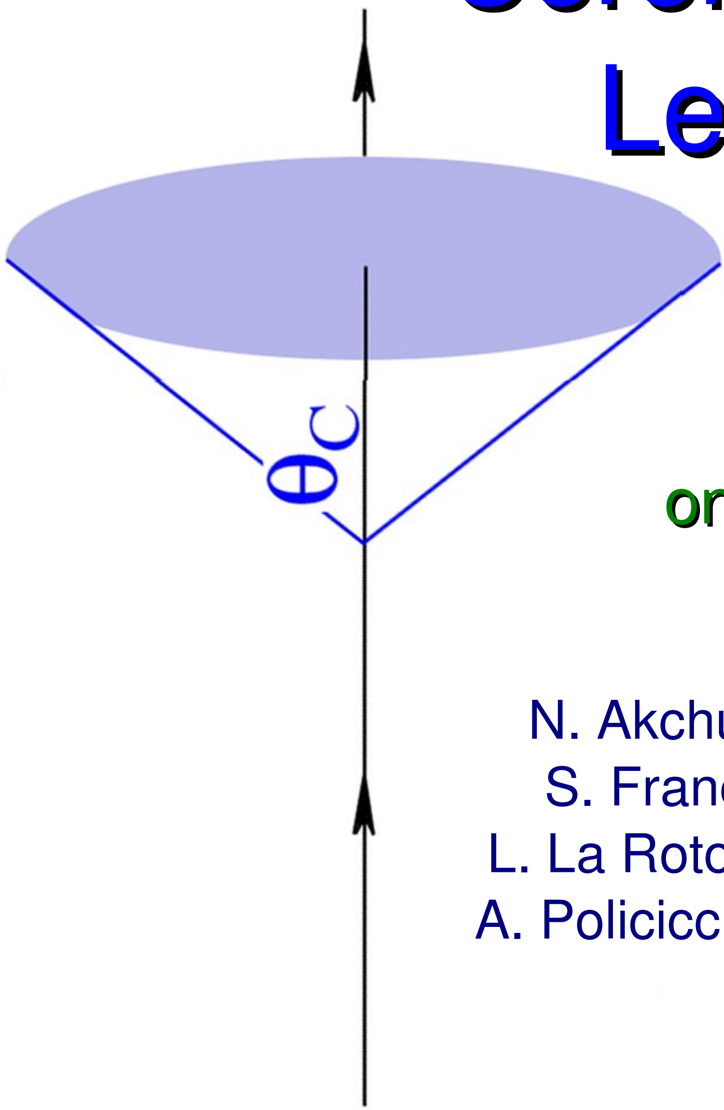

Čerenkov Light Contribution in Lead Tungstate Crystals

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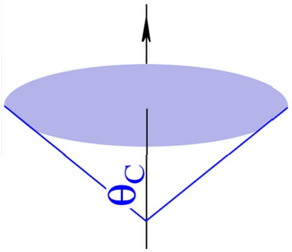
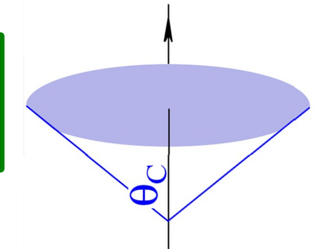
Outline



- DREAM approach to hadronic calorimetry
- Extending the DREAM principle to a homogeneous detector
- Evidence of Čerenkov light in $PbWO_4$ crystals
- Experience with a small $PbWO_4$ electromagnetic calorimeter
- Preliminary results with a BGO crystal

Performance in hadronic calorimetry



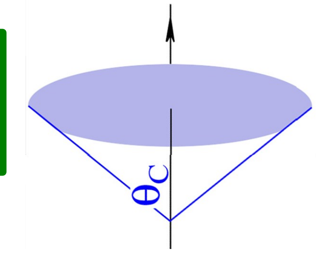
- Main limitations caused by
  - mostly different detector response to em component ($\pi^0 \rightarrow \gamma\gamma$) and non-em component (i.e. e/h>1)
  - fluctuations in em component (f_{em}) are large and non-Poissonian

non-Gaussian, non-linear hadronic response function
hadronic energy resolution deviates from $E^{-1/2}$ scaling

- Dealing with the problem
  - best performance delivered by compensating calorimeters at a cost of a small sampling fraction
  - the DREAM approach: resolution determined by fluctuations in f_{em}

Measure f_{em} event-by-event

DREAM approach: measure f_{em}



- $e^{\pm}$ in em component are relativistic down to 1MeV
- hadronic particles in non-em component are usually non relativistic

Independent measurements of the scintillation and Čerenkov light yields can allow to estimate the two components and measure f_{em}

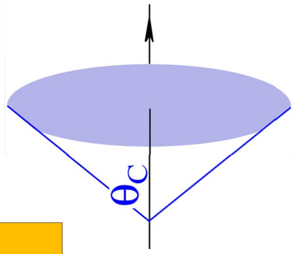
Sampling calorimeter with separate active materials

Dual-REAdout Module

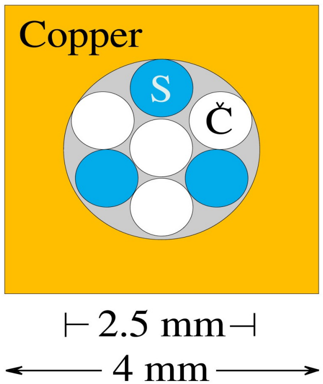
Homogeneous calor. exploiting differences between scintillation and Čerenkov light emissions

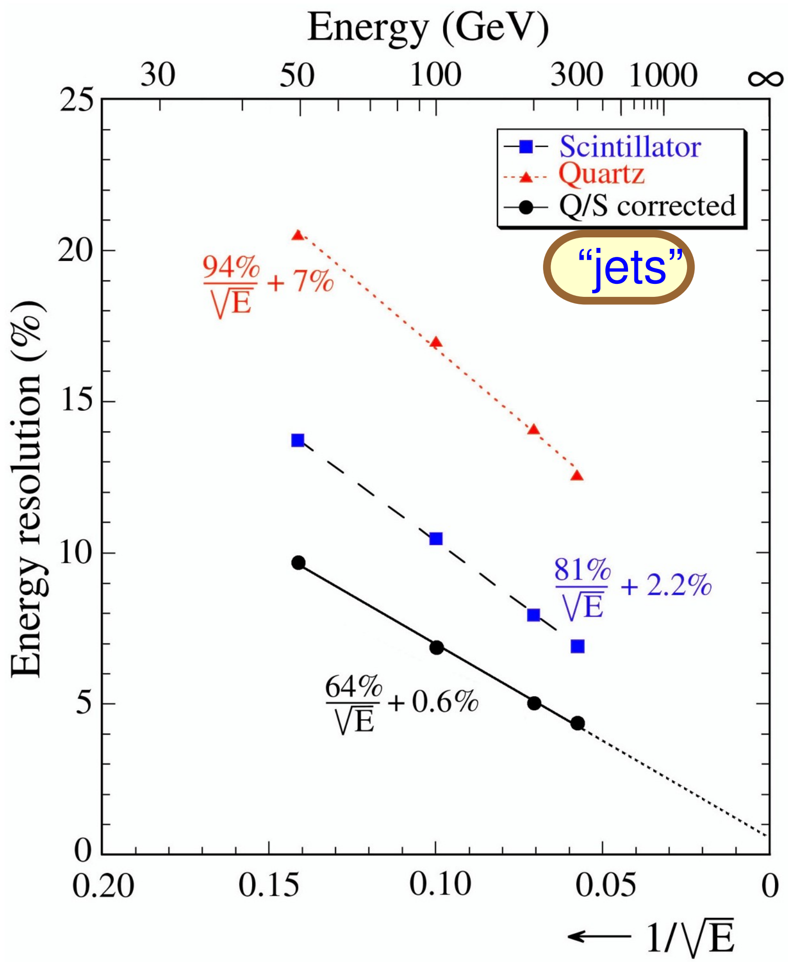
Under study

Dual-REAdout Module



- Consists of 5880 copper rods equipped with scintillating (S) and undoped quartz (Č) fibers, grouped in 19 towers read-out by 38 PMTs

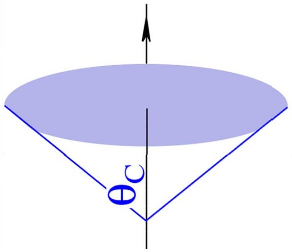




- Improved resolution exploiting the Q/S~f_{em} ratio
- Calibrated with electrons
- Resolution dominated by
  - Leakage fluctuations
  - Fluctuations in invisible energy
  - Sampling fluctuations

N. Akchurin et al., Nucl. Instr. and Meth. A 536 (2005) 29
N. Akchurin et al., Nucl. Instr. and Meth. A 537 (2005) 537

Extending DREAM principle: $PbWO_4$



- Čerenkov light produced in any optical medium
- How to distinguish the light components in a uniform medium:

	Čerenkov	Scintillation
Directionality	Cone	Isotropic
Timing	Prompt	Decay
Spectrum	λ^{-2}	Limited band
Polarization	yes	no

