Pentaquarks in E949

Can we settle the issue?

L. Littenberg

14 Sept 04

Sources

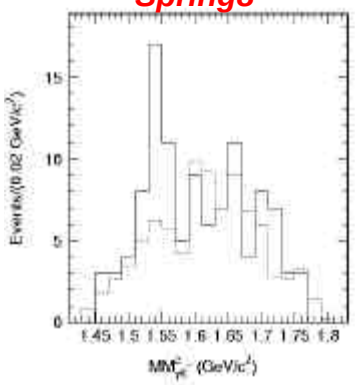
- Many of the slides I'm going to show are from Takashi Nakano's 9 Sept 04 talk to the BNL HENP PAC
- Lots of relevant material on our web site

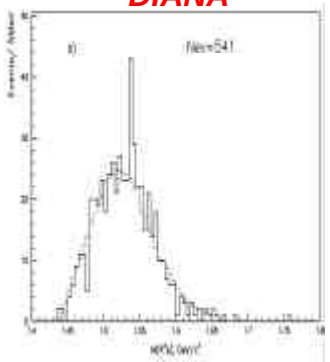
  http://www.phy.bnl.gov/e949/analysis/pentaquark/

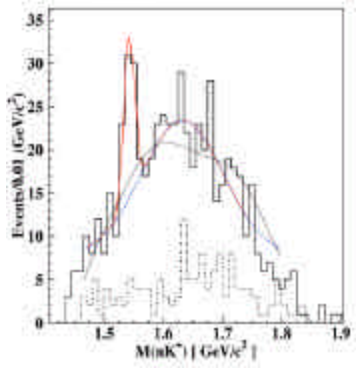
Pentaquarks To be or not to be?

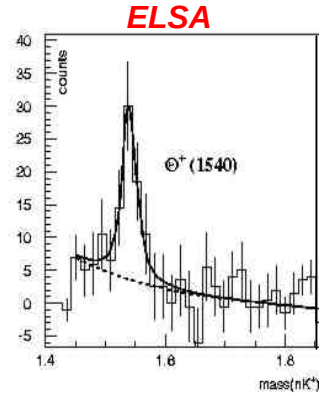
- **Minimum quark content is 5 quarks.**
- **"Exotic" pentaquarks are those where the antiquark has a different flavor than the other 4 quarks.**
- **Quantum numbers not possible for 3 quarks alone.**
- **The $\Theta^+(1540)$, an S=+1 exotic pentaquark, has been seen by several groups.**
  - **The quark content would be** $uudd\,\bar{s}$
  - **The width is narrow, below a few MeV**
  - **It is seen in K^+N and pK_s**
  - **No signal is seen in pK^+ so most likely to be I=0**

