Energy and time resolution for a LYSO matrix prototype of the Mu2e experiment

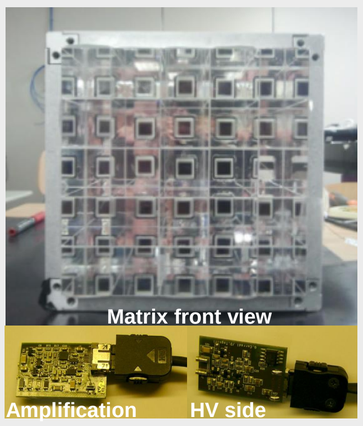
N. Atanov,[a] V. Baranov,[a] F. Colao,[b] M. Cordelli,[b] G. Corradi,[b] E. Danè,[b] Yu.I. Davydov,[a] K. Flood,[c] S. Giovannella,[b] V. Glagolev,[a] F. Happacher,[b] D.G. Hitlin,[c] M. Martini,[b,d] S.~Miscetti,[b] T. Miyashita,[c] L. Morescalchi,[e,f] G. Pezzullo,[e,g] A. Saputi,[b] I. Sarra,[b] S.R. Soleti,[b] G. Tassielli,[h] V. Tereshchenko[a]

[a] *Joint Institute for Nuclear Research, Dubna, Russia* [b] *Laboratori Nazionali di Frascati, INFN, Frascati, Italy* [c] *California Institute of Technology, Pasadena, United States*
[d] *Università ``Guglielmo Marconi'', Roma, Italy* [e] *INFN, Pisa, Italy* [f] *Università di Siena, Siena, Italy* [g] *Università di Pisa, Pisa, Italy* [h] *INFN, Lecce, Italy*

The LYSO matrix prototype

- 5×5 LYSO crystals, (30×30×130) mm^3, by SICCAS
- Each crystal wrapped with a 60 μm thick layer of super reflective ESR-3M
- Crystal readout: (10×10) mm^2 S8664 Hamamatsu APD
- APDs optically connected to crystals with Saint-Gobain BC-630 grease
- Custom made FEE providing both amplification and regulation of bias voltage

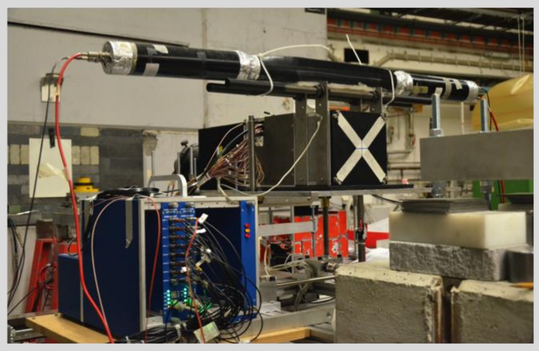
- Matrix transverse dimension ~ 2.8 R_M
- Matrix longitudinal dimension ~ 11.2 X_0



All crystals characterized with a ^{22}Na source and a spectrophotometer: good characteristics in light yield, longitudinal response uniformity and transmittance

