Cryogenic Liquid Detectors for Future Particle Physics
LNGS - March 13th-14th, 2006

The liquid xenon scintillation calorimeter for the MEG experiment or news from an anomalous accelerator experiment

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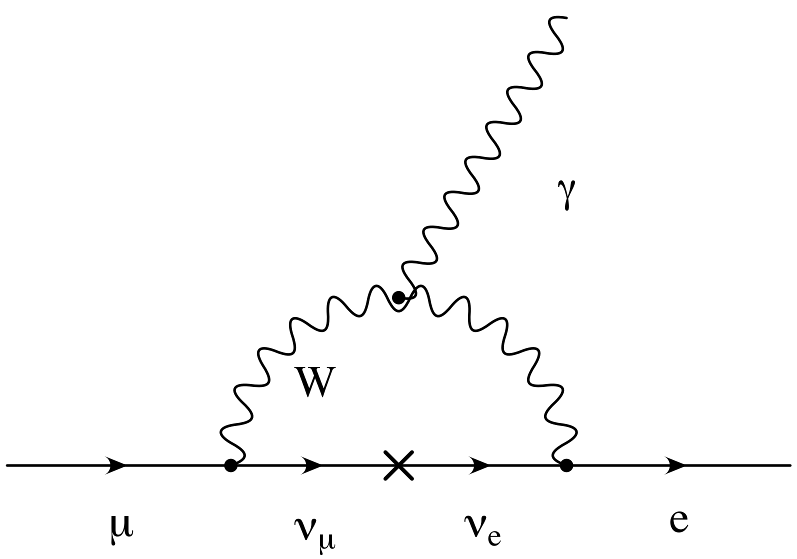
The μ→eγ decay

- MEG experiment to be performed at Paul Scherrer Institute (Zurich)
  - A search for a "rare process"
- The μ→eγ decay is forbidden in the Standard Model of elementary particles because of the (accidental) conservation of lepton family numbers
- The introduction of neutrino masses and mixings induces μ→eγ radiatively, but at a negligible level

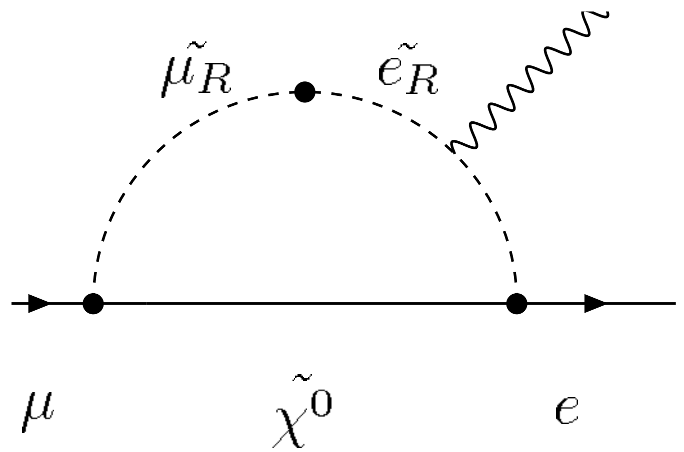


$$\Gamma(\mu \to e\gamma) \approx \frac{G_F^2 m_\mu^2}{192\pi^3}\left(\frac{\alpha}{2\pi}\right)\sin^2 2\theta \sin^2\left(\frac{1.27\Delta m^2}{M_W^2}\right)$$

Relative probability ~ 10^{-55}

- All SM extensions enhance the rate through mixing in the high energy sector of the theory

For instance... predictions



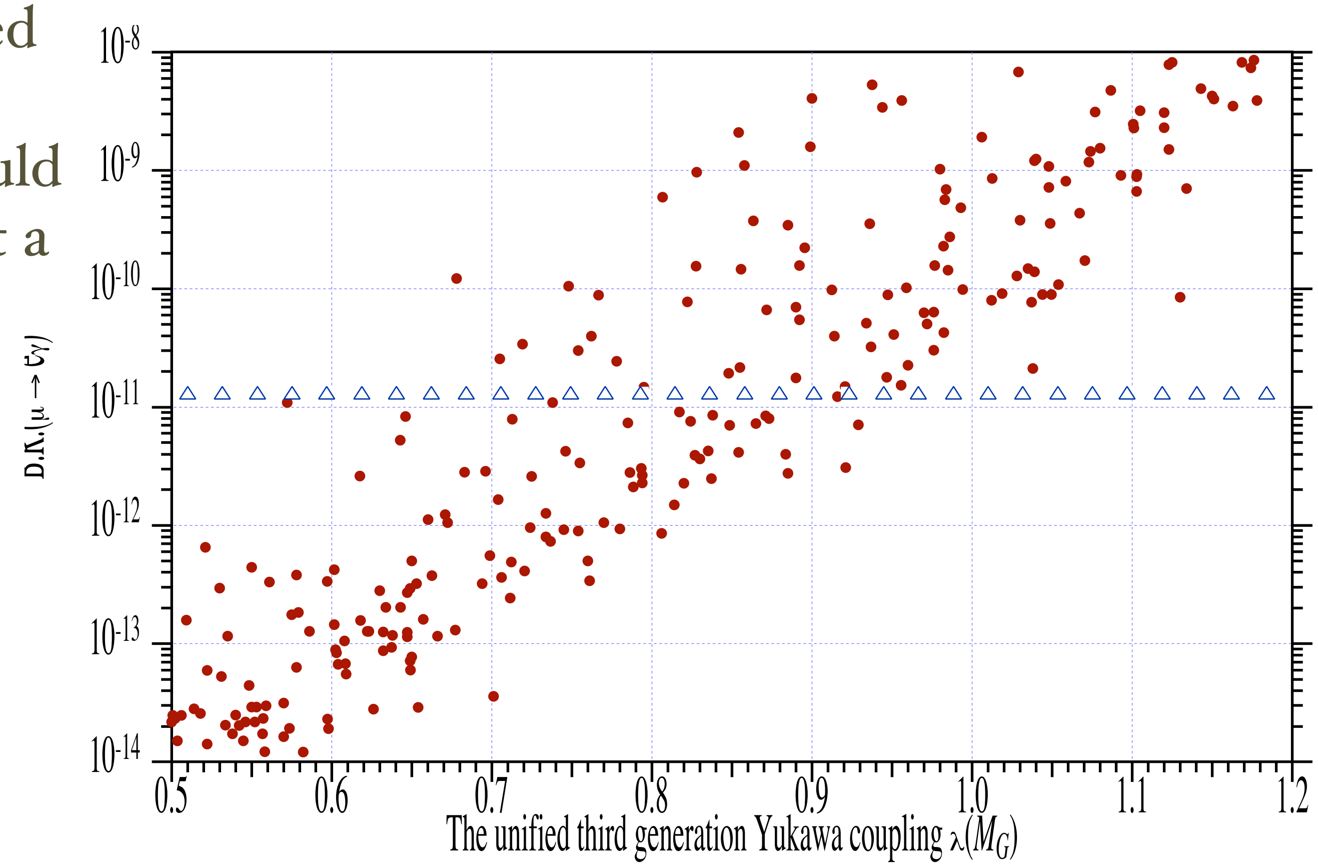
R. Barbieri et al.,Nucl. Phys. B445(1995) 215

J.Hisano et al.,Phys. Lett. B391 (1997) 341

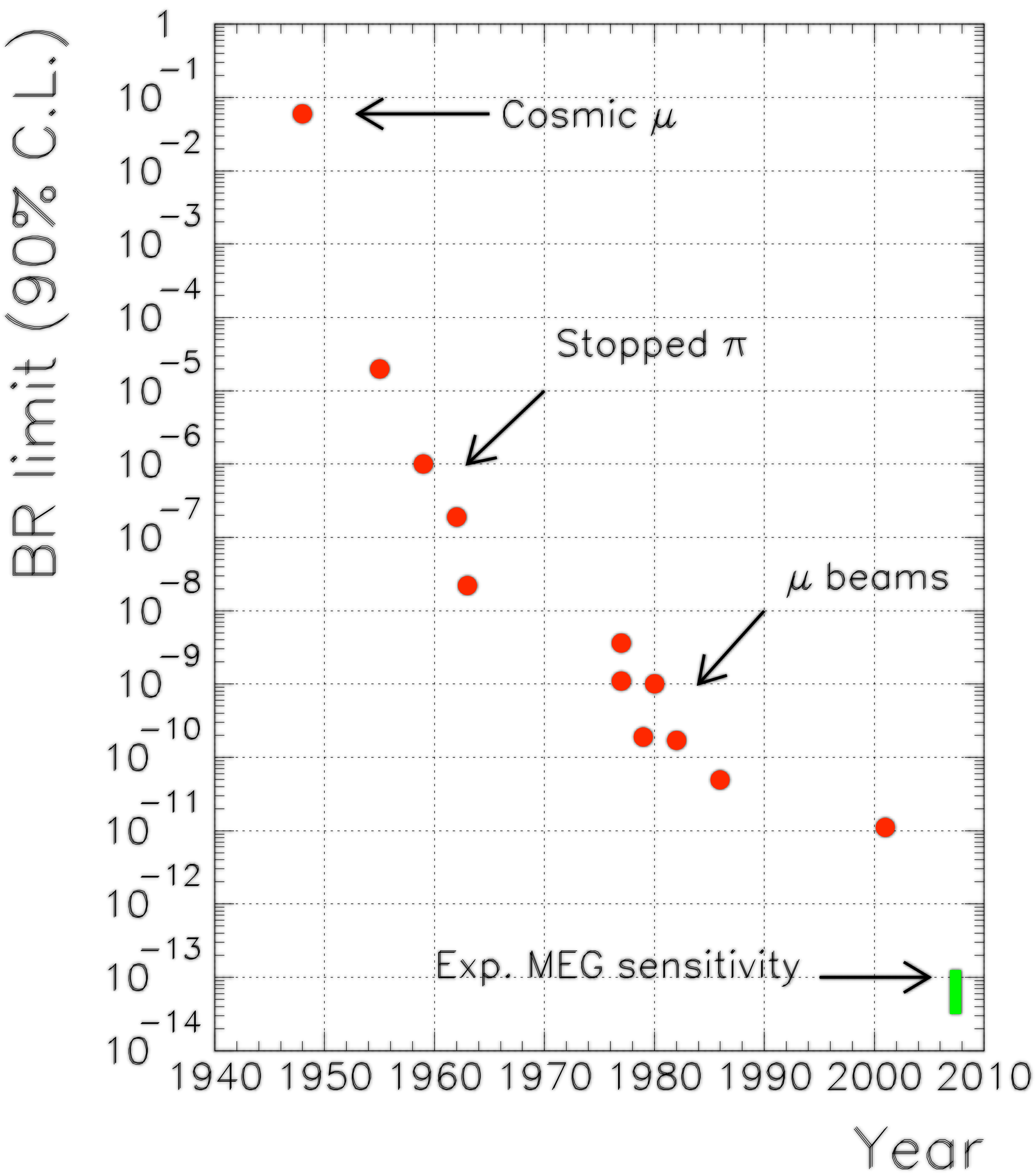
P. Ciafaloni, A. Romanino, A. Strumia, Nucl. Phys. B458 (1996)

J. Hisano, N. Nomura, Phys. Rev. D59 (1999)

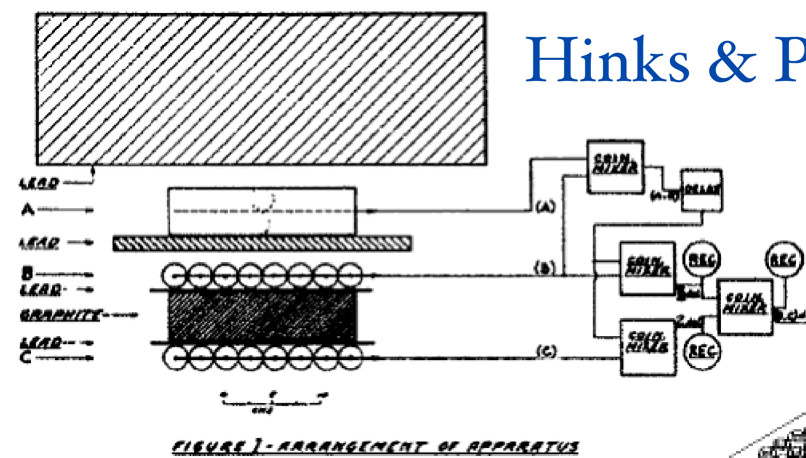
- SUSY SU(5) predictions: LFV induced by finite slepton mixing through radiative corrections. The mixing could be large due to the top-quark mass at a level of 10^{-12} 10^{-15}
- SO(10) predicts even larger BR:
  - m(τ)/m(μ) enhancement
- Models with right-handed neutrinos also predict large BR
- ⇒ clear evidence for physics beyond the SM.



