Calorimetry with meta-crystals

Etiennette Auffray, Paul Lecoq, Georgios Mavromanolakis

European Organization for Nuclear Research
CERN, CH-1211 Geneva, Switzerland

Outline

- **Introduction - General**
- **Calorimetry with meta-crystals**
- **Dual readout and energy correction**
- **Case studies and simulation results**
- **Questions - Outlook**

Introduction - General

► . **R&D for future hep calorimetry** : mainly 3 lines of approach

- ▷ . partifle flow approach (CALICE)
- ▷ . dual readout calorimetry (DREAM)
- ▷ . crystal calorimetry (e.g. see HHCAL workshop)

▷ . particle flow paradigm

highly granular EM and HADR calorimeters to allow very efficient pattern recognition for excellent shower separation and pid within jets to provide excellent jet reconstruction efficiency

▷ . dual readout calorimetry

measurement of both the ionisation/scintillation and the Cherenkov signals generated by a hadronic shower in order to determine on an event by event basis the electromagnetic fraction of the shower and so to cancel/correct for this source of fluctuation that degrades the energy resolution of the calorimeter

▷ . crystal calorimetry

an approach that could combine the excellent energy resolution of crystals (homogeneous detector) with dual readout, if scintillation and Cherenkov signals can be separated and recorded, and with particle flow/imaging capabilities if the detector is segmented with high granularity

Dual readout with metamaterials

- · **the meta-crystals concept**

  : consisting of **undoped** and ***Ce doped*** heavy crystal fibers of identical material. The undoped crystals behave as **Cherenkov radiators** while the doped crystals behave as ***scintillators***

  : a candidate material is the Lutetium Aluminium Garnet (LuAG) crystal $(Lu_3Al_5O_{12})$

Physical properties		**Optical properties**	
Density	6.73 gr/cm^3	Light yield (Ce doped)	> 25000 ph/MeV (50% of NaI)
Zeff	62.9	Emission wavelength	535 nm (Ce doped)
Radiation length X_0	1.41 cm	Decay time	60 nsec (Ce doped)
Interaction length λ_I	23.3 cm	Refractive index	1.842 at 633 nm
Melting point	2260 °C	Cherenkov threshold	97 keV
Thermal expansion	8.8 $10^{-6}/°C$	Max Cherenkov angle	57 °
Thermal conductivity	31 W/m°C	Total reflection angle	33 °

R&D activities

- · **material development**

  : comprehensive program of studies within the framework of the Crystal Clear Coll. with focus on hep and medical imaging applications

- · **testbeam activities**

  : very first testbeam studies with bundles of fibers exposed to electron beam

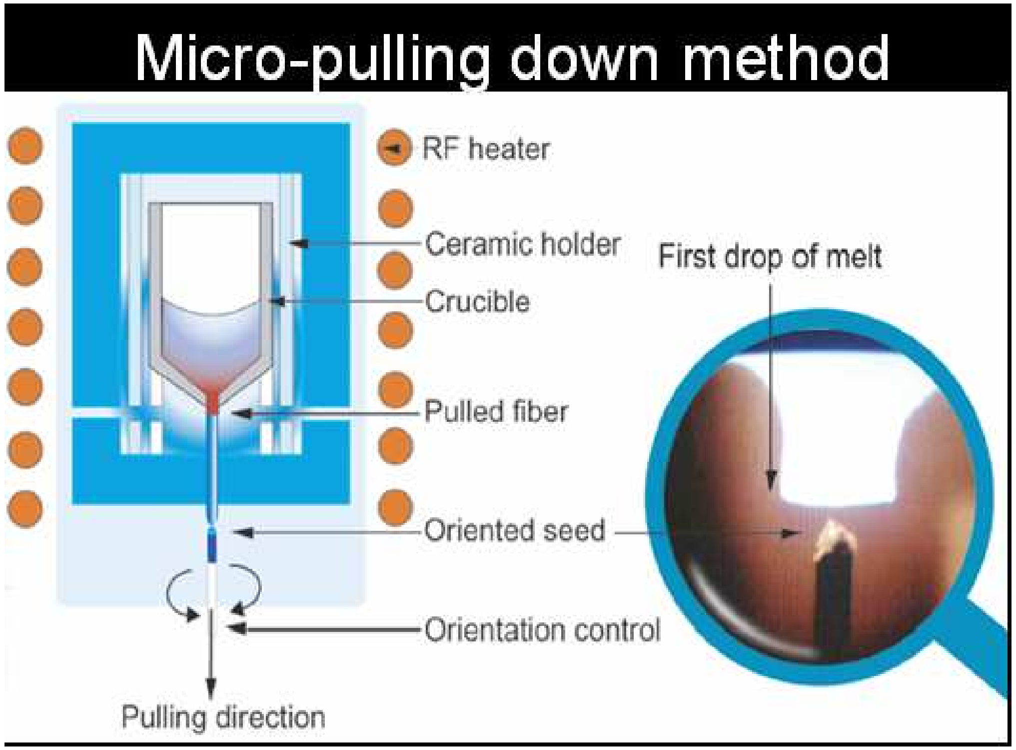
  : small scale tests i.e. equivalent to a level of a single calorimetric channel

  : data collection during Sep08, May09, Nov09

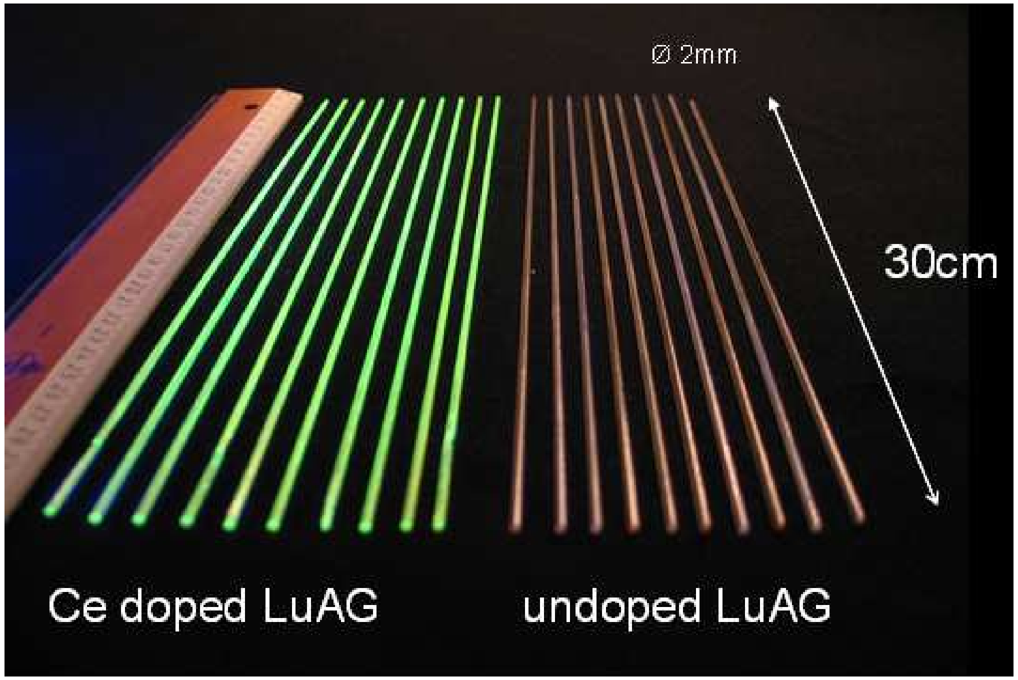
- · **simulation studies**

  : systematic scanning of the parametric space wrt granularity, sampling fraction, readout fraction, total length etc, for first understanding of performance trends and showstoppers and to proceed from an ideal case to a realistic one