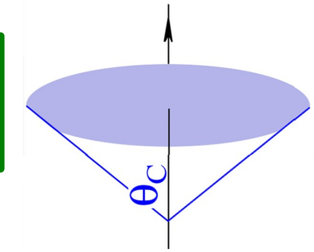
- Started investigating $PbWO_4$*. Well known and "largely" available scintillating medium
  - 2.2 x 2.2 x 18 cm^3, $2X_0$ (transversal plane)

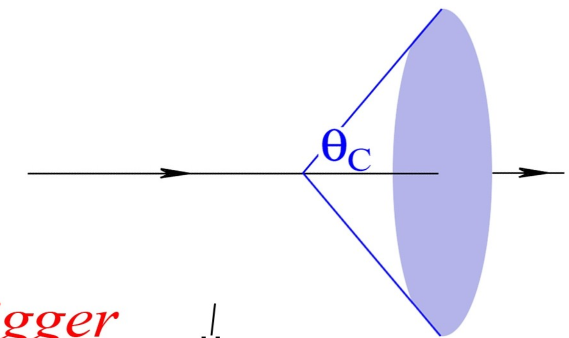
Rel. (NaI) Light yield	Decay time (ns)	Peak wavel. (nm)	Cutoff wavel. (nm)	Refr. index	Density (g/cm^3)
1.3%	10	440	350	2.2	8.3

- Search for Čerenkov contribution using particle beams at SPS@CERN

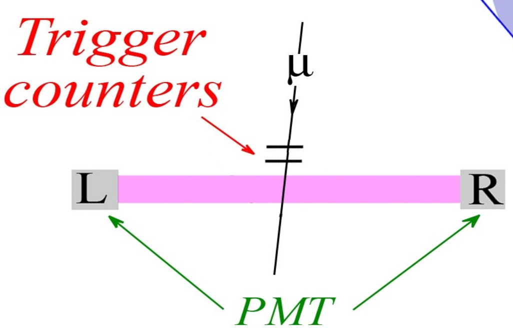
* *Kindly provided by the PHOS group of the ALICE experiment*

Asymmetry measurement



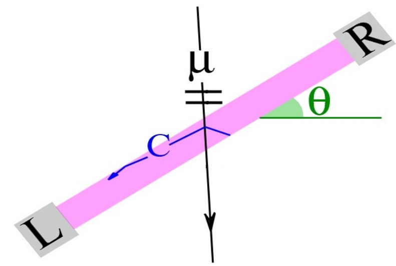


$n = 2.2\,, \qquad \cos\theta_C = 1/n \longrightarrow \theta_C = 63^o$

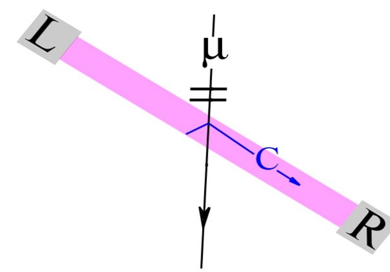


Calibration:

L = R



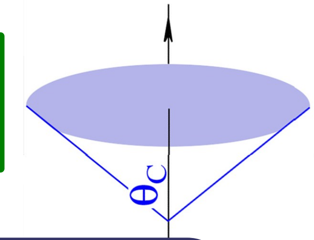
L > R



L < R

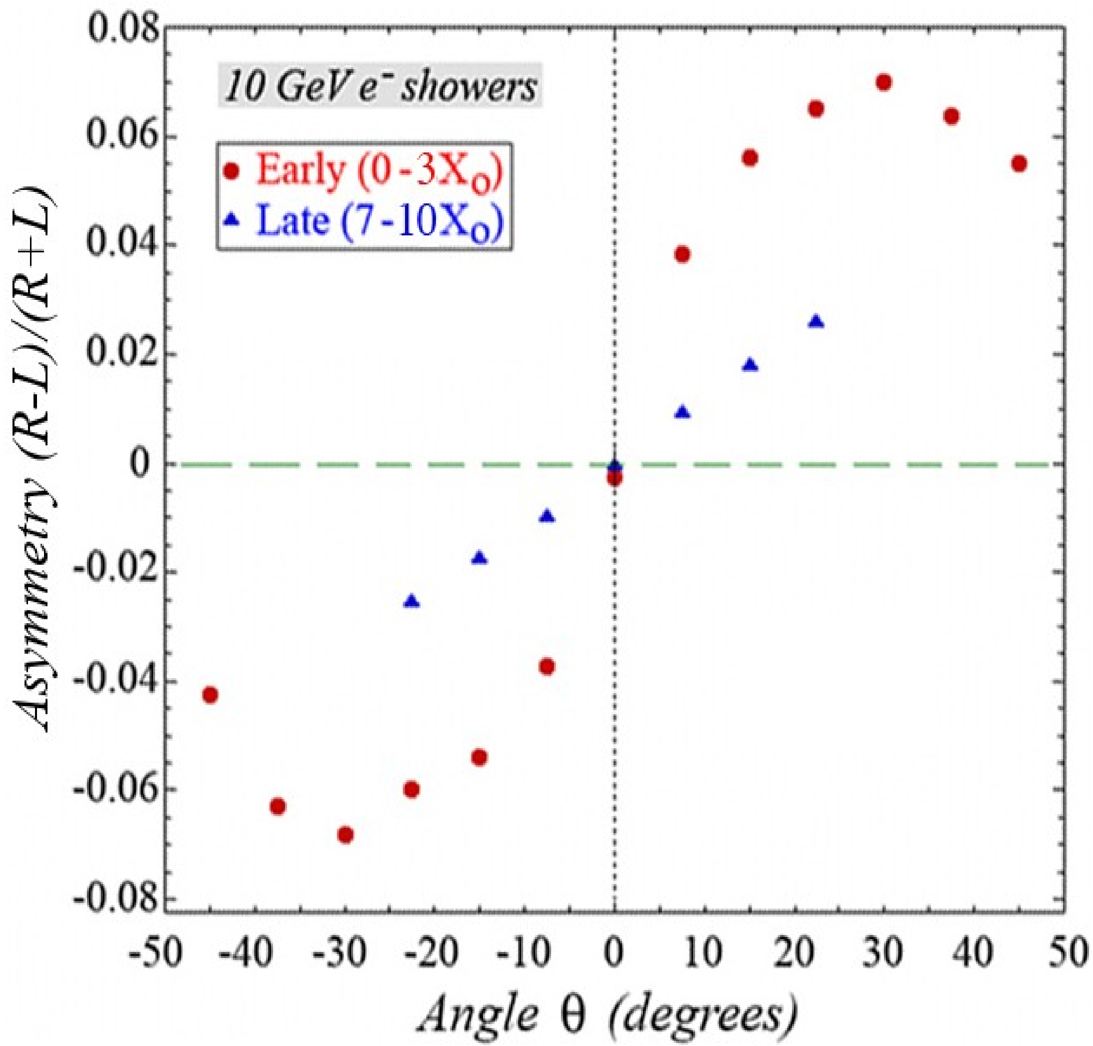
- Use directionality to reveal Čerenkov light and measure its contribution
- Crystal signals acquired by means of
  - charge integrators
  - fast digitizer (800MHz sampling frequency)
- Define charge asymmetry: $\alpha = \frac{R-L}{R+L} = \frac{\epsilon_R - \epsilon_L}{2+\epsilon_R+\epsilon_L} \qquad \epsilon_x = \frac{\check{C}_x}{S_x}$

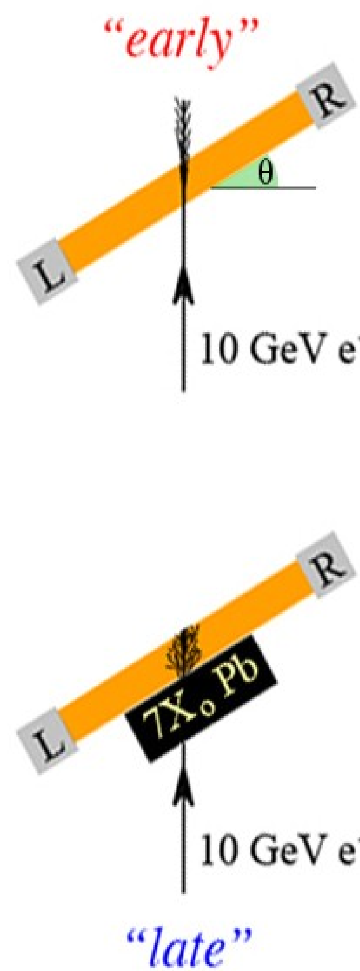
Charge asymmetry



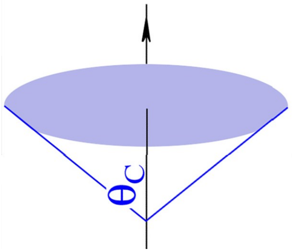
- Č contribution up to 13%
- No sensitivity ($\sigma \simeq 5\%$) on a single event basis due to small photoelec. statistic
  - ~1 p.e./MeV
- Smaller asymmetry for a "late" showers
  - isotropic component
- 150 GeV μ^- α=15% - 20%
  - no shower at all

