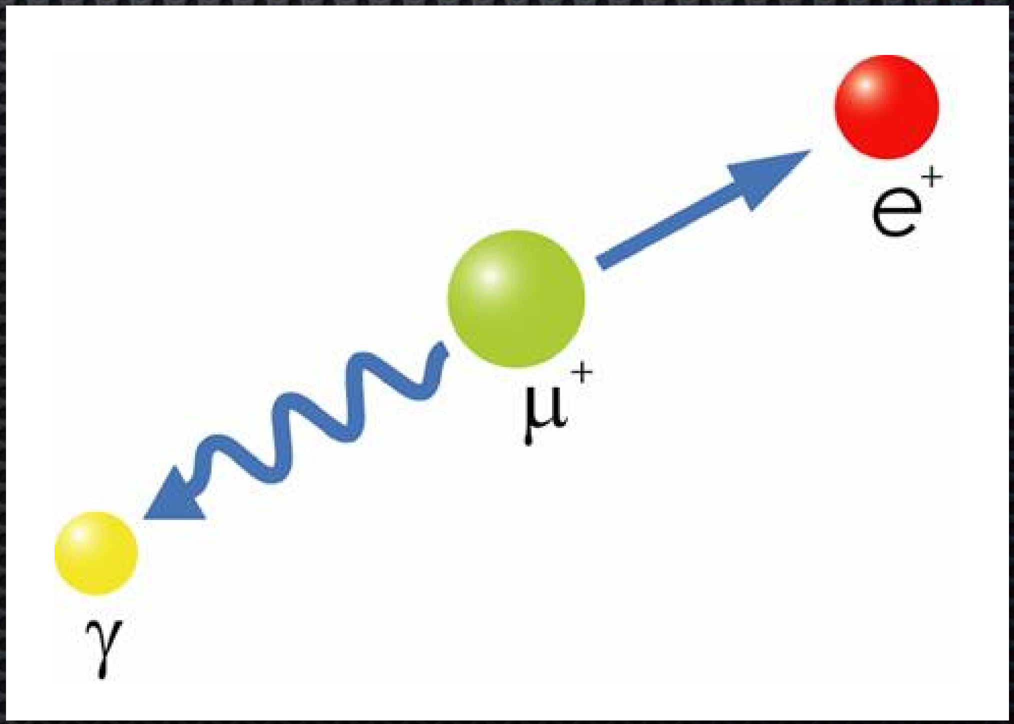
フレーバーを破る
ミューオン崩壊の探索

MEG / MEG II 実験

森俊則
東京大学素粒子物理国際研究センター

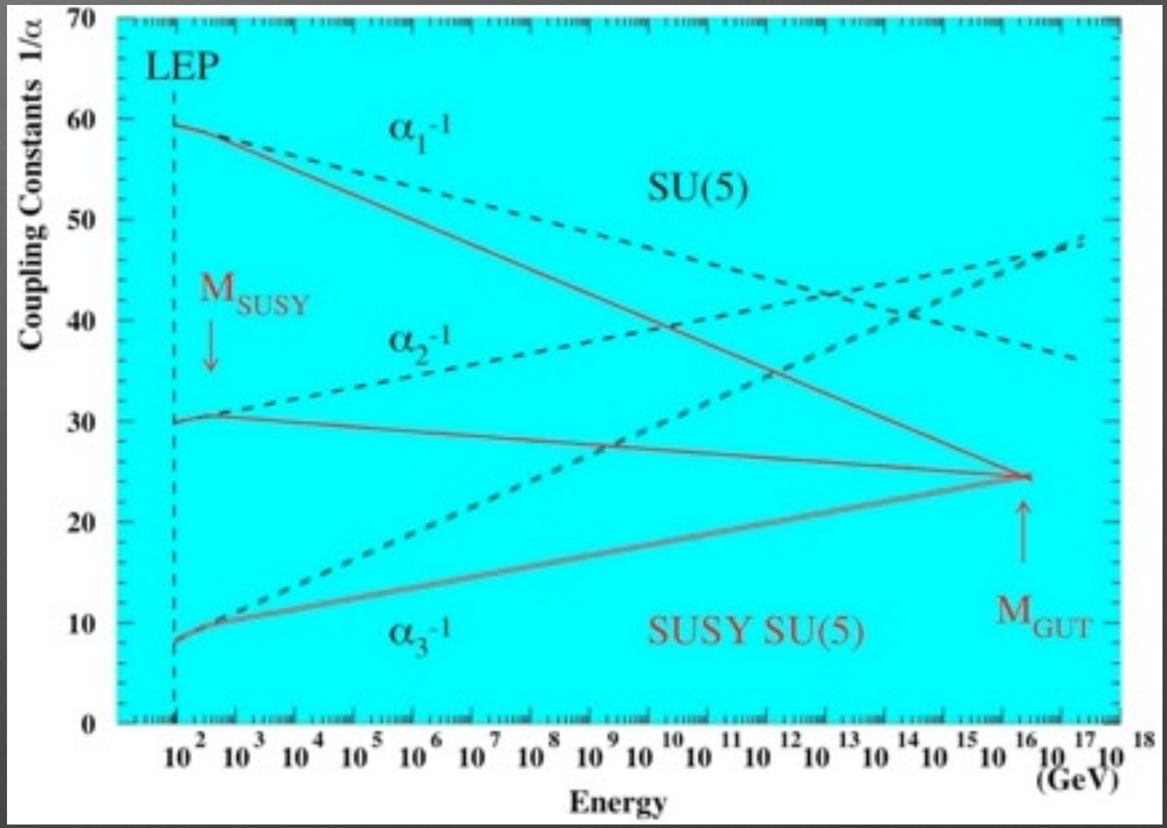
講演内容

- 与太話と物理
- MEG実験のコンセプト
- MEG実験の現状と展望
- MEG II 実験の準備状況
- 将来のミューオンを使ったcLFV探索実験



History of MEG

- ~1990: LEPでSUSY GUTのヒント
  陽子崩壊では難しいかも?
- ~1995: SUSY GUTだとμ→eγ起こる
  PSIへ行って研究会始める
- 1998: LoIをPSIに提出
  ニュートリノ振動でもμ→eγ
- 1999: ProposalをPSIに提出、承認
- 2002: 「MEG」Collaboration 発足
- 2008: MEG実験データ取得開始
- 2013: MEG II 実験 Proposal 承認； MEGデータ取得終了

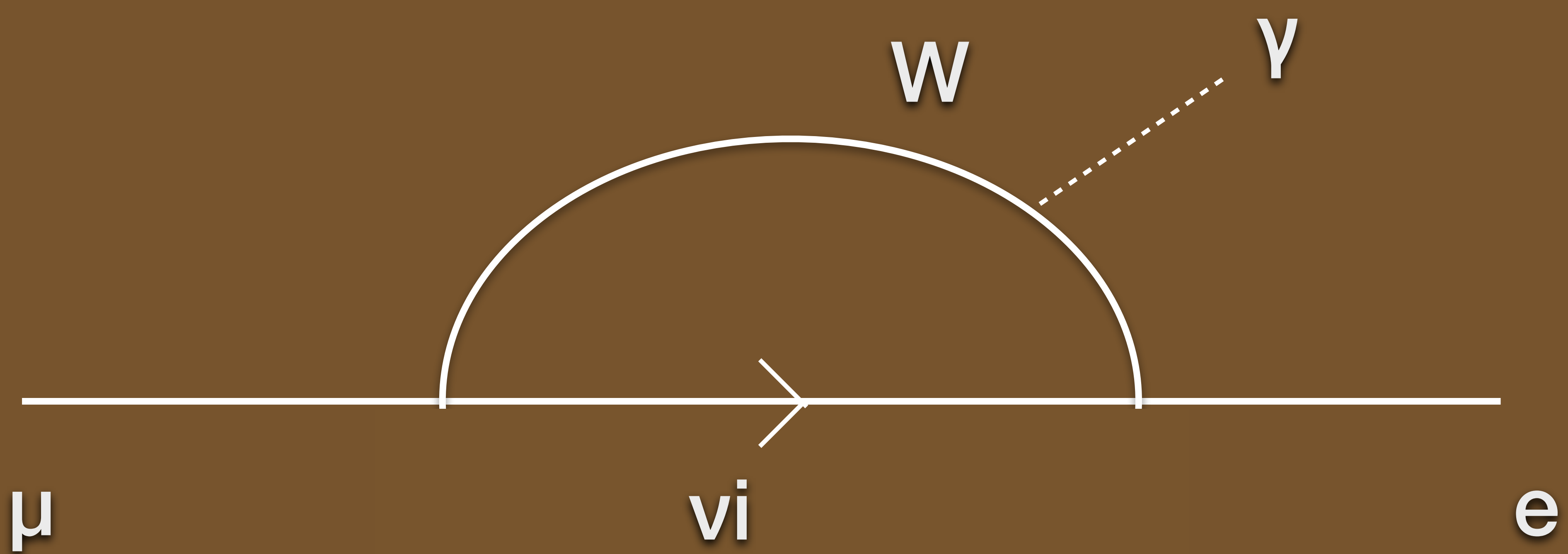


Lepton Flavor Violation

i.e. mixings between generations

- Lepton flavor is severely violated in neutrino oscillations
- It must be violated in charged leptons !! (cLFV)

Charged leptons should also mix flavors !

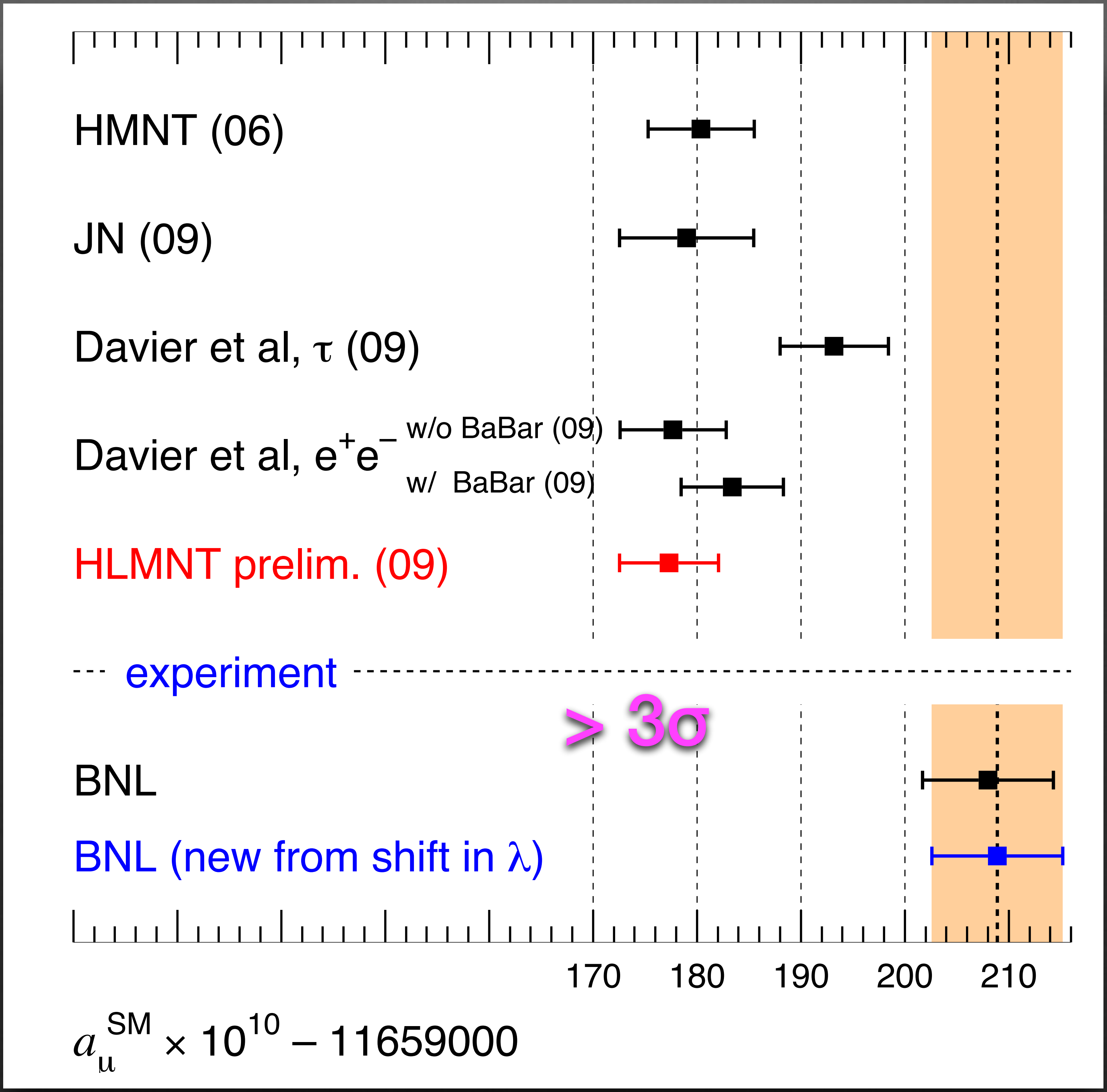


$$\frac{3\alpha}{32\pi}\left|\sum_i U^*_{\mu i}\left(\frac{m^2_{\nu_i}}{M^2_W}\right)U_{ei}\right|^2 \leq 10^{-50}$$

neutrinos are too light

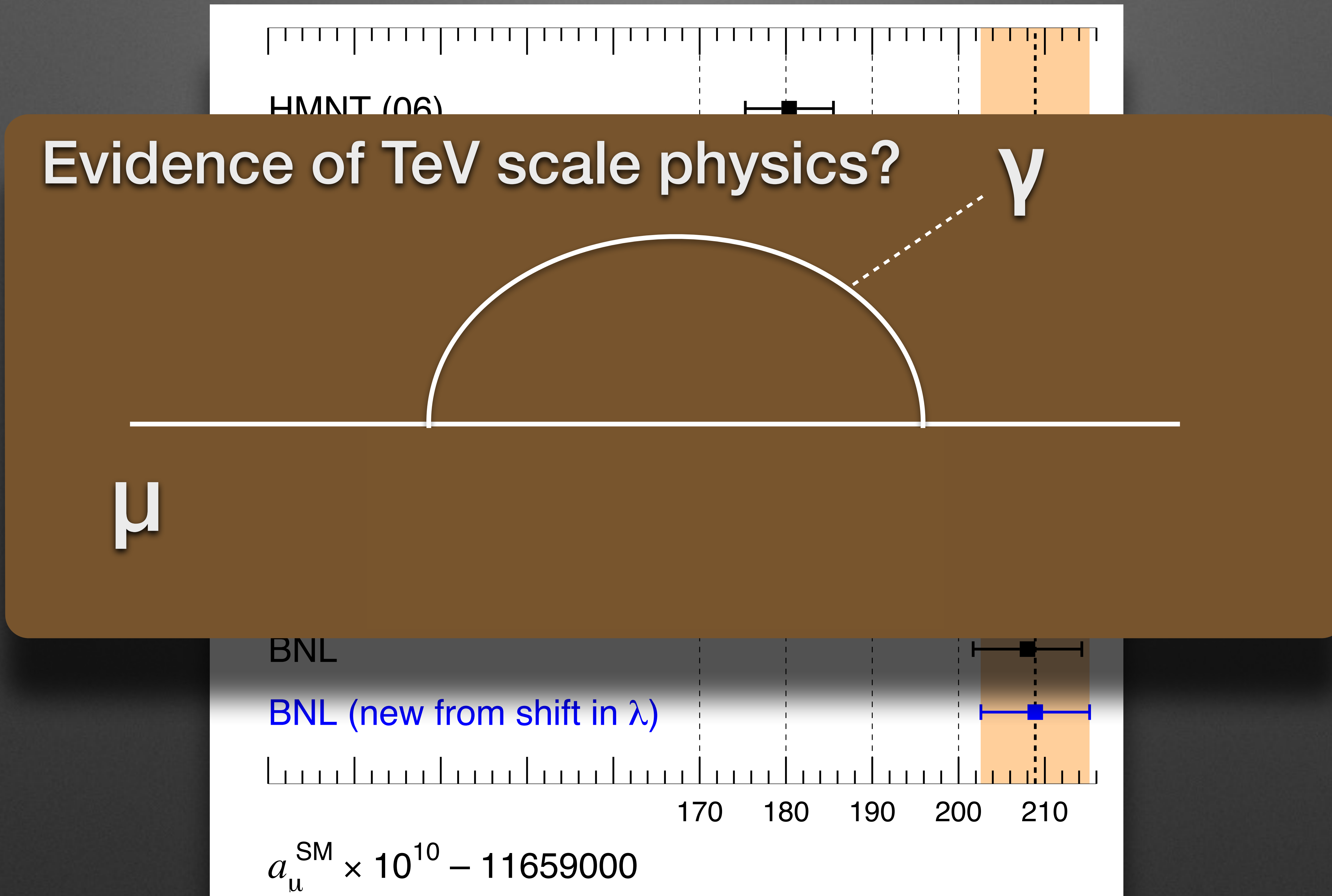
...but practically no mixing

muon (g-2) anomaly



muon's anomalous magnetic moment

muon (g-2) anomaly



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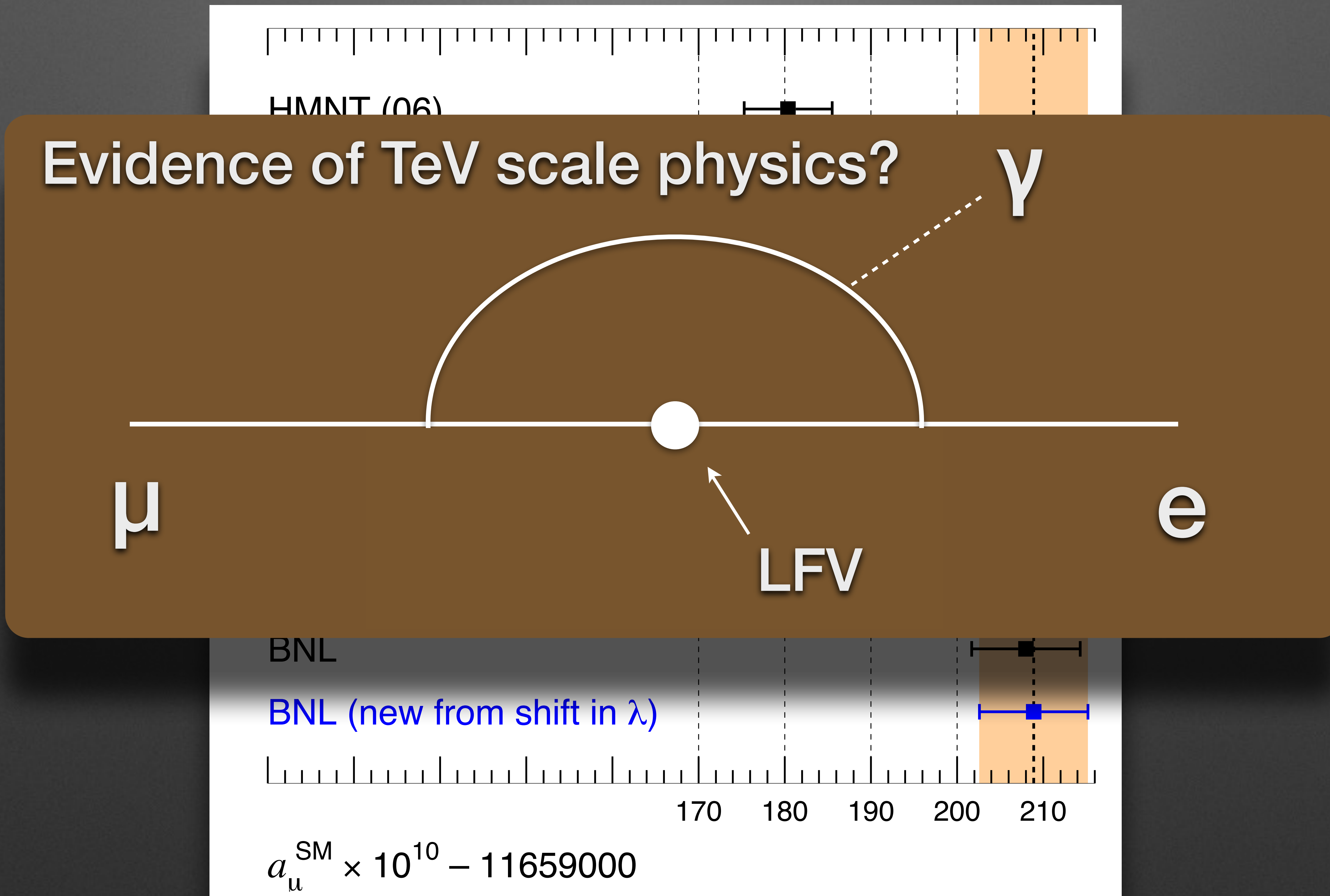
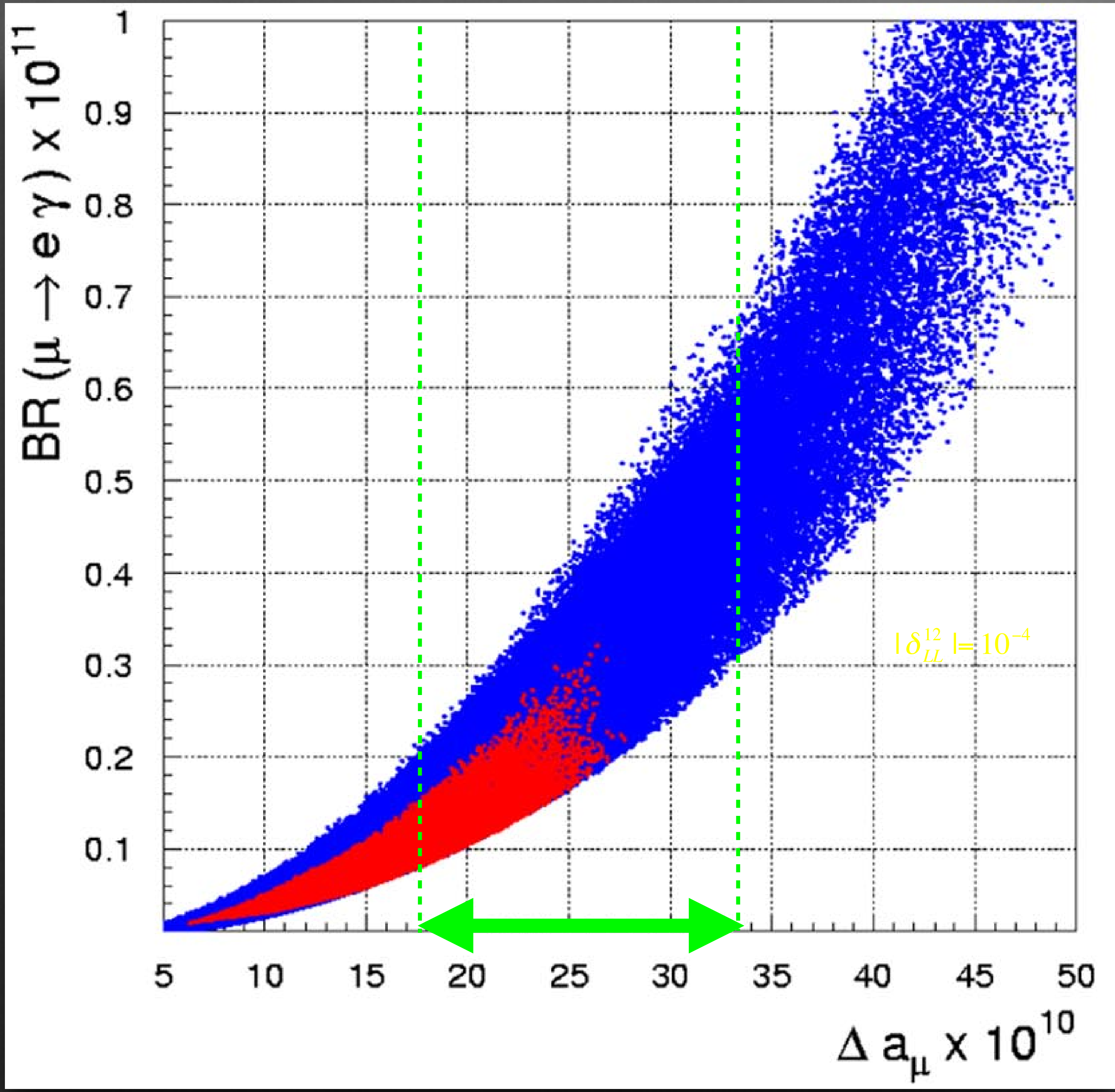


muon’s anomalous magnetic moment

muon (g-2) anomaly



G.Isidori et al. PRD75, 115019

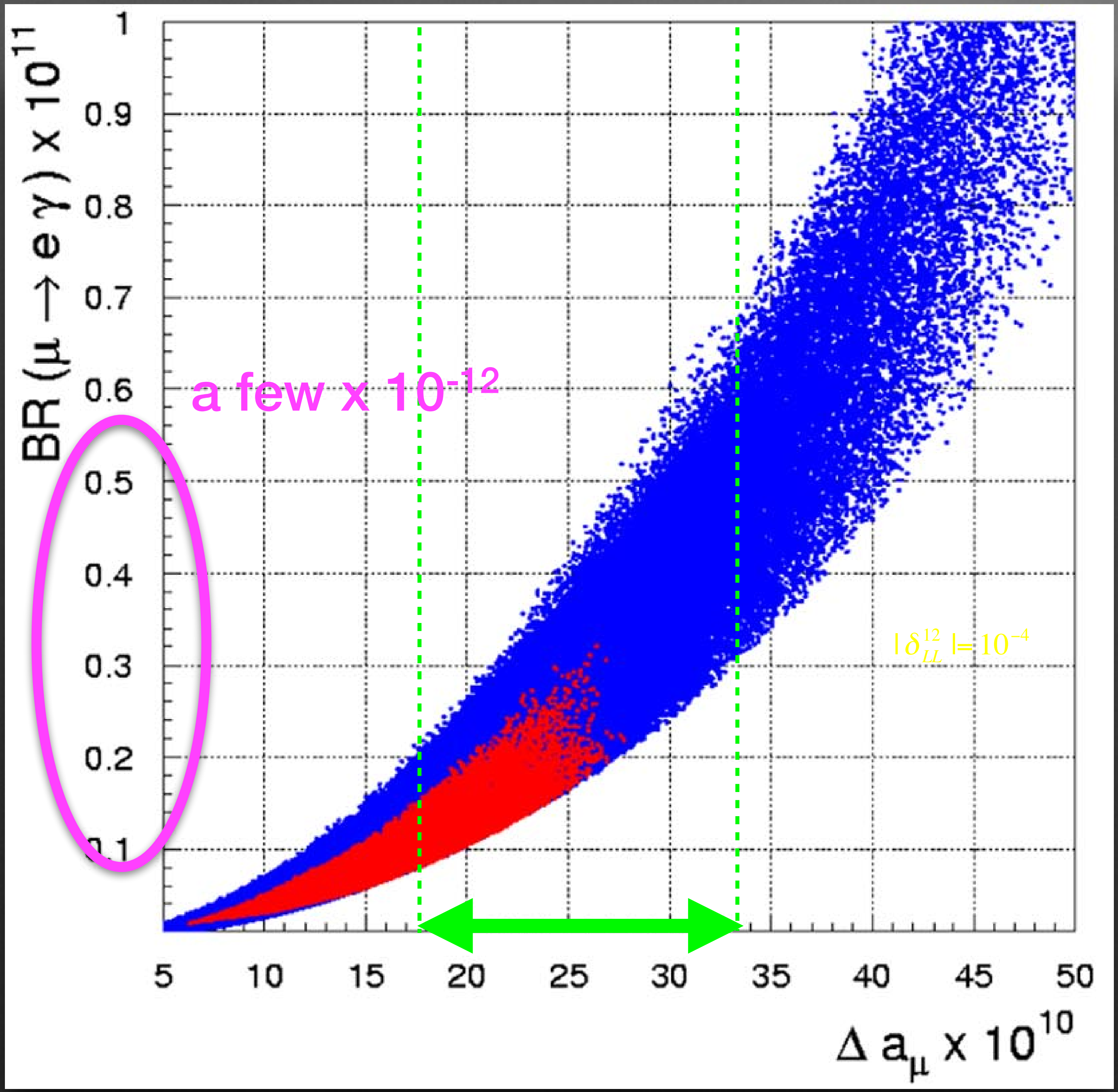
There is a generic relation with BR(μ→eγ) :

$$\mathcal{B}(\mu \to e\gamma) \approx 10^{-4} \left(\frac{\Delta a_\mu}{200 \times 10^{-11}} \right)^2 |\delta^{12}_{LL}|^2$$

unknown cLFV constant

$|\delta^{12}_{LL}| = 10^{-4}$ assumed here

muon (g-2) anomaly



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unknown cLFV constant

$|\delta_{LL}^{12}| = 10^{-4}$ assumed here

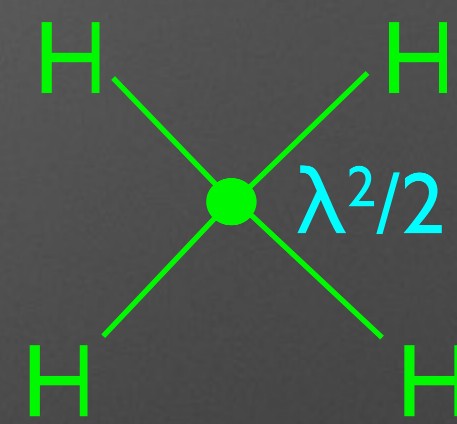
Recent Progress in Particle Physics

- Discovery of “Higgs”
  - Higgs is light（125GeV)

    ➡ Higgs is likely to be elementary

    ➡ Good prospects for GUT/seesaw

$M_H = \lambda\ v$

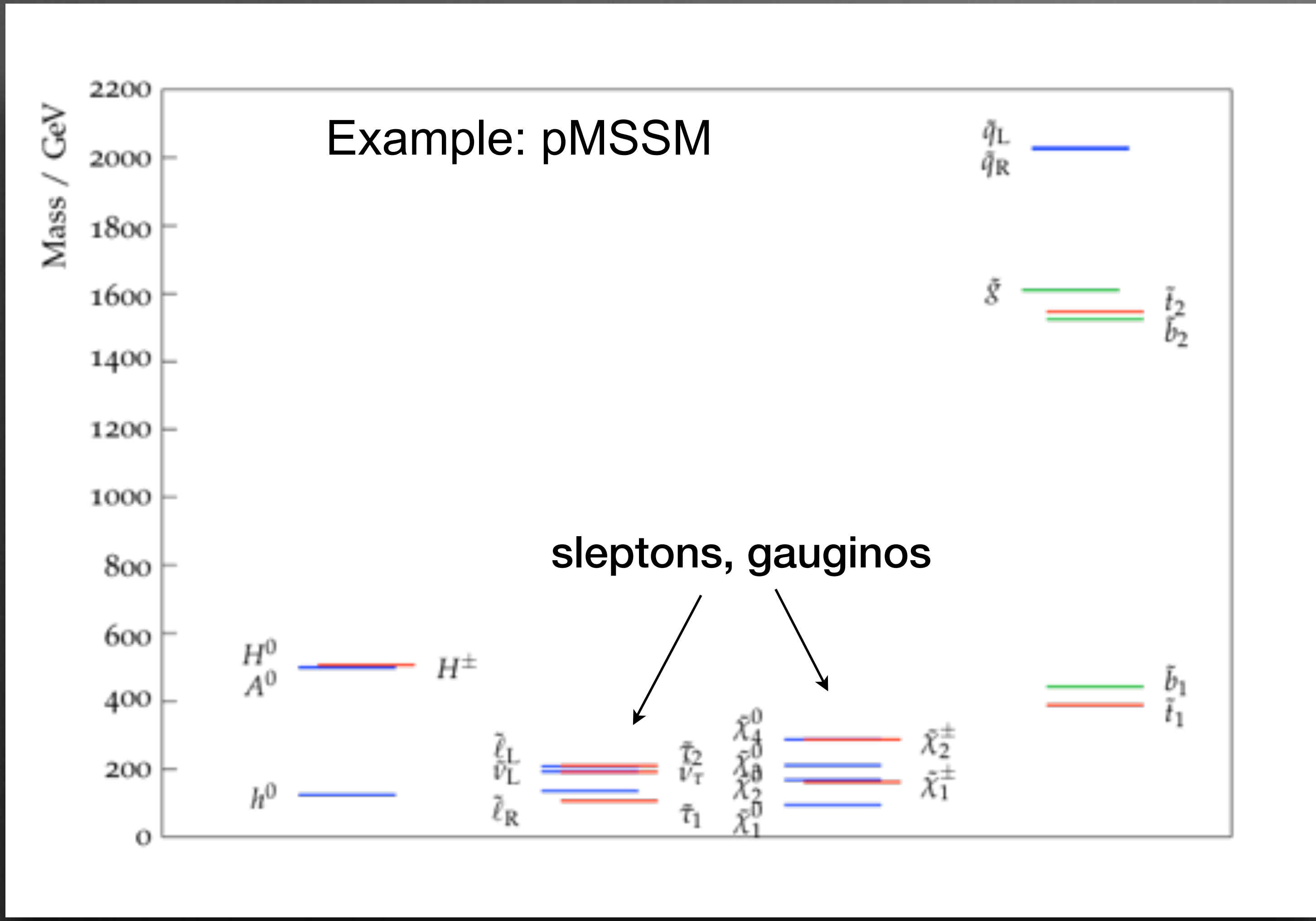


- Discovery of the third neutrino oscillation
  - Mixing is large（mixing angle ~9deg)

    ➡ Large BR($\mu \to e\gamma$) expected

Expectations rising high for cLFV searches

TeV scale physics strongly constrained by LHC



- But :
- Particles not strongly interacting are NOT strongly constrained
- Dark matter may relate to unknown TeV scale physics!

  not necessarily SUSY

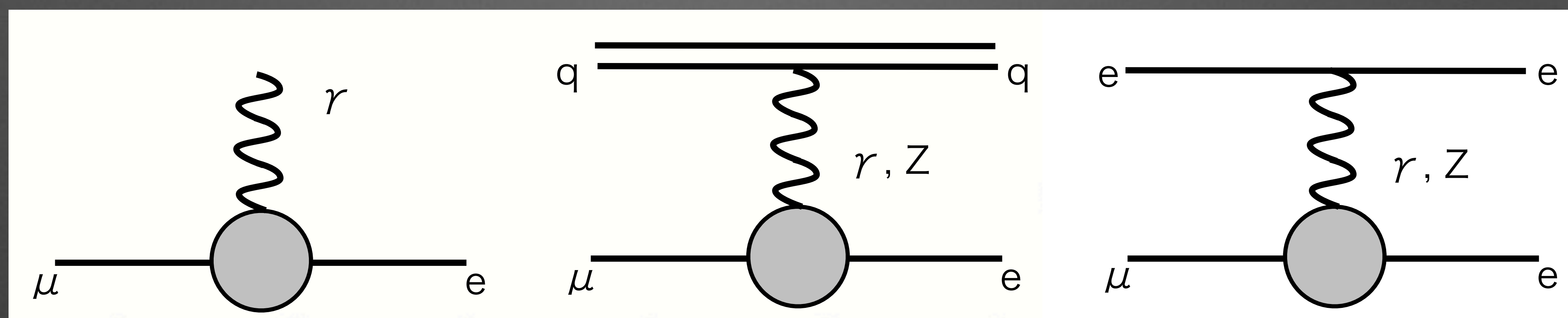
cLFV Search is Complementary to LHC

Muon cLFV
Sensitivity comparisons

$\mu \to e\gamma$ $\mu N \to eN$ $\mu \to 3e$

"dipole" dominant

(SUSY etc)



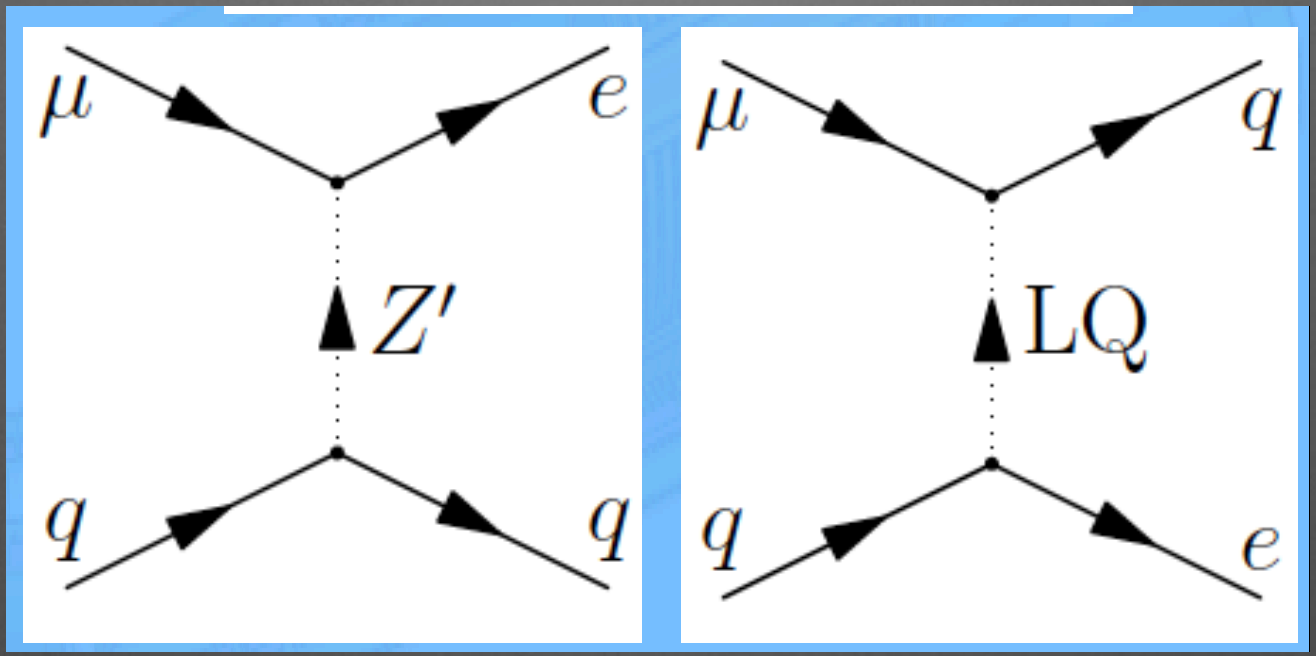
1 : 1/390 : 1/170

BR = 4×10^{-14} : 1×10^{-16} : 2×10^{-16}

~MEG II goal

for Al target

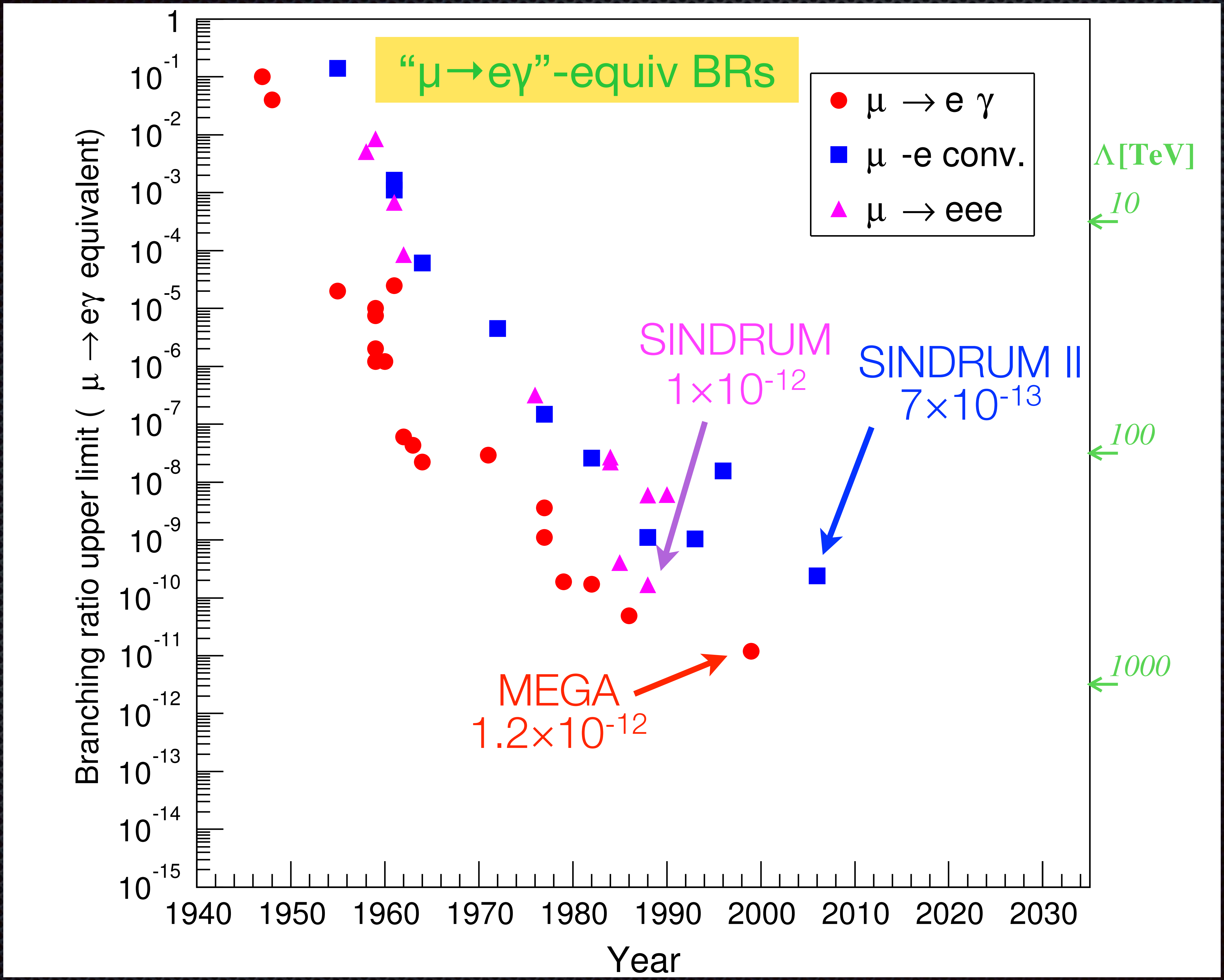
a caveat !



