Scintillator Detector Design and Prototype

WS PDR-2, 13th December 2016, Trieste

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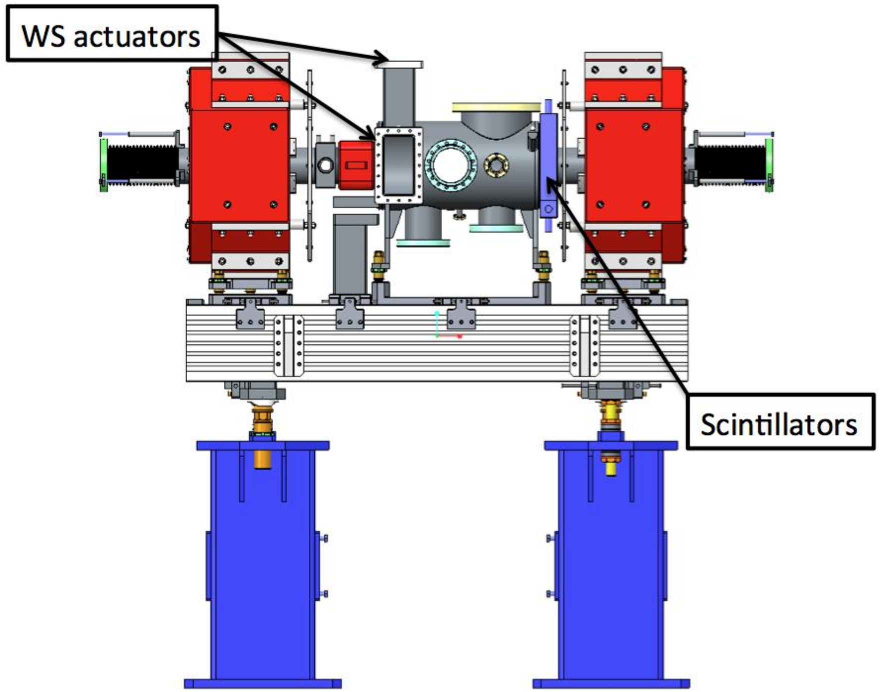
Introduction

- Above ≈200 MeV, the secondary emission might be too weak to reconstruct the beam profile. The reconstruction can be done by measuring the shower created in the wire.

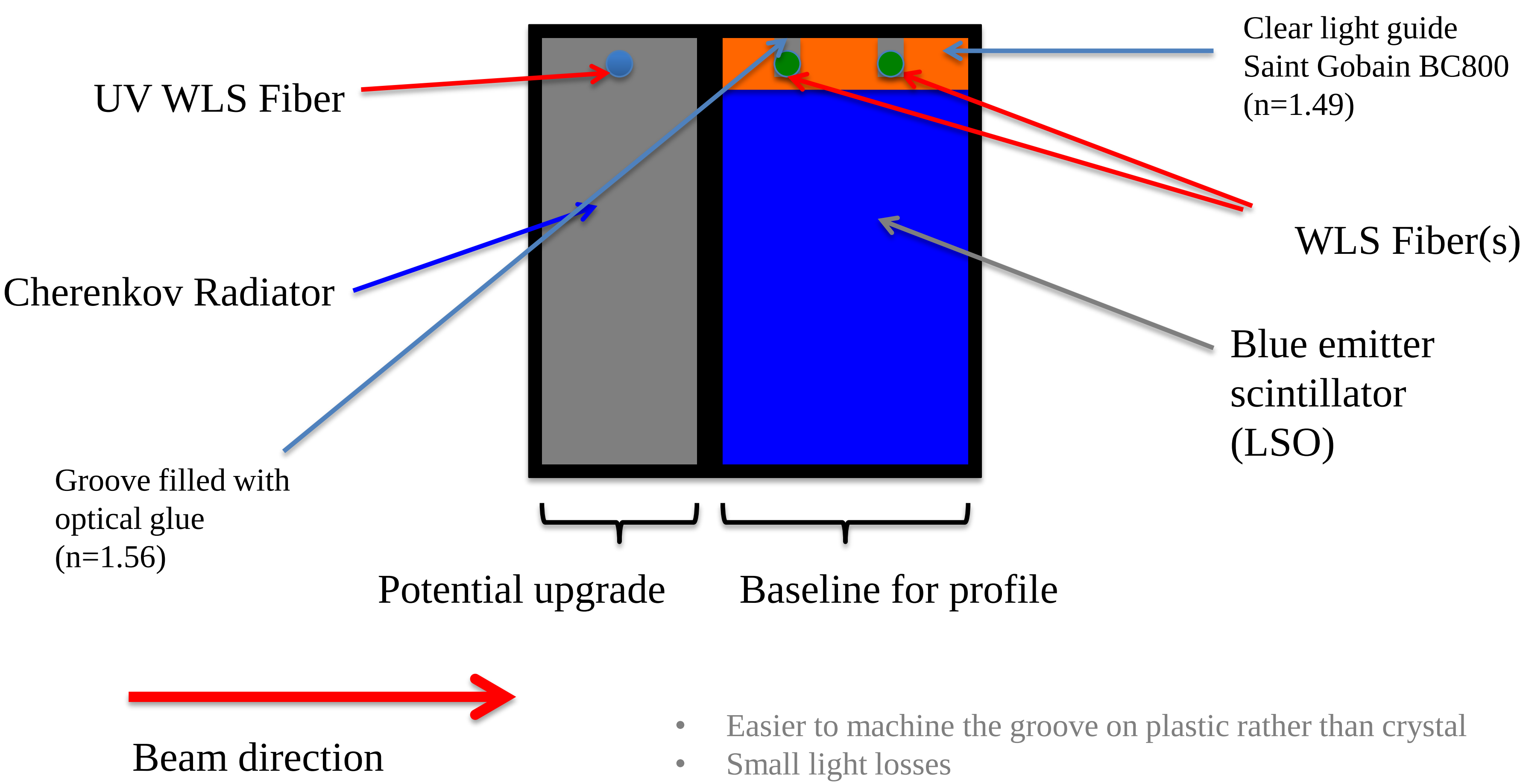


Preliminary layout of a typical Linac Warm Unit (LWU) foreseen to be installed in the elliptical and HEBT section.

Scintillator can be seen as a Calorimeter, light collection efficiency must be known and optimized in order to defined the acquisition electronic.

