Lepton Flavour Violation and Rare Lepton Decays

T. Mori
The University of Tokyo

HQL2006, Munich

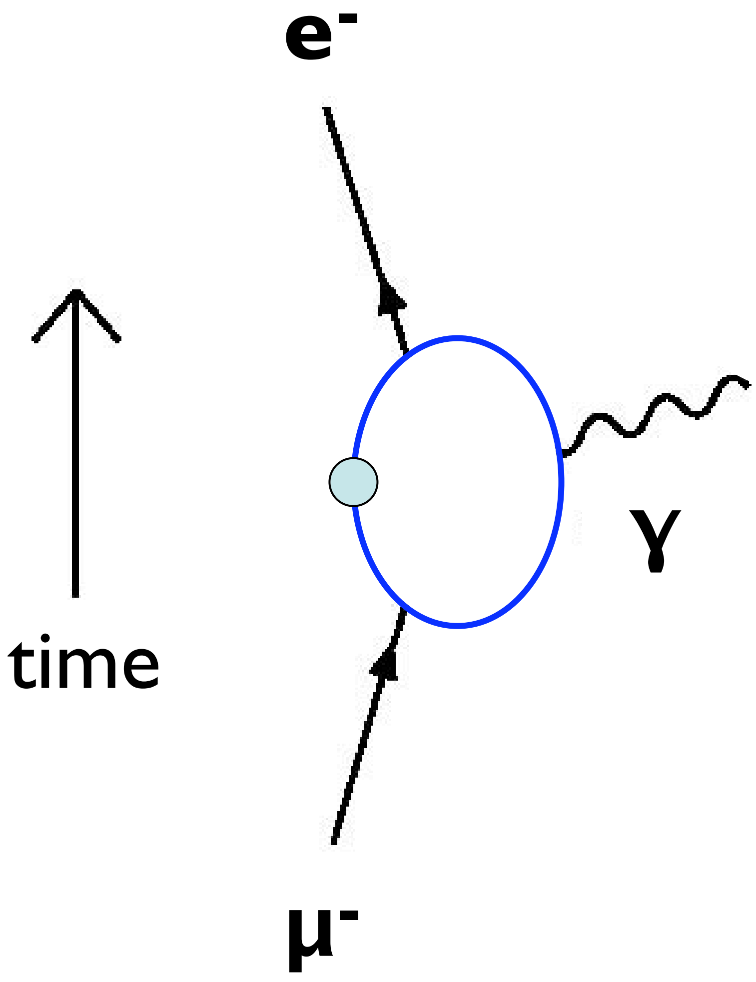
Topics to Cover

- Why Is Lepton Flavor Violation Interesting?
- LFV Tau Decays at B Factories (very briefly)
- LFV Muon Decays
  - ✓ Muon to Electron Conversion
  - ✓ Muon Decay to Electron and Gamma
    - MEG experiment

Why LFV interesting?

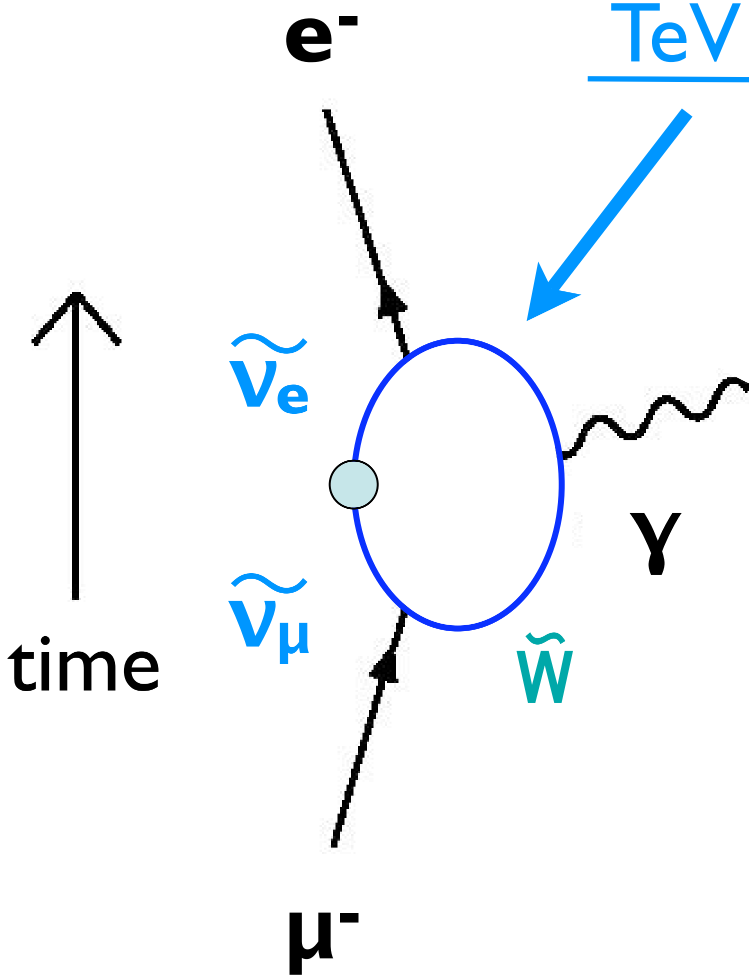
- Neutrino LFV --> LFV among charged leptons!
- LFV in charged leptons Is NEW PHYSICS.
  - ✓ Some experiments are already sensitive to SUSY GUTs, seesaw, and possibly more.
  - ✓ So just find it!
- Quark FV is generally contaminated by SM.
  - ✓ Looking for tiny deviations is not easy.

Lepton Flavor Violating Process



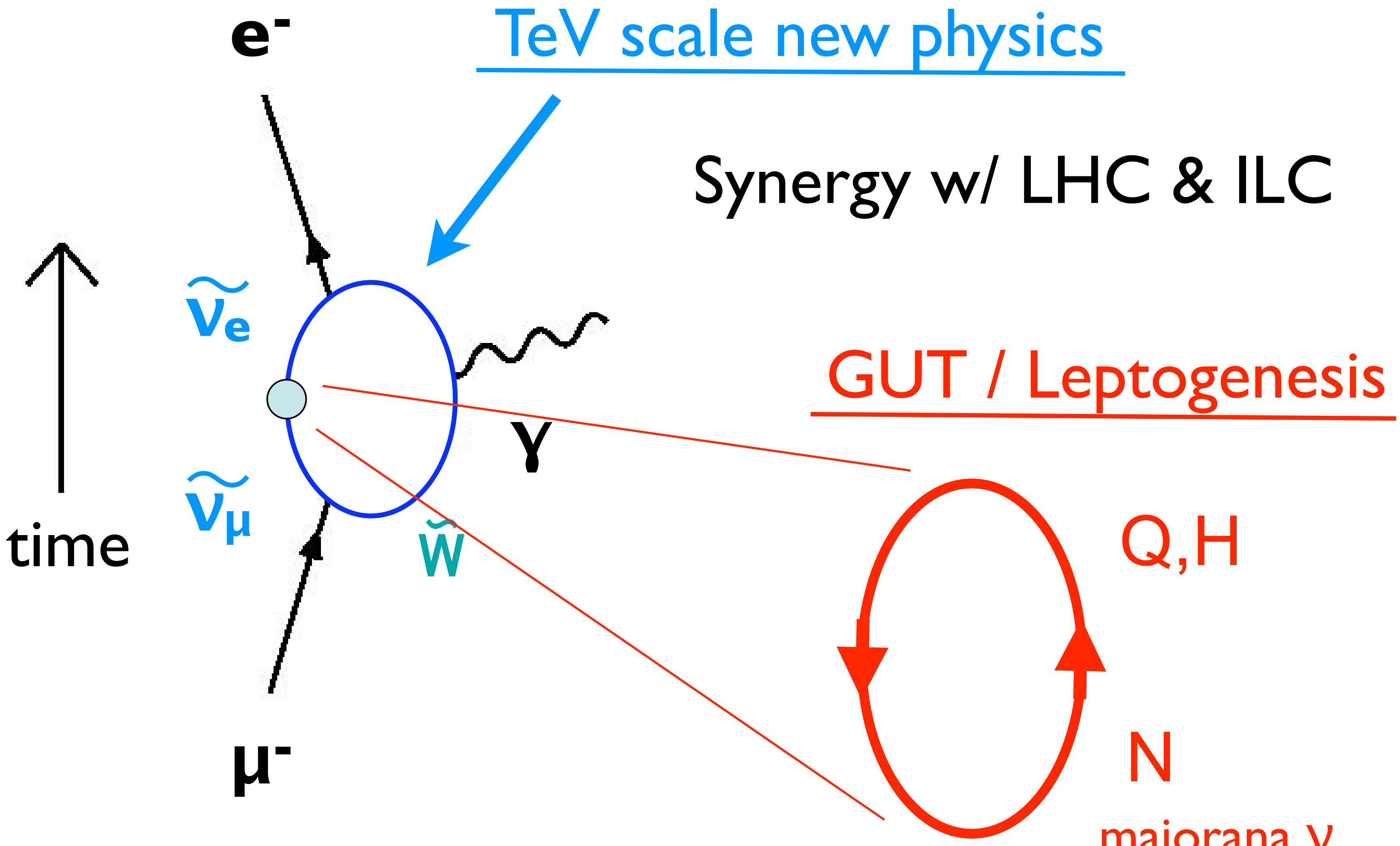
Lepton Flavor Violating Process

TeV scale new physics



Synergy w/ LHC & ILC

Lepton Flavor Violating Process



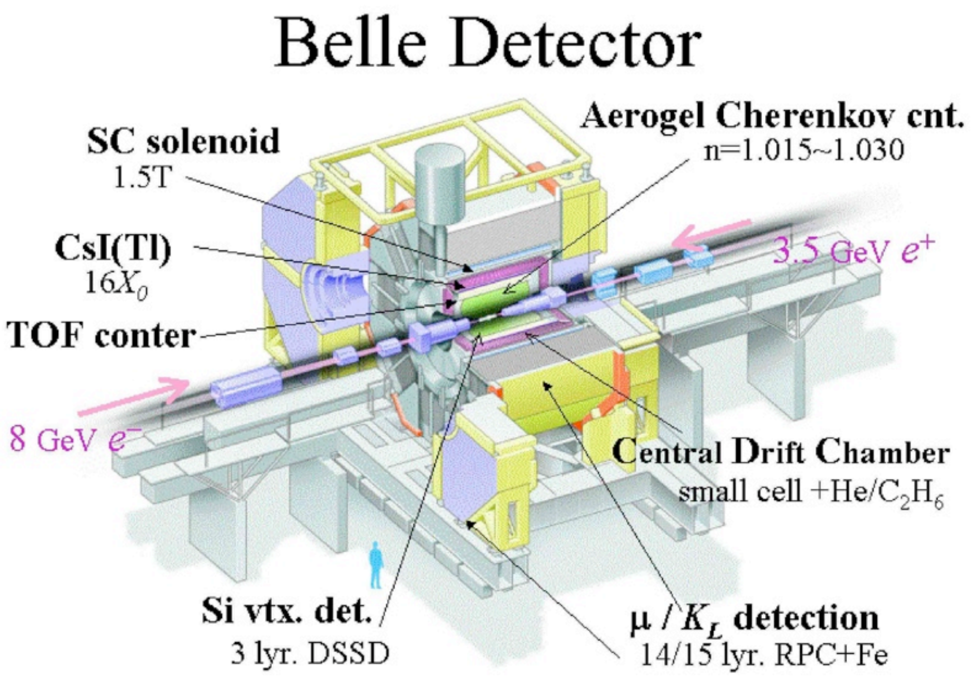
Beyond LHC & ILC

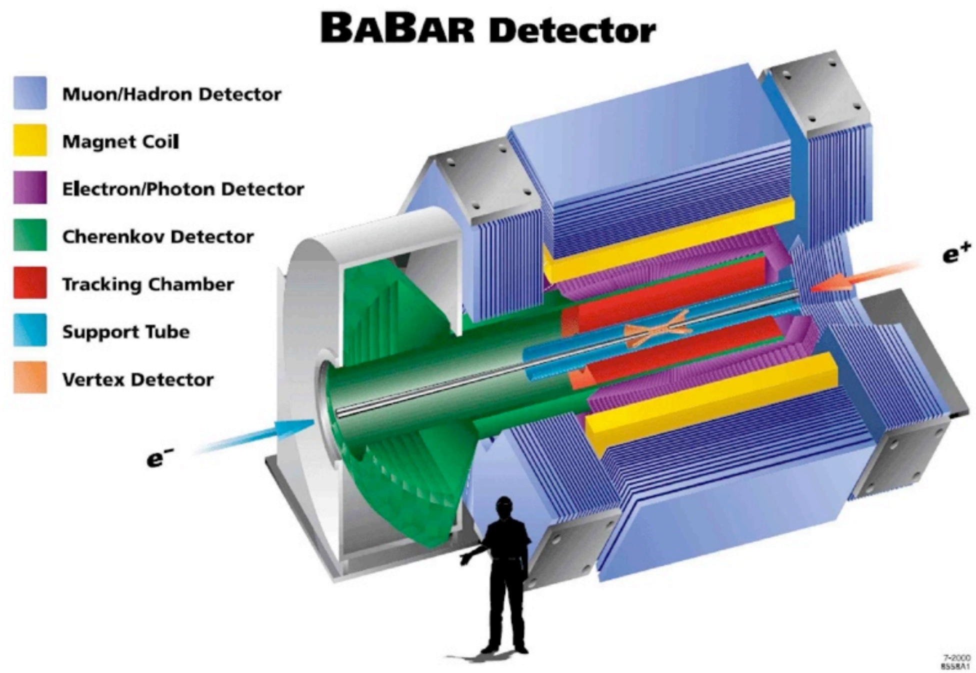
LFV Tau Decays at B Factories

B Factory Experiments

F/B asymmetric detectors

Good vertex resolution and particle ID ability



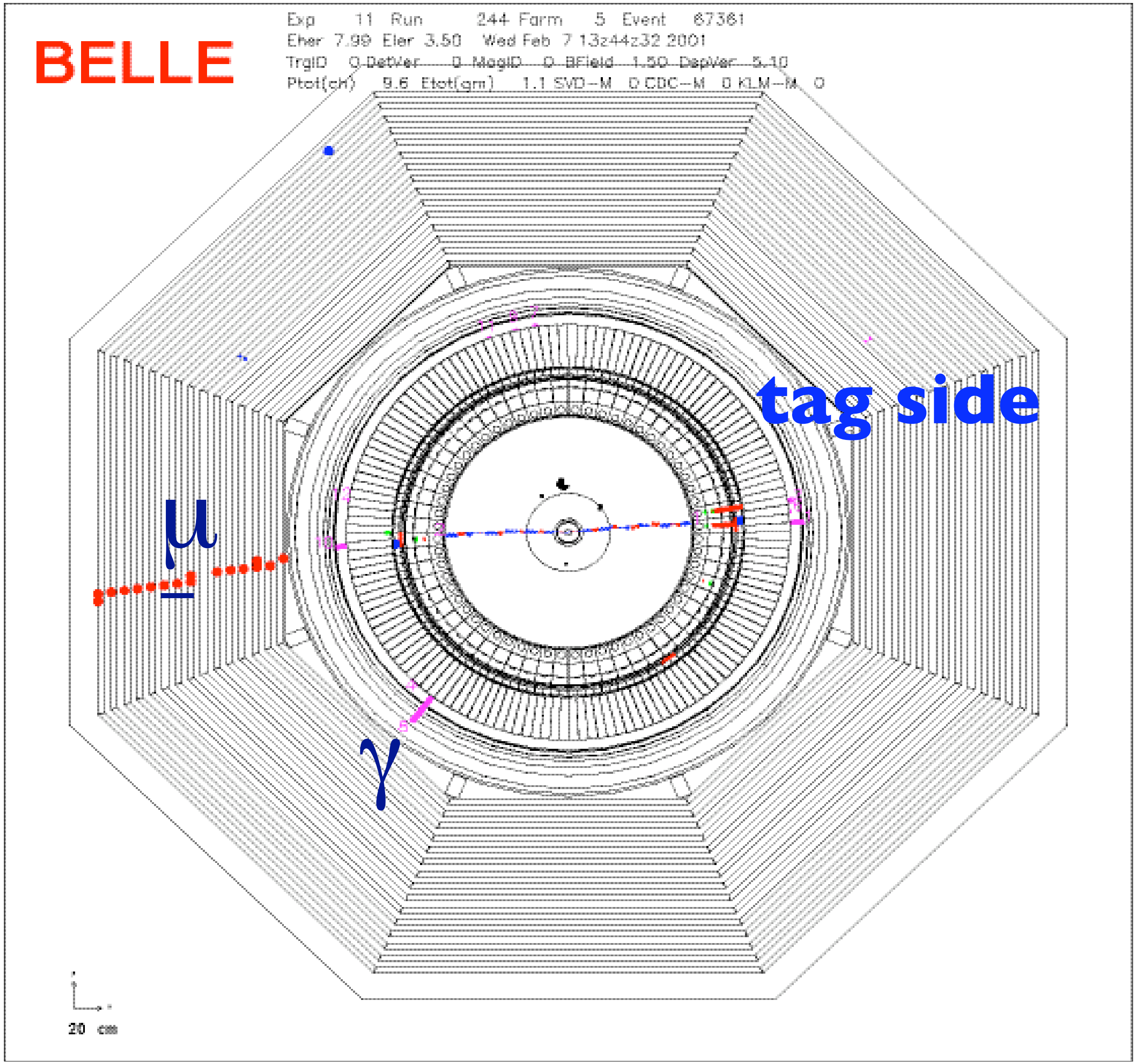


Accumulated data:

>4.5x10^8 τ-pairs at Belle, >3.0x10^8 τ-pairs at BaBar

Br~O(10^{-8}) sensitivity!

