http://highenergy.phys.ttu.edu/dream/

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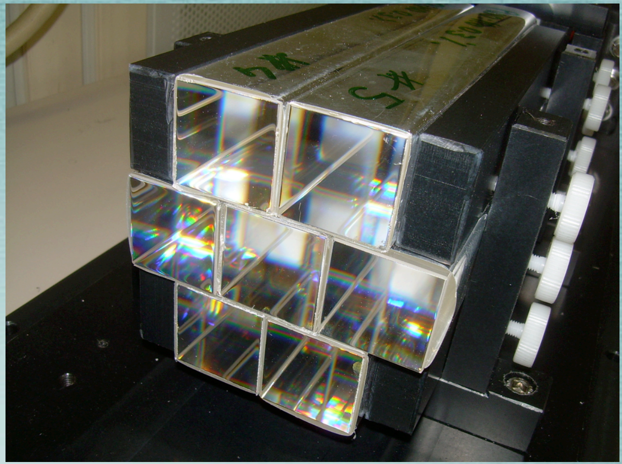

CRYSTALS FOR DUAL-READOUT CALORIMETRY

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on behalf of the RD52 Dream Collaboration

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Dual Readout Method

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- Addresses the limiting factors to the resolution of hadron calorimetry with the aim of reaching the theoretical resolution limit (15%/√E) and in addition allows for
  - Calibration of an hadron calorimeter just with electrons
  - High resolution EM and HAD calorimetry
  - fulfillment of ILC/CLIC or Muon collider physics requirements

- The Dual-Readout technique is based on the simultaneous measurement, on an **event-by-event** basis, of
  - **Čerenkov light:** only produced by relativistic particles, dominated by electromagnetic hadron shower component
  - **Scintillation**: a measure of dE/dx

- This allow to measure the electromagnetic fraction (fem) of the hadron shower

Dual readout calorimetry with crystals

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Motivations:

- high density scintillating crystal widely used in particle physics experiment
  - ensure excellent energy resolution for electromagnetic showers
- calorimeters using a crystal electromagnetic compartment usually have a poor hadronic resolution due to
  - fluctuation of the starting point of the hadronic shower in the EM section
  - different response to the em and non-em component of the shower in the two calorimeters

Dual readout applied to an hybrid system:

- measuring fem on an event-by-event basis allows to correct for such fluctuations and allows to eliminate the main reasons poor hadronic resolution

In this talk:

- We have done many measurements with individual crystals over the past few years
  - 4 methods were found to split signals in the Č and S components
- Now we have performed tests with crystal calorimeters large enough to contain em showers.
  - split the signals from these calorimeters in 2 components
  - study performances in each of these 2 channels

Dual readout in crystal calorimeter

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Requirements for using crystals in dual readout based calorimeter (to reduce the contribution of photoelectron statistics to the resolution)

- Good Čerenkov vs Scintillation separation
- Response uniformity
- High light yield (to reduce contribution of p.e. fluctuation to the resolution)

If crystal are optimized for dual readout: do they guarantee a good em resolution ?

Properties	Čerenkov	Scintillation
Angular distribution	Light emitted at a characteristic angle by the shower particles that generate it $\cos\theta = 1/(n\beta)$	Light emission is isotropic: excited molecules have no memory of the direction of the particle that excited them
Time structure	Instantaneous, short signal duration	Light emission is characterized by one or several time constants. Long tails are not unusual (slow component)
Optical spectra	$\frac{dN_C}{d\lambda} = \frac{k}{\lambda^2}$	Strongly dependent on the crystal type, usually concentrated in a (narrow) wavelength range
Polarization	polarized	not polarized

→ Time structure readout

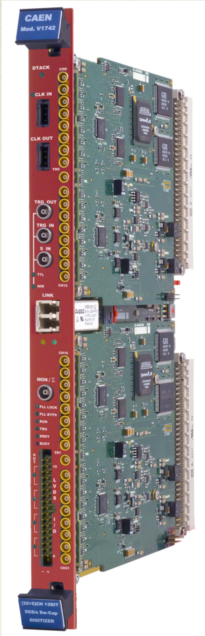
→ Optical filters

Dual readout "tools"

Optical Filters :

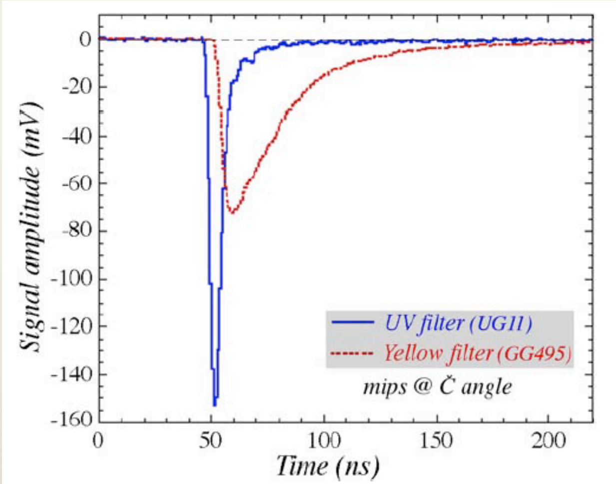
- crystals used for tests are bright scintillators
- need to suppress the scintillation component in order to extract the Čerenkov light
- Using UV filters for Čerekov light and yellow filter for scintillation

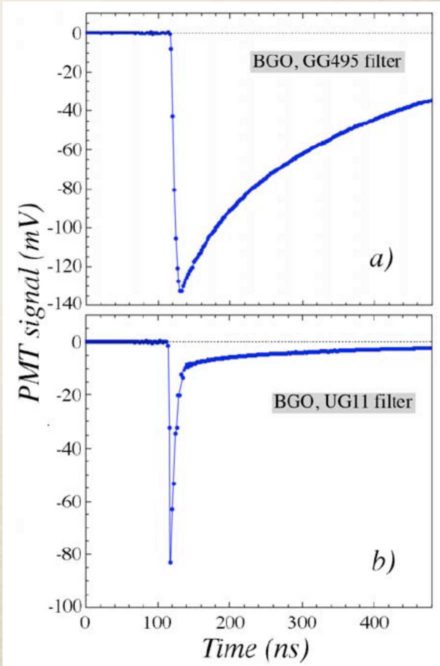
Filter type	Filter name	> 90% transmission for
UG11	"UV"	$\lambda < 400$ nm
U330		$\lambda < 410$ nm
UG5	"Blue"	$\lambda < 460$ nm
GG495	"Yellow"	$\lambda > 495$ nm



