Calorimetria a cristalli

M. Lucchini[1], P. Paolucci[2]

[1] INFN & University of Milano-Bicocca

[2] INFN Napoli

Discussione con referees di CSN1

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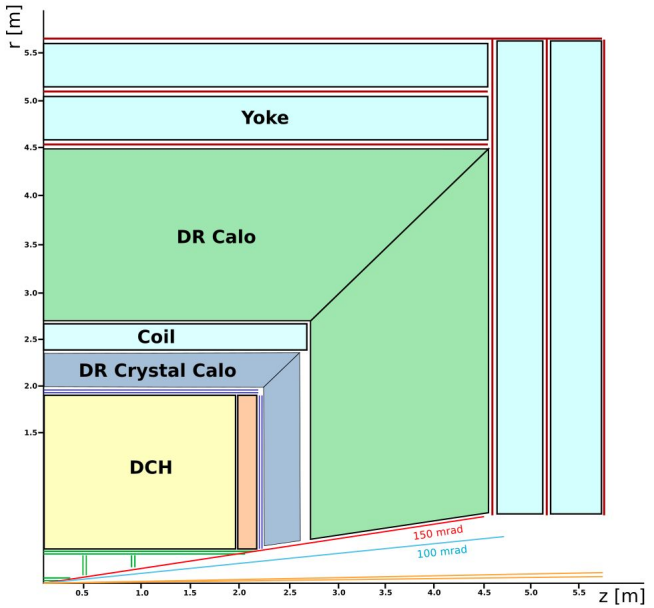
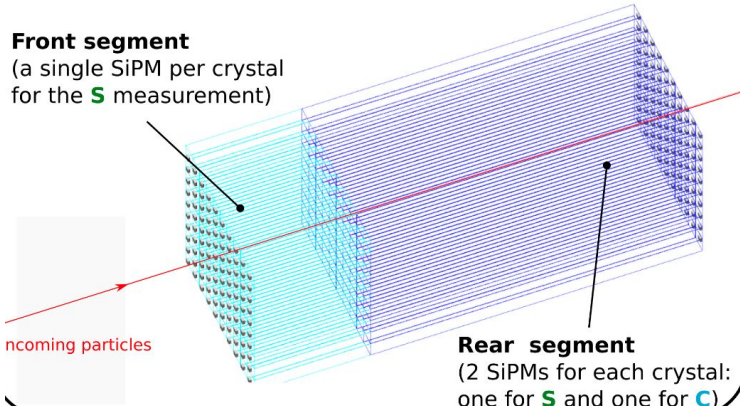
Overview of the activity

- Evaluate the potential and the feasibility of integrating a **cost-effective** **dual-readout** **homogeneous** **segmented** crystal **EM** calorimeter in the IDEA detector
- First studies and concept descriptions in:
  - M.T. Lucchini *et al* 2020 *JINST* **15** P11005
  - M.T. Lucchini *et al* 2022 *JINST* **17** P06008
- Activity at 360 degrees:
  - Simulation studies (from standalone to fullsim)
  - R&D on technology and proof-of-principle
  - Prototyping of a calorimetric module

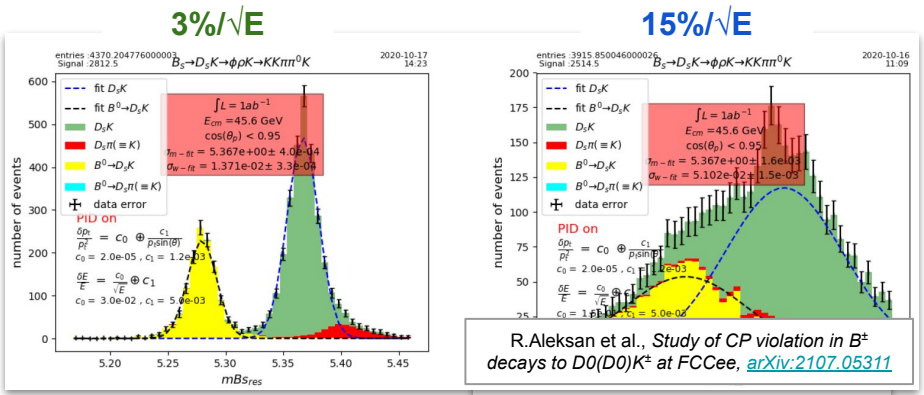




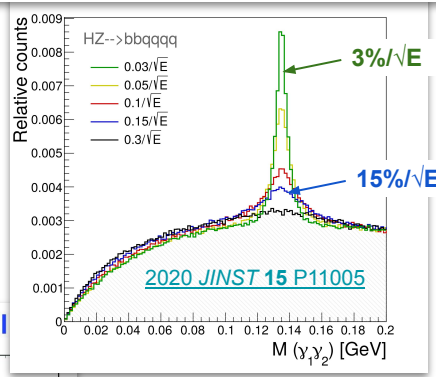
High EM energy resolution potential at e+e- Higgs factories

