Photoproduction of θ^+ via the $\gamma D \rightarrow \theta^+ \Lambda$ Reaction

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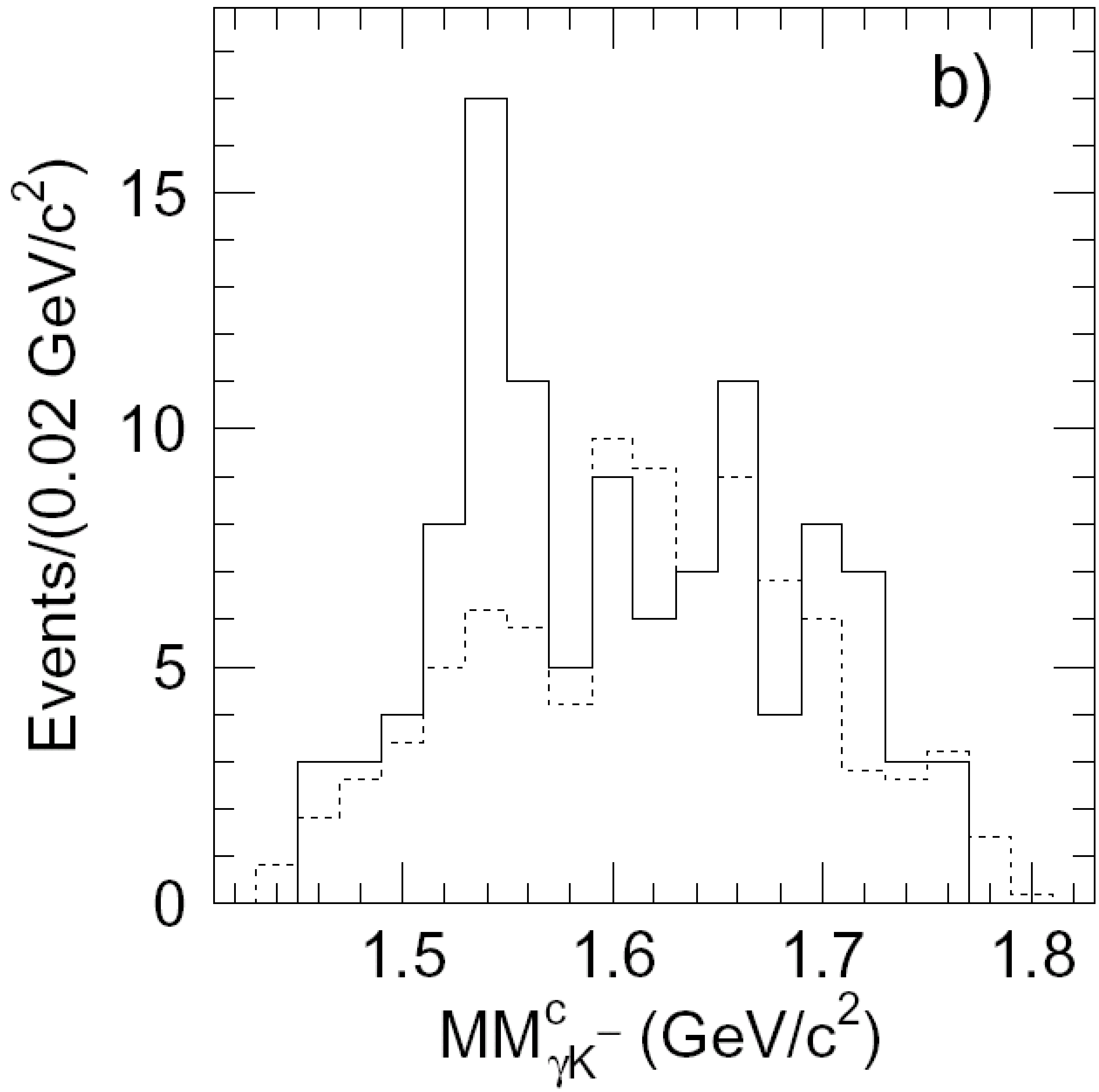
20 coauthors from 7 institutions
requesting 160 hours for exploratory study

- Motivation
- Experimental Details
- Summary

The Original Pentaquark Spectrum

- Spring-8/LEPS first pentaquark signal, the 1.54 GeV peak in the spectrum: Nakano et al., Phys Rev Lett 91, 012002 (2003)
- Confirmations from several labs have followed, in various reactions and kinematics



Is The θ^+ Peak Real?
Recent Review by Trilling (PDG)

- θ^+ seen in experiments some or all of which
  - Have limited acceptance
  - Need cuts to eliminate most events and enhance signal
  - Might underestimate background
  - Do not show Dalitz plots
  - Have nuclear targets and possible nuclear effects
- In contrast, no evidence in KN scattering sets upper limits on width Γ near 1 MeV
- Recommendation for photo-experiments:
  - High statistics
  - Improved PID
  - Improved mass resolution
- This experiment attempts to provide all 3!