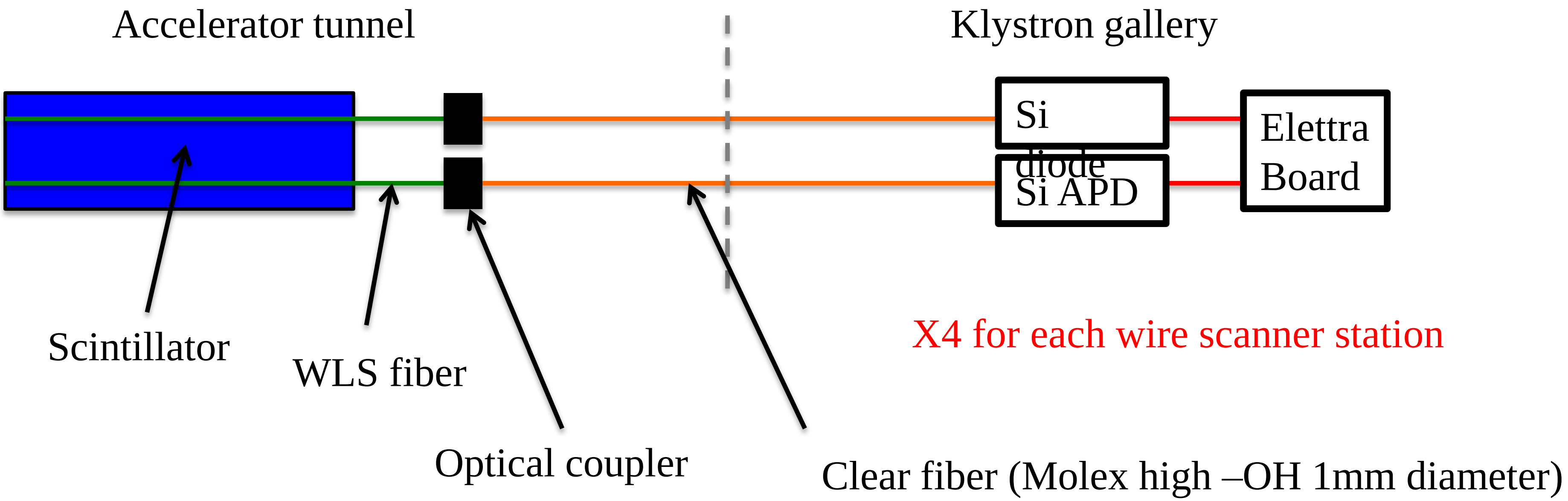
Cavities background might be an issue.

Detector geometry



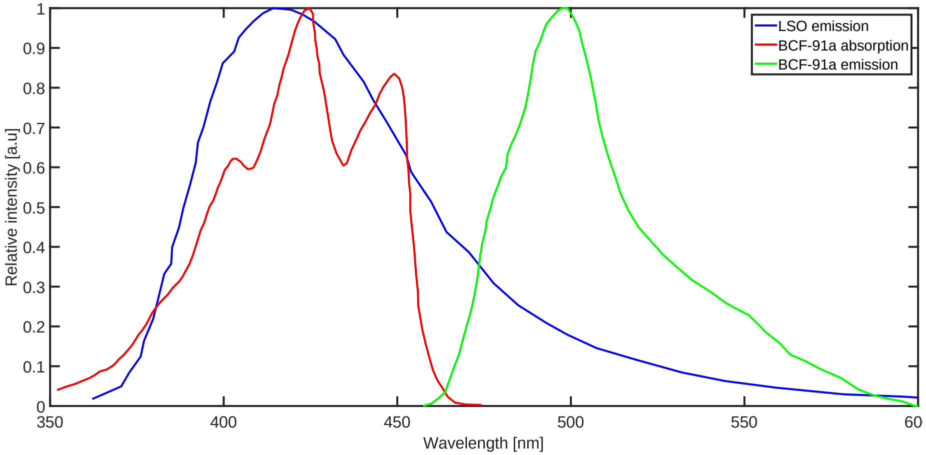
- Easier to machine the groove on plastic rather than crystal
- Small light losses
- Interface between the LSO crystal and the light guide might be filled with optical glue (not in simulation)

Acquisition chain concept

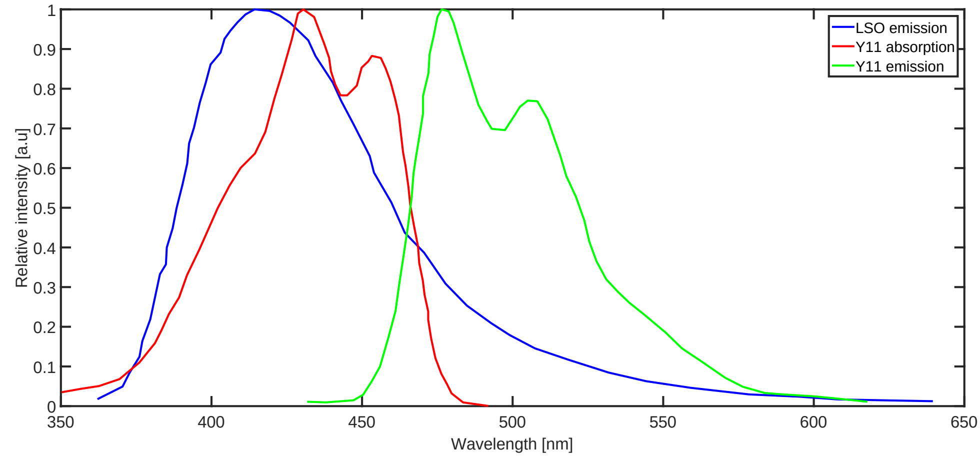


- Similar concept as the SEM mode readout:
  - High gain/low gain separated channel
- Si diode and APD might be actively cooled
- APD gain might be controlled by bias voltage

Wavelength shifting fiber (WLS)



Optical spectra of the Saint Gobain BCF-91A wavelength shifter



Optical spectra of the Kuraray Y11 wavelength shifter

- Two WLS fibers can be used for this application (NA ~ 0.5)
  - Saint Gobain BCF-91A
  - Kuraray Y-11
  - Y-11 has a higher light yield
  - BCF-91a has a higher emission peak
- For both, the higher wave length of the LSO emission are not absorbed
  - ~20% of the LSO spectrum is not absorbed

Clear fiber

- Two options:
  - Pure silica fiber (same as BL system at Elettra)
  - Silica fiber with polymer cladding
- Pure silica fiber
  - "Radiation hard"
  - NA~0.2, ~40% of the light is collected
- Fiber with polymer cladding (SPC)
  - NA~0.48, 80-90% of light is collected
  - Not as radiation hard as the pure silica