Time structure readout:

- CAEN V1742 digitizer based on the DRS-IV chip:
  - 8+1 channels sampler, GHz range sampling and a 1024 cells buffer.
  - Sampling frequency set at 2.5 - 5 GS/s
- integration on part of the pulse shape contribute to (optimize) the signal separation

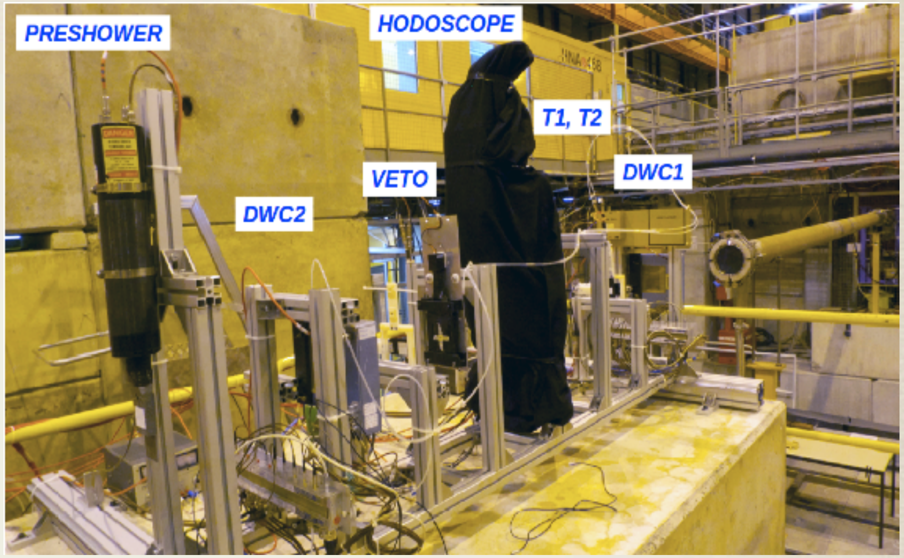


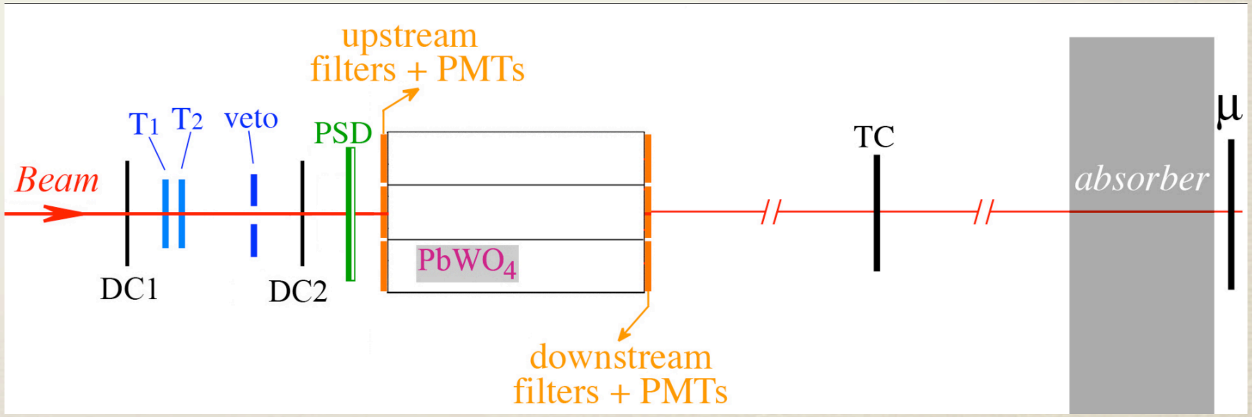


Experimental setup

- Data taken at the H8 line of SPS in CERN North area
  - electron beam from 4 to 180 GeV

- Trigger and auxiliary detectors:
  - Trigger:
    - 2 scintillators + 1 veto
    - FPGA based logic,
  - Beam position:
    - 2 Delay Wire Chambers (DWC)
  - Beam cleaning:
    - preshower (PSD),
    - tail catcher (TC),
    - muon (μ) detector

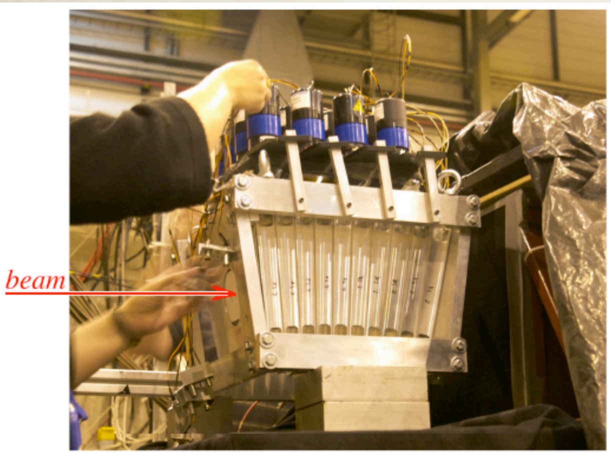


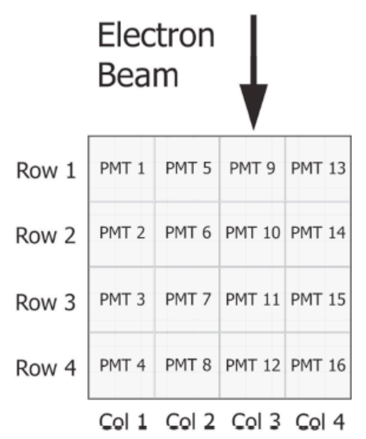


Crystals used for test

BGO

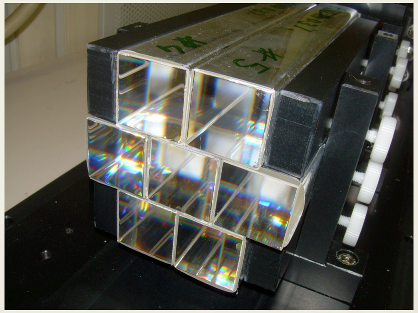
- 100 BGO crystals from a projective tower of the L3 experiment
- Dimensions:
  - 24 cm long and tapered
  - end faces: 2.4×2.4 cm^2, 3.2×3.2 cm^2
  - effective thickness: 28 cm = 25 X_0
- 16 PMTs Hamamatsu R1355
  - each PMT collected light produced by clusters of at least 9 adjacent crystals