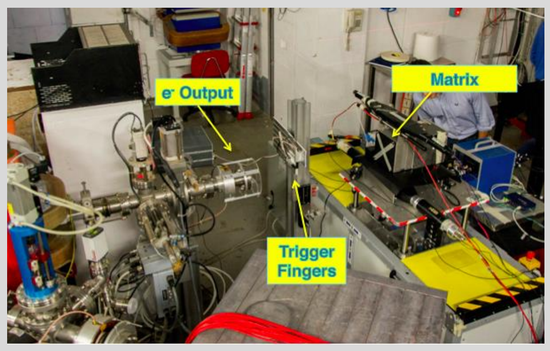
Test beam setup

MAMI @ Mainz: September 2014



- Tagged photons with energy 20-380 MeV, with few permil precision

BTF @ LNF: December 2014 & April 2015



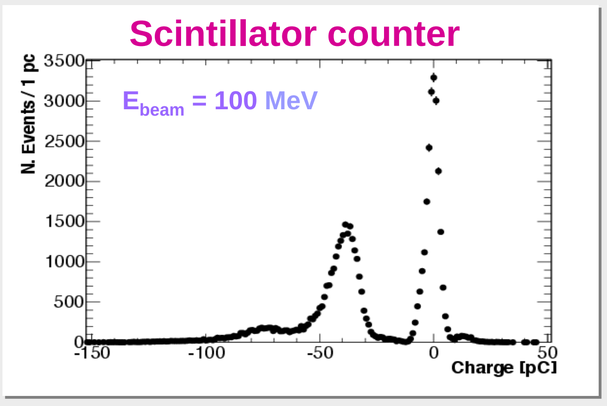
- e^+, e^- from DAΦNE LINAC, energy range: 100-500 MeV
- Trigger provided by two orthogonal (0.6×1×5) cm^3 plastic scintillator counters (fingers) read out by (3×3) mm^2 SiPM

- Data acquired with CAEN waveform digitizer V1720, 250 Msps, 12 bit resolution, 0-2 V dynamic range
- APDs illuminated by green laser (λ = 530 nm) through 250 μm Ø fused silica optical fibers. Laser pulsed syncronized with an external trigger with a frequency of ~ 1 Hz.
- Equalization of matrix channels at 10% level with minimum ionizing particles crossing vertically the detector
- Calibration of cell response with beam (450 MeV @ BTF, 92.5 MeV @ MAMI) firing on each cell center

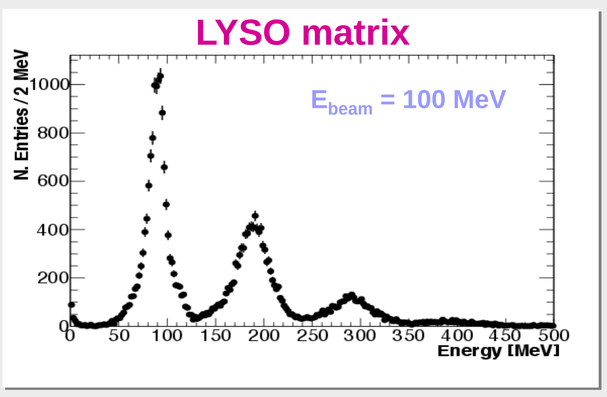
e^+/e^- multiplicity @ BTF

- BTF particle multiplicity greater than one
- Particle multiplicity, tunable by adjusting beam intensity and collimators, set to μ ~0.8
- Two and three particle events clearly visible
- Single particle events selected with a cut in the total charge of both scintillator counters and matrix