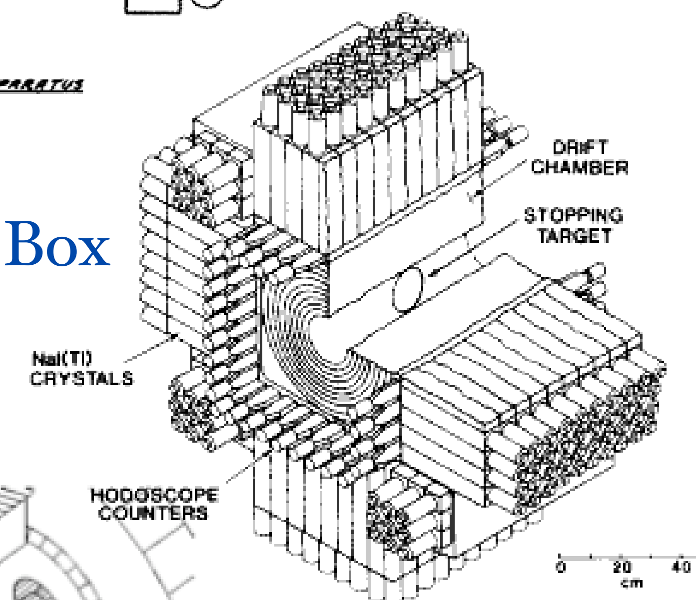
Historical perspective

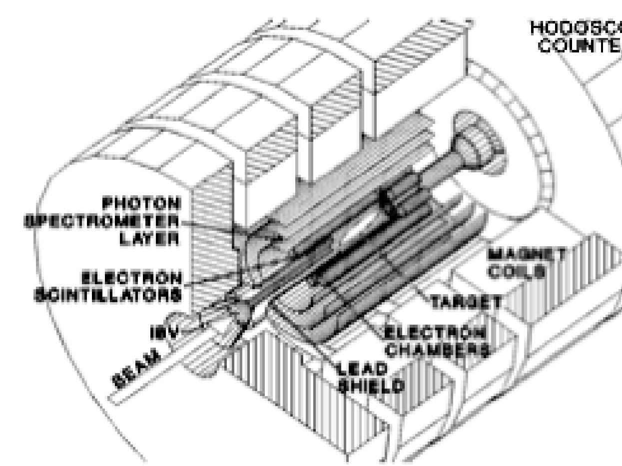


Hinks & Pontecorvo



Crystal Box



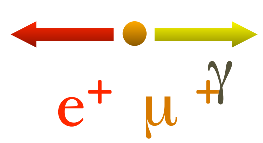


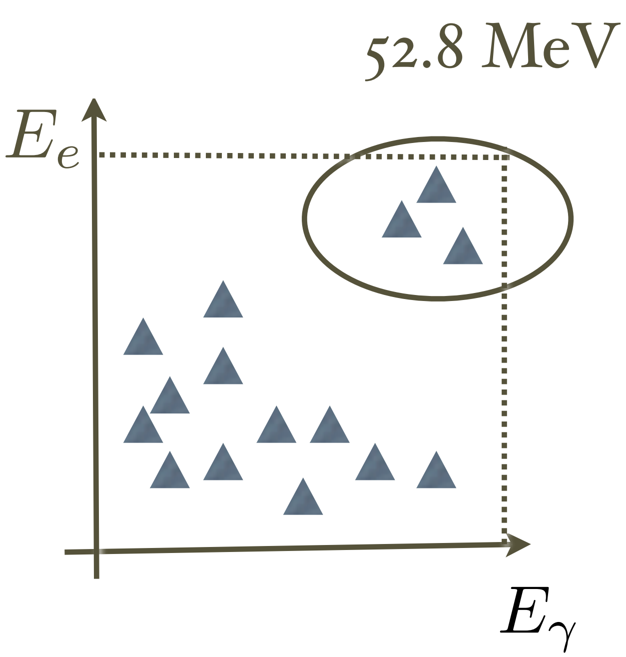
MEGA

Each improvement linked to an improvement in the technology

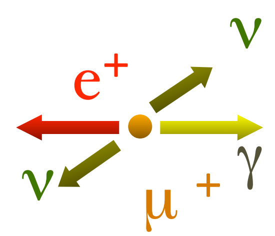
Signal and Background

"Signal"



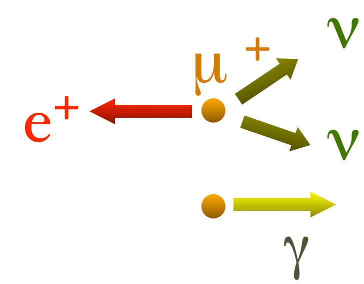


"Prompt"



$\mu \to e\nu\nu\gamma$

"Accidental"



$\mu \to e\bar{\nu}\nu$

$\mu \to e\bar{\nu}\nu\gamma$

$e\mathcal{N} \to e\mathcal{N}\gamma$

$e^+e^- \to \gamma\gamma$

$B_{Prompt} \sim 0.1 * B_{acc}$ $\quad$ $B_{acc} \sim R_\mu \, \Delta E_e \, \Delta E_\gamma^2 \, \Delta\theta^2 \, \Delta t$

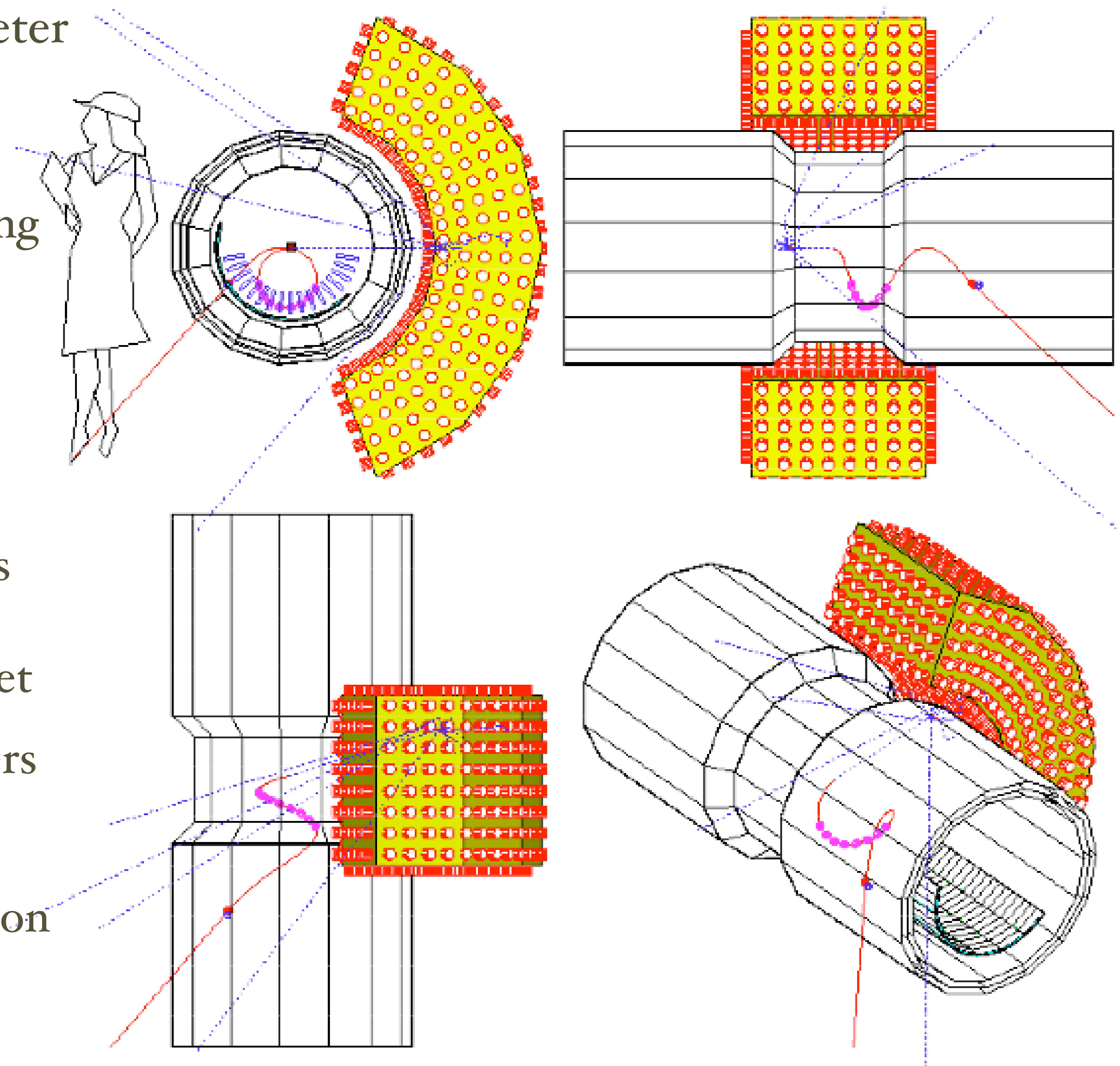
The accidental background is dominant and it is determined by the experimental resolutions

View of a Monte Carlo simulated event:

the photons enters the LXe calorimeter and the positron is measured by the drift chambers + timing counters.

Positron: energy, Momentum and timing

Photon: energy, direction and timing



Stopped μ-beam: up to 10^8 μ /sec

The presently most intense continuous muon beam in the world, PSI (CH) is brought to rest in a 100 μm mylar target

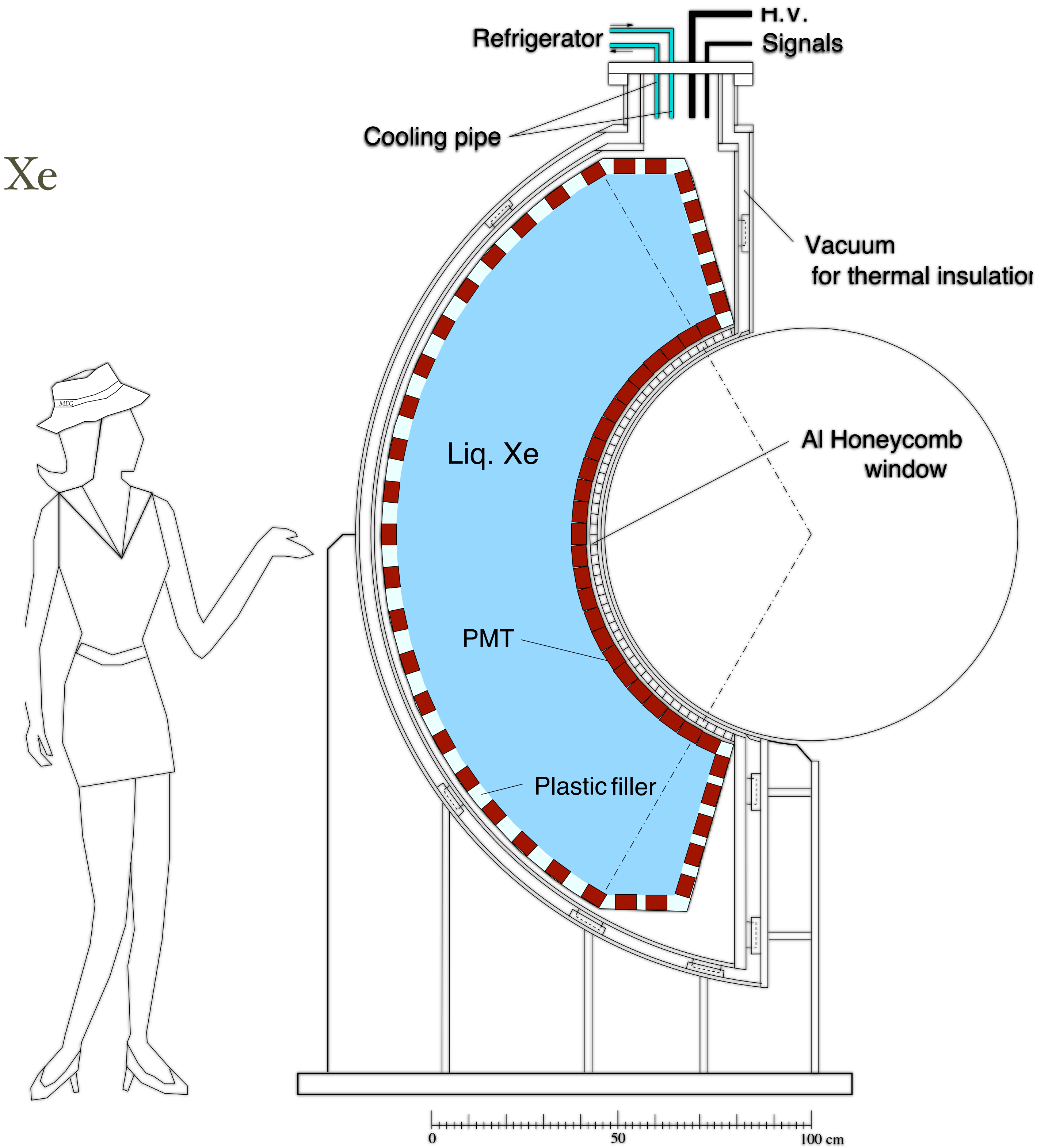
Solenoid spectrometer & drift chambers

Timing Counter for e+ timing

Liquid Xenon calorimeter for γ detection (scintillation)

The calorimeter

- γ Energy, position, timing
- Homogeneous 0.8 m^3 volume of liquid Xe
  - pulse tube refrigerator
  - 65 < r < 112 cm
  - |cosθ| < 0.35 |φ| < 60o
  - 10 % solid angle
- 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



