

The $\mu^+ \rightarrow e^+ \gamma$ decay as a sensitive probe for physics beyond the SM: first results from the MEG experiment



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on behalf of the MEG collaboration

Université Catholique de Louvain, 3 Décembre 2009

The MEG collaboration



Tokyo U.
Waseda U.
KEK



INFN & U Pisa
INFN & U Roma
INFN & U Genova
INFN & U Pavia
INFN & U Lecce



PSI



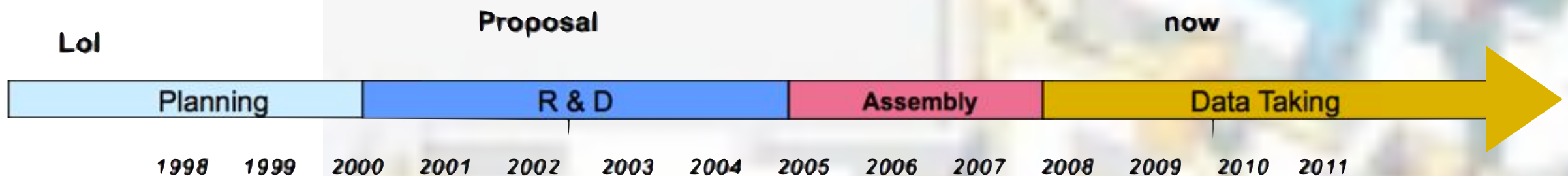
UCIrvine



JINR Dubna
BINP Novosibirsk

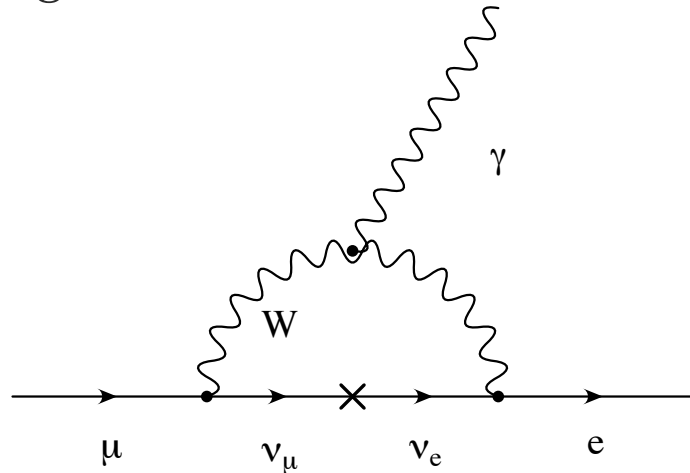
Outline

- Physics **motivation** for a $\mu \rightarrow e\gamma$ experiment
- The $\mu \rightarrow e\gamma$ decay
- The **detector**
 - Overview of sub-detectors
 - Calibration methods
- **Analysis** of 2008 run
- **Status**
 - Run 2009
- Next year(s)



The $\mu \rightarrow e \gamma$ decay

- The $\mu \rightarrow e \gamma$ decay in the **SM** is radiatively induced by **neutrino masses and mixings** at a negligible level

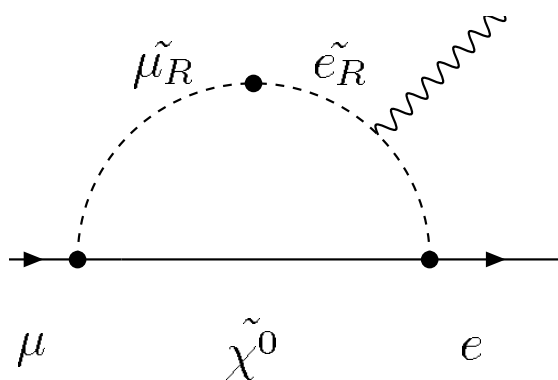


$$\Gamma(\mu \rightarrow e \gamma) \approx \underbrace{\frac{G_F^2 m_\mu^5}{192 \pi^3}}_{\mu - \text{decay}} \underbrace{\left(\frac{\alpha}{2\pi}\right)}_{\gamma - \text{vertex}} \underbrace{\sin^2 2\theta \sin^2 \left(\frac{1.27 \Delta m^2}{M_W^2}\right)}_{\nu - \text{oscillation}}$$

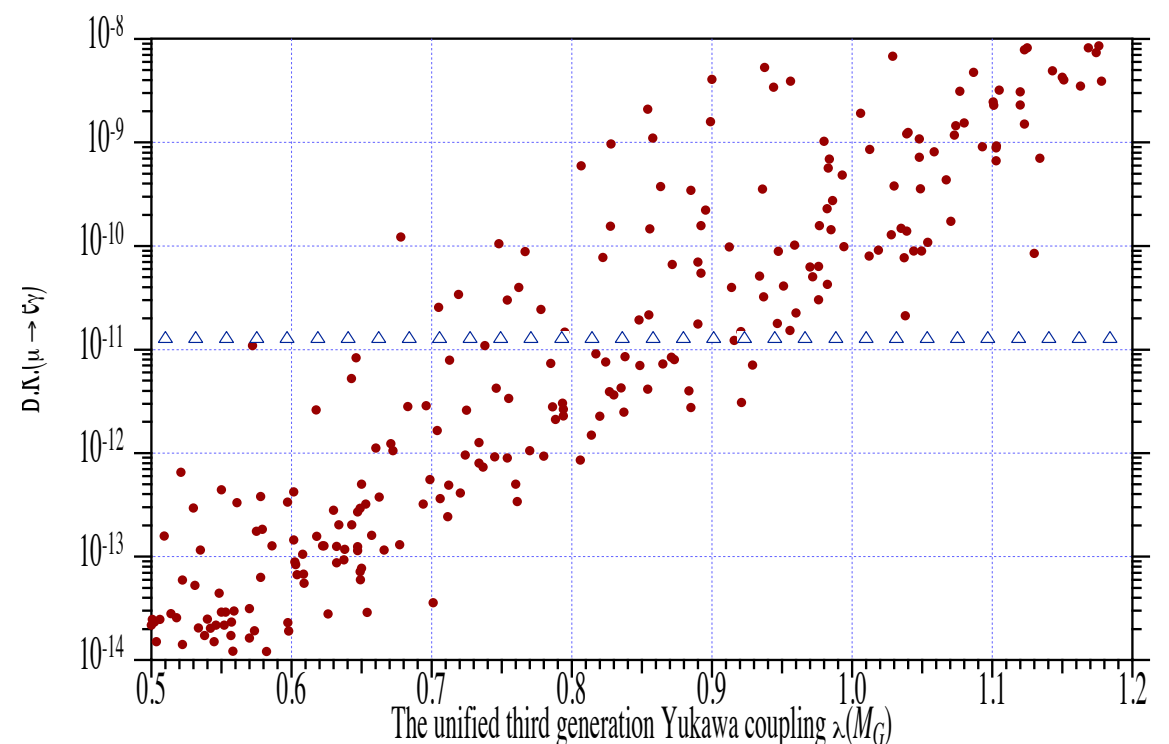
$$\approx \frac{G_F^2 m_\mu^5}{192 \pi^3} \left(\frac{\alpha}{2\pi}\right) \sin^2 2\theta_\odot \left(\frac{\Delta m^2}{M_W^2}\right)^2,$$

Relative probability $\sim 10^{-54}$

- All **SM extensions enhance the rate** through mixing in the high energy sector of the theory (other particles in the loop...)



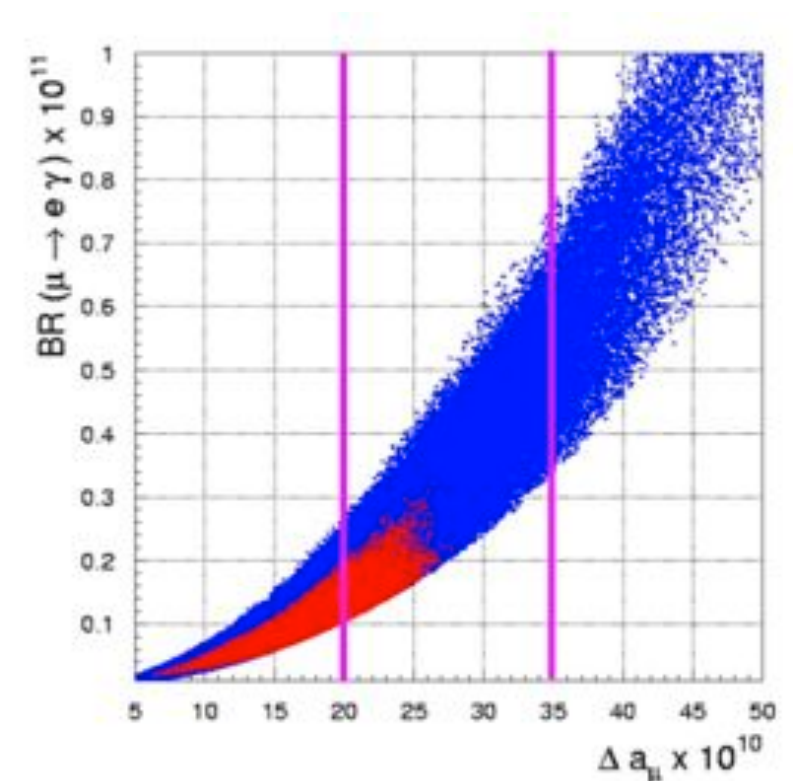
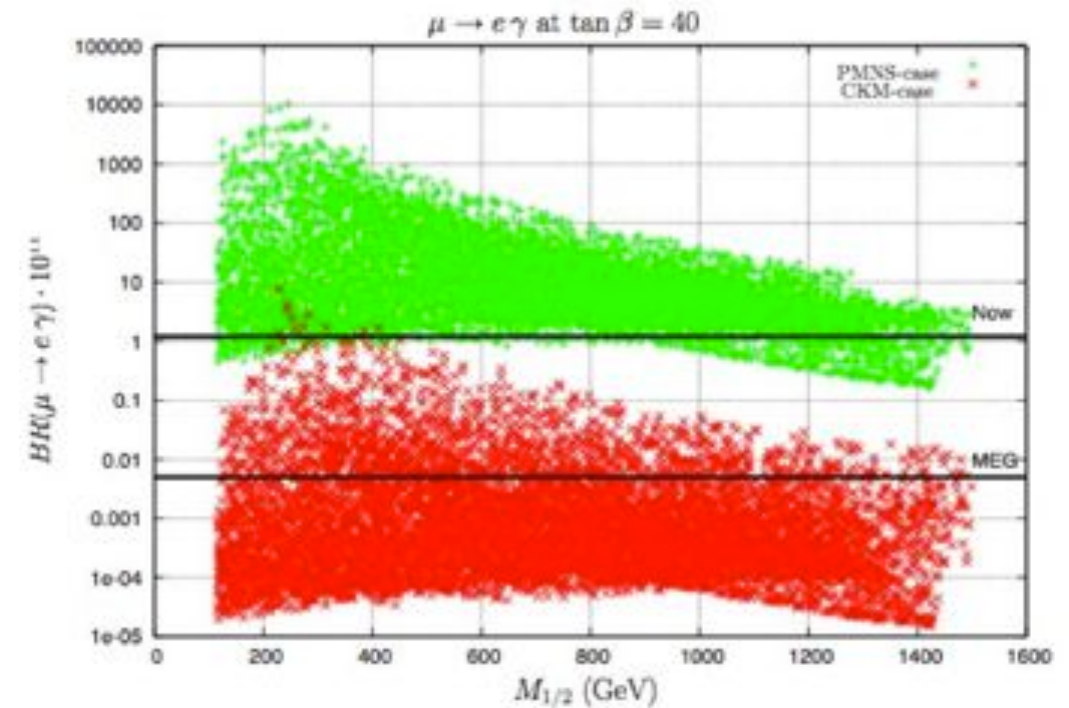
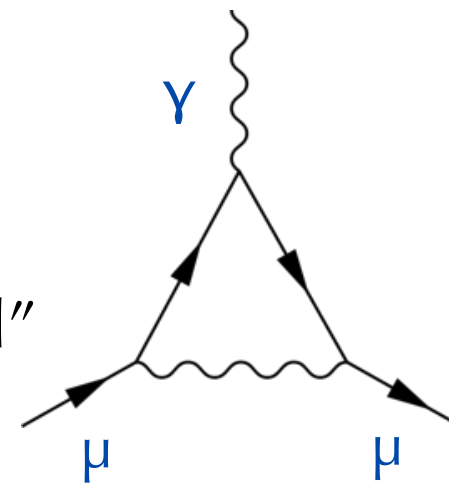
- Clear **evidence for physics beyond the SM**
- Restrict parameter space** of SM extensions



Connections

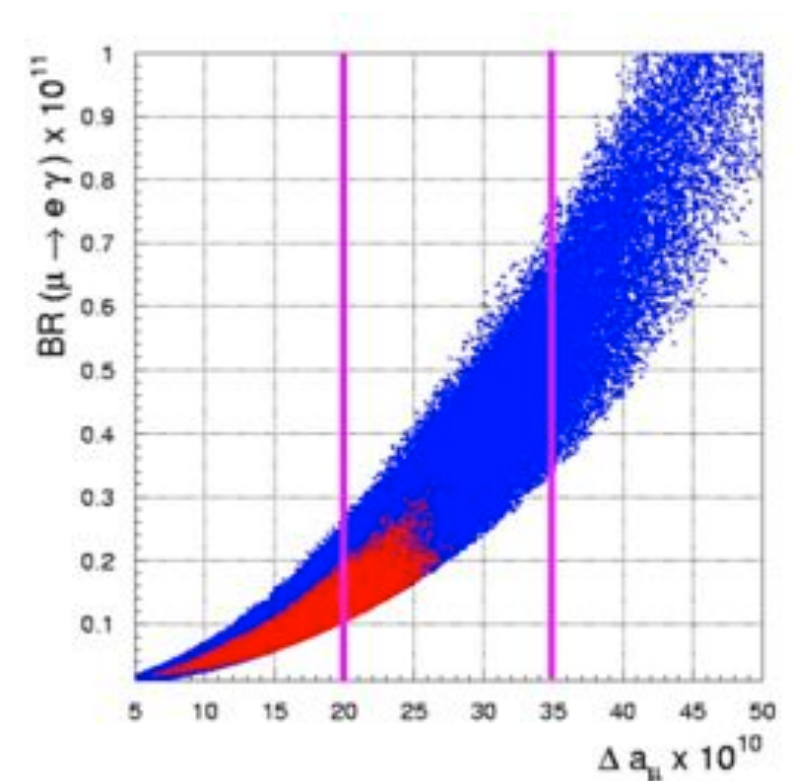
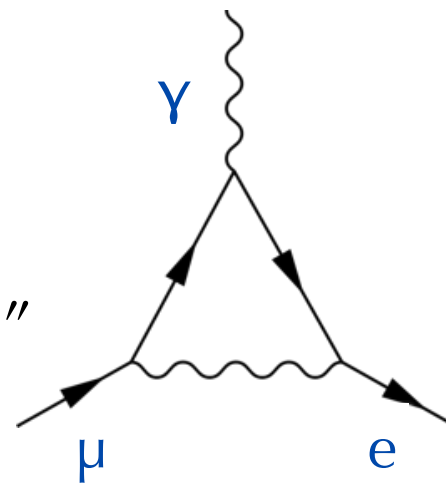
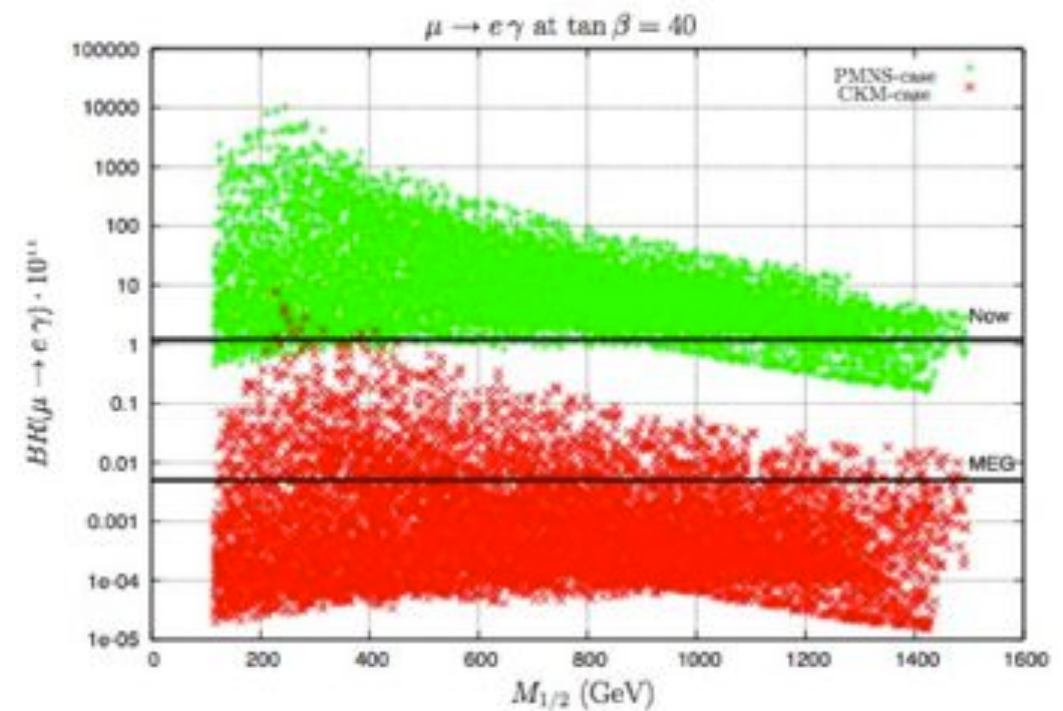
- **LHC**
 - it is Super Symmetry + Grand Unification that predicts new particles in the loop.
 - alternate search for (E/M_{SUSY}) suppressed effects
- **neutrino oscillations**
 - mixing matrix in charged sector can be proportional to
 - PMNS
 - CKM
- muon **$g-2$**
 - a_μ is the “diagonal” term
 - $\mu \rightarrow e \gamma$ diagram is the “off-diagonal”

Barbieri *et al.*, Nucl. Phys B445 (1995) 225
 Hisano *et al.*, Phys. Lett. B391 (1997) 341
 Masiero *et al.*, Nucl. Phys. B649 (2003) 189
 Calibbi *et al.*, Phys. Rev. D74 (2006) 116002
 Isidori *et al.*, Phys. Rev. D75 (2007) 115019
 ...



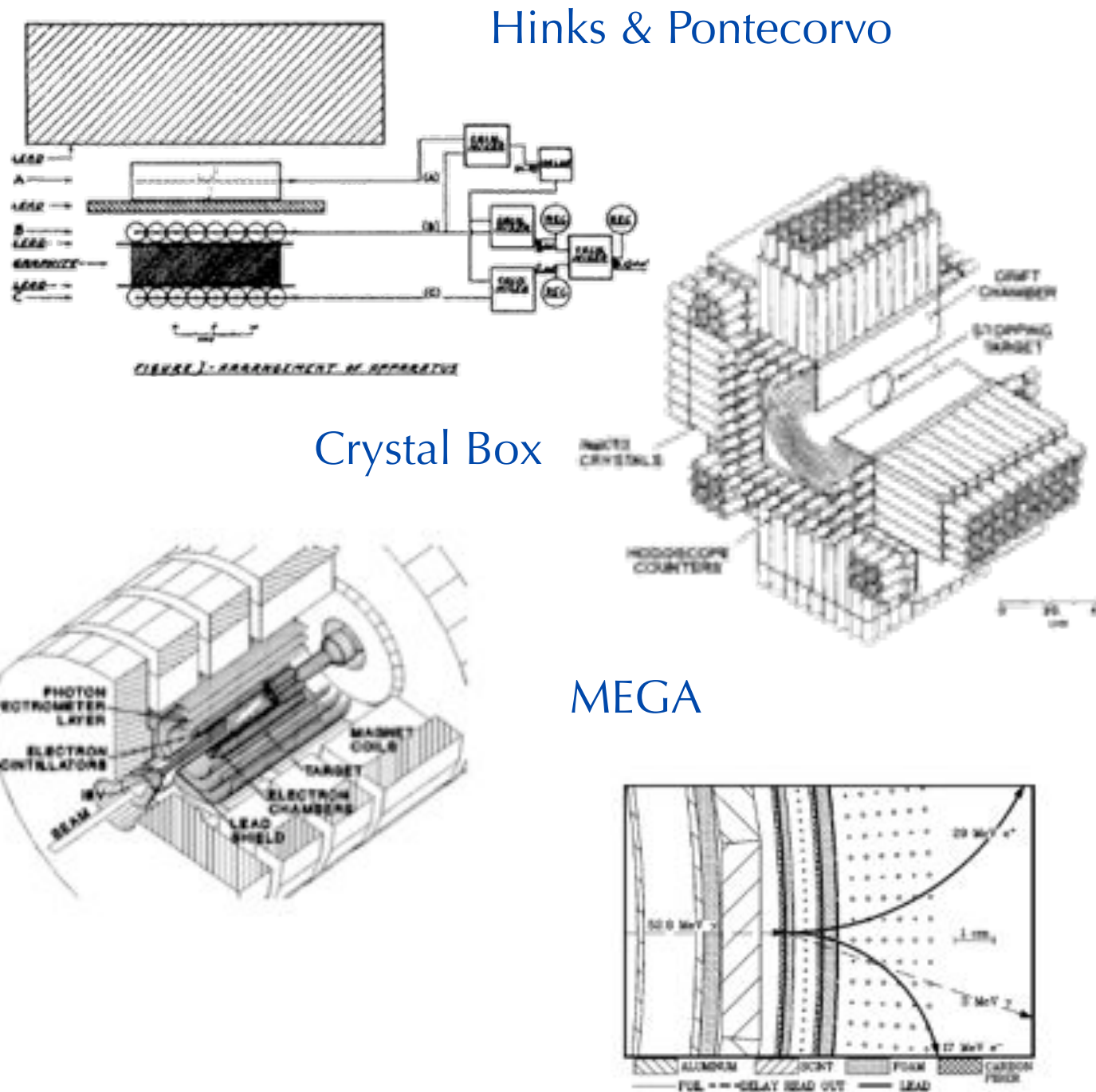
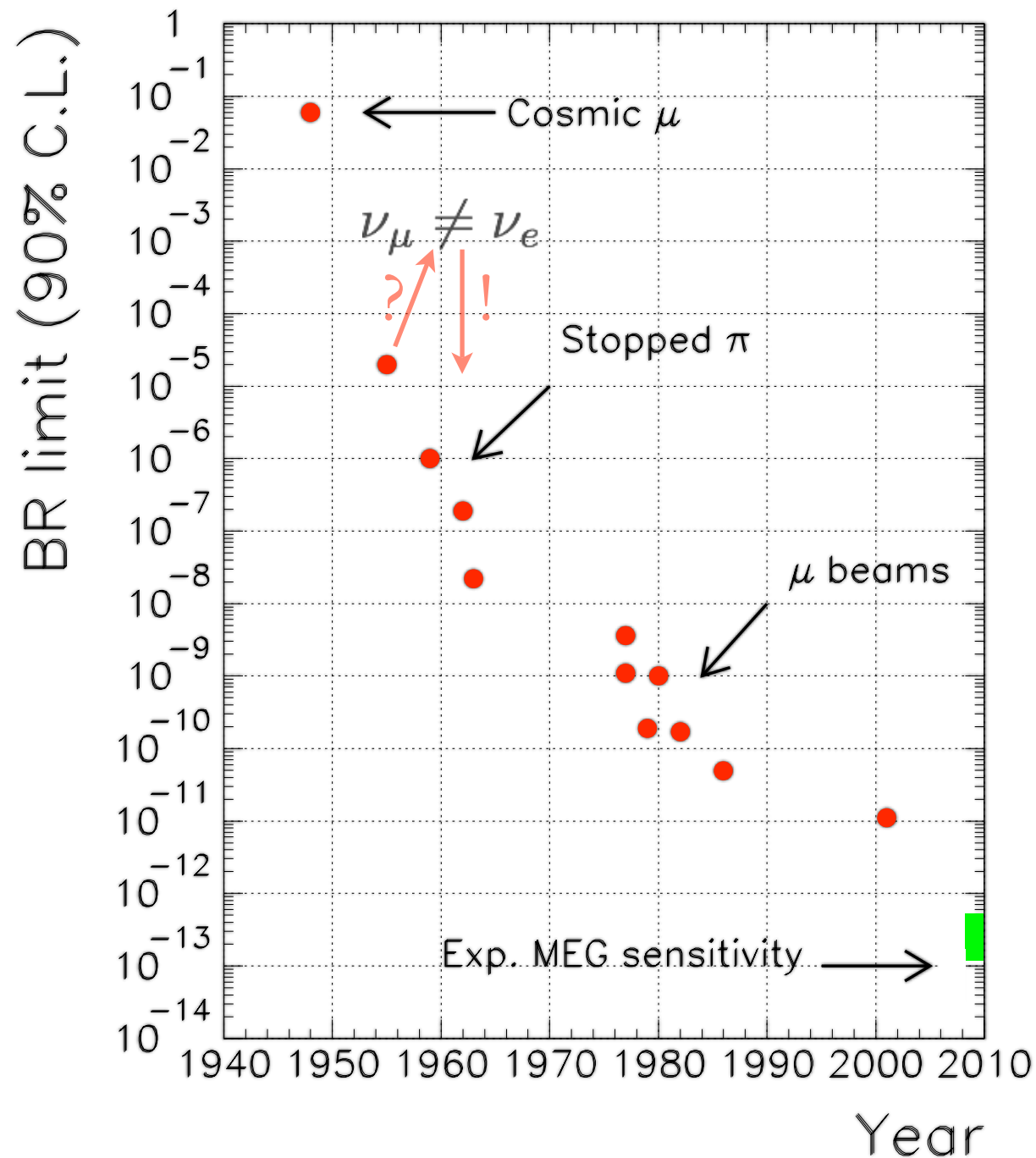
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Historical perspective



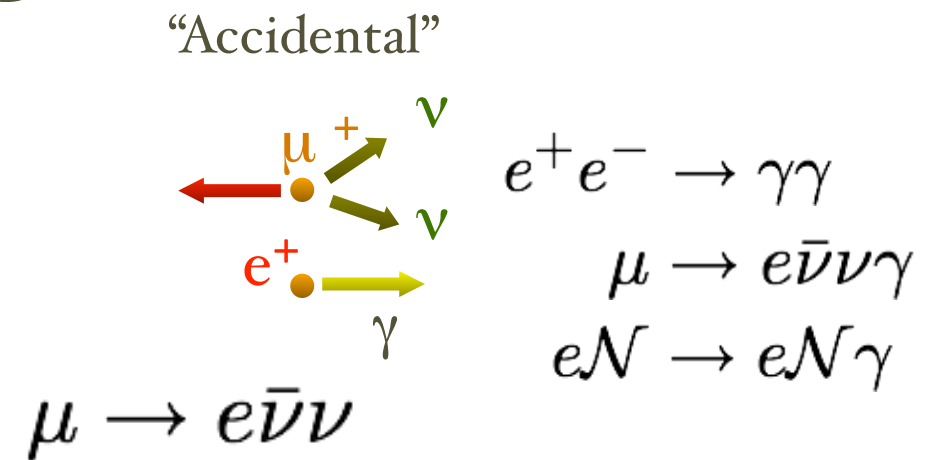
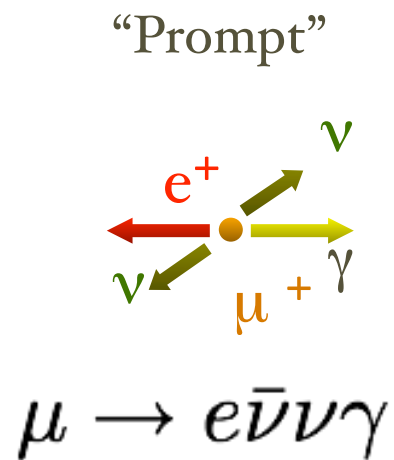
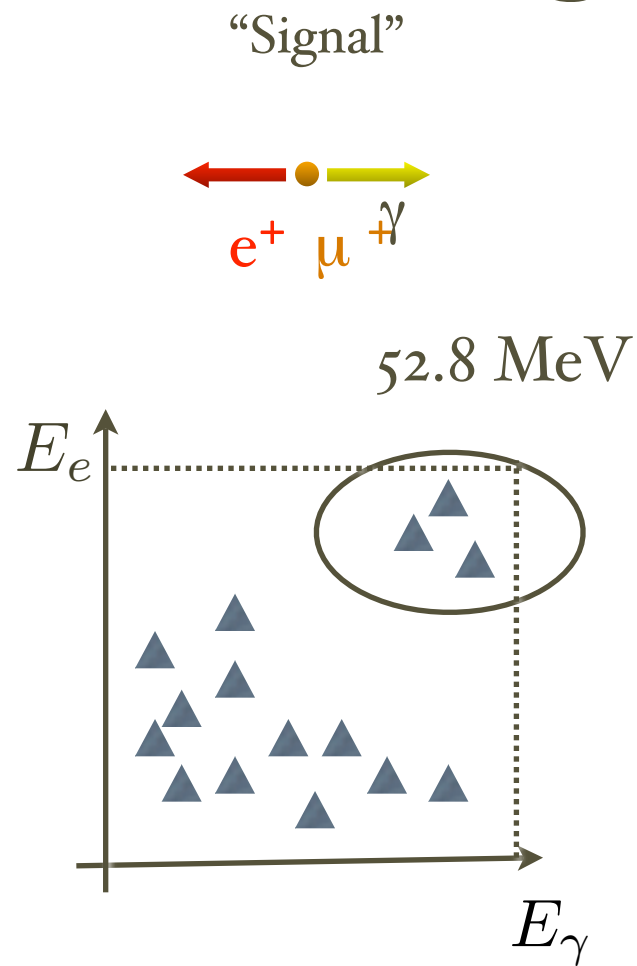
Each **improvement** linked to the **technology** either in the **beam** or in the **detector**

Always a **trade-off** between various elements of the detector to achieve the best “**sensitivity**”

Signal and Background

- To better understand why **MEG** was designed the way it is we have to understand exactly:
 - what are we searching for? **signal**
 - in which environment? **background**
- which **handles** can we use for discrimination?