Analysis Method



Tag a tau decay on one side

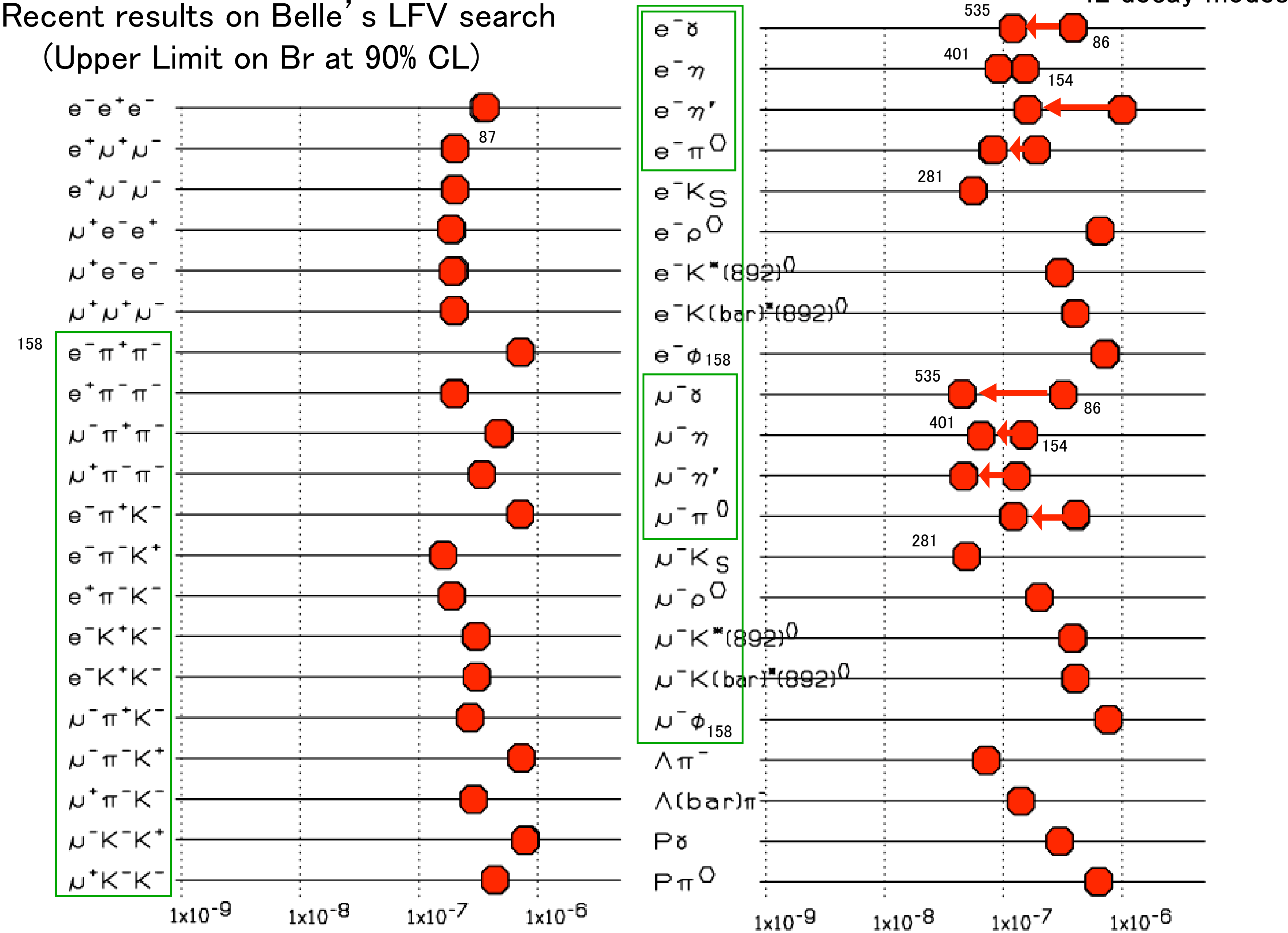
Look for a LFV decay on the other side

a candidate $\tau \rightarrow \mu\gamma$ event

Recent Updates by Belle

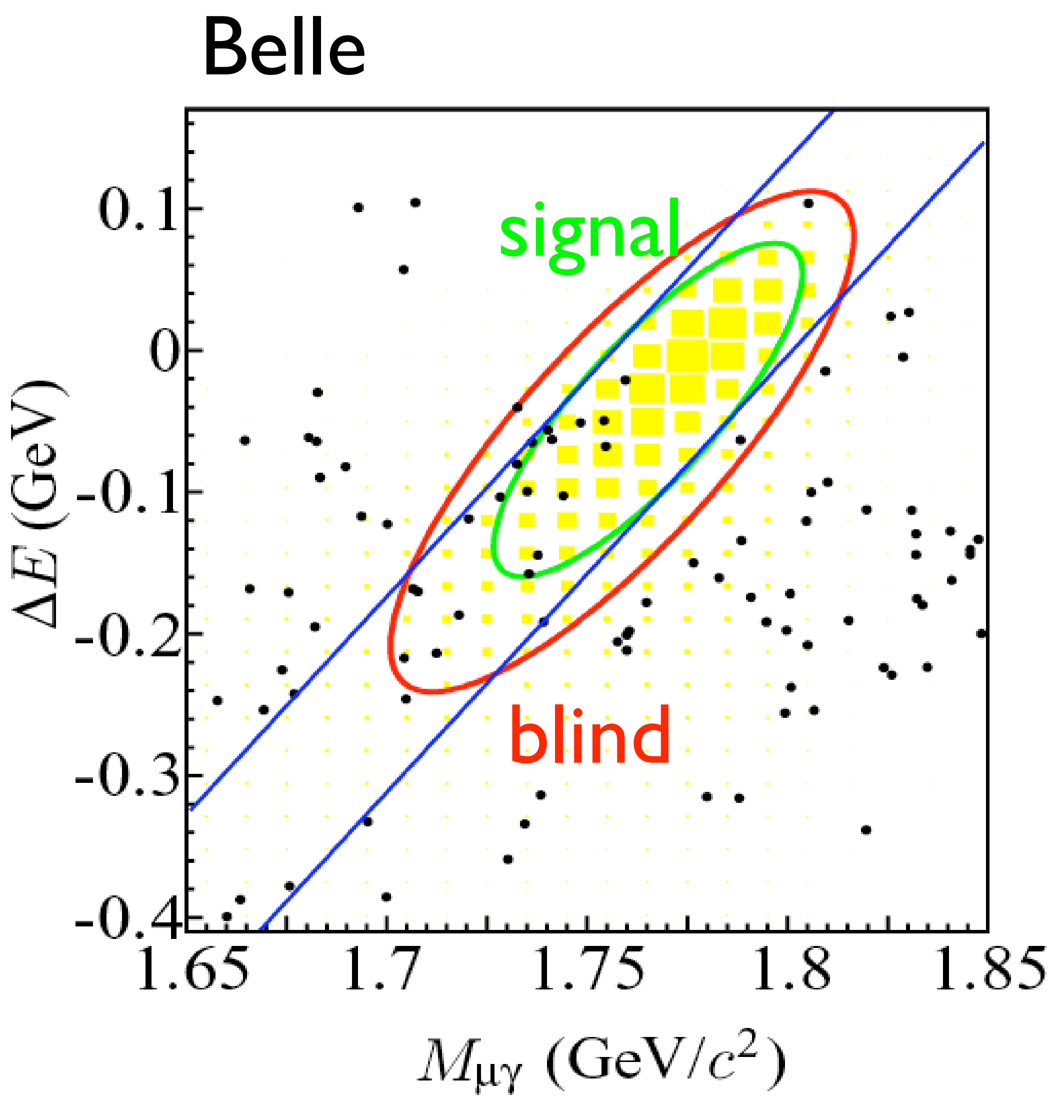
Recent results on Belle's LFV search
(Upper Limit on Br at 90% CL)

42 decay modes



T.Ohshima @Tau06

$\tau \rightarrow \mu\gamma$ search



blind analysis

efficiency:
11% → 6.7%

background:
radiative μ/τ-pairs

unbinned extended maximum likelihood fit
s=-3.9, b=13.9

optimization of selection criteria for increased data

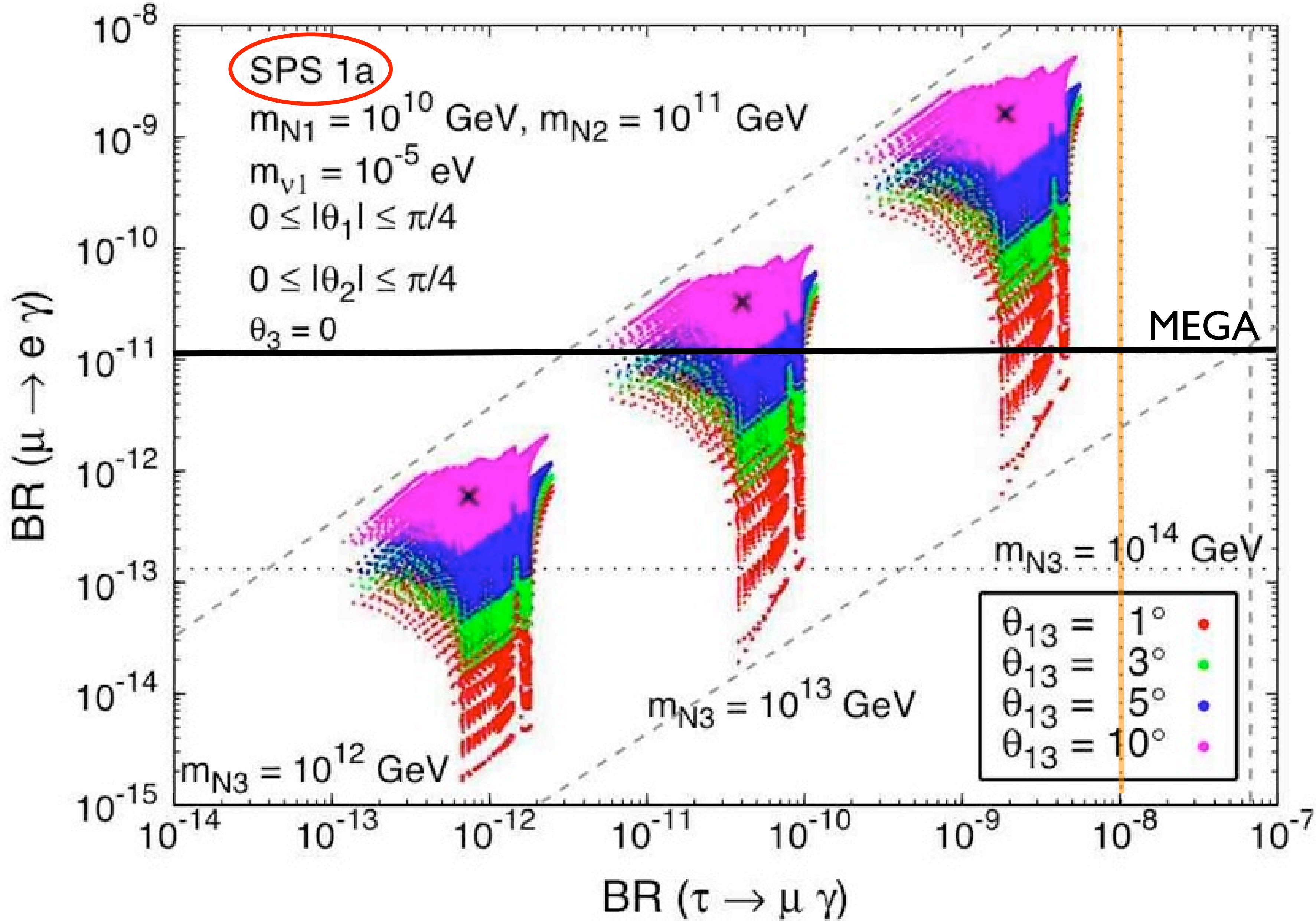
Belle + BaBar

$\tau^\pm \to e^\pm \gamma$	Luminosity	ε	Background events	
		(%)	Expected	Observed
BaBar	232.2 fb^{-1}	4.70 ± 0.29	1.9 ± 0.4	1
Belle	535.0 fb^{-1}	2.99 ± 0.13	$5.14^{+2.6}_{-1.9}$	5
BaBar & Belle	767.2 fb^{-1}	3.51 ± 0.13	7.0 ± 2.3	6
$\mathcal{B}(\tau^\pm \to e^\pm \gamma) < 9.4 \times 10^{-8}$ @ 90% C.L.				

$\tau^\pm \to \mu^\pm \gamma$	Luminosity	ε	Background events	
		(%)	Expected	Observed
BaBar	232.2 fb^{-1}	7.42 ± 0.65	6.2 ± 0.5	4
Belle	535.0 fb^{-1}	5.07 ± 0.20	$13.9^{+3.3}_{-2.6}$	10
BaBar & Belle	767.2 fb^{-1}	5.78 ± 0.24	20.1 ± 3.0	14
$\mathcal{B}(\tau^\pm \to \mu^\pm \gamma) < 1.6 \times 10^{-8}$ @ 90% C.L.				

S.Banerjee @Tau06

Tau decays vs. Muon decays

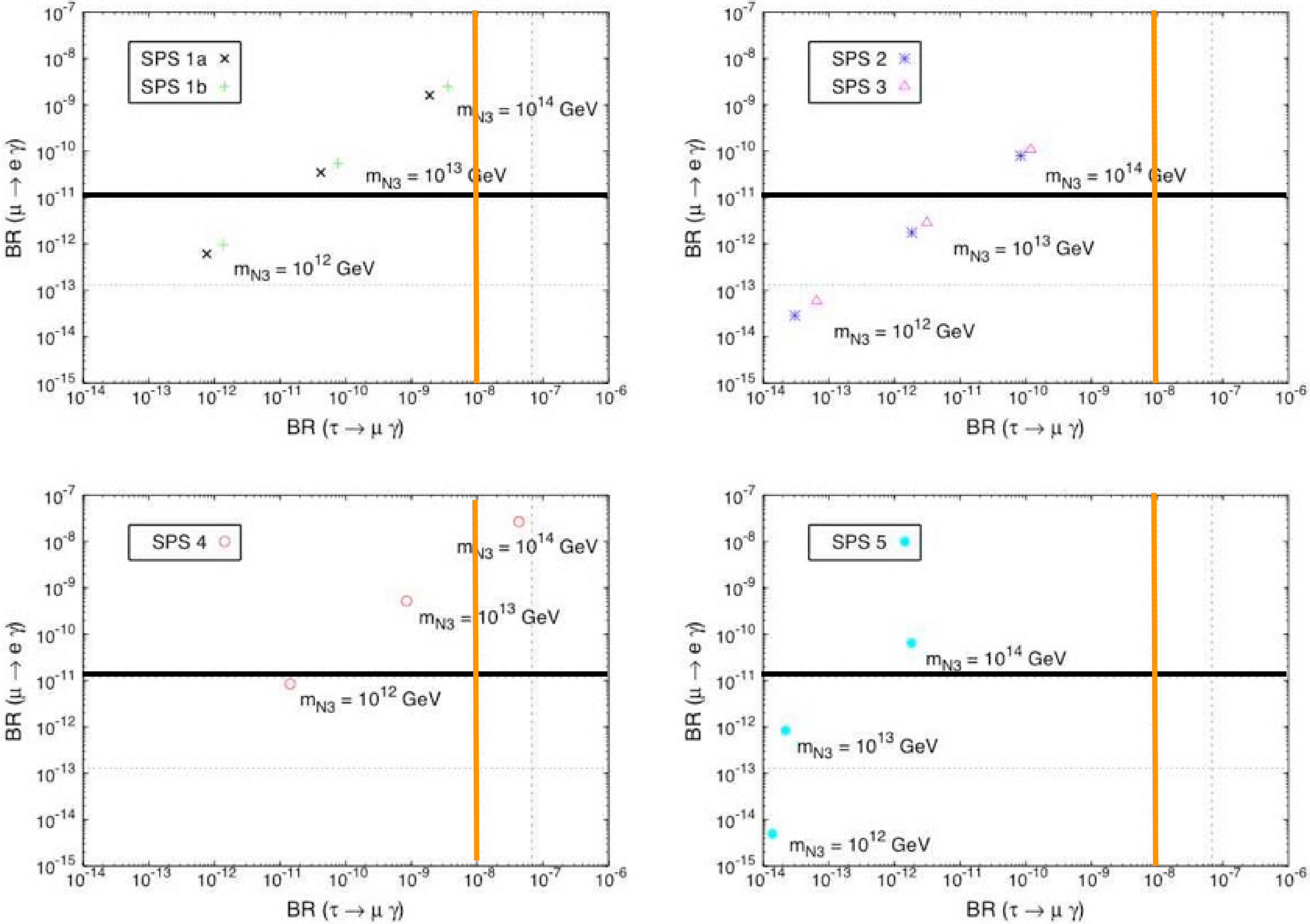


CMSSM (full RGE) + ν_R + seesaw
+ viable BAU + EDM limits

M.J.Herrero @Tau06

PRD73 055003(2006), hep-ph/0607263

other SPS points



LFV Muon Decays

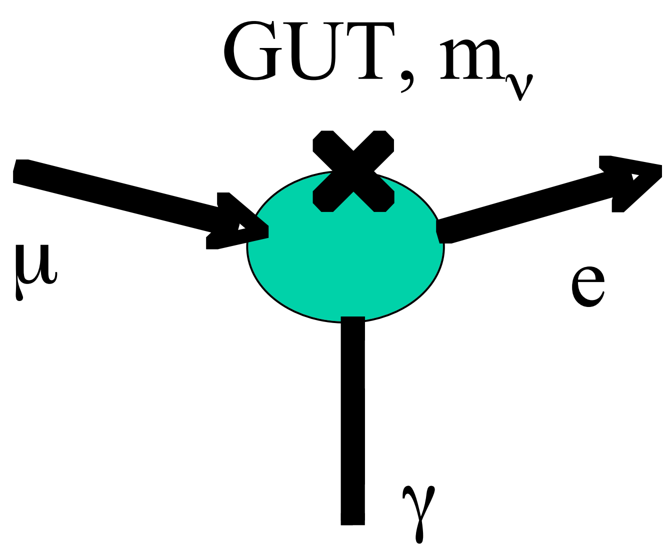
LFV Muon Decays

- Most sensitive to SUSY GUT and SUSY Seesaw models
- Predicted branching ratios are within the reach of the next experiments !
- Two processes: $\mu \to e$ conversion vs. $\mu \to e\gamma$
  - ✓ a comment on prospects for $\mu \to eee$

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

Physics sensitivity

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



1×10^{-14} $\mu \rightarrow e\gamma$

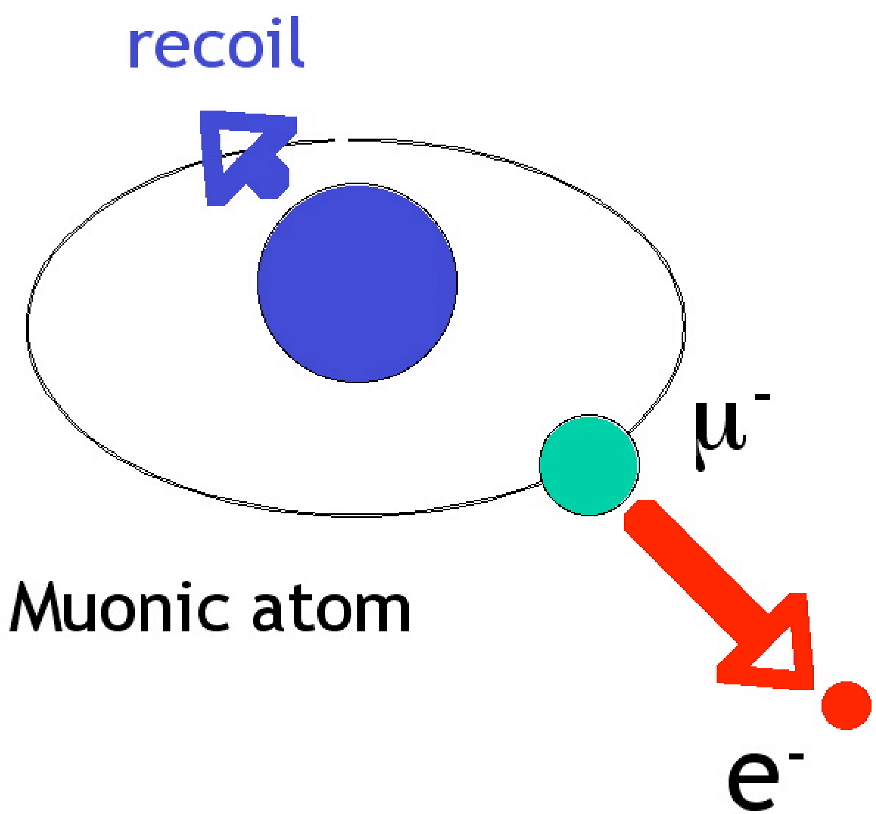
10^8/sec DC beam

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

10^{11}/sec pulse beam

Muon to Electron Conversion

$\mu \rightarrow e$ conversion



μ^- to make a muonic atom

a single electron with

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

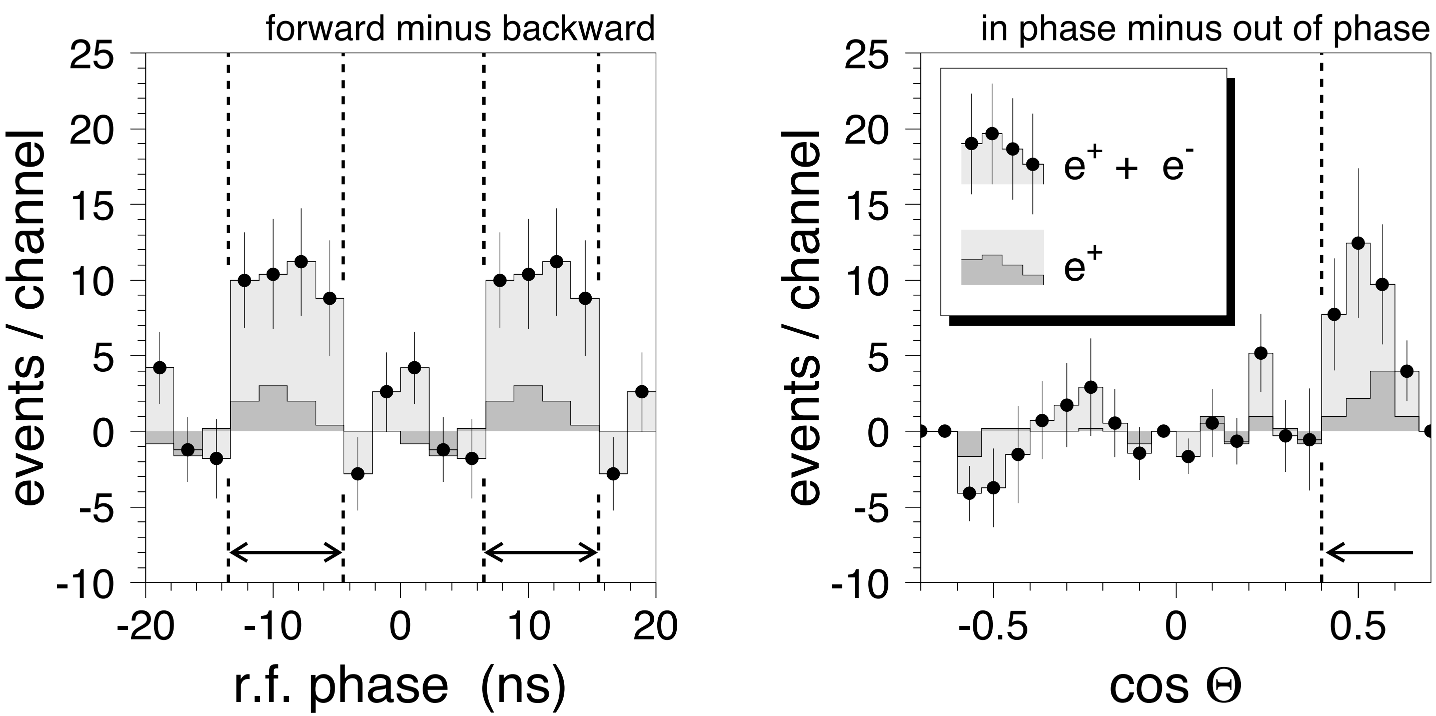
Background:

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

μ → e conversion

Prompt Beam Induced Background

SINDRUM II @PSI

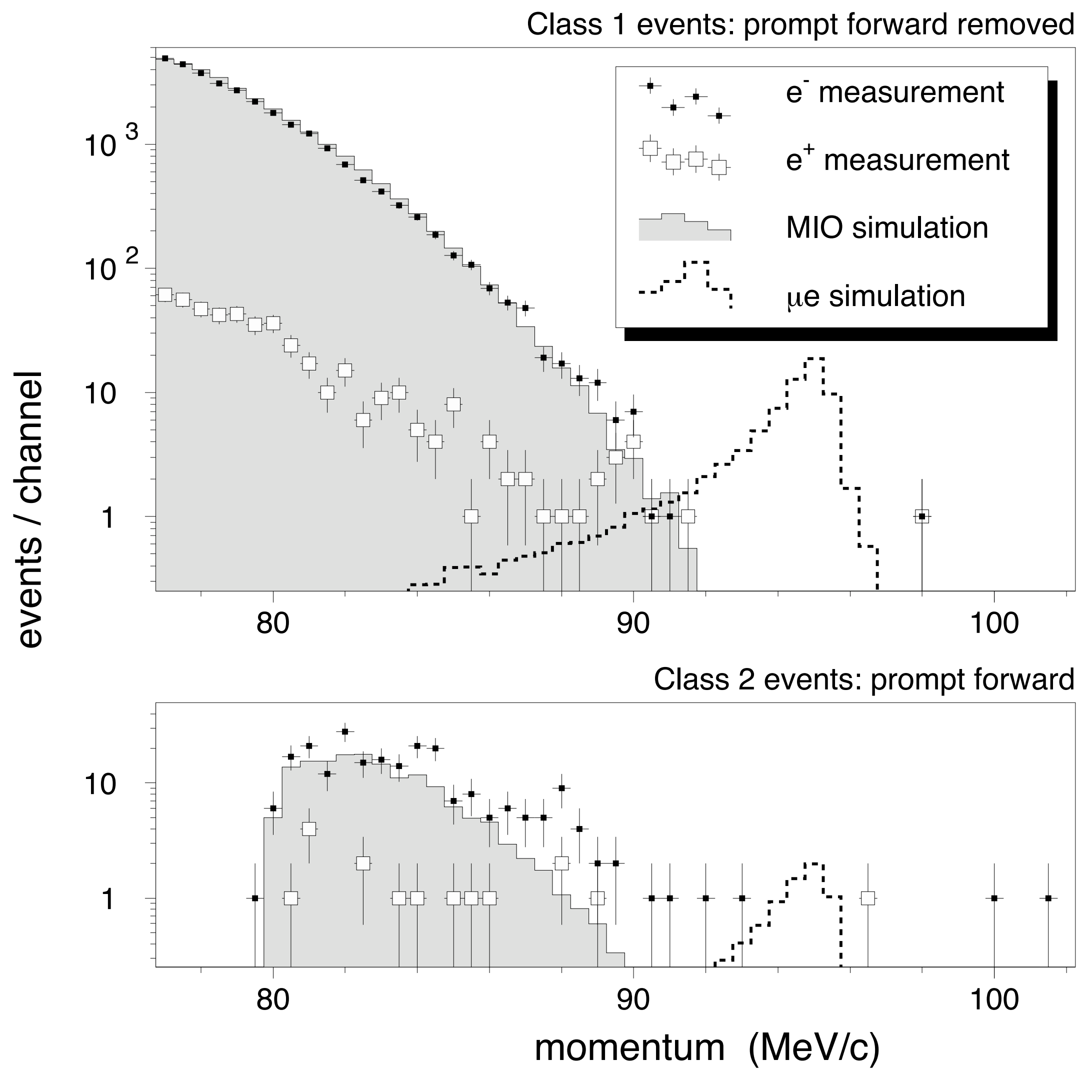


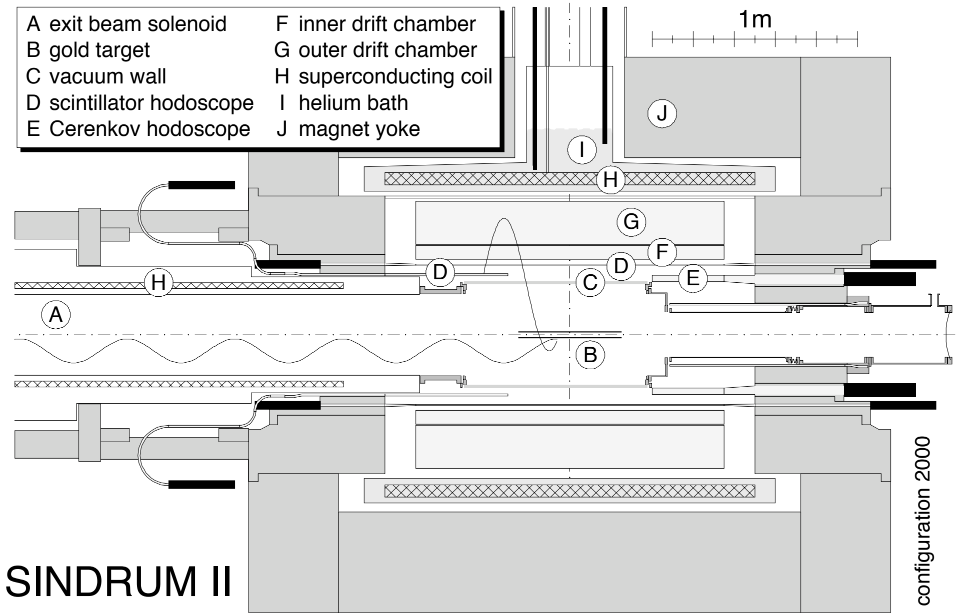
in coincidence with 20nsec Cyclotron RF

~ 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

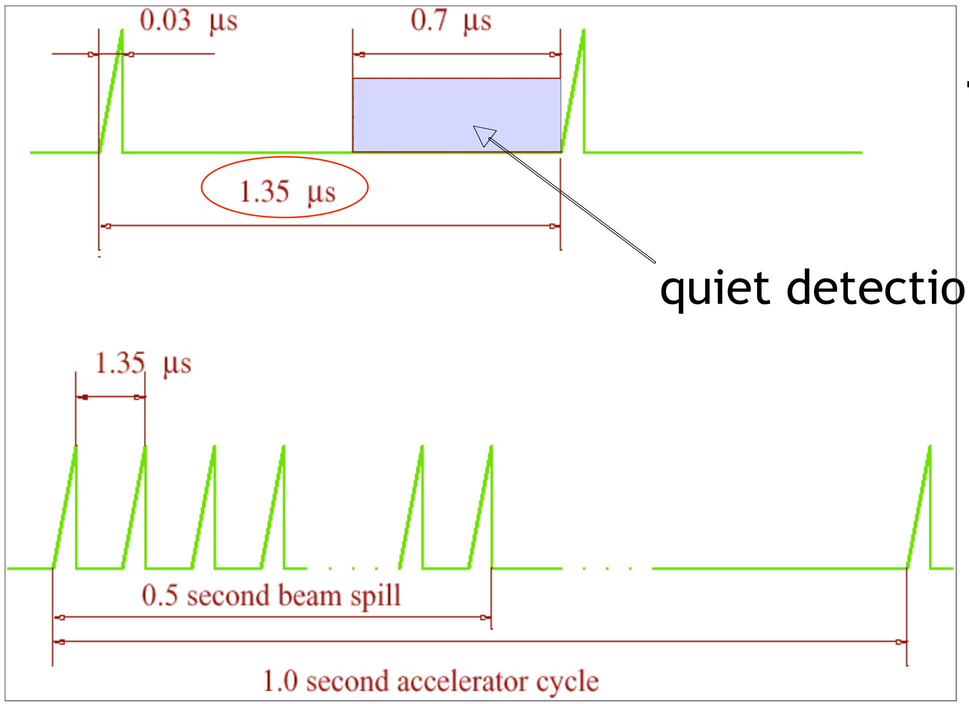
$\sim 2 \times 10^{-10}$ for $\mu \rightarrow e\gamma$

MECO Experiment @BNL (cancelled)

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

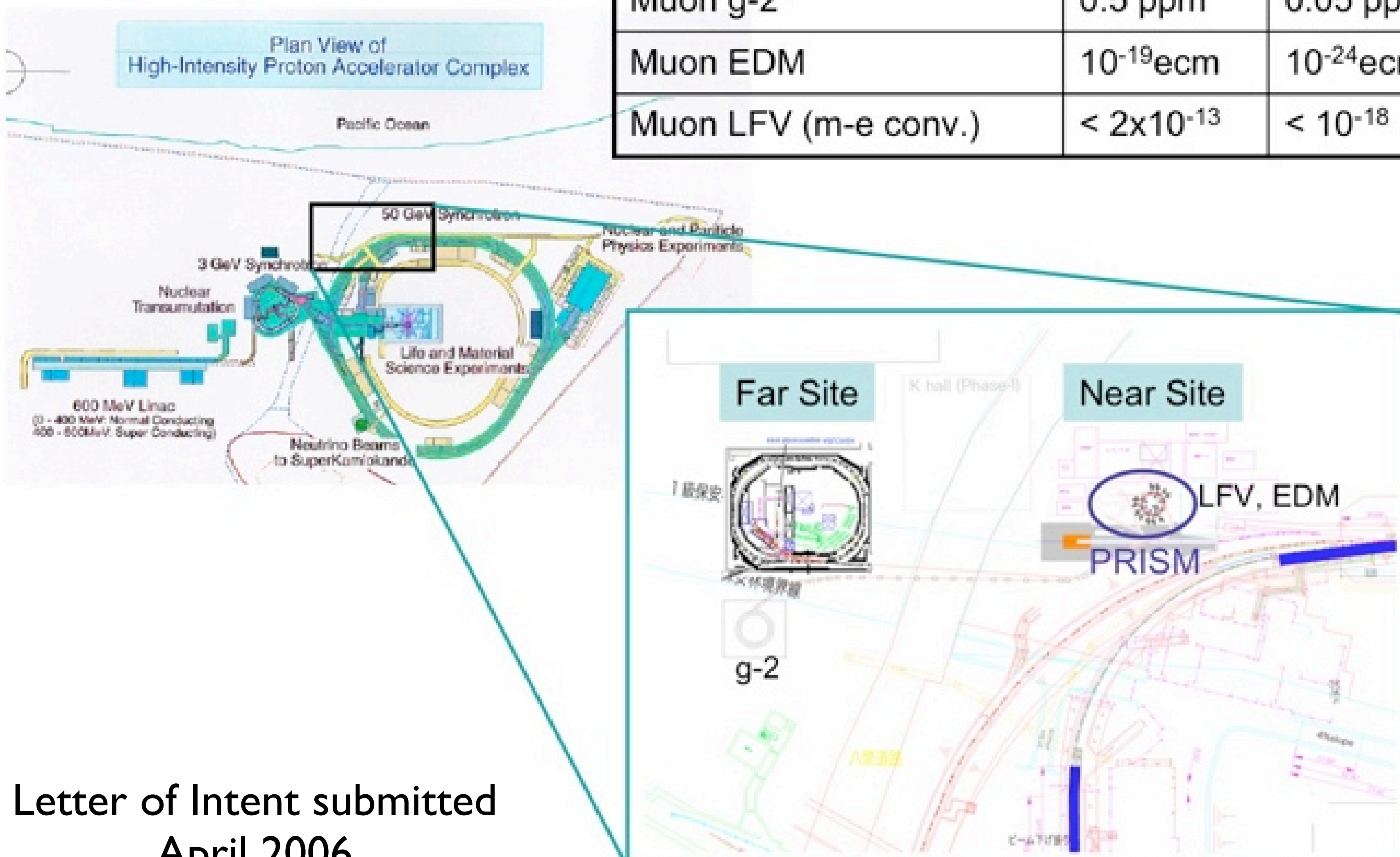
0.9 μs	for Al
0.3 μs	Ti
0.06 μs	Pb

MECO @AGS
Uses Al target

Good beam is essential

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.)	< 2×10^{-13}	< 10^{-18}

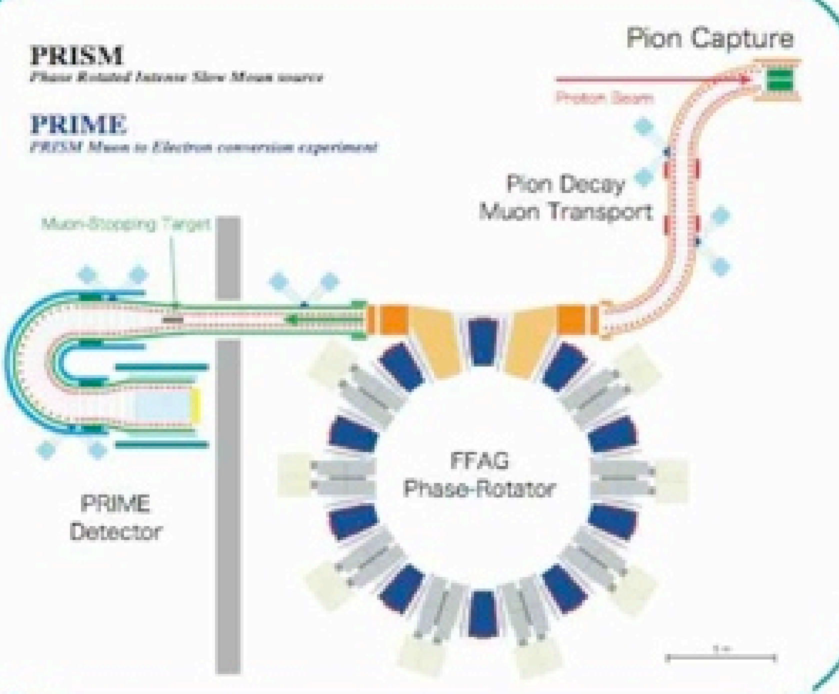


Letter of Intent submitted
April 2006

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)
  - $\Delta E/E = \pm 0.5 \sim 1.0$ MeV
  - thinner muon-stopping target
  - Better e^- momentum/energy resolution while keeping high muon stopping efficiency
- Less beam contamination
  - Practically no pion contamination $\pi/\mu \sim 10^{-18}$



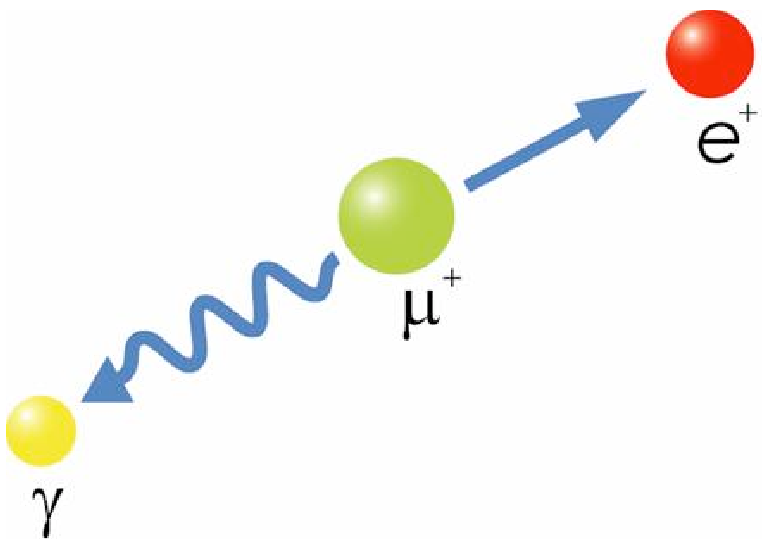
- Year 2003-2007
  - PRISM-FFAG (phase rotator) is under construction
- Phase-I : construction and test of PRISM
- Phase-II : installation of PRISM to high intensity proton machine for mu-e. search.
- **GOAL: $B(\mu^- N \rightarrow e^- N) < 10^{-18}$**

Not Funded

Accelerator Studies in Progress

$$\mu \rightarrow e\gamma$$

$\mu \rightarrow e\,\gamma$



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

MEG Experiment

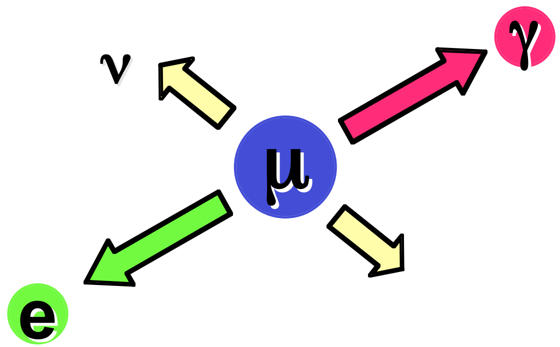
a simple arithmetic to achieve a 10^{-13}-10^{-14} sensitivity

10^{13} muons / a year ~ 10^{7} sec / efficiency ~ 0.1

= ~ 10^{7} muons / sec

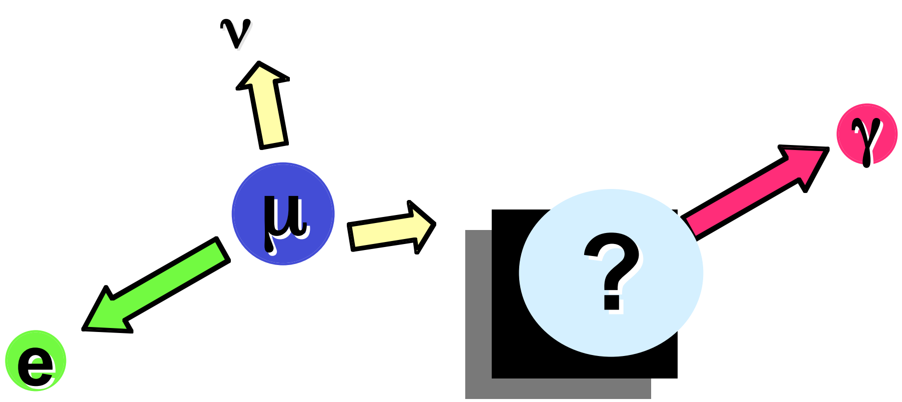
➡ **High rate experiment**

Two Types of Backgrounds



radiative decays

~ manageable



radiative decays
e^+ annihilation in flight

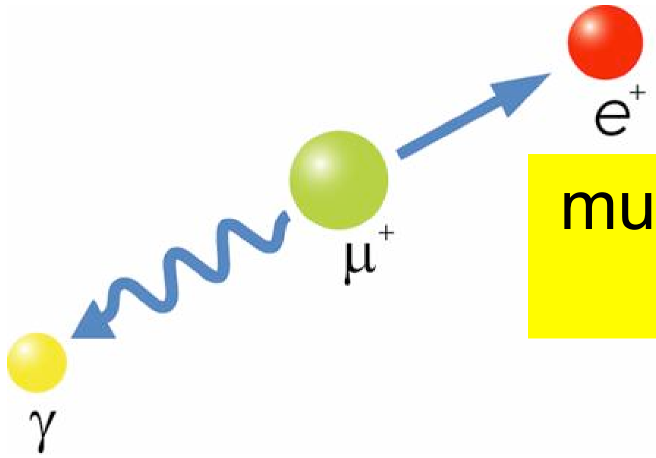
accidental overlaps

dominant

lower μ rate is better
➡ DC beam

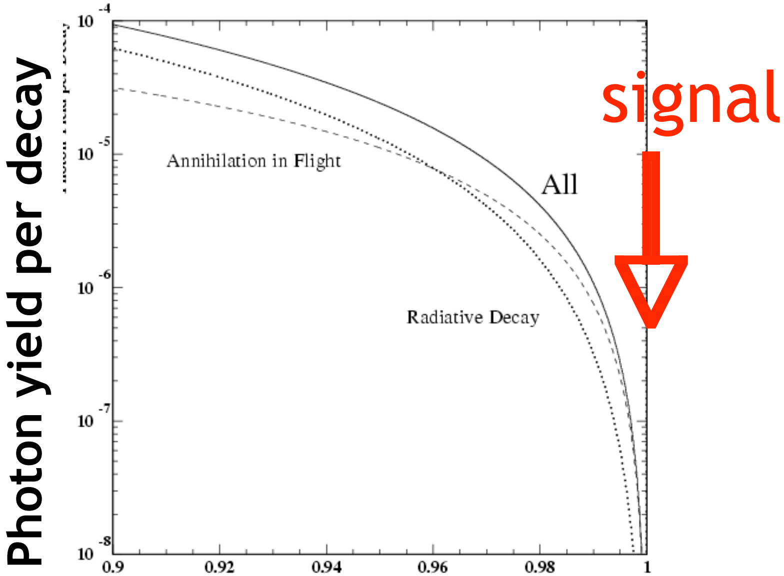
Accidental coincidence of γ and e⁺ is the main background

γ ray measurement
Is most important!



