Summary of WP3 Parallel Session

Sehwook Lee (Kyungpook National University) on behalf of WP3 and April 11, 2024

Talks in WP3 Session

09:00 → 10:30 **WP3 - Parallel Session 1** — 222/R-001 — zoom Join

- **09:00** **Welcome** — 5m
  Speaker: Philipp Roloff (CERN)
  drd6_collaboration_...

- **09:05** **Trends, needs and synergies in scintillating materials** — 15m
  Speaker: Etiennette Auffray Hillemanns (CERN)
  DRDcalo_WP3_EAuf...

- **09:30** **Exploiting Cherenkov in calorimetry** — 15m
  Speaker: Nural Akchurin (Texas Tech University (US))
  CherenkovCalorime... CherenkovCalorime...

- **09:50** **Simulation of optical properties** — 15m
  Speaker: Marco Pizzichemi (Universita Milano-Bicocca (IT) and CERN)
  Simulation of Optic...

11:00 → 12:30 **WP3: Parallel Session 2** — 222/R-001 — zoom Join

- **11:00** **Photosensors for optical calorimetry** — 15m
  Speaker: Randy Ruchti (University of Notre Dame (US))
  Photosensors for C...

- **11:25** **WP3 Organization matter** — 20m
  Speaker: Gabriella Gaudio (INFN-Pavia)
  20240410_WP3_org...

Overview of WP3 activities

P. Roloff

Project	Scintillator/WLS	Photodetector	DRDTs	Target
Task 3.1: Homogeneous and quasi-homogeneous EM calorimeters				
HGCCAL	BGO, LYSO	SiPMs	6.1, 6.2	e^+e^-
MAXICC	PWO, BGO, BSO	SiPMs	6.1, 6.2	e^+e^-
Crilin	PbF_2, PWO-UF	SiPMs	6.2, 6.3	$\mu^+\mu^-$
Task 3.2: Innovative Sampling EM calorimeters				
GRAiNITA	$ZnWO_4$, BGO	SiPMs	6.1, 6.2	e^+e^-
SpaCal	GAGG, organic	MCD-PMTs,SiPMs	6.1, 6.3	e^+e^-/hh
RADiCAL	LYSO, LuAG	SiPMs	6.1, 6.2, 6.3	e^+e^-/hh
Task 3.3: (EM+)Hadronic sampling calorimeters				
DRCal	PMMA, plastic	SiPMs, MCP	6.2	e^+e^-
TileCal	PEN, PET	SiPMs	6.2, 6.3	e^+e^-/hh
Task 3.4: Materials				
ScintCal	-	-	6.1, 6.2, 6.3	$e^+e^-/\mu^+\mu^-$/hh
CryoDBD Cal	TeO, ZnSe, LiMoO NaMoO, ZnMoO	n.a.	-	DBD experiments

Ongoing Development

E. Auffray

- R&D on garnet materials: YAG, LuAG, GAGG, LuGAGG, GYAG, etc..
  ⇒ Accelerate decay time and preserving radiation hardness

- R&D on exploitation Cherenkov in scintillating materials
  - Improve transmission in UV
  - Investigation of the readout of both signal

- R&D on crossluminescence for fast timing calorimeter and time tagger

Need UV photodetectors
=> DRD4 development

- R&D on radiation hard plastic
  Synergy with DRD4-WP5 => need to work together

Explore new developments
with nanocomposite
scintillators

- R&D on radiation hard wavelength shifters

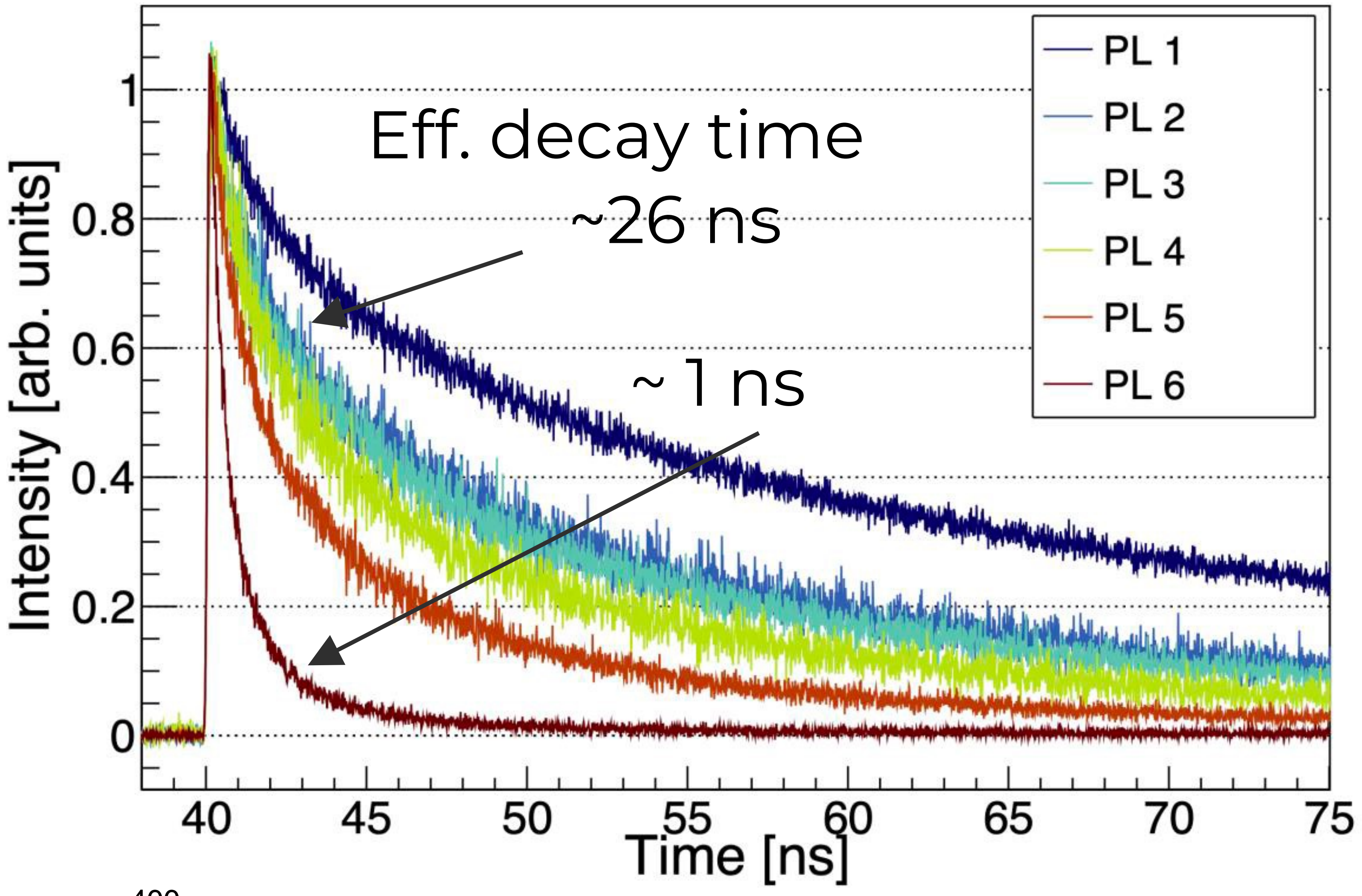
- R&D of scintillating glasses or Ceramics