Signal and Background



$$B_{\text{prompt}} \approx 0.1 \times B_{\text{acc}}$$

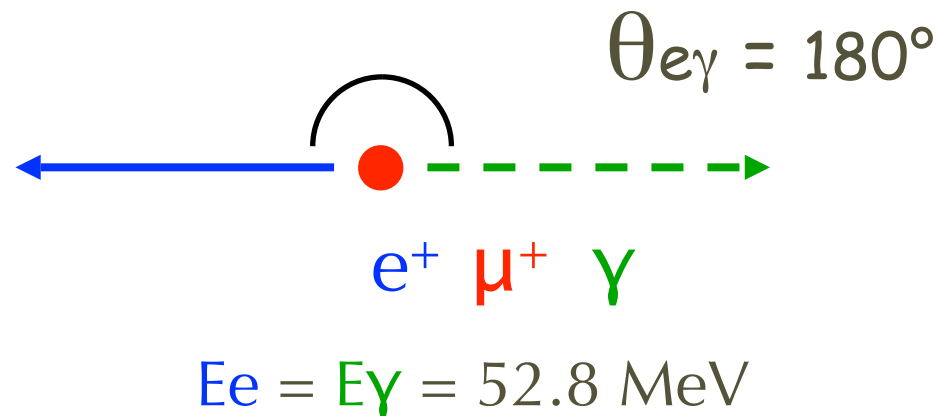
$$B_{\text{acc}} \approx R_\mu \Delta E_e \Delta E_\gamma^2 \Delta \theta^2 \Delta t$$

The **accidental background** is **dominant** and it is determined by the experimental resolutions

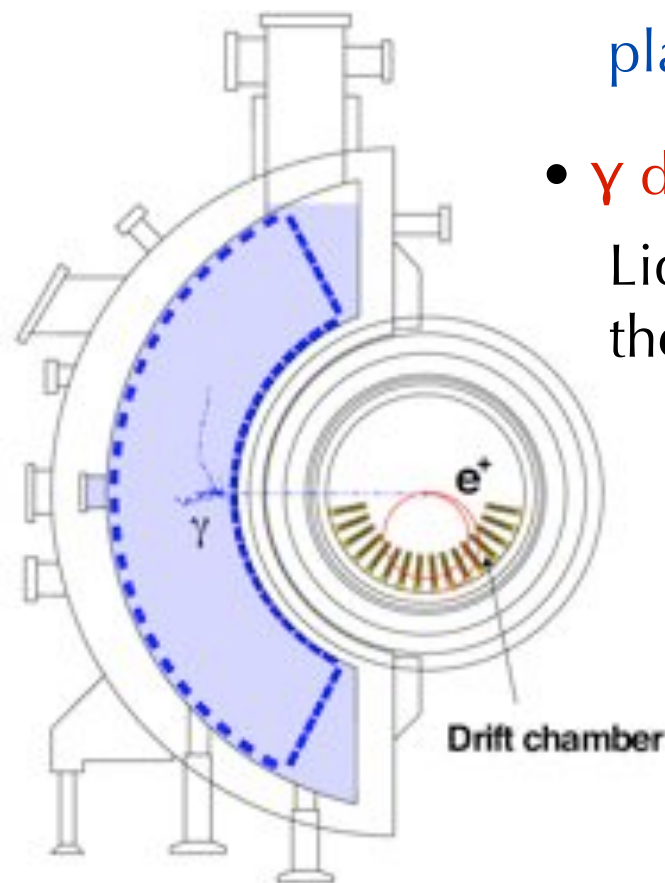
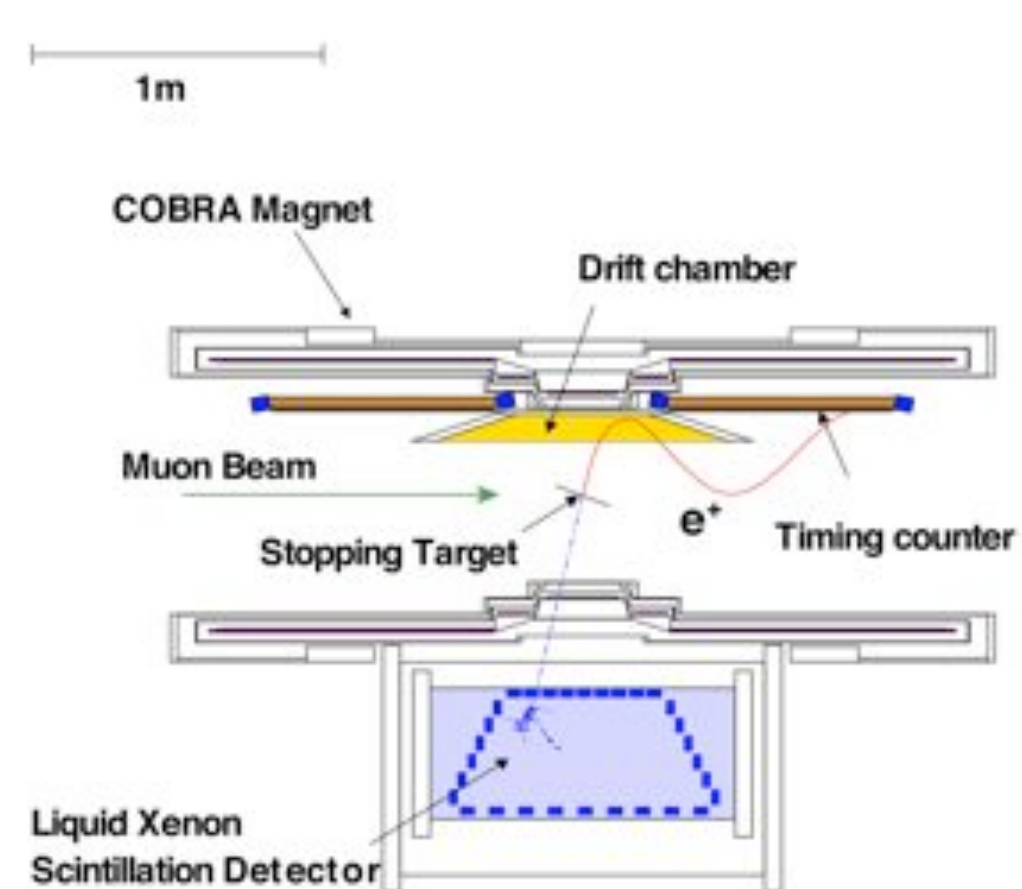
Exp./Lab	Year	$\Delta E_e/E_e$ (%)	$\Delta E_\gamma/E_\gamma$ (%)	$\Delta t_{e\gamma}$ (ns)	$\Delta \theta_{e\gamma}$ (mrad)	Stop rate (s ⁻¹)	Duty cyc. (%)	BR (90% CL)
SIN	1977	8.7	9.3	1.4	-	5×10^5	100	3.6×10^{-9}
TRIUMF	1977	10	8.7	6.7	-	2×10^5	100	1×10^{-9}
LANL	1979	8.8	8	1.9	37	2.4×10^5	6.4	1.7×10^{-10}
Crystal Box	1986	8	8	1.3	87	4×10^5	(6..9)	4.9×10^{-11}
MEGA	1999	1.2	4.5	1.6	17	2.5×10^8	(6..7)	1.2×10^{-11}
MEG	2009	1	4.5	0.15	19	3×10^7	100	2×10^{-13}

MEG experimental method

Easy signal selection with μ^+ at rest

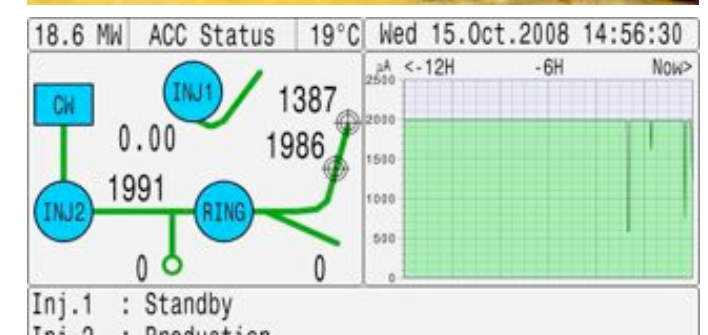


- μ : stopped beam of $>10^7 \mu/\text{sec}$ in a $175 \mu\text{m}$ target
- e^+ detection
magnetic spectrometer composed by solenoidal magnet and drift chambers for momentum
plastic counters for timing
- γ detection
Liquid Xenon calorimeter based on the scintillation light
 - fast: 4 / 22 / 45 ns
 - high LY: $\sim 0.8 * \text{NaI}$
 - short X_0 : 2.77 cm



Machine

- “Sensitivity” proportional to the number of muons observed
- Find the **most intense** (continuous) **muon beam**: Paul Scherrer Institut (CH)
- 1.6 MW proton accelerator
 - 2 mA of protons - towards 3 mA (replace with new resonant cavities)!
 - extremely **stable**
 - $> 3 \times 10^8$ muons/sec @ 2 mA

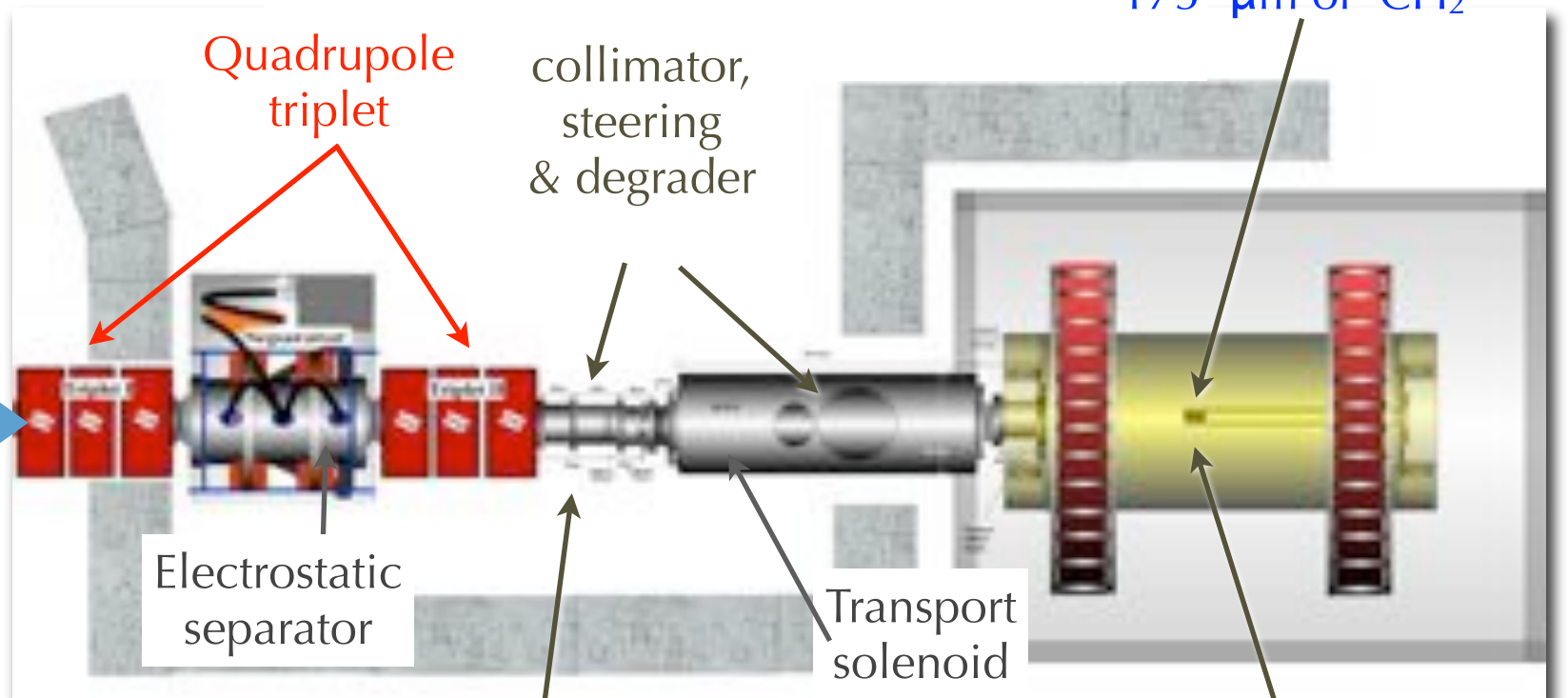
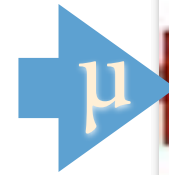


Beam line

$\pi E5$ beam line at PSI

Optimization of the beam elements:

- Muon momentum $\sim 29 \text{ MeV}/c$
- Wien filter for μ/e separation
- Solenoid to couple beam and spectrometer (BTS)
- Degradator to reduce the momentum for a $175 \text{ } \mu\text{m}$ target



μ/e separation 11.8 cm (7.2σ)

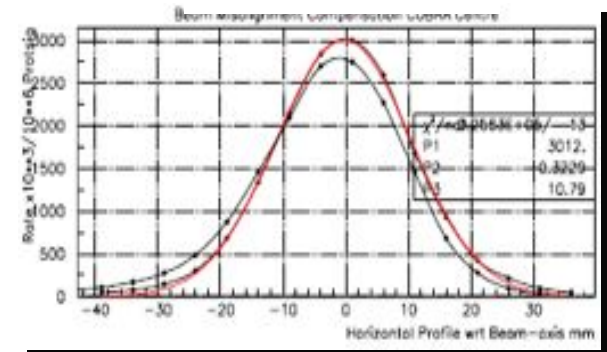
R_μ (exp. on target)

μ spot (exp. on target)

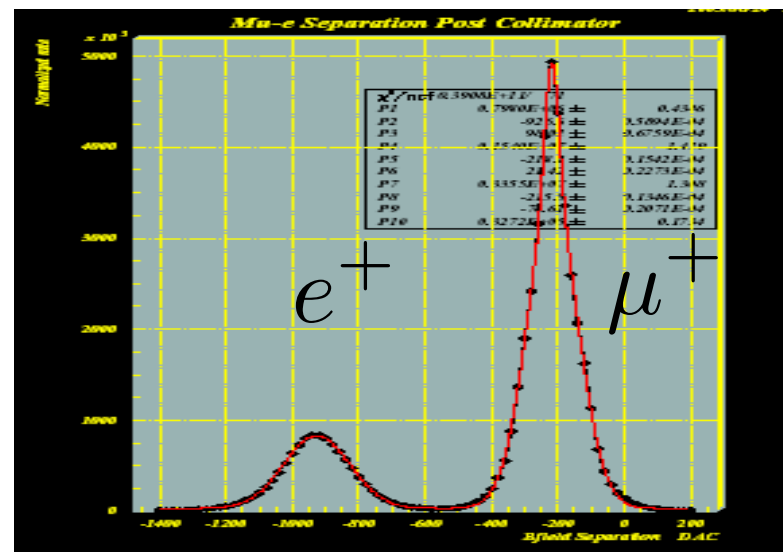
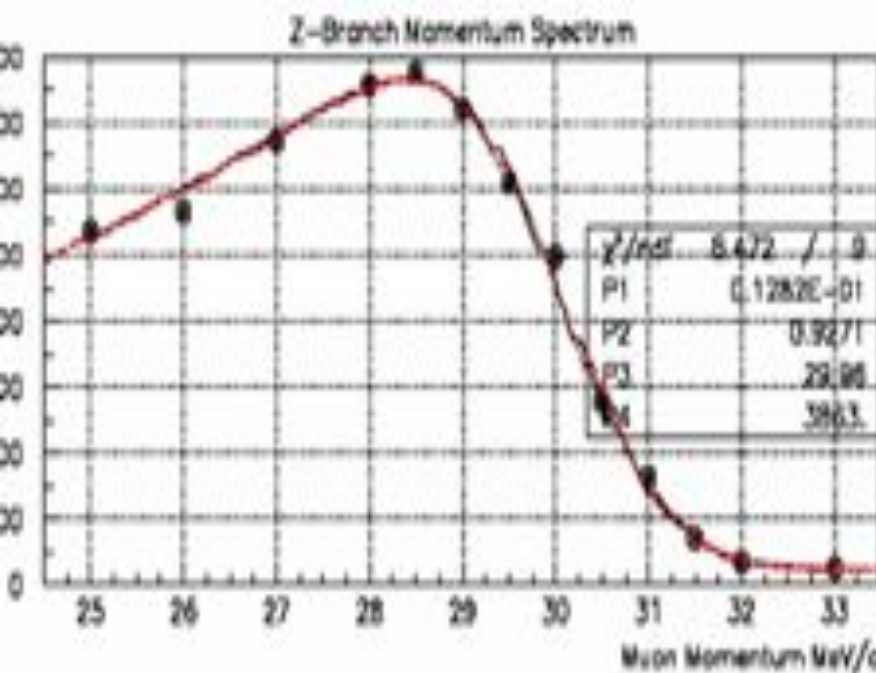
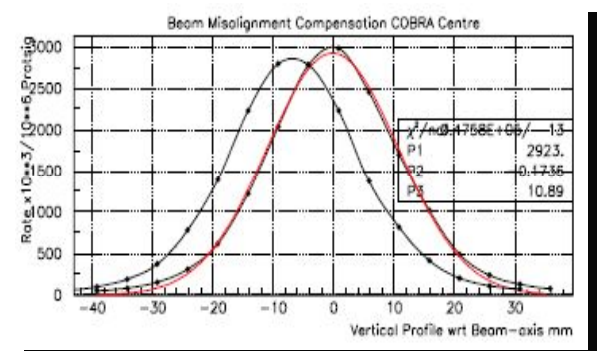
$>6 \cdot 10^7 \mu^+/s$

$\sigma_V \approx \sigma_H \approx 11 \text{ mm}$

$\sigma_x = 11 \text{ mm}$

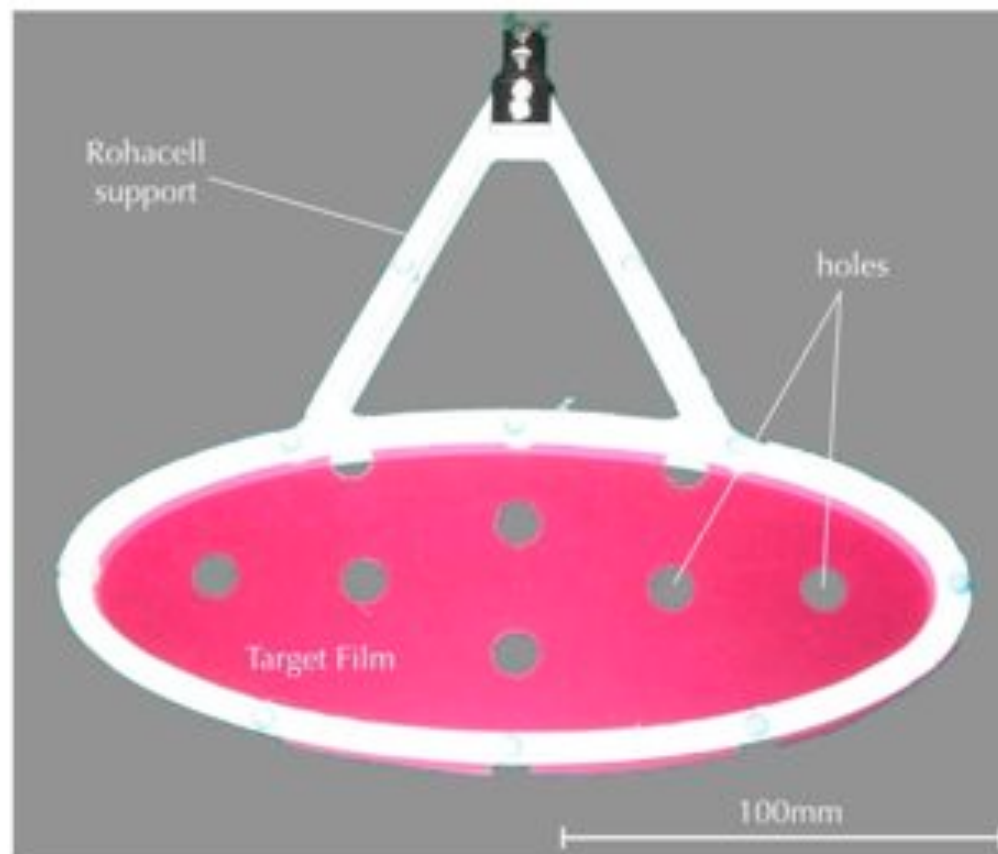


$\sigma_y = 11 \text{ mm}$



Target

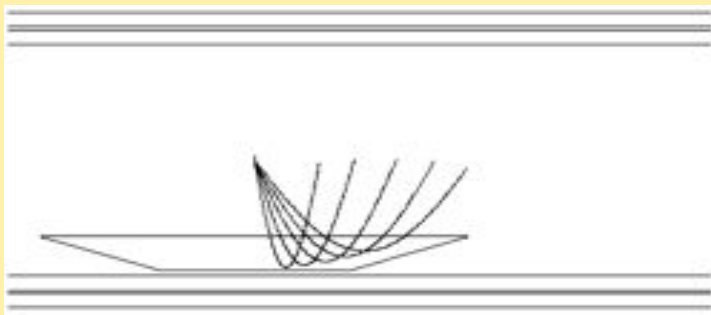
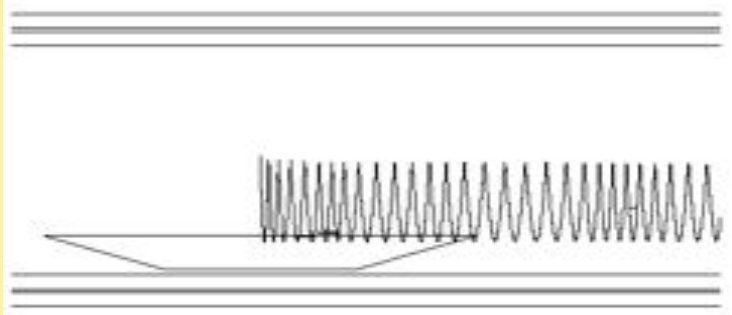
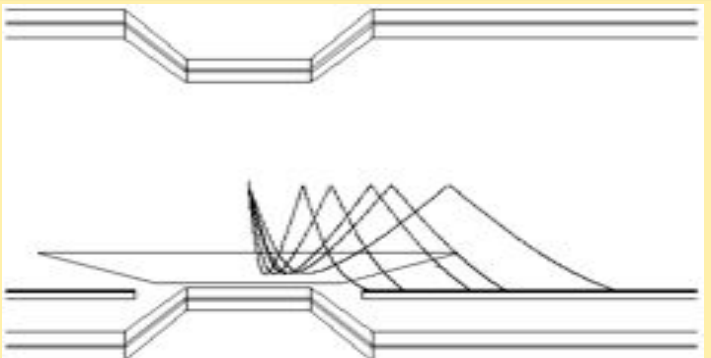
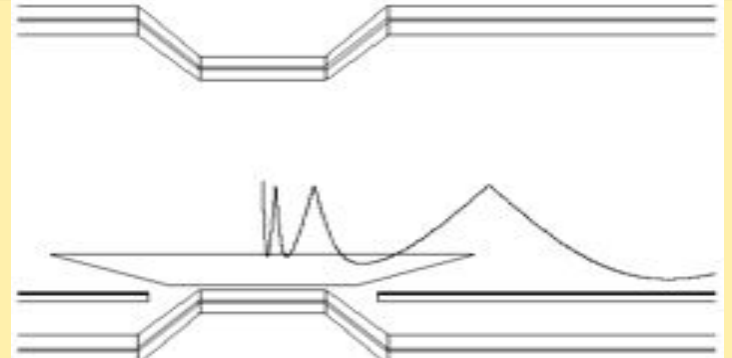
- Stop muons on the **thinnest** possible target $175\text{ }\mu\text{m CH}_2$:
 - need **low energy** muons (lots of multiple scattering) but...
 - the **MS** of the decaying positron is minimized: precise direction/timing
 - **bremsstrahlung** reduced
 - the **conversion** probability of the photon in the target is negligible



Holes to study position reconstruction resolution

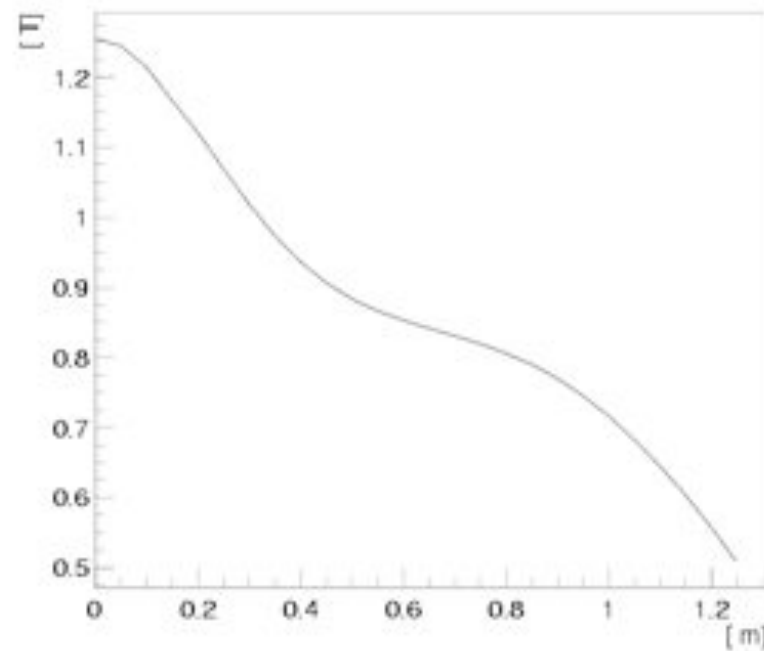
COBRA spectrometer

- The emitted **positrons** tend to **wind** in a **uniform** magnetic **field**
 - the tracking detector becomes easily “**blind**” at the high rate required to observe many muons
- A **non uniform** magnetic **field** solves the rate problem
- As a bonus: **CO**nstant **B**ending **RA**dius

	Constant $ p $ track	High p_T track
Uniform field		
CoBRa: Constant bending quick sweep away		

