TOF with LYSO + G-APD

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Logic of using LYSO for TOF ?

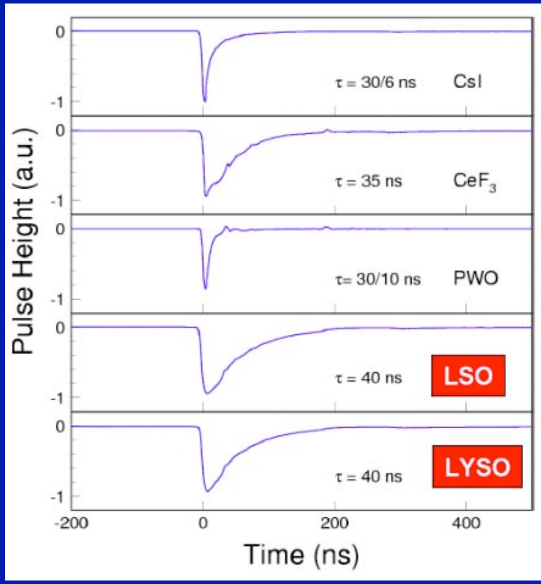
Crystals for HEP Calorimeters

Crystal	NaI(Tl)	CsI(Tl)	CsI	BaF_2	BGO	LYSO(Ce)	PWO	PbF_2
Density (g/cm^3)	3.67	4.51	4.51	4.89	7.13	7.40	8.3	7.77
Melting Point (°C)	651	621	621	1280	1050	2050	1123	824
Radiation Length (cm)	2.59	1.86	1.86	2.03	1.12	1.14	0.89	0.93
Molière Radius (cm)	4.13	3.57	3.57	3.10	2.23	2.07	2.00	2.21
Interaction Length (cm)	42.9	39.3	39.3	30.7	22.8	20.9	20.7	21.0
Refractive Index [a]	1.85	1.79	1.95	1.50	2.15	1.82	2.20	1.82
Hygroscopicity	Yes	Slight	Slight	No	No	No	No	No
Luminescence [b] (nm) (at peak)	410	550	420 310	300 220	480	402	425 420	?
Decay Time [b] (ns)	245	1220	30 6	650 0.9	300	40	30 10	?
Light Yield [b,c] (%)	100	165	3.6 1.1	36 4.1	21	85	0.3 0.1	?
d(LY)/dT [b] (%/ °C)	-0.2	0.4	-1.4	-1.9 0.1	-0.9	-0.2	-2.5	?
Experiment	Crystal Ball	BaBar BELLE BES III	KTeV	(L*) (GEM) TAPS	L3 BELLE	KLOE-2 SuperB SLHC?	CMS ALICE PANDA	HHCAL?

a. at peak of emission; b. up/low row: slow/fast component; c. QE of readout device taken out.

October 29, 2009 Paper N43-1, NSS09, Ren-yuan Zhu, Caltech 3

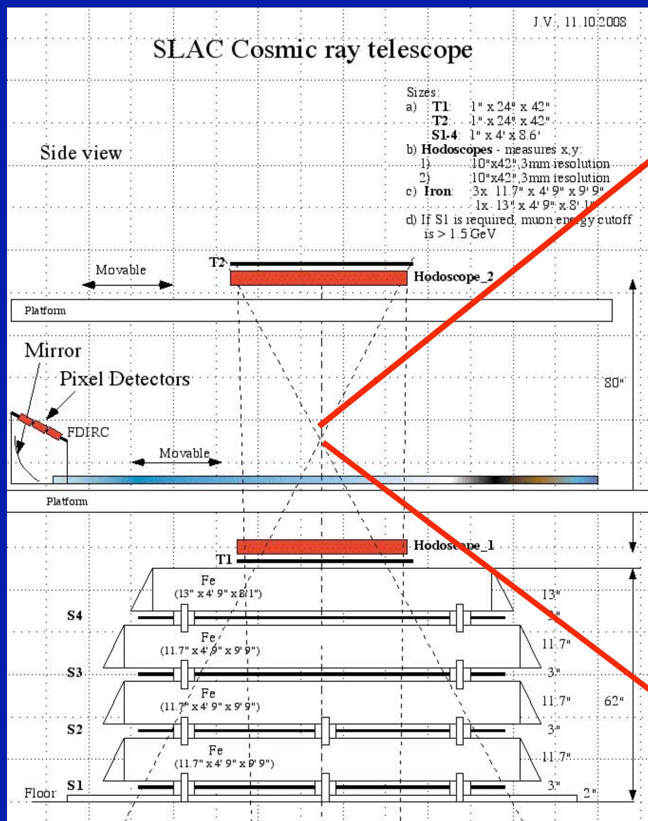
Pulse shapes:



