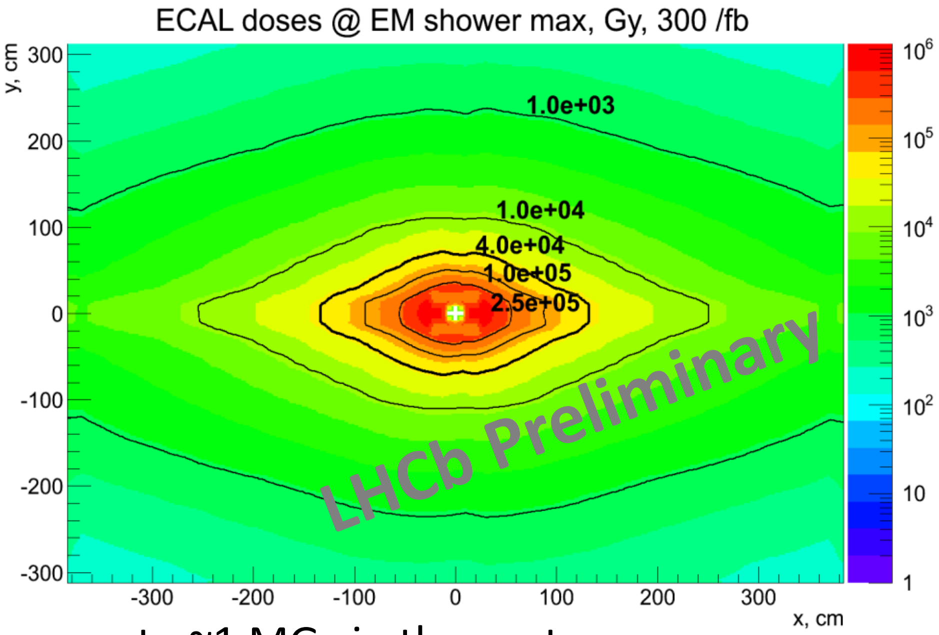
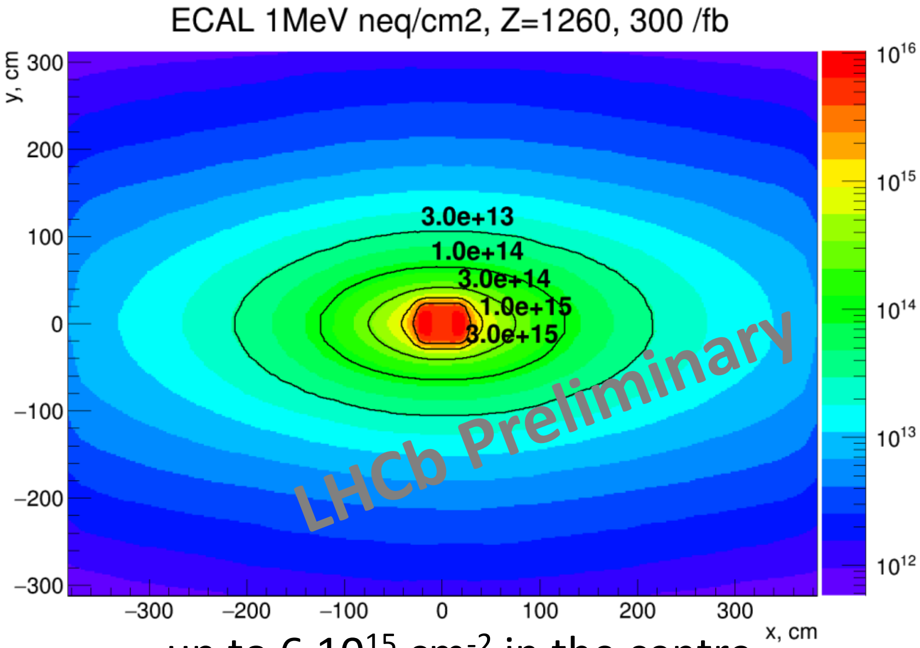
R&D plans for 2019

The SPACAL-RD group

LHCb ECAL, doses and 1 MeV neq (Matthias)


ECAL doses @ EM shower max, Gy, 300 /fb

up to ~1 MGy in the centre


ECAL 1MeV neq/cm2, Z=1260, 300 /fb

up to $6 \cdot 10^{15}$ cm^{-2} in the centre

(Shashlik is operational till $4 \cdot 10^4$ Gy).

