γ – LASER Mode
Beam Monitoring & Scintillation Detectors

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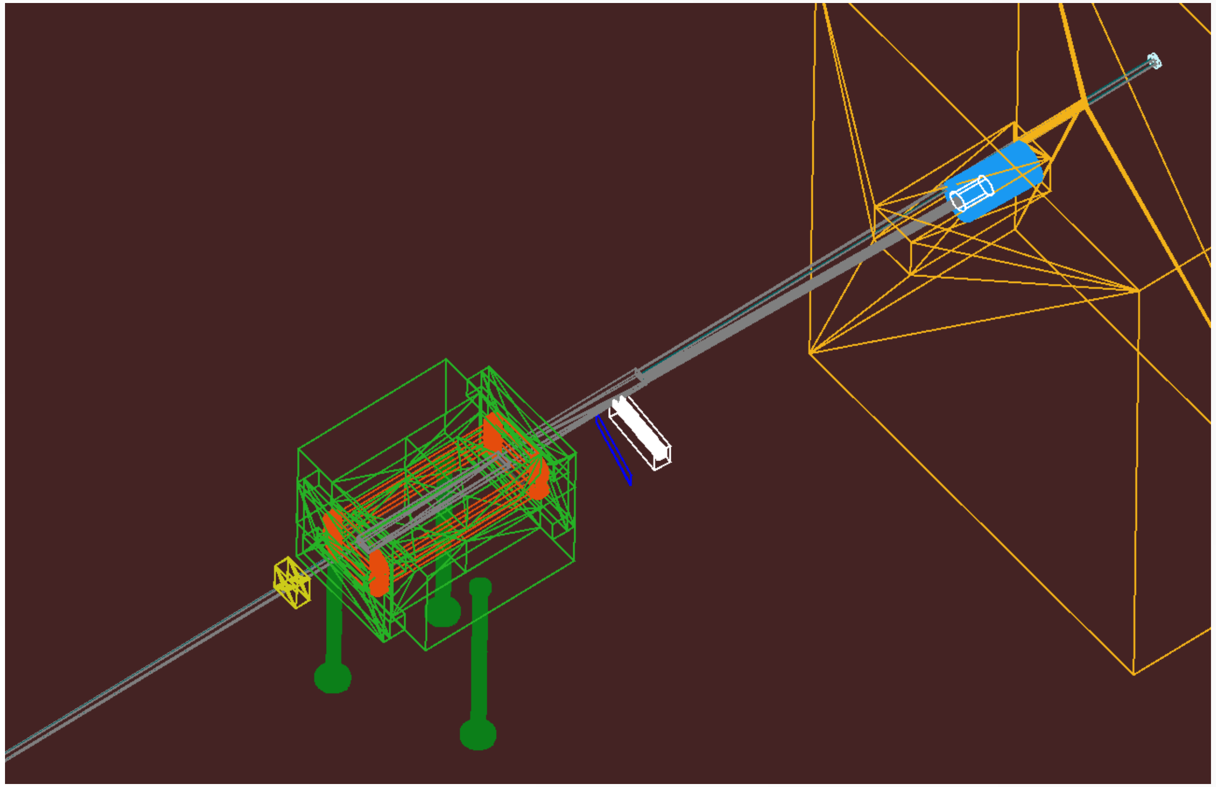
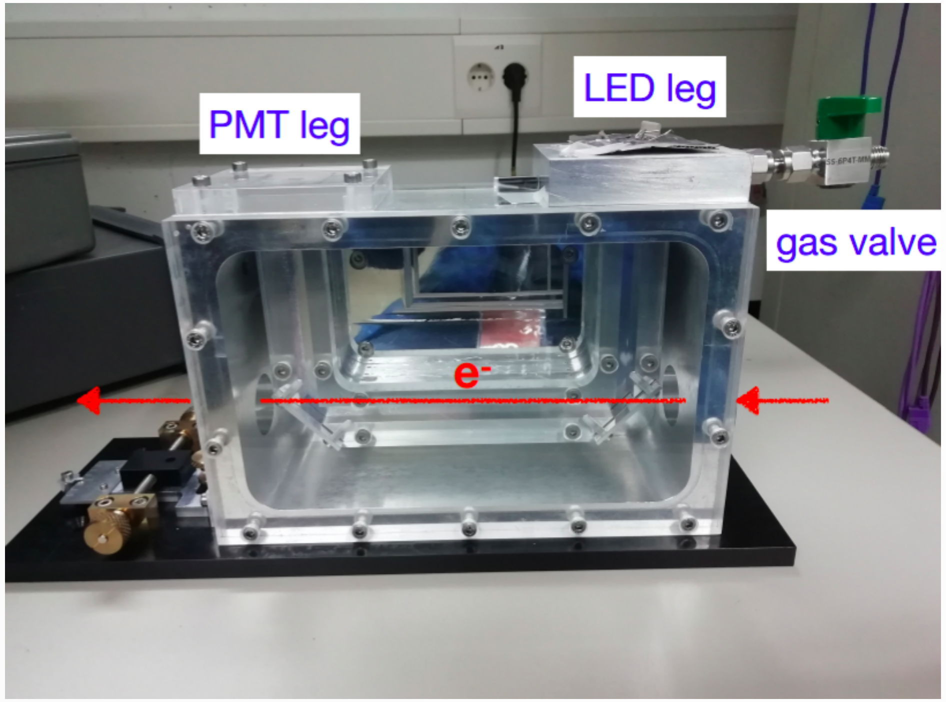
Scintillator/Cerenkov in GEANT4