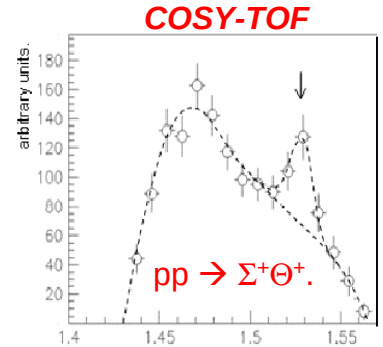
Evidence for Penta-Quark States

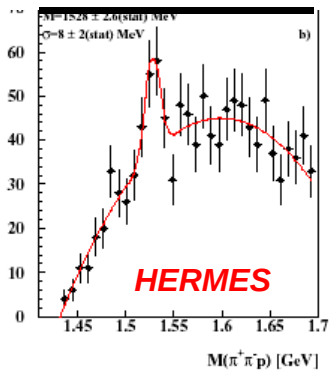


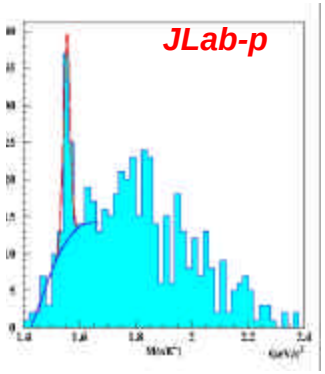


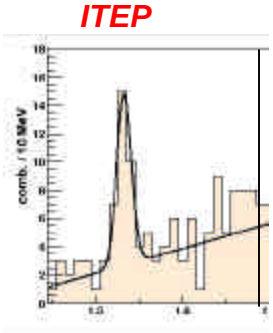


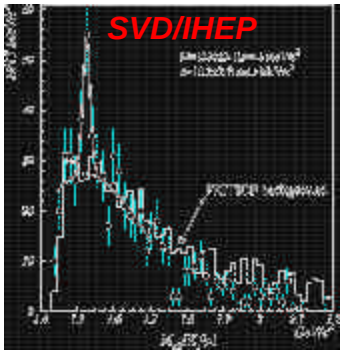




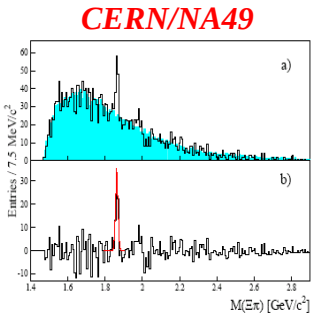


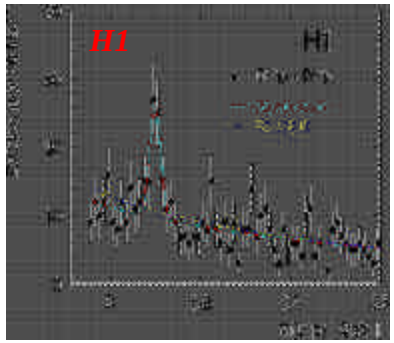


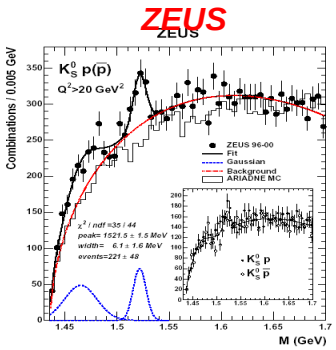


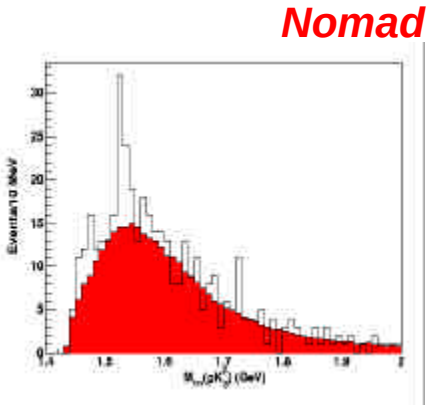


This is a lot of evidence. However,…

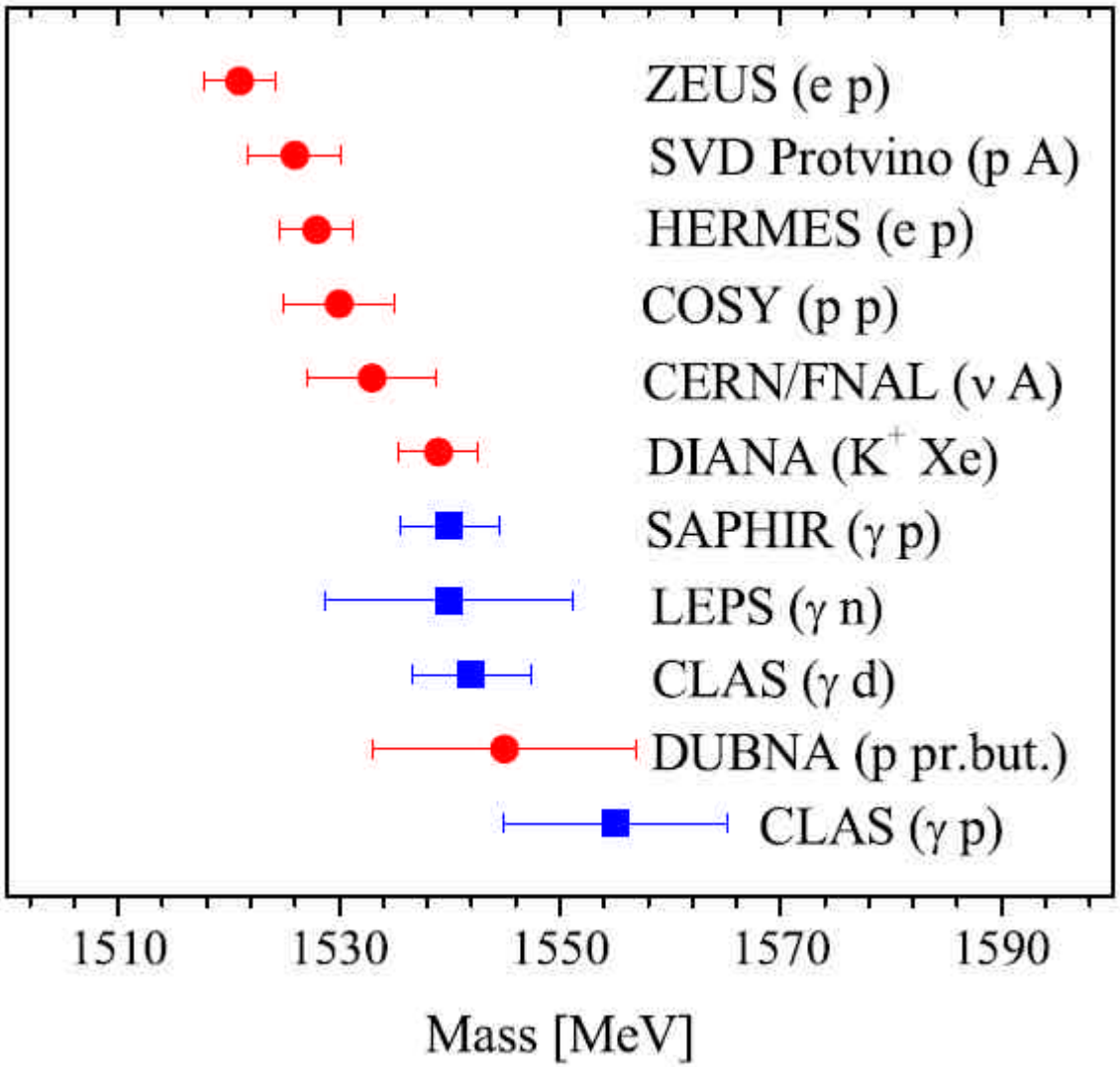








Mass



Final state:

$K^+ + n$

$K_s + p$

$(K_s + \overline{p})$

A few % difference from zero, but ~20% difference from the KN threshold.

Width

- **Again, there is inconsistency:**
  - **Most measurements give upper limits.**
  - **DIANA has $\Gamma < 9$ MeV.**
  - **The cross-section implies Γ=0.9 MeV.**
  - **HERMES: Γ = 13 +- 9 stat. (+- 3 sys.) MeV**
  - **ZEUS: Γ = 8 +- 4 stat. (+- 5 sys.) MeV**
  - **Arndt *et al.* and Cahn *et al.* analysis of KN phase shifts suggests that $\Gamma < 1$ MeV !!**
- **The small width is the hardest feature for theorists to understand…**

Null Results

- **HERA-B (Germany):**
  - **reaction: p+A at 920 GeV**
  - **measured: K^-p and K^0p invariant mass**
  - **Clear peak for $\Lambda(1520)$, no peak for Θ^+**
  - **production rate: $\Theta^+/\Lambda(1520)<0.027$ at 90% C.L.**
- **BES (China):**
  - **reaction: $e^+e^- \rightarrow J/\psi \rightarrow \Theta^+\overline{\Theta}^-$**
  - **limit on B.R. of $\sim 10^{-5}$**

And many unpublished negative results

(HyperCP, CDF, E690, BaBar, LEP,,,).

If the Θ^+ does exist, its production in high energy reactions must be highly suppressed.

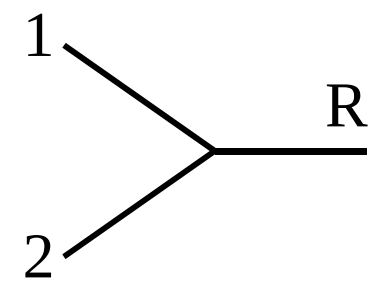
$\rightarrow$ Model independent experimental search is most desirable.

We propose to

Search for the Θ^+ in
Formation experiment with
High intensity kaon beam and
Large acceptance detector.

Cross Section for Formation

(Courtesy of M. Praszalowicz)



Breit-Wigner cross-section (GM + MP)

1/2

$$\sigma_{BW}(E) = \frac{2J+1}{(2S_1+1)(2S_2+1)} \frac{\pi}{k^2} B_{in} B_{out} \frac{\Gamma^2}{(E-M)^2 + \Gamma^2/4}$$

0 1/2 1/2 1/2

$$\sigma_{BW}(M) = \frac{\pi}{k^2} \sim 16.8 \text{ [mb]}$$

$$\boxed{\sigma_{BW}^{tot} = \frac{\pi}{4k^2} 2\pi\Gamma \sim 26.4 \times \frac{\Gamma}{1 \text{ MeV}} \text{ [mb} \times \text{MeV]}}$$

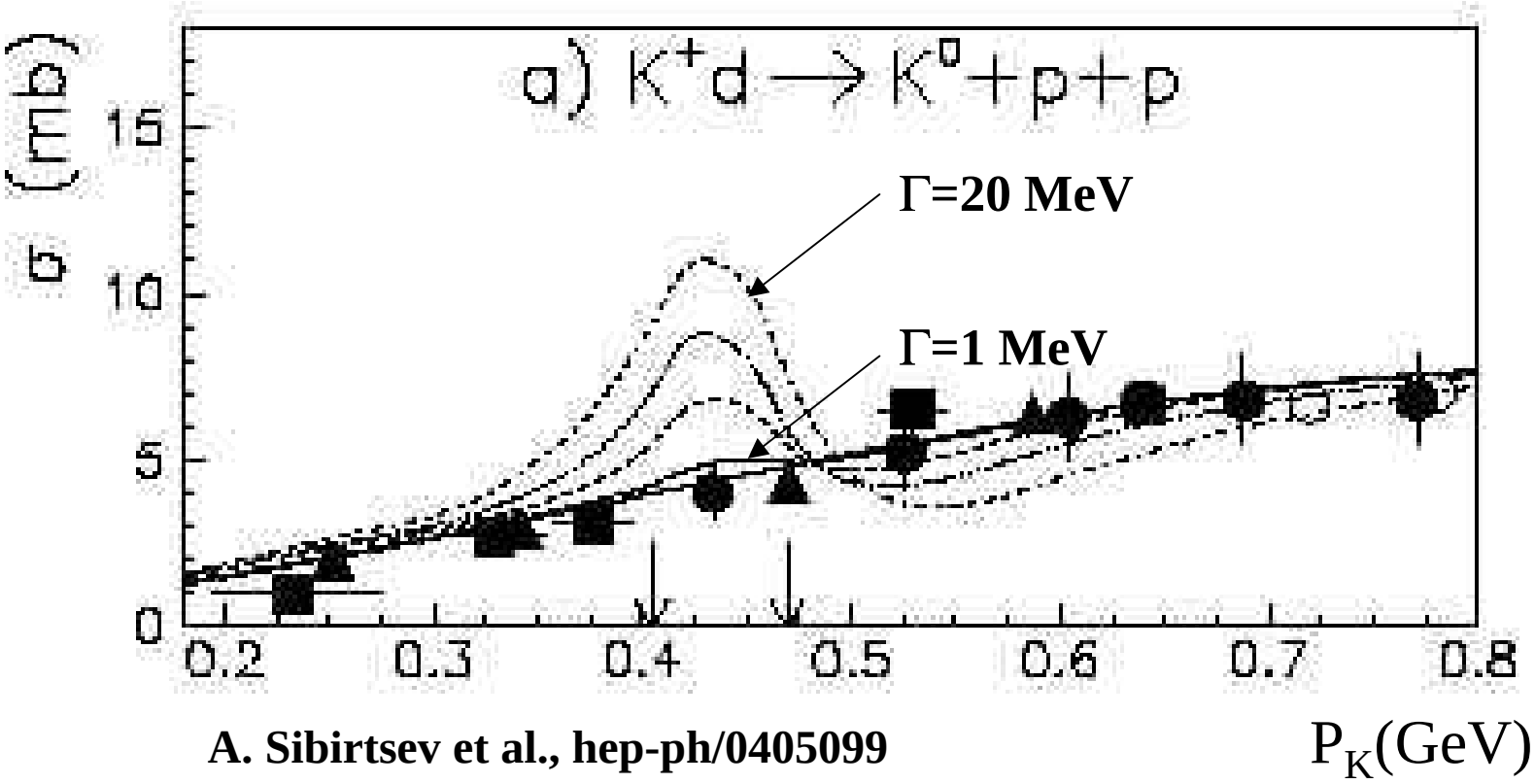
C-G, not energy !