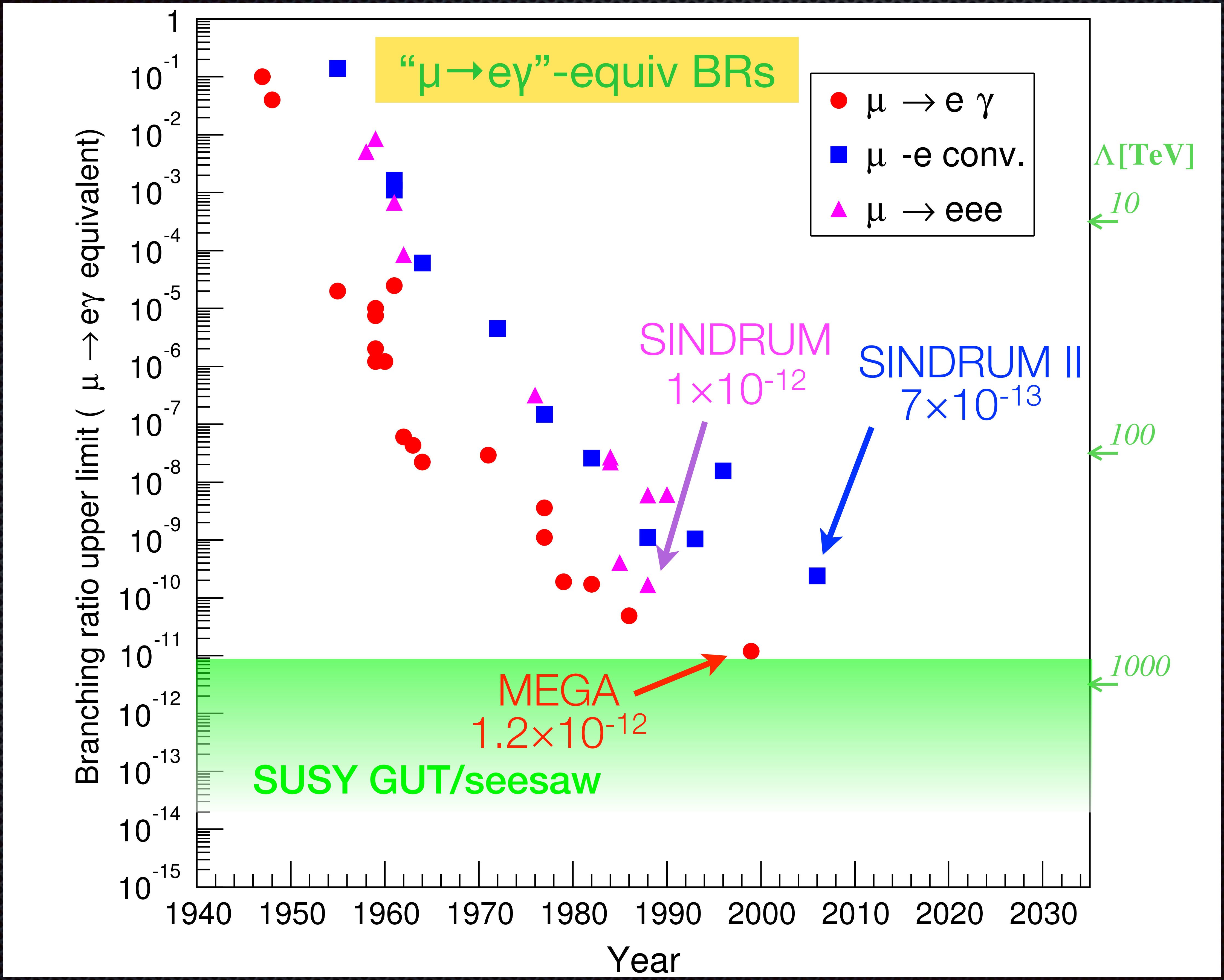
Some models have “four-fermion” *tree* terms which could strongly enhance

$$\mu N \to e N \qquad \mu \to 3e$$

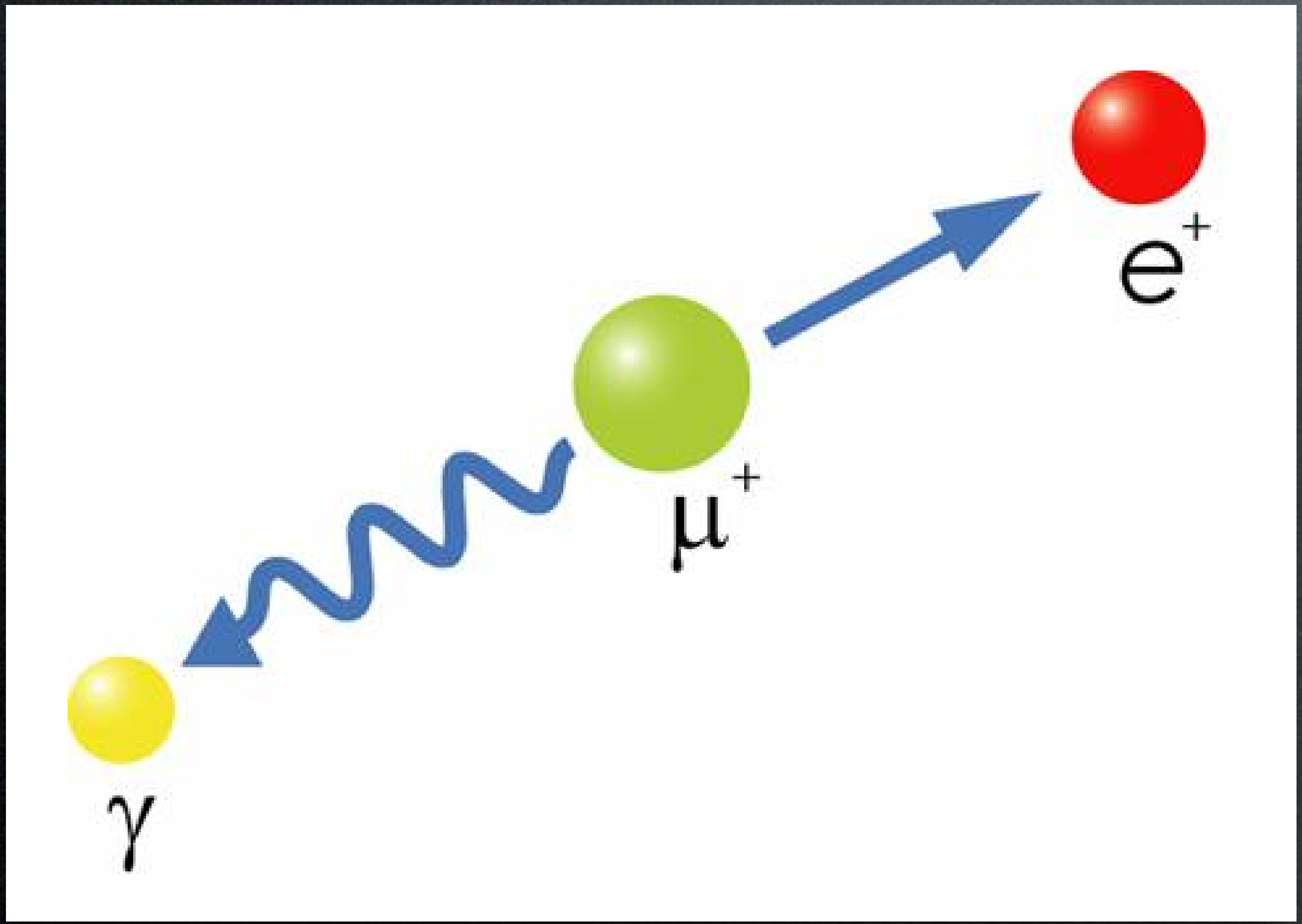
Muon cLFV History before MEG



Muon cLFV History before MEG



The $\mu^+ \to e^+\gamma$ process



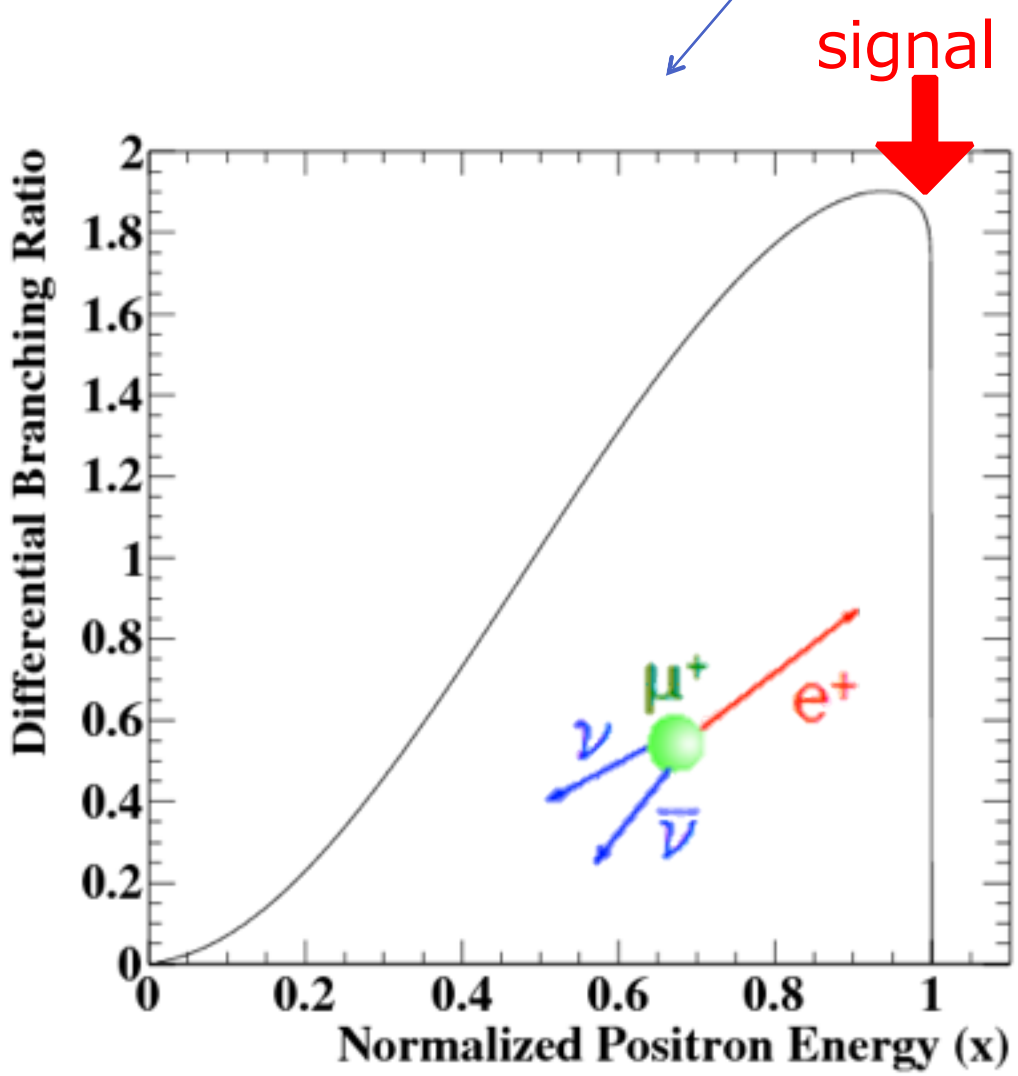
- clear 2-body kinematics
- need positive muons to avoid formation of muonic atoms
- high rate ~10^8/sec muon beam necessary to reach BR ~10^{13}
- accidental background limits the experiment
    - DC beam, rather than pulsed beam, gives lowest instantaneous rate and thus lowest background

Accidental background

- $R_{BG} \propto R_{\mu}^{2} \cdot f_{e} \cdot f_{\gamma} \cdot \delta\omega/4\pi \cdot \delta t$

Accidental coincidence

Accidentally back-to-back



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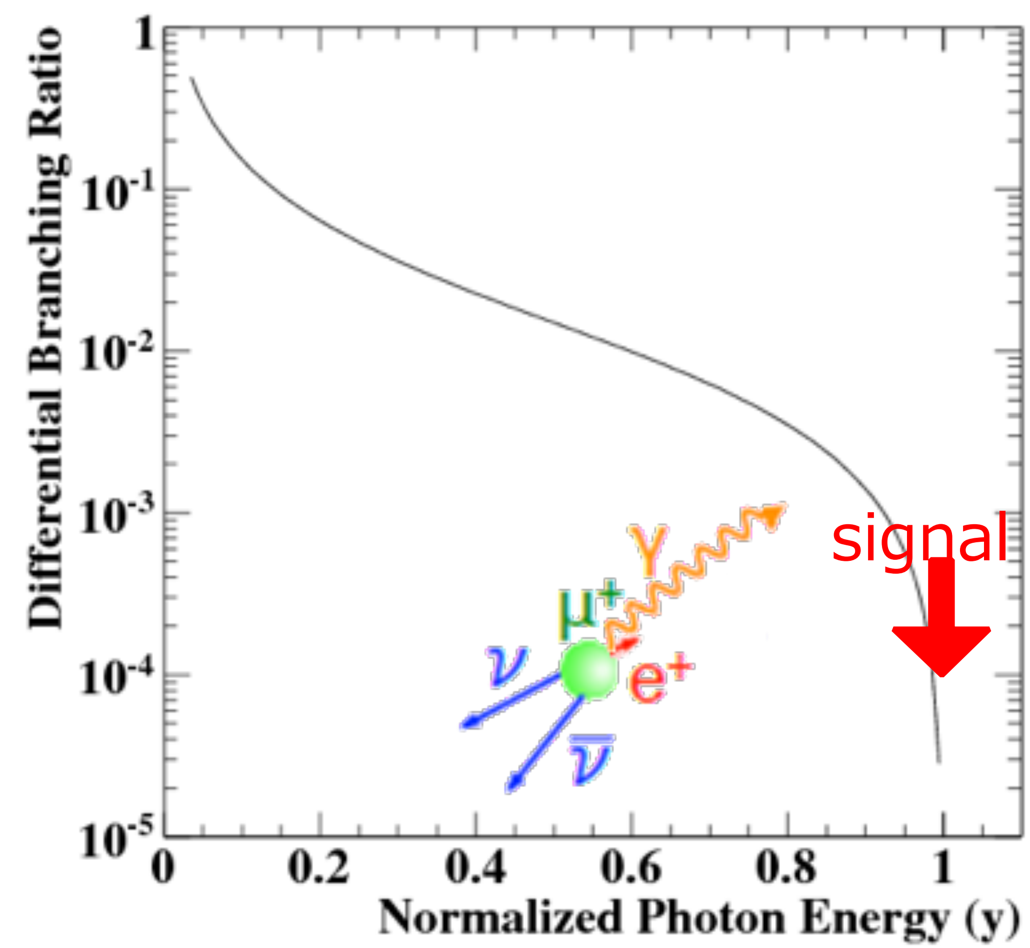

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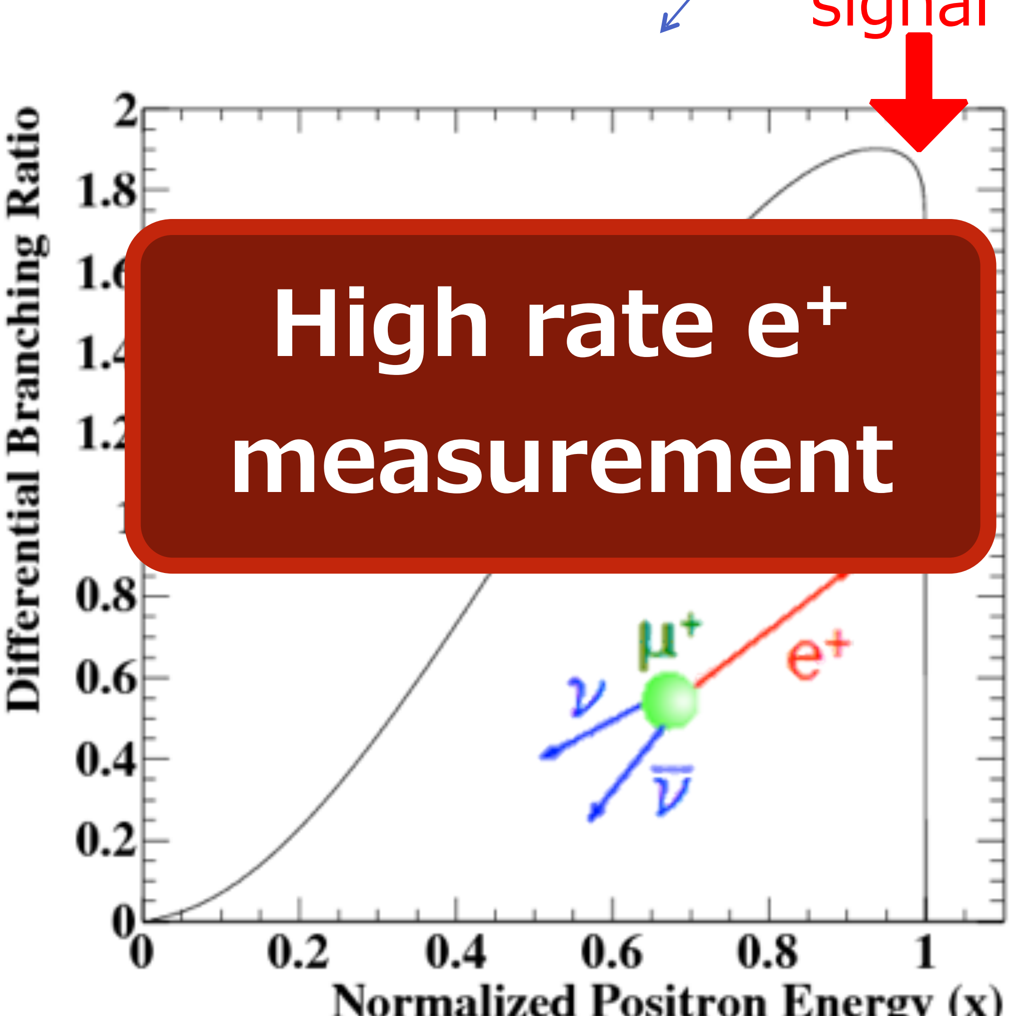

High rate e+ measurement

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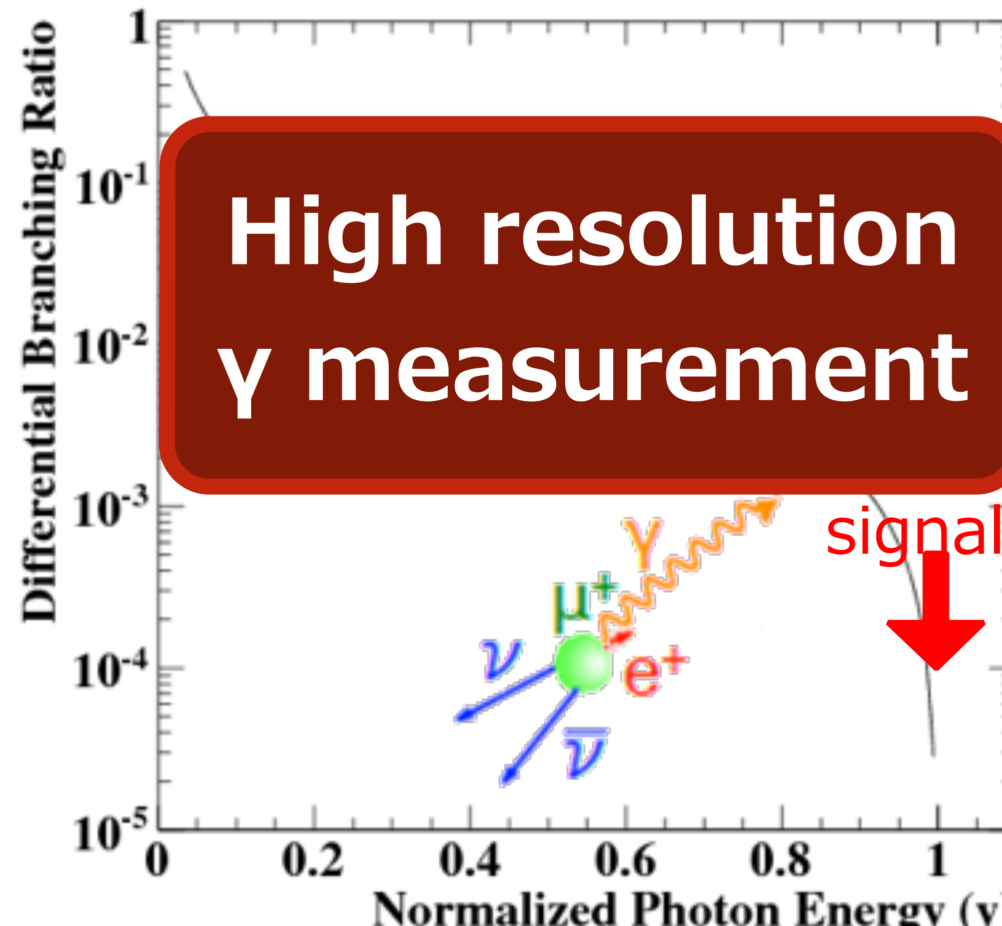


High resolution γ measurement

Three key points

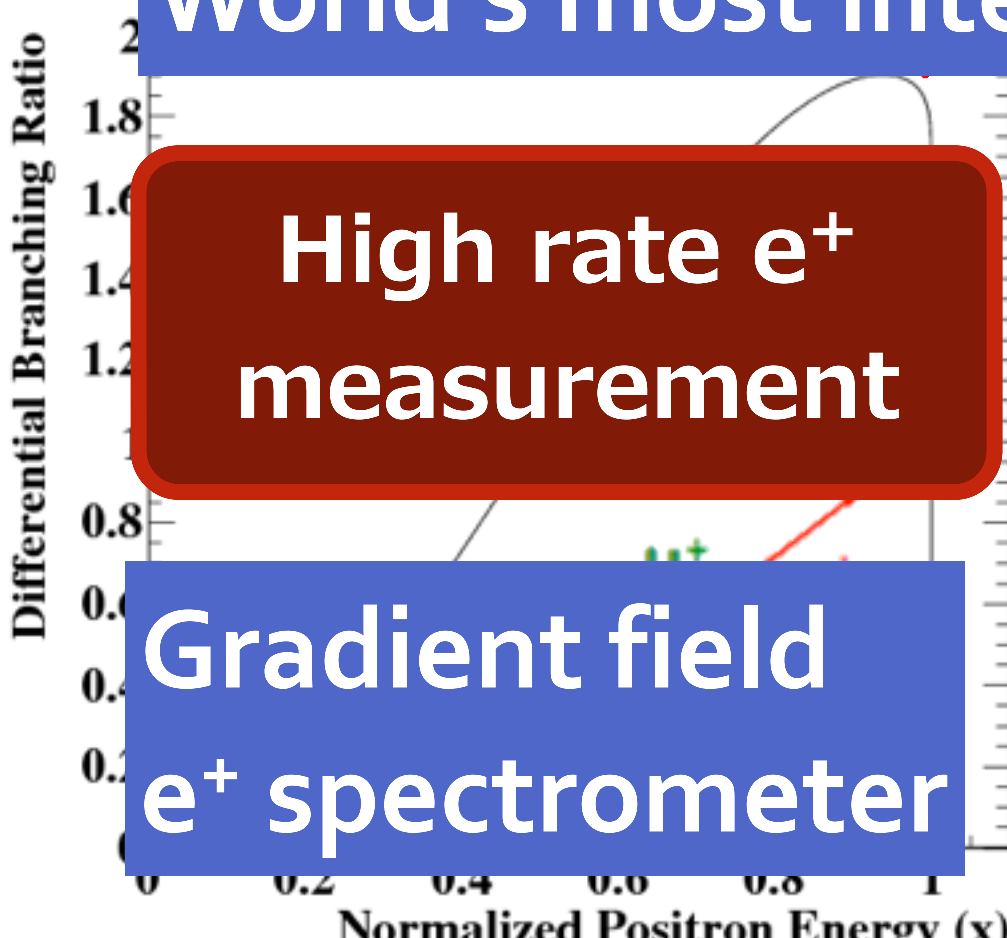
Accidental background

- $R_{BG} \propto R_\mu \cdot f_e \cdot f_\gamma \cdot \delta\omega/4\pi \cdot \delta t$

Accidental coincidence

Accidentally back-to-back

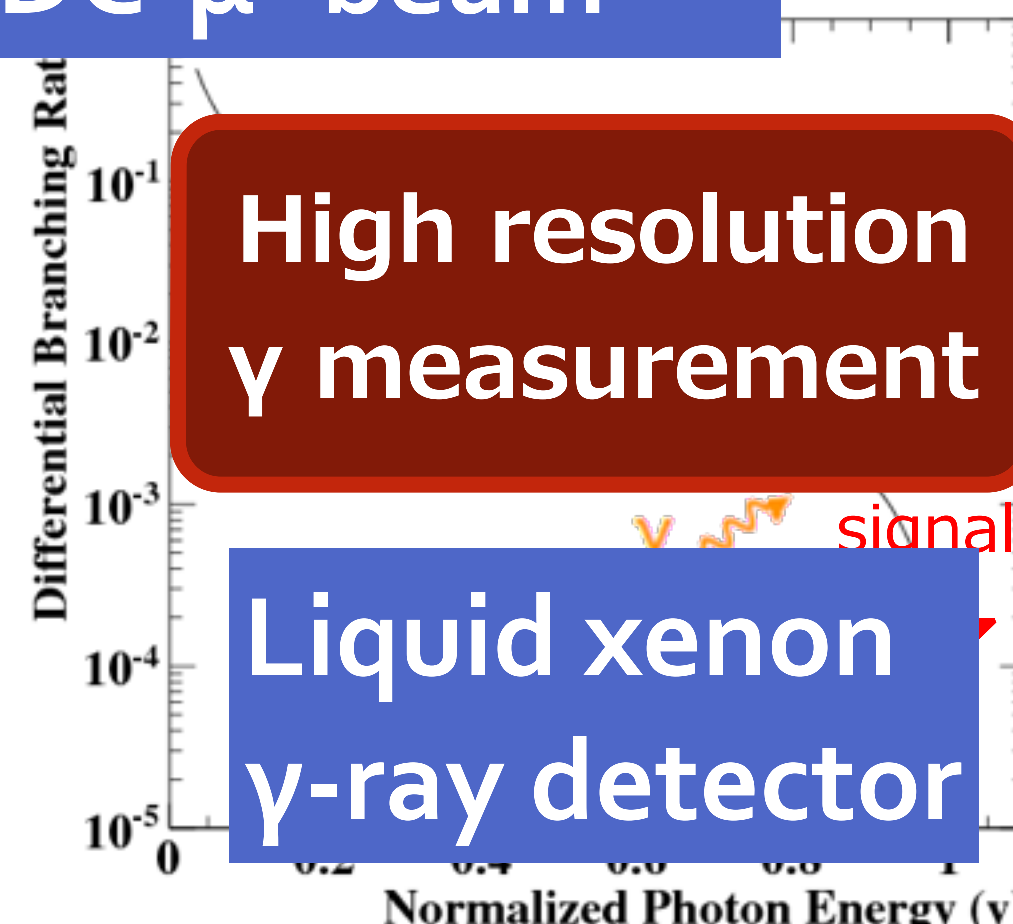
World's most intense DC-μ⁺ beam



High rate e⁺ measurement

Gradient field e⁺ spectrometer

×



High resolution γ measurement

Liquid xenon γ-ray detector

Three key points

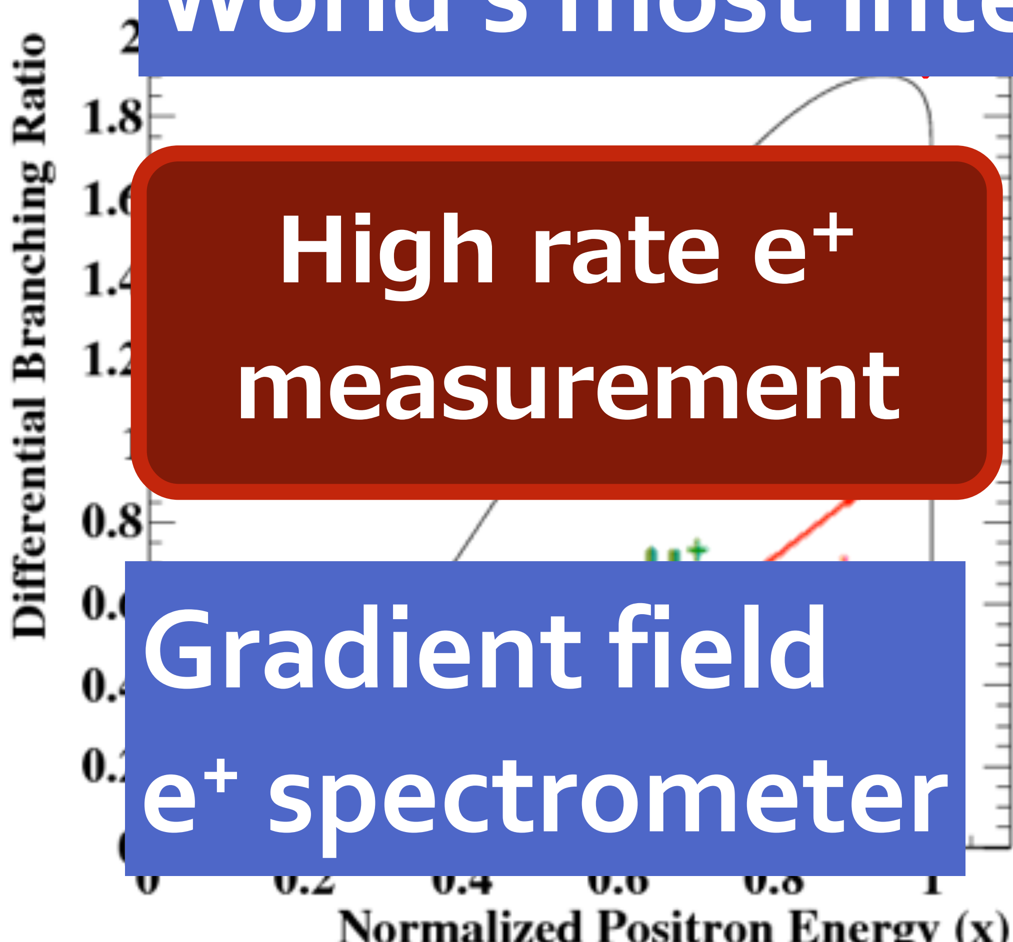
Accidental background

- $R_{BG} \propto R_{\mu} \cdot f_e \cdot f_\gamma \cdot \delta\omega/4\pi \cdot \delta t$

Accidental coincidence

Accidentally back-to-back

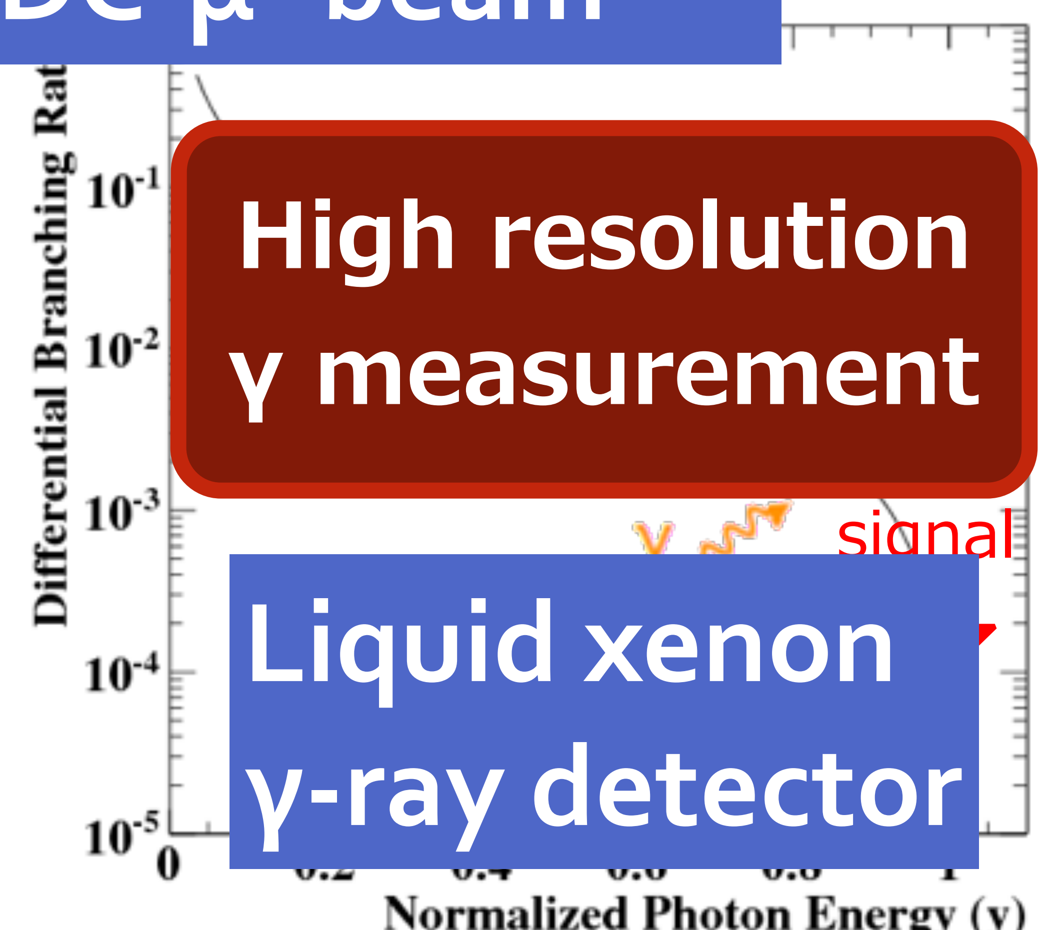
World's most intense DC-μ⁺ beam



High rate e⁺ measurement

Gradient field e⁺ spectrometer

×



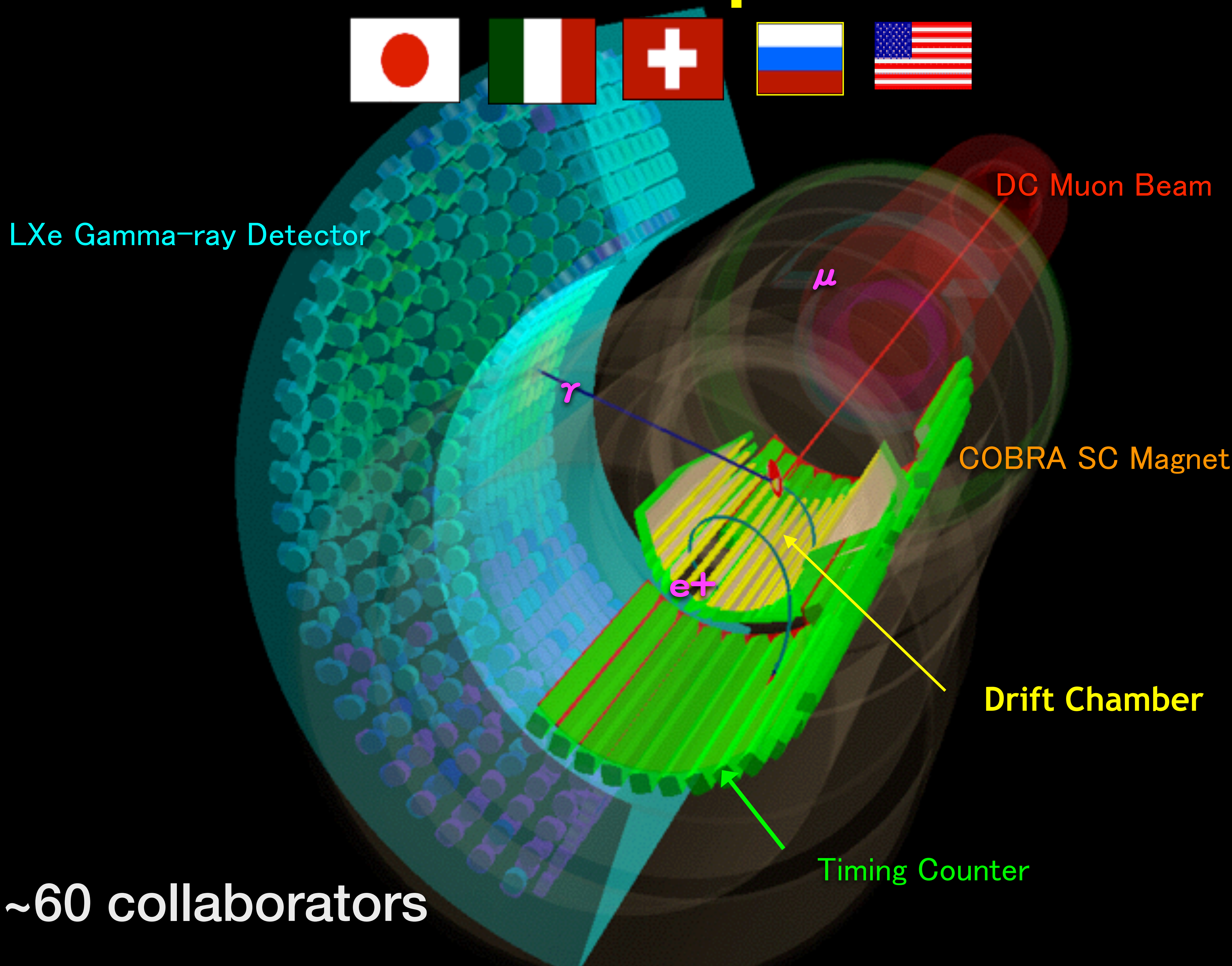
High resolution γ measurement

Liquid xenon γ-ray detector

Three key points

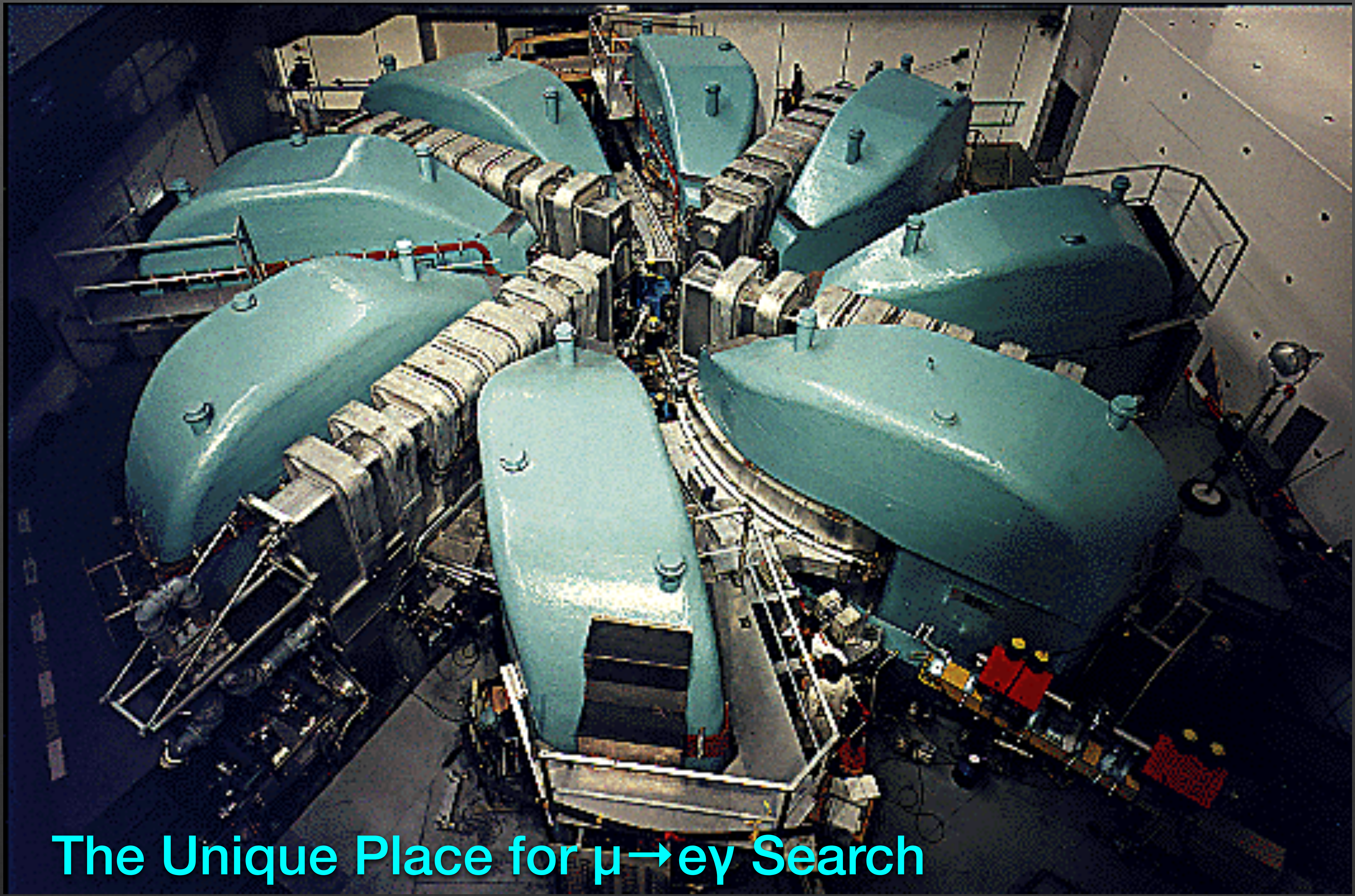
⇒ MEG exp.

The MEG Experiment



~60 collaborators

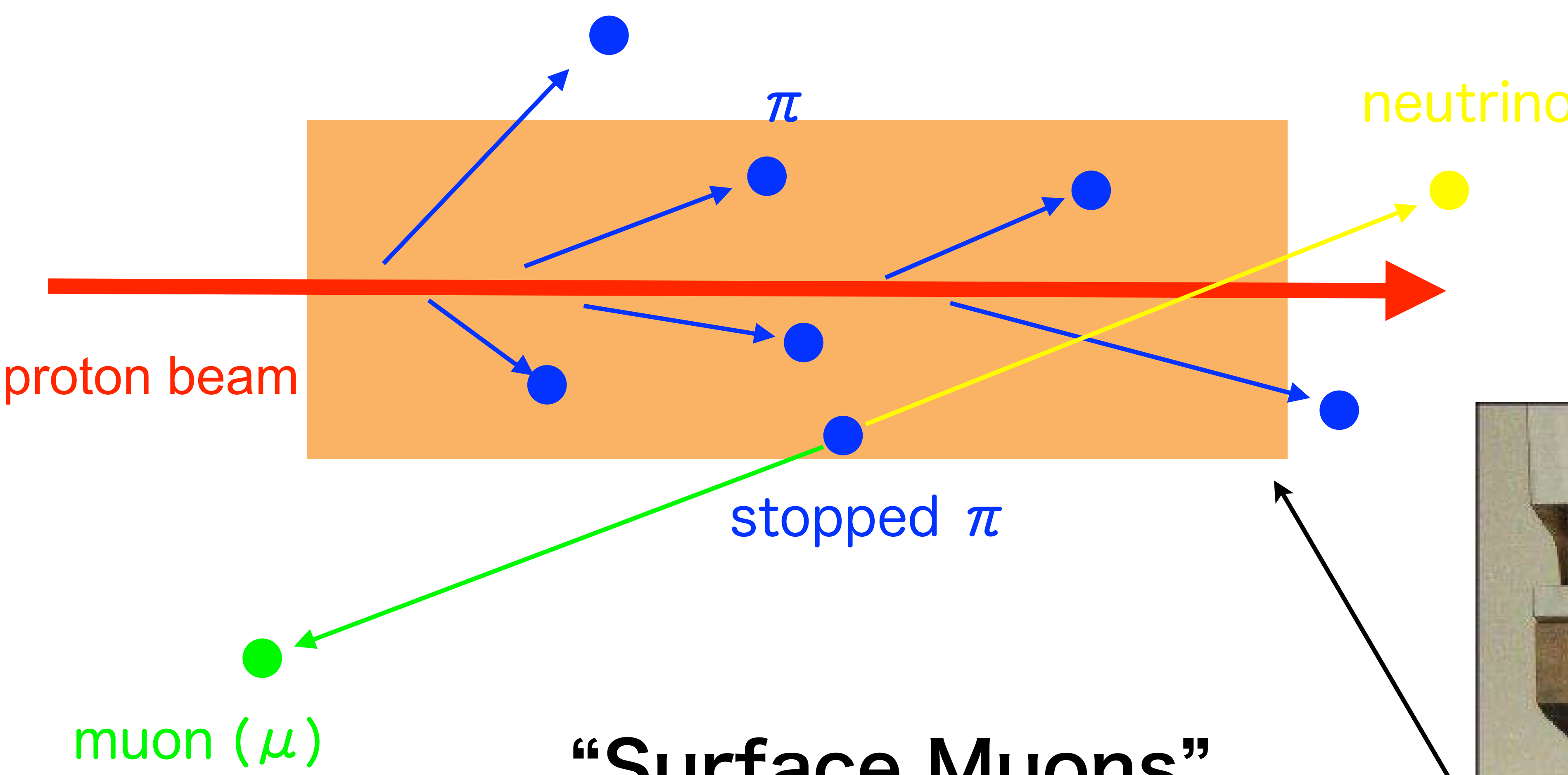
1.4MW Proton Cyclotron at PSI



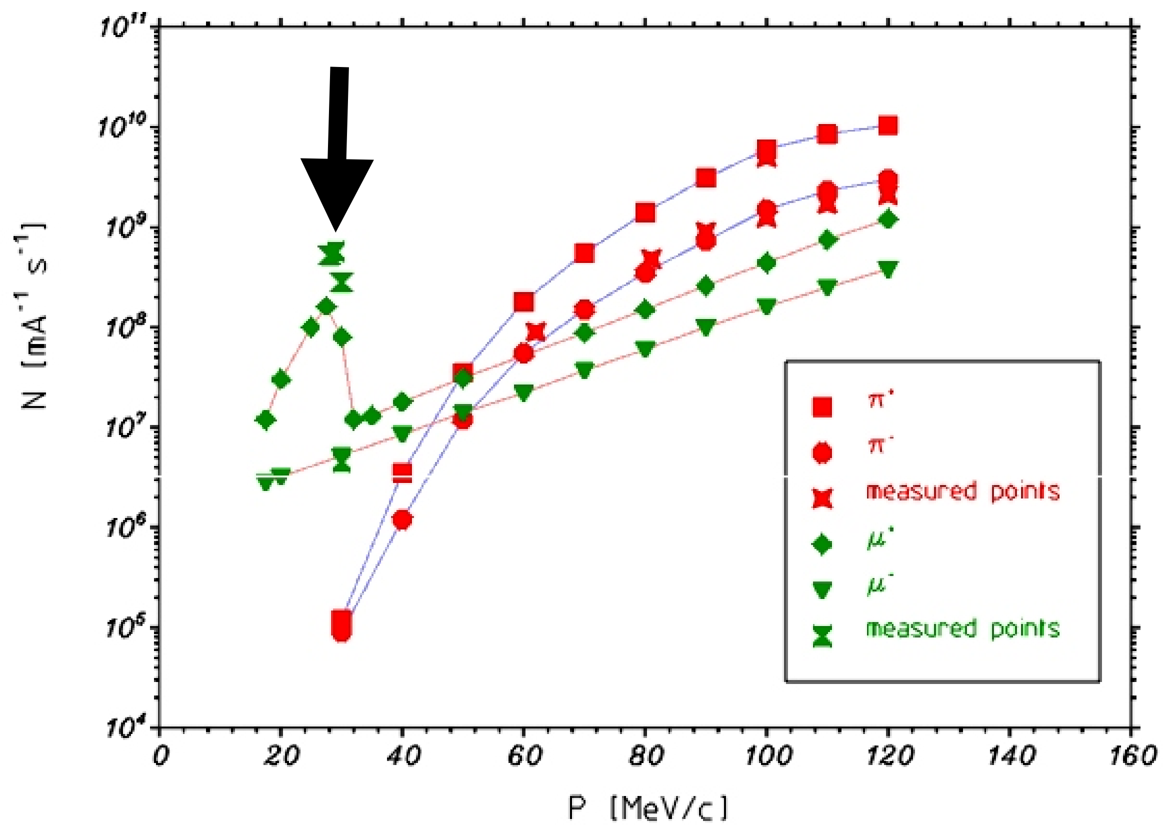
Provides world's most powerful DC muon beam > 10^8/sec


Switzerland
CERN
LHC
MEG
PSI
GERMANY
FRANCE
AUSTRIA
LIECHTENSTEIN
ITALY
Basel
Liestal
Schaffhausen
Winterthur
Frauenfeld
Zürich
Aarau
Porrentruy
Delémont
St. Gallen
Herisau
Appenzell
Solothurn
Biel
Burgdorf
Lucerne
Zug
Schwyz
Neuchâtel
Bern
Köniz
Altdorf
Sarnen
Yverdon
Fribourg
Thun
Interlaken
Chur
Lausanne
Montreux
Sion
Sierre
Geneva
Martigny
Locarno
Bellinzona
Lugano
St. Moritz
Buchs
Lake Constance
Allgäuer Alpen
Zürichsee
Aare
Jura Mts.
Lac de Neuchâtel
Vierwaldstätter See (Lake Lucerne)
Thuner See
Lac Léman (Lake Geneva)
Rhône
Rhine
Arve
Doubs
Saône
Inn R.
Adda
Lago di Como
Lago Maggiore
Glarner Alps
Bernese Alps
Pennine Alps
Lepontine Alps
Rhaetian Alps
National Park
Stelvio National Park
Mt. Tendre 5,508 ft. (1,679 m)
Jungfrau 13,642 ft. (4,158 m)
Tödi 11,856 ft. (3,614 m)
Piz Kesch 11,214 ft. (3,418 m)
Rheinwaldhorn 11,161 ft. (3,402 m)
Splügenpass 6,932 ft. (2,113 m)
Great St. Bernard Tunnel 8,100 ft. 2,469 m
Matterhorn 14,692 ft. (4,478 m)
Dufourspitze 15,203 ft. (4,634 m)
0 25 Miles
0 25 Kilometers
7° E
8° E
9° E
10° E
47° N
46° N

