C. Pena[1], A. Apresyan[1], D. Anderson[1], A. Bornheim[1], J. Duarte[1], A. Ronzhin[2], M. Spiropulu[1], J. Trevor[1], S. Xie[1].

Precision Timing Calorimetry for High Energy Physics

NSS/MIC 2014 Seattle

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Outline

- High Energy Physics motivation for pursuing precision timing in calorimeter
- Physical processes that affect precision timing (TOF resolution)
- Experimental results
  - LYSO-based sampling calorimeter
  - LYSO-Tungsten Shashlik calorimeter
- Summary and future prospects

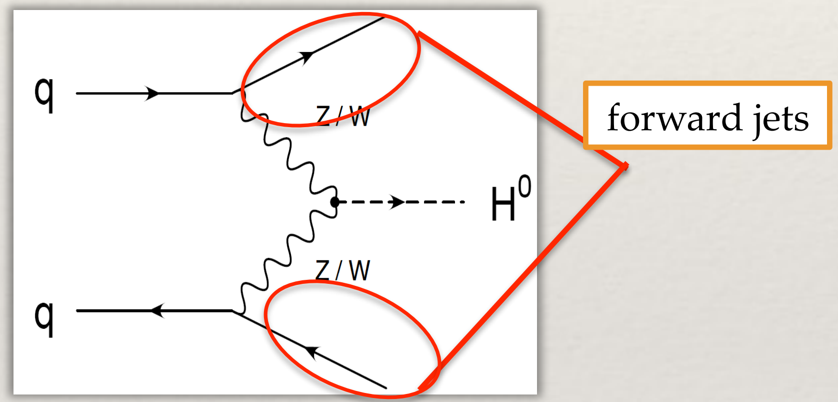
Physics Motivation for Precision Timing

High-Luminosity Large Hadron Collider (HL-LHC)

Goals

Precise measurements of Higgs properties:

- couplings, tensor structure, rare decay
- role in EW-SB ($W_L W_L$ scattering)



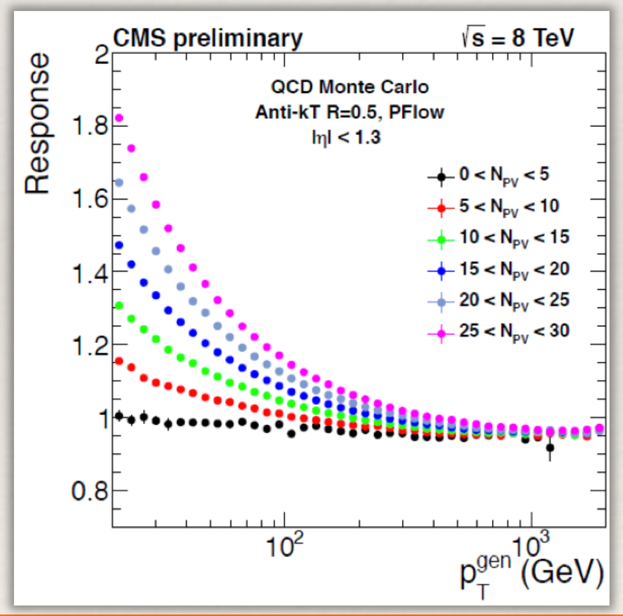
Explore signals of new physics:

- Supersymmetry, DM direct production
- Many analyses require jets and MET

Challenges

Collect more data to increase LHC reach:

- Pileup interactions up to 140
- Key measurements will be affected by this harsh environment



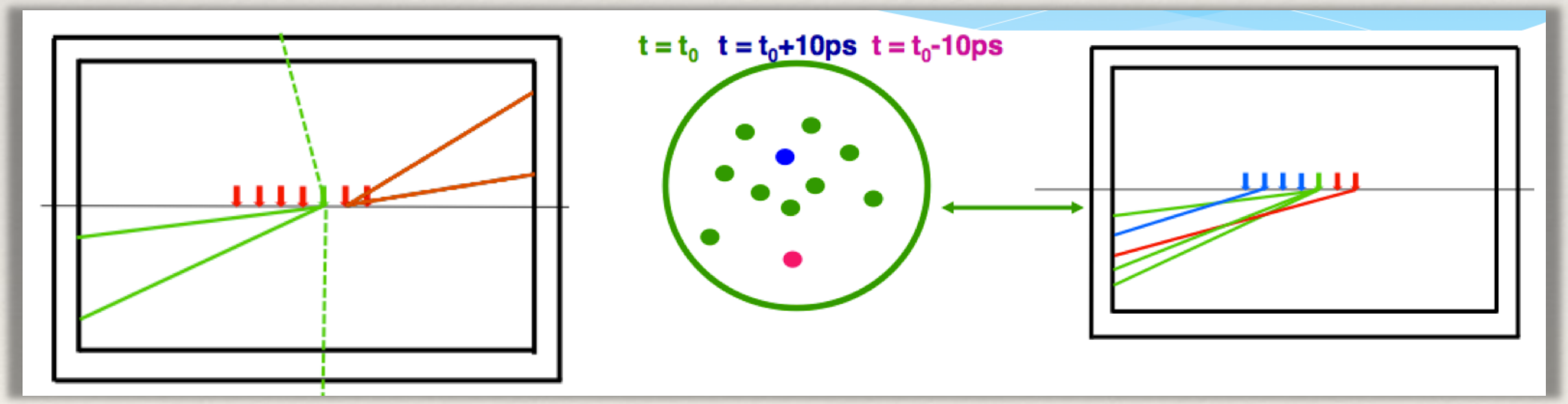
Precision Timing Calorimeters

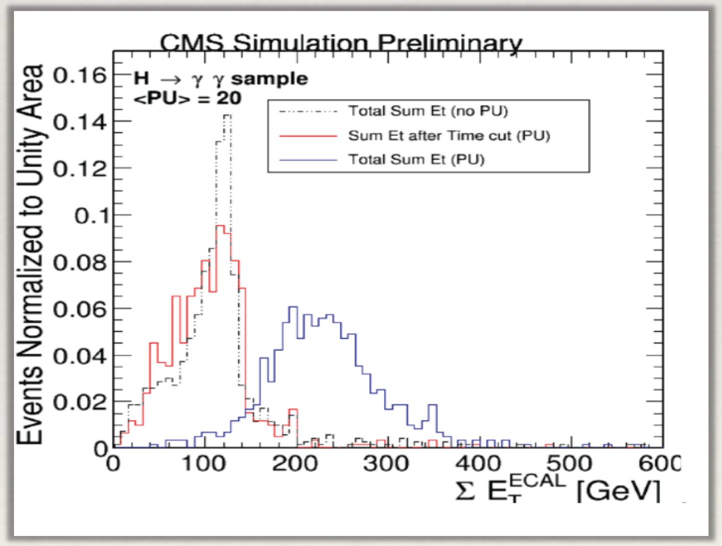
Calorimeter with time resolution of the O(20-30) ps

- Allows a H→γγ vertex reconstruction with approximately 1 cm resolution
- Reduces pileup (PU) energy by a factor of 5-10

Possible physics applications of timing information

- *Object level*: identify forward PU jets (improve VBF higgs and WW scattering)
- *Single hit level:* e.g timing-base ECAL clustering cleaning
- Spatially separate overlapping vertices that corresponds to different time





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Precision Timing Using Crystal

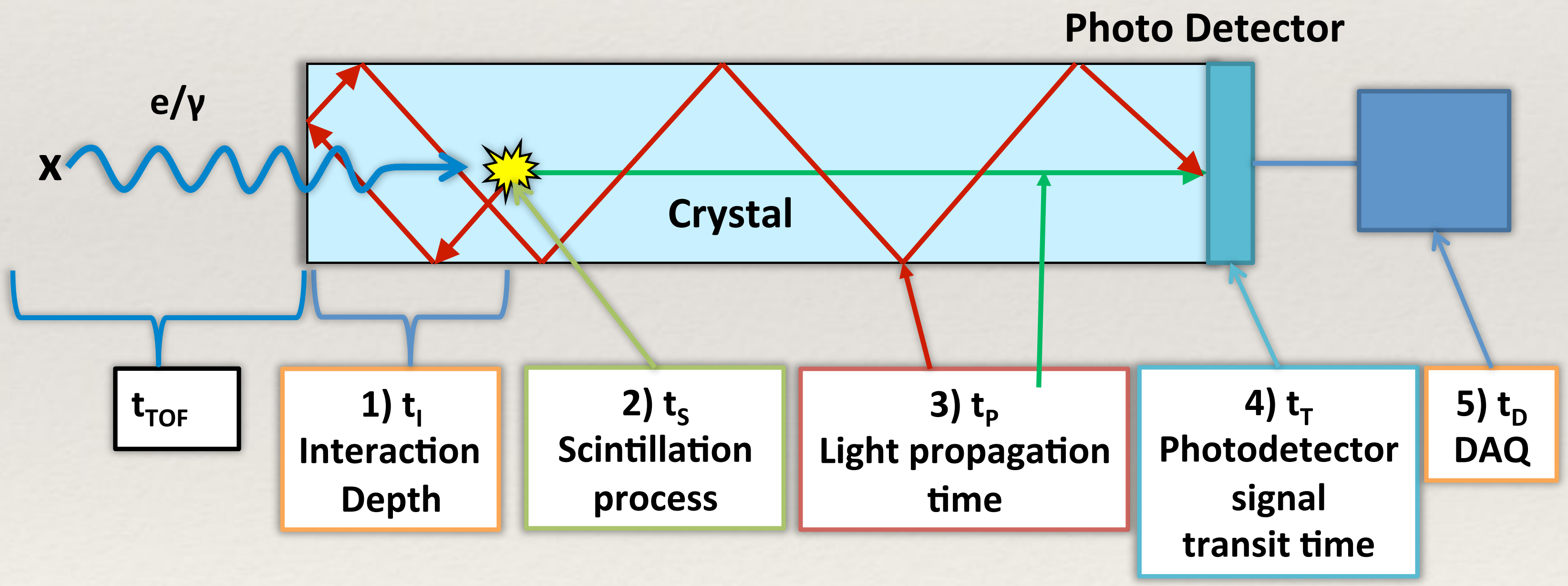
TOF resolution driven by a number of different effects

