LXe (part B)

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MEG internal meeting

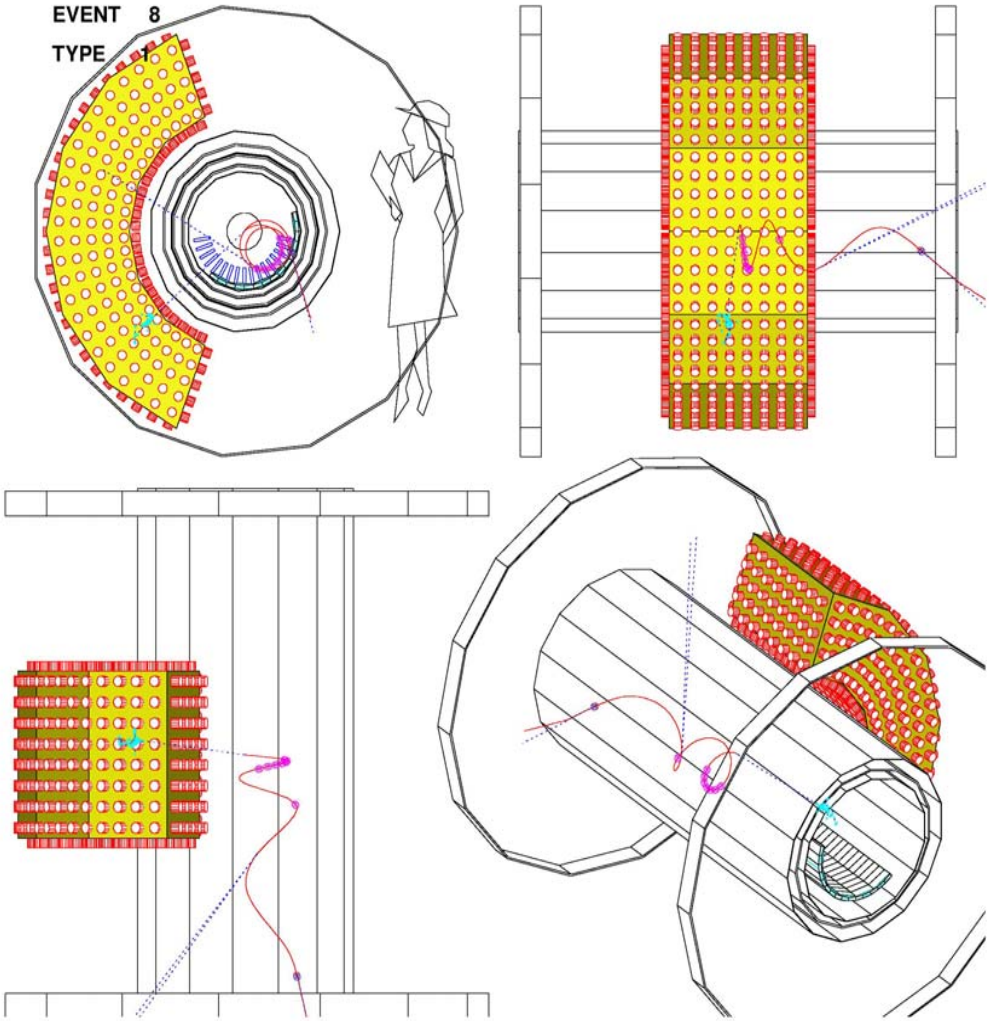
Outline

- MC:
  - shape-QE studies summary
  - pile up in LXe
- LP data analysis:
  - gain/QE/λ_{Abs}/λ_{Ray}
  - Radioactive Background
  - Timing resolution
  - v_{light}-n
  - Liquid Xe level

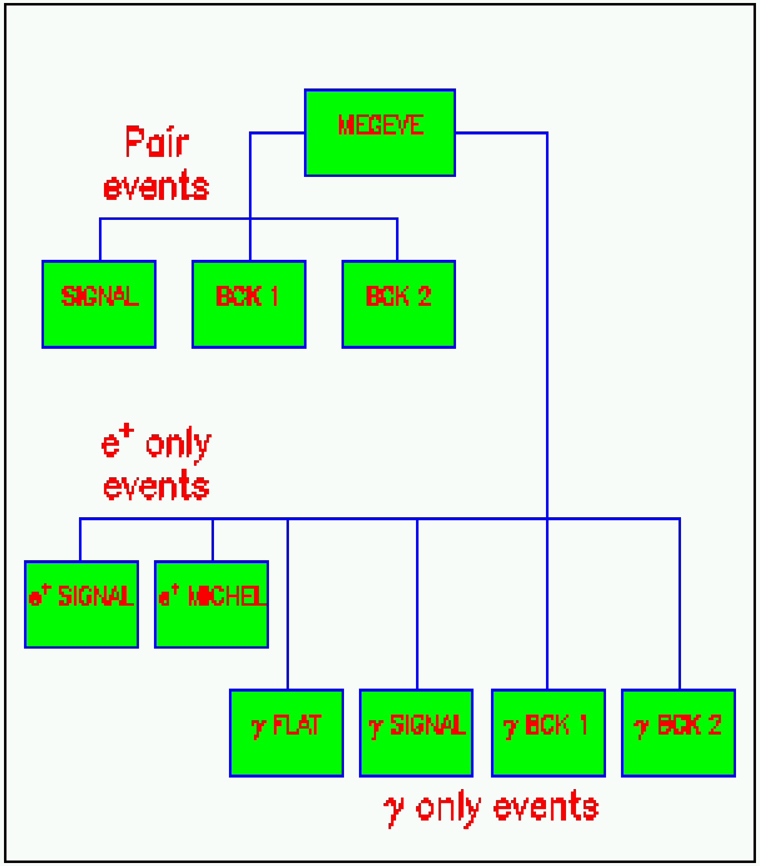
Monte Carlo

- QE - shape
- Pile-up
- segmentation

An example of $\mu \rightarrow e\,\gamma$ decay



Event Generation: MEGEVE



Pair events:

- Signal: $\mu \to e\gamma$
- Radiative decay (correlated bck)
- Michel positron + γ-bck

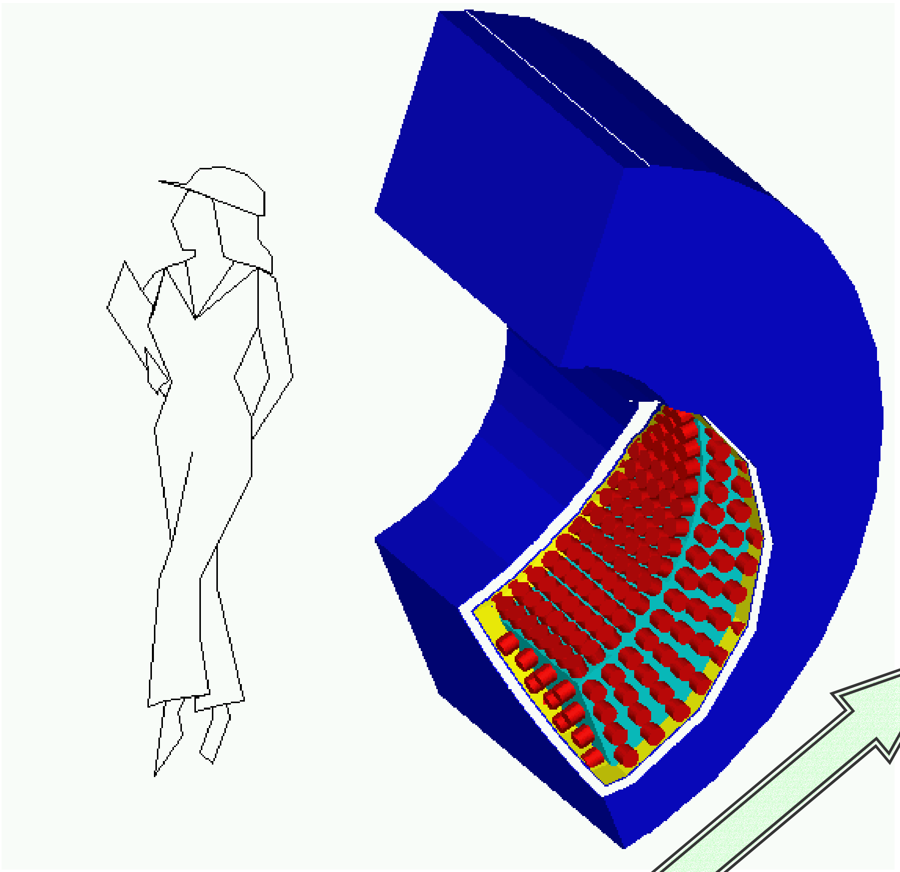
Positron only events:

- Signal positron
- Michel positron

Gamma only events:

- Signal γ
- γ with flat spectrum
- Bck: γ from radiative decay or annihilation in flight

Simulation of LXe calorimeter



Blu: external vessel (Al)

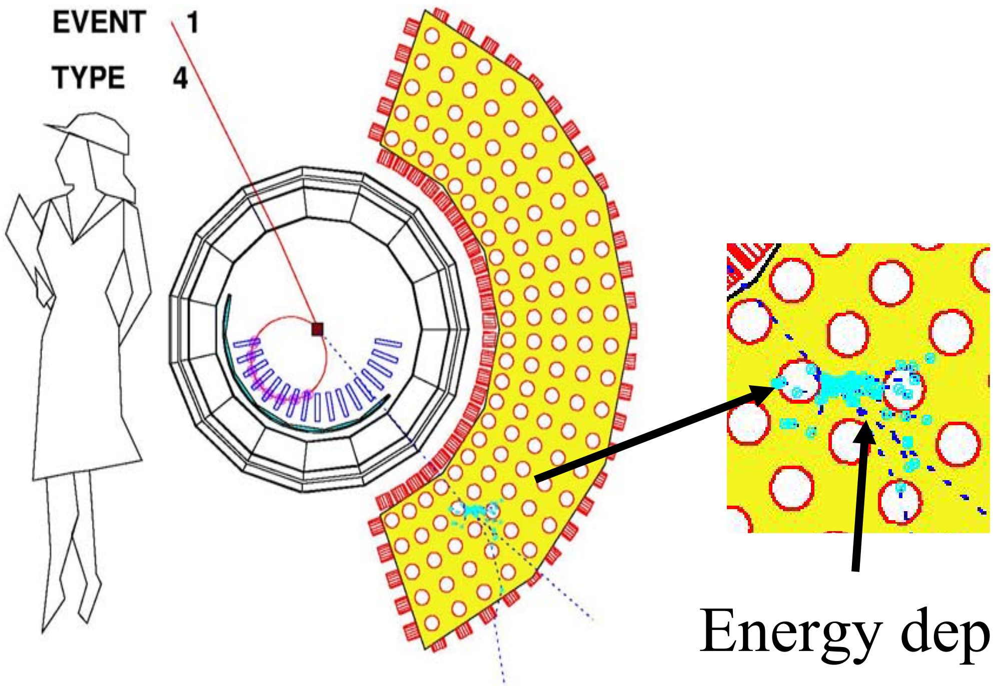
Yellow: honeycomb support (plastic)

Red: PMTs (glass mixture)

- $0.8\ m^3$
- 848 PMTs (312 FF)
- $65 < r < 112$ cm
- $|\cos\theta| < 0.35$
- $|\varphi| < 60^o$

Maximum PMT density on Inner Face (FF)

γ interaction in Lxe.



Energy deposit

E

Interaction point

θ, φ, z, t

- Scintillation photons are traced inside the liquid Xenon and followed until they reach the PMTs
- Absorption and diffusion may occur

LiXe energy resolution

QE studies:

QE	λ_{abs}=1 m	$\lambda_{abs}=\infty$
5%	6%	2.0%
10%	6%	1.7%
20%	6%	1.5%

- Ineffective for short absorption length
- Important for timing resolution (see later on…)

Shape studies:

Compare LiXe and a VLP (100 x 50 x 50 cm^3) to check the effects of a different geometry on position and energy resolution.

- no difference with the curved detector for position resolution (10.6 mm FWHM in both cases for a realistic situation); **a 3% systematic correction** is needed on both coordinates for VLP
- slight improvement in energy resolution (from 4% to 3.5%);
- however, more critical problems of energy containment

a much larger volume (1.5 m^3) of Xenon would be needed (and PMTs!).

LiXe energy resolution

QE studies:

•Ineffective for short (1 m) absorption length

•Important for timing resolution (see later on…)

QE	λ_{abs}=1 m	$\lambda_{abs}=\infty$
5%	6%	2.0%
10%	6%	1.7%
20%	6%	1.5%

Shape studies:

Curved vs BOX (100 x 50 x 50 cm^3): different geometry on position and energy resolution.

• position resolution: no difference. (10.6 mm FWHM)

  •**a 3% systematic correction** is needed on both coordinates for VLP

• energy resolution: slight improvement (from 4% to 3.5%);

• energy containment: more critical problem

a much larger volume (1.5 m^3) of Xenon would be needed (and PMTs!).

Position evaluation

- weighted average of PMT charge (bias !);
- PMT with the maximum charge only (trigger);
- MINUIT fit on all PMTs;
- MINUIT fit on the Inner Face only;
- MINUIT fit on a circle around the PMT with the maximum charge;
- MINUIT fit on a circle around the PMT with the maximum charge (improved).

Best results with the fifth method: $\sigma_x \approx \sigma_y \approx 5\,\mathrm{mm}$

Energy evaluation

Energy reconstruction requires **more sophisticated algorithms** than a simple "sum of charges" **(Q_{sum})**.

Two methods:

❖ **full MINUIT fit** on expected vs measured charge on all PMTs:

$$Q_{\mathrm{expected}} = \frac{\mathbf{const}\, E \exp(-r_{eff}/\lambda)}{r^2} \Delta\Omega$$

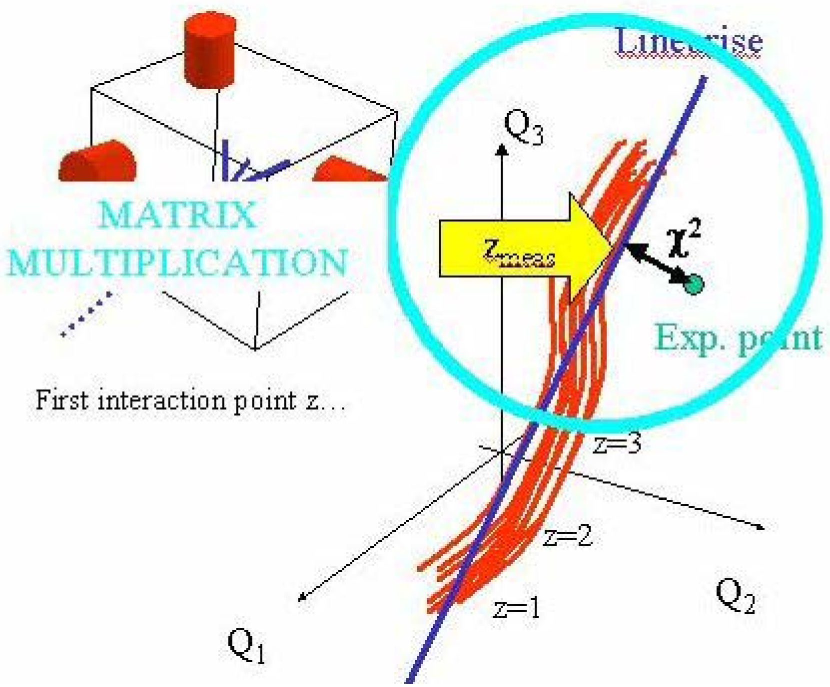
$\Delta\Omega$ = PMT solid angle as seen from the interaction point;
r_{eff} = effective path in LXe for taking into account diffusion.

It requires a shower model (dipole) and long time.