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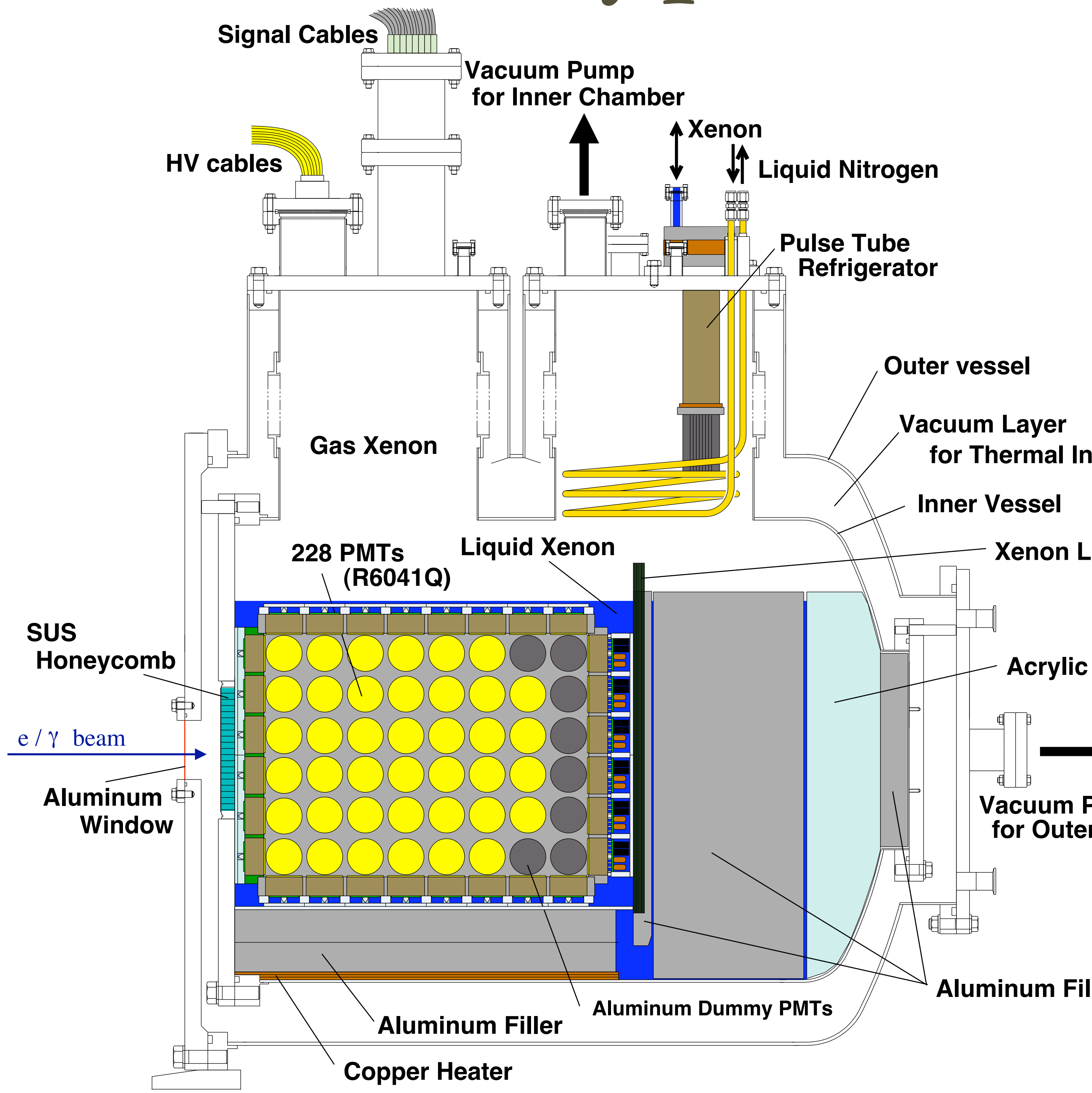
Xe Calorimeter Prototype

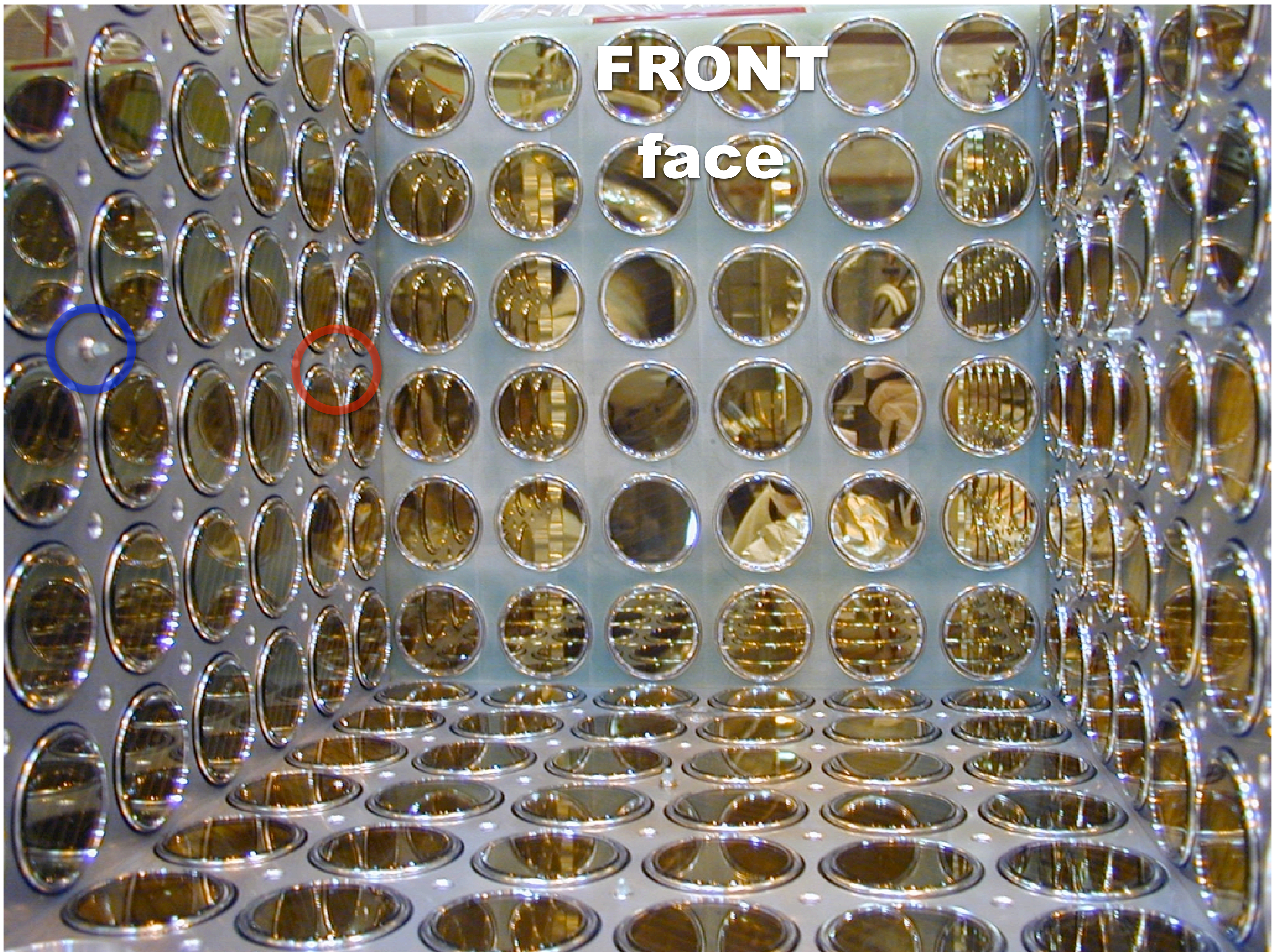
- 40 x 40 x 50 cm^3
    - 228 PMTs, 100 litres Lxe
- HAMAMATSU R6041 & R9288
    - Rb(K)-Cs-Sb photocathode
    - Mn layer/al fingers (resistivity at low T)
    - Quartz window
    - Metal channel dynode
- Used for the measurement of:
    - Test of cryogenic and long term operation
    - Energy/Position/Timing resolution



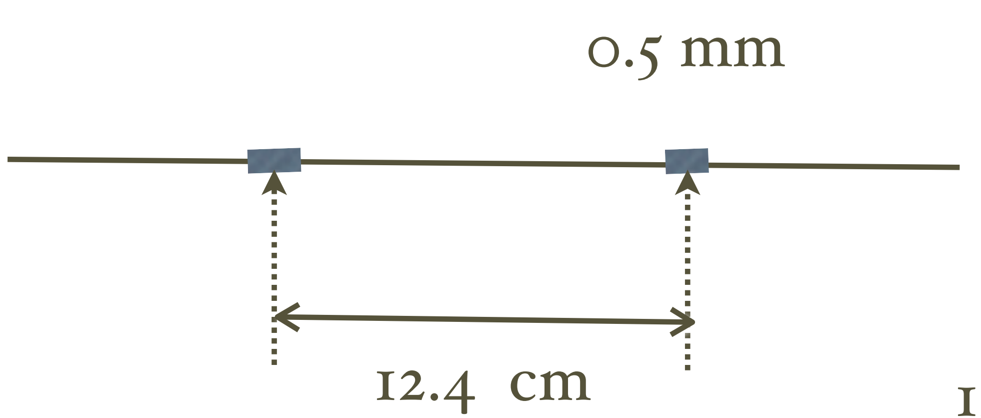
Biggest existing LXe calorimeter

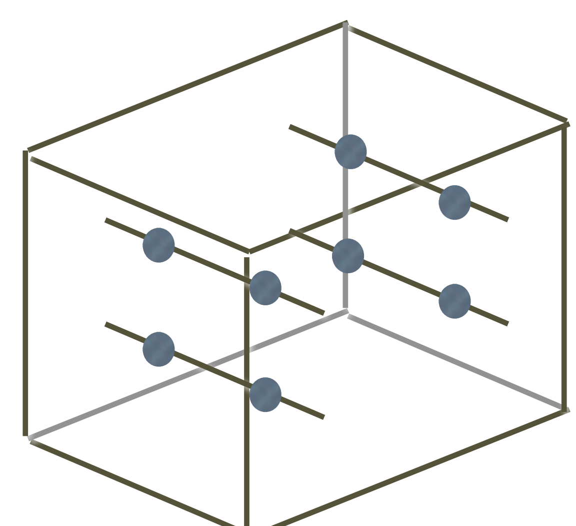
The LP from "inside"

α-sources and LEDs used for PMT calibrations and monitoring



- Home-made Polonium alpha sources
- 50 Bq/each
- 50 micron tungsten wires
- exploit the uniqueness of this homogeneous device





I selected two topics

- This is a search for a rare signal with an enormous background, thing that makes it comparable to proton decay or dark matter search
- Anyway the problems to face are somehow different
- I selected just two topics, one which is common to underground experiment, and one which is not
  - LXe purity
    - purification & monitoring
  - PMT development
    - photo-cathode resistivity increases at low temperature
    - high rate of low energy photons
    - low current in our PMT's bleeder circuit

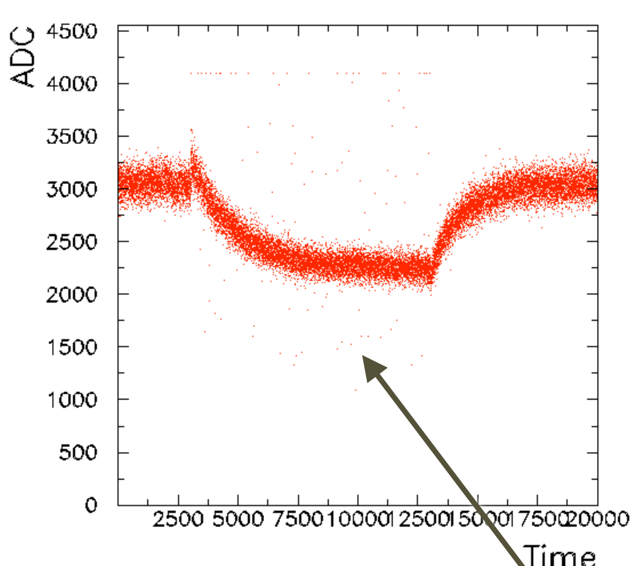
PMT R&D history

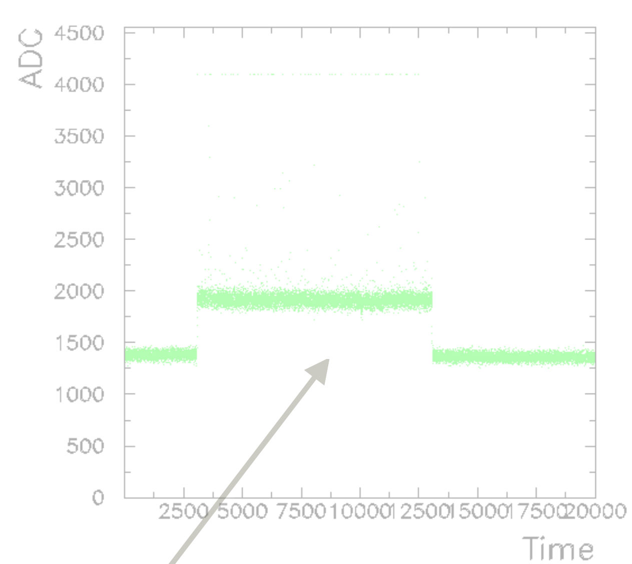
First Ver.

Second Ver.