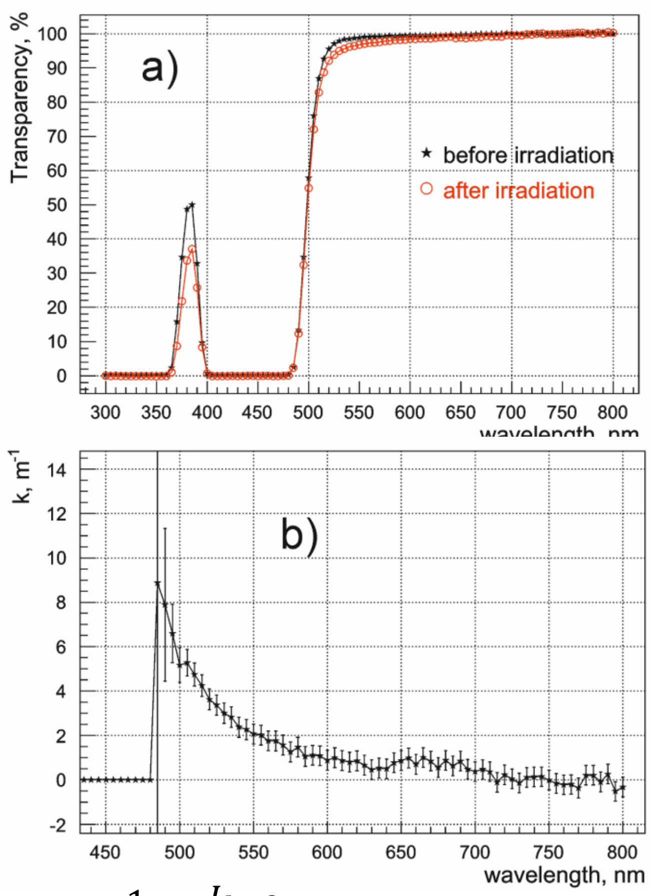
From simulation, we have to understand general requirements to the detector:

- occupancies, and how to mitigate them
  - detector zones
    - cell sizes, technologies, Molière radii, longitudinal segmentation *etc*
- Time measurements – requirements and options

Radiation hard scintillating crystals - GAGG

Irradiation 2017: 1 cm thick sample

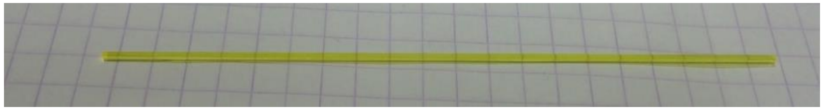
$3.1 \cdot 10^{15}$ ***p***/cm^2, 24 GeV (0.91 MGy)

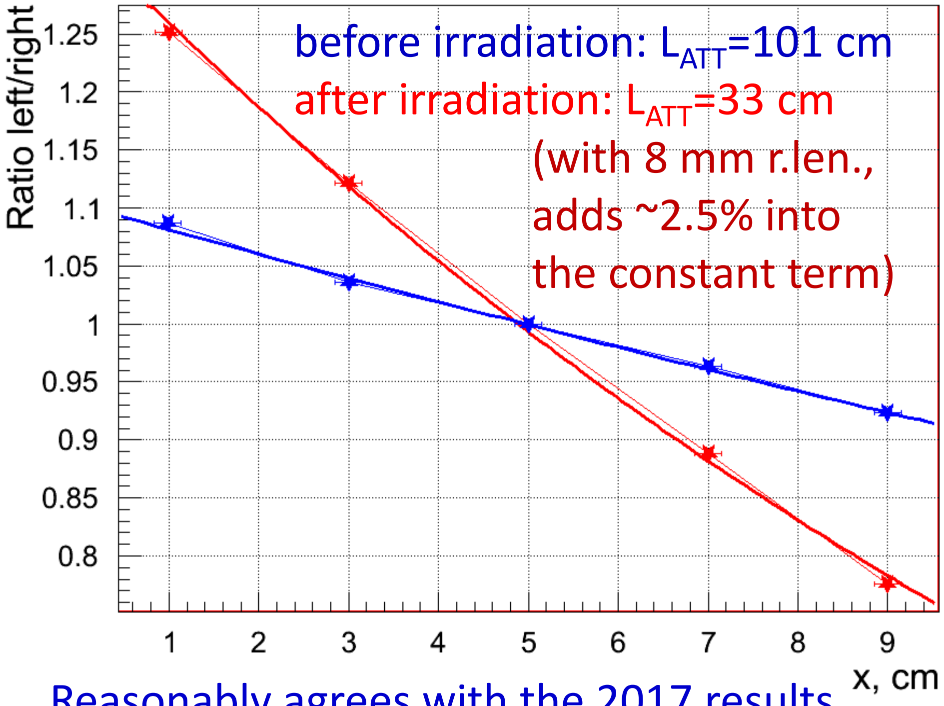


$$\kappa = \frac{1}{d} ln \frac{I_{before}}{I_{after}} = 3.6\ m^{-1}$$ at 520 nm

Irradiation 2018: SPACAL GAGG fiber, 10 cm

$3.5 \cdot 10^{15}$ ***p***/cm^2, 24 GeV (1.03 MGy)





before irradiation: L_{ATT}=101 cm

after irradiation: L_{ATT}=33 cm

(with 8 mm r.len., adds ~2.5% into the constant term)

Reasonably agrees with the 2017 results

(YAG:Ce has similar rad hardness)

GAGG- or YAG-based SPACAL is a viable solution for LHCb Upgrade-2!