❖ principal component analysis:

- A vector of **parameters** **$\{p_i\}$ = E, θ, φ, z…**
- A vector of **observables** **$\{q_j\}$ = PMT charges**

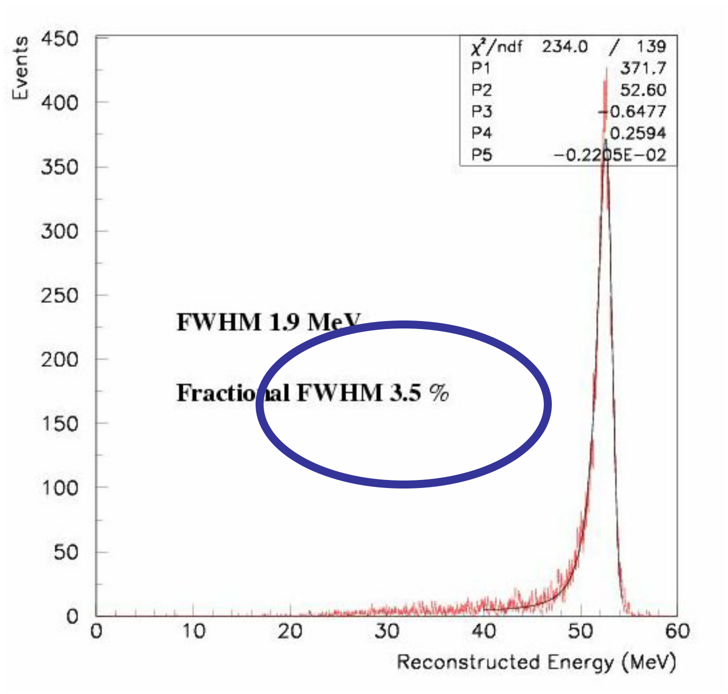
$$\{q_j\} \rightarrow \{p_i\}$$

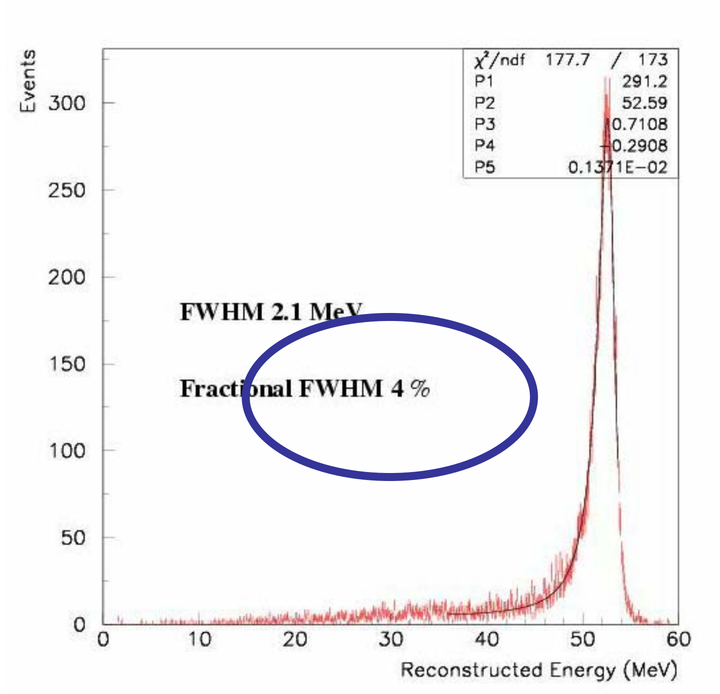


Energy resolution comparison

•Absorption length = 1 m, various positions

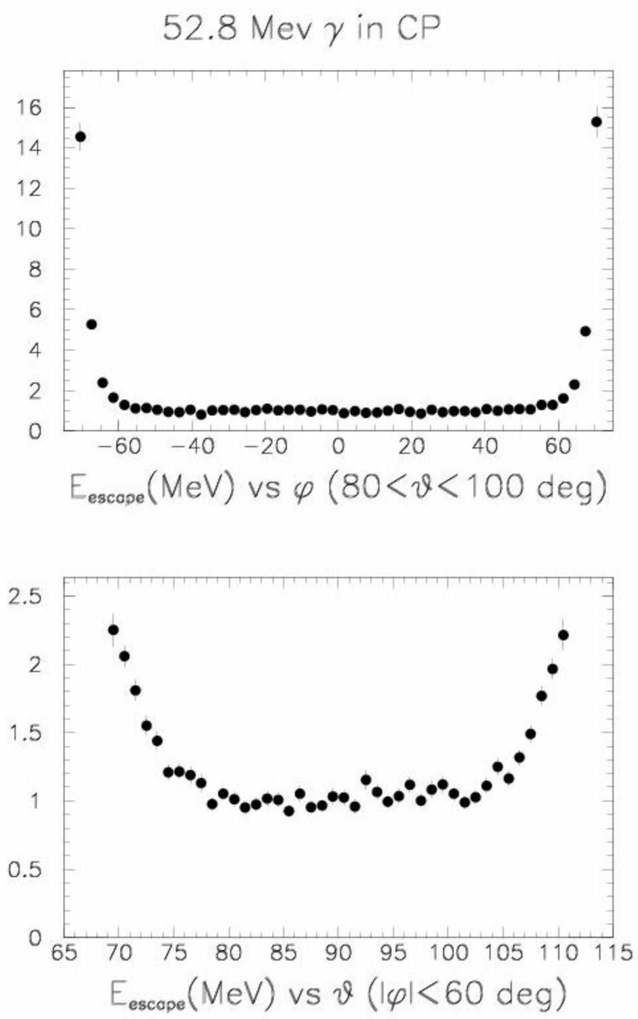
•linear fit (PCA)





VLP: 3.5 % **Curved detector: 4 %**

Energy escape (LiXe)



$\cos 70^0 = 0.34$

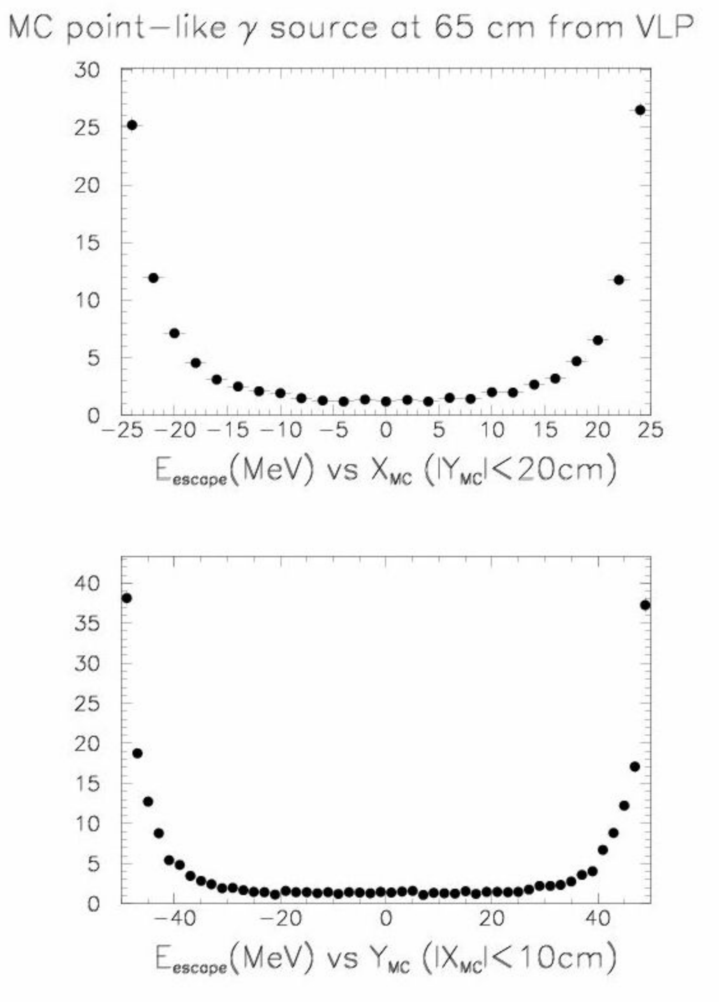
The fiducial region:

$-60 < \varphi < 60$

$|\cos \theta| < 0.35$

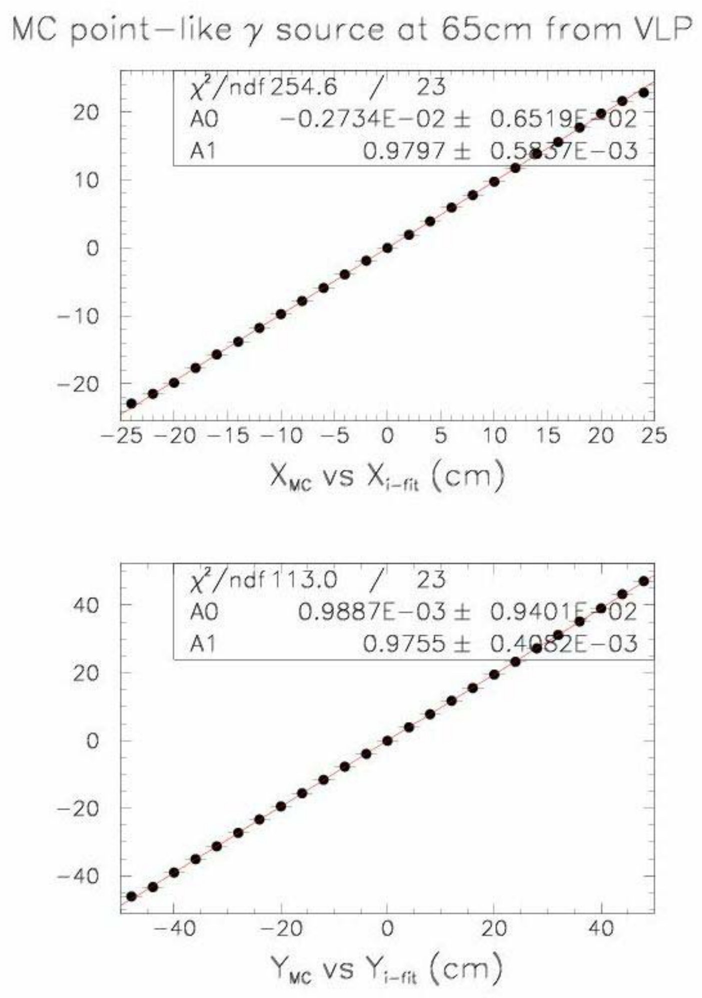
looks ok !

Energy escape from VLP



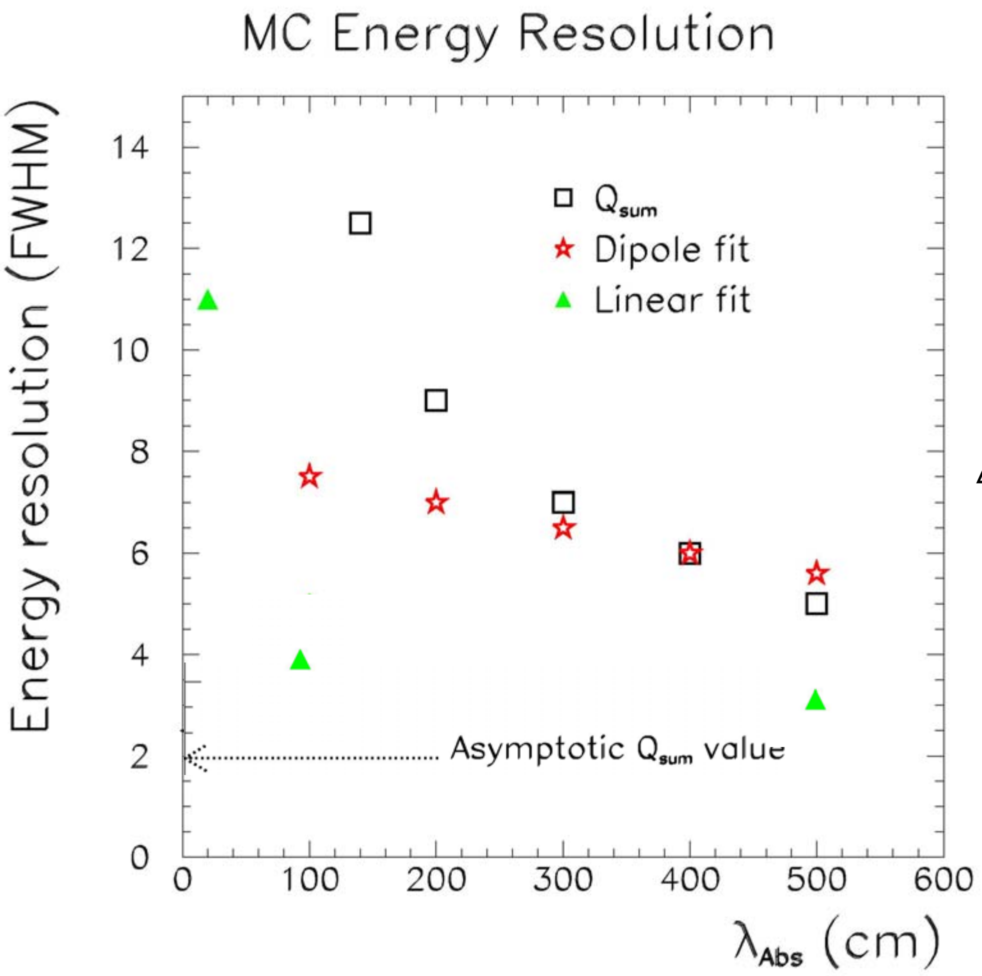
Significant energy losses also **rather close to the center.**

Position correction



No bias needed for position reconstruction in proposed detector !

Energy resolution vs. absorption

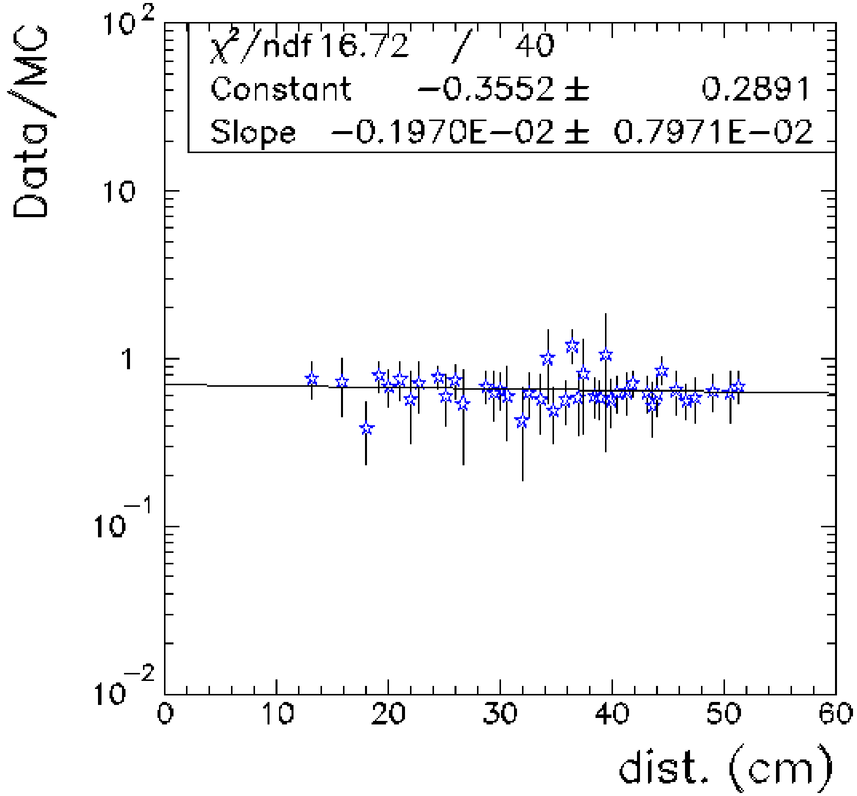


$\Delta E/E < 4\%$ for $\lambda_{Abs} > 1$ m

(linear fit, PCA)

λ_{Abs} for last test

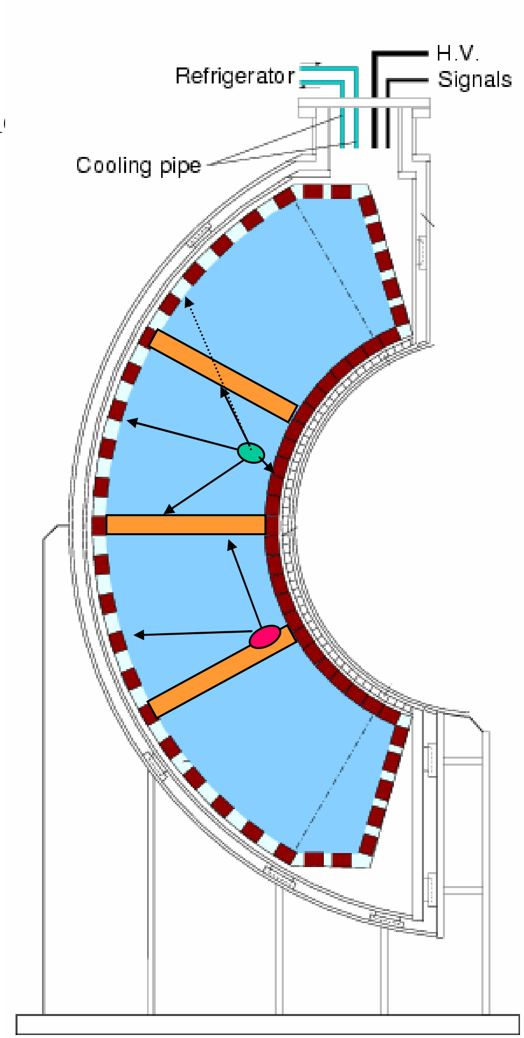
Observed/Expected light vs distance



$\lambda_{Att.}$>1 m

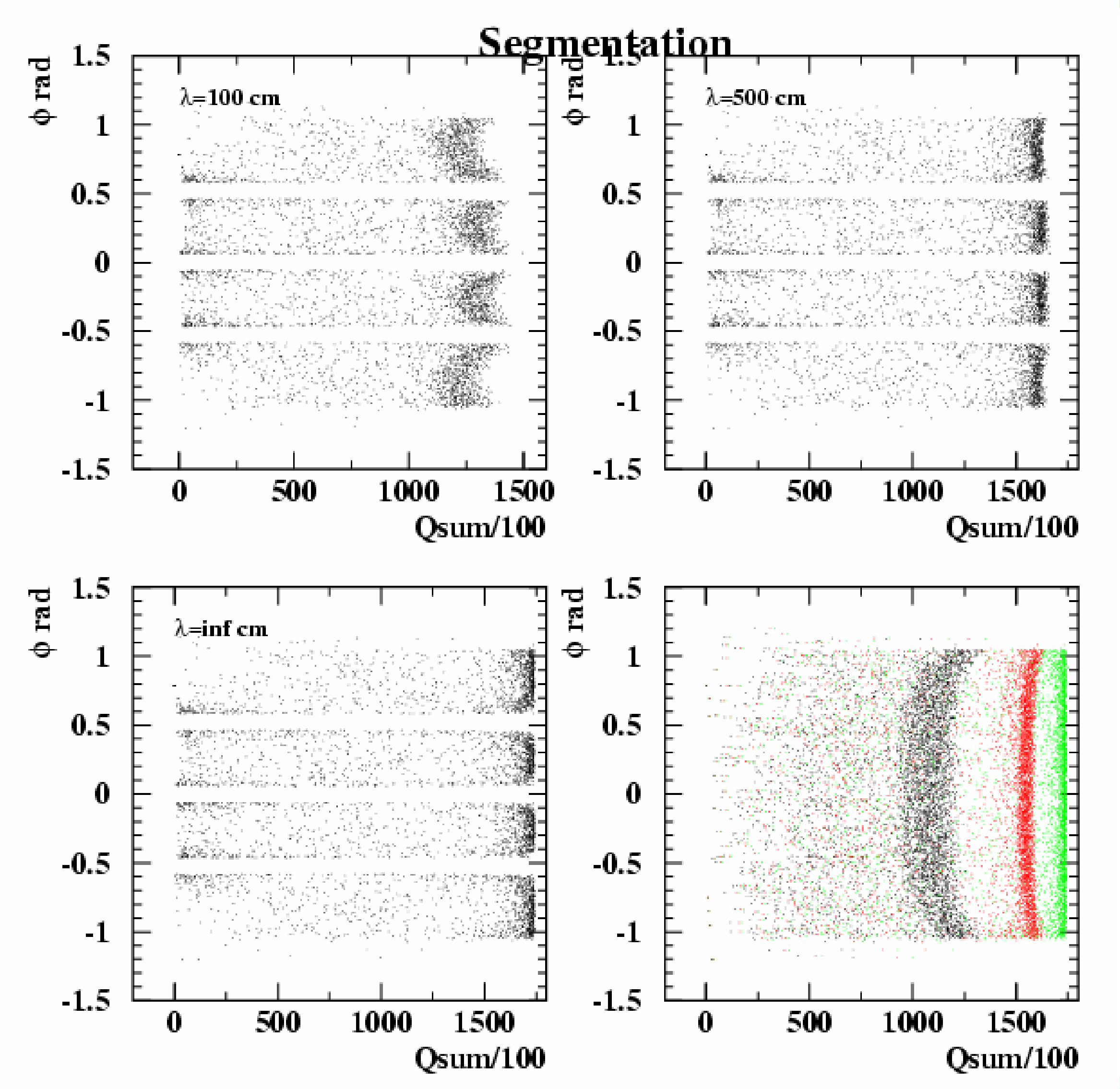
Segmentation

- 6 layers of PMTs inserted at –30, 0, and 30 degrees
  - PMTs are placed on all walls **with maximum density** to keep the homogeneity same in both segmented and non-segmented cases.
  - Resolution is estimated by using simple Qsum
- We can observe more pe in case of short λ_{abs}
  - λ_{abs}=1m: resolution 15.4%→11%
- We loose efficiency due to the dead volume occupied by inserted layers of PMTs in any case.
- In case of long λ_{abs}, energy leakage in the PMT layers cause deterioration of resolution in addition to the efficiency loss.



