First results from the Askaryan Calorimeter Experiment T530

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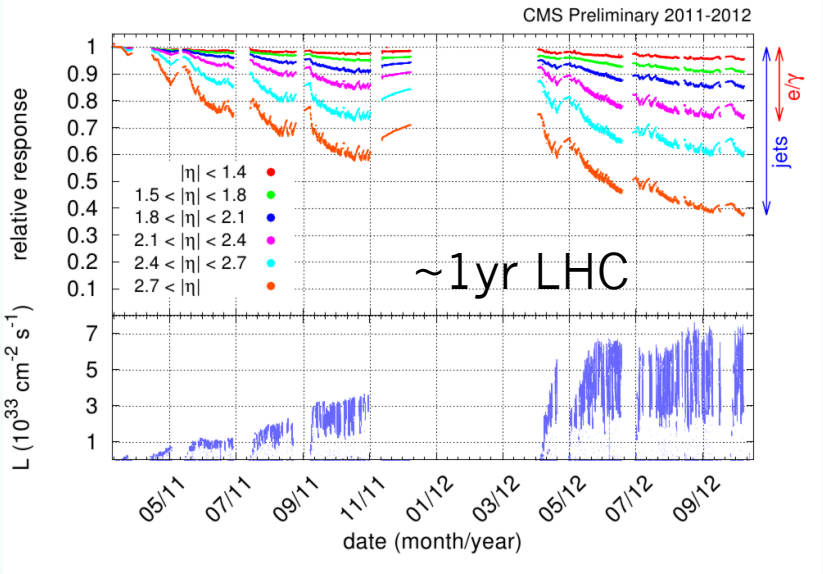
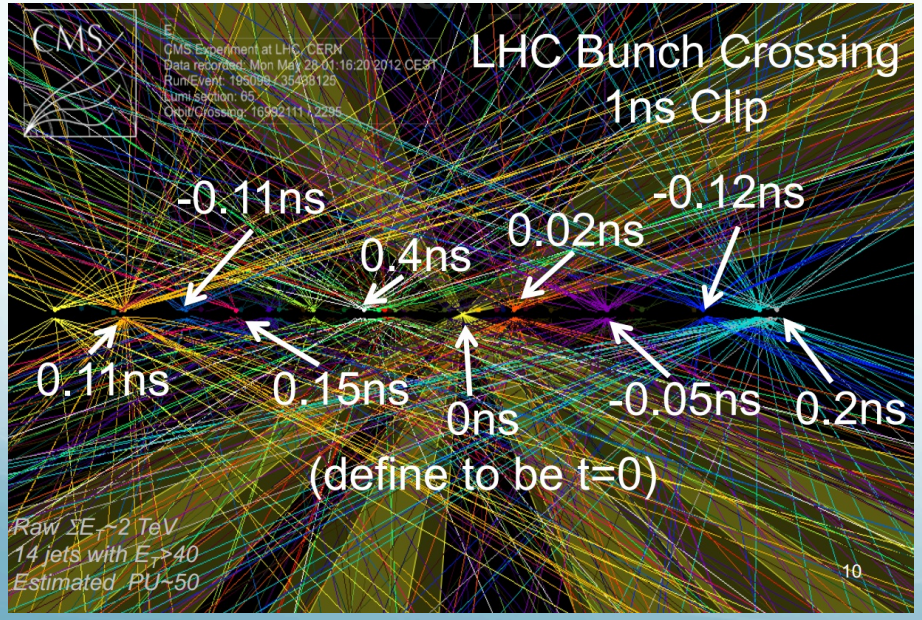
The future…100 TeV, ++10^{35} cm^{-2} s^{-1} ??!

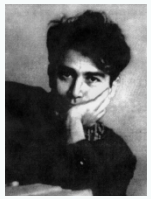


F. Nessi-Tedaldi 2012

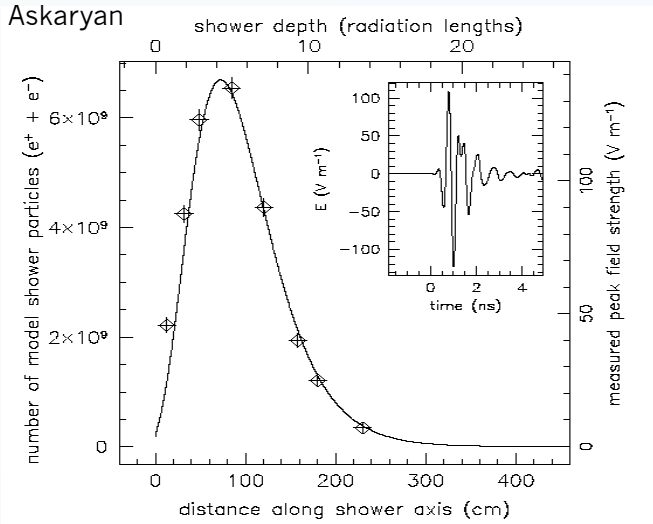


- Tens of Gigarad at η > 2.5 for 3000 fb^{-1},
  - ~100 Grad at 15K fb^{-1}
  - η ~ 6 , Tera-rad?
- Kilowatts of beam power in a calorimeter
- Pileup of ~hundreds per beam crossing
- → **New tools will be needed!**

