DREAM Collaboration:
Recent Results on Dual Readout Calorimetry .

F.Lacava

for the DREAM Collaboration
Cagliari – Cosenza – Iowa State – Pavia – Pisa – Roma 1 – Texas Tech.

HEP 2011 *Grenoble, 22-7-2011*

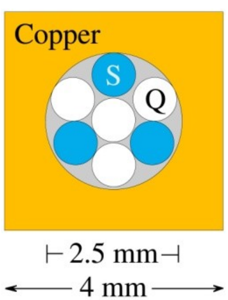
The Dual Readout Method   The DREAM calorimeter

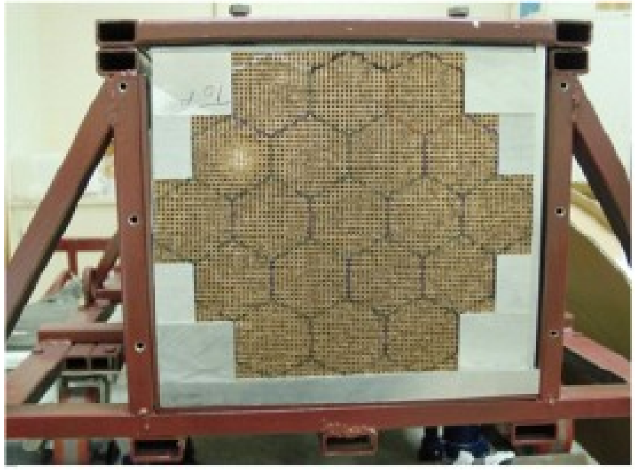
✓ *In hadronic calorimeters the fluctuations of the e.m. fraction of the shower (**f_{em}**) dominate the energy resolution for hadrons and jets.*

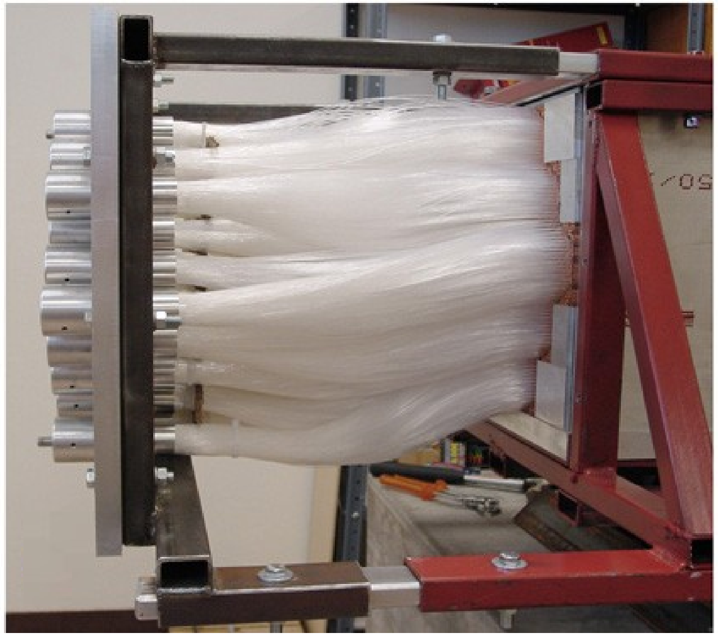
✓ *In non compensating calorimeters (i.e. where $e/h \neq 1$) it is possible to eliminate this effect by measuring **f_{em}** event by event.*

✓ *This was achieved in 2003 in the DREAM Calorimeter with two active media:*
- *the signal **S** in scintillating fibers to measure dE/dx from all charged particles,*
- *the signal **Q** in clear fibers (quartz or plastic) for Cherenkov light mostly from the e.m. component of the showers.*

- *Copper – Scintillating and Quartz (clear) fibers*
- *19 hexagonal towers,*
- *each tower: 270 hollow copper rods,*
- *2 m (10 λ_{Int}) in depth , radius ≈ 16 cm (< 1 λ_{Int}).*







✓ If R = 1 for e.m. shower , the response of the active media for a hadronic shower is:

$$R(f_{em}) = f_{em} + \frac{1}{e/h}(1 - f_{em})$$

where e/h is 1.3 for Scintill. and 4.7 for clear fibers

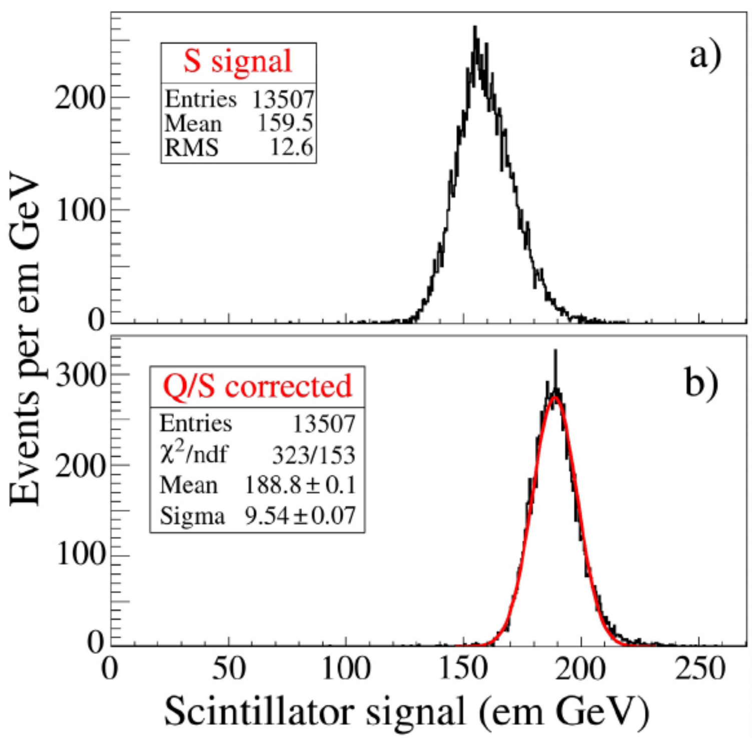
✓ From the ratio of the signals in the quartz (clear) fibers Q and in scintillating fibers S :

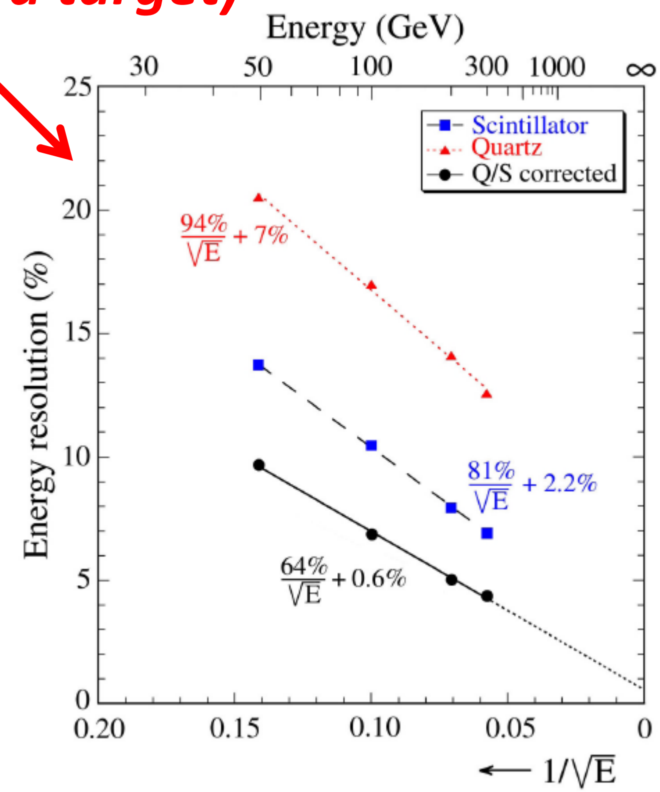
$$\frac{Q}{S} = \frac{f_{em} + 0.21\,(1 - f_{em})}{f_{em} + 0.77\,(1 - f_{em})}$$

f_{em} is measured and the energy is corrected.

