Kaon Electroproduction on Few-Body Systems

Jefferson Lab Experiment E91-016

Joerg Reinhold
Florida International University

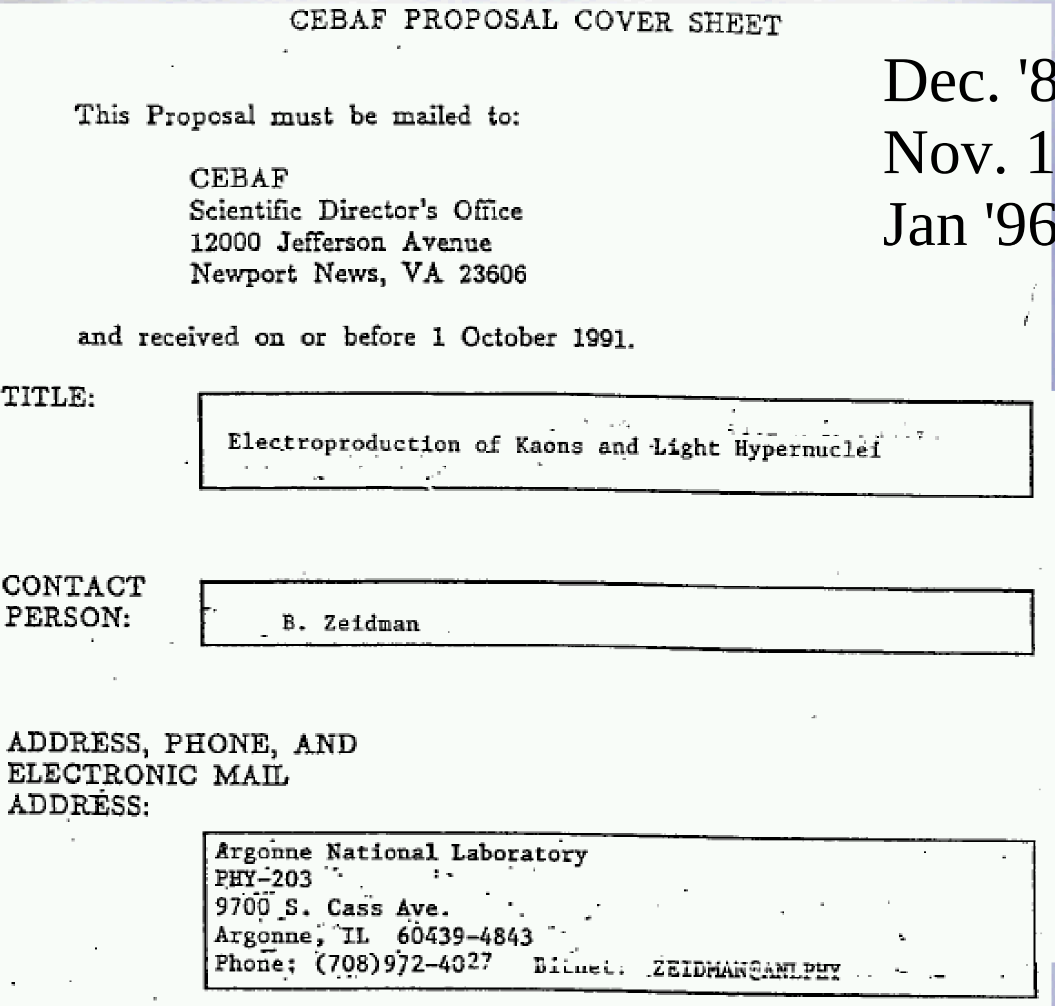
presented at
HYP2003
October 17, 2003

Outline

- Motivation/history
- Experimental program
- Ln final state interaction
- S production off the neutron
- 3,4He data
- Parasitic analyses: w, ^{12}C, ^{27}Al

Once Upon a Time
(last millenium)

Dec. '89 & Mar '90: PAC4 deferes PR89-013
Nov. 1991: PAC5 approves E91-016
Jan '96: PAC10 gives E91-016 A- rating



CEBAF PROPOSAL COVER SHEET

This Proposal must be mailed to:

CEBAF
Scientific Director's Office
12000 Jefferson Avenue
Newport News, VA 23606

and received on or before 1 October 1991.