Some recent(ish) past: Askaryan Effect SLAC '01

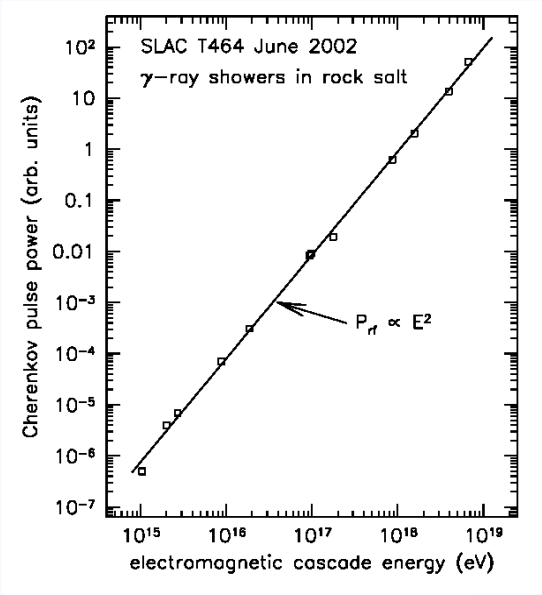


G. Askaryan



Saltzberg & Gorham et al. PRL 2001

David Saltzberg, UCLA



Gorham et al. PRD 2003

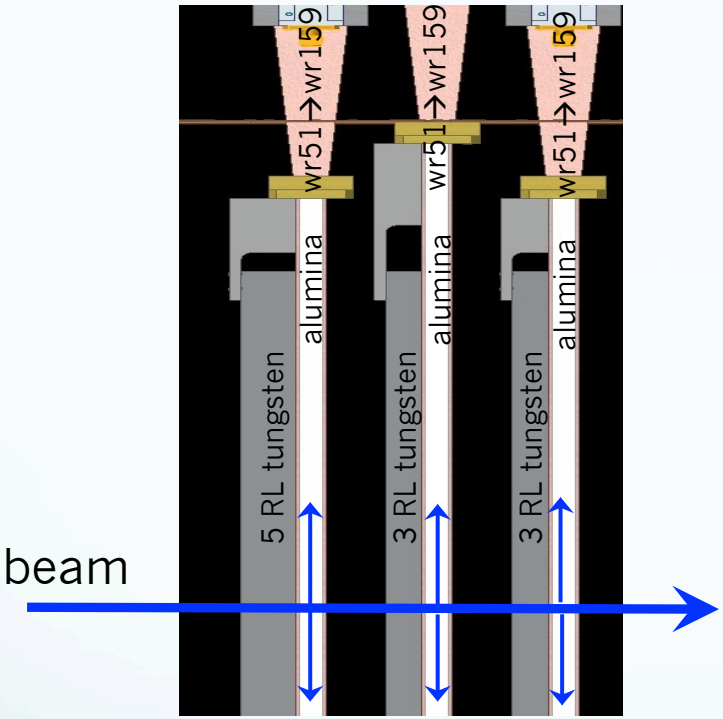
- Radio Cherenkov from excess negative charge in an EM shower
  - e- up-scattered into shower, e+ annihilated → ~25% -ve asymmetry
- 100 % linearly polarized impulse encodes shower properties
- Radiation is coherent → $(Ze)^2$ effect, from λ >>1m to few mm
- Measure vector **E**-field → vector potential A(**x**,t)
  - → In principle entire four-current J^μ = **J**(**x**,t) can be reconstructed

How does this relate to HEP detectors?

