Scintillators for MUSE

PSI Experiment R-12-01.1

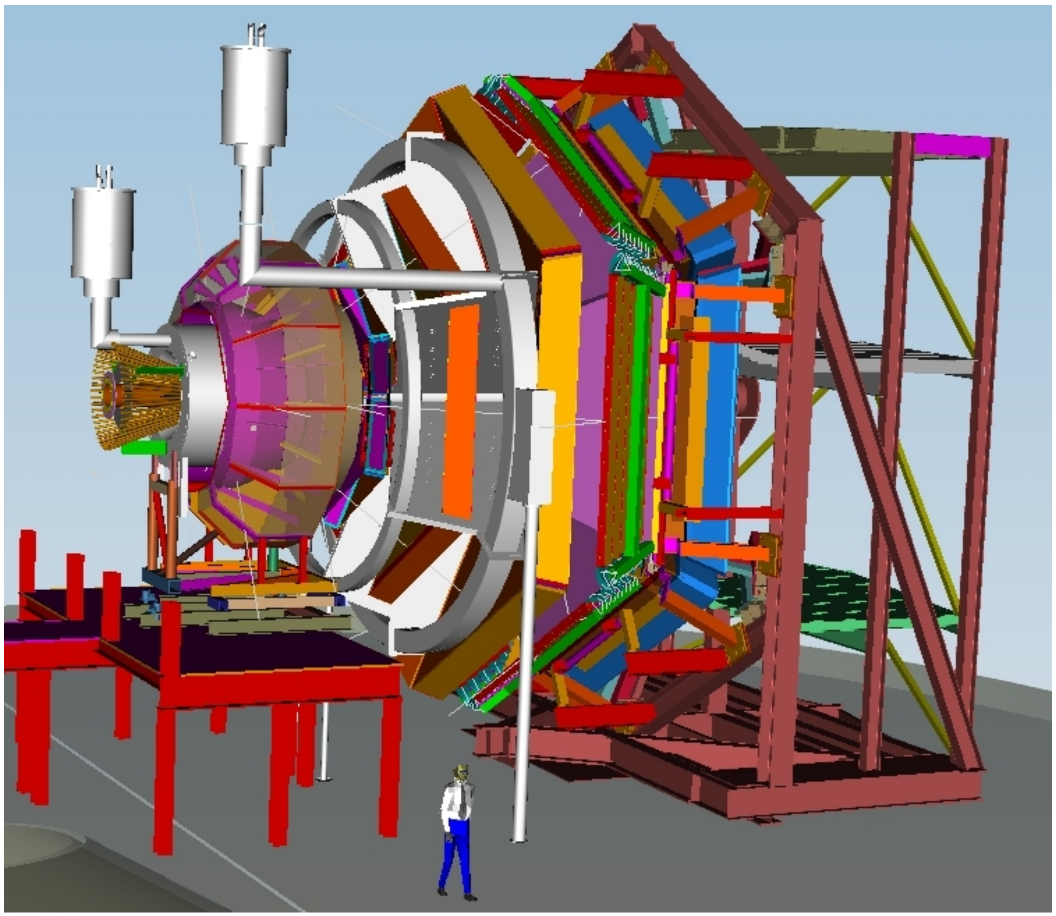
- Efficient trigger scintillator
- Particle identification through high-resolution time-of-flight detector

Steffen Strauch
University of South Carolina

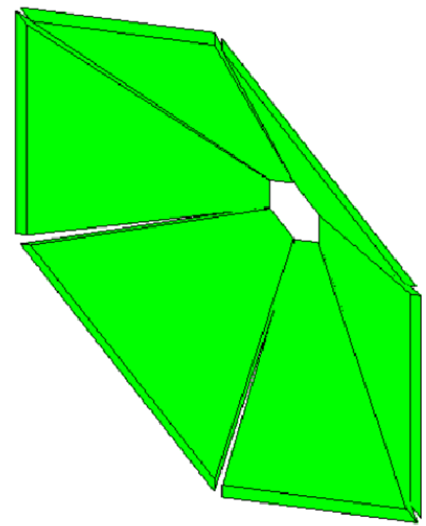
MUSE Review Meeting, PSI, 07/25/12

Forward Time-of-Flight Upgrade

CLAS12 Detector



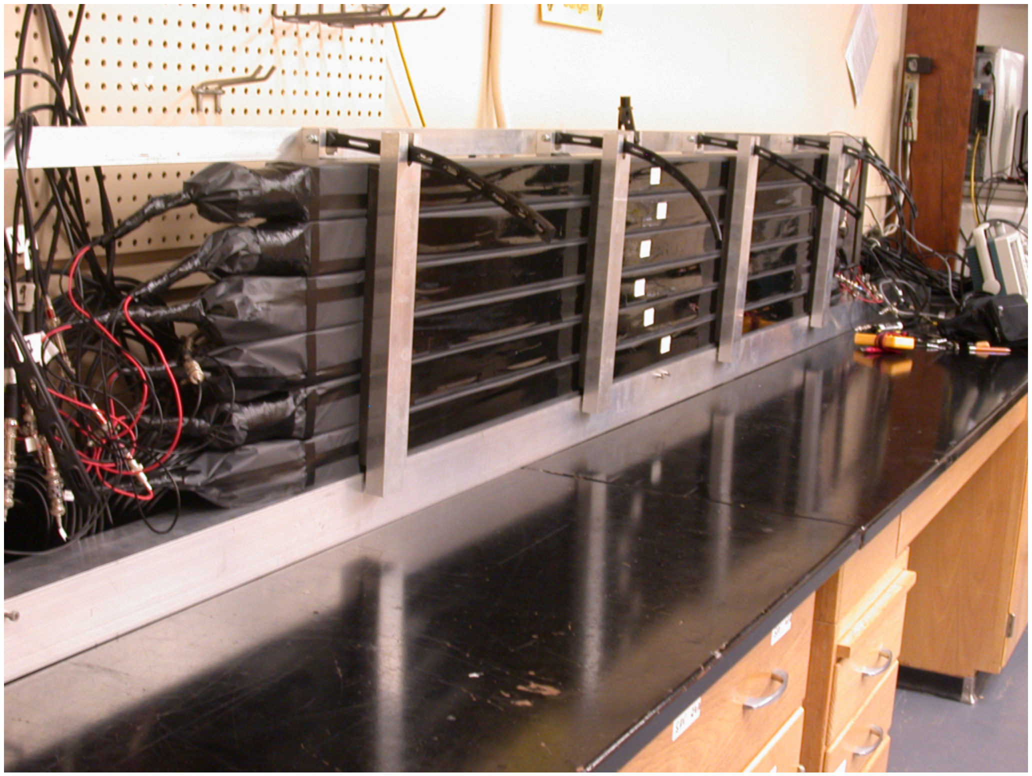
FTOF Panel 1b



Scintillator bars:
6 cm x 6 cm x (50 - 375) cm

The USC group (Ralf Gothe et al.) has been in charge of designing, prototyping, and building the forward Time-of-Flight scintillation counters.