✓ Resolution was limited by the small Cherenkov photon yield (8-18 ph.e. per deposited GeV).

"Jets" 200 GeV (pions interacting in a target)



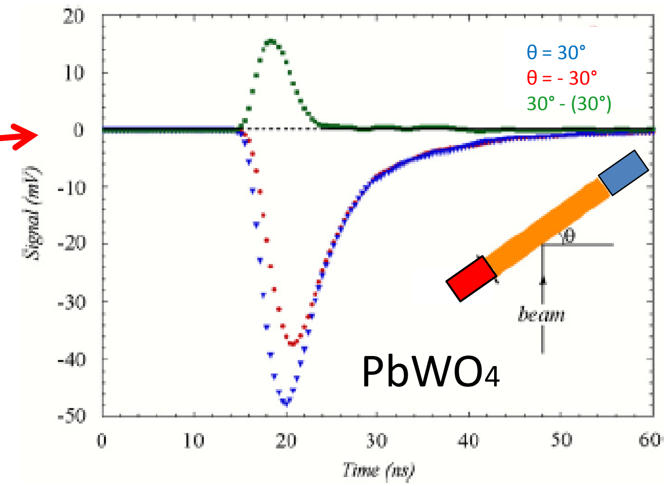


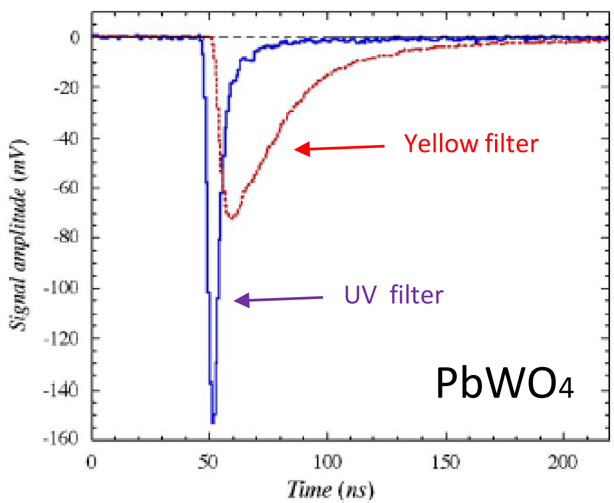
Dual Readout in crystals

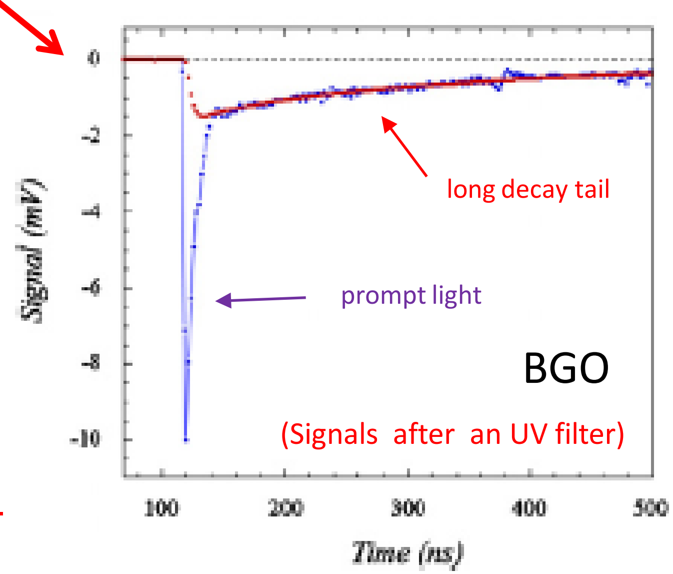
✓ *In last years extensive studies were performed to extend the Dual Readout in crystals used in homogeneous calorimeters . In these crystals a fraction of the light yield is due to Cherenkov emission (1% in BGO, up to 15% in PWO).*

✓ *The peculiar features of the Cherenkov light can be exploited to separate the two types of light:*

- *Directionality : $\cos\vartheta = 1/\beta n$*
- *Timing : Cherenkov light is prompt (few ns) while scintillation light has decay costant.*
- *Spectral properties: $1/\lambda^2$ distribution*



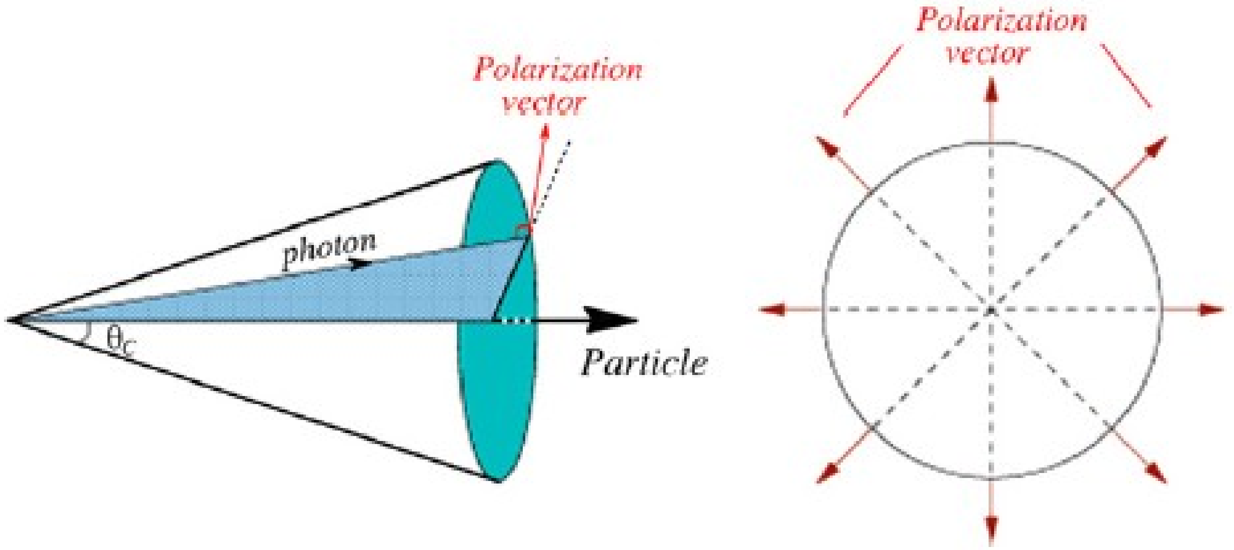




- *One more tool: polarization of the Cherenkov light.*

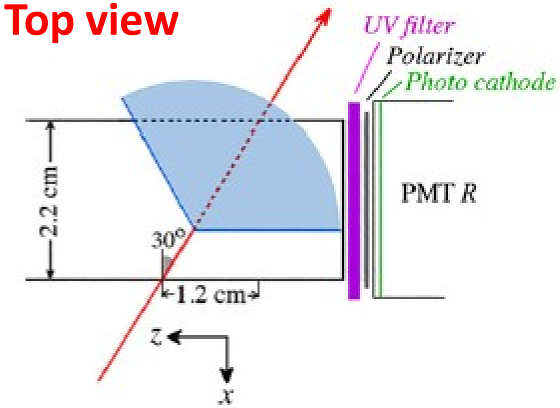
Polarization in dual read out

- ✓ *Cherenkov light is emitted by molecules that are excited and polarized by a superluminal particle crossing the medium.*
- ✓ *The molecules emit coherent radiation at an angle ϑ_C = arcos $(1/\beta n)$ with respect to the particle direction and with the polarization vector perpendicular to the cone whose central axis is the particle track.*