Crystal fiber production



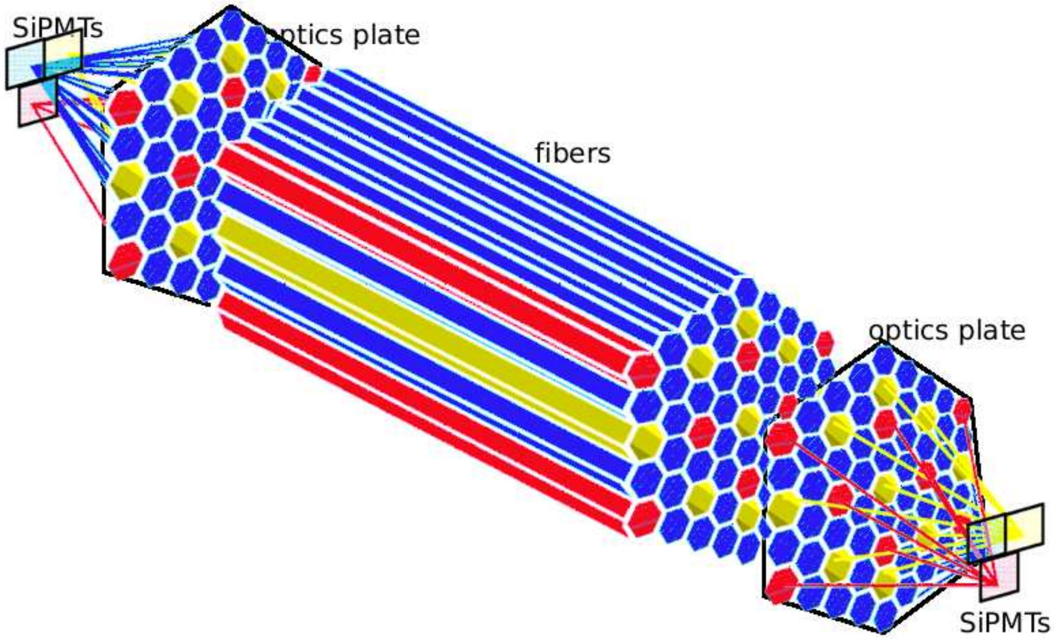
(courtesy of Fibercryst-Lyon, Cyberstar-Grenoble)



(20 fibers of diameter=2 mm, length=30 cm)

- fiber diameter between 0.3-3 mm, length up to 2 m
- pulling rate ranging from 0.1 to 0.5 mm/min
- capillary die can be non-cylindrical (e.g. square, hexagonal etc)
- overall cost per unit volume of production expected to be comparable to that of standard crystal growth methods

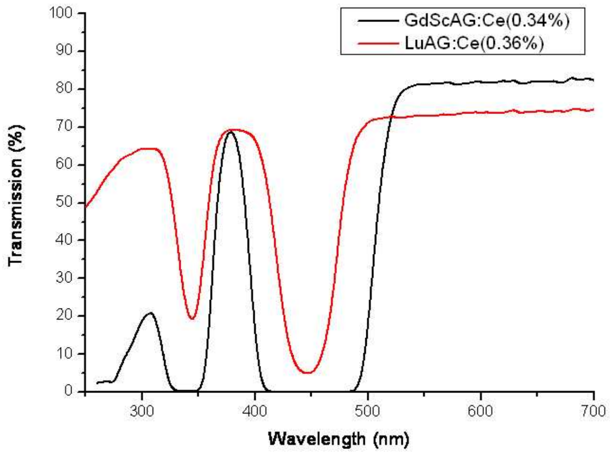
Concept of a readout unit



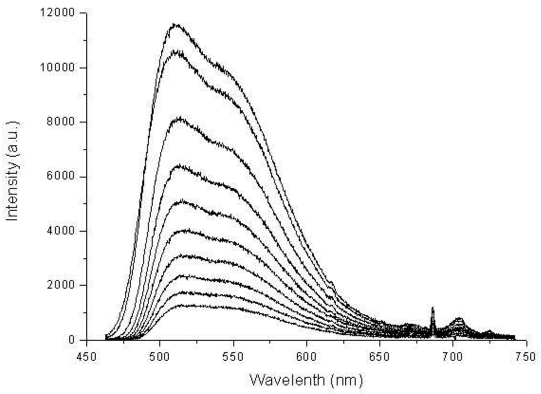
- **a unit consists of a structured distribution of different types of fibers**
- **typical dimensions of a unit :**
  $\mathbf{d = 1 - 1.5\ R_M,\ L = 20 - 25\ X_0}$
- **light from different types of fibers is directed to different SiPMTs by using diffractive optics light concentrators (micro-lenses)**
- **diffractive optics plate with pattern to match the structure of fibers**