Performance of technologies

To be studied:

SPACAL (no WLS – good option for high rad. zone)

- Angular dependence of energy resolution
- Optimization of sampling (fiber pitch, converter density)
- Intrinsic limitations on time measurement capability
  - shower fluctuations
  - scintillation process
  - light propagation in scintillating fibers
  - photodetector

Shashlik (good for the Outer zone(s))
(formally not SPACAL-RD, but also an important part of the future ECAL)

- Optimization of sampling (scintillator : converter)
- Intrinsic limitations on time measurement capability
  - shower fluctuations
  - scintillation process
  - light propagation in scintillator tiles
  - light absorption, re-emission and light propagation in WLS fibers
  - photodetector

Performance of components

Performance of optical components:

- GAGG
- YAG

innermost zone

- Plastic scintillators
- Plastic WLS fibers
- photodetector

outer zone(s)

In terms of:

- Radiation hardness
- Timing performance
- Constraints in dimension (for crystals)
- Cost

Performance of converter material:

- X0 and Molière radius
- Capability of tuning X0 and Molière radius (alloy)
- Flexibility and cost effectiveness for different geometries

Prototype studies

- Validation of simulation of SPACAL energy resolution
  - as function of angle and energy

- Performance of time measurement with SPACAL for electrons as function of
  - Scintillator type (GAGG or YAG)
  - Energy
  - Angle
  - longitudinal segmentation

- Performance of time measurement with Shashlik

Component studies

- Test bench measurements of GAGG and YAG
  - Light yield
  - Attenuation length
  - Scintillation kinetics (rise time, decay time)

- Photodetector studies
  - including samples irradiated to 1 MGy in 2018

- Development of different alloys for
  - tuning of X0 and Molière radius
    - Lead/W alloys
    - Cu/W alloys
  - Identifying best technology for integrating fibers

Prototypes

Components that we have at hand:

- SPACAL Cu/W converter with given fiber density
- GAGG
  - ~280 fibers of 10cm length
    - one 2cm x 2cm cell with 2 sections (10cm long) in Z
  - ~250 additional fibers to come
    - not quite a complete cell of 2cm x 2cm (?)
  - Few tiles for accordion type module investigations
- YAG
  - ~200 old + 900 new fibers of 10cm length
    - total of 4 cells of 2cm x 2cm (with 2 sections in Z)
- Kuraray SCSF-78 fibers:
  - ~580 of 20 cm length (4 cells of 2cm x 2cm)
  - Additional 500m ordered (-100 m to reimburse DT)

Prototypes

We could factorize different studies by use of different prototypes

- the 20 cm long prototype filled with Kuraray fibers to study SPACAL energy resolution and angle dependence for the MC validation
- 1 cell (2x2 cm^2) GAGG and YAG to study timing or
- 3cm x 3cm proto with GAGG and/or YAG with smaller cell size (e.g. 1cm?) to study timing
- 1 cell prototype (with smaller cell size?) to test photodiodes and other photodetectors
- Small prototype(s) to test different converter options

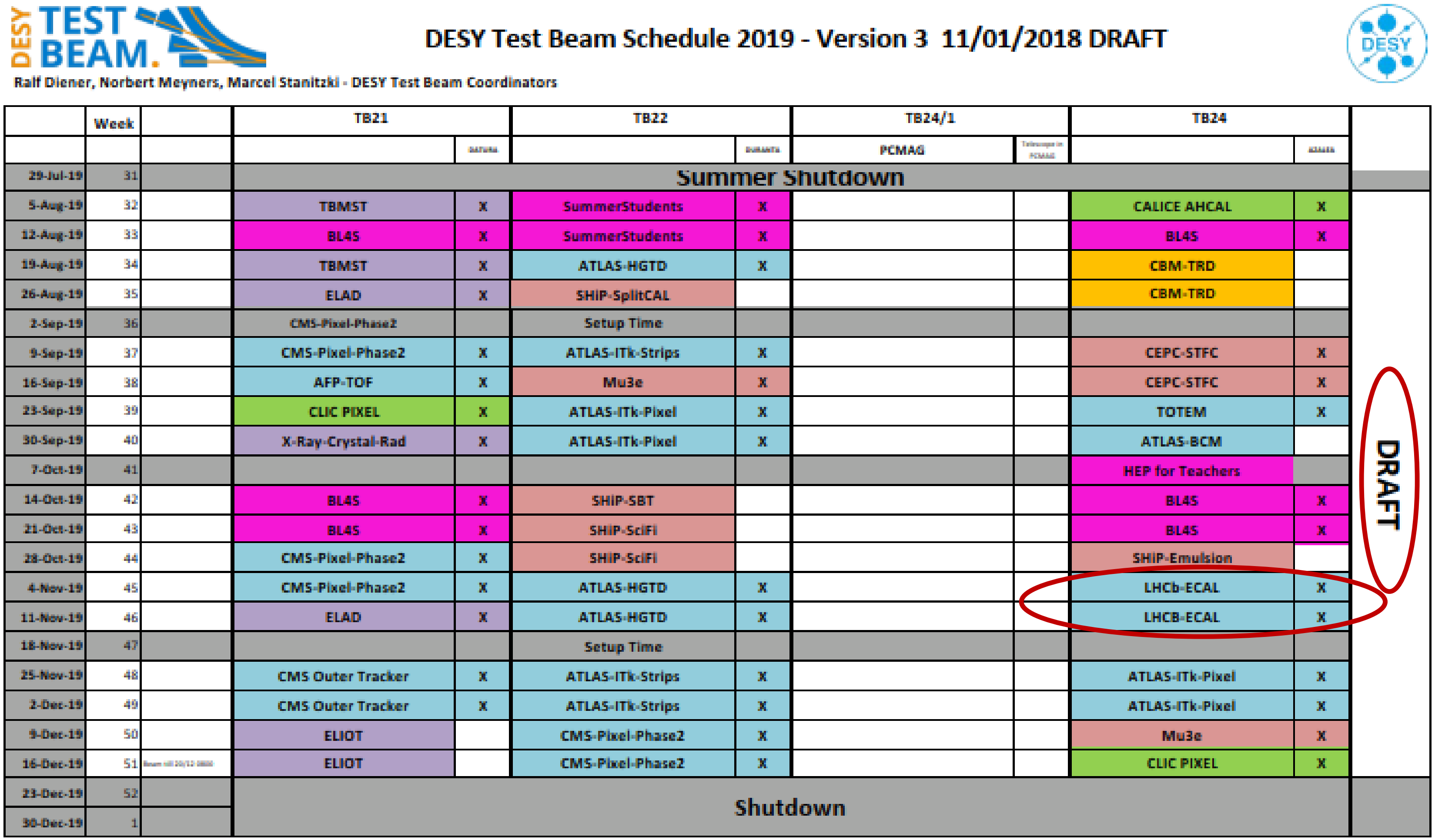
Components that we would need to order:

- GAGG?
- YAG?
- Pb/W converter for small prototype (3cmx3cm)?
- KURARAY WLS fibers (Y11)?

quantities are under discussion

beam test 2019 - DESY

We have beam time at the TB24 line of DESY II: preliminarily, two weeks

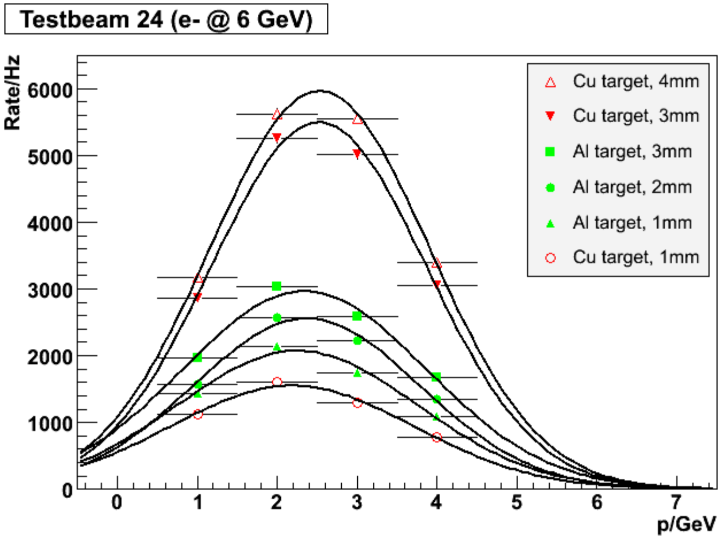


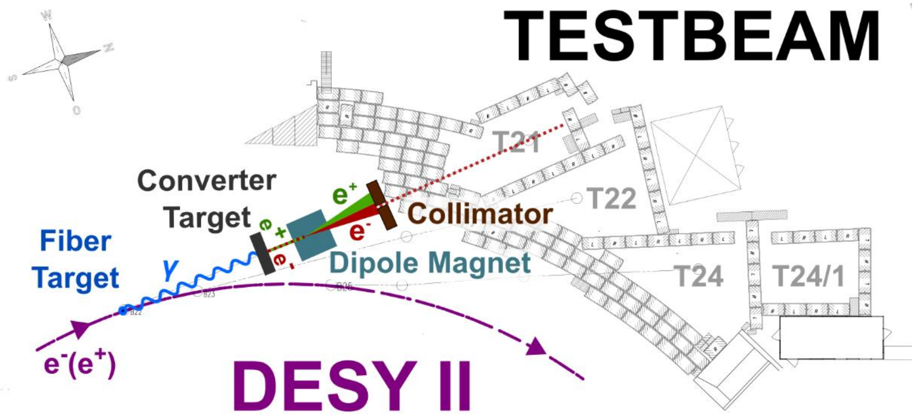
DESY Test Beam Schedule 2019 - Version 3 11/01/2018 DRAFT

