Imperial College
London

Charged Lepton Flavour Violation

—COMET & PRISM—

25 September 2015

Yoshi Uchida

PPAP Community Meeting at Imperial

The First PPAP Community Meeting

The experimental intense muon physics session at the 2009 meeting:

16:00 **LHC Upgrades (LHCb + GPDs)** *15'*

Speaker: Chris Parkes (Glasgow)

Material: **Slides**

16:15 **e+e- machines (SuperB, Belle upgrade, tau-charm factories)** *15'*

Speaker: Adrian Bevan (QMUL)

Material: **Slides**

16:30 **NA62 + kaons at JPARC/FNAL** *10'*

Speaker: Cristina Lazzeroni (Birmingham)

Material: **Slides** **more information**

16:40 **COMET + muons at FNAL** *10'*

Speaker: Yoshi Uchida (Imperial College)

Material: **Slides**

Discussion *50'*

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1947

Nuclear Capture of Mesons and the Meson Decay

B. Pontecorvo
National Research Council, Chalk River Laboratory, Chalk River Ontario, Canada

June 21, 1947

...Returning to the actual decay of the meson, an experiment suggests itself which might answer the following question: Is the electron emitted by the meson with a mean life of about 2.2 microseconds accompanied by a photon of about 50 Mev? This experiment is being attempted at the present time, since it is felt that the available analysis[10] of the soft component in equilibrium with its primary meson component is probably insufficient to decide definitely whether the meson decays into either an electron plus neutral particle(s) or electron plus photon.

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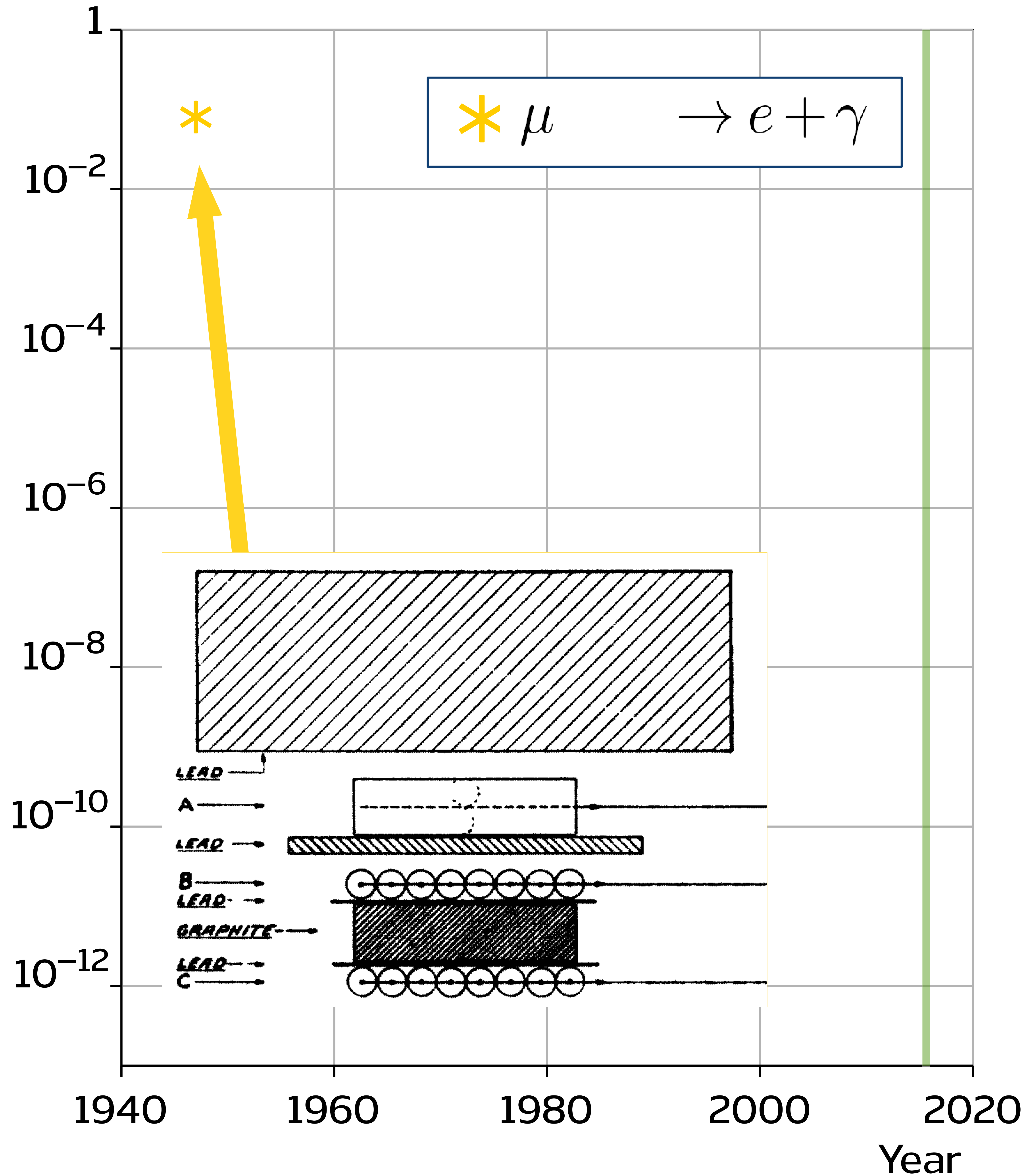

90% C.L. upper limit on branching ratios

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Muon CLFV: Global Activities

- MEG
- MEG Upgrade
- Mu2e
- COMET
- DeeMee
- Mu3e
- PRISM

Lepton Flavour Conservation in the Standard Model

- In the Standard Model:
  - Lepton flavour is conserved absolutely
    - not through a fundamental principle, but **through the *choice* of fields**
    - an *accidental* symmetry
- Deviations from the SM can introduce Lepton Flavour Violation

Charged Lepton Flavour Violation

- **Beyond-the-Standard Model Physics** can cause CLFV

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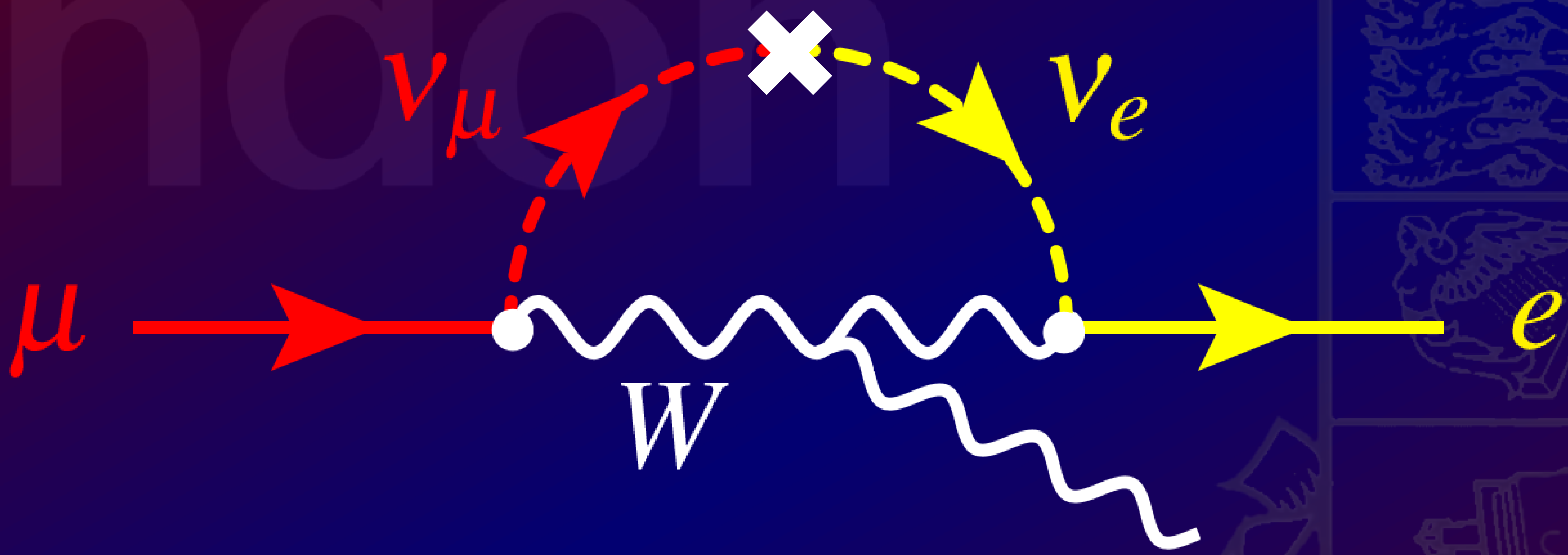
- **Beyond-the-Standard Model Physics** can cause CLFV
  - e.g. **introduction of non-zero neutrino mass**



  - but this is ***GIM-suppressed:***

$$B(\mu \to e + \gamma) = \frac{3\alpha}{32\pi} \left| \sum_\ell V^*_{\mu\ell} V_{e\ell} \frac{\Delta m^2_{\nu_\ell}}{m^2_W} \right|^2$$

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Charged Lepton Flavour Violation

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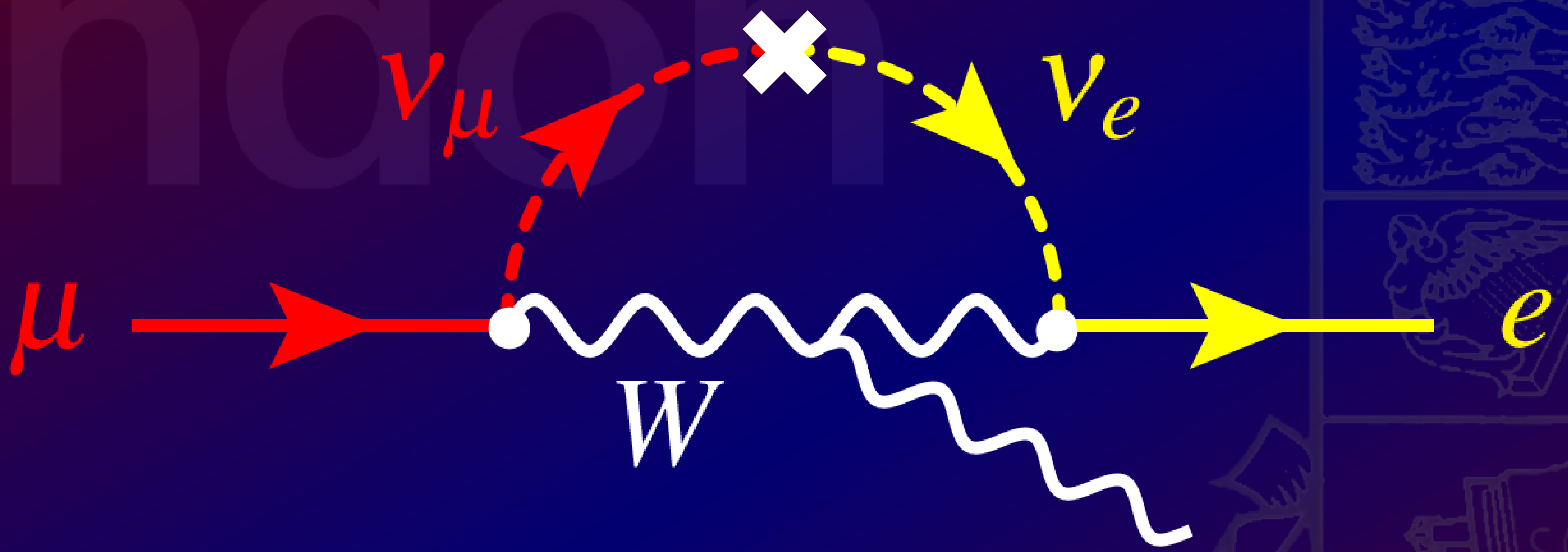
  - e.g. **introduction of non-zero neutrino mass**



- but this is ***GIM-suppressed:***

$$B(\mu \to e + \gamma) \sim 10^{-54} \times \frac{\sin^2 2\theta_{13}}{0.15}$$

Charged Lepton Flavour Violation

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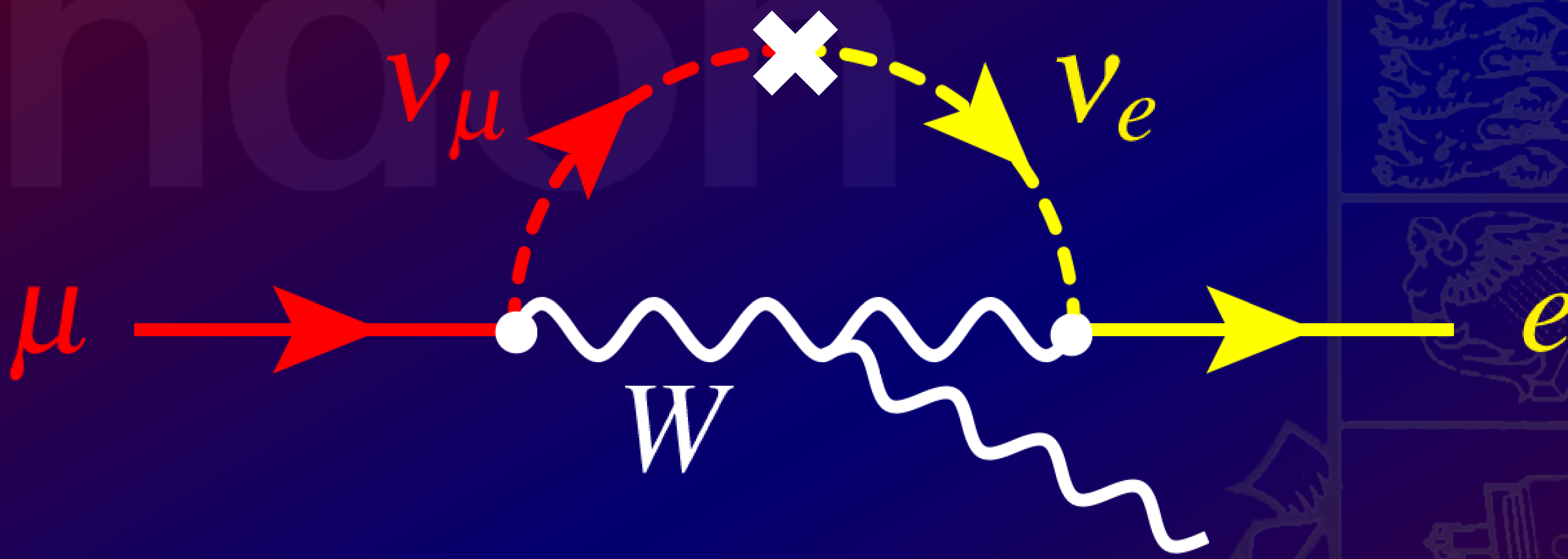
  - e.g. **introduction of non-zero neutrino mass**

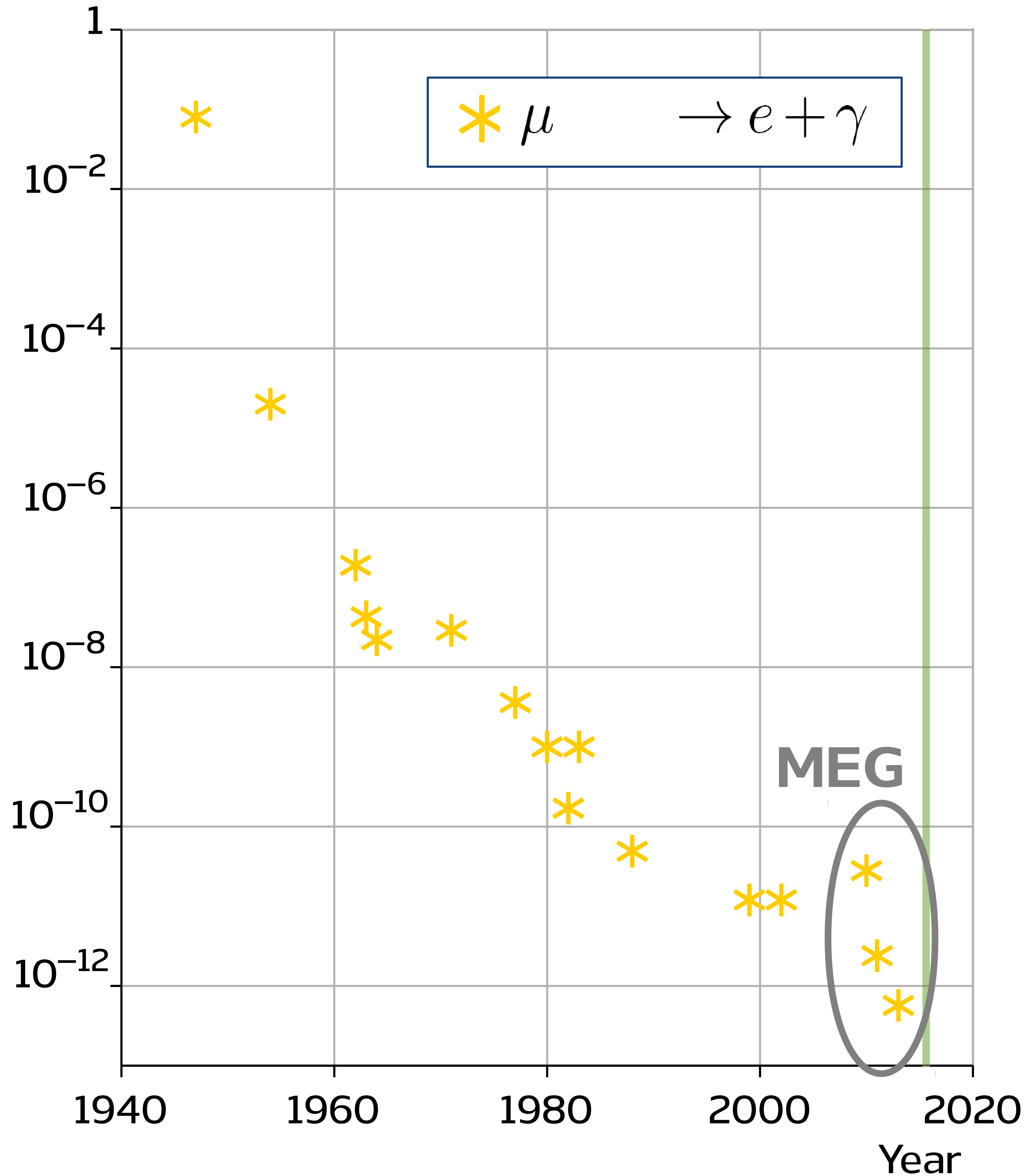


- but this is ***GIM-suppressed:***

$$B(\mu \to e + \gamma) \sim 10^{-54} \quad \left(\sim \frac{m_\mu}{30 m_\oplus} \right)$$

- **if CLFV seen, *unambiguous signal* for new physics (beyond Dirac $m_\nu > 0$)**
- without such cancellations, CLFV signal can be much larger

Charged Lepton Flavour Violation



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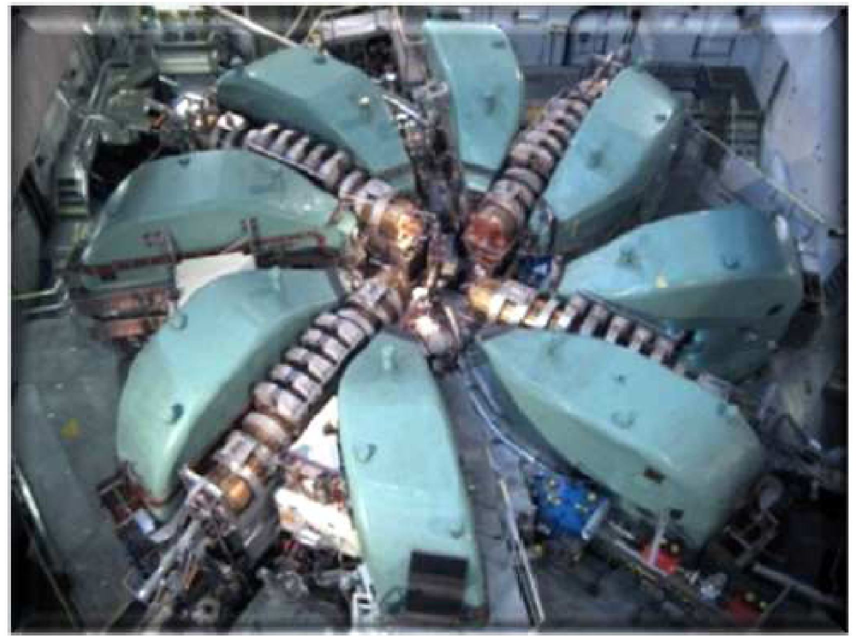
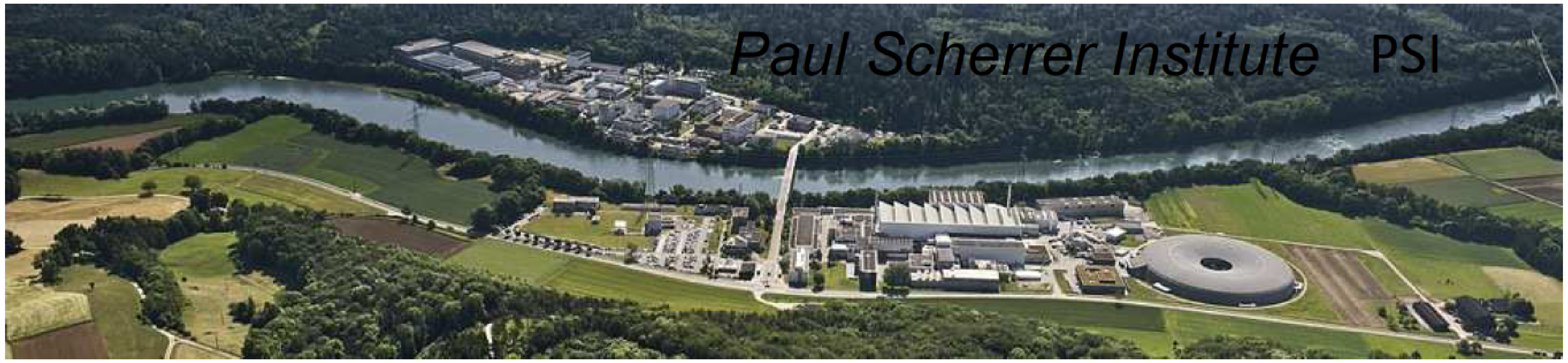
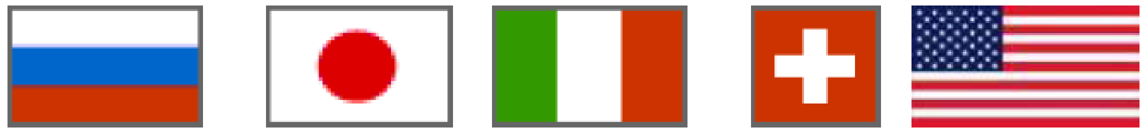
MEG HOME





Switzerland

PSI, ETH-Z



MEG Collaboration

some 65 Physicists

5 Countries, 14 Institutes

Russia

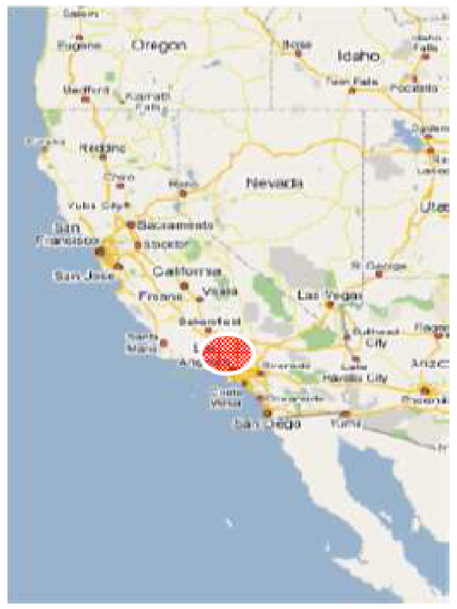
BINP, Novosibirsk,
JiNR, Dubna

Italy

INFN + Univ. :
Pisa, Genova,
Pavia, Roma I
& Lecce

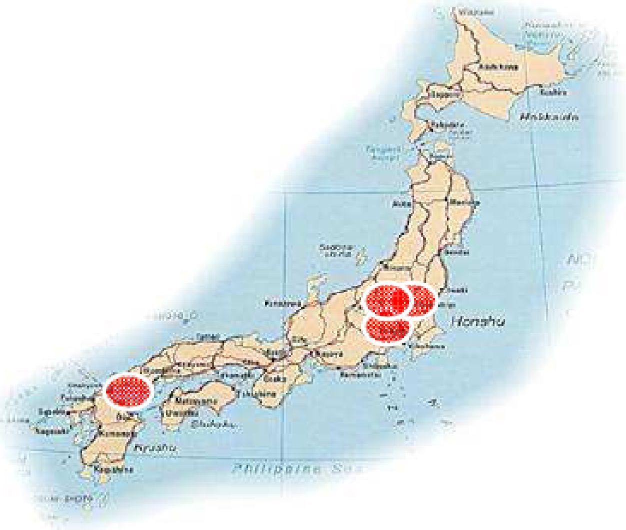
USA

University of
California Irvine
UCI



Japan

Univ.Tokyo, KEK
Waseda Univ.,
Kyushu Univ.



