Lepton Flavor Violation Status and Prospects

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Charged Lepton Flavor Violation
Experimental Status and Prospects

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Topics to Cover

- Why Charged Lepton Flavor Violation?
- “Tau Processes” :
  - ✓ Muon to Tau Conversion
  - ✓ Tau Decays at B Factories
- “Non-Tau Processes” :
  - ✓ Muon to Electron Conversion
  - ✓ Muon Decay to Electron and Gamma

Topics to Cover

- Why Charged Lepton Flavor Violation? WG3
- "Tau Processes" :
  - ✓ Muon to Tau Conversion Y.Kuno, G.Marchio
  - ✓ Tau Decays at B Factories S.Banerjee
- "Non-Tau Processes" :
  - ✓ Muon to Electron Conversion Y.Kuno
  - ✓ Muon Decay to Electron and Gamma A.Baldini

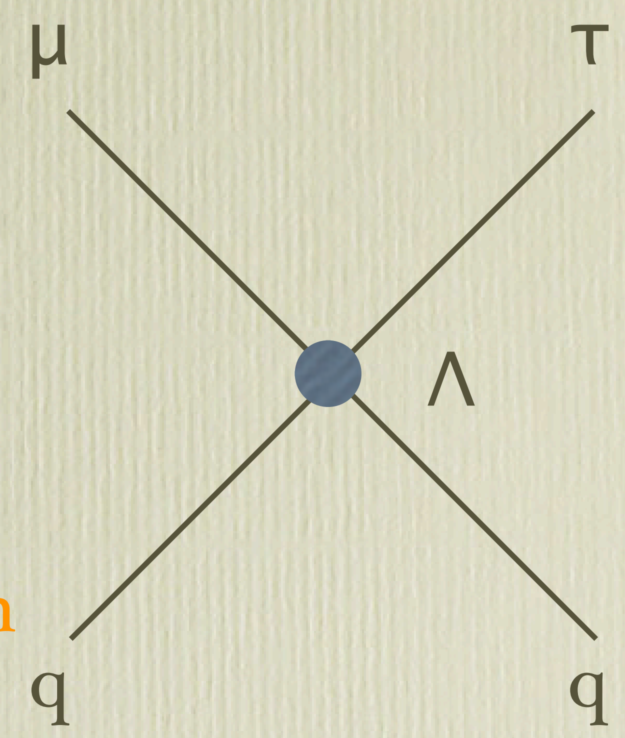
Why Charged Lepton Flavor Violation?

- Quark FV is generally contaminated by SM.
  - Look for tiny deviations from SM
- Charged LFV Is Beyond SM.
  - Some already reach the sensitivity.
  - Just Find It !

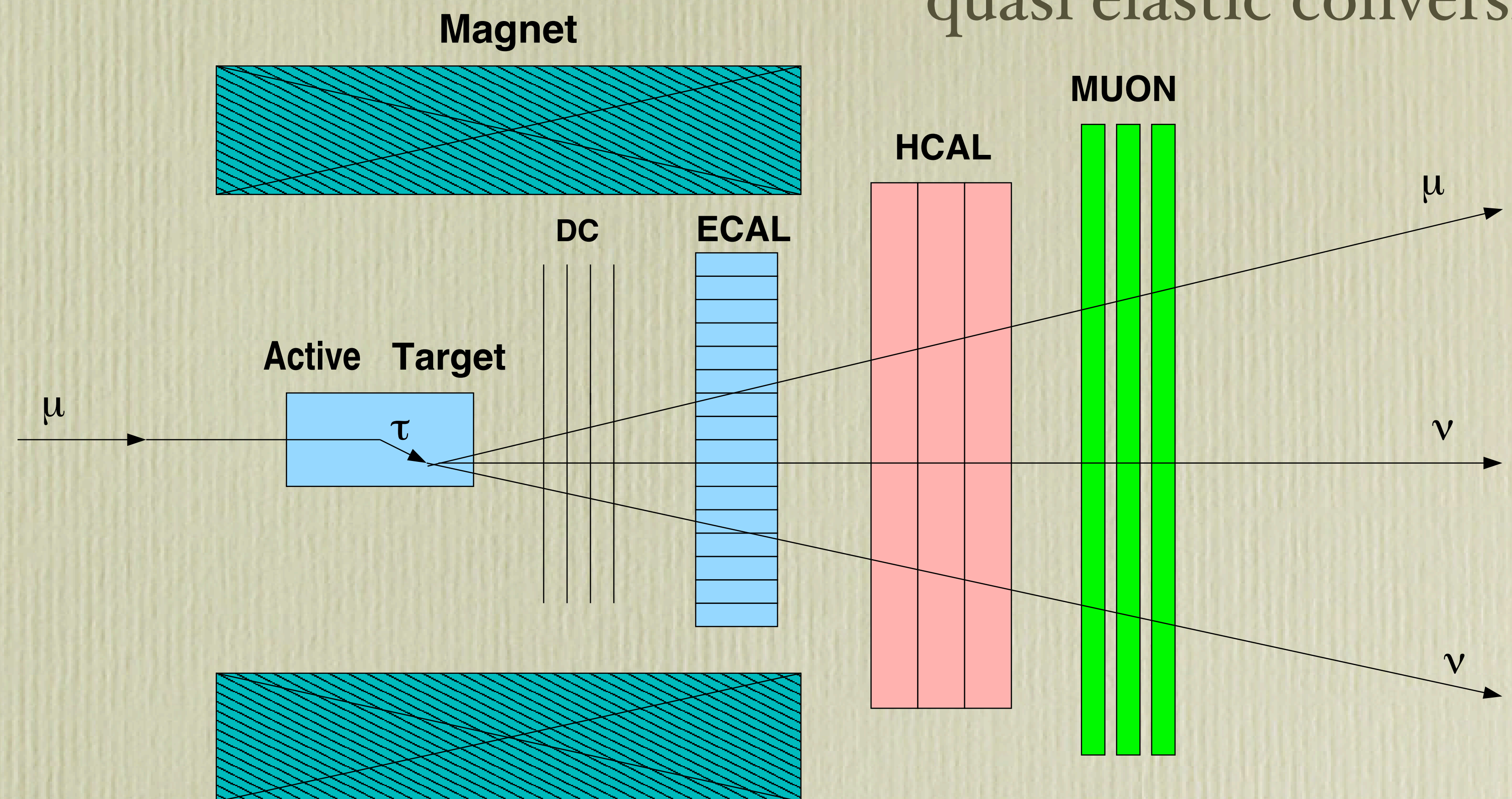
“Tau Processes”

Mu - Tau Conversion with High Intensity Muon Beam

- "Bottom Up" Approach:
  - ✓ Effective 4-Fermi interaction experimentally constrained
  - ✓ Some couplings only loosely constrained by tau decays (scalar by $\tau \to \mu\pi\pi$) Sher, Turan
  - ✓ Not constrained by tau decays if (qq) = (uc), etc. Gninenko et al



quasi elastic conversion



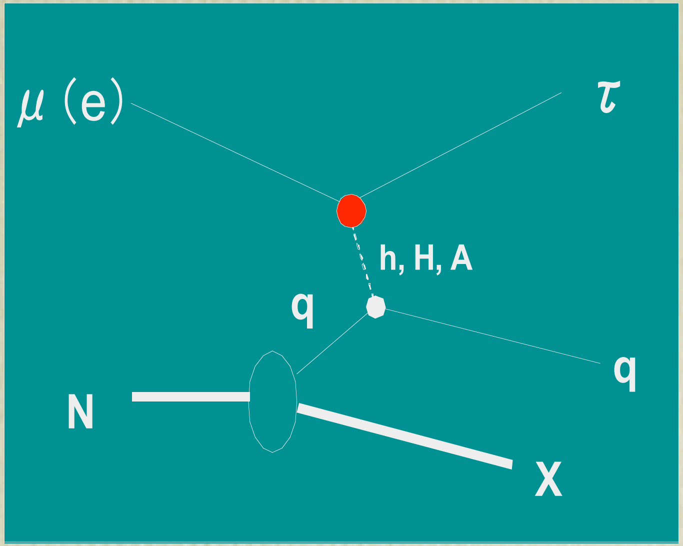
Less constrained coupling as large as 0.5fb at 50GeV could yield signal events for ~10^{15} muons/year on ~100g/cm^2 target

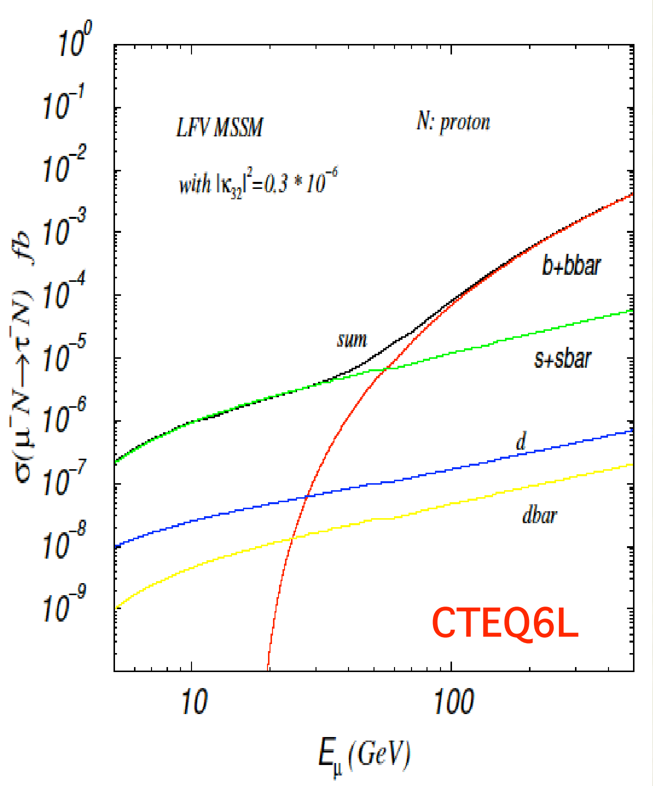
Experimental Feasibility at SPS or Neutrino Factory?

G. Marchio

Deep Inelastic Conversion

- In SUSY models, possible enhancement due to Higgs mediation
  Constrained by τ→μη, 3μ
  ~100ρ events for 10^{20} muons at 50GeV; more for higher E
- For above 60GeV, b-quark subprocess dominates and increases the cross-section
- Gauge-boson mediation strongly constrained by τ→μγ





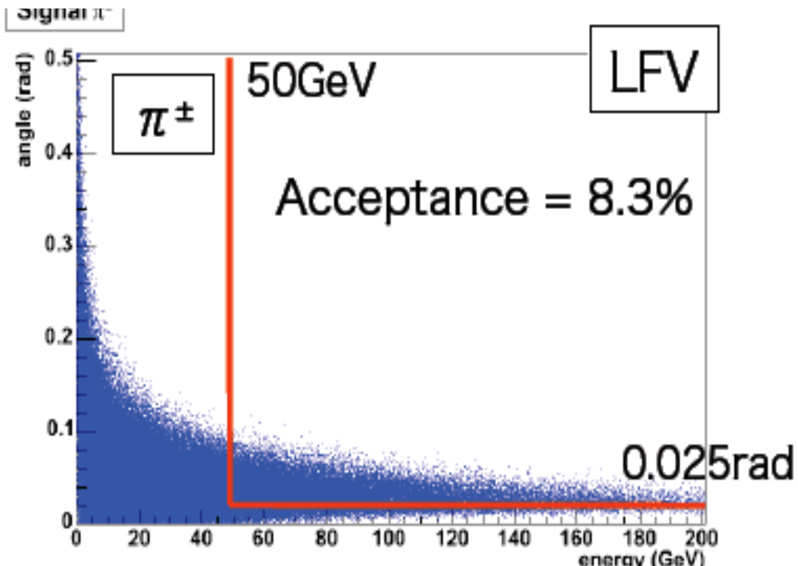
Monte Carlo Simulation

- 500GeV muon beam
- Generator: Signal Modified LQGENEP
  (leptoquark generator)
  Bellagamba et al
  Background LEPTO γDIS
  Q^2>1.69GeV^2,σ=0.17μb
- MC_truth level analysis

Work in progress

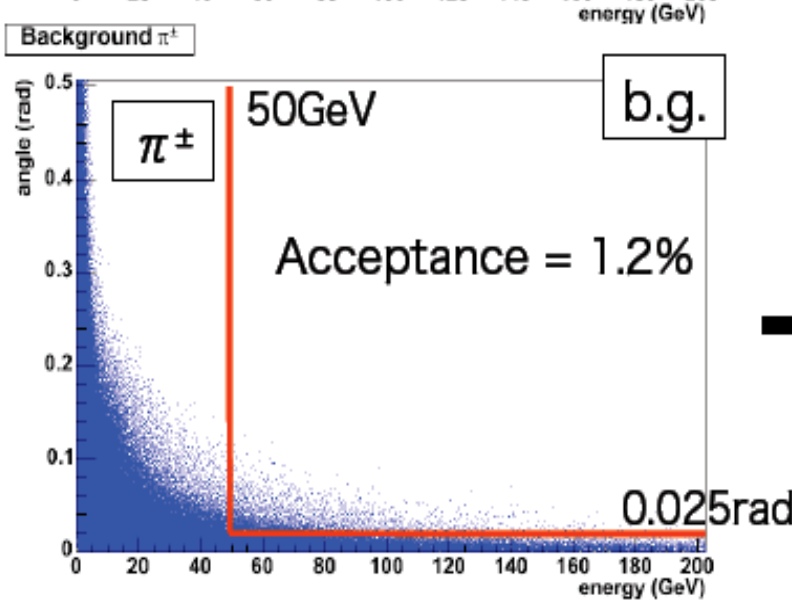
Kanemura, Kuno, Kuze, Ota, Takai

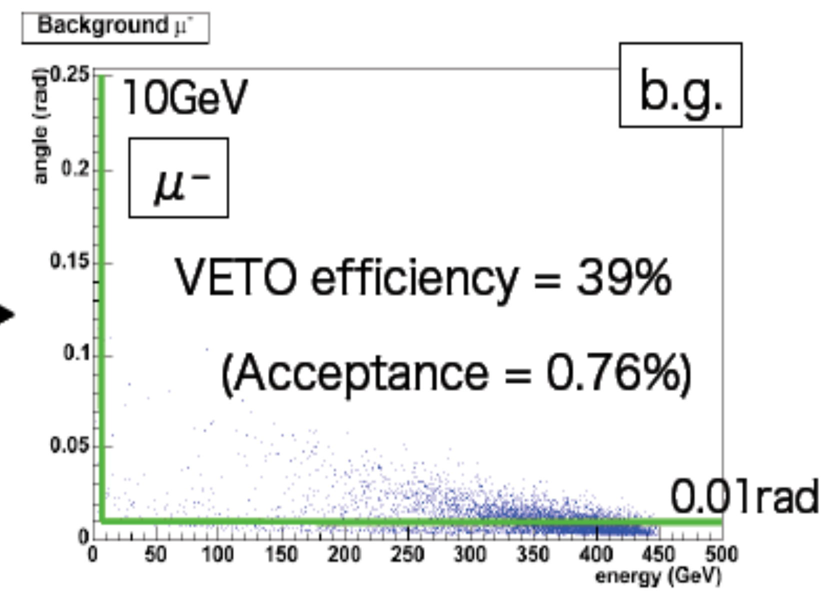
Hadrons from μN→τX and backgrounds



$E\pi > 50GeV$,
$\theta\pi > 0.025rad$
$\Delta\mu$ 0.01rad

Takai





Scattering angle of μ is small, it would be difficult to tag background events for reduction

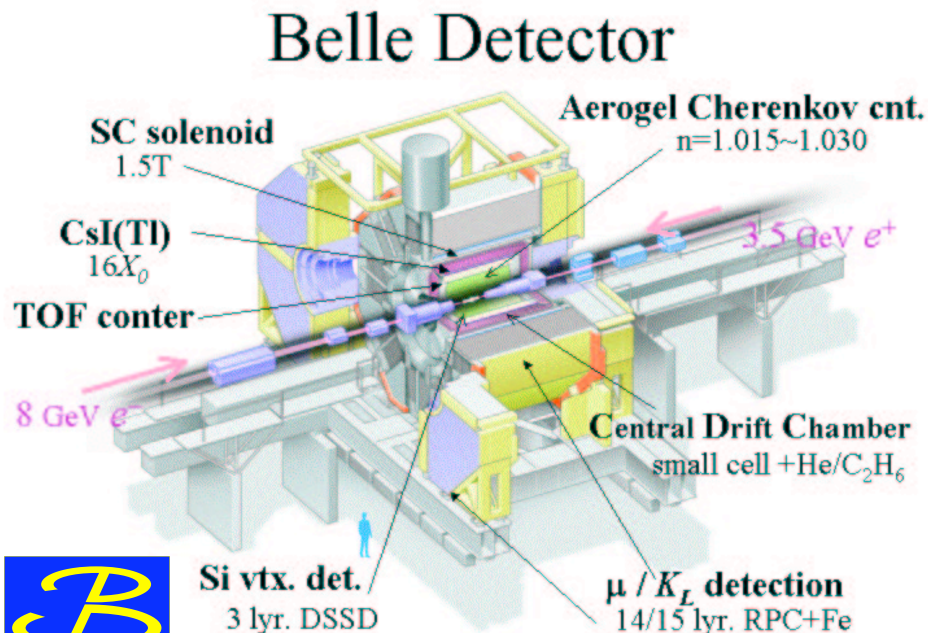
Y. Kuno

LFV Tau Decays at B Factories

Detectors at B-factories

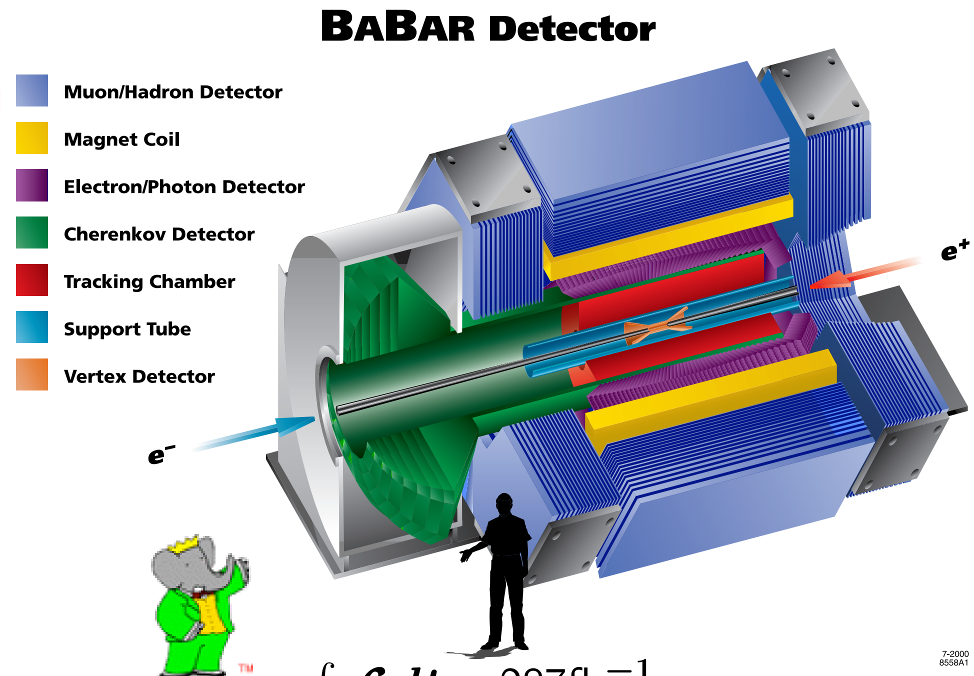
Asymmetric-energy collider at $\sqrt{s} = 10.58$ GeV $= \Upsilon(4S)$

$\sigma(\tau\tau) \sim 0.9$ nb, $\sigma(B\bar{B}) \sim 1.1$ nb $\Rightarrow$ B-factory is also τ factory!!!