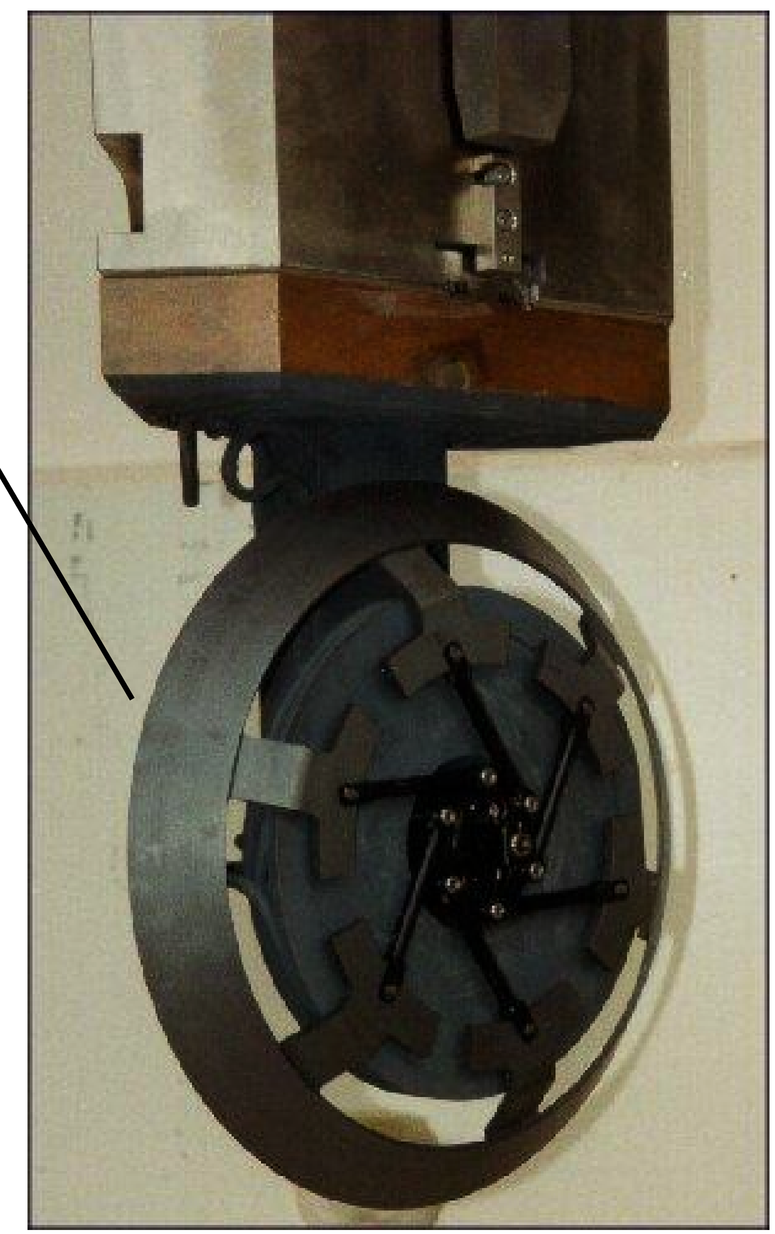
Production of World's Highest Intensity Muon Beam



"Surface Muons"



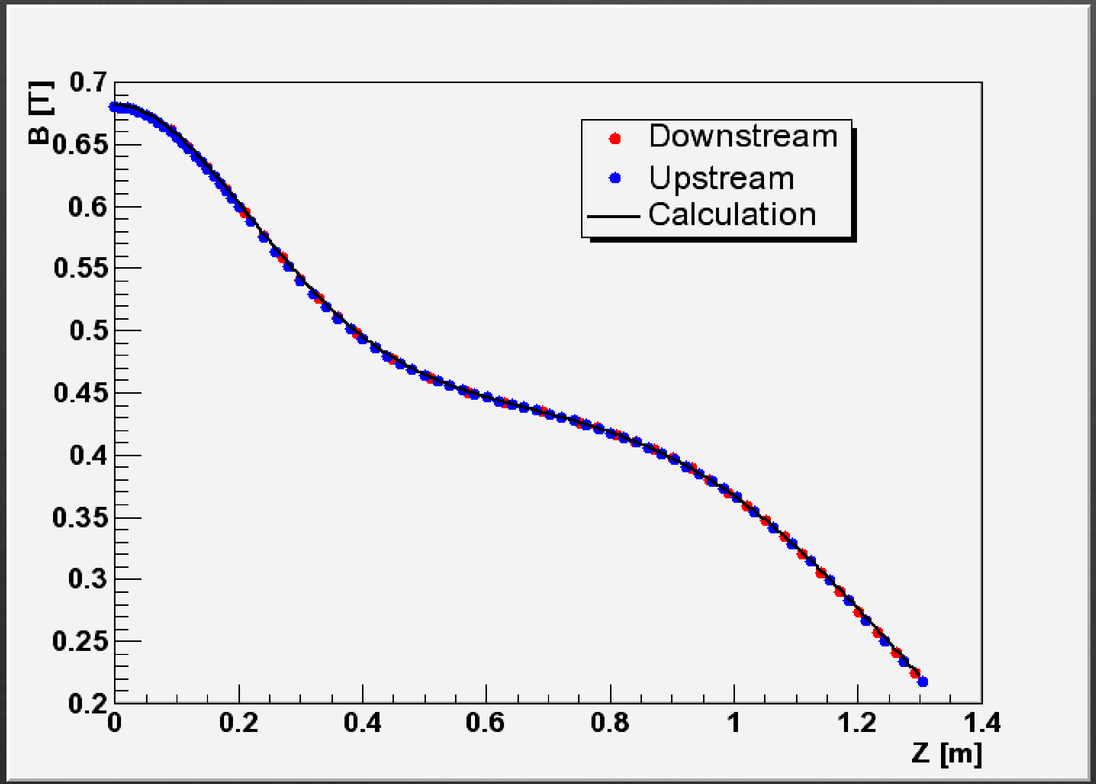
4cm graphite target

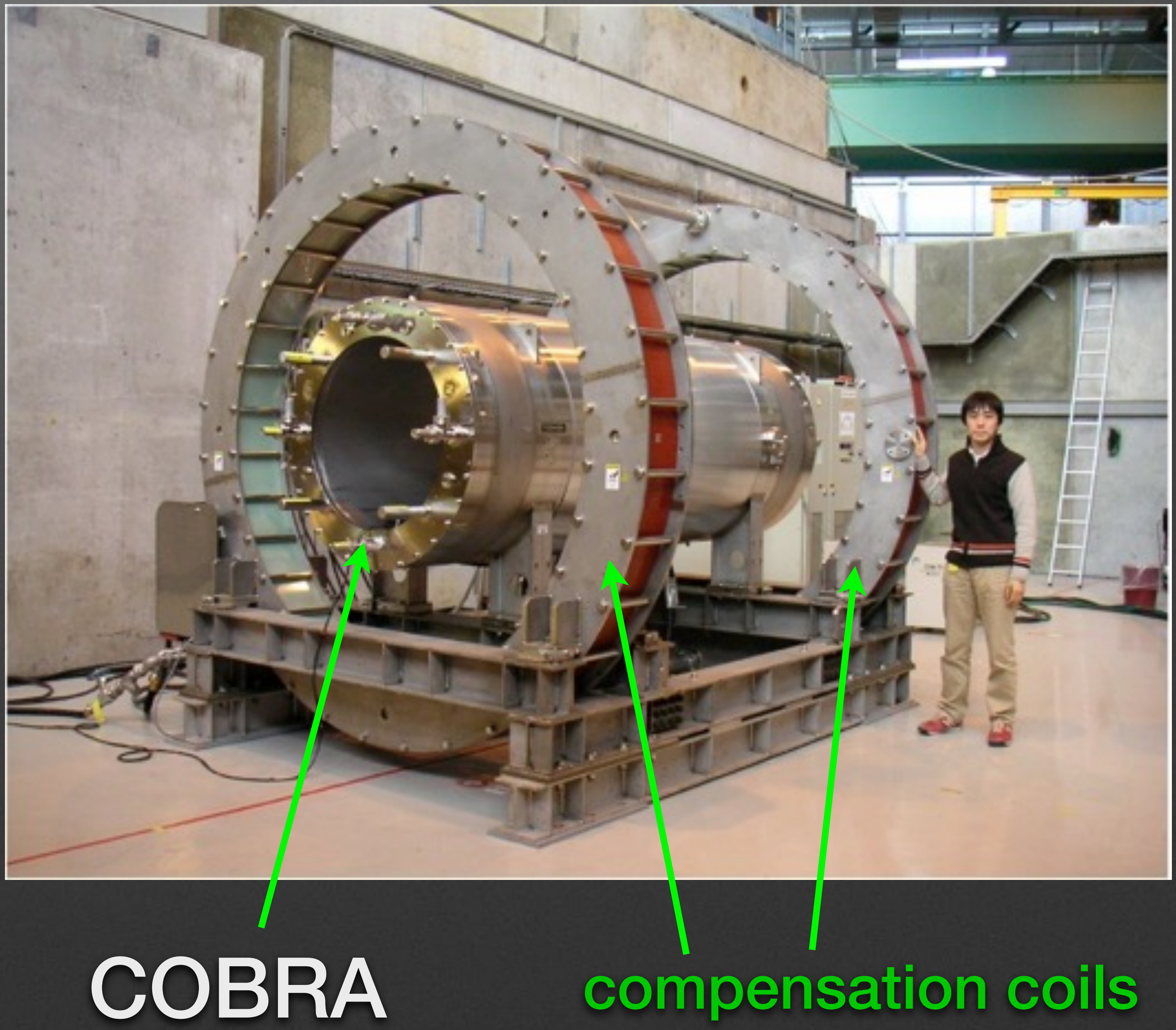


COBRA Positron Spectrometer

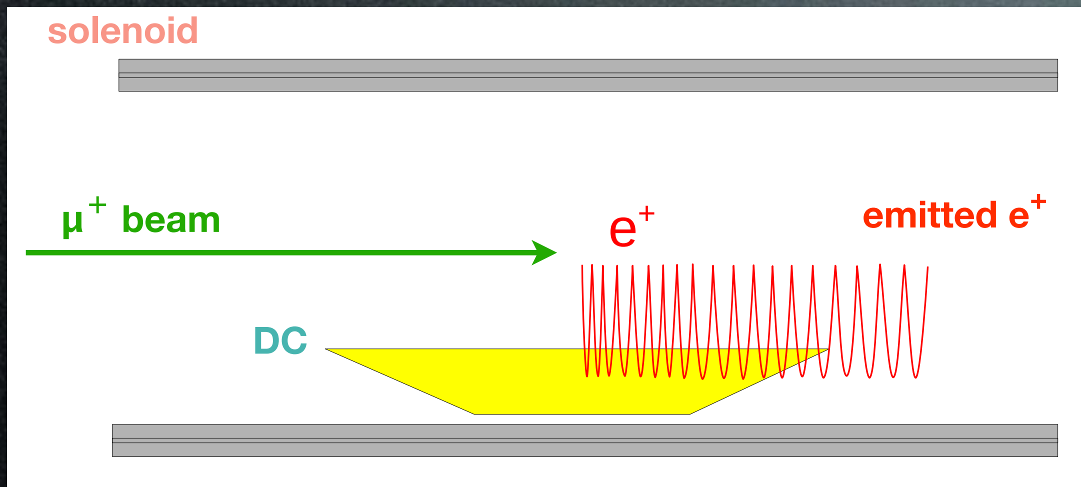
Gradient B field helps to manage high rate e^+

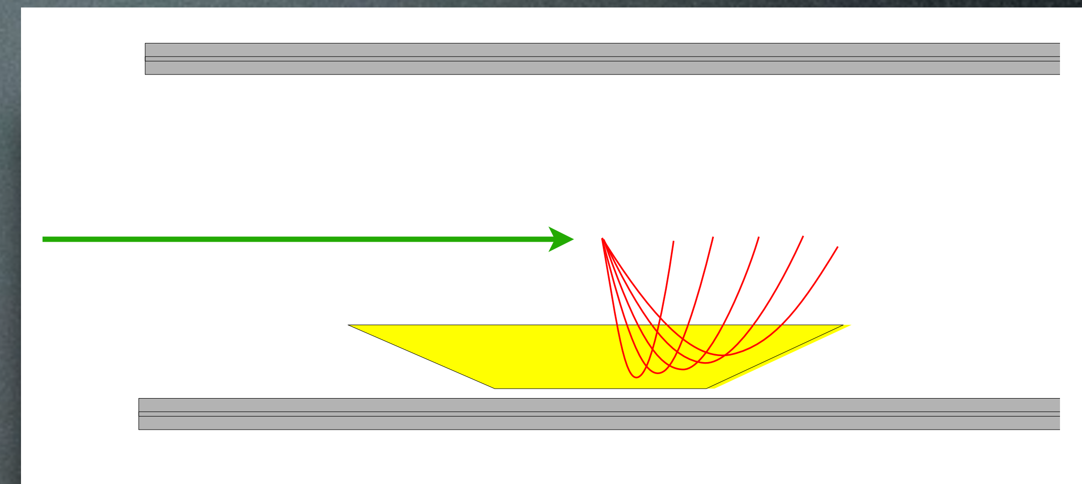
- thin-walled SC solenoid with a gradient magnetic field: 1.27 - 0.49 Tesla



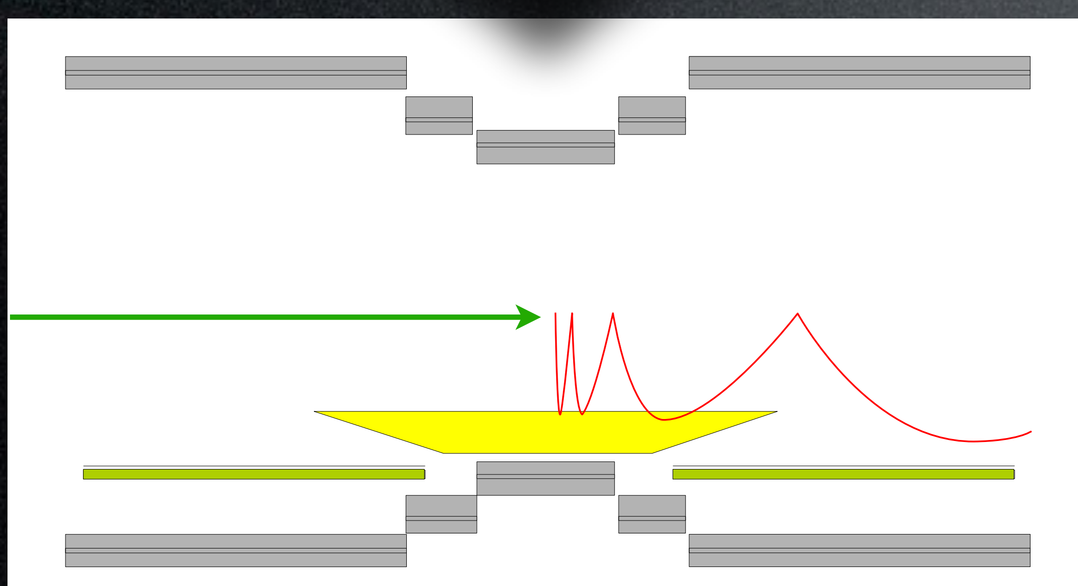


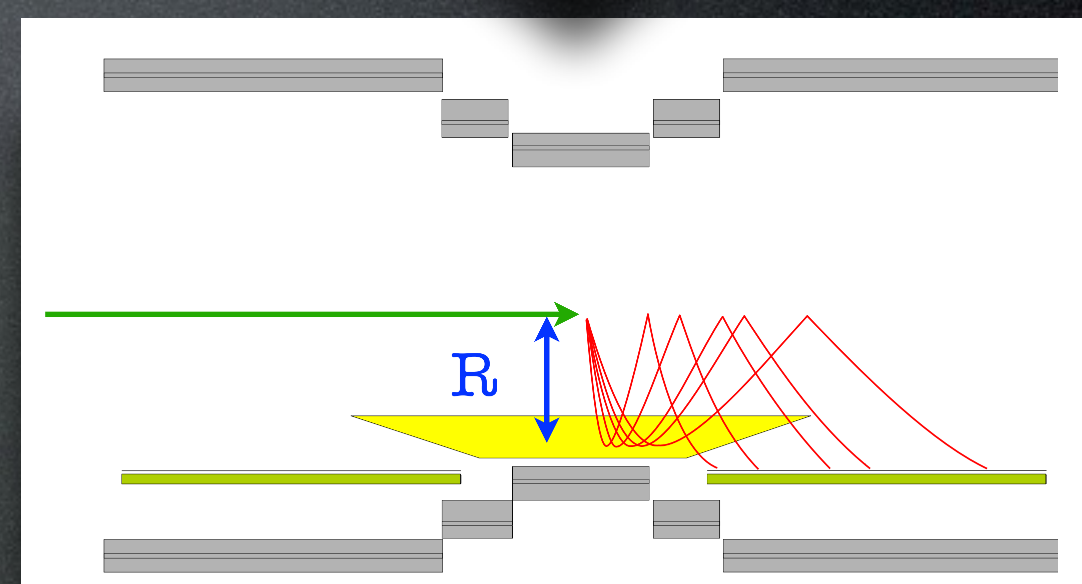
uniform B-field





gradient B-field

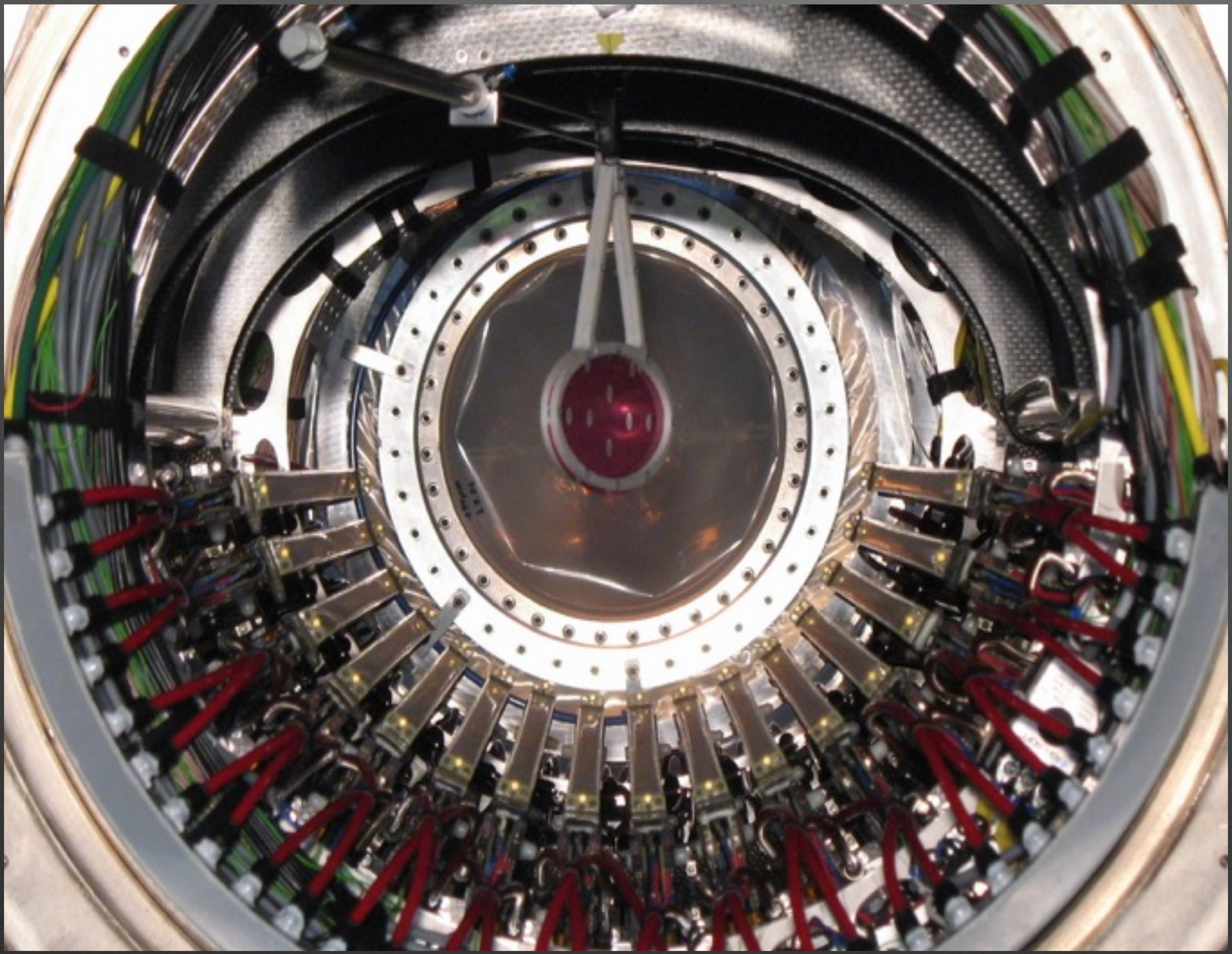




Low energy positrons quickly swept out

Constant bending radius independent of emission angles

Drift Chambers



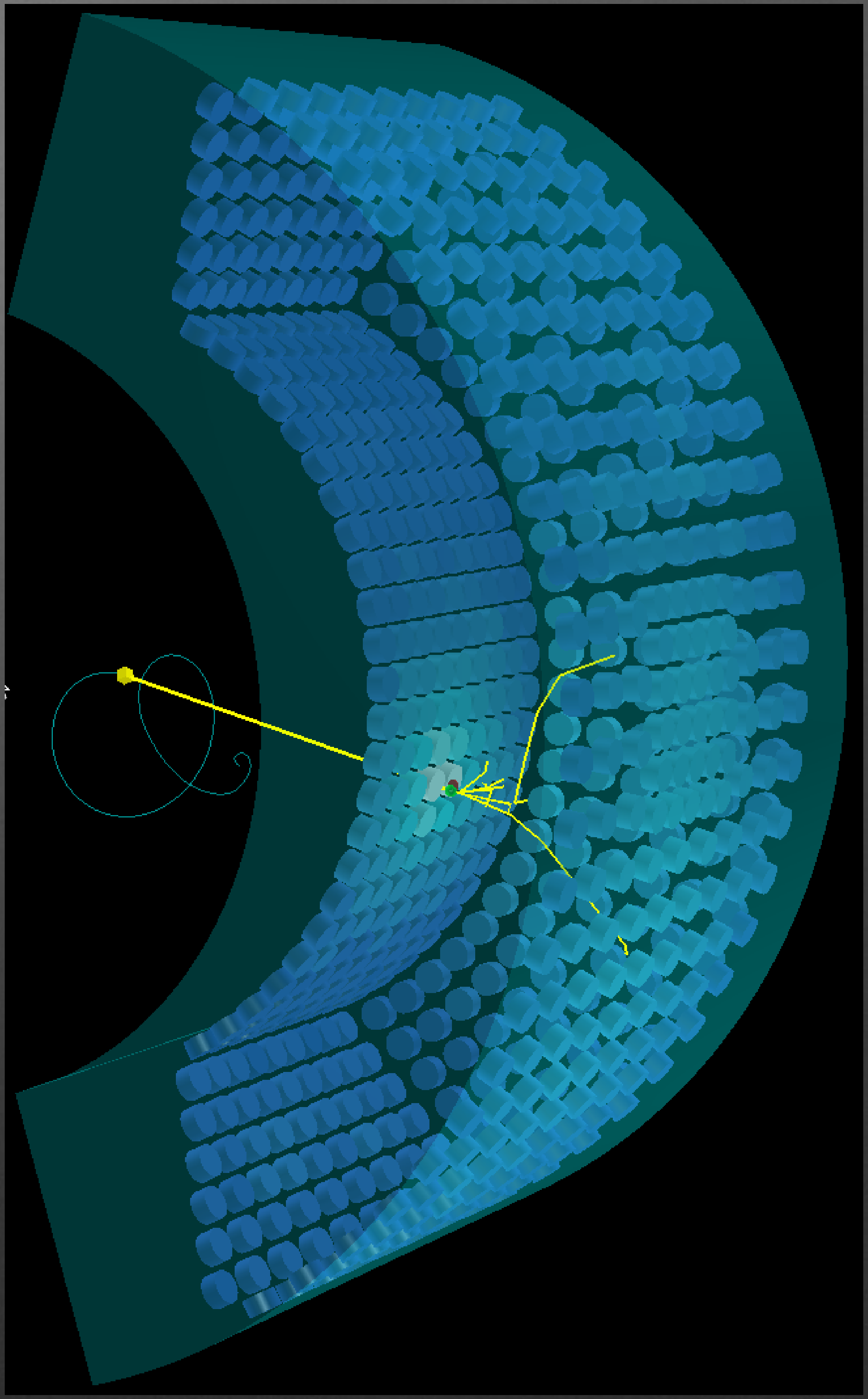
- 16 radially aligned modules, each consists of two staggered layers of wire planes
- 12.5um thick cathode foils with a Vernier pattern structure
- He:ethane = 50:50 differential pressure control to COBRA He environment
- ~2.0×10^{-3} X_0 along the positron trajectory

filled with He inside COBRA

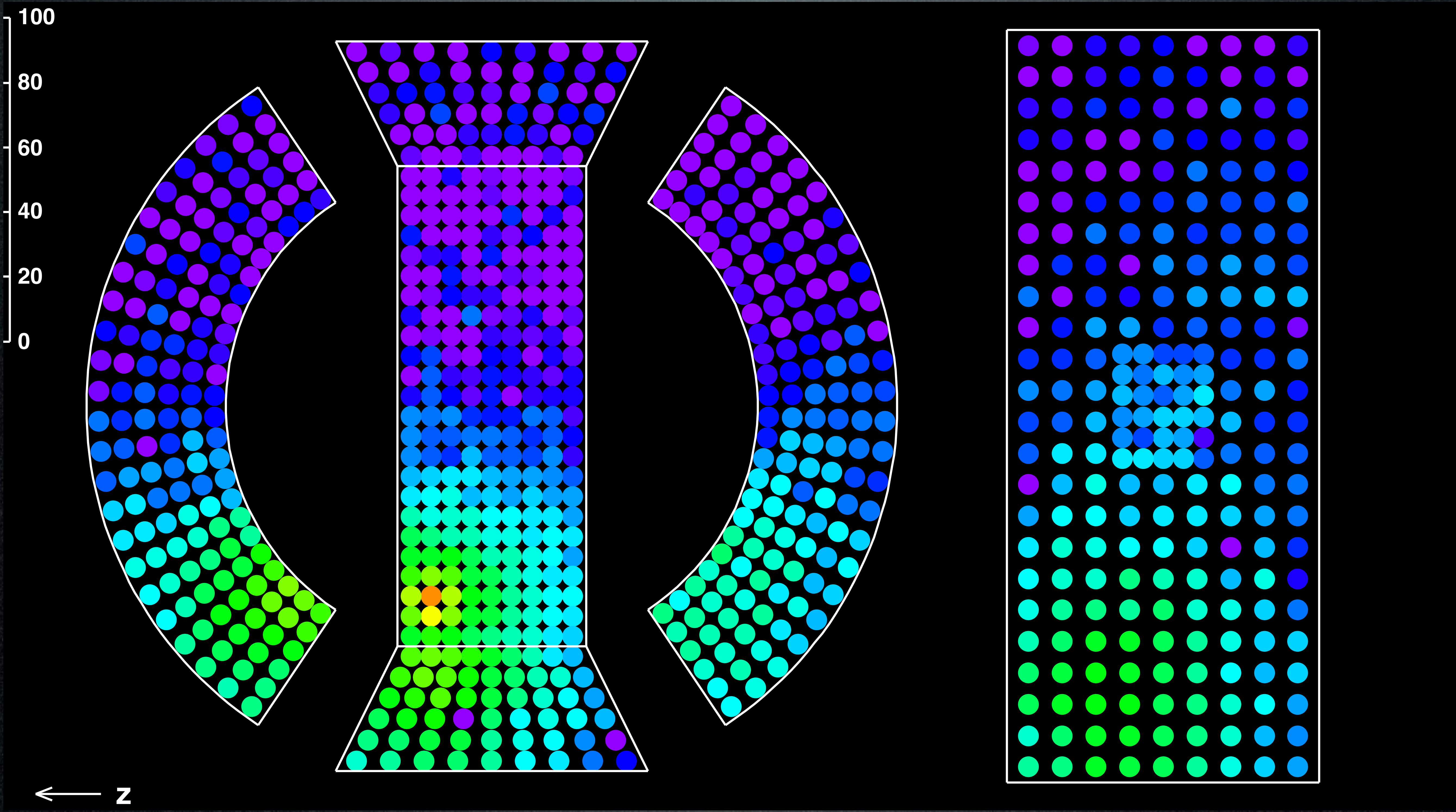
2.7t Liquid Xenon Photon Detector

High resolution detector

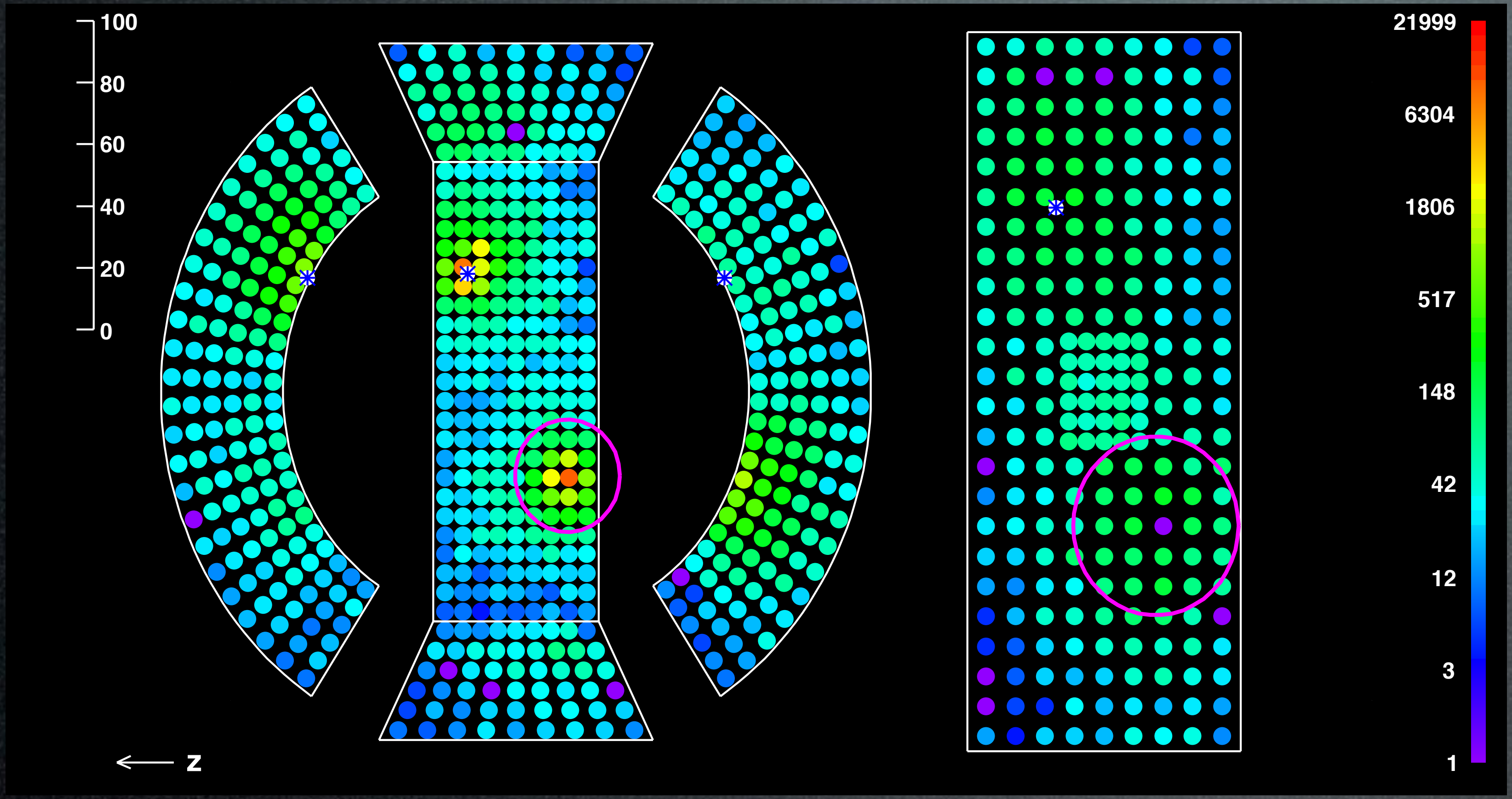
- Scintillation light from 900 liter liquid xenon is detected by 846 PMTs mounted on all surfaces and submerged in the xenon
- fast response & high light yield provide good resolutions of E, time, position
- kept at 165K by 200W pulse-tube refrigerator
- gas/liquid circulation system to purify xenon to remove contaminants



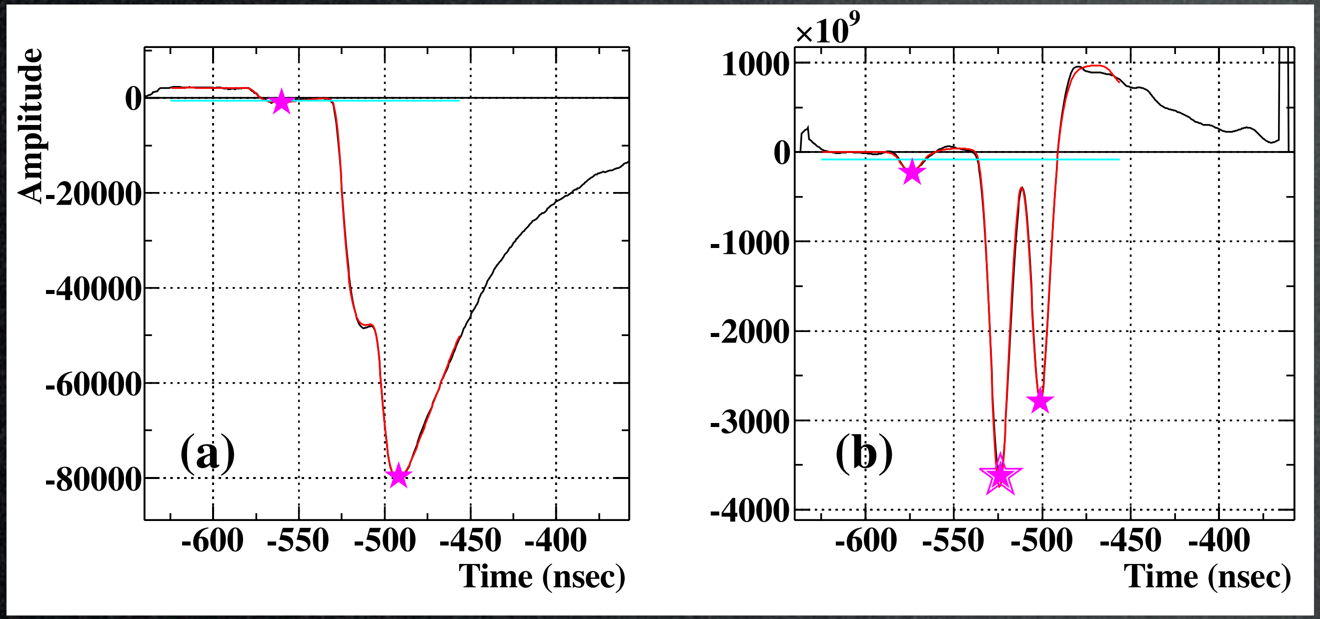
Energy = total light yield
Position = light peak



Pile-up Photon Removal



- Good position/timing resolutions enable to remove pile-up photons
- All the PMTs are read out by waveform digitizers (DRS)
- Events are not thrown away

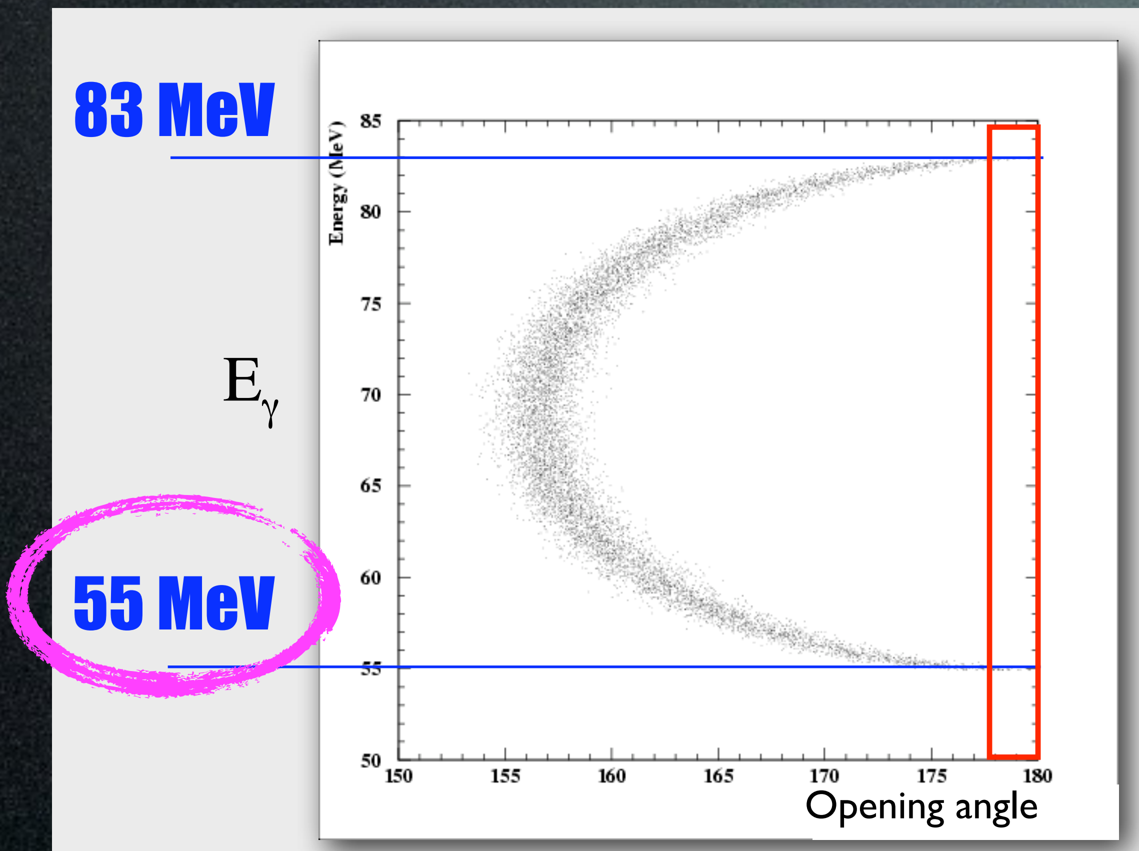


Improved pileup elimination algorithms implemented for this analysis

↓

7% better efficiency

Absolute γ Energy Calibration

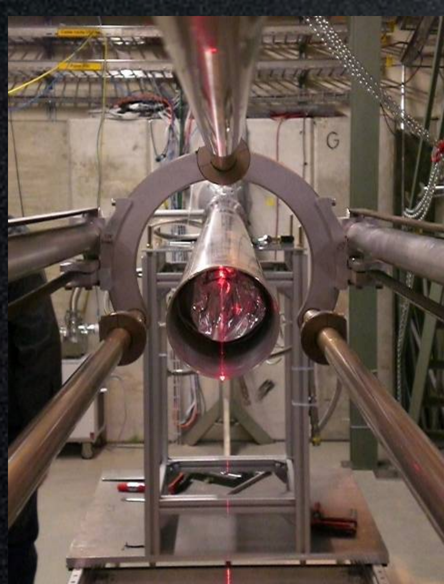


$$\pi^- p \rightarrow \pi^0 n \rightarrow \gamma\gamma n$$

charge exchange reaction (CEX)

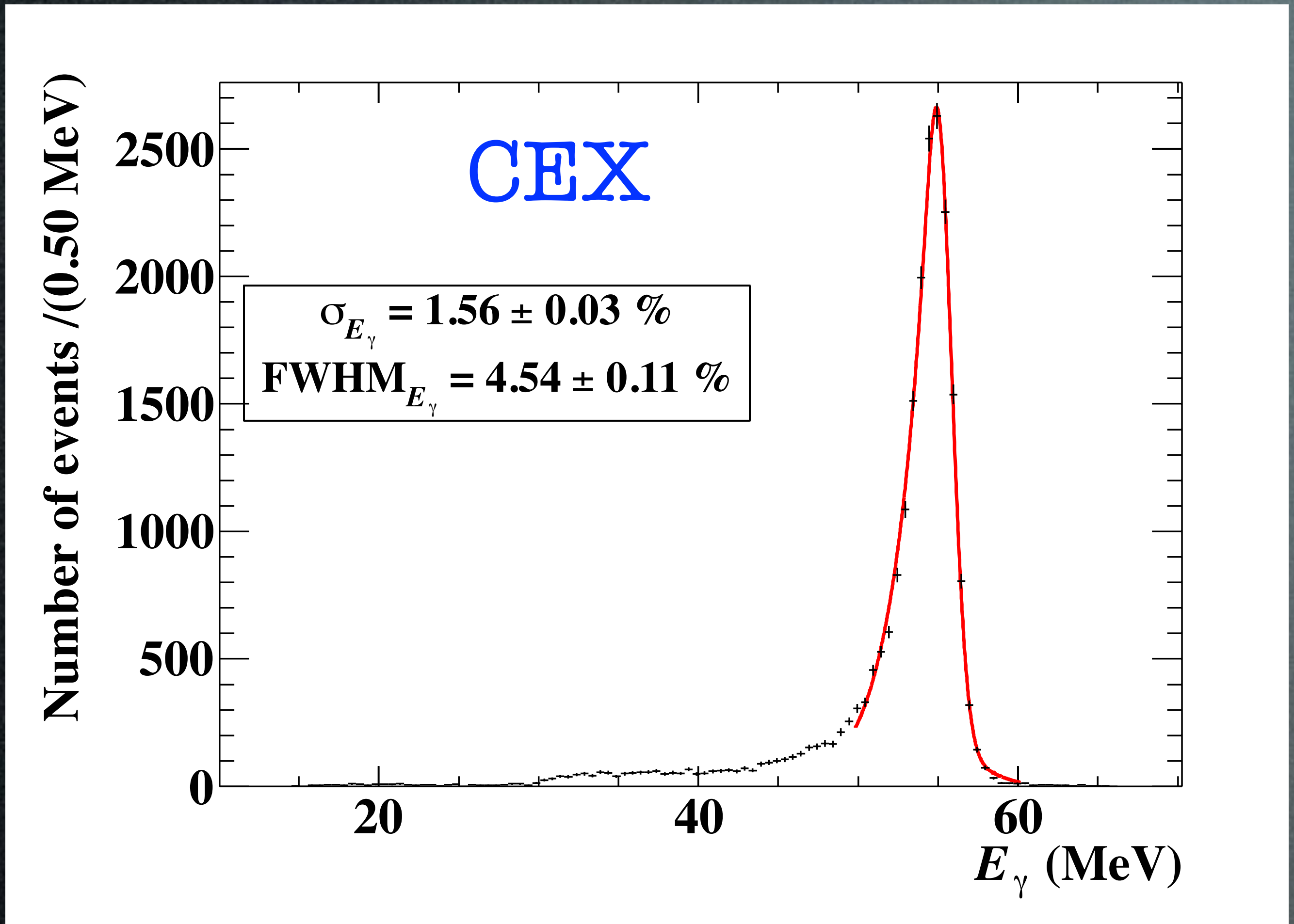
- negative pions stopped in liquid hydrogen target
- Tagging the other photon at 180° provides monochromatic photons
- Dalitz decays were used to study positron-photon synchronization and time resolution

