Nufact 2016
Working Group 4 Summary

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Road Map’s Summary

WG4 Questions nuFACT2016

DC μ beams
- PSI/piE5
- MuSIC

- MEG
- MEGII
- Mu3e
- next generation of μ -> 3e

Pulsed μ beams
- FNAL
- JPARC

- DeeMe
- COMET
- Mu2e
- $g\text{-}2|_{\mu}$
- $EDM|_{\mu}$

Others
- CERN
- KEK
- BEPCII

- BelleII
- BESIII
- LHCb
- ATLAS
- CMS

↓

DC μ beams
- PSI/HiMB
- PSI/muCool

- next generation of cLFV and muon precision physics

Pulsed μ beams
- JPARC/PRISM

- next generation of cLFV: PRIME

↓

Precision test of SM, hints/evidence of physics beyond SM, strong interrelationship between muon/neutrino physics and low/high energy physics

Guide lines 2016

- Q1: Neutrino/Muon Physics:

What overlaps exist in non-standard interactions?
How would these manifest in both the near term muon/precision measurements sector & in the neutrino sector?

- Q2: Beam/Machine Design:

How can we improve experiments without increasing the beam power?
Cooled muon beams w/ phase rotations?
New methods?

- Q3: Program Planning:

How do you support the physics needs for both DC and pulsed (high sculpted) beam structures in the planning (and cost) of new facilities?

Color code:

Beam features vs experiment requirements

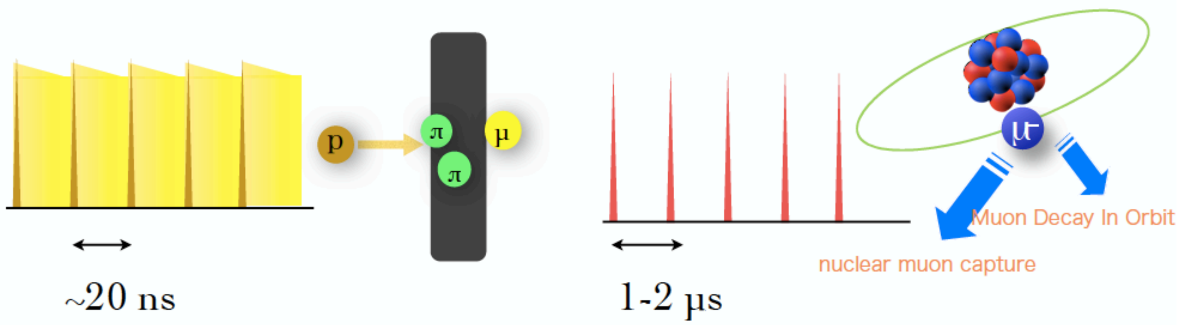
- Dedicated beam lines for high precision/sensitive SM test/BSM probe

muon cLFV searches

S. Mihara
WG4 review-2

DC or Pulse?

- DC beam for coincidence experiments
  - $\mu \to e \gamma$, $\mu \to e e e$
- Pulse beam for non-coincidence experiments
  - μ-e conversion



Beam features vs experiment requirements

- Dedicated beam lines for high precision/sensitive SM test/BSM probe

muon c

DC c

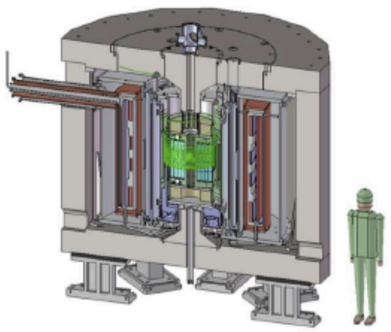
- DC beam for coincide experiments
  - $\mu \to e\gamma$, $\mu \to e\,e\,e$

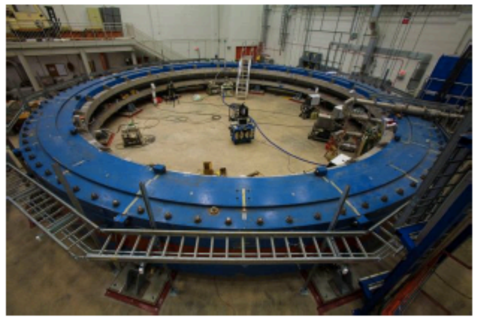
muon g-2 / EDM

P. Winter
WG4 review-3

The new Muon g-2 experiments: A comparison

See also WG4 talks today:
- R. Kitamura @ 10:45am
- W. Gohn @ 11:15am





	E34 @ JPARC	E989 @ Fermilab
Beam	High-rate, ultra-cold muon beam (p = 300 MeV/c)	High-rate, magic-momentum muons (p = 3.094 GeV/C)
Polarization	P_{max} = 50%	P ≈ 97%
Magnet	MRI-like solenoid ($r_{storage}$ = 33cm)	Storage ring (7m radius)
B-field	3 Tesla	1.45 Tesla
B-field gradients	Small gradients for focusing	Try to eliminate
E-field	None	Electrostatic quadrupole
Electron detector	Silicon vanes for tracking	Lead-fluoride calorimeter
B-field measurement	Continuous wave NMR	Pulsed NMR
Current sensitivity goal	400 ppb	140 ppb

Beam features vs experiment requirements

- Dedicated beam lines for high precision/sensitive SM test/BSM probe

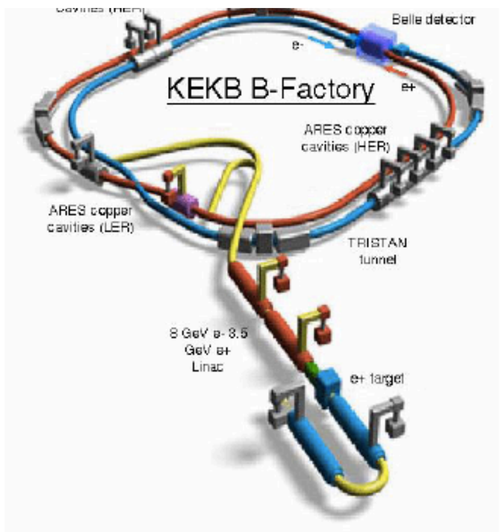
tauon cLFV

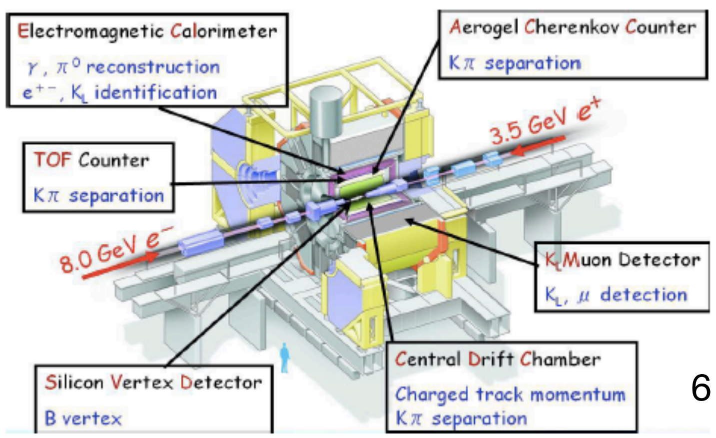
T. Konno WG34

B-factory at KEK

- KEKB: asymmetric e+(3.5GeV) e-(8GeV)
  - Peak luminosity: **2.1×10^{34} cm^{-2}s^{-1}**
  - => World highest peak luminosity
  - $\sigma(\tau\tau)$~0.9nb, $\sigma(bb)$~1.1nb
  - => **B-factory is also τ factory!**
- Belle Detector:
  - Good track reconstruction
  - Good particle identification
  - => Lepton efficiency:90%
    Fake rate : O(0.1) % for e
    O(1)% for μ

Collected ~10^9 τ pairs





DC muon beam lines

- Discussed beam lines at nuFACT2016: PSI/piE5 beam line

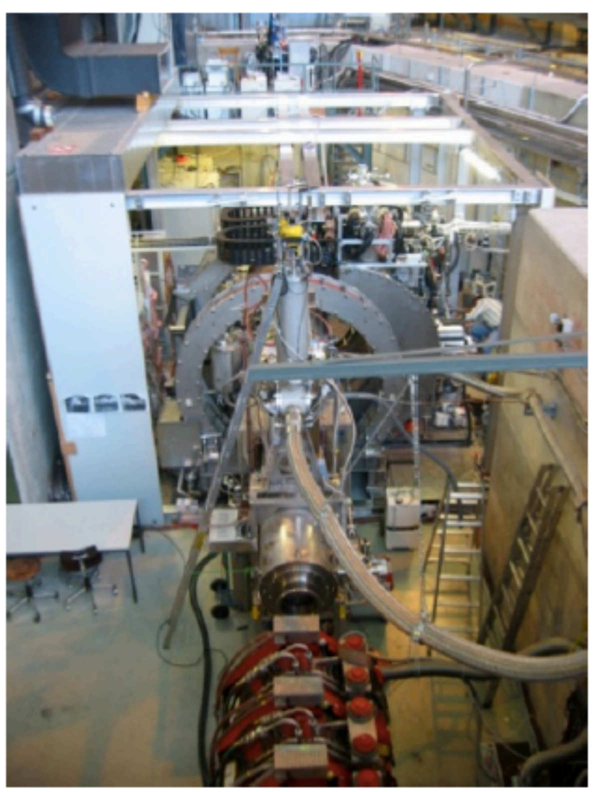
A. Papa
WG4

The piE5 beam line

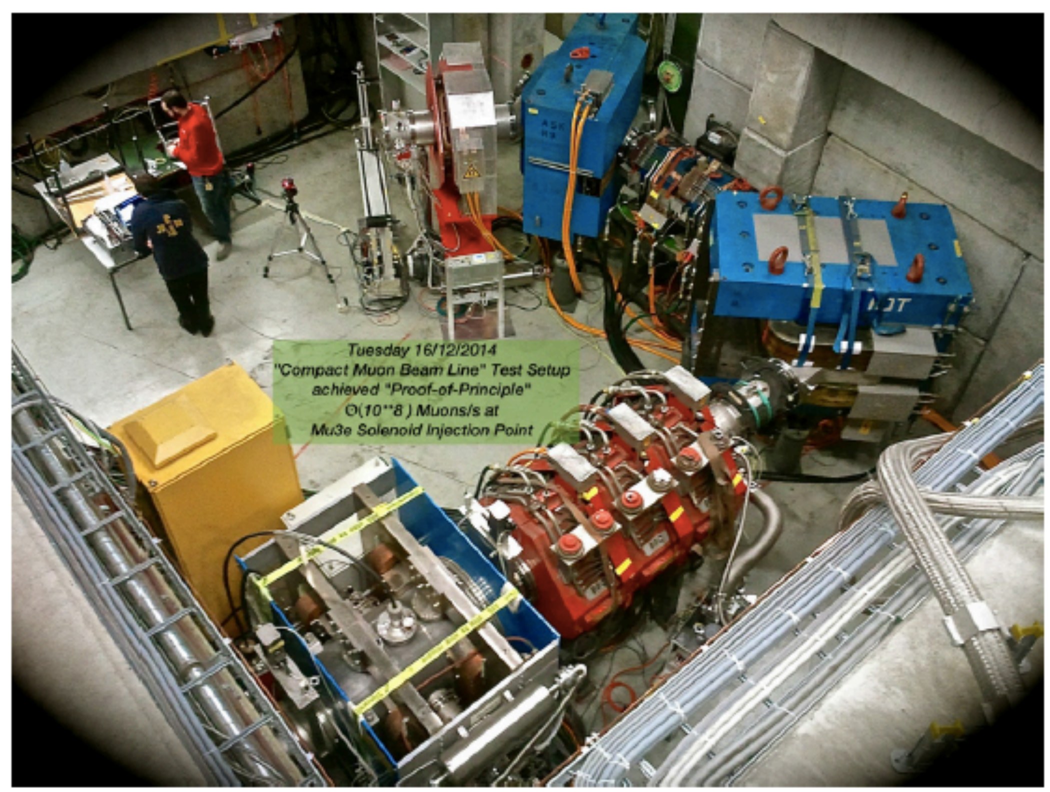
- MEGII and Mu3e (phase I) similar beam requirements:
  - Intensity O(10^8 muon/s), low momentum p = 28 MeV/c
  - Small straggling and good identification of the decay region

Only possible in piE5!

MEG/MEGII Beam Line



Mu3e Compact Muon Beam Line

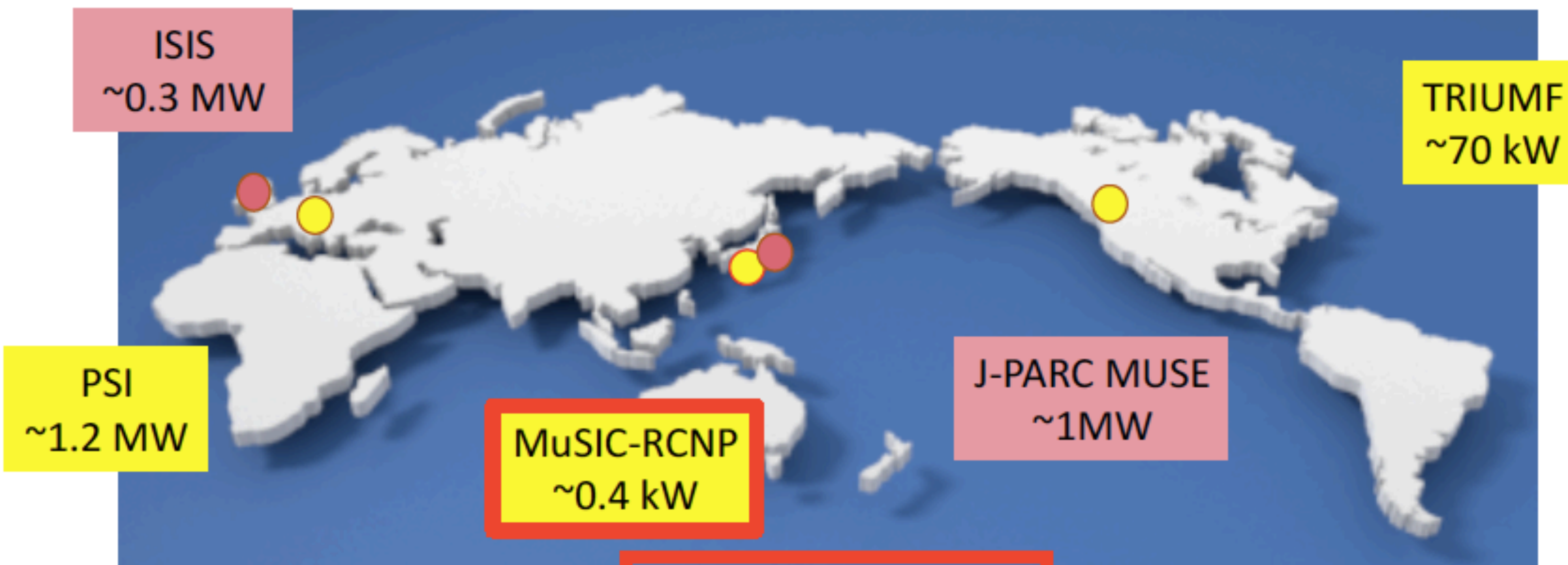


DC muon beam lines

- Discussed beam lines at nuFACT2016: MuSIC/M1 beam line

D. Tomono WG4

Muon Facilities in the world



	MuSIC-RCNP	PSI	J-PARC
Proton beam intensity	0.4 [kW]	1.2 [MW]	1 [MW]
Maximum μ+ beam intensity [μ+/sec]	~ 10^8 (at the solenoid end)	10^8 - 10^9	~10^8
Efficiency [μ+/ (sec kW)]	~1000	0.08 – 0.8	~0.1
Beam structure	continuous	continuous	pulsed (25Hz)

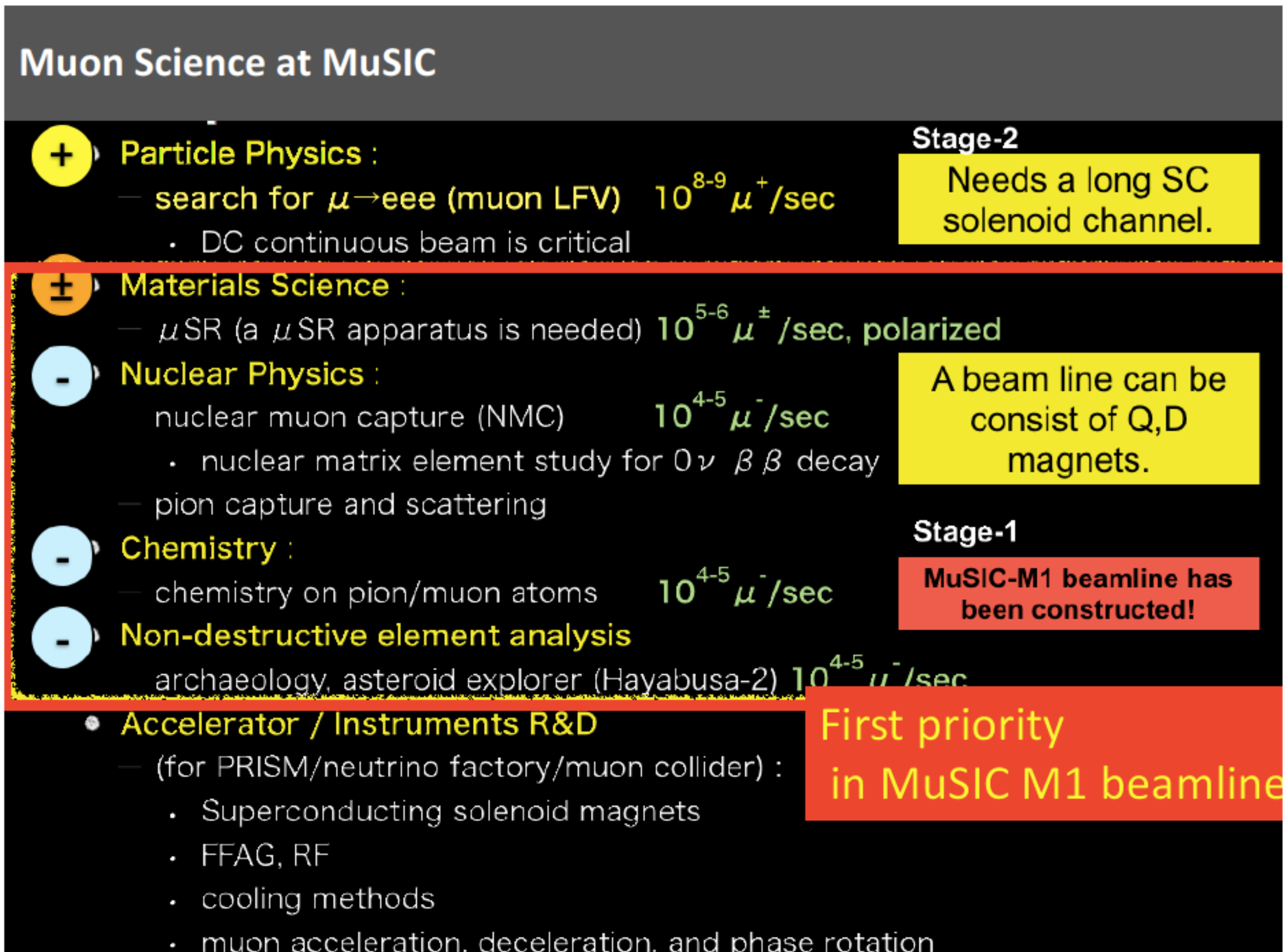
DC and pulsed muon sources in Japan ➡ complemental use to each other

Achieved performances:
p: 28-110 MeV/c
I: 10^5-10^6 $\mu^{+/-}$
I: 3 x 10^4 surface μ^+

