Penta-Quark Workshop
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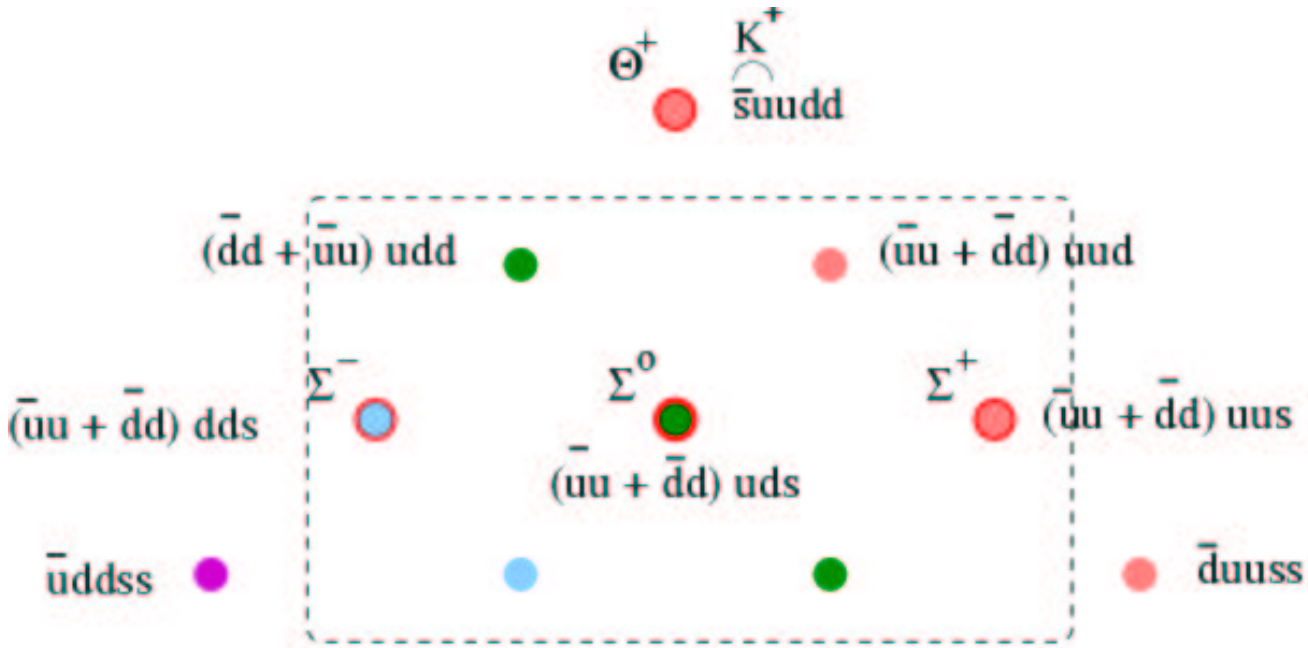
The possibilities of the High Resolution studies of the Θ family in Hall A

Bogdan Wojtsekhowski, JLab



$D(e,e' K^- p_s)\Theta^+$

$D(e,e' K^+ p_s)\Sigma^-$

$D(e,K^-\Theta^+)\, e'p$

$\hookrightarrow K^+ + n$

$D(e,K^+\Sigma^-)\, e'p$

$\hookrightarrow K^- + n$

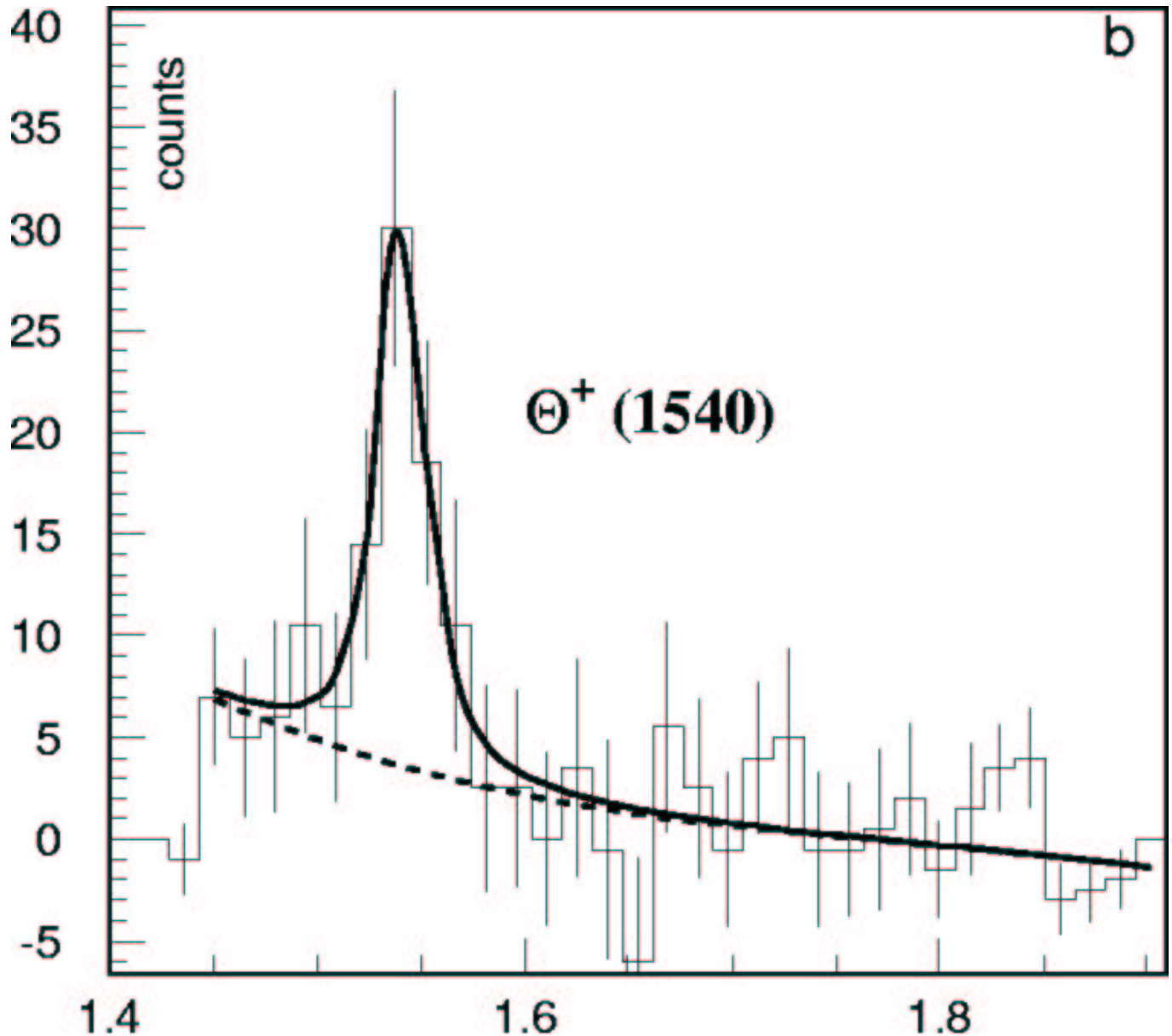
$\Theta^+ \rightarrow \boxed{K^+ + n}\,;\ K^o + p$

$\Sigma^+ \rightarrow K^- + \Delta^{++}\,;\ \bar{K}^o + p$

$\Sigma^o \rightarrow \boxed{K^- + p}\,;\ \bar{K}^o + n$

$\Sigma^- \rightarrow \boxed{K^- + n}\,;\ \bar{K}^o + \Delta^-$

Are two corners found ?



