DRD6 MAXICC
Tentative plans for T9 test beam setup

CERN PS T9 beamline

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Context - synergies

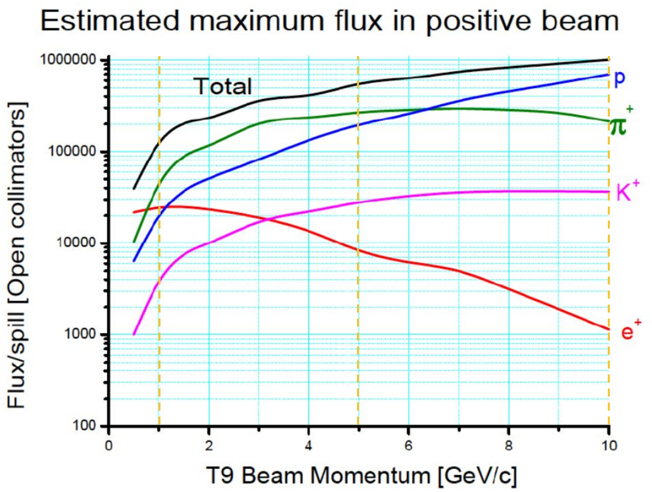
- Commitment to demonstrate the feasibility of a dual-readout crystal calorimeter concept for future Higgs factories paved with milestones and deliverables on several fronts in 2024-2026
  - DRD6 on calorimetry (international collaboration anchored at CERN)
  - INFN RD_FCC (italian national FCC collaboration)
  - Italian grant at Milano-Bicocca started on Oct 2023 for development of a MAXICC prototype (PI: M.Lucchini, VicePI: A.Benaglia)

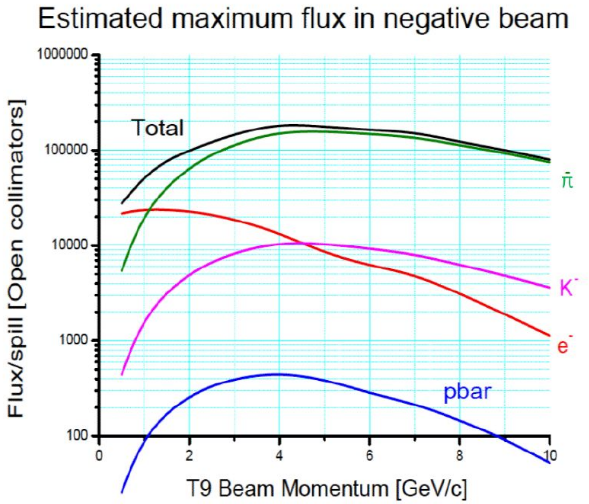
- We (Milano-Bicocca) plan to
  - Help at DESY Calvision TB on April 22
  - Test on beam a few single crystals+filters+SiPM on beam in **2024** → CERN **PS** T9
    - Last two weeks of July (or October) works for us
  - Build and test a full EM calorimeter prototype module in **2025** → CERN **SPS**