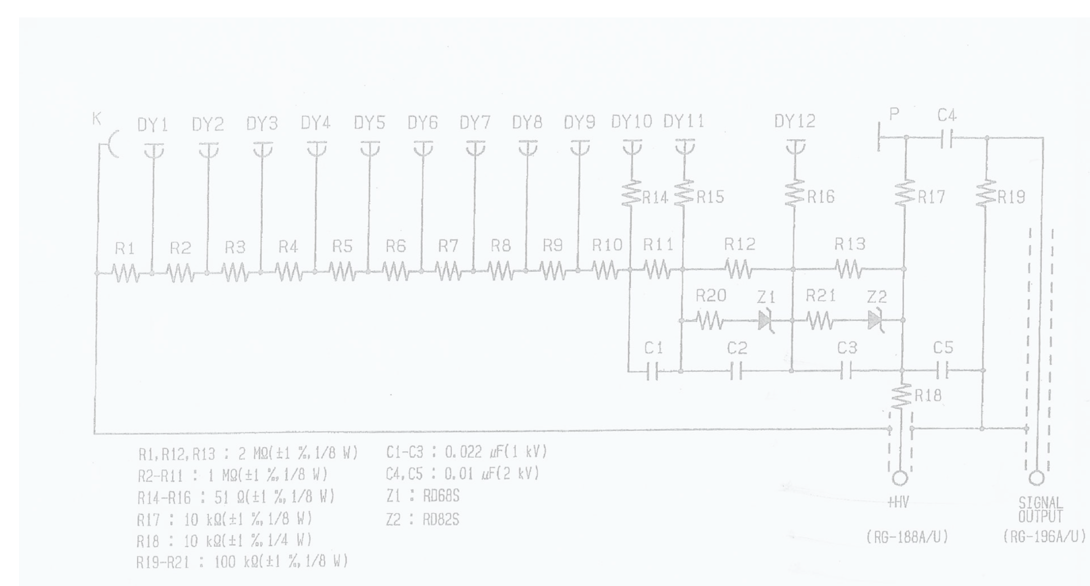
Final Ver.

	First Ver.	Second Ver.	Final Ver.
Photocathode	Rb-Cs-Sb	K-Cs-Sb	K-Cs-Sb
Material to reduce surface R	Mn layer	Al Strip	Al Strip (doubled)
Q.E. @ 165K	~5%	~15%	~15%





noise light on



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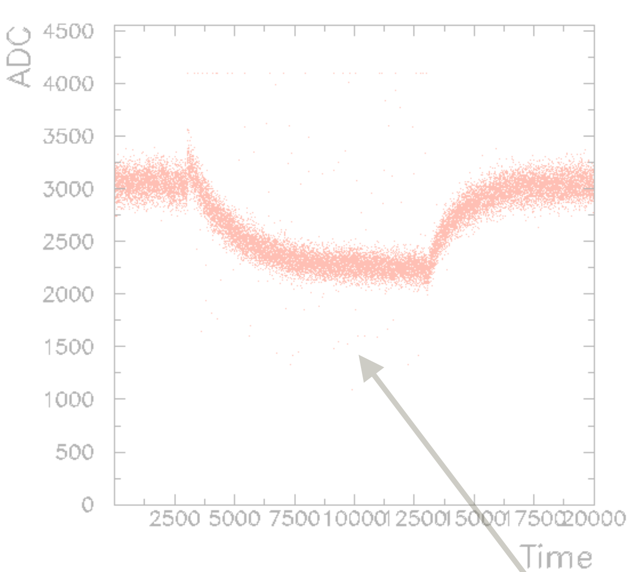

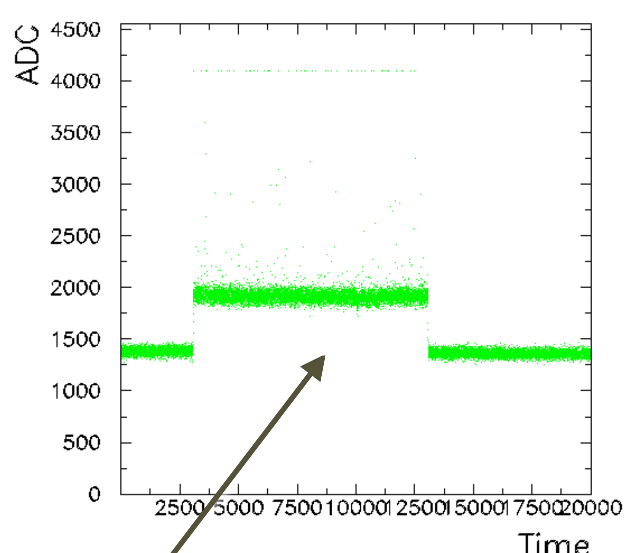

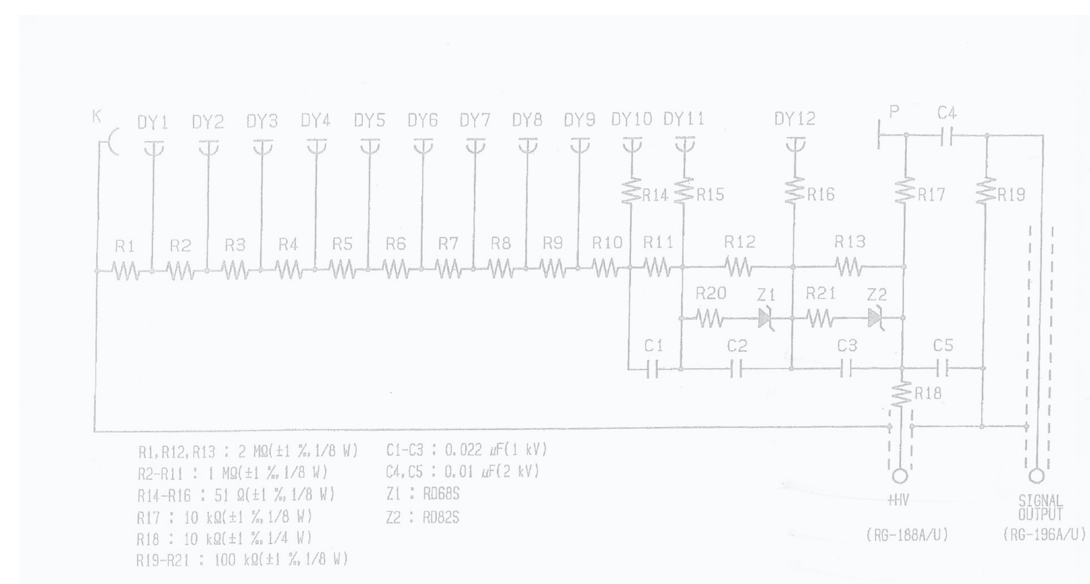

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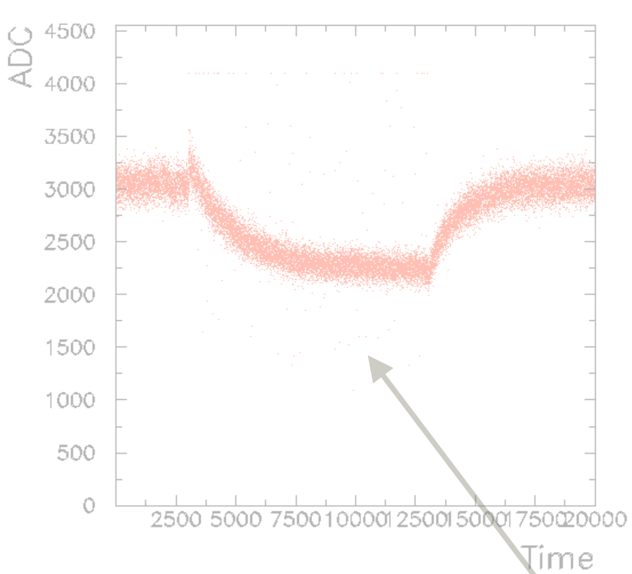
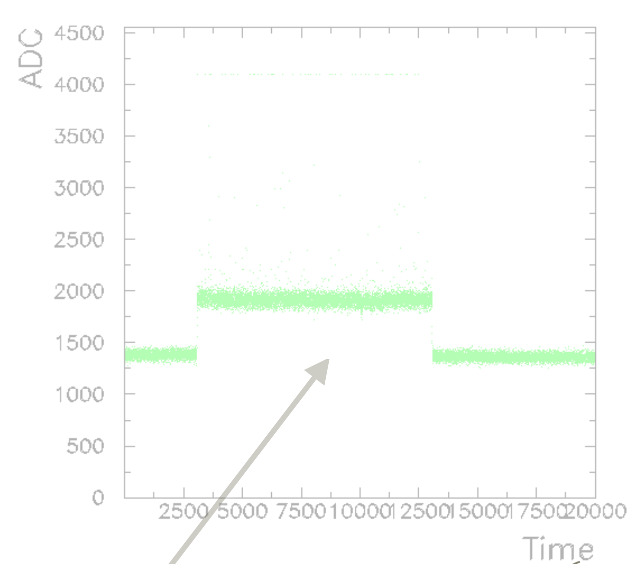
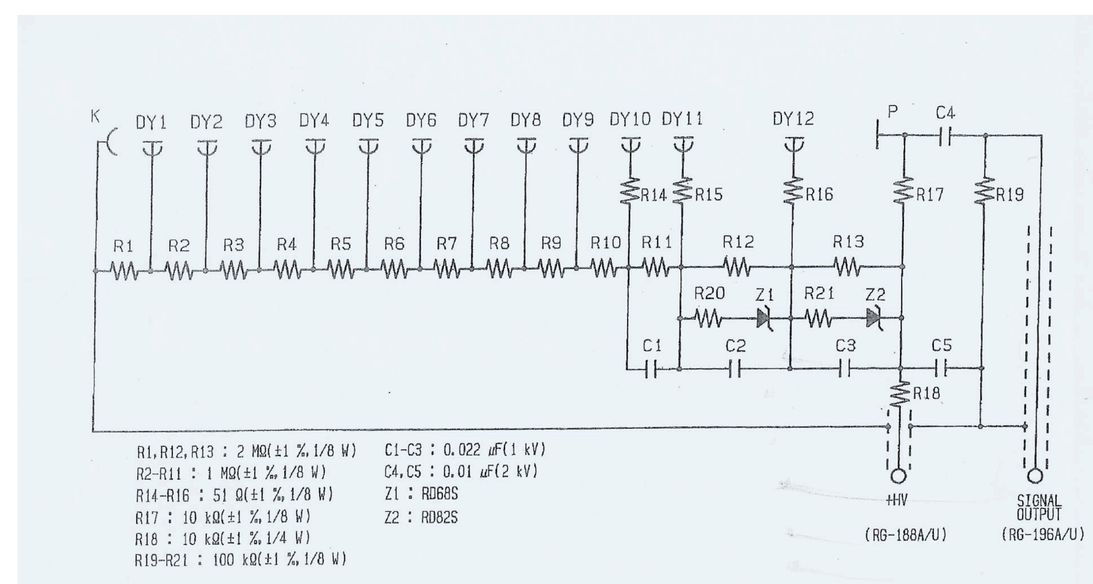




noise light on



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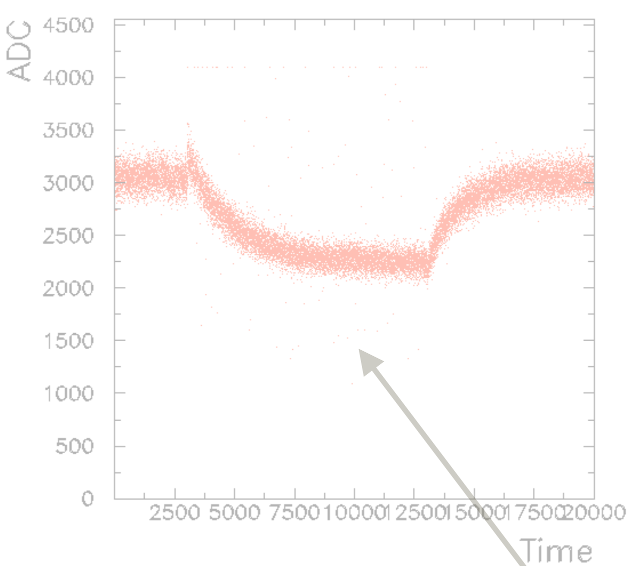
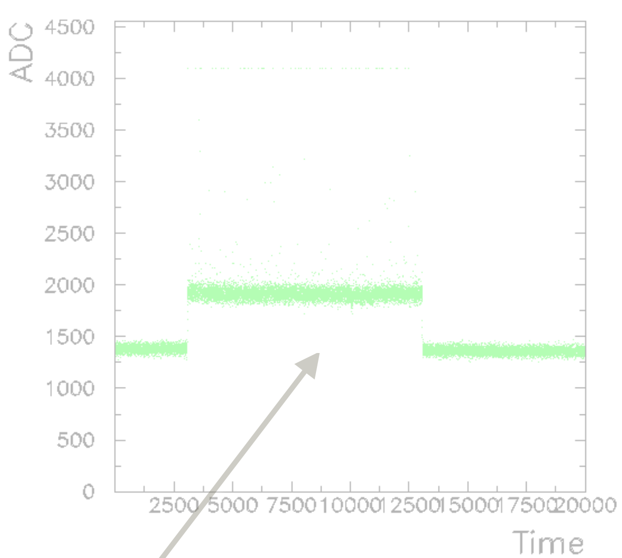
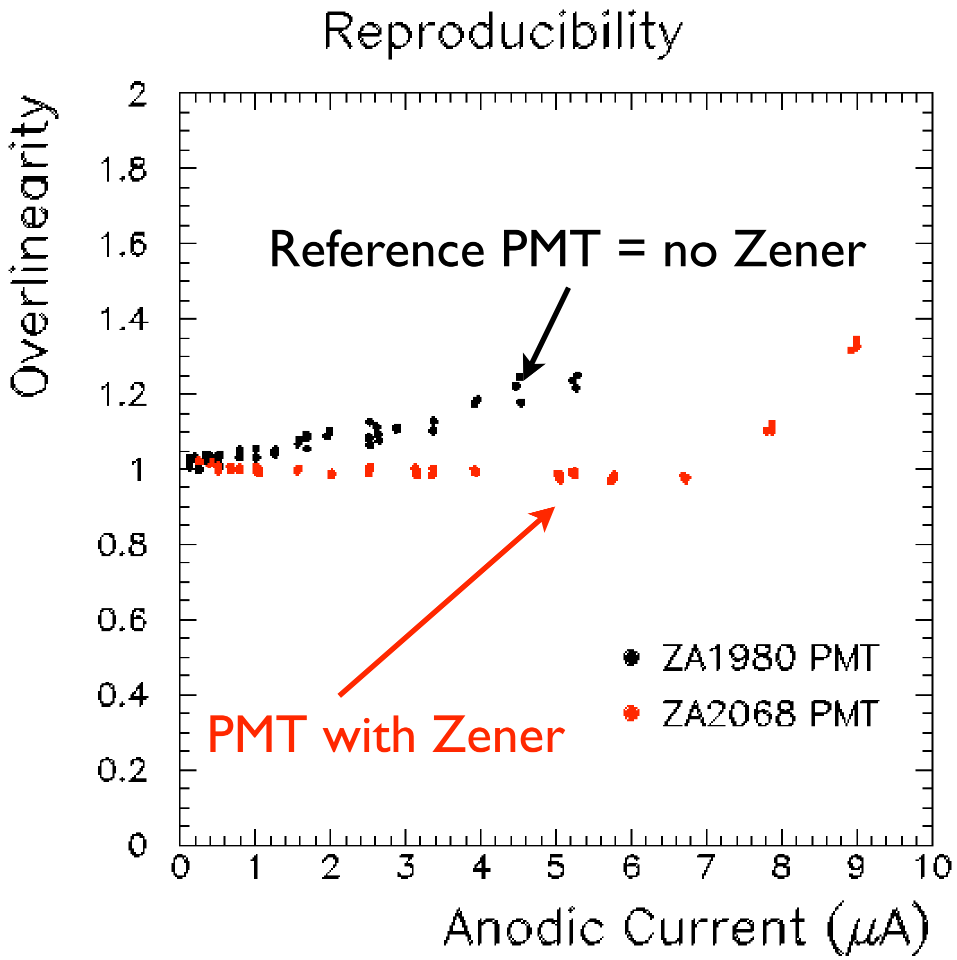