New higher resolution BGO array introduced to tag the other photon



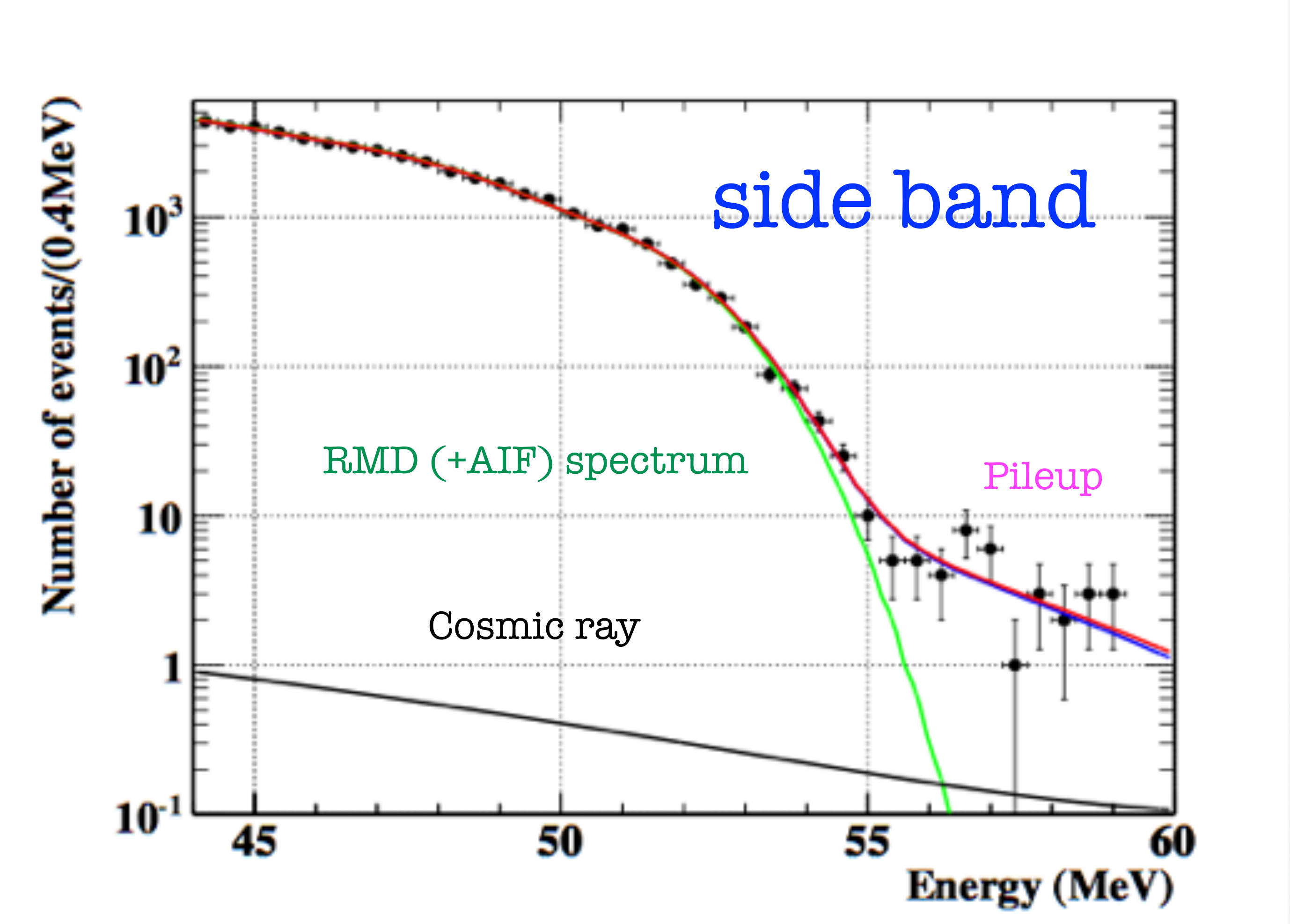
LH_2 target

BGO crystal array on a movable stand to tag the other photon



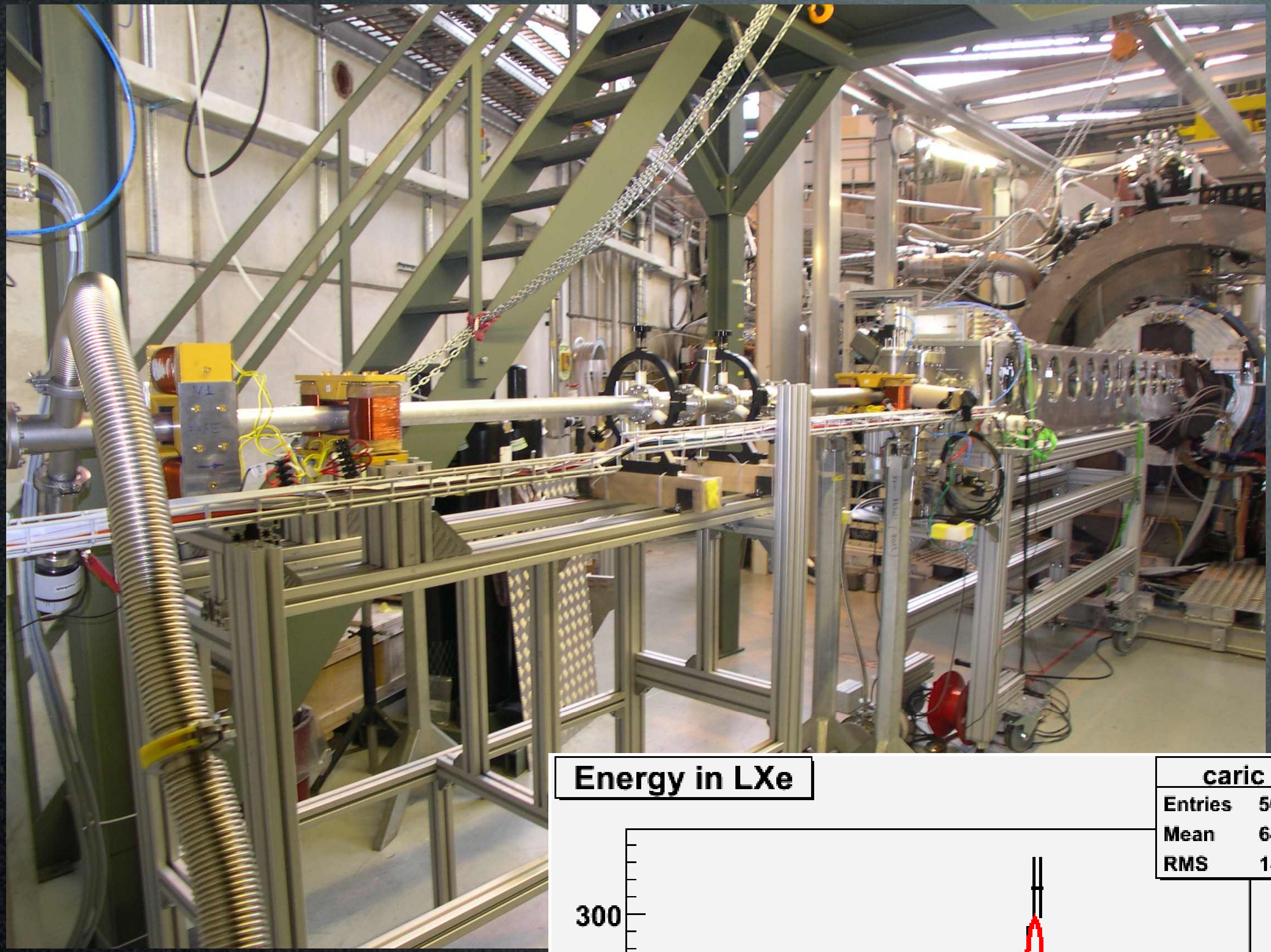
- Gamma ray energy

  - Signal PDF from the CEX calibration data
  - Accidental PDF from the side bands



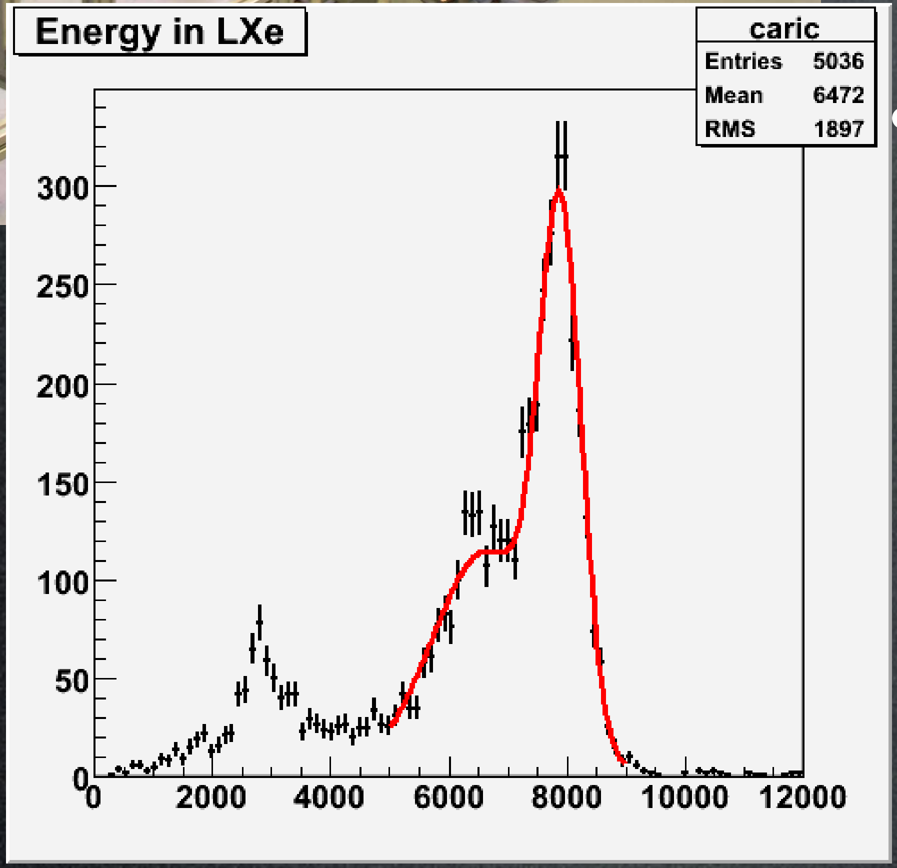
- Scale & resolutions verified by radiative decay spectrum
- systematic uncertainty on energy scale: 0.3%

Monitor E_γ during Run



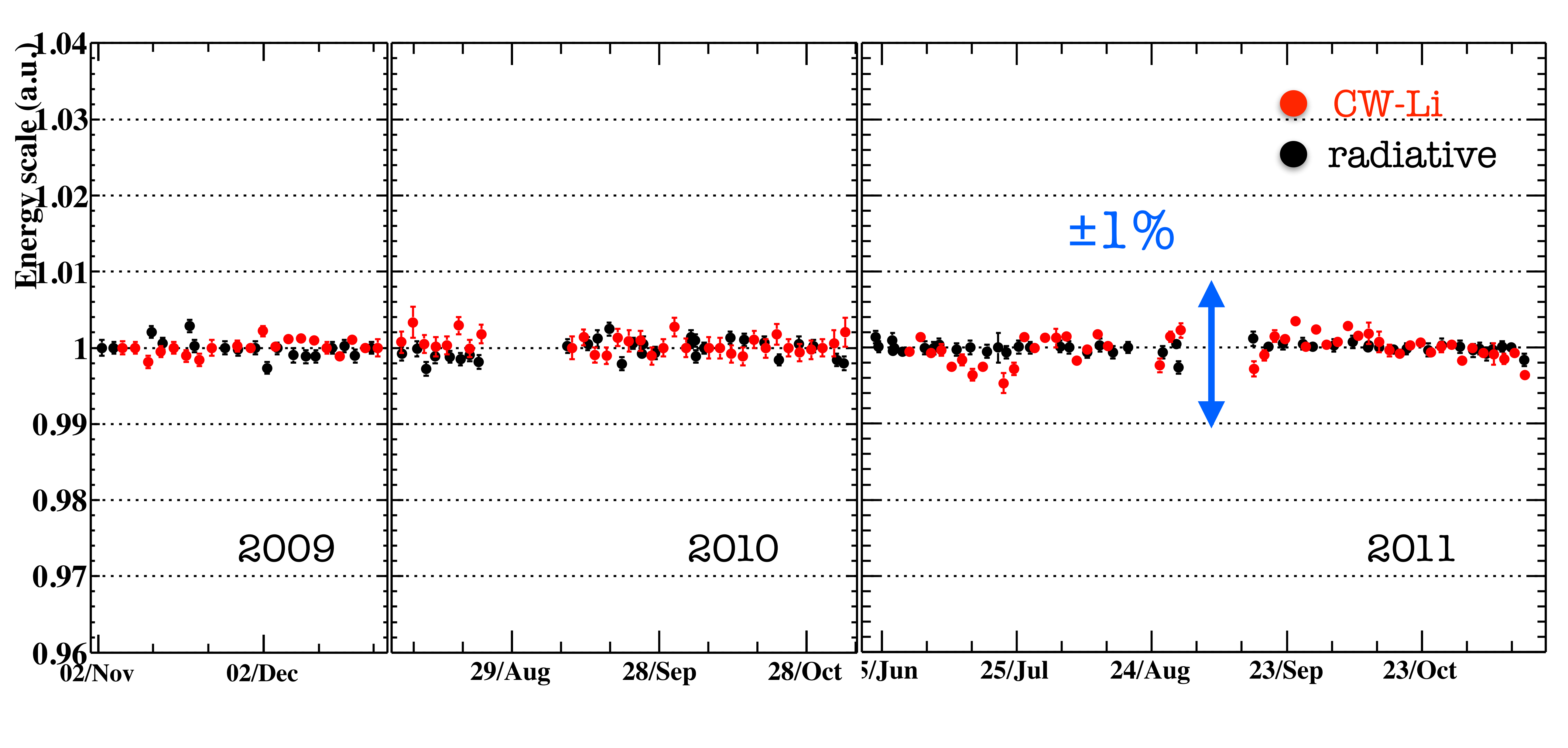
- sub-MeV proton beam from a dedicated Cockcroft-Walton accelerator are bombarded on $Li_2B_4O_7$ target.
- 17.67MeV from ^{7}Li
- 2 coincident photons (4.4, 11.6) MeV from ^{11}B: synchronization of LXe and TC
- Short runs two-three times a week

remotely extendable beam pipe of CW proton beam (downstream of muon beam line)



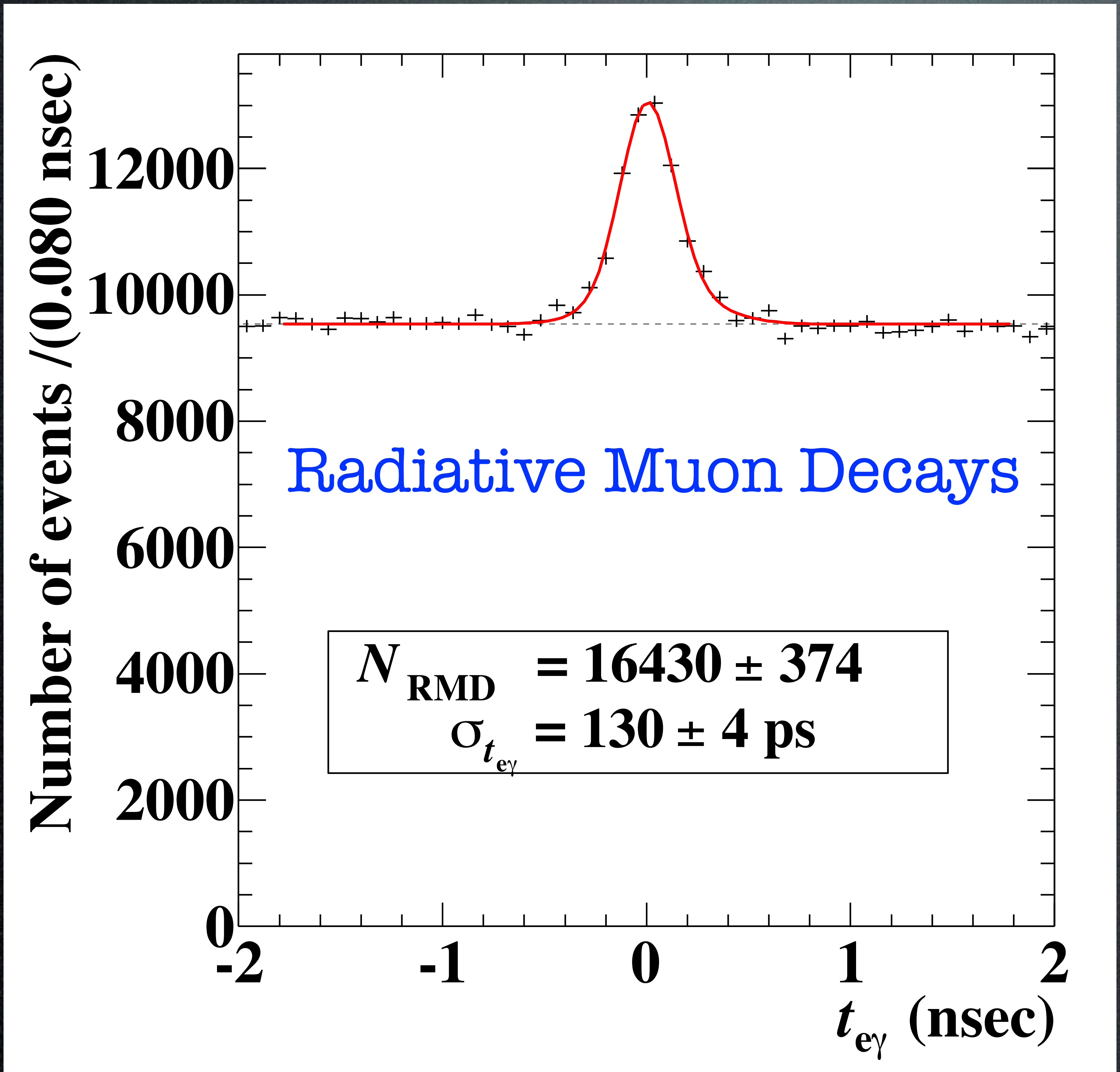
17.67MeV Li peak

Stability of E_γ Scale



rms ~0.2%

Positron - Photon Timing

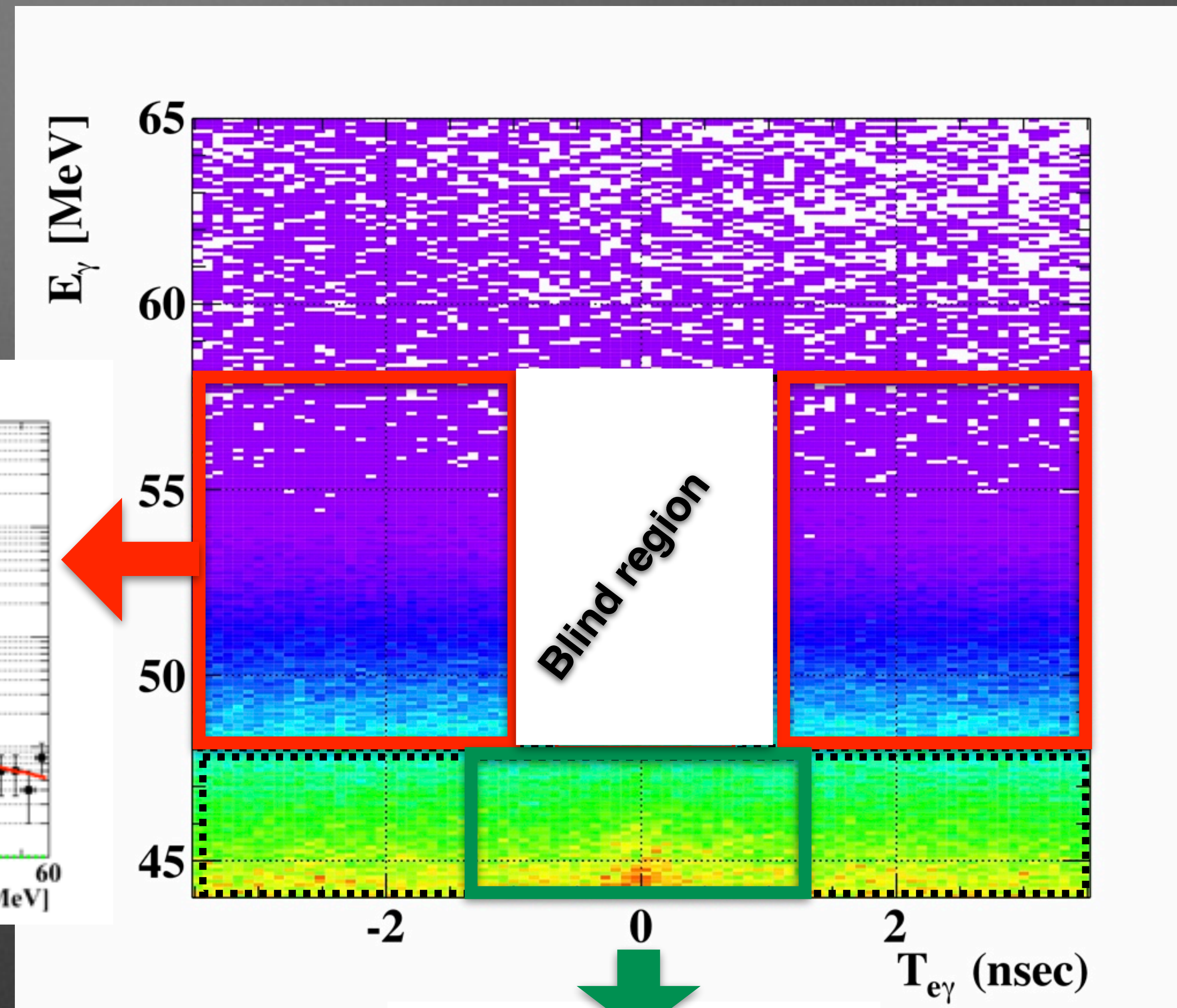


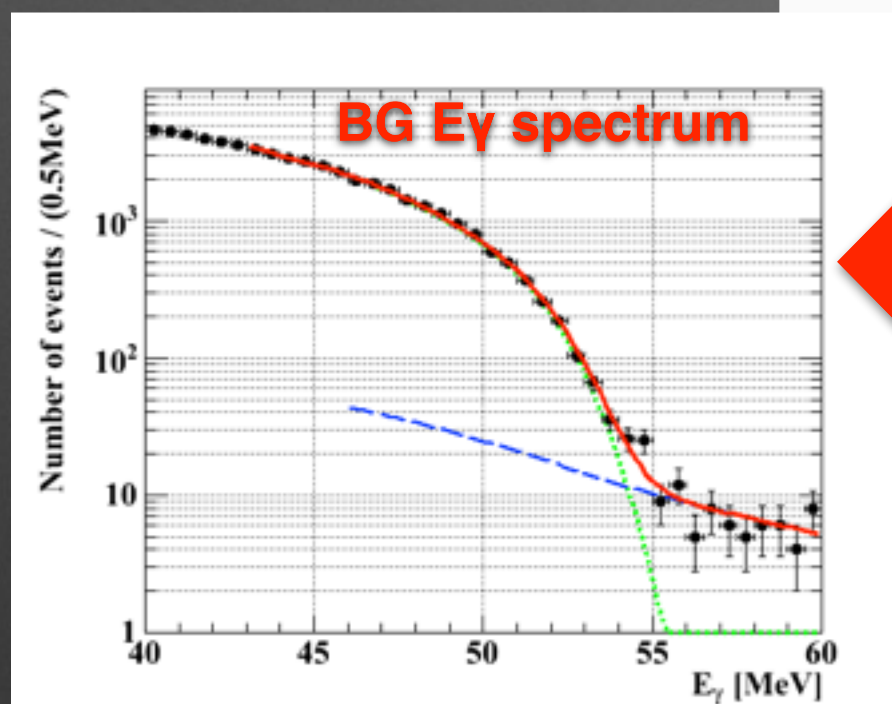
- Positron time measured by TC and corrected by ToF (DC trajectory)
- LXe time corrected by ToF to the conversion point
- RMD peak in a normal physics run corrected by small energy dependence; stable < 20ps

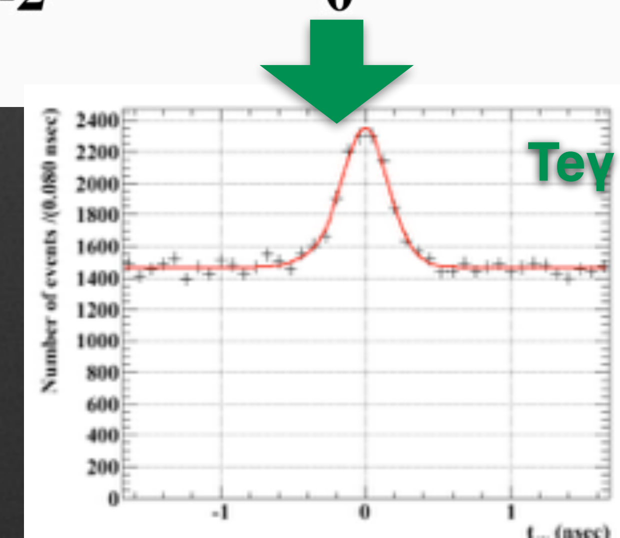
Blind & Likelihood Analysis

$(E\gamma, Ee, Te\gamma, \theta e\gamma, \phi e\gamma)$ → signal, acc BG, RD BG

- **Blind analysis**
  - Optimization of analysis and BG study are done in sidebands







PDFs mostly from data

accidental BG: side bands

signal: measured resolution

radiative BG: theory + resolution

Maximum Likelihood Fit

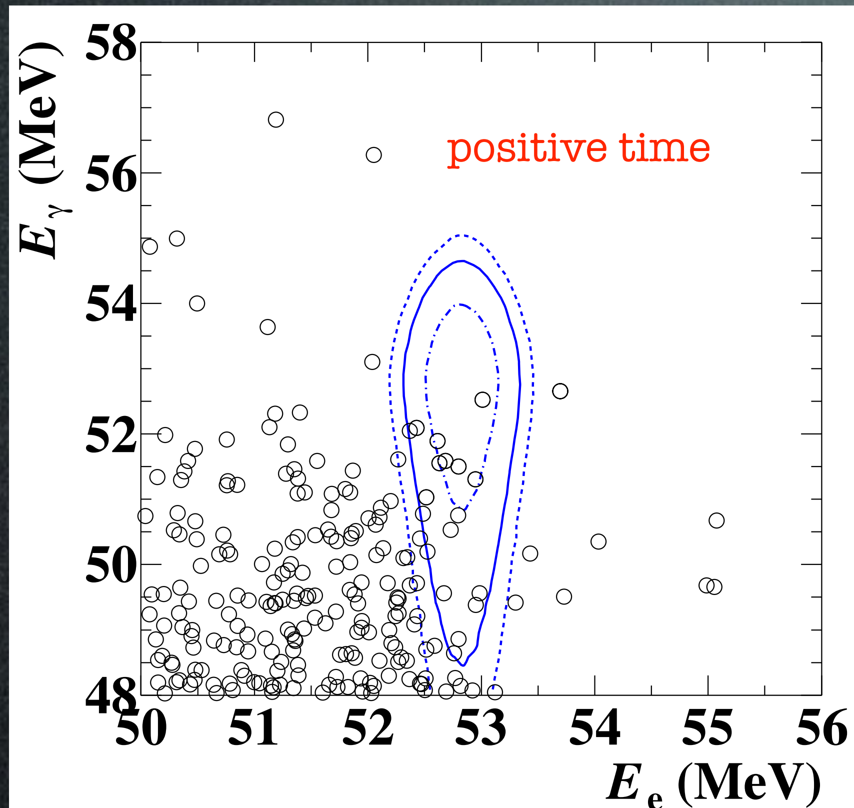
- fully frequentist approach (Feldman & Cousins) with profile likelihood ratio ordering

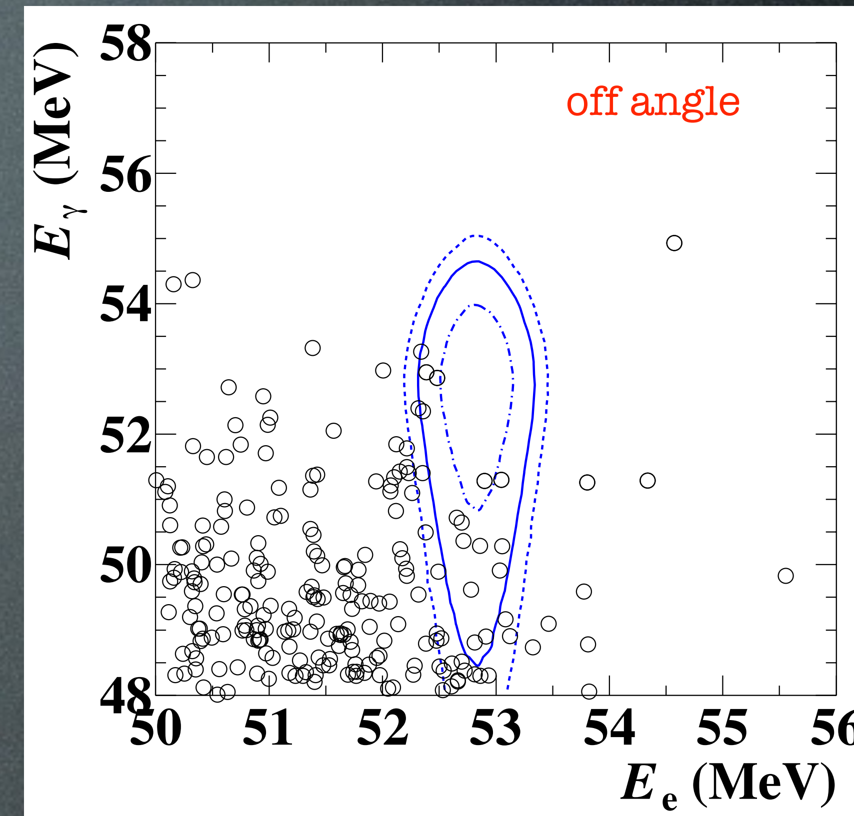
$$\mathcal{L}\left(N_{\text{sig}}, N_{\text{RMD}}, N_{\text{BG}}\right) = \frac{e^{-N}}{N_{\text{obs}}!} e^{-\frac{1}{2}\frac{(N_{\text{BG}}-\langle N_{\text{BG}}\rangle)^2}{\sigma_{\text{BG}}^2}} e^{-\frac{1}{2}\frac{(N_{\text{RMD}}-\langle N_{\text{RMD}}\rangle)^2}{\sigma_{\text{RMD}}^2}} \times \prod_{i=1}^{N_{\text{obs}}} \left(N_{\text{sig}} S(\vec{x}_i) + N_{\text{RMD}} R(\vec{x}_i) + N_{\text{BG}} B(\vec{x}_i)\right),$$

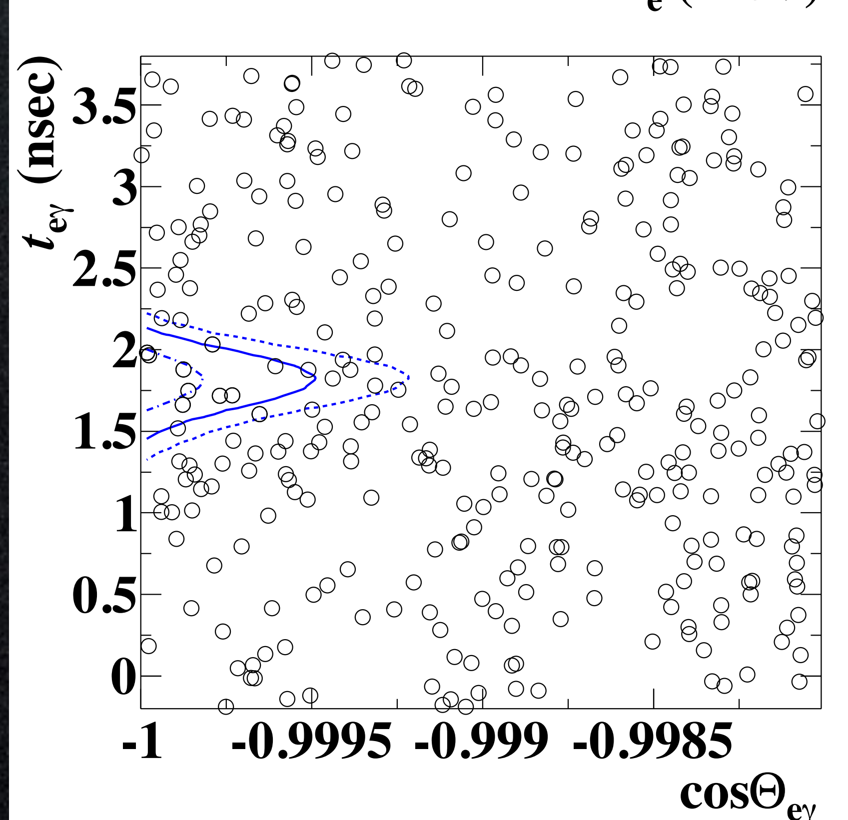
$$LR_p(N_{\text{sig}}) = \frac{\max_{N_{\text{BG}},N_{\text{RMD}}} \mathcal{L}(N_{\text{sig}}, N_{\text{BG}}, N_{\text{RMD}})}{\max_{N_{\text{sig}},N_{\text{BG}},N_{\text{RMD}}} \mathcal{L}(N_{\text{sig}}, N_{\text{BG}}, N_{\text{RMD}})}.$$

New: per-event PDFs introduced also for positrons
→ sensitivity improvement by 10%

2009-2011 Side band data

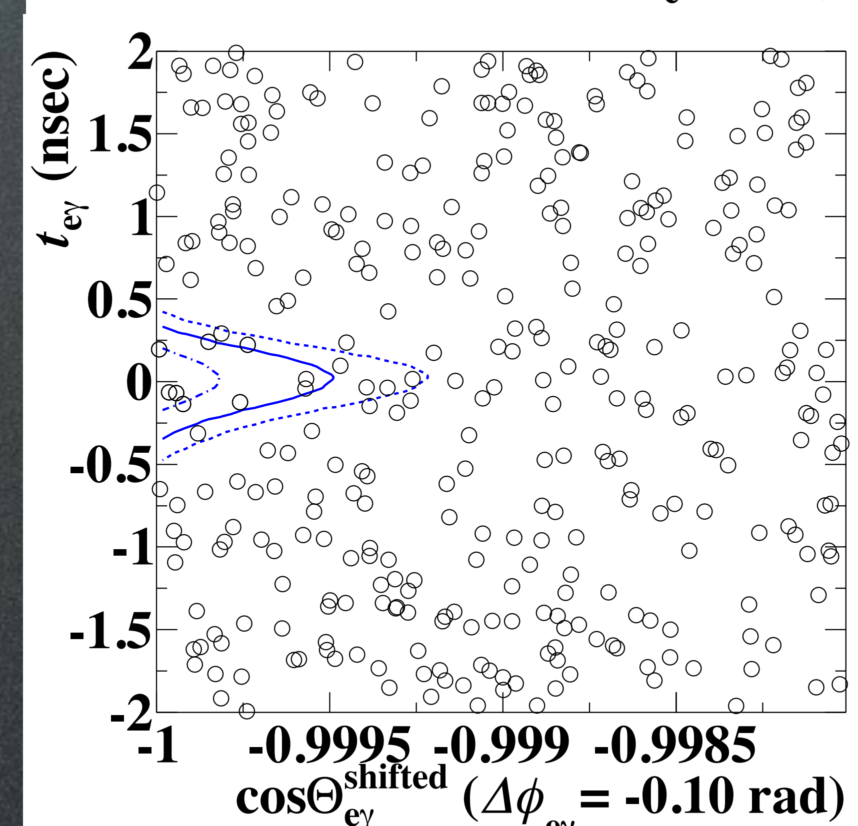






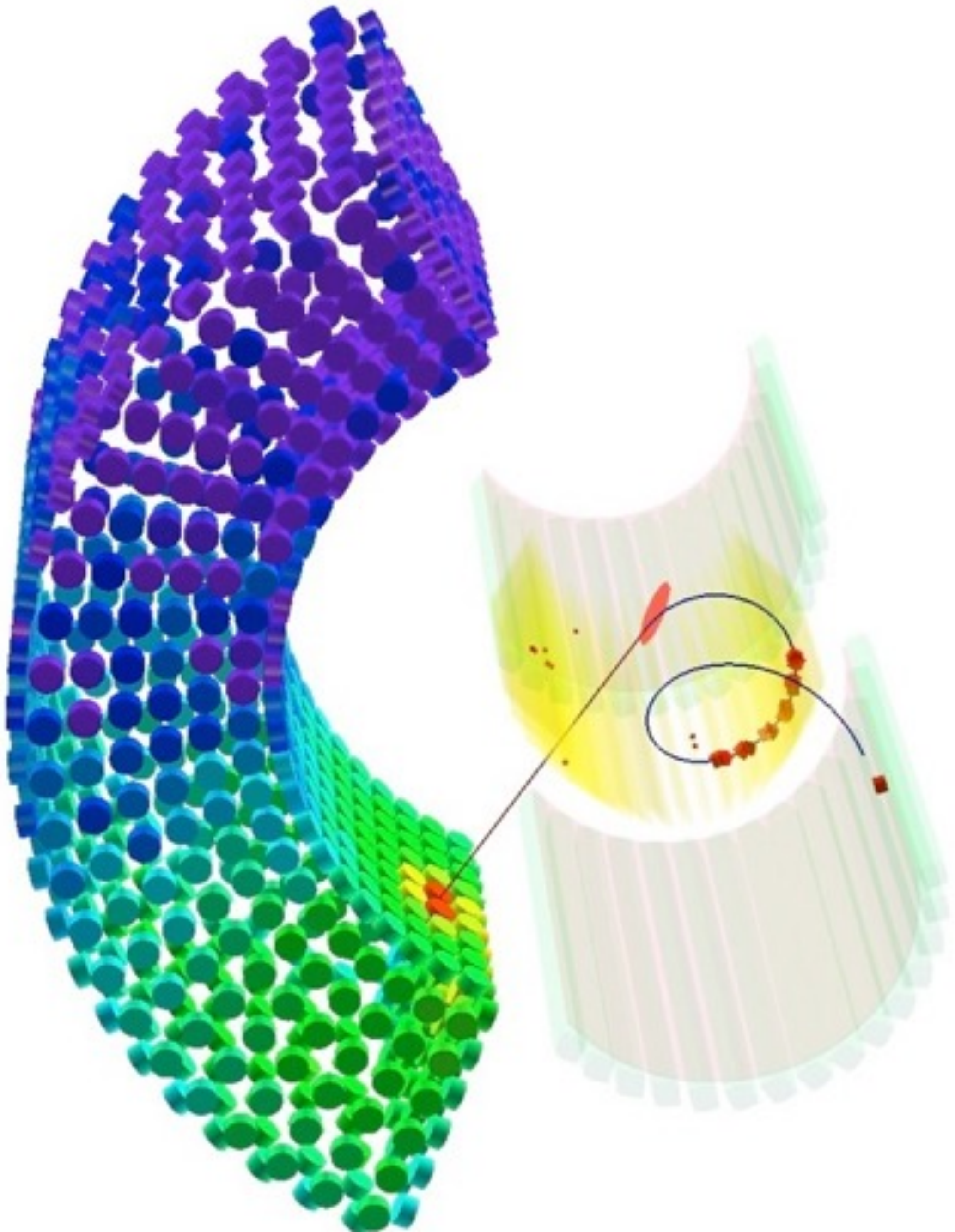
2009-2010 reprocessed ~20% better sensitivity

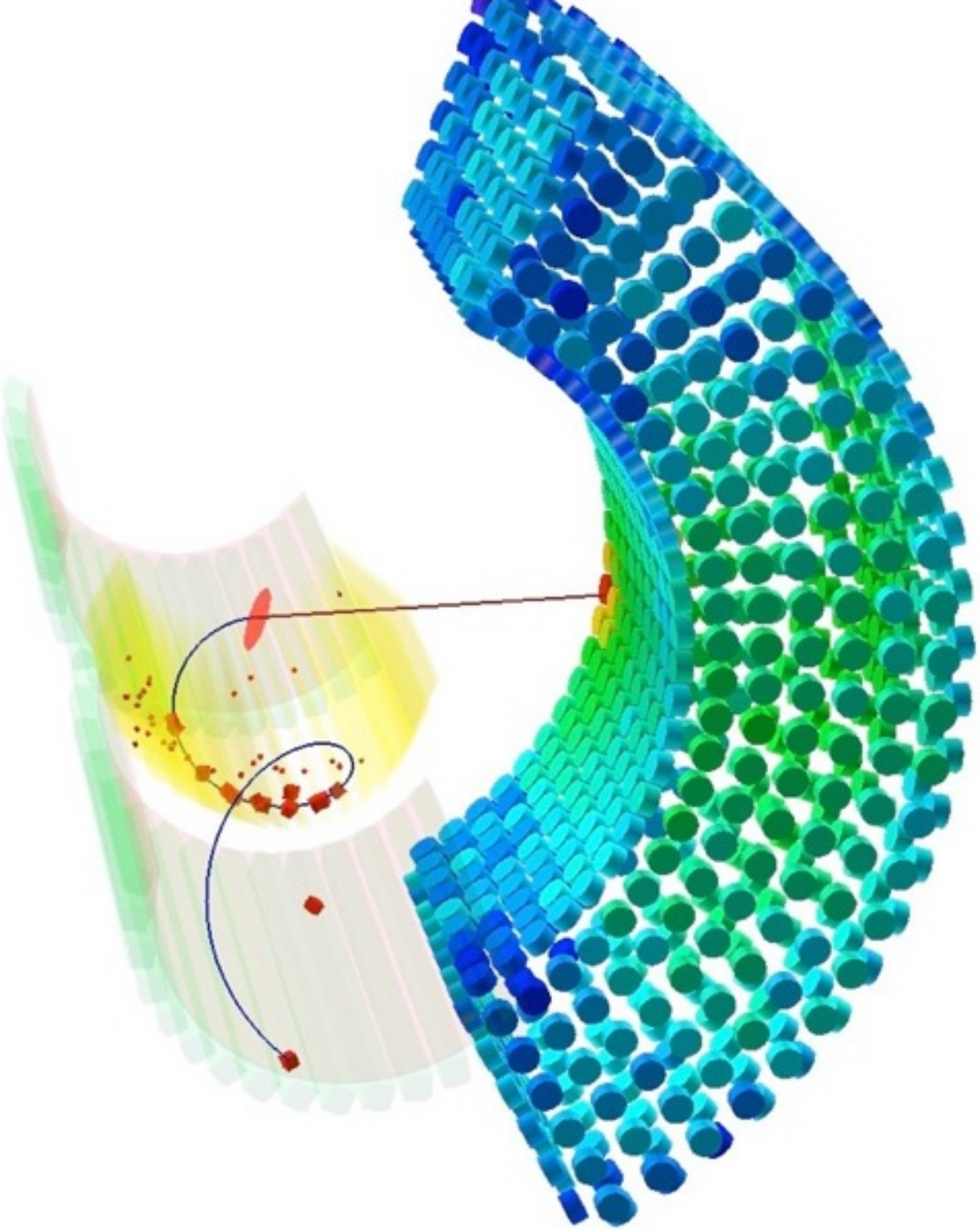
1, 1.64, 2σ contours



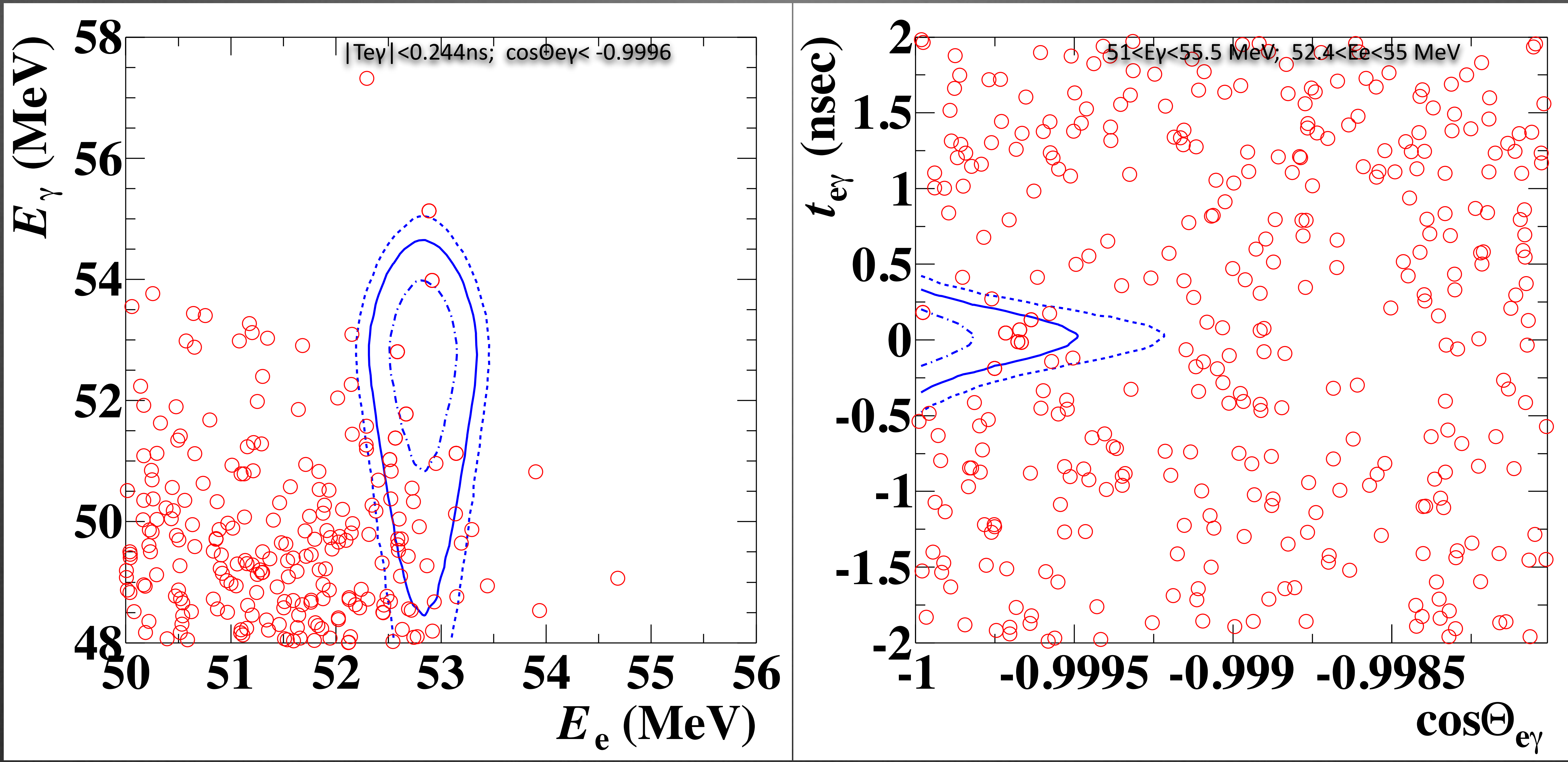
side band BG rates are consistent with the expected sensitivity for 2009-11 data = 7.7×10^{-13} @90% C.L.