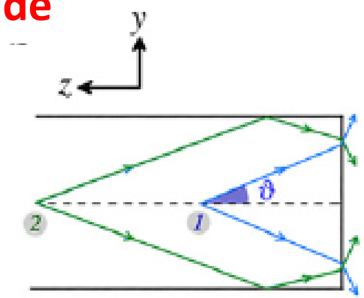


- ✓ *Then the Cherenkov component can be separated from the scintillation light by a polarizer in front of the PMT.*
- ✓ *This was done by the DREAM Collaboration in the 2010 test beam. see NIM A 638 (2011) 47-54.*

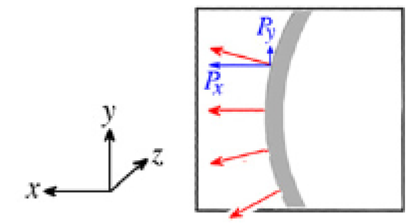
Top view



Side

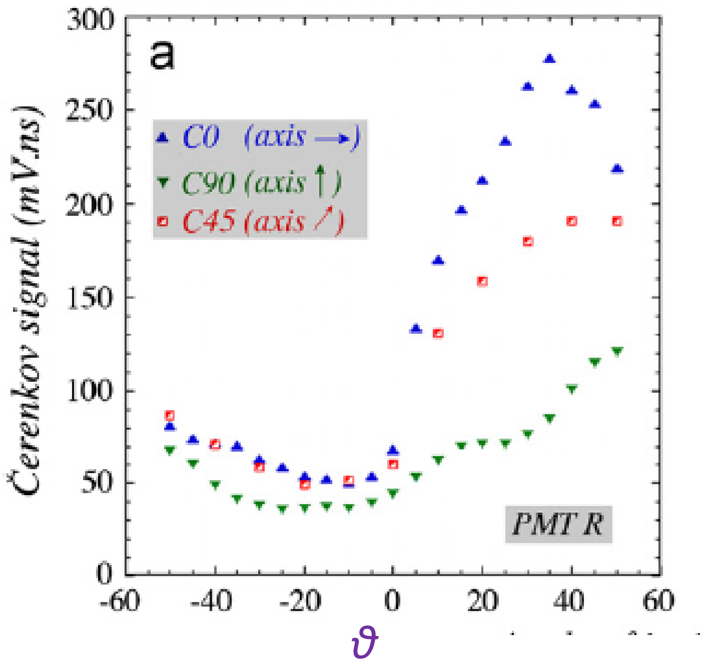


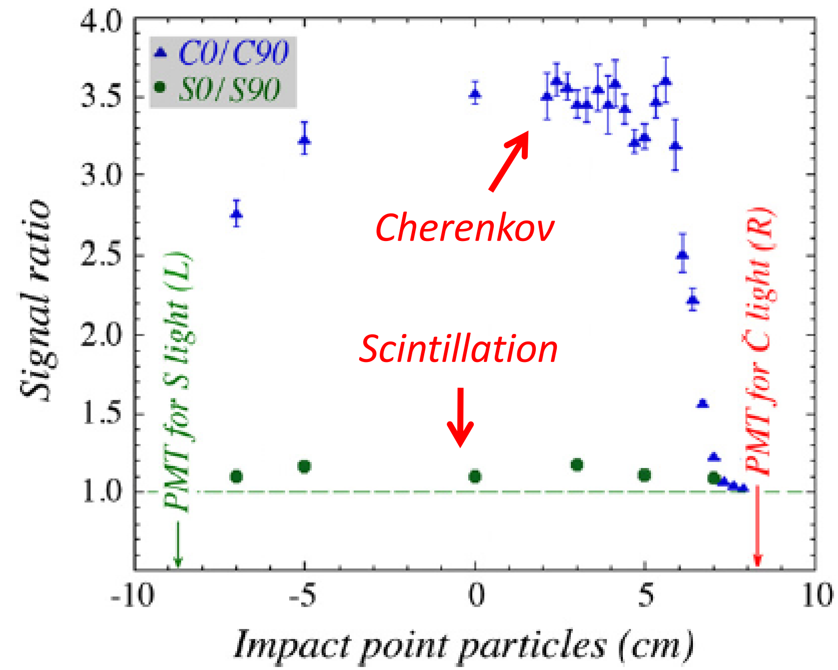
Edge



Mostly horizontal polarization

- ✓ *180 GeV/c pion beam crossing a BSO crystal ,*
- ✓ *UV filter followed by a polarizer to separate the Cherenkov light.*





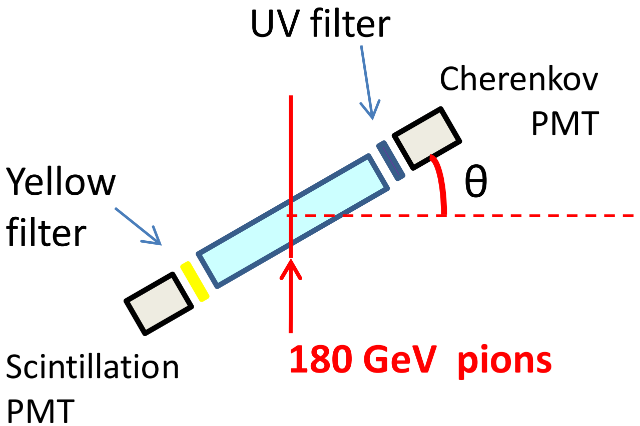
BSO vs BGO crystals

- ✓ *High density scintillating crystals are used as excellent e.m. calorimeters but they have poor performance for detection of hadrons and jets (very large e/h ratio).*
- ✓ *The possibility to separate the Scintillation/Cherenkov components in crystals demonstrated by the DREAM Collab. allows to extend the dual-readout also in e.m. crystals calorimeters.*
- ✓ *Extensive studies have been performed in the last years by the DREAM Collaboration on PWO and BGO crystals (see NIMA) .*
- ✓ *A recent test beam compared two crystals of BSO (Bismuth Silicate) and BGO (Bismuth Germanate) of equal dimensions (2.2 x 2.2 x 18 cm^3).*