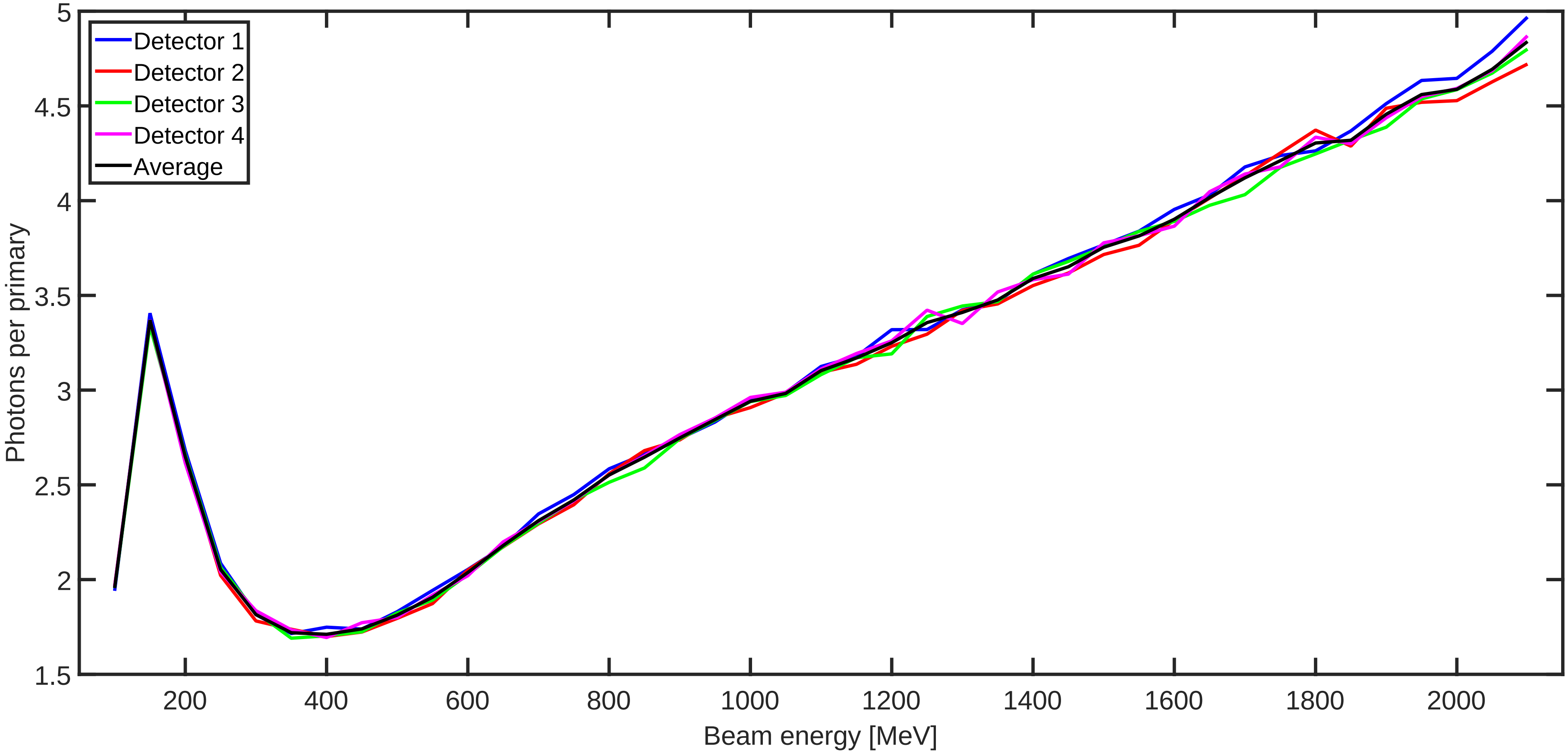
- Proposal:
  - Use a single pure silica fiber from the scintillator to the klystron gallery
    - full efficiency ~32 % (i.e with the connector loss and the loss due to the different aperture)
  - Use 2 SPC fibers:
    - One from the scintillator to the penetration, can be easily replaced
    - One form the penetration to the rack
    - Full efficiency equal to 60%

Light power estimation

- Simulation of light collection in the WLS fiber with a reduced geometry
  - Different reflective material has been used
  - Air gap between with scintillator and the reflective material has been simulated
  - Light collection > 10% for reflectivity > 95%, 11% has been used in the estimation of the signal
- Simulations from 100 MeV to 2100 MeV in step of 50 MeV with MC code
  - Energy deposited in the scintillator has been measured
  - Converted in number of photons with the LSO yield (32 photons.keV^{-1})
  - Number of photons scaled almost linearly with the energy for 400 MeV to 2100 MeV, Minimum is at 400 MeV

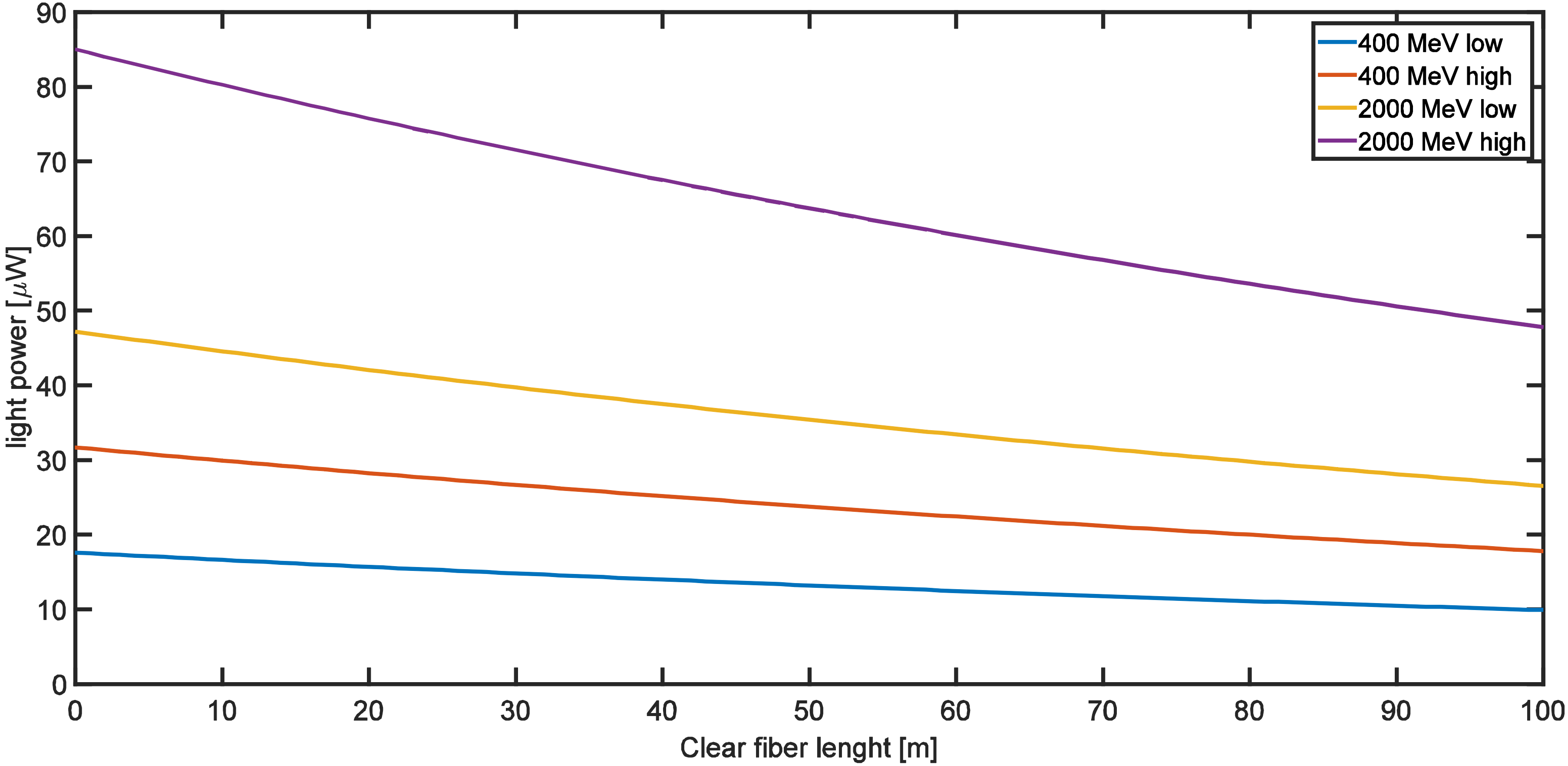
- Other parameters have been simulated in post processing:
  - Absorption of the fiber (80%)
  - Efficiency of the giber (85%)
  - WLS trapping efficiency (3%)
  - Attenuation of the light power in the fiber coupling (see previous slide)
  - Attenuation of clear fiber equal to 25 dB.km^{-1}