$\int \mathcal{L}dt = 469$ fb^{-1}

Data samples: 4.2×10^8 $\tau^+\tau^-$ pairs



$\int \mathcal{L}dt = 287$fb^{-1}

Data samples: 2.6×10^8 $\tau^+\tau^-$ pairs

$\Rightarrow$ LFV sensitivity of $\mathcal{B} \sim$O(10^{-8})) at B-factories

Y.Miyazaki @EPS

Analysis method for LFV τ decay

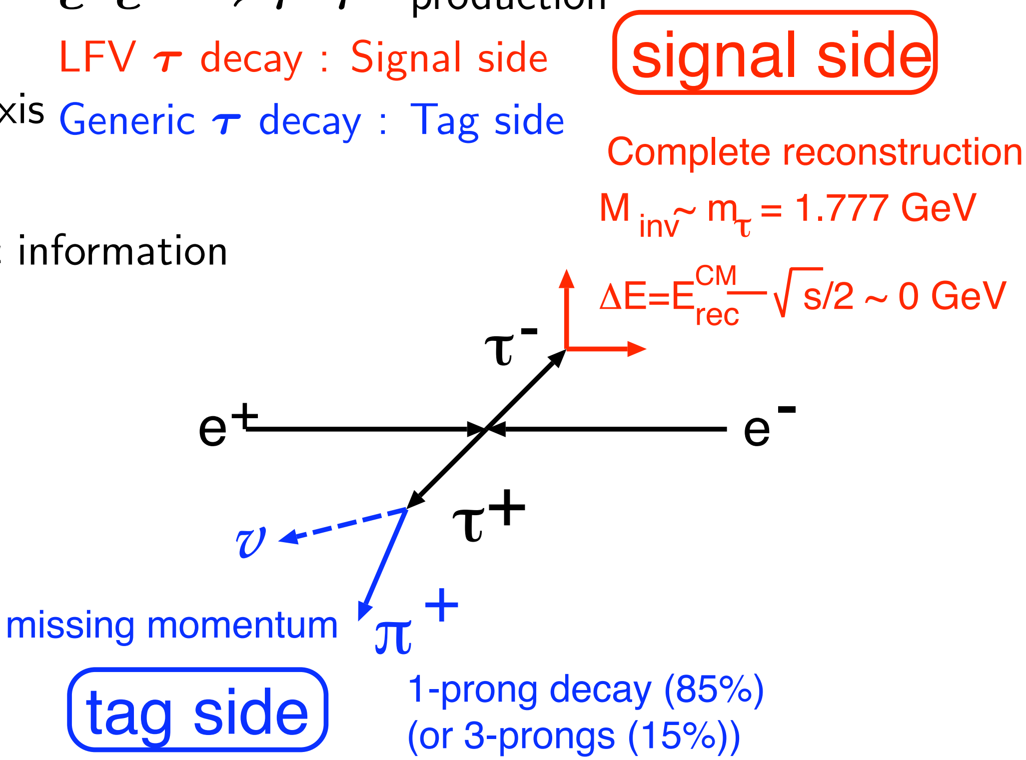
Procedure for LFV τ decay

1. Select tracks with zero net charge
2. Separate into two hemispheres using thrust axis
   $\longrightarrow$ Signal and Tag side
3. Reduce Background using PID and kinematic information
   $\longrightarrow$ missing momentum, # of γ's etc.
4. Calculate M_{inv} and ΔE on signal side
   $\longrightarrow$ Blind the signal region
5. Estimate the background in signal region using sideband data
6. Open the blinded region
   $\longrightarrow$ LFV observation or set an upper limit

$e^+e^- \longrightarrow \tau^+\tau^-$ production

LFV τ decay : Signal side

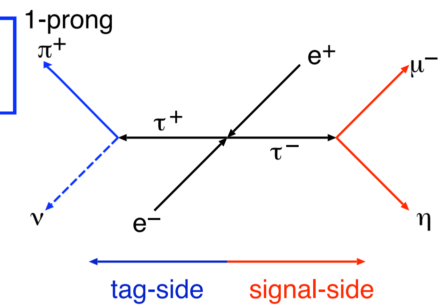
Generic τ decay : Tag side



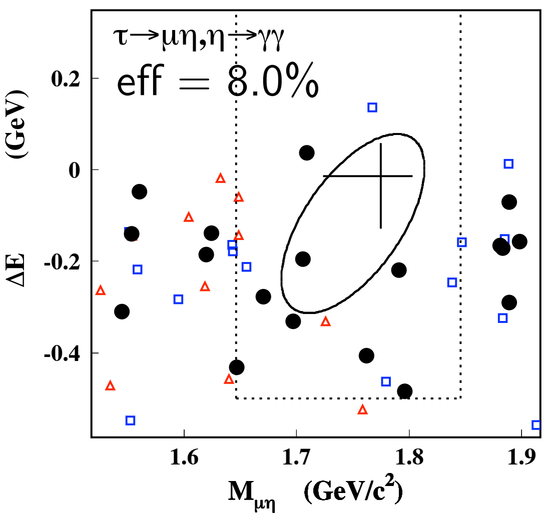
$$\mathcal{B} < \frac{s_{90\%CL}}{2\varepsilon N_{\tau\tau}}$$

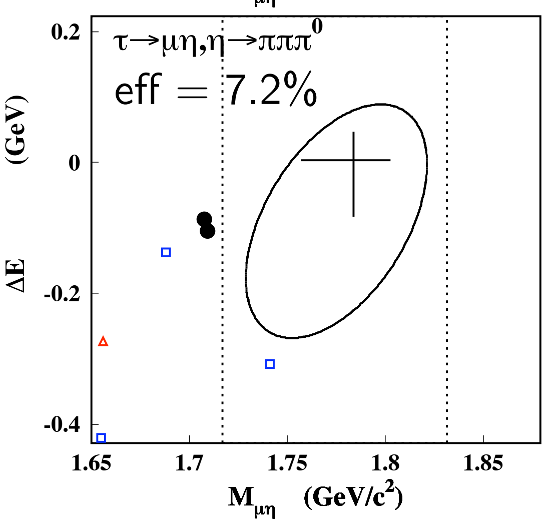
$\Rightarrow$ Will show results for $\tau \rightarrow \ell K_S^0, \ell\gamma, \mu\eta, \ell h h'$ modes

Search for LFV in $\tau^- \to \mu^- \eta$



●:data △:uds □:$\tau\tau$





	CLEO	Belle	
Luminosity	4.7fb^{-1}	154fb^{-1}	$\Rightarrow \times$ 33
Efficiency			
$\eta \to \gamma\gamma$	7.2%	8.0%	Total efficiency
$\eta \to \pi^+\pi^-\pi^0$	not used	7.2%	$\Rightarrow \times$ 1.7
# of observed events	0 event	1 event	Keeping low BG

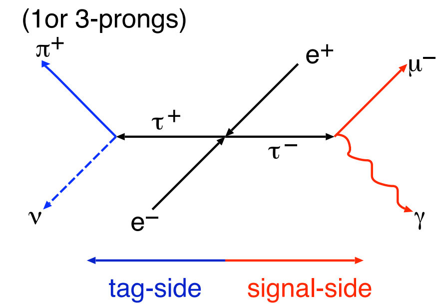
$\mathcal{B}(\tau \to \mu\eta) < 1.5 \times 10^{-7}$ (90%C.L.) (154/fb@Belle)

$(\mathcal{B}(\tau \to \ell\eta, \ell\eta'\ell\pi^0) <(1.5-10)\times 10^{-7})$

(hep-ex/0503041 accepted by PLB)

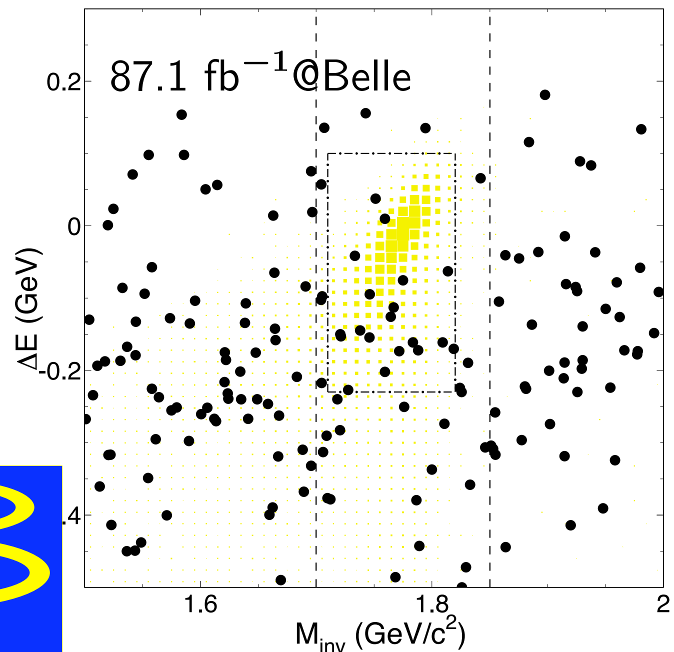
(CLEO:$\mathcal{B}(\tau \to \mu\eta) < 9.6 \times 10^{-6}$)

$\Rightarrow$ Improved by a factor of 64 compared with CLEO



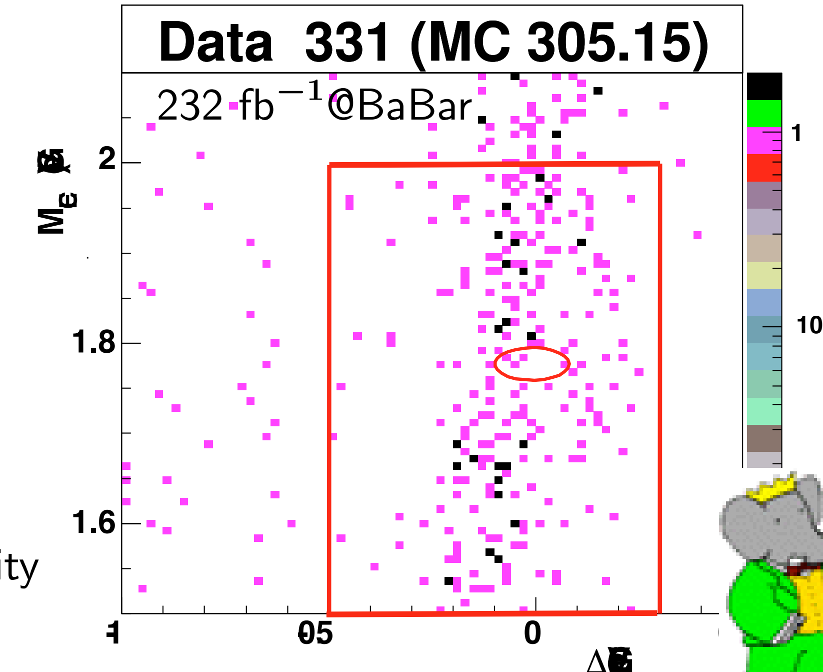
Search for LFV in $\tau^- \to \mu^- \gamma$

Background from
$\mu^-\mu^+$ and $\tau^+\tau^-$ events



$\Rightarrow$

Increase Luminosity

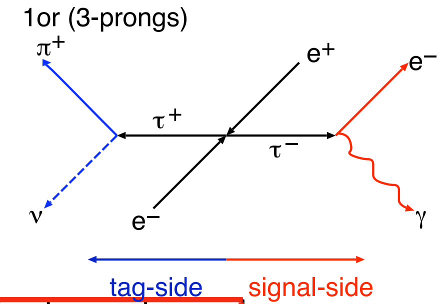


Similar region as Belle

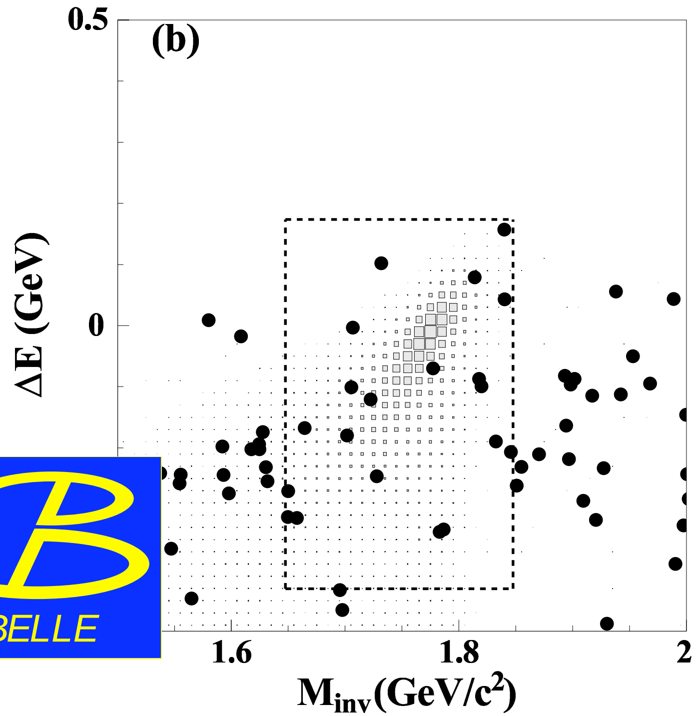
Upper limit : (Eff=11.2%@$\pm 5\sigma$ box)
$\mathcal{B}(\tau \to \mu\gamma) < 3.1\times10^{-7}$ (90%C.L.)
Phys. Rev. Lett. 92, 171802 (2004)
$\longrightarrow$ Analysis in progress using full data sample

Upper limit : (Eff=7.42%@ 2 σ ellipse)
($\mathcal{B}(\tau \to \mu\gamma) < 6.8\times10^{-8}$ (90%C.L.)
(hep-ex/0502032 submitted to PRL)

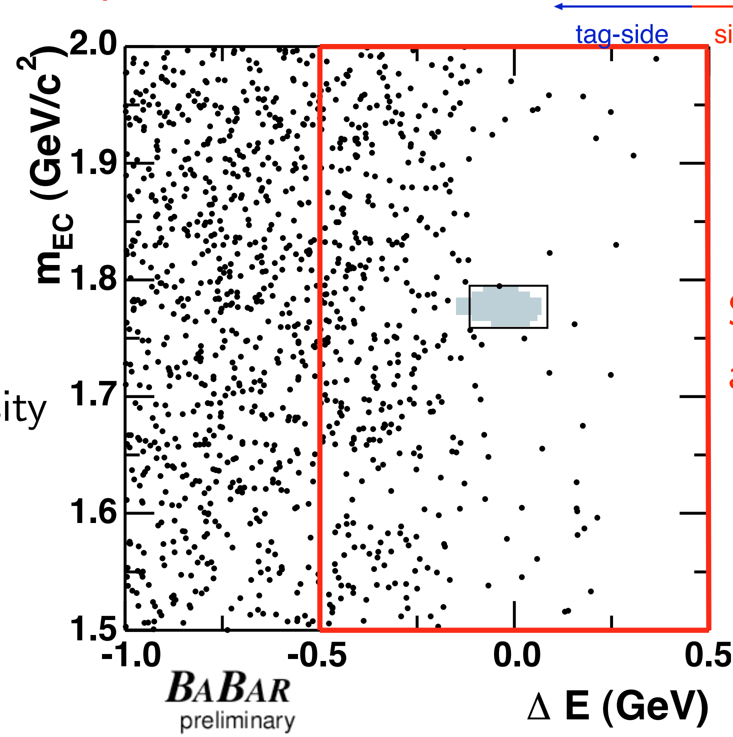
Search for LFV in $\tau^- \rightarrow e^-\gamma$