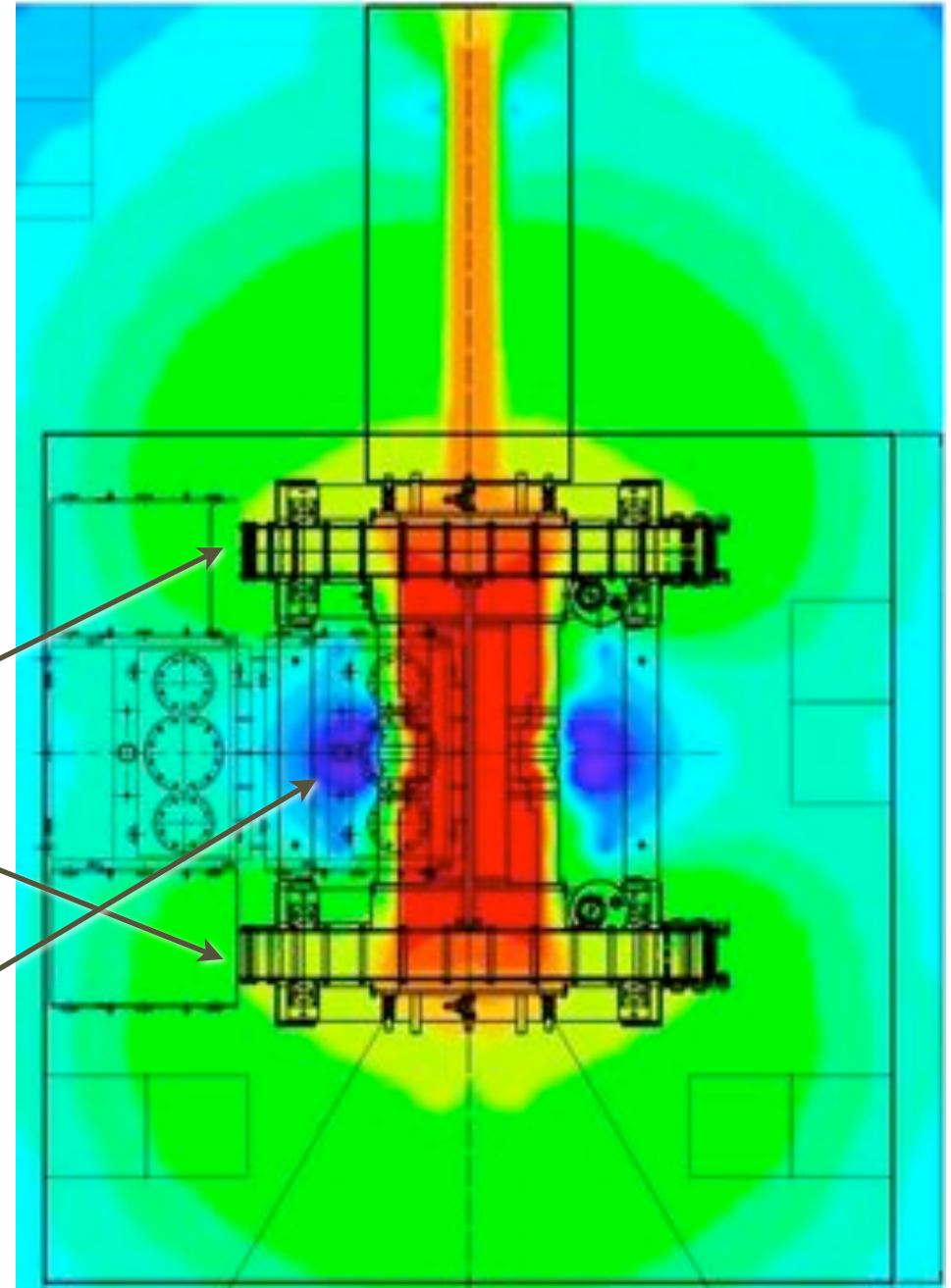
COBRA spectrometer

Non uniform
magnetic field
decreasing from the
center to the
periphery

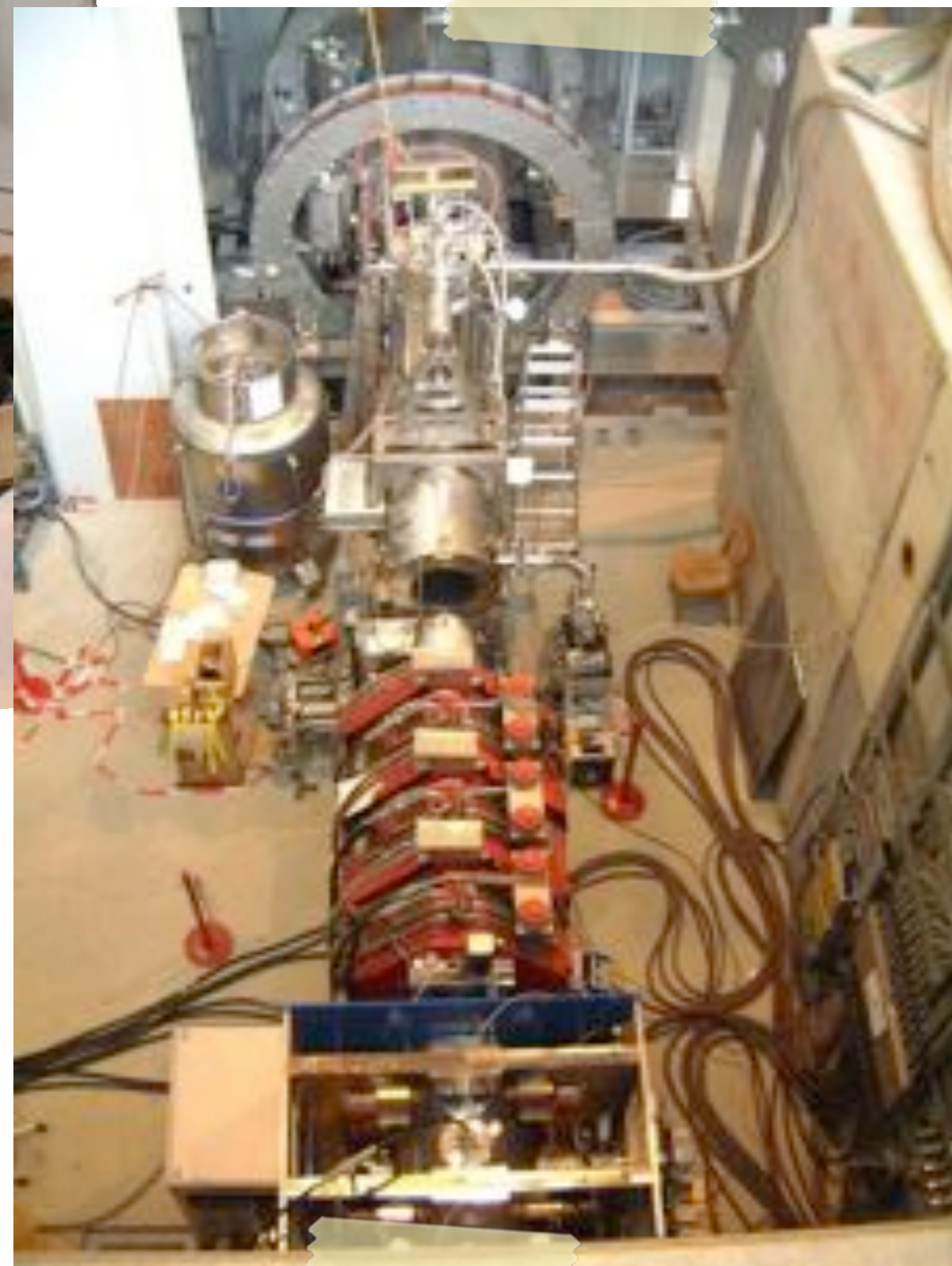
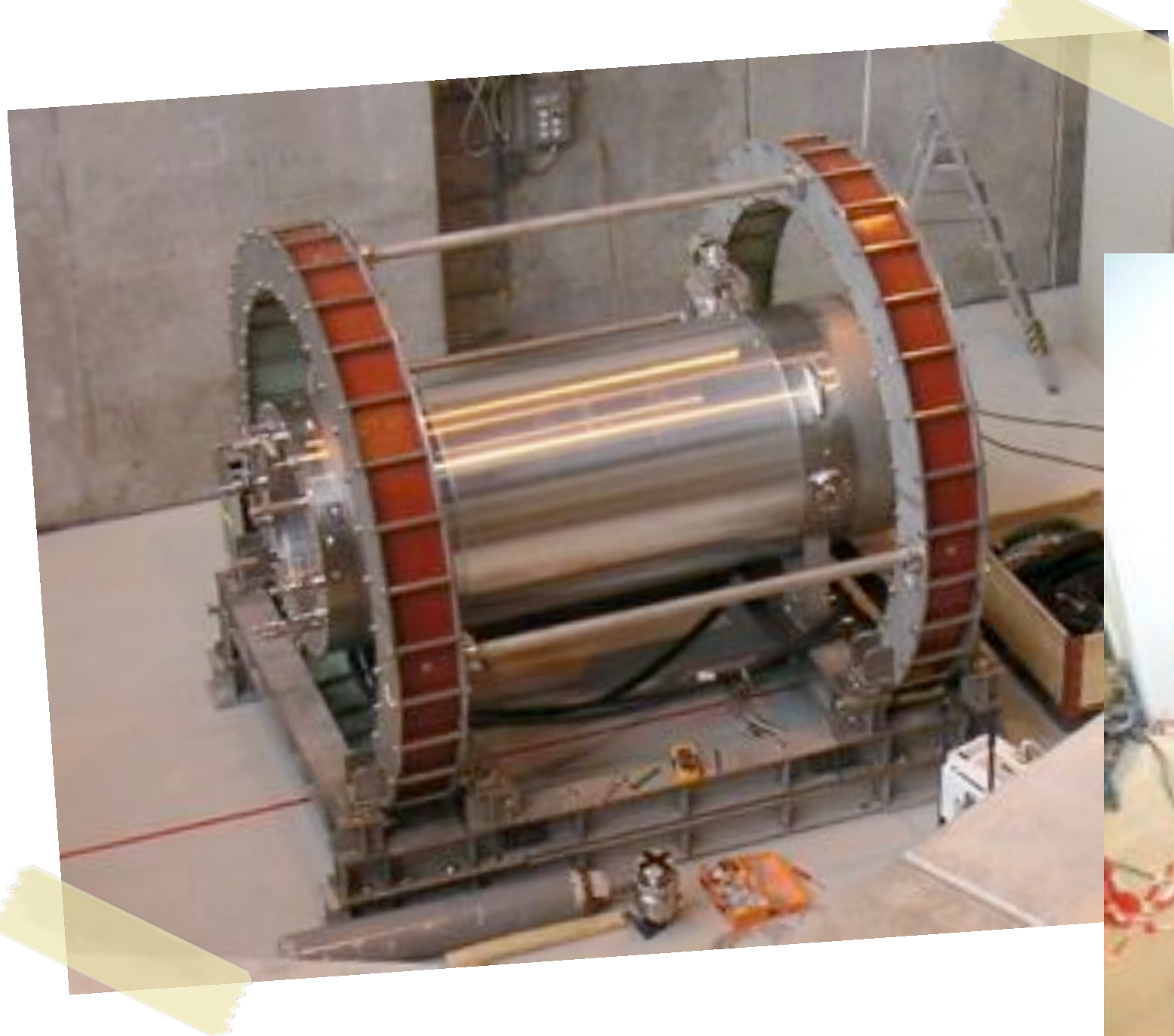


Compensation
coil for LXe
calorimeter

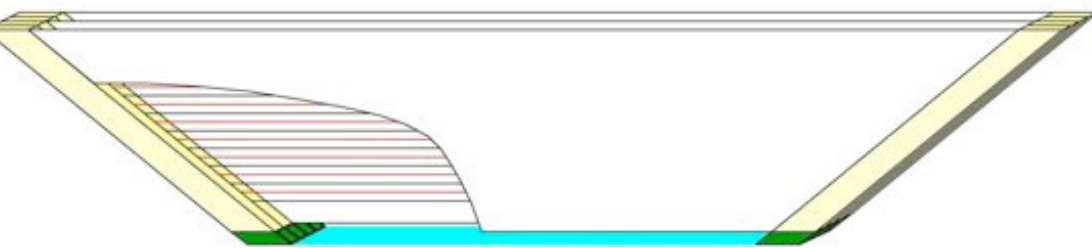
$$|\vec{B}| < 50 \text{ G}$$



- The superconducting magnet is very thin ($0.2 X_0$)
- Can be kept at 4 K with GM refrigerators (no usage of liquid helium)

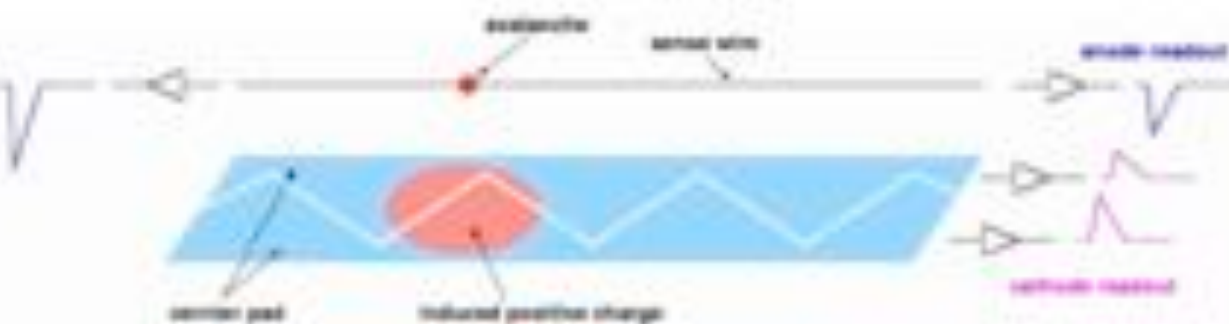
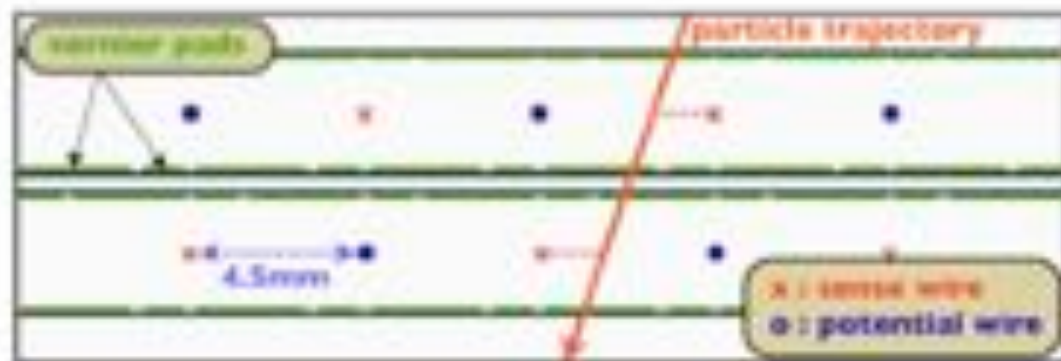


Positron Tracker

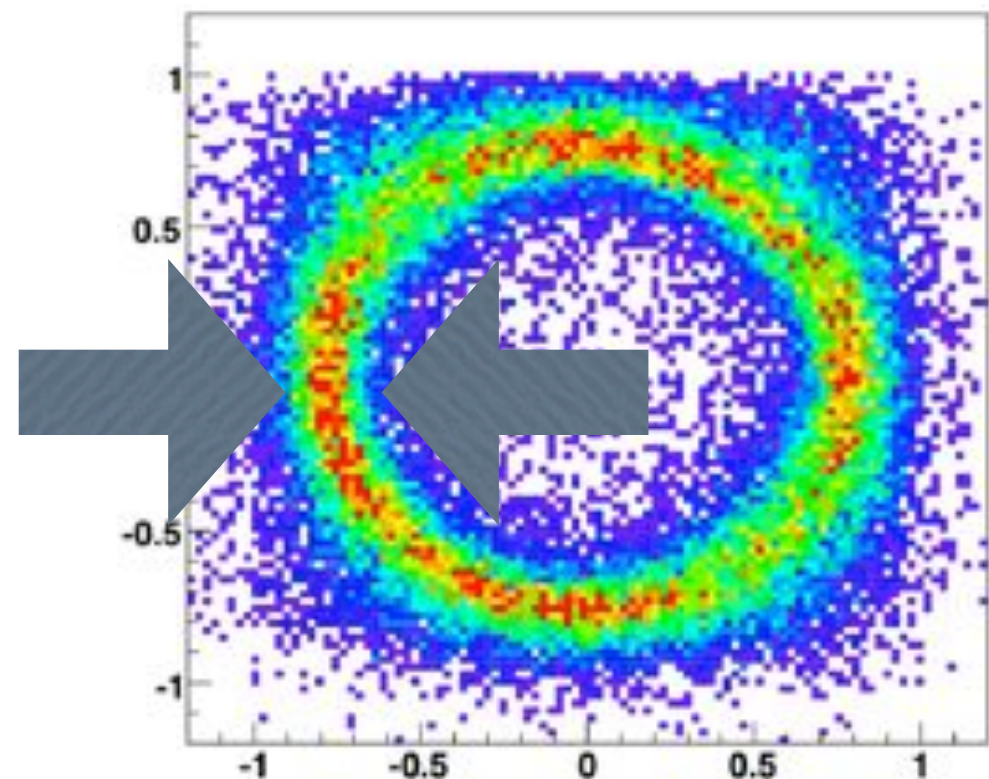


transverse coordinate (t drift)

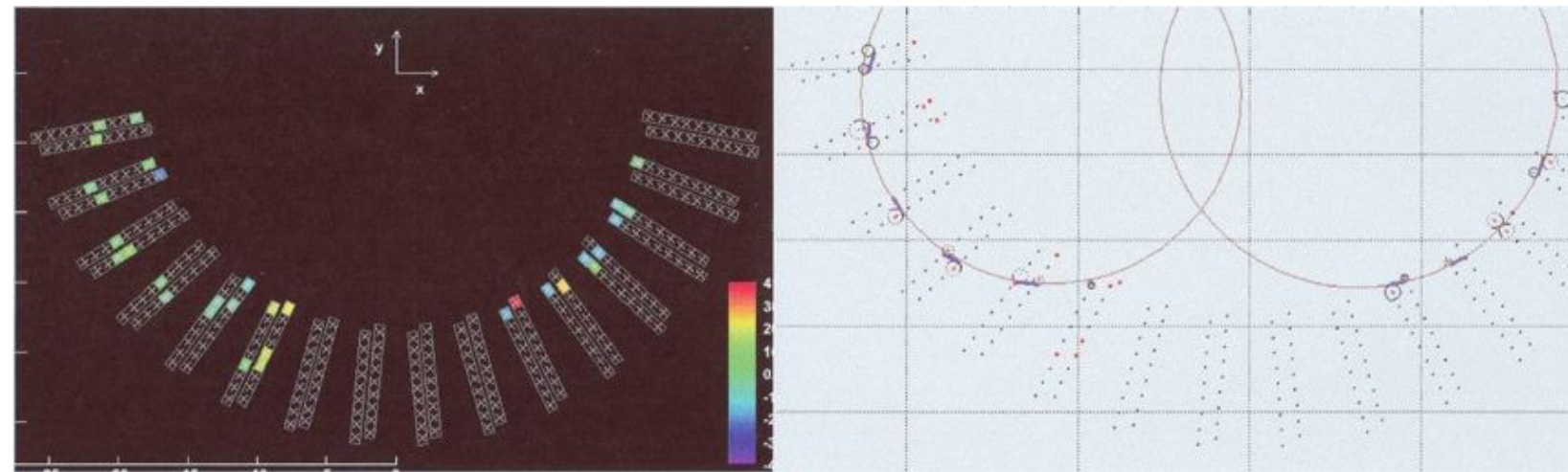
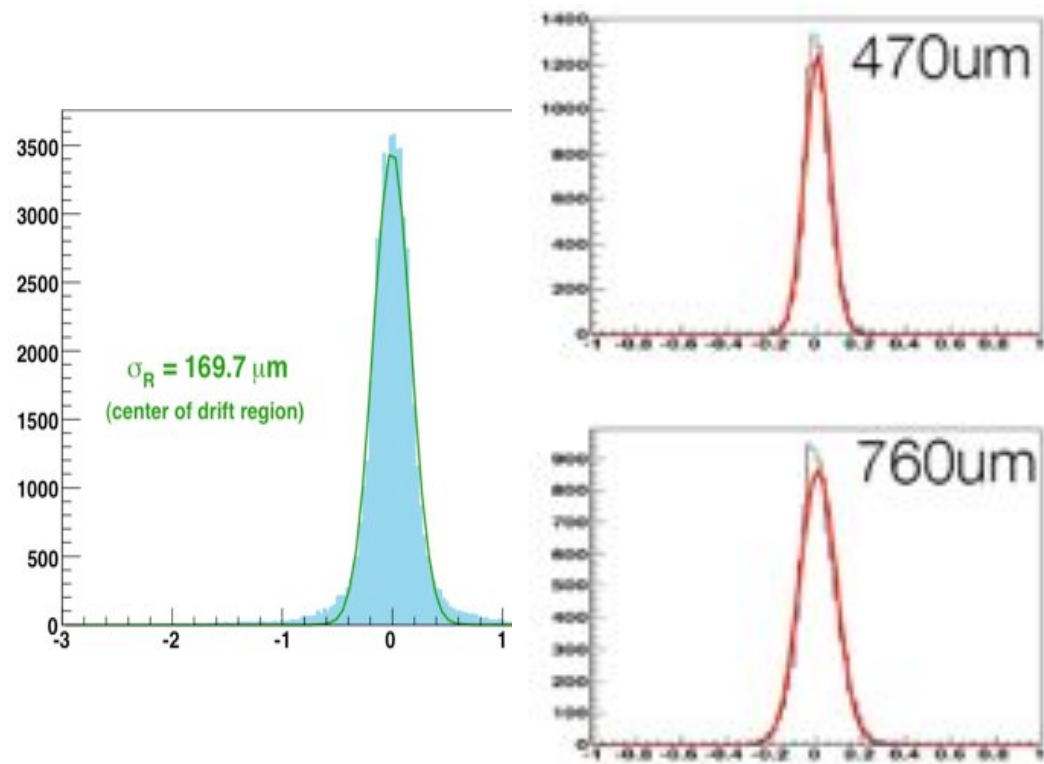
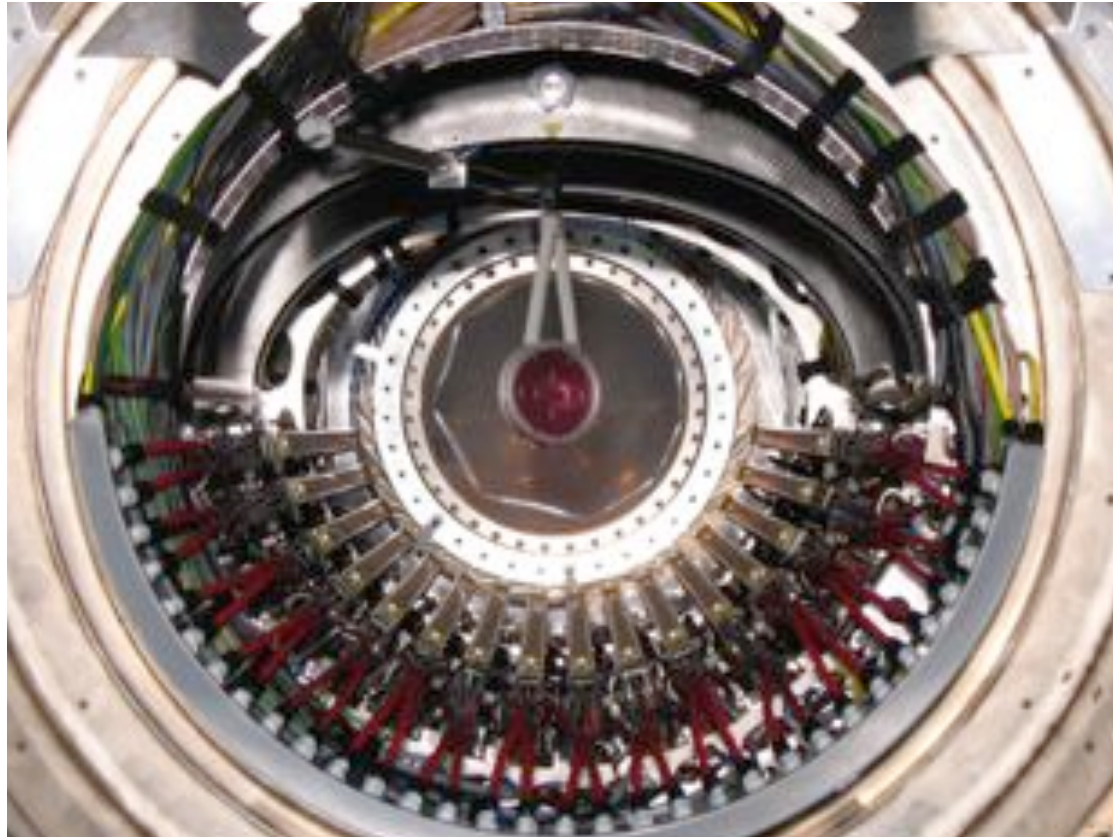
- 16 chambers radially aligned with 10° intervals
- 2 staggered arrays of drift cells
- 1 signal wire and 2 x 2 vernier cathode strips made of $15\ \mu\text{m}$ kapton foils and $0.45\ \mu\text{m}$ aluminum strips
- Chamber gas: He-C₂H₆ mixture
- Within one period, fine structure given by the Vernier circle



longitudinal coordinate (charge division + Vernier)

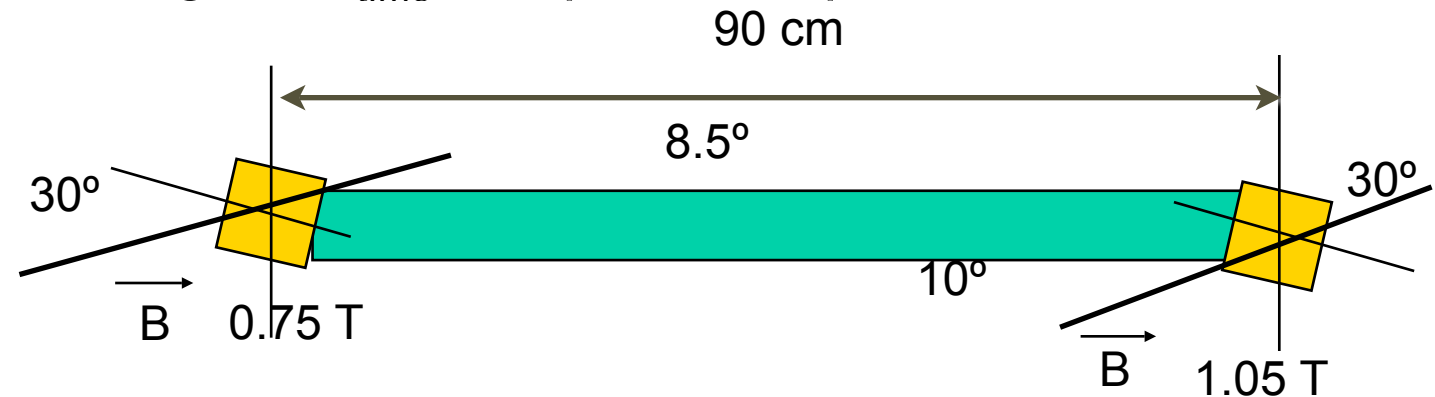


Drift chambers



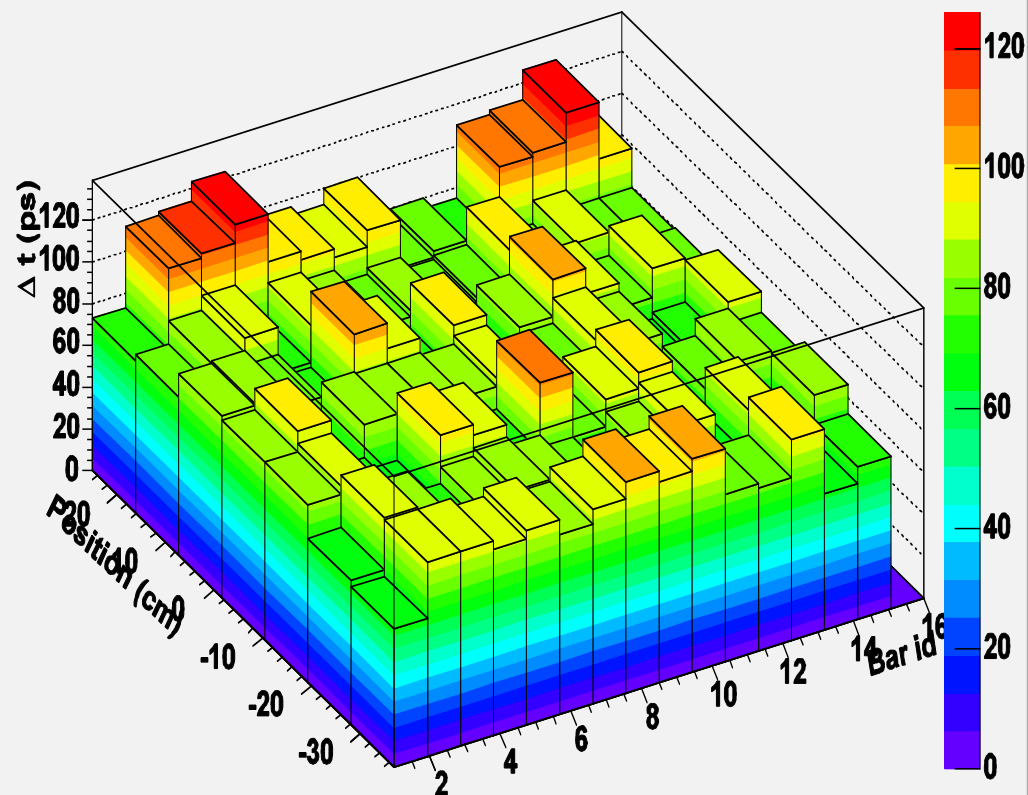
Timing Counter

- Must give excellent rejection
- **Two layers** of scintillators:
 - Outer** layer, read out by **PMTs**: timing measurement
 - Inner** layer, read out with **APDs** at 90°: z-trigger
- Obtained goal $\sigma_{\text{time}} \sim 40$ psec (100 ps FWHM)



