A pixilated TOF with LYSO crystals

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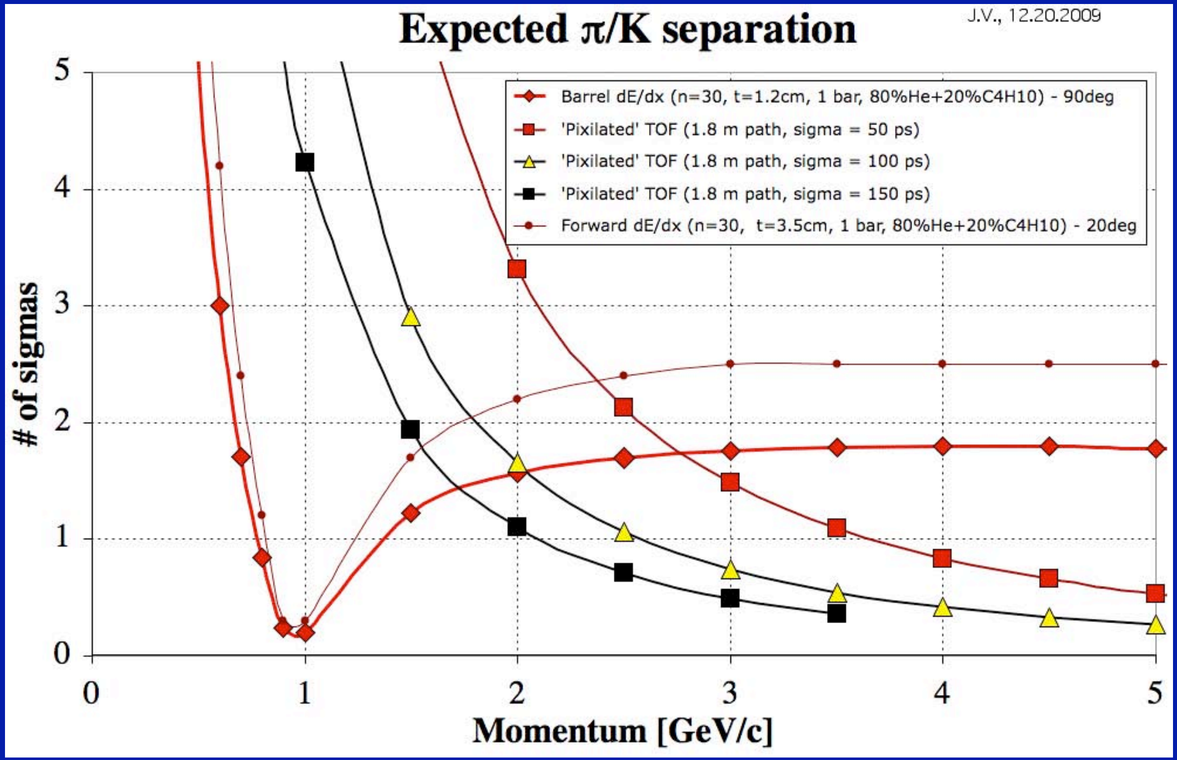
Initial comments

- **Blair's points:**
- **Can we use a LYSO crystal as a radiator ? Or something else ?**
- **If one can achieve a timing resolution of ~100 ps and if it will cost <$1M, we might simply do it, to plug a dE/dx hole in the π/K separation up to ~1.5 GeV/c.**
- **Endcap represent a 10% of solid angle. The cost should be consistent with this ratio.**
- So, I started to think about this.
- Frank Porter kindly provided two small LYSO crystals.
- Decided to do the first timing test with MCP-PMTs, although the final solution could be done with G-APDs.

Is σ =100-150 ps interesting enough ?

Assume ~1.8m-long flight path in the forward direction:



- **A 100 ps resolution would give us a ~3σ π/K PID up to ~1.5 GeV/c.**
- **Even a 150 ps resolution would provide ~ 4σ π/K separation in the dE/dx hole near 1 GeV/c.**

LYSO parameters

R. Zhu:

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.

