GEANT4 Simulation Of The Super-Bigbite Hadron Calorimeter

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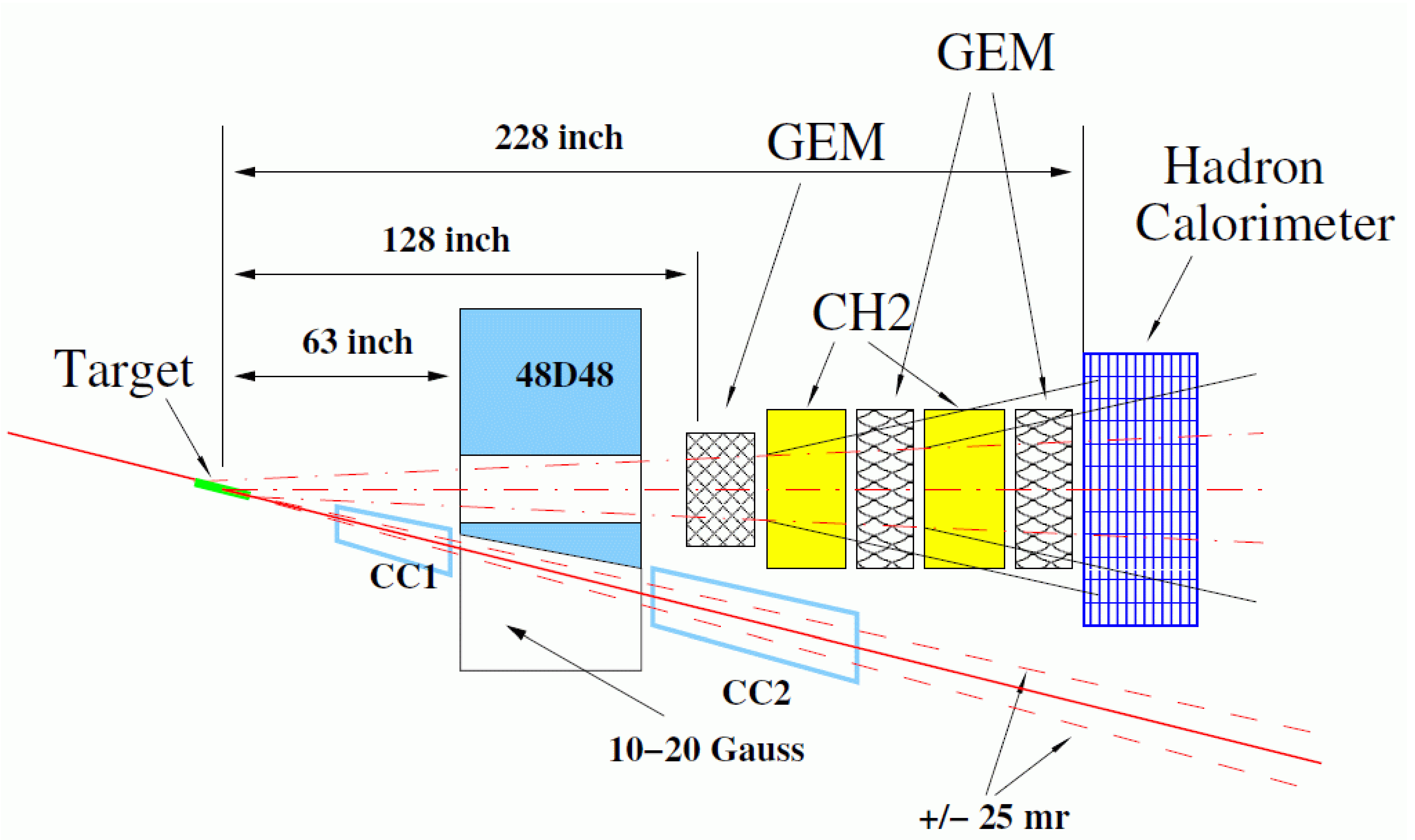
Design Goals

Intended to be used for 12 GeV nucleon Form- Factor and nucleon transversity experiments.

- **Good time resolution to reject accidental events in coincidence experiments.**
- **Position resolution to help in track reconstruction and event selection.**
- **Good energy resolution to suppress low energy background.**

