PAUL SCHERRER INSTITUT

MEG Lepton Flavor Violation Search: Challenges and Solutions

Stefan Ritt

Paul Scherrer Institute, Switzerland

Agenda

- Motivation to search for $\mu \rightarrow e\,\gamma$
- Challenges:
  - Beam, Detectors, Electronics
- Status and Outlook

Motivation

Why should we search for $\mu \to e \gamma$?

The Standard Model

	Fermions (Matter)			Bosons
Generation	I	II	III	Force carriers
Quarks	u up	c charm	t top	γ photon
Quarks	d down	s strange	b bottom	g gluon
Leptons	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson
Leptons	e electron	μ muon	τ tau	Z Z boson

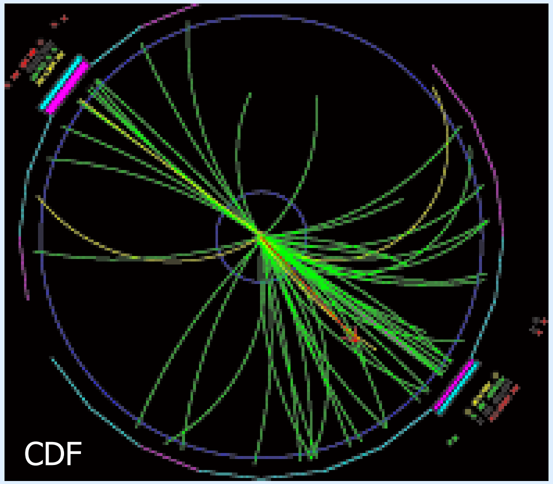
Higgs* boson

*) Yet to be confirmed

The success of the SM

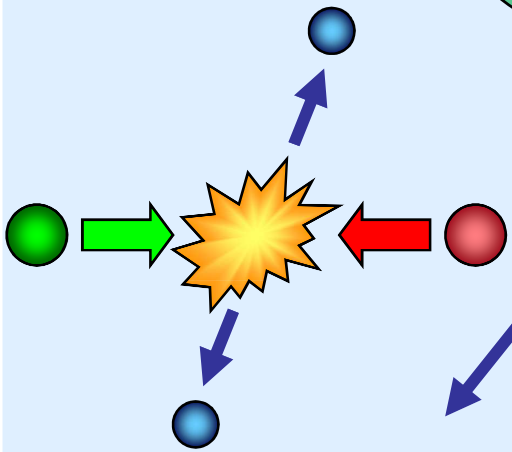
- The SM has been proven to be extremely successful since 1970's
  - Simplicity (6 quarks explain >40 mesons and baryons)
  - Explains all interactions in current accelerator particle physics
  - Predicted many particles (most prominent *W*, *Z*)
- Limitations of the SM
  - Currently contains 19 (+10) free parameters such as particle (neutrino) masses
  - Does not explain cosmological observation such as Dark Matter and Matter/Antimatter Asymmetry

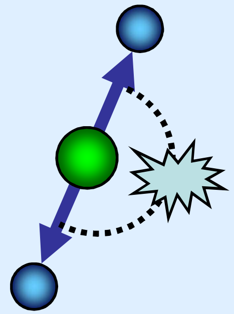
Today's goal is to look for physics beyond the standard model



Beyond the SM

Find New Physics
Beyond the SM





High Energy Frontier

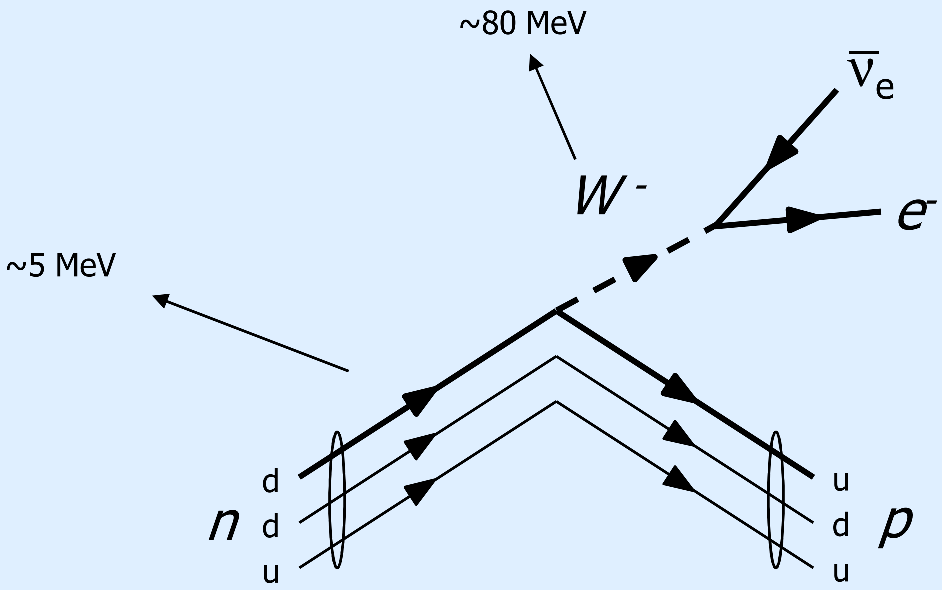
- Produce heavy new particles directly
- Heavy particles need large collider
- LHC / ILC

High Precision Frontier

- Look for small deviations from SM (g-2)
- Look for forbidden decays
- Requires high precision at low energy

Neutron beta decay

Neutron β decay via intermediate heavy W^- boson



$$n \rightarrow p^+ + e^- + \bar{\nu}_e$$

Neutron mean life time:

886 s

β decay discovery:

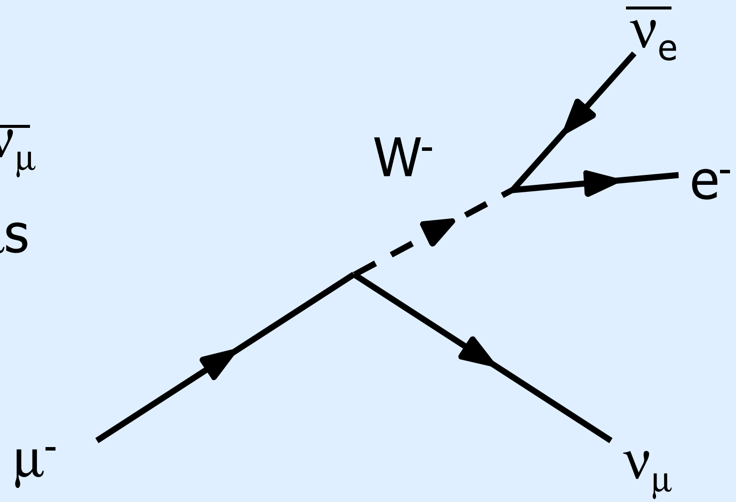
~1934

W^- discovery:

1983

The Muon

- Discovery: 1936 in cosmic radiation
- Mass: 105 MeV/c^2
- Decay: $\mu^+ \rightarrow e^+ \nu_e \overline{\nu}_\mu$
- Mean lifetime: 2.2 μs



Seth Neddermeyer

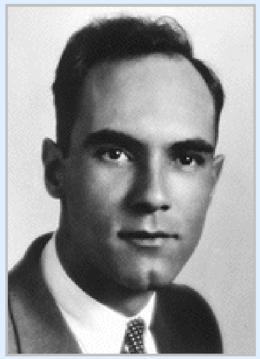
MAY 15, 1937 PHYSICAL REVIEW VOLUME 51

Note on the Nature of Cosmic-Ray Particles

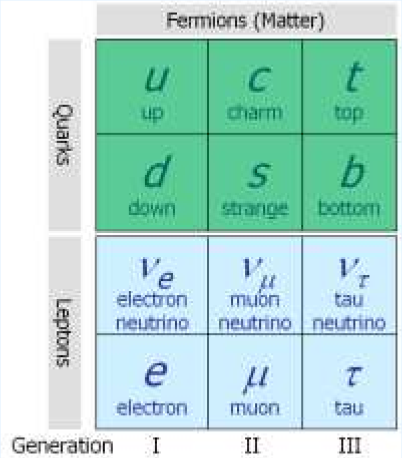
SETH H. NEDDERMEYER AND CARL D. ANDERSON
California Institute of Technology, Pasadena, California
(Received March 30, 1937)

MEASUREMENTS[1] of the energy loss of particles occurring in the cosmic-ray showers have shown that this loss is proportional massive than protons but more penetrating than electrons obeying the Bethe-Heitler theory, we have taken about 6000 counter-tripped photo-

Carl Anderson



Lepton number conservation



↑ L_e ↑ L_μ ↑ L_τ

$$\mu^+ \rightarrow e^+ \nu_e \overline{\nu_\mu}$$

≈ 100%

L_e:	0	=	-1	+1	0
L_μ:	-1	=	0	0	-1

$$\mu^+ \rightarrow e^+ \nu_e \overline{\nu_\mu} \gamma$$

0.014

L_e:	0	=	-1	+1	0	0
L_μ:	-1	=	0	0	-1	0

$$\mu^+ \rightarrow e^+ \gamma$$

$< 10^{-11}$

L_e:	0	≠	-1	0
L_μ:	-1	≠	0	0

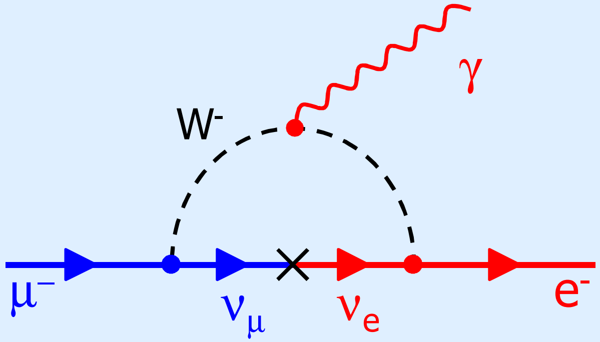
↑

Violates Lepton Number Conservation!

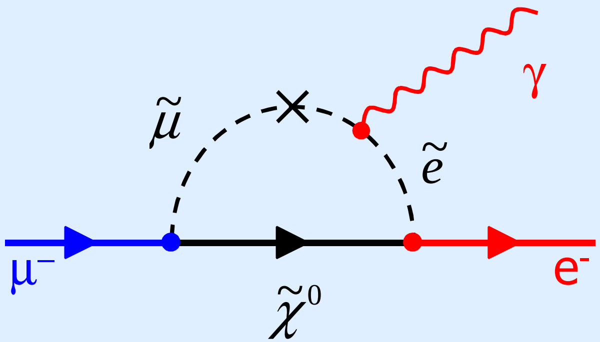
PAUL SCHERRER INSTITUT

LFV in SUSY

- While LFV is forbidden in SM, it is possible in SUSY



$$BR(\mu^- \to e^-\gamma)\big|_{SM} \propto \frac{m_\nu^4}{m_W^4} \approx 10^{-60}$$

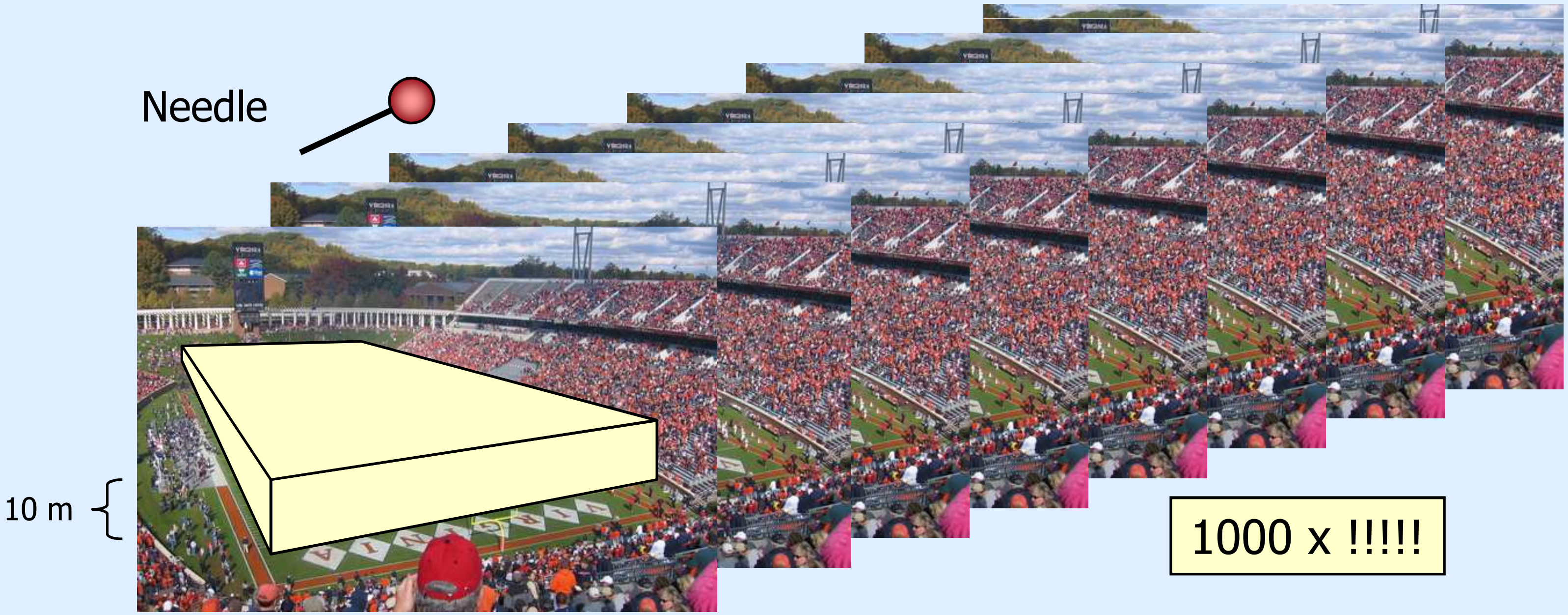


$$BR(\mu^- \to e^-\gamma)\big|_{SUSY} \approx 10^{-5} \frac{\Delta m^2_{\tilde{e}\tilde{\mu}}}{\bar{m}^2_{\tilde{\ell}}} \left(\frac{100\ \text{GeV}}{m_{SUSY}}\right)^4 \tan^2\beta \approx 10^{-12}$$

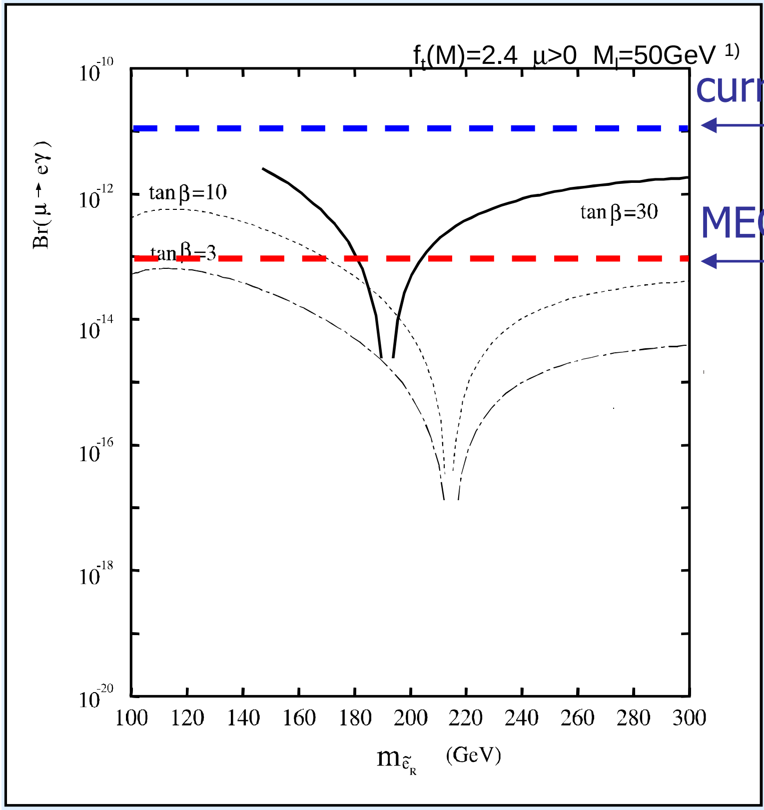
Current experimental limit: $BR(\mu \to e\,\gamma) < 10^{-11}$

LFV Summary

- LFV is forbidden in the SM, but possible in SUSY (and many other extensions to the SM) though loop diagrams ($\rightarrow$ heavy virtual SUSY particles)
- If $\mu \rightarrow e \gamma$ is found, new physics beyond the SM is found
- Current exp. limit is 10^{-11}, predictions are around 10^{-12} … 10^{-14}
- Goal of 10^{-13} is a big experimental challenge!

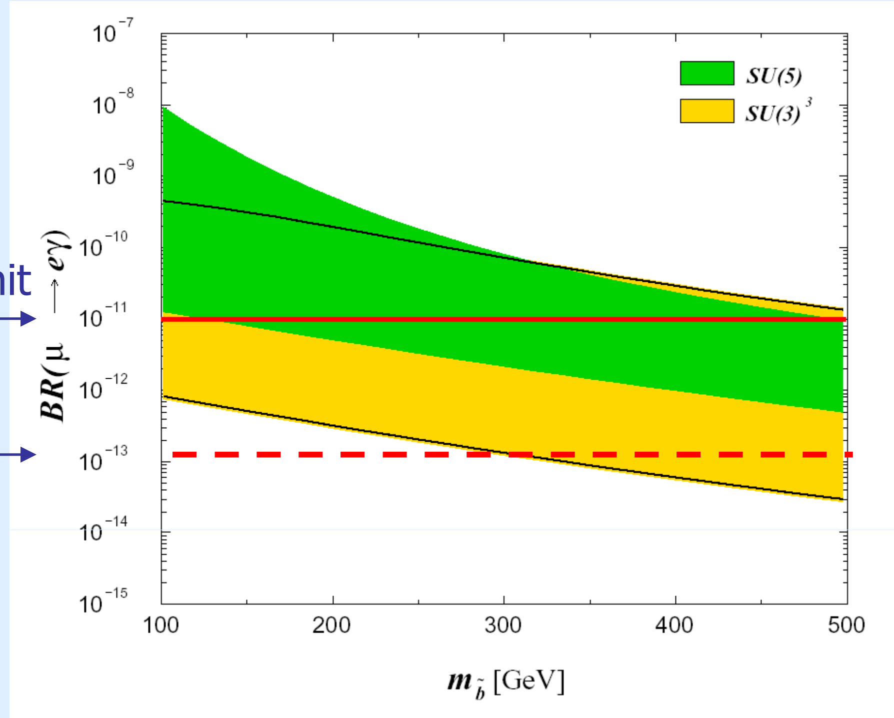


Current SUSY predictions



current limit

MEG goal



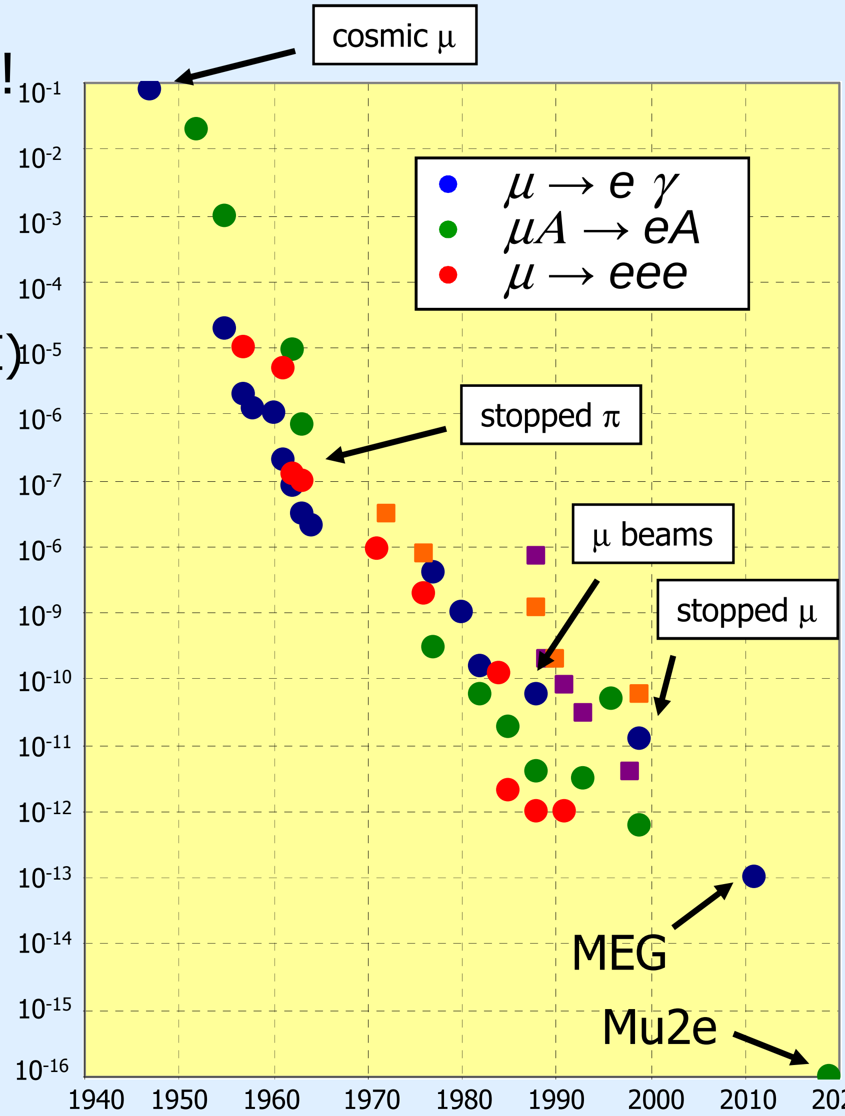
"Supersymmetric parameterspace accessible by LHC"

1) J. Hisano et al., Phys. Lett. B391 (1997) 341
2) MEGA collaboration, hep-ex/9905013

W. Buchmueller, DESY, priv. comm.

History of LFV searches

- Long history dating back to 1947!
- Best present limits:
  - 1.2 x 10^{-11} (MEGA)
  - $\mu Ti \rightarrow eTi < 7 \times 10^{-13}$ (SINDRUM II)
  - $\mu \rightarrow eee < 1 \times 10^{-12}$ (SINDRUM II)
- MEG Experiment aims at 10^{-13}
- Improvements linked to advance in technology



SUSY SU(5)

$BR(\mu \rightarrow e\ \gamma) = 10^{-13}$

$\Leftrightarrow$

$\mu Ti \rightarrow eTi = 4 \times 10^{-16}$

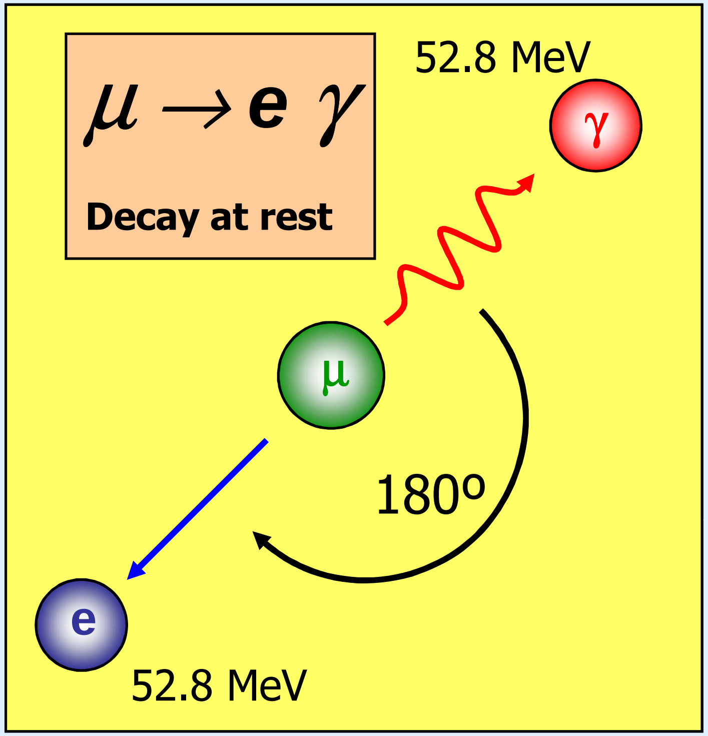
$\Leftrightarrow$

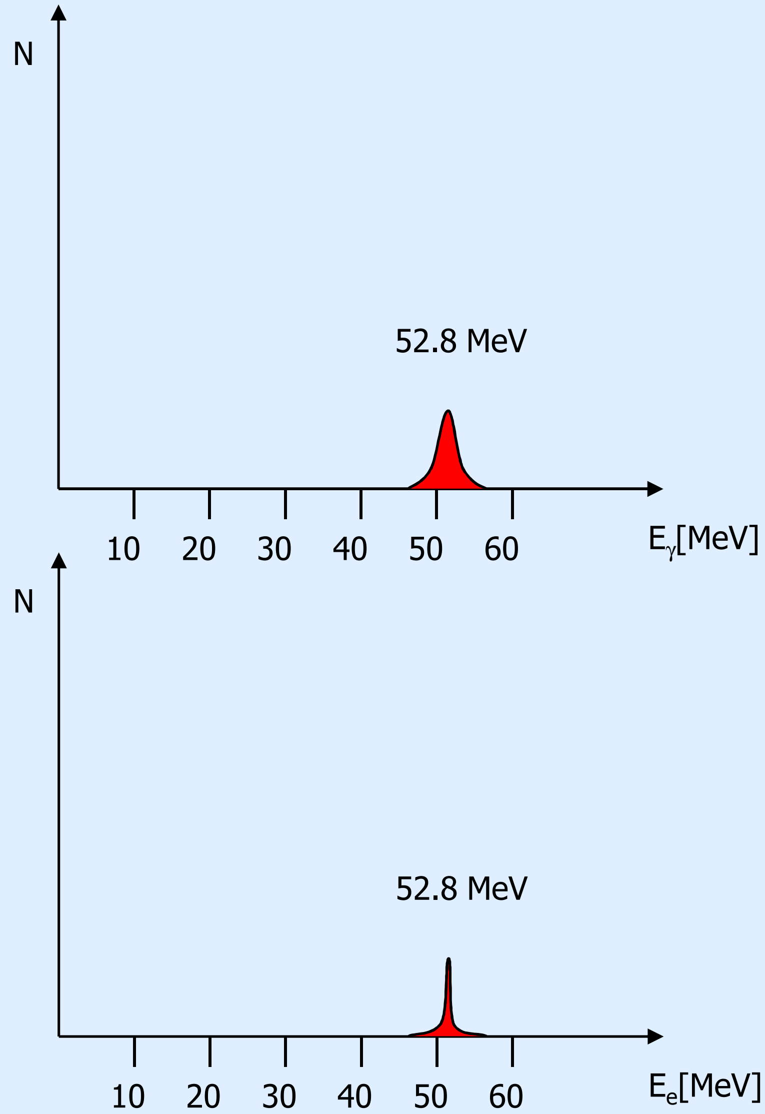
$BR(\mu \rightarrow eee) = 6 \times 10^{-16}$

Experimental Method

How to detect $\mu \rightarrow e\,\gamma$?