Background from
$\tau^+\tau^-$ and Bhabha events



$\Rightarrow$ Increase Luminosity



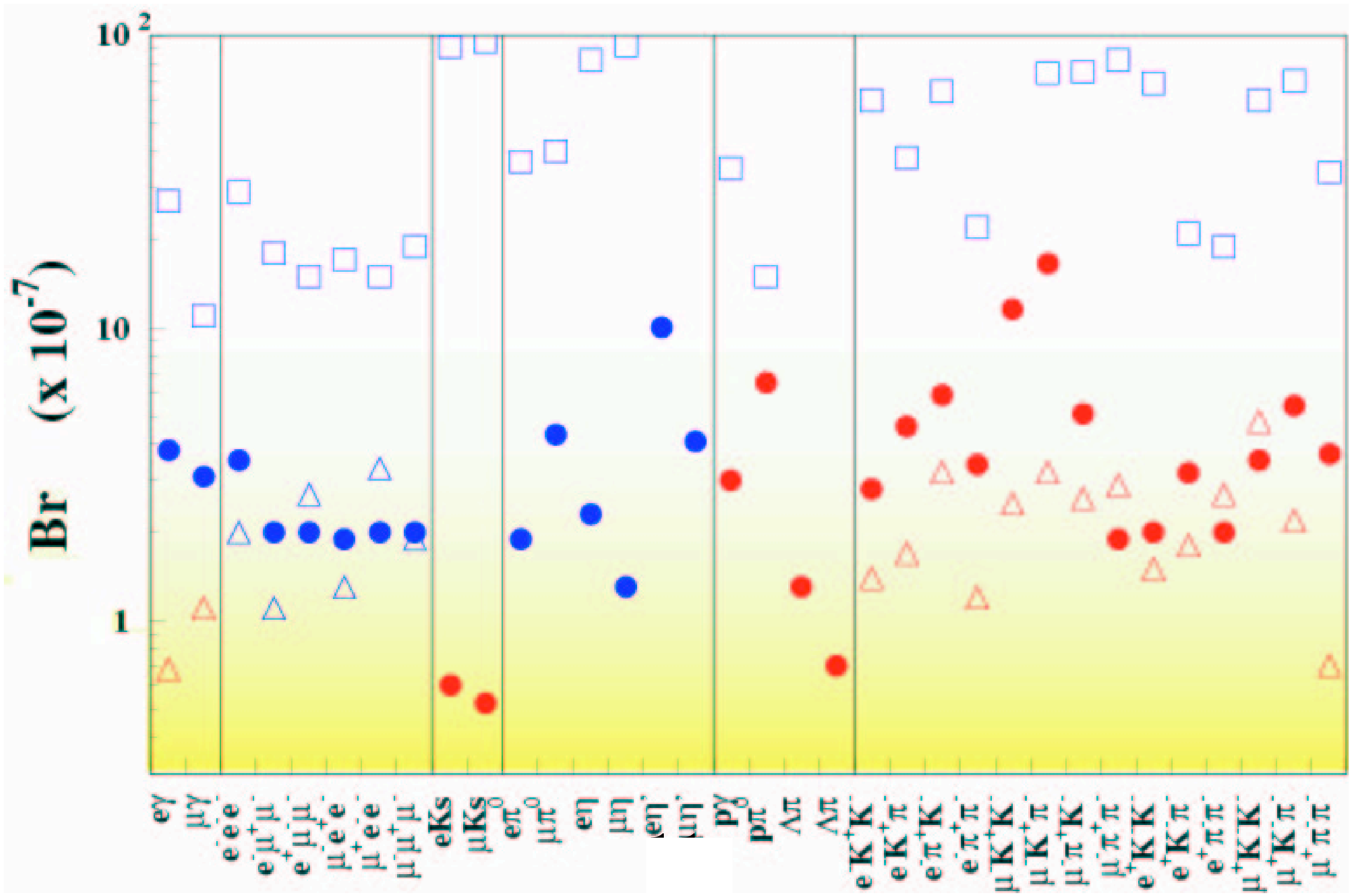
Similar region as Belle

Upper limit : (Eff=6.37%@±5σ box)
$\mathcal{B}(\tau \rightarrow e\gamma) < 3.9\times10^{-7}$ (90%C.L.)
(86.7/fb@Belle)
Phys. Lett. B613, 20 (2005)

Upper limit : (Eff=4.7%@2σ box)
($\mathcal{B}(\tau \rightarrow e\gamma) < 1.1\times10^{-7}$ (90%C.L.)
(232.2/fb@BaBar) (Preliminary)

Tau LFV limits are approaching 10^{-8} at B factories

(□ : CLEO, ● Belle, △ BaBar, Blue:Published, Red: Preliminary)



S.Banerjee

... but already suffering background

Constraints on theoretical models from LFV τ decay

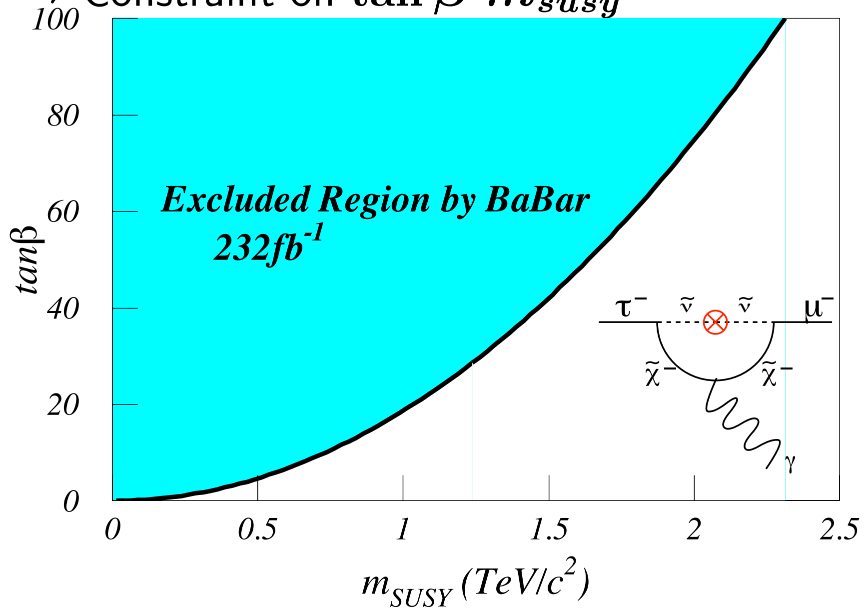
Constrain SUSY parameters from LFV τ decay

MSSM with Seesaw

(J. Hisano et al., PR**D60**(1999)055008)

$$\mathcal{B}(\tau \to \mu\gamma) \simeq 7 \times 10^{-7} \left(\frac{\tan\beta}{60}\right)^2 \left(\frac{1\text{TeV/c}^2}{m_{SUSY}}\right)^4$$

$\longrightarrow$ Constraint on $\tan\beta$-m_{susy}

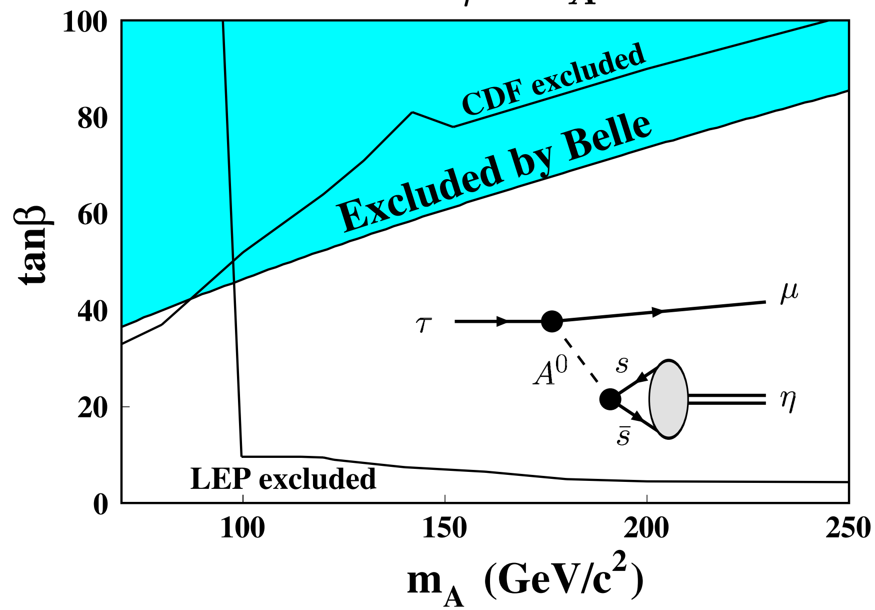


Higgs mediated in MSSM

(M. Sher, Phys. Rev. D **66**, 057301 (2002))

$$\mathcal{B}(\tau \to \mu\eta) = 8.4 \times 10^{-7} \left(\frac{\tan\beta}{60}\right)^6 \left(\frac{100\text{GeV/c}^2}{m_A}\right)^4$$

$\longrightarrow$ Constraint on $\tan\beta$-m_A

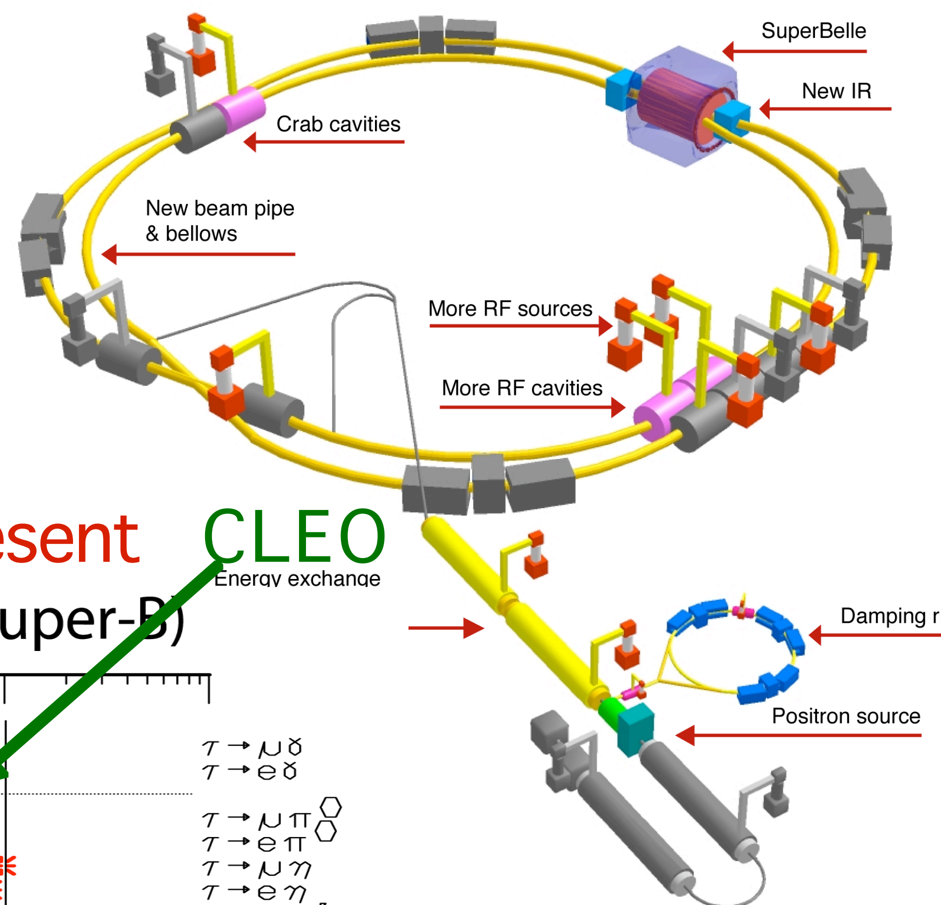


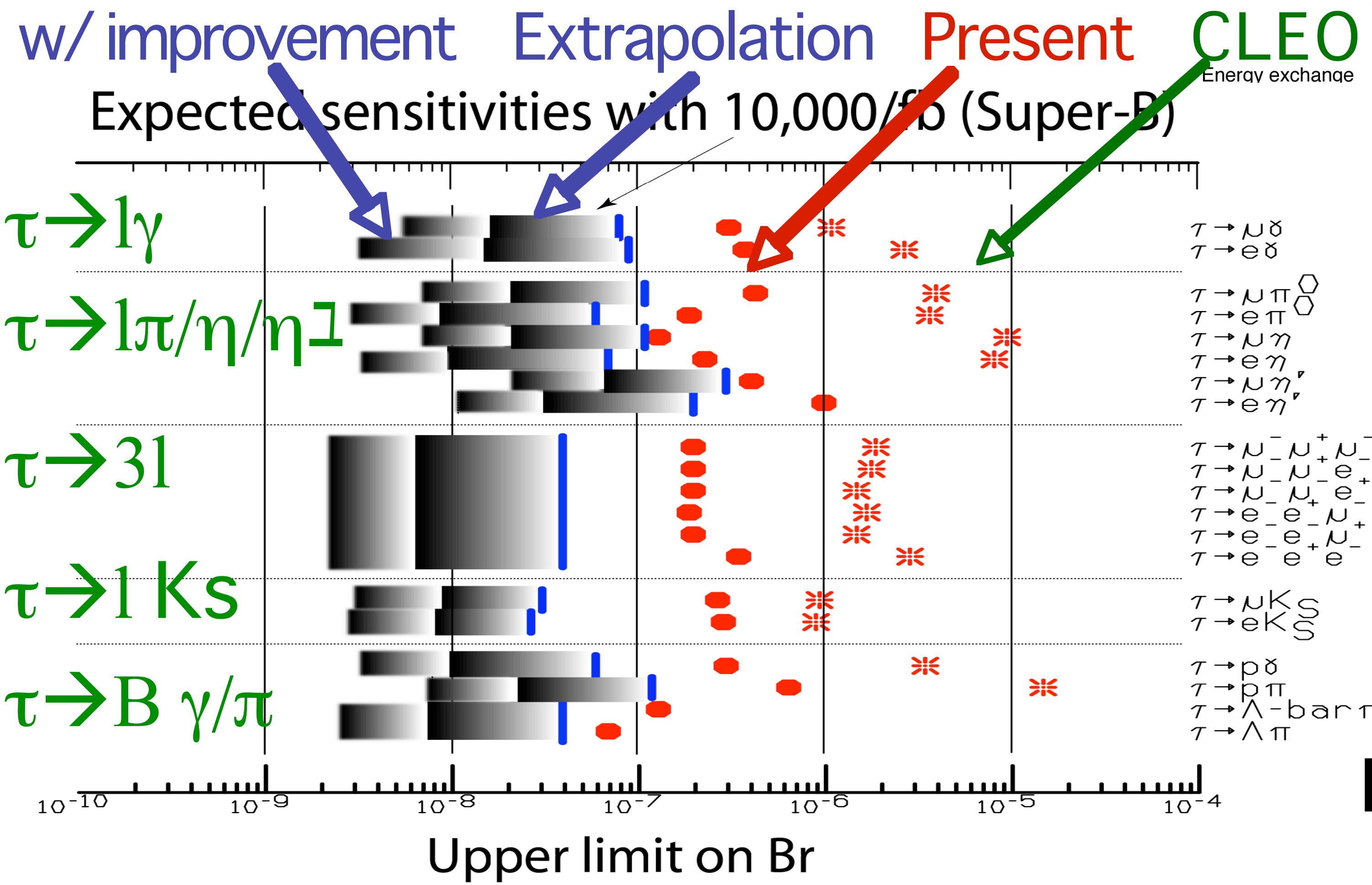
($\tan\beta$: the ratio of the vacuum expectation values of the two Higgs doublets,
m_{susy}: SUSY mass scale, m_A: the pseudo-scalar Higgs mass)

Constraining MSSM for Higgs mediation and large tanβ

Super B Factory
with ~4 x $10^{35}/cm^2/sec$

4 x 10^9 tau pairs /year





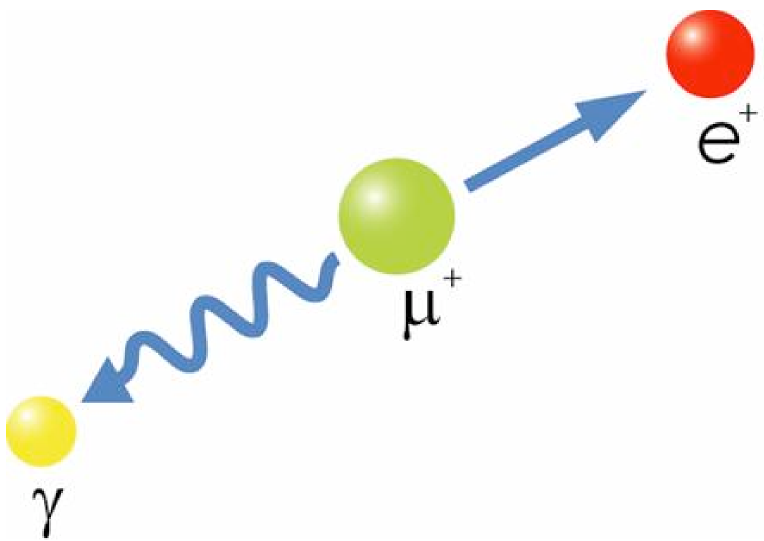
Background?

“Non-Tau Processes”

Muon to Electron

- Most Sensitive to SUSY GUT and SUSY Seesaw Models
  - ✓ $\tau \to \mu\gamma < 10^{-9}$ for SUSY SO(10)
- Predicted Branching Ratios are Within the Reach of the Next Experiments !

