HEP and Neutrino Project status (Japan/Asia)

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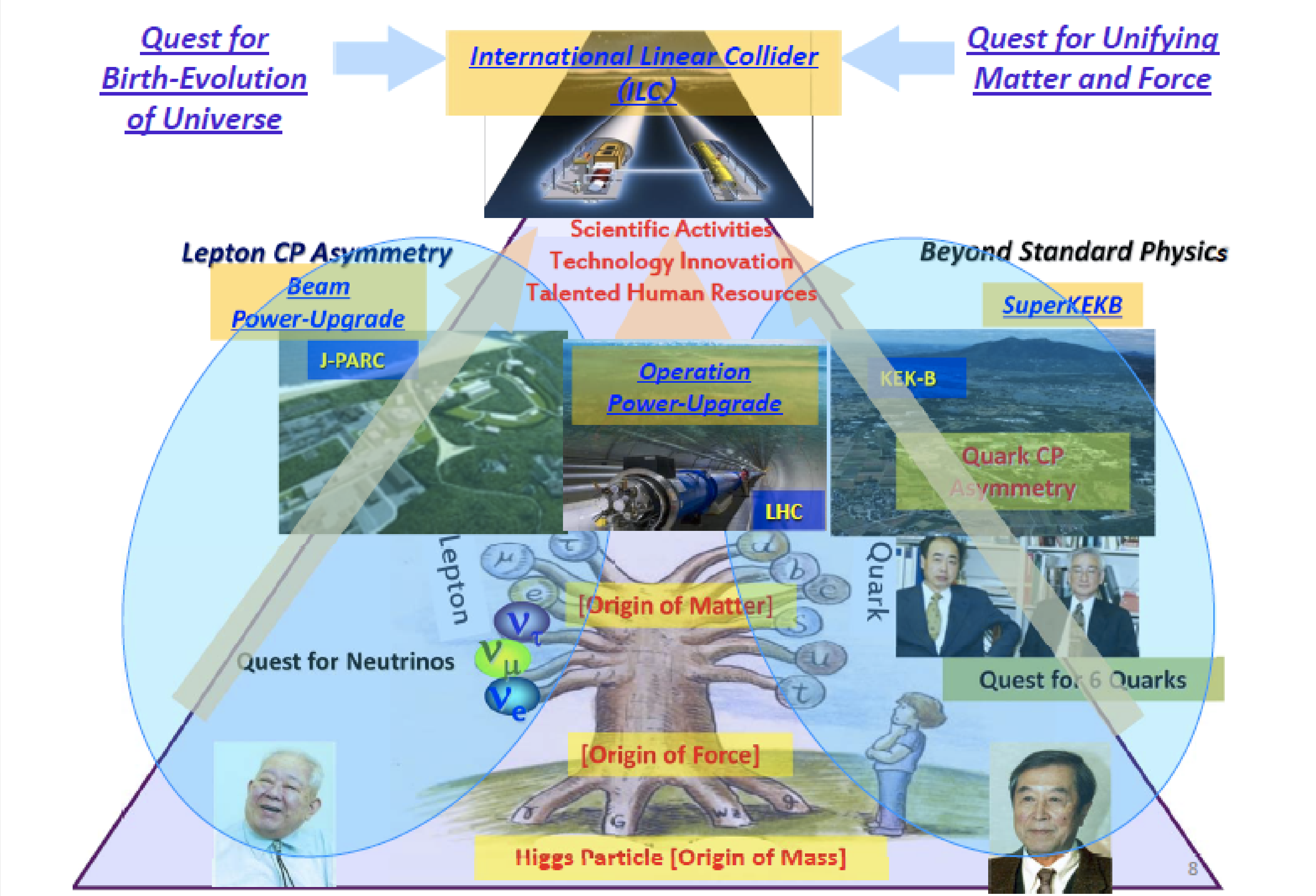
Open Meeting for the Hyper Kamiokande Project

August 22, 2012, KIPMU, Kashiwa , Japan

Contents

- HEP in Japan
  - SuperKEKB/Belle II
  - ILC project
  - Kaon and Muon rare decays at J-PARC
  - Neutrino projects in Japan (T2K, KamLAND-Zen)
- Neutrino projects in Asia
  - Daya Bay in China
  - RENO in Korea
  - INO in India

Thanks to Yifang Wang, Soo-Bong Kim and Naba Mondal.


Quest for Birth-Evolution of Universe
International Linear Collider (ILC)
Quest for Unifying Matter and Force
Scientific Activities
Technology Innovation
Talented Human Resources
Lepton CP Asymmetry
Beam Power-Upgrade
J-PARC
Operation Power-Upgrade
LHC
Beyond Standard Physics
SuperKEKB
KEK-B
Quark CP Asymmetry
Lepton
Quark
[Origin of Matter]
Quest for Neutrinos
Quest for 6 Quarks
[Origin of Force]
Higgs Particle [Origin of Mass]

Super KEKB

KEKB/Belle → SuperKEKB/Belle II

- Success of B-Factories: world Highest Luminosity
- confirmation of Kobayashi-Maskawa mechanism:

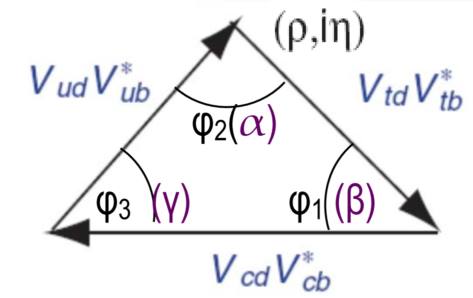
CP violation due to a complex phase in CKM matrix

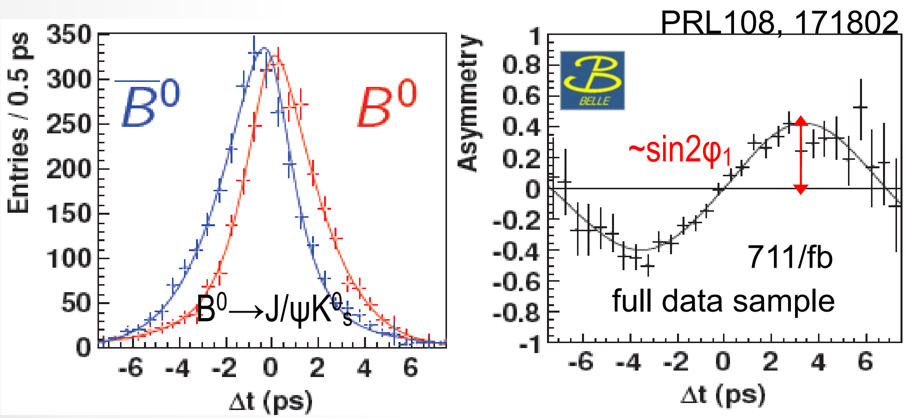
2001: Discovery of CPV in B mesons

2008: Nobel Prize for Kobayashi and Maskawa

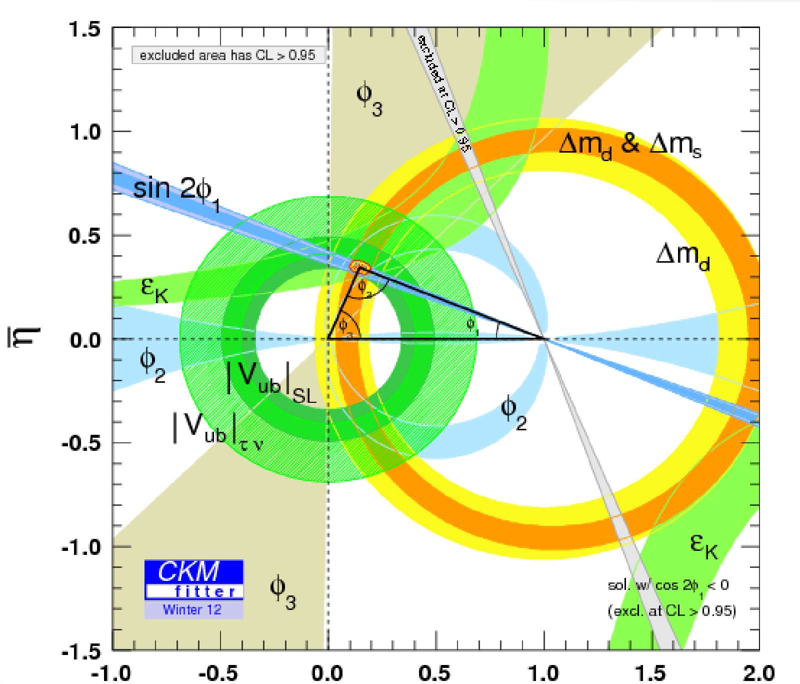
2011: Most precise sin2φ_1 from b→c$\underline{c}$s processes

Unitarity Triangle for B system





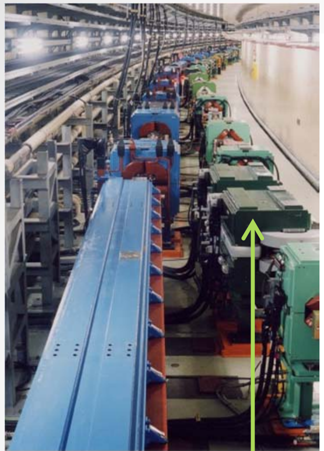
$$\sin 2\phi_1^{B\to(c\bar{c})K^0} = 0.67 \pm 0.02 \pm 0.01$$



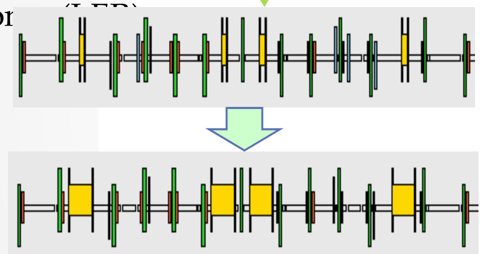
- 10 years of precise measurements of UT
- Hints of New Physics in flavor sector

SuperKEKB and Belle II

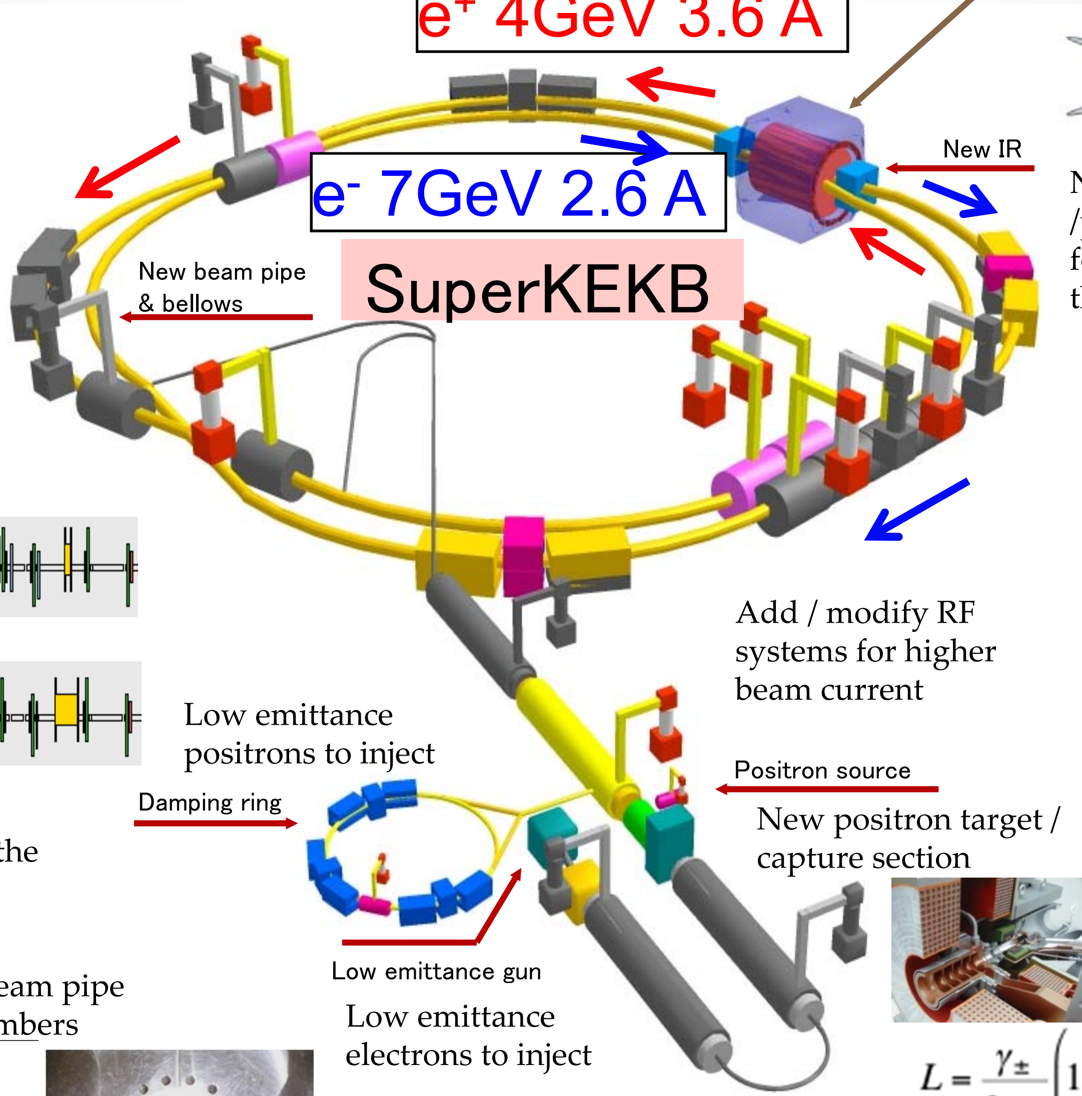
Belle II

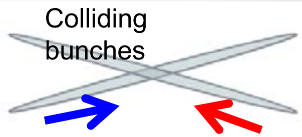


Replace short dipoles with longer



Redesign the lattices of HER & LER to squeeze the emittance





New superconducting /permanent final focusing quads near the IP

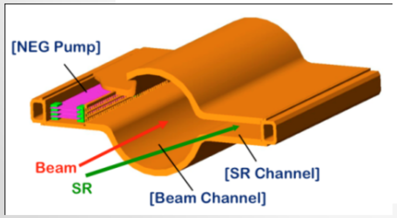
Add / modify RF systems for higher beam current

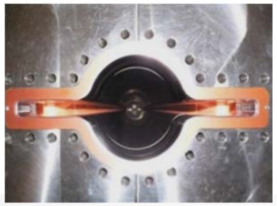
Low emittance positrons to inject

New positron target / capture section

Low emittance electrons to inject

TiN-coated beam pipe with antechambers

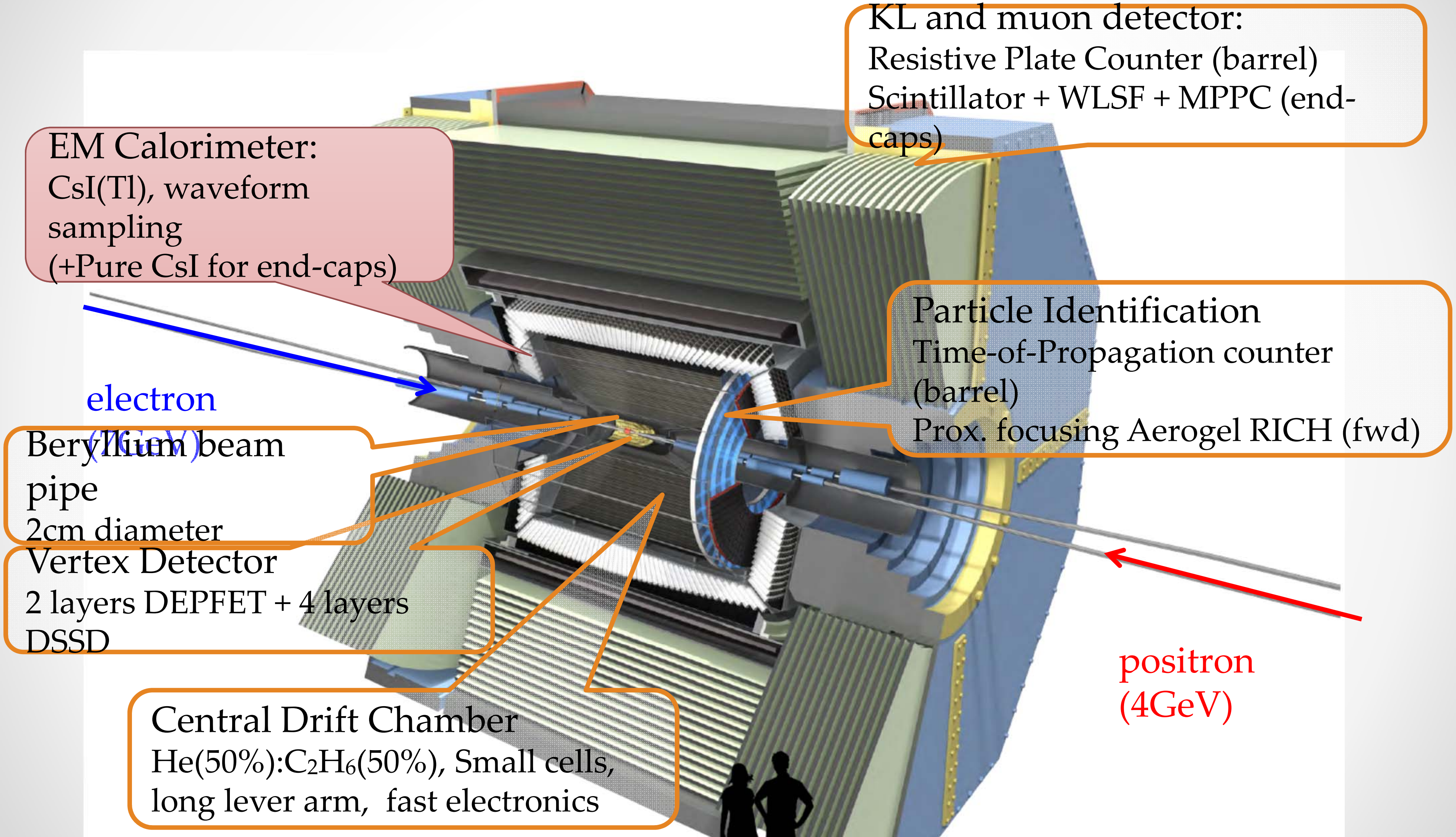




$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

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

Belle II Detector



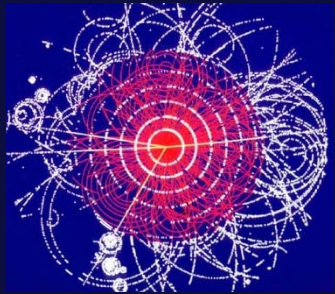
20 countries, 67 institutes, ~400 collaborators (as of Jul. 2012)

