Andrey Golutvin
Imperial College London

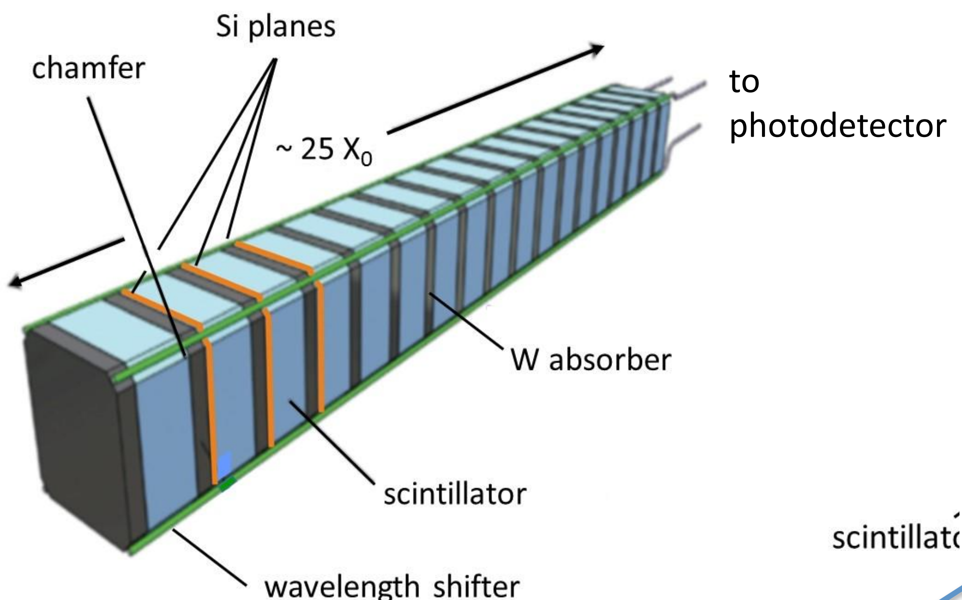
Some ideas(*) on the scintillating part of the calorimeter module

(*) *Ideas from Sergey Didenko (MISIS), Yuri Guz (IHEP), Pavel Shatalov (ITEP) and Andreas Schopper (CERN)*

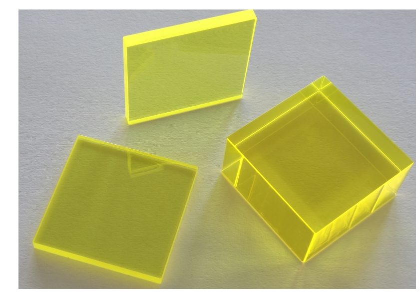
LHCb upgrade ECAL module will have the same geometrical dimension as the current module, i.e. 12×12 cm^2 cross section

BUT:

LHCb upgrade calorimeter will run in extreme radiation conditions up to a few tens Mrad
→ Require very RH scintillator and light guides transporting the scintillating light at the rear of the module



Samples of GAGG crystals produced by FOMOS for irradiation at CERN



Main goals of R&D study:

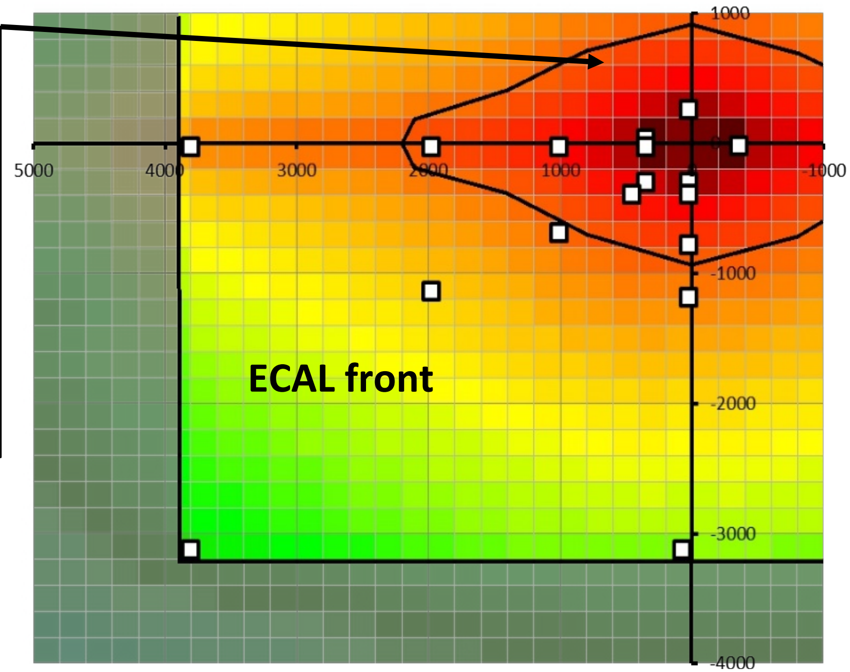
- Optimisation of the scintillating light output
- Study of radiation hardness and performance of different scintillators
  Our favorite choice is GAGG crystal (see next talk by Oleg), annealing of $PbWO_4$ (CMS crystal) is also worth to be understood
- Construction of module prototypes and evaluation at test beams