$\mu \rightarrow e\ \gamma$



Clear 2-body kinematics

Use μ^+ to avoid capture inside stopping target

Background dominated by Accidental coincidence

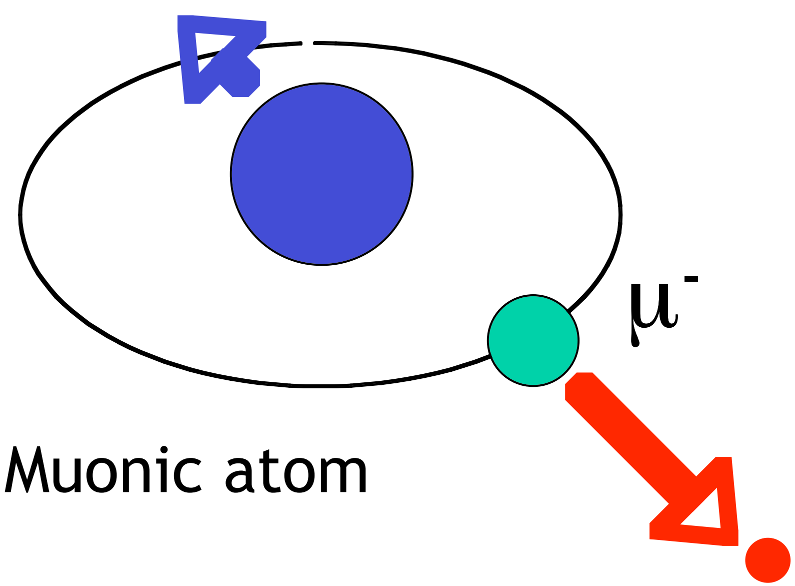
→ lower μ rate is better

→ DC μ beam is best

"surface muon beam": 100% polarized

Good detector system Is essential

$\mu \rightarrow e$ conversion



μ^- to make a muonic atom

a single electron with

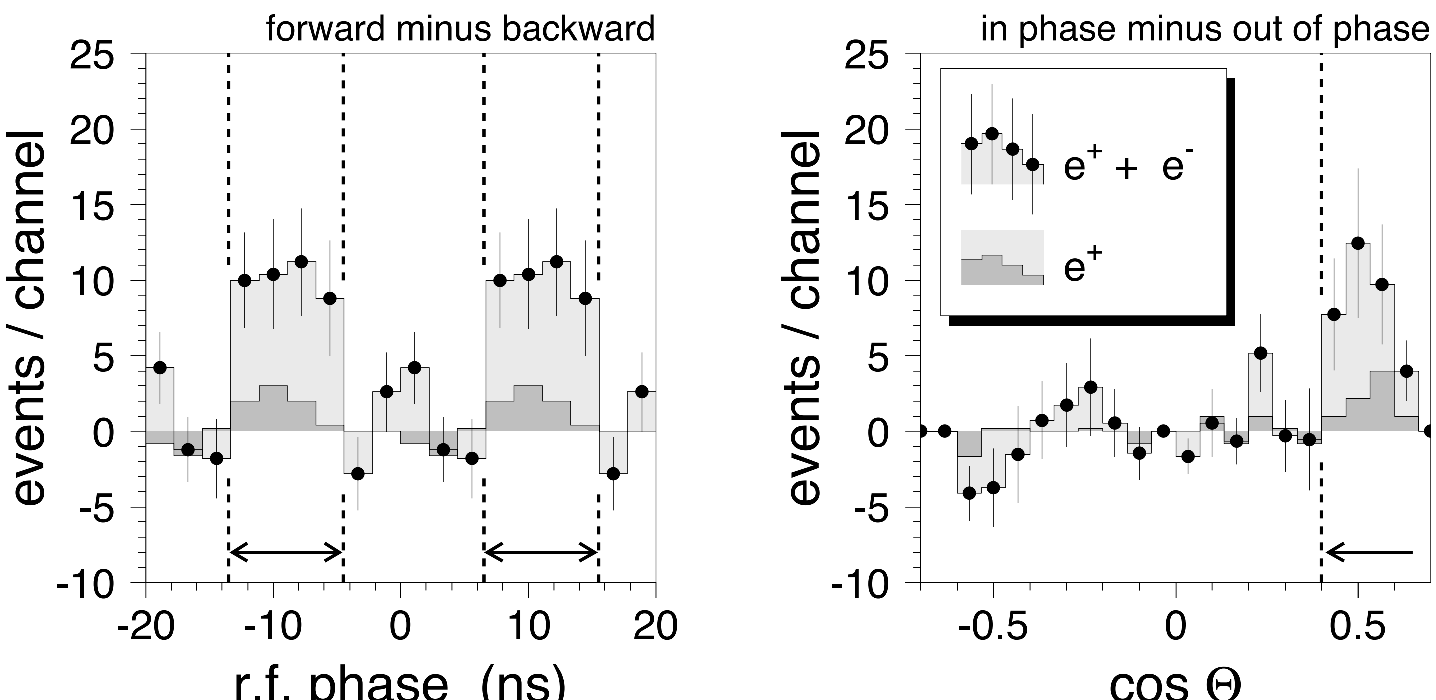
$$E_e = M_\mu - \delta$$

Background:

- Decay in orbit
  $\sim(E_{max} - E_e)^5$
- Beam related
  → next page

Prompt Beam Induced Background

SINDRUM II @PSI

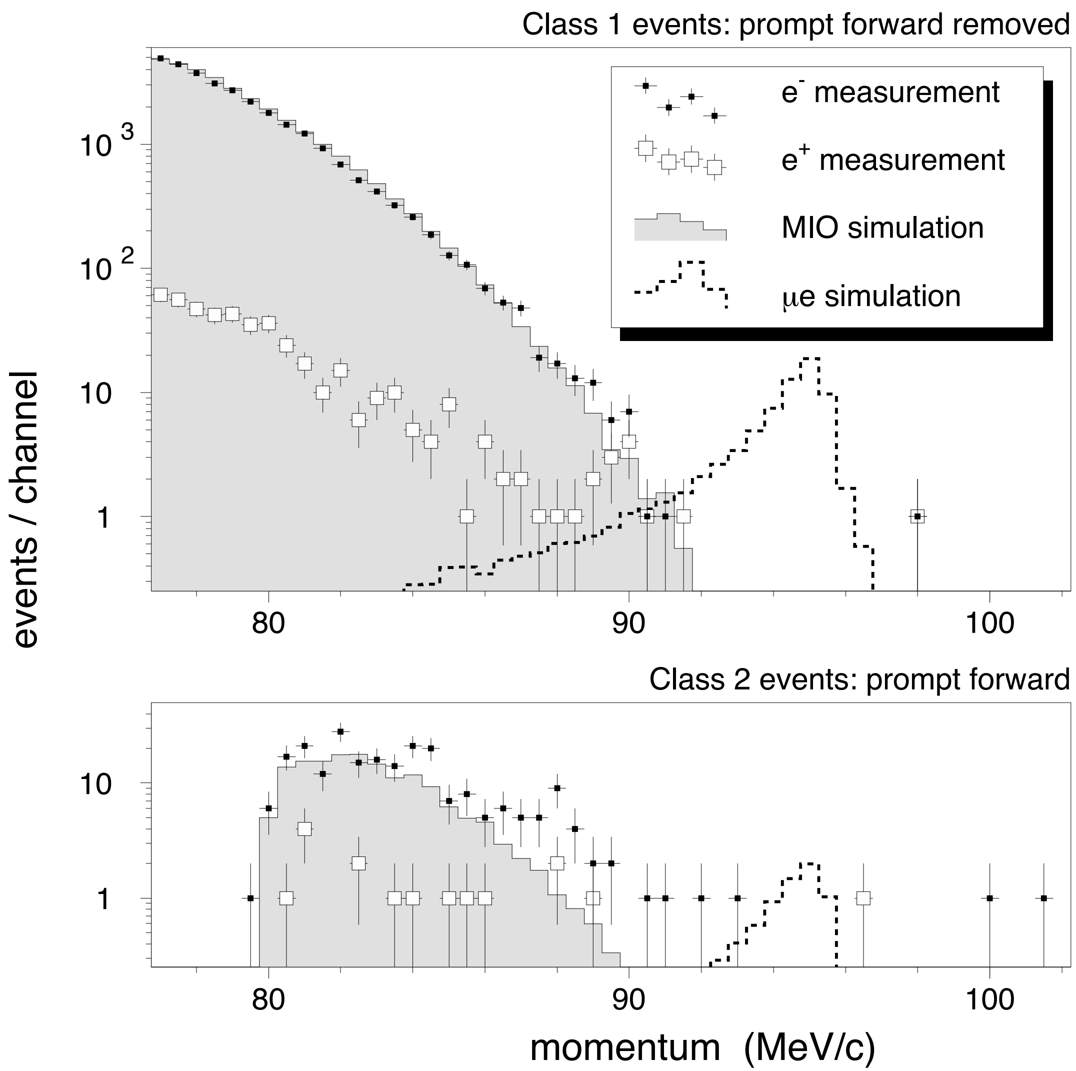


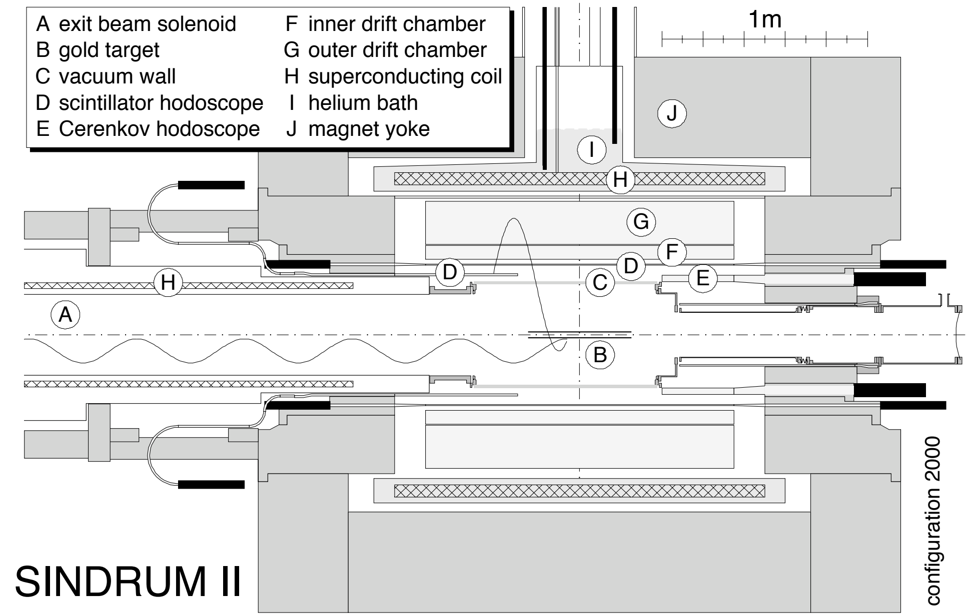
in coincidence with 20nsec Cyclotron RF

~ pion decay in flight

SINDRUM II

@ PSI





Final result on mu - e conversion on Gold target is being prepared for publication

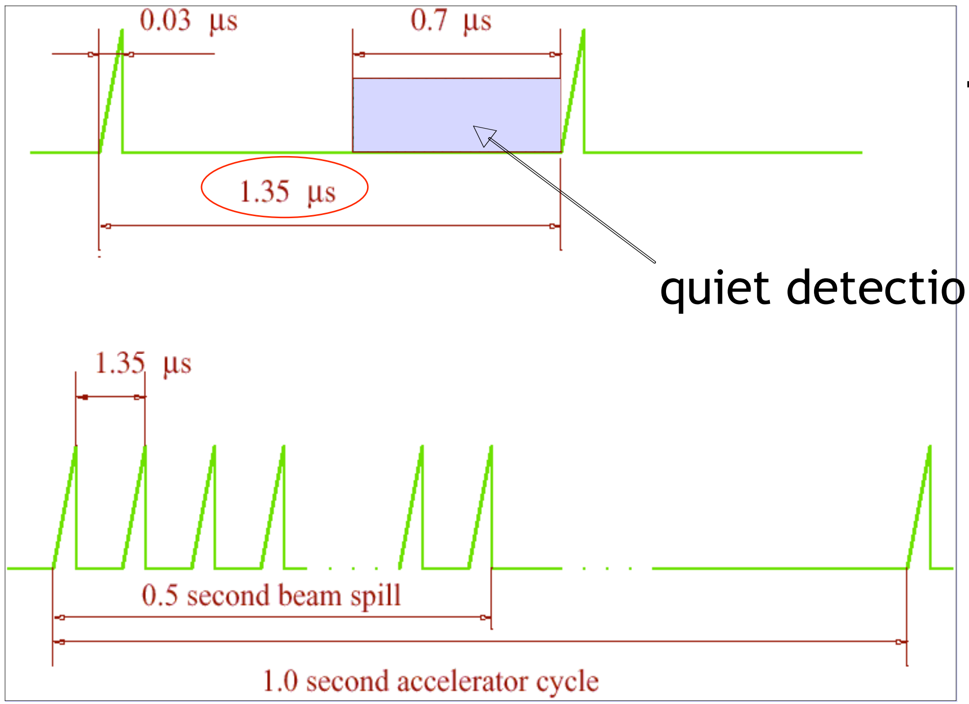
$< 7 \times 10^{-13}$ 90%CL

MECO Experiment @BNL

Beam-related background

e.g. radiative pion capture

Proton beam



quiet detection time

→ Use pulsed beam
Measure only in between

"beam extinction"

Note:
muon capture ~ Z^4

Effective μ lifetime

0.9 μs	for Al
0.3 μs	Ti
0.06 μs	Pb

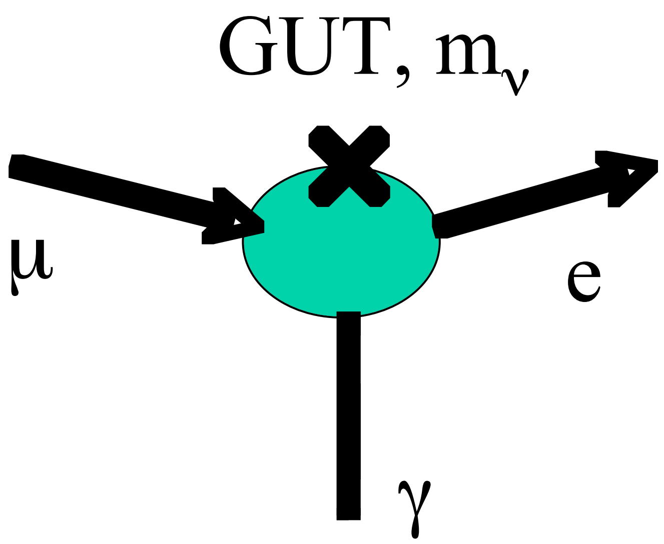
MECO @AGS
Uses Al target

Good beam is essential

$\mu \to e\,\gamma$ vs $\mu \to e$ conversion

Physics sensitivity

$$\frac{\mu \to e\,\gamma}{\mu \to e \text{ conversion}} = \begin{cases} \sim 390 & \text{Al target} \\ \sim 240 & \text{Ti} \\ \sim 340 & \text{Pb} \end{cases}$$