Decay Topology $\mu \to e\,\gamma$



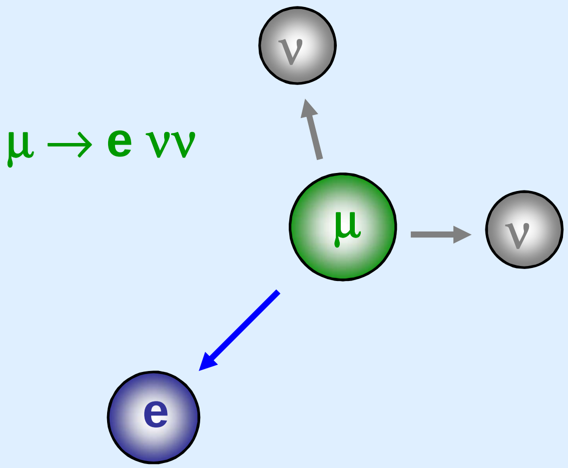


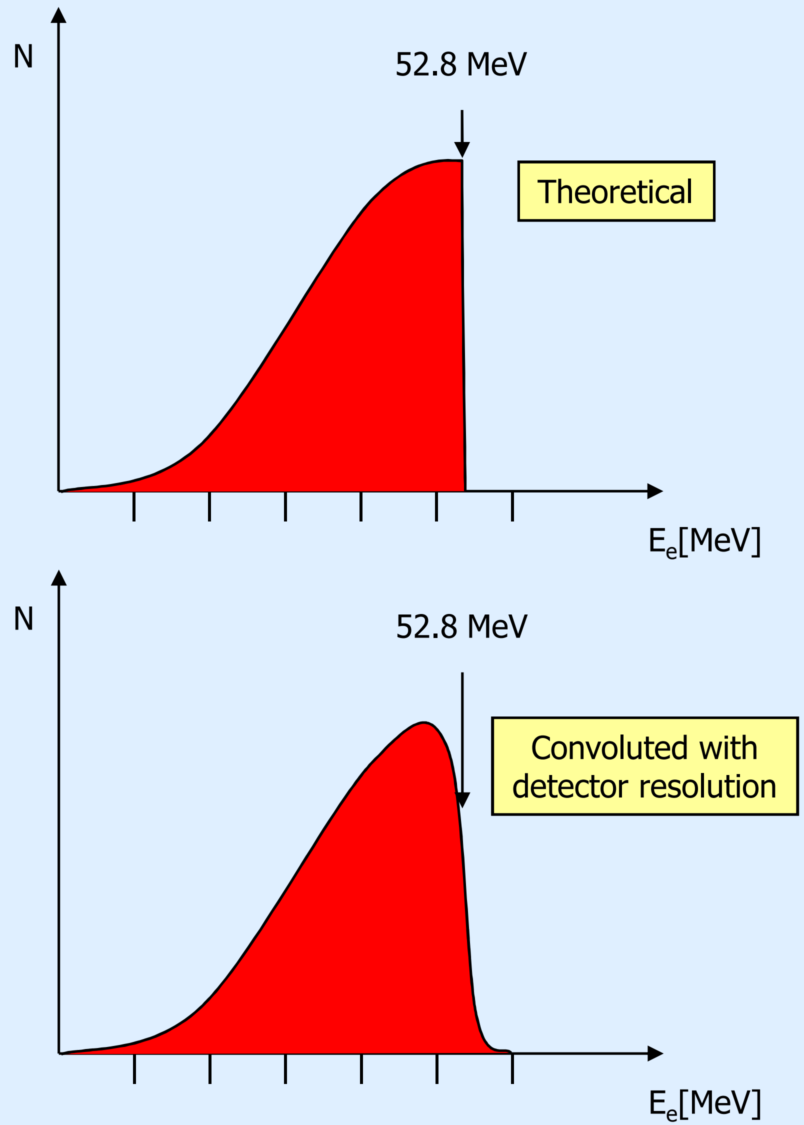
$\mu \to e\,\gamma$ signal very clean

- $E_g = E_e = 52.8$ MeV
- $\theta_{\gamma e} = 180°$
- e and γ in time

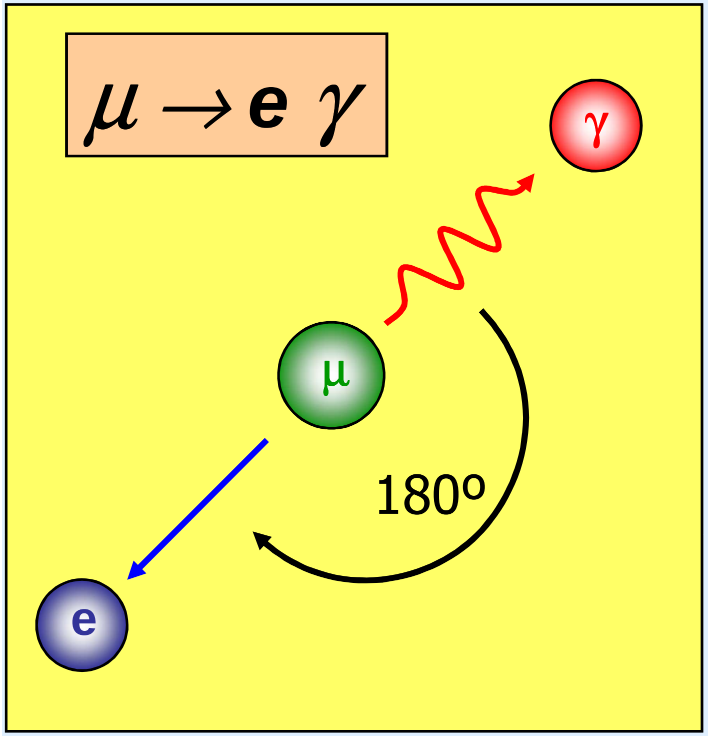
Michel Decay (~100%)

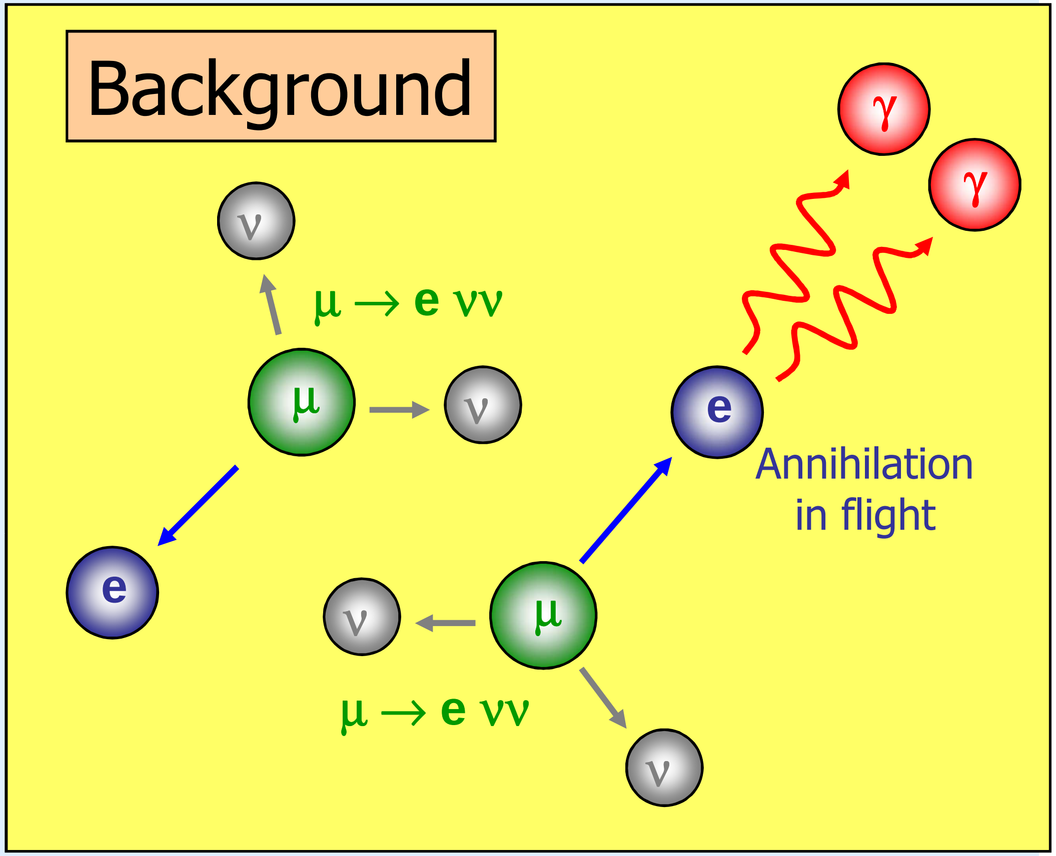
Three body decay: wide energy spectrum





“Accidental” Background





$\mu \rightarrow e\,\gamma$ signal very clean

- $E_g = E_e = 52.8$ MeV
- $\theta_{\gamma e} = 180^o$
- e and γ in time

⇨ Good energy resolution
⇨ Good spatial resolution
⇨ Excellent timing resolution
⇨ Good pile-up rejection

Sensitivity and Background Rate

Aimed experiment parameters:

N_μ	3×10^7 /s
T	2×10^7 s (~50 weeks)
$\Omega/4\pi$	0.09
ε_e	0.90
ε_γ	0.60
ε_{sel}	0.70

Aimed resolutions:

	FWHM
ΔE_e	0.8%
ΔE_γ	4.3%
$\Delta\theta_{e\gamma}$	18 mrad
$\Delta t_{e\gamma}$	180 ps

Single event sensitivity $(N_\mu \bullet T \bullet \Omega/4\pi \bullet \varepsilon_e \bullet \varepsilon_\gamma \bullet \varepsilon_{sel})^{-1} = 3.6 \times 10^{-14}$

Prompt Background $B_{pr} \cong 10^{-17}$

Accidental Background $B_{acc} \propto \Delta E_e \bullet \Delta t_{e\gamma} \bullet (\Delta E_\gamma)^2 \bullet (\Delta\theta_{e\gamma})^2 \rightarrow 4 \times 10^{-14}$

90% C.L. Sensitivity $\rightarrow 1.3 \times 10^{-13}$

~70 People (40 FTEs) from five countries

Tokyo U.
Waseda U.
KEK

INFN & Uni
Pisa
Roma
Genova
Pavia
Lecce

PSI

UC Irvine

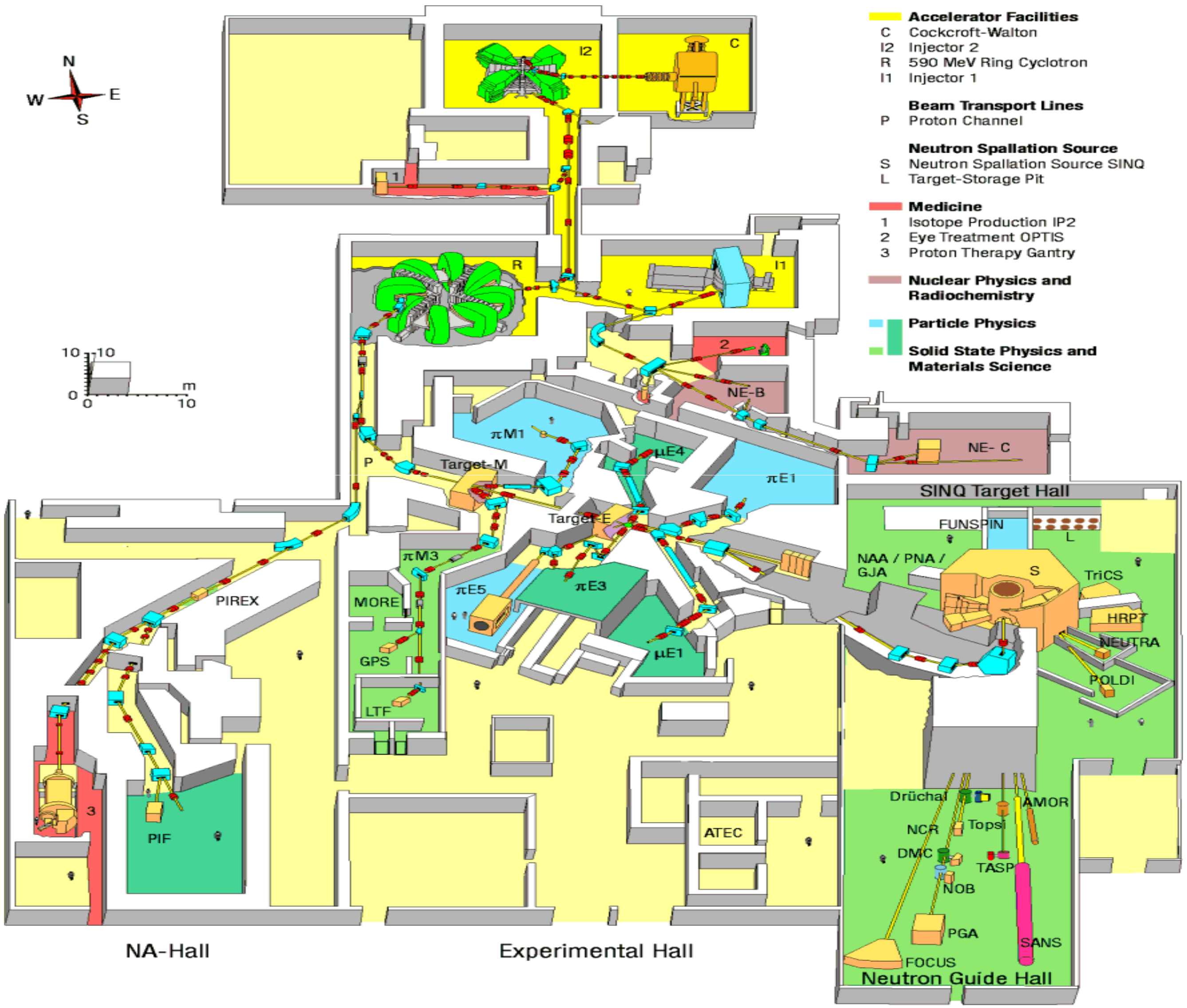
JINR Dubna
BINP Novosibirsk

Paul Scherrer Institute

Proton Accelerator

Swiss Light Source

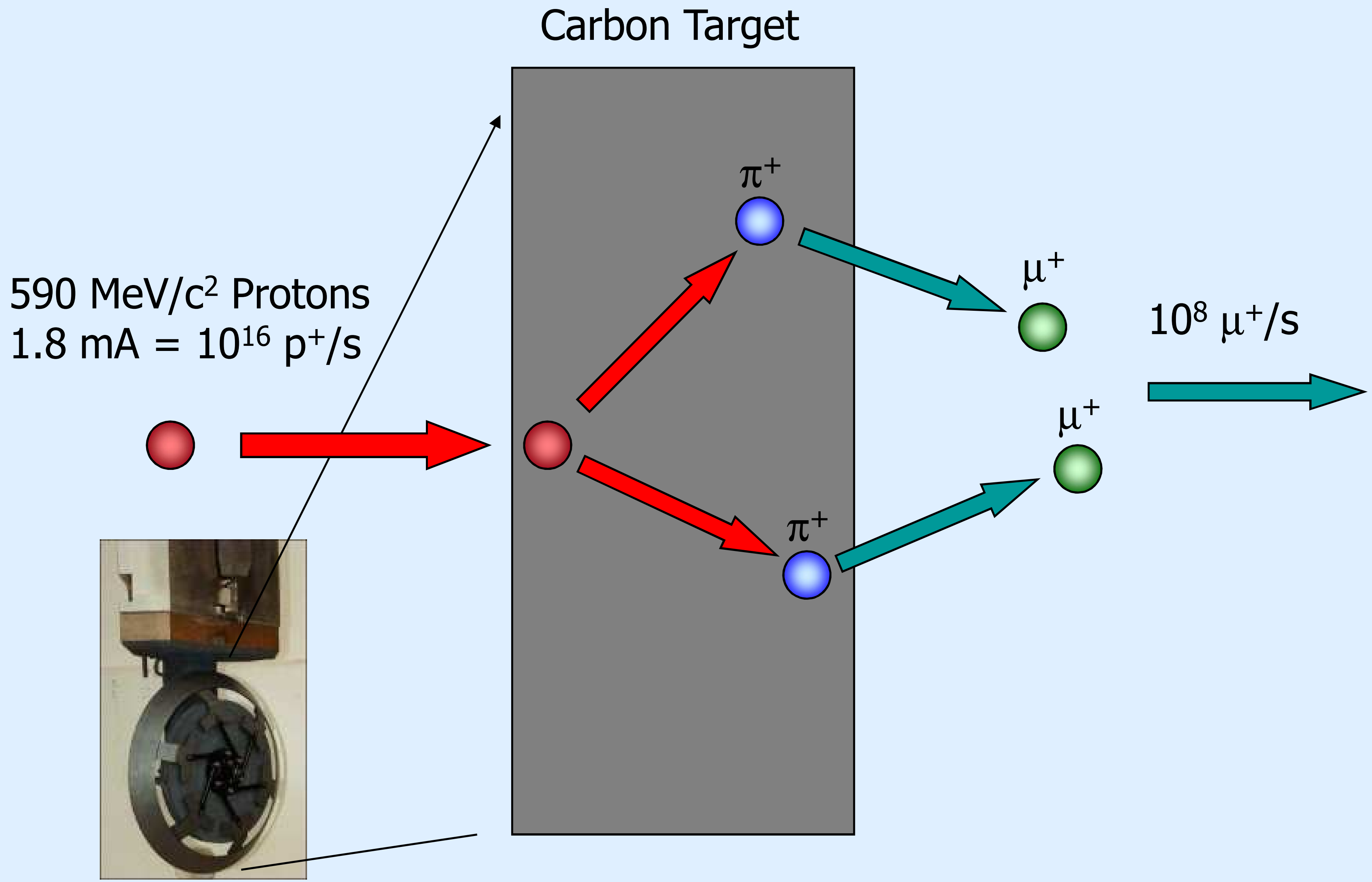
PSI Proton Accelerator



Challenge 1: Muon Beam

How to get 10^8 μ/sec on a small stopping target?

Generating muons

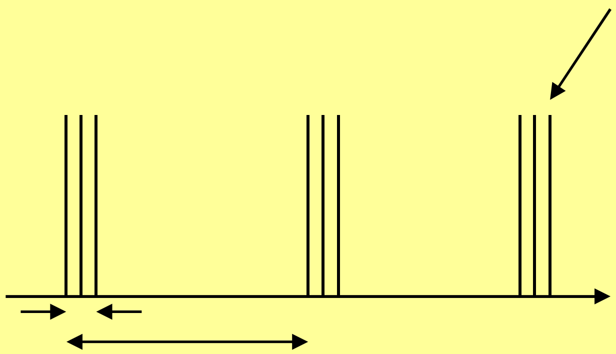


Muon Beam Structure

Muon beam structure differs for different accelerators

Instantaneous rate much higher in pulsed beam

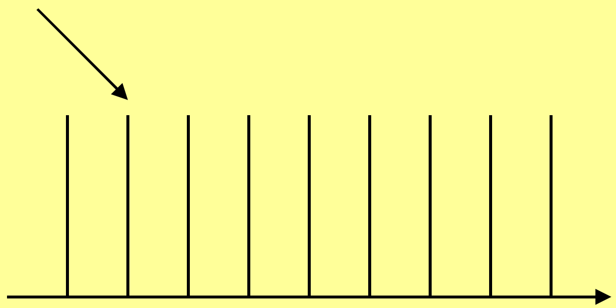
Pulsed muon beam, LANL



Duty cycle: Ratio of pulse width over period

Duty cycle: 6 %

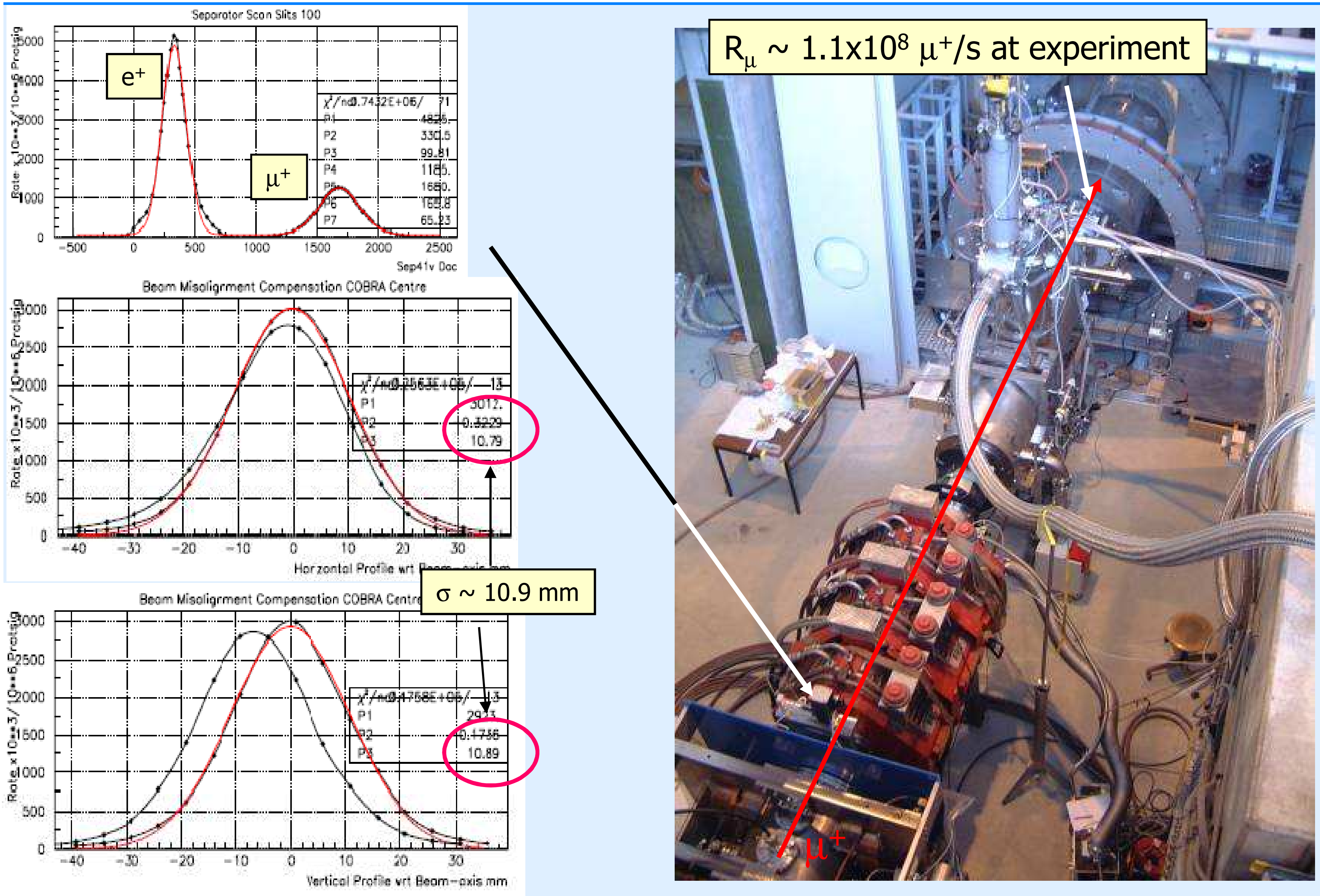
DC muon beam, PSI



Duty cycle: Ratio of pulse width over period

Duty cycle: 100 %

Results of beam line optimization



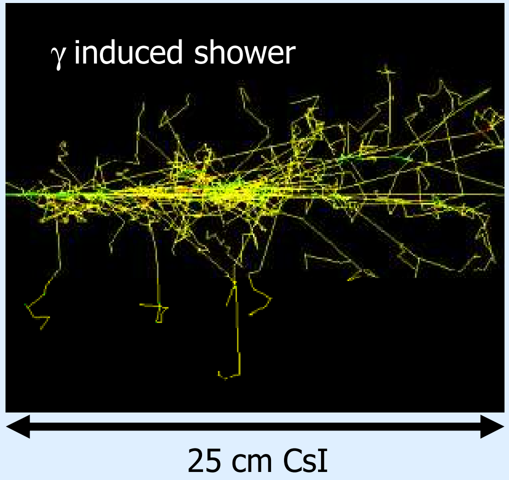
Challenge 2: Calorimeter

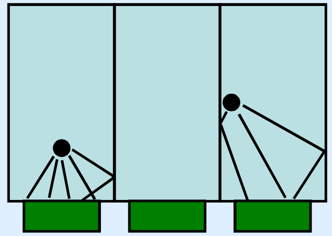
$$\mu \rightarrow e\ \gamma$$

Energy
Position
Time

Photon Detectors (@ 50 MeV)