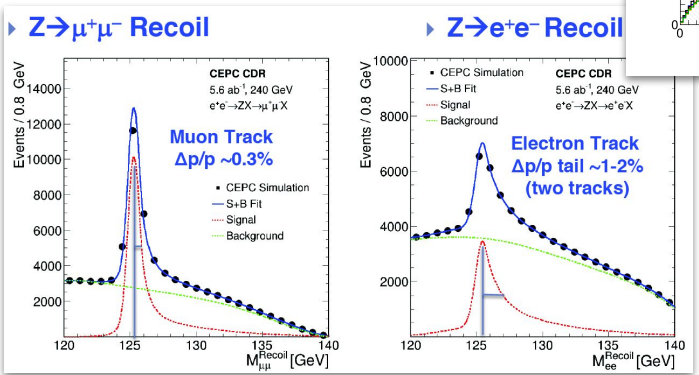
A calorimeter with **3%/√E** EM energy resolution has the potential to improve event reconstruction and **expand the landscape of possible physics studies** at e^+e^- colliders

- **CP violation studies** with B_s decay to final states with low energy photons
- **Clustering of π^0's photons** to improve performance of jet clustering algorithms
- **Improve the resolution of the recoil mass signal from Z→ee decays** to ~80% of that from Z→ μμ decays (recovering Brem photons)



R.Aleksan et al., *Study of CP violation in B± decays to D0(D0)K± at FCCee*, arXiv:2107.05311

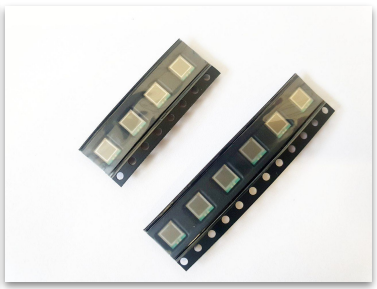


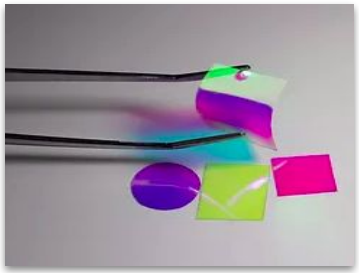


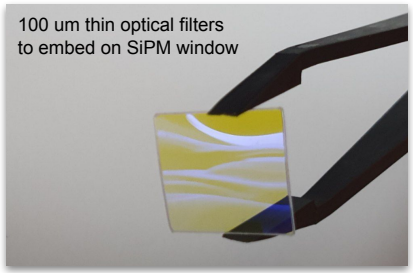
Example from CEPC CDR

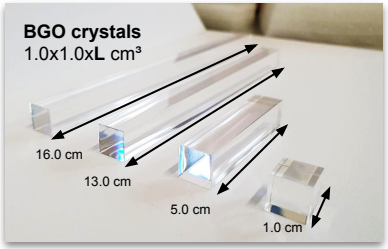
Key R&D challenges

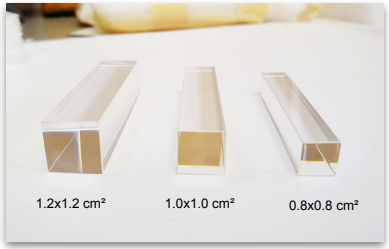
- Demonstrate feasibility of SiPM readout (dynamic range, linearity, etc)
  - Explore very small cell size SiPMs (<10 um)
- Demonstrate capability of simultaneous scintillation and Cherenkov light readout (sufficient light yield and purity)
  - Develop/identify custom thin wavelength filters
- Identify optimal crystal segmentation
- Versatile **mechanics** for module prototype
- Front end **electronics** for SiPM readout