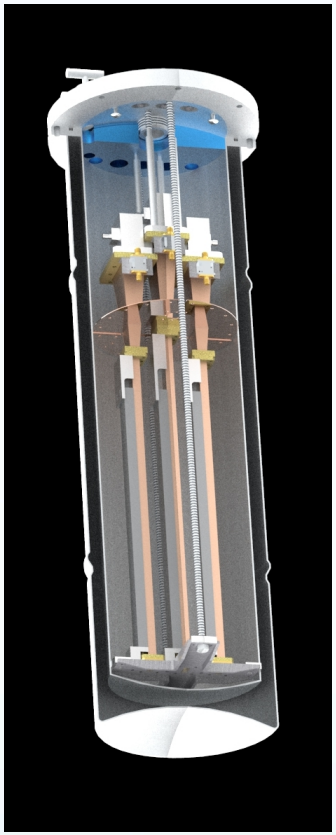
- Askaryan field-strength directly proportional to shower energy
  - Calorimeters are obvious application
- Radio detectors → copper antennas, dielectrics:
  - Ultra-high dynamic range (pWatts to Kwatts) and rad hardness
  - Dielectrics such as Alumina → very low RF loss & very rad hard
- Radio receivers & tech: GIANT economy of scale, consumer, commercial, military, etc.
  - Example: 0.4dB noise figure microwave LNA is now <$100 OTS
- *Askaryan 1.0 (1995-2015)*: detectors for cosmogenic neutrinos in unbounded natural dielectrics (ANITA, ARA, ARIANNA)
- *Askaryan 2.0 (2015++?)*: Apply this to bounded, precision HEP measurements in controlled dielectrics!
- **→ ACE is exploring this latter branch**

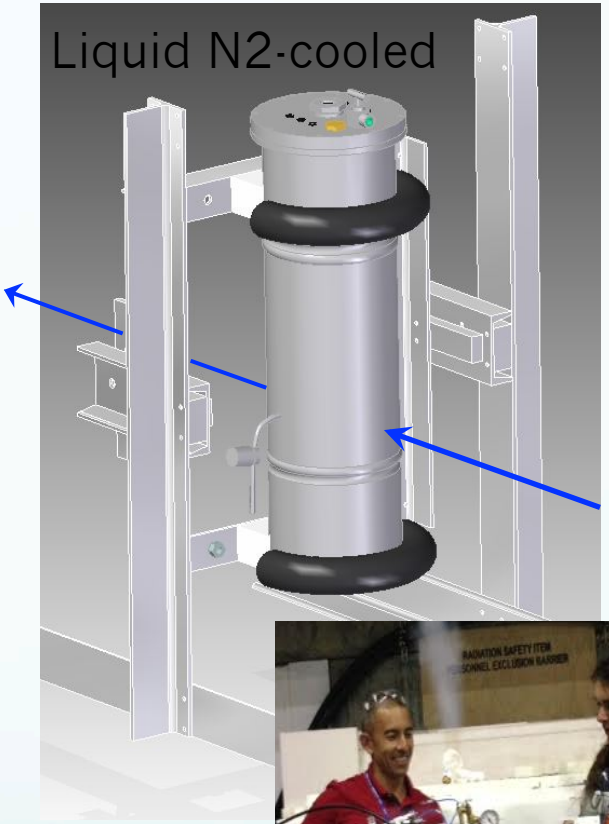
Askaryan Calorimeter Element (ACE)