TC with fibers exposed

Timing Resolution

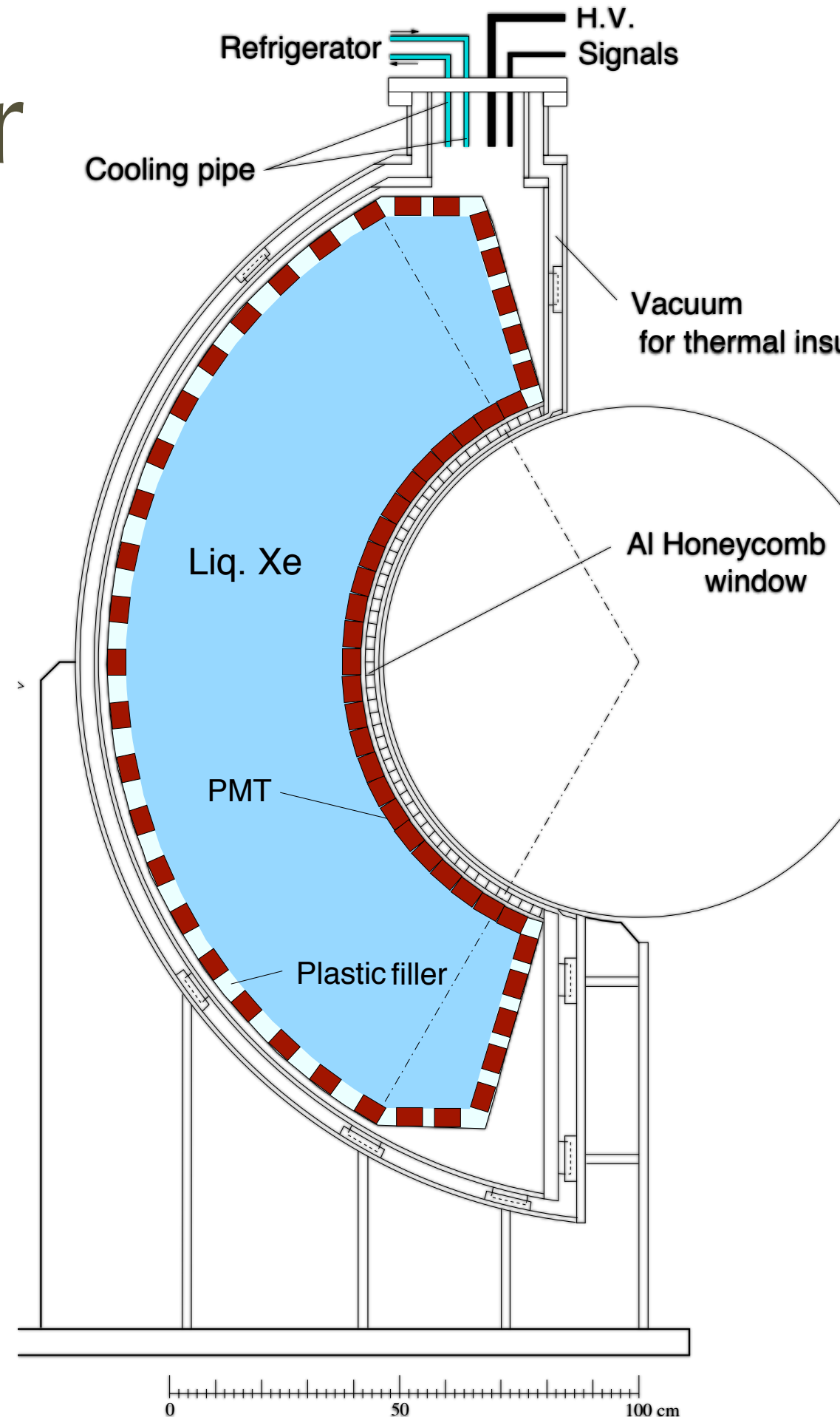


Exp. application (*)	Counter size (cm) (T x W x L)	Scintillator	PMT	λ_{em} (cm)	$\sigma_t(\text{meas})$	$\sigma_t(\text{exp})$
G.D. Agostini	3 x 15 x 100	NE114	XP2020	200	120	60
T. Tanimori	3 x 20 x 150	SCSN38	R1332	180	140	110
T. Sugitate	4 x 3.5 x 100	SCSN23	R1828	200	50	53
R.T. Gile	5 x 10 x 280	BC408	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	

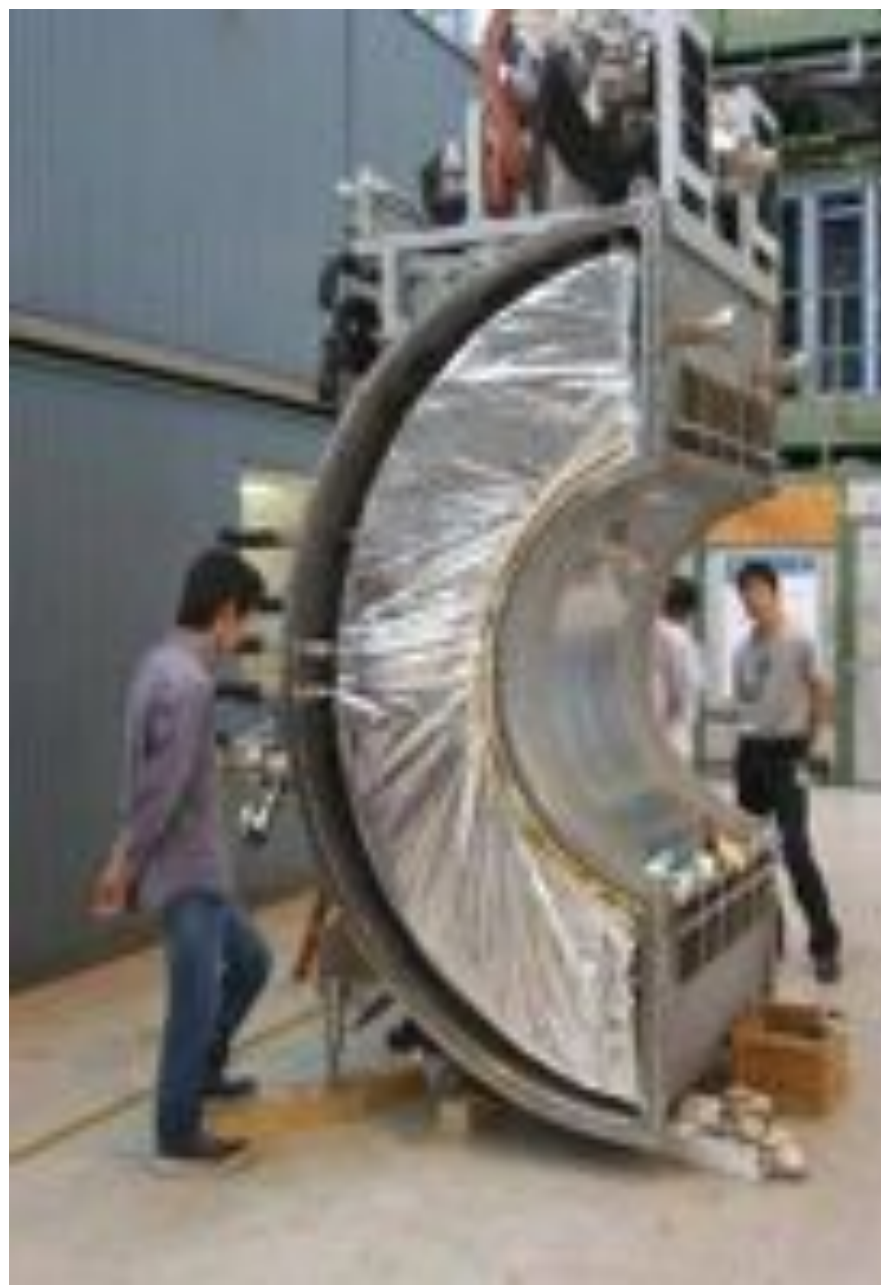
Best existing TC

The photon detector

- γ Energy, position, timing
- **Homogeneous 0.8 m^3** volume of liquid Xe
 - 10 % solid angle
 - $65 < r < 112 \text{ cm}$
 - $|\cos\theta| < 0.35 \quad |\phi| < 60^\circ$
- Only **scintillation light**
- Read by **848 PMT**
 - 2" photo-multiplier tubes
 - Maximum coverage FF (6.2 cm cell)
 - Immersed in liquid Xe
 - **Low temperature** (165 K)
 - **Quartz window** (178 nm)
- Thin entrance wall
- Singularly applied HV
- Waveform digitizing @2 GHz
 - Pileup rejection

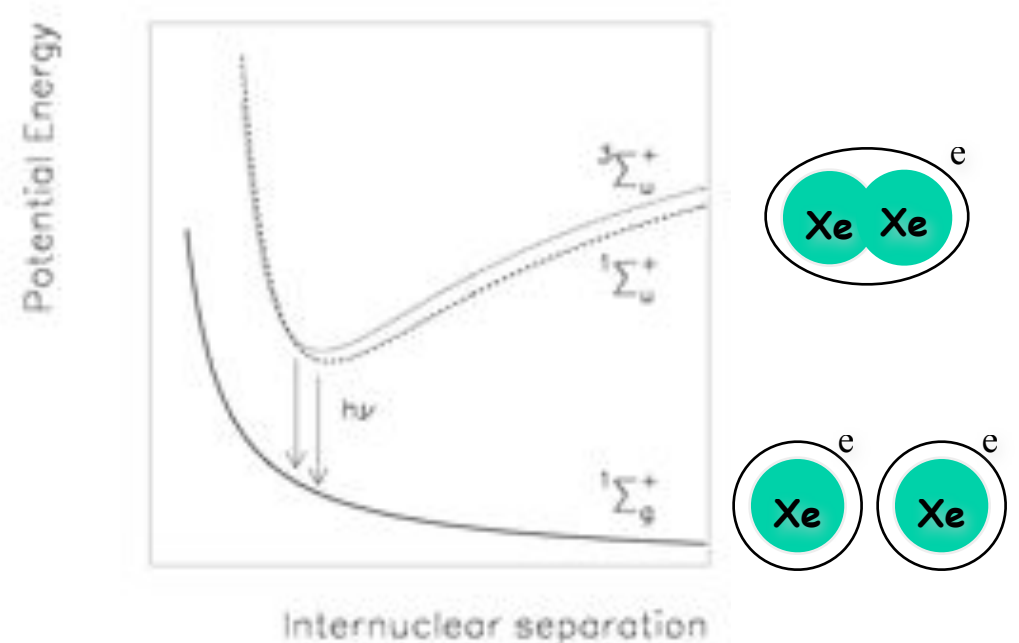
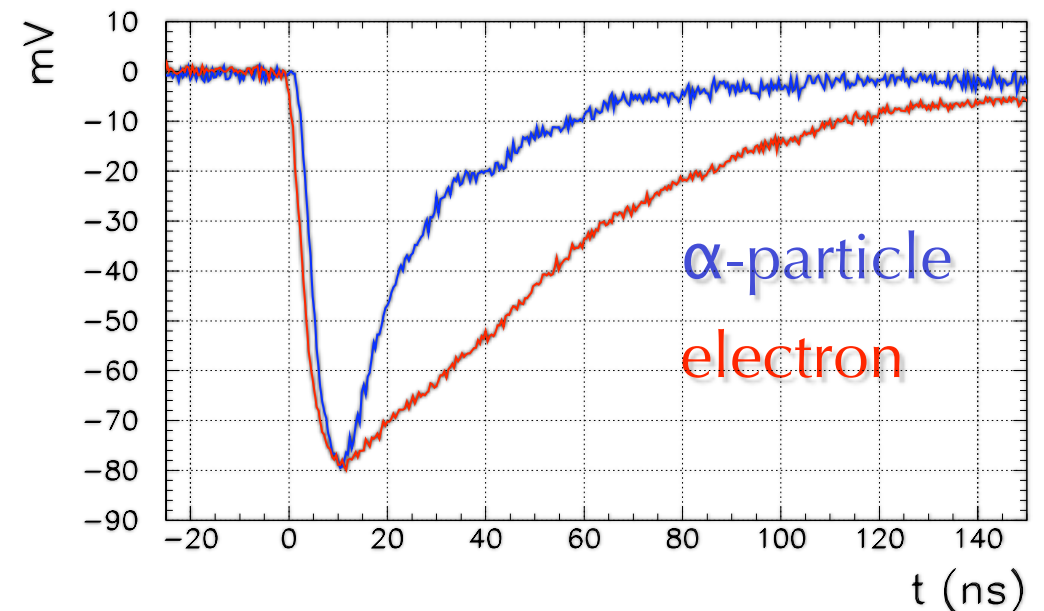


γ -detector construction



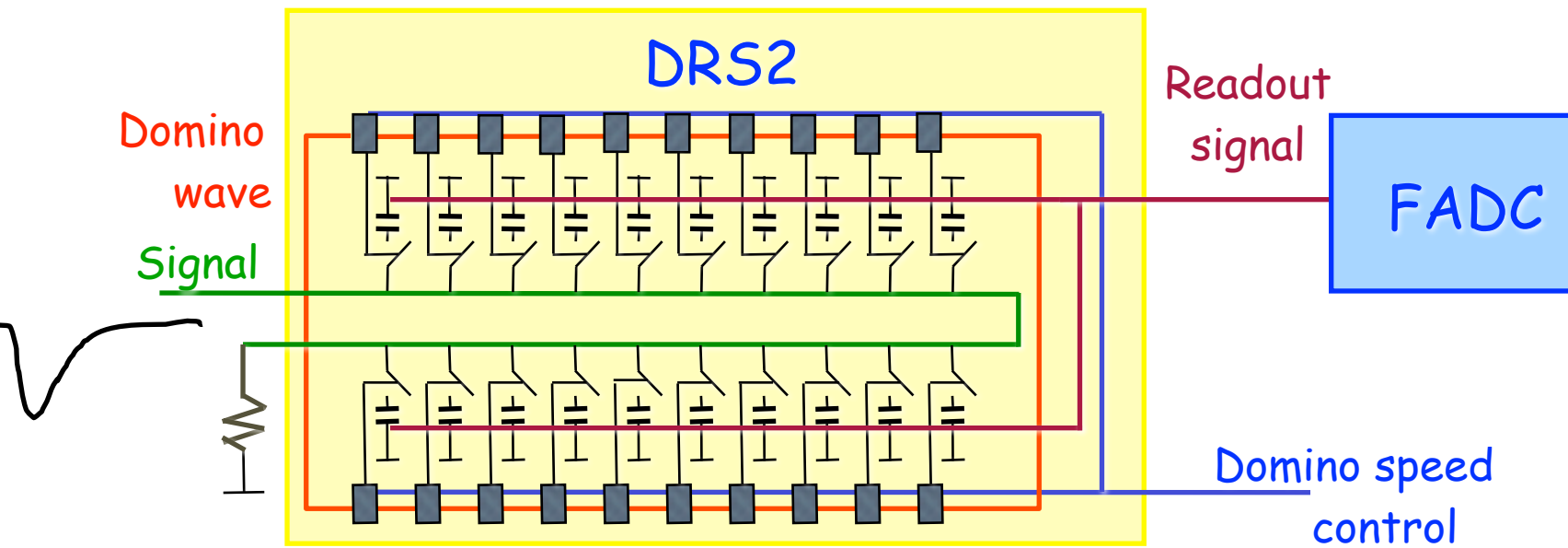
Xe properties

- **Liquid Xenon** was chosen because of its **unique** properties among radiation detection active media
- $Z=54$, $\rho=2.95 \text{ g/cm}^3$ ($X_0=2.7 \text{ cm}$), $R_M=4.1 \text{ cm}$
- High light yield (similar to NaI)
 - 40000 phe/MeV
- Fast response of the scintillation decay time
 - $\tau_{\text{singlet}} = 4.2 \text{ ns}$
 - $\tau_{\text{triplet}} = 22 \text{ ns}$
 - $\tau_{\text{recomb}} = 45 \text{ ns}$
- Particle ID is possible
 - $\alpha \sim \text{singlet} + \text{triplet}$, $\gamma \sim \text{recombination}$
- Large refractive index $n = 1.65$
- **No self-absorption** ($\lambda_{\text{Abs}} = \infty$)



Readout electronics

2 GHz waveform digitization for all channels



DRS chip (Domino Ring Sampler)

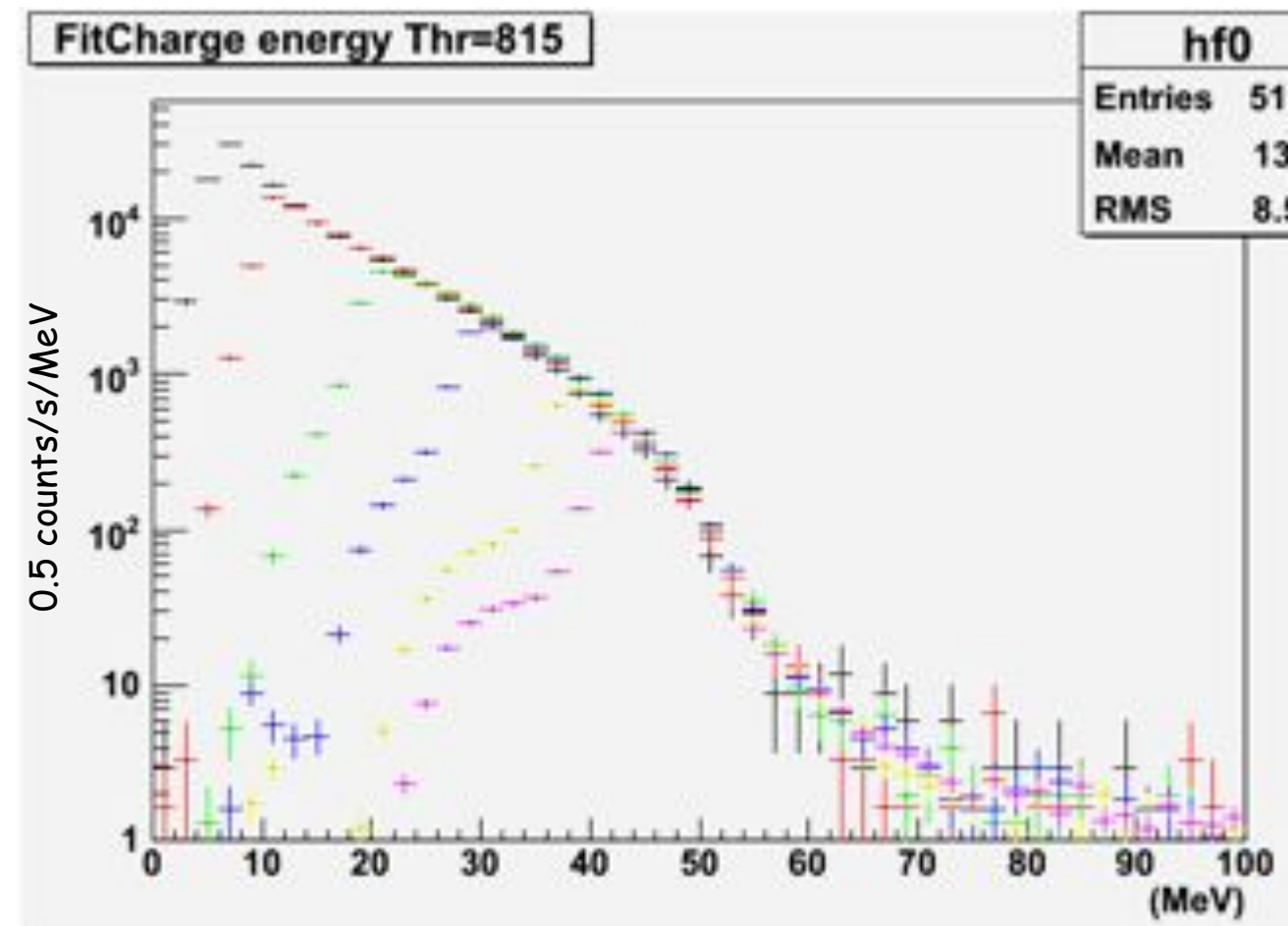
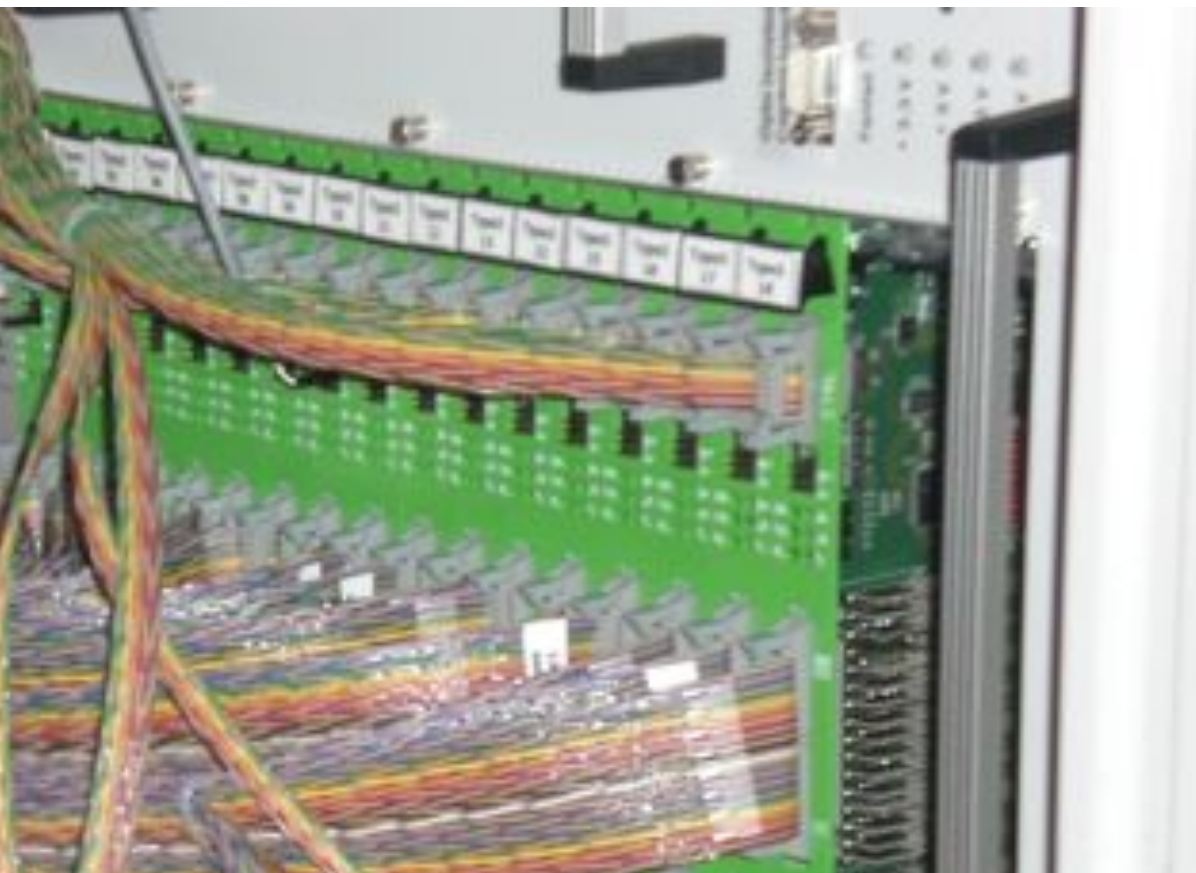
- Custom sampling chip designed at PSI
- 2 GHz sampling speed @ 40 ps timing resolution
- Sampling depth 1024 bins for 8 channels/chip
- Full waveform is a unvaluable handle to do pile-up rejection



Trigger

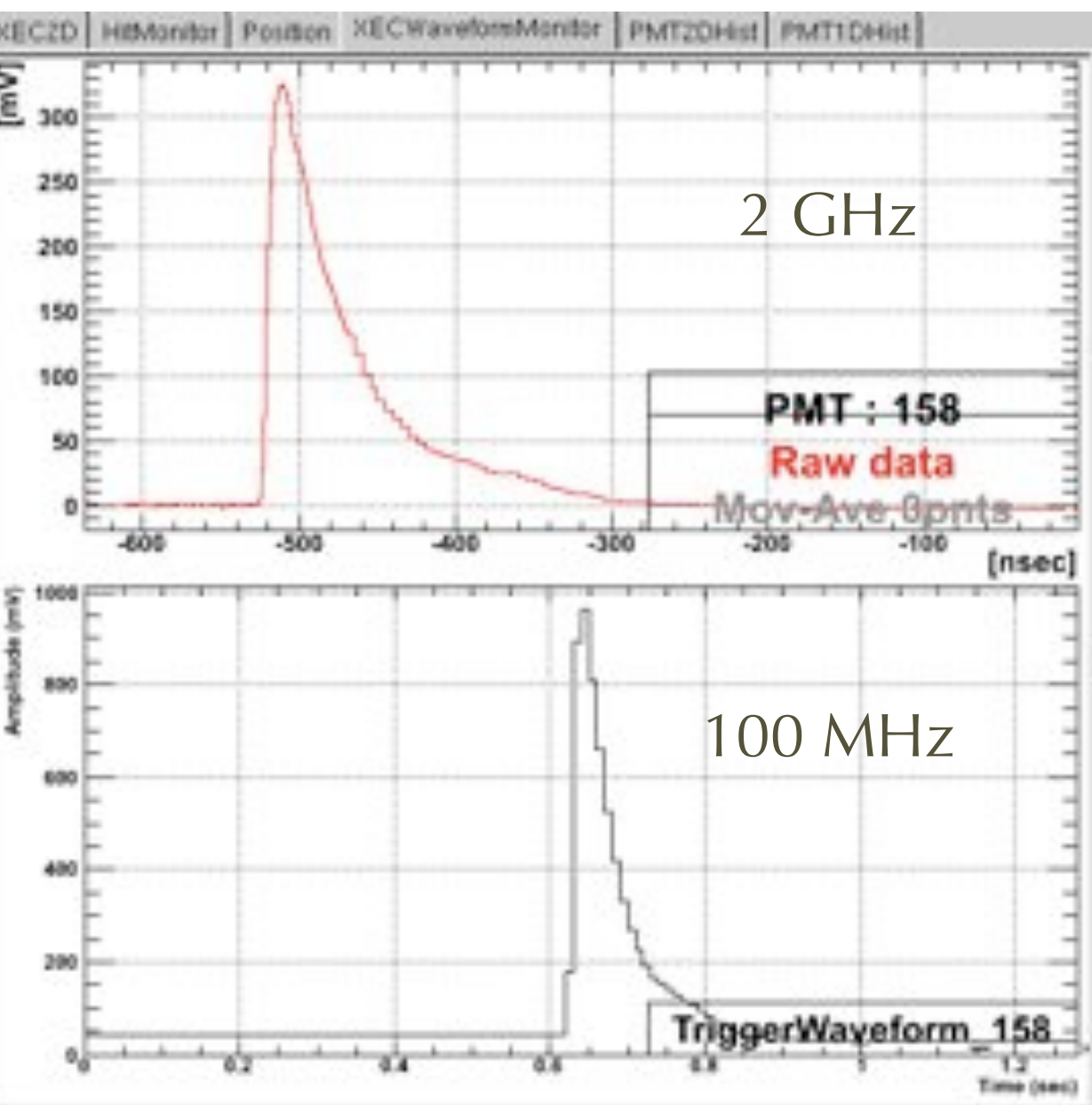
- 100 MHz **waveform digitizer** on VME boards that perform online pedestal subtraction
- Uses :
 - γ energy
 - e^+ - γ time coincidence
 - e^+ - γ collinearity
- Built on a FADC-FPGA architecture
- More performing algorithms could be implemented

- * Beam rate $\sim 3 \cdot 10^7 \text{ s}^{-1}$
- * Fast LXe energy sum $> 45 \text{ MeV}$ $2 \times 10^3 \text{ s}^{-1}$
 - * gamma interaction point (PMT charge)
 - * e^+ hit point in timing counter
- * time correlation $\gamma - e^+$ 100 s^{-1}
- * angular correlation $\gamma - e^+$ 10 s^{-1}



TRG + DAQ example

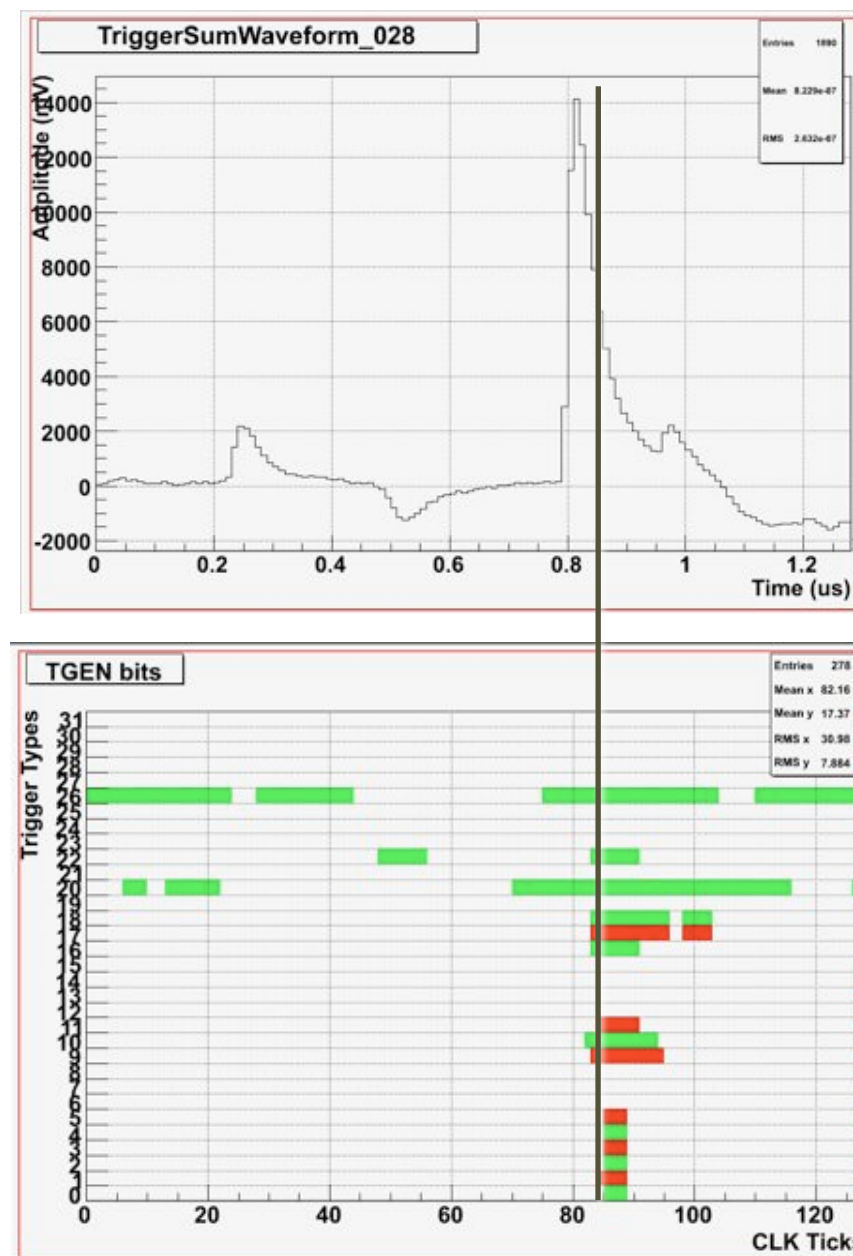
- For (almost) **all channels**, for each sub-detector we have **two** waveform **digitizers** with **complementary** characteristics



online
pedestal
subtraction
for LXe

info from all
subdetectors
is combined

Trigger!