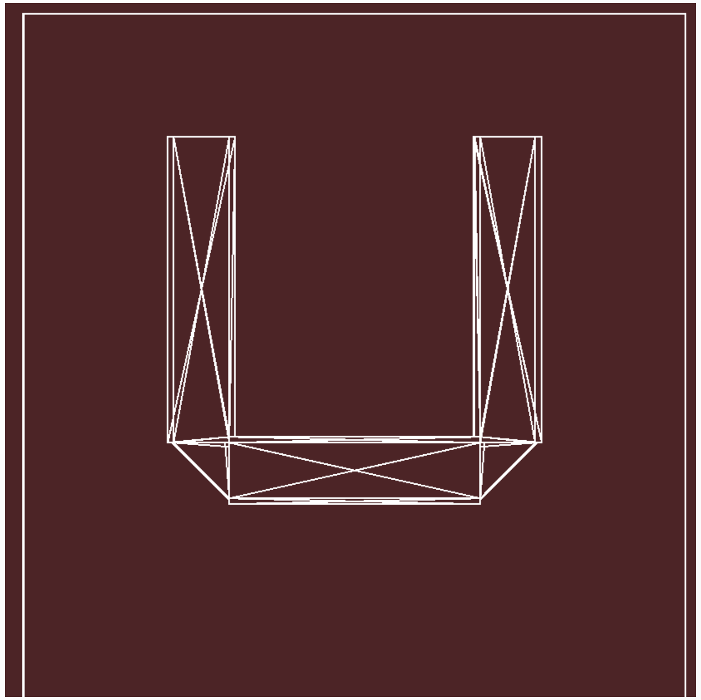
Have implemented geometries for an example simple Scintillating screen and more detailed Cerenkov Devices. Instantiated by

DetectorConstruction::ConstructScintCerenkov()

Takes key parameters from LXSetUp.cc







Scintillator/Cerenkov in GEANT4

I have set up Cerenkov and Scintillation Physics which can be turned on or off, and collect data for histograms (HistoManager) in SteppingAction.

These processes slow down simulation but should not affect validity of background simulation at IP.

Will push a version with these detectors to lxsim git stash (new branch) with physics/histograms commented out

```
ScintCerenkovPhysics = false;
ScintAngle = 15. *deg;
ScintXpos = -350. *mm;
ScintZpos = DumpMagnetZpos + (1520./2. + 300.) *mm; //  defining in relation to position of the beam-dump magnet and its length
CerenkovAngle = 5. *deg;
CerenkovXpos = -340. *mm;
CerenkovZpos = DumpMagnetZpos + (1520./2. + 500.) *mm;
ScintX = 500. *mm;
ScintY = 100. *mm;
ScintZ = 1. *mm;
CerenkovWallWidth = 0.15 *mm;
CerenkovBoxThickness = 1. *mm;
CerenkovWindowThickness = 0.3 *mm;
CerenkovchannelX = 9. *mm;
CerenkovchannelY = 9. *mm;
CerenkovchannelZ = 50. *mm;
CerenkovChannels = 50;          // will crash if not even!! unfortunately..
CerenkovLegHeight = 50. *mm;
ScintMaterial = "Polystyrene";
CerenkovMetal = "Aluminium";
CerenkovMedium = "ArgonGas";
```

