Flavor Physics at SuperKEKB and J-PARC

Shoji Hashimoto (KEK, Sokendai)

@ "QCD for New Physics at Precision Frontier,"
INT, U. Washington, Seattle, Oct 1, 2015

KEK Facilities

KEK Tsukuba

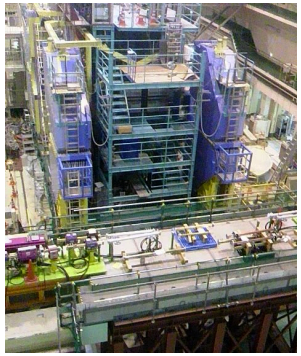
KEKB → SuperKEKB
ATF/STF
Photon Factory
cERL
…
Theory

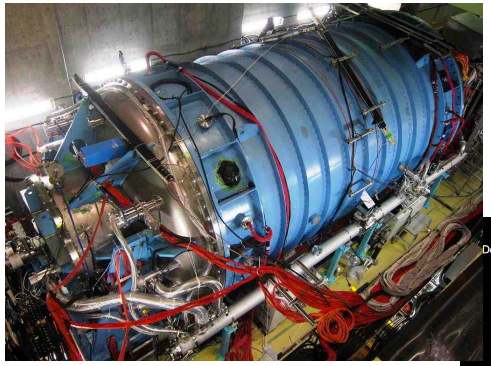
JAERI / KEK Tokai

J-PARC
- MLF (muon, neutron)
- Hadron
- T2K neutrino

Physics Programs at KEK

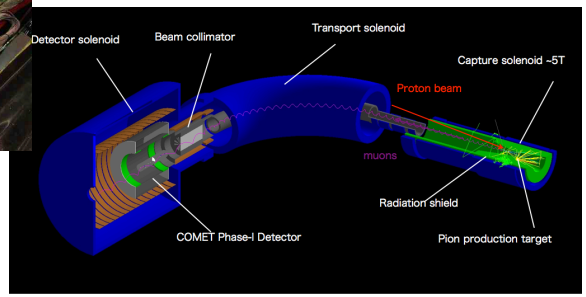
SuperKEKB / Belle II

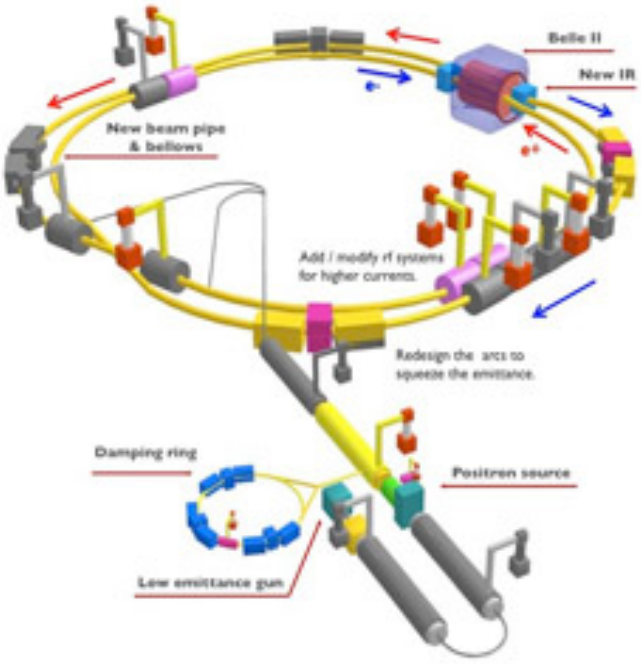




KOTO

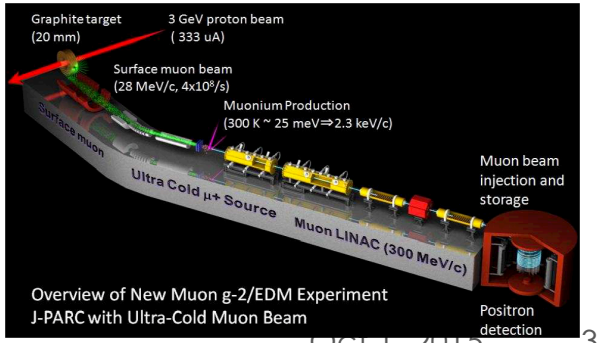
COMET





T2K

g-2/EDM



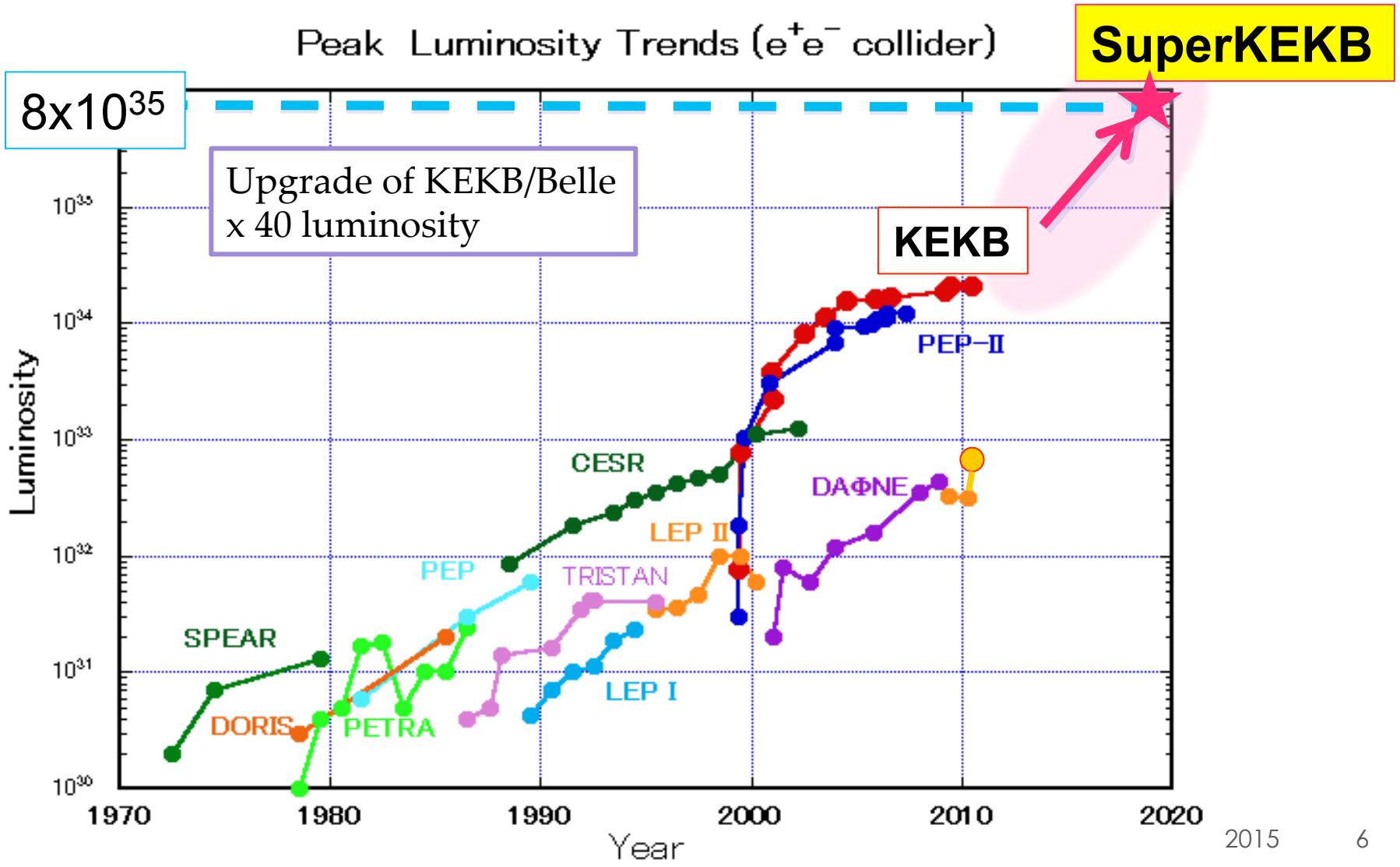
This talk

- Overview of the KEK physics program from my (theory/ lattice) viewpoint.
  - Do not ask experimental details to me…
  - Do not ask political details (budget/beam time plans) to me…!

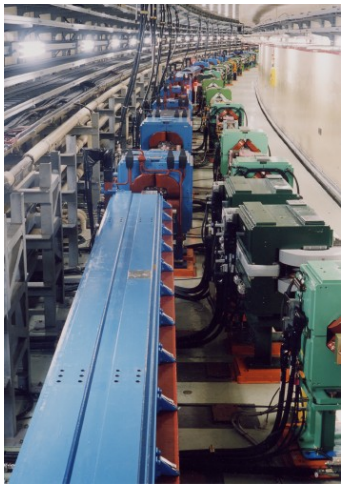
- Plus, some QCD issues related to the subjects of this workshop.
  - Maybe already covered in other talks.
  - Could be very challenging.

SuperKEKB / Belle II

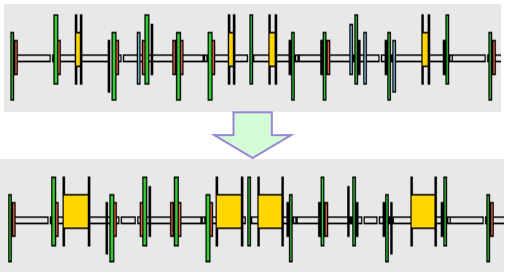
SuperKEKB / Belle II



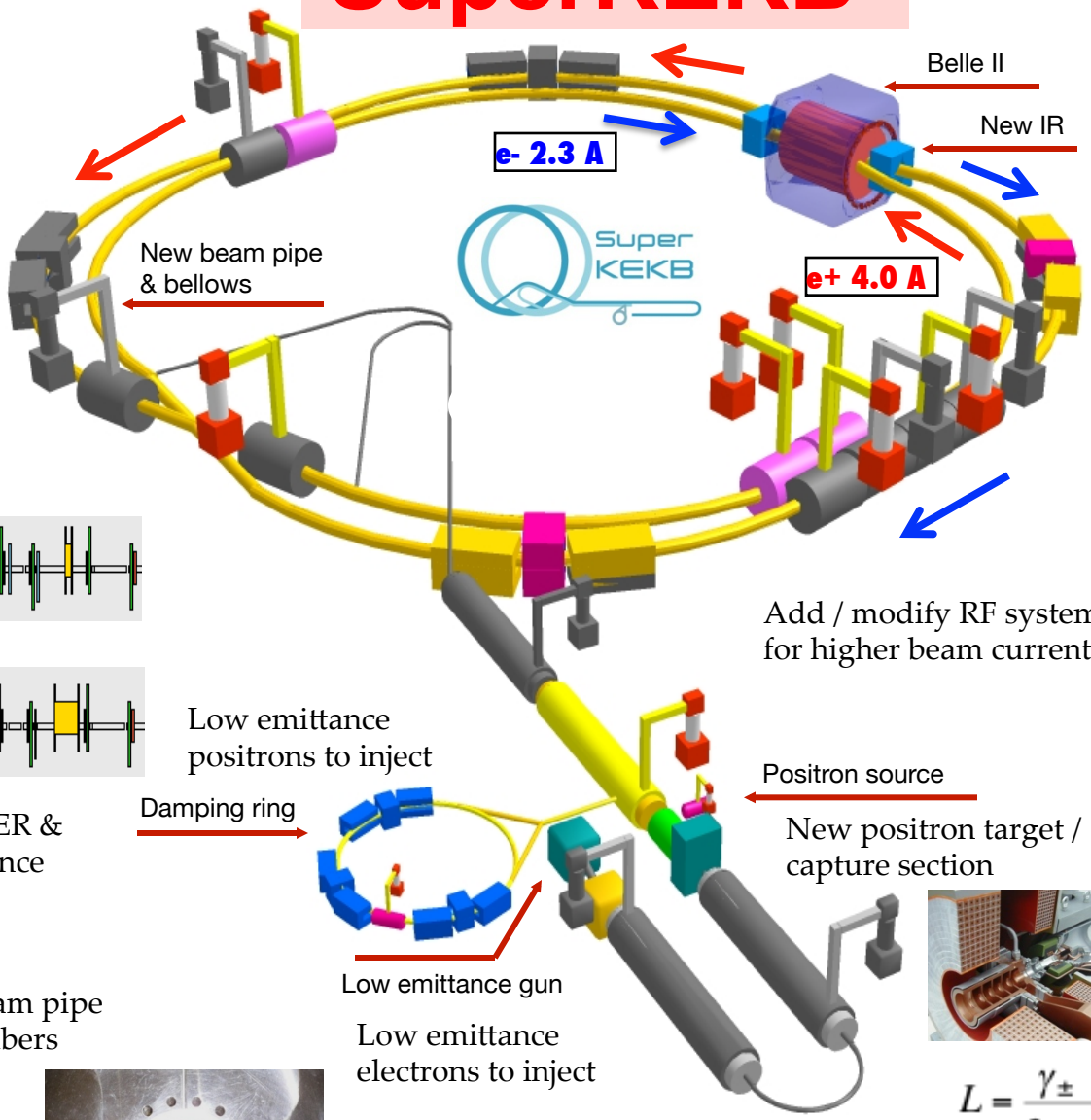
SuperKEKB



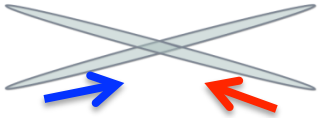
Replace short dipoles with longer ones (LER)



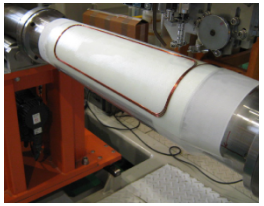
Redesign the lattices of HER & LER to squeeze the emittance



Colliding bunches



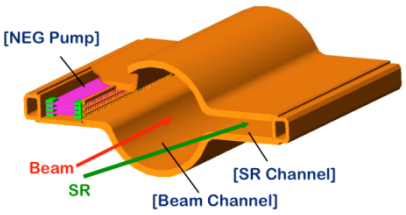
New superconducting / permanent final focusing quads near the IP