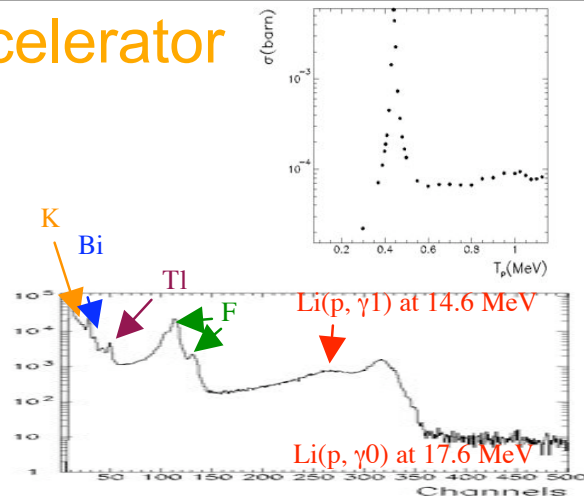
Calibrations

- It is understood that in such a complex detector a lot of **parameters** must be **constantly checked**
- We are prepared for **redundant calibration** and **monitoring**
- **Single** detector
 - PMT equalization for LXe and TIC
 - Inter-bar timing (TIC)
 - Energy scale
- **Multiple** detectors
 - relative timing



Calibrations

Proton Accelerator



Li(p,γ)Be

LiF target at
COBRA center

17.6 MeV γ

~daily calib.

also for initial
setup

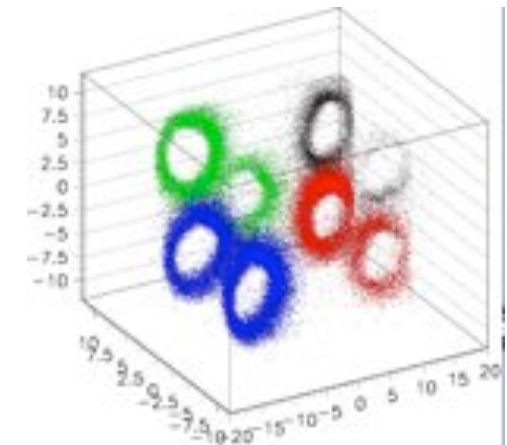
Alpha on wires



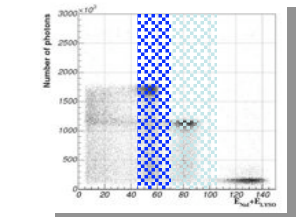
PMT QE & Att. L

Cold GXe

LXe



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

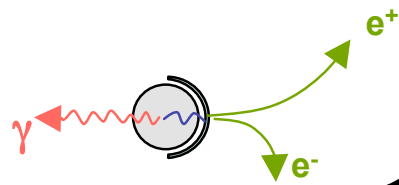


$\pi^- + p \rightarrow \pi^0 + n$

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

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

LH₂ target

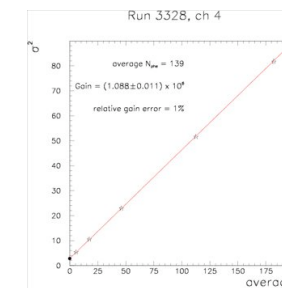


Xenon Calibration

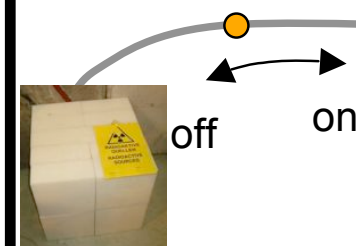
LED

PMT Gain

Higher V with
light att.

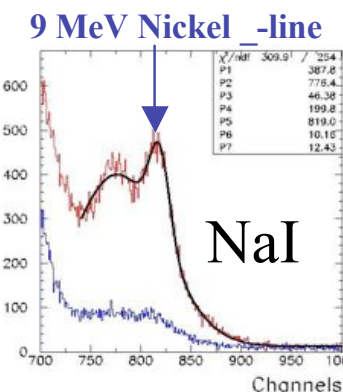


Nickel γ Generator

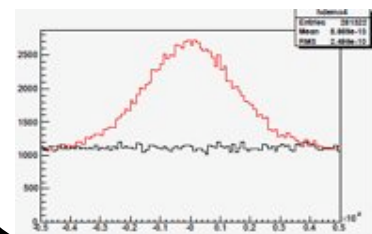
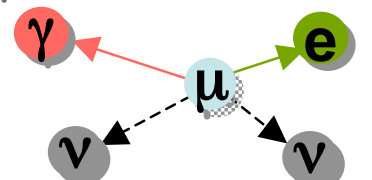


Illuminate Xe from
the back

Source (Cf)
transferred by
comp air $\rightarrow$ on/off



μ radiative decay



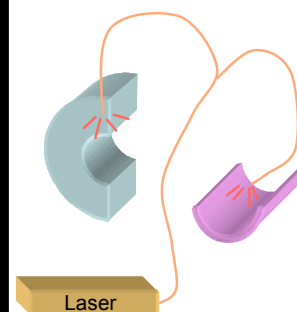
Lower beam intensity $< 10^7$

Is necessary to reduce pile-
ups

A few days ~ 1 week to get
enough statistics

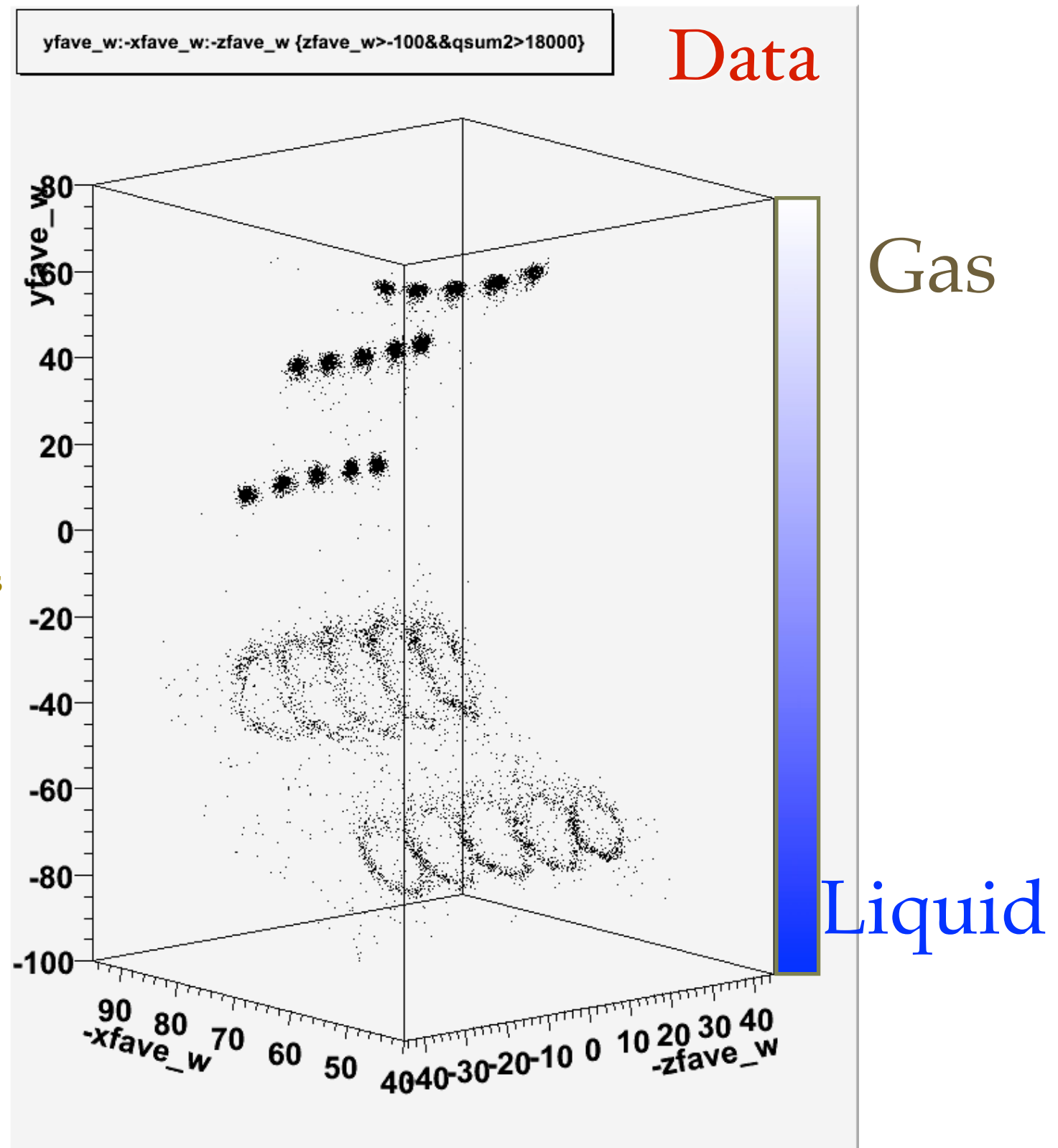
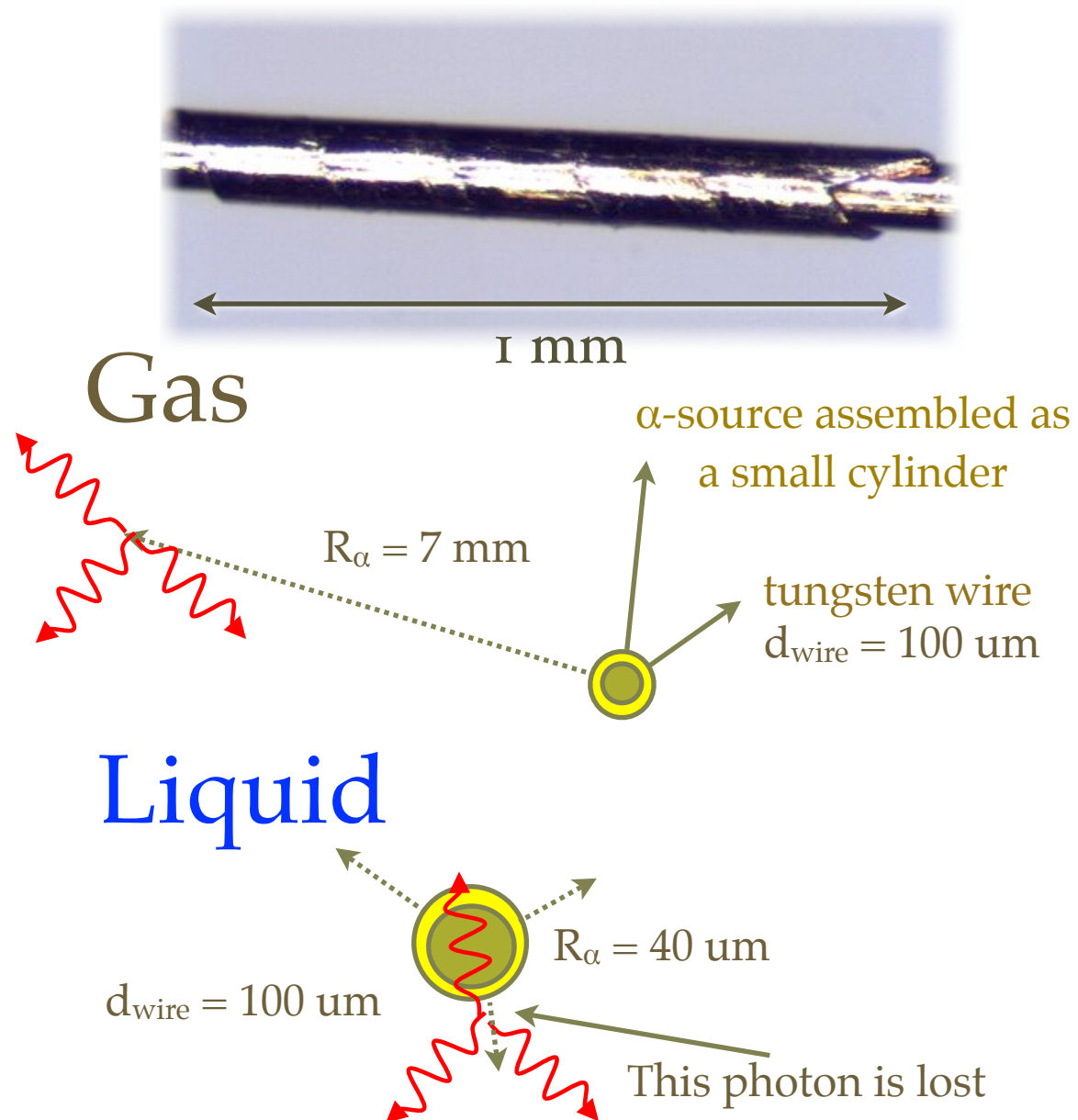
Laser

relative
timing calib.



Example: α -sources in Xe

- Specially developed Am sources:
 - 5 dot-sources on thin (100 μm) tungsten wires
 - SORAD Ltd. (Czech Republic)



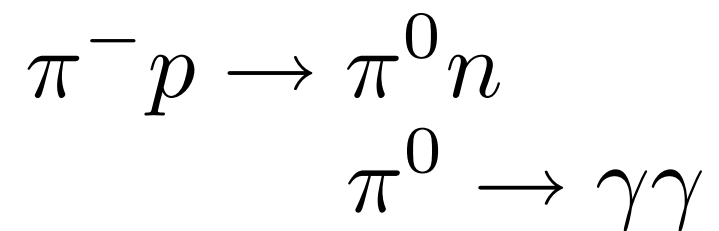
γ -energy scale calibration

- A reliable result depend on a constant **calibration** and **monitoring** of the apparatus
- We are prepared for **continuous** and **redundant** checks
 - different **energies**
 - different **frequency**

Process		Energy	Frequency
Charge exchange	$\pi^- p \rightarrow \pi^0 n$ $\pi^0 \rightarrow \gamma\gamma$	55, 83, 129 MeV	year - month
Proton accelerator	${}^7\text{Li}(p, \gamma_{17.6}){}^8\text{Be}$	14.8, 17.6 MeV	week
Nuclear reaction	${}^{58}\text{Ni}(n, \gamma_9){}^{59}\text{Ni}$	9 MeV	daily
Radioactive source	${}^{60}\text{Co}$, AmBe	1.1 -4.4 MeV	daily

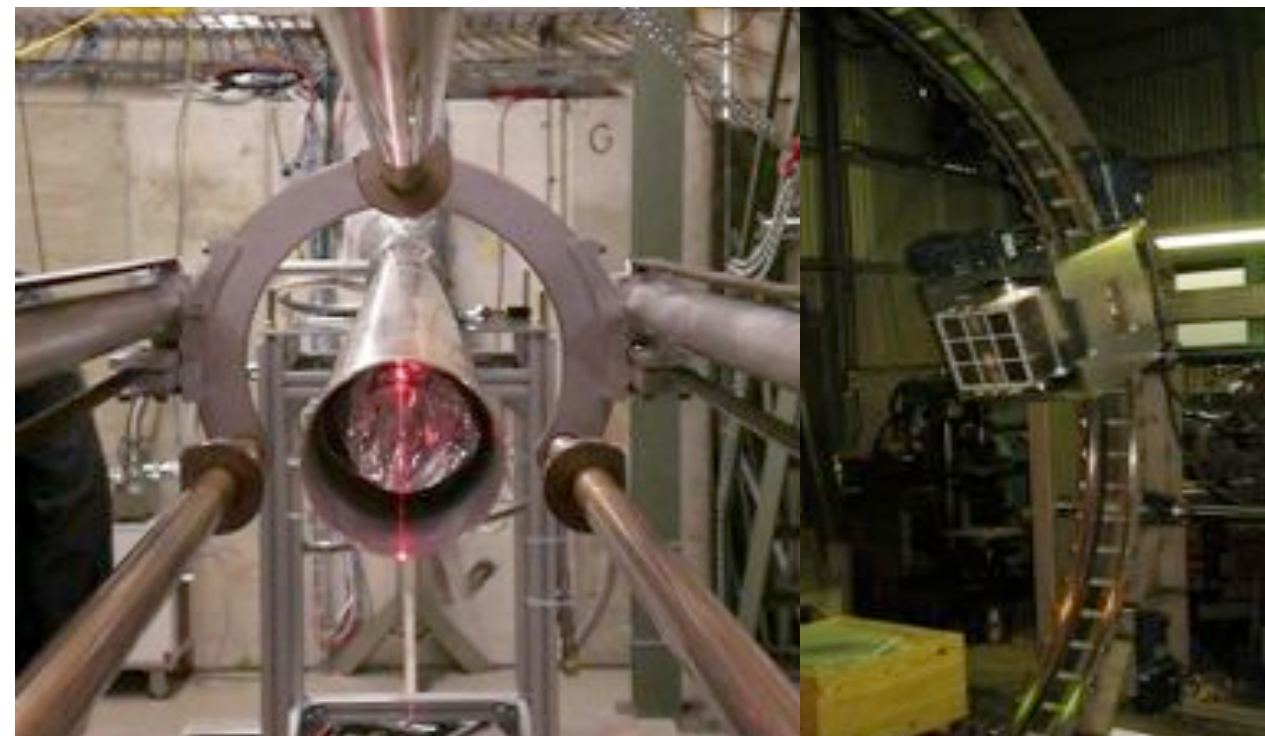
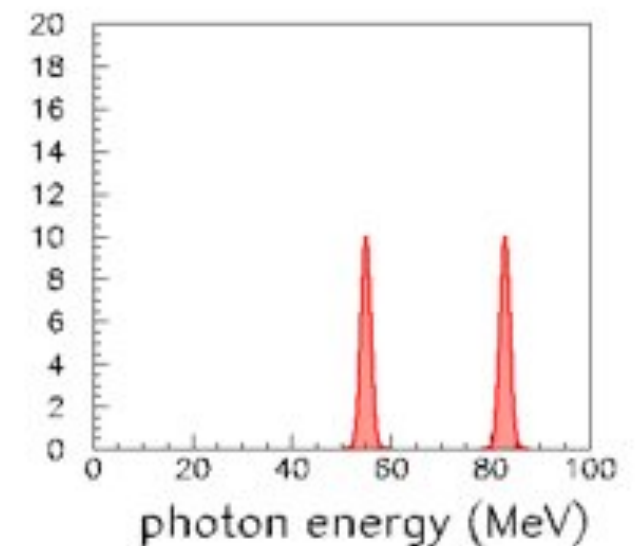


CEX measurement

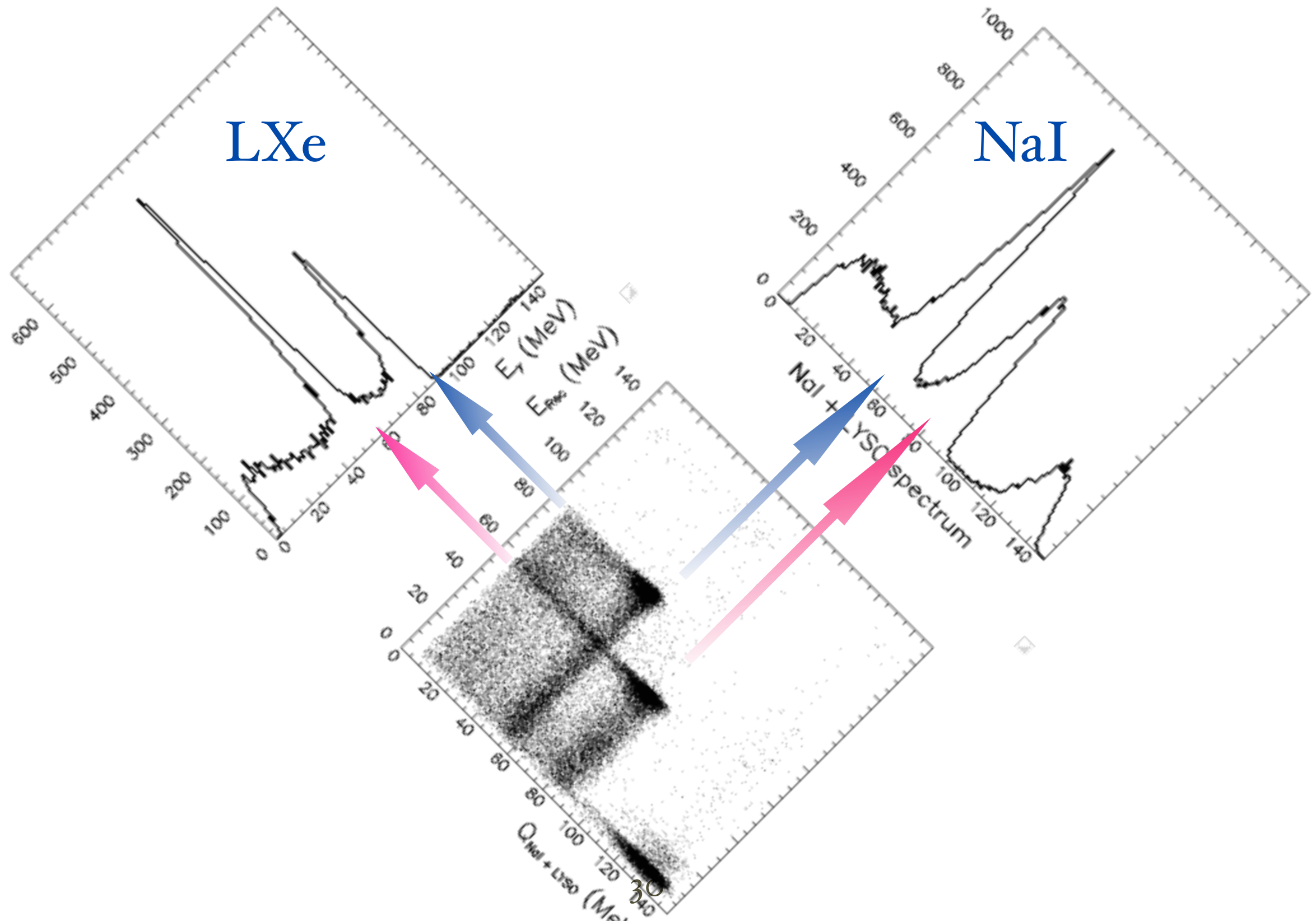


- The monochromatic spectrum in the pi-zero rest frame becomes flat in the Lab
- In the **back-to-back** configuration the energies are **55 MeV** and **83 MeV**
- Even a **modest collimation** guarantees a sufficient monochromaticity
- Liquid **hydrogen target** to maximize photon flux
- An “**opposite side detector**” is needed (NaI array)

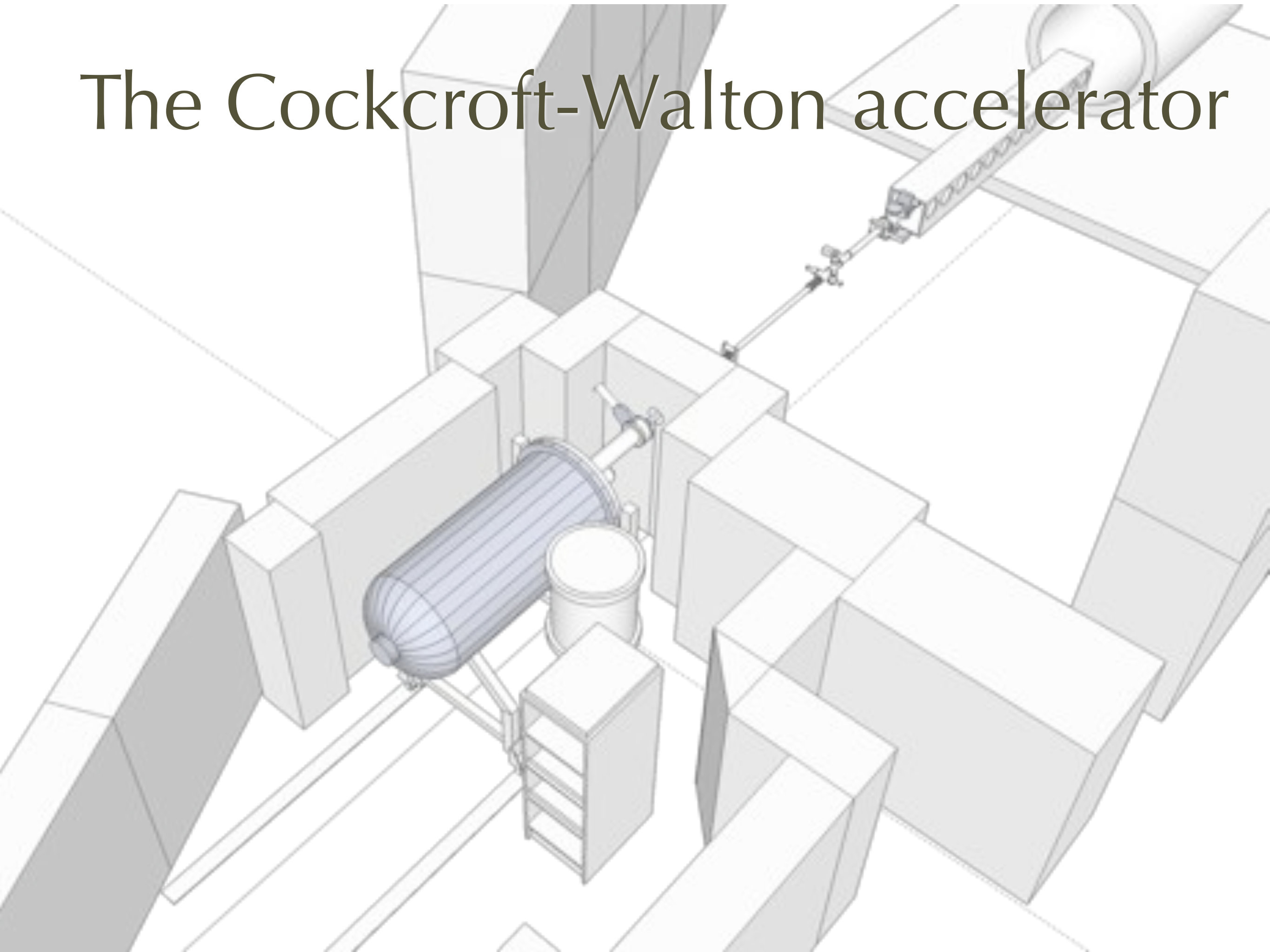
Lab Frame



- In the **back-to-back** raw spectrum we see the **correlation**
 - 83 MeV $\Leftrightarrow$ 55 MeV
 - The 129 MeV line is visible in the NaI because Xe is sensitive to neutrons (9 MeV)