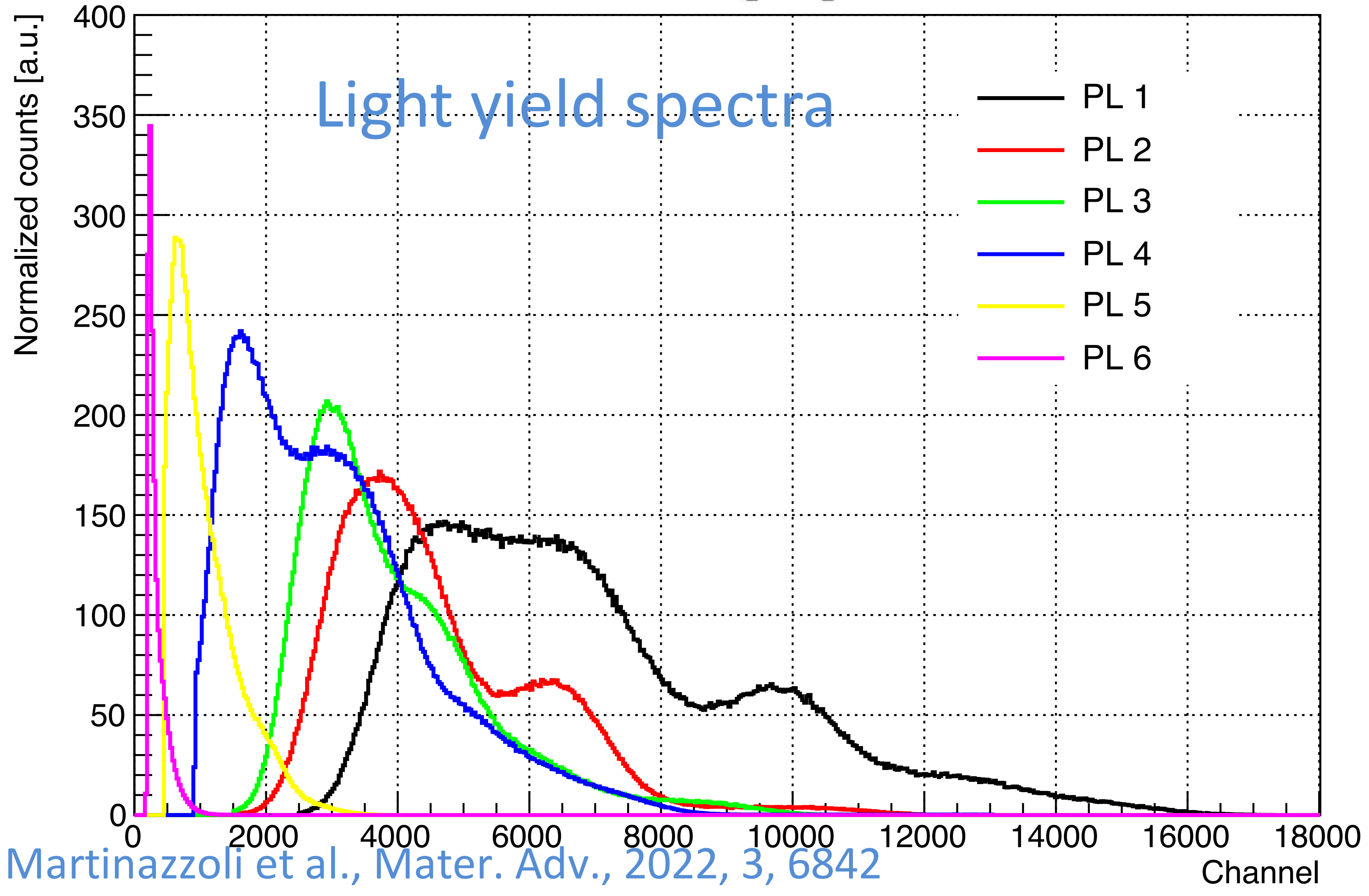
E. Auffray

Acceleration of GAGG emission

Heavy co-doping Ce^{3+}/Mg^{2+}

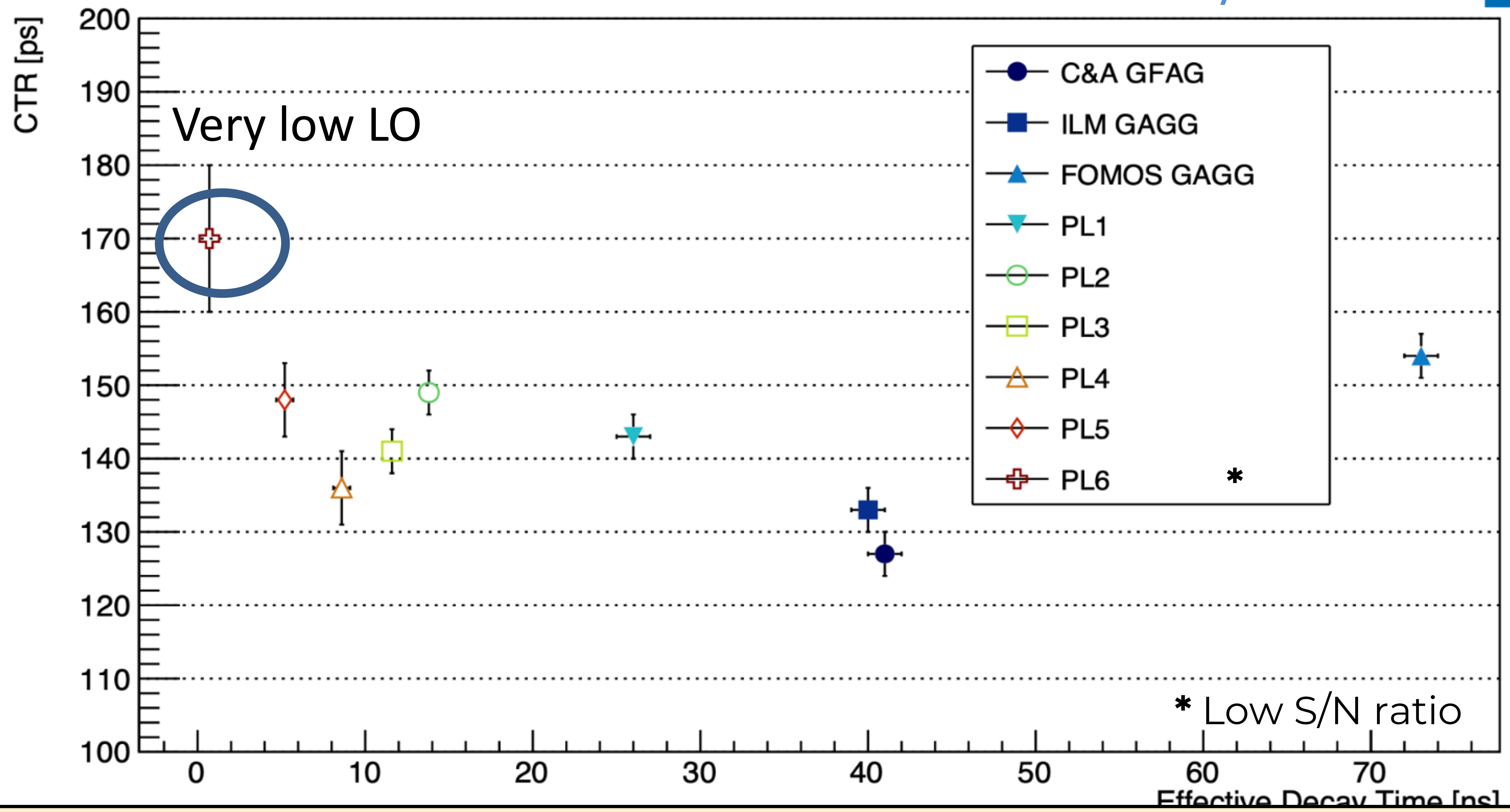
Scintillation decay - Pulsed X-Rays





L. Martinazzoli et al., Mater. Adv., 2022, 3, 6842

Coincidence time resolution vs effective decay time

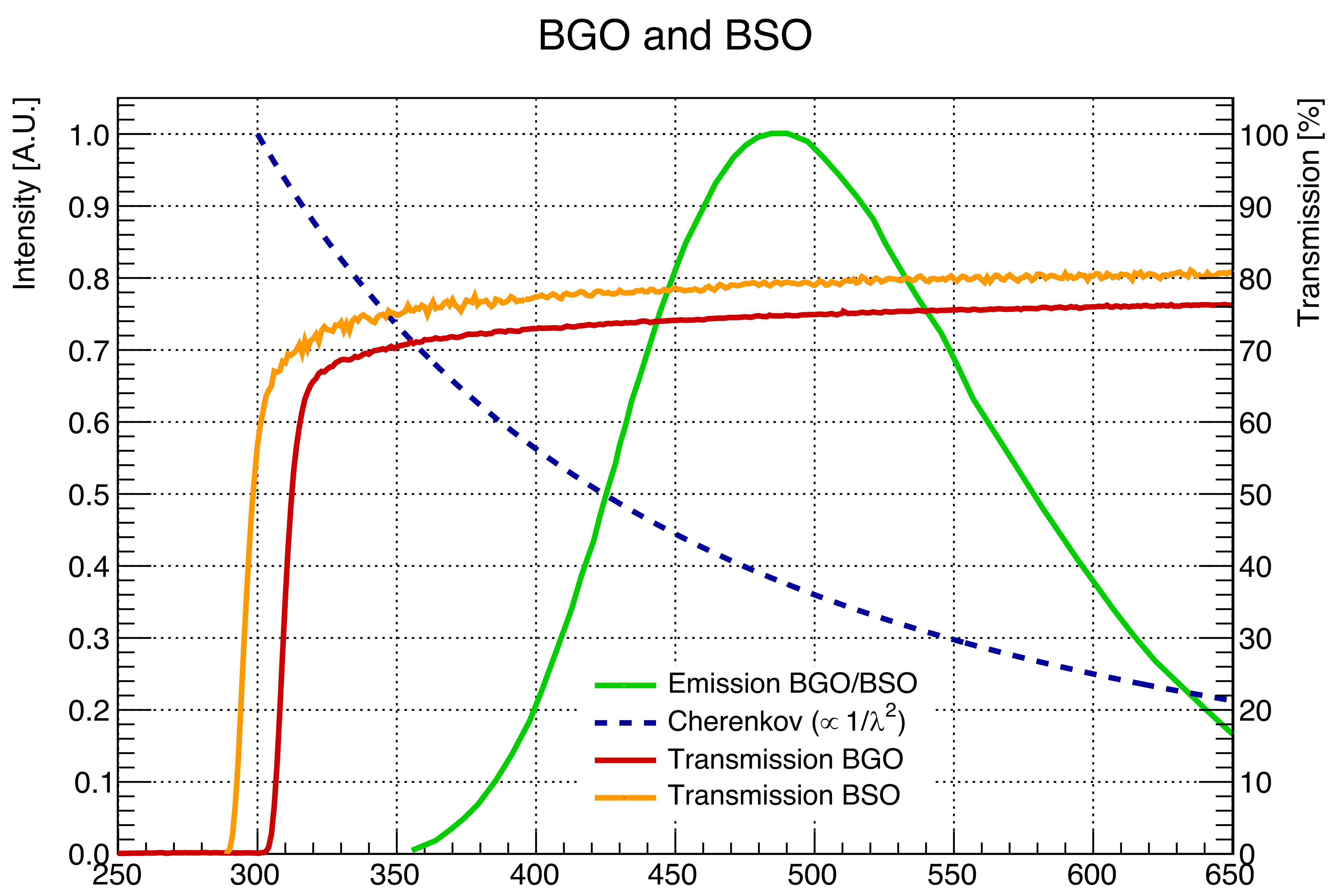


No major loss of time resolution!
Decay time decrease compensated the Light output reduction
=> the same photon time-density

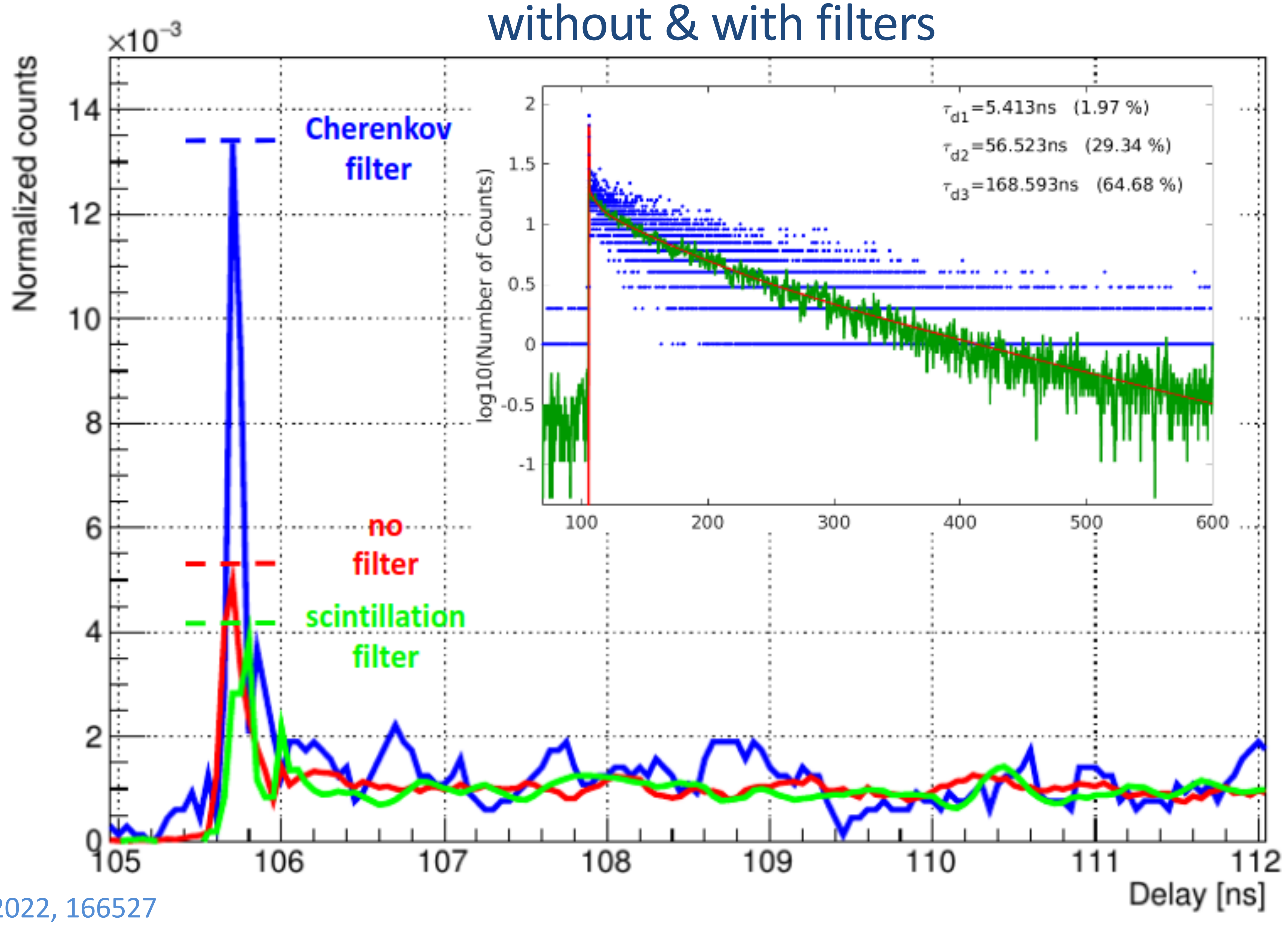
R&D on going in different groups for define optimal composition and production

