Current Status and Future Prospects of

Fundamental Science at J-PARC

The 6th Workshop on Hadron Physics in China and Opportunities in US
July 21- 24, 2014, Lanzhou, China

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齊藤　直人

(KEK/J-PARC)

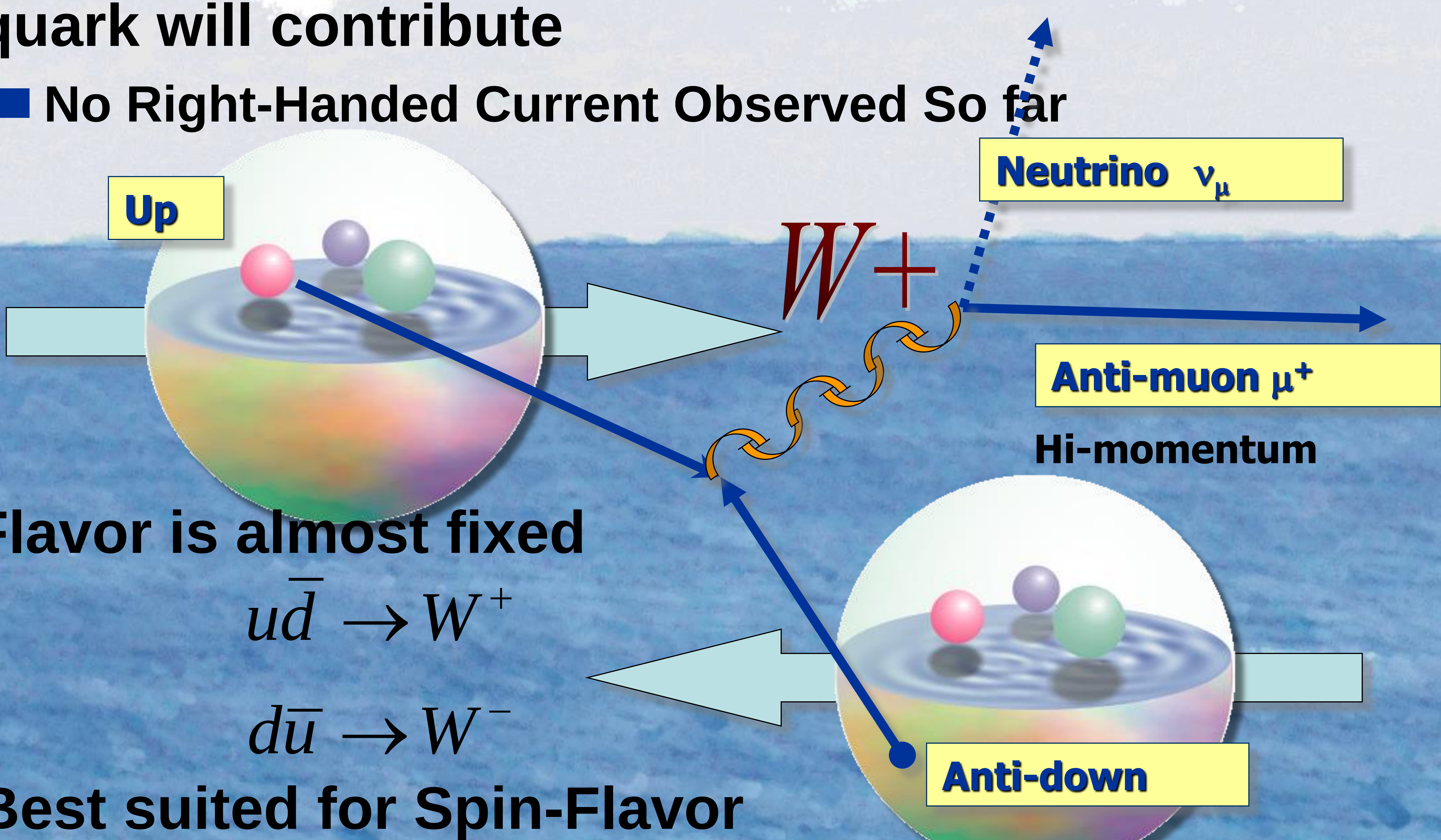
um 2014

ants

countries & ~60 students

W^+ Production in pp Collisions

- **Only Left-Handed Quark and Right-Handed Anti-quark will contribute**
  - **No Right-Handed Current Observed So far**



- **Flavor is almost fixed**

$$u\bar{d} \to W^+$$

$$d\bar{u} \to W^-$$

- **Best suited for Spin-Flavor Structure Studies!**

Polarized pp Collisions at 500 GeV!

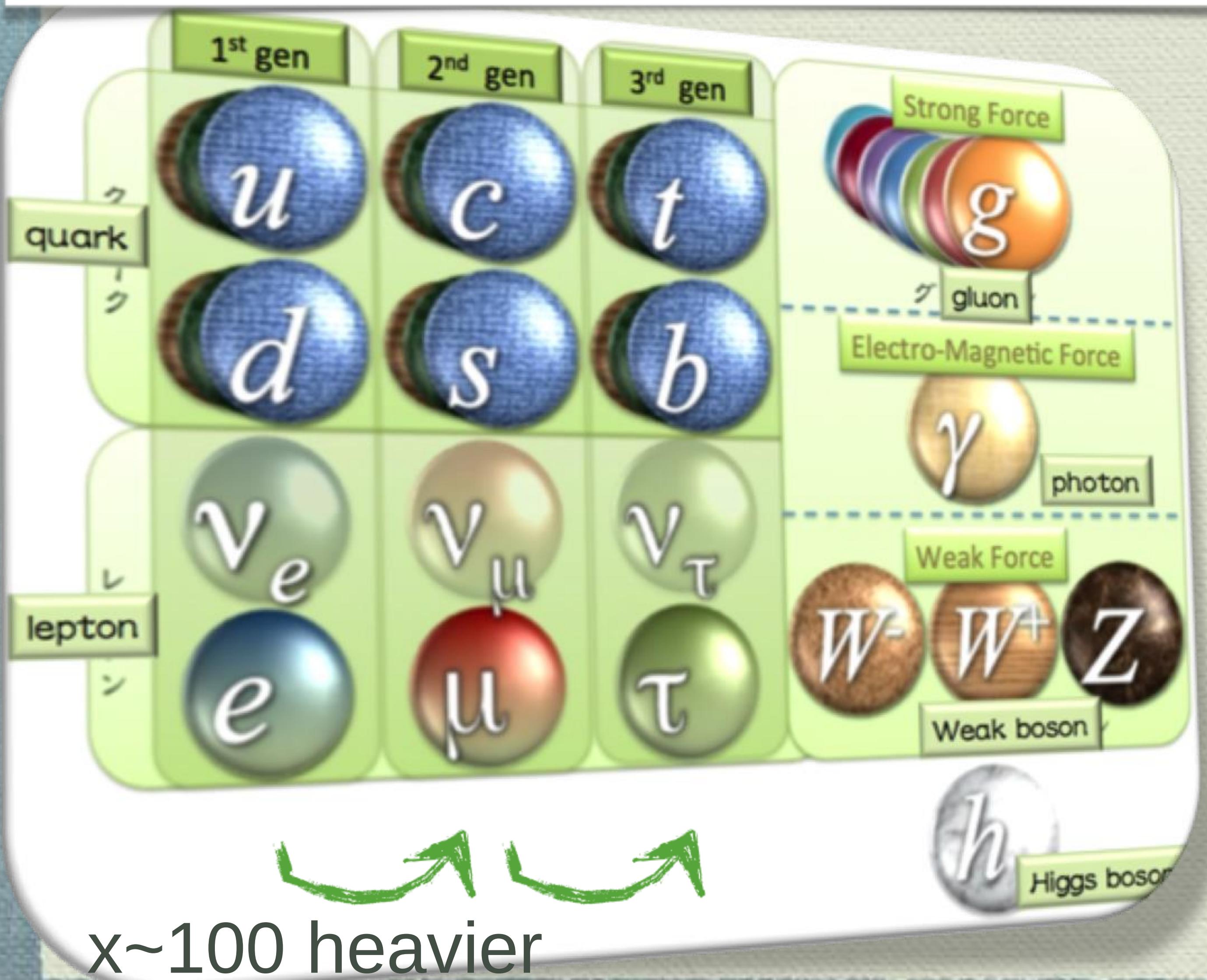
Outline

- J-PARC as Intensity Frontier Facility
- Recovery from Accident
- Physics
  - Flavor Physics
  - Strong Interaction
  - Muon Physics
- Summary

Higgs Particle Discovery

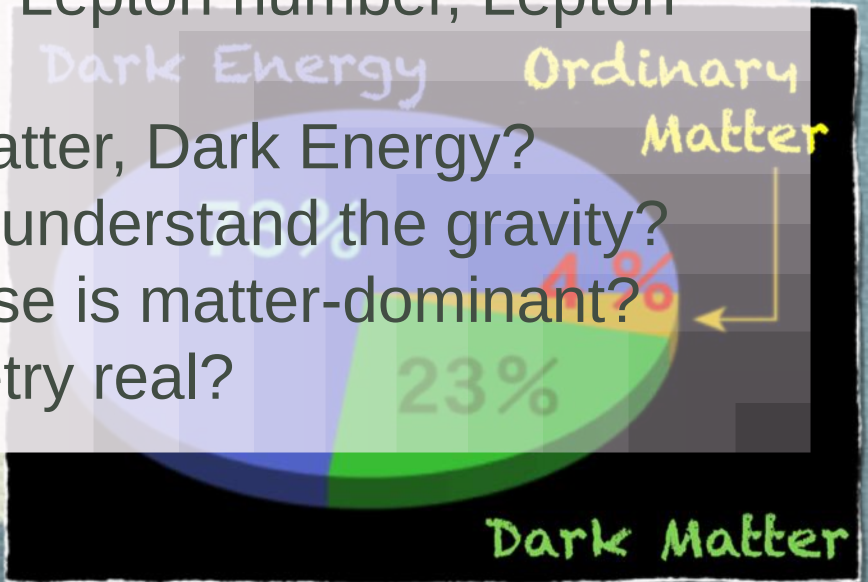
- Completion of the Standard Model

Beginning of New Physics Era

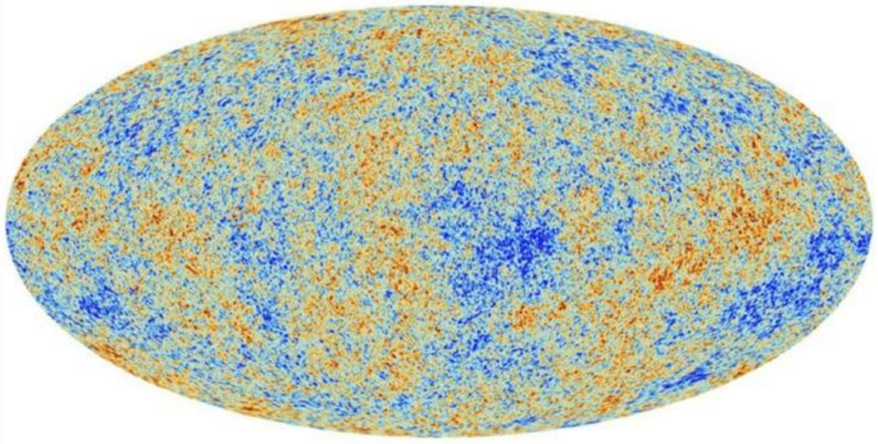


x~100 heavier

Why 3 generations?
Why CP violates? (particle-anti-particle asymmetry)
Why mass distributed this way?
Baryon number, Lepton number, Lepton flavor violated?
What is Dark Matter, Dark Energy?
How we should understand the gravity?
Why our Universe is matter-dominant?
Is super-symmetry real?

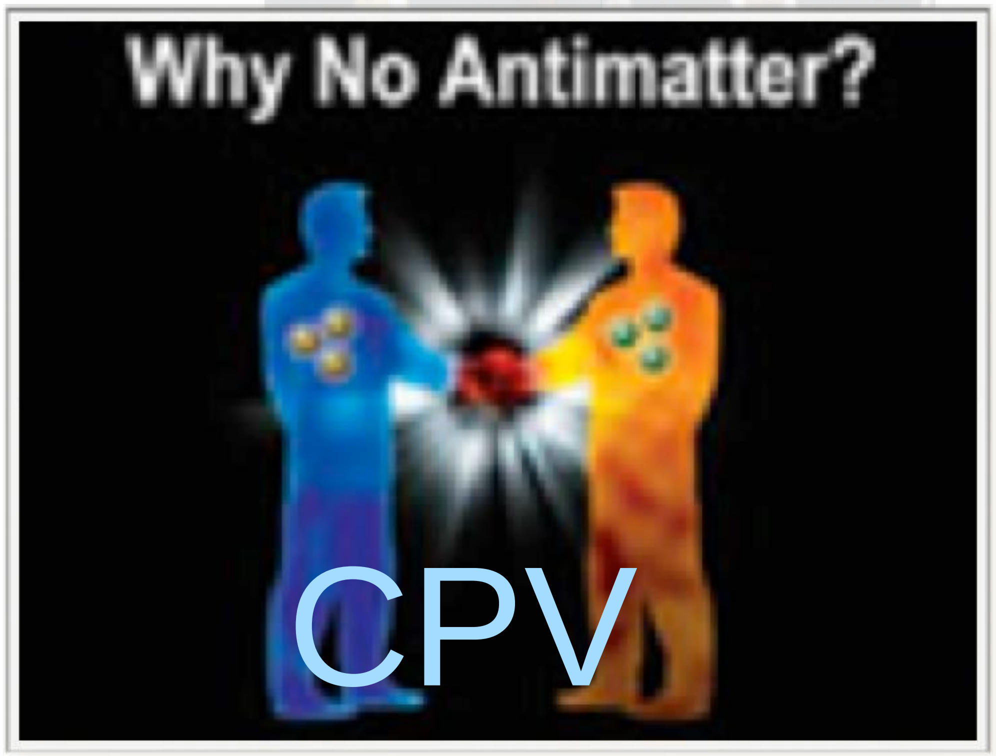


Baryon Asymmetric Universe



- Particle-Anti-Particle Symmetry right after Big-Bang !
- Observation：$1/10^9$ Asymmetry
  - Cosmic Microwave BG $\eta_B = (6.1^{+0.3}_{-0.2}) \times 10^{-10}$
  - Nucleosynthesis $\eta_B = (2.6 - 6.2) \times 10^{-10}$

- CKM theory can explain ONLY ~ 10^{-19}
  → need more asymmetry !
  → need CP violation !

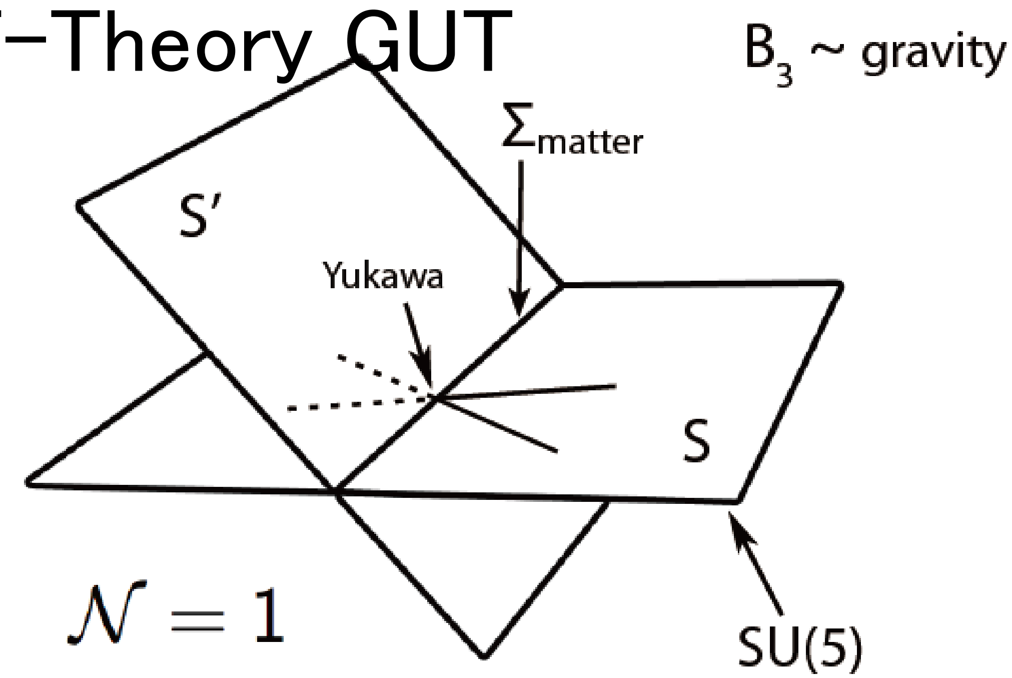


- Three Conditions for BAU（1967 Sakharov）
  - Baryon # violation（ex.：proton decay）
  - CP Violation
  - Out of equiliburium

Flavor and Space-Time

- **CPV and Flavor Structure can be explained from higher dimensions / higher energies?**

F−Theory GUT



dim.	internal dim.	feature
10	$6 = \dim(B_3)$	gravity
8	$4 = \dim(S)$	gauge fields
6	$2 = \dim(S \cap S')$	matter
4	$0 = \dim(S \cap S' \cap S'')$	interactions

$$|V_{CKM}^{F-th}| \sim \begin{pmatrix} 1 & \alpha_{GUT}^{1/2} & \alpha_{GUT}^{3/2} \\ \alpha_{GUT}^{1/2} & 1 & \alpha_{GUT} \\ \alpha_{GUT}^{3/2} & \alpha_{GUT} & 1 \end{pmatrix} \sim \begin{pmatrix} 1 & 0.2 & 0.008 \\ 0.2 & 1 & 0.04 \\ 0.008 & 0.04 & 1 \end{pmatrix}$$

$$|V_{CKM}^{obs}| \sim \begin{pmatrix} 0.97 & 0.23 & 0.004 \\ 0.23 & 0.97 & 0.04 \\ 0.008 & 0.04 & 0.99 \end{pmatrix}$$

$$|V_{PMNS}^{F-th}| \sim \begin{pmatrix} U_{e1} & \alpha_{GUT}^{1/4} & \alpha_{GUT}^{1/2} \\ \alpha_{GUT}^{1/4} & U_{\mu 2} & \alpha_{GUT}^{1/4} \\ \alpha_{GUT}^{1/2} & \alpha_{GUT}^{1/4} & U_{\tau 3} \end{pmatrix} \sim \begin{pmatrix} 0.87 & 0.45 & 0.2 \\ 0.45 & 0.77 & 0.45 \\ 0.2 & 0.45 & 0.87 \end{pmatrix}$$

$$|V_{PMNS}^{obs}| \sim \begin{pmatrix} 0.77-0.86 & 0.50-0.63 & 0-0.22 \\ 0.22-0.56 & 0.44-0.73 & 0.57-0.80 \\ 0.21-0.55 & 0.4-0.71 & 0.59-0.82 \end{pmatrix}$$

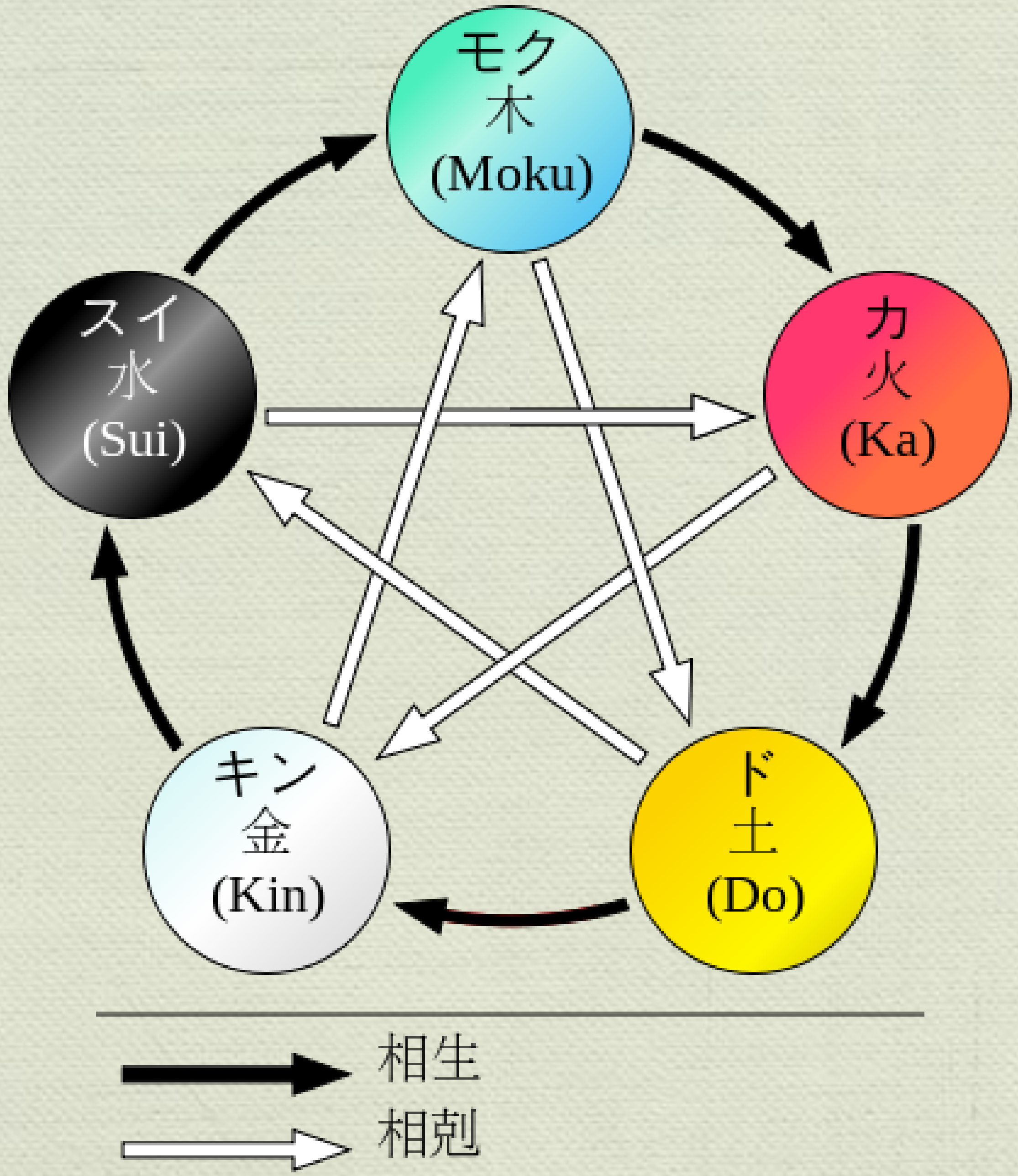
$$\left|J_{\text{quark}}^{F-th}\right| \sim \alpha_{GUT}^3 \sim 6 \times 10^{-5}$$

$$\left|J_{\text{lepton}}^{F-th}\right| \sim \alpha_{GUT} \sim 4 \times 10^{-2}.$$

Quarks
Neutron
Hydrogen nucleus
Hydrogen atom
Protogalaxy
Electron
Proton
Helium nucleus
Helium atom
THE BIG BA
ORY
CUP NOODLE
カップヌードル
Galaxy
TIME BEGINS
ONE SECOND
PRESENT DAY
Time
Temperature
10^{-43} sec.
10^{-32} sec.
10^{27}°C
10^{-6} sec.
10^{13}°C
3 min.
10^{8}°C
300,000 yrs.
10,000°C
1 billion yrs.
-200°C
15 billion yrs.
-270°C
1 The cosmos goes through a superfast "inflation," expanding from the size of an atom to that of a grapefruit in a tiny fraction of a second
2 Post-inflation, the universe is a seething, hot soup of electrons, quarks and other particles
3 A rapidly cooling cosmos permits quarks to clump into protons and neutrons
4 Still too hot to form into atoms, charged electrons and protons prevent light from shining; the universe is a superhot fog
5 Electrons combine with protons and neutrons to form atoms, mostly hydrogen and helium. Light can finally shine
6 Gravity makes hydrogen and helium gas coalesce to form the giant clouds that will become galaxies; smaller clumps of gas collapse to form the first stars
7 As galaxies cluster together under gravity, the first stars die and spew heavy elements into space; these will eventually form into new stars and planets

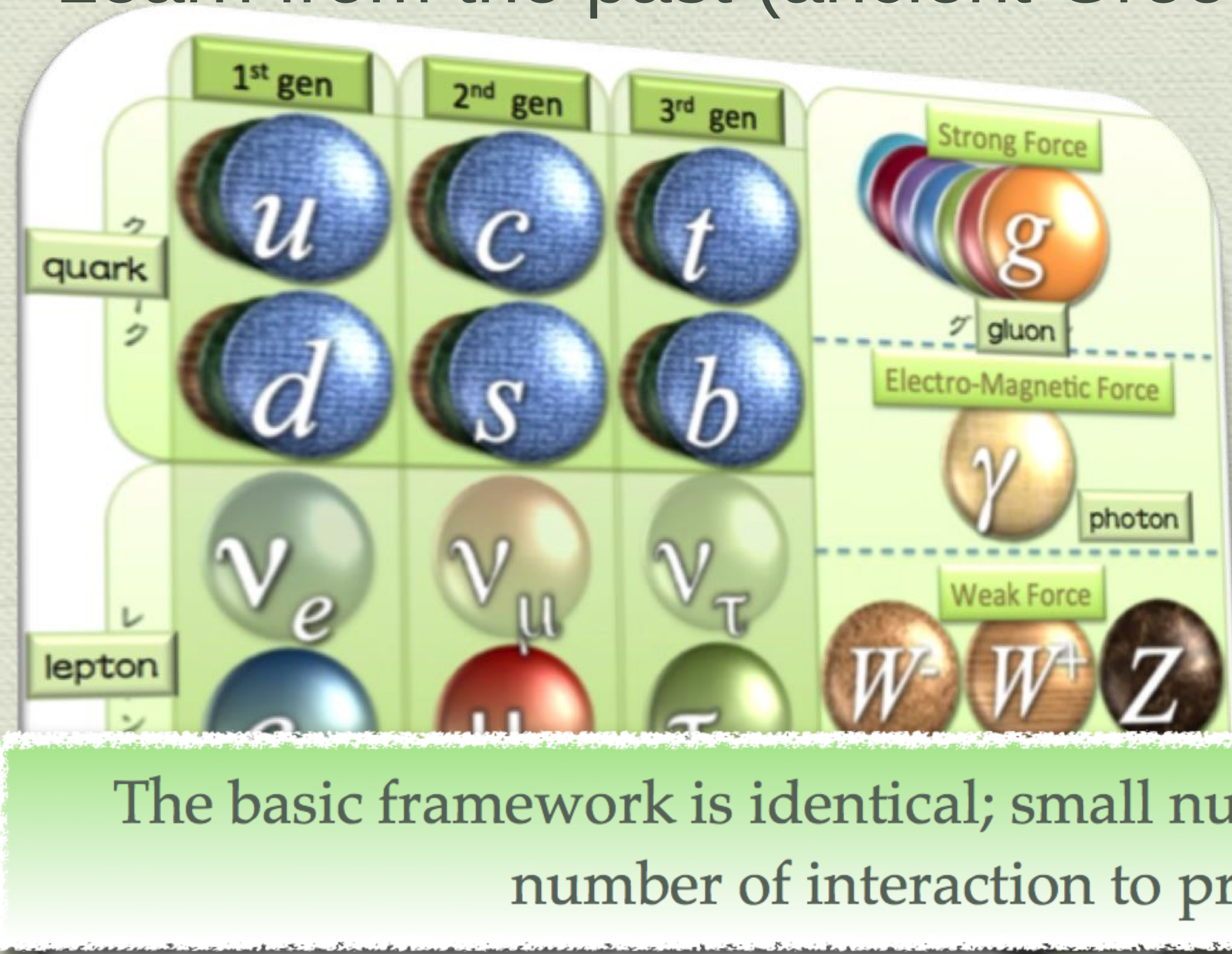
温故知新：五行説

- Everything is composed of five elements, which interacts through
  - their changes 相生
  - their conflicts 相剋
- Ancient Chinese Natural Philosophy 古代中国的自然哲学



Go Beyond the SM

- Learn from the past (ancient Greek Philosophy) !

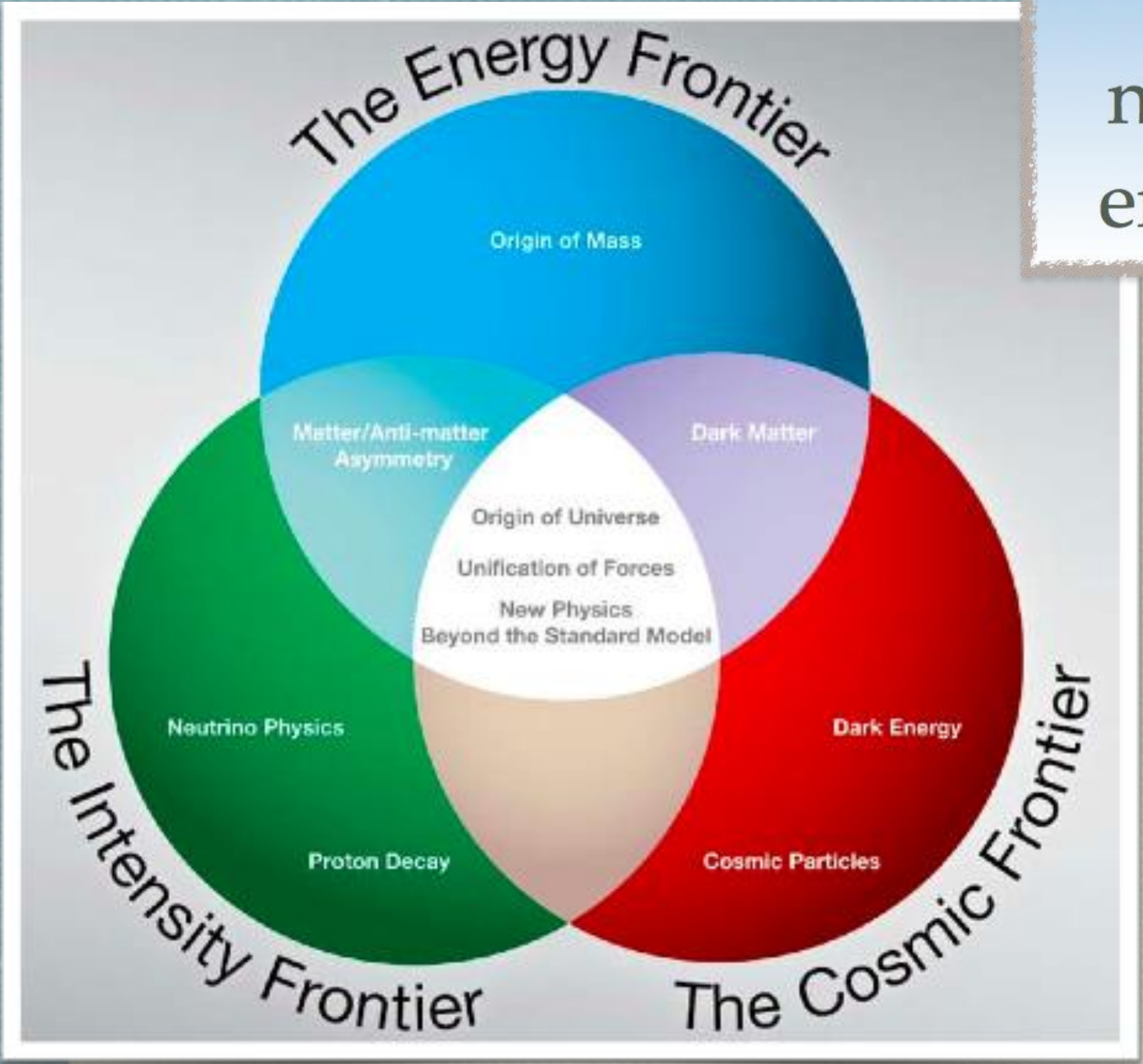


The basic framework is identical; small number of elements interacts thru a number of interaction to produce everything!

Our view is limited by what we can see, touch, and feel !

We need to extend our "sense" ; micro scope / ultra-sensitive devices

“Microscope” = Accelerator



High Energy Frontier?
new phenomena in the unprecedented energy region may provide an answer?

→ High Energy Accelerator

Look at a sky for a hint of New Physics?

→ Cosmic Frontier

Precision measurement may provide a hint for New Physics?