Light power estimation



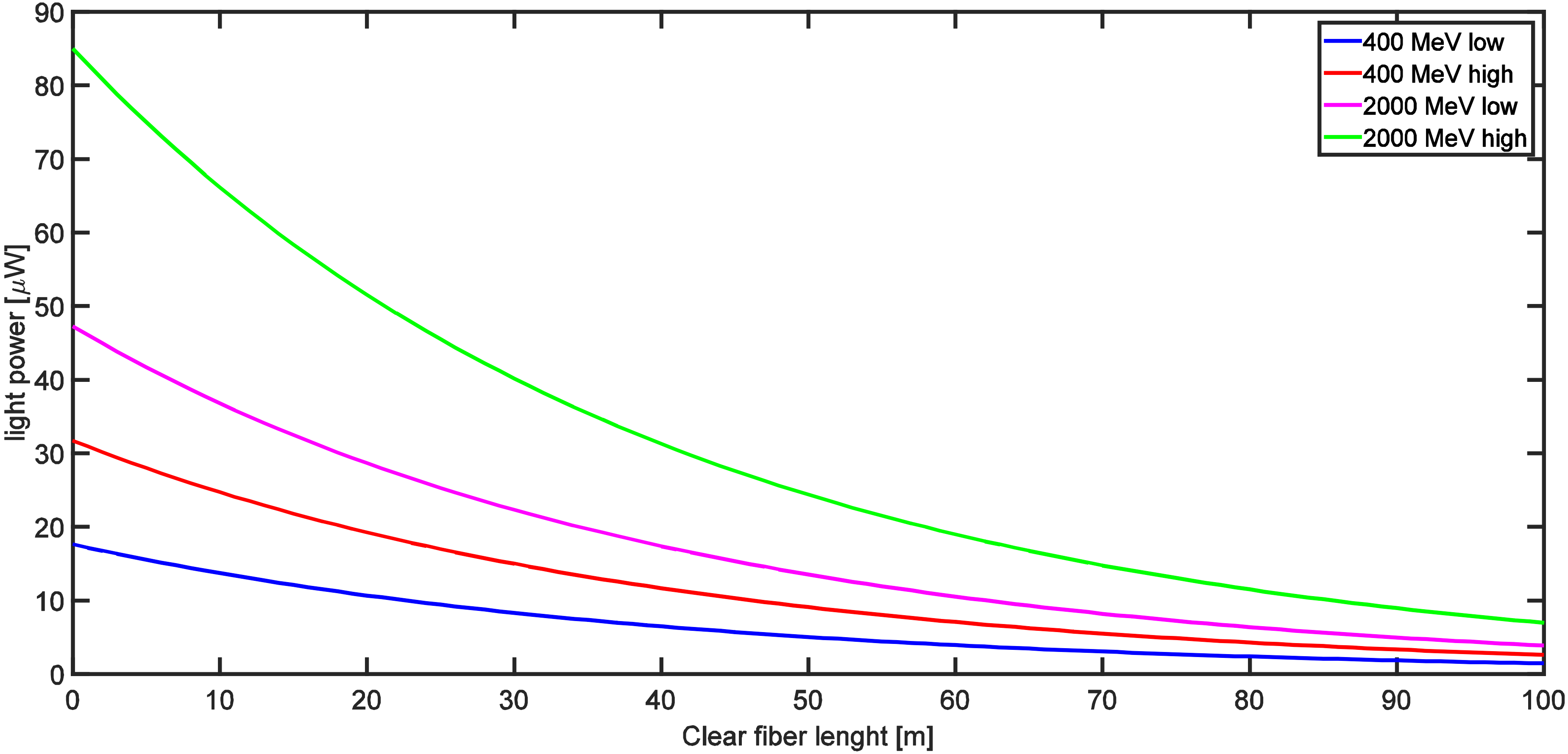
Number of photons generated per proton crossing the wire as function of the beam energy

Light power estimation



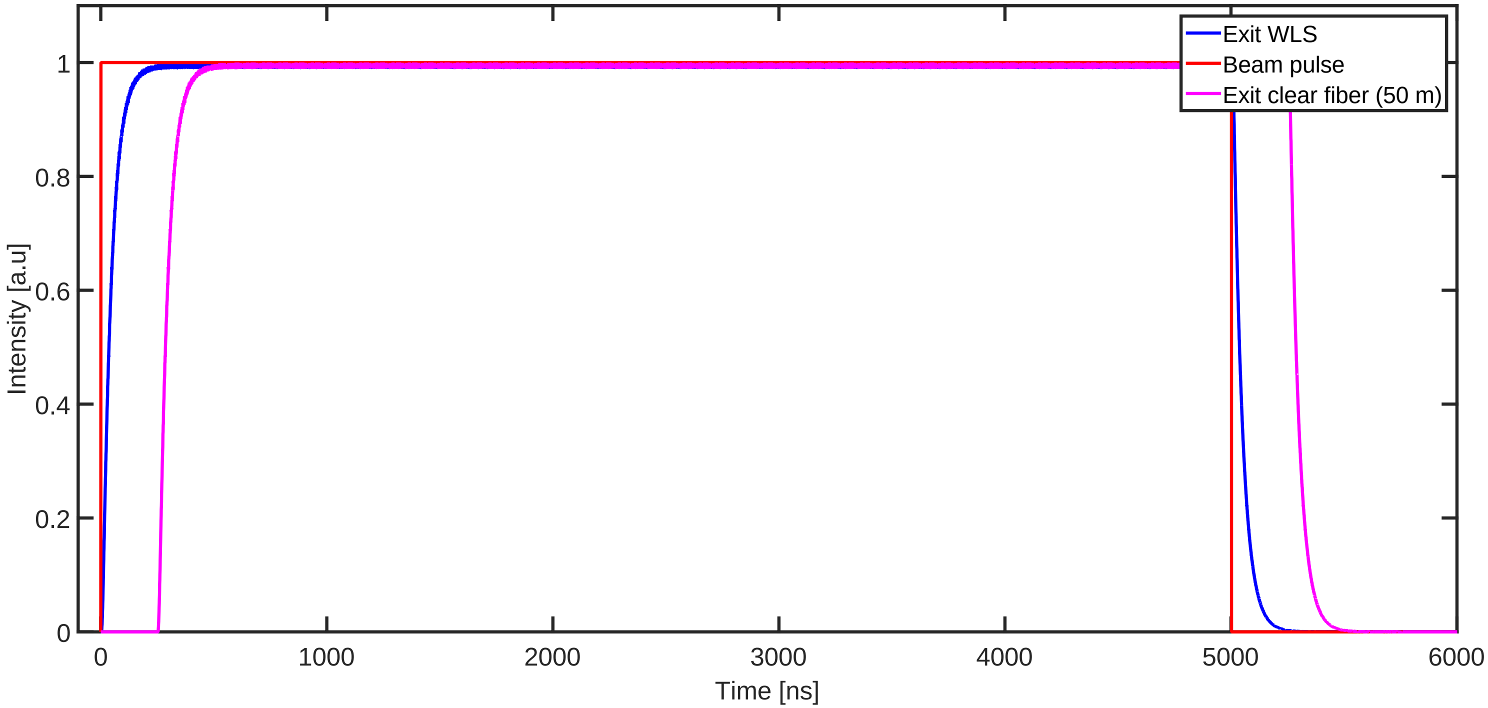
Light power as function of the clear fiber length, “low” corresponds to the efficiency of a pure silica fiber, “high” corresponds to the efficiency of a SPC fiber

Light power estimation



Peak light power as function of the clear plastic fiber length for a beam energy equal to 400 and 2000 MeV. low corresponds to optical connector(s) efficiency equal to 30 %, high corresponds to optical connector(s) efficiency equal to 60 %

Rise/fall time of the signal



Expected rise/fall time signal for (i.e light) a single wire position, beam pulse is 5 μs