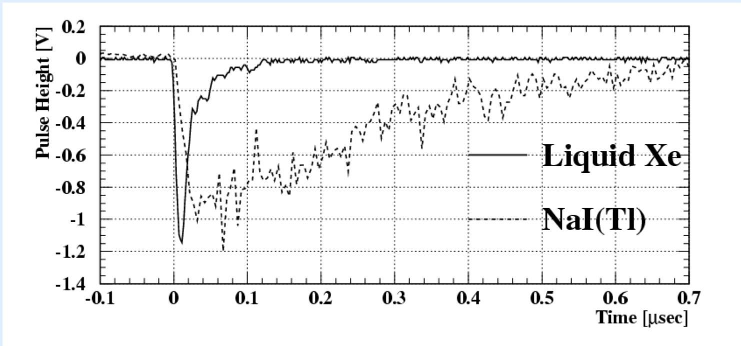
- Anorganic crystals (NaI, CsI):
  - Good efficiency, good energy resolution, poor position resolution, poor homogeneity
- Liquid Noble Gases:
  - No crystal boundaries
  - Good efficiency, resolutions





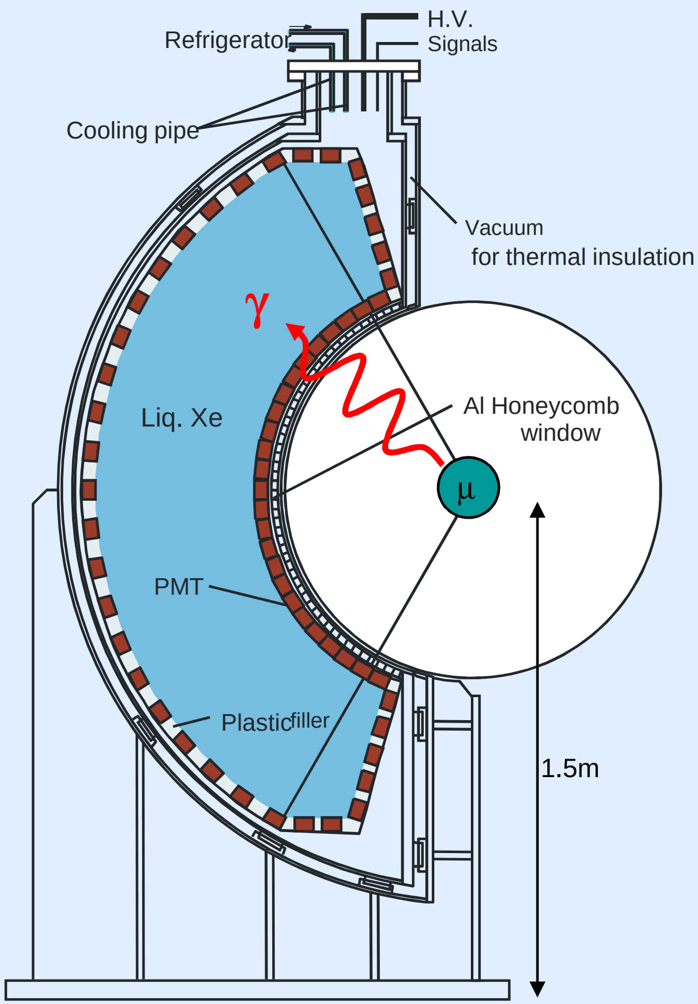
Liquid Xenon:

Density	3 g/cm^3
Melting/boiling point	161 K / 165 k
Radiation length	2.77 cm
Decay time	45 ns
Absorption length	> 100 cm
Refractive index	1.57



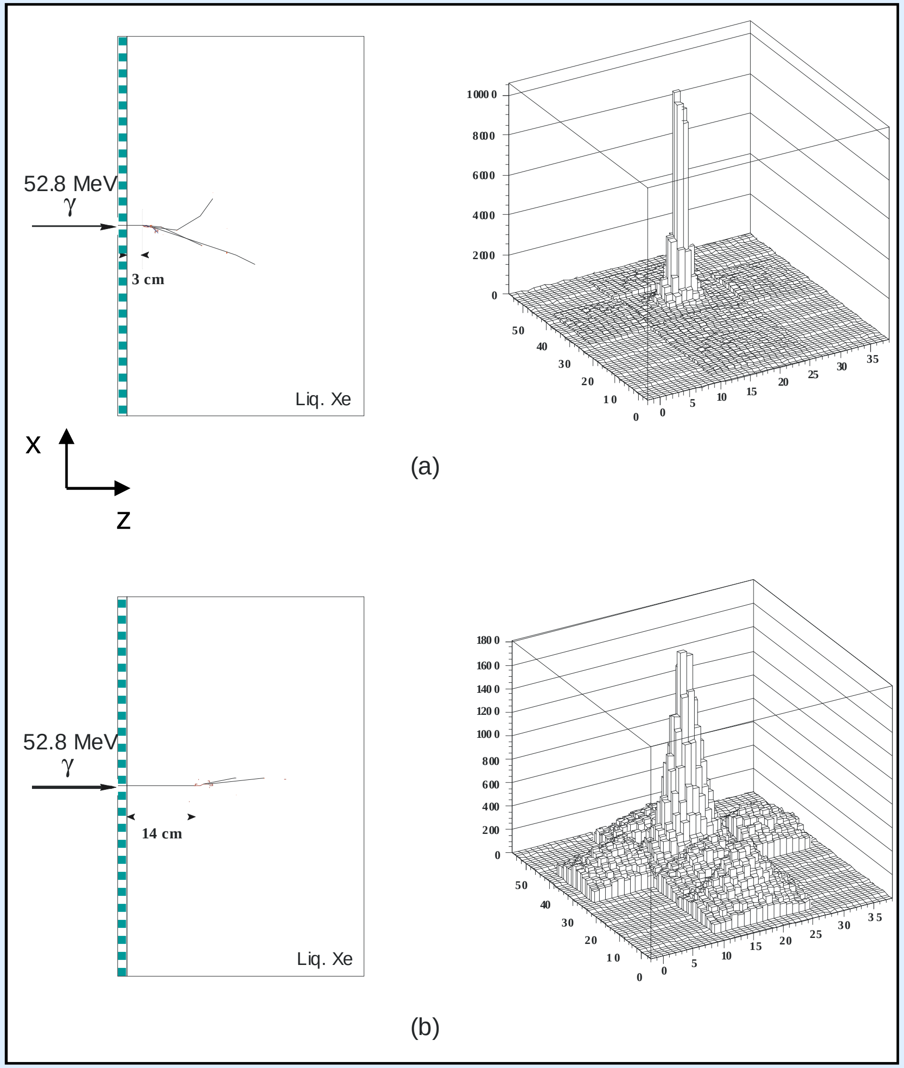
Liquid Xenon Calorimeter

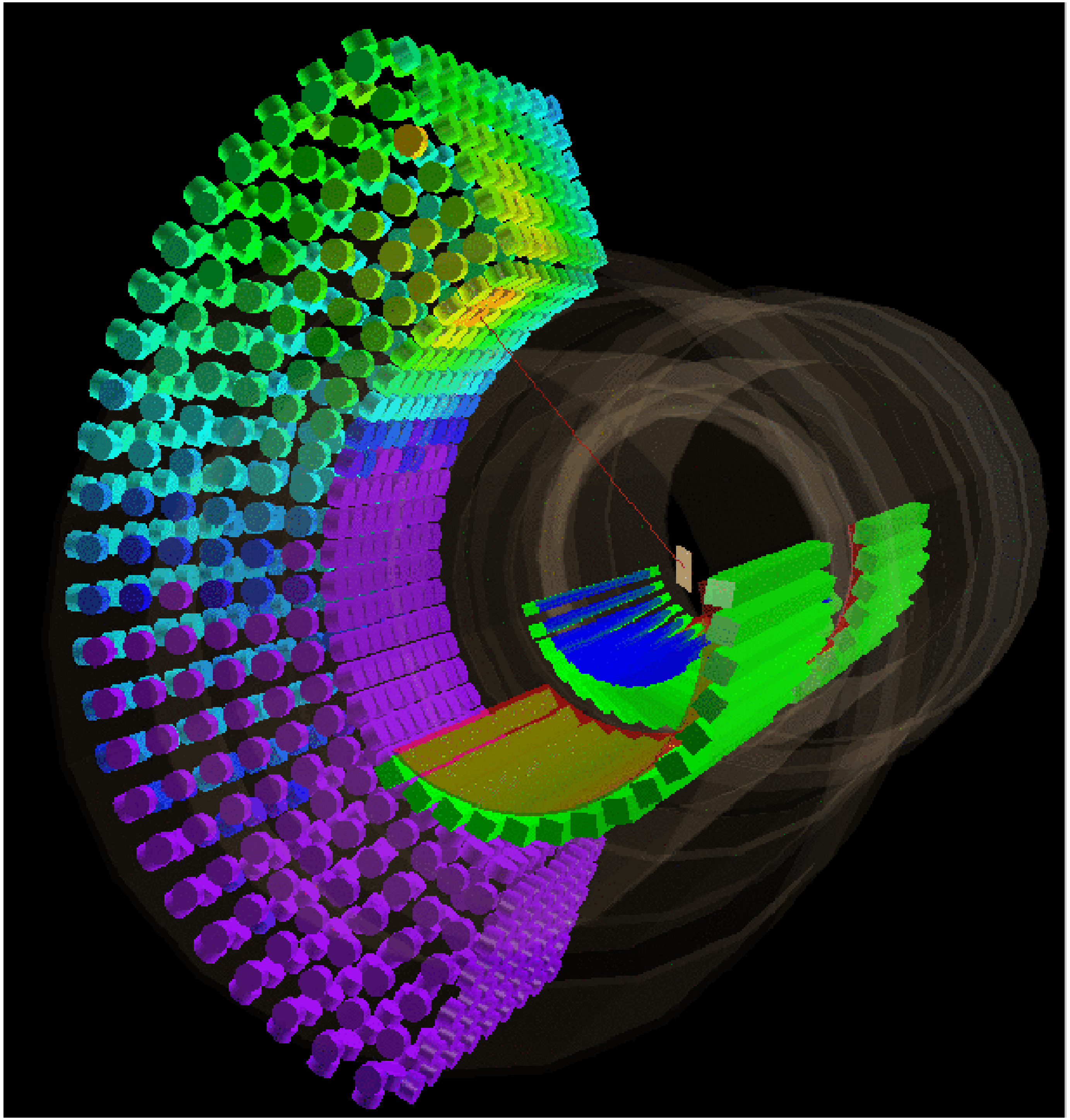
- Calorimeter: Measure γ Energy, Position and Time
- Liquid Xenon has high Z and homogeneity
- ~900 l (3t) Xenon with ~850 PMTs
- Cryogenics required: -120°C … -108°
- Extremely high purity necessary:
  1 ppm H_2O absorbs 90% of light
- Currently largest LXe detector in the world: Lots of pioneering work necessary



LXe γ response

- Light is distributed over many PMTs
- Weighted mean of PMTs on front face
  $\rightarrow$ dx ~ 10 mm FWHM
- Broadness of distribution
  $\rightarrow$ dz ~ 16 mm FWHM
- Timing resolution
  $\rightarrow$ dt ~ 100 ps FWHM
- Energy resolution
  ~ 4.3% FWHM
  depends on light attenuation in LXe

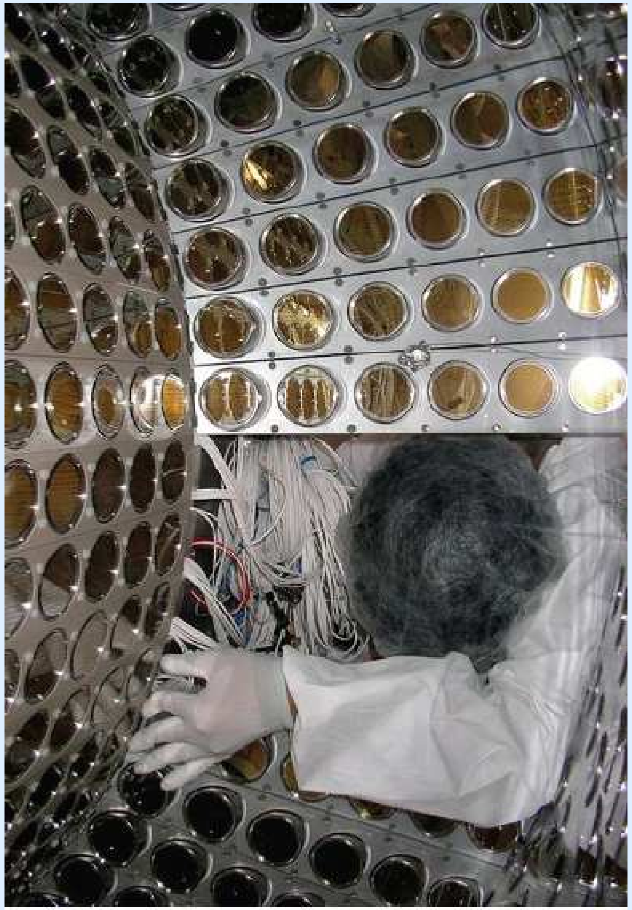


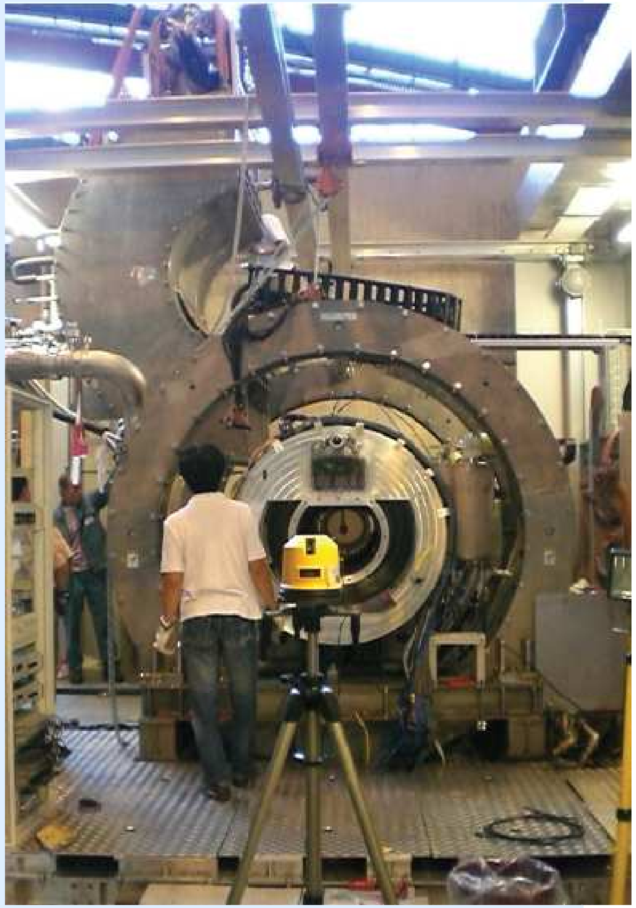


- Use "Monte Carlo" simulation (GEANT) to carefully study detector
- Placement of PMTs were optimized according to MC results

Final Calorimeter

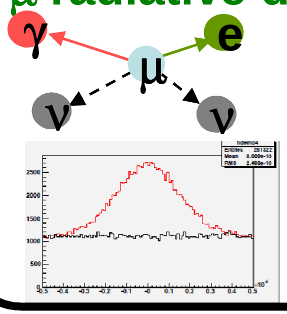
Currently being assembled, will go into operation summer '07





Calorimeter Calibrations

μ radiative decay



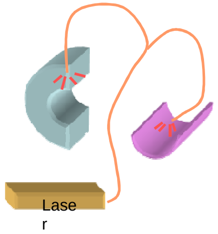
Lower beam intensity < 10^7 to reduce pile-ups

A few days ~ 1 week to get enough statistics

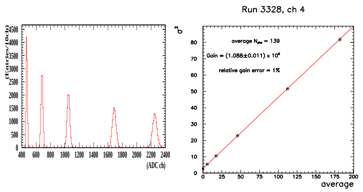
Laser

(rough) relative timing calib.

< 2~3 nsec



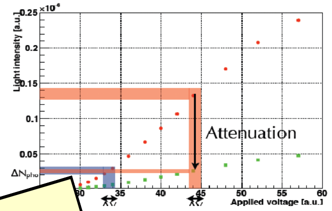
LED



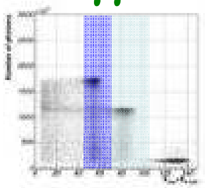
PMT Gain

Higher V with light att.

Can be repeated frequentl...



$\pi^0 \rightarrow \gamma\gamma$



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

$\pi^0 \rightarrow \gamma\gamma$ (55MeV, 83MeV)

$\pi^- + p \rightarrow \gamma + n$ (129MeV)

10 days to scan all volume precisely

LH_2 target

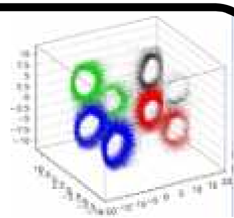
γ

Dedicated Talk!

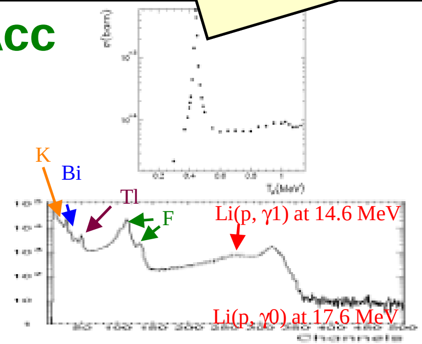
...ONS

...MT QE & Att. L

Cold GXe LXe



Proton Acc



Li(p,γ)Be

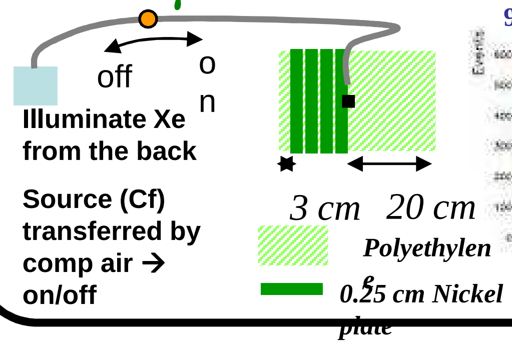
LiF target at COBRA center

17.6MeV γ

~daily calib.