- Main effects can be approximately factorize
- EM shower development (t_I): shown to be around 20 ps (A. Ronzhin et. al. NIM A, vol 749 p.65-73)

We focus our studies on **scintillation** and **transit time (t_S and t_T)**

Setup allows to control:

Photodetector jitter (t_P) at the 10 ps level and DAQ resolution (t_D) to about 6ps



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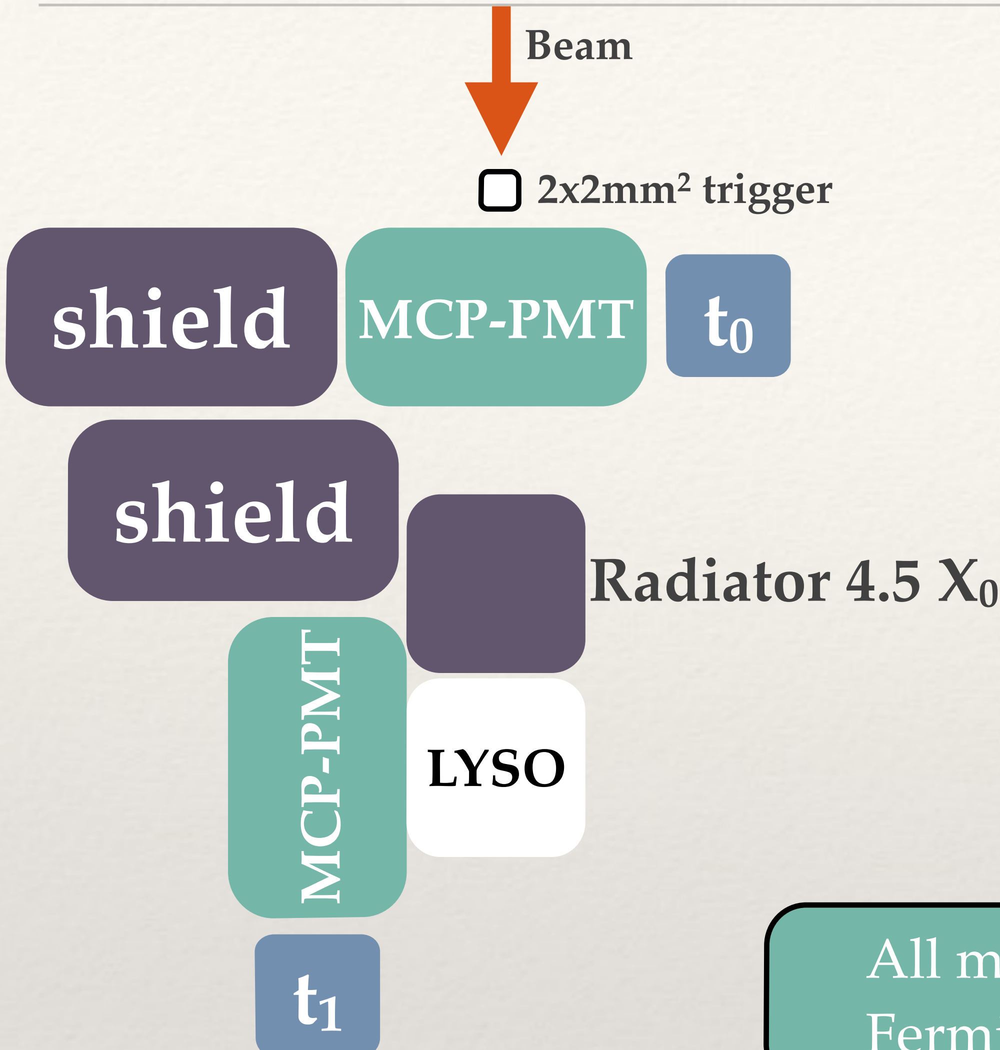
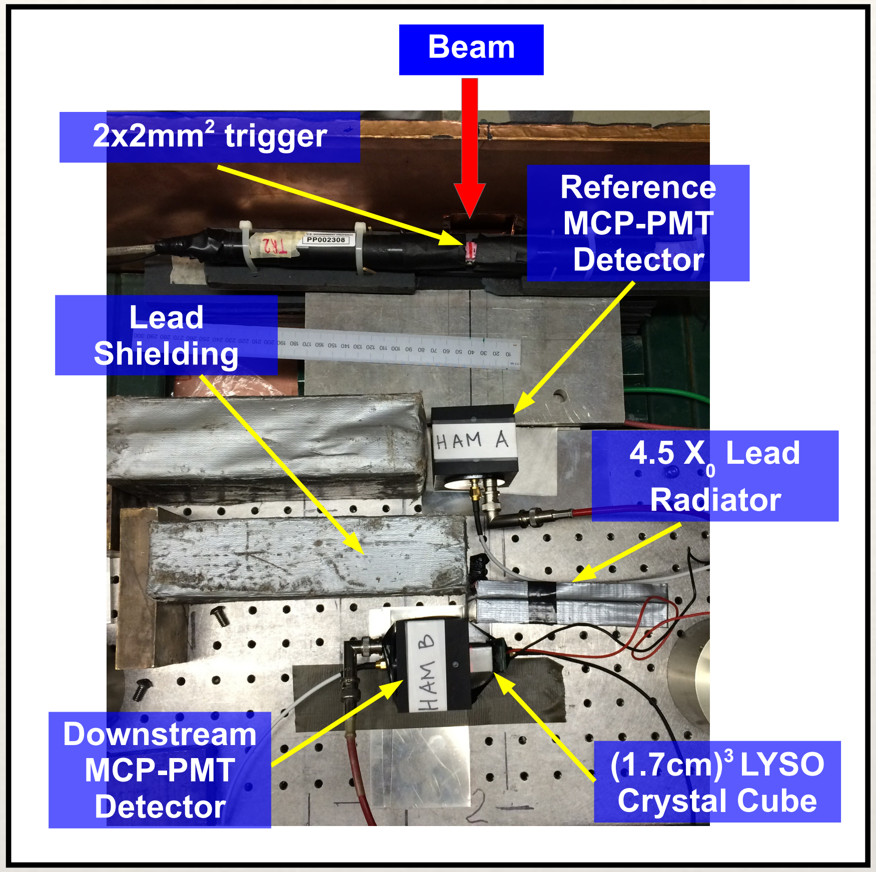
LYSO-based Sampling Calorimeter





All measurement carried out at the Fermilab Test Beam Facility (FTBF)

DAQ = DRS4 wave digitizer + laptop

Goal: **study the effect of scintillation light by reducing optical transport.**

Electromagnetic Shower developed in the lead radiator, then sampled by the LYSO crystal

TOF = t_1 - t_0 (1)