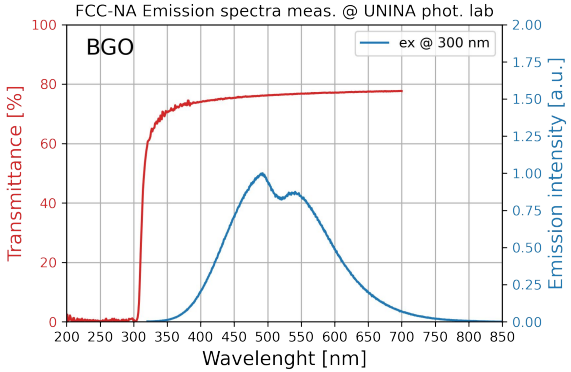


Groups involved and synergies

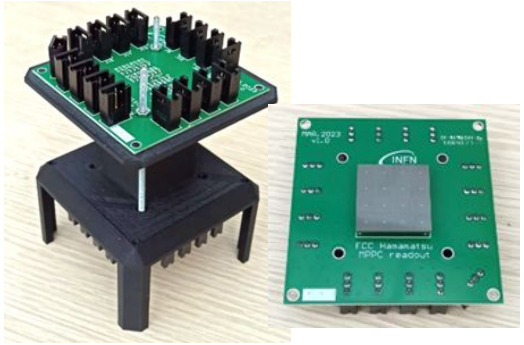
- This line of R&D is relatively new and efforts have been ramping up in 2023:
  - INFN Napoli (1.4 FTE)
  - INFN MIB (0.1 FTE)
- Efforts at MIB will ramp up in 2024 thanks to the synergy with a PRIN2022 on "Maximum Information Crystal Calorimetry - MAXICC" *funded at 80%*
  (1 additional FTE expected to be hired + 0.3 FTE from project PI and vicePI)
- **The project goals are aligned with the strategic objectives identified in the ECFA R&D roadmap** and part of the forming DRD6 collaboration (on calorimetry)
- The activity is in **synergy with** an ongoing DOE funded project (CALViSION) bringing together several US institutions (Maryland, Princeton, UVa, Caltech, FNAL, ANL, …)

Status and progress in 2023 (Napoli)

- Different crystal candidates (BGO, PWO, …) have been procured and characterized (scintillation and optical properties)
- Commercially available multi channel SiPM arrays have been purchased along with multi-channel electronics (FE+DAQ) and first tests of the readout chain have been performed



Mechanics, FE and SiPM array

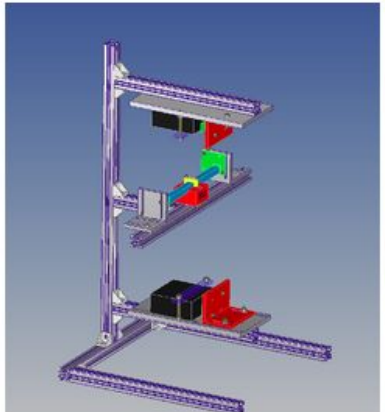


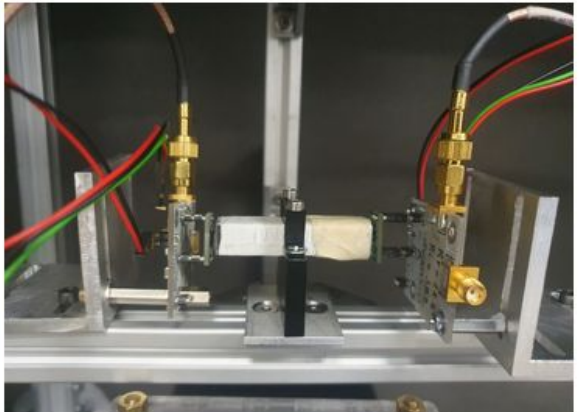
CAEN A5202 board with CITIROC ASIC

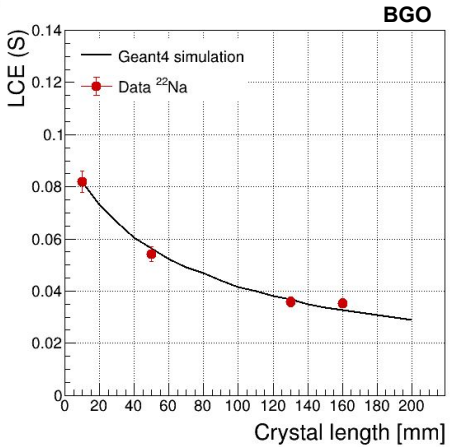
CAEN DT5751 2Gs/s 10 bit - 2/4 channels digitizer