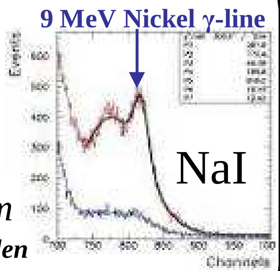
Can be used also for initial setup

Nickel γ Generator

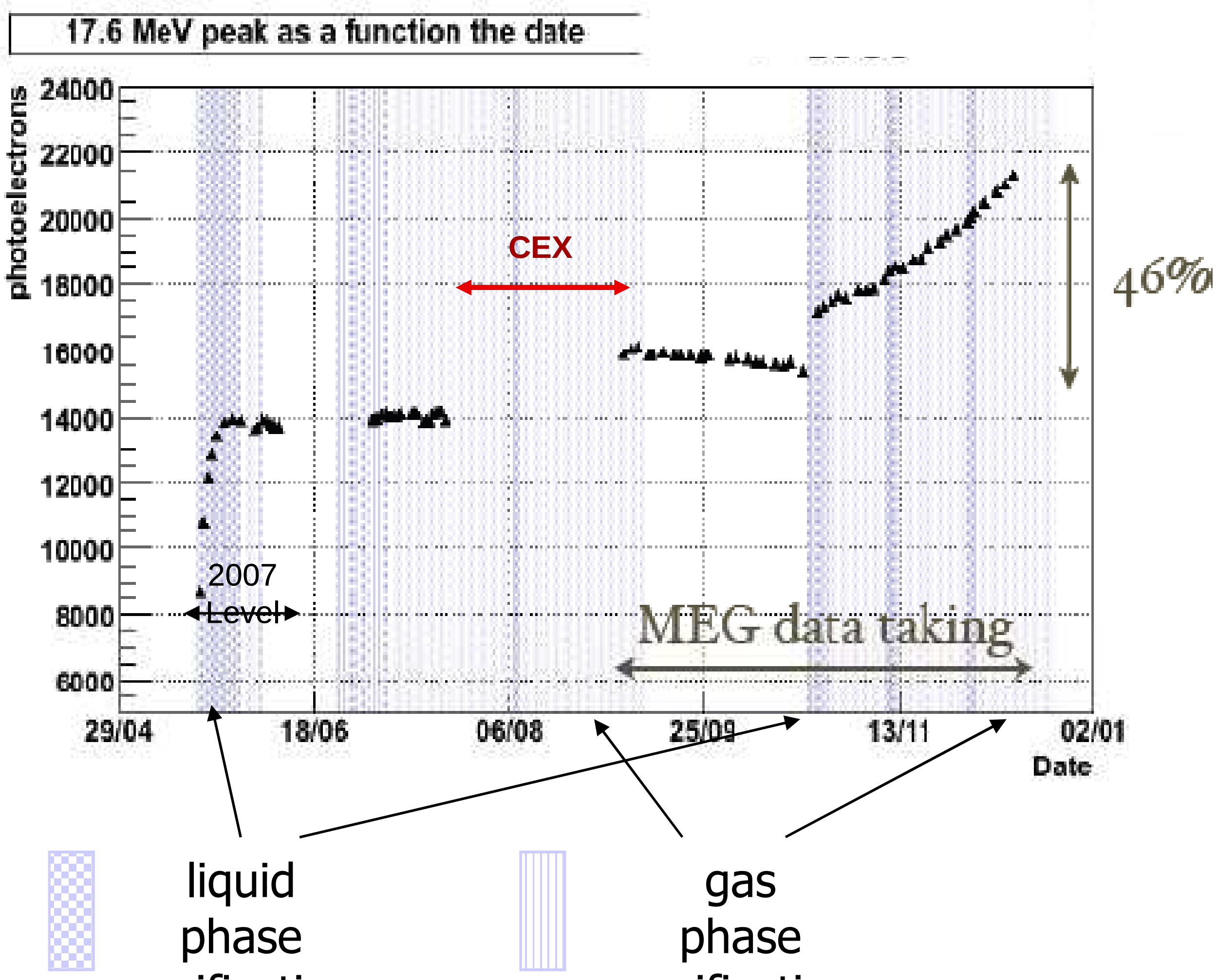


Illuminate Xe from the back

Source (Cf) transferred by comp air → on/off



Calorimeter Light Monitoring



liquid phase purification

gas phase purification

Challenge 2: Spectrometer

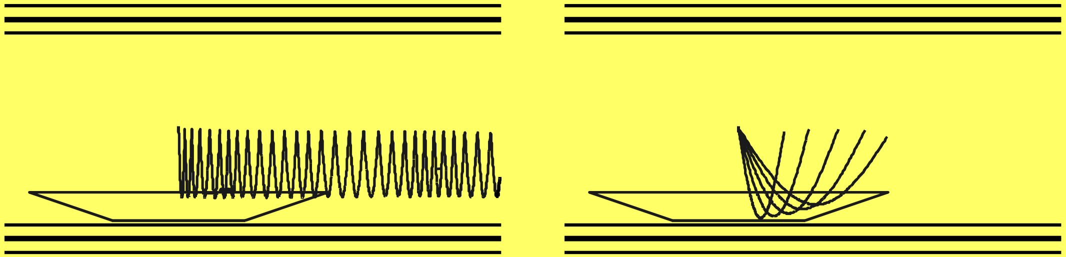
$$\mu \rightarrow e \, \gamma$$

Energy
Position

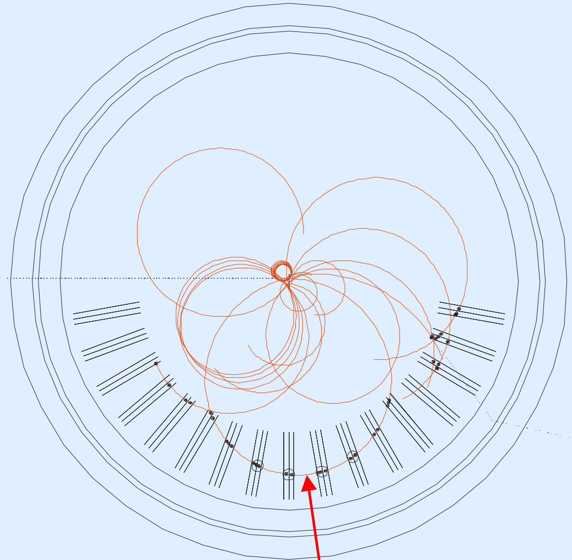
Positron Spectrometer

Ultra-thin (~3g/cm2) superconduction solenoid with 1.2 T magnetic field

Homogeneous Field

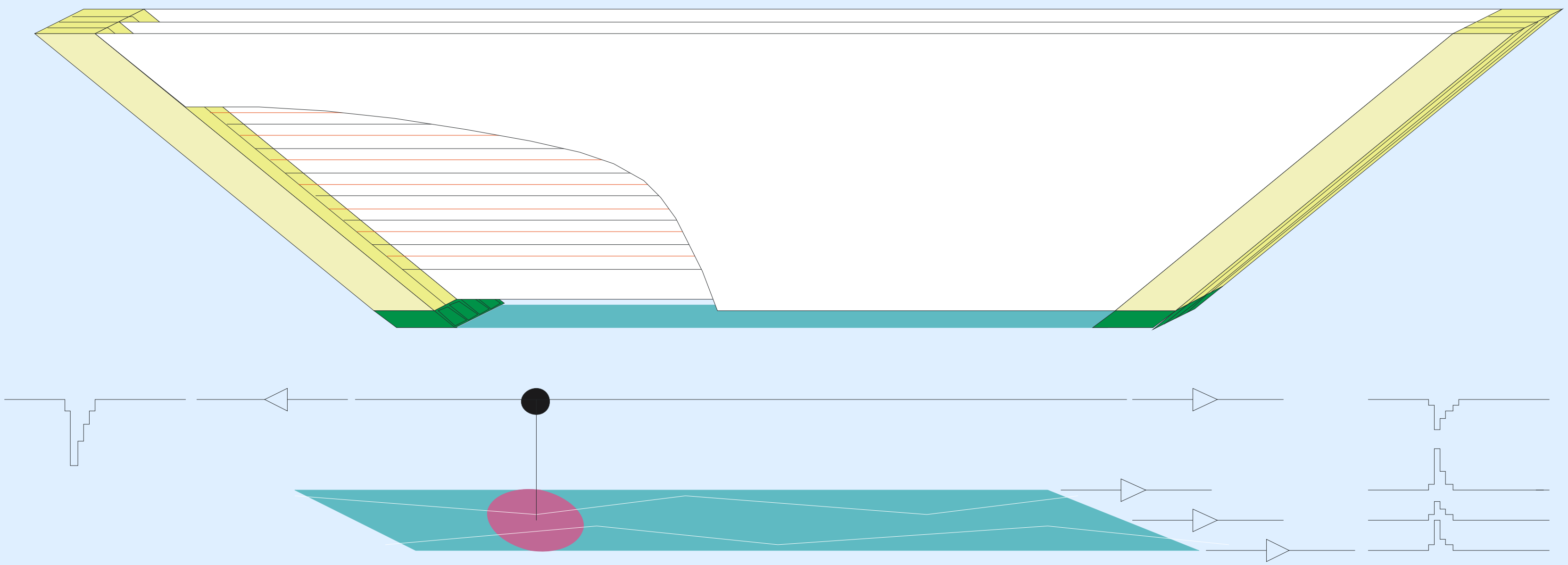


Gradient Field
(COnstant-Bending-RAdius)

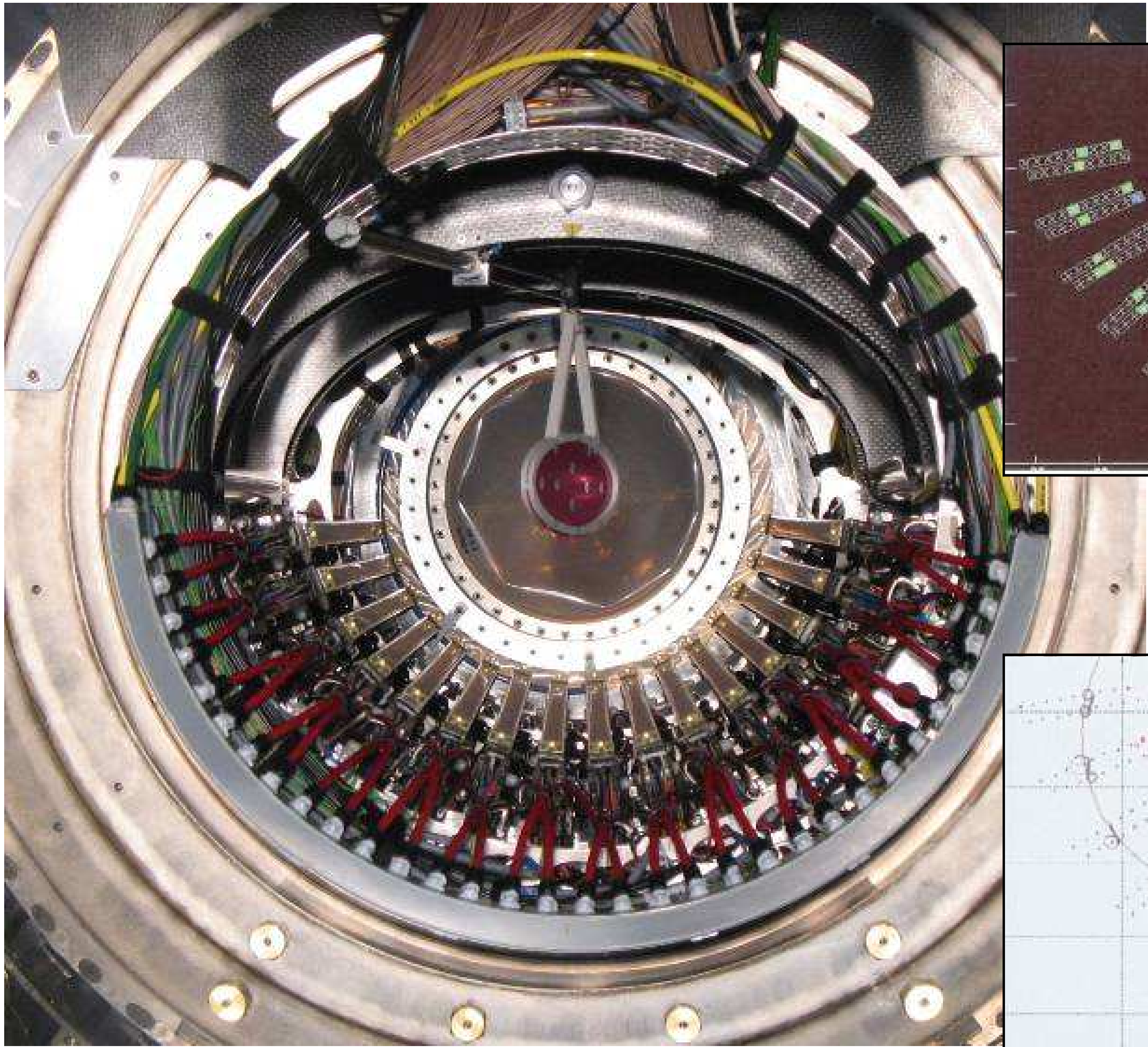


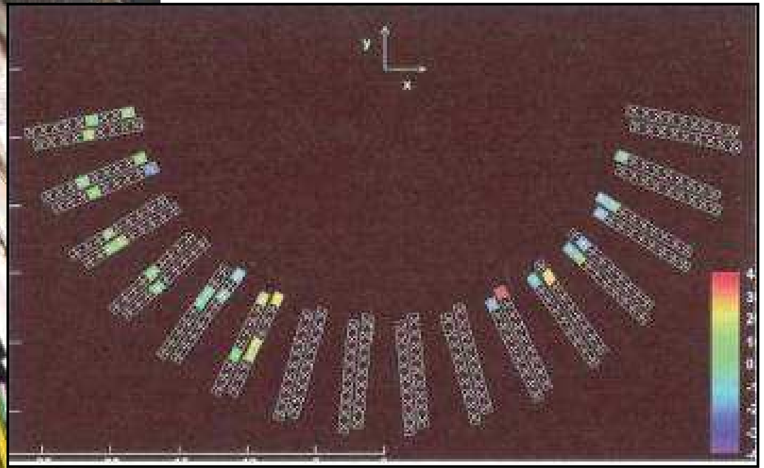
Drift Chamber

- Measures position, time and curvature of positron tracks
- Cathode foil has three segments in a vernier pattern $\rightarrow$ Signal ratio on vernier strips to determine coordinate along wire

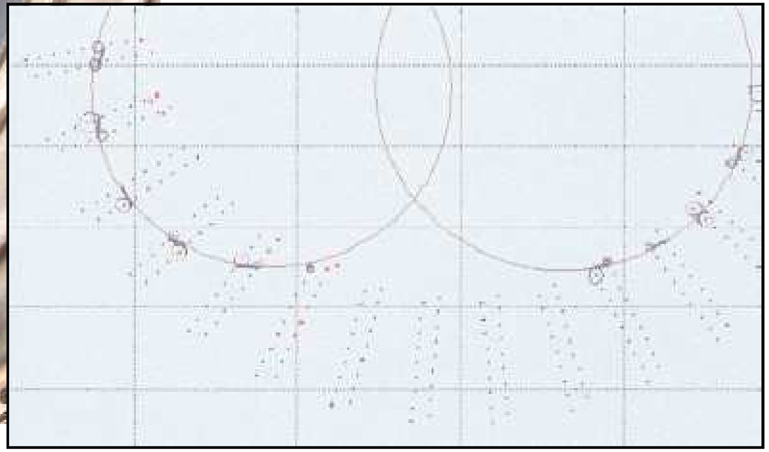


Final Spectrometer





σ_R=470 um (FWHM)
σ_Z=760 um (FWHM)

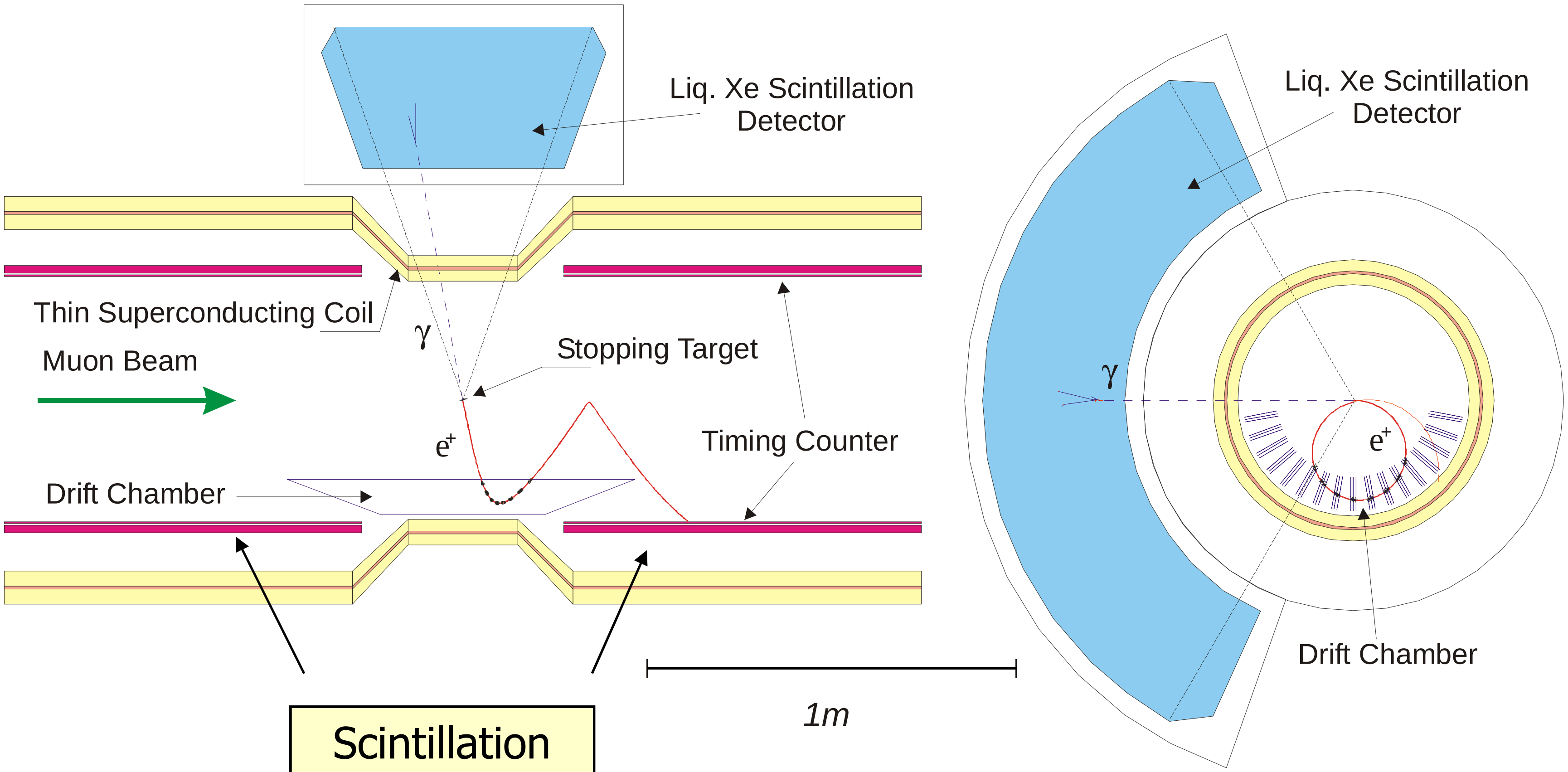


Challenge 3: Timing Counter

$$\mu \rightarrow e \, \gamma$$

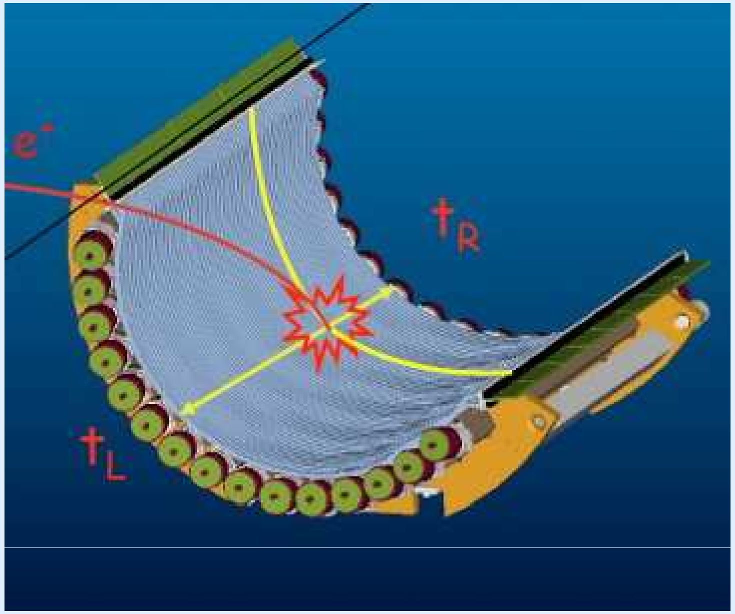
Time

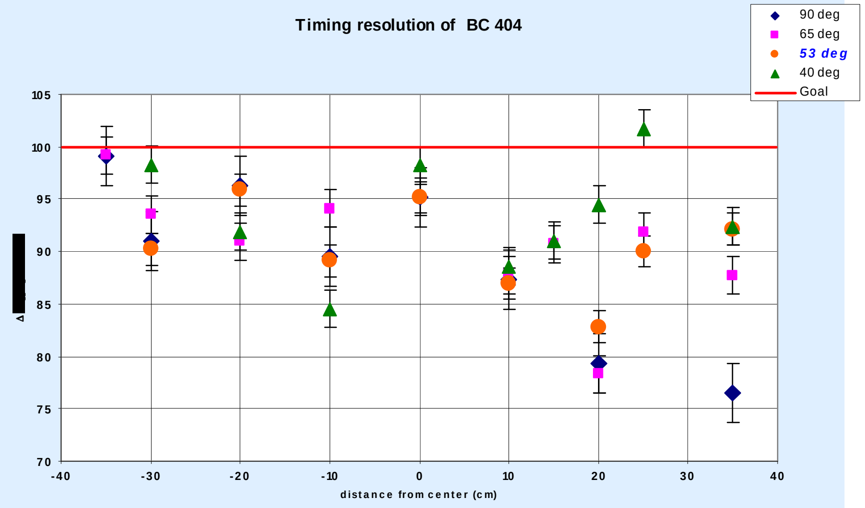
Timing Counter Location

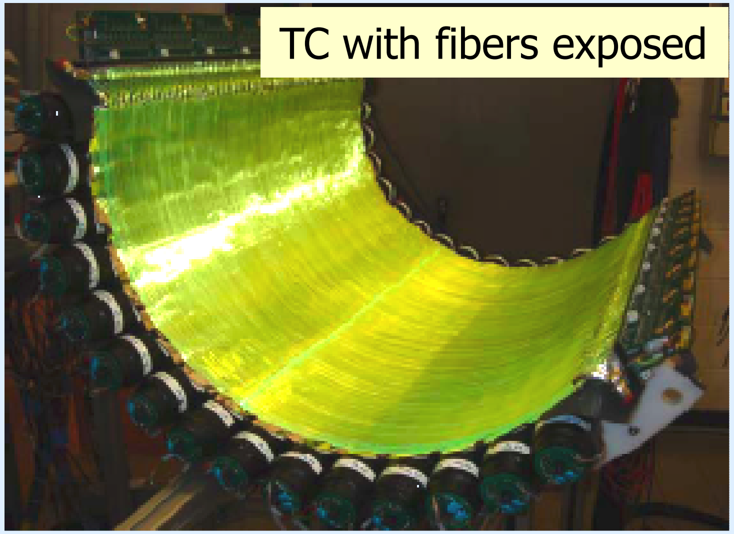


Scintillation counter for precise timing (~100 ps)

Timing Counter







TC with fibers exposed

- Staves along beam axis for timing measurement
- Curved fibers with APD readout for z-position
- Resolution 90 ps FWHM measured at e^- - beam
- Resolution in experiment: 140-200 ps FWHM preliminary

Exp./ Lab	Author	Year	$\Delta E_e/E_e$ %FWHM	$\Delta E_\gamma/E_\gamma$ %FWHM	$\Delta t_{e\gamma}$ (ns)	$\Delta\theta_{e\gamma}$ (mrad)	Inst. Stop rate (s^{-1})	Duty cycle (%)	Result
SIN (PSI)	A. Van der Schaaf	1977	8.7	9.3	1.4	-	(4..6) x 10^5	100	$< 1.0 \times 10^{-9}$
TRIUMF	P. Depommier	1977	10	8.7	6.7	-	2 x 10^5	100	$< 3.6 \times 10^{-9}$
LANL	W.W. Kinnison	1979	8.8	8	1.9	37	2.4 x 10^5	6.4	$< 1.7 \times 10^{-10}$
Crystal Box	R.D. Bolton	1986	8	8	1.3	87	4 x 10^5	(6..9)	$< 4.9 \times 10^{-11}$
MEGA	M.L. Brooks	1999	1.2	4.5	1.6	17	2.5 x 10^8	(6..7)	$< 1.2 \times 10^{-11}$
MEG		**2008**	**0.8**	**4.3**	**0.18**	**18**	**3 x 10^7**	**100**	**~ 10^{-13}**

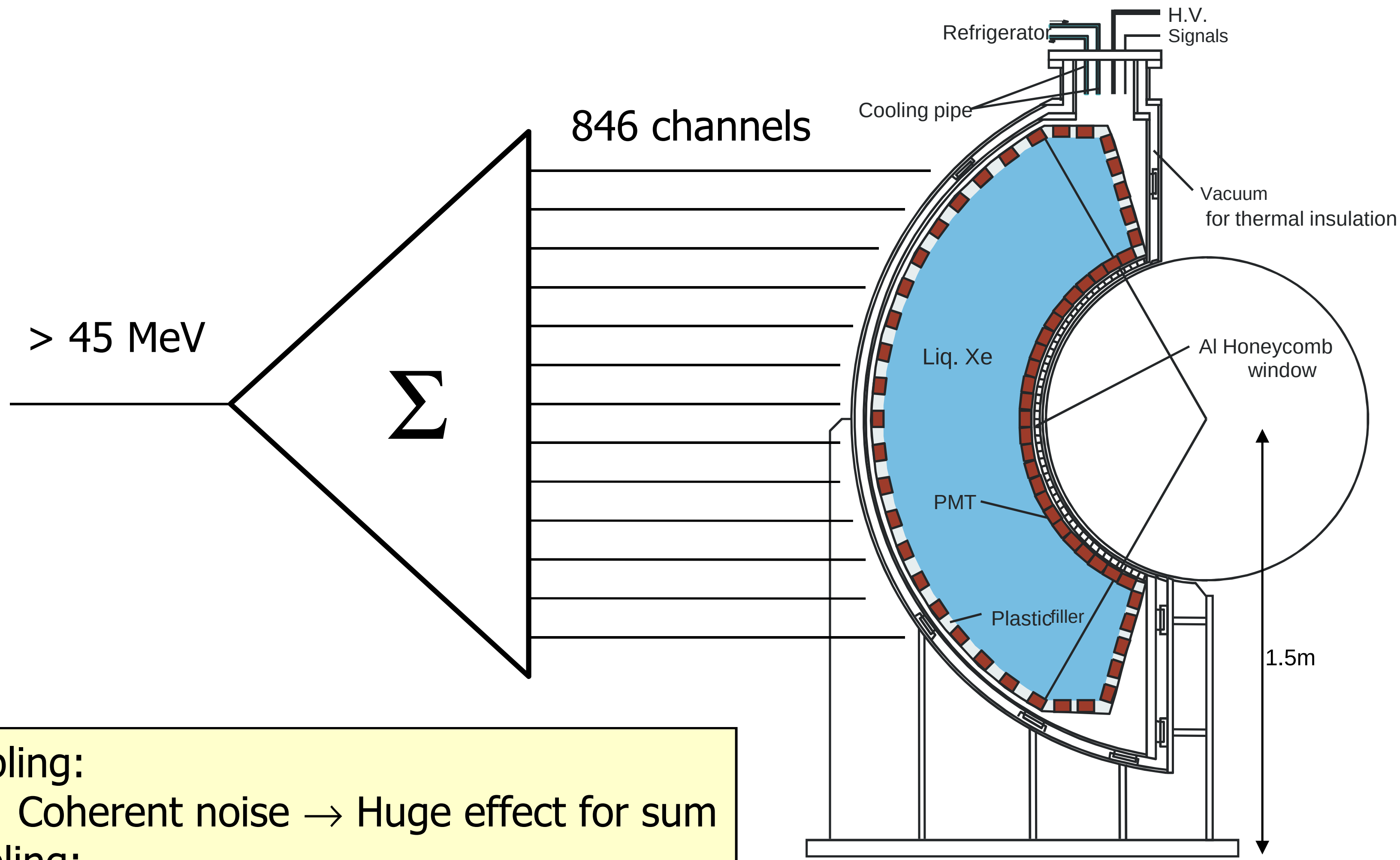
Challenge 4: Electronics

How to do effective triggering?

How to deal with pile-up?

How to measure timing for ~1000 channels with <100 ps accuracy?