Perspective on θ^+ Experiments

- To put this experiment in perspective:
- The first high-statistics, second-generation experiments are already underway:
  - SPRING-8/LEPS: data taken, analysis underway, and
  - Jefferson Lab Hall B: on schedule for early 2004
- With larger data sets, ~1000 events, these experiments should settle the issue of the reality of the pentaquark peak
- There appear to be about 10 pentaquark proposals and LOIs to this PAC – Hall A P04-012 (Wojtsekhowski et al.) and Hall C P04-004 (Gao et al.) are the closest to this one, in that they also feature high resolution

Is The Peak a Pentaquark?

- There are occasional suggestions that the peak is a ``kinematic reflection'', it actually reflects for example the production of some higher mass meson that has not been recognized.
  - Many knowledgeable people have looked at the possibility; as yet no good candidate for the reflected particle exists
- The peak appears in the $K^{+}n$ and $K^{0}p$ channels, so it definitely involves 5 quarks, uuddš
- Every peak is not a resonance; it could reflect the $K^{+}n$ interaction, e.g., a ``molecular state''

Goals for New Pentaquark Experiments

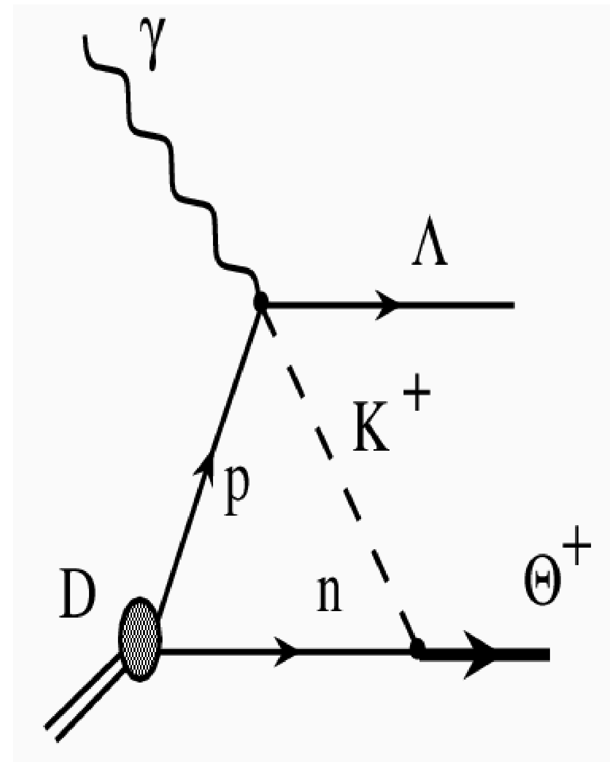
- We know:
  - Mass ~ 1540 MeV
  - Width < 10 MeV (direct observation, 1 MeV from KN?)
  - Hall B and SPRING-8/LEPS are taking ~ 1000 event data sets
- We would like to determine
  - Spin
  - Parity
  - Isospin
  - Other members of family
  - Form factor (3rd generation experiment?)
  - Width – would help confirm reality of pentaquark in an experiment with very different equipment

Hall A / C Experiments

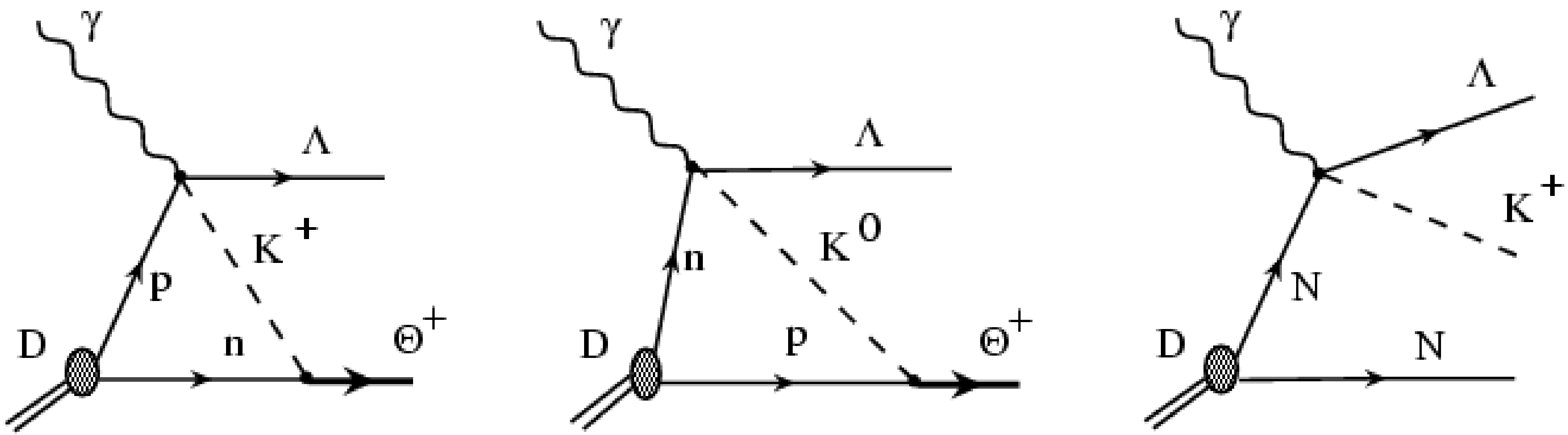
- Halls A and C, with their high resolution spectrometers, are well suited to determining the width of the pentaquark state, since we already know its mass
- Width measurement of a few MeV is interesting
- However, we do not really know the cross section for producing the pentaquark – we have to make educated guesses based on:
  - The idea of t-channel production dominance, suspected in the existing data but not cleanly proved, or
  - Model calculations, which assume a particular structure for the θ^{+}, which might not reflect reality
- In this proposal, we will use the calculation of V. Guzey