Muon-to-Electron Conversion

- Search for the process

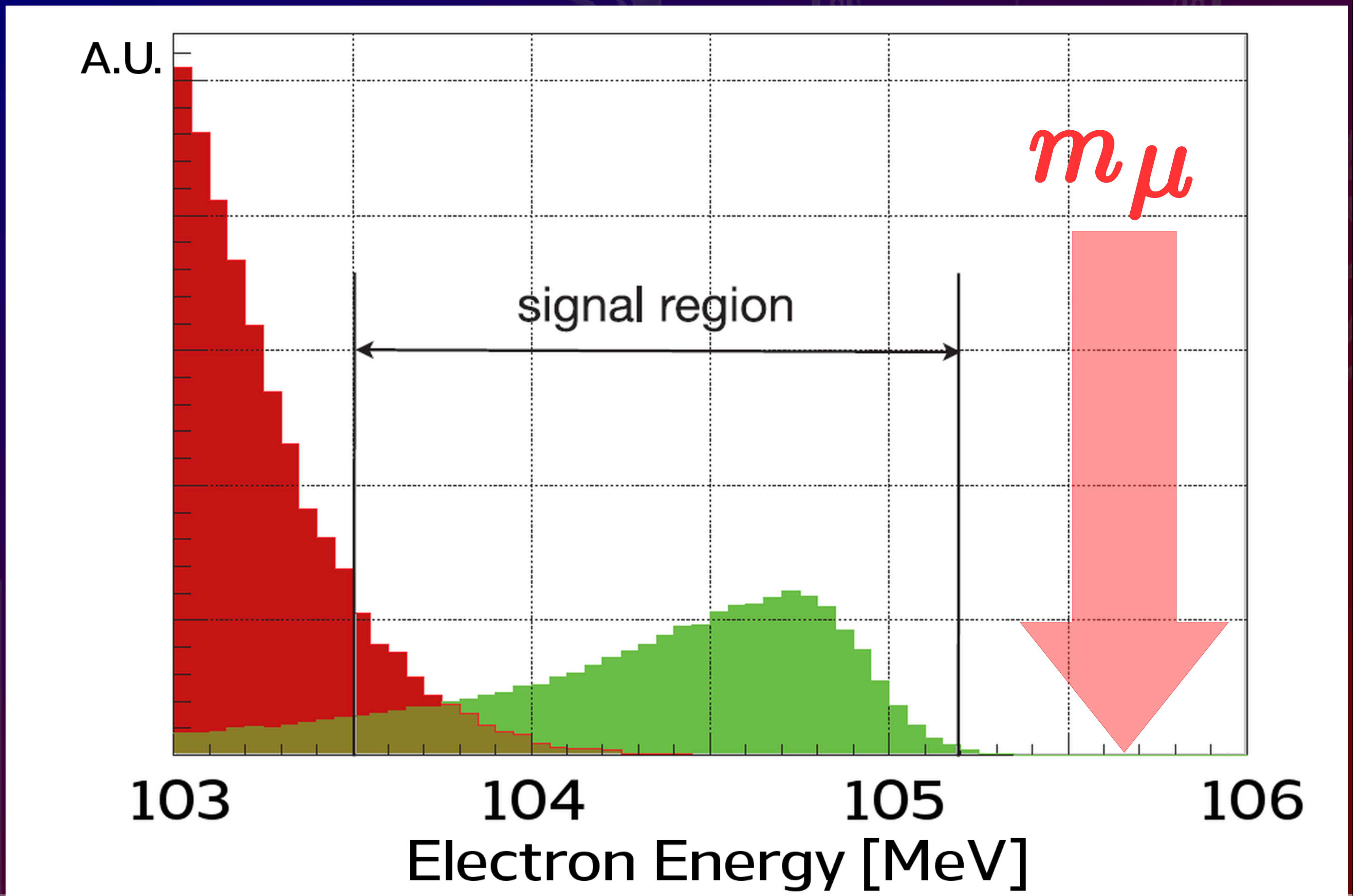
$$\mu^- + N(A,Z) \rightarrow e^- + N(A,Z)$$

muonic atom — mono-energetic electron ($E_e \leq$105 MeV)

- Time available after formation of muonic atom: up to about 1 microsecond (Z-dependent)

- $E_e = m_\mu - E_{\mathrm{bind}} - E_{\mathrm{recoil}}$

- **observed signal is smeared** because of detector effects



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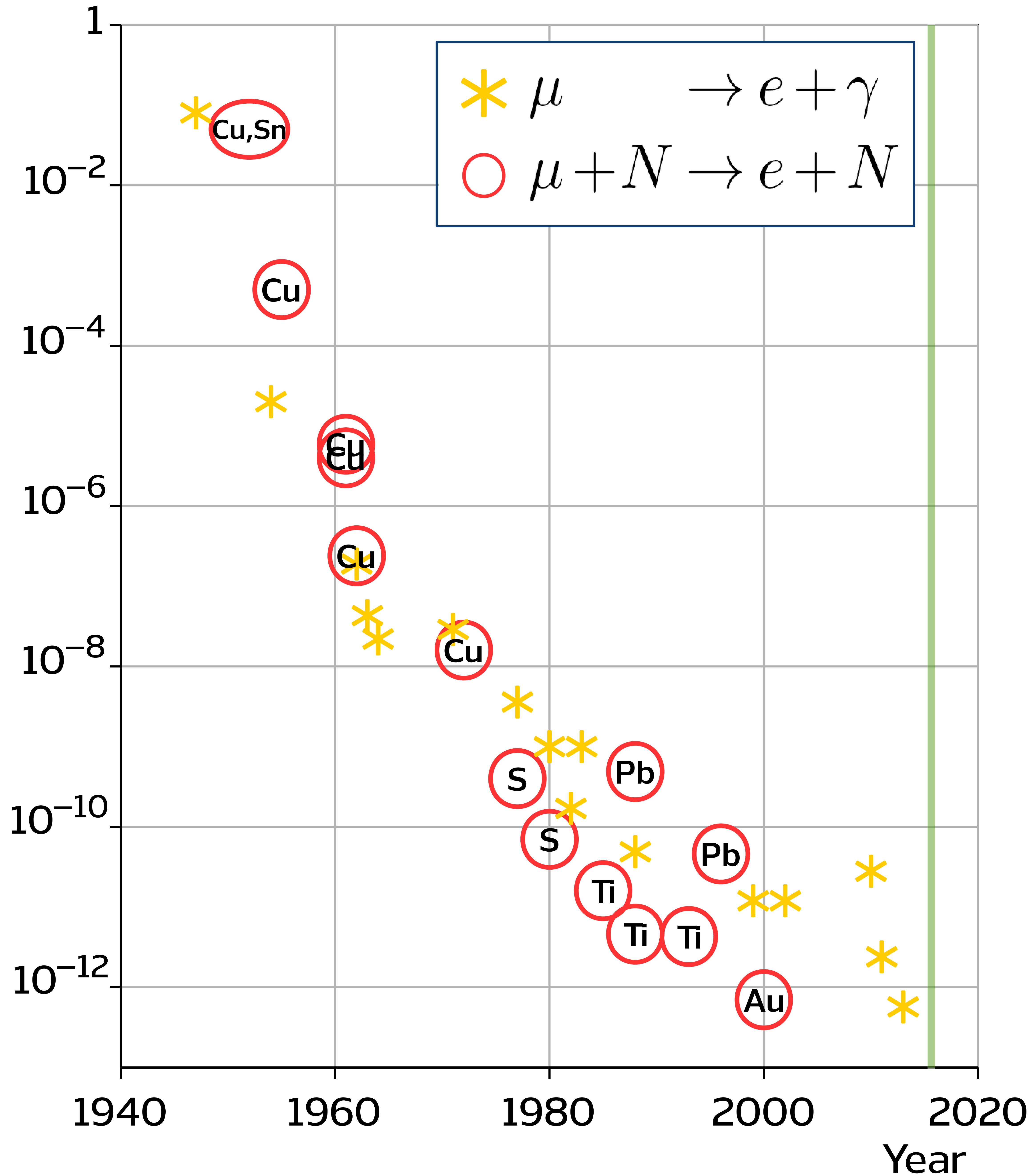

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Search for Lepton-Flavor-Violating Rare Muon Processes

"MELC" proposal from 1980s

R. M. Djilkibaev* and V. M. Lobashev**

Institute for Nuclear Research, Russian Academy of Sciences, pr. Shestidesyatiletiya Oktyabrya 7a, Moscow, 117312 Russia

Received March 26, 2010; in final form, July 12, 2010

Abstract—A new approach to seeking three lepton-flavor-violating rare muon processes ($\mu \to e$ conversion, $\mu \to e + \gamma$, and $\mu \to 3e$) on the basis of a single experimental facility is proposed. This approach makes it possible to improve the sensitivity level of relevant experiments by factors of 10^5, 600, and 300 for, respectively, the first, the second, and the third of the above processes in relation to the existing experimental level. The approach is based on employing a pulsed proton beam and on combining a muon source and the detector part of the facility into a unified magnetic system featuring a nonuniform field. A new detector design involving separate units and making it possible to study all three muonic processes at a single facility that admits a simple rearrangement of the detectors used is discussed.

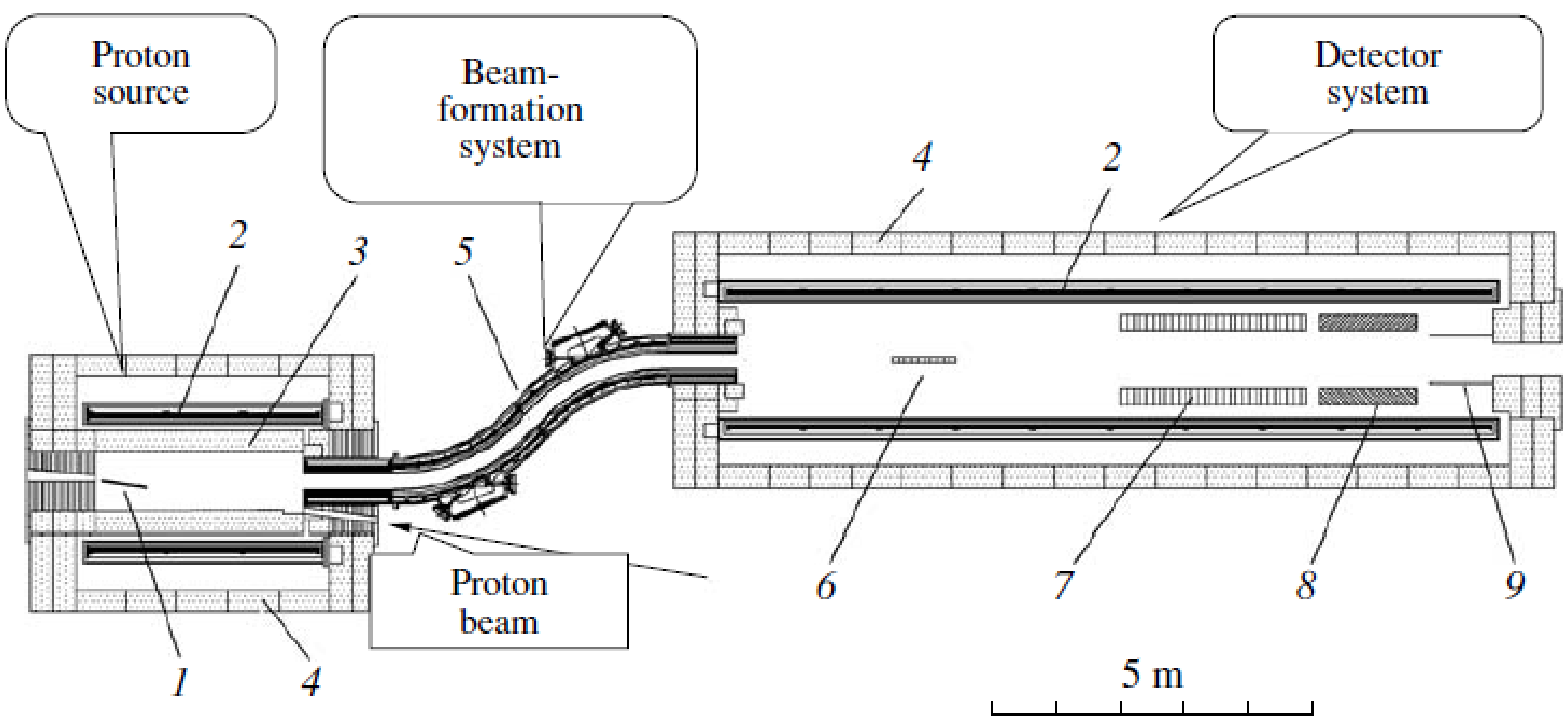
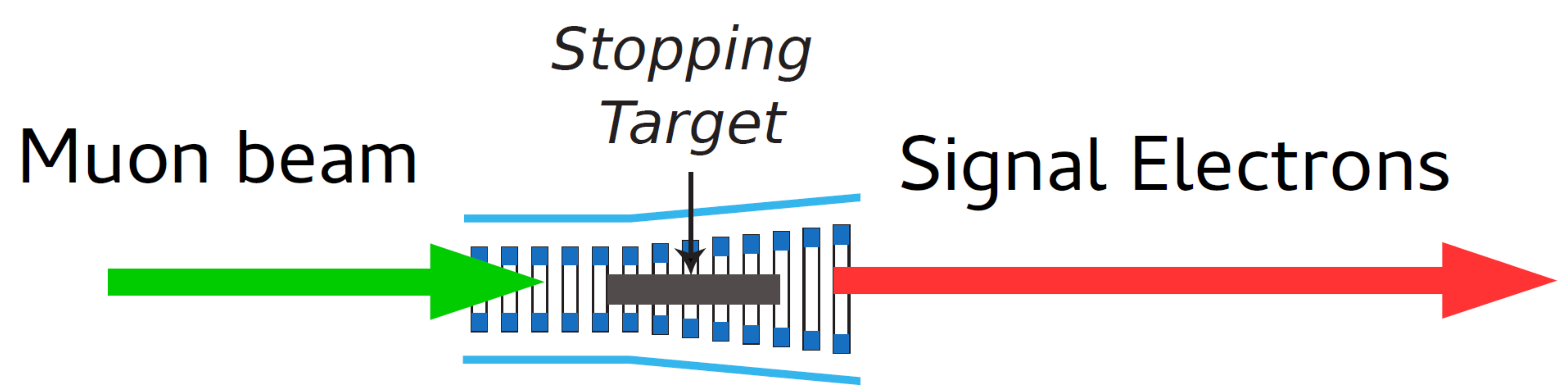
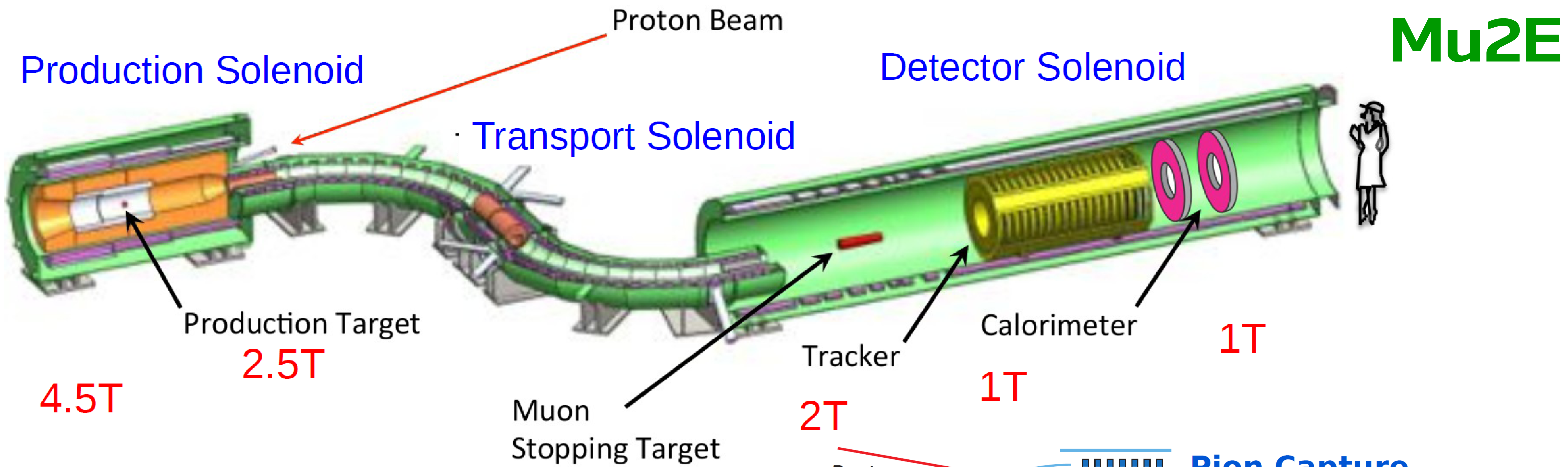


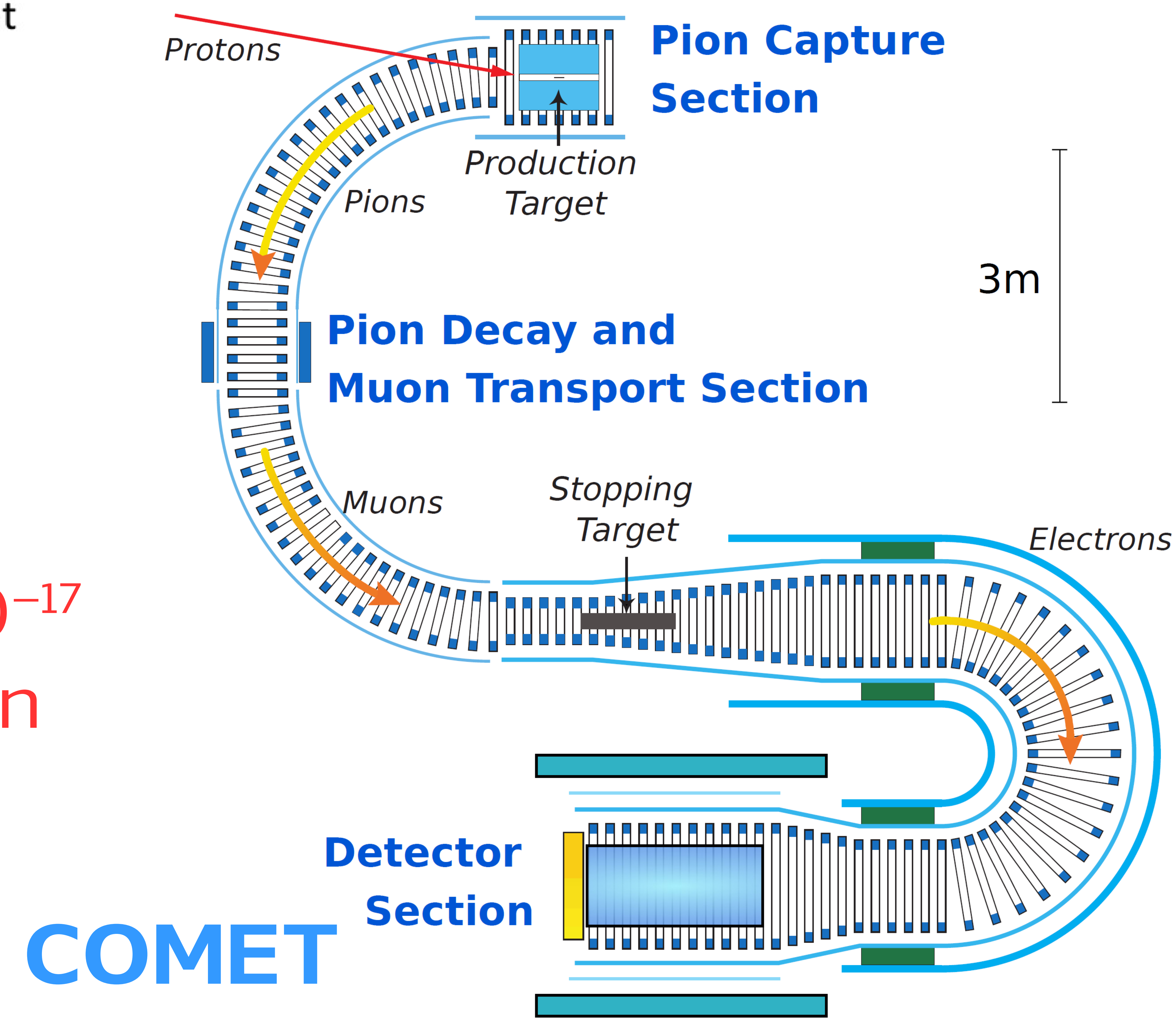
Fig. 1. Central horizontal cut of the MELC facility: (*1*) proton target, (*2*) superconductor solenoid, (*3*) shield of the solenoid, (*4*) steel yoke, (*5*) transport solenoid and collimator, (*6*) detector target, (*7*) coordinate detector, (*8*) calorimeter, and (*9*) detector shield and beam trap.

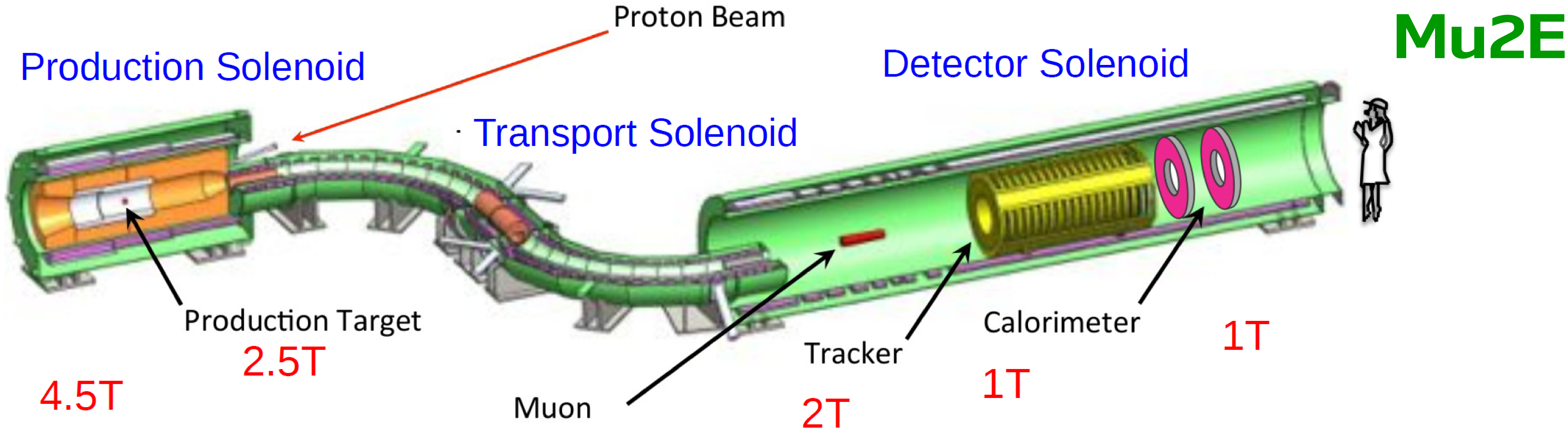

Muon beam
Stopping Target
Signal Electrons



Experimental Layouts

Similar nominal target sensitivities of about 10^{-17} (10,000 improvement on current world record)