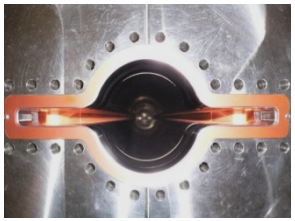


Add / modify RF systems for higher beam current

New positron target / capture section

TiN-coated beam pipe with antechambers



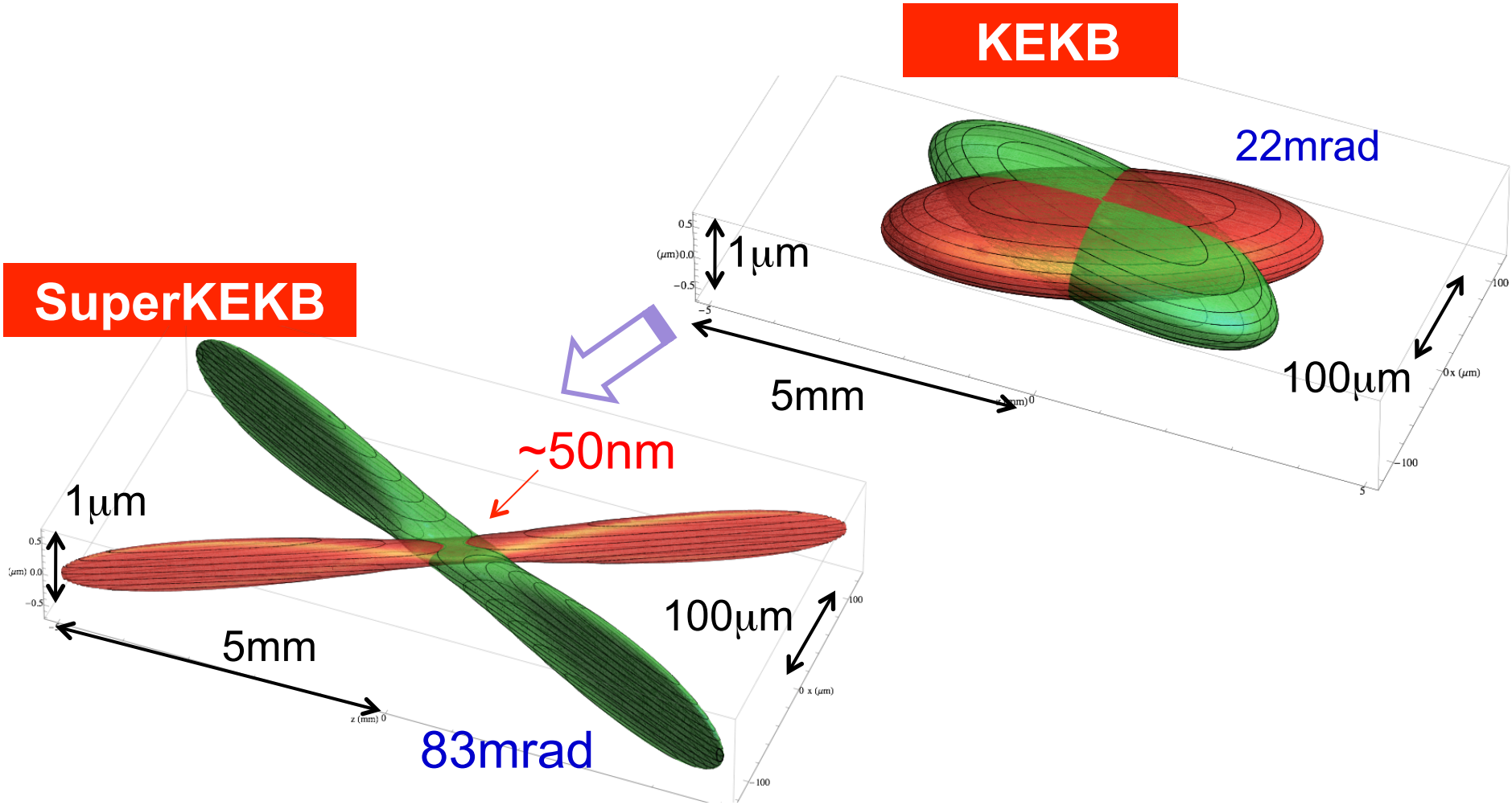


$L = 8 \cdot 10^{35}\ s^{-1}cm^{-2}$

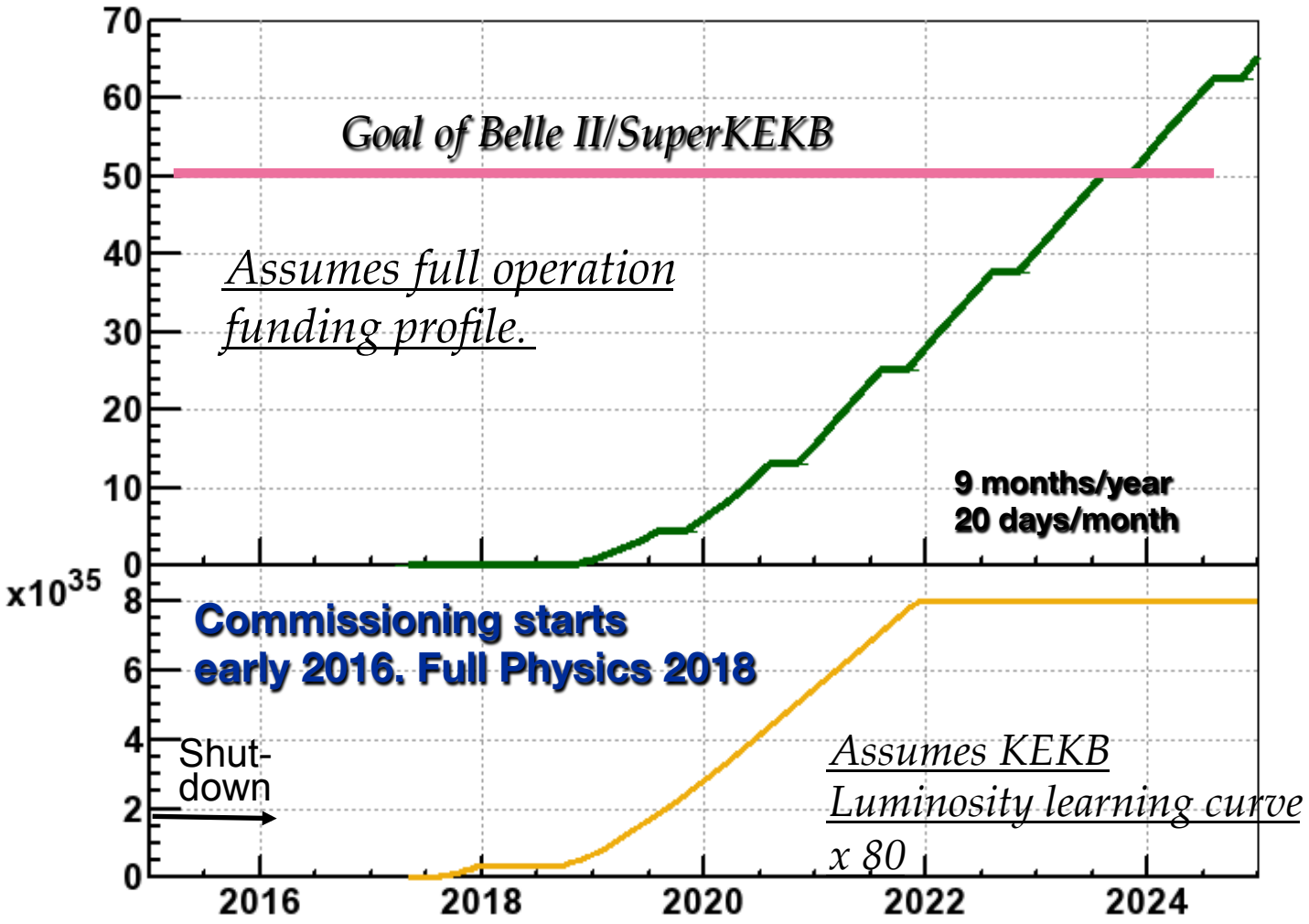
$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\left(\frac{R_L}{R_y}\right)$$

x 40 Gain in Luminosity

Crab waist

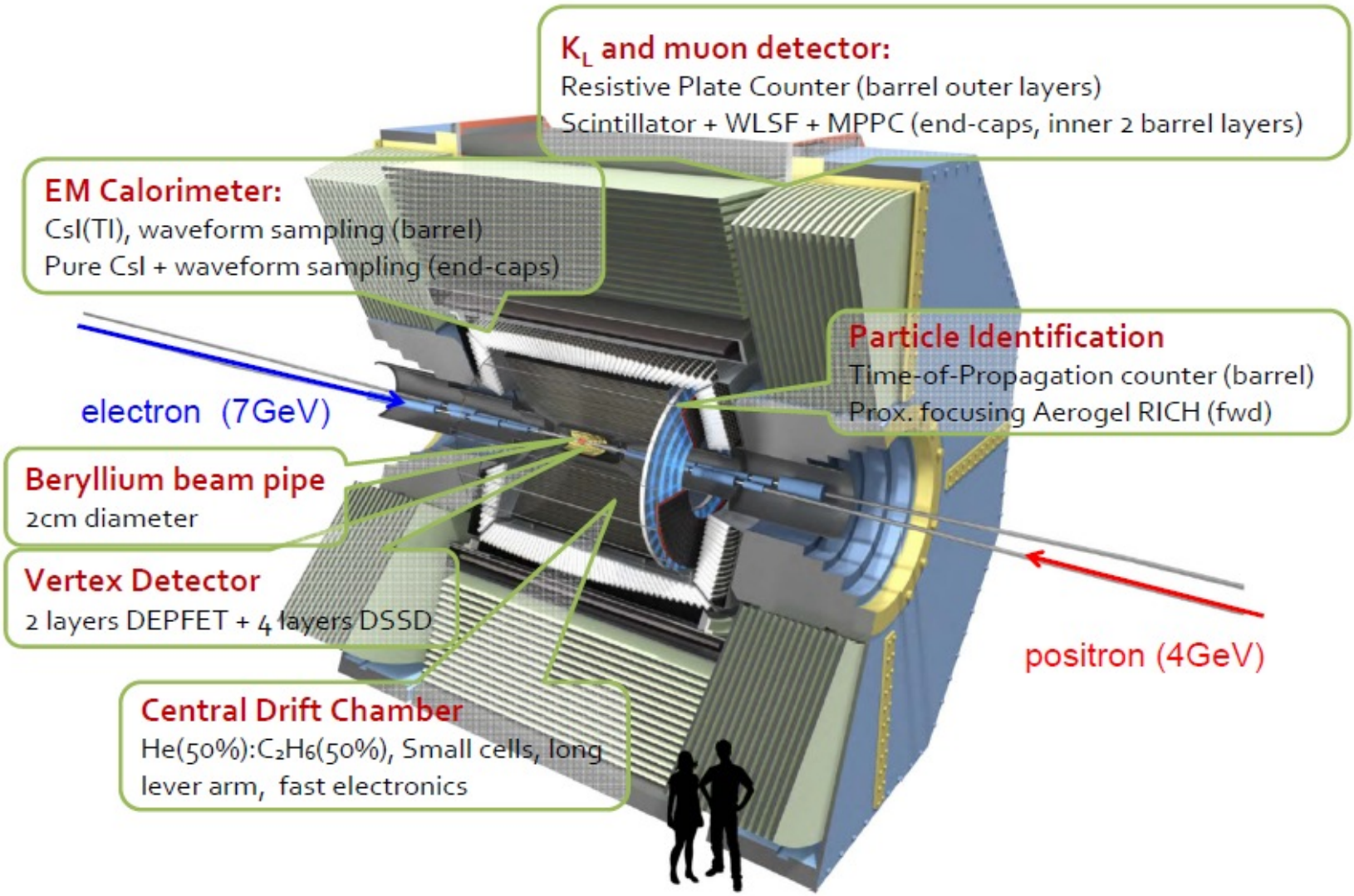

KEKB
22mrad
1μm
5mm
100μm
SuperKEKB
~50nm
1μm
5mm
100μm
83mrad

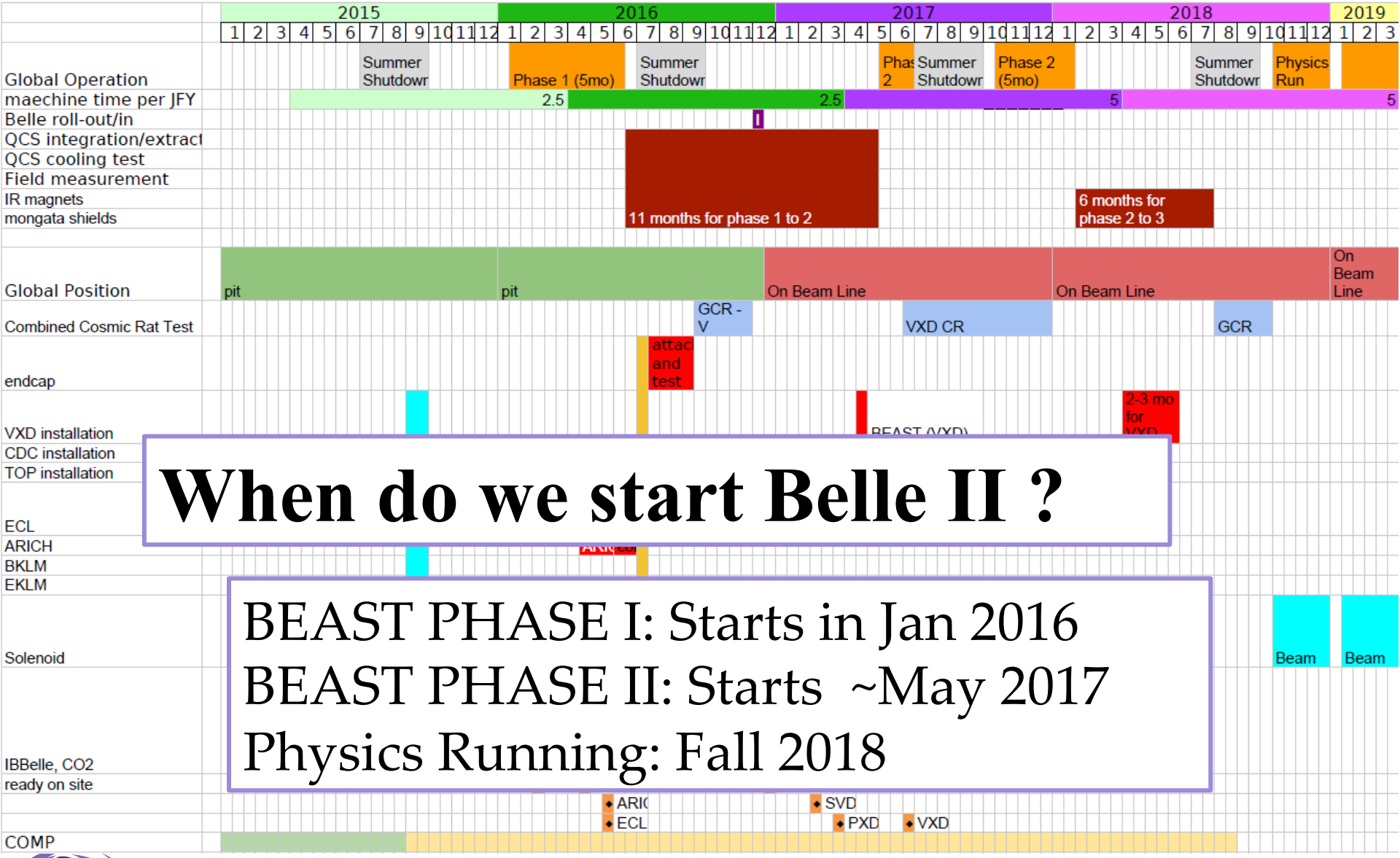
Projected luminosity



From Sakai @ LP2015

Belle II





When do we start Belle II ?

BEAST PHASE I: Starts in Jan 2016
BEAST PHASE II: Starts ~May 2017
Physics Running: Fall 2018

QCD for B

(Too) many examples:

- Perturbation theory (+OPE) for inclusive decays
  - $B \to (u,c) l \nu$, $B \to s(\gamma, ll)$, …
  - + shape function
- Decay constant, form factors
  - $B \to D^{(*)} l \nu$, $(\pi, \rho) l n$, $K^{(*)} ll$, …
  - + excited states

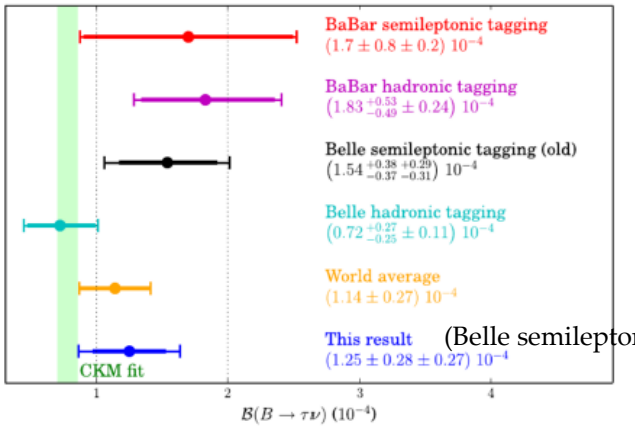
- Perturbation theory for exclusive decays
  - QCD Factorization: $B \to \pi\pi$, $K\pi$, $D\pi$, …
  - + light-cone distribution amplitude

Some examples…

Charged Higgs?

- Leptonic

$$\frac{B(B \to l\nu)}{B_{SM}(B \to l\nu)} = \left(1 - \frac{m_B^2}{m_{H^\pm}^2}\tan^2\beta\right)^2$$



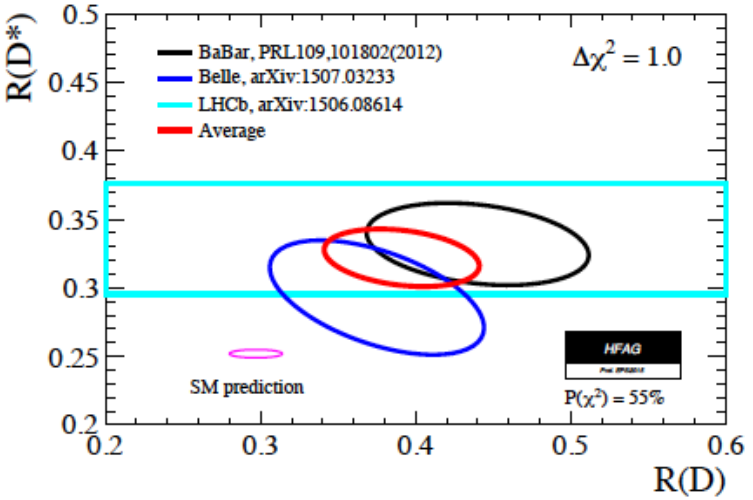
(Belle semileptonic tag)

➔ 3% at 50 ab^{-1}

- Semi-leptonic

$$A_{NP} \sim \frac{m_b m_\tau}{m_{H^\pm}^2}\tan^2\beta$$

$$R(D^{(*)}) = \frac{B(\bar{B} \to D^{(*)}\tau\nu)}{B(\bar{B} \to D^{(*)}l\nu)}$$



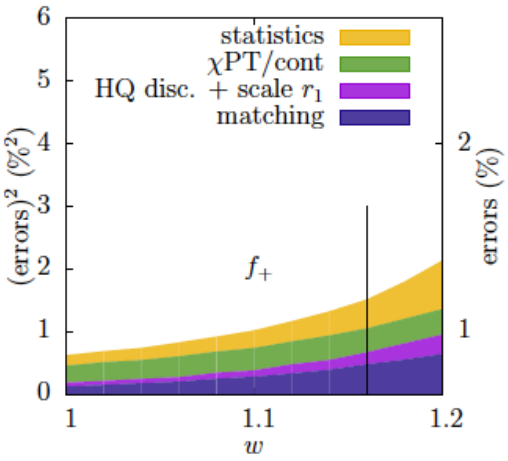
➔ 2.5% at 50 ab^{-1}

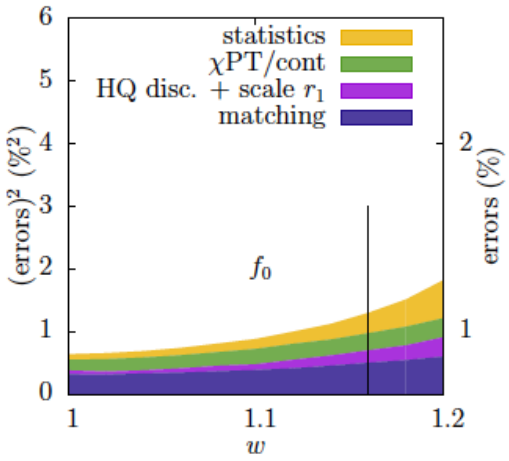
Charged Higgs?

