Study Of Excited Intermediate States In $p(e, e'K)\Sigma^0$ Reaction Jefferson Lab - PAC17 (January 26, 2000)

1. Introduction
2. Physics Motivations
3. Proposed Experiment
4. Conclusion

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What Are We Looking For ?

1-Investigate region around $W = 1.9$ GeV

$$\Delta^* \rightarrow \begin{cases} K + \Sigma^0 \\ \pi^0 + p \end{cases}$$

$\Rightarrow$ **SU(3) violation**

2-Fishing expedition around $W = 2.0$ GeV

$$H(e, e'K)\Sigma^0$$

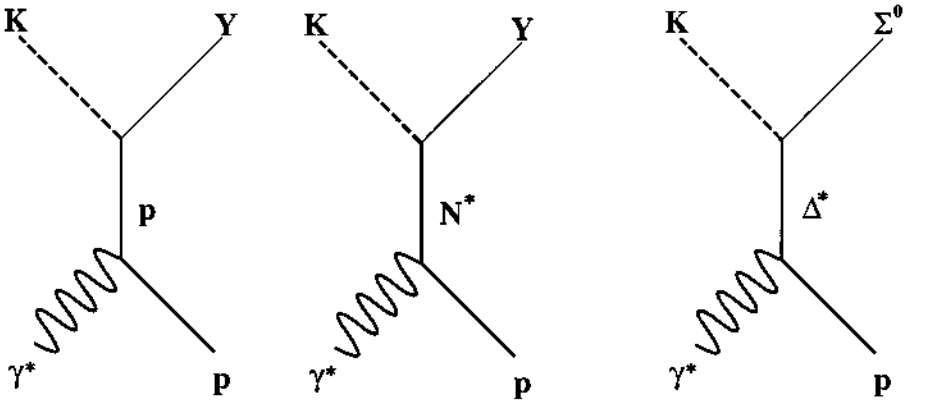
$\Rightarrow$ **Missing (narrow) resonances ?**

[Hall C (1996): E93018 & E91016 @ $W = 1.84$ GeV]

$p(e, e'K)[\Lambda, \Sigma^0]$ Reaction: Definition

$$\begin{cases} \gamma^* + p & \rightarrow K^+ + Y = [\Lambda, \Sigma^0] \\ \gamma^* + \begin{pmatrix} u \\ u \\ d \end{pmatrix} & \rightarrow \begin{pmatrix} u \\ \bar{s} \end{pmatrix} + \begin{pmatrix} u \\ d \\ s \end{pmatrix} \end{cases}$$

S-Channel Feynman Diagrams



1. N^* Resonances: in both Λ and Σ^0
2. Δ^* Resonances: in Σ^0 only (Isospin conservation)

Physics Motivations: $SU(3)$ Violation

$$W = 1.9 \text{ GeV} \begin{cases} \Delta^* \to \pi^0 p \\ \Delta^* \to K\Sigma^0 \end{cases}$$

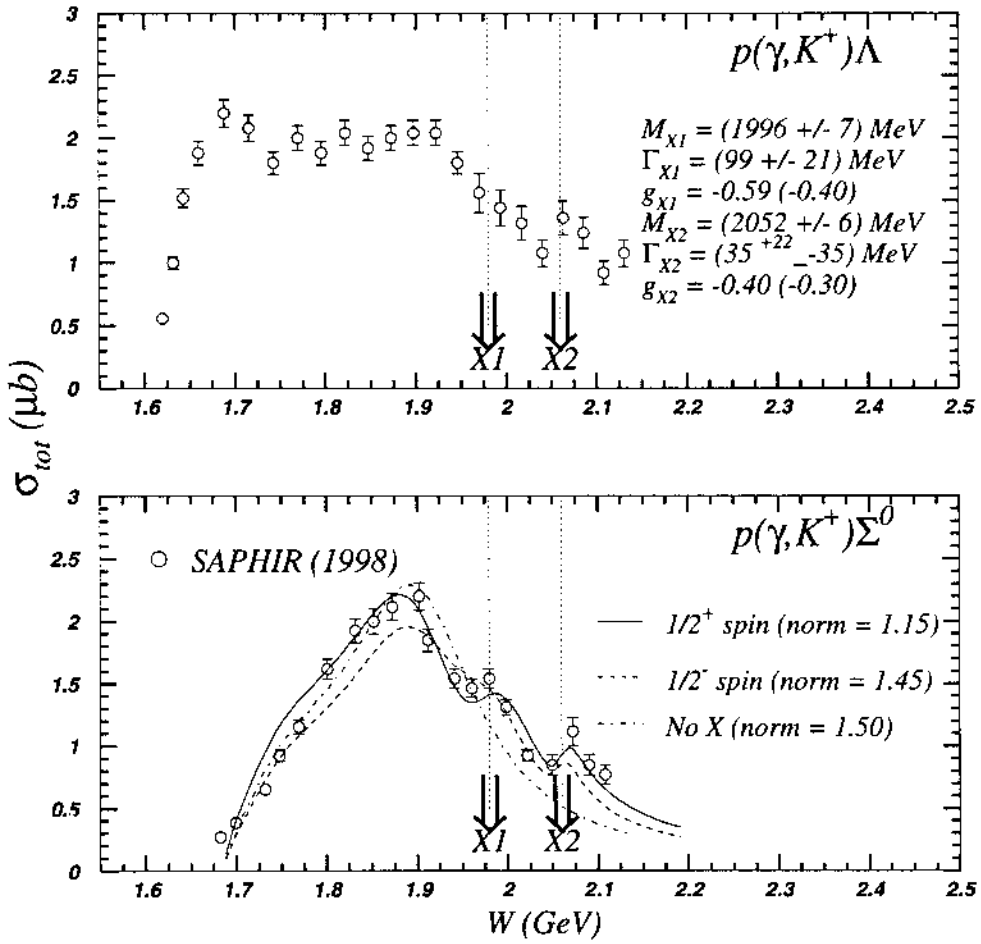
$$R = \frac{\Gamma_{\Delta^* \to K^+\Sigma^0}}{\Gamma_{\Delta^* \to \pi^0 p}} = \left(\frac{c_{K\Sigma^0\Delta^*}}{c_{\pi^0 p\Delta^*}}\right)^2 \left(\frac{g_{K\Sigma^0\Delta^*}}{g_{\pi^0 p\Delta^*}}\right)^2 \left[\frac{|\mathbf{P}_K|}{|\mathbf{P}_\pi|}\right]^{2l+1}$$

SU(3): $c_{\Delta^* \to \Sigma^0 + K^+} = -c_{\Delta^* \to p + \pi^0} = \frac{2}{\sqrt{3}}$ **, and** $g_{K\Sigma^0\Delta^*} = g_{\pi^0 p\Delta^*}$

1. **At threshold:** $g_{K\Sigma^0\Delta^*} \neq g_{\pi N\Delta^*}$ **(Final State Interactions)**
2. **Detect** $K^+ \& p$ **separately with same setup**
3. $W \simeq 1.9$ **GeV:**
   - **Other background processes**
   - **K-matrix analysis to isolate the reactions**

Physics Motivations: Missing Resonances ?

$$\begin{cases} QCD, Molecular & : (q\bar{q}) - (qqq) \\ Regge & : L = \alpha_0 + \alpha'_C M_L^2 \end{cases}$$