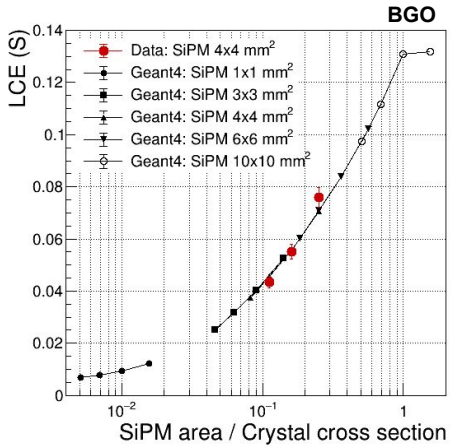
Status and progress in 2023 (MIB)

- Development of dedicated cosmic bench and experimental setup for crystal and SiPM characterization
- Experimental box + cooling currently shared with CMS, will need to develop dedicated setup in 2024
- First results on various crystal and SiPM configurations used to validate Geant4 simulation

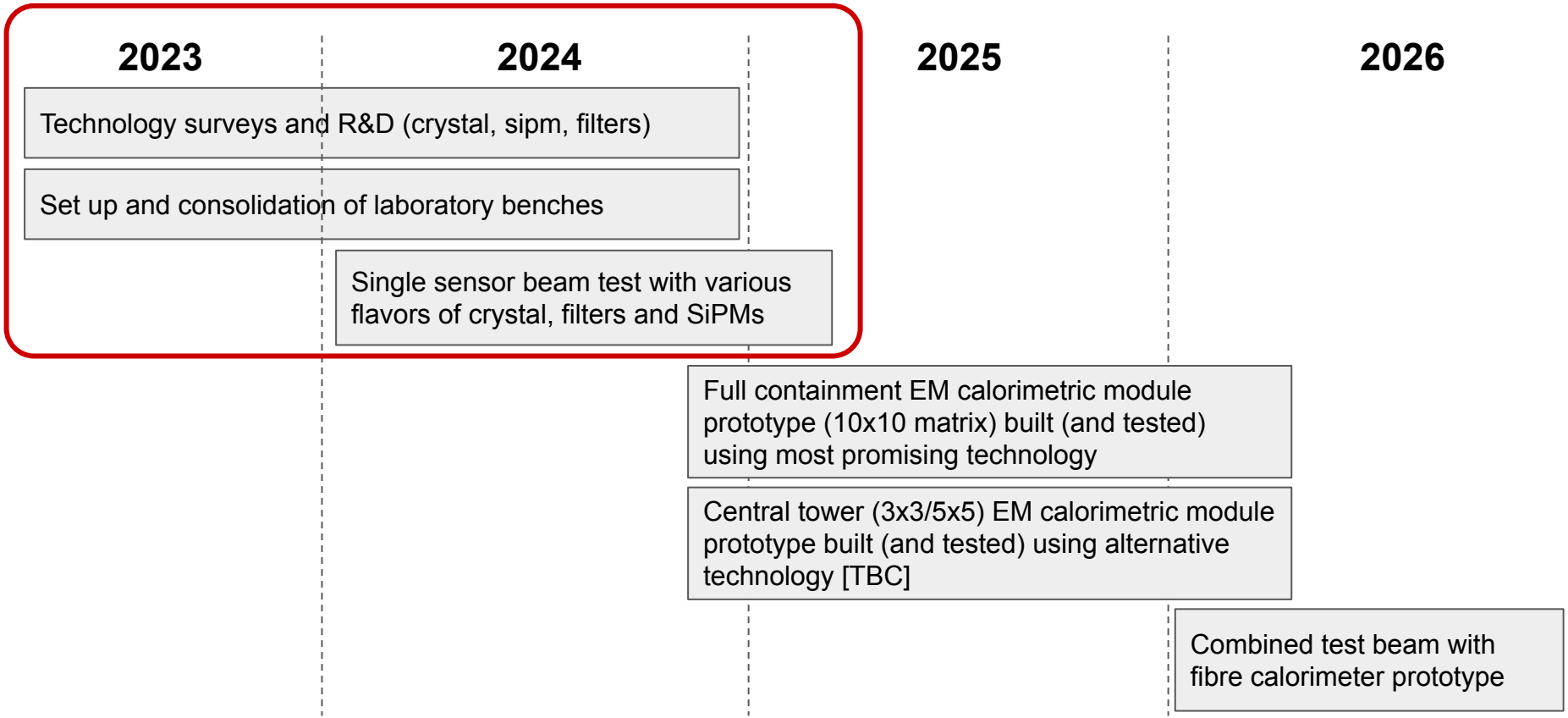








Mid-term plans



Piani e preventivi (Napoli)