TITLE:	Electroproduction of Kaons and Light Hypernuclei
CONTACT PERSON:	B. Zeidman
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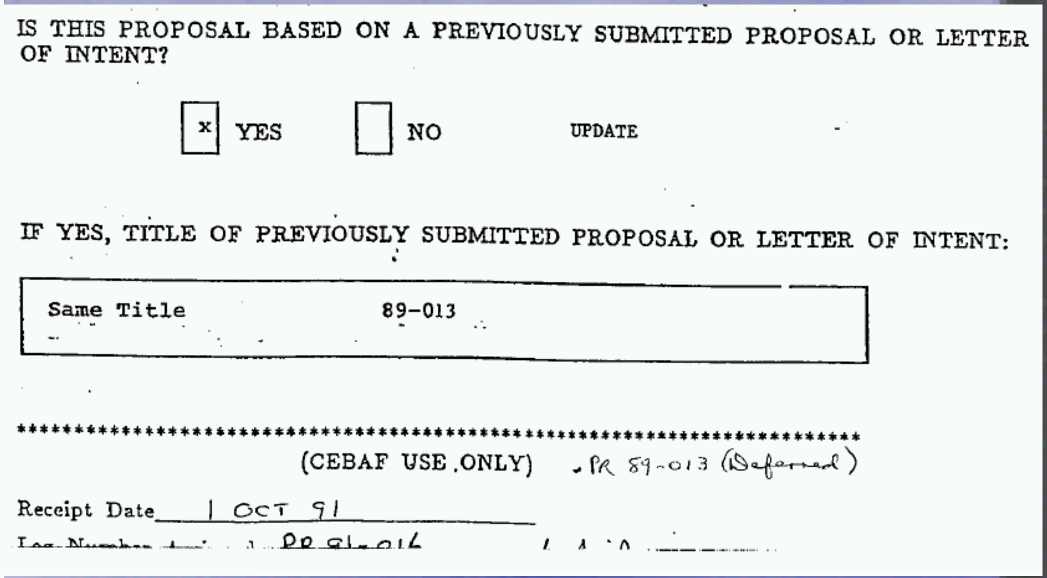


IS THIS PROPOSAL BASED ON A PREVIOUSLY SUBMITTED PROPOSAL OR LETTER OF INTENT?

☒ YES ☐ NO UPDATE

IF YES, TITLE OF PREVIOUSLY SUBMITTED PROPOSAL OR LETTER OF INTENT:

Same Title 89-013

****

(CEBAF USE ONLY) PR 89-013 (Deferred)

Receipt Date 1 OCT 91

E91-016 Goals

Electroproduction of K^+ on D, 3He, 4He

First survey of the (e,e'K) reaction on complex nuclei

Choose light nuclear targets because of large cross sections for Kaon production; Measurements have good signal/background ratios; good yields with short runs.

Measure quasifree L and S production on D, ^{3,4}He at E_e=3 GeV,
$E_{e'}$=1-1.5 GeV, g_v=1.5-2 GeV

Measurement of K+ production on D, ^{3,4}He with high precision provides:
a) <3% statistical error over most of the missing mass spectrum
b) the 3HL and 4HL bound state yields with <3% errors
c) experimental data for K+-p and mass dependence of various rates, backgrounds, etc.