Trigger



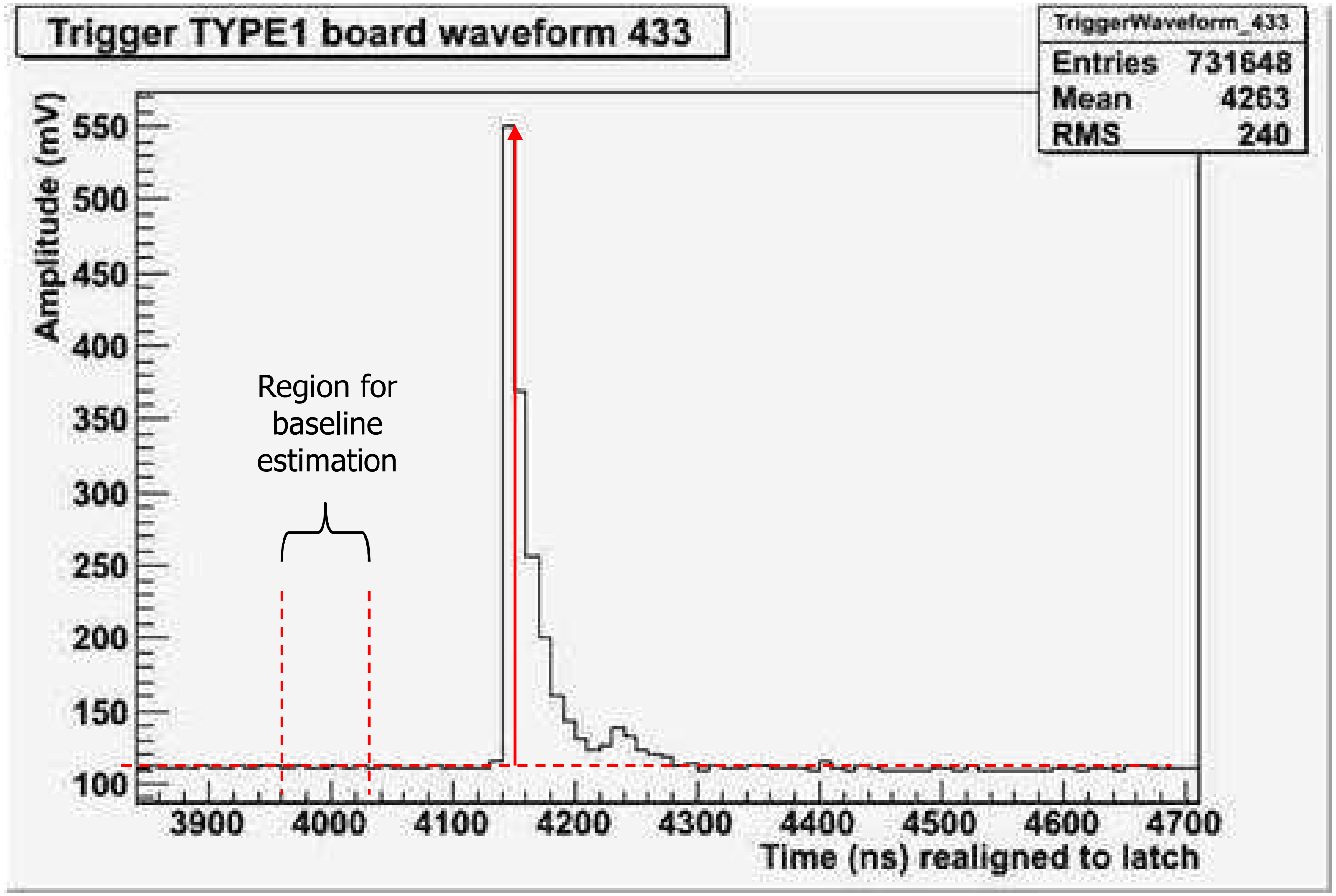
DC-coupling:

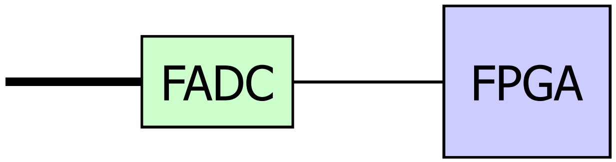
Coherent noise → Huge effect for sum

AC-coupling:

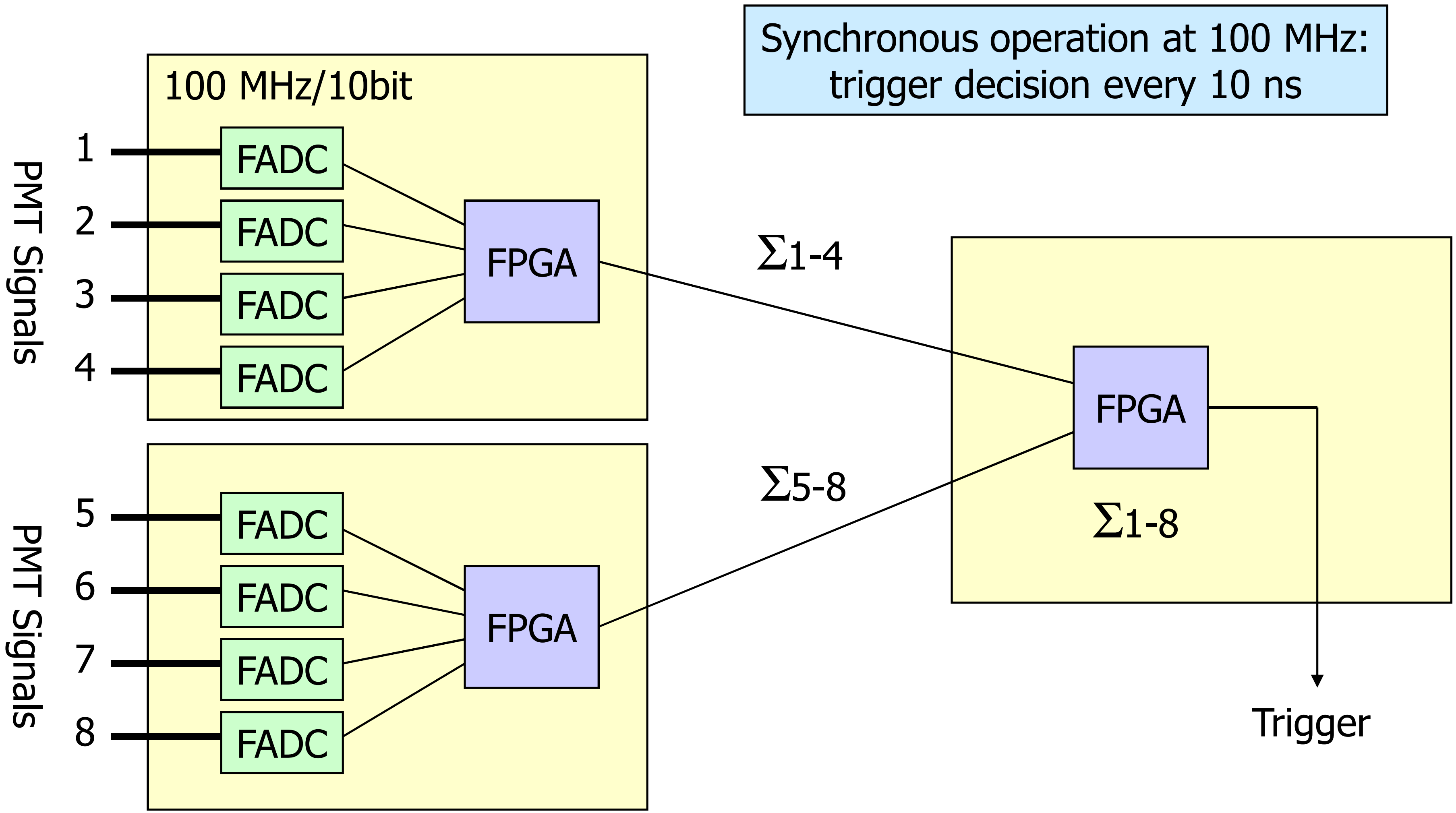
Varying baseline with intensity

Digital Pulse Shape Analysis





Global Sum



Synchronous operation at 100 MHz:
trigger decision every 10 ns
100 MHz/10bit
PMT Signals
1
2
3
4
FADC
FADC
FADC
FADC
FPGA
PMT Signals
5
6
7
8
FADC
FADC
FADC
FADC
FPGA
Σ1-4
Σ5-8
FPGA
Σ1-8
Trigger

Complete Trigger System

PAUL SCHERRER INSTITUT

LXe

Inner face
(216 PMTs)

Side faces
lat. (144x2 PMTs) 4x1
back (216 PMTs) 4x1
u/d (54x2 PMTs) 4x1

TC

Bars
(30x2 PMTs)
Fibers
(512 APDs) 8x1

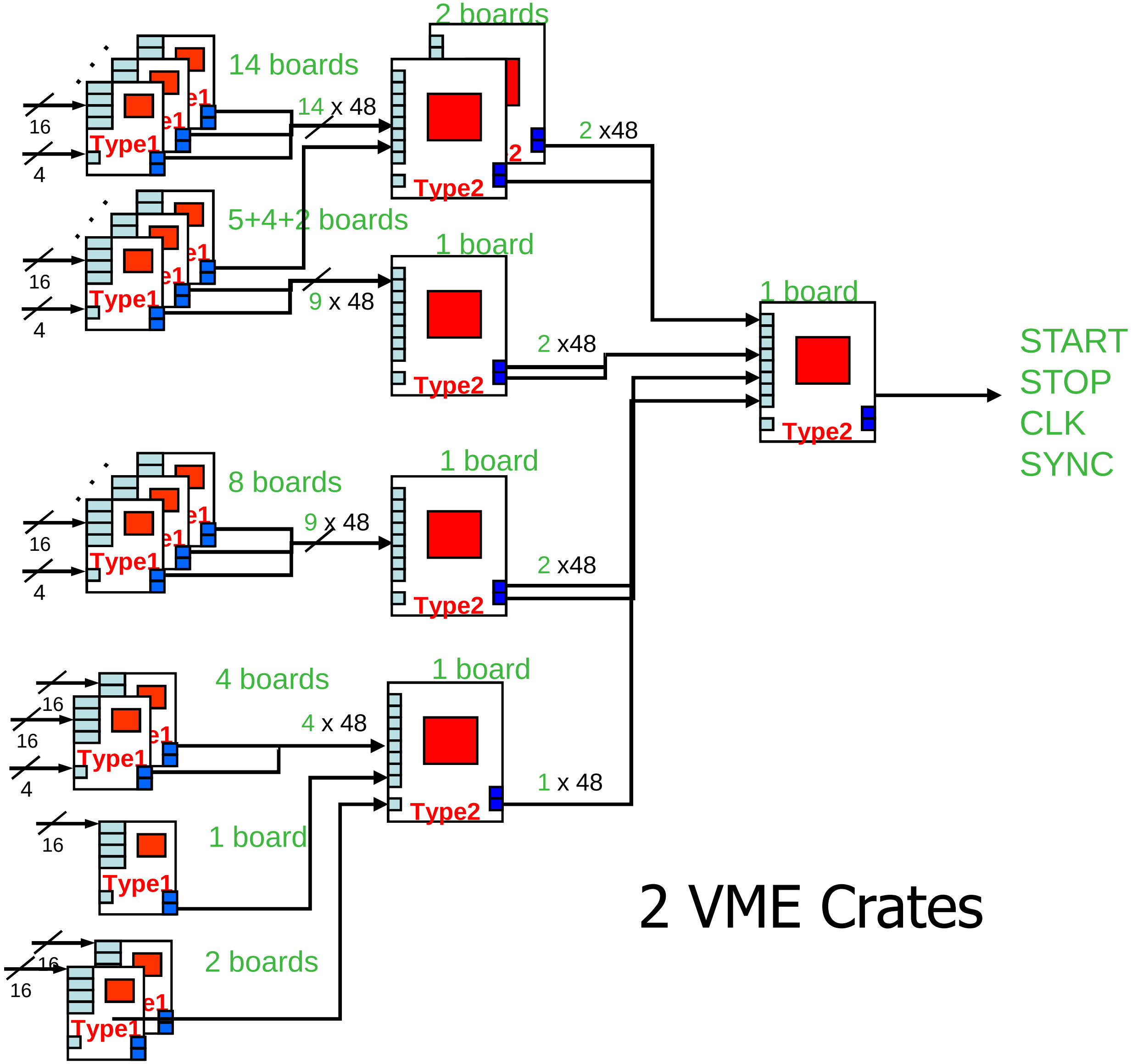
DC

Wires
64 channels

Aux

NaI+pre-shower
16 channels

CR counters
32 channels



2 VME Crates

Trigger Mix

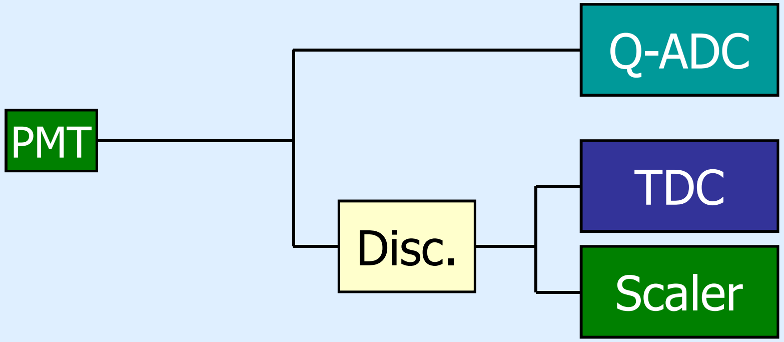
TRGDAQRateMeter

Proton Current	Total trigger rate	Live Time	Total Time	Live Time (%)
1988.4 μ Amp	6.096 Hz	3.738 sec	4.593 sec	81.382

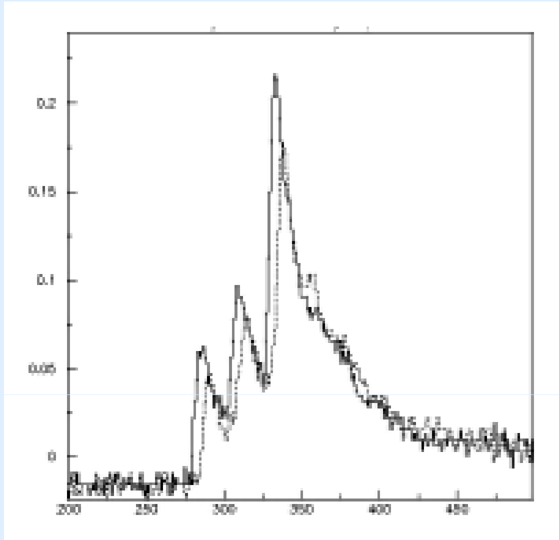
	#Ev(#DAQ)	EvRate(DAQ Rate,%)		#Ev(#DAQ)	EvRate(DAQ Rate,%)
Id0 MuEGamma	32 (26)	7.0Hz(5.7Hz,92.9)	Id16 Michel	1.3e+06 (0)	2.8e+05Hz(0.0Hz,0.0)
Id1 MEG LowQ	106 (0)	23.1Hz(0.0Hz,0.0)	Id17 DC Trackout	3.6e+06 (0)	7.8e+05Hz(0.0Hz,0.0)
Id2 MEG WidAng	170 (0)	37.0Hz(0.0Hz,0.0)	Id18 DC Track	3.7e+06 (0)	8.1e+05Hz(0.0Hz,0.0)
Id3 MEG WidTime	58 (0)	12.6Hz(0.0Hz,0.0)	Id19 DC Cosm	0 (0)	0.0Hz(0.0Hz,0.0)
Id4 Rad NarTime	326 (0)	71.0Hz(0.0Hz,0.0)	Id20 DC single	6.4e+06 (0)	1.4e+06Hz(0.0Hz,0.0)
Id5 Rad WidTime	614 (0)	133.7Hz(0.0Hz,0.0)	Id21 Cosm Alone	0 (0)	0.0Hz(0.0Hz,0.0)
Id6 Pi0	0 (0)	0.0Hz(0.0Hz,0.0)	Id22 TC Alone	5.0e+06 (0)	1.1e+06Hz(0.0Hz,0.0)
Id7 Pi0 NPrSh	0 (0)	0.0Hz(0.0Hz,0.0)	Id23 CR Coinc	0 (0)	0.0Hz(0.0Hz,0.0)
Id8 NaI	2 (0)	0.4Hz(0.0Hz,0.0)	Id24 TC Pair	4.6e+05 (0)	1.0e+05Hz(0.0Hz,0.0)
Id9 LXe HighQ	1.2e+04 (1)	2.6e+03Hz(0.2Hz,3.6)	Id25 NaI Cosmic	0 (0)	0.0Hz(0.0Hz,0.0)
Id10 LXe LowQ	4.9e+04 (0)	1.1e+04Hz(0.0Hz,0.0)	Id26 APD Single	7.2e+06 (0)	1.6e+06Hz(0.0Hz,0.0)
Id11 CW Bo	1.1e+04 (0)	2.4e+03Hz(0.0Hz,0.0)	Id27 LXe Cosmic	856 (1)	186.4Hz(0.2Hz,3.6)
Id12 Alpha	3.9e+04 (0)	8.5e+03Hz(0.0Hz,0.0)	UNUSED	32 (0)	7.0Hz(0.0Hz,0.0)
Id13 Laser	0 (0)	0.0Hz(0.0Hz,0.0)	UNUSED	106 (0)	23.1Hz(0.0Hz,0.0)
Id14 LED	4 (0)	0.9Hz(0.0Hz,0.0)	UNUSED	0 (0)	0.0Hz(0.0Hz,0.0)
Id15 NeutronNi	0 (0)	0.0Hz(0.0Hz,0.0)	Id31 Pedestal	4.6e+03 (0)	1.0e+03Hz(0.0Hz,0.0)

How to digitize signals?

"Old fashioned"



Problem: Pile-up

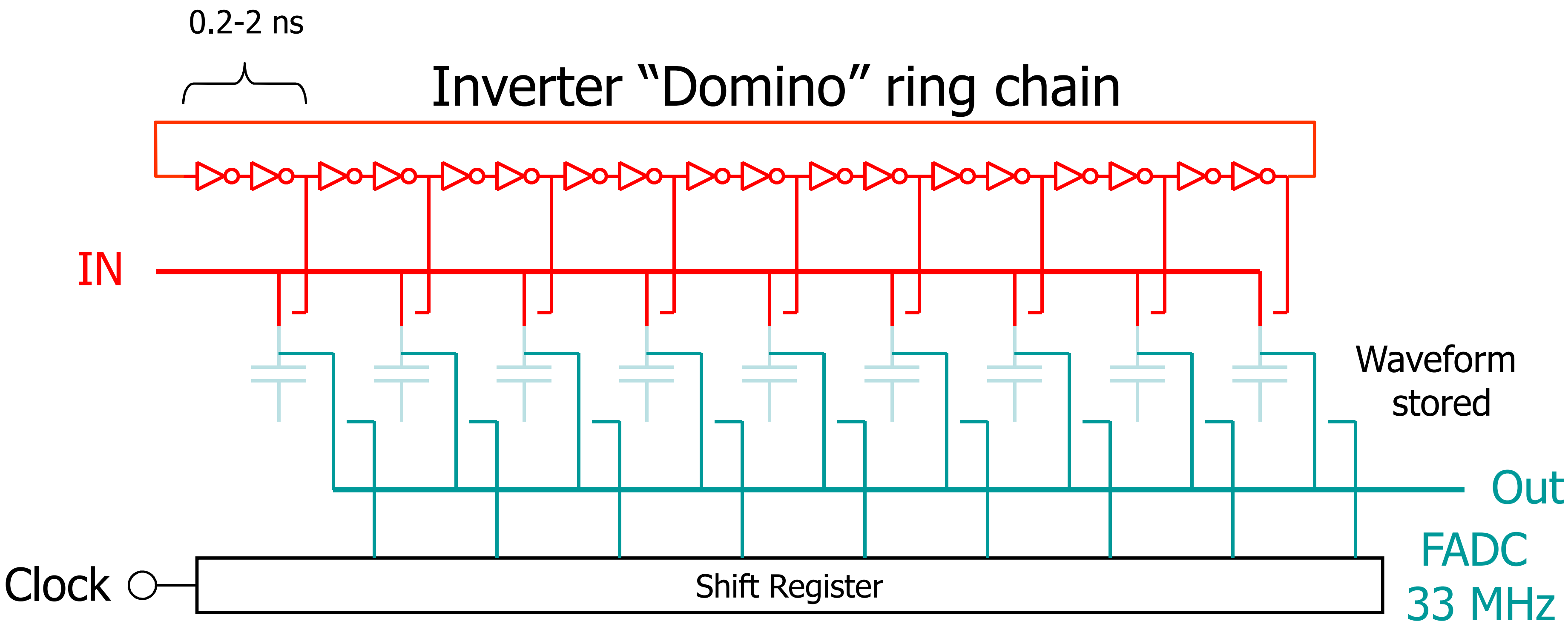


"Modern"

~500 MHz
10 bit

Problems:
- Power consumption
- Price
- Limited timing resolution

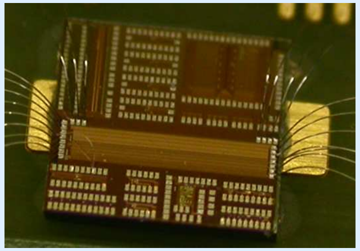
Switched Capacitor Array

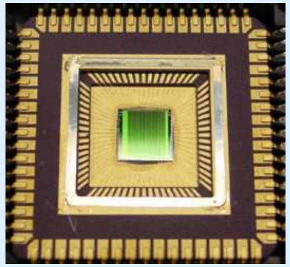


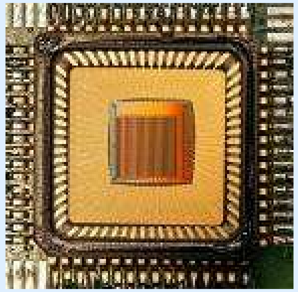
"Time stretcher" GHz → MHz

The DRS Chip

- Development of SCA chip based on experience in $\pi\beta$ experiment
- Took four iterations to produce a flexible and powerful chip
- Goal was to design a chip which can be used in many experiments