→ High Intensity Accelerator

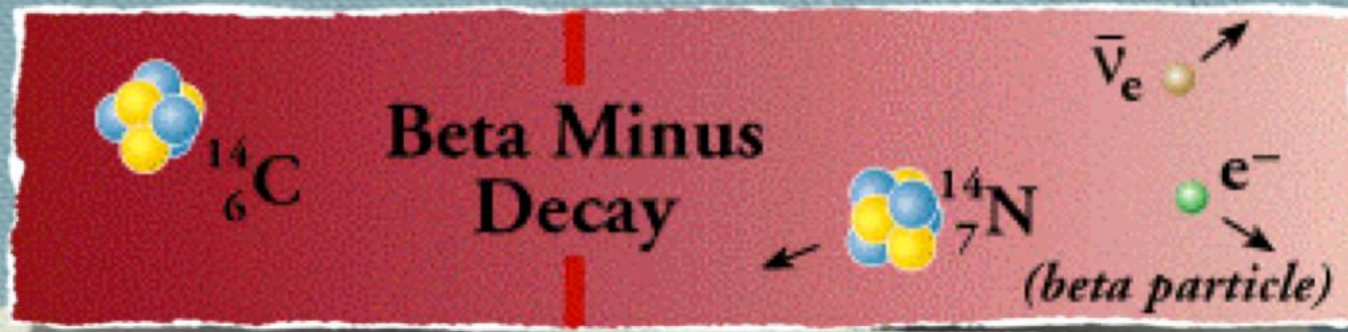
Uncertainty Principle

- Position and Momentum cannot be determined simultaneously
  - Measurement of position would disturb the quantum state so that momentum measurement would become inaccurate
- Time and Energy cannot be determined simultaneously
  - Energy conservation can be violated if in a short time interval

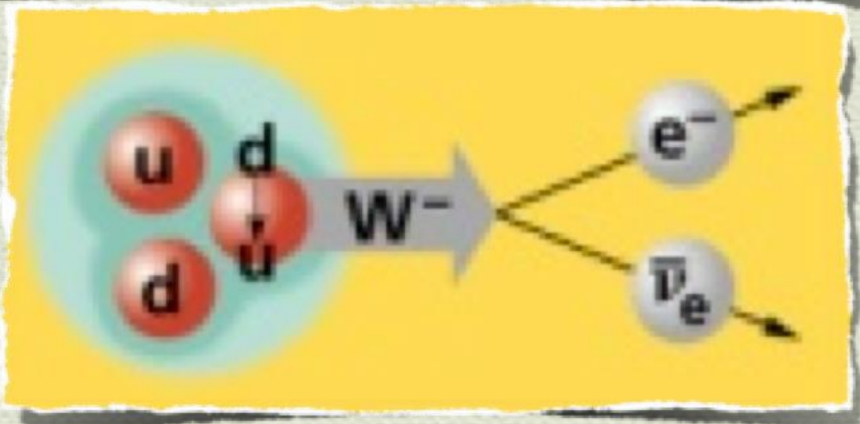
$$\Delta x \cdot \Delta p \geq \frac{\hbar}{2}$$

$$\Delta t \cdot \Delta E \geq \frac{\hbar}{2}$$

Examples

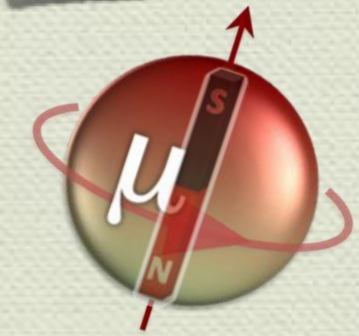


- Beta decay of neutron to proton
  - mediated by W boson

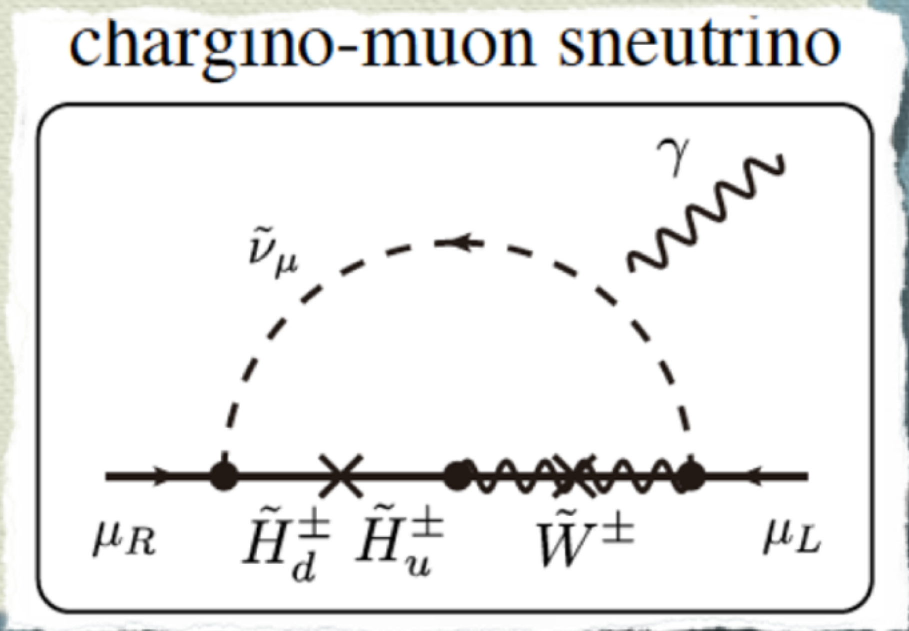


neutron mass ~ 1 GeV/c^2

W boson mass ~ 80 GeV/c^2



- Muon g-2 (anomalous magnetic moment)
- measured value > the SM theory by 3 standard deviation --> possible explanation is NEW PHYSICS



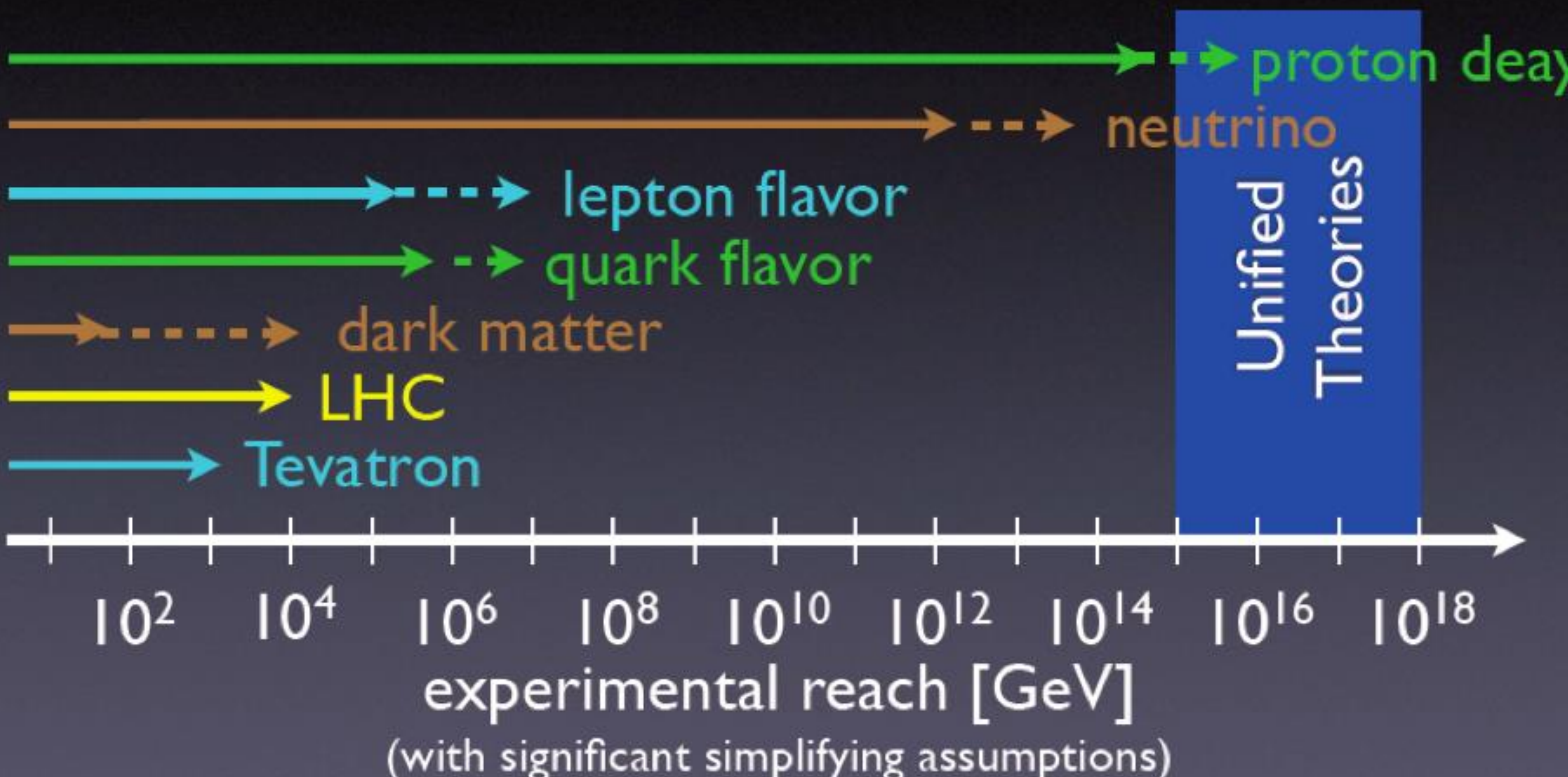
muon mass ~ 0.1 GeV/c^2

possible new physics scale ~ 1 TeV/c^2

IPMU

BERKELEY CENTER FO
THEORETICAL PHYSIC

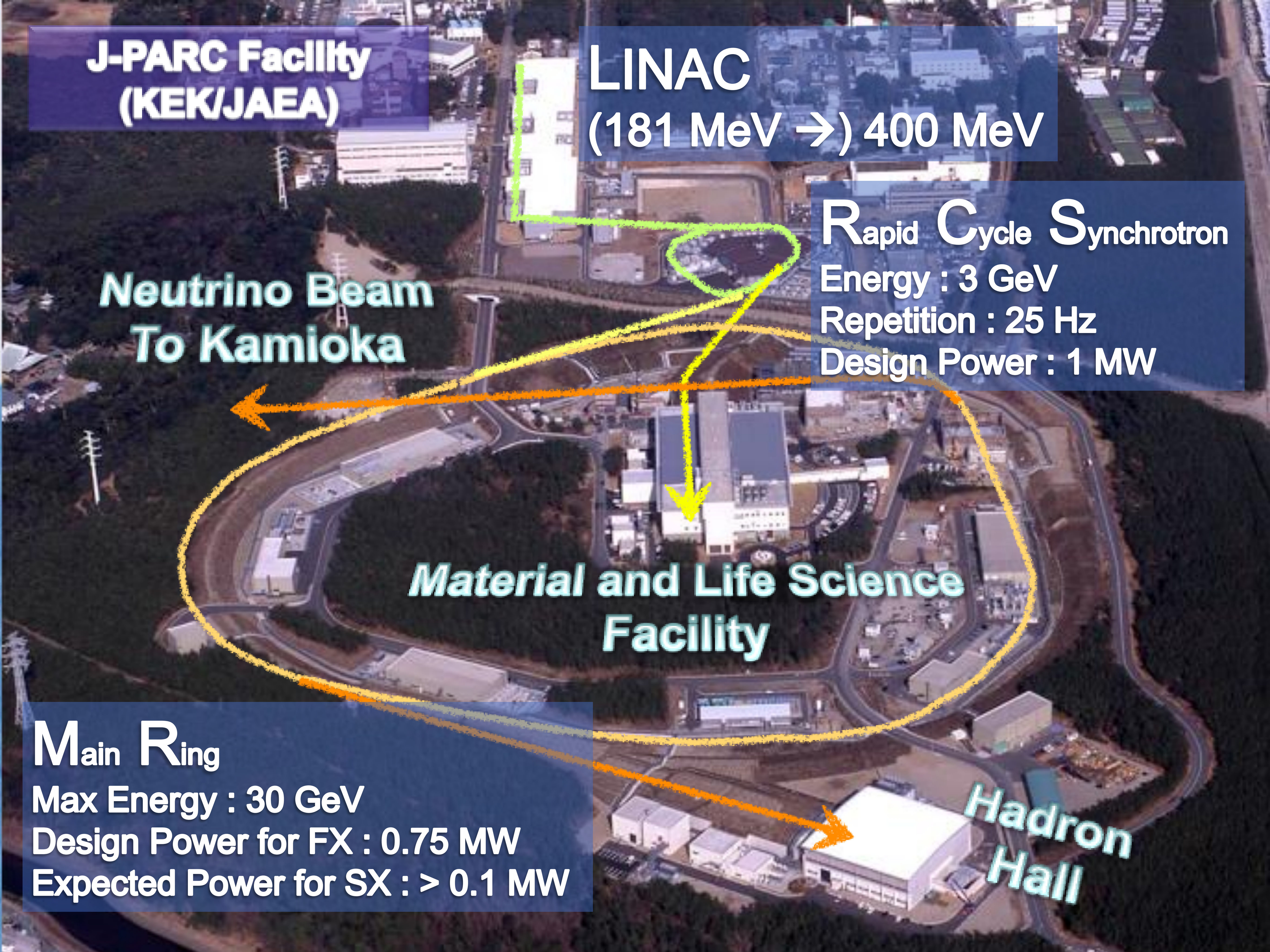
Power of Expedition



courtesy Zoltan Ligeti

a slide by Hitoshi Murayama

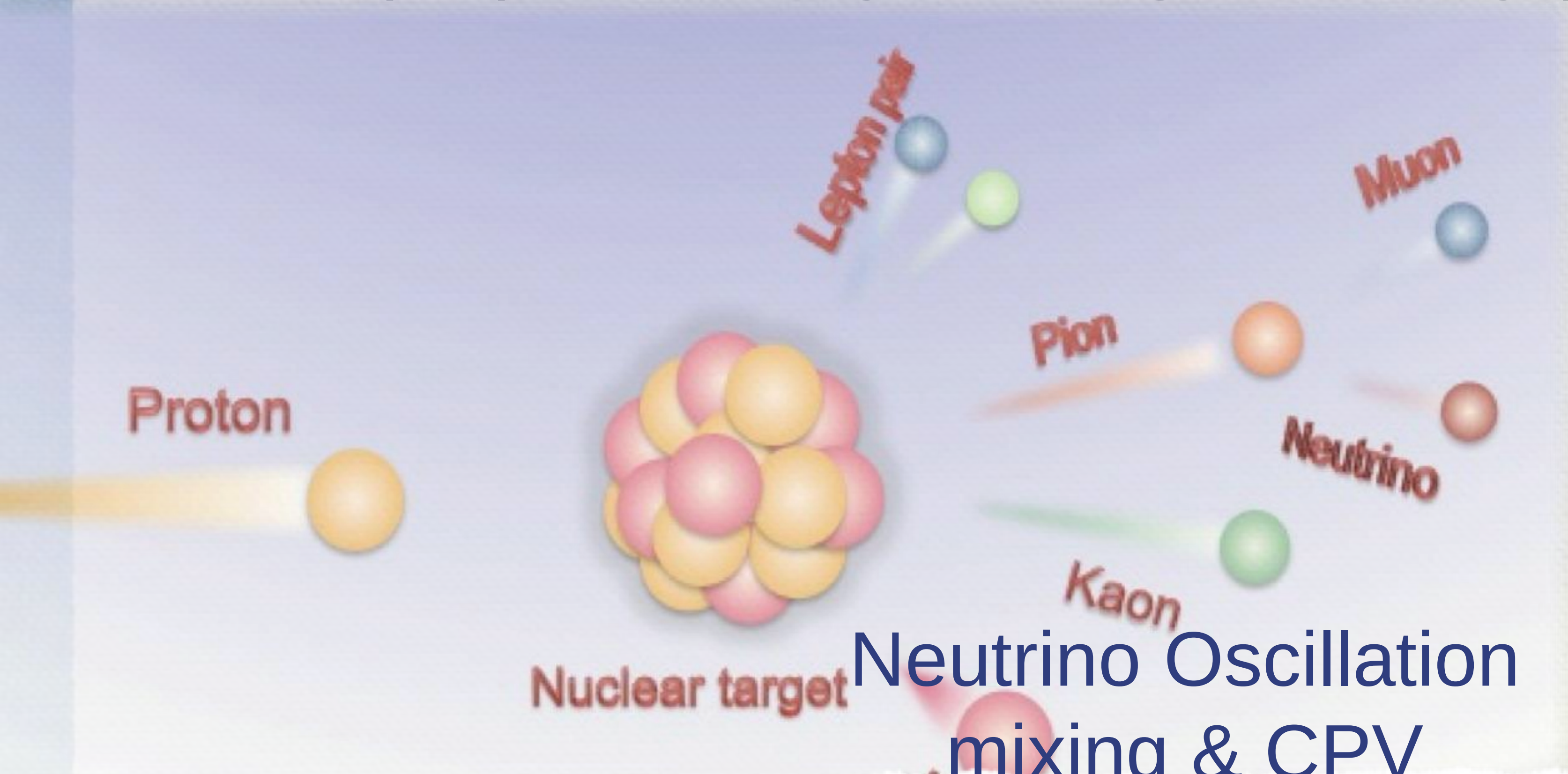
J-PARC

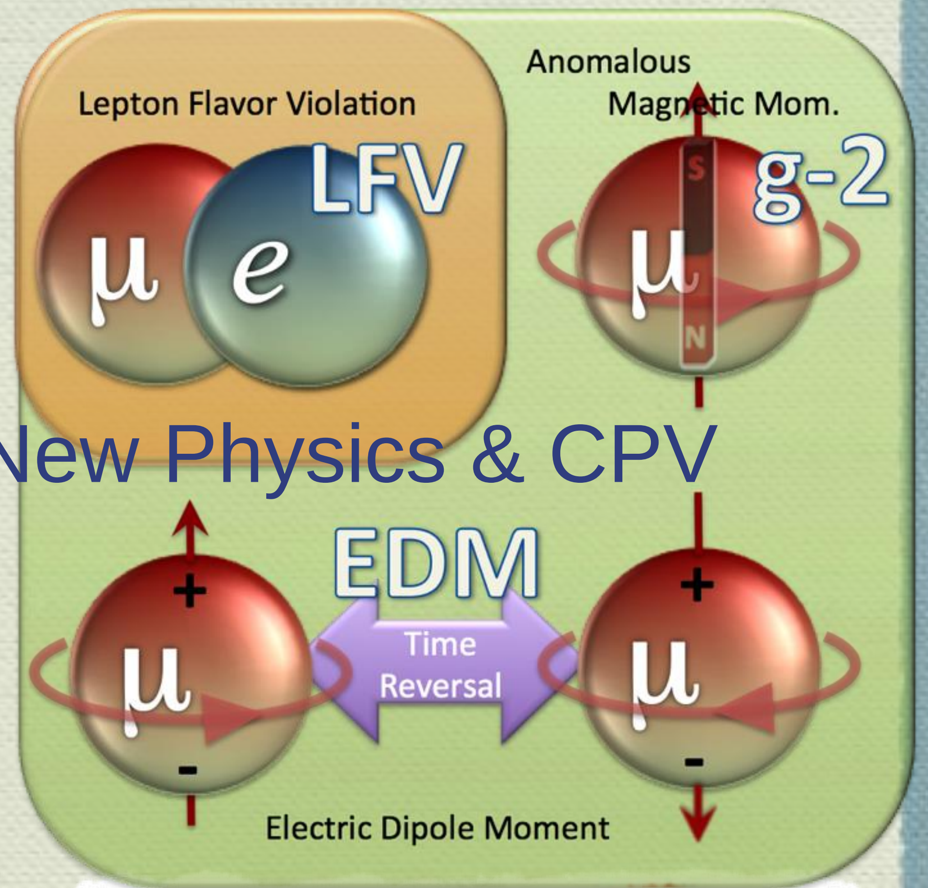

J-PARC Facility
(KEK/JAEA)
LINAC
(181 MeV →) 400 MeV
Rapid Cycle Synchrotron
Energy : 3 GeV
Repetition : 25 Hz
Design Power : 1 MW
Neutrino Beam
To Kamioka
Material and Life Science
Facility
Main Ring
Max Energy : 30 GeV
Design Power for FX : 0.75 MW
Expected Power for SX : > 0.1 MW
Hadron
Hall

High Intensity Frontier

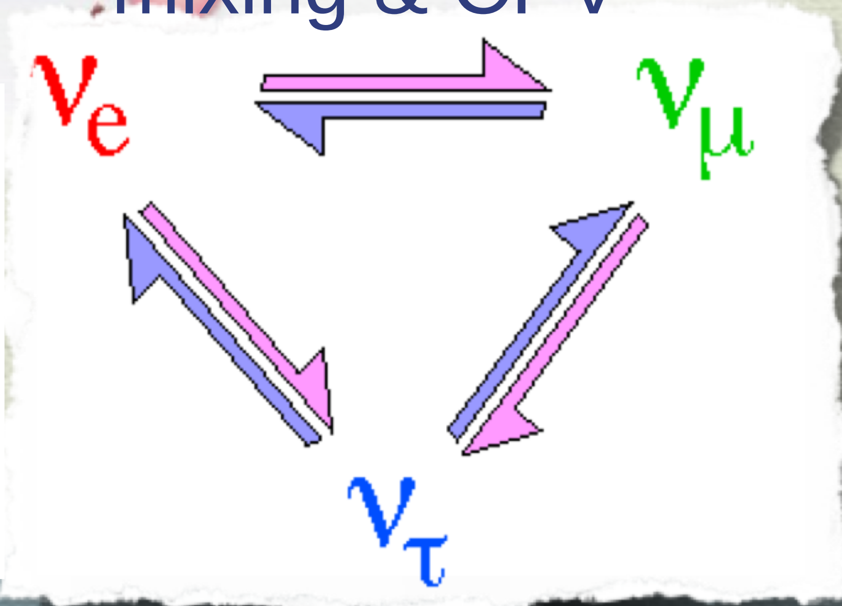
J-PARC (Japan Proton Accelerator Research Complex)

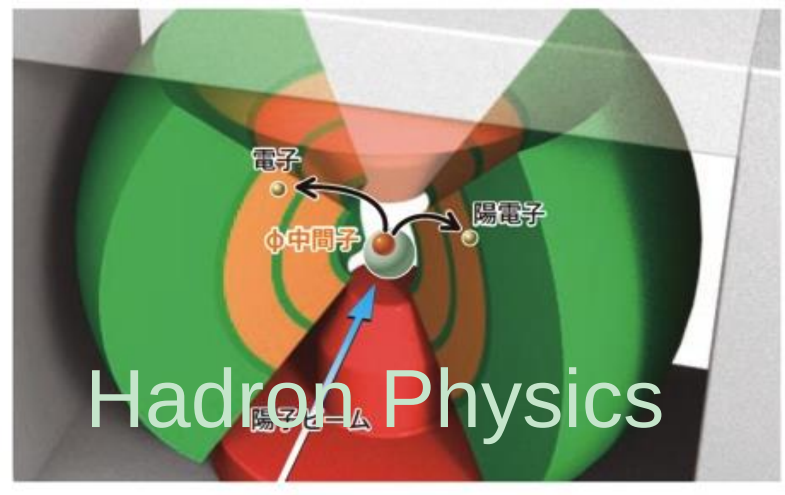
- Multi-purpose facility with high-intensity proton driver

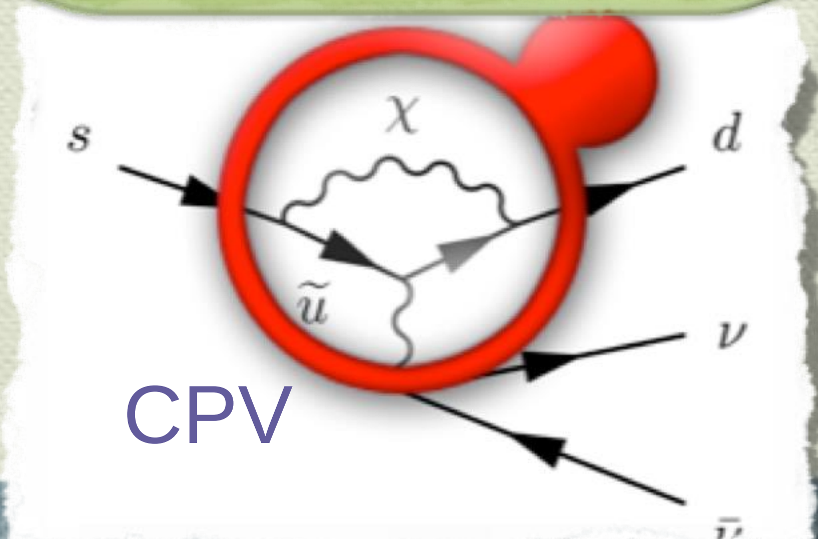




Neutrino Oscillation mixing & CPV

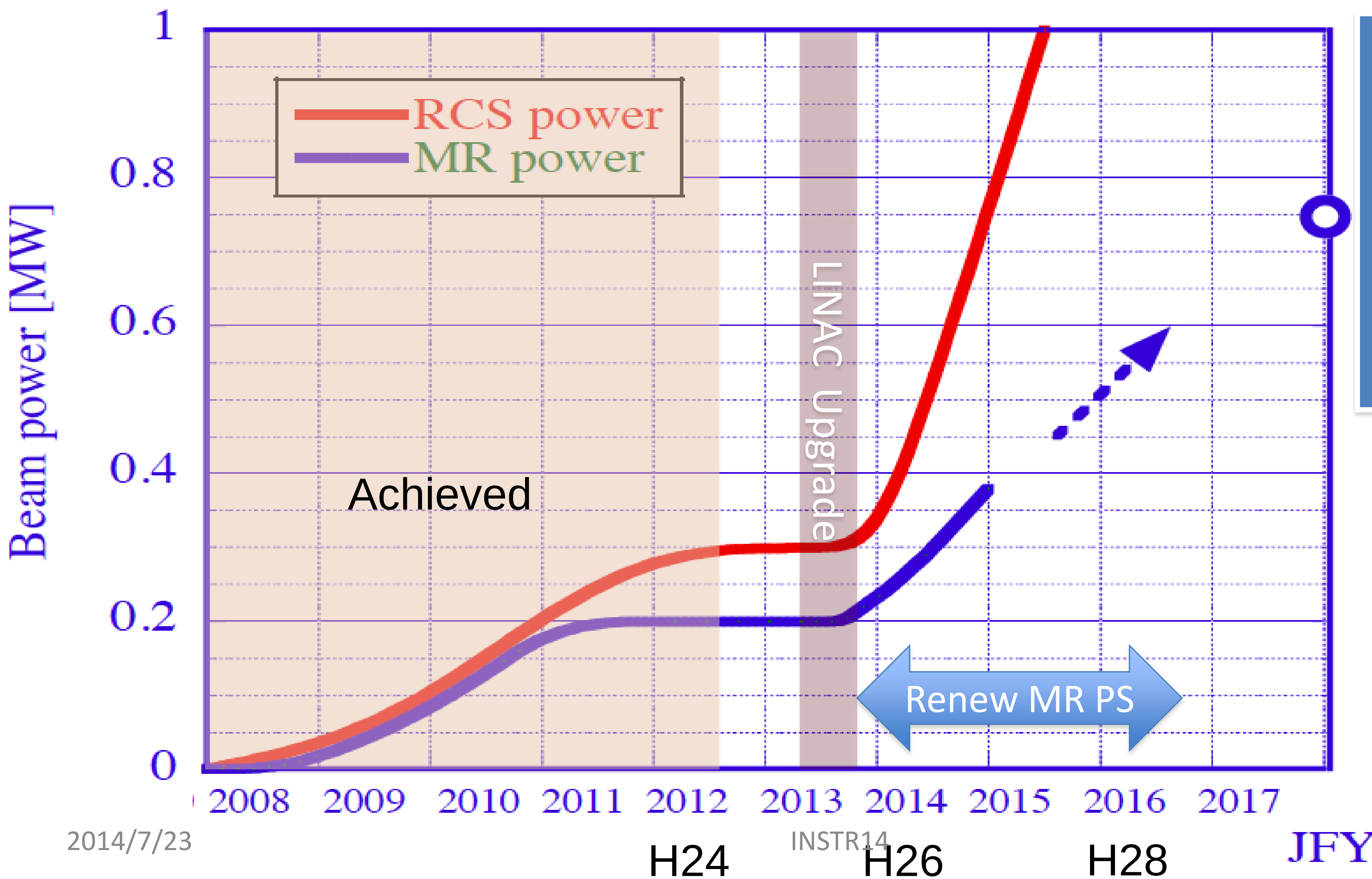






Beam Power Expectation

Upgrade MR Power to 0.75 MW by high Repetition Rate



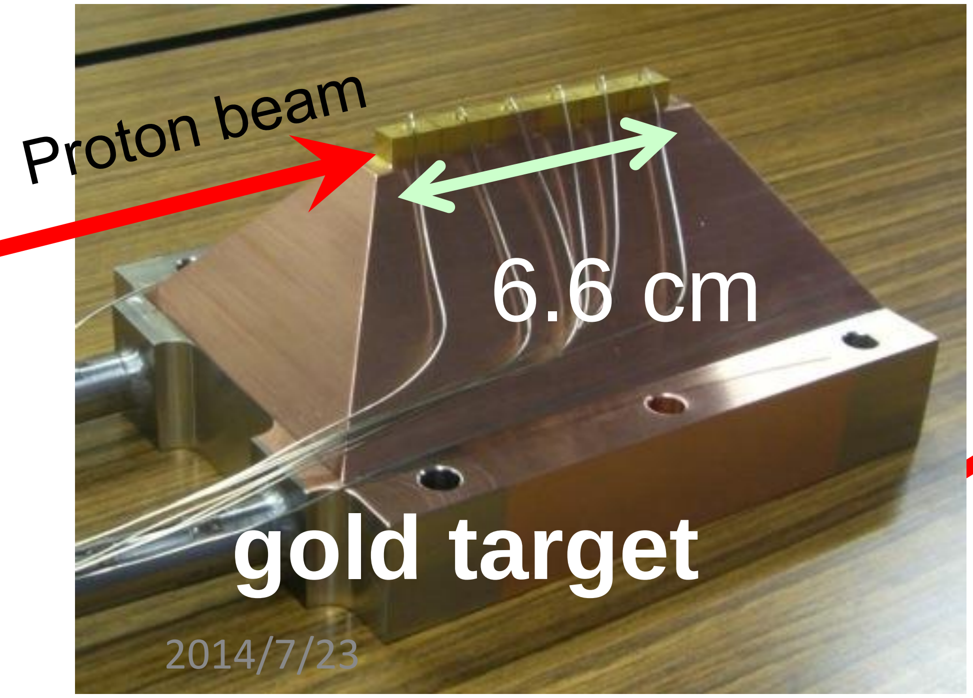
- MR PS renew
- High-rep rate in/ex
- Shield
- RF Core w/ hi grad.

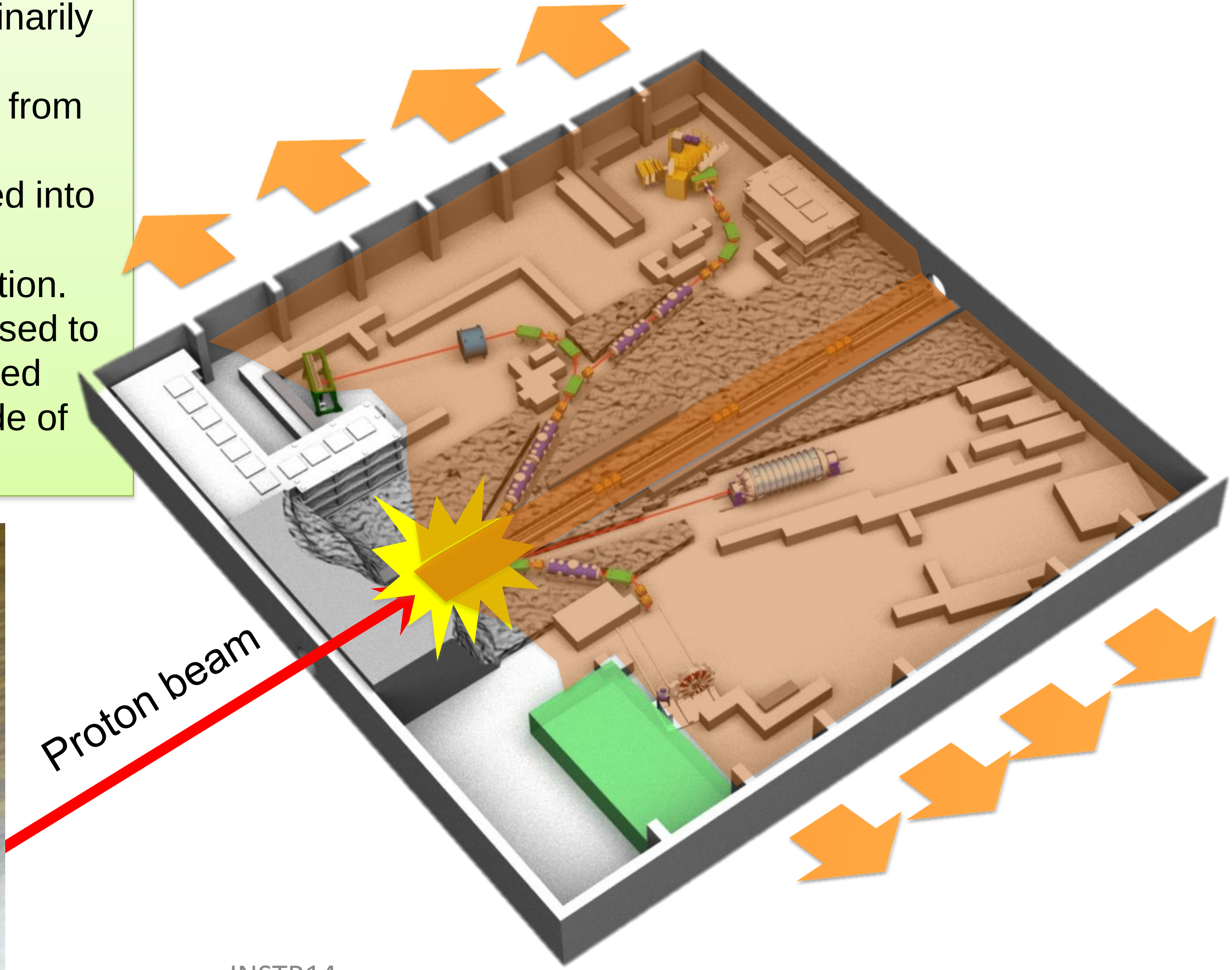
the Accident at HD Experimental Hall

11:55 on May 23

- An abnormal proton beam was injected to the gold target.
- The target heated up to a extraordinarily high temperature.
- Radioactive material was released from the target.
- The radioactive material was leaked into the HD hall.

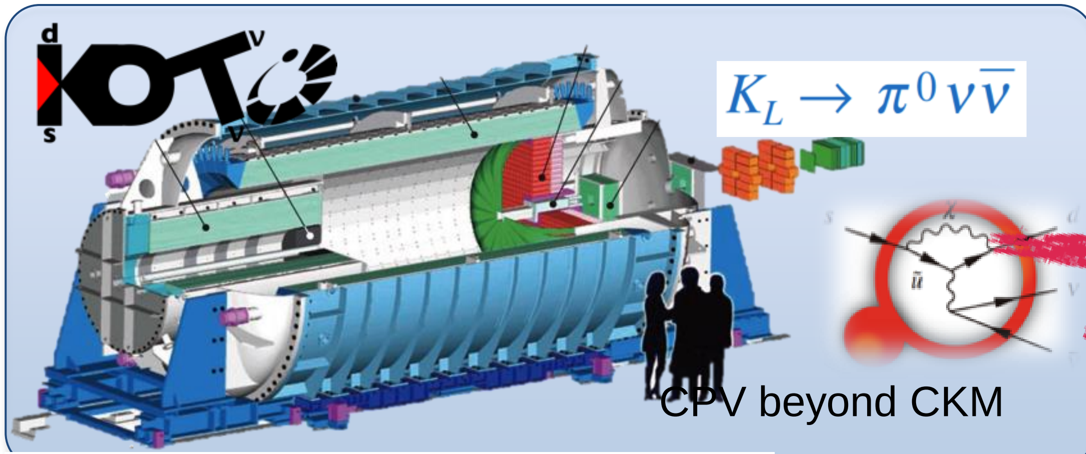
  → Workers were exposed to radiation.
- The radioactive material was released to the outside of the radiation controlled area and to the environment outside of the HD hall.



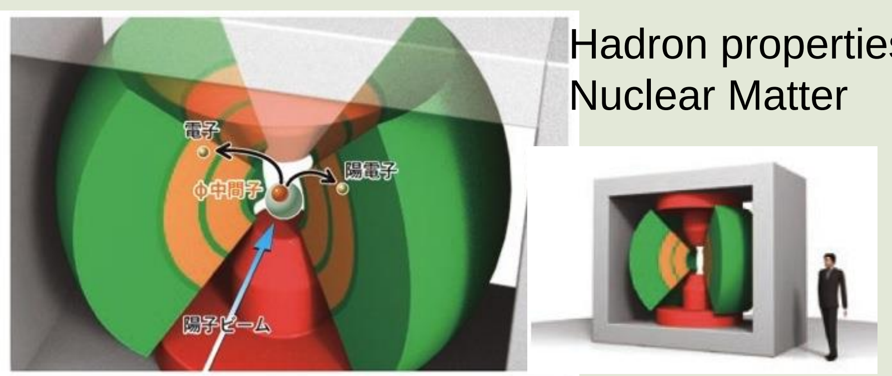


Origin of Matter :
Explored with High Intensity Proton Driver = J-PARC

Neutrino Experiment : T2K
～Mixing Angle, CP phase, and Mass Hierarchy ～



Hadron Experiments
～CP beyond CKM; Mass modification～

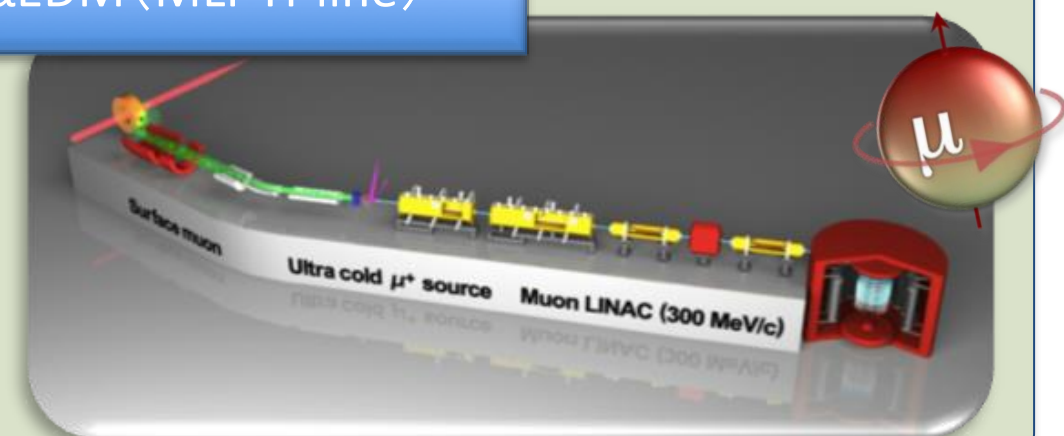


Hadron properties in Nuclear Matter

Muon Fundamental Physics
～Flavor and CP are violated in the charged Leton sector?～

COMET（Hadron Hall）

g-2/μEDM（MLF H-line）

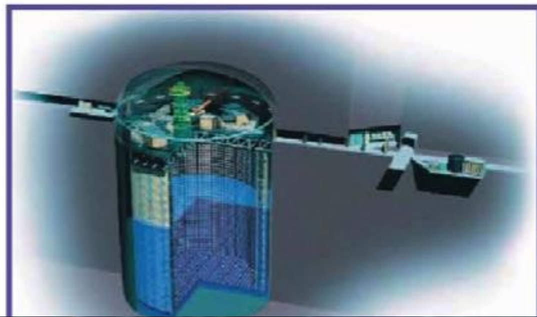


Origin of Matter

- Search for Physics Beyond SM in Quark and Lepton sectors
- Deeper understanding of Strong Int.

Flavor Physics

T2K : Long Baseline Neutrino Experiment



THE YEAR IN SCIENCE

SCIENCE FOR THE CURIOUS

Discover

January/February 2014

100 top stories of 2013

Math and Physics

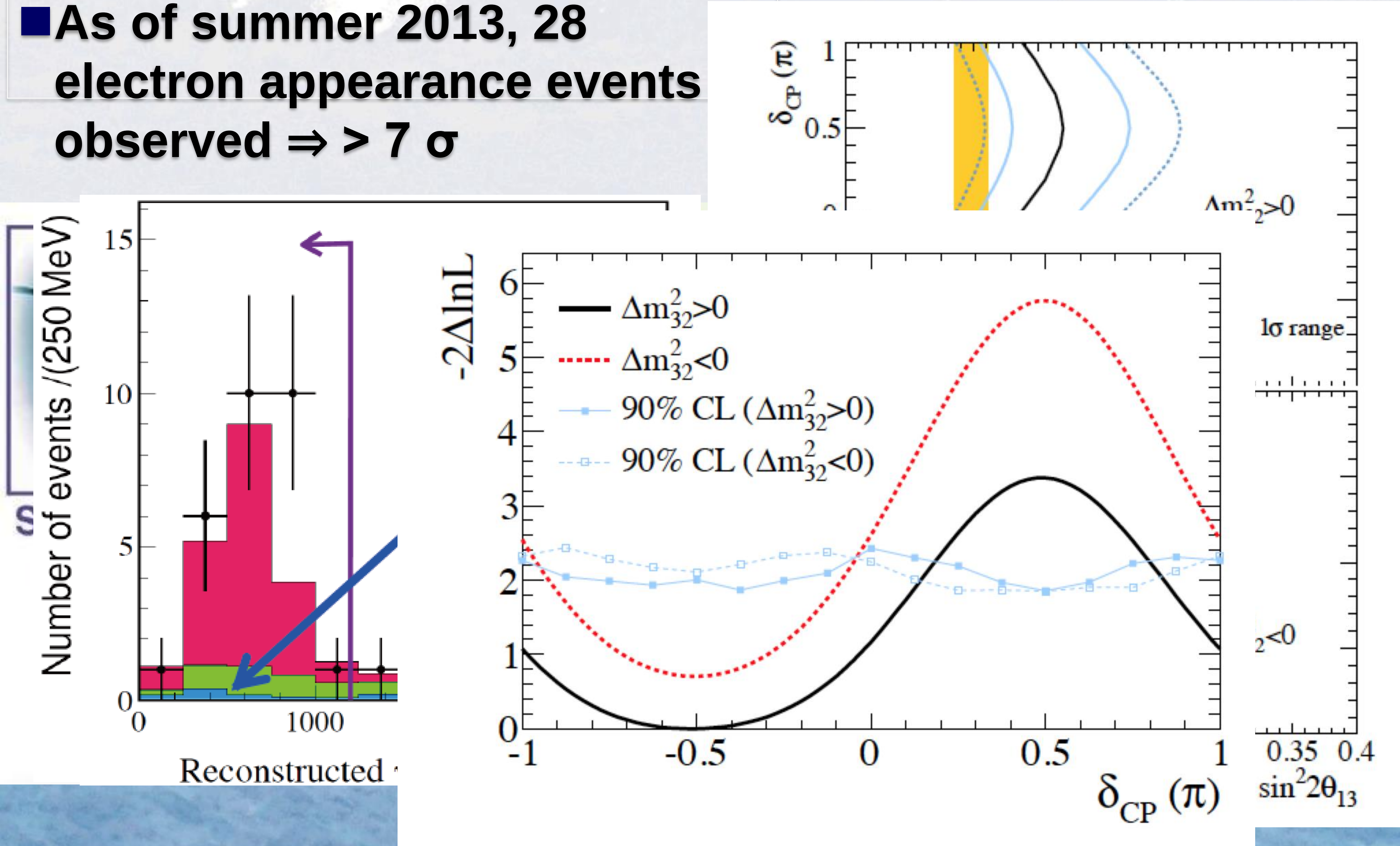
66

Particle Finds a New Identity

About 15 years ago, physicists discovered that the neutrino, a subatomic particle, seems to be able to switch from one type, or flavor, to another while in flight. Last year, an international coalition called the Tokai to Kamioka (T2K) collaboration produced new evidence for this strange phenomenon, which may lead to insights about why there is more matter than antimatter in the universe.