Crystal fiber studies - material development

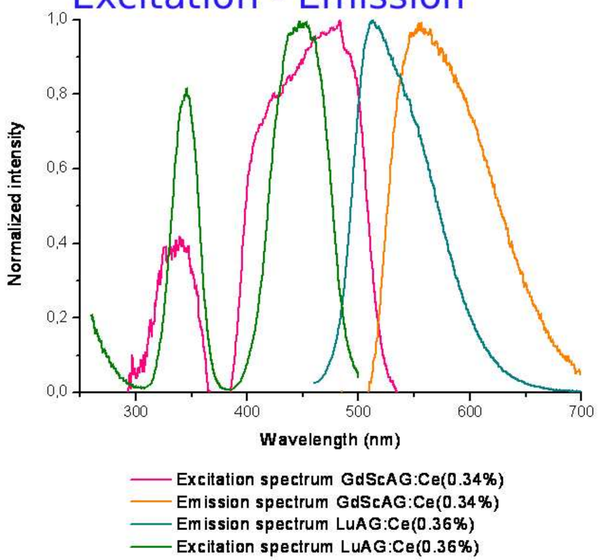
Transmission

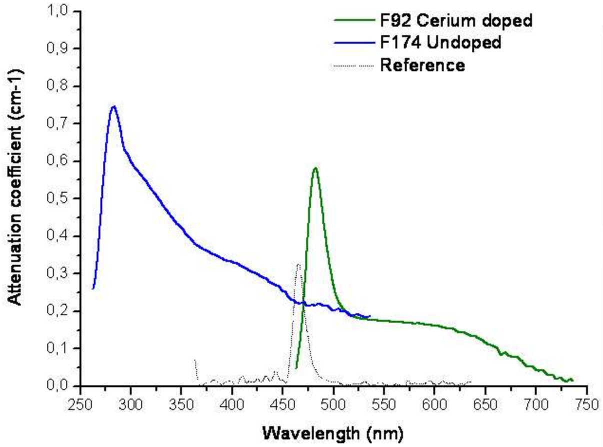


Attenuation

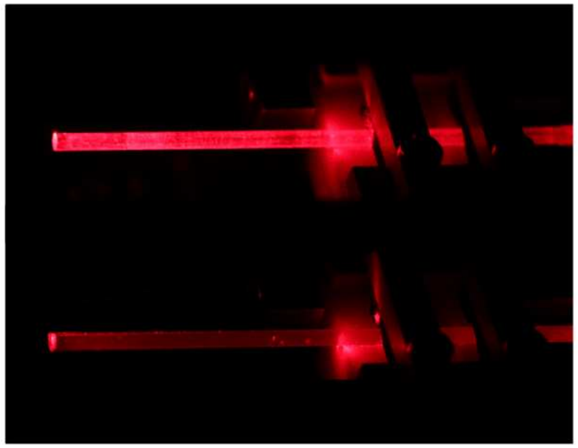


Excitation - Emission



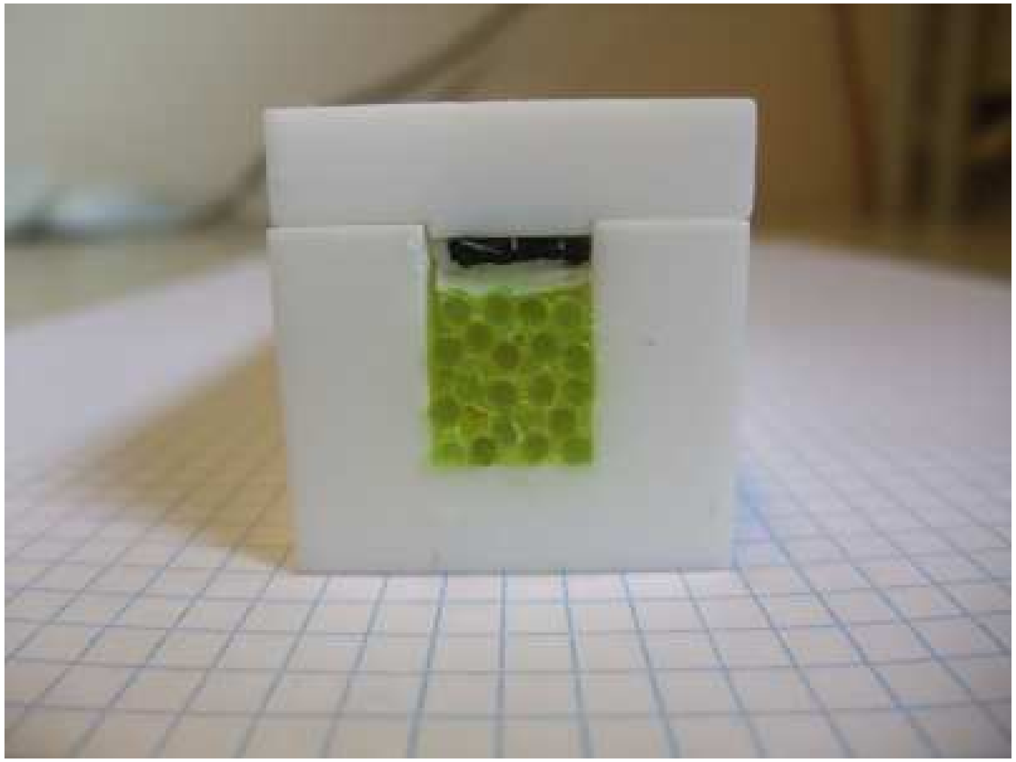


Diffusion



(see also talk by P.Lecoq at HHCAL Workshop)

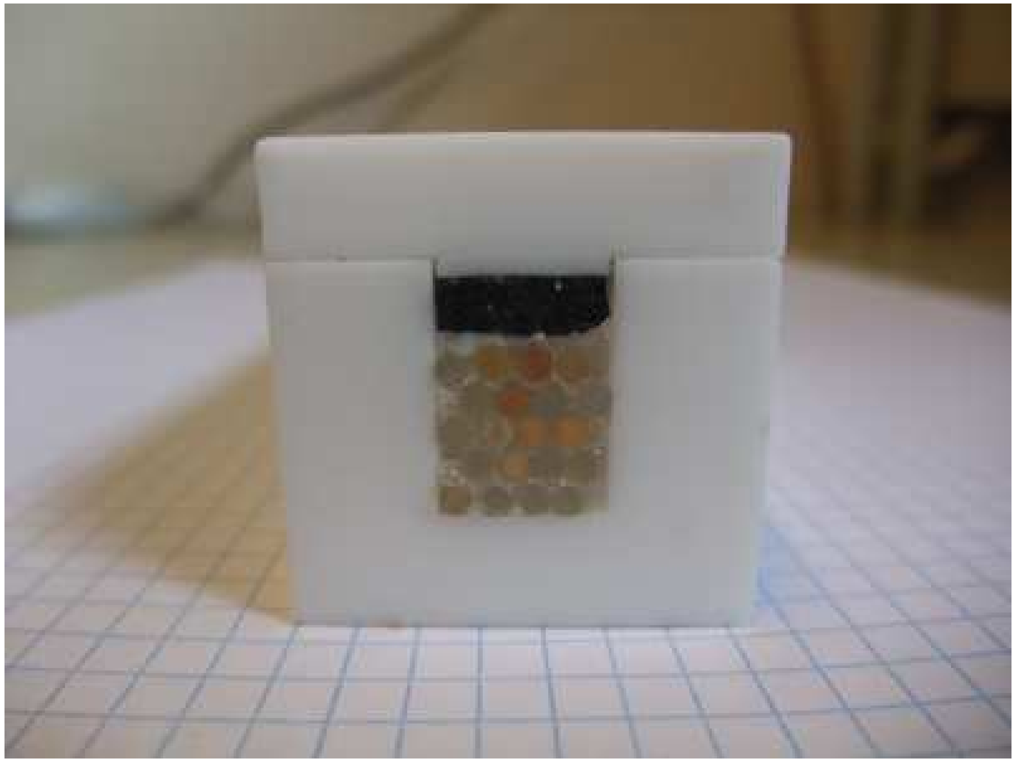
Fiber bundles exposed to beam



(20 fibers of diameter=2 mm, length=80 mm)

scintillator

Ce doped LuAG

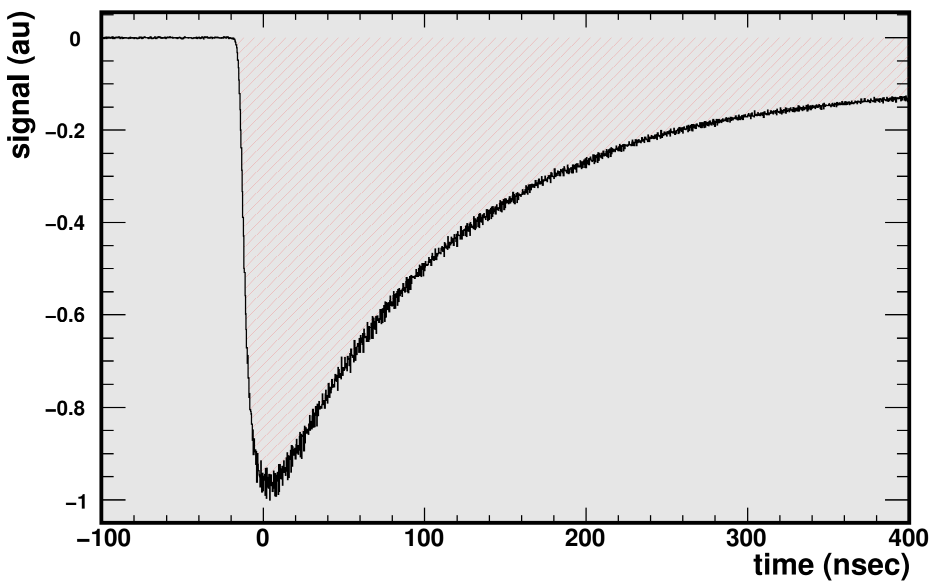


(20 fibers of diameter=2 mm, length=80 mm)