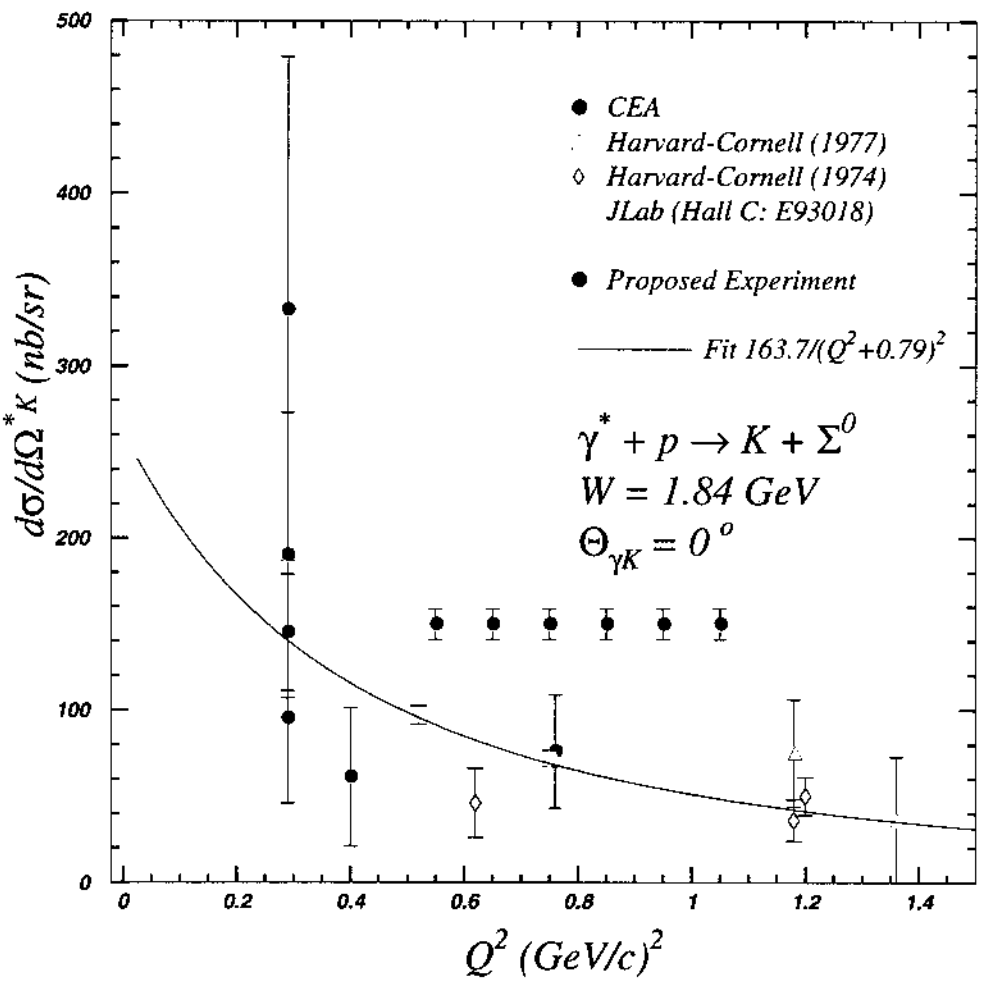


1. New high precision $(\gamma, K)Y$ data from SAPHIR
2. Need complementary of photo-production data
3. Measure data around $W = 2$ GeV
4. Side physics

Methodology

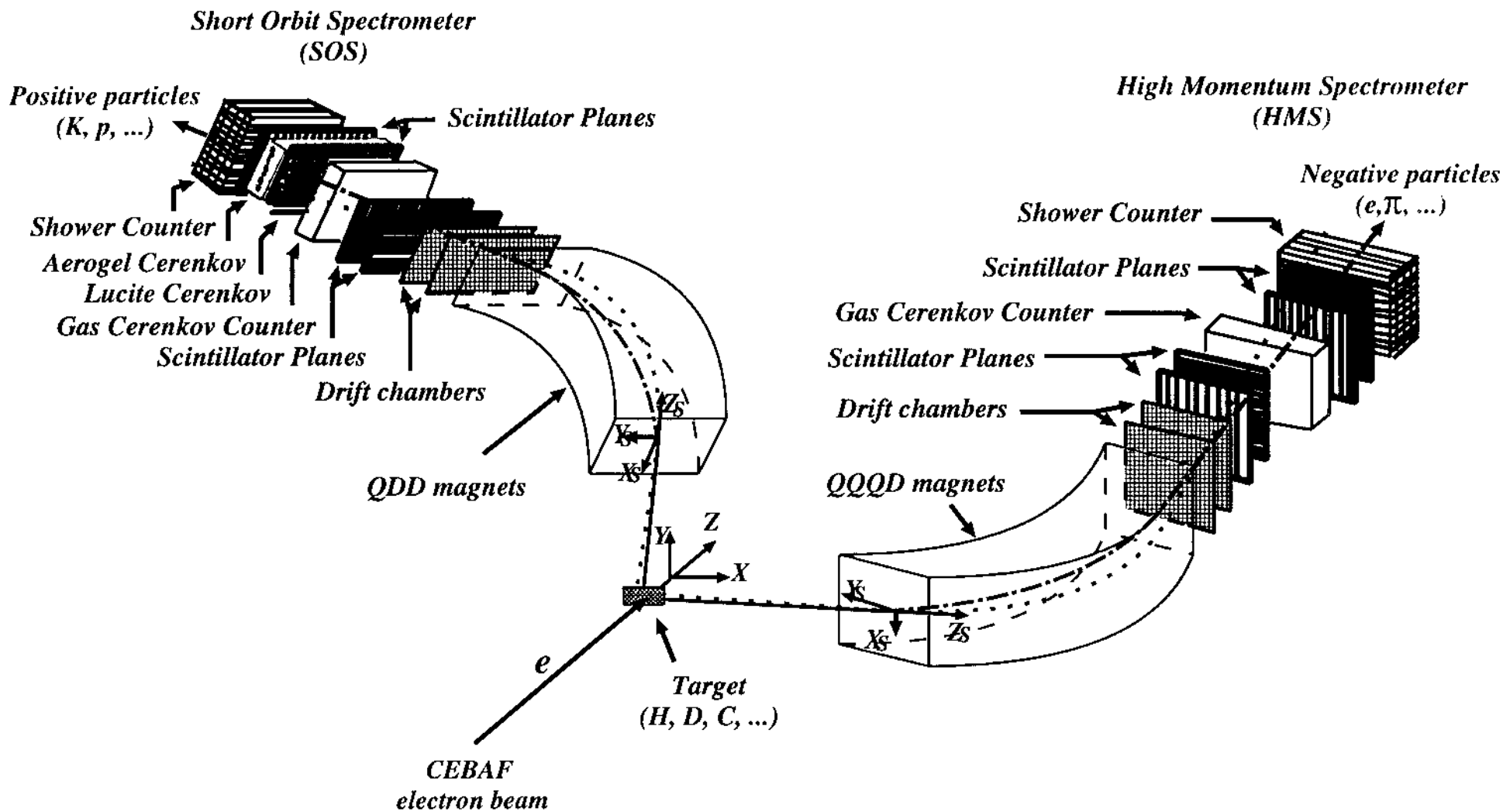
$$\Delta(1900), \Delta(1910), \Delta(1920) \rightarrow \begin{cases} \pi^0 p \\ K\Sigma^0 \end{cases}$$

1. **Coupled channel based analysis: K-matrix**
2. $\pi N \rightarrow \pi N, \pi N \rightarrow K\Lambda, \pi N \rightarrow K\Sigma, \gamma N \rightarrow K\Lambda, \gamma N \rightarrow K\Sigma \ldots$
3. Q^2**-dependence to gauge the model**