Super Bigbite Spectrometer



Requirements Of HCal

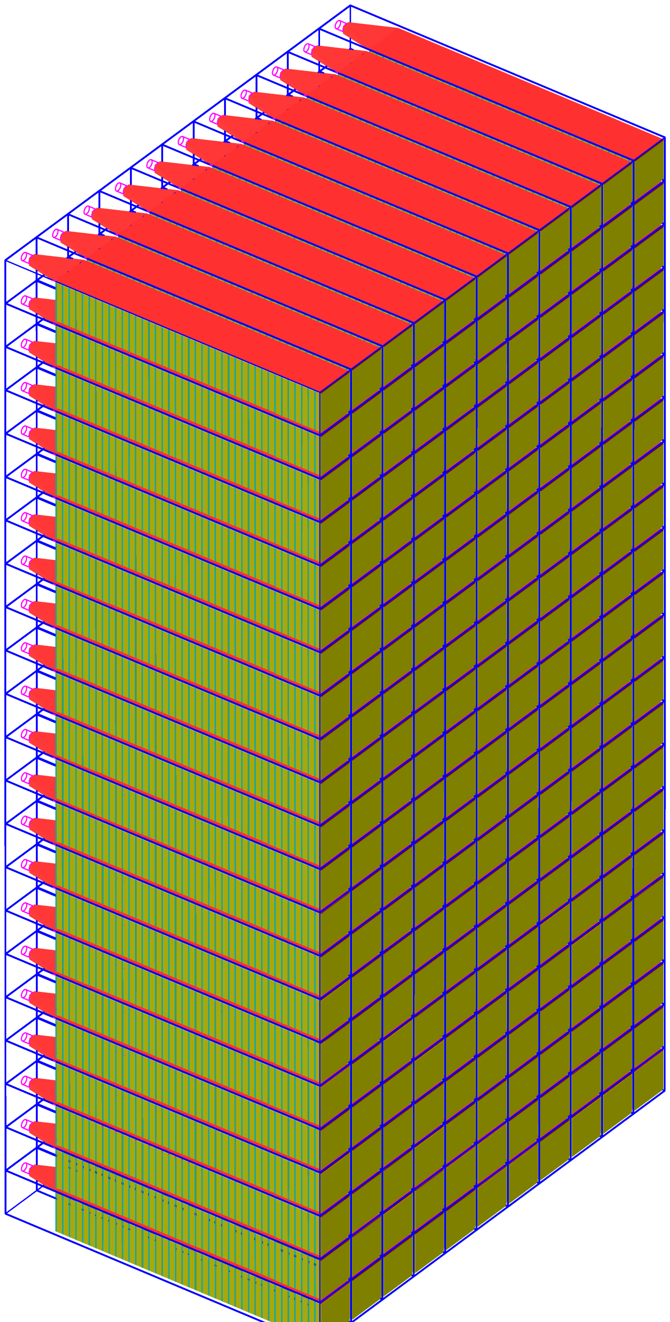
- **Linear response as a function of incident energy, 2-10 GeV.**
- **Minimize nonlinear response to hadrons.**
- **Ratio of electron to hadron energy deposit should be close to unity.**
- **Coordinate resolution 1-2 cm is necessary.**
- **Timing resolution of FWHM = 0.5 ns is desirable.**

Follow COMPASS calorimeter design.

$$\frac{\sigma_\pi(E)}{E[GeV]} = \frac{59.4 \pm 2.9}{\sqrt{E}} \circ (7.6 \pm 0.4)$$ **and** $$\sigma_{x,y} \approx 1.5\, cm$$