Scintillator counter



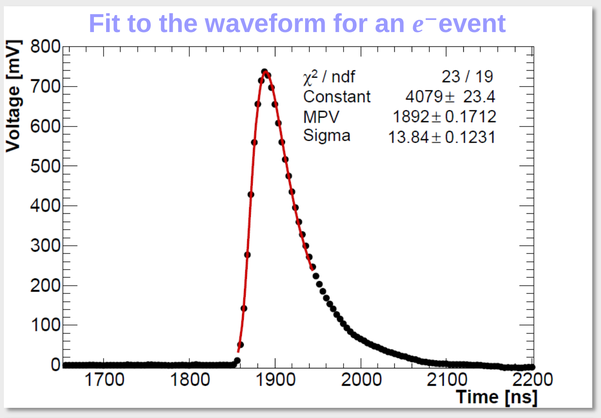
LYSO matrix



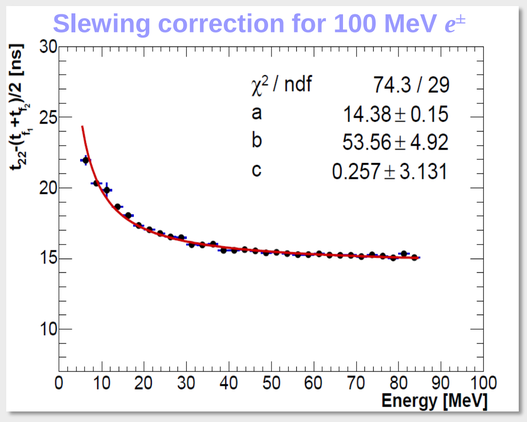
Energy and time reconstruction

- Time extracted from a fit to the waveform shape of the digitizer with a Landau function
- Residual slewing correction applied
- Time of the external trigger subtracted event by event
- Energy scale (pC/MeV) set by MC by comparing total reconstructed charge in data with the expected energy deposit
- Multiple scattering events reduced by cutting on the energy weighted centroid