Nussinov (hep-ph/0307357)

$$\sigma_{K^+n}(p) = \frac{4\pi}{p^2} \Sigma_l (2l+1)\ E\ \sin^2 \delta_l(p)$$

$$\sigma_{\Theta^+}|_{res} \simeq \frac{4\pi}{p^2} \cdot 3 \cdot \left(\frac{1}{2}\right) \cdot \left(\frac{1}{3}\right) \simeq \frac{37}{2} \text{ mb} \rightarrow 18.5$$

Cross section for background

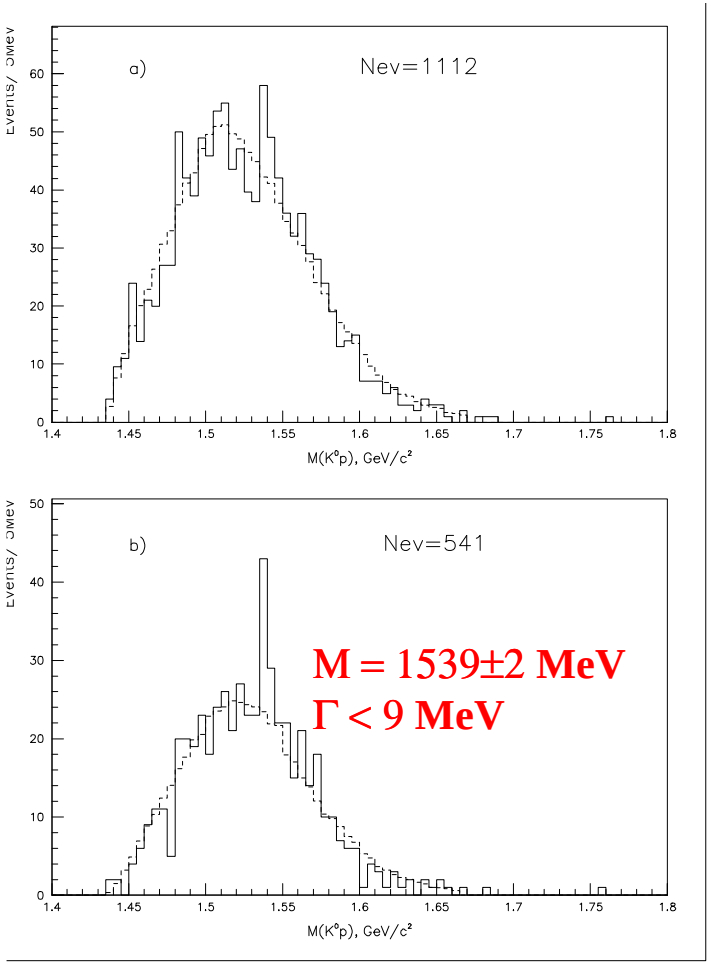


A. Sibirtsev et al., hep-ph/0405099

- **The background is smooth and well known (~4 mb).**
- **The Θ^+ with a narrow width should appear as a bump.**
- **If not, a strong limit on the width can be put.**

Previous formation experiment

K^+ Xe K^0 p X
(K^+ n K^0 p)



hep-ex/0304040

- **Xenon bubble chamber**
- **P_{K+} entered with 530 MeV/c**
- **K^+ ranged out in the Xenon**
- **Require θ_K<100deg. & θ_p<100 deg.**
- **Remove cos ϕ_{pK} <0 ← back-to-back**

K^+ n Θ^+ ↔ Θ^+ K^+ n

$\Gamma = 0.9 \pm 0.3$ **MeV**

Cahn and Trilling hep-ph/0311245

consistent with KN phase shift analysis by Arndt et. al.

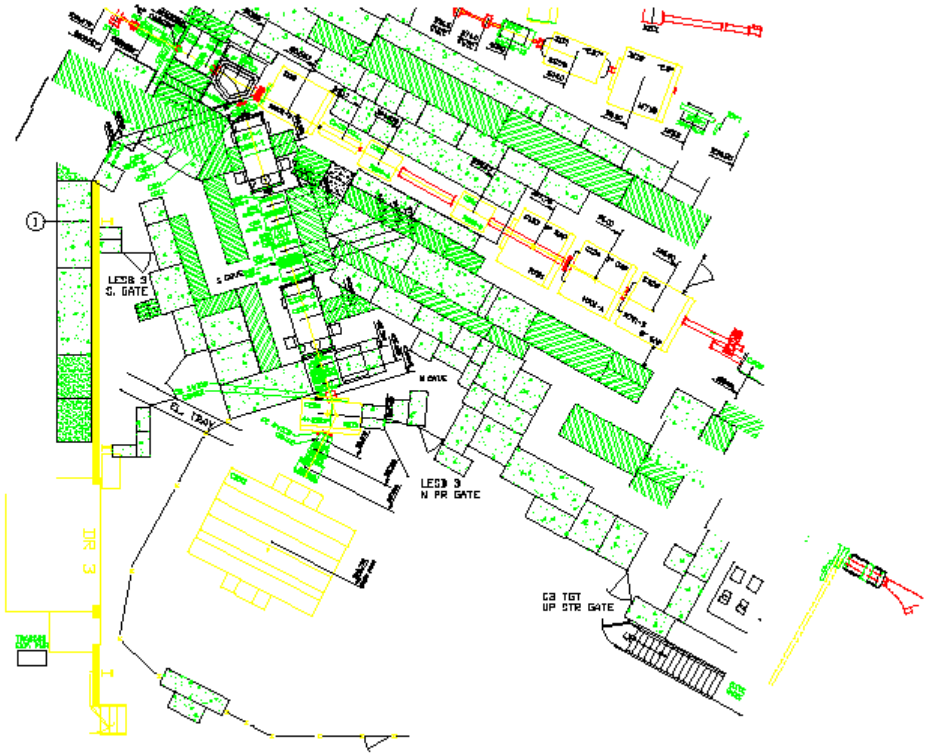
Phys. Rev. C68, 042201(R)

Kaon supply

•AGS will be running for polarized protons for RHIC.

• In principle, available between fills (i.e. most of the time). Flux of 10^{12} protons per spill should be easy.

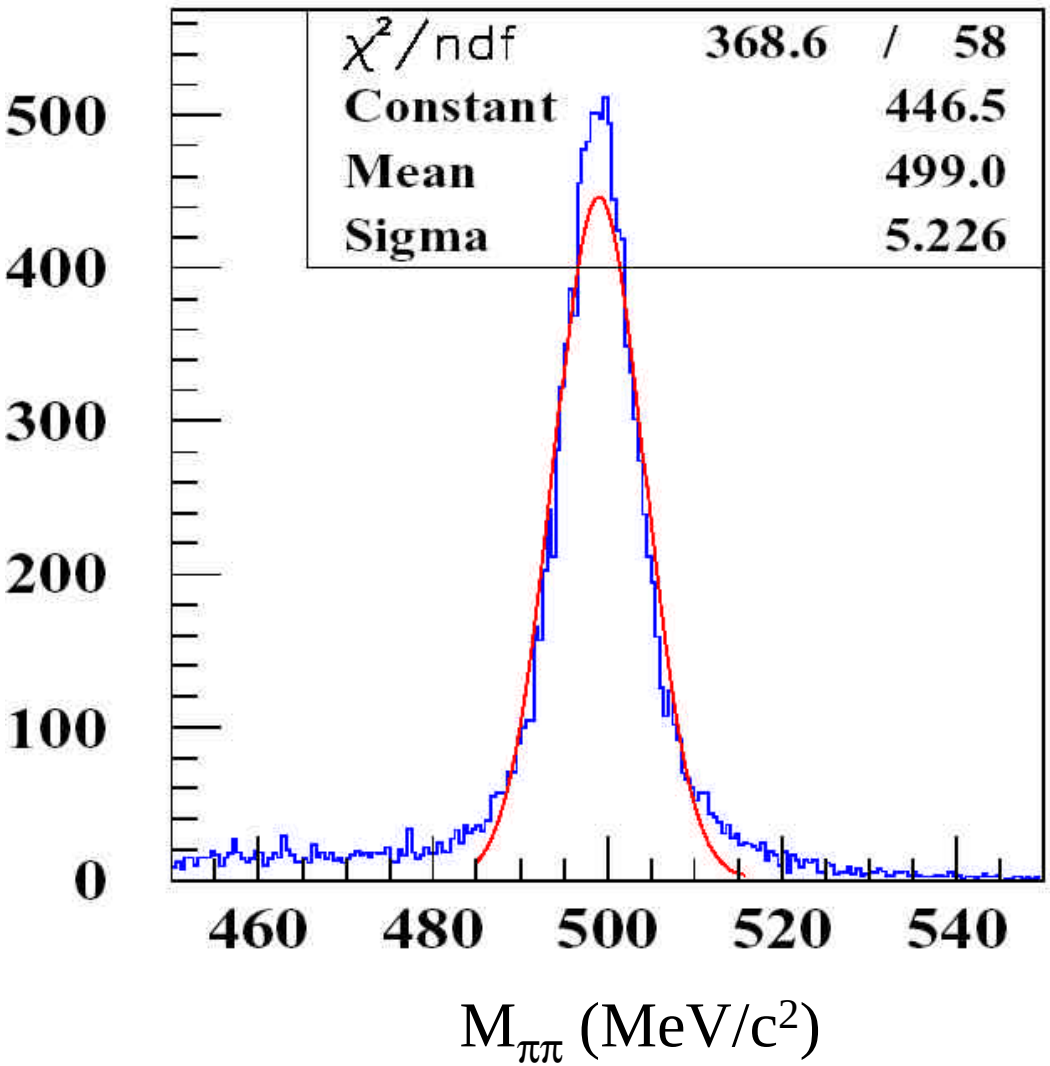
•Can get 2.8 x 10^4 475-MeV/c K^+ per 10^{12} on target.