PS T9 beam composition

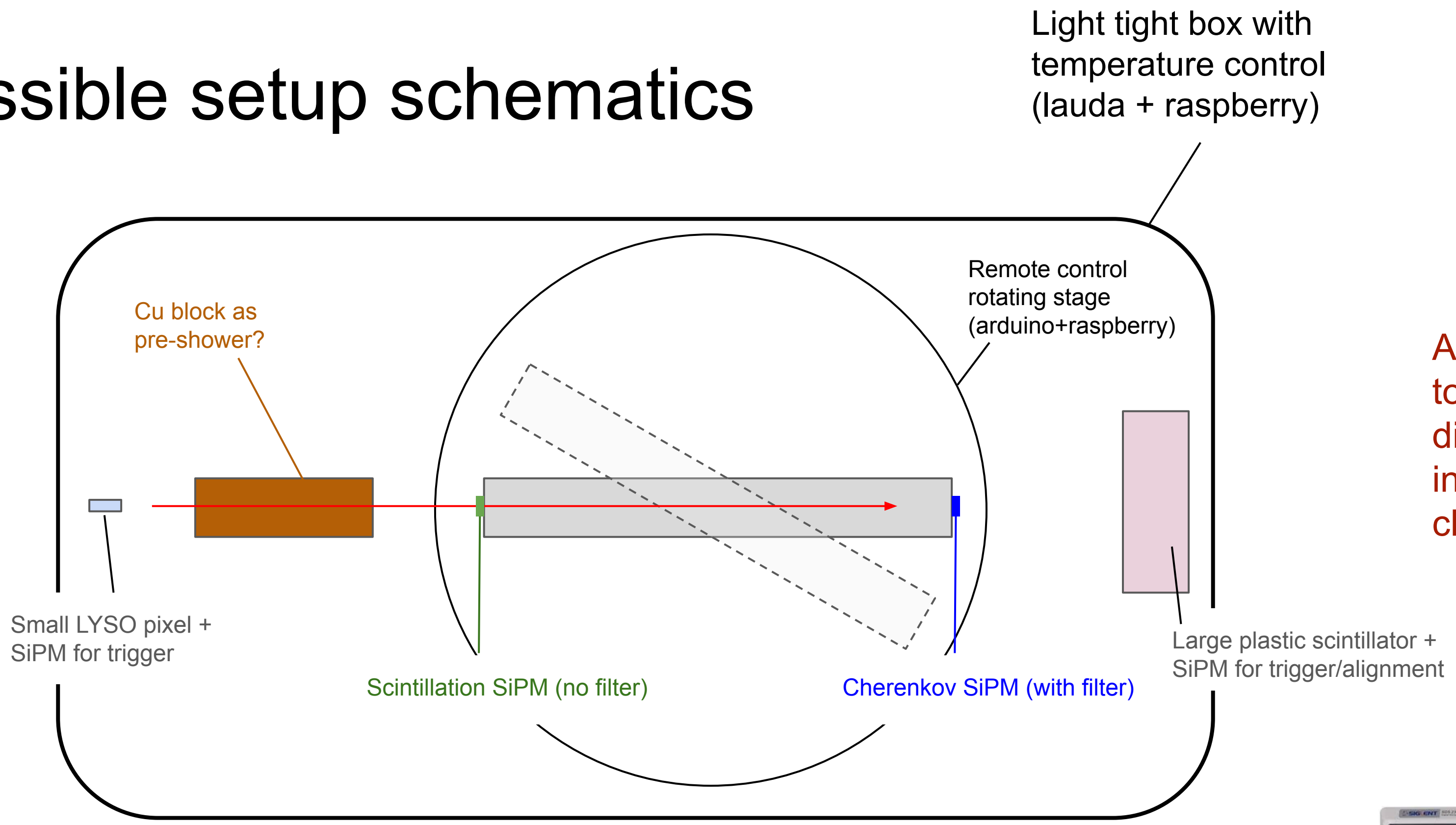
- Protons and pions have highest rate (10^5/spill)
  - @ 1 GeV
    - 50% positrons
    - 50% protons/pions
  - @ 5 GeV
    - 1.6% positrons
    - 98.4% protons/pions
- Low rate muons (~700/spill) can be used during installation in open access for debugging/aligning the setup
- 1 spill ~0.4 s, ~2 spills per cycle (~20 s)

- Need to discriminate e+/pi+
  (can try do that with our own setup)