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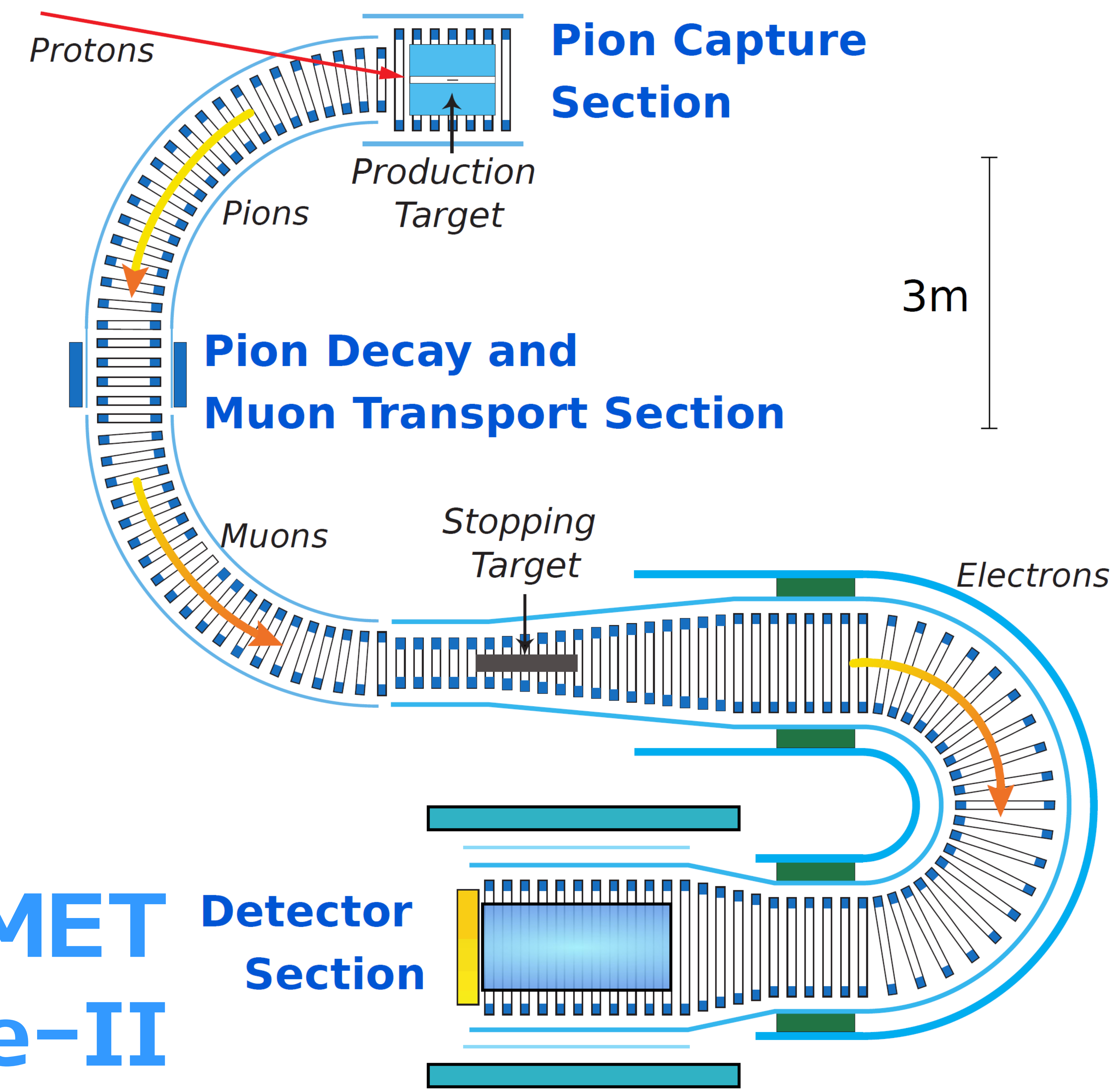
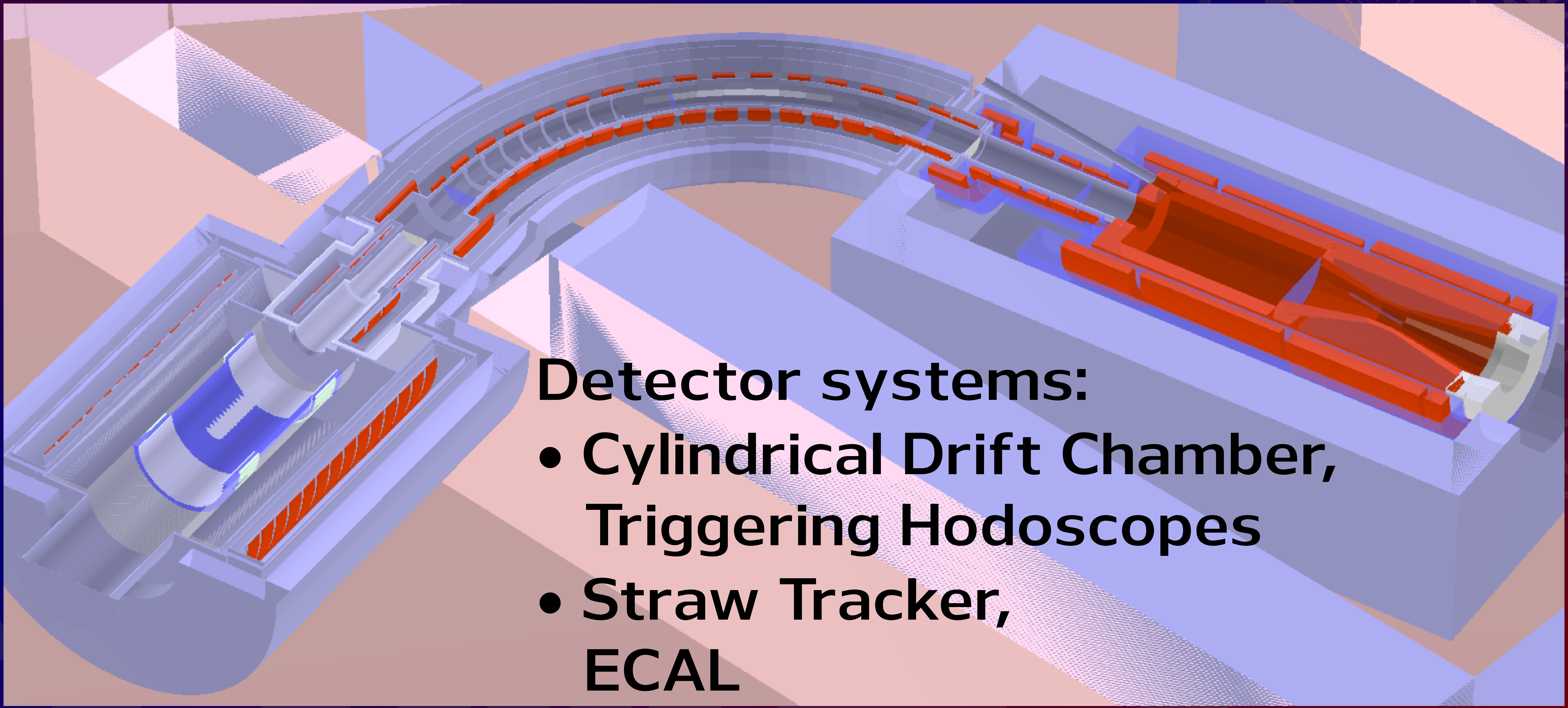
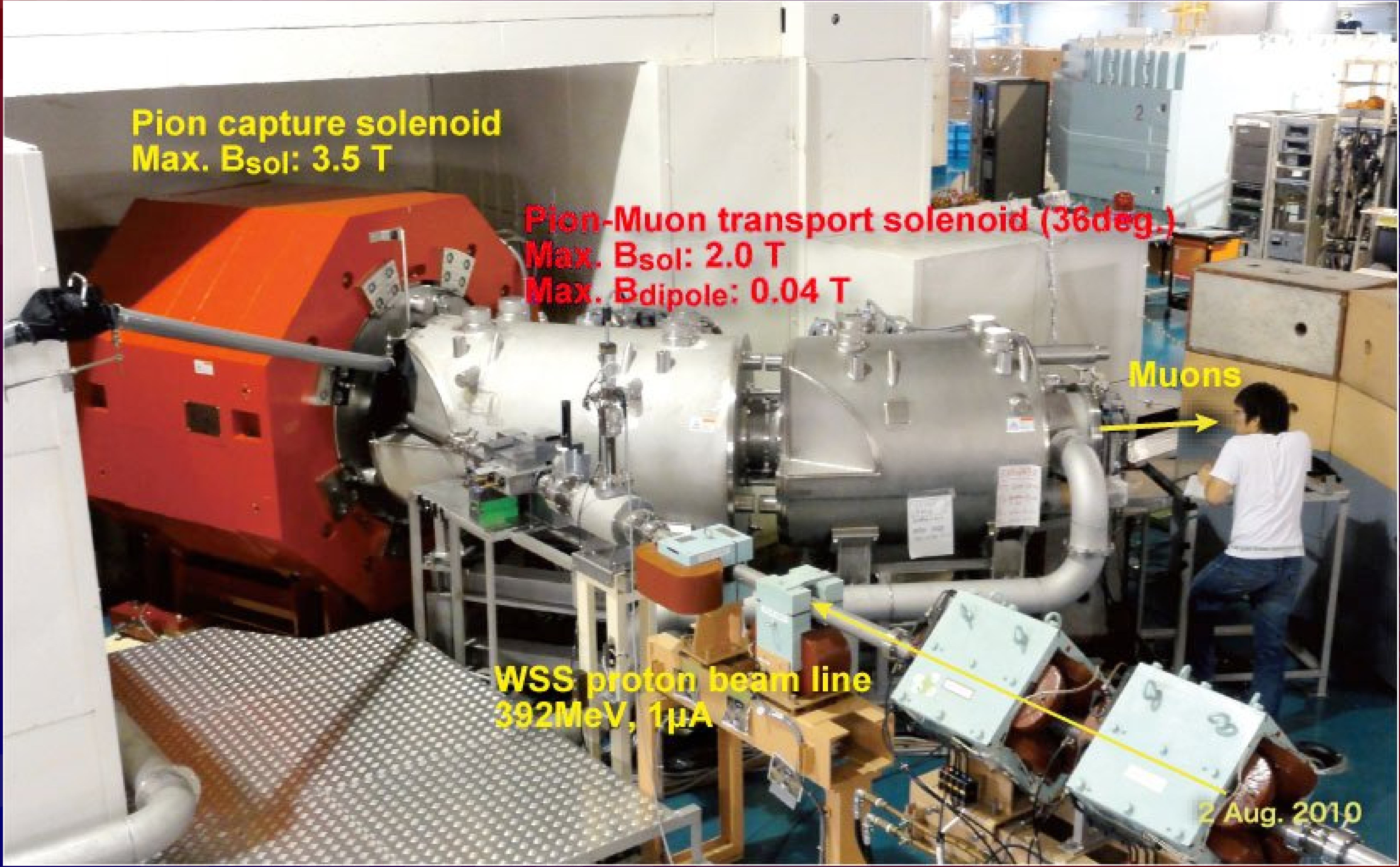


COMET Phase-I

- COMET is the first experiment of its type to be built
  - strong desire to study pion/muon production in detail
- Decision in 2012 to build and run the first 90 degrees of the beam line
  - to study beam characteristics and perform CLFV physics
    - 1/100th of the sensitivity of the full COMET configuration



MUSIC Facility at Osaka



The COMET Collaboration

- Belarus
- Canada
- China
- Czech Republic
- France
- Georgia
- India
- Japan
- Malaysia
- Russia
- Saudi Arabia
- South Korea
- United Kingdom
- Vietnam

14 countries,
32 institutes,
about 170
collaborators

- Recent new participation from Germany (Kai Zuber)

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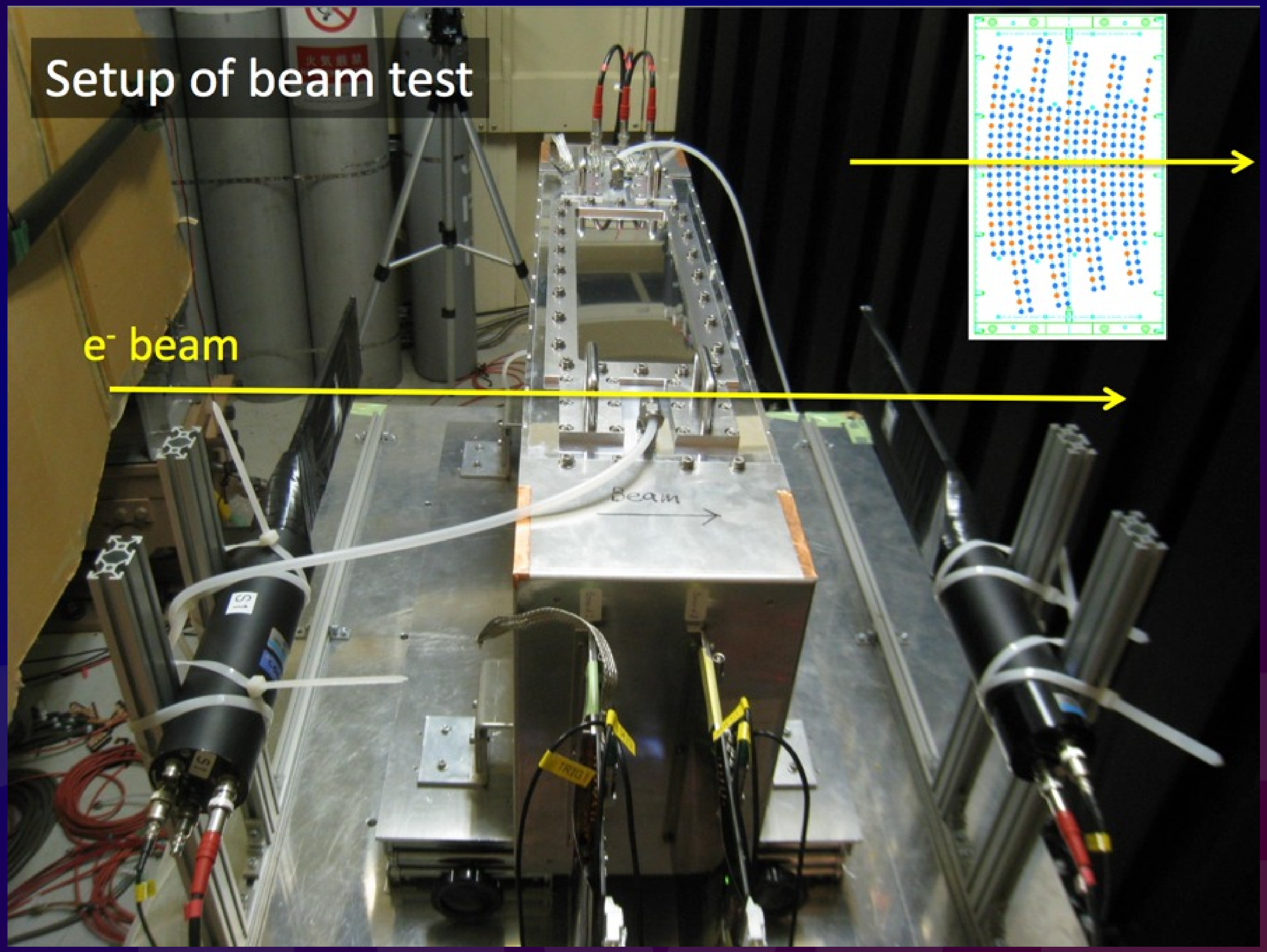
COMET Construction Status

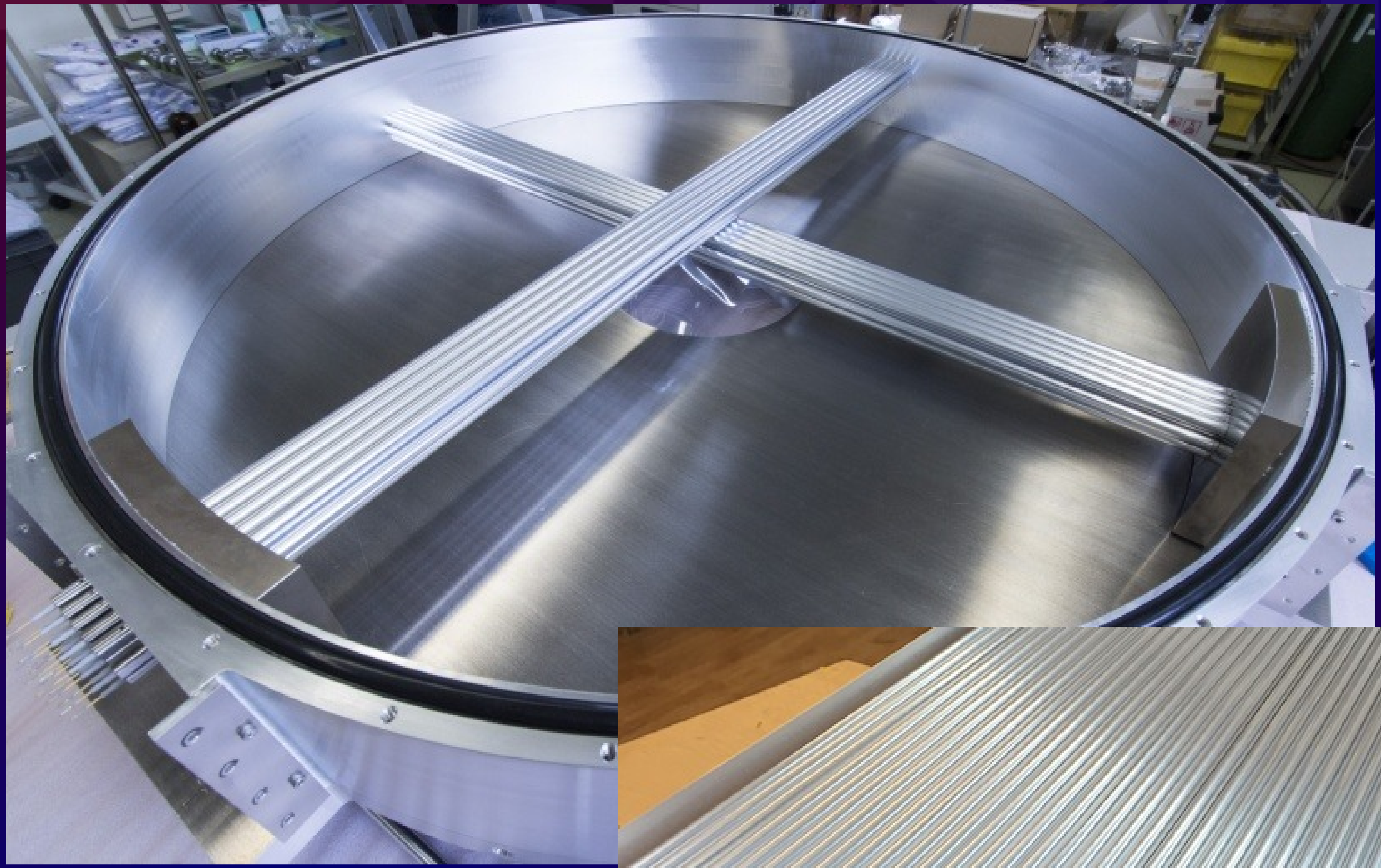
Phase-I Drift Chamber Status

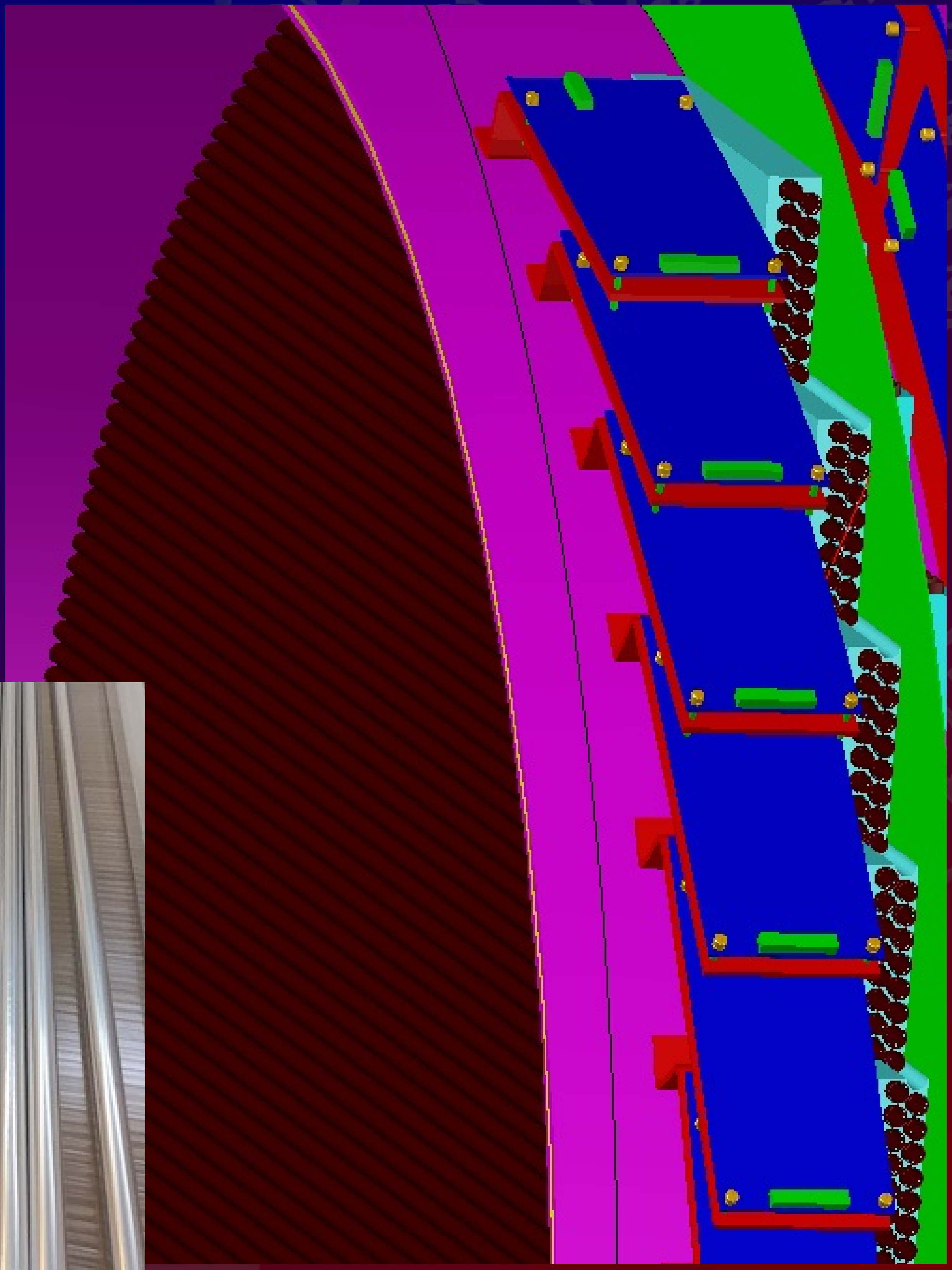
- Four prototypes built, beam-tested
- All Front-end Boards built and undergoing testing (IHEP)
- Full detector ready Summer 2016
  - Wires about 60% strung
    - to be completed later this year
- Triggering algorithm being developed in UK



Phase-I Straw Tracker Status

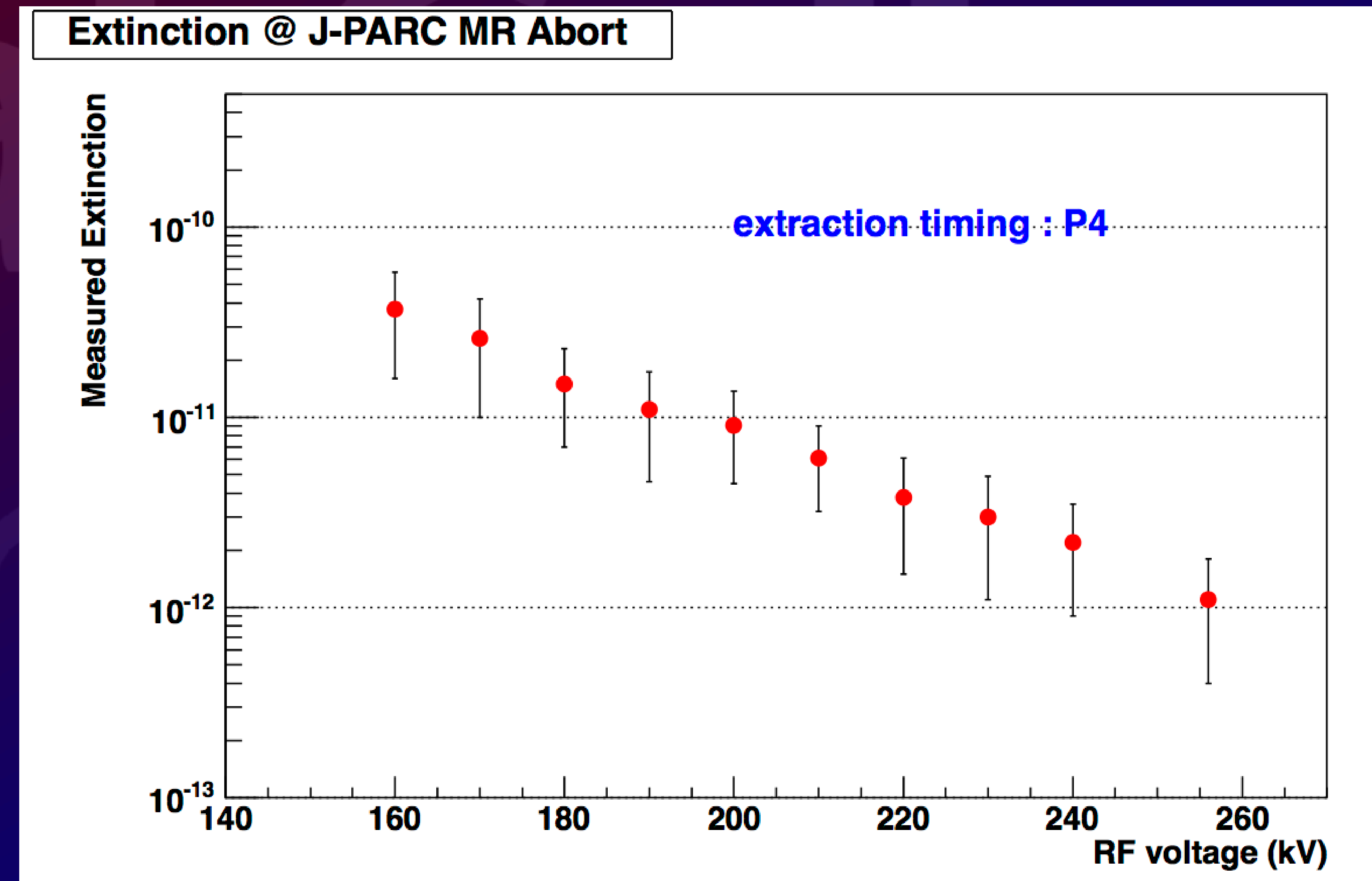
- Straw Tubes produced at JINR (based on NA62)
  - all 2,500 Phase-I straws delivered (20 μm walls)
  - Phase-II straws (thinner 12 μm design) being developed
- Testing and enclosure development underway



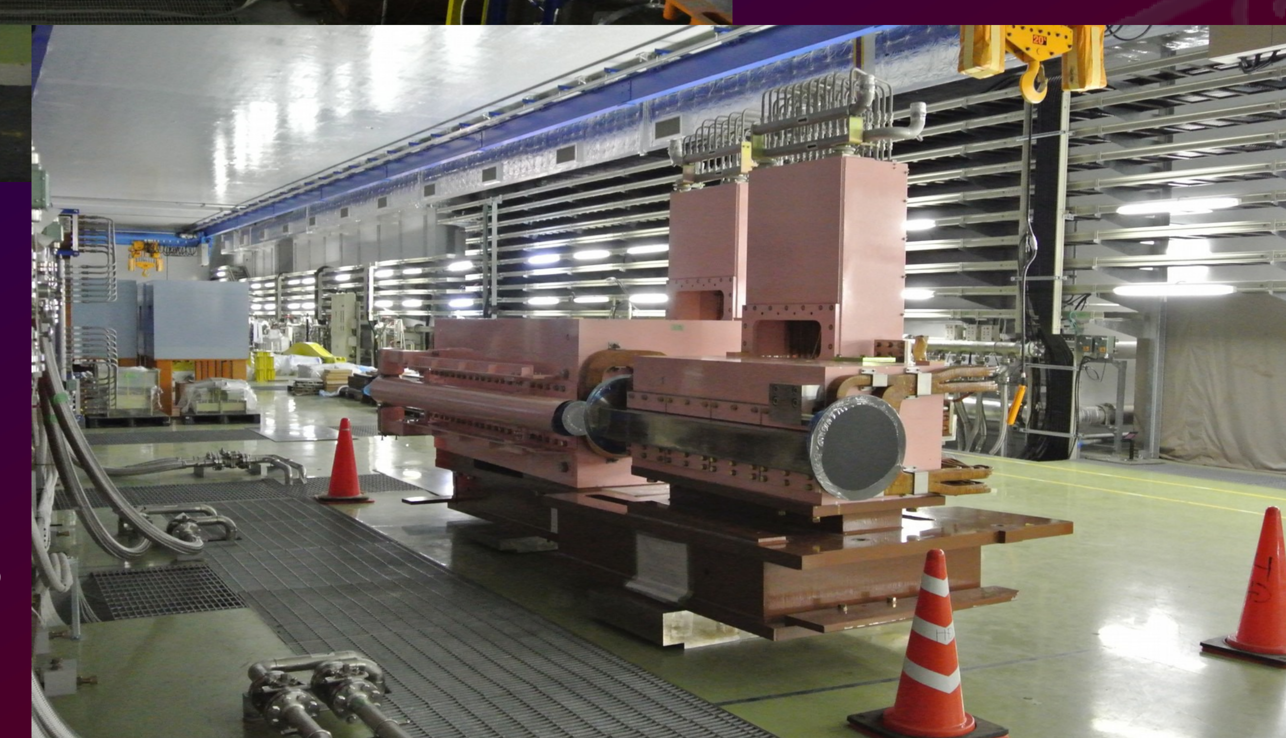


Proton Beam

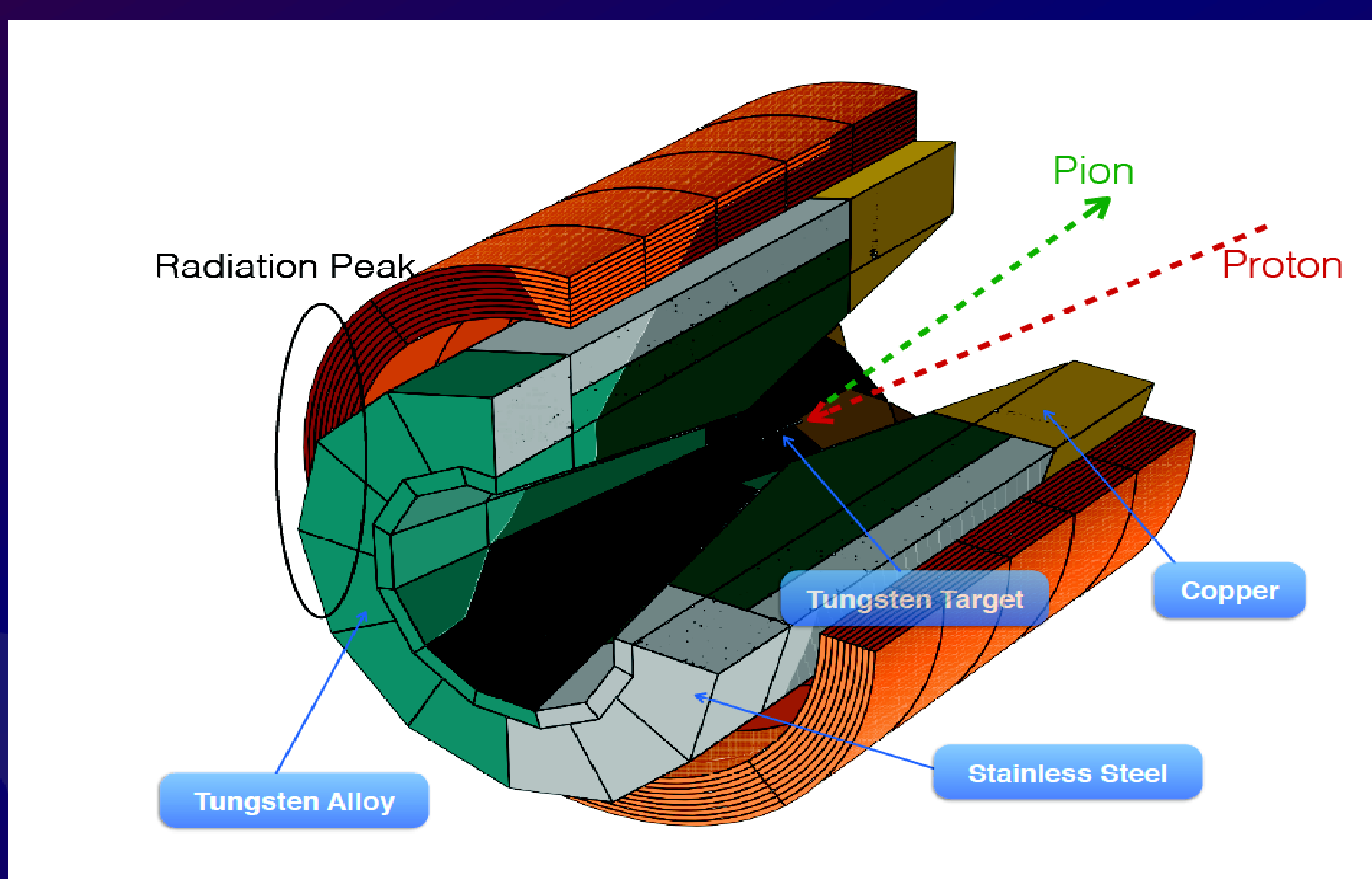
- Beam extinction (critical for μ-e conversion) reduced to $O(10^{-12})$ at 8 GeV
- Graphite target for Phase-I, Tungsten for Phase-II (UK concept)
- Shielding designed for 56 kW (Phase-II specs)