Final goal (stage 2):
I: 10^8-10^9 μ^+

DC muon beam lines

- Discussed beam lines at nuFACT2016: MuSIC/M1 beam line



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WG4

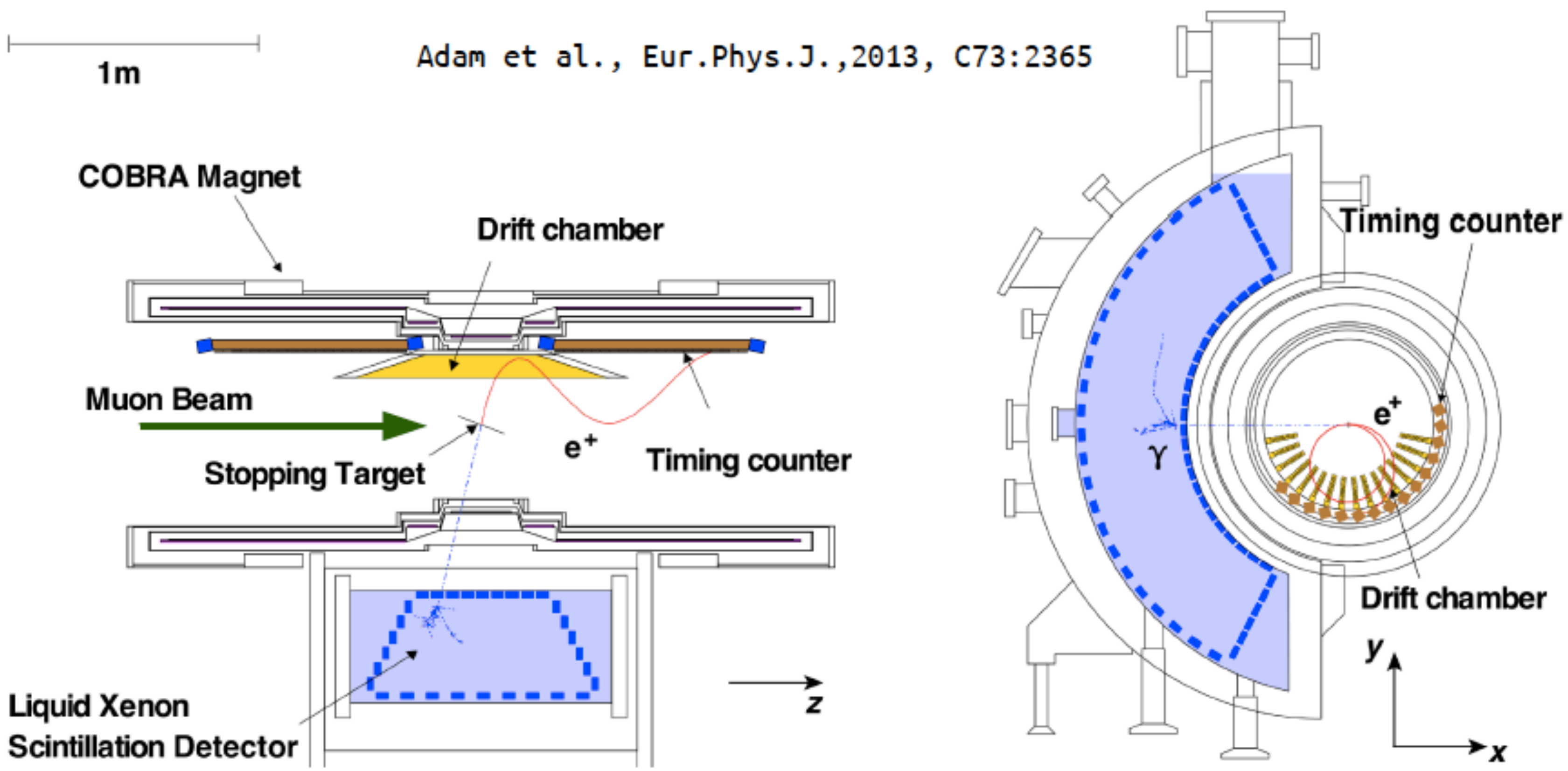
muon cLFV searches

- μ^+ -> e^+ γ decay searches with the MEG experiment

M. Venturini
WG4

The MEG apparatus

Tailored to take advantage of the well-defined kinematics of the decay



Positive muons stopped in a thin polyethylene target

Positrons detected by a **spectrometer** with a **non-uniform** magnetic field

Photons detected by a **liquid Xenon** calorimeter

muon cLFV searches

- μ^+ -> e^+ γ decay searches with the MEG experiment: The Final result with the full data set (7.5 x 10^{14} stopped muons)

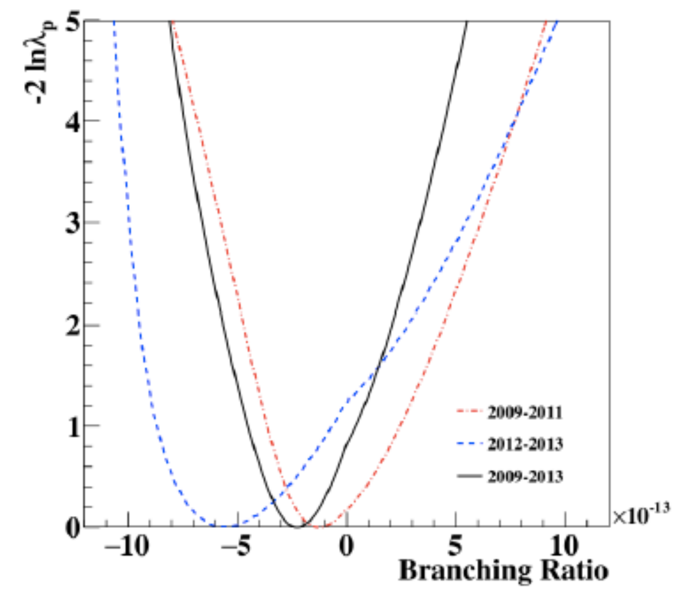
M. Venturini WG4

Upper limit

Confidence interval calculated with Feldman & Cousins approach with profile likelihood ratio ordering.

$$\mathbf{B\ (\mu \rightarrow e\gamma) < 4.2 \times 10^{-13}}$$
$$\mathbf{@\,90\%\ C.L.}$$

Baldini et al.,
Eur.Phys.J. C76 (2016) no.8, 434



Systematic uncertainties:

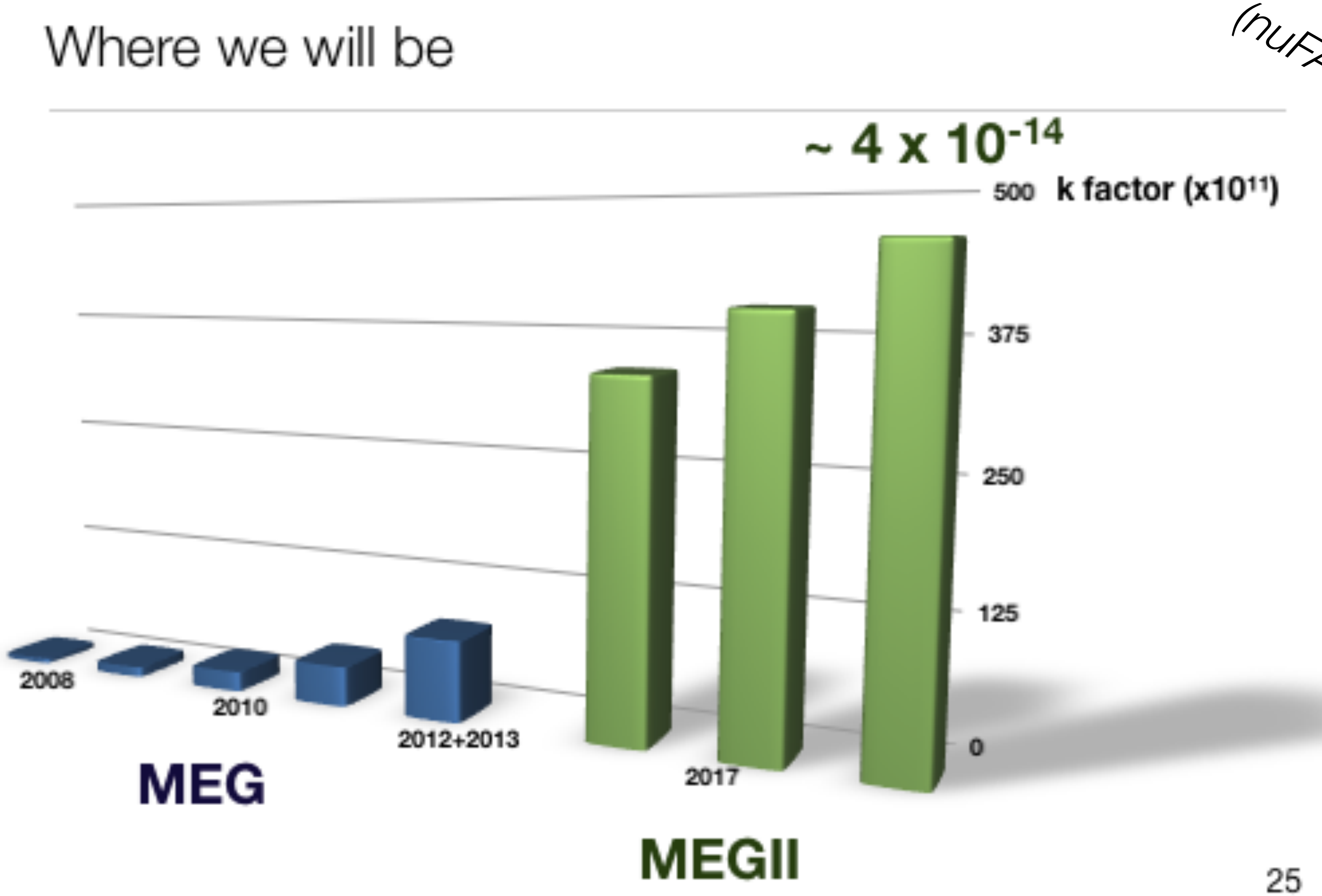
- Target alignment: 5%
- Other sources: <1%

dataset	2009–2011	2012–2013	2009-2013
$\mathcal{B}_{\rm fit} \times 10^{13}$	−1.3	−5.5	−2.2
$\mathcal{B}_{90} \times 10^{13}$	6.1	7.9	4.2
$\mathcal{S}_{90} \times 10^{13}$	8.0	8.2	5.3

muon cLFV searches

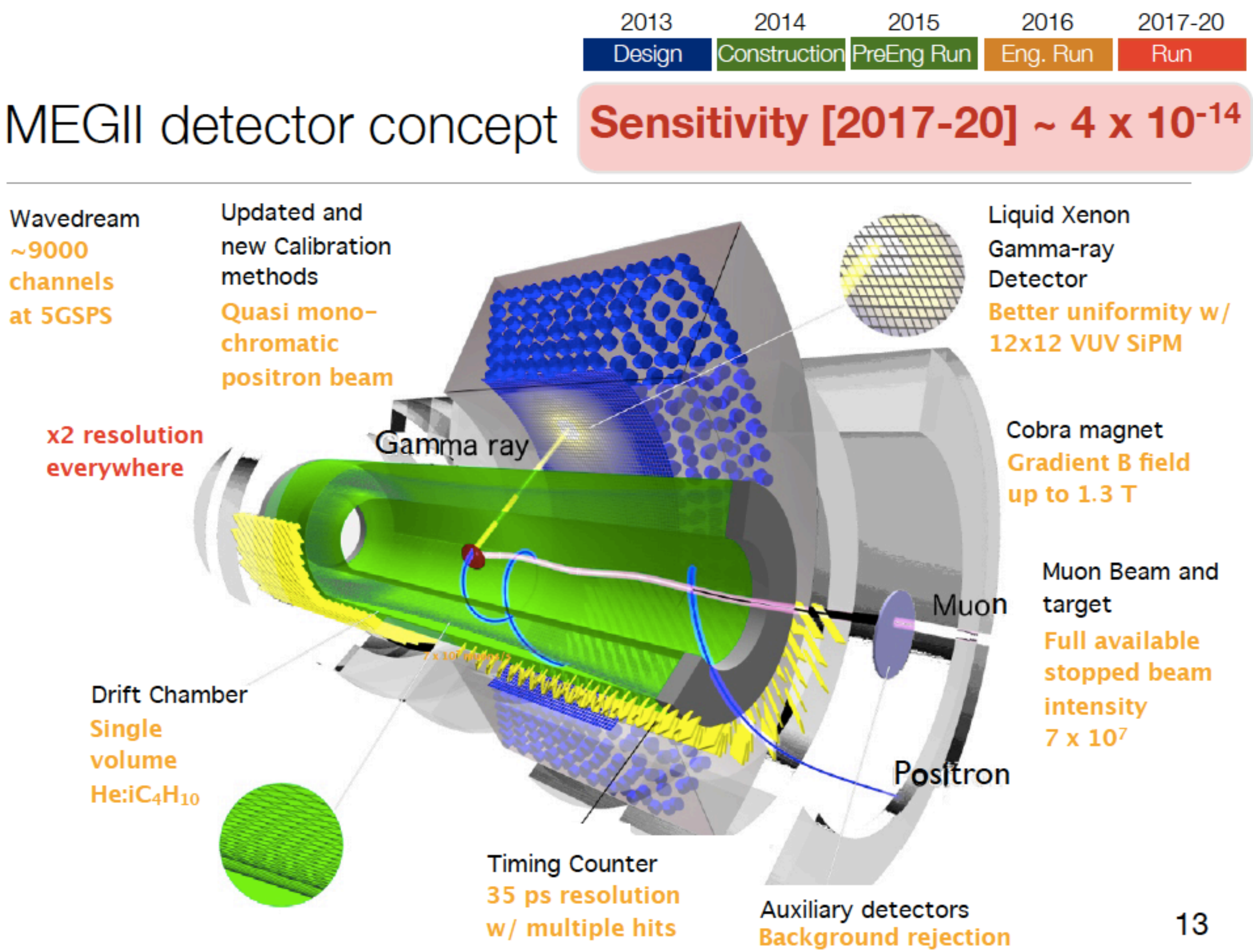
- $\mu^+ \to e^+ \gamma$ decay searches with the MEGII experiment

A. Papa
WG4
(nuFACT2015)



muon cLFV searches

- $\mu^+ \to e^+ \gamma$ decay searches with the MEGII experiment



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muon cLFV searches

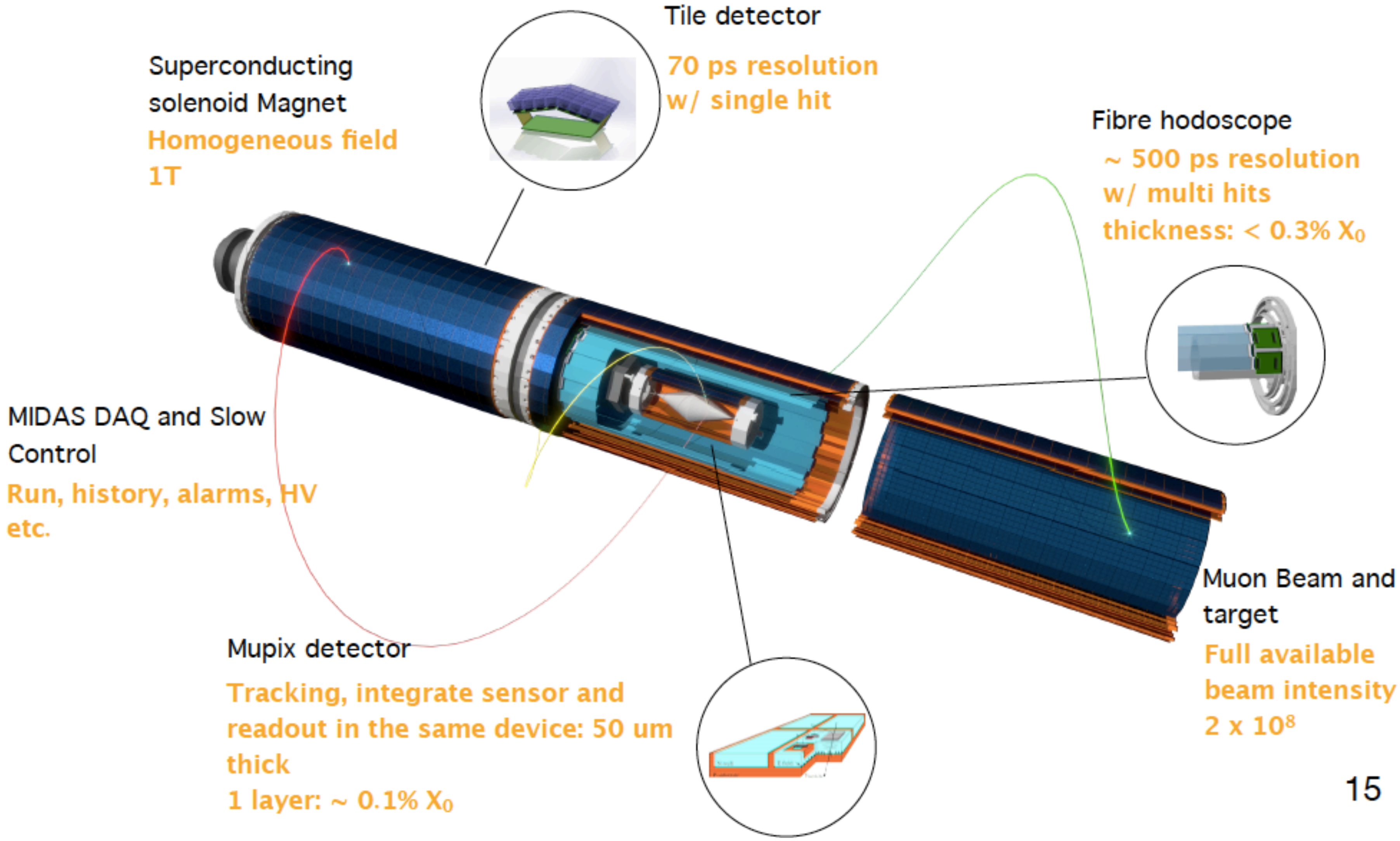
- $\mu^+ \to e^+ e^+ e^-$ decay searches with the Mu3e experiment

A. Papa WG4

2013-5	2015-7	2017	2018-20
Design	Construction	Eng Run	Run

Sensitivity phase I [2018-20] ~ 10^{-15}
(Final sensitivity phase II [202x] ~ 10^{-16} needs 10^9 muons/s)

Mu3e detector concept



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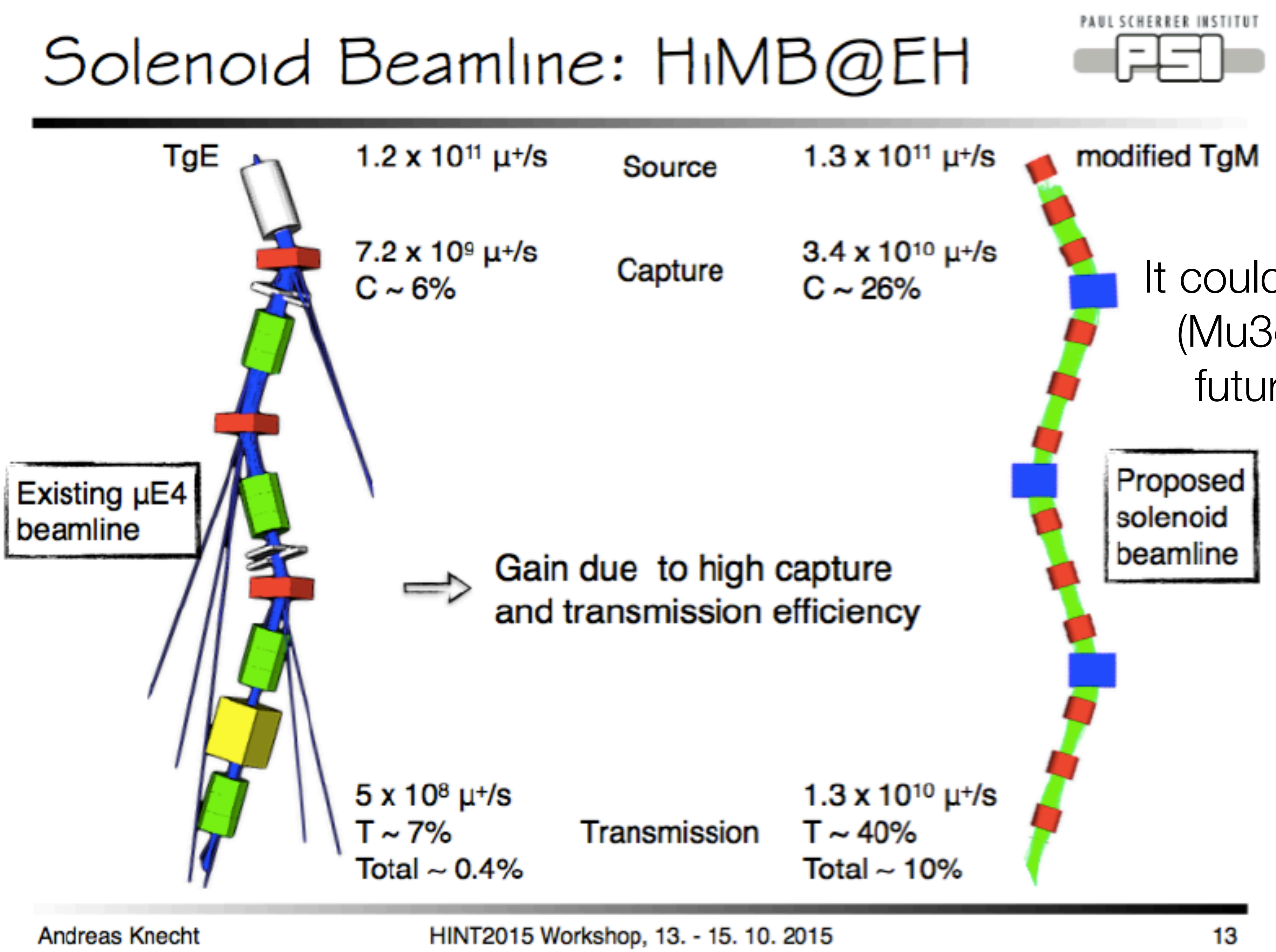
Future DC beam lines