CLAS12 FTOF System Construction at USC



Scintillation bars for the CLAS12 FTOF detector under cosmic ray tests at USC

- A state-of-the-art **laboratory** has been fully equipped at USC to mount and test more than 400 large scintillators for the CLAS12 project.
- After initial development:
  - Production prototype:
    1 bar / week
  - Optimized production:
    6 bars / week, more in summer

R. Gothe and E. Phelps, private communication.

The CLAS12 Scintillator Detector

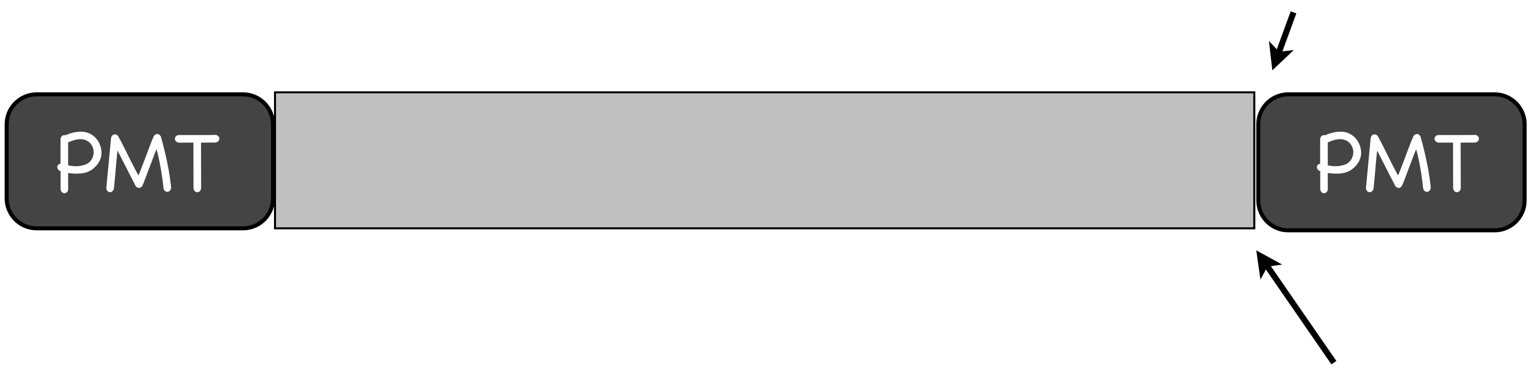
Scintillators:

BC-404; 6 cm x 6 cm x (50 - 200) cm and

BC-408 for the longer bars

PMT: Hamamatsu R9779, d = 51 mm.

(2) No Light guides
PMT directly glued to SC

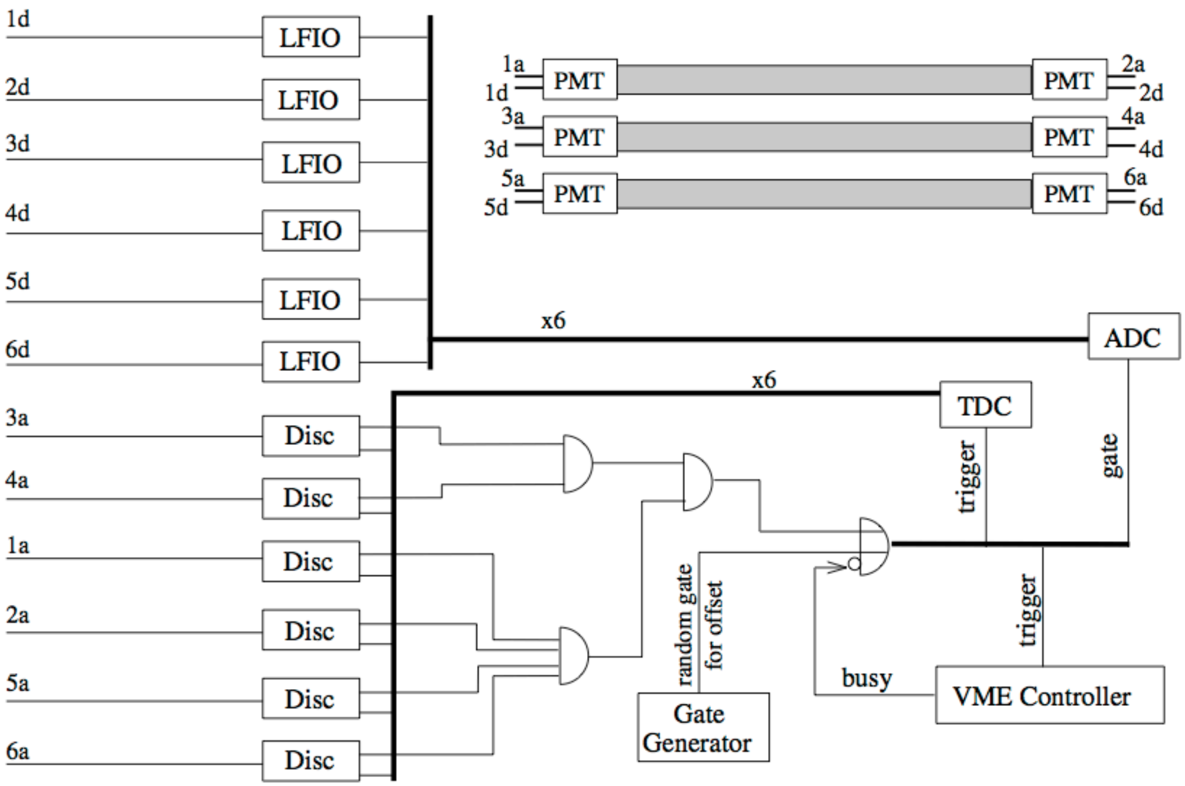


(3) Scintillator wrapped in **Aluminized Mylar**

(4) Light tight **DuPont Tedlar** encases entire counter

(1) Corners masked with black tape

Electronics Used for Test Measurements



- Leading Edge Discriminators: LeCroy 623B
- Pipeline TDC (25 ps) CAEN V1290N
- QDC for time-walk correction CAEN V792N