Our Idea, Simplified

- The reaction $\gamma p \rightarrow K^+ \Lambda^0$ has a large cross section; the Λ^0 subsequently decays about 2/3 of the time to $p\pi^-$
- Detecting the $p\pi^-$ allows reconstruction of the Λ^0 four momentum, and produces a ``tagged'' K^+ beam
- Running the experiment on a deuteron target gives a neutron in close proximity to the K^+, which enhances the possibility of θ^+ production
- By operating at low energy, and requiring the Λ^0, we largely eliminate the possibility of kinematic reflections



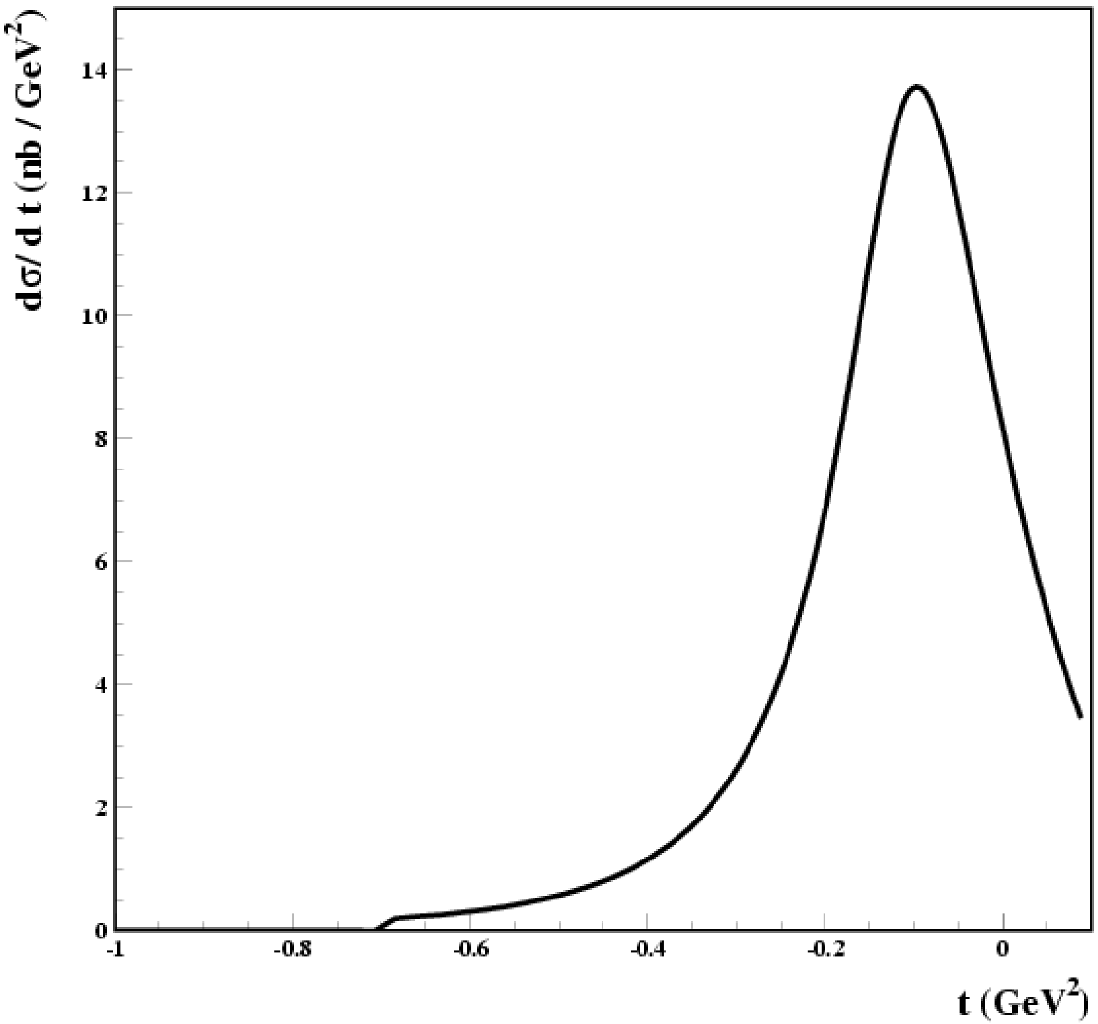
The Calculation I



- Left two diagrams: photoproduction of $\Lambda^0\theta^+$ from the deuteron
- Right diagram: non-θ^+ background production of $K^+\Lambda^0$
- $K^+\Lambda^0$ photoproduction based on existing data – amplitudes parameterized in MAID
- Deuteron wave function known (Paris)
- Dominant contribution when intermediate neutron and K^+ on shell