Two zones of the LHCb ECAL: Super rad. hard zone and "conventional" zone

300 fb^{-1}: up to 100 Mrad
(hadrons >20 MeV: ~$10^{15}/cm^2$)

zone >5 Mrad.
Plastic scint. not applicable.

~300 modules
12x12 cm^2



Gloria & Matthias
LHCb-PUB-2017-13

- ✓ *Super radiation hard ECAL module requires dedicated R&D*
- ✓ *"Conventional" zone requires pragmatically thought approach to ensure long term operation (spare modules etc…)*
- ✓ *R&D on new electronics to improve time resolution for both zones*

Brief summary of the relevant GAGG properties
(More details in the next talk by Oleg)

Density, X0, R_M	Peak emission	LY, Ph/MeV	Decay time	Energy Resolution	Time Resolution
6.68 g/cm^3 15.9 mm 21 mm	520 nm	38000 46000 (-45°C)	30 ns (25%) 80 ns (60%) >100 ns (15%)	6.2% (511 keV) 3.6% (1270 keV) SiPM readout at -20°C	170 ps (-20° to 20°C)

Brief summary of GAGG parameters:

- *Very dense crystal with small Moliere radius and short radiation length*
- *"Green" scintillating light*
- *Very large Light Yield → Good energy resolution for the homogeneous calorimeter*
- *Fast crystal*

Radiation hardness to be tested but preliminary studies indicate very good radiation hardness

Irradiation tests at the PS beam

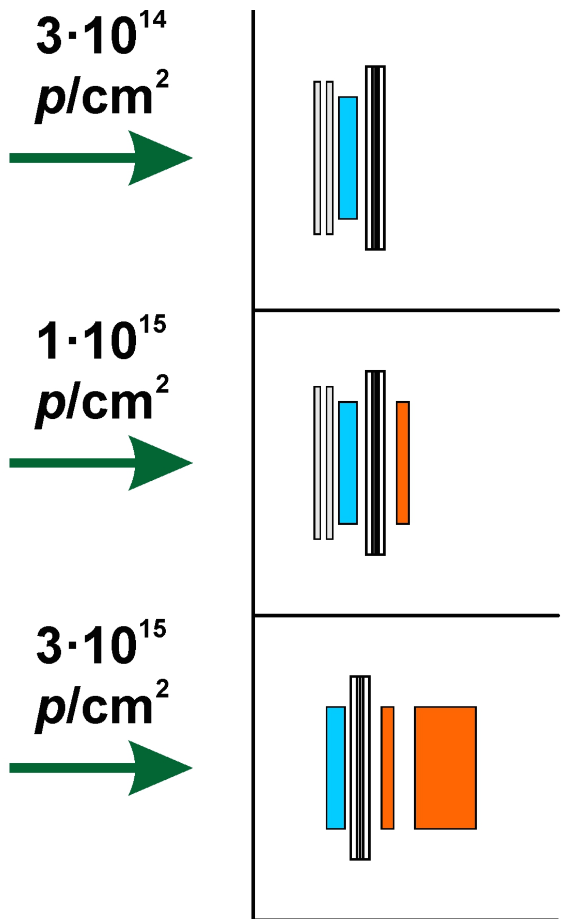
Irradiation test of the module components: GAGG crystals and GaAs detectors