August 6-10, 2015, first run at End Station A, using <=5Hz of LCLS 120Hz



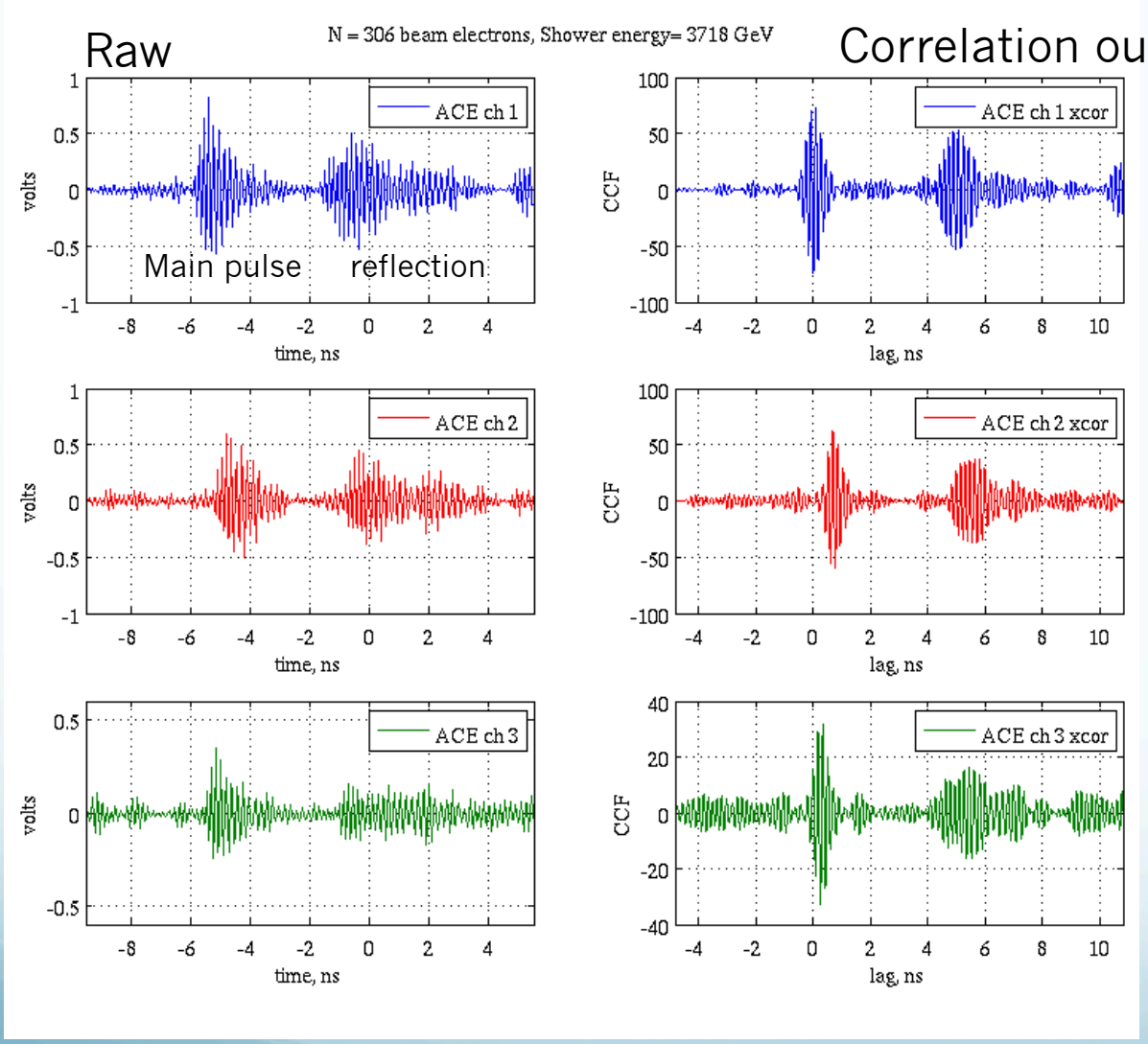
WG short at bottom→ reflection





- Alumina-loaded WR51 waveguide to contain shower segment
  - 12mm x 6mm section, unloaded: 15-20 GHz, loaded (n=3.1): 5-8 GHz single-mode band
- Off-the-shelf microwave LNAs: 40K noise at 296K, 15K at LN_2
  - Thermal noise in radio → all electromagnetic modes are 'pre-loaded' with noise photons