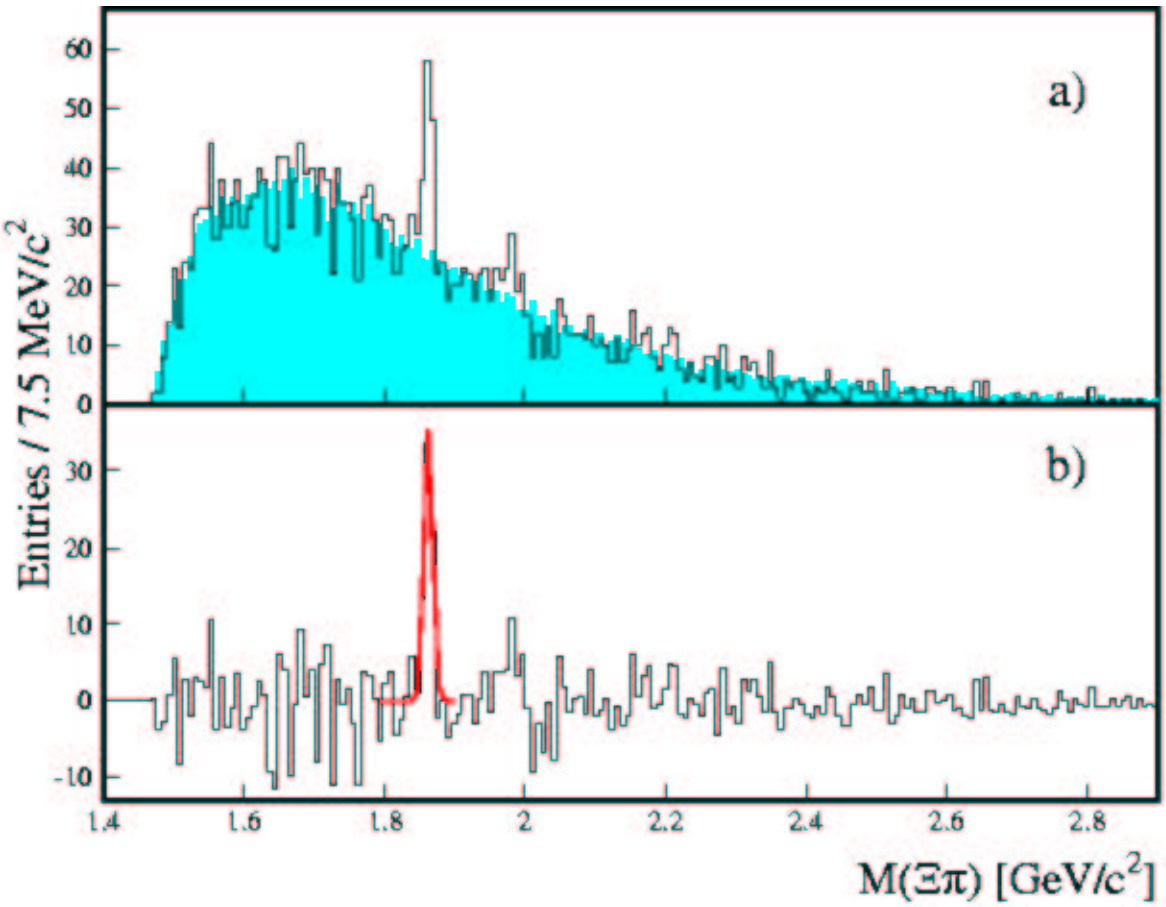


FIG. 3: (Color online) (a) The sum of the $\Xi^-\pi^-$, $\Xi^-\pi^+$, $\bar{\Xi}^+\pi^-$ and $\bar{\Xi}^+\pi^+$ invariant mass spectra. The shaded histogram shows the normalised mixed-event background. (b) Background subtracted spectrum with the Gaussian fit to the peak.

The questions are

- What is the mass of the resonance ?
- What is the width of the resonance ?
- What is the isospin? Where is the Θ^{++}?
- What is parity of Θ^{+} and what can reveal it?
- What is a cross section in process $\gamma n \to \Theta^{+}$?
- How to get best E/B event sample for study of the spin, the form factor, the production mechanism.
- Where are the decuplet partners?
- How large it is ? What is the formfactor ?
- Is any linear photon polarization effect ?

The mass and width of the Θ^+

	mass, MeV	width, MeV
DPP prediction	1530	< 15
SPring-8	1540 ± 10	< 25
DIANA	1539 ± 2	< 9
CLAS,γn	1542 ± 5	< 21
CLAS,γp	1540 ± 10	< 32
ELSA	$1540 \pm 4 \pm 2$	< 25
ITEP ν	1533 ± 5	< 20
USC /hep-ph/0307357	at 1543	< 6
GWU/nucl-th/0308012	at $1520 - 1560$	up to 0.1
GWU/nucl-th/0308012	at $1540 - 1550$	up to ~ 1
Juelich/hep-ph/0309243	at 1540	< 5

The reactions of interest in Hall A

- $D(e, K^-\Theta^+)e'p \quad \Theta^+ \to K^+n$
- $D(e, e'K^-p_{soft})\Theta^+$.
- ${}^3\vec{H}e(e, K^-\Theta^+)e'pp \quad \Theta^+ \to K^+n$
- $H(e, e'K^+)\Sigma^o$.
- $D(e, e'K^+p_{soft})\Sigma^-$.
- $D(e, K^+\Sigma^-)e'p \quad \Sigma^- \to K^-n$.
- $H(e, K^-\Theta^{++})e' \quad \Theta^{++} \to K^+p$
- $H(e, e'K^-)\Theta^{++}$.
- $H(e, e'K^-\pi^+)\Theta^+$.

