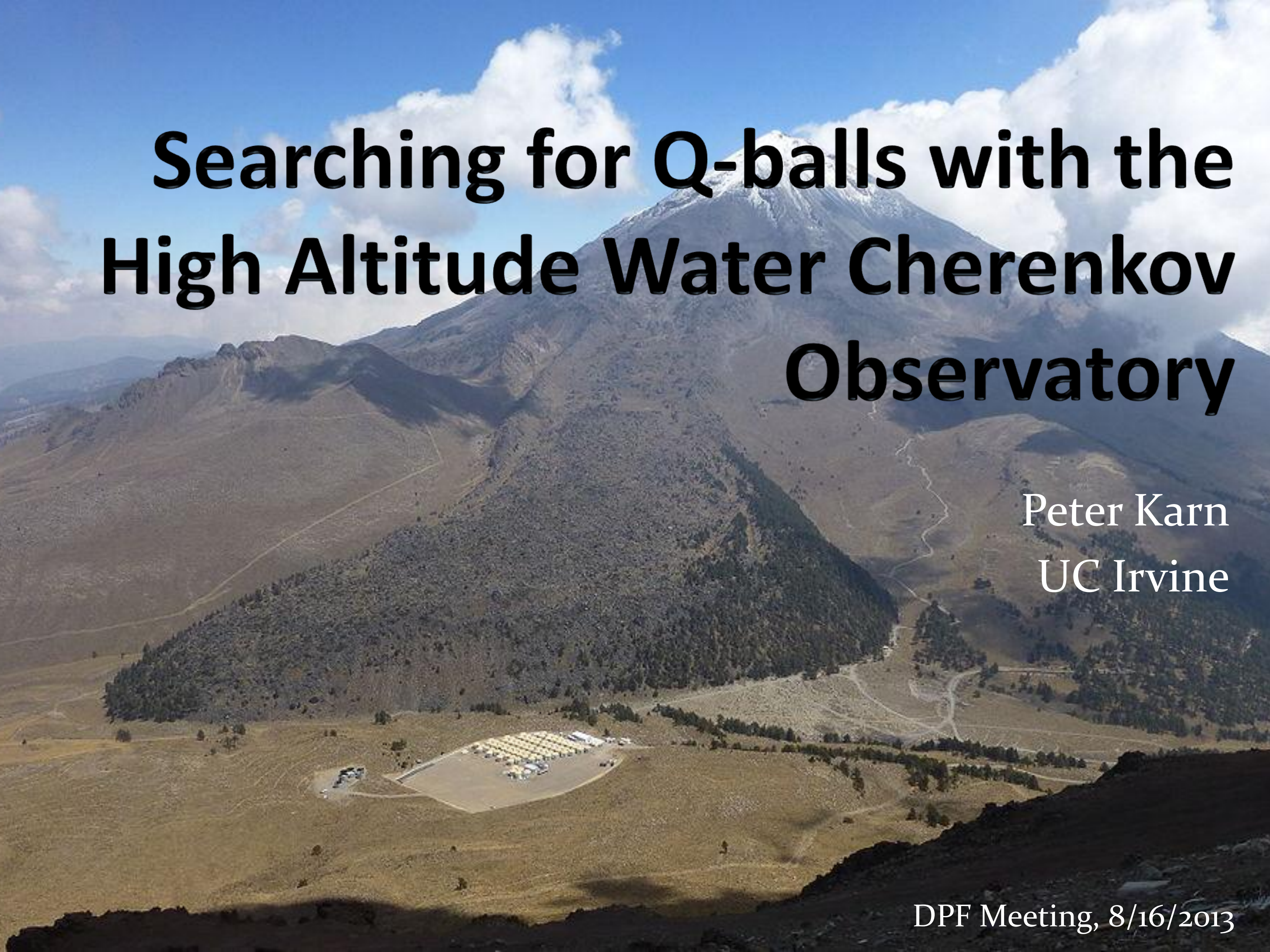


Searching for Q-balls with the High Altitude Water Cherenkov Observatory

Peter Karn
UC Irvine

DPF Meeting, 8/16/2013

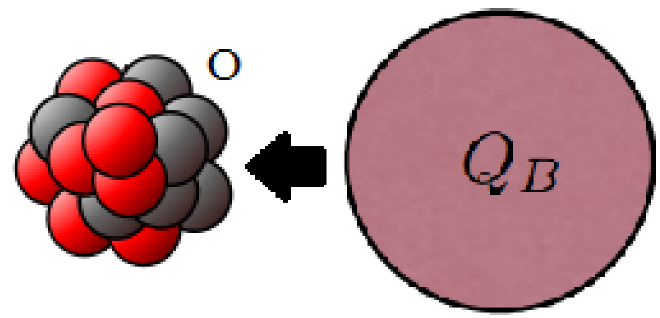
What's a Q-ball?

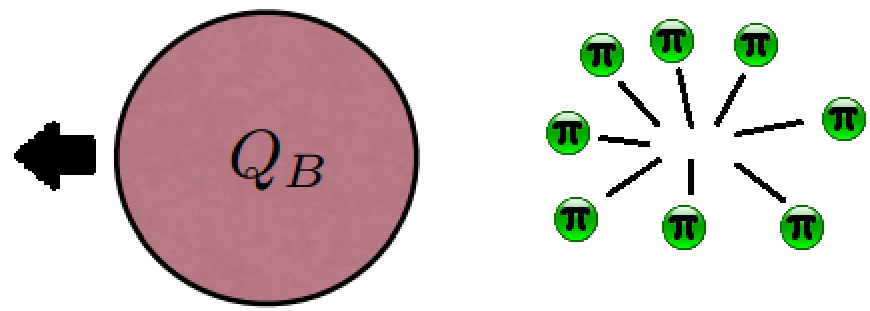
- Heavy, **subrelativistic** particle predicted by SUSY
- Scalar condensate of squarks, sleptons, and Higgs fields
- Large baryon number (> 10^{12} for stability)
- Potentially stable, created in the early universe through Affleck-Dine mechanism
- Dark matter candidate
- Affleck-Dine also explains baryon asymmetry

Coleman. Nucl. Phys. B **262**, 1985.
Kusenko, et al. PRL **80**, 1998.
Affleck and Dine. Nucl. Phys. B **249**, 1985.

Q-ball Interactions

- Interior of Q-ball:
  SU(3)$_{color}$ and U(1)$_{baryon}$ broken
- Dissociates nucleons into quarks: release energy as pions
- 1 GeV released *per nucleon*
- Oxygen nucleus -> ~40 pions with ~400 MeV each (Q-ball moves on unaffected)
- 16 GeV of energy to detect, easy to see with…