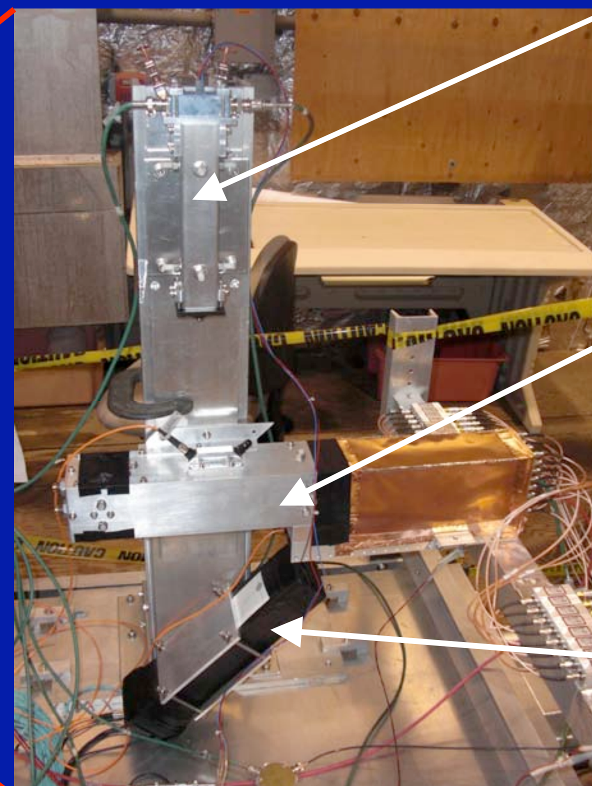
- It is not as fast as CsI or PWO, but it has much larger light yield copared the two (almost as high as NaI(Tl)). If one could "parasit" on the forward EMC calorimeter and achieve a good timing, why not ? A cheap simple way...

SLAC CRT setup

Cosmic Ray Telescope (CRT):
(described in SLAC-PUB-13873 (2010):



Present tests:



LYSO + Hamamatsu 4 x 4 G-APD array:

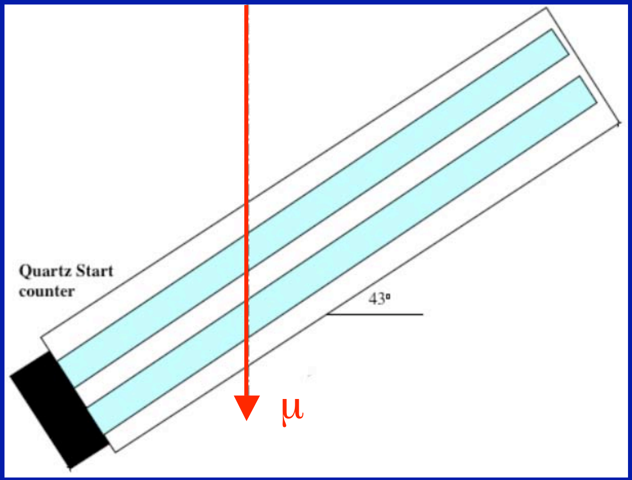
DIRC-like TOF (fTOF)

Start Counter (t_0 defining counter in CRT)

- **T1*T2*S1*Qtz_counter rate ~ 5k/24 hours <=> E_{muon} > 1.6 GeV**
- **Can accumulated more than 150k triggers/month.**