Exploitation of Cherenkov/scintillation in intrinsic scintillating crystals

E. Auffray



Decay time spectra of BSO under 511 keV excitation without & with filters

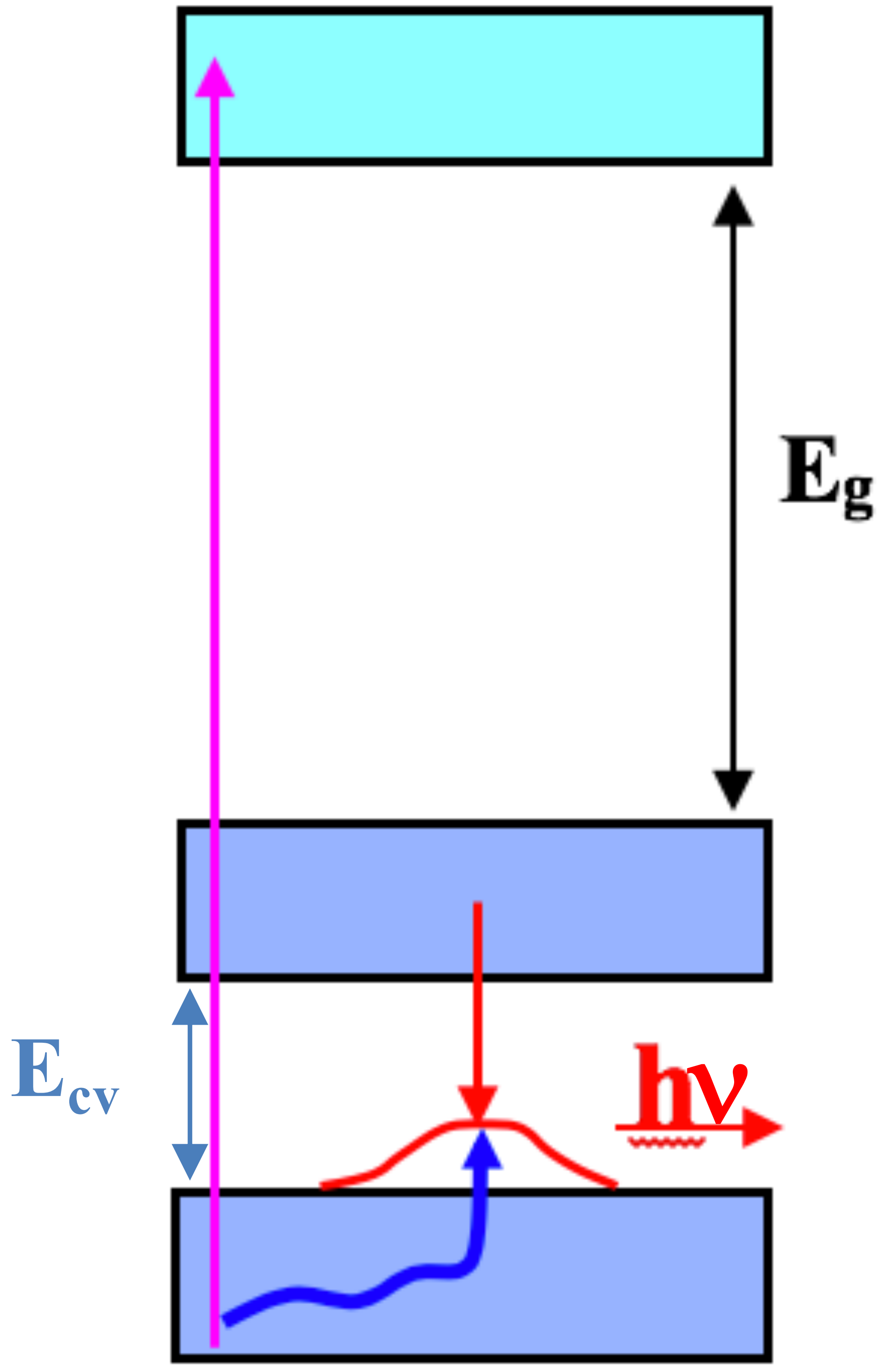


R. Cala et al, NIMA 1032, 2022, 166527

Crossluminescence material

E. Auffray

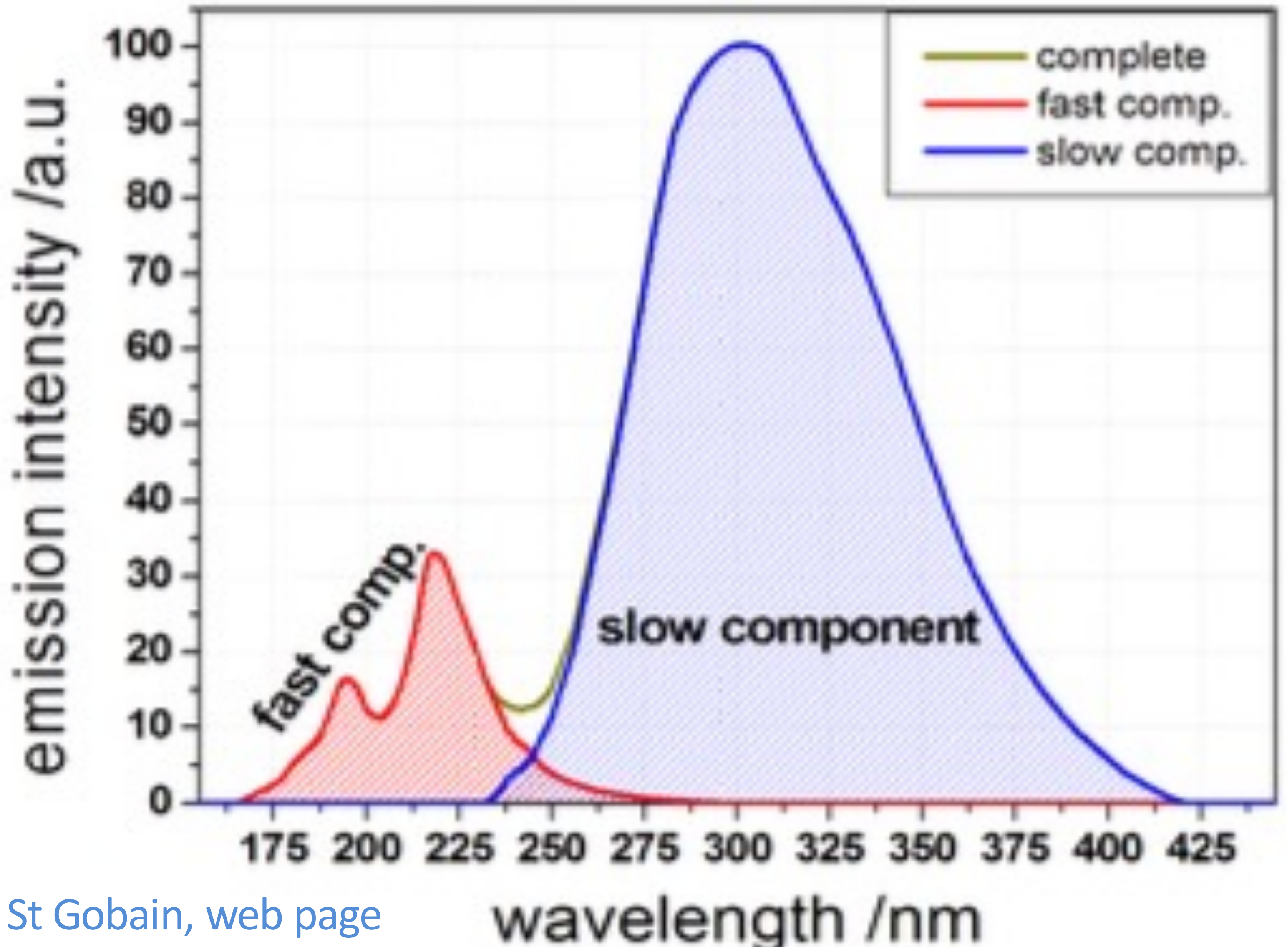
Radiative transition between the core- and valence bands.



$E_{cv} < E_g$

Very fast emission < 2ns but generaly in UV emission

BaF$_2$ emisison spectra



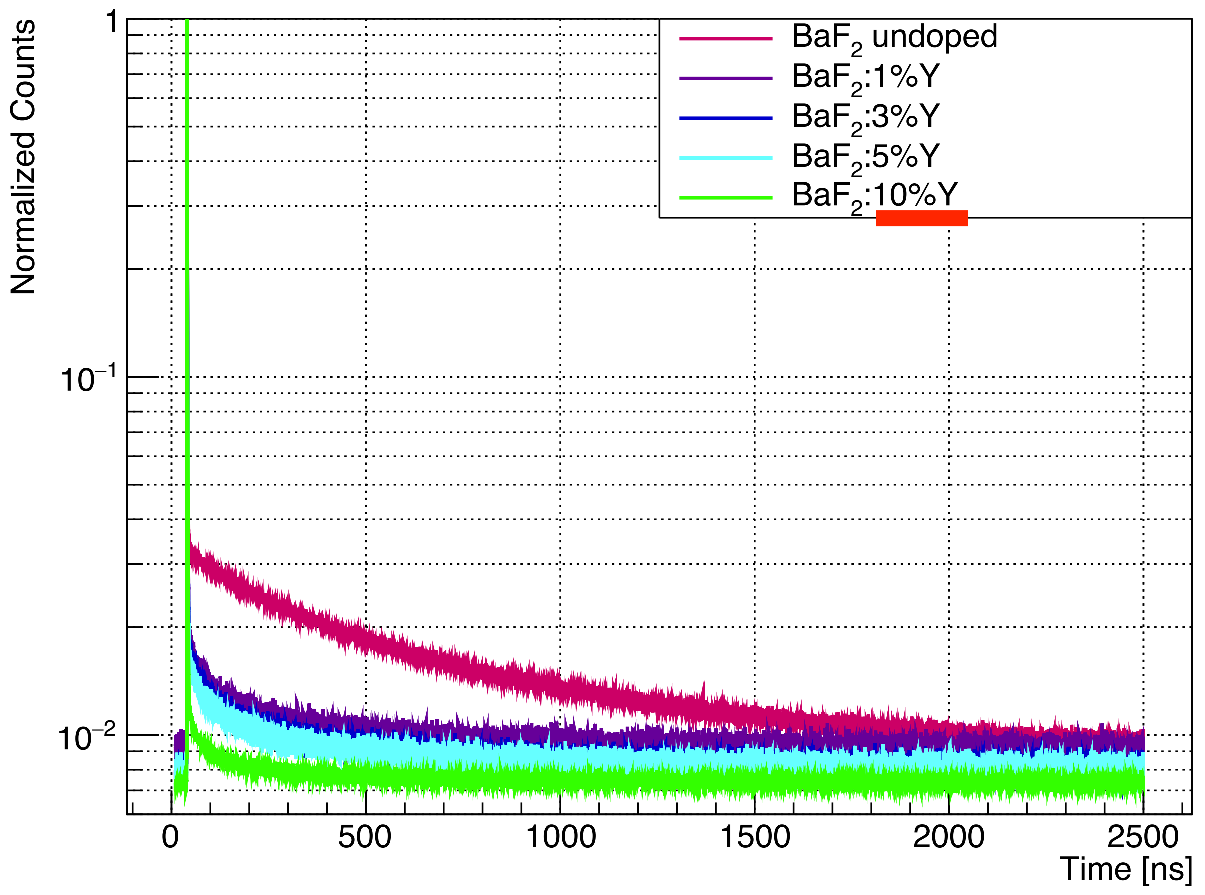
St Gobain, web page

R&D to **suppress the slow component in BaF_2 by doping**

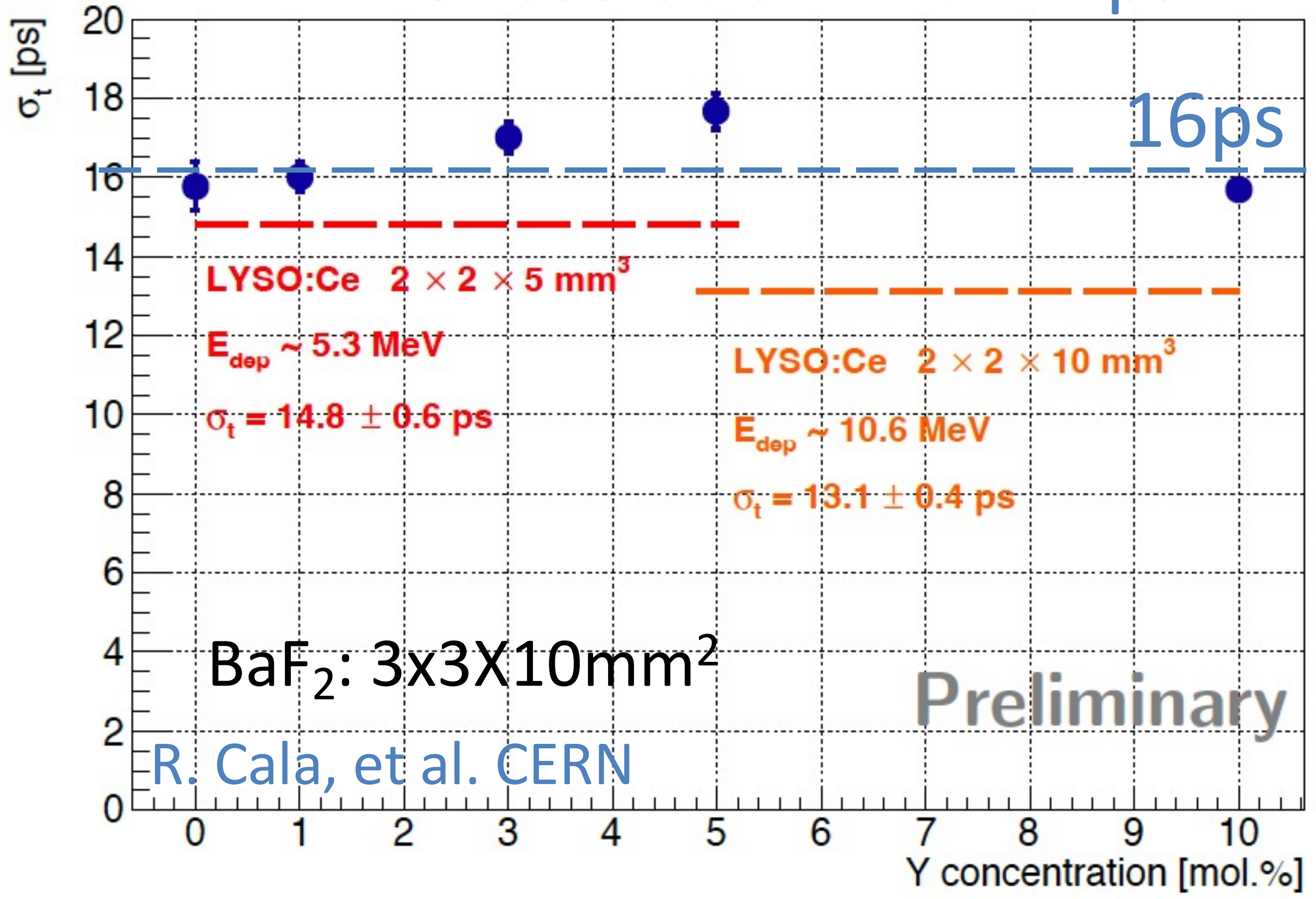
⇒ No change in short decay

⇒ No impact on time resolution

Decay time spectra



Time resolution with mips



J. Chen, et al., IEEE Trans. Nucl. Sci., vol. 65, no. 8, pp. 2147-2151, 2018.
R. Cala et al, SCINT2022 conference SantaFe Sept2022