Ralf Diener, Norbert Meyners, Marcel Stanitzki - DESY Test Beam Coordinators

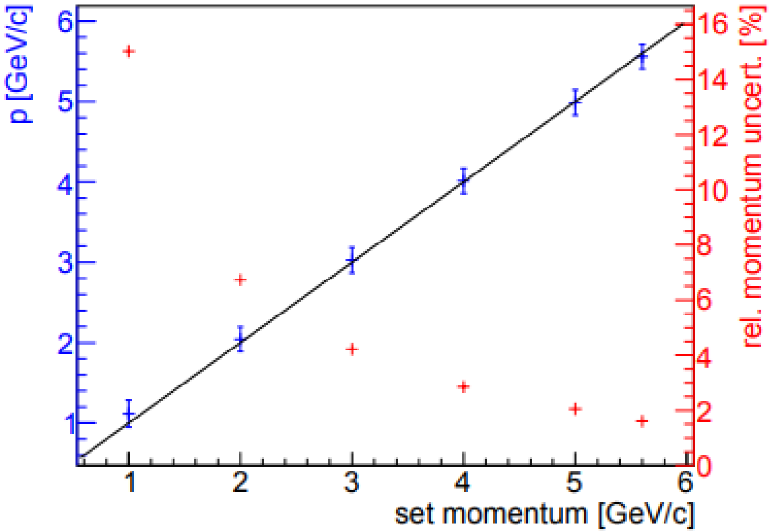
	Week		TB21		TB22		TB24/1		TB24		
				[illegible]		[illegible]	PCMAG	Telescope in PCMAG		[illegible]	
29-Jul-19	31		Summer Shutdown								
5-Aug-19	32		TBMST	X	SummerStudents	X			CALICE AHCAL	X	
12-Aug-19	33		BL4S	X	SummerStudents	X			BL4S	X	
19-Aug-19	34		TBMST	X	ATLAS-HGTD	X			CBM-TRD		
26-Aug-19	35		ELAD	X	SHiP-SplitCAL				CBM-TRD		
2-Sep-19	36		CMS-Pixel-Phase2		Setup Time						
9-Sep-19	37		CMS-Pixel-Phase2	X	ATLAS-ITk-Strips	X			CEPC-STFC	X	
16-Sep-19	38		AFP-TOF	X	Mu3e	X			CEPC-STFC	X	
23-Sep-19	39		CLIC PIXEL	X	ATLAS-ITk-Pixel	X			TOTEM	X	
30-Sep-19	40		X-Ray-Crystal-Rad	X	ATLAS-ITk-Pixel	X			ATLAS-BCM		DRAFT
7-Oct-19	41								HEP for Teachers		
14-Oct-19	42		BL4S	X	SHiP-SBT				BL4S	X	
21-Oct-19	43		BL4S	X	SHiP-SciFi				BL4S	X	
28-Oct-19	44		CMS-Pixel-Phase2	X	SHiP-SciFi				SHiP-Emulsion		
4-Nov-19	45		CMS-Pixel-Phase2	X	ATLAS-HGTD	X			LHCb-ECAL	X	
11-Nov-19	46		ELAD	X	ATLAS-HGTD	X			LHCB-ECAL	X	
18-Nov-19	47				Setup Time						
25-Nov-19	48		CMS Outer Tracker	X	ATLAS-ITk-Strips	X			ATLAS-ITk-Pixel	X	
2-Dec-19	49		CMS Outer Tracker	X	ATLAS-ITk-Strips	X			ATLAS-ITk-Pixel	X	
9-Dec-19	50		ELIOT		CMS-Pixel-Phase2	X			Mu3e	X	
16-Dec-19	51	[illegible]	ELIOT		CMS-Pixel-Phase2	X			CLIC PIXEL	X	
23-Dec-19	52		Shutdown								
30-Dec-19	1										

beam test 2019 - DESY



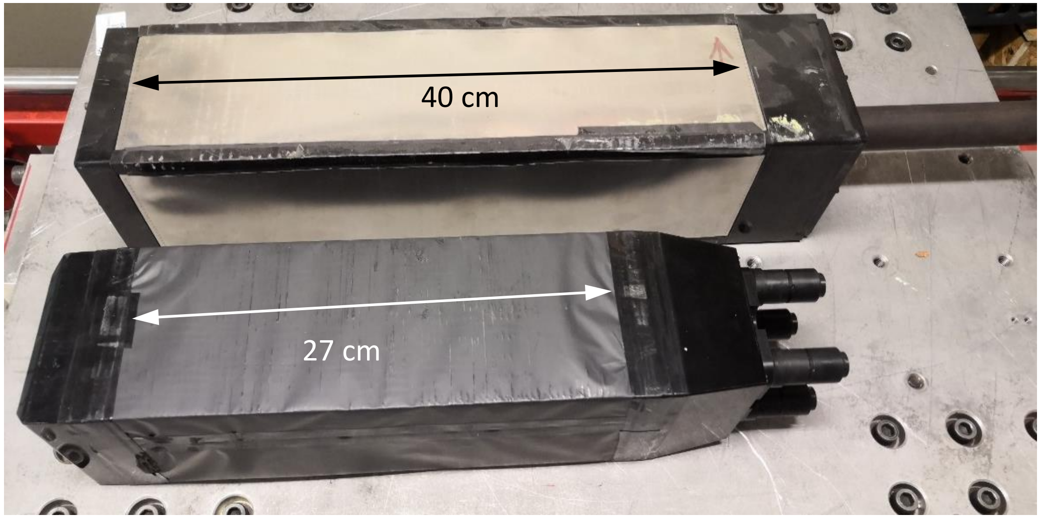


$14{\cdot}10^9$ e^- in DESY II, 6 GeV, collimators @ 5x5 mm^2.



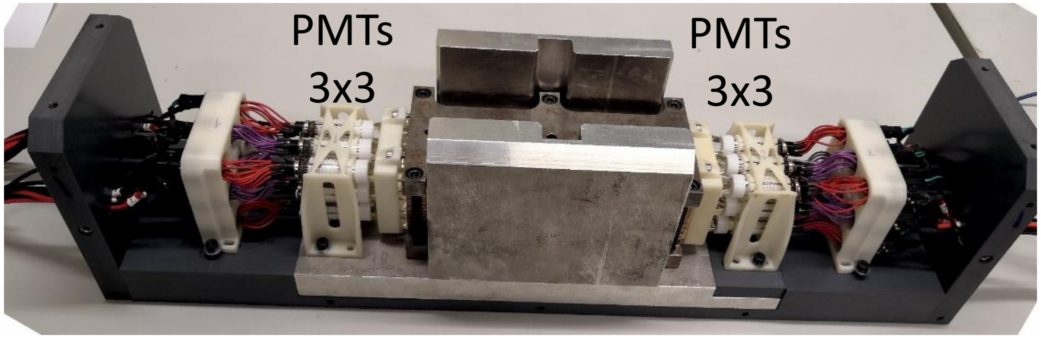
electrons or positrons
reasonable rate (~kHz) at 3-4 GeV
~3% momentum uncertainty