Calorimeter Design

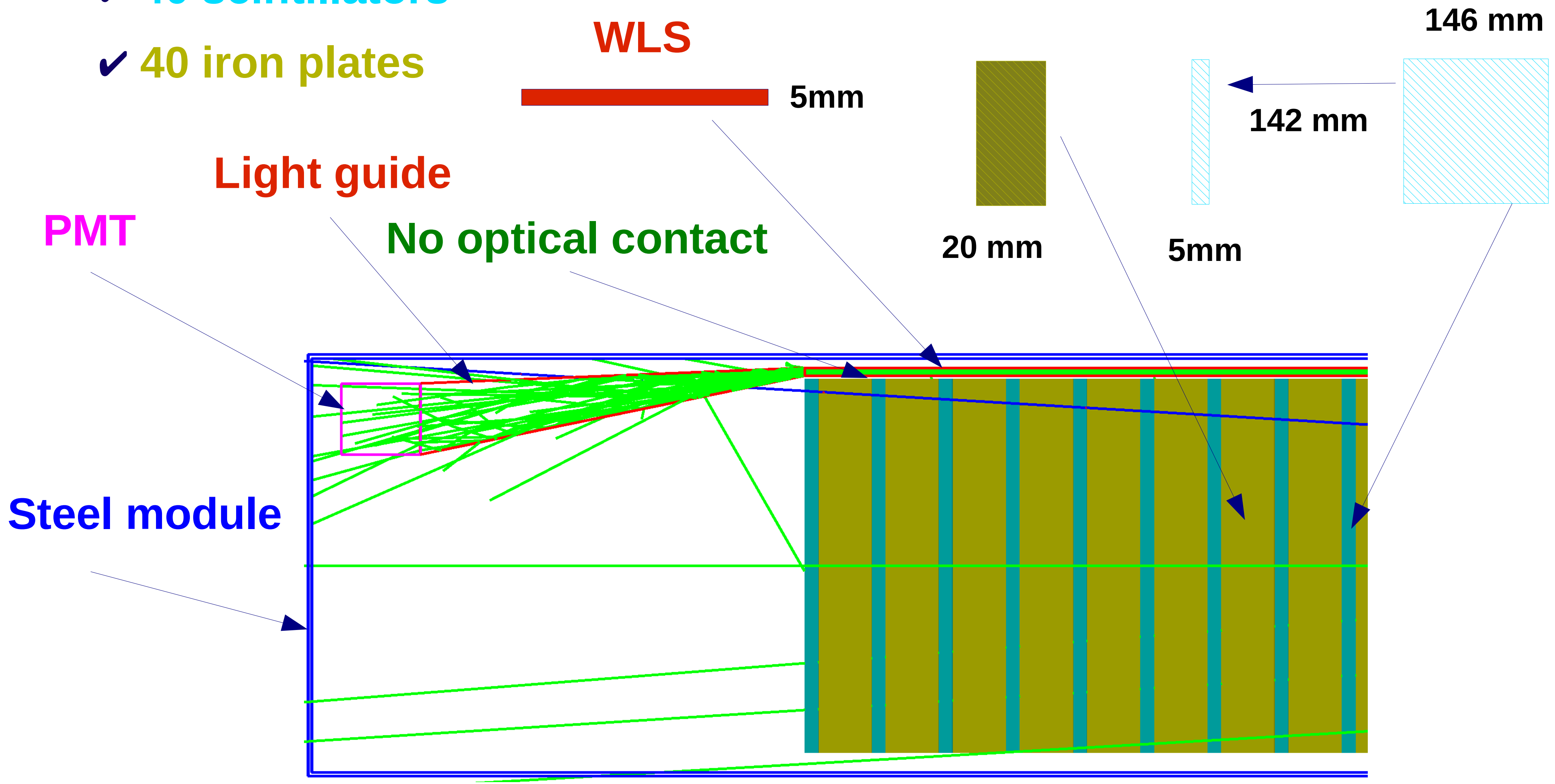
- ✔ Calorimeter has 22 x 11 modules.
- ✔ Every module has 40 iron and scintillator plates.
- ✔ Active length of a single module is 80 cm, 4.8 λ_{nucl}.
- ✔ Light is collected by 1 m long WLS bars.



Calorimeter Module

Calorimeter module is based on COMPASS design.

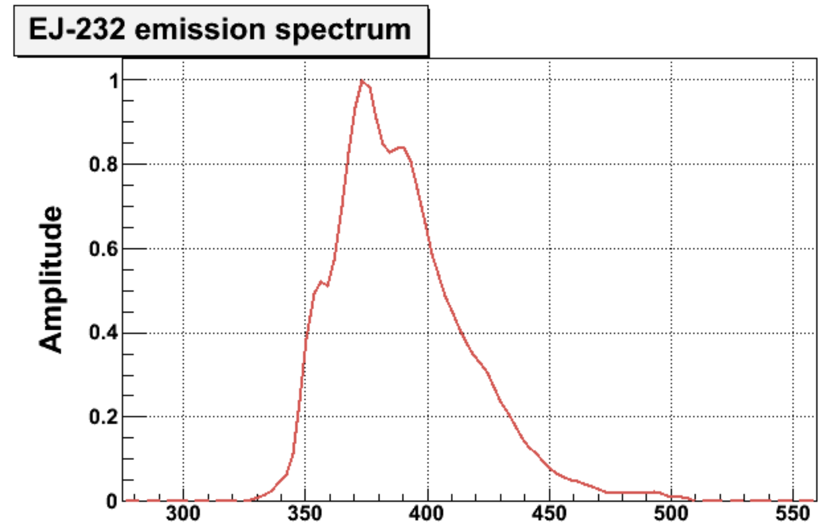
- ✔ 40 scintillators
- ✔ 40 iron plates



Scintillator and Wave-length Shifter

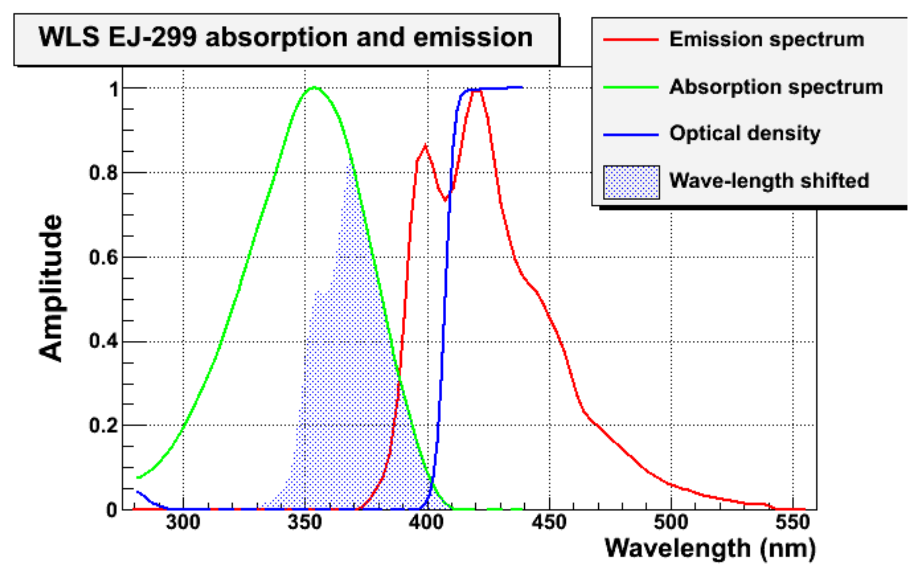
Physical and scintillation constants of EJ-232 scintillator.