Magnets aligned

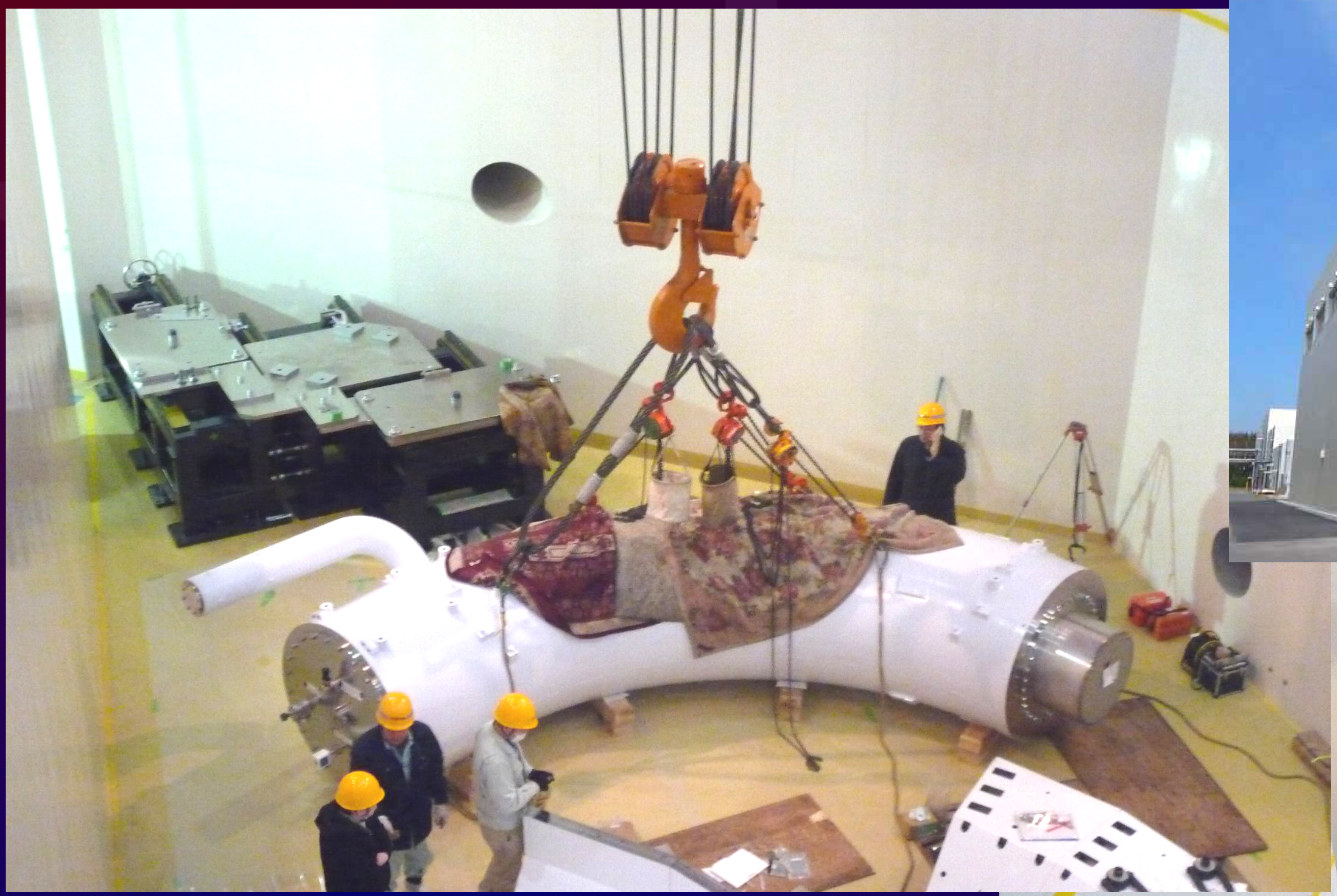


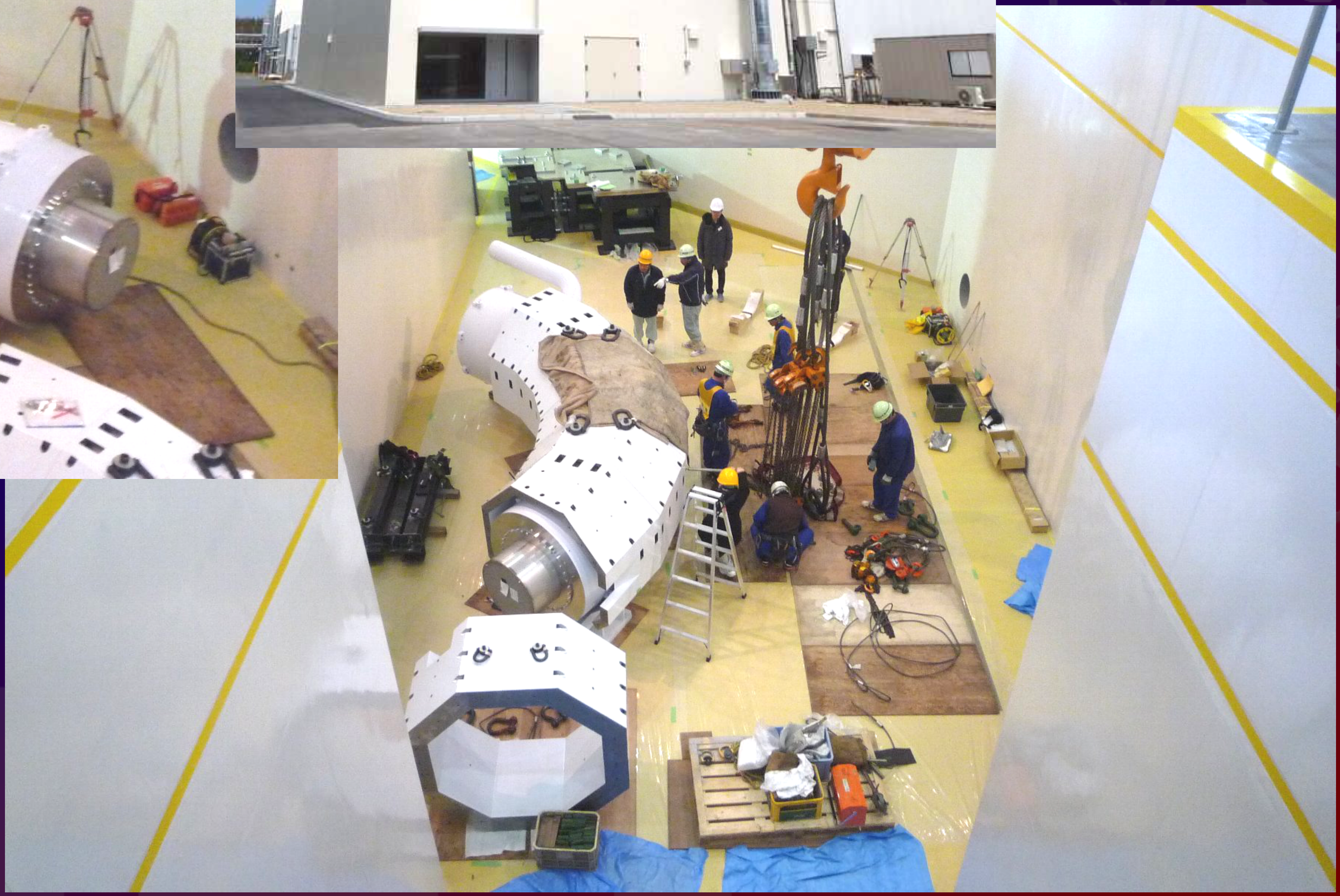
Septum magnets delivered



π/μ Transport Solenoid

- Experimental hall completed March 2015, and first curved solenoid installed





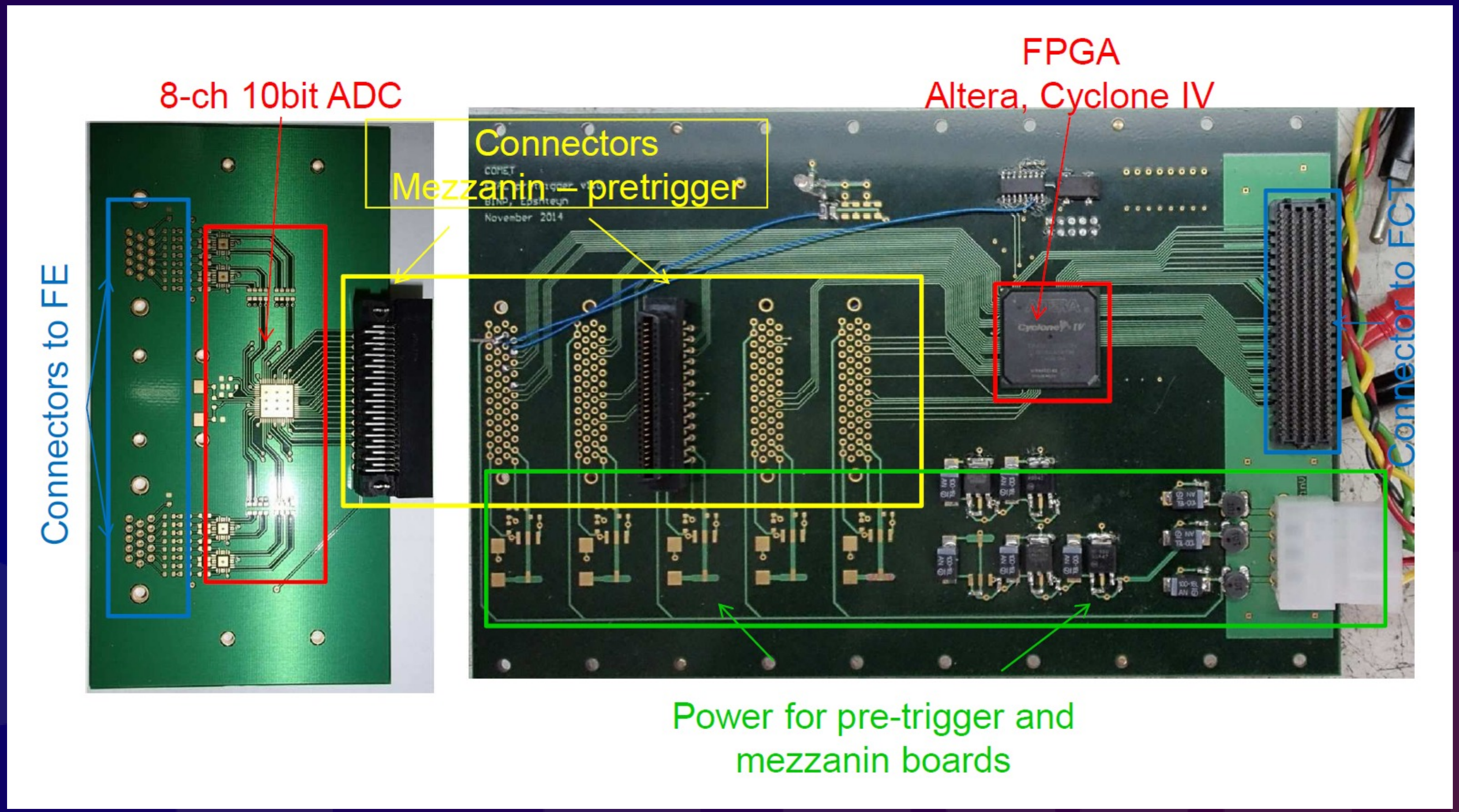
π/μ Transport Solenoid

- Undergoing extensive testing this year
- Close R&D partnership with manufacturer (Toshiba)
  - proprietary technology to superimpose a vertical dipole field on curved solenoid
  - ongoing iterative testing and feedback with Toshiba
- Gain experience towards rapid production of Phase-II solenoids

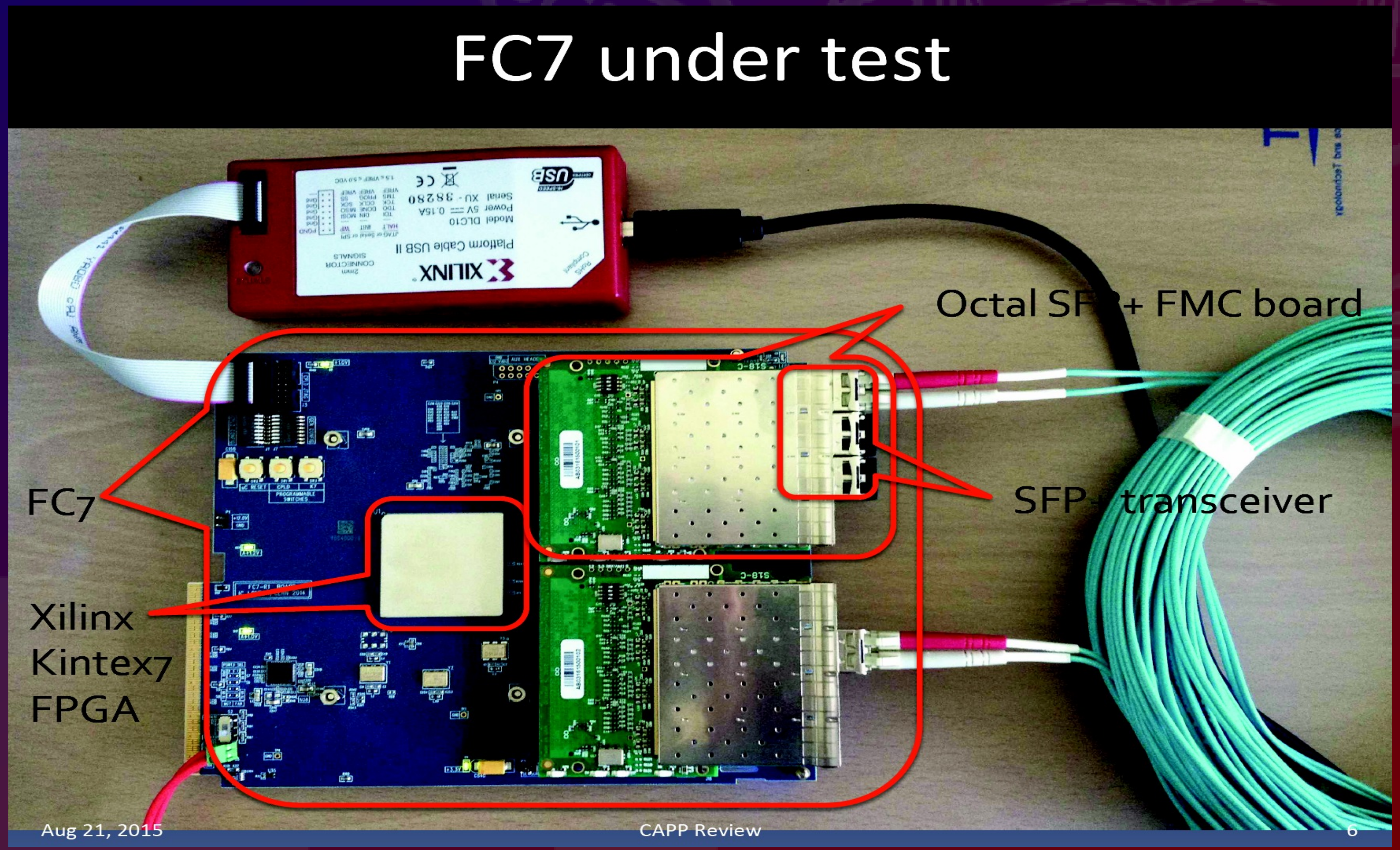
Trigger/Fast Control/DAQ

- UK-designed Fast Control/Trigger/DAQ systems to be used across all subdetectors
- Prototype custom "FCT" boards and FC7 boards (developed here for CMS upgrade) distributed to/purchased by Japan, China, India, Russia, South Korea
  - interfaces with subdetectors being developed
- Performing radiation tests at Brunel and ISIS

Russian interface with FCT

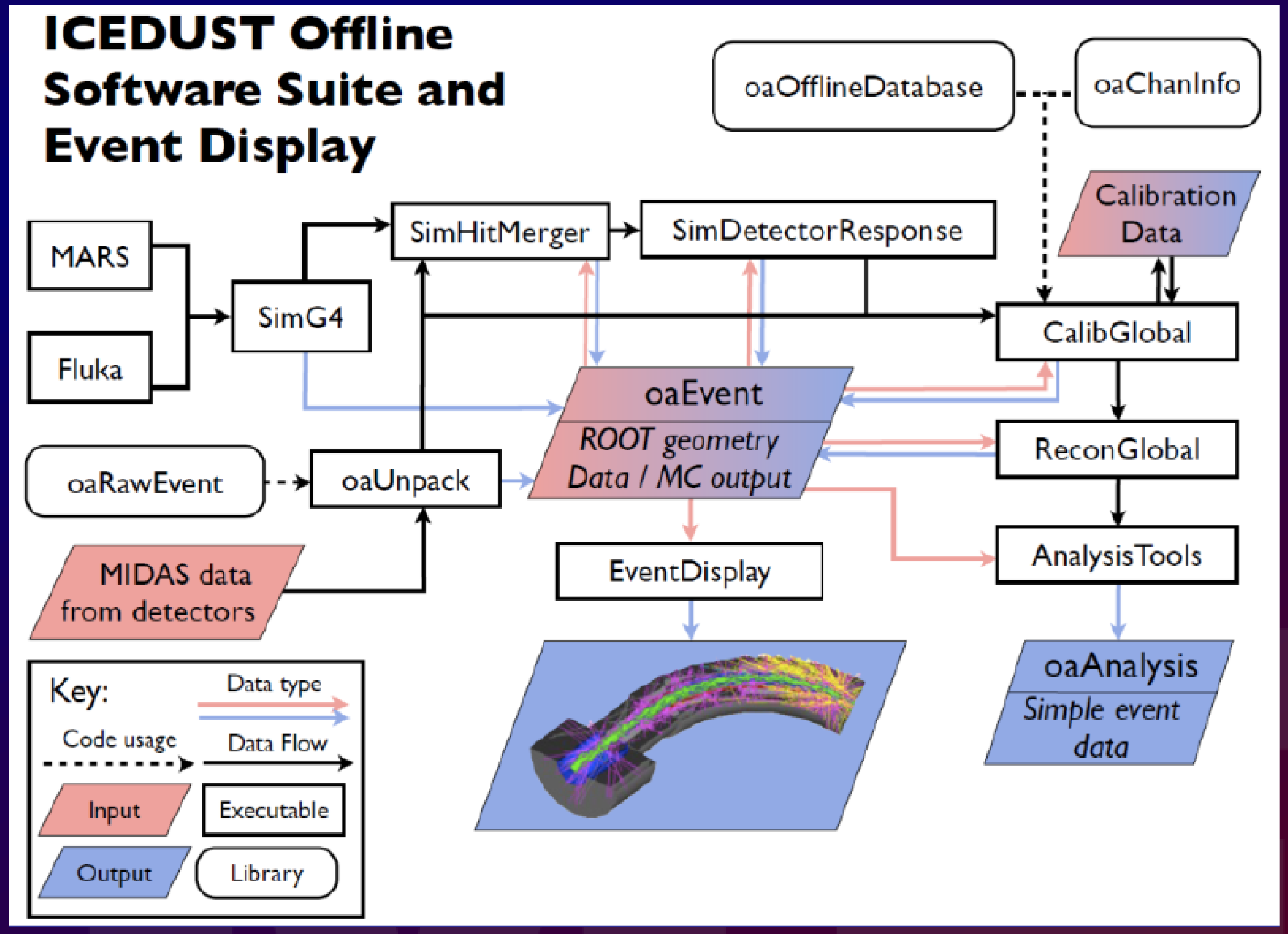


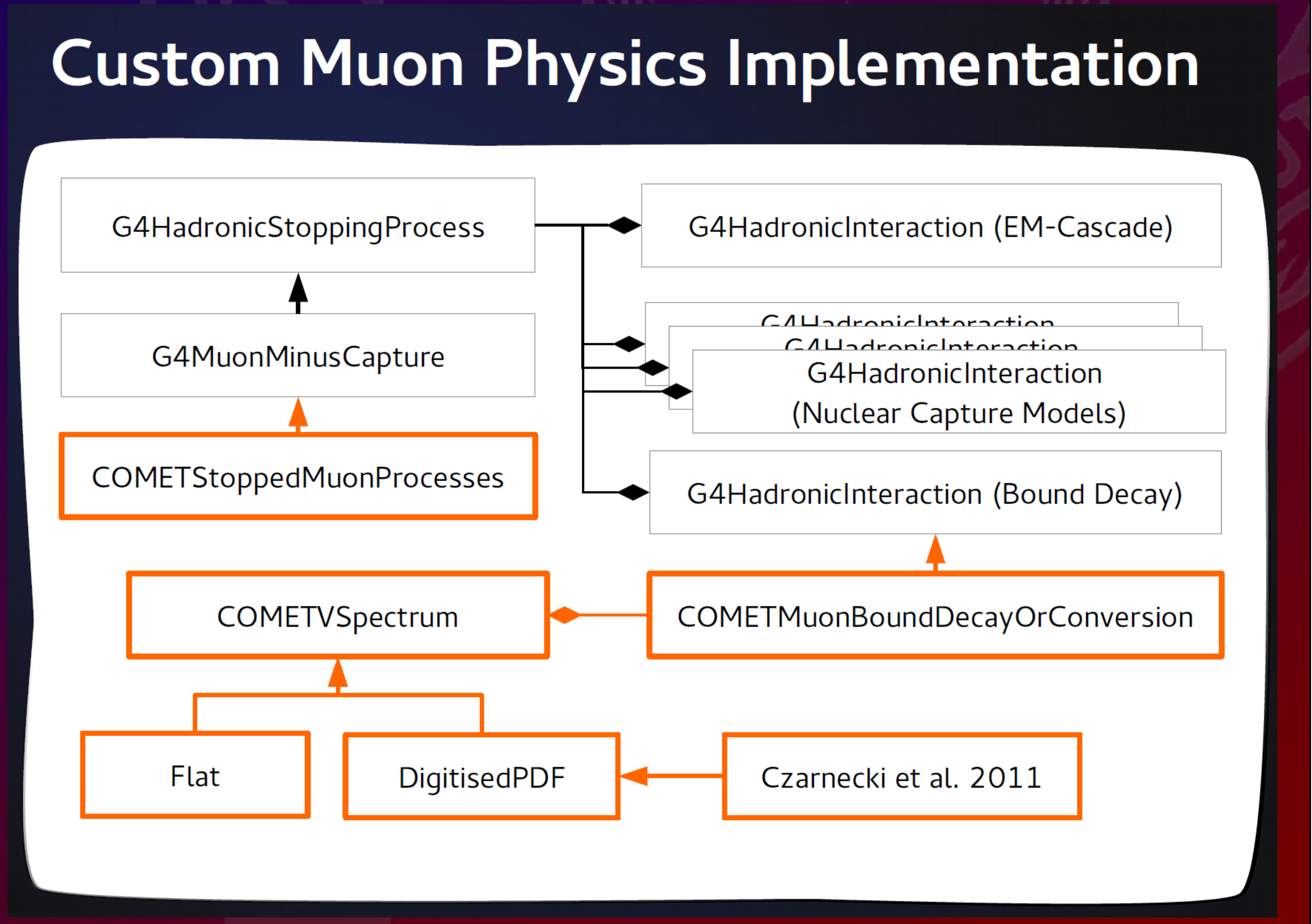
FC7 Testing in Korea



Software

- Decision made in 2013 to build dedicated software framework ICEDUST
  - based on T2K ND280 software, re-organised from the bottom up
  - truly UK-led effort, coordinating work across the collaboration
    - highly active participation in software effort from other nations
    - has become a very substantial and high-quality software suite