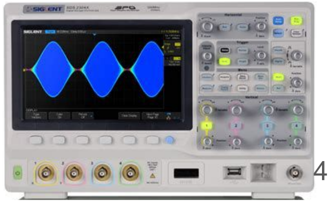


Possible setup schematics



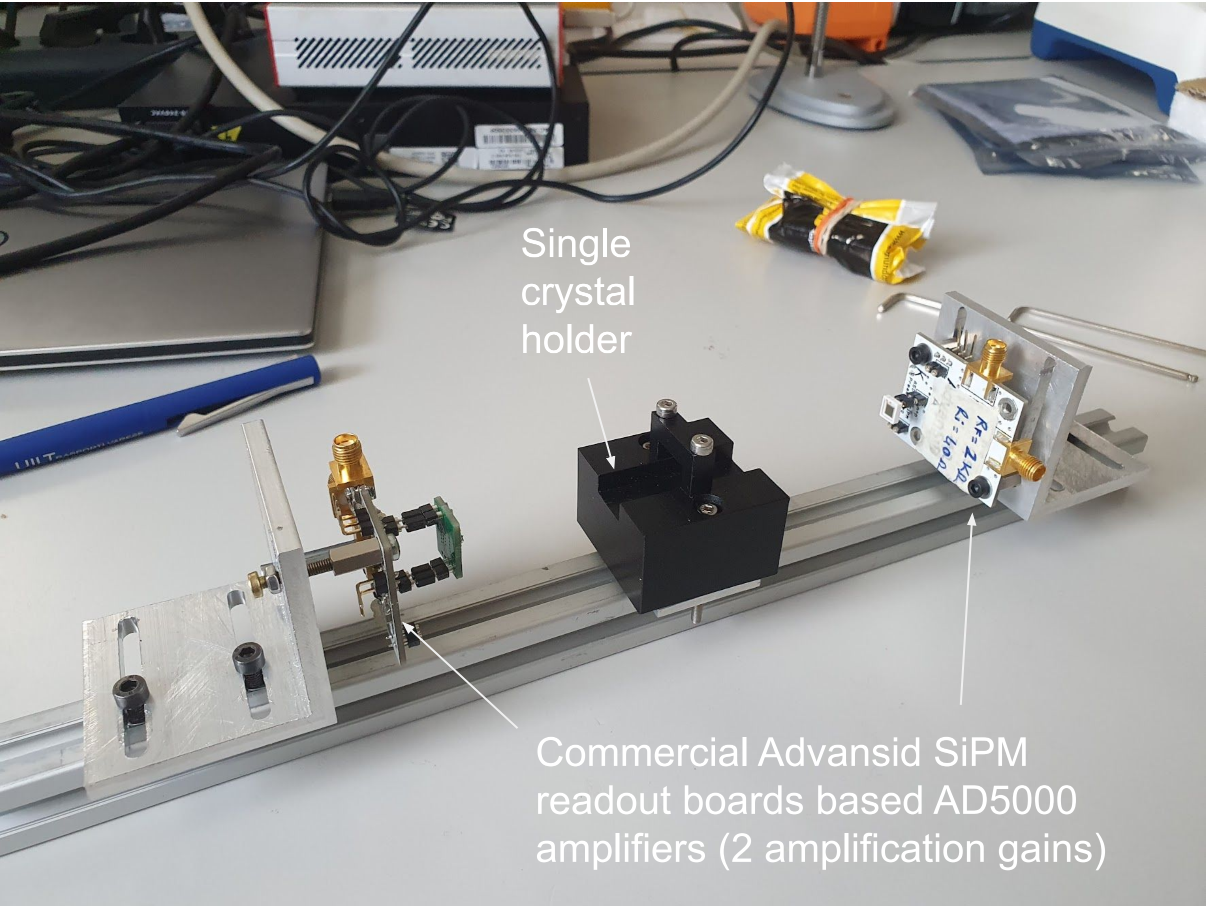
Also possibility to use to digitizer and integrate wire chambers

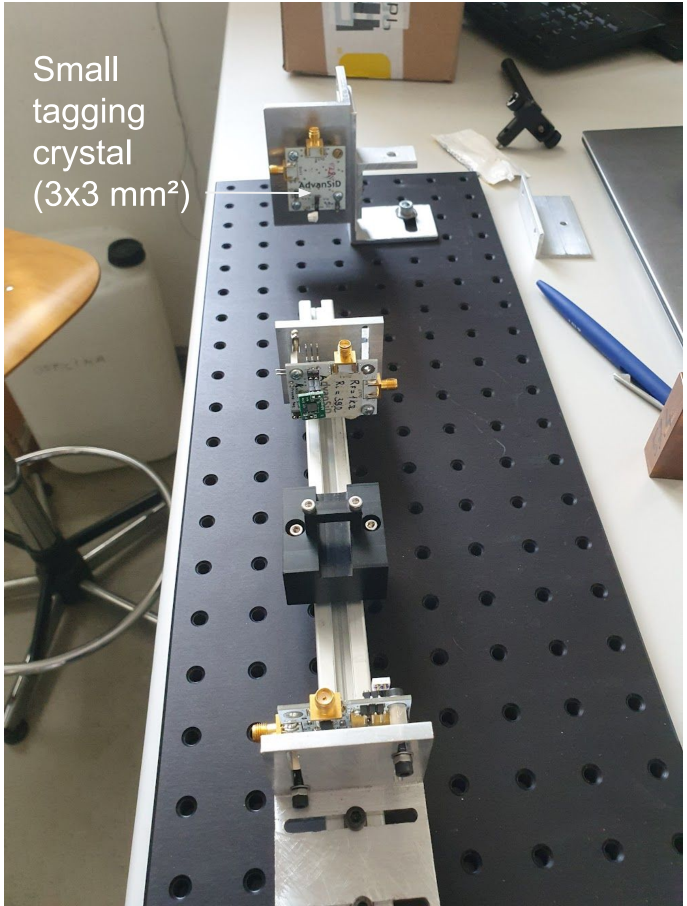
4ch. Oscilloscope (should sit outside the TB area)