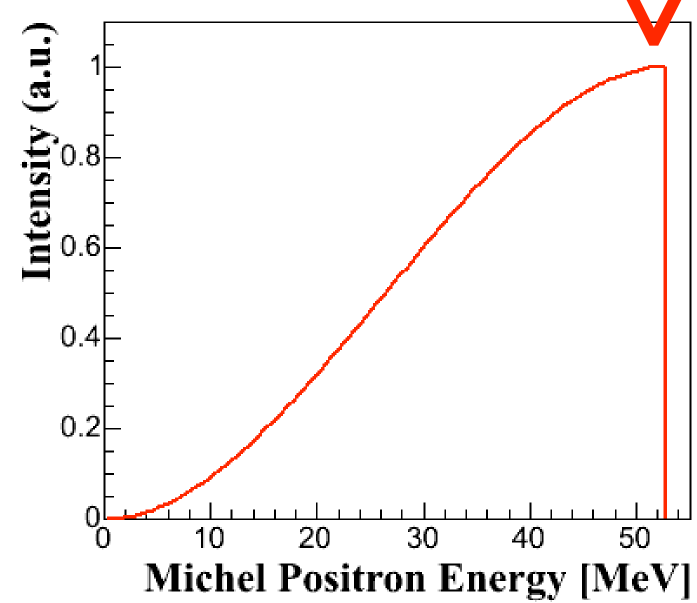
must manage to track
high rate e+

Background γ spectrum



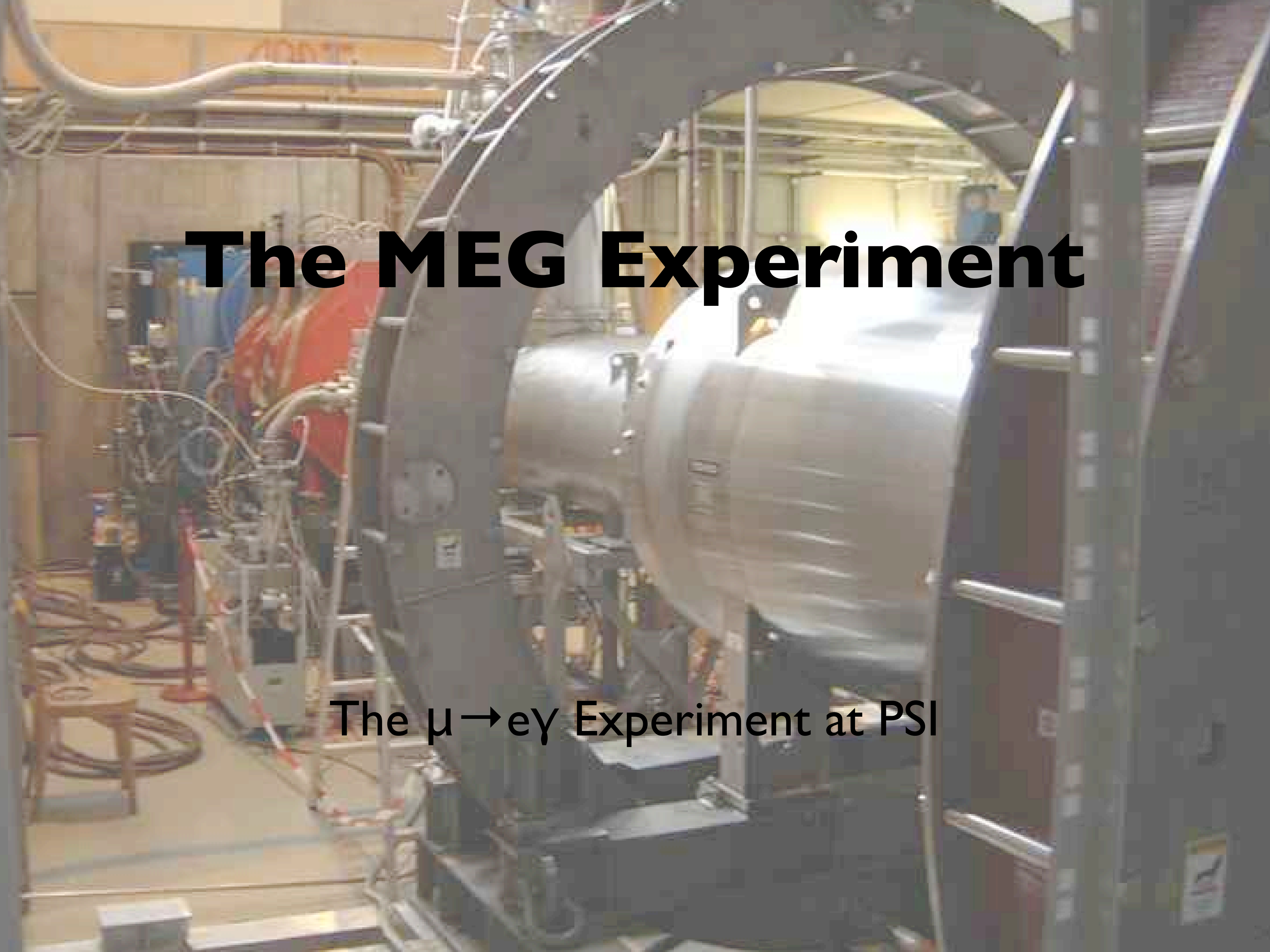
signal

Background e⁺ spectrum



So we need:

- High rate (~10^7/sec) DC muon beam
- Spectrometer that can manage high rate e^+
- High resolution γ-ray detector

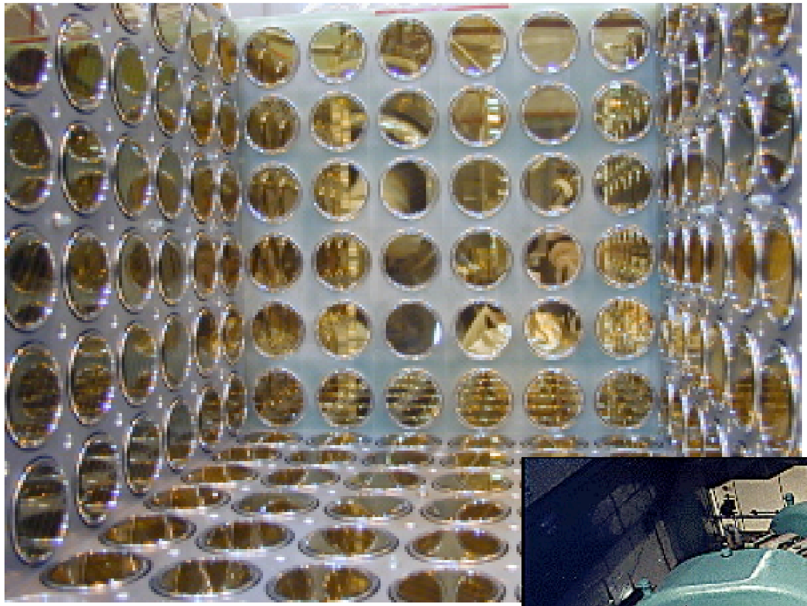


The MEG Experiment

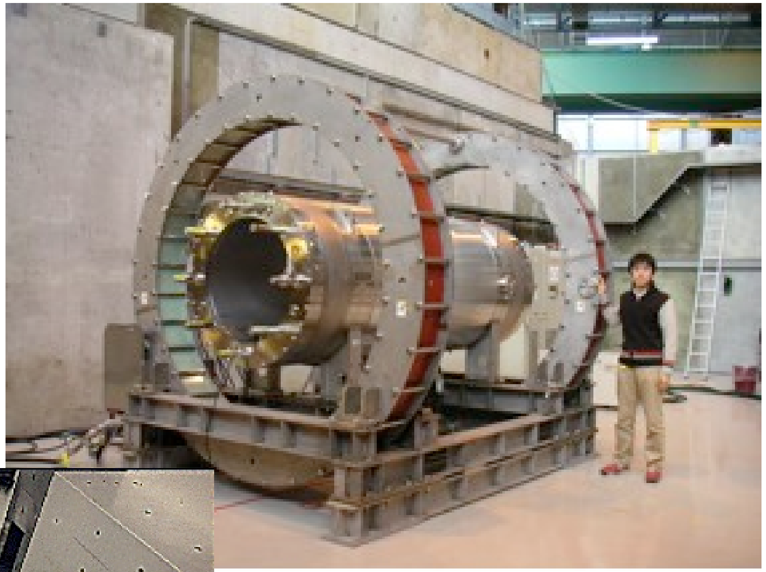
The $\mu \rightarrow e\gamma$ Experiment at PSI

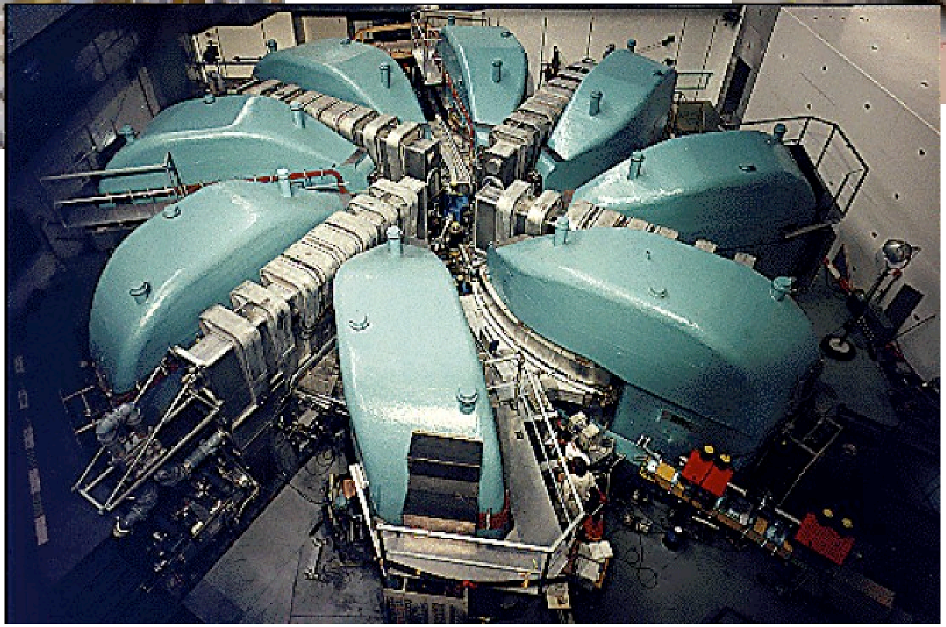
3 Techniques that enabled the experiment

LXe scintillation γ-ray detector



COBRA magnet
w/ graded B field





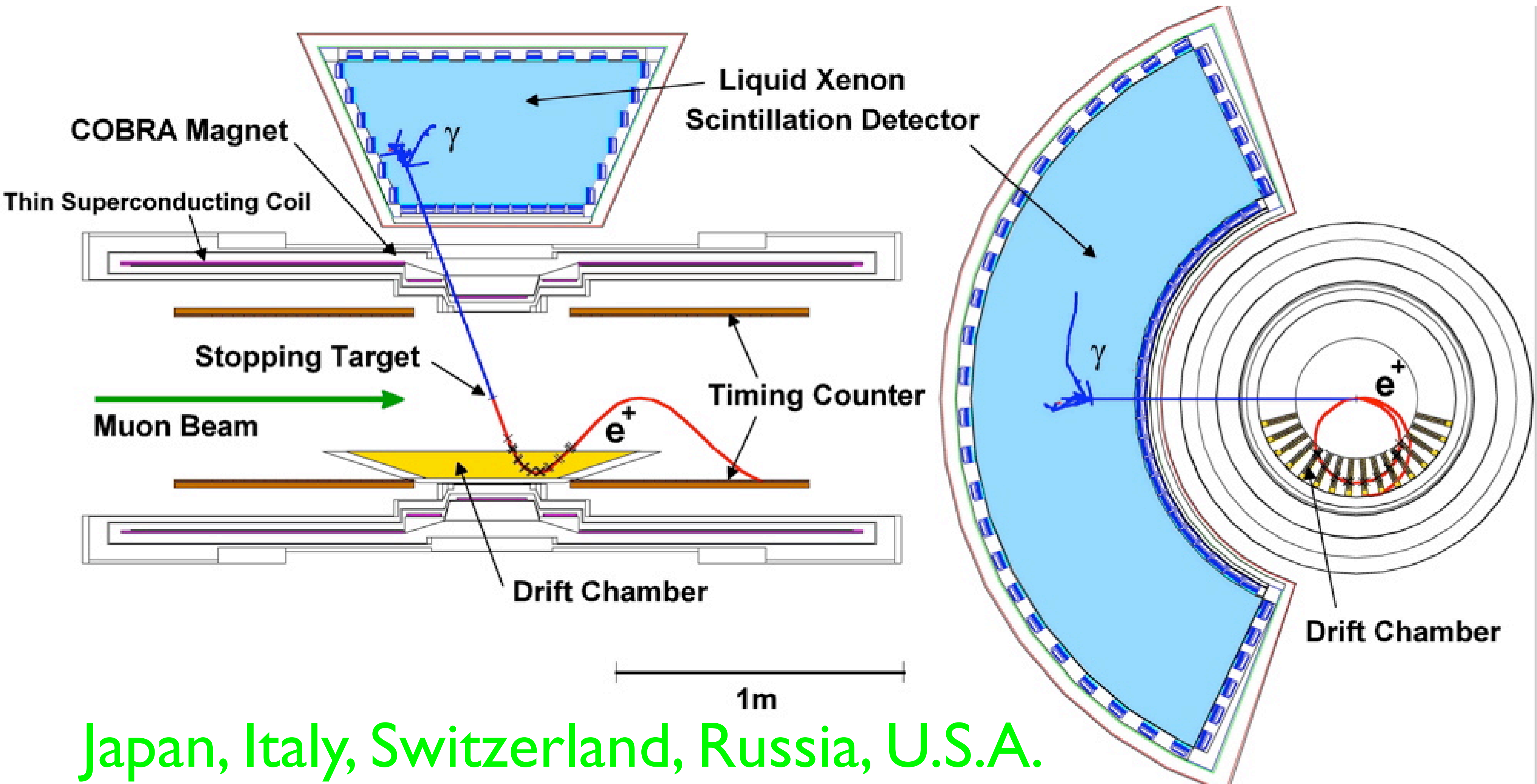
Most intensive DC muon beam (10^8/sec)

The MEG experiment

Approved at Paul Scherrer Institut, Switzerland in 1999

Aiming at a sensitivity of 10^{-13}, a possible future upgrade to 10^{-14}

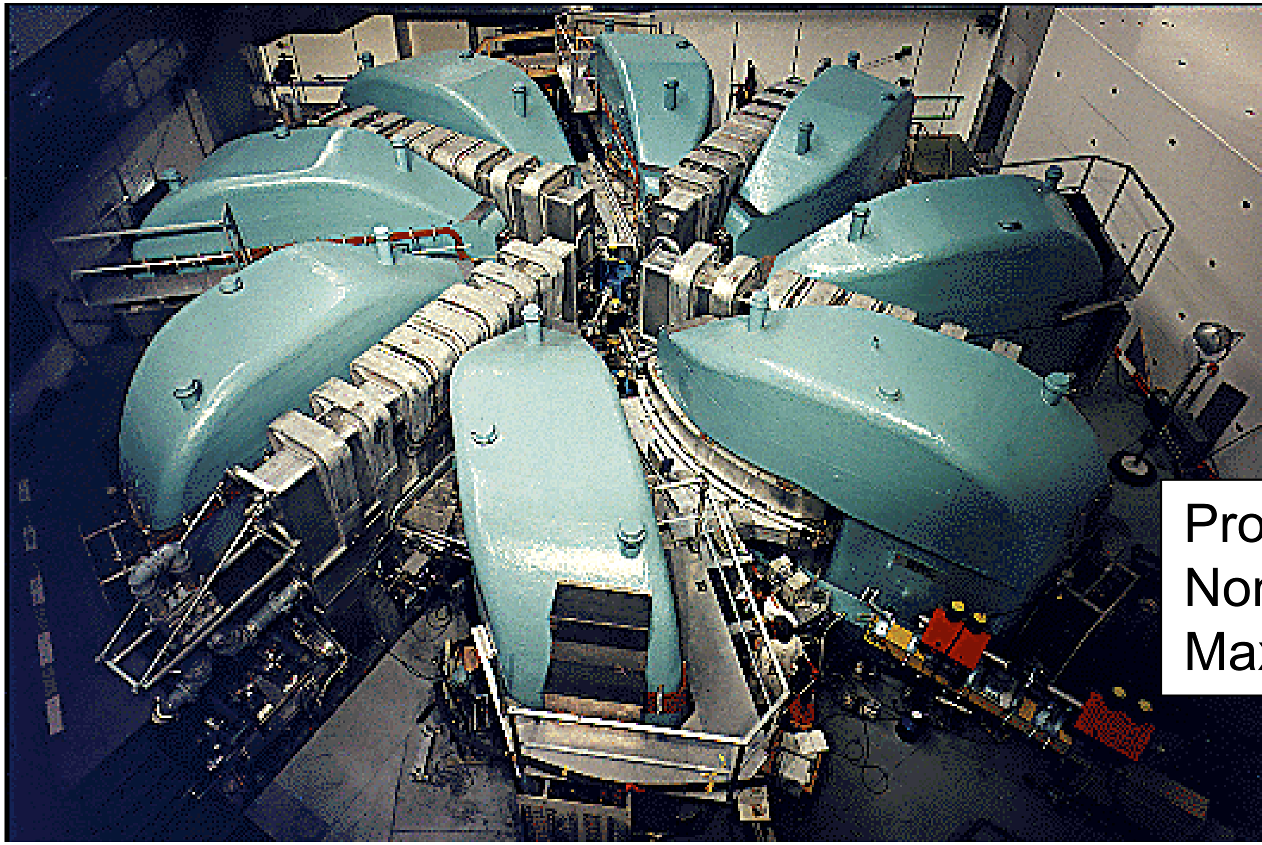
Detectors currently being built and installed



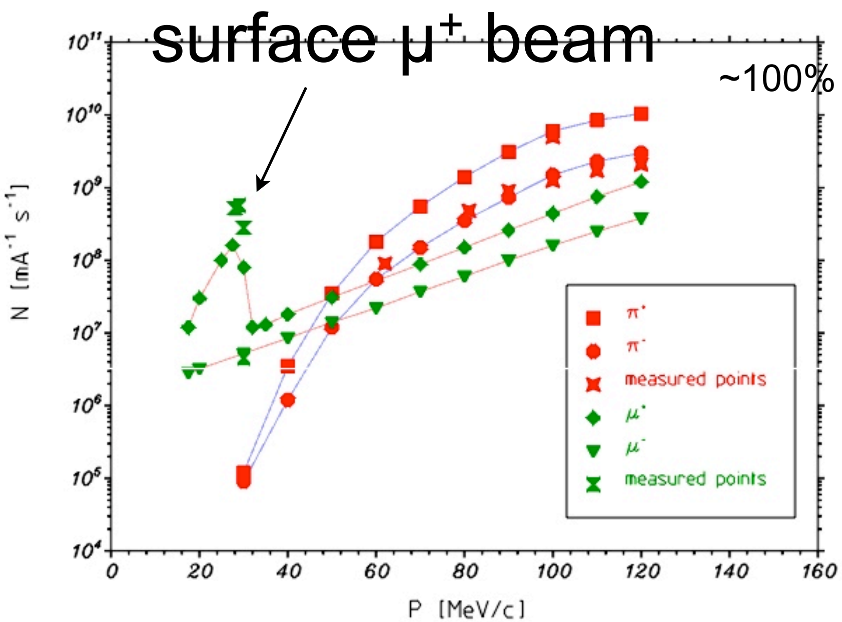
Japan, Italy, Switzerland, Russia, U.S.A.