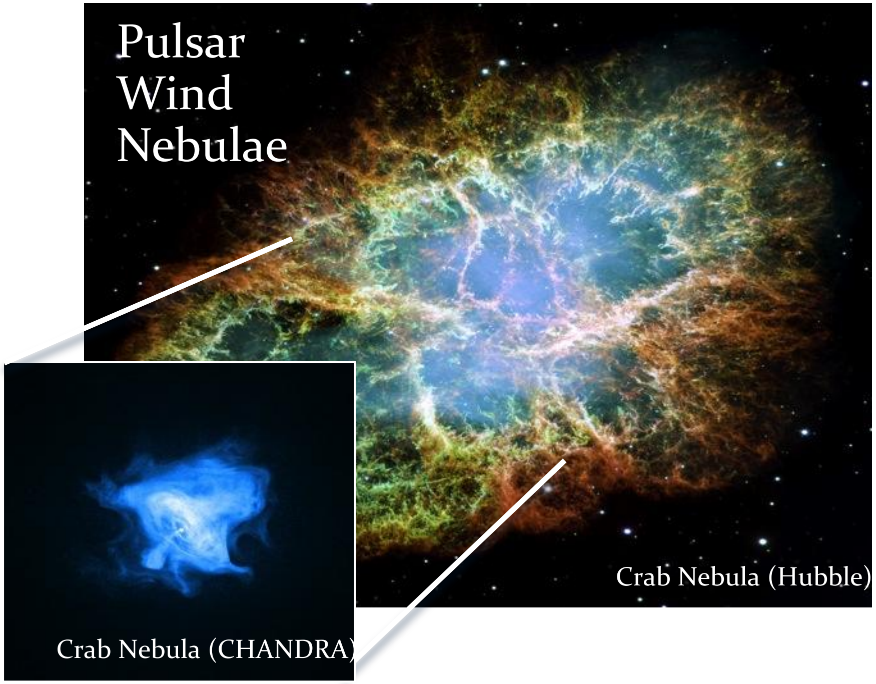


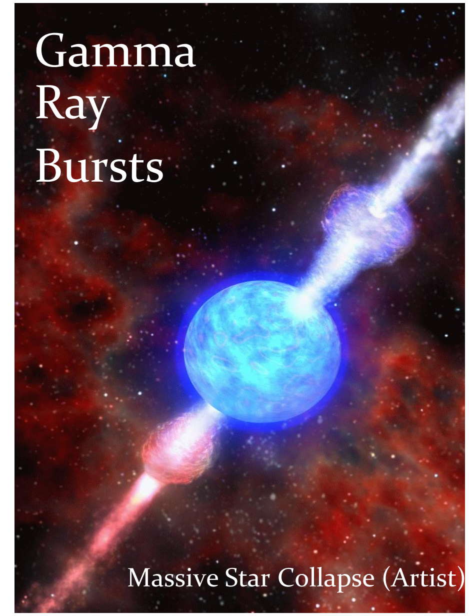
Kusenko, et al. Phys. Rev. D **72**,2005.

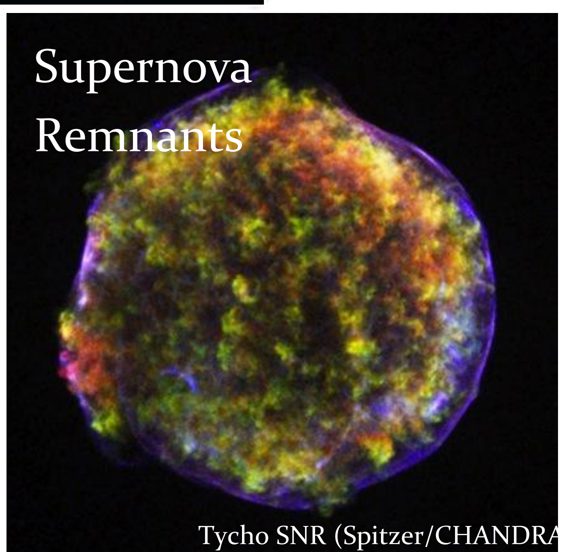
The High Altitude Water Cherenkov (HAWC) Observatory

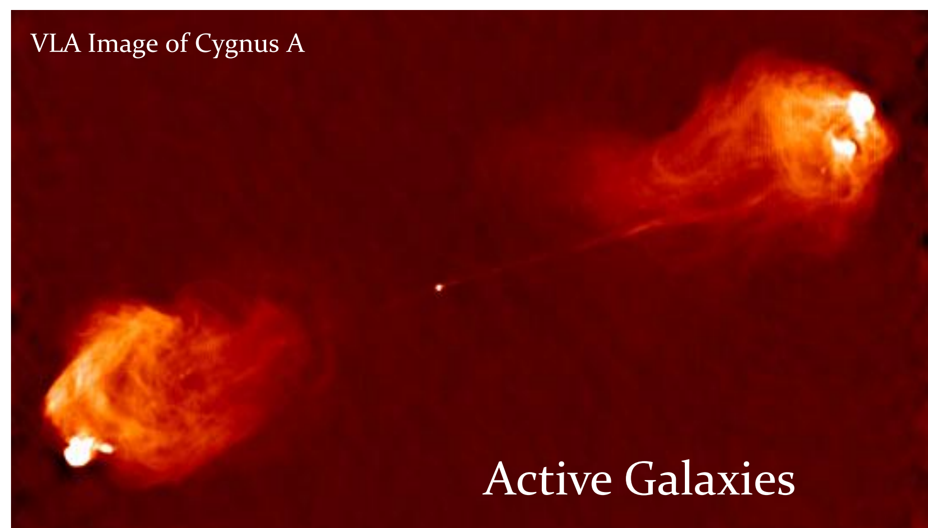
- Site at 13,500 ft, next to Pico de Orizaba in Mexico
- Array of 300 water Cherenkov detectors, ~60 ktons total
- Area of ~22,000 m^2
- Sensitive to gamma rays from 100 GeV to 100 TeV
- Wide field of view, high duty cycle, ~50% sky coverage
- Successor to Milagro experiment
- Operating now with 111 detectors, To be completed: 2014