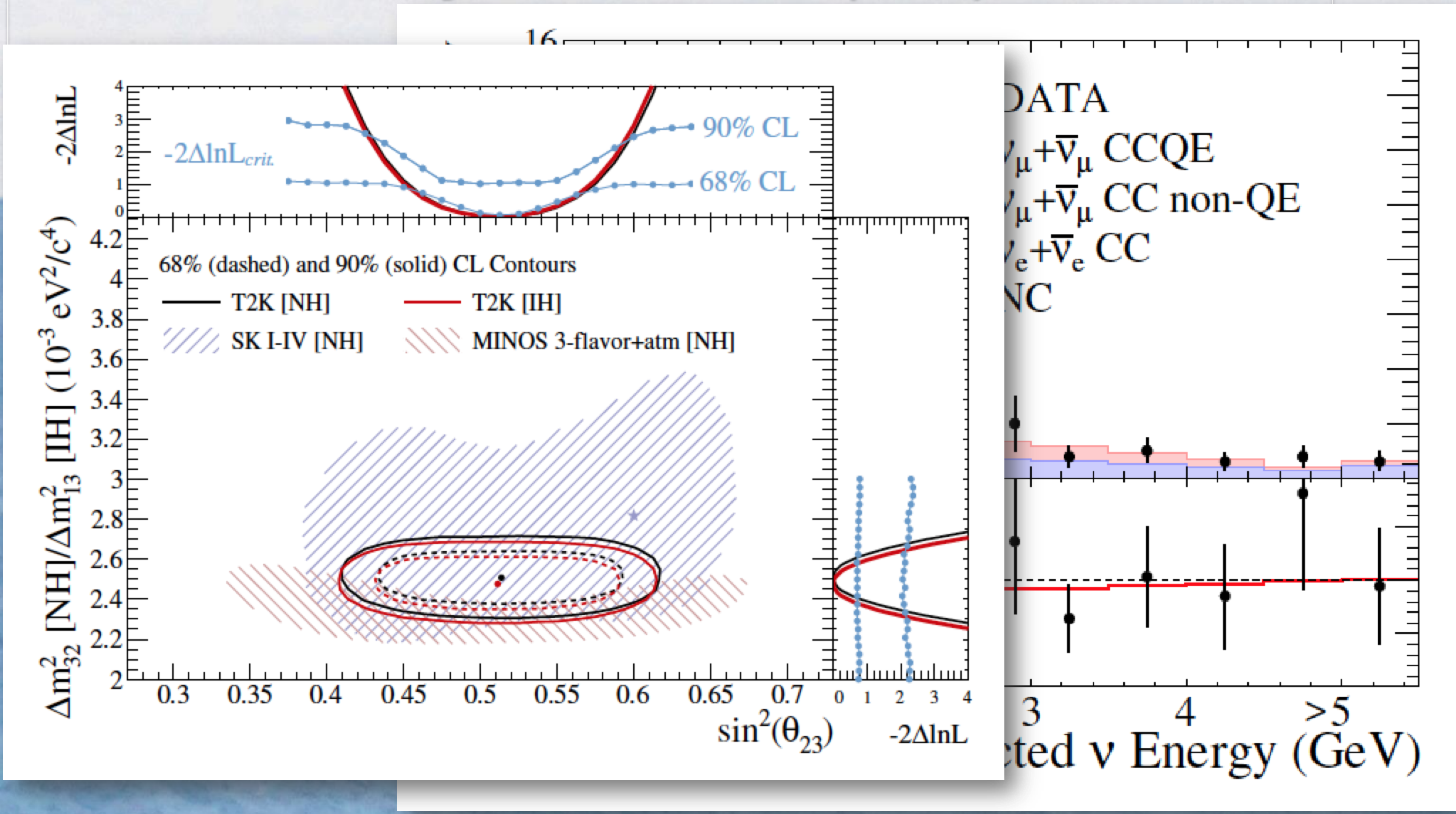
ν_e Appearance at T2K Established $\theta_{13} \neq 0$

- As of summer 2013, 28 electron appearance events observed ⇒ > 7 σ

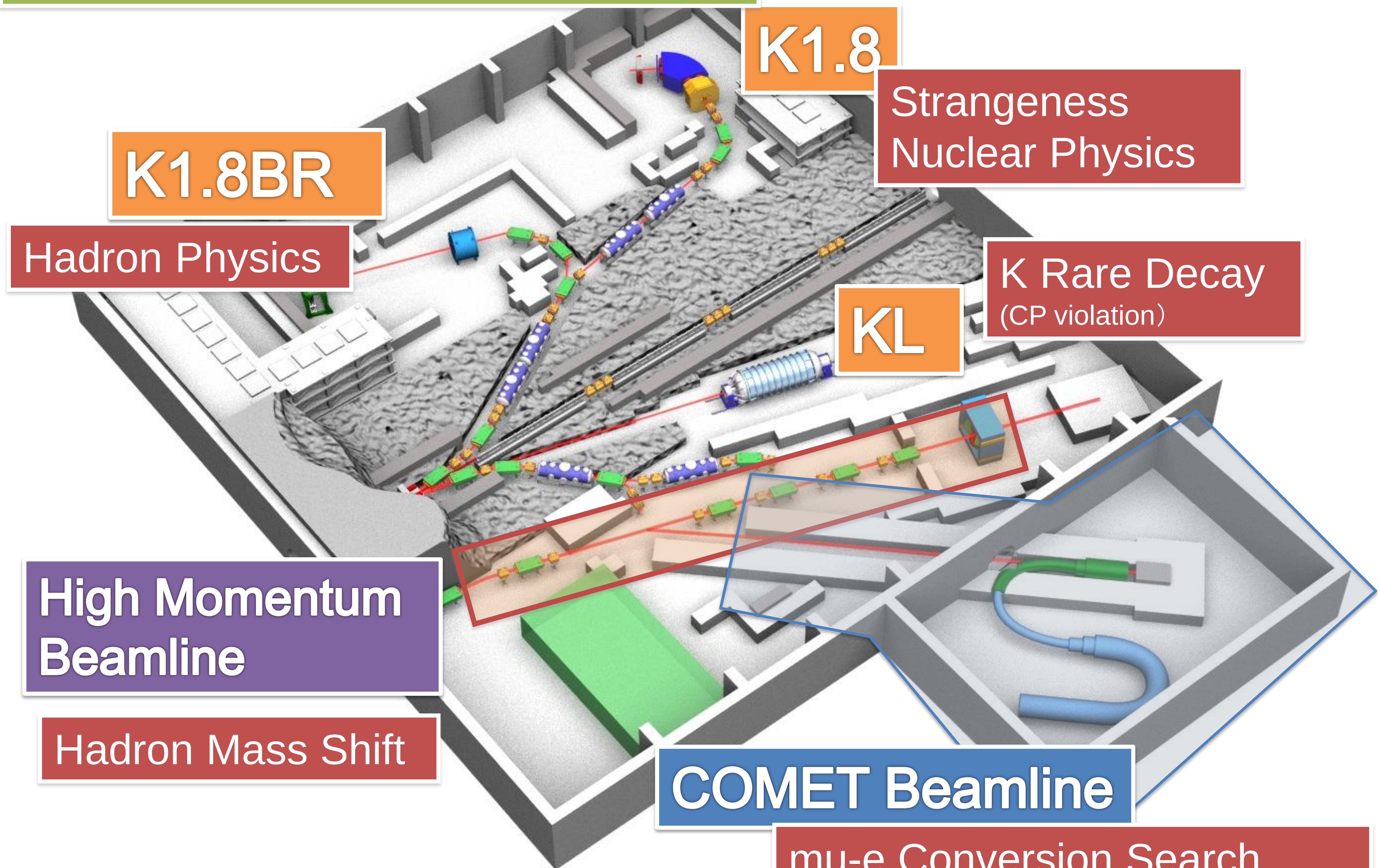


ν_μ Disappearance at T2K Determined θ_{23}

- Published in Phys.Rev.Lett. 112 (2014) 181801



Hadron Hall in 2016

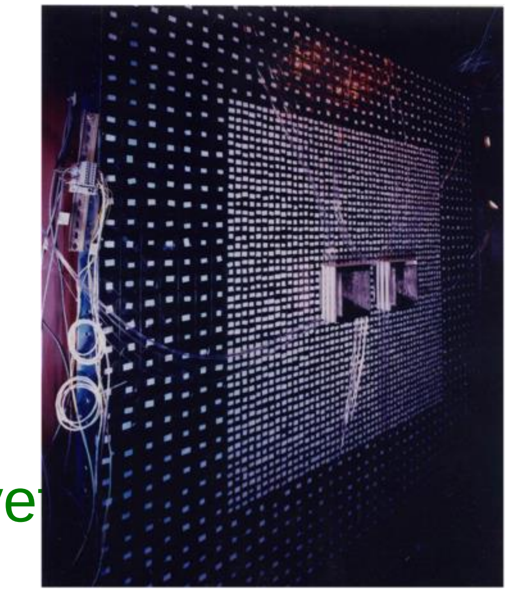


65 participants from Japan, US, Korea, Taiwan, Russia

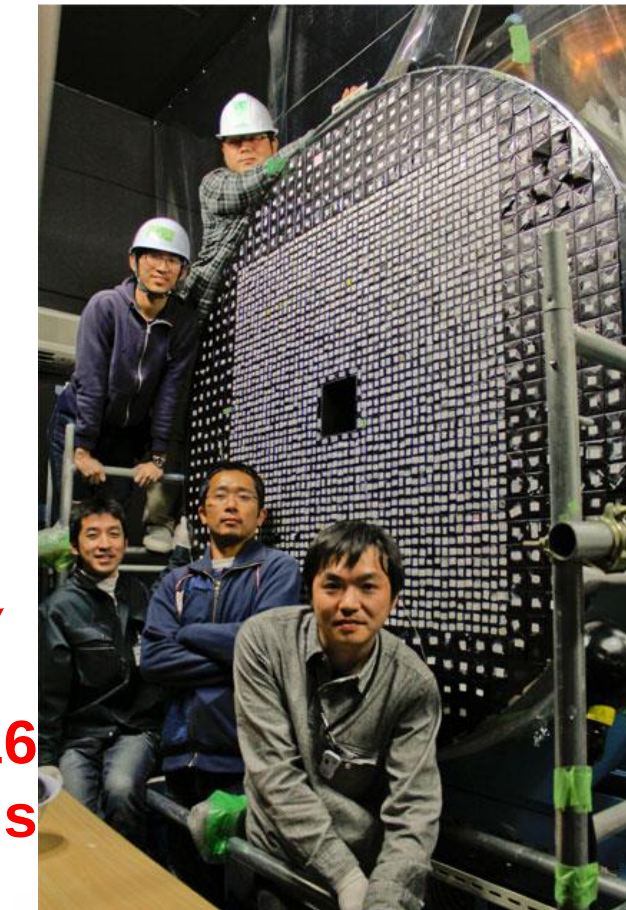
J-PARC Step1 Experiment, E14

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

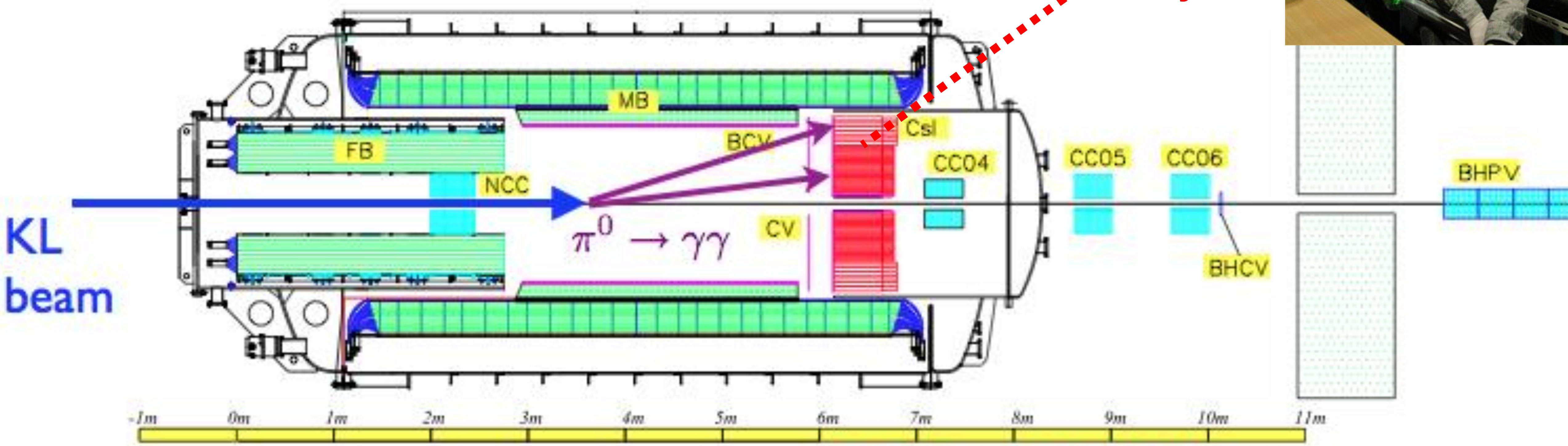
- **new beam line**
- **Moved and modified E391a detector**
  - **CsI calorimeter**
    to measure $\pi^0 \to \gamma\gamma$
  - background rejection:
    hermetic extra-particle detection (“ve
  - Trig / DAQ :
    waveform digitization
    pipeline readout



Fermilab



2716 Crystals



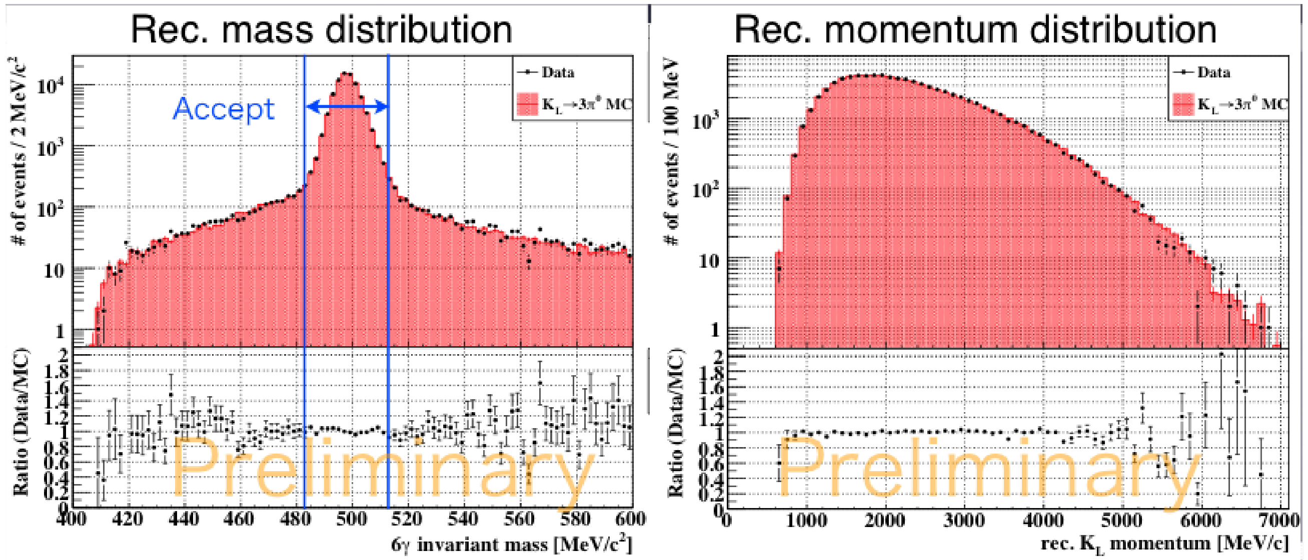
CsI Crystals (KTeV)

data in 2013

$K_L \rightarrow 3\pi^0$

分岐比

20%

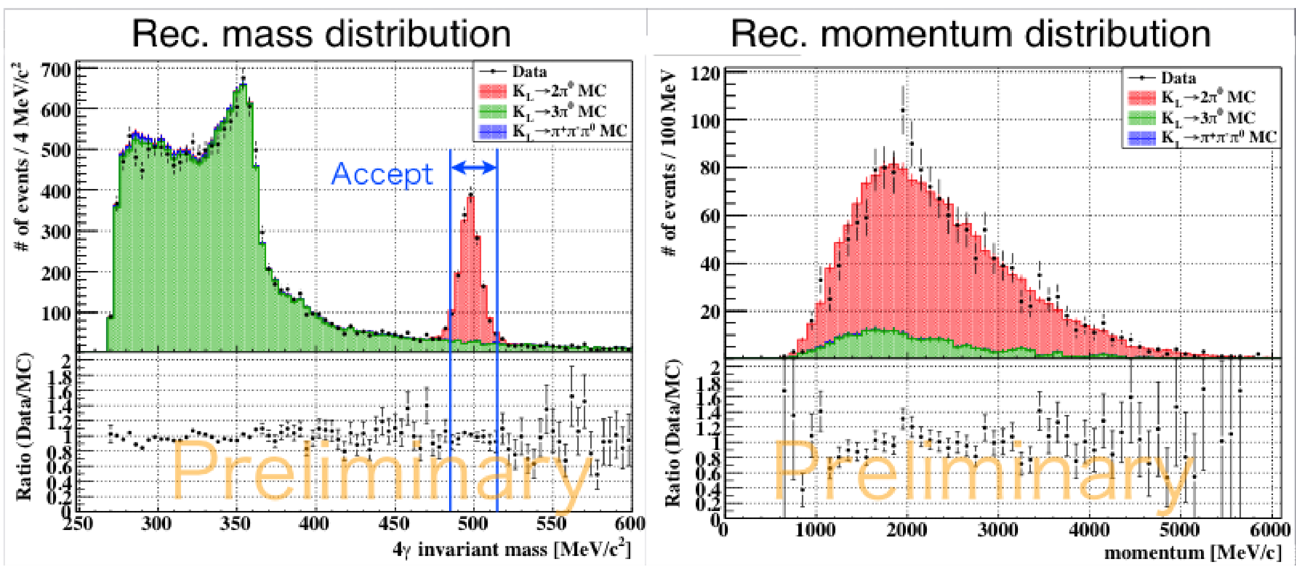


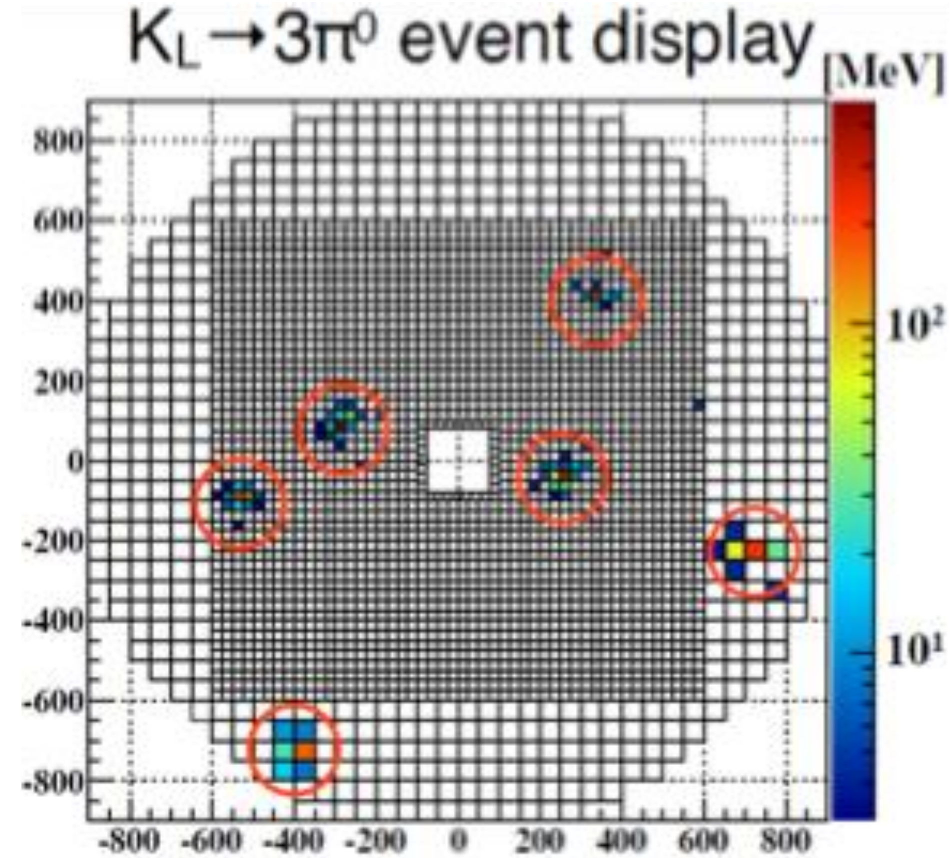
$K_L \rightarrow 2\pi^0$

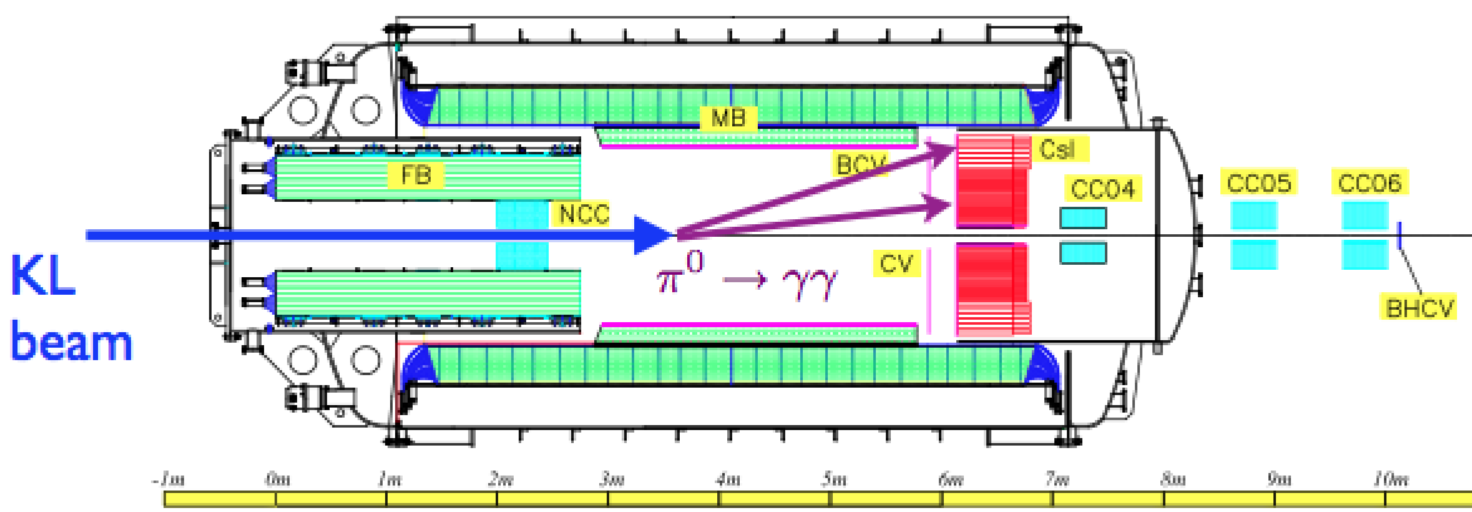
w/ loose veto

分岐比

0.09%







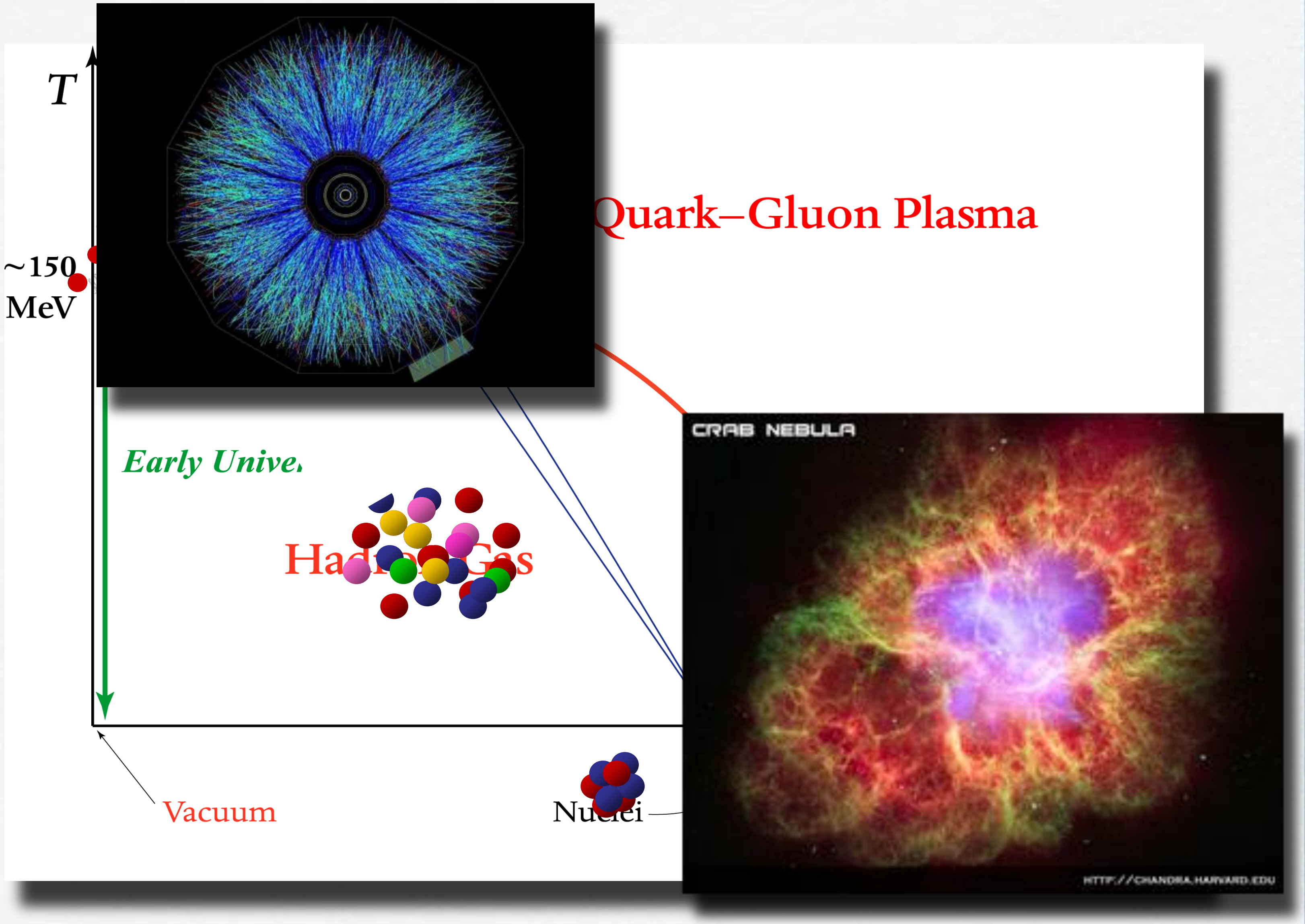
CsI Crystals (KTeV)

Strong Interaction

Quark-Gluon Matter Physics

$$L_{QCD} = -\frac{1}{4} F^{A}_{\alpha\beta} F^{\alpha\beta}_{A} + \sum_{\text{flavors}} \bar{q}_a (i\not{D} - m)_{ab} q_b$$

- Simple Equation
- Variety of Emergent Phenomena
- Quark confinement
- hadron mass
- ultra-high density matter



Kaonic Nuclei as Ultra-High Density Matter

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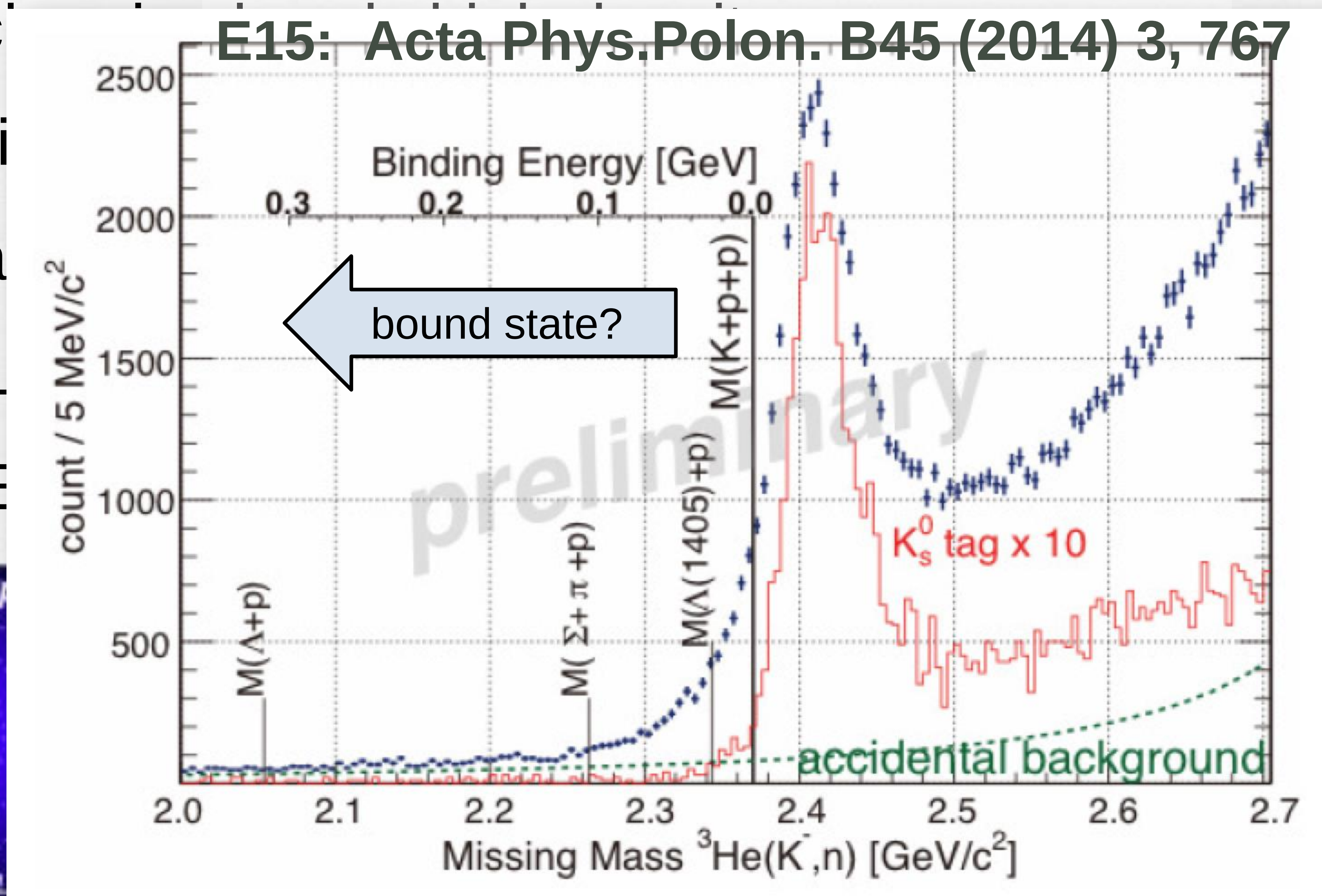
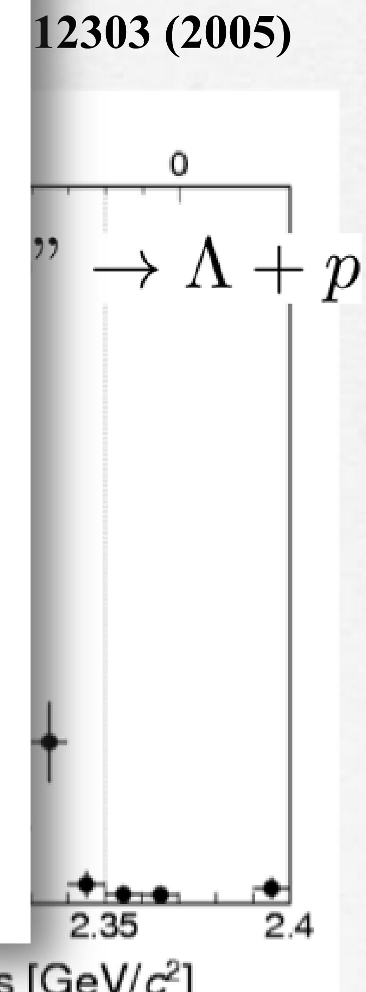
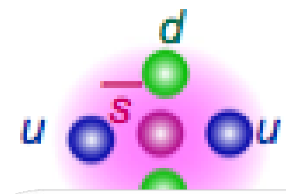




A. Dote et al. : PLB590 (2004) 51, etc.

E19: Search for pentaquark, Θ^+, by $\pi^- p \to K^- X$ reaction ~2GeV/c

- Exotic five quark state ($qqqq\bar{q}$)
  c.f. meson($q\bar{q}$), baryon(qqq)



KEK-PS E522
with CH_2 target

- Existence/No existence is not establishe
  - Positive results at low energy
    LEPS, etc
  - Negative results at high energy
  - Acceptance is different . LEPS .vs.

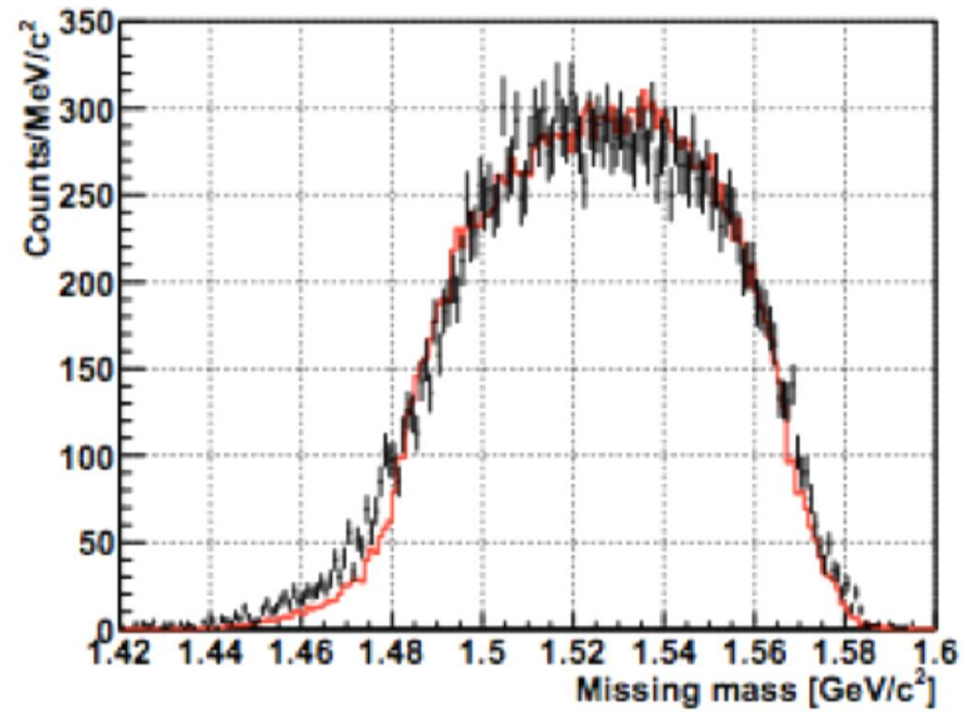


FIG. 2. The missing mass spectrum and the background shape for the $\pi^- p \to K^- X$ reaction at the beam momentum of 1.92 GeV/c. The black points with error bars are the experimental data. The contribution of the simulated background is indicated by red histogram.