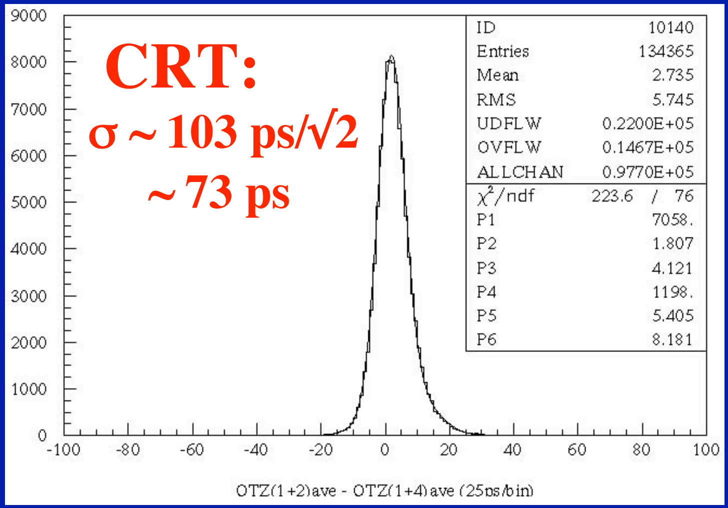
Double-quartz counter performance in CRT

4-pad MCP-PMT & 2 quartz bars:



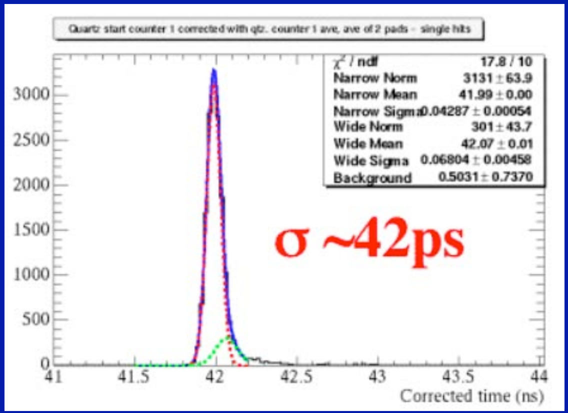
Form a difference between two pairs of pads:

$\Delta T = (Pad_1+Pad_2)/2 - (Pad_3+Pad_4)/2$



(Integrated over a CRT run lasting several months)

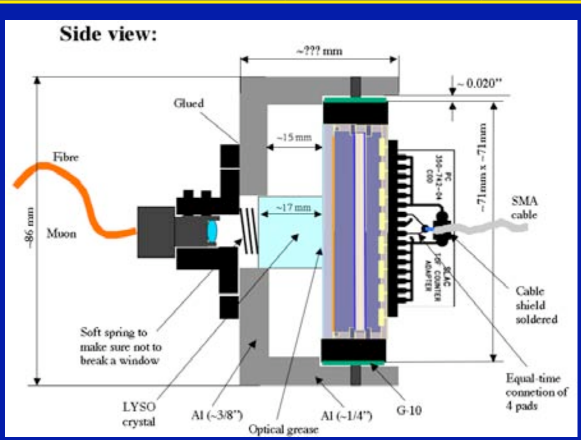
The same counter in the ESA test beam lasting a few hours and measured relative to an accelerator start pulse:

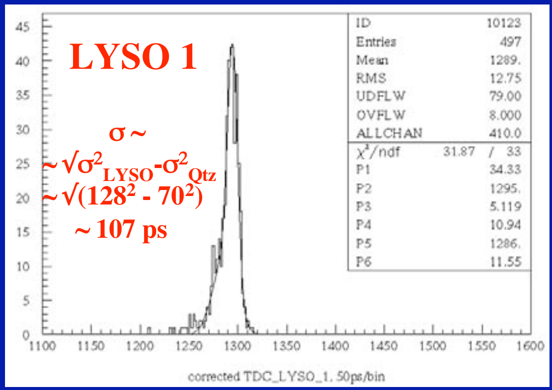


- **The start counter gives a resolution consistently of about 70-75 ps in a long CRT run, averaged over all CRT track angles, temperature drifts, etc.**

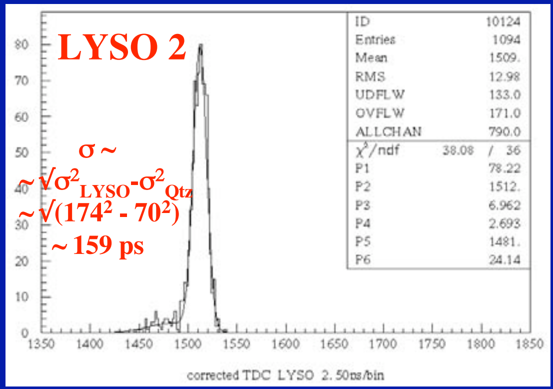
SLAC tests with small LYSO

Small LYSO + MCP-PMT (sum of 4 pixels):