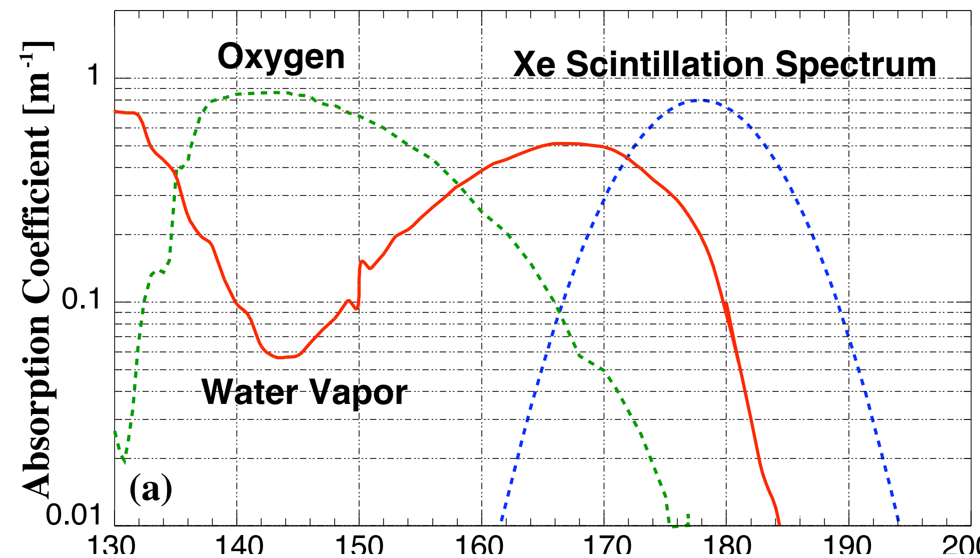


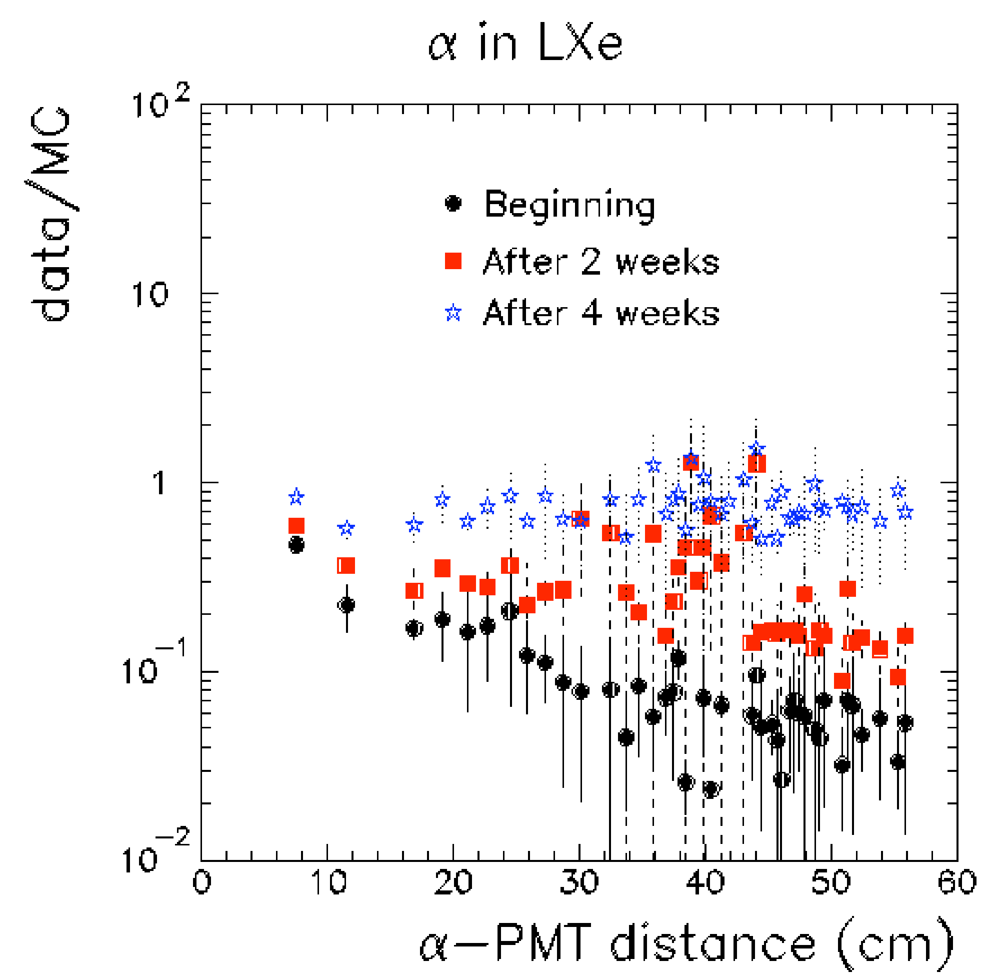
noise light on

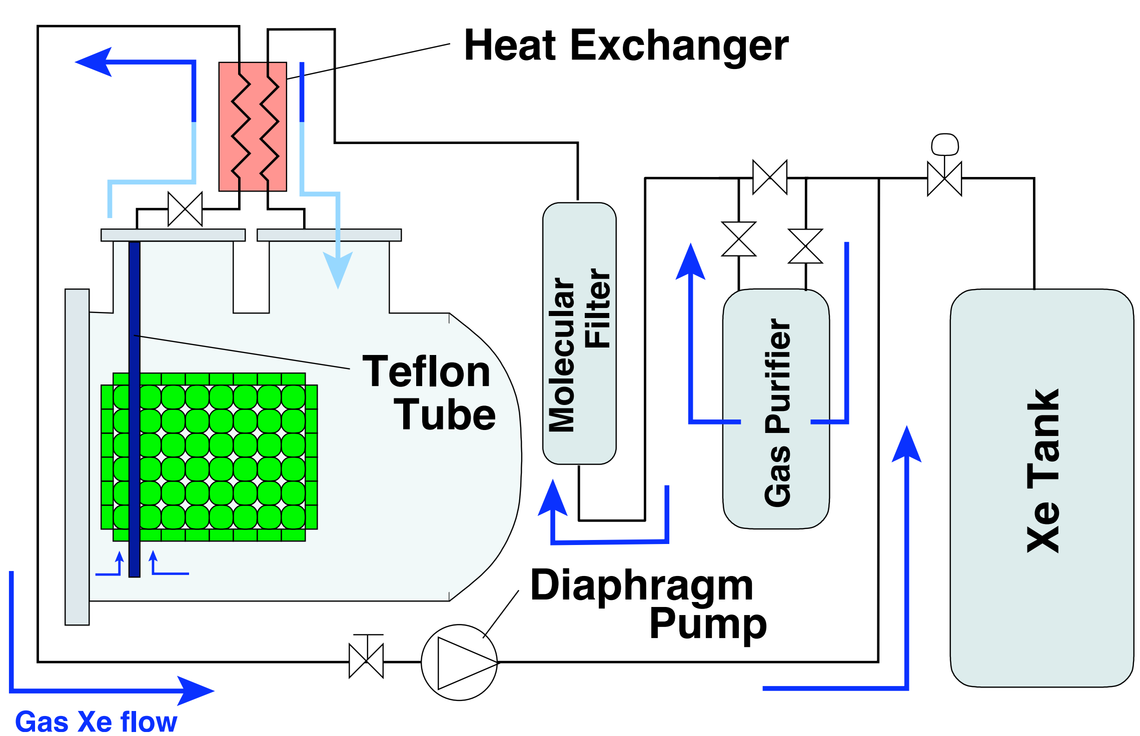


Xenon purity

- Energy resolution strongly depends on absorption
- We developed a method to measure the absorption length with alpha sources
- We added a purification system (molecular sieve + gas getter) to reduce impurities below ppb

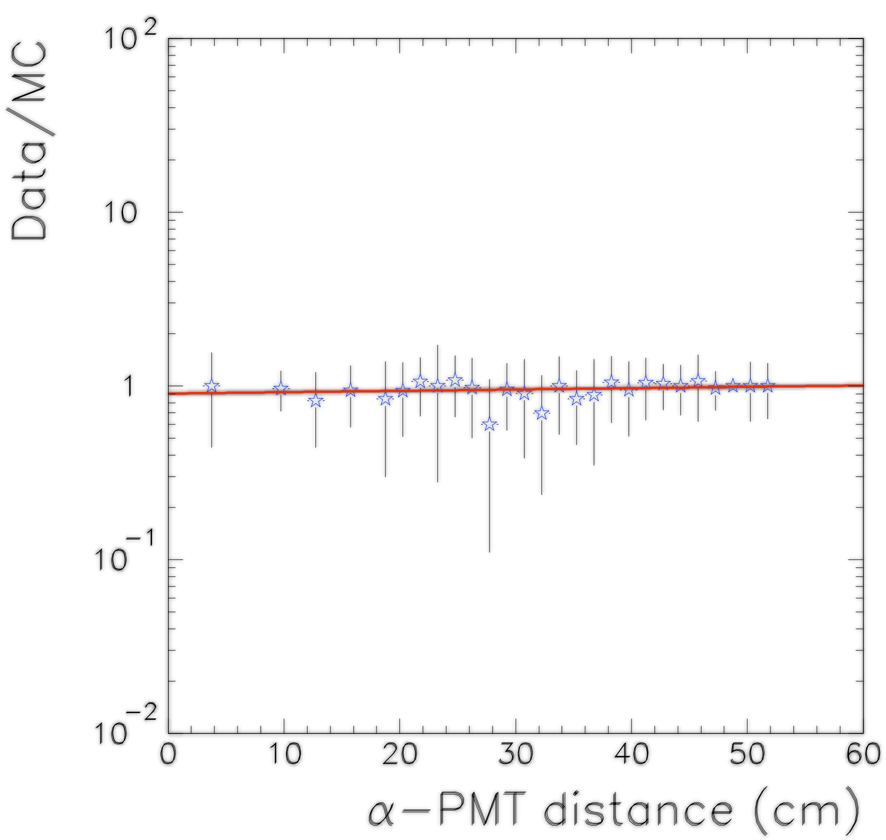


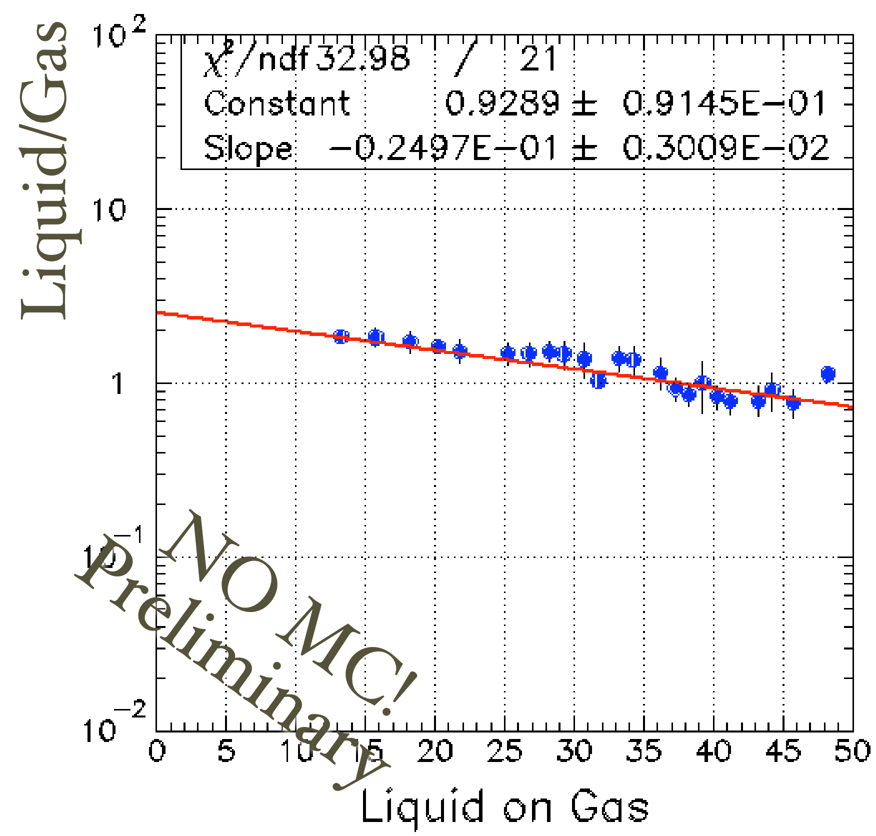




λ_{Abs} measurement

- It is possible to estimate a lower limit on the xenon absorption length
- Typical plots shown
  - $\lambda_{Abs} > 125$ cm (68% CL) or $\lambda_{Abs} > 95$ cm (95 % CL)
  - LY ~ 37500 scintillation photons/MeV (0.9 NaI)