- 2024
  - Consolidation of experimental laboratory benches (5 k€), optical filter procurement (3k€) and mechanics for single crystal tests (2 k€)
  - Participation to beam test for single sensor tests (BTF or CERN PS) → 3 k€
- 2025-2026
  - Participation to high energy beam tests in synergy with DRD6 and PRIN (MAXICC) activities
  - Primary responsibility in mechanics and readout of the prototype

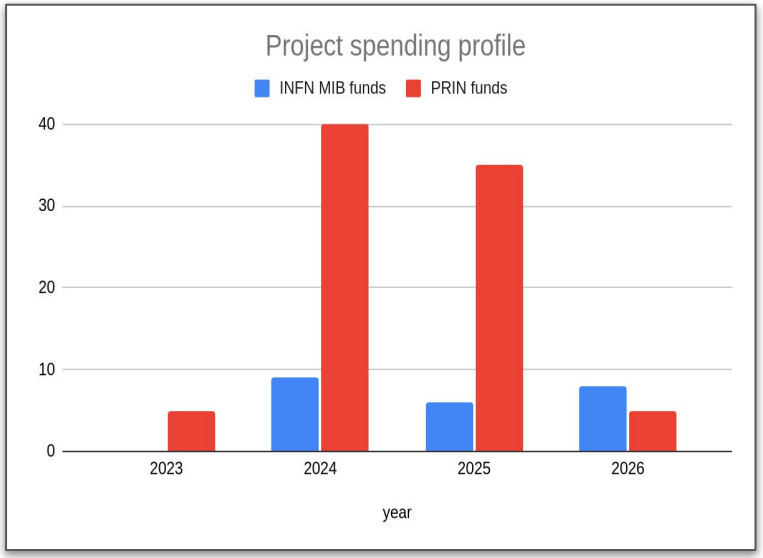
Prospetto temporale	2023	2024	2025	2026	
Realizzazione di un set-up per cristalli con double-readout					
Single crystal qualification					
SIPM qualification					
low energy test beam*					
high energy test beam**					

Prospetto finanziario (keuro)	2023*	2024	2025	2026	TOT
Single crystal qualification	**10 €**	**3 €**	**1 €**		14 €
Optical Filter		3 €	1 €		
SIPM qualification	**4 €**	**5 €**	**2 €**		11 €
FE + DAQ	**16 €**				16 €
Low energy test beam**		**5 €**	**21 €**		26 €
mechanic for single crystal		2 €			
mechanic for 5x5 matrix			3 €		
second 5x5 complete tower			15 €		
travel		3 €	3 €		
High energy test beam***			**5 €**	**4 €**	9 €
mechanic design and construction			5 €	1 €	
travel				3 €	
TOTALE	**30 €**	**13 €**	**29 €**	**4 €**	**76 €**

Piani e preventivi (MIB)

- 2024
  - Construction of dedicated light tight box with controlled temperature for cosmic and source measurements→**2k€** mechanics, **5k€** cooling unit
  - Participation to beam test for single sensor tests (BTF or CERN PS) →**2 k€**

- 2025-2026
  - Consolidation and maintenance of experimental setup (PCBs, mechanics, …) → 3 k€/year
  - Participation to beam tests in synergy with DRD6 and PRIN (MAXICC) activities →3 k€ in 2025 (CERN), 5 k€ in 2026 (non EU facility)
  - Primary responsibility in construction of 10x10 prototype module with fundings from PRIN



Summary

- The **potential of an enhanced EM energy resolution** of the IDEA calorimeter by mean of a crystal calorimeter is seeing a renewed interest in the international community (DRDs, US, etc.)

- INFN has the opportunity to have a **key role in the R&D and proof-of-principle** of this calorimeter concept, with efforts that have been ramping up in 2023

- **A path forward t**o achieve the demonstration of this calorimetric technique using a full scale EM calorimeter prototype **by the next european strategy for particle physics update** has been identified

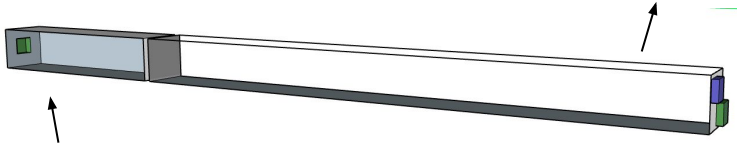
- The role (and funds request) of italian institutes is **strategic to maximize the impact and optimize synergies** with other funds (PRIN and international FA),
  funds requested tagged as ECFA DRD6.WP6.3