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- **LYSO is not the fastest calorimetric crystal by far. Use BaF_2 instead ?**

BaF_2 scintillation properties

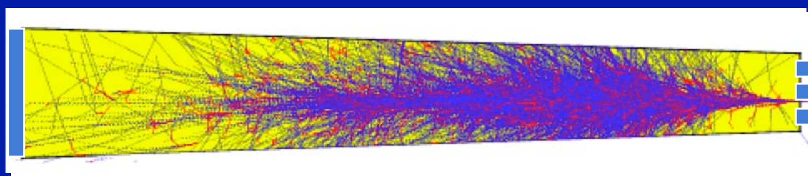
Scintillation Properties	
Space group	Fm3m
Cleavage	(111)
Density ($g.cm^{-3}$)	4.89
Melting point (°C)	1280
Hardness (Mho)	3
Hygroscopic	No
Radiation length (cm)	2.06
Peak emission (nm)	310(slow), 220(fast)
Decay constant (ns)	620(slow), 0.6(fast)
Refractive index at peak emission	1.51(slow), 1.49(fast)
Afterglow (after 3ms) (%)	0.005
Light output relative to NaI(Tl) (%)	20%(slow), 4%(fast)

- **Unfortunatelly the fast component is in far UV light region.**

Possible options

Option #1:

add 4 G-APDs to front

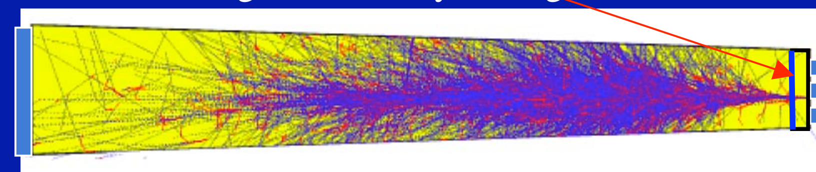


Works with scintillation light from LYSO

Simplest solution, but will not work

Option #2:

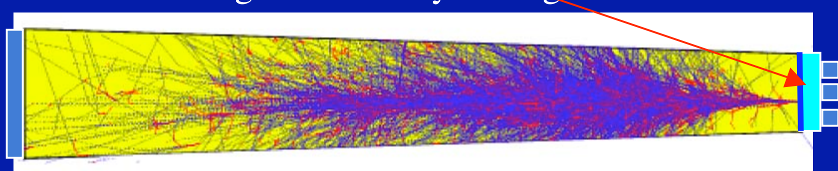
Add 1cm-long LYSO crystal, add 16 G-APDs to front,
Increase the light amount by adding a mirror



Works with Cherenkov light from LYSO

Option #3:

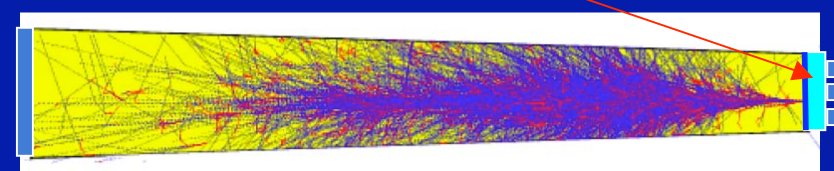
Add 1cm-long **$PbWO_4$ crystal**, add 4 G-APDs to front,
Increase the light amount by adding a mirror



Works with a scintillation light from PWO

Option #4:

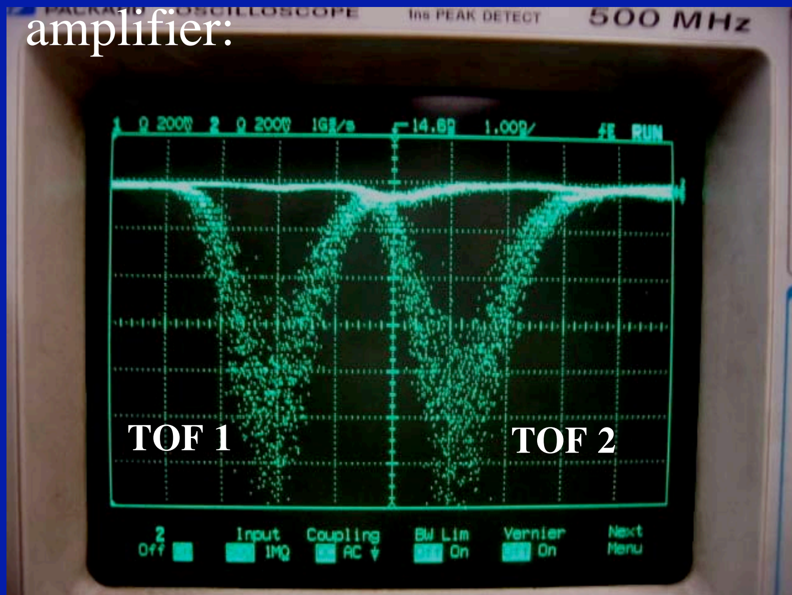
Add a 1cm-long **fast scintillator**, add 4 G-APDs to front,
Increase the light amount by adding a mirror