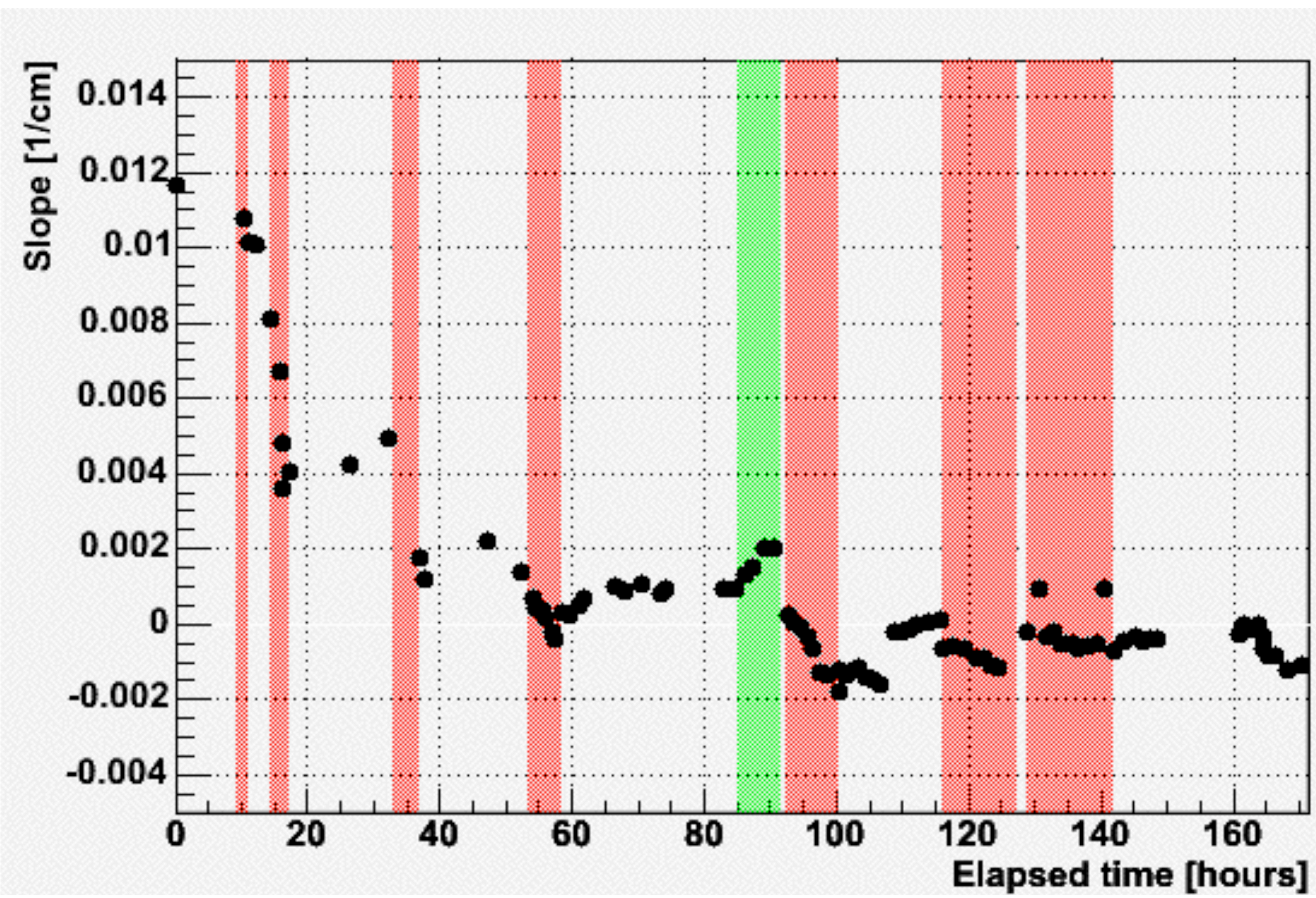
Attenuation = Rayleigh

$\lambda_{Att} \sim 40$ cm

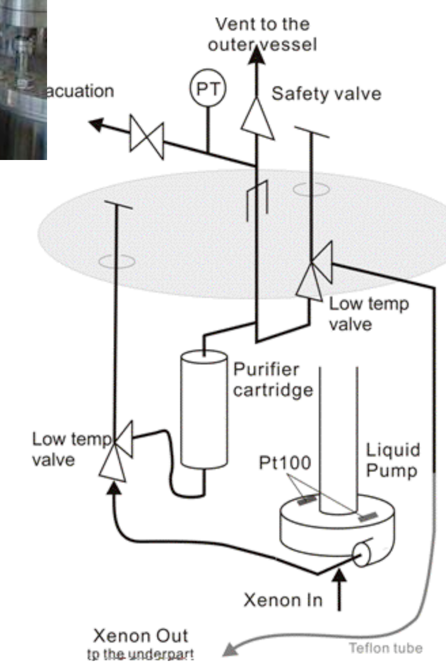
L.Y.(liquid) $\sim 3 \times$ L.Y.(gas)

Liquid phase purification

- Xenon circulation in liquid phase.
- Impurity (water) is removed by a purifier cartridge filled with molecular sieves.
- 100 l/hour circulation.



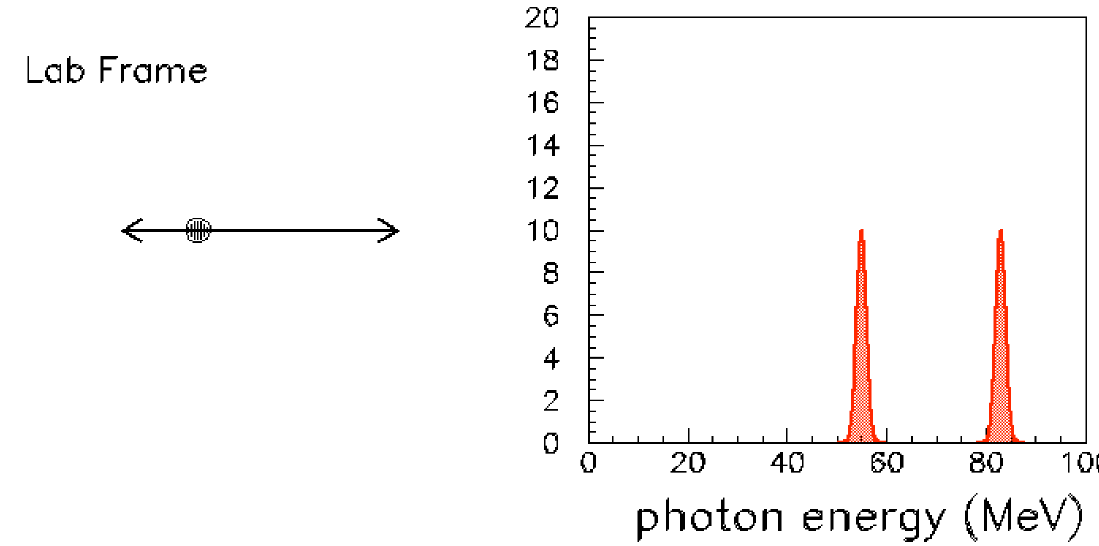
molecular sieve 13X
25g water



- Cryogenic fluid pump
  - Barber-Nicols BNCP-62-000
  - Flow rate: 100L/hr in liquid (design)
  - Rot. speed: 3175rpm