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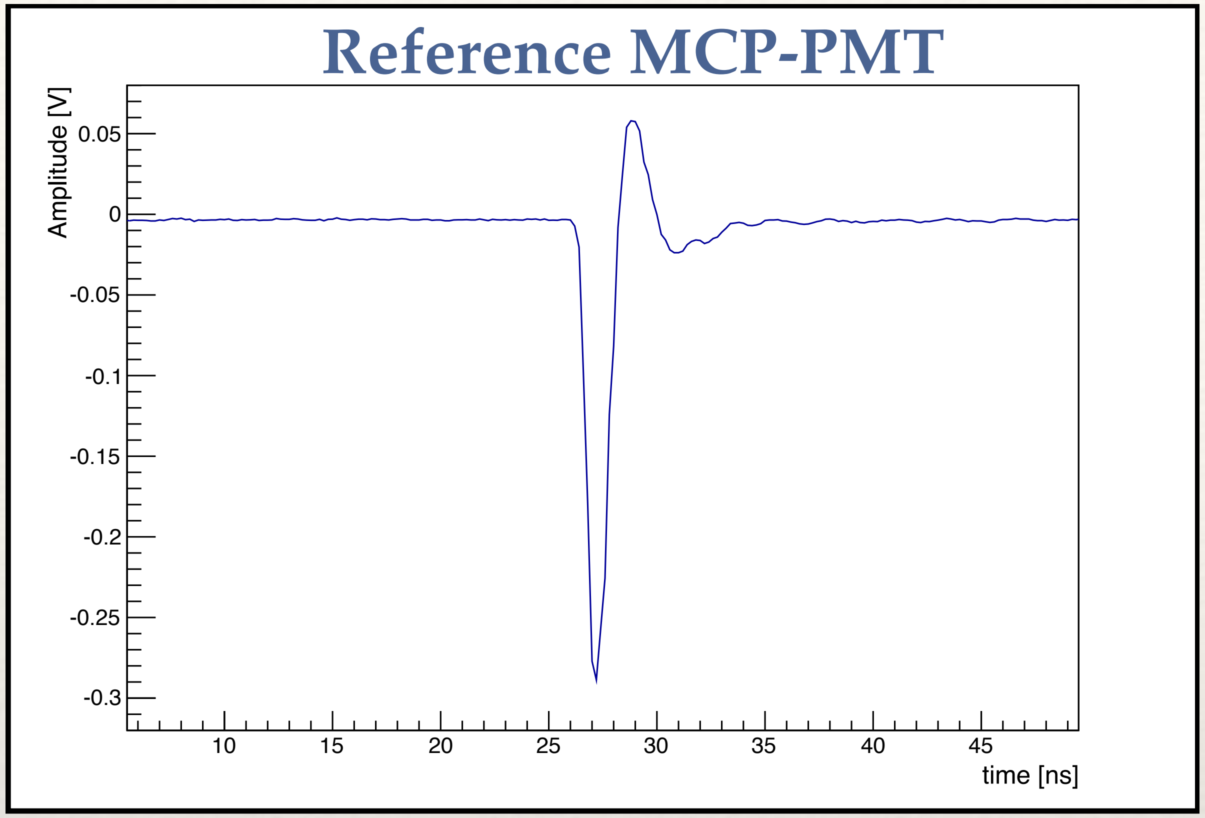
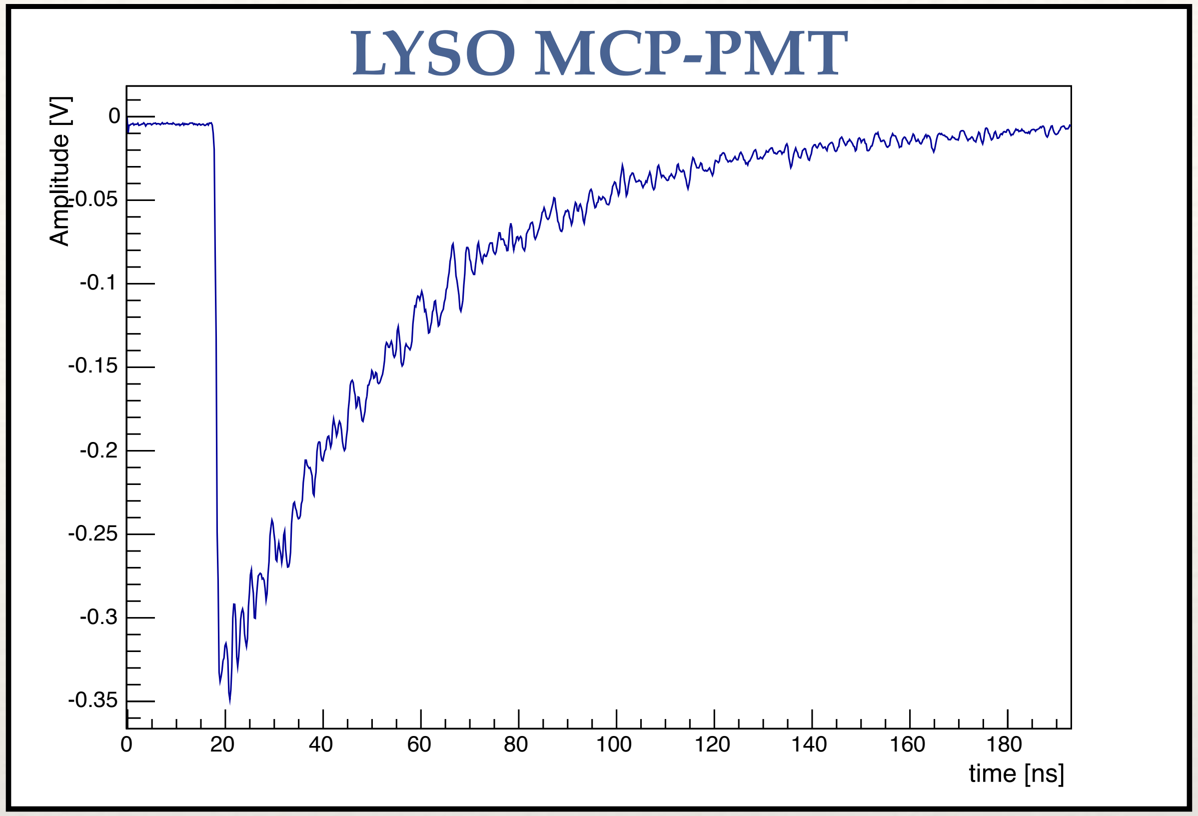
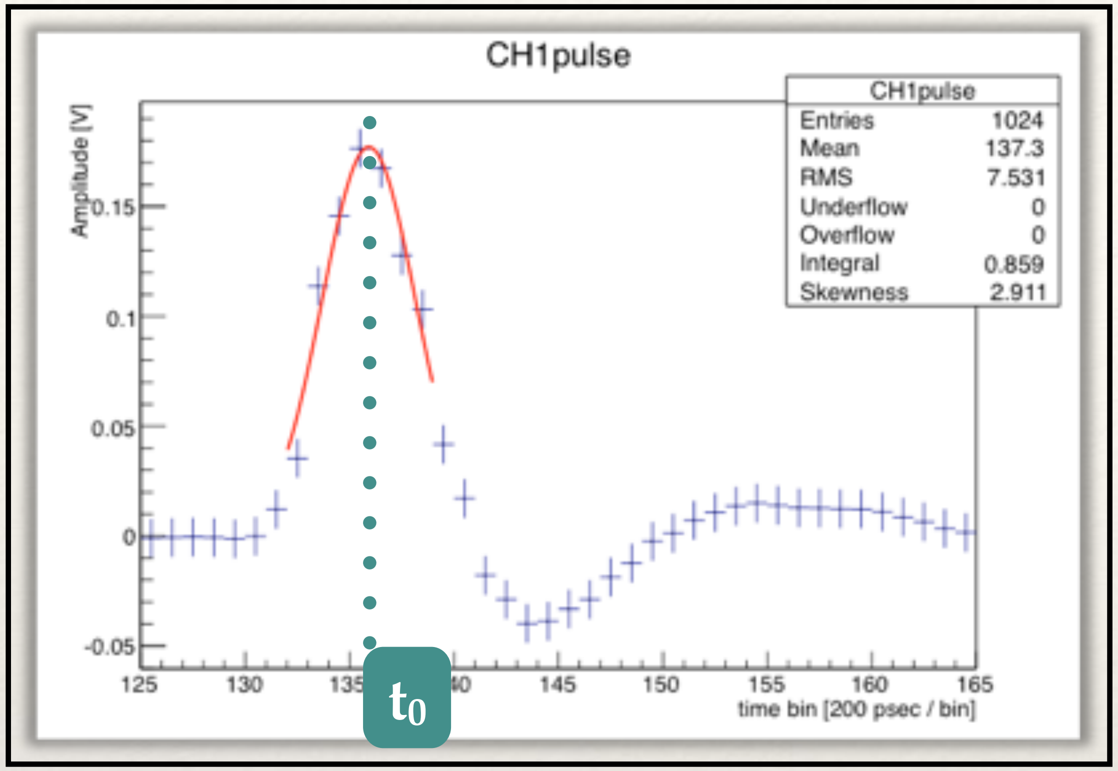
LYSO-based Sampling Calorimeter II