- LSO has a decay time of 40 ns
- WLS fiber ~2-5 ns
- Different TOF in the WLS fiber
- Shift in the clear fiber

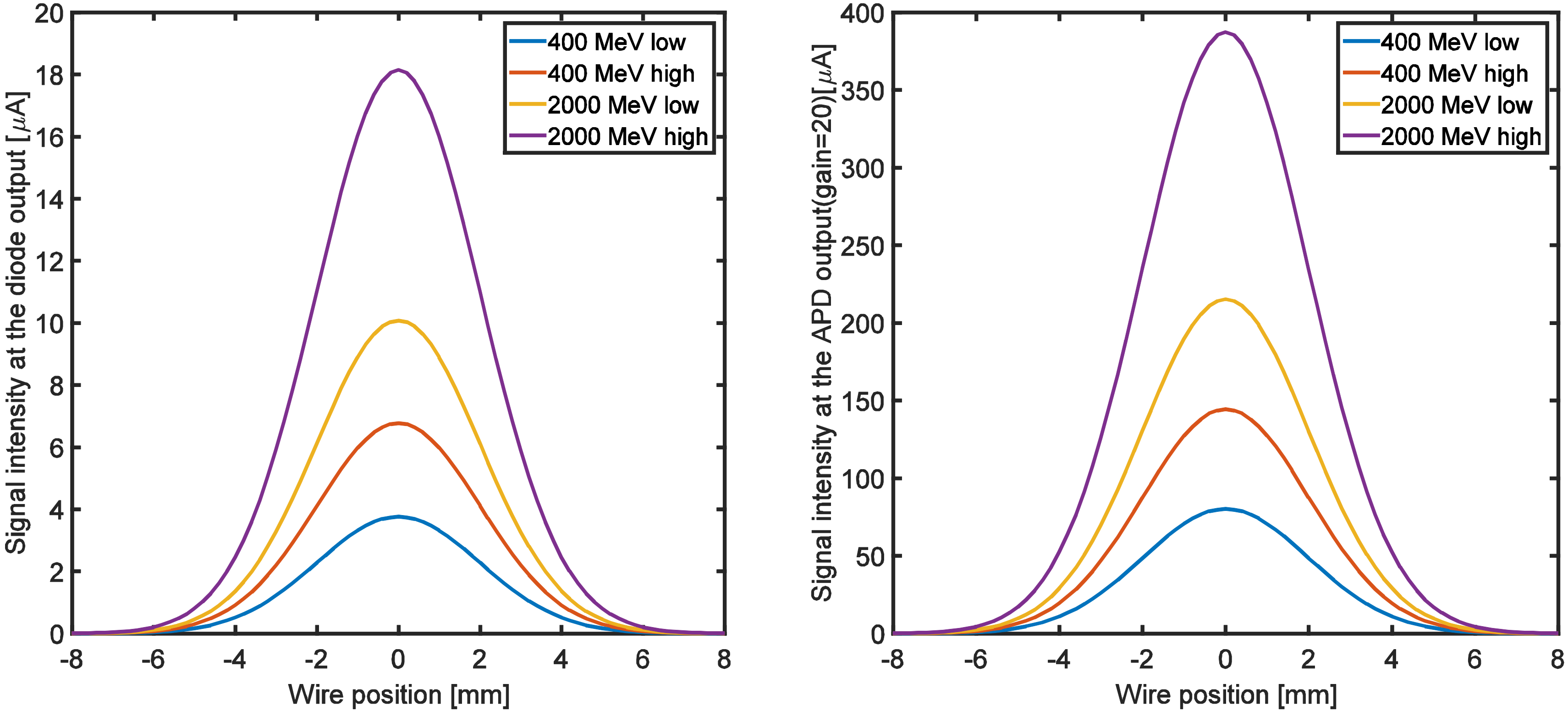
Expected signal-silica fiber

Si diode: Hamamatsu S1227-33BR (2.4X2.4mm)

- Photo sensitivity: 0.3 A.W^{-1} @ 500 nm

Si APD: Hamamatsu S5344 (Φ=3mm)

- Photo sensitivity: 20 A.W^{-1} @ 500 nm, gain =20



Expected signal at the output of the Si diode (right) and APD (left) after 60 m of clear silica fiber.

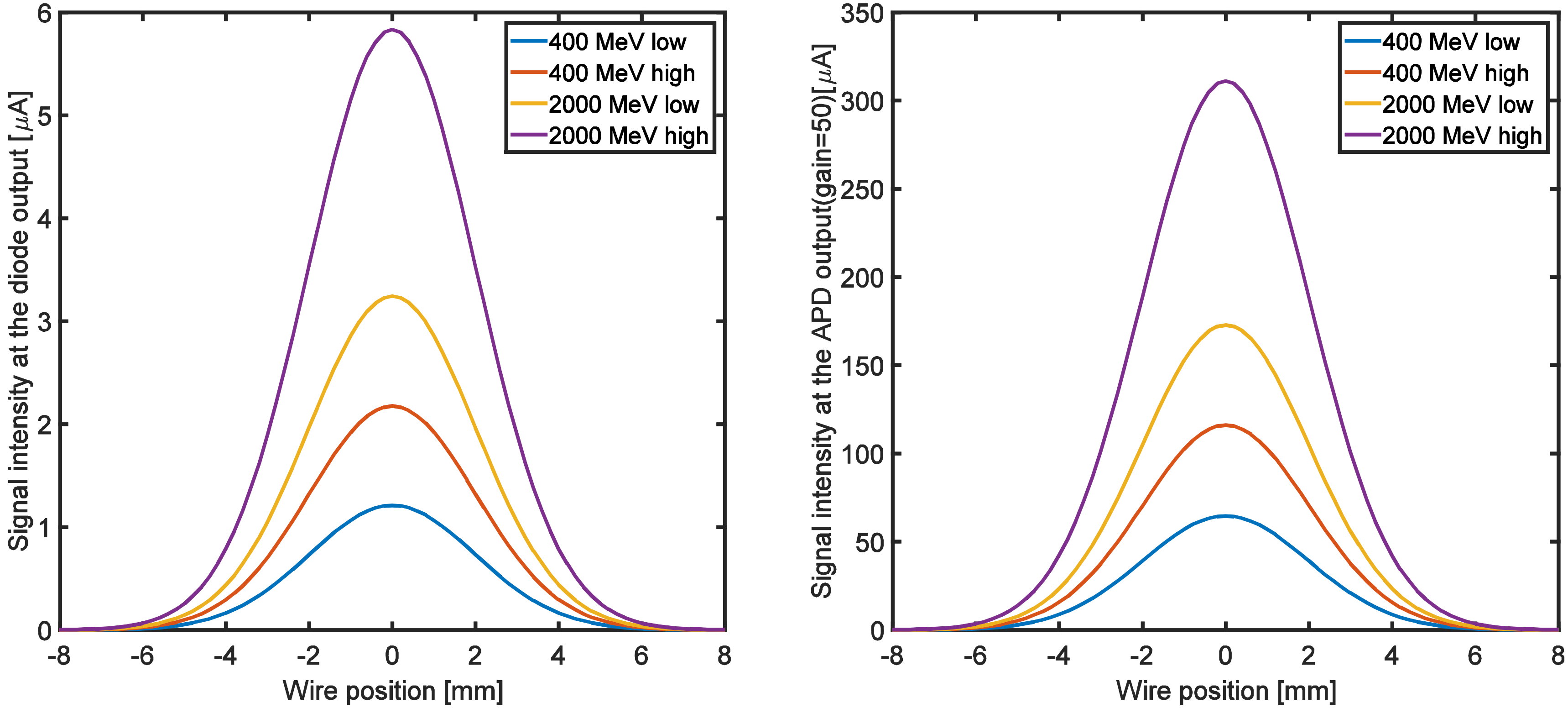
Expected signal-plastic fiber

Si diode: Hamamatsu S1227-33BR (2.4X2.4mm)