Cherenkov radiator

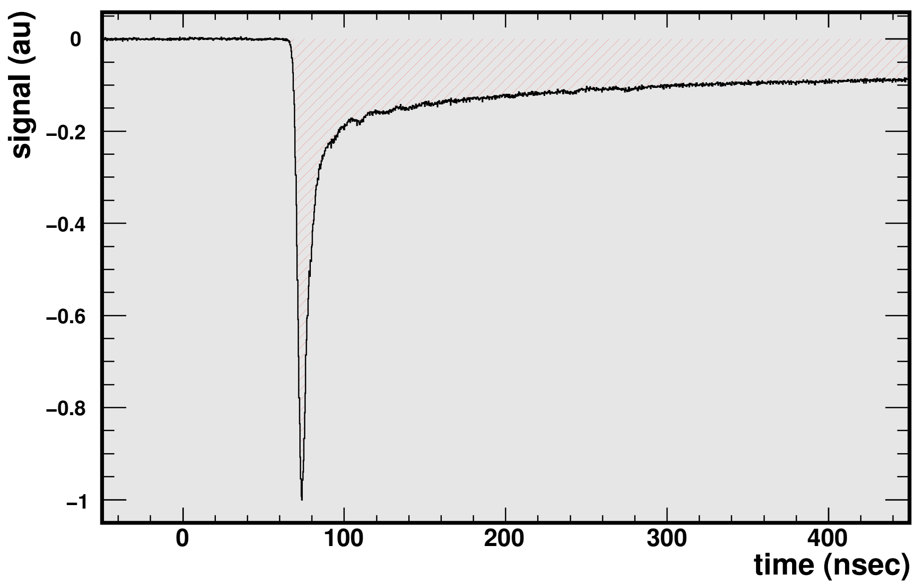
undoped LuAG

Average pulses



(scintillator)

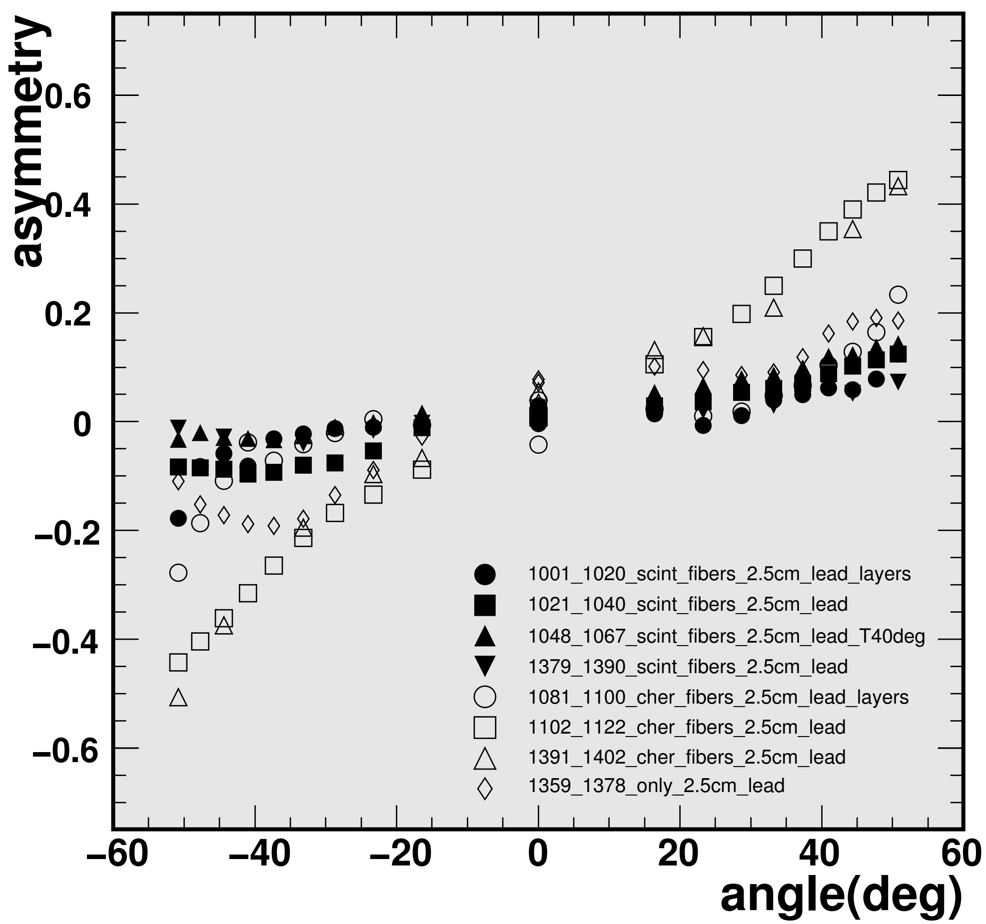
Ce doped LuAG



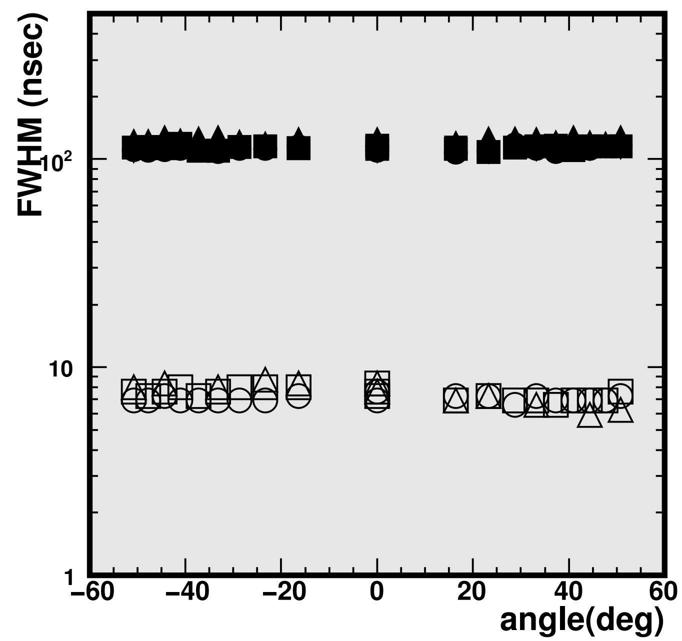
(Cherenkov radiator)

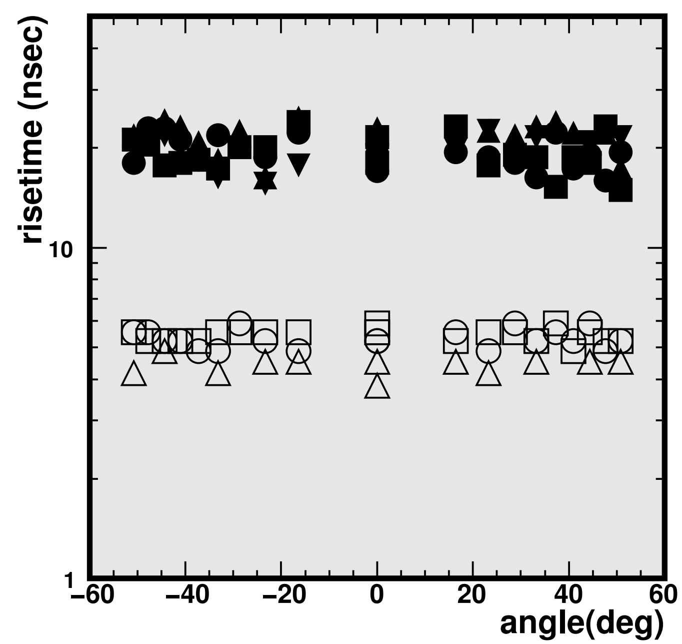
undoped LuAG

Testbeam results



Left-Right asymmetry of signal





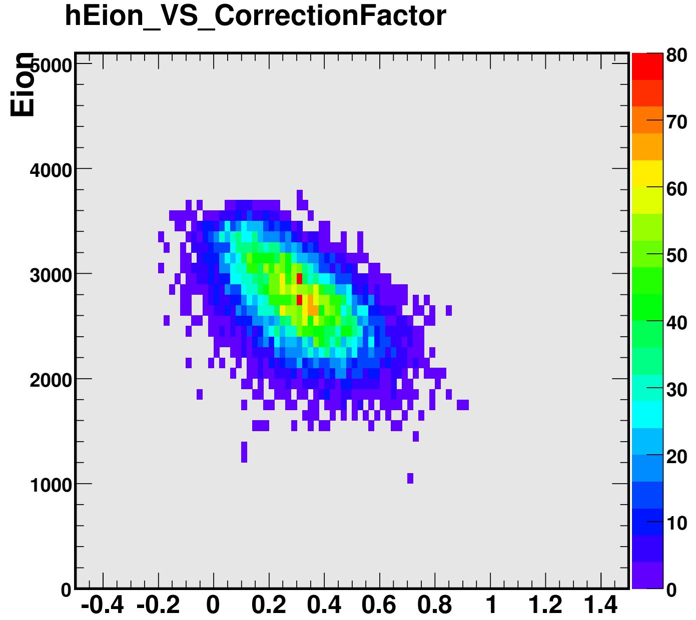
Dual readout and energy correction

► · **correct Eionz for single pions**

: define CorrectionFactor = 1 - calibr * Echer/Eionz
with calibr = Eionz/Echer for electrons at given energy