- A new generation of high intensity DC muon beam lines: The HiMB project



S. Mihara
WG34

It could serve incoming (Mu3e phase II) and future muon cLFV searches

Future tertiary beam lines

- A novel low energy, high-brightness muon beam: The muCool project

D. Taqqu, PRL **97**, 194801 (2006)

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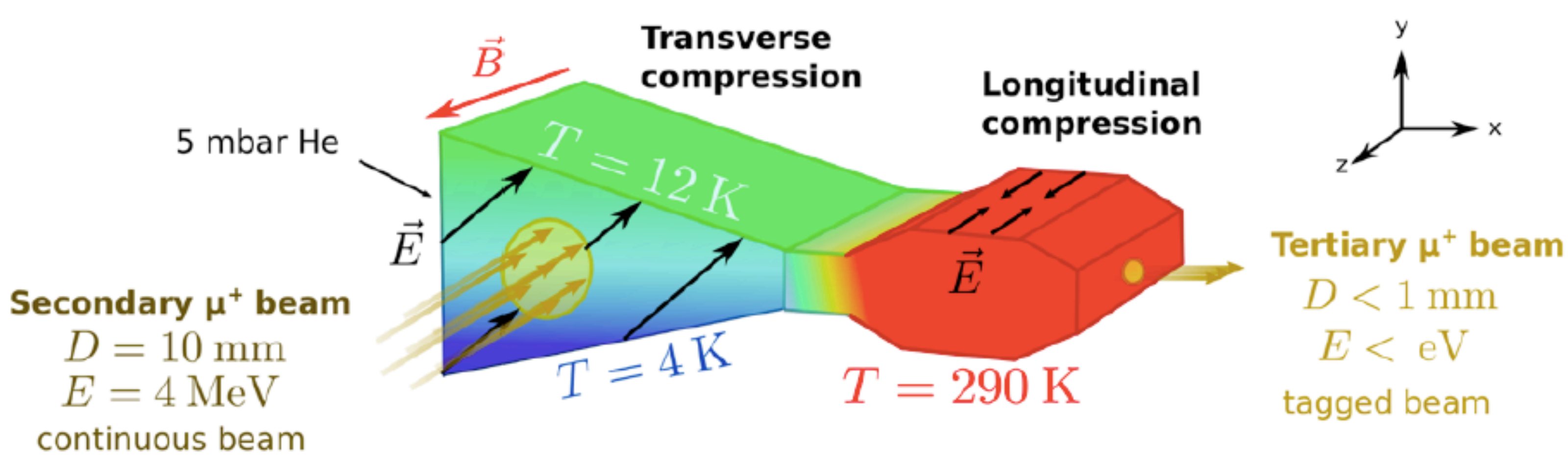
muCool principle



- Stages approach
  - transverse compression
  - longitudinal compression
  - extraction in vacuum
- Phase space reduction based on
  - dissipative energy loss in matter (He gas)
  - position dependent drift of muon swarm
- Increase in brillance (after reaccelerating to ~ 10 keV) by factor **10^7** : $B = [\varepsilon/(\varepsilon_L\ \varepsilon_T)]$
  - longitudinal emittance ε_L ($\Delta E\ \Delta t$) reduced by factor **10^4**
  - transverse emittance ε_T ($\Delta r\ \Delta\phi$) reduced by factor **10^6**
  - efficiency ε ~ **10^{-3}**

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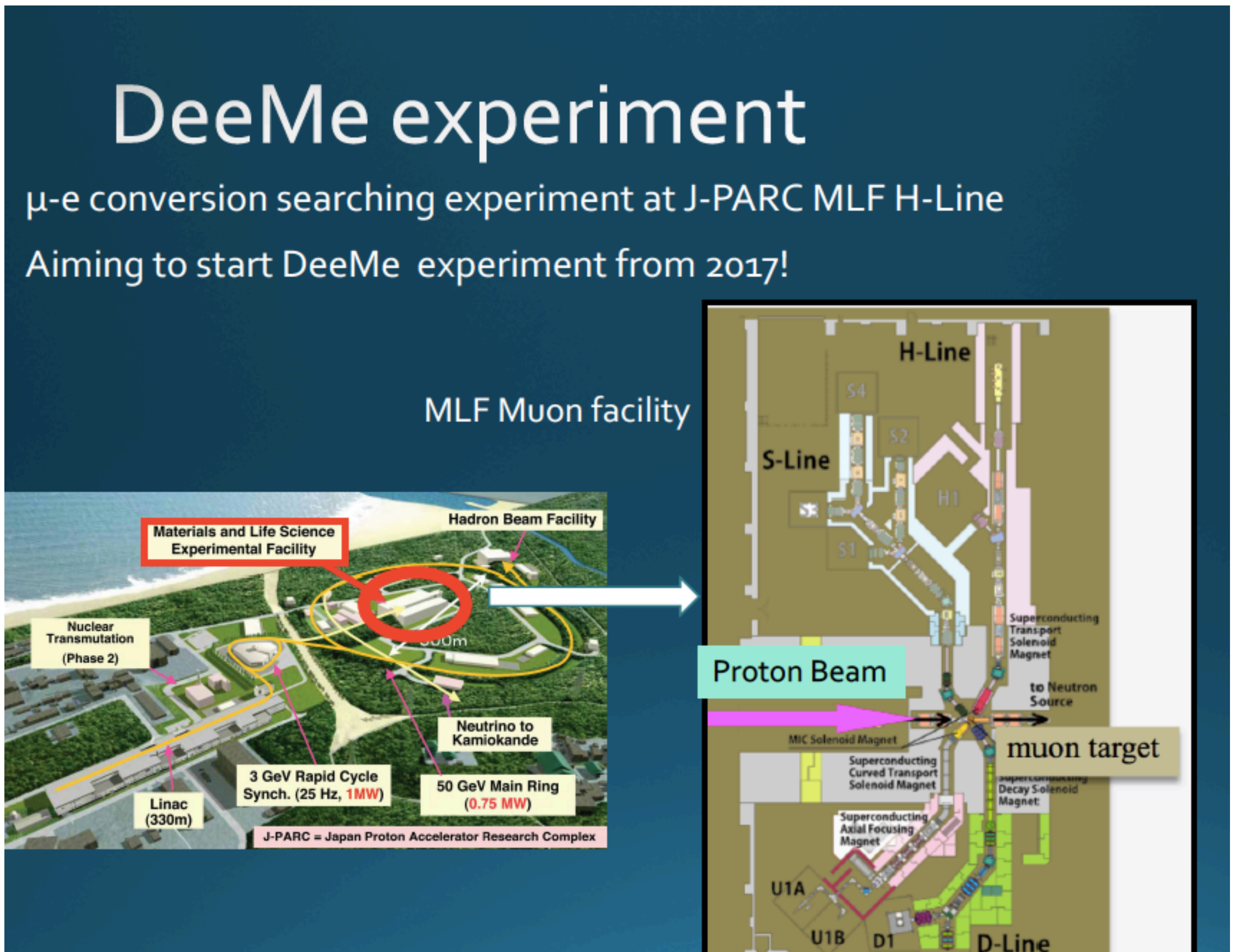
Precision physics, muonium physics, muSR could greatly benefit from it

muon cLFV with Pulsed muon beam lines

- μ^- N -> e^- N convertion searches with the DeeMe experiment

D. Nagao
WG4



muon cLFV with Pulsed muon beam lines

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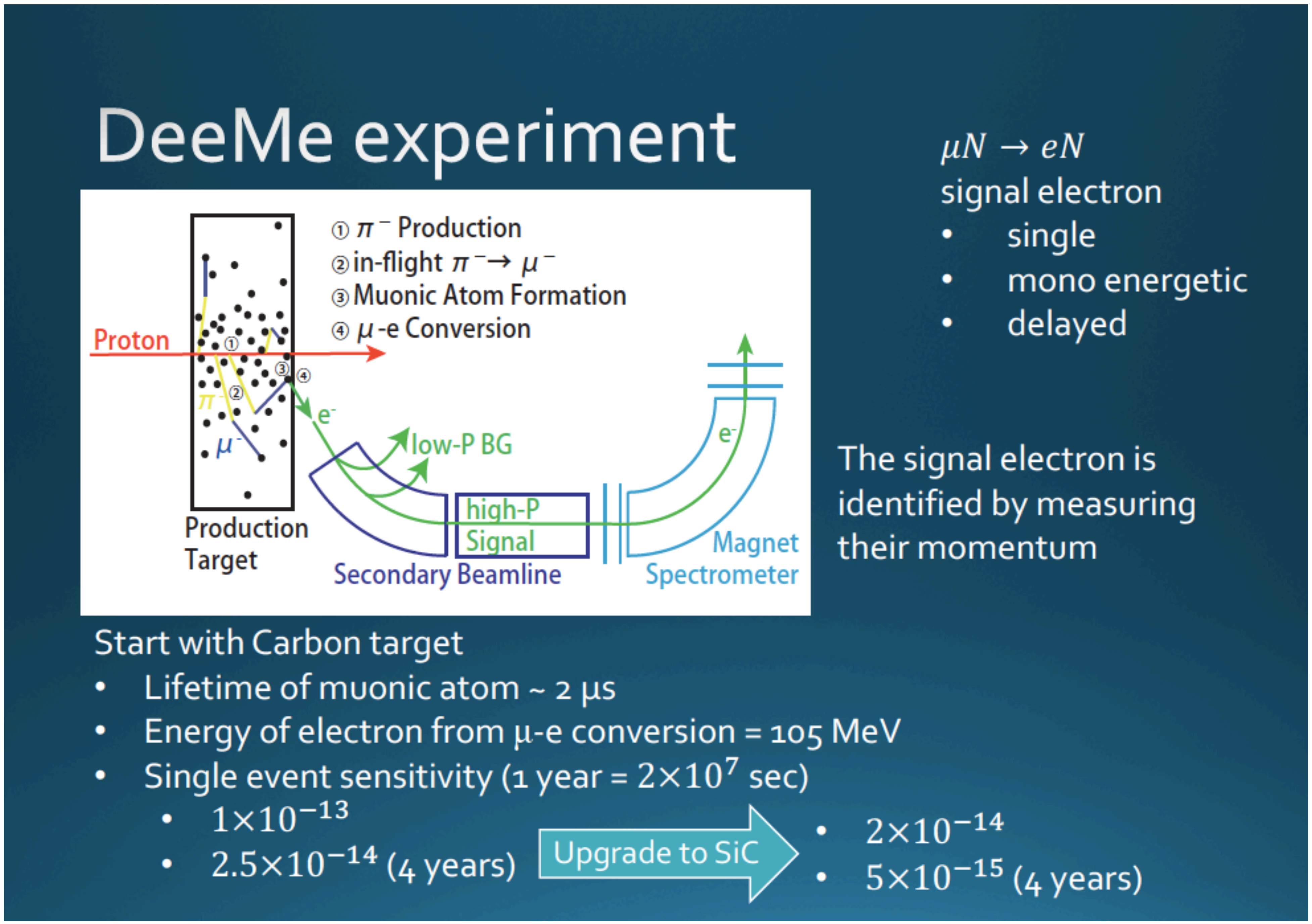
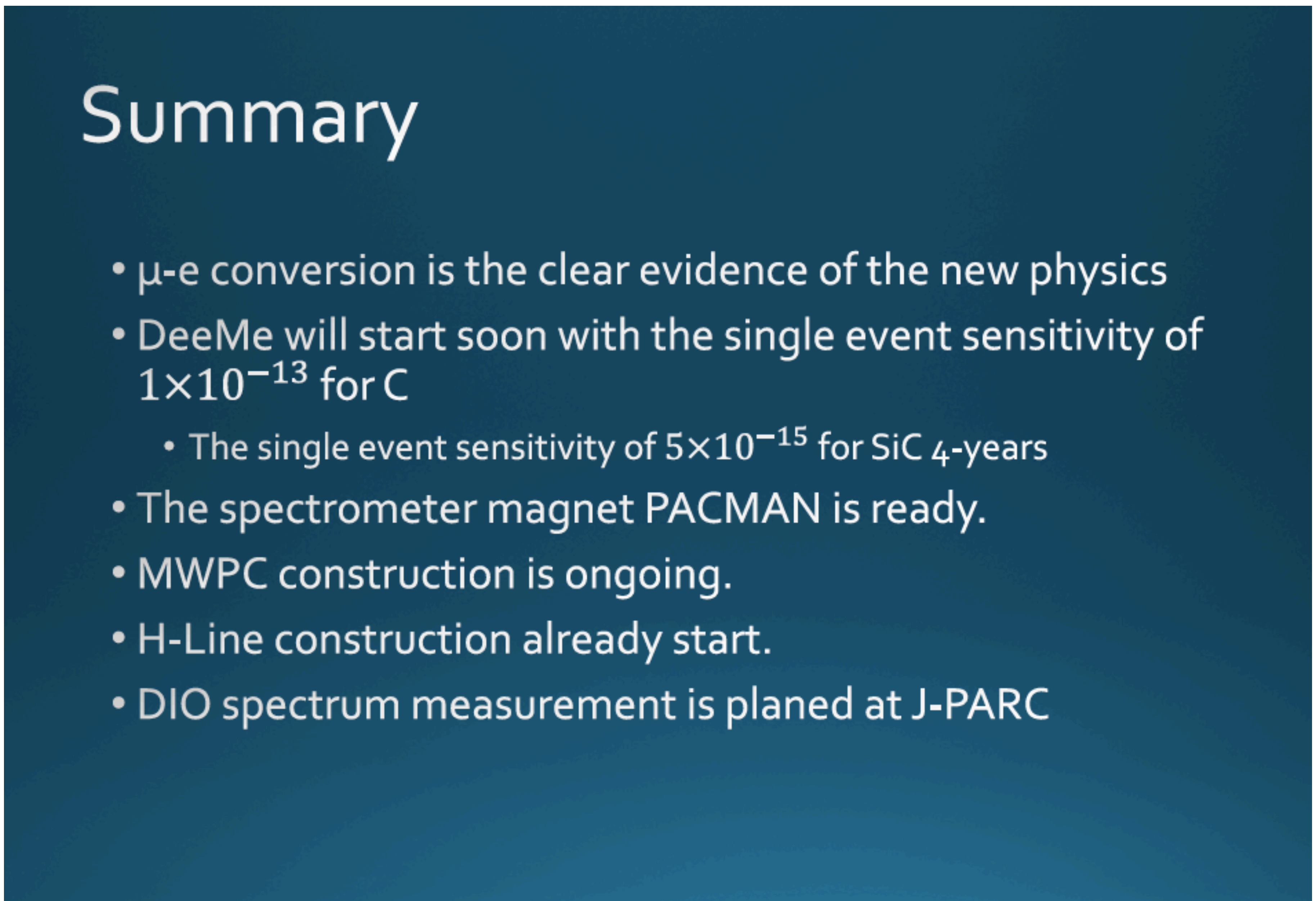


muon cLFV with Pulsed muon beam lines

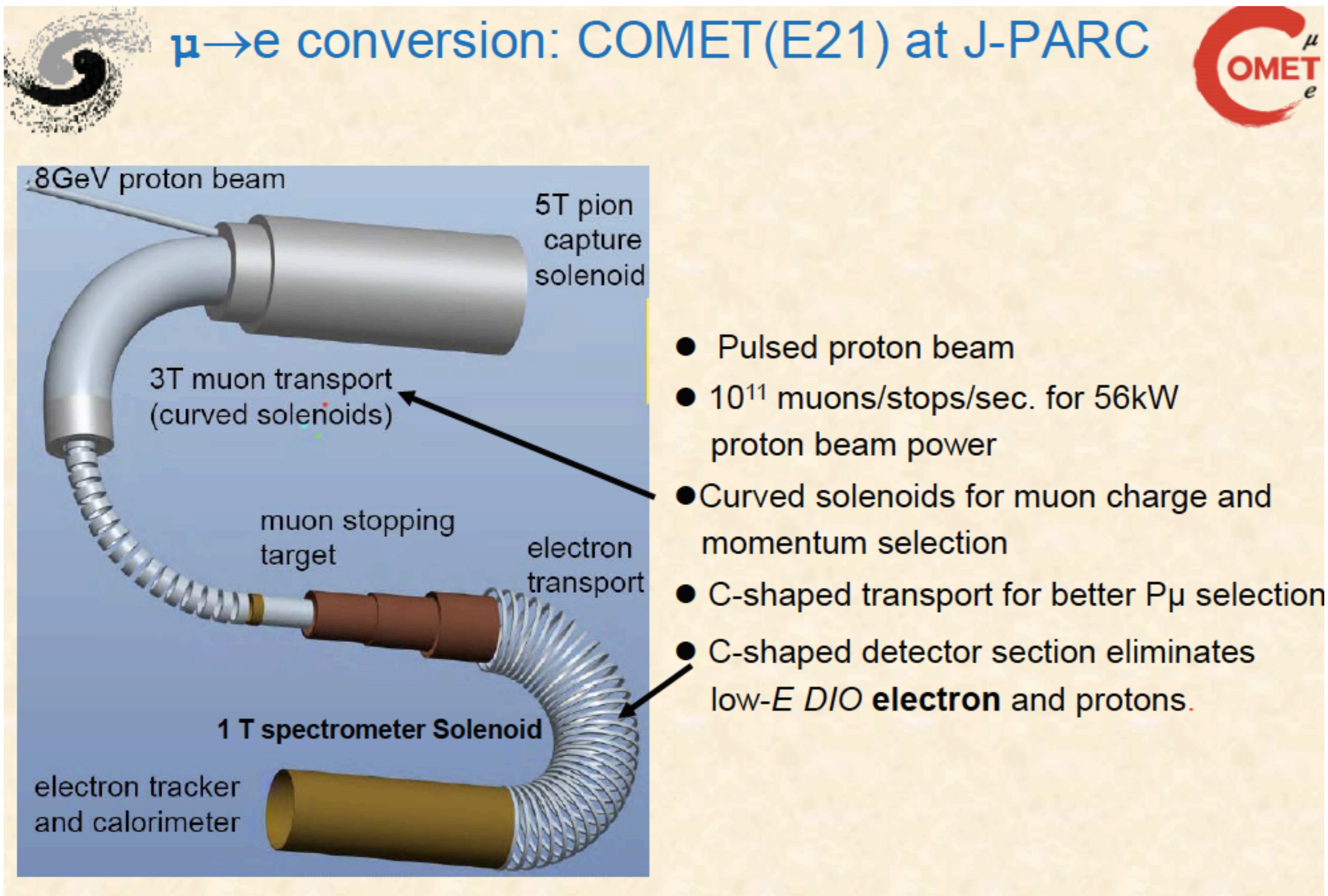
- $\mu^- N \to e^- N$ convertion searches with the DeeMe experiment