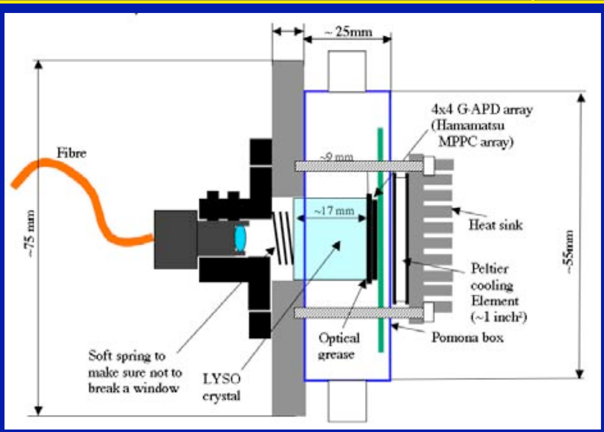


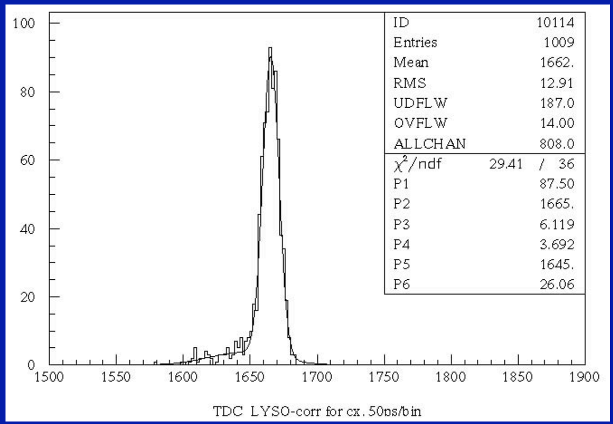


Time difference between LYSO and Start counter:



Small LYSO + G-APD (4x4 array):





Time difference between LYSO and Start counter:

$\sigma \sim \sqrt{\sigma^2_{LYSO} - \sigma^2_{Start}}$

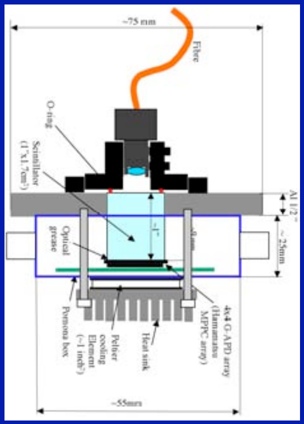
$< \sqrt{(152^2 - 70^2)}$

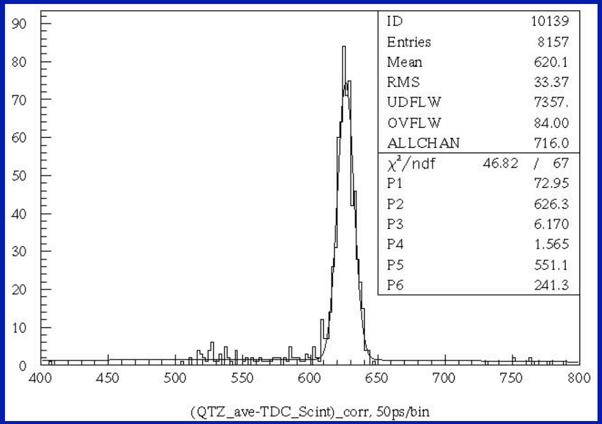
< 136 ps

Corrections & cuts: k_z & ADC corrections, cuts on Spot & ADC & Energy

SLAC tests with small LYSO

Scintillator + MCP-PMT (4x4 array):