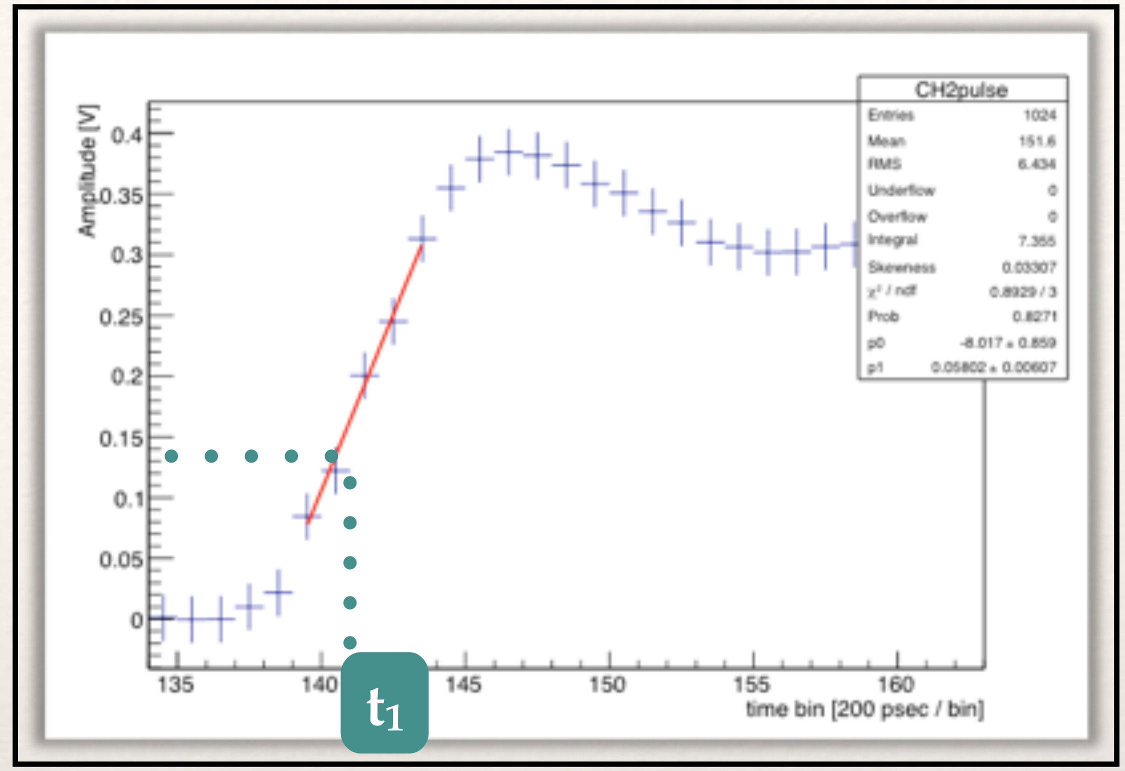




Reference MCP-PMT: **very fast response (2-3 ns)**
LYSO MCP-PMT: **fast rising edge; pulse shape consistent with scintillation light**

LYSO-based Sampling Calorimeter Analysis





Reference MCP-PMT timestamp (t_0): **mean of gaussian fit around peak of pulse shape**

LYSO MCP-PMT timestamp (t_1): **linear fit to rising edge (10-60% of maximum); $t_1 \rightarrow$ time at 20% of the maximum amplitude**

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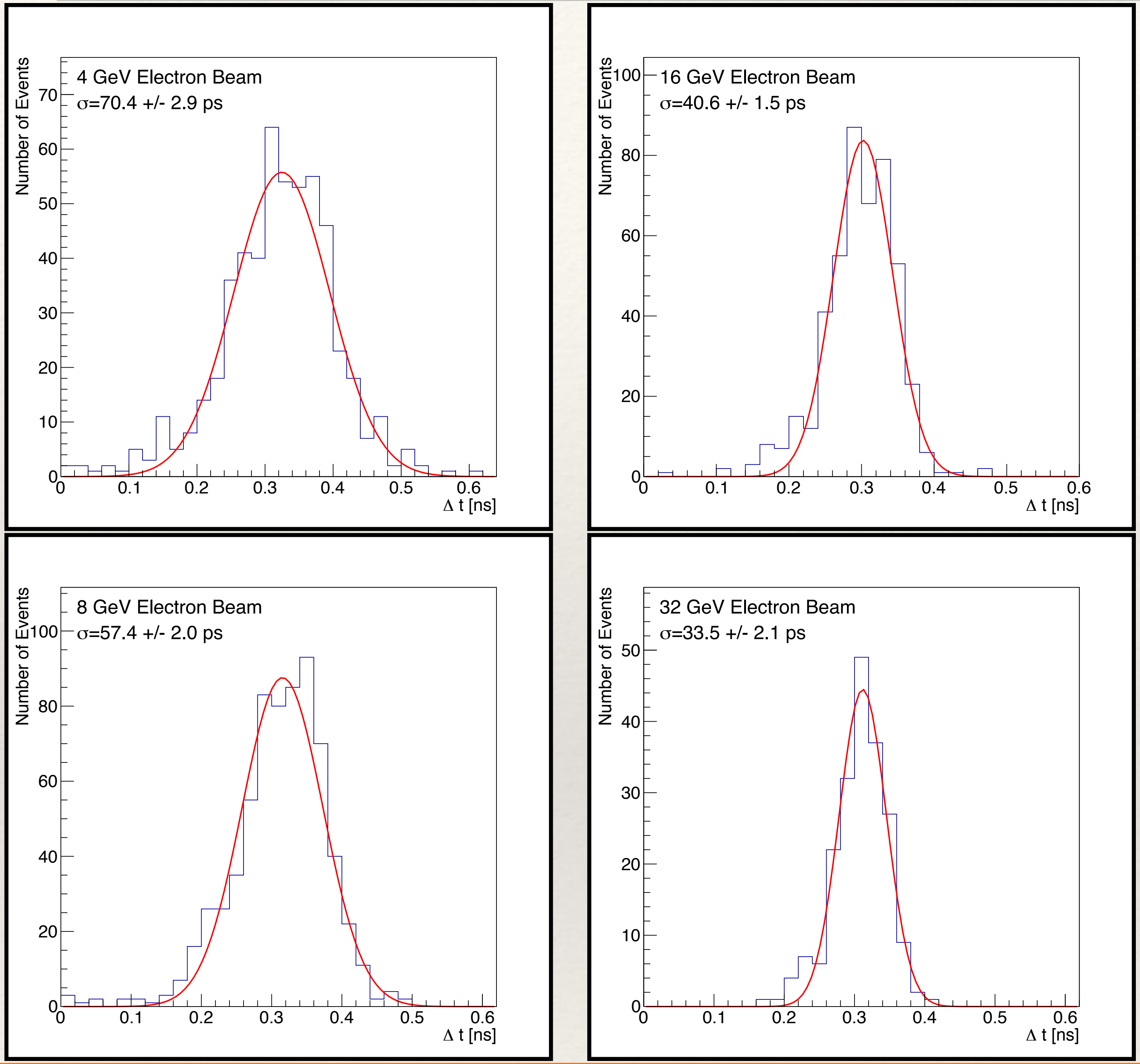
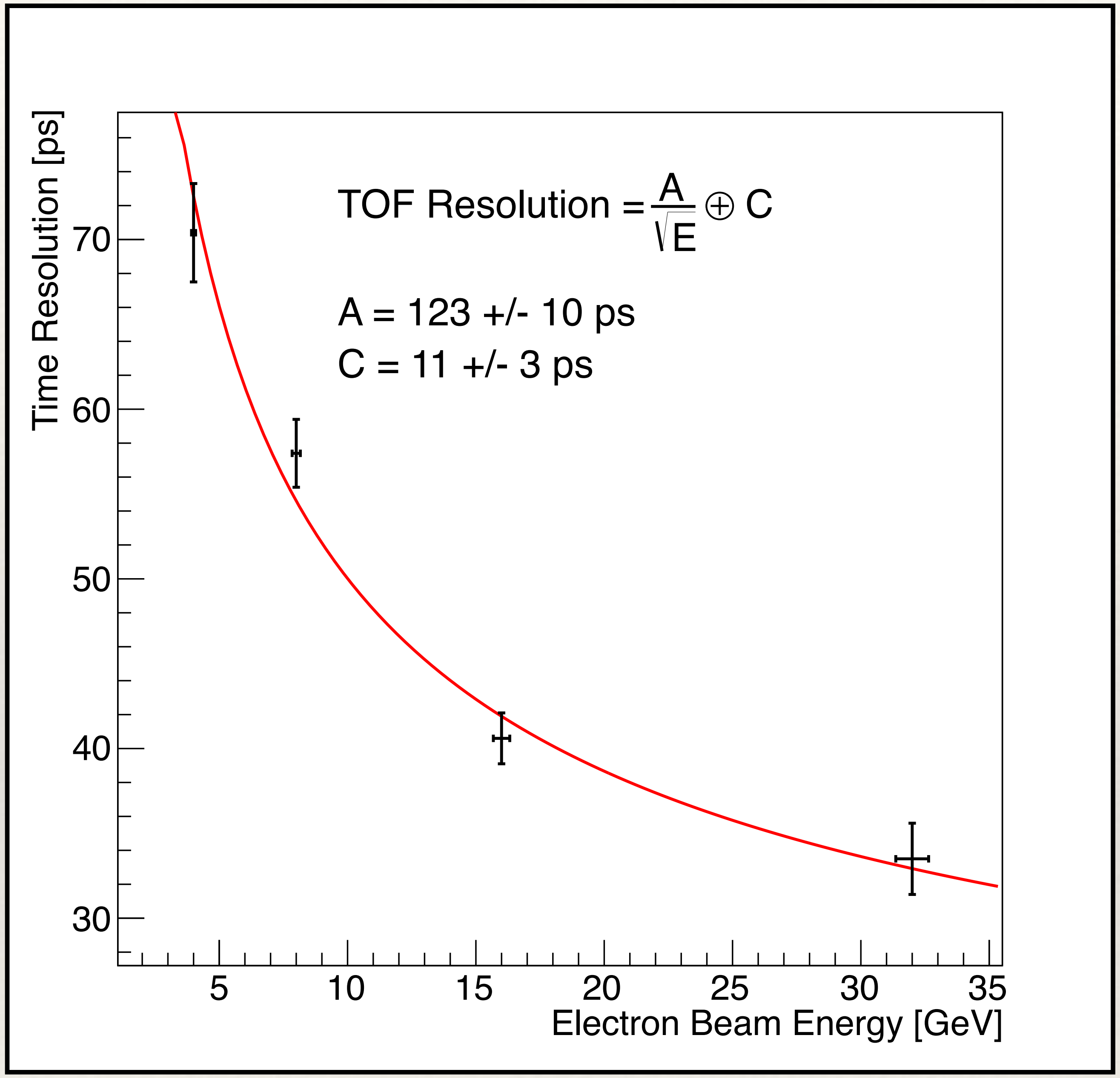
LYSO-based Sampling Calorimeter Results