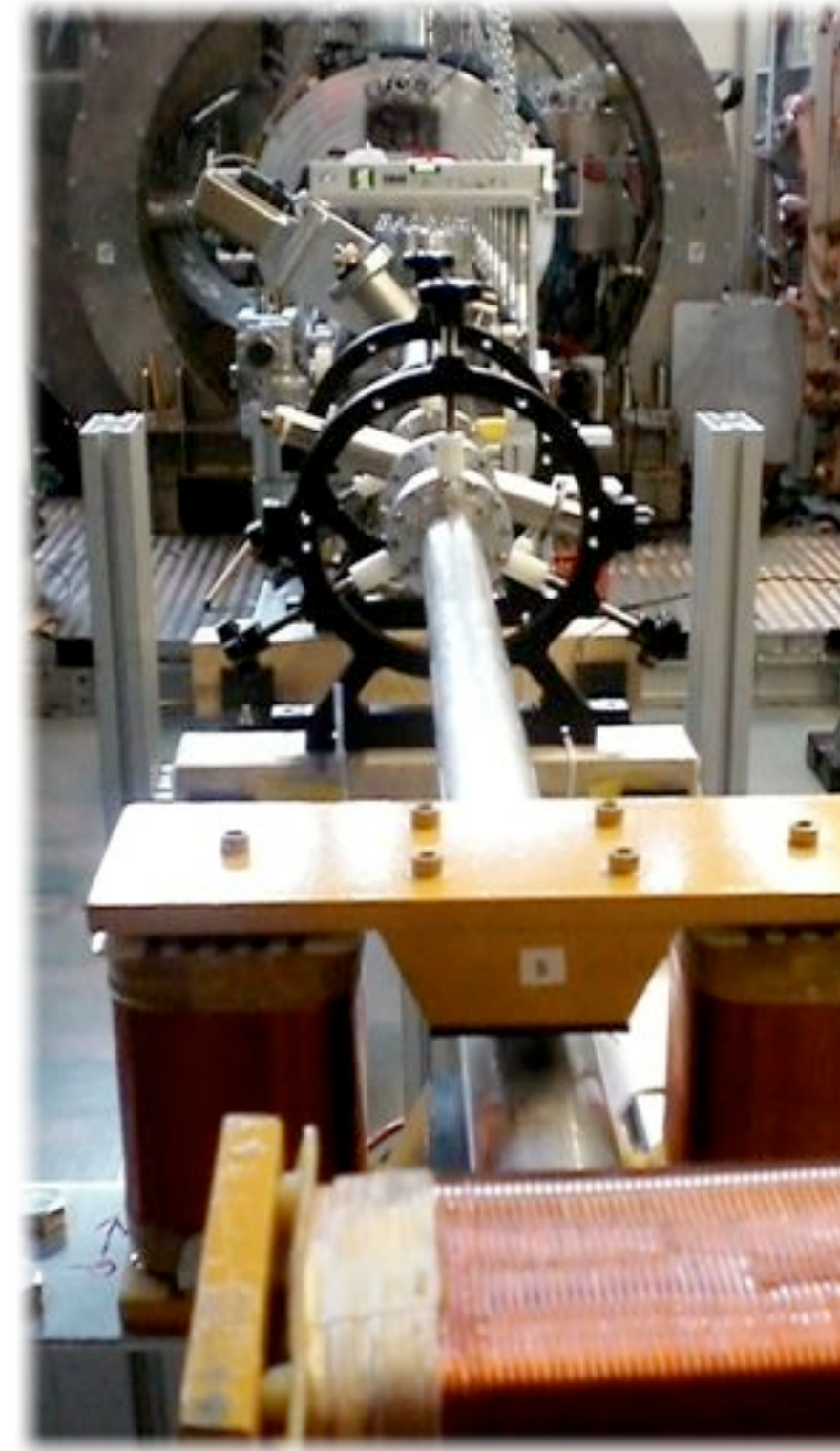
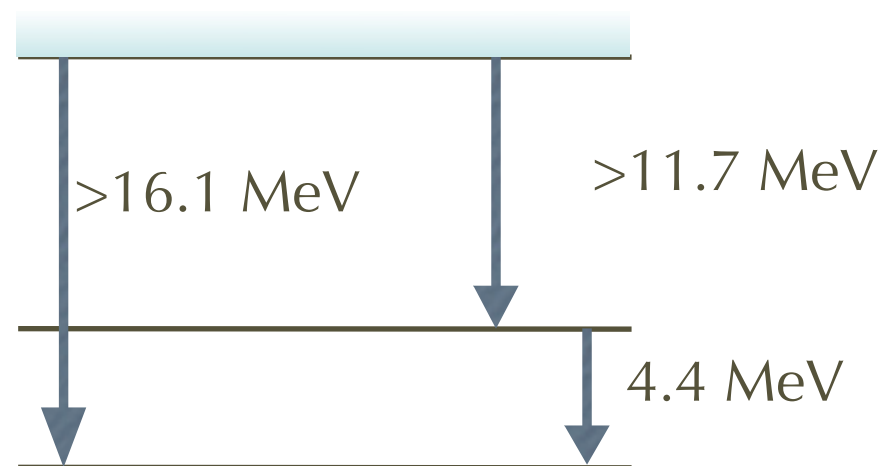
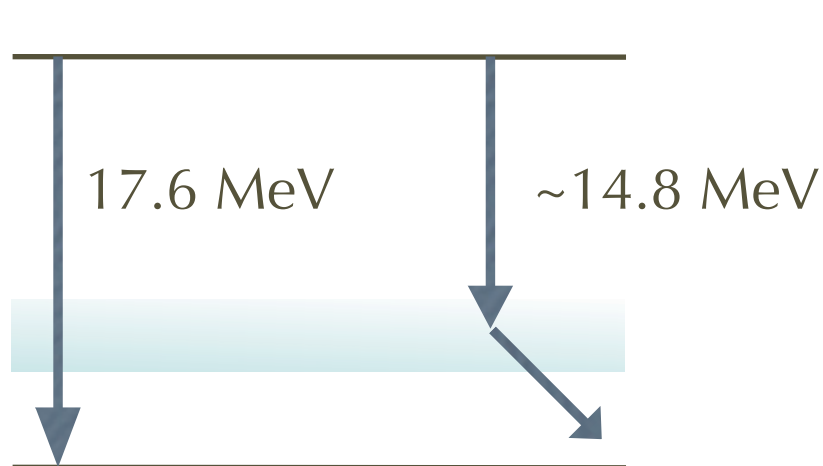
The Cockcroft-Walton accelerator



Reactions

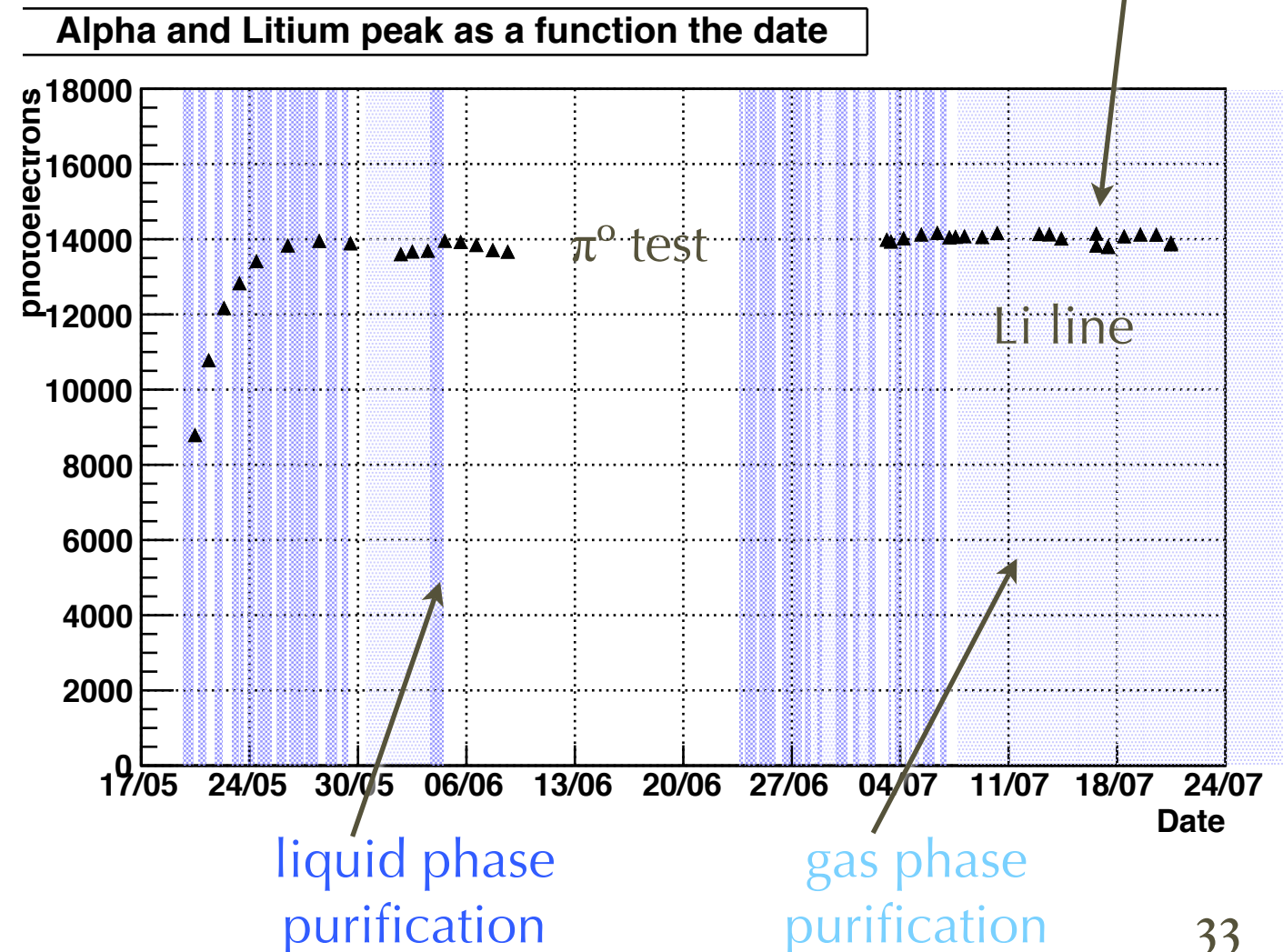
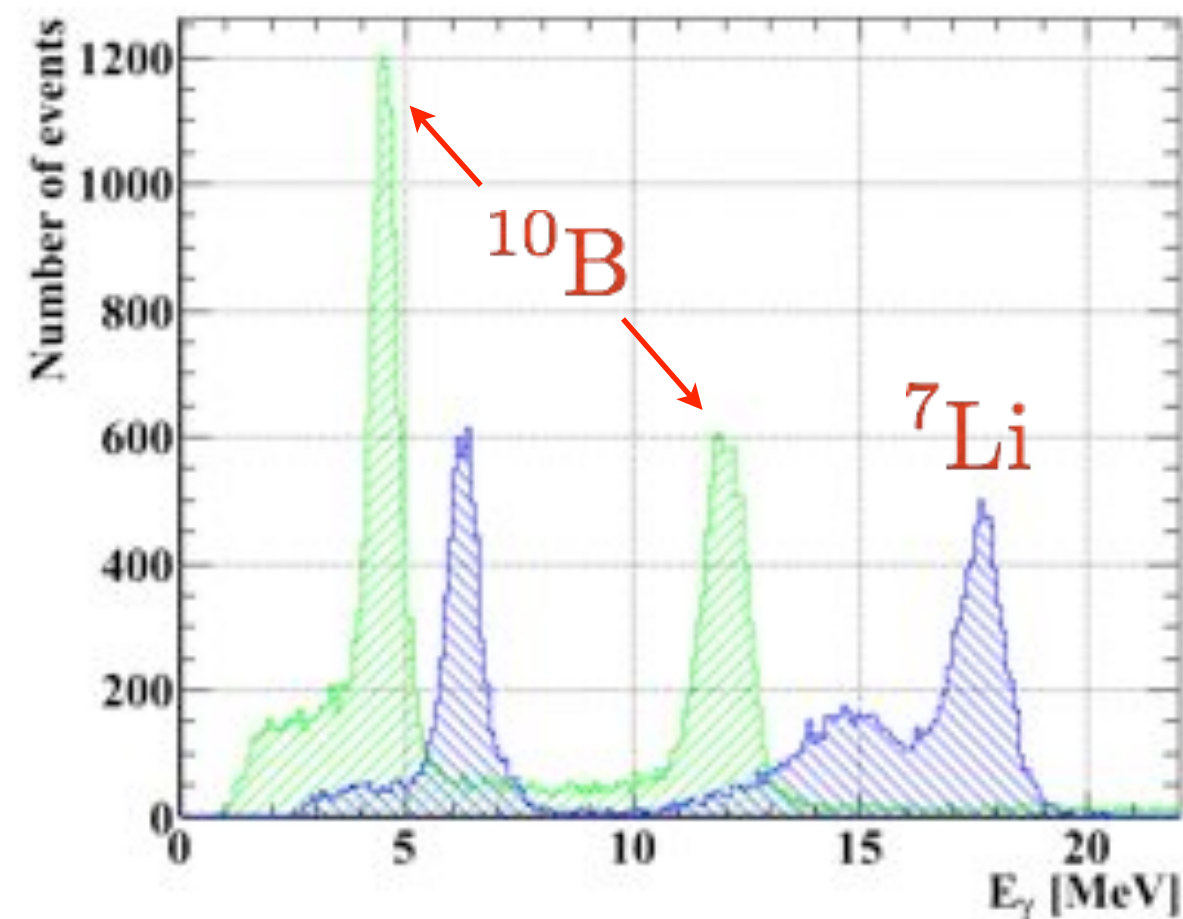
- The **Cockcroft-Walton** is an extremely powerful tool, installed for monitoring and calibrating *all* the **MEG** experiment
- Protons of up to 1 MeV on **Li** or **B**
 - Li: high rate, higher energy photon
 - B: two (lower energy) time-coincident photons

Reaction	Peak energy	σ peak	γ -lines
Li(p,γ)Be	440 keV	5 mb	(17.6, 14.6) MeV
B(p,γ)C	163 keV	$2 \cdot 10^{-1}$ mb	(4.4, 11.7, 16.1) MeV



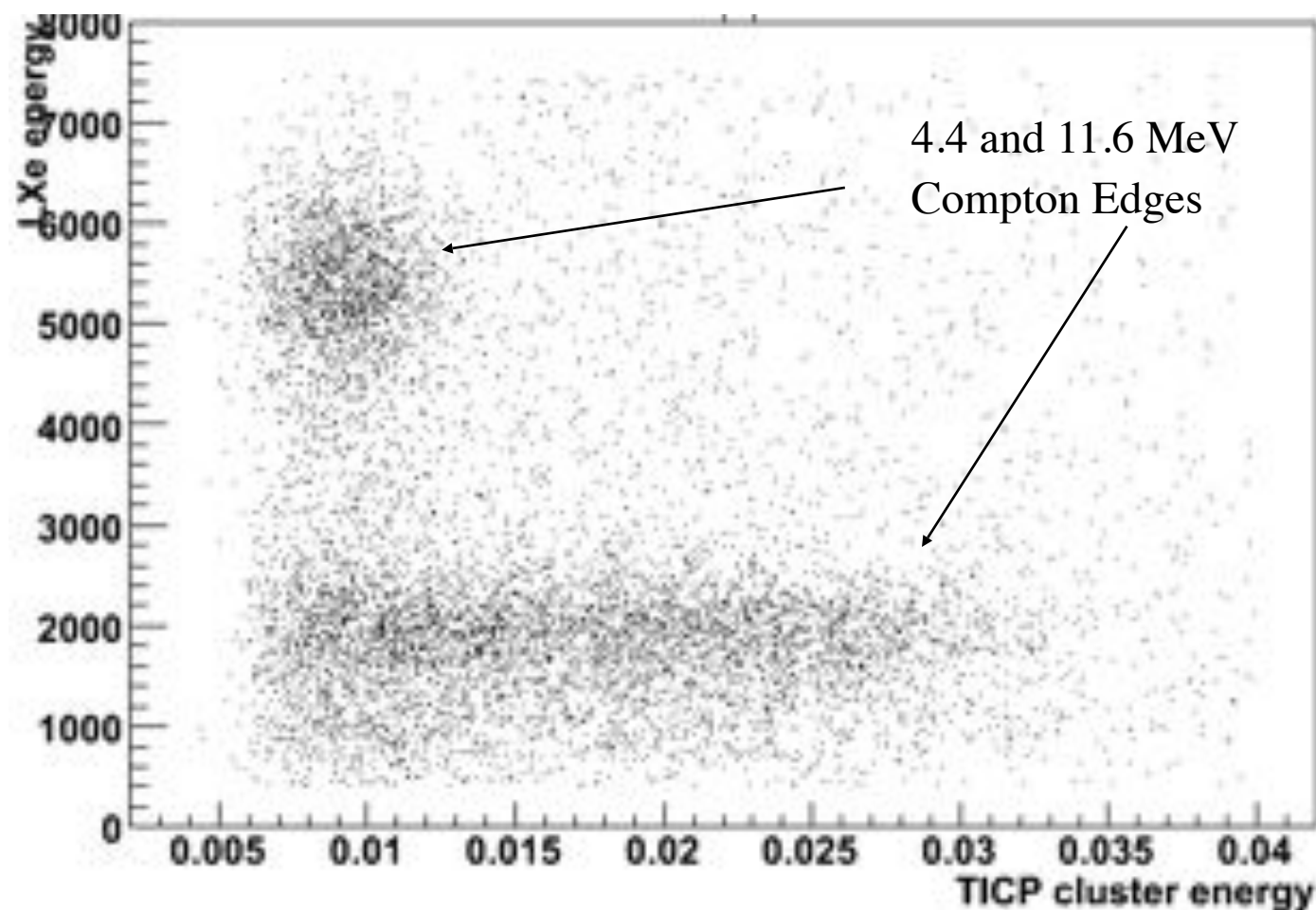
CW - daily calibration

- This calibration is performed **every other day**
 - Muon target moves away and a crystal target is inserted
- Hybrid target ($\text{Li}_2\text{B}_4\text{O}_7$)
 - Possibility to use the same target and select the line by changing proton energy

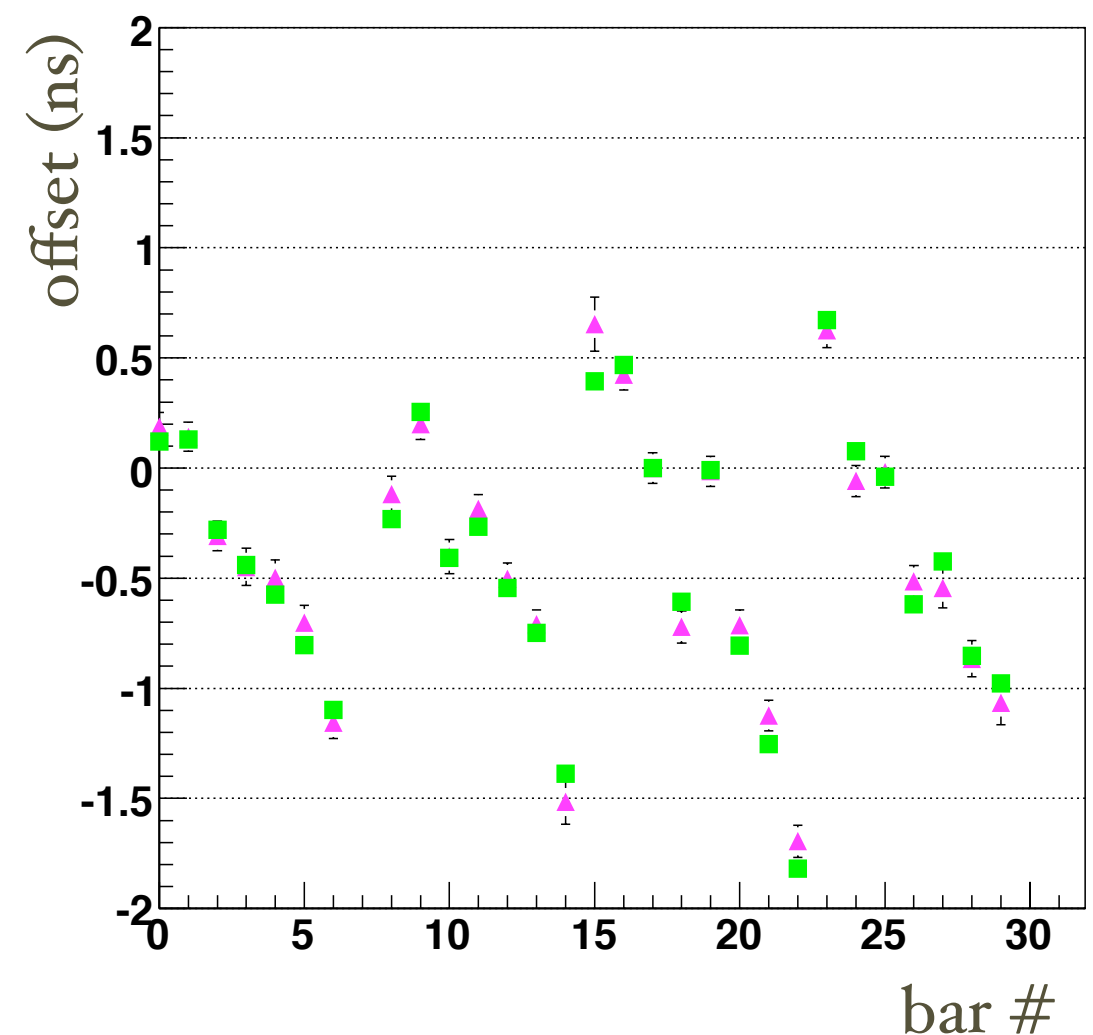


CW and timing counter

- The simultaneous emission of two photons in the Boron reaction is used to
 - determine relative timing between Xe and TIC
 - Inter-calibrate TIC bar



Graph



2008: First run of the experiment

(... after a short engineering run in 2007)

Time shedule

Winter - Spring

- detector dismantling
- improvement (after run 2007)
- re – installation

Spring - Summer

- LXe purification
- CW and π^0 calibration
- beam line setup

September – December

- **MEG** run
- short π^0 calibration

Running conditions

MEG run period

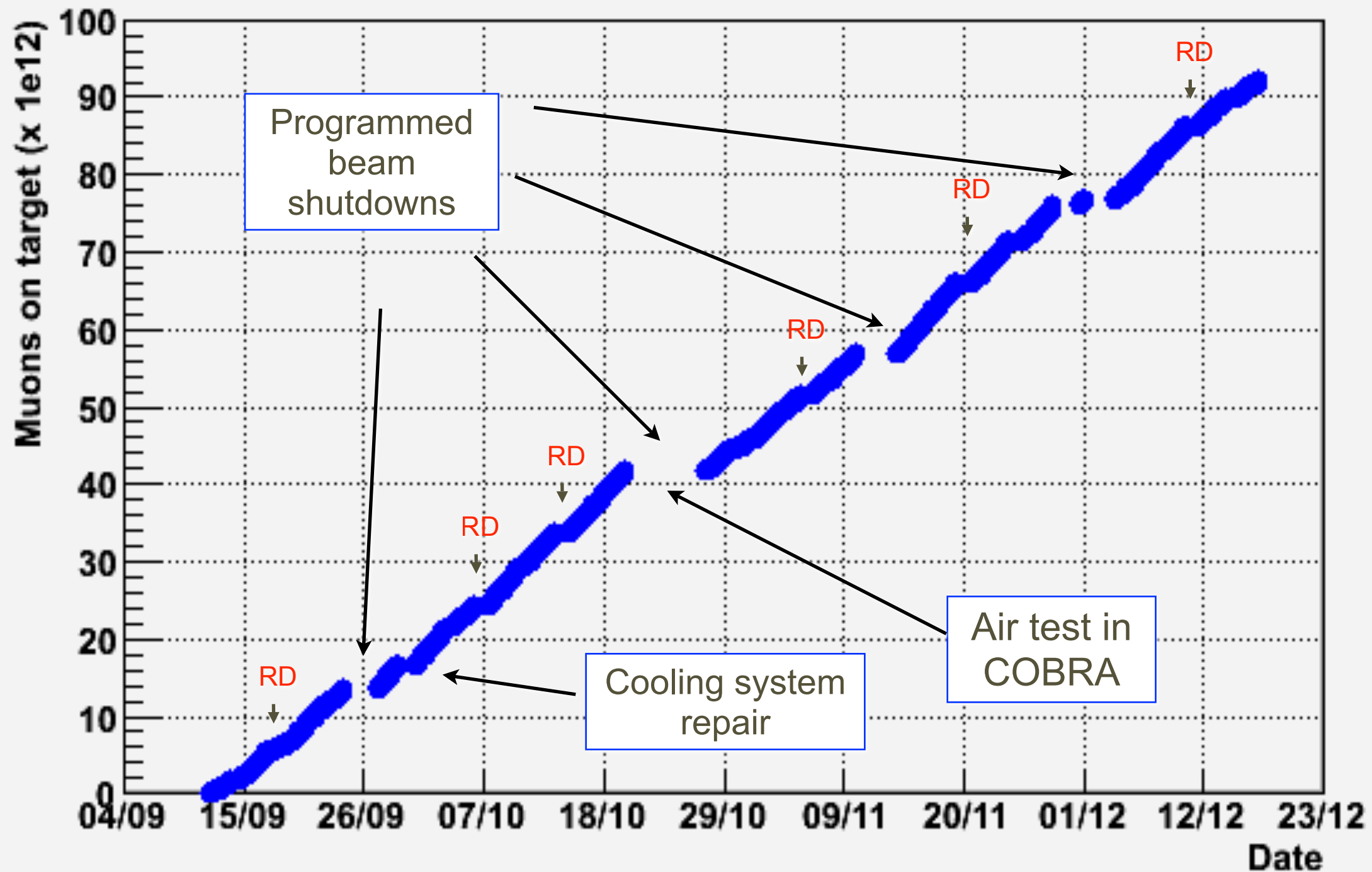
- Live time ~ **50% of total time**
- Total time ~ **7×10^6 s**
- μ stop rate: **3×10^7 μ /s**
- Trigger rate **6.5 ev/s ; 9 MB/s**

The missing 50% is composed of:

- **17%** DAQ dead time
- **14%** programmed beam shutdowns
- **7%** low intensity Radiative muon decay runs (**RMD**)
- **11%** calibrations
- **2%** unforeseen beam stops

Muons on target

We also took RMD data once/week at reduced beam intensity

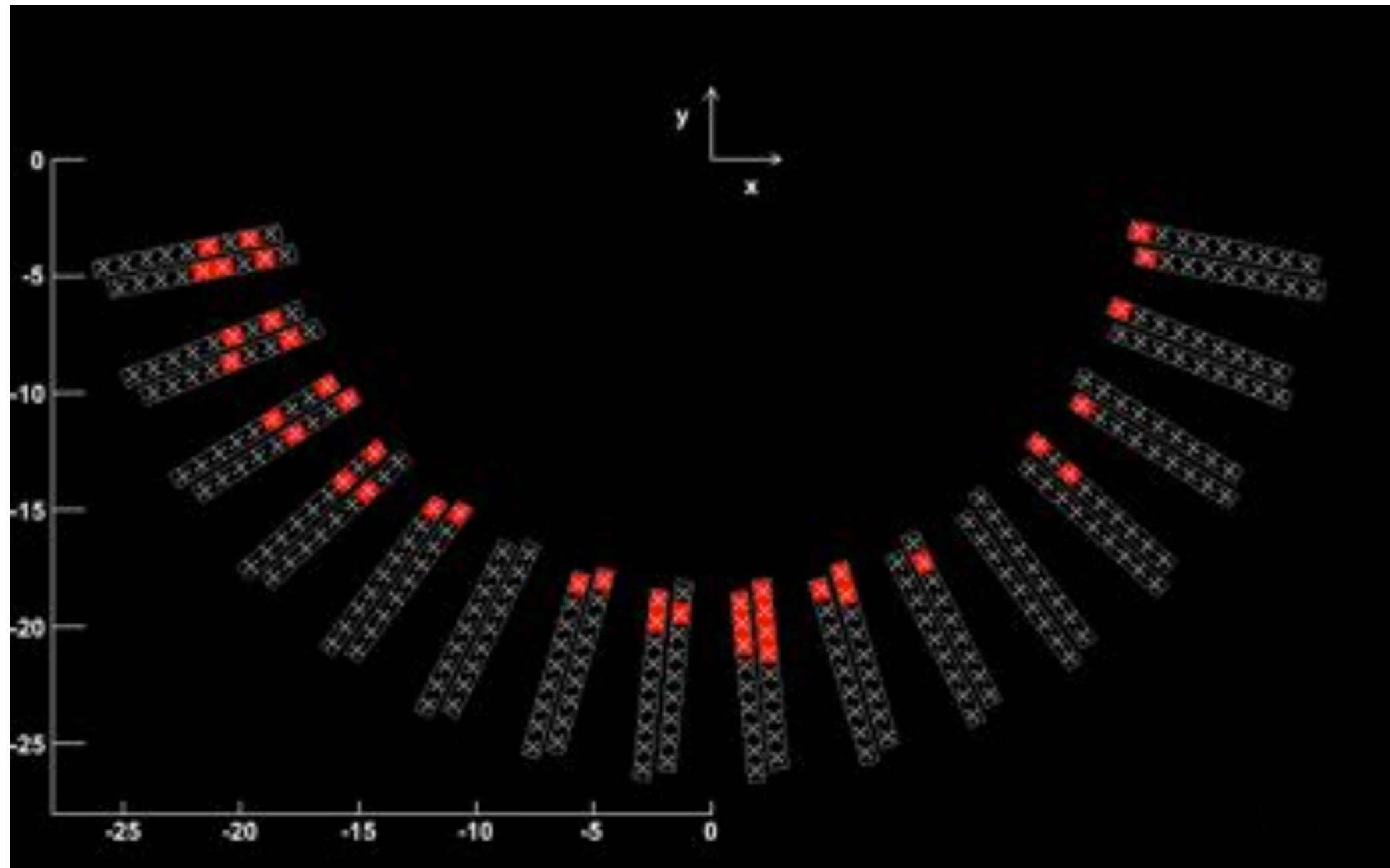


2008 run DCH instabilities

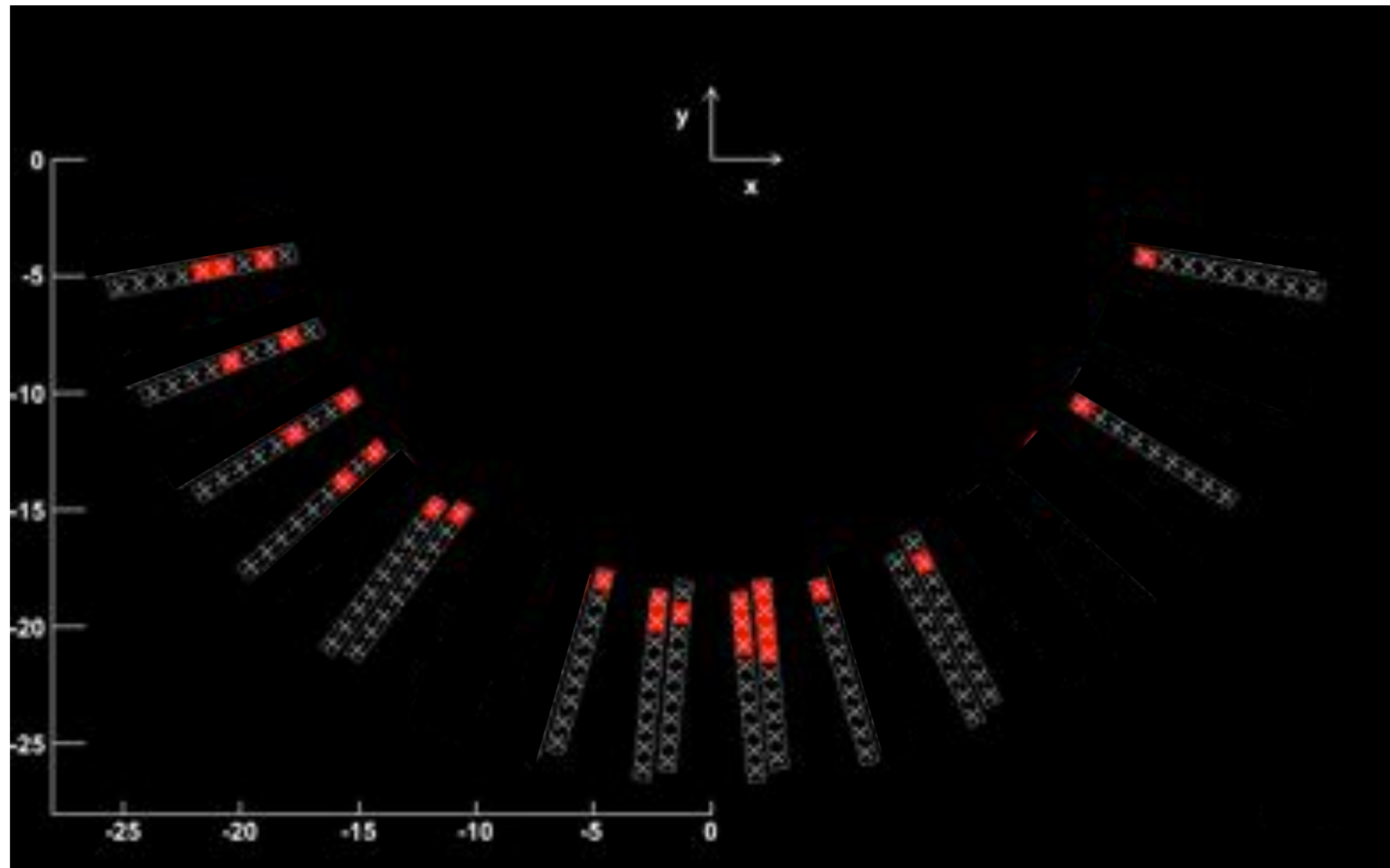
- DCH started to show frequent **HV trips** after 2–3 months of operation
 - an increasing number of DCH had to be operated with **reduced HV** settings
 - reduced **efficiency** and **resolution**
 - problem due to long-term exposure to helium
 - the DC instability **cancels out** in the evaluation of the branching ratio
 - normalized to Michel decays
- The DCH modules have **now** been **modified** and are **successfully** being operated in this 2009 run
- HV spark reproduced in lab