- Photo sensitivity: 0.3 A.W^{-1} @ 500 nm

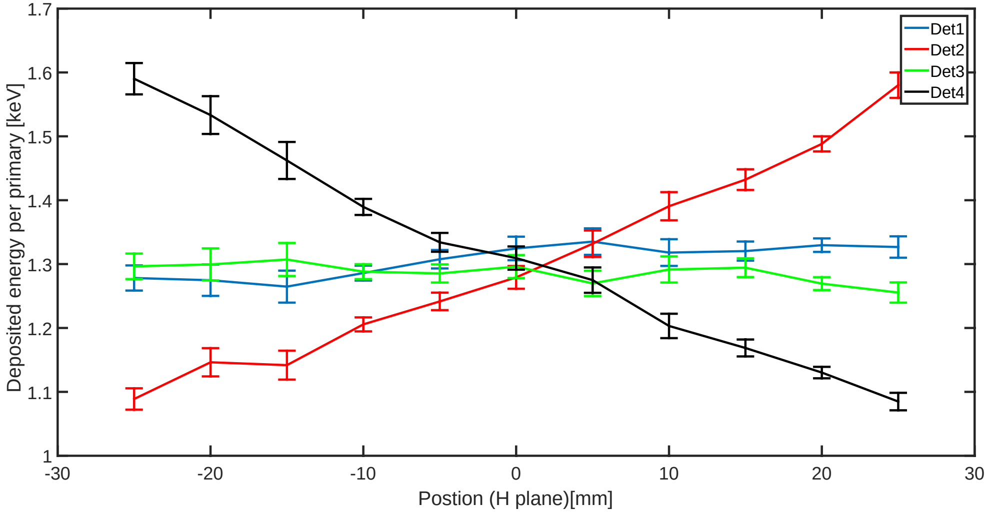
Si APD: Hamamatsu S5344 (Φ=3mm)

- Photo sensitivity: 20 A.W^{-1} @ 500 nm, gain =50

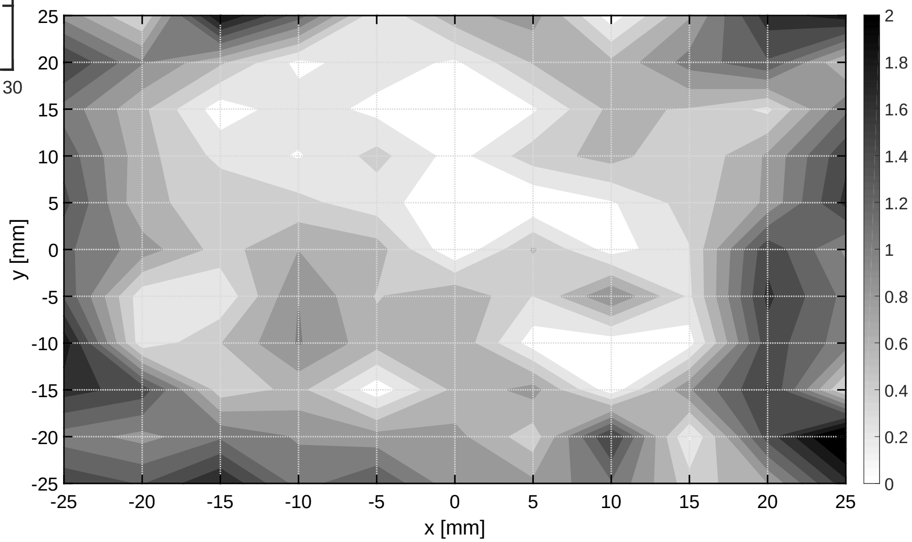


Expected signal at the output of the Si diode (right) and APD (left) after 60 m of plastic fiber.

Detector Homogeneity



Energy deposited in each of the detectors at y=0 when the horizontal plane is scanned. Similar results are observed in the vertical plane with an inversion of the detector curves (i.e the flat curves are obtained with detector 2 and 4)



Absolute error map as function of the wire position, the beam energy is equal to 2000 MeV.

General comments on the simulations

- Optical boundary are perfect in the MC code
  - Some adjustment needed between the different component
- Some margin have been taken
  - A higher trapping efficiency of the WLS fiber is not unlikely
  - Margin in the attenuation coefficient and light collection yield, almost worst case scenario has been simulated in this case

Prototype

- Prototype is mandatory to qualify the simulations
  - Measure in the lab the coupling efficiency of the fibers
  - Estimate the loss in the fiber
  - Redo the simulation with the measured values
  - Beam test

Prototype

- Saint Gobain was contacted for the prototype
  - LSO and plastic based crystal
  - Fully assemble detector
  - Same geometry as the one presented for this PDR

- Next step procure the fiber
  - Silica fiber from Molex (pure and with Tefzel clad)
  - Plastic fiber from leoni

Prototype

- Beam test in collaboration with Elettra
- MC simulation of the detector at is location in the beam line
- Installation in the line
- Test campaign