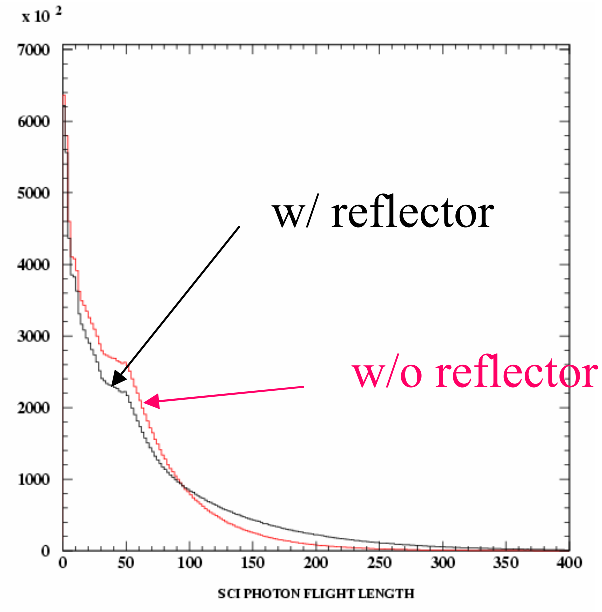
λabs	non-segmented	segmented	Eff loss(relative)
1m	15.4%	9.7%	11%
5m	3.7%	3.7%	28%
∞	1.5%	2.0%	44%

Segmentation[2]

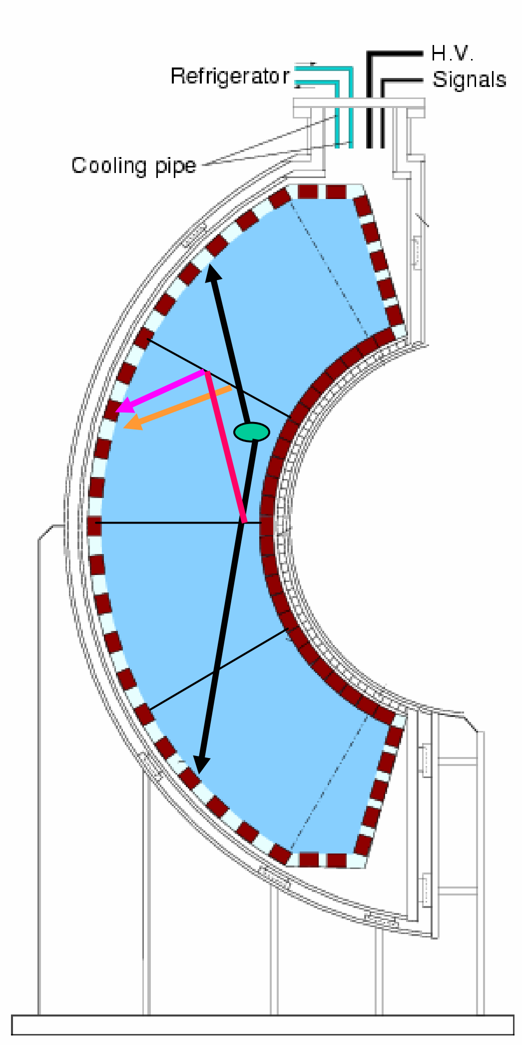


Reflector

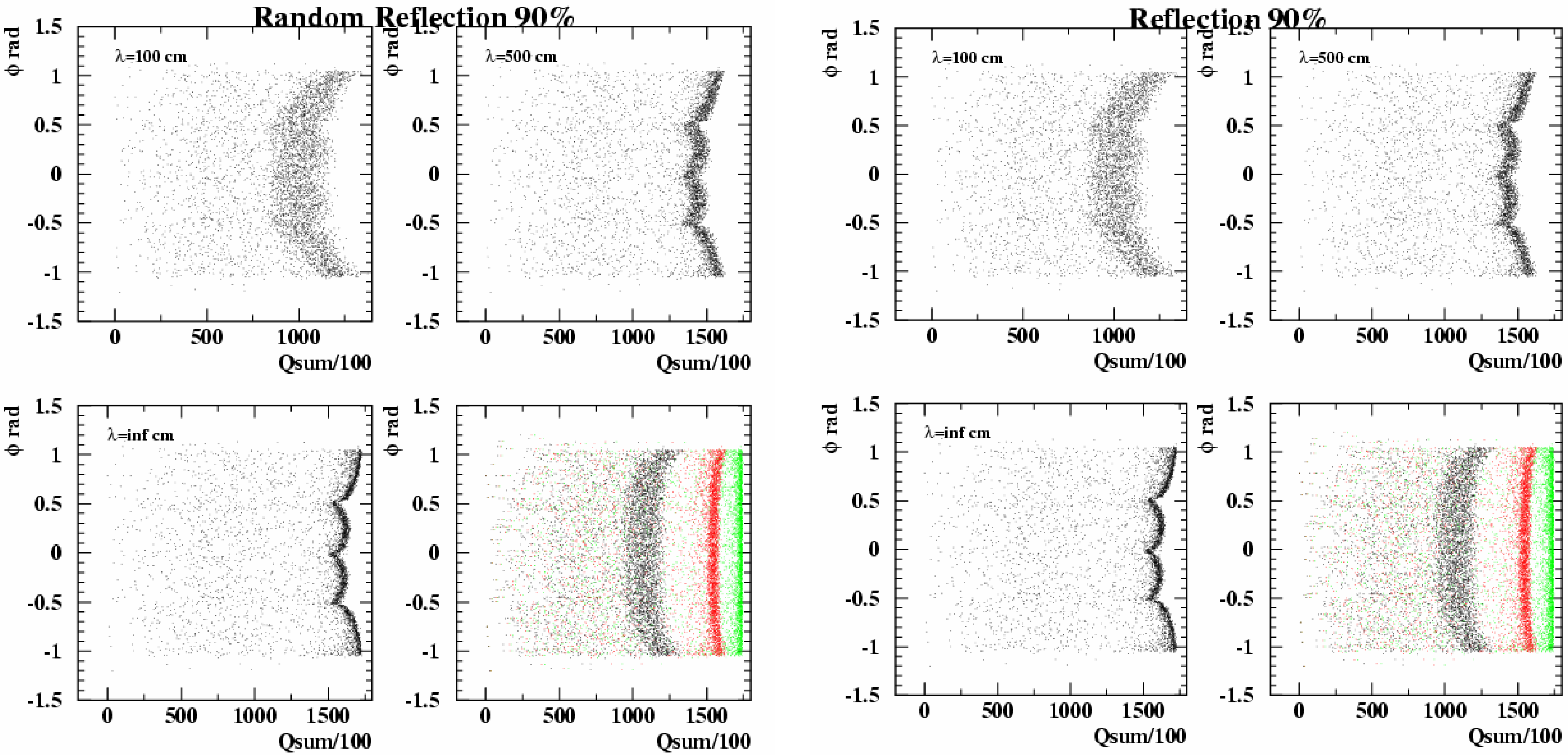
- Reflector does not help to reduce the path length of scintillation light.
- Reflection efficiency (< 100%) can cause nonuniformity.



λ_{Ray}=30cm
Ref eff =100%
No absoption



Reflector[2]



Random Reflection 90%
Reflection 90%
λ=100 cm
λ=500 cm
λ=inf cm
φ rad
Qsum/100

Pile-up and sensitivity

	FWHM
ΔE_e	$0.7 \div 0.9\%$
ΔE_γ	4%
$\Delta\theta_{e\gamma}$	$17 \div 20.5$ mrad
$\Delta t_{e\gamma}$	0.15 ns

And S.E.S. $3.6 \div 5.6 \times 10^{-14}$

$2 \div 3 \times 10^{7}\ \mu^{+}$/sec

In the 90% acceptance window

Prompt background:

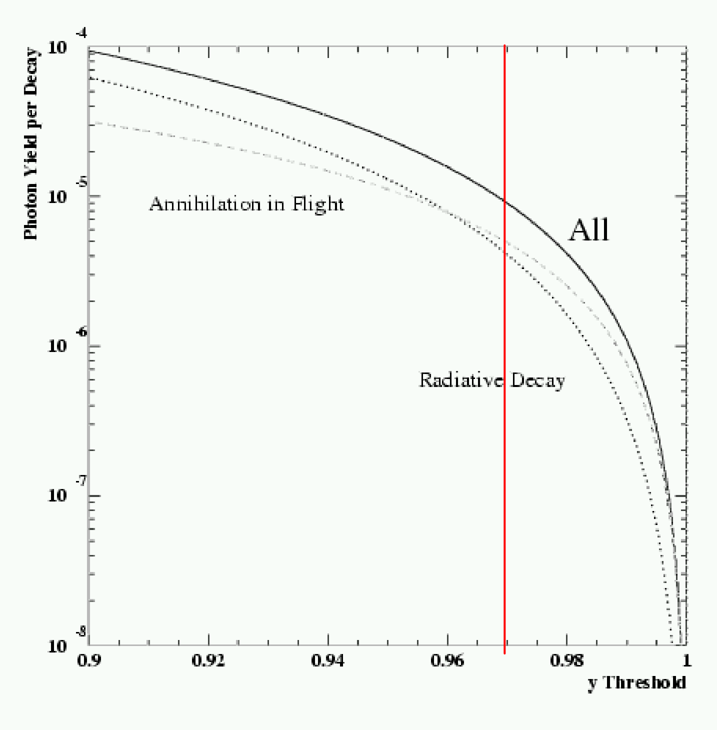
$3 \div 4 \times 10^{-15}$ per μ^{+} decay

Accidental background:

$2.2 \div 3.5 \times 10^{-14}$ per μ^{+} decay

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

$e^{+}e^{-} \rightarrow \gamma\, \gamma$

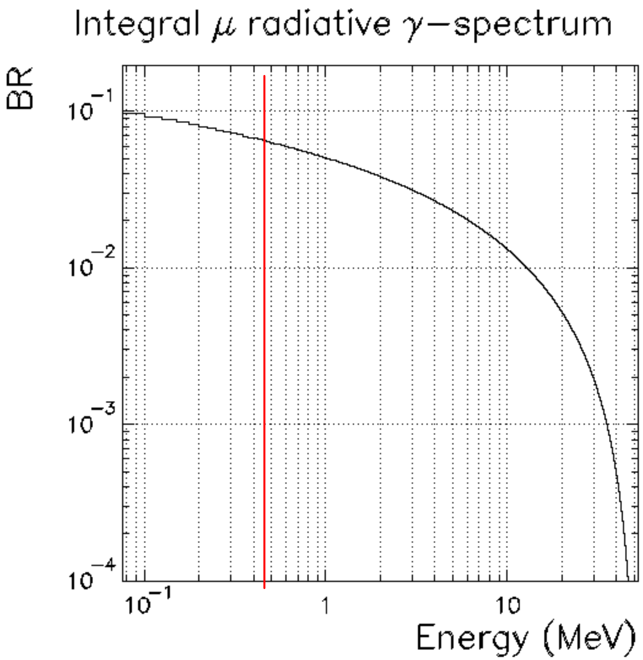


Besides these high energy photons...

FULL SIM of pile up in LXe

Rate=2÷3 10^7 μ/sec

There is a **180 kHz** rate of photons with **E>0.5 MeV** due to $\mu \rightarrow e\, \nu\, \nu\, \gamma$



FULL SIMULATION!

How often an accidental superposition of **two** background events gives a signal in the 90% acceptance window around 52 MeV?

1 intrusion every 50 gates 100 ns wide

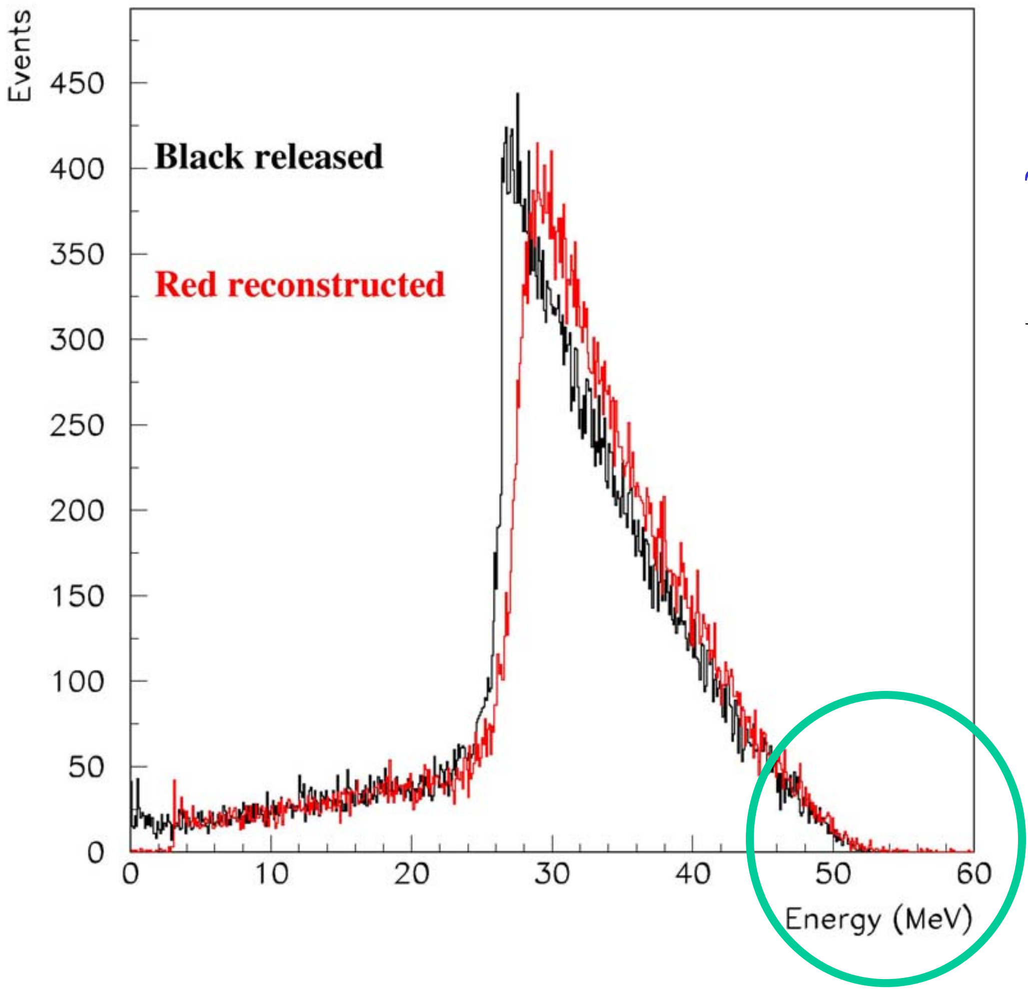
With this proportion add the signals PMT by PMT

Perform the energy reconstuction

+ 5% events in the signal region

Made use of no topological cut (clusters, electron, pulse shape….)