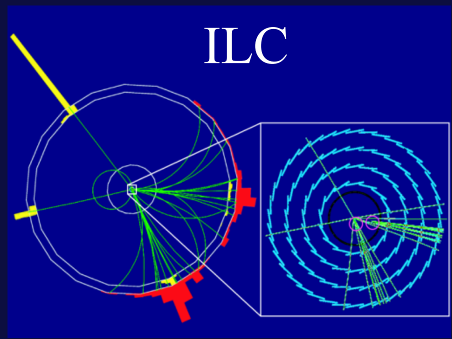
ILC project

ILC Physics

- LHC discovery of Higgs-like particle :
  - Beginning of new era of particle physics
    - Is it the Standard Model Higgs?
    - Where is the dark matter?
    - Is there really new physics at Terascale?
- ILC Higgs
  - Generate ~10K Higgs (can be tagged!)
    - 5 σ sensitivity in ~ 1 day (LHC : ~1 year)
  - Higgs Brs to a few % (LHC : a few 10s %)
    - e.g. $H \rightarrow cc$ (LHC : cannot)
  - Γ_{tot} to 5% (challenging at LHC)
  - CP to 3~4% (mix coeff)
- ILC top
  - m_t(msbar) to 100 MeV (LHC: ~ 1 GeV)
  - Anomalous ttZ, tbW, ttg coupl (LHC: hint of ttg only)
- ILC new physics
  - Composite Higgs scale to 45 TeV (LHC: ~7 TeV)
  - Anomalous WWV coupl (x10 better than LHC)

LHC



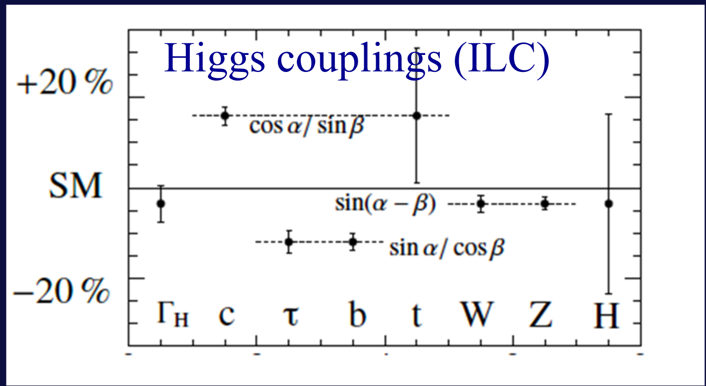


ILC: Simple and clean initial&final states

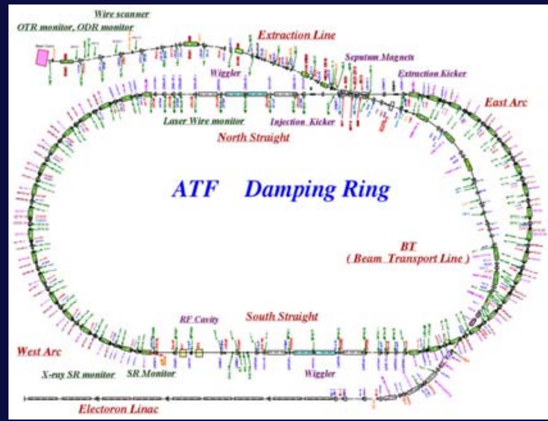
Specify Initial-state 4-momentum

& beam polarization : control intermediate state

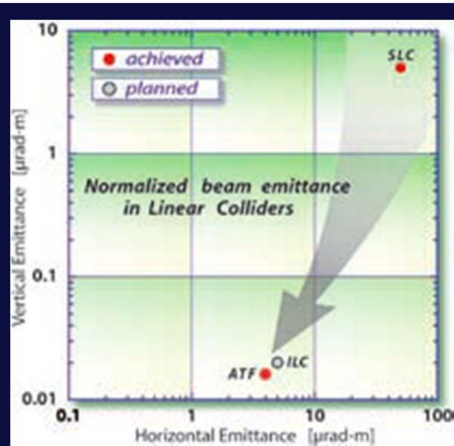
(e.g. e_R turns of $W^{\pm}$&A^0)



ILC Accelerator



- Ultra-small beam
  - Low emittance : KEK ATF (Accelerator Test Facility)
    - Achieved the ILC goal.
  - Small vertical beam size : KEK ATF2
    - Goal = 37 nm, 160 nm achieved
      - Limit is in measurement. No basic problem seen.
  - Stabilize the beam at nm scale: KEK ATF2
    - Feedback system successful (FONT)



- Main acceleration
  - Accelerating cavity
    - Spec: 31.5 MV/m ±(<20%)
    - 80% yield achieved (90% goal is in sight)
  - Cryomodule assembly
    - Combine cavities from all over the world
      - KEK S1-global successful

- ILC technology is now ~ready

ILC Detector

- Concept : Particle Flow
  - × 2 better jet energy resolution than LHC
  - Quark (b/c) flavor identification by vertexing

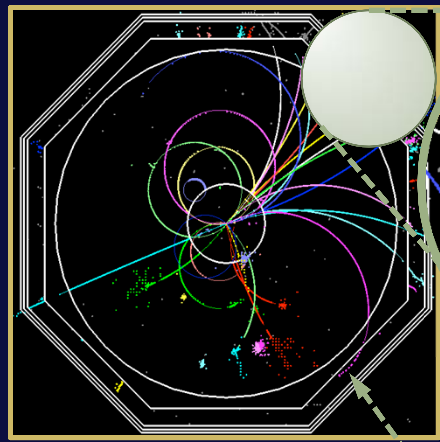
→ Requires high granularity

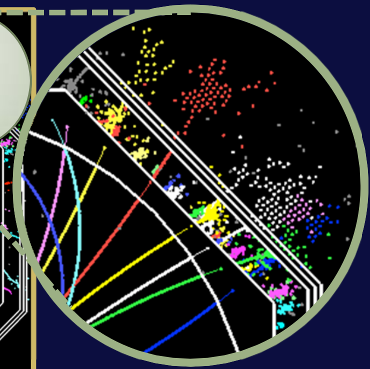
Vertexing (fine-pixel CCD)
- Pixel area 1/1000
- Material 1/30
- Vertex resolution 1/20

Main tracker (TPC)
- Material 1/6
- Momentum resolution 1/10

Calorimeter (Si-W and Schint+MPPC-W/Fe)
- Cell area 1/200

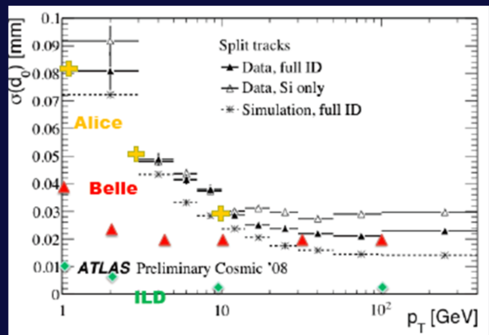
Detector elements:
Principles proven
Now R&D is in systematization

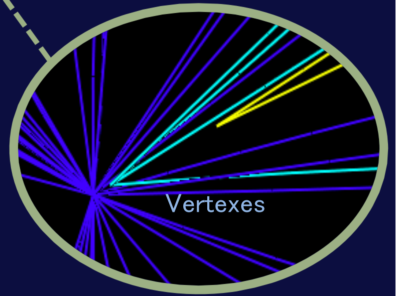




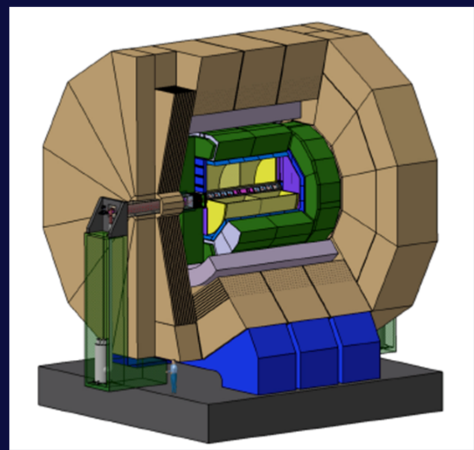
ILC: detect track of each particle

Vertex resolution





1 mm



ILD detector:
32 countries
850 signatories

ILC Status

- International

Up to ~ Feb 2013

ILC steering committee
- Global Design Effort (accelerator)
- Reesarch Directorate (physics&detector)

Lyn Evans

2013 ~

LC board
- LC directorate
  - ILC (accelerator)
  - CLIC (accelerator)
  - ILC+CLIC (physics&detector)

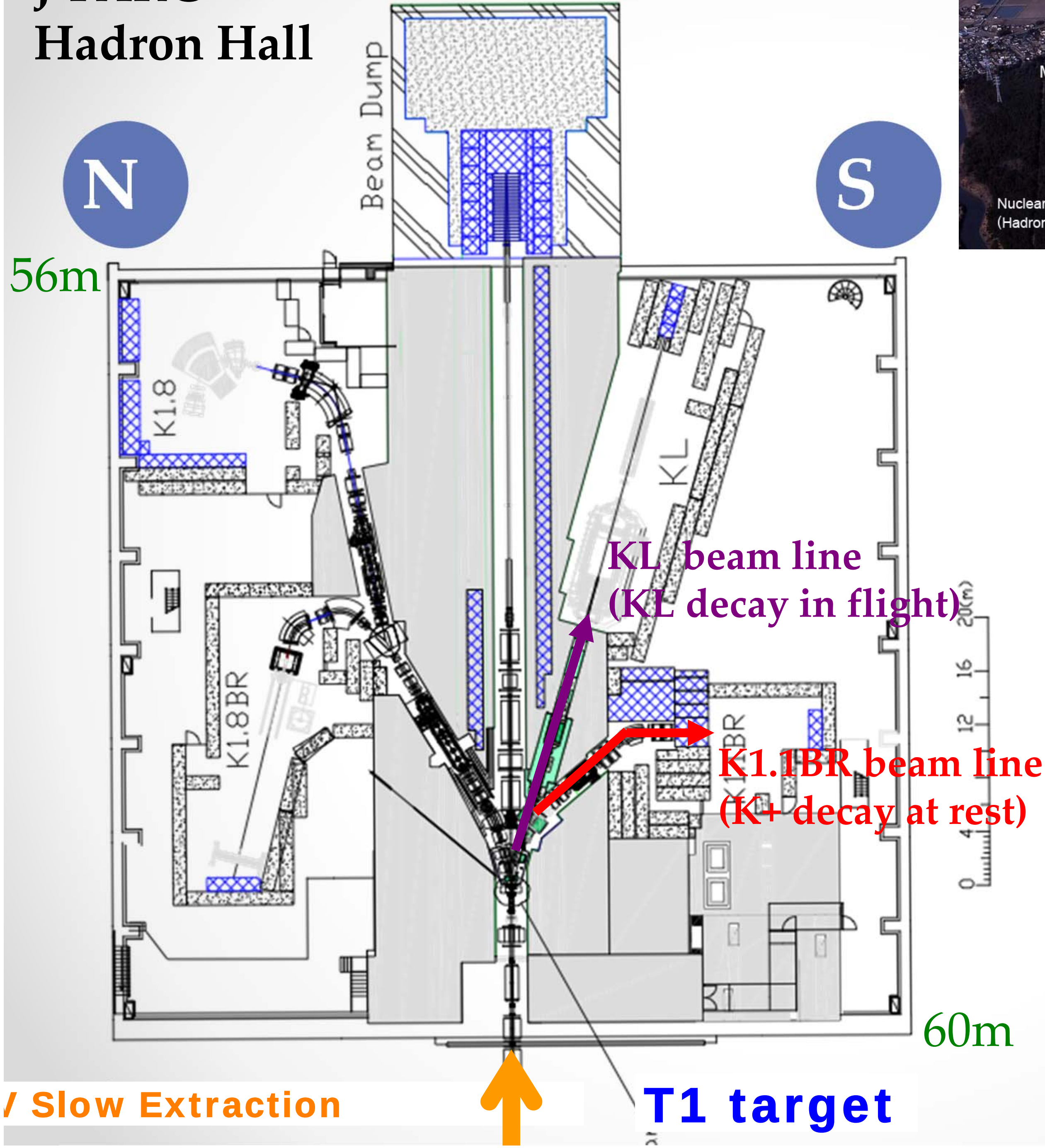
- Mandate of current org ends with production of TDR in end 2012

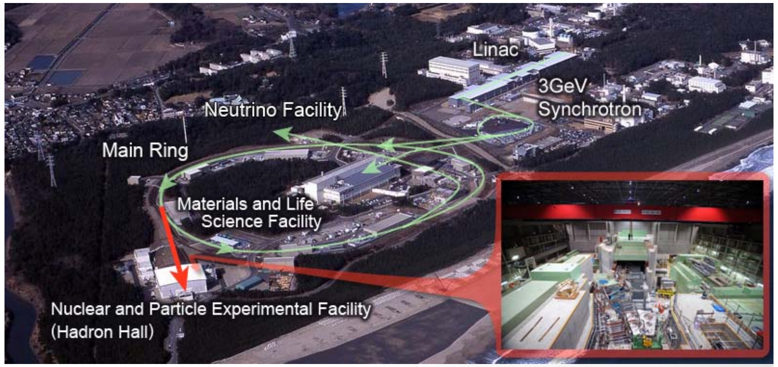
- New director selected (Lyn Evans)
- LD board being defined

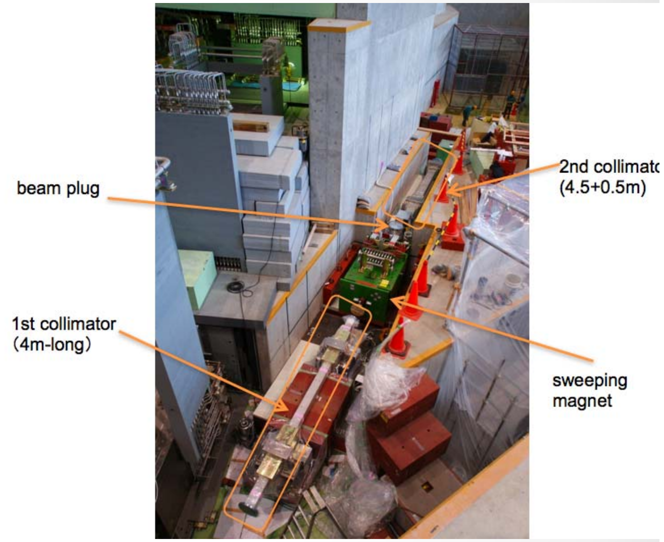
- Domestic
  - Japanese high-energy physics committee:
    - 'Japan should take the leadership role in an early realization of ILC' (2012 report)
  - Two candidate sites
    - Kyushu Sefuri mountains
    - Tohoku Kitakami mountains
  - Japanese government's third supplementary budget: 5 oku-yen to ILC