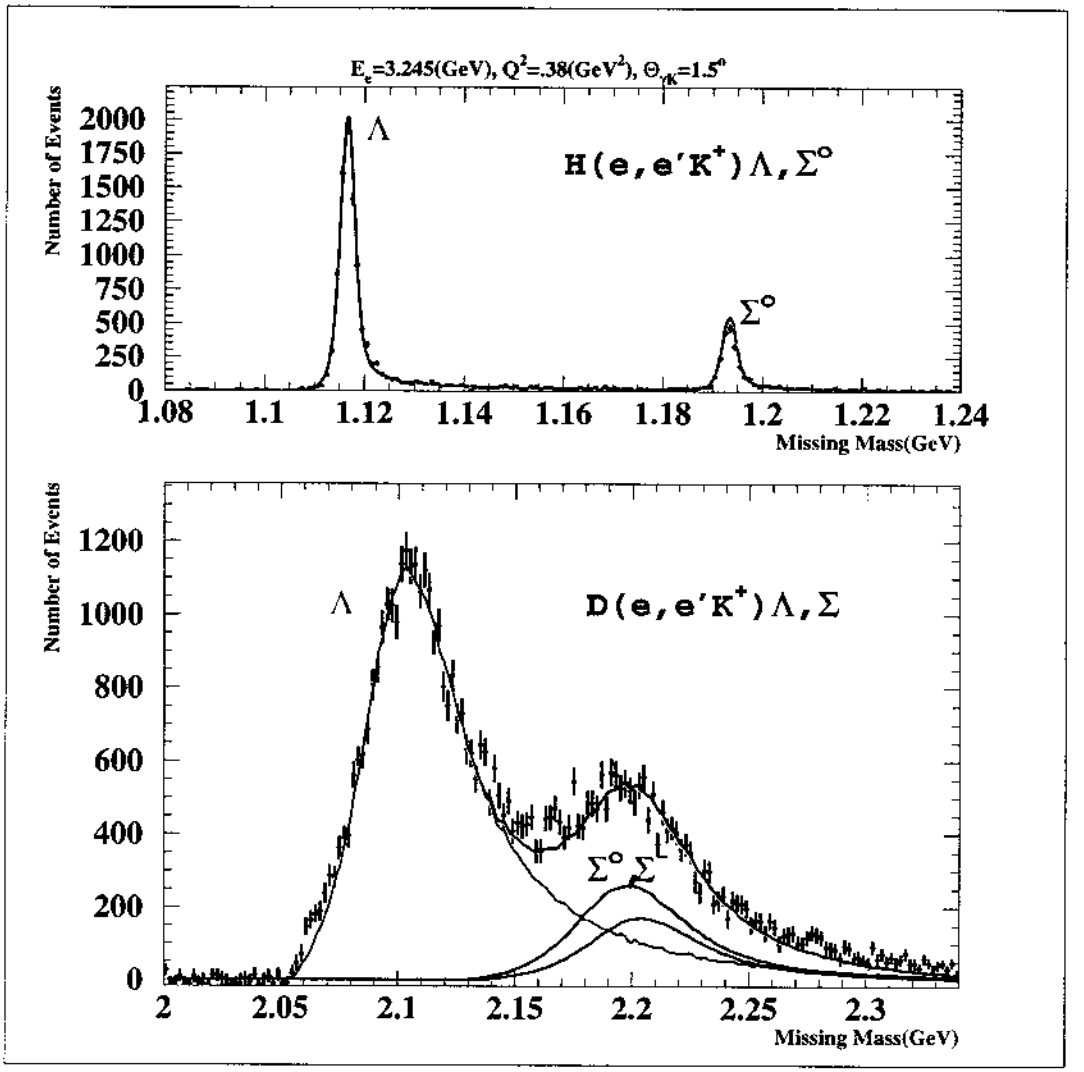


Statistics: 1%
Systematics: 6%

Where to do it ?
Hall C

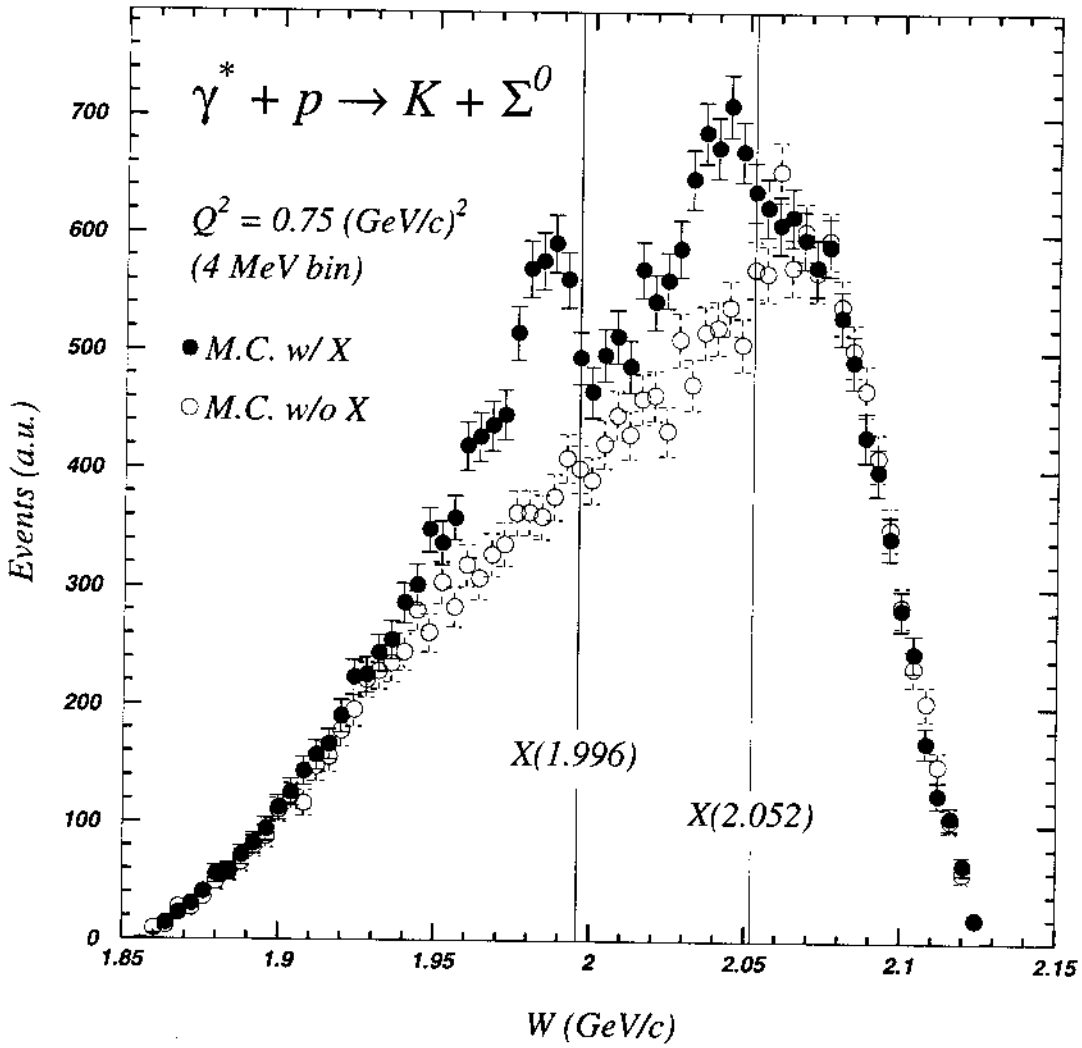


Monte Carlo Simulation



1. Used in E93018 and E91016 data analysis
2. Very good agreement between data and Monte Carlo

Monte Carlo Simulation Proposed Experiment



1. Model: R. Williams *et al.*
2. Added X with relativistic Breit-Wigner shapes

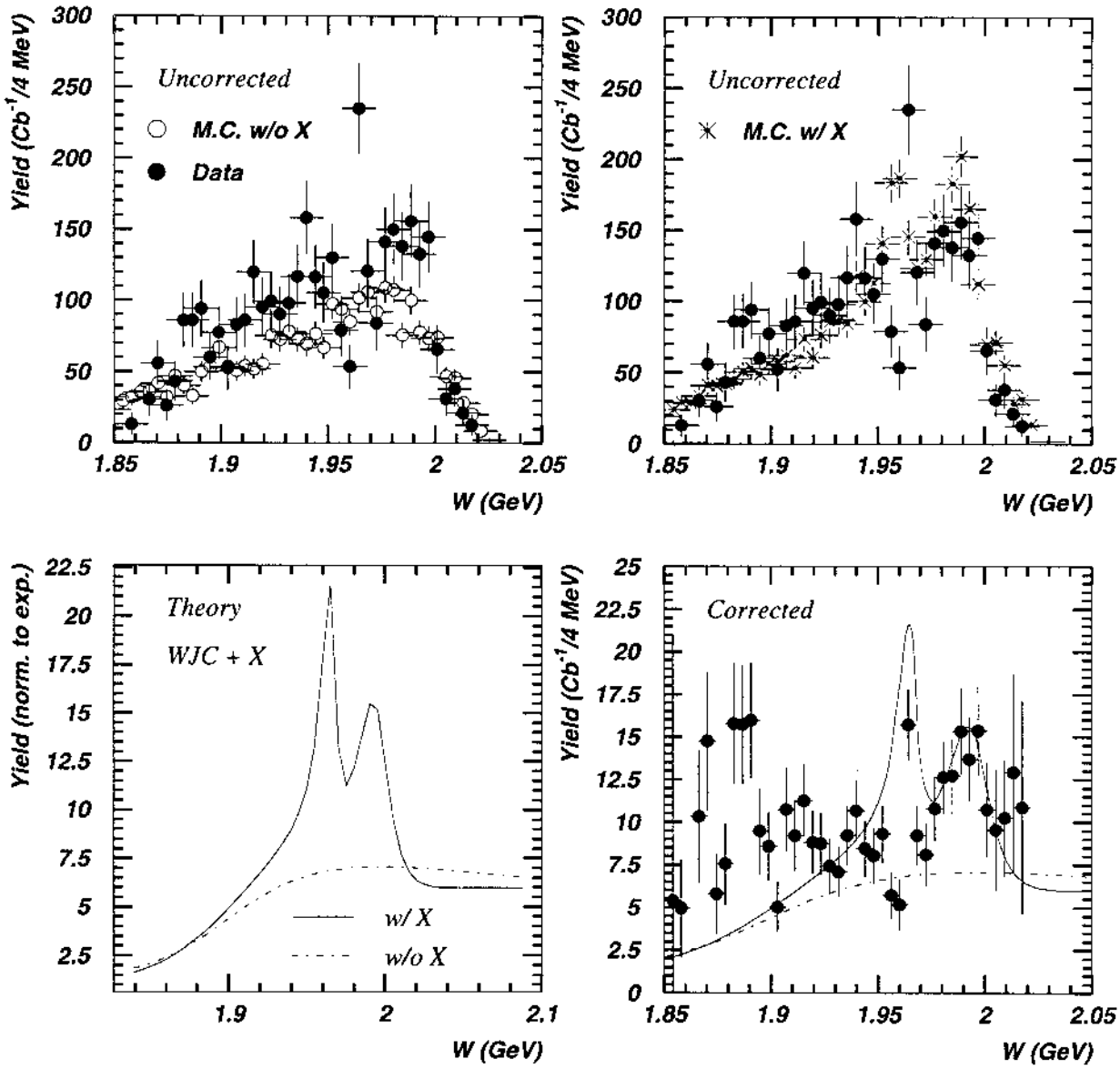
Experimental Test: December 13, 1999

Item	Comments
Reaction	$p(e, e'K)[\Lambda, \Sigma^0]$
$\mathbf{I}_{beam}$	30 μA
$\mathbf{E}_{beam}$	3.245 GeV
$\mathbf{P}_{HMS} = P_{e'}$	1.432 GeV/c
$\theta_{HMS} = \theta_{e'}$	19.64°
$\mathbf{P}_{SOS} = P_K$	1.290 GeV/c
$\theta_{SOS} = \theta_K$	14.23°
W	1.925 GeV
$\mathbf{Q}^2$	0.55 (GeV/c)^2
Total time	$\simeq$ 2 hours $\Leftarrow$
Total coincidence events	122596
Dummy events	17454
Corrected missing mass	11910