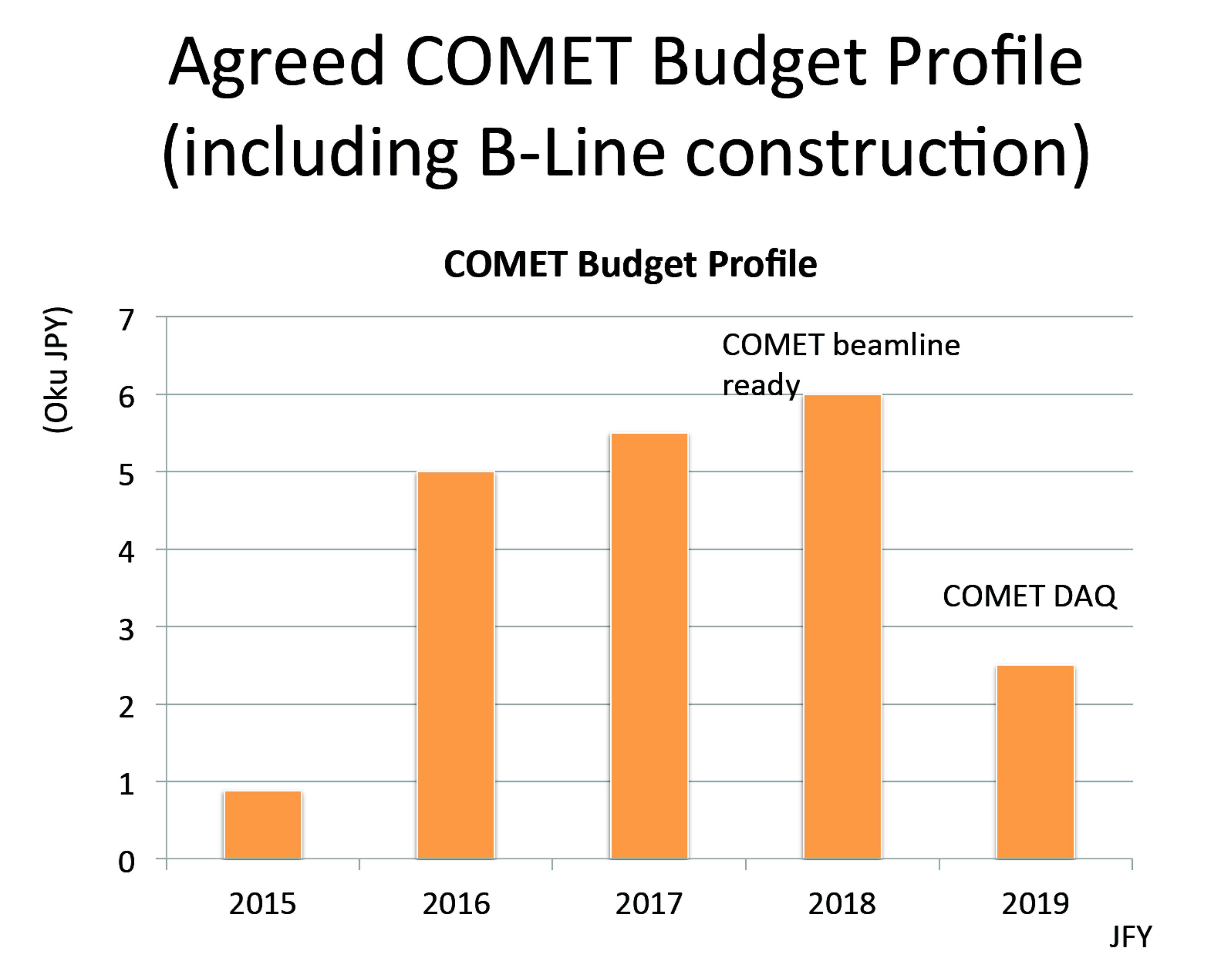




Timeline

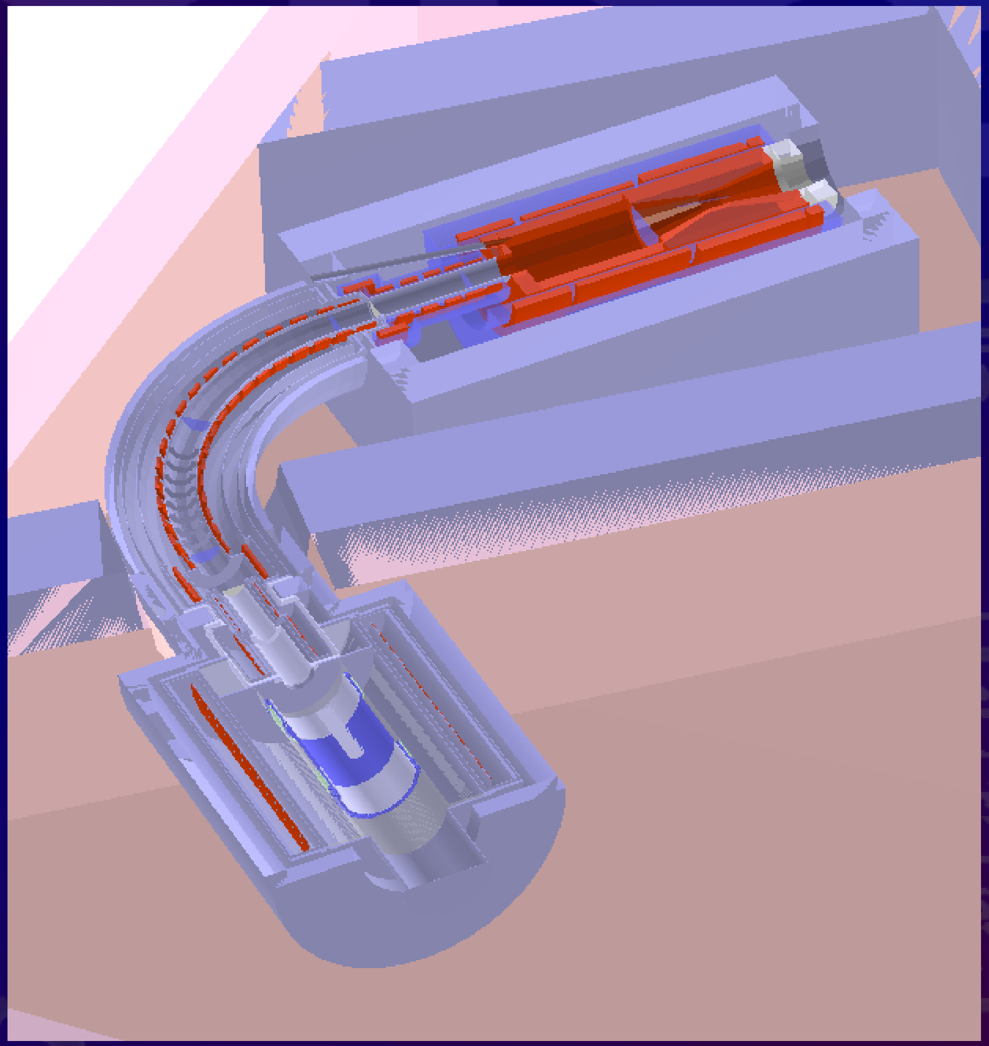
- J-PARC radiation accident (May 2013)
  - COMET, being under construction, impacted directly
- J-PARC/KEK Stakeholders (all experiments) agreement to prioritise funding for COMET
  - budget profile for "baseline" funding scenario shown below
  - more optimistic scenarios move data-taking forward

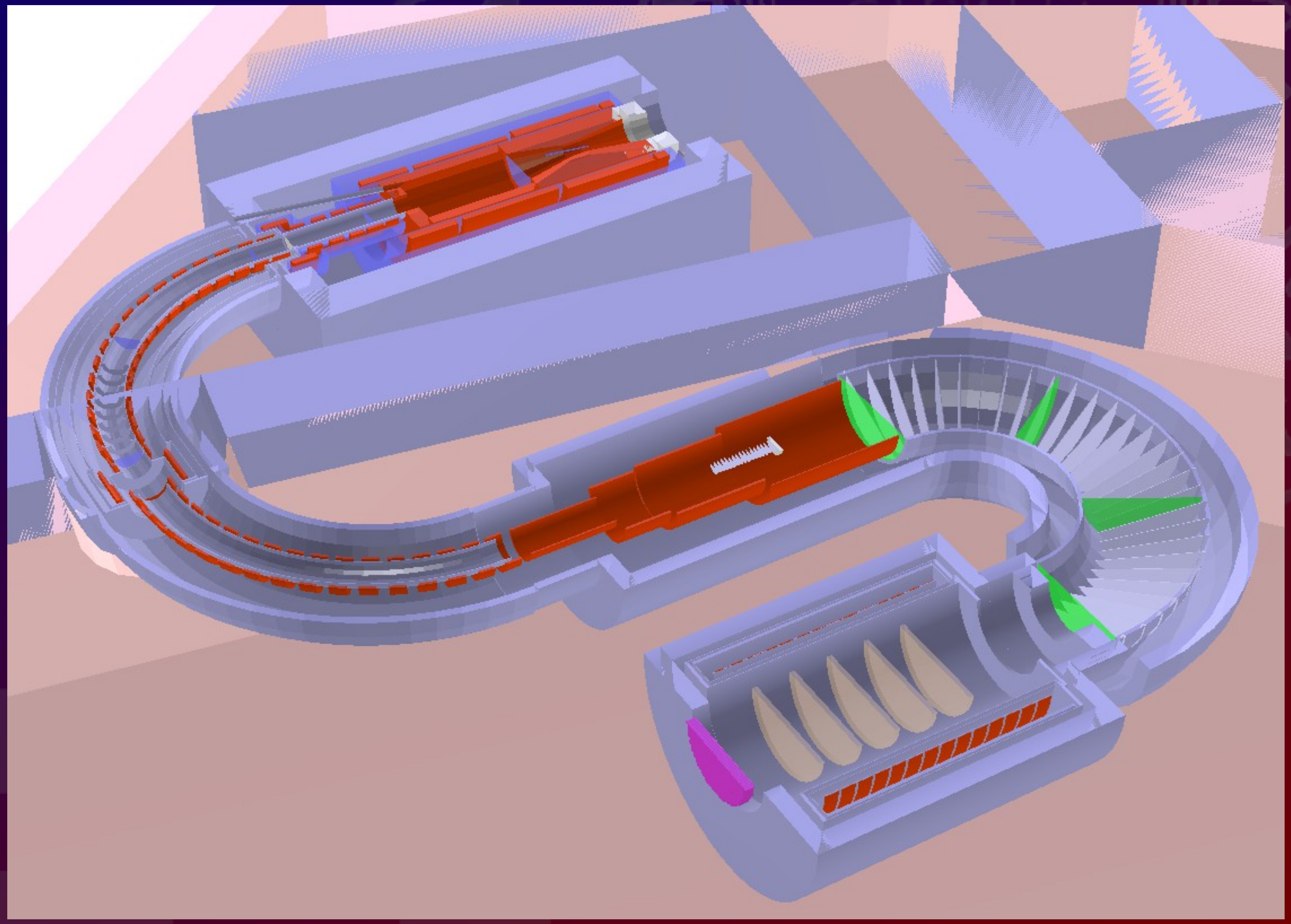
⇒ Data-taking in 2018 or 2019



Phase-I to Phase-II

- Rapid transition from Phase-I to Phase-II (about two years)
  - same pion capture solenoid
  - same detector solenoid, with extension
  - re-use of Straw Tracker components
  - re-use of ECAL
- Main new component: electron spectrometer solenoid
  - build on Phase-I experience; superconducting cable can be produced in advance
- UK-led Phase-II physics studies ongoing
  - to be reflected in Phase-I running and analysis
  - sensitivity improvements





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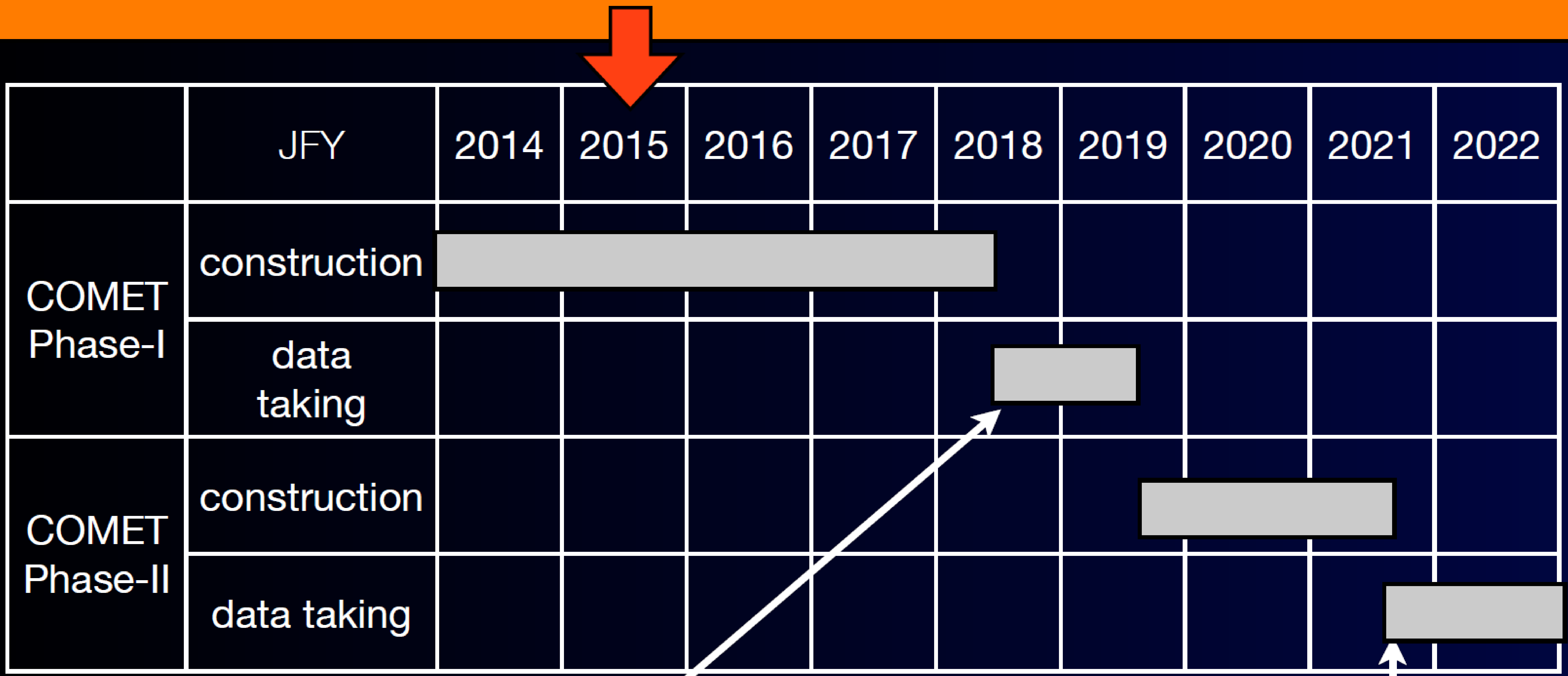
COMET & Mu2E Comparison

- COMET has *tunable*, vertical dipole fields to select particle charge and momentum
  - "C-shaped" solenoids v "S-shaped" solenoids
  - muon beam momentum selection
  - electron spectrometer for background rejection
- Different beam power (pion production solenoid design):
  - 56 kW for COMET, 8 kW for Mu2E
    - 3 years v 1 year data for full sensitivity
- "Phased approach" for COMET
  - to study partial beam line while preparing full experiment
- Also planning PRISM to allow precision measurements of CLFV

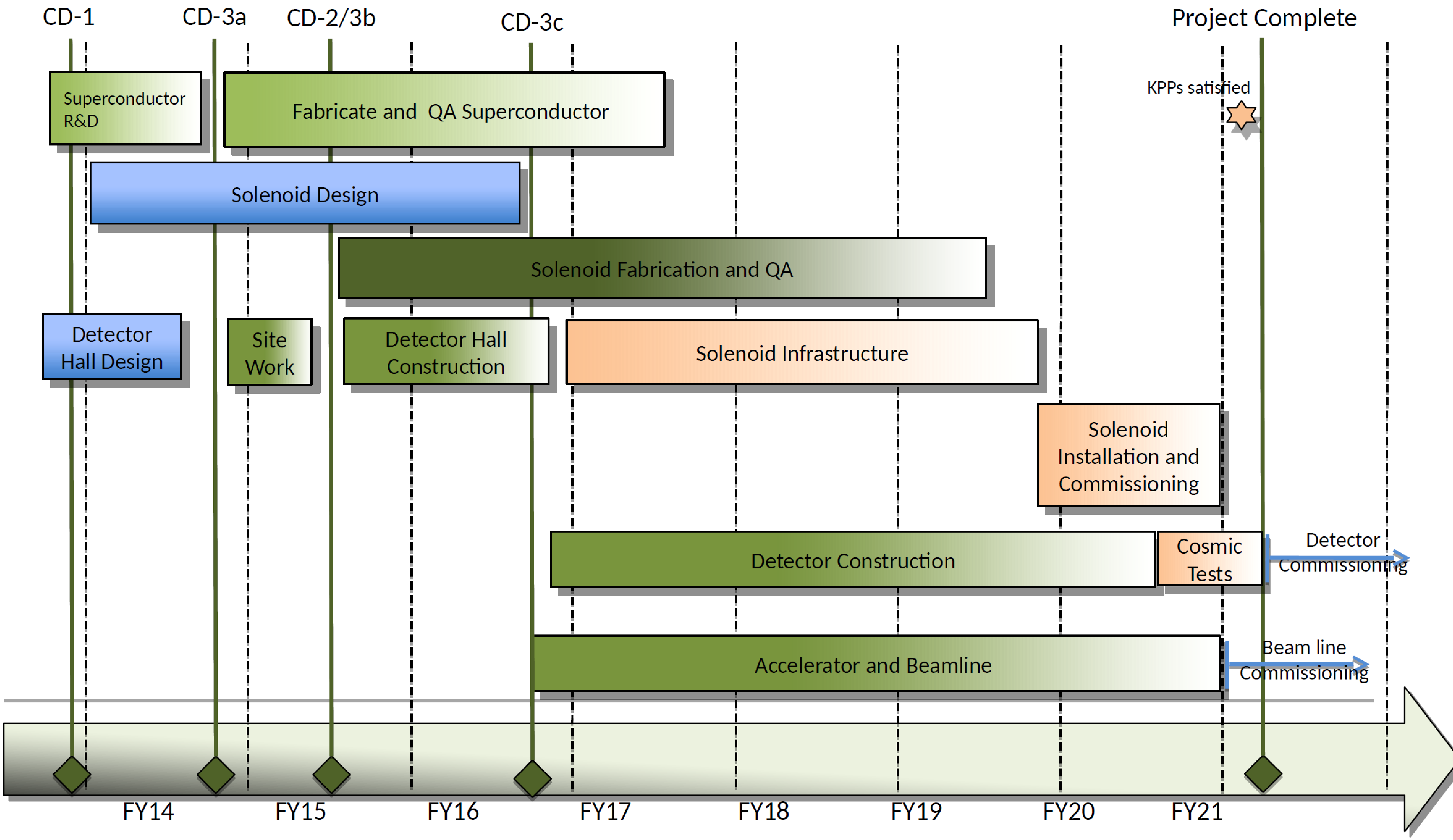
Schedule of COMET Phase-I and Phase-II



COMET Phase-I :
2018 ~
S.E.S. ~ 3×10^{-15}
(for 110 days
with 3.2 kW proton beam)

COMET Phase-II :
2021~
S.E.S. ~ 3×10^{-17}
(for 2×10^{7} sec
with 56 kW proton beam)

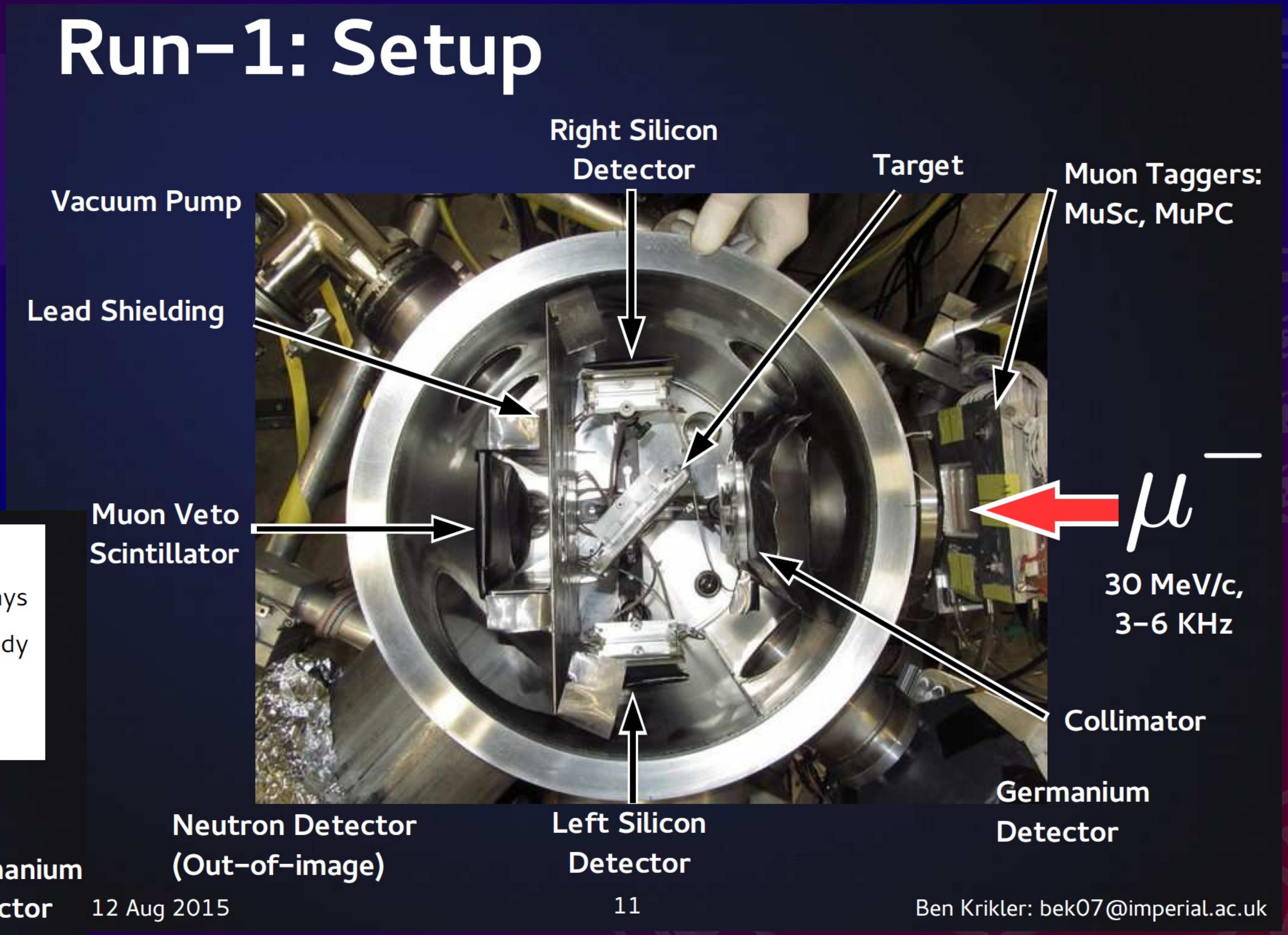
Mu2e has a technically limited schedule that will lead to data very early in the 2020s

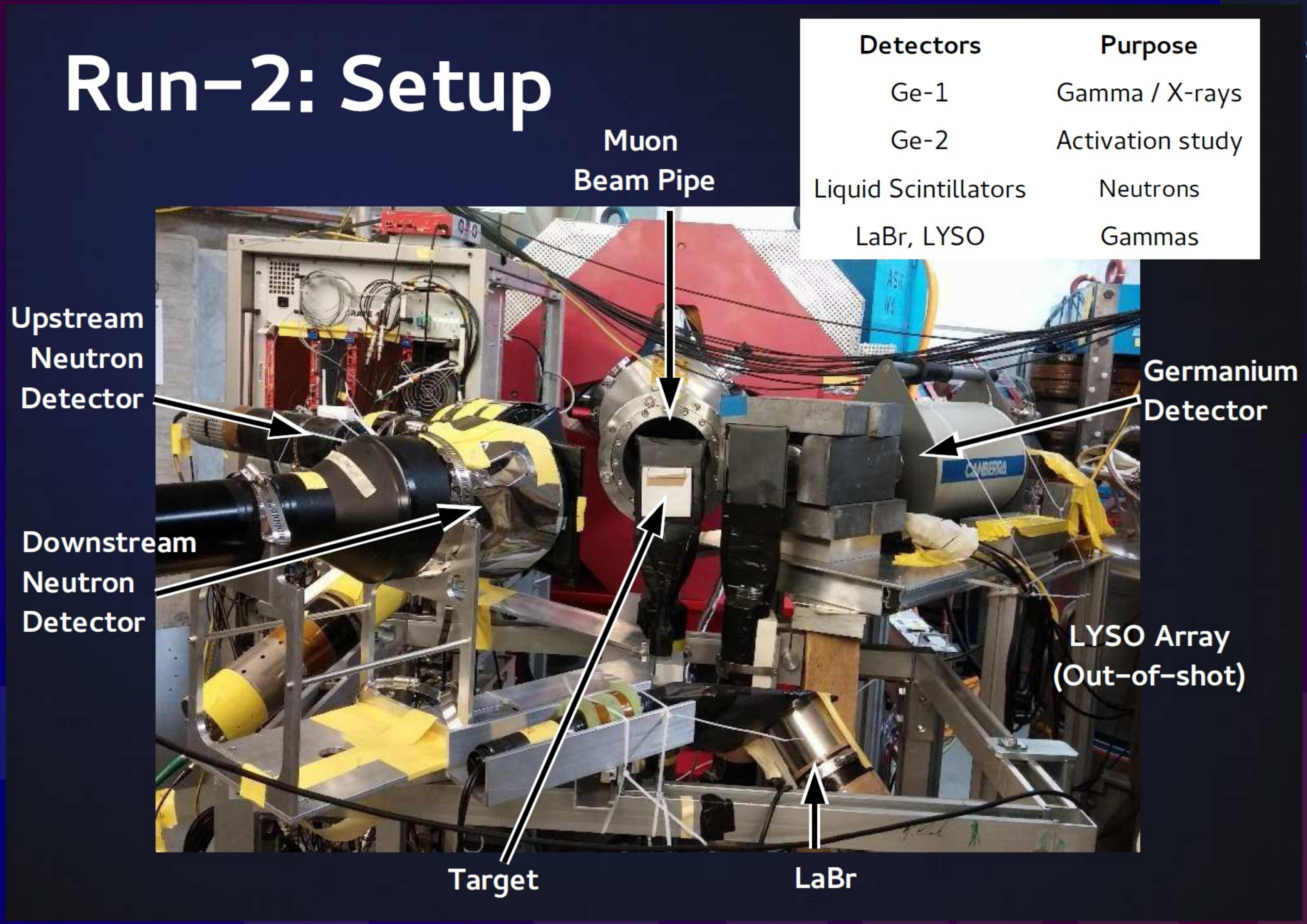


Produced: February 2015

AlCap

- Support experiment at PSI to measure particle emissions when muons stop in Al
- Charged (Runs 1 & 3) and neutral emissions
- Joint COMET/Mu2E effort