Clear evidence of Čerenkov light

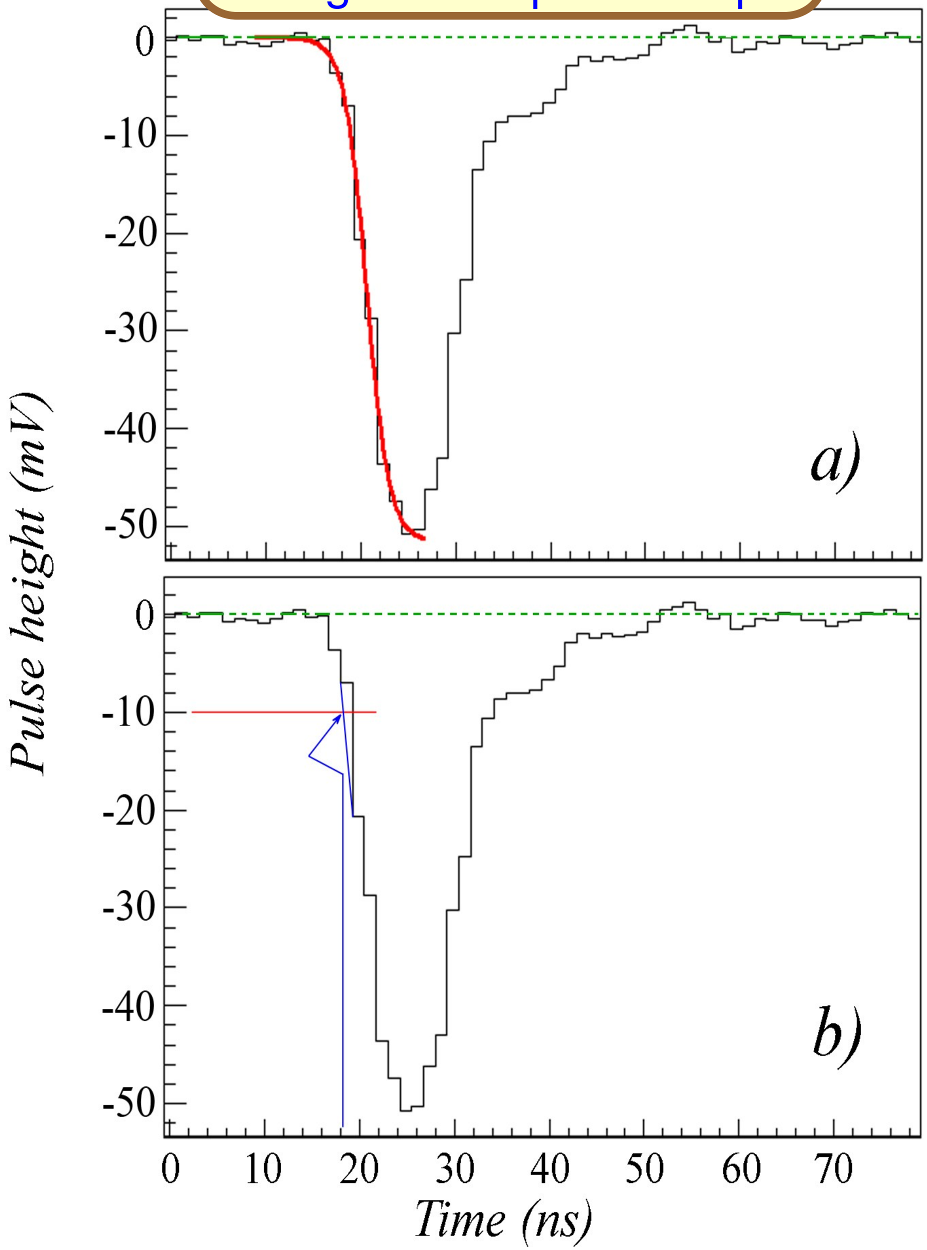




Čerenkov light in pulse shape



Single PMT pulse shape



- Looking for Čerenkov signatures in the pulse shapes (exploiting Č timing properties)
- $PbWO_4$ fast scintillator. Components are superimposed

a) Fitting the leading edge with

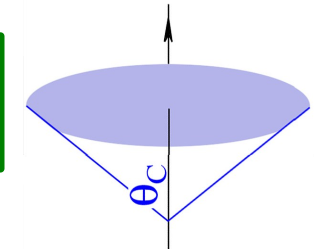
$$V(t) = |A| \left[\frac{1}{e^{(t-t_L)/\tau_L} + 1} - 1 \right]$$

- lead constant τ_L should decrease with increasing Č content

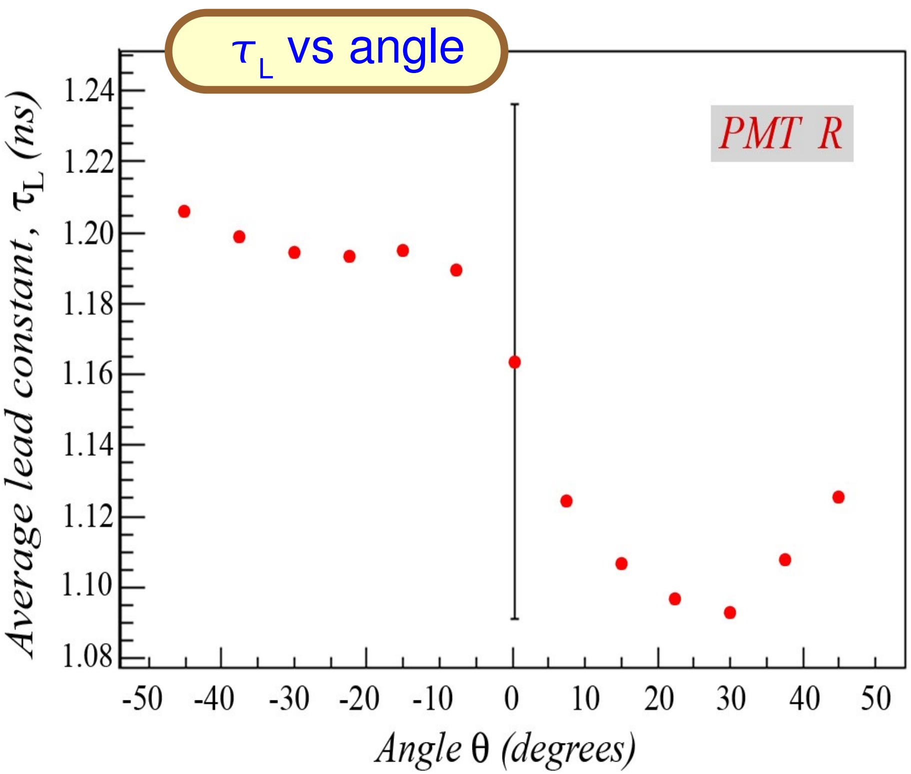
b) Looking for the time at which a given threshold is reached

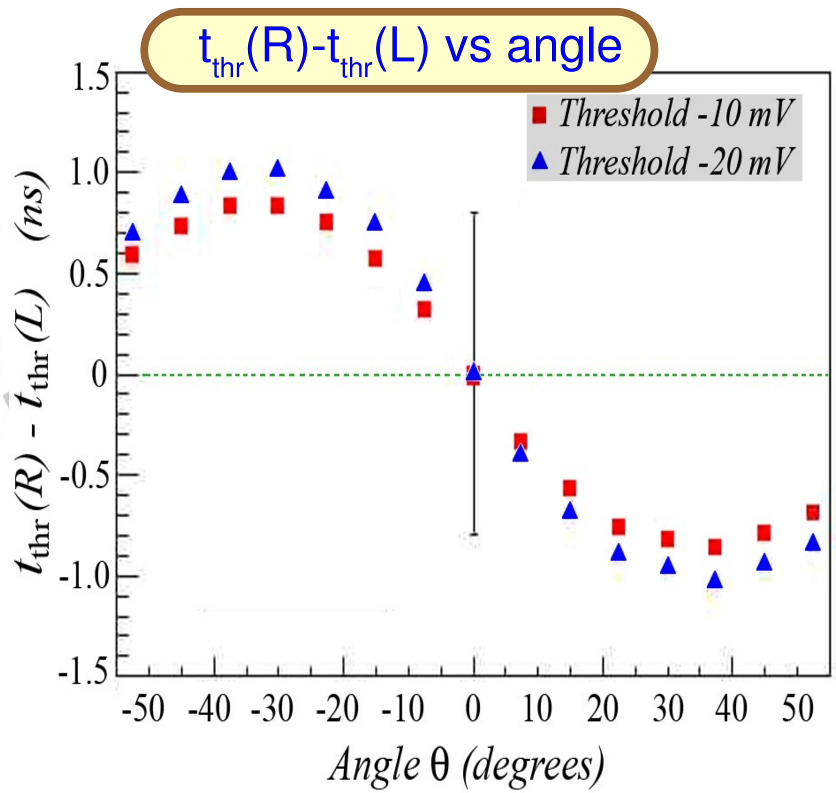
- crossing time t_{thr} should decrease with increasing Č content

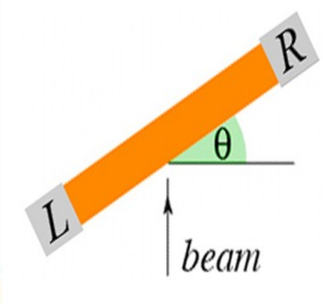
Pulse shape results



- Both methods disclose the Č light presence
- In particular the lead constant analysis provides Č information from a single side
- Error bars show the distribution widths (σ)
  - again event-by-event analysis not possible (p.e. statistics)