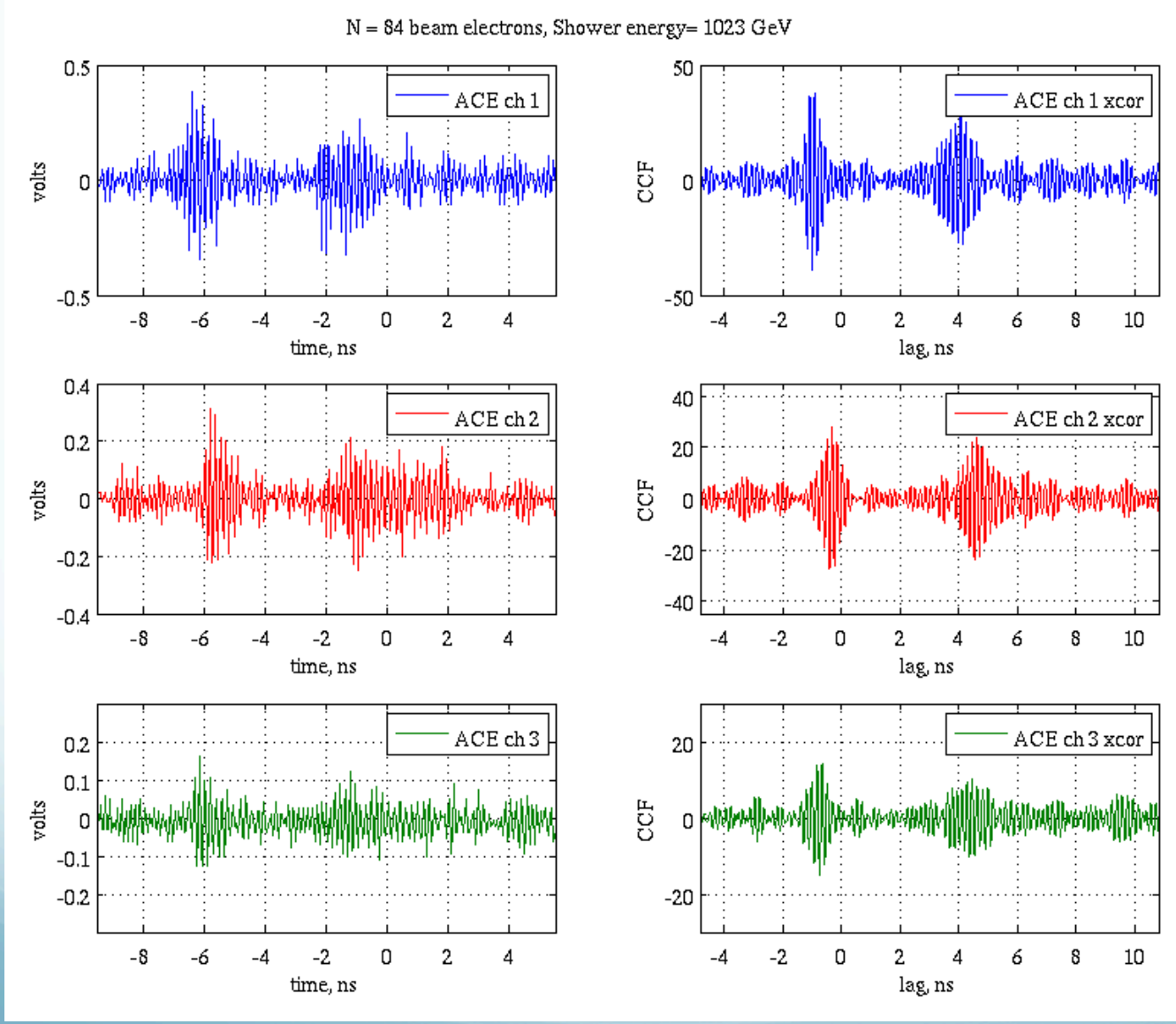
12 GeV x 300e- bunch →4TeV, high SNR



- Raw signals: primary pulse, reflection
  - → cross correlate with measured impulse response to improve SNR, timing
  - Amplitude tracks both shower energy & form factor
- Shower development observed*
  - Ch1 at 4RL
  - Ch2 at 6.6RL
  - Ch3 at 9.2RL

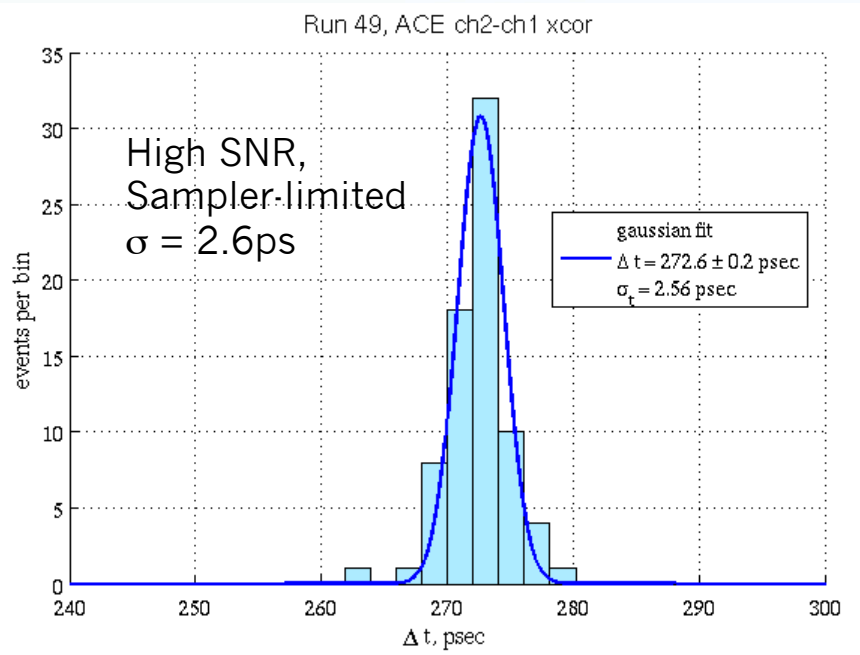
*account for autoscaling!