Reconstruction of bkg events



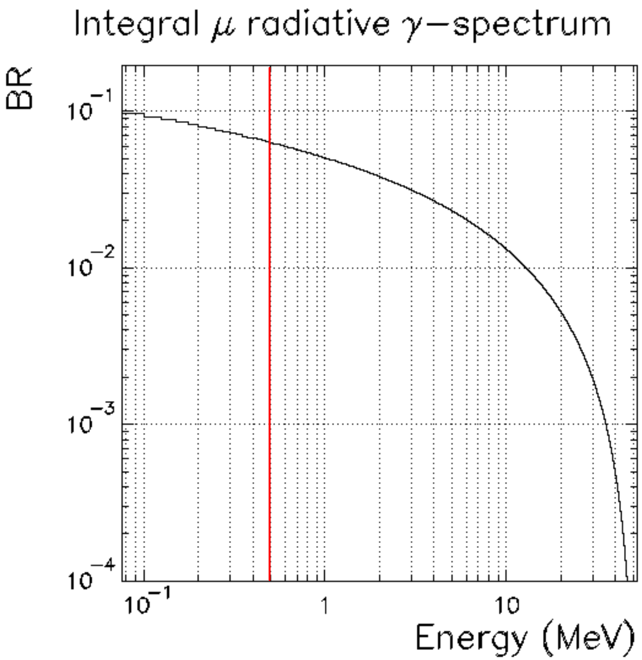
γ's from radiative decay; set of constants computed using **signal events**.

A small bias, but **very small spill-in of background** in the signal region.

FULL SIM of pile up in LXe

Rate=2÷3 10^7 μ/sec

There is a **180 kHz** rate of photons with **E>0.5 MeV** due to μ→e ν ν γ



How often an accidental superposition of **two** background events gives a signal in the 90% acceptance window around 52 MeV?

1 intrusion every 50 gates 100 ns wide

With this proportion add the signals PMT by PMT

Perform the energy reconstuction

10 % increase in the acceptance window for the radiative fraction

2.5 % increase in the acceptance window for the annihilation-in-flight fraction

→ + 5% events in the signal region

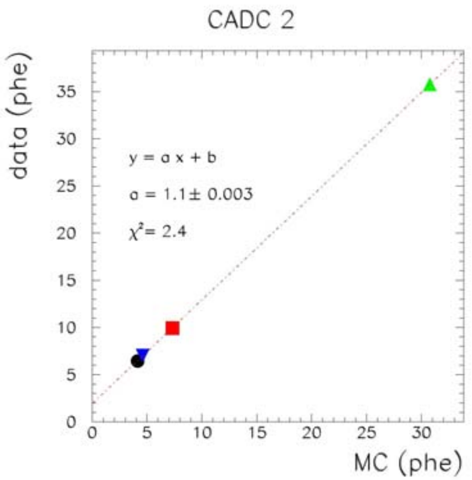
Made use of no topological cut (clusters, electron, pulse shape….)

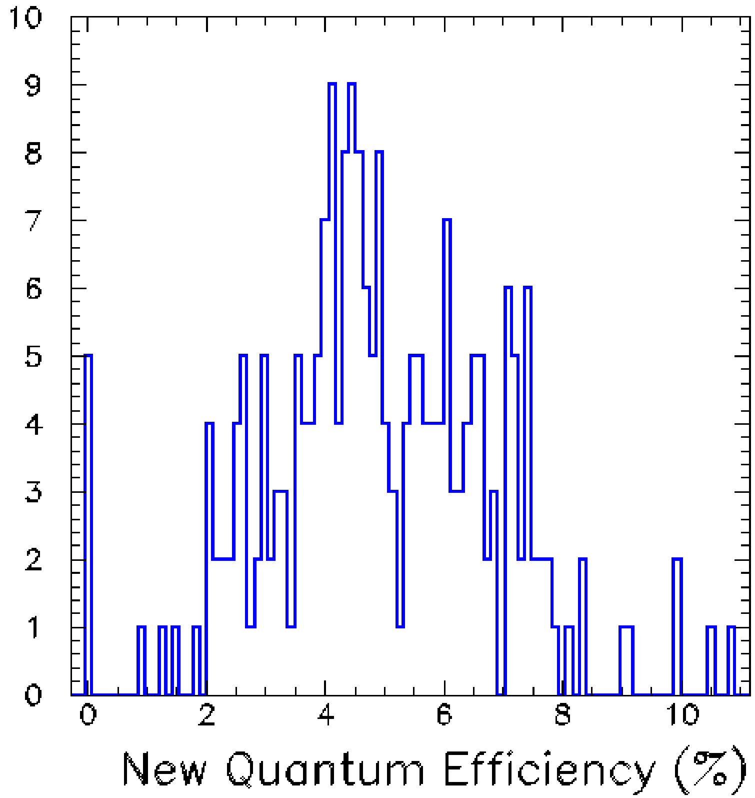
MC conclusion

- High absorption length $\Rightarrow$ curved shape is ok.
- QE improvement welcome (see timing resolution…)
- $(\text{accidental})^2$ background not harmful

MC for QE measurement?

•Use the 4 alpha-sources inside the Large Prototype and compare data and MC with NO ABSORPTION (⇒ need to use Gxe @ 170 K)



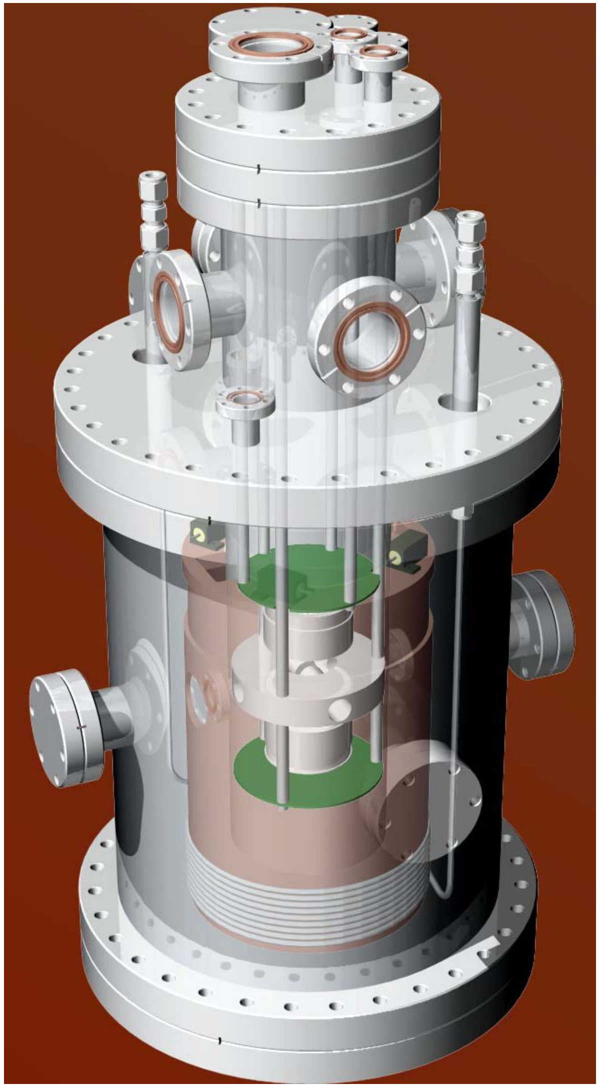


•The method depends very much on the details of the simulation (reflection on the PMT window and on walls….)

• we excluded PMTs on the alpha face but only three points left

•Need for a dedicated test station to measure all QE

PMT characterization



- FULL DESIGN AND MECHANICAL DRAWINGS COMPLETED
- CALL FOR TENDERS MADE AND JOB ASSIGNED TO THE COMPANY CINEL- Vigonza (PD), Italy
- CRYOSTAT DELIVERY EXPECTED BY THE END OF FEBRUARY
- ORDERS MADE FOR DRY UHV PUMPING GROUP, LEAK DETECTOR, UHV COMPONENTS, CRYOGENIC BOTTLE, PMT's …
- LABORATORY PREPARATION UNDER WAY
- FOR MORE INFORMAITON ASK FRANCO

Data

- With α
- With α runs
- With electrons
- ….

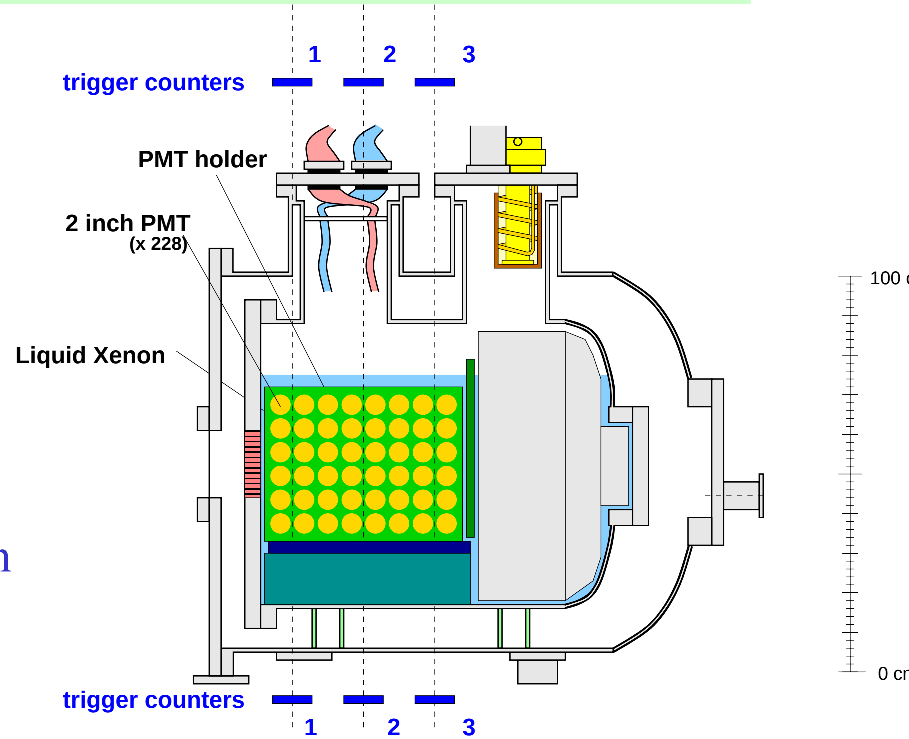
Xenon Calorimeter Prototype

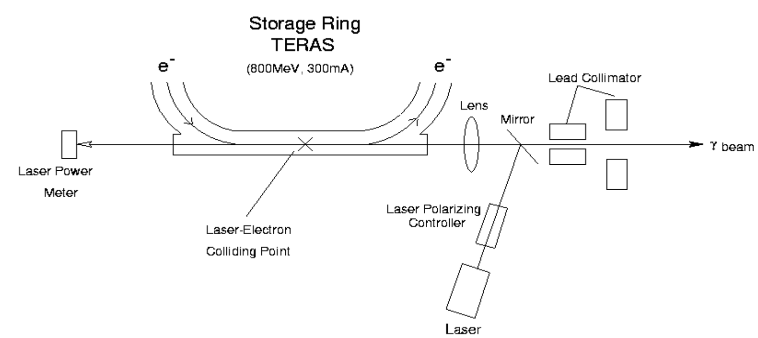
•Tests on the LXe calorimeter are currently under way in KEK Japan using a “LARGE PROTOTYPE”:

- •40 x 40 x 50 cm^3
- •264 PMTs, 100 litres Lxe

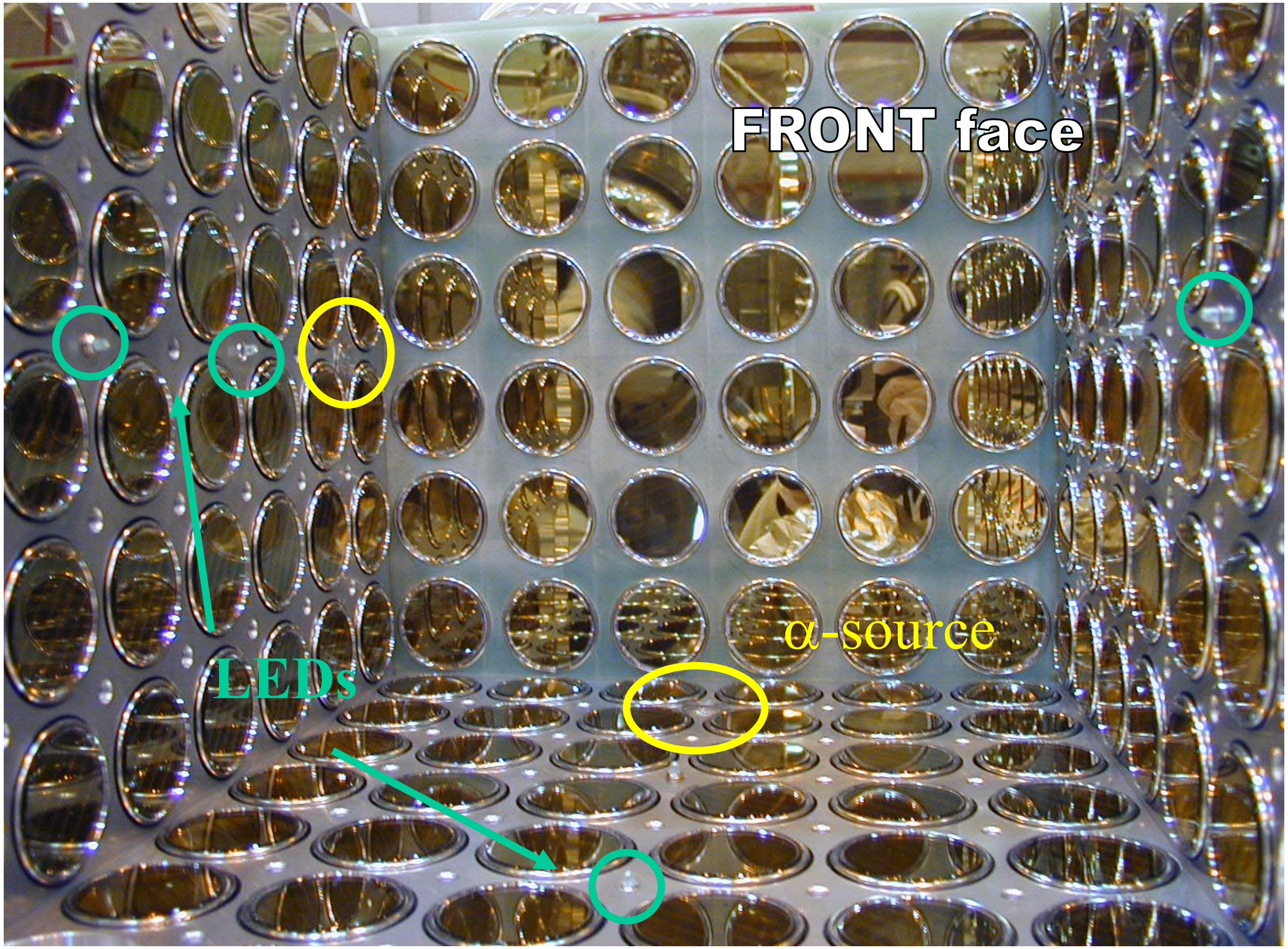
•Used for the measurement of:
- •Test of cryogenic and long term operation
- •Energy resolution (expected 1.4 – 2 %)
- •Position resolution (few mm)
- •Timing resolution (100 ps)

•Measurement done with:
- •Cosmic rays
- •40 MeV γ from Compton Backscattering
- •α-sources
- •electron beam (@ KSR)





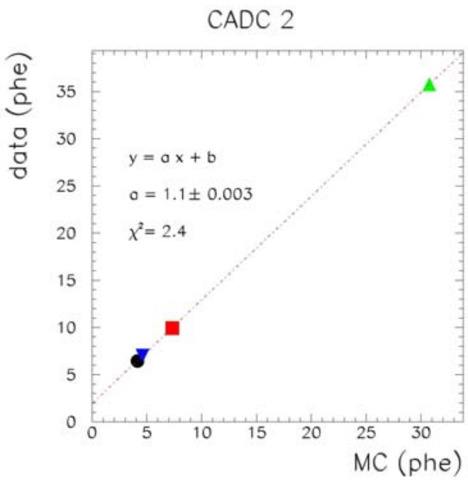
The LP from "inside"

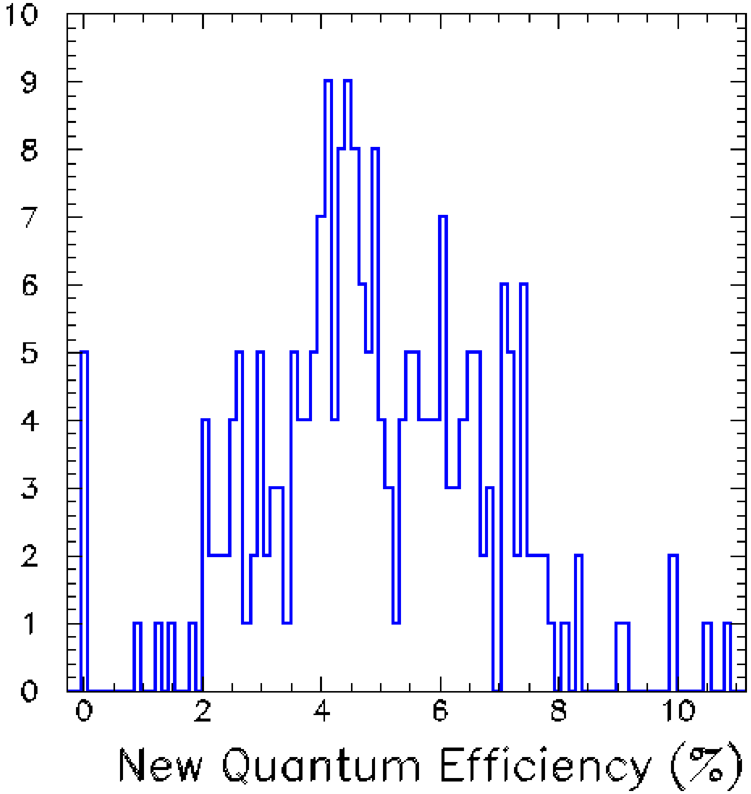


α-sources and LEDs used for PMT calibrations and monitoring

QE measurement

•Use the 4 alpha-sources inside the Large Prototype and compare data and MC with NO ABSORPTION (⇒ need to use Gxe @ 170 K)





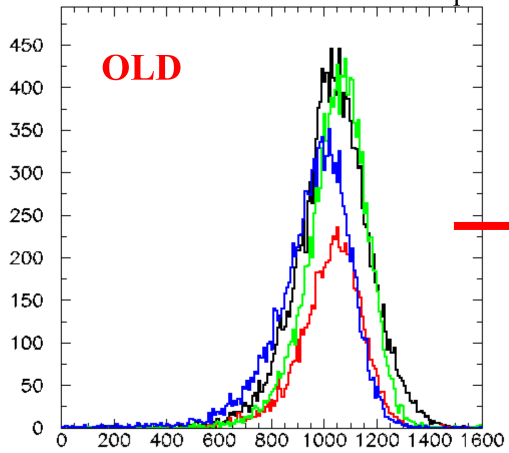
•The method depends very much on the details of the simulation (reflection on the PMT window and on walls….)