Now on NIM A 640 (2011) 91-98

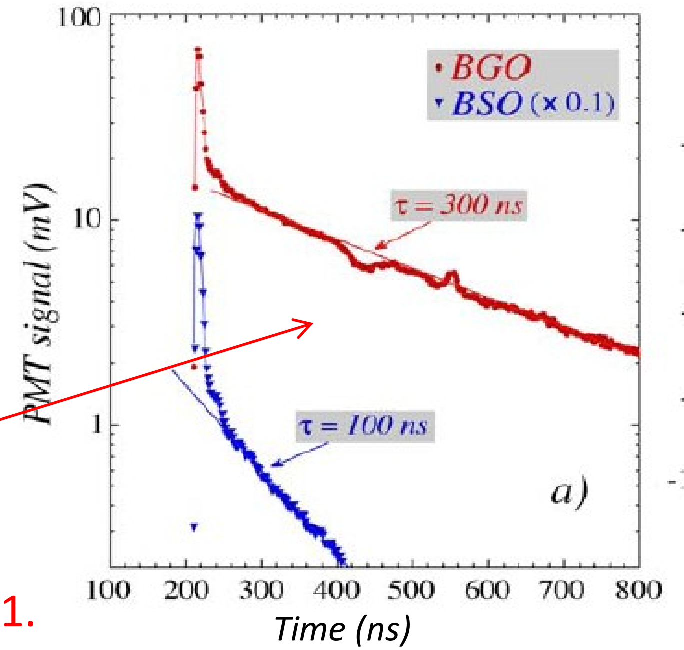
Some relevant properties of BSO and BGO crystals. The light output is normalized to that of NaI(Tl) crystals.

Crystal	Density (g cm^{-3})	Radiation length (mm)	Decay constant	Peak emission	Refractive index n	Relative light output
BSO	6.80	11.5	~100 ns	480 nm	2.06	0.04
BGO	7.13	11.2	~300 ns	480 nm	2.15	0.15

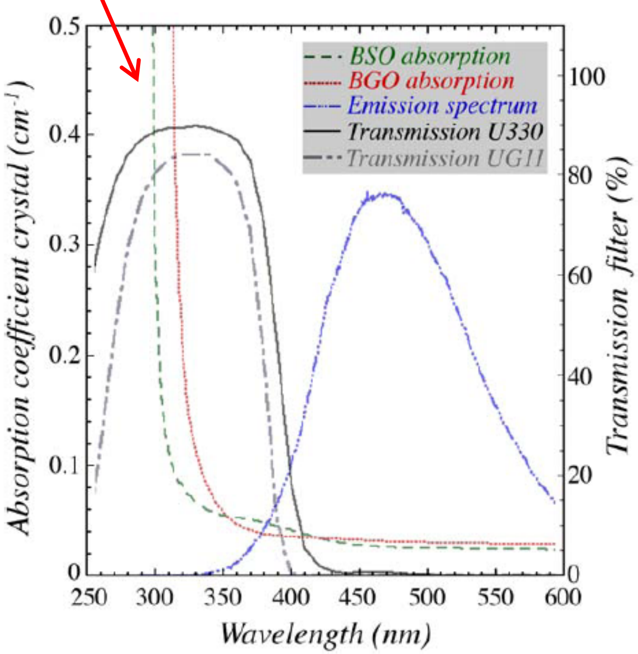


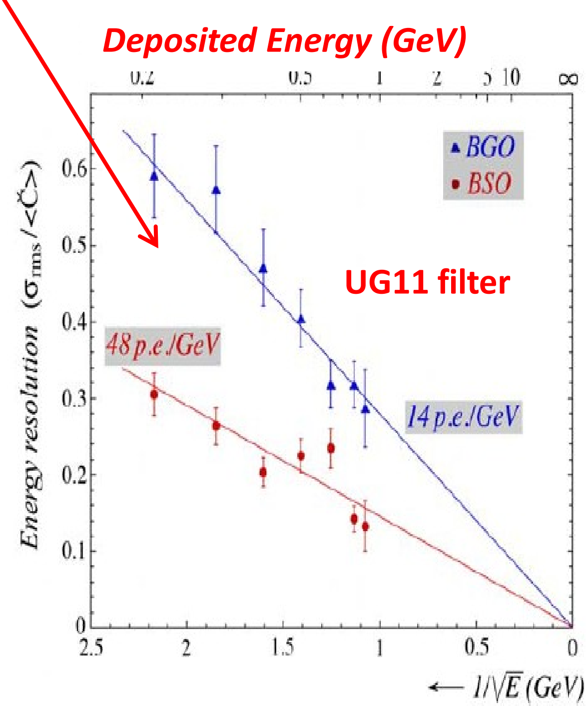
- ✓ Crystals on a rotating platform,
- ✓ UV filter (UG11/U330) for Cherenkov PMT
- ✓ Yellow filter for Scintillation PMT

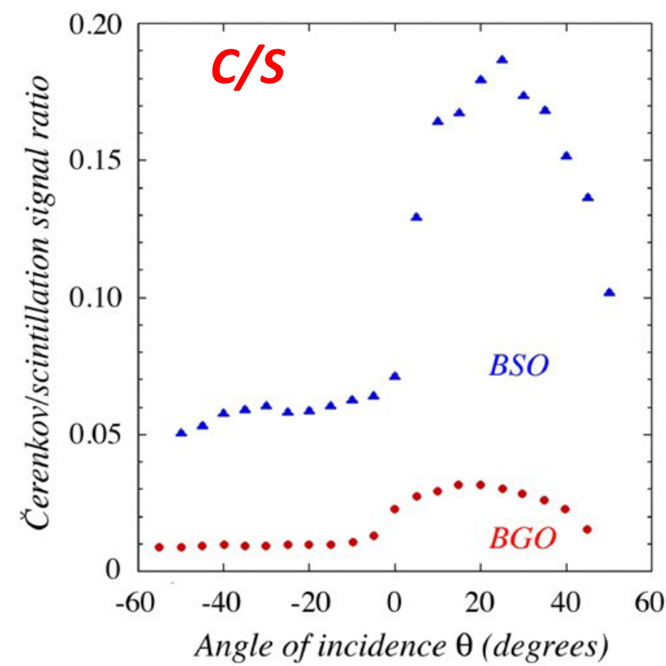
Average signals



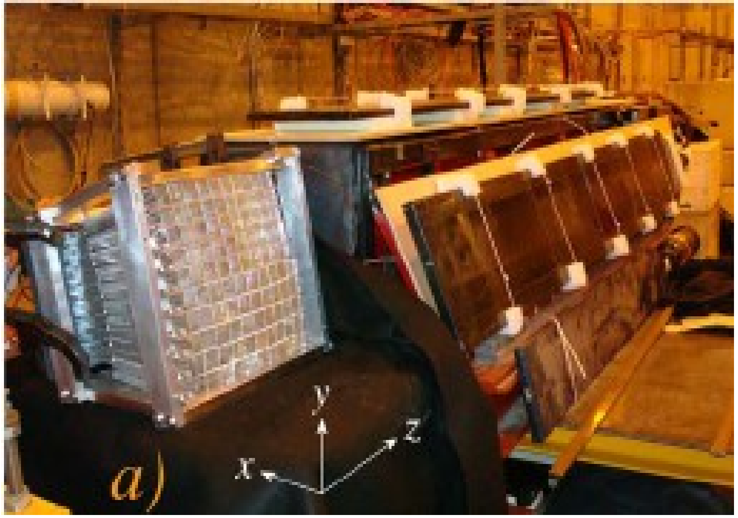
- ✓ Faster scintillation in BSO (Scint. yield BGO / BSO ≈ 4),
- ✓ Same attenuantion length (Cher. and Scint.) ≈ 34 cm ,
- ✓ Absorption for Cherenkov ($1/\lambda^2$) smaller in BSO ,
- ✓ Cherenkov yield BSO / BGO ≈ 5 with U330 , less with UG11.







