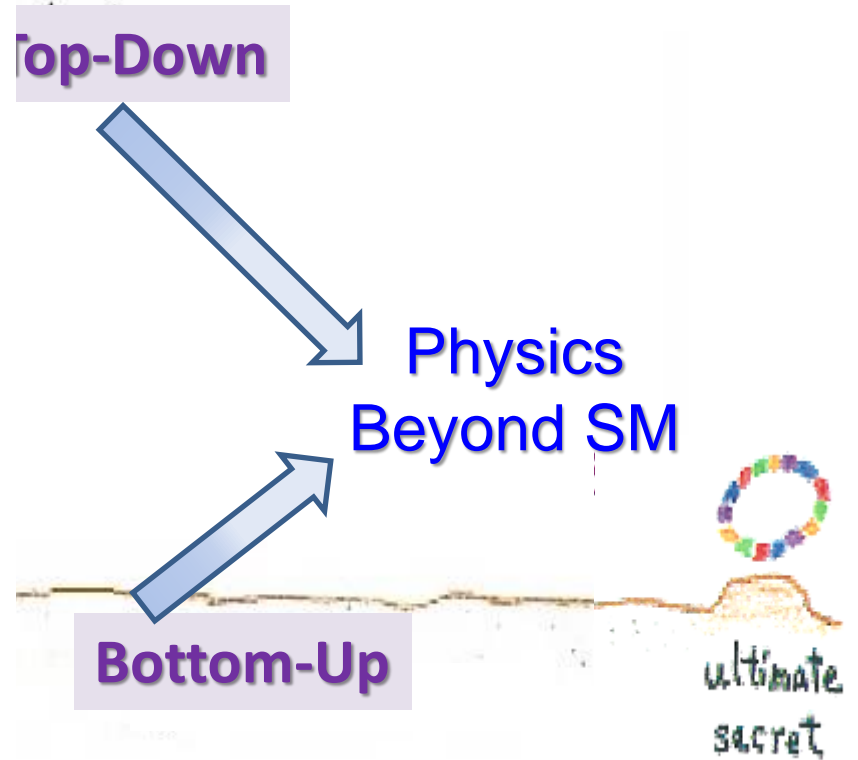


### Laser Interferometer Gravitational wave Observatory

- ❑ Gravitational Wave (GW) science holds the potential to address some of the key questions in fundamental physics, astrophysics and cosmology - General Relativity
- ❑ Interferometric GW detectors have been built in the USA (LIGO), Europe (GEO600 and VIRGO) and Japan (TAMA300).
- ❑ Originally LIGO was an international collaboration involving the LIGO-USA and the Australian consortium for gravitational astronomy (ALIGO)
- ❑ The project has now been formally offered to India
- ❑ 16 Indian institutions are expected to participate in the project.
- ❑ NSF USA will contribute towards setting up the facility