Technique

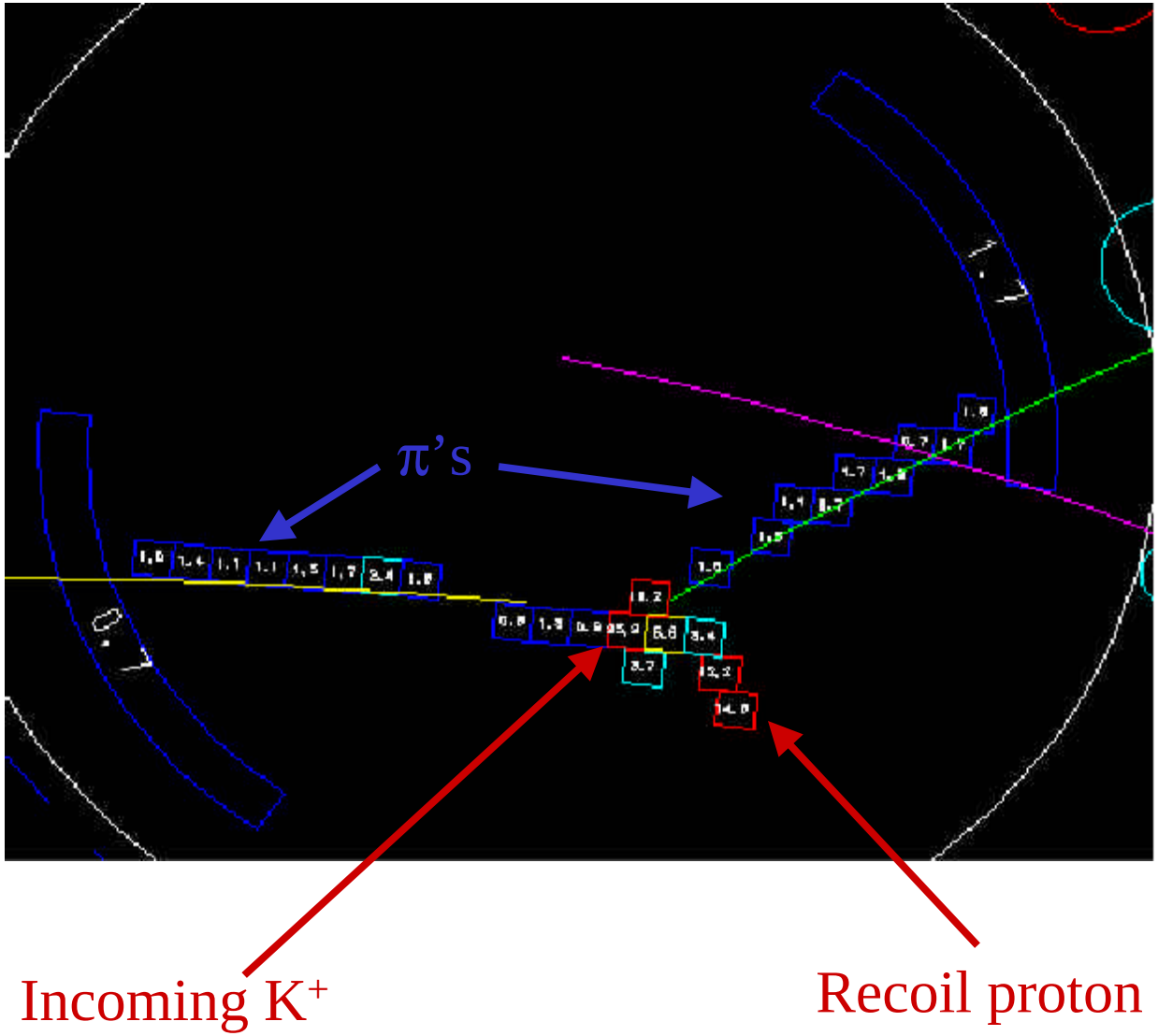
1. **Trigger on $K_S \rightarrow \pi^+,\pi^-$, measure in drift chamber + tgt.**
2. **dE/dx across 20cm width of tgt spans 40 MeV range in CM energy.**
3. **Reconstruct proton in target (& sometimes in chamber). Can get momentum except for sign of P_L (but usually is +) from transverse range + energy.**
4. **From K_S + p reconstruct center of mass - remove Fermi momentum.**
5. **Multiple cross-checks:**
   - **Excitation curve (already limits width to 1-2 MeV).**
   - **K_S missing mass technique**
   - **Some p's seen in the chamber.**
   - **Run at different momenta to cover wide range, decouple geometry from kinematics.**
   - **Run K- and study Λ(1520).**

$M_{\pi\pi}$ distribution from E949 showing $K_S \rightarrow \pi^+\pi^-$



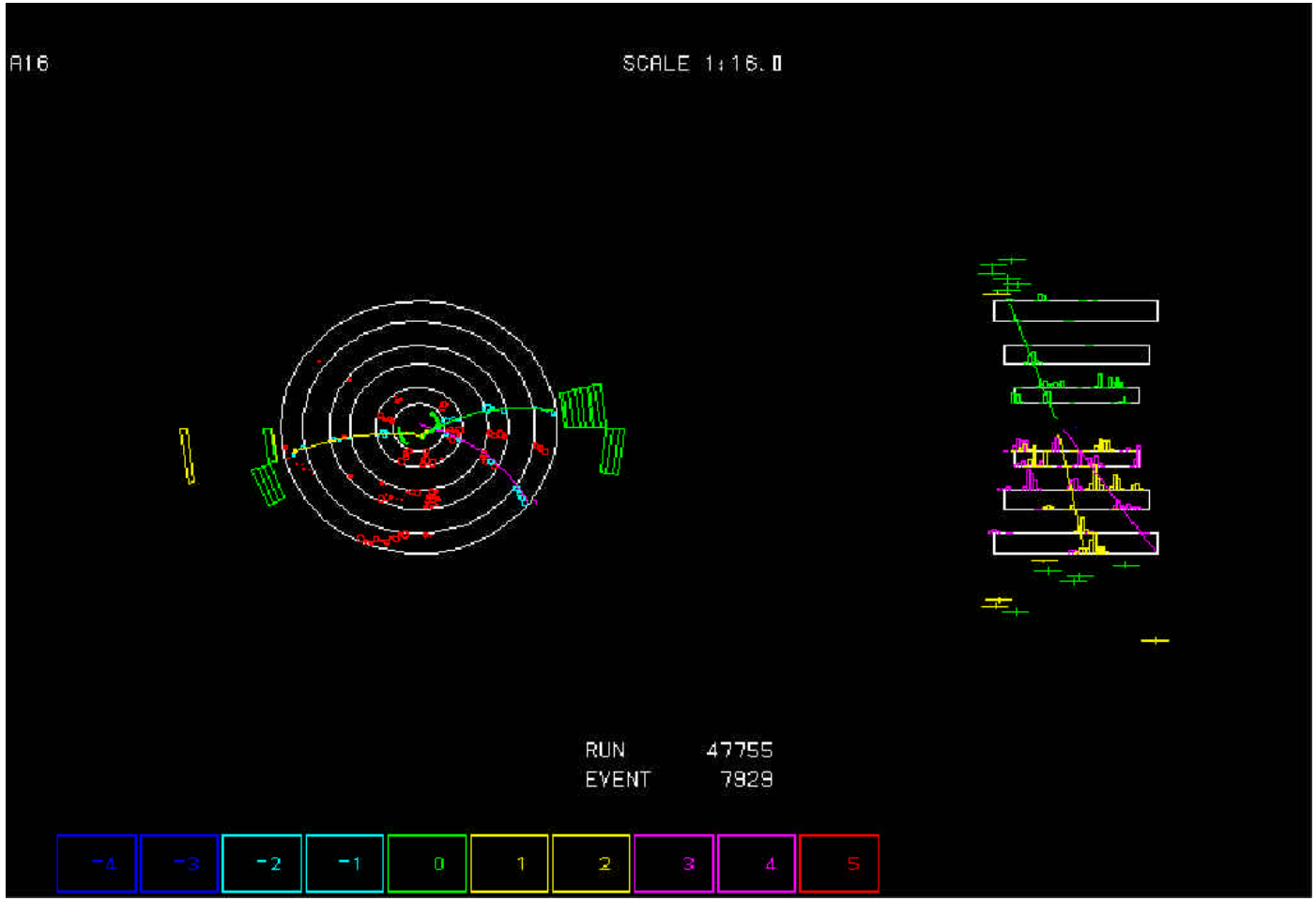
K_S candidate in the E949 target

Beam's-eye view of event in E949 target. Kaon enters at ~300 MeV/c. At this low momentum proton doesn't get very far