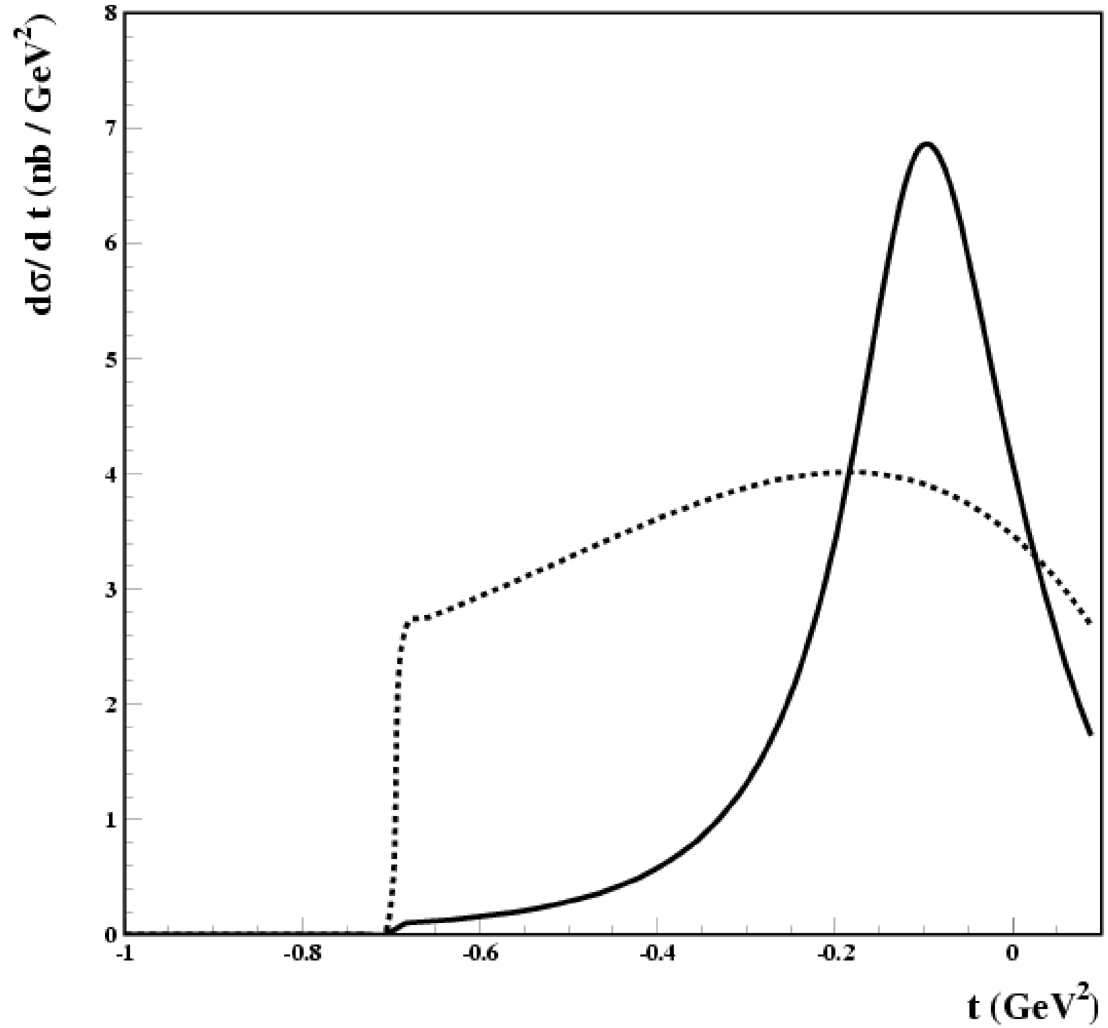
The Calculation II

- Resonant θ^+ production amplitude ~ imaginary
- ⇨ K^+n are on shell
- ⇨ Production amplitude is proportional to width of θ^+
- Differential cross section reflects elementary $K\Lambda$ amplitudes, nuclear effects, and θ^+ width