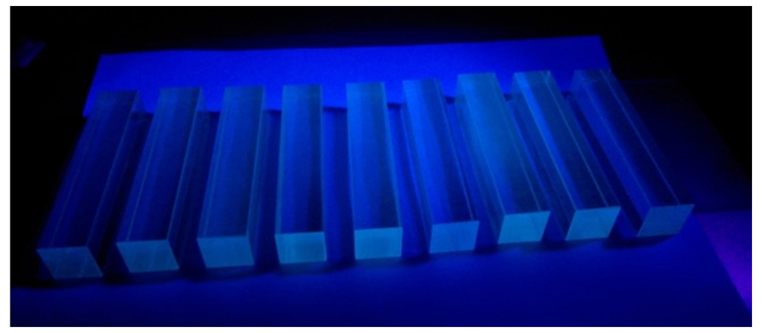
Development on Scintillating Glasses

- Since some years new developments on glasses within different projects (eg ATTRACT project, EIC R&D)
  - Oxyde and Fluoro glasses
    - Attempt to increase the density and the radiation hardness
    - Progress in production scale

E. Auffray

Exemple DSB Glasses

Intelum

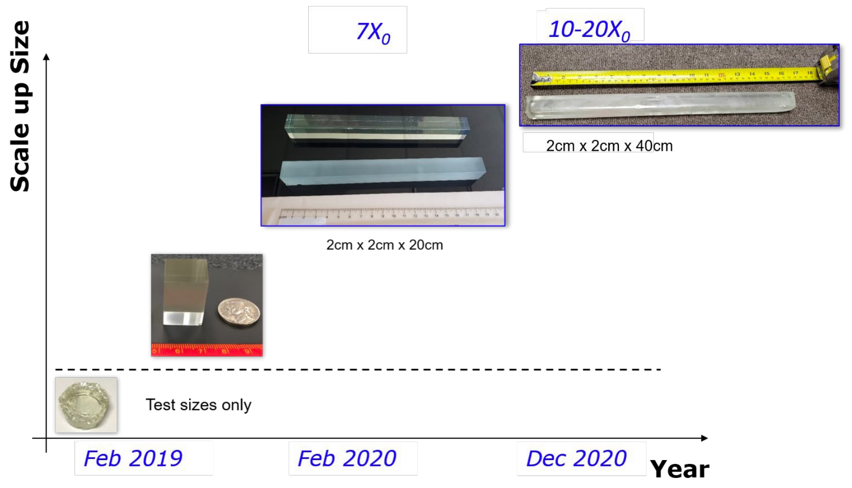


Industrial development via ScintiGlass: Attract project with Preciosa Company

ATTRACT

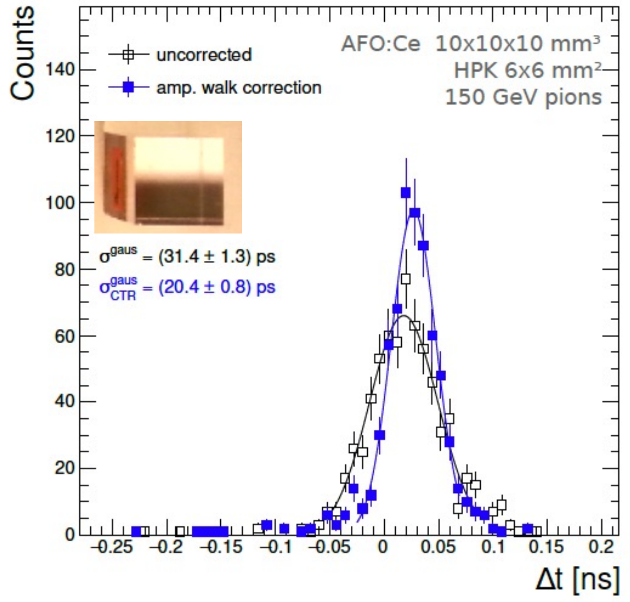
V. Dormenv et al, NIMA, 1015, 2022, 165762

EIC R&D: eRD105 (SciGlass)



From T. Horn, CERN EP R&D, Nov21

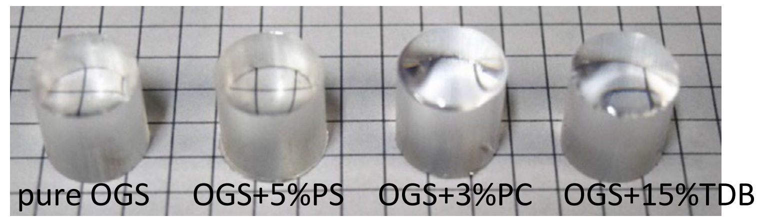
Fluorophosphate AFO glasses
Timing resolution with mip

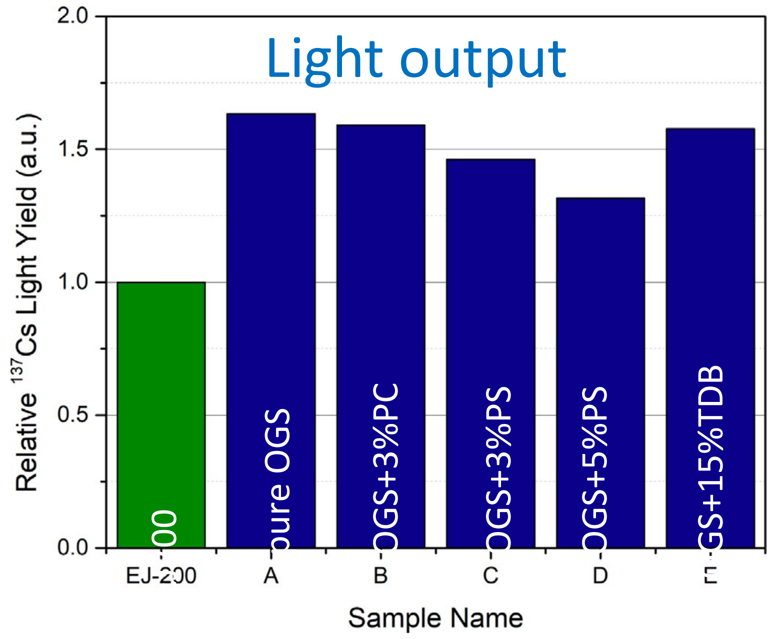


M. Lucchini et al., arXiv:2212.03368, submitted to NIMA

R&D for Organic Scintillators

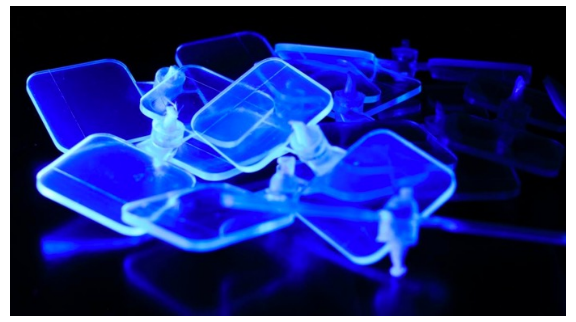
Organic glasses developed in Sendai National lab

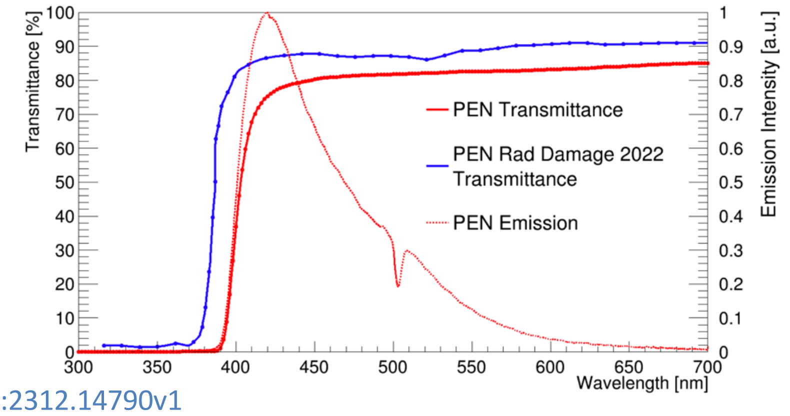




From L. Q Nguyen et al., NIMA 1036 (2022) 166835

Polyethylene Naphtalate(PEN)



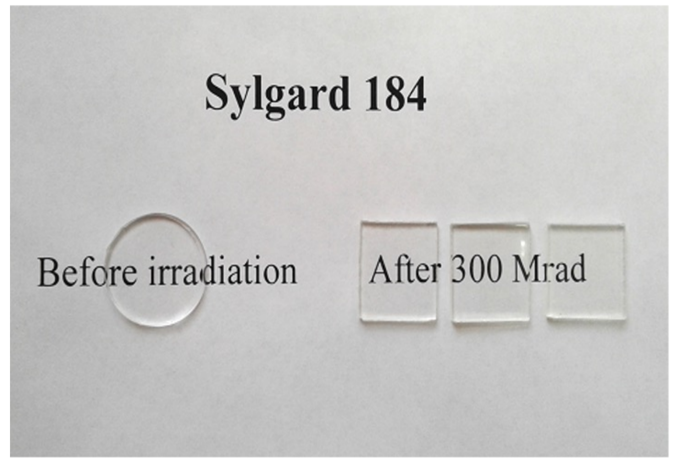


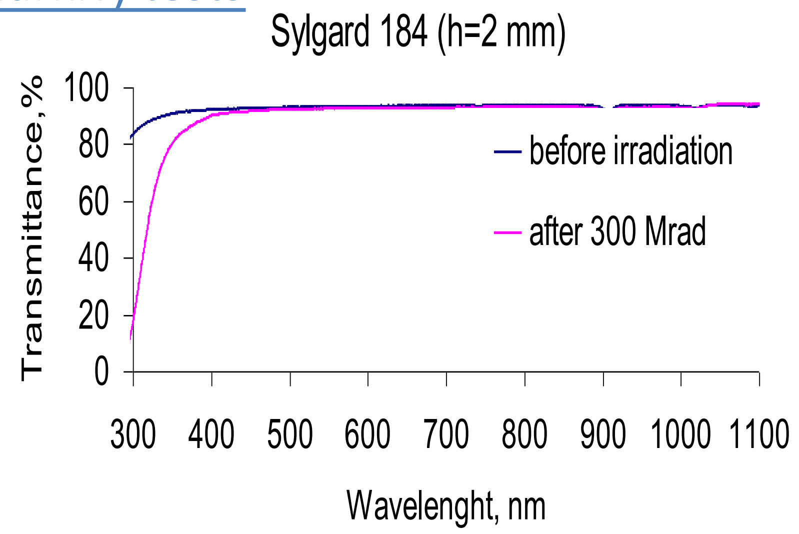
P. Conde Muino et al. , arXiv:2312.14790v1

Polysiloxane materials

Irradiation with electrons (E_0 = 8.3 MeV) up to 300 MRad dose

ISMA (Kharkiv) tests





See also A. Boyarintsev NIMA 930, 2019, 180–184
A. Quaranta et al. NIM B, 268, Issue 19, 2010, Pages 3155-3159