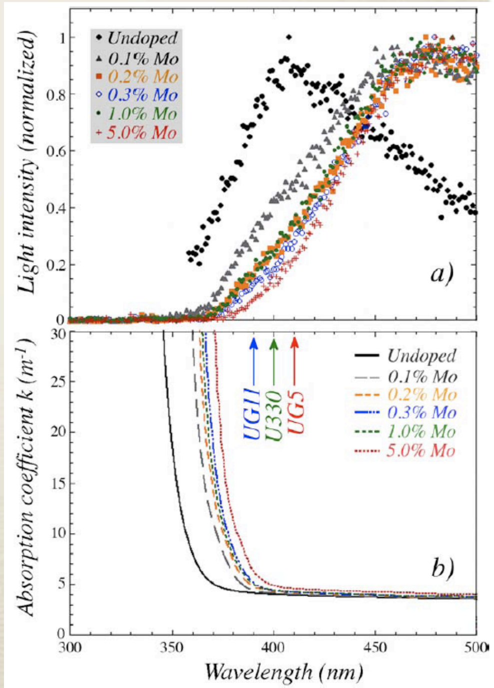


Mo:$PbWO_4$

- 7 custom made(*) $PbWO_4$ crystals doped with 0.3 % Molybdenum
- Dimensions:
  - 3×3×20 cm^3
  - 22.5 X_0 , 1.36ρ_M
- 2 PMTs for each crystal, 14 in total
  - Hamamatsu 8900 and 8900-100 (SBA)



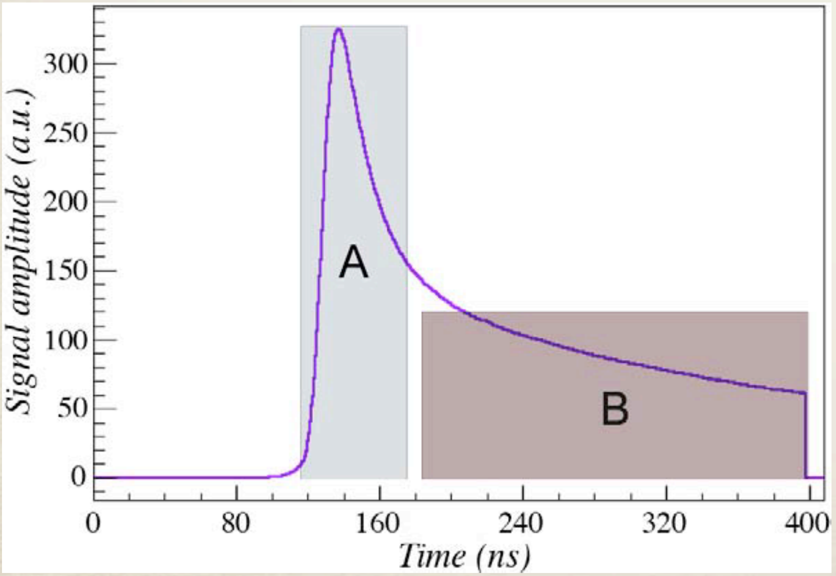
(*) Radiation Instruments & New Components company, Minsk, Belarus



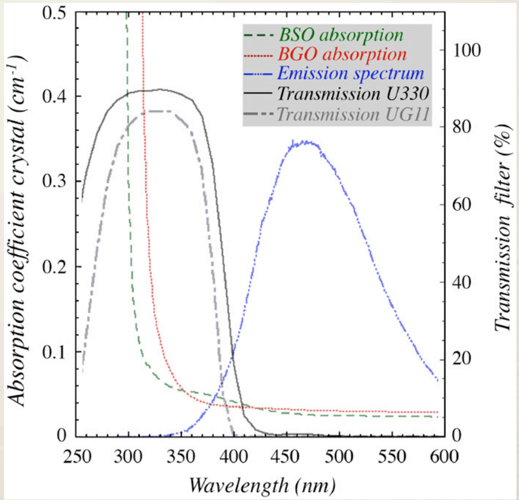
BGO matrix measurements

- BGO crystals readout from a single side, equipped with UG11 filter
  - less then 1% of the scintillation light survived
- inter-calibration of PMT done both with LED and electron beam steered in each column
- signal integrated over different time windows of the pulse shape in order to extract
  - Č (fast component - gate A)
  - S (slow - gate B)
  - correction of the charge integration based on pure scintillation pulse shape (yellow filter)

$$S = 1.36 \times Q_B \qquad C = Q_A - 0.36 \times Q_B$$



Spectral characteristics



BGO matrix results

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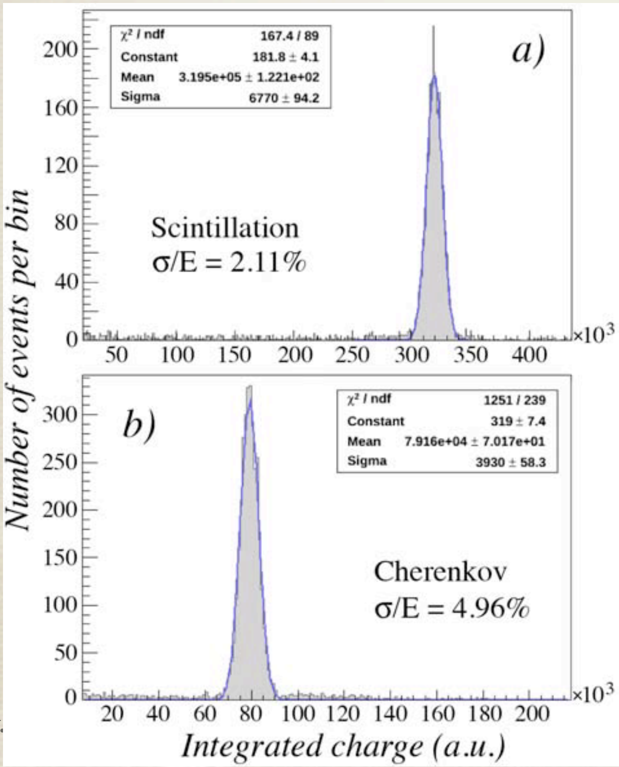
Measurement performed with electron beam of 30, 60, 100, 150 GeV