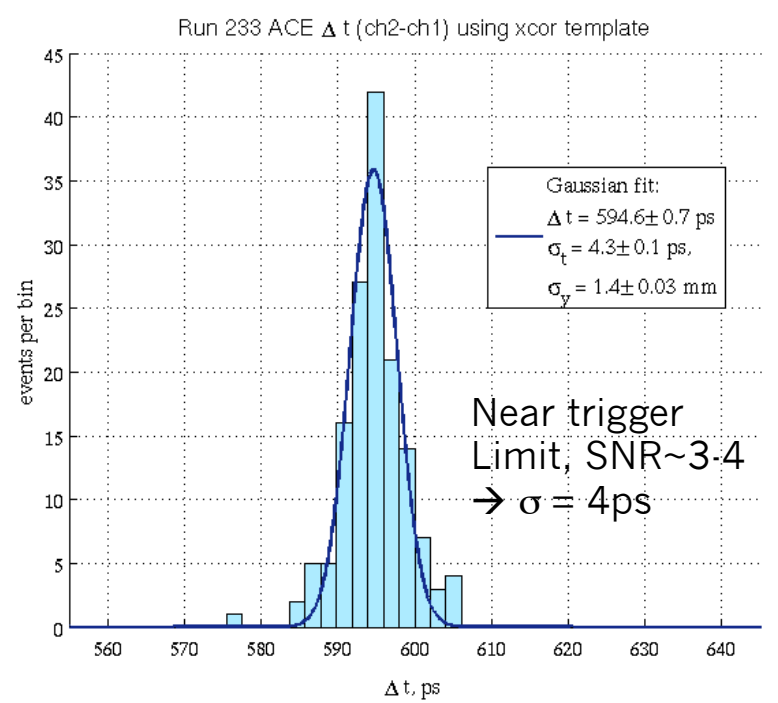
12 GeV x ~80e-, near 1TeV trigger minimum



- Si-PMT device used for trigger
  - → minimum bunch current around 90 electrons
  - ~ 1000 GeV
- ACE still has usable SNR at this energy
- → ACE intrinsic threshold of order 500 GeV for this expt.