BGO Matrix (1)



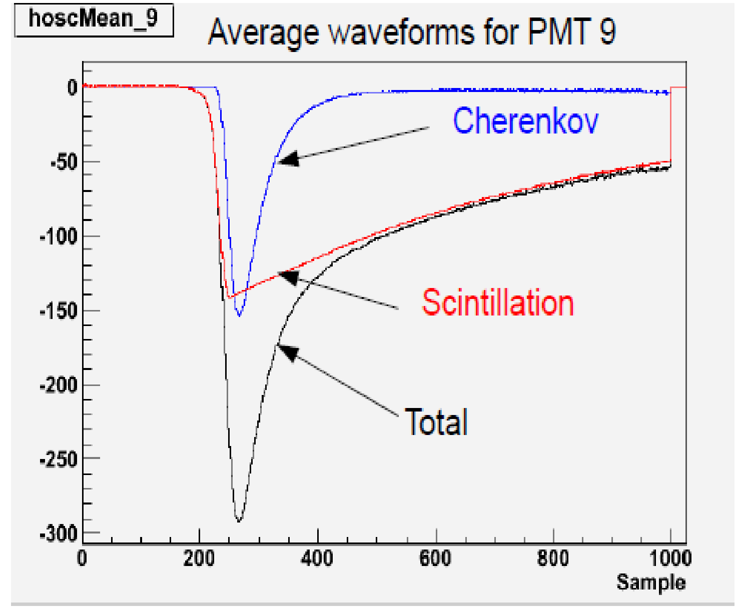
- ✓ *Often in present experiments the e.m. calorimeter is realized with crystals and a hadronic calorimeter is behind.*
- ✓ *Since the dual read out was proven to be possible in crystals, the DREAM Collaboration has tested a full size BGO Calorimeter backed by the original DREAM calorimeter.*
- ✓ *The e.m. section was a matrix of 100 BGO crystals, 24 cm long and tapered (2.4 x 2.4 cm^2 – 3,2 x 3.2 cm^2) from L3 experiment.*
- ✓ *A first test was performed in 2009 ,* see NIMA 610 (2009), 488-501 .
- ✓ *In the 2010 test beam 16 PMTs with UV UG11 filters (scintillation strongly attenuated).*

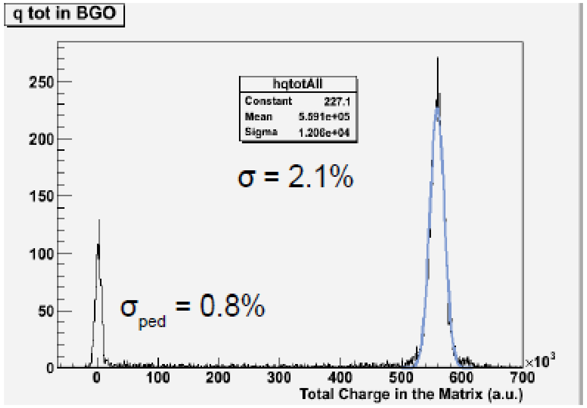
BGO Matrix (2)

- ✓ *Both Scintillation and Cherenkov signals read out in the same PMT : signal from scintillation extracted by a fit on the tail of the signal, Cherenkov = total – scintillation.* →
- ✓ *Preliminary results for 100 GeV e.m. shower.*

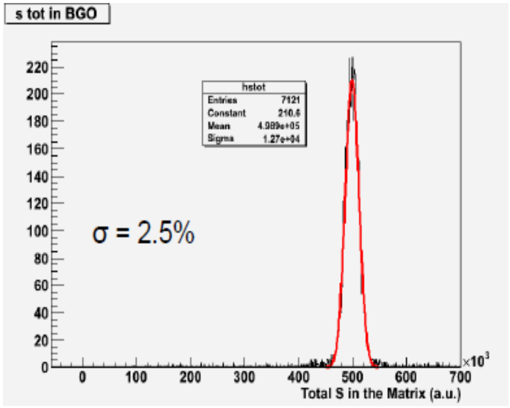
Scintillation - Cherenkov yields = 67 - 8 ph.e. /GeV

- ✓ *Work on the extension of the dual readout to both e.m. and hadronic sections is in progress.*