D. Nagao
WG4



muon cLFV with Pulsed muon beam lines

- μ^- N -> e^- N convertion searches with the DeeMe experiment



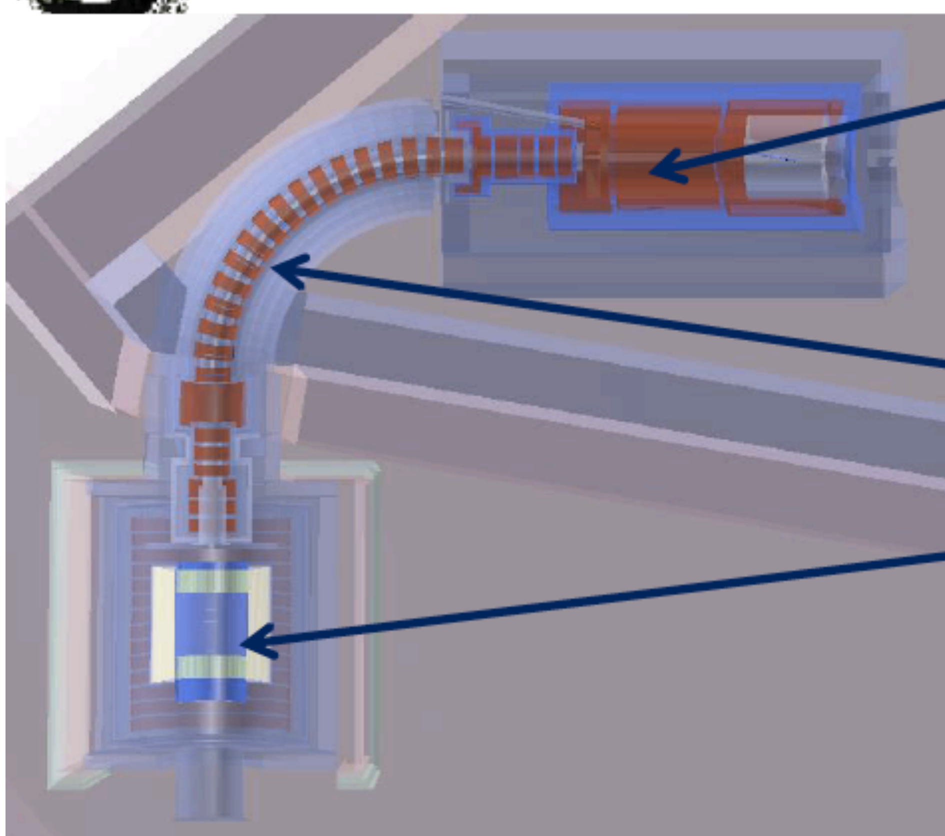
Y. Yuan
WG4

muon cLFV with Pulsed muon beam lines

- μ^- N -> e^- N convertion searches with the DeeMe experiment

COMET(Phase-I)

Y. Yuan WG4

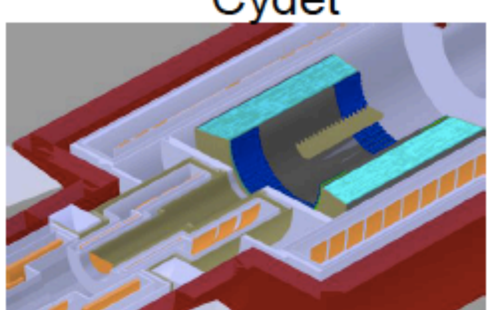


Pion Capture Section
Has a high(5T) magnetic field to collect the low momentum, backwards travelling pions, same to Phase-II, 3.2KW proton beam

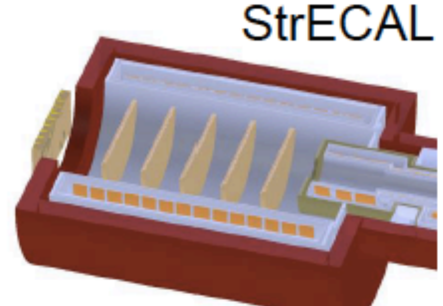
Muon Transport section
Construct to the first 90 degree

Phase-I Detector
A cylindrical drift chamber system(Cydet) for the μ→e conversion search
A prototype ECAL and straw tube tracker (StrECAL) for beam and background studies

Cydet



StrECAL



Phase-I Aims
Search for μ→e conversion process with a S.E.S. of 3×10^{-15}
Beam and background study for Phase-II

muon cLFV with Pulsed muon beam lines

- μ^- N -> e^- N convertion searches with the DeeMe experiment

COMET(Phase-II)

Y. Yuan
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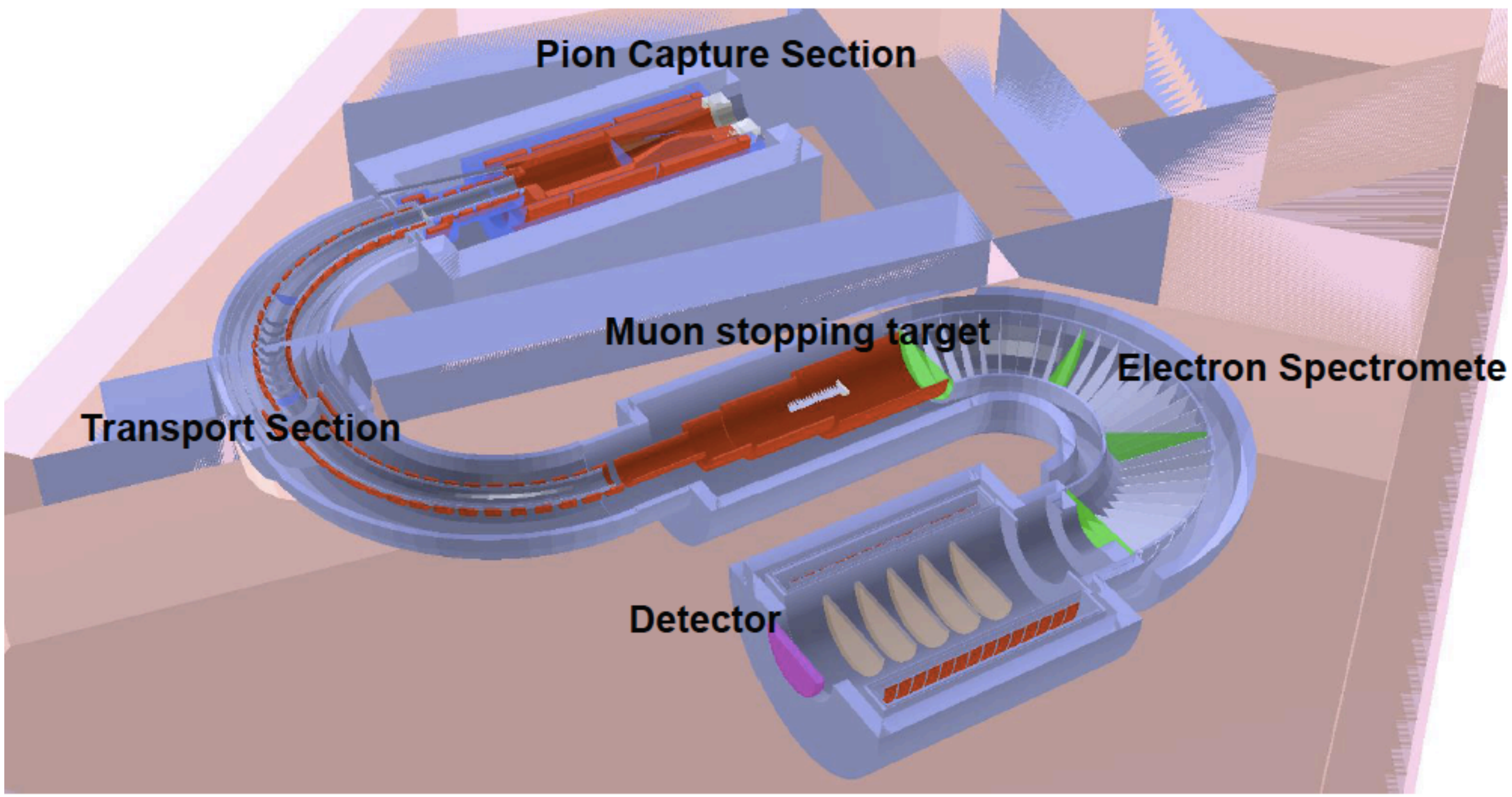
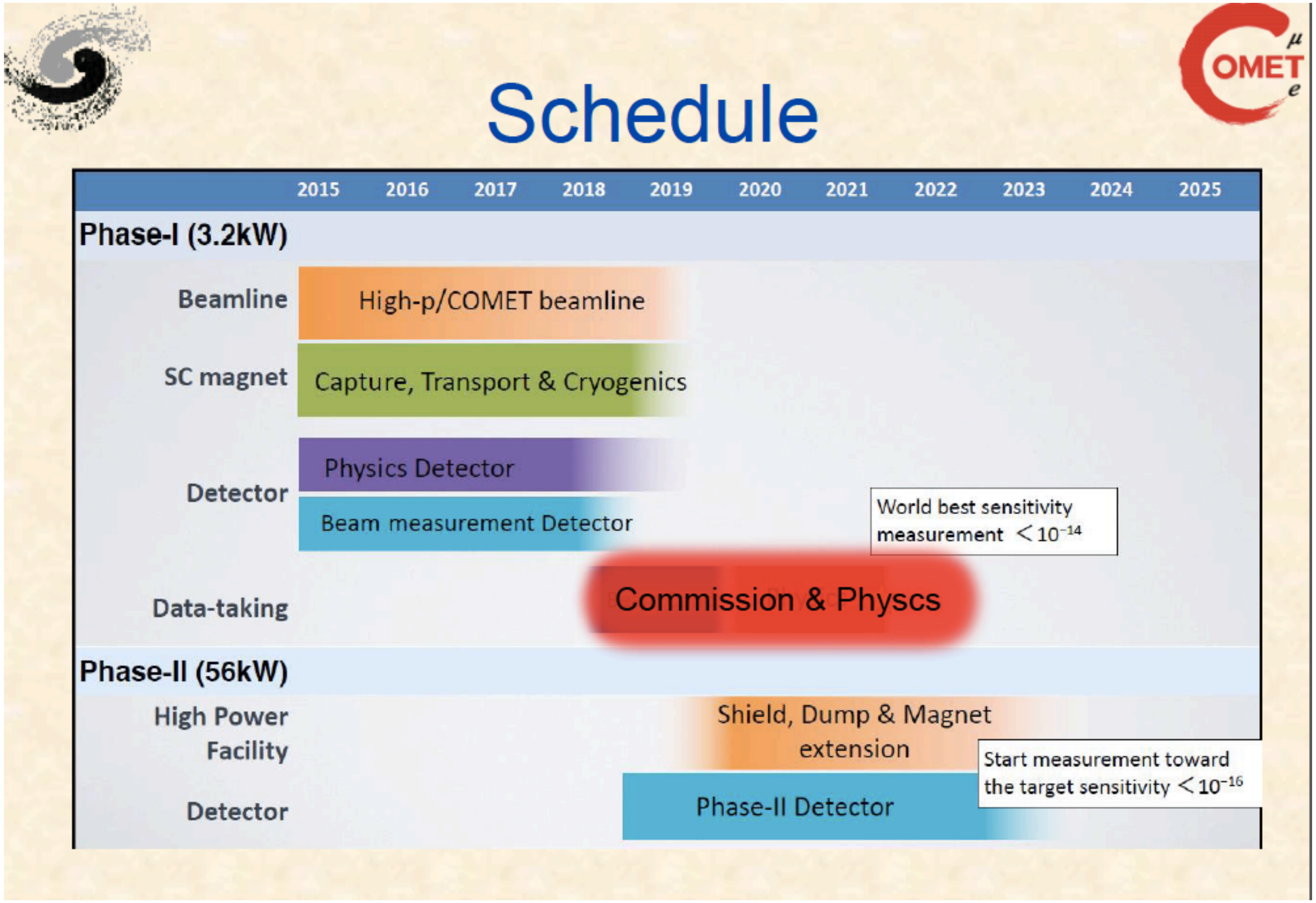


Aiming at 3 X 10^{-17}, 10000 times better than the current limit

muon cLFV with Pulsed muon beam lines

- μ^- N -> e^- N convertion searches with the DeeMe experiment



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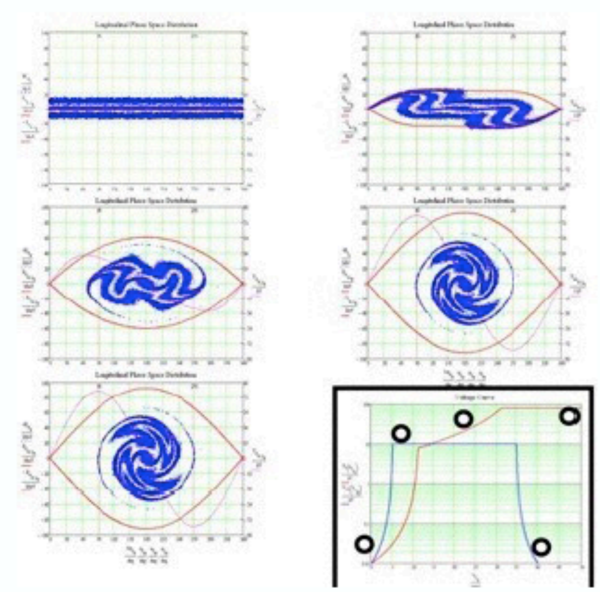
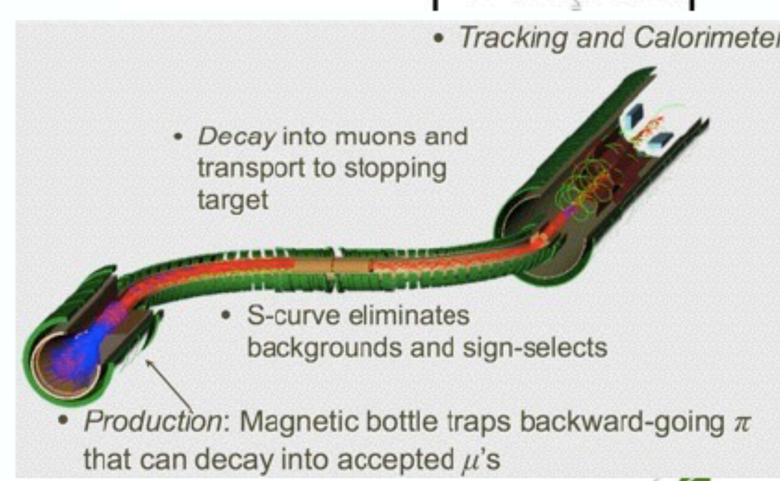
muon cLFV with Pulsed muon beam lines

- μ^- N -> e^- N convertion searches with the DeeMe experiment

Mu2e at FNAL

- **Target S.E.S. 2×10^{-17}**
- uses the antiproton accumulator/debuncher rings to manipulate proton beam bunches
- No interference with NOvA experiment
  - Mu2e uses beam NOvA can't
- pion production target in a solenoid magnet
- S-shape muon transport to eliminate BG and sign-select
- Tracker and calorimeter to measure electrons





S. Mihara
WG4 review-2

KEK 大学共同利用機関法人 高エネルギー加速器研究機構

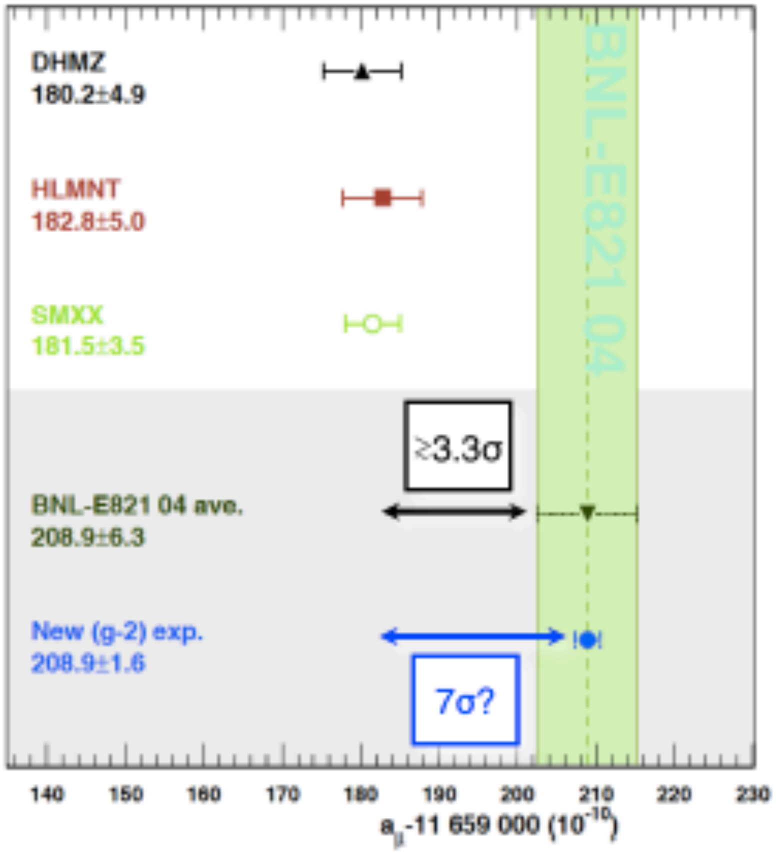
J-PARC

Precision muon physics

- muon g-2 at FNAL

Experimental goal: 5σ

W. Gohn
WG4



- BNL E821 measured g-2 to have a 3.3σ discrepancy from the standard model (2006).
- Fermilab E989 will measure 20 times the number of muons, reducing the uncertainty on this measurement by a factor of 4.
- Without theory improvements, discrepancy could reach $> 5\sigma$.

Uncertainty $\delta(a_\mu)$	Current value (ppb)	E989 Projection (ppb)
Theory	420	310
Experiment	540	140

Precision muon physics

- muon g-2 at FNAL

Measurement procedure

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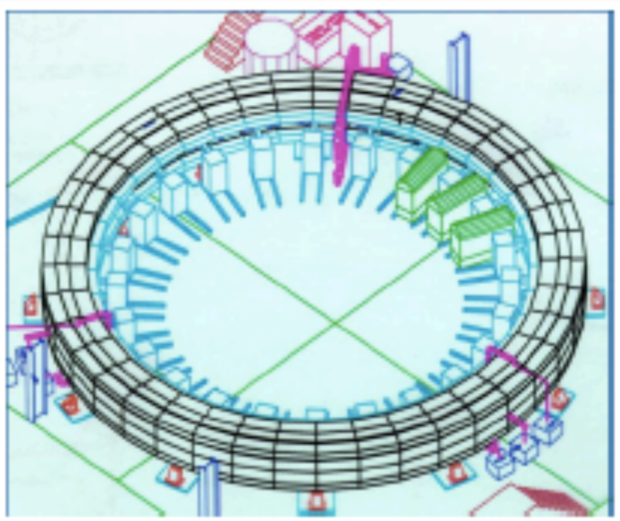
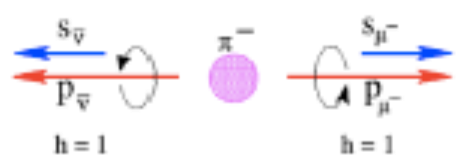
WG4

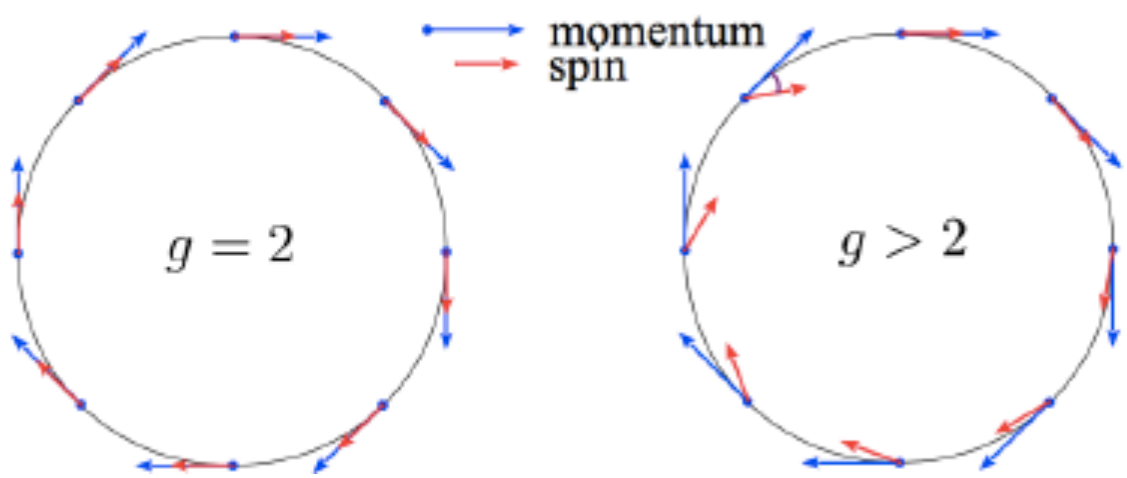




- Inject polarized muons into a magnetic storage ring.
- Muons will precess in the magnetic field.
- Measure the precession frequency via the timing of muon decays to positrons.
- Measurements of the precession frequency and magnetic field lead to a_μ.