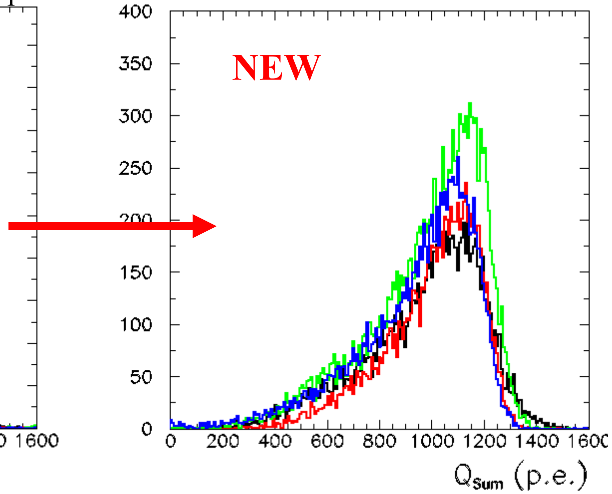
• we excluded PMTs on the alpha face but only three points left

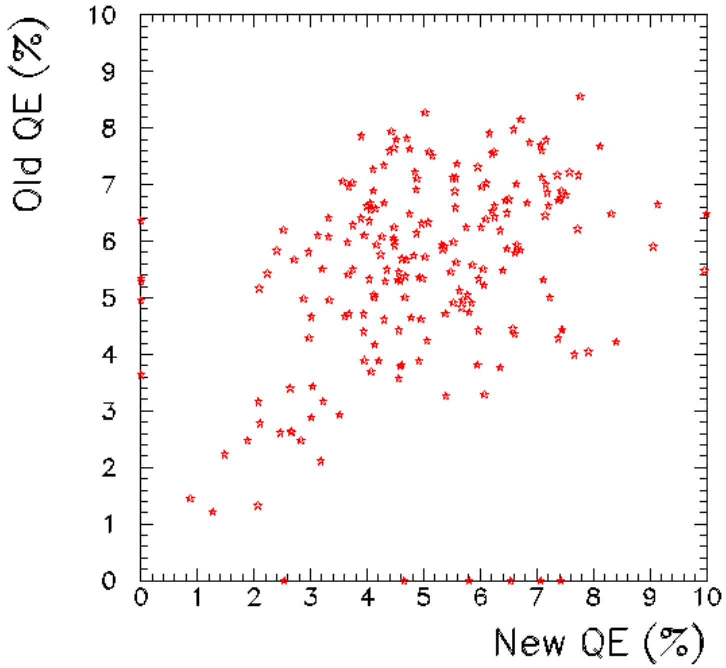
•Need for a dedicated test station to measure all QE

QE: better go 5 ×10^6

•Due to the higher W_{ph} for Gas Xenon the alpha signal in gas used to be cut





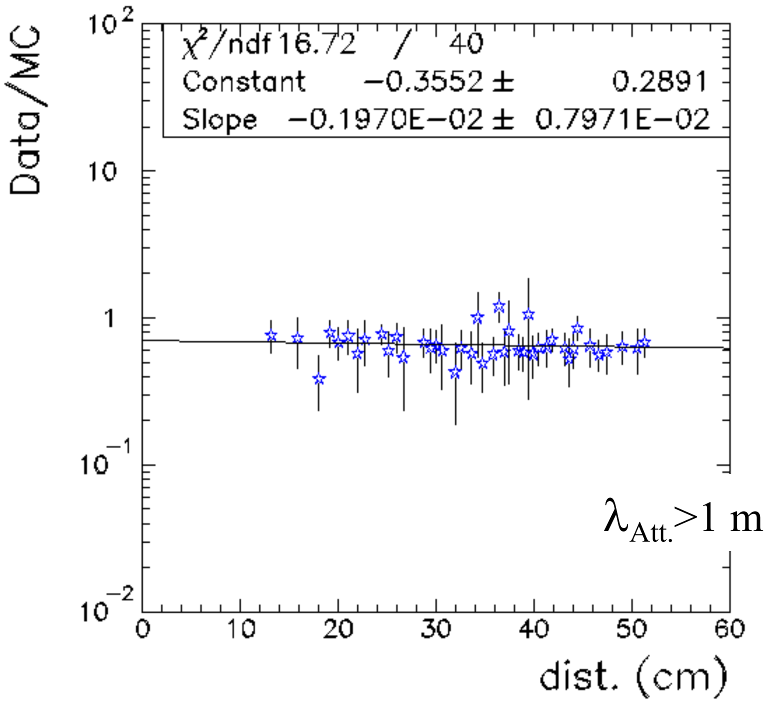


The old quantum efficiencies were slightly over-estimated

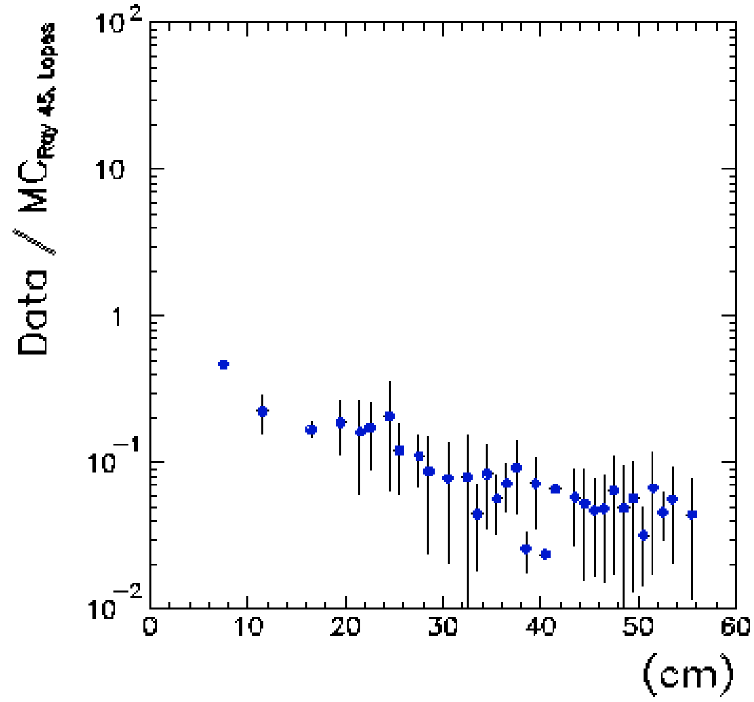
Purity and other α uses

Alpha source: measured/expected light as a function of the α-PMT distance

Present...



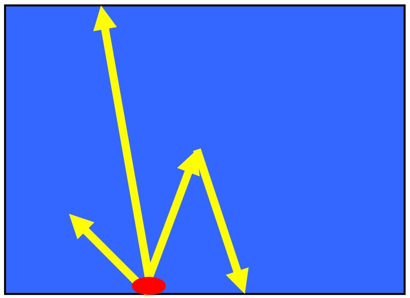
Cfr. May test

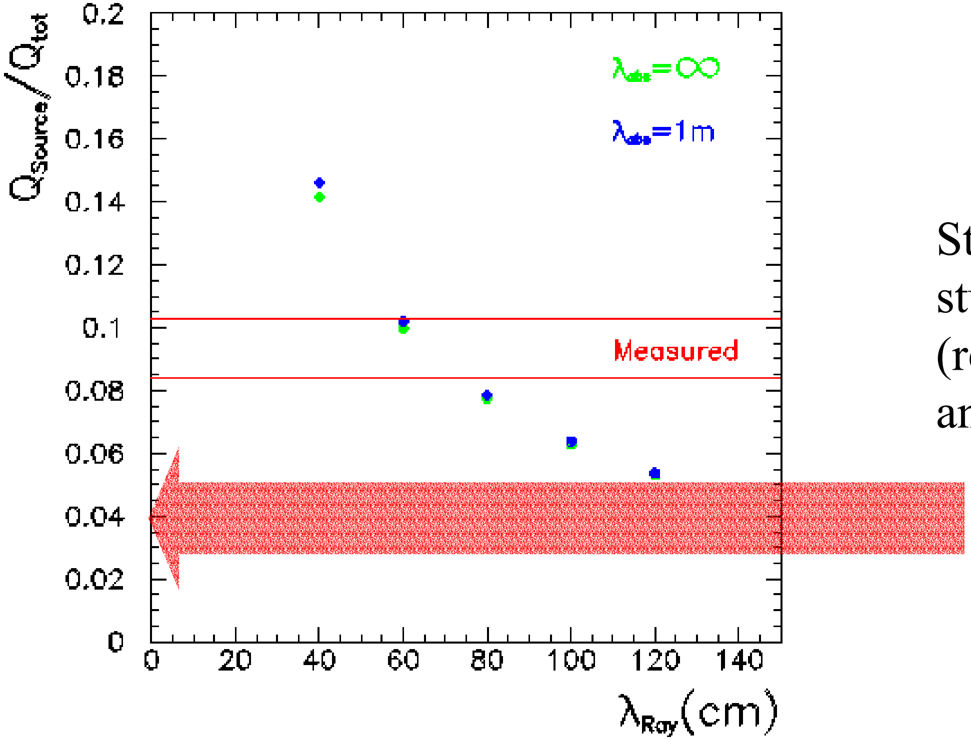


Alpha source measurements: essential for purity monitor and physics measurements (n, $\lambda_{Rayleigh}$,…)

Diffusion length ($\lambda_{Rayleigh}$)

- Ratio of the charge collected on the face containing the alpha source to the total collected charge
- Independent of the absorption





$\lambda_{Ray} \approx 70$ cm

Still some systematics to be studied depending on the MC (reflections on PMT windows and LP material…)

In Gxe consistent with $\lambda_{Ray} = \infty$

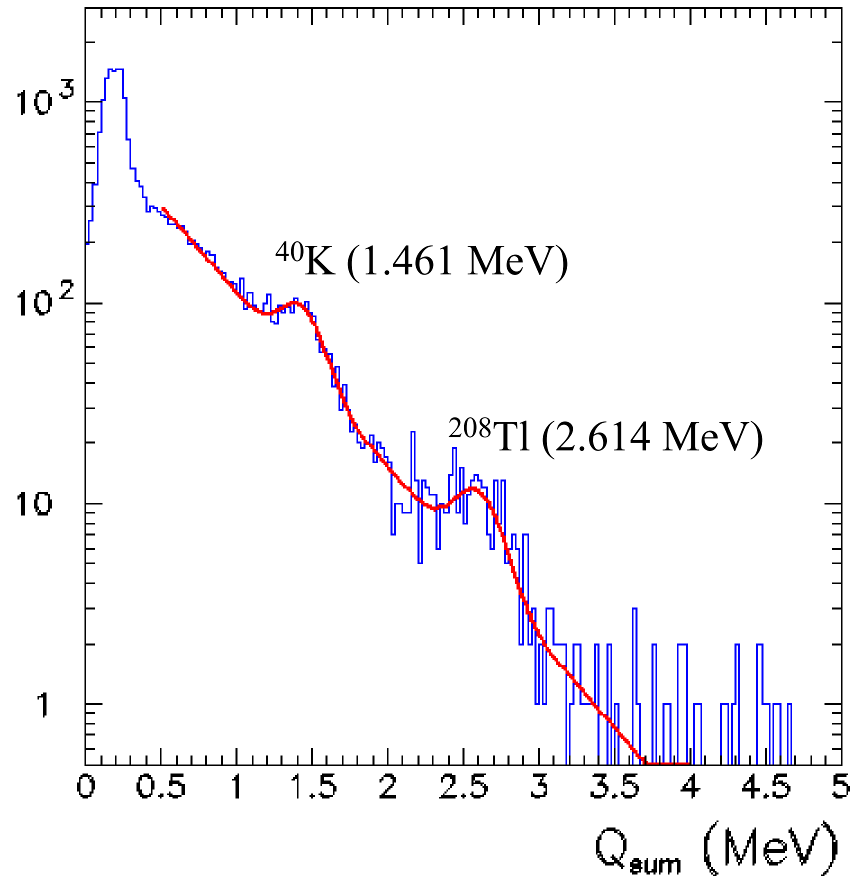
Radioactive background w/LP

- α-trigger with 5×10^6 gain
- Geometrical cuts to exclude α-sources

- Energy scale: α-source
  - ^{208}Tl (2.59±0.06) MeV
  - ^{40}K (1.42 ± 0.06) MeV
  - ^{214}Bi ^{208}Tl ??

- uniform on the front face
- few 10 min (with non-dedicated trigger)

- nice calibration for low energy γ's



- Seen for the first time! Studies are going on: spatial distribution of background inside the detector

Timing resolution test

$$\sigma_t = (\sigma_z^2 + \sigma_{sc}^2)^{1/2} = (80^2 + 60^2)^{1/2} \text{ ps} = 100 \text{ ps (FWHM)}$$

Time-jitter due to photon interaction

Scintillation time, photon statistics

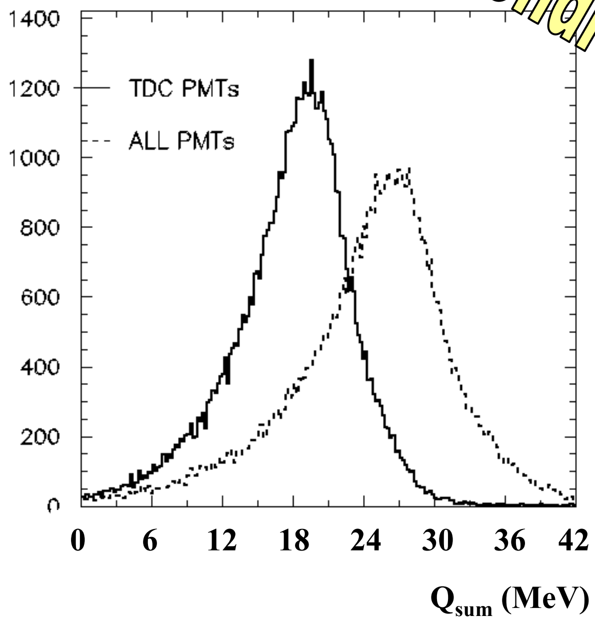
Measurement of σ_{sc}^2 ⇒electron beam

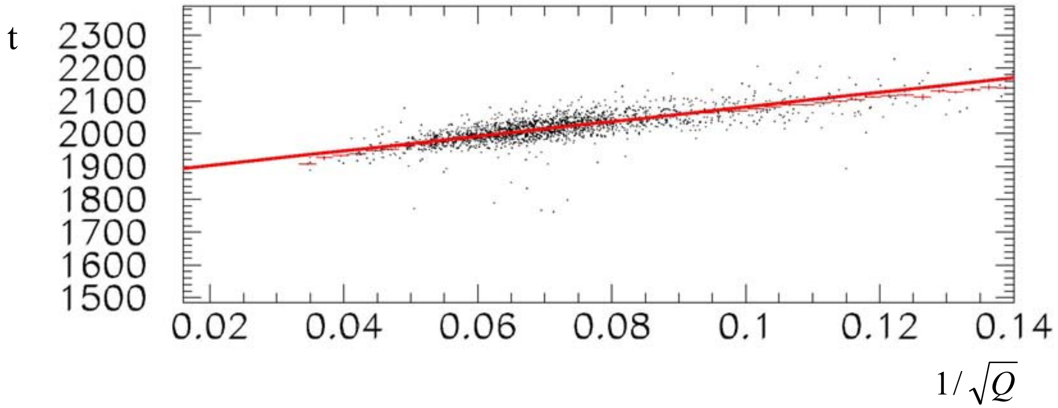
Use of Kyoto Syncrotron Ring (KSR) @ 60 MeV (2/12/02→6/12/02)

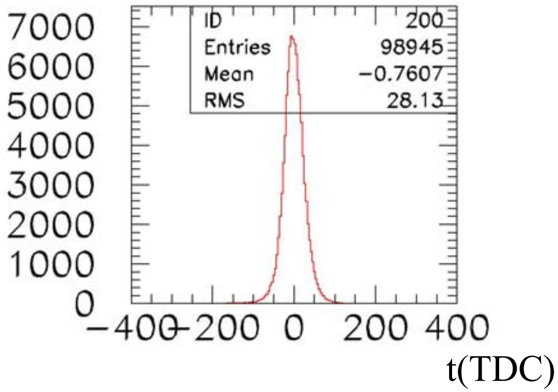
Timing resolution

Various conditions

- 60 MeV e^- → material degradation → only 128 channels (out of 228) had the TDC
- We estimate the *intrinsic* timing resolution *vs p.e.*
- divide PMTs in two groups: σ_{sc}=**RMS[(T_L-T_R)/2]** at center
- $T_{L,R}$ = weighted average of the PMT TDCs (time-walk corrected)