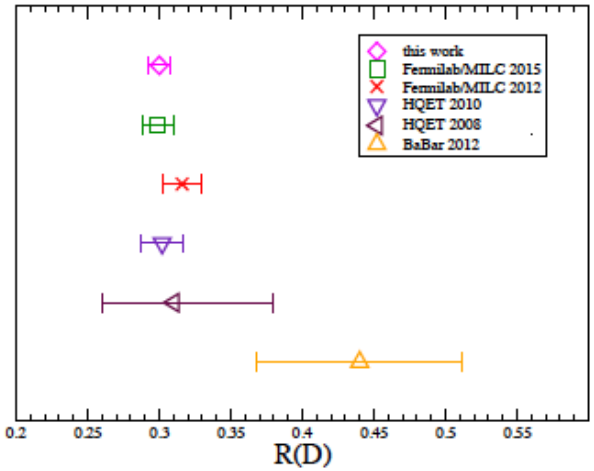
Matched lattice calc exists! B→D form factor

- Fermilab-MILC, PRD92, 034506 (2015), arXiv:1503.07237.
- HPQCD, PRD92, 054510 (2015), arXiv:1505. 03925.

Err (stat+syst) ~ O(1%)

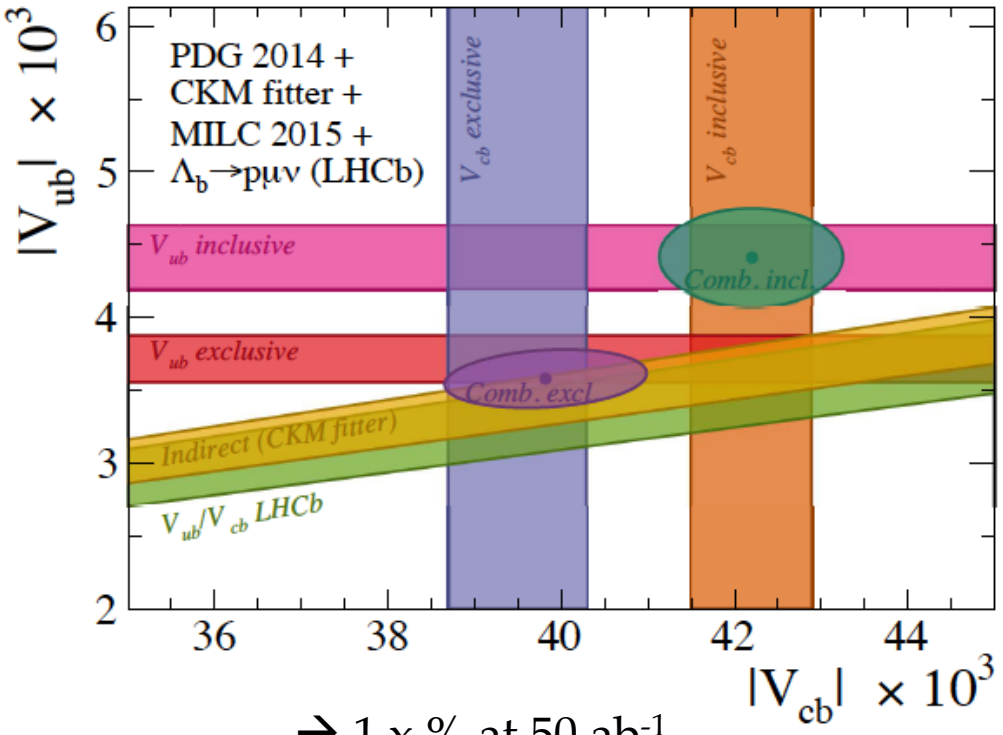






$|V_{cb}|$, $|V_{ub}|$ puzzle?

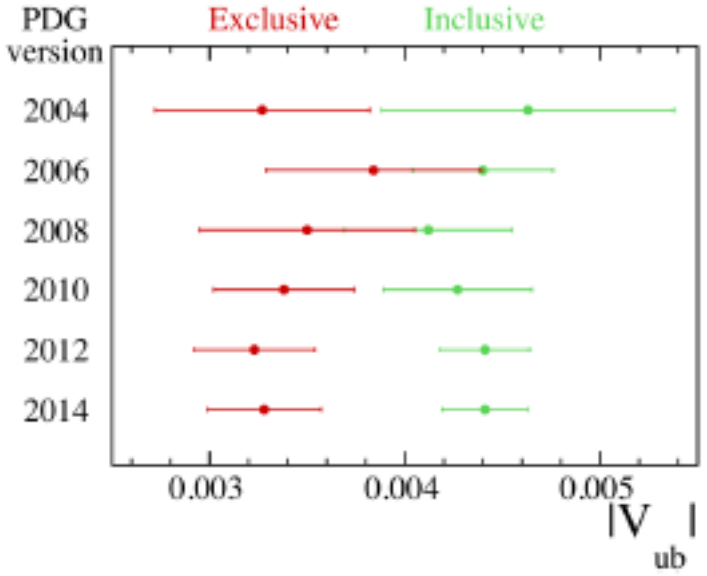
inclusive vs exclusive



→ 3% at 50 ab^{-1}

→ 1.x % at 50 ab^{-1}

Koppenburg @ EPS2015

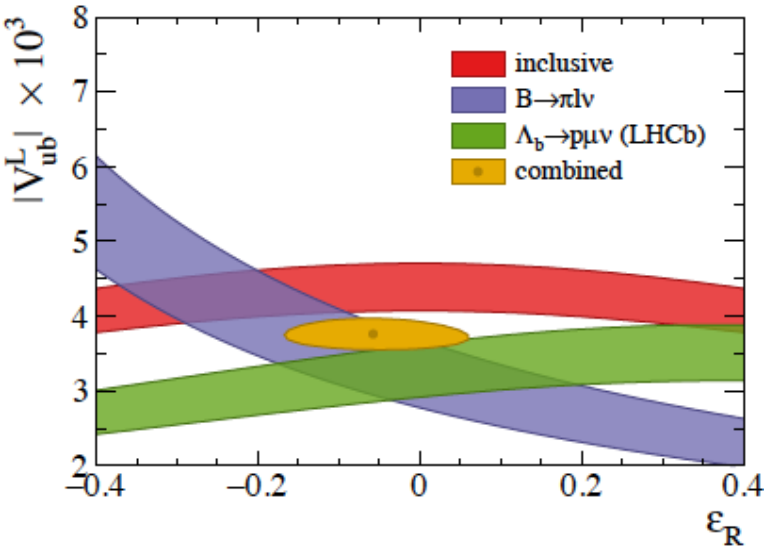


New Physics or
QCD problem?

$|V_{cb}|$, $|V_{ub}|$ puzzle?

New physics, such as right-handed current?

- Bernlochner, Ligeti, Turczyk, PRD85, 094033 (2012).



Not very successful, given Λ_b→plν.

$|V_{cb}|$, $|V_{ub}|$ puzzle?

Hadronic uncertainty?

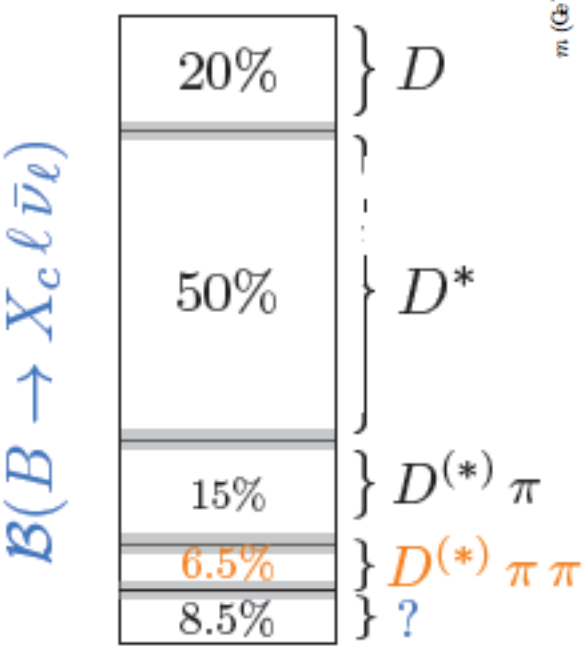
- Exclusive
  - Steady progress expected from lattice. 5%→3%→1%→…
  - But, for limited channels; B→ρlν remains challenging, for instance.
- Inclusive
  - Improvements by higher order calculations
  - But, problems remain, e.g.
  - Duality violation? b→c is dominated by D and D*
  - OPE convergence?
  - Shape function?

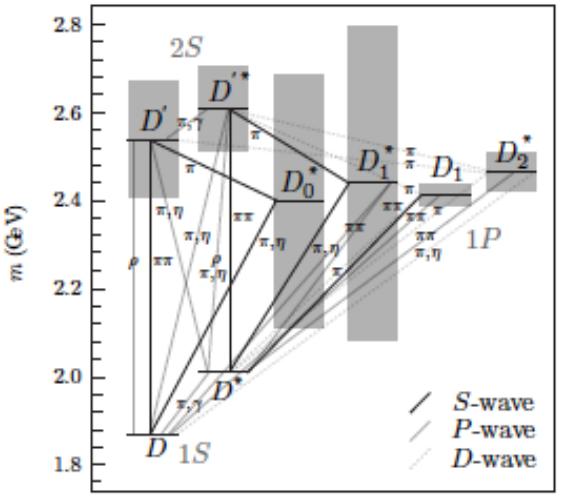
What can we (lattice) do to resolve the issue?

Form factors for excited states?

$$\text{incl} \stackrel{?}{=} \sum \text{excl}$$

Bernlochner @ CKM2014





1P and
2S states

1/2-3/2 Puzzle?

- Narrow state dominates the B→D** rates, in HQET.
- Not supported by Exp.

Challenge: reproduce
- spectrum, width
- B(B→D**)

of 1P states by lattice

c.f. Blossier @ CKM2014

B2TIP

- Belle II Theory Interface Platform

  https://belle2.cc.kek.jp/~twiki/bin/view/B2TiP

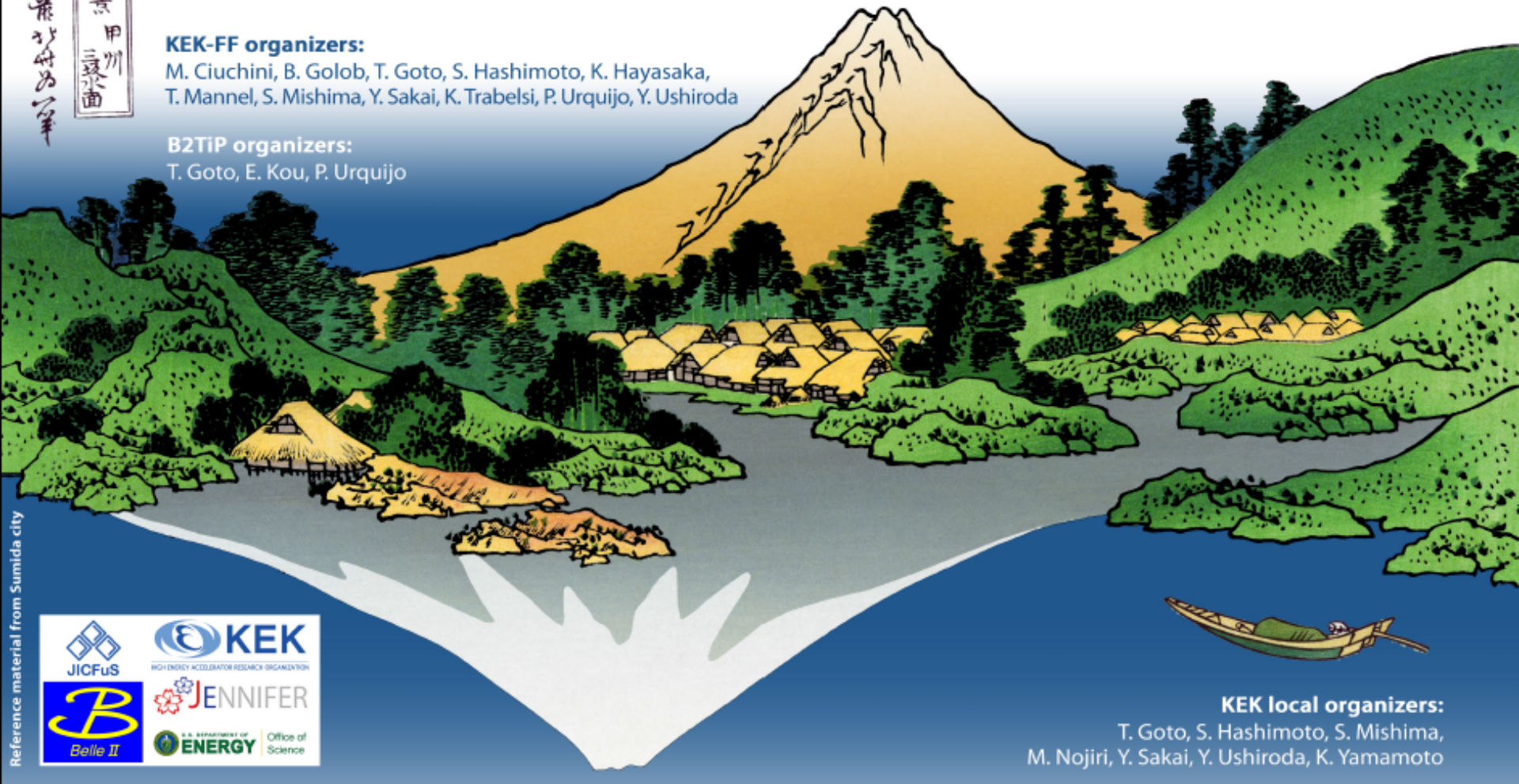
  - Initiative to coordinate a joint theory-experimental effort to study the potential impacts of the Belle II program.
  - Outcome = summary report of experimentally achievable precision and their impacts on SM and NP.

- WG1: Semileptonic & leptonic B decays
  - G. De Nardo (Naples), A. Zupanc (IJS Slovenia), M. Tanaka (Osaka), F. Tackmann (DESY), A. Kronfeld (Fermilab)
- WG2: Radiative and electroweak penguins
  - A. Ishikawa (Tohoku), J. Yamaoka (PNNL), U. Haisch (Oxford), T. Feldman (Siegen)
- WG3: phi2 and phi1
  - T. Higuchi (IPMU), L. Li Gioi (MPI Munich), J. Zupan (Cincinnati), S. Mishima (Rome)
- WG4: phi3
  - J. Libby (Madras), Y. Grossman (Cornell), M. Blanke (CERN)
- WG5: Charmless, hadronic B decays
  - P. Goldenzweig (KIT), M. Beneke (TUM), C.W. Chiang (NCU), S. Sharpe (Washington)
- WG6: Charm
  - G. Casarosa (Pisa), A. Schwartz (Cincinnati), A. Petrov (Wayne), A. Kagan (Cincinnati)
- WG7: Quarkonium(like)
  - R. Mizuk (ITEP), R. Mussa (Torino), C. Shen (Beihang), Y. Kiyo (Juntendo), A. Polosa (Rome), S. Prelovsek (Ljublijana)
- WG8: Tau, low multiplicity & EW
  - K. Hayasaka (Nagoya), H. Nakazawa (NCU), E. Passemar (Los Alamos), J. Hisano (Nagoya)
- WG9: New Physics
  - R. Itoh (KEK), F. Bernlochner (Bonn), U. Nierste (KIT), L. Silvestrini (Rome), J. Kamenik (IJS Ljubljana), V. Lubicz (Rome3)
- Lattice QCD board:
  - Secretary: T. Kaneko (KEK)

The 5th KEK Flavor Factory Workshop / The 3rd Belle II Theory Interface Platform Workshop

KEK-FF and B2TiP workshops

KEK-FF: 26-27th October 2015 (Waterras Common, Tokyo, Japan) / **B2TiP: 28-29th October 2015** (KEK, Tsukuba, Japan)



KEK-FF organizers:
M. Ciuchini, B. Golob, T. Goto, S. Hashimoto, K. Hayasaka, T. Mannel, S. Mishima, Y. Sakai, K. Trabelsi, P. Urquijo, Y. Ushiroda