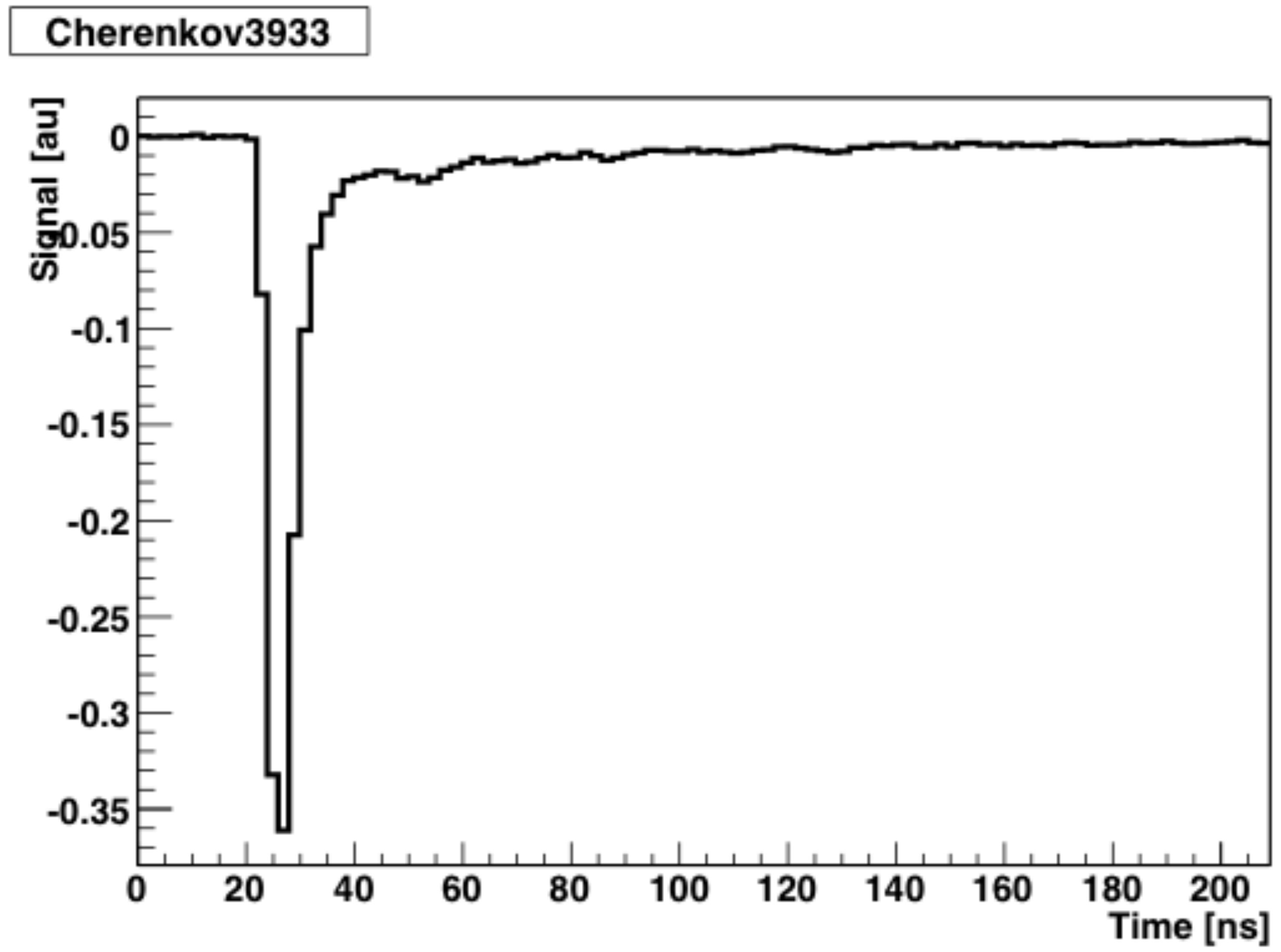
Courtesy A Boyarintsev, ISMA, Kharkiv

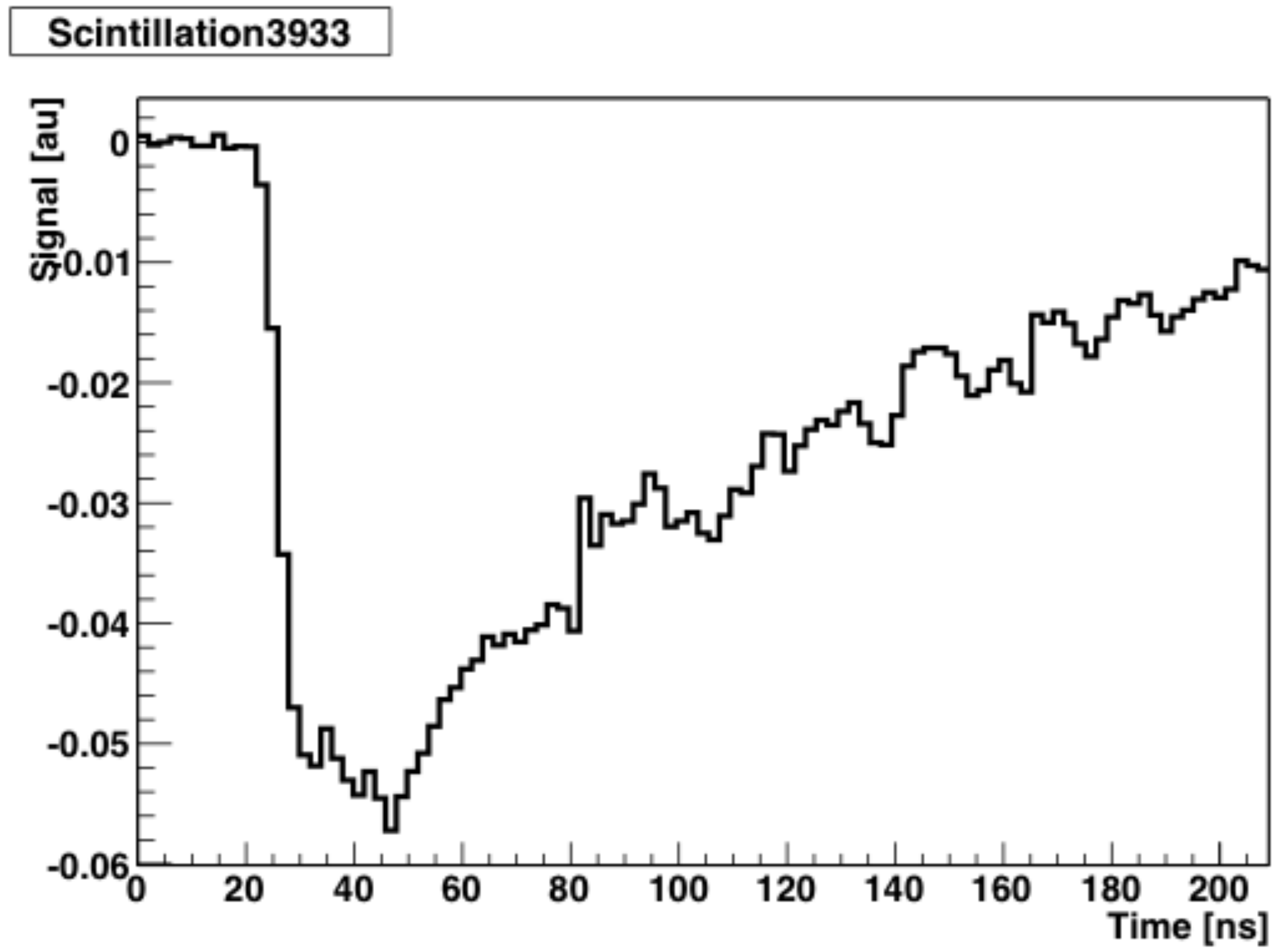
Start with an Example : BSO

N. Akchurin

Six distinct features distinguish Cherenkov radiation from scintillation:

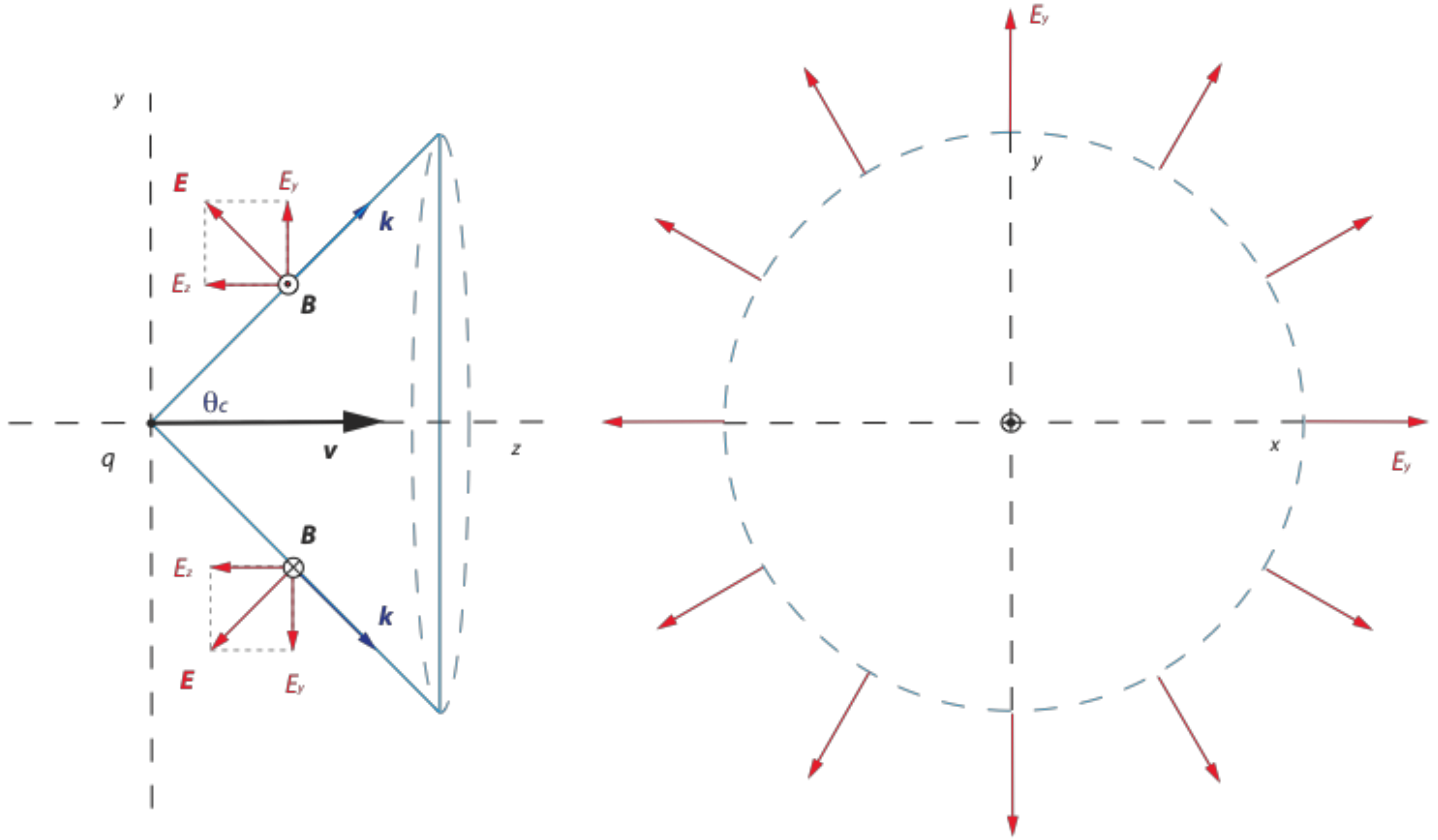
1. Directionality (Cherenkov cone, $\theta_c = \cos^{-1}(1/\beta n(\lambda)$), *vs* isotropic emission)
2. Emission/wavelength spectrum ($1/\lambda^2$ *vs* scintillator specific)
3. Cherenkov threshold ($T=(\gamma-1)mc^2$, for n=2 electrons:~80 keV, protons: ~140 MeV)
4. Timing (Prompt *vs* ~several ns)
5. Polarization (linearly polarized *vs* unpolarized)
6. Cherenkov light is feeble (scintillation is often not)