10 Mrad

30 Mrad

100 Mrad

beam protons 24 GeV



Section 1: **fluence $3\cdot10^{14}$ *p*/cm^2**

1-1 - UV glass type I Ø25 mm x 1 mm
1-2 - UV glass type II Ø25 mm x 1 mm
1-3 - plastic scintillator 20x20x3 mm^3
1-4 - GaAs chips

Section 2: **fluence $1\cdot10^{15}$ *p*/cm^2**

2-1 - UV glass type I Ø25 mm x 1 mm
2-2 - UV glass type II Ø25 mm x 1 mm
2-3 - plastic scintillator 20x20x3 mm^3
2-4 - GaAs chips
2-5 - GaGG sample 20x20x2 mm^3

Section 3: **fluence $3\cdot10^{15}$ *p*/cm^2**

3-1 - plastic scintillator 20x20x3 mm^3
3-2 - GaAs chips
3-3 - GaGG sample 20x20x2 mm^3
3-4 - GaGG sample 20x20x10 mm^3

Irradiated components will be available for the post-irradiation analysis in January / February 2018

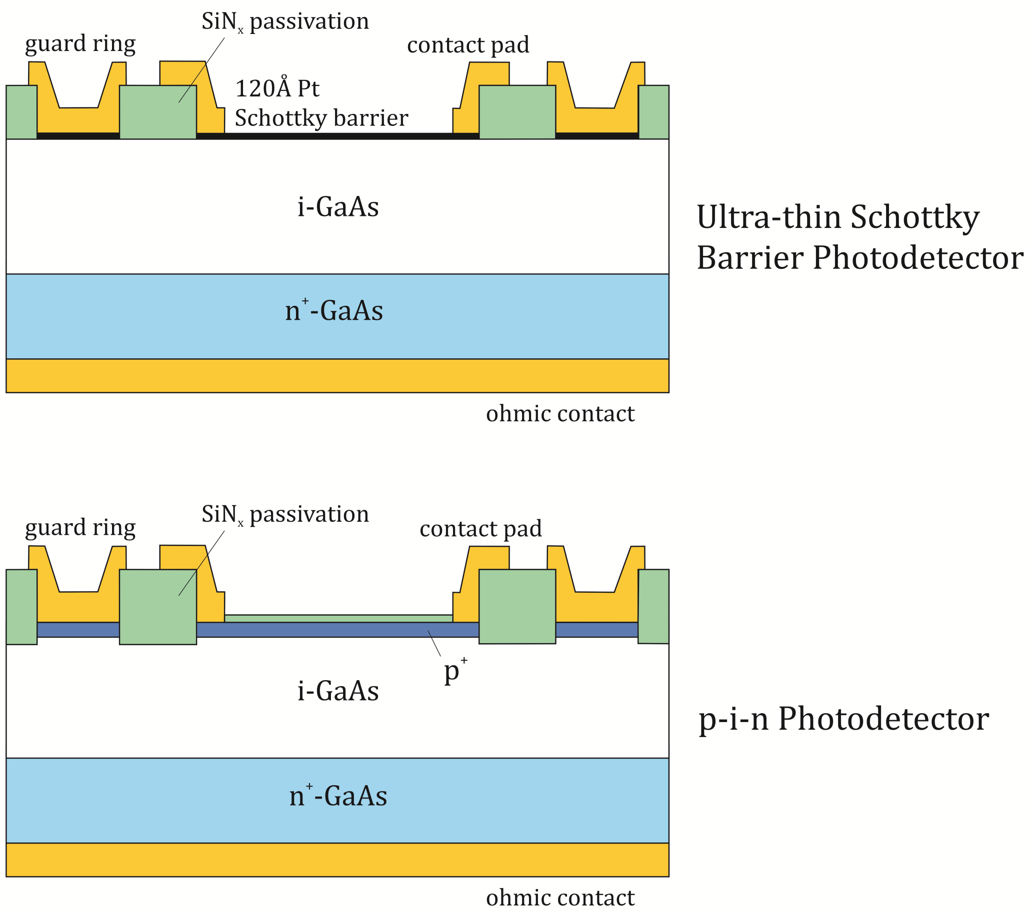
Segmented readout of the scintillating light