- **Light output – 8400 photons/MeV e-**
- **Rise time – 0.35 ns**
- **Decay time – 1.4 ns**
- **Density – 1.02 g/cc**
- **Polymer base – polyvinyltoluene**
- **Refraction index – 1.58**



Physical and scintillation constants of EJ-299 wave-length shifter.

- **Time delay between absorption and emission – 1.5 ns**
- **Density – 1.02 g/cc**
- **Polymer base – polyvinyltoluene**
- **Refraction index – 1.58**



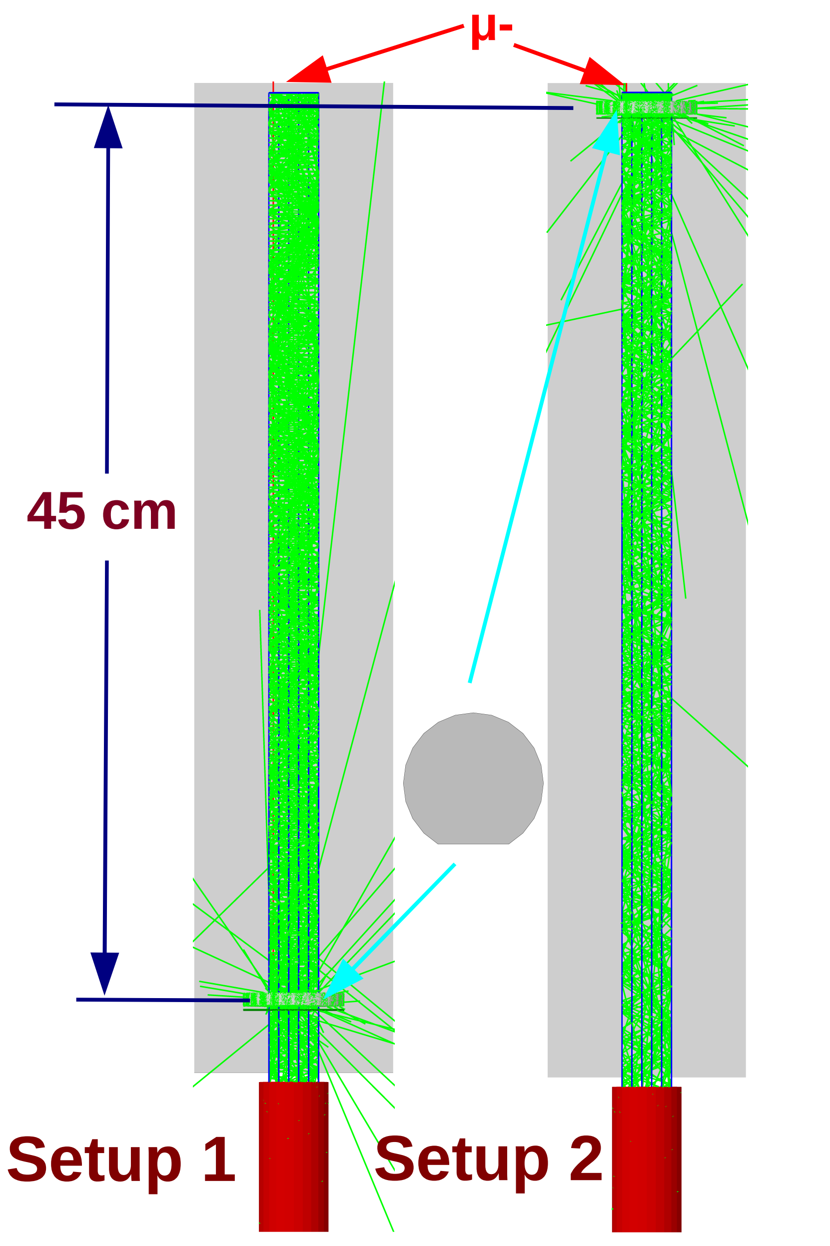
Wavelength Shifter and Scintillator Suitability Tests

Cosmic muons are used to study properties of EJ-232 scintillator and EJ-299 wavelength shifter.