Resolution obtained from distribution of integrated charge

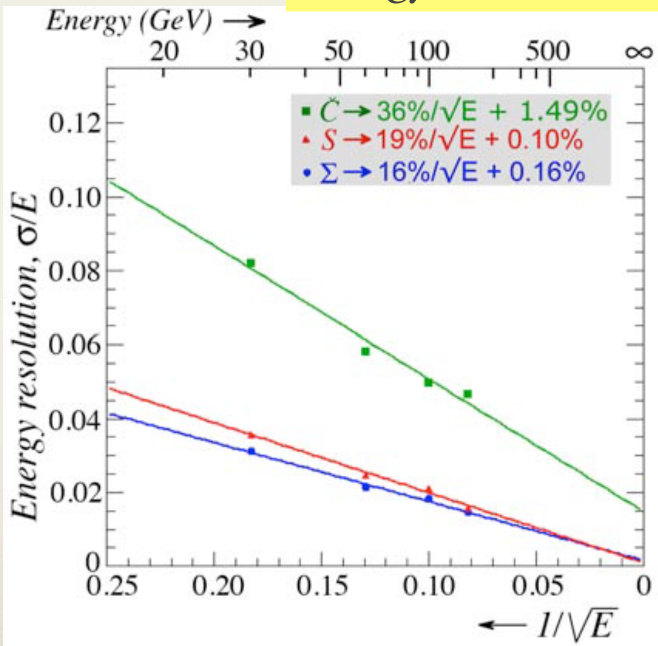
Results:

- Čerenkov energy resolution shows a constant term of about 1.5%
- good linearity (within ± 3%)
- Čerenkov light yield about 6 p.e./GeV

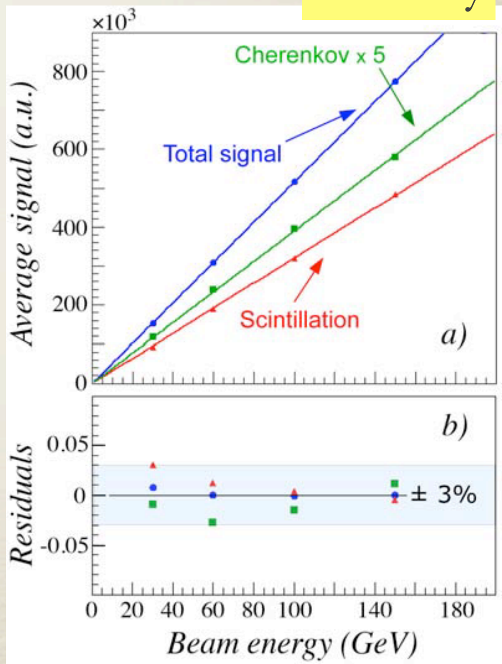
100 GeV electron



Energy Resolution



Linearity



BGO vs BSO: single crystals

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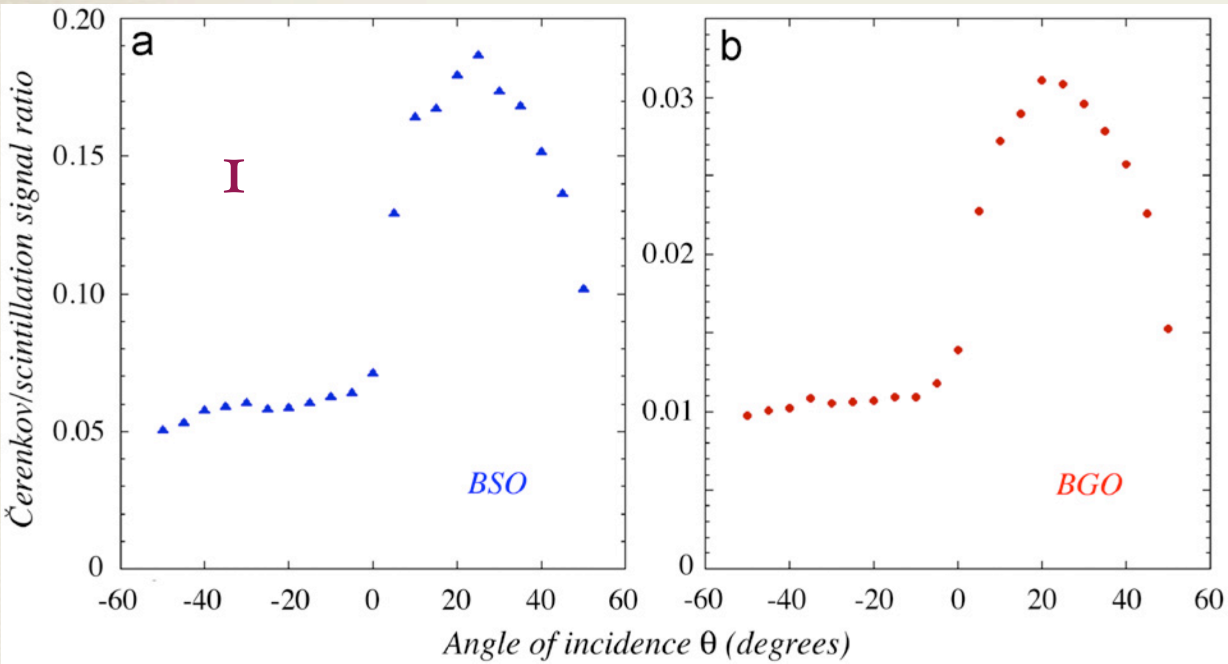
Comparison of BGO and BSO in terms of properties for use for dual readout calorimetry