Works with a scintillation light from fast scint.

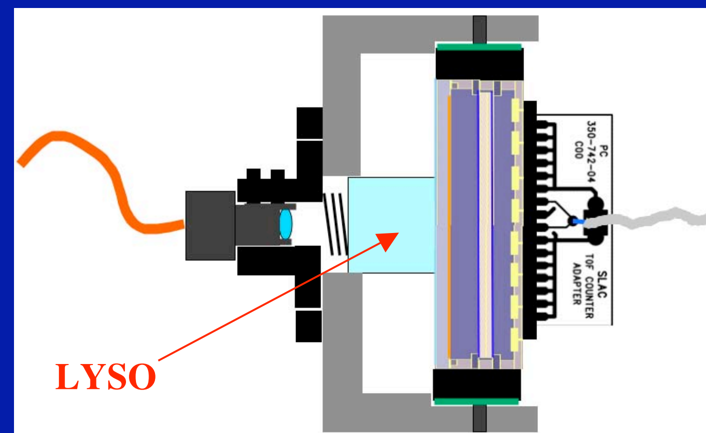
Laser test to setup the voltages

Laser pulses with VT-120 amplifier:



1ns/div

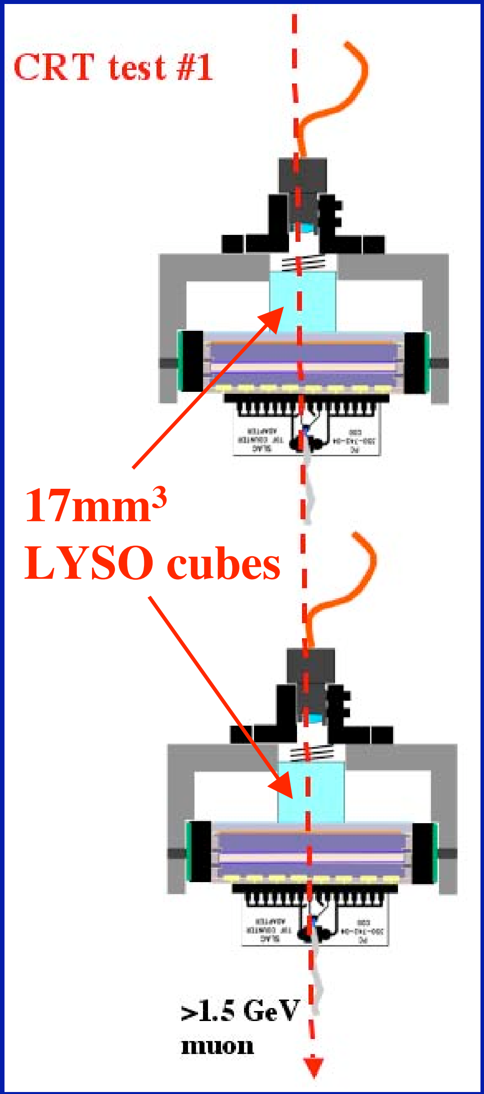
LYSO crystal coupled to a MCP-PMT



25µm holes MCP

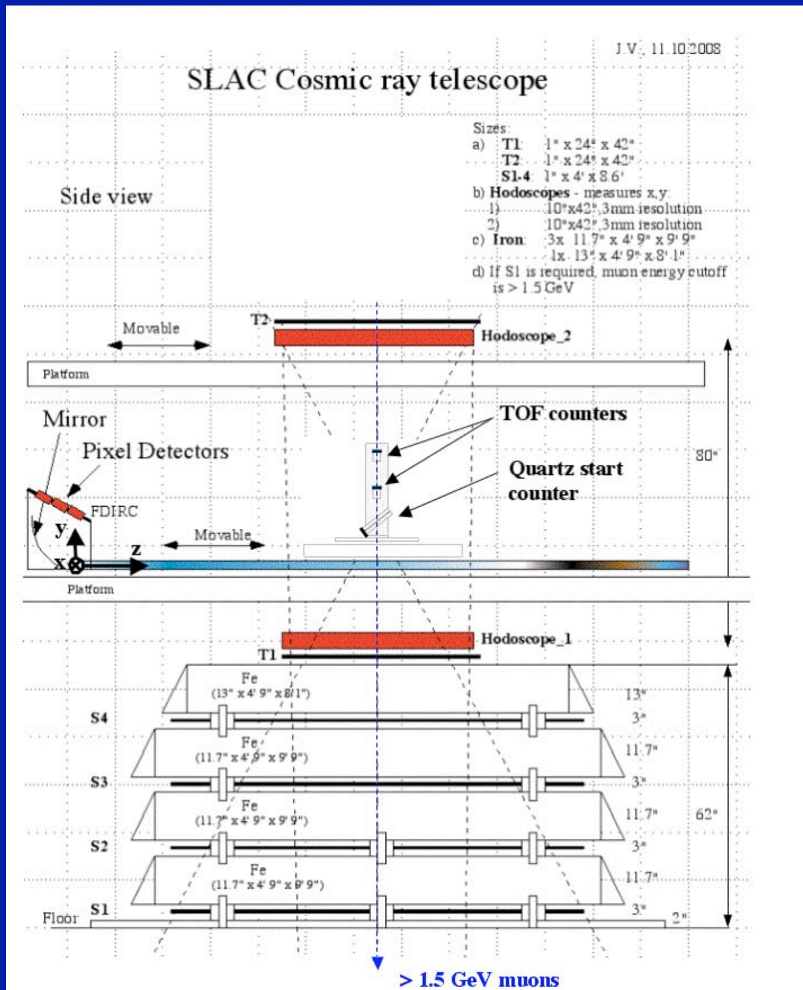
- Use the HPK amplifier first, which was used in the Fermilab test, and set the laser intensity & voltages so that the detector response is the same as the signal during the Fermilab test with a 1cm-long quartz radiator.
- Set MCP-PMT voltages to: 1.74 & 1.53 kV (a bit too low perhaps).
- Then switch to VT-120 amplifier, which is used in the CRT test.
- Observe ~1ns risetime with a laser and this amplifier.