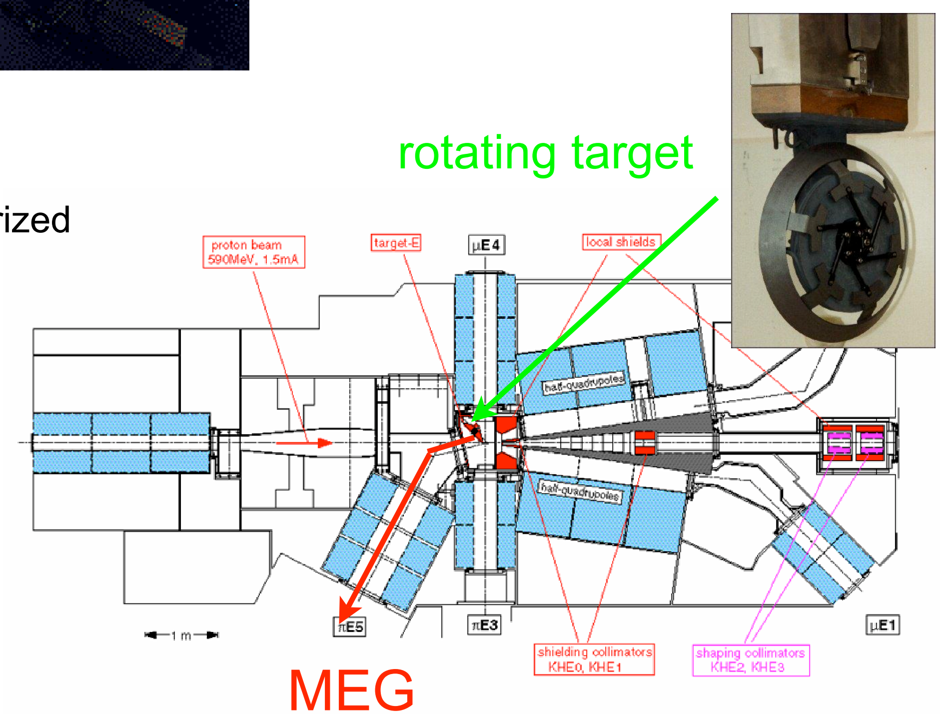
The Muon Beam

The 1 MW Cyclotron
Paul Scherrer Institut
Switzerland

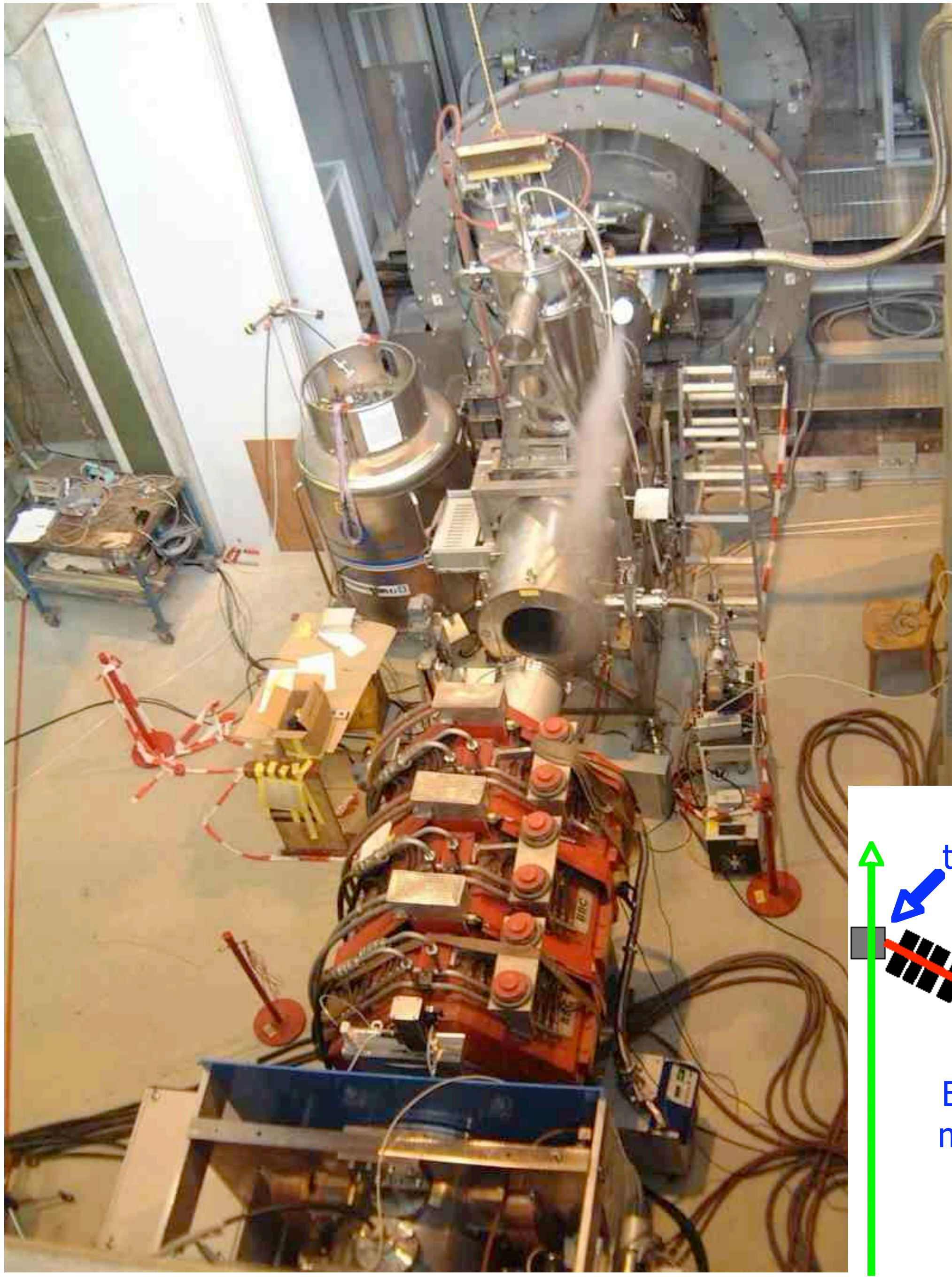


Proton energy: 590MeV
Nominal operation current: 1.8mA.
Max > 2.0mA possible.





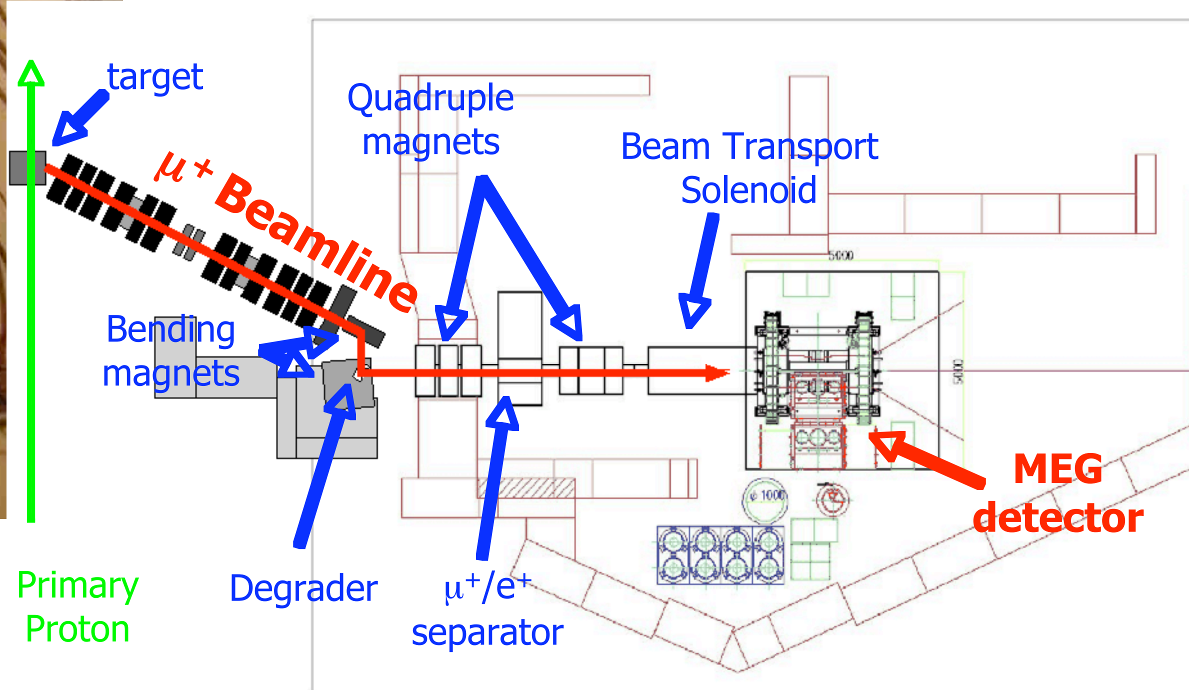
πE5 area @PSI



PSI Proton Cyclotron
590MeV, >1.8mA

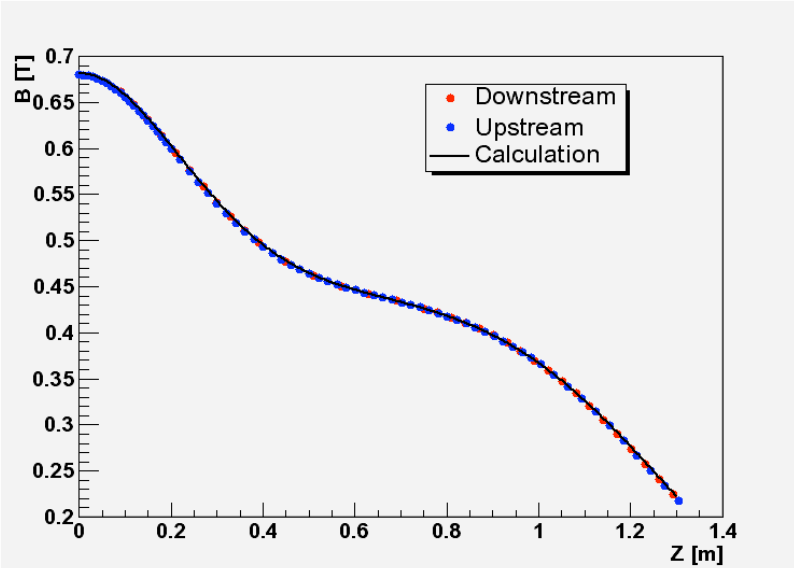
Muon beam being tuned down to the target position