Scintillator/Cerenkov in GEANT4

These materials take a fair load of memory (compared to the rest of the geometry)

So, given time, I can make a simplified version, if necessary

This was done in lxsim retrieved Sunday. Code has changed since (Dump + magnet rotated 90°) and needs tweaks

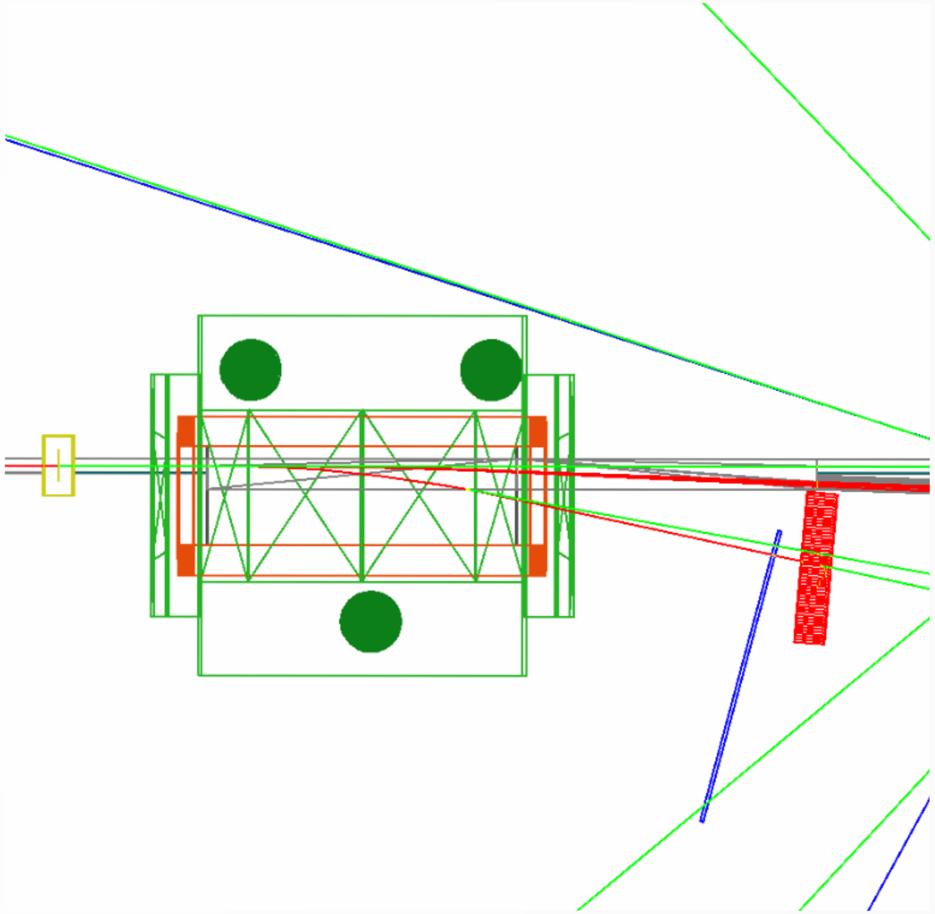
```
G4GeometryManager::ReportVoxelStats -- Voxel Statistics

    Total memory consumed for geometry optimisation:   405 kByte
    Total CPU time elapsed for geometry optimisation: 0.01 seconds

    Voxelisation: top CPU users:
    Percent   Total CPU    System CPU       Memory  Volume
    -------   ----------   ----------     --------  ----------
     100.00         0.01         0.00         96k  World
       0.00         0.00         0.00          1k  logicTAUICContainer
       0.00         0.00         0.00         24k  logicTypMBMagnetContainer
       0.00         0.00         0.00         24k  logicTypMBMagnetContainer
       0.00         0.00         0.00          0k  logicComptonDetContainer
       0.00         0.00         0.00          1k  logicBPipeComptonContainer
       0.00         0.00         0.00          0k  logicDetContainer
       0.00         0.00         0.00          0k  logicBremsTargetContainer
       0.00         0.00         0.00          1k  logicGMContainer
       0.00         0.00         0.00          0k  logicGammaTargetContainer

    Voxelisation: top memory users:
    Percent     Memory      Heads    Nodes   Pointers    Total CPU    Volume
    -------   --------     ------   ------   --------   ----------    ----------
      63.54       257k        647     2892       9828         0.00    CerenkovWingLogical
      23.69        96k        212     1260       2838         0.01    World
       5.79        23k         57      286        779         0.00    logicTypMBMagnetContainer
       5.79        23k         57      286        779         0.00    logicTypMBMagnetContainer
       0.32         1k          7       10         44         0.00    logicGMContainer
       0.27         1k          4       13         28         0.00    logicTAUICContainer
       0.19         0k          3        9         19         0.00    logicBPipeComptonContainer
       0.15         0k          3        5         20         0.00    logicVCContainer
       0.07         0k          1        3          8         0.00    logicComptonDetContainer
       0.07         0k          1        3          8         0.00    logicDetContainer
G4WT5 > /run/verbose 2
```