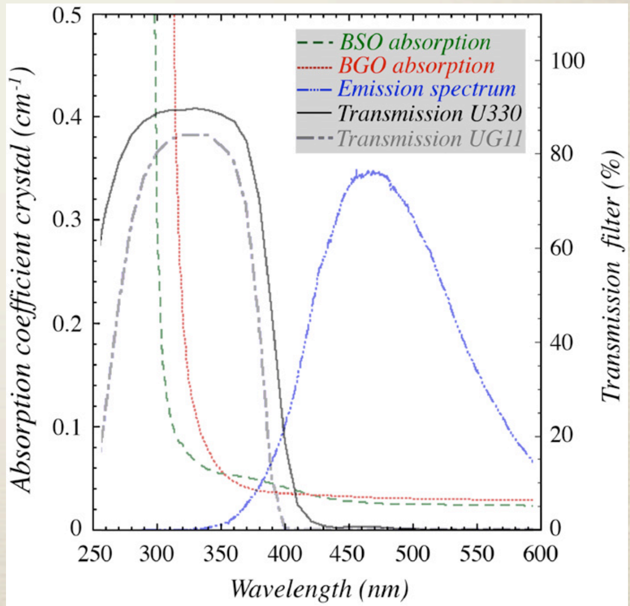
- single crystal test (18 cm long, 2.2 x 2.2 cm^2 in x-sect)
- pion beam 180 GeV

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

Results:

1. purity of the $\check{C}$ signal obtained with filters: separation power better by a factor of 6



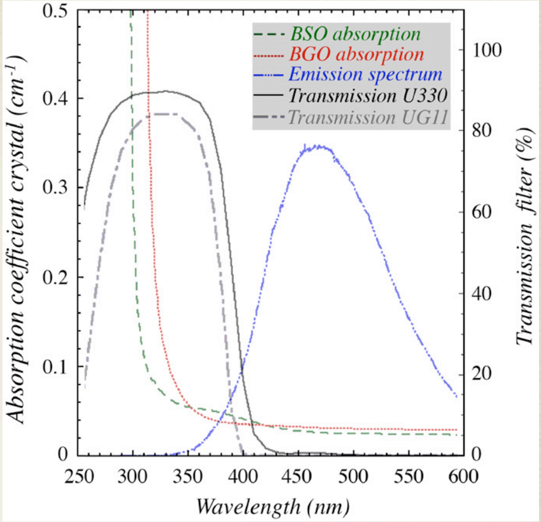


BGO vs BSO: single crystals

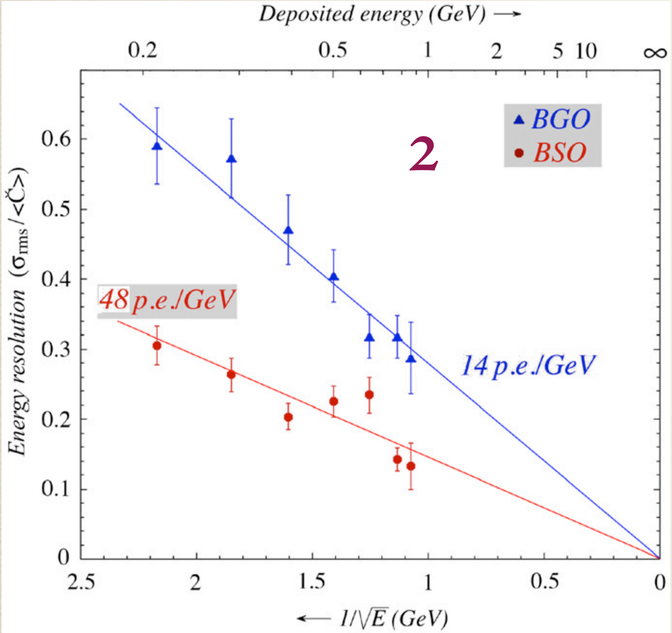
Results:

2. $\check{C}$ light yield: p.e. detected per unit deposited energy 2-3 times larger in BSO

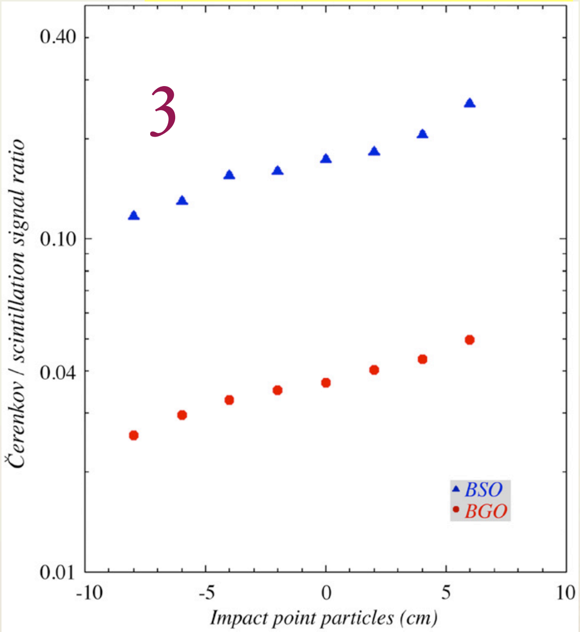
3. light attenuation length for $\check{C}$ light: mostly the same in both crystals



Energy Resolution



Response Uniformity



BSO is promising as crystal for dual readout
No further test performed at the moment

Mo:PbWO4 measurement

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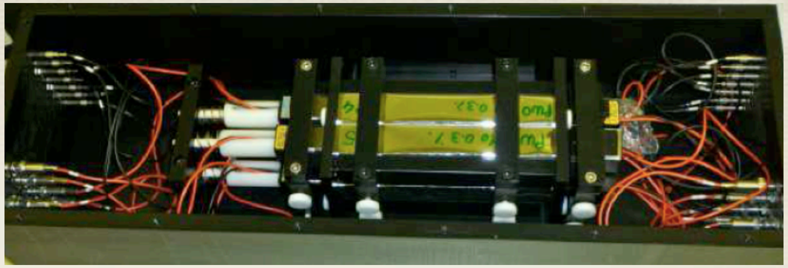
Calibration done with 30 (80) GeV electrons