- ✔ **Attenuation of light.**
- ✔ **Rise time of EJ-232 and EJ-299.**
- ✔ **Light propagation speed in WLS.**

GEANT4 simulation is done for the same setup.

- ✔ **Realistic simulation of surface parameters of the scintillator and the WLS.**
- ✔ **One photoelectron response of the RCL 8875 is measured and used in the simulation to study pulse rise times.**



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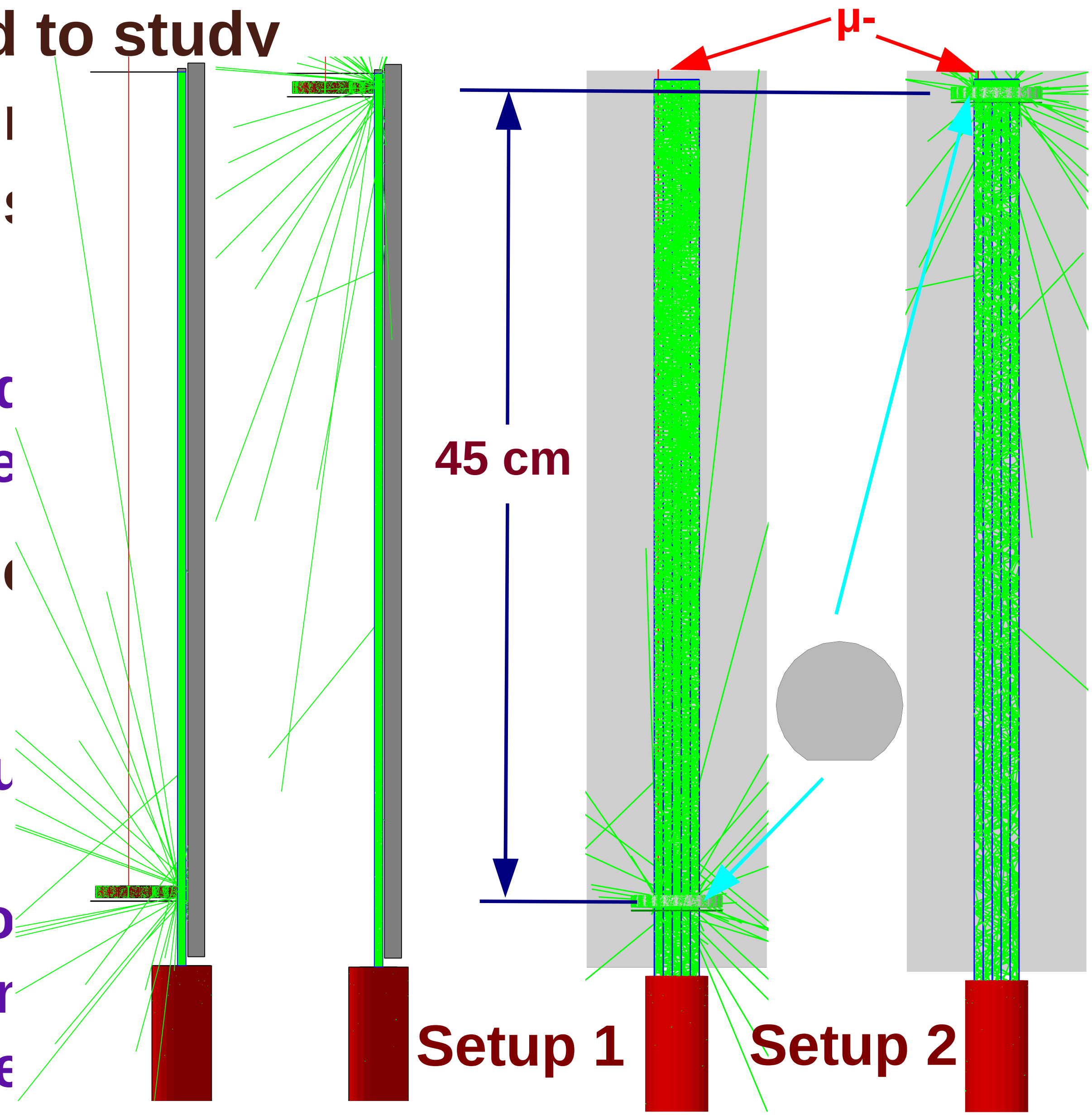


Results Of The Cosmic Tests And Simulation

	Cosmic Test	Simulation
Signal attenuation	2.65	2.05
Pulse rise time 10-90% bottom, top (ns)	3.67 ± 0.11 4.12 ± 0.27	3.24 3.40
Pulse rise time 5-95% Bottom, top (ns)	4.64 ± 0.17 5.47 ± 0.41	4.11 4.31
Light propagation speed	0.482 ± 0.013 c	0.484 c
Photo-electrons Bottom, top	27.5 ± 1.8 10.3 ± 0.4	17.1 8.3

Calorimeter Simulation

Geant4 provides a few "reference physics lists" which are routinely validated and updated with each release.