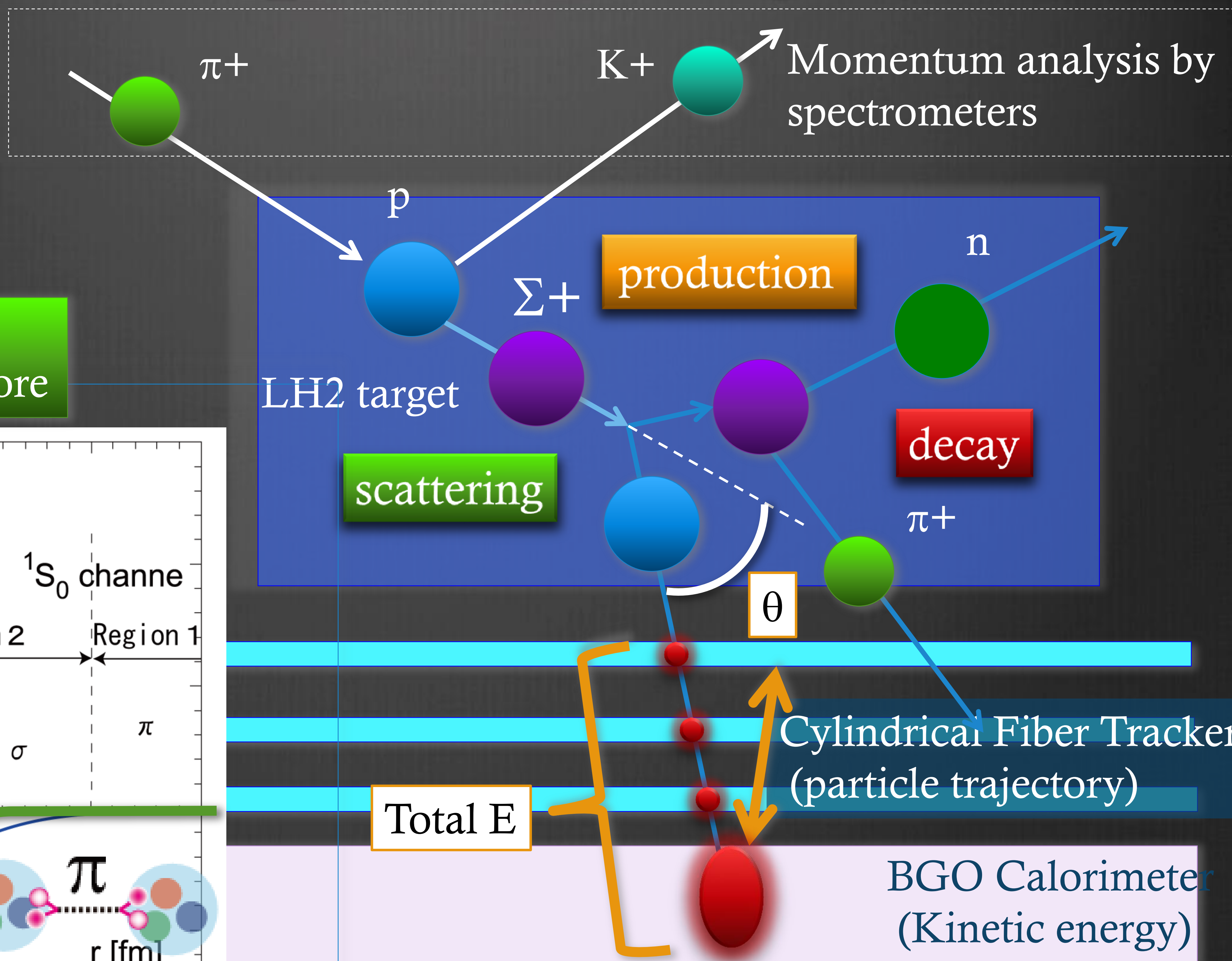
- Very narrow width. Why ?

Search for Θ^+ by hadronic reaction,
$\pi^- p \to K^- \Theta^+$ channel with Liq. H_2
high resolution of ~2MeV
high statistics of 62σ

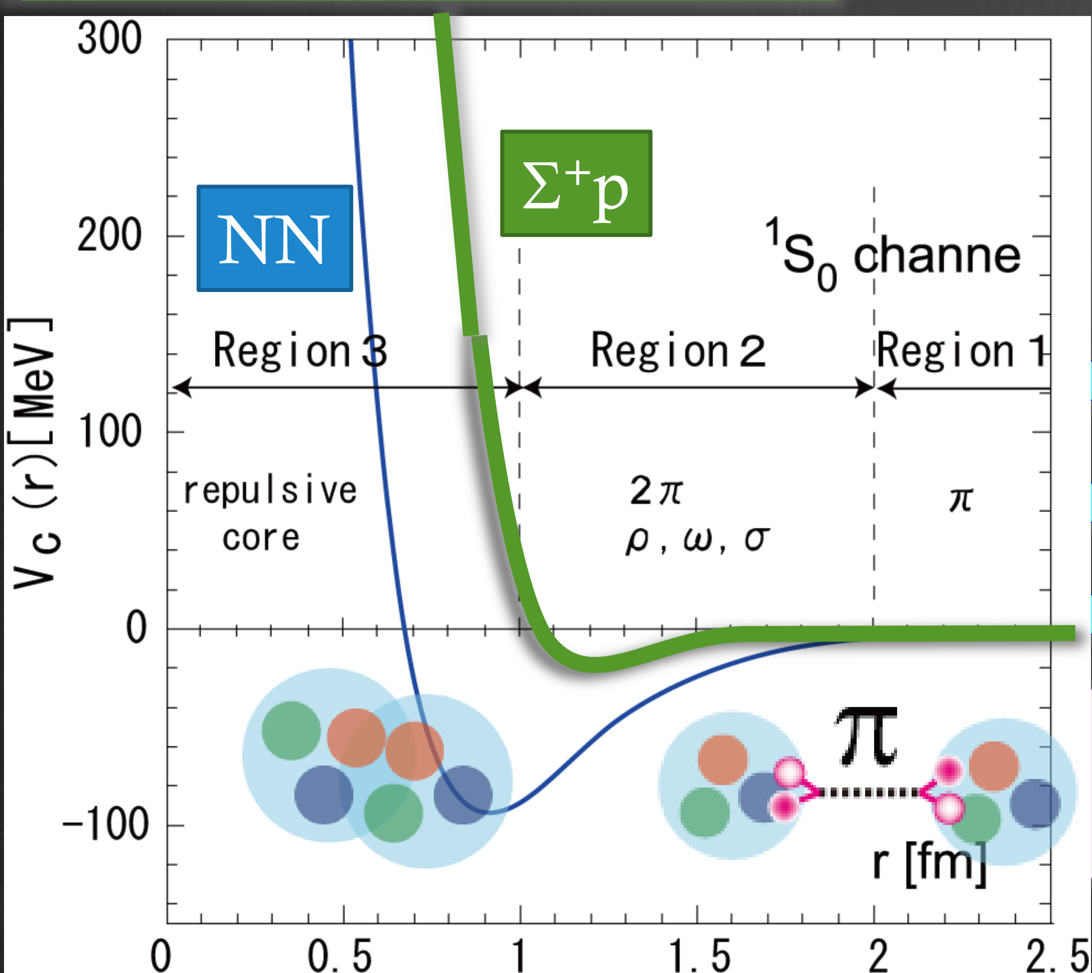
1 week data-taking with 10^7/spill beam based on KEK-E522 result

Day-1 experiment!

P40: Σp scattering



Larger repulsive core
Origin of short range core



New Activities

Lepton and EDM Physics at Intensity Frontier Machine : J-PARC

cLFV

Improve by x 100 and more (10^{-12}--> $10^{-14; -16}$)

Search for Charged Lepton Flavor Mixing

Charged Lepton Flavor Mixing and Origin of Matter

g–2

Improve by x 5 (0.1 ppm)

Precision Measurement of Anomalous Magnetic Moment

Muon Precision Experiment to search for New Physics

μEDM

Improve by x 100 and more ($1\times10^{-21; -24}$ e cm)

Search for Electric Dipole Moment

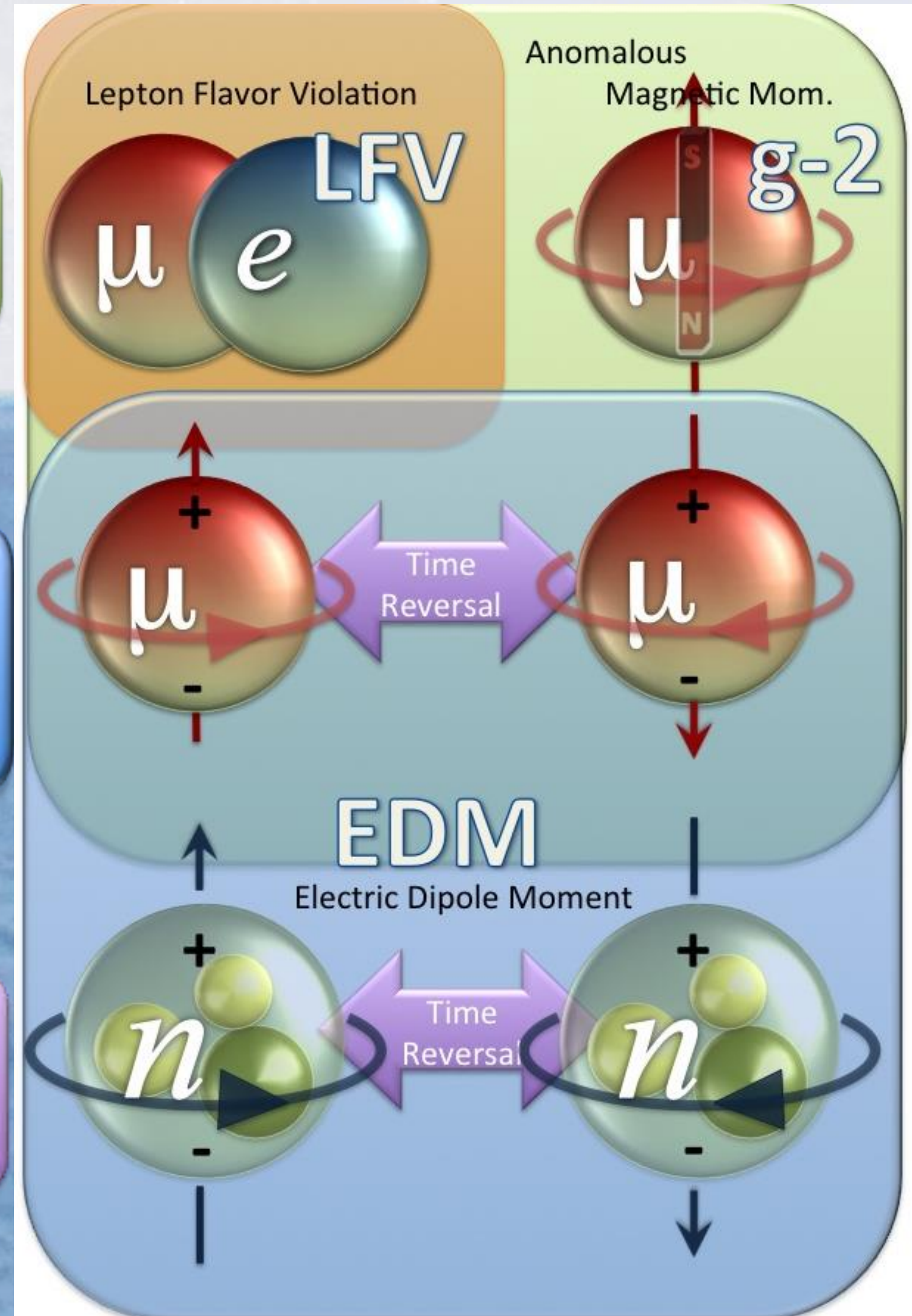
Space-time Symmetry and Origin of Matter

nEDM

Improve by 100 and more ($1\times10^{-28; -29}$ e cm)

Search for Electric Dipole Moment

Space-time Symmetry and Origin of Matter



$$\mathrm{EDM} \propto \mathrm{Im}(m^2_{\tilde{\mu}\tilde{\mu}})$$

$$\mathrm{cLFV} \propto \Delta m^2_{\tilde{e}\tilde{\mu}} + \Delta m^2_{\tilde{\mu}\tilde{e}}$$

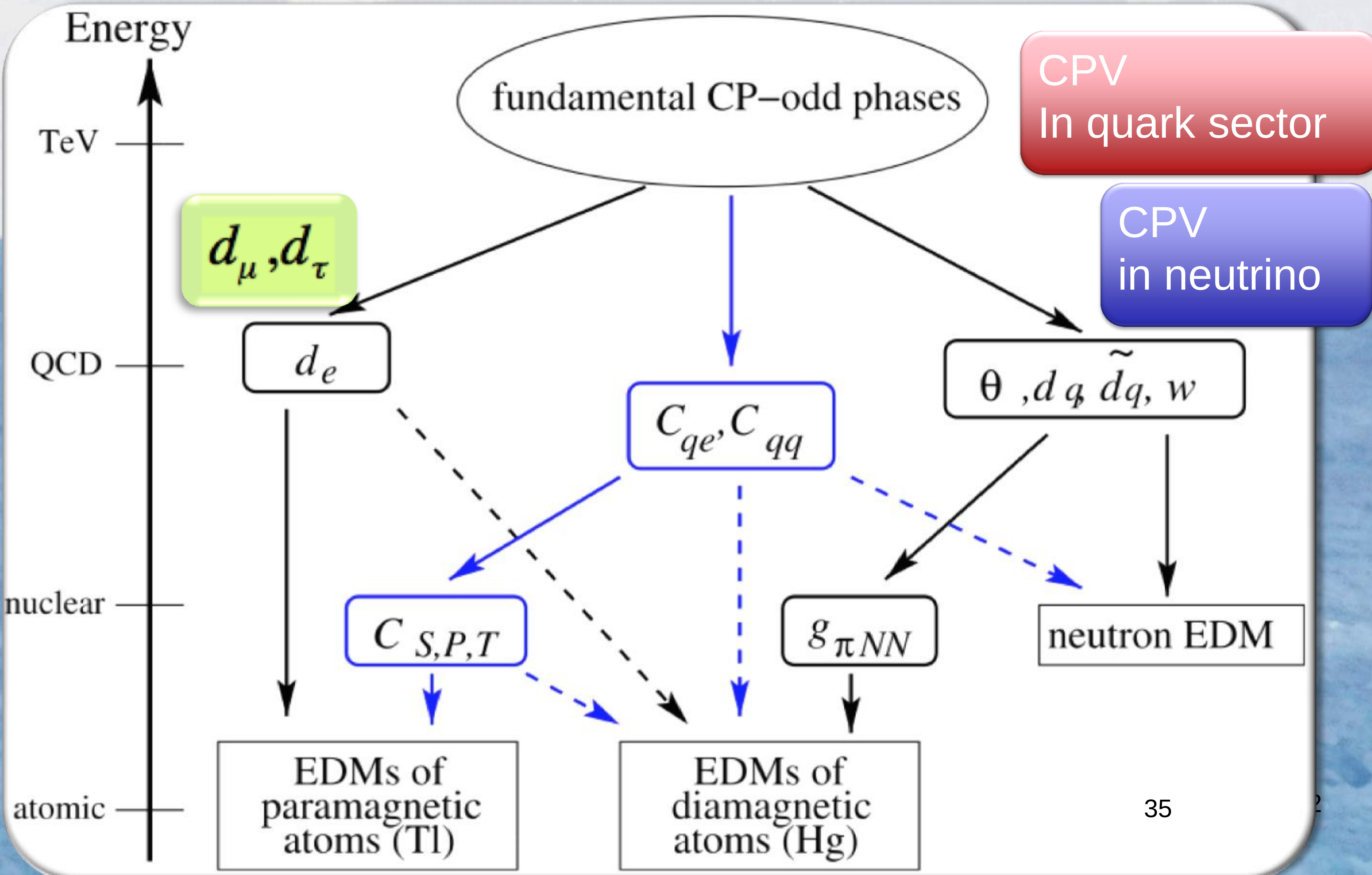
$$\mathrm{g\text{-}2} \propto \mathrm{Re}(m^2_{\tilde{\mu}\tilde{\mu}})$$

$$M^2_{\tilde{l}\tilde{l}'} = \begin{pmatrix} m^2_{\tilde{e}\tilde{e}} & \Delta m^2_{\tilde{e}\tilde{\mu}} & \Delta m^2_{\tilde{e}\tilde{\tau}} \\ \Delta m^2_{\tilde{\mu}\tilde{e}} & m^2_{\tilde{\mu}\tilde{\mu}} & \Delta m^2_{\tilde{\mu}\tilde{\tau}} \\ \Delta m^2_{\tilde{\tau}\tilde{e}} & \Delta m^2_{\tilde{\tau}\tilde{\mu}} & m^2_{\tilde{\tau}\tilde{\tau}} \end{pmatrix}$$

SUSY Mass Matrix

Origin of EDM and CPV

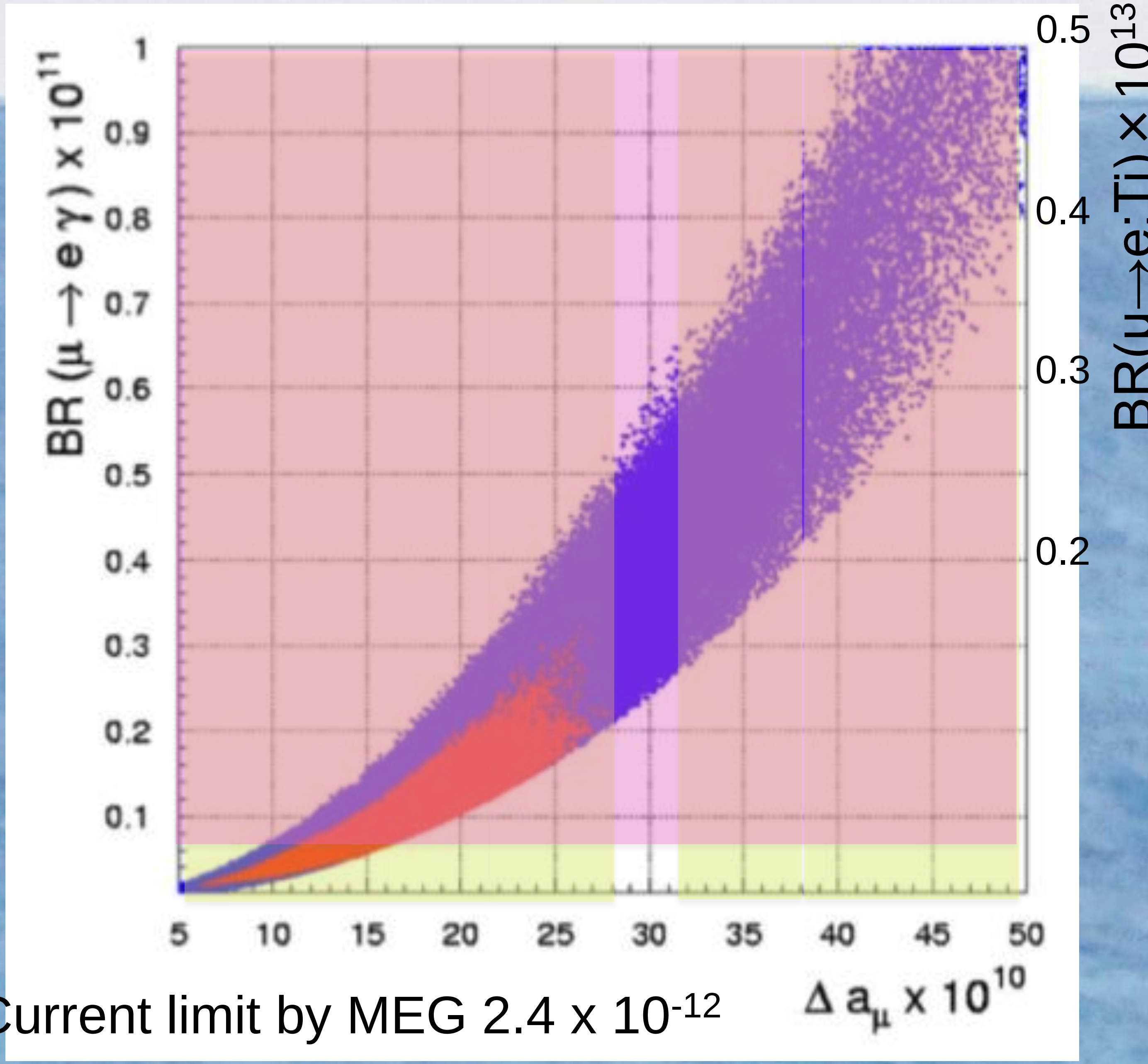
M.Pospelov and A.Ritz, Ann.Phys. 318 (2005) 119



g-2, EDM and cLFV

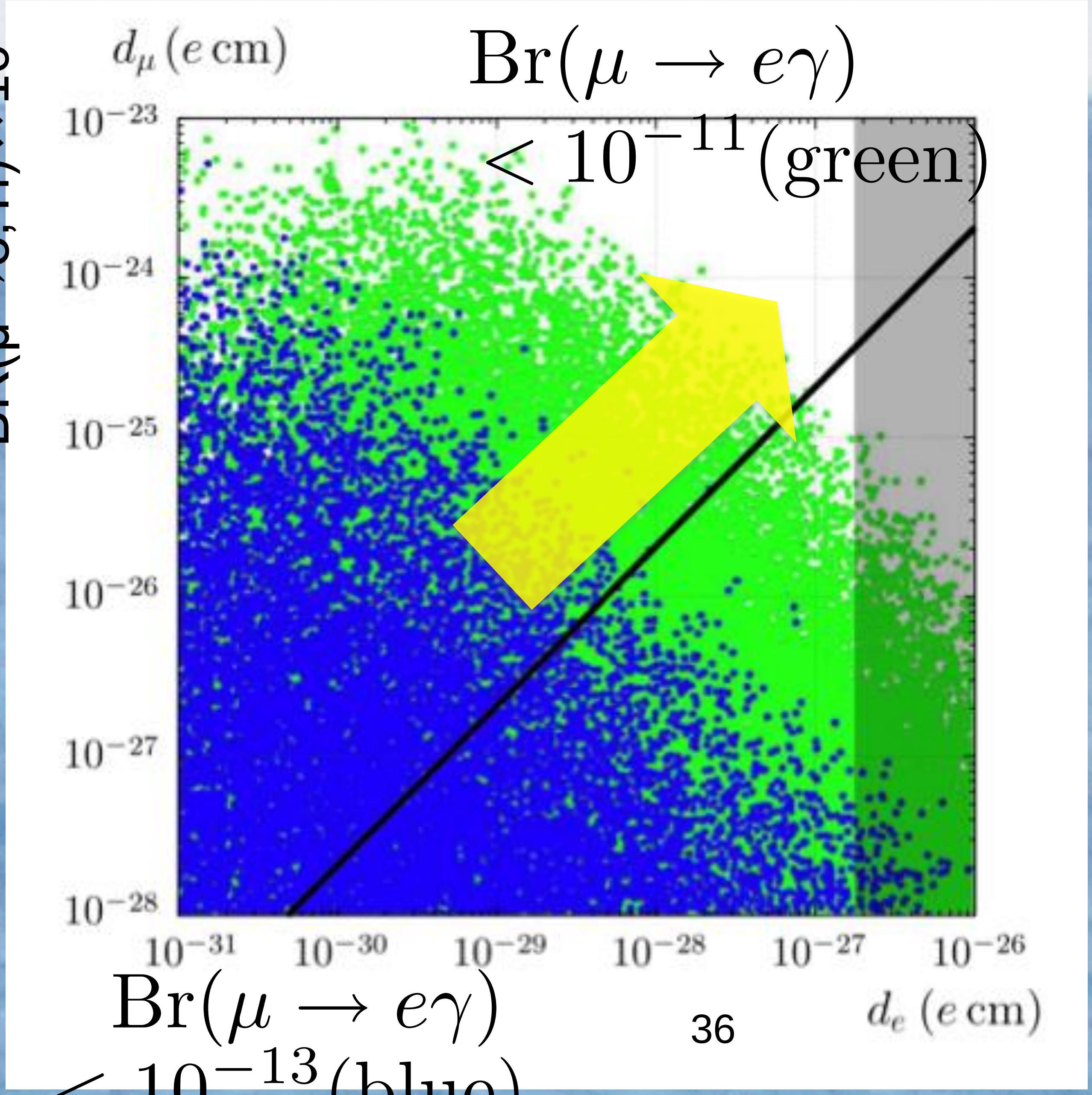
- Large g-2 → Large cLFV → Large EDM

G. Isidori, F. Mescia, P. Paradisi, and D. Temes, PRD 75 (2007) 115019



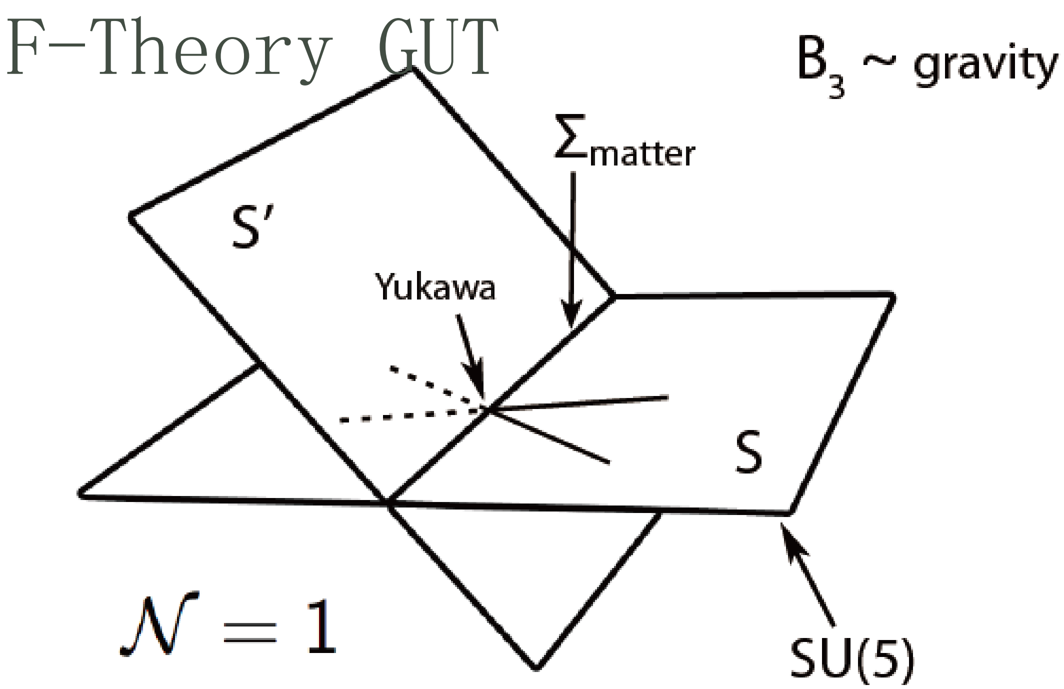
Current limit by MEG 2.4 x 10^{-12}

J. Hisano, Nagai, Paradisi



Flavor and Space-Time

- **CPV and Flavor Structure can be explained from higher dimensions / higher energies?**



dim.	internal dim.	feature
10	$6=\dim(B_3)$	gravity
8	$4=\dim(S)$	gauge fields
6	$2=\dim(S\cap S')$	matter
4	$0=\dim(S\cap S'\cap S'')$	interactions

$$\left|V_{CKM}^{F-th}\right| \sim \begin{pmatrix} 1 & \alpha_{GUT}^{1/2} & \alpha_{GUT}^{3/2} \\ \alpha_{GUT}^{1/2} & 1 & \alpha_{GUT} \\ \alpha_{GUT}^{3/2} & \alpha_{GUT} & 1 \end{pmatrix} \sim \begin{pmatrix} 1 & 0.2 & 0.008 \\ 0.2 & 1 & 0.04 \\ 0.008 & 0.04 & 1 \end{pmatrix}$$

$$\left|V_{CKM}^{obs}\right| \sim \begin{pmatrix} 0.97 & 0.23 & 0.004 \\ 0.23 & 0.97 & 0.04 \\ 0.008 & 0.04 & 0.99 \end{pmatrix}$$

$$\left|V_{PMNS}^{F-th}\right| \sim \begin{pmatrix} U_{e1} & \alpha_{GUT}^{1/4} & \alpha_{GUT}^{1/2} \\ \alpha_{GUT}^{1/4} & U_{\mu 2} & \alpha_{GUT}^{1/4} \\ \alpha_{GUT}^{1/2} & \alpha_{GUT}^{1/4} & U_{\tau 3} \end{pmatrix} \sim \begin{pmatrix} 0.87 & 0.45 & 0.2 \\ 0.45 & 0.77 & 0.45 \\ 0.2 & 0.45 & 0.87 \end{pmatrix}$$

$$\left|V_{PMNS}^{obs}\right| \sim \begin{pmatrix} 0.77-0.86 & 0.50-0.63 & 0-0.22 \\ 0.22-0.56 & 0.44-0.73 & 0.57-0.80 \\ 0.21-0.55 & 0.4-0.71 & 0.59-0.82 \end{pmatrix}$$

$$\left|J_{\text{quark}}^{F-th}\right| \sim \alpha_{GUT}^{3} \sim 6\times 10^{-5}$$

$$\left|J_{\text{lepton}}^{F-th}\right| \sim \alpha_{GUT} \sim 4\times 10^{-2}.$$

Muon g-2/EDM

“Final Report” of Anomalous MDM

BNL- E821 Experiment : Phys.Rev.D73:072003,2006.

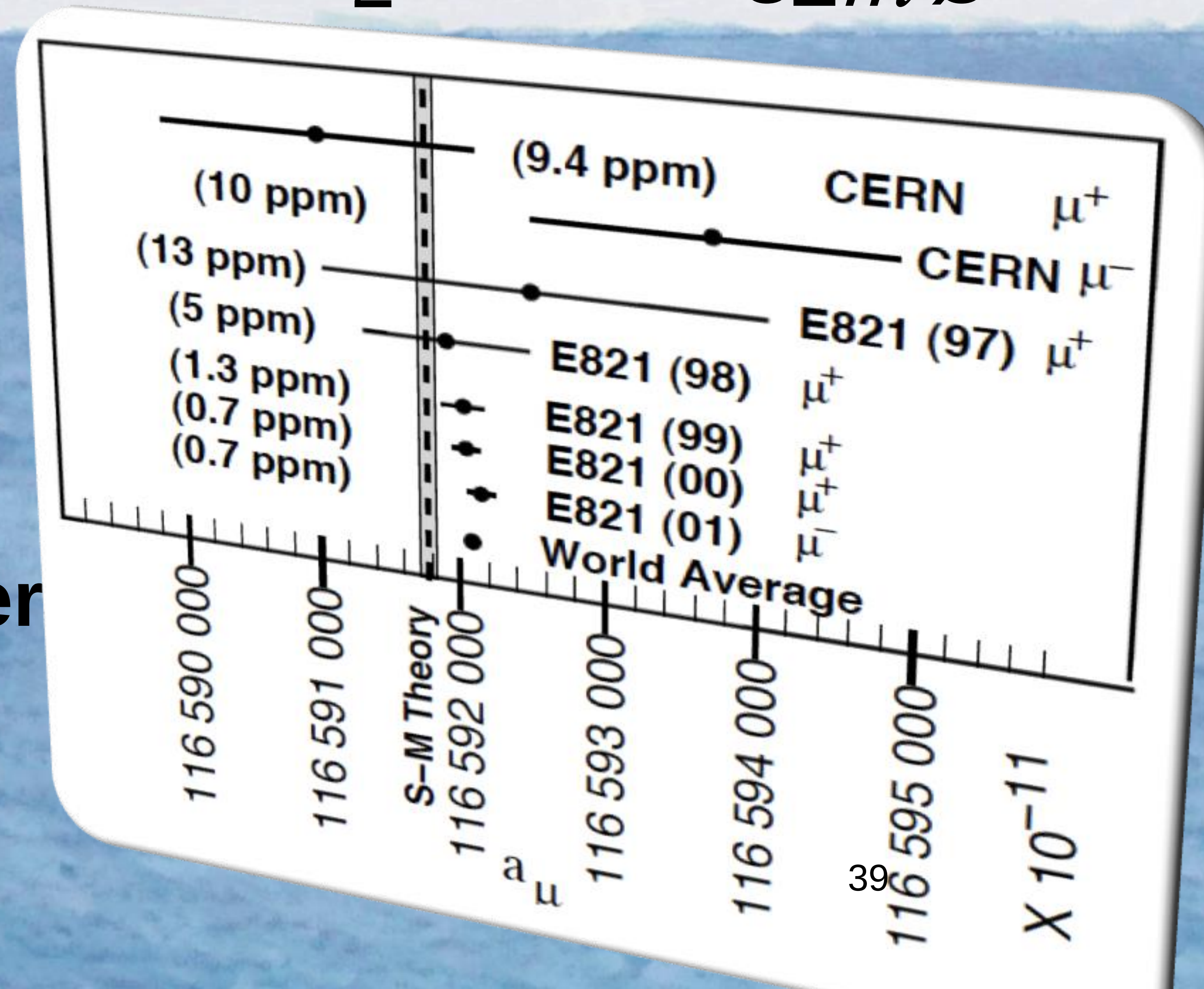
$$\Delta a_\mu^{(\text{today})} = a_\mu^{(\text{Exp})} - a_\mu^{(\text{SM})} = (295 \pm 88) \times 10^{-11}$$

$$a = \frac{g-2}{2} \qquad \vec{\mu} = g\left(\frac{e}{2m}\right)\vec{s}$$

- **E821 at BNL-AGS measured down to 0.7 ppm for both μ^+ and μ^-**
- **3.4 sigma deviation from the SM**
  - **SM prediction OK?**
  - **New Physics?**
- **Need to explore further**

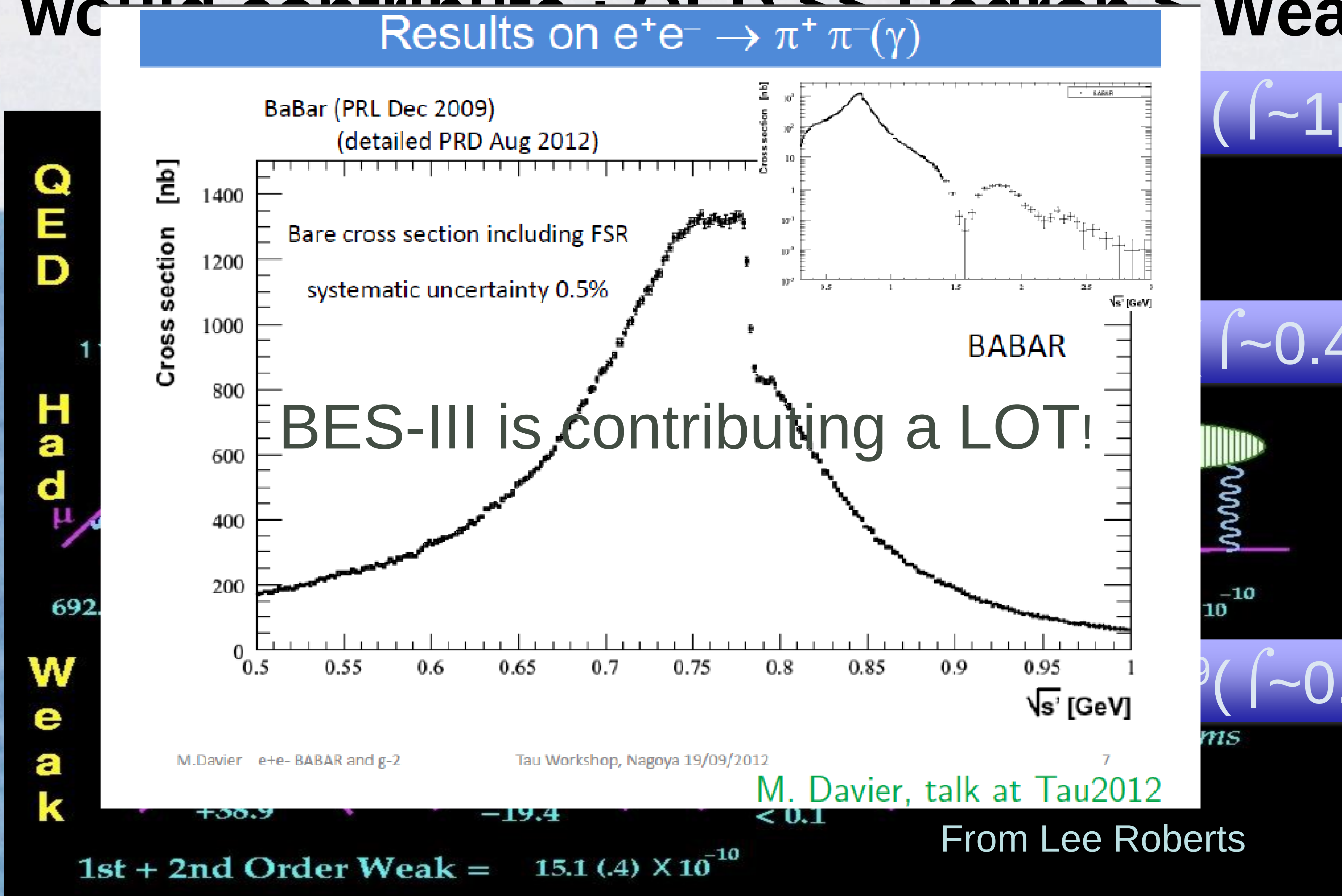
Preferably by

NEW METHOD!