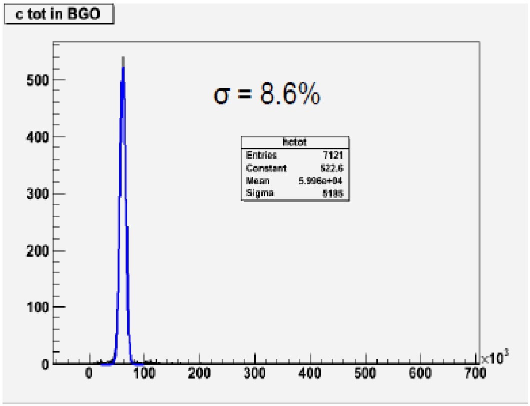




Total



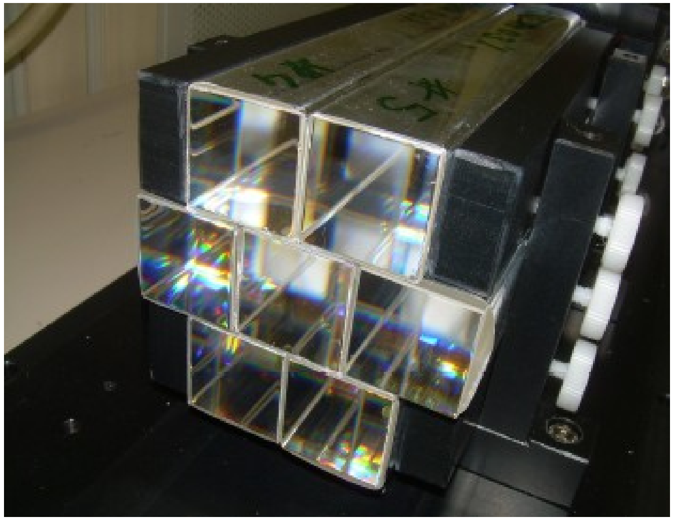
Only scintillator

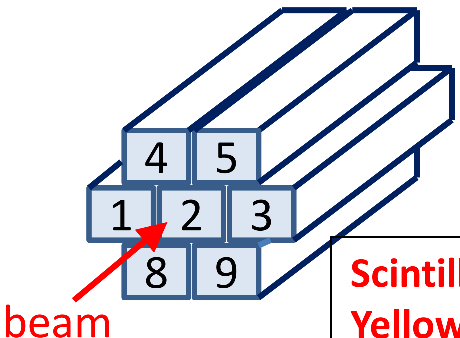


Only Cherenkov

PWO Matrix

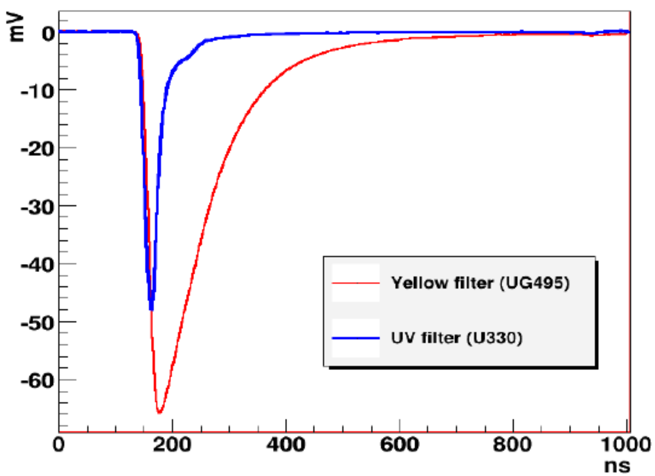
- ✓ *In 2010 tested also a matrix of seven $PbWO_4$ crystals doped with 0.3% Molybdenum already characterized (NIM A621,212-221),*
- ✓ *Each crystal: $(3 \times 3 \times 20\ cm^3)$,*
- ✓ *Both wavelenght and timing analysis.*



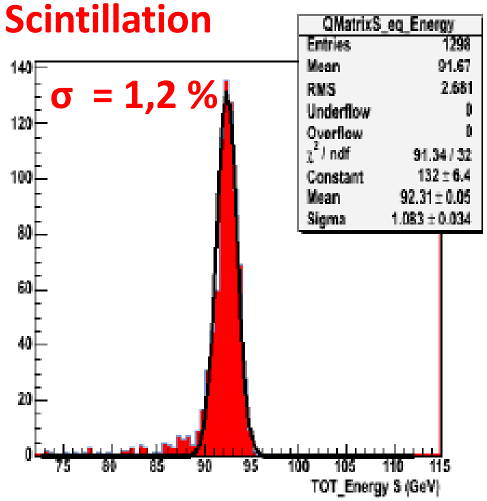


Cherenkov side
U330 filters

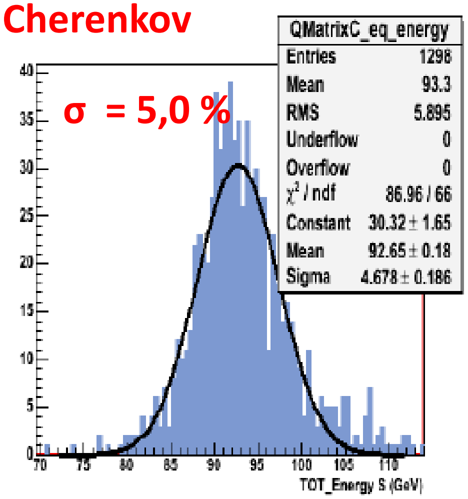
Scintillation side
Yellow filters



Scintillation



Cherenkov

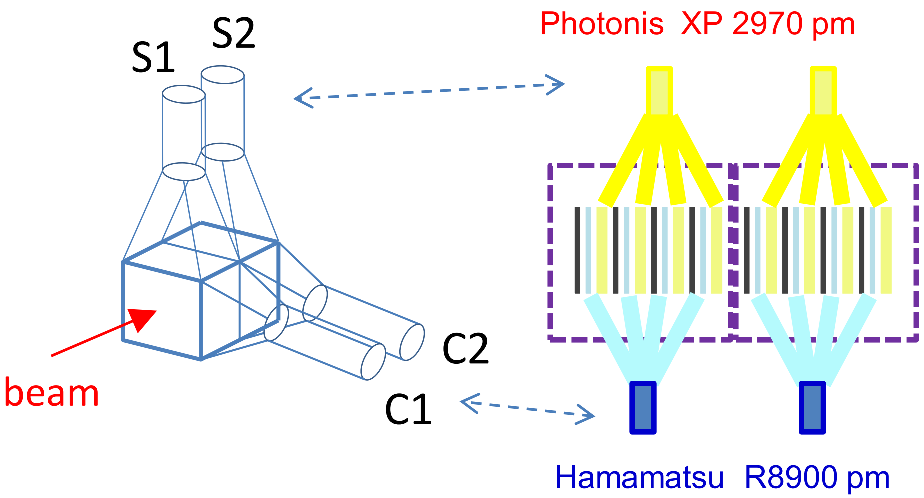


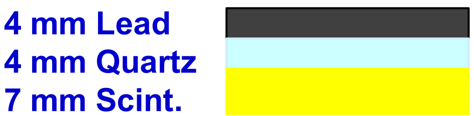
100 GeV electrons (analysis in progress)

Dual Readout with Tiles

Dual Readout can be also implemented in a tile sampling calorimeter.
A test of a small prototype 9 x 9 cm² was performed in the 2010 test beam.

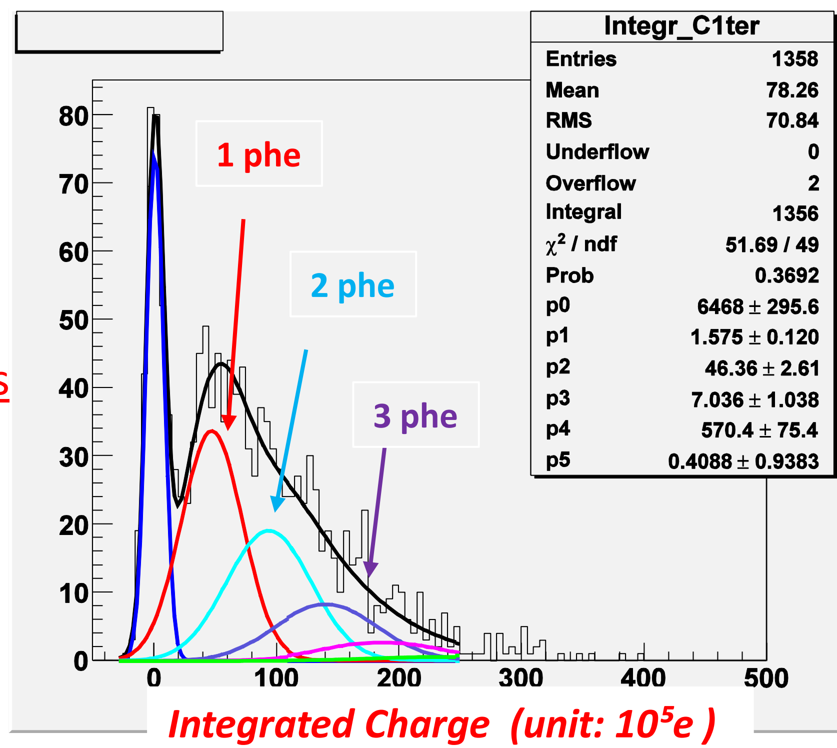
- ✓ *Two samplings: 4 x (4mm Lead + 4 mm Quartz + 7 mm Scint), for a total of 6 R.L.*
- ✓ *Separate readout of Cherenkov and scintillation light in each sampling.*