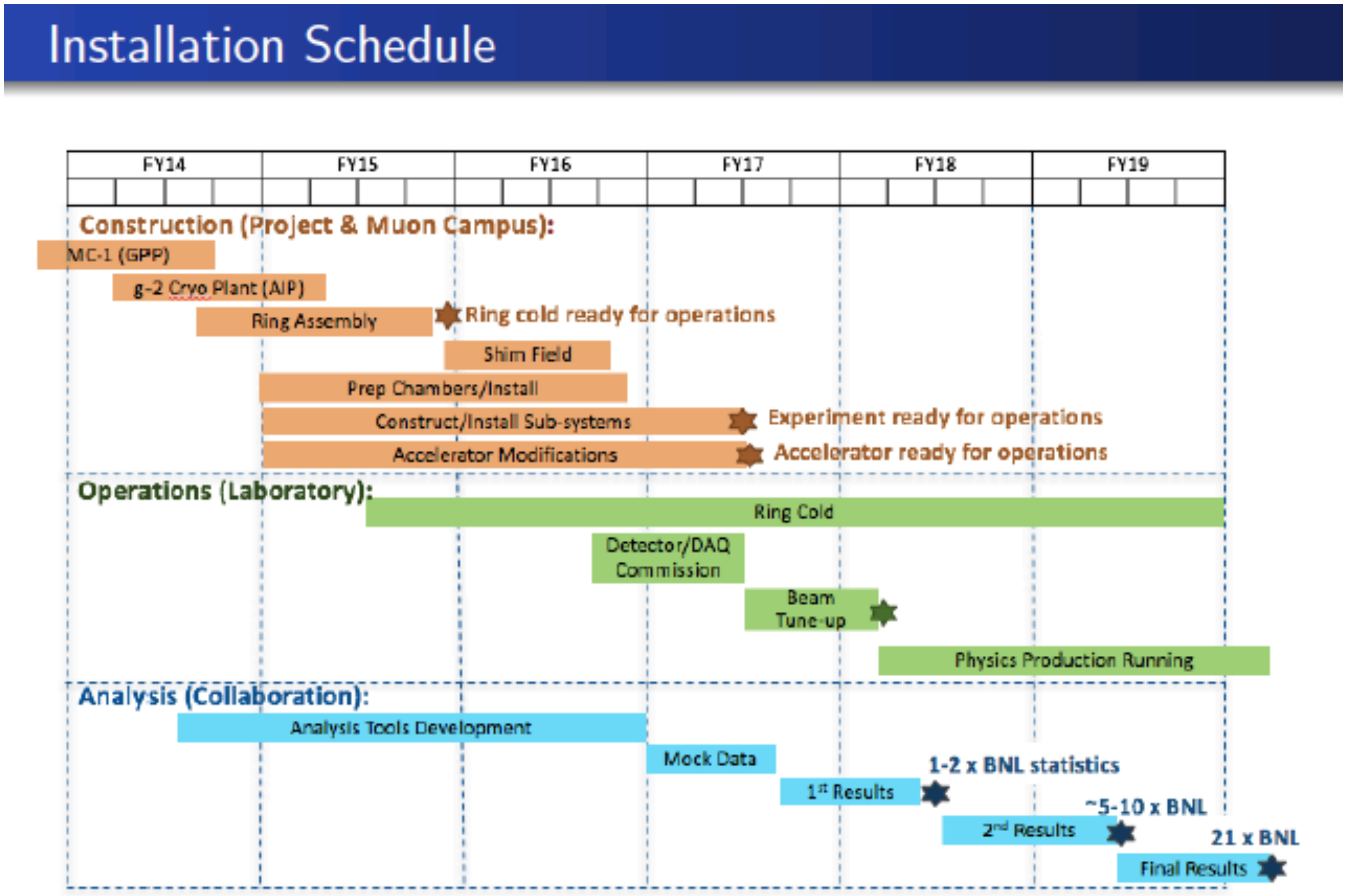
Magic momentum at $\gamma = 29.3$.

$$\vec{\omega}_a = -\frac{Qe}{m}\left[a_\mu \vec{B} - \left(a_\mu - \left(\frac{mc}{p}\right)^2\right)\frac{\vec{\beta}\times\vec{E}}{c}\right]$$



Precision muon physics

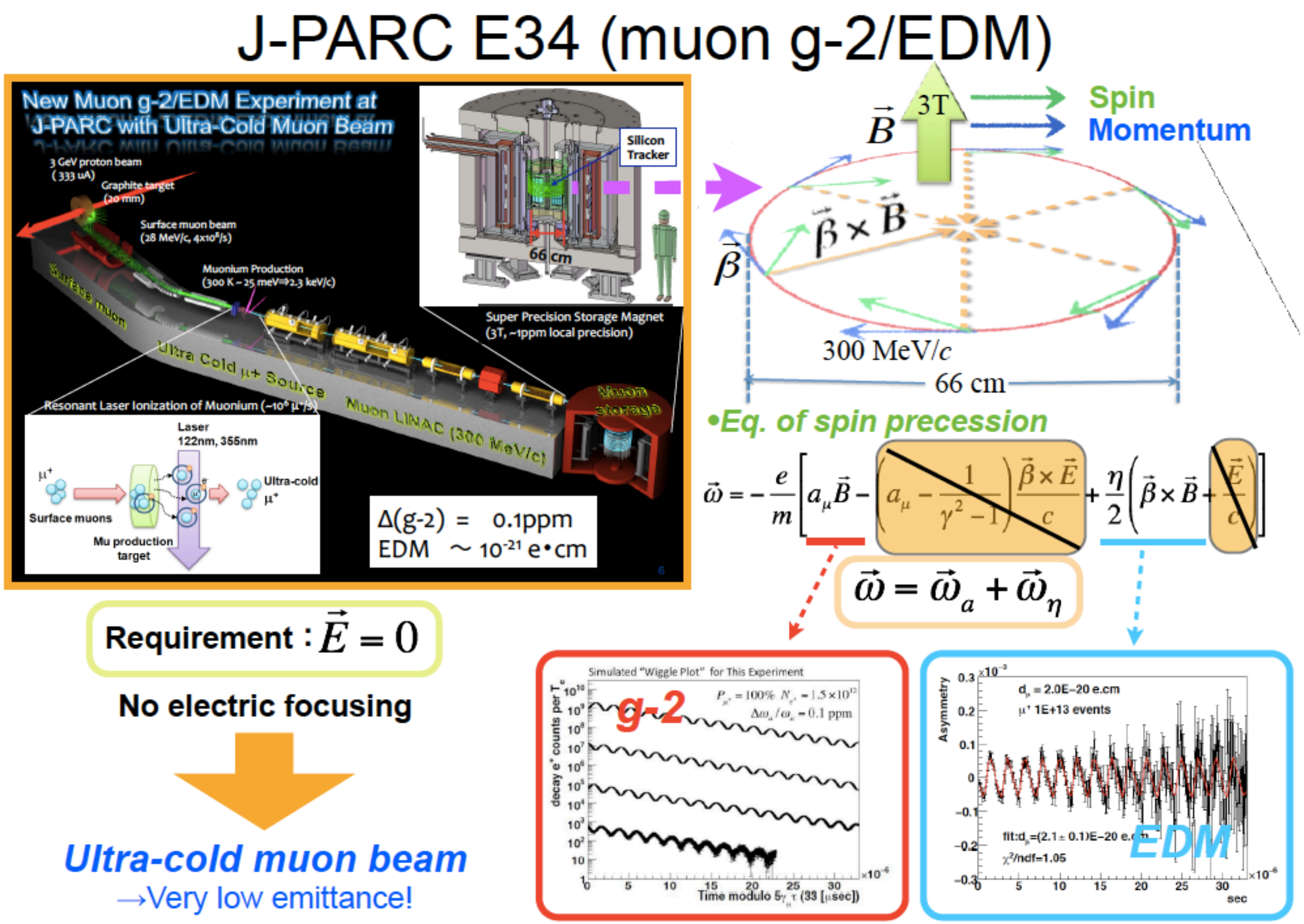
- muon g-2 at FNAL



W. Gohn WG4

Precision muon physics

- muon g-2/EDM at JPARC



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

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

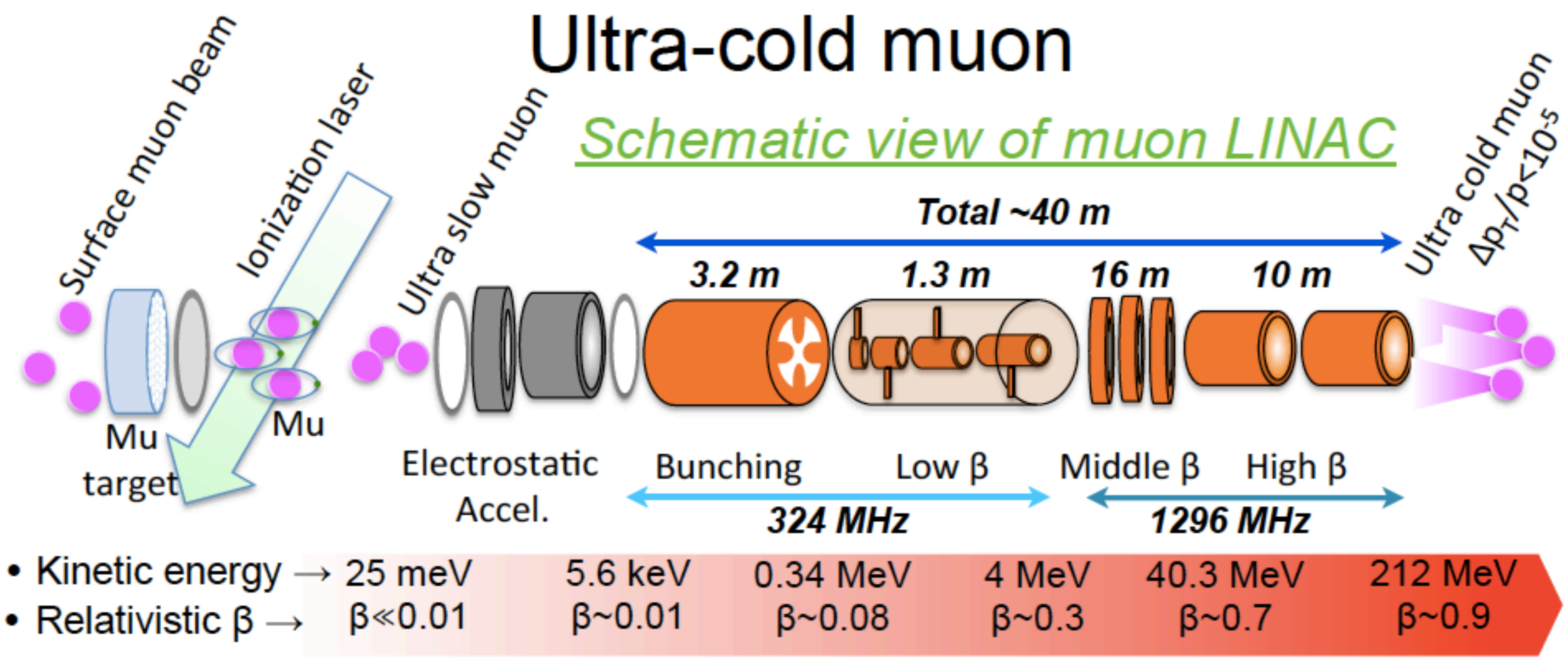
R. Kitamura
WG4

Precision muon physics

- muon g-2/EDM at JPARC

R. Kitamura WG4

Ultra-cold muon



- ☐ Muon acceleration
  → innovative technique in the world!
- ☐ Tertiary muon beam
  →~1000 π mm mrad
  - ☐ Large emittance
- ☐ Ultra cold muon
  →**1.5 π mm mrad** @ injection
  - ☐ *Very low emittance*

Design parameters of muon LINAC

Beam intensity	~10^6 /sec
Repetition frequency	25 Hz
Pulse width	10 ns
Transverse emittance	1.5 π mm mrad (Normalized)
Momentum dispersion	0.1%

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Precision muon physics

- muon g-2/EDM at JPARC

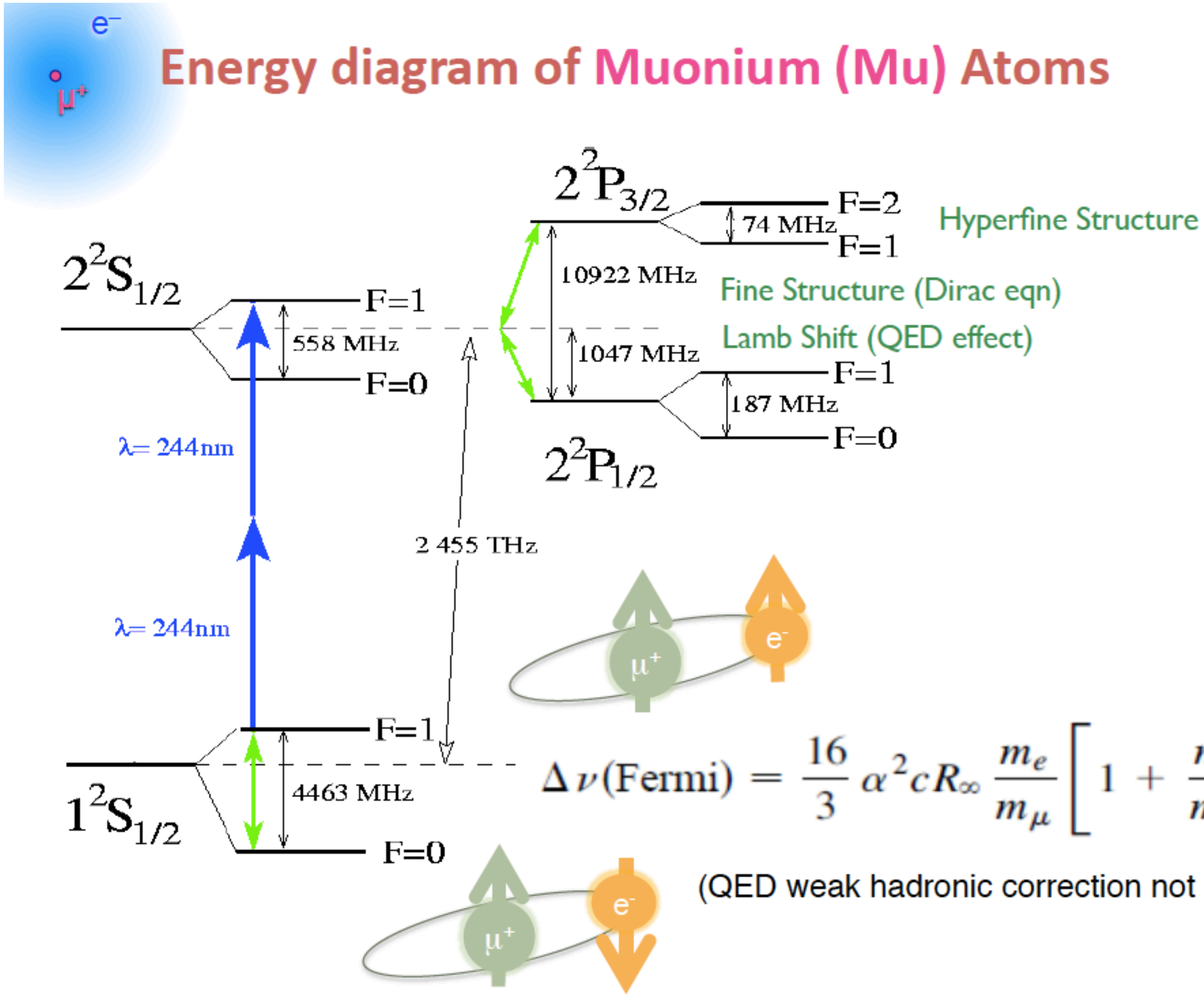
Summary

Accelerator	Design	Prototype	Production	Commissioning
Initial				
RFQ				
IH-DTL				
DAW				
DLS				

R. Kitamura
WG4

- ❑ We are developing the world's first muon dedicated LINAC for J-PARC E34 experiment.
- ❑ The first trial of the muon acceleration test is prepared. The preparation of the muon source and the initial accelerator were done. The RFQ test will be started soon when the beam line is constructed.
- ❑ Subsequent accelerators are also prepared. The first production of the ultra-cold muon will be planned within a few years.

Precision muon physics



$$\Delta\nu(\mathrm{Fermi}) = \frac{16}{3}\alpha^2 c R_\infty \frac{m_e}{m_\mu}\left[1 + \frac{m_e}{m_\mu}\right]^{-3}.$$

(QED weak hadronic correction not included)

H.A. Torii
WG4

Future Pulsed beam line

- PRISM: Phase Rotated Intense Slow Muon source

PRISM

PRISM task force

Aims:

- Address the technological challenges in realising an FFAG-based muon-to-electron conversion experiment,
- Strengthen the R&D for muon accelerators in the context of the Neutrino Factory and future muon physics experiments.

Areas of work:

- the physics of muon to electron conversion,
- proton driver,
- pion capture,
- muon beam transport,
- injection and extraction for PRISM-FFAG ring,
- FFAG ring design including the search for a new improved version,
- FFAG hardware systems R&D.

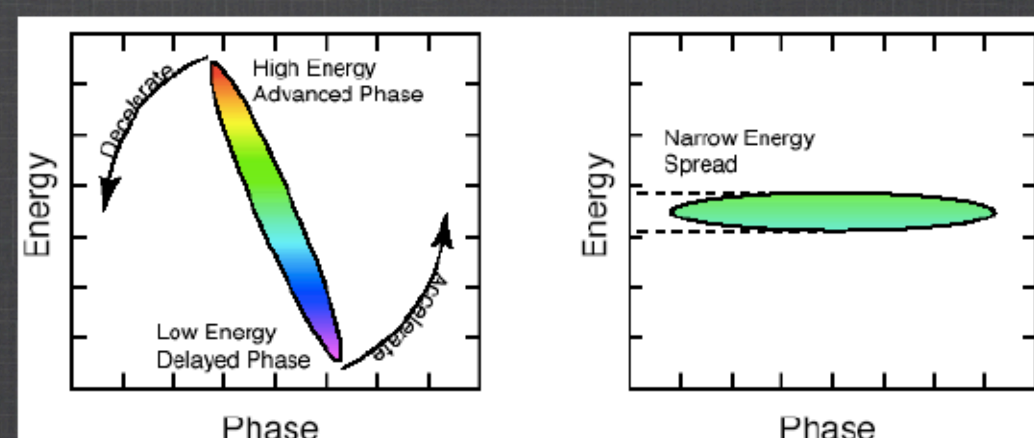
J.B. Lagrange
WG4

Future Pulsed beam line

- PRISM: Phase Rotated Intense Slow Muon source

PRISM features

- High muon intensity (10^{11}-10^{12} μ^-/s): large 6D acceptance (FFAG),
- Pulsed beam (for background rejection): >100 Hz,
- Low momentum muon (for less scattering backgrounds),
- Quasi-monoenergetic muon beam (for thinner muon-stopping target): phase rotation,



- No pion contamination (<10^{-18}), ~150 m in FFAG, beam extinction between pulses.