1. **Feasibility study, rate estimation ?**
2. **Invariant mass distribution at $W \simeq 2$ GeV ?**
3. **Possibility of missing resonance ?**

Experimental Test: Results

$$e + p \rightarrow e' + K^+ + \Sigma^0$$



Dedicated experiment with:
high Luminosity, high resolution, very good PID

1 hour in Hall C $\approx$ 300 hours in Hall B

Proposed Experiment: Kinematics

Kine.	Q^2 $(GeV/c)^2$	W (GeV)	E_{beam} (GeV)	P_{HMS} (GeV/c)	θ_{HMS} (Degrees)	P^K_{SOS} (GeV/c)	θ_{SOS} (Degrees)	P^p_{SOS} (GeV/c)	ε
1	0.55	1.901	4.045	2.295	13.98	1.218	16.96	0.172	0.835
2	0.65	1.900	4.045	2.244	15.38	1.252	17.55	0.198	0.821
3	0.75	1.900	4.045	2.190	16.73	1.289	17.94	0.224	0.805
4	0.85	1.900	4.045	2.137	18.04	1.323	18.20	0.248	0.790
5	0.95	1.901	4.045	2.083	19.33	1.360	18.35	0.272	0.773
6	1.05	1.901	4.045	2.030	20.60	1.395	18.42	0.296	0.757
7	0.55	2.001	4.045	2.088	14.66	1.468	14.63		0.792
8	0.65	2.000	4.045	2.036	16.15	1.506	15.17		0.775
9	0.75	2.000	4.045	1.983	17.59	1.545	15.54		0.758
10	0.85	2.000	4.045	1.929	19.00	1.585	15.78		0.740
11	0.95	2.000	4.045	1.876	20.38	1.621	15.95		0.722
12	1.05	2.000	4.045	1.822	21.76	1.661	16.01		0.703

1. Q^2 **range: 0.55-1.05 (GeV/c)^2**
2. W **range: 1.900-2.000 GeV**
3. **Parallel kinematics:** $\theta_{\gamma^* K} = \theta_{\gamma^* p} = 0^\circ$

Expected Systematic Uncertainties

From Hall C E93018 and E91016 experiments (1996 period)

Counter dead time	1.5%
Wire chamber inefficiencies	0.5%
HMS shower counter inefficiencies	1.0%
SOS Čerenkov counter inefficiencies	2.0%
Kaon absorption (target/detectors)	1.0%
Kaon decay	3.0%
Knock-on events firing SOS Čerenkov	1.0%
Target wall events	0.5%
Randoms	1.0%
In time kaon losses	1.0%
Radiative corrections	3.0%
Acceptance correction	2.0%
Total	**6%**

Expected systematic uncertainty = 6%

Conclusion

1. Investigate (threshold) region around $W = 1.9$ GeV

$$\Delta^* \begin{cases} H(e,e'p)\pi^0 \\ H(e,e'K)\Sigma^0 \end{cases}$$

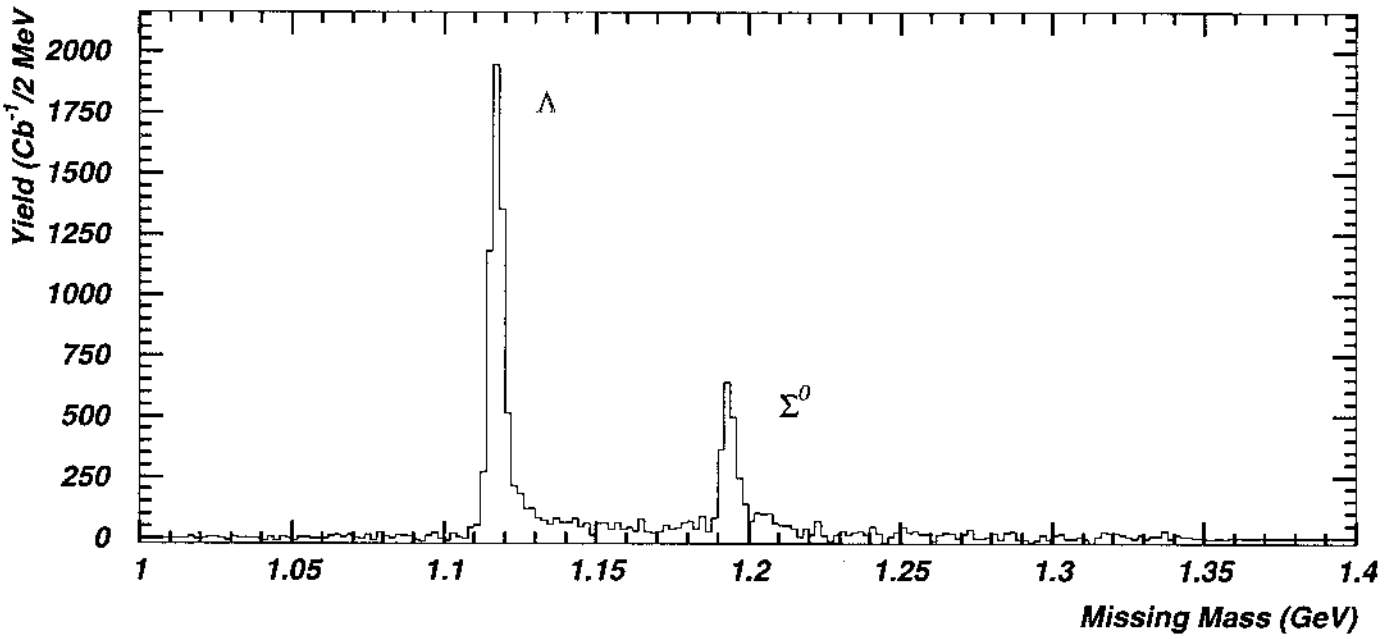
   Exist definit predictions (Quark model)

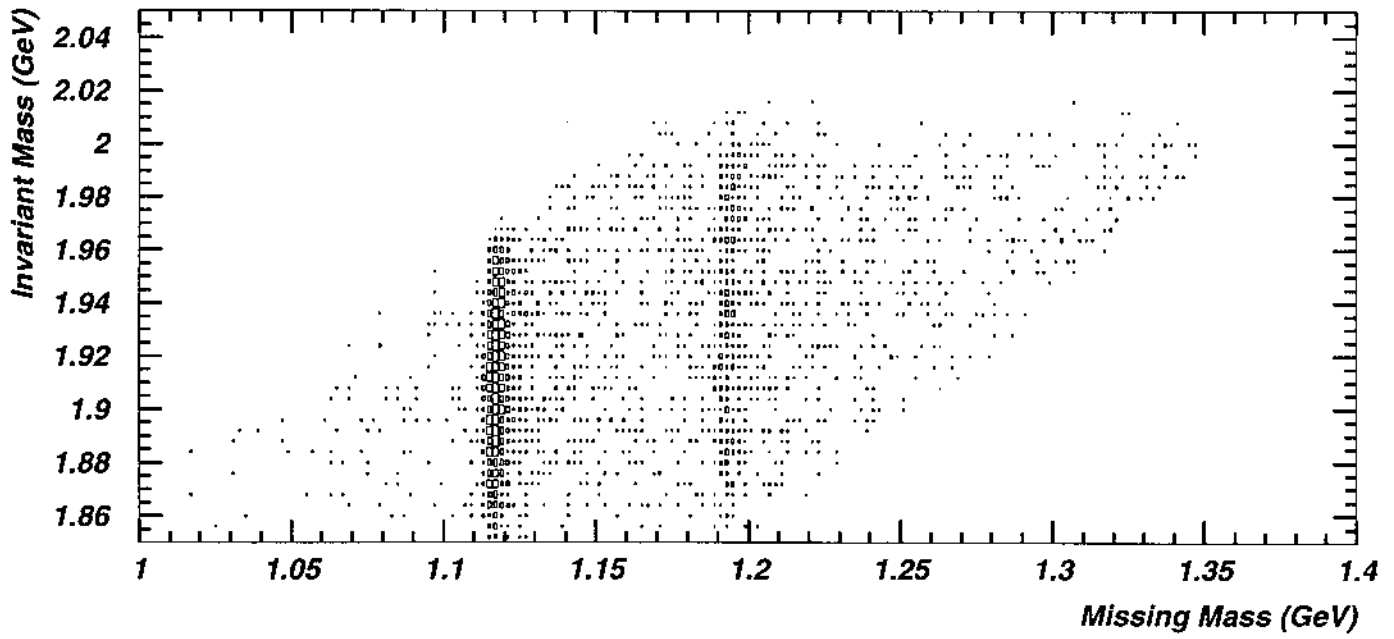
2. Side physics at $W = 2.0$ GeV
   Missing (narrow) resonances
   - HMS-SOS type setup
   - Q^2 dependence to gauge our analysis (K-matrix)