a few examples of events



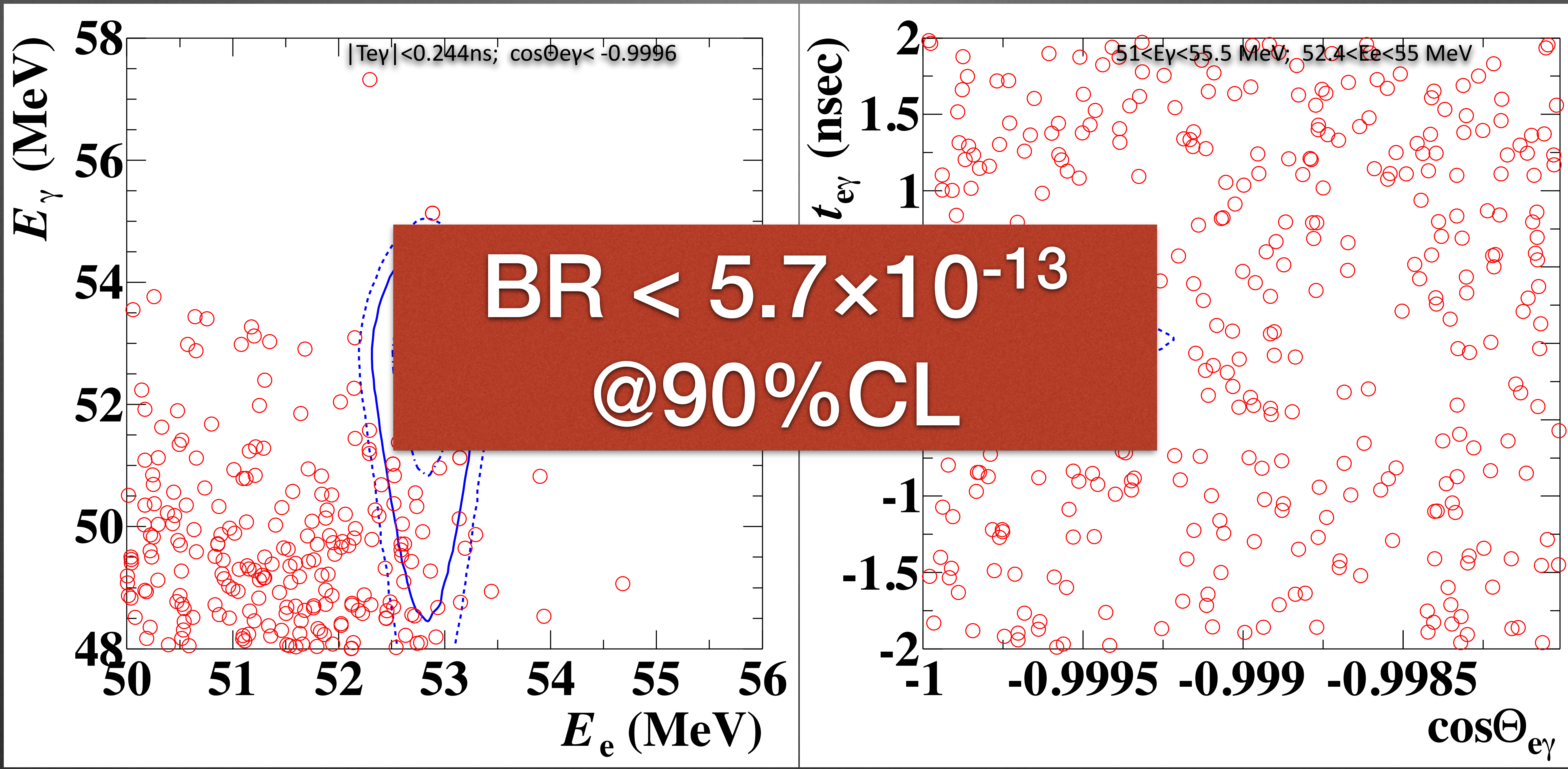


2009-2011 Combined MEG Data



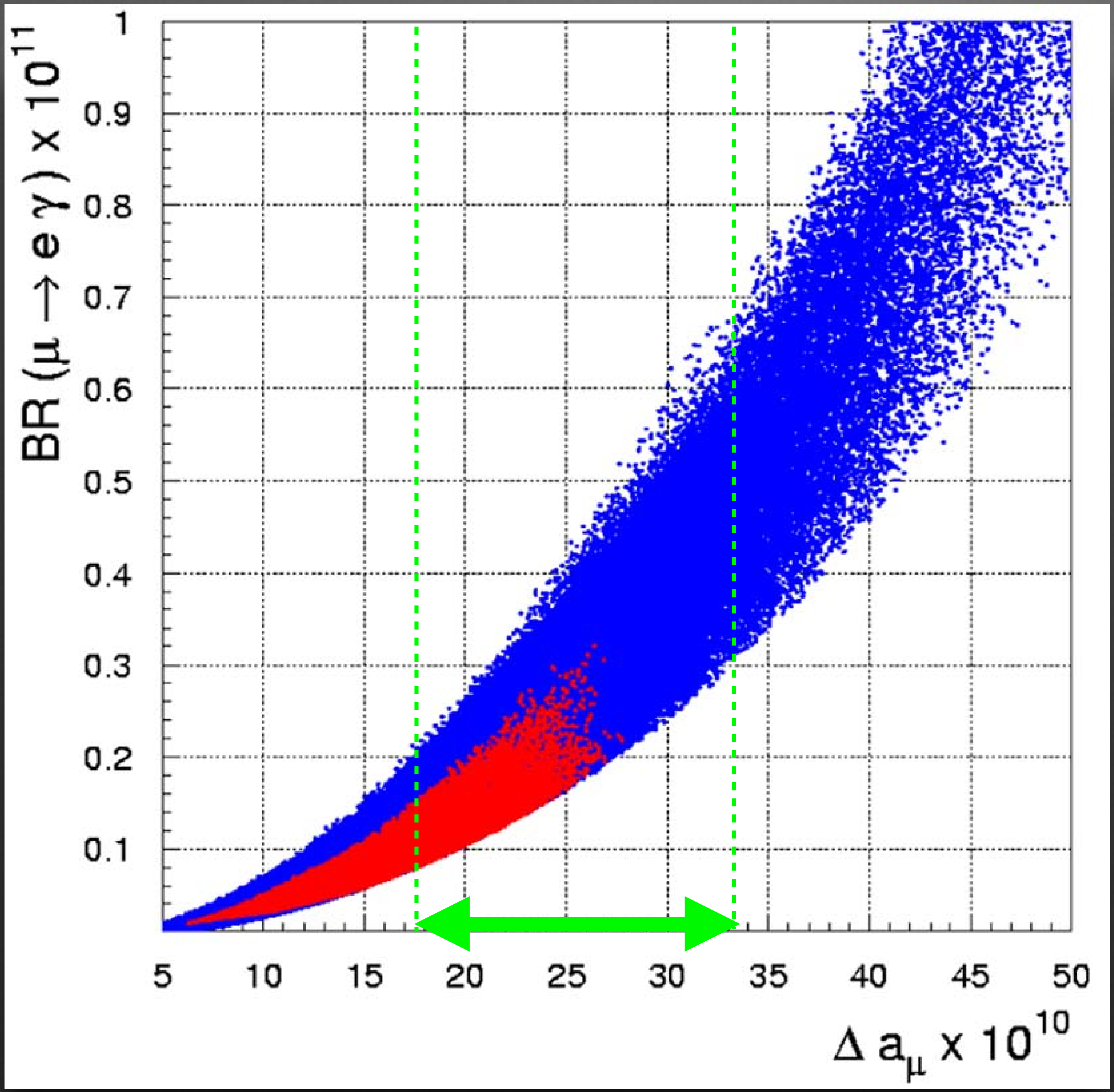
1, 1.64, 2σ contours

2009-2011 Combined MEG Data



1, 1.64, 2σ contours

muon (g-2) anomaly

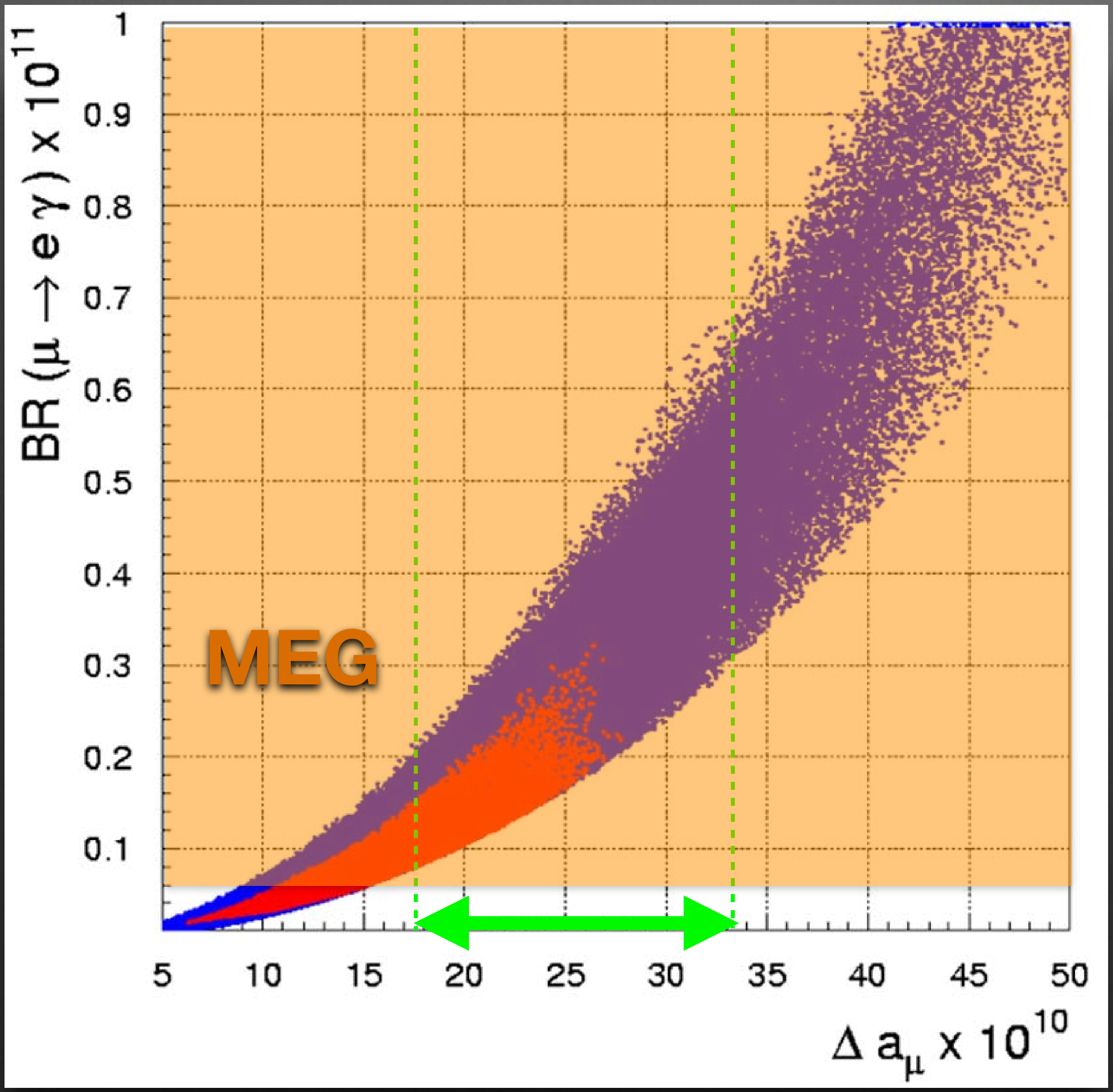


$|\delta_{LL}^{12}| = 10^{-4}$ assumed

G.Isidori et al. PRD75, 115019

muon's anomalous magnetic moment

muon (g-2) anomaly



$|\delta_{LL}^{12}| = 10^{-4}$ assumed

G.Isidori et al. PRD75, 115019

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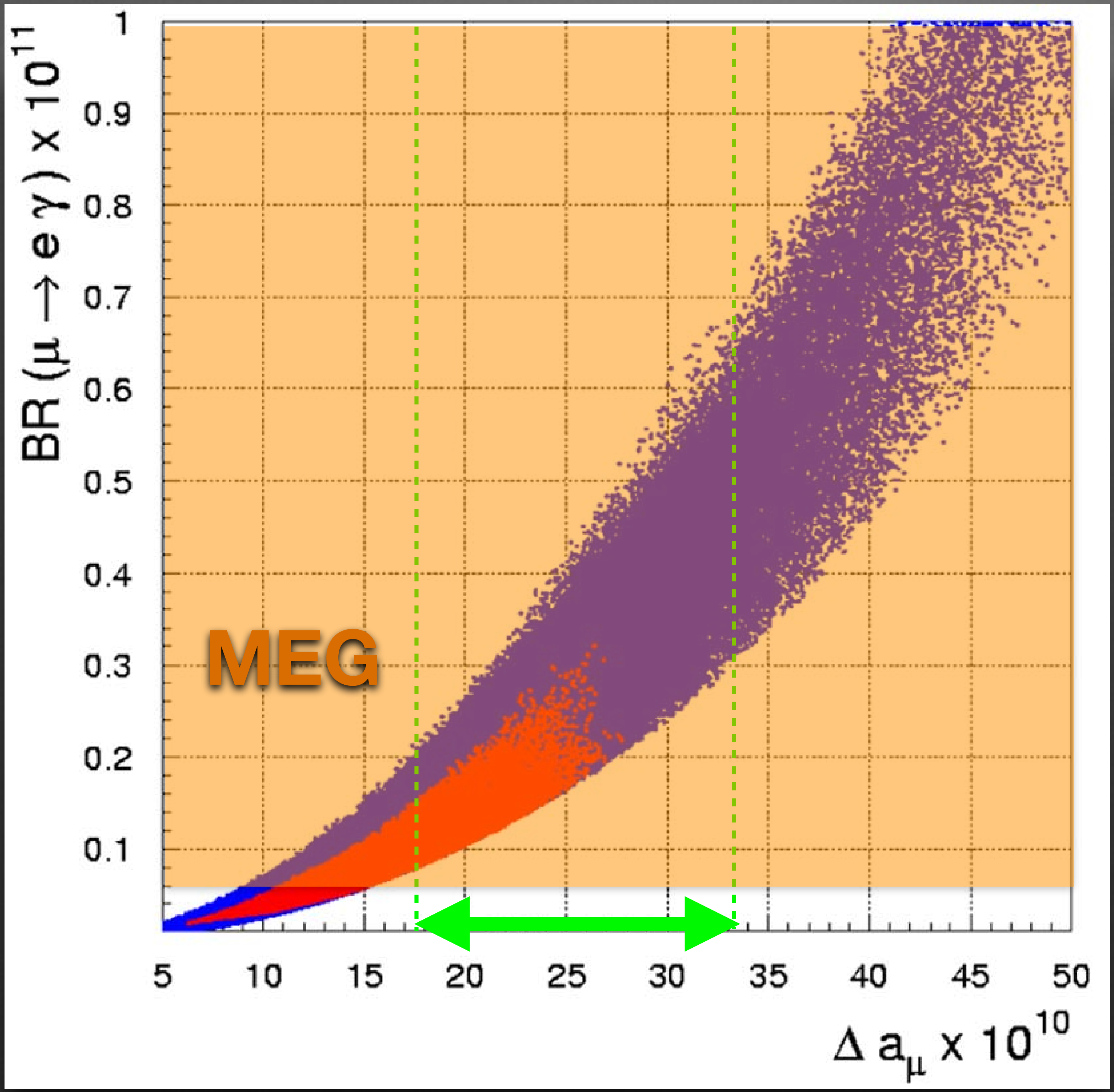


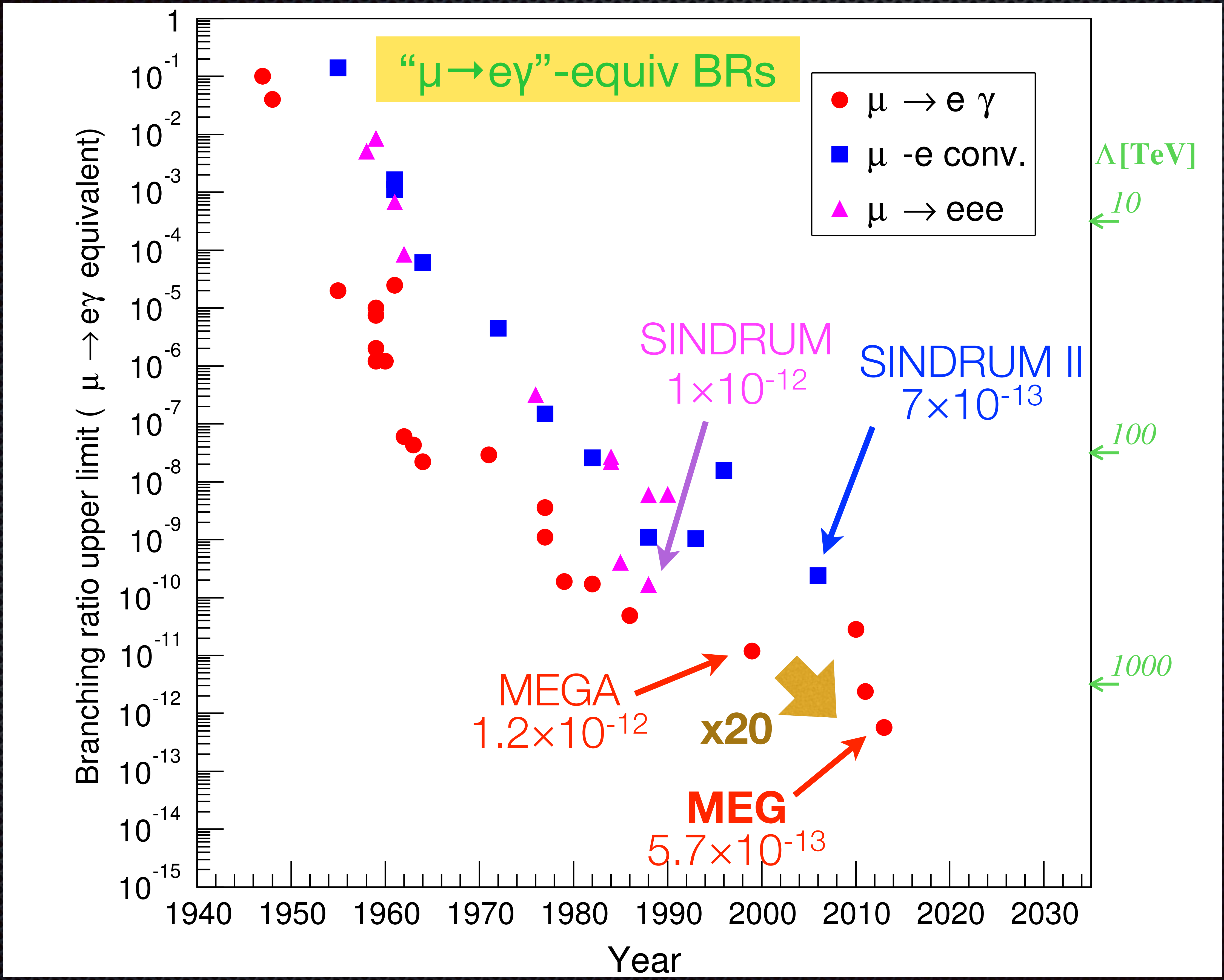
G.Isidori et al. PRD75, 115019

tighter limit on this

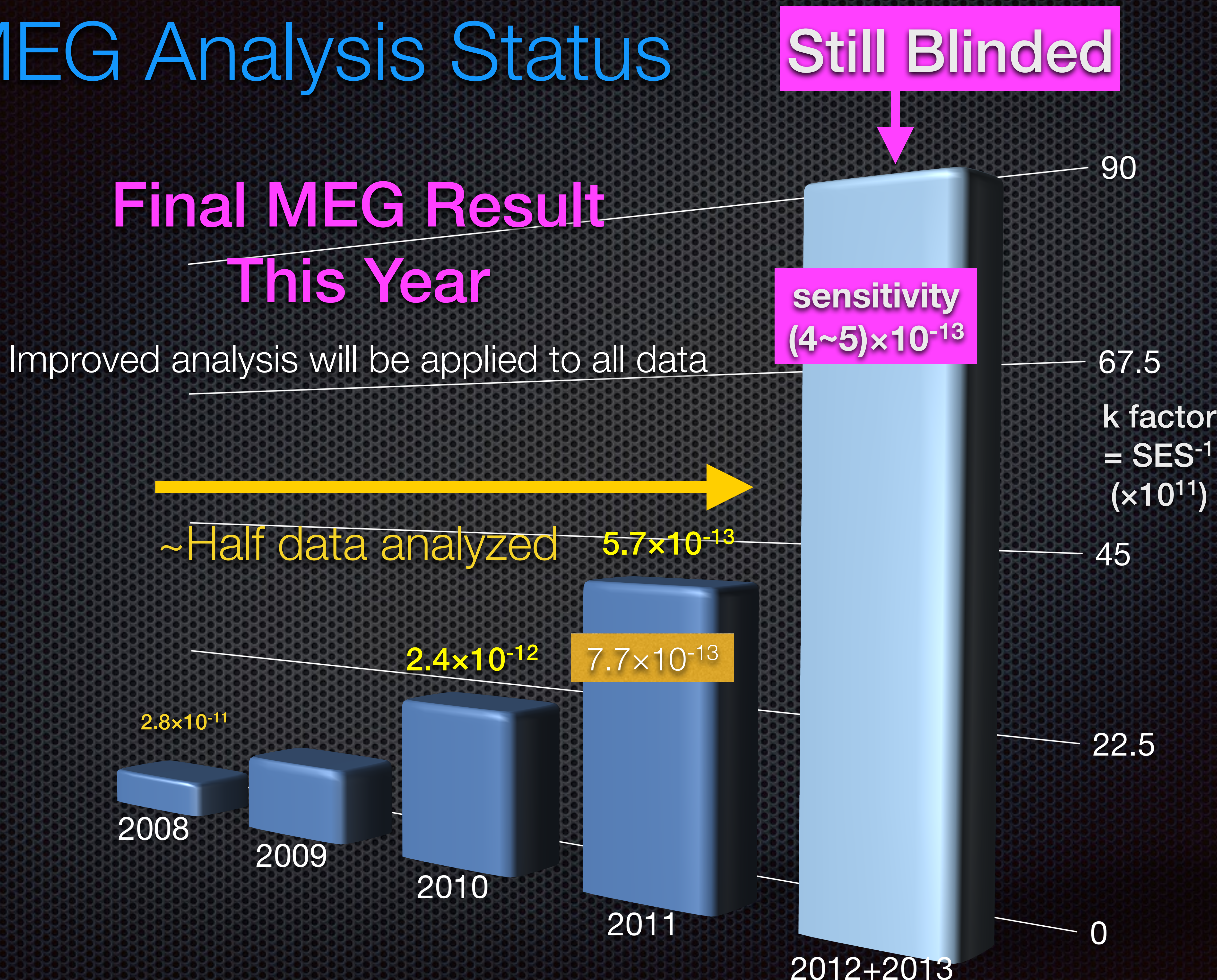
$|\delta_{LL}^{12}| = 10^{-4}$ assumed

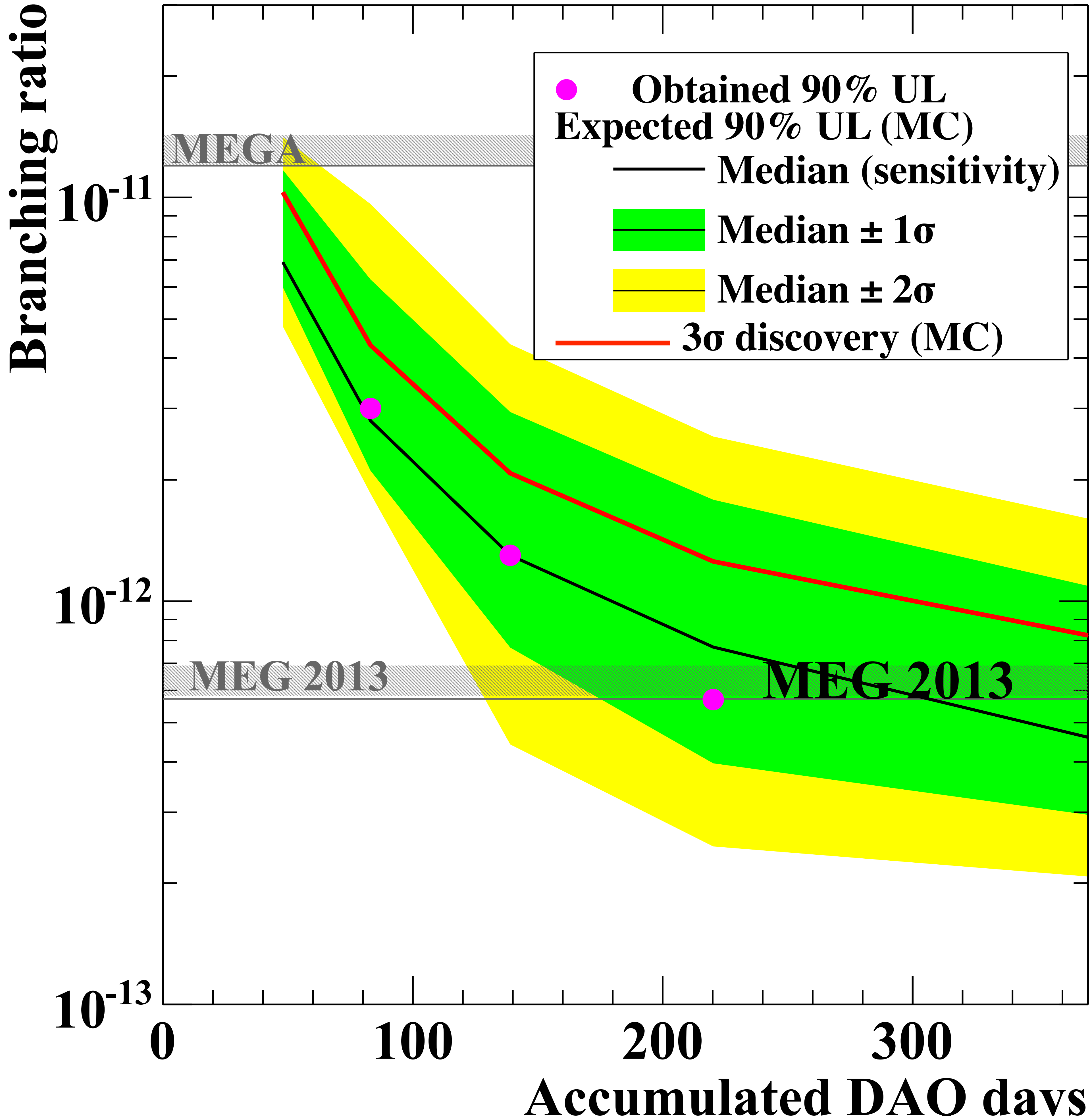
muon's anomalous magnetic moment

Where we stand now



MEG Analysis Status

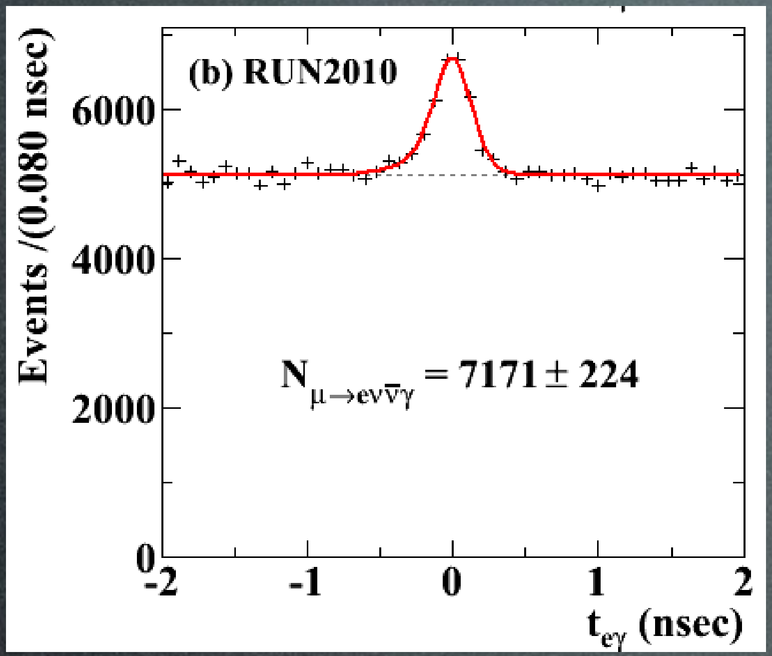


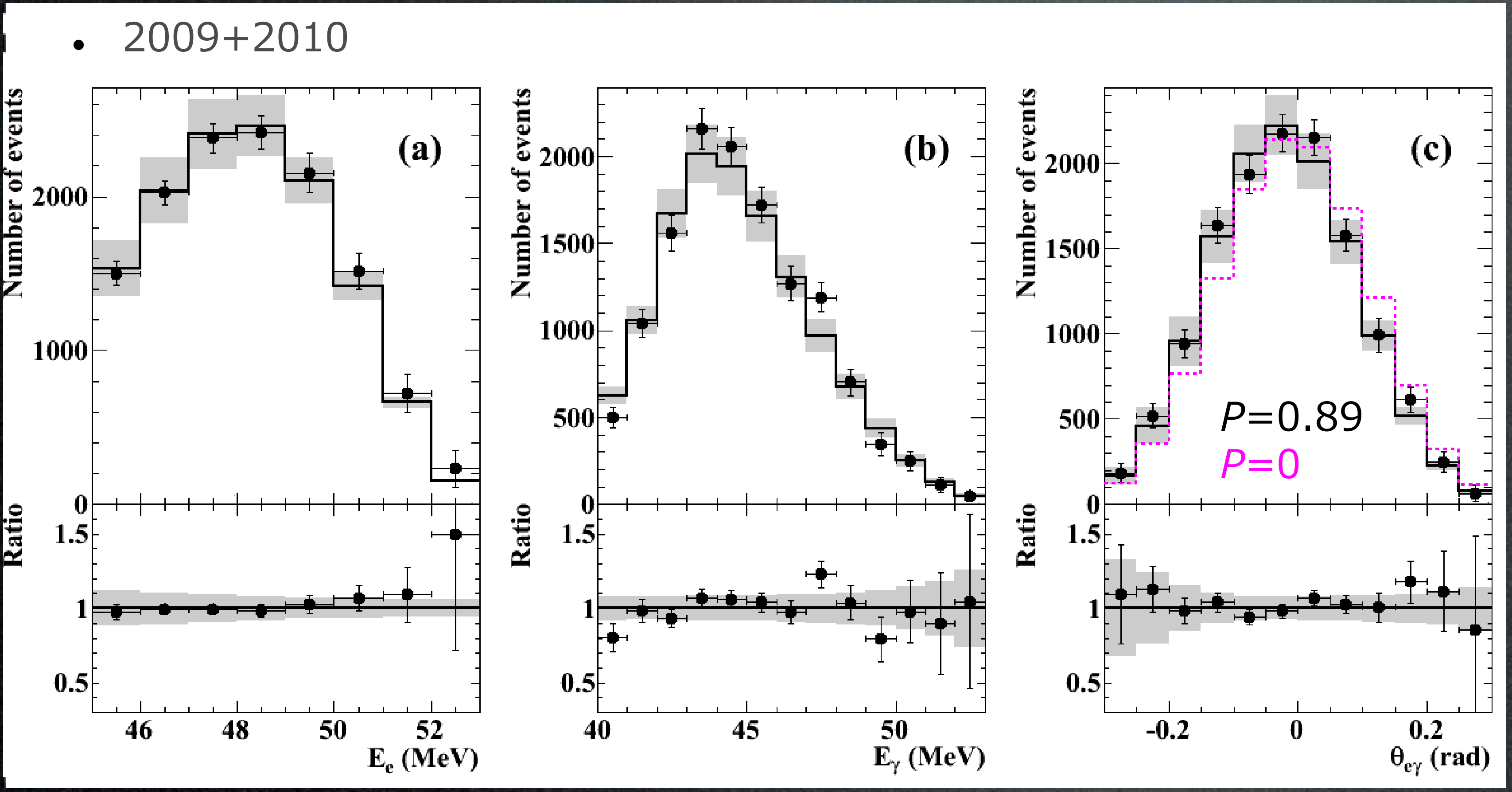


Branching ratio
10^{-11}
10^{-12}
10^{-13}
0
100
200
300
Accumulated DAQ days
MEGA
MEG 2013
MEG 2013
Obtained 90% UL
Expected 90% UL (MC)
Median (sensitivity)
Median ± 1σ
Median ± 2σ
3σ discovery (MC)

Other physics results

Radiative Muon Decays

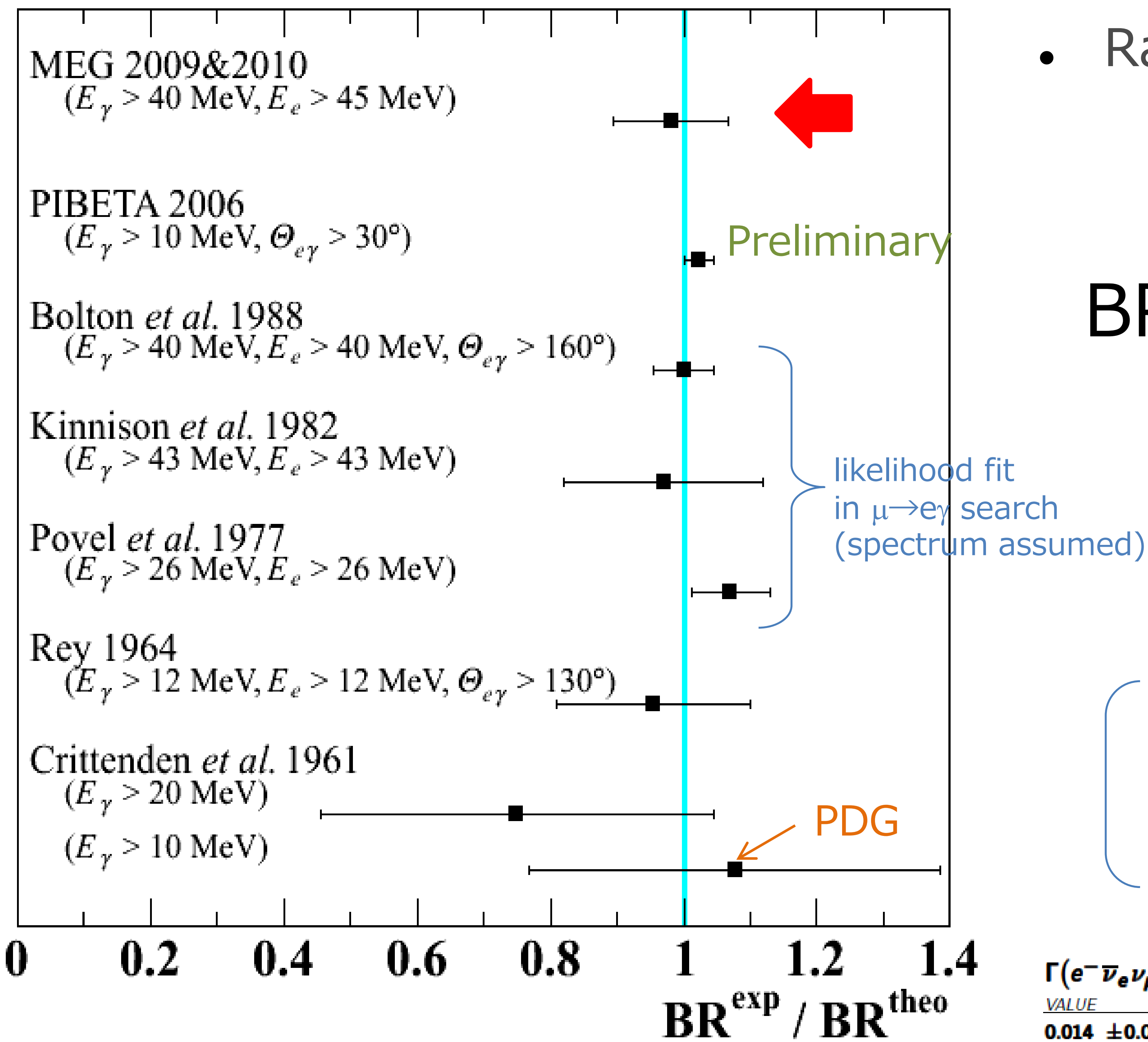




to be published soon

- Important check of μ→eγ analysis
  - BG, calibration, normalization
- Close to kinematical edge w/ polarization ~89%
  - sensitive to BSM
  - determine Michel parameters: η, κ

Comparisons



- Ratio to theory (SM)

$$\mathcal{B}^{\rm SM}(\mu^+ \to e^+\nu_e\bar{\nu}_\mu\gamma) = 6.15 \times 10^{-8}$$

BR^{exp}/BR^{theo}

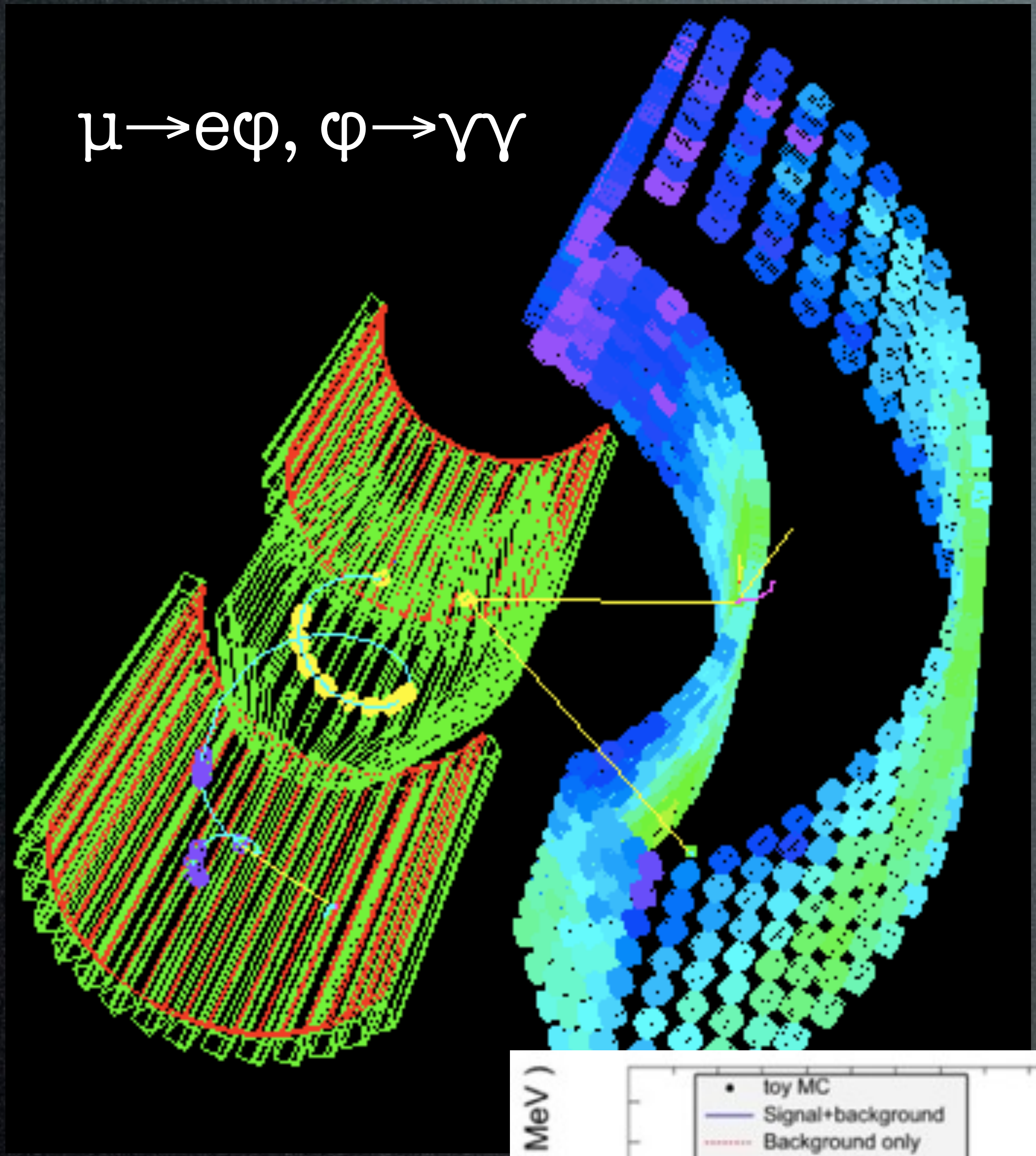
$= 0.98 \pm 0.09$

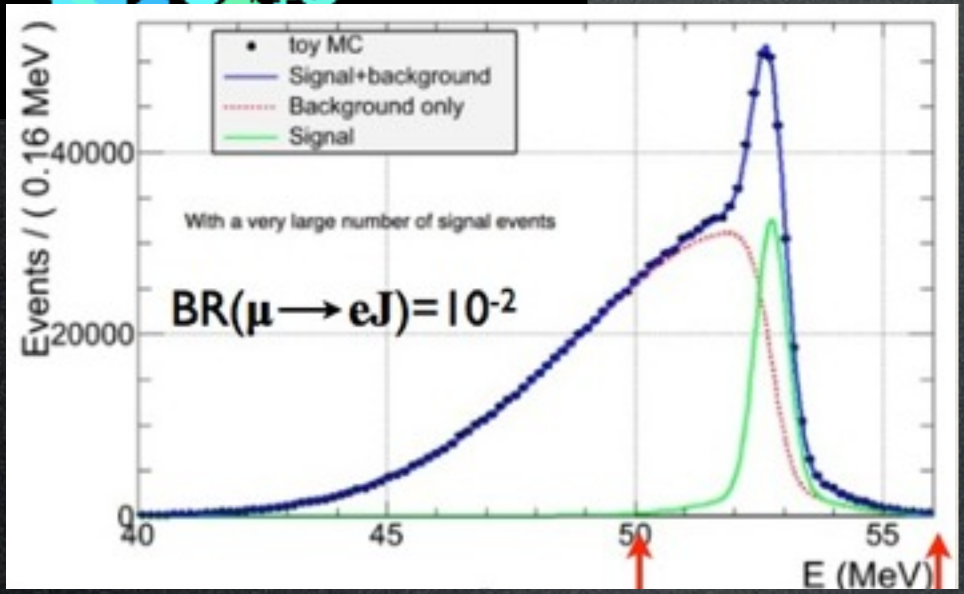
No definition of ‘total’ BR
(infrared divergent)
BR in limited phase space

$\Gamma(e^-\overline{\nu}_e\nu_\mu\gamma)/\Gamma_{total}$ Γ_2/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.014 ±0.004		CRITTENDEN	61	CNTR	γ KE > 10 MeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
	862	BOGART	67	CNTR	γ KE > 14.5 MeV
0.0033±0.0013		CRITTENDEN	61	CNTR	γ KE > 20 MeV
	27	ASHKIN	59	CNTR	

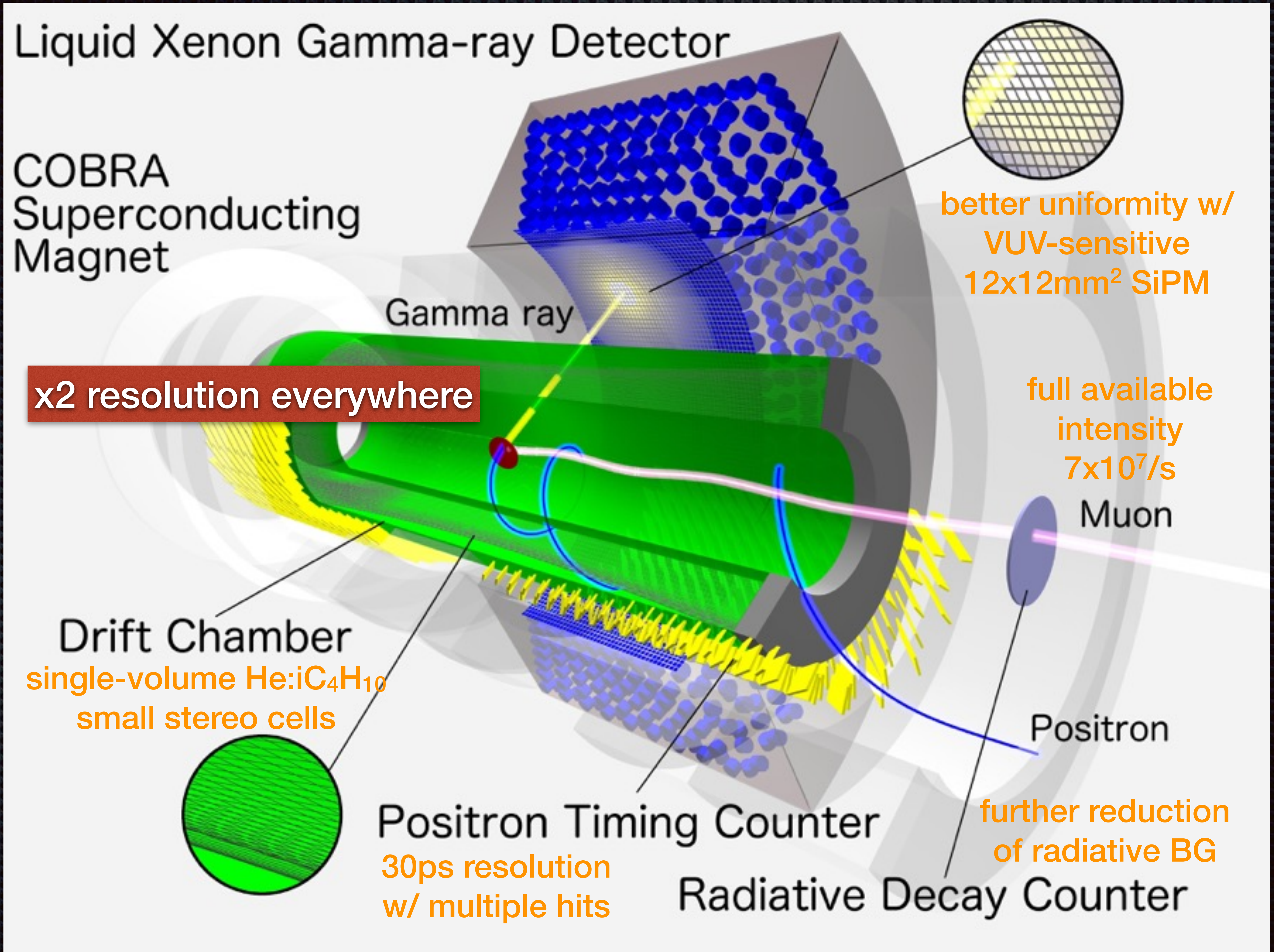
Exotics





- μ→eφ, φ→γγ
  - light, long-lived pseudo scalar
  - first search
  - expected 90% UL 10^{-11}–10^{-10} for 2009+2010 data
- μ→eJ (Majoron)
  - TWIST result (not published) $< 6.7\times10^{-5}$