EUROPEAN
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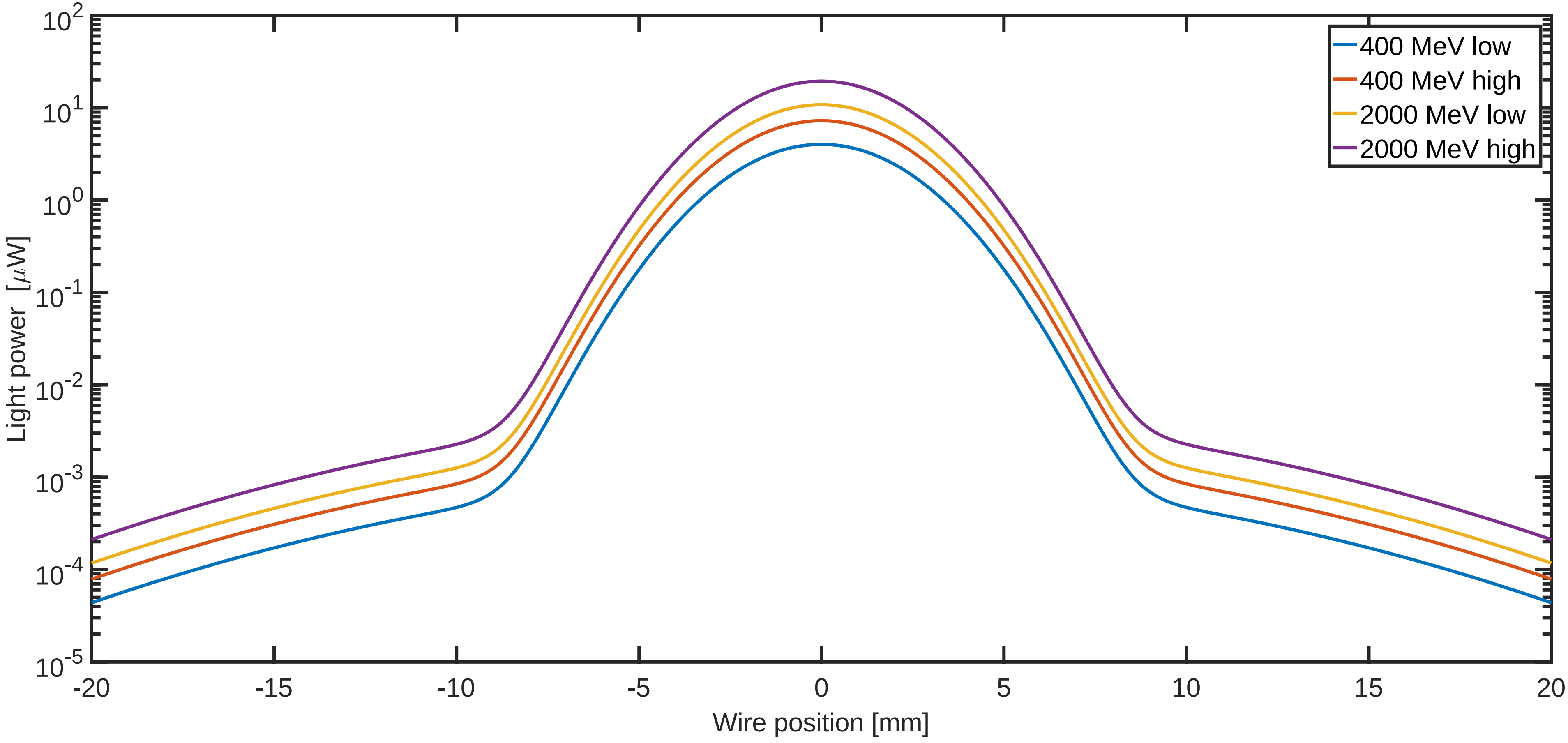
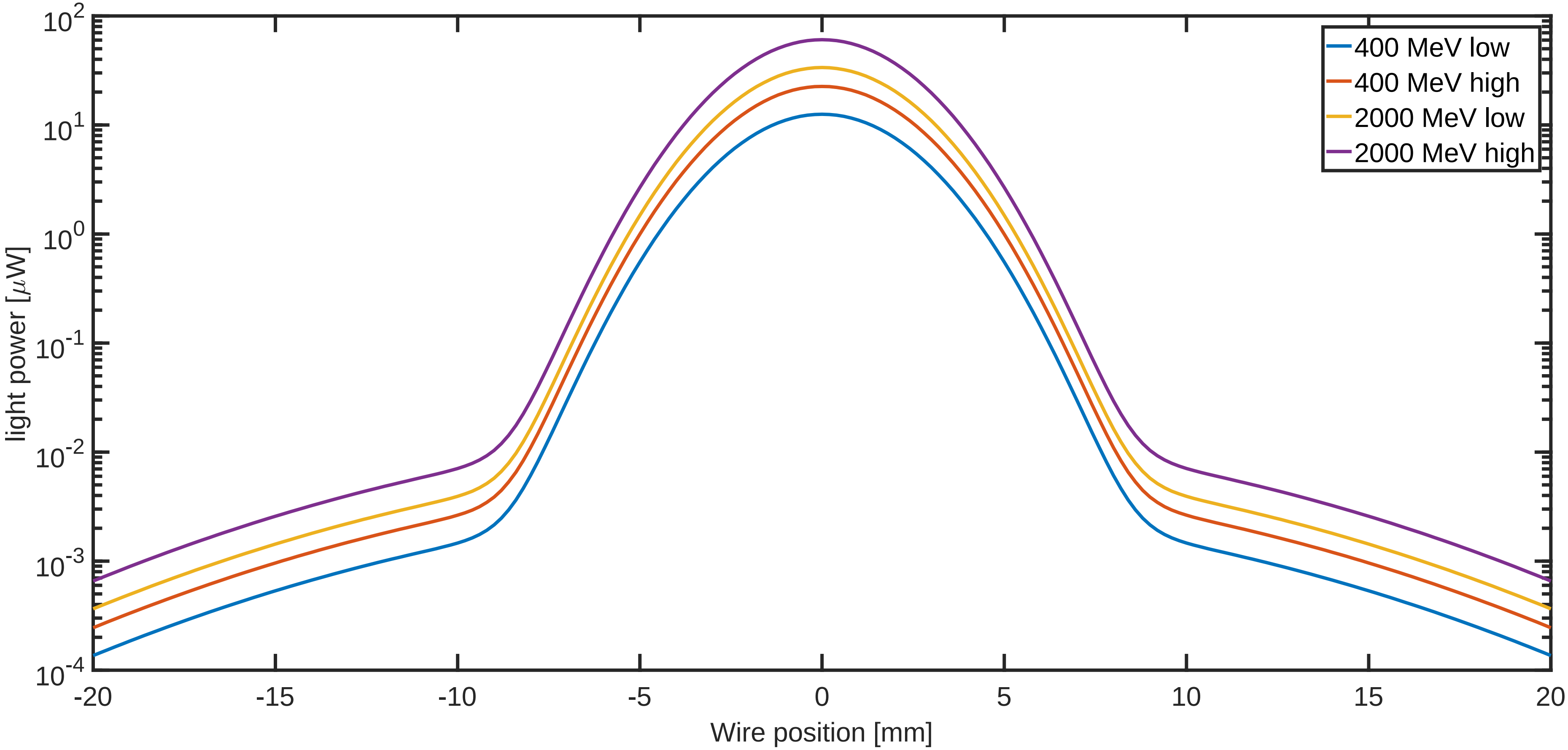
SOURCE

Light power



Expected light power as function of the wire position (plastic fiber)

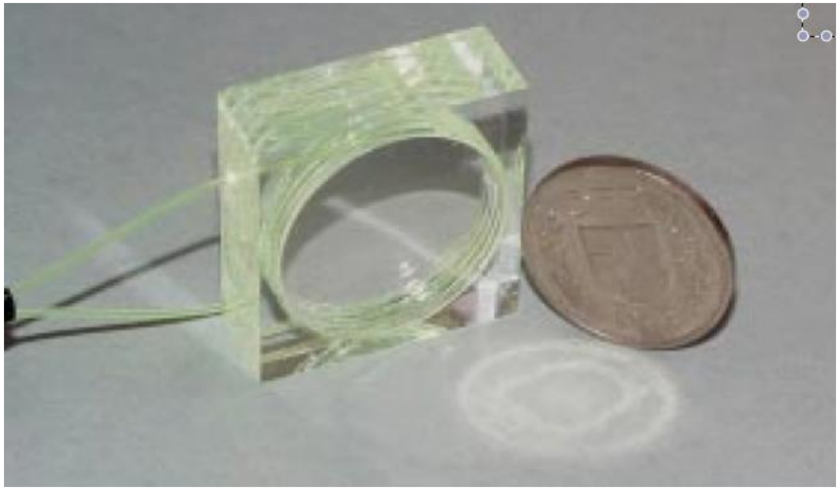
Light power



Expected light power as function of the wire position (Silica fiber)