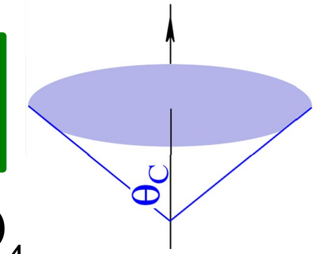




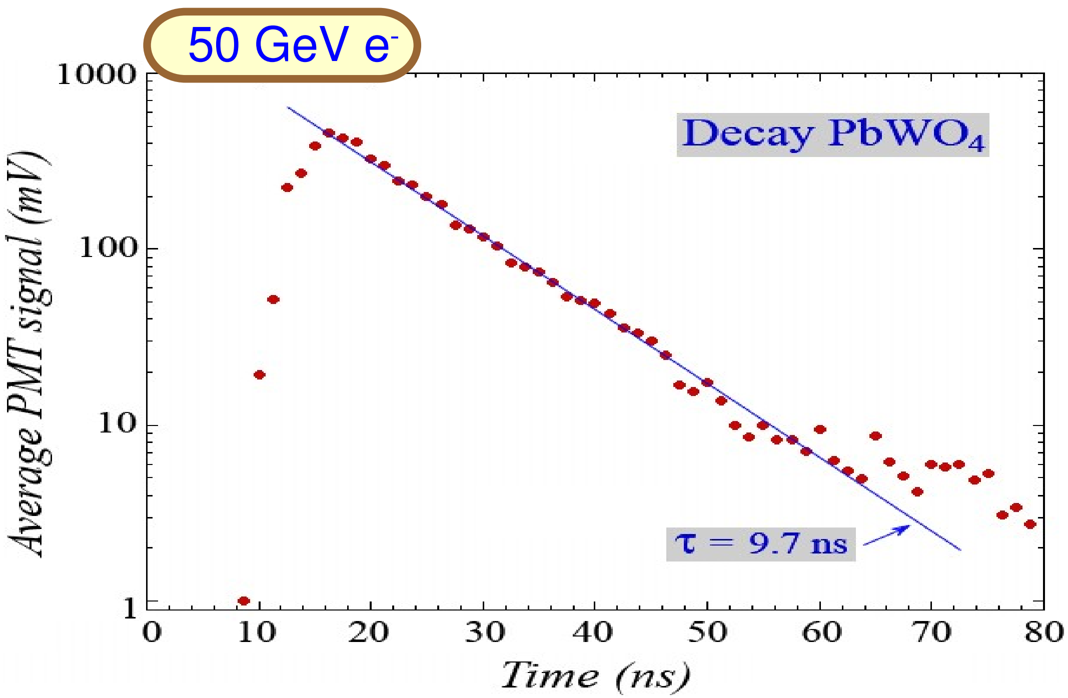


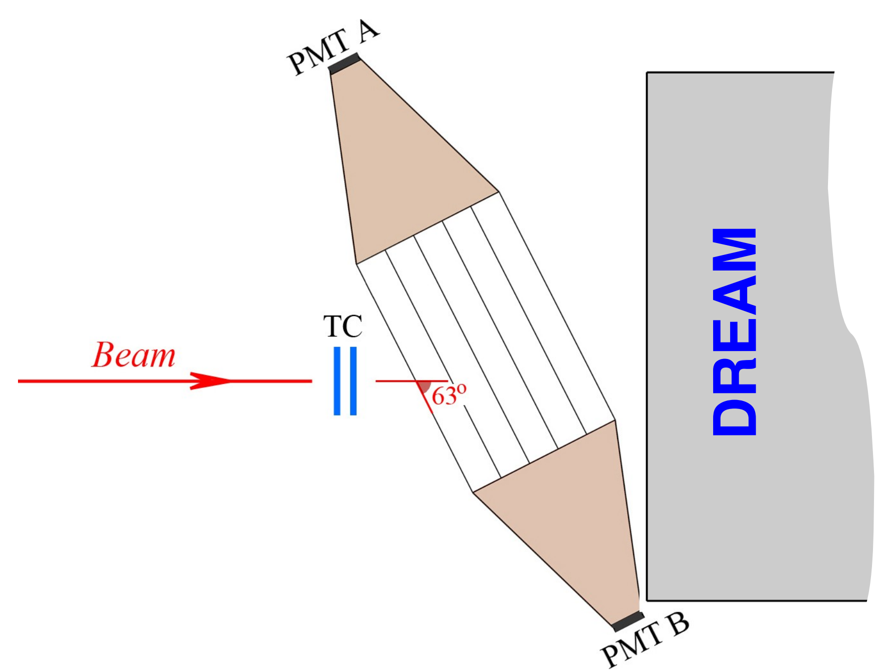
10 GeV e^-

ECAL

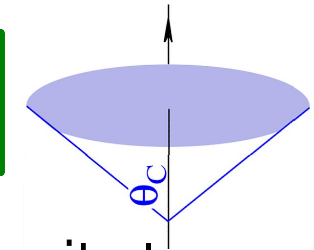


- Small electromagnetic calorimeter (ECAL) made of 19 $PbWO_4$ crystals in front of DREAM (HCAL)
  - ECAL: $14X_0$, $0.5\lambda_{int}$ HCAL: $100X_0$, $10\lambda_{int}$
- Calibrated in 90° geometry (perpendicular to the beam), operated in an optimised 63° geometry
- Try to estimate S and Č components of ECAL signals (and correlate with HCAL). Use asymmetry (B-A)/(B+A)