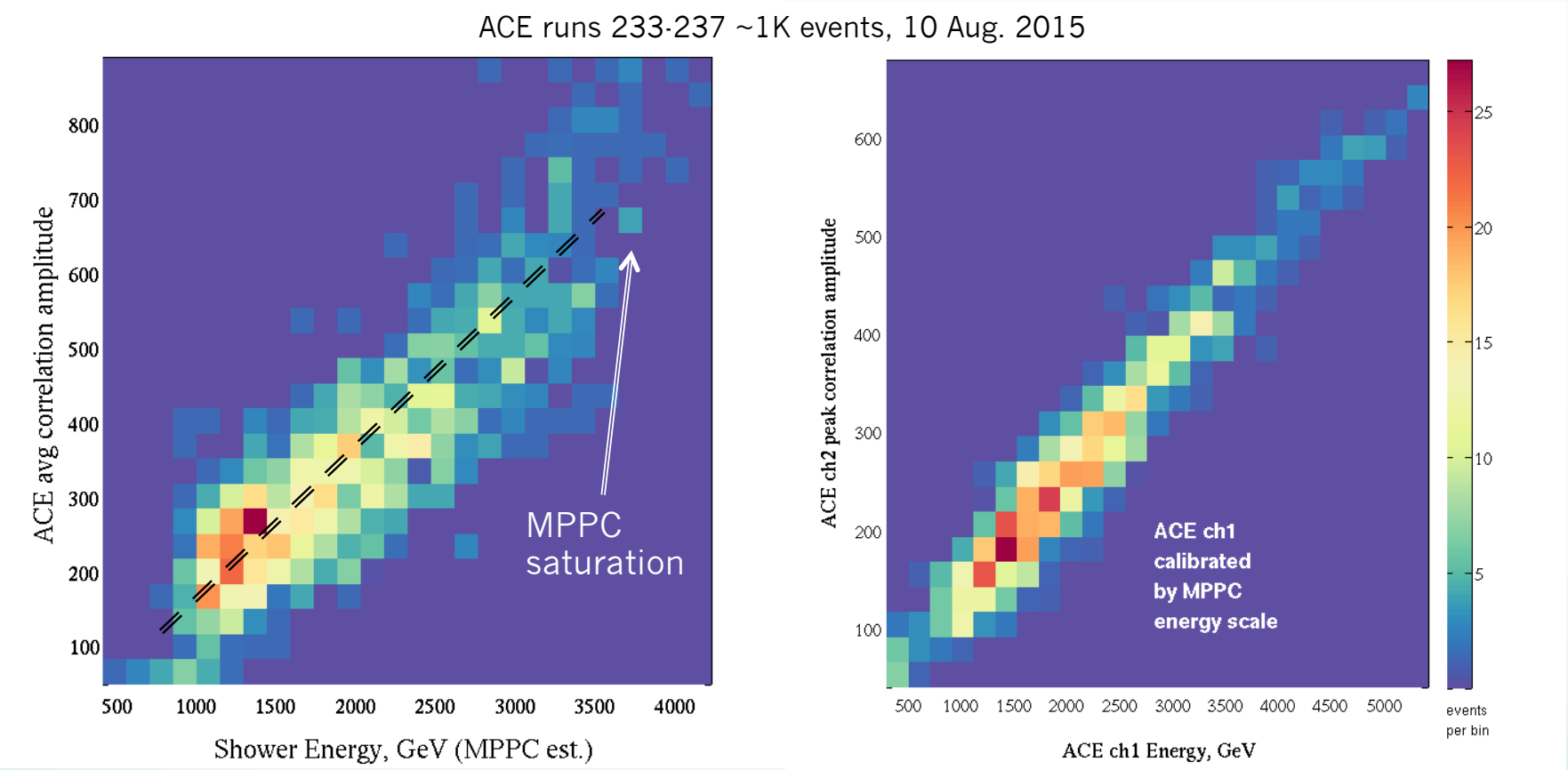
Shower time resolution





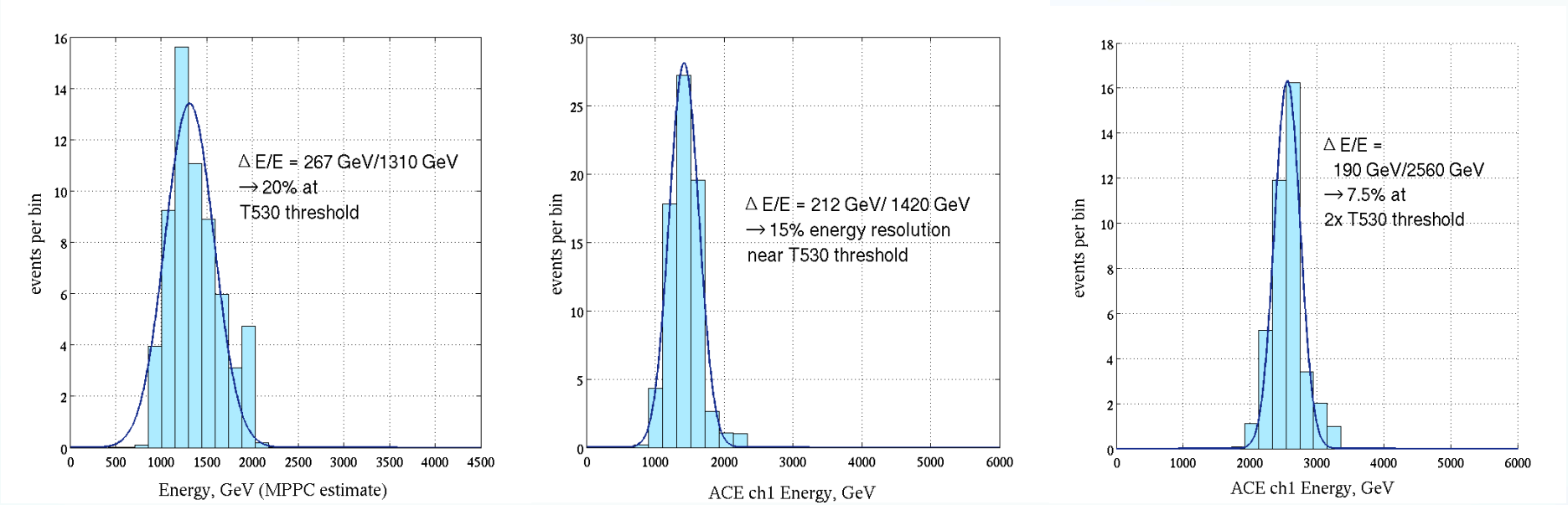
- Left: run at very high SNR, time resolution 2.6 ps, probably hitting instrinsic oscilloscope sampling limit
- Right: 12 GeV, low current runs, near thermal noise threshold
  - Timing resolution 4.1 ps, corresponds to 1.4mm in Alumina
- **At this timing resolution, need new kinds of ADCs:**
  - → **Gary Varner:** "*Based upon the success of the PSEC4 and other ASICs at the few picosecond level, in order to address this and other fast, precision timing detector needs, compact, multichannel ASICs are being designed to work in the sub picosecond regime.*"

Energy resolution



- Left: correlated amplitude vs. Si-PMT shower energy estimate (w/ ~20% photoelectron statistical scatter)
- Right: ACE 2 vs. ACE 1, using MPPC slope estimate to calibrate ACE 1