Sep. 2008

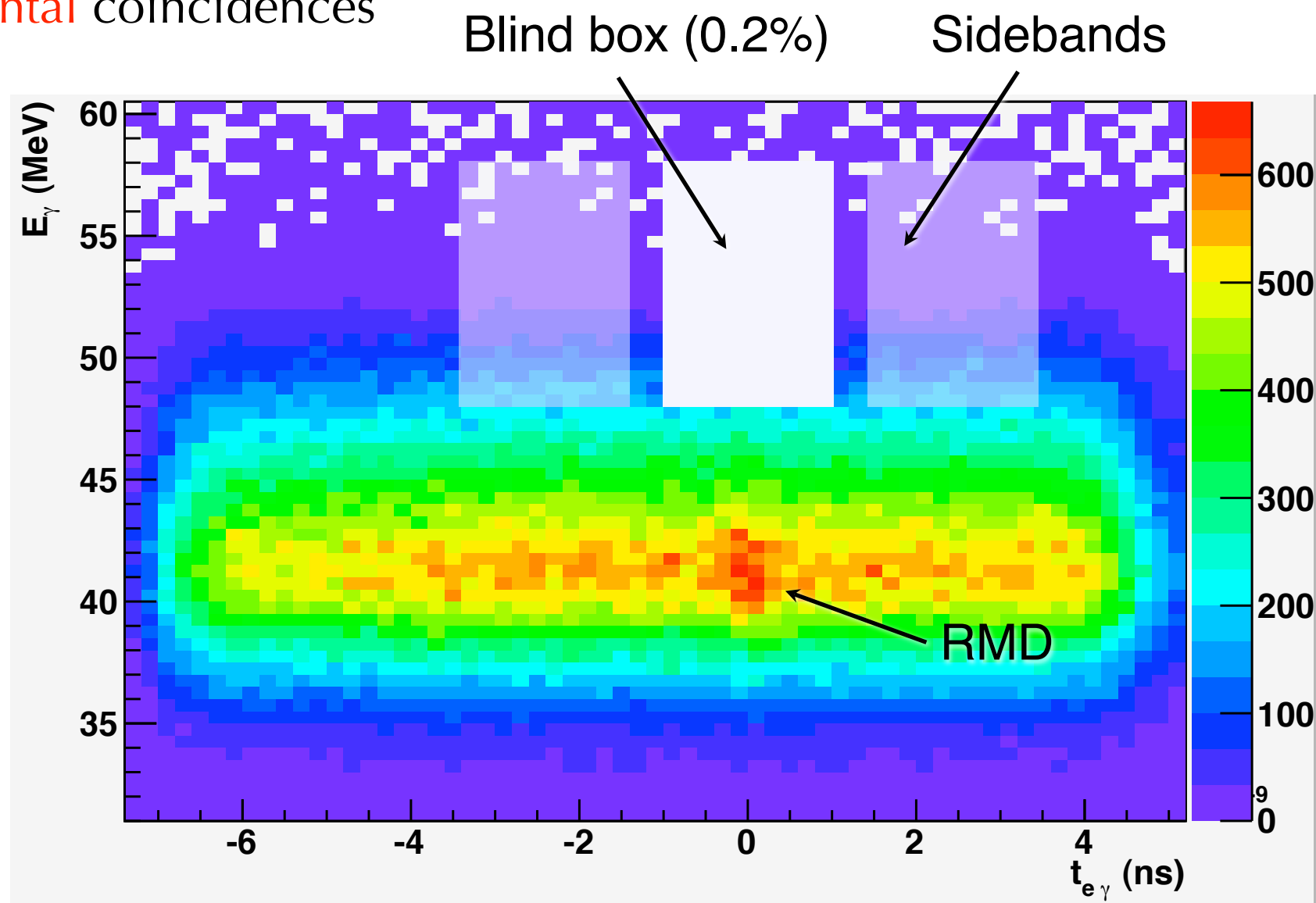


Dec. 2008



Analysis

- We decided to adopt a **blind-box likelihood analysis** strategy
 - Three independent blind likelihood analyses
- The blinding variables are E_γ and $t_{e\gamma}$
- Use of the **sidebands** justified by the fact that our **main background** comes from **accidental** coincidences

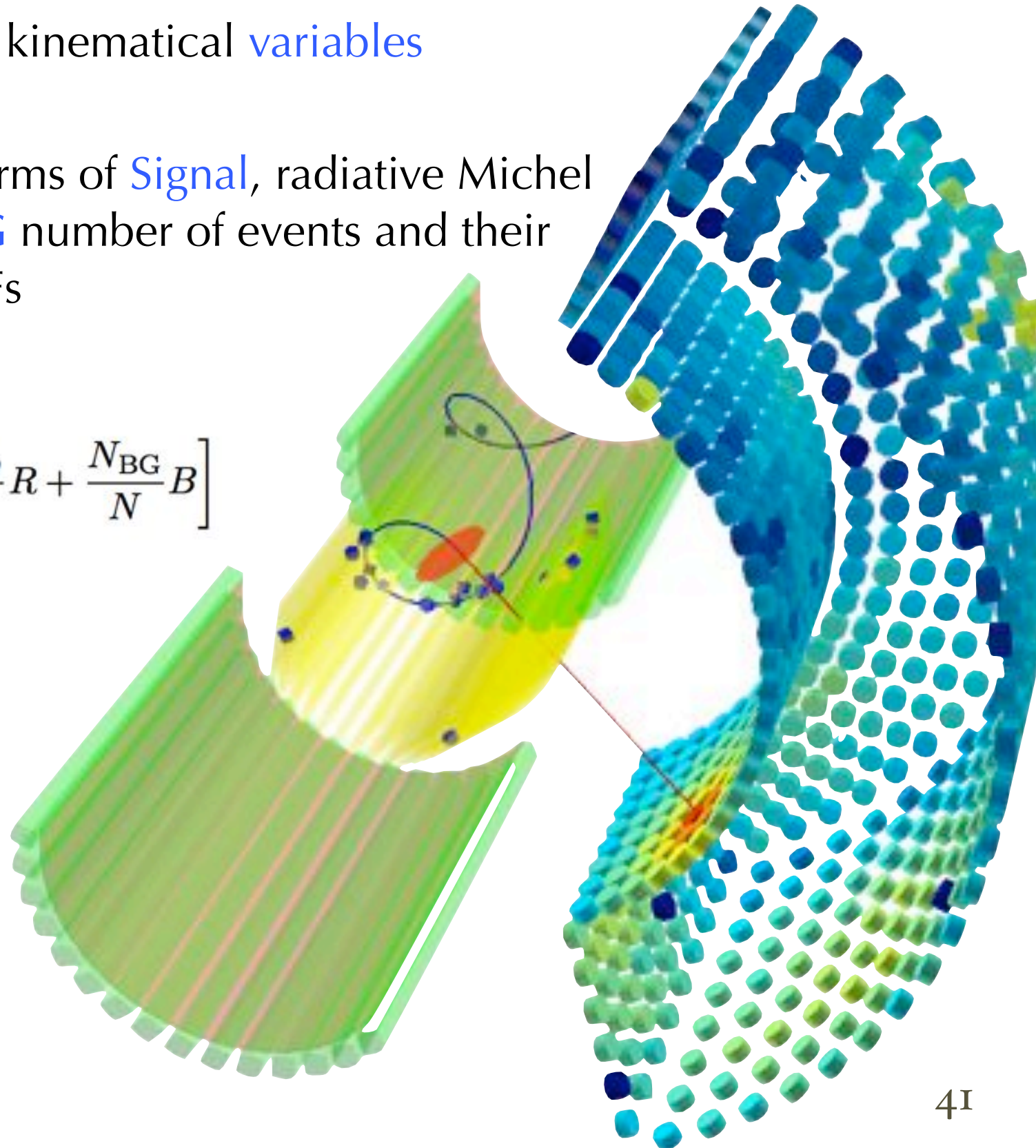


Analysis principle

- A $\mu \rightarrow e \gamma$ event is described by 5 kinematical variables
 - $E_e, E_\gamma, (\Delta\theta, \Delta\phi), t_{e\gamma}$
- Likelihood function is built in terms of Signal, radiative Michel decay RMD and background BG number of events and their probability density function PDFs

$$\mathcal{L}(N_{\text{sig}}, N_{\text{RMD}}, N_{\text{BG}})$$
$$= \frac{N^{N_{\text{obs}}} \exp^{-N}}{N_{\text{obs}}!} \prod_{i=1}^{N_{\text{obs}}} \left[\frac{N_{\text{sig}}}{N} S + \frac{N_{\text{RMD}}}{N} R + \frac{N_{\text{BG}}}{N} B \right]$$

- PDFs taken from
 - data
 - MC tuned on data



Probability Density Functions

- SIGNAL

E_γ : from full signal MC (or from fit to endpoint)
 E_e : 3-gaussian fit on data
 $\theta_{e\gamma}$: combination of e and gamma angular resolution from data
 $t_{e\gamma}$: single gaussian from MEG trigger Radiative Decay (no cut on E_g)

- RADIATIVE

$E_e, E_\gamma, \theta_{e\gamma}$: 3D histo PDF from toy MC that smears and weighs Kuno-Okada distribution taking into account resolution and acceptance
 $t_{e\gamma}$: single gaussian with same resolution as signal

- ACCIDENTAL

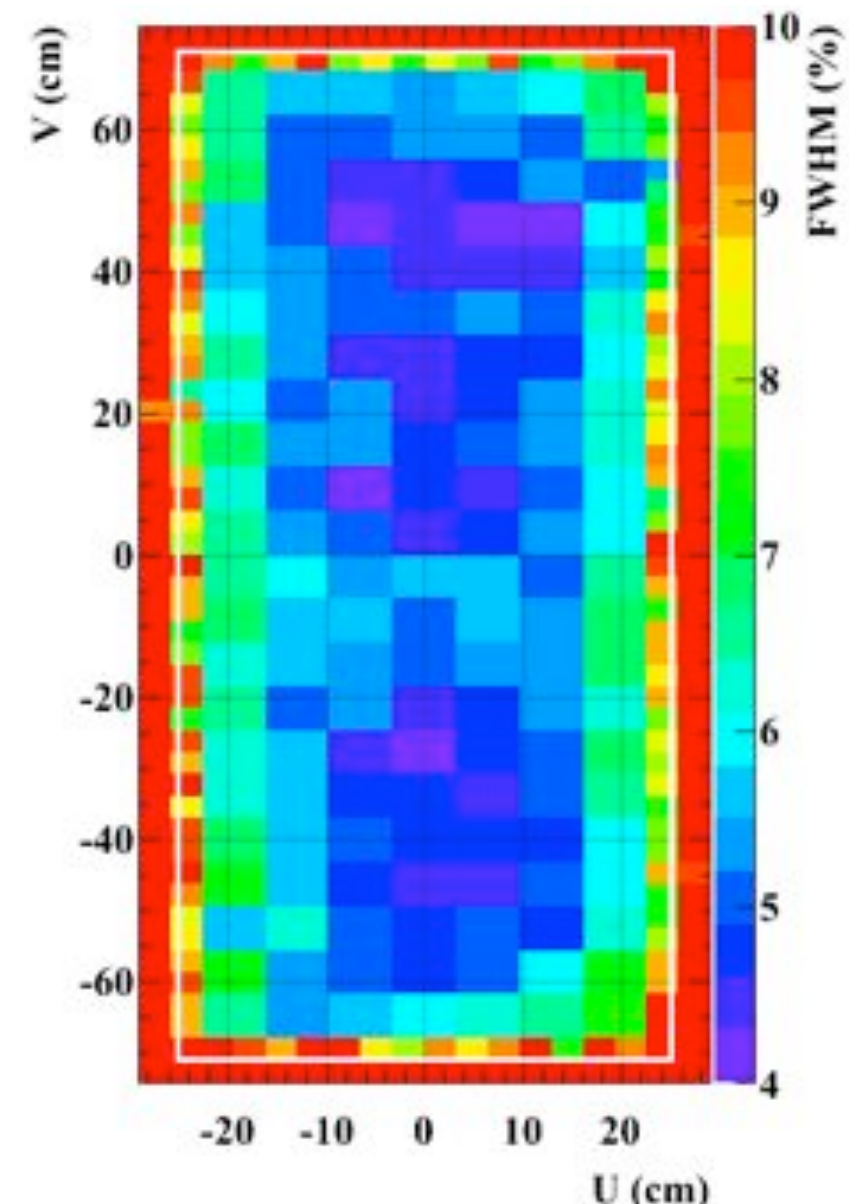
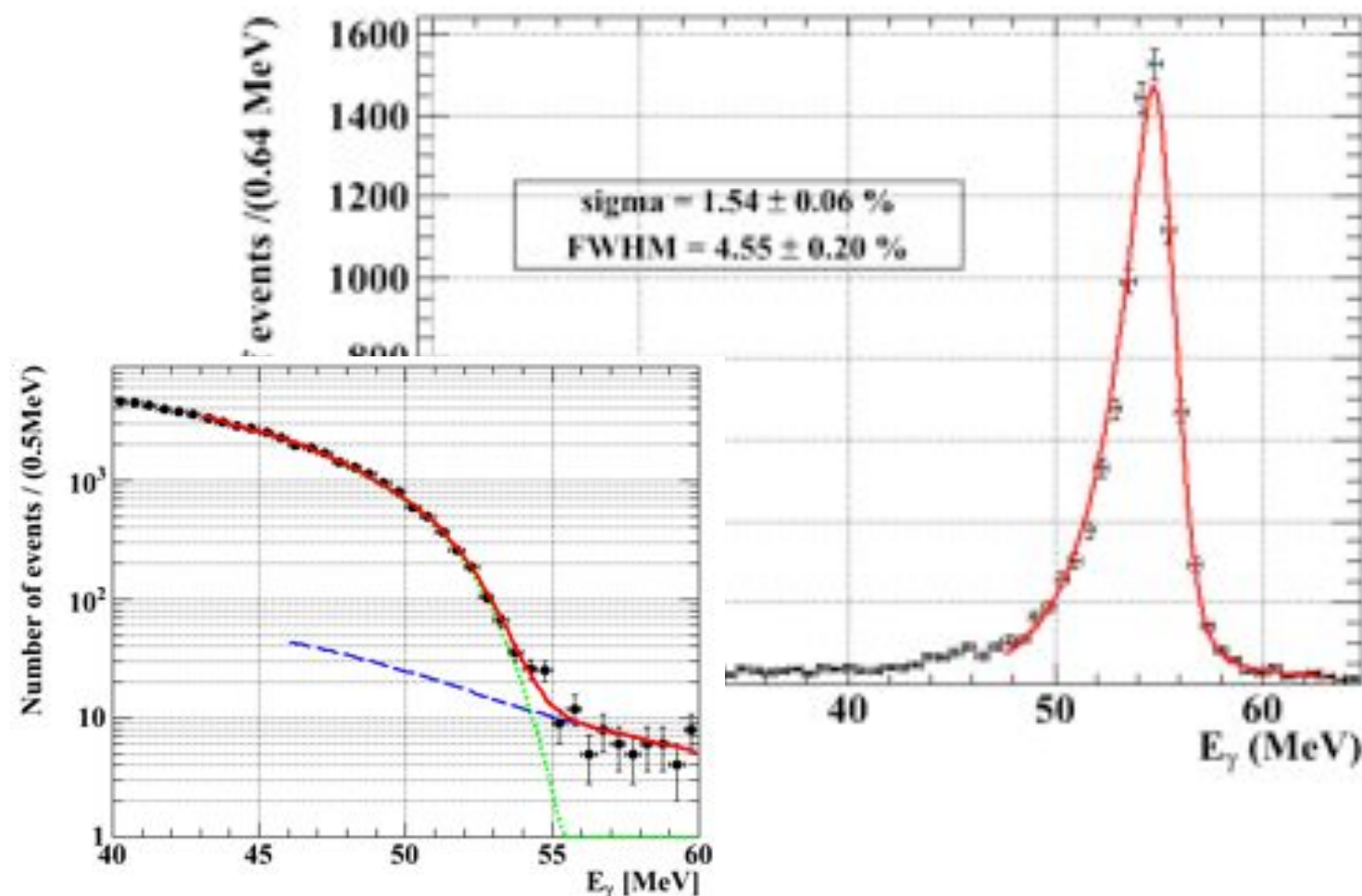
E_γ : from fit to $t_{e\gamma}$ sideband
 E_e : from data
 $\theta_{e\gamma}$: from fit to $t_{e\gamma}$ sideband
 $t_{e\gamma}$: flat

Alternative observables definition

- 1) *different algorithm for LXe Timing*
- 2) *Trigger LXe waveform digitizing electronics (E_γ)*

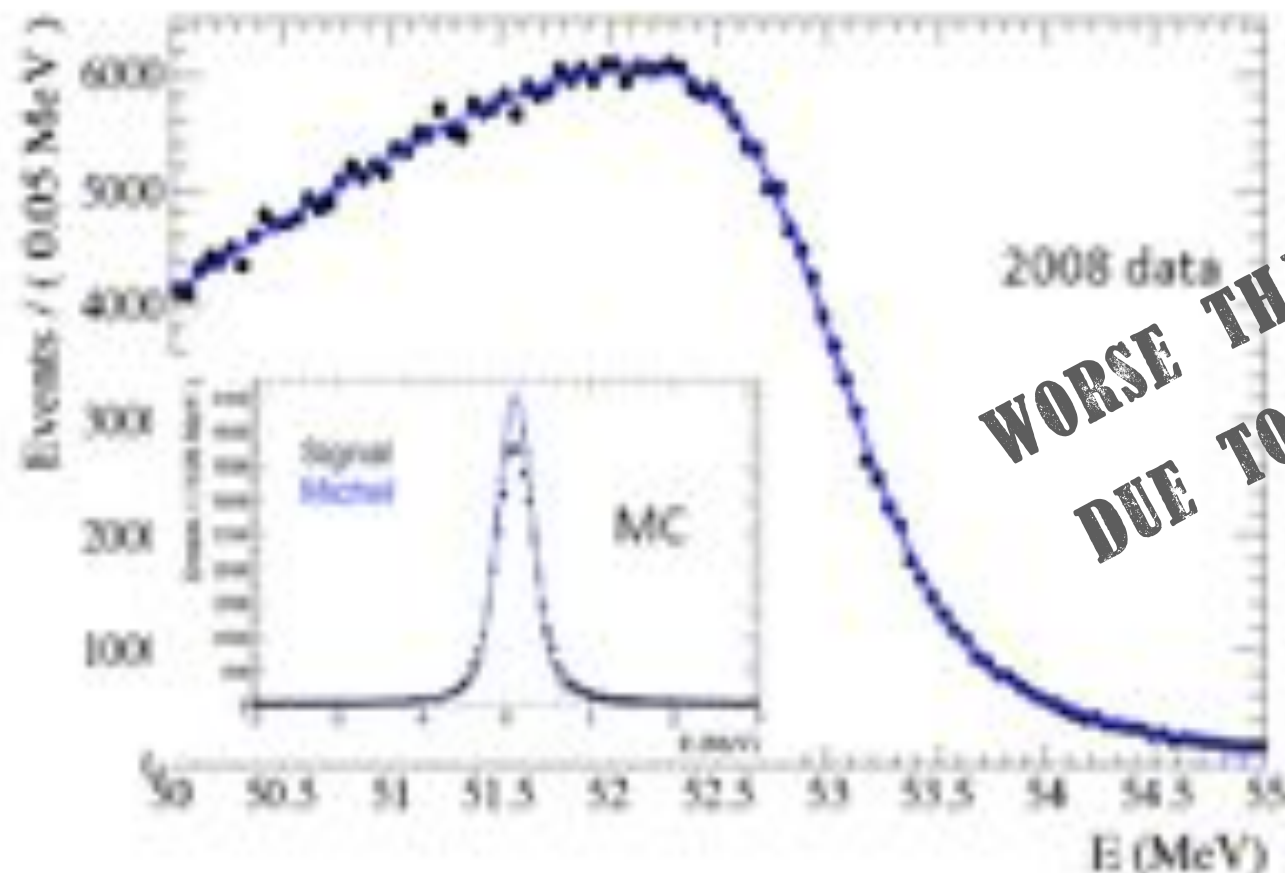
Some examples: γ -ray energy

- The **energy resolution** and energy **scale** is extracted by the **CEX data** (55 MeV photons)
 - verified by RMD (+AIF) spectrum
- Average upper tail for deep conversions
 - $\sigma = 2.0 \pm 0.15 \%$
- Systematic uncertainty on energy scale $< 0.6\%$

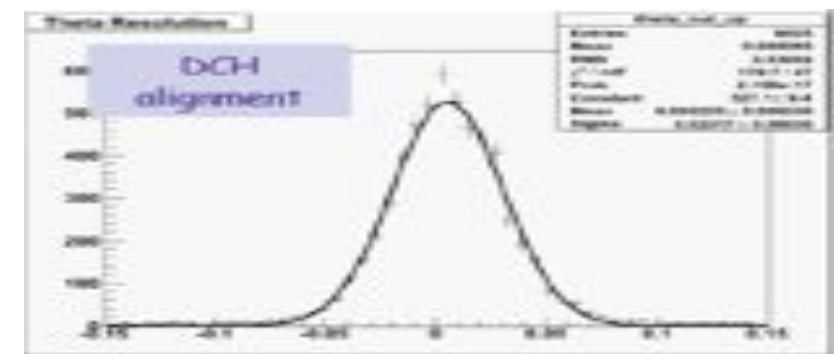
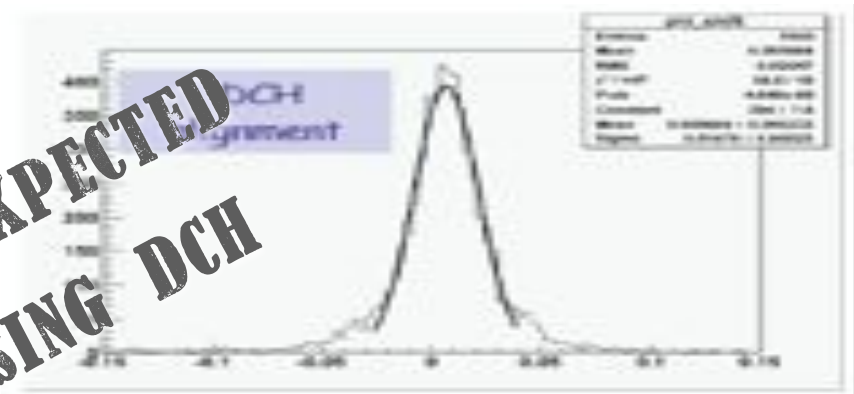


Positron momentum

- e^+ energy scale and resolution are evaluated by fitting the kinematic edge of the Michel positron spectrum at 52.8 MeV
- Resolution functions of core and tail components
 - core = 374 keV (60%)
 - tail = 1.06 MeV (33%) and 2.0 MeV (7%)
- Positron angle resolution measured using multi-loop tracks
 - $\sigma(\varphi) = 10$ mrad
 - $\sigma(\theta) = 18$ mrad

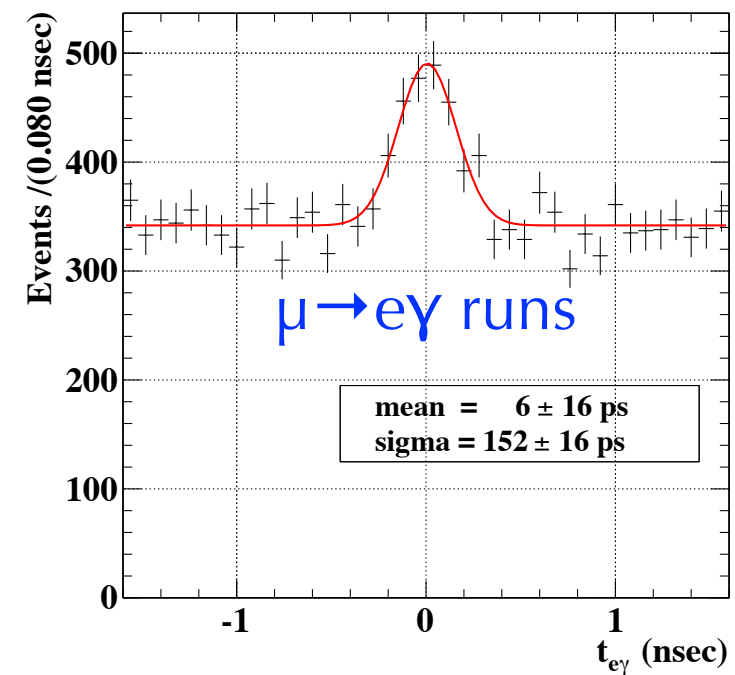
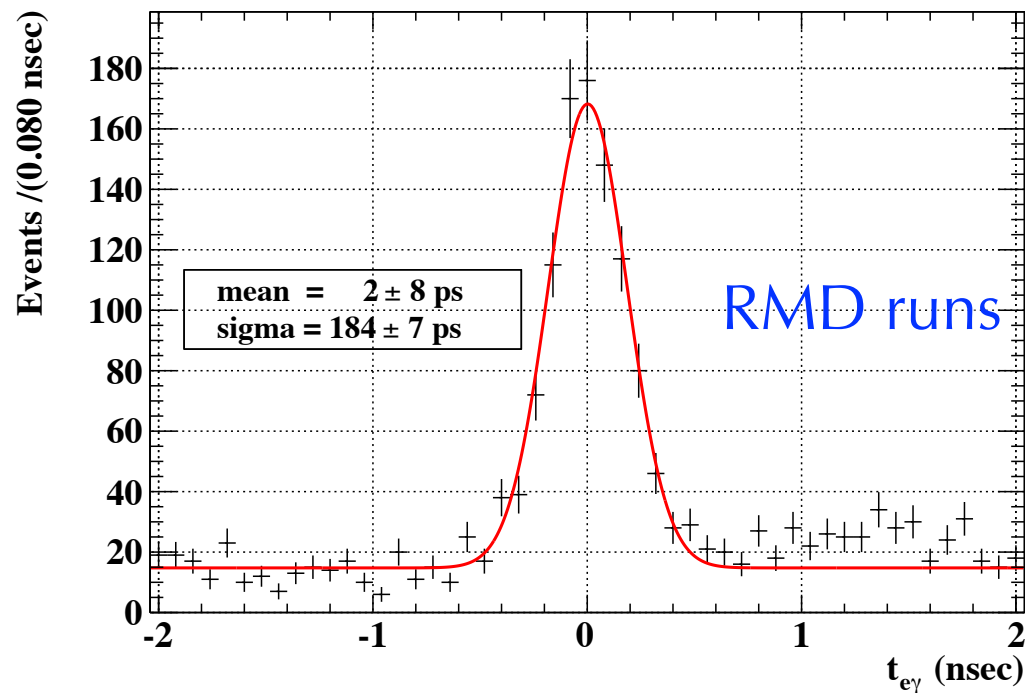