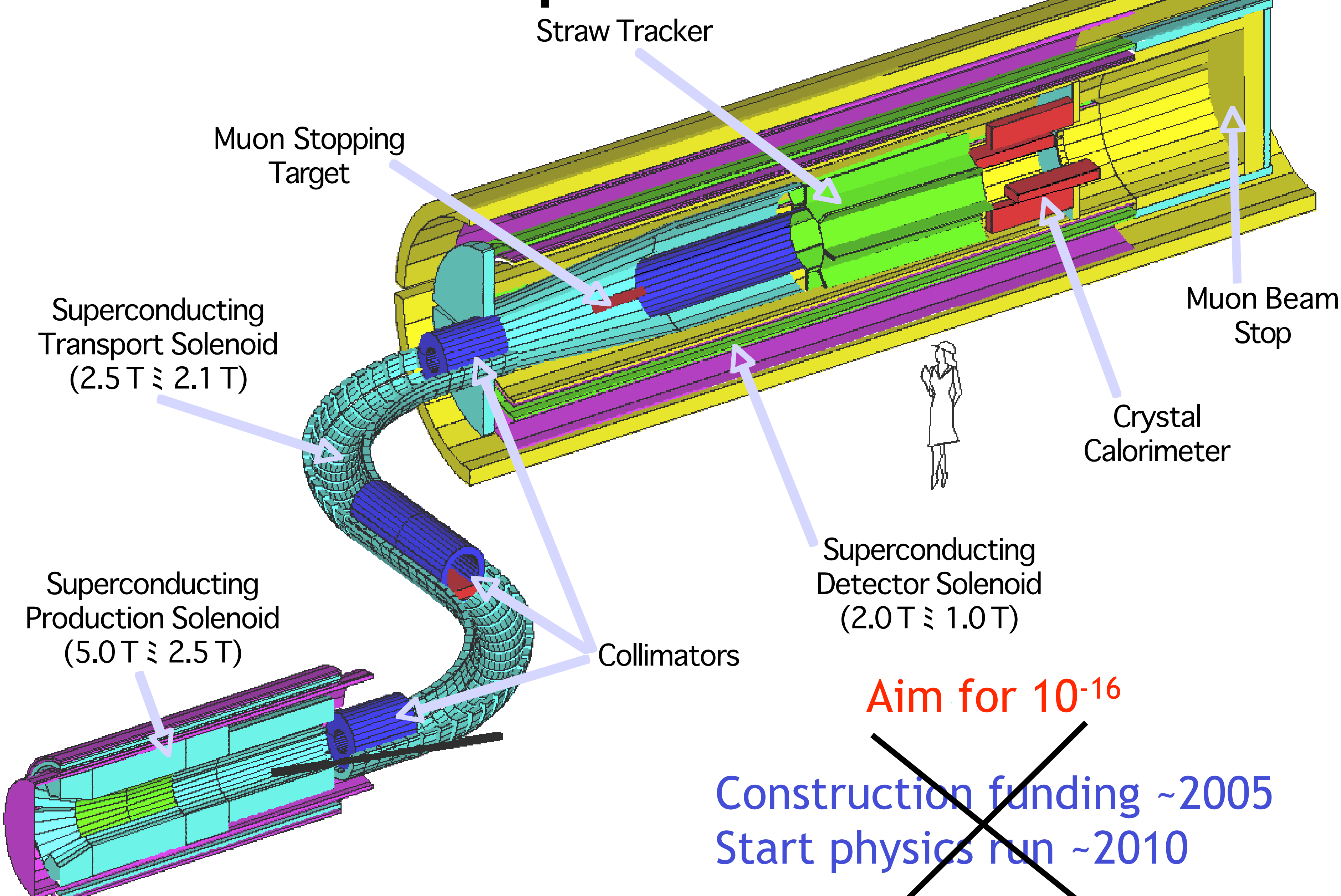
1×10^{-14} $\mu \to e\gamma$

10^{8}/sec DC beam

$\sim 3 \times 10^{-17}$ $\mu \to e$ conv

10^{11}/sec pulse beam

The MECO experiment



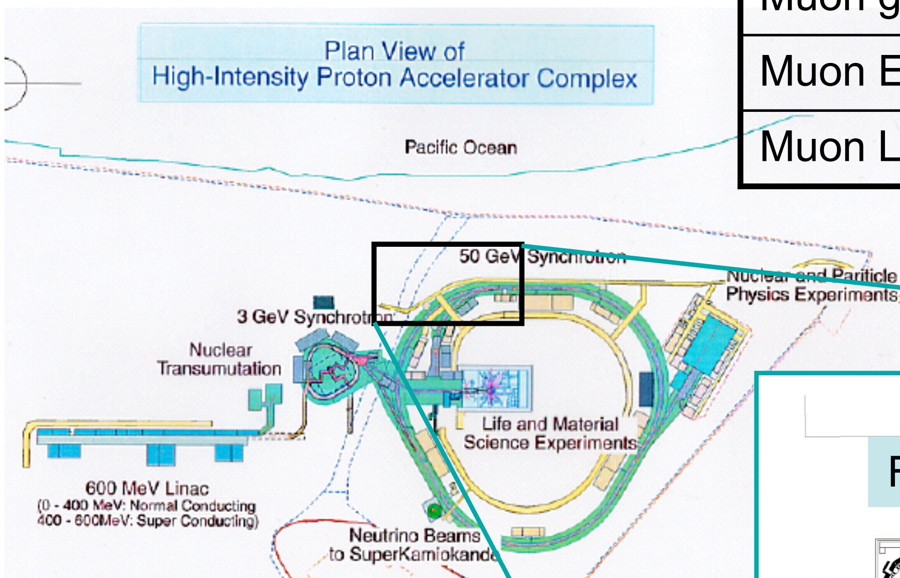
Aim for 10^{-16}

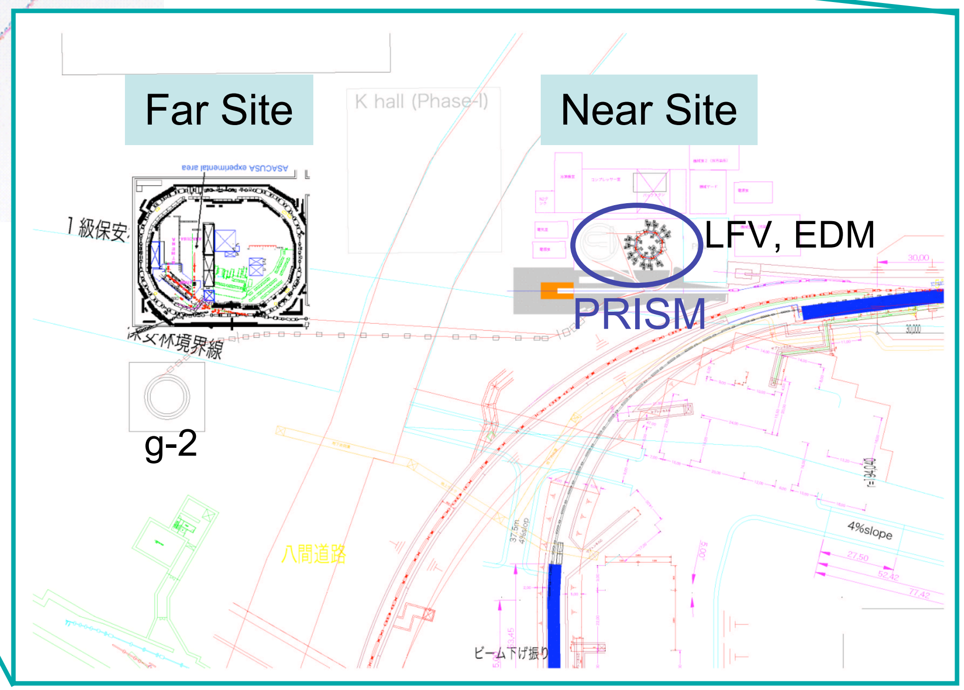
~~Construction funding ~2005~~
~~Start physics run ~2010~~

CANCELLED

Proposed Muon Facility at J-PARC

mode	Present	Goal
Muon g-2	0.5 ppm	0.05 ppm
Muon EDM	10^{-19}ecm	10^{-24}ecm
Muon LFV (m-e conv.)	$< 2\times10^{-13}$	$< 10^{-18}$

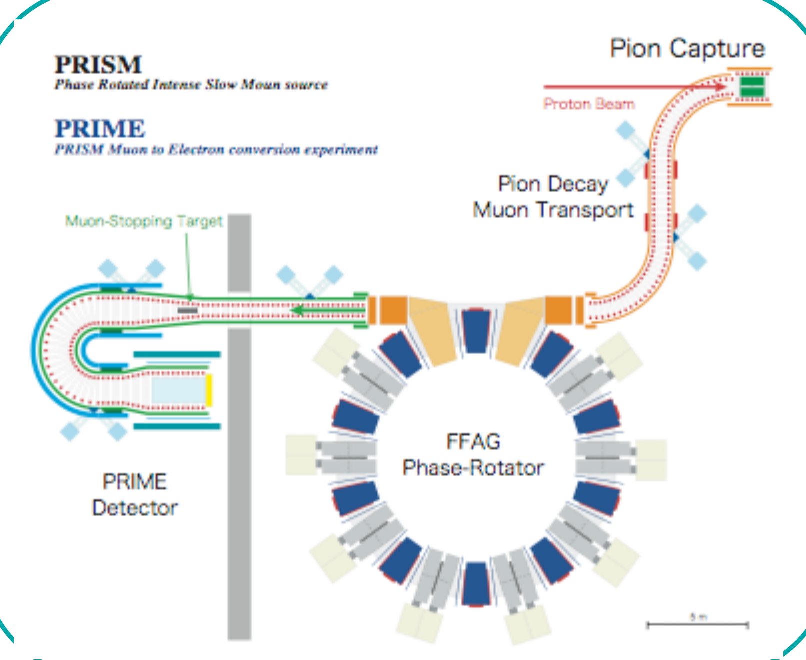




PRISM/PRIME for $\mu^- N \rightarrow e^- N$

A high-quality beam is essential to carry out $\mu^- N \rightarrow e^- N$ at high sensitivity.

- PRISM
- (=Phase Rotated Intense Slow Muon source)
- High muon intensity
  - 10^{11} - 10^{12} μ^-/sec
- Low energy 68 MeV/c
- Pulsed beam
  - Rejection of background coming from proton
- Narrow energy spread (by phase rotation)
  - **ΔE/E** = ±0.5~1.0 MeV
  - thinner muon-stopping target
  - Better e^- momentum/energy resolution while keeping high muon stopping efficiency
- Less beam contamination
  - Practically no pion contamination **$\pi/\mu \sim 10^{-18}$**



- Year 2003-2007
  - PRISM-FFAG (phase rotator) is under construction
- Phase-I : construction and test of PRISM
- Phase-II : installation of PRISM to high intensity proton machine for mu-e. search.
- **GOAL: $B(\mu^- N \rightarrow e^- N) < 10^{-18}$**

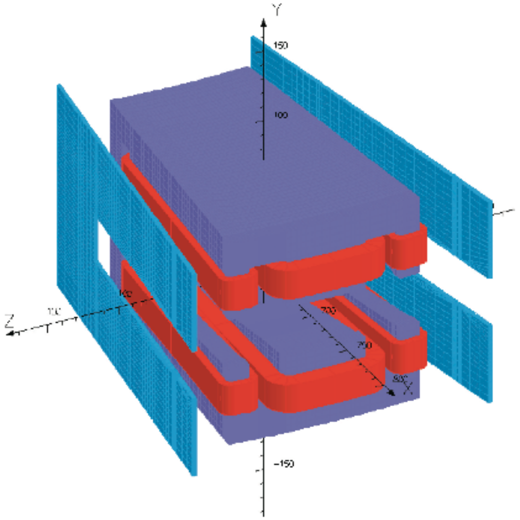
Y. Kuno

Construction of PRISM-FFAG Phase-Rotator

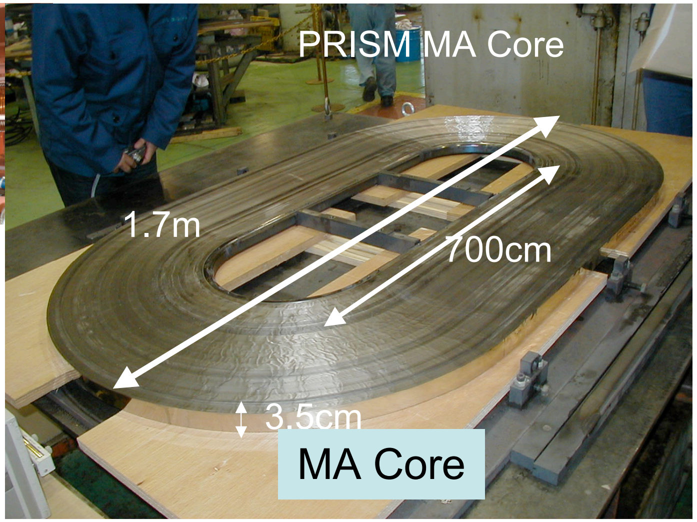
2003 - 2007
The PRISM FFAG magnets are under construction.
The RF system has been completed and tested.


FFAG D coils

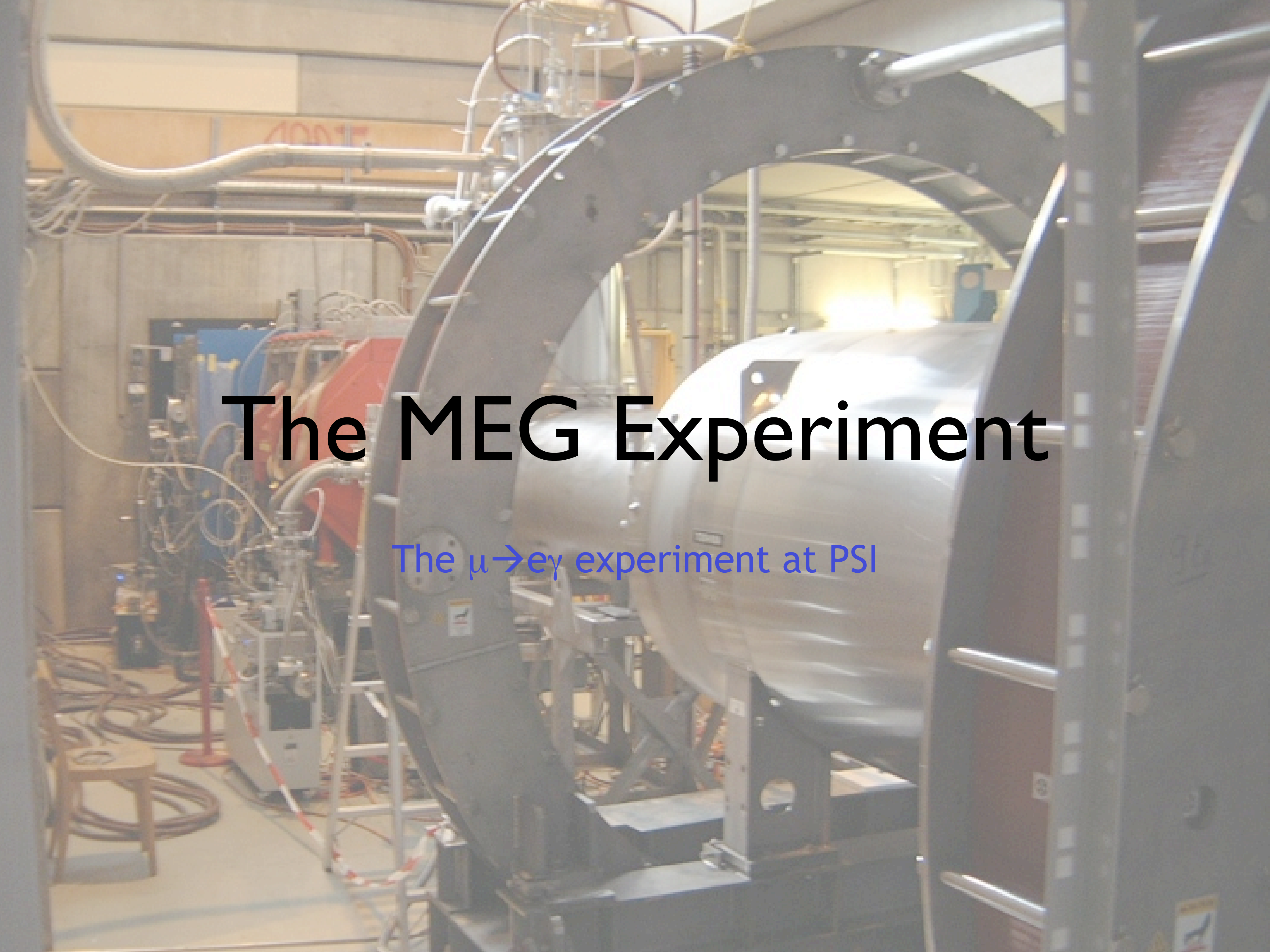

FFAG F coils


FFAG TOSCA model


RF Amp



MA Core



The MEG Experiment

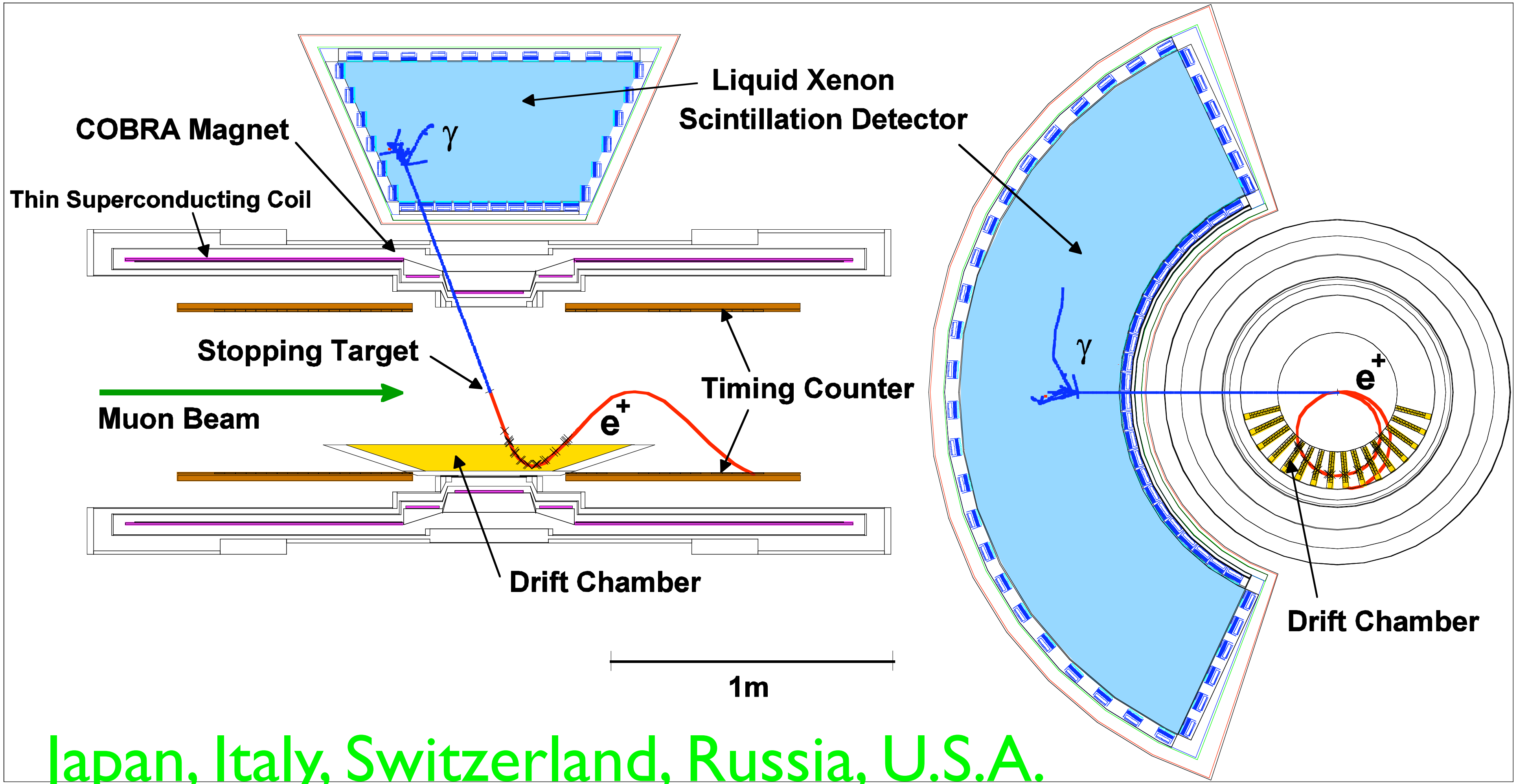
The $\mu \rightarrow e\gamma$ experiment at PSI