Energy resolution per channel

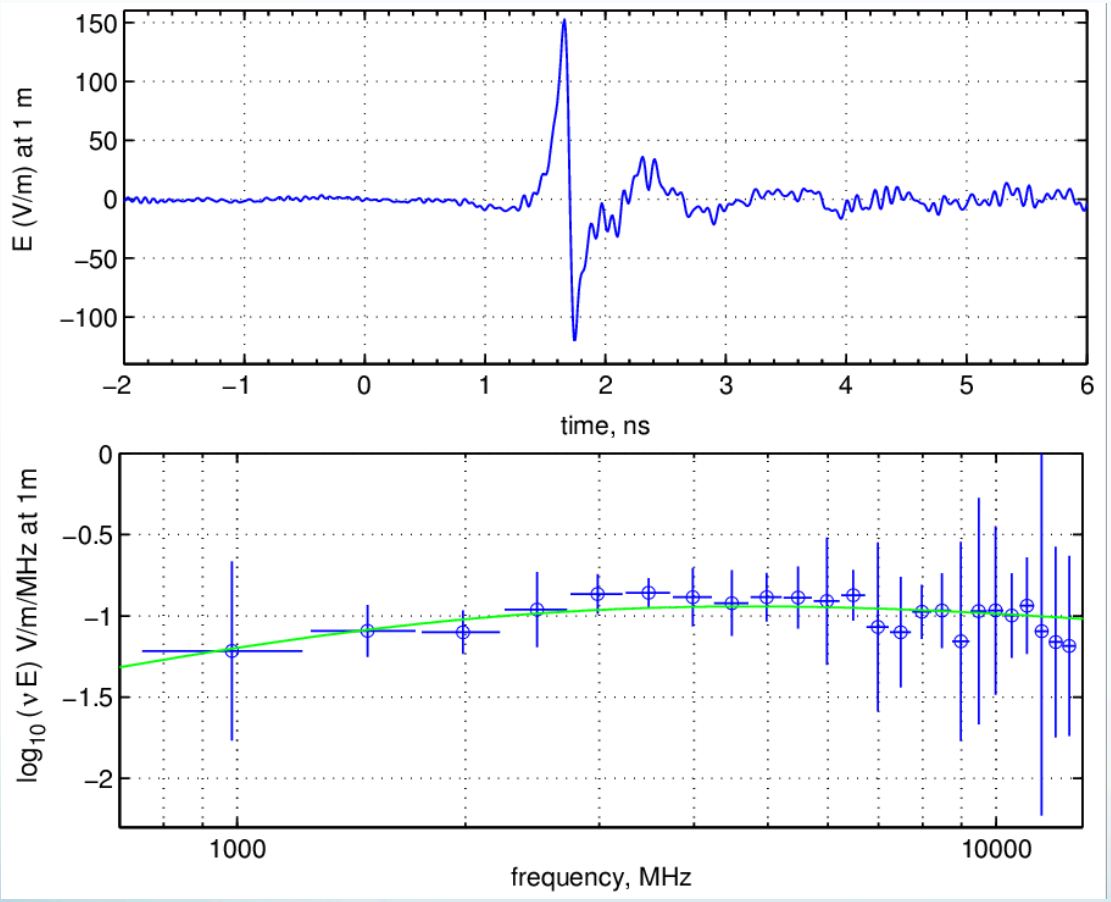


- Energy resolution near least-count : ~20% in raw data, probably better than 15% intrinsic at trigger limit, ~7.5% at 2x threshold
  - This is for a single ACE waveguide channel, transverse sample; resolution for mult-channel sampling should improve as sqrt(N)
- ~1TeV threshhold set by experiment parameters, could be x10 lower with LHe cooling, longer track lengths in Alumina, magnetic field etc…

Summary

- RF/microwave Cherenkov signals in bounded detector demonstrated in SLAC T530 initial runs
- Least-count energy ~several hundred GeV for ACE
  - Could likely be 10--100 GeV with careful design, LHe cooling, more bandwidth, channels, tracklength, & signal processing
- Results show good energy correlation (better than our external calibration) and very large dynamic range (data linear from ~100 e- to 1e7 e-)
- **Starting to develop new kinds of tools we will likely need for next generation pp and heavy ion colliders!**

T460: intrinsic Askaryan radio spectrum



- Ultra-broadband measurements of full-band Askaryan emission (0.5-15 GHz) in salt (n=2.5)
- Idealized point-particle: Cherenkov would rise linearly with frequency
- In practice spectral & spatial signature encodes shower form factor → **J**(**x**,t) again