J-PARC : Kaon and Muon rare decays

J-PARC Hadron Hall

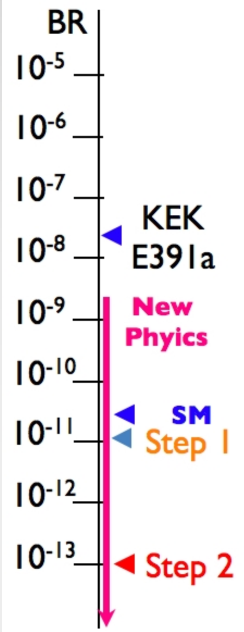


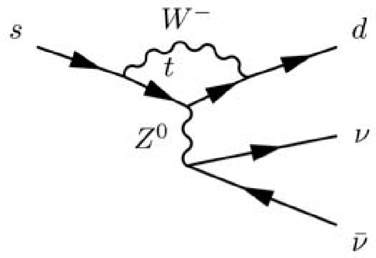


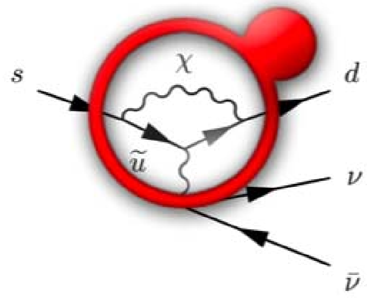


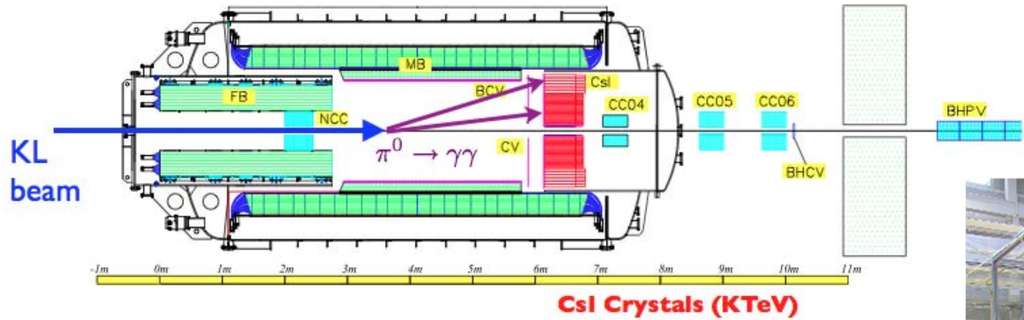
Rare Kaon Decay

$$K_L^0 \to \pi^0 \nu \bar{\nu}$$

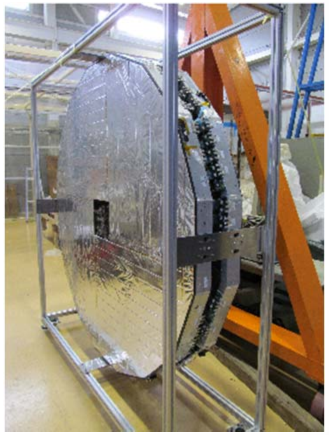




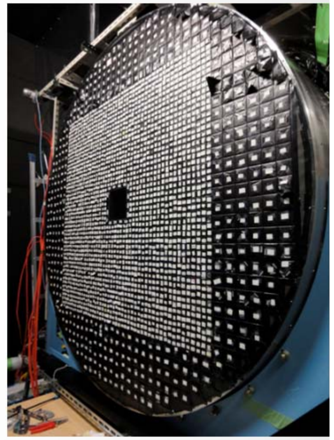




CV



CsI



KL beam line
(KL decay in flight)

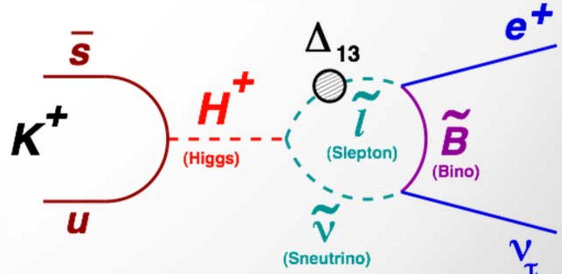
K1.1BR beam line
(K+ decay at rest)

E36 (LFU)

$$\Gamma(K^+ \to e^+\nu)/\Gamma(K^+ \to \mu^+\nu)$$

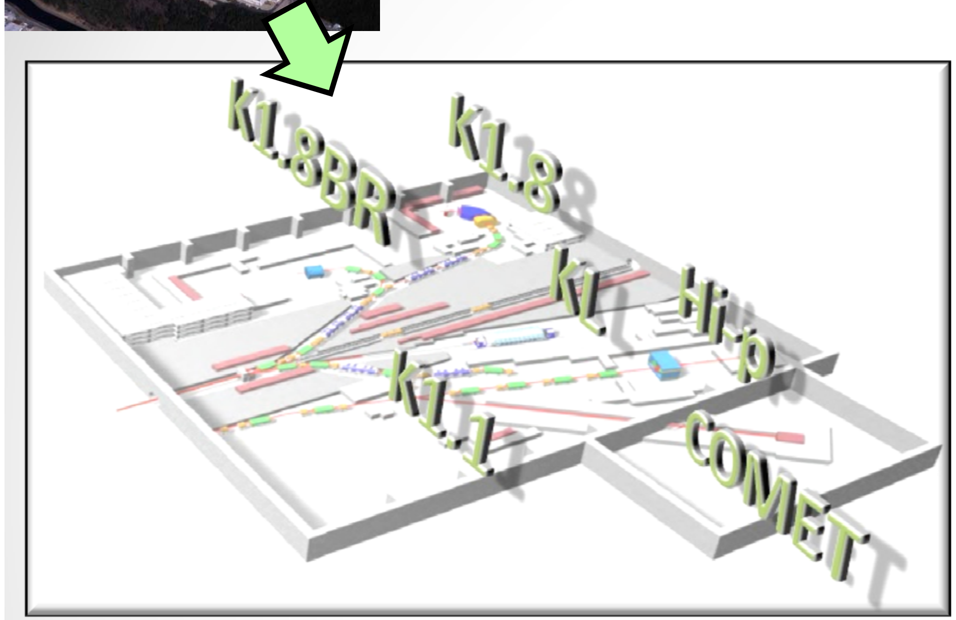
SM: $(2.477 \pm 0.001) \cdot 10^{-5}$

- $$R_K = \frac{\Sigma_i\, \Gamma(K \to e\nu_i)}{\Sigma_i\, \Gamma(K \to \mu\nu_i)} \simeq \frac{\Gamma_{SM}(K \to e\nu_e) + \Gamma(K \to e\nu_\tau)}{\Gamma_{SM}(K \to \mu\nu_\mu)}$$



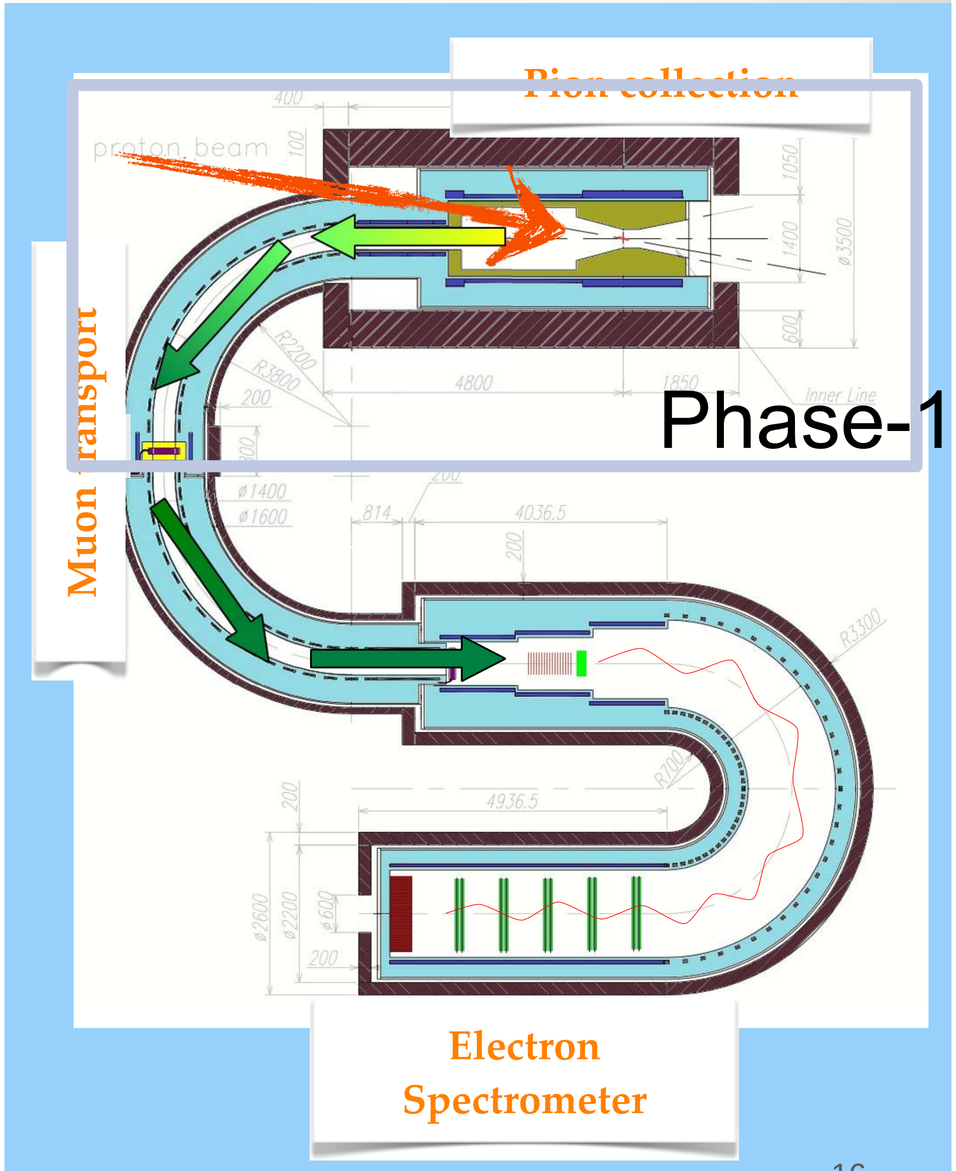
SUSY LFV loop

μ-e Conversion Experiment : COMET



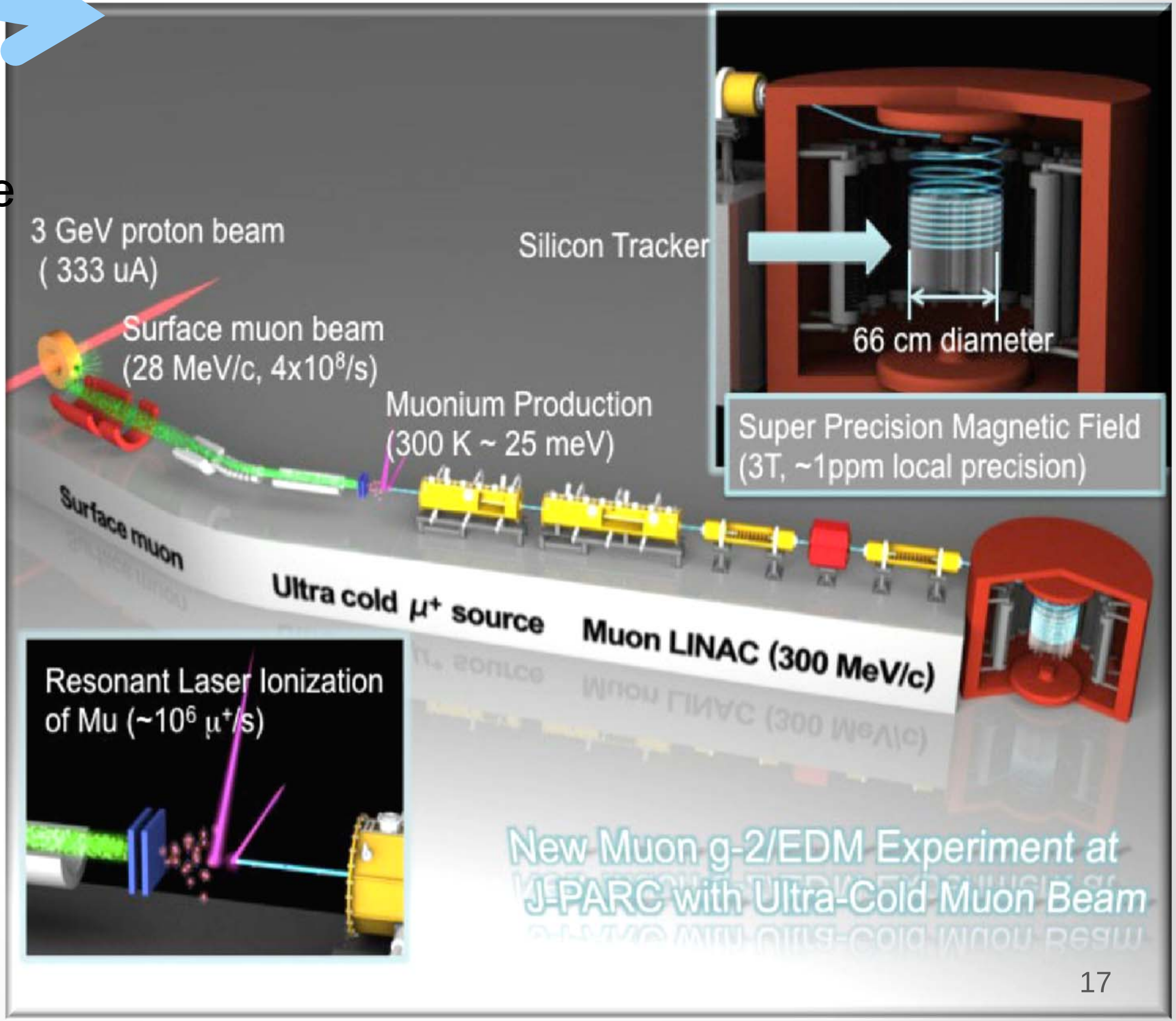
- COMET-1(Physics Run 2017-)
  S.E.S. 3×10^{-15}
- COMET full (Physics Run 2021-)
  S.E.S. 3×10^{-17}

c.f. Fermilab Mu2e (Physics Run 2021-)
S.E.S. 3×10^{-17}



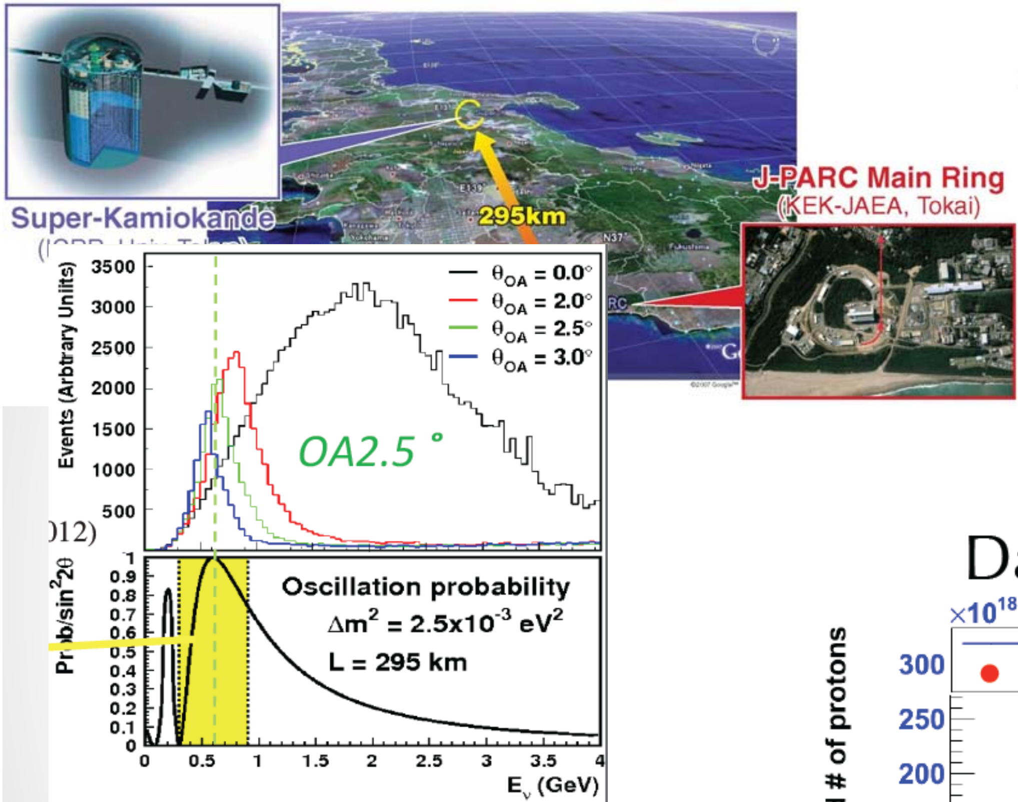
Muon g-2/EDM Measurement

- Novel technique to measure g-2/EDM off "magic" momentum
  - g-2 precision to be improved by x 5 → 0.1 ppm
  - EDM to be searched for at 5×10^{-21} e cm sensitivity
- Extensive R&D studies for early realization