R. Gothe et al., CLAS12 Forward Time-of-Flight at USC: A Comprehensive Update (2009)

Measurement of the Time Resolution

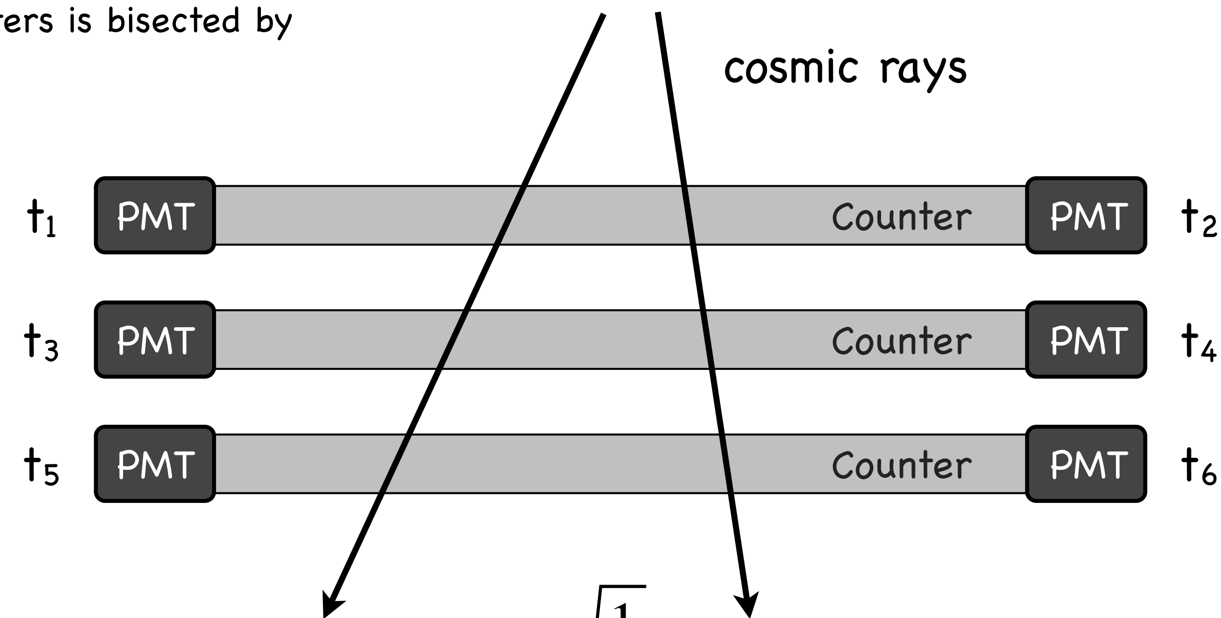
- Three-Bar Cosmic Ray Method

  The three counters are equally spaced such that any path between top and bottom counters is bisected by the middle counter.

top reference counter

middle counter
(under investigation)

bottom reference counter



$$\sigma_{Counter} = \sqrt{\frac{1}{2}}\,\sigma_{PMT}$$

$$T = \frac{t_t + t_b}{2} - t_m = const.$$

$$T = \frac{1}{4}\left(t_1 + t_2 + t_5 + t_6\right) - \frac{1}{2}\left(t_3 + t_4\right)$$

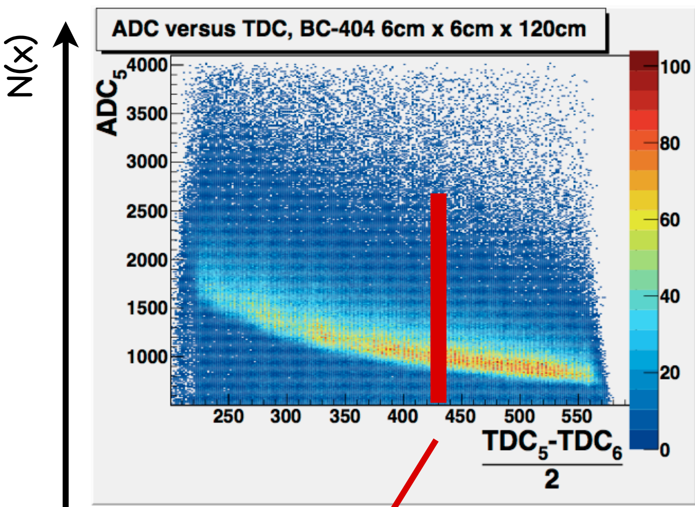
$$\sigma_m = \sqrt{\sigma_T^2 - \frac{1}{2}\sigma_r^2}$$

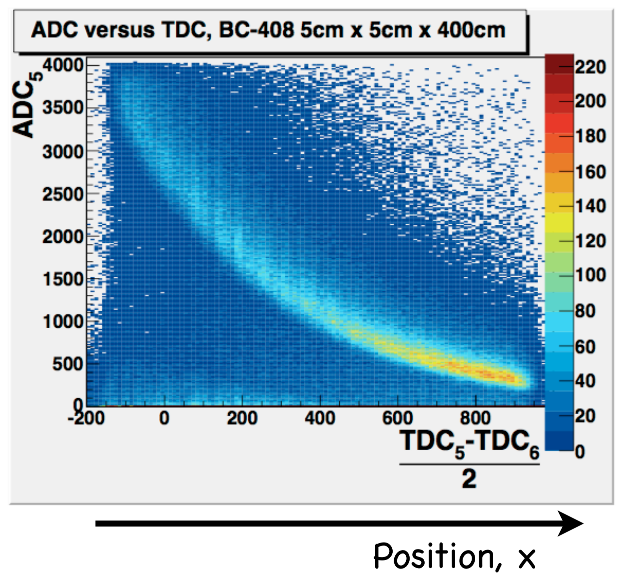
$$\sigma_m = \sqrt{\frac{2}{3}}\,\sigma_T$$