The detectors in Hall A

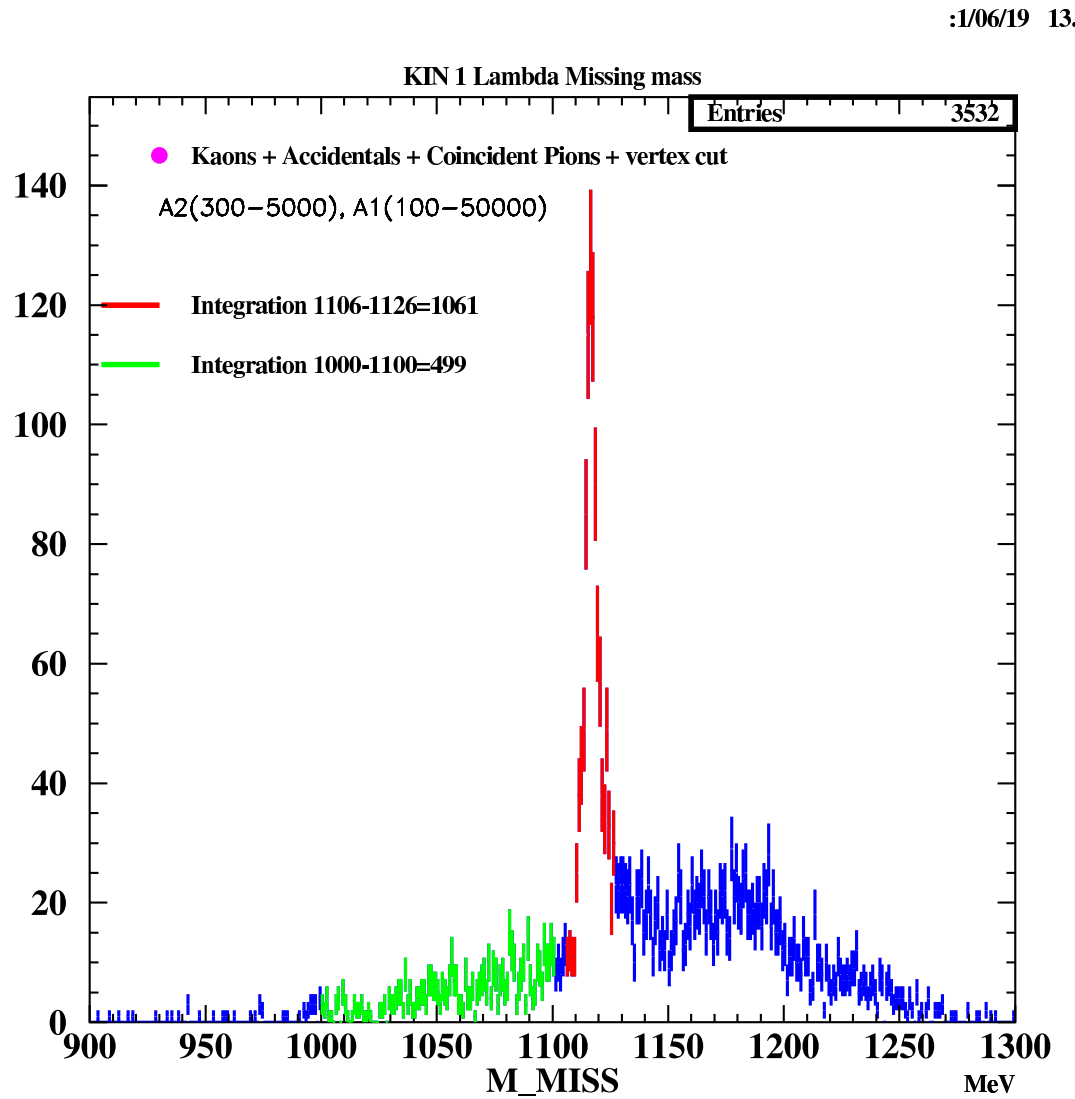
- High Resolution Spectrometers, $\sigma_p/p = 1.5 \cdot 10^{-4}$, $\sigma_\theta \sim$ 2 mr, momentum bite $\Delta p/p \sim 0.09$, $\Omega =$ 6 msr, $\theta_{min}^{cent} = 6°, \Delta\theta_{in\,plane} = 2.8°$.
  PID package consists of Gas Cherenkov, Lead Glass Shower, Aerogel Cherenkov counters, RICH-freon, ToF resolution of 0.15 ns, path from the target of 25 m.

- BigBite Spectrometer, $\sigma_p/p = 0.01 * p$ GeV, $\Delta p/p \sim 80\%$, $\sigma_\theta \sim$ 3 mr, $\Omega \sim$ 80 msr (for $\theta > 45°$), path from the target of 4 m, 40 cm long target.

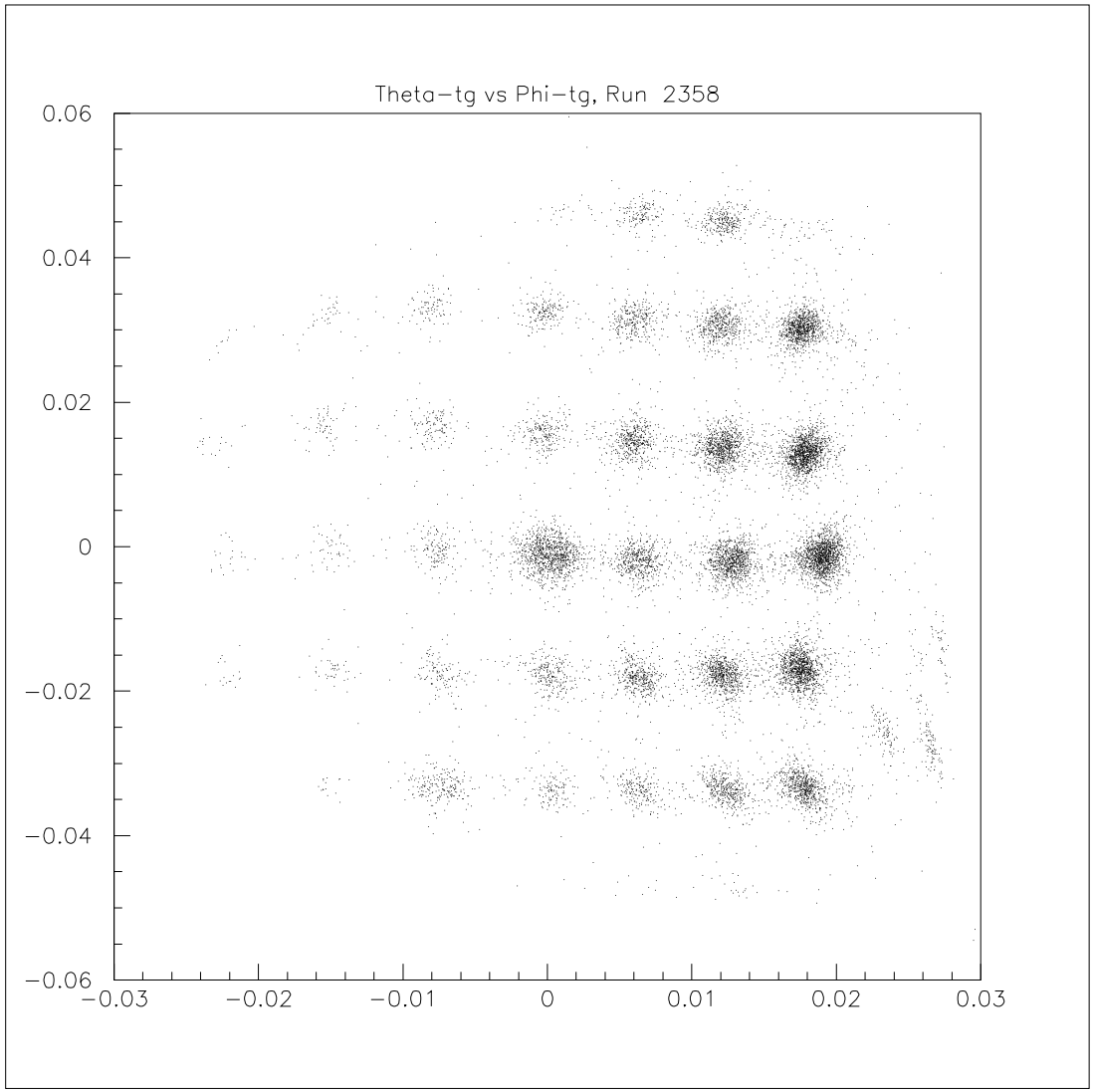
- Large Neutron Detector, 180 veto counters , 230 neutron bars, surface area of 1.6x5 m^2, an efficiency of 30%, ToF resolution of 0.30 ns, position resolution of 5 cm.