Neutrino Projects in Japan

T2K experiment

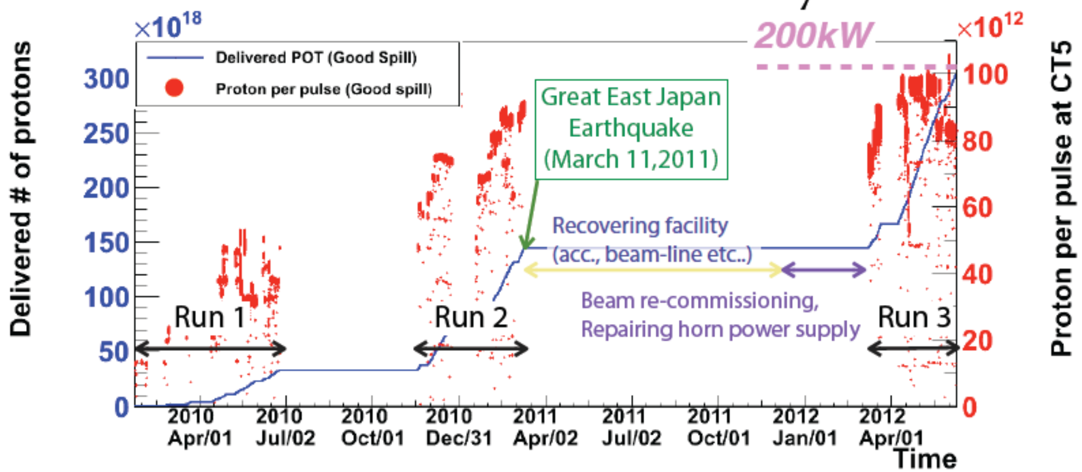


- Started data taking in Jan 2010
- **Resumed data taking in Mar. 2012**
- New results w/ data until June 9, 2012 (**3.01×10^{20}pot**)

- Off-axis ν_μ beam @ ~600MeV from J-PARC 30GeV MR
  - 200kW achieved (>100T p/pulse)
- Super-Kamiokande @ 295km
- Main physics goals
  - **νe appearance**
  - ν_μ disappearance

K.Sakashita

Data collected and analyzed



Run1 + 2 (2010-2011)
1.43×10^{20} p.o.t.

* ND280 Run1+2 data is used for oscillation analysis

Run3 (2012) : 1.58×10^{20} p.o.t

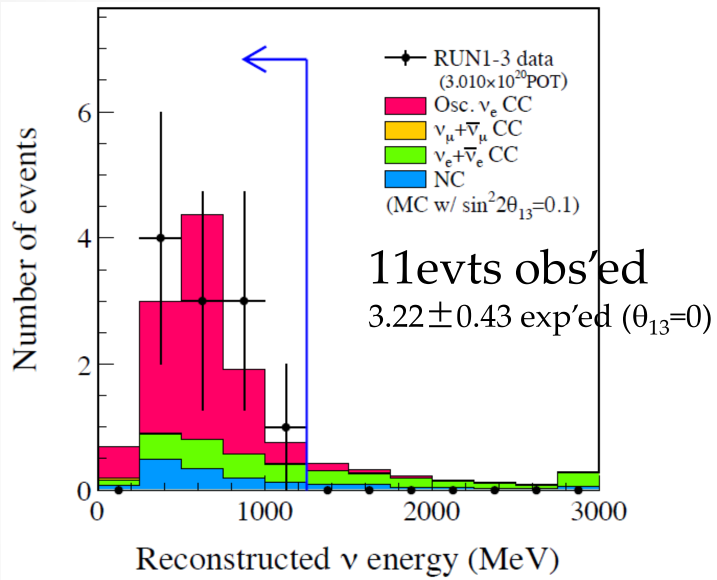
* including 0.21×10^{20} p.o.t. with 200kA horn operation (13% flux reduction at peak) (250kA horn current for nominal operation)

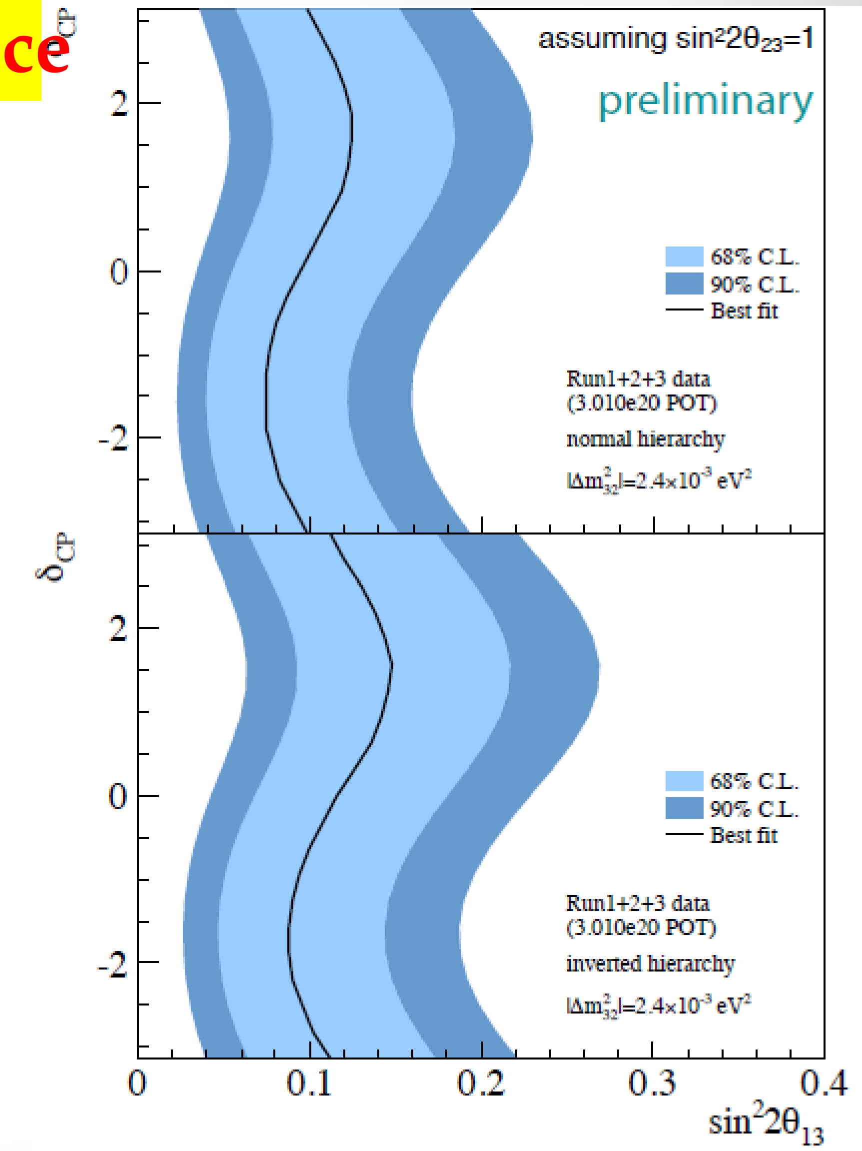
* ND280 Run3 data is checked and consistent with Run1+2

Data for today's talk (full data set up to now) = 3.01×10^{20} p.o.t.
(18% of increase from Neutrino2012)

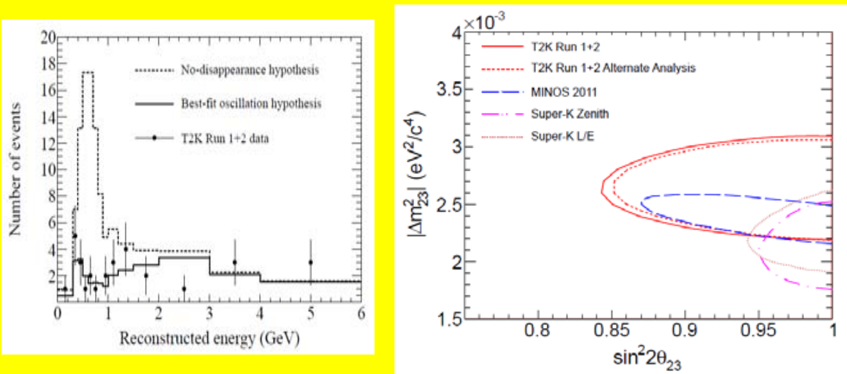
T2K results

3.2σ evidence of ν_e appearance



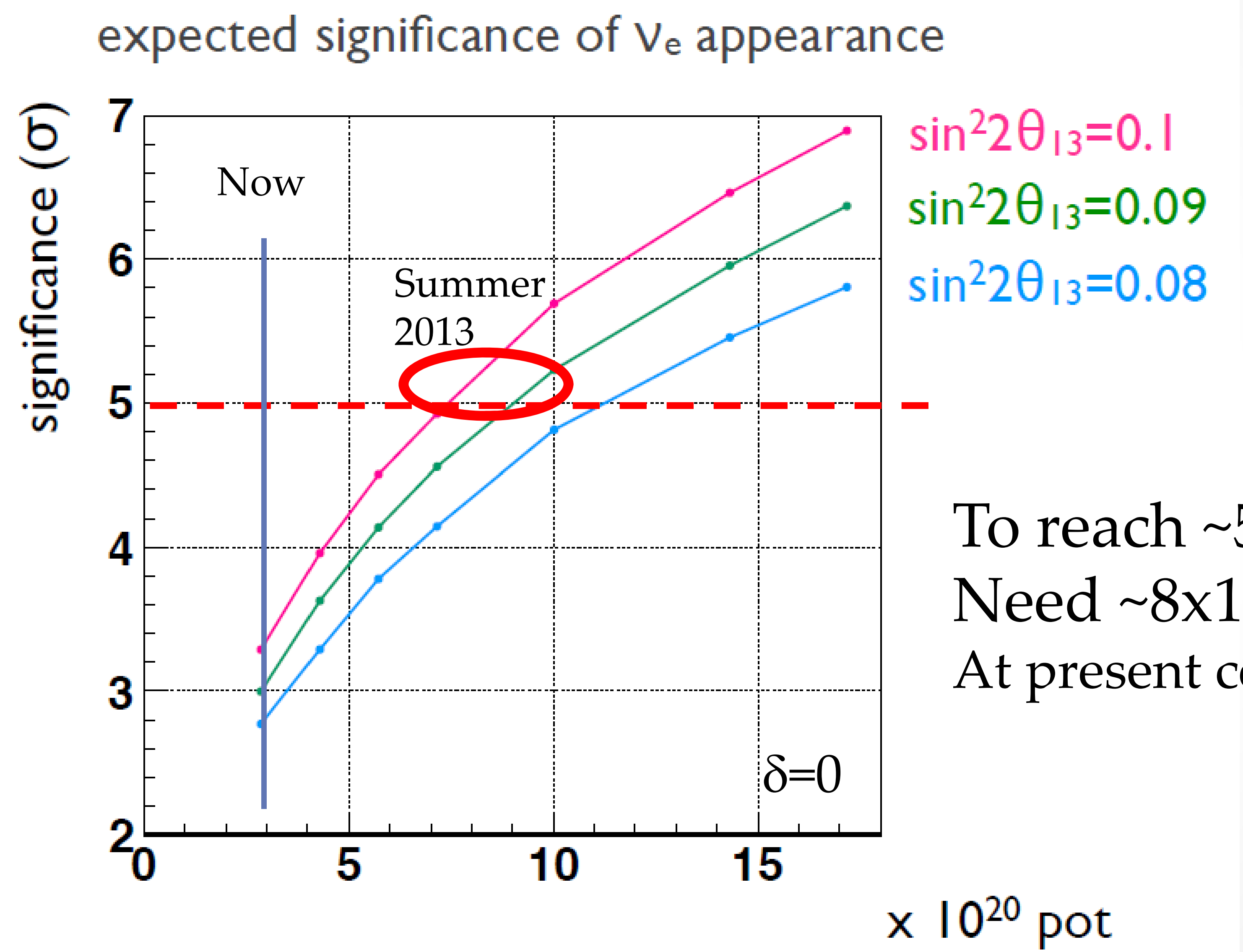


ν_μ disappearance 1.43x10^20 pot



Phys. Rev. D 85, 031103(R) (2012)

T2K Near term expected sensitivity



To reach ~5σ level

Need ~$8\text{x}10^{20}$POT

At present central value

Precision measurements of appearance and disappearance

Acc ν_e appearance measurement

➔ $P_{\mu\rightarrow e}=f(s_{12}s_{23}s_{13}s_\delta)$

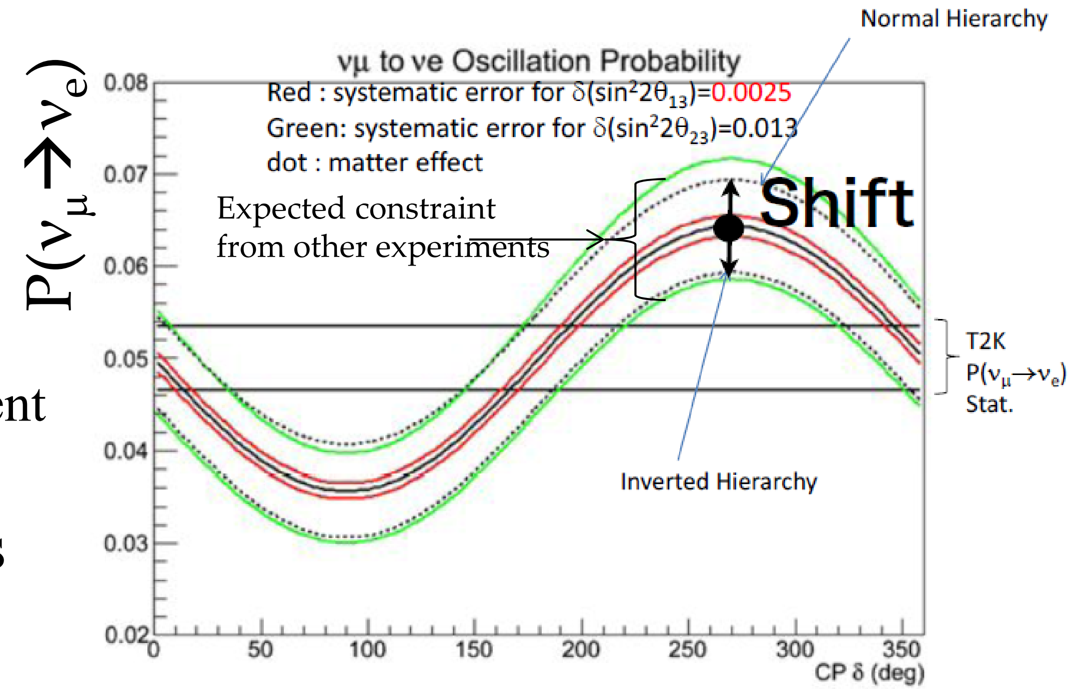
ν_μ disappearance measurement

➔ Precise θ_{23}

Reactor $\overline{\nu}_e$ disappearance measurement

➔ Precise θ_{13}

➡ Could give hint on mass hierarchy and δ_{CP}



Approved POT (~8x10²¹pot)
~750kW x 5x(1e7sec)

G.Fogli@Nu2012

Fractional 1σ accuracy [defined as 1/6 of ±3σ range]

δm^2	$\sin^2\theta_{12}$	$\sin^2\theta_{13}$	$\sin^2\theta_{23}$	Δm^2
2.6%	5.4%	13%	13%	3.5%

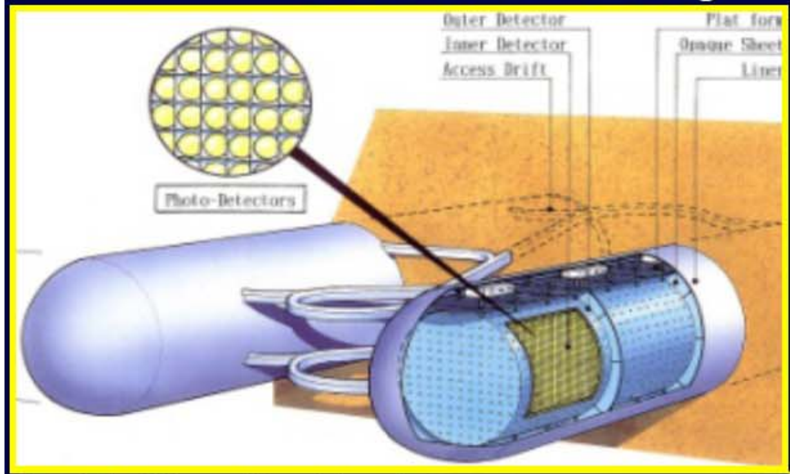
Already similar precision!