: get correction function Fionz() by fitting Eionz vs CorrectionFactor
of single pions at given energy

: corrected energy = Eionz/Fionz(), applied to pions of various energies



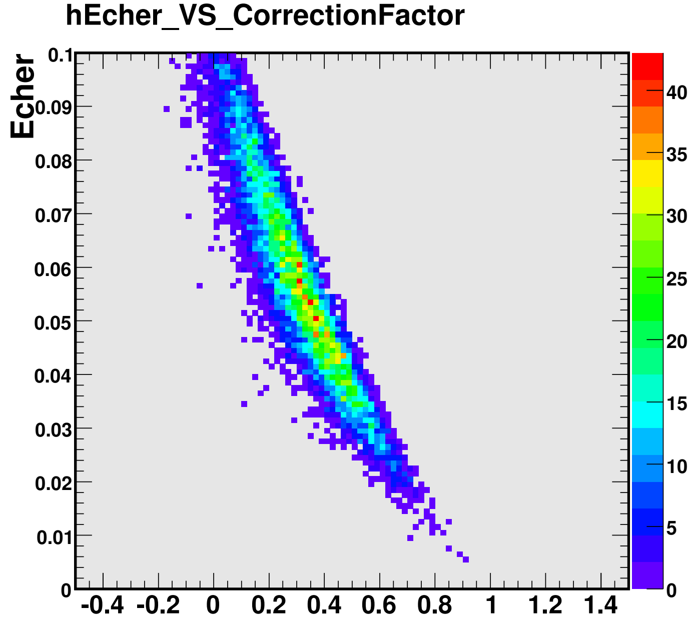
Or equivalently

► · **correct Echer for single pions**

: define CorrectionFactor = 1 - calibr * Echer/Eionz
with calibr = Eionz/Echer for electrons at given energy

: get correction function Fcher() by fitting Echer vs CorrectionFactor
of single pions at given energy