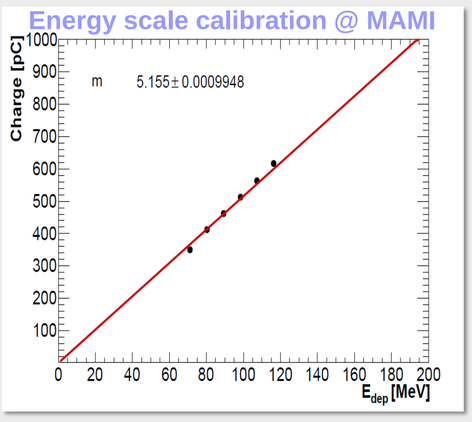
Fit to the waveform for an e^-event



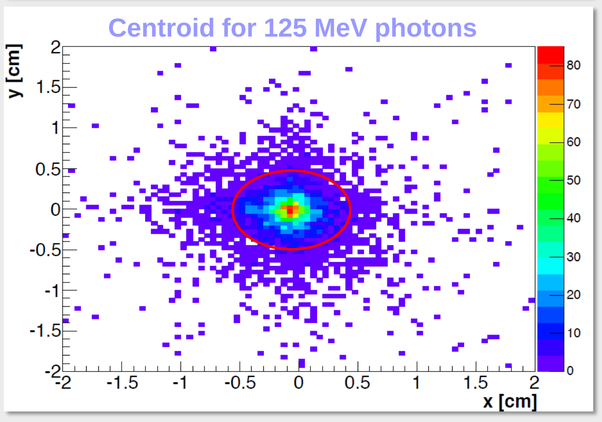
Slewing correction for 100 MeV $e^\pm$



Energy scale calibration @ MAMI

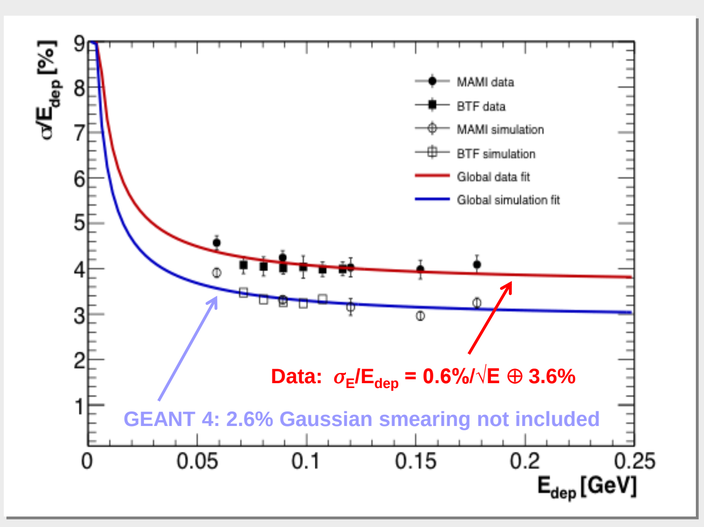


Centroid for 125 MeV photons

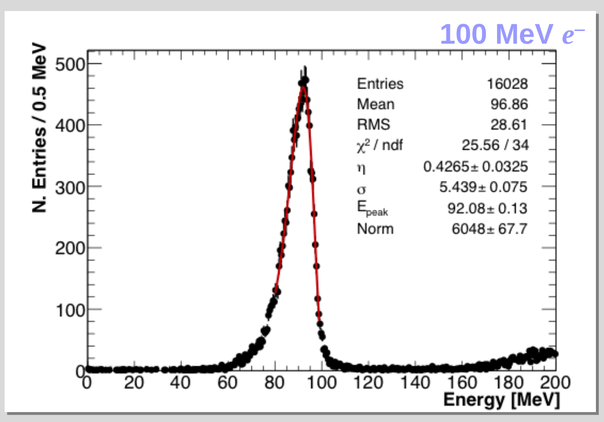


Energy resolution

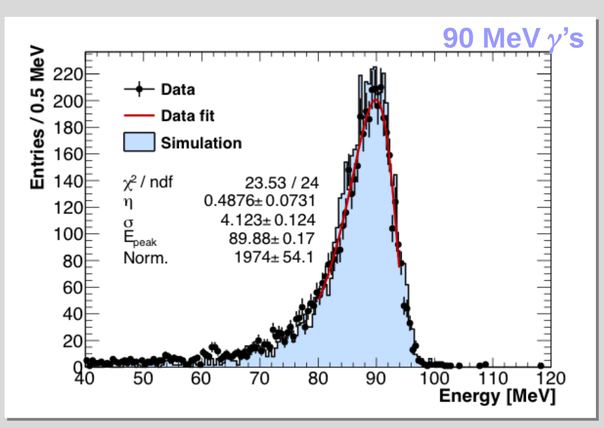
- Total energy spectra compared with GEANT4 MC simulation, with 2 mm beam spread included
- Additional 2.6% Gaussian smearing needed in MC, accounting for miscalibration, non uniformity and non linearity
- Energy resolution obtained from fit with a Lognormal distribution



100 MeV e^-



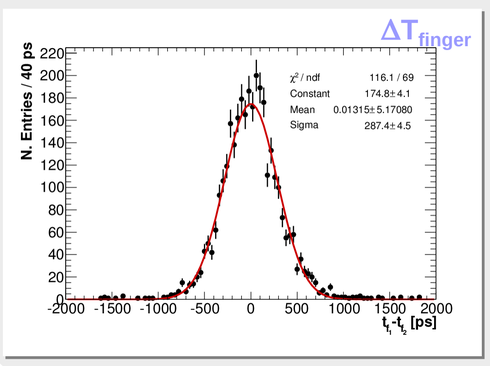
90 MeV γ's



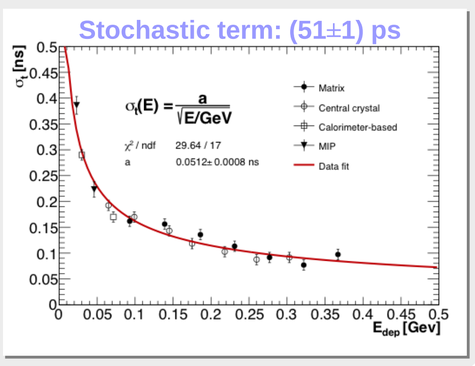
Time resolution

- Time resolution measured @ BTF using both central crystal and the energy-weighted time of the whole matrix
- Trigger jitter estimated from a Gaussian fit to the Δt_{finger} distribution
- Minimum ionizing particles used to exploit the low energy region

ΔT_{finger}



Stochastic term: (51±1) ps



Conclusions

- A (150×150×130) mm^3 LYSO crystal matrix has been tested with $e^\pm$ and γ beams in the energy range 20-450 MeV
- The energy resolution is well parametrized by the function: σ_E/E_{dep} = 0.6% / $\sqrt{E[GeV]} \oplus$ 3.6%
- After subtracting the measured time jitter, the time resolution follows the scaling law: σ_T = (51±1) ps / $\sqrt{E[GeV]}$