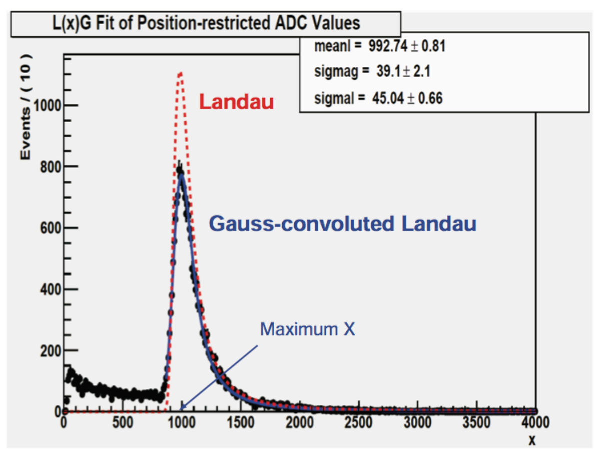
three identical counters

R. Gothe et al., CLAS12 Forward Time-of-Flight at USC: A Comprehensive Update (2009)

Attenuation Length







$$N(x) = N_0 \exp(-x/\lambda)$$

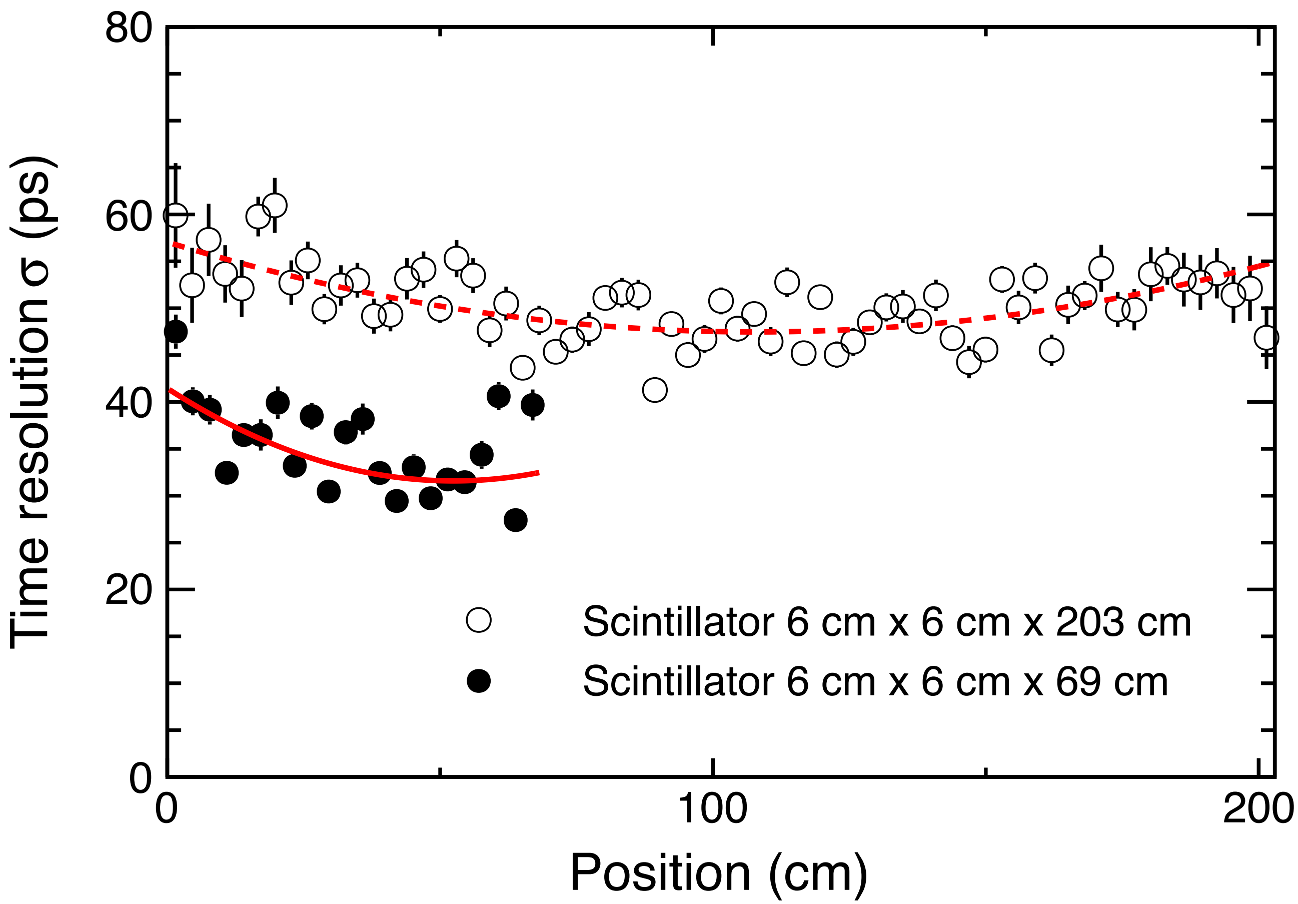
$$N(x) = N_{0T} \exp(-x/\lambda_T) + N_{0B} \exp(-x/\lambda_B)$$

- The attenuation-length measurement is incorporated into the unit **testing** of **each counter** constructed for CLAS12 Panel 1B
- Example: Bulk attenuation length of the 6 cm × 6 cm × 120 cm **BC-404** scintillator,

  λ_B = (330 ± 50) cm

R. Gothe et al., CLAS12 Forward Time-of-Flight at USC: A Comprehensive Update (2009)

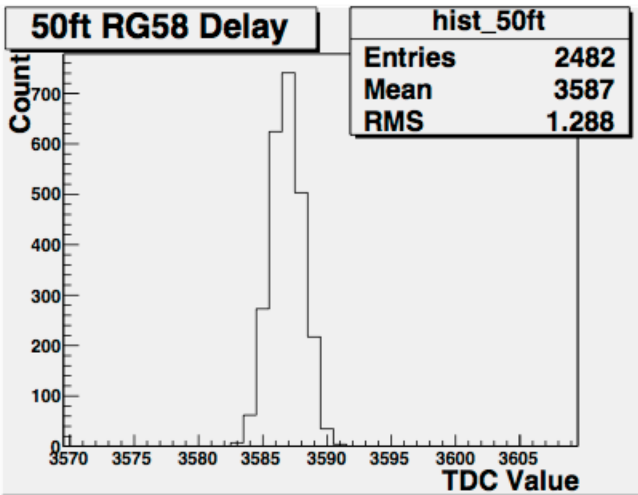
Achieved Time Resolutions

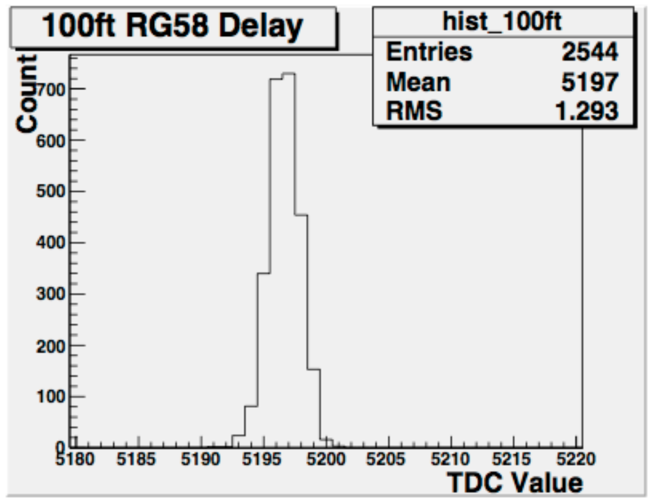


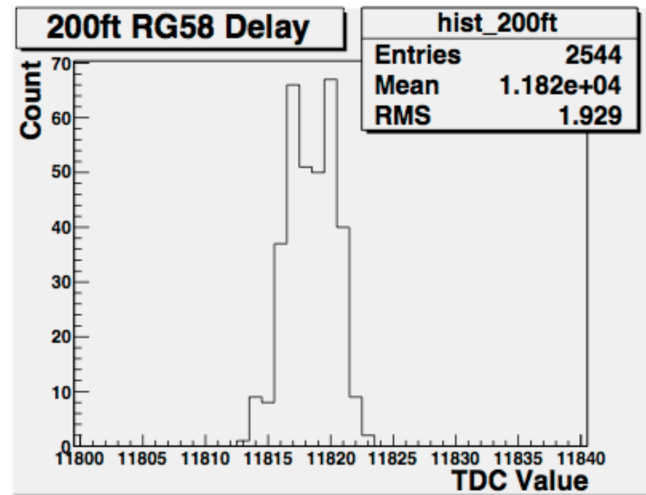
- Time resolution after calibration, event selection, time-walk correction:
  - σ_{avg} = 51 ps for 203-cm bar
  - σ_{avg} = 34 ps for 69-cm bar