SM Contribution to a≠0

- **Any particle which couples to muon/photon would contribute : QED >> Hadron > Weak**



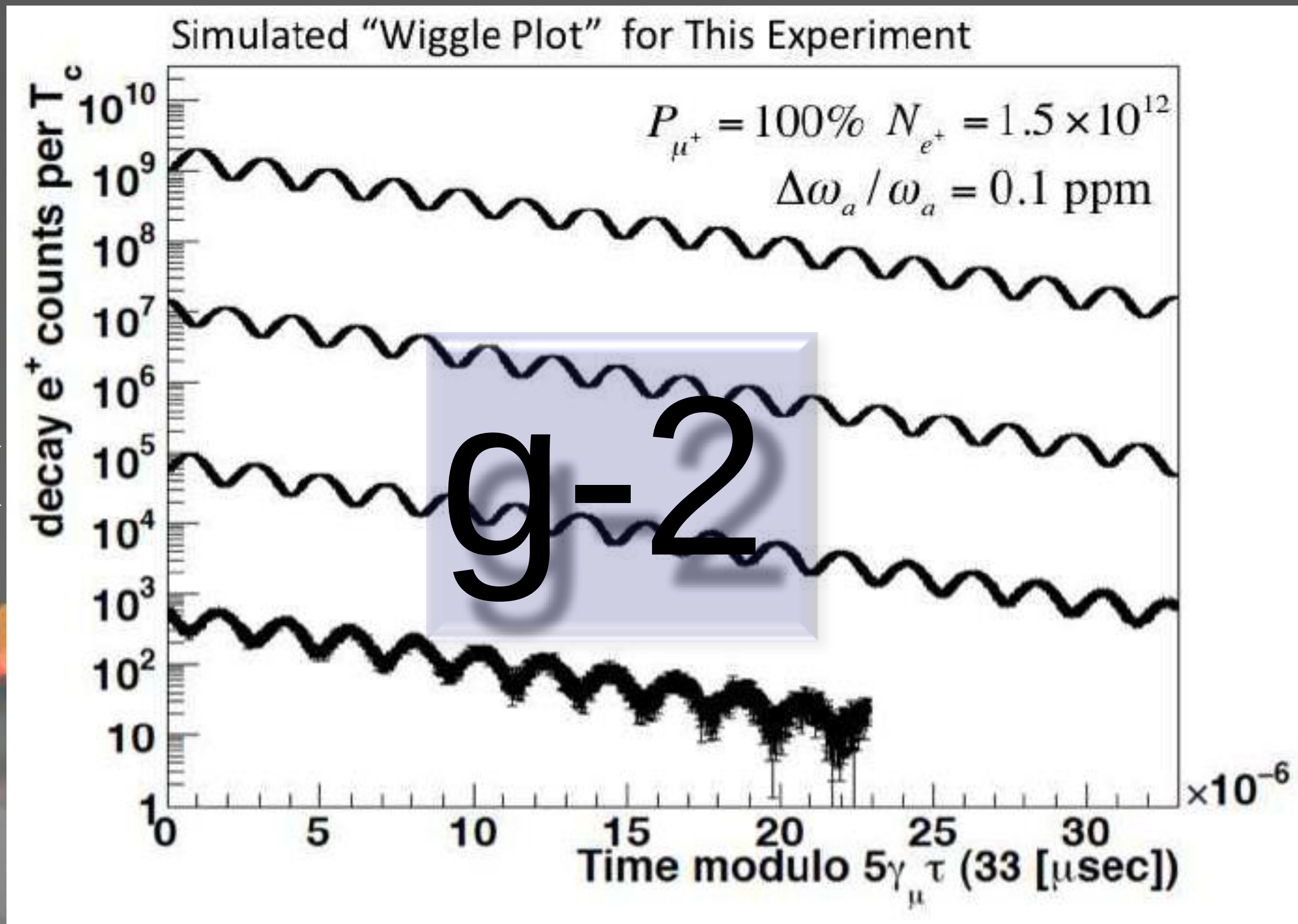
(∫~1ppb)

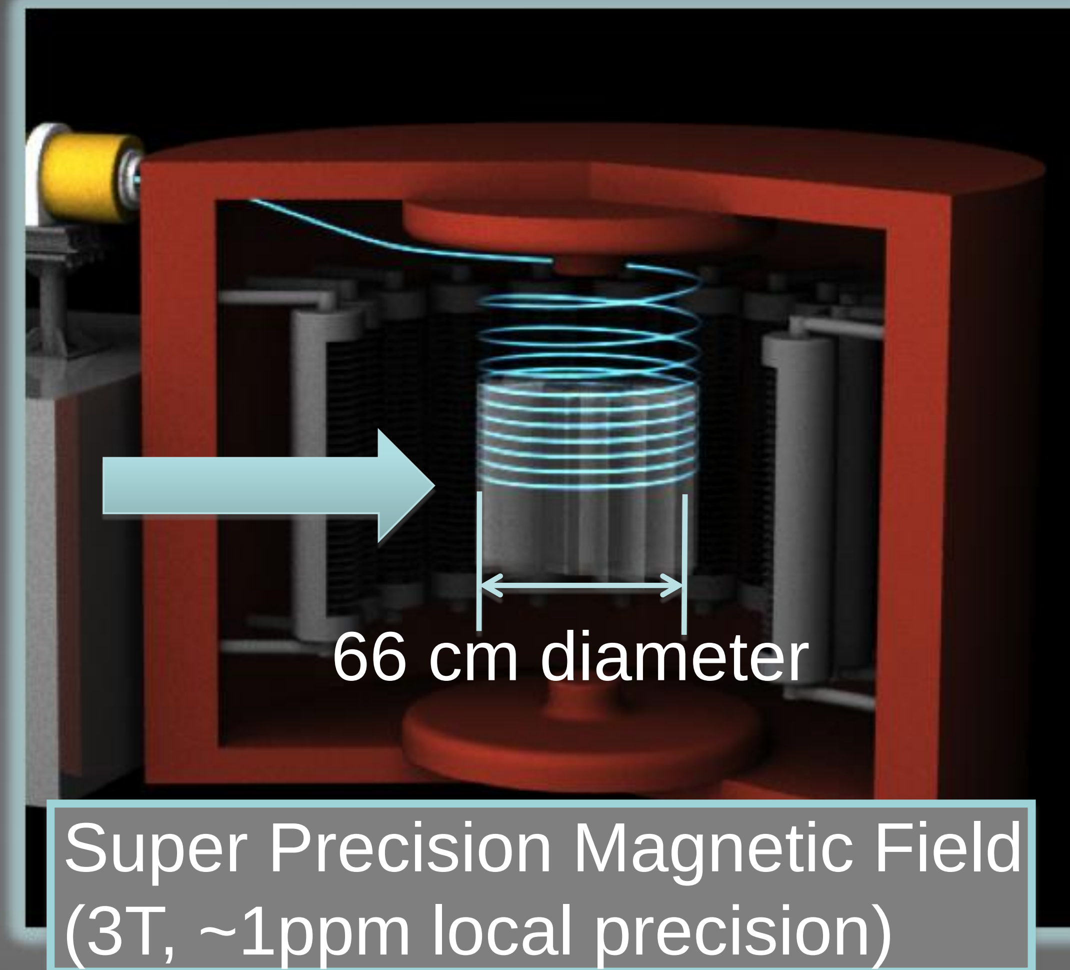
(∫~0.41ppm)

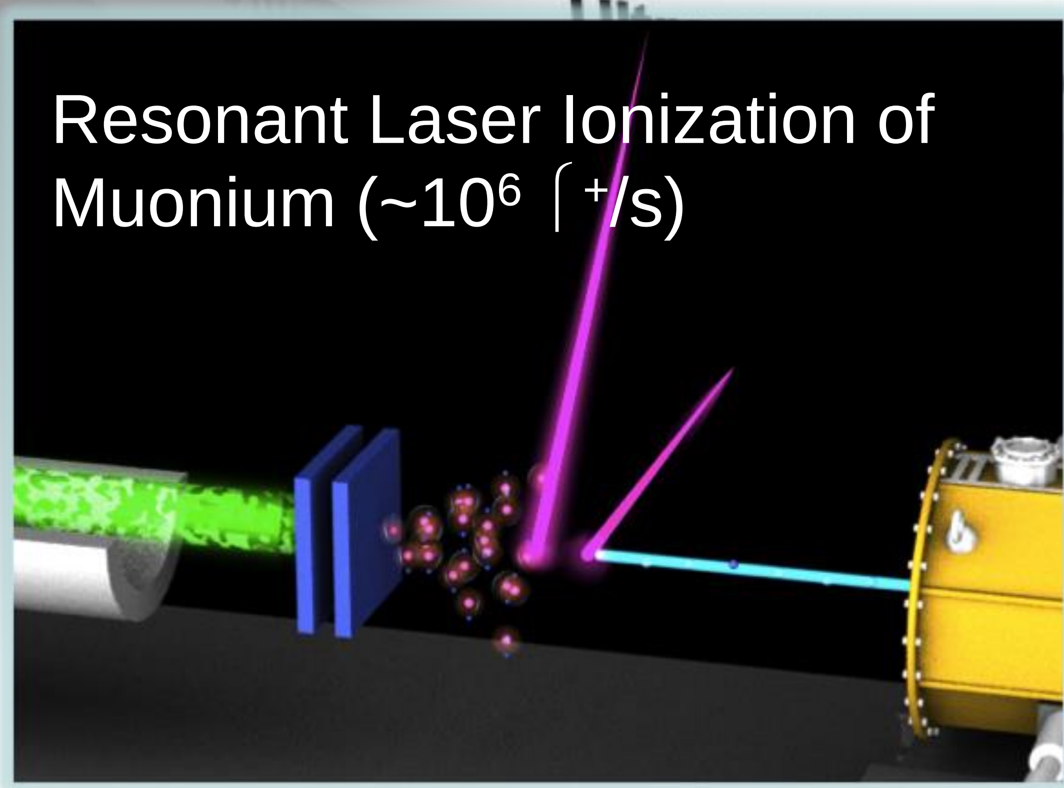
(∫~0.02ppm)

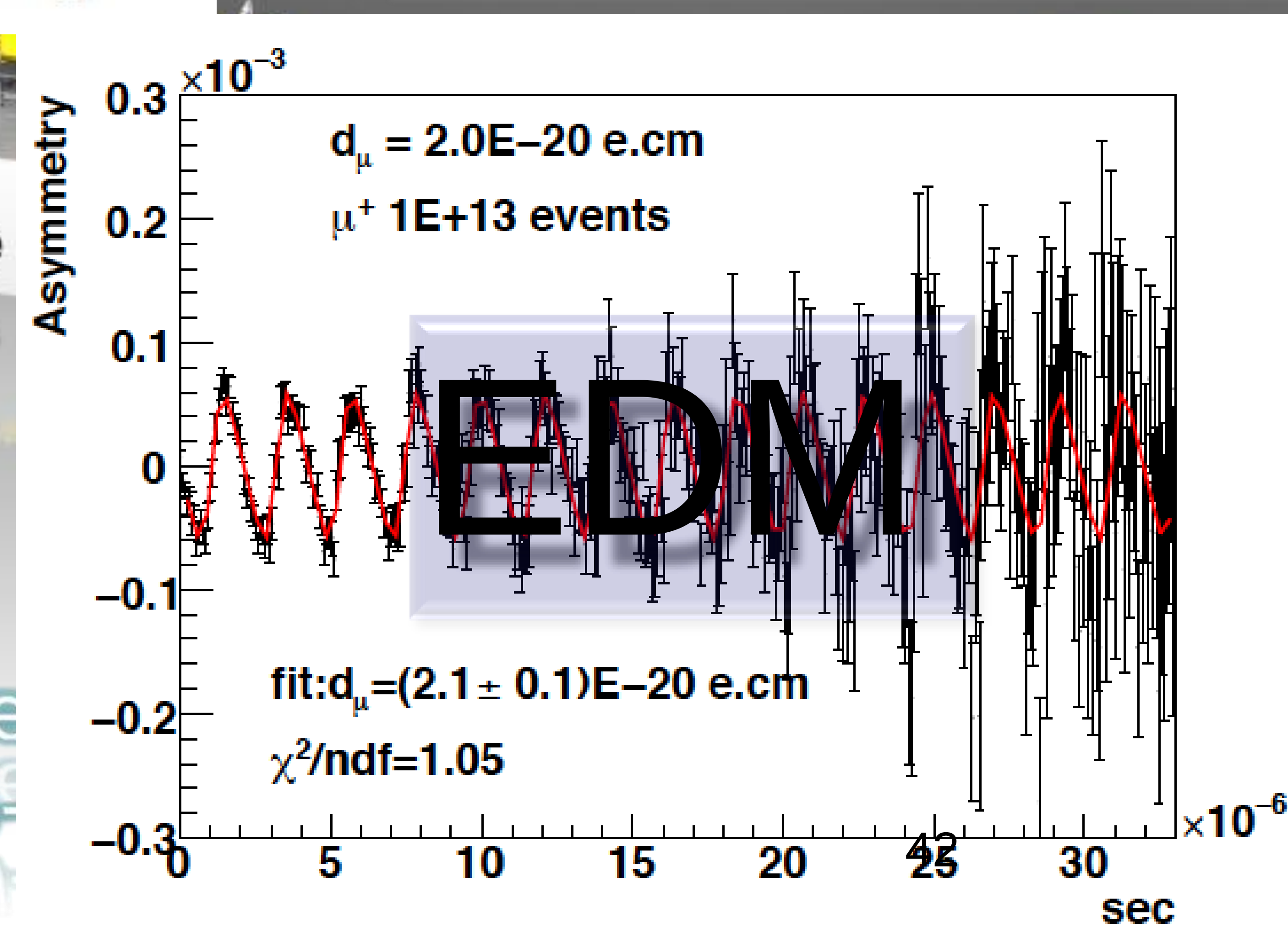
From Lee Roberts

J-PARC Facility
(KEK/JAEA)
LINAC
3 GeV
Synchrotron
Neutrino Beam
To Kamioka
(3
HFS
DeeMe
g-2/EDM
H-Line for
Muon Fundamental Physics


Simulated "Wiggle Plot" for This Experiment
$P_{\mu^+} = 100\%$ $N_{e^+} = 1.5 \times 10^{12}$
$\Delta\omega_a / \omega_a = 0.1$ ppm
decay e^+ counts per T_c
Time modulo $5\gamma_\mu\tau$ (33 [μsec])
g-2


66 cm diameter
Super Precision Magnetic Field
(3T, ~1ppm local precision)


Resonant Laser Ionization of
Muonium (~10^6 ⌈$^+$/s)


d_μ = 2.0E−20 e.cm
μ^+ 1E+13 events
Asymmetry
fit:d_μ=(2.1 ± 0.1)E−20 e.cm
χ^2/ndf=1.05
sec
EDM

Magic vs "New Magic"

- **Complimentary!**

$$\vec{\omega} = -\frac{e}{m}\left[a_\mu \vec{B} - \left(a_\mu - \frac{1}{\gamma^2 - 1}\right)\frac{\vec{\beta}\times\vec{E}}{c} + \frac{\eta}{2}\left(\vec{\beta}\times\vec{B} + \frac{\vec{E}}{c}\right)\right]$$

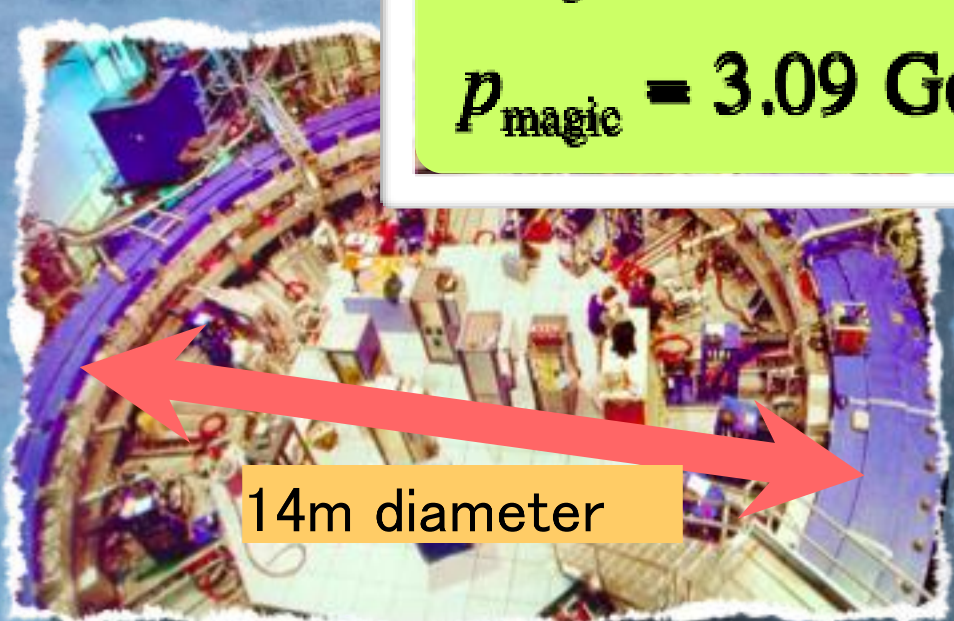
BNL/Fermilab Approach

$$a_\mu - \frac{1}{\gamma^2 - 1} = 0$$

$$\eta \approx 0$$

$$\gamma_{magic} = 29.3$$

$$p_{magic} = 3.09\ \text{GeV}/c$$

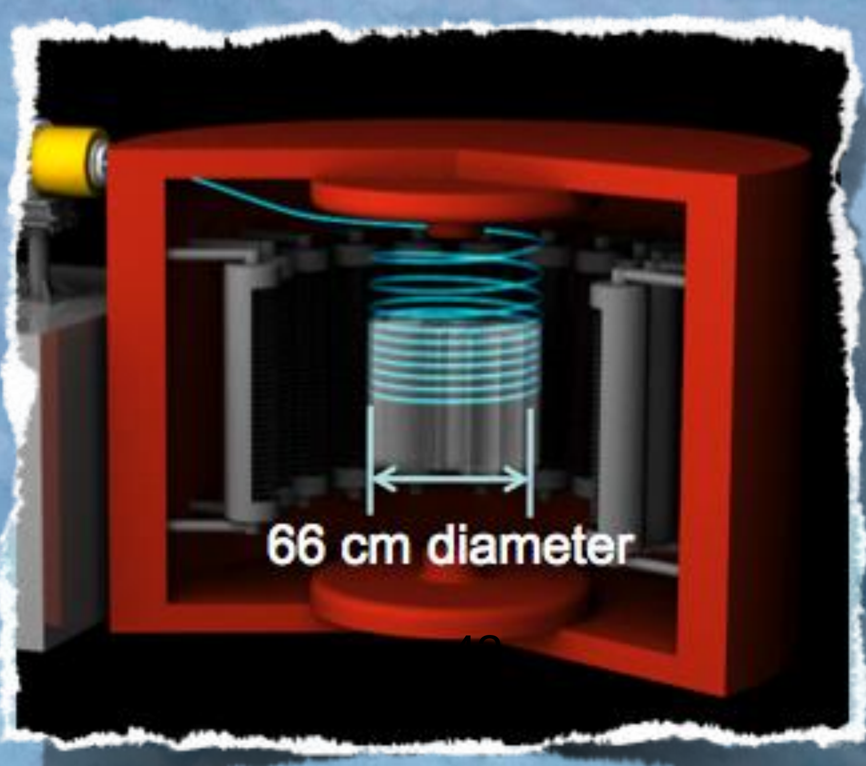


J-PARC Approach

$$\vec{E} = 0$$

$$\vec{\omega} = \vec{\omega}_a + \vec{\omega}_\eta$$

$$\vec{\omega}_a = -\frac{e}{m} a_\mu \vec{B}$$



BNL, FNAL, and J-PARC

- Both Fermilab and J-PARC intend to start physics run around 2015

Table 1.1: Comparison of the previous experiment BNL-E821, FNAL-E989, and this experiment.

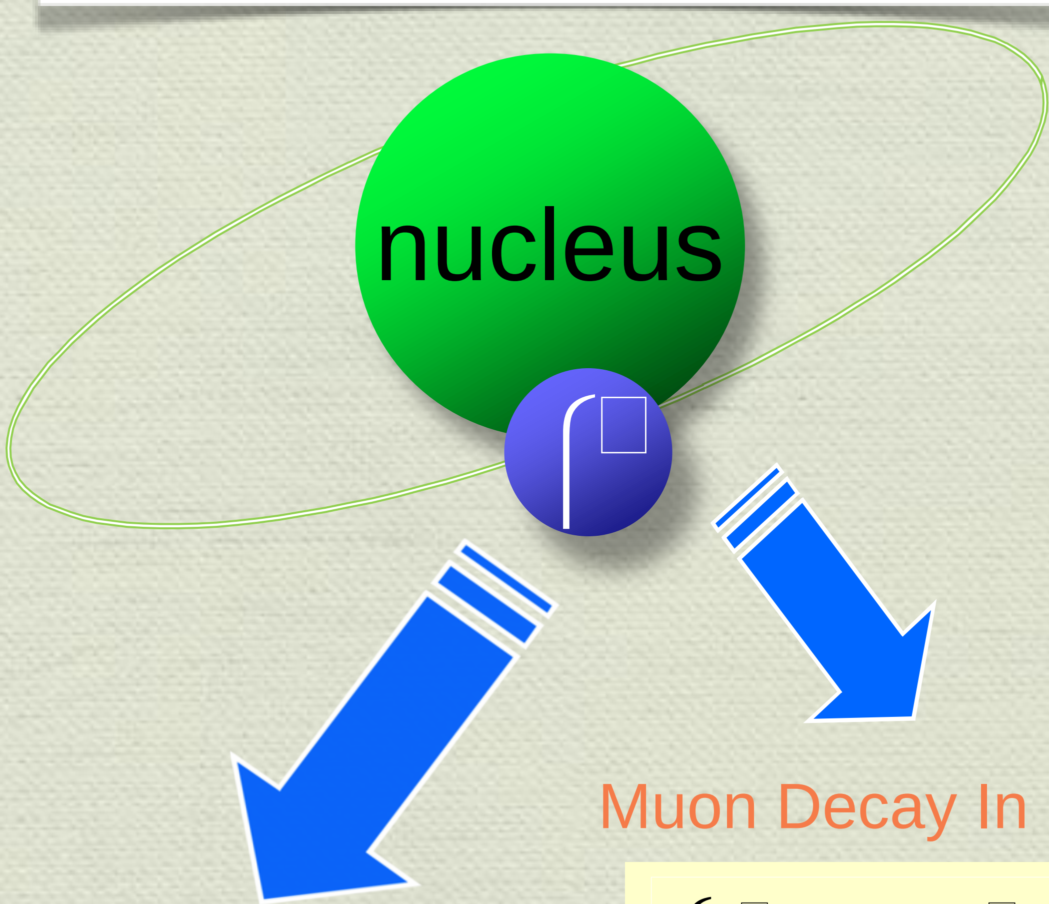
	BNL-E821	FNAL-E989	This Experiment
Muon momentum	3.09 GeV/c		0.3 GeV/c
γ	29.3		3
Polarization	100%		$> 90\%$
Storage field	$B = 1.45$ T		$B = 3.0$ T
Focusing field	Electric Quad.		very-weak magnetic
Cyclotron period	149 ns		7.4 ns
Anomalous spin precession period	4.37 μs		2.11 μs
# of detected e^+	5.0×10^9	1.8×10^{11}	1.5×10^{12}
# of detected e^-	3.6×10^9	–	–
Statistical precision	0.46 ppm	0.1 ppm	0.1 ppm

Spin Flipper

μ-e Conversion Experiments COMET

What is mu-e conversion?

1s state in a muonic atom



Muon Decay In Orbit

$$\mu^- \rightarrow e^- \nu \bar{\nu}$$

nuclear muon capture

$$\mu^- + (A,Z) \rightarrow \nu_\mu + (A, Z-1)$$

Neutrino-less muon nuclear capture (=μ-e conversion)

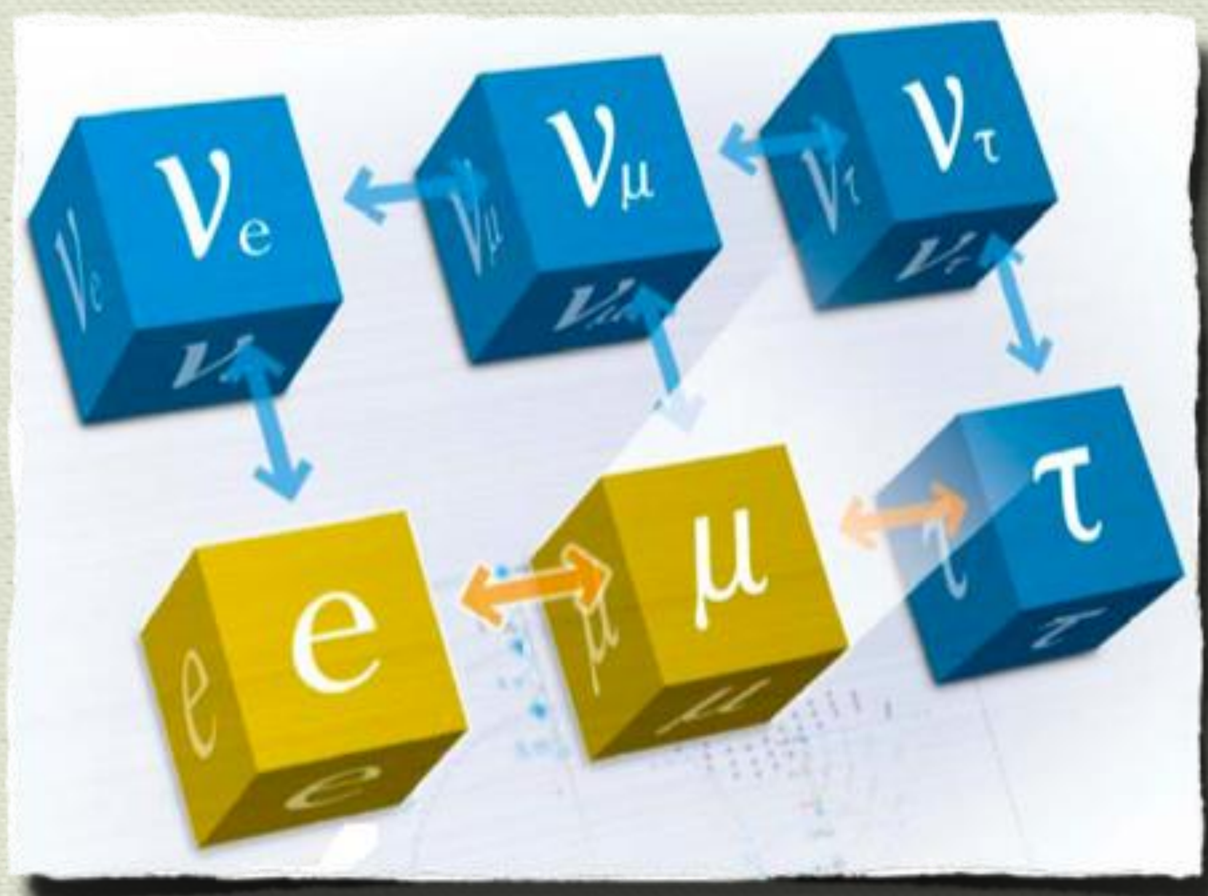
$$\mu^- + (A,Z) \rightarrow e^- + (A,Z)$$

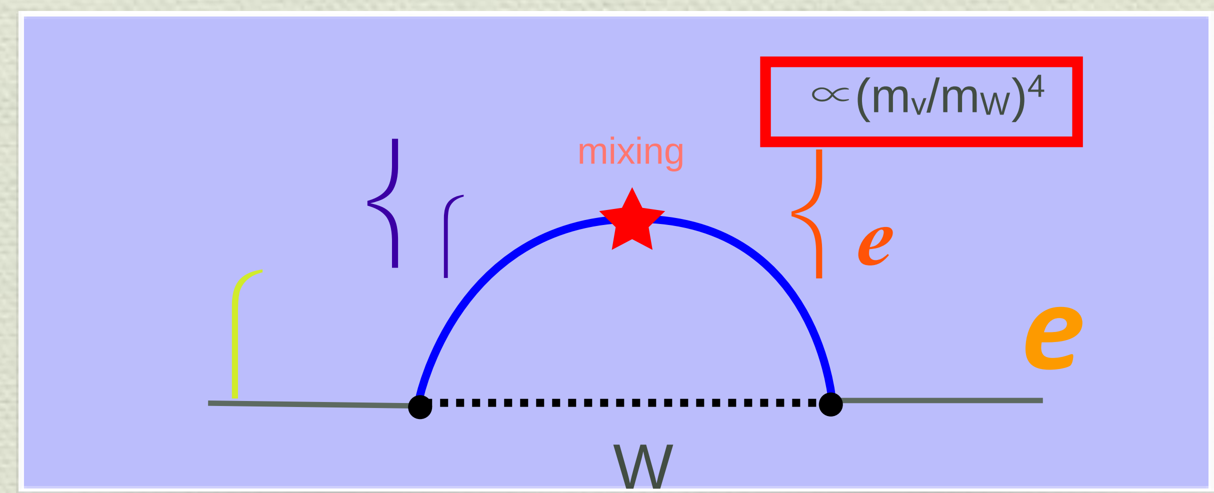
lepton flavours changes by one unit

- $E_{\mu e} \sim m_\mu - B_\mu$
  - B_μ: binding energy of the 1s muonic atom

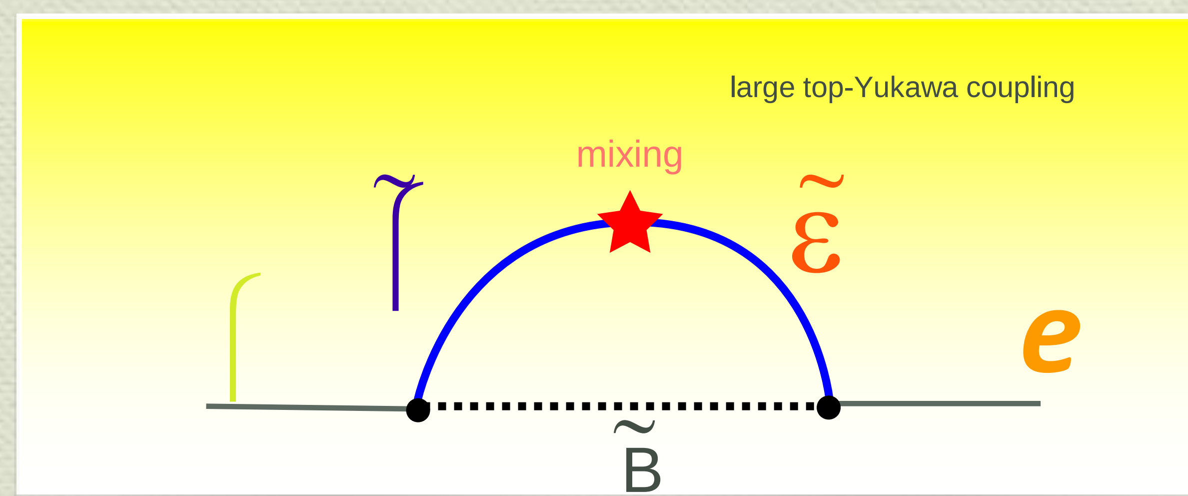
$$B(\mu^- N \rightarrow e^- N) = \frac{\Gamma(\mu^- N \rightarrow e^- N)}{\Gamma(\mu^- N \rightarrow \nu N')}$$

Lepton-Flavor Violation in Charged Lepton Sector





Very Small (10^{-54})



Sensitive to new Physics beyond the Standard Model

Slide by Y.Kuno

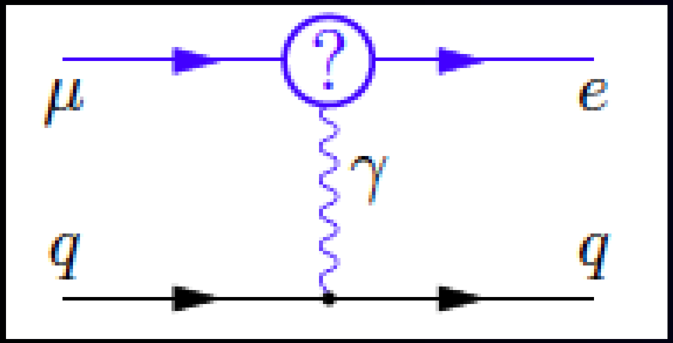
constructive

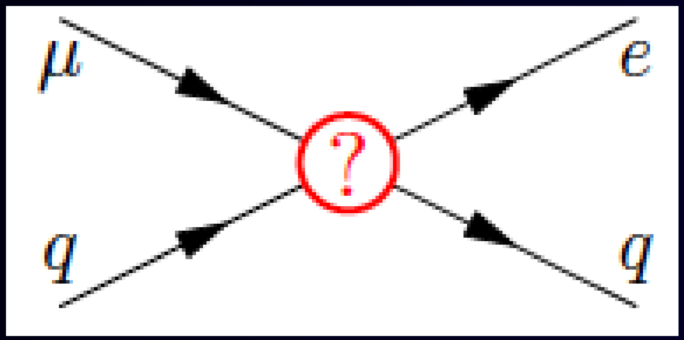
Physics Sensitivity: μ→eγ vs. μ-e conversion

$$L_{\rm CLFV} = \frac{1}{1+\kappa}\frac{m_\mu}{\Lambda^2}\bar{\mu}_{\rm R}\sigma^{\mu\nu}e_{\rm L}F_{\mu\nu} + \frac{\kappa}{1+\kappa}\frac{1}{\Lambda^2}(\bar{\mu}_{\rm L}\gamma^\mu e_{\rm L})(\bar{q}_{\rm L}\gamma_\mu q_{\rm L})$$

Photonic (dipole) interaction

Contact interaction

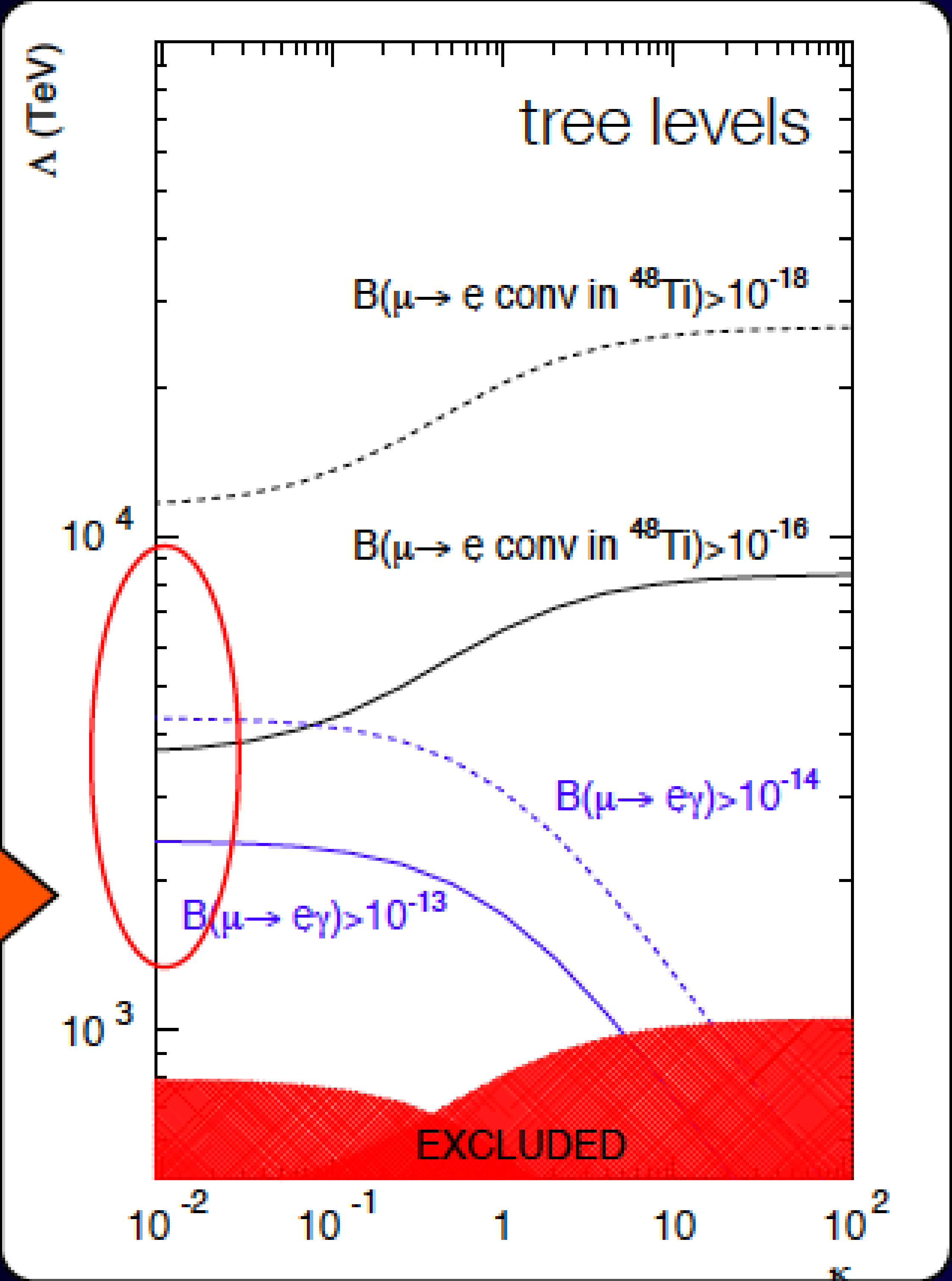




if photonic contribution dominates,

$$\frac{B(\mu N \to eN)}{B(\mu \to e\gamma)} = \frac{G_F^2 m_\mu^4}{96\pi^3\alpha} \times 3 \times 10^{12} B(A,Z) \sim \frac{B(A,Z)}{428}$$