Very High Energy Gamma Ray Sources



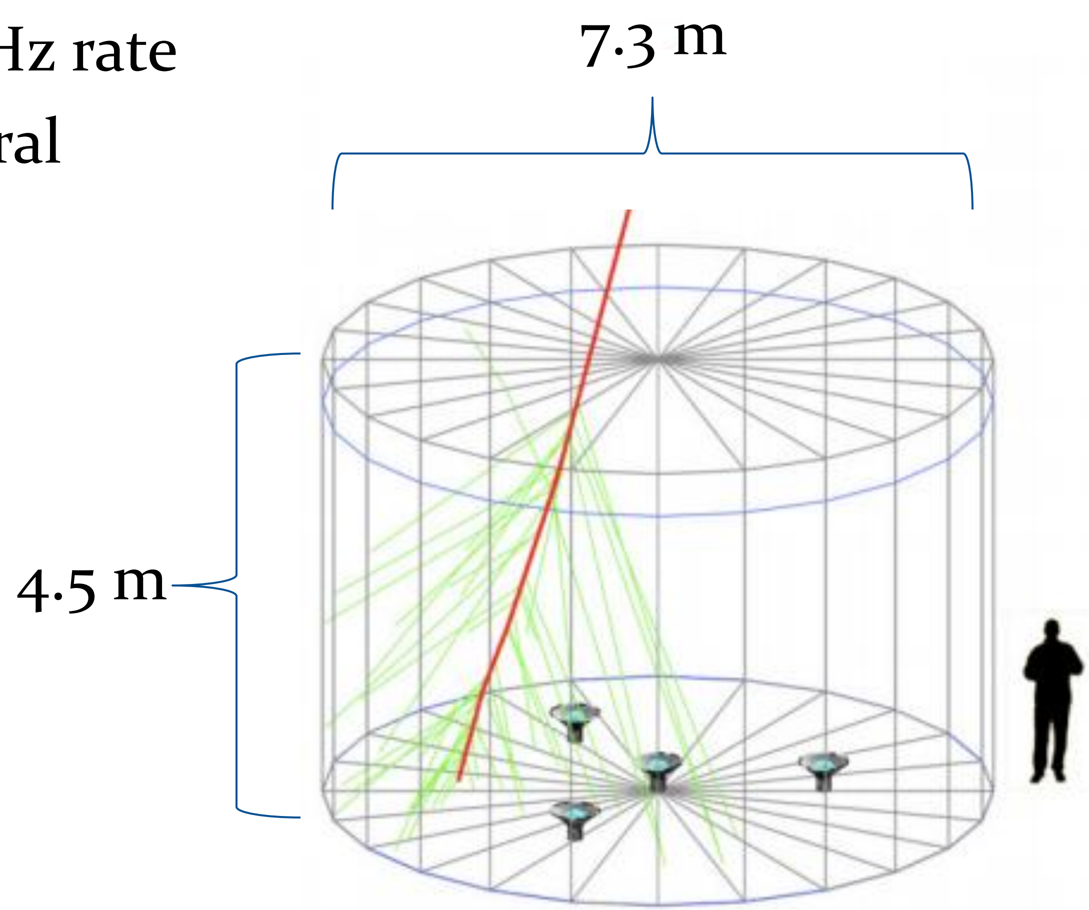






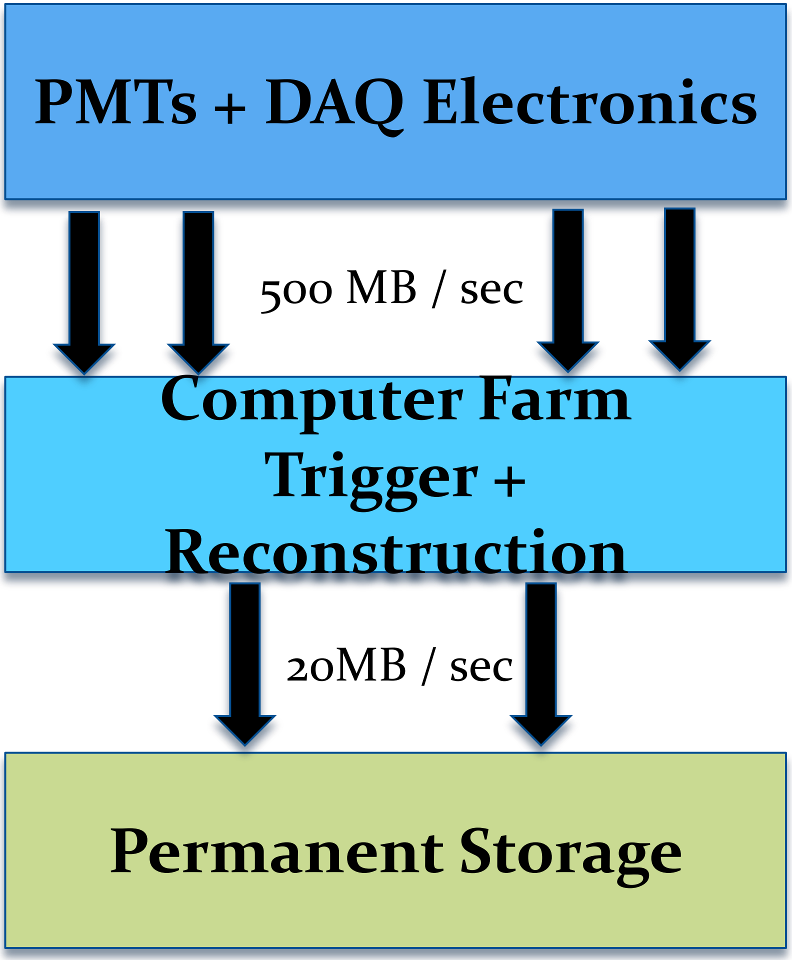
Water Cherenkov Detectors

- 4 PMTs on bottom
  - 3 Hamamatsu R5912 tubes from Milagro: ~30 kHz rate
  - Hamatsu R7081 central tube: ~60 kHz rate