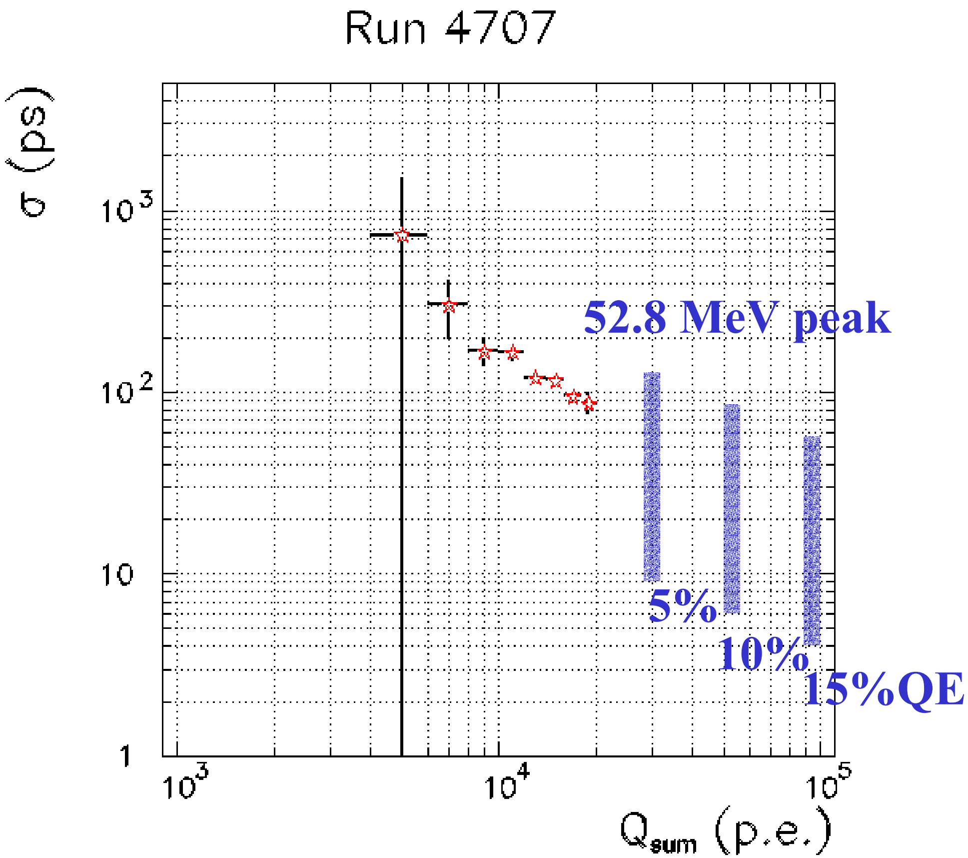






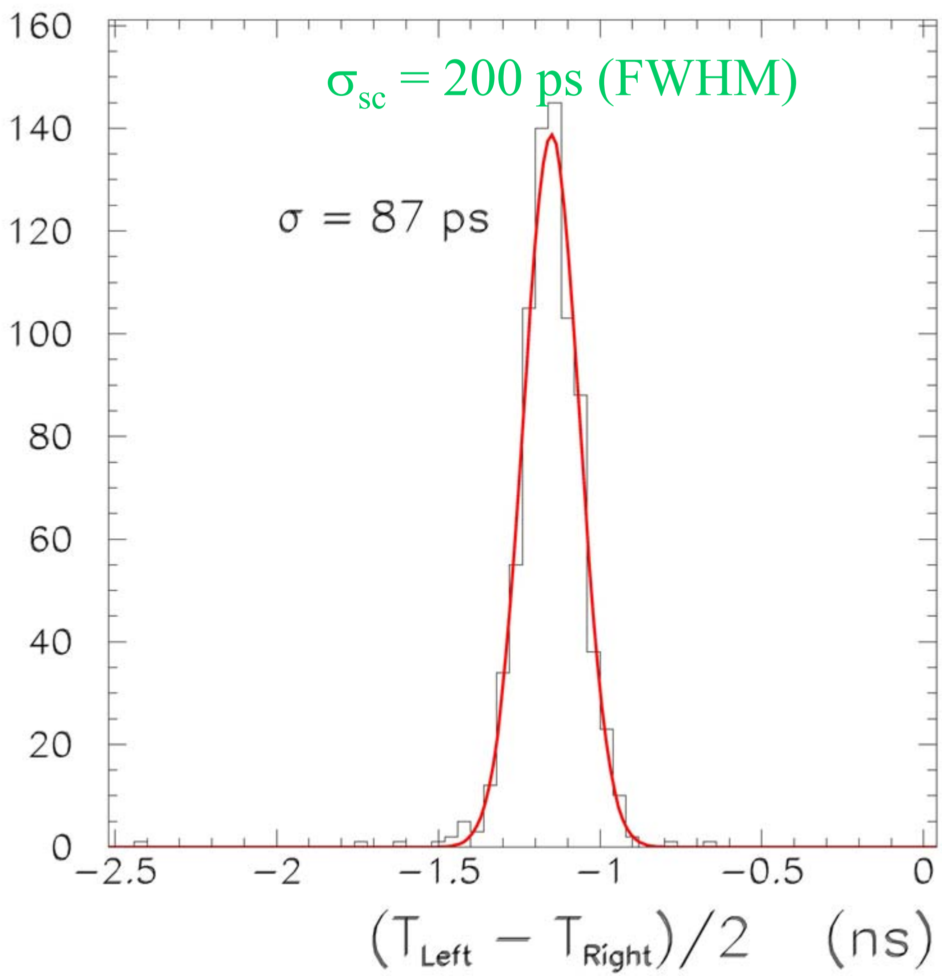
TR (2)

•A factor of 10 in number of photo-electrons w.r.t. the Small Prototype



•Analysis still in progress: position-depentent corrections and cross talk problems

Resolution (preliminary)



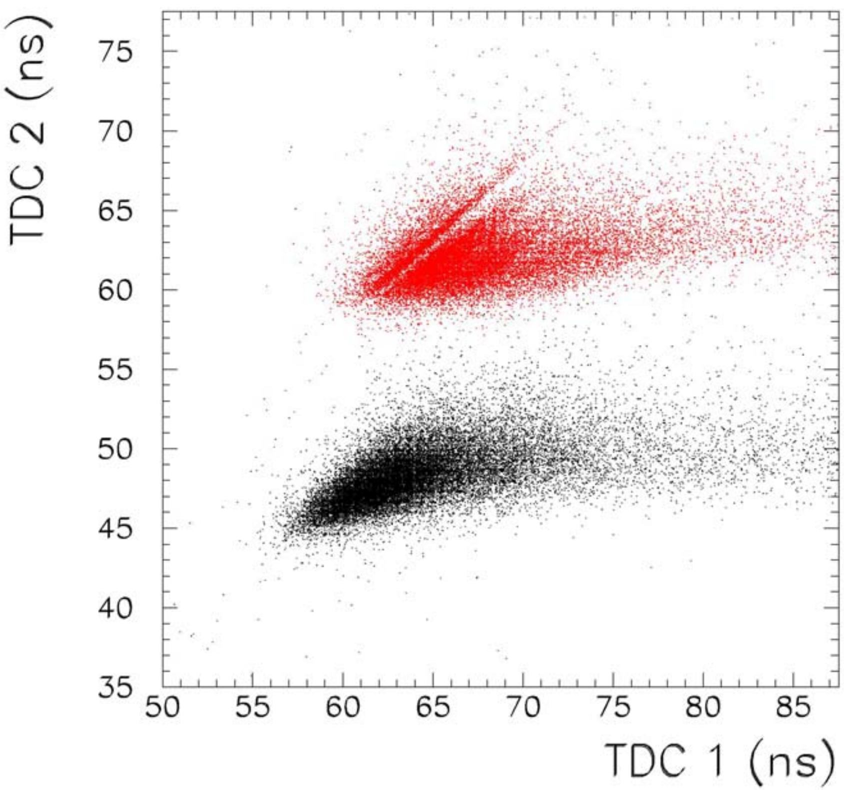
Still to be done:

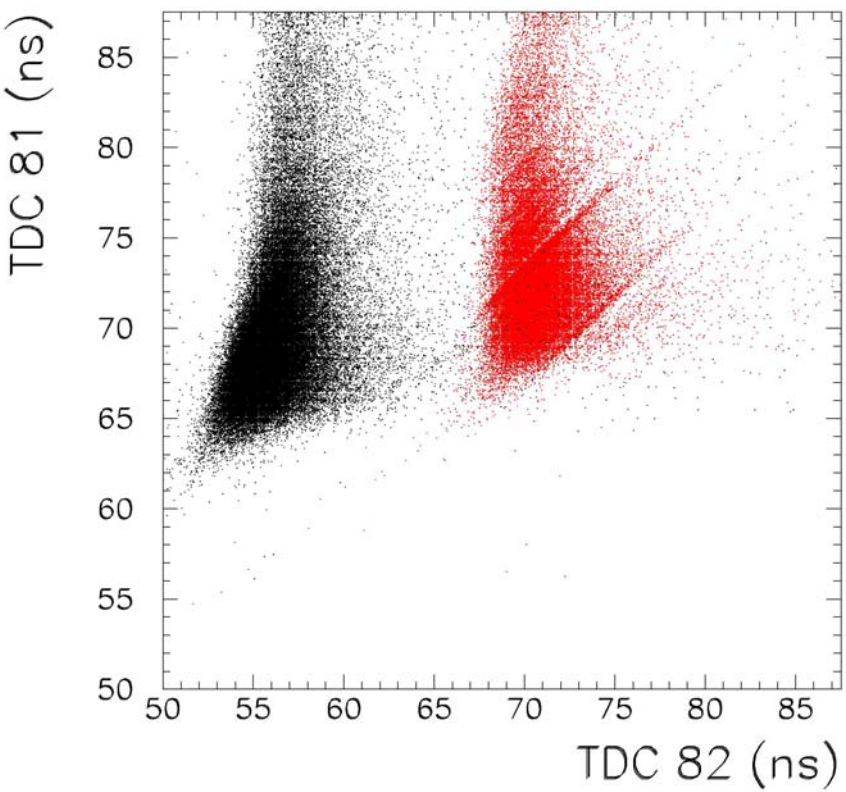
- event filtering
- full event reconstruction

(need to account for position correction)

Cross-talk care

10 ns delay cables added to increase the phase of discriminator input pairs

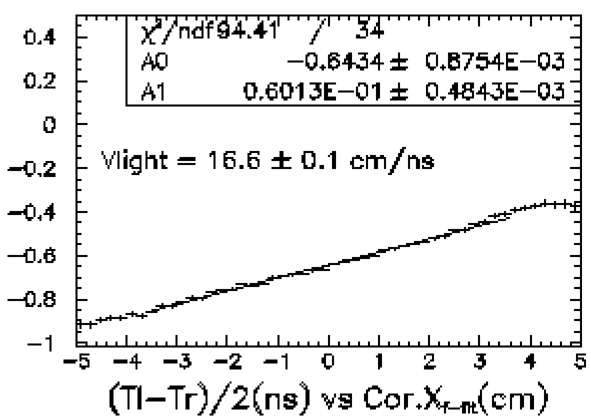


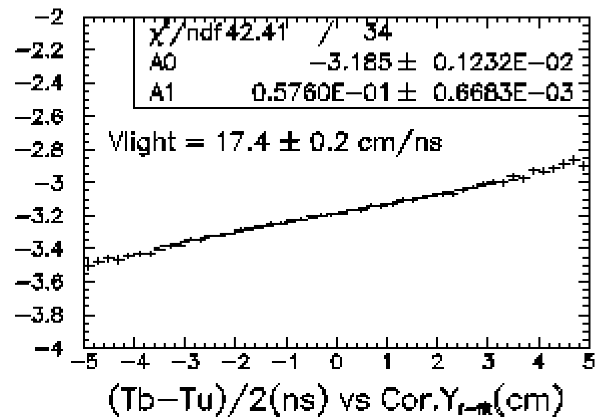


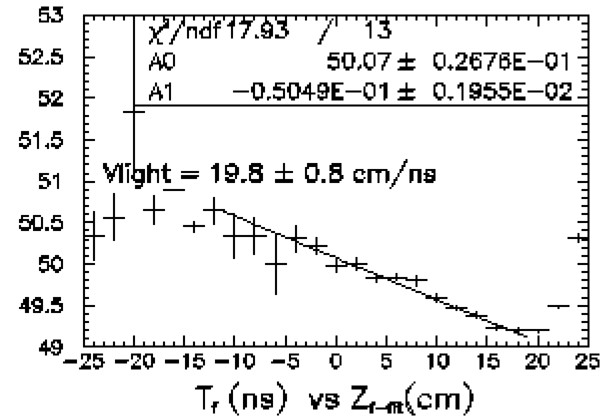
Problems fixed only with 19 over 64 pairs

V light in Xe?

•Using the correlation between the fitted coordinates of the "center" of the shower and the difference in arrival times on the various LP faces one can estimate v_{light} and *n* for Xenon.







$n \approx 1.7$

•Need to refine the technique

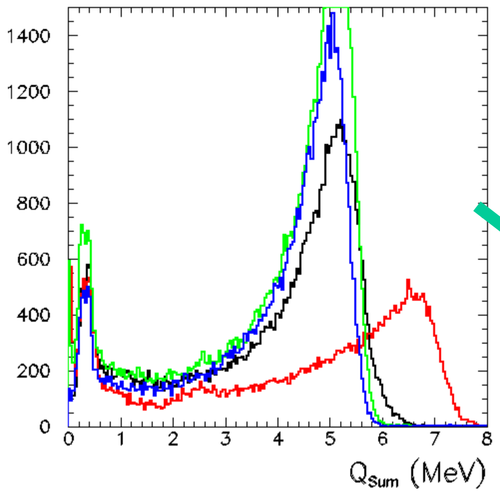
•Understand via MC what is the meaning of "center of shower" and $T_{L,R,\ldots}$

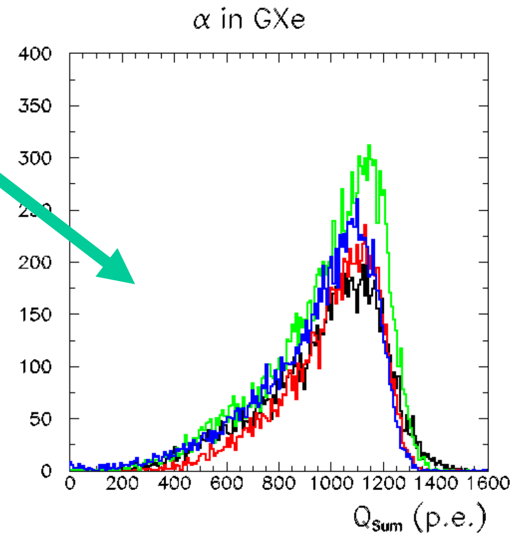
Data conclusion

- α runs are essential for monitoring
- Xenon is pure!
- The timing resolution is consistent with the expectations but needs to be checked

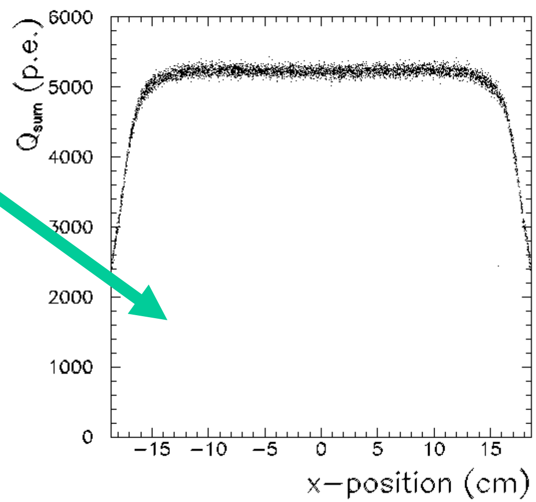
Is LP completely full of LXe?