3. Beam time requested:
   - Measurements: 10 days
   - Calibrations: 5 days
     (also, overlap kinematics with E93018 @ $W = 1.84$ GeV)

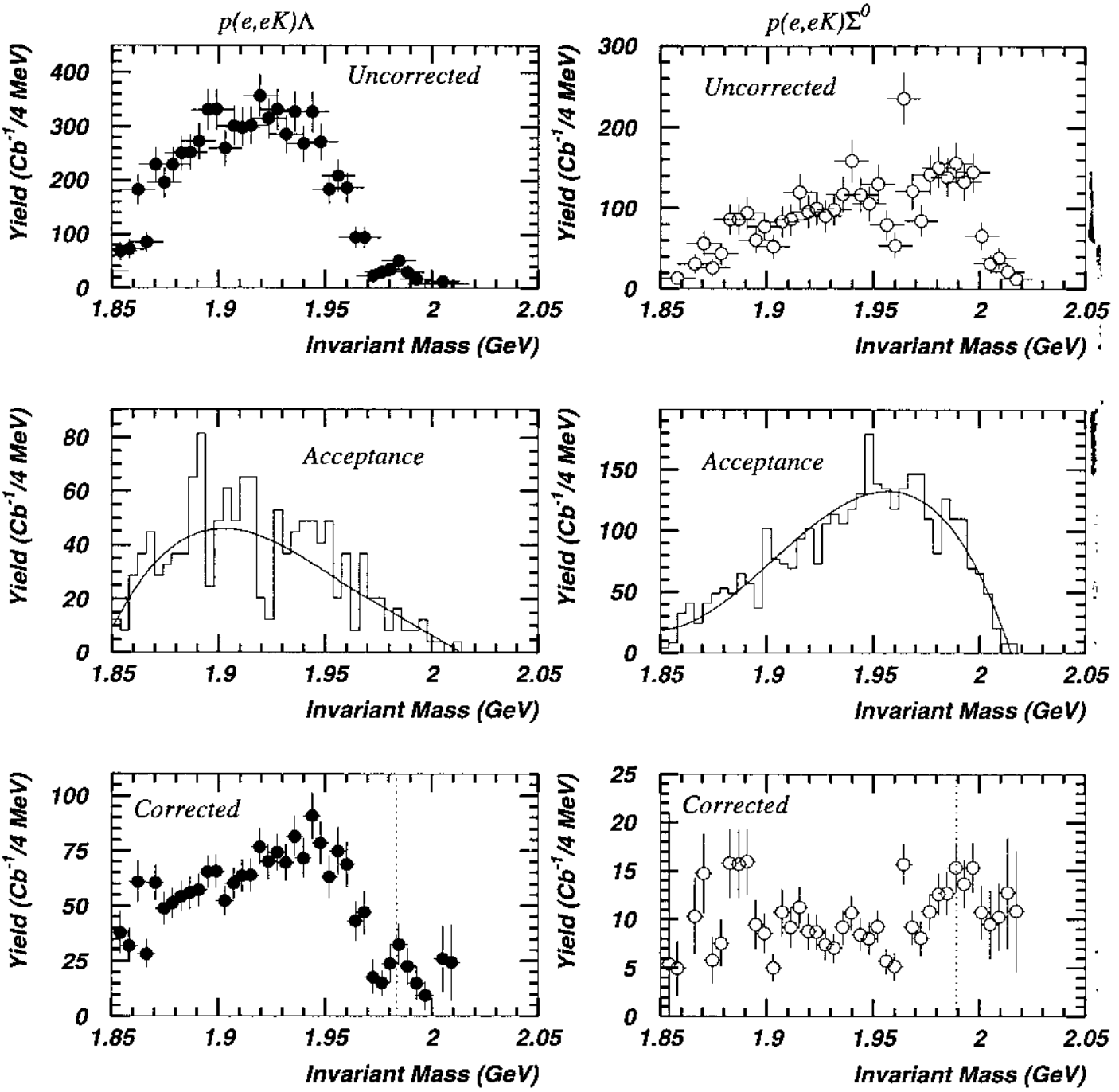
4. Never been done before

Experimental Test: PID



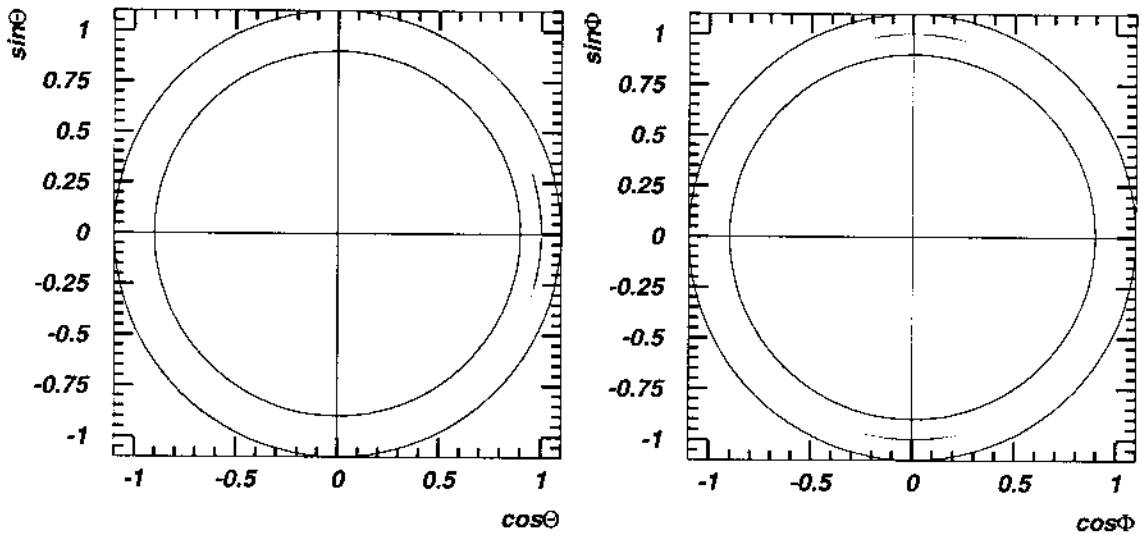


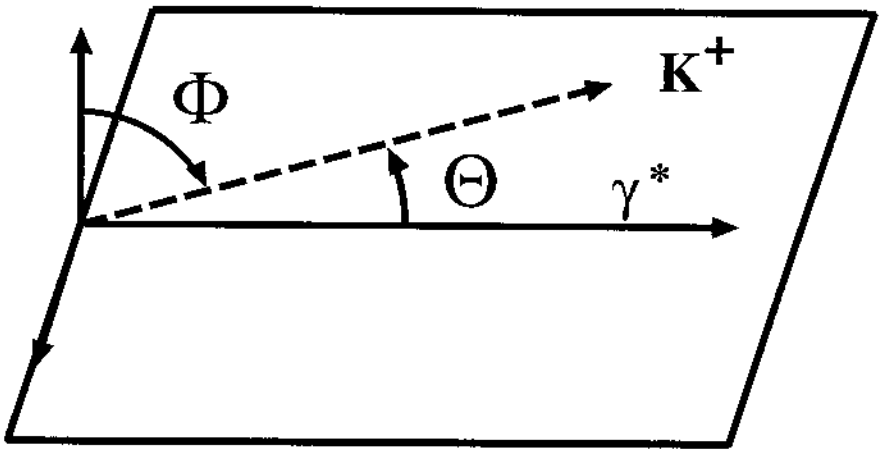
Experimental Test: Missing Resonances ?



Experimental Test: Angular Distribution

$$p(e, e'K)Y[Y = \Lambda, \Sigma^0]$$





Experimental Test: Results ...

Item	Comments
Counts in $W(\Sigma^0)$	822 (6.9%)
Counts in $W(\Sigma^0)$	822 (6.9%)
Counts in $W = 1.989$ GeV	200 (24.33% of Σ^0)
$M^1_{\Sigma^0}(X)$	(1989.2 ± 7.9) MeV
$\sigma^1_{\Sigma^0}(X)$	(16.097 ± 14.951) MeV
$\mid \chi^2/Ndf \mid^1_{\Sigma^0}$	0.026/8
Counts in $W = 1.966$ GeV	53 (6.45% of Σ^0)
$M^2_{\Sigma^0}(X)$	(1966.1 ± 6.9) MeV
$\sigma^2_{\Sigma^0}(X)$	(4.006 ± 6.006) MeV
$\mid \chi^2/Ndf \mid^2_{\Sigma^0}$	10.72/4
Counts in $W(\Lambda)$	1683 (14.13%)
Counts in $W = 1.983$ GeV	7 (0.4% of Λ)
$M_\Lambda(X)$	(1983.5 ± 1.3) MeV
$\sigma_\Lambda(X)$	(6.984 ± 1.312) MeV
$\mid \chi^2/Ndf \mid_\Lambda$	0.065/5

Experimental Test: Summary

1. **Possible evidence of narrow structures ?**
   $M_1 = (1989.2 \pm 7.9)$ **MeV**, $FWHM_{M_1} = 25\ MeV$
   $M_2 = (1966.1 \pm 6.9)$ **MeV**, $FWHM_{M_2} = 10\ MeV$
2. **Low production:**
   $P_{\Sigma^0}(M_1) = 10\%$ **and** $P_{\Sigma^0}(M_2) = 25\%$
3. $M_1 = 1989$ **MeV resonance seen in** Λ **channel:**
   New result !