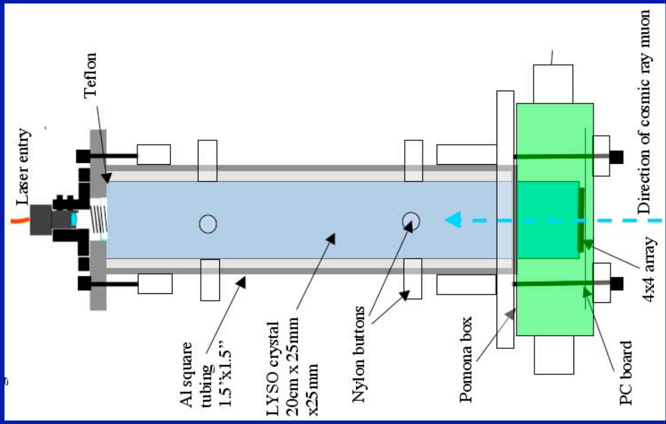


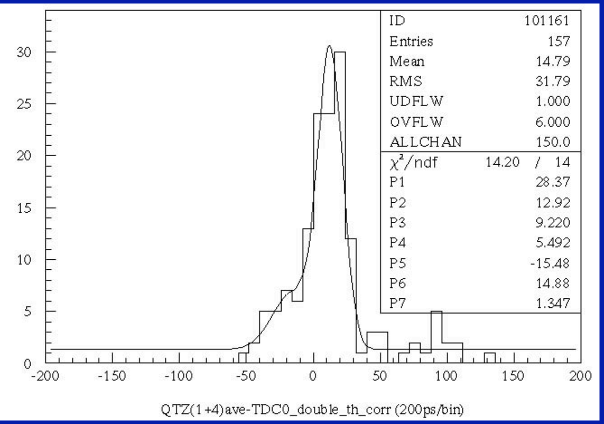


Time difference between scintillator and Start counter:

$\sigma \sim \sqrt{\sigma^2_{scintillator} - \sigma^2_{Start}}$
$< \sqrt{(154^2 - 70^2)}$
< 136 ps

Full size LYSO + G-APD (4x4 array):





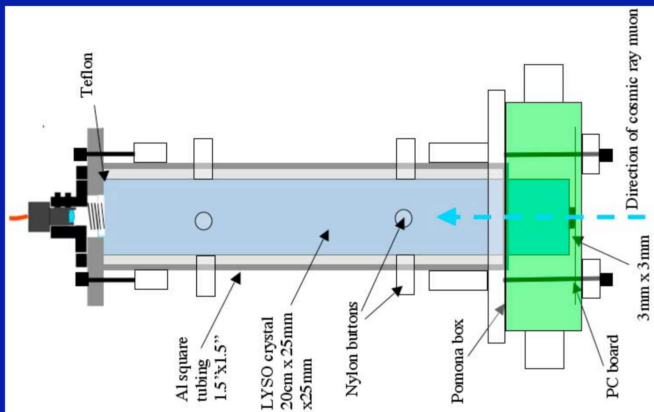
Time difference between LYSO and Start counter:

$\sigma \sim \sqrt{\sigma_{LYSO}^2 - \sigma_{START}^2}$
$\sim \sqrt{230^2 - 70^2}$
~ 220 ps

Corrections & cuts: k_z & ADC corrections, cuts on Spot & ADC & Energy

SLAC tests with full size LYSO

Full size LYSO + G-APD (single 3x3mm^2 MPPC S10362-33-025C):



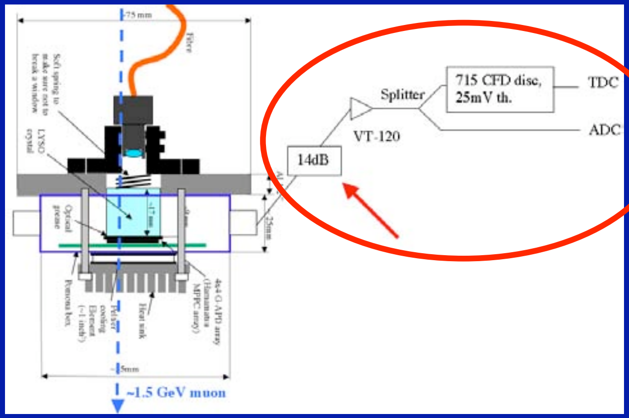
Plan to run it in CRT in April

$\sigma \sim$?

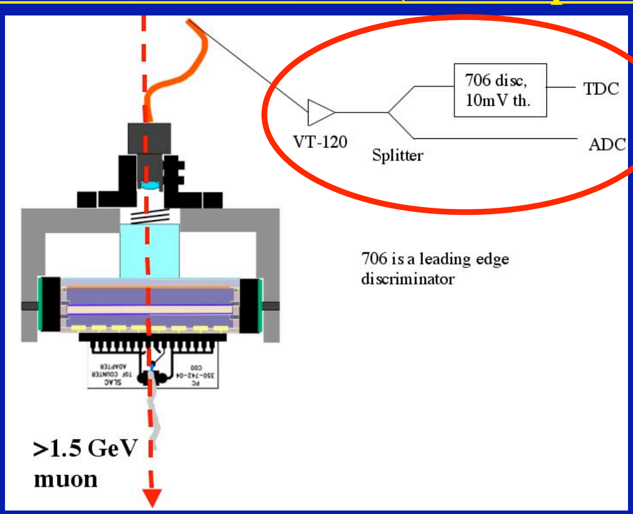
To be done befor CRT shutdown for FDIRC tests