J.B. Lagrange
WG4

Future Pulsed beam line

- PRISM: Phase Rotated Intense Slow Muon source

PRISM parameters

Proton Driver:	
Proton beam power	1–4 MW
Proton beam energy	several GeV
Proton bunch duration	10 ns
Target and pion capture:	
Target type	solid
Pion capture field	4–10 T
Phase rotator:	
Reference μ^- momentum	40–68 MeV/c
Momentum acceptance	±20%
Acceptance (H/V)	38/5 mm.rad
Harmonic number	1
RF frequency	3–6 MHz
RF voltage per turn	3–5.5 MV
Repetition rate	100–1000 Hz
Final momentum spread	±2%

J.B. Lagrange
WG4

to serve cLFV with unprecedent sensitivity (~10^{-19})

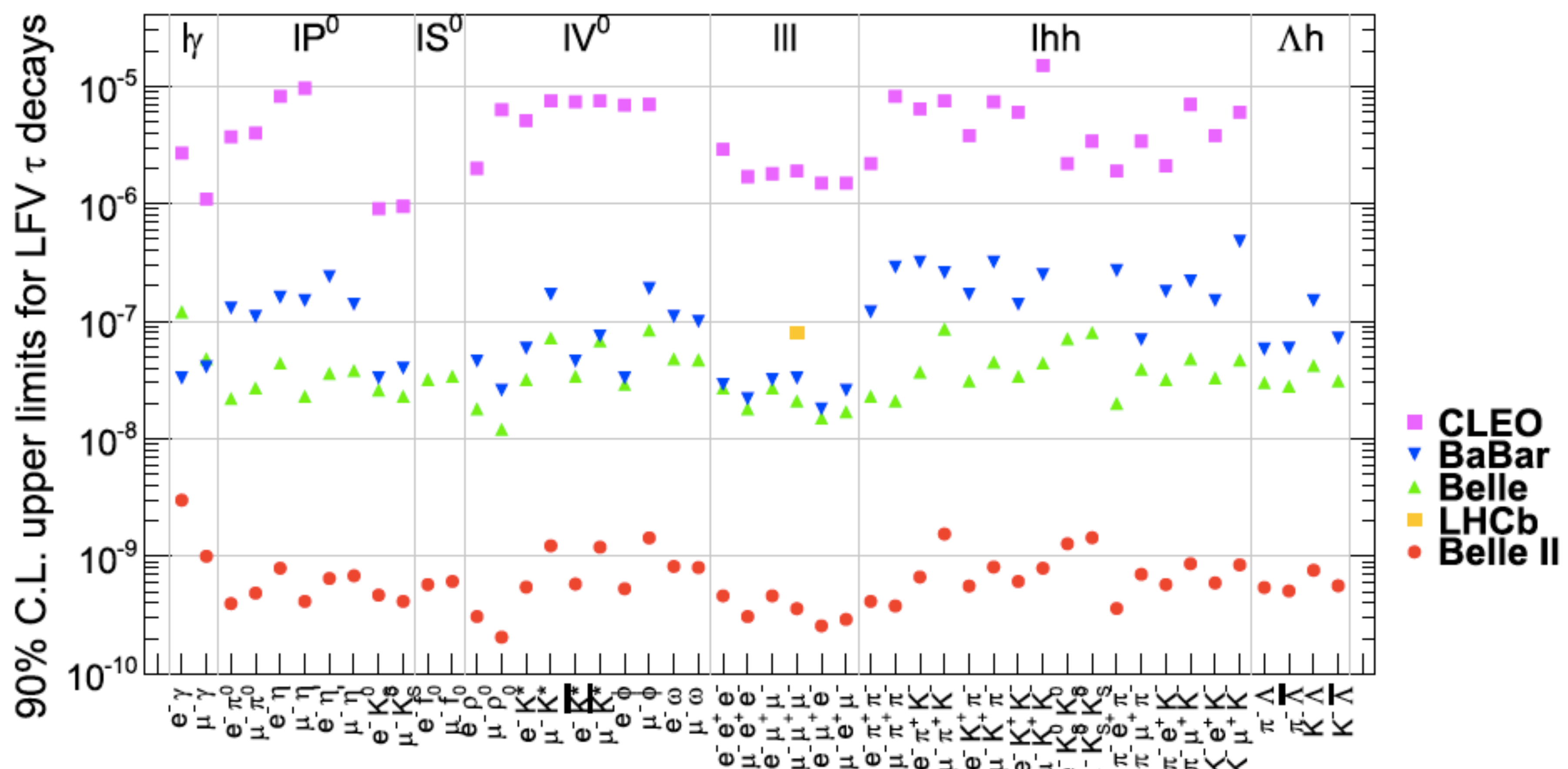
tauon cLFV

- with BELLEII

LFV Upper limits @ B factories

T. Konno
WG4

- Current estimation with Belle II final statistics : ~10^{-2} lower
  - Many decay modes are accessible



KEK Report 2009-12 (arXiv:1002.5012)
belle II internal node #21

tauon cLFV

- with BELLEII

Summary

- Belle collected a 1ab^{-1} data sample containing ~10^9 τ pairs
  - Almost all upper limits on BF for τLFV are analyzed with Belle's full data sample and reach O(10^{-8})
- Belle II experiment is scheduled to start at 2018 and collect ~5 x 10^{10} τ pairs in 50ab^{-1} data sample
  - LFV Sensitivity depends on statistics
  - Background free modes, such as $\tau \to \ell\ell\ell$ can be reached to O(10^{-10}) branching ratio sensitivity while $\tau \to \ell\gamma$ modes will be O(10^{-9}), highly depends on the background situation
- First tuning of SuperKEKB was succeeded
  - BEAST II will provide more knowledge of beam background
- Detector construction is ongoing with cosmic ray/beam tests
  - Belle II rolls in at the end of the year

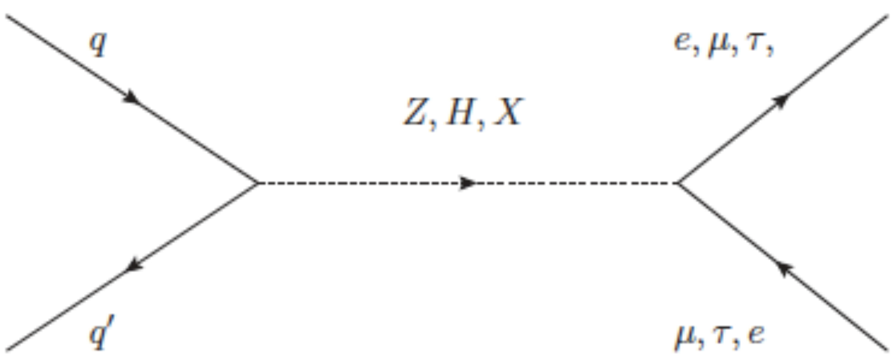
T. Konno
WG4

cLFV searches with ATLAS

Introduction: searches for cLFV

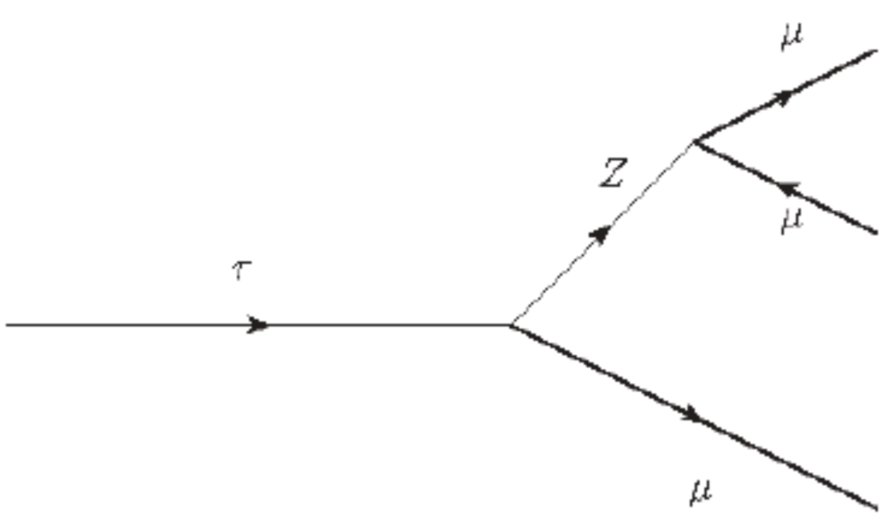
M. Bret
WG4

- Muon decays
  - $\mu \to e\gamma$
  - $\mu \to 3e$
  - $\mu \to e$ conversion
- Tau decays
  - $\tau \to e\gamma$
  - $\tau \to 3\ell$
- Meson LFV decays ($B^0/D^0 \to e\mu$)



Searches in ATLAS focus on:

- $\tau \to 3\mu$
- Decays of existing particles (Z or Higgs)
- Possible new particles decaying to flavour-violating final states



cLFV searches with ATLAS

- Z -> μe/ τμ decay searches

at $\sqrt{s}$ = 8 TeV, 20.3 fb^{-1}

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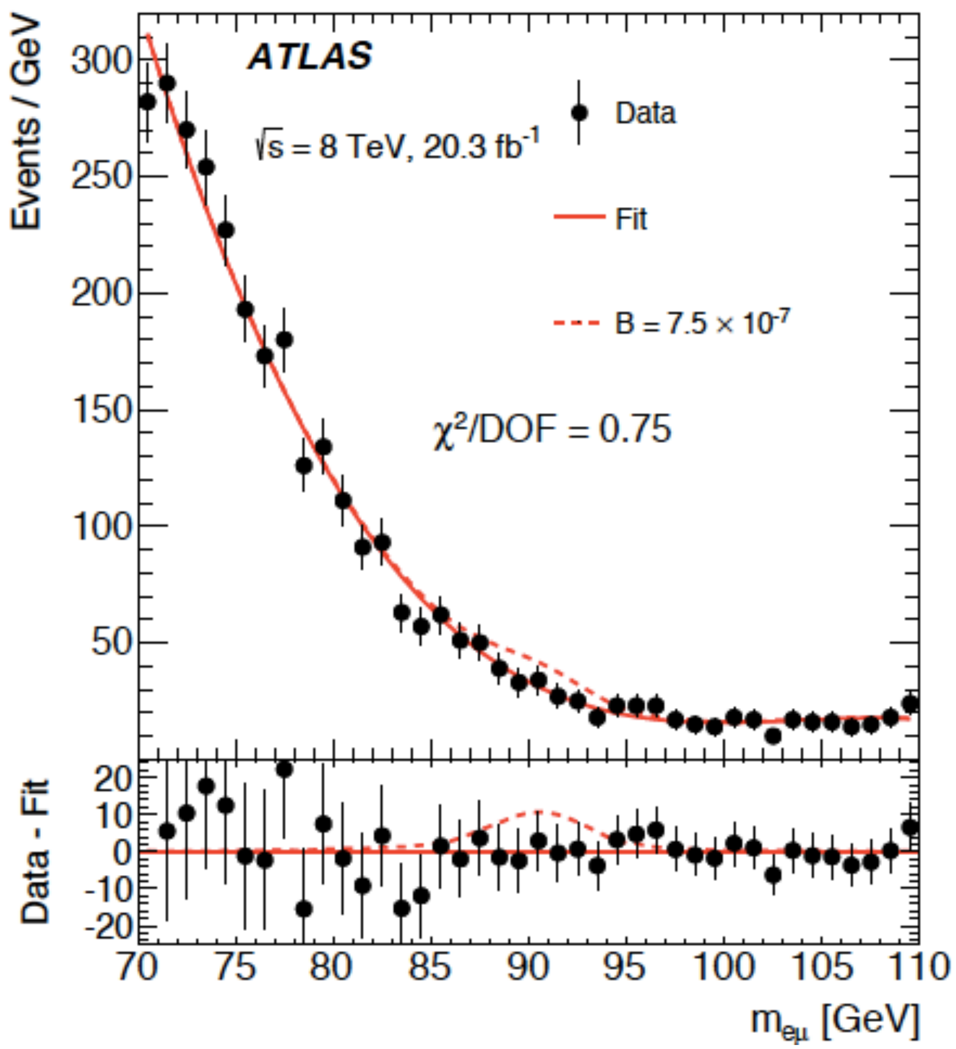
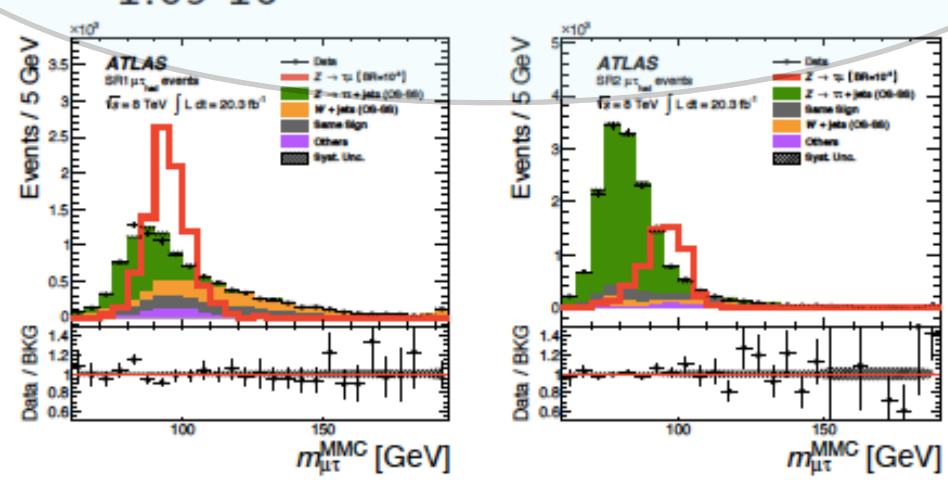
LFV decays of the Z boson: Results



- A 3rd order Chebyshev polynomial fit is performed on the $m_{e\mu}$ distribution
- 95% CL at a BR of $7.5{\cdot}10^{-7}$ (previous result $1.7{\cdot}10^{-6}$)
- Limits on the BR to a $\mu\tau$ final state extracted in arXiv:1604.07730 at $1.69{\cdot}10^{-5}$



cLFV searches with ATLAS

- H -> τμ/ τμ decay searches

Search for LFV H→ $e/\mu\tau_{had}$ decays: Results

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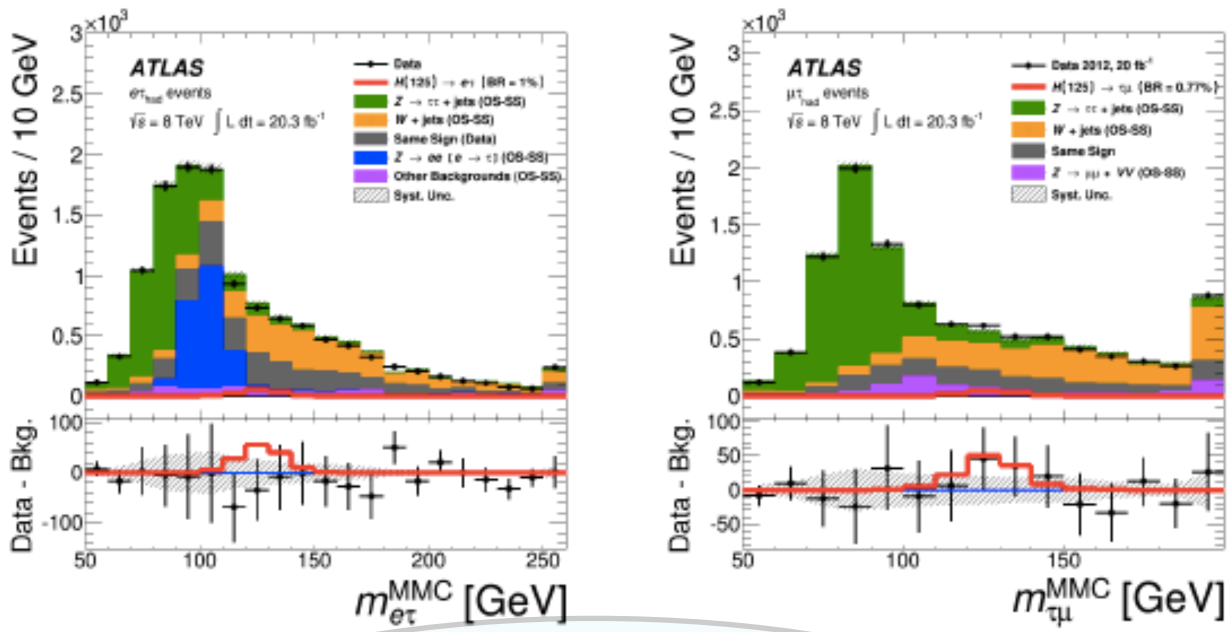
$H \to \mu\tau$ Yields:

	SR1	SR2
Signal	$69.1 \pm 0.8 \pm 9.2$	$48.5 \pm 0.8 \pm 7.5$
$Z \to \tau\tau$	$133.4 \pm 6.9 \pm 9.1$	$262.6 \pm 9.7 \pm 18.6$
W+jets	$619 \pm 54 \pm 55$	$406 \pm 42 \pm 34$
Top	$39.5 \pm 5.3 \pm 4.7$	$19.6 \pm 3.1 \pm 3.3$
Same–Sign events	$335 \pm 19 \pm 47$	$238 \pm 16 \pm 34$
$VV + Z \to \mu\mu$	$90 \pm 21 \pm 16$	$81 \pm 22 \pm 17$
$H \to \tau\tau$	$6.82 \pm 0.21 \pm 0.97$	$13.7 \pm 0.3 \pm 1.9$
Total background	$1224 \pm 62 \pm 63$	$1021 \pm 51 \pm 49$
Data	1217	1075

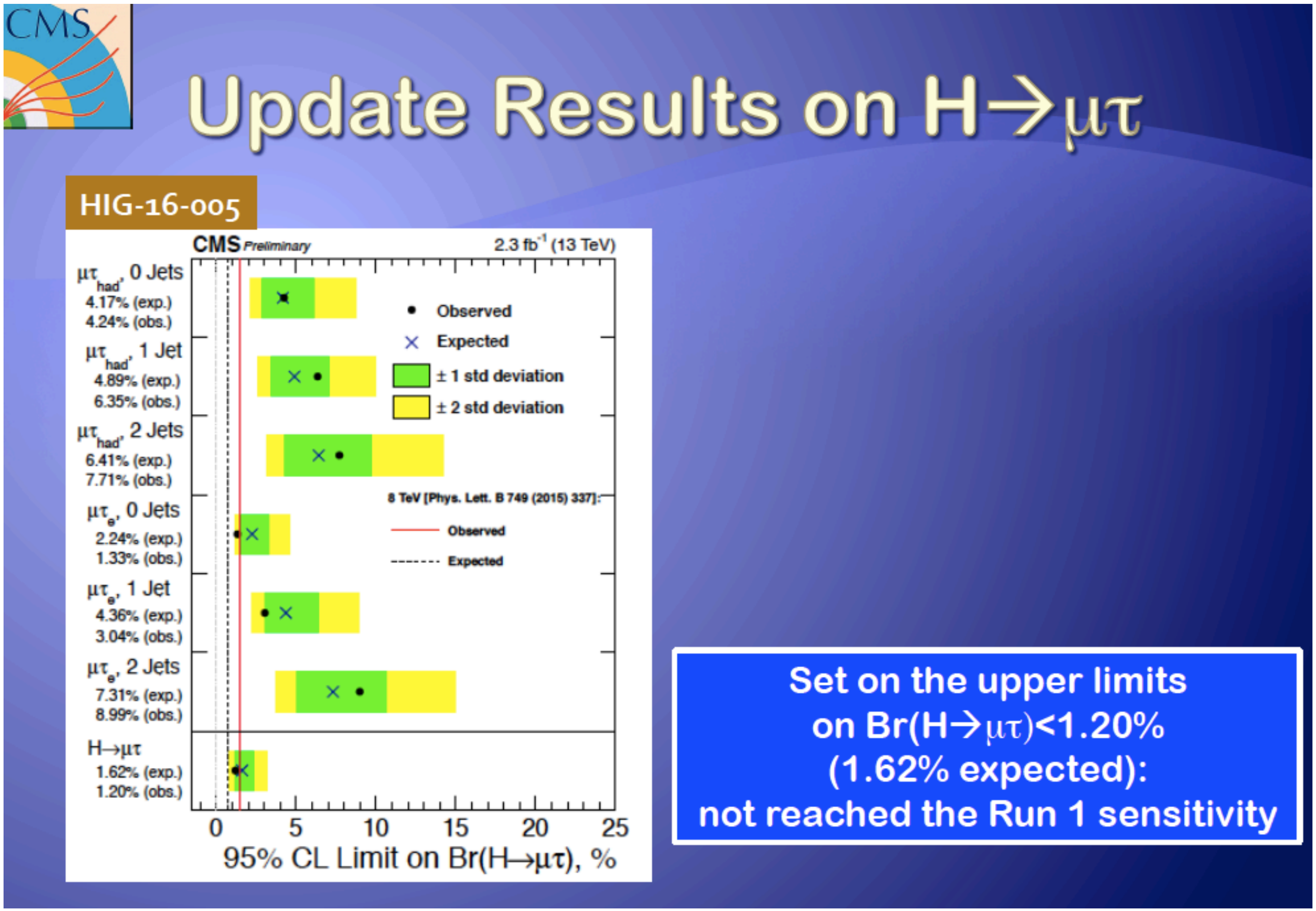
$H \to e\tau$ Yields:

	SR1	SR2
LFV signal (Br($H \to e\tau$) = 1.0%)	75 ± 1 ± 8	59 ± 1 ± 8
W+jets	740 ±80 ±110	370 ±60 ±70
Same-Sign events	390 ±20 ± 60	570 ±30 ±80
$Z \to \tau\tau$	116 ± 8 ± 11	245 ±11 ±20
$VV + Z \to ee(jet \to \tau_{had}^{misid})$	71 ±31 ± 30	60 ±20 ±40
$Z \to ee(e \to \tau_{had}^{misid})$	69 ±17 ± 11	320 ±40 ±40
Top	18 ± 5 ± 4	10.2± 2.6± 2.2
$H \to \tau\tau$	4.6± 0.2± 0.7	10.5± 0.3± 1.5
Total background	1410 ±90 ± 70	1590 ±80 ±70
Data	1397	1501



- Results compatible with the null hypothesis
- Placed 95% CL on BR($H \to e/\mu\tau$) at 1.81 & 1.85% , respectively
- More stringent limits than previous indirect searches

cLFV searches and heavy neutrinos with CMS



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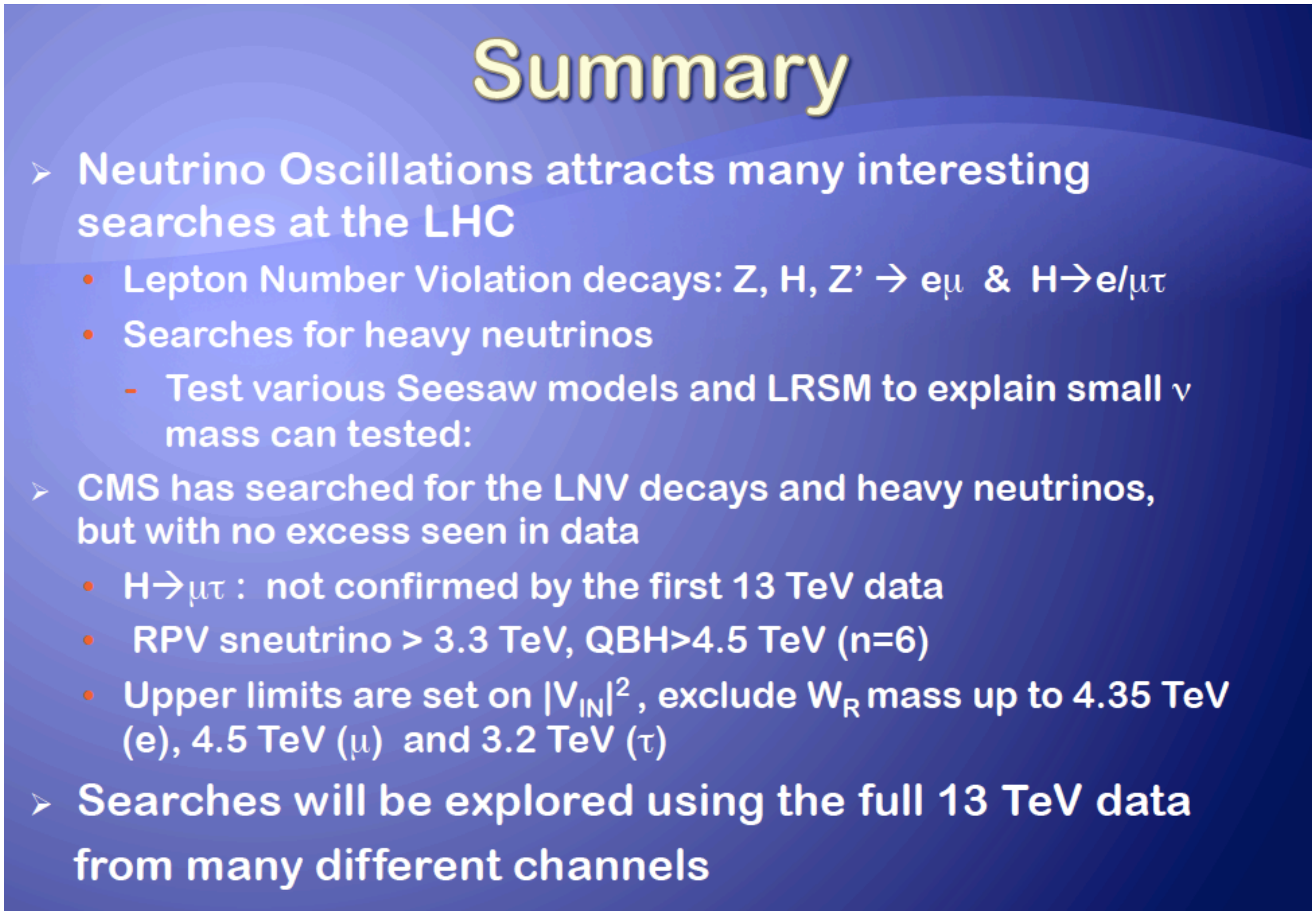
cLFV searches and heavy neutrinos with CMS



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Lepton flavour universality test with LHCb

The R_{D^*} measurement

$$R_{D^*} = \frac{\overline{B^0} \to D^{*+}\tau^-\overline{\nu_\tau}}{\overline{B^0} \to D^{*+}\mu^-\overline{\nu_\mu}}$$

F. Lionetto
WG4

- Branching fraction ratio of $\overline{B^0} \to D^{*+}\tau^-\overline{\nu_\tau}$ to $\overline{B^0} \to D^{*+}\mu^-\overline{\nu_\mu}$
  - $R_{D^*} \stackrel{SM}{=} 0.252 \pm 0.003$
  - previously measured by BaBar and Belle

Experiment	R_{D^*}	SM discrepancy
BaBar*	$0.332 \pm 0.024 \pm 0.018$	$2.7\ \sigma$
Belle**	$0.293 \pm 0.038 \pm 0.015$	$1.8\ \sigma$
	$0.302 \pm 0.030 \pm 0.011$	$1.6\ \sigma$

* Phys. Rev. Lett. 109, 101802 (2012), Phys. Rev. D 88, 072012 (2013)

** Phys. Rev. D 92, 072014 (2015), arXiv:1607.07923, Belle-CONF-1602

Lepton flavour universality test with LHCb

Results for R_{D^*}

- First measurement of $b \to \tau$ decays at hadron colliders
- Compatible with the SM at 2.1 σ

$$R_{D^*} = 0.336 \pm 0.027(\text{stat}) \pm 0.030(\text{syst})$$

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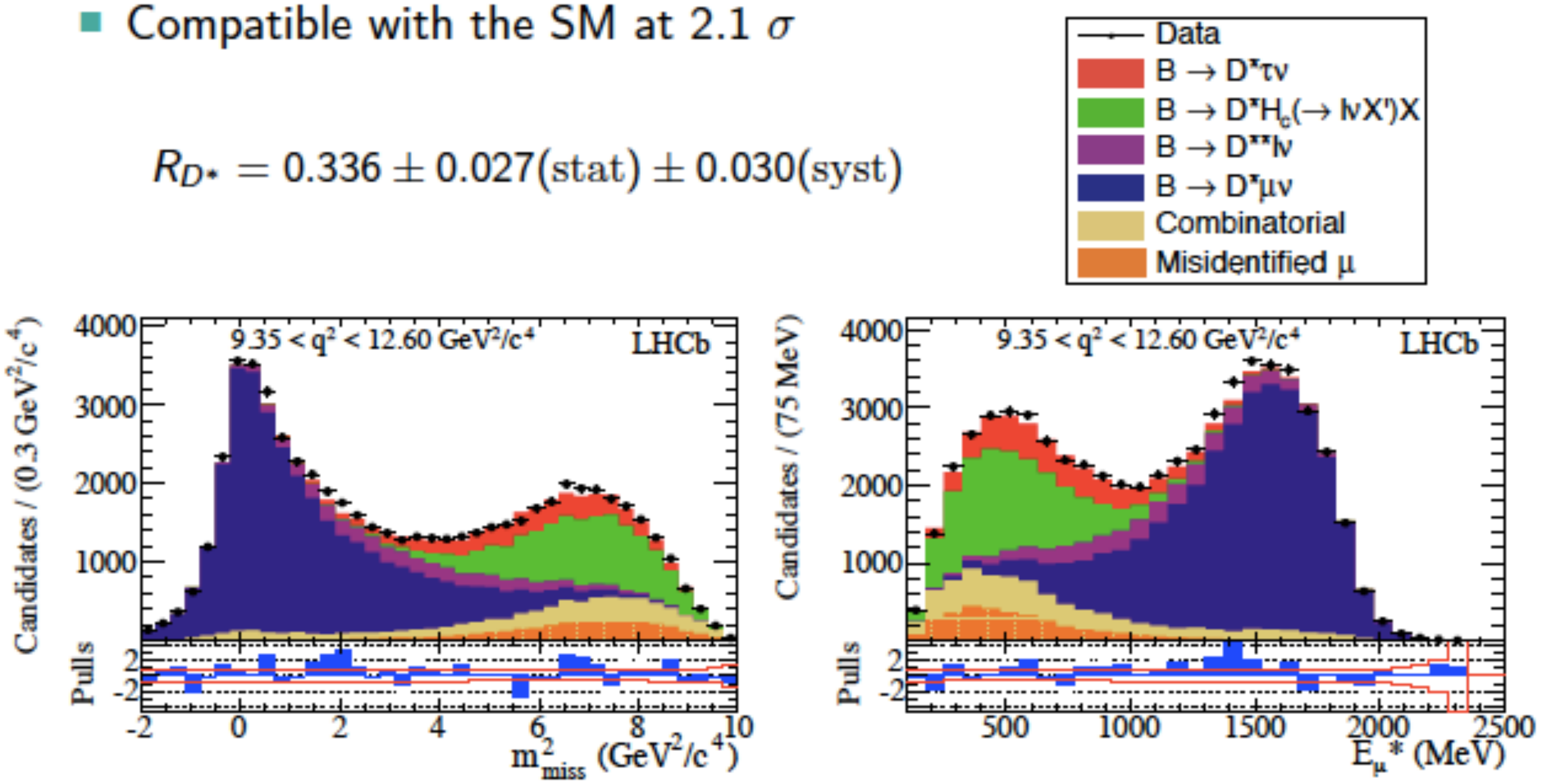
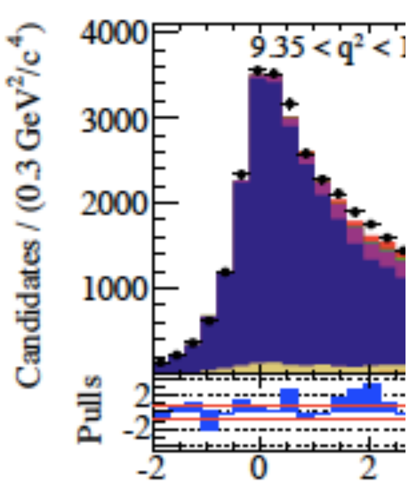


Lepton flavour universality test with LHCb

Results for R_{D*}

- First measur
- Compatible

$R_{D*} = 0.336$



Combined results for R_D and R_{D*}

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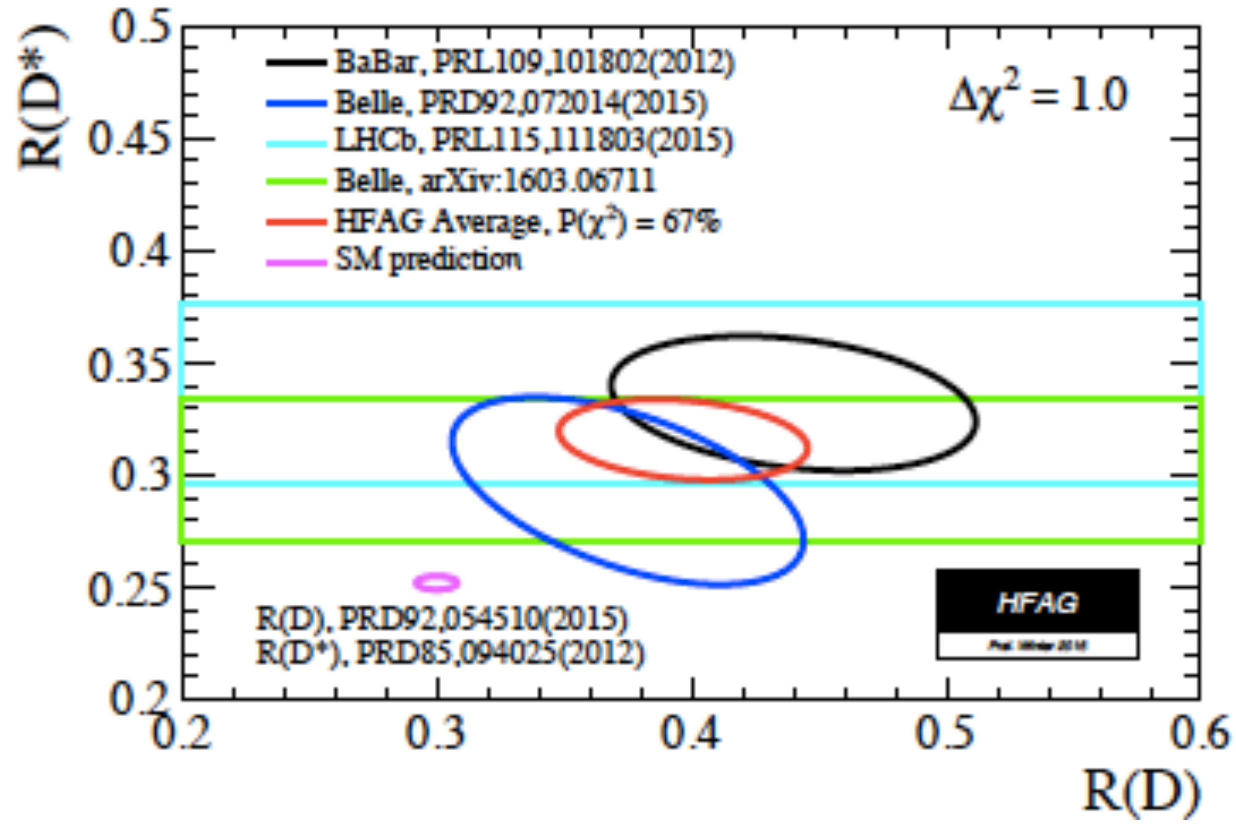
- Excess w.r.t. SM prediction observed by several experiments
  - corresponding to 4 σ according to latest HFAG average



Lepton flavour universality test with LHCb

The R_K measurement

$$R_K = \frac{B^+ \to K^+\mu^+\mu^-}{B^+ \to K^+e^+e^-}$$

F. Lionetto
WG4

- Ratio of branching fractions of $B^+ \to K^+\mu^+\mu^-$ and $B^+ \to K^+e^+e^-$
  - $R_K \stackrel{\text{SM}}{=} 1 + \mathcal{O}(10^{-2})$
  - sensitive to new scalar and pseudoscalar interactions or Z' bosons
  - previously measured by BaBar and Belle

Experiment	q^2 (GeV^2)	R_K
BaBar*	$0.1 - 16.0$	$1.00^{+0.31}_{-0.25} \pm 0.07$
	$0.1 - 8.12$	$0.74^{+0.40}_{-0.31} \pm 0.06$
	> 10.11	$1.43^{+0.65}_{-0.44} \pm 0.12$
Belle**	$0.00 - 16.0$	$1.03 \pm 0.19 \pm 0.06$

* Phys. Rev. D 86 (2012) 032012

** Phys. Rev. Lett. 103 (2009) 171801

Lepton flavour universality test with LHCb

Results for R_K

- Distrib
  - trig
  - *bre*
- Most
- Comp
  at 2.6
- Func
  the f

Conclusions

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WG4

- Search for NP in the $b \to c\tau^-\overline{\nu_\tau}$ transition
  - excess of 4 σ w.r.t. SM prediction observed in R_{D^*}
  - might be a hint to LFU violation between μ and τ
- Search for NP in the $b \to s\ell^+\ell^-$ transition
  - hints of tension with SM predictions observed in R_K and $B^0 \to K^{*0}\mu^+\mu^-$
  - possible coherent pattern in terms of $\mathcal{C}_9$ (and possibly $\mathcal{C}_{10}$)
- Update with Run II statistics
- Further measurements foreseen at LHCb, stay tuned!