Implementation

We are implementing a union of the two detectors to measure the e- energy spectrum.

A Cherenkov set-up to measure the high-flux high-energy part of the spectrum, and a scintillator – with some cross-over region – to measure the low-energy (more important!) part of the distribution.

The cross-over region may be constructed as long as desired, as the Scintillating screen will have little effect on the Cherenkov signal.



Scintillating Material

Plastic-based materials are cheap and flexible in molds.

This material is unfortunately susceptible to radiation damage, in a way that is not well understood.

It's unlikely, given this and the typically lower light output, that a plastic mold will be used.

PROPERTIES	EJ-200	EJ-204	EJ-208	EJ-212
Light Output (% Anthracene)	64	68	60	65
Scintillation Efficiency (photons/1 MeV e^-)	10,000	10,400	9,200	10,000
Wavelength of Maximum Emission (nm)	425	408	435	423
Light Attenuation Length (cm)	380	160	400	250
Rise Time (ns)	0.9	0.7	1.0	0.9
Decay Time (ns)	2.1	1.8	3.3	2.4
Pulse Width, FWHM (ns)	2.5	2.2	4.2	2.7
No. of H Atoms per cm^3 ($x10^{22}$)	5.17	5.15	5.17	5.17
No. of C Atoms per cm^3 ($x10^{22}$)	4.69	4.68	4.69	4.69
No. of Electrons per cm^3 ($x10^{23}$)	3.33	3.33	3.33	3.33
Density (g/cm^3)	1.023	1.023	1.023	1.023
Polymer Base	Polyvinyltoluene			
Refractive Index	1.58			
Softening Point	75°C			
Vapor Pressure	Vacuum-compatible			
Coefficient of Linear Expansion	7.8×10^{-5} below 67°C			
Light Output vs. Temperature	At 60°C, L.O. = 95% of that at 20°C No change from 20°C to -60°			
Temperature Range	-20°C to 60°C			

example plastic scintillators from https://eljentechnology.com/products/plastic-scintillators/ej-200-ej-204-ej-208-ej-212

Scintillating Material

Inorganic, crystalline scintillators will typically produce more light per unit energy.

Will also be more sensitive to temperature fluctuations but this should be controllable.

Scintillator	Light yield (photons/keV)	Light ouput(%) of NaI(Tl) bialkali pmt	Temperature coefficient of light output(%/C) 25°C to 50°C	1/e Decay time(ns)	Wavelength of max emission lm(nm)	Refractive index at lm	Thickness to stop 50% of 662 keV photons (cm)	Thermal expansion (/C)x10^{-6}	Density g/cm^3	Hygroscopic	Comments
$LaBr_3$(Ce+Sr)	73	190	0	25	385	-2.0	1.8	8	5.08	yes	Ultimate energy resolution (2.2% @ 662keV)
$LaBr_3$(Ce) BrilLanCe™ 380	63	165	0	16	380	-1.9	1.8	8	5.08	yes	General purpose, excellent energy resolution
CLLB $Cs_2LiLaBr_6$(Ce)	43	115		180 1080	420	-1.85	2.2	--	4.2	yes	Dual Gamma-Neutron detection, excellent
NaI(Tl)	38	100	-0.3	250	415	1.85	2.5	47.4	3.67	yes	General purpose, good energy resolution
NaI(Tl+Li)	35	100	-0.3	230. 1.1μs 240, 1.4μs	419	1.85	2.5	47.4	3.67	yes	Neutron-Gamma Scintillator
$LaCl_3$(Ce) BrilLanCe™ 350	49	70-90	0.7*	28	350	-1.9	2.3	11	3.85	yes	General purpose, good energy resolution
CsI(Na)	41	85	-0.05	630	420	1.84	2	54	4.51	yes	High Z, rugged
LYSO $Lu_{1.8}Y_{.2}SiO_5$(Ce)	33	87	-0.28	36	420	1.81	1.1	--	7.1	no	Bright, high Z, fast, dense, background from ^{176}Lu activity
CdWO4	12-15	30-50	-0.1	14000	475	-2.3	1	10.2	7.9	no	Low afterglow, for use with photodioides
CaF2(Eu)	19	50	-0.33	940	435	1.47	2.9	19.5	3.18	no	Low Z, α & β detection