R. Gothe and Y. Tian, private communication.

Cable Attenuation





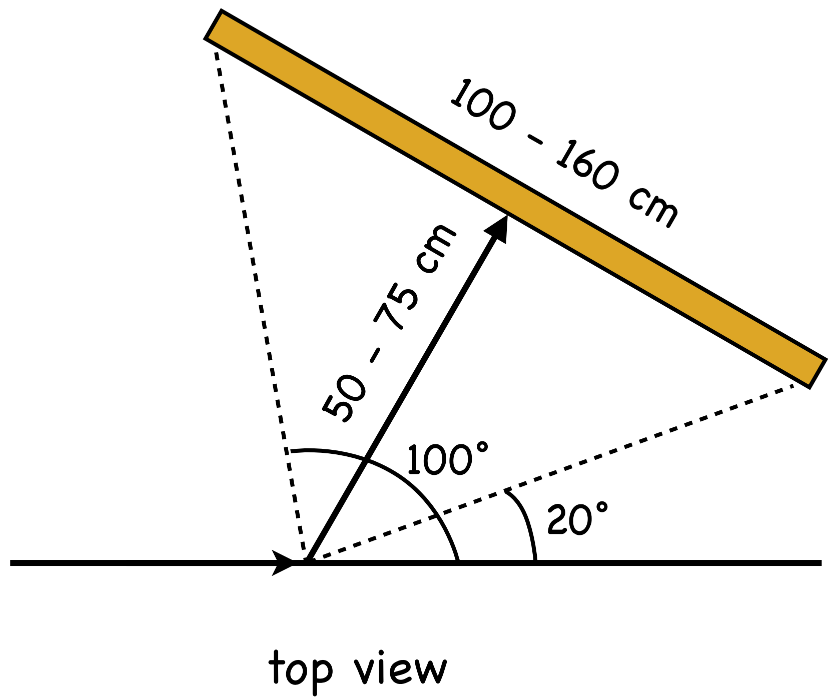


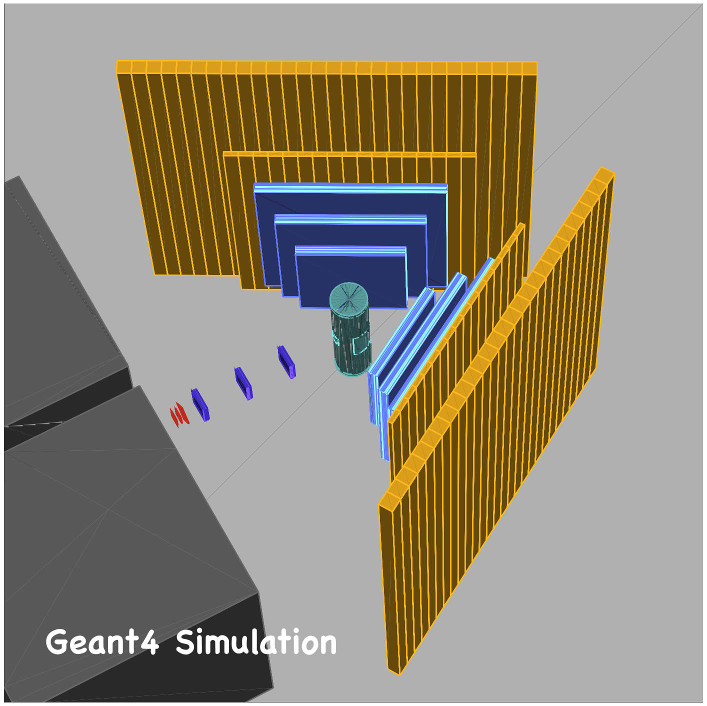
Time resolution remains within the 30 ps to 35 ps TDC resolution

Time resolution increased by 50% between 100 ft and 200 ft of RG58 cable delay

R. Gothe et al., CLAS12 Forward Time-of-Flight at USC: A Comprehensive Update (2009)

Cartoon of the Setup / Geometry





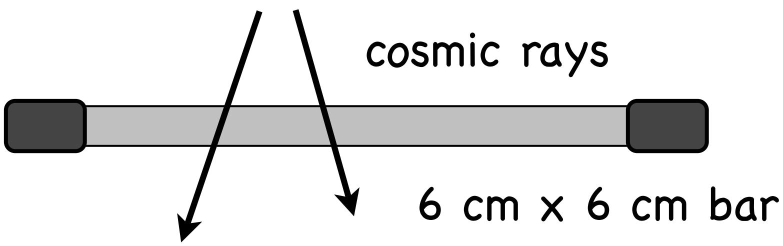
- The detector wall is rectangular with vertically oriented bars.
- The front wall covers the full angular range from everywhere within the target: $20° < \theta_H < 100°$ and $-45° < \theta_V < +45°$.
- The back-wall is increased in size to also account for multiple scattering in the front wall while maintaining high coincidence efficiency.