K^+ production on D sensitive to L-N and S-N intercations; study L-N and S-N intercations in the cusp region
Very few data available, even for H; theoretical calculations by Cotanch, Donelly, and others

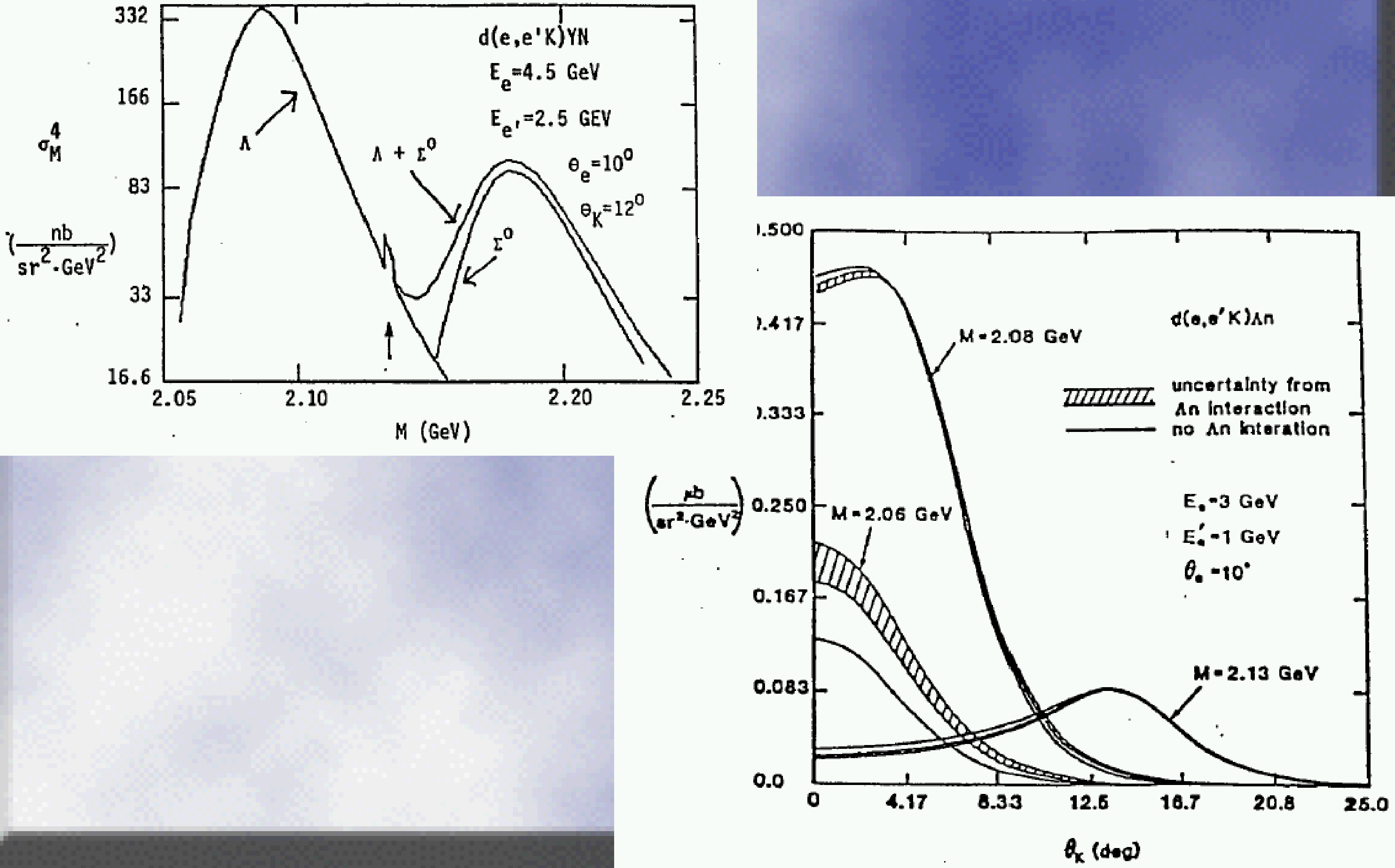
Measure hypernuclear bound state production on ^{3,4}He
Tests reaction dynamics and wave functions

Possibility of observing: bound S hyper-nuclear states; di-baryons

Provides a solid basis for planning future studies; a comprehensive base for hyper-nuclear studies; measurements extendable to cover wide range of energies and angles

Predictions for D(e,e'K$^+$)