B2TiP organizers:
T. Goto, E. Kou, P. Urquijo

Reference material from Sumida city

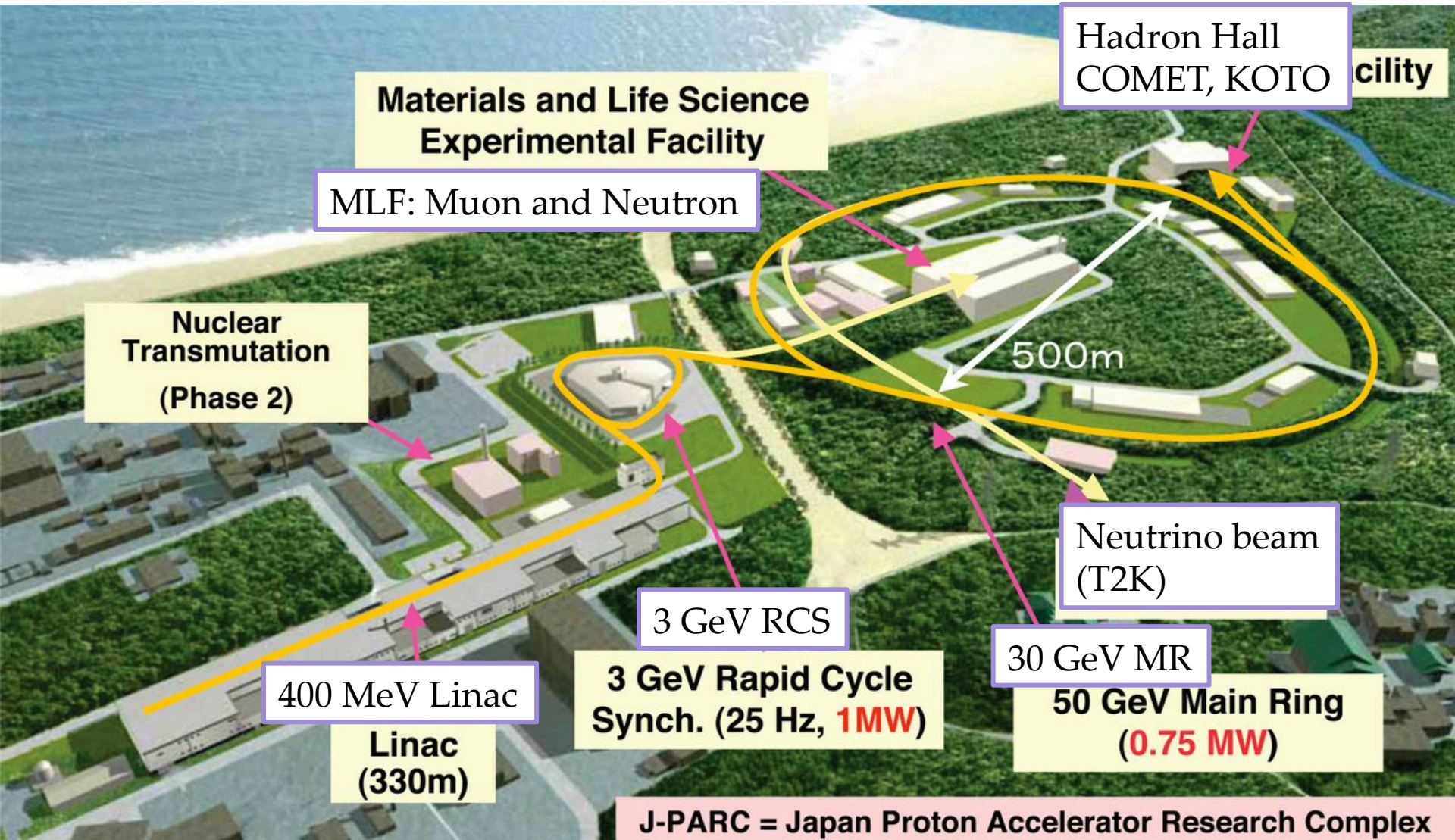
JICFuS Belle II KEK JENNIFER U.S. DEPARTMENT OF ENERGY Office of Science

KEK local organizers:
T. Goto, S. Hashimoto, S. Mishima, M. Nojiri, Y. Sakai, Y. Ushiroda, K. Yamamoto

https://kds.kek.jp/indico/event/19103/

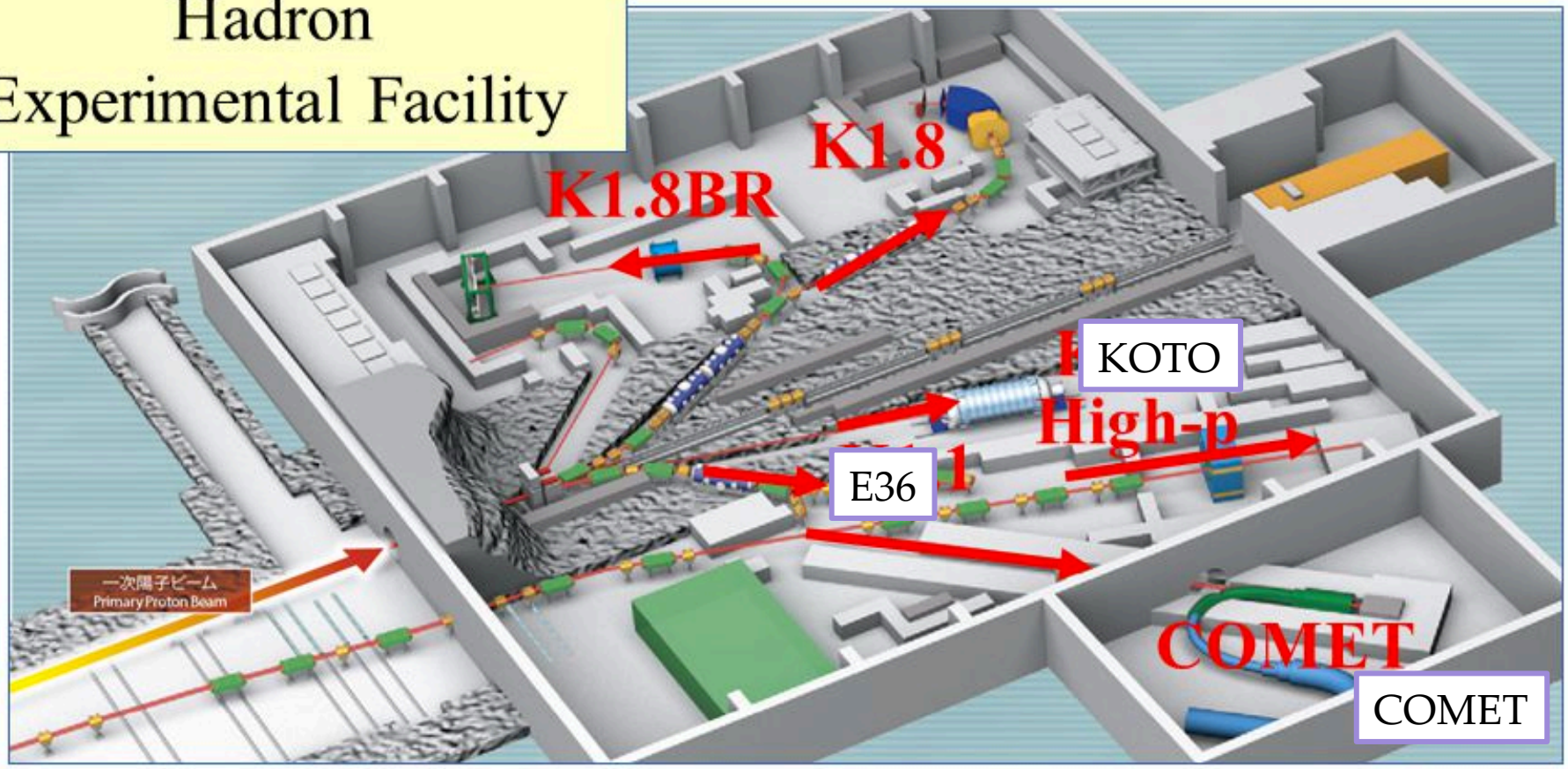
J-PARC

J-PARC overview



From K. Ozawa

Hadron Experimental Facility



Name	Species	Energy	Intensity	
K1.8	$\pi^{\pm}$, $K^{\pm}$	< 2.0 GeV/c	~10^5 Hz for K^+	
K1.8BR	$\pi^{\pm}$, $K^{\pm}$	< 1.0 GeV/c	~ 10^4 Hz for K^+	
K1.1	$\pi^{\pm}$, $K^{\pm}$	< 1.1 GeV/c	~ 10^4 Hz for K^+	
High-p	proton	30GeV	~ 10^{10} Hz	Under Construction
	Unseparated	< 20GeV/c	~ 10^8 Hz	

E36 (Lepton universality)

- Lepton universality test with K_{l2} $\Gamma(K_{l2}) = g_l^2 \frac{G^2}{8\pi} f_K^2 m_K m_l^2 \left(1 - \frac{m_l^2}{m_K^2}\right)^2$

$$R_K^{SM} = \frac{\Gamma(K^+ \to e^+\nu)}{\Gamma(K^+ \to \mu^+\nu)} = \frac{m_e^2}{m_\mu^2}\left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 (1+\delta_r)$$

helicity suppression

radiative correction (Internal Brems.)

SM $R_K^{SM} = (2.477 \pm 0.001) \times 10^{-5}$ (with $\delta_r = -0.036$); $\delta R_K/R_K = 0.04\%$

V. Cirigliano, I. Rosell, Phys. Rev. Lett. 99, 231801 (2007)

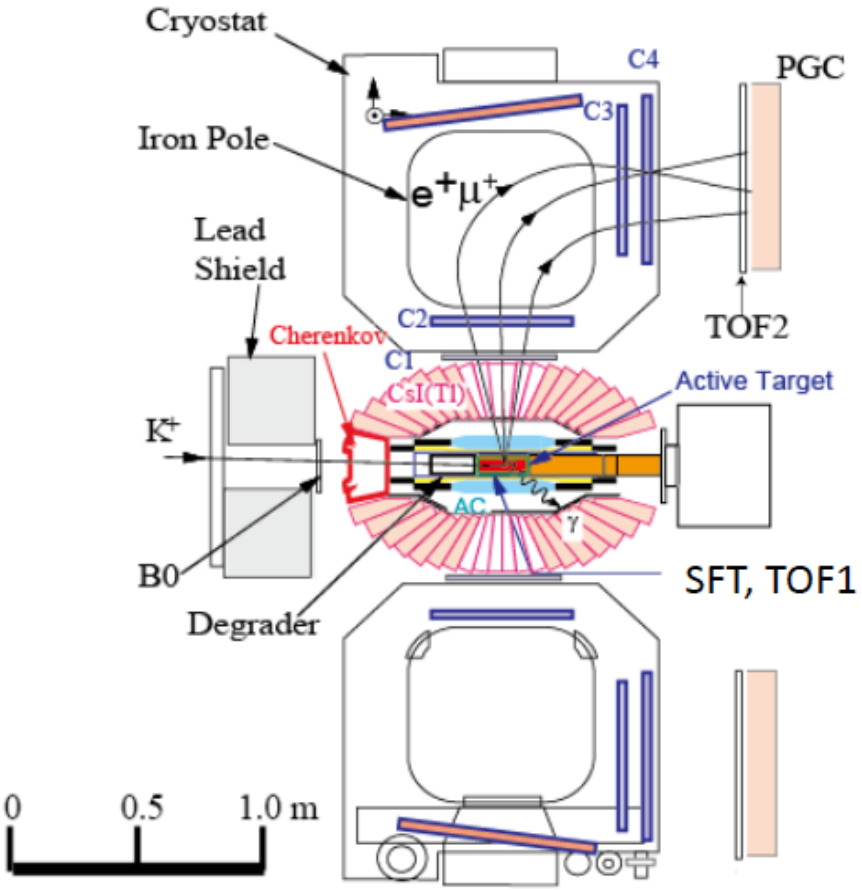
- Experimental status
  - KLOE @ DAΦNE (2009), NA62 @ CERN (2012)

WA $R_K = (2.488 \pm 0.009) \times 10^{-5}$, $\delta R_K/R_K = 0.4\%$

  - E36 goal: ± 0.2% (stat) ± 0.15% (syst) [0.25% total]

E36 (Lepton universality)

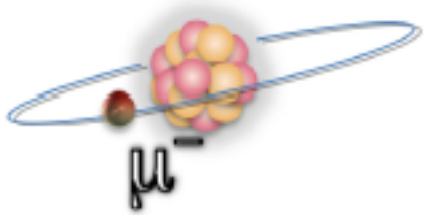
- Detector from KEK-PS E246
  - stopped kaon
  - μ/e id with TOF, Aerogel Cherenkov, Lead glass; miss id probability ~ 10^{-6}.
- Run
  - commissioning run: Apr-Jun 2015.
  - physics run: FALL 2015
  - (moved after that, for the construction of COMET)



QCD issues?

- SM calculation is already sufficiently precise…

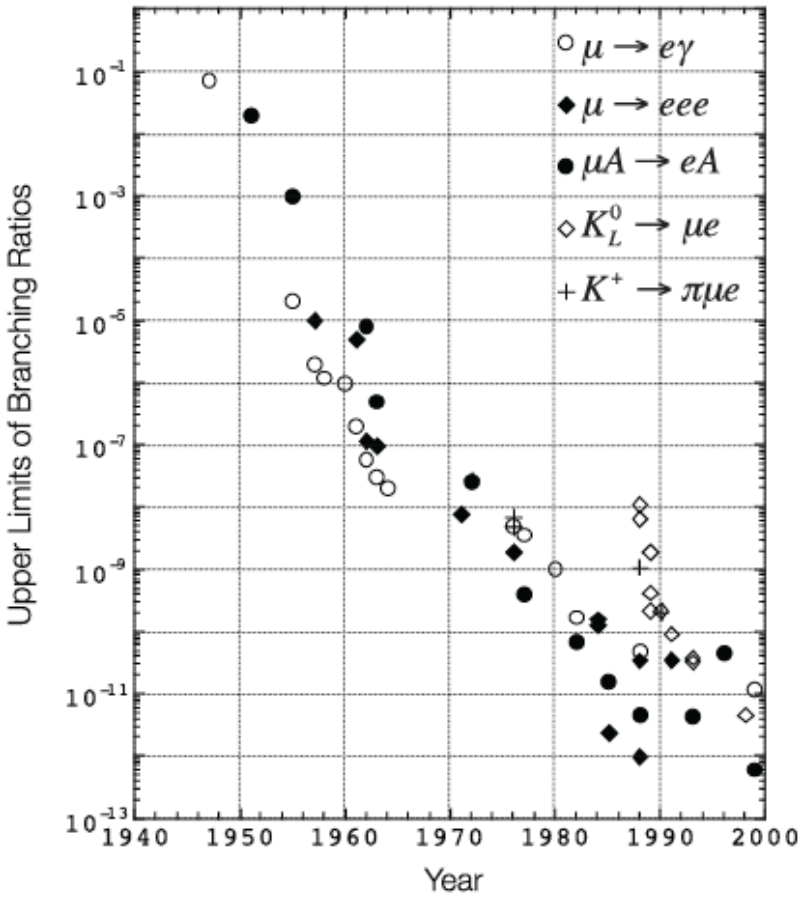
E21 COMET



- μ-e conversion $\mu N \rightarrow eN$
  - Charged Lepton Flavor Violation (CLFV)
  - Standard model expectation through neutrino mixing is too small to observe.

- Experimental limit
  - SINDRUM II @ PSI: Br < 7 x 10^{-13}
  - COMET goal:

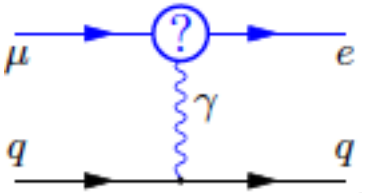
    Phase I Br ~ 7 x 10^{-15},
    Phase II Br ~ 6 x 10^{-17}



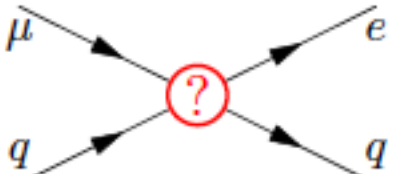
E21 COMET

- μ-e conversion $\mu N \rightarrow eN$

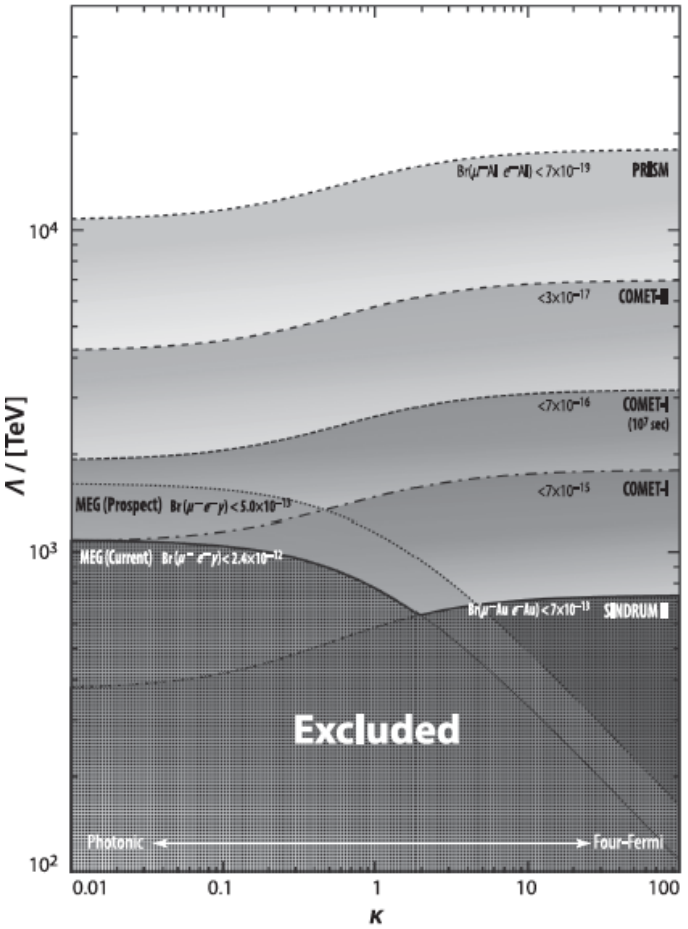
$$L_{CLFV} = \frac{1}{1+\kappa}\frac{m_\mu}{\Lambda^2}\bar{\mu}_R \sigma^{\mu\nu} e_L F_{\mu\nu}$$



$$+\frac{\kappa}{1+\kappa}\frac{1}{\Lambda^2}(\bar{\mu}_L\gamma^\mu e_L)(\bar{q}_L\gamma_\mu q_L)$$