Example inorganic scintillators from https://www.crystals.saint-gobain.com/products/crystal-scintillation-materials

Camera

We can effectively measure the screen from nearly any angle as light emission is isotropic. We can also make use of mirrors to reflect the light toward the camera, as long as the light intensity is high enough for the optical path distance. We therefore have some freedom here. Must study the possible adverse effects of background radiation with simulation.

Scientific Cameras + Lens can be very expensive. Need to understand if we really need such an expensive setup!

One thing we might not need is fast shutter speed with bunch arrival 10 Hz. Will investigate soon..

Exact camera used in AWAKE:
Andor iStar 340T can cost ~ €50k

Alternatively for ~ €1k:

acA2000-340km - Basler ace

The Basler acA2000-340km Camera Link camera with the CMOSIS CMV2000 CMOS sensor delivers 340 frames per second at 2 MP resolution.

Summary

Scintillator and Cerenkov Devices instantiated in lxsim GEANT4 branch 'ScintCerenkov'.

Scintillator screen Dimensions/Geometry – Largely figured out

Scintillator screen Material – Working out an optimal choice

Scintillator Supporting structures – Depends on Scintillator material

Optical Path – depends on Calculations/simulation still to be done

Camera – Requires further understanding before advancing

DAQ – Details depend on camera

Extra – Beampipe modifications – To be simulated to determine if this is necessary/useful

Backup

Further Reading:

Evidence of deep-blue photon emission at high efficiency by common plastic
H. Nakamura, Y. Shirakawa, S. Takahashi and H. Shimizu
https://iopscience.iop.org/article/10.1209/0295-5075/95/22001/fulltext/

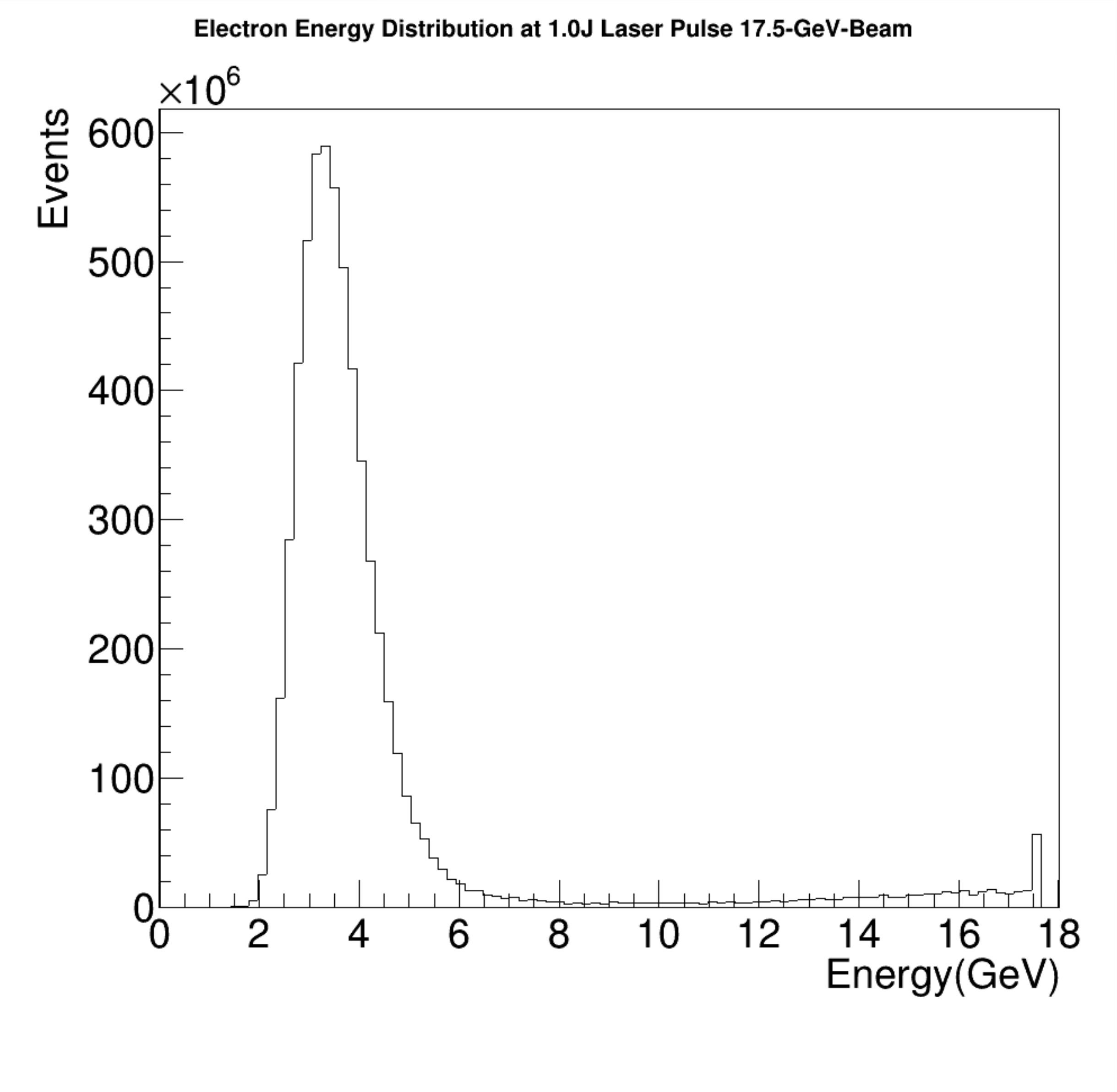
Matthew's talk, present on the indico Main meeting page. Wednesday, 15 January 2020
https://indico.desy.de/indico/event/25104/