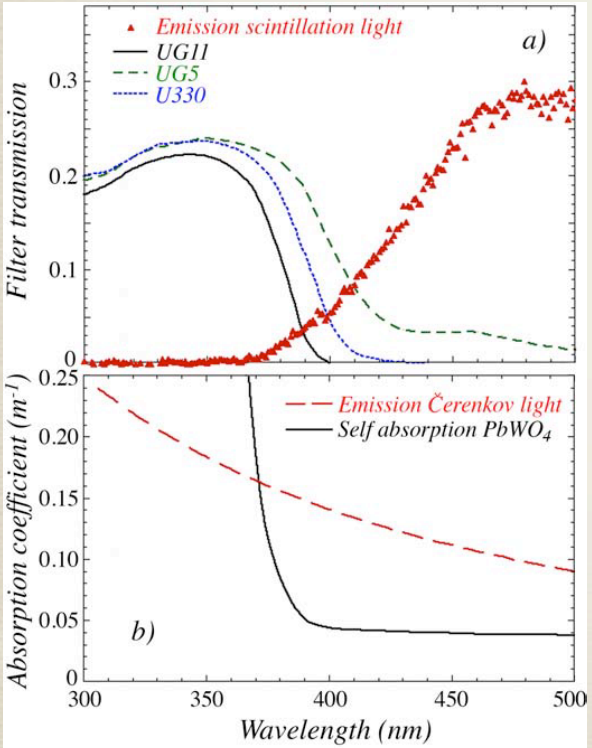
- beam steered in each crystal
- using Geant4 simulation to get the calibration constant
    - 77% of energy deposited in the hit crystal, 93 % in the entire matrix

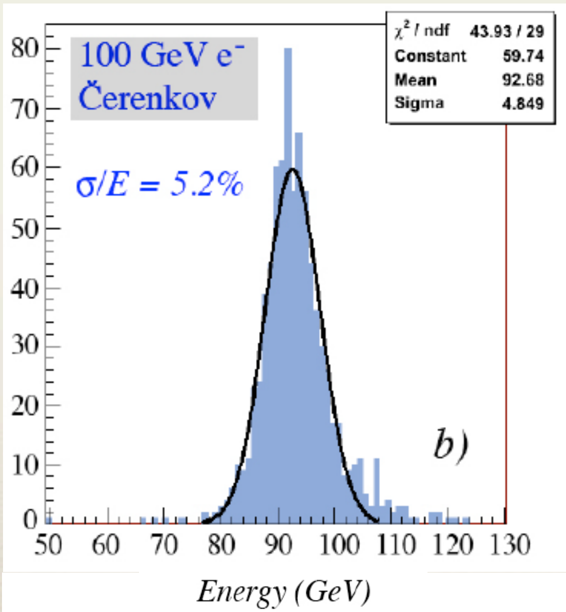


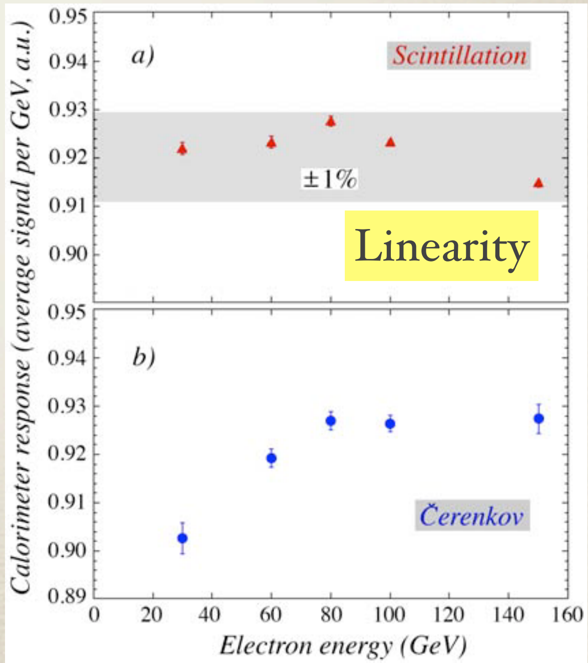
Different filter combinations were used during the $PbWO_4$ matrix test, each optimizing one aspect of the readout

Upstream GG495 (yellow), downstream U330:

- good for S: measured resolution: ~ 1% for 100 GeV electrons
- poor for Č due to self absorption. Strong non linearity.