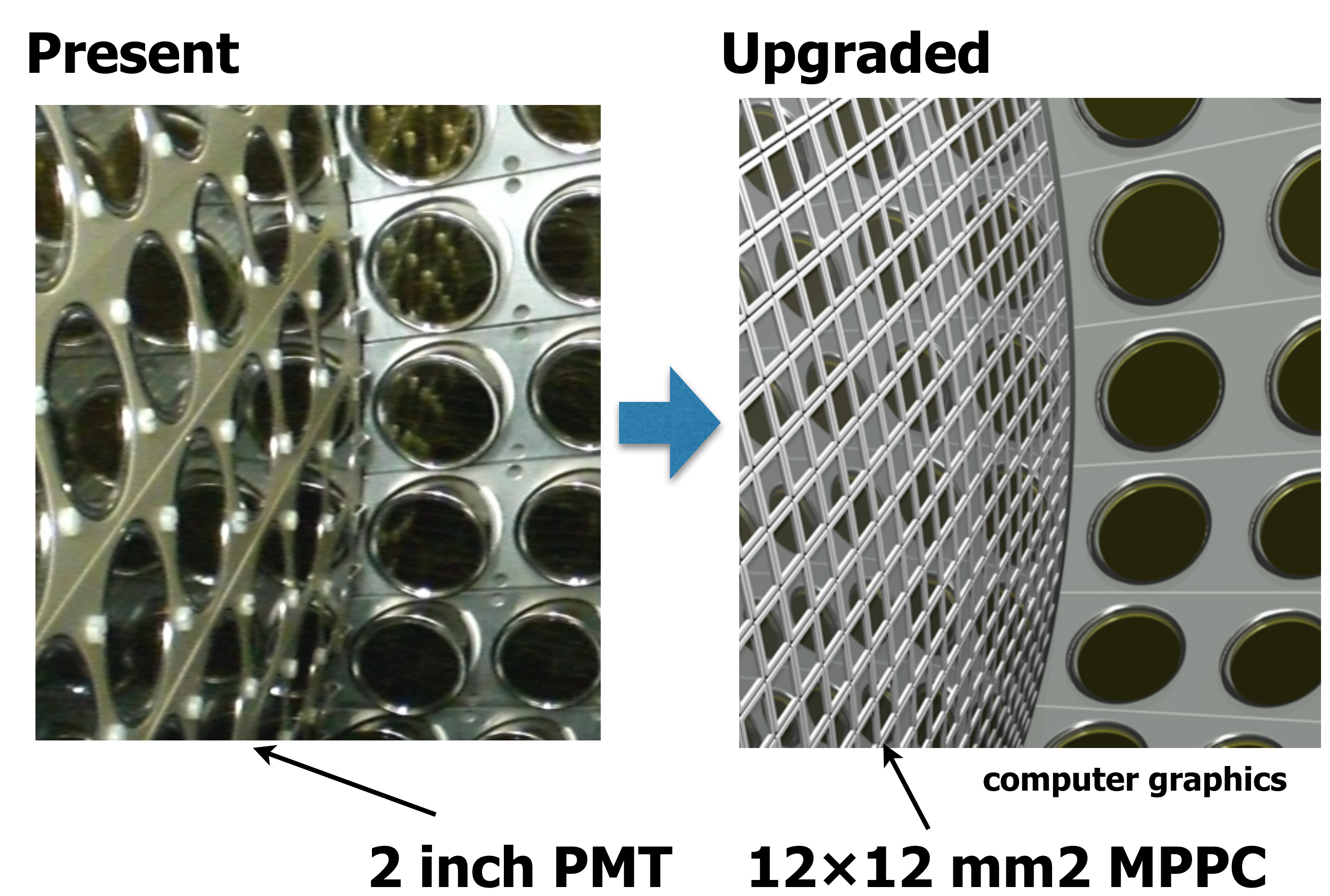
MEG II Experiment



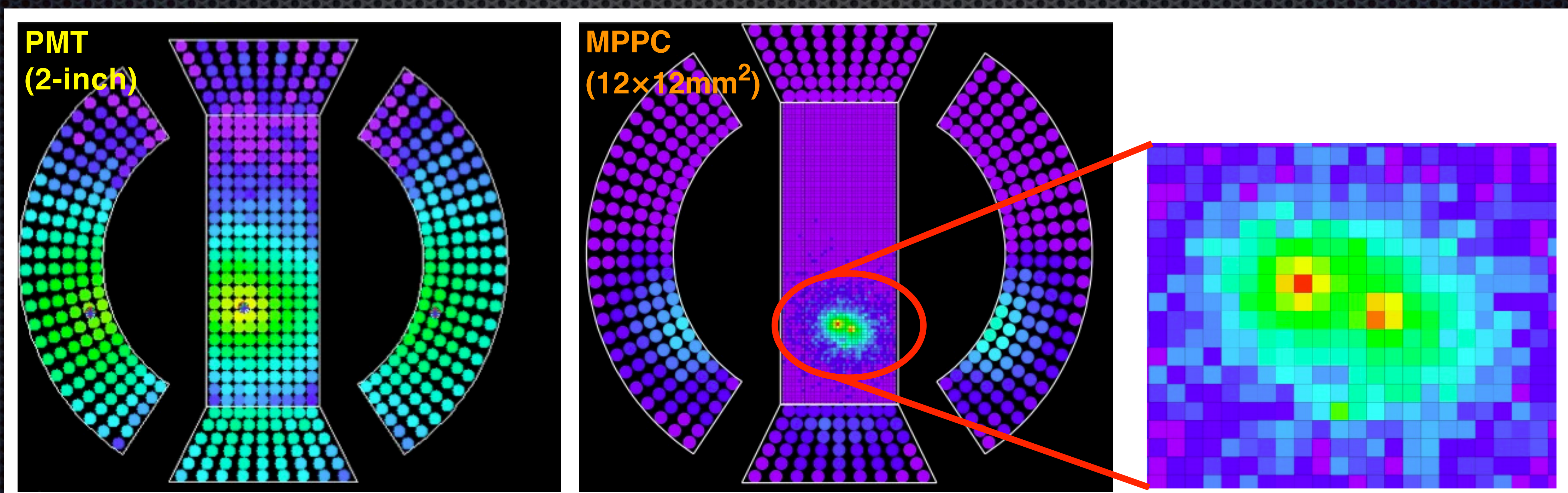
MEG II

- Major upgrade of the experiment for 10 times higher sensitivity.
- Upgrade concept
  - Double beam intensity → **full intensity of available μ beam**
  - Double detector efficiency
  - Factor ~30 background suppression
    - Improved detector resolutions
    - Possibility to add a new detector to identify background events
- Start the new experiment from 2016

LXe Photon Detector



	Present	Upgraded
Energy resolution [%]	2.4 / 1.7	1.1 / 1.0
Position resolution [mm]	5 / 5	2.6 / 2.2
Detection Efficiency	63	69

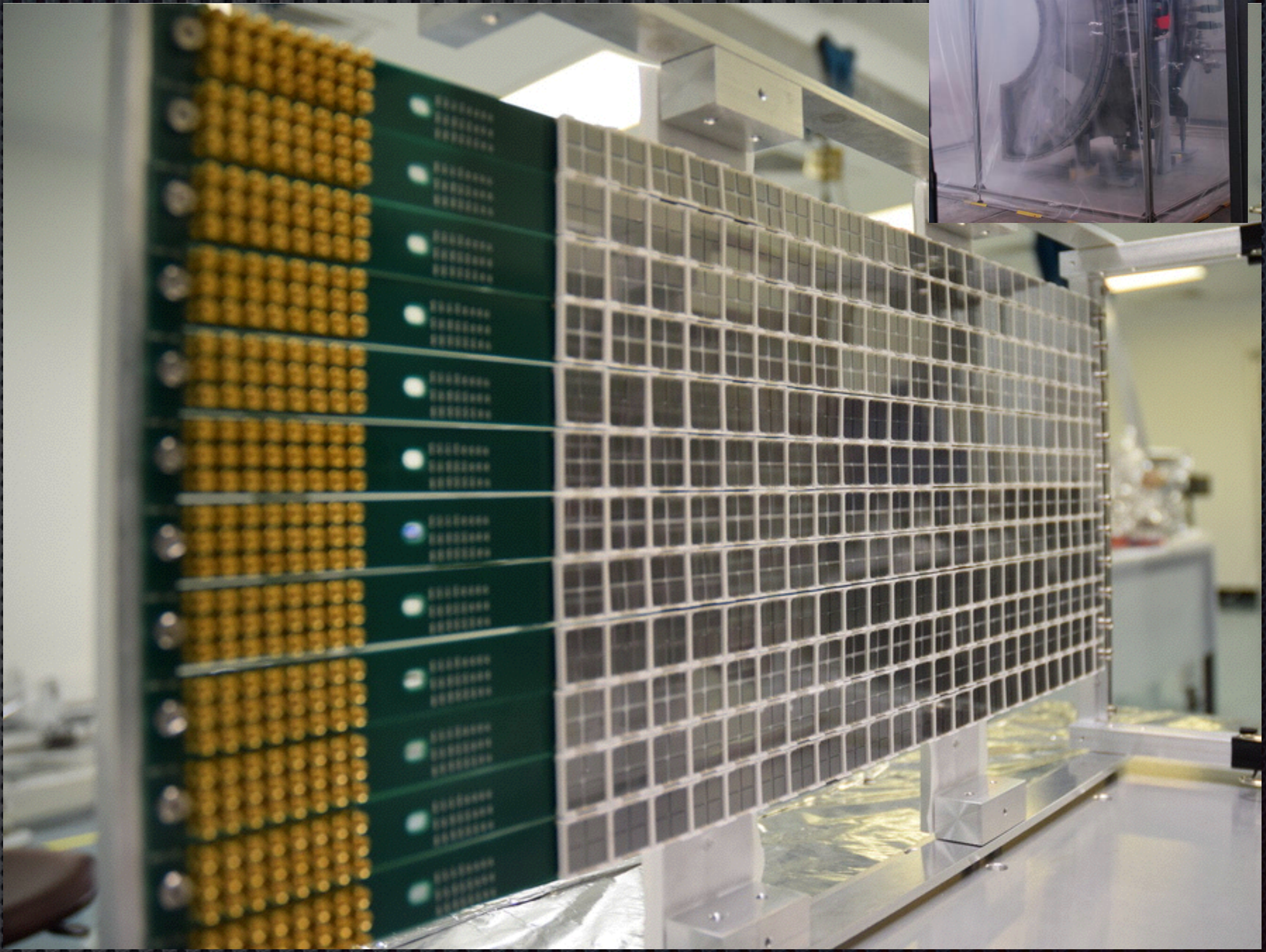


higher uniformity → higher resolutions

LXe Photon Detector

Assembled detector will move to πE5 area at the end of this year

Liquefaction, tests, purification, & calibration will continue at πE5 area until it gets ready by summer 2016

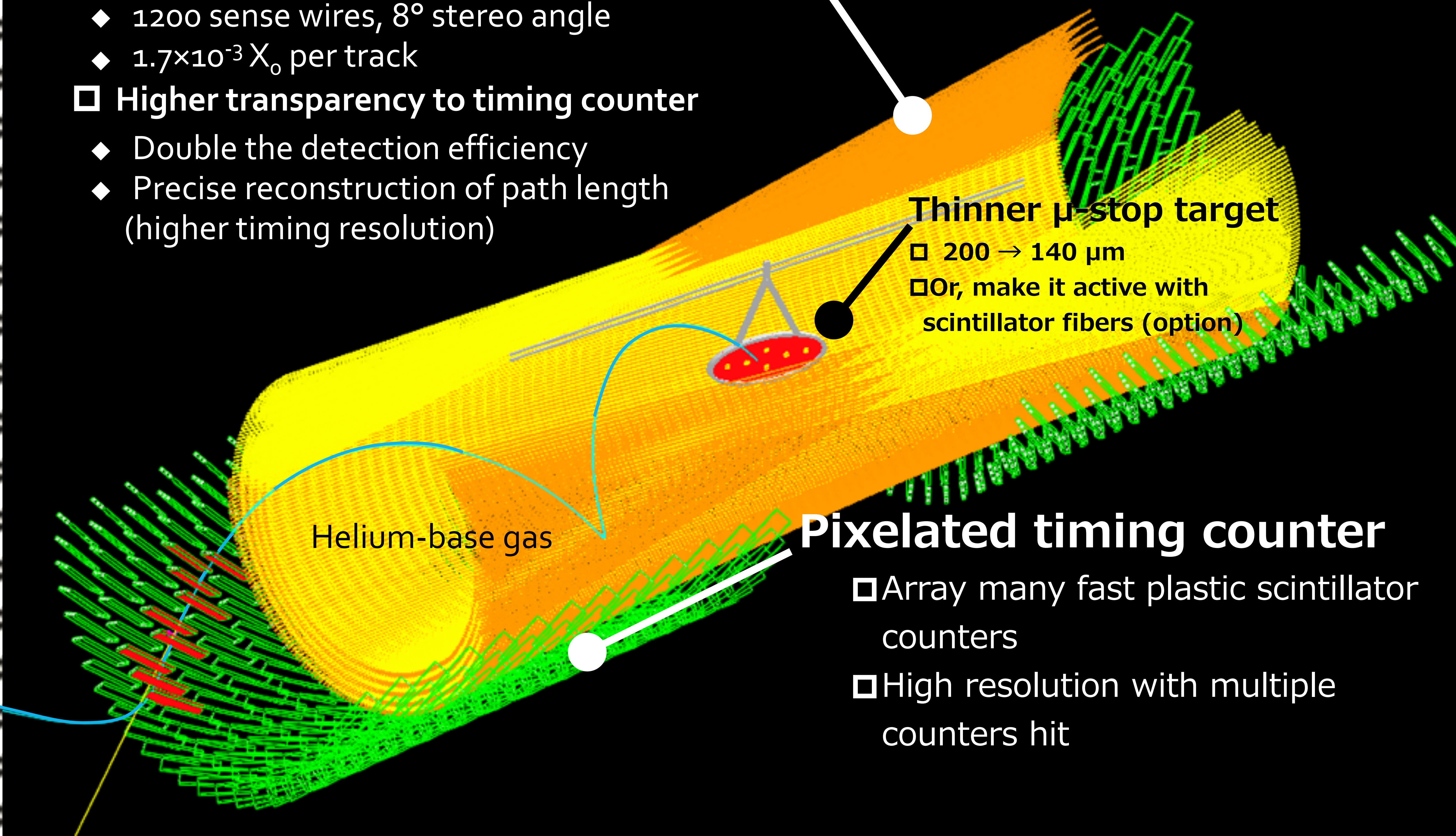


- VUV-sensitive 12x12mm^2 SiPM (MPPC) to test at low temperature inside “large prototype” cryostat

New e^+ Tracker

Single-volume drift chamber

- ☐ **2-m long, stereo wire, low mass chamber**
  - 1200 sense wires, 8° stereo angle
  - $1.7\times10^{-3}\,X_0$ per track
- ☐ **Higher transparency to timing counter**
  - Double the detection efficiency
  - Precise reconstruction of path length (higher timing resolution)



Thinner μ-stop target

- ☐ **200 → 140 μm**
- ☐ **Or, make it active with scintillator fibers (option)**

Pixelated timing counter

- ☐ Array many fast plastic scintillator counters
- ☐ High resolution with multiple counters hit

New e^+ Tracker

Single-volume drift chamber

- **2-m long, stereo wire, low mass chamber**
  - 1200 sense wires, 8° stereo angle
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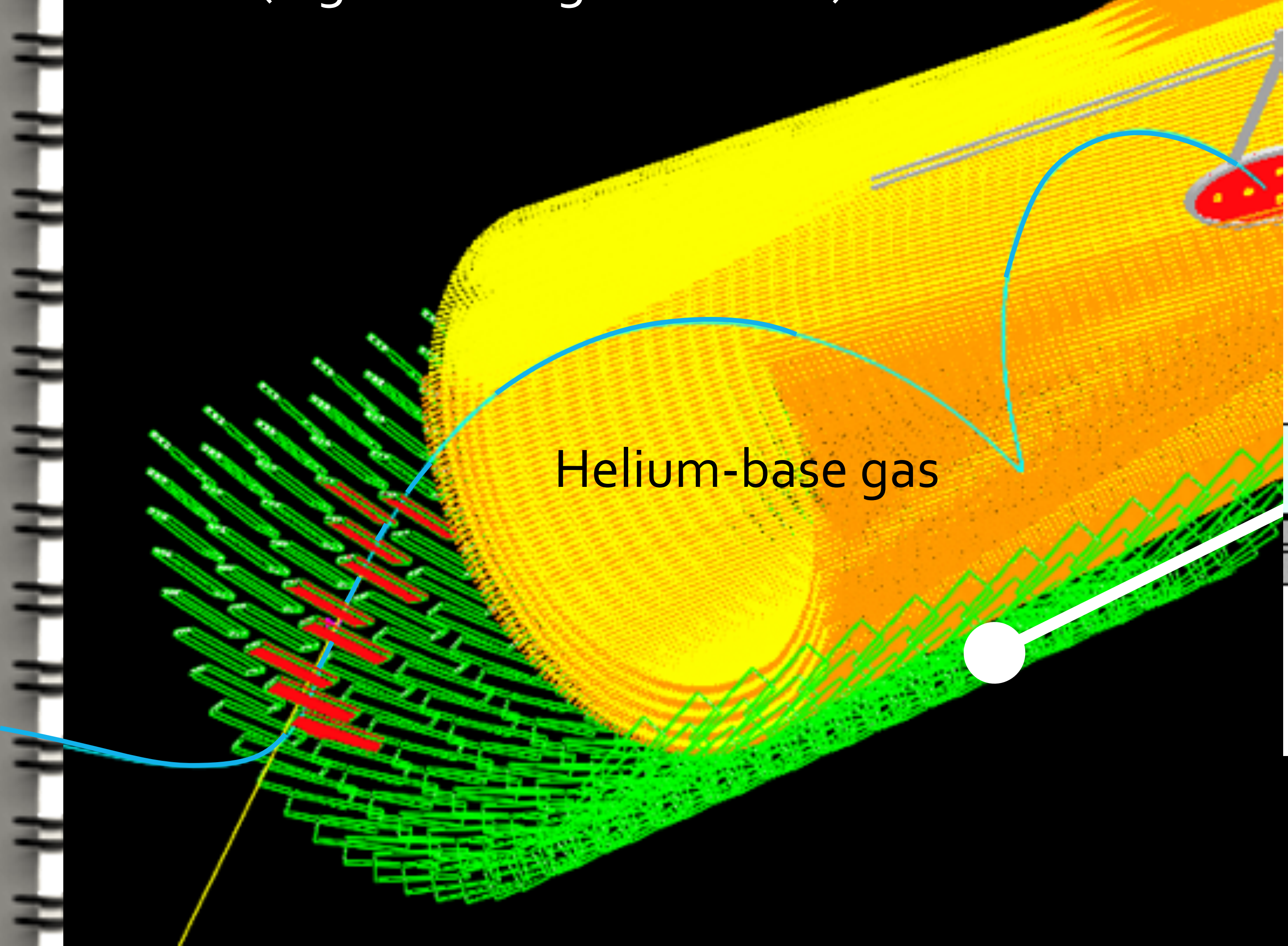
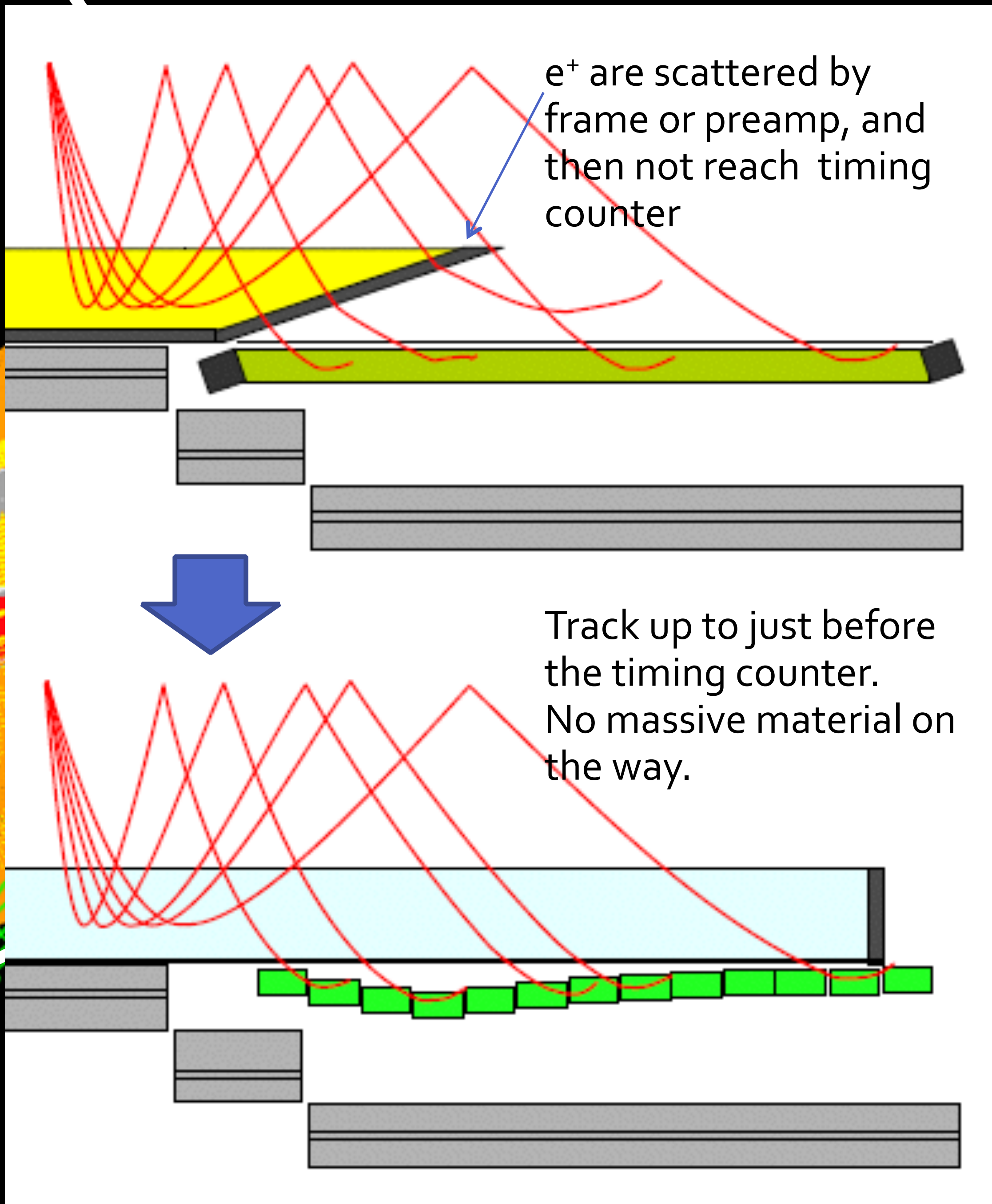




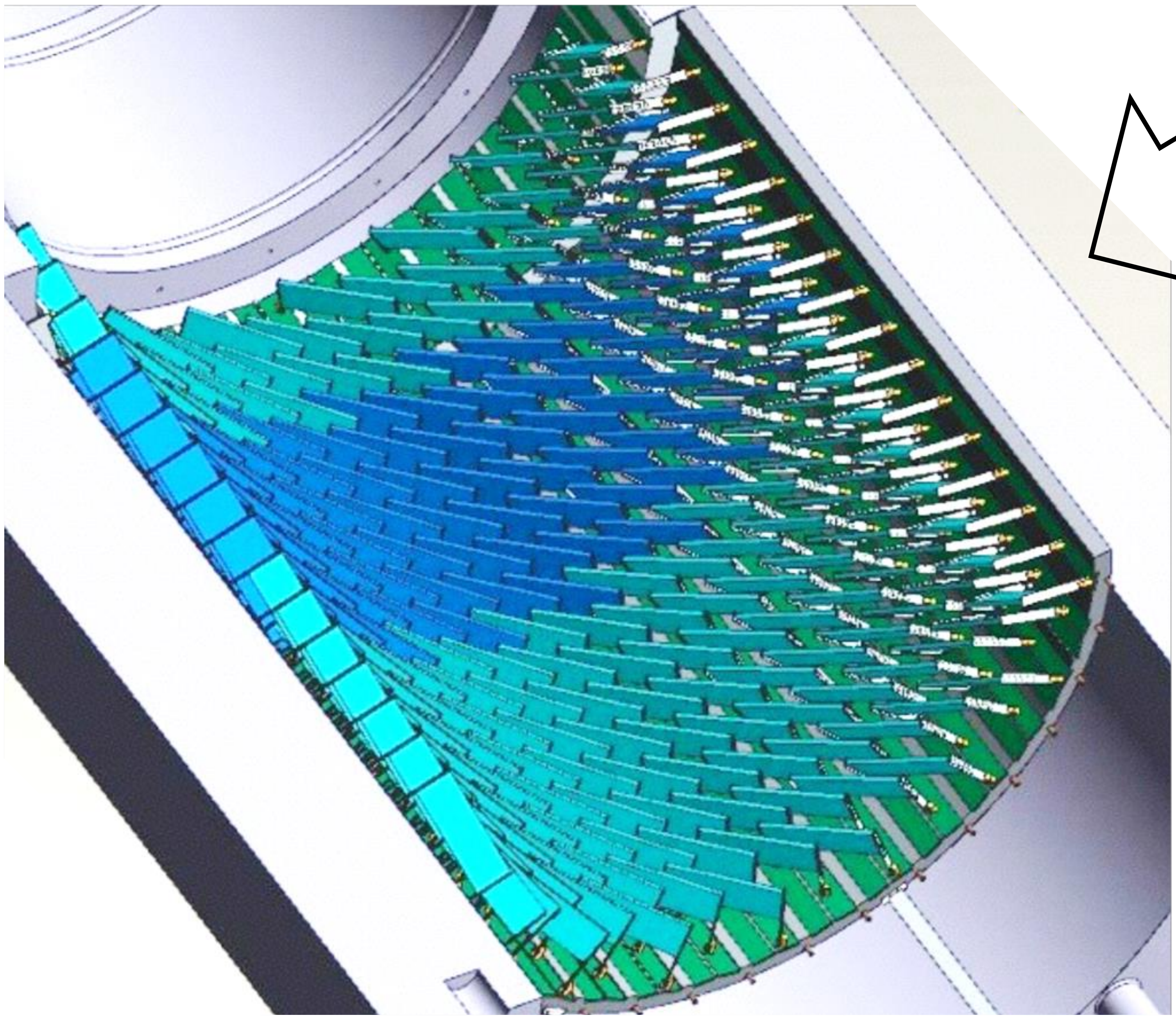
counters hit

Drift Chamber

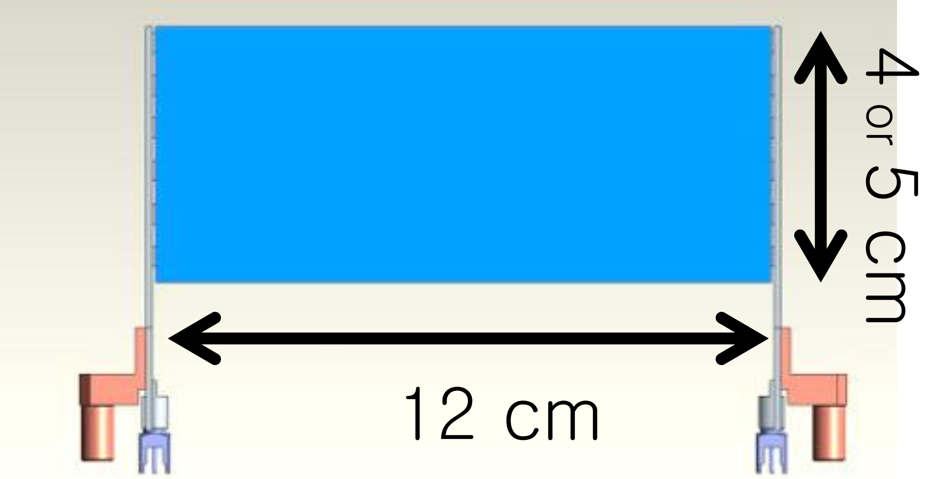
- Successful studies (ageing OK w/ 3 yr operation, single cell 106um resolution, etc) & detailed designs finished
- Construction started: wiring machine, assembly machine, FE electronics, etc
- Partially wired "Mock-up Chamber" w/ HV & gas system delivered to PSI in July for mechanical integration & operational tests

Timing Counter

◆ New TC = pixelated TC

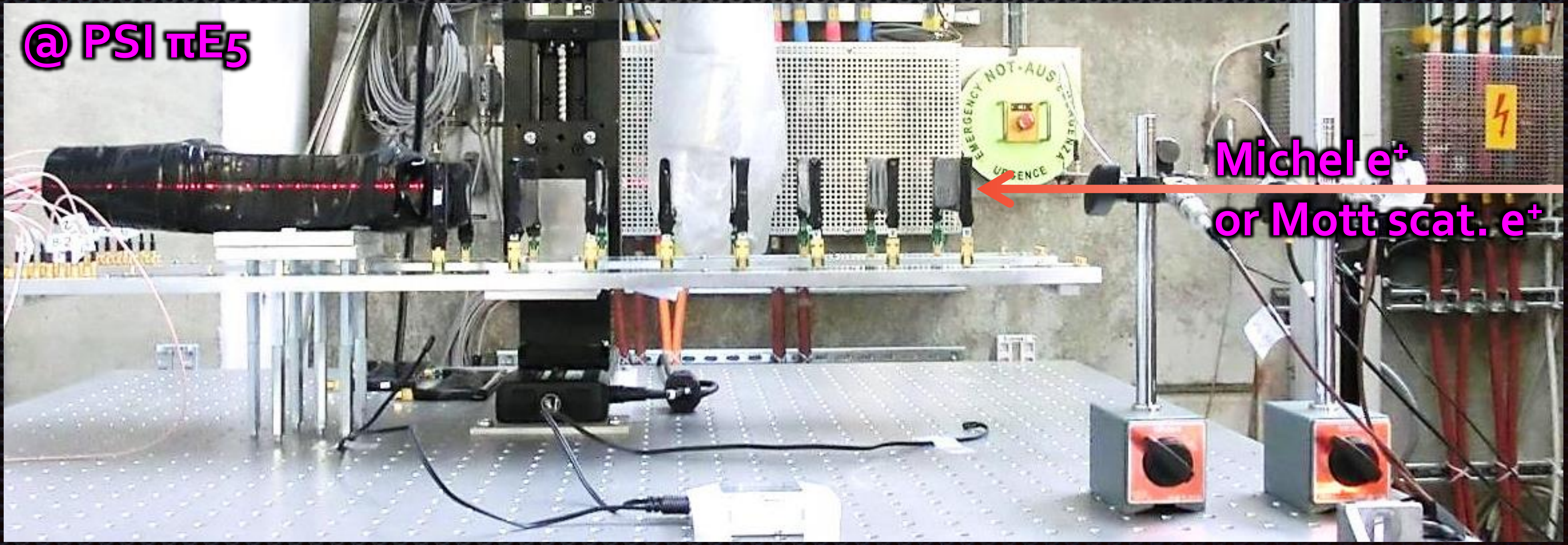


- ☐ 256×2 small counters
- ☐ Readout by SiPMs
- ☐ σ ~ 30 ps with multi-hits



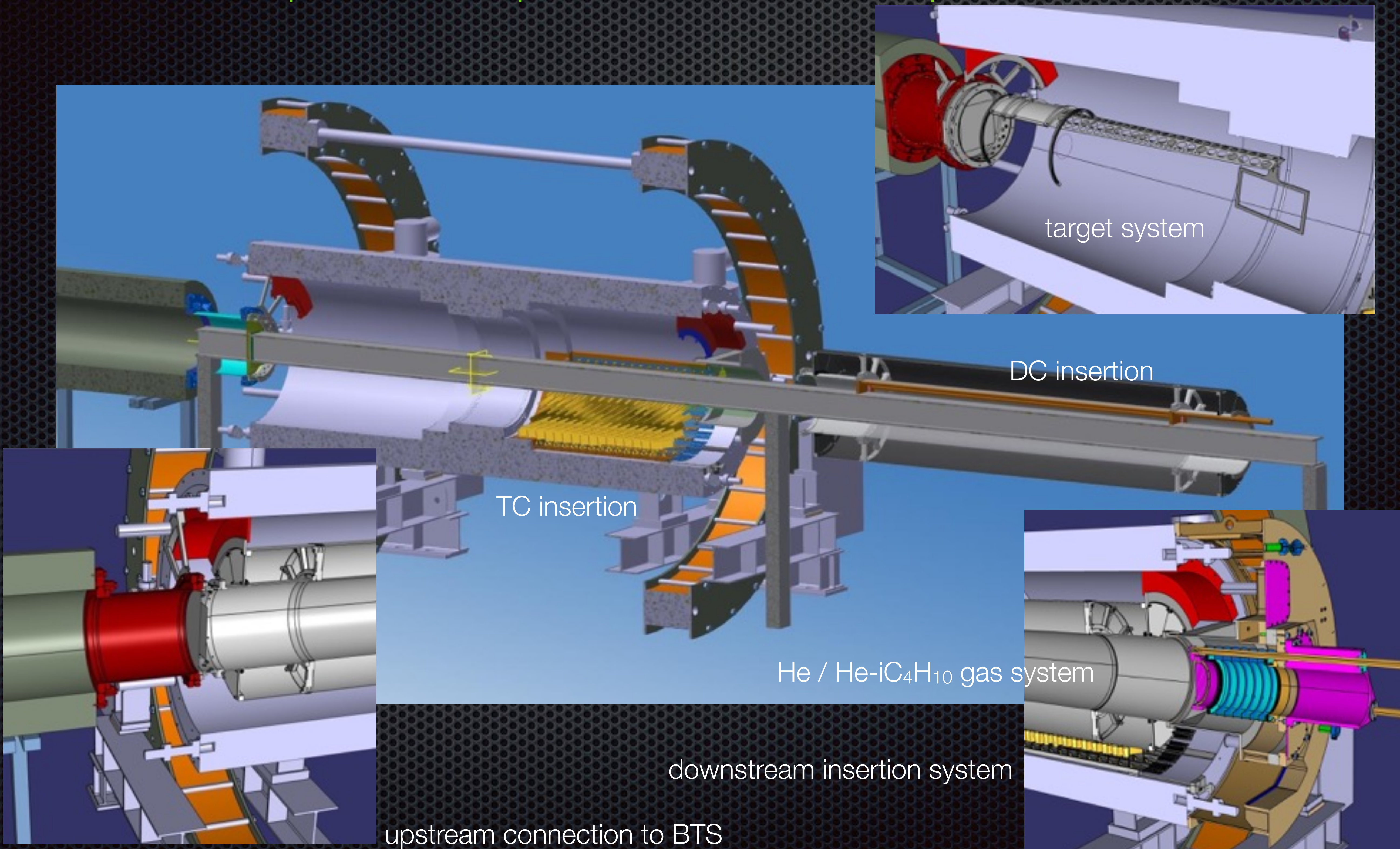
Timing Counter

- ~30psec resolution demonstrated under ~MEG II conditions
- Michel & laser calibration developed very promising
- Downstream TC should be ready @πE5 this autumn
  - various tests (mechanics, electronics, calibration) foreseen
  - Michel decay measurements at end 2015 indispensable



- Mechanical integrity & functionality of MEG II design will be thoroughly checked this year

Indispensable step for successful start-up in 2016

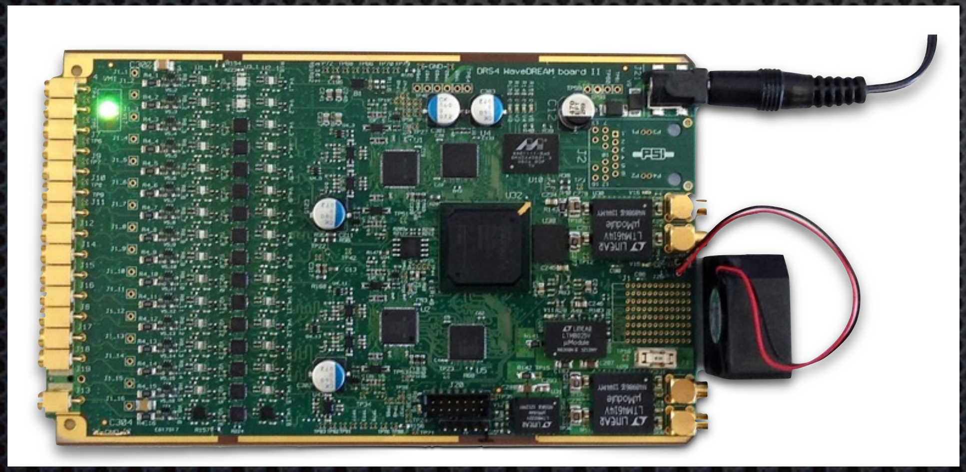


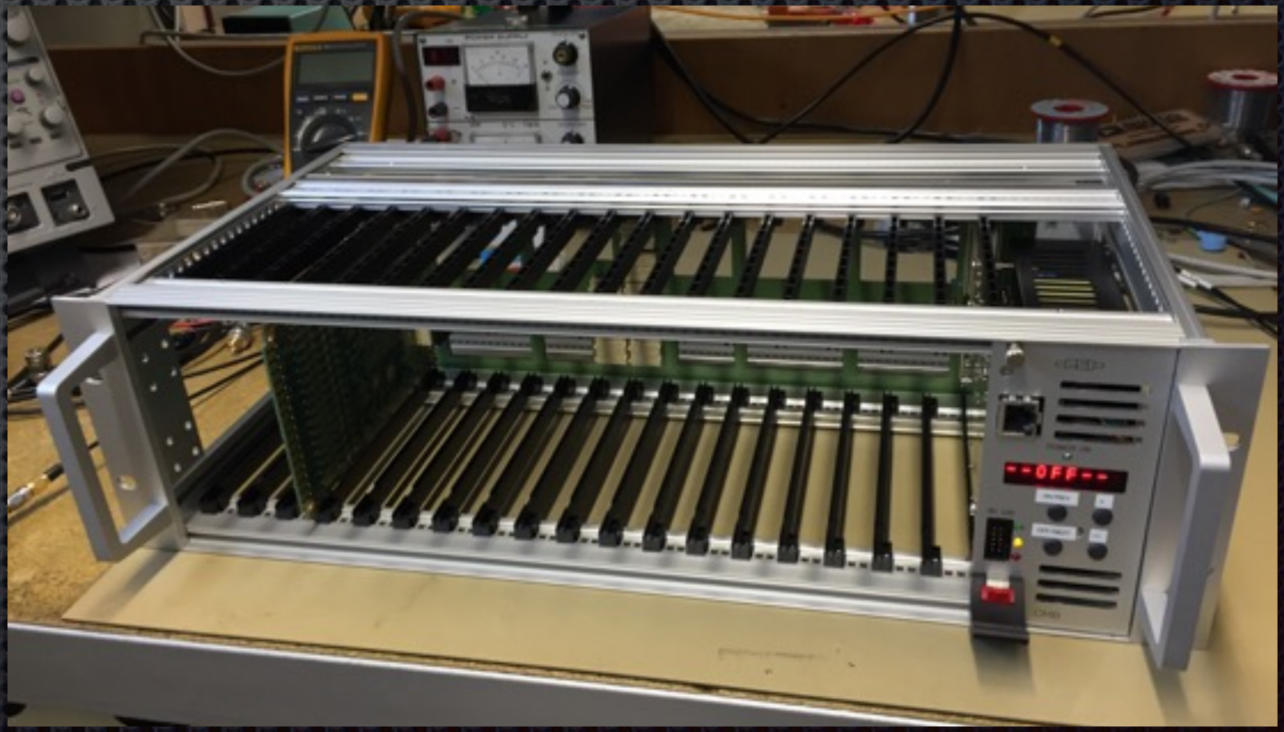
Trigger, DAQ & Computing

- Innovative solution for Trigger+DAQ
  - WaveDREAM Board + Trigger Concentrator Board
  - can handle expected trigger rate of ~30 Hz
  - e^+ track based second level trigger to reduce rate by 2

	MEG	MEG II
beam rate	3x10^7	7x10^7
# channels	~3500	~10000
DAQ rate	10 Hz	30 Hz*
DAQ eff	>95%	>95%

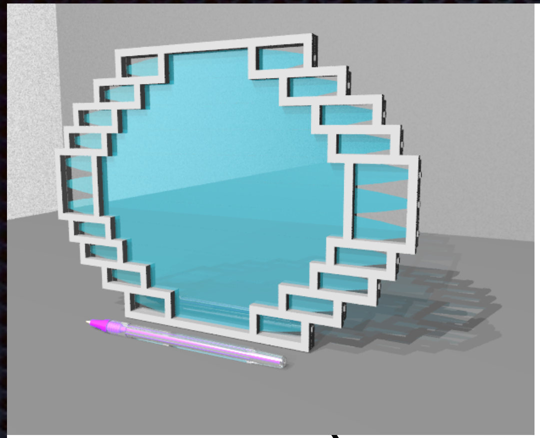
- "Software Trigger" consisting of multiple PCs under consideration to reduce data volume
- A single full crate (256 channels) available in Sep-Oct for pre-engineering run
- Complete system will be ready at the beginning of 2016

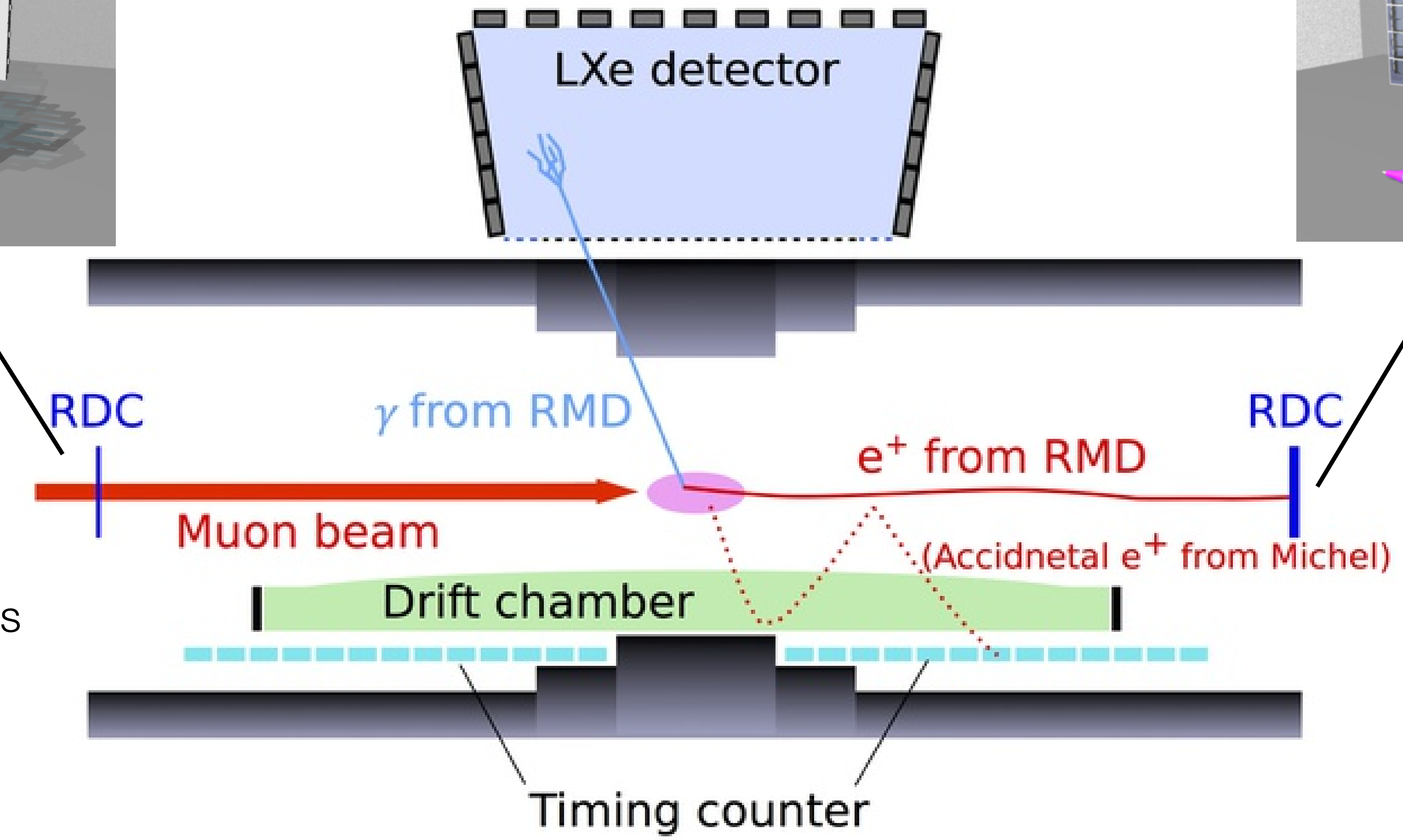


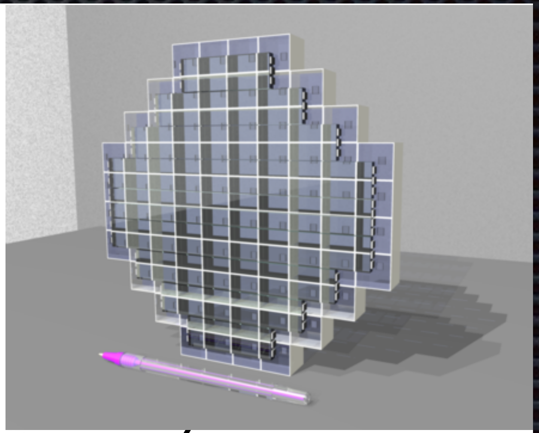


Optional Detectors

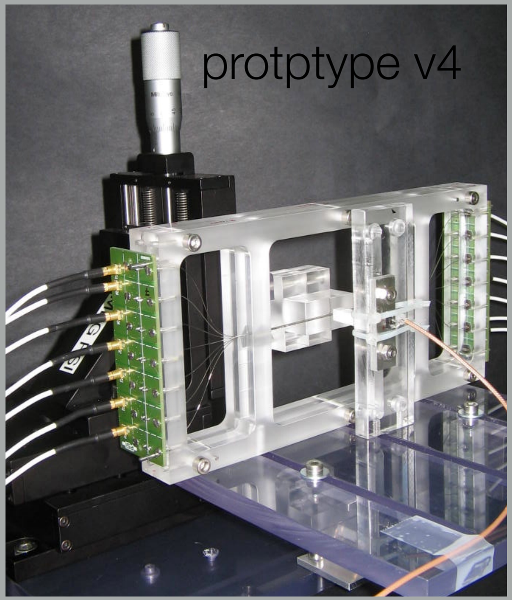
Radiative Decay Counter (RDC)