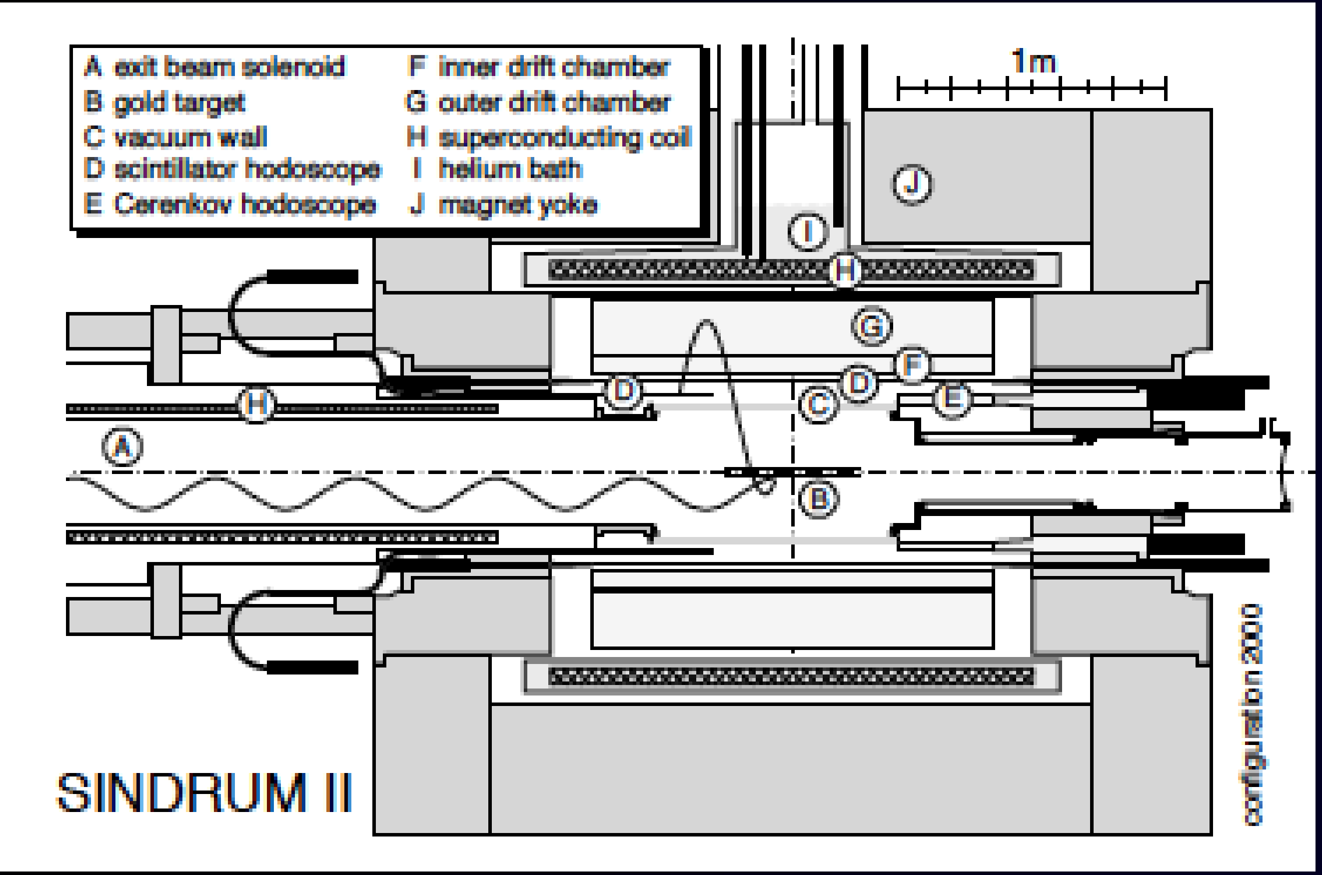
- for aluminum, about 1/390~0.003
- for titanium, about 1/230



Slide by Y.Kuno

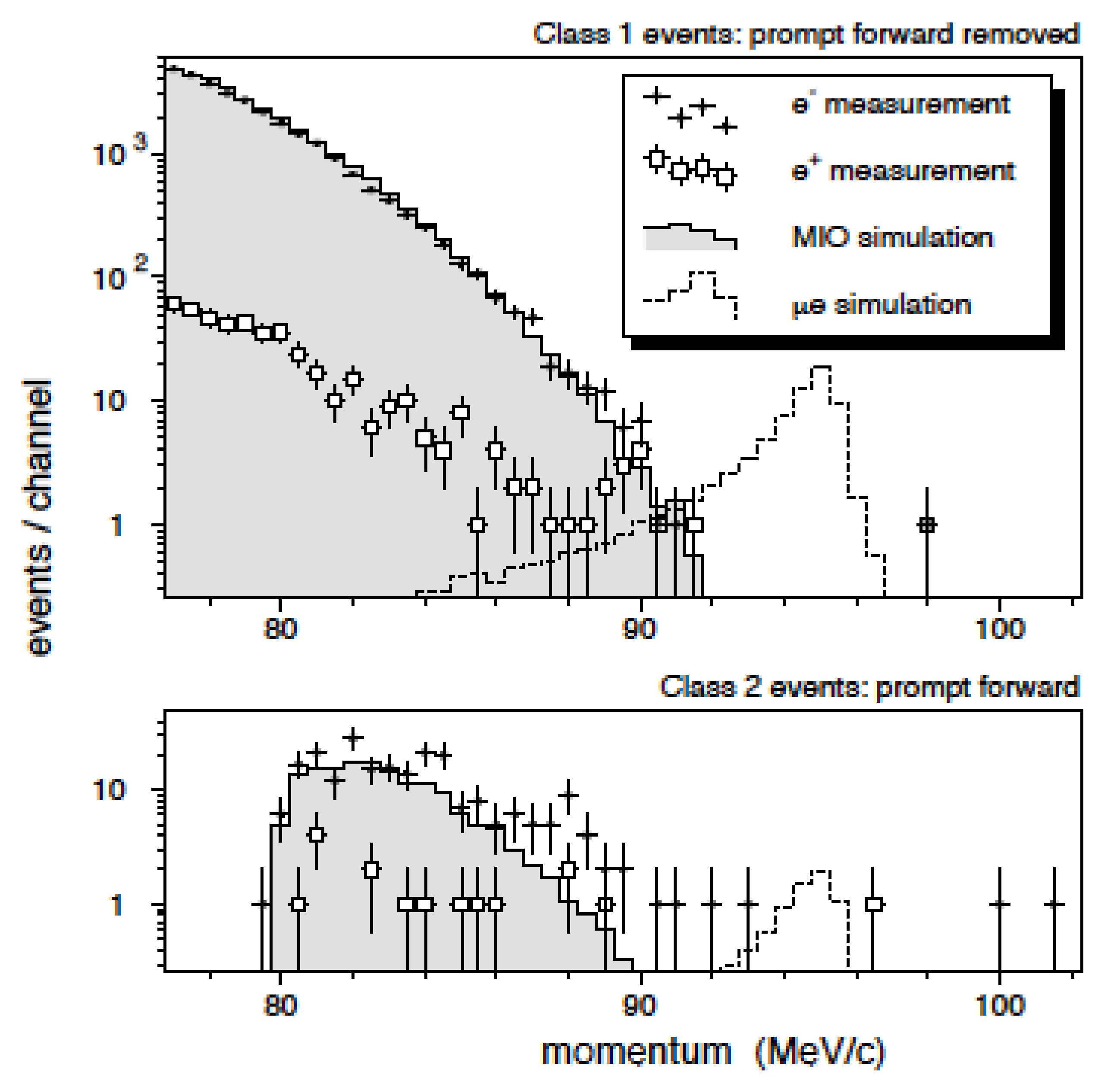
Previous Measurements

SINDRUM-II (PSI)



Published Results (2004)

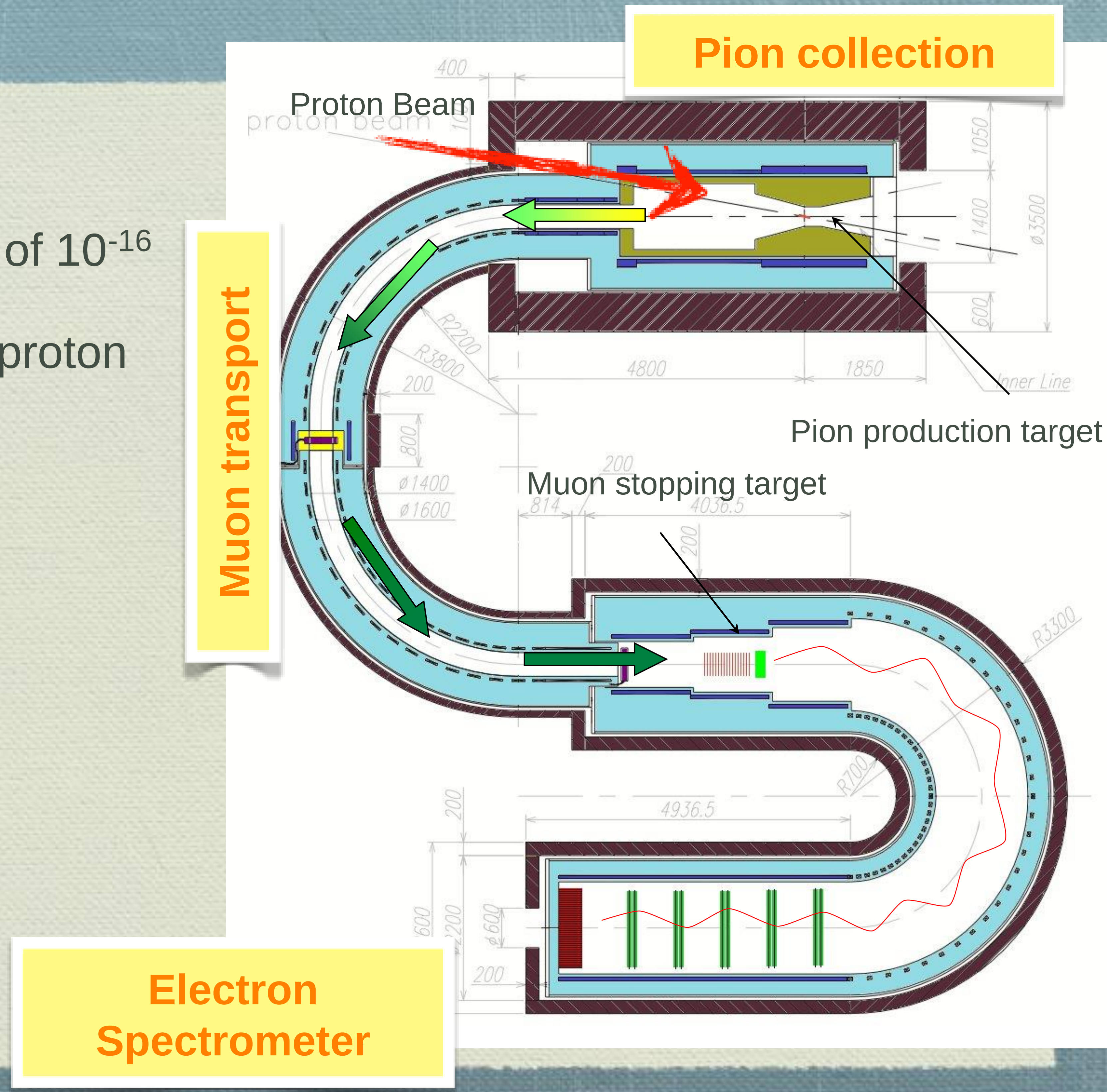
$$B(\mu^- + Au \to e^- + Au) < 7 \times 10^{-13}$$



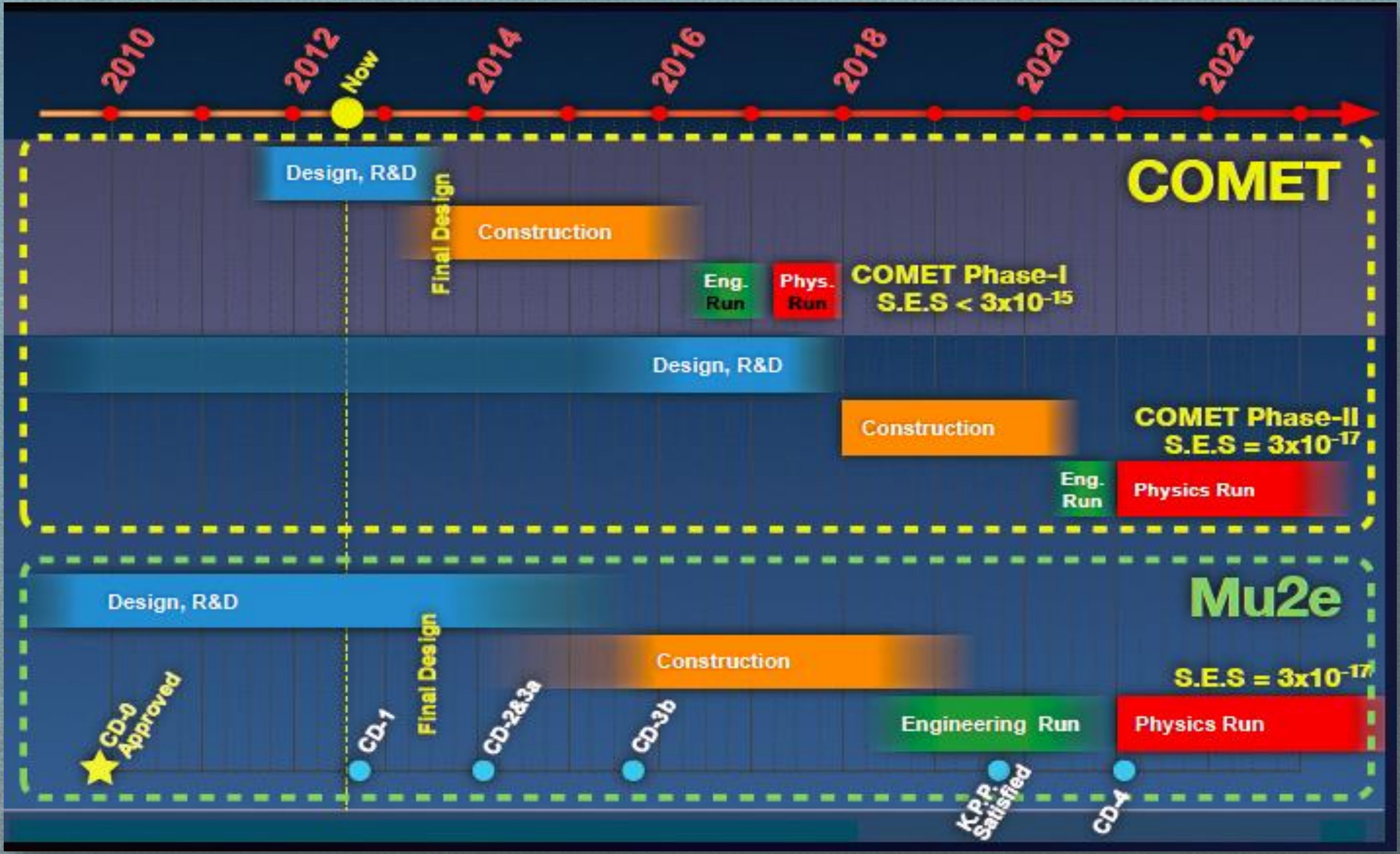
PSI muon beam intensity ~ $10^{7\text{-}8}$/sec beam from the PSI cyclotron. To eliminate beam related background from a beam, a beam veto counter was placed. But, it could not work at a high rate.

COMET J-PARC E21

- Search for LFV process, μ-e conversion with a sensitivity of 10^{-16}
- Utilize J-PARC Hi- Intensity proton beam
  - 8GeV, 7μA
- Innovative apparatus
  - Pion collection
  - Muon Transport
  - Electron Spectrometer

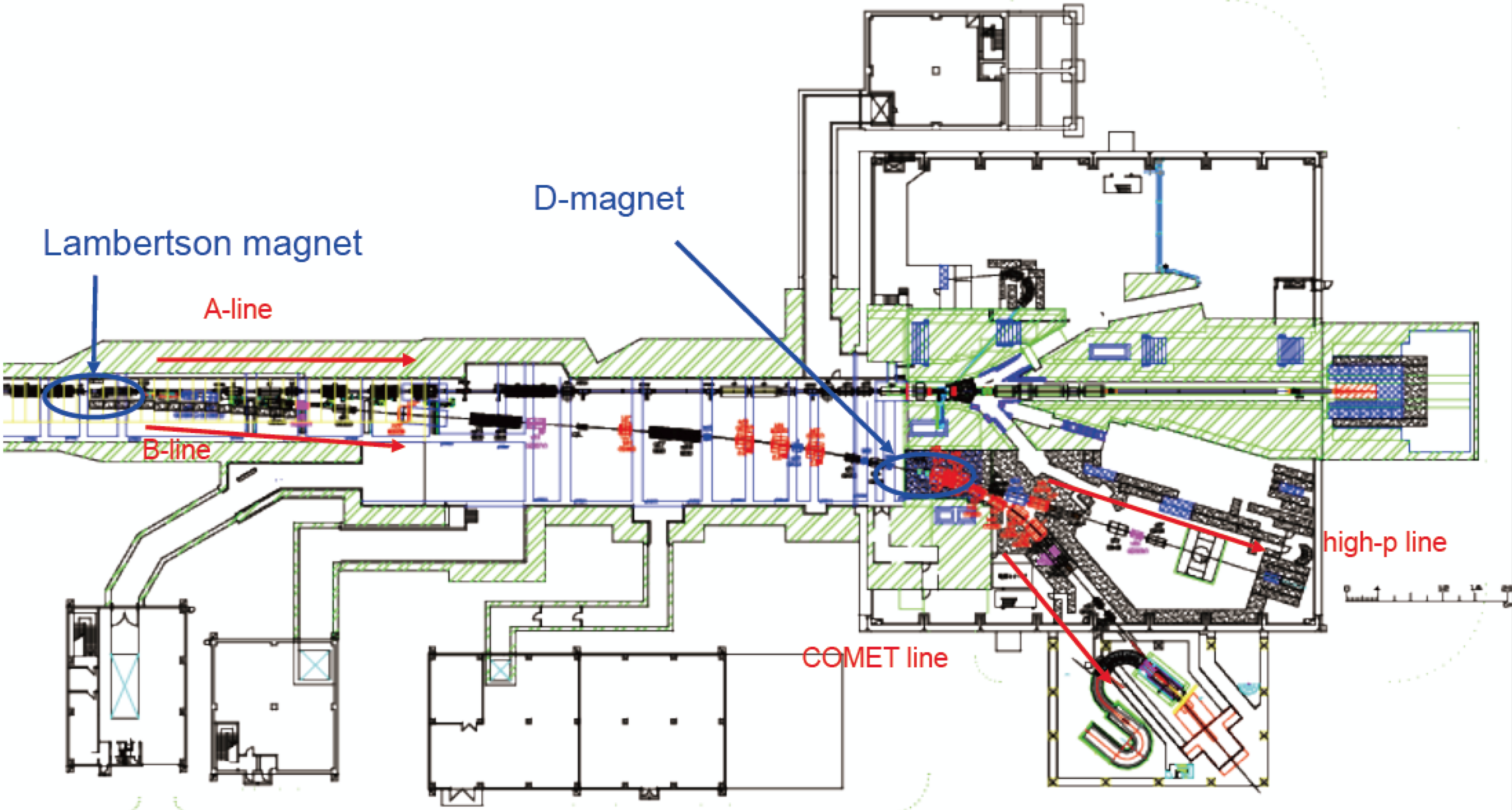


Schedule



2010
2012
Now
2014
2016
2018
2020
2022
COMET
Design, R&D
Final Design
Construction
Eng. Run
Phys. Run
COMET Phase-I
S.E.S < 3x10^-15
Design, R&D
Construction
COMET Phase-II
S.E.S = 3x10^-17
Eng. Run
Physics Run
Mu2e
Design, R&D
Final Design
Construction
S.E.S = 3x10^-17
Engineering Run
Physics Run
CD-0 Approved
CD-1
CD-2&3a
CD-3b
K.P.P. Satisfied
CD-4

COMET Hall & Beamline

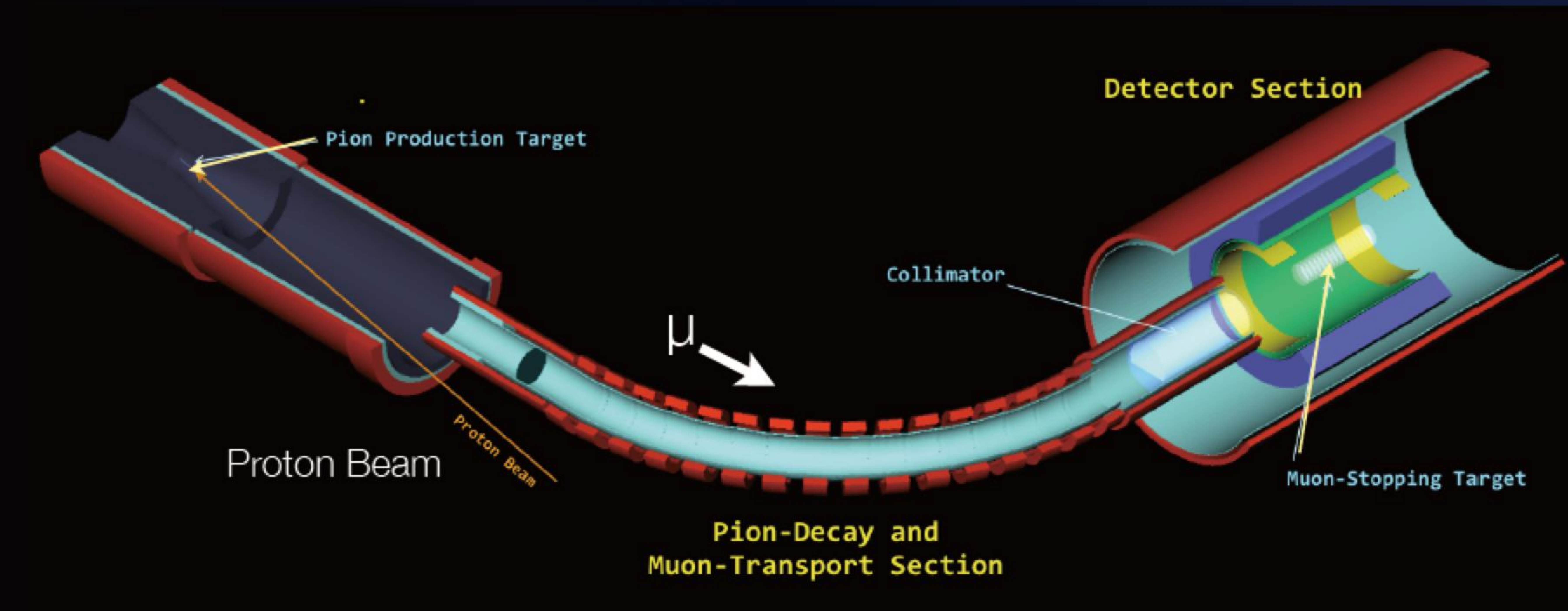


Branch for COMET and high-p is realized by normal dipole magnets.
(No simultaneous operation of COMET and other hadron-hall experiments)

Photo by S. Mihara


Photo by S. Mihara
HITACHI

COMET Phase-I Experimental Layout



COMET muon beam-line：

(1~3)x10^9 muon/sec with 3kW beam produced. The world highest intensity.

COMET Phase-I detector：

About 10^{16} muons are stopped in the target. Electron from μ-e conversion will be measured

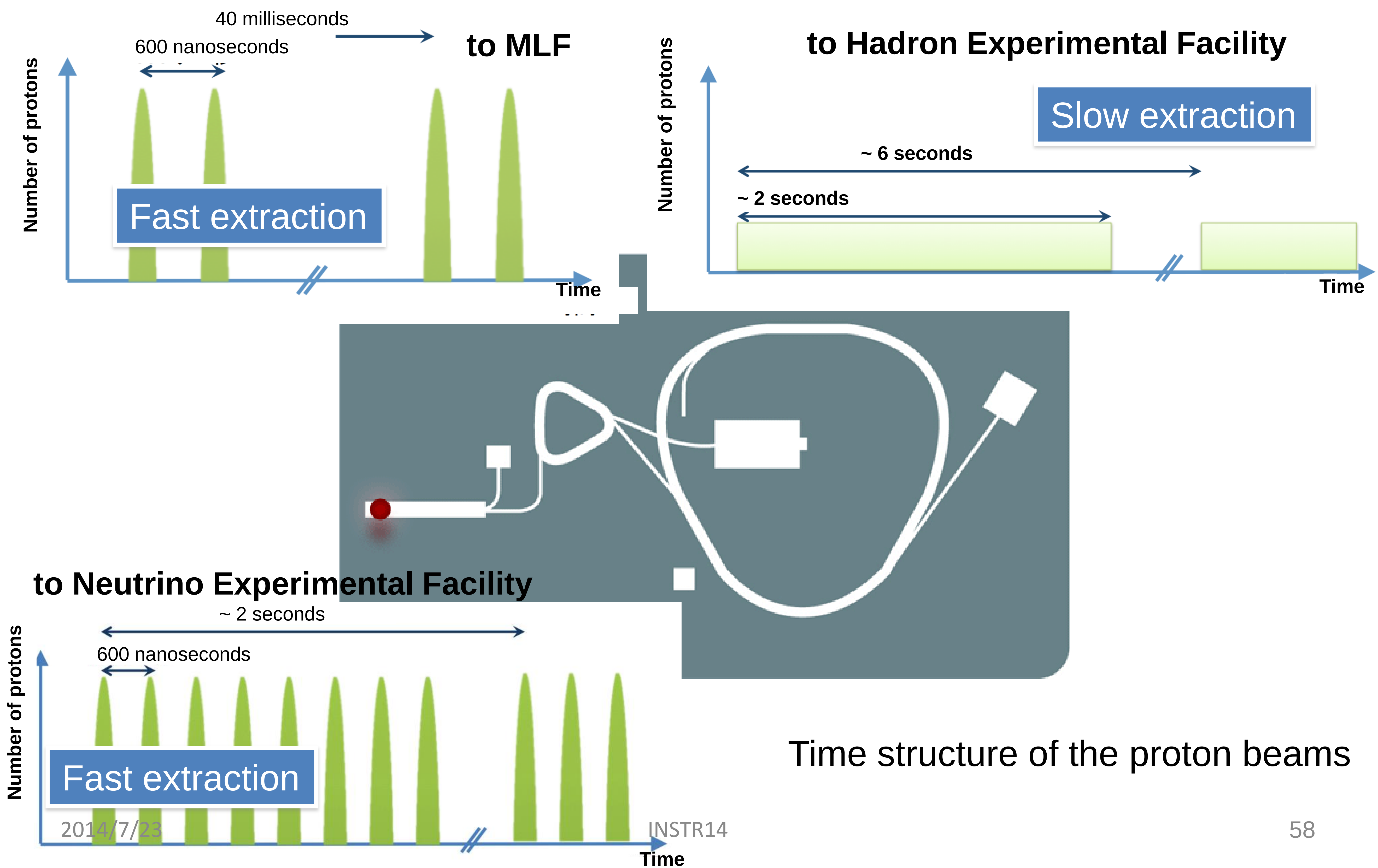
Summary

- We investigate the origin of matter from various aspects at J-PARC
- J-PARC provides exciting opportunities in Fundamental physics !
- Physics Production
  - Hadron & Nuclear Physics
  - Neutrino Physics
  - Kaon Rare Decays
  - Muon Physics
  - And more!

We invite young colleague to join our challenges to explore origin of the matter at J-PARC!!!

including young at heart!

J-PARC Accelerators and Beam Extractions

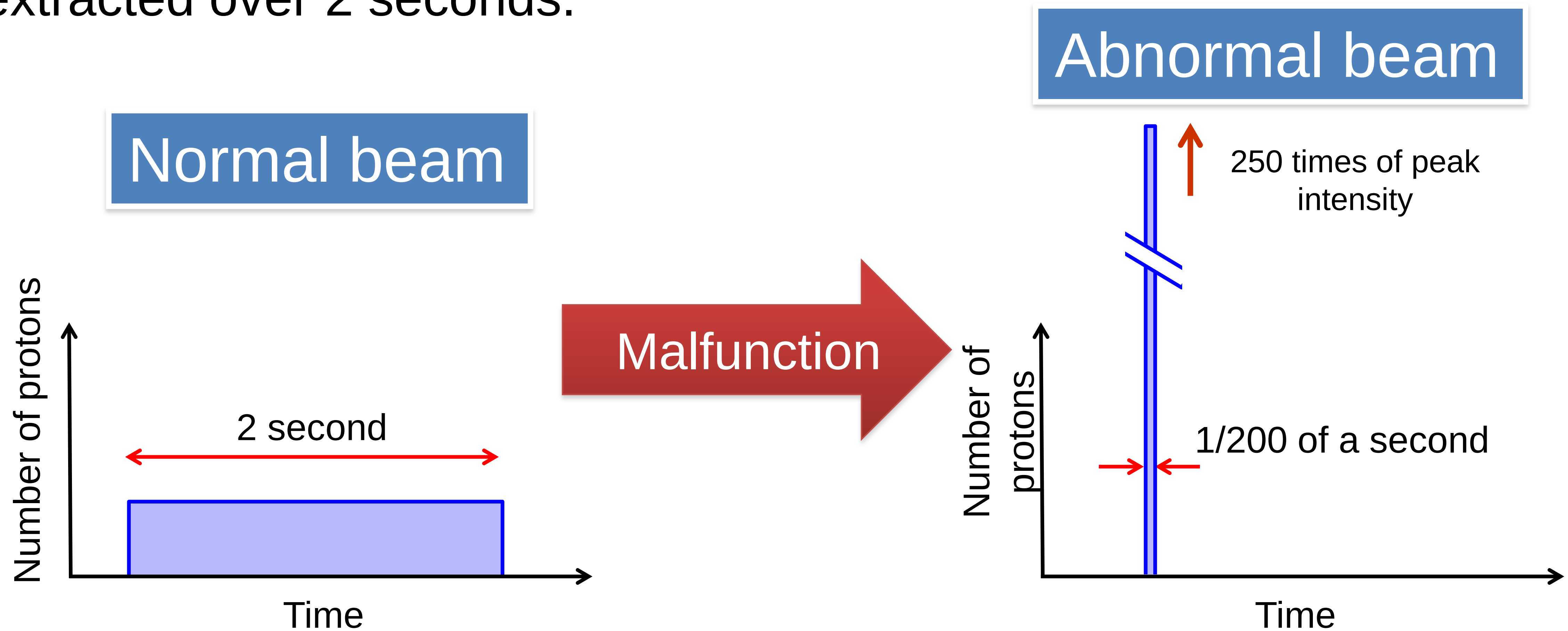


Time structure of the proton beams

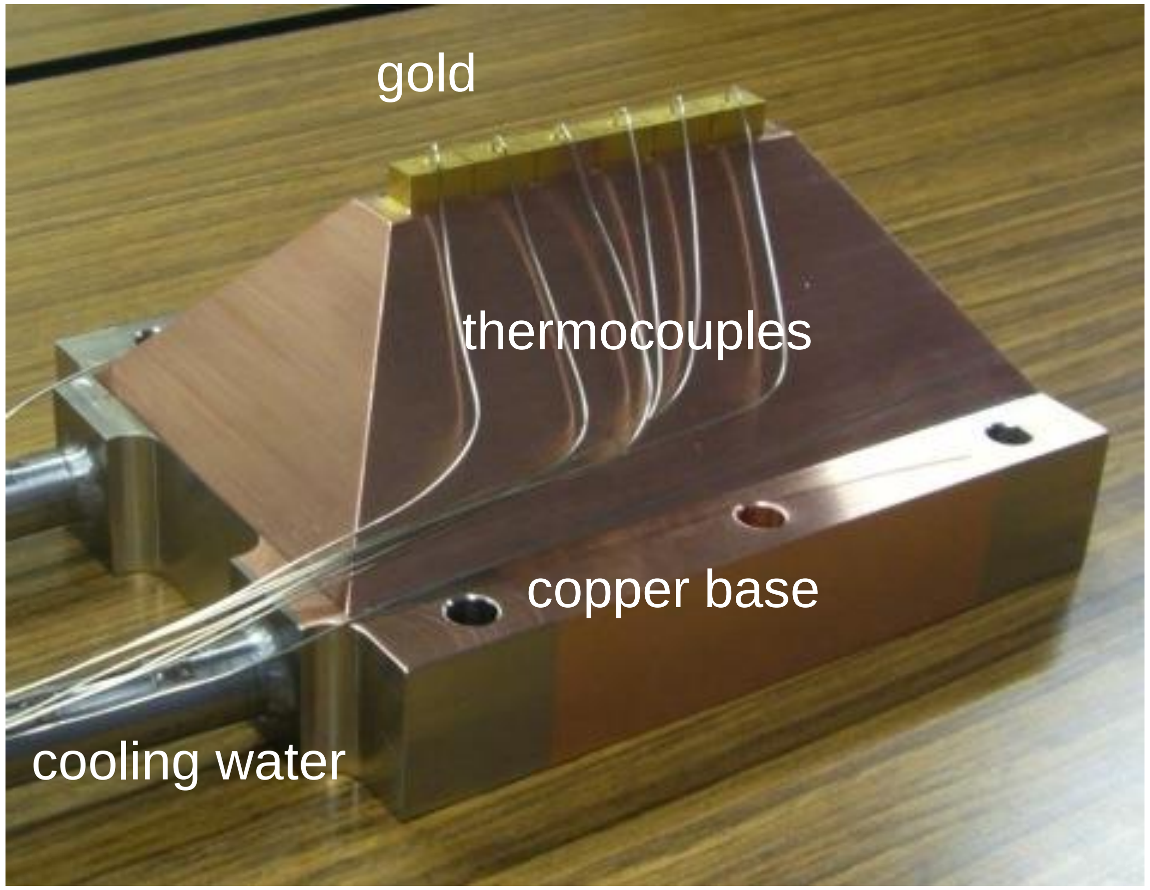
Abnormal Beam

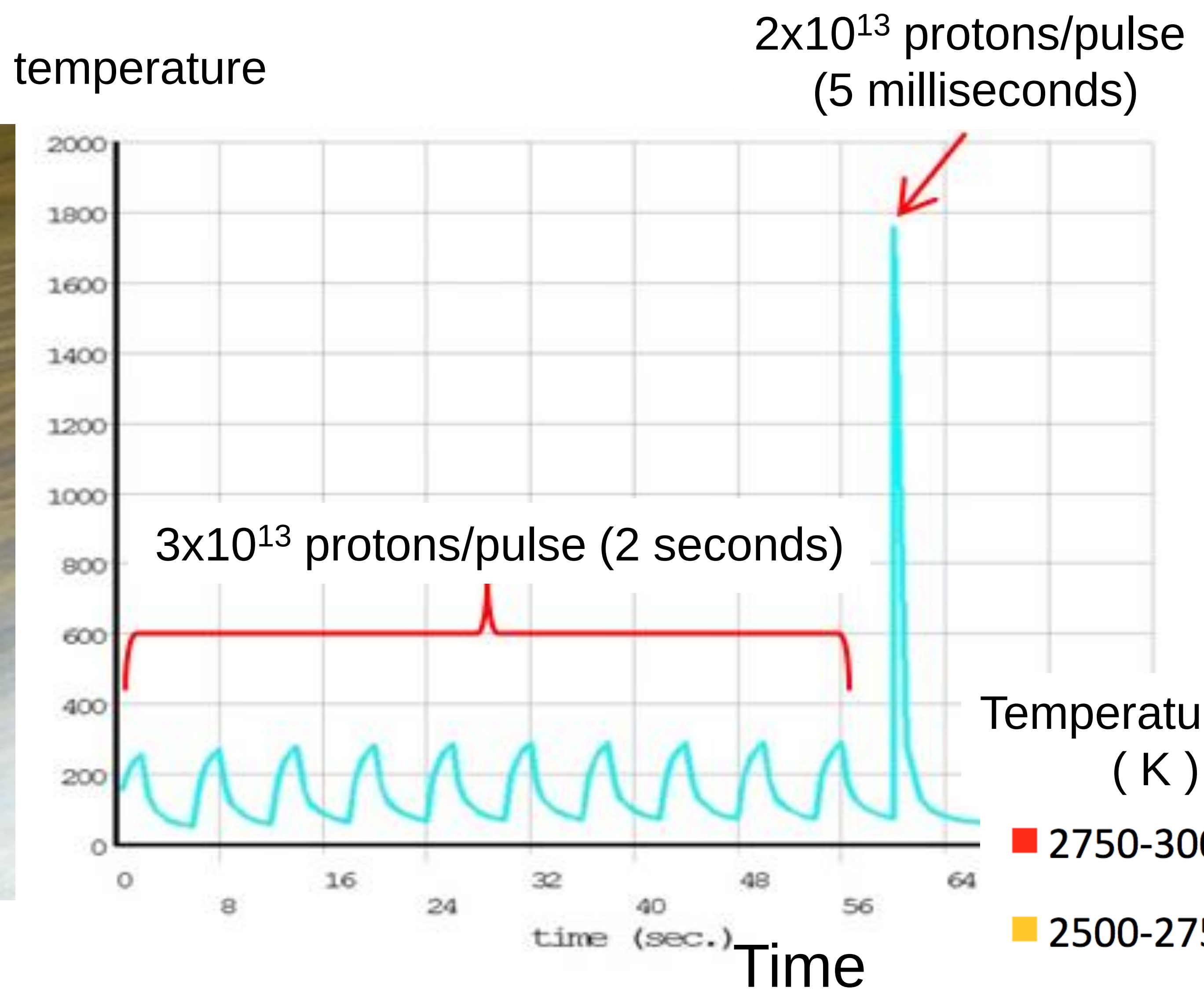
- At around 11:55 on May 23, the power supply system of a special magnet in the 50 GeV Synchrotron malfunctioned.

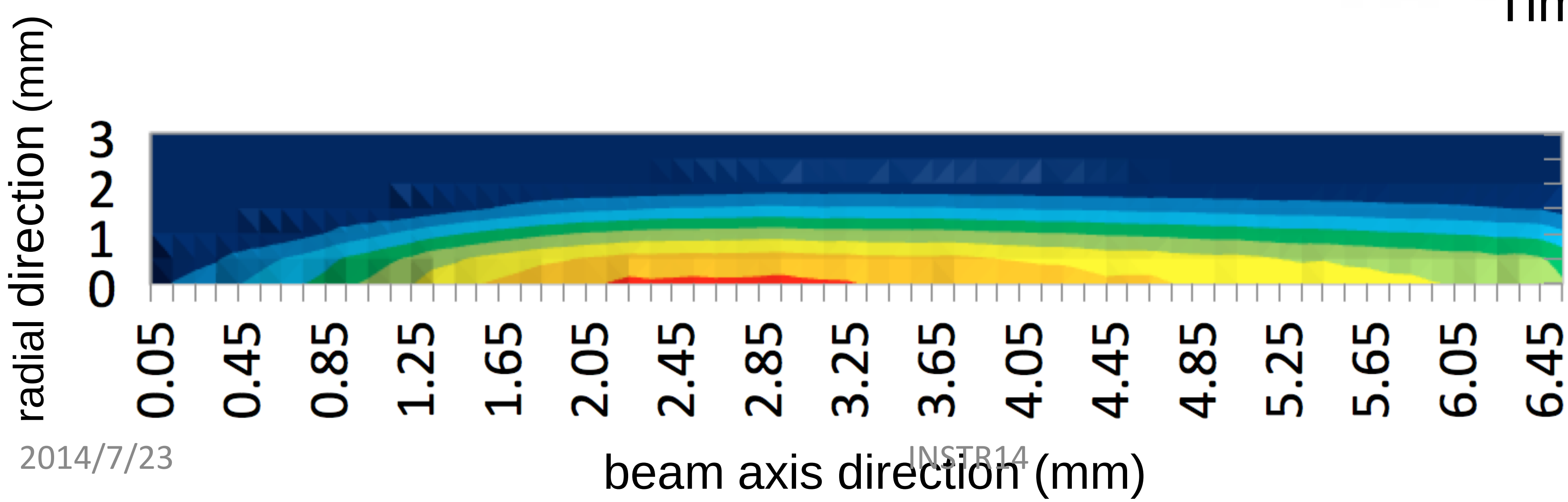
→ 2×10^{13} protons were extracted in a very short period of 5 milliseconds, while in normal operation 3×10^{13} protons should have been slowly extracted over 2 seconds.