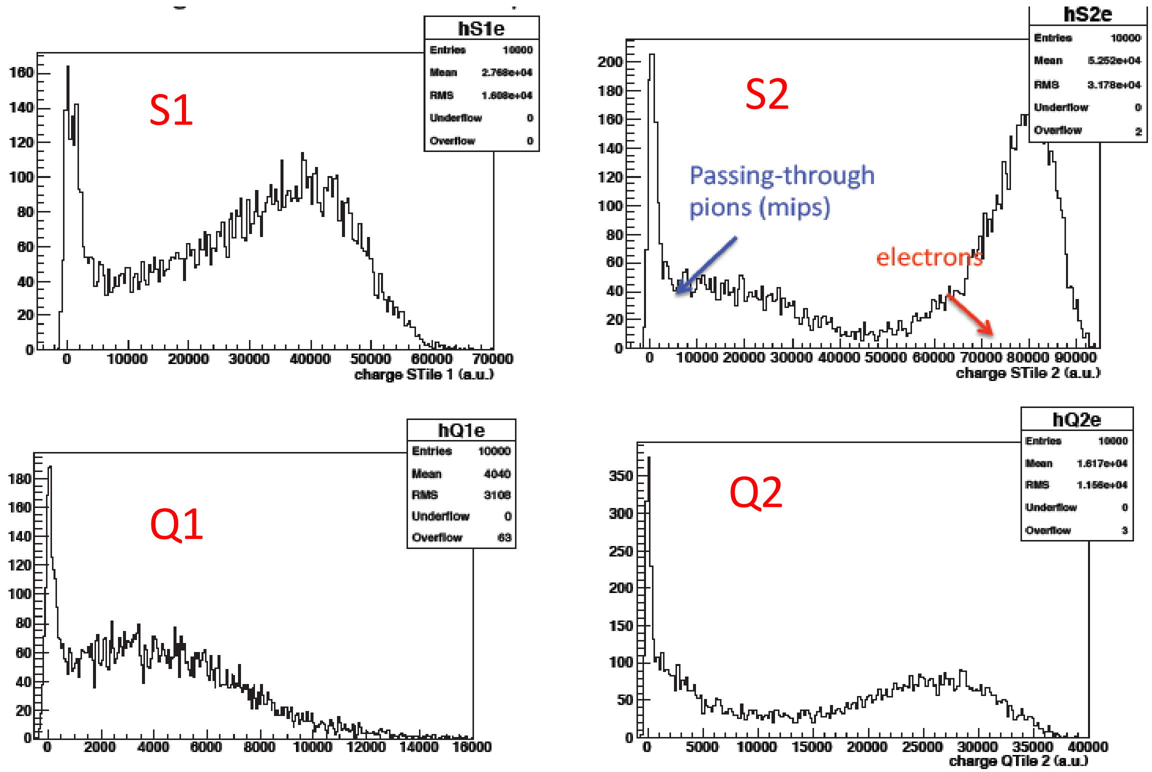


Charge distribution in C1 PMT for 180 GeV/c muons

- ✓ Fit of a poissonian for the *Nphe* convoluted with a gaussian with $\sigma^2 = a + b \cdot N_{phe}$.
- ✓ In both modules: *Nphe* = 1.3 for normal beam,
  1.6 for 12° tilted detector.
- ✓ Average signal for 1 *phe* = PMT gain.



80 GeV electrons in Quartz – Scint. Tiles



Integrated Charge (a.u.)

- *From a Geant4 simulation: 1.7 GeV / 11.3 GeV deposited in module 1 / 2.*
- *From average signals in C1 and C2 and PMT gains :*

58 Nphe/ GeV in module 1 , 47 Nphe /GeV in module 2

Cherenkov yield comparable with Cherenkov crystal yield.

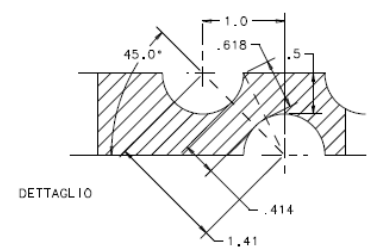
The New Dream Calorimeter

The DREAM Collaboration is now preparing a new prototype of fiber calorimeter with better performances.

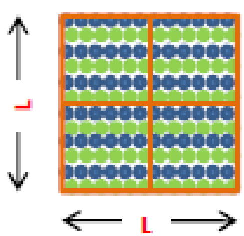
- Two options: copper or lead (as the module tested in 2010),
- Extensive studies performed for clear fibers to have the largest Cherenkov light yield,
- Sampling fraction : 5% (was 2.6% in the original DREAM calorimeter),
- Quantum efficiency ~ 50% larger,

Expected 90 Cherenkov phe /GeV , was 8-18 in DREAM

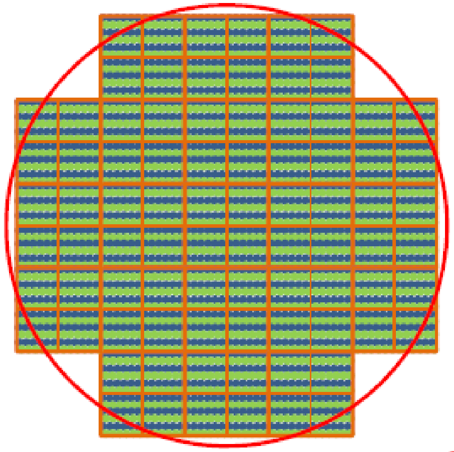
- *1 module:* 46 equal fibers per layer, 46 fiber layers of each type (scintillating/clear)
  Dimensions of the module: 92 x 92 mm², 2,5 m in length
  Divided in 4 towers readout for Cherenkov and scintillation signals.



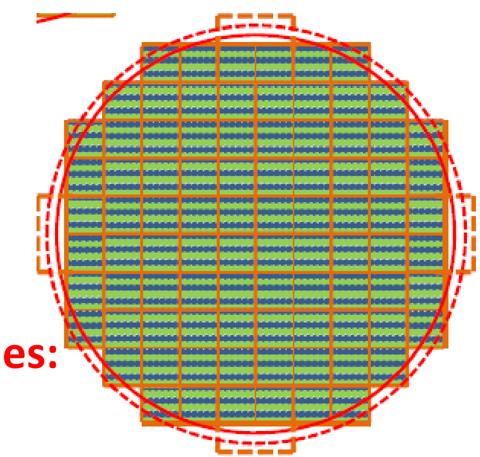
For copper : X_0 = 2.31 cm , R_M = 2,33 cm , λ_{Int} = 22.5 cm
For lead : X_0 = 0.92 cm , R_M = 2,38 cm , λ_{Int} = 25 cm