Additional material

Implementation of dual-readout in the crystal section

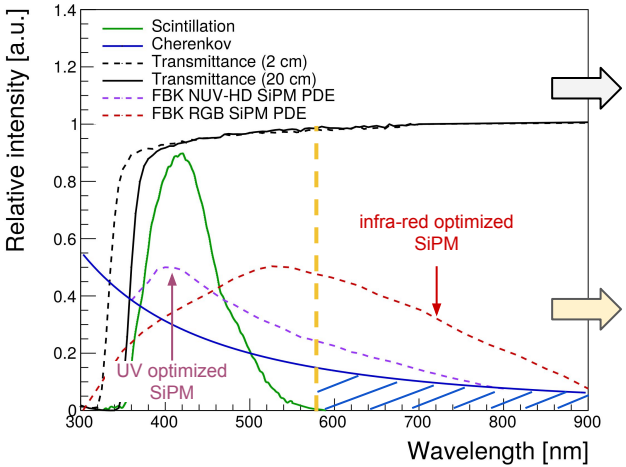
- Simultaneous readout of scintillation and Cherenkov light from the rear segment with dedicated SiPMs+wavelength filters

Rear crystal ECAL segment:
Two 4x4 mm² SiPMs with optical filters optimized for scintillation and cherenkov detection resp.



Front crystal ECAL segment:
Single 5x5 mm² SiPM per crystal optimized for scintillation light detection

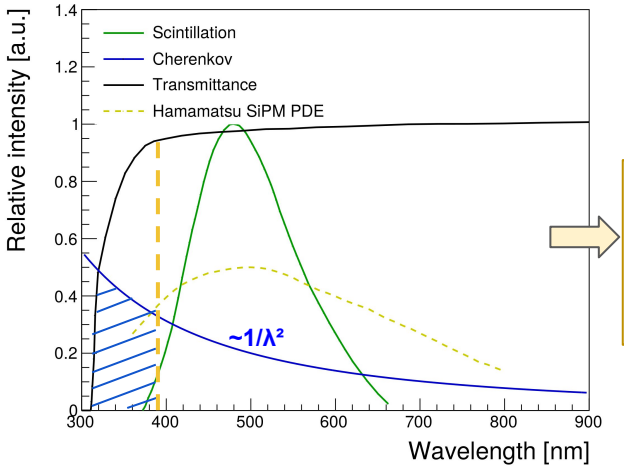
PWO



Estimated:
- >2000 phe/GeV for scintillation photons
- >100 phe/GeV for Cherenkov photons

Cherenkov photons above scintillation peak are much less affected by self-absorption