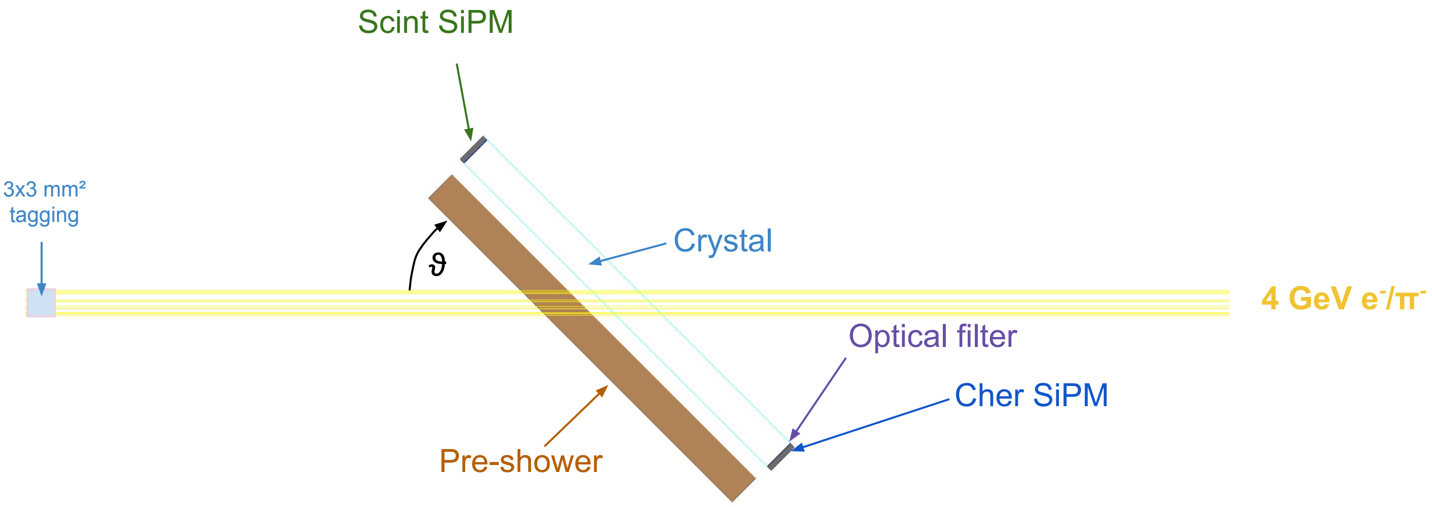
All SiPMs readout with Advansid boards

Mechanics - single crystal stand (to be updated)