Design Parameters for the Scintillator Walls

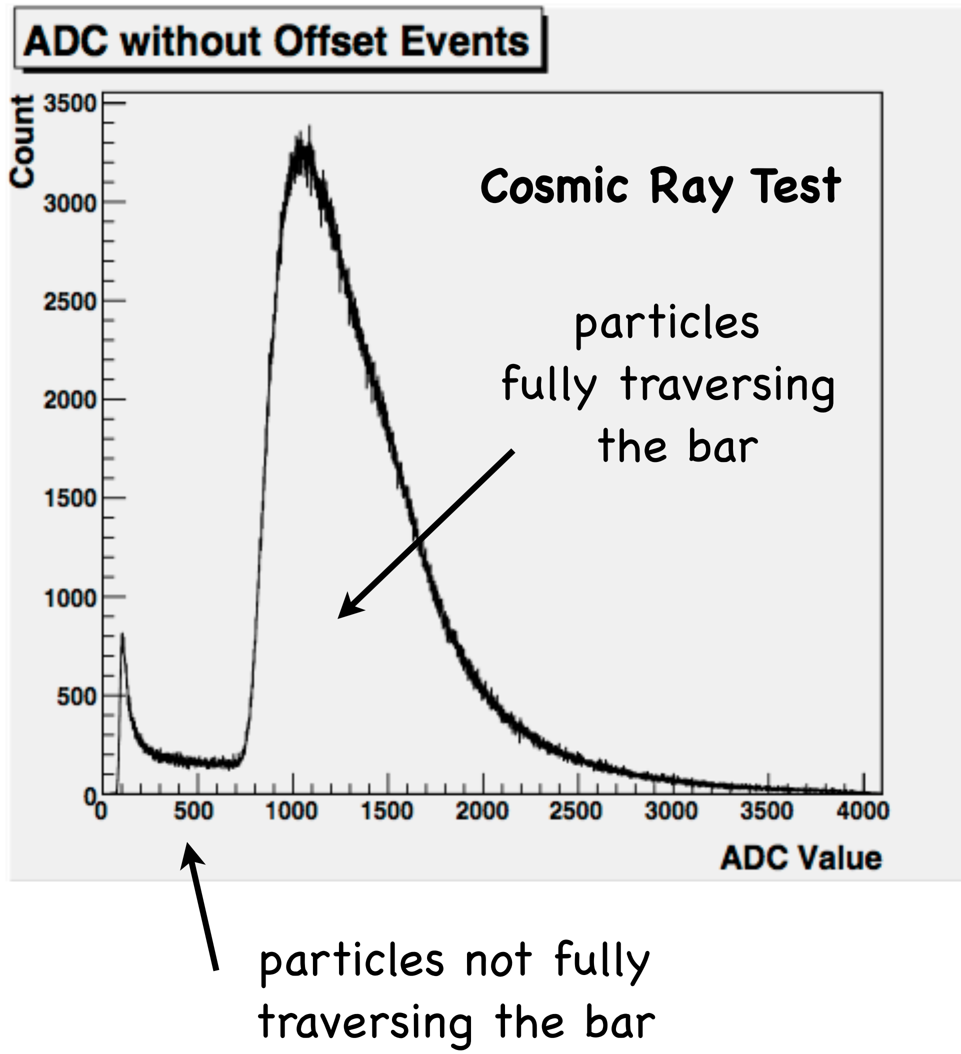
	Front wall	Back wall
Number of scintillator bars	17	27
Scintillator cross section	6 cm x 2 cm	6 cm x 6 cm
Scintillator length	103 cm	163 cm
Target to front-face distance	50 cm	73 cm
Gap between scintillator bars	0.02 cm	0.02 cm
Scintillation material	BC-404	BC-404
Photomultiplier	Hamamatsu R9779	Hamamatsu R9979

- The Number and dimensions of scintillator bars may vary slightly in the final design.

Energy Deposition

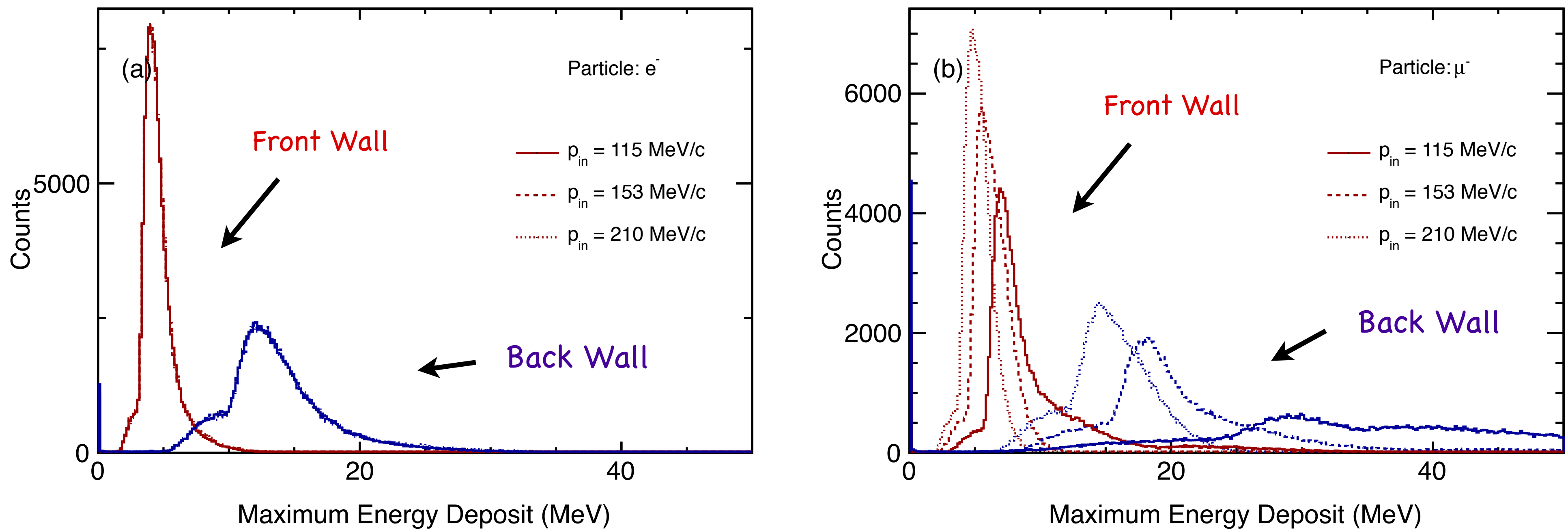


- Specific energy loss for JLab and MUSE experiments are similar for electrons.
- We expect similar ADC distributions in the MUSE experiment.