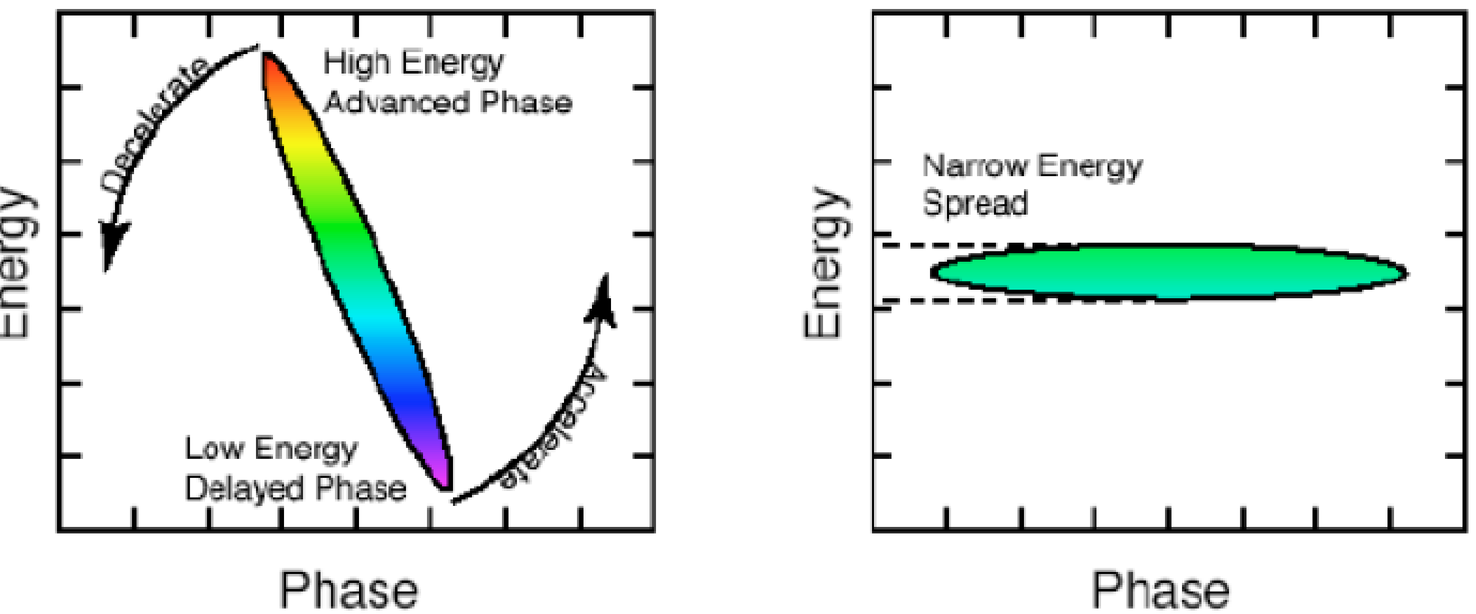




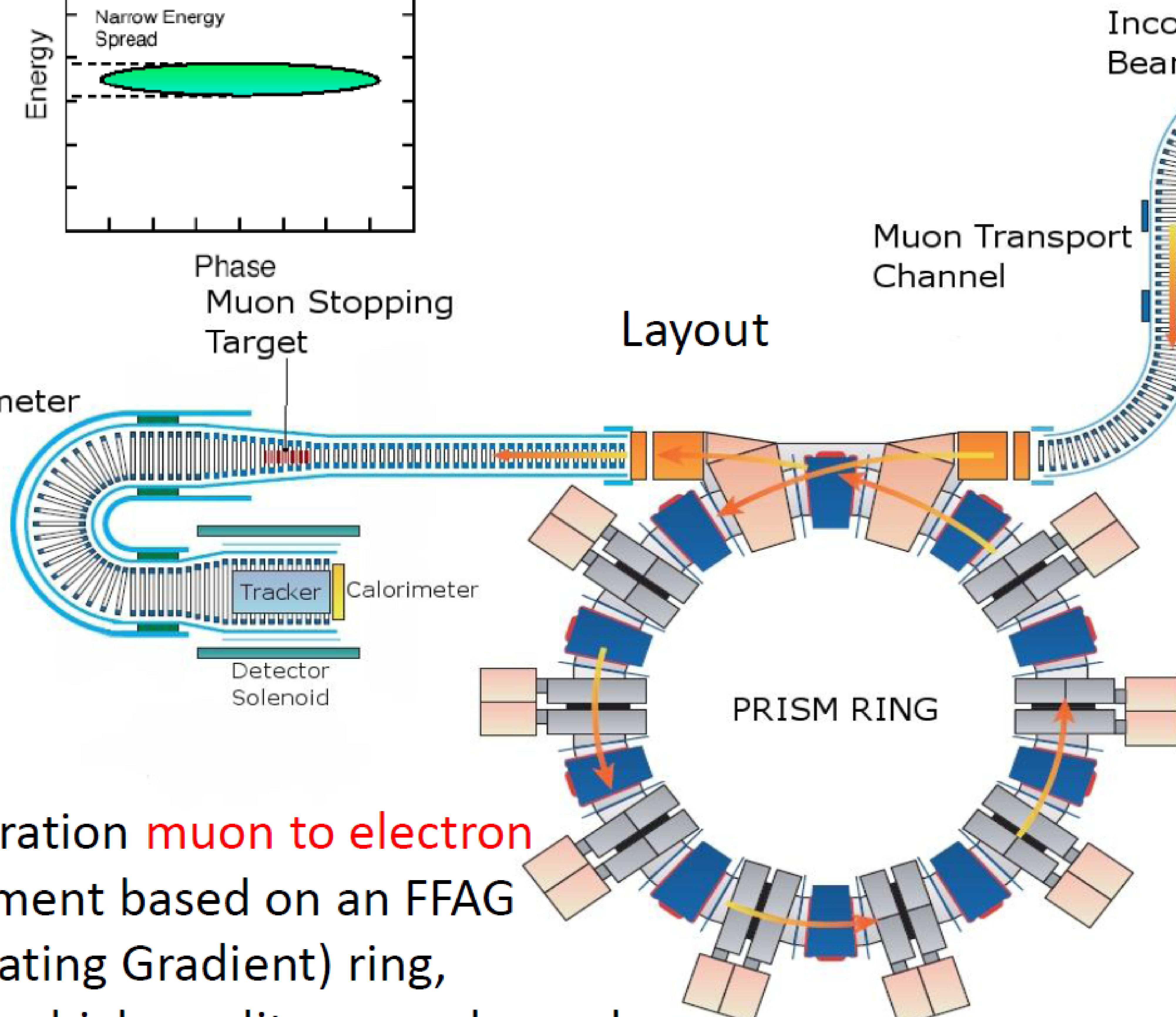
UK involvement in all AlCap runs; publications forthcoming

PRISM

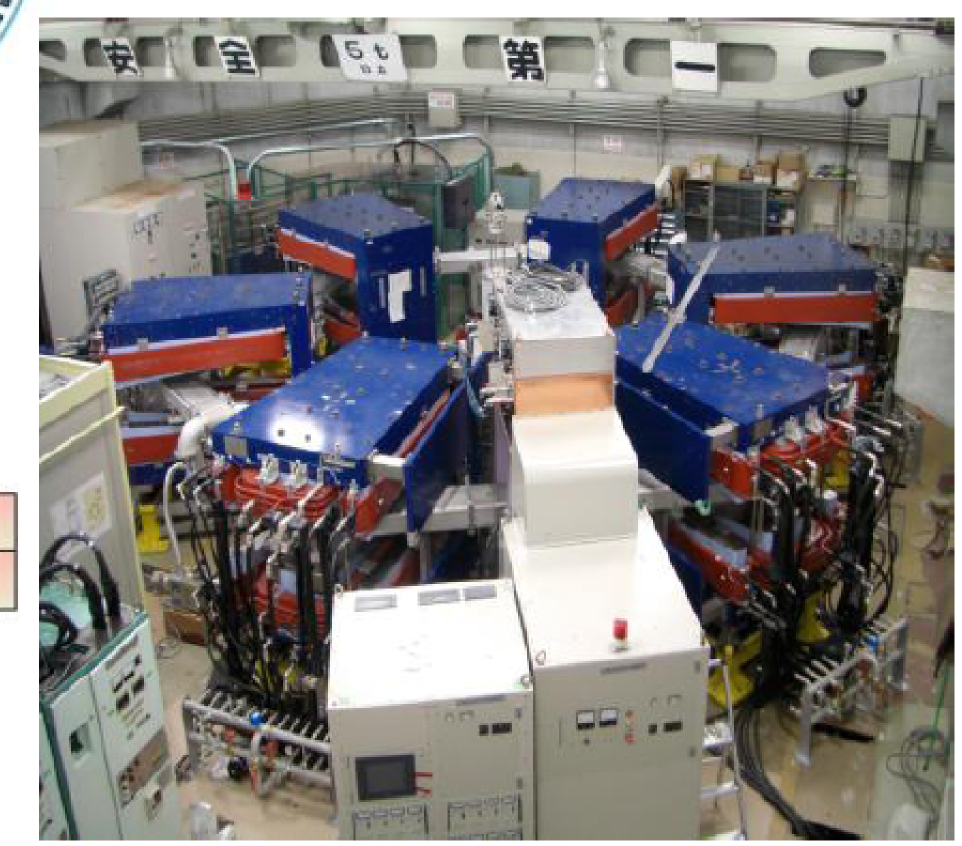
PRISM - Phase Rotated Intense Slow Muon beam



Phase Rotation



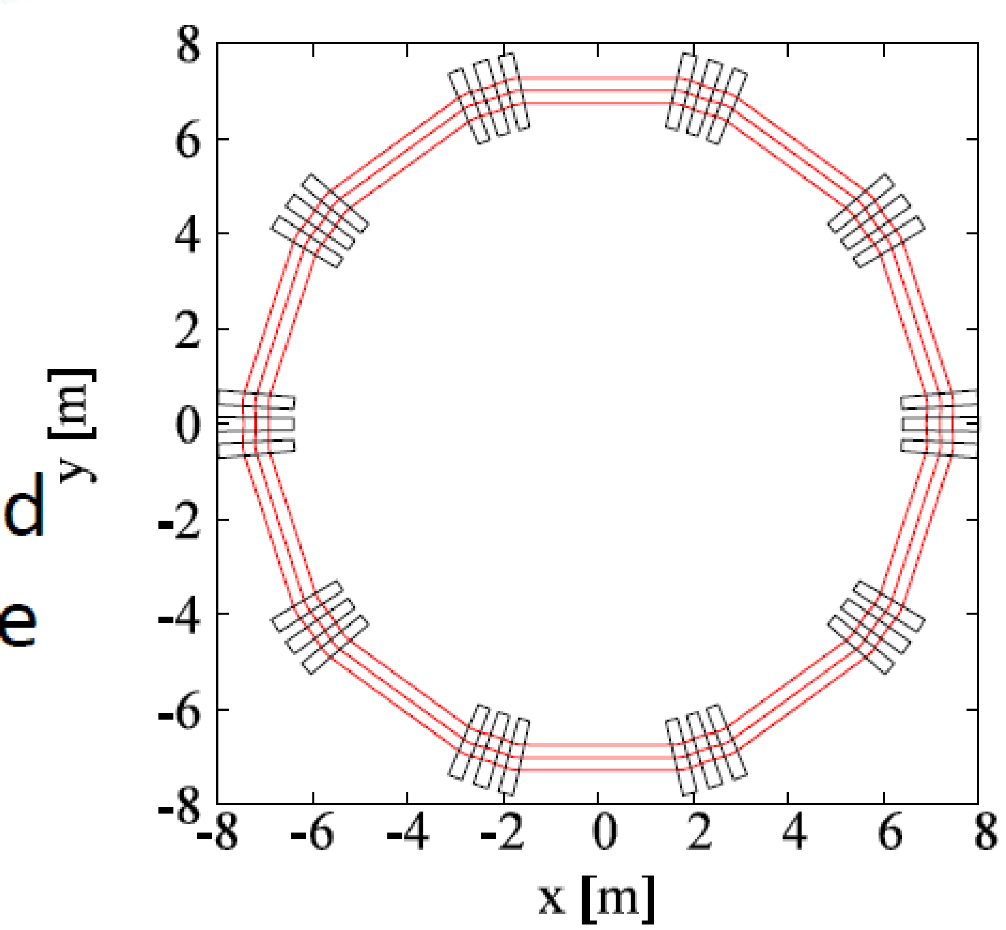
Test ring in Osaka



PRISM:

- It is the next generation muon to electron conversion experiment based on an FFAG (Fixed Field Alternating Gradient) ring,
- It allows to create a high quality muon beam by:
  - reducing the muon beam energy spread by RF phase rotation,
  - purifying the muon beam in the storage ring.
- It will have single event sensitivity – 3×10^{-19}
- Design details are being addressed by the Task Force led by Jaroslaw Pasternak (contact him for more details).

Alternative ring designed by Task Force



UK Timeline

- Participation since 2007; before the start of COMET
- Contributed to approval of Phase-I construction in 2012
- In 2013, had Subproject Manager roles in:
  - **Trigger DAQ hardware/firmware**
  - **DAQ Readout**
  - **Software**
  - **Proton beam target**
  - **(Muon monitor detector)**
- Inaugural Collaboration Board Chair

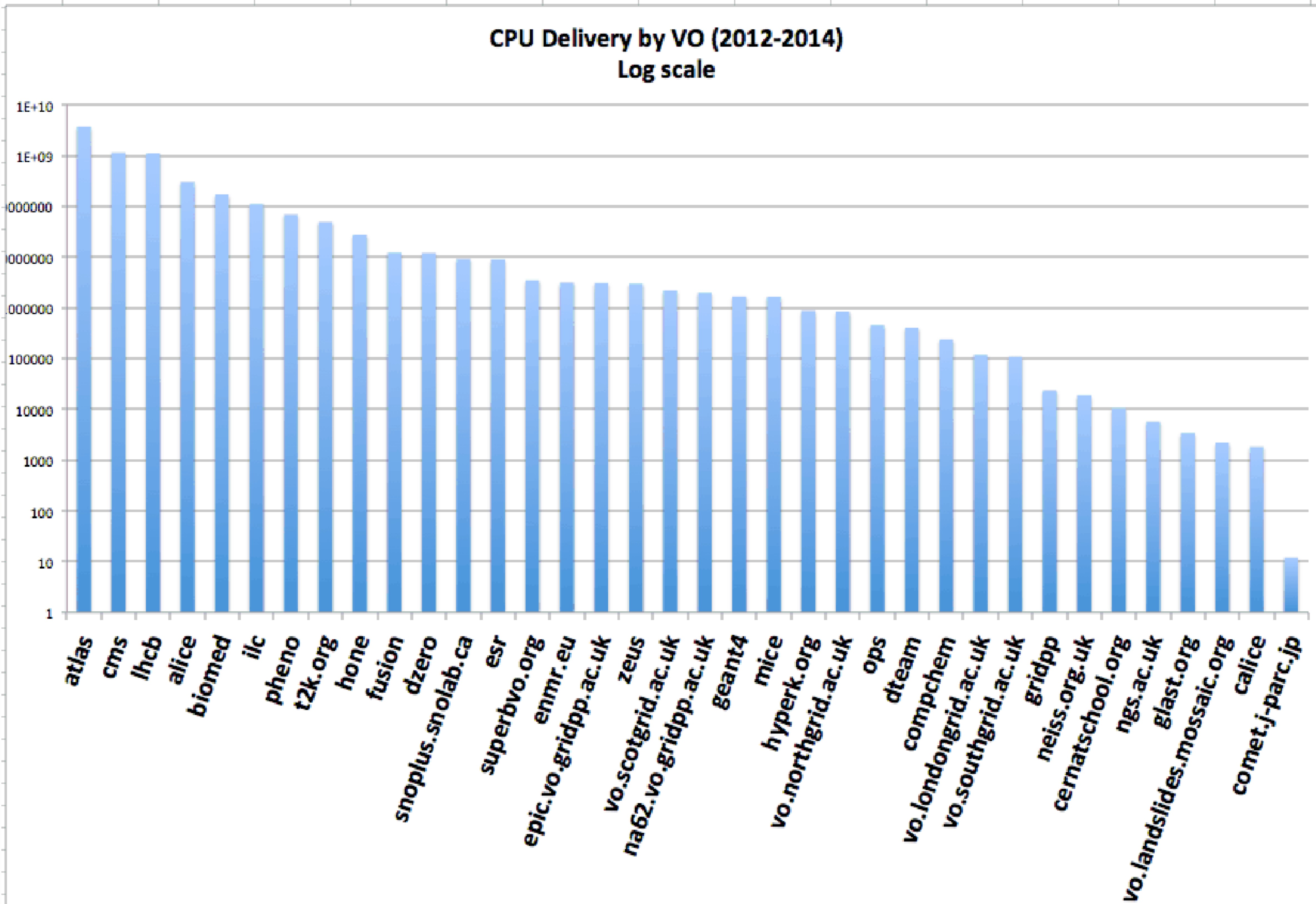
- Phase-I recommended by PPRP for funding in 2013
- Science Board: "proposal fits well within the STFC Roadmap and that the Particle Physics Advisory Panel's 2012 report had concluded there was a strong science case"
- Science Board decision to not fund

UK Status

- Reduced UK role significantly
  - cannot reduce further
- Closely coordinating with other countries to cover UK responsibilities
  - UK-designed trigger hardware and readout, proton targetry etc, being built by other groups
- Current UK positions in collaboration:
  - (new) Collaboration Board Chair
  - Physics Analysis Coordinator
  - Software Coordinator
- UK GridPP expertise, working with CC-IN2P3

UK Status

LHC and More



David Britton, University of Glasgow PPAP

UK Status

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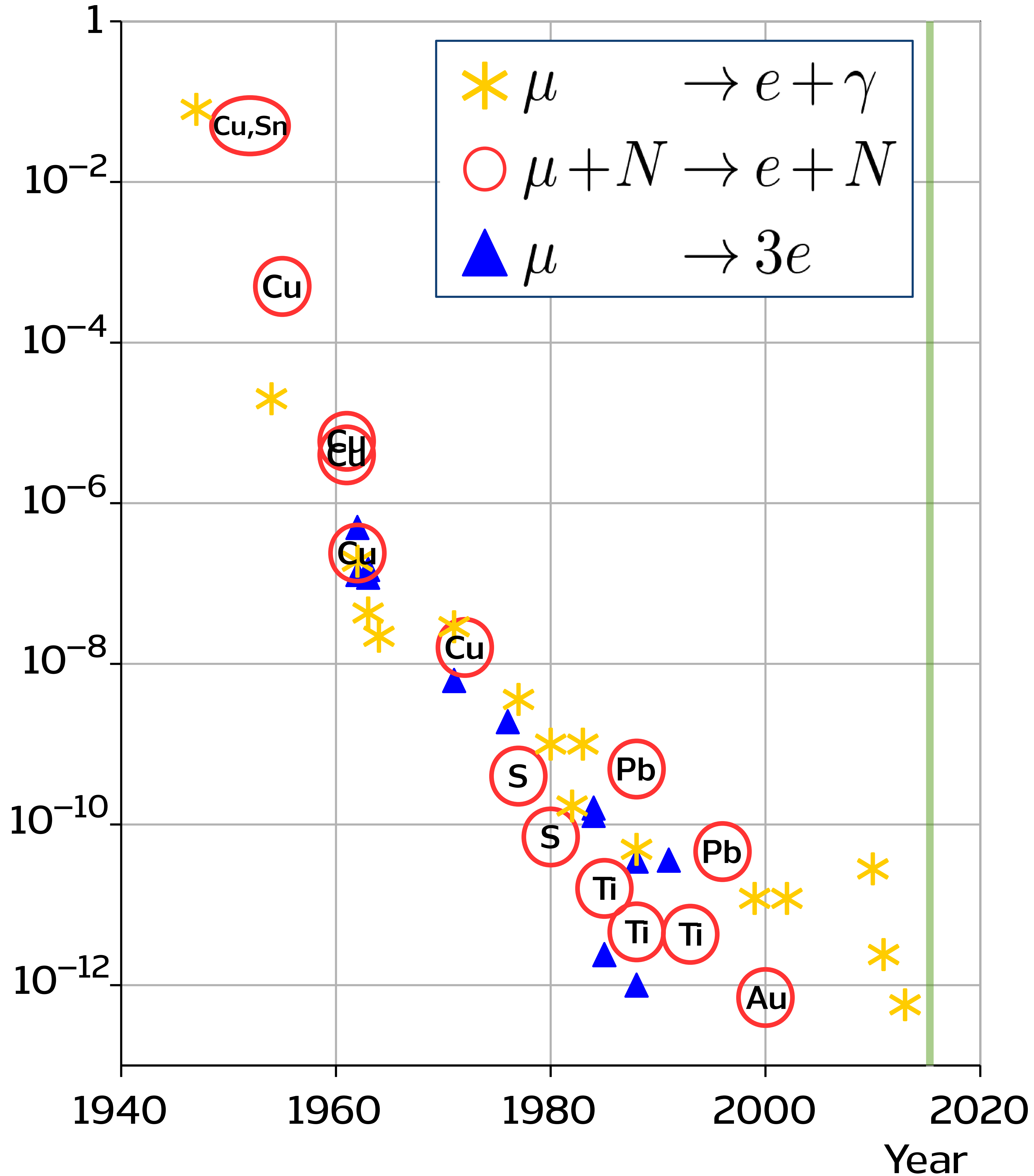
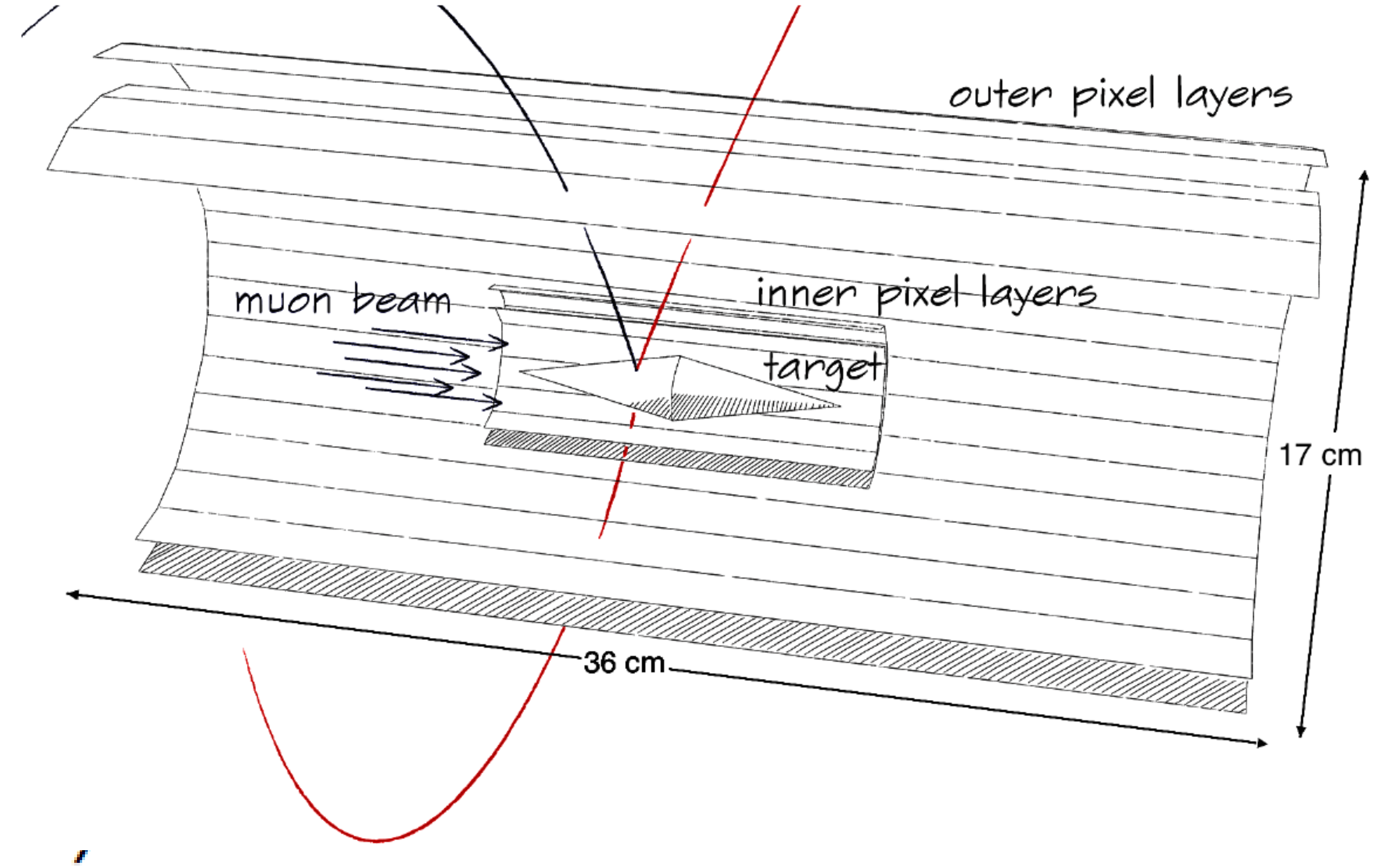
  - cannot reduce further
- Closely coordinating with other countries to cover UK responsibilities
  - UK-designed trigger hardware and readout, proton targetry etc, being built by other groups
- Current UK positions in collaboration:
  - Collaboration Board Chair
  - Physics Analysis Coordinator
  - Software Coordinator
- UK GridPP expertise, working with CC-IN2P3
- Continued AlCap/MUSIC exploitation
  - Participation in AlCap runs in 2013 and 2015
- Leadership of PRISM Task Force