## 6. Summary

# Particle Physics Activity in Asia

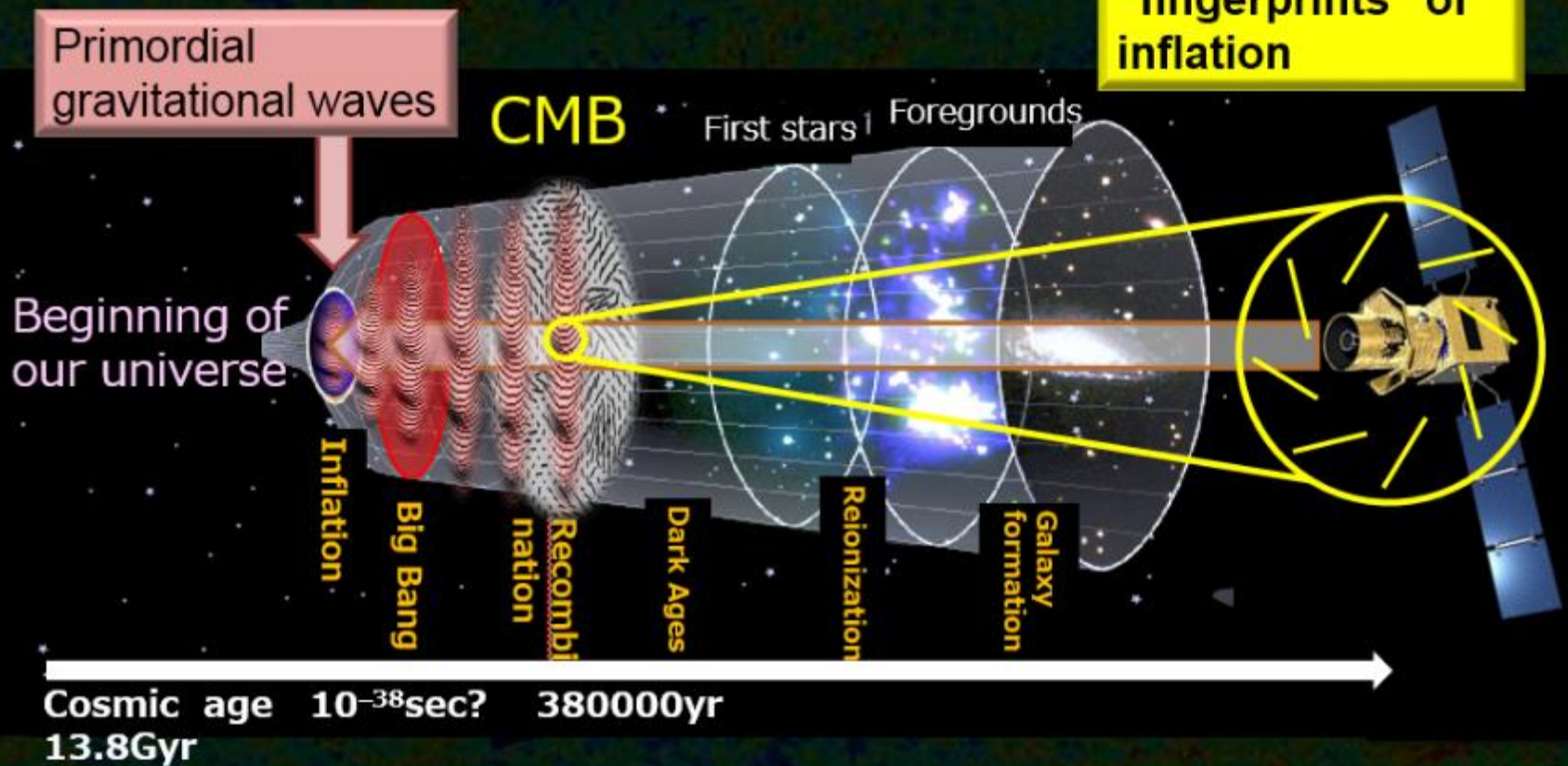


## 5. Astro-Particle Physics Projects

# Probing cosmic inflation with CMB polarization

Essence: CMB is an “experimental apparatus” to record primordial gravitational waves

**CMB B-mode**  
curl patterns as  
“fingerprints” of  
inflation





# KEK: CMB B-Mode Detection

QUIET, POLARBEAR, LiteBIRD

Cosmic Microwave Background (CMB) polarization B-mode is the smoking-gun evidence for **inflation** and **primordial gravitational waves**.

Experimental Cosmology and **Super High-Energy Physics !**



## KEK CMB Group Roadmap



QUIET (2008.9 First Light) :

**Atacama,  
Chile**

KEK, FNAL, Chicago,  
Caltech, Princeton,  
Columbia etc.

POLARBEAR  
(2012.1 First Light) :

**Atacama,  
Chile**

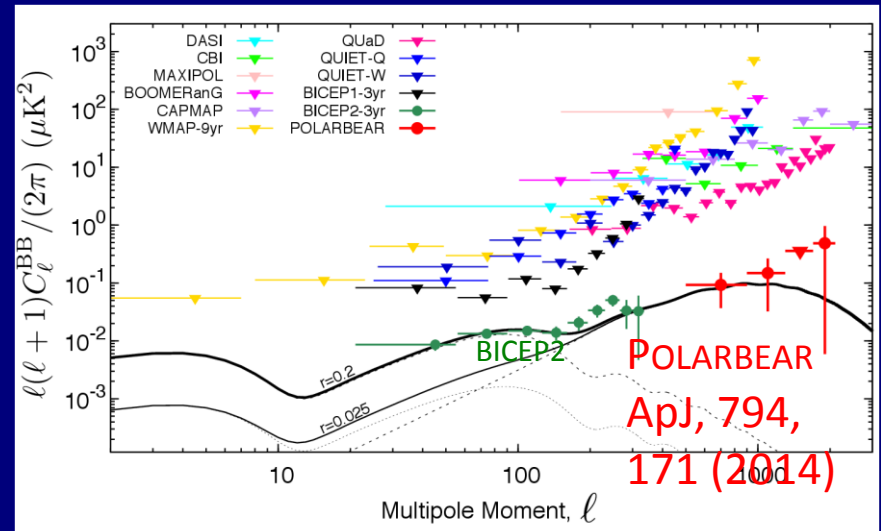
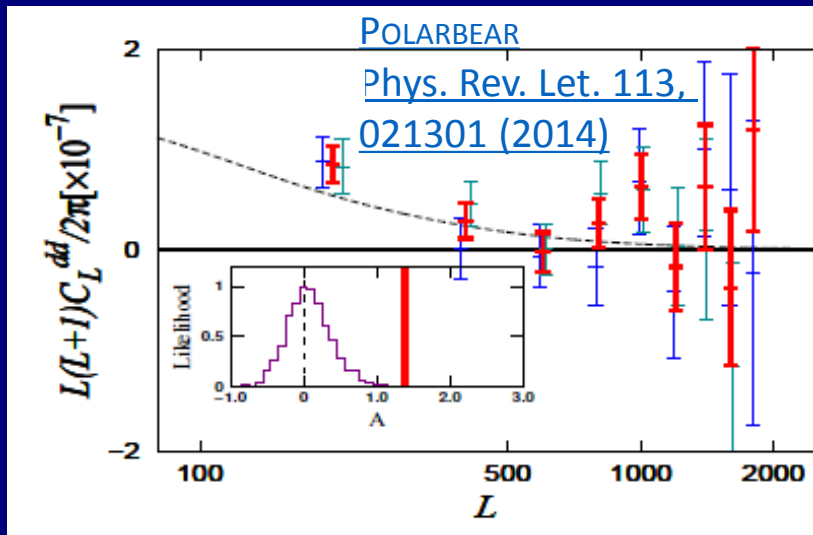
KEK, JAXA, Kavli IPMU, NIFS,  
UC Berkeley, LBNL, UCSD,  
Colorado, McGill, APC, Cardiff,  
SISSA, IC, Dalhousie etc.

POLARBEAR Group



# New Results from POLARBEAR

## FIRST DIRECT EVIDENCE FOR B-MODE POLARIZATION LENSING BASED ON PURELY CMB INFORMATION



4.7 $\sigma$  (two results combined)

Paving the way for

- Precise neutrino mass measurements
- Detection of inflationary gravitational waves