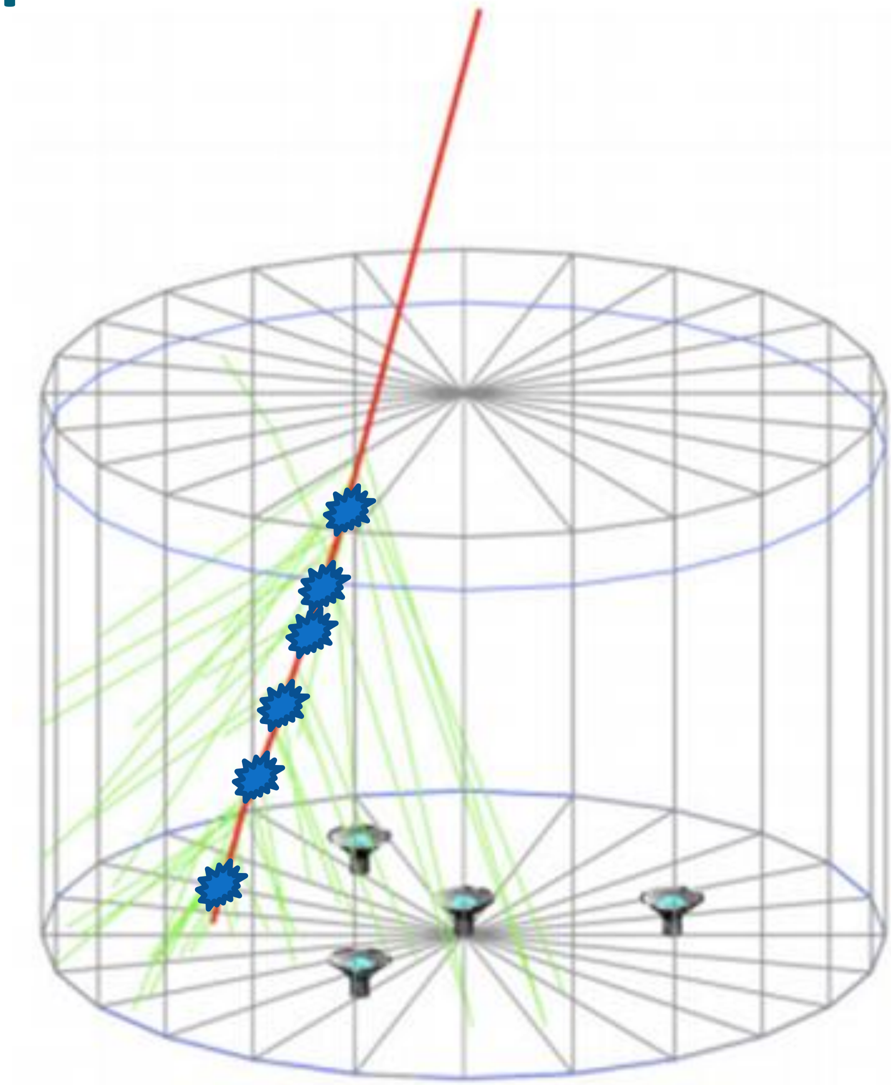
Software Trigger

- Flexible, completely software-based trigger
- Allows creative algorithms to increase low-energy sensitivity
- Main trigger algorithm based on multiplicity, and short time window, O(us)
- Searches for other, more exotic signatures allowed