Initial CRT test with LYSO crystals

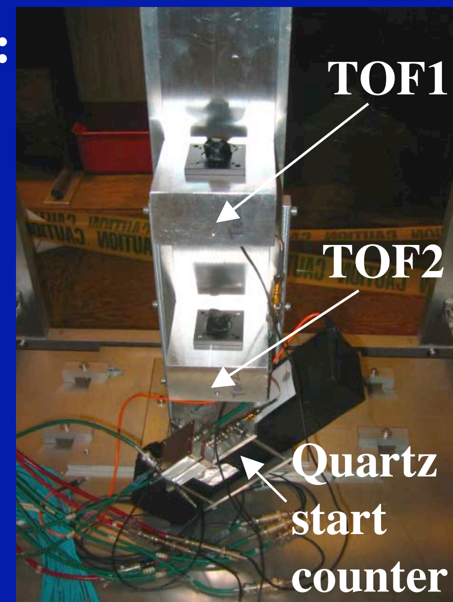


- Use two MCP-PMTs with 25µm holes, which were previously used in the FDIRC prototype in ESA beam test. This is NOT a plan for a final detector !
- Short 4 MCP pads together to provide 12mm x 12mm photosensitive footprint for the LYSO light readout.
- Use Ortec VT-120 amplifier (200x).
- LYSO crystals, obtained from Frank Porter, are cubes with size $17mm^3$.
- Use grease for the optical coupling between LYSO and MCP window.
- Phillips 25ps/count TDC and LeCroy ADC for the amplitude-to-time correction.
- Orient the crystals for the fast Cherenkov light detection - in the test #1.