The Calculation III

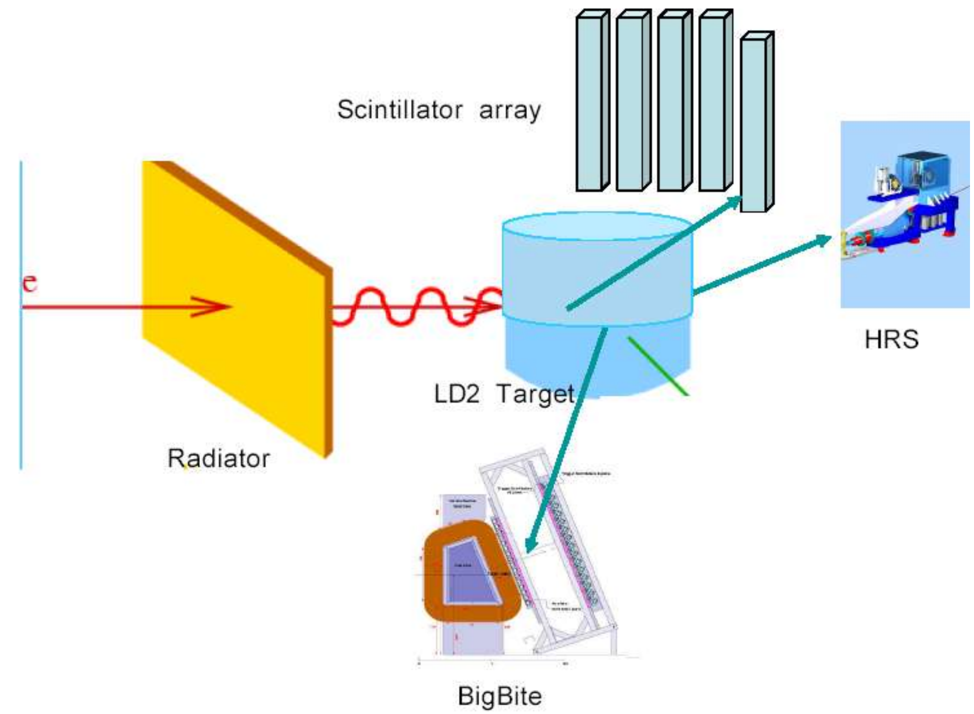
- Solid line: Cross section for resonant θ^+ production, assuming a 5 MeV width
- Dashed line: cross section for background – $K^+\Lambda^0$ photoproduction without θ^+ production, integrated over W = 1530 – 1550 MeV



- Narrower θ^+ ⇨ smaller cross section, but also decreased range for background

The Experiment: Overview

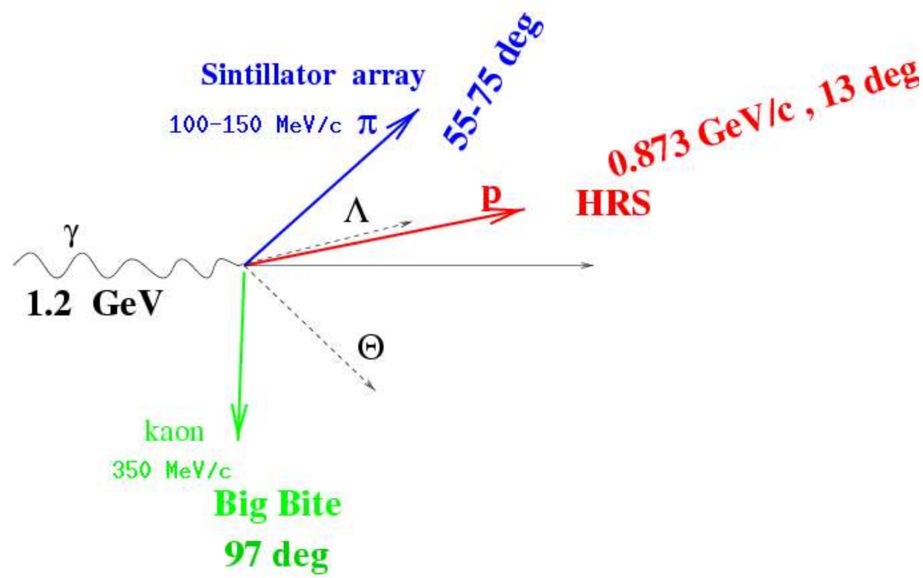
- Hall A,
- ~50 μA unpolarized beam
- 6 % radiator, ~ 73 cm up-stream of target center
- 15 cm cryogenic LD_2 target
- Triple coincidence
  - Protons from Λ^0 decay into HRS
  - π^- from Λ^0 decay into scintillator array
  - K^+ into BIGBITE



- Low precision cross section experiment, 20 % more than sufficient
- Interest is in good resolution, to determine the width