: corrected energy = Echer/Fcher(), applied to pions of various energies



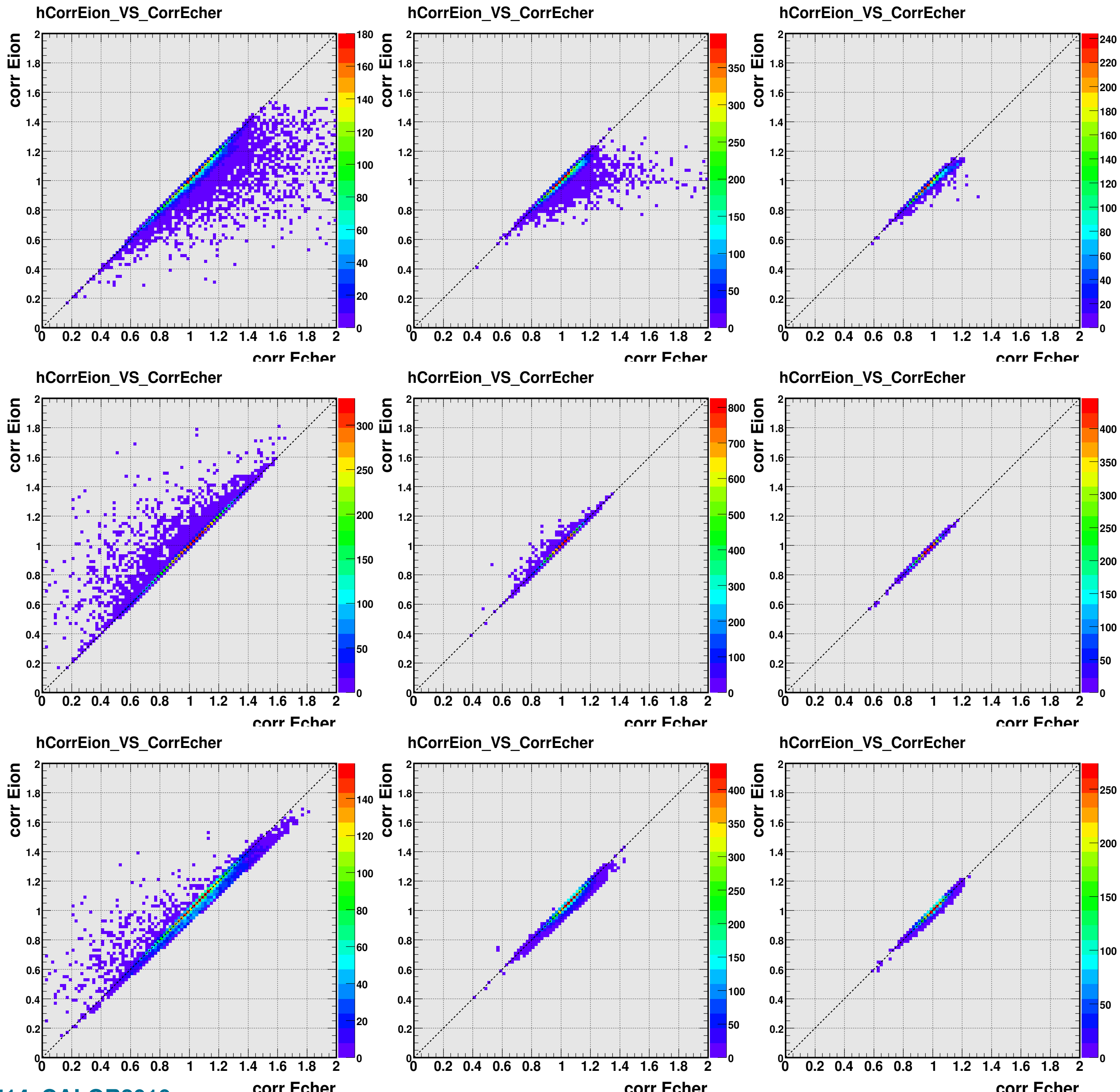
case of an homogeneous detector

π^- 1 GeV | π^- 5 GeV | π^- 10 GeV

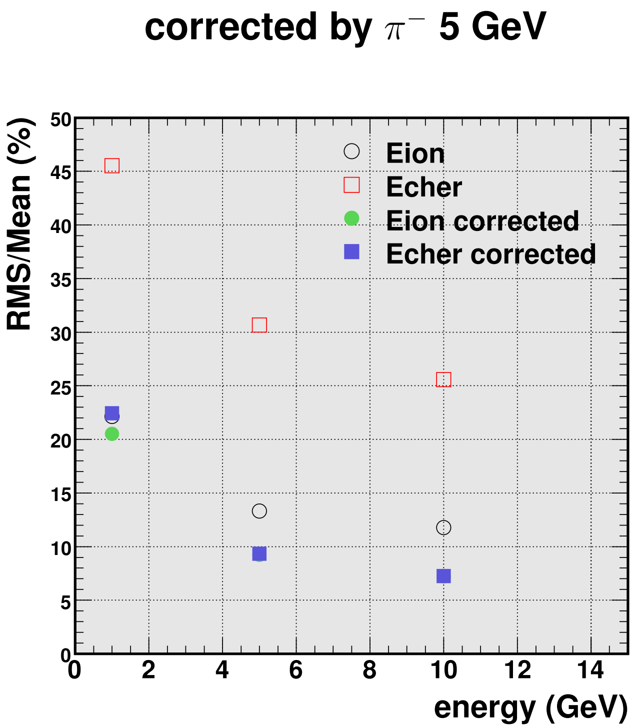
corrected by 1 GeV

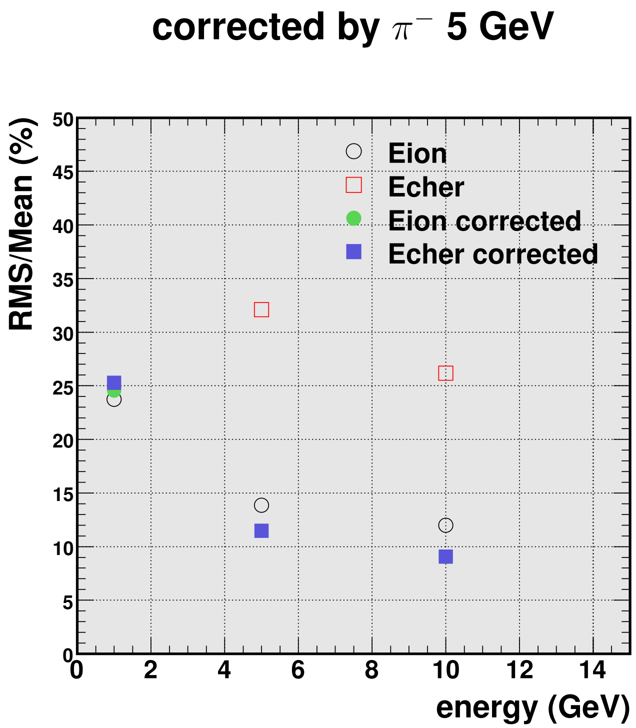
corrected by 5 GeV

corrected by 10 GeV



Energy resolution for single pions





homogeneous case

sampling case (e.g. abs:ion:cher 5:18:2)

Case studies

- **· in brief**

  : systematic scanning of the parametric space wrt granularity, sampling fraction, readout fraction, total length, mixture of conventional and dual readout components, corresponding composition, etc

  . "single cases"

  calorimeter with dual readout at full depth

  . "mixed cases"

  calorimetric volume composed of conventional and dual readout parts

- **· in the following**

  : discuss a "single case" calorimeter without leakage ($4.3 \times 4.3 \times 8.6\ \lambda_{\mathrm{I}}^{3}$)

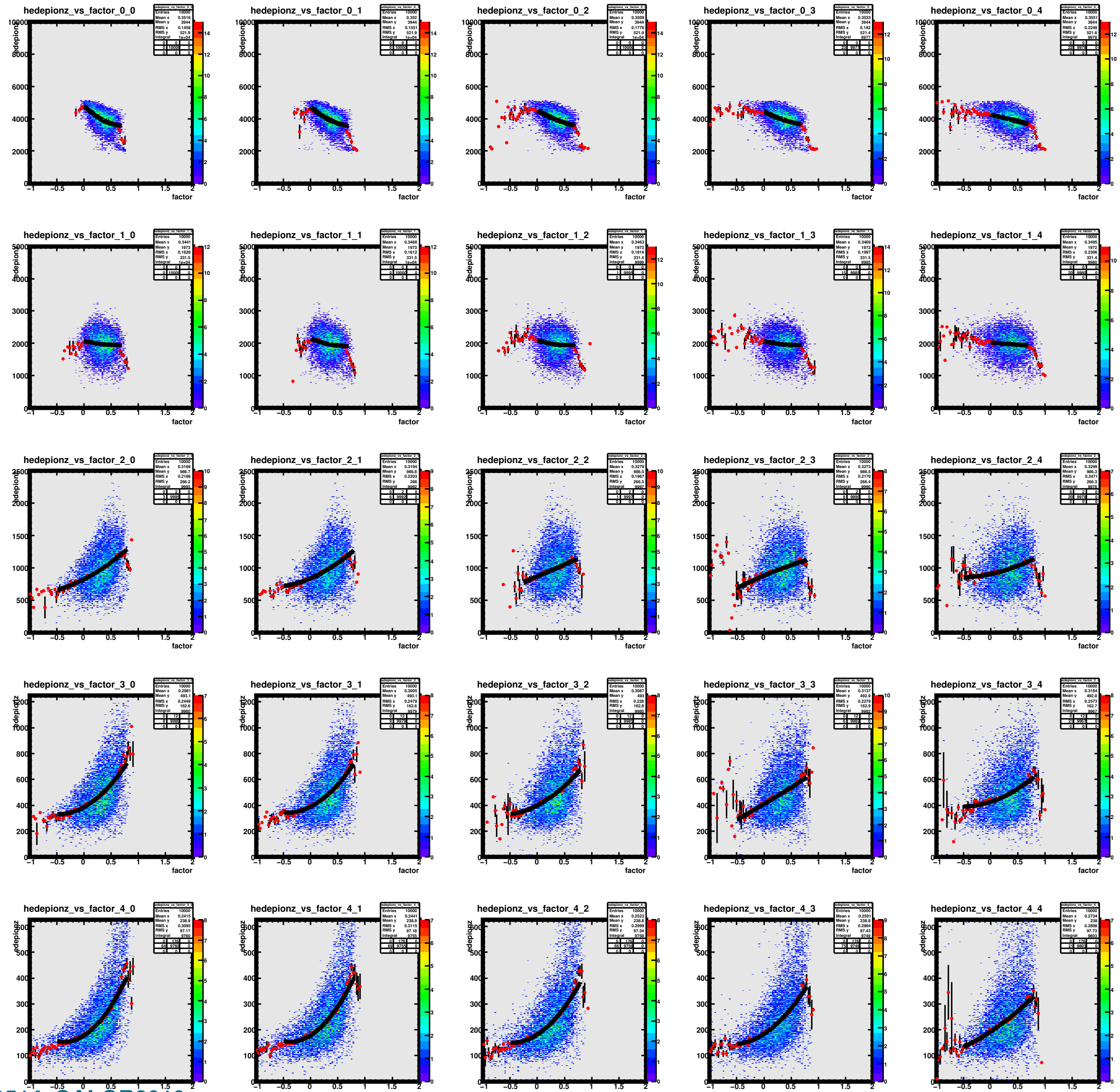
Correlation plots for various readout fractions