2001  DRS1

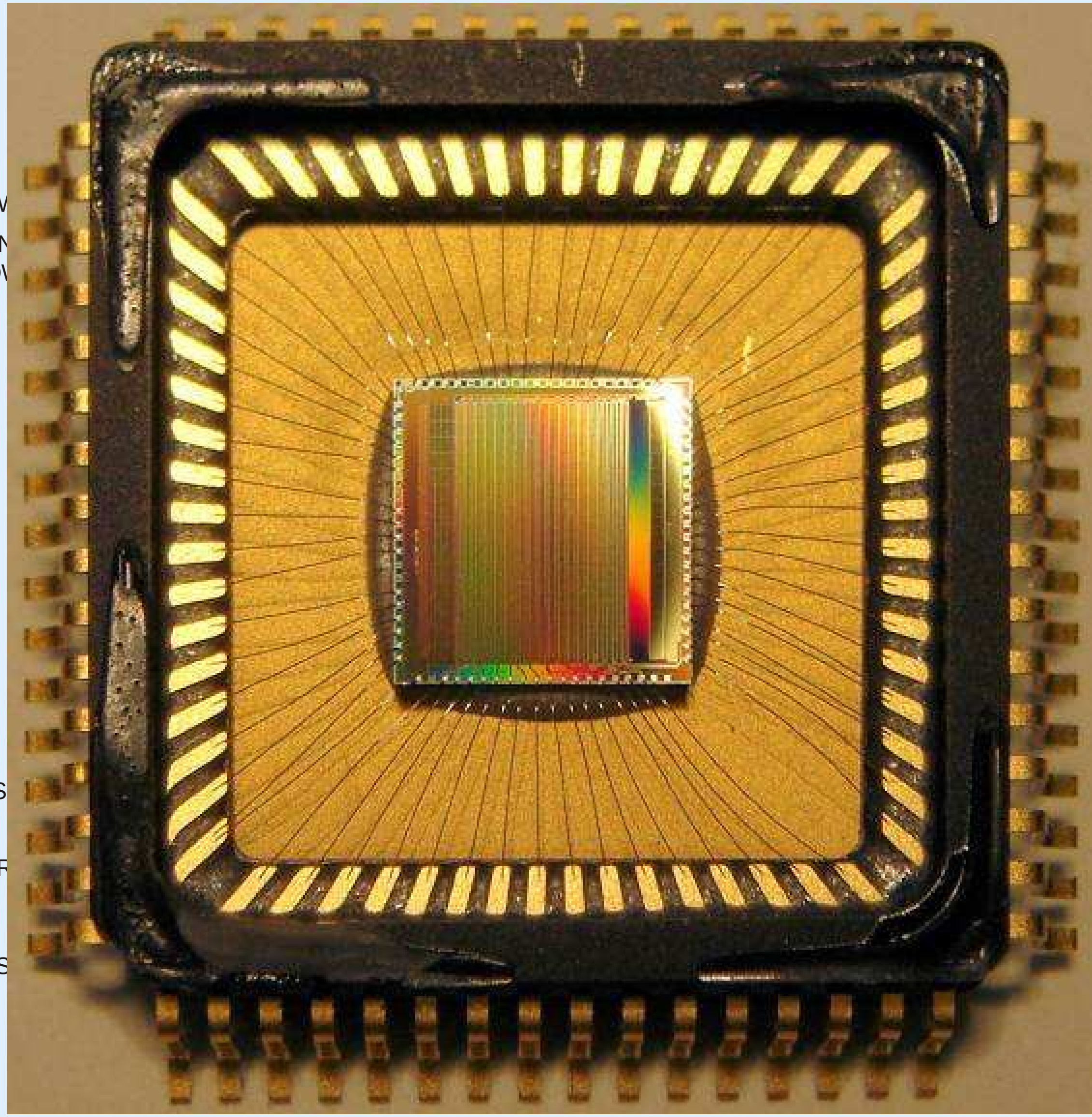
2004  DRS2

2006  DRS3

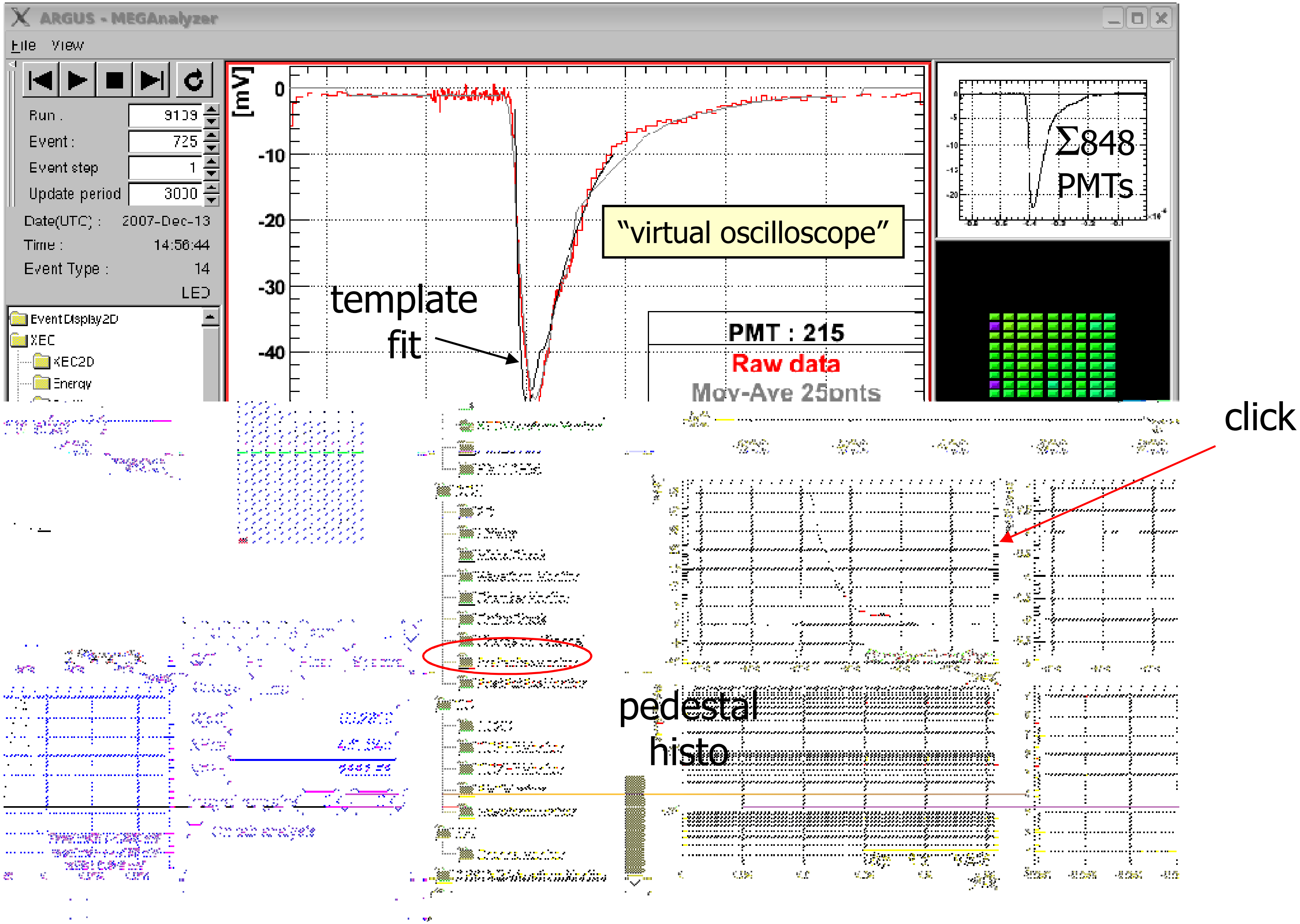
2008  DRS4

DRS4

- Fabricated in 0.25 µm 1P5M MMC process (UMC), 5 x 5 mm2, radiation hard
- 8+1 ch. each 1024 bins, 4 ch. 2048, …, 1 ch. 8192
- Differential inputs/ outputs
- Sampling speed 500 MHz … 6 GHz
- On-chip PLL stabilization
- Readout speed 30 MHz, multiplexed or in parallel

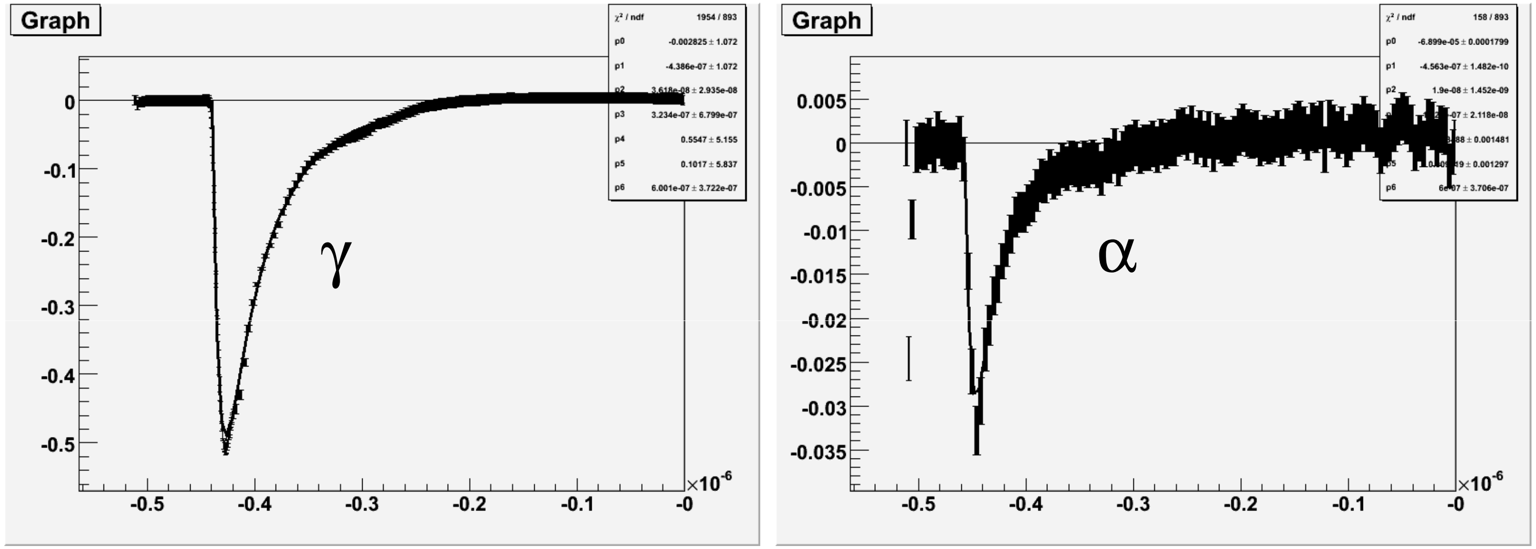


On-line waveform display



Pulse shape discrimination

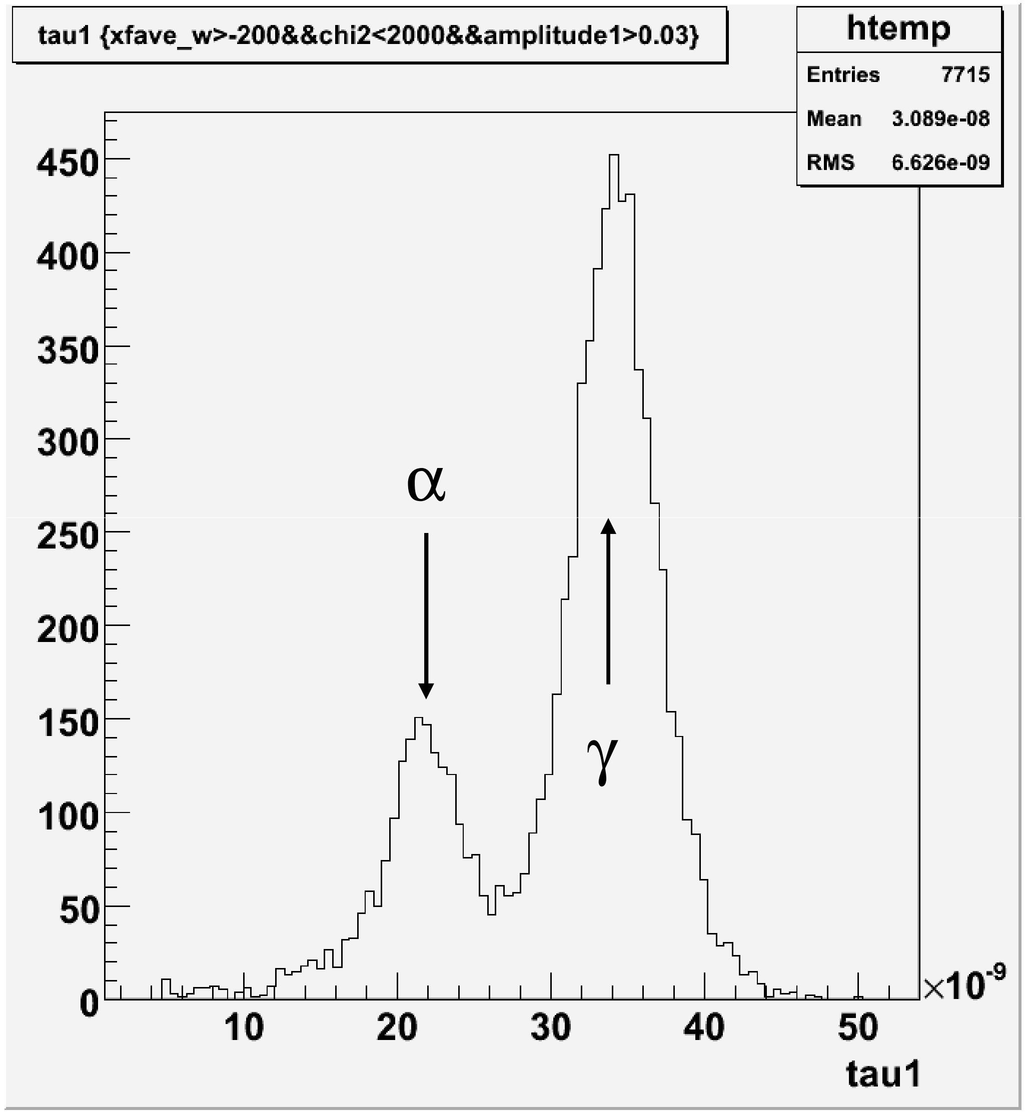
Example: α/γ source in liquid xenon detector (or: γ/p in air shower)



$$V(t) = \left[A\,e^{-(t-t_0)/\tau_i} + B\,e^{-(t-t_0)/\tau_s} + C\,e^{-(t-t_0)/\tau_d} \right] \theta(t - t_0) + [\ldots]\,\theta..\ - t_0 - t_r)$$

Leading edge — Decay time — AC-coupling — Reflections

τ-distribution

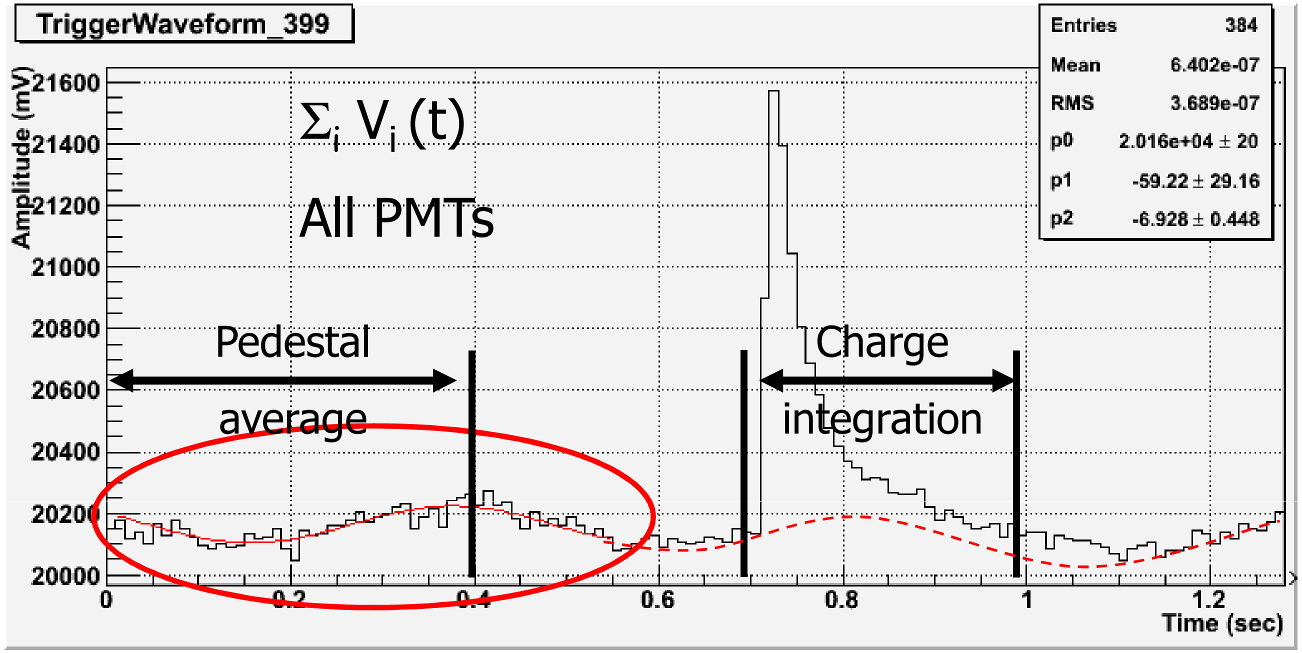


τ_α = 21 ns

τ_γ = 34 ns

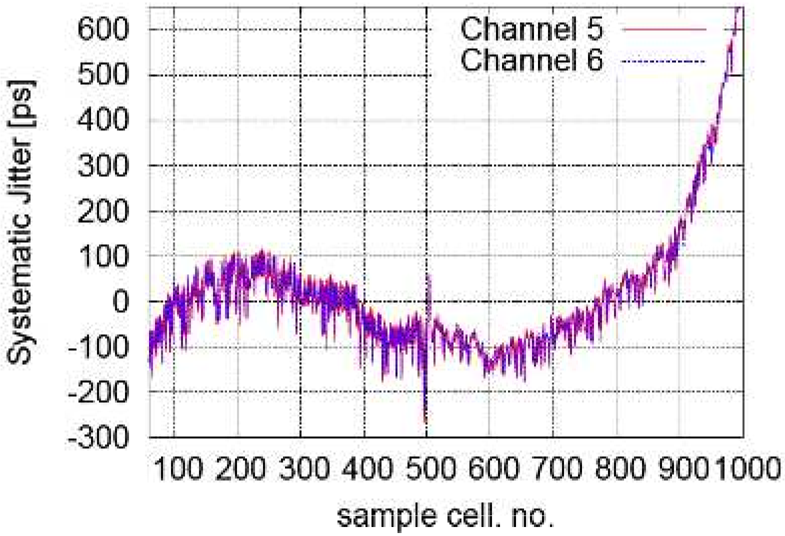
Waveforms can be clearly distinguished

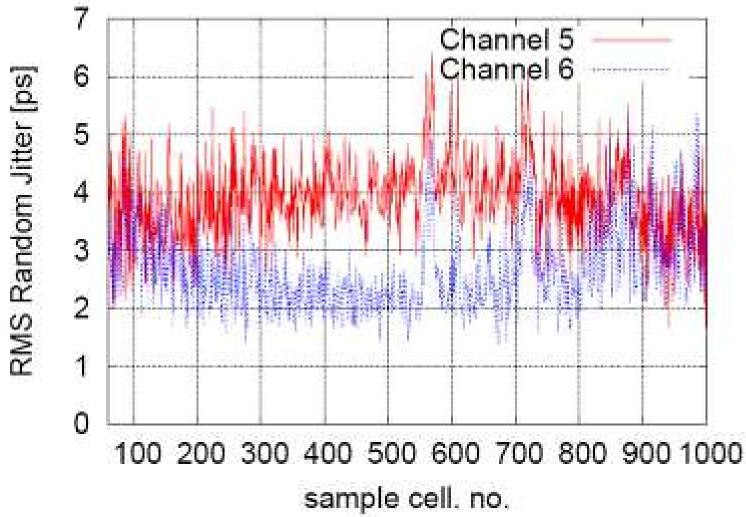
Coherent noise



- Found some coherent low frequency (~MHz) noise
- Energy resolution dramatically improved by properly subtracting the sinusoidal background
- Usage of "dead" channels for baseline estimation

Fixed Pattern Jitter Results

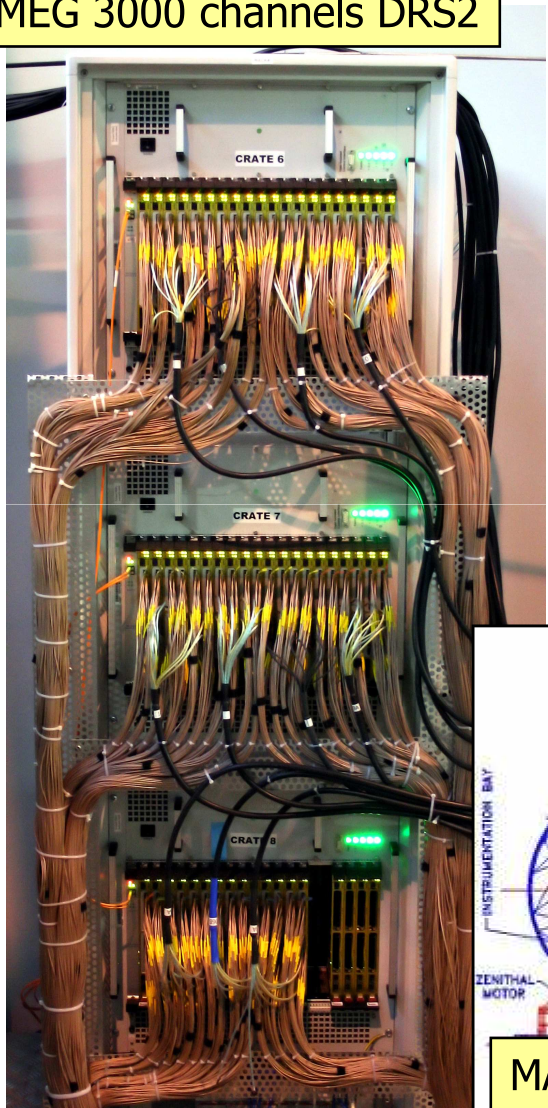




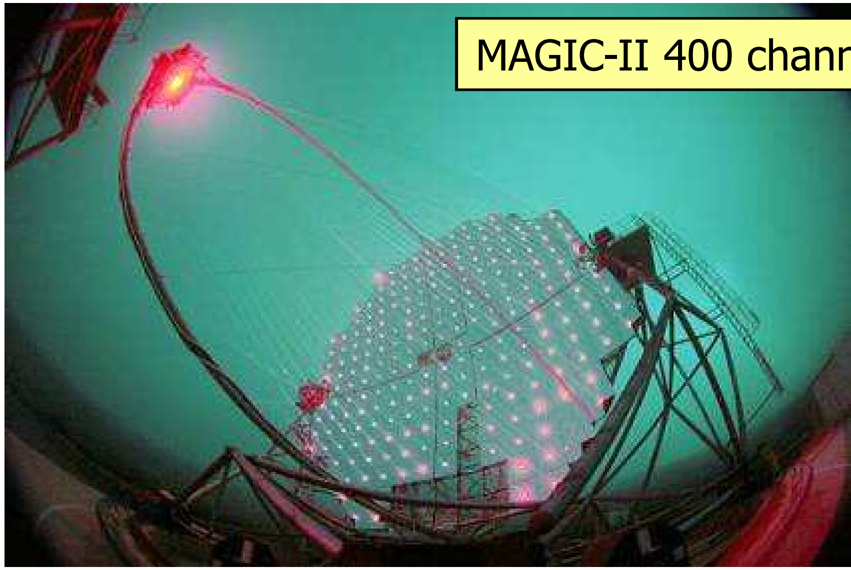
- TD_i typically ~50 ps RMS @ 5 GHz
- TI_i goes up to ~600 ps
- Jitter is mostly constant over time, → measured and corrected
- Residual random jitter 3-4 ps RMS

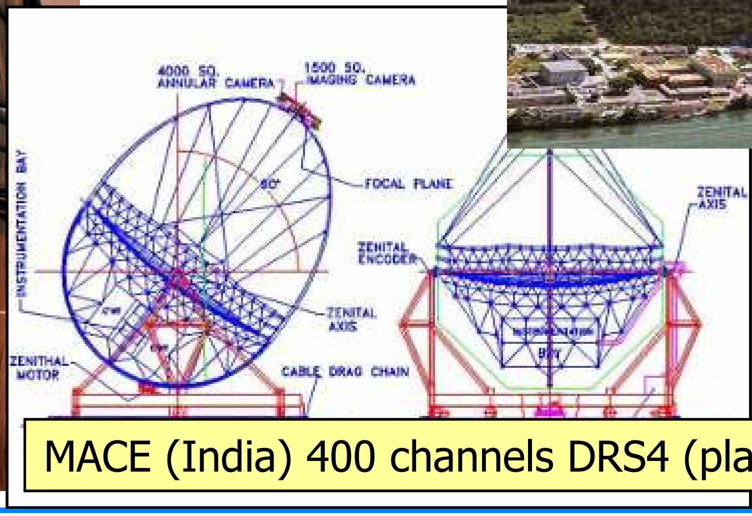
Experiments using DRS chip

MEG 3000 channels DRS2



MAGIC-II 400 channels DRS2



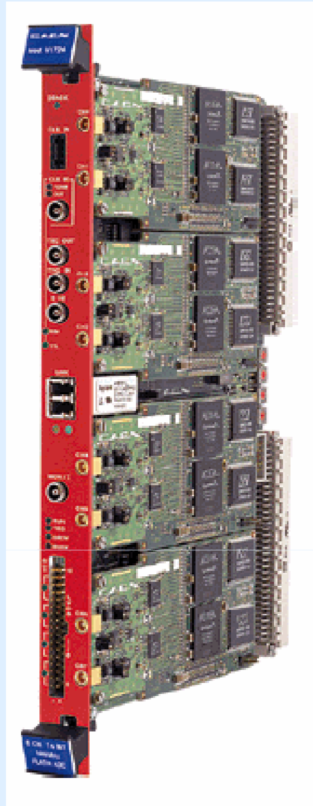


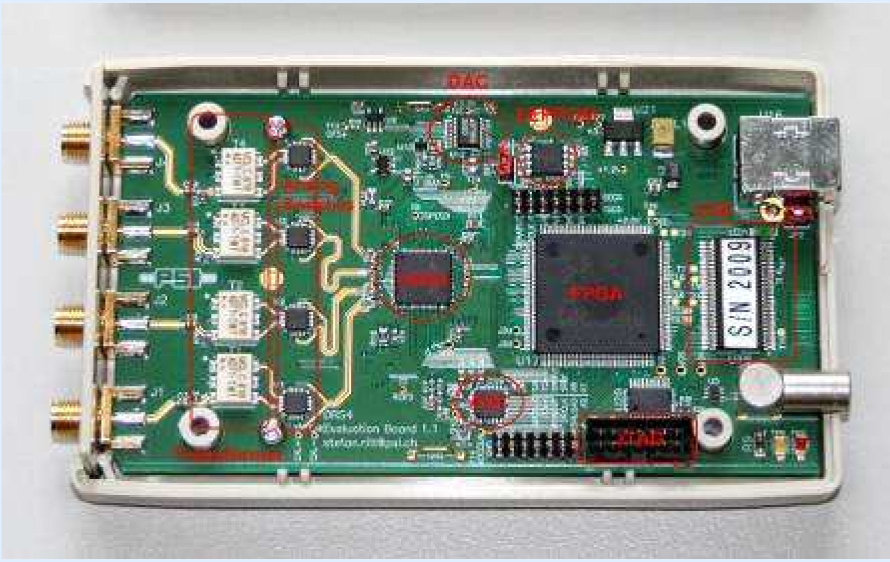
MACE (India) 400 channels DRS4 (planned)

BPM for XFEL@PSI
1000 channels DRS4 (planned)

Availability

- DRS4 can be obtained from PSI on a “non-profit” basis
  - Delivery “as-is”
  - Costs ~ 10-15 USD/channel
- USB Evaluation board as reference design
- VME boards from industry in 2009





32-channel
65 MHz/12bit digitizer
“boosted” by
DRS4 chip to 5 GHz

Challenge 5: Monitoring

How to keep the experiment stable f

Challenge 6: Control

How to control 50 (HV, Temperatures, Pressures)?