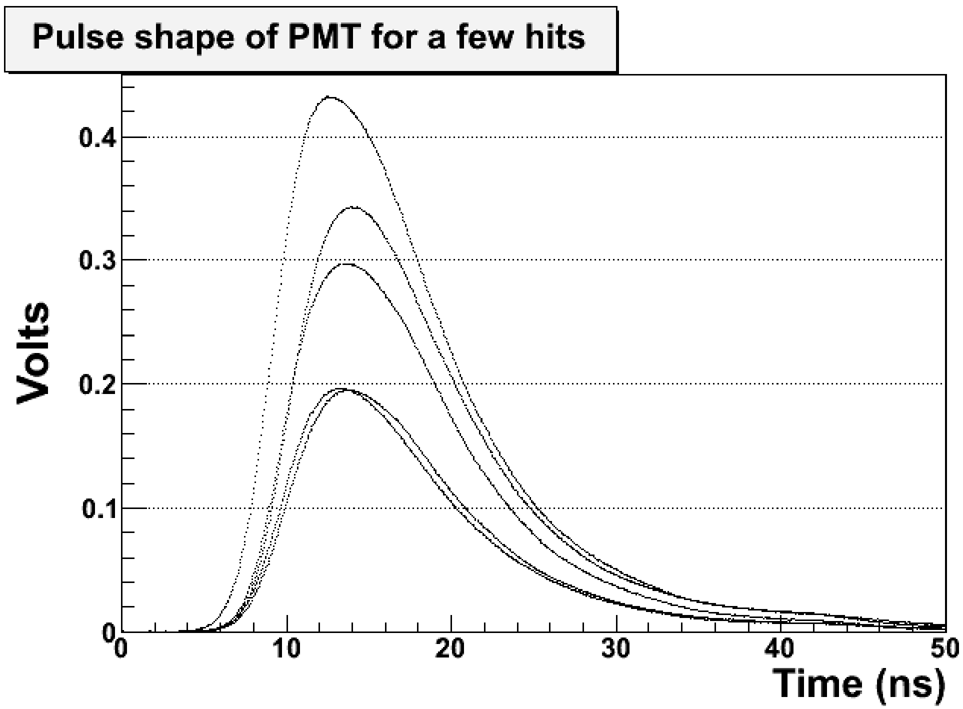
- ✔ **In this simulation Bertini Cascade Model (~<10 GeV) is used.**
- ✔ **A standard electromagnetic physics list is used.**
- ✔ **Simulation allows to chose any available physics list.**
- ✔ **Surface parameters found in WLS tests are used in simulation. No light absorption was observed in WLS for 480 nm laser. Polishing the surface of the WLS will decrease light attenuation.**
- ✔ **Optical photons are tracked (4 minutes CPU time for each event) for each WLS until they are absorbed by the PMT cathode.**
- ✔ **Quantum efficiency of the photo-cathode is simulated.**