Determine the maximum length of the GAGG crystal which can sustain the radiation; readout each crystal separately

✓ ***GaAs photodiode***
Ultrathin Schottky barrier or p-i-n photodetector

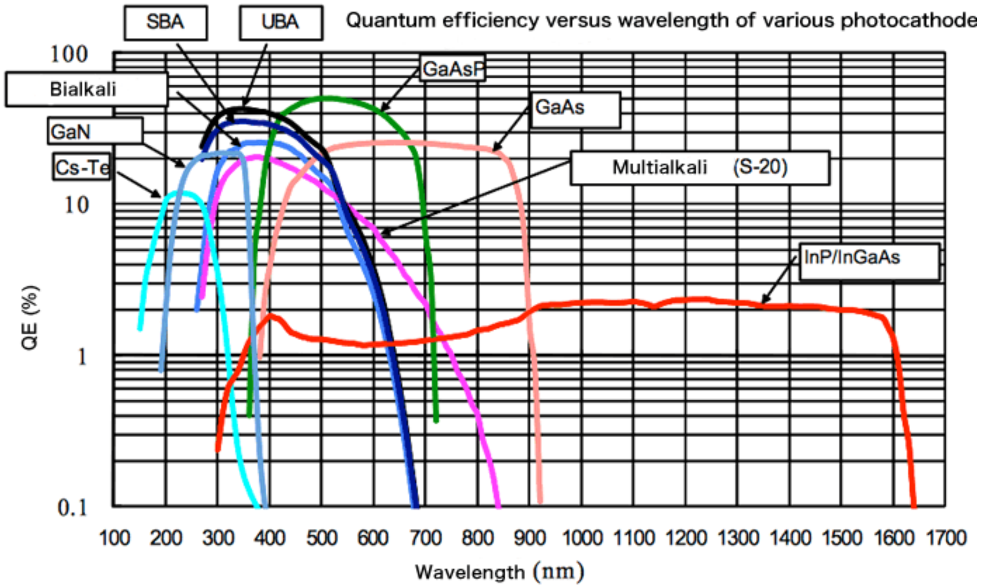
Parameters (epitaxial process:)

type	n
growth rate, mm/h	9–10
i-layer thickness, μm	up to 120
carrier concentration, cm^{-3}	$\sim 10^{11}$
$\mu_e \cdot \tau_e$, cm^2/V	$2 \cdot 10^{-4}$
$\mu_h \cdot \tau_h$, cm^2/V	$2 \cdot 10^{-5}$
EL2 concentration, cm^{-3}	$\sim 10^{12\,(*)}$



Note: EL2 defects concentration in GaAs produced by Czochralski process is ~10^{16} per cm^3

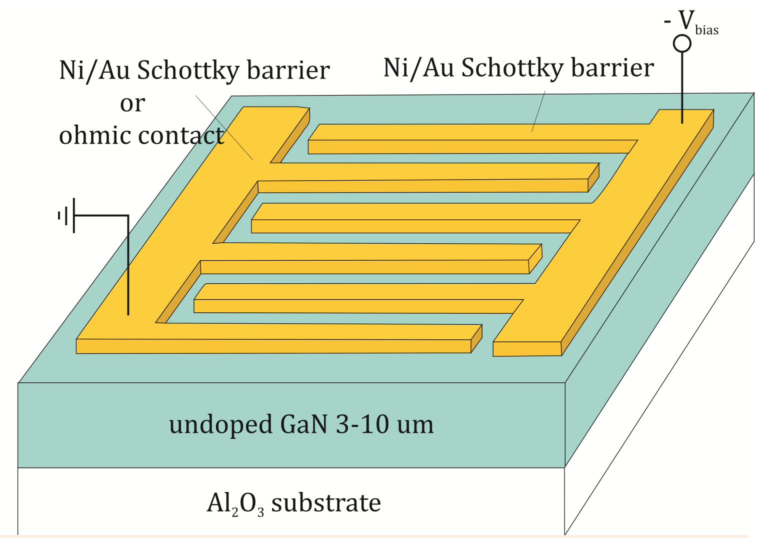
GaAs vs GaN photodiode



The maximum spectral sensitivity of GaAs is in the wavelength range of 450 to 800 nm
→ ***Ideally matching the green light from the GAGG crystal***