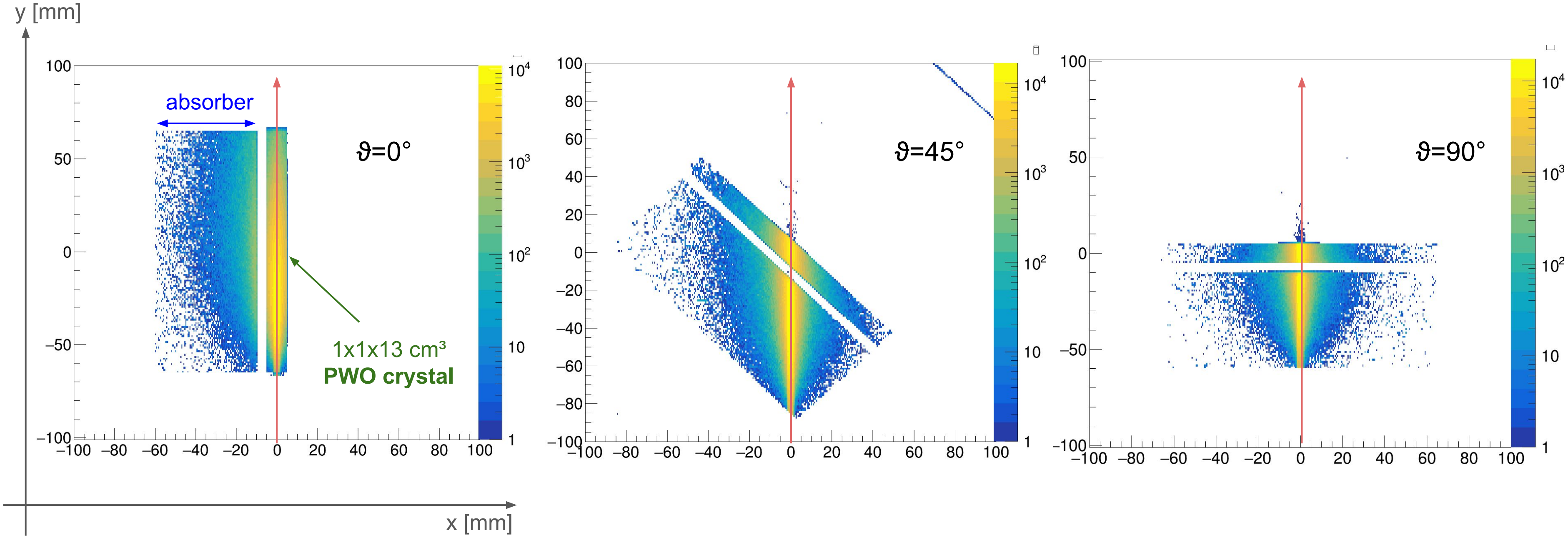




Setup - Geant4 simulation



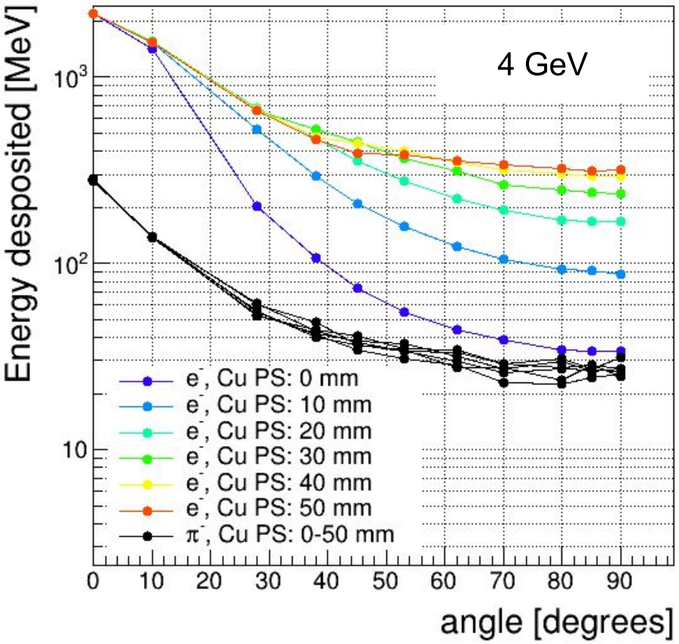
Geant4 simulation of energy deposits vs angles



Energy deposits vs angle

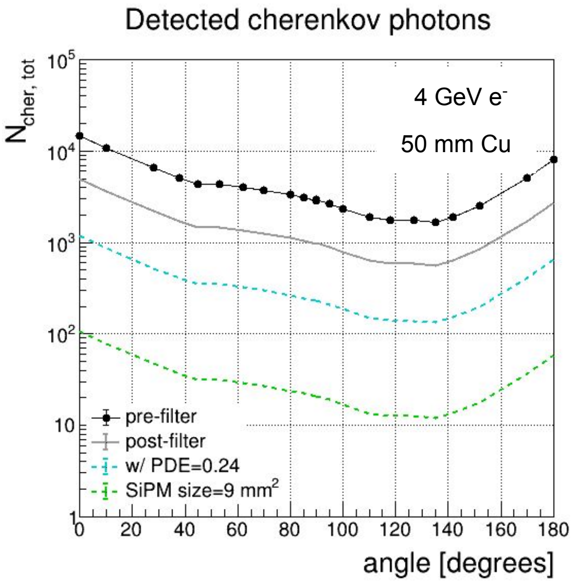
- Smaller dependence of the energy deposit in the crystal using a 50 mm Cu absorber as pre-shower (compared to no or thinner pre-shower)

- $1X_0$ (Cu) = 1.436 cm

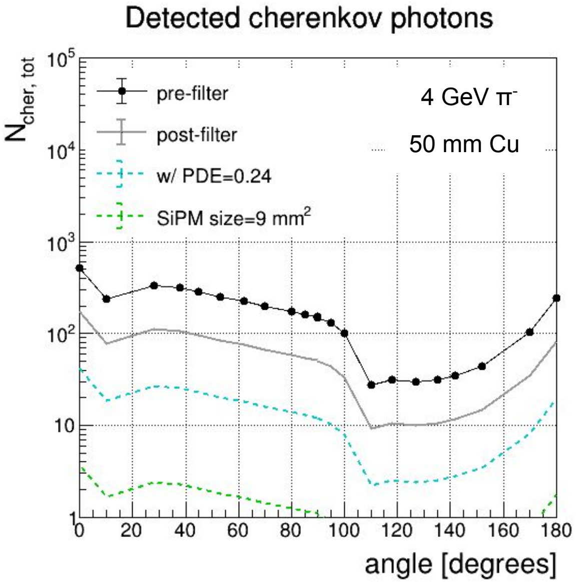


Cherenkov yield

- Number of photoelectrons expected (after high pass filter 560-1000 nm, PDE=0.24, SiPM active area=9 mm²) is 10-100