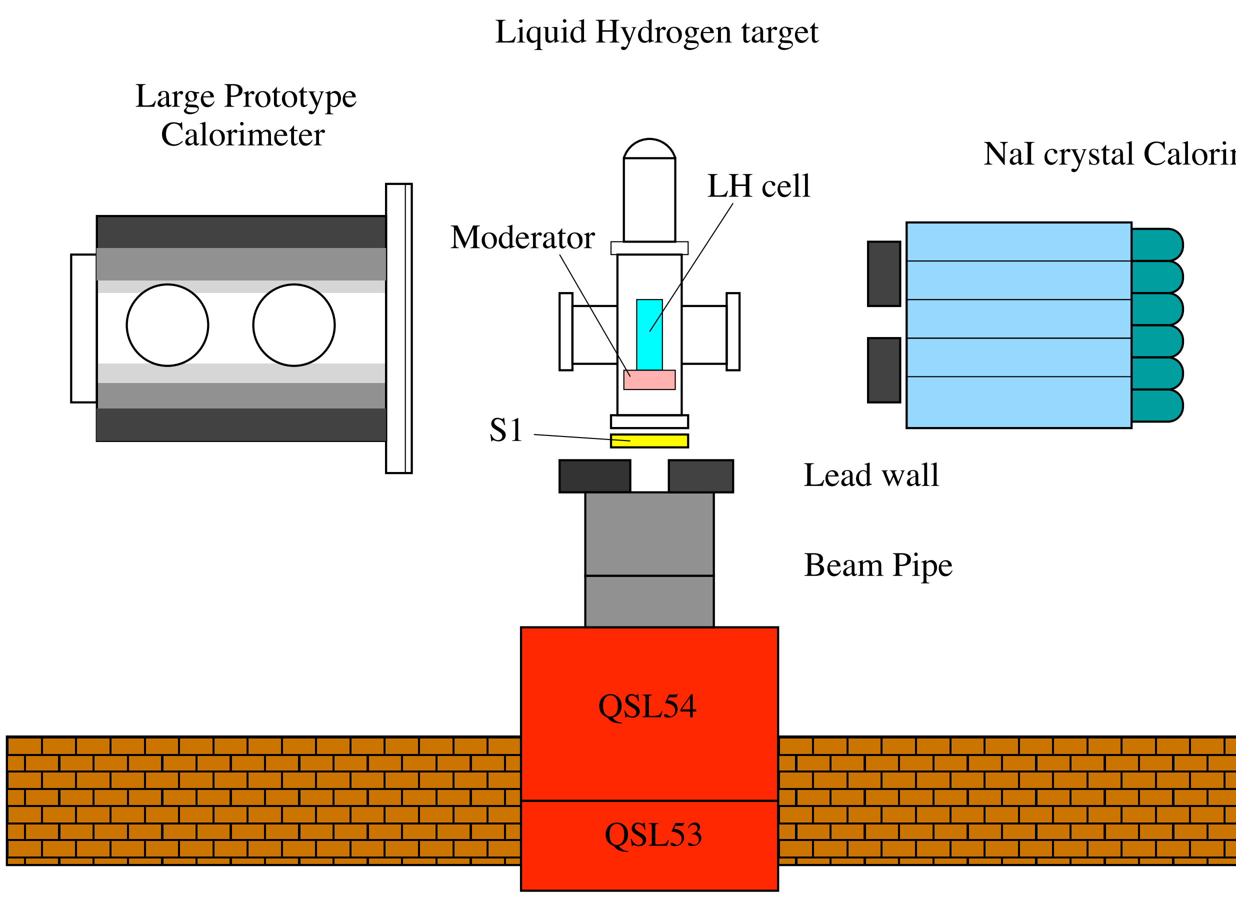
Energy resolution measurement

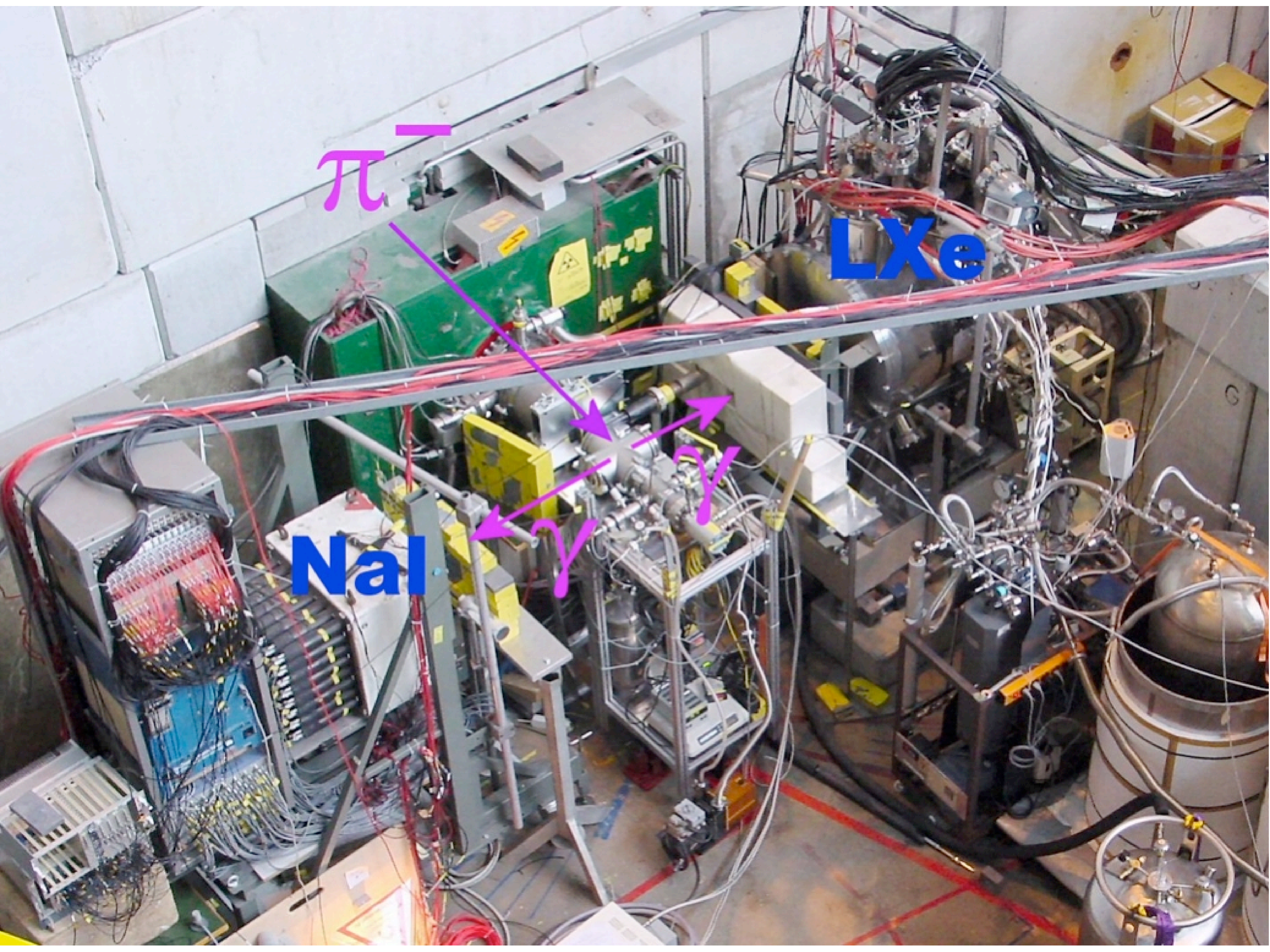
$$\pi^- p \to \pi^0 n$$
$$\pi^0 \to \gamma\gamma$$



- 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

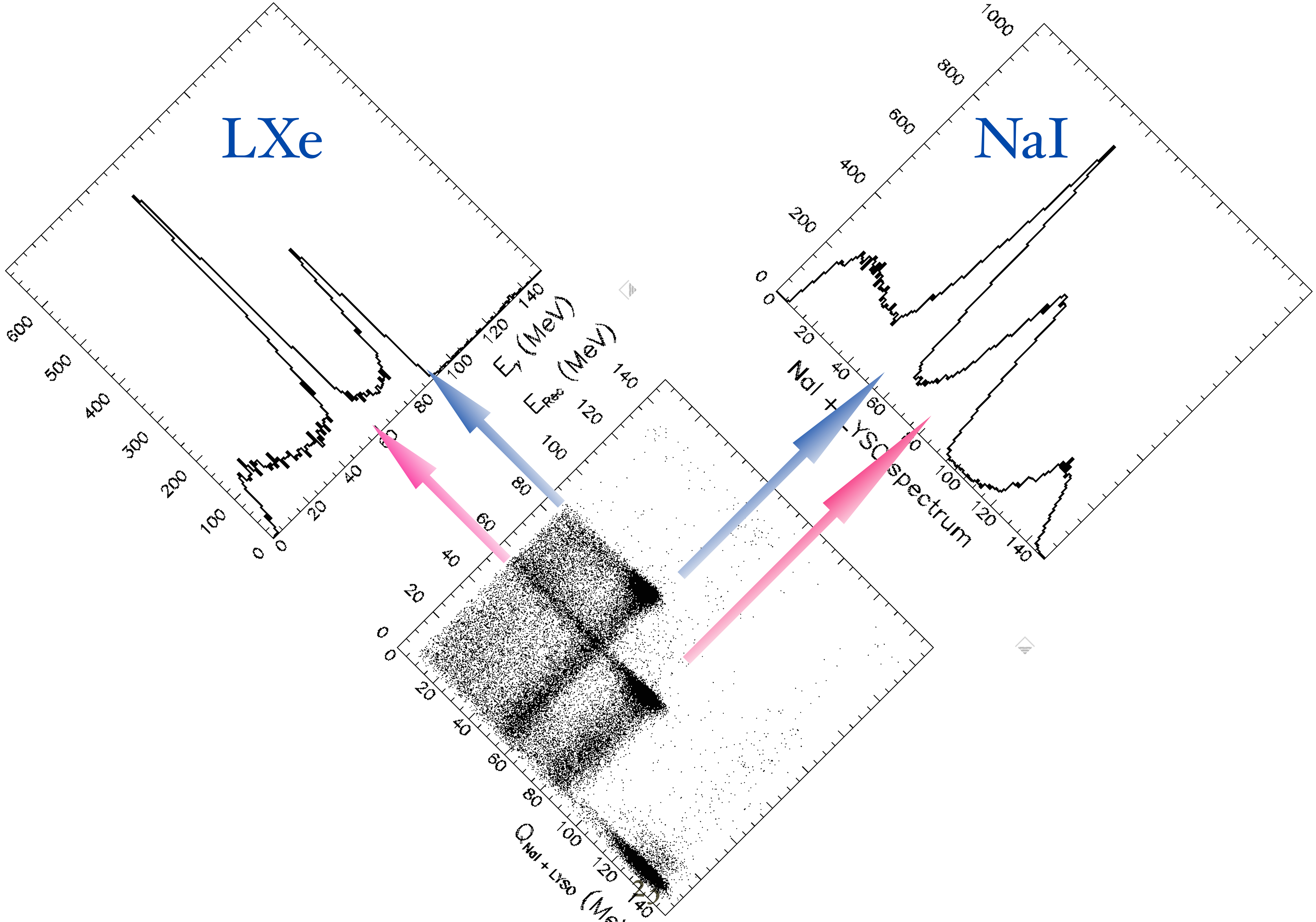
- Even a modest collimation guarantees a sufficient monochromaticity
- Liquid hydrogen target to maximize photon flux
- An "opposite side detector" is needed (NaI array)





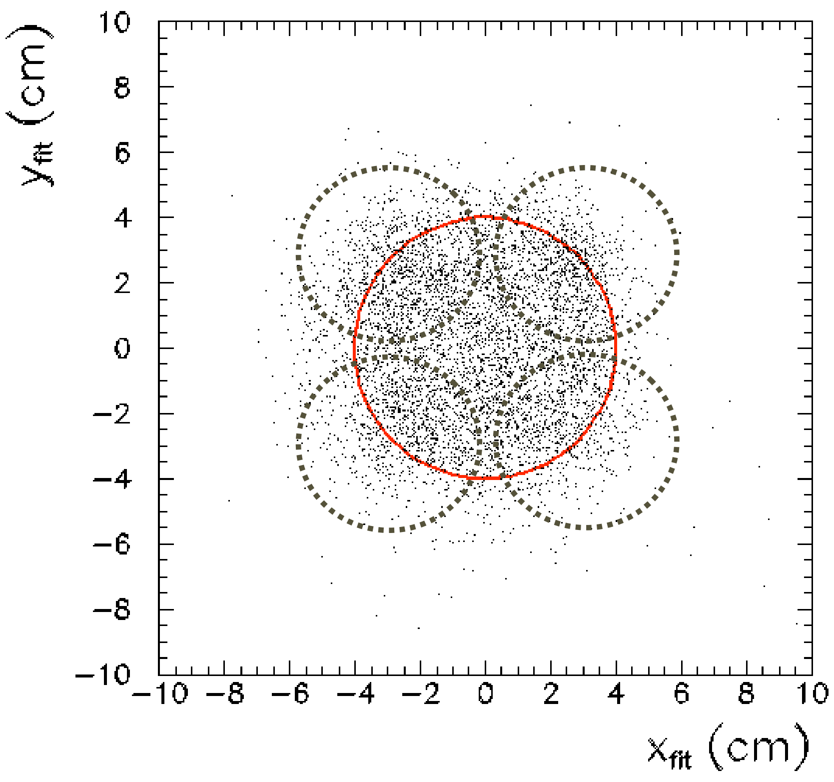
π⁻
LXe
γ
γ
NaI

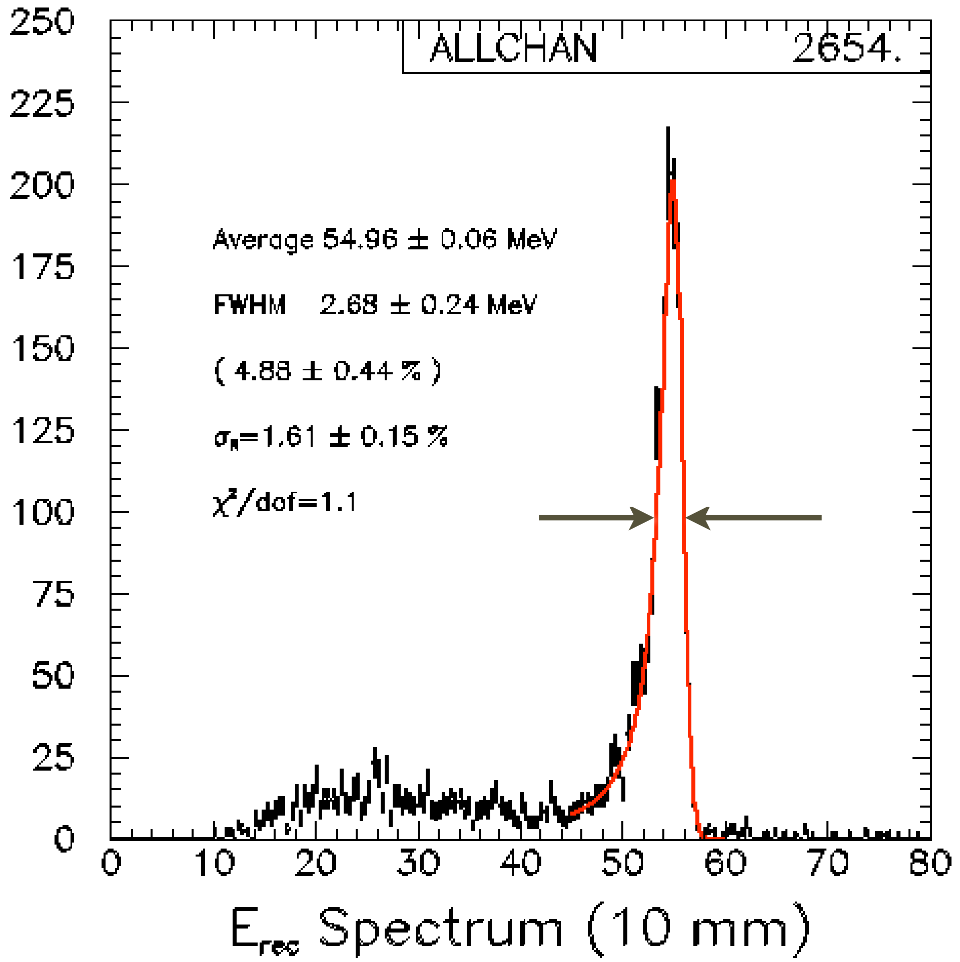
- In the back-to-back raw spectrum we see the correlation
  - 83 MeV ⇔ 55 MeV
  - The 129 MeV line is visible in the NaI because Xe is sensitive to neutrons (9 MeV)



Resolution @ 55 MeV

- Select negative pions in the beam
- 65 MeV < E(NaI) < 95 MeV
- Collimator cut (r < 4 cm)