SLAC tests: differences in electronics

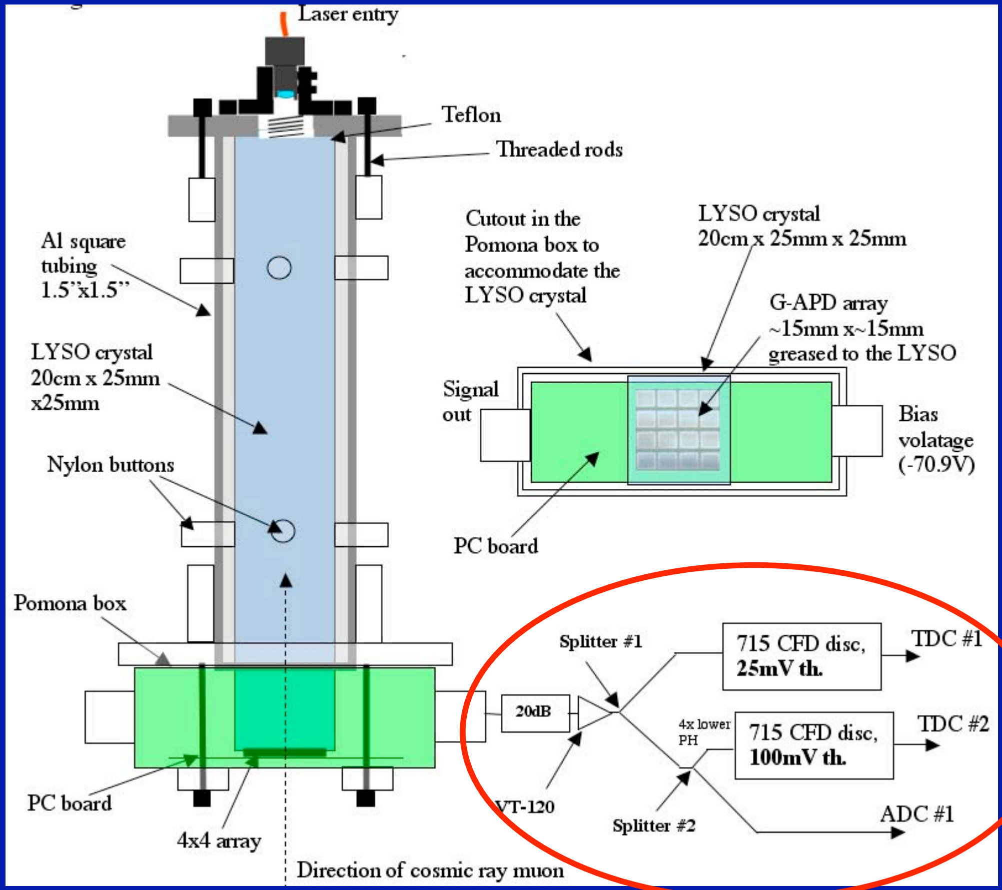
Small LYSO + G-APD (4x4 array):



Small LYSO + MCP-PMT (sum all pixels):



Full size LYSO + G-APD (4x4):