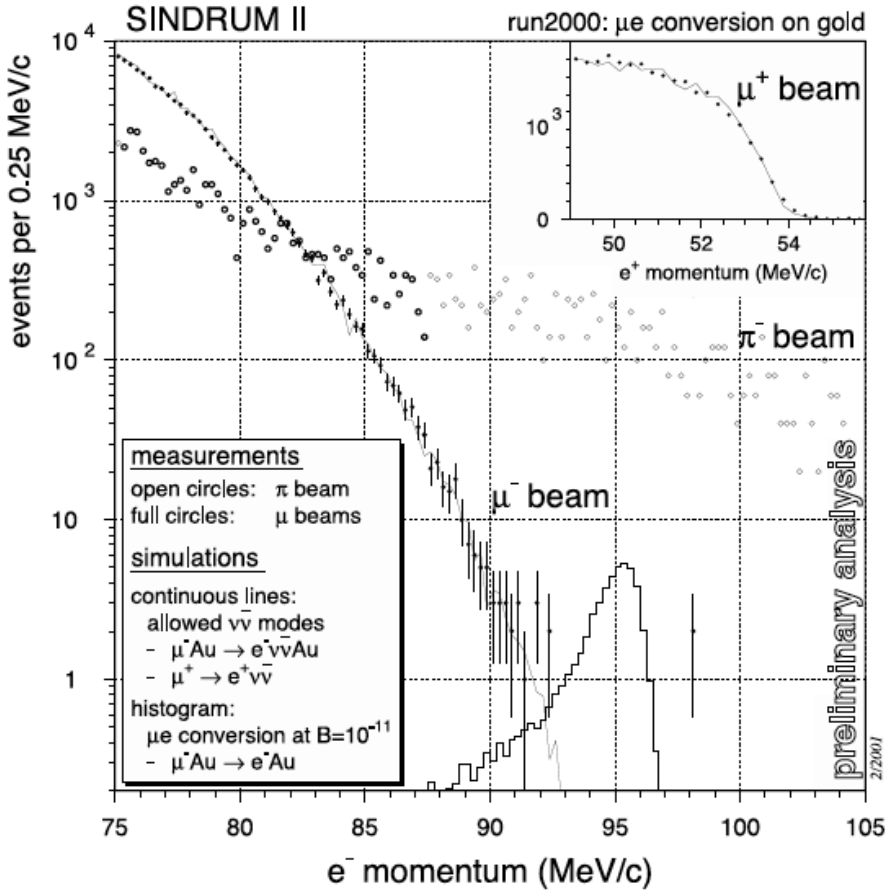


Kuno, PTEP 2013, 022C01



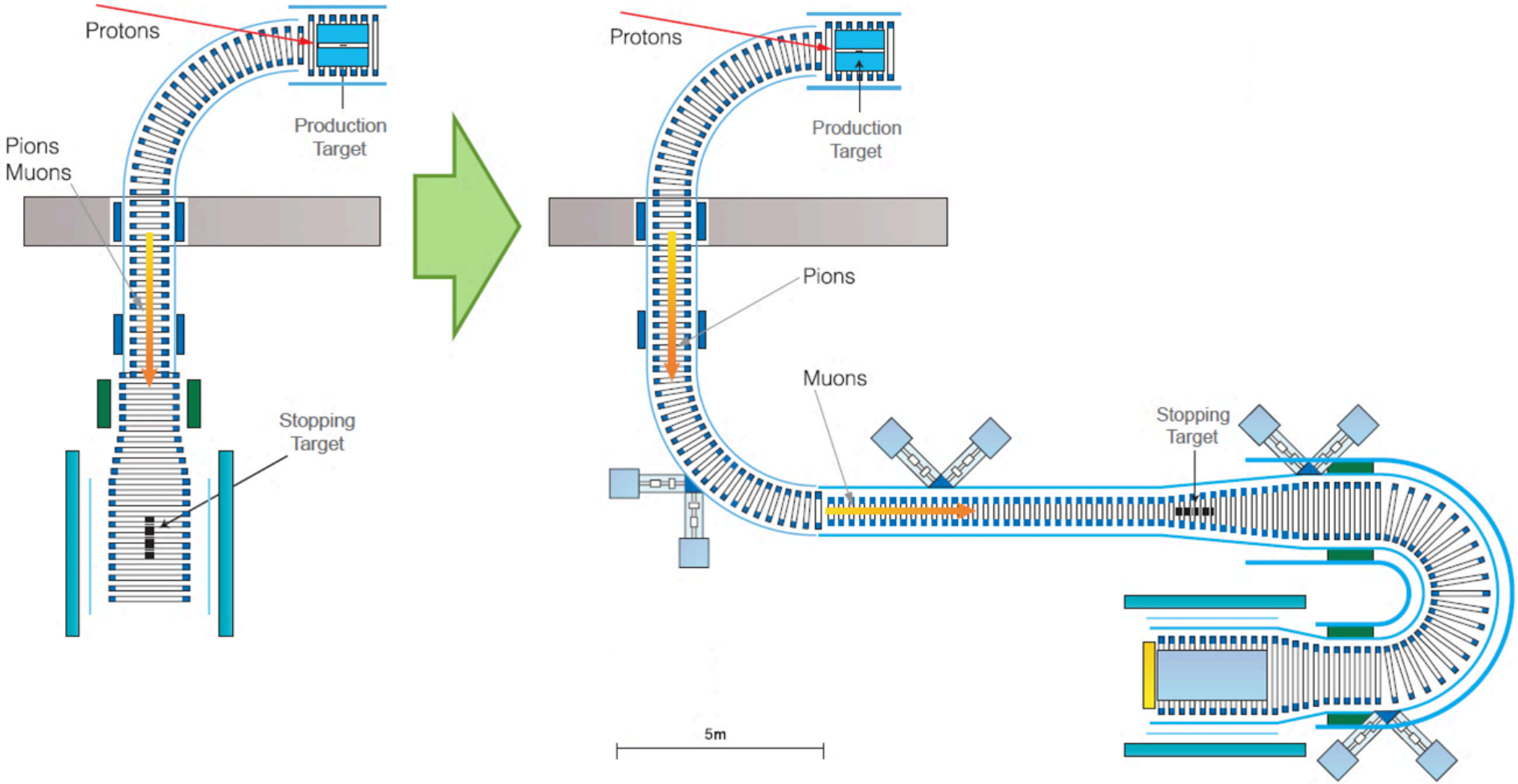
E21 COMET

- μ-e conversion $\mu N \rightarrow eN$
- Signal: single e^- of energy $m_\mu - B_\mu$
- Background:
  - μ decay in orbit: less energy
  - μ decay in flight: suppressed if muon momentum is low.
  - pion capture: suppressed by long transport
  - pulsed beam suppresses prompt backgrounds

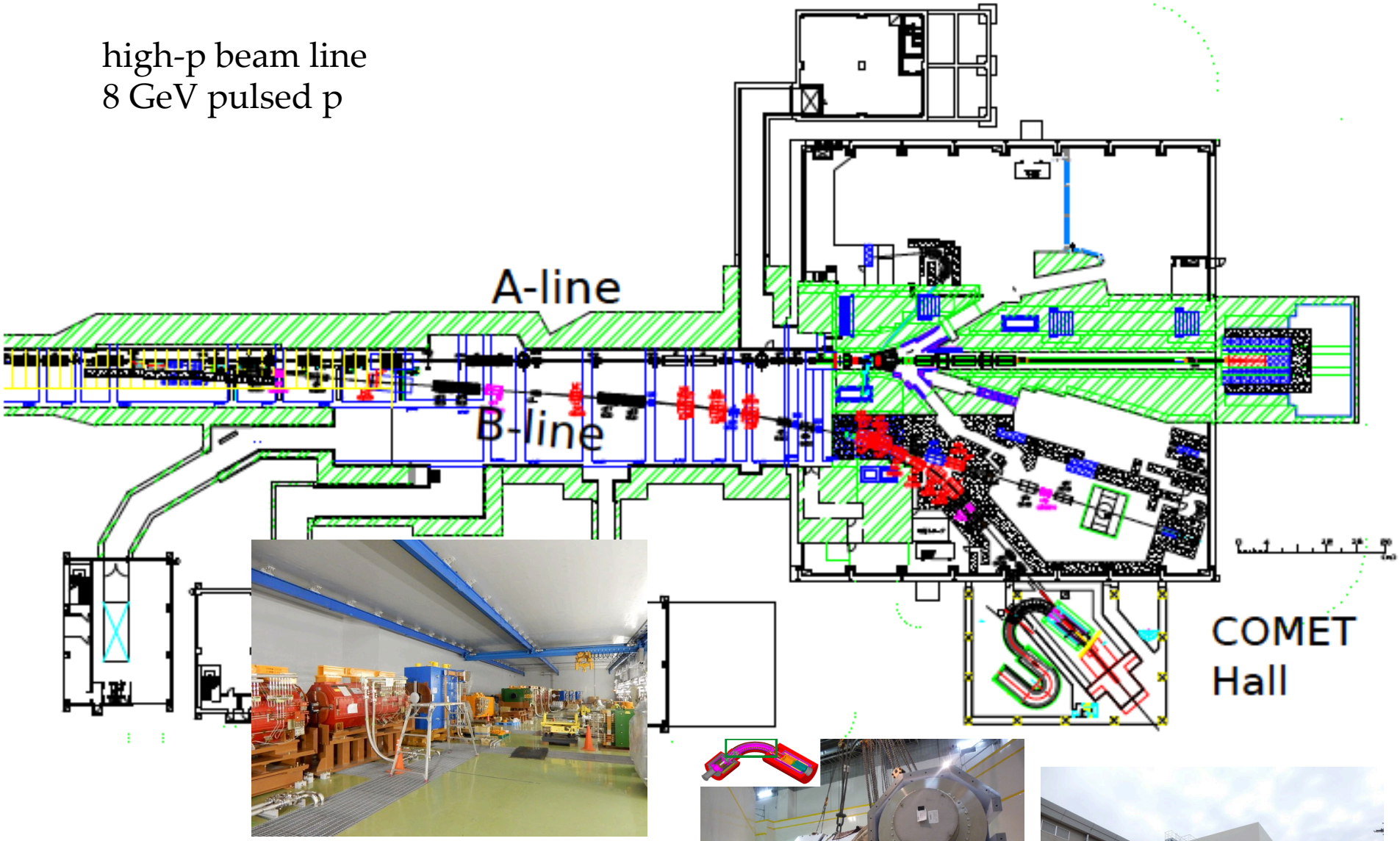


Phase I

Phase II



high-p beam line
8 GeV pulsed p



Completion of the
construction in 2019

QCD issues?

- Spatial distribution of proton/neutron in nuclei.
  - Affects the overlap integral of the muon wave-function. Leads to O(10%) uncertainty in μ-e conversion rate.

Kitano, Koike, Okada, PRD66, 096002 (2002).

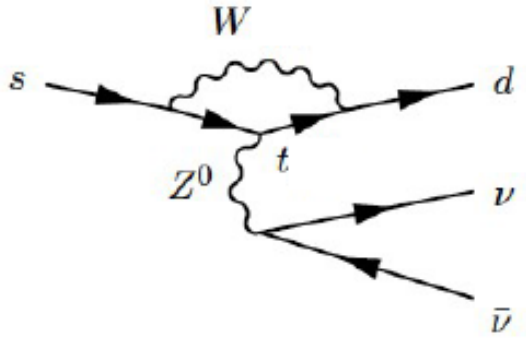
- πN σ term & strange quark content of nucleon
  - "Higgs" mediating models induces the scalar operator.

Cirigliano, Kitano, Okada, Tuzon, PRD80, 013002 (2009).

Once observed, these will become one of main issues.

E14 KOTO

- Measurement of $K_L \to \pi^0 \nu\bar{\nu}$
  - FCNC through penguin
  - SM very small BR ~ 3 x 10^{-11} (small theoretical uncertainty ~ 2%)



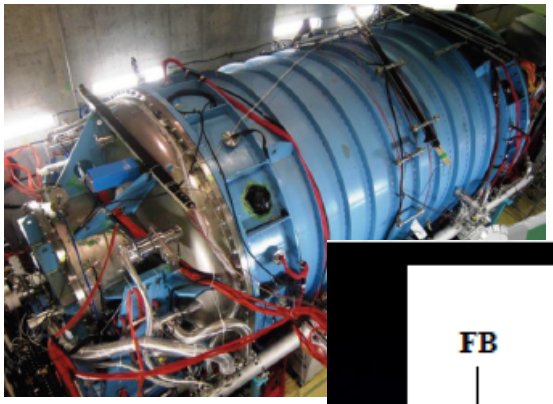
CP-violating process $\mathcal{A}(K_L) \propto \mathcal{A}(K^0) - \mathcal{A}(\overline{K_0}) \propto \mathrm{Im}(\mathcal{A}_{s\to d})$

Related to charged mode $K^+ \to \pi^+\nu\nu$ $\mathcal{A}(K^+) \propto |\mathcal{A}_{s\to d}|$

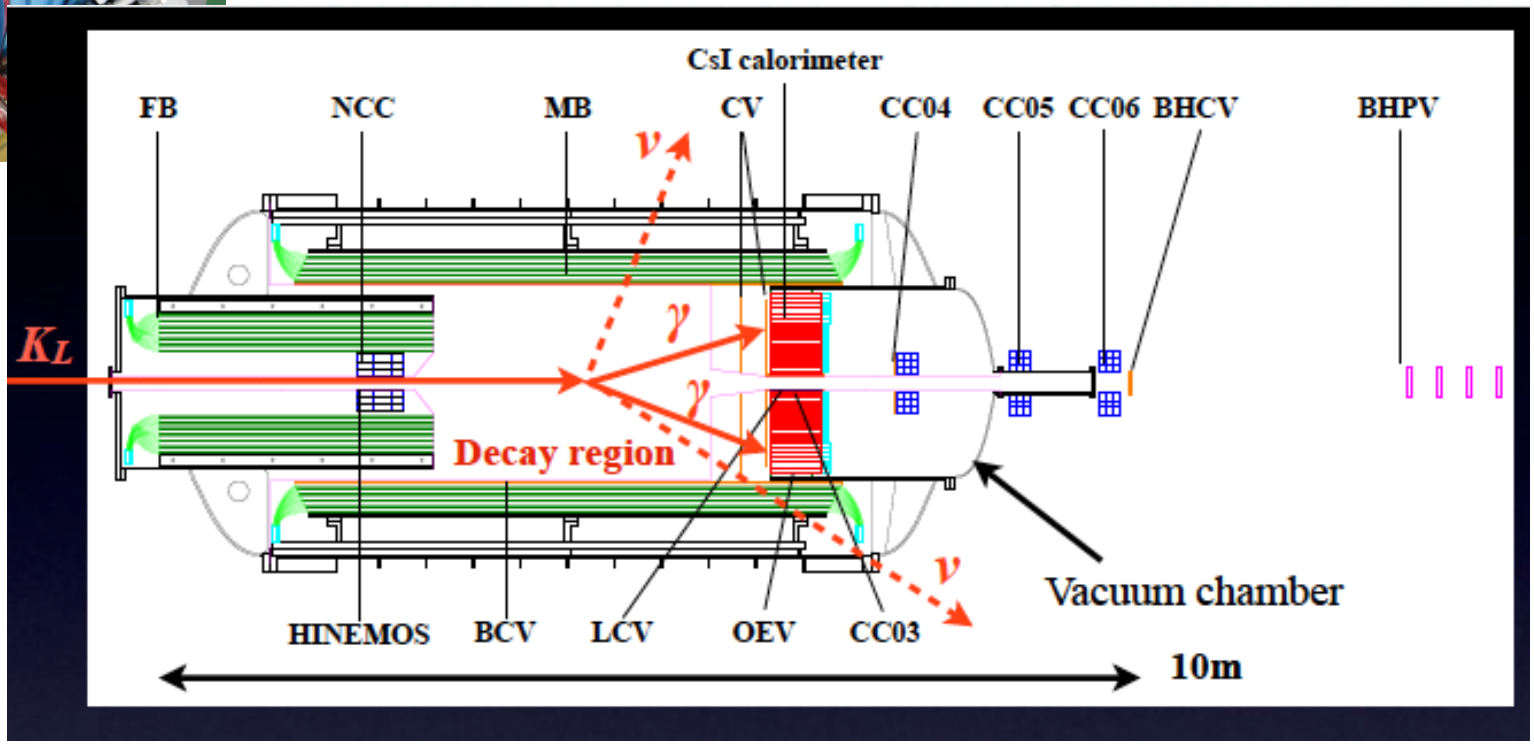
- Grossman-Nir bound :