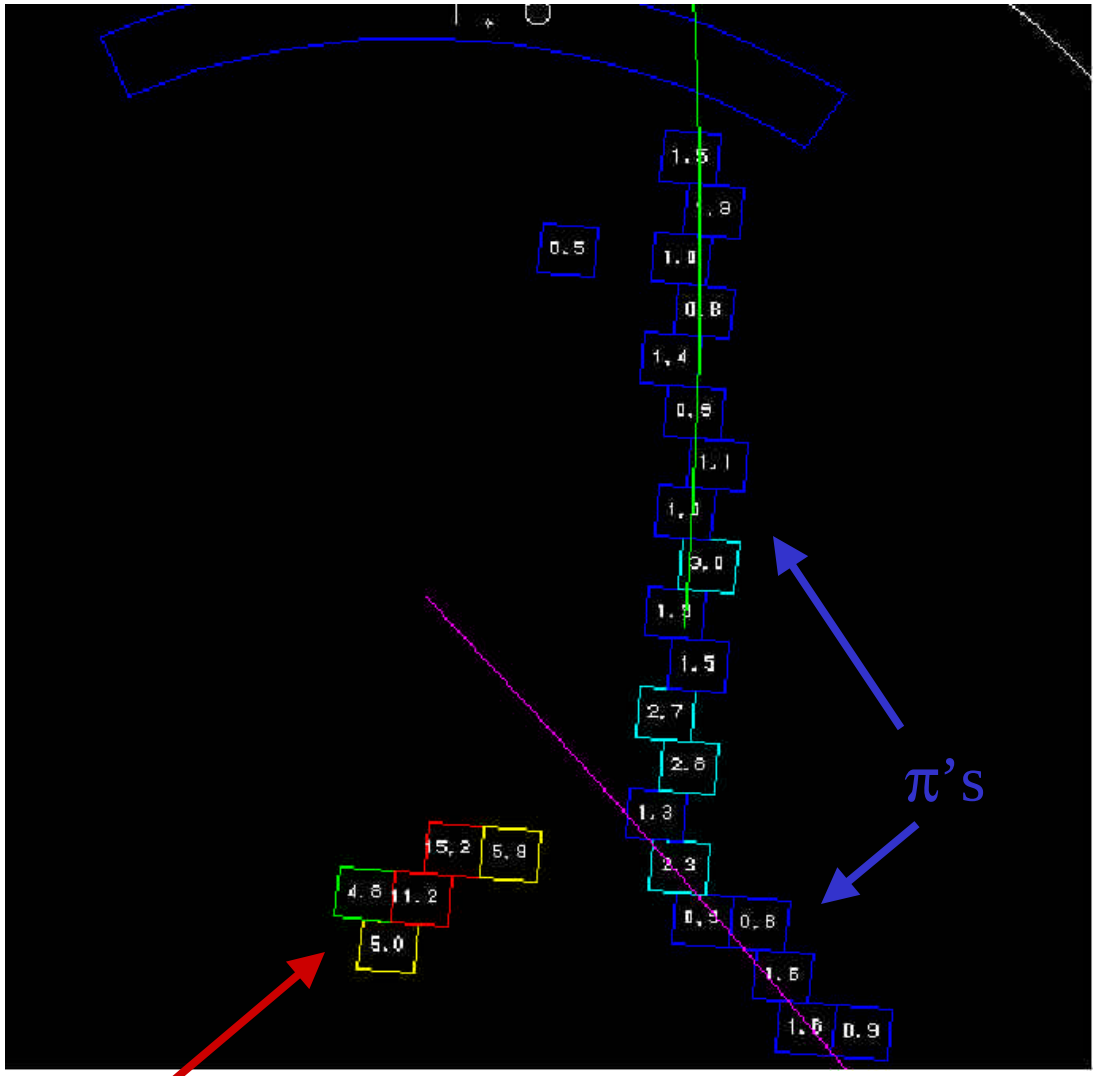
K_S candidate in the E949 detector

End and side views of event in E949 detector. Green rectangles outside of drift chamber are range stack scintillators with in-time energy. Purple drift chamber track is out-of-time random.



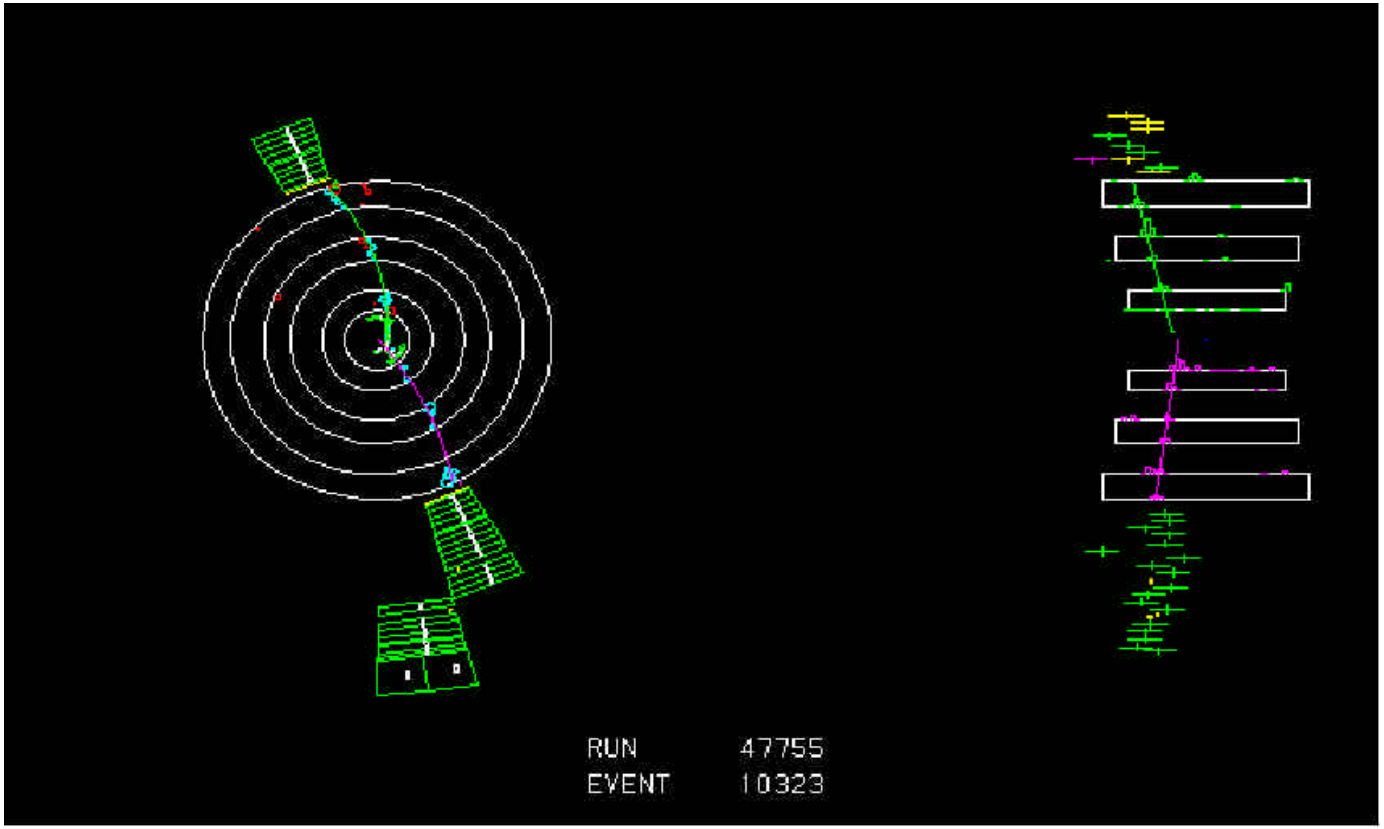
2nd K_S candidate in the E949 target

Beam's-eye view of 2nd event in E949 target. This time the recoil proton either overlaps the incoming K or is absent



2nd K_S candidate in the E949 detector

End and side views of event in E949 detector.



Spin Considerations

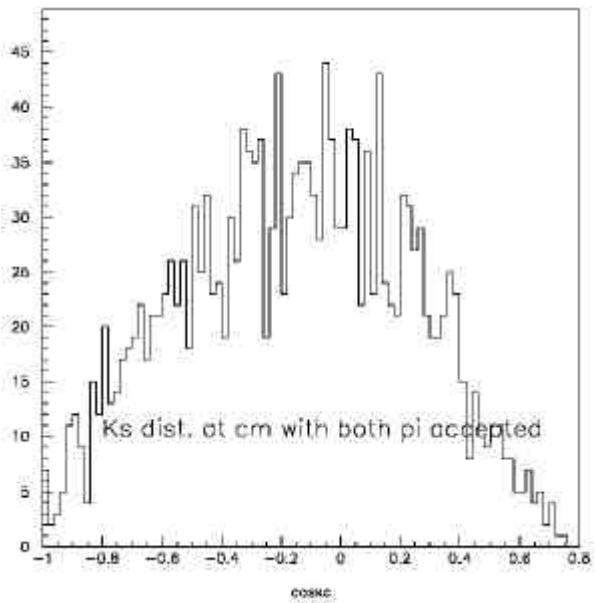
- The Θ^+ spin can be determined by the decay angular distribution
- For $K^+n \rightarrow \Theta^+ \rightarrow K^o\, p$, spins of the K's are 0 and of the nucleons are ½.
- Can define z-axis as the direction of the incoming K^+ in the Θ^+ CoM.
- Follows that the z component of the Θ^+ spin, J_Z must have the values of ±½.
- Can then calculate the K^o angular distribution in the Θ^+ CoM system for various values of its spin J:

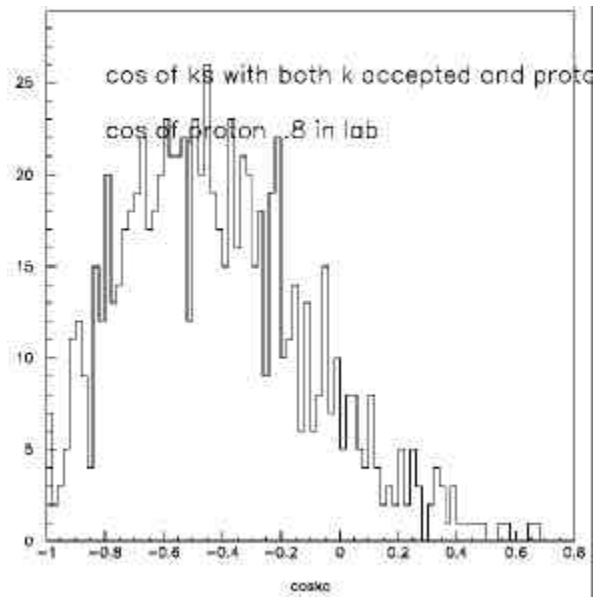
J^P	$I(\Theta)$
$1/2^\pm$	1
$3/2^\pm$	$1+3\cos^2\Theta$
$5/2^\pm$	$1-2\cos^2\Theta+5\cos^4\Theta$

- One notes that $I(\Theta)$ is the same for both parities of a given spin.
- To unravel the parity, look for interference with background waves since
  - such effects give rise to odd powers of $\cos\Theta$.
- There's a significant S wave amplitude in the Θ^+ region and the flat $J^P = ½^+$
  - distribution converted by interference to asymmetric $\cos\Theta$ form.

Monte Carlo of CM angle acceptance

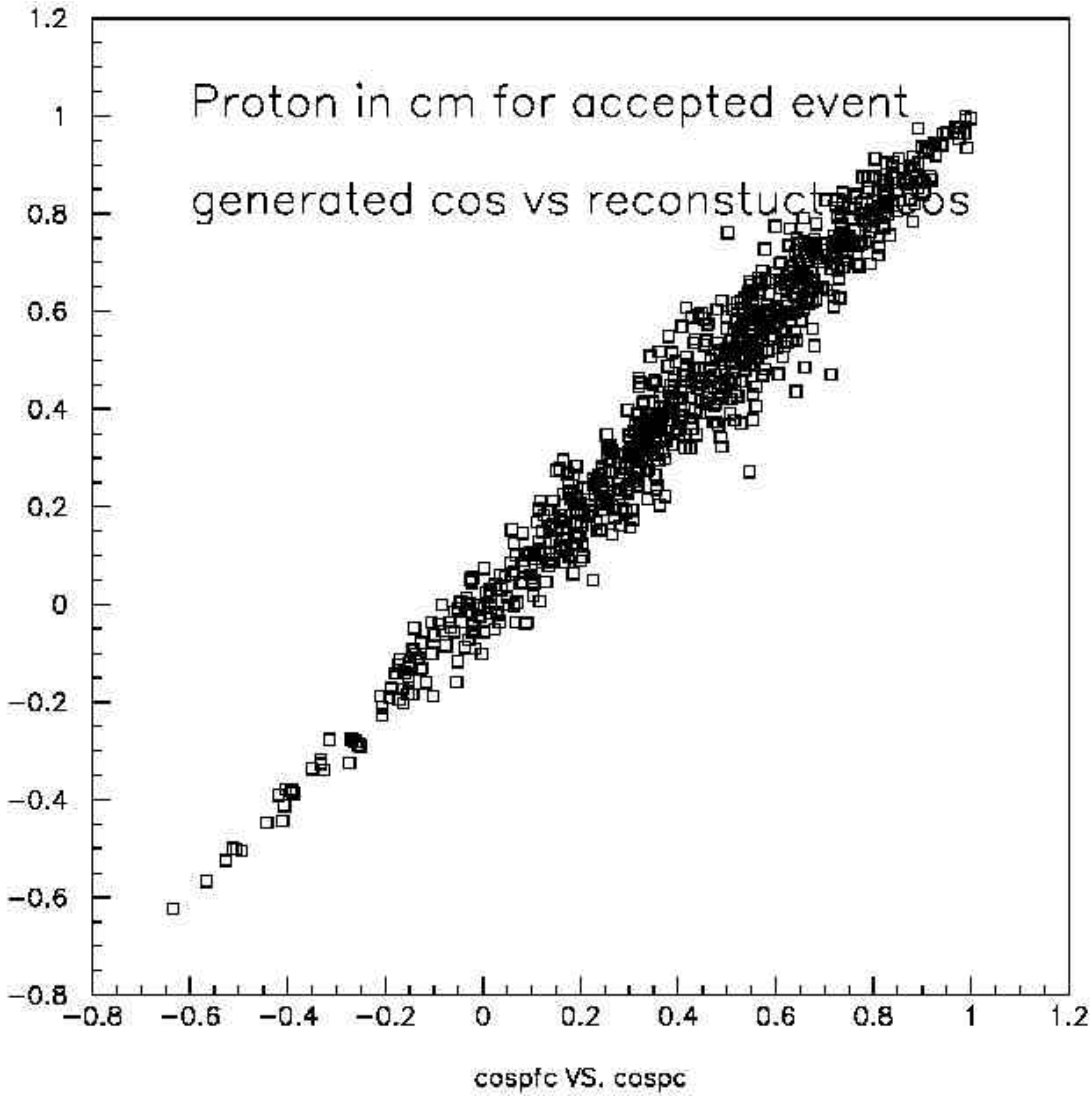
Distribution generated isotropic in CM





If the decay angle of the Θ^+ is measured , its spin and parity may be determined through interference with BG.

Reconstructing the CoM K scattering angle



Rates

1. **"Background" rate ~800 K_s/pulse.**
2. **For Θ^+ width 1MeV, integrated cross-section is 26.4mb-MeV, which would give about 1/6 as many events, 1/10 with K_S into π^+,π^-.**
3. **AGS spill to be optimized, assume e.g. 1.3sec/3.6sec, gives 10^5 spill per 100 hours or 8M produced Θ^+ per 10^{12} POT for 1-MeV width.**
4. **Acceptance for K_S ~ 10%, so 800,000 Θ^+/week in which we see K_S. Proton acceptance not yet known, but geometrical acceptance high. Overall shouldn't be <10%, so at least 80,000 Θ^+/week, going in.**

Running requests : ~ 10^{12} POT for 5 weeks

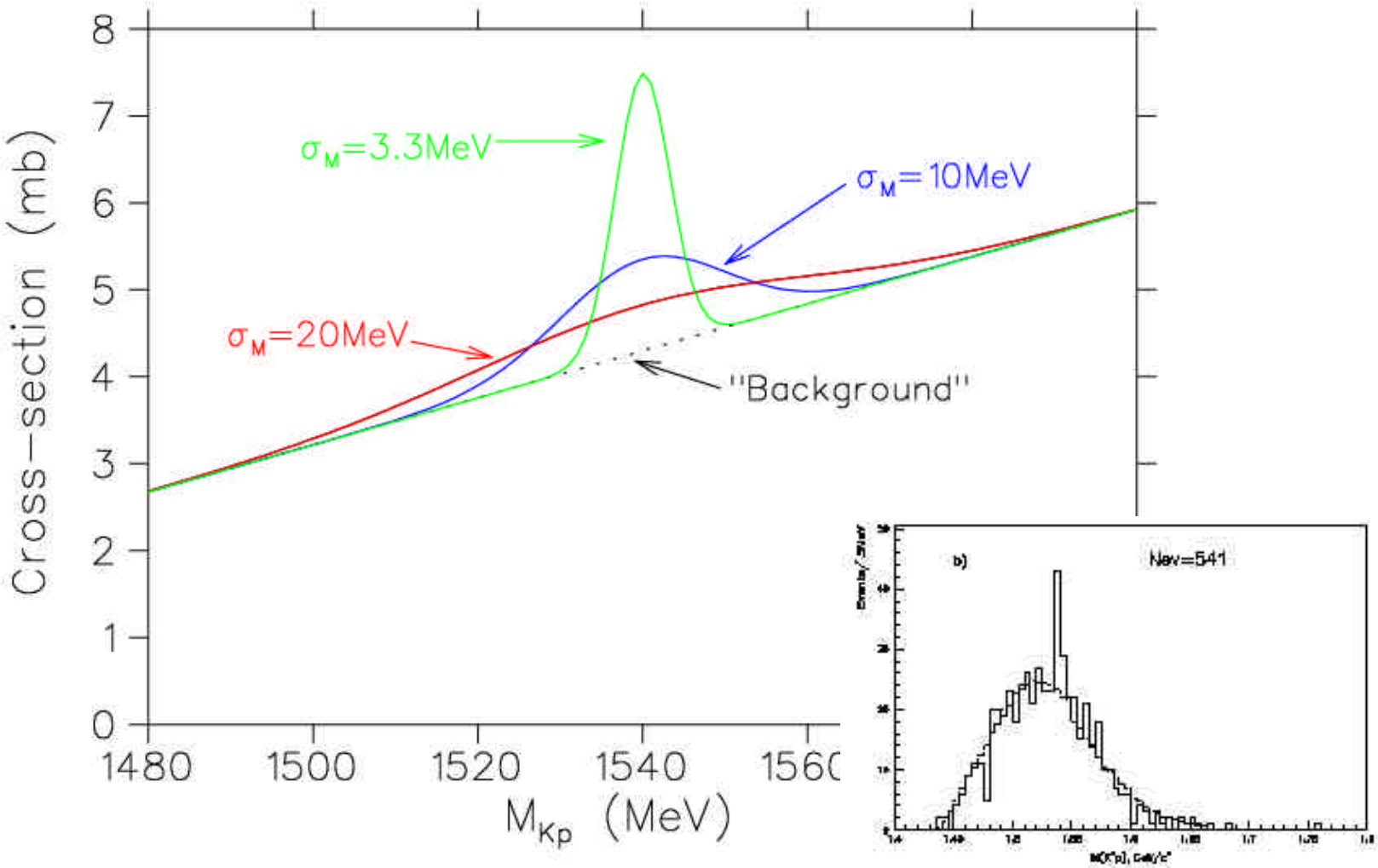
- need to get detector on air, vary momenta, do K^- runs.