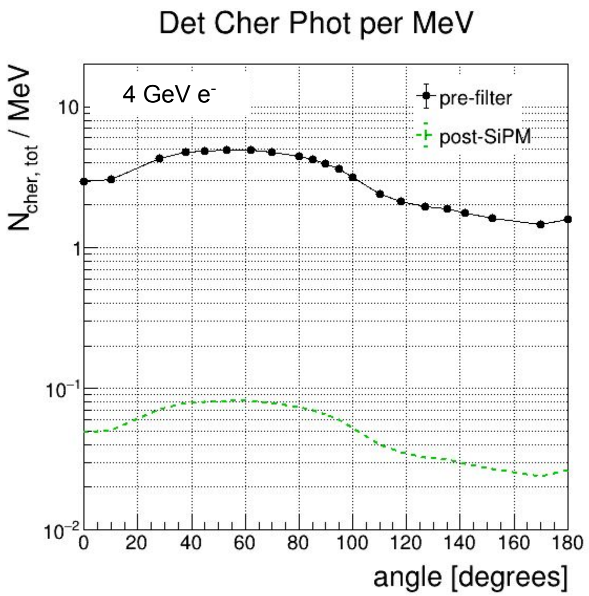


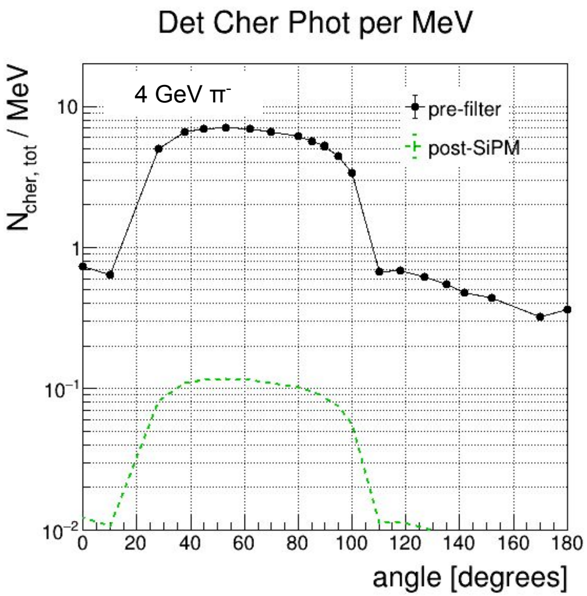
- Number of photoelectrons expected (after high pass filter 560-1000 nm, PDE=0.24, SiPM active area=100 mm²) is 0-4



C / E_{dep}

- Light collection efficiency of Cherenkov photons has a pronounced angular dependence (as expected)
- Can measure this by comparing front (S) signal with rear (C) signal





Tentative run plan and TB goal

For each crystal+SiPM configuration:

- Run with protons/pions or muons at fixed energy (10 GeV), wide beam (2x2 cm^2)
  - Perform angle rotation from 0 to 180° (a few angles, including C emission angle)
  - Do a small over-voltage scan

- Run with electrons (to decide optimum, possibly ~4 GeV)
  - Perform angle rotation from 0 to 180° (a few angles, including C emission angle)
  - Do a small over-voltage scan

Goal:

- Compare S and C signals as a function of angle and vs simulation
- Assess amount of C(S) photons/GeV and purity of the C(S) signal

Possible configurations [TBC]

- Possible crystal configurations to test
    - **PWO** 1x1x130 cm^3
        - S: 3x3 mm^2 15 um HPK
        - C: Hoya 056 filter (or similar) + SiPMs (large cell, sensitive above 600 nm, TBD)

    - **BGO & BSO** 1x1x130 cm^3
        - S: Dry coupling (+ neutral density filter?) + 3x3 mm^2 HPK SiPM 10 um?
        - C: Hoya R64/U330 filter (or similar) + SiPMs (large cell, sensitive above 600 nm, TBD)

- Plan to test various filters/SiPM configurations ahead of time to identify best configurations

Hardware at hand (Milano-Bicocca / Napoli)

Crystals

- PWO, BGO, BSO, LYSO
- Different **vendors** explored: SICCAS, EPIC, Hilgher
- **Geometries**:
  - 1x1xL (L=1, 5, 13, 16) cm^3
  - 0.8 x 0.8 x 5.0 cm^3
  - 1.2 x 1.2 x 5.0 cm^3
  - 1.2 x 1.2 x 15 cm^3

Optical filters

- **SCHOTT** colored glass (3 mm thick)
  - UG11
  - RG610
- **HOYA**
  - O560 (∅=12.5 mm, t=2.5 mm)
  - U330 (∅=12.0 mm, t=1.0 mm)
- **Everix** interference ultra-thin (0.2 mm thick)
  - Commercial band-pass
  - Customized for PWO/BGO
- **Kodak** (0.1 x 75 x 75 mm^3)
  - High pass: yellow, yellow-orange, deep orange, red

SiPMs

- Mostly from **Hamamatsu**:
  - 3x3 mm^3 - 10 um
  - 3x3 mm^3 - 15 um
  - 4x4 matrix of 6x6 mm^2 50 um
- Some from **FBK**
  - Advansid NUV/RGB (4x4 mm^2, 1x1 mm^2) 40 um cell size
  - Some single 3x3 mm^2 SiPMs of various flavors (~15 um cell size)