Improving precision of both $P(\nu_\mu\rightarrow\nu_e)$ and θ_{23} are important

Future LBL plans using J-PARC

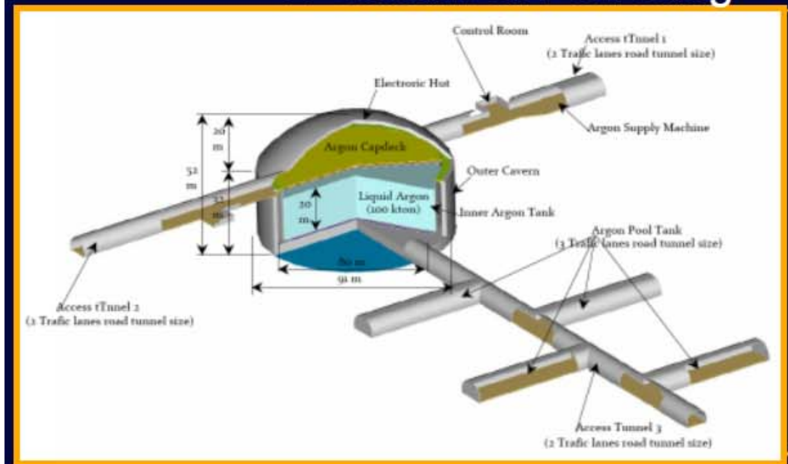
Current: T2K
J-PARC ~0.75MW
+ 50kt WC @ 295km 2.5°

J-PARC+HK @ Kamioka
L=295km OA=2.5deg

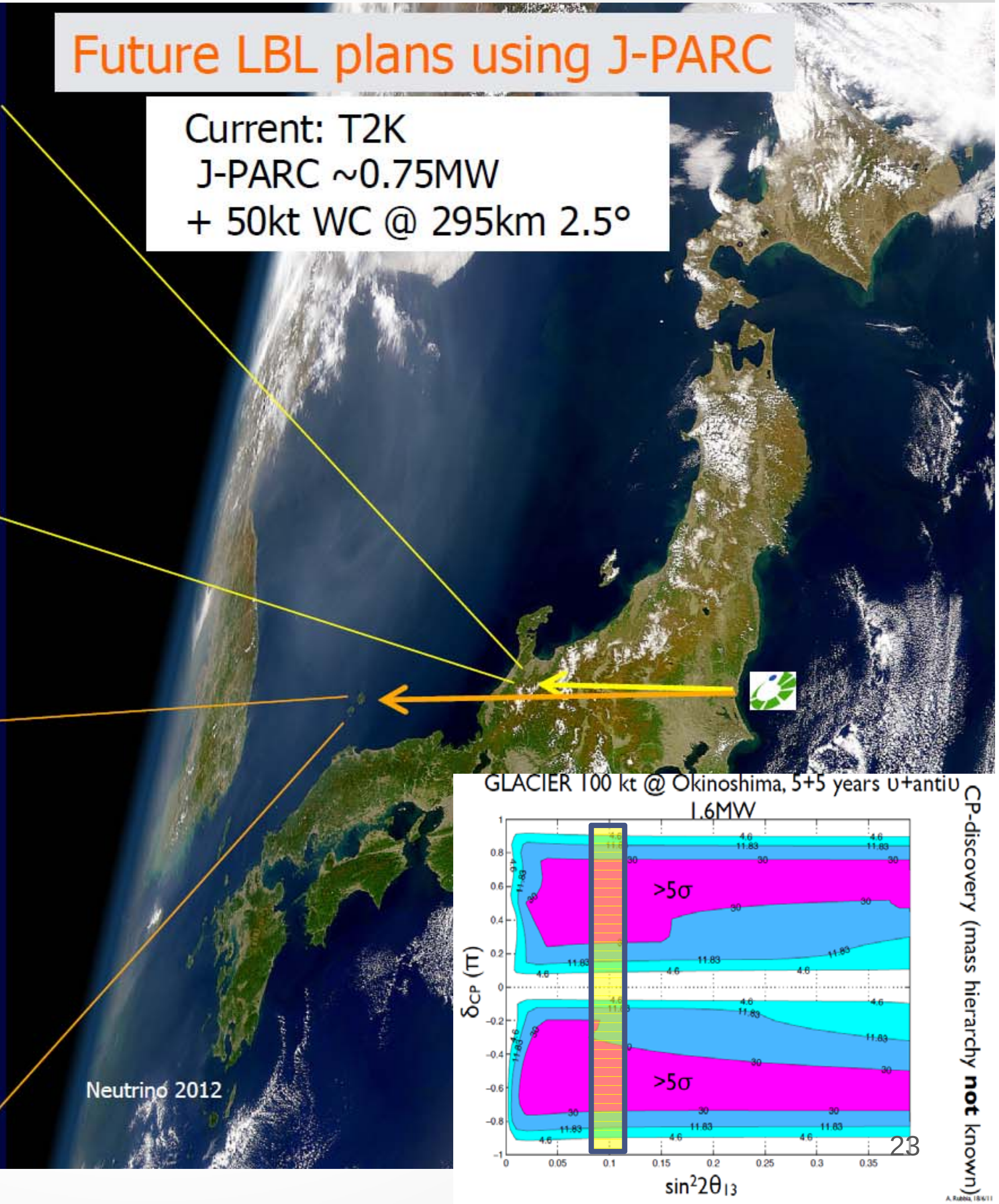


LoI: The Hyper-Kamiokande Experiment
arXiv:1109.3262v1

J-PARC+LAr @ Okinoshima
L=658km OA=0.78deg

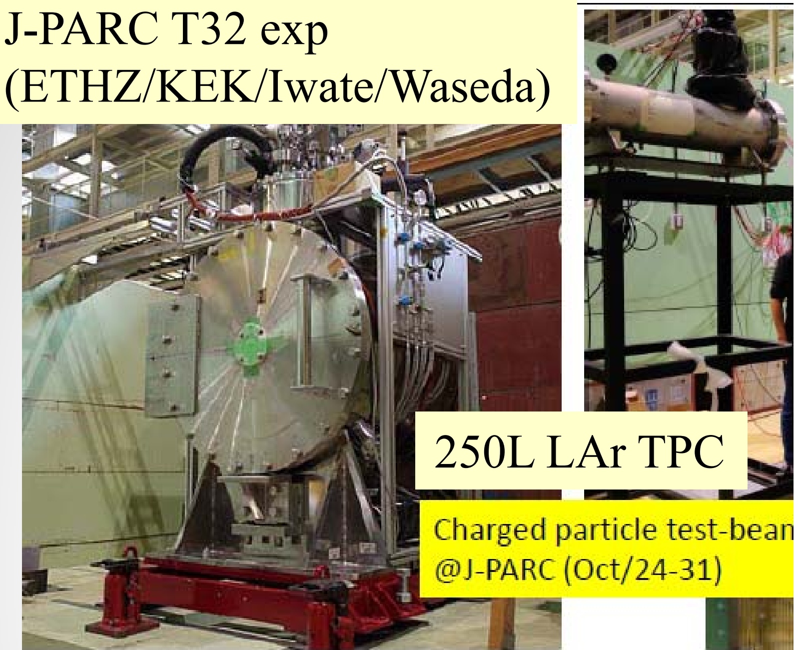


J-PARC P32 (LAr TPC R&D), arXiv:0804.2111



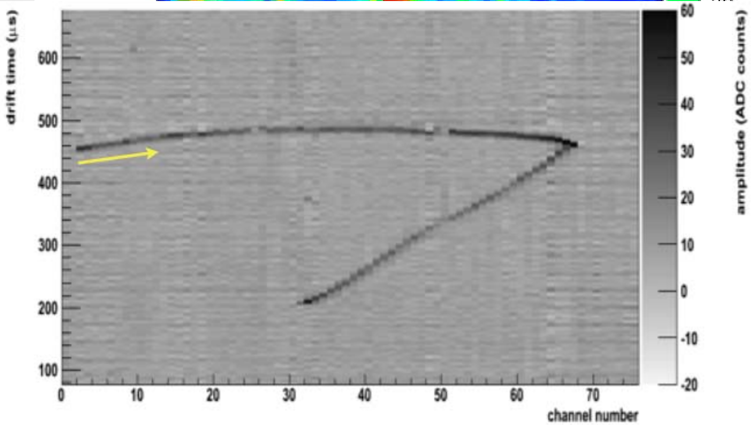
LiqAr TPC R&D

J-PARC T32 exp
(ETHZ/KEK/Iwate/Waseda)



250L LAr TPC

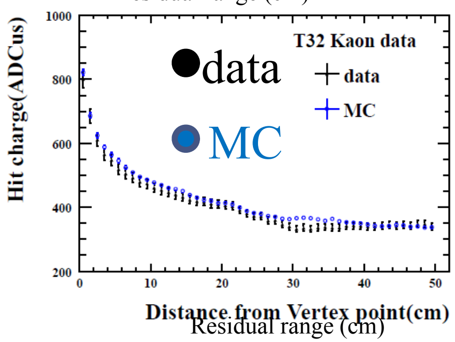
Charged particle test-beam
@J-PARC (Oct/24-31)



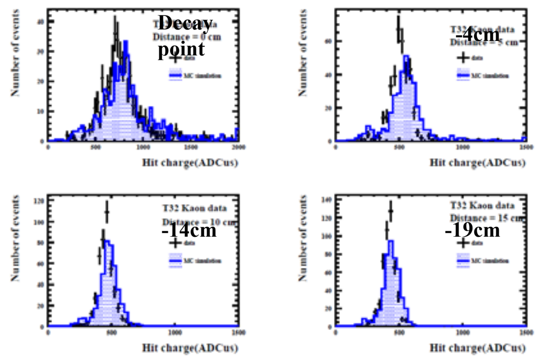
World largest Kaon sample ever taken by Lar TPC

Event Category	No. of events
K^+ 800 MeV/c with degrader → 540 MeV/c	7,000
K^+ 800 MeV/c with degrader → 630 MeV/c	40,000
K^+ 800 MeV/c with degrader → 680 MeV/c	35,000
π^+ 200 MeV/c	70,000
e^+ 800 MeV/c	2,500
P 800 MeV/c	1,500
e^+ 200 MeV/c	10,000
π^+ dominant 800 MeV/c	~ 3,000
total	~170,000

Charge / strip as a function of
Residual range (cm)



Kaon dQ/dx distributions



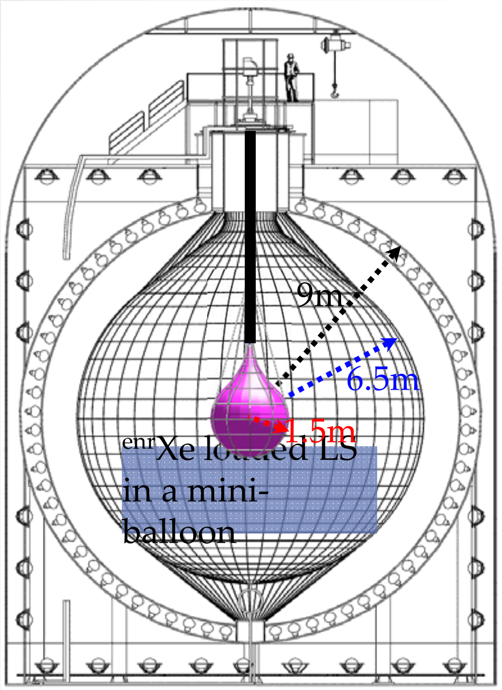
Charge / strip

Experimentally measured performance of Liq Ar TPC are well reproduced by simulation

- ➔ Applicable for predicting performance of Large detector

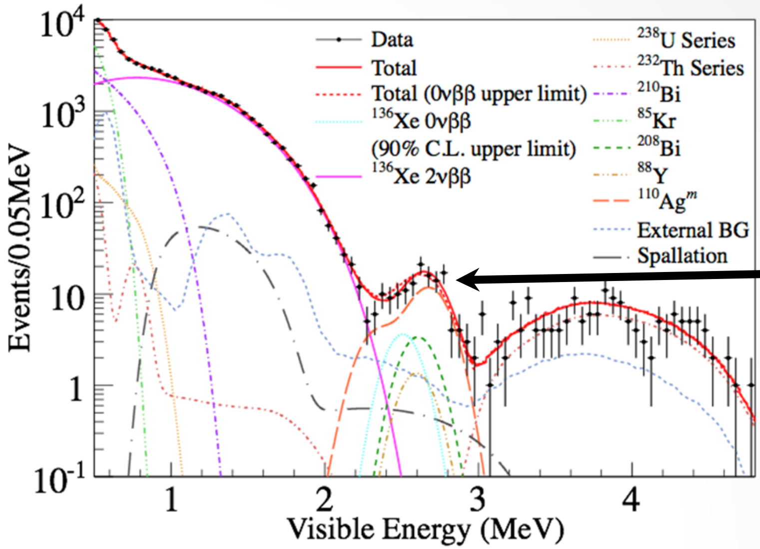
KamLAND-Zen

Zero Neutrino double beta decay search



- running detector
  → relatively low cost and quick start
- huge and clean (1200m^3, U: 3.5x10^{-18} g/g, Th: 5.2x10^{-17})
  → negligible external gamma
- Xe-LS can be purified, mini-balloon replaceable
  if necessary, with relatively low cost
  → highly scalable (up to several tons of Xe)
- No escape or invisible energy from β, γ
  → BG identification relatively easy
- anti-neutrino observation continues
  → geo-neutrino w/o japanese reactors

1st run with ~320kg 90% enriched ^{136}Xe
results from initial 38.5kg-yr data



unexpected impurity ^{110m}Ag found, to be removed by the ongoing purification, ~80meV sensitivity expected

$\langle m_{\beta\beta} \rangle$<0.26~0.54 eV @90% C.L.

quickly started and running a forefront race

planned improvement (FY2013)

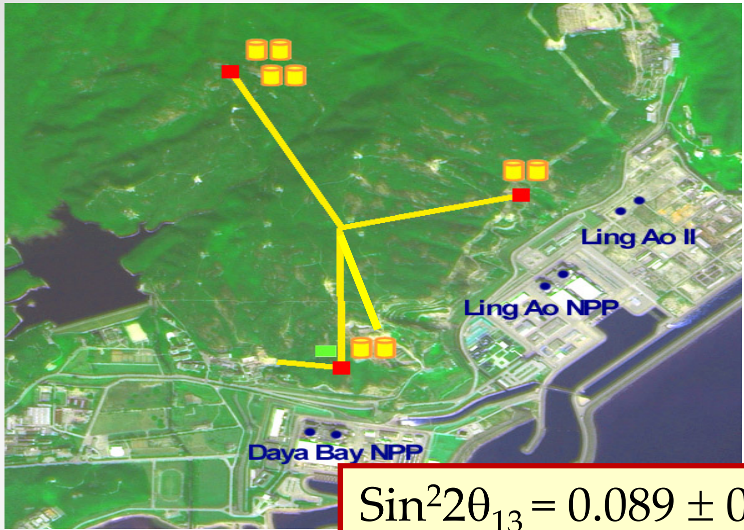
scale up to ~700kg (already in the mine) planned
estimated sensitivity ~40meV
reaching the inverted hierarchy