Target Temperature（Simulation Results）

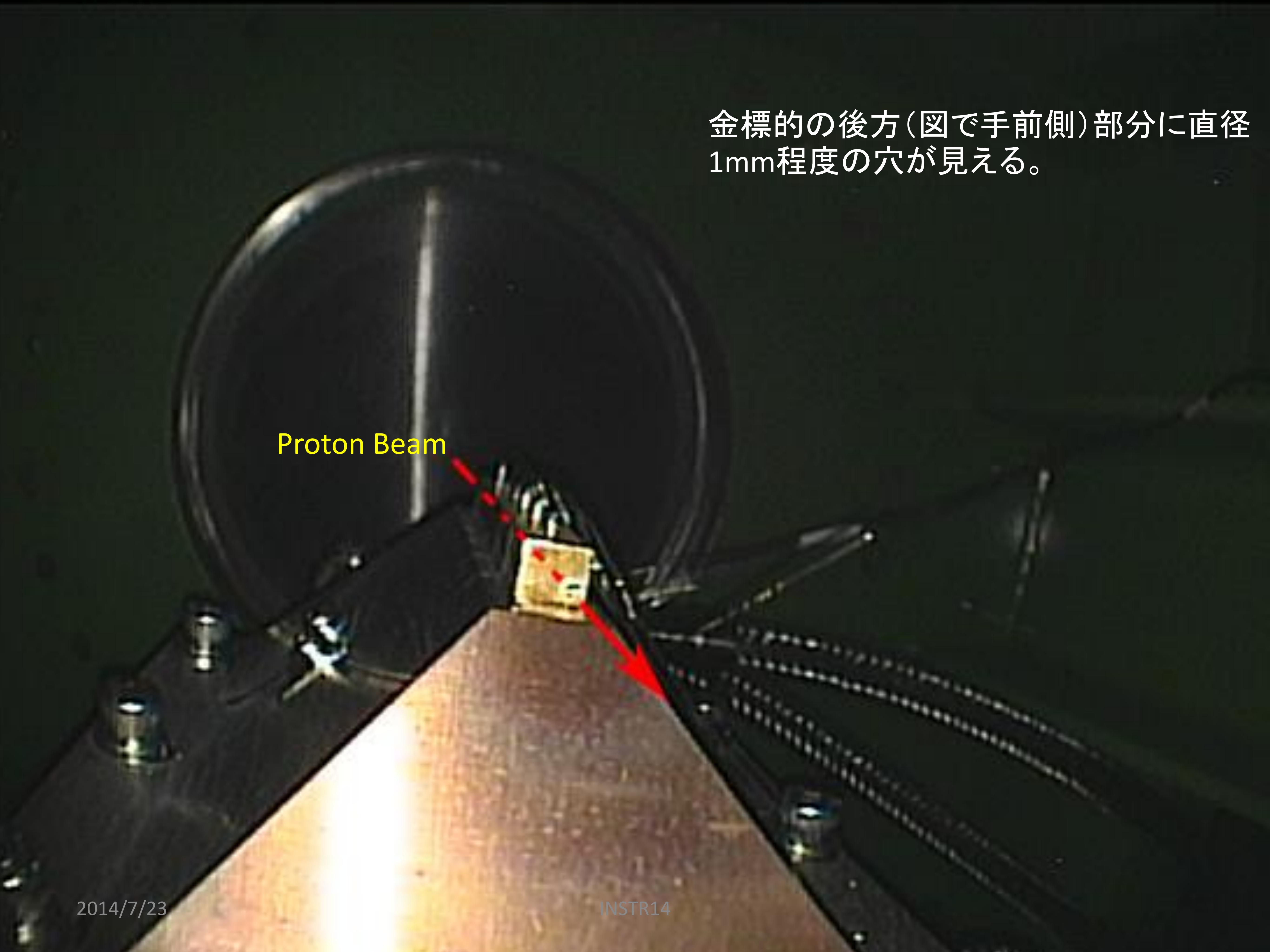




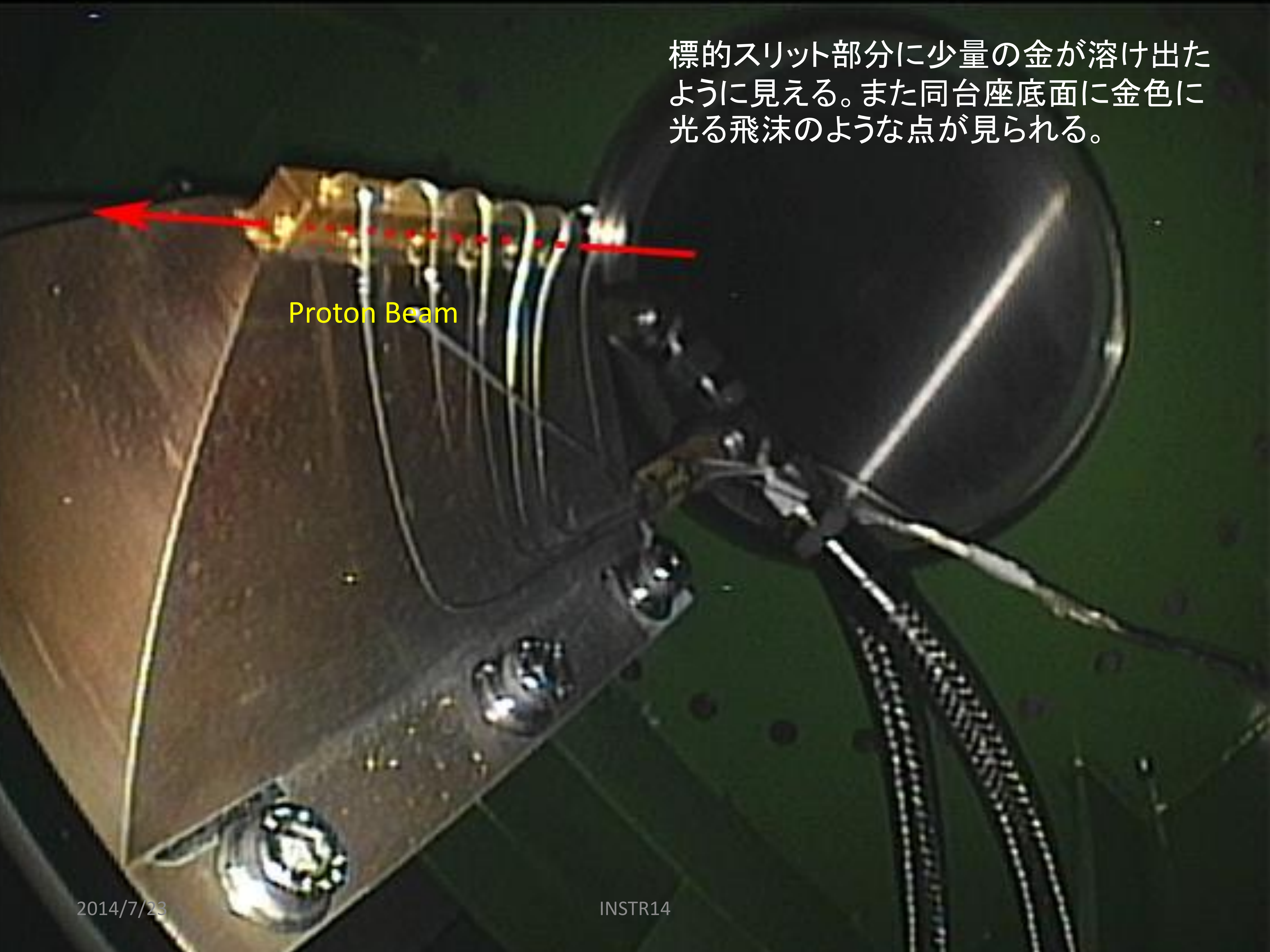


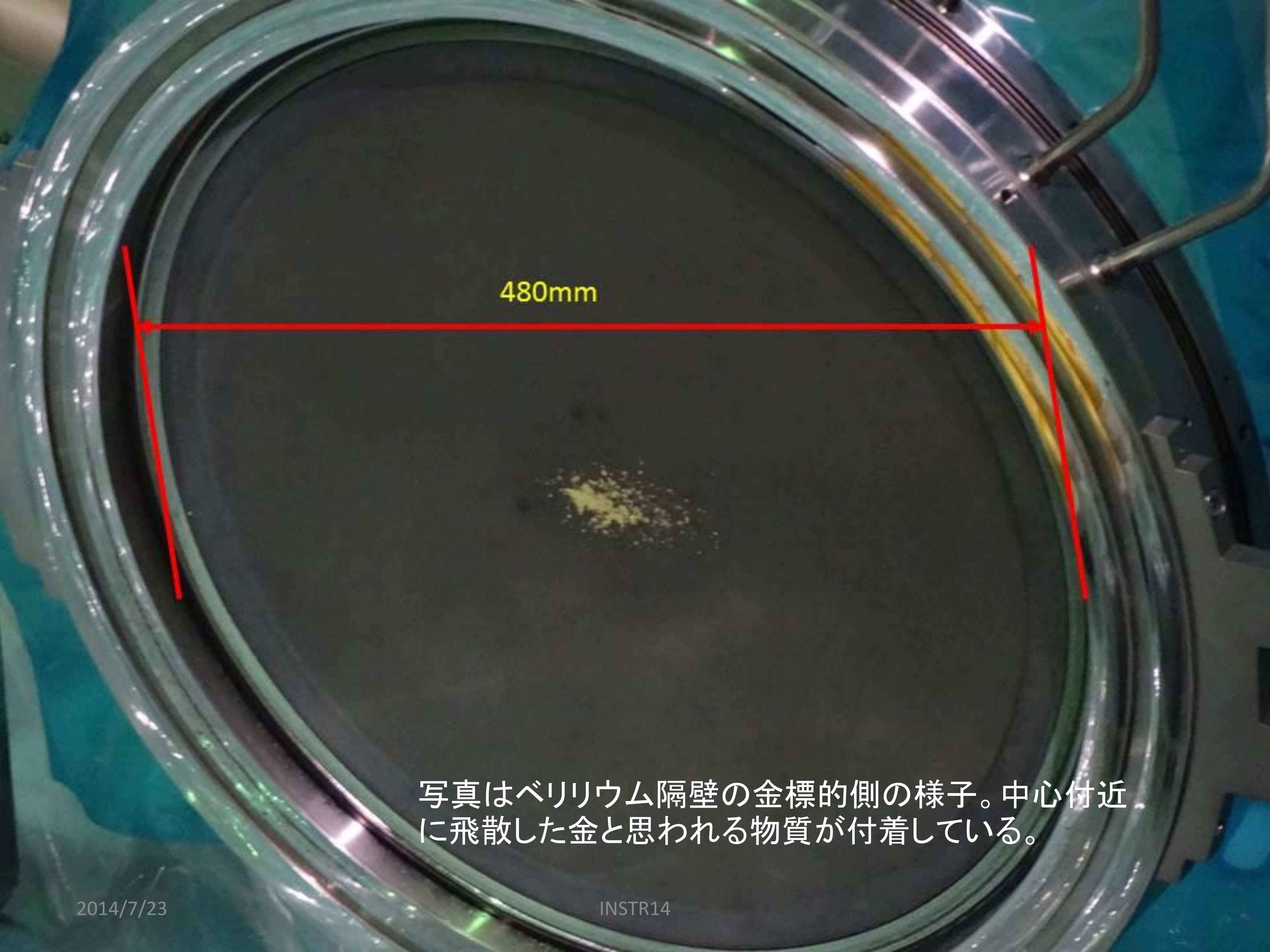
Temperature rise
(K)

- 2750-3000
- 2500-2750
- 2250-2500
- 2000-2250
- 1750-2000
- 1500-1750
- 1250-1500
- 1000-1250


金標的の後方（図で手前側）部分に直径
1mm程度の穴が見える。
Proton Beam

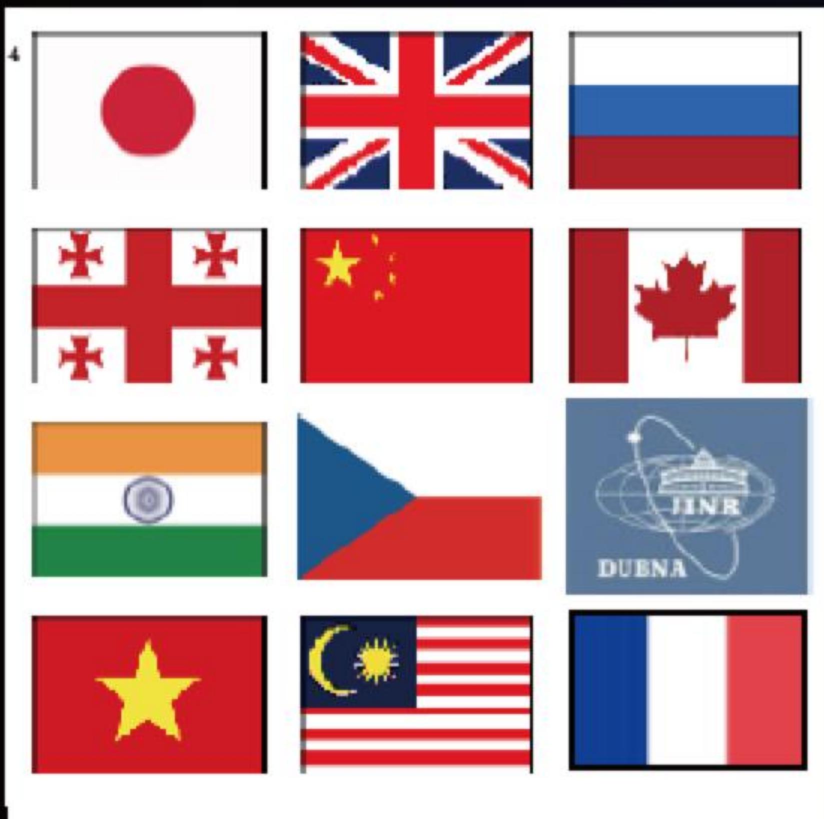
標的スリット部分に少量の金が溶け出たように見える。また同台座底面に金色に光る飛沫のような点が見られる。





写真はベリリウム隔壁の金標的側の様子。中心付近
に飛散した金と思われる物質が付着している。

COMET Collaboration is international.



129 collaborators
28 institutes, 11 countries

The COMET Japan group funded.

The COMET China group funded.

The COMET JINR group funding underway.

The COMET Collaboration

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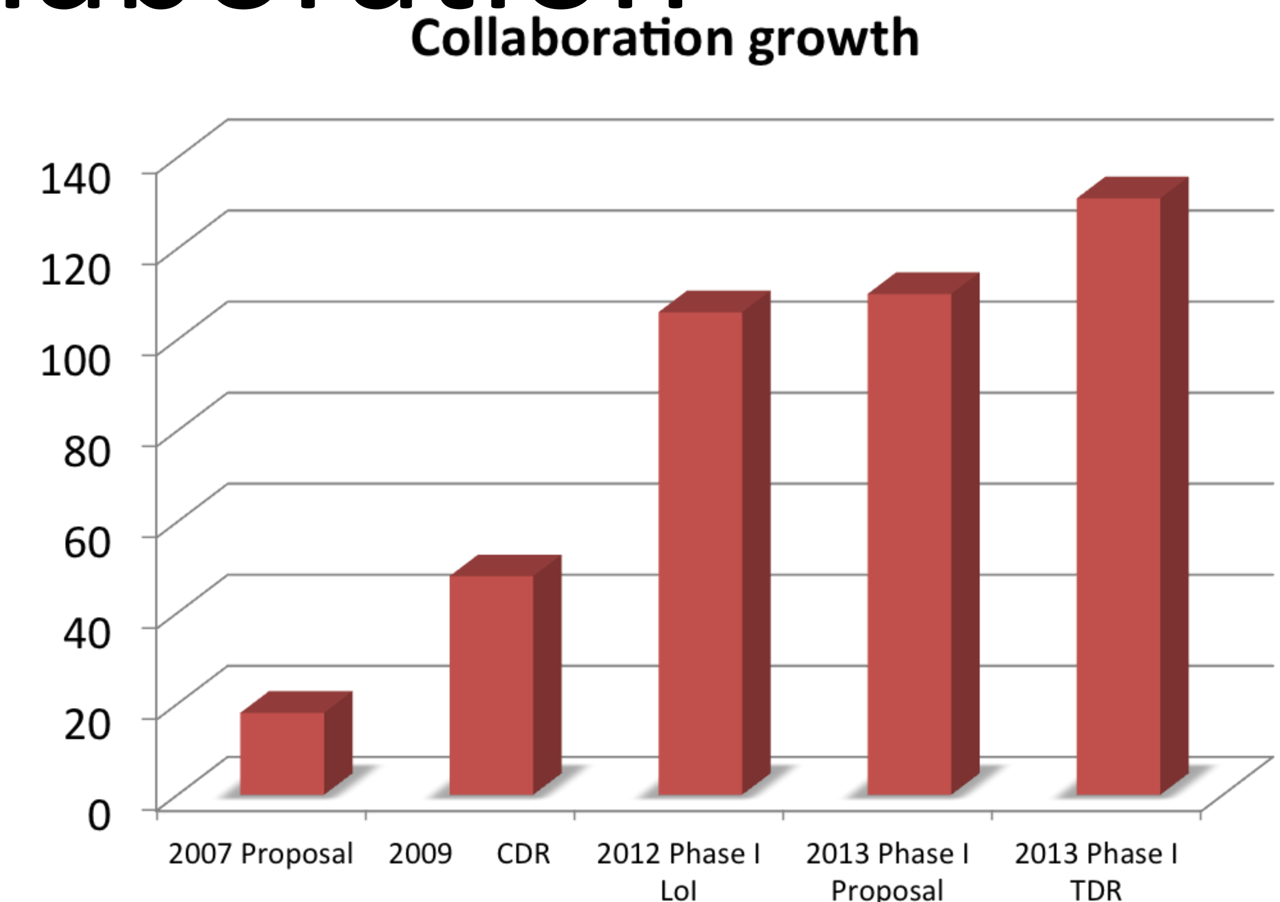
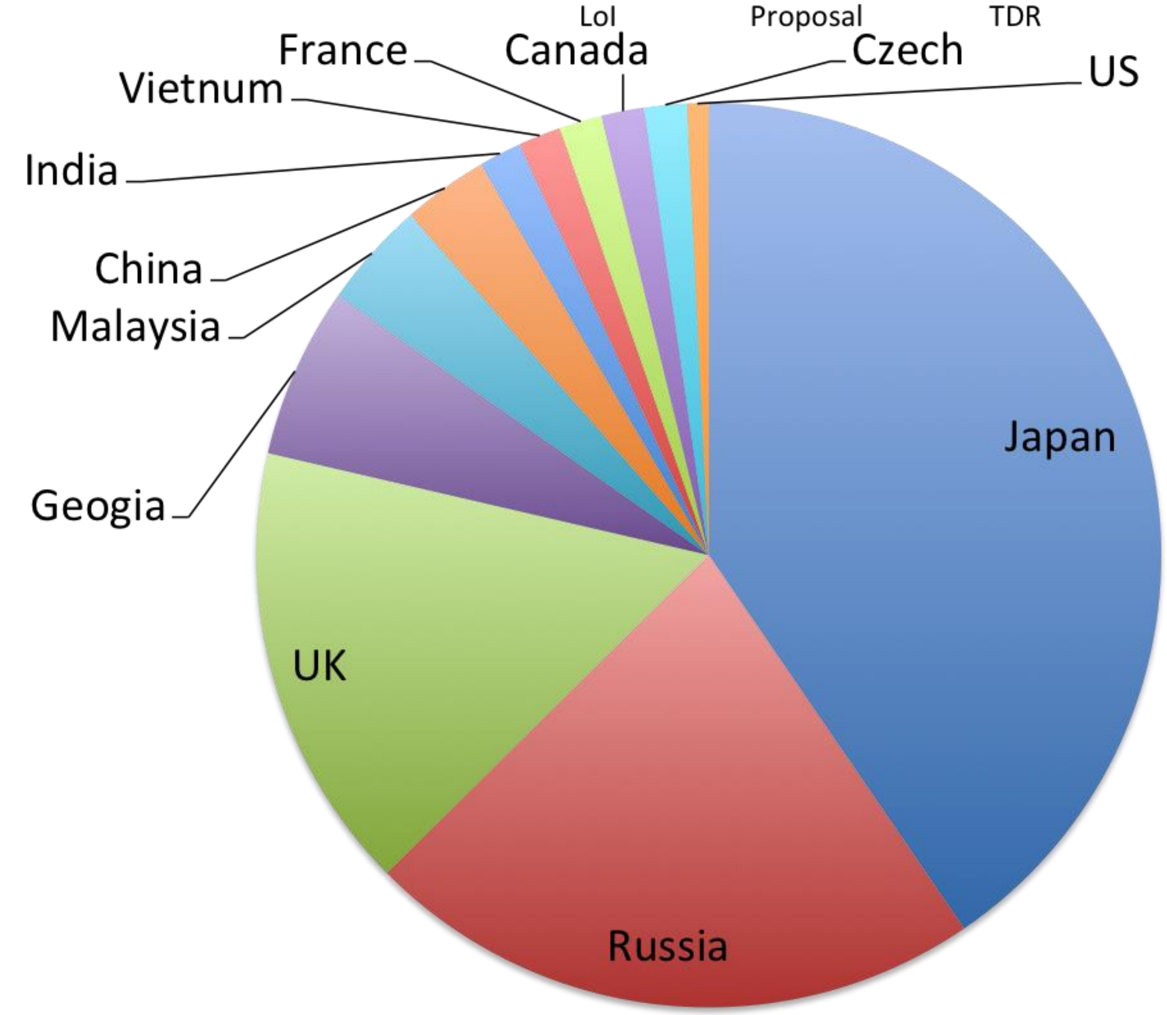
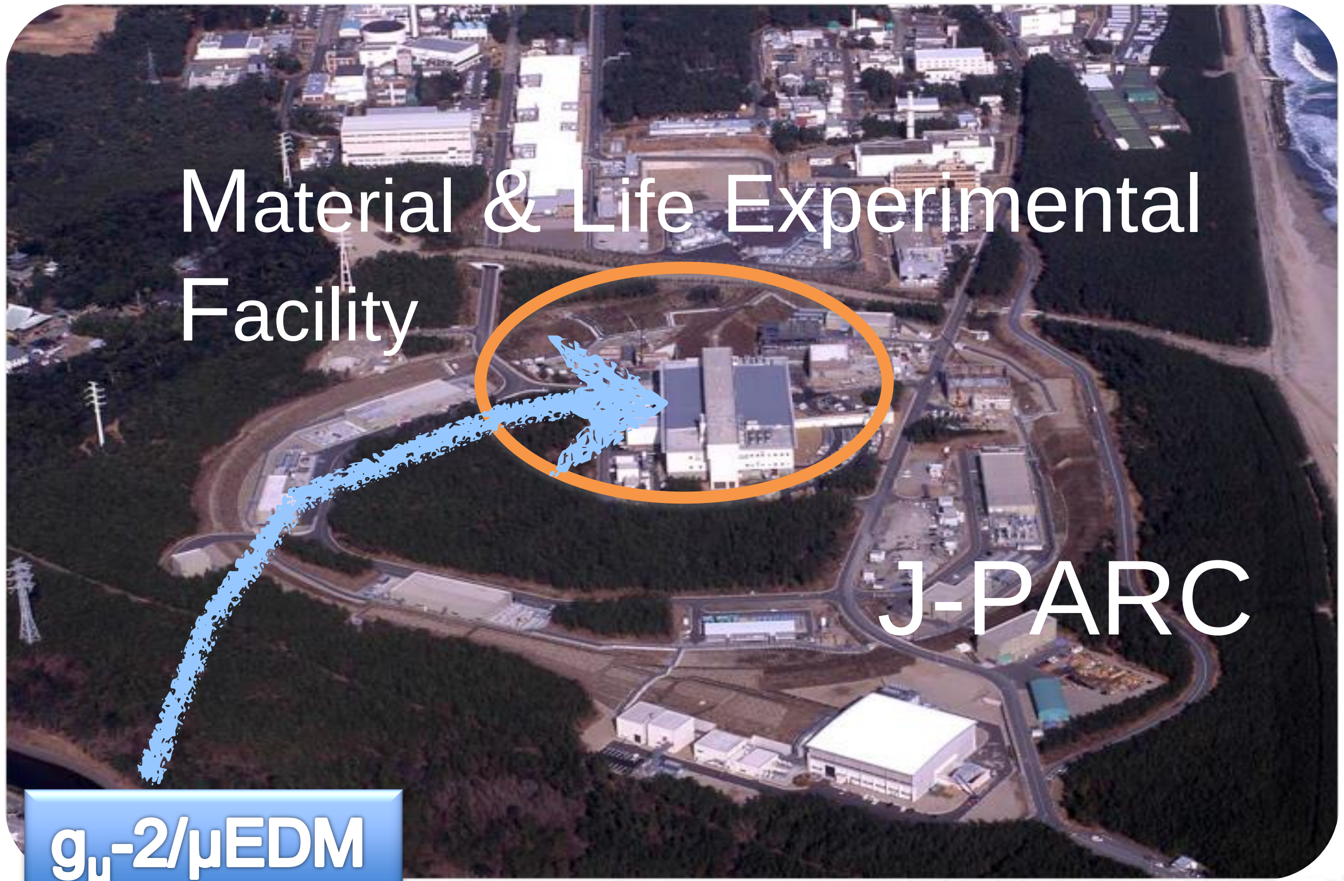
COMET Collaboration

- Proposal 2007
  - 18 members from 3 countries
- CDR 2009
  - 48 members from 4 countries
- Phase I LoI 2012
  - 106 members from 11 countries
- Phase I Proposal 2013
  - 110 members from 11 countris
- Phase I TDR 2013
  - **131 members from 12 countries**





Muon g-2/EDM w/ Ultra-Cold Muon Beam

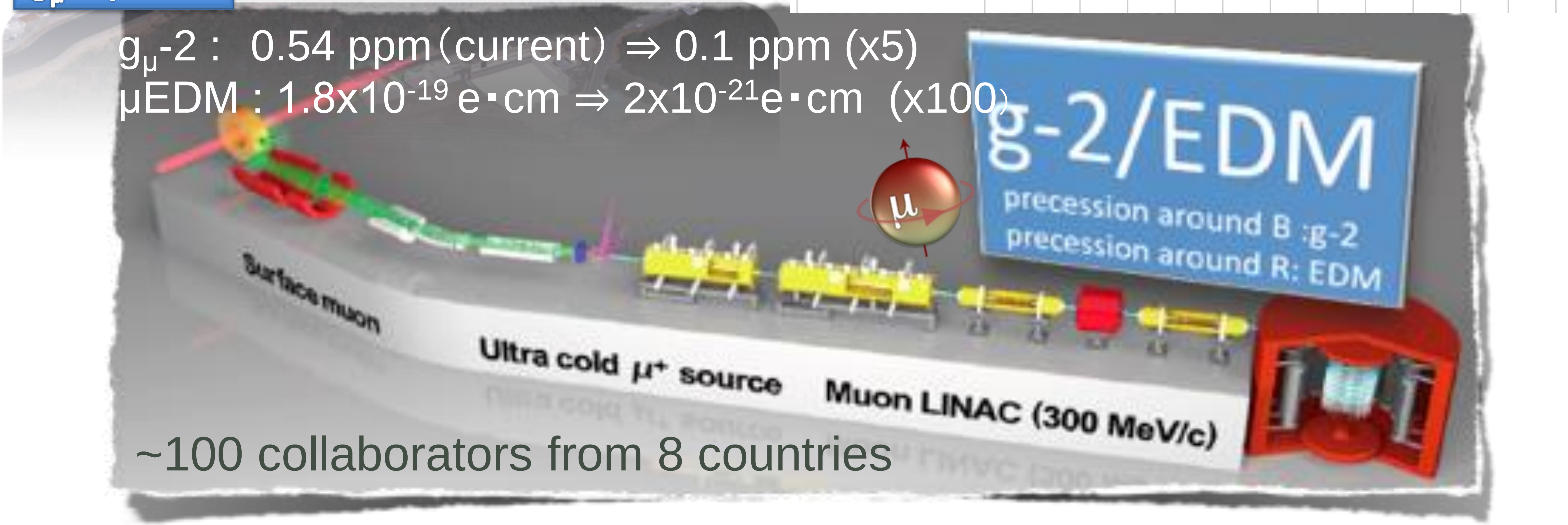


Intended Schedule

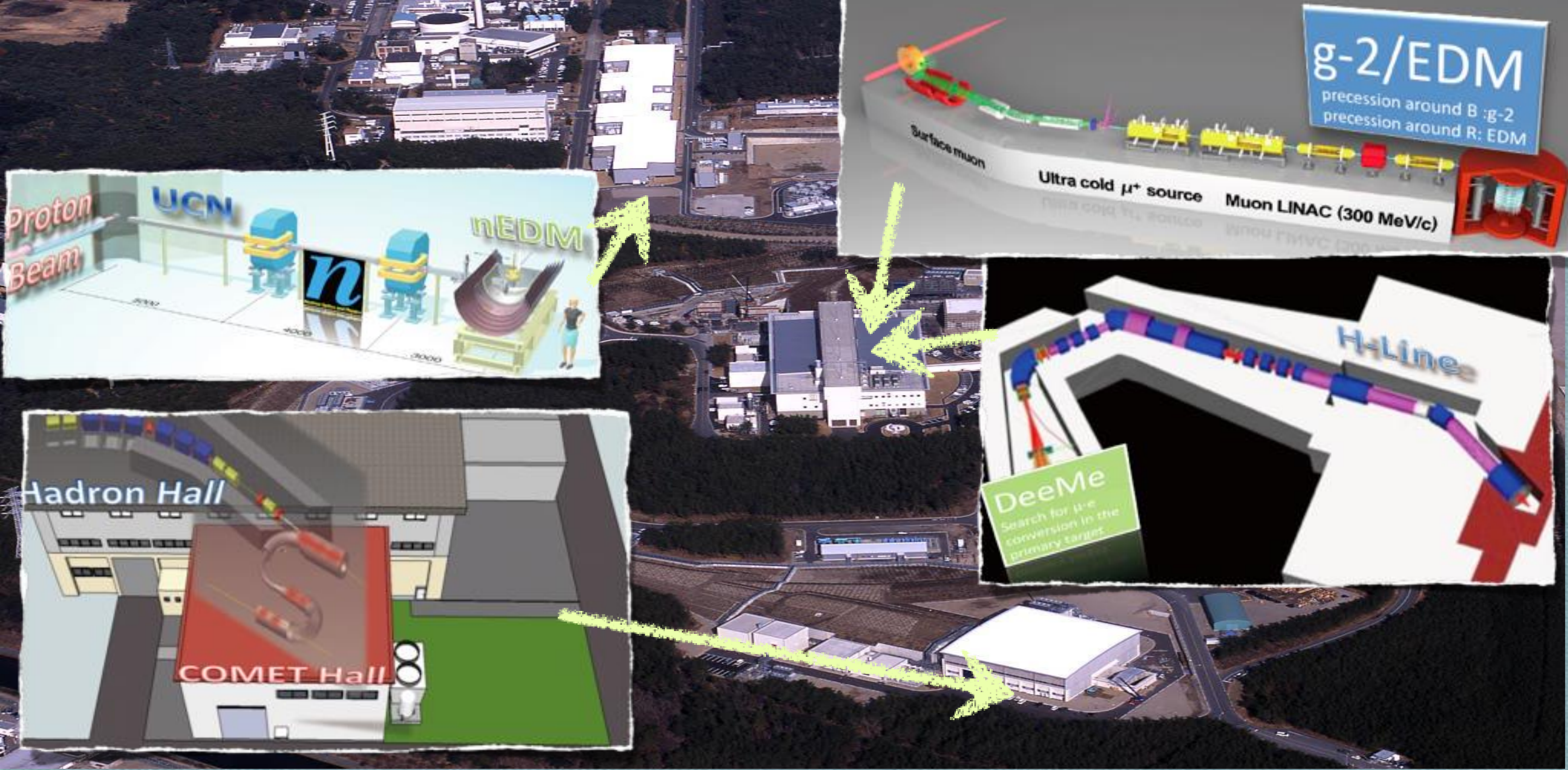
	2013	2014	2015	2016	2017	2018
Muon Sounrce	R&D / Design	R&D / Design		Construction	Construction	Experiment
Muon LINAC	R&D / Design	R&D / Design		Construction	Construction	Experiment
Ultra-Precision Magnet	R&D / Design	R&D / Design		Construction	Construction	Experiment
Detector	R&D / Design	R&D / Design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

g_μ-2 : 0.54 ppm（current）⇒ 0.1 ppm (x5)

μEDM : 1.8×10^{-19} e･cm ⇒ 2×10^{-21} e･cm (x100)



~100 collaborators from 8 countries



cLFV: COMET and DeeMe
muon g-2/EDM
neutron EDM

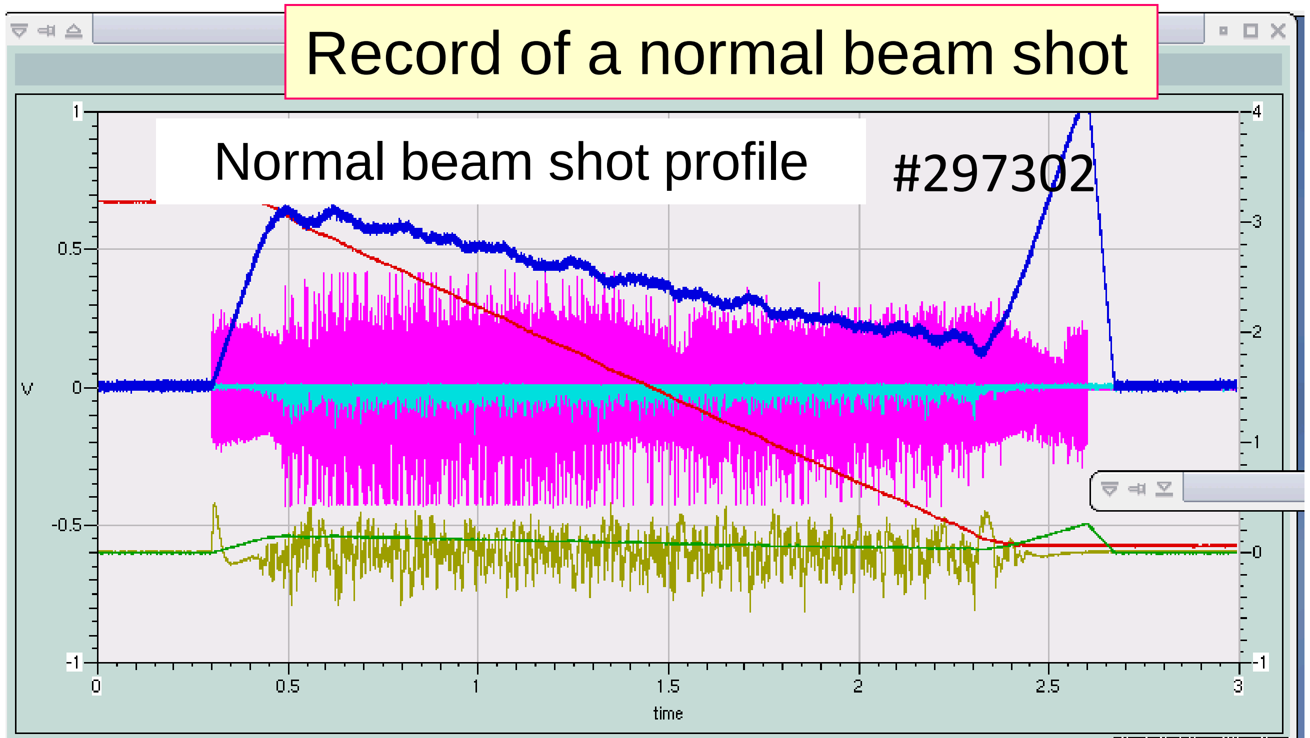
Slide by Y.Kuno

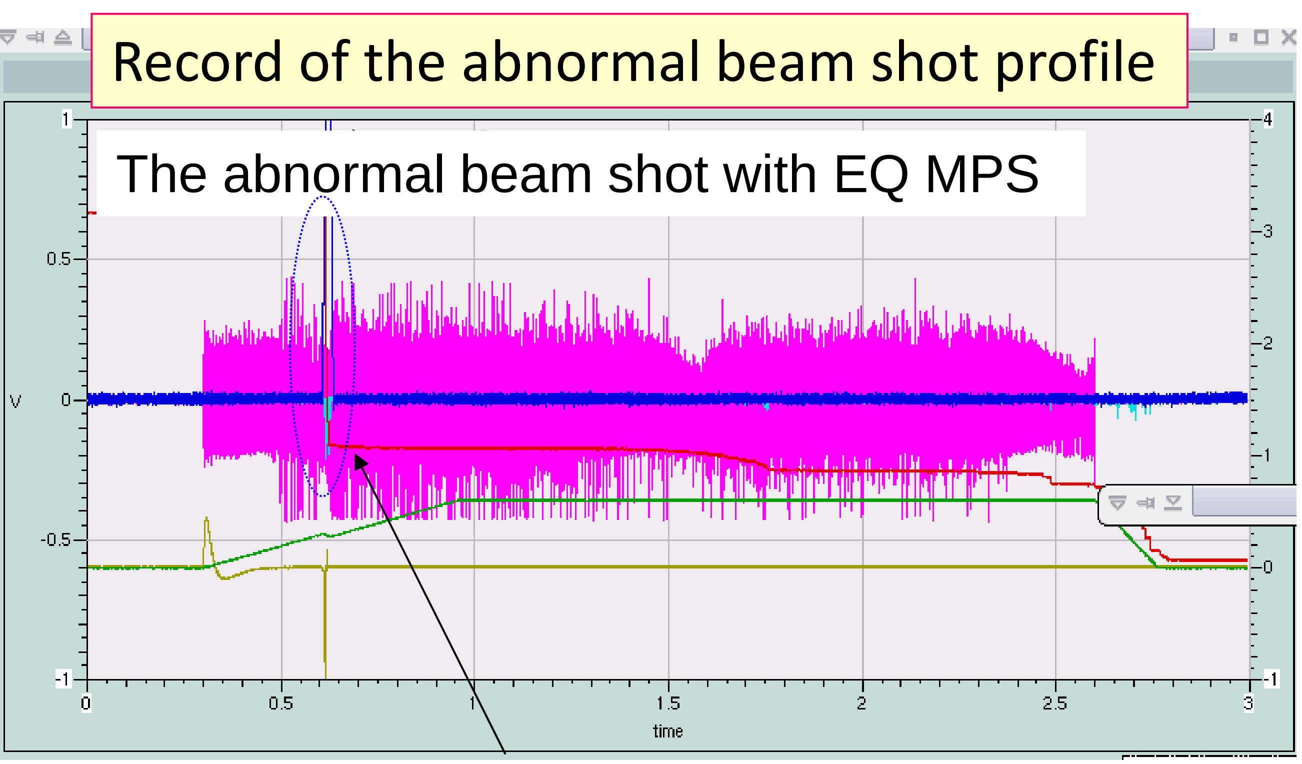
Comparison of COMET Phase-I / Phase-II and Mu2e

90% C.L. upper limit is 7×10^{-13} (SINDRUM)

	S.E. sensitivity	BG events at aimed sensitivity	running time (sec)	Year	Comments
COMET Phase-I	3×10^{-15}	0.03	1.5×10^{6}	~2016	Proposal (2012)
COMET Phase-II	3×10^{-17}	0.34	2×10^{7}	~2019	CDR (2009)
Mu2e	3×10^{-17}	0.4	$3 \times (2 \times 10^{7})$	~2019	J. Miller's talk at SSP2012

2. Main causes of the radioactive material leakage
Stage 1: Delivery of abnormal beam





EQ: instantaneous high current output

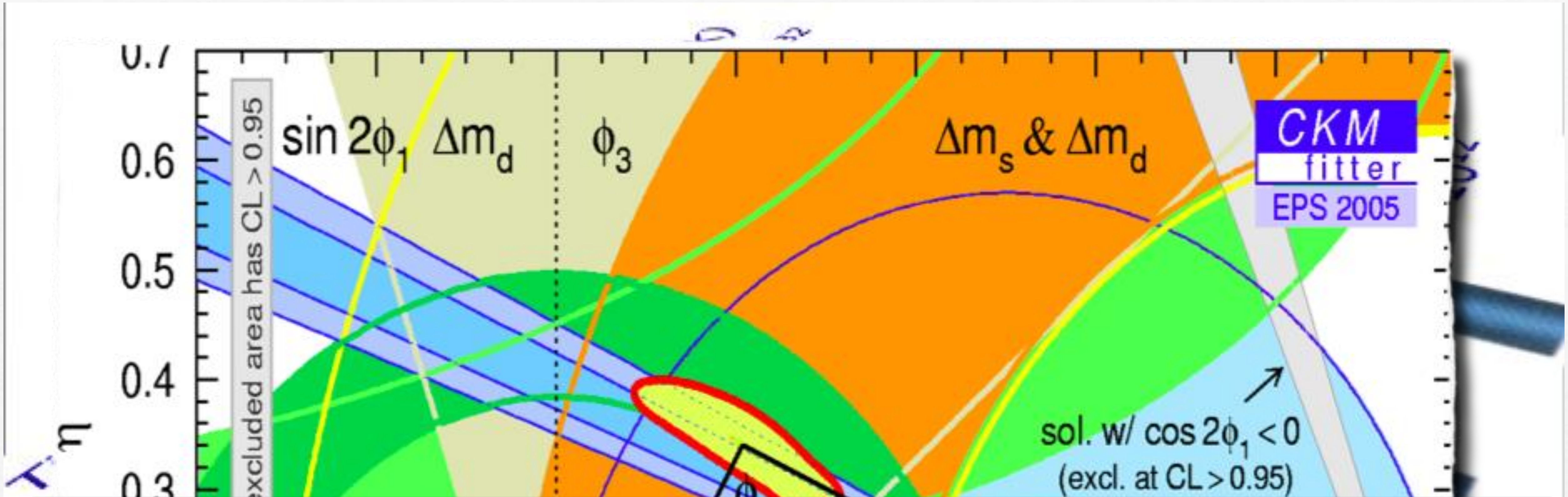
The monitor display for beam extraction

Cause

A power supply for driving a magnet, which controls the slow beam extraction, did not properly respond to the control signal during the first fraction of a second in the designated period of beam spill, and then it abruptly brought a large current to the magnet.