- Big Calorimeter (with Hall C), 1700 lead glass counters, surface area of 1.3 x 2.1 m^2, resolution of 5% at 1 GeV, position resolution of 0.5 cm.

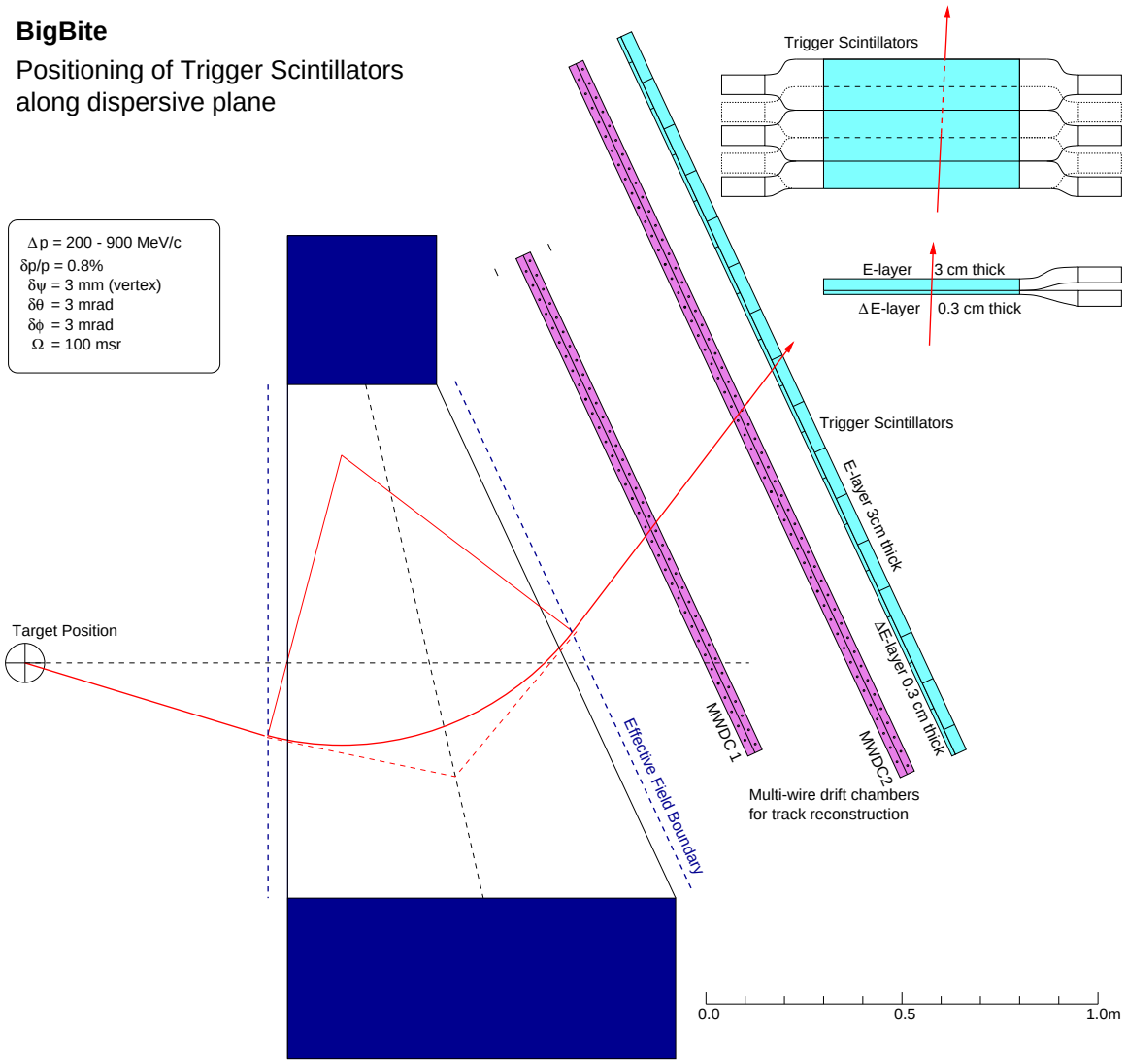
H(e,e'K+)X spectra from HRS in Hall A



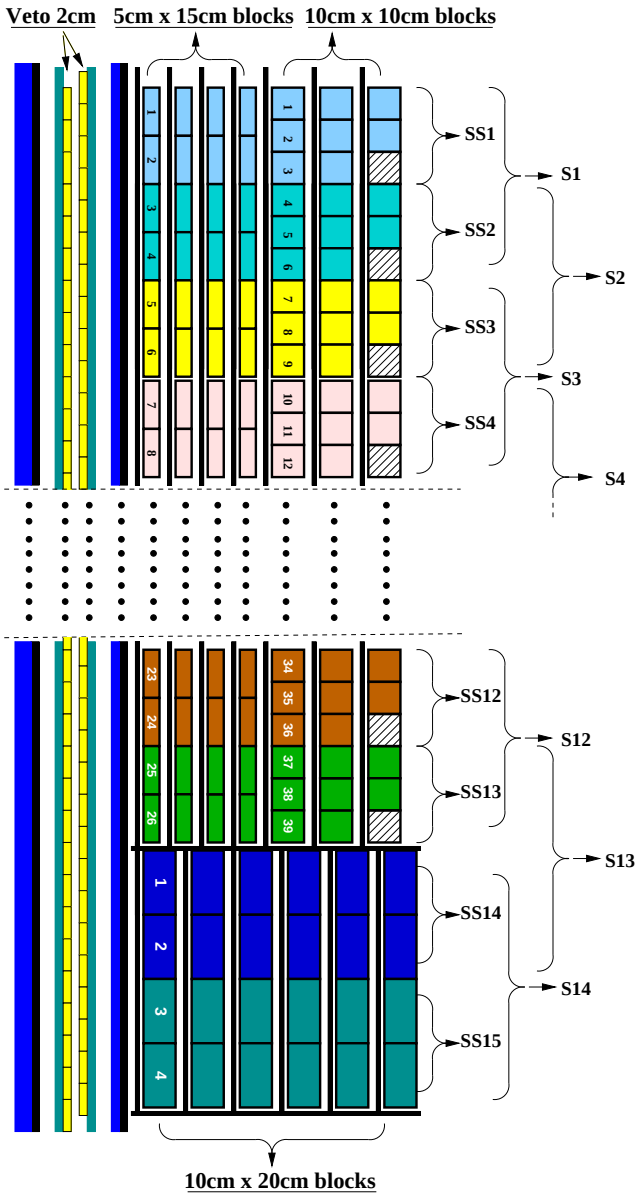
Optics calibration with septum+HRS



The scheme of BigBite



The scheme of Neutron arm



A resonance can be found in

- Phase Shift Analysis of the scattering data - require fine energy scan, angular coverage.

- Missing mass spectrum - require a good tag of the reaction.

- Invariant mass spectrum - require a multi particle detector.

Considerations for the missing mass approach

- High resolution, high momentum, small angle spectrometer for the forward $K^{-(+)}$.

- High resolution, small scattering angle spectrometer for the scattered electron.

- Large acceptance, low momentum detector for the spectator proton.

- Cold gas target D_2 (H_2), 40 cm long, minimum wall thickness.

Considerations for the invariant mass approach

- High resolution, high momentum, small angle spectrometer for the forward $K^{-(+)}$.