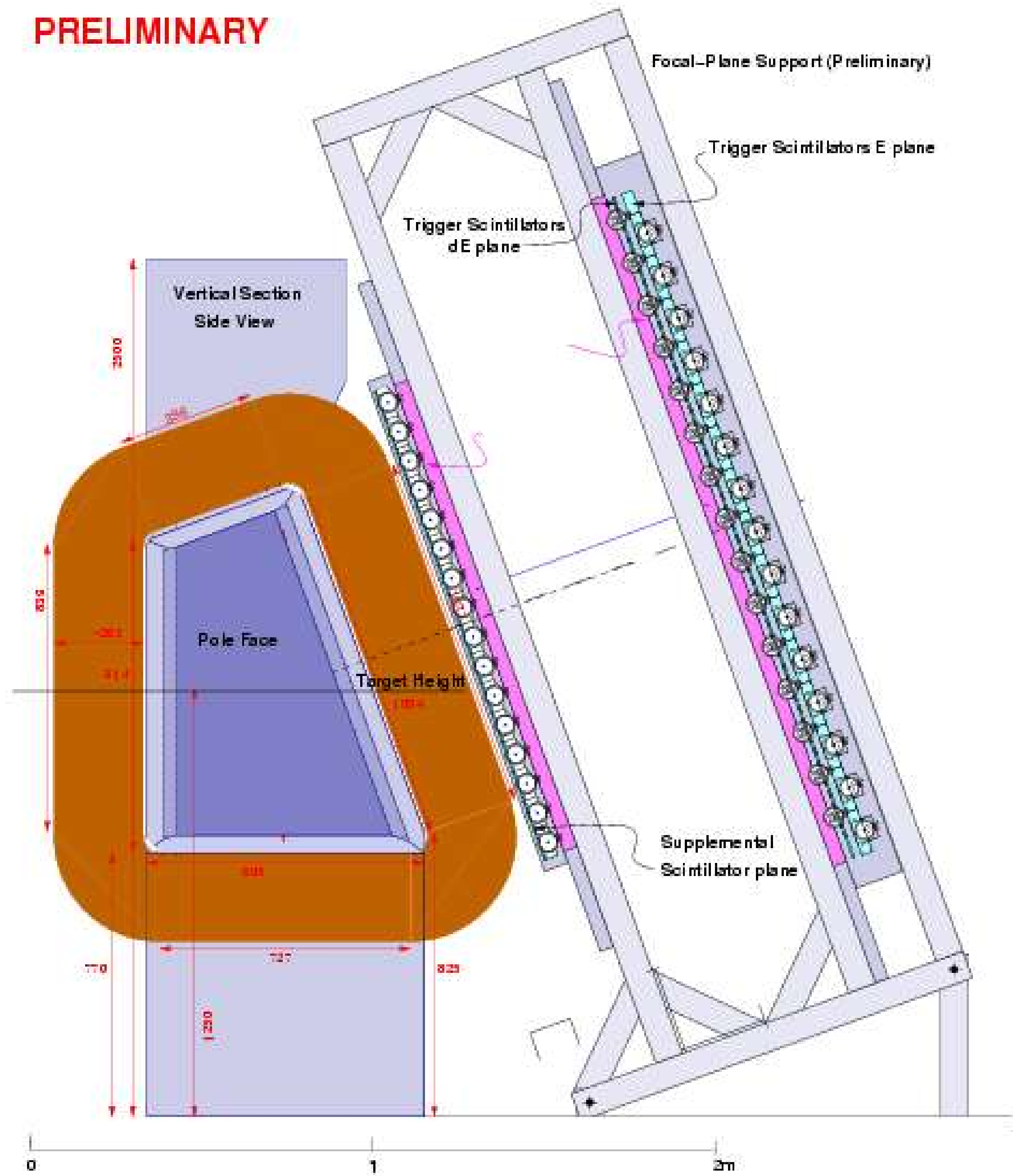
The Experiment: HRS

- HRS detects protons with momentum ~870 MeV/c at 13 degrees
- Central HRS setting corresponds to about 515 MeV $\gamma D \rightarrow pn$, photodisintegration rate will be ~ 1 kHz
- QF ep gives ~ 300 Hz of 1.5 GeV/c protons at this angle
- Use NOT-Aerogel to reject π^+
- ⇨ Several kHz rate of p triggers



The Experiment: BIGBITE

- BIGBITE detects K+ with momentum ~ 350 MeV/c at ~97 degrees
- PID from
  - ΔE vs E in trigger scintillator
    - π: 2 MeV/(g/cm^2)
    - P: 10 MeV/(g/cm^2)
  - TOF (with auxiliary scintillator plane) vs p:
    - ΔTOF(π-K) = 2.2 ns
    - ΔTOF(K-p) = 3.8 ns
  - Aerogel Cerenkov