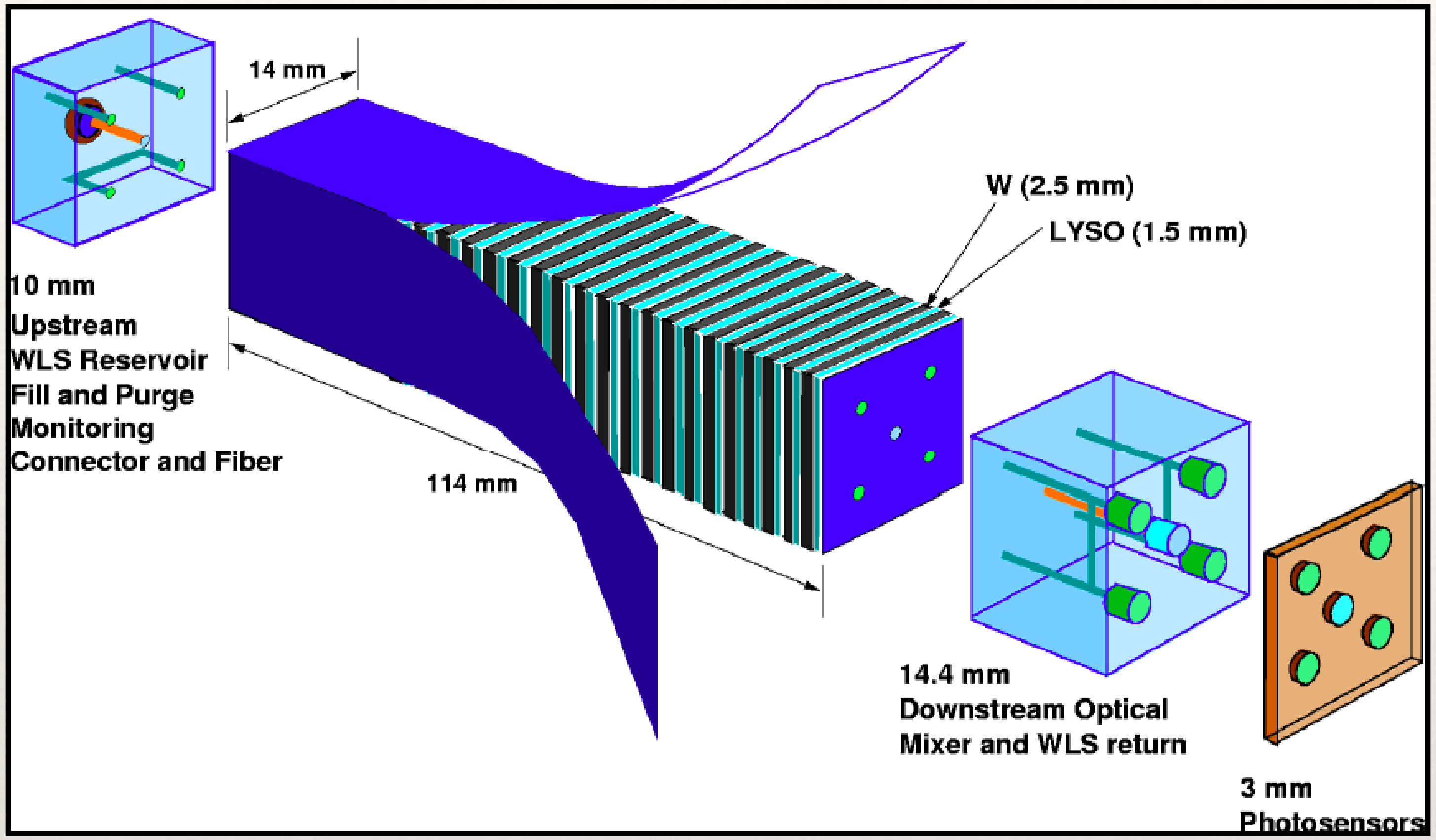
- Measure **TOF resolution** for different electron energies (4, 8, 16, 32 GeV)
- Measure **<u>33 ps TOF resolution</u>** for 32 GeV electrons
- **TOF resolution**: width of gaussian fit to the TOF distribution (**σ**)

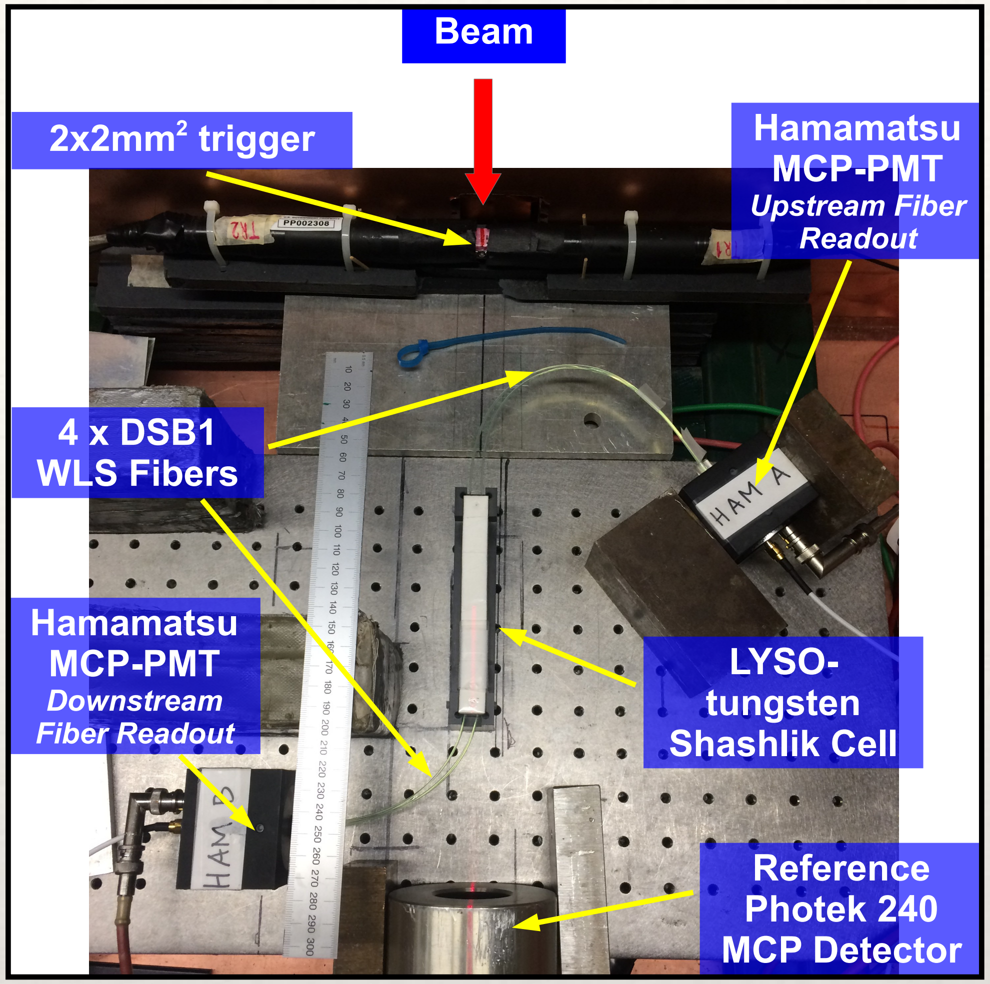
LYSO-based Sampling Calorimeter Results II



- Observe a **$1/\sqrt{E}$ behavior** for **TOF resolution**
- Fit the TOF resolution distribution to the superposition of an stochastic term and a constant term
- **Summary:** **<u>20-30 ps TOF resolution goal is achievable</u>** for ~50 GeV e/γ objects; provided enough light collection