Experimental issues to maximize counting rates:

1. **Need high luminosity**
2. **Need high resolution**
3. **Need very good PID**
4. **Need correlated experiment**
5. **Need fixed** $[W = 1.9\ (\mathrm{GeV}), t = t_{min}]$ **setting**

Rates and Beam Time Request

Kine.	Q^2 $(GeV/c)^2$	W GeV	Σ^0-Rate (sec^{-1})	Days
1	0.55	1.901	0.16	0.80
2	0.65	1.900	0.14	0.91
3	0.75	1.900	0.12	1.06
4	0.85	1.900	0.10	1.27
5	0.95	1.901	0.08	1.59
6	1.05	1.901	0.04	3.18
7	0.55	2.001	1.21	0.10
8	0.65	2.000	1.18	0.11
9	0.75	2.000	1.16	0.11
10	0.85	2.000	1.14	0.11
11	0.95	2.000	1.13	0.11
12	1.05	2.001	1.11	0.11
Total				**10**

Need 10 days of data taking

TAC Review

A-Extraction of information in region of overlapping resonances and search for a missing resonance which may not exist

1. Will perform K-matrix analysis:
   (a) Use photo & hadron induced reactions: 4π C.M. coverage
   (b) Constraint existing fit with coupled-channel analysis:
   Q^2-dependence to gauge analysis
   Constraint on individual Δ^* quantum numbers
2. Test run: possible indication of missing resonances ?
   Σ^0 channel: $M = 1.99$ GeV observed at SAPHIR
   New results: Σ^0 ($M = 1.96$ GeV) & Λ ($M = 1.99$ GeV):
   Need more statistics

B-Confusion about spectrometer settings

1. Change $(P_{e'}, \theta_{e'}, P_K, \theta_K)$ to $(P_{HMS}, \theta_{HMS}, P_{SOS}, \theta_{SOS})$

C-Transition form factor may need an L/T separation

1. Not our goal to perform an L/T separation
2. Proposed: $\mid \mathcal{F}(Q^2) \mid^2 = \frac{\sigma}{\sigma_{point}}$
3. Physics issues:
   (a) Q^2 dependence: $\Delta(1232)$, η, ...
   (b) Information on structure of the wave function

D-$p(e,e'p)\gamma$ versus $p(e,e'p)\pi^0$ [exp. E94-14: P. Stoler *et al.*]

1. **Overall, E94-14 settings closed to elastic kinematics High Q^2 experiment**

2. **Corresponding elastic kinematics (Δ^*)**

Q^2 (GeV/c)^2	Q^2_{elas} (GeV/c)^2	E_{beam} (GeV)	P^{elas}_{HMS} (GeV)	θ^{elas}_{HMS} (Degrees)	$P^{p,elas}_{SOS}$ (GeV)	$\theta^{p,elas}_{SOS}$ (Degrees)
0.55	0.860	4.045	3.587	13.98	1.034	56.93
0.65	1.015	4.045	3.504	15.38	1.144	54.35
0.75	1.171	4.045	3.421	16.73	1.249	52.01
0.85	1.327	4.045	3.338	18.04	1.352	49.87
0.95	1.484	4.045	3.254	19.33	1.452	47.87
1.05	1.640	4.045	3.171	20.60	1.551	46.02

3. **Proposed kinematics:**
   $\bar{P}_{HMS} = 2$ **GeV/c and** $\bar{\theta}_{HMS} < 20°$
   $\bar{P}^p_{SOS} = 200$ **MeV/c and** $\bar{\theta}_{HMS} < 20°$

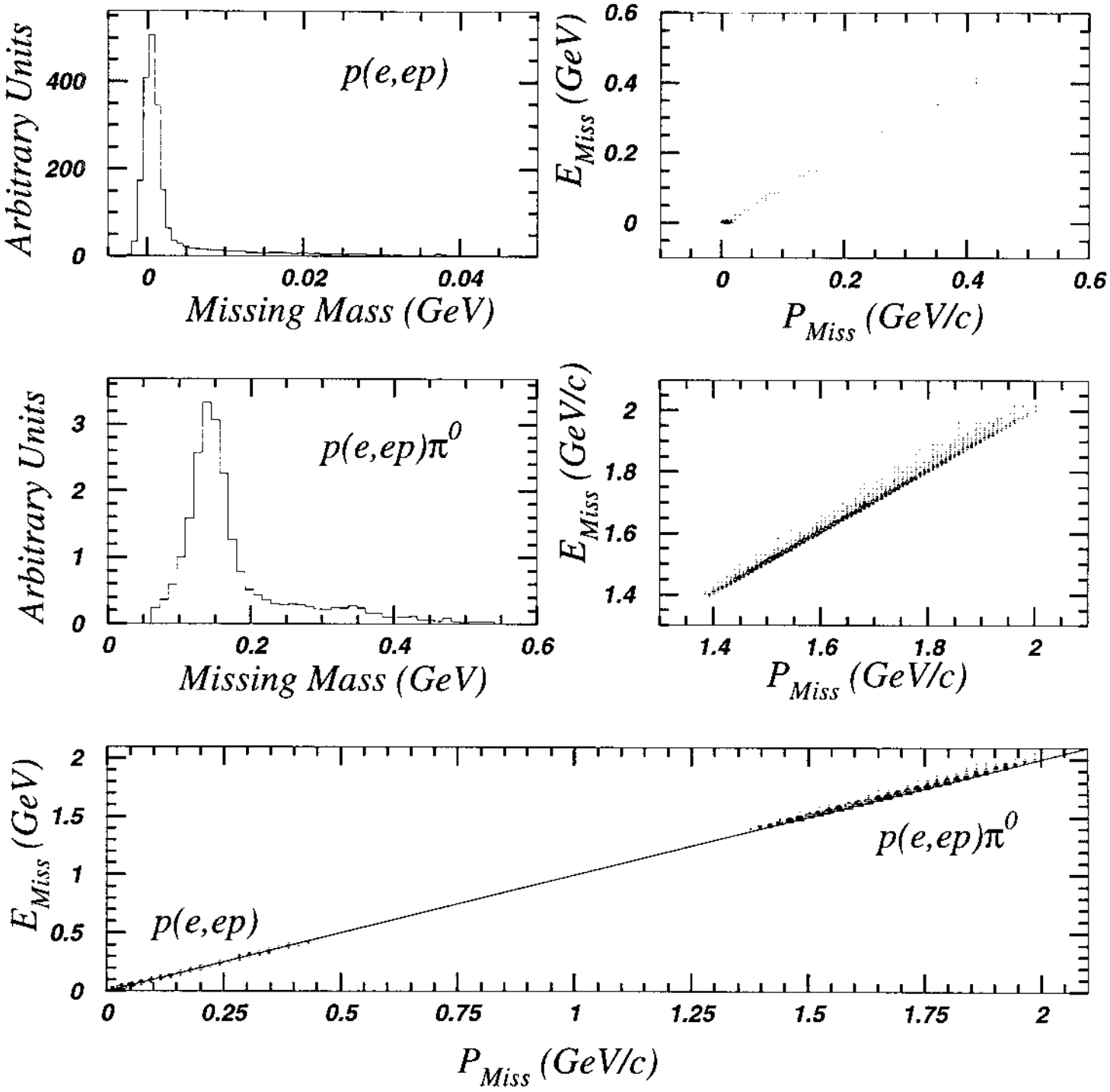
$\Rightarrow$ **Not an issue at all**

D-$p(e,e'p)\gamma$ versus $p(e,e'p)\pi^0$ ...