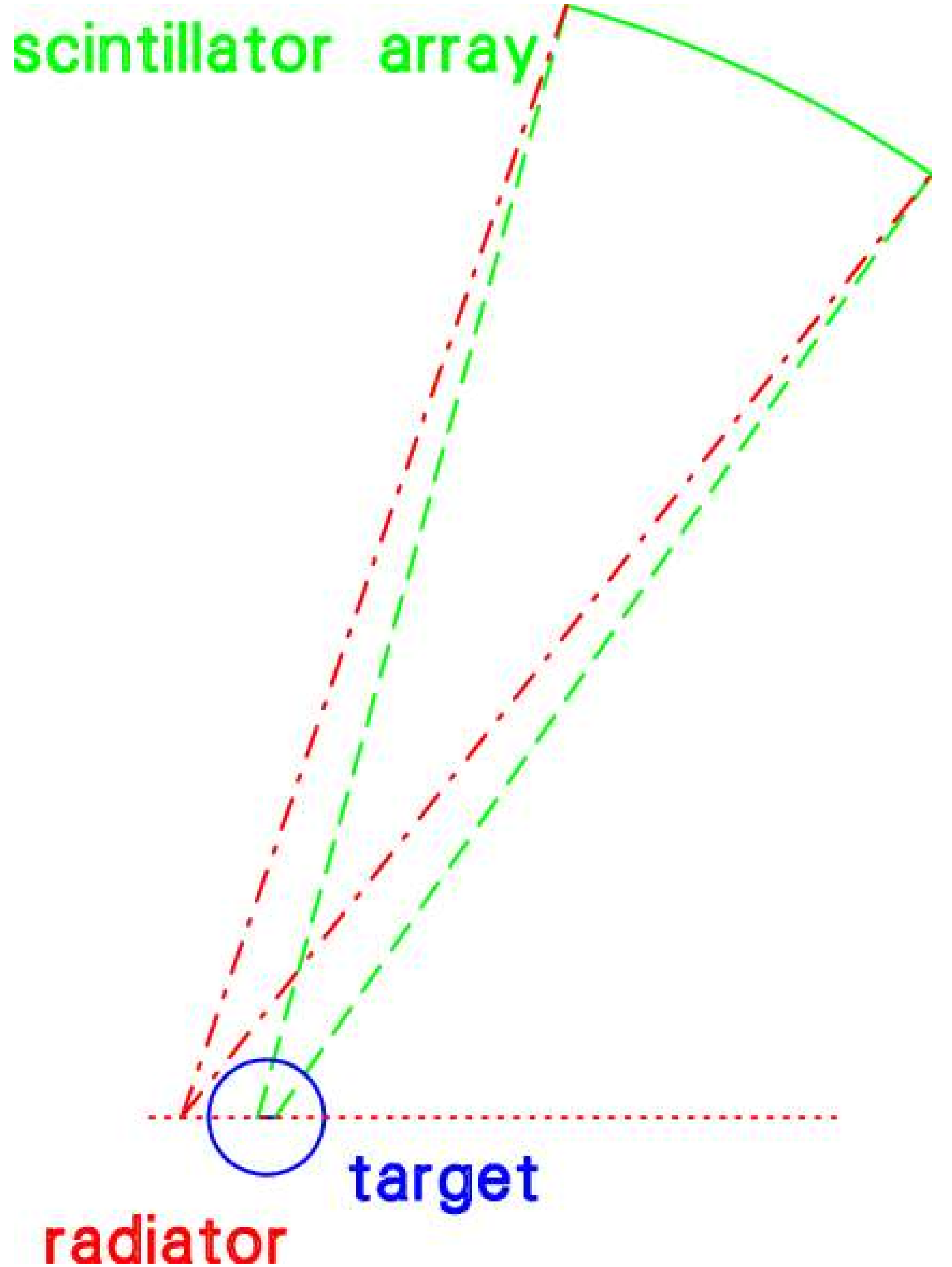


The Experiment: BIGBITE Rates

- What about singles rates in BIGBITE?
- Tests for SRC experiment ⇨ 3-4 Mhz rate in BIGBITE, for similar luminosity, at about the same BIGBITE setting, but E_e=4 GeV
  - Lower E_e will help
  - Line-of-sight shielding of radiator assumed
- Each of 24 trigger scintillator paddles will have about 100-200 kHz rate
- Rate ~OK for chambers

The Experiment: Scintillator Array

- Scintillator array detects π^- with momenta 100-150 MeV/c at 55-75 degrees
- ~50 ns TOF at 10 m, 0.5 ns ⇨ ~1 % momentum resolution
- Angular resolution ~ 5 mr
- Rates are lowered by HRS shielding the array from the beam dump; will add line-of-sight shielding to screen out radiator