Prototypes used for beam test – 2018



present ECAL module
shashlik, Pb:Sc = 1:2 (vol)
$25X_0$ = 40cm; R_M=36mm

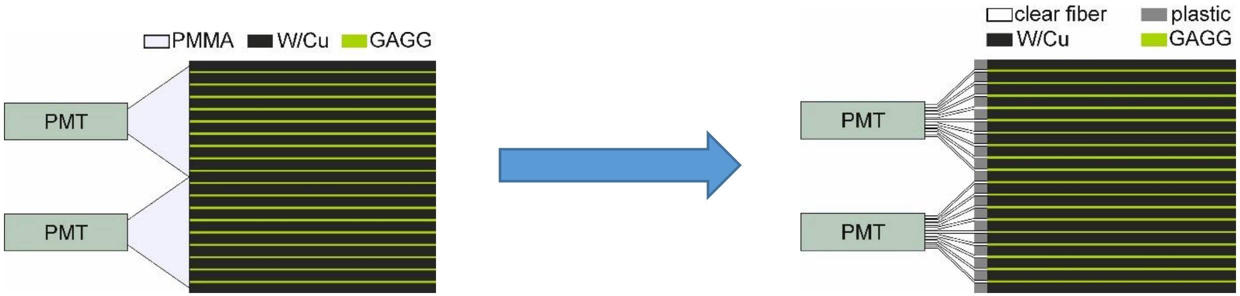
“short” shashlik module
Pb:Sc = 1:1 (vol)
$25X_0$ = 27cm; R_M=27mm
(produced in Protvino, 2017)



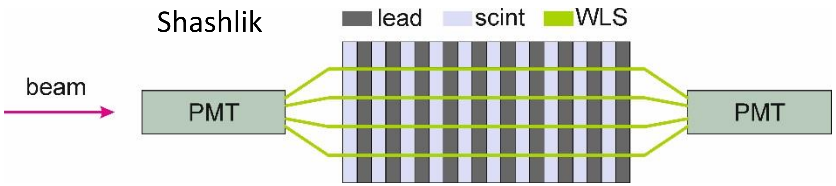
crystal/W
SPACAL, *W:Sc = 1:0.6,*
~$28X_0$ = 20cm; R_M=16mm

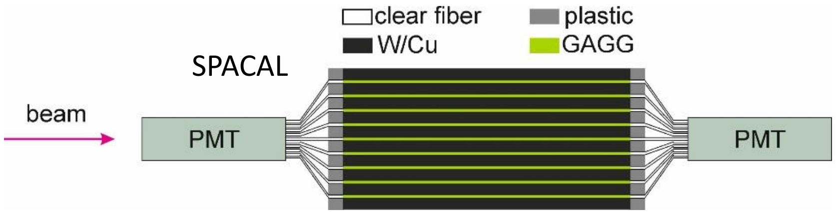
beam test 2019 - DESY

- The measured SPACAL energy resolution is *better* than in MC
  - investigations are ongoing from both sides, MC and data analysis
  - there are few things in the setup which can affect calibration and measurement of energy resolution (now under study):
    - converter density
    - light cross talk, due to light guides design
    - calibration procedure(s)
  - to validate the MC, we may have to re-measure the resolution in a simpler configuration
    - only one sort of fibers (plastic)
    - modified light readout, to eliminate the cross talk and improve uniformity: replace PMMA cones with individual clear-PSM fiber for each GAGG fiber



beam test 2019 - DESY

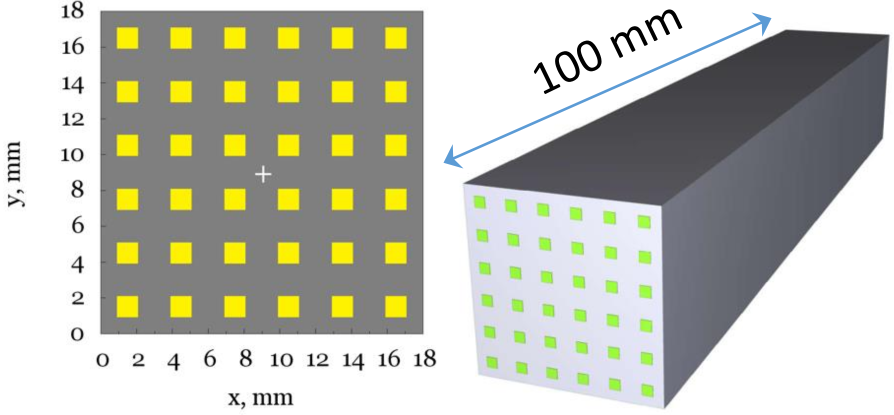




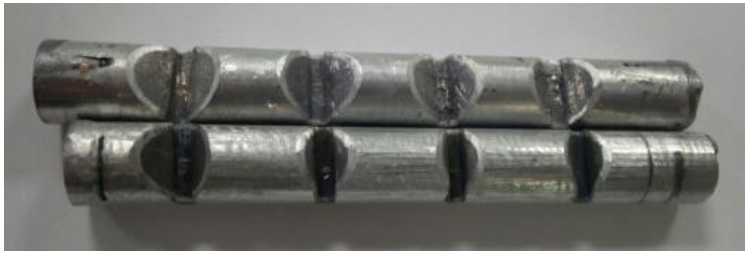
- The time resolution of the prototypes (even of Shashlik, even with PMT readout) turned out to be reasonably good, but still worse than needed
  - there is an indication that it is largely due to the longitudinal fluctuations of shower
  - we can try to improve the resolution by reading out the same light from both front and back
    - the shower longitudinal position will be resolved
    - to be tested

For SPACAL, we can either use existing prototype (available, courtesy M. Korjik), or produce a new one

GAGG+W/Cu<12.7 g/cm^3>



Absorber production R&D



The idea consists in baking the crystal fibers in W/Pb powder:
as crystal fibers can stand high temperature, this can be an attractive option.