The MEG experiment

Approved at Paul Scherrer Institut, Switzerland in 1999

Start physics run in 2006

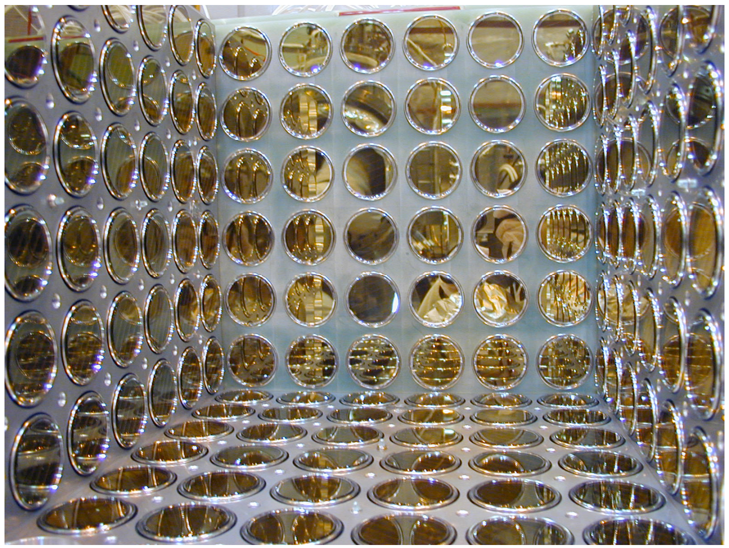
Initial aim at 10^{-13} eventually down to 10^{-14}



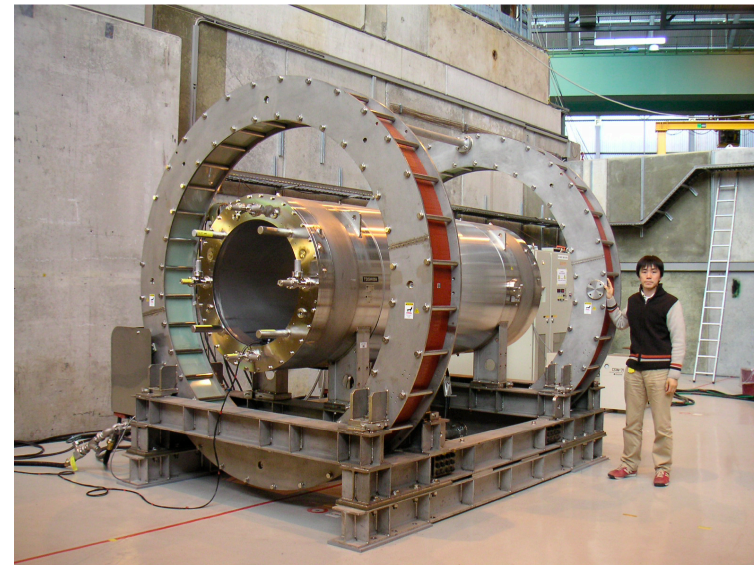
Japan, Italy, Switzerland, Russia, U.S.A.

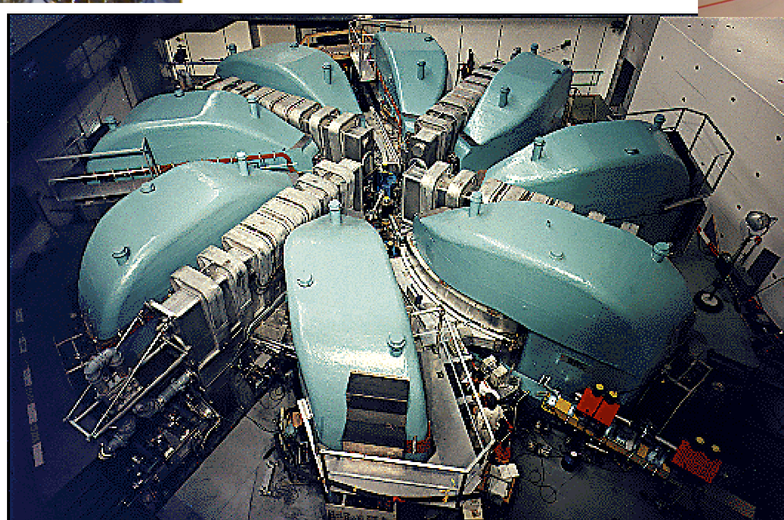
3 Techniques that enabled the experiment

LXe scintillation γ-ray detector



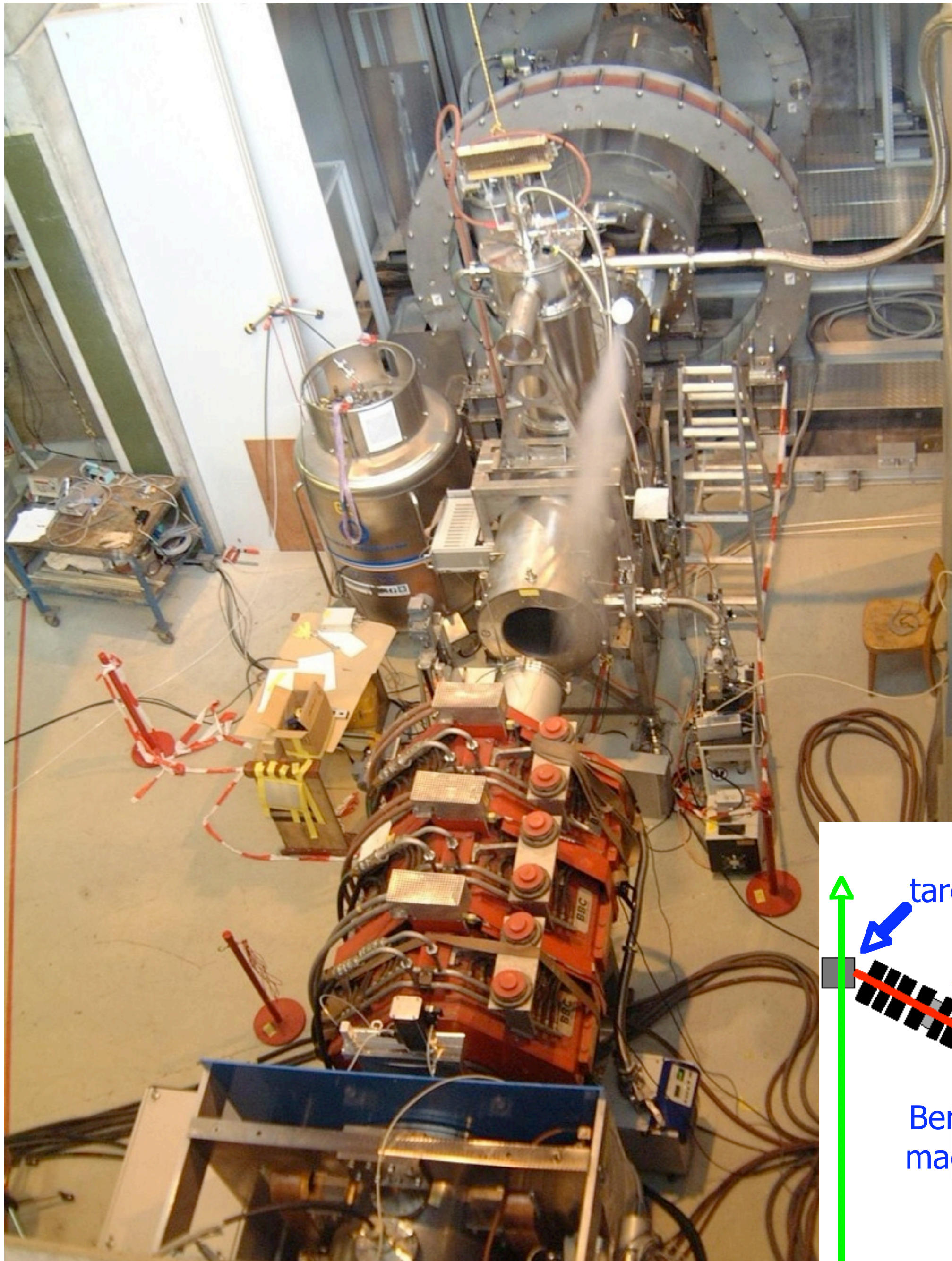
COBRA magnet
w/ graded B field





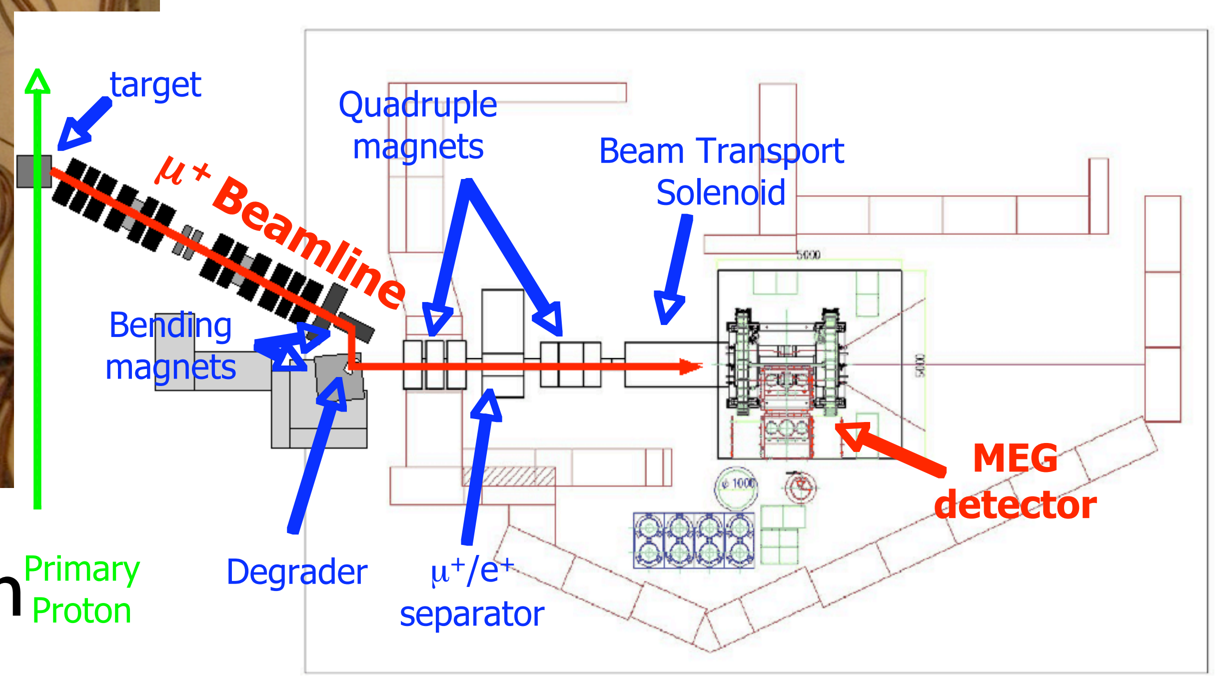
Most intensive DC muon beam (10^8/sec)

πE5 area @PSI



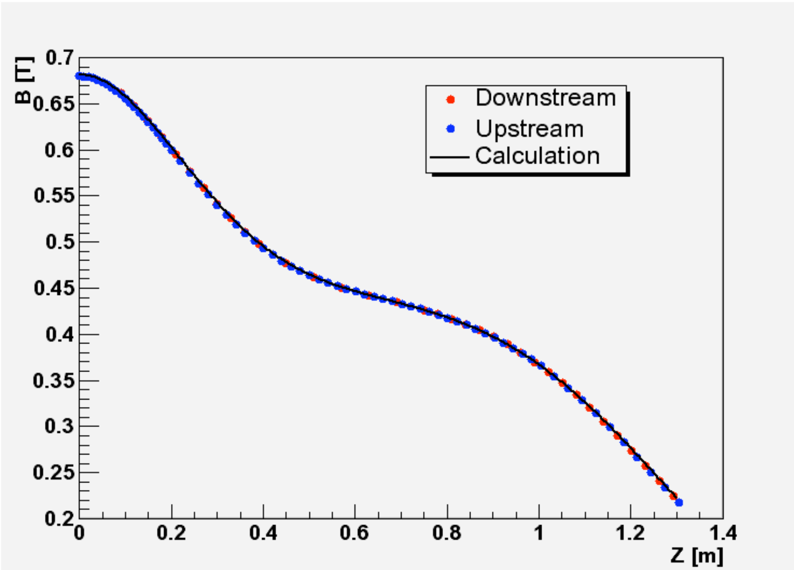
Presently tuning the beam down to the target position