- Large acceptance, short path, out-off-plane spectrometer for the kaon.

- Large acceptance, out-off plane detector for the neutron(proton).

- Cold gas target D_2 (H_2), 40 cm long.

An effective "tag" particle

reaction like $\gamma + n \rightarrow K^- + \Theta^+$

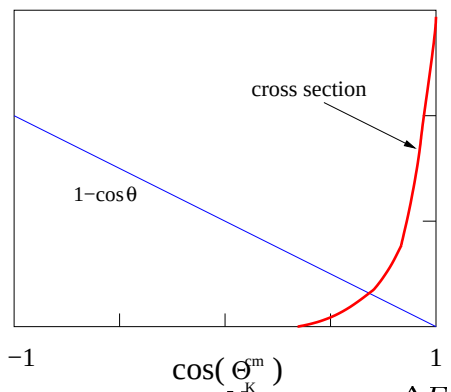
an invariant $\Delta t = t_{min} - 2E_\gamma^{cm} E_K^{cm}(1 - cos\,\theta_K^{cm})$

for typical conditions the value of $2\,E_\gamma^{cm} E_K^{cm} \sim 4$ GeV^2

the cross section $d\sigma/dt \sim exp(B\Delta t)$,

assuming the value of B = 3 GeV^{-2} have

$d\sigma/dt \sim exp(-12 \cdot (1 - cos\,\theta_K^{cm}))$



Probability of K^- detection:

$$\int^{HRS} \sigma_{\gamma,K^-}^{\Theta^+} d\Omega_{K^-} = 0.034 \cdot \sigma_{t;\gamma}^{\Theta^+}$$

$$\int^{HRS} \sigma_{\gamma^*,K^-}^{\Theta^+} d\Omega_{K^-} = 0.050 \cdot \sigma_{t;\gamma^*}^{\Theta^+}$$

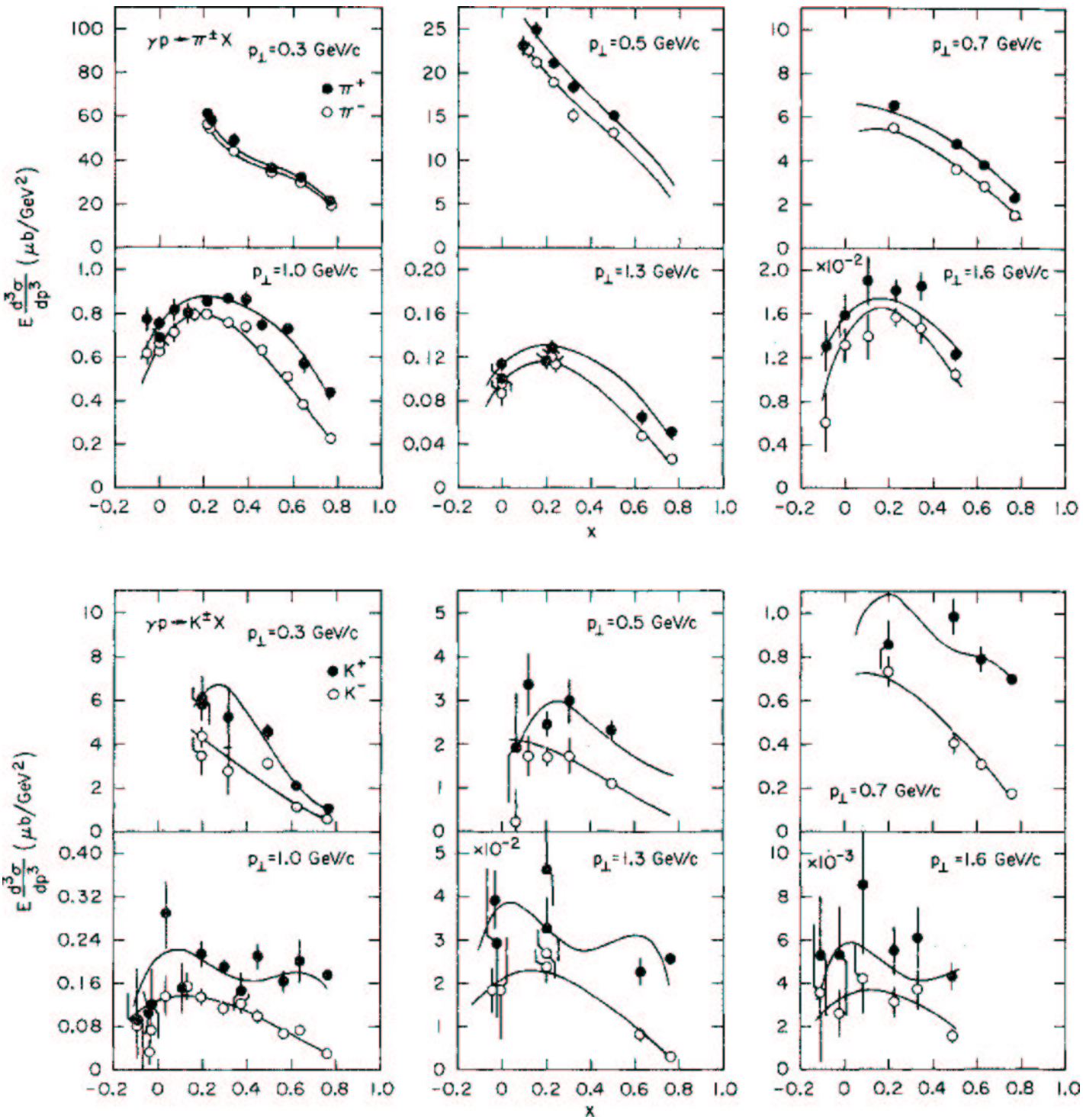
$$\mathcal{L}_{\gamma n(eutron)} = \frac{N}{A} \cdot 0.015 \cdot \frac{\Delta E_\gamma}{E_\gamma} \cdot \mathcal{L}_{eN(ucleon)} \sim 3 \cdot 10^{-4} \cdot \mathcal{L}_{eN} = 3 \cdot 10^{34}$$