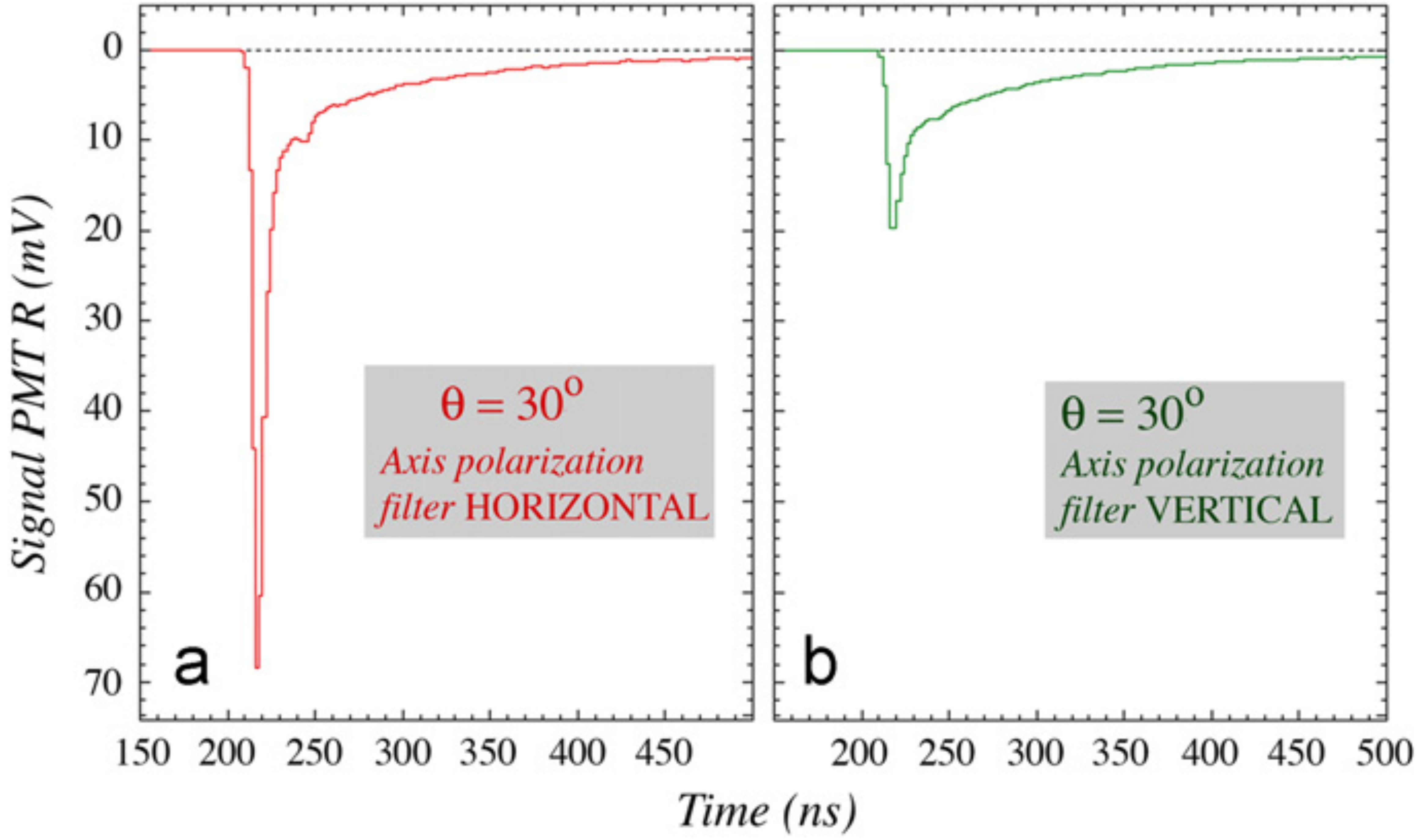




N. Akchurin

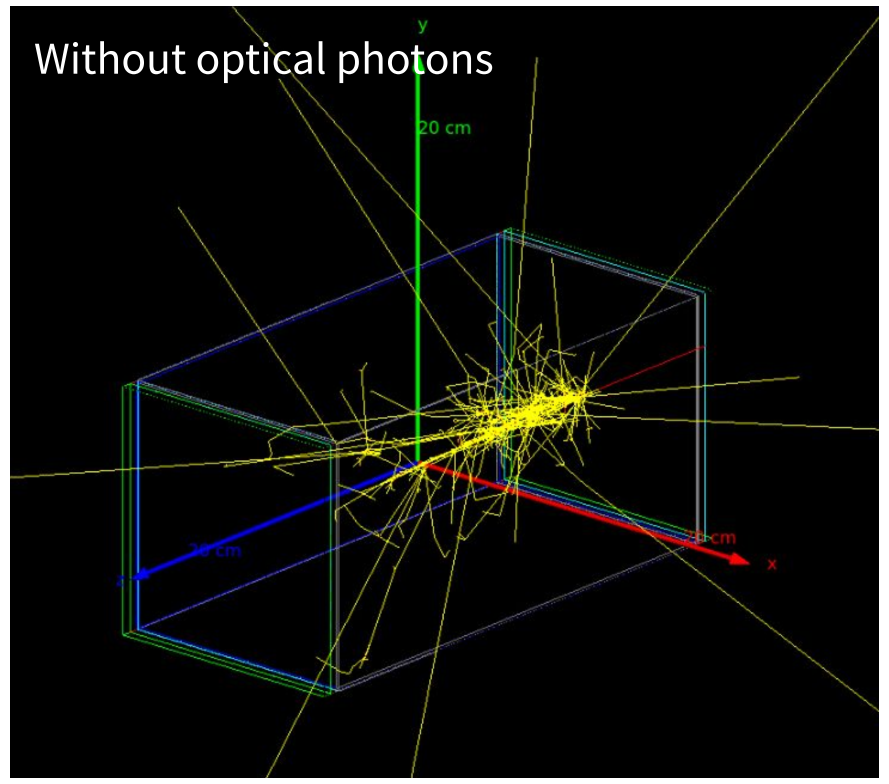
Cherenkov Radiation and Polarization - I

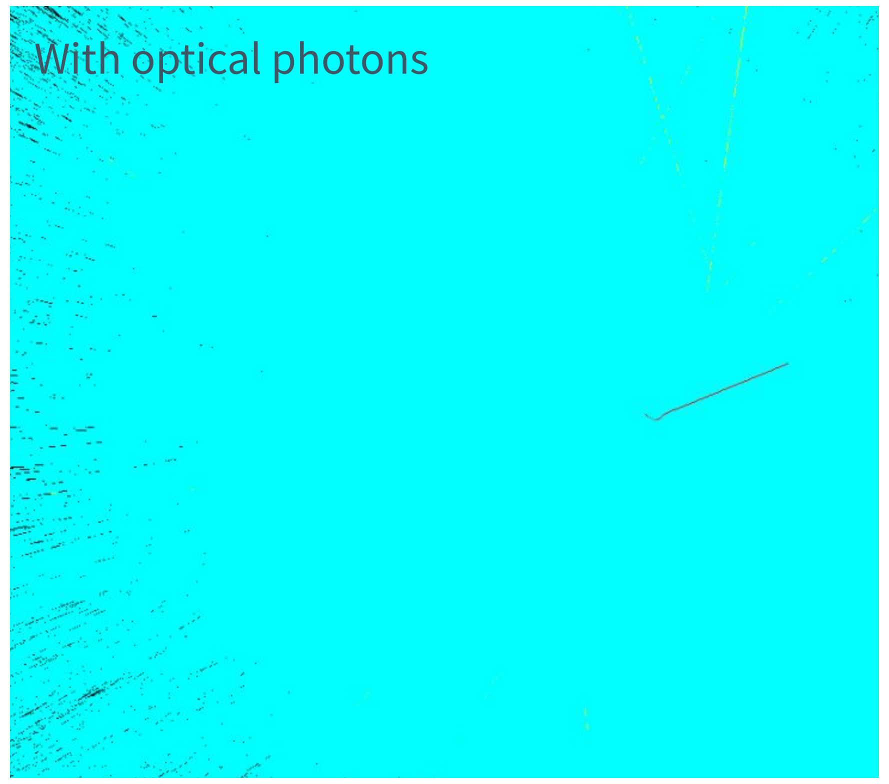




Number of tracks and optical photons

When optical photons are involved, the number of particles to propagate through the geometry greatly increases



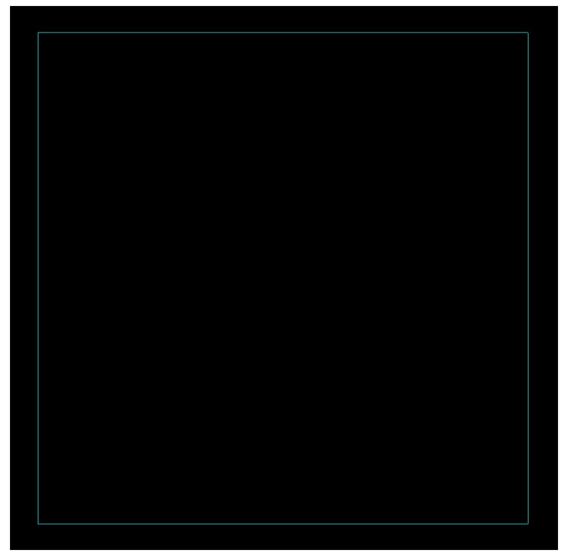


- Homogeneous **PWO crystal** (120x120x250 mm^3) hit by a single **1 GeV electron**:
  - On the left, only em shower particles → **2.5k tracks**
  - On the right, adding optical photons → **100k tracks**
- Remember that PWO has a low light yield (100 Ph/MeV), typical scintillators have in the order of 10kPh/MeV

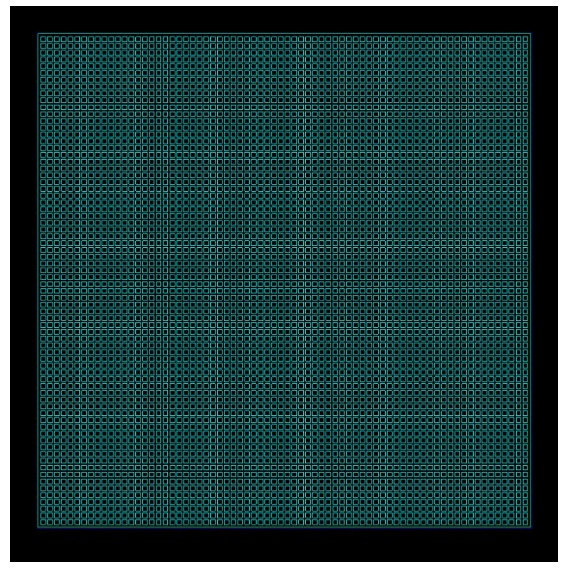
marco.pizzichemi@cern.ch

CPU time and optical photons

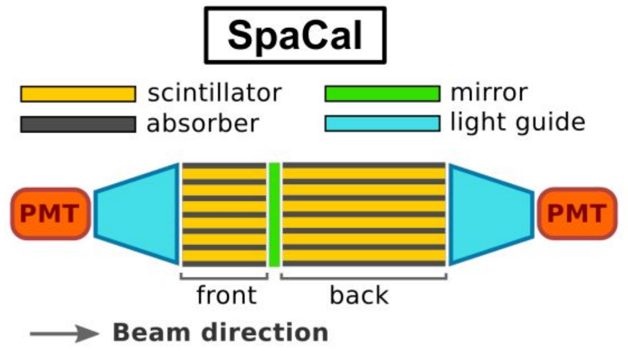
Simple test performed with Geant4.11 on 2 different configurations, on local PC



- **Homogeneous** PWO crystal (120x120x250 mm^3):
  - No optical photons → **0.06s** per GeV of primary electron
  - With optical photons → **3.2s** per GeV of primary electron
- About **50x slower** with optical photons
  - 1 crystal 120x120x250 mm^3
  - PWO light yield 100 Ph/MeV



- **SpaCal** module made of W and Polystyrene (120x120x200 mm^3):
  - No optical photons → **0.25s** per GeV of primary electron
  - With optical photons → **633s** per GeV of primary electron
- About **2500x slower** with optical photons
  - 5184 crystals, each 1x1x200 mm^3
  - Sampling fraction about 5%
  - Polystyrene light yield 10000 Ph/MeV



M. Pizzichemi

Speedup strategies

At least to my knowledge, the main strategies to reduce computation time with Geant4 fall into 3 categories

Parameterization

Skipping the optical photon propagation entirely, reproducing the effects in a parameterized way

- Can be very CPU-efficient
- Applicability is highly application dependent
- Can result in loss of information

Ray tracing on GPU

Moving the ray tracing classes of Geant4 on GPU

- Few physics processes need to be implemented on GPU
- Little data transfer CPU-GPU
- Minimal communication between threads
- Can benefit from available efficient algorithms and hardware (NVIDIA CUDA, NVIDIA OptiX)

Rendering technologies on GPU

Performing the propagation of optical photons outside Geant4, using rendering technologies

- Active development, often used in animated movies
- Can be performed on GPUs as well

Opticks in Geant4

- Opticks is an open-source project that **accelerates optical photon simulation in Geant4** by:
  - Translating the Geant4 geometry to NVIDIA OptiX without approximation
  - Implementing the Geant4 optical processes on the GPU
  - Integrating NVIDIA GPU ray tracing
- Geant4 handles on CPU all particles but optical photons
- Information on Cherenkov and Scintillation photons stored
- Generation and tracing of optical photons is **offloaded to Opticks** and performed on GPU