L =92 mm



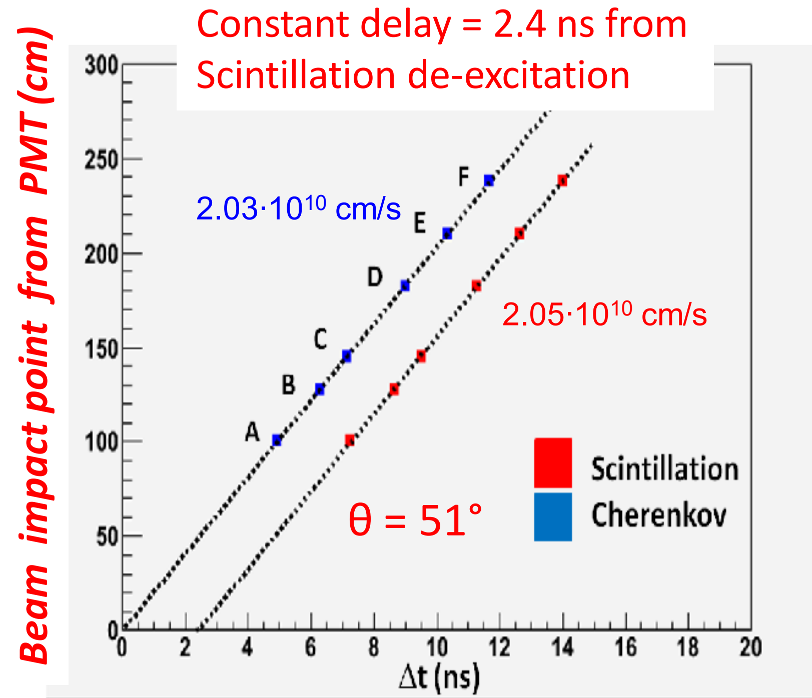
21 modules :
R_{eq} = 23.8 cm

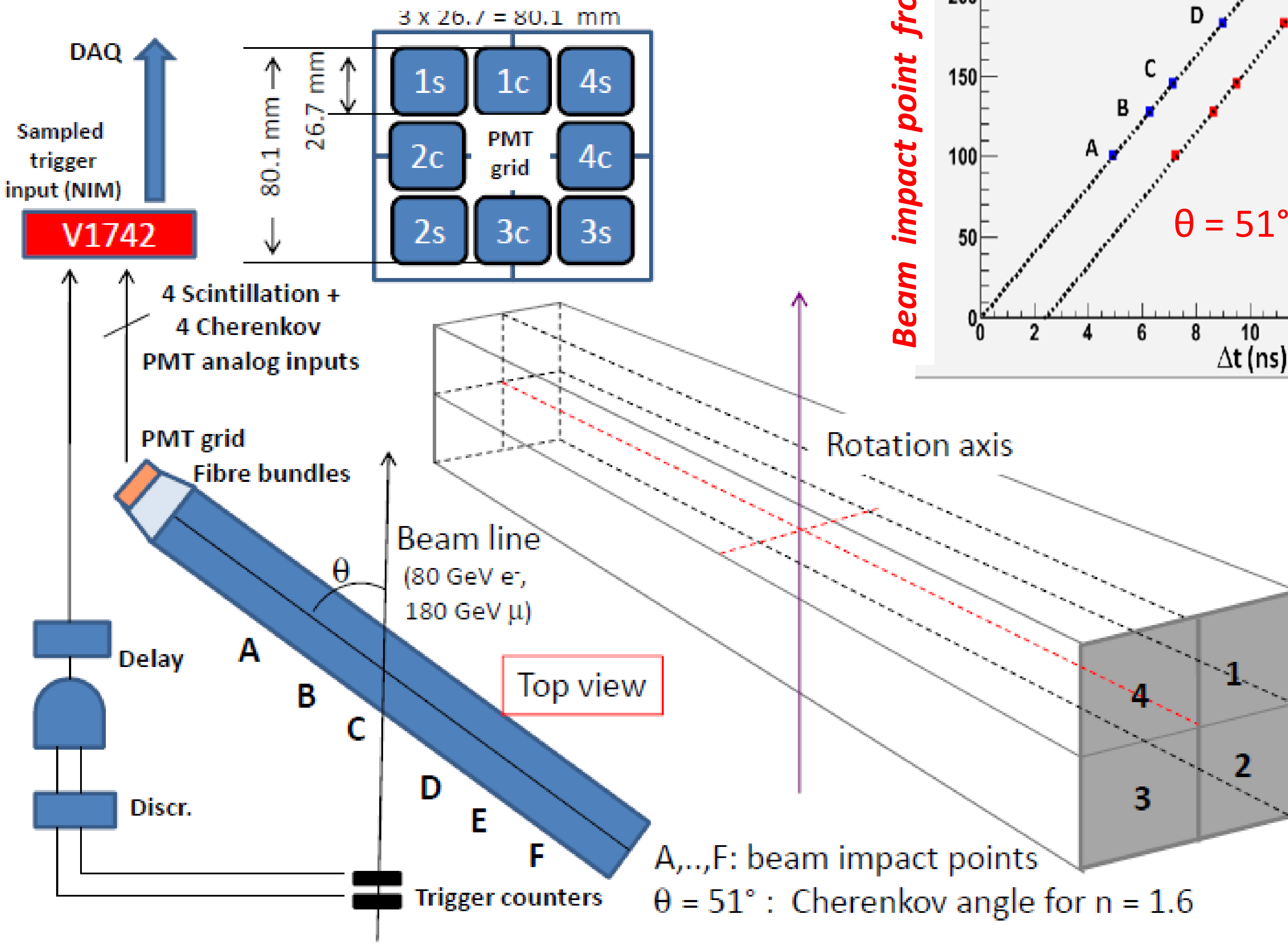


16 modules
+ 12 half modules:
R_{eq} = 24,35 cm

Test of the first New Dream module in the 2010 test beam

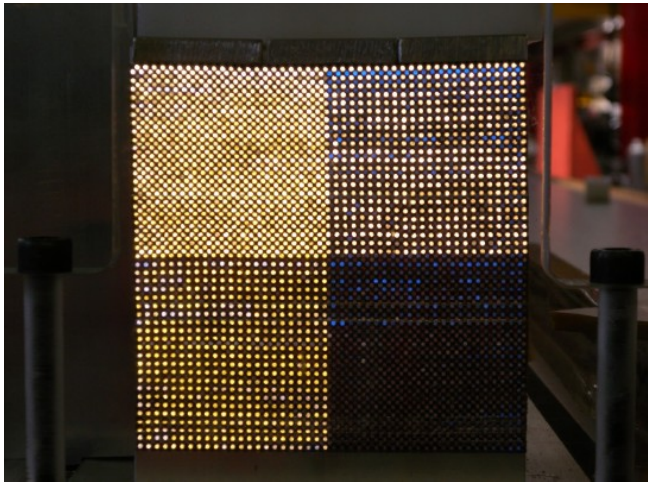
(Pb absorber)





A new lead module built in Pavia and next week in the test beam →

↓



A copper module in preparation in Pisa will be ready for October test beam.

Conclusions

- ✓ *After the pioneering tests of the first Dual Readout calorimeter, the DREAM Collaboration has extensively studied the Dual Readout in crystals.*
- ✓ *The separation of Cherenkov and Scintillation light can be achieved with several techniques based on the peculiar features of the Cherenkov radiation.*
- ✓ *Dual Readout e.m. calorimeters composed with crystals have been tested also followed by a hadronic calorimeter (DREAM).*
- ✓ *Dual Readout can be used also in tile calorimeters.*
- ✓ *The DREAM Collaboration is now preparing and testing a new fiber Dual Readout calorimeter larger than the original DREAM calorimeter.*