$$\nu_{\gamma,K^-nK^+}^{\Theta^+} = \mathcal{L}_{\gamma n} \cdot \sigma_{\gamma n}^{\Theta^+} \cdot f_{\gamma,K^-}^{HRS} \cdot f_{nK^+} \cdot f_{K^-}^{decay} \cdot \eta_n \cdot f_{K^+}^{decay}$$

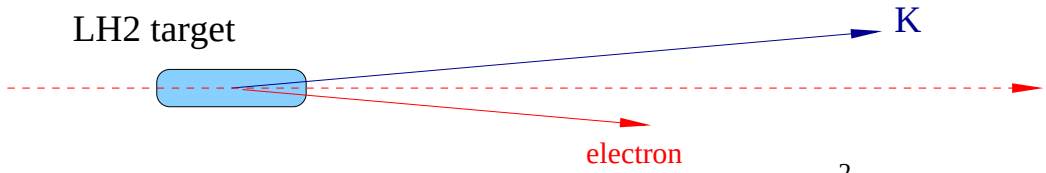
$$\mathcal{L}_{\gamma^* n} = \frac{N}{A} \cdot 1 \cdot 10^{-5} \cdot \mathcal{L}_{eN(ucleon)} = 5 \cdot 10^{32} \text{ Hz/cm}^2$$

$$\nu_{\gamma^*,K^-}^{\Theta^+} = \mathcal{L}_{\gamma^* n} \cdot \sigma_{\gamma^* n}^{\Theta^+} \cdot f_{\gamma^*,K^-}^{HRS} \cdot f_{K^-}^{decay} \sim 80k \text{ events per day}$$

$$\nu_{\gamma^*,K^-p_{soft}}^{\Theta^+} = \nu_{\gamma^*,K^-}^{\Theta^+} \cdot P_{soft} \cdot \frac{\Delta\Omega}{4\pi} \sim 80 \text{ per day}$$


γp → π±X
p⊥=0.3 GeV/c
π+
π−
p⊥=0.5 GeV/c
p⊥=0.7 GeV/c
p⊥=1.0 GeV/c
p⊥=1.3 GeV/c
×10−2
p⊥=1.6 GeV/c
E d3σ/dp3 (μb/GeV2)
x
γp → K±X
K+
K−
×10−3

Missing mass approach for Σ^{o} and Θ^{++}



$Q^2 = 4*6*2/400 \sim 0.1\ GeV^2$

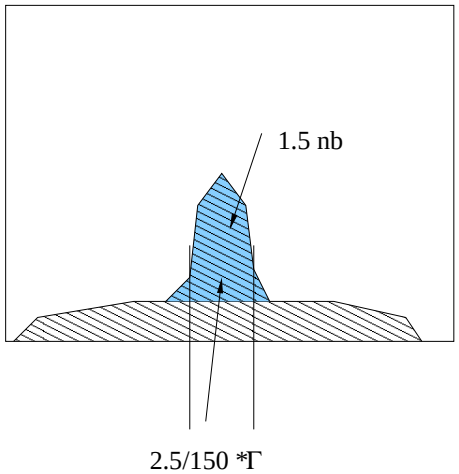
$\left.\frac{E\ d\sigma}{p^2\,dp\ d\Omega}\right|$ $\sim 1.0\ \mu\ b/GeV^2$ at $x_F \sim 0.75$ and $p_\perp = 0.3$ GeV −> 2.5 nb will be detected

distributed over ~ 150 MeV
in the missing mass spectra !

inclusive
γ, K^- DESY, 6 GeV

from the photo production cross section σ_t ~ 130 nb of the resonance −> 1.5 nb will be detec

at eN luminosity of $1*10^{38}$ and 1.3 nb cross section resonance detection rate of 470 per day

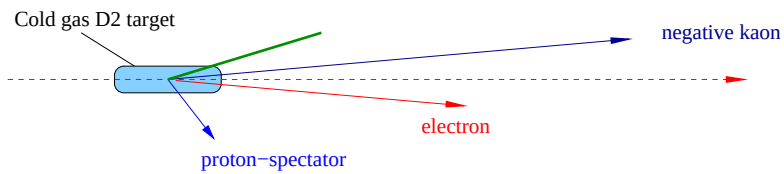


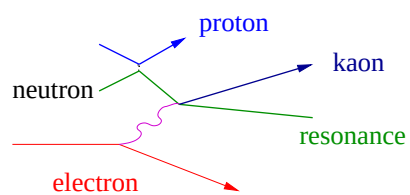
the upper limit (3 sigma) after 2 days of running:

on the level of 0.07 nb: 0.05% of Θ^+value for Γ= 20 MeV

on the level of 0.20 nb: 0.15% of Θ^+value for Γ= 3 MeV

Missing mass approach for Θ^+





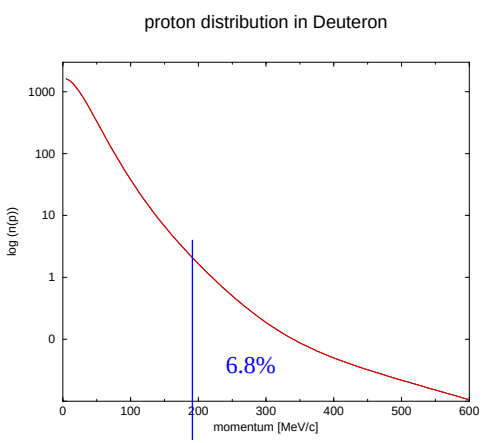
electron, kaon, proton are detected

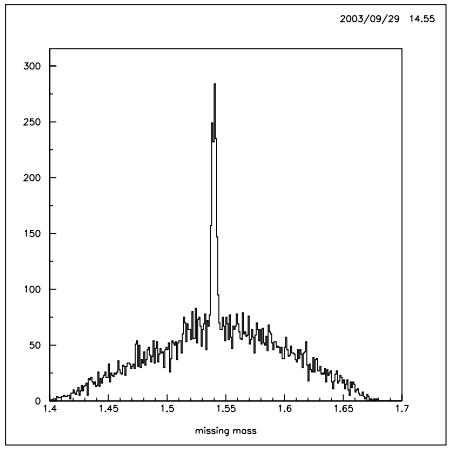
sept/HRS_r, sept/HRS_l, BigBite

$$MM_x^2 = MM_{x0}^2 + 2\,\vec{P}_x\,\delta\,\vec{P}_x$$

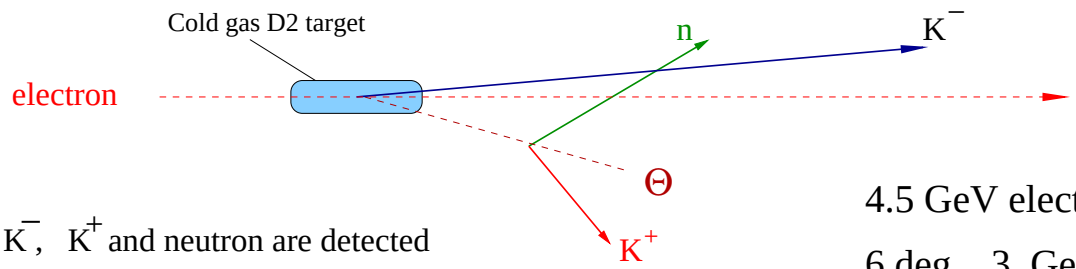
~2 x 1000 x 2 -> σ_{MM} ~ 2 MeV

Probability of proton tag ~ 8−12% * Ω /4π ~ 0.001





Invariant mass approach for Θ^+



K^-, K^+ and neutron are detected

sept/HRS_l, BigBite and plastic array

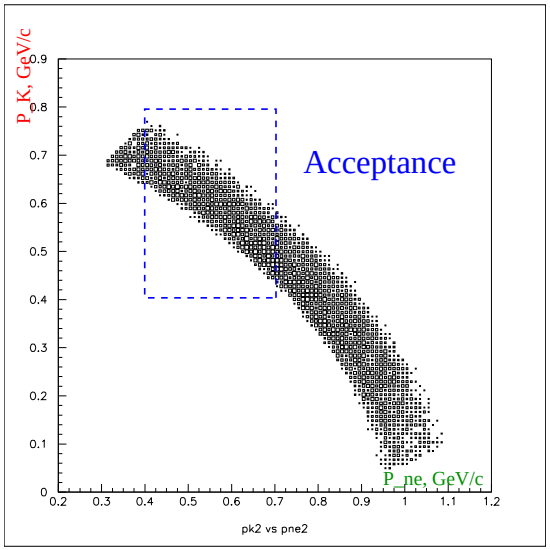
4.5 GeV electron beam

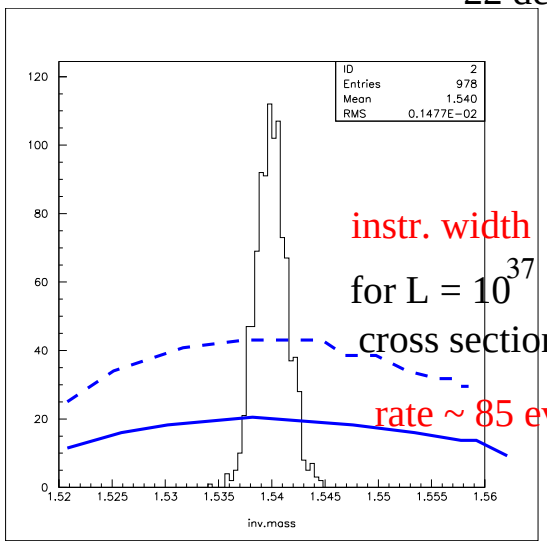
6 deg., 3 GeV/c K^- tag

22 deg. in−plane angle

15 deg. down − K^+