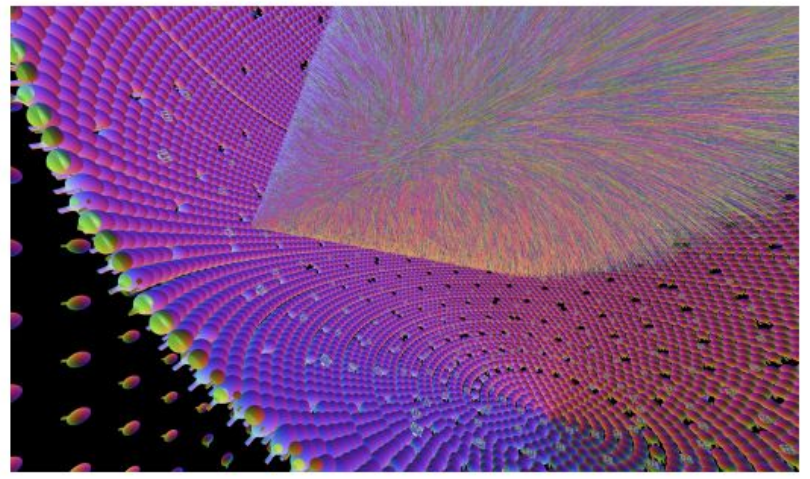
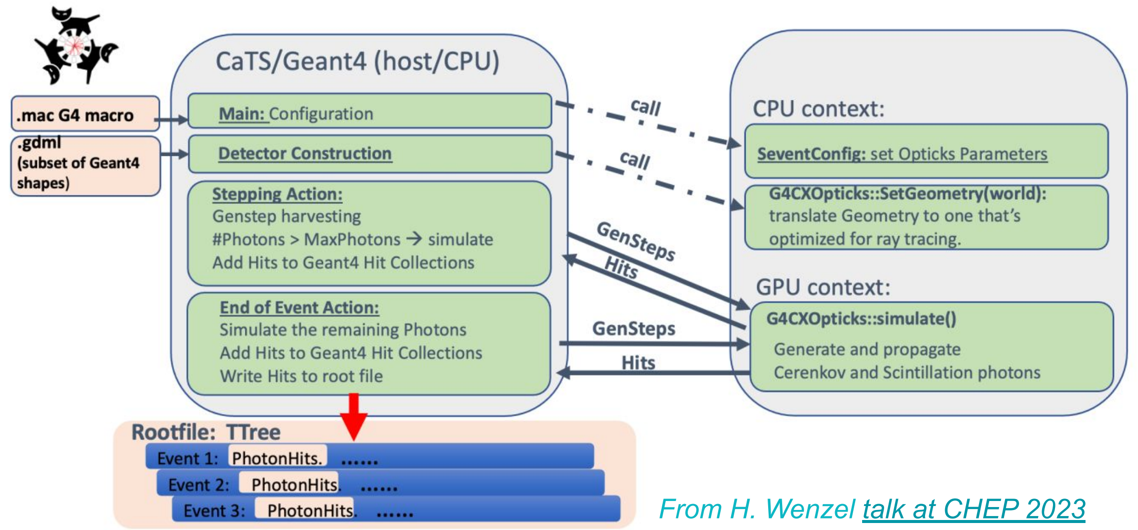


Figure 1. Cutaway OpenGL rendering of millions of simulated optical photons from a 200 GeV muon crossing the JUNO liquid scintillator. Each line corresponds to a single photon with line colors representing the polarization direction. Primary particles are simulated by Geant4, scintillation and Cherenkov "gensteps" are uploaded to the GPU and photons are generated, propagated and visualized all on the GPU. Representations of some of the many thousands of photomultiplier tubes that instrument the liquid scintillator are visible. The acrylic vessel that contains the liquid scintillator is not shown.

S. Blyth, Integration of JUNO simulation framework with Opticks: GPU accelerated optical propagation via NVIDIA OptiX



From H. Wenzel talk at CHEP 2023

- Primarily developed for simulation of the JUNO detector
  - Demonstrated **speedup factor up to 1500x** using a single NVIDIA Quadro RTX 8000 GPU compared to a single threaded Geant4 simulation
- Example using Opticks is **available in Geant4.11**:
  - **CaTS**: Calorimeter and Tracking Simulation
  - Demonstrated speedup of a factor about 200x

Photosensor types under current use/investigation

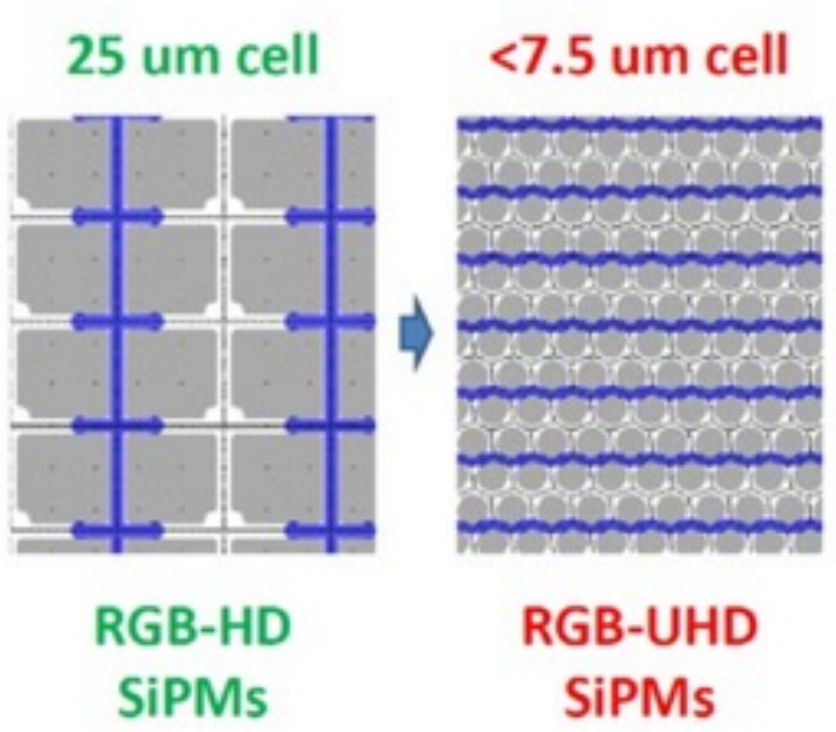
R. Ruchti

Detector	Photosensor Locations in Detectors	Light Detection	Measurement Objectives	Photosensor options - examples
EM Calorimetry	• Crystal faces	• Scintillation • Cherenkov	Energy Timing Position	SiPM arrays: HPK S14160/S14161 SiPM: HPK HDR2 SiPM: FBK NUV-HD SiPM: FBK RGB
	• Ends of scintillating waveshifting fibers and • capillaries	• Scintillation • Waveshifter • Cherenkov	Energy Timing Position Sampling at strategic depths	PMT: R12421 MCD-MT: R7600U-20 SiPM: HPK HDR2
Hadron Calorimetry	• On scintillator tiles	• Scintillation	Energy Timing Position	SiPM: HPK HDR2
	• At ends of fibers	• Scintillation • Cherenkov	Energy Timing Position	SiPM arrays of selected pixel dimensions MCP-PMT: PLANACON XP85112, PLANACON XP85012

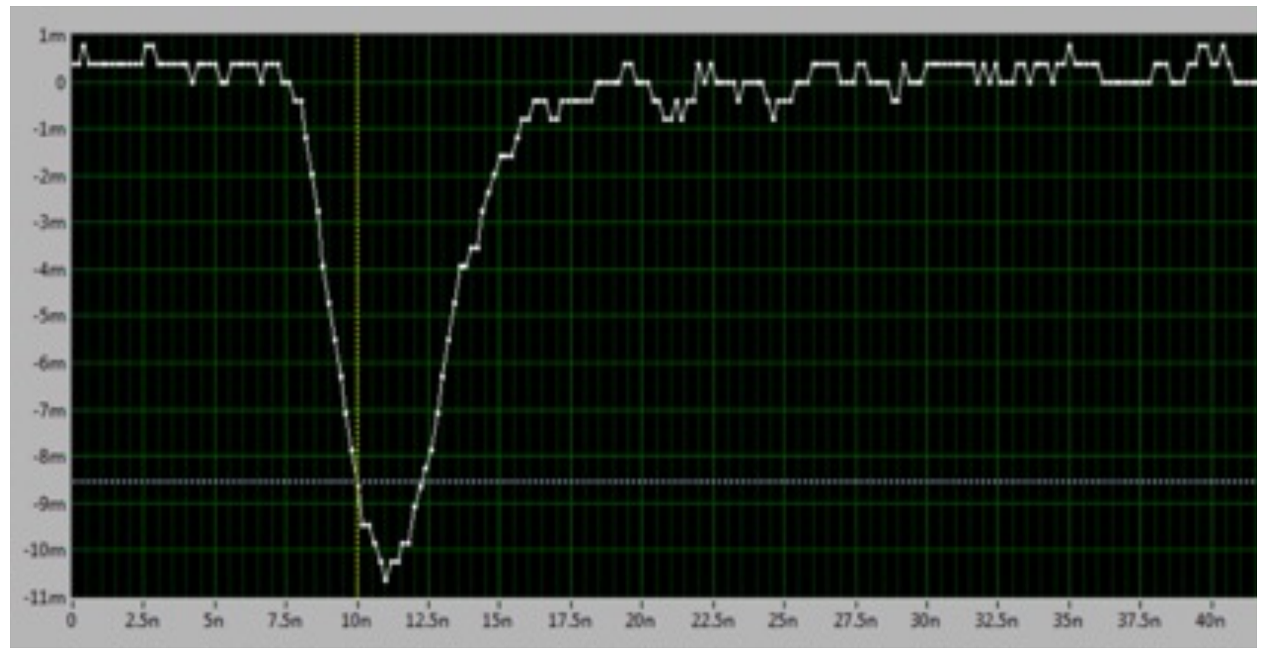
R. Ruchti

FBK SiPM development for RADiCAL
(arXiv:2203.12806) for fast timing, avoid saturation

Format to reduce boundary regions between SiPM pixels



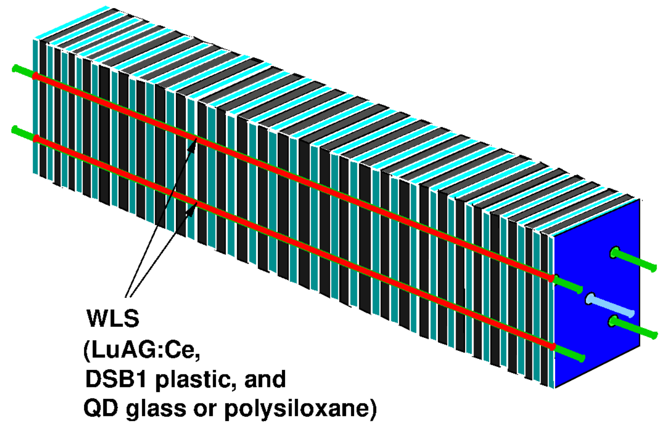
Pulse from a FBK SiPM with 5μm pixels. Horizonal scale division is 2.5ns.

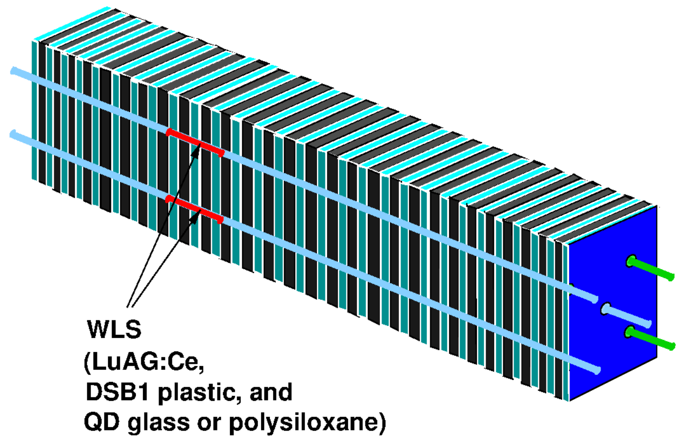


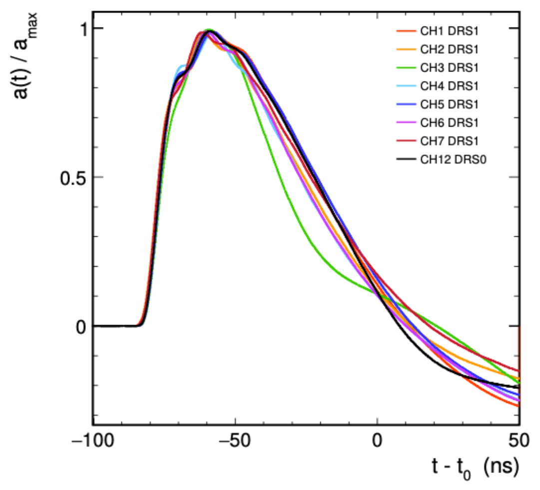
SiPM signals and front electronics/DAQ

RADiCAL example, using WLS capillaries

Energy resolution - detect full EM shower - low gain signals



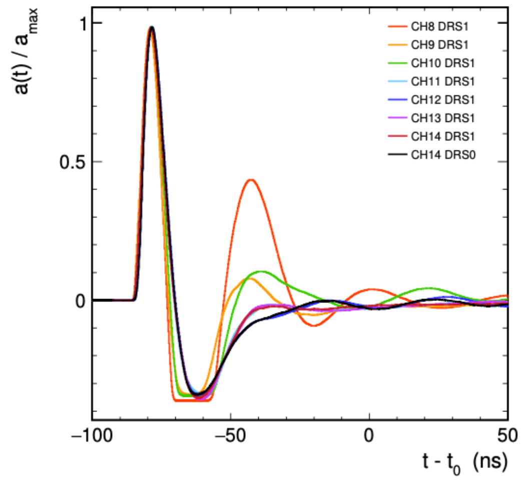




Low gain for energy and position

Position and Timing resolution - selected locations in EM shower depth. Position uses local energy deposition

High and Low gain signals needed.