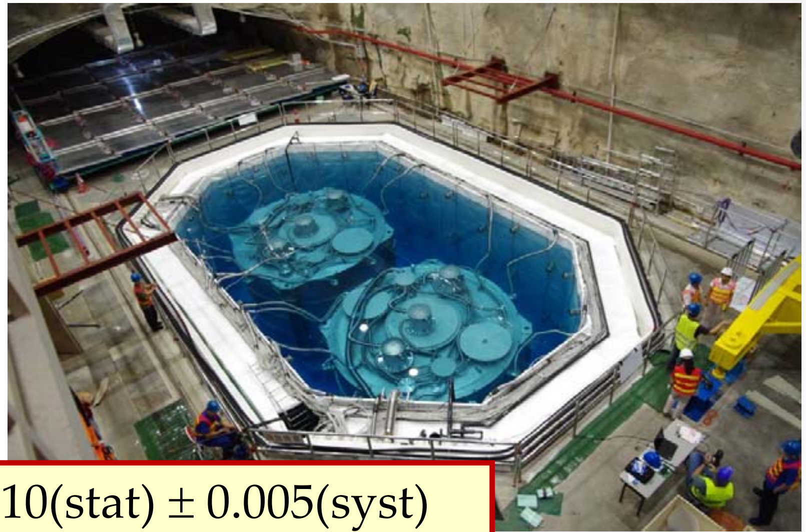
proposed modification (FY2016 or later)

winstone cone, higher yield LS and 1000kg ^{enr}Xe
estimated sensitivity ~20meV
covering most of the inverted hierarchy

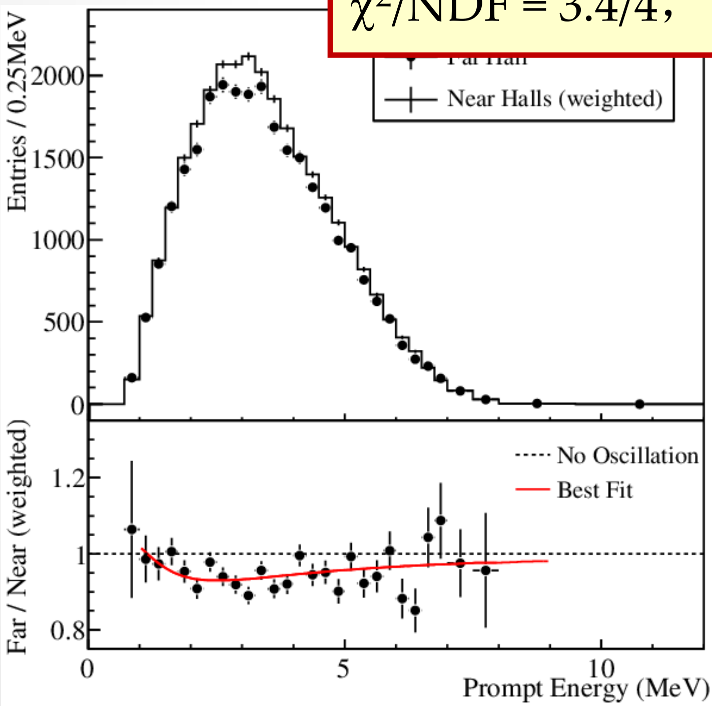
Neutrino Project in China

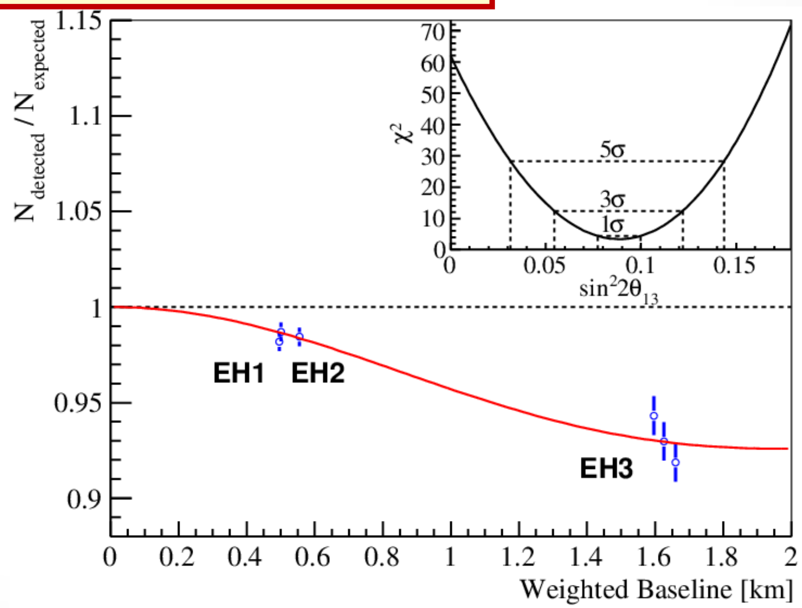
Daya Bay Experiment





$\mathrm{Sin}^2 2\theta_{13} = 0.089 \pm 0.010(\mathrm{stat}) \pm 0.005(\mathrm{syst})$
$\chi^2/\mathrm{NDF} = 3.4/4$, 7.7 σ for non-zero θ_{13}

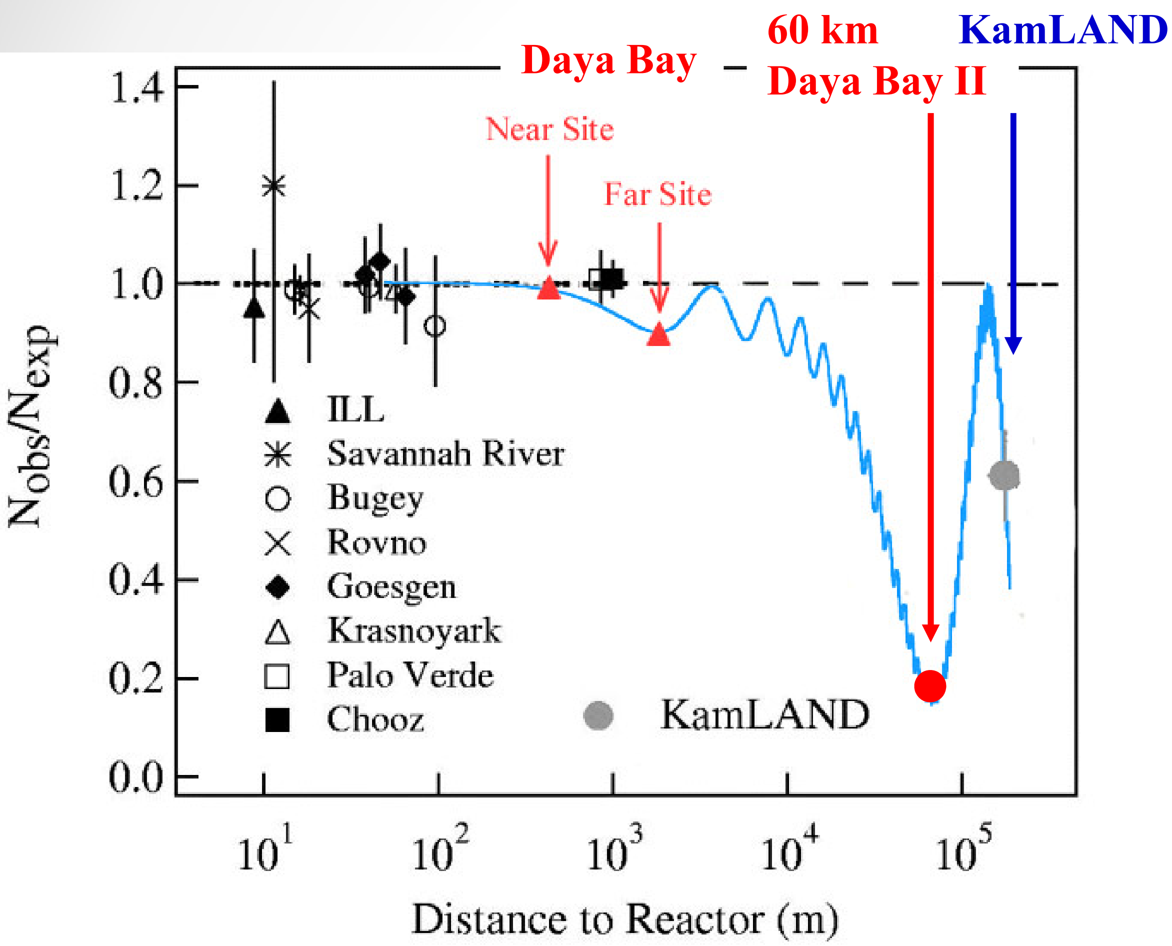




Future plan of Daya Bay

- Assembly of AD7 and AD8 is underway now, to be completed before summer
- Summer activities:
  - **Installation of AD7 & AD8**
  - **Detector calibration**
- Final goal：~5% precision on $\sin^2 2\theta_{13}$

Next Step: Daya Bay-II Experiment



- **20 kton LS detector**
- **3% energy resolution**
- Rich physics possibilities
  - ⇨ **Mass hierarchy**
  - ⇨ **Precision measurement of 4 mixing parameters**
  - ⇨ **Supernovae neutrino**
  - ⇨ **Geoneutrino**
  - ⇨ **Sterile neutrino**
  - ⇨ **Atmospheric neutrinos**
  - ⇨ **Exotic searches**

Neutrino Project in Korea

Future Plan for Precision Measurement of θ_{13}

RENO

$$\sin^2 2\theta_{13} = 0.113 \pm 0.013(stat.) \pm 0.019(syst.)$$

0.113 ± 0.023 (4.9 σ) → ± 0.01

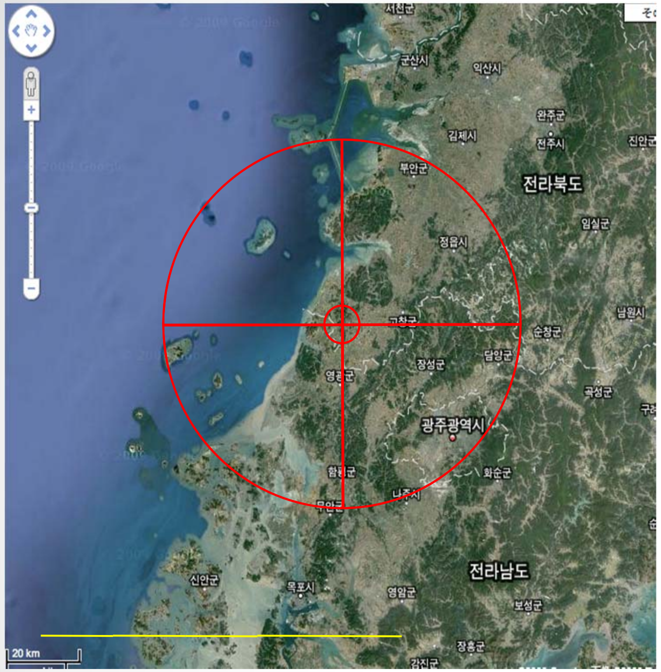
(230 days) (3 years)

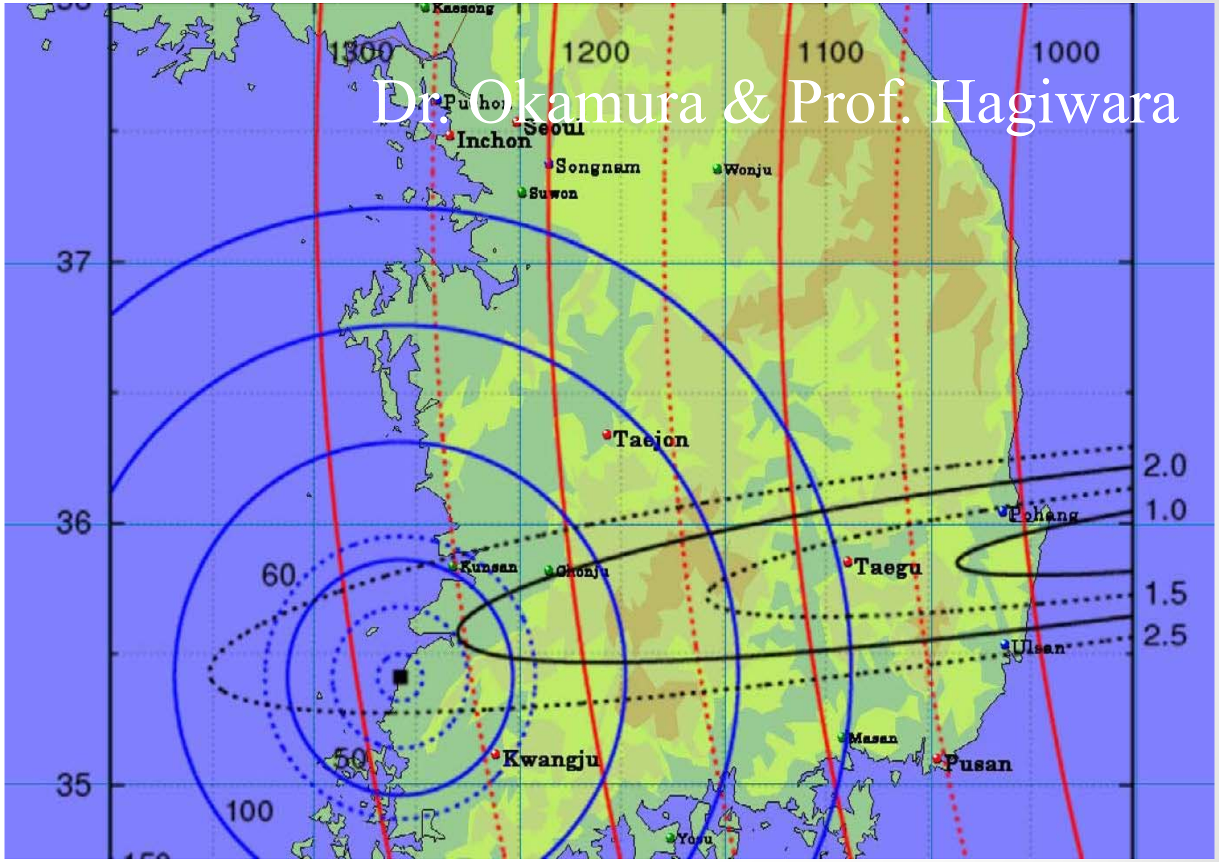
- 3 years of data : ~ 1% for the total measurement error
  - **- statistical error : 1.3% (~200 days) → 0.6%**
  - **- systematic error : 1.9% → 1.4% (background reduction)**
    1.0% (reduction of reactor uncertainty + shape analysis)
    0.5% (reduction of detection efficiency uncertainty)

- Remove backgrounds
- Spectral shape analysis (with precise energy calibration)
- Reduce uncertainties of reactor neutrino flux & detector efficiency

RENO-50

J-PARC neutrino beam direction





L~50km experiment may be a natural extension of current Reactor-θ_{13} Experiments

*** Large θ_{12} neutrino oscillation effects at 50 km + 5kton liquid scintillator detector**

*** θ_{13} detectors can be used as near detector**

*** Small background from other reactors.**

Physics with RENO-50

- Precise measurement of θ_{12}

  $$\frac{\delta \sin^2\theta_{12}}{\sin^2\theta_{12}} \sim 1.0\%(1\sigma)$$ in a year ← current accuracy : 5.4%

- Determination of mass hierarchy Δm^2_{13}

- Neutrino burst from a Supernova in our Galaxy :

  ~1500 events (@8 kpc)

- Geo-neutrinos : ~ 300 geo-neutrinos for 5 years

- Solar neutrinos : with ultra low radioacitivity

- Reactor physics : non-proliferation

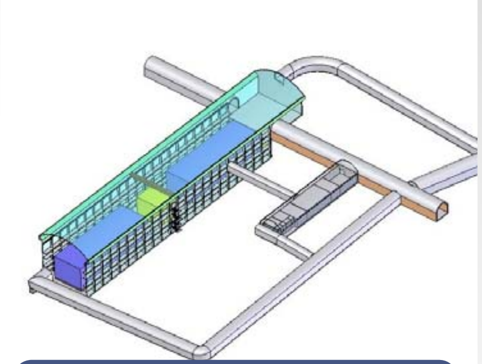
- Detection of T2K beam : ~120 events/year

- Test of non-standard physics : sterile/mass varying neutrinos

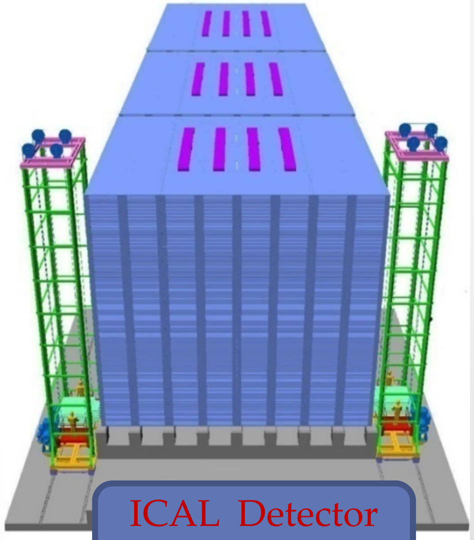
Neutrino Project in India

India-based Neutrino Observatory (INO)

- *An underground laboratory with ~1.2 km all-round rock cover accessed through a 2 km long tunnel. A large and several smaller caverns to facilitate many experimental programmes*
- ***Frontline neutrino issues e.g., mass parameters and other properties, will be explored in a manner complementary to ongoing efforts worldwide.***
- *50 kton ICAL detector, with its charge identification ability, will be able to address questions about the neutrino mixing parameter space specially the issue of neutrino mass hierchy.*
- *Distance from CERN (Switzerland) and JPARC (Japan) ~ 7000 km, close to "magic baseline" for experiments with neutrino beams in a few decade from now*
- *Will support several experiments in Physics, Biology, Geology etc. when operational. Neutrino-less Double Beta Decay and Dark Matter Search experiments foreseen in the immediate future.*
- *Welcome international participation.*



INO Underground Lab (conceptual)



ICAL Detector (conceptual)

Current status

- Full size RPCs (2m X 2m) are now being fabricated not only in the lab but also by the Industry. Ready for large scale production.
- Development & fabrication of various electronic modules for the INO-ICAL detector are advancing well.
- Two prototype detectors- one at TIFR and the 2nd one at VECC are running.
- Detailed Project Reports (DPR) for site infrastructure as well as for the magnet structure are ready.
- Obtained forest as well as environmental clearances for the INO project.
- TN govt. has handed over 66 acres of land to DAE for the construction of INO facilities at site. It has also offered 33 acres of land at Madurai for the INO centre.
- INO graduate training program with strong emphasis on hands on training for detector development is running for the last three years.
- INO-ICAL will have an important role specially due to the large value of θ_{13} announced recently.