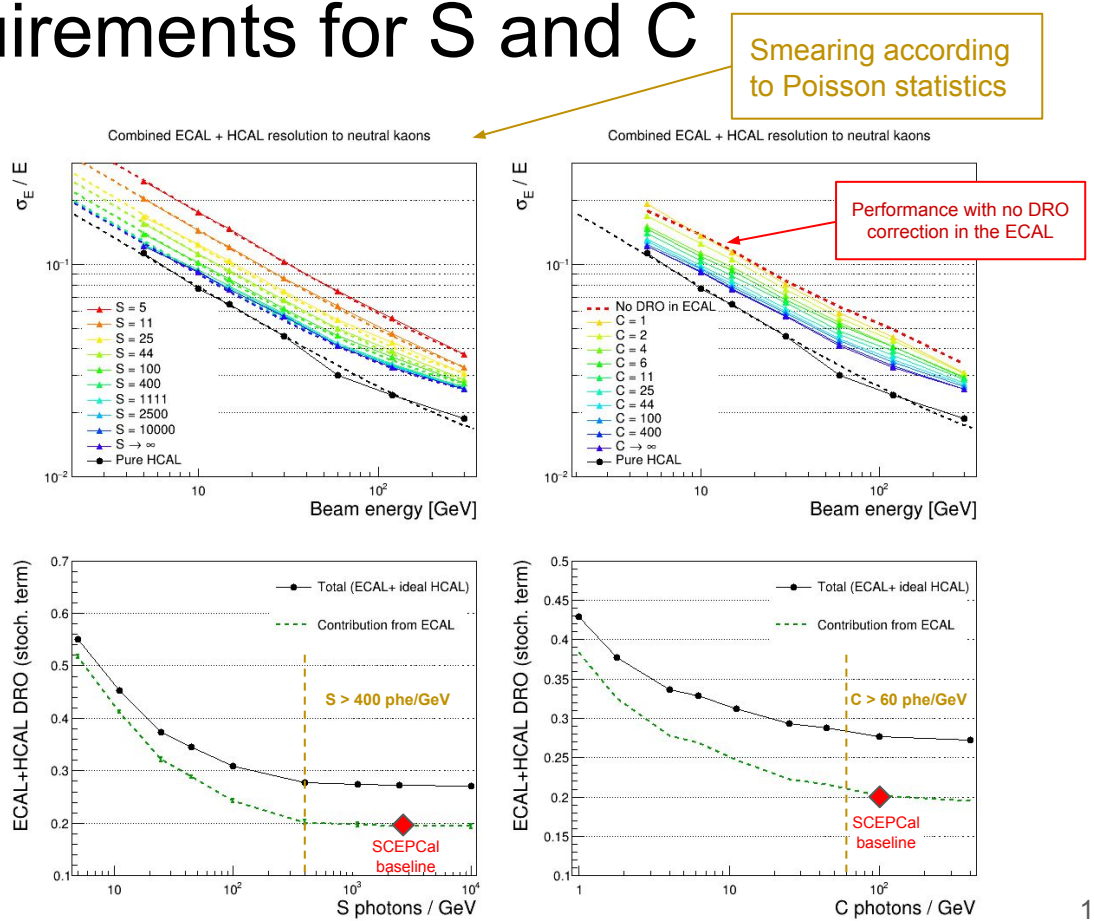
BGO / BSO



BGO/BSO have larger stokes shift, i.e. a wider range of transparency for 'UV Cherenkov'

Photo-statistic requirements for S and C

- A poor S (scintillation signal) impacts the hadron (and EM) resolution stochastic terms:
  - S > 400 phe/GeV
- A poor C (Cherenkov signal) impacts the C/S and thus the precision of the event-by-event DRO correction
  - C > 60 phe/GeV
- **Baseline layout choices** (granularity and SiPM size) to **provide sufficient light collection efficiency** in Geant4
  - Need experimental validation with lab and beam tests

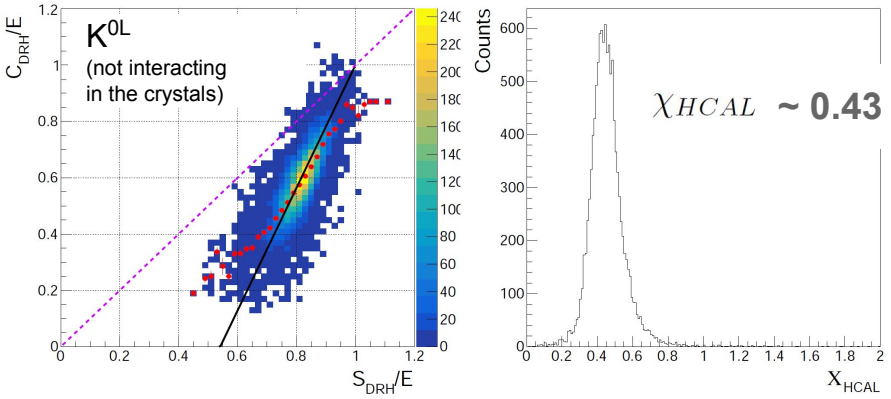


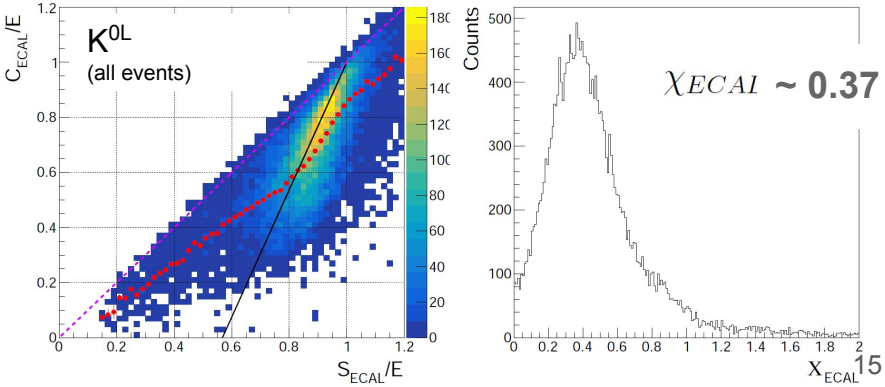
The **dual-readout method** in a hybrid calorimeter

1. Evaluate the χ-factor for the crystal and fiber section
2. Apply the DRO correction on the energy deposits in the crystal and fiber segment independently
3. Sum up the corrected energy from both segments

$$\chi_{HCAL} = \frac{1-(h/e)_s^{HCAL}}{1-(h/e)_c^{HCAL}}$$
$$\chi_{ECAL} = \frac{1-(h/e)_s^{ECAL}}{1-(h/e)_c^{ECAL}}$$