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

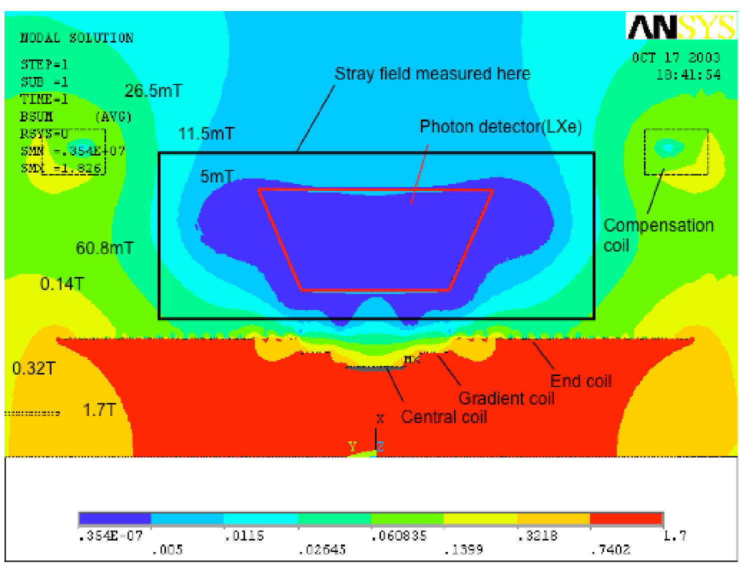


The Positron Spectrometer

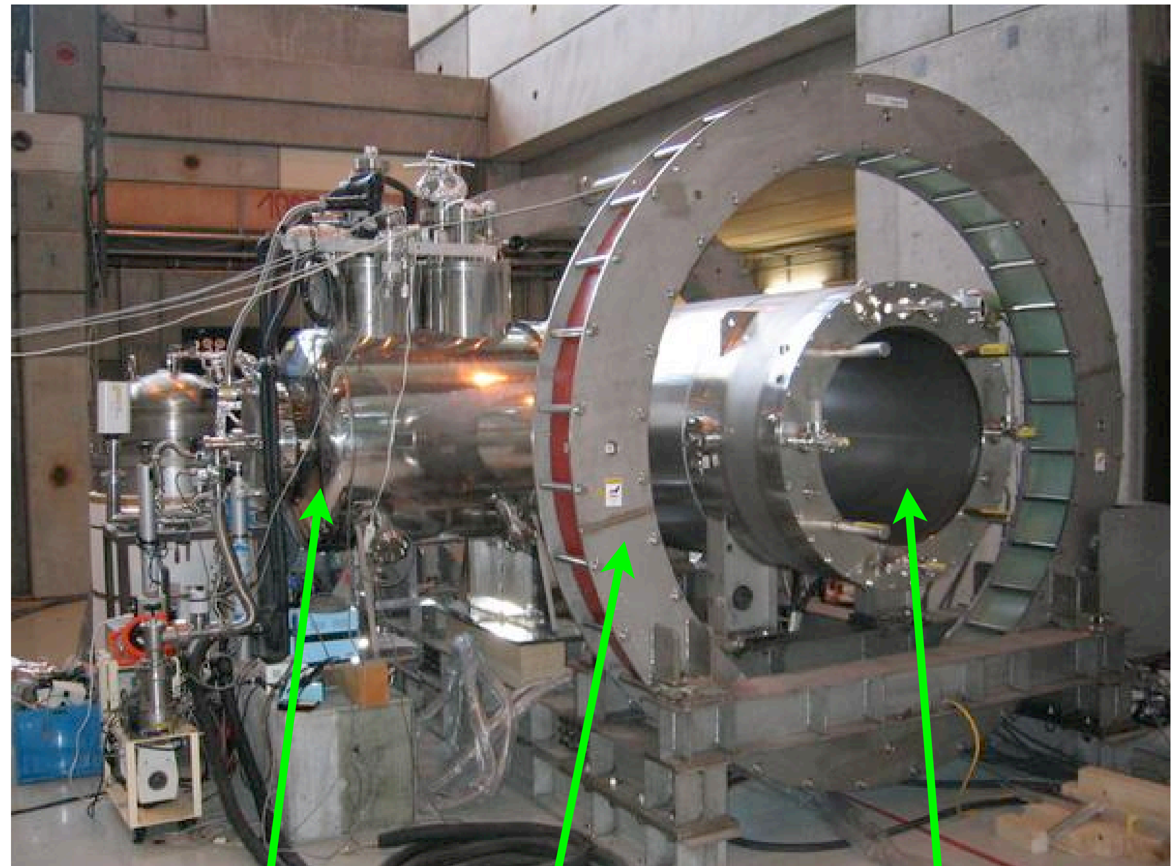
The COBRA Spectrometer



specially graded B field



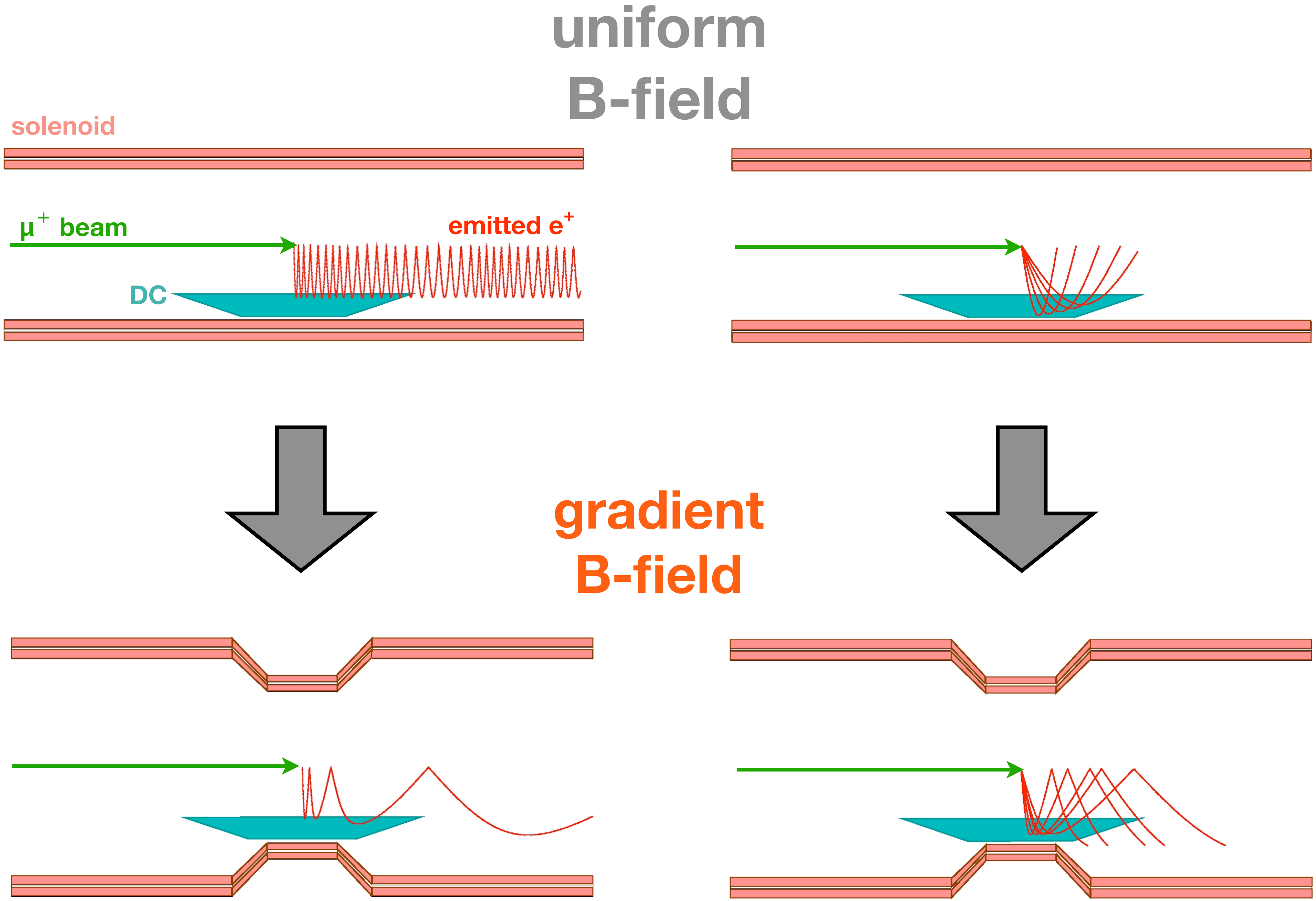
low B field at LXe detector



compensation coils

LXe detector prototype

COBRA magnet

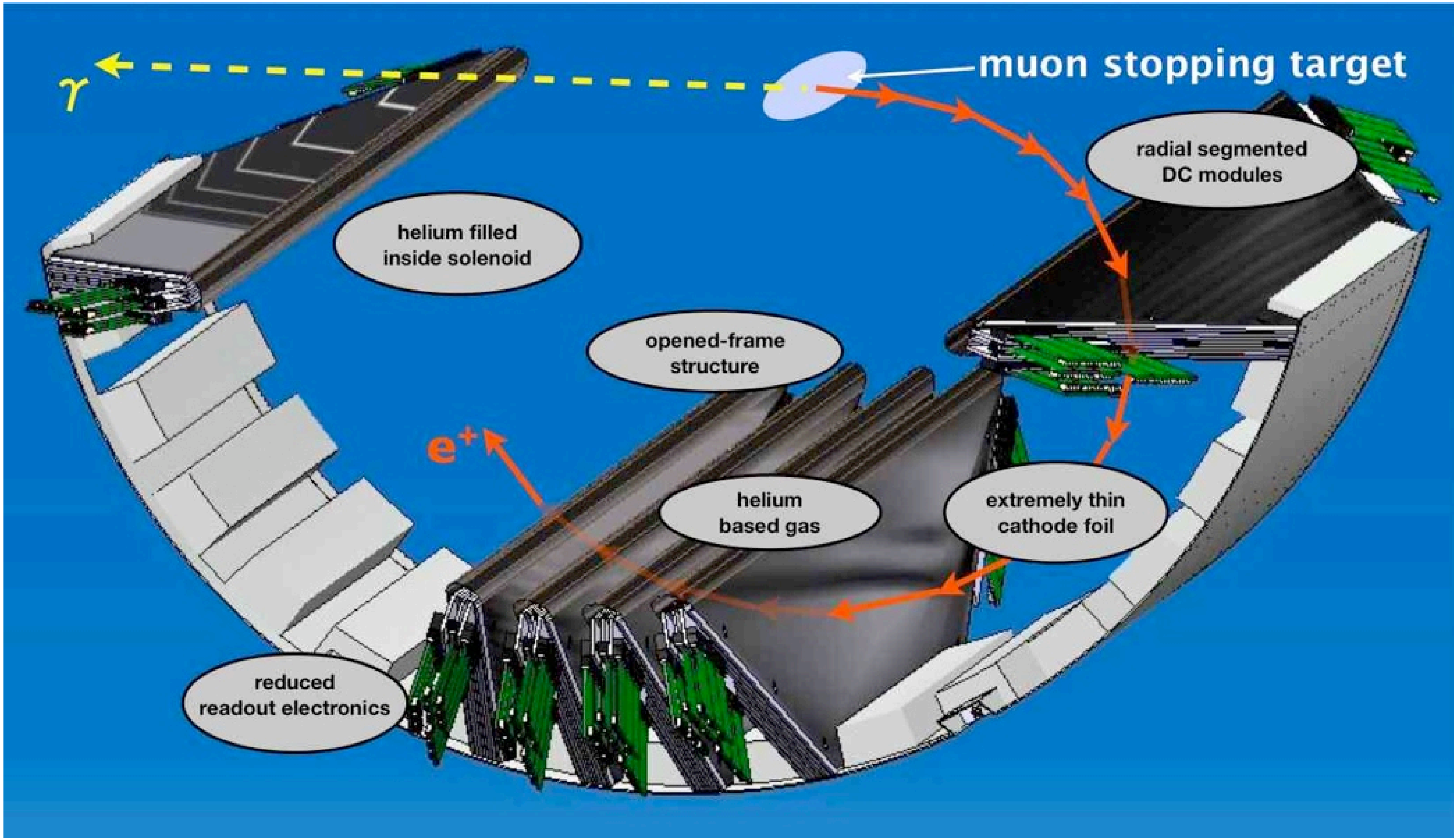


Low energy positrons quickly swept out

Constant bending radius independent of emission angles

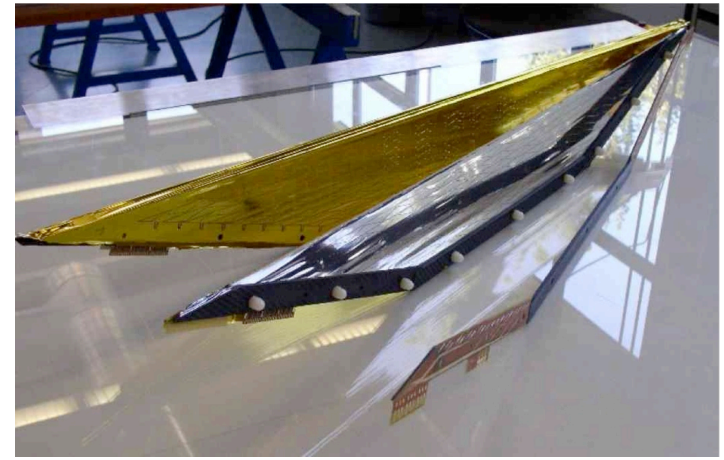
Drift Chambers

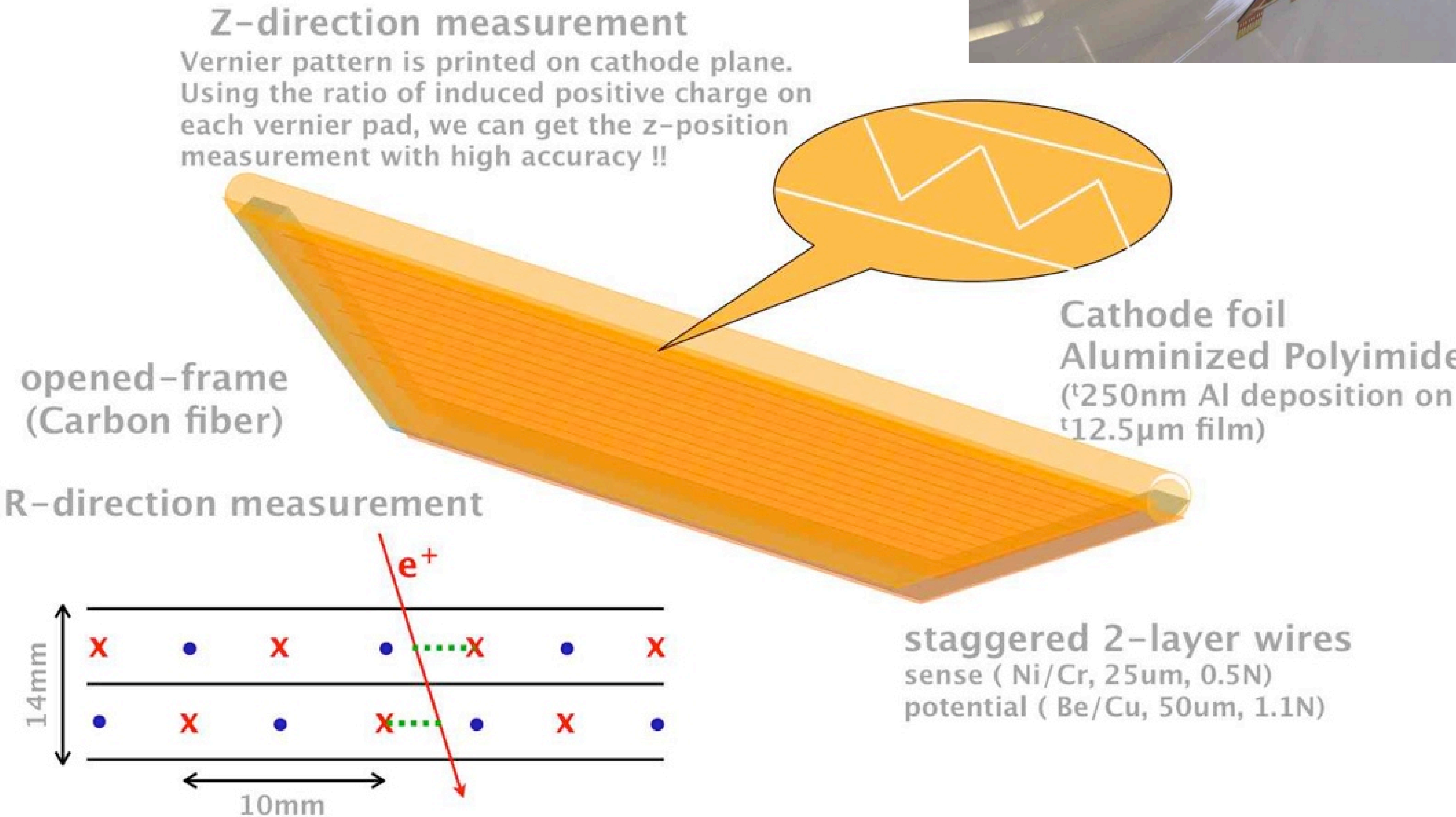
very low material to avoid multiple scattering and positron annihilation in flight



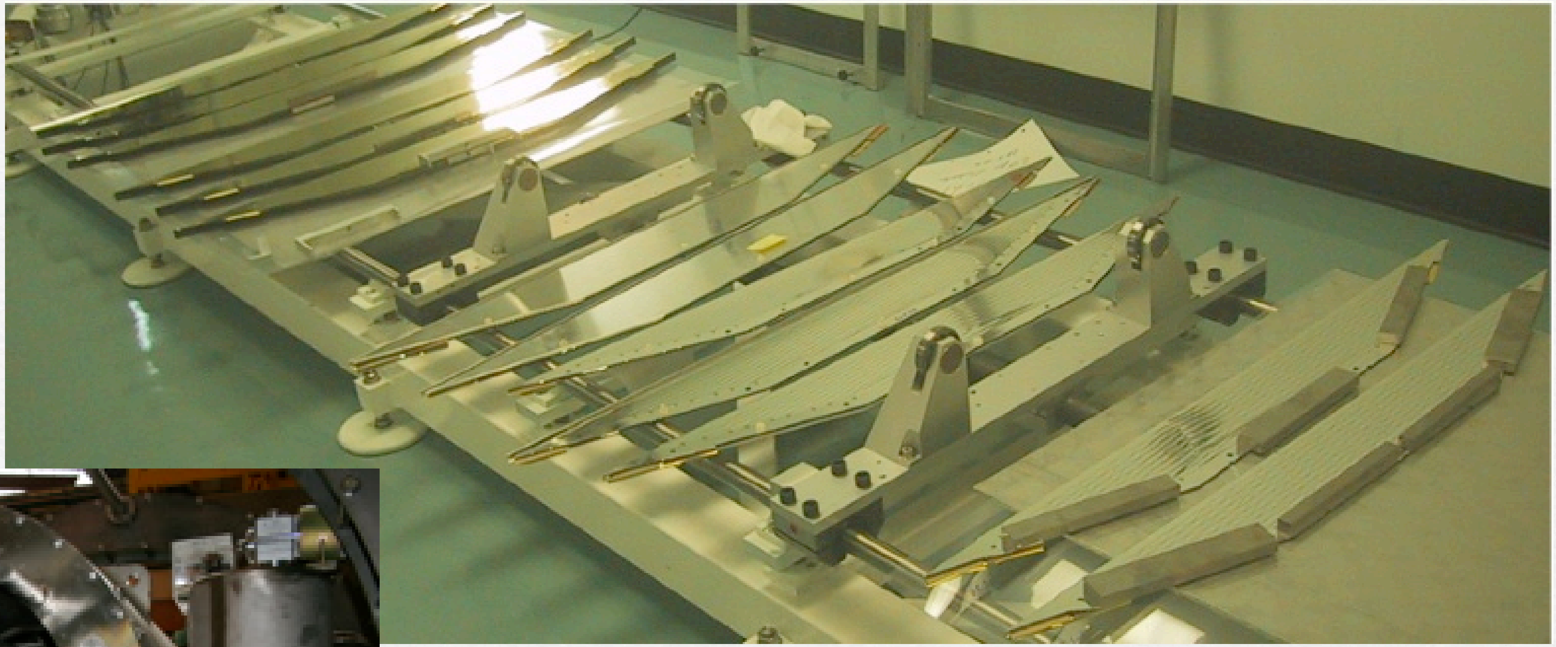
mom resolution	angle	vertex	FWHM
0.7-0.9%	9-12mrad	2.1-2.5mm	

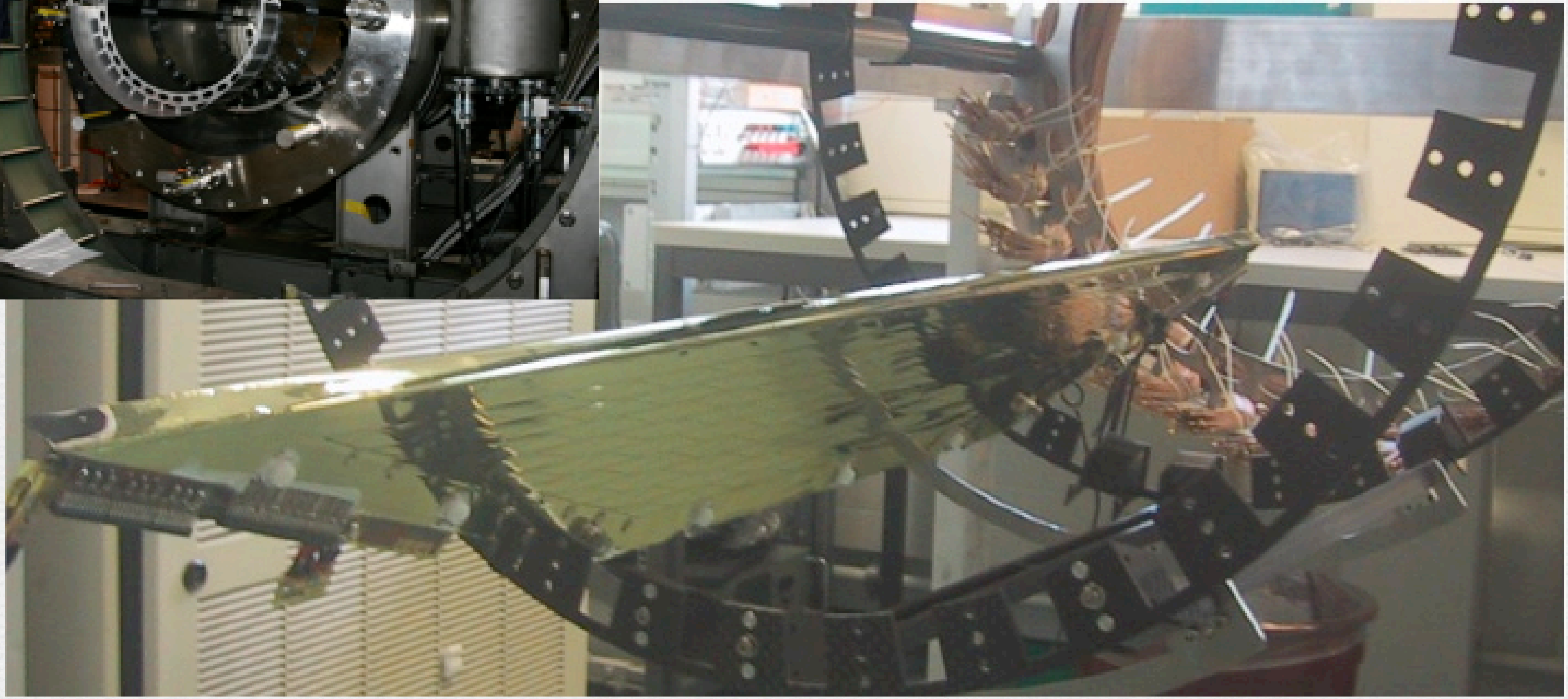
Drift Chamber Design



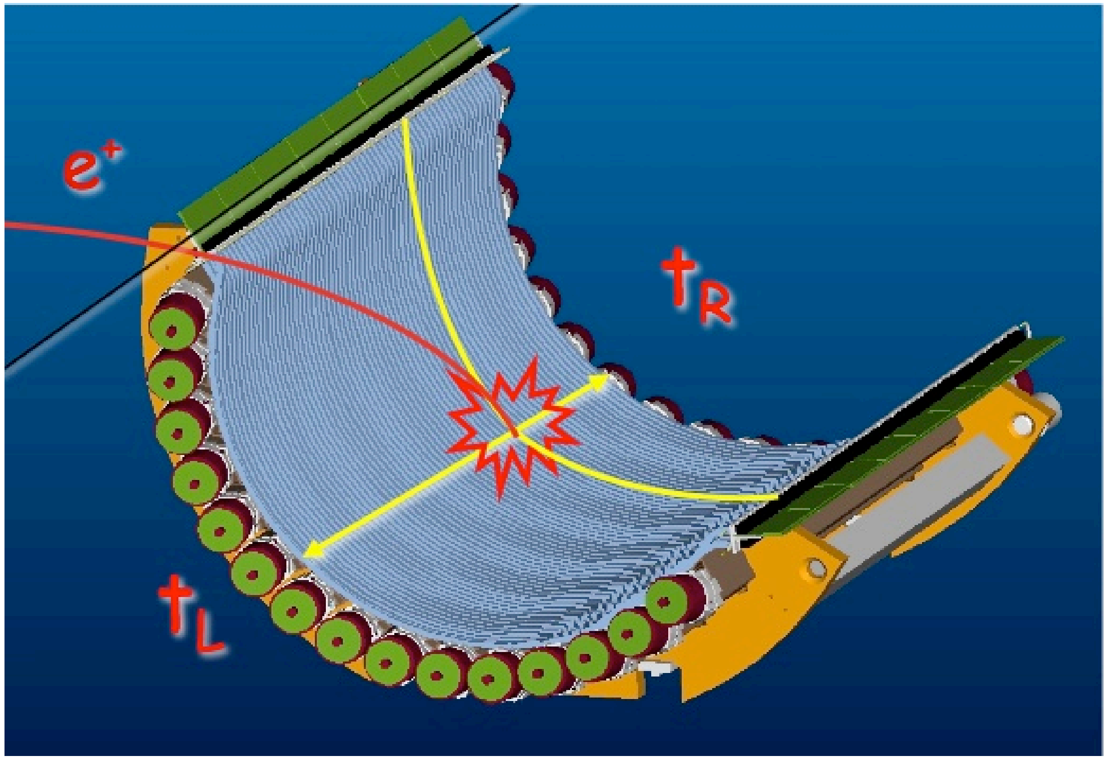


Half the DCs to be installed next week



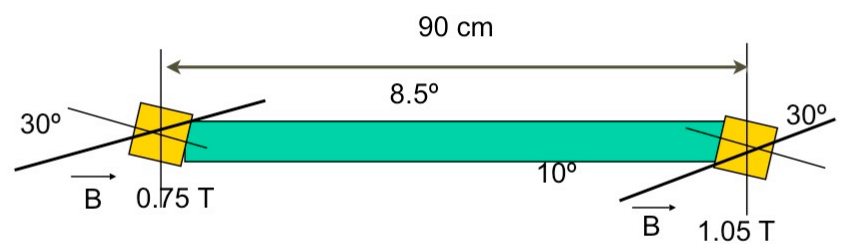


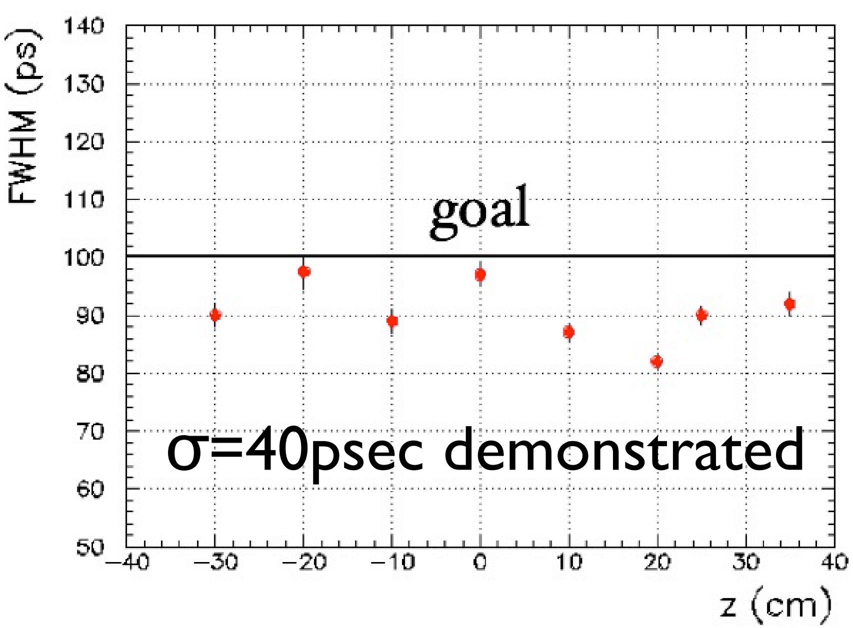
Timing Counters



Two layers of scintillators:

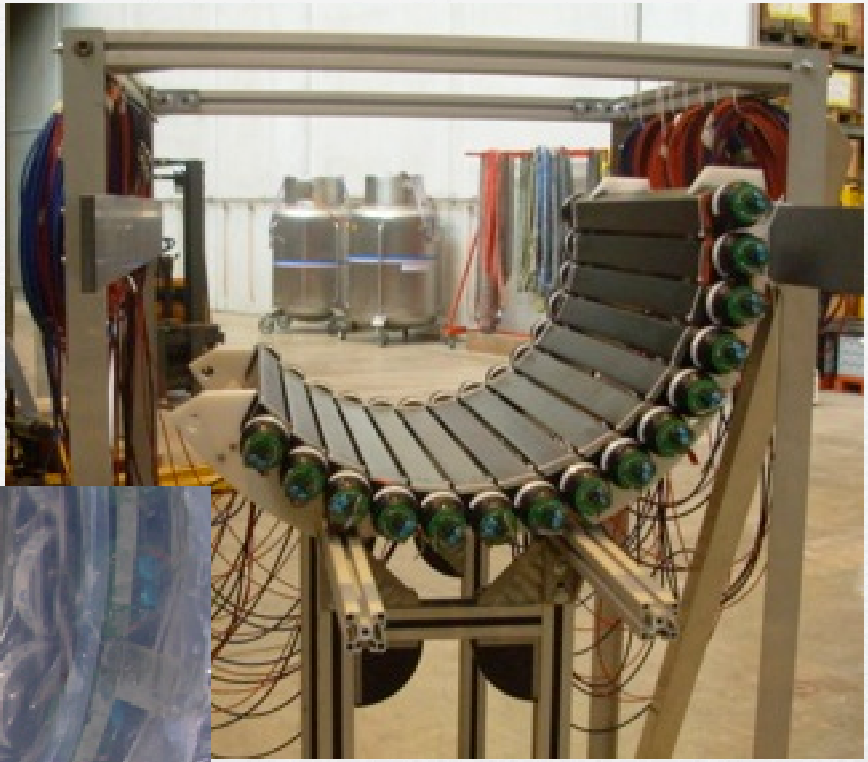
- outer thick bars - timing
- inner thin fibers - redundant Z meas





Expe. application	size(cm)	Scinti.	PMT	L(att) cm	σmeas)	σ(exp)
G.D.Agostini	3x15x100	NE114	XP2020	200	120	60
T.Tanimori	3x20x150	SCSN38	R1332	180	140	110
T.Sugitate	4x3.5x100	SCSN23	R1828	200	50	53
R.T.Gile	5x10x280	BC408	XP2020	270	110	137
TOPAZ	4.2x13x400	BC412	R1828	300	210	240
R.Stroynowski	2x3x300	SCSN38	XP2020	180	180	420
Belle	4x6x255	BC408	R6680	250	90	143
MEG	4x4x90	BC404	R5924	270	38	43