1. Multiple scattering
   - ⇒ About 2 mrad in average
   - ⇒ No correlation with our kinematics
2. Punch through collimator & Bethe Heitler contamination
   - ⇒ Need elastic proton to lose about 1 GeV total
   - ⇒ Unlikely to happen
   - ⇒ No contamination at all

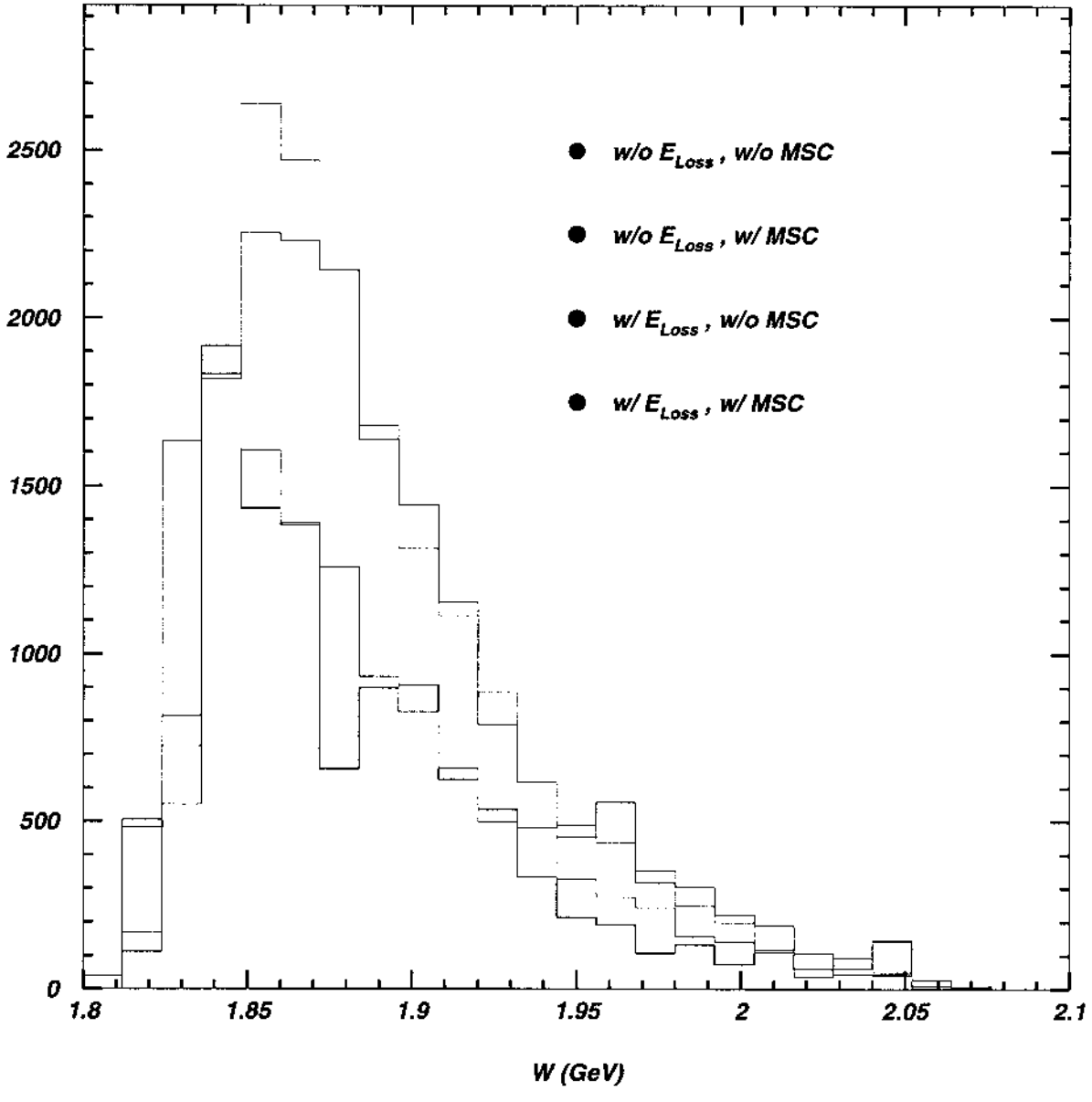
D-$p(e,e'p)\gamma$ versus $p(e,e'p)\pi^0$

Monte Carlo Simulation: $Q^2 = 0.55$ (GeV/c)^2



Energy Loss And Multiple Scattering

Monte Carlo Simulation: $Q^2 = 0.55$ (GeV/c)^2



Comparison with Hall B

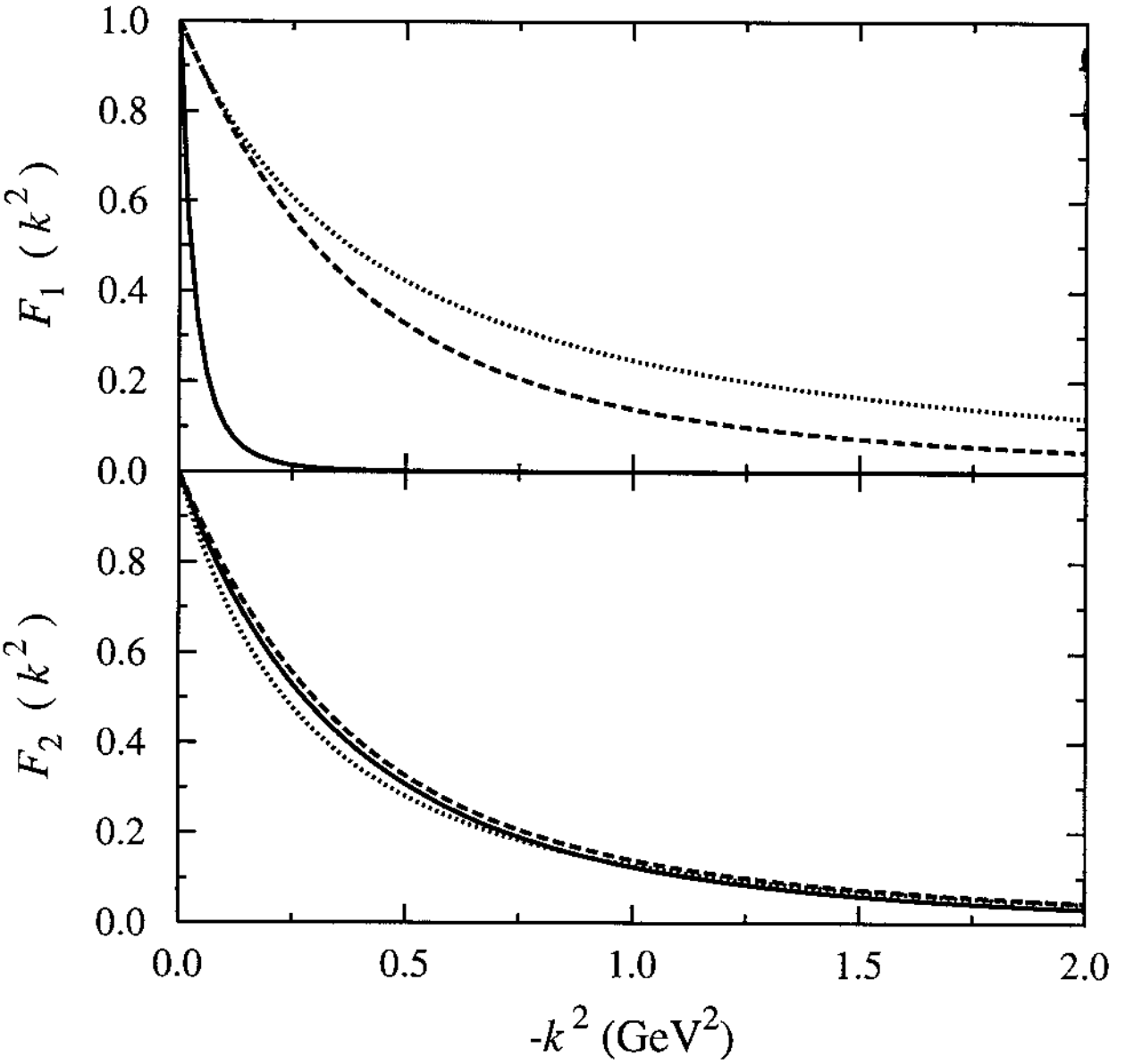
1. **Luminosity** $R_L = \frac{\mathcal{L}_C}{\mathcal{L}_B} = \frac{10^{37}}{10^{34}} = 10^3$
2. **Solid angle** $R_\Omega = \frac{1}{\int d\phi cos\theta d\theta} = 8 \times 10^{-2}$
3. **Back of the envelope from g1c/e1 (Hall B)**
   Number of events within $W = 2000 \pm 30$ **MeV**
   Σ^0 **channel only, assuming 3 MeV bin and** $\theta_{\gamma^* K} = 0°$

Hall C	Hall B
200 evts in 2 hours	$Q^2 = 0$ (g1c): 10k evts in 6 weeks
100 cnts/hr [Fixed angle]	7 cnts/hr $[0 - 90°]$
	$Q^2 = 0.75$ (GeV/c)^2, 7 msr, 60% eff.
	2×10^{-3} cnts/hr [Fixed angle]

Hall C is better suitable for the proposed experiment !