LYSO-Tungsten Shashlik Calorimeter



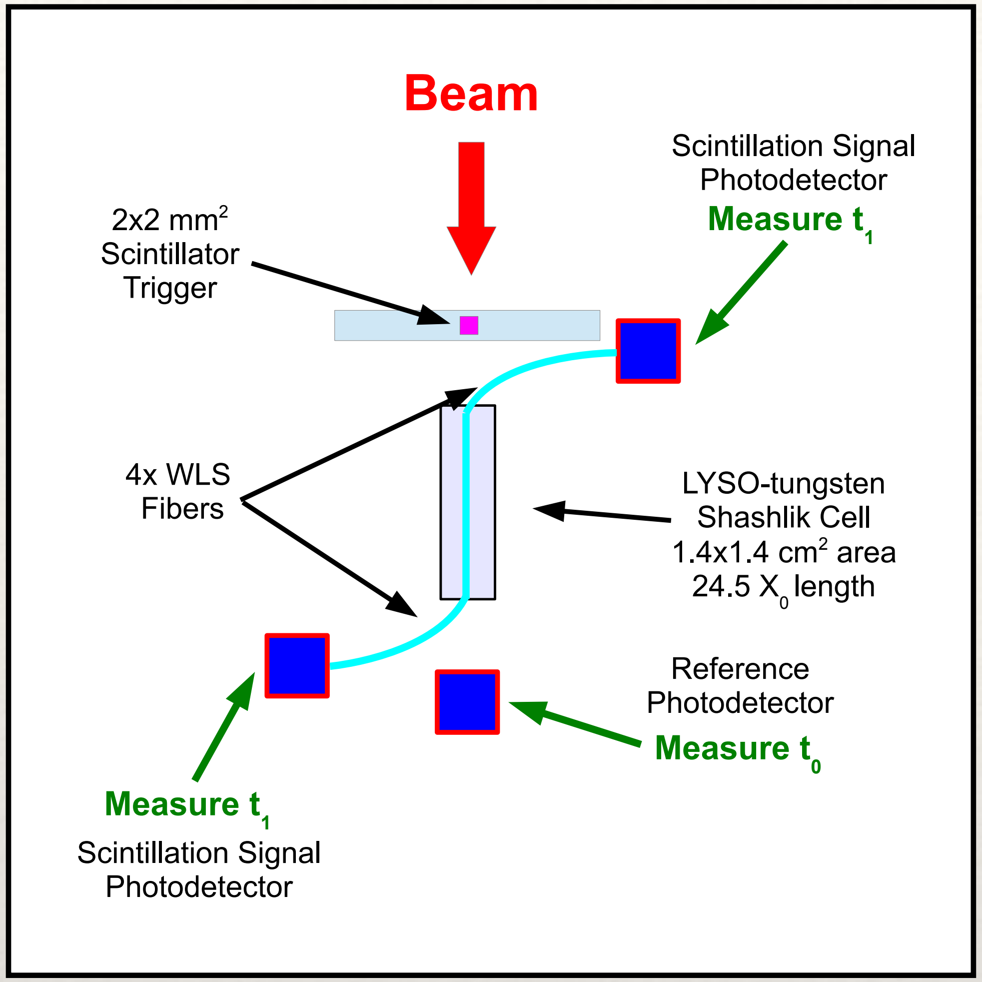


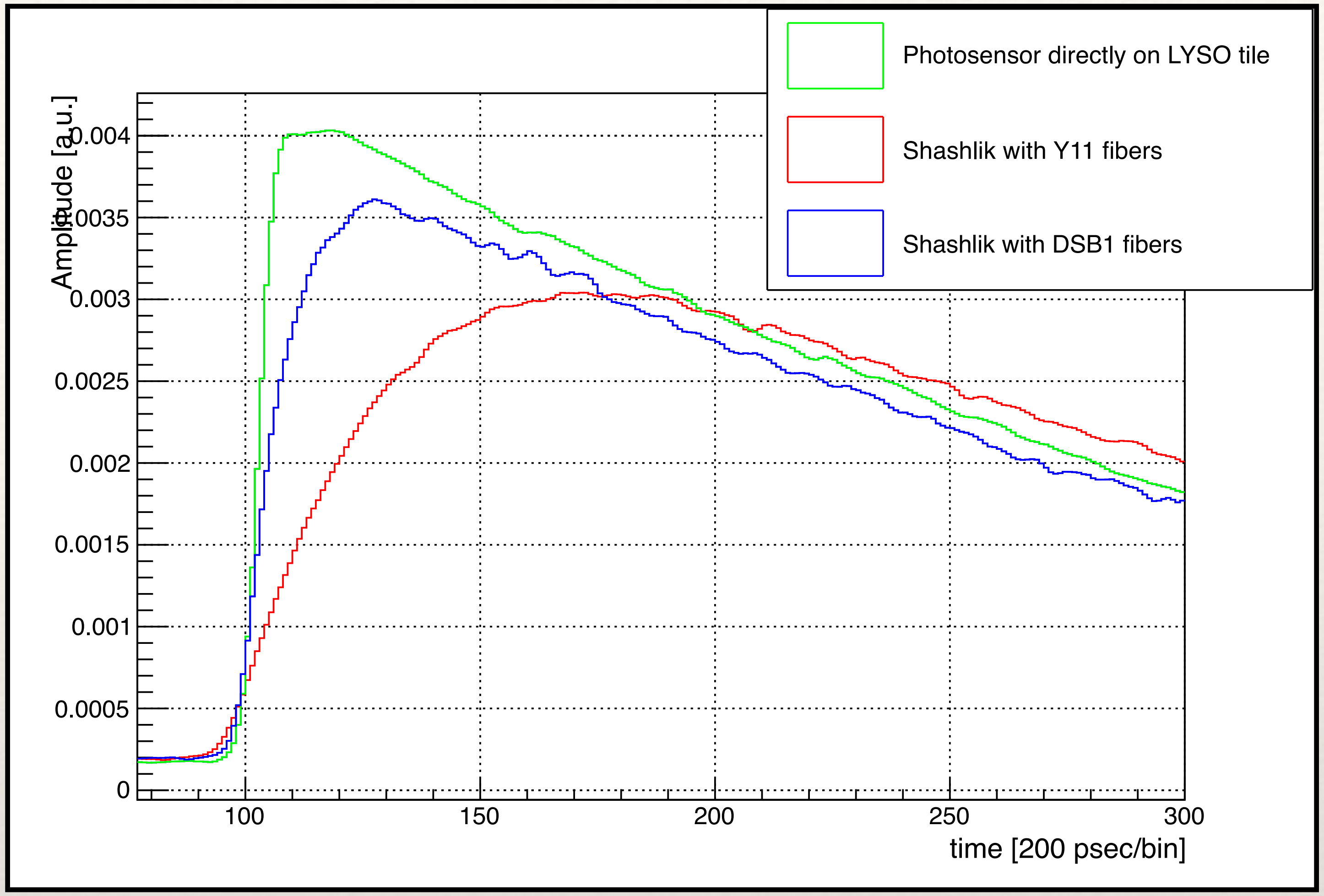
Goal: study the effect of optical transit by increasing the distance traveled by the light

Goal: measure the TOF resolution using WLS fiber and side readout (a la sampling calorimeter)

Build single shashlik module with WLS fibers and MCP-PMT readout

Shashlik WLS fibers Readout Results I





Test the response of different WLS fiber, **particularly the rise time**.

Measure rise times to be ~10 ns and ~4ns for the Y11 (kuraray) and DBS1 WLS fibers respectively.

In terms of TOF resolution **the faster (DBS1) fiber performs better**.