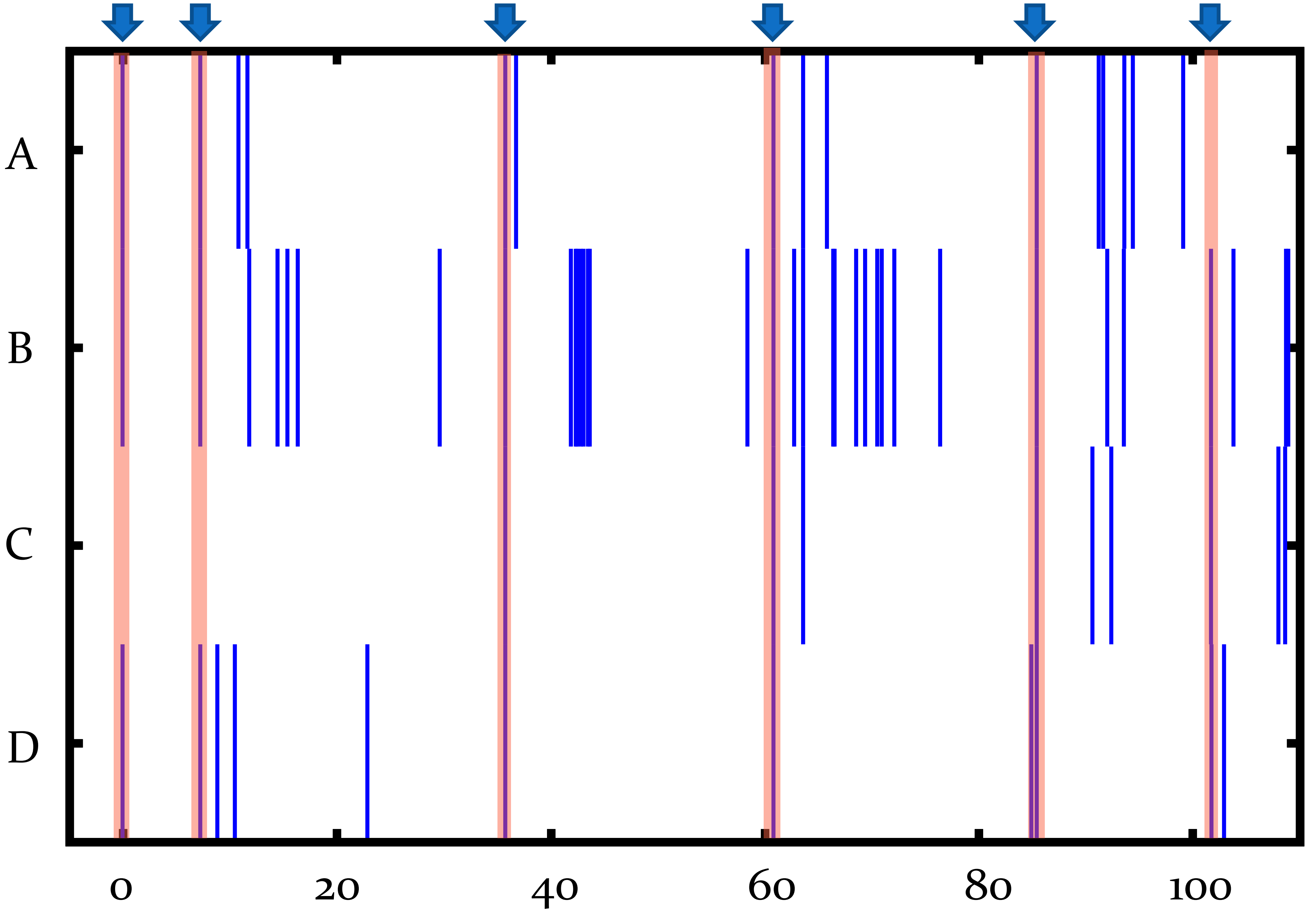


Trigger Algorithm

- Above ~100 mb cross section, can expect Q-ball to interact several times
- A "hit" = 3 or 4 PMTs above threshold within 50 ns
- To beat down background from uncorrelated incidentals, require 6 hits in ~100 us
- Size of tank and times of hits -> maximum speed