The Experiment: Scintillator Rates

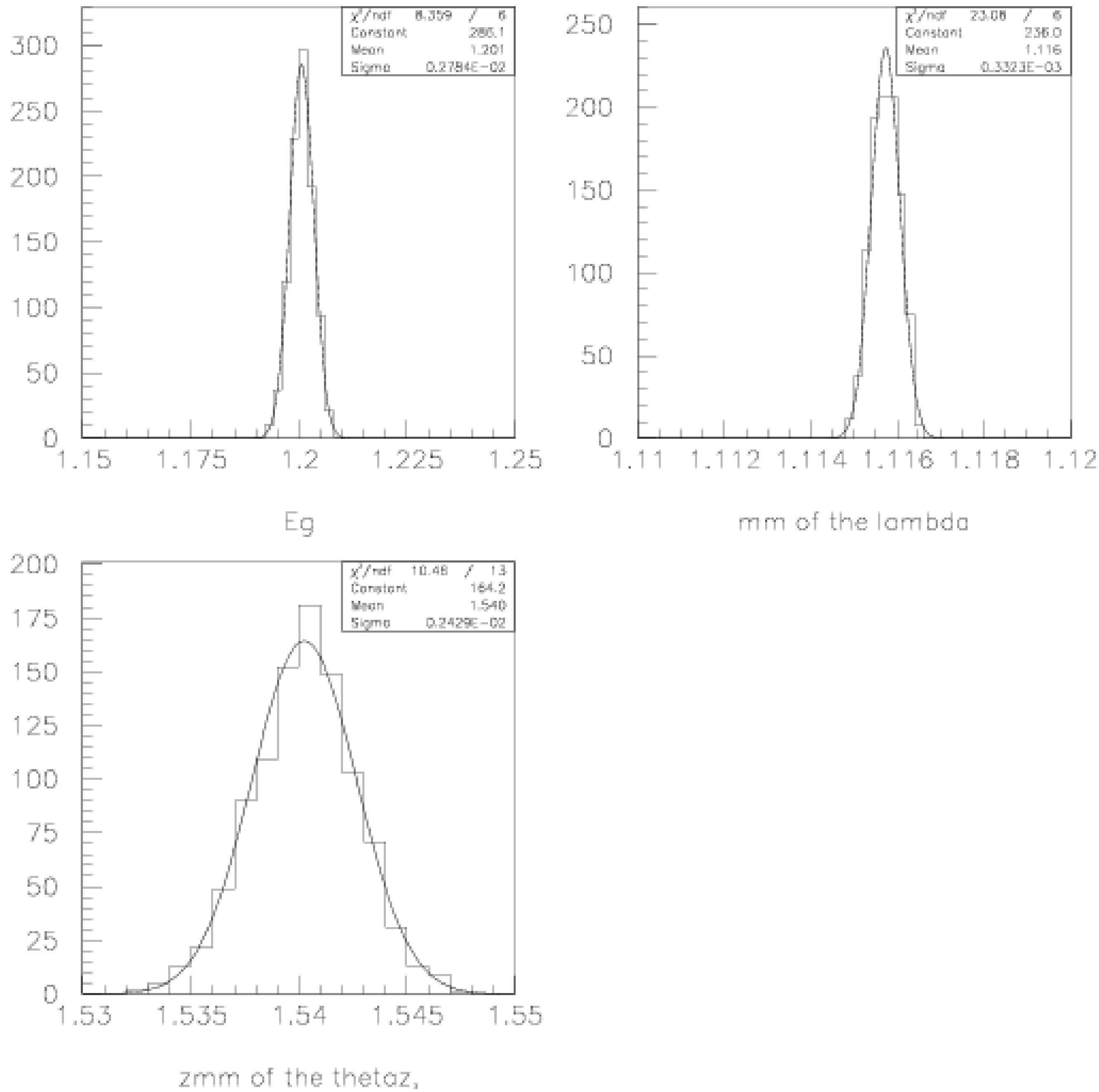
- One worries about high rates with unshielded scintillator and high luminosity
- Minimum ionizing particles lose about 20 MeV in a 10 cm thick scintillator bar
- The 100 – 150 MeV/c π^- stop within 10 cm of plastic and usually deposit large energies, ~200 MeV, in the scintillator bar – note quasi-deuteron absorption, $\pi^- d \rightarrow nn$, with the nn getting all the π^- energy, is actually uncommon, 3+ body absorption dominates
- Setting a high threshold on the bars eliminates much of the background

Reaction Identification

- We identify p with HRS, K^+ with BIGBITE, and π with scintillator array
- There has to be at least one neutron in the final state; there might be additional mesons
- We reconstruct the Λ four momentum using $p_\Lambda = p_p + p_\pi$, and we require $p_\Lambda^2 = m_\Lambda^2$, which removes background
- We now reconstruct the reaction from two-body kinematics, assuming $\gamma d \rightarrow Xn$, with $p_X = p_K + p_\Lambda$
- Requiring endpoint events, E_γ near E_e, eliminates events in which there are extra pions, ..., in the final state
- In the (unphysical) no-FSI limit, we measure the $K^+n \rightarrow K^+n$ reaction

Simulation of Resolution

- Top left: recon-stuction of E_γ, assumes $\gamma D \rightarrow \theta^+ \Lambda^0$
- Top right: re-construction of Λ^0 missing mass, from p, π^- four momenta
- Bottom left: re-construction of θ^+ missing mass, from K^+, n four momenta



Confirmation of Resolution

- To extract a (limit on the) width of the θ^+ from the data, one needs assurance that the experimental resolutions are well understood.
- The reconstruction of the Λ^0 missing mass, from p, π^- four momenta, checks the resolutions and offsets of these detectors
- The BIGBITE resolution needs to be calibrated / understood; if it is not well enough known it can be checked with, for example, recoil protons at large angle in ep elastic scattering: for E_e = 1.2 GeV, p_p = 350 MeV/c at 70 degrees

Time Estimate

- Estimated rate in these kinematics, assuming isotropic Λ^0 decay, including survival fractions for π^- and K^+, is about 3.7 Γ(MeV) / hour
- 100 hours of data give (theory BG only)
  - 370 counts for 1 MeV width, S/BG ~ 10
  - 740 counts for 2 MeV width, S/BG ~ 20
  - 1850 counts for 5 MeV width, S/BG ~ 35
  - 3700 counts for 10 MeV width, S/BG ~ 50
- Even if cross section is an order of magnitude smaller, can see signal if Γ ~ 2 MeV or so
- 60 hours requested for setup, calibrations

Summary / Conclusion

- Pentaquark is of high interest – recent workshop at Jlab, lots of new proposals
- Its reality should be clearly demonstrated by second-generation high-statistics SPRING-8/LEPS and Hall B experiments
- Hall A has the opportunity to determine its width, with a relatively low impact, high resolution experiment, which has very different systematics from already approved experiments: we feel this experiment is well justified at this time
- 160 hours requested in Hall A, using HRS + BIGBITE + scintillator array