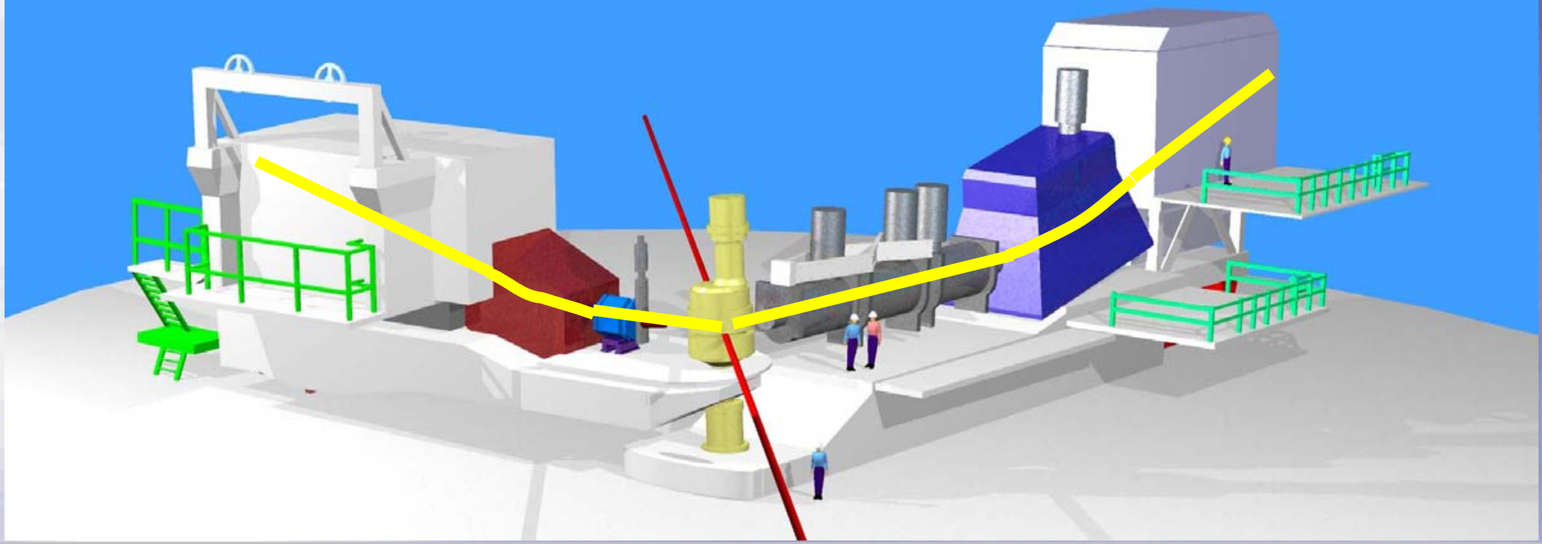
S.R. Cotanch and S.S. Hsiao, T.W. Donnelly and S.R. Cotanch



Experimental Program

Short Orbit Spectrometer, SOS
kaon arm

High Momentum Spectrometer, HMS
electron arm



Targets: ^{1}H, ^{2}H, Carbon, Aluminum

1996	Kinematics			
	(Q^2(GeV^2), W(GeV))	$\theta_{\gamma K}$,lab (^{o})	(Q^2(GeV^2), W(GeV))	$\theta_{\gamma K}$,lab (^{o})
Ebeam=3.245 GeV	(0.50, 1.80) (0.52,1.76)	0.0, 4.3, 8.3, 13.3	(0.38,1.90)	(1.5, 6.0, 11.5)
Ebeam=2.245 GeV	(0.50, 1.80) (0.52,1.76)	1	(0.38,1.90)	1.5