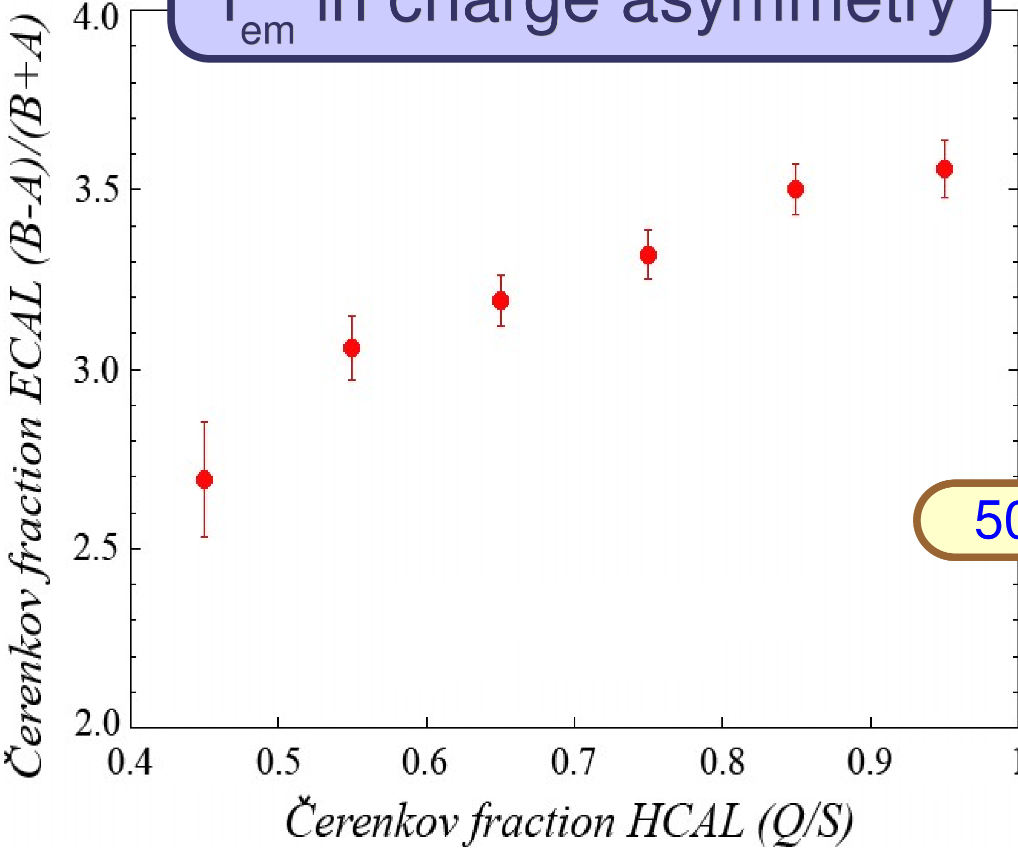


f_{em} detection with ECAL



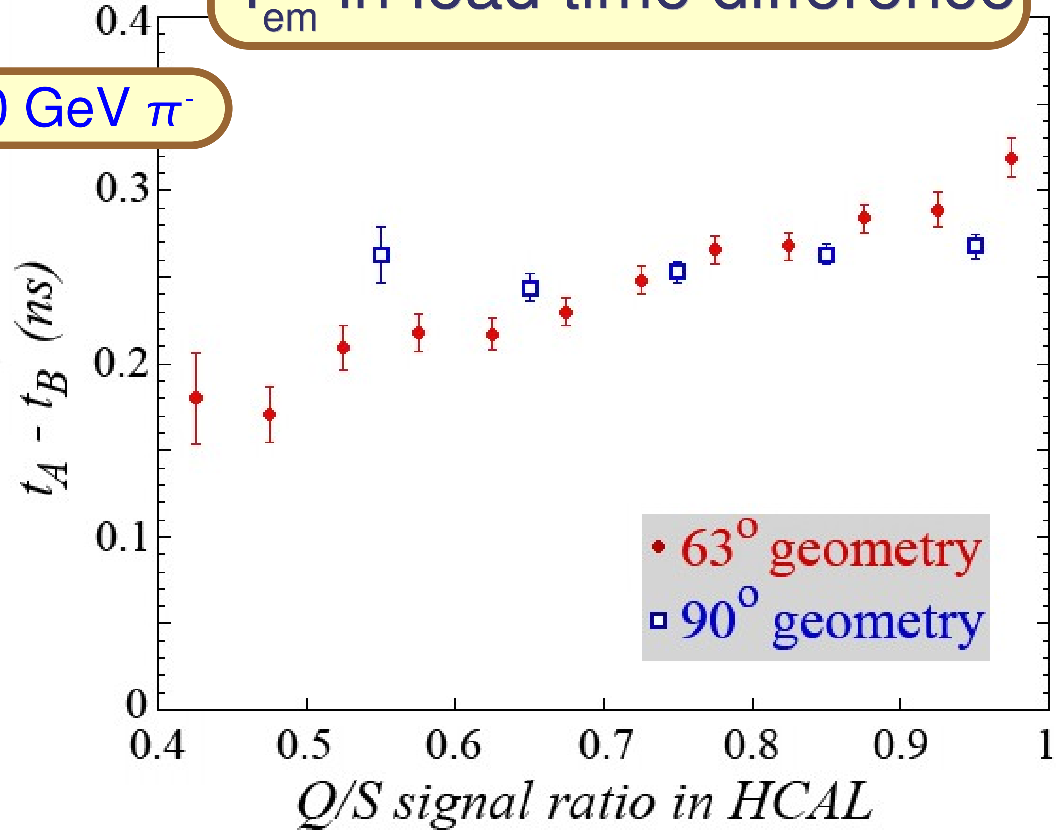
- Select events that deposit at least 10 GeV in ECAL

f_{em} in charge asymmetry



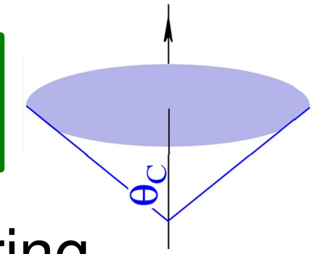
50 GeV π^-

f_{em} in lead time difference



ECAL measurements correlate well with HCAL $Q/S \sim f_{em}$

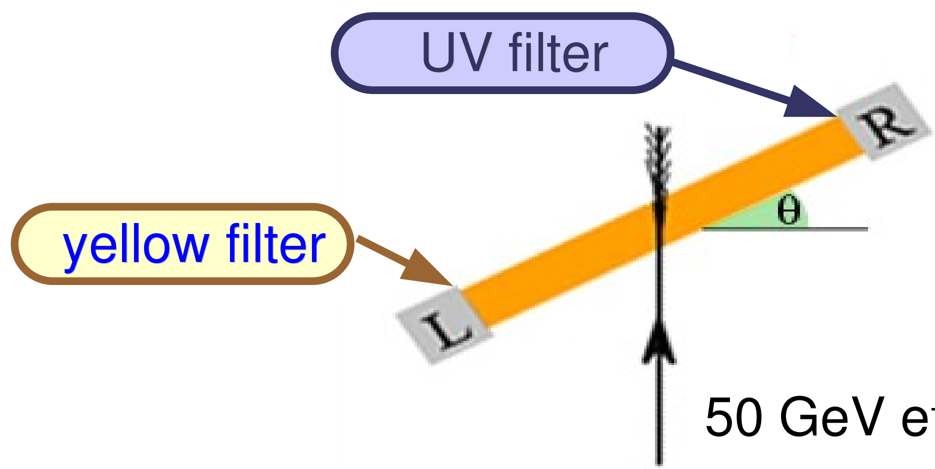
Exploit the spectrum: BGO



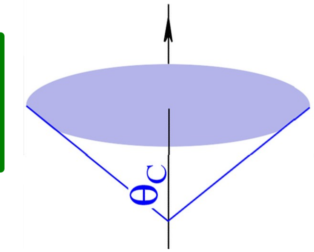
- Promising results obtained with $PbWO_4$. Proceed exploring different (more suitable) crystals
- In a real detector Č directionality hardly usable
  - Time structure provides information
  - What about the spectrum?

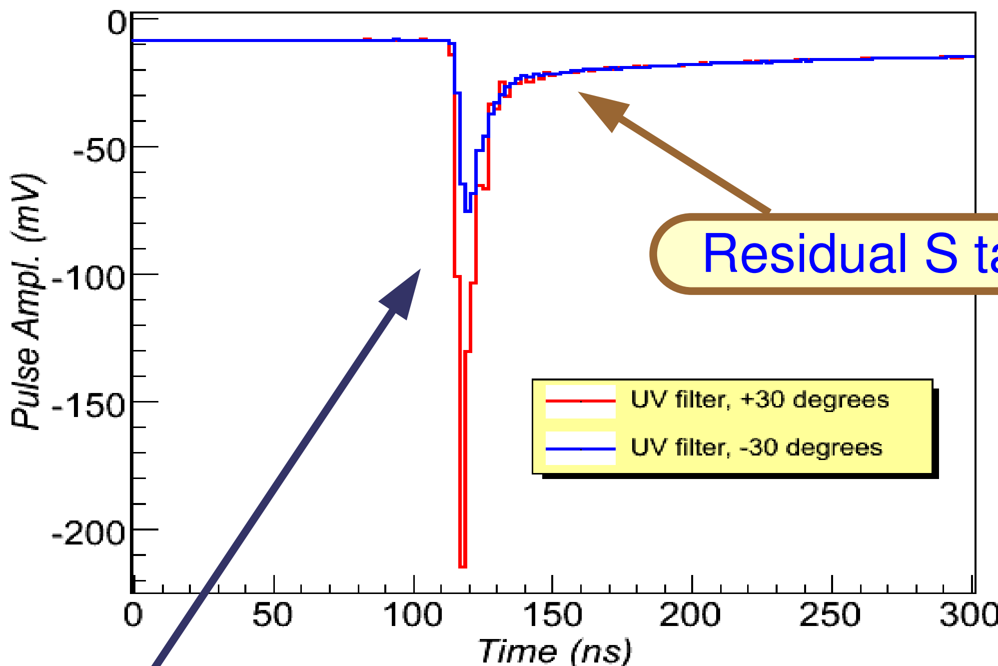
Crystal	Rel. (NaI) Light yield	Decay time (ns)	Peak wavel. (nm)	Cutoff wavel. (nm)	Refr. index	Density (g/cm^3)
$PbWO_4$	1.3%	10	440	350	2.2	8.28
BGO	20%	300	480	320	2.15	7.13

- BGO crystal (from L3) equipped with PMTs and optical filters exposed to beams at SPS@CERN
- Signals recorded with charge integrators and digitized with a scope (up to 2.5GHz sampling)