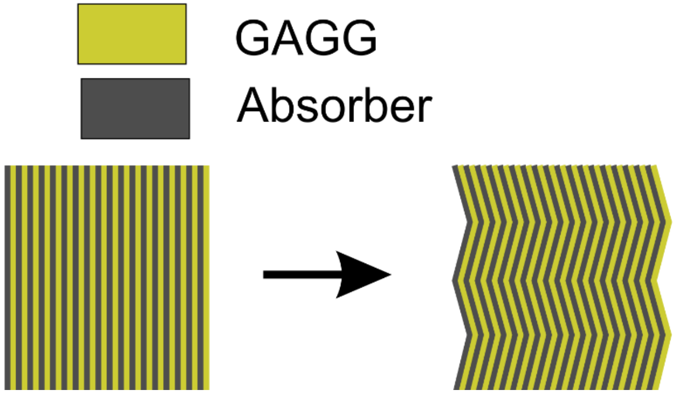
R&D is ongoing in MISIS. The aim for 2019 is to build a 1-cell prototype, 10 cm long.

GaAs photodiode R&D

- Irradiation tests on MOCVD GaAs diodes with an active area of 4800 sq. microns carried out in 2017 with 24 GeV protons (the irradiation doses were 10, 30, 100 Mrad)
- all samples remained in good working order after irradiation
- measured increase in the generation current was a few tens of μA/cm^2 at irradiation dose of 100 Mrad

- The PIN photodiodes were then produced for subsequent studies, including irradiation.
  - The samples of GaAs photodiodes irradiated in 2018 up to ~1 MGy are on the way to Moscow for measurements.

SPACAL⊗Accordion



In order to improve the SPACAL performance at incident angles ~90°: the front section can be built as an Accordion-like structure.

The scintillating element:

- can have cross section ~ 10x1 mm^2;
- the GAGG refraction index is ~1.9
  - at bending angles ~10° most of the light will be kept by total internal reflection
  - eventual difference between the light yield of the sections can be compensated, e.g., by varying the section's thickness

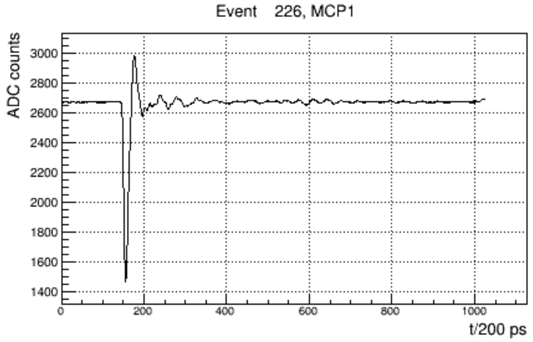
The absorber:

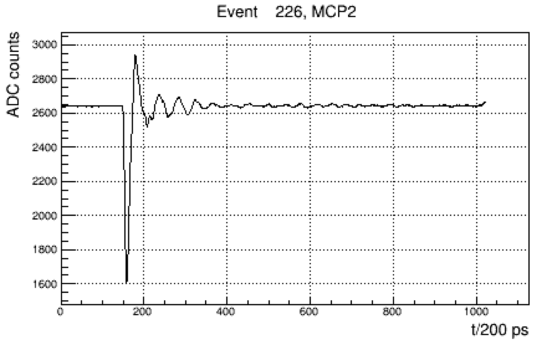
- for the front section, the showers are narrow -> Lead can be considered

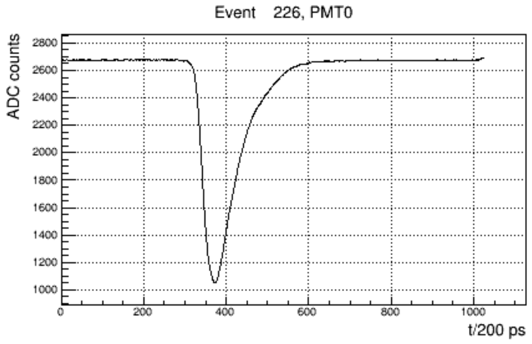
- the scintillating element can be produced by
  - gluing of pieces (produced, R&D is ongoing in FOMOS, Moscow)
  - welding
  - or continuous cut from ingot