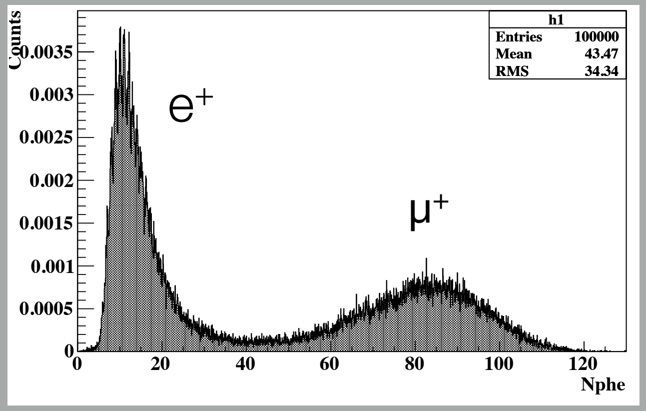




- effects on stopping muons needs to be checked
- pileup study



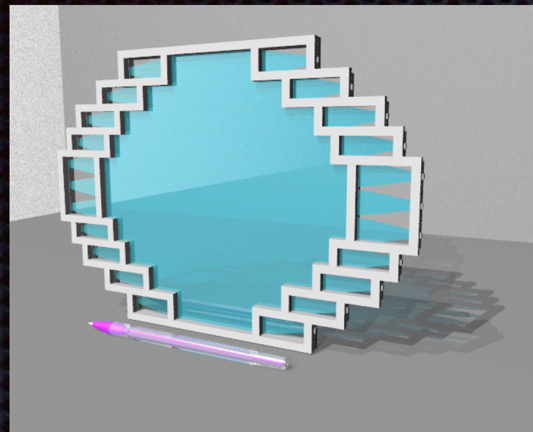
Active Target (ATAR)

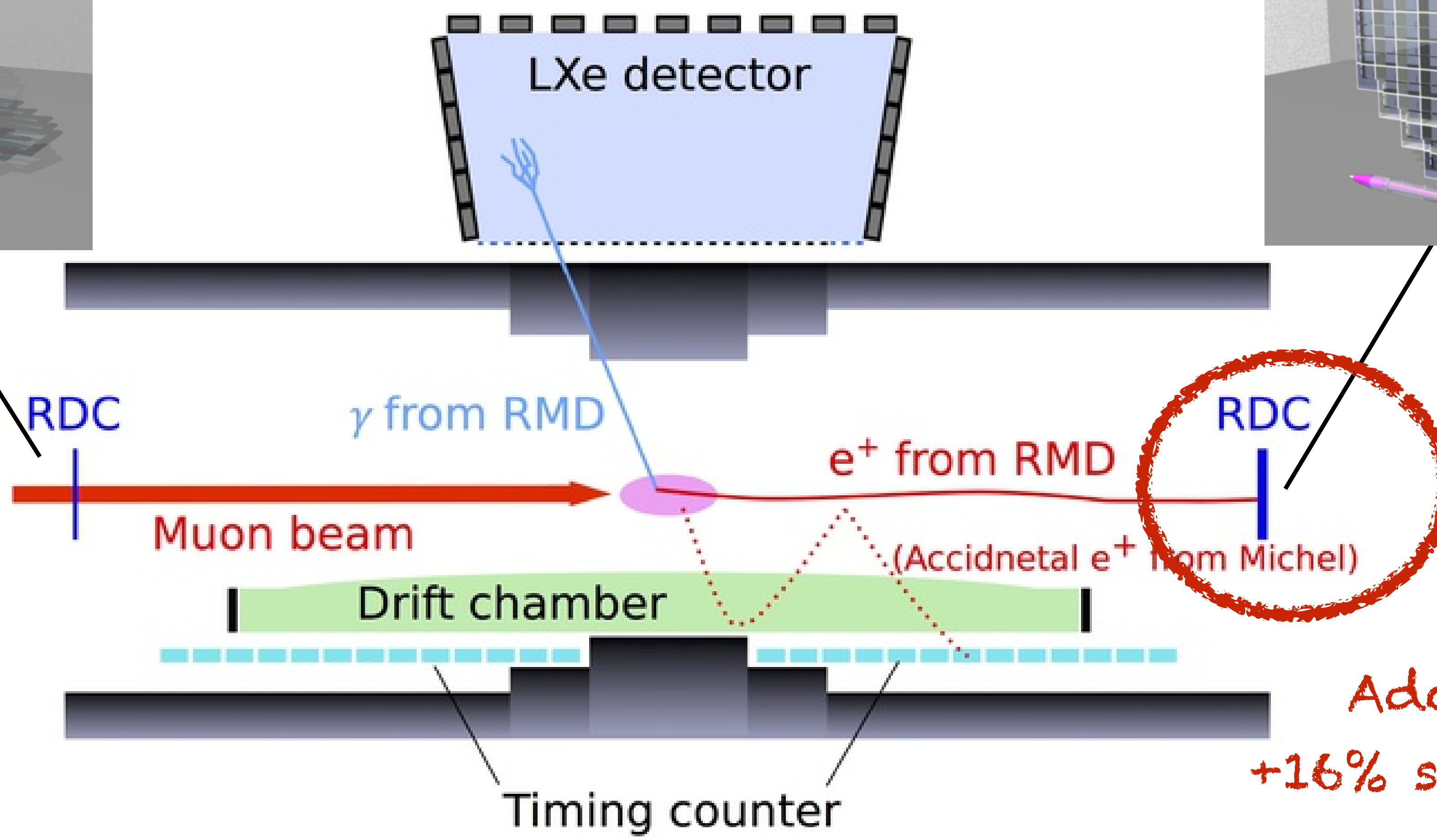


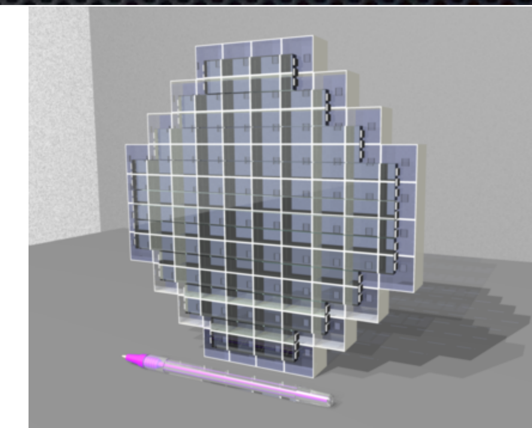
- single-layer 250um fibers
- successful R&D
- risks for higher background
- mechanical issues
- useful for beam tuning
- technology for upstream RDC

Optional Detectors

Radiative Decay Counter (RDC)







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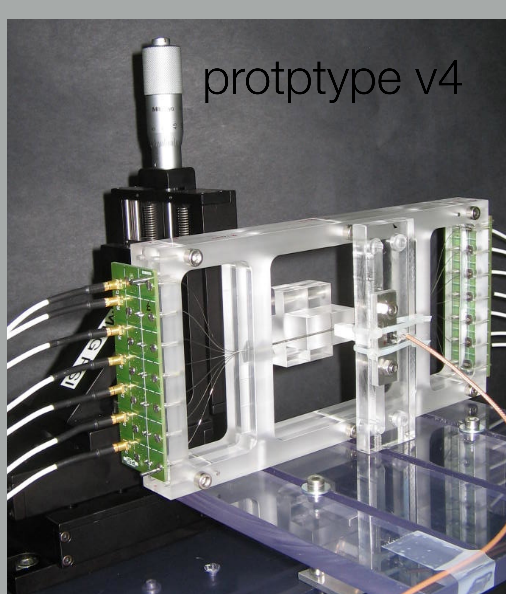

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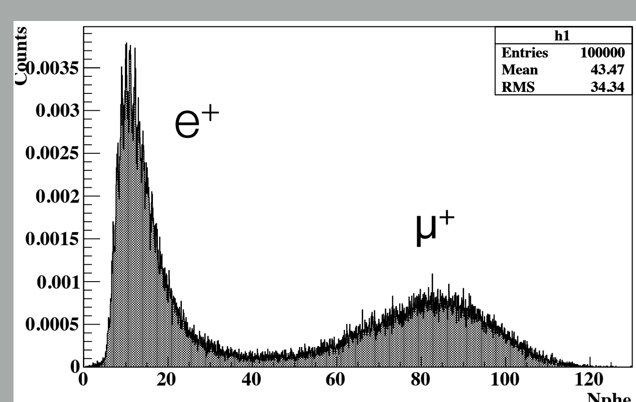
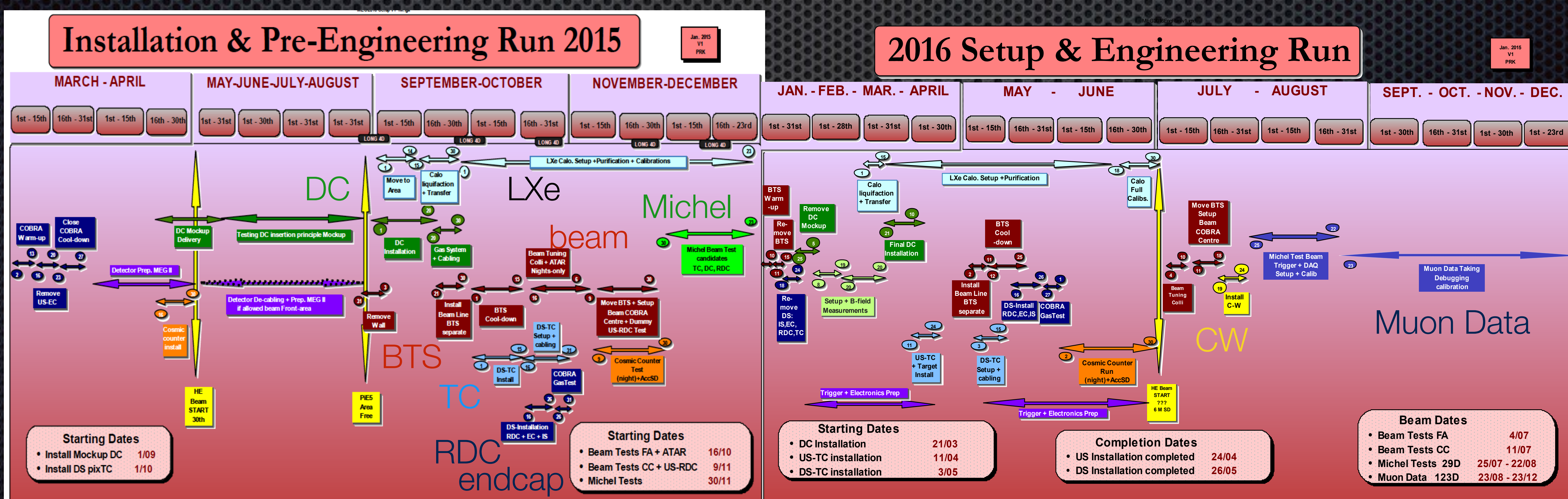


- single-layer 250um fibers
- successful R&D
- risks for higher background
- mechanical issues
- useful for beam tuning
- technology for upstream RDC

Schedule towards MEG II Run

- Pre-Engineering Run in 2015 & Engineering Run followed by ~120 day Data Taking Run in 2016
    - Pre-Engineering Run in 2015 will allow to test mechanical integrity, fully optimize beam with new target + degrader, and test particularly downstream TC w/ Michel e$^+$s



Pre-Engineering Run

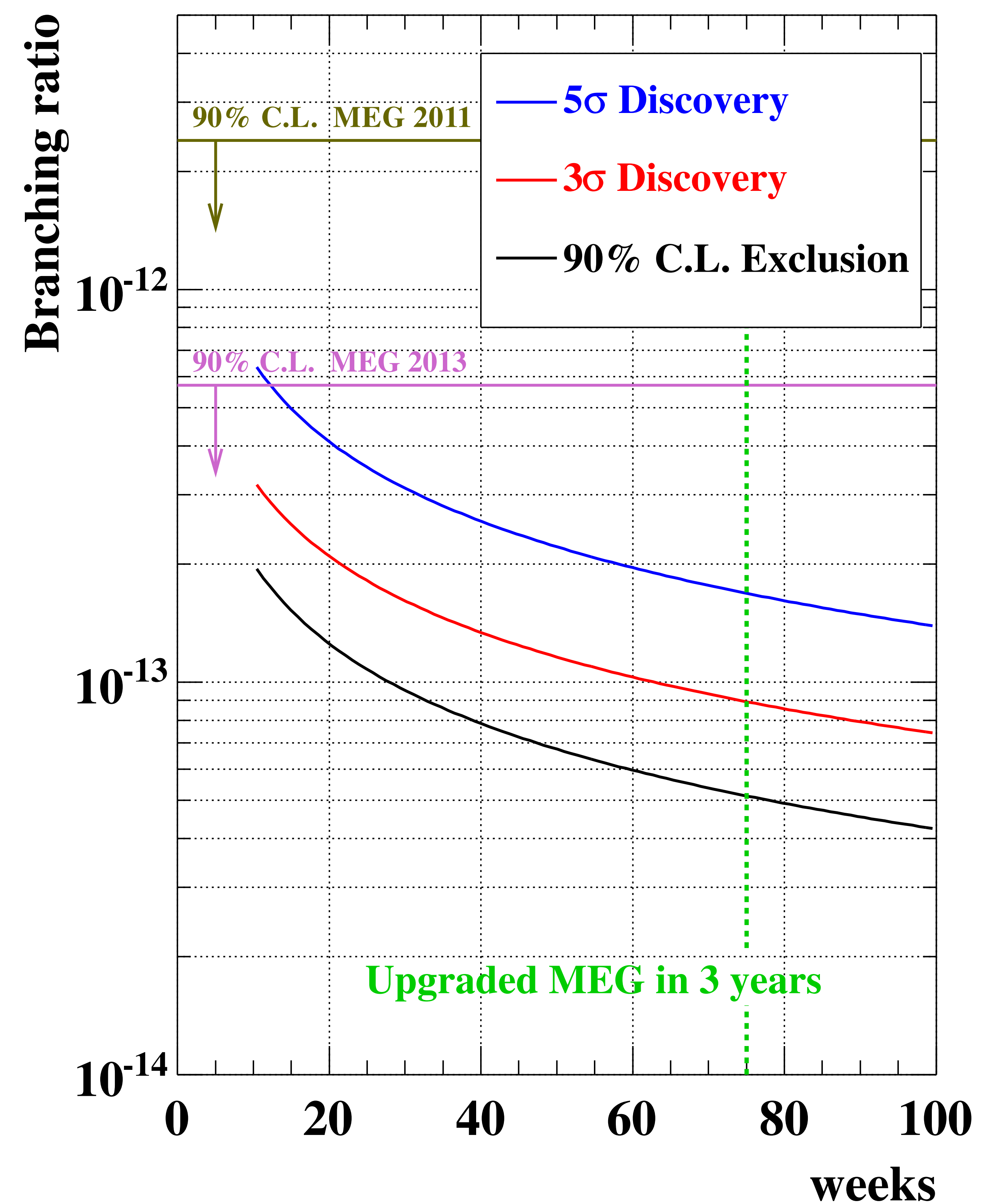
Engineering & Data Run

Expected performance and sensitivity

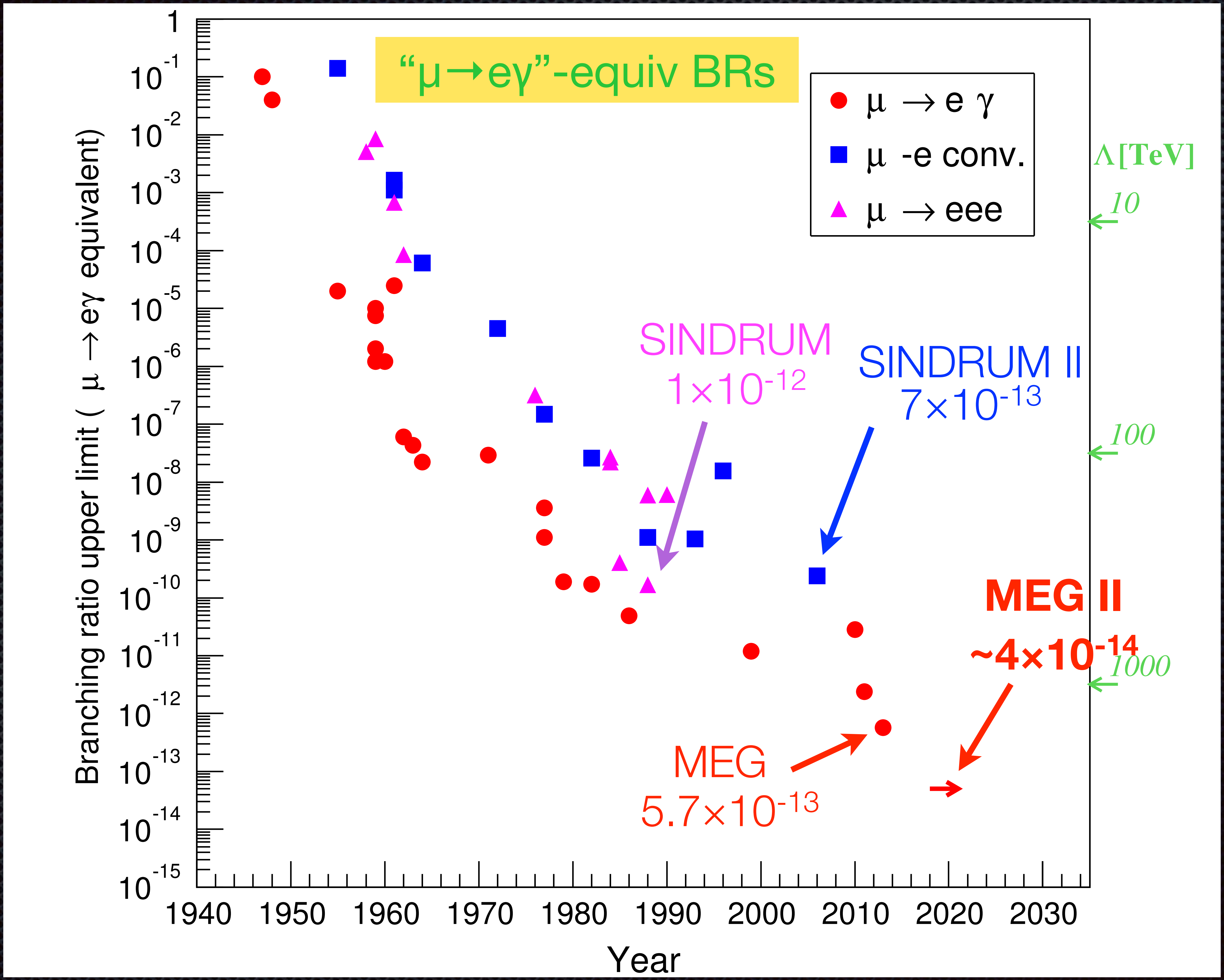
Resolution (Gaussian σ) and efficiencies for MEG upgrade

PDF parameters	Present MEG	Upgrade scenario
$\sigma_{E_{e^+}}$ (keV)	380	110
e^+ σ_θ (mrad)	9	5
e^+ σ_ϕ (mrad)	11	5
e^+ σ_Z / σ_Y(core) (mm)	2.0/1.0	1.2/0.7
$\frac{\sigma_{E_\gamma}}{E_\gamma}$ (%) w>2 cm	1.6	1.0
γ position at LXe $\sigma_{(u,v)}$-σ_w (mm)	4	2
γ-e^+ timing (ps)	120	80
Efficiency (%)		
trigger	≈ 99	≈ 99
γ reconstruction	60	60
e^+ reconstruction	40	95
event selection	80	85

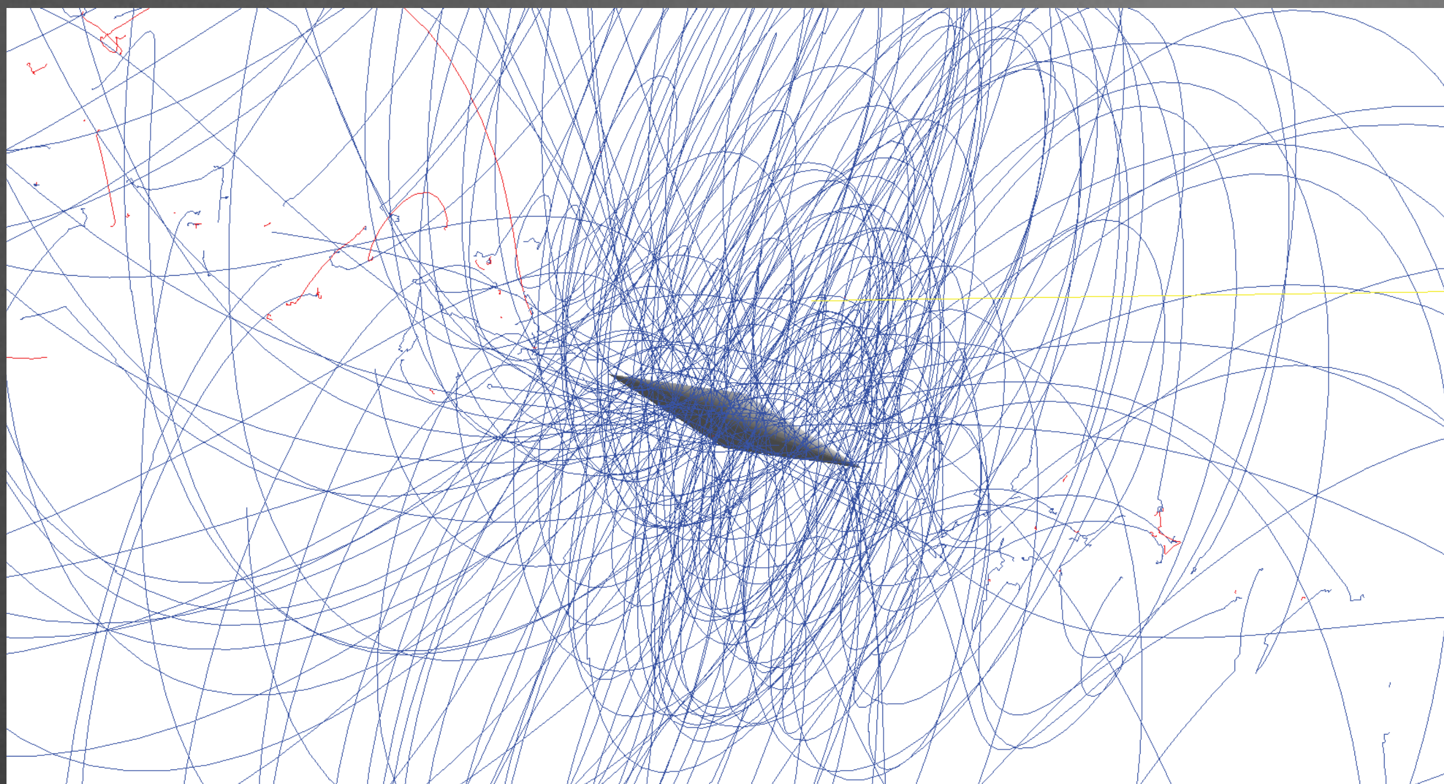
Sensitivity prospect

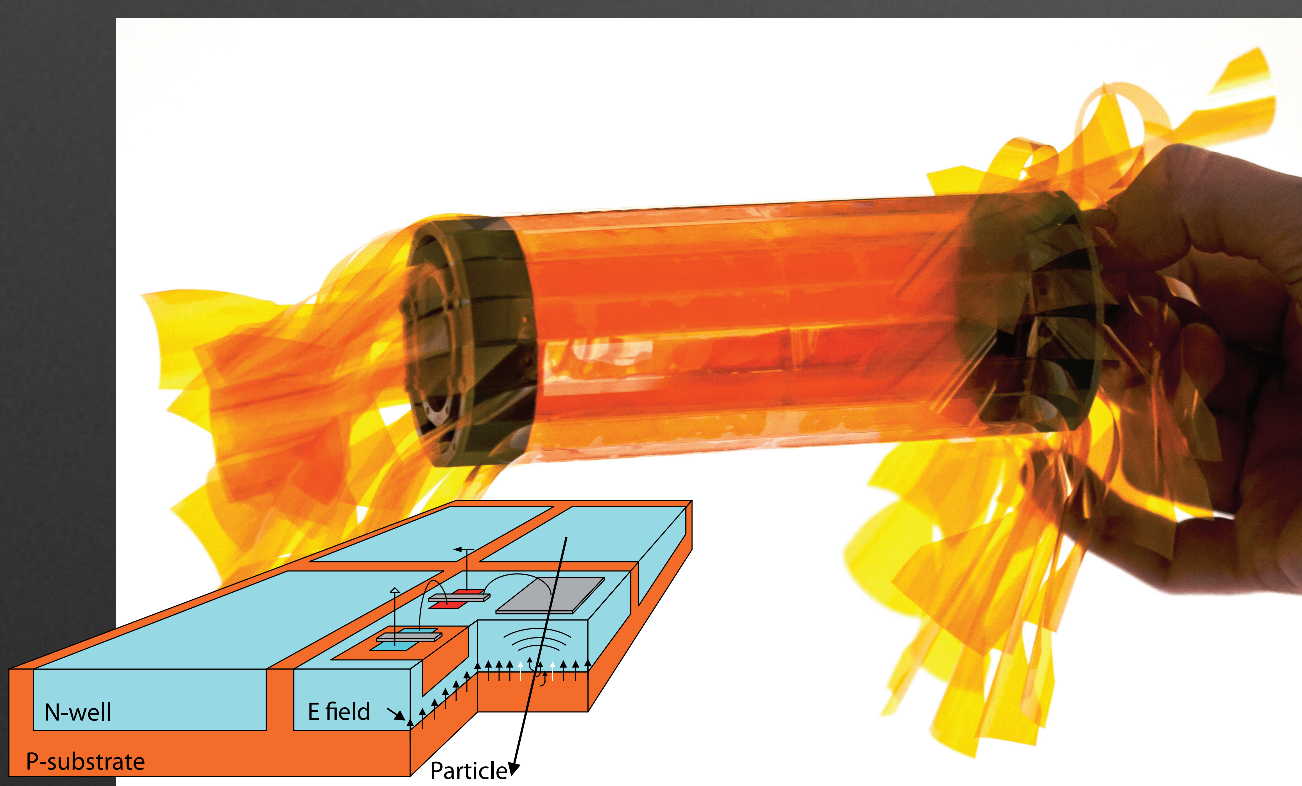


where MEG II will reach



Mu3e - Enabling Technology

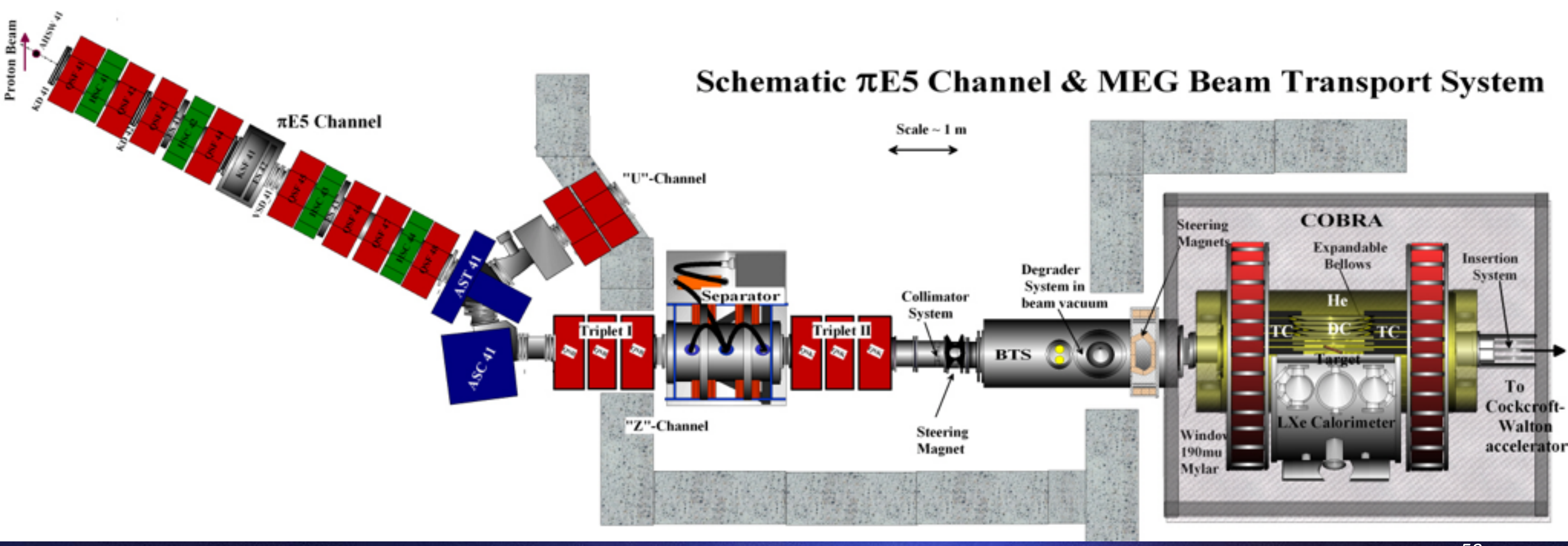




- No experiment since ~a quarter century
- Precision reconstruction of 3-body decay $\mu \rightarrow 3e$ in high rate environment of 2×10^9 muons/sec sounds daunting.
- Scattering & E loss dominate — Minimum material required for O(10 MeV) tracking.
- HV-MAPS: < 50μm possible, Advanced R&D underway

PiE5 Layout Scheme for MEG & Mu3e

- Both Experiments "MEG II" & "Mu3e Phase I" need to share PiE5
- Mu3e has similar beam requirements to MEG II $\mathcal{O}(10^8)$ μ^+/s , 28 MeV/c - ONLY πE5 possible!!!
- Solution ➔ Mu3e "Compact Muon Beam Line" Ultra-compact beam line - Allowing both experiments to **CO-EXIST** with minimal switch-over & without compromising the physics goals



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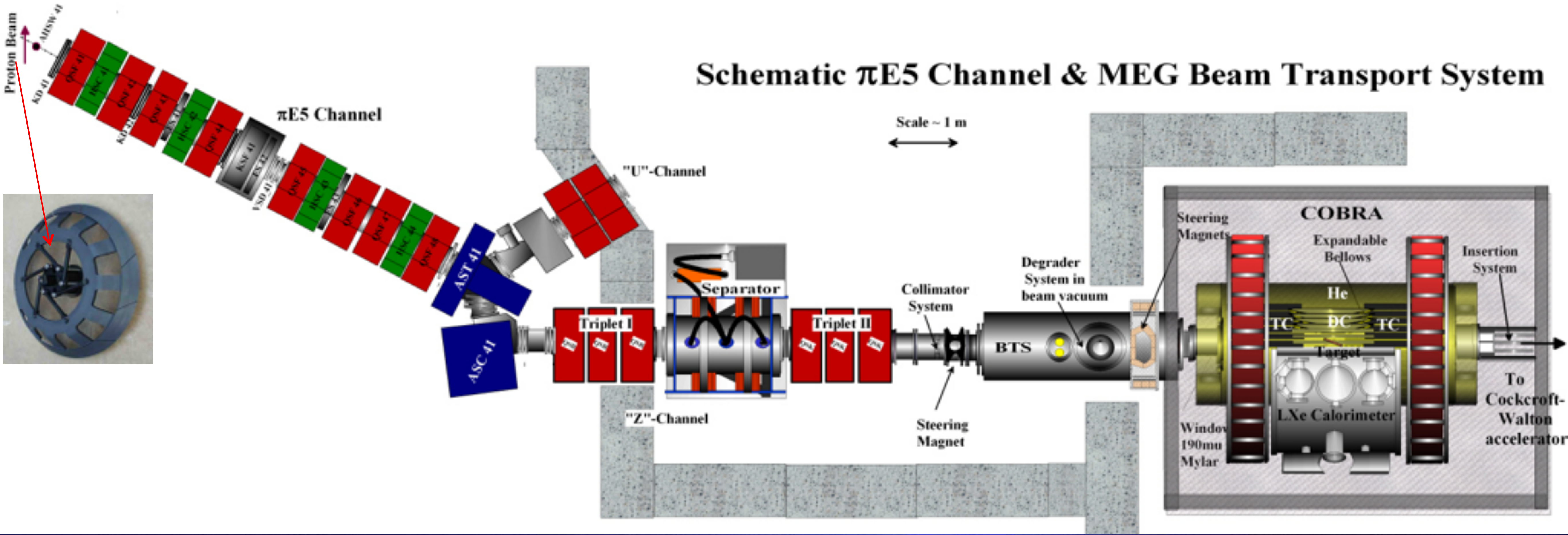
- Solution → Mu3e "Compact Muon Beam Line" Ultra-compact beam line - Allowing both experiments to **CO-EXIST** with minimal switch-over & without compromising the physics goals



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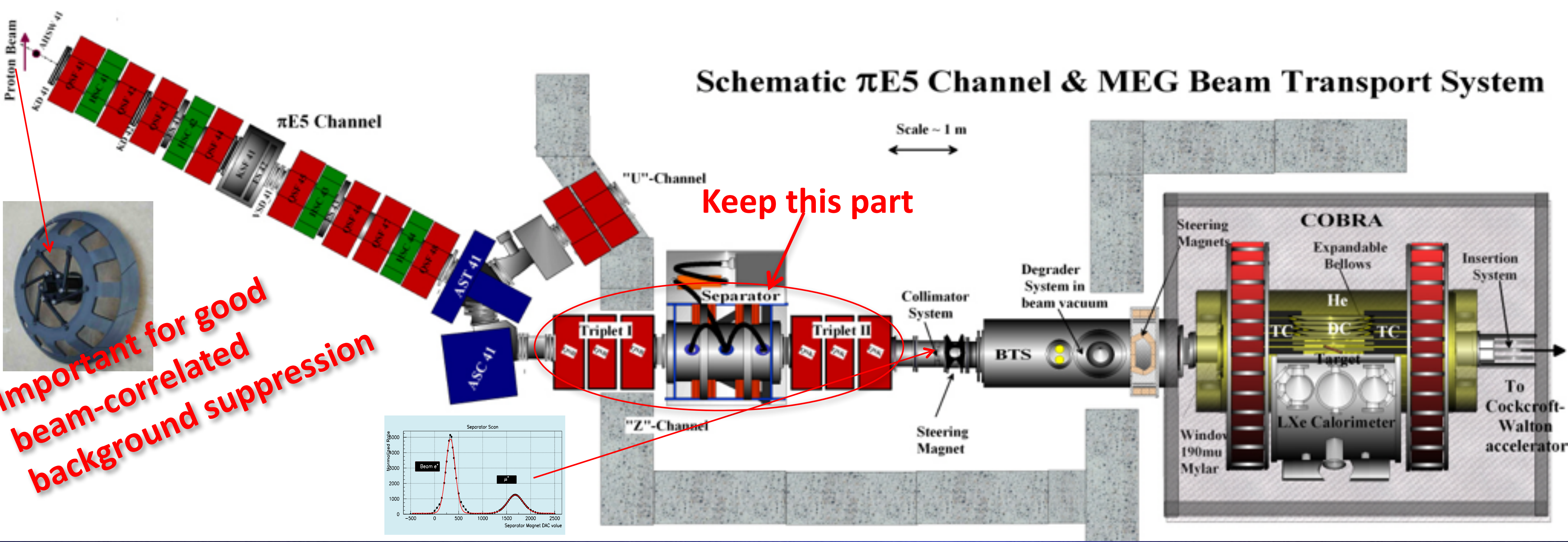

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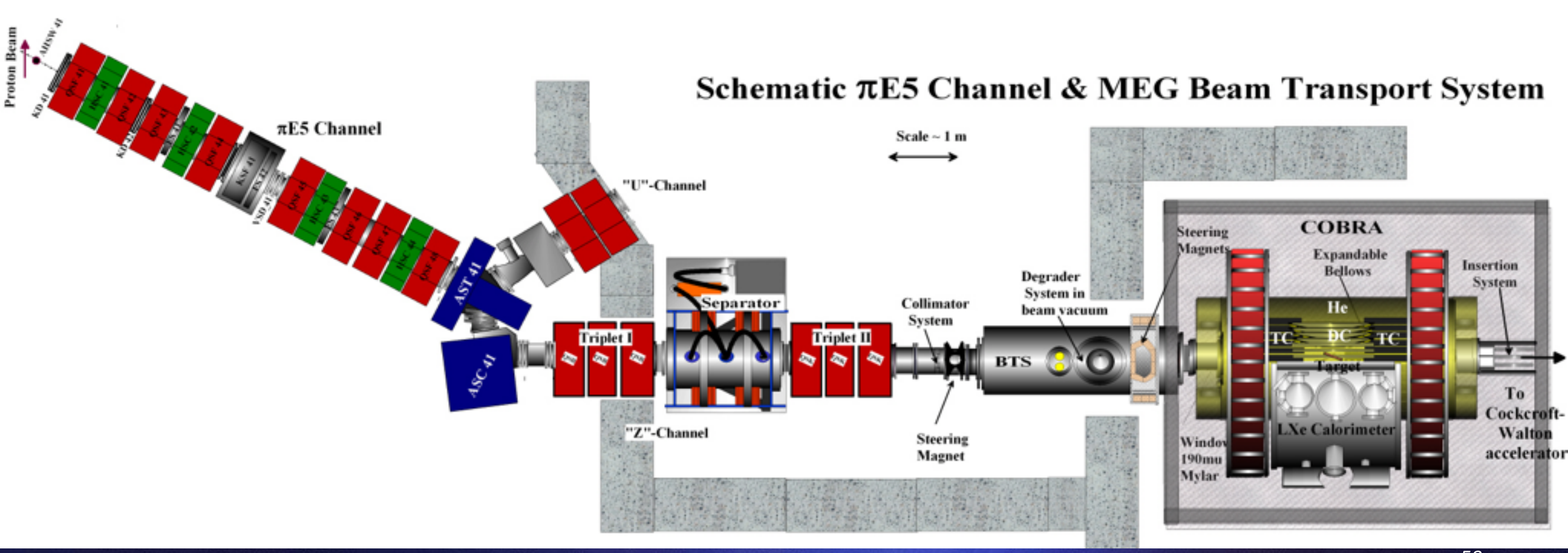

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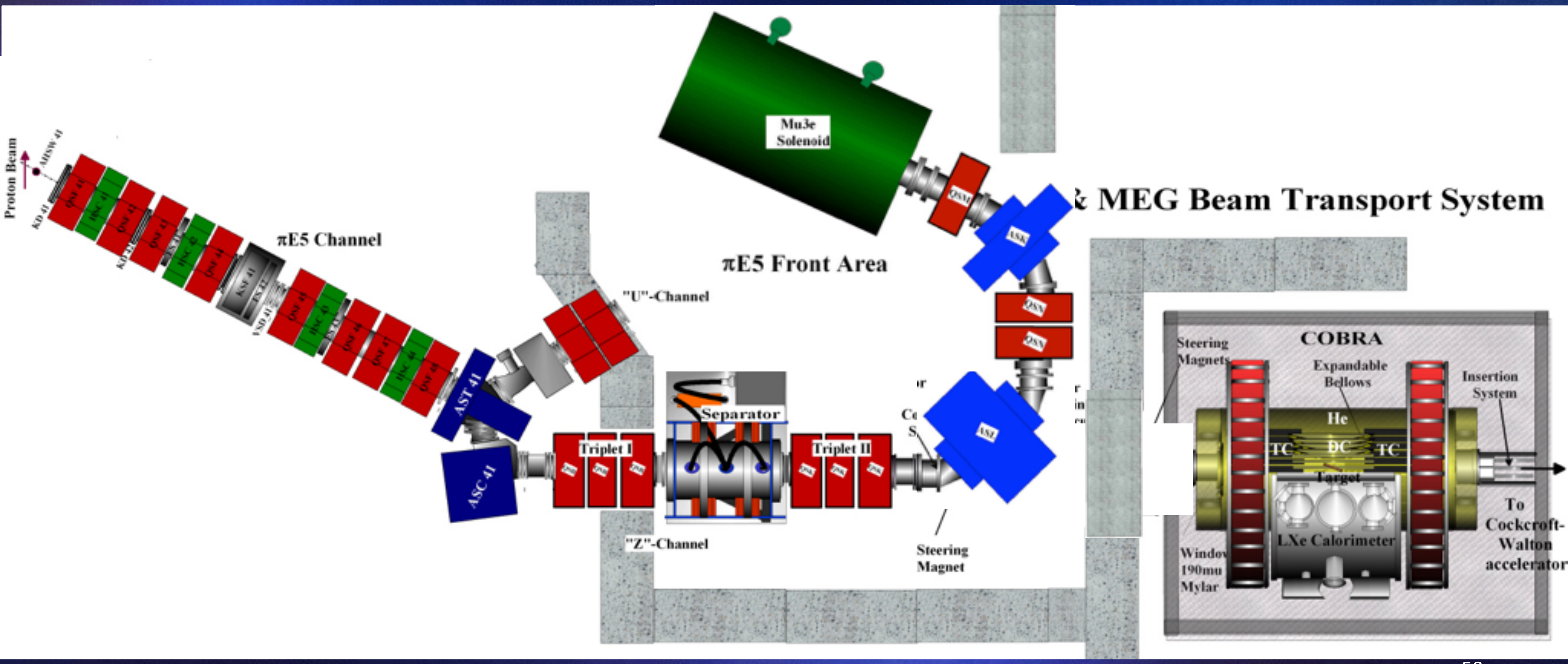

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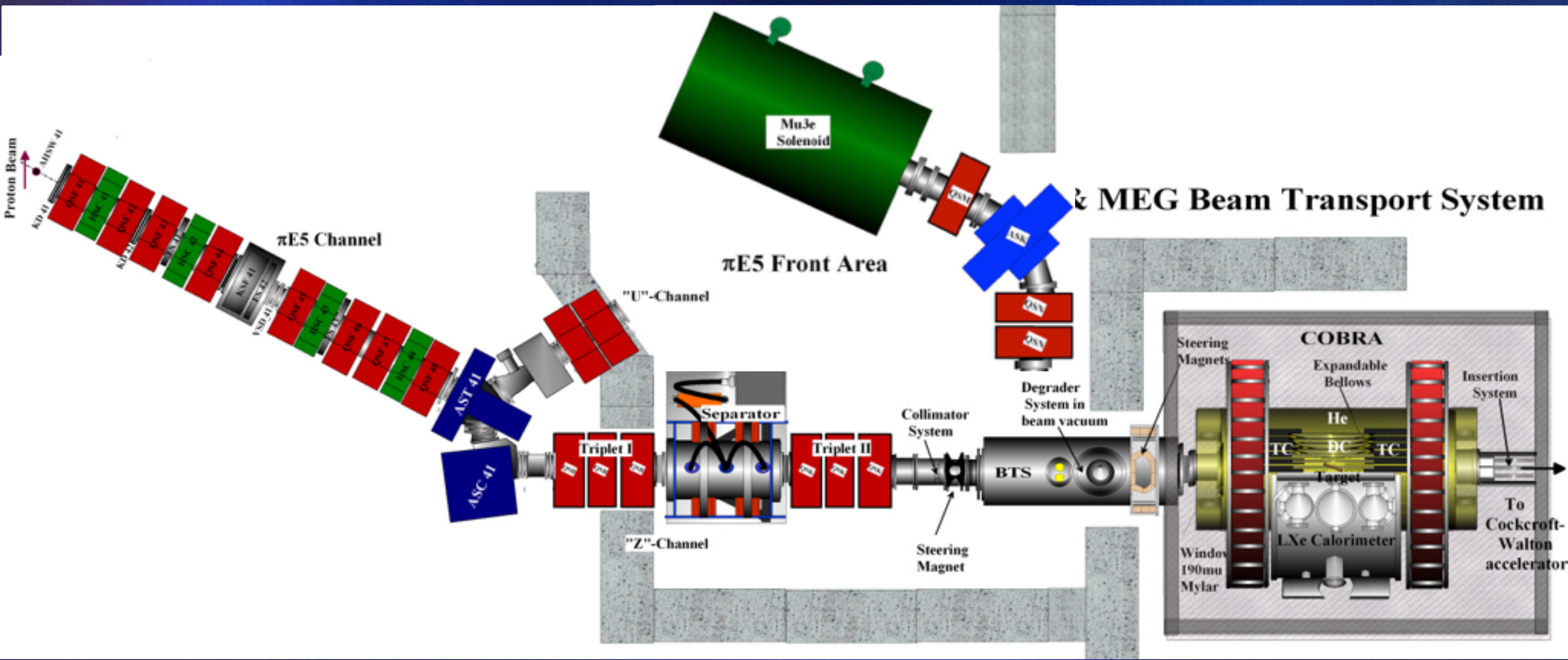
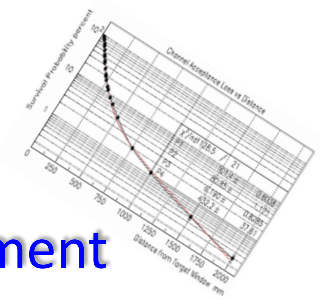


HiMB – midterm conclusions:

- Source Characteristics

  Detailed study shows muon 50% survival length λ_{50} ~ 80 mm

  ➔ Requires front-end capture element just below target



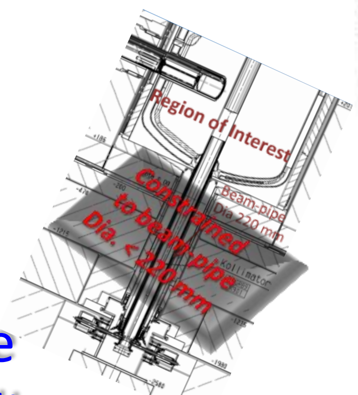
- SINQ Beam Line Constraints

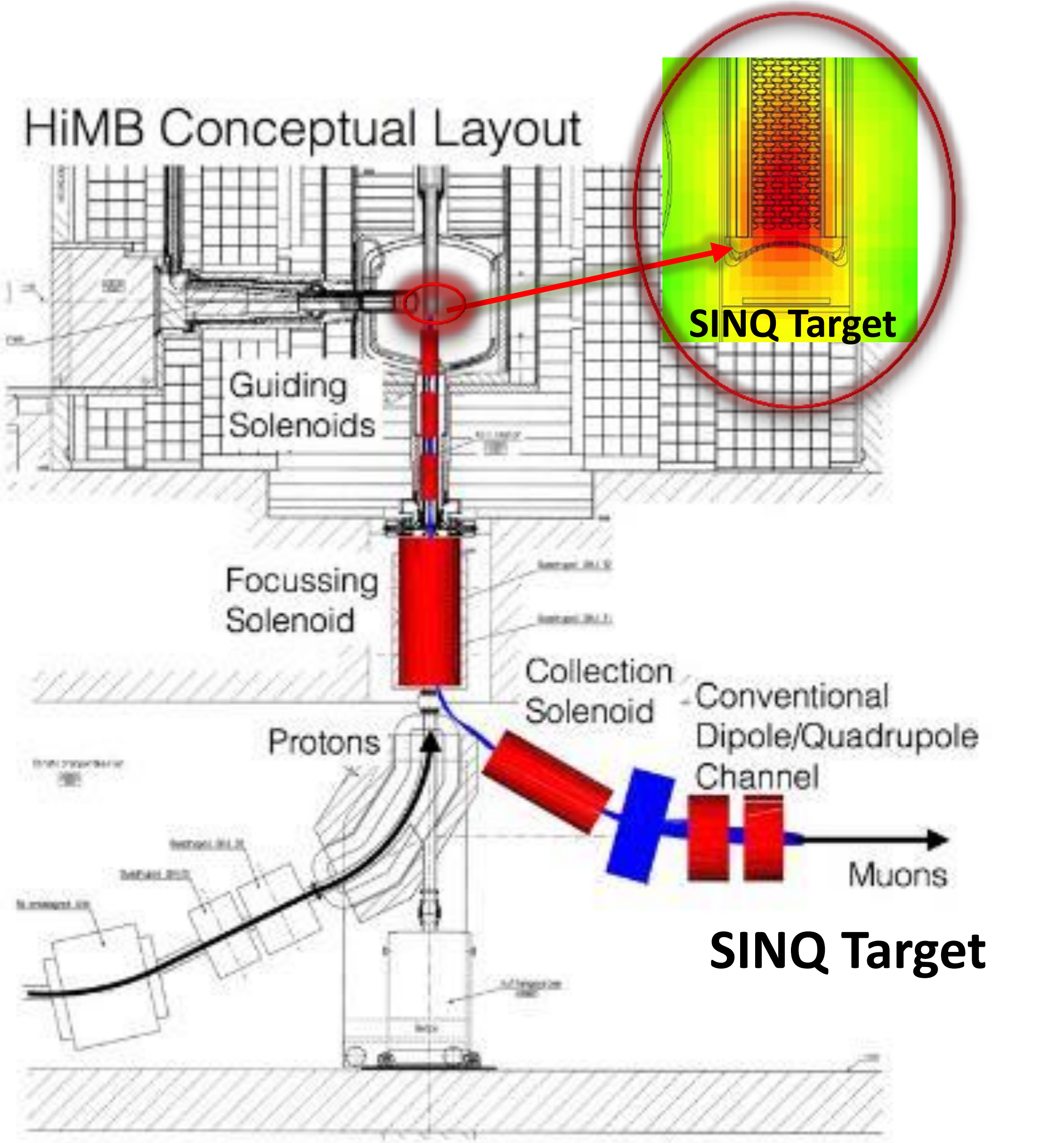
  SINQ Beam-pipe diameter constrained by moderator tank dia. = 220 mm

  ➔ Front-end Toroidal/Solenoidal capture efficiency not sufficient to meet baseline intensity ~ 10^{10} Muons/s if restricted to beam-pipe dia.