Prototype ICAL at VECC

2mX2m RPC Test Stand at TIFR

Summary

- HEP in the next ~5 years in Japan

  Very active on-going programs

  SuperKEKB/Belle II

  T2K

  Kaon and Muon rare decay experiments at J-PARC

  Preparation/decision making for the next step

  ILC project

  The next generation neutrino experiment

- Neutrino initiatives in Asian countries

  Daya Bay/ Day Bay-II in China

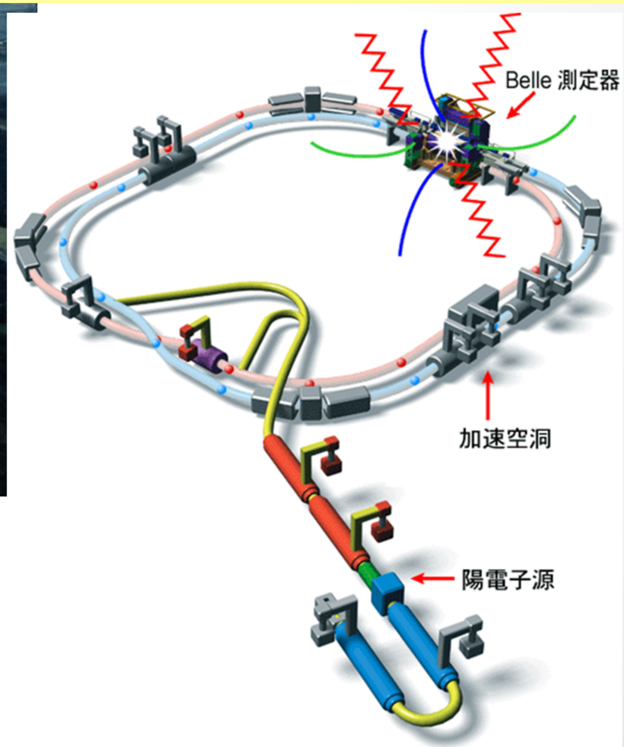
  RENO/RENO-50 in Korea

  INO in India

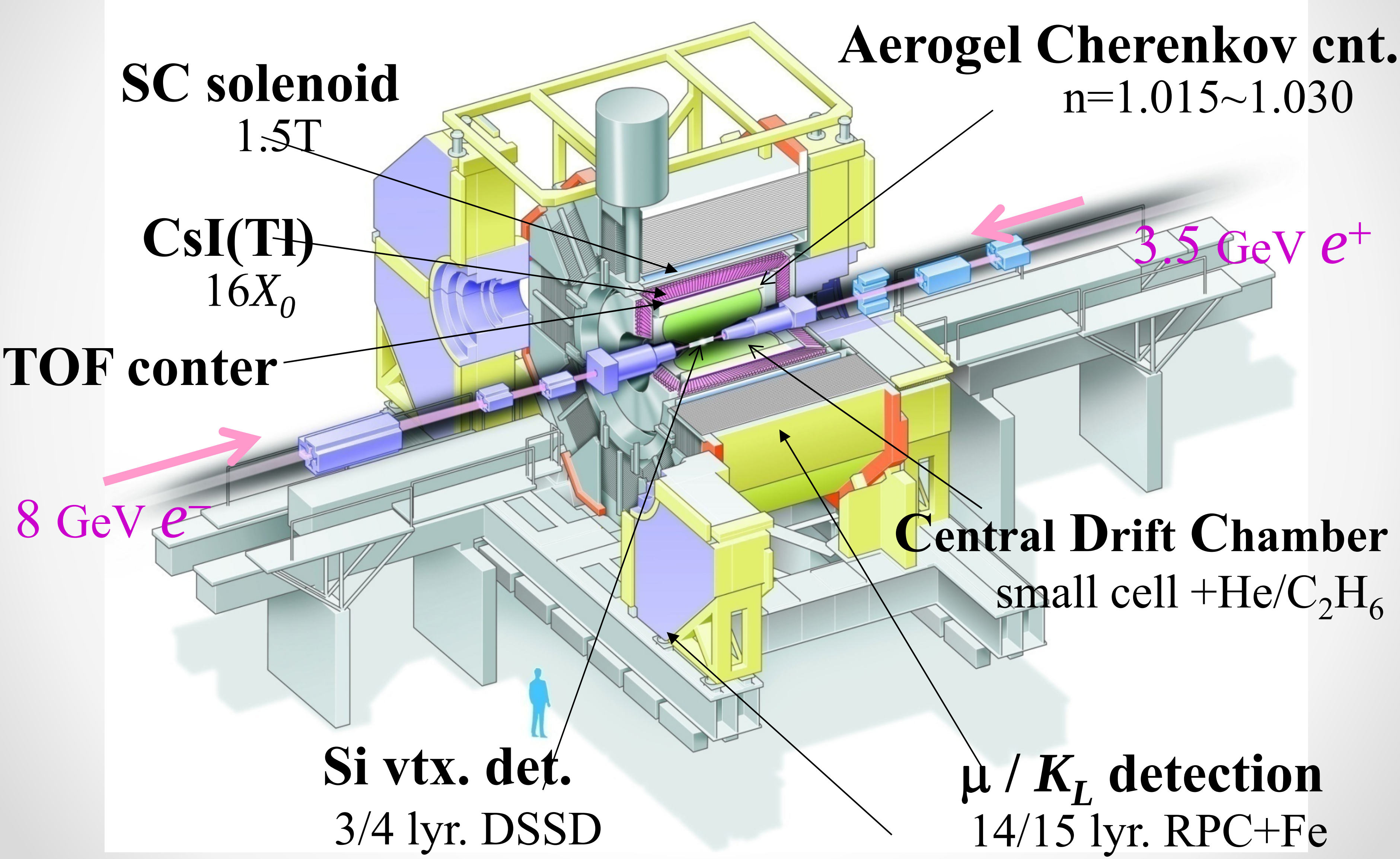
Backup slides

KEK and KEKB

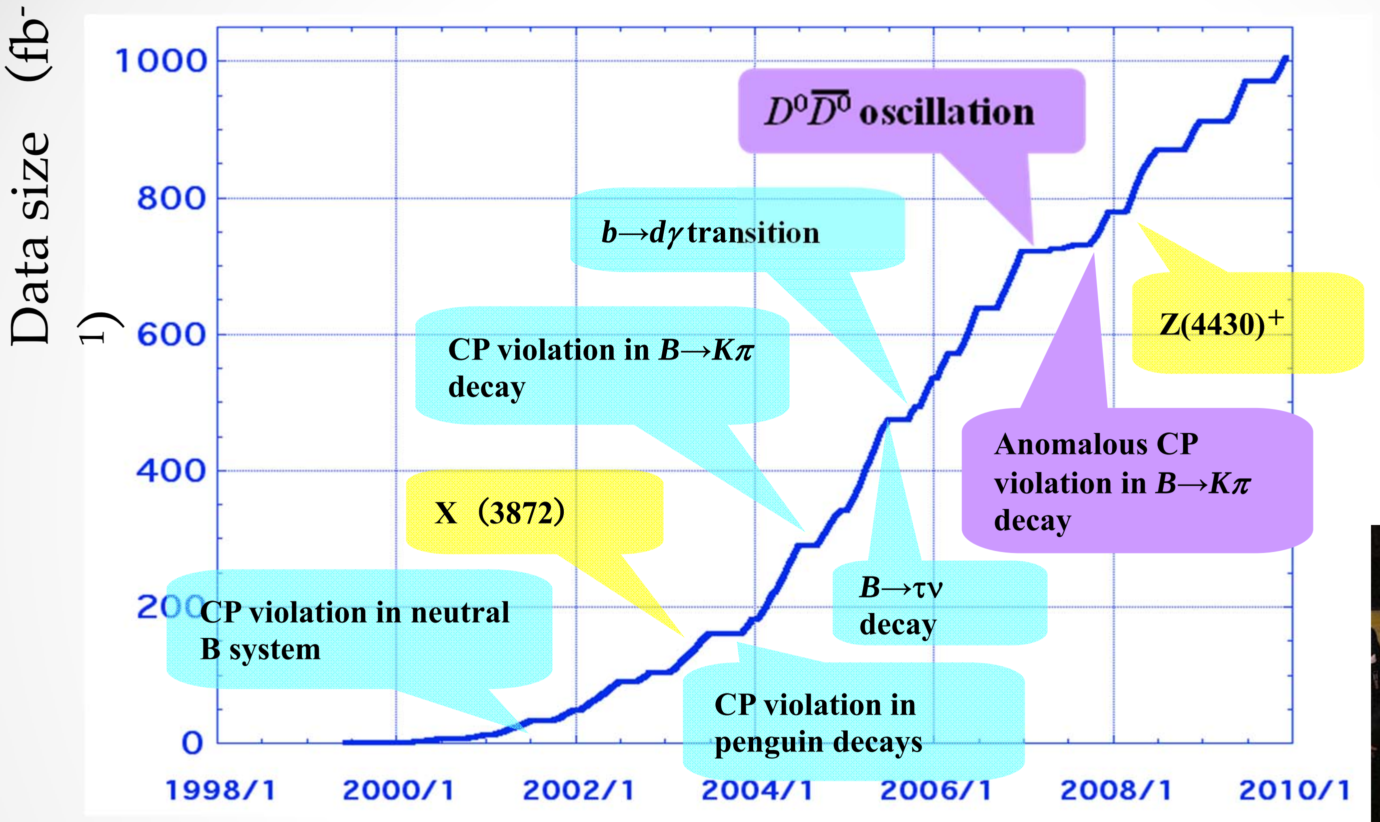
3.5 GeV e^+ X 8.0 GeV e^-
crossing angle = ±11 mrad.



Belle Detector

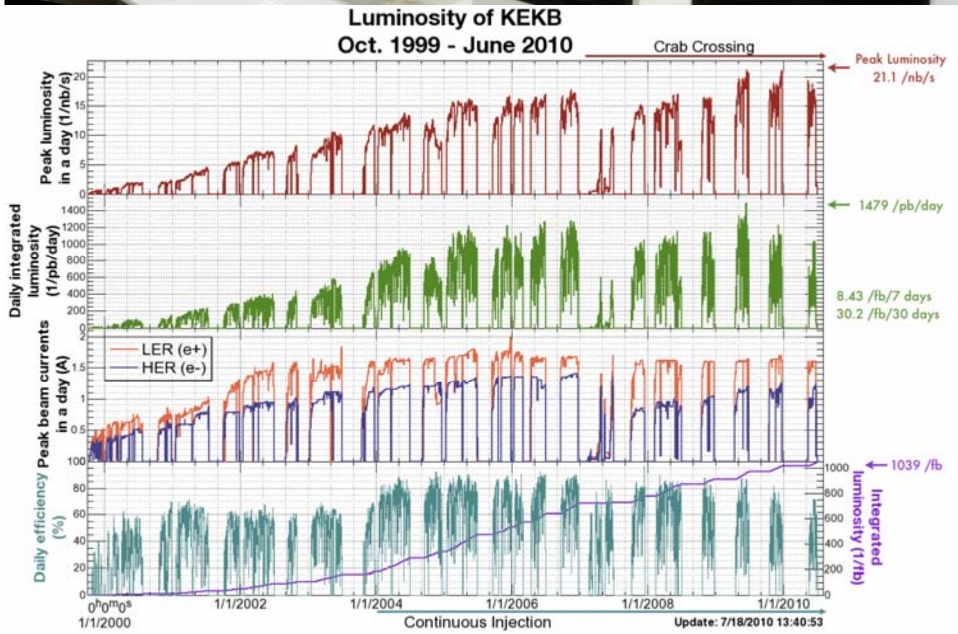


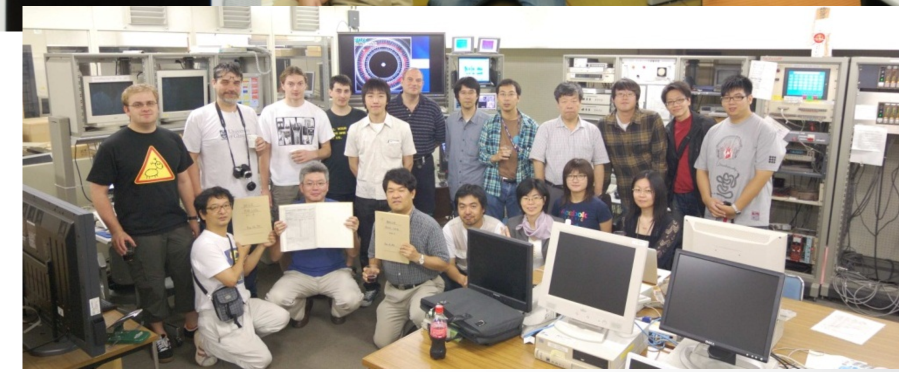
past



1. Precise determination of SM (CKM)
2. Some unexpected observations such as new hadronic resonances (possible, but omitted in SM)
3. (Yet unclear) hints of new physics (impossible in SM, possible in NP)

The last beam abort of KEKB on June 30, 2010

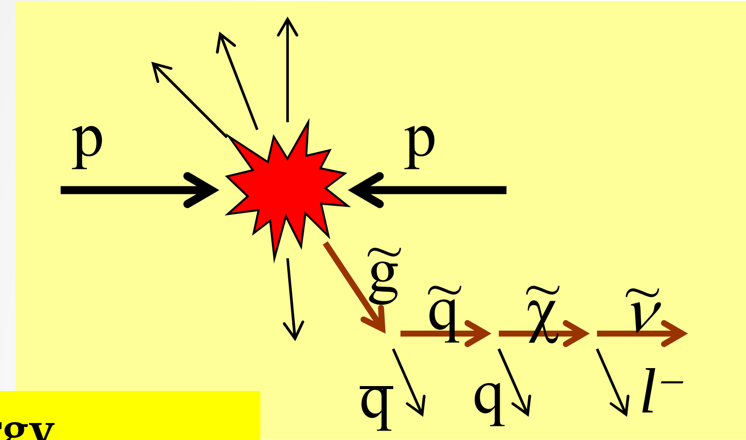




First physics run on June 2, 1999
Last physics run on June 30, 2010
$L_{peak} = 2.1\text{x}10^{34}/\text{cm}^2/\text{s}$
$L > 1\text{ab}^{-1}$

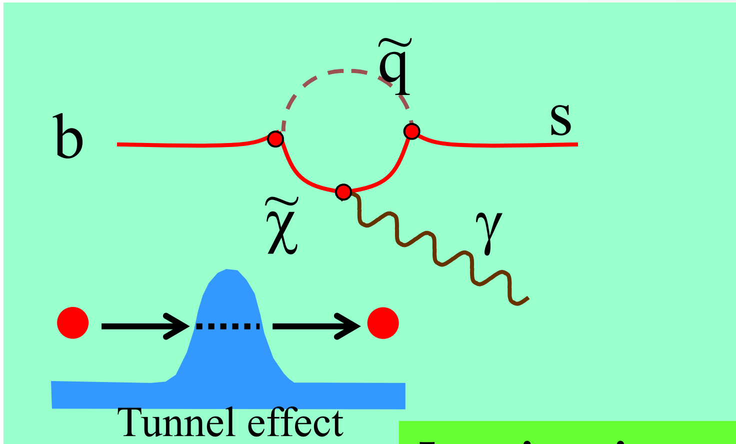
Energy Frontier and Luminosity Frontier

Direct Production by High Energy Col



Energy Frontier

Virtual Production via Quantum Eff.