1st clue: the **top-source** peak is higher in Lxe but not in GXe





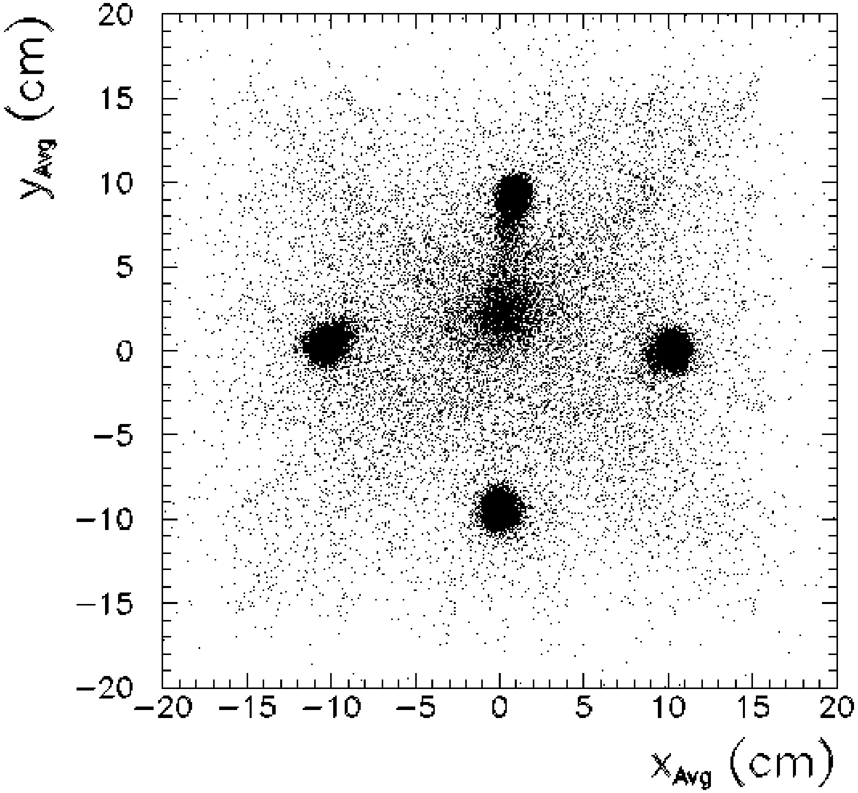
MC charge collected



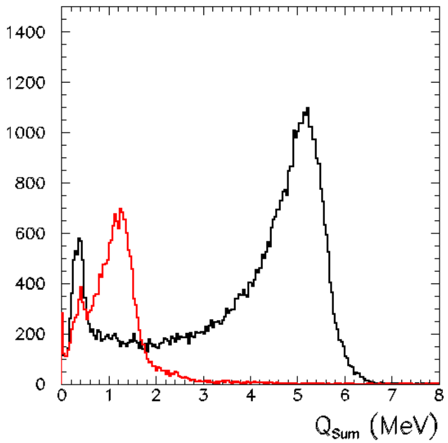
The source somehow gets more distant from the wall! (5 mm)

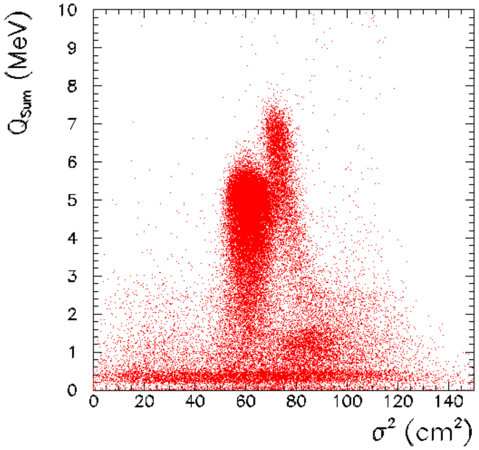
Lxe full? (2)

2nd clue: central spot:



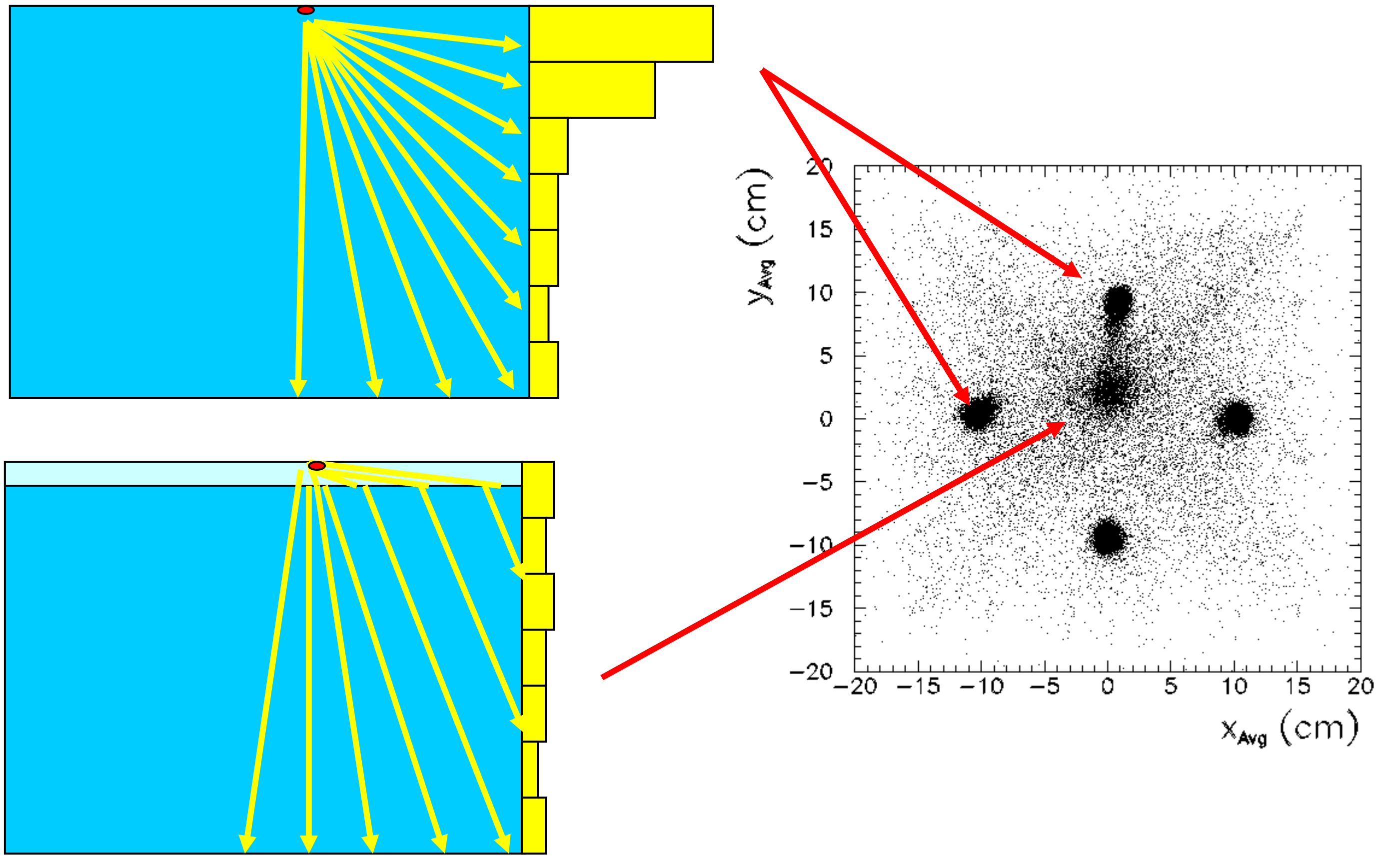
a) gives a lower peak at correct *z*





Central Spot (2)

B) easy explanation for its position

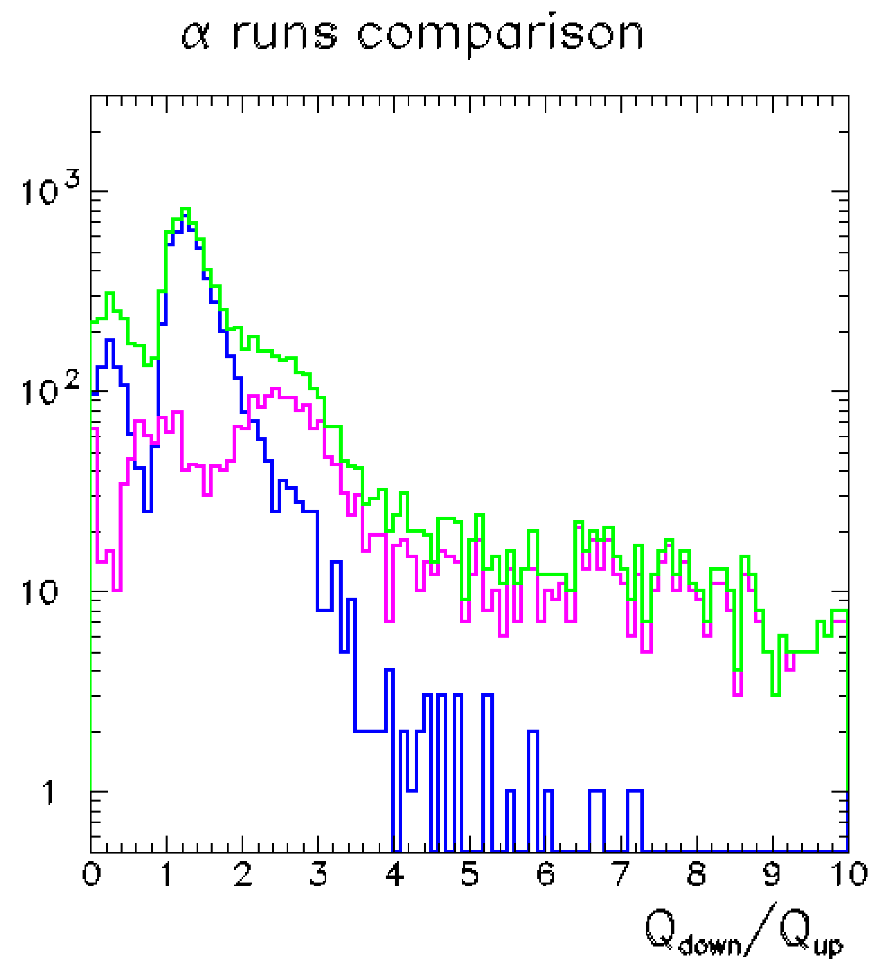


Face Q ratio

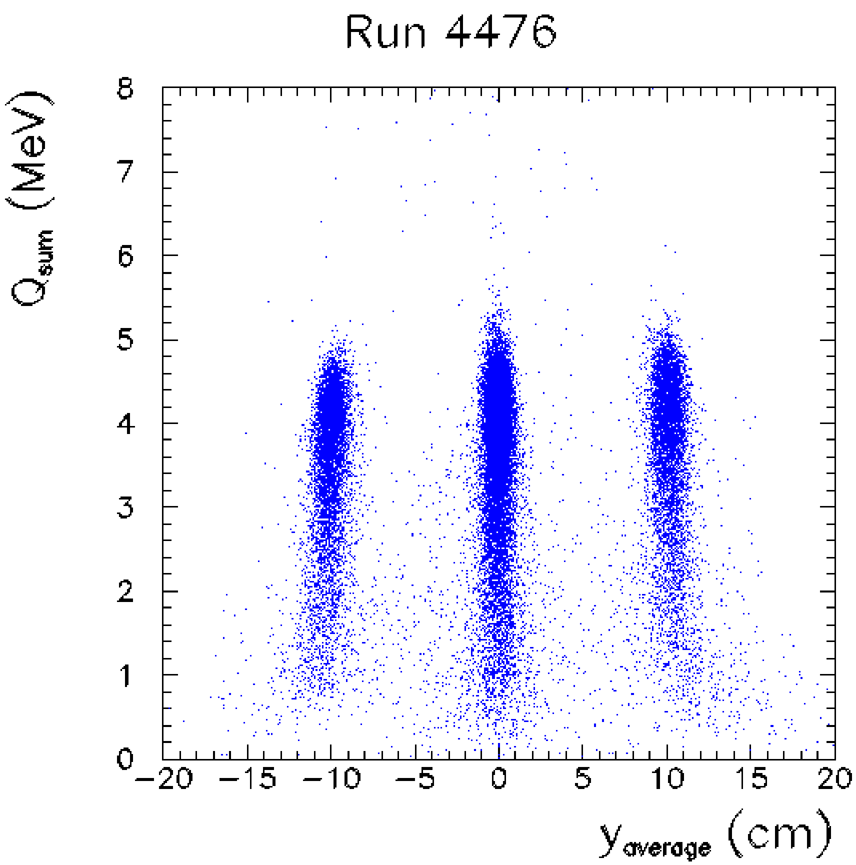
•R^{-1}= Charge of the face with alpha/ Charge on opposite face

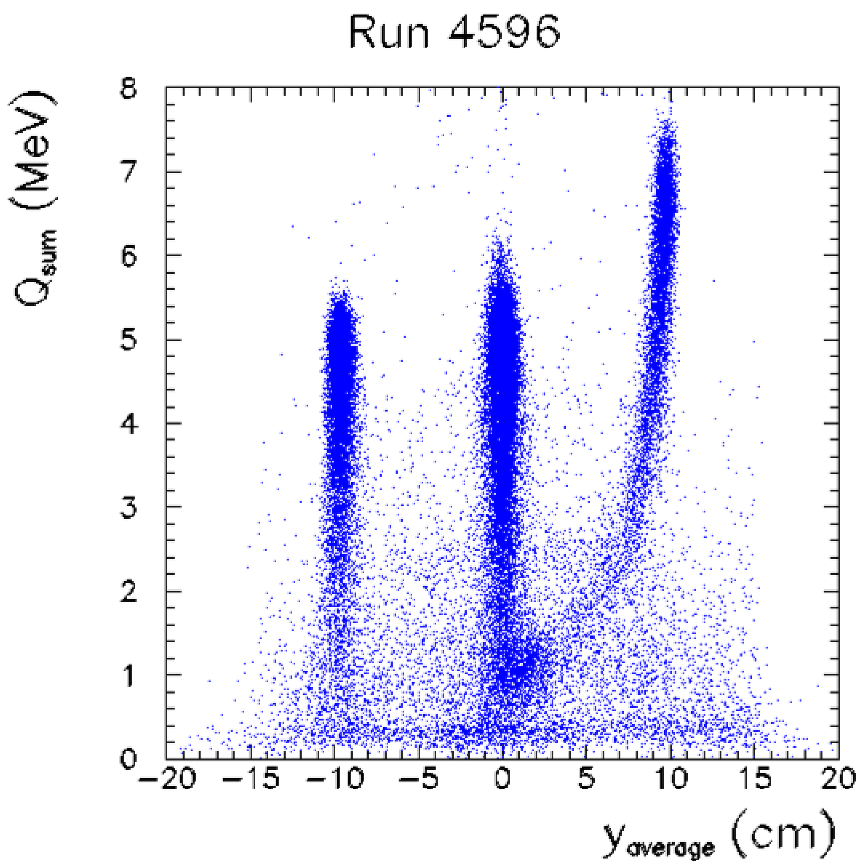
•R is different for LIQUID and GAS because of Rayleigh scattering

•$R_{liquid} \approx 1$ $R_{Gas} \approx 3$



Time Evolution



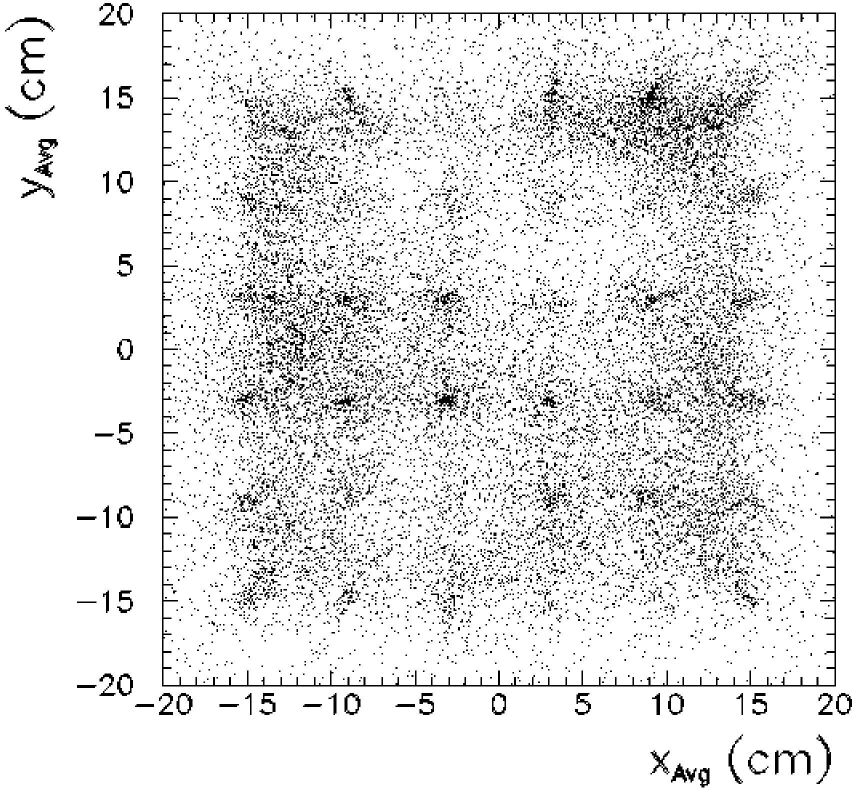


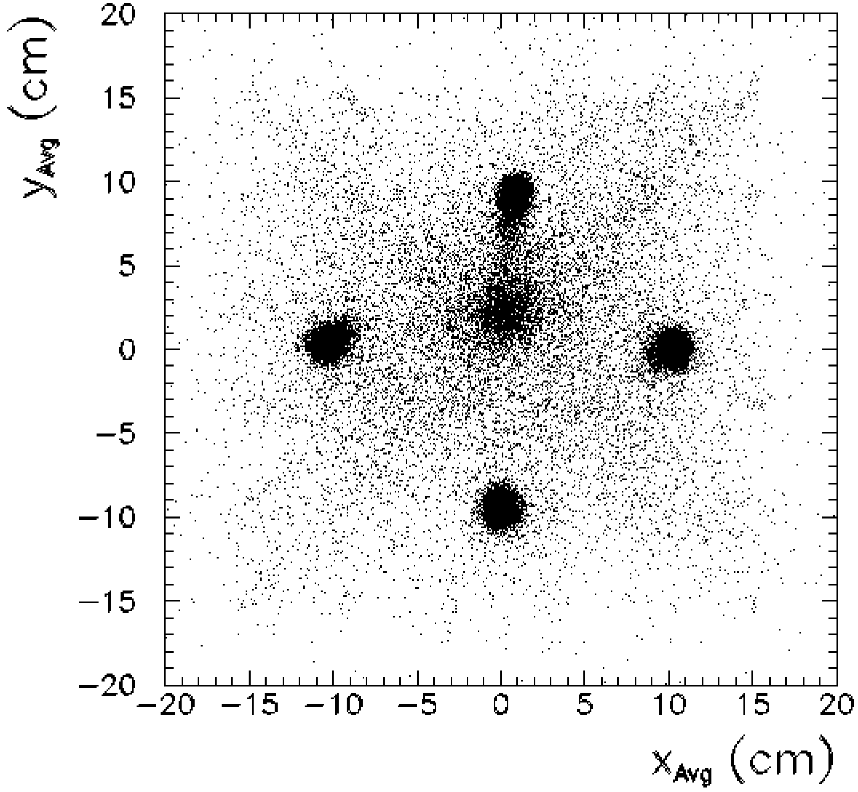
Data conclusion

- α runs are essential for monitoring
- Xenon is pure!
- The timing resolution is consistent with the expectations but needs to be checked