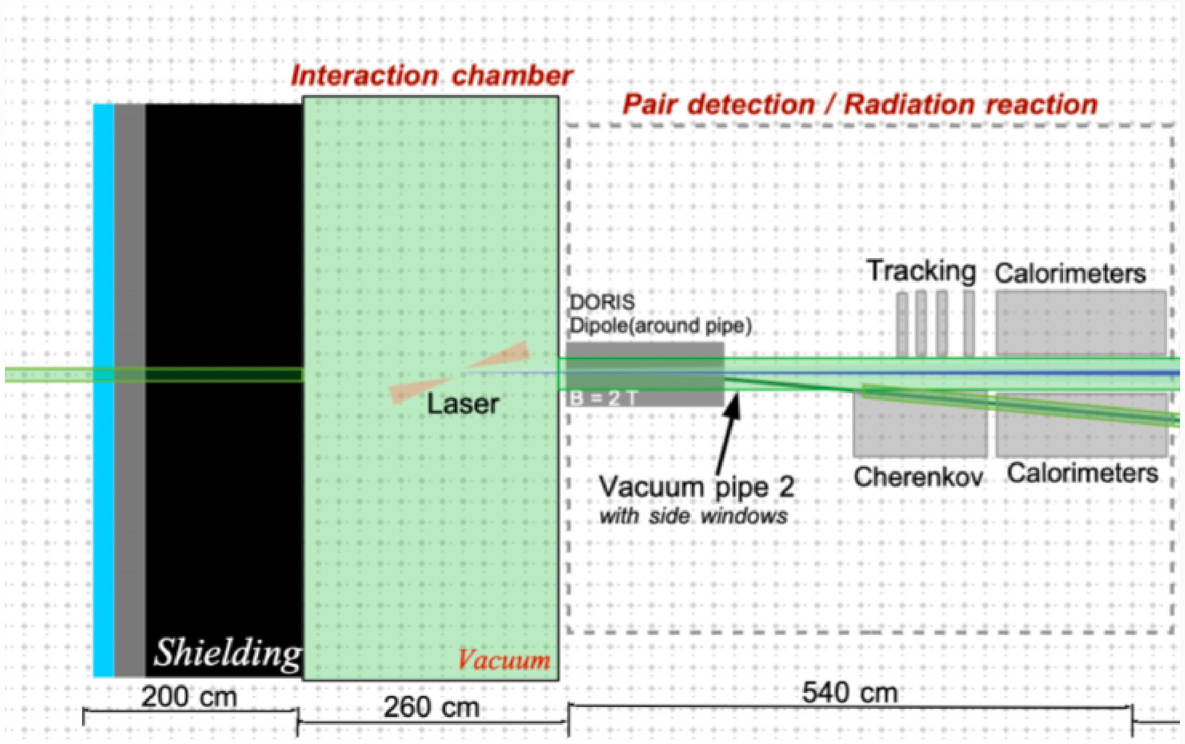
The AWAKE Electron Spectrometer
F. Keeble et al.
https://cds.cern.ch/record/2649943