C enge 7: Data Analysis

How to deal with 130 TB of data per year?

Challenge 8: ...

For my next visit to UVa ...

Status and Outlook

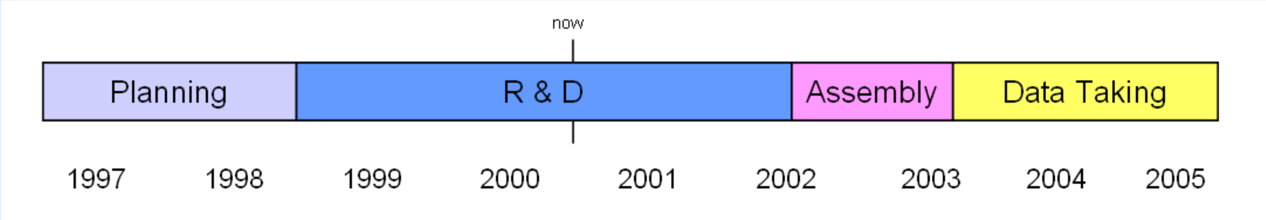
Where are we, where do we go?

Current Schedule

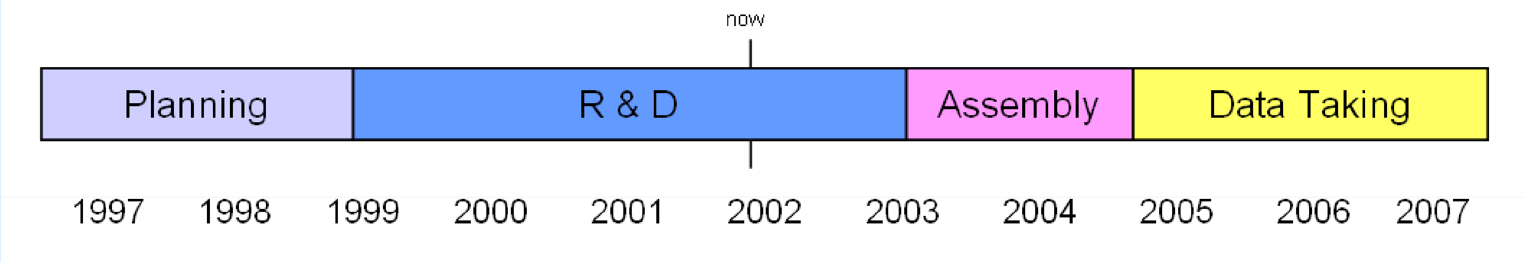
1999

We request a total of 6,000 hours of beam time starting in year 2003 with a proton intensity above 1 mA. Tests and engineering runs with πE5 will be requested in years 2000 to 2002. A

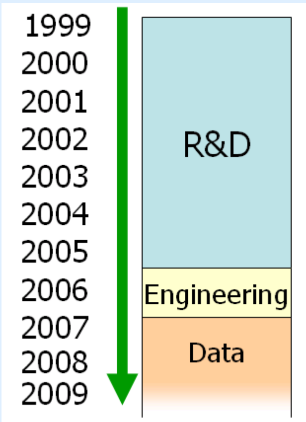
2000



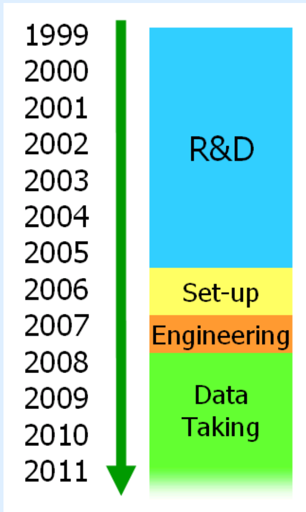
2002



2006



2008



PAUL SCHERRER INSTITUT

Current Efficiencies

CAUTION: All 2008 numbers are provisional

Still lots of things to learn from the data

Efficiencies

- Blue numbers likely to change - Grey numbers may vanish

(%)	"Goal"	2008 Provisional Lower Limits	2009 Provisional Prospects
Gamma	> 40	> 50 x (65 x 85) (depth, pileup)	> 50 x 90
e+	65	30 x 40 (DC, DC-TC)	85 x 50
Trigger	100	100 x 99 x 80 (energy, time, direction)	> 99
Selection	$90^4 = 66$	$90^3 \times 95 = 69$	69
DAQ	(> 90)	> 80 x 93 (live, run transition)	> 90 x 99
Calibration Run etc	(> 95)	~70	90
Running Time (week)	100*	11.5**	11.5
Single Event Sensitivity (10^{-13})	0.5	< 30 - 50	< 3 - 5

* 1 week = 4×10^5 sec (66%) ** CEX runs not included

Current Resolutions

CAUTION: All 2008 numbers are provisional

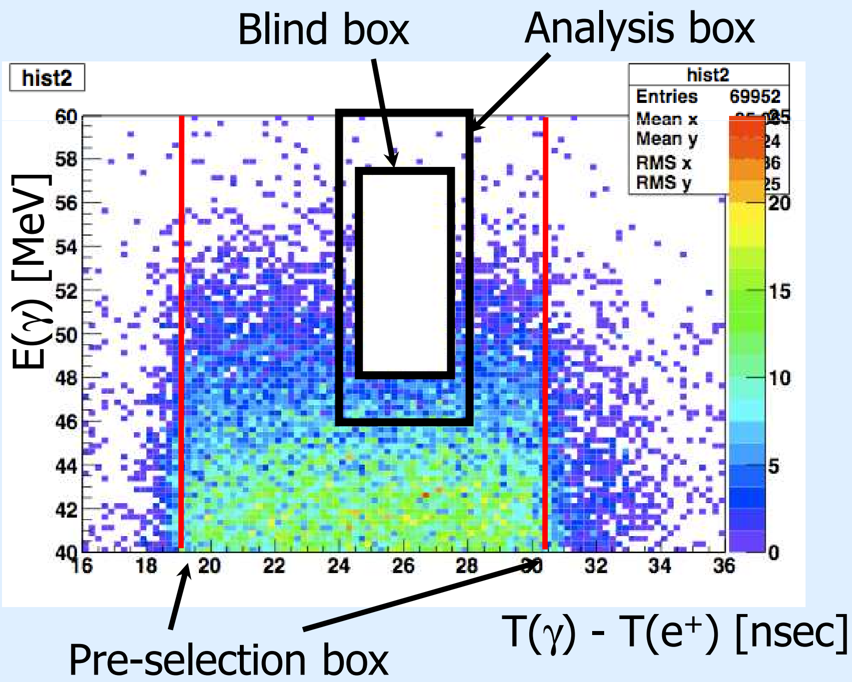
Resolutions

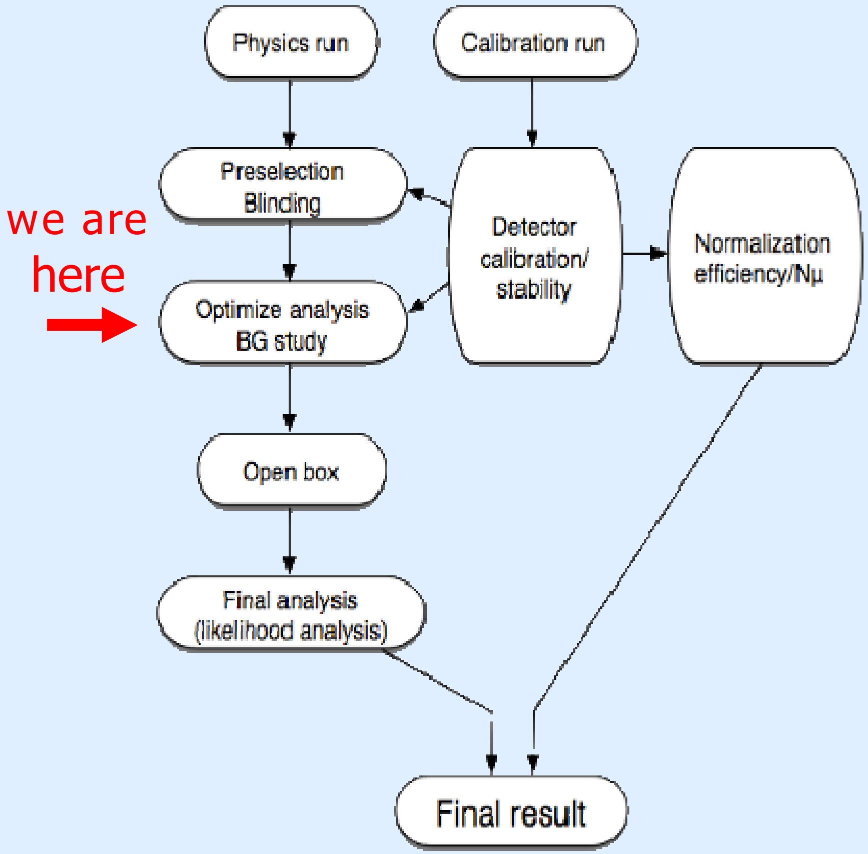
Resolutions are improving as we understand the detectors better.

(in sigma)	"Goal"	2008 Provisional	2009 Provisional Prospects
Gamma Energy (%)	1.2 - 1.5	< 2.3	< 1.7
Gamma Timing (ps)	65	< 100*	< 80
Gamma Position (mm)	2 - 4	5 - 6.5	5
e+ Momentum (%)	0.35	1.5 - 2.0	0.7 - 0.8
e+ Timing (ps)	45	< 60 - 90	60
e+ Angle (mrad)	4.5	9 - 18	11
mu Decay Point (mm)	0.9	3 - 4	2
Gamma - e+ Timing (ps)	80	150	100
Background (10^{-13})	0.1 - 0.3	-	< 0.6 - 3

First Results

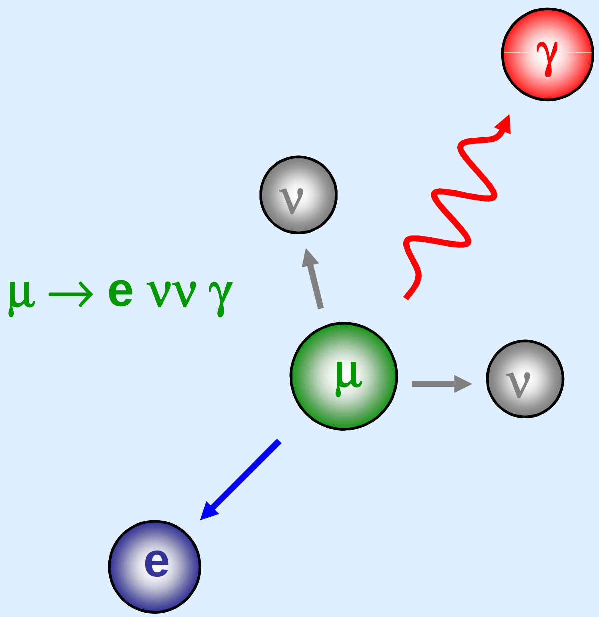
- 11.5 weeks of data taking in 2008 (130 TB)
- Currently doing blind analysis

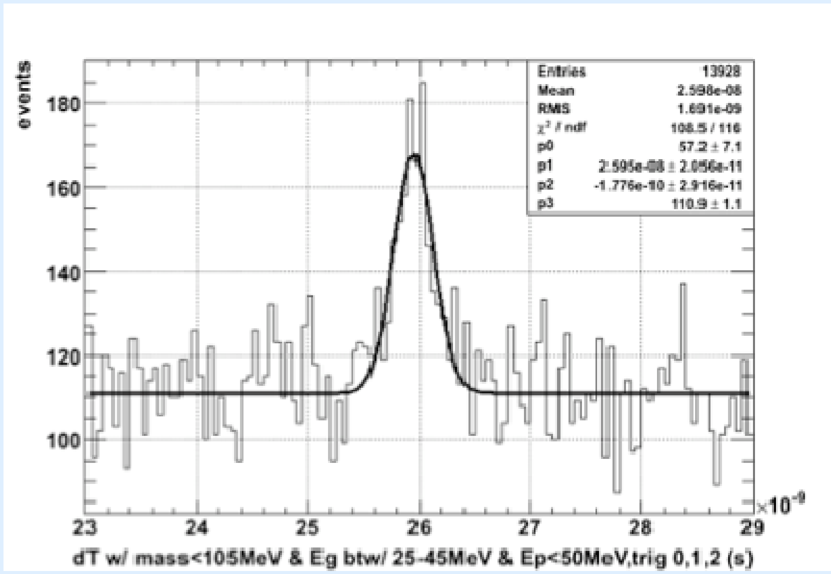




Radiative Muon Decay

- This decay is a benchmark for the whole detector
- Branching ratio 1.4%
- Decays clearly visible in high rate environment



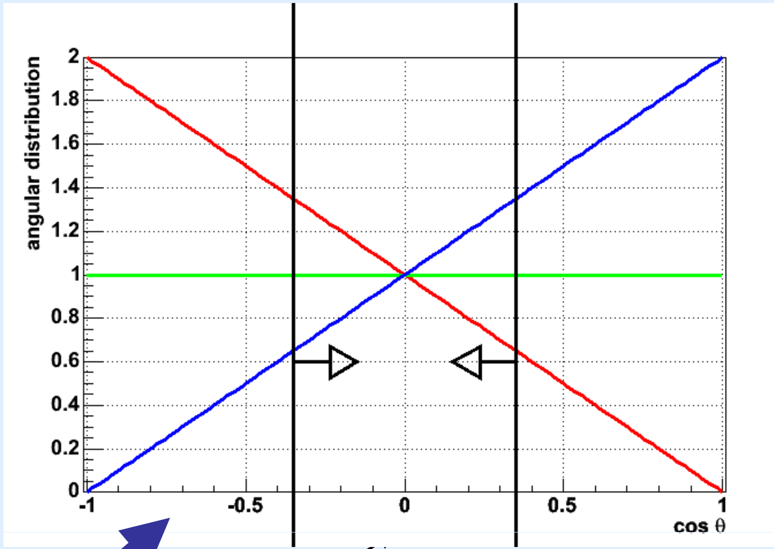


$T(\gamma) - T(e^{+})$

"Polarized" MEG

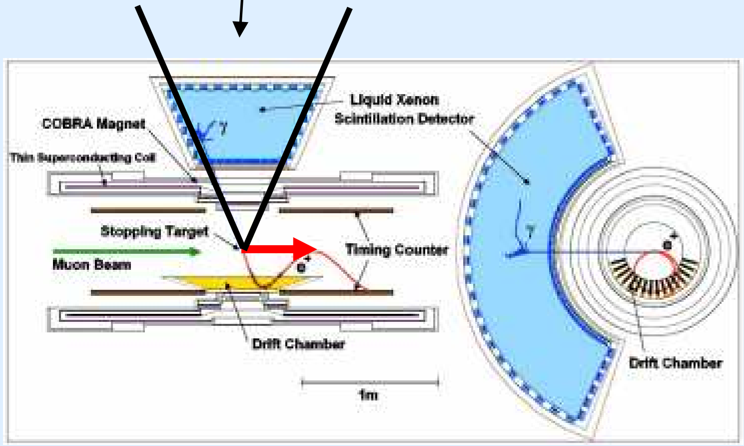
- μ are produced already polarized
- Different target to keep μ polarization
- Angular distribution of decays predicted differently by different theories (compare Wu experiment for Parity Violation)

$$\frac{dN(\mu^+ \to e^+\gamma)}{d\cos\theta_e} \propto BR(\mu^+ \to e^+\gamma)\cdot\frac{1+AP_\mu\cos\theta_e}{2}$$



Detector acceptance

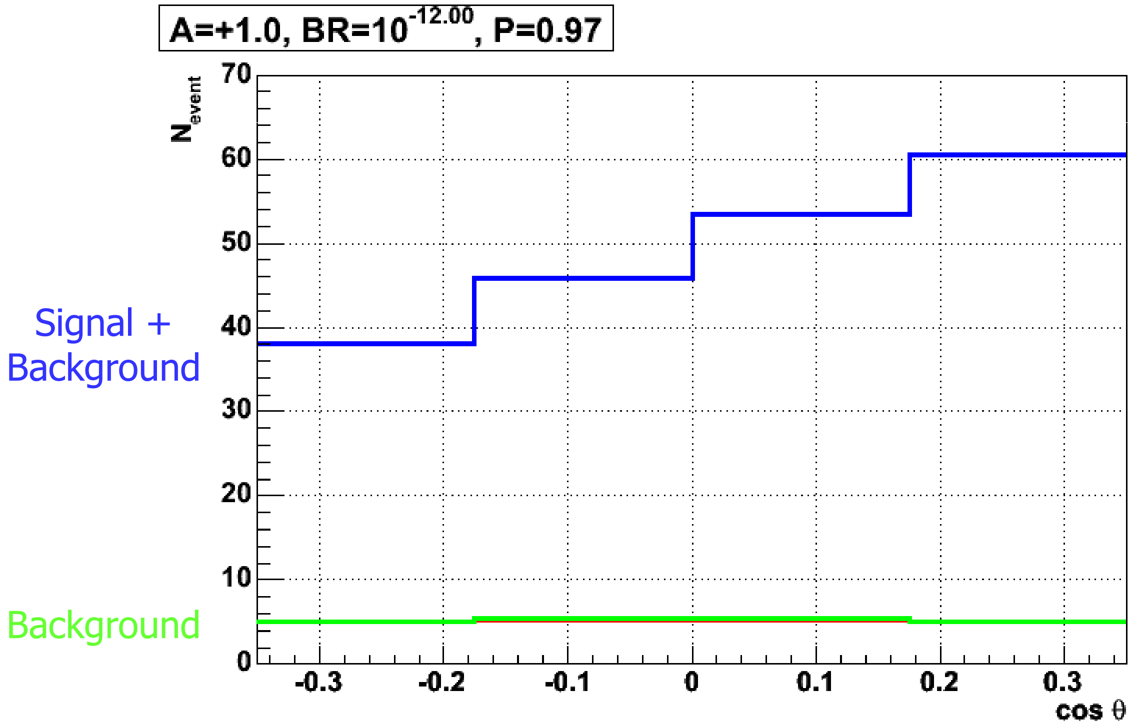
SU(5) SUSY-GUT
A = +1
SO(10) SUSY-GUT
A ≈ 0
MSSM with ν_R
A = -1



Y.Kuno *et al.*,
Phys.Rev.Lett. 77 (1996) 434

Expected Distribution

- $A = +1$
- $B(\mu^+ \rightarrow e^+ \gamma) = 1 \times 10^{-12}$
- $1 \times 10^8\ \mu^+/s$
- 5×10^7 s beam time (2 years)
- $P_\mu = 0.97$



S. Yamada
@ SUSY 2004, Tsukuba

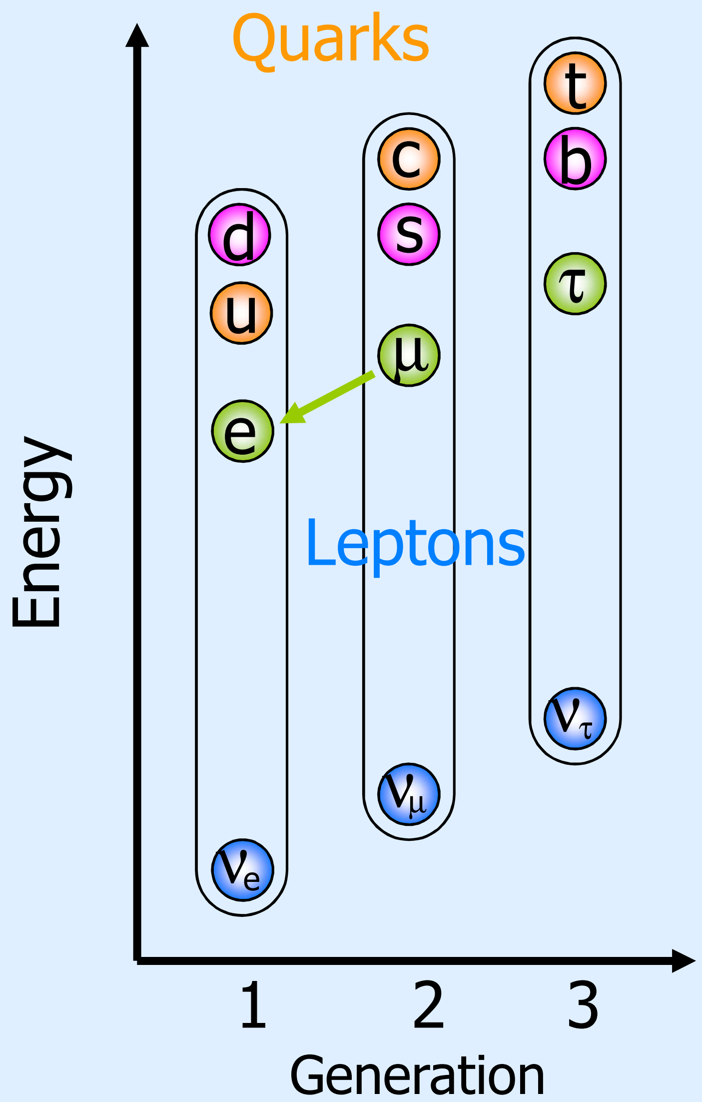
Conclusions

- Many challenges faced in the MEG Experiment, solutions have been worked out
- Some technologies might be interesting for other experiment
  - Liquid Xenon Calorimetery
  - Fast Waveform Digitizing using the DRS chip
- MEG just started taking data, so expect exciting results in the upcoming years

http://meg.psi.ch

Backup Slides

Mixing of Generations

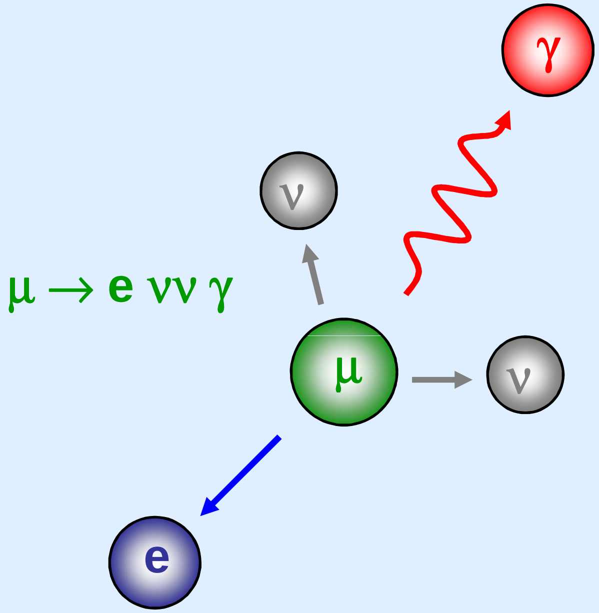


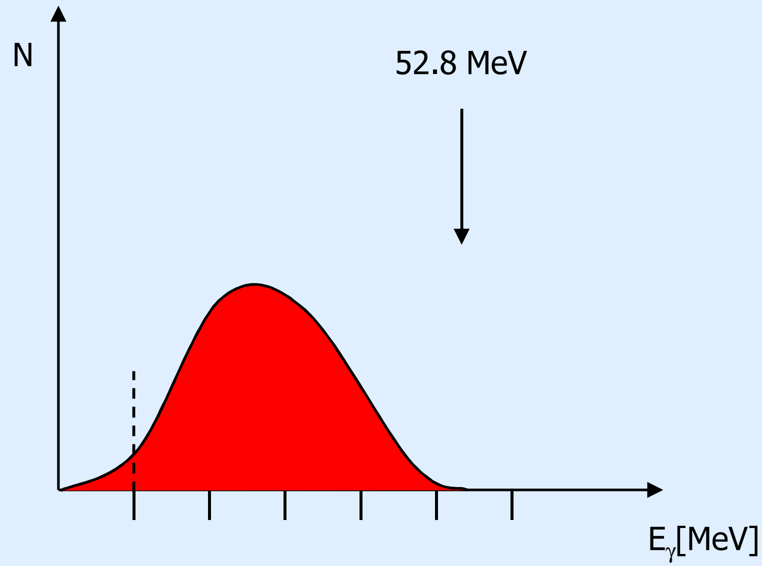
Quark mixing (CKM)

Mixing in the charged Lepton sector?