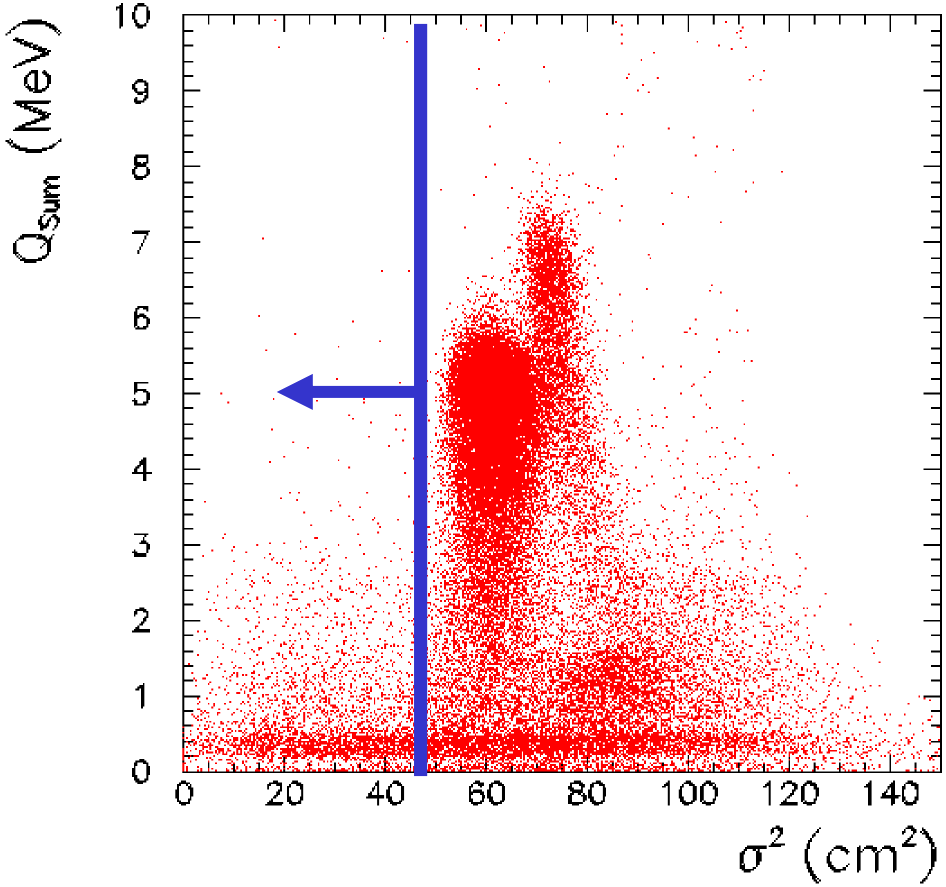
End

Background distribution



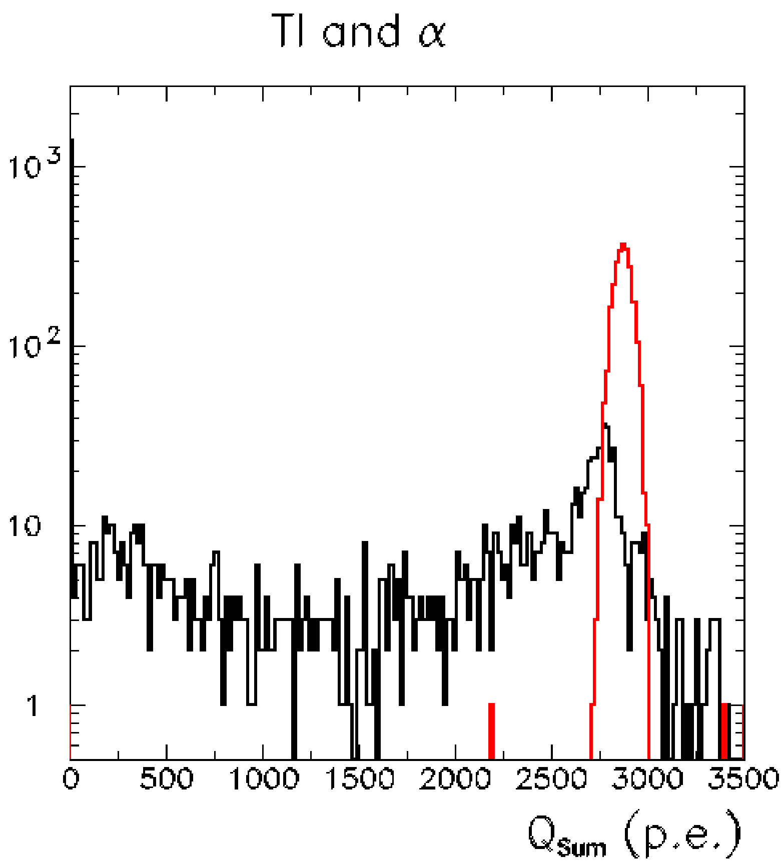


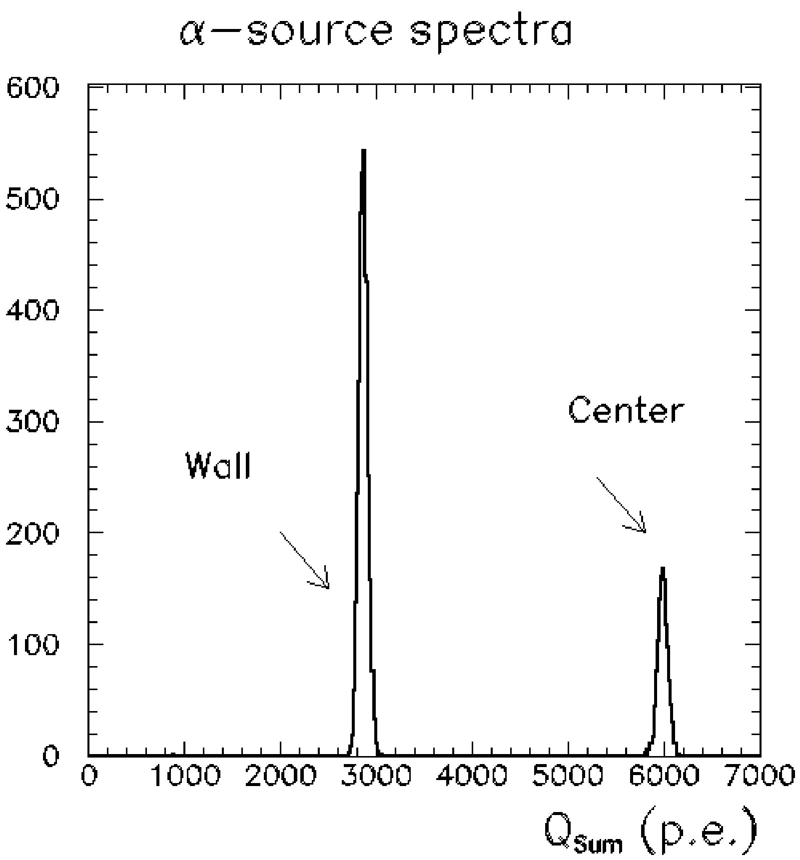
Selection in *z*



σ^2 is the rms of the front face charge distribution

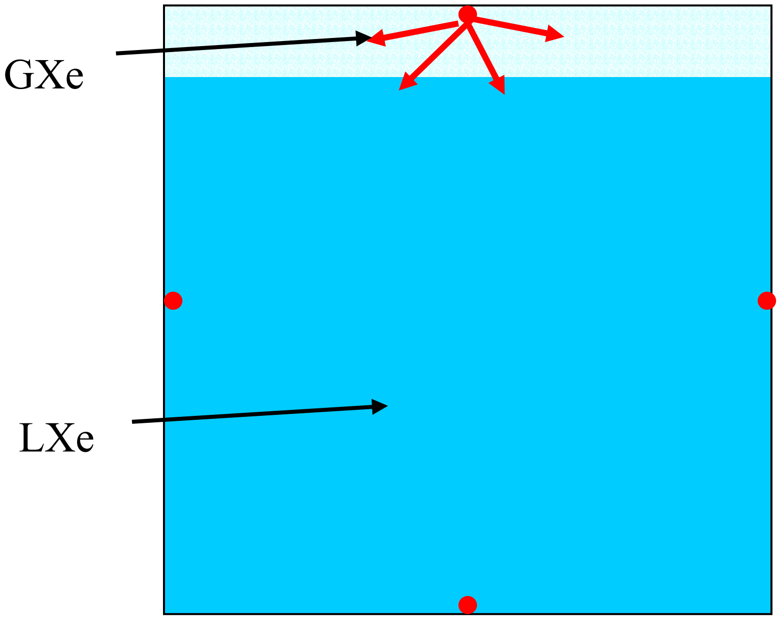
Predicted ^{208}Tl position





- Tl peak slightly below α-peak
- Take the difference in light-yield between α and γ (20 %)

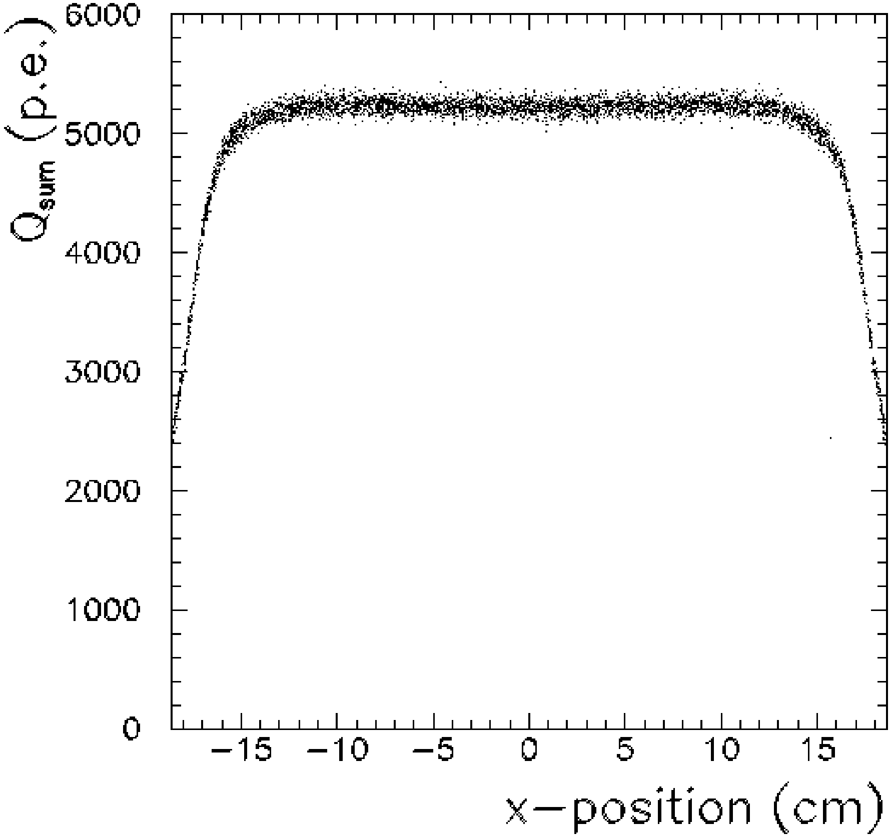
Is the LP full of Xenon?

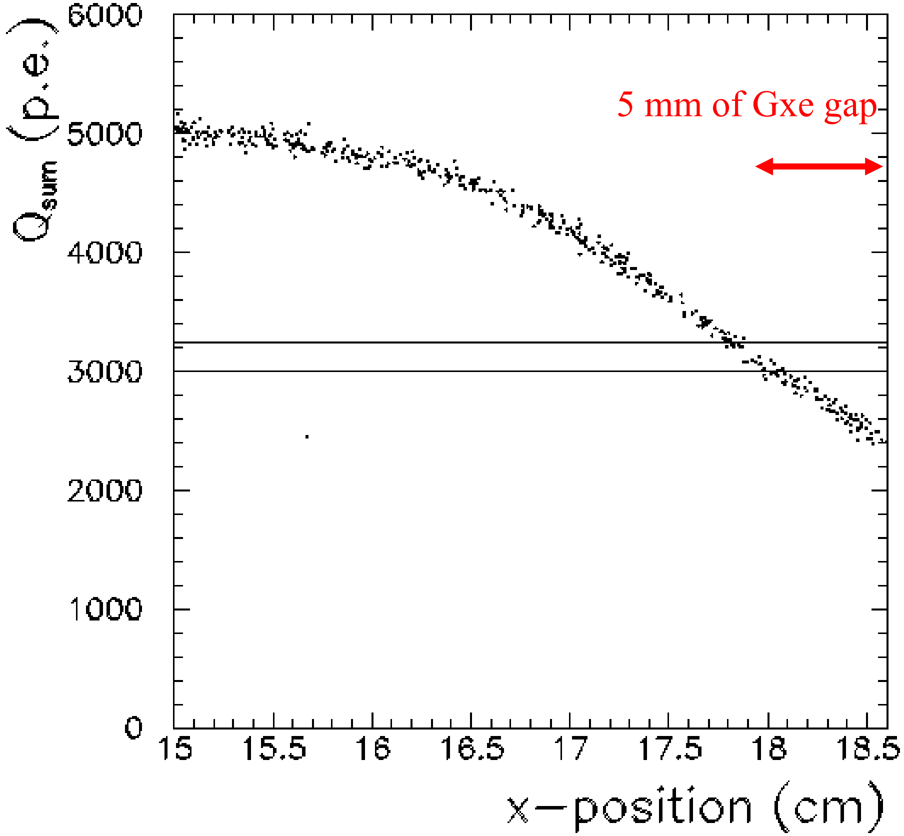


Clues

- Higher peak
- Position: central spot
- A low-energy peak.
- Ratio of face charges
- Develop in time

Possible Xe level





Kyoto Storage Ring

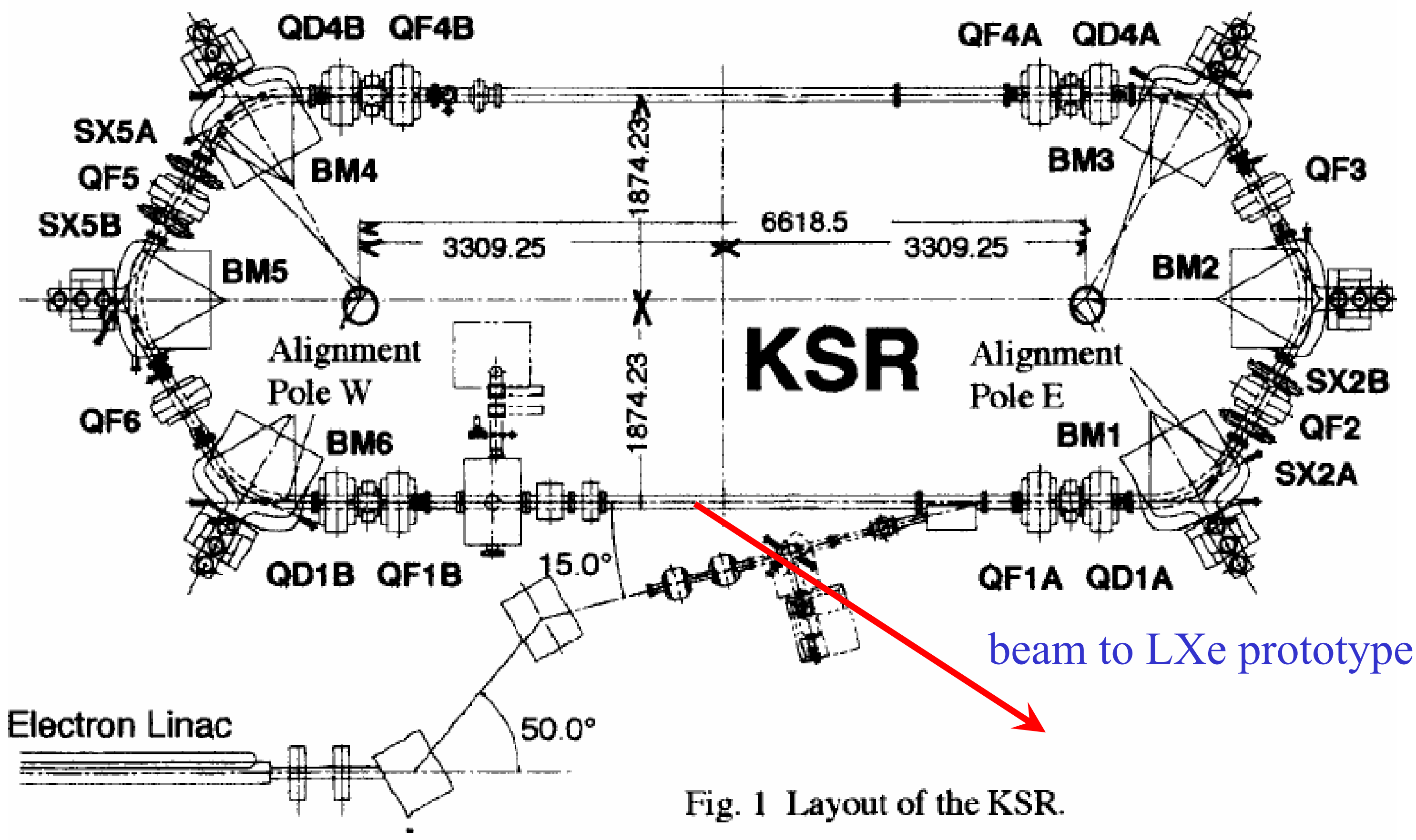


Fig. 1 Layout of the KSR.