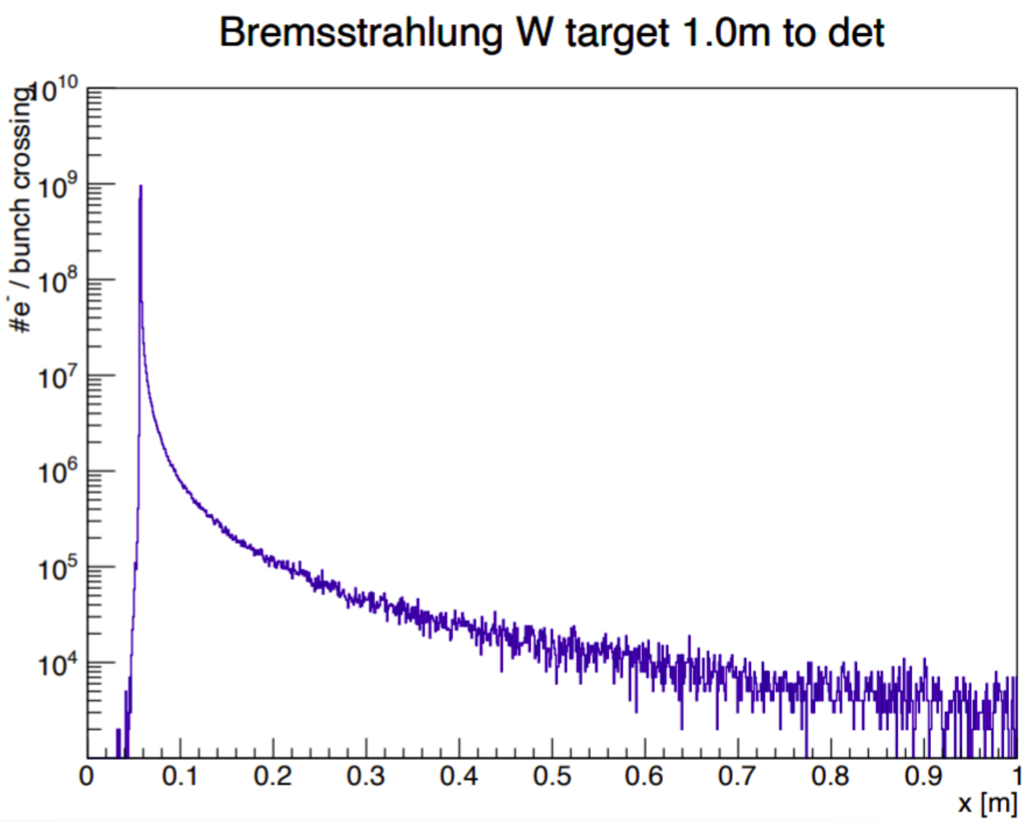
Example plastic scintillators from:
https://eljentechnology.com/products/plastic-scintillators/ej-200-ej-204-ej-208-ej-212