Currently being installed inside the magnet

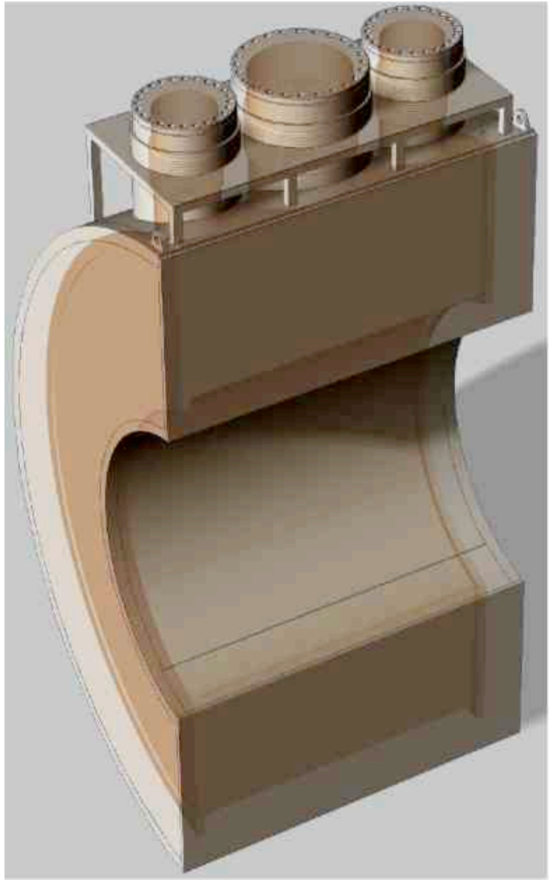


N_2 bag to protect PMTs from He

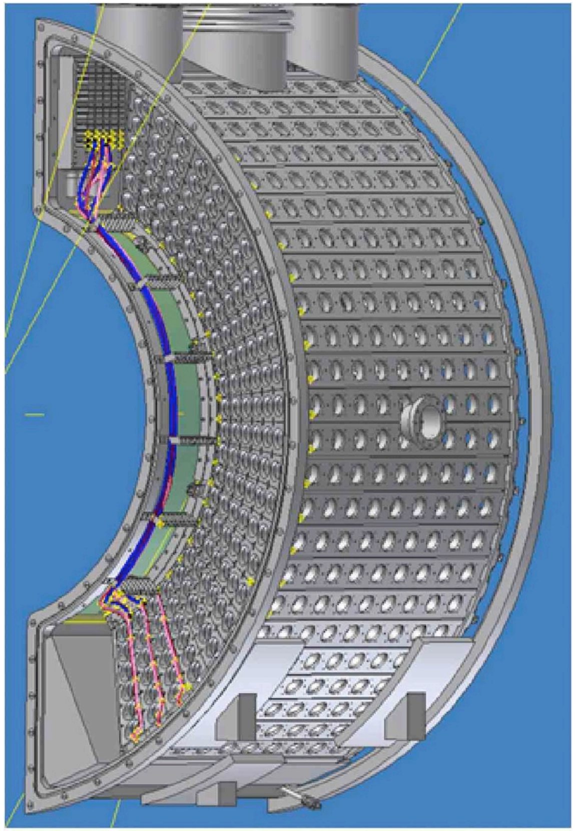
The LXe Gamma-ray Detector

LXe Gamma Ray Detector

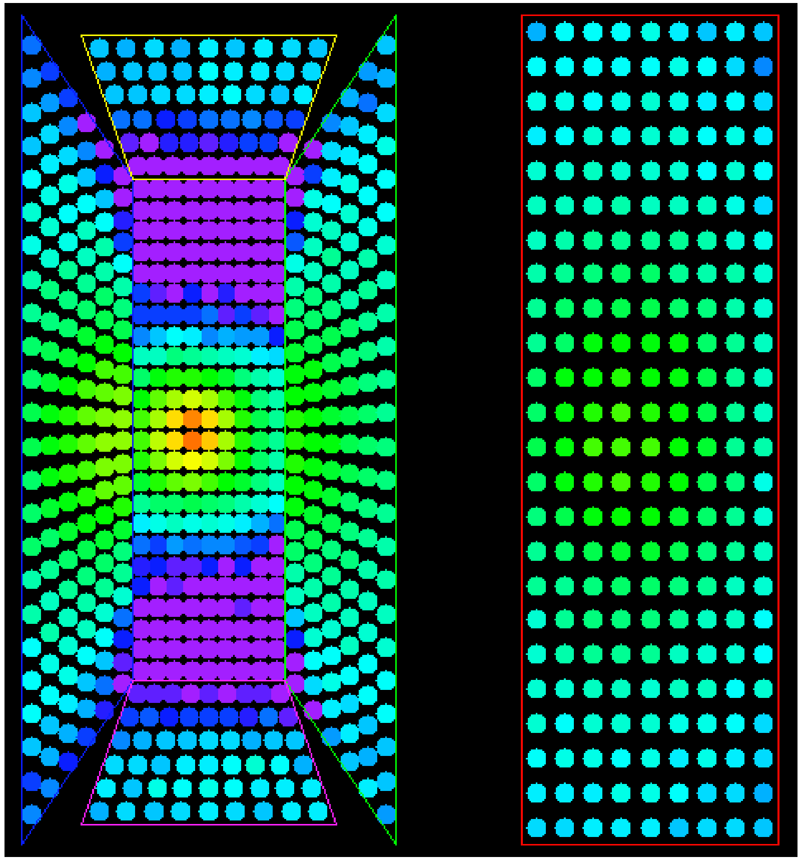
- Scintillation only: High Light Yield, Fast Signal -- Good Resolutions
  - Measures Energy, Time and Position of Gamma Rays
- 3 ton (1000 liters) LXe with ~850 PMTs
- waveform digitizing to reject pile-up
- R&D issues: low temperature (165K), VUV light, H_2O purification



cryostat



PMT holder

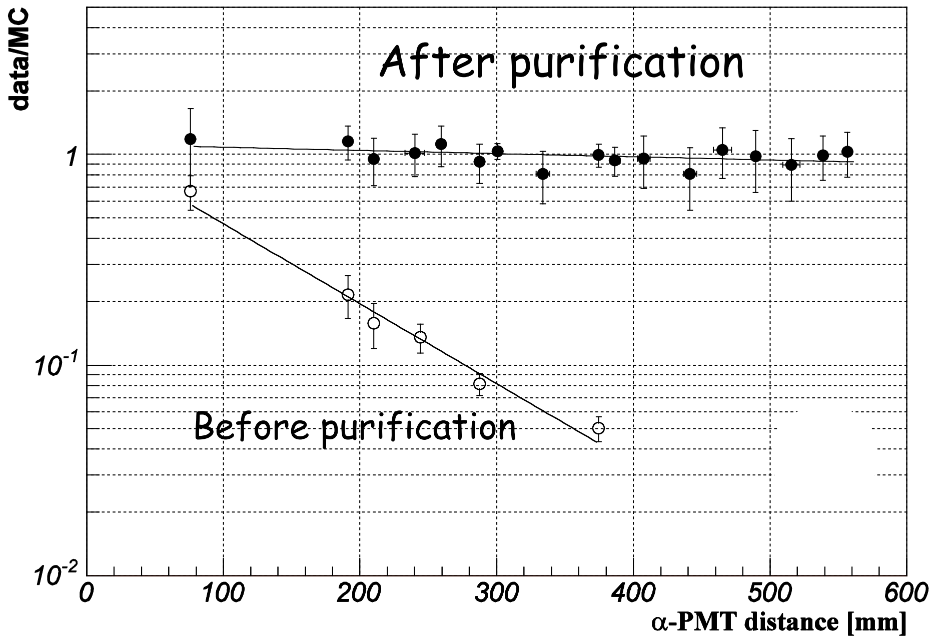


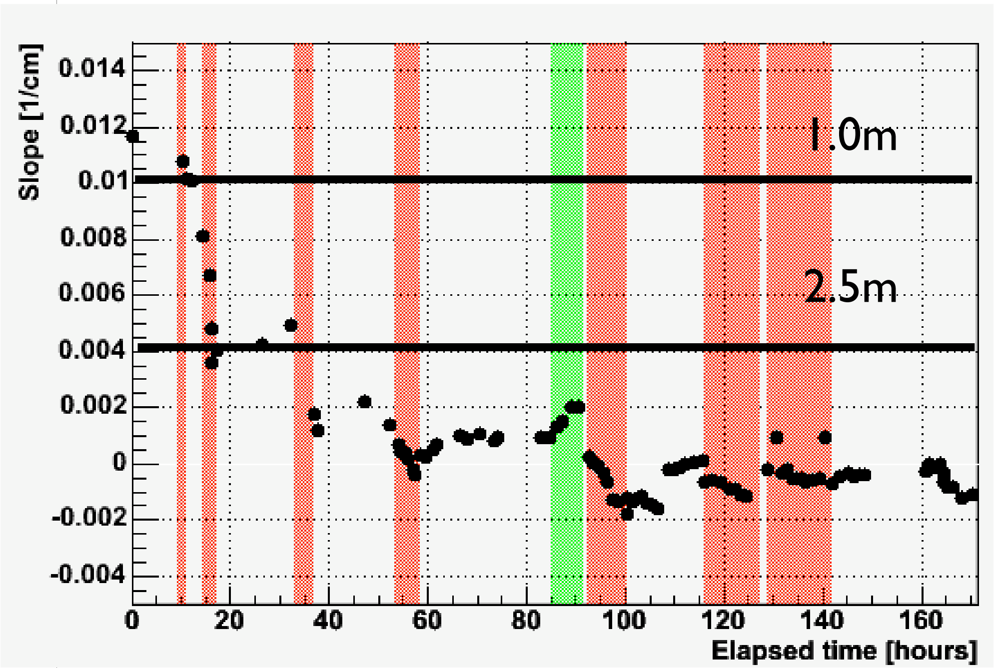
a gamma ray simulation

Scintillation Light Attenuation by Water

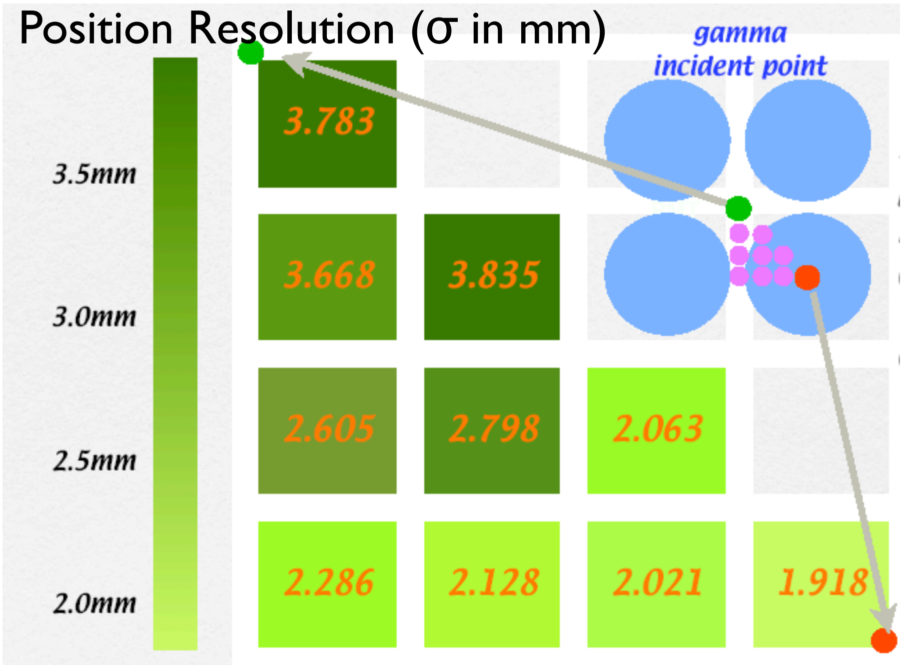
Gas & liquid phase purification successfully tested:
gas - metal getter (zirconium) ~0.5 l/h
liquid - molecular sieves ~100 l/h