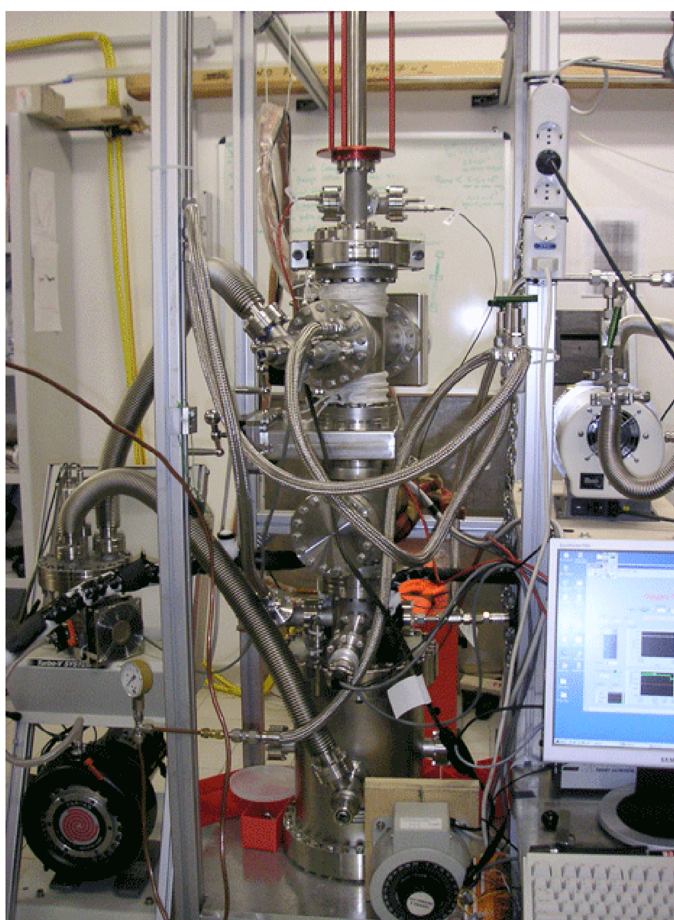
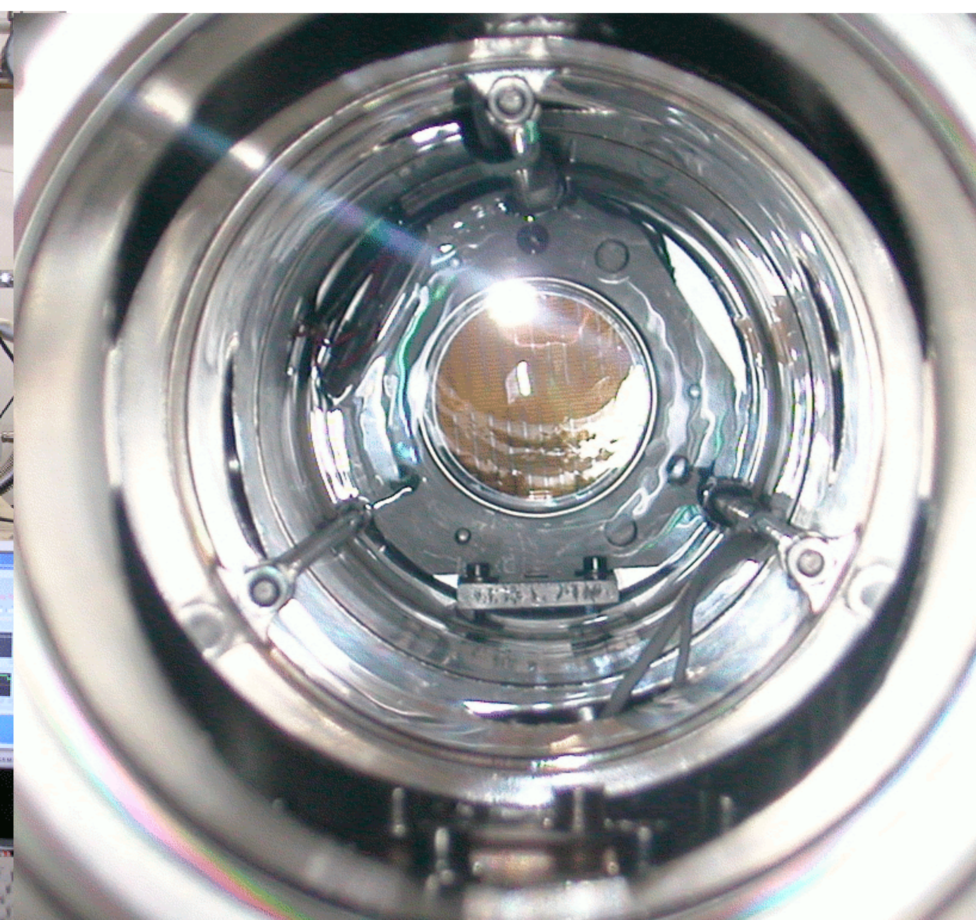
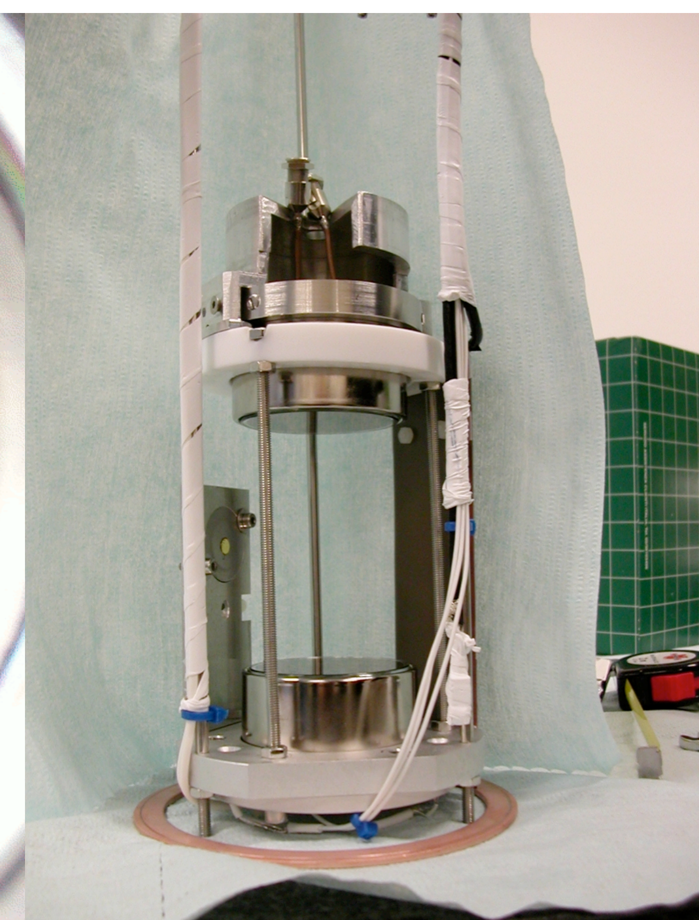


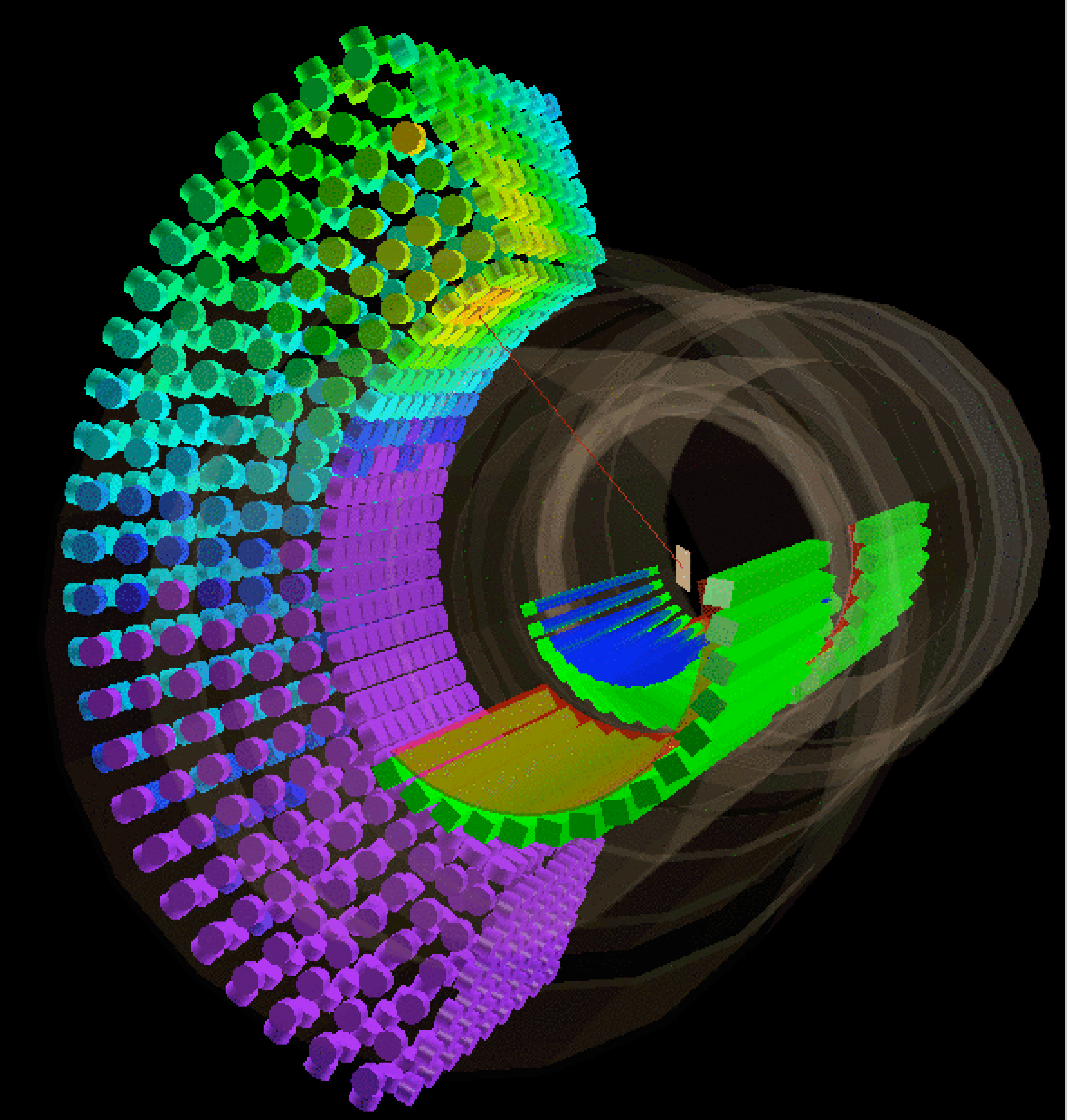
Resolution (FWHM)

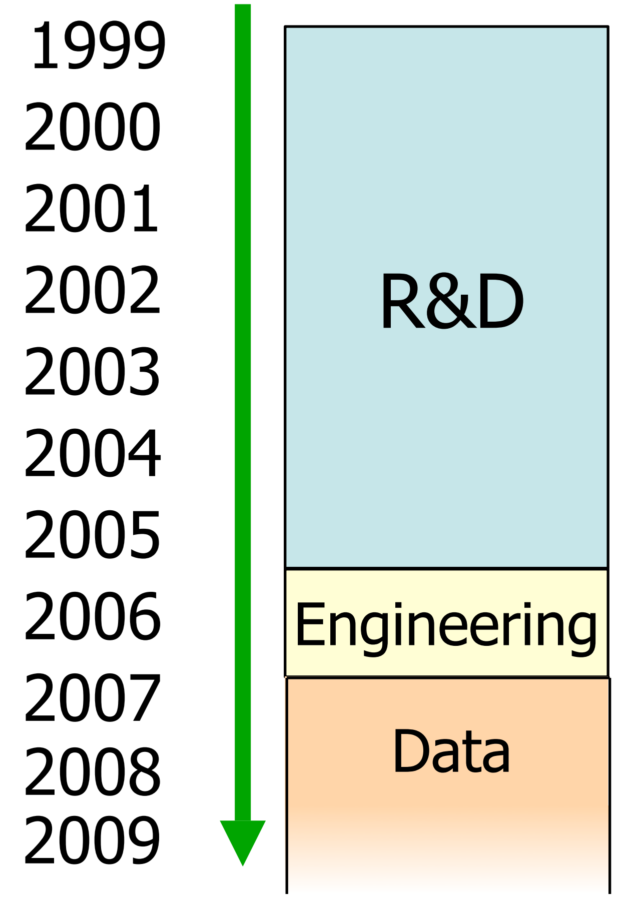
(4.9 ± 0.4) %

Conclusion

- The MEG experiment is expected to start engineering run in 2006
- Tests of the most advanced sub-detector were shown
    - Absorption length > 100 cm
    - Energy resolution < 5% FWHM at 55 MeV
    - Successful PMT and energy calibration and monitoring
- First application (to our knowledge) of sources on wires
- Tests of 800 PMTs for the final calorimeter ongoing in PSI / Pisa / Tokyo





Plans

- Data taking from 2007 on to reach 10^{-13} sensitivity (90% CL)
- Obtain a "significant" result before the LHC era
- Eventual reach 10^{-14} during LHC era

MEG sensitivity

- Computation of the sensitivity based on the measured resolutions

FWHM E_γ/E_γ	5 %
FWHM E_e/E_e	0.9 %
$\delta t_{e\gamma}$	105 ps
$\delta\theta_{e\gamma}$	23 mrad

- The resolutions determine the accidental background
- For a given background we choose R(μ) and running time.
  - BG = 0.5 events
  - R(μ) = 1.2 10^7 μ/sec
  - T = 3.5 10^7 sec (2 years running time)
  - ⇒SES = 6 10^{-14} (1.7 10^{13} muons observed)
- NO candidate ⇒ BR(μ→eγ) < 1.2 10^{-13} @ 90% CL
- Unlikely fluctuation (4 events) ⇒ BR(μ→eγ) ≈ 2.4 10^{-13}

Pulse-tube refrigerator

- MEG 1st spin-off
- Technology transferred to a manufacturer, Iwatani Co. Ltd
- Performance obtained at Iwatani
  - 189 W @165K
  - 6.7 kW compressor
  - 4 Hz operation