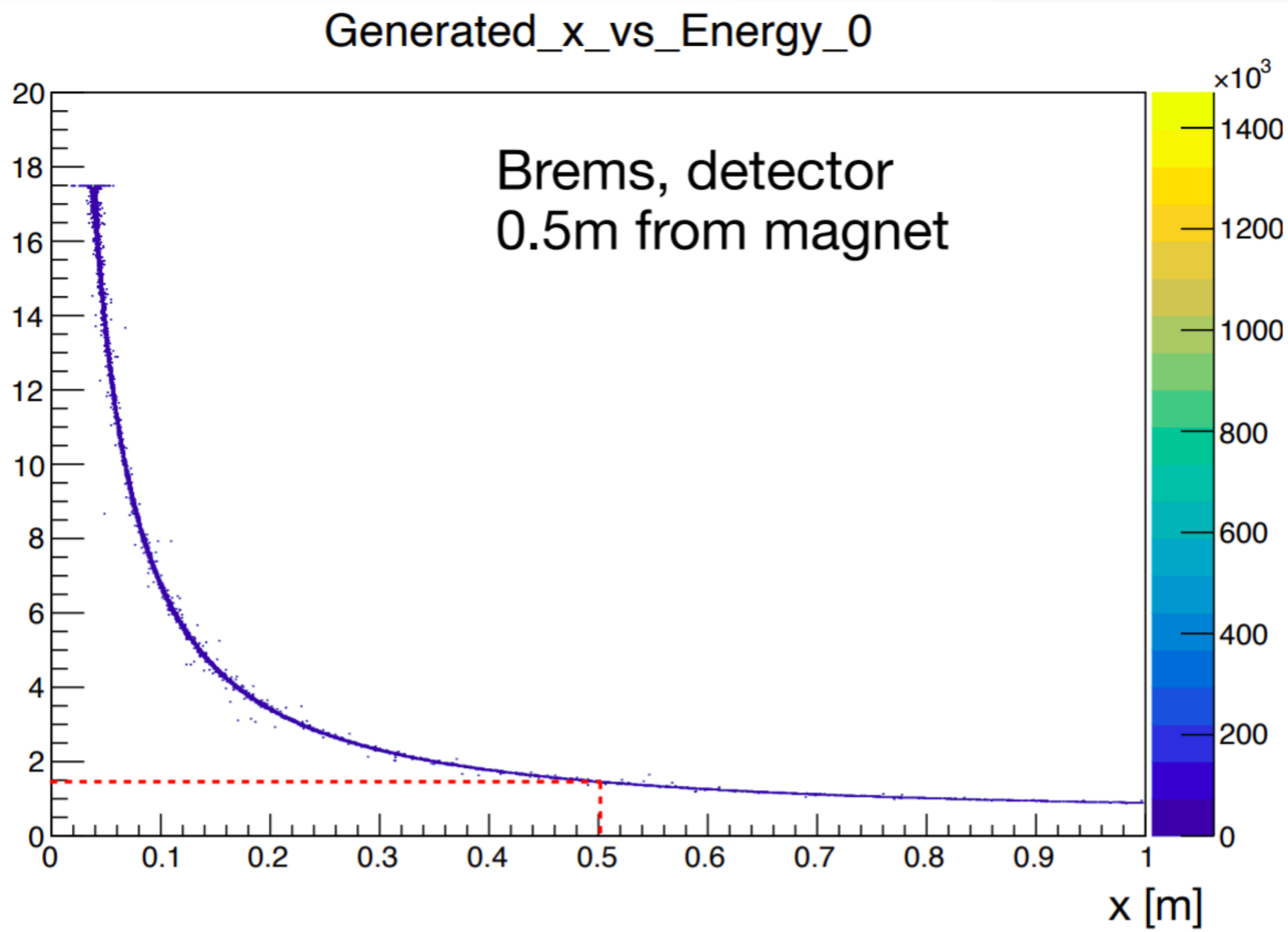
Example inorganic scintillators from
https://www.crystals.saint-gobain.com/products/crystal-scintillation-materials

Example cameras as in AWAKE:
https://andor.oxinst.com/products/istar-intensified-cameras


Electron Energy Distribution at 1.0J Laser Pulse 17.5-GeV-Beam
×10^6
Events
600
500
400
300
200
100
0
0
2
4
6
8
10
12
14
16
18
Energy(GeV)


Interaction chamber
Pair detection / Radiation reaction
Tracking
Calorimeters
DORIS
Dipole(around pipe)
B = 2 T
Laser
Vacuum pipe 2
with side windows
Cherenkov
Calorimeters
Shielding
Vacuum
200 cm
260 cm
540 cm


Bremsstrahlung W target 1.0m to det
#e⁻ / bunch crossing
x [m]


Generated_x_vs_Energy_0
Brems, detector
0.5m from magnet
x [m]
×10³

Comparison with Cherenkov

- Finer spatial resolution than with Cherenkov devices

- Constructing an especially wide Cherenkov device becomes increasingly labour-intensive & technologically complex, but no complication for a Scintillator Detector

- A camera's dynamic range limits the granularity of the intensity – but the same will be true for photodetectors attached to Cherenkov

- High-energy or high intensity particle flux can lead to saturation, depending on material, which can complicate recovering the energy spectrum

- Sensitive to high-energy photons including synchrotron radiation.

-Naturally, we can measure with resolution in 'y' direction. This can be used for gauging background (if uniform with y) levels.