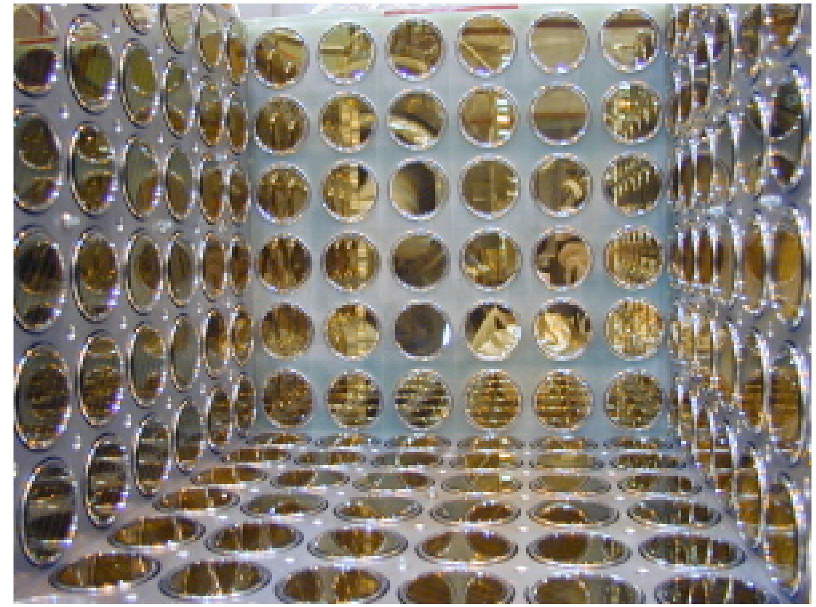
light attenuation > ~3m



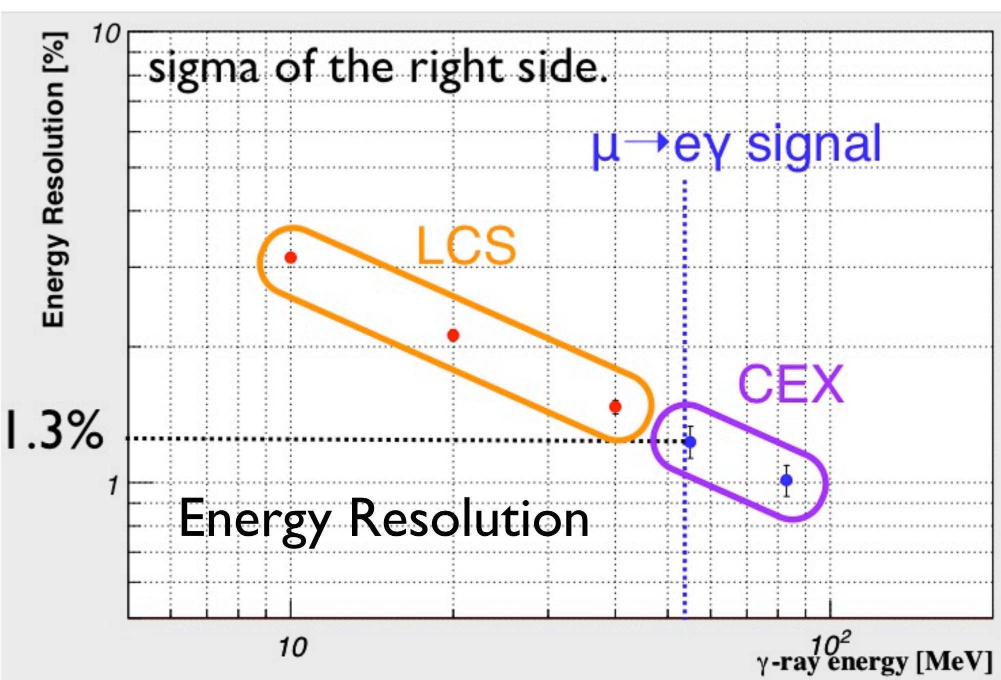


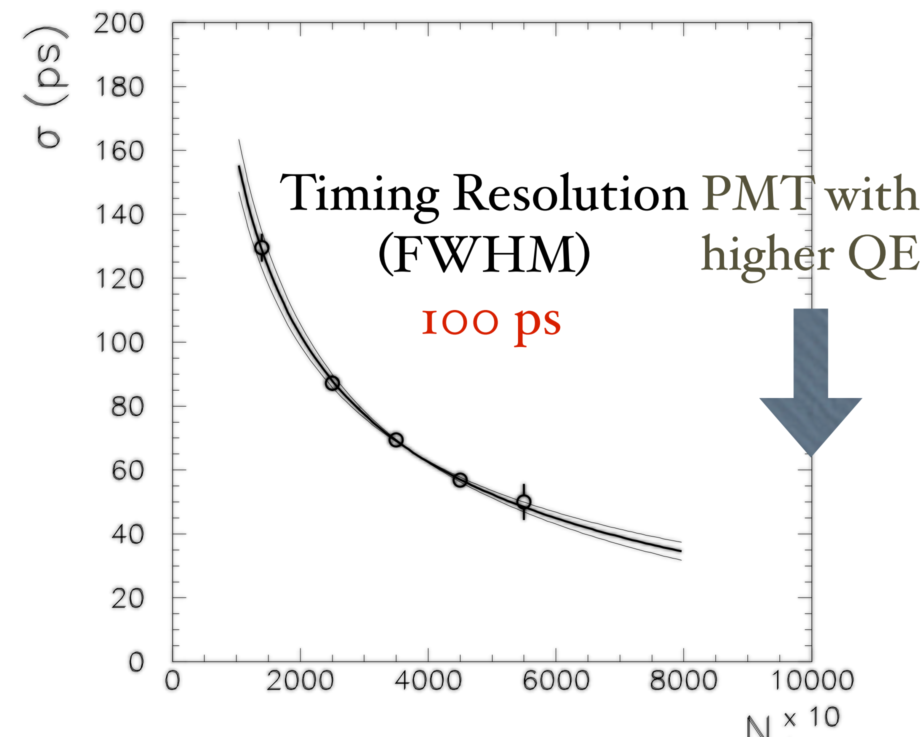
Detector Performance Verified



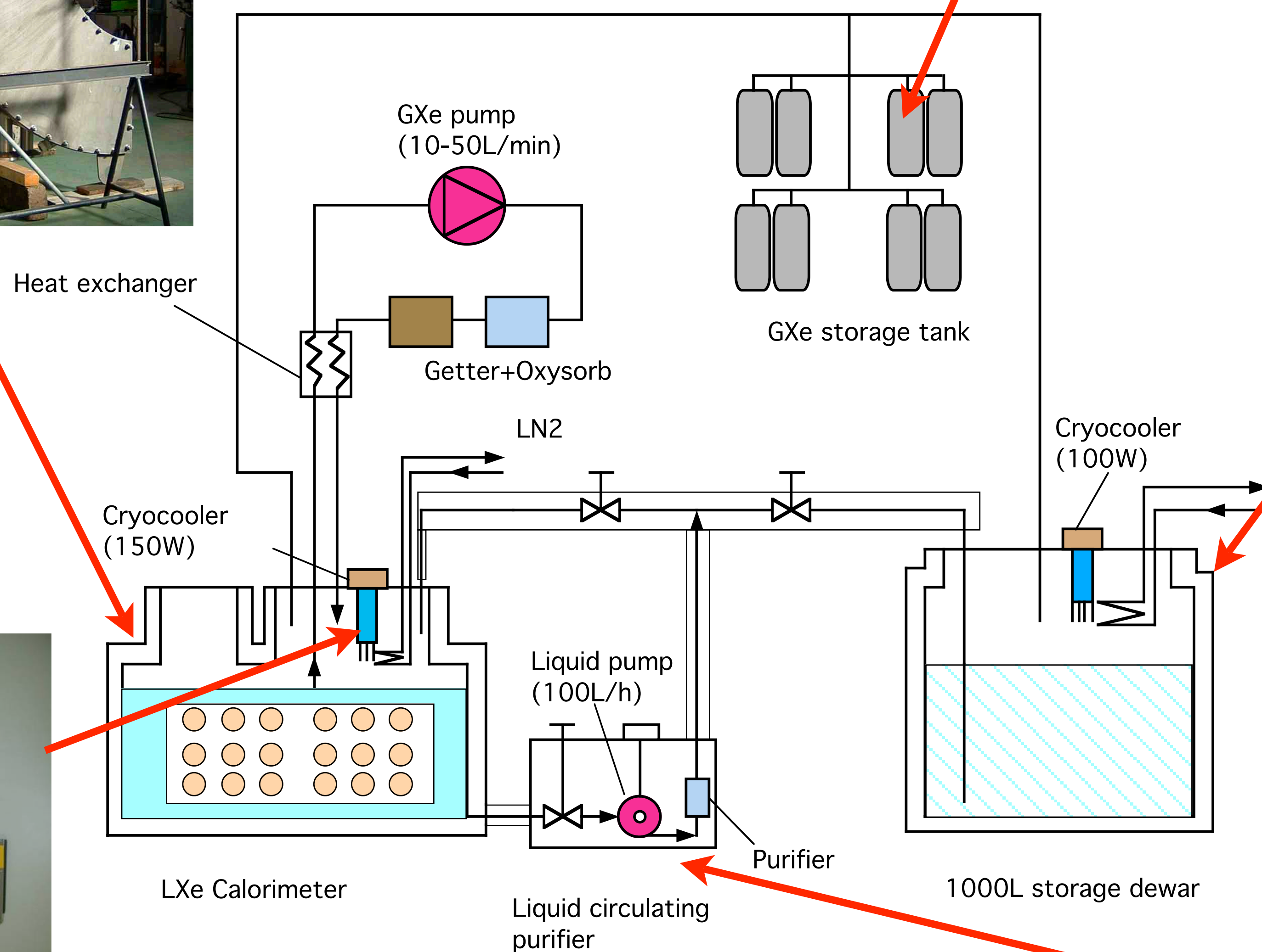


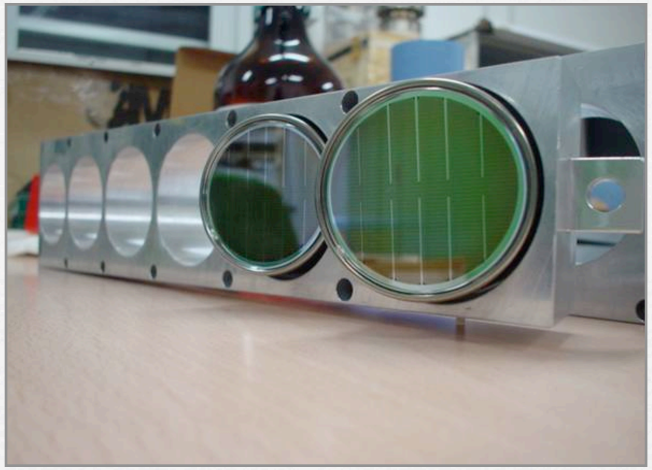
100 liter Prototype Detector





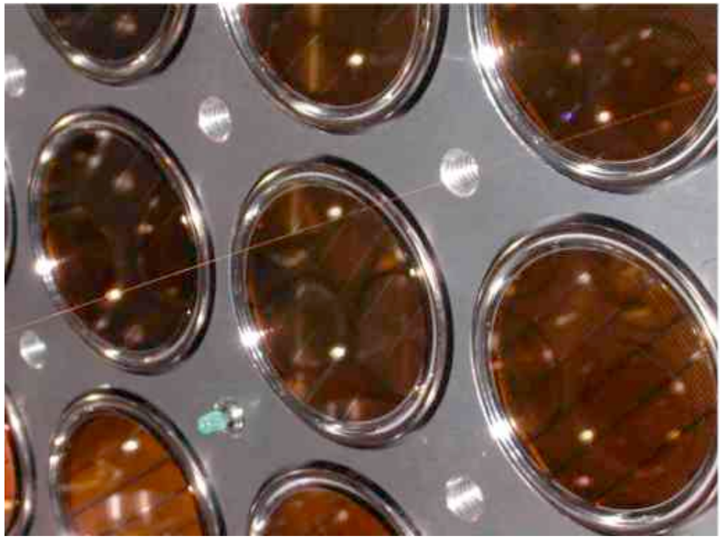
Detector System





Now Under Construction

Calibration & Monitoring of LXe Detector



α sources on thin wires

CW proton accelerator for $^{7}Li(p,\gamma)^{8}Be$

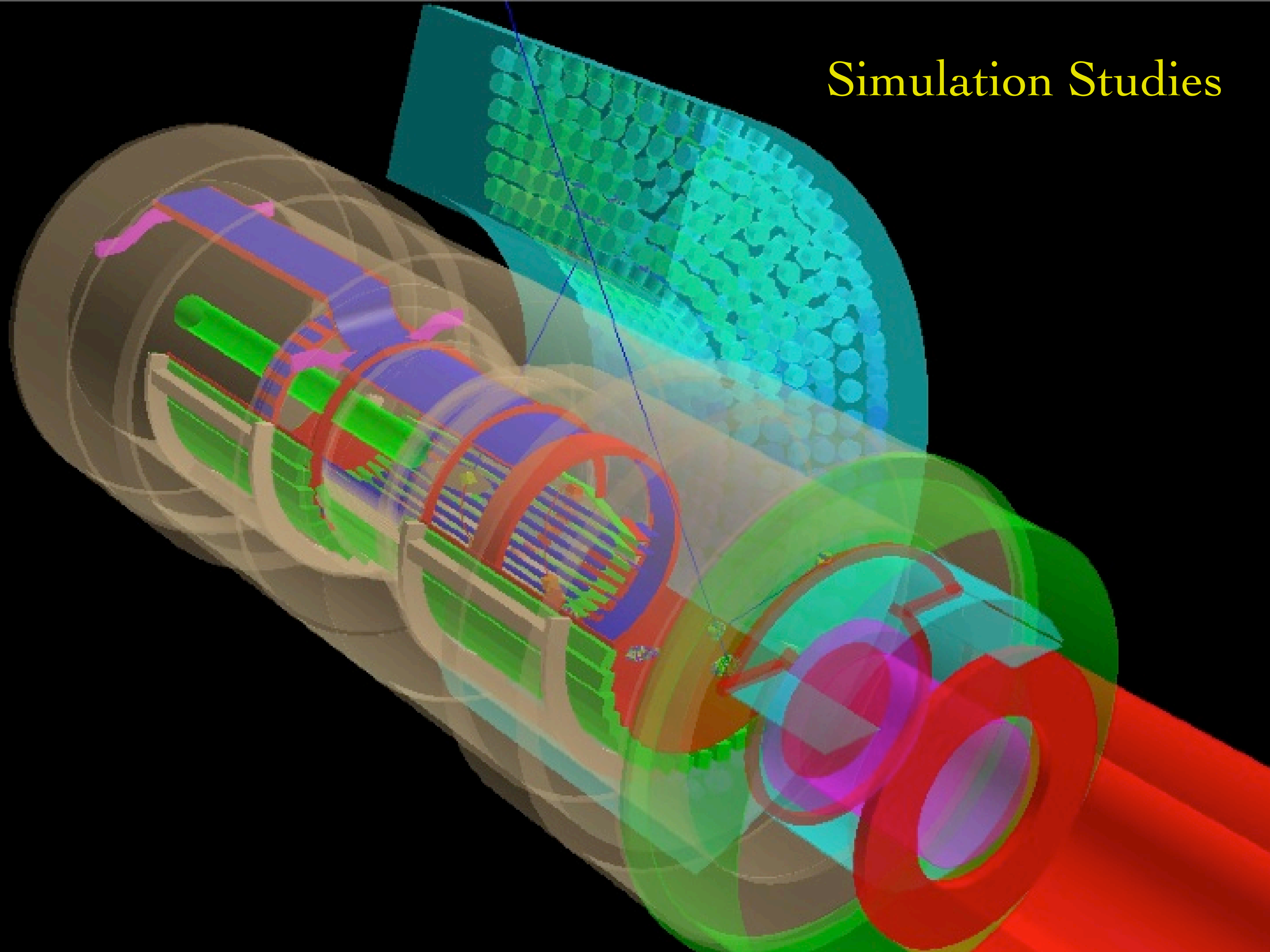
monochromatic γ 17.6MeV

$\pi^{-}p \rightarrow \pi^{0}n$, one γ tagged by NaI

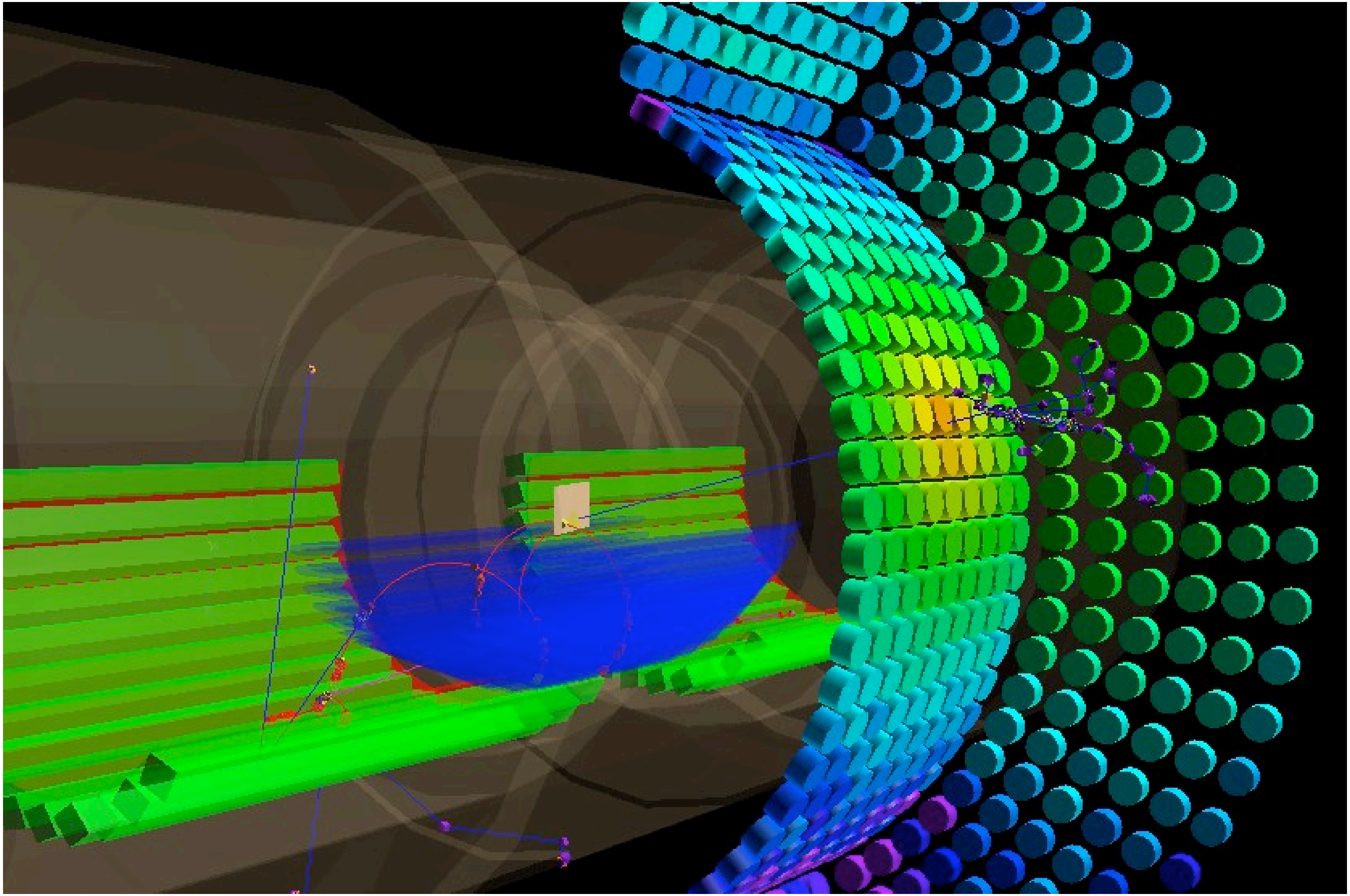
monochromatic γ 55MeV

LH_2 target

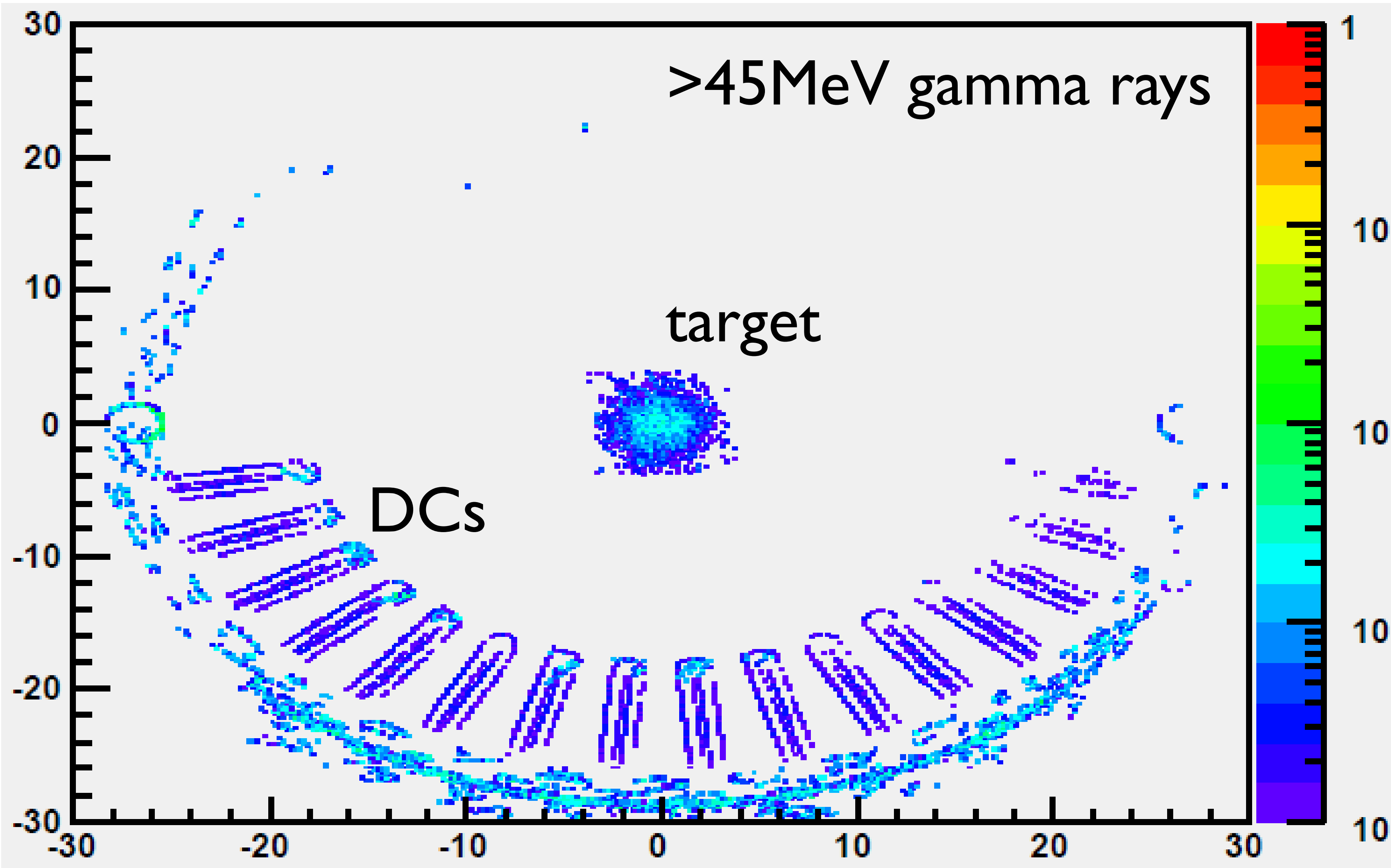
Simulation Studies



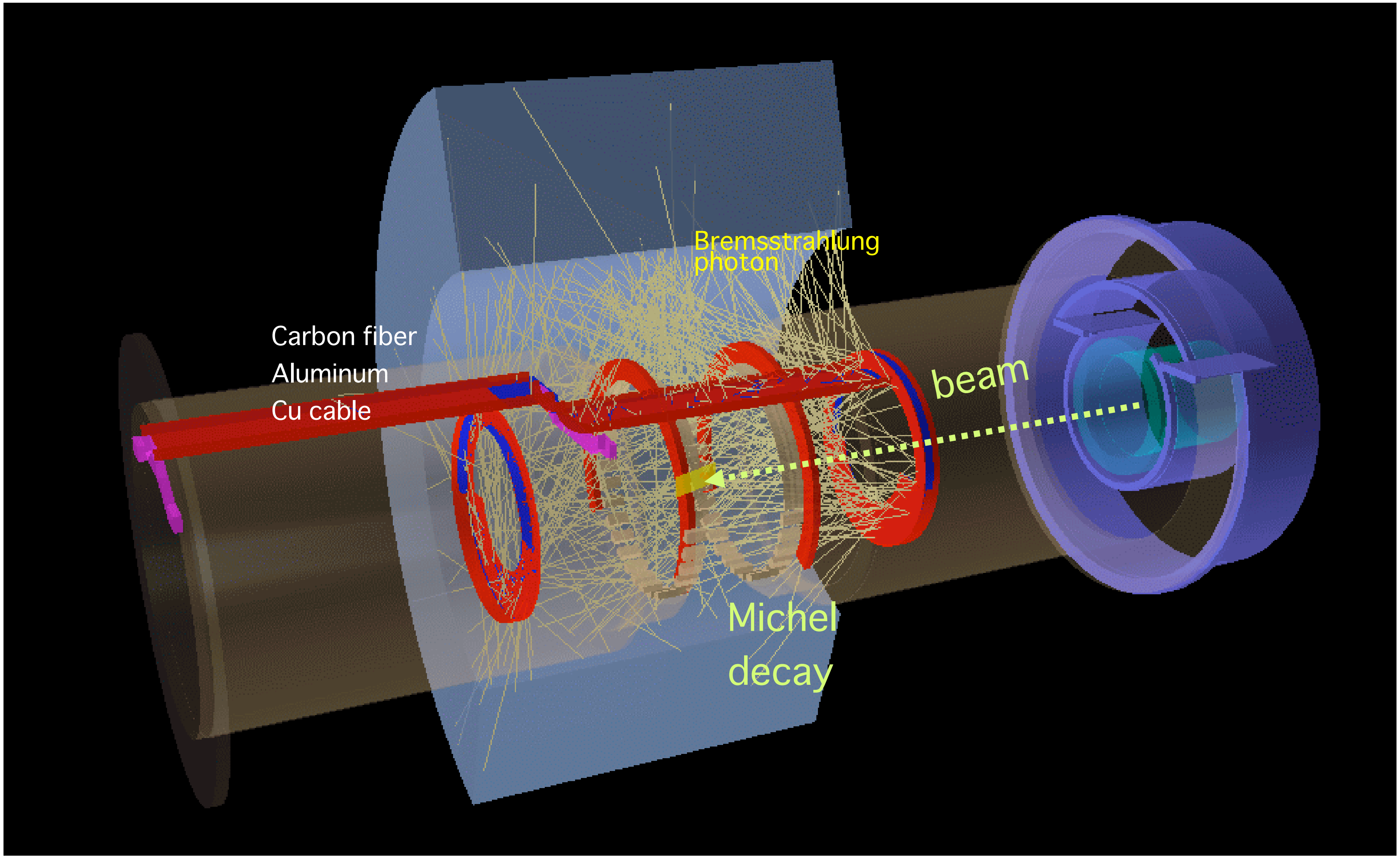
A Simulated Event



Study of sources of gamma rays by e^+ annihilation in flight



Detailed background studies are underway

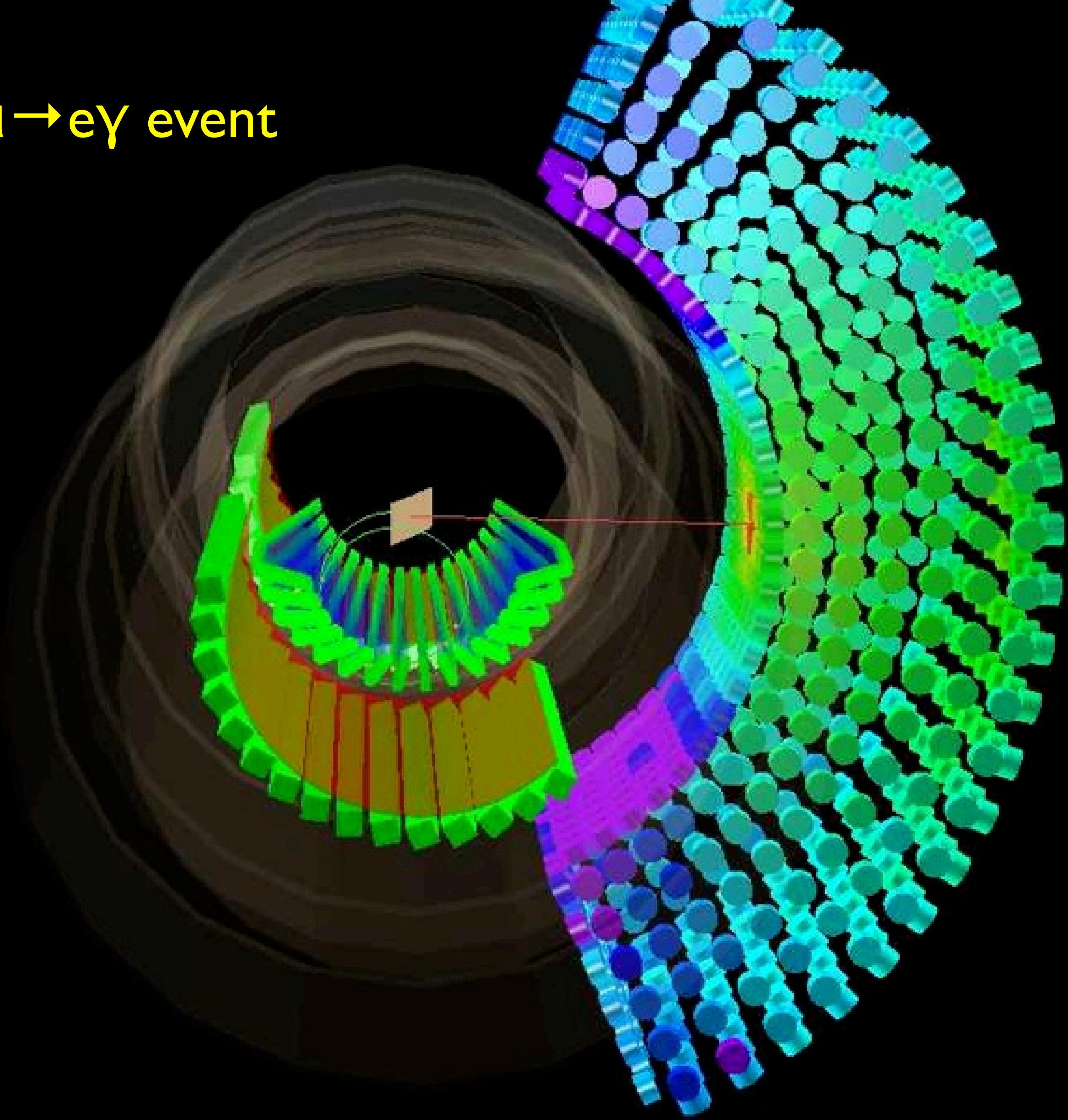


background gamma rays from the drift chamber cable ducts

MEG Prospects

- Physics run to start next year (spring - summer).
  - Beam line commissioning to be completed this autumn.
  - Engineering run with positron spectrometer toward end of this year.
  - LXe detector installation & commissioning this winter.
- Should exceed the MEGA limit after a few months running.
- Data taking takes ~2 years with a muon beam of (1-3) x 10^{7} /sec to reach ~1 x 10^{-13} sensitivity (90% CL).
- Aim for a significant result before LHC.

a $\mu \rightarrow e\gamma$ event



Personal Prospects for Muon LFV

$\mu \to e\gamma$ MEG upgrade for 10^{-14} @PSI

to measure angular distribution of $\mu \to e\gamma$

or to further constrain it

$\mu \to 3e$ A new experiment for 10^{-14} @PSI

$\mu \to e$ conversion

A new experiment for $10^{-14} \sim 10^{-16}$

@PSI/J-PARC/FNAL?

a step toward PRISM/PRIME $\sim 10^{-18}$

Conclusion

- LFV is a clear & sensitive signal of new physics
  -- SUSY GUT, SUSY seesaw, extra-d
- The B Factories have greatly improved the τ LFV limits but start to suffer background events.
- The MEG experiment will soon start an engineering run; Physics run expected to start next year. Stay tuned.
- Expect more LFV experiments to follow.