10^8 muon stops /sec
~10mm spot size



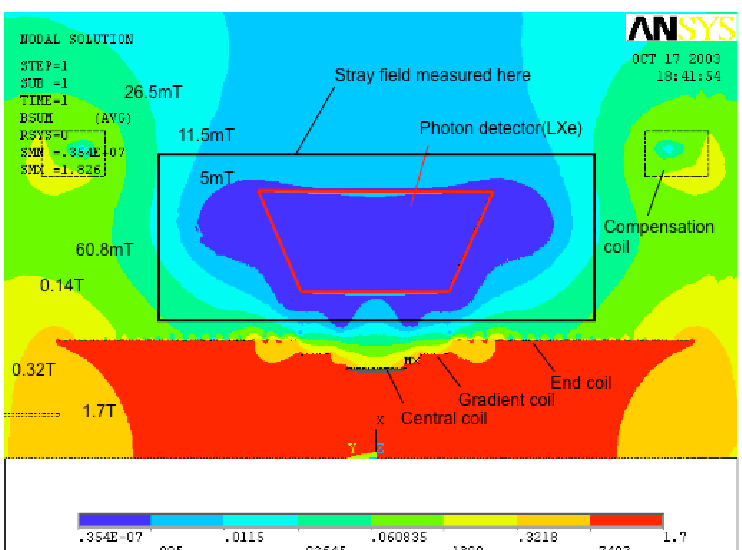
PSI Proton Cyclotron
590MeV, >1.8mA

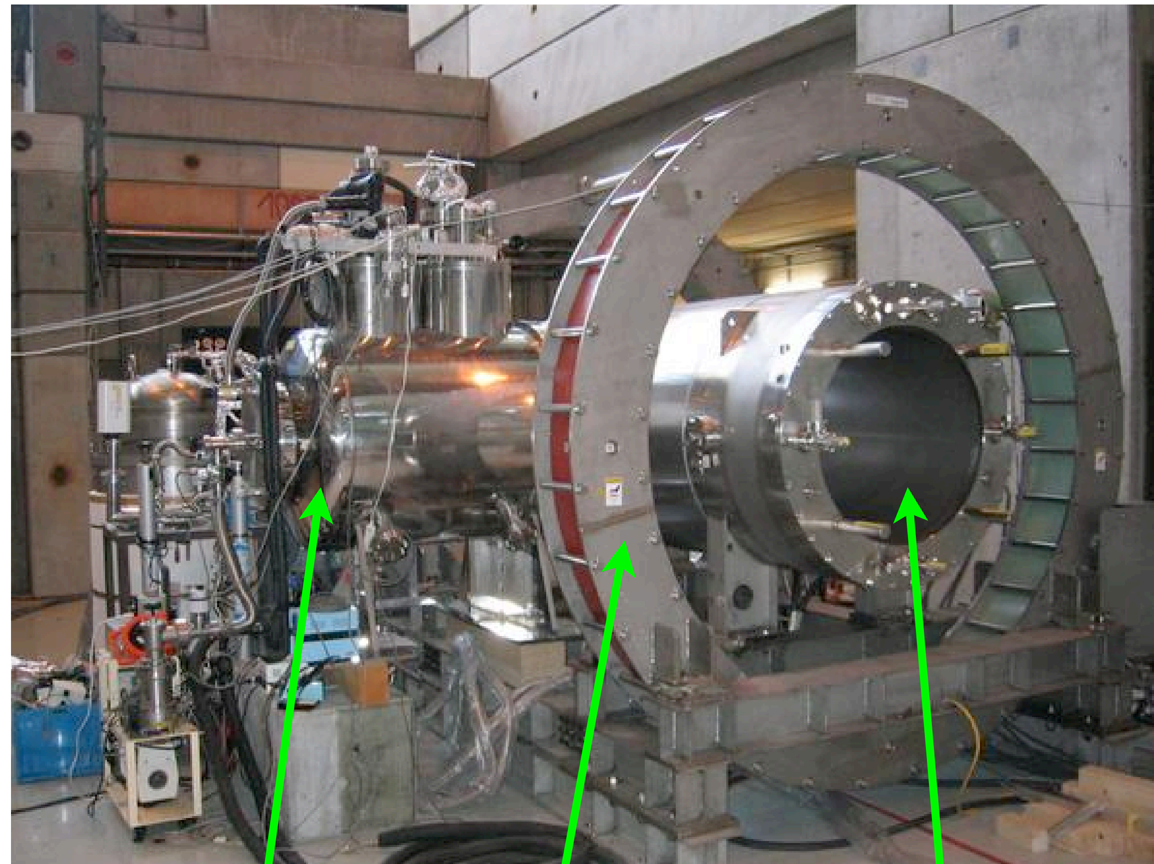
The COBRA Spectrometer



specially graded B field

low B field at LXe detector

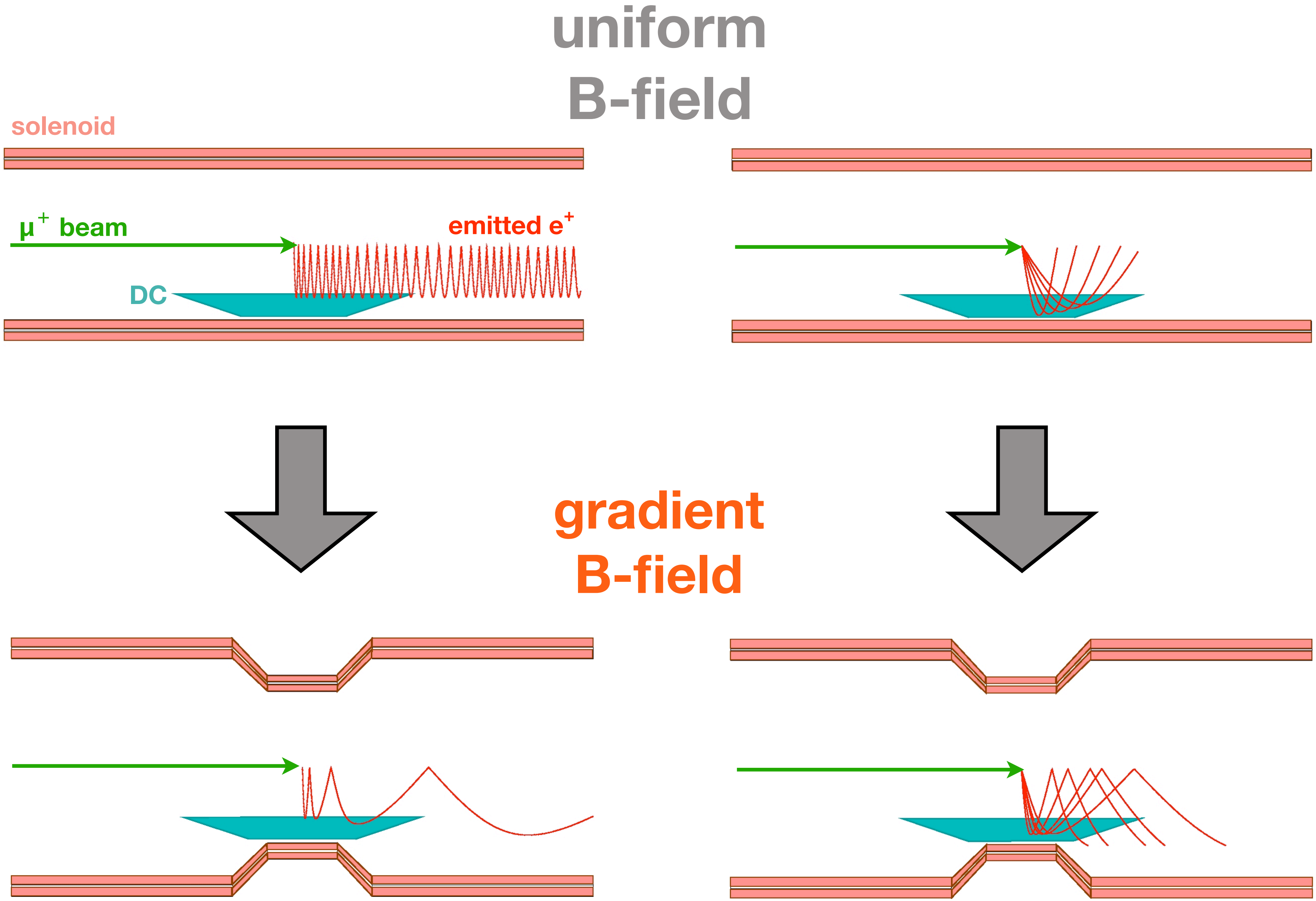




compensation coils

LXe detector prototype

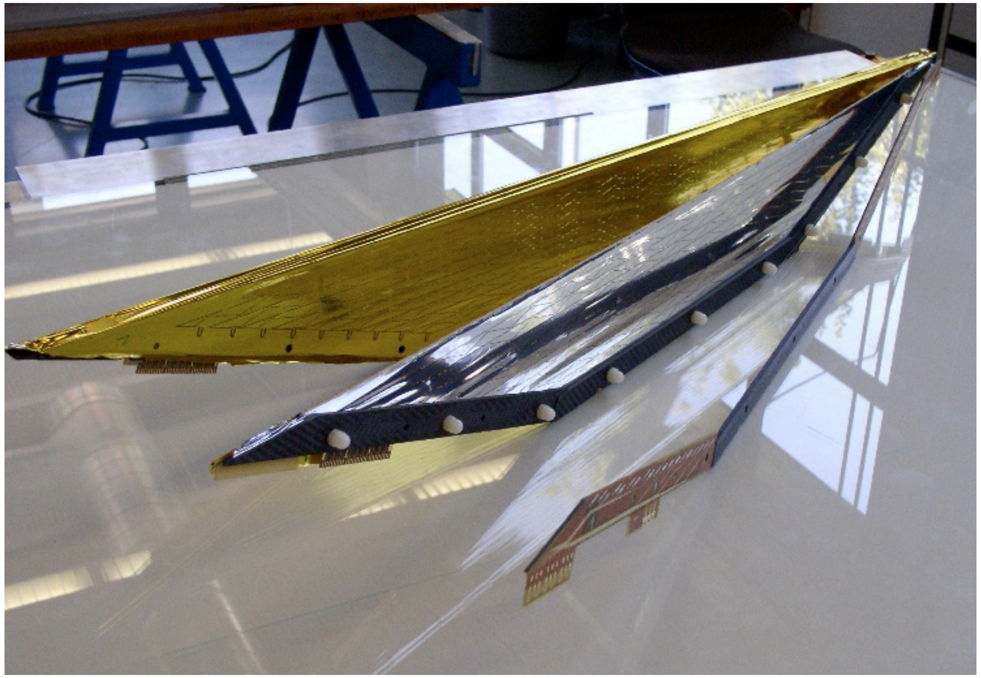
COBRA magnet



Low energy positrons quickly swept out

Constant bending radius independent of emission angles

Drift Chambers for Positrons



very low material to avoid multiple scattering and positron annihilation in flight

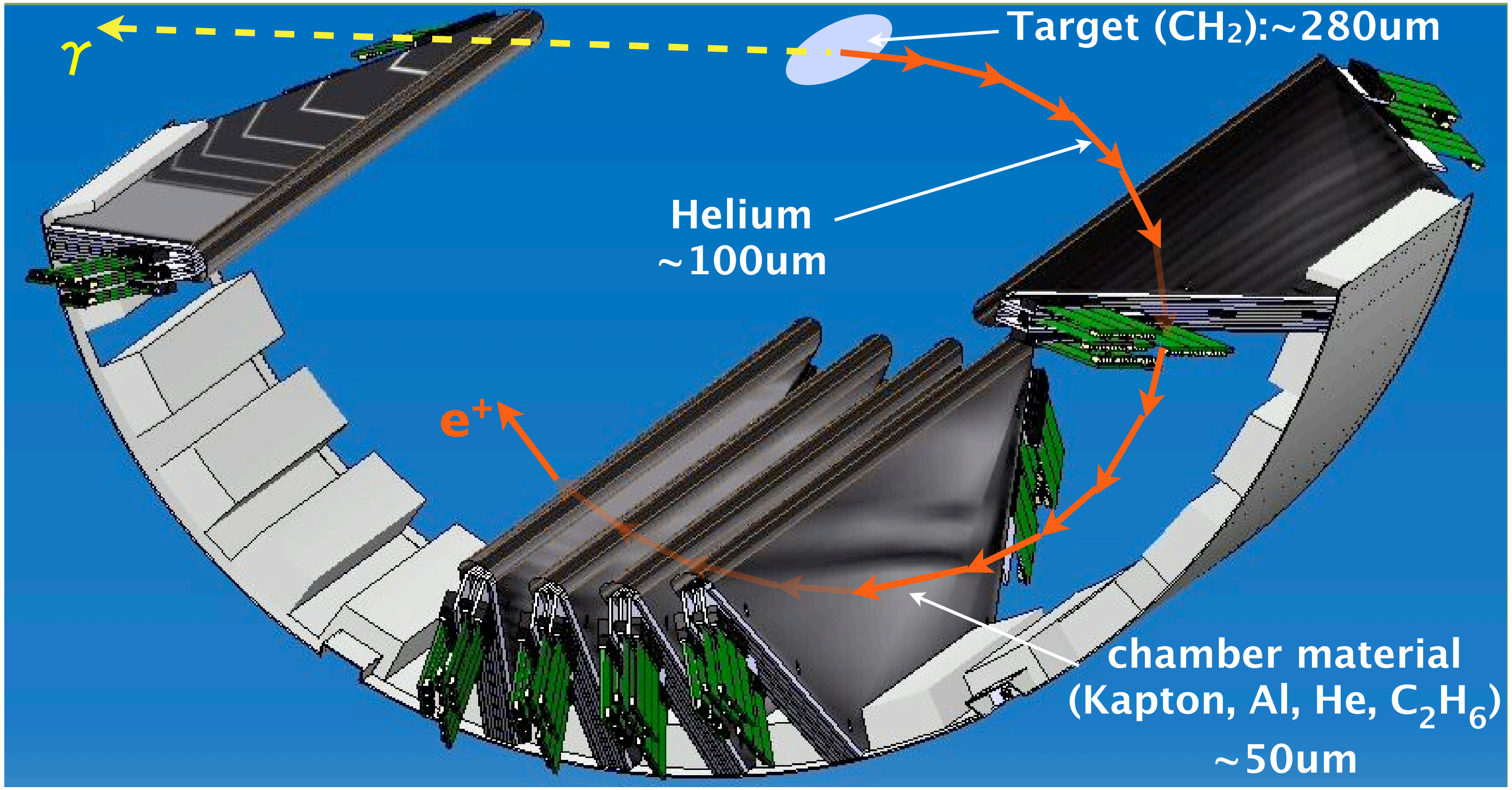
special vernier pads for z measurement

mom resolution
0.7-0.9%

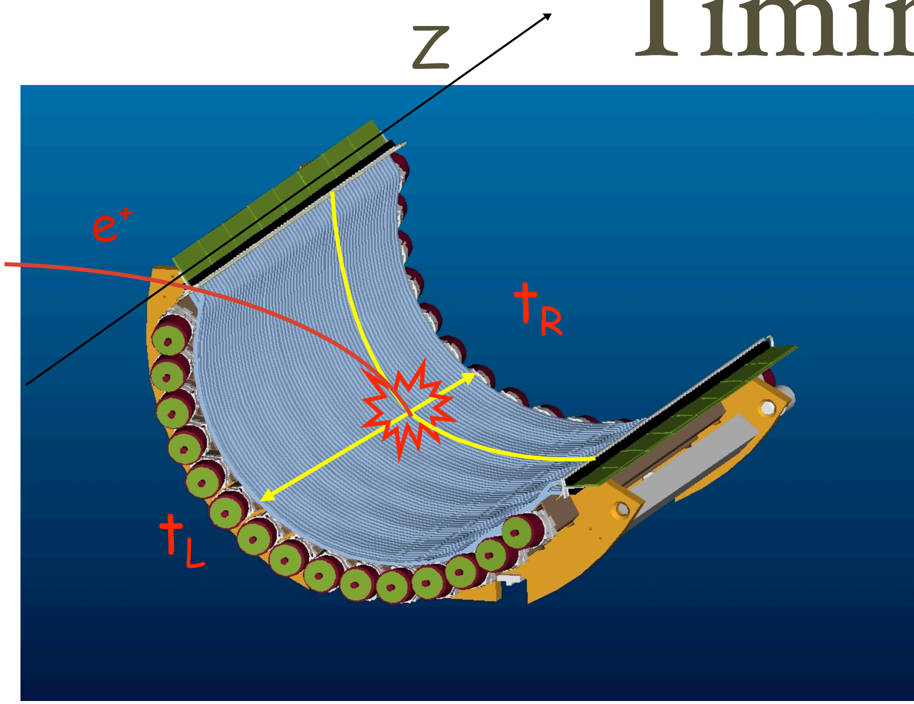
angle
9-12mrad

vertex
2.1-2.5mm

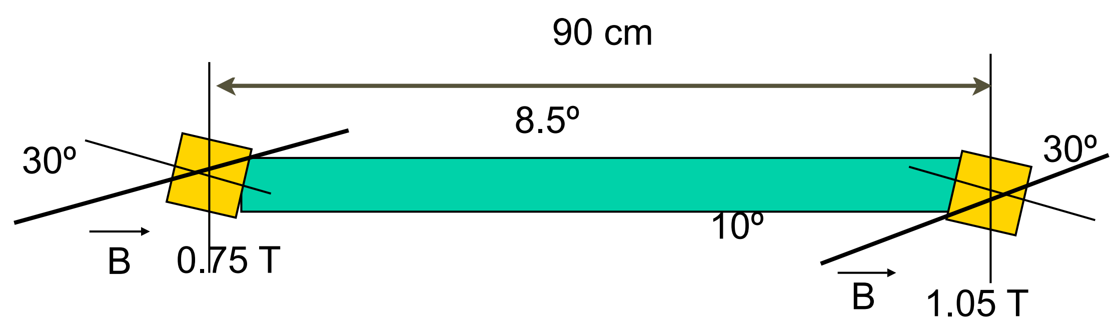
FWHM

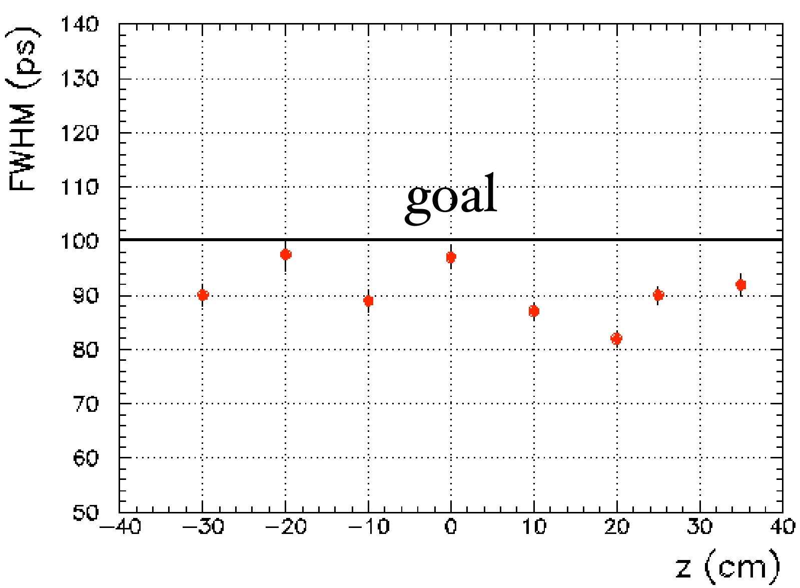


Timing Counter



- Two layers of scintillators:
  - Outer layer, read out by PMTs: timing measurement
  - Inner layer, read out with APDs at 90°: z-trigger
- Obtained goal σ_{time}~ 40 psec (100 ps FWHM)



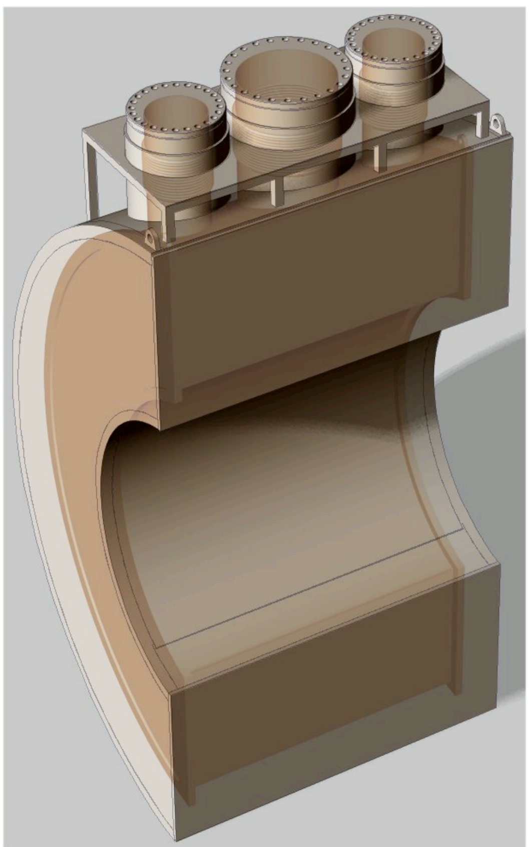


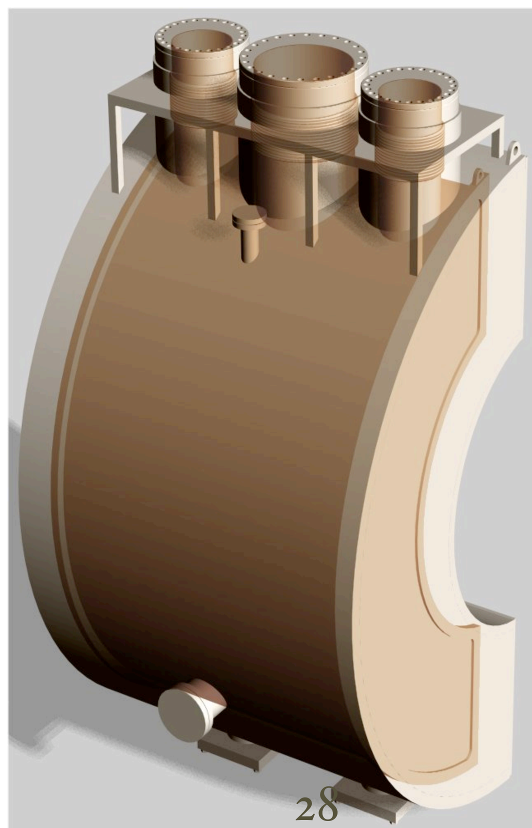
Exp. application (*)	Counter size (cm) (T x W x L)	Scintillator	PMT	λ_{att} (cm)	σ_t(meas)	σ_t(exp)
G.D.Agostini	3x 15 x 100	NE114	XP2020	200	120	60
T. Tanimori	3 x 20 x 150	SCSN38	R1332	180	140	110
T. Sugitate	4 x 3.5 x 100	SCSN23	R1828	200	50	53
R.T. Gile	5 x 10 x 280	BC408	XP2020	270	110	137
TOPAZ	4.2 x 13 x 400	BC412	R1828	300	210	240
R. Stroynowski	2 x 3 x 300	SCSN38	XP2020	180	180	420
Belle	4 x 6 x 255	BC408	R6680	250	90	143
MEG	**4 x 4 x 90**	**BC404**	**R5924**	**270**	**38**	