An Example Trigger

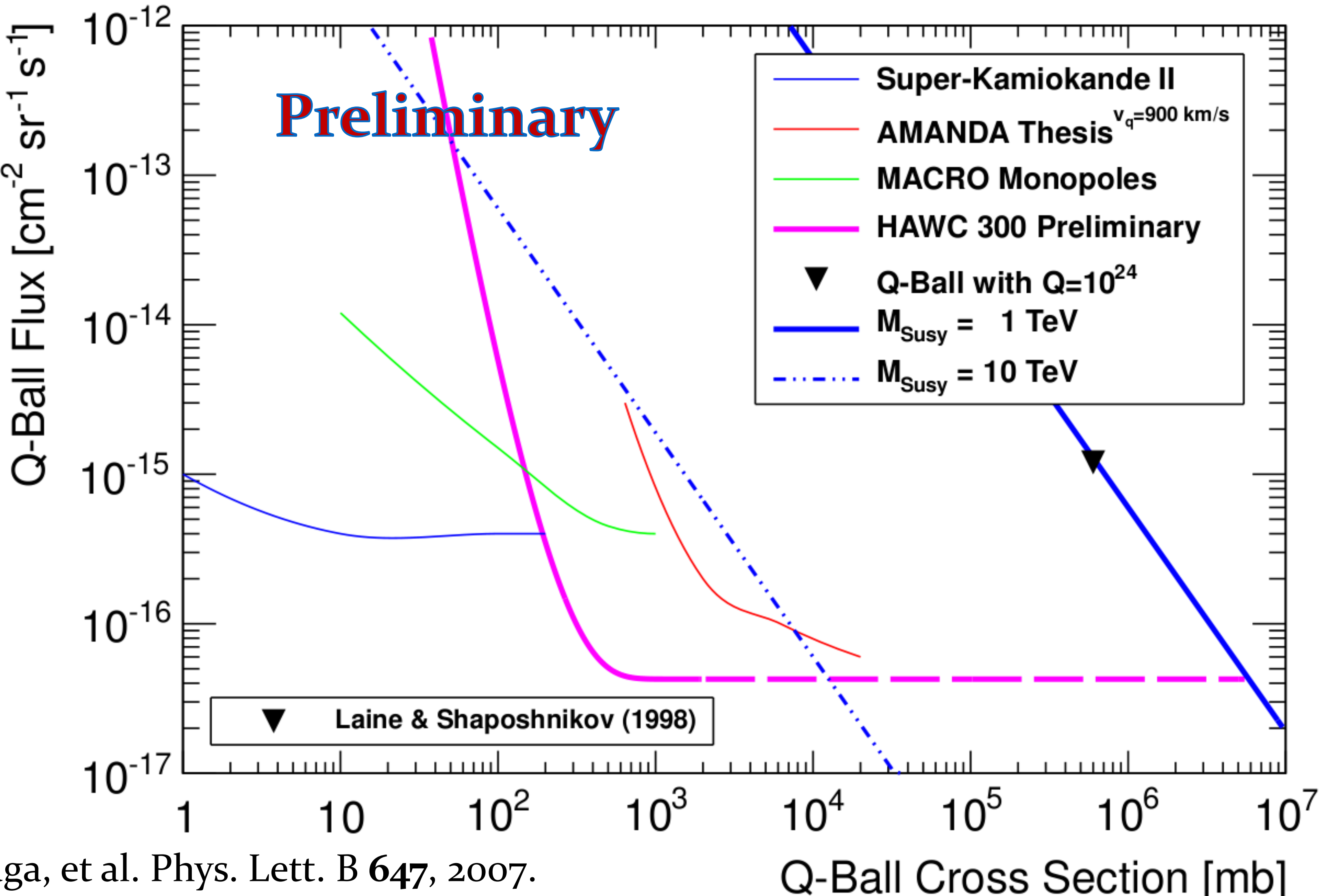


The Data

- 2.5 months of Q-ball triggers so far
- O(0.001) Hz/tank trigger rate
- Analysis (work in progress)
  - Filter out hits associated with air showers
  - Apply calibrations and timing cuts
  - Reconstruct location of interaction using max. likelihood
  - Fit interaction locations to a line, perform cuts

- Signal Monte Carlo
  - Model a Q-ball interaction as 8 p-pbar annihilations
  - Produce pions (average of 40 per Q-ball interaction)
  - Propagate with GEANT4

Estimated One Year Sensitivity for HAWC
with Zero Background Events



Takenaga, et al. Phys. Lett. B **647**, 2007.
Pohl, Ph.D. Thesis, 2009.
Ambrosio, et al. Eur. Phys. J. C **26**, 2002.

Conclusion

- HAWC is being constructed as we speak
- Data taking (including Q-balls) continues
- New, improved, and hopefully constraining limits on Q-ball dark matter coming soon

Backup

Mass and size relations

$$M_Q = \frac{4\pi\sqrt{2}}{3} M_S Q_B^{3/4}$$

$$R_Q = \frac{1}{\sqrt{2}} M_S^{-1} Q_B^{1/4}$$

$$\sigma = \pi R_Q^2$$

$$\Phi(\sigma) = \frac{\rho_{DM}\langle v\rangle}{(4\pi\cdot\mathrm{sr})M_Q} = 6\times10^{-7}\cdot\left(\frac{1\mathrm{mb}}{\sigma}\right)^{3/2}\cdot\left(\frac{1\mathrm{TeV}}{\mathrm{M_S}}\right)^4 \frac{1}{\mathrm{sr}\cdot\mathrm{cm}^2\cdot\mathrm{s}}$$