✓ ***GaN photodiode***

- *High radiation tolerance*
- *High temperature stability*
- *Simple design*
- ***Spectral range 250 – 350 nm***
  Good for LYSO crystal



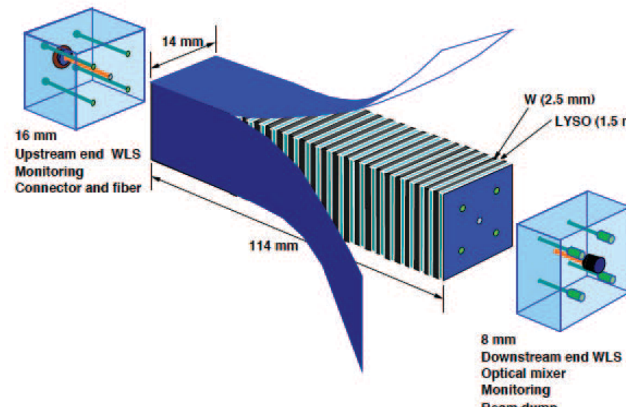
✓ ***If radiation hard, a combination of the GAGG (or LYSO) crystal with GaAS (or GaN) readout would provide very fast ECAL with good energy and spatial resolution, and longitudinal segmentation (+ directionality)***

Readout of the scintillating light at the rear of the module
(no longitudinal segmentation)
Need for radiation hard light guide to transport the light

✓ ***WLS fibres***

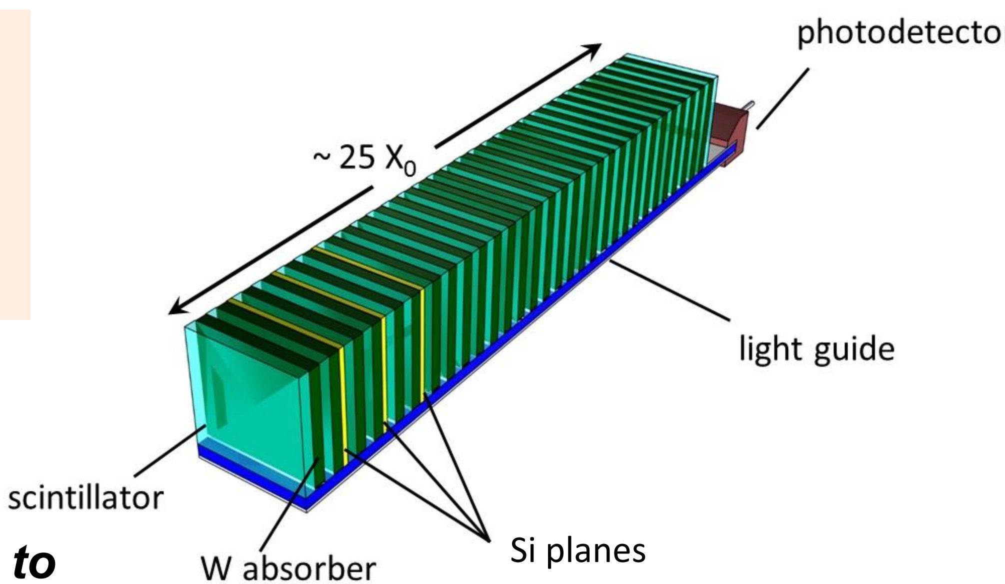
A "shashlik"-like solution for W-LYSO structure, with WLS fibers made of quartz capillaries filled with liquid WLS.

Not impossible also for W-GAGG structure, with, e.g., Rhodamine-6G as a WLS liquid (5-7 ns decay time).