The Current State of Muon Flavour Violation Searches



90% C.L. upper limit on branching ratios

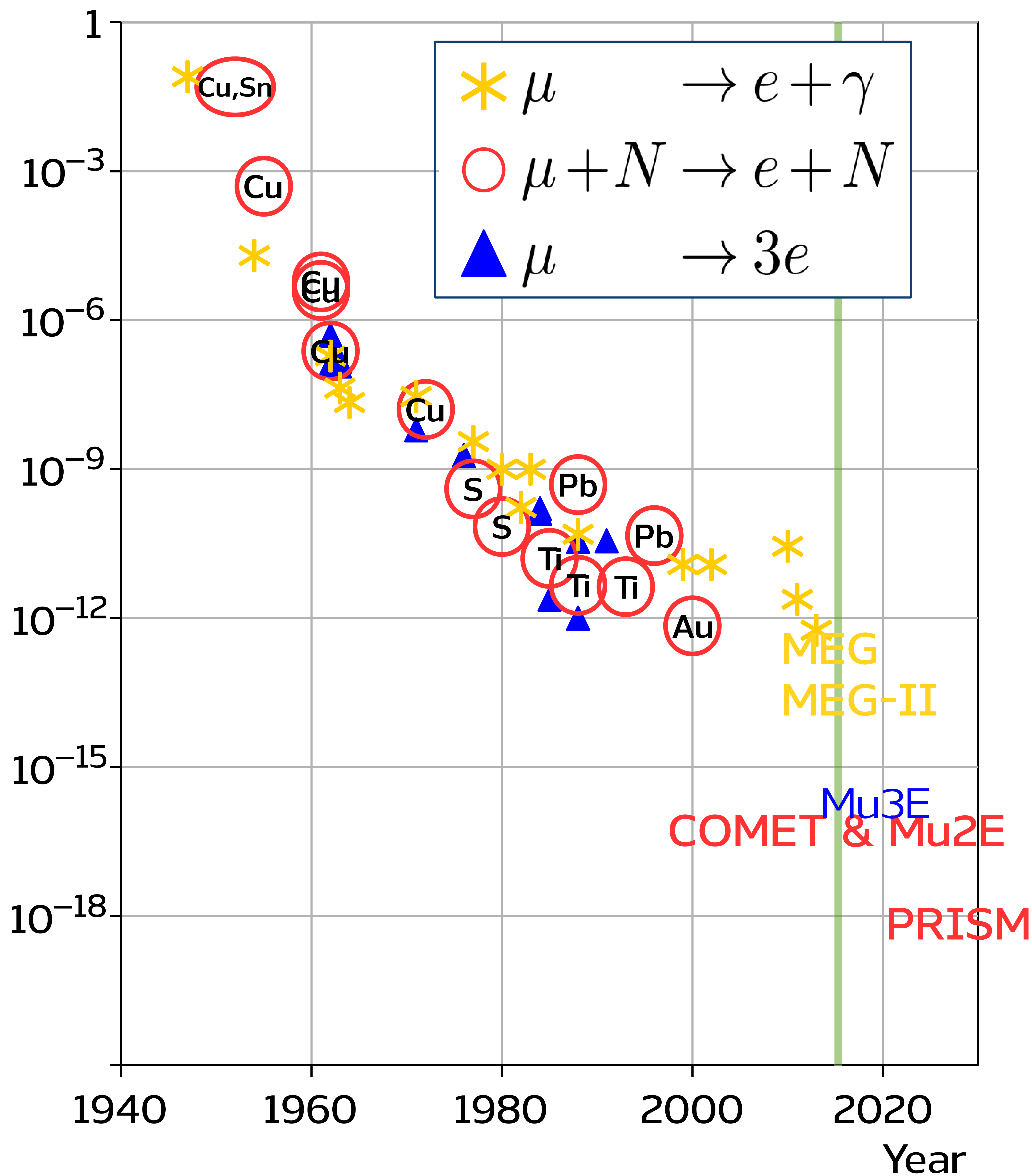
Yoshi.Uchida@imperial.ac.uk



The Mu3e Collaboration:

- beam and target (PSI)
- solenoidal magnet (PI-HD)
- pixel detector (PI-HD, KIT, Ma
- scintillating fibre detector (ETHZ, PSI, UniGe, UZH)
- scintillating tile detector (KIP-HD)
- detector readout and filter farm (Mainz)
- mechanics and cooling (PSI, PI-HD)
- experimental infrastructure (PSI)
- slow control (PSI)

Future Muon Flavour Violation Searches



90% C.L.
upper limit on
branching ratios

Yoshi.Uchida@imperial.ac.uk

Experimental Limits on Lepton Flavour Violation

Reaction	Present limit
$\mu^+ \to e^+\gamma$	$< 5.7 \times 10^{-13}$
$\mu^+ \to e^+e^+e^-$	$< 1.0 \times 10^{-12}$
$\mu^- Ti \to e^- Ti$	$< 6.1 \times 10^{-13}$
$\mu^- Au \to e^- Au$	$< 7 \times 10^{-13}$
$\mu^+e^- \to \mu^-e^+$	$< 8.3 \times 10^{-11}$
$\tau \to e\gamma$	$< 3.3 \times 10^{-8}$
$\tau \to \mu\gamma$	$< 4.4 \times 10^{-8}$
$\tau \to \mu\mu\mu$	$< 2.1 \times 10^{-8}$
$\tau \to eee$	$< 2.7 \times 10^{-8}$
$\pi^0 \to \mu e$	$< 3.8 \times 10^{-10}$
$K_L^0 \to \mu e$	$< 4.7 \times 10^{-12}$
$K^+ \to \pi^+\mu^+e^-$	$< 1.3 \times 10^{-11}$
$K_L^0 \to \pi^0\mu^+e^-$	$< 7.6 \times 10^{-11}$
$Z^0 \to \mu e$	$< 1.7 \times 10^{-6}$
$Z^0 \to \tau e$	$< 9.8 \times 10^{-6}$
$Z^0 \to \tau\mu$	$< 1.2 \times 10^{-5}$

90% C.L.
upper limits on
branching ratios

Complementarity of CLFV Channels

- The various CLFV channels *complement* each other
  - CLFV muons and tau decays
    - different muon-to-electron conversion nuclei
  - CLFV decays of heavier particles
    - mesons, vector bosons, Higgses....
- The relative rates can tell us the nature of the BSM physics

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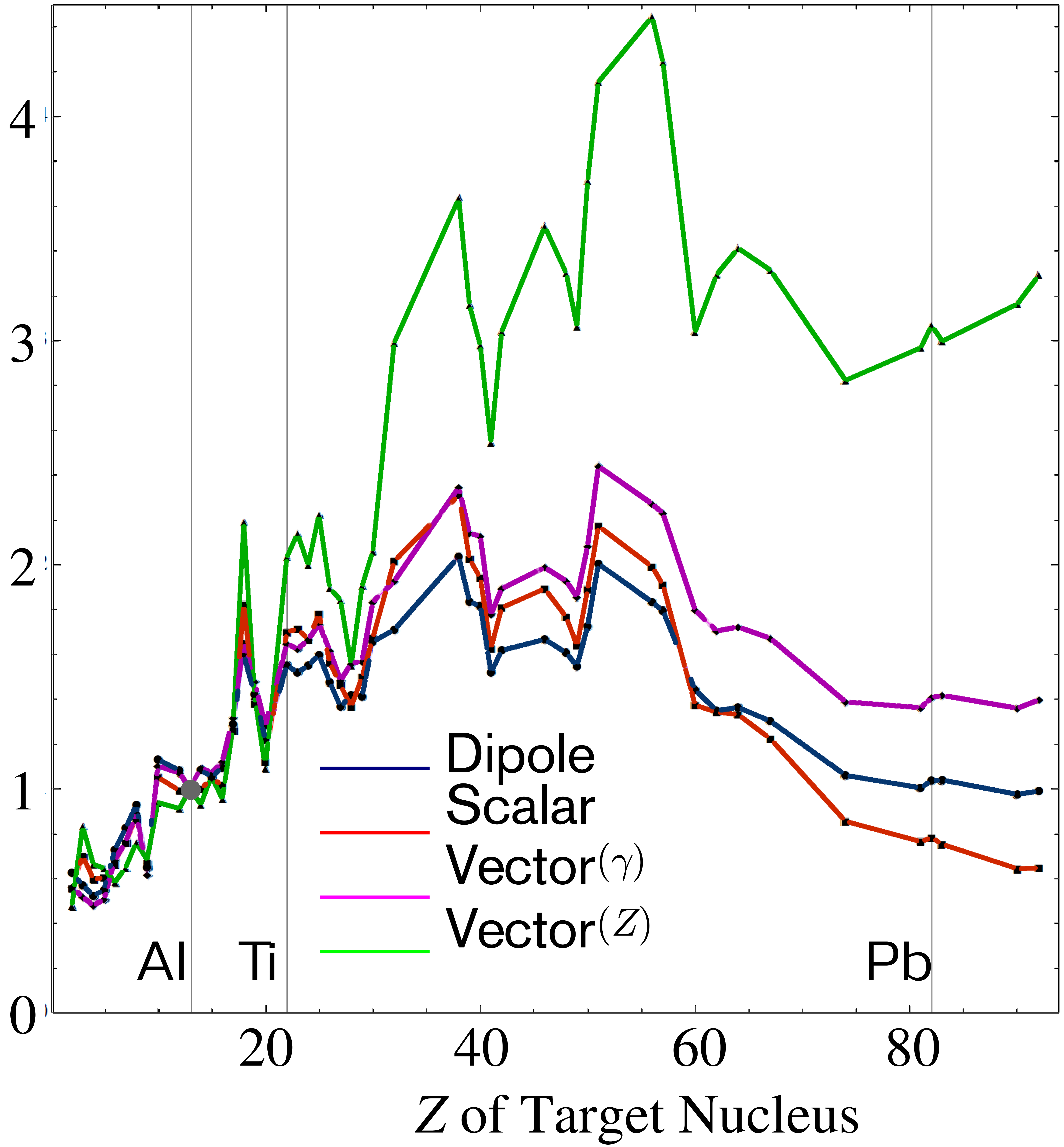
Relative dependences of the muon-to-electron conversion branching ratio on the target nucleus

For different nuclei, different

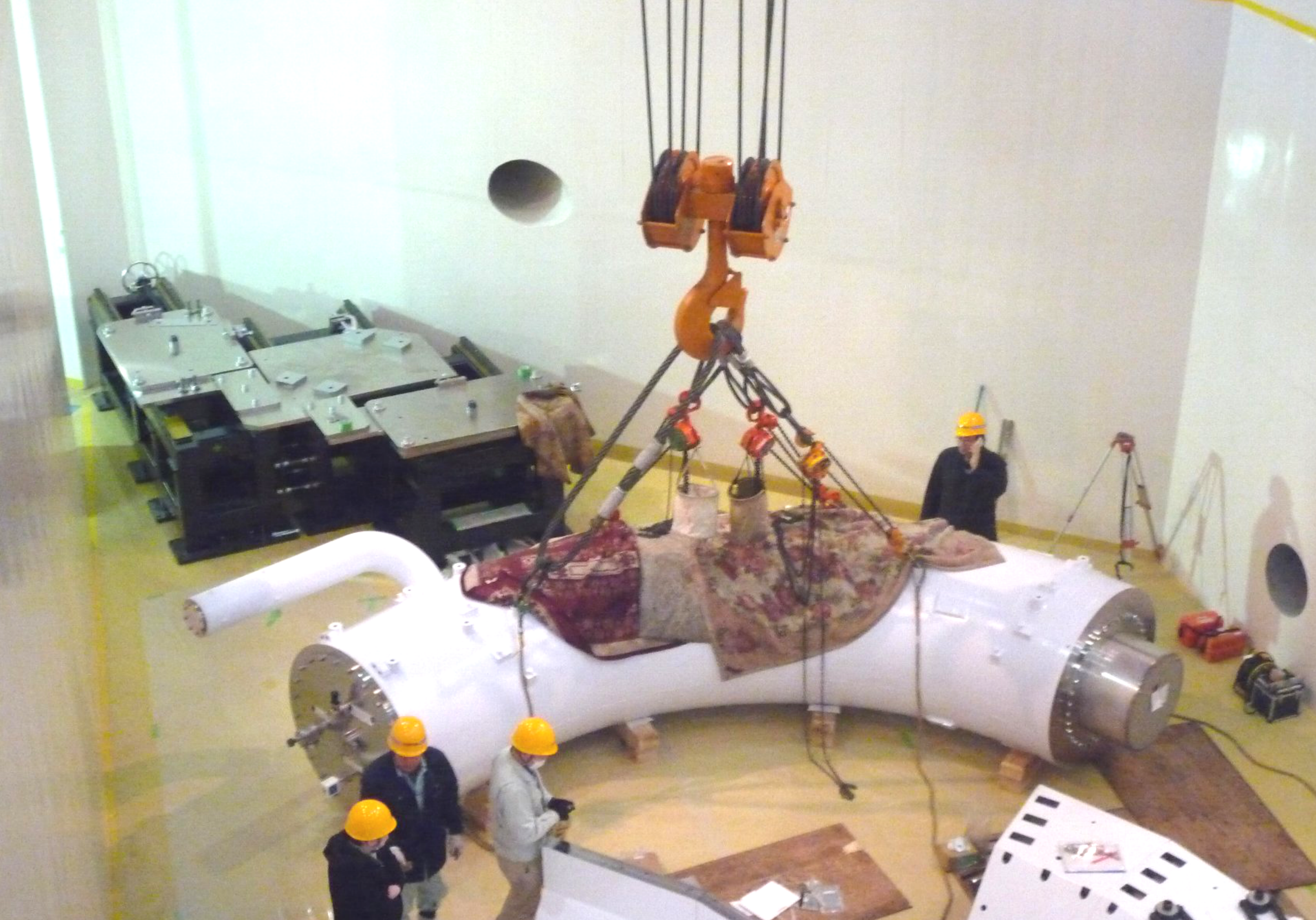
size of nucleus,
radius of orbit,
u- and d-quark composition



Conclusions

- An exciting time for muon CLFV experimentation
  - a thriving global effort to probe beyond the SM
- COMET on track to perform world's first new muon-to-electron conversion experiment since SINDRUM-II (which last took data in 2000)
  - First example of novel, pulsed-beam measurement
  - Also considering other BSM physics channels
  - Phase-II to follow Phase-I within about two years
    - significant opportunities for UK leadership
      - based on Phase-I experience
      - if STFC agrees CLFV is worth it after all
    - experimental design allows for further improvement
- PRISM presents unique future possibility within muon CLFV of a factor 1,000,000 improvement


Comet
AUG
California
CPFC




PHYSICAL REVIEW D **74,** 116002 (2006)

Lepton flavor violation from supersymmetric grand unified theories: Where do we stand for MEG, PRISM/PRIME, and a super flavor factory

L. Calibbi,[1] A. Faccia,[1] A. Masiero,[1] and S. K. Vempati[2,3]

(Received 29 August 2006; published 13 December 2006)

We analyze the complementarity between lepton flavor violation (LFV) and LHC experiments in probing the supersymmetric (SUSY) grand unified theories (GUT) when neutrinos get a mass via the seesaw mechanism. Our analysis is performed in an SO(10) framework, where at least one neutrino Yukawa coupling is necessarily as large as the top Yukawa coupling. Our study thoroughly takes into account the whole renormalization group running, including the GUT and the right-handed neutrino mass scales, as well as the running of the observable neutrino spectrum. We find that the upcoming (MEG, SuperKEKB) and future (PRISM/PRIME, super flavor factory) LFV experiments will be able to test such SUSY framework for SUSY masses to be explored at the LHC and, in some cases, even beyond the LHC sensitivity reach.

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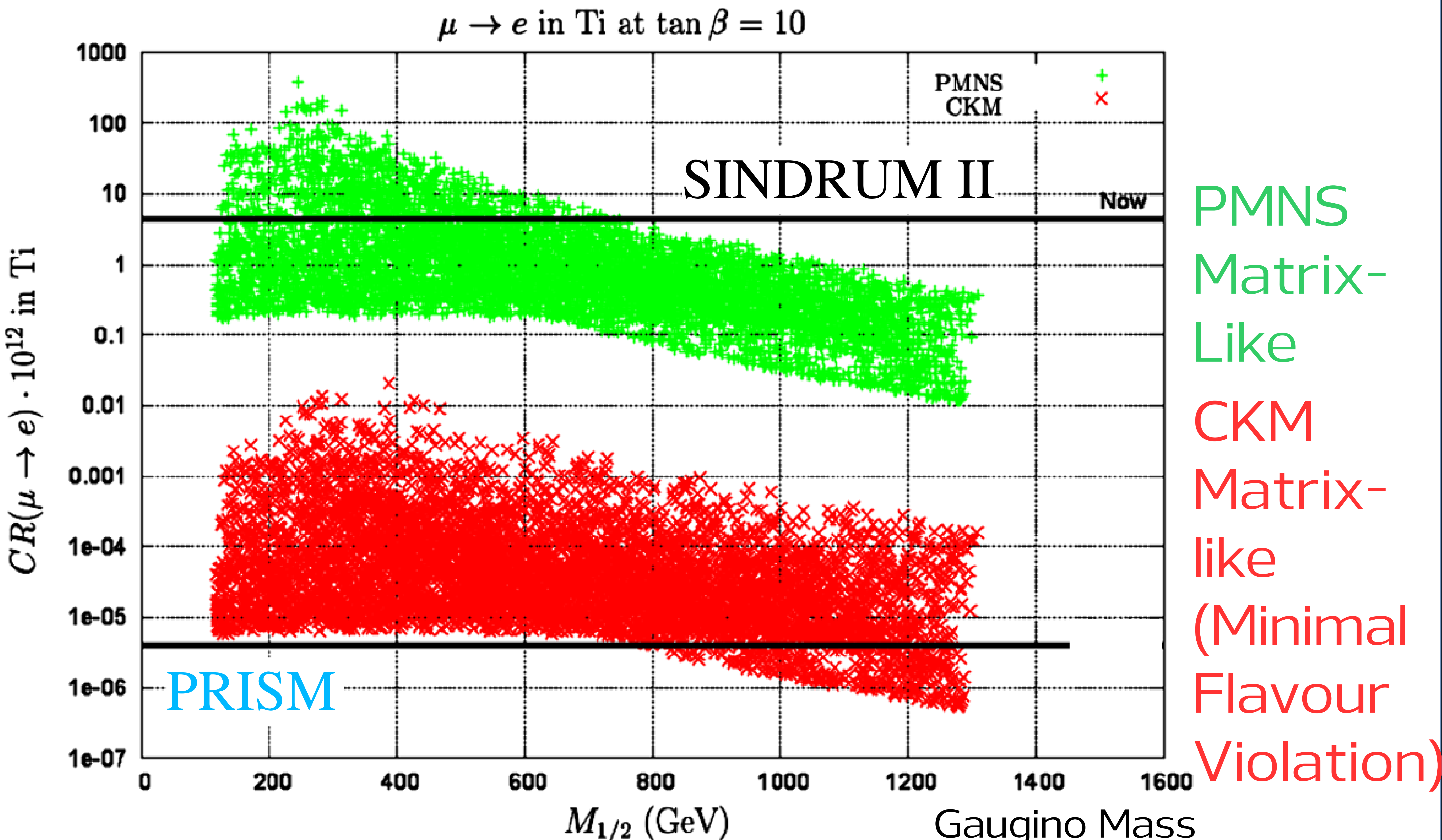
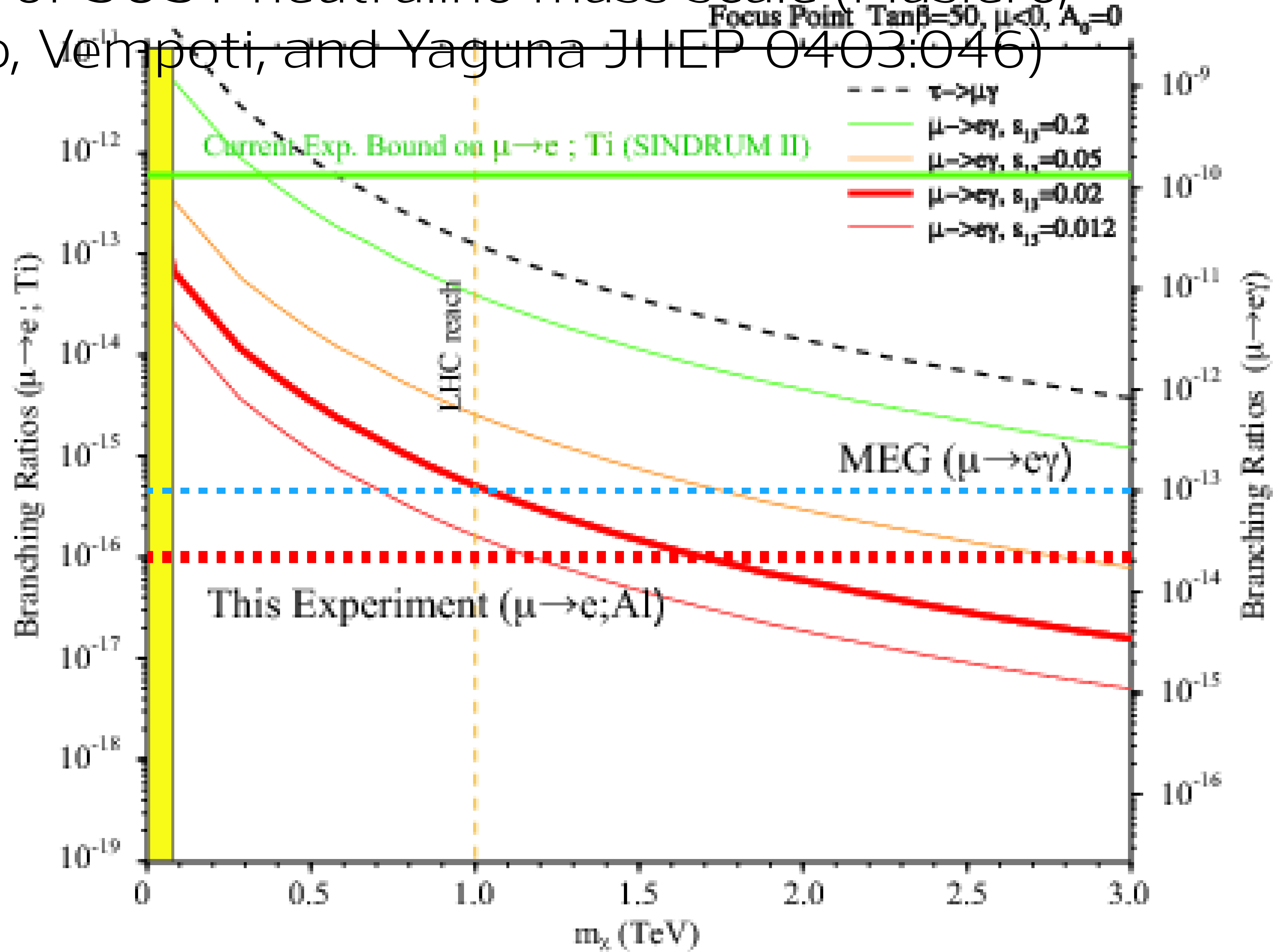


$\mu \longrightarrow e$ in Ti as a probe of SUSY-GUT scenarios. The plots are obtained by scanning the LHC accessible parameter space. The horizontal lines are the present (SINDRUM II) bound and the planned (PRISM/PRIME) sensitivity to the process. We see that PRIME would be able to severely constrain the low $\tan\beta$, low mixing angles case and to completely test the other scenarios.

Prediction of the muon-to-electron conversion branching ratio in the SUSY-seesaw models as a function of SUSY neutralino mass scale (Masiero, Profumo, Vempoti, and Yaguna JHEP 0403:046)

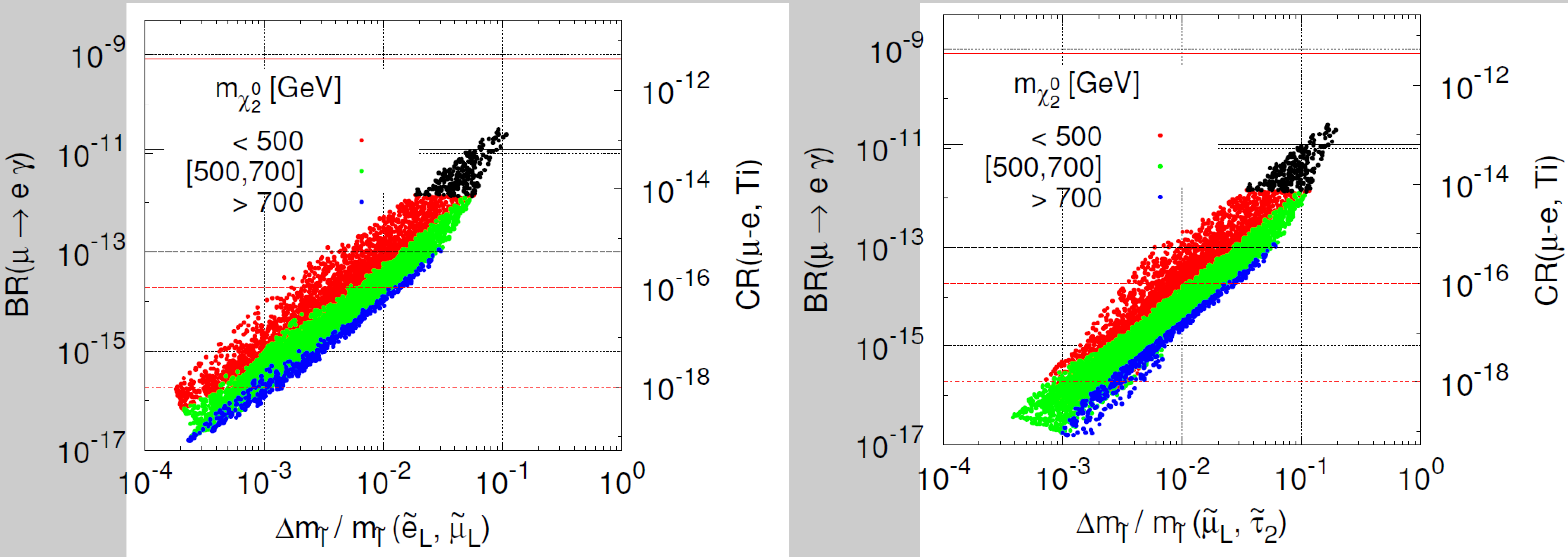


JHEP 1010:104,2010

Interplay of LFV and slepton mass splittings at the LHC as a probe of the SUSY seesaw

A. Abada[a], A. J. R. Figueiredo[b], J. C. Romão[b] and A. M. Teixeira[c]

We study the impact of a type-I SUSY seesaw concerning lepton flavour violation (LFV) both at low-energies and at the LHC. The study of the di-lepton invariant mass distribution at the LHC allows to reconstruct some of the masses of the different sparticles involved in a decay chain. In particular, the combination with other observables renders feasible the reconstruction of the masses of the intermediate sleptons involved in $\chi_2^0 \to \tilde{\ell}\,\ell \to \ell\,\ell\,\chi_1^0$ decays. Slepton mass splittings can be either interpreted as a signal of non-universality in the SUSY soft breaking-terms (signalling a deviation from constrained scenarios as the cMSSM) or as being due to the violation of lepton flavour. In the latter case, in addition to these high-energy processes, one expects further low-energy manifestations of LFV such as radiative and three-body lepton decays. Under the assumption of a type-I seesaw as the source of neutrino masses and mixings, all these LFV observables are related. Working in the framework of the cMSSM extended by three right-handed neutrino superfields, we conduct a systematic analysis addressing the simultaneous implications of the SUSY seesaw for both high- and low-energy lepton flavour violation. We discuss how the confrontation of slepton mass splittings as observed at the LHC and low-energy LFV observables may provide important information about the underlying mechanism of LFV.