- Operation of the accelerator was automatically stopped upon detection of the malfunction of the power supply and of signals from the beam loss monitors.
- While the operation staff of the accelerator misunderstood that it was due to a malfunction of the fast extraction kicker, a large fraction of the beam in fact was delivered to the hadron target.
- The accelerator staff did not recognize the incident as one which led to any possibility of partial melting of the gold target.

red line: intensity monitor for the circulating-beam
light blue line: beam spill monitor
green line: preset value for the EQ power supply
blue line: output current of the EQ power supply
pink line: preset value for the RQ power supply
olive-green line: output current of the RQ power supply



Particle-Nuclear Physics at J-PARC

Strong Interaction

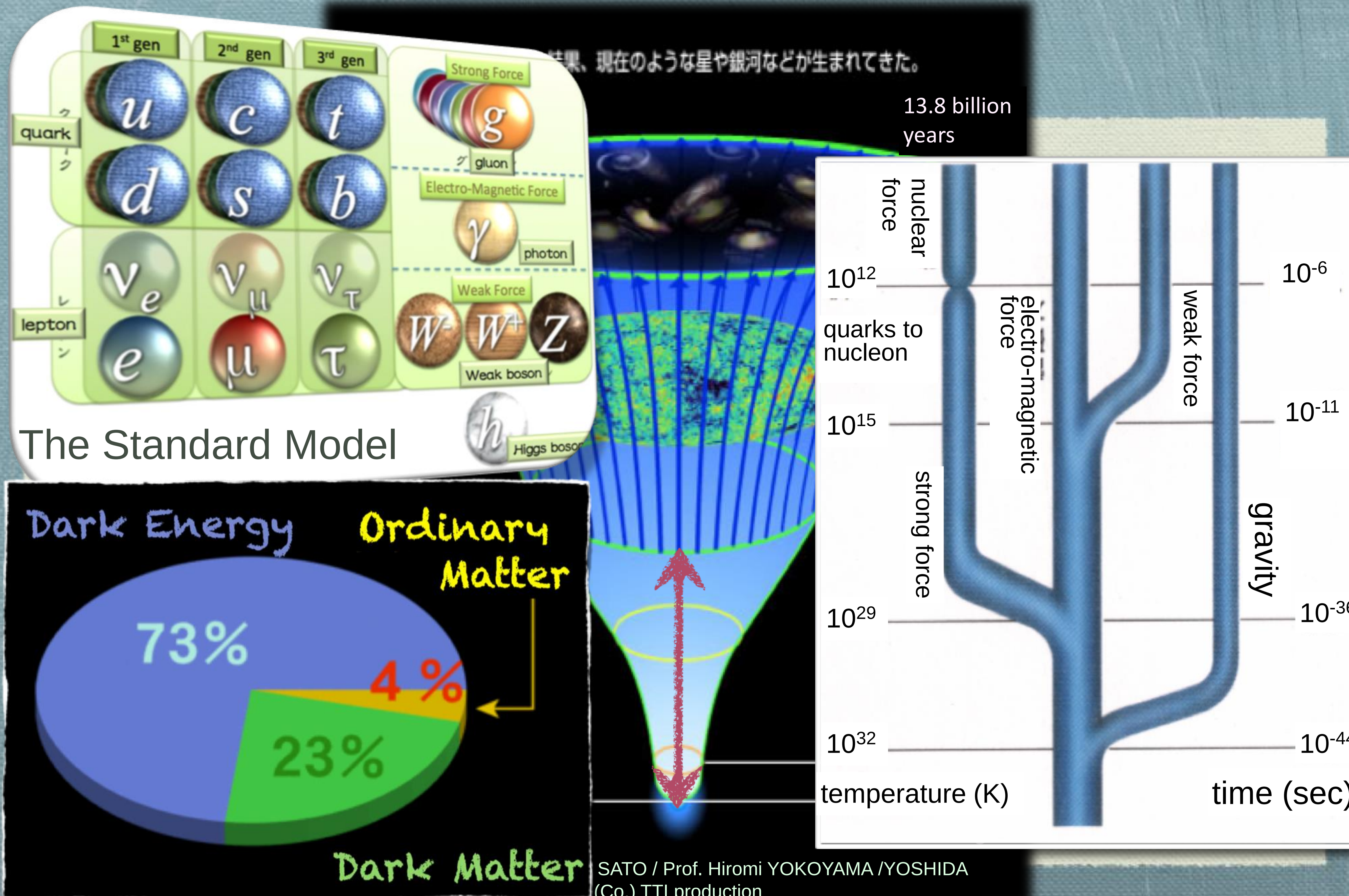
CP Violation・T-Violation

Quark and Lepton Sectors

Lepton Flavor Violation

⇒Origin of Matter

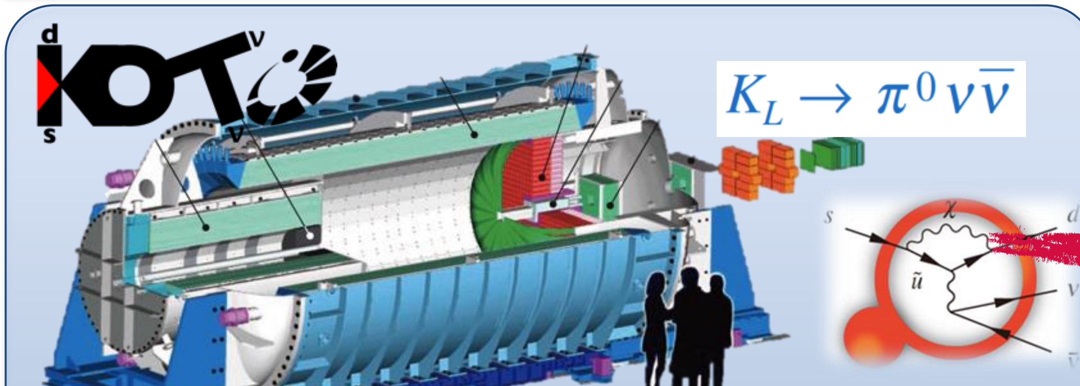
History of Universe & the Standard Model



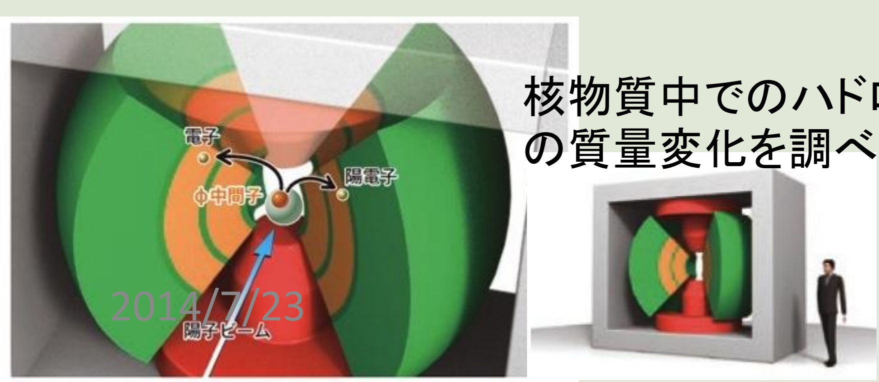
SATO / Prof. Hiromi YOKOYAMA /YOSHIDA
(Co.) TTI production

Origin of Matter :
Explored with High Intensity Proton Driver

Neutrino Experiment : T2K
～Mixing Angle, CP phase, and Mass Hierarchy ～



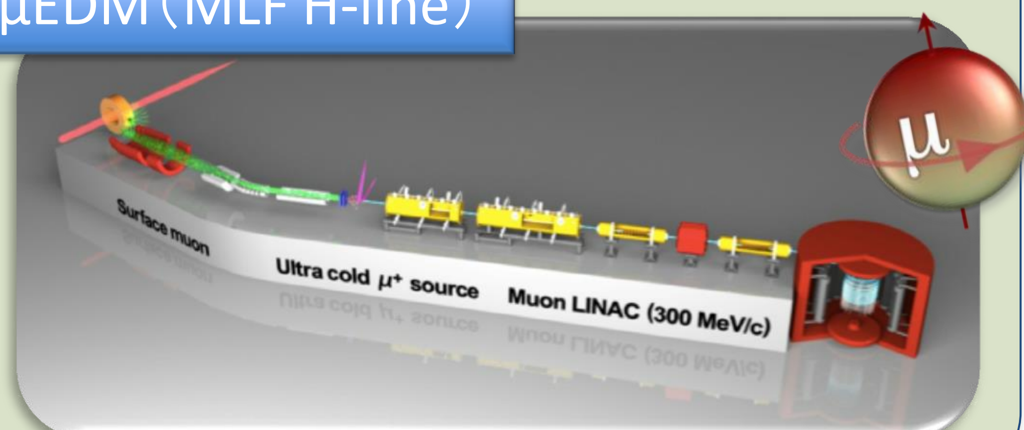
Hadron Experiments
～CP beyond CKM; Mass modification～



Muon Fundamental Physics
～Flavor and CP are violated in the charged Leton sector?～

COMET（Hadron Hall）

g-2/μEDM（MLF H-line）



Origin of Matter

- Serach for new CPV to find the origin of CPV
- Deeper understanding of Strong Int.

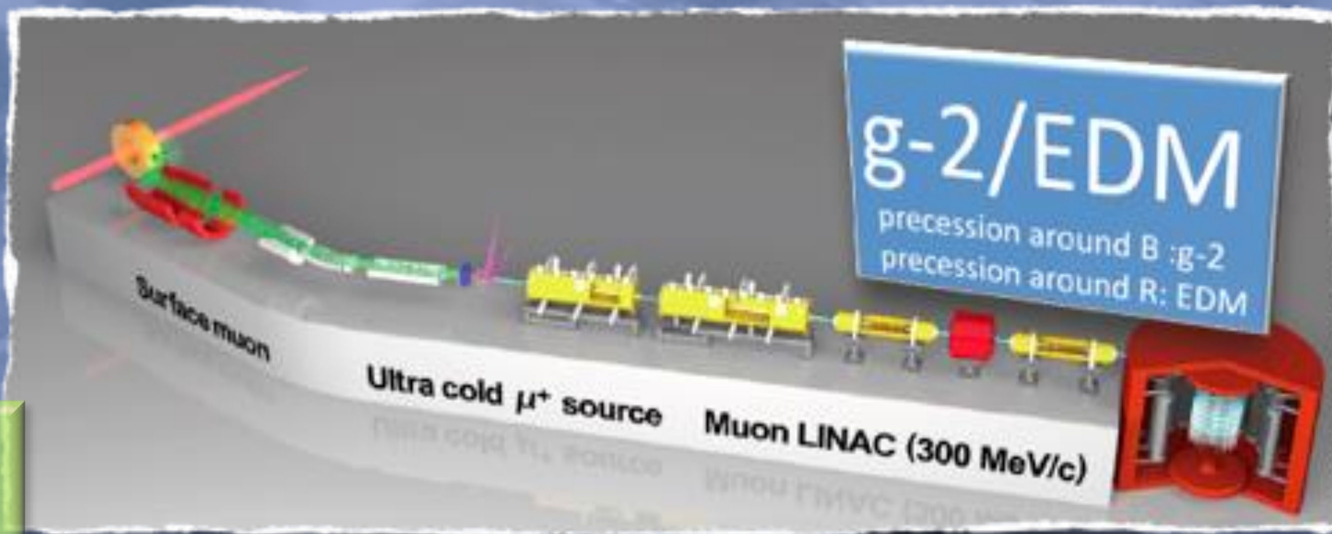
g-2/EDM (0.1ppm/10^{-21} e cm)

Ultra-Cold Muon Beam

Off-Magic Momentum

Ultra-Precision Magnetic Field

g-2 and EDM Simultaneously !!



COMET (I<10^{-14}; II < 10^{-16})

Search for muon to electron conversion

Adopted staging approach

Phase-I: 10-14

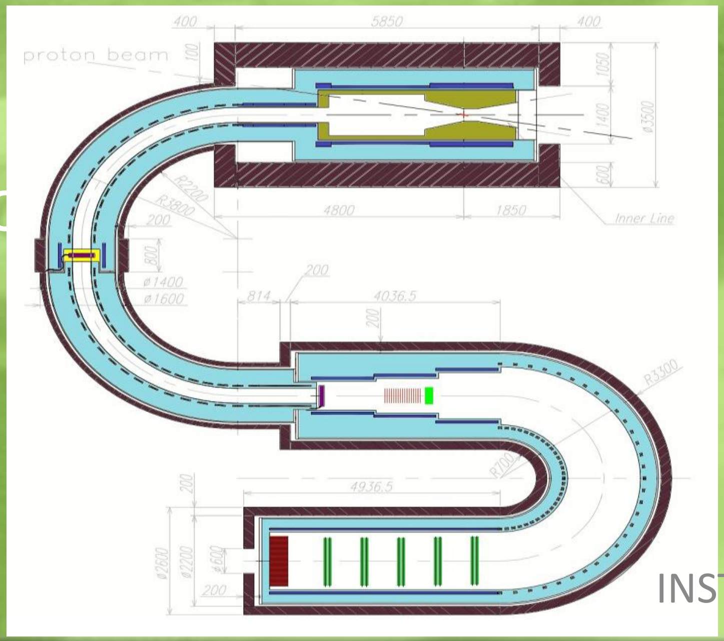
Phase-II: 10-16

Phase-I constructio

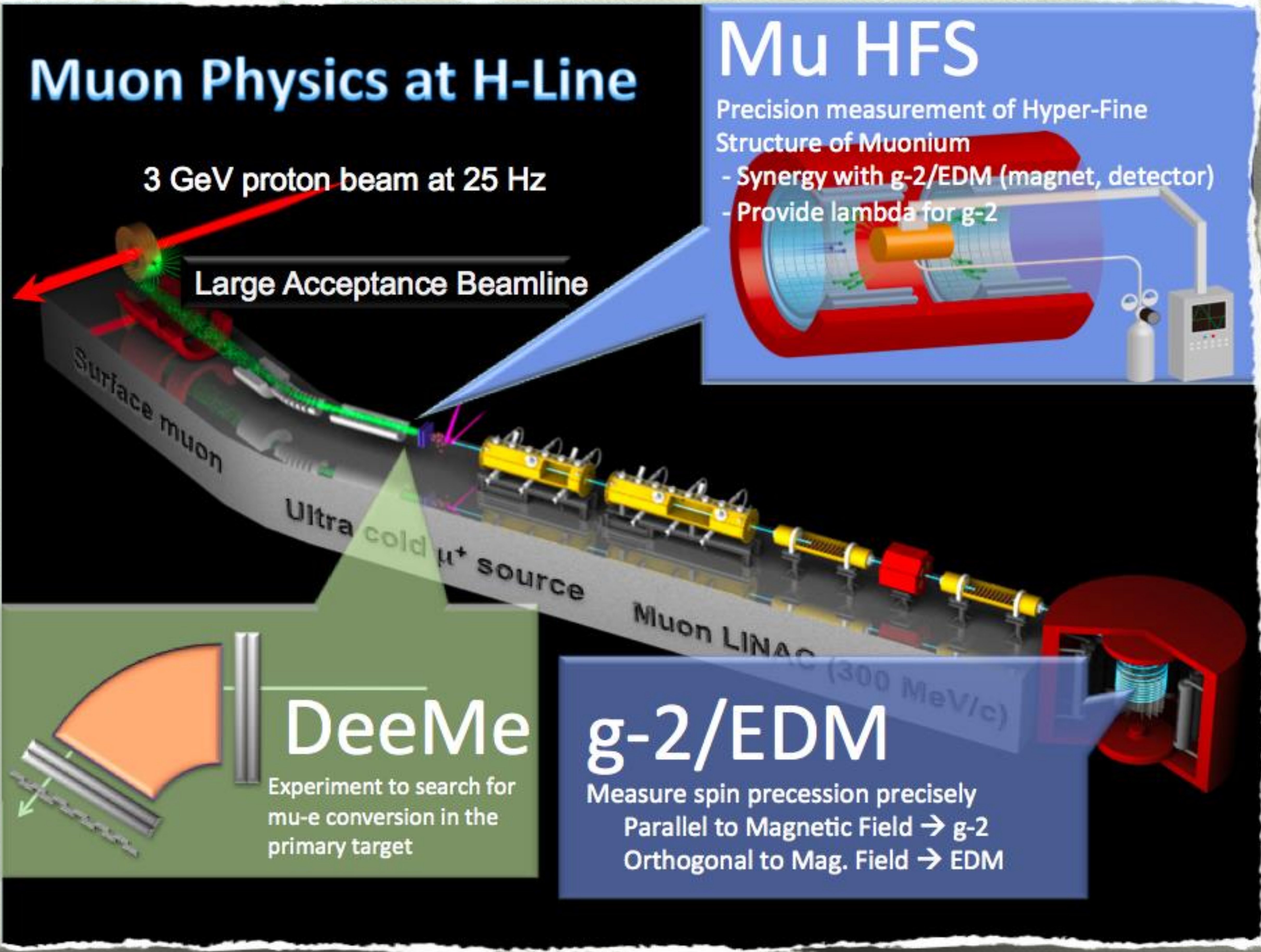
Started!

Physics starts

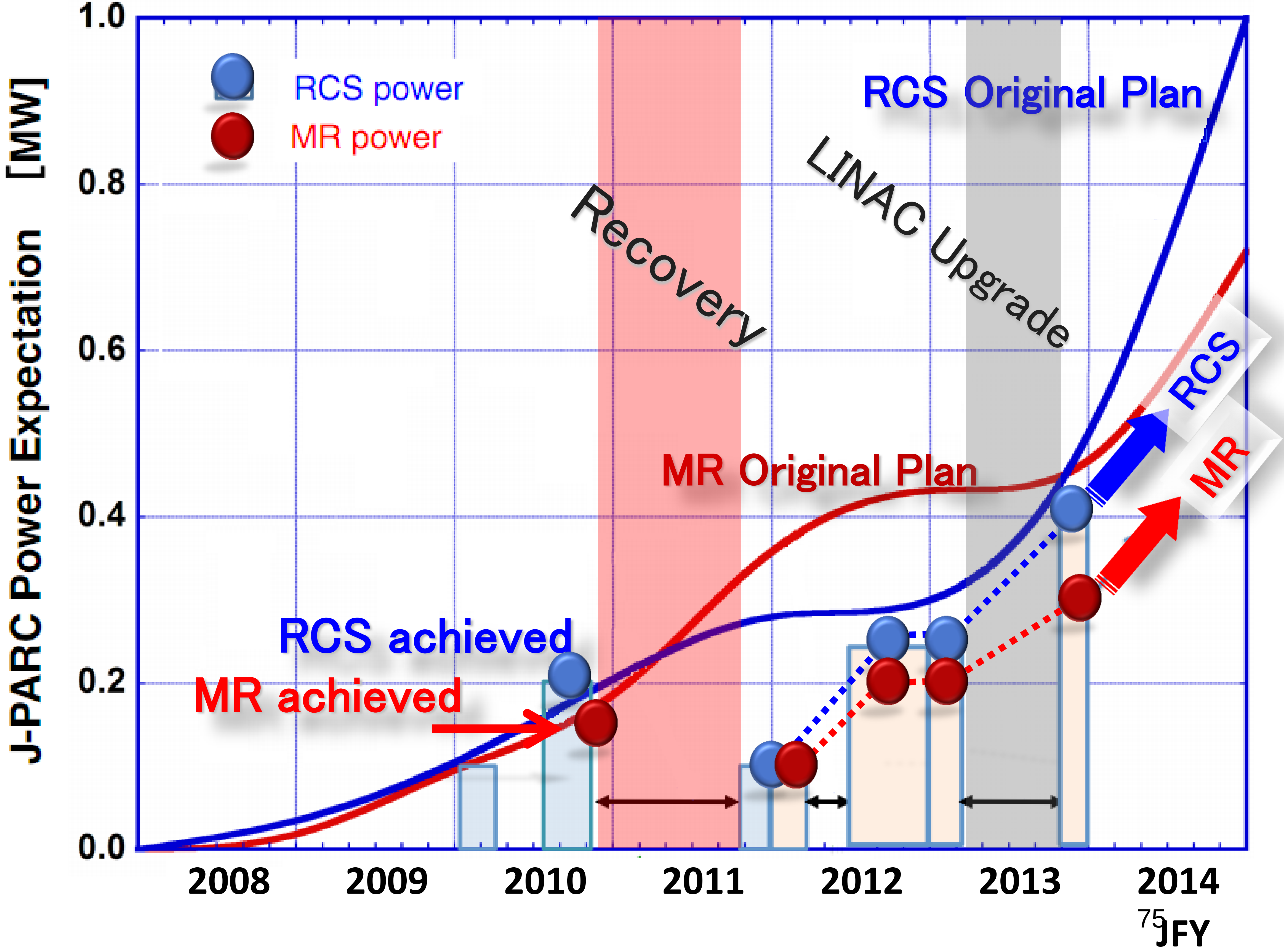
in 2017



Muon Physics at H-Line



Operation plan of RCS/MR-FX: made after the earthquake

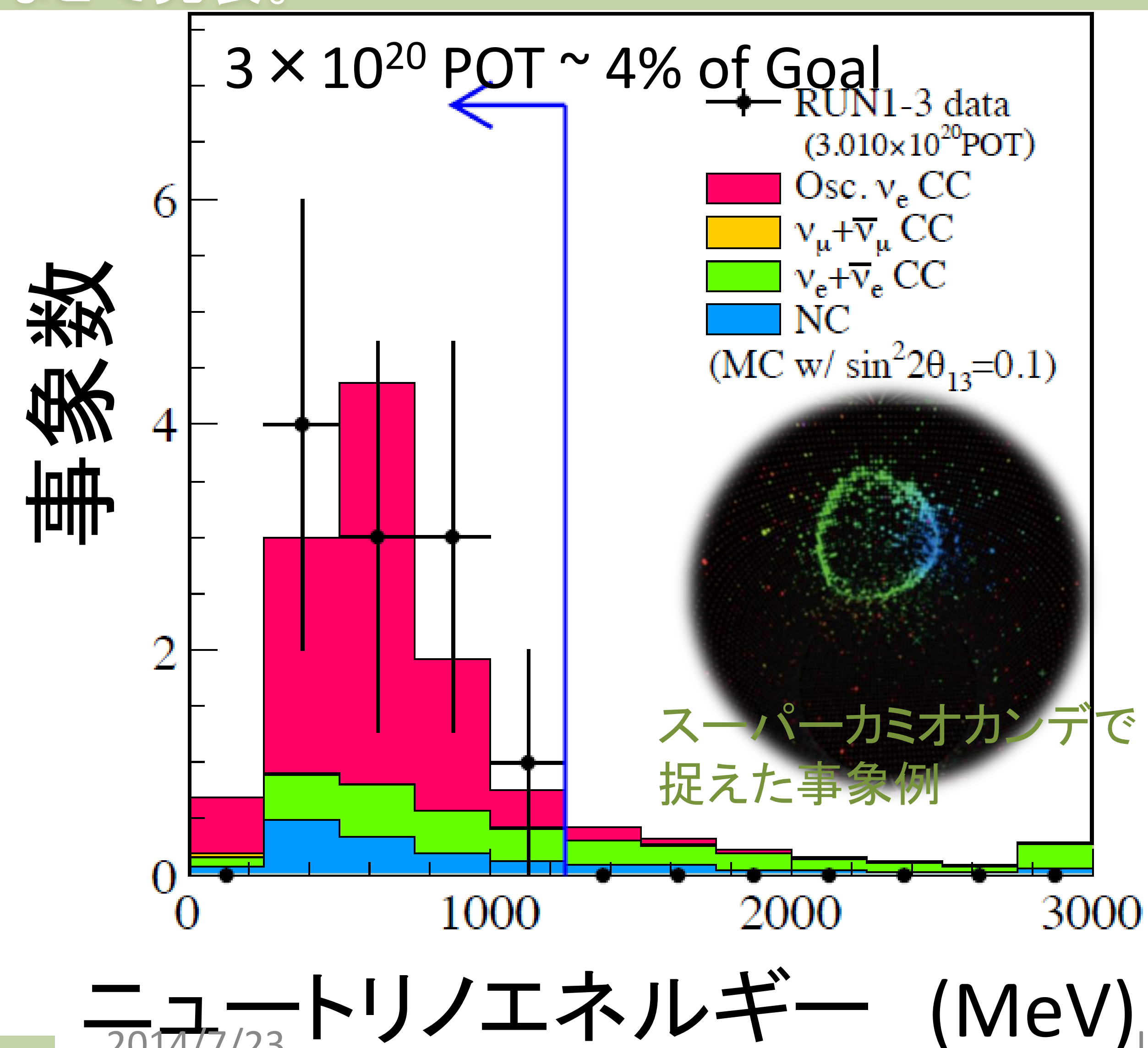


これまでの成果

ニュートリノ

T2K実験

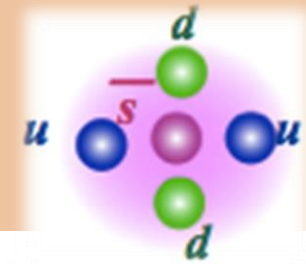
・ニュートリノ振動による電子ニュートリノ出現現象の兆候⇒Physics World誌Top 10 Breakthrough of 2011 の一つに！
•2012年7月までに11事象をみつけて、国際会議などで発表。



ハドロン

J-PARC E19実験

▪ペンタクォークの探索。生成断面積に強い制限を与えた。
フィジカルレビューレター誌に掲載：
PRL109,132002 (2012)



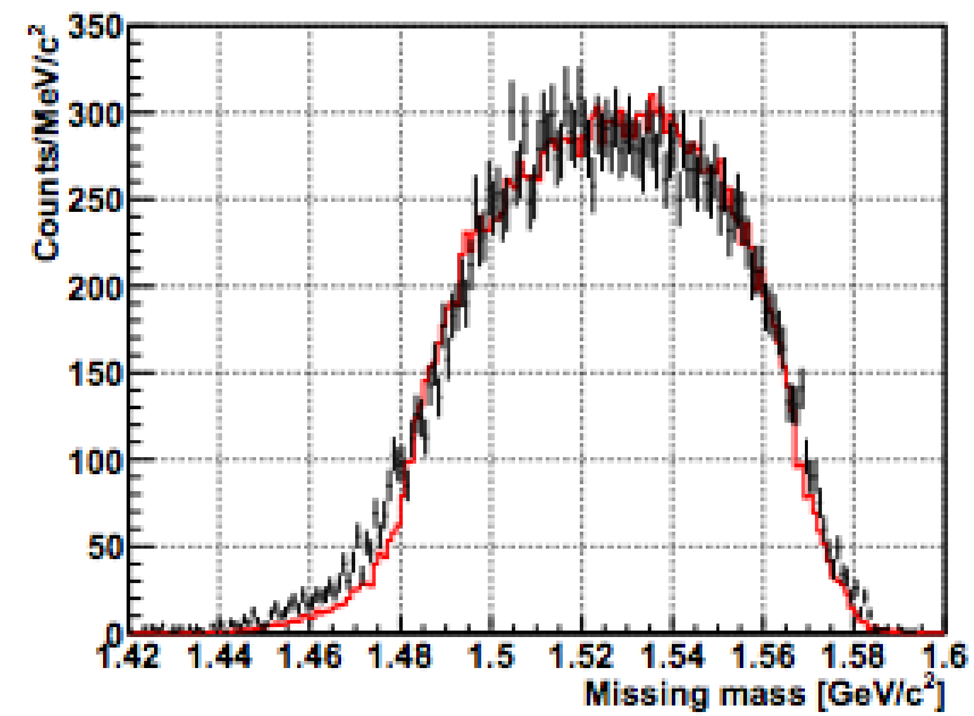


FIG. 2. The missing mass spectrum and the background shape for the $\pi^- p \to K^- X$ reaction at the beam momentum of 1.92 GeV/c. The black points with error bars are the experimental data. The contribution of the simulated background is indicated by red histogram.

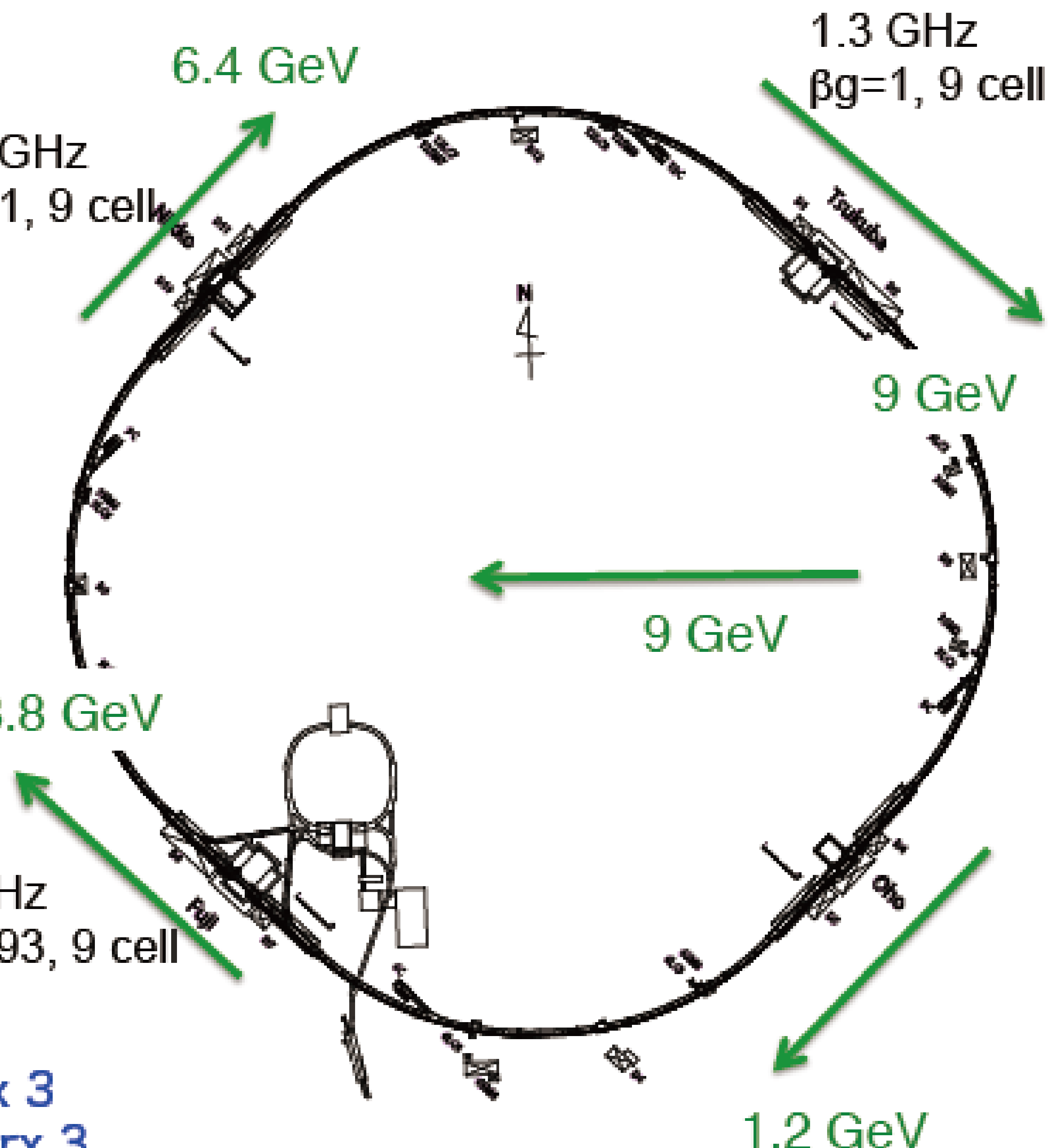
Proton driver in the KEKB tunnel

KEKB tunnel:
Circumference ~3 km
LS section 200 m x 4

Proton linac:
E = 9 GeV

- 509 MHz, 5 cell (TRINSTAN)
E0=10 MV/m
Real estate grad. ~3.2 MeV/m
900台以上の空洞
アークに空洞？、2周以上？

- 1.3 GHz, 9 cell (ILC)
E0=37.5 MV/m
Real estate grad. 13.3MeV/m



最初の直線部で1~1.2 GeV.
その後、3つの直線部で 9 GeV.
第1アークに650 MHz rebuncher x 3
第2、3アークに1.3 GHz rebuncherx 3

Nuclear & Hadron Physics at J-PARC