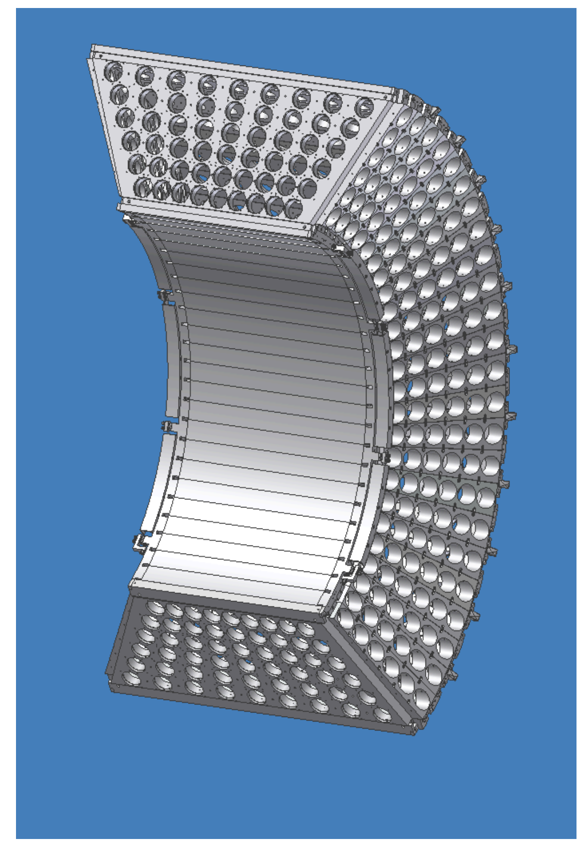
Best existing TC

LXe Gamma Ray Detector

LXe Scintillation: High Light Yield, Fast Signal
Measures Energy, Time and Position of Gamma Rays
3 ton LXe with ~850 PMTs
waveform digitizing to reject pile-up

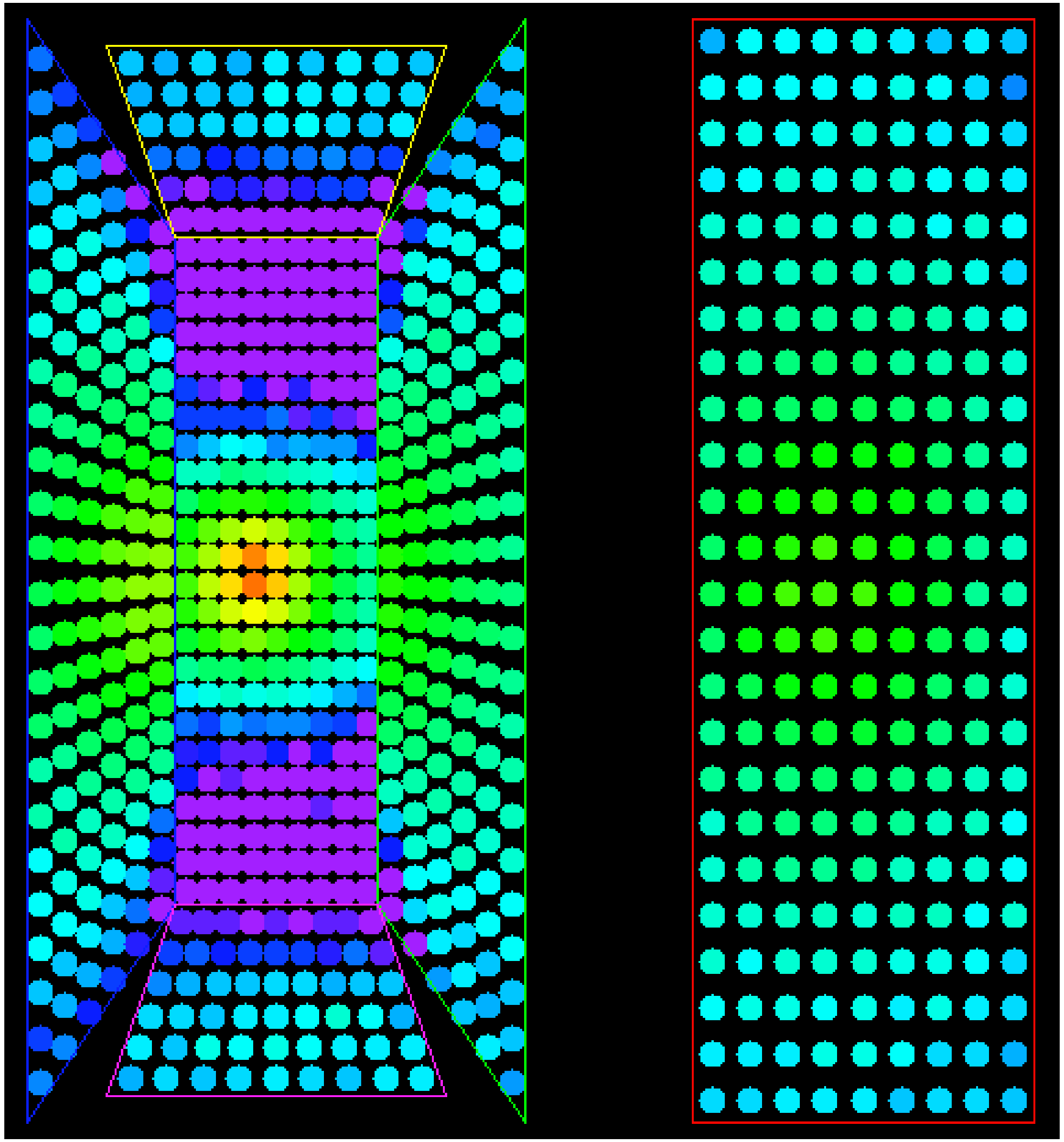


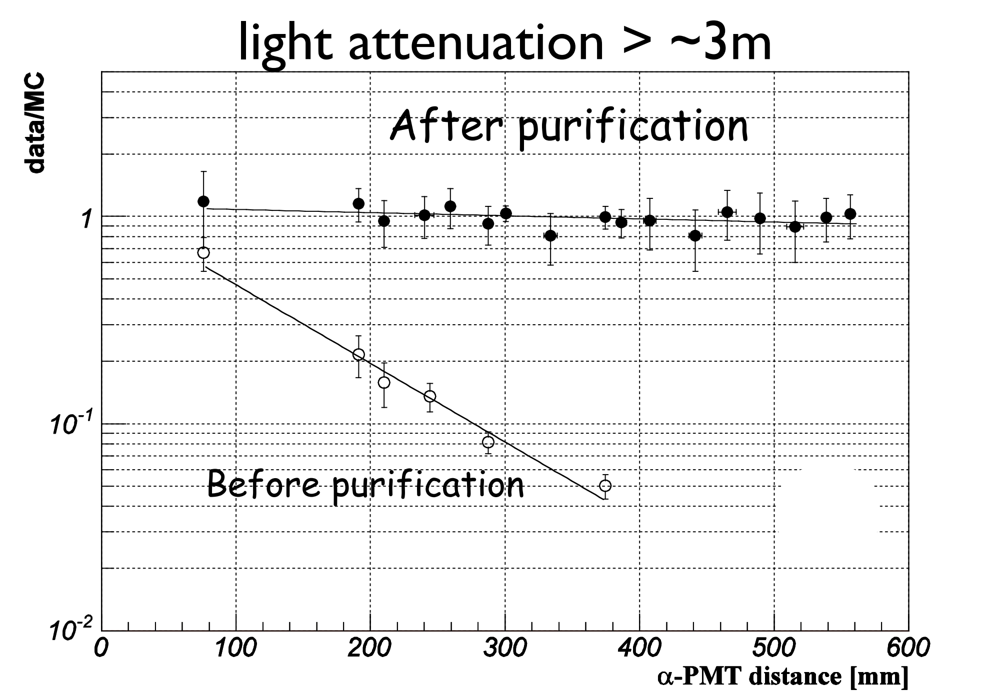


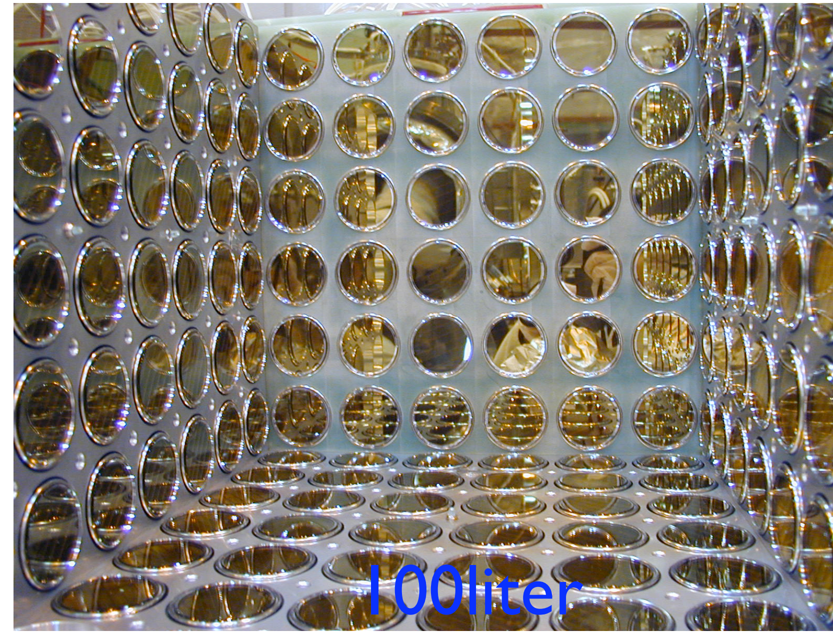


low temperature 165K, VUV light

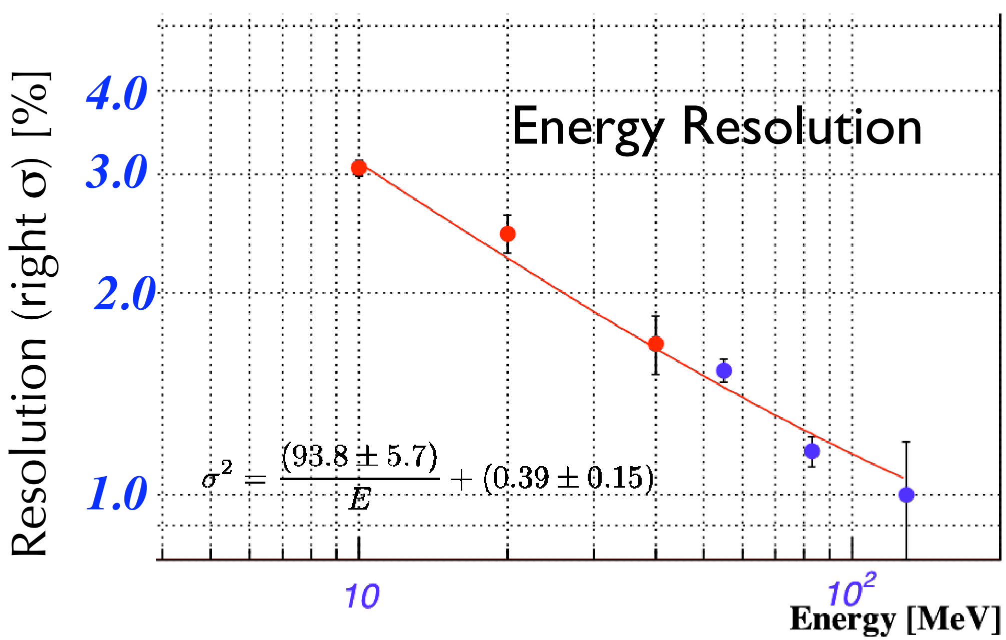
A Simulated Event

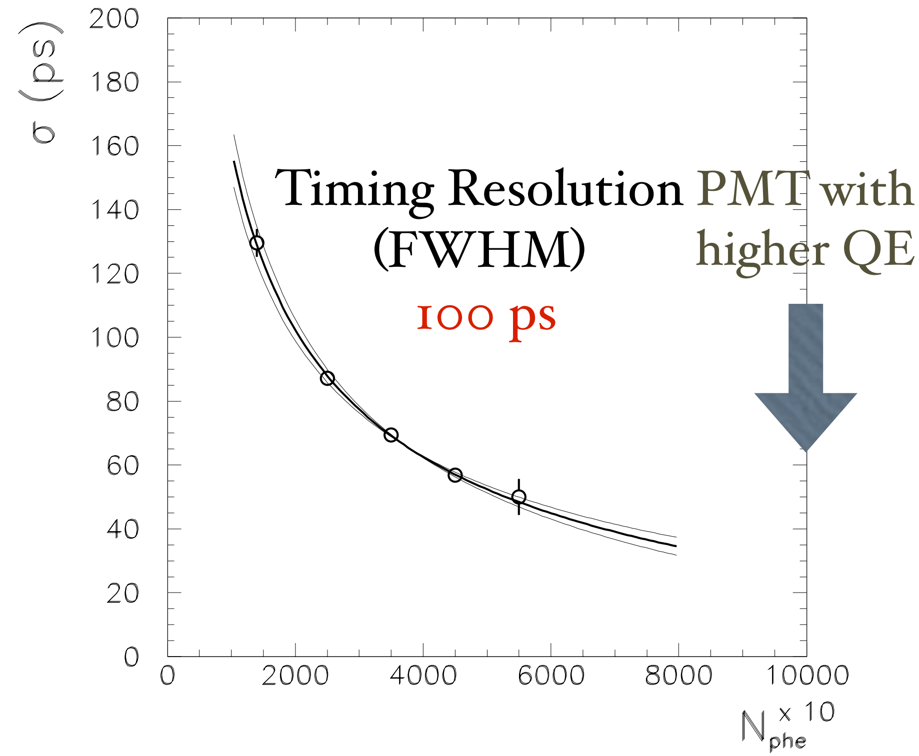






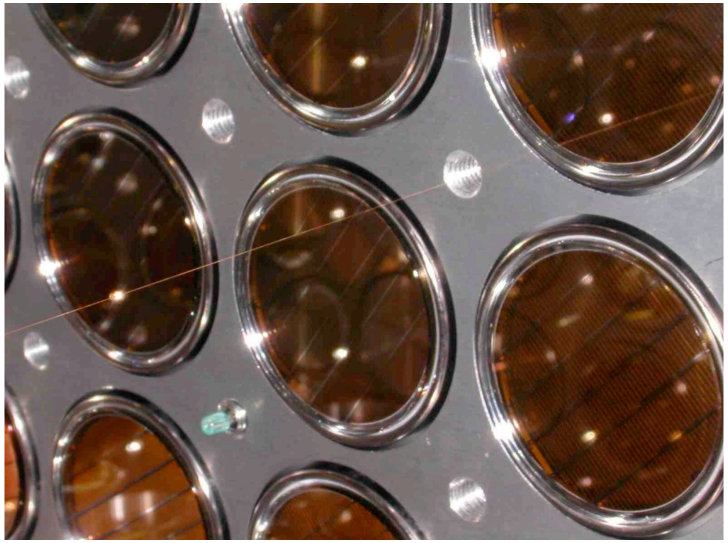
Prototype Detector





Calibration of LXe Detector

- alpha Sources (on wires and wall)
- Proton accelerator $^{7}\mathrm{Li}(p,\gamma_{17.6})^{8}\mathrm{Be}$ design under way
- Neutron generator $^{58}\mathrm{Ni}(n,\gamma_{9})^{59}\mathrm{Ni}$
- Charge exchange reaction (Panofsky) $\pi^{-}p \rightarrow \pi^{0}n$



MEG Prospects

- Detectors are presently under construction and will be ready next year (2006).
- Data taking takes ~2 years with muon beam of (1-2) x 10^7 /sec to reach ~1 x 10^{-13} sensitivity (90% CL).
- A pre-LHC era Experiment !
- Eventual reach to 1 x 10^{-14} with 10^8 /sec in the LHC era ?

A. Baldini

Conclusion

- Charged LFV experiments are now as highly expected as ever!
- The B Factories are rapidly improving the tau LFV limits though seeing background events.
- The MEG experiment will become ready next year and may obtain a significant result (discovery!) before entering the LHC era.
- New experiments are waiting to join them!