Alternative design

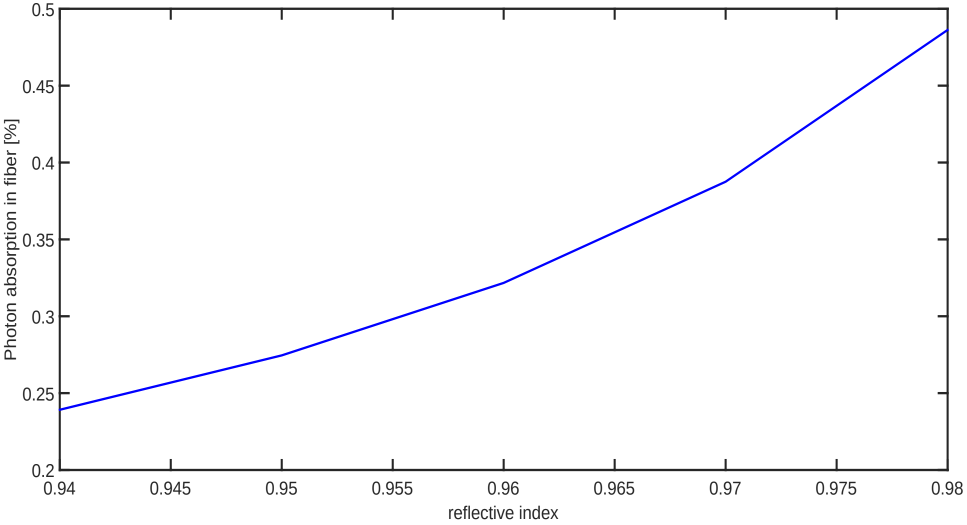
- LSO crystal might be expensive
- Alternative design with plastic scintillator
  - Remove Cherenkov radiator
  - Increase the size of the detector
  - Remove the light guide
  - New geometry for the WLS fiber (similar at LHCb)
- Similar light power expected



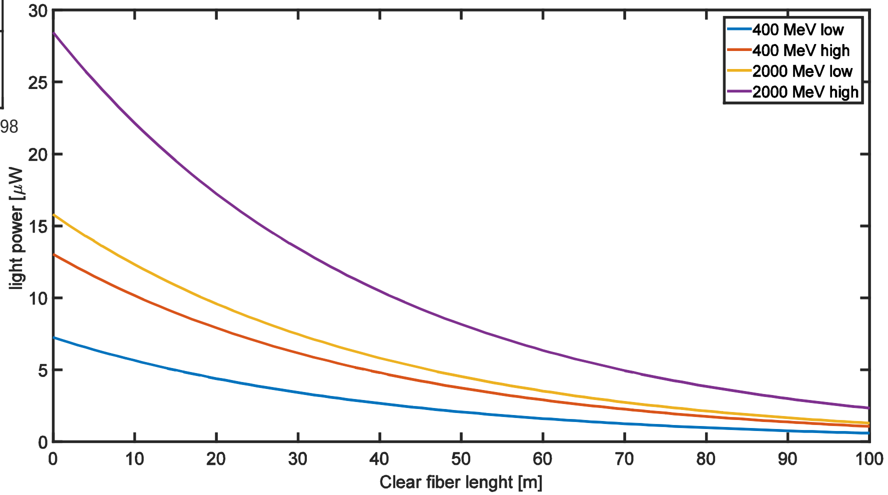
LHCb PSD prototype (plastic scintillator and WLS fiber)

- BC404 Plastic scintillator
- Dimension of the detector equal to 300x100x50 mm
- Single WLS fiber:
  - Arrange in hippodrome-like shape
  - Readout from both ends

Alternative design

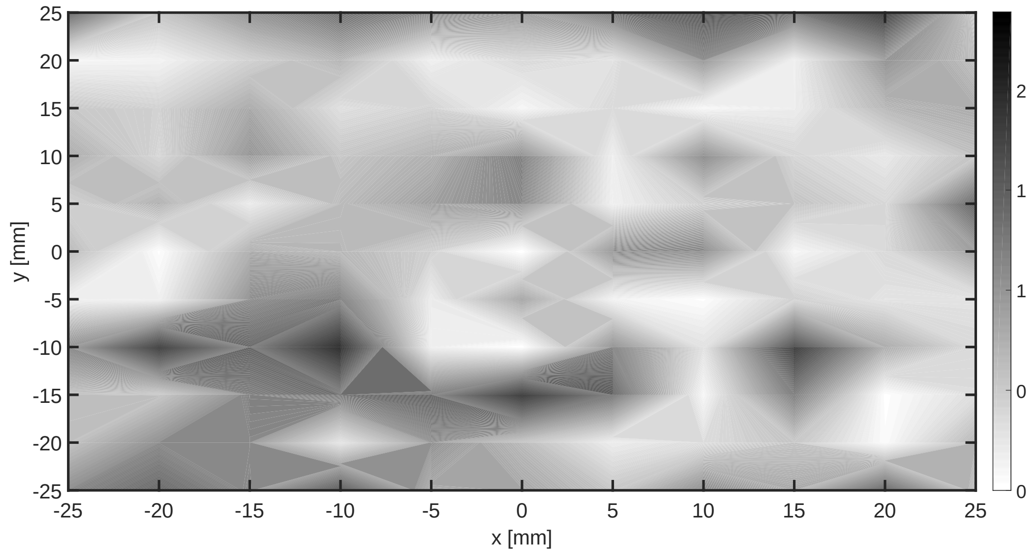


Light collection efficiency of the plastic based detector as function of the reflective index of the wrapping material.

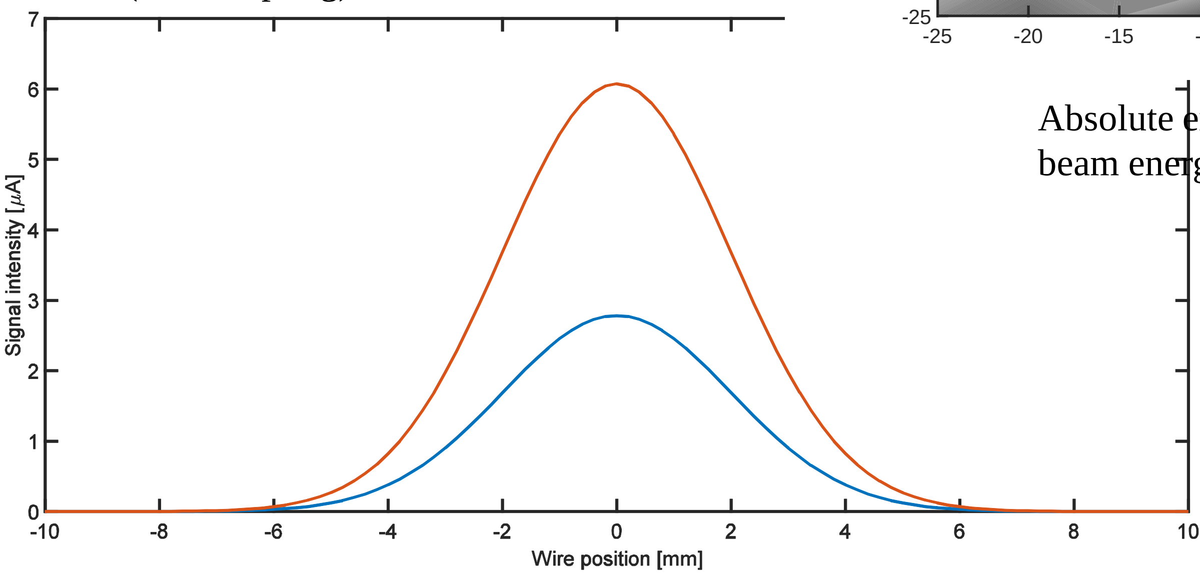


Light power as function of clear plastic fiber length.

Alternative design



Expected signal after 60 meter of plastic fiber on the diode (best coupling)



Absolute error map as function of the wire position, the beam energy is equal to 1000 MeV.