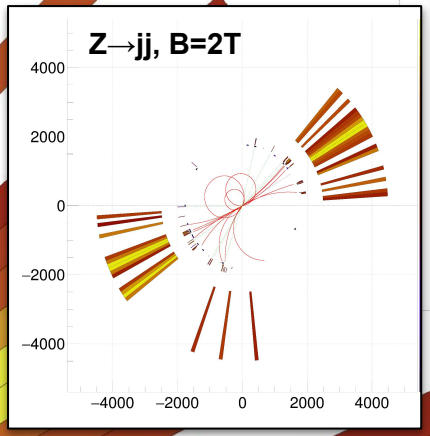
$$E_{HCAL} = \frac{S_{HCAL} - \chi_{HCAL} C_{HCAL}}{1-\chi_{HCAL}}$$
$$E_{ECAL} = \frac{S_{ECAL} - \chi_{ECAL} C_{ECAL}}{1-\chi_{ECAL}}$$
$$E_{total} = E_{HCAL} + E_{ECAL}$$

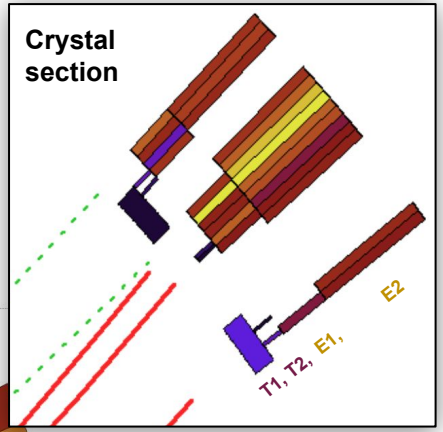




A Dual-Readout ‘prototype’ Particle Flow Algorithm (DR-pPFA)

- Full calorimeter simulation in Geant4
- Tracker MC truth momentum smeared





photons

HCAL fiber towers

EM crystal rear

EM crystal front

Timing rear

Timing front

Solenoid gap

neutral hadron

charged hadron

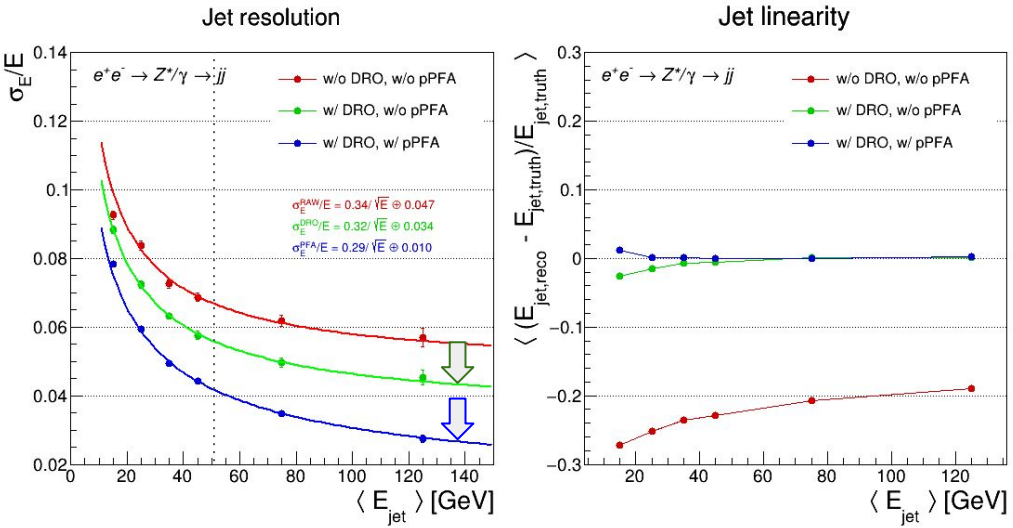
More details in: [2022 *JINST* **17** P06008]

Jet resolution: with and without DR-pPFA

More details in:
2022 *JINST* **17** P06008

Jet energy resolution and linearity as a function of jet energy in off-shell $e^+e^- \rightarrow Z^* \rightarrow jj$ events (at different center-of-mass energies):

- crystals + IDEA w/o DRO
- crystals + IDEA w/ DRO
- crystals + IDEA w/ DRO + pPFA



Sensible improvement in jet resolution using dual-readout information combined with a particle flow approach → 3-4% for jet energies above 50 GeV