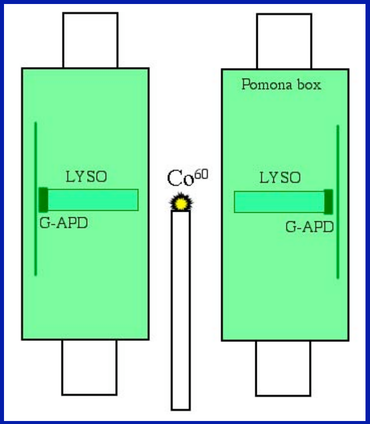


- **The first LYSO tests had more simple electronics.**

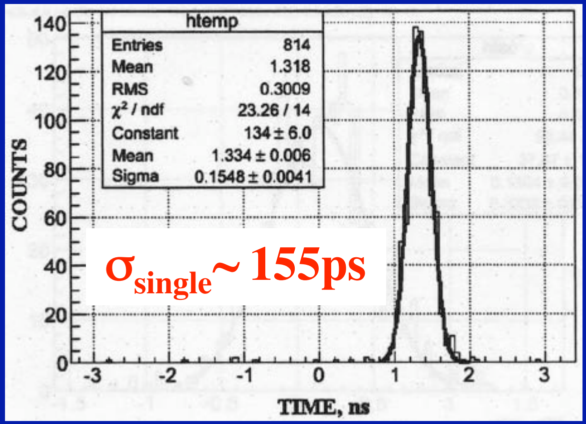
Fermilab test: tiny LYSO + G-APD array

A. Ronzhin, S. Los, et al., Fermilab internal pub, 2011

Setup:



Time difference between two identical LYSO counters:

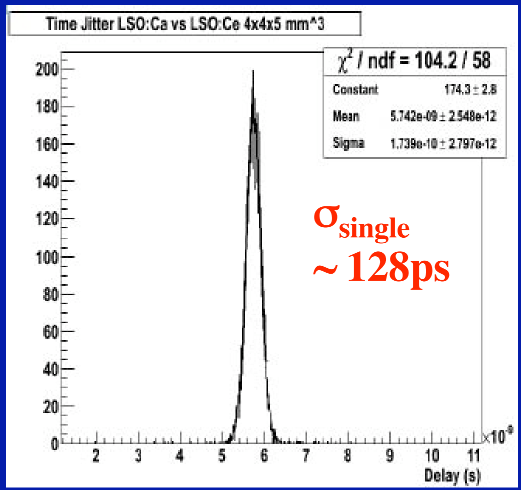


- **Their aim: to develop a fast PET detector using LYSO.**
- **Co^{60} source and trigger on back-to-back γ's.**
- **3mm x 3mm Hamamatsu G-APDs.**
- **Very tiny LYSO crystal of 3mm x 3mm x 7mm.**
- **The DRS4 waveform digitizer to analyze data (5 GHz sampling).**
- **With a PiLas laser diode they obtained a resolution of σ ~ 39ps for a signal of ~25 pe's.**
- **With a Co^{60} source they obtained σ ~ 155ps (their best resolution).**

4D-MPET: tiny LYSO + G-APD

M.S. Bisogni, Department of Physics, Pisa, 2010

Time difference between
two identical LYSO counters:



Summary of results from a Na^{22} source:

LSO Ca %	Size (mm^3)	FWHM (ps)	$\sigma\sqrt{(2)}$ (ps)
0	$2\times2\times10$	345	104
0.3	$3\times3\times10$	357	107
0	$4\times4\times5$	475	143
0.3	$4\times4\times5$	427	128

- **For a development of a fast PET detector using LYSO.**
- **3mm x 3mm FBK G-APDs (the same G-APDs as Padova is using presently).**
- **Noise rate: 1-3MHz for threshold of 1-2 pe's, and 3-4kHz for threshold of 3-4 pe's.**
- **The best resolution was obtained with a very tiny LYSO crystal of 3mm x 3mm x 10mm. He compared this result with other small crystal sizes.**
- **With a Na^{22} source, the best resolution obtained was $\sigma \sim 107$ ps.**

Conclusion

- **Results so far:**

Test	Radiator	Detector	Particle	Resolution
SLAC	Small LYSO 17mm x 17mm x 17mm	MCP-PMT	CRT μ's	109 & 159 ps
SLAC	Small LYSO 17mm x 17mm x 17mm	G-APD array	CRT μ's	~ 140 ps
SLAC	Small scint. 17mm x 17mm x 17mm	G-APD array	CRT μ's	~ 136 ps
SLAC	Long LYSO 25mm x 25mm x 200mm	G-APD array	CRT μ's	~ 220 ps
Fermilab	Tiny LYSO 3mm x 3mm x 7mm	$3mm^2$ G-APD	γ's from Co^{60}	~ 155 ps
Pisa	Tiny LYSO 3mm x 3mm x 10mm	$3mm^2$ G-APD	2γ's from Na^{22}	~ 107 ps

- **Still one more test is planned in CRT, but things do not look hopeful to me that we can achieve σ ~ 100ps. But would like to go at it once more.**