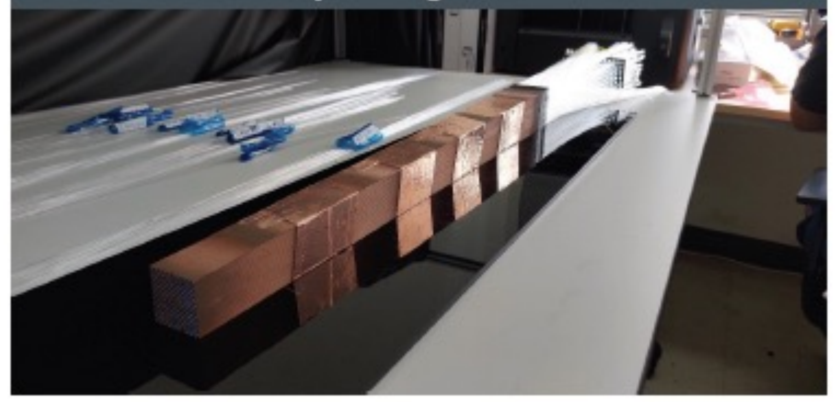


High gain for timing

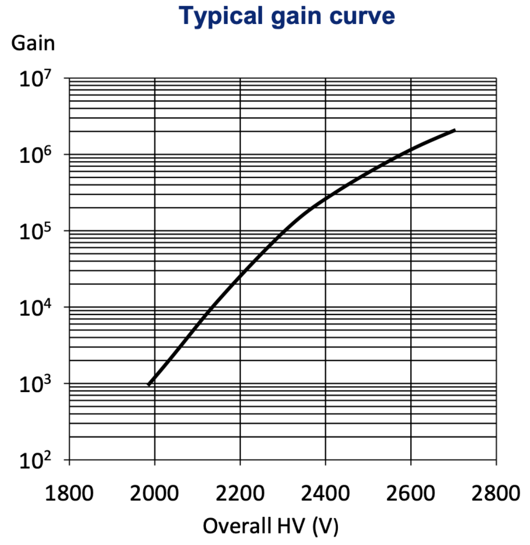
MCP-PMT for DRCAL

Model	Effective Area	Rise Time [ns]	Max V [V]
PLANACON XP85112	53 mm × 53 mm (8 × 8 cells)	0.5	2800
PLANACON XP85012		0.6	2400

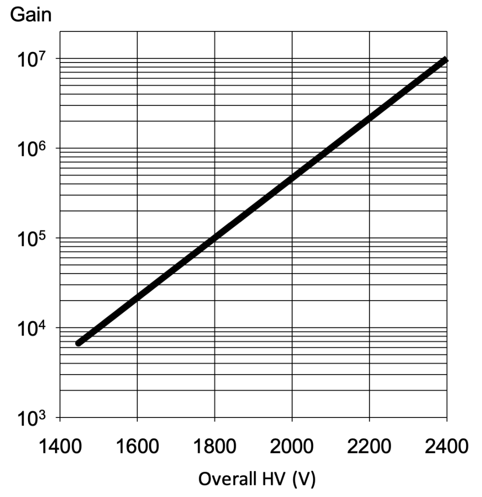
3D printing module



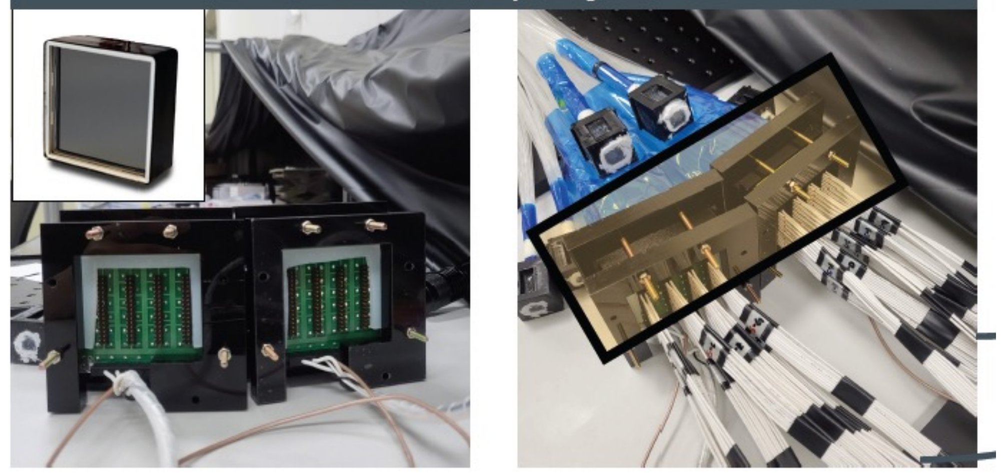
XP85112 (Scifi)



XP85012 (Cherenkov)

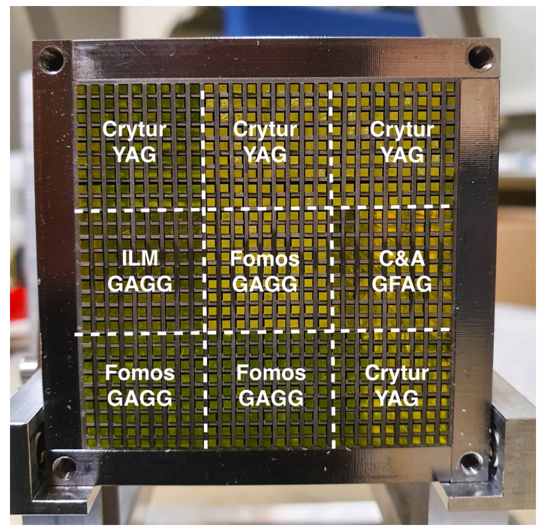


Readout side of 3D printing module

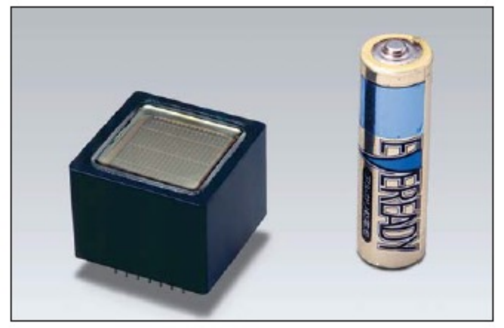


Haeun Jang (Yonsei Univ) 2023 KPS Fall Meeting
Objective: To use timing to locate shower depth

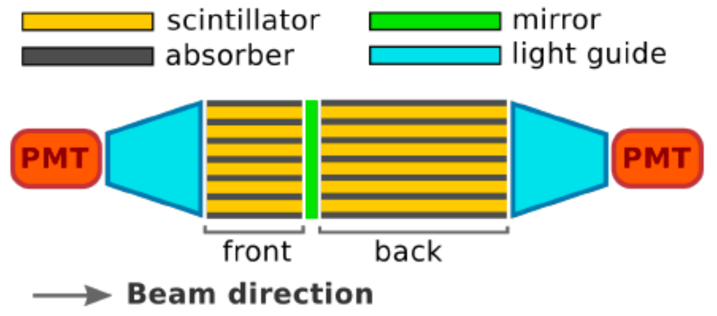
MCD-PMT for LHCb

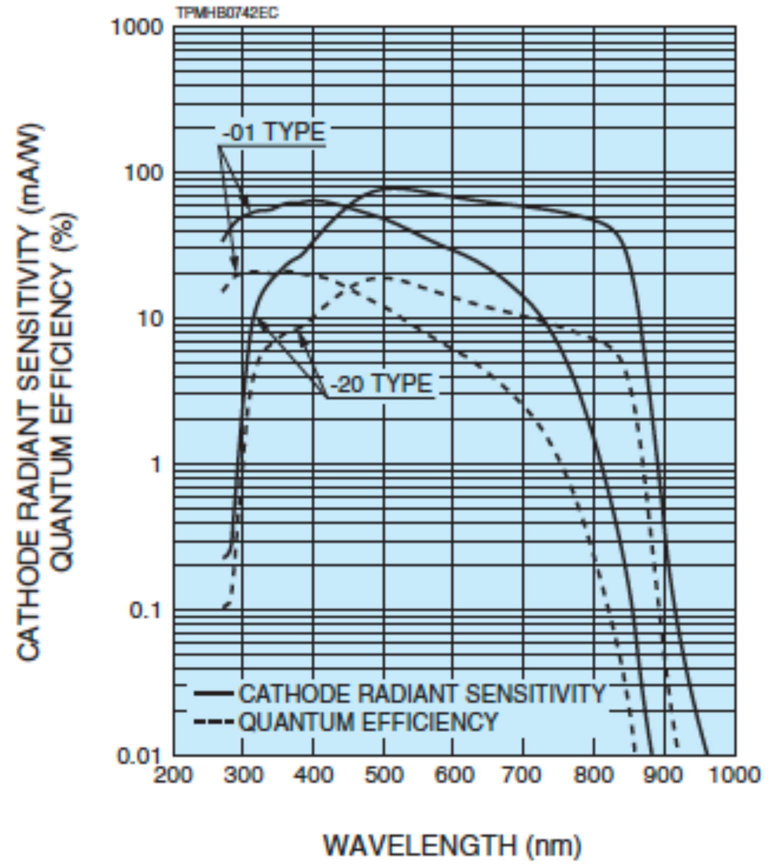


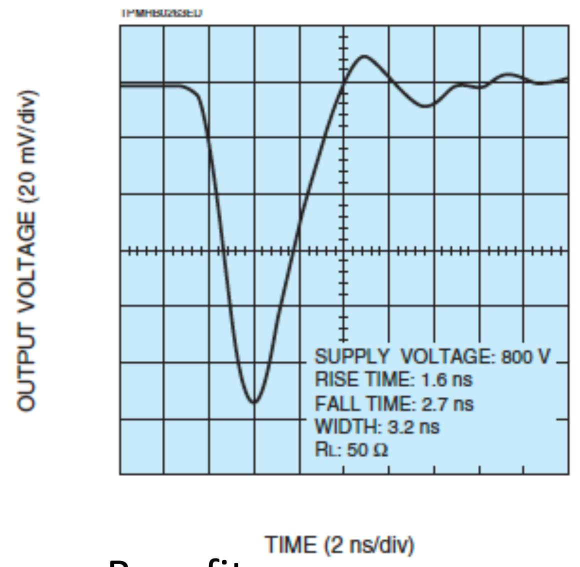
Garnet/Tungsten SPACAL
P. Roloff, EPS 2021



Some characteristics of R7600U-20 MCD PMT







DESY: Electron beam energy up to 5 GeV.
Using: R7600U-20, ~20psec time resolution
Using: R12421 , 10%/sqrt(E) constant term for beam angle θx, θy = 3°

Benefit:
Fast, effient, room temperature.

WP3 coordinator election

G. Gaudio

- To be done soon after the Collaboration Workshop
- Nominations:
  - The nomination is open to the whole community, as individuals, groups or projects. Self-nominations are also allowed
  - Mail will be sent around with information with detailed procedure
- Short-list
  - The search committee verifies availability of nominees to stand for election
  - A meeting will be organised for candidates presentation and Q&A session
- Election
  - Electronic vote will be put in place
  - 1 project = 1 vote

Summary

- R&D groups in WP3 introduced the achievements and ongoing studies.
- Efforts for further development will continue to satisfy the requirement for future experiments.
- Stay tuned to WP3 studies for more interesting results!