spares

Time measurements – I



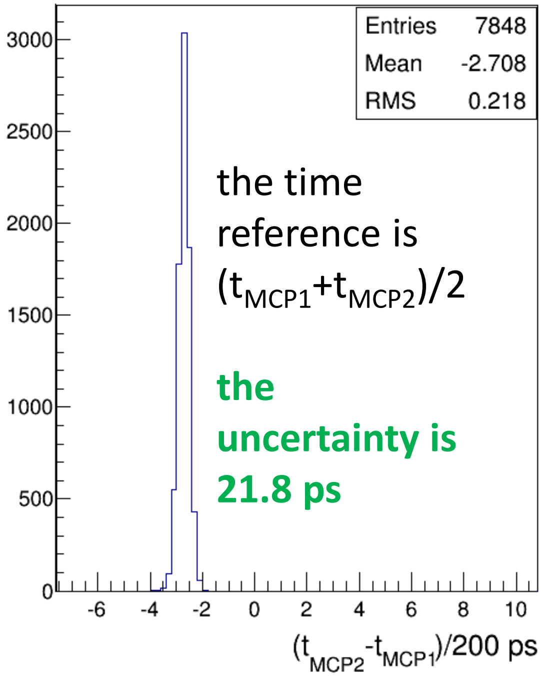




Here: standard shashlik, 30 GeV electrons, PMT readout
The time measurement: moment of time, corresponding to crossing of 50% of amplitude ("offline CFD").

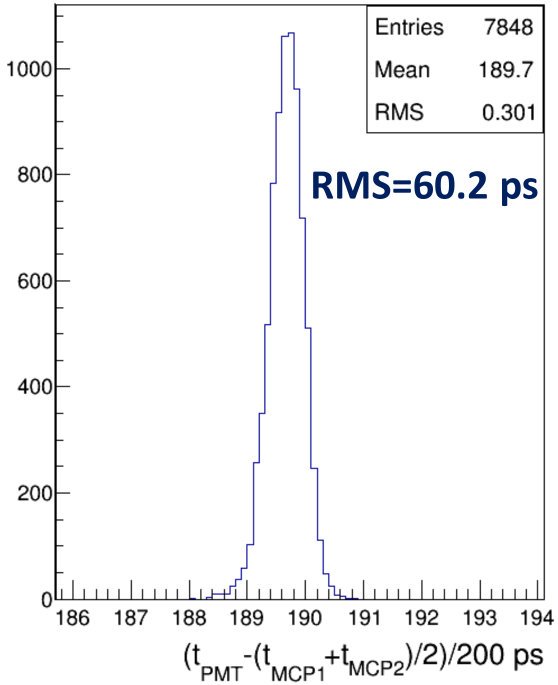
The ECAL module time resolution for 30 GeV:

$$\sqrt{60.2^2 - 21.8^2} \approx 56.1 \text{ ps}$$



the time reference is $(t_{MCP1}+t_{MCP2})/2$

the uncertainty is 21.8 ps



RMS=60.2 ps

Time measurements – II

Present ECAL module with present PMT readout (R7899-20)

E, GeV		<t>, **n**s	σ(t), ps	
20	APD @ 385V	17.4	77	worse than PMT?
20	PMT @ 800V	37.9	69	
30	PMT @ 800V	37.9	56	
30	PMT @ 750V	38.6	57	
30	PMT @ 700V	40.0	77	noise contribution?

Time measurements – II

Short Shashlik module with present PMT readout (R7899-20)
Here, tests were done with beam entering from front and from back (PMT side)

E, GeV		beam dir	<t>, **ns**	σ(t), ps
20	PMT @ 1000V	normal	34.3	66
20	PMT @ 1000V	back	34.9	177

Such a big difference suggests that the time resolution is mainly determined by longitudinal shower fluctuations. For two identical showers started at z and z+Δz, the time difference is $\frac{\Delta z}{c}(n-1)$ for normal beam direction and $\frac{\Delta z}{c}(n+1)$ otherwise (n is the refractive index of the WLS fibres of Shashlik, n≈1.59).

The time resolution is not much better than with present ECAL
- a noisy PMT was accidentally installed

Time measurements – III

SPACAL module with PMT readout (R12421), GAGG section

E, GeV		<t>, **n**s	σ(t), ps
20	PMT @ 630V	27.5	85
20	PMT @ 730V	26.1	78

The time resolution is modest. However the beam enters from the back side (see previous slide). For a different configuration, with a beam entering from “front”, one can expect 2-3 times better (30-40 ps), if the speculations at the previous slide are valid and the time resolution is mainly determined by longitudinal shower fluctuations.

	$Y_3Al_5O_{12}$:Ce (YAG)*	**$Lu_3Al_5O_{12}$: Ce (LuAG)***	**$Gd_3Al_2Ga_3O_{12}$**: Ce (GAGG)**	**Lu_2SiO_5:Ce (LSO)**
density (g/cm^3)	4.57	6.73	6.63	**7.4**
X_0 (cm)	3.5 cm	1.3	1.59	1.1
Refraction index	1.83	1.84	1.85	1.82
Λ_{max} (nm)	**550**	**535**	**520**	**420**
LY @ RT (ph/MeV)	**35000**	**25000**	**50000**	**30000**
decay time (ns)	70 + slow component	70 + slow component	60 + slow component	**40**

Requirements to the detector

From simulation, we have to understand general requirements to the detector:

- radiation doses (mostly known from FLUKA simulations by Gloria and Matthias)
- occupancies, and how to mitigate them
  - detector zones, cell sizes
  - required detector structure in each zone (technologies, Molière radii, longitudinal segmentation *etc*)

- Also contribute to the resulting detector structure
  - time measurement requirements to disentangle pileup
  - time measurement algorithms
    - and their implementation into electronics