$$Br(K_L) < 4.4 \times Br(K^+) \to 1.5 \times 10^{-9} (90\% C.L.)$$

E14 KOTO

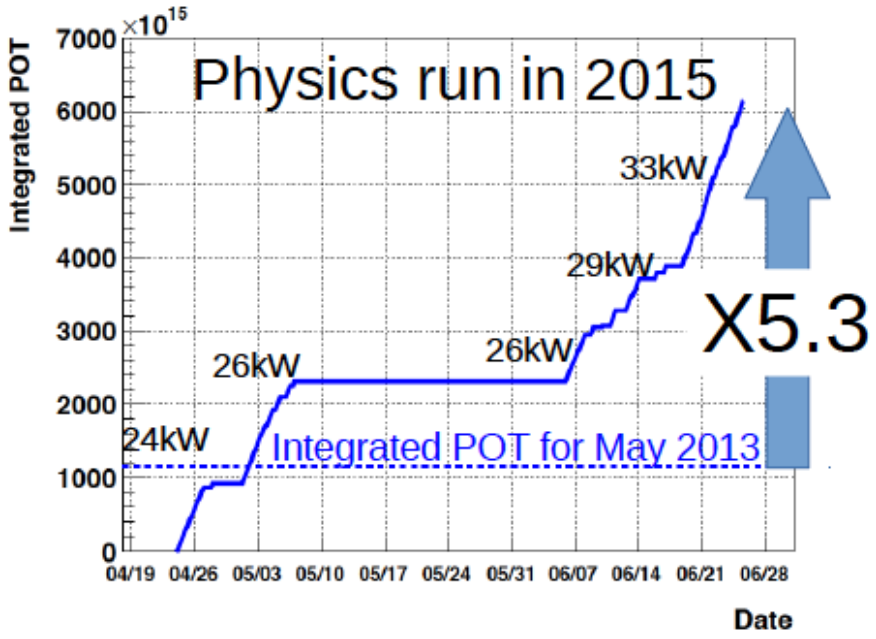


signal: $\pi^0 \rightarrow 2\gamma$ + nothing



E14 KOTO

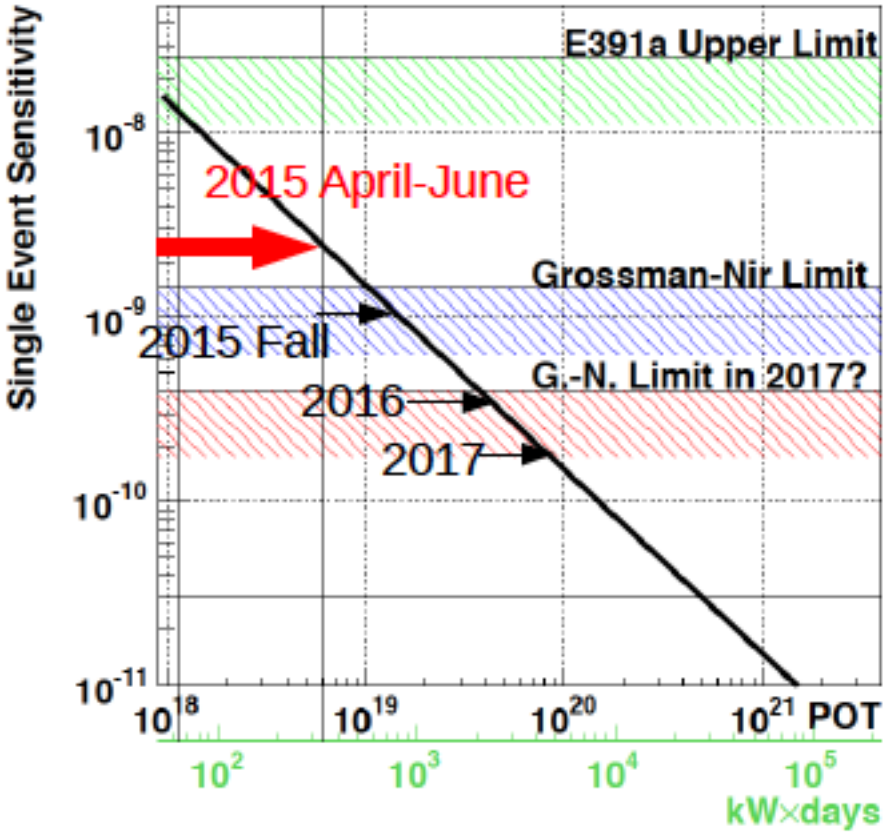
- First physics run in 2013:
  - sensitivity 1.29 x 10^{-8}
  - reached E391a sensitivity with only 100 hrs.
- Physics run in 2015:
  - x5 more data taken
- Backgrounds:
  - $K_L \rightarrow \pi^0\pi^0$ and one missing into the beam pipe
  - halo neutron hitting calorimeter twice.

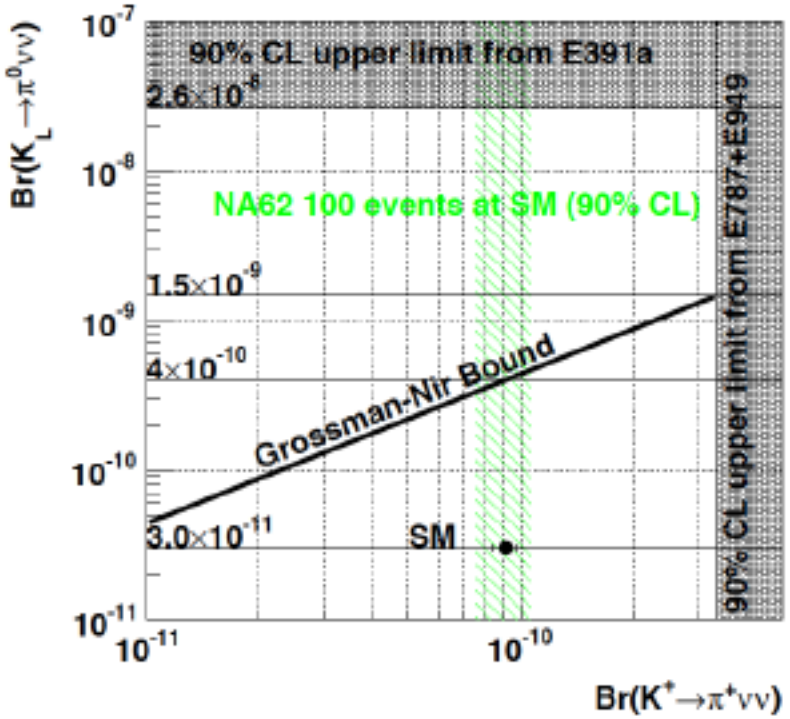


Improvements by
- adding downstream detectors
- upstream collimeters

E14 KOTO

Projection:



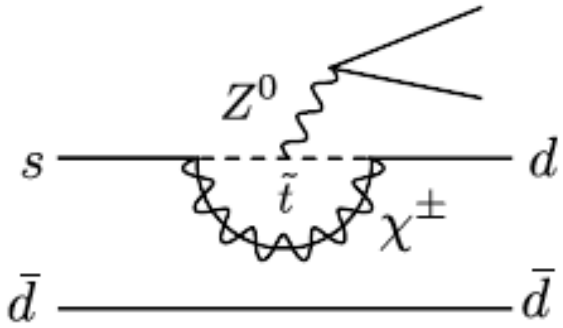


NA62 ~100 events from 2015-17

QCD issue?

- Very small theoretical uncertainty for $K_L \to \pi^0 \nu\nu$
- Expected new physics contribution?

Electroweak penguin, such as



M. Endo's talk @ JPS 2015
(Yamamoto, Tanimoto, to appear)

- νν: enhanced signal of $K_L \to \pi^0 \nu\nu$
- qq: deviation of ε′/ε from SM?

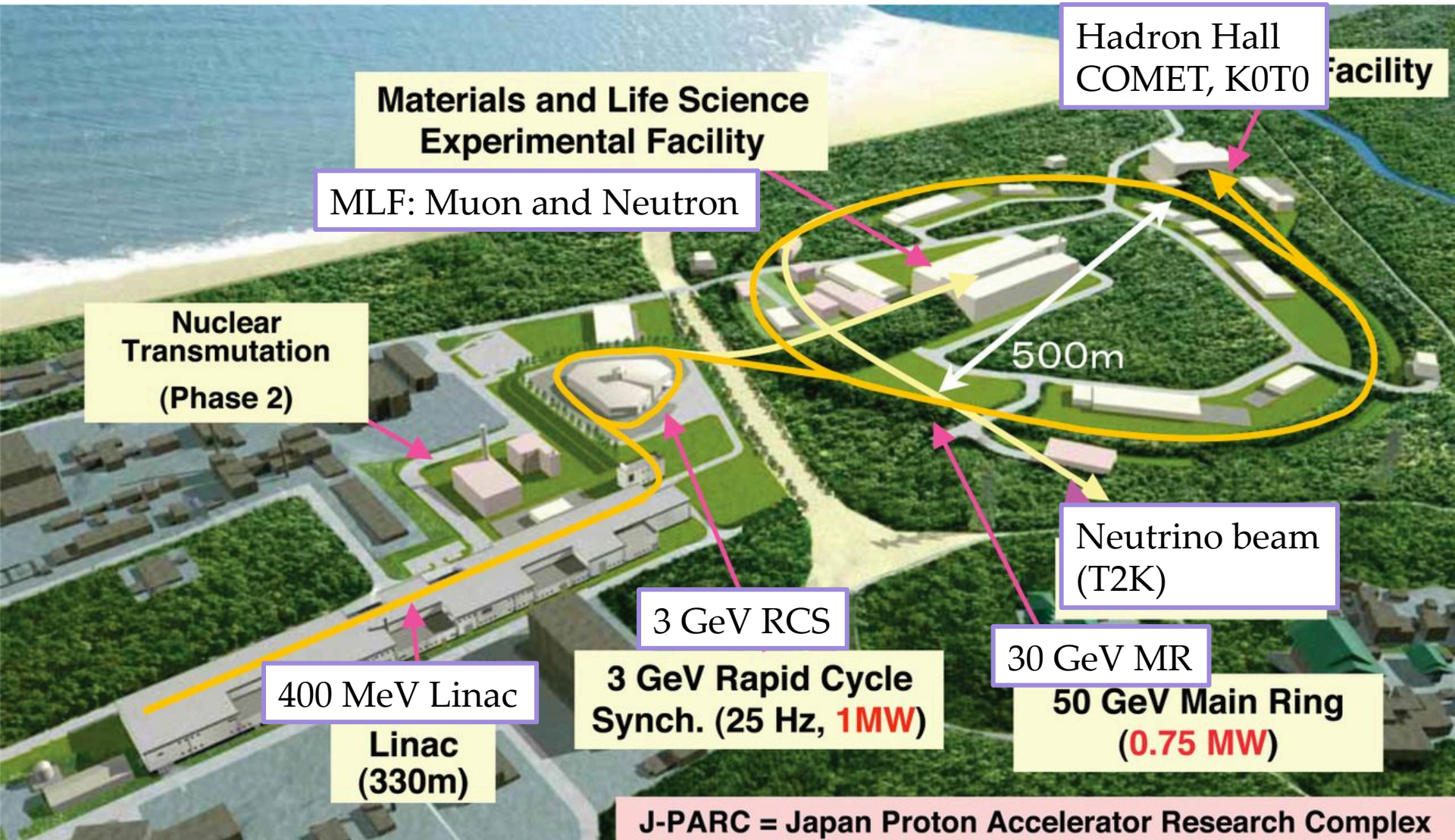
$$(\varepsilon'/\varepsilon)_{\rm exp} = (16.6 \pm 2.3) \times 10^{-4}$$

$$(\varepsilon'/\varepsilon)_{\rm SM} = (1.4 \pm 7.0) \times 10^{-4} \quad \text{[RBC-UKQCD'15]}$$

$$(\varepsilon'/\varepsilon)_{\rm SM} = (2.2 \pm 3.7) \times 10^{-4} \quad \text{[Buras et.al'15]}$$

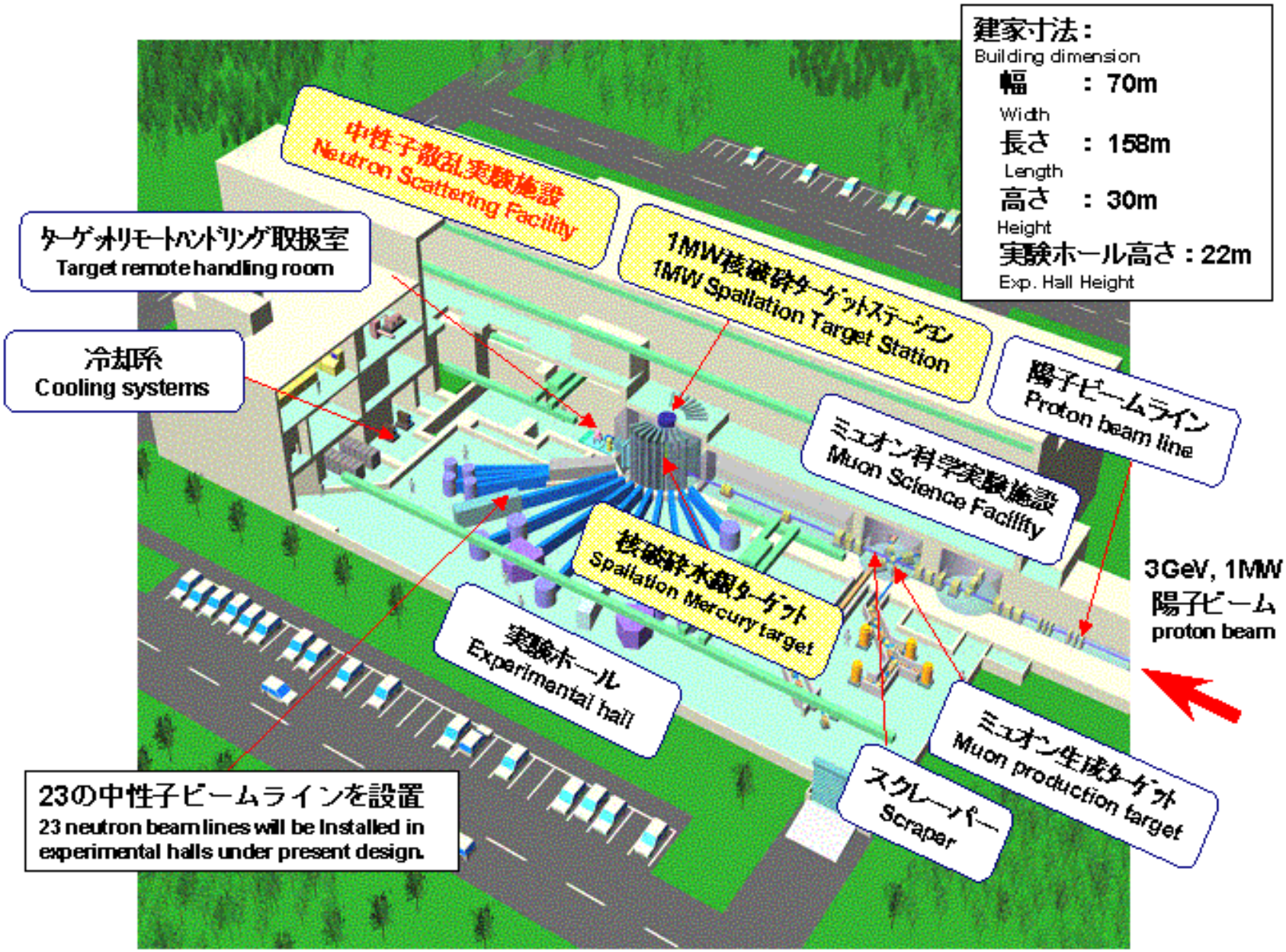
3.5 σ: real?