CHER READOUT FRACTION

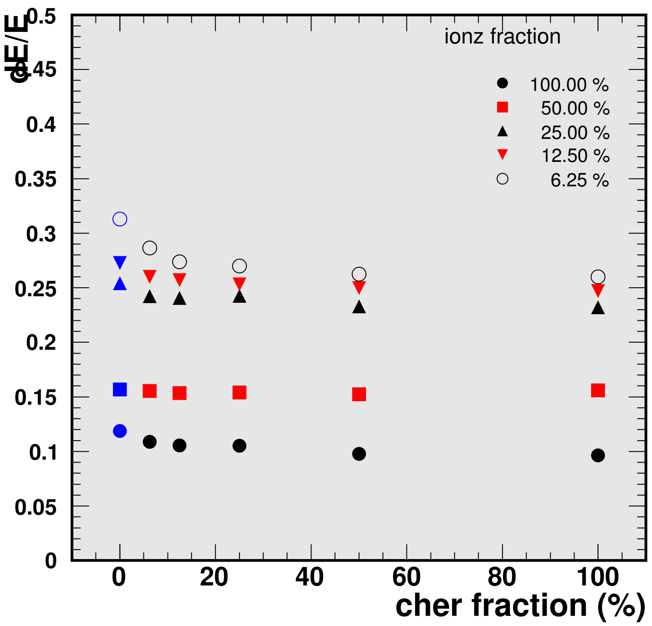
100% | 50% | 25% | 12.5% | 6.25%

IONZ READOUT FRACTION

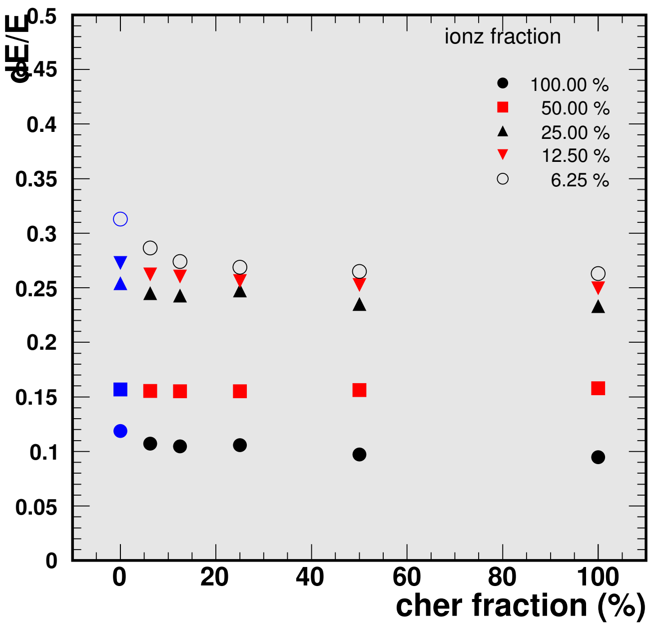
100% / 50% / 25% / 12.5% / 6.25%



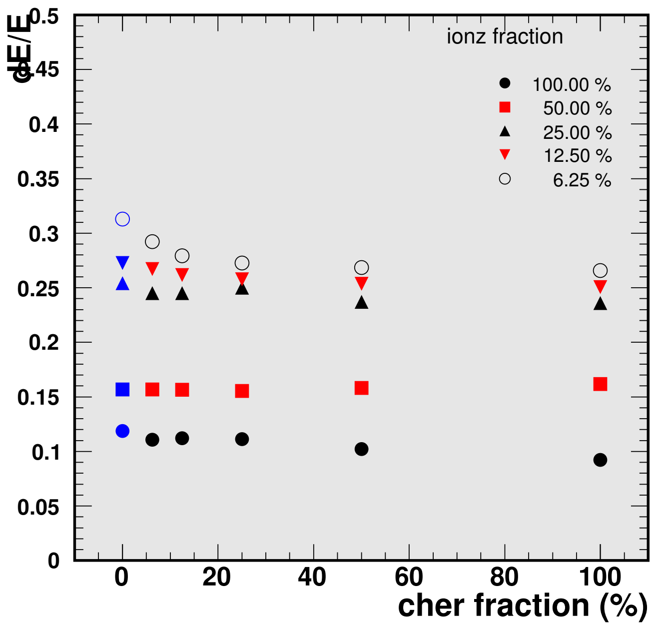
Energy resolution vs readout fraction (π^- 5 GeV)