One of the most interesting results consists in the fact that almost the entire region in parameter space associated with a $\tilde{e}_L - \tilde{\mu}_L$ mass splitting $\sim \mathcal{O}(1\%)$ is also within the future sensitivity of low-energy facilities, especially for CR($\mu - e$, Ti) (even without the expected upgrade to $\mathcal{O}(10^{-18})$ for PRISM/PRIME) [5]. Also, any $\tilde{e}_L - \tilde{\mu}_L$ mass splitting above 4% would also be associated with a $\mu \to e\gamma$ signal within MEG sensitivity. A similar situation (albeit not so striking) is observed for $\tilde{\mu}_L - \tilde{\tau}_2$ mass differences: as an example, mass splittings above 3%, 4% and 6% would be associated to low-energy signals of LFV within PRISM/PRIME, SuperB, and MEG reach, respectively.

PHYSICAL REVIEW D **74,** 053011 (2006)

Probing the Randall-Sundrum geometric origin of flavor with lepton flavor violation

Kaustubh Agashe,[1] Andrew E. Blechman,[2] and Frank Petriello[3]

[1]*Department of Physics, Syracuse University, Syracuse, New York 13244, USA*
and School of Natural Sciences, Institute for Advanced Study, Princeton, New Jersey 08540, USA
[2]*Department of Physics, The Johns Hopkins University, Baltimore, Maryland 21218, USA*
[3]*Department of Physics, University of Wisconsin, Madison, Wisconsin 53706, USA*
(Received 23 June 2006; published 28 September 2006)

The anarchic Randall-Sundrum model of flavor is a low energy solution to both the electroweak hierarchy and flavor problems. Such models have a warped, compact extra dimension with the standard model fermions and gauge bosons living in the bulk, and the Higgs living on or near the TeV brane. In this paper we consider bounds on these models set by lepton flavor-violation constraints. We find that loop-induced decays of the form $l \rightarrow l'\gamma$ are ultraviolet sensitive and incalculable when the Higgs field is localized on a four-dimensional brane; this drawback does not occur when the Higgs field propagates in the full five-dimensional space-time. We find constraints at the few TeV level throughout the natural range of parameters, arising from $\mu - e$ conversion in the presence of nuclei, rare μ decays, and rare τ decays. A tension exists between loop-induced dipole decays such as $\mu \rightarrow e\gamma$ and tree-level processes such as $\mu - e$ conversion; they have opposite dependences on the five-dimensional Yukawa couplings, making it difficult to decouple flavor-violating effects. We emphasize the importance of the future experiments MEG and PRIME. These experiments will definitively test the Randall-Sundrum geometric origin of hierarchies in the lepton sector at the TeV scale.

DOI: 10.1103/PhysRevD.74.053011 PACS numbers: 13.35.−r, 11.10.Kk

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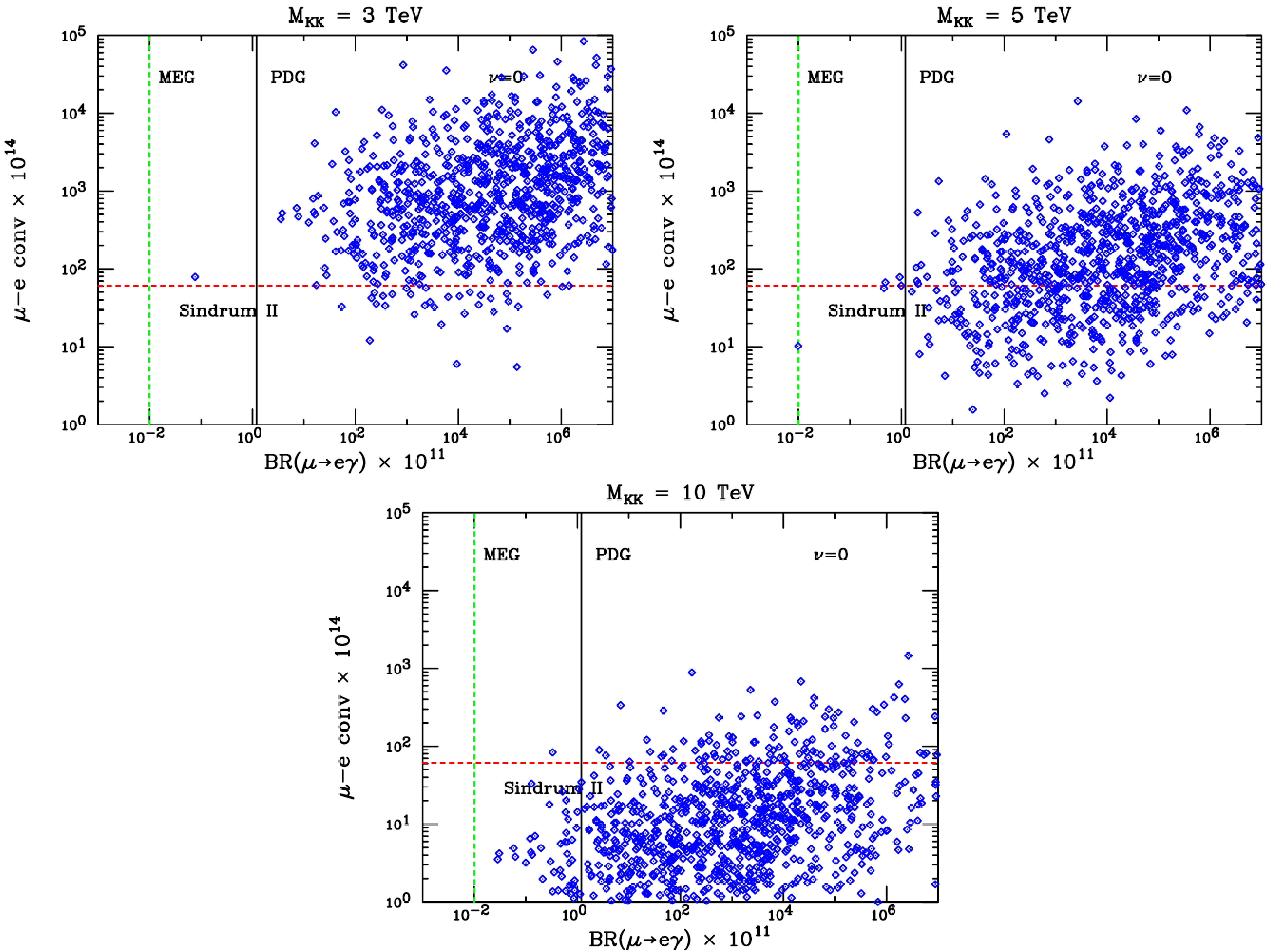

FIG. 6 Scan of the $\mu \to e\gamma$ and $\mu - e$ conversion predictions for $M_{\mathrm{KK}} = 3$, 5, 10 TeV and $\nu = 0$. The solid line denotes the PDG bound on $BR(\mu \to e\gamma)$, while the dashed lines indicate the SINDRUM II limit on $\mu - e$ conversion and the projected MEG sensitivity to $BR(\mu \to e\gamma)$.

Charged lepton flavour violation and $(g-2)_\mu$ in the Littlest Higgs model with T-Parity: a clear distinction from Supersymmetry

Monika Blanke,[ab] **Andrzej J. Buras,**[a] **Björn Duling,**[a] **Anton Poschenrieder**[a] **and Cecilia Tarantino**[a]

[a] *Physik Department, Technische Universität München*
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[b] *Max-Planck-Institut für Physik (Werner-Heisenberg-Institut)*
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E-mail: mblanke@ph.tum.de, aburas@ph.tum.de, bduling@ph.tum.de, aposchen@ph.tum.de, ctaranti@ph.tum.de

Abstract: We calculate the rates for the charged lepton flavour violating decays $\ell_i \to \ell_j \gamma$, $\tau \to \ell\pi$, $\tau \to \ell\eta$, $\tau \to \ell\eta'$, $\mu^- \to e^- e^+ e^-$, the six three body leptonic decays $\tau^- \to \ell_i^- \ell_j^+ \ell_k^-$ and the rate for $\mu - e$ conversion in nuclei in the Littlest Higgs model with T-parity (LHT). We also calculate the rates for $K_{L,S} \to \mu e$, $K_{L,S} \to \pi^0 \mu e$ and $B_{d,s} \to \ell_i \ell_j$. We find that the relative effects of mirror leptons in these transitions are by many orders of magnitude larger than analogous mirror quark effects in rare K and B decays analyzed recently. In particular, in order to suppress the $\mu \to e\gamma$ and $\mu^- \to e^- e^+ e^-$ decay rates and the $\mu - e$ conversion rate below the experimental upper bounds, the relevant mixing matrix in the mirror lepton sector $V_{H\ell}$ must be rather hierarchical, unless the spectrum of mirror leptons is quasi-degenerate. We find that the pattern of the LFV branching ratios in the LHT model differs significantly from the one encountered in the MSSM, allowing in a transparent manner to distinguish these two models with the help of LFV processes. We also calculate $(g-2)_\mu$ and find the new contributions to a_μ below $1 \cdot 10^{-10}$ and consequently negligible. We compare our results with those present in the literature.

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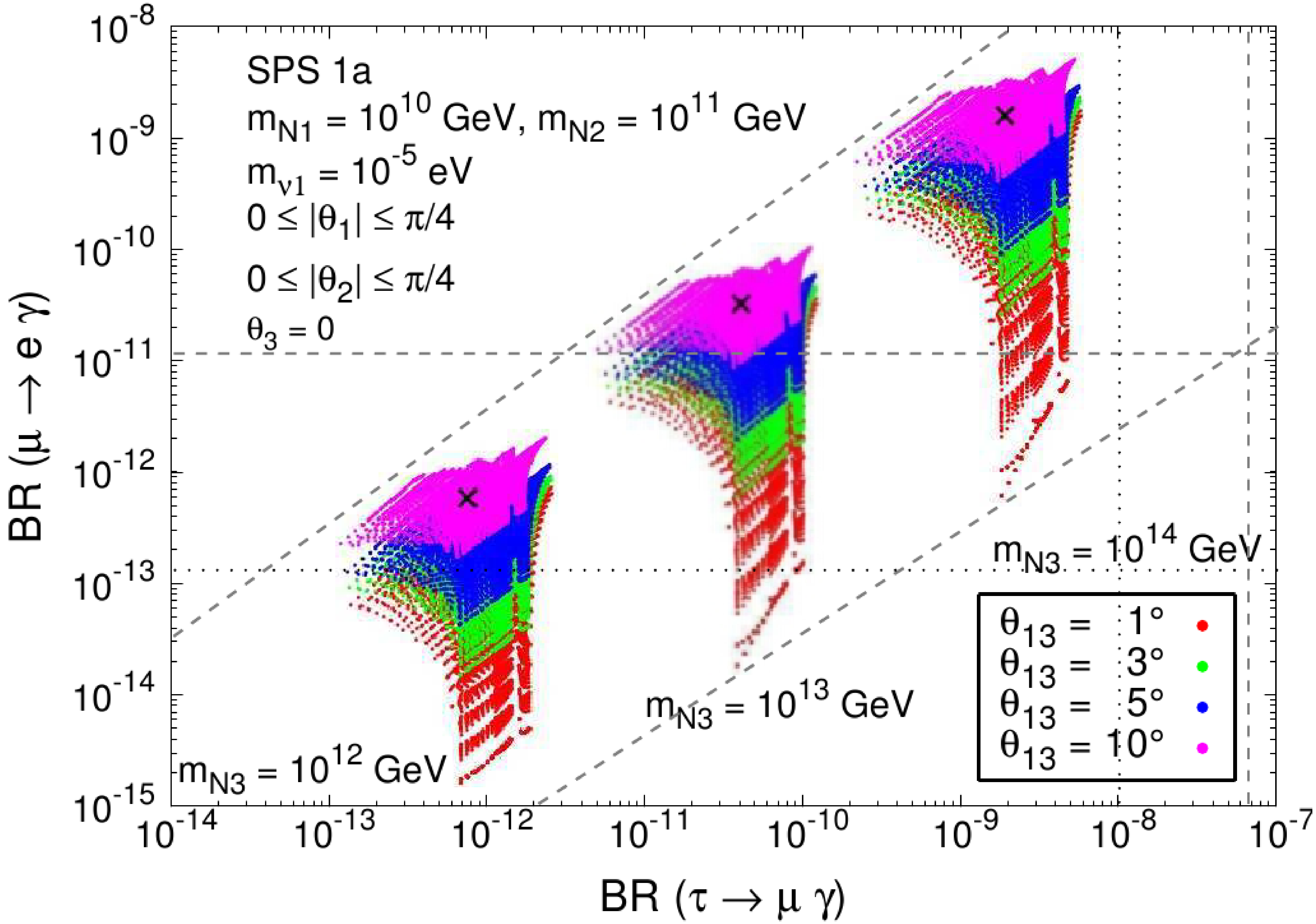
LFV in tau and muon decays within SUSY seesaw

S. Antusch et al. / Nuclear Physics B (Proc. Suppl.) 169 (2007) 155–165



Correlation between $\mathrm{BR}(\mu \to e\,\gamma)$ and $\mathrm{BR}(\tau \to \mu\,\gamma)$ as a function of m_{N_3}, for SPS 1a.

PHYSICAL REVIEW D **75,** 115019 (2007)

Flavor physics at large tan β with a binolike lightest supersymmetric particle

G. Isidori,[1] F. Mescia,[1] P. Paradisi,[2] and D. Temes[1]

[1]*INFN, Laboratori Nazionali di Frascati, Via E. Fermi 40, I-00044 Frascati, Italy*

[2]*Departament de Física Teòrica and IFIC, Universitat de València-CSIC, E-46100 Burjassot, Spain*

(Received 23 March 2007; published 28 June 2007)

The minimal supersymmetric extension of the standard model with large $\tan\beta$ and heavy squarks ($M_{\tilde{q}} \gtrsim 1$ TeV) is a theoretically well-motivated and phenomenologically interesting extension of the standard model. This scenario naturally satisfies all the electroweak precision constraints and, in the case of not too heavy slepton sector ($M_{\tilde{\ell}} \lesssim 0.5$ TeV), can also easily accommodate the $(g-2)_\mu$ anomaly. Within this framework nonstandard effects could possibly be detected in the near future in a few low-energy flavor violating observables, such as $\mathcal{B}(B \to \tau\nu)$, $\mathcal{B}(B_{s,d} \to \ell^+\ell^-)$, $\mathcal{B}(B \to X_s\gamma)$, and $\mathcal{B}(\mu \to e\gamma)$. Interpreting the $(g-2)_\mu$ anomaly as the first hint of this scenario, we analyze the correlations of these low-energy observables under the additional assumption that the relic density of a binolike lightest supersymmetric particle accommodates the observed dark-matter distribution.

DOI: 10.1103/PhysRevD.75.115019 PACS numbers: 12.60.Jv, 13.25.Hw, 13.35.−r, 95.35.+d

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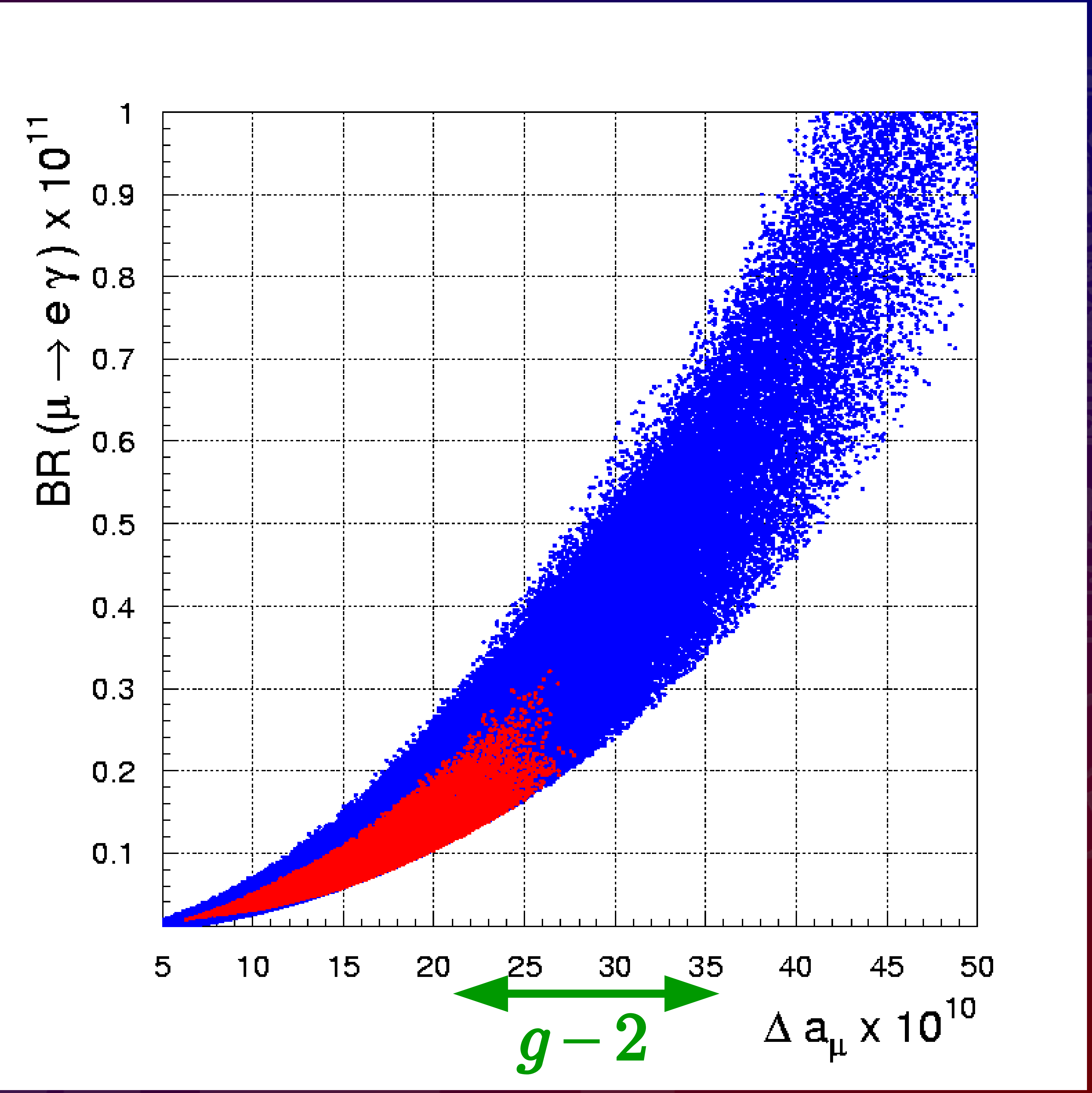
Isidori et al Phys Rev D75 (2007) 1150

MSSM with Large tan β & Heavy Squarks

- Accommodates $g-2$ signal
- Red points satisfy B-physics constraints
- Predicted $\mu \to e + \gamma$ at 10^{-12}
    - further factor O(100s) for $\mu + N \to e + N$



"DNA" of flavour physics effects for the most interesting observables in a selection of SUSY and non-SUSY models ★★★ signals large effects, ★★ visible but small effects and ★ implies that the given model does not predict sizable effects in that observable.

	AC	RVV2	AKM	δLL	FBMSSM	LHT	RS
$D^0-\bar{D}^0$	★★★	★	★	★	★	★★★	?
ϵ_K	★	★★★	★★★	★	★	★★	★★★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★	★★★	★★★
$S_{\phi K_S}$	★★★	★★	★	★★★	★★★	★	?
$A_{CP}(B \to X_s\gamma)$	★	★	★	★★★	★★★	★	?
$A_{7,8}(B \to K^*\mu^+\mu^-)$	★	★	★	★★★	★★★	★★	?
$A_9(B \to K^*\mu^+\mu^-)$	★	★	★	★	★	★	?
$B \to K^{(*)}\nu\bar{\nu}$	★	★	★	★	★	★	★
$B_s \to \mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★	★	★
$K^+ \to \pi^+\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$K_L \to \pi^0\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$\mu \to e\gamma$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
$\tau \to \mu\gamma$	★★★	★★★	★	★★★	★★★	★★★	★★★
$\mu + N \to e + N$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
d_n	★★★	★★★	★★★	★★	★★★	★	★★★
d_e	★★★	★★★	★★	★	★★★	★	★★★
$(g-2)_\mu$	★★★	★★★	★★	★★★	★★★	★	?

W. Altmannshofer et al. / Nuclear Physics B 830 (2010) 17–94

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new physics →	AC	RVV2	AKM	δLL	FBMSSM	LHT	RS
$D^0 - \bar{D}^0$	★★★	★	★	★	★	★★★	?
ϵ_K	★	★★★	★★★	★	★	★★	★★★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★	★★★	★★★
$S_{\phi K_S}$	★★★	★★	★	★★★	★★★	★	?
$A_{\mathrm{CP}}(B \to X_s\gamma)$	★	★	★	★★★	★★★	★	?
$A_{7,8}(B \to K^*\mu^+\mu^-)$	★	★	★	★★★	★★★	★★	?
$A_9(B \to K^*\mu^+\mu^-)$	★	★	★	★	★	★	?
$B \to K^{(*)}\nu\bar{\nu}$	★	★	★	★	★	★	★
$B_s \to \mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★	★	★
$K^+ \to \pi^+\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$K_L \to \pi^0\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$\mu \to e\gamma$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
$\tau \to \mu\gamma$	★★★	★★★	★	★★★	★★★	★★★	★★★
$\mu + N \to e + N$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
d_n	★★★	★★★	★★★	★★	★★★	★	★★★
d_e	★★★	★★★	★★	★	★★★	★	★★★
$(g-2)_\mu$	★★★	★★★	★★	★★★	★★★	★	?

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"DNA" of flavour physics effects for the most interesting observables in a selection of SUSY and non-SUSY models ★★★ signals large effects, ★★ visible but small effects and ★ implies that the given model does not predict sizable effects in that observable.

observables	AC	RVV2	AKM	δLL	FBMSSM	LHT	RS
$D^0-\bar{D}^0$	★★★	★	★	★	★	★★★	?
ϵ_K	★	★★★	★★★	★	★	★★	★★★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★	★★★	★★★
$S_{\phi K_S}$	★★★	★★	★	★★★	★★★	★	?
$A_{\mathrm{CP}}(B\to X_s\gamma)$	★	★	★	★★★	★★★	★	?
$A_{7,8}(B\to K^*\mu^+\mu^-)$	★	★	★	★★★	★★★	★★	?
$A_9(B\to K^*\mu^+\mu^-)$	★	★	★	★	★	★	?
$B\to K^{(*)}\nu\bar{\nu}$	★	★	★	★	★	★	★
$B_s\to\mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★	★	★
$K^+\to\pi^+\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$K_L\to\pi^0\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$\mu\to e\gamma$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
$\tau\to\mu\gamma$	★★★	★★★	★	★★★	★★★	★★★	★★★
$\mu+N\to e+N$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
d_n	★★★	★★★	★★★	★★	★★★	★	★★★
d_e	★★★	★★★	★★	★	★★★	★	★★★
$(g-2)_\mu$	★★★	★★★	★★	★★★	★★★	★	?

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"DNA" of flavour physics effects for the most interesting observables in a selection of SUSY and non-SUSY models ★★★ signals large effects, ★★ visible but small effects and ★ implies that the given model does not predict sizable effects in that observable.

	AC	RVV2	AKM	δLL	FBMSSM	LHT	RS

- AC: Abelian model by Agashe and Carone based on a U(1) flavour symmetry
- RVV2: the non-Abelian model by Ross, Velasco-Sevilla and Vives
- AKM: Antusch, King and Malinsky model based on the flavour symmetry SU(3)
- δLL: flavour models predicting pure, CKM-like, left-handed currents
- FBMSSM: flavour-blind MSSM
- LHT: Littlest Higgs Model with T-Parity
- RS: Randall–Sundrum model with custodial protection

SUSY models non-SUSY models

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“DNA” of flavour physics effects for the most interesting observables in a selection of SUSY and non-SUSY models ★★★ signals large effects, ★★ visible but small effects and ★ implies that the given model does not predict sizable effects in that observable.

	AC	RVV2	AKM	δLL	FBMSSM	LHT	RS
$D^0-\bar{D}^0$	★★★	★	★	★	★	★★★	?
ϵ_K	★	★★★	★★★	★	★	★★	★★★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★	★★★	★★★
$S_{\phi K_S}$	★★★	★★	★	★★★	★★★	★	?
$A_{\mathrm{CP}}(B\to X_s\gamma)$	★	★	★	★★★	★★★	★	?
$A_{7,8}(B\to K^*\mu^+\mu^-)$	★	★	★	★★★	★★★	★★	?
$A_9(B\to K^*\mu^+\mu^-)$	★	★	★	★	★	★	?
$B\to K^{(*)}\nu\bar{\nu}$	★	★	★	★	★	★	★
$B_s\to\mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★	★	★
$K^+\to\pi^+\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$K_L\to\pi^0\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$\mu\to e\gamma$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
$\tau\to\mu\gamma$	★★★	★★★	★	★★★	★★★	★★★	★★★
$\mu+N\to e+N$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
d_n	★★★	★★★	★★★	★★	★★★	★	★★★
d_e	★★★	★★★	★★	★	★★★	★	★★★
$(g-2)_\mu$	★★★	★★★	★★	★★★	★★★	★	?

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