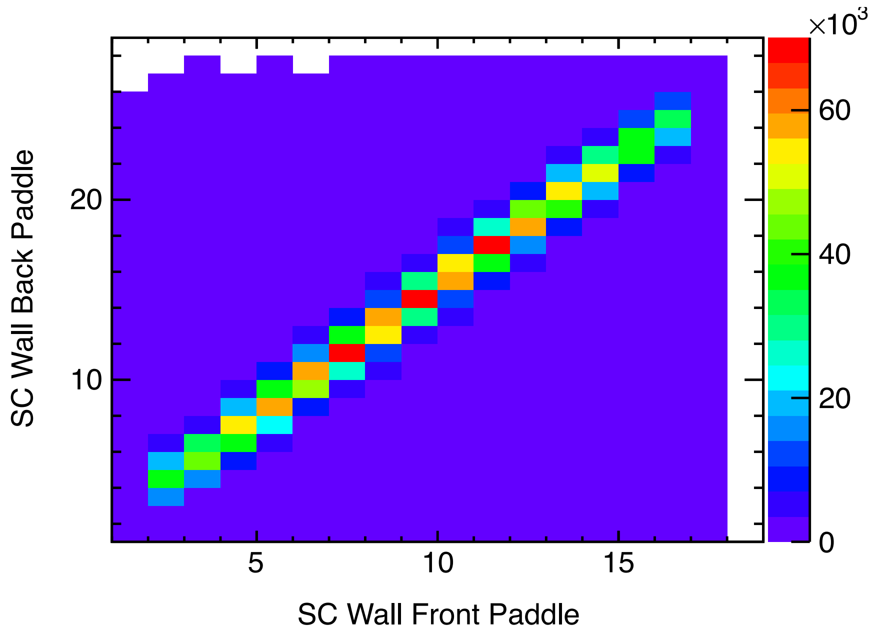
R. Gothe et al., CLAS12 Forward Time-of-Flight at USC: A Comprehensive Update (2009)

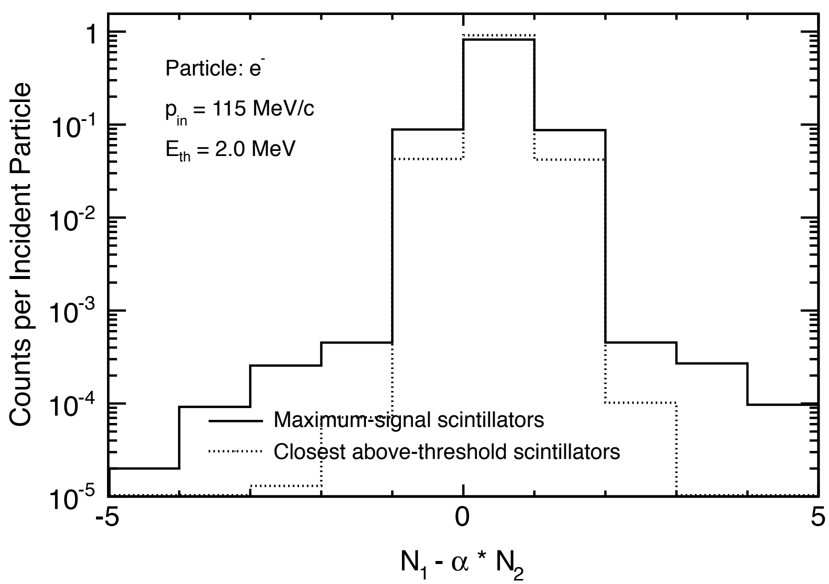
Simulated Energy Deposition



- Maximum energy deposition in any front- or back-wall bar is for nearly all events above threshold, E_{th} = 2 MeV.
- Distributions of energy deposition can be studied with beam tests.

Directional Cut

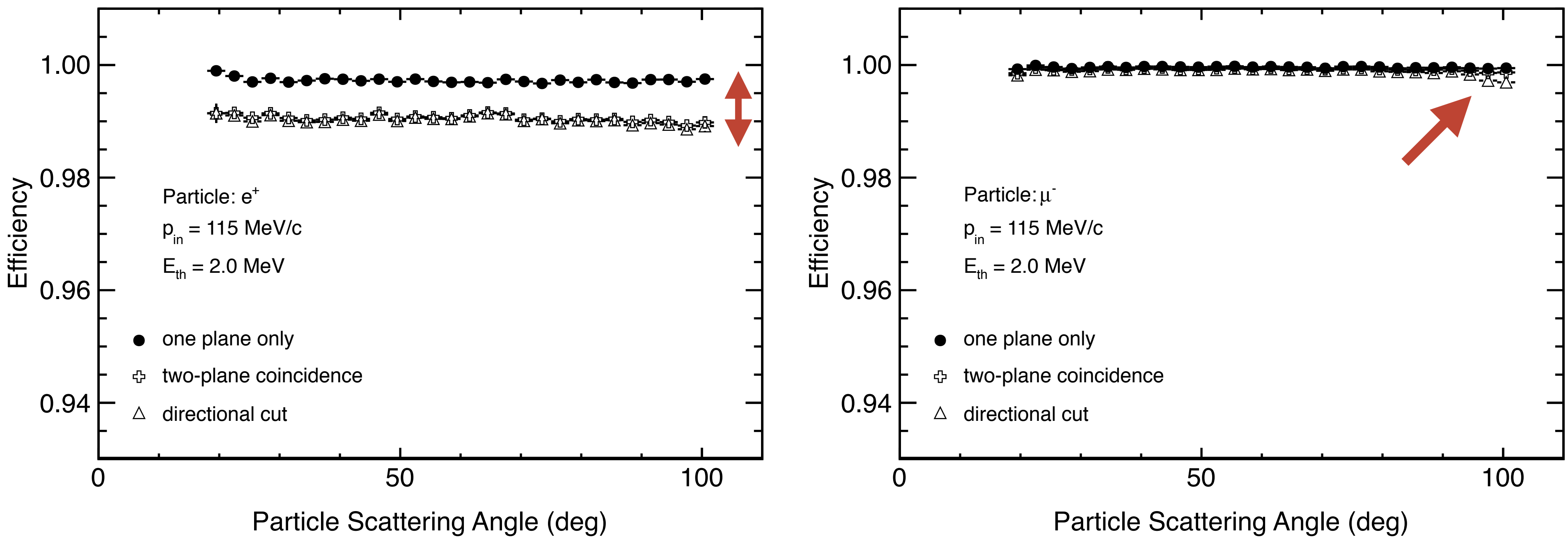




- Front- and back-wall hits are highly correlated if the event originated in the target.
- Hardly ever are the correlated bars further apart than by one bar.
- Imposing a hardware coincidence with the expected correlation does reduce accidental background.
- The directional restriction, however, is limited.
- Measured correlation will help validate the simulation.