corrected by π^- 5 GeV



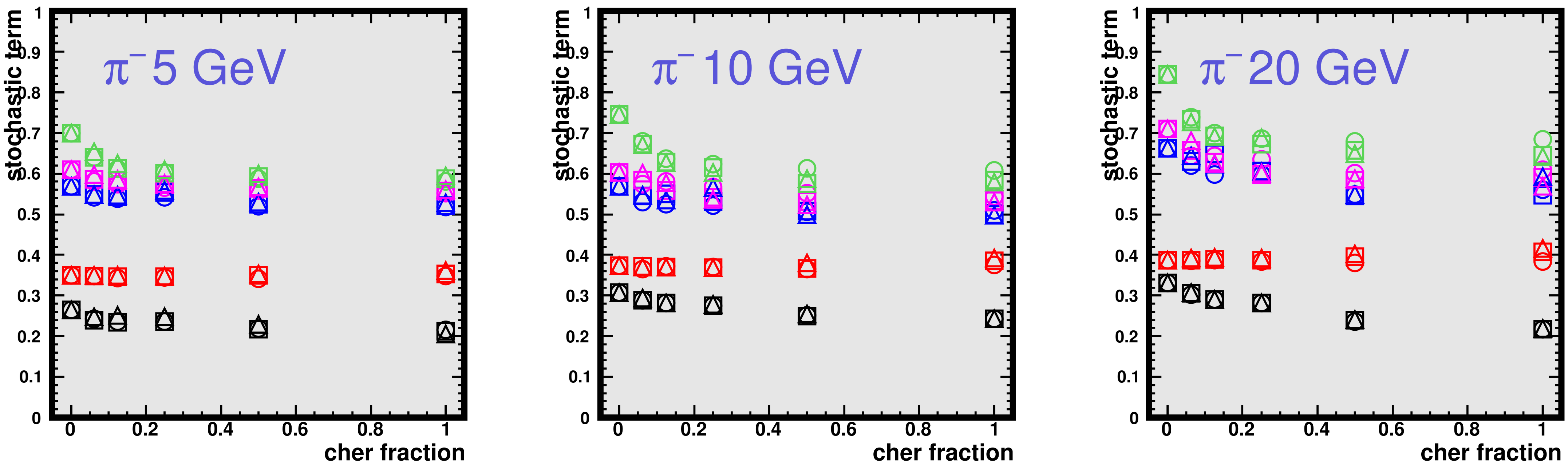
corrected by π^- 10 GeV



corrected by π^- 20 GeV

similar results with different correction energies

Energy resolution for different correction energies

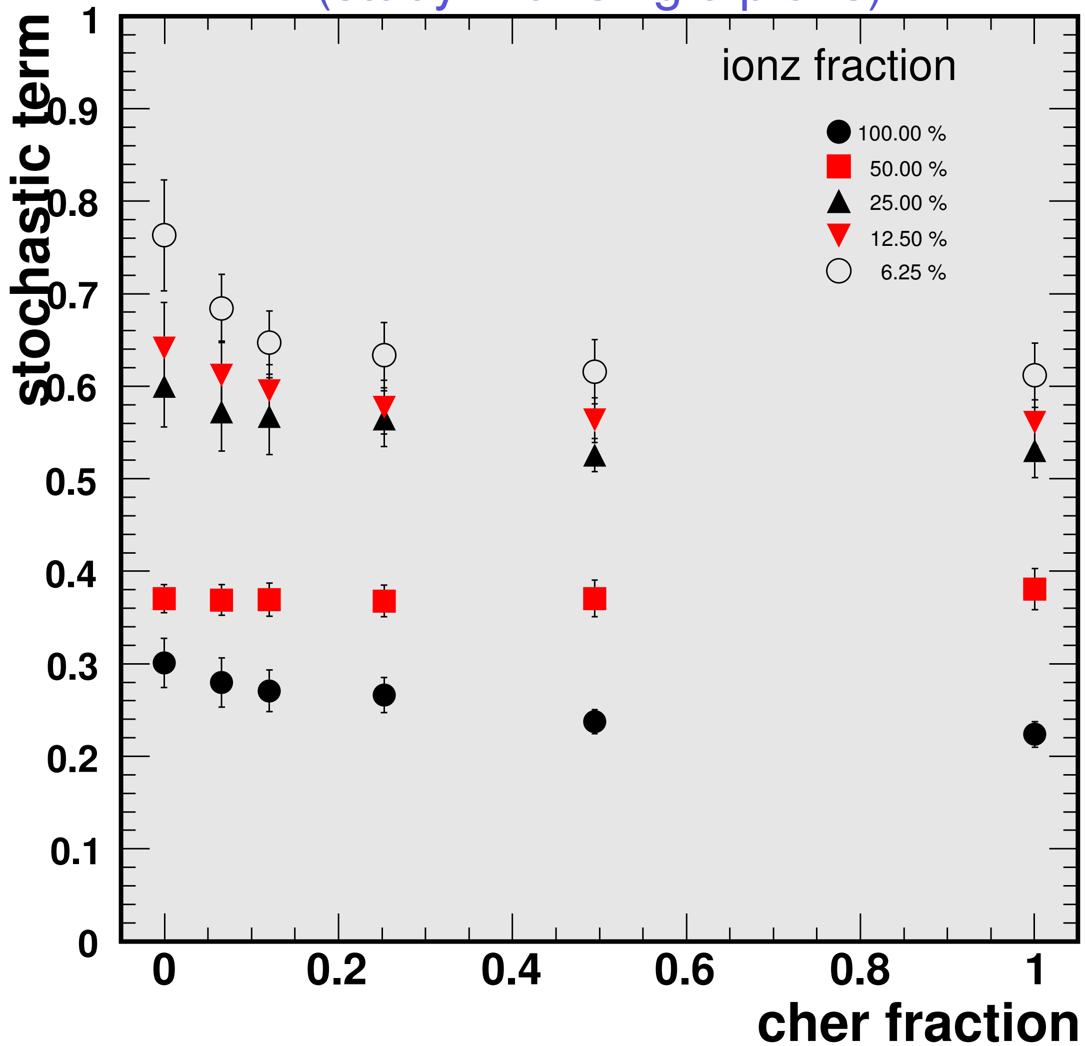


(different colors denote different ionz readout fractions)

(different symbols denote different energy samples used for correction)

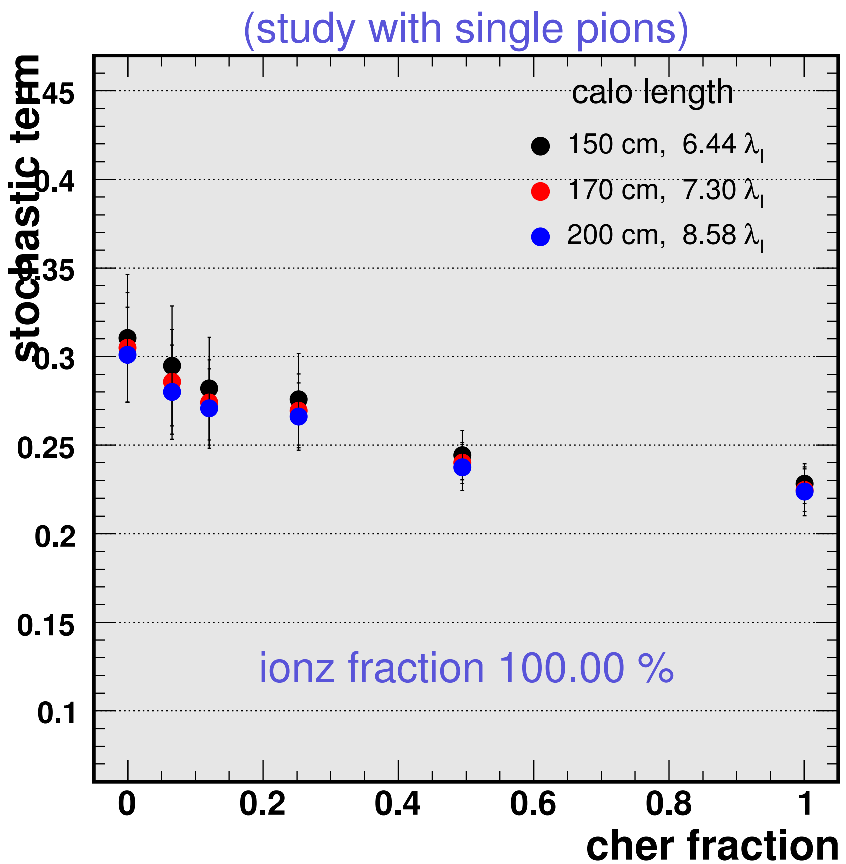
Stochastic term vs readout fraction

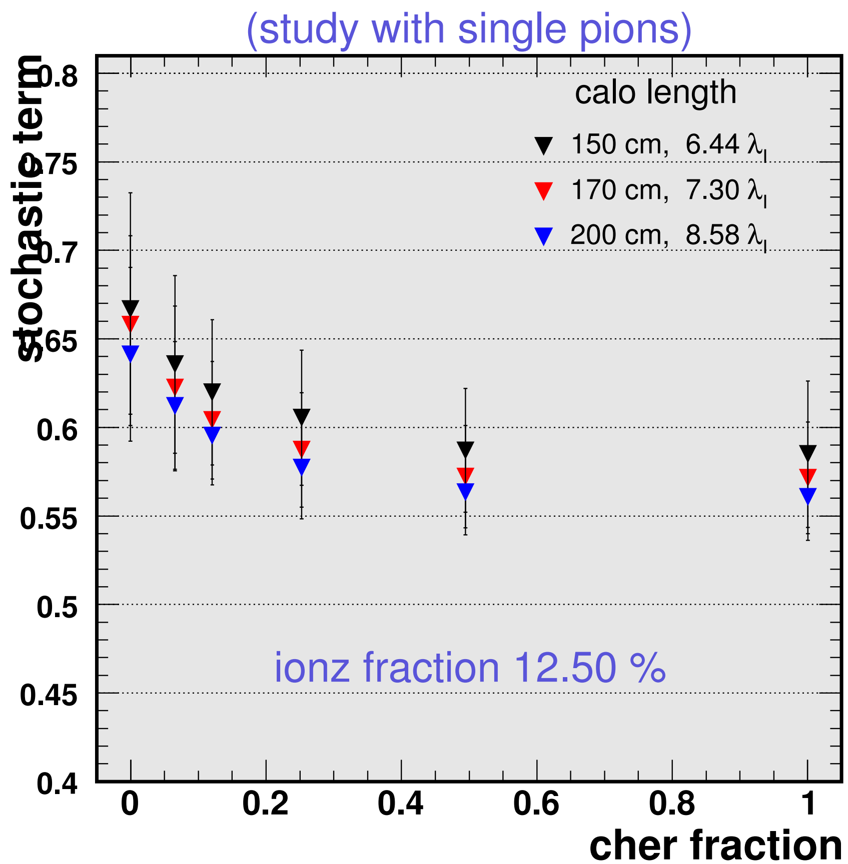
(study with single pions)



case of a calorimeter of $\approx 4.3 \times 4.3 \times 8.6\ \lambda_I^3$ ($1 \times 1 \times 2\ \mathrm{m}^3$ LuAG)

Stochastic term and calorimeter length





Open questions

- · **Design issues and practical questions**

  : though we are at the very early stage of development of such a concept we always have in mind some design issues that should be studied soon and which need rigorous **R&D effort and prototyping**

  - ▷ **material production and cost drivers**
  - ▷ **readout scheme**
  - ▷ **construction**
  - ▷ **scale-up problems**
  - ▷ **+ ...**

  : can only be answered through the usual phase of prototype development, test and study of 1 permille $\rightarrow$ 1 percent $\rightarrow$ 10 percent modules of the final detector

Summary - Outlook

- **· metacrystals for calorimetry**

  : R&D effort on 3 fronts

  ▷ **material development**

  ▷ **testbeam activities**

  ▷ **simulation studies**

  : briefly discussed first results with bundles of crystal fibers exposed to beam and mc parametric scan of an ideal calorimeter

- **· next steps**

  : continue simulation studies and material development

  : near-term goal to build **a multichannel module** (e.g. miniEcal) and expose it to beam