**WORSE THAN EXPECTED
DUE TO MISSING DCH**



Relative time resolution

- Quote directly the $t_{e\gamma}$ from **RMD** resolution (recall: MEGA 700 ps) $\mu \rightarrow e\bar{\nu}\nu\gamma$
 - e^+ time from TC and corrected by ToF (DCH trajectory)
 - LXe time corrected by ToF to the conversion point



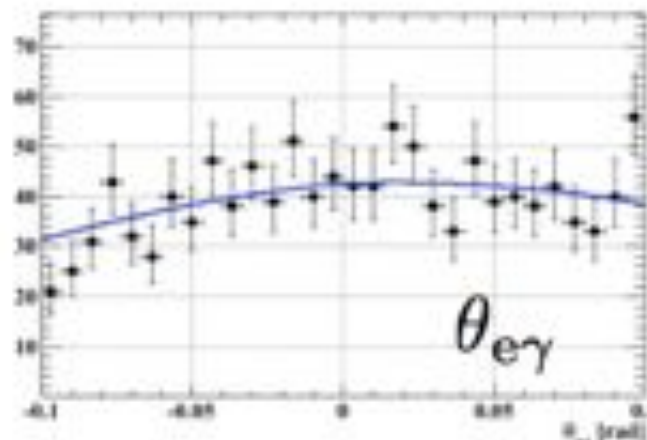
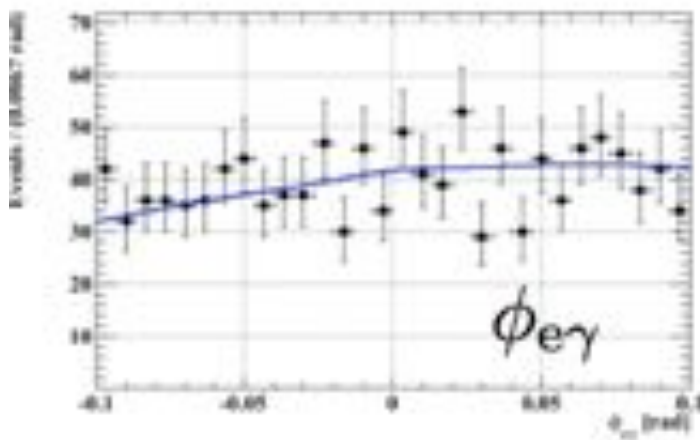
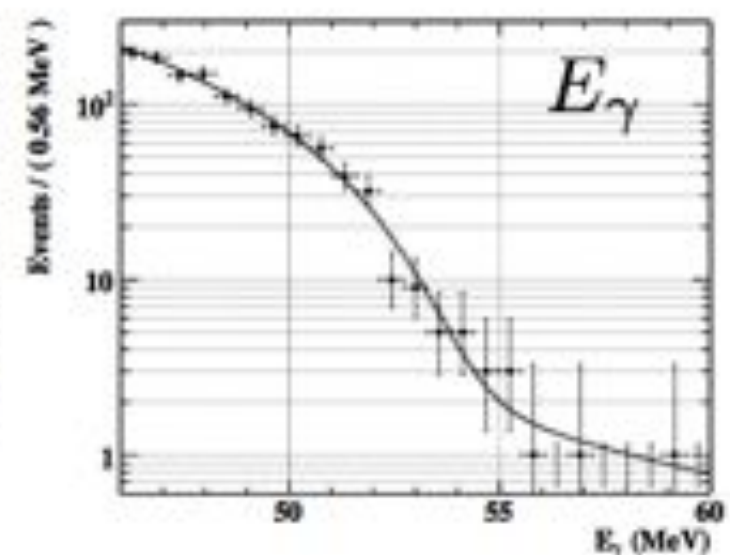
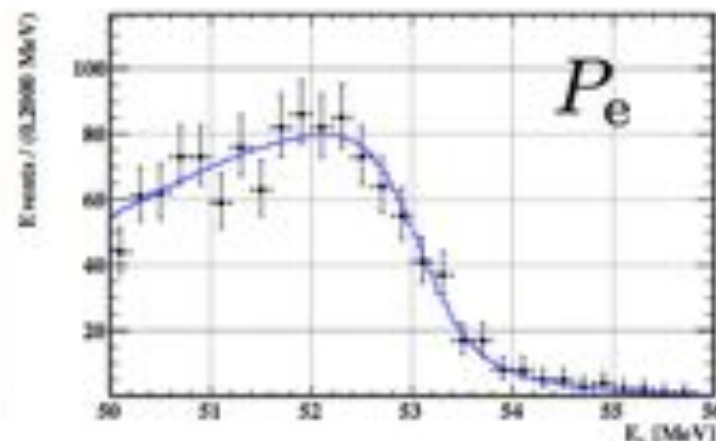
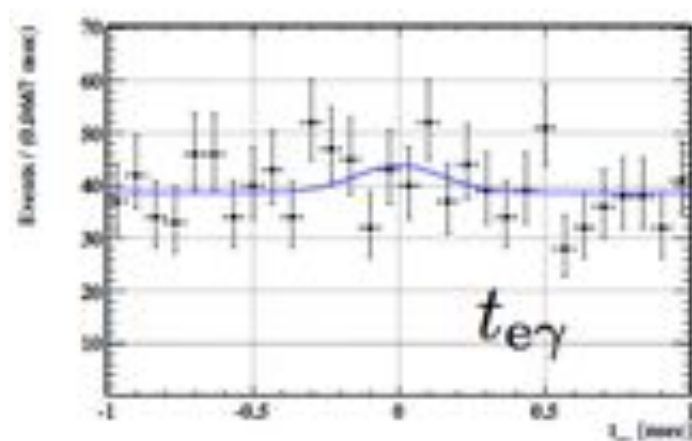
- σ_t is corrected for a small energy-dependence
 - (148 ± 17) ps
 - stable within 20 ps along the run

Likelihood fit

- A “Feldman-Cousins” approach was adopted for the **likelihood** analysis
 - The **sensitivity** (average expected 90% CL upper limit) on N_{sig} assuming no signal by means of toy MC:
 - $N_{\text{sig}} < 6$
 - 90% CL upper limit from the **sidebands**
 - $N_{\text{sig}} < (4.2 \div 9.7)$

Likelihood fit

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 - $N_{\text{sig}} < (4.2 \div 9.7)$



$N_{\text{sig}} < 14.7$ @90% CL

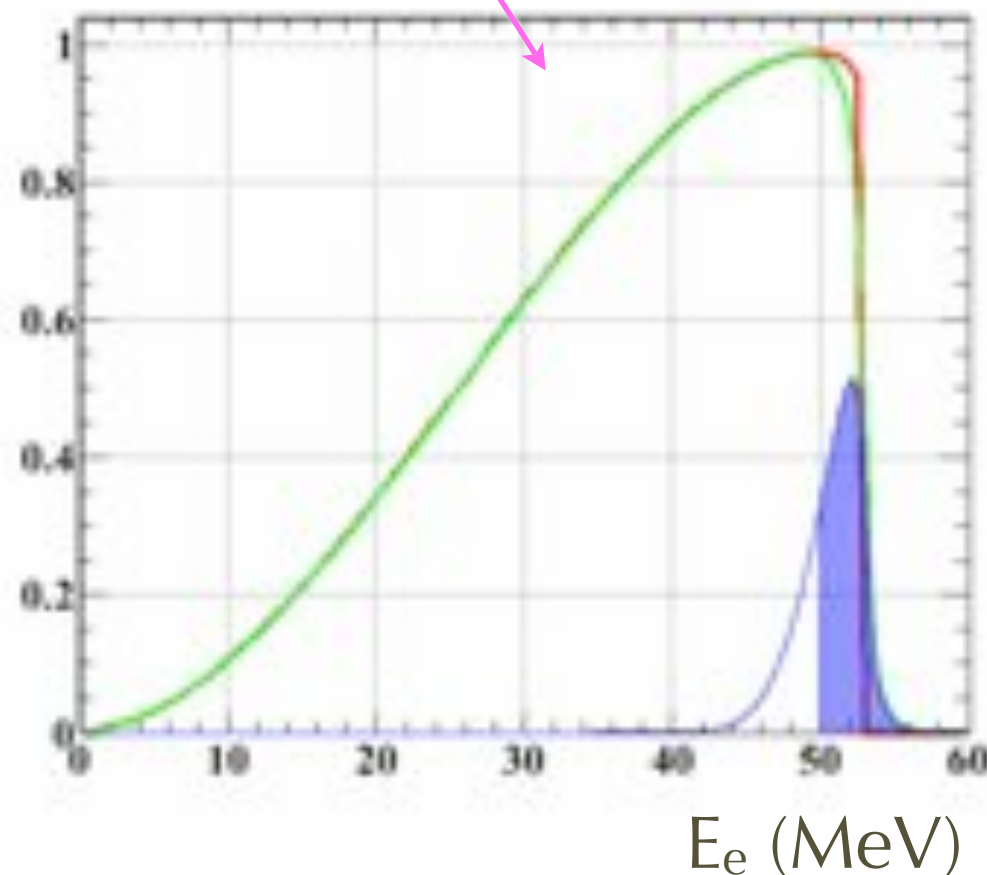
N_{RMD} consistent with
sideband estimate: 25^{+17}_{-16}

Normalization

- The N_{sig} are normalized to the detected Michel positrons

$$\text{BR}(\mu^+ \rightarrow e^+ \gamma) = \frac{N_{\text{sig}}}{N_{e\nu\bar{\nu}}} \times \frac{f_{e\nu\bar{\nu}}^E}{P} \times \frac{\epsilon_{e\nu\bar{\nu}}^{\text{trig}}}{\epsilon_{e\gamma}^{\text{trig}}} \times \frac{A_{e\nu\bar{\nu}}^{\text{TC}}}{A_{e\gamma}^{\text{TC}}} \times \frac{\epsilon_{e\nu\bar{\nu}}^{\text{DC}}}{\epsilon_{e\gamma}^{\text{DC}}} \times \frac{1}{A_{e\gamma}^{\text{LXe}}} \times \frac{1}{\epsilon_{e\gamma}^{\text{LXe}}}$$

count # of
Michel decays
in the analysis
window with a
pre-scaled
trigger

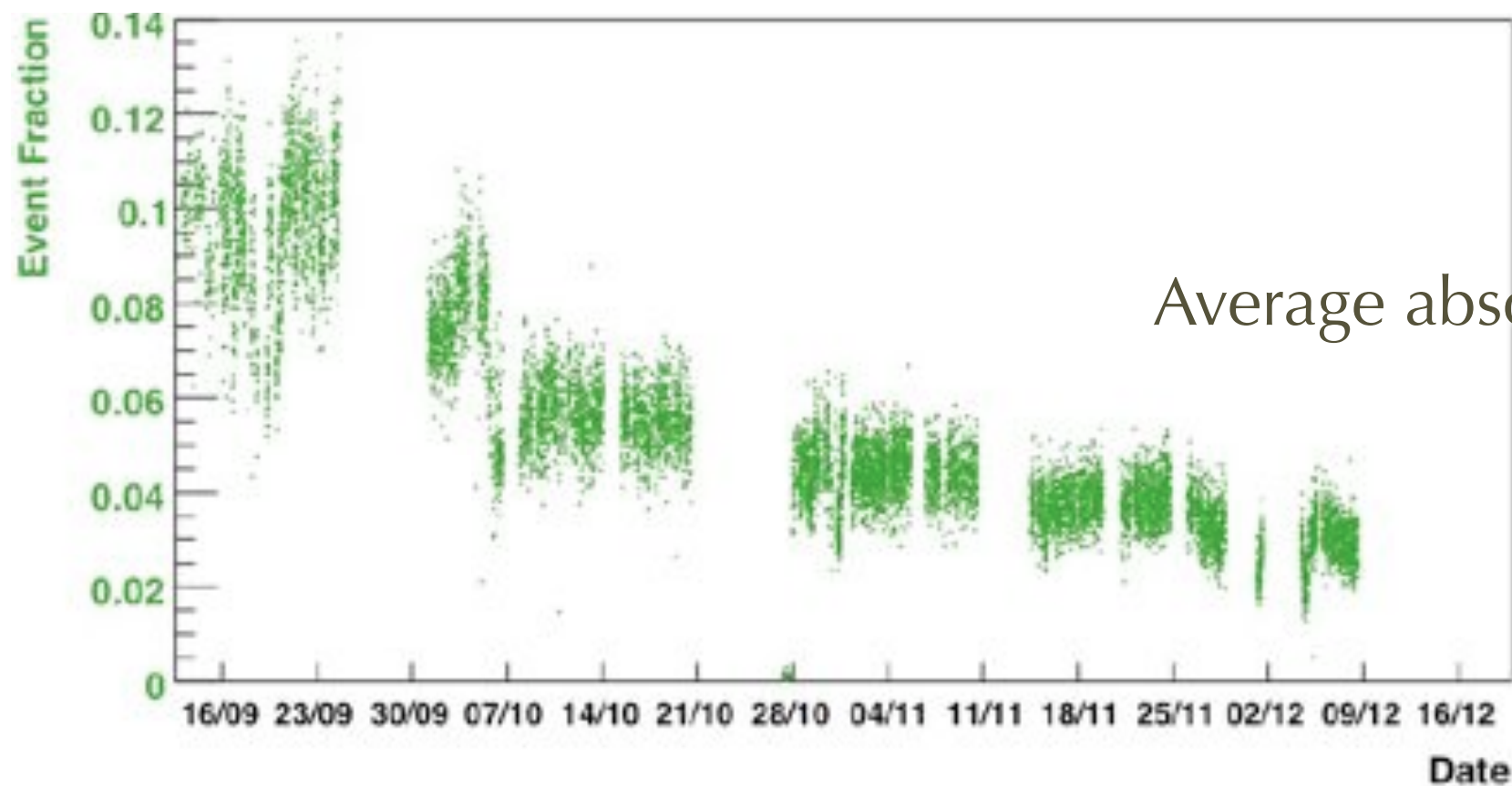


theory
resolution
acceptance

Normalization

- The N_{sig} are normalized to the detected Michel positrons

$$\text{BR}(\mu^+ \rightarrow e^+ \gamma) = \frac{N_{\text{sig}}}{N_{e\nu\bar{\nu}}} \times \frac{f_{e\nu\bar{\nu}}^E}{P} \times \frac{\epsilon_{e\nu\bar{\nu}}^{\text{trig}}}{\epsilon_{e\gamma}^{\text{trig}}} \times \underbrace{\frac{A_{e\nu\bar{\nu}}^{\text{TC}}}{A_{e\gamma}^{\text{TC}}}}_{= \sim 1} \times \frac{\epsilon_{e\nu\bar{\nu}}^{\text{DC}}}{\epsilon_{e\gamma}^{\text{DC}}} \times \frac{1}{A_{e\gamma}^{\text{LXe}}} \times \frac{1}{\epsilon_{e\gamma}^{\text{LXe}}}$$



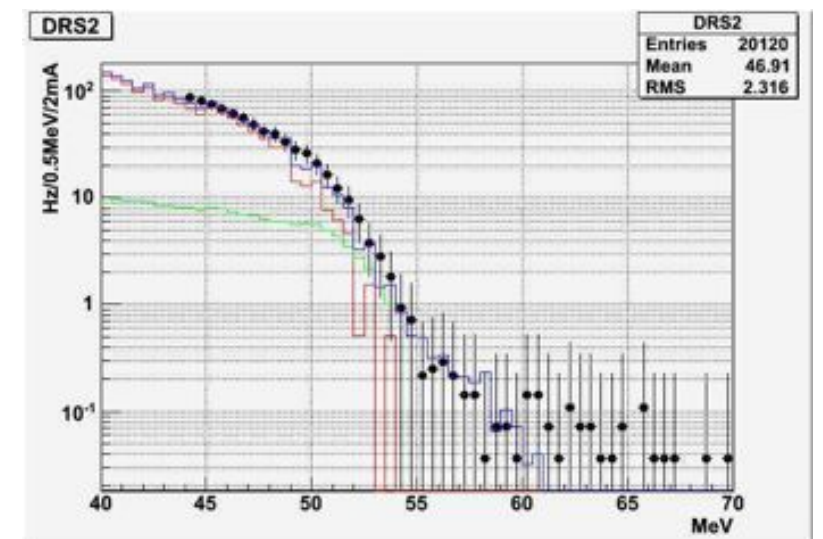
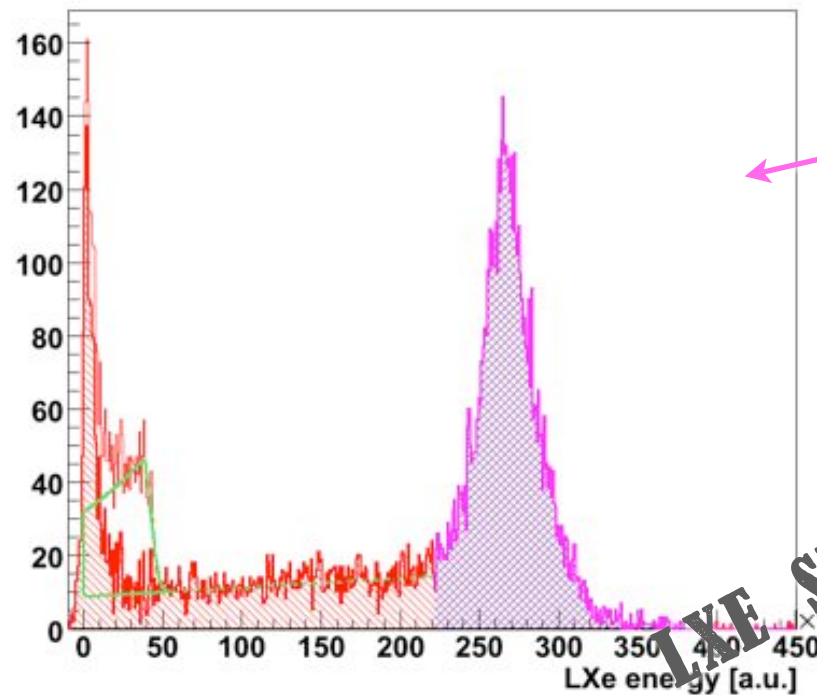
Average absolute efficiency $> 30\%$

- The **fraction** of events with **at least one** reconstructed **track** at high momentum is a measure of **relative tracking efficiency**

Normalization

- The N_{sig} are normalized to the detected Michel positrons

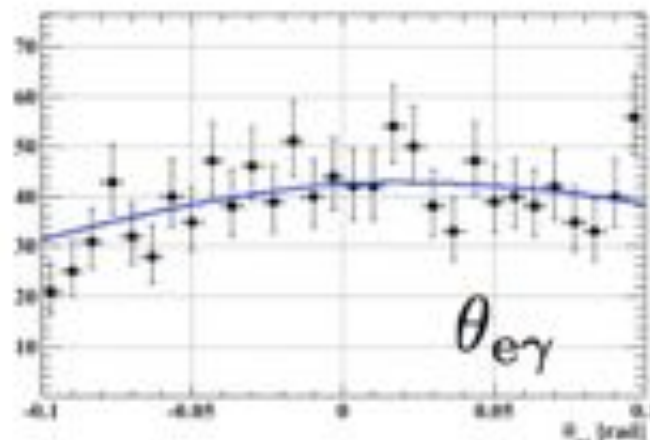
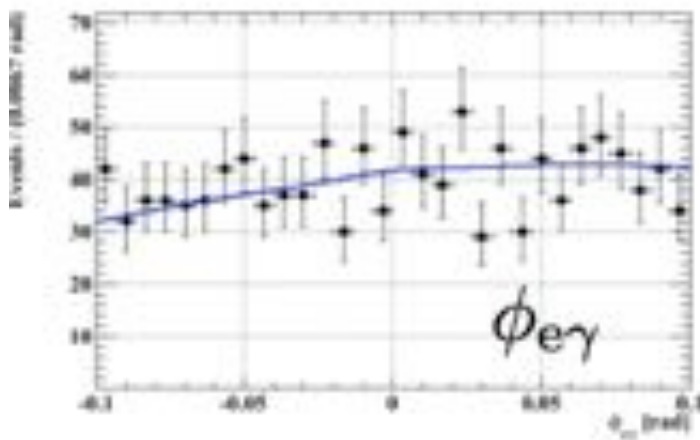
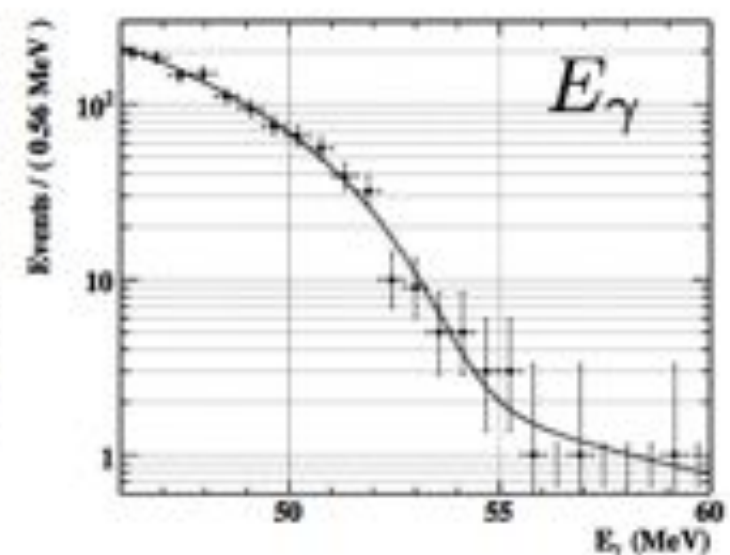
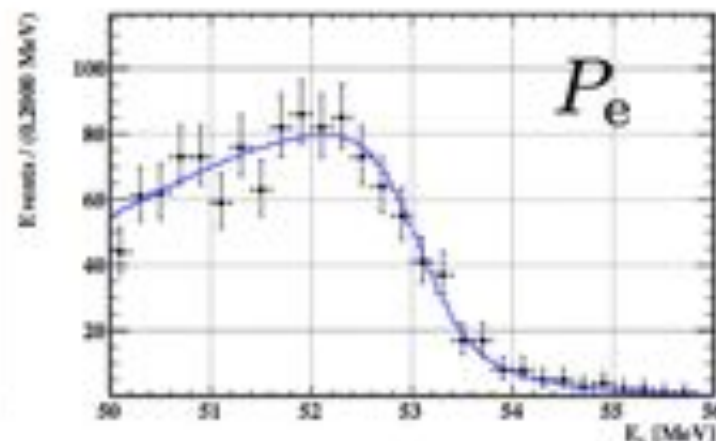
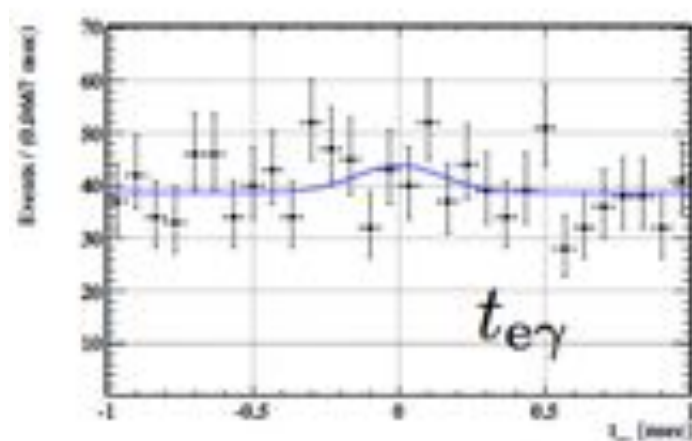
$$\text{BR}(\mu^+ \rightarrow e^+ \gamma) = \frac{N_{\text{sig}}}{N_{e\nu\bar{\nu}}} \times \frac{f_{e\nu\bar{\nu}}^E}{P} \times \frac{\epsilon_{e\nu\bar{\nu}}^{\text{trig}}}{\epsilon_{e\gamma}^{\text{trig}}} \times \frac{A_{e\nu\bar{\nu}}^{\text{TC}}}{A_{e\gamma}^{\text{TC}}} \times \frac{\epsilon_{e\nu\bar{\nu}}^{\text{DC}}}{\epsilon_{e\gamma}^{\text{DC}}} \times \frac{1}{A_{e\gamma}^{\text{LXe}}} \times \frac{1}{\epsilon_{e\gamma}^{\text{LXe}}}$$



- The probability to detect a **signal** γ -ray computed using the **MC** simulation:
 - corrected for smearing and acceptance
 - $\epsilon_{(\gamma)} = 0.61 \pm 0.03$, confirmed by π^0 and RD spectra
- Norm = $(2.0 \pm 0.2) \times 10^{-12}$

Likelihood fit

- A “Feldman-Cousins” approach was adopted for the **likelihood** analysis
 - The **sensitivity** (average expected 90% CL upper limit) on N_{sig} assuming no signal by means of toy MC:
 - $\text{BR} < 1.3 \times 10^{-11}$
 - 90% CL upper limit from the **sidebands**
 - $\text{BR} < (0.9 \div 2.1) \times 10^{-11}$



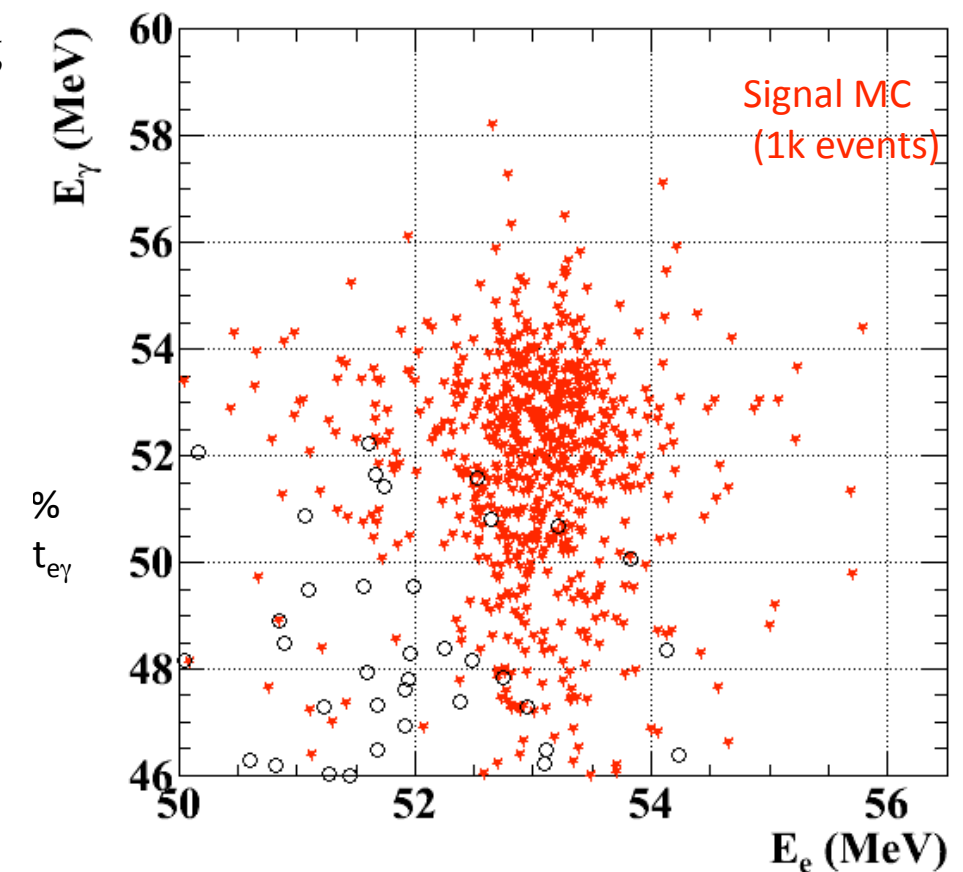
$N_{\text{sig}} < 14.7$ @90% CL

N_{RMD} consistent with
sideband estimate: 25^{+17}_{-16}

Result on BR

$$\text{BR}(\mu^+ \rightarrow e^+ \gamma) < 3.0 \times 10^{-11}$$

- Effect of **systematics** on evaluation of limit on N_{sig}
 - E_γ energy scale (~ 0.6)
 - e^+ angle (~ 0.35)
 - e^+ energy spectrum (~ 1.18)
- ~ 2 times **worse** than expected sensitivity
- **Probability** of getting this result by statistical fluctuations is $\sim 5\%$
- see [arXiv:0908.2594v1](https://arxiv.org/abs/0908.2594v1) [hep-ex]



Conclusion

- Data from the **first three months** of operation of the **MEG** experiment give a result competitive with the previous limit
 - **2008 run** suffered from detector **instabilities**
- During 2009 shutdown the problem with the **DCH instability** was **solved**
 - **DCH operated** for **6 months** with no degradation
- Data taking **restarted** in **October** 2009 till 23 December
 - improved **efficiency**
 - improved read-out **electronics** (DRS2 → DRS4)
 - improved **resolutions** (tracking, timing...)
- Confident in a sensitivity $\sim 5 \times 10^{-12}$ for this year's data
- We will need to **run until** the end of **2011** for reaching the **target sensitivity**

Thank you

- Visit us on <http://meg.psi.ch>



Back-up slides