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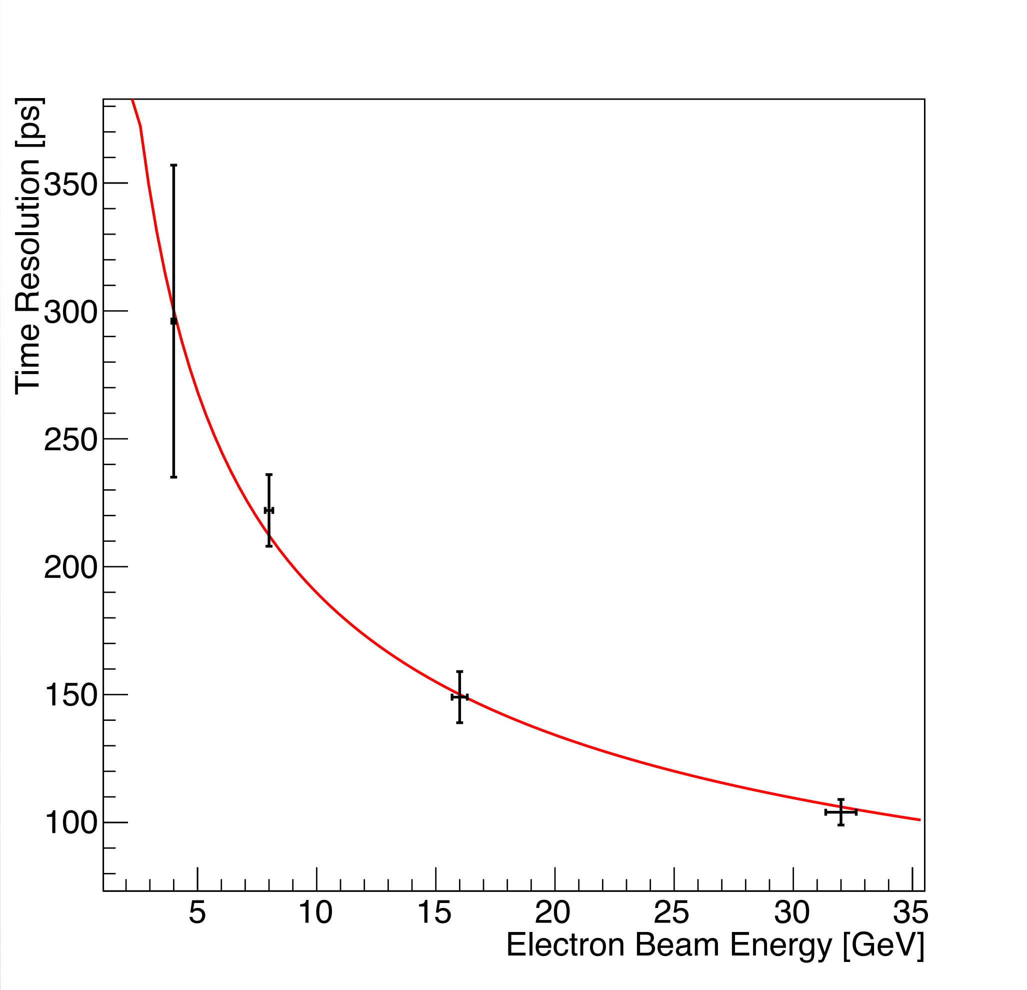
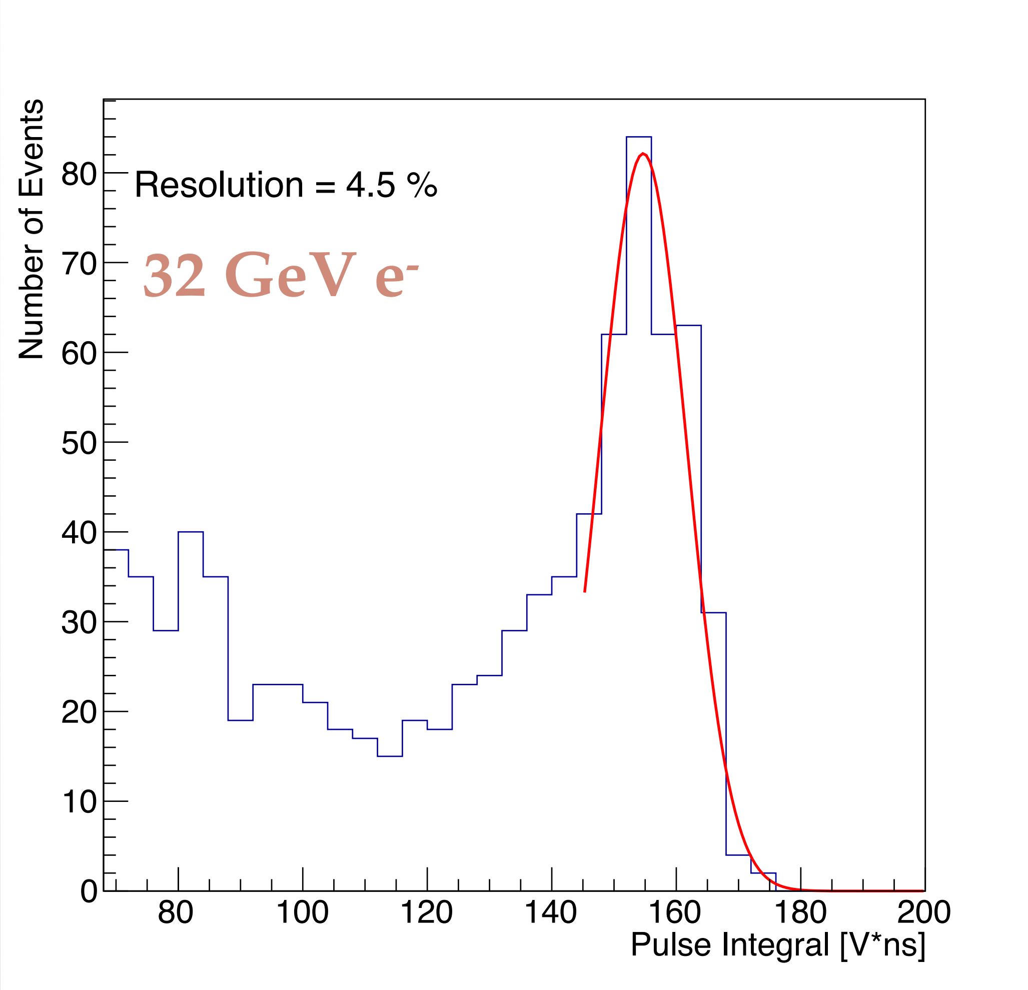
Shashlik WLS fibers Readout Results II





Use same TOF algorithm as in the LYSO-sampling calorimeter.

Measure a **~4.5% energy resolution** using a single shashlik cell readout by WLS fiber and MCP-PMTs

Observe a 1/√E behavior for the **TOF resolution,** measure ~100 ps time resolution for 32 GeV e^-

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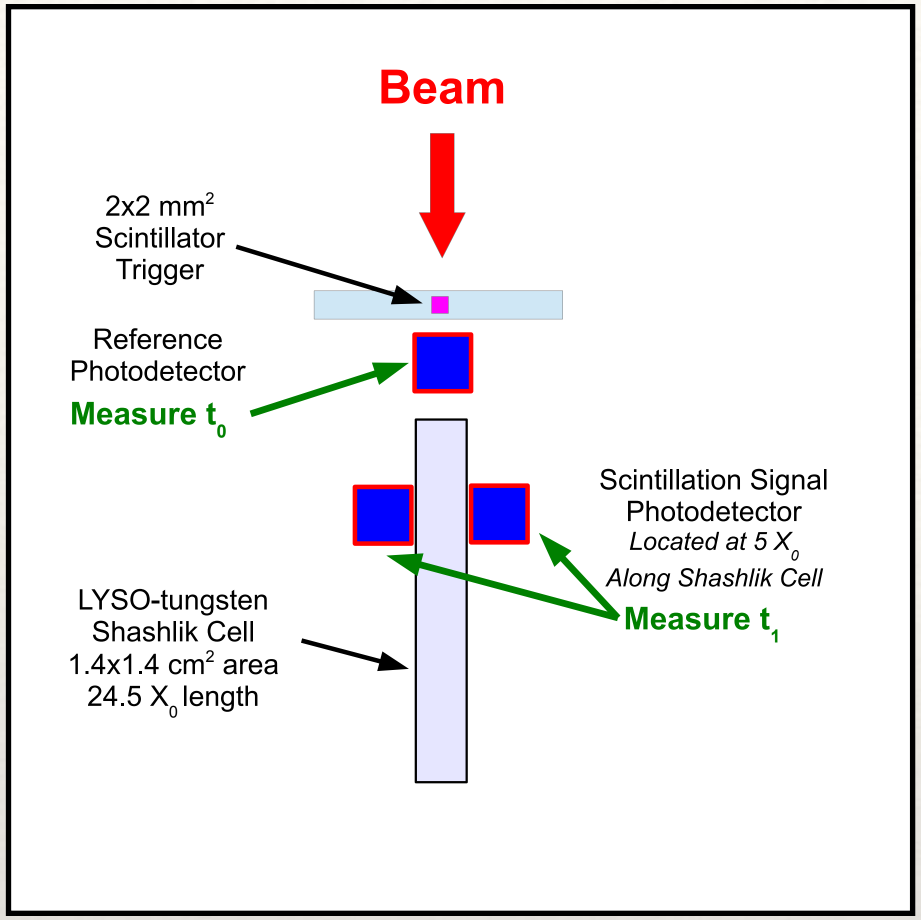
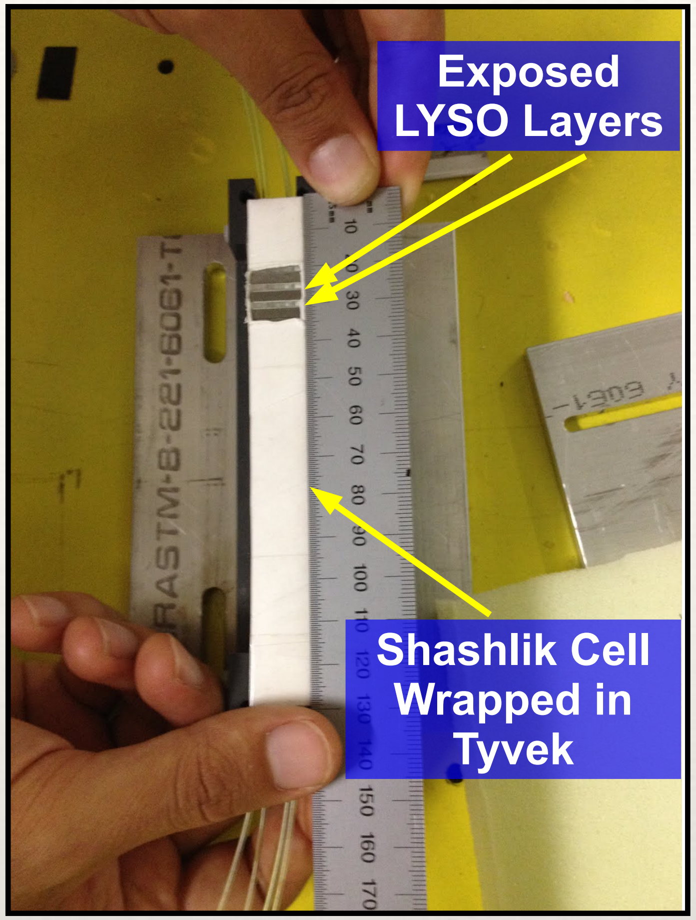
Shashlik Side Readout