Detector Efficiency

- Efficiency of scattered particle scintillators is ≳ 99%
- Problematic cases:
  - Annihilation of positrons in the front wall
  - Multiple scattering of low-momentum muons (with directional cut)



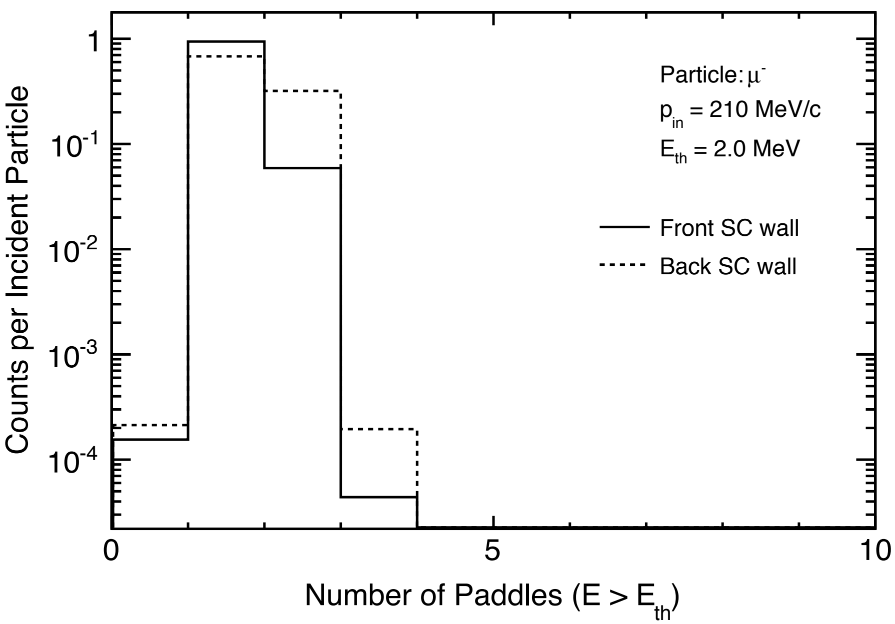
Detector Efficiency Threshold Dependence

Particle	Beam Momentum (MeV/c)	Coincidence efficiency for various signal thresholds 0 MeV	1 MeV	2 MeV	3 MeV
e^+	115	0.9944	0.9918	0.9902	0.9833
	153	0.9955	0.9934	0.9920	0.9852
	210	0.9964	0.9948	0.9939	0.9874
e^-	115	0.9992	0.9989	0.9987	0.9929
	153	0.9994	0.9992	0.9990	0.9933
	210	0.9996	0.9994	0.9993	0.9937
μ^+	115	0.9991	0.9990	0.9989	0.9989
	153	0.9996	0.9995	0.9995	0.9994
	210	0.9997	0.9997	0.9997	0.9995
μ^-	115	0.9991	0.9990	0.9990	0.9989
	153	0.9995	0.9995	0.9994	0.9994
	210	0.9997	0.9997	0.9997	0.9995

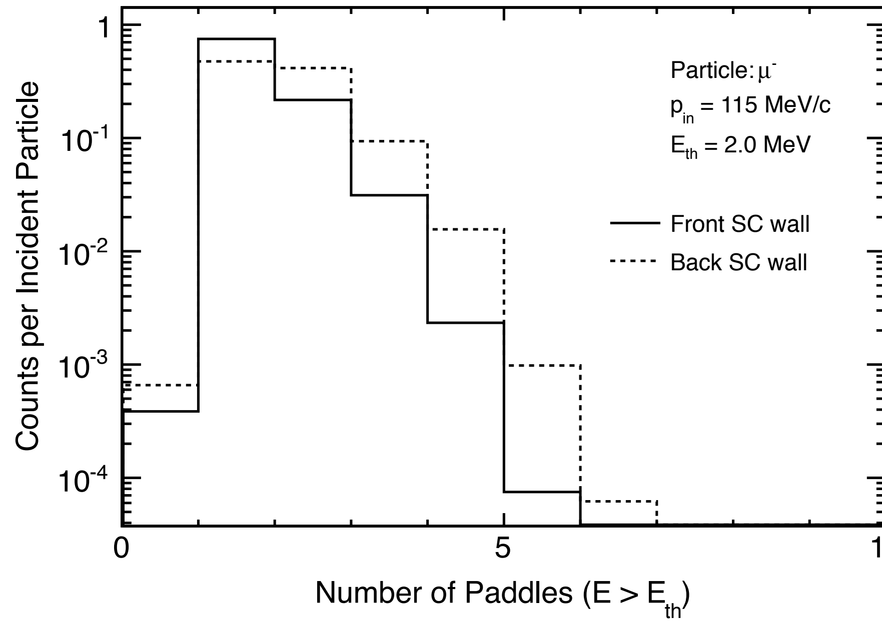
- Efficiencies include the effect of the directional cut.
- Efficiencies are ≈ 99.9% or better; except for positrons where the efficiency is ≈ 99.0% or better.

Multiplicity of Scintillator-Paddle Hits

Typically low multiplicity



Highest multiplicity



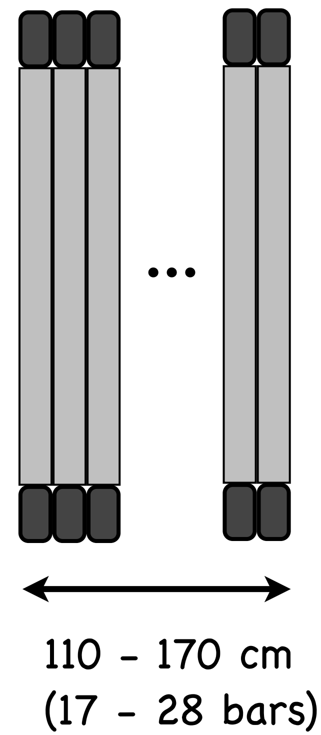
- In nearly all cases one or maximally two bars trigger per scintillator wall.
- Hit multiplicities can be used to validate the simulation.

Approximate Cost

- The average scintillator costs for the JLab project was about **$600** per scintillator. This is the per scintillator cost for the FTOF project with an average scintillator length of 2 m.

- The cost for the Hamamatsu PMT is about **$800** per PMT.

- Scintillator walls total:
  - Front wall: **$37,400** (scintillators + PMTs)
  - Back wall: **$59,400** (scintillators + PMTs)
  - Total for both sides: ≈ **$220,000**



Quality Assurance

- **6 cm x 6 cm BC-404/BC-408 Scintillators**
  are inspected for damages, inclusions, and refraction index inhomogeneities
- **Hamamatsu R9779 PMTs**
  are tested for signal integrity, signal-to-noise ratio, gain, HV requirements, and magnetic field shielding
- **Counter Pre-Check**
  counters are inspected for void-free glued PMT-to-scintillator transition and light tightness, set to final gain-balanced HVs
- **Counter Full-Check with Three-Bar-Method**
  position dependent and overall time resolutions, effective speed of light, left and right attenuation lengths (BAL and TAL) are programmatically analyzed and automatically stored
- **Database**
  all acquired information is stored and retraceable

R. Gothe et al., CLAS12 Time-of-Flight System Review 2009

Summary

- Scattered-particle scintillator walls will be used in the trigger and will measure time-of-flights for particle identification and background suppression.
- The scintillator detectors are fast, $\sigma \approx 50$ ps, and highly efficient, $\varepsilon > 99\%$.
- The scintillator performance can be monitored online.
- Measured and simulated detector responses can be compared to validate the simulation.