Luminosity Frontier

Diagonal terms

Off-diagonal terms

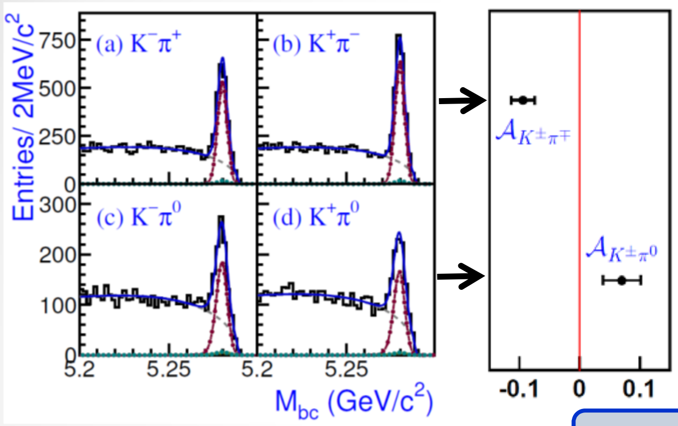
$$\left(m_{\tilde{q}}^2\right)_{ij} = \begin{pmatrix} m_{11}^2 & m_{12}^2 & m_{13}^2 \\ m_{21}^2 & m_{22}^2 & m_{23}^2 \\ m_{31}^2 & m_{32}^2 & m_{33}^2 \end{pmatrix}$$

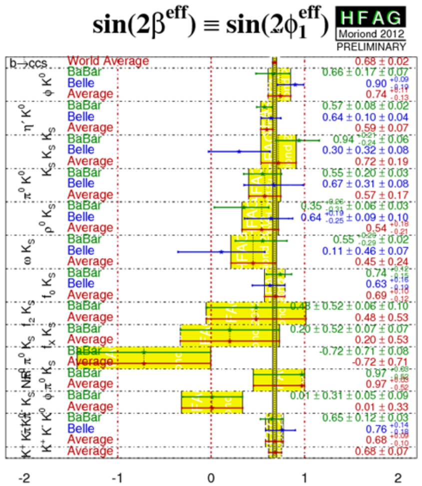
Continue search at luminosity frontier (the more data, the higher sensitivity to high energy scale). Once NP is found, investigate couplings.

Hints of NP at Belle (tbc at Belle II)

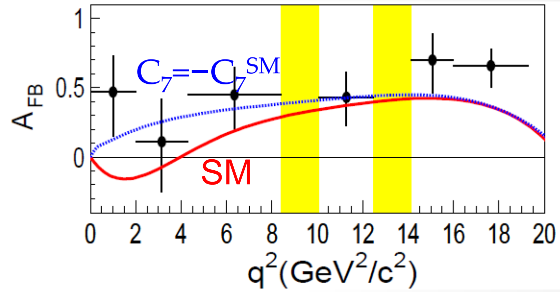
Anomalous CPV in b→s penguins

CPV difference in between B^0 and $B^\pm$

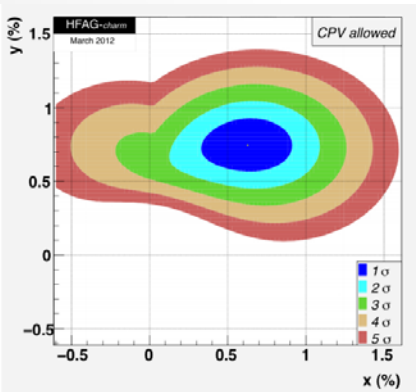




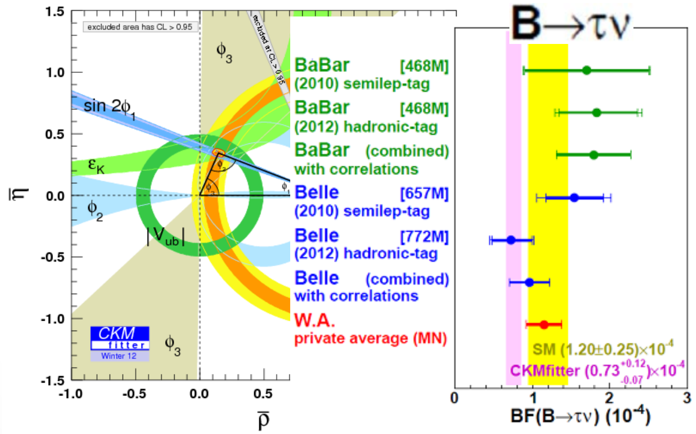
Anomalous AFB in $B \to K^* \ell^+ \ell^-$



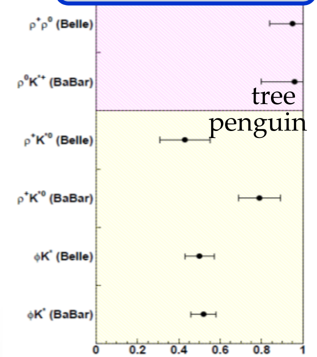
Large D^0-$\bar{D}^0$ mixing



Inconsistency in unitarity triangle



$f_L(B \to VV) \neq 1$



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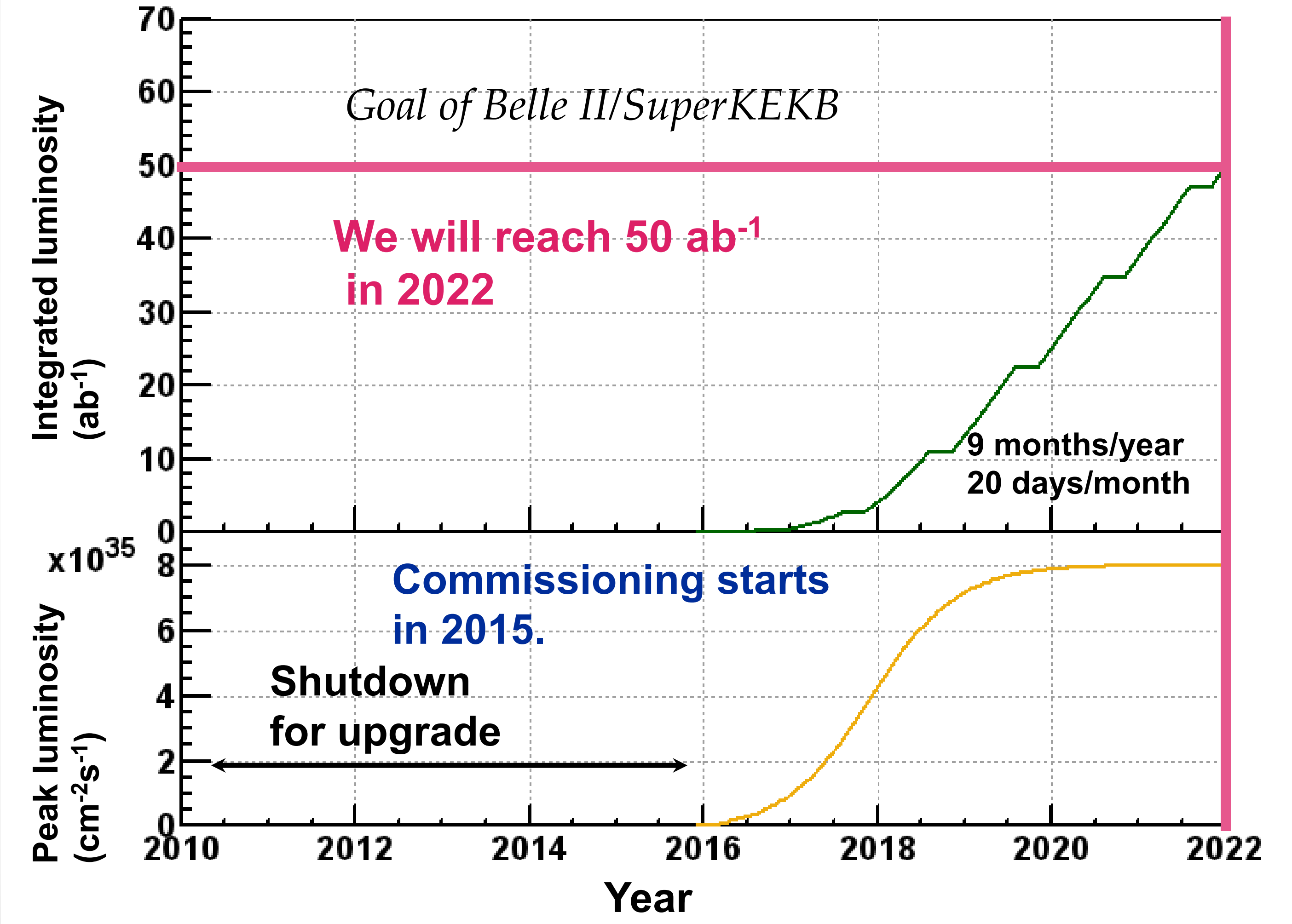
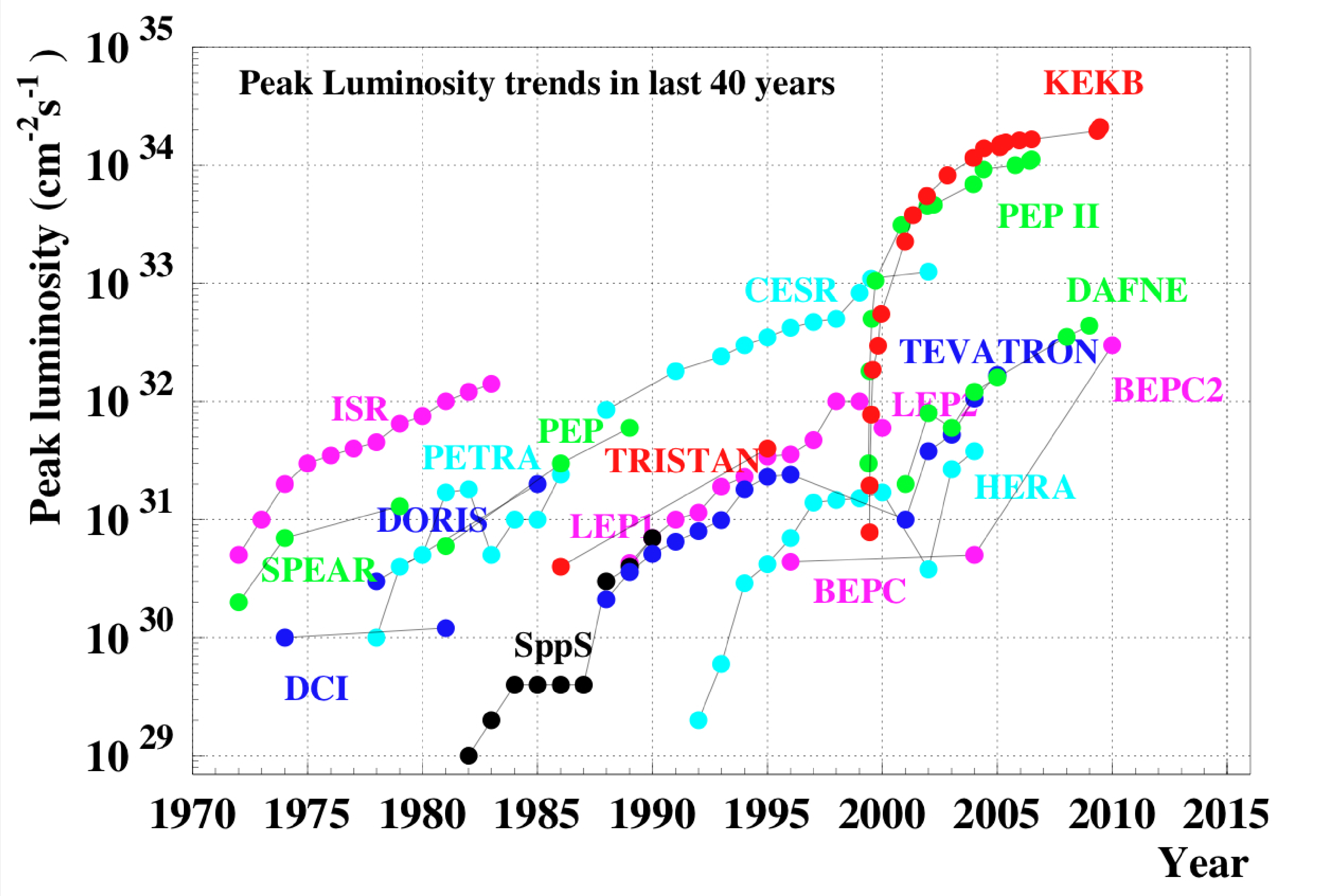
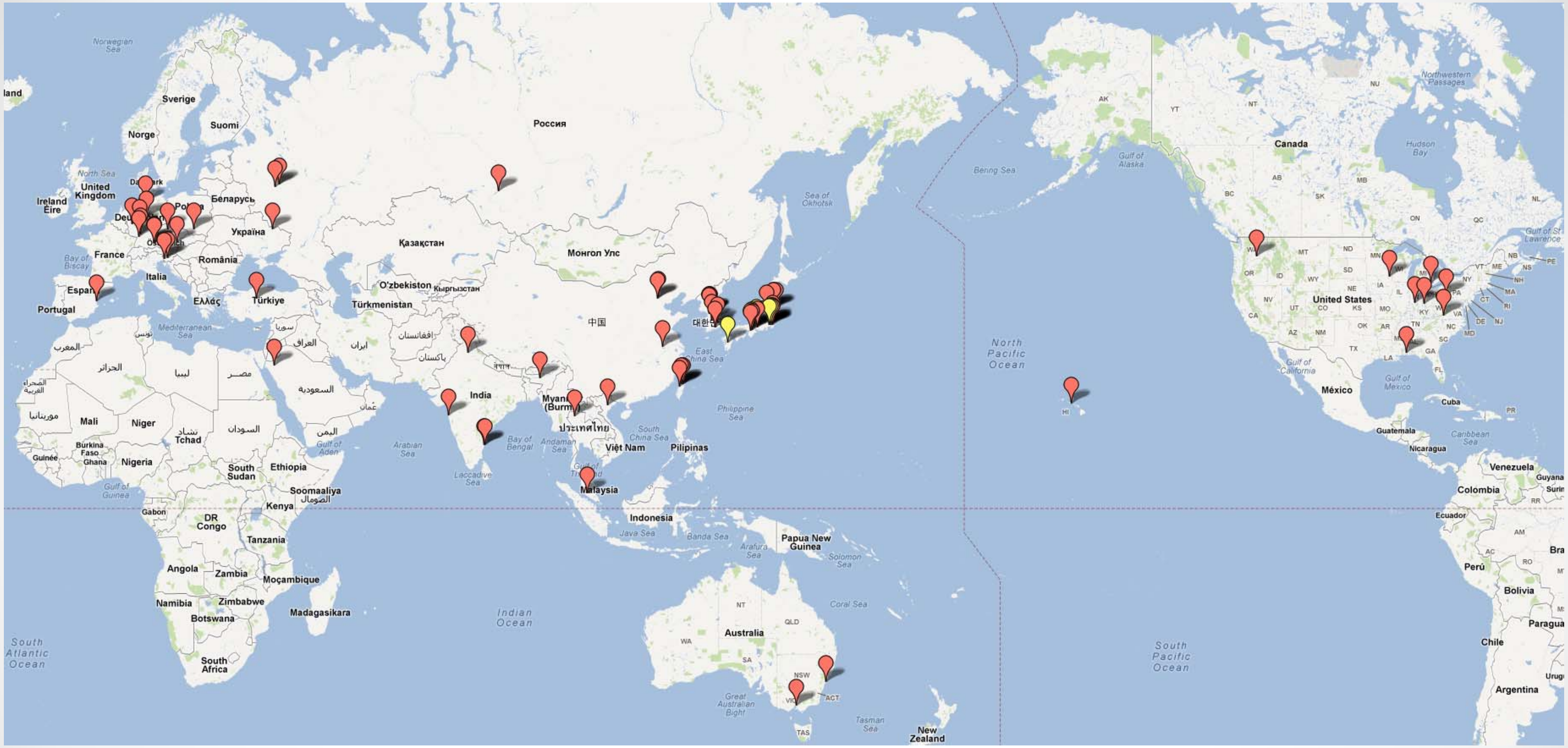
SuperKEKB luminosity prospect



Peak Luminosity Trend



The Belle II collaboration



20 countries, 67 institutes, ~400 collaborators (as of Jul. 2012)