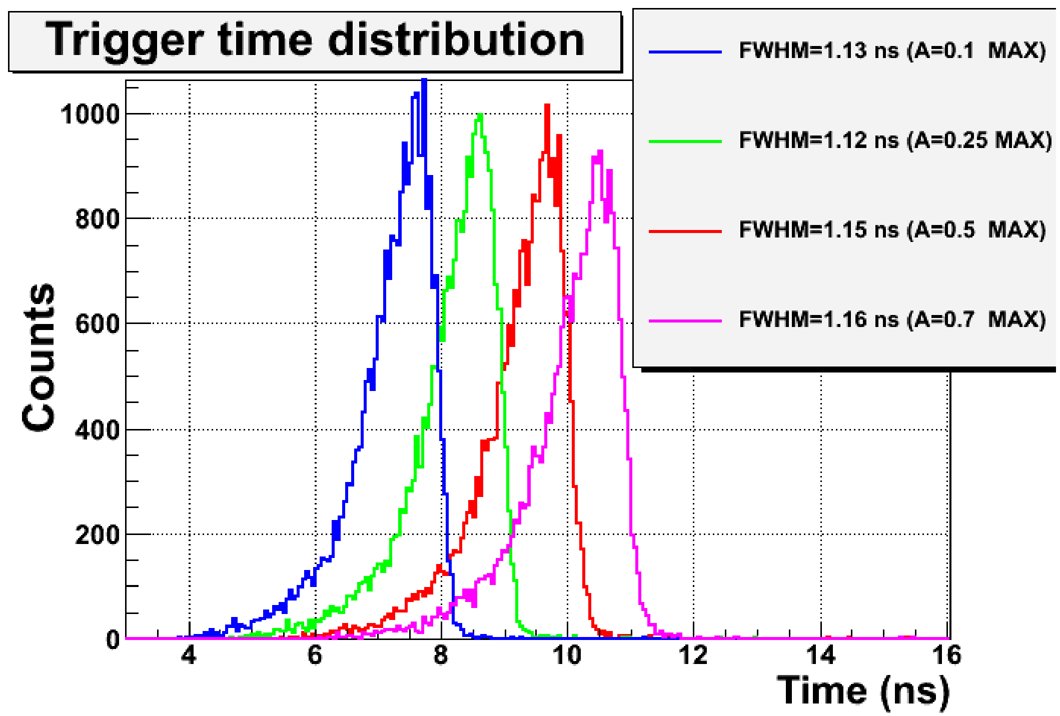
Calorimeter Timing

- Start time is defined as the hadron enters the calorimeter.
- For each photon that reaches the WLS coupled PMT the arrival time is recorded. Number of hits is counted as well.
- Pulse response of the PMT is obtained by summing measured SPE response of PMT with corresponding photon arrival times.
- After all photons are tracked, the module with most hits is selected and the pulse shape is saved.
- Pulse time information is extracted at different leading edge values to find the best timing.

Trigger Time Resolution

Simulating constant fraction discriminator with fraction A.





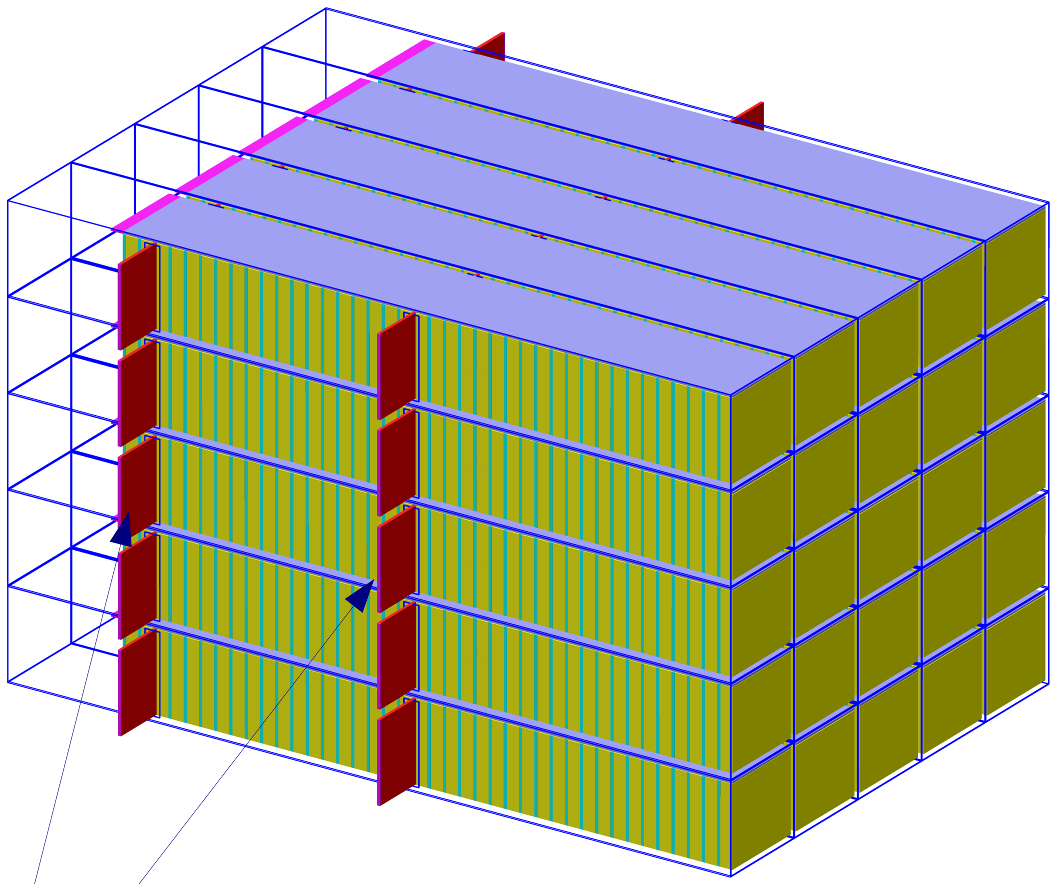
Full width of trigger time distribution at 0.25 of amplitude MAX is ~ 1.12 ns.

Factors Limiting Time Resolution

- Longitudinal form of the shower defines the calorimeter time resolution.
- The choice of WLS decay time constant smaller than 1 ns does not impact the time resolution.
- Photon collection efficiency is reasonable and does not impact time resolution.
- Light propagation speed in WLS.
- Using a curved light-guide improves the time resolution (~10%) at the expense of less photon statistics and is probably not acceptable.
- Time resolution is better than that obtained in COMPASS calorimeter (σ = 1.5 ns, FWHM = 3.53 ns) due to faster WLS and scintillator.

Alternate Approach

- Each time scintillator has two PMTs attached.
- Lots of photons!
- Hope for better time resolution.
- Simulation is in progress.
  - Trigger efficiency.
  - Time resolution improvement?
  - Optimal position of timing scintillator planes.