J-PARC overview



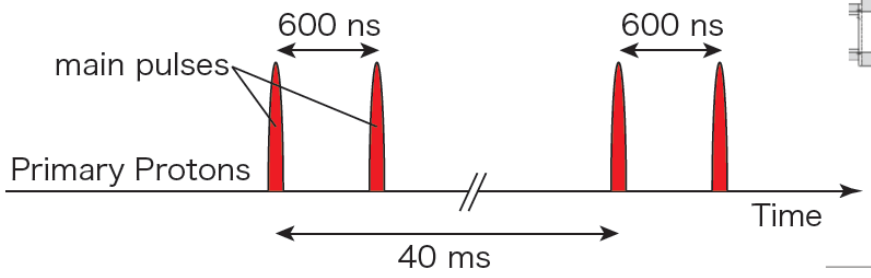
物質・生命科学実験施設 （中性子散乱 / ミュオン科学 実験施設）

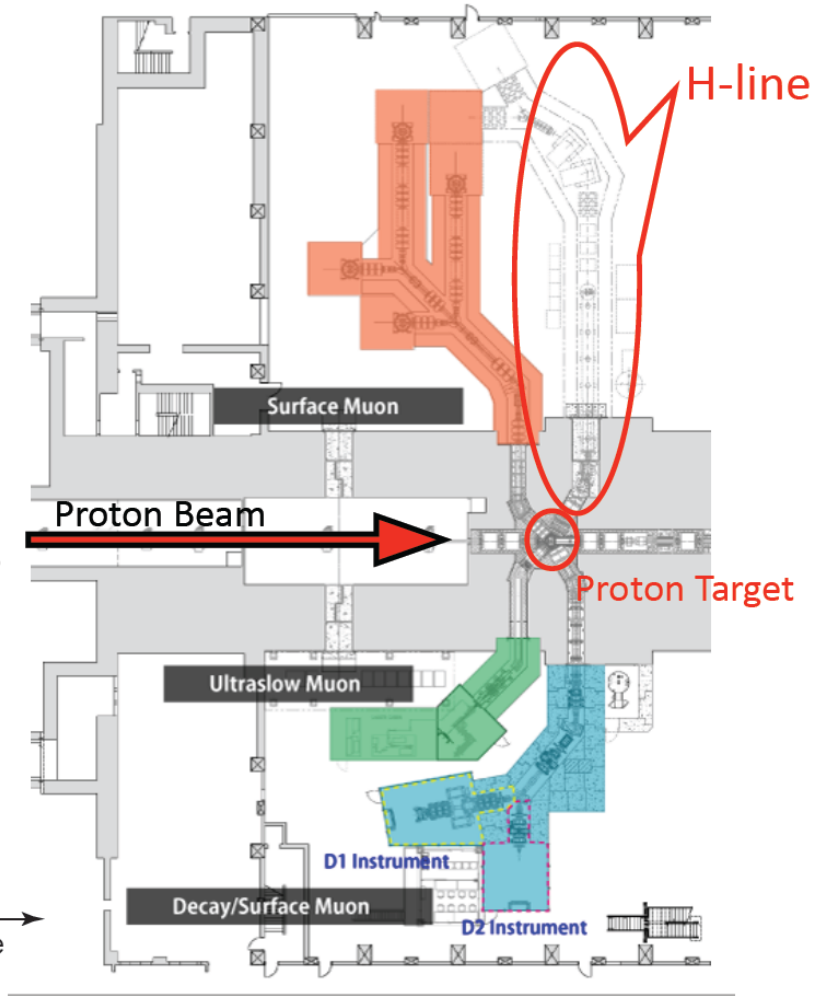
Material and Life Science Experimental Facility *Neutron Scattering / Muon Science Facility*



J-PARC MLF Muon Facility

- 1 MW : 3 GeV, 333 μA
  - High statistics
- Fast-Extracted Pulse Beam: 25 Hz 50 pulses
  - Extremely small after-protons





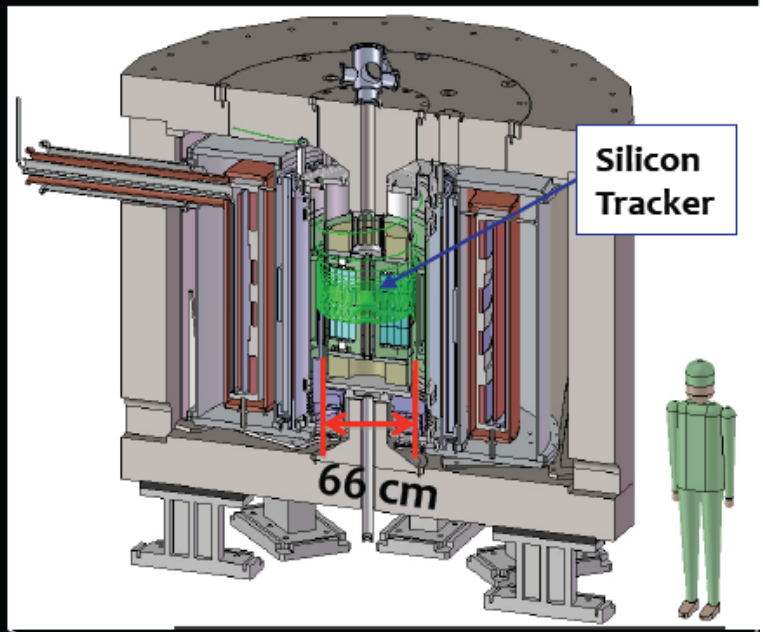
E34 (μ g-2/EDM)

- ~~Magic momentum~~, No E field $a_\mu = \frac{g_\mu - 2}{2}, \quad \vec{\mu} = g\frac{e}{2m}\vec{s}, \quad \vec{d} = \eta\frac{e}{mc}\vec{s}$

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

  - a_μ from precise measurement of ω and B
  - η from top-bottom asymmetry
- Storage ring without focusing E field
  = Need super-low emittance muon beam ($P_T/P_L < 10^{-5}$)
- Precise uniform B field (< 0.1 ppm)
  = Technology from MRI

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



3 GeV proton beam
(333 uA)

SiC target
(20 mm)

Surface muon beam
(28 MeV/c, 3x10^8/s)

Muonium Production
(300 K ~ 25 meV⇒2.3 keV/c)

Surface muon

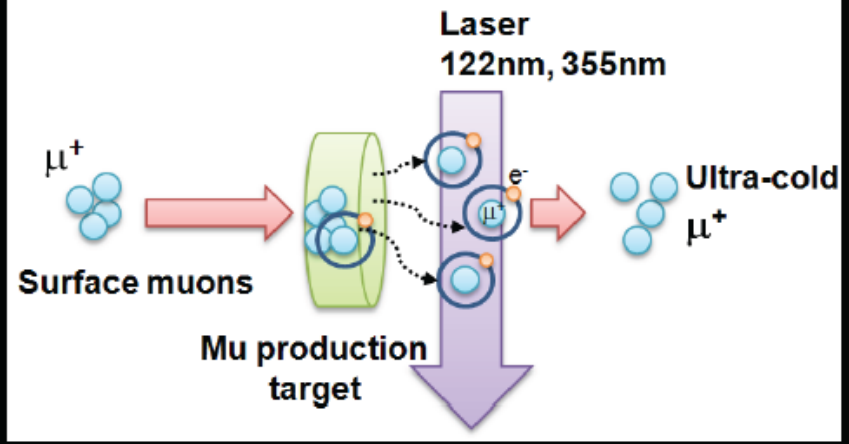
Ultra Cold μ+ Source

Muon LINAC (300 MeV/c)

Muon storage

Super Precision Storage Magnet
(3T, ~1ppm local precision)

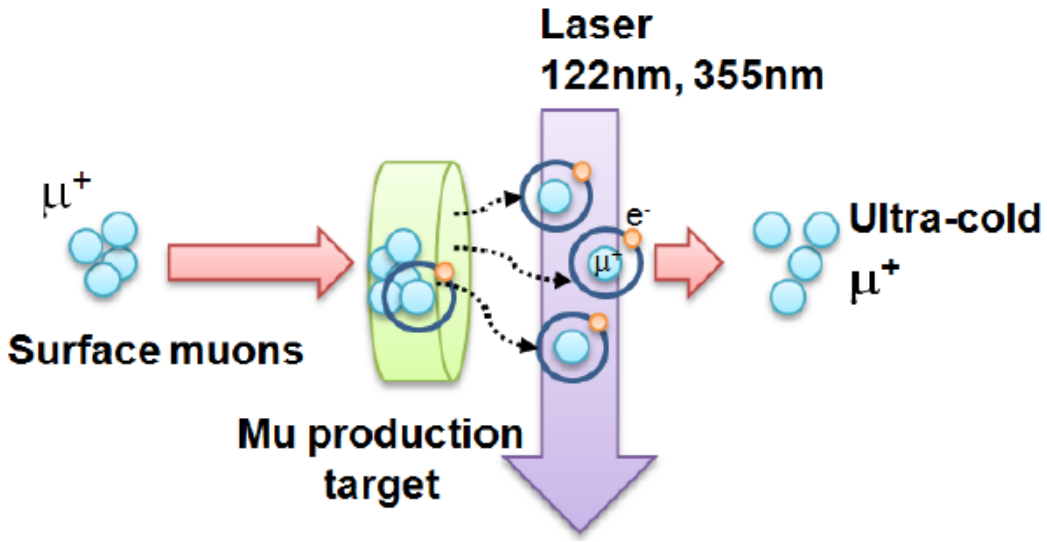
Resonant Laser Ionization of Muonium (~10^6 μ$^+$/s)



Interesting ideas!

Many R&D items

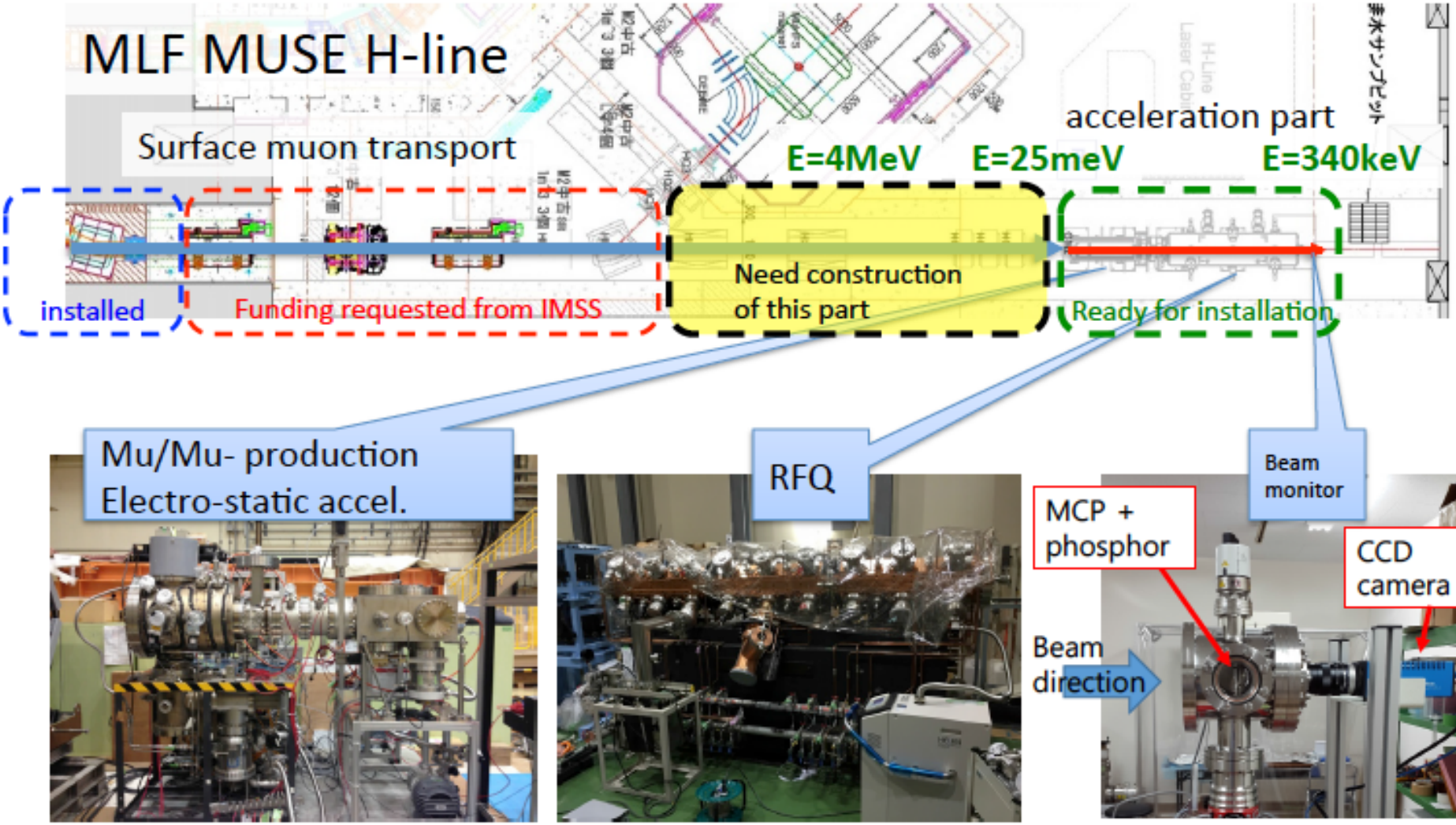
- Initial muon beam intensity
- Muonium production efficiency
- Laser ionization



- Muon acceleration

From Mibe @ J-PARC PAC

- World first muon accelerator!



Muon storage magnet and detector

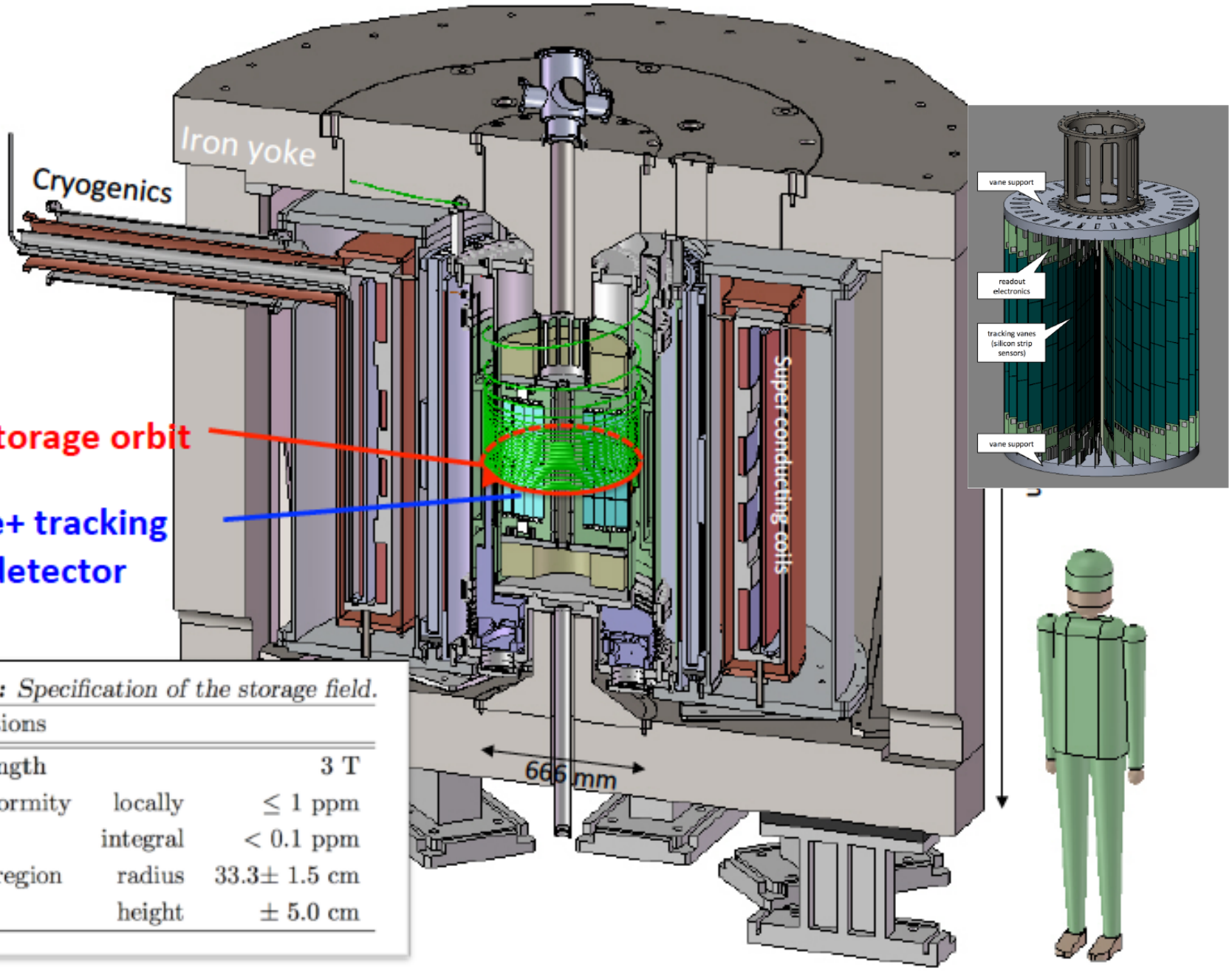


Table 1.2: *Specification of the storage field.*

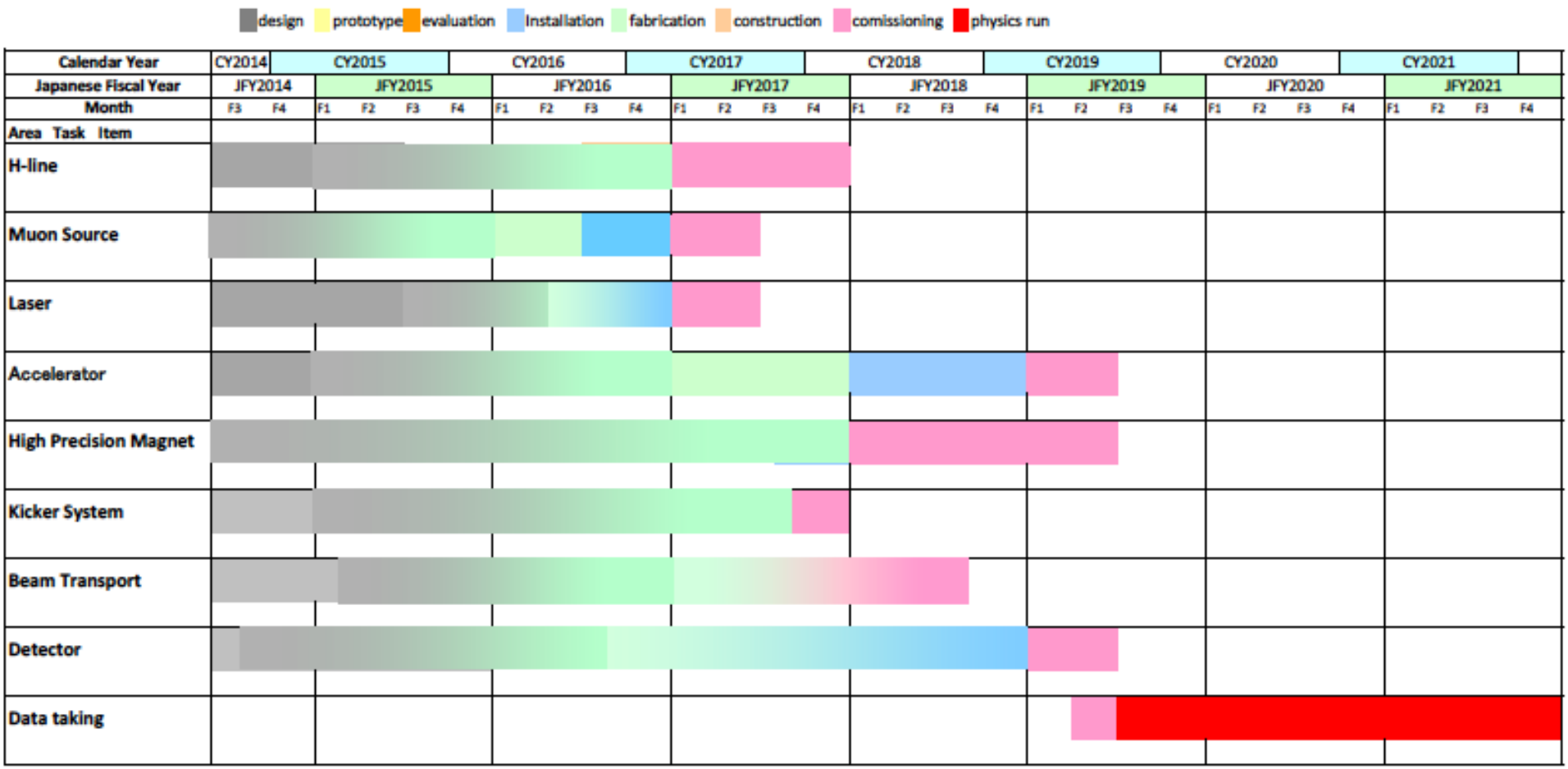
specifications		
field strength		3 T
field uniformity	locally	$\leq$ 1 ppm
	integral	$<$ 0.1 ppm
uniform region	radius	33.3$\pm$ 1.5 cm
	height	$\pm$ 5.0 cm