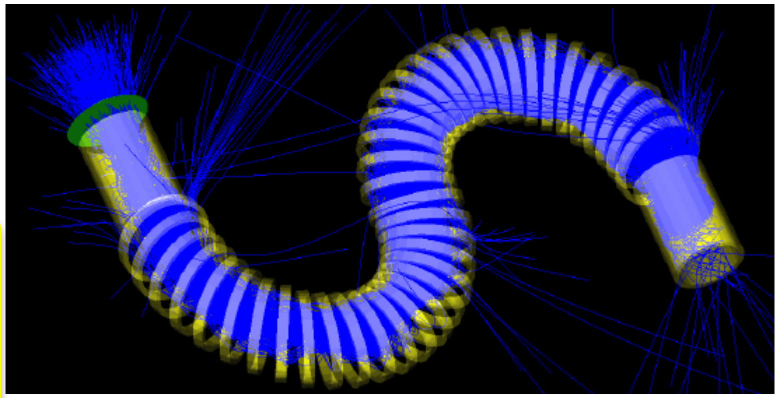
  Factor 2 in dia. needed

  ➔ would require redesign of moderator tank NOT FEASIBLE!



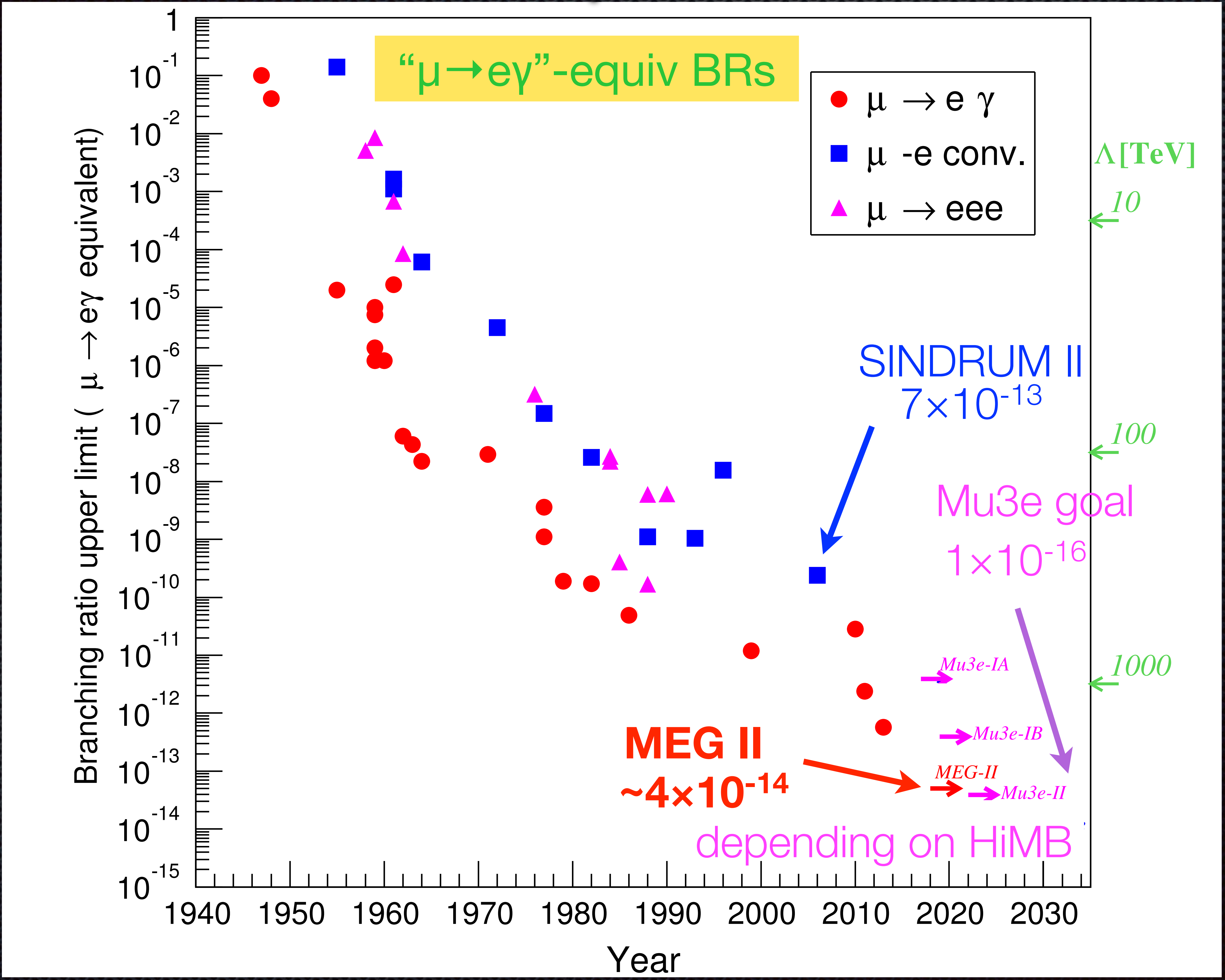


CONCLUSION – without lifting constraint on beam-pipe diameter NOT POSSIBLE to achieve Goal 10^{10} muons/s from SINQ Window



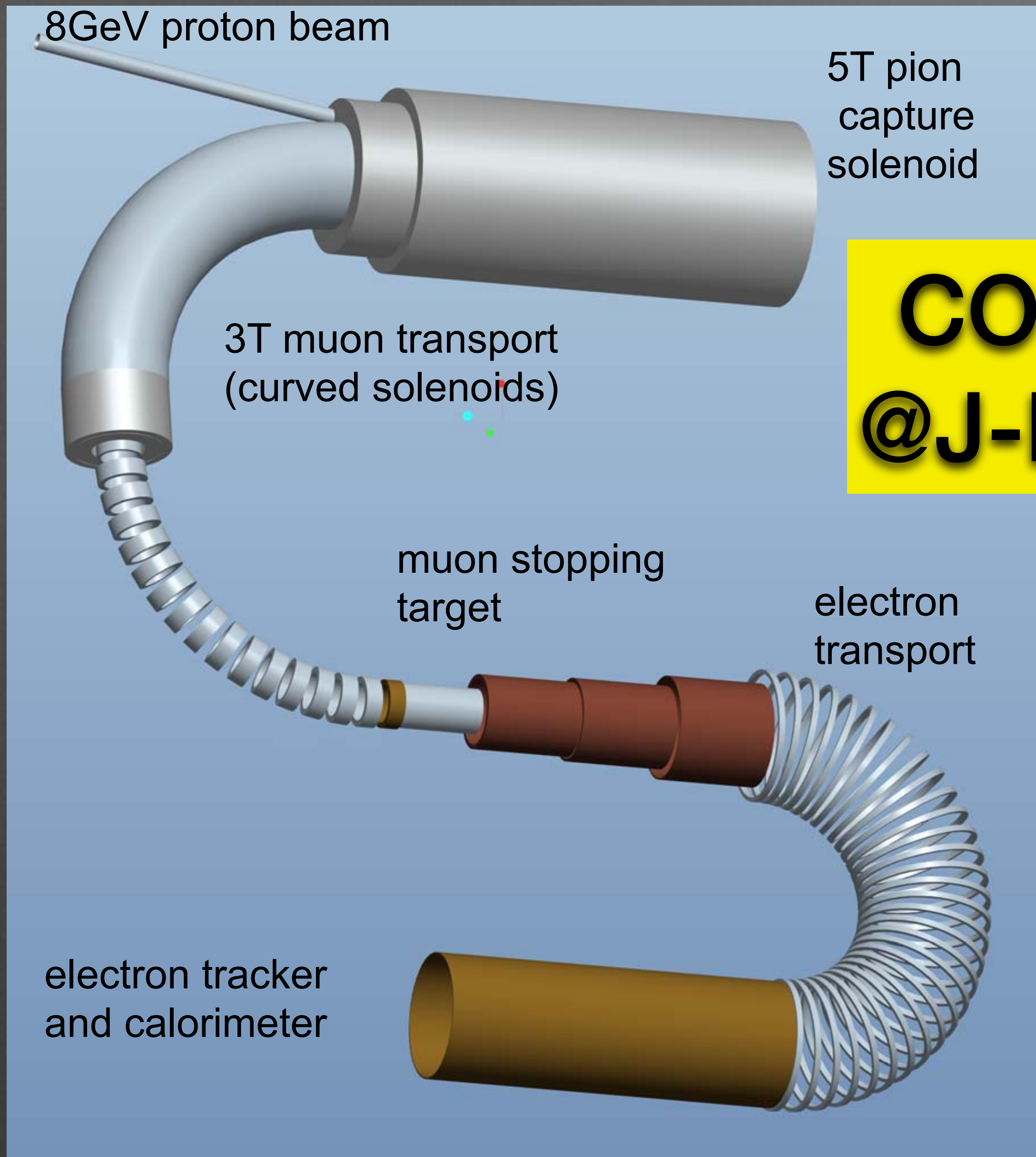
➔ HiMB Study CONTINUES with Solenoidal Target Station option in p-channel

Mu3e follows up MEG II

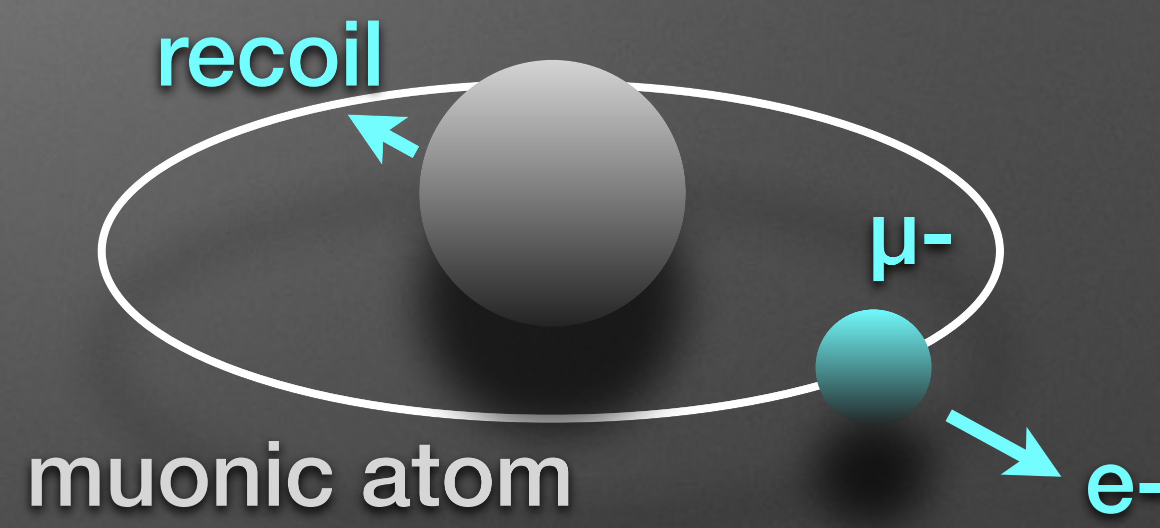


cLFV in further future

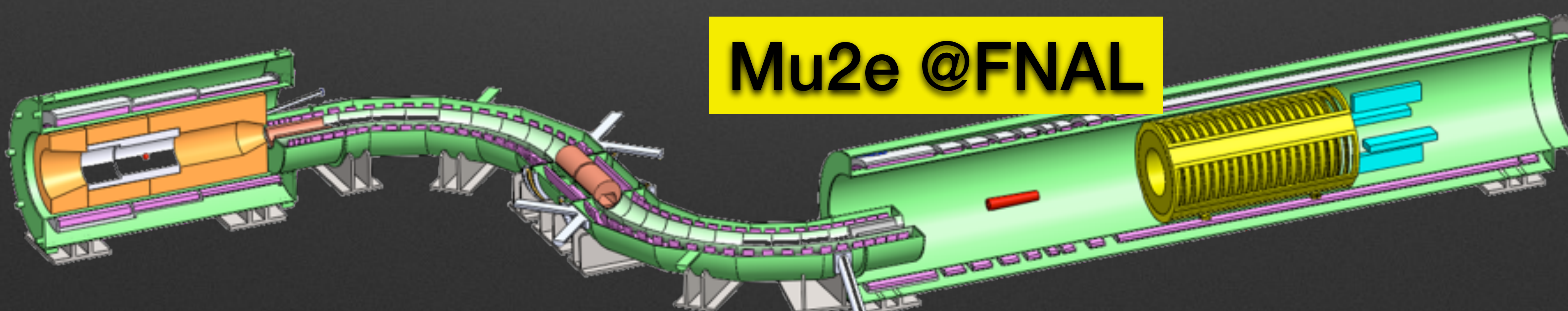
$\mu \rightarrow e$ conversion at 6×10^{-17}



COMET @J-PARC



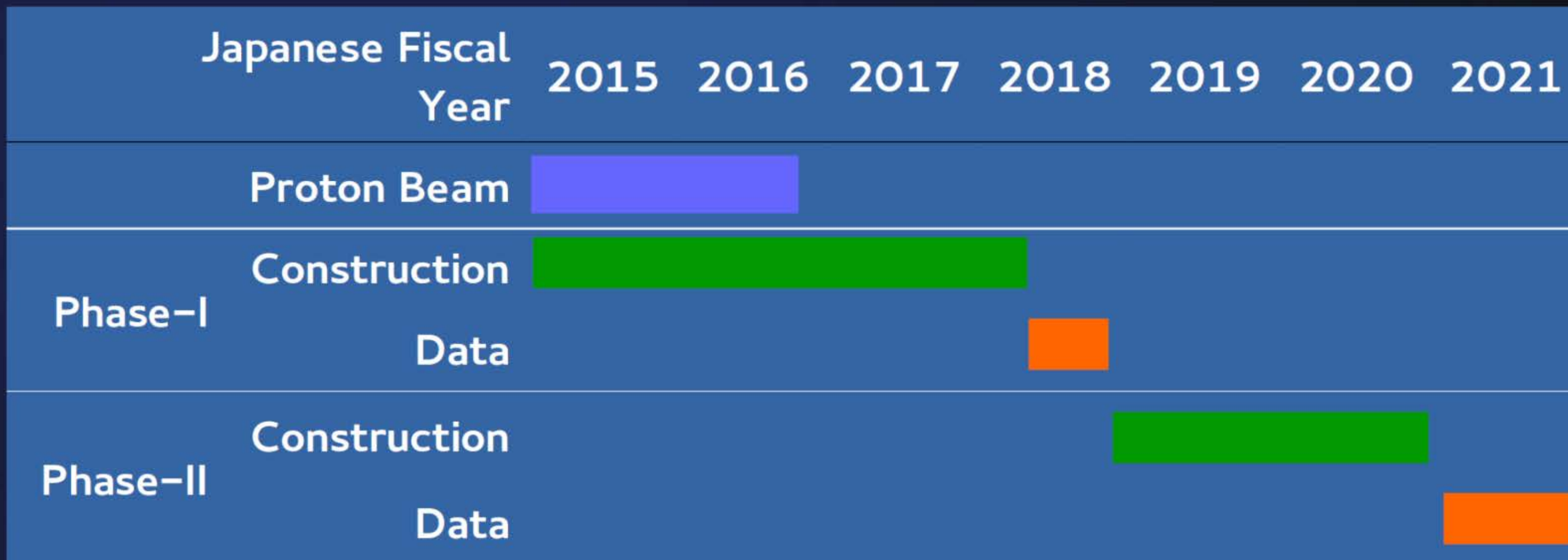
Mu2e @FNAL



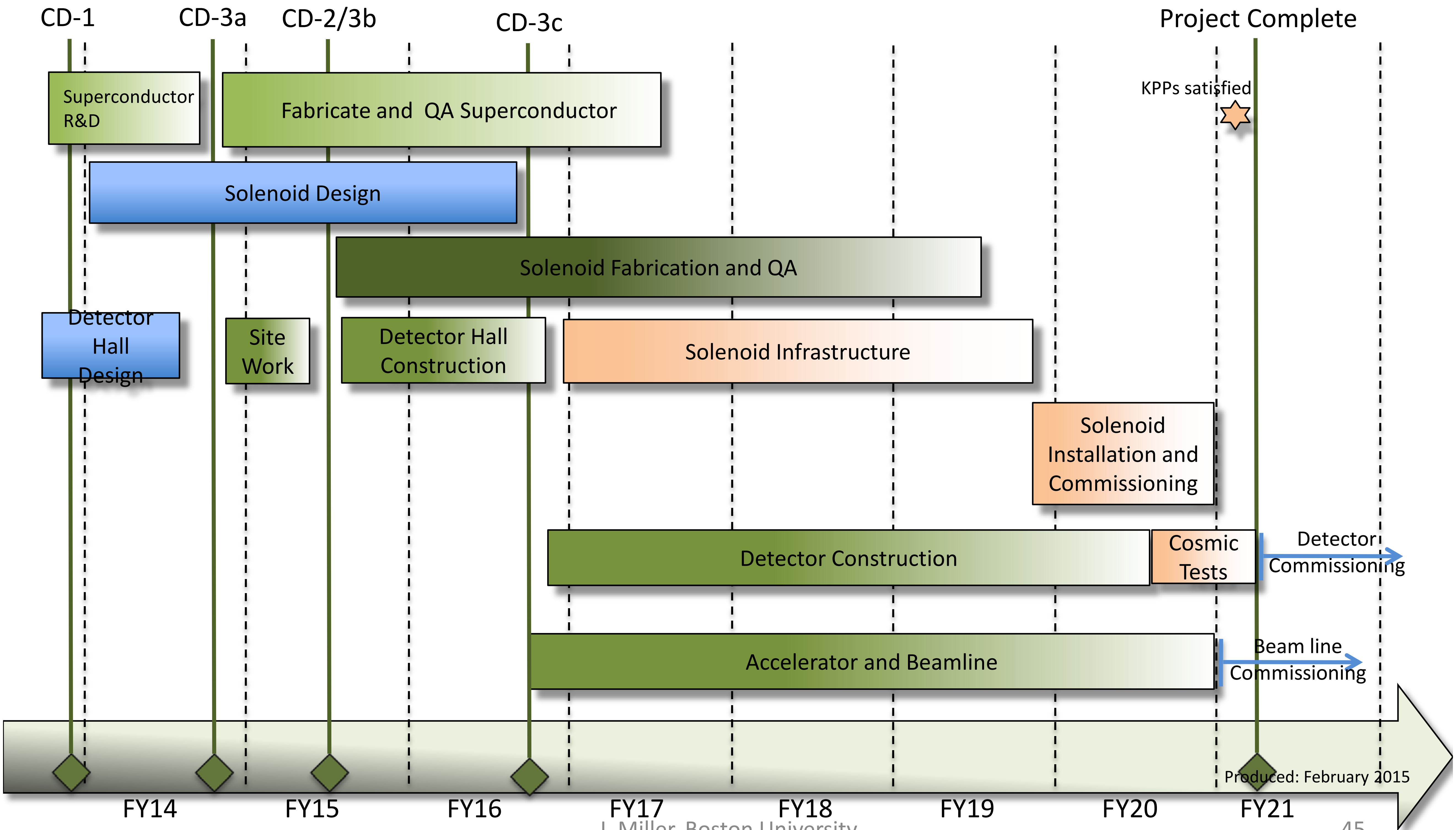
COMET Phase I and II

Schedule

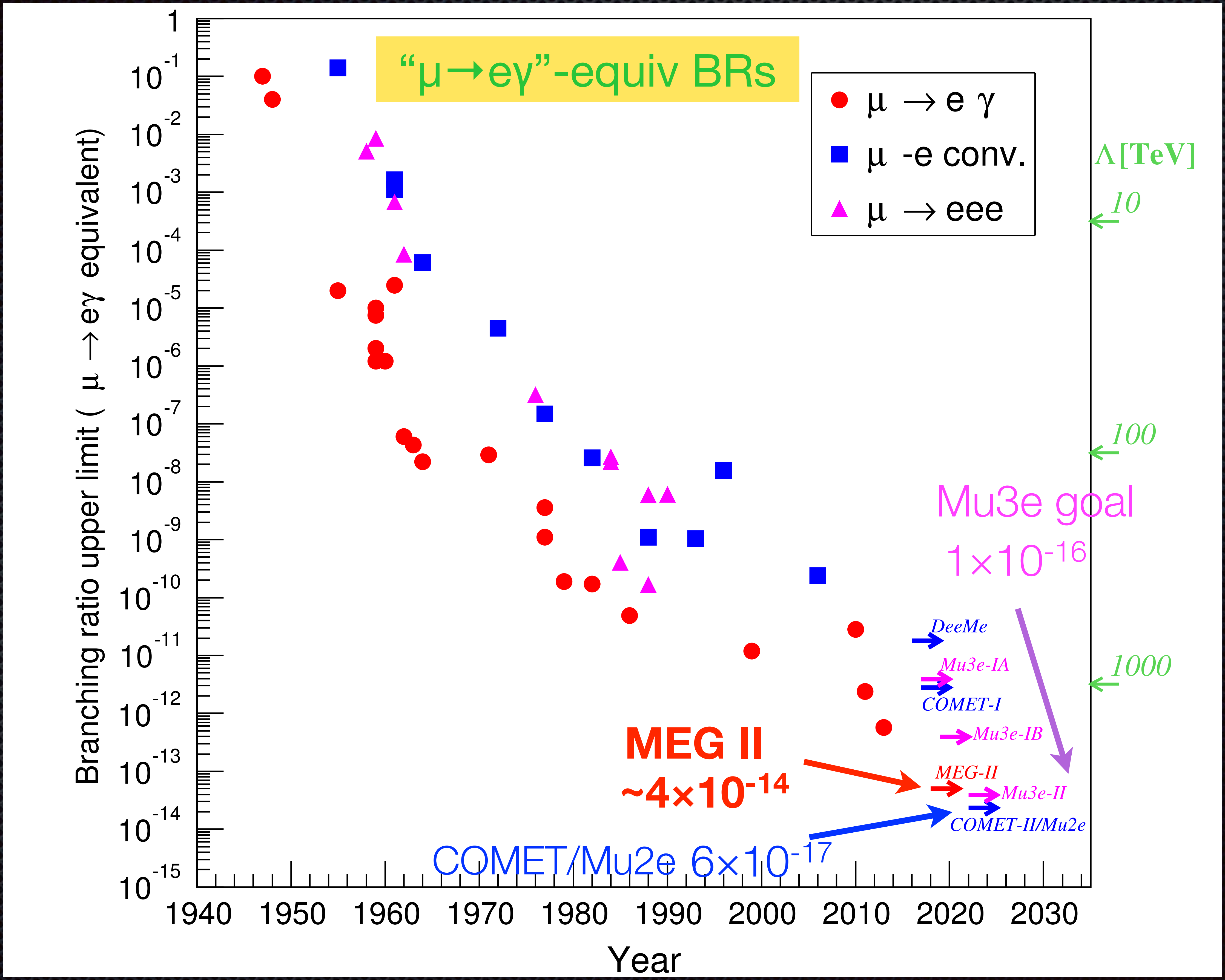
COMET: Ben Krikler



Mu2e Schedule



...and COMET & Mu2e



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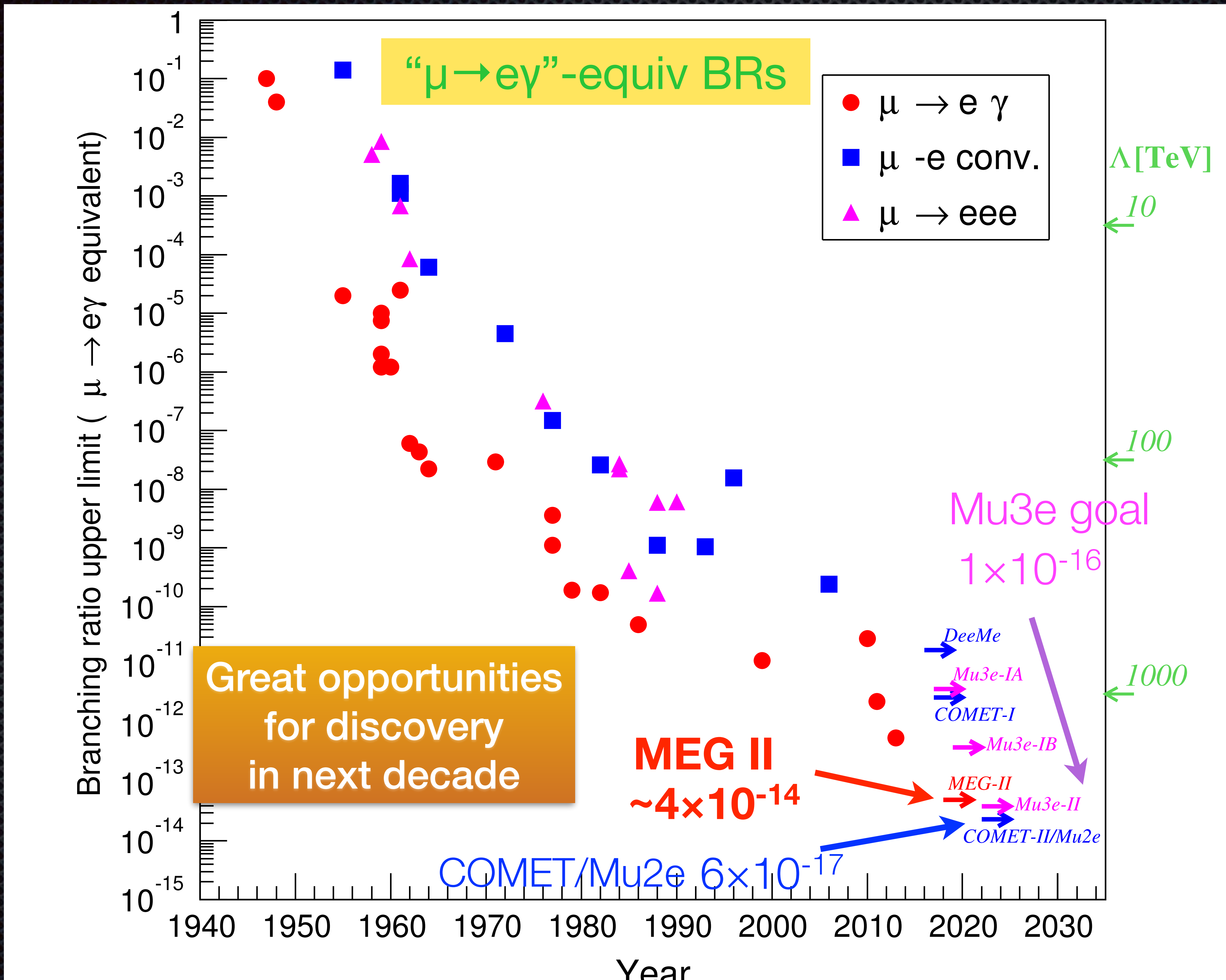


Beyond Mu2e/COMET

- $\mu \to e\gamma$ experiment for $O(10^{-15})$ at HiMB (PSI) ?
  - Needs a clever experimental design based on new technology
- $\mu \to 3e$ needs a higher intensity source than HiMB
  - Mu3e-type experiment still feasible?
- $\mu \to e$ conversion experiments have a potential for a higher sensitivity if a higher intensity muon source becomes available.
  - Perhaps better to think after looking at what will happen at Mu2e/COMET

μ→eγ Statistics & BG

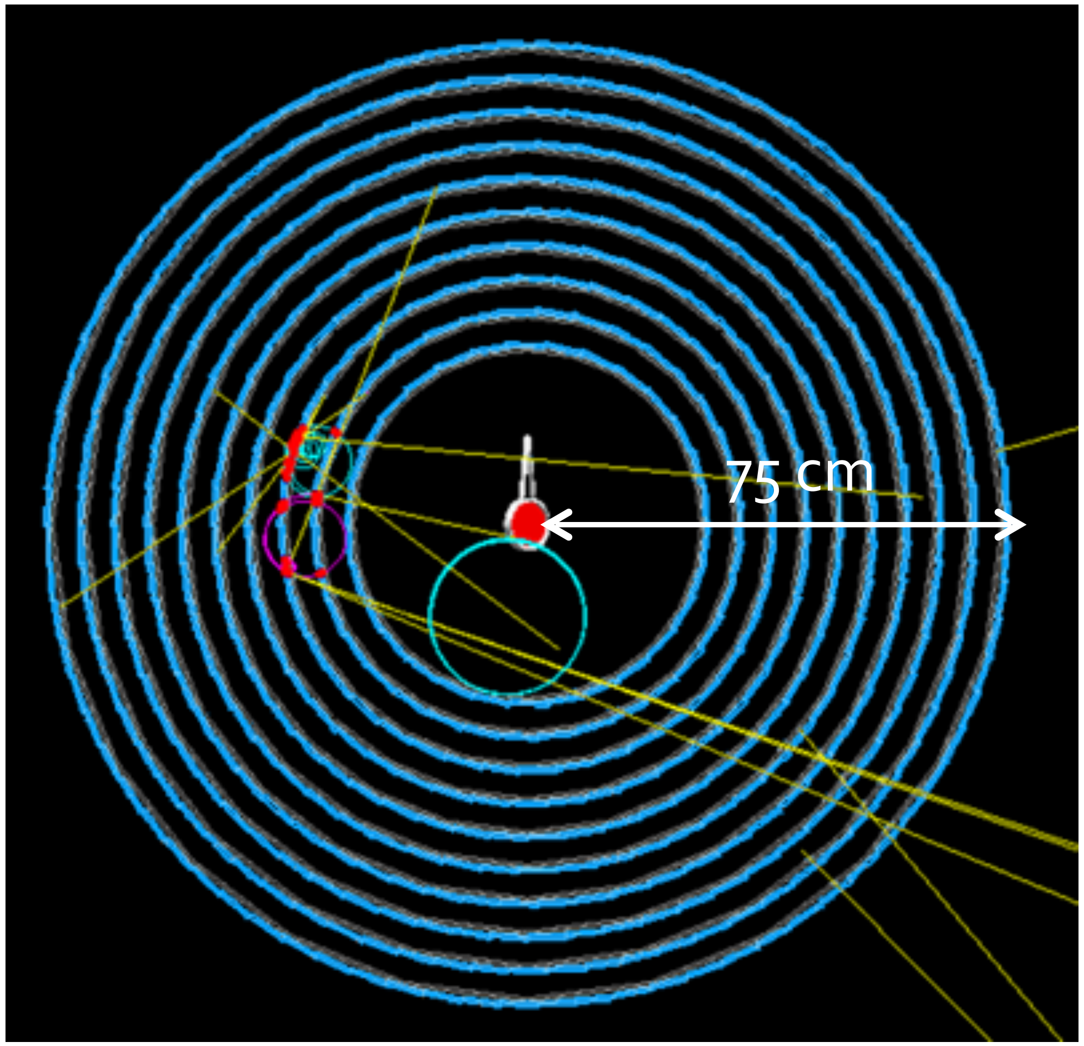
$$N_{BG} \propto (R_\mu)^2 \cdot \epsilon \cdot \delta E_e \cdot (\delta E_\gamma)^2 \cdot (\delta \vartheta_{e\gamma})^2 \cdot (\delta t_{e\gamma})$$

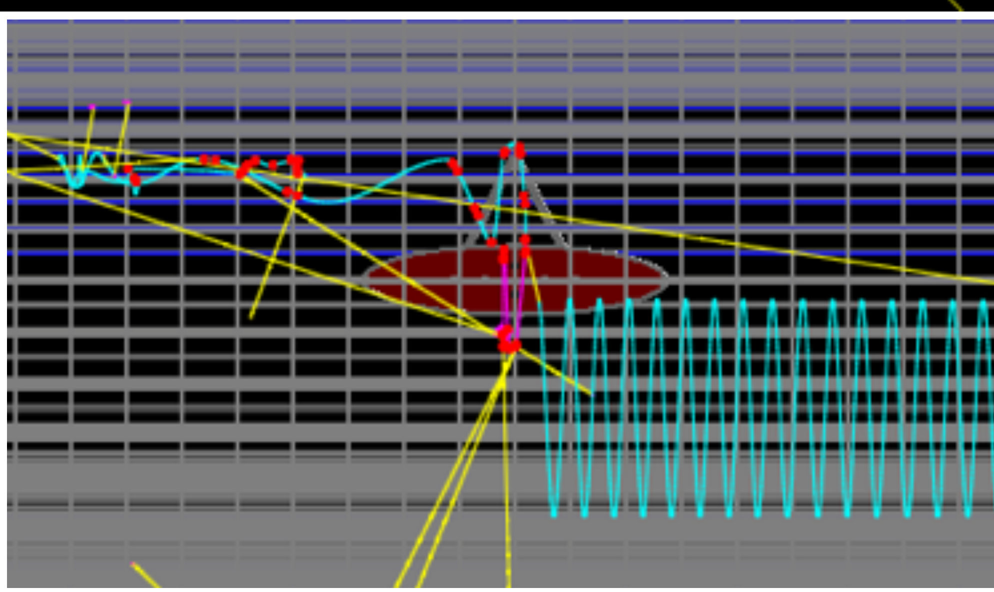
S: Increase factor of the statistics ($\propto R_\mu \cdot \epsilon$)
B: Increase factor of number of BG events ($\propto N_{BG}$)

	ε x 1		ε x 3		ε x 5		ε x 10	
	S	B	S	B	S	B	S	B
Rμ x 1	MEG II		3	3	5	5	10	10
Rμ x 3	3	9	9	27	15	45	30	90
Rμ x 5	5	25	15	75	25	125	50	250
Rμ x 10	10	100	30	300	50	500	100	1000
Rμ x 100	100	10000	300	30000	500	50000	1000	10^5

*Assuming same running time as MEG II

Possible configuration





- **In 1.5 T uniform B-field**
- **10 super layers**
  - first layer from r=26 cm
  - at 5 cm radial distance
- **A super layer consists of**
  - two 100 um Pb converters
  - two Si pixel layers put both outside the conversion double layer
- **Target**
  - 100 um plastic sheet
  - slant angle of 10° to spread vertex distribution

□ **~15% conversion eff.**
assuming 50% rec. eff. ⇒ 7–8% eff.

◆ **Need active area of 160 m^2**
CMS level!
⇒ Increase B-field, increase sub-layers

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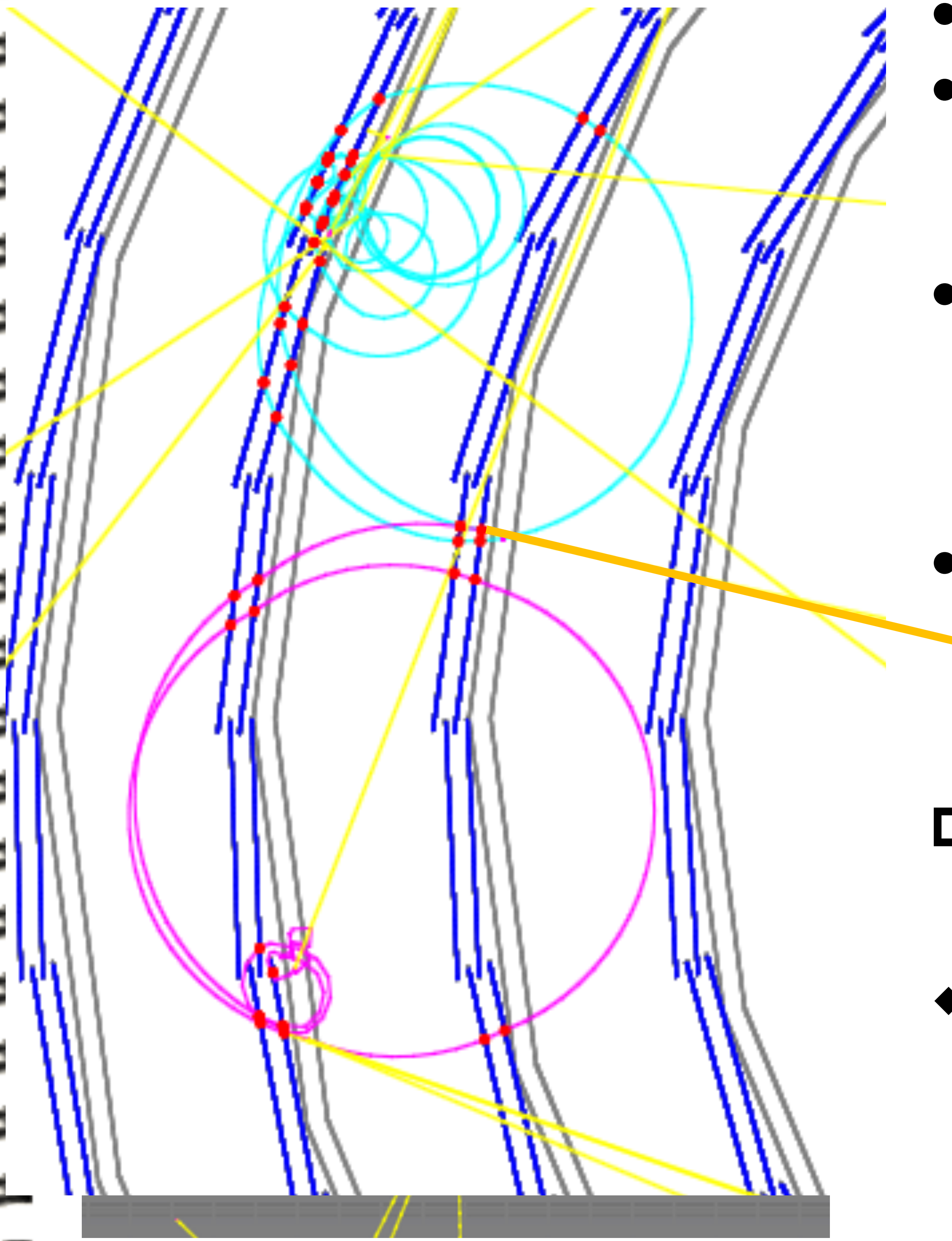

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Detector requirement

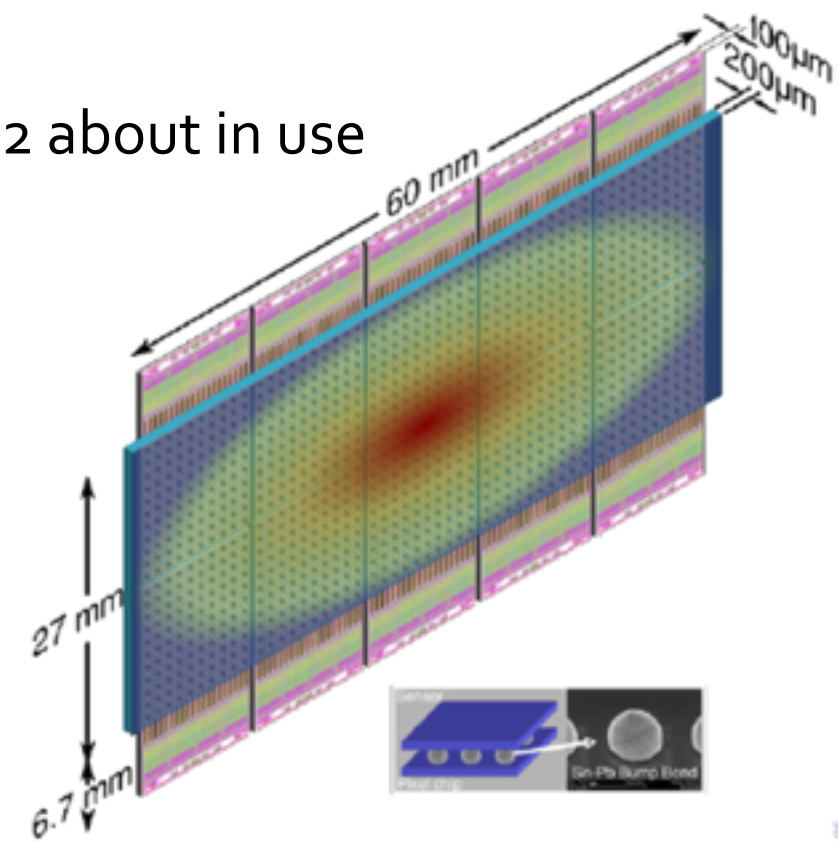
- **Si pixel tracker with**
  - Large area
  - High time resolution (O(100 ps))
  - Ultra thin (~50 um)
    - If build e^+ side as well, <50 um important

- **No available device today**

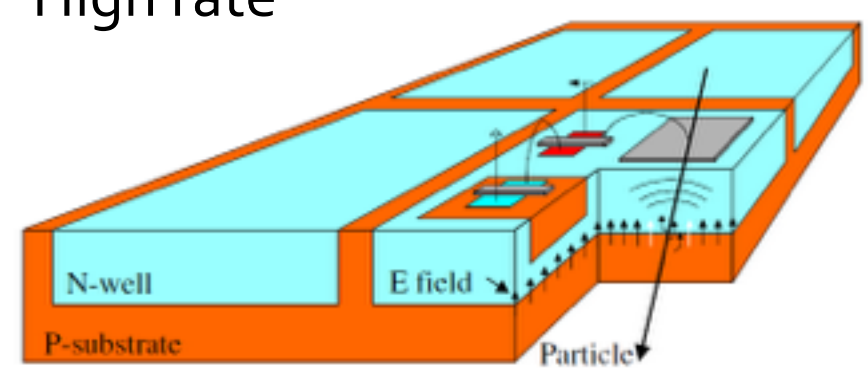
  Need device development

Giga-tracker for NA62 about in use

Hybrid pixel
σt = 200 ps
200 um thick



HV-MAPS for Mu3e
50 um thick
High rate



(High voltage monolithic active pixel sensors)
I. Peric et.al. NIMA 582 (2007) 876

New technologies open new physics!

Toward $\mu \to e\gamma$ $O(10^{-15})$

- **10 times larger statistics achievable by**
  - 5 times higher intensity beam
  - twice higher signal acceptance (compared to MEG II)
- **with multi-layer converting photon spectrometer**
  - multi layers to gain efficiency
  - sub layers for good resolution retaining efficiency
- **Suppress increased BG by**
  - Vertex matching (compensate increased beam rate)
  - Better γ energy resolution (3 times better)

◆ **However, realization seems really challenging**
  - Need further detailed studies
  - Need technological development
  - Need more or completely different idea

Summary

- No $\mu \to e\gamma$ event has been found.
- 20× more stringent constraint than the previous experiment on possible new physics:
  $BR(\mu \to e\gamma) < 5.7 \times 10^{-13}$ @90% C.L.
- Final MEG result (x2 statistics) should be ready this year; So stay tuned!
- Upgrade to MEG II underway:
  expected to start in 2016 with 10× higher sensitivity
  $(4\text{-}5) \times 10^{-14}$
- A full lineup of cLFV experiments in the next decade lead by MEG II