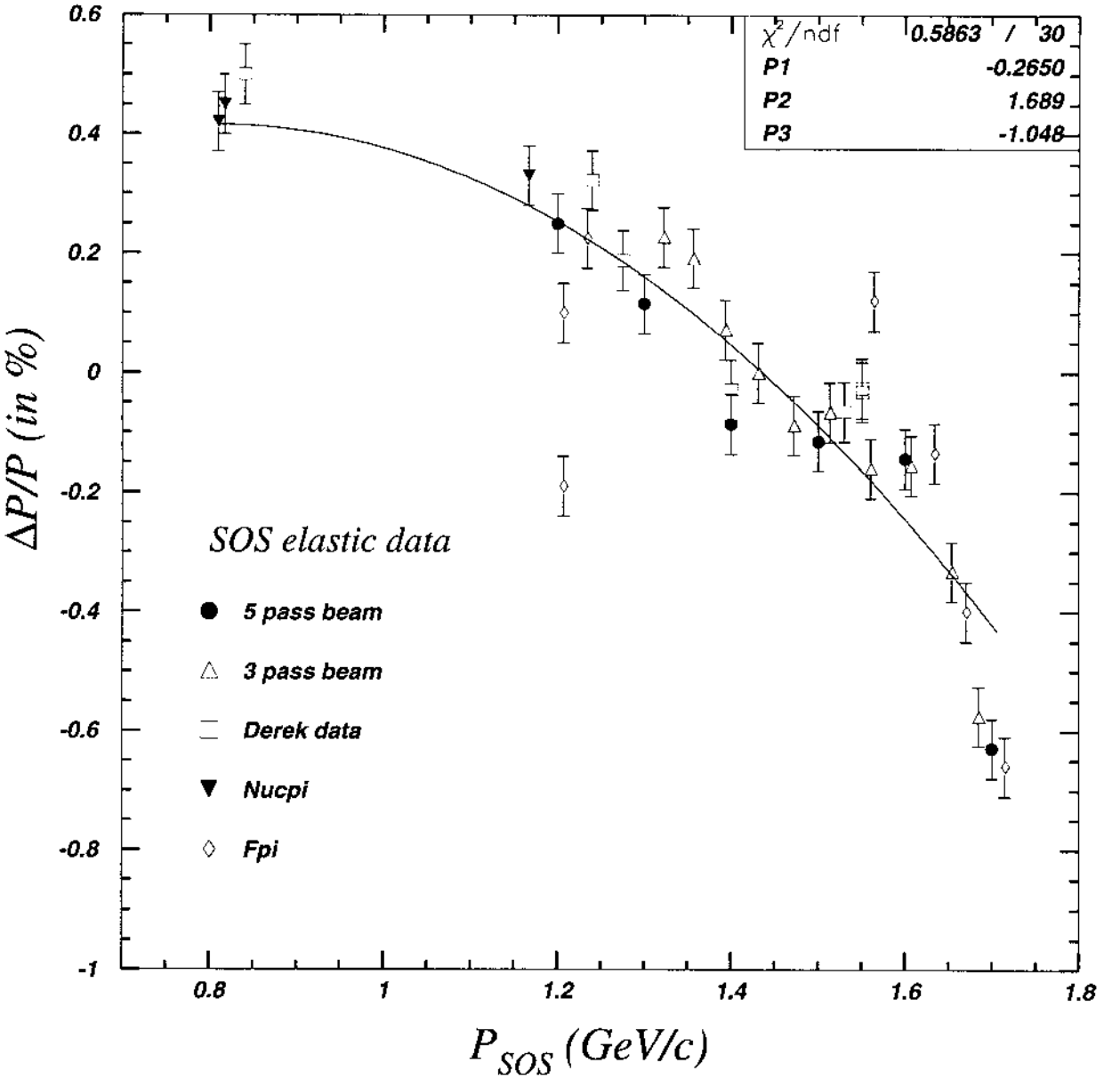
Form Factors In $p(e, e'K)\Sigma^0$

C. Benhold and T. Mart, *nucl-th/9909022 & Phys. Rev.*, **C61 (1999)**

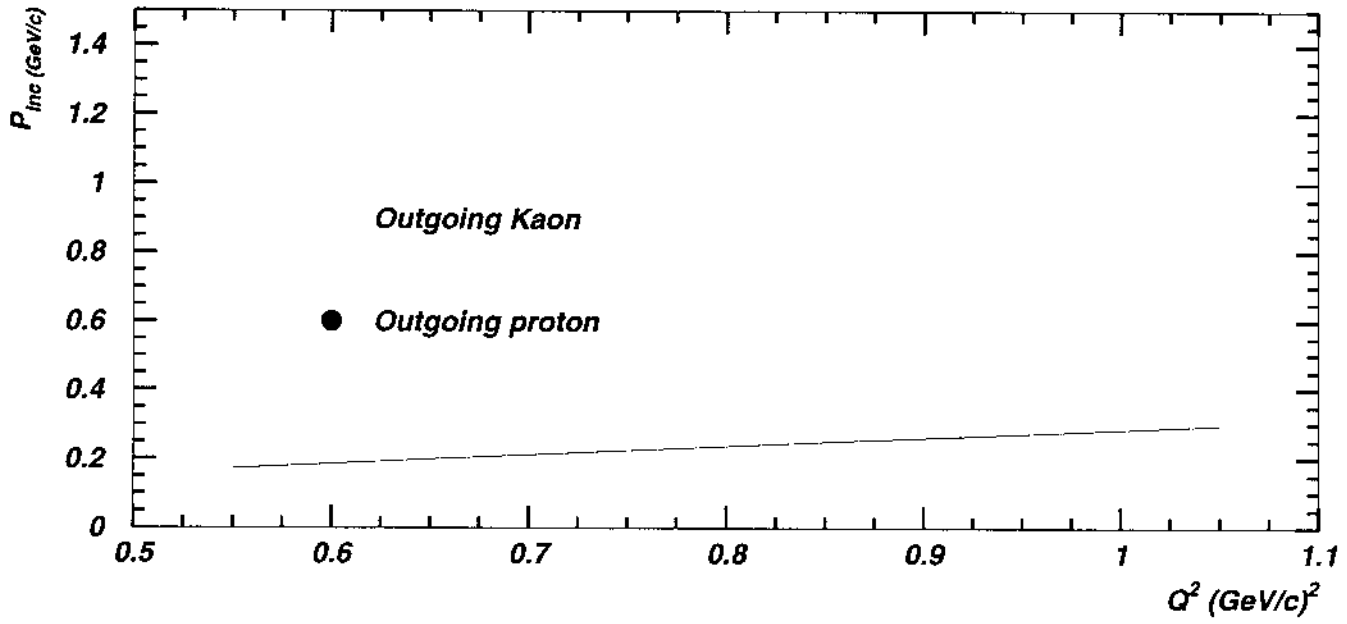


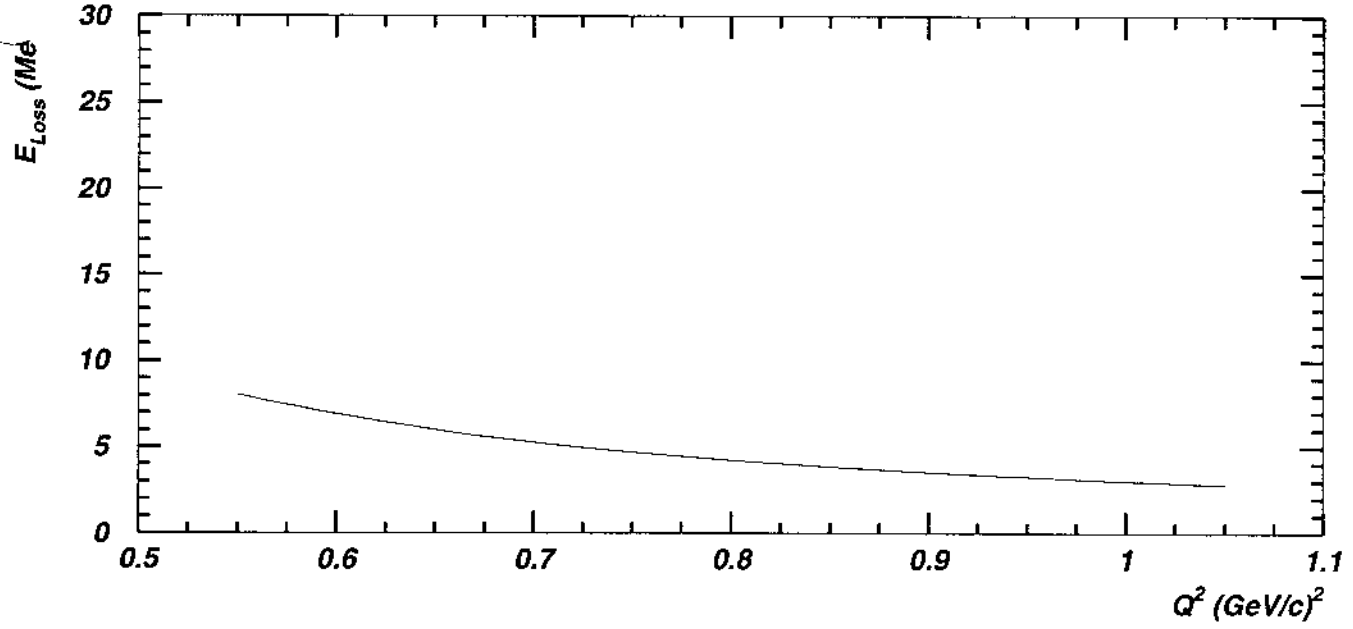
- $D_{13}(1895)$: **solid line**
- $\Delta(1232)$: **dashed line**
- **Proton: dotted line**

SOS Saturation Curve



For proposed experiment: about 0.45% correction !
(Checked with Nucpi analysis)


P_{inc} (GeV/c)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Outgoing Kaon
Outgoing proton
0.5
0.6
0.7
0.8
0.9
1
1.1
Q^2 (GeV/c)^2


E_{Loss} (Me
30
25
20
15
10
5
0
0.5
0.6
0.7
0.8
0.9
1
1.1
Q^2 (GeV/c)^2