Additional material

Synergies and international collaboration - **DRD6**

- Development of a "maximum information crystal calorimeter" prototype is one task of the DRD6 work package 3
- Groups involved on the DRD6 related task are:
  - INFN & University of Milano-Bicocca and Napoli (**Italy**)
  - CERN Lab27 (**Switzerland**)
  - IN2P3-I2PI (**France**)
  - University of Maryland, University of Michigan, University of Virginia, Princeton University, Caltech, FNAL, Argonne National Lab, MIT, Purdue University, Texas Tech University (**USA**)
- High level milestones from 2024 to 2026+

M3.5		Completion of qualification tests on components and selection of crystal, filter and SiPM candidates for prototype	2025
M3.6		Report on the characterisation of crystal, SiPM and optical filter candidates and their combined performance for Cherenkov readout	2025
	D3.3	Full containment dual-readout crystal EM calorimeter prototype and testbeam characterisation	2026
M3.7		Joint testbeam of EM module prototype with dual-readout fibre calorimeter prototype (DRCAL)	>2026

DRD6 Proposal Draft

DRD 6: Calorimetry

Proposal Team for DRD-on-Calorimetry

November 15, 2023

- Subtask 3.1.2: The *Maximum Information Crystal Calorimeter* (**MAXICC**) is a cost-effective homogeneous calorimeter concept for e^+e^- Higgs factories based on high-density crystals (e.g. PWO, BGO, BSO) readout with SiPMs [29]. It features a moderate longitudinal segmentation and includes the dual readout of scintillation and Cherenkov light from the same active element (by means of optical filters for instance) for optimal integration with a dual-readout hadronic calorimeter. It targets an electromagnetic energy resolution of $3\%\sqrt{E}$, a time resolution of O(30) ps and a jet energy resolution of about $30\%\sqrt{E}$ when combined with a dual-readout hadron calorimeter.
  Key R&D required: Identification of optimal components (crystal, optical filters, SiPMs) for the isolation and extraction of the Cherenkov signal, development of an EM-shower-scale prototype.
- Subtask 3.1.3: The *Crystal calorImeter with Longitudinal InformatioN* (**Crilin**) [30] is a quasi-homogeneous calorimeter based on PbF_2 crystals and SiPMs for a future Muon Collider. It relies on longitudinal segmentation and fast detector response to mitigate the Beam Induced Background (BIB) expected at muon colliders. It targets an EM energy resolution in the $5-10\%\sqrt{E}$ range, limited by BIB and SiPM noise effects due to radiation-induced damage (for an expected 10^{14} 1-MeV n_{eq}/cm^2 fluence). The series connection of SiPMs for signal readout allows close events (below 100 ps) to be temporally resolved. Time resolution measurements will be performed in test beams.
  Key R&D required: Validation of the concept design and simulations with an EM-shower-scale prototype.

Ongoing lab activities

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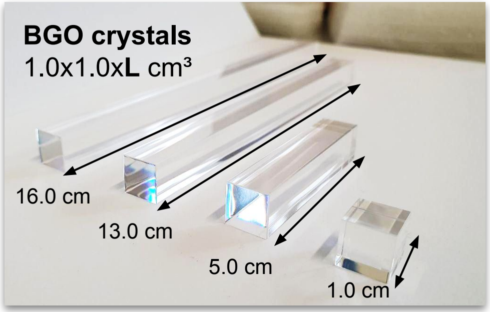
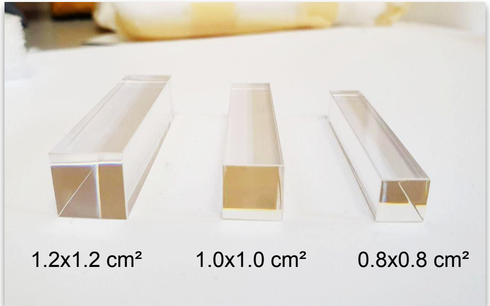
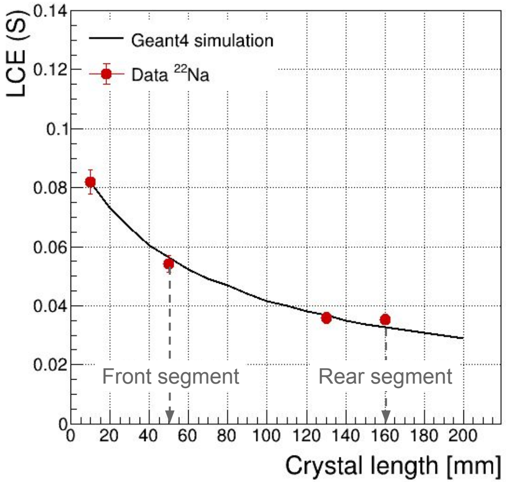
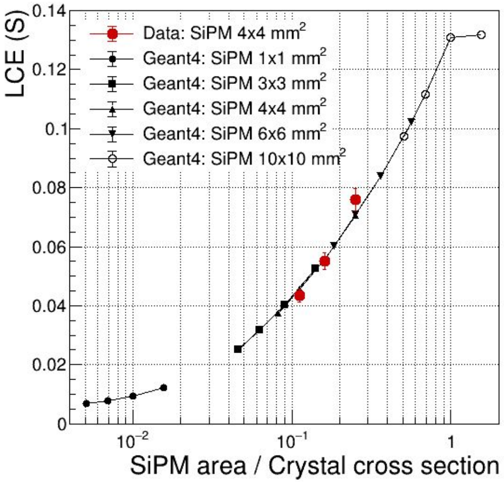
- **Laboratory tests** for optimization of crystal cross section (granularity) and longitudinal segmentation
- Evaluation of light output for different crystal and SiPM geometries using ^{22}**Na radioactive source**
- First experimental results show **good agreement with Geant4 ray-tracing simulation**