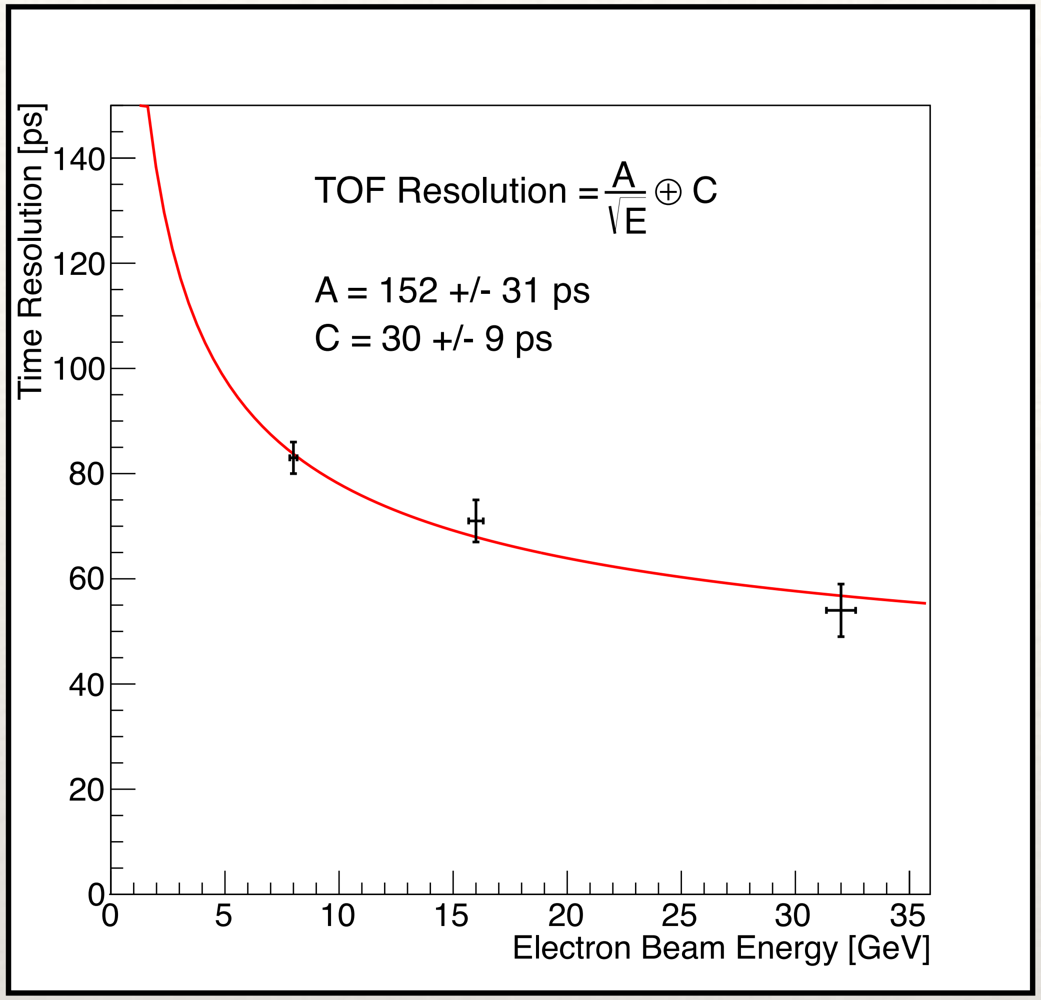


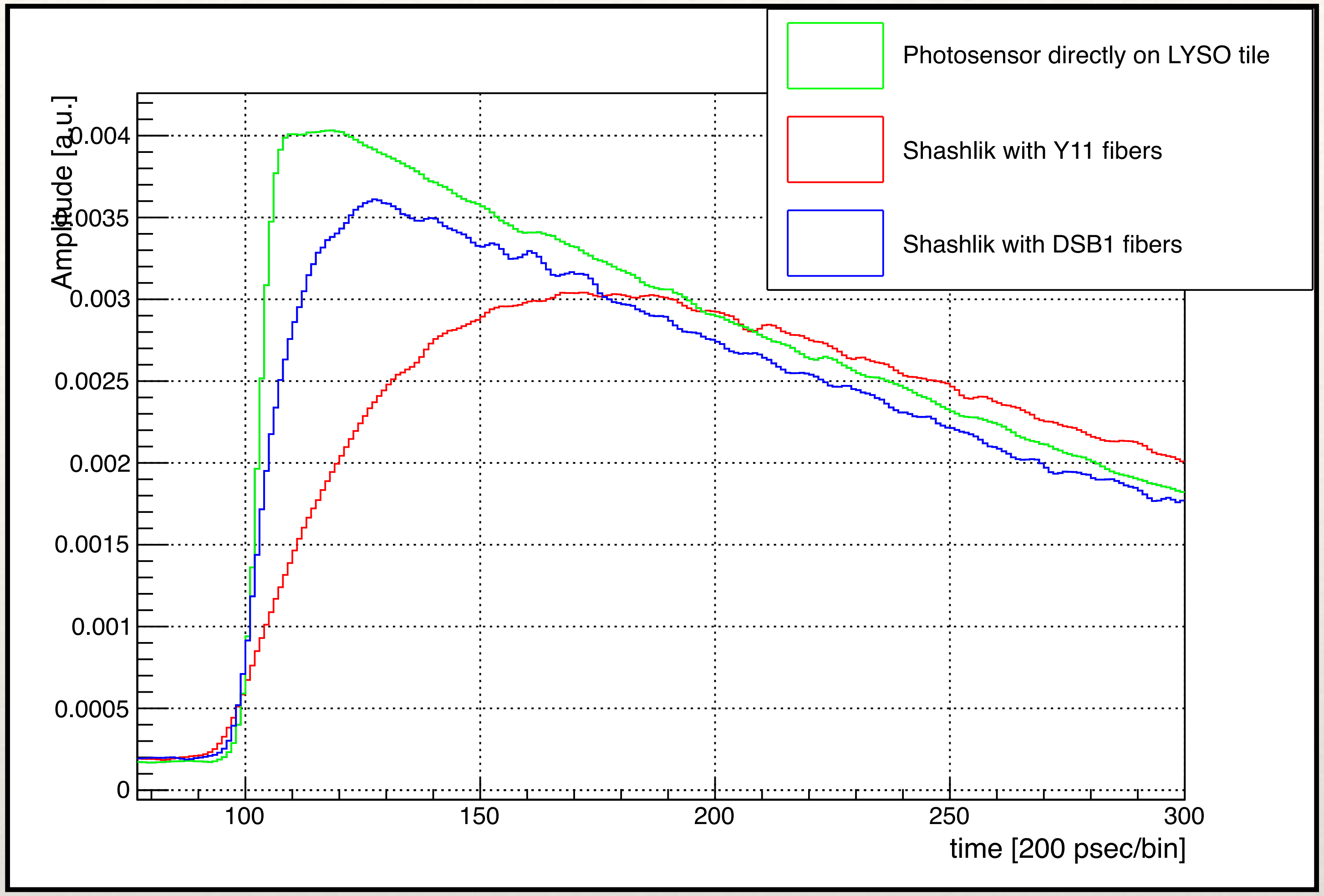


Alternative timing readout: direct coupling of photodevice to the edges of the shashlik cell. Decreases transit time; Exposing two LYSO tiles

Similar approach as a sampling calorimeter by **direct optical coupling of MCP-PMTs at ~5X_0**.
Reduces transit time jitter with at the expense of collecting less light.
Energy measurement obtained with WLS fibers

Shashlik Side Readout Results





Measure a faster rise time form direct side coupling readout compared to that of the WLS fibers.

Observe a 1/√E behavior for the **TOF resolution,** measure ~50 ps time resolution for 32 GeV e⁻

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Summary

- Carried out measurement in beam test with standalone LYSO-based sampling and LYSO-Tungsten Shashlik calorimeter prototypes.
- The 20-30 ps TOF resolution goal is achieved using a LYSO-based sampling calorimeter with MCP-PMT and DRS4 read out.
- Study the optical transit time effect on TOF resolution by using different WLS fiber readout and by direct optical coupling to sides of the Shashlik cell.
- Measure ~50/100 ps TOF resolution for a single Shashlik cell using side/WLS(DBS1) read out

BACKUPS