Neutrino Oscillations

Radiative Muon Decay (1.4%)

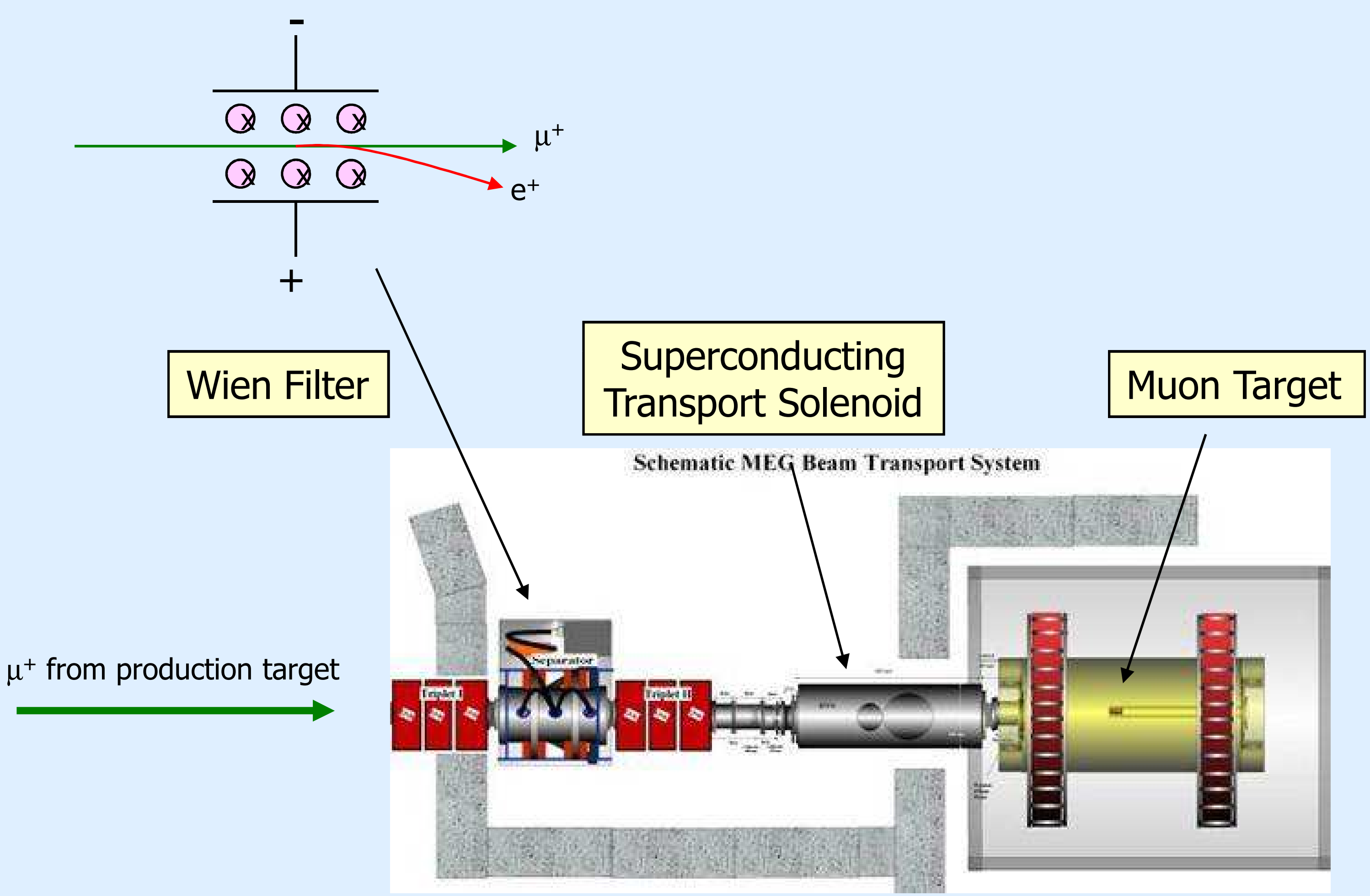




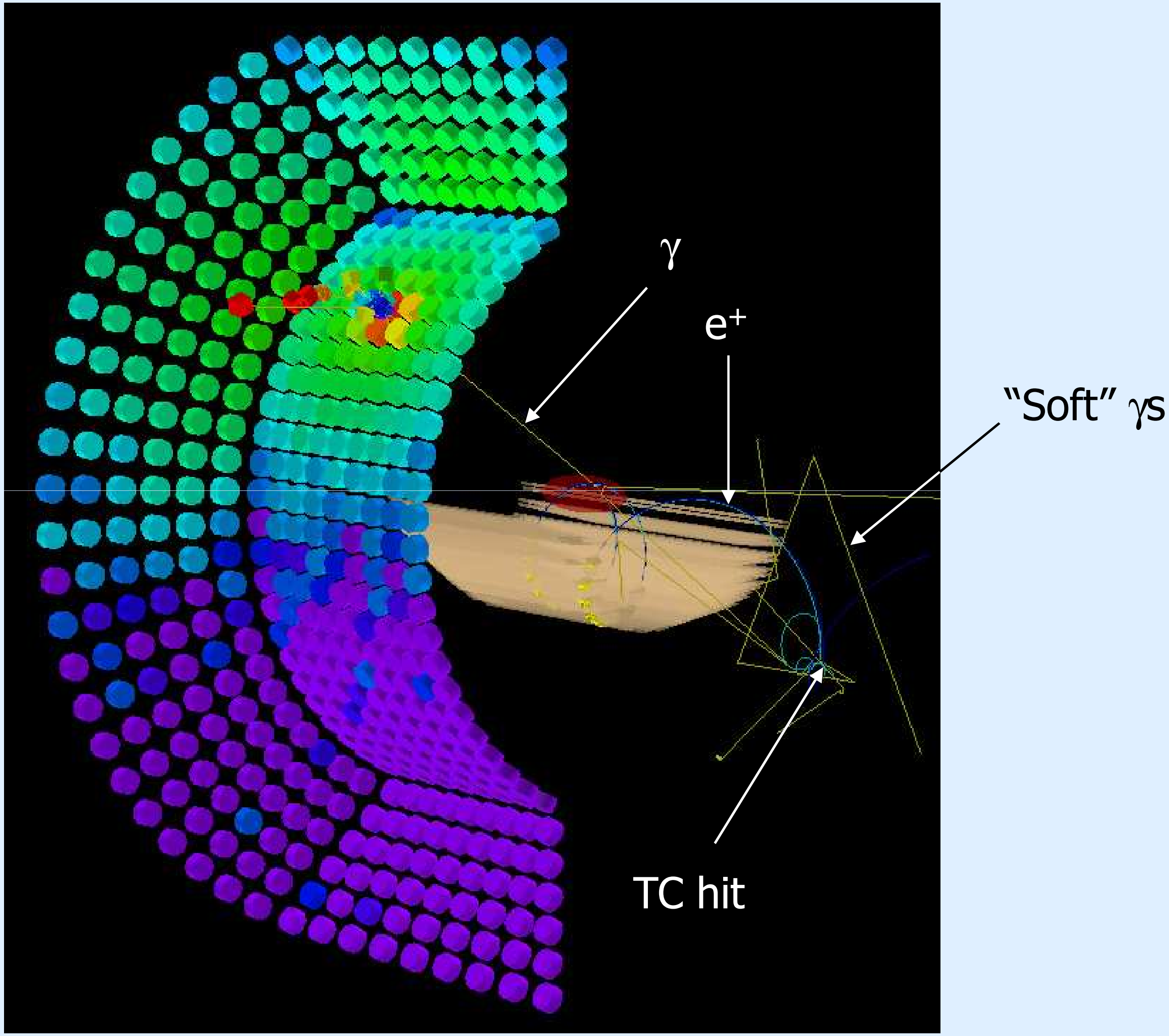
"Prompt" Background: < 10^{-17}

Muon Beam Line

Transport 10^8 μ^+/s to stopping target inside detector with minimal background

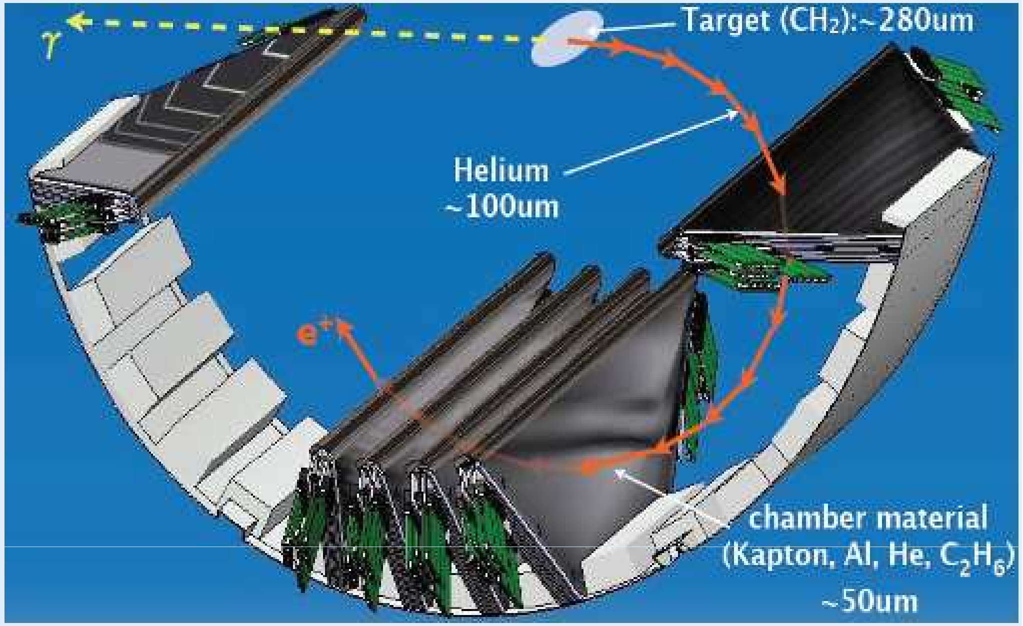


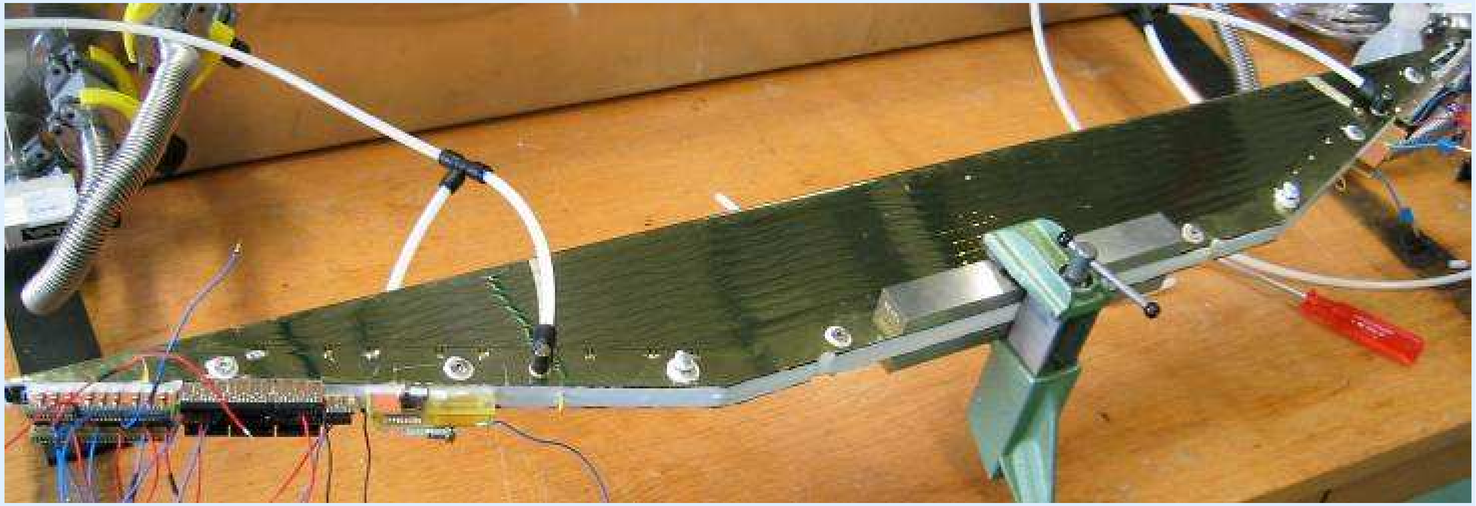
MC Simulation of full detector



Positron Detection System

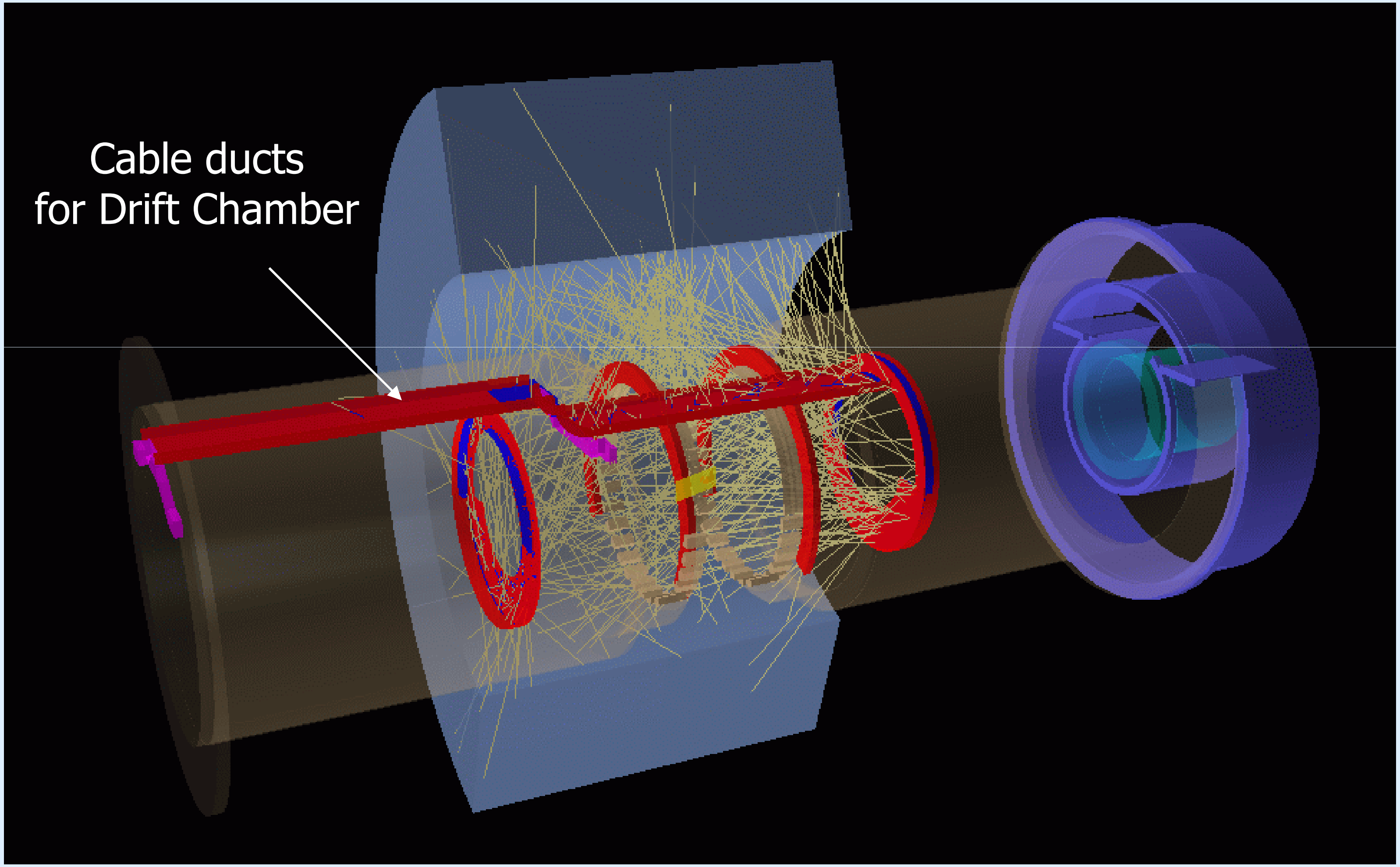
- 16 radial DCs to measure positron tracks
- Extremely low mass
- He:C_2H_6 gas mixture
- Scintillation counter for precise timing



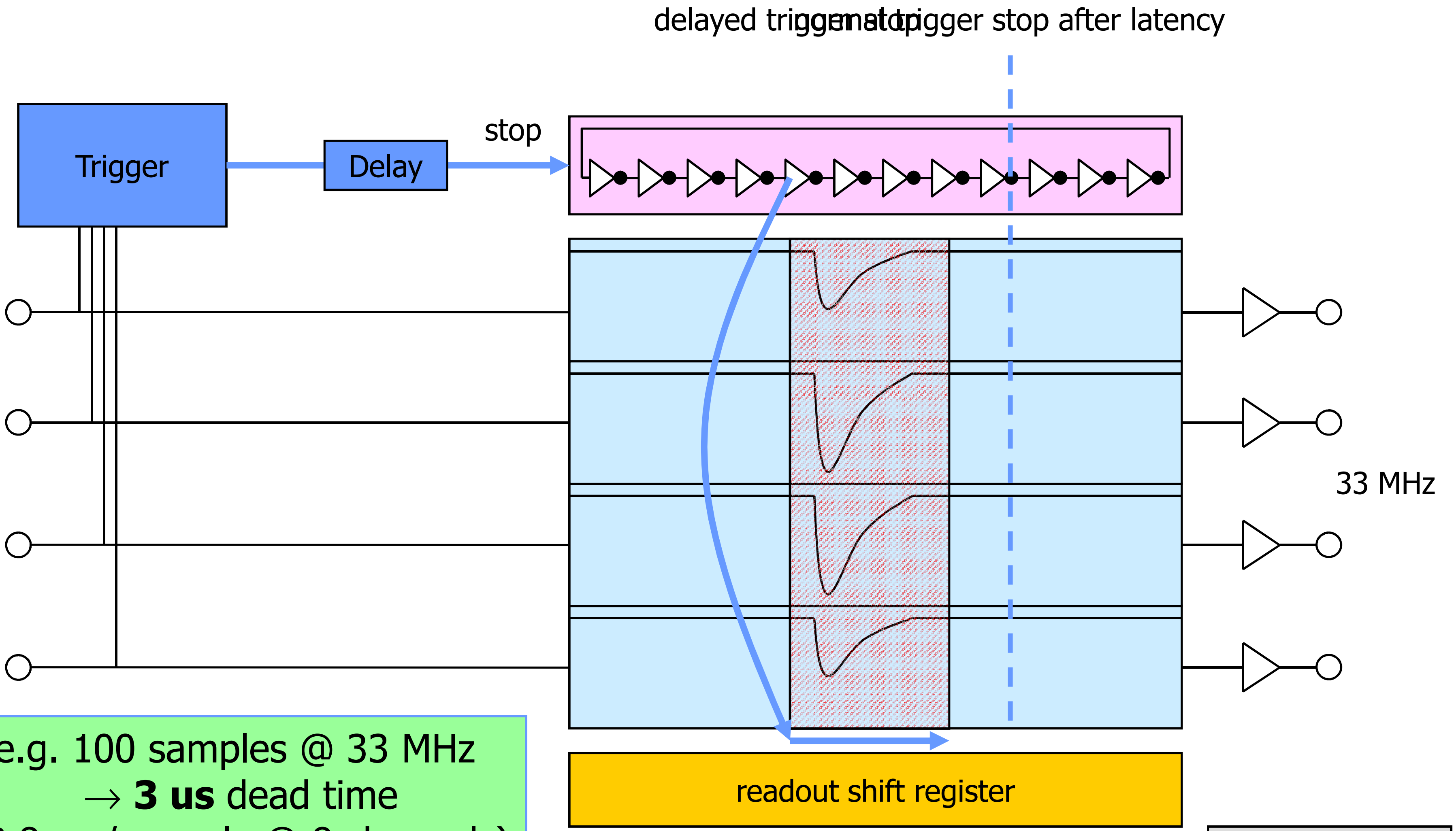


Beam induced background

10^8 μ/s produce 10^8 e^+/s produce 10^8 γ/s



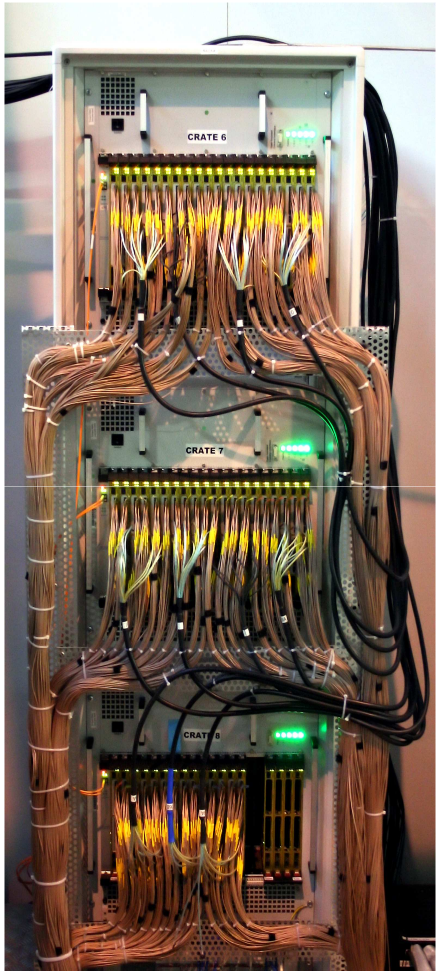
ROI readout mode



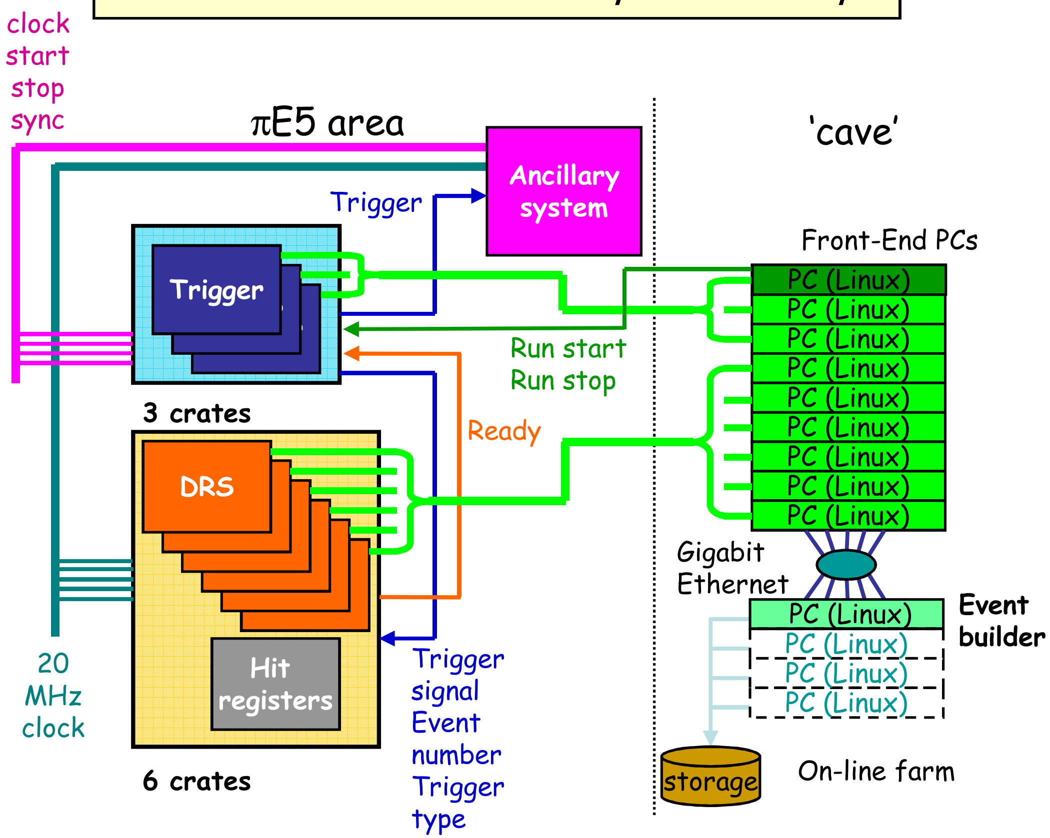
e.g. 100 samples @ 33 MHz
→ **3 us** dead time
(3.8 ns / sample @ 8 channels)

Patent pending!

Complete DAQ System



Data reduction: 900 MB/s → 5 MB/s



What next?

Will we find
$\mu \rightarrow e\,\gamma$?

No

- Improve experiment from 10^{-13} to 10^{-14}:
  - Denser PMTs
  - Second Calorimeter

Yes

- Carefully check results
- Be happy ☺
- Result must be combined with other experiments:
  - $\mu \rightarrow e$ conversion
  - $\mu \rightarrow eee$