Initial CRT test with LYSO crystals



Setup:



Scope trigger: T1*T2*Qtz

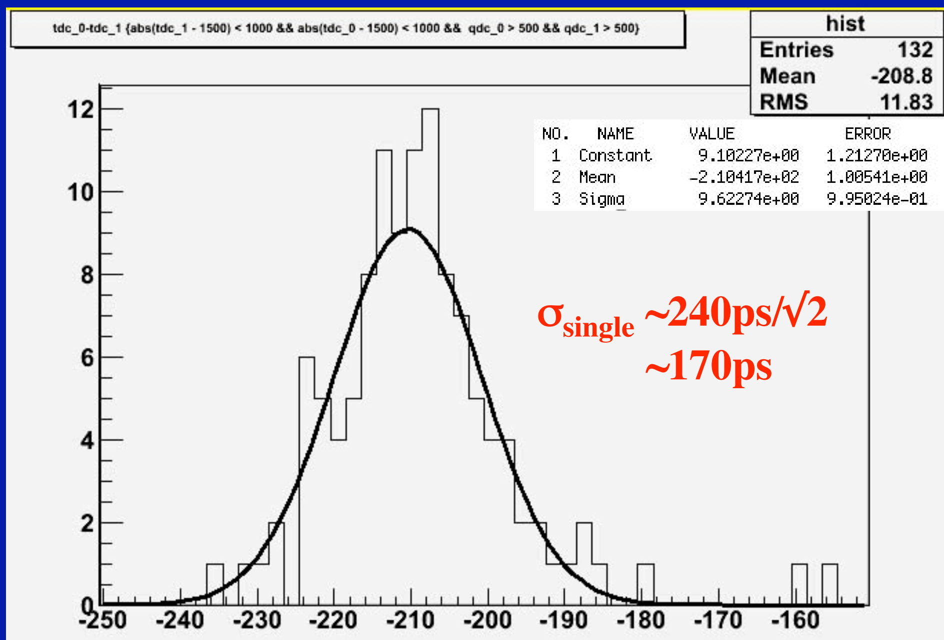
Scope signals in CRT (a fast ~1-2 ns risetime + slow many ns-long component)

2ns/div

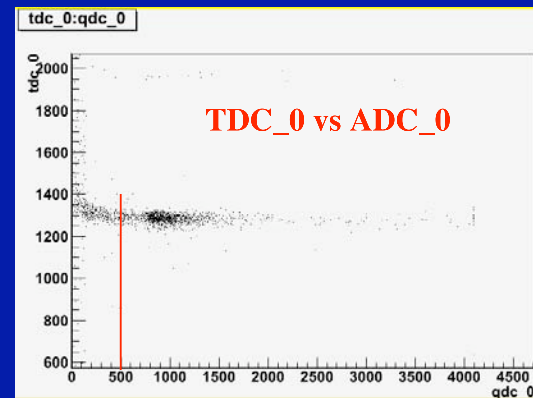
Very soft particles in this trigger

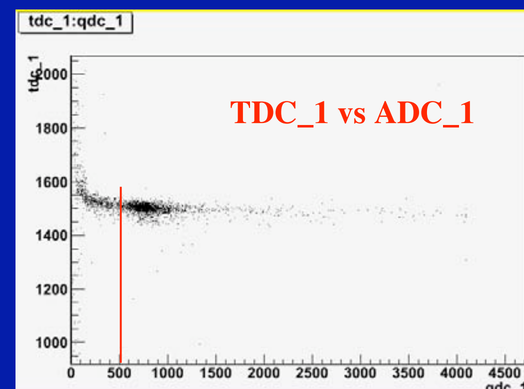
- **Test is in progress**

The first results



TDC_{TOF1} - TDC $_{TOF2}$ [50ps/bin]





- **All this is with very soft particles. No hard muons yet.**
- **No ADC correction of timing, only an ADC cut.**
- **No tracking involved in this estimate.**
- **Very preliminary, likely can be improved, as the analysis with the CRT tracking is in progress - this will allow to require a cut on hard muons.**