$PbWO_4$ results: Cerenkov

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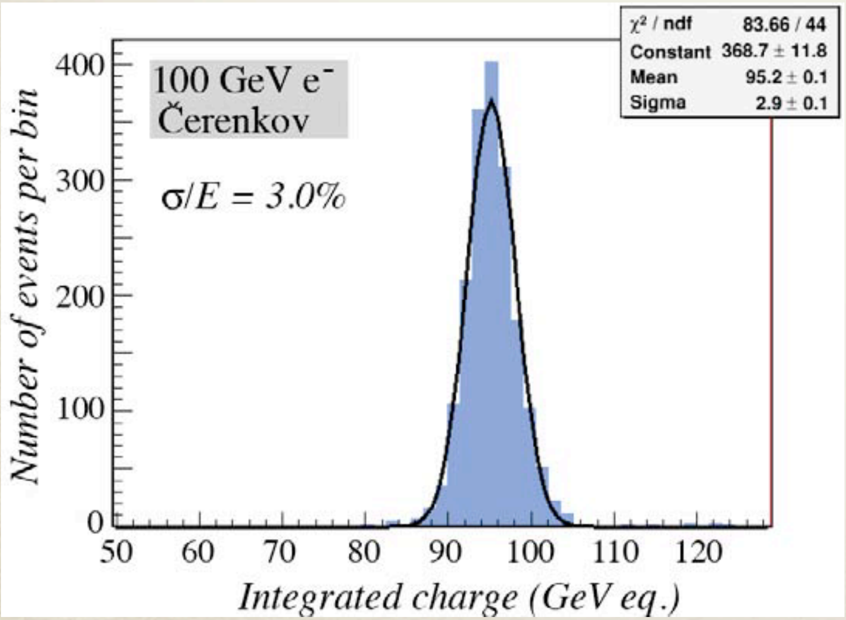
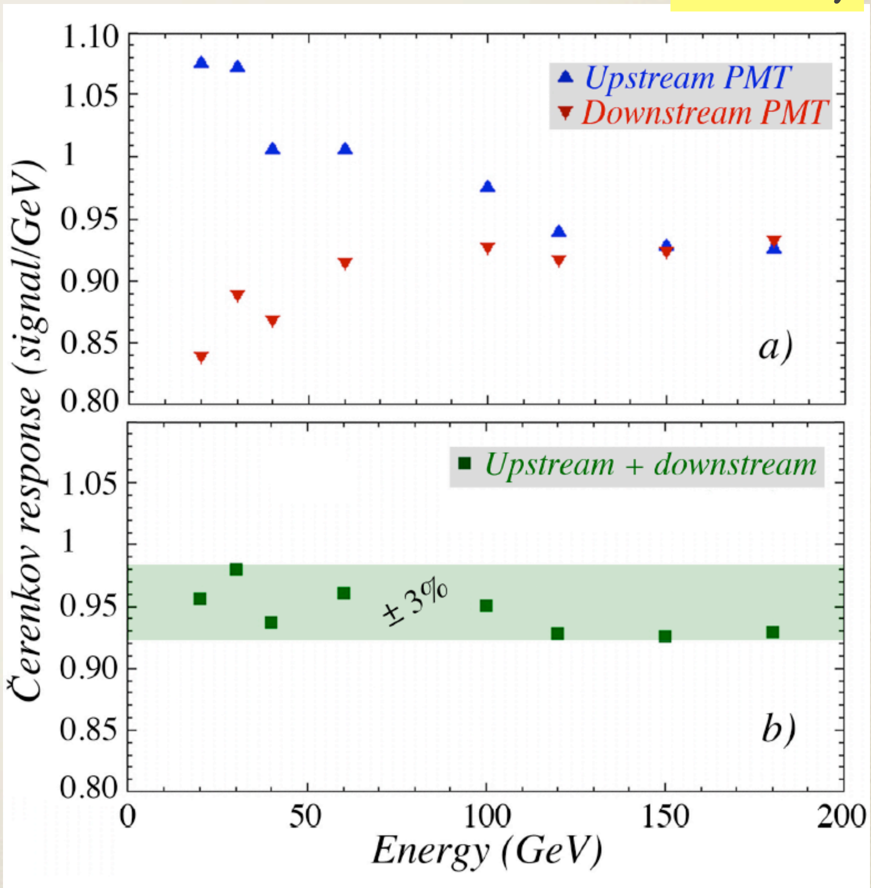
Different filter combination were used during the $PbWO_4$ matrix test, each optimizing one aspect of the readout

U330 both sides

- good for Č (sum of two sides)
- almost no S signal



Linearity

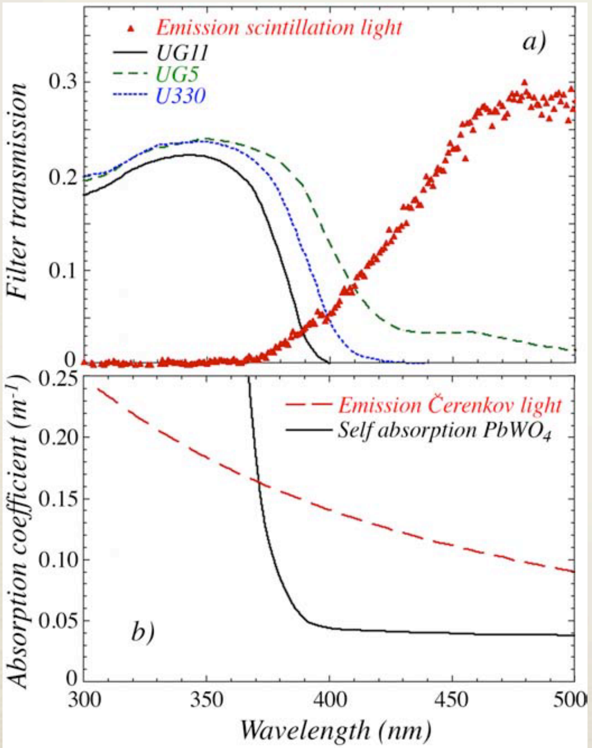


$PbWO_4$ results: Cerenkov

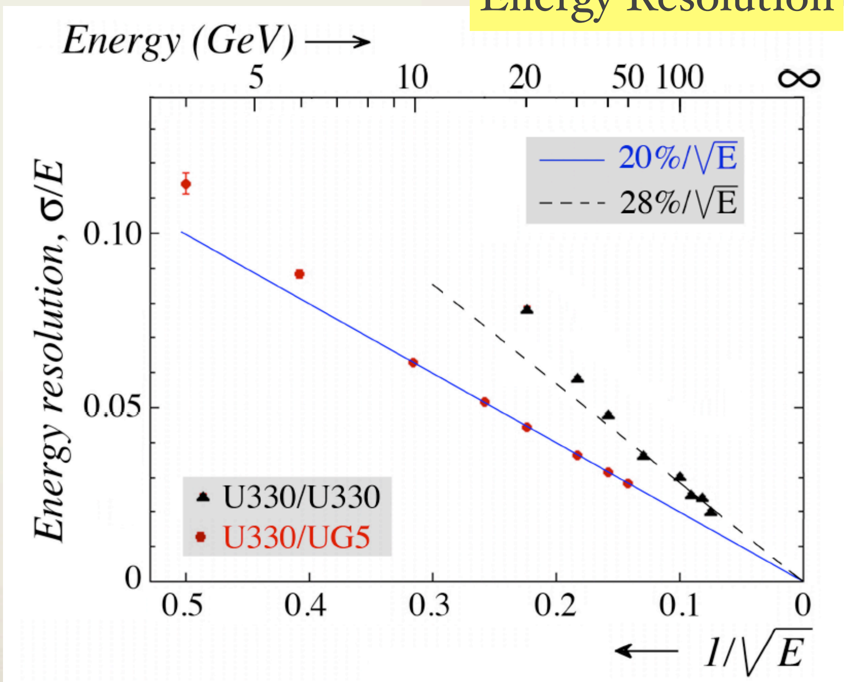
Different filter combination were used during the PbWO4 matrix test, each optimizing one aspect of the readout