Pulse shapes with BGO





Residual S tail

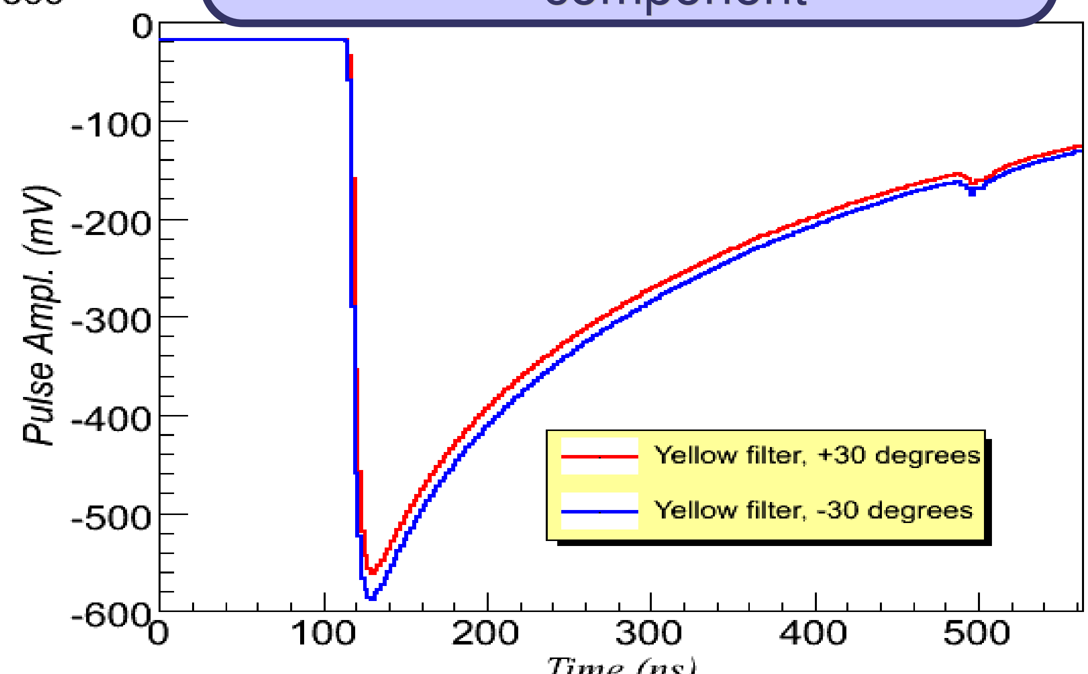
Preliminary

UV side

Angular dependent Č component

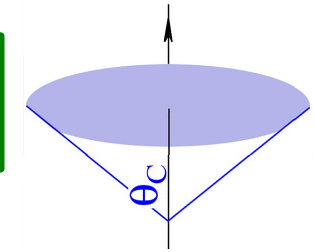
Yellow side

Pure angular independent S component

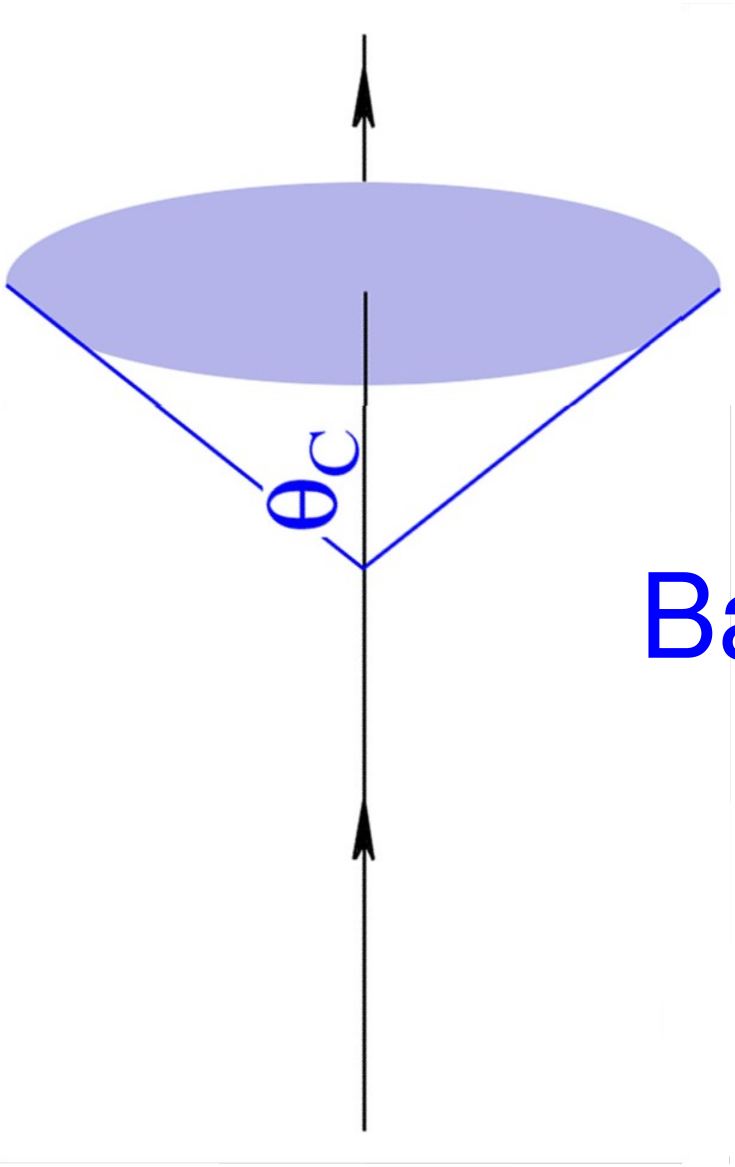


- Average pulse shapes
- S and Č components definitively separated
  - confirmed by the directionality effect

Conclusions

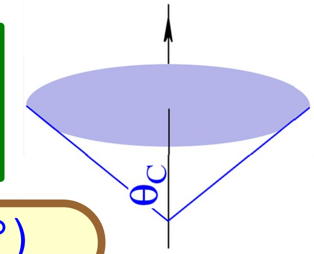


- We measured the Čerenkov contribution to signals from electrons and muons in lead tungstate crystals
- Time structure of signals proved to be a powerful investigation tool
- Information on the electromagnetic content of hadronic showers have been determined with a small lead tungstate calorimeter. This information is well correlated with explicit measurements in a dual-readout calorimeter
- Preliminary results from a BGO crystal are really exciting. Exploiting both the timing and the spectrum properties of Čerenkov light, precise measurements of the electromagnetic fraction event-by-event in a homogeneous calorimeter may be possible
- We will continue our R&D with the aim of providing an improved hadronic calorimetry technique, suitable for future experiments as well as for refining existing crystal calorimeters

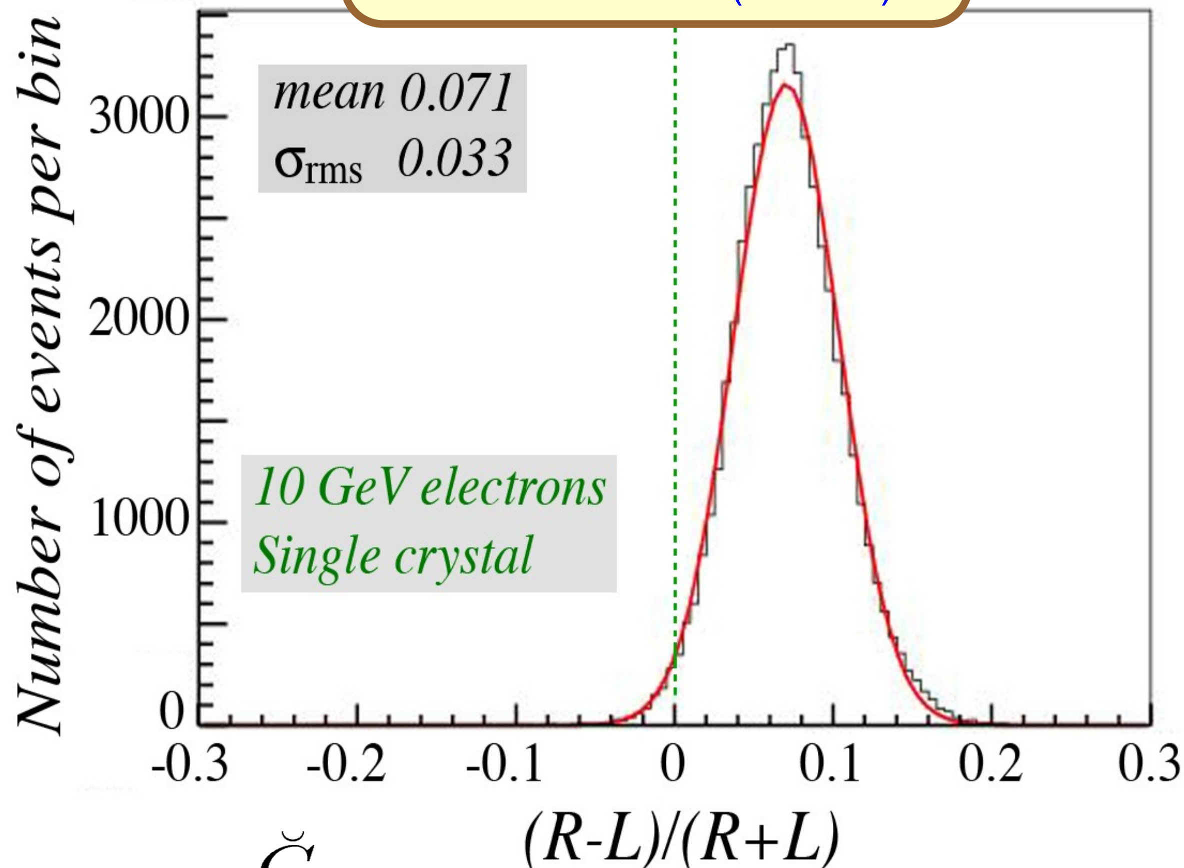


Backup Slides

SC asymmetry: precision



α distribution (θ=30°)



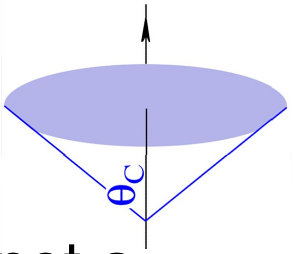
- Low photoelectron statistics led to a poor asymmetry precision
  - Cannot evaluate asymmetry event-by-event
- Estimated ~340 p.e./PMT at θ=0° for a 10 GeV e^-
- Given asymmetry:

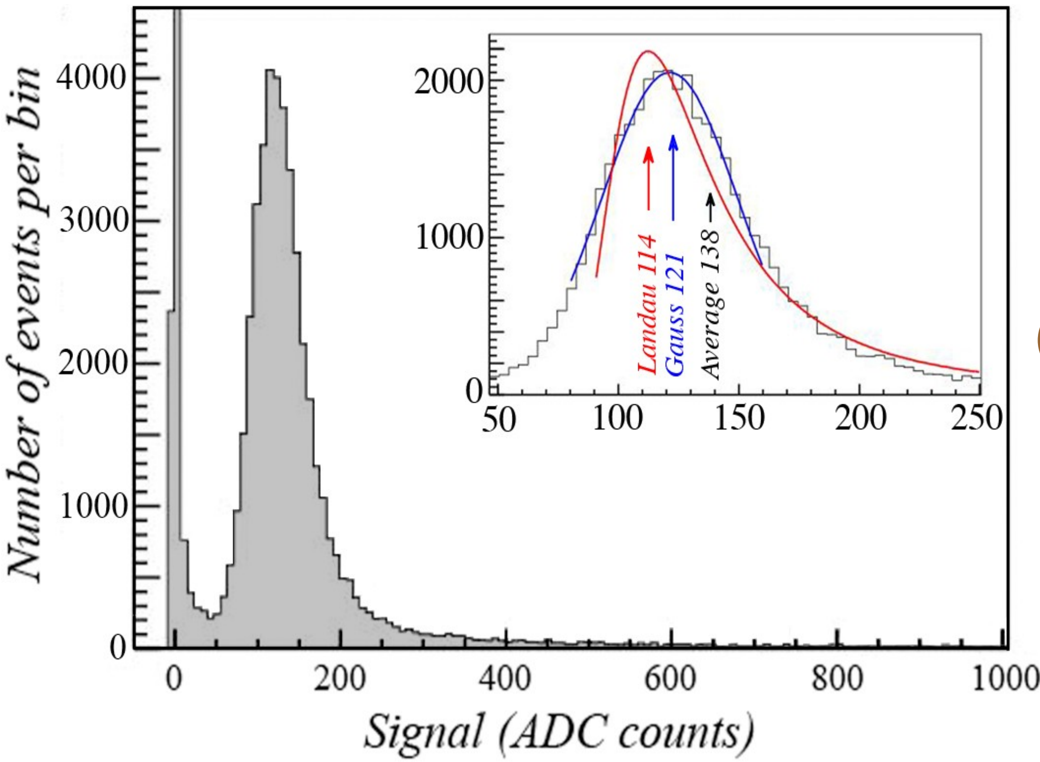
$$\alpha = \frac{R-L}{R+L} = \frac{\epsilon_R - \epsilon_L}{2+\epsilon_R+\epsilon_L} \qquad \epsilon_x = \frac{\check{C}_x}{S_x}$$

- Č fraction in the forward PMT signal is

$$f_C = \frac{2\alpha}{1+\alpha}$$

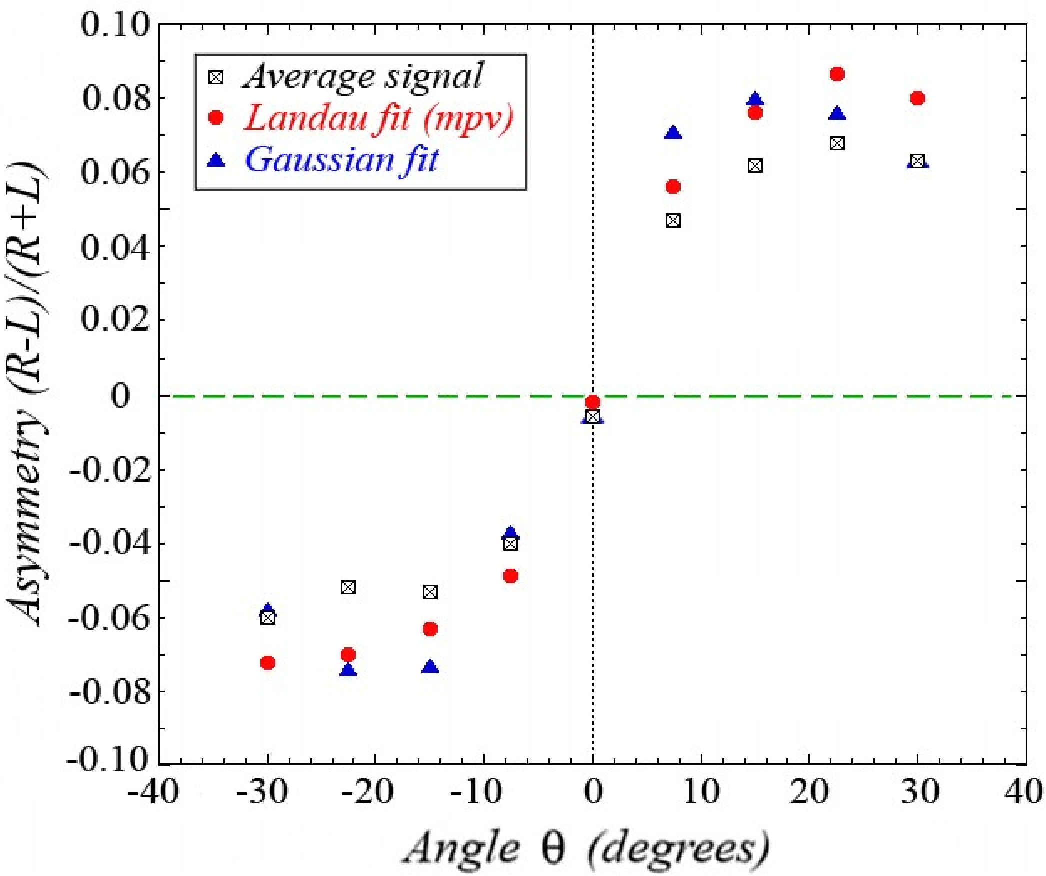
SC asymmetry for MIPs





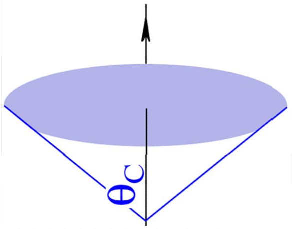
- Signal distribution has not a Landau shape

150 GeV μ^-

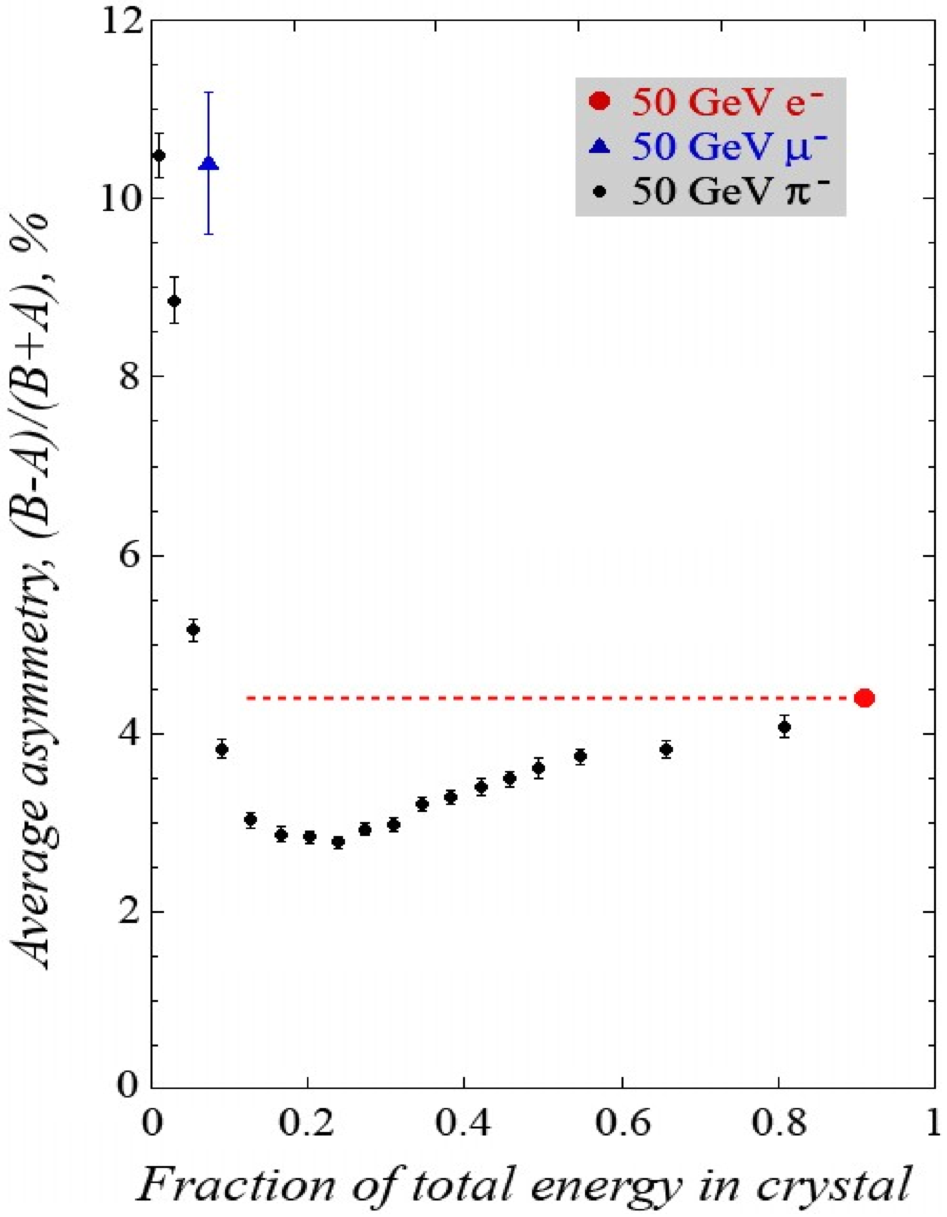


- Beam spot bigger than crystal. Hence particles can
  - miss the crystal: large pedestal
  - interact close to edge and scatter out: sub-MIP signal