Things to do

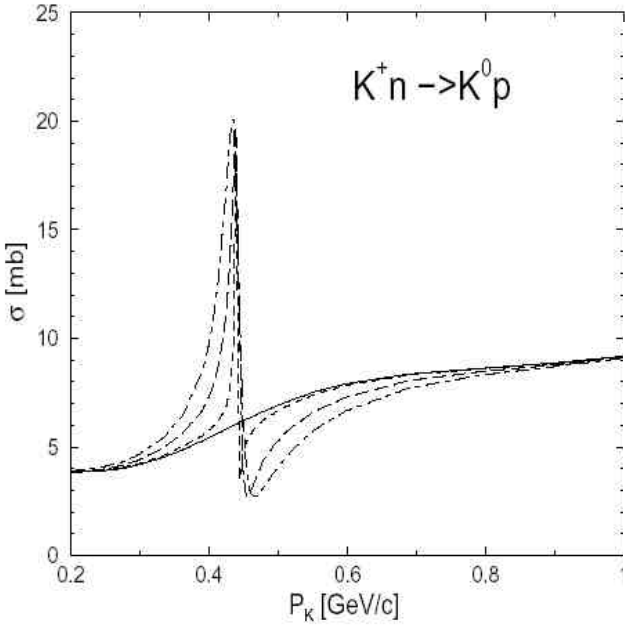
–before deciding if a proposal is warranted.

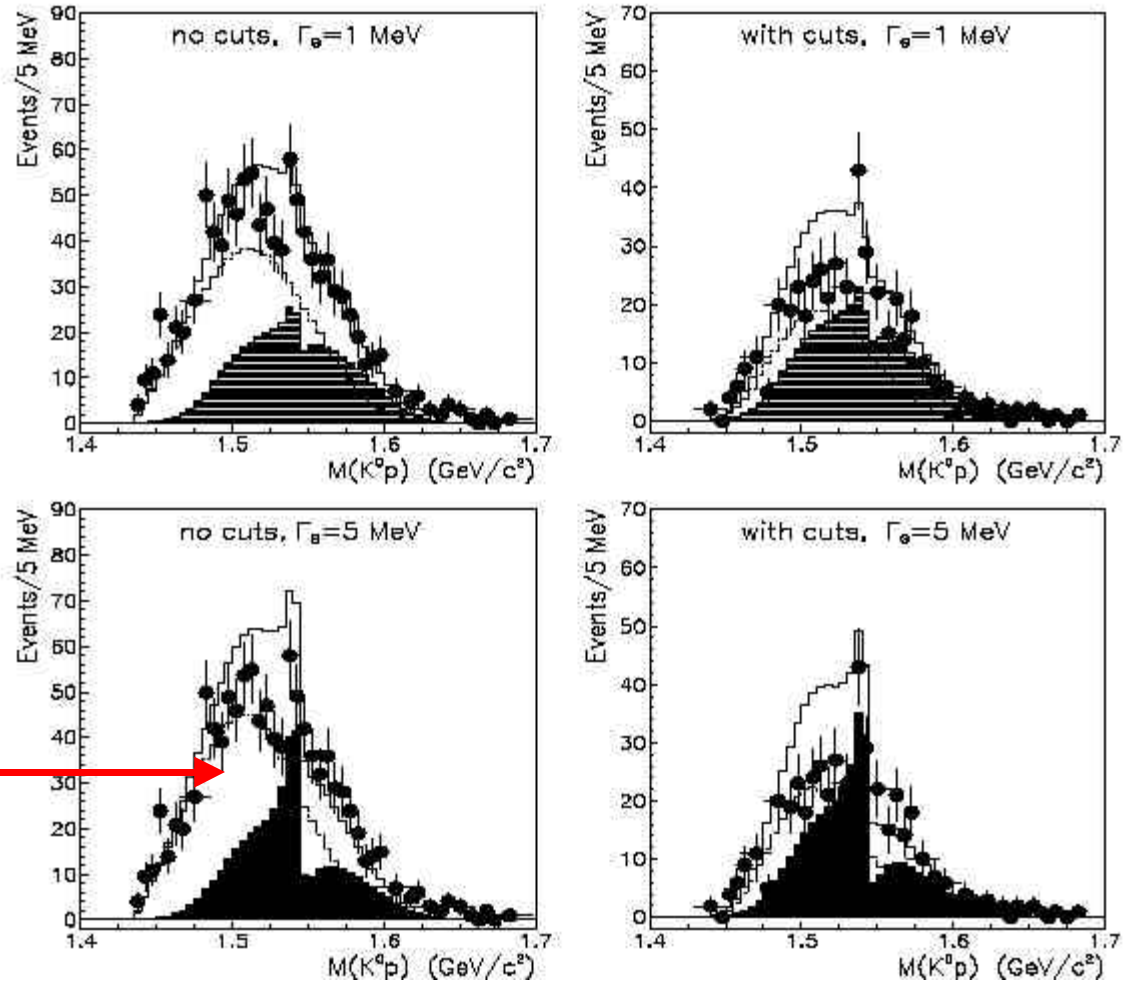
- **Detailed Monte Carlo & studies of E949 data to get resolutions and acceptances. Requires mods to E949 software.**
- **Studies of pattern recognition in target**
- **Fine tuning of strategy**