Quantities	Description	Value	
		CDR	This estimate
T	Running time	1×10^7 sec	2×10^7 sec
P	Muon polarization	1.0	0.5
$\frac{dN_\mu}{dt}$	Average muon rate in the storage magnet	1.0×10^6/sec	0.334×10^6/sec
N_μ	Total number of muon in the storage magnet	1.0×10^{13}	0.668×10^{13}
ϵ_{acc}	Acceptance of the e^+ detector and momentum cut [11]	0.13	0.133
ϵ_{trk}	Track reconstruction efficiency [12]	1.0	0.9
N_{e^+}	Total number of positrons ($N_\mu \epsilon_{acc} \epsilon_{trk}$)	1.3×10^{12}	0.80×10^{12}
$\frac{\Delta\omega_a}{\omega_a}$	Uncertainty on anomalous spin precession frequency	0.14 ppm	0.36 ppm
Δd_μ	Uncertainty on EDM	$4.8 \times 10^{-22} e \cdot$ cm	$1.3 \times 10^{-21} e \cdot$ cm

	BNL E821	J-PARC E34
g-2:	0.46 ppm	→ 0.37 ppm (→0.1ppm)
EDM:	0.9 x 10^{-19} ecm	→ 1.3 x 10^{-21} ecm

From Mibe @ J-PARC PAC

Technically driven schedule

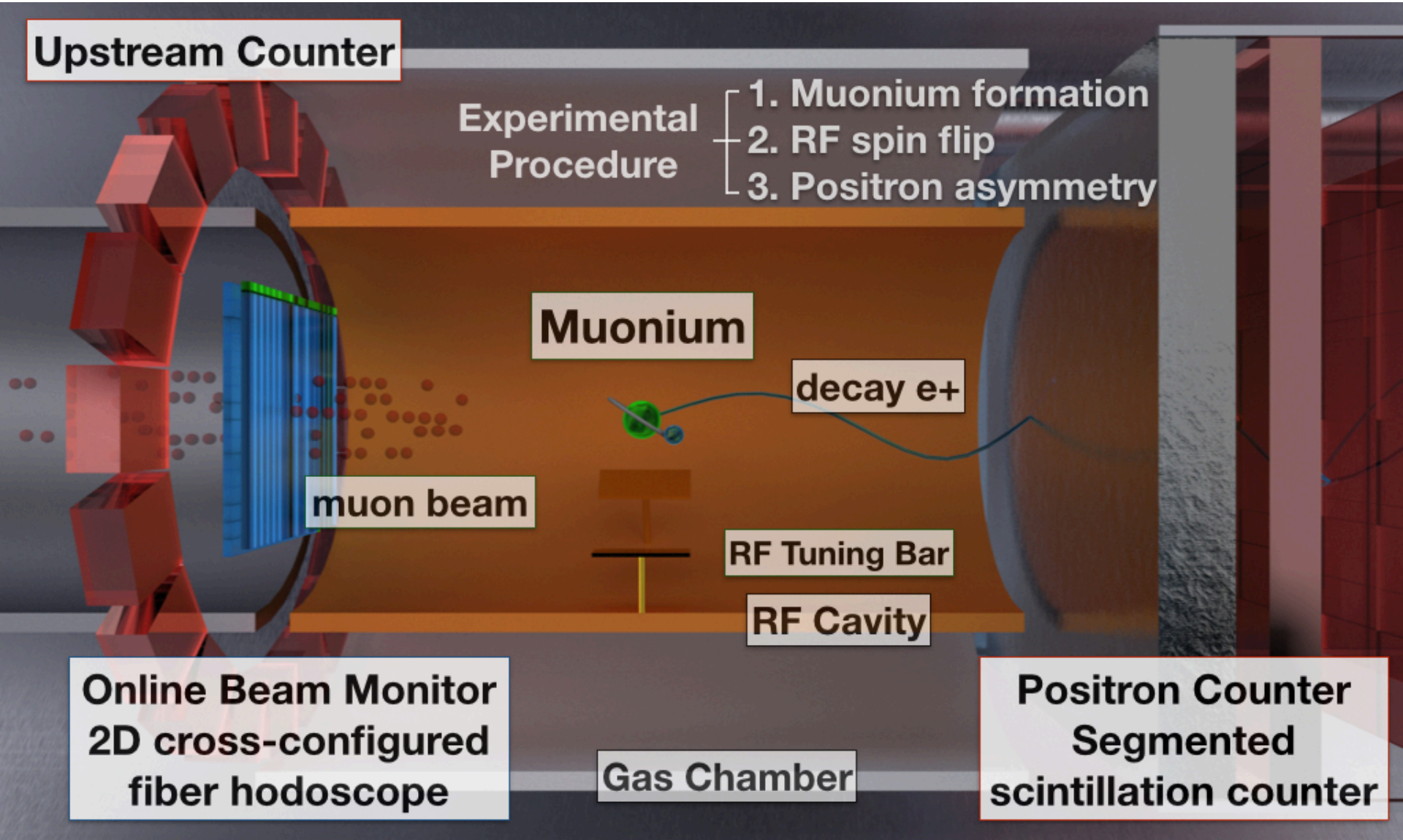


QCD issues?

- Already discussed on Tue.

Not covered

MuSEUM (Muonium Spectroscopy Experiment Using Microwave)

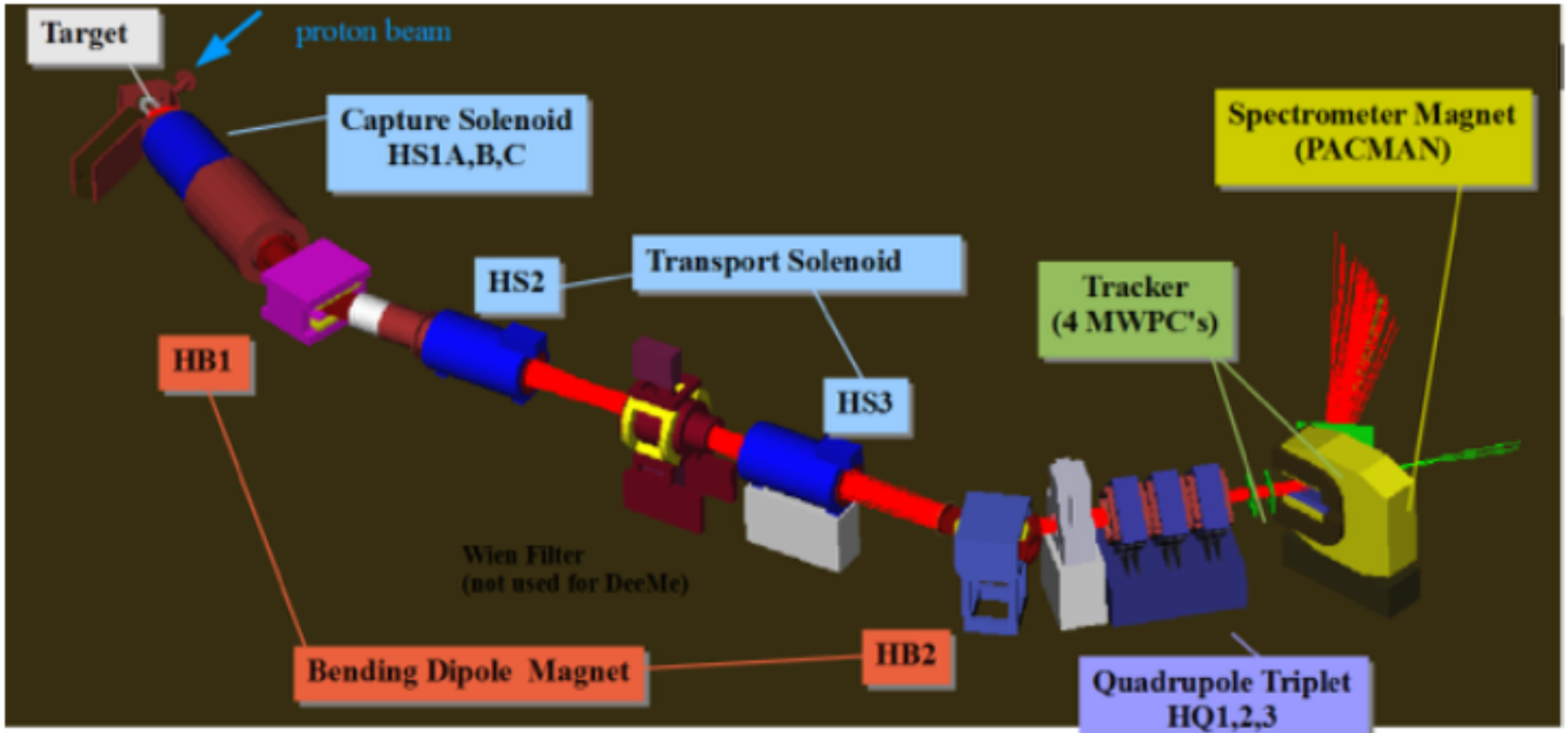


DeeMe Project

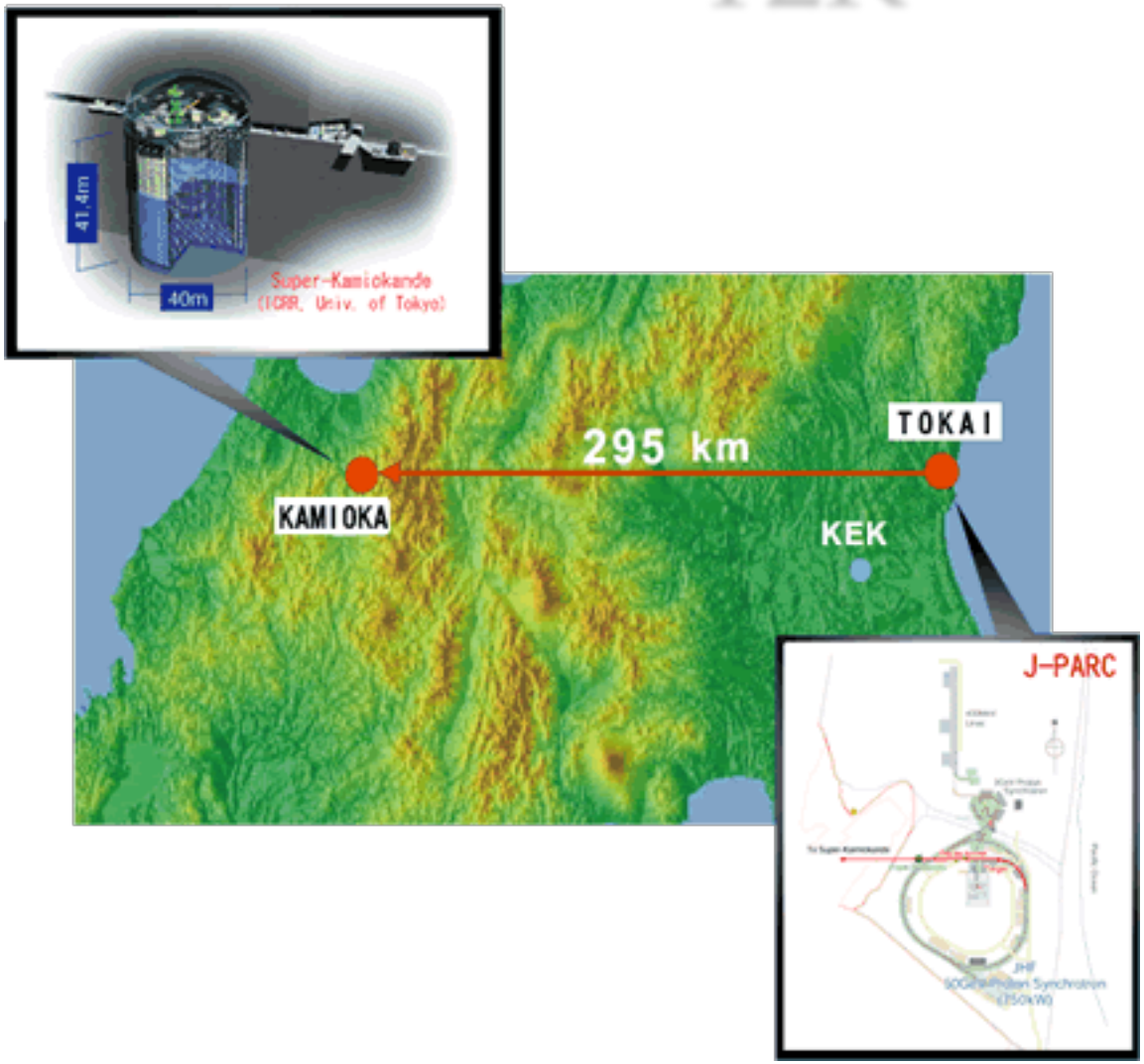
yet another
mu-e conversion

- High-Power High-Purity Pulsed Proton from J-PARC RCS
- Start with Graphite Target
  - Upgrade to a SiC Target
- Large-Acceptance Beam line (H-Line)
- State-of-the-Art HV-Switching MWPC
- Single Event Sensitivity
  - 1×10^{-13} (Graphite, 2×10^{7}sec)
  - 2×10^{-14}(SiC)、 5×10^{-15}(8×10^{7}sec)

- Schedule
  - Stage-2 Approved from Muon PAC IMSS
  - Grant-in-Aid for detector construction
    - detector completed in 2015
  - H-Line under construction
    - upstream-half completed
    - beamline shield under a bid
    - downstream at 2016 summer
  - Aiming to start in 2016.



T2K


41.4m
40m
Super-Kamiokande
(ICRR, Univ. of Tokyo)
295 km
TOKAI
KAMIOKA
KEK
J-PARC

ABOUT THIS WORKSHOP

The international workshop on future potential of high intensity proton accelerator for particle and nuclear physics (HINT2015) will be held at J-PARC, Tokai-Village, Ibaraki, Japan from 13th to 15th October, 2015. This workshop follows the workshop held in December 2012 at J-PARC on "Future direction of Proton Intensity Frontier"; http://kds.kek.jp/conferenceDisplay.py?confId=11459

The workshop will focus on future prospects of high intensity proton accelerators and beams toward Multi-MW beam power and, new frontier of particle and nuclear physics enabled by the high intensity beams.

First bulletin

TOPICS

There will be sessions covering the following topics;

- Present status and future plan of world high intensity proton accelerators
- Technical challenges to realize Multi-MW accelerators
- Technical challenges to realize Multi-MW beam facilities
- Neutrino physics with high intensity beam
- Kaon particle physics with high intensity beam
- Muon particle physics with high intensity beam

Summary

- Experimental programs at KEK
- SuperKEKB
  - Wide variety of physics (CP, CKM, rare decays, tau, exotica)
  - Acc commissioning in 2016; Phys run 2018~
- J-PARC
  - Experiments at Hadron Hall and at MLF
  - COMET, KOTO, g-2/EDM, …

- QCD at precision frontier
  - Close collaboration between theorists and experimentalists desired/need, e.g. B2TiP.