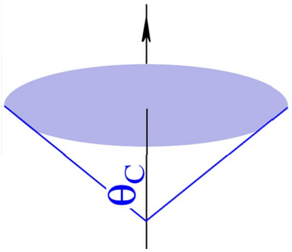
Charge asymmetry in ECAL

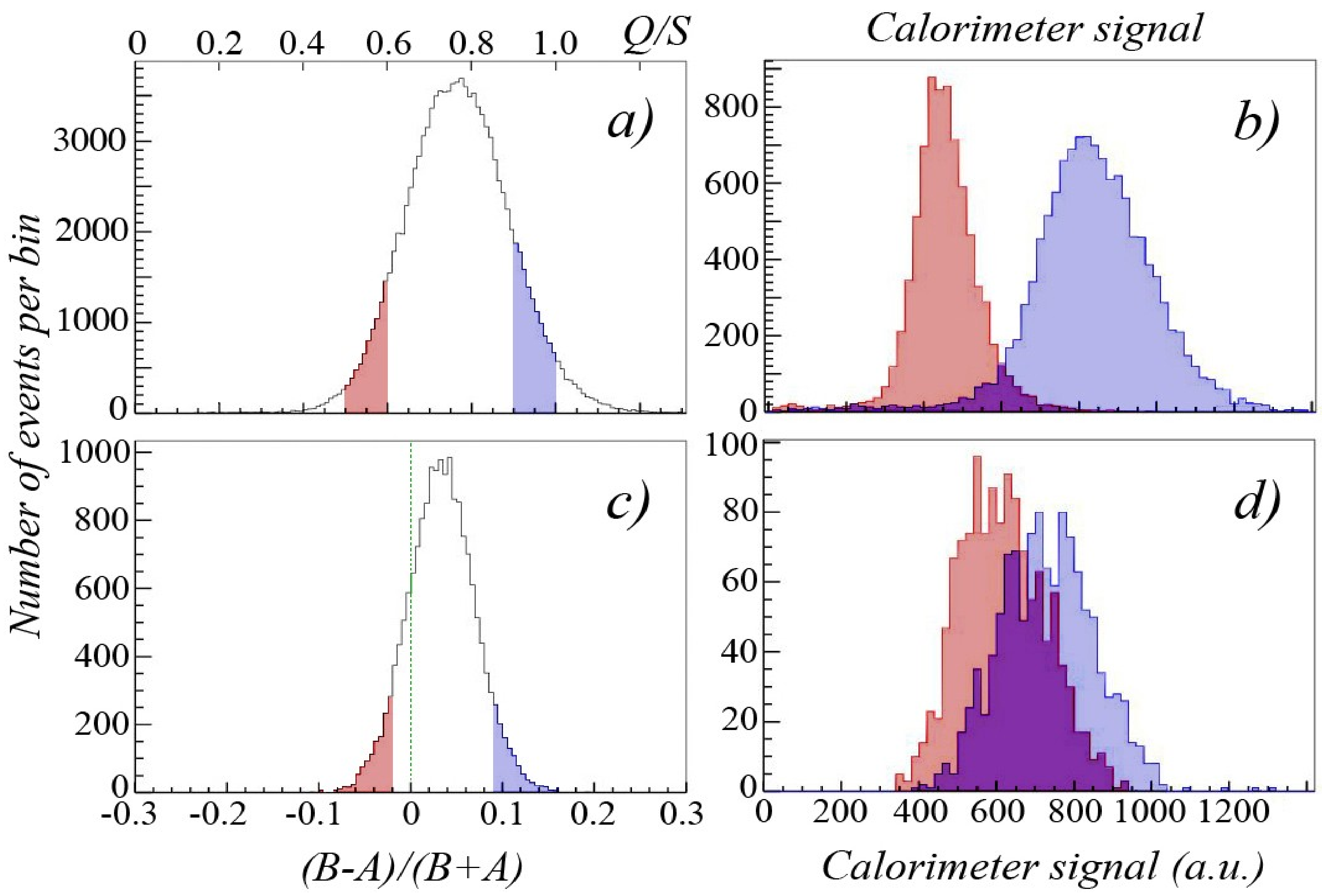


- ECAL is only $0.5\lambda_{int}$
- 40% pions behave as MIPs in ECAL
- Asymmetry for MIPs is larger than for showers
- The Landau tail of these MIPs perturbs the asymmetry measurements up to ~10 GeV of deposited energy

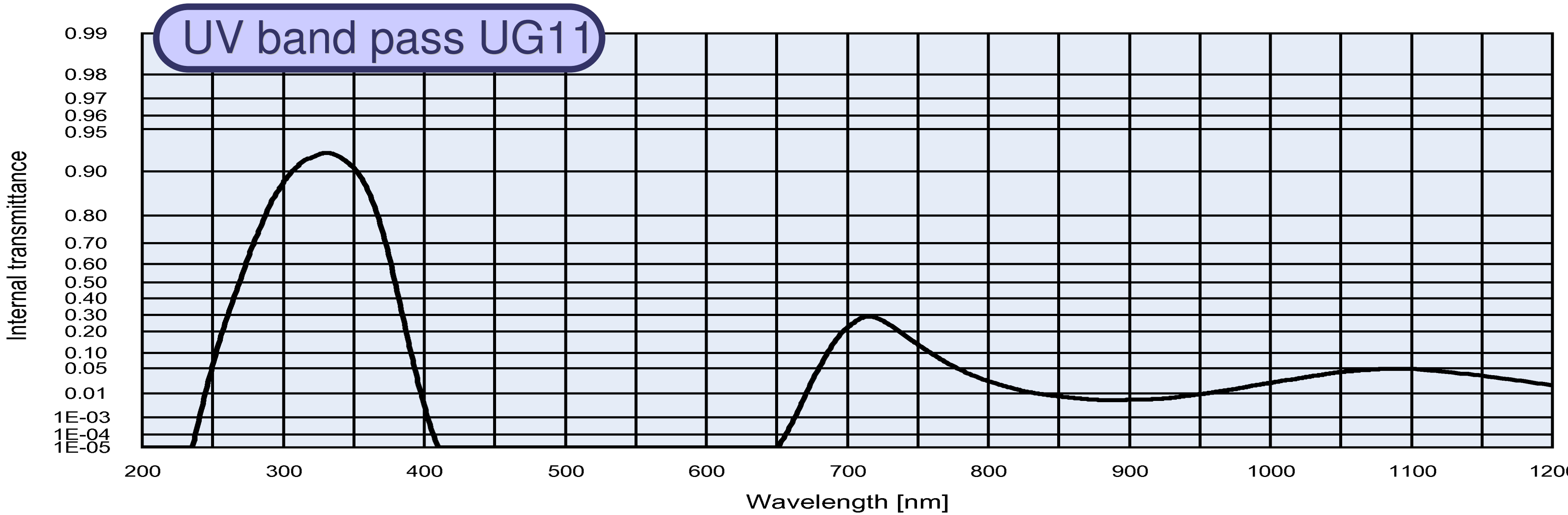


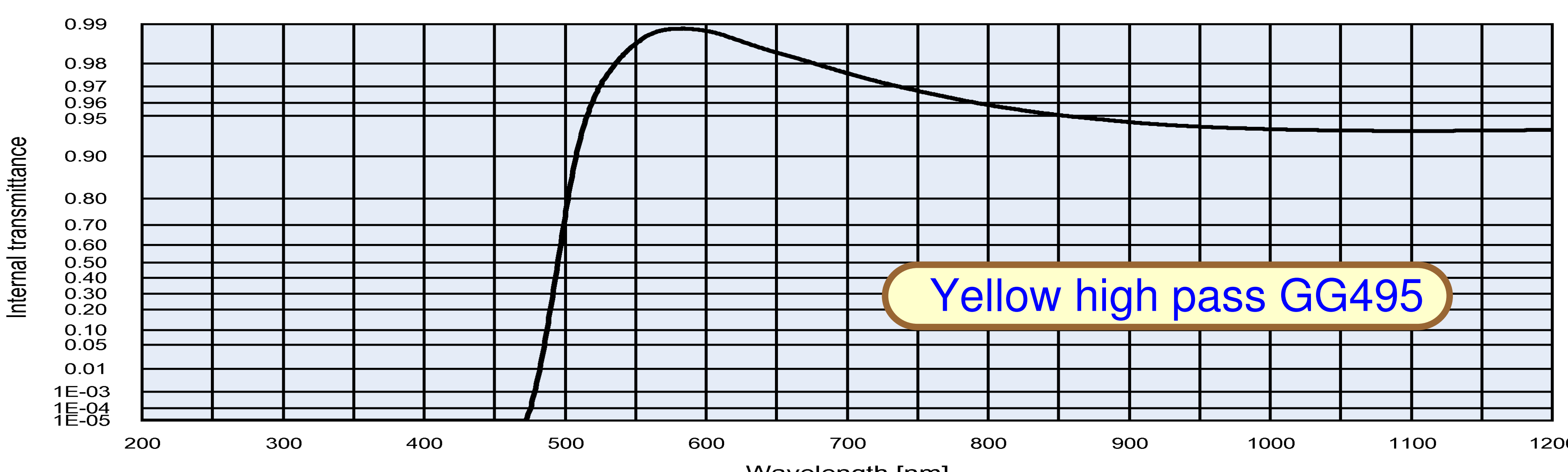
ECAL vs HCAL f_{em} resolution





Schott filters





http://www.schott.com/optics_devices/english/

BGO geometry