Background + resonance



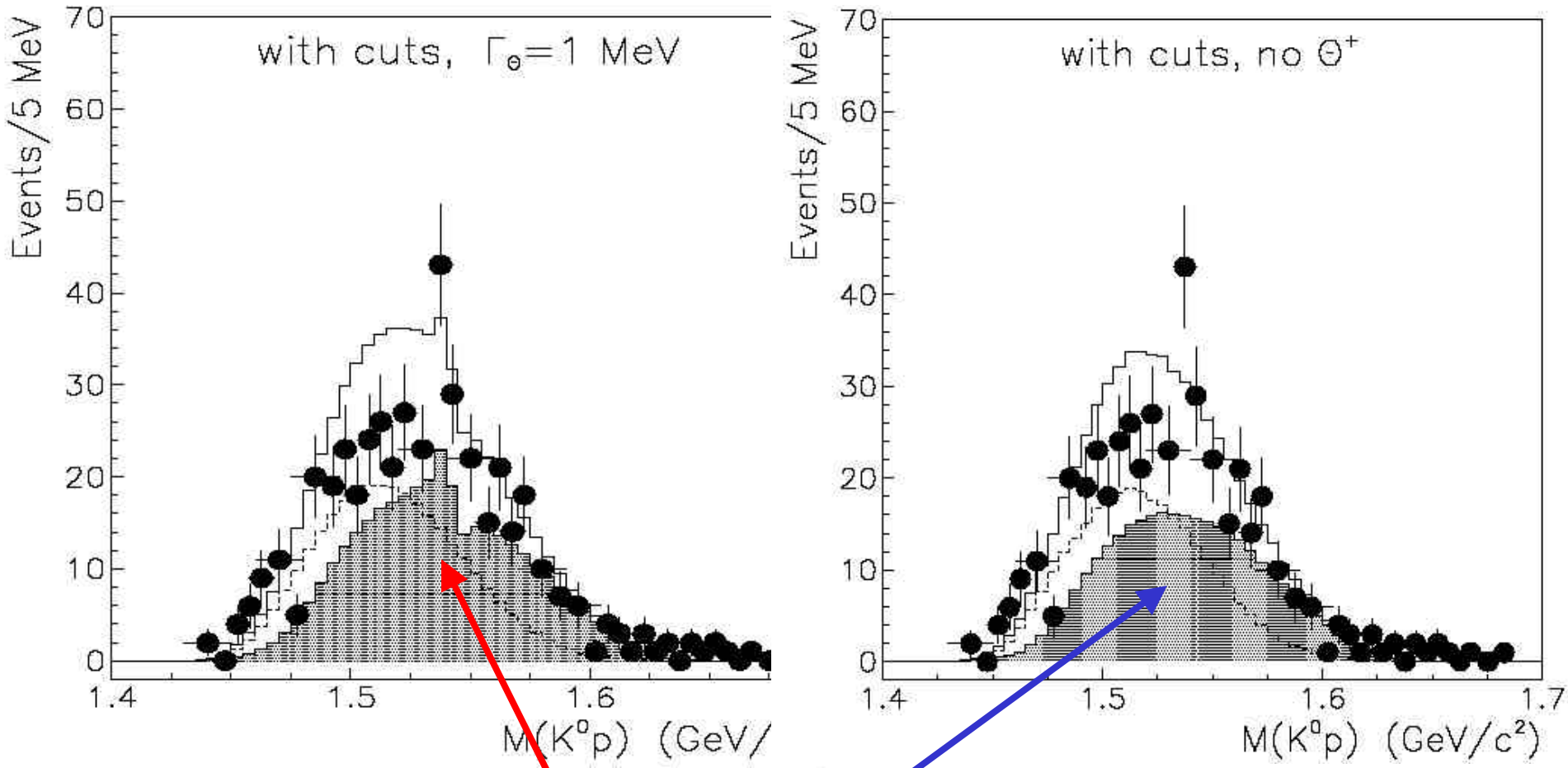
Interference





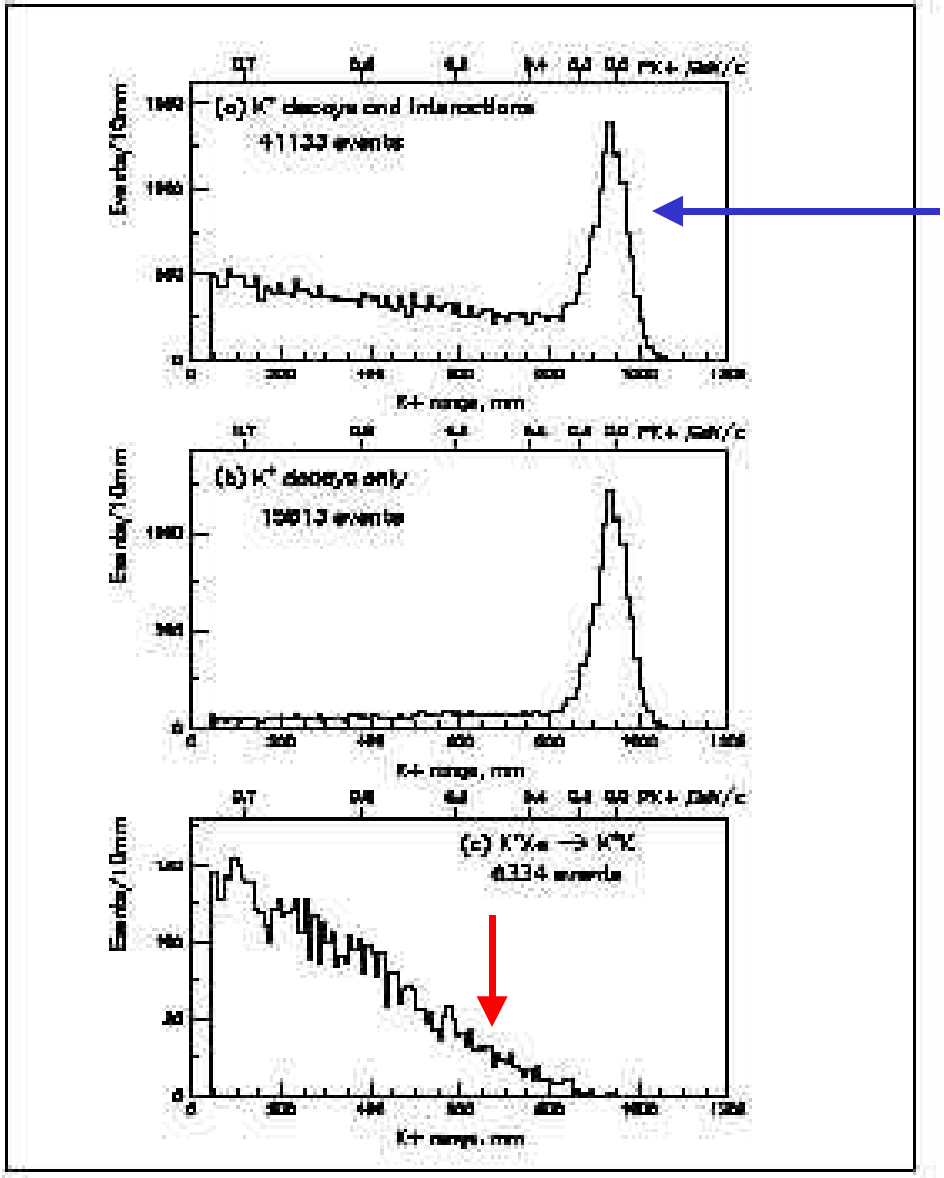
Sibirtsev et al. in nuc-th/0407011 claim very strong interference. Also v. large rescattering in Xenon. Note that we're working in C-12 vs Xe-131. Still need to worry about resolution!

Closeup

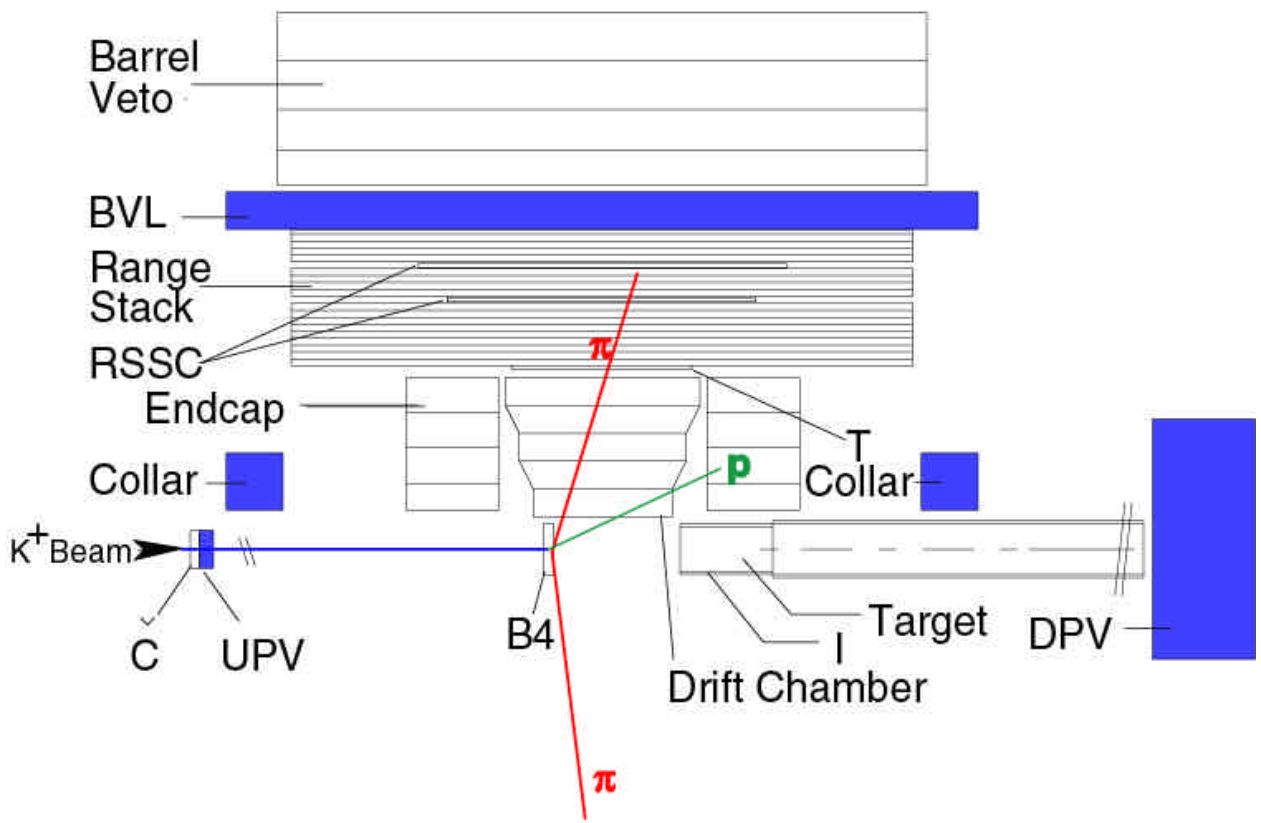


Need to distinguish this from this with resolution of ~10MeV
want to be sensitive to effect 10x smaller than on left!

What if you don’t reconstruct?



K stops

Possible modified geometry

Move tgt DS. Use present B4 hodoscope as tgt. Many more protons get to DC. Energy measured in tgt and CsI endcap. Lower evt rate, but more would be fully reconstructed.