22 deg. up − neutron





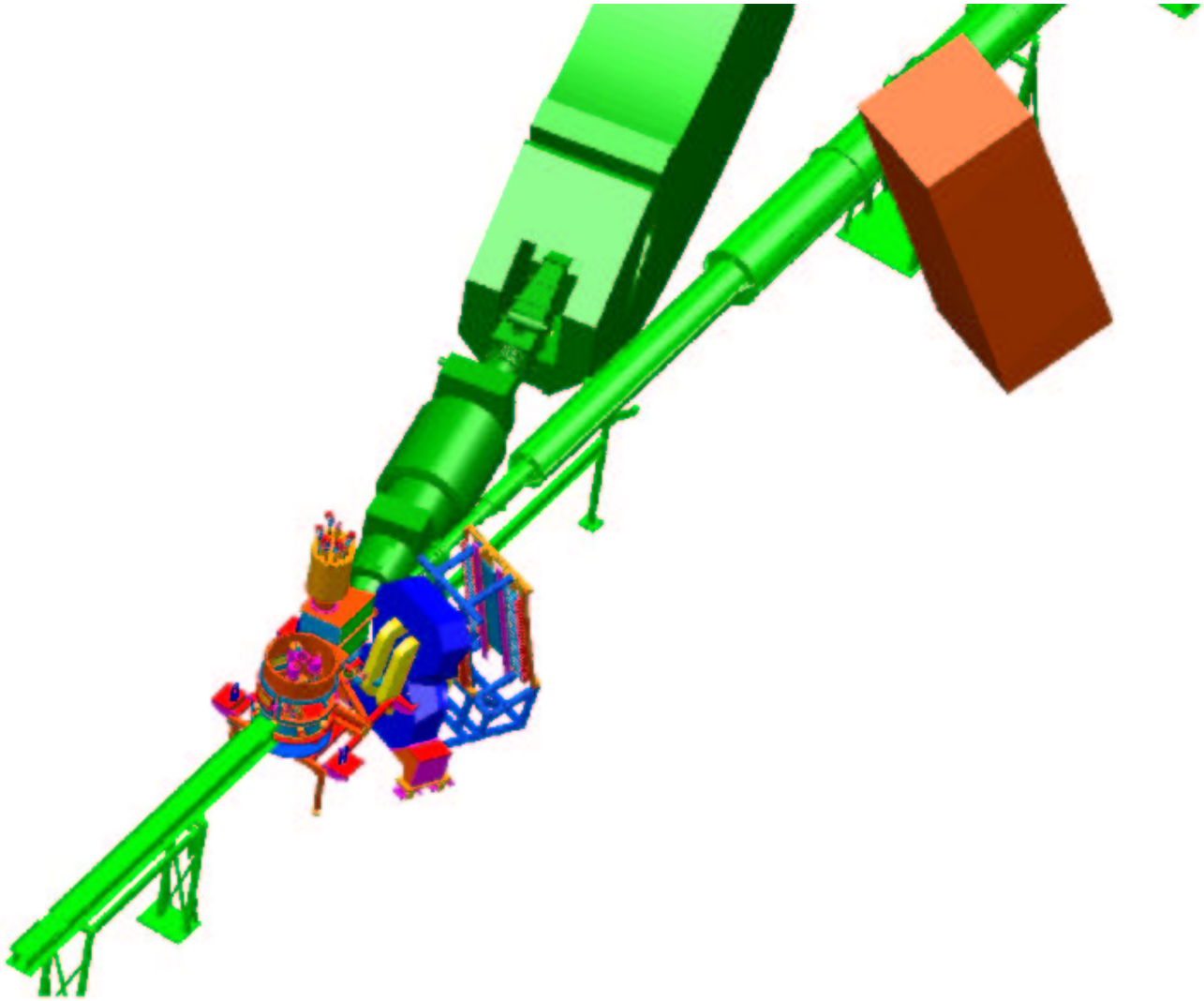
instr. width ~ 3.5 MeV

for L = 10^{37} Hz/cm^2 and

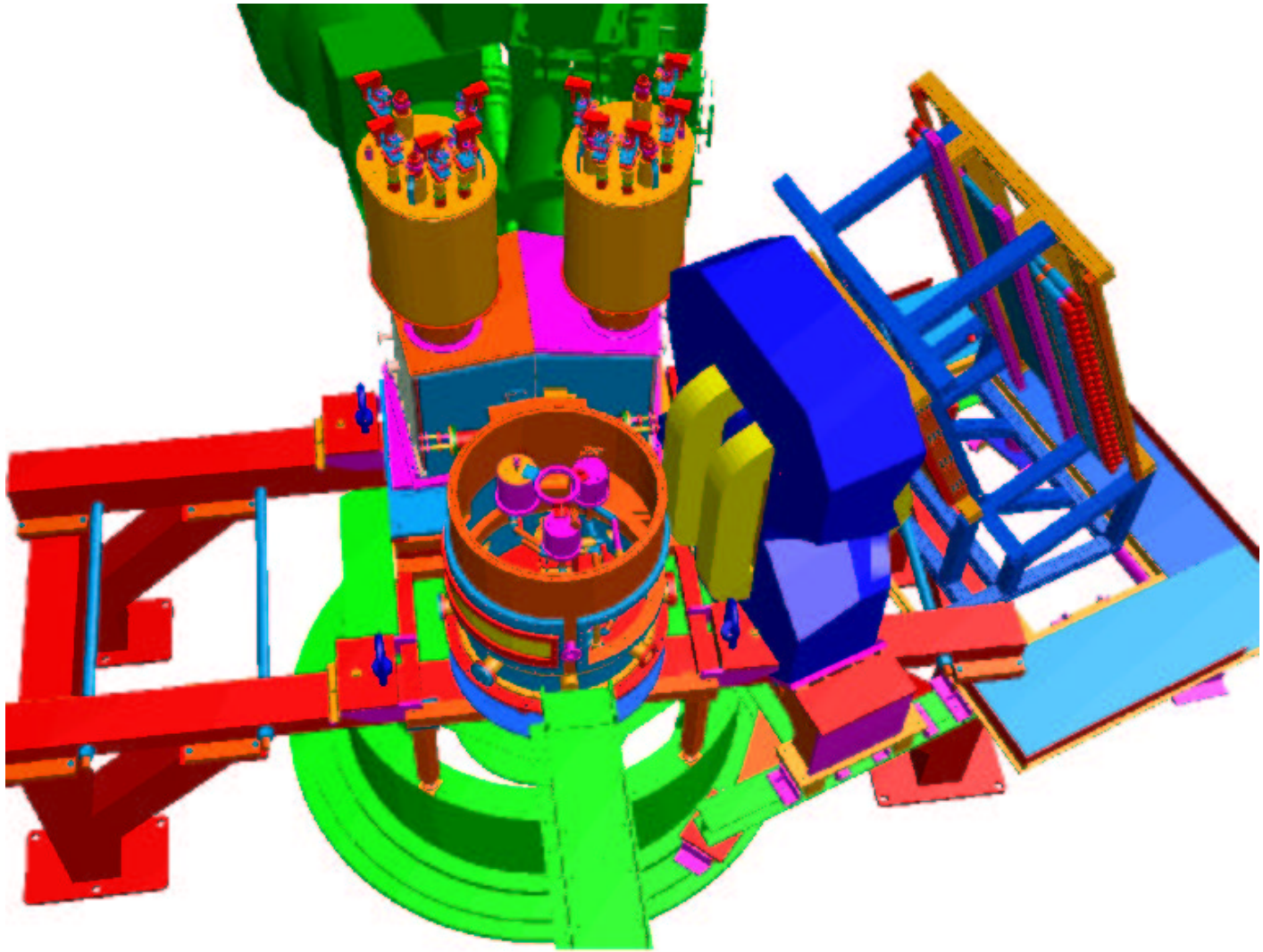
cross section of 130 nb

rate ~ 85 events/day

The first measurement



The second measurement



Summary

- Two schemes for the high resolution study of the Θ^+ are developed.
- The Hall A basic equipment is a key element in both schemes. The new equipment of approved GEN and ChPT experiments will make the rest.
- The high resolution search of the Σ^o and the Θ^{++} was evaluated.

It is a pleasure to thank I. Strakovsky for numerous discussions of the subject and to acknowledge a crucial contribution of V. Nelyubin in MC simulation of the setup.

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