Upstream UG5 (blue), downstream U330

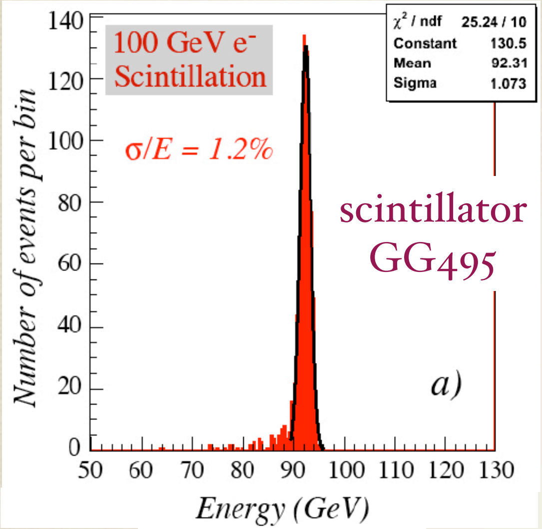
- good for Č: sum of two sides, reduction of effects of self absorption. Linearity at 3%
- poor for S: S extracted from the tail of the time structure, hence few photoelectrons.



Energy Resolution



$PbWO_4$ results: Scintillation

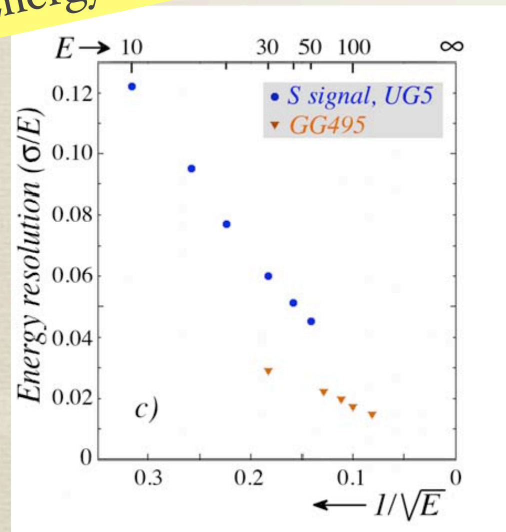


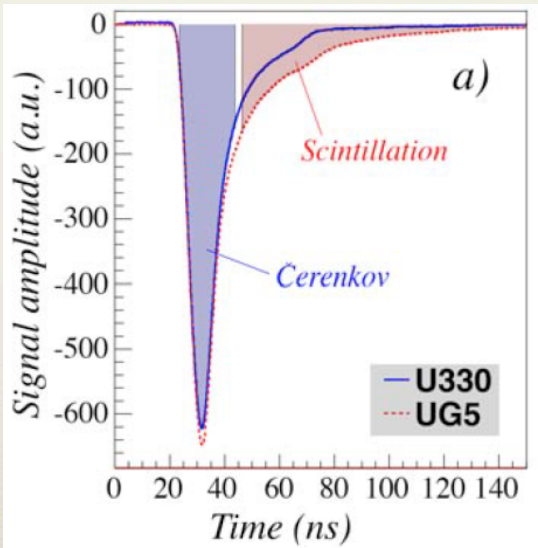
Optimal resolution for Scintillation light reached using yellow filter (large photo-statistic)

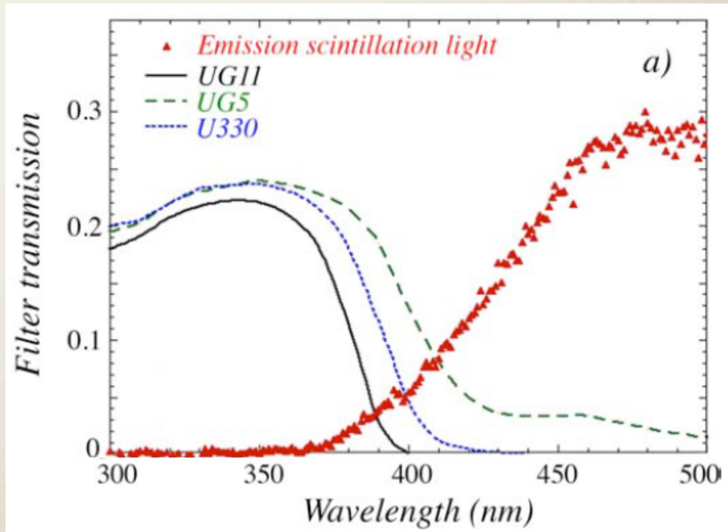
If one uses UV+UV filter configuration to improve the Čerenkov resolution

- scintillation signal has to be obtained from integration of the tail of the signal (largely reducing the p.e. photostatistic)
- U330 filter reduce almost completely the scintillation light.
- UG5 usable but energy resolution worse by a factor 2 wrt to GG495

Energy Resolution







Conclusions

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- In order to use crystals in the context of dual readout calorimetry, they have to be readout in a non conventional way, and this leads to results in terms of electromagnetic energy resolution of separated Č and S components that are far from being optimal and not as good as the ones obtained in standard em calorimetry
- Extracting sufficiently pure Č signals from these scintillating crystals implies
    - a large fraction of the potentially available Č photons needs to be sacrificed (by optical filters)
    - the light that does contribute to the Č signals is strongly attenuated (by UV self absorption).
- Our results show that the stochastic fluctuations in the Č channel are at best 20%/√E in the case of our Mo-doped $PbWO_4$ crystal matrix. Assuming that these fluctuations are completely determined by photoelectron (p.e.) statistics, this would mean that the Č light yield for the electron showers was 25 p.e./ GeV of deposited energy.
- Crystals in combination with filters does not seem to offer a benefit in terms of the Č light yield in dual-readout calorimeters. We recently measured a light yield in excess of 50 Č p.e./GeV in our new dual-readout fiber calorimeter. Nonetheless there are room for improvements...
- Long term project: we foresee to have combined test of crystal matrix and full containment fiber module

BACKUP SLIDES

Test performed so far

- PbWO4 crystals (N. Akchurin et al., NIM. A582 (2007), N. Akchurin et al., NIM A584 (2008), N. Akchurin et al., NIM A593 (2008))
- BGO (N. Akchurin et al., NIM. A598 (2009), N. Akchurin et al., NIM A598 (2009), N. Akchurin et al., NIM A 610 (2009))
- Doped PbWO4 crystals [Praseodymium, Molybdenum] (N. Akchurin et al., NIM A604 (2009))