✓ ***Thin plane light guide attached to side of the ECAL cell***
No WLS, but the scint. light can be transported using mirror reflection

Quartz plate or air gap with embedded system of micro mirrors to provide light transportation by mirror reflection.
The mechanical implementation has to be properly thought about



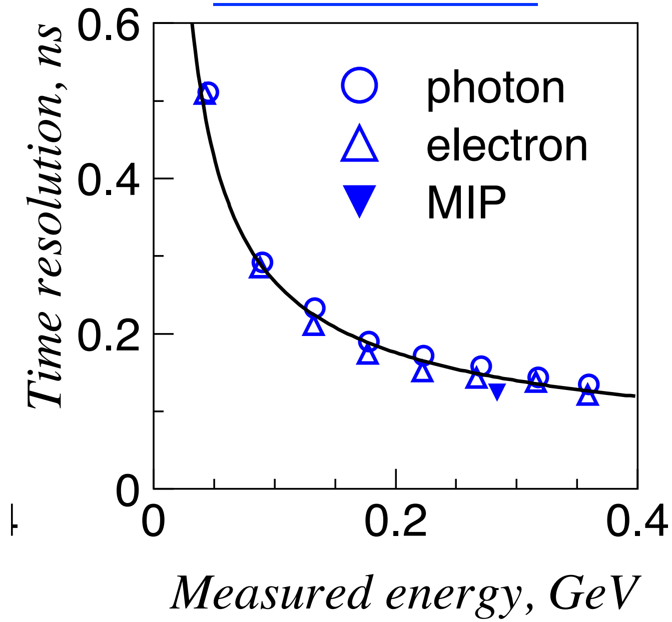
R&D towards improving time resolution

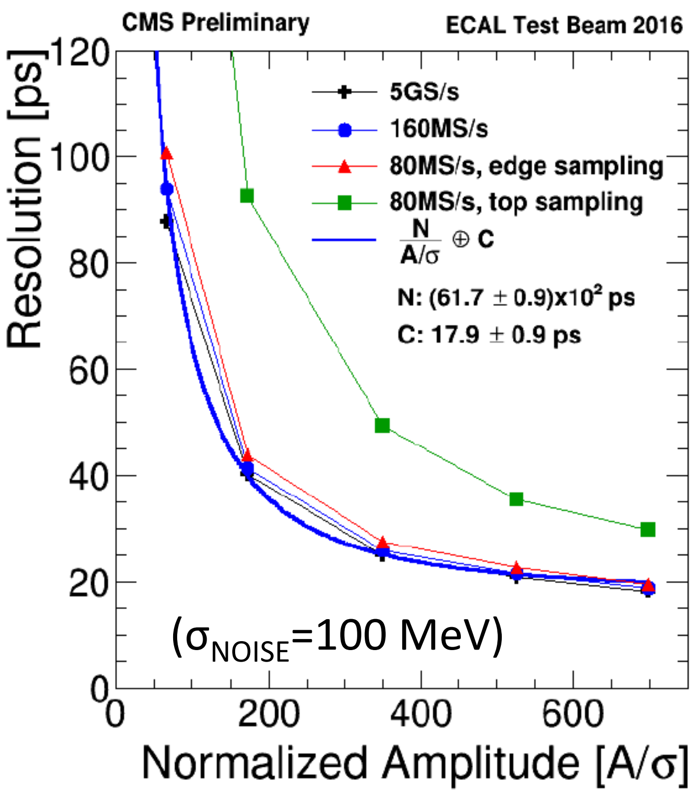
Timing measurements with good enough precision with (plastic or crystal based) Shashlik calorimeter can be feasible, see, e.g.: arXiv:0709.4514 – measurements for plastic based Shashlik (KOPIO), they claim

***$\sigma_T = (72 \pm 4)/\sqrt{E} \oplus (14 \pm 2)/E$ (ps)** for low energy photons by measuring the time difference of the same shower propagation in the two adjacent modules. Longitudinal shower fluctuations have been corrected by simulation.*

Data are well described by MC

arXiv:0709.4514





CMS $PbWO_4$ ECAL module (CMS CR -2016/408) has demonstrated very good time resolution (~20 ps) at the test beam → Hope to achieve a similar, or even better time resolution with GAGG crystal thanks to its large Light Yield