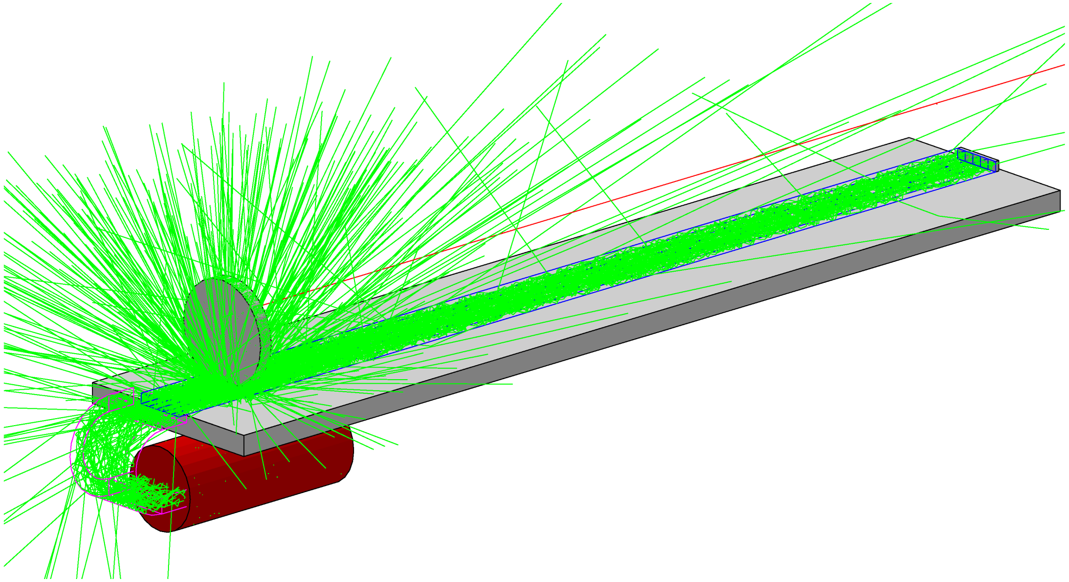


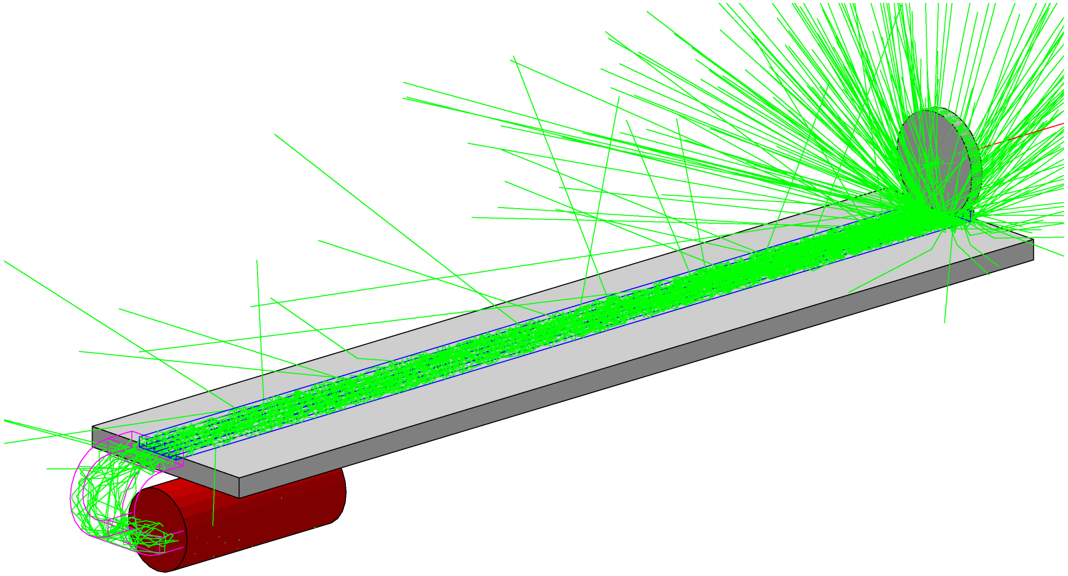
Timing scintillator planes (BC-408).

Summary and Outlook

- ✔ Cosmic muons are used to study WLS and scintillator suitability for HCal.
- ✔ GEANT4 simulation of the cosmic test setup allows to tune surface parameters of the WLS.
- ✔ GEANT4 simulation of HCal allows to study and improve trigger time resolution.
- ✔ The simulation predicts HCal trigger time resolution FWHM ~ 1.12 ns.
- ✔ Near future plans are development of coordinate and energy reconstruction programs, study HCal trigger efficiency and try different setups to improve trigger time resolution.

Test With Curved Lightguide





Light Propagation Speed In WLS