Test of mu-e universality with kaons

R_K in the SM

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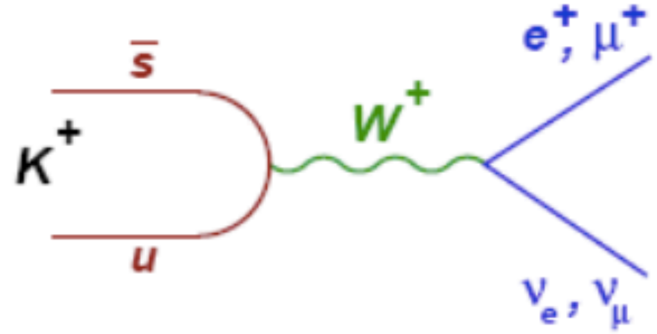
WG4

Leptonic decays of light pseudoscalar mesons
not directly usable due to hadronic uncertainties

measure the ratio



- hadronic uncertainties cancel
- R_K very well predicted within the SM, well below 10^{-3}
- K_{e2} strongly helicity suppressed (V-A coupling)

→ enhanced sensitivity to non-SM effects

[V. Cirigliano and I. Rosell, Phys. Rev. Lett. (2007) 231801]

$$R_K = \frac{\Gamma(K^\pm \to e^\pm \nu_e)}{\Gamma(K^\pm \to \mu^\pm \nu_\mu)} = \frac{m_e^2}{m_\mu^2}\left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2}\right)^2 (1 + \delta R_{QED}) = (2.477 \pm 0.001) \cdot 10^{-5}$$

helicity suppression ~10^{-5} radiative corrections

radiative corrections R_{QED} (few %) due to the IB part of the radiative decay $K^\pm \to e^\pm \nu \gamma$ are included in R_K definition and well computed in the SM

Test of mu-e universality with kaons

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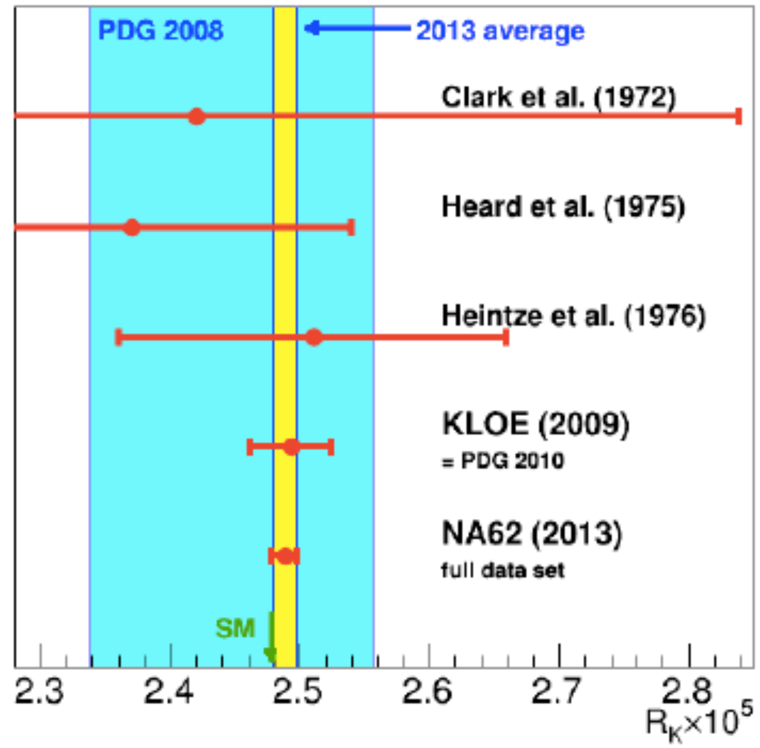
WG4

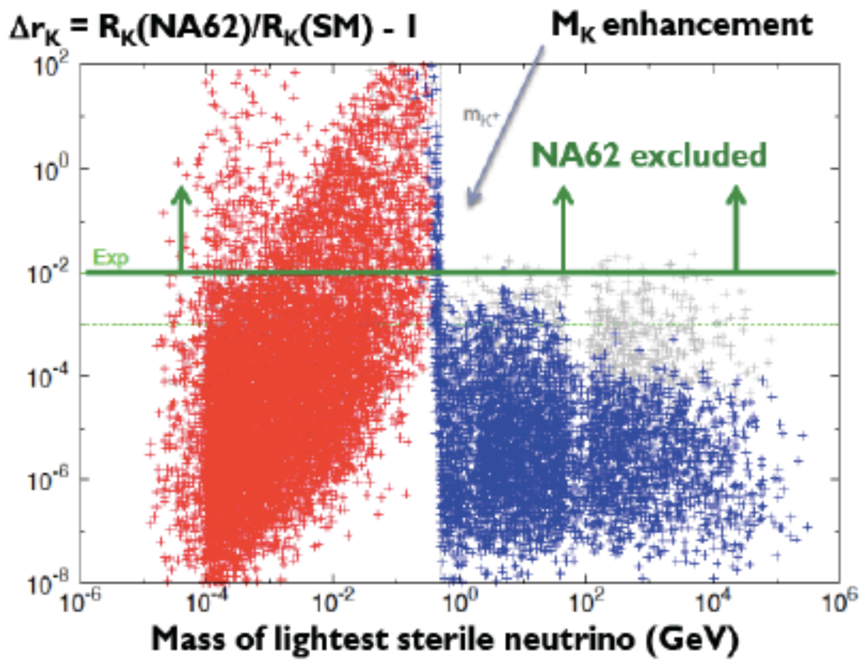
R_K final result

$$R_K = \left(2.488 \pm 0.007_{stat} \pm 0.007_{syst}\right) \cdot 10^{-5}$$

Phys Lett B 719 (2013) 326

- World Ke2 statistics increased by a factor of 10
- In agreement with SM expectation, within 1.2 σ
- Motivation for improved precision R_K measurem





[Abada et al., JHEP 1402 (2014) 091]

World average	R_K x 10^5	precision
PDG 2008	2.447 ± 0.109	4.5%
2014	2.488 ± 0.009	0.4%

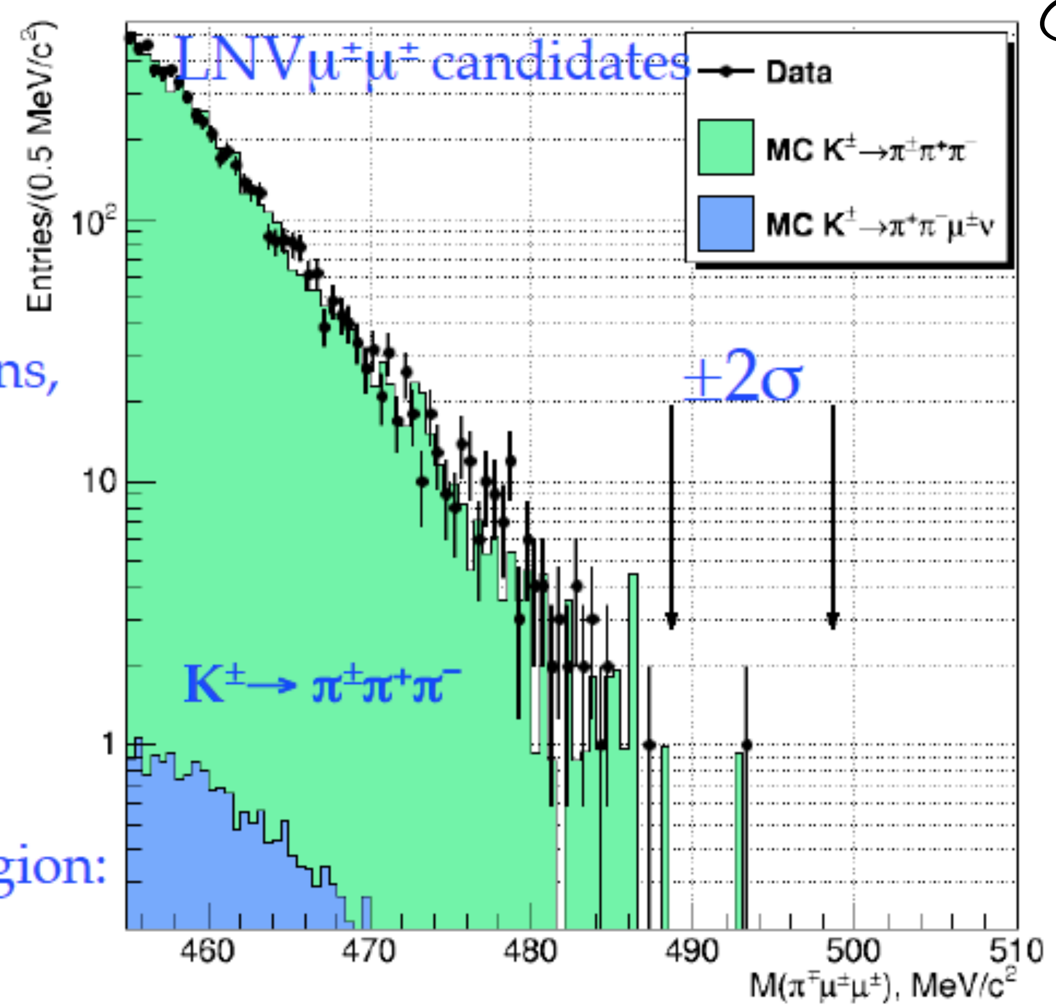
Prospects: NA62 → 1 M events (downscaled trigger) expected (2 years data taking), statistical uncentainty ~ 0.1% → Total uncertainty expected ~ 0.2%

LNV searches with Kaons

LNV - Same Sign muon sample

Blind analysis

- Selection based on simulation of $K^{\pm} \to \pi^{\mp}\mu^{\pm}\mu^{\pm}$ and $K^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ (background, $\pi \to \mu$, similar topology)
- 3-track vertex topology, 2-same sign muons, 1 odd-sign pion, no missing momentum, muon ID
- Signal region: $|M_{\pi\mu\mu} - M_K| < 5$ MeV/c²
- Control region: $M_{\pi\mu\mu} < 480$ MeV/c²



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Result

Number of Kaon decays in fiducial decay region: 1.64×10^{11} (from reconstructed $K^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$)

Events in signal region: $N_{obs} = 1$

Expected background (from MC): $N_{exp} = 1.16 \pm 0.87$

$BR(K^{\pm} \to \pi^{\mp}\mu^{\pm}\mu^{\pm}) < 8.6 \times 10^{-11}$ @ 90% CL

factor of ~ 13 improvement, paper in preparation

Rolke-Lopez statistical treatment

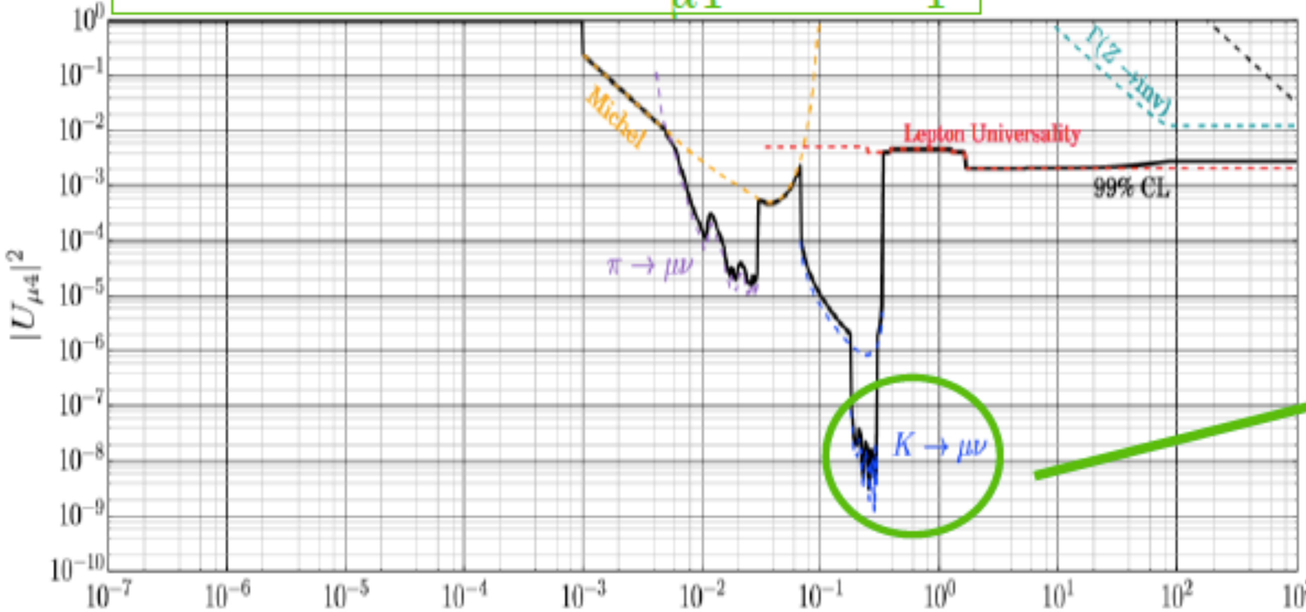
HNL global limits

Y. Yuan
WG4

HNL global limits

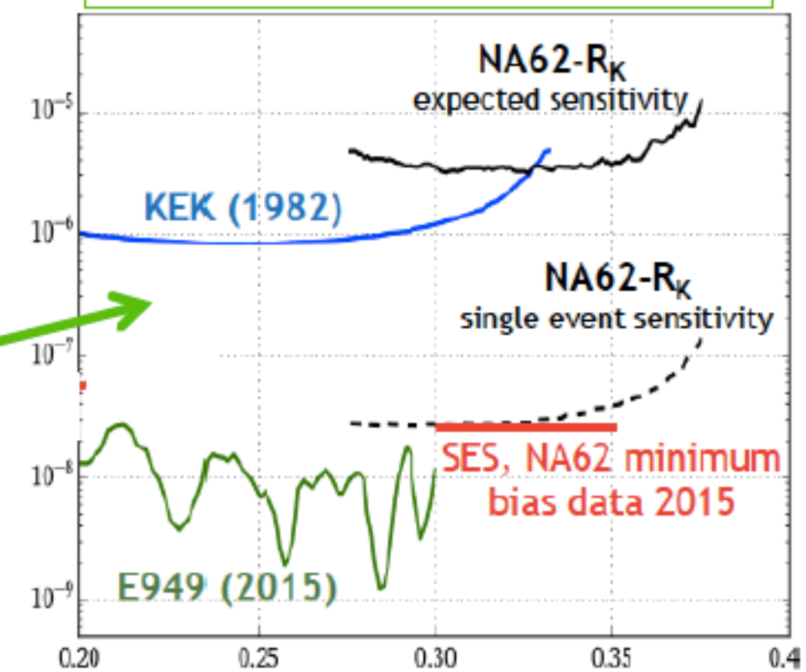
- In contrast to decay searches, production searches are model independent
- Most stringent limits are set by Kaon experiments

Global limits on $|U_{\mu 4}|^2$ vs m_4



[De Gouvea and Kobach, PRD93 (2016) 033005]

Limits on $|U_{\mu 4}|^2$ vs m_4 from $K^{\pm} \to \mu^{\pm}\nu$



cLFV with BESIII

Experimental status

Y. Yuan
WG4

- cLFV in quarkonium resonances decay

$\ell_1\ell_2$	$\mu\tau$	$e\tau$	$e\mu$
$\mathcal{B}(\Upsilon(1S) \to \ell_1\ell_2)$	6.0×10^{-6}	–	–
$\mathcal{B}(\Upsilon(2S) \to \ell_1\ell_2)$	3.3×10^{-6}	3.2×10^{-6}	–
$\mathcal{B}(\Upsilon(3S) \to \ell_1\ell_2)$	3.1×10^{-6}	4.2×10^{-6}	–
$\mathcal{B}(J/\psi \to \ell_1\ell_2)$	2.0×10^{-6}	8.3×10^{-6}	1.6×10^{-7}
$\mathcal{B}(\phi \to \ell_1\ell_2)$	n/a	n/a	4.1×10^{-6}

cLFV with BESIII

- cLFV in c

$\ell_1\ell_2$
$\mathcal{B}(\Upsilon(1S) \to \ell_1\ell_2)$
$\mathcal{B}(\Upsilon(2S) \to \ell_1\ell_2)$
$\mathcal{B}(\Upsilon(3S) \to \ell_1\ell_2)$
$\mathcal{B}(J/\psi \to \ell_1\ell_2)$
$\mathcal{B}(\phi \to \ell_1\ell_2)$

J/ψ Data Sample

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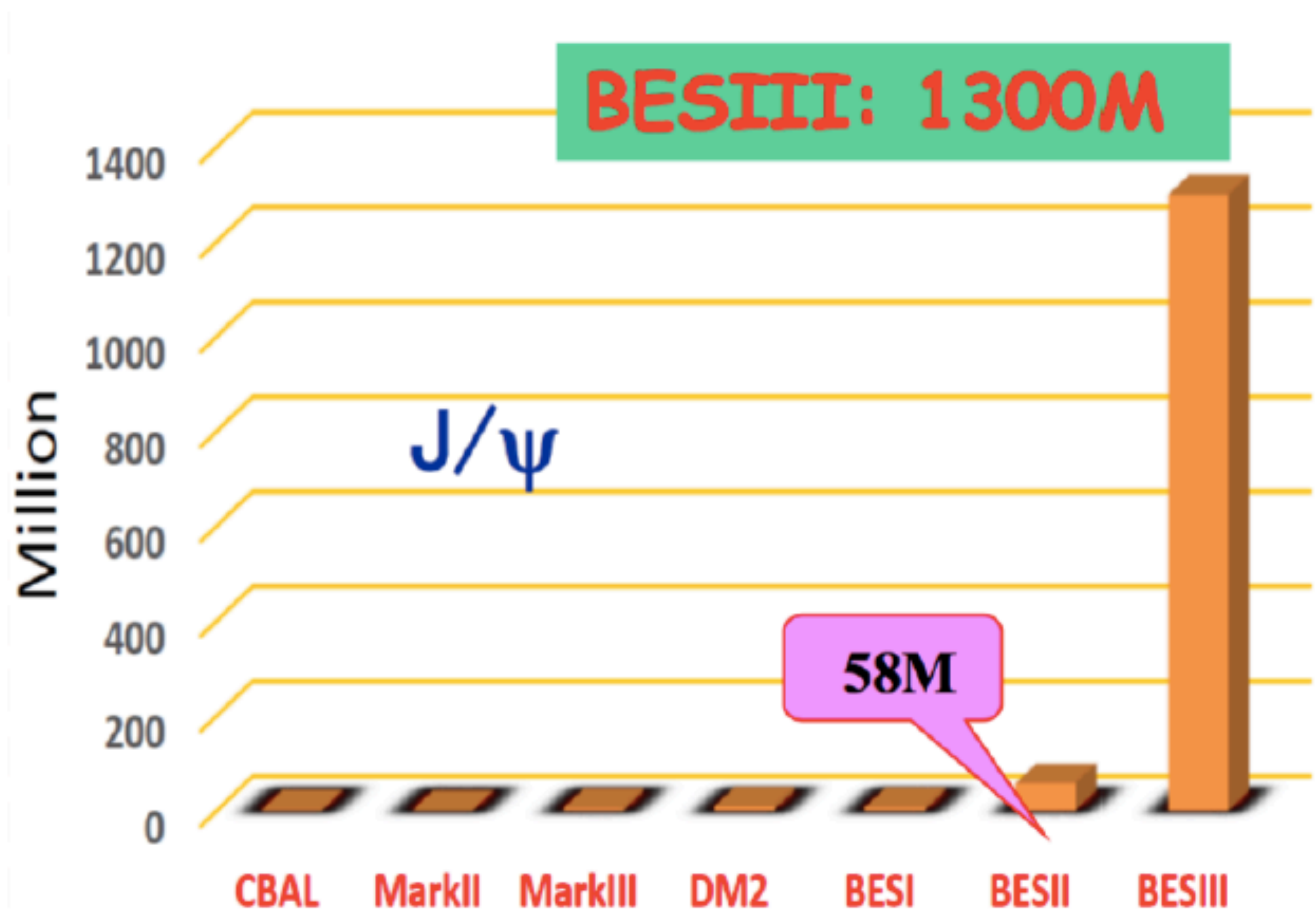
WG4



Huge and clean data which provide a good lab to probe rare decays such as cLFV process.

cLFV with BESIII

$J/\psi \to e\tau$ at BESIII

Simulated based on BESIII software and hardware systems

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WG4

- $J/\psi \to e\tau$, $\tau \to \mu \upsilon_{\mu} \upsilon_{\tau}$
- Event topology: two opposite charged tracks, two missing tracks
- Most of the backgrounds are from $J/\psi \to \pi^+ K_L K^-$, $J/\psi \to K_L K_L$, $J/\psi \to K^{*0} K^0$
- After background suppression, the detection efficiency is estimated to be 14%

With 1300 M J/ψ data

$$B(J/\psi \to e\tau)^{sensitivity} < N^{UL}_{obs}/(N_{J/\psi}\varepsilon) < 6.3\times10^{-8} \text{ @ 90\% C.L.}$$

where N^{UL}_{obs} is calculated based on the POLE program which is a Feldman-Cousins method including the number of background events and its uncertainty, and the systematic uncertainties (assumed to be 5%), where the number of observed events is set to be zero.

Interrelationship and observables

Interrelationship and observables

G.M. Pruna
WG4 review-1

Interrelationship: the way in which two or more things are connected and affect one another.

ν physics: phenomena connected with neutrinos.

$(g-2)$ and EDM of leptons: observables.

cLFV: a clear signal of new physics.

Research associated to these points is actually testing the same overall picture.

The Standard Model: $SU(3) \times SU(2) \times U(1)$, and 3 flavours.

Low and high energy connection

A scale dependent limit

G.M. Pruna
WG4 review-1

MEG sets a limit on $\mu \to e\gamma$ at the $\lambda = m_\mu$ scale; we combine it with the information on the interacting current to obtain:

$$\left.\frac{\sqrt{|C_{TL}(\lambda)|^2 + |C_{TR}(\lambda)|^2}}{\Lambda^2}\right|_{\lambda \ll \Lambda} \leq 4.3 \cdot 10^{-14}\,[\text{GeV}]^{-1}\,.$$

In this formula there are two scale dependencies:

- Λ: this is the scale $\gg \Lambda_{EW}$ at which the theory is defined, according to the decoupling theorem.
- λ: this is the scale at which the coefficient is probed by the experiment.

Next step: connecting low and high energy scales.

Preliminary Questions for nuFACT2017

- Q1: Beam/Machine/Experiment Design (WG3-4)

Are the ultimate sensitivities really exploited with current facilities?
How can we improve experiments without increasing the beam power?
How can muon physics benefit from future neutrino facilities?
Could new ideas from muon physics developments turn out to be useful for future neutrino facilities?

- Q2: Neutrino/Muon Physics (WG1-4-5)

What overlaps exist in non-standard interactions?
How would these manifest in both the near term muon/precision measurements sector & in the neutrino sector?