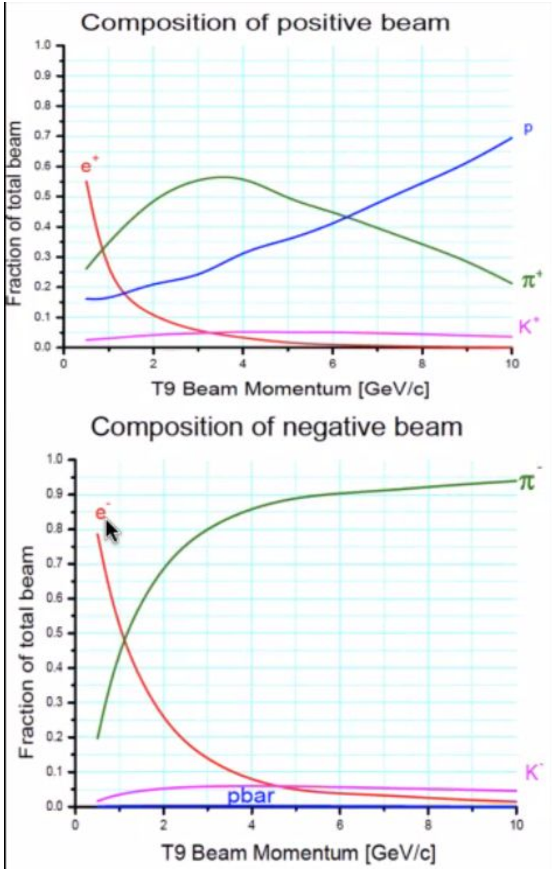








Purity



Composition of positive beam
Fraction of total beam
T9 Beam Momentum [GeV/c]
e+
p
π+
K+
Composition of negative beam
Fraction of total beam
T9 Beam Momentum [GeV/c]
e-
π-
K-
pbar

Hardware available at UNIMIB

In hand

- Crystals from SICCAS (1 pcs for each type)
  - BGO: 1x1xL cm^3 (L=1,5,13,16)
  - BSO: 1x1xL cm^3 (L=1,5,13)
  - PWO: 1x1xL cm^3 (L=1,5,13)
- Crystals for tagging/trigger (from CPI):
  - LYSO plates (1x1x0.3 cm^3), LYSO pixels (3x3x5 mm^3)
- SiPMs / filters
  - 3 FBK NUV-HD, 4x4 mm^2, 40 um cell size
  - 3 FBK RGB, 4x4 mm^2, 40 um cell size
  - Few HPK 3x3 mm^2 15 um / 10 um cell size
  - 2 Hoya 056 filters (for PWO)
  - 2 Hoya U330 filters (for BGO/BSO)
- 2 Advansid SiPM evaluation boards (1ch./board)
- DRS4 evaluation board (4 ch. digitizer)
- Preshower Cu blocks (X_0=1,3,7,11)
- Raspberry Pi for temp humidity monitoring

Hardware required (missing)

- Power supplies
  - Need 1 PSU to provide +5/-5V to all boards
  - Need 2/3 Keithleys for SiPM bias voltage
    - 1 for two SiPMs on crystal
    - 1 for LYSO trigger and plastic scint
- Need Lauda cooler for box
- Need a 4ch. oscilloscope:
  - S(cintillation) SiPM on crystal
  - C(herenkov) SiPM on crystal
  - Front trigger SiPM
  - Rear trigger/alignment SiPM
- Need a DAQ PC to remotely connect to oscilloscope?
  - Can dump “trends” of signal integrals and amplitude of all channels in txt for most of events
  - Dump pulse shapes for a subset of the events