Targets: ^{1}H, ^{2}H, ^{3}He, ^{4}He, Carbon, Aluminum

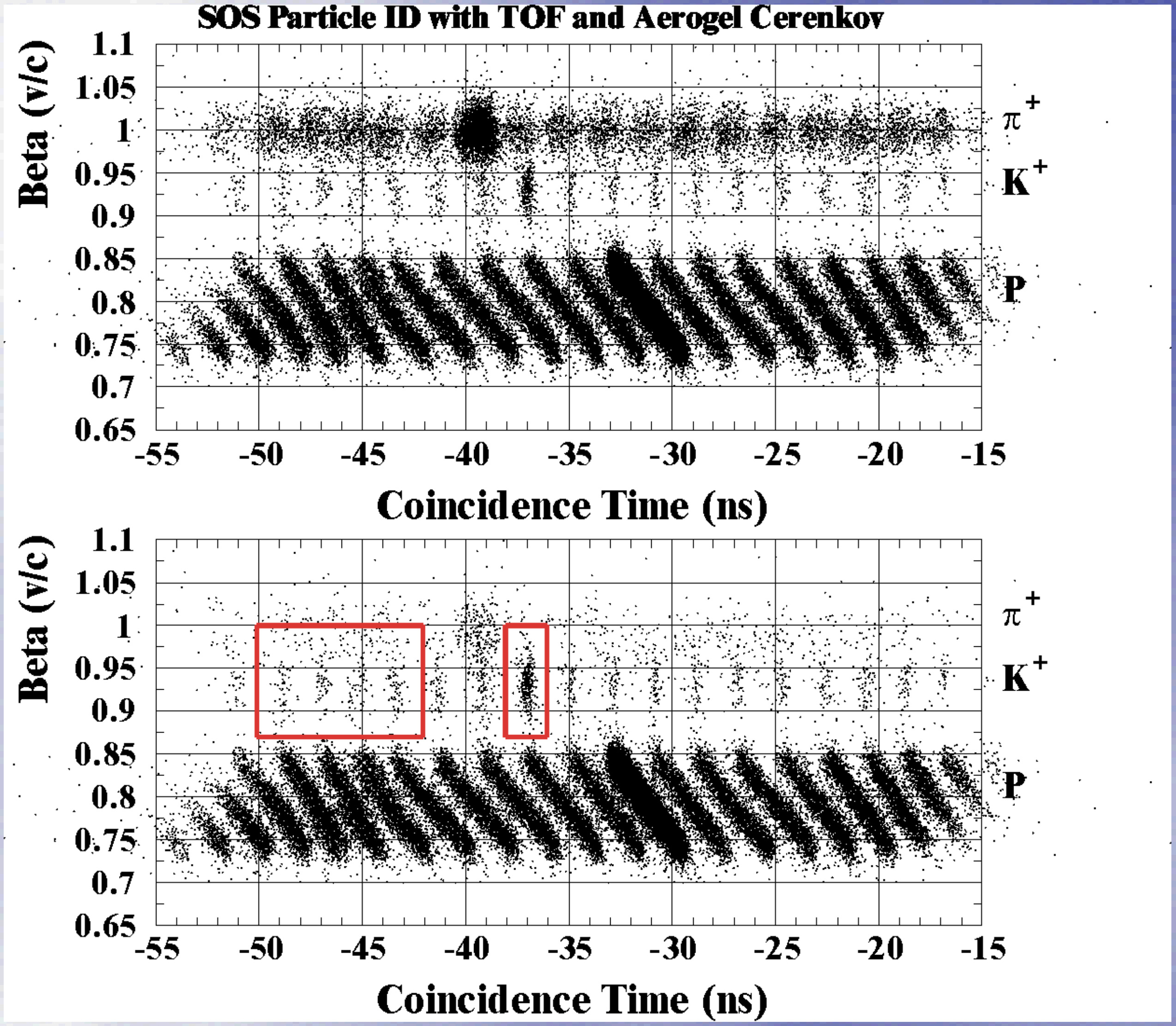
1999	Kinematics			
	(Q^2(GeV^2), W(GeV))	$\theta_{\gamma K}$,lab (^{o})	(Q^2(GeV^2), W(GeV))	$\theta_{\gamma K}$,lab (^{o})
Ebeam=3.245 GeV			(0.35, 1.91)	(0.0, 6.0, 12.0)

Particle Identification

K+ PID:

Coincidence time cuts separate 99.9 % reak K^+, π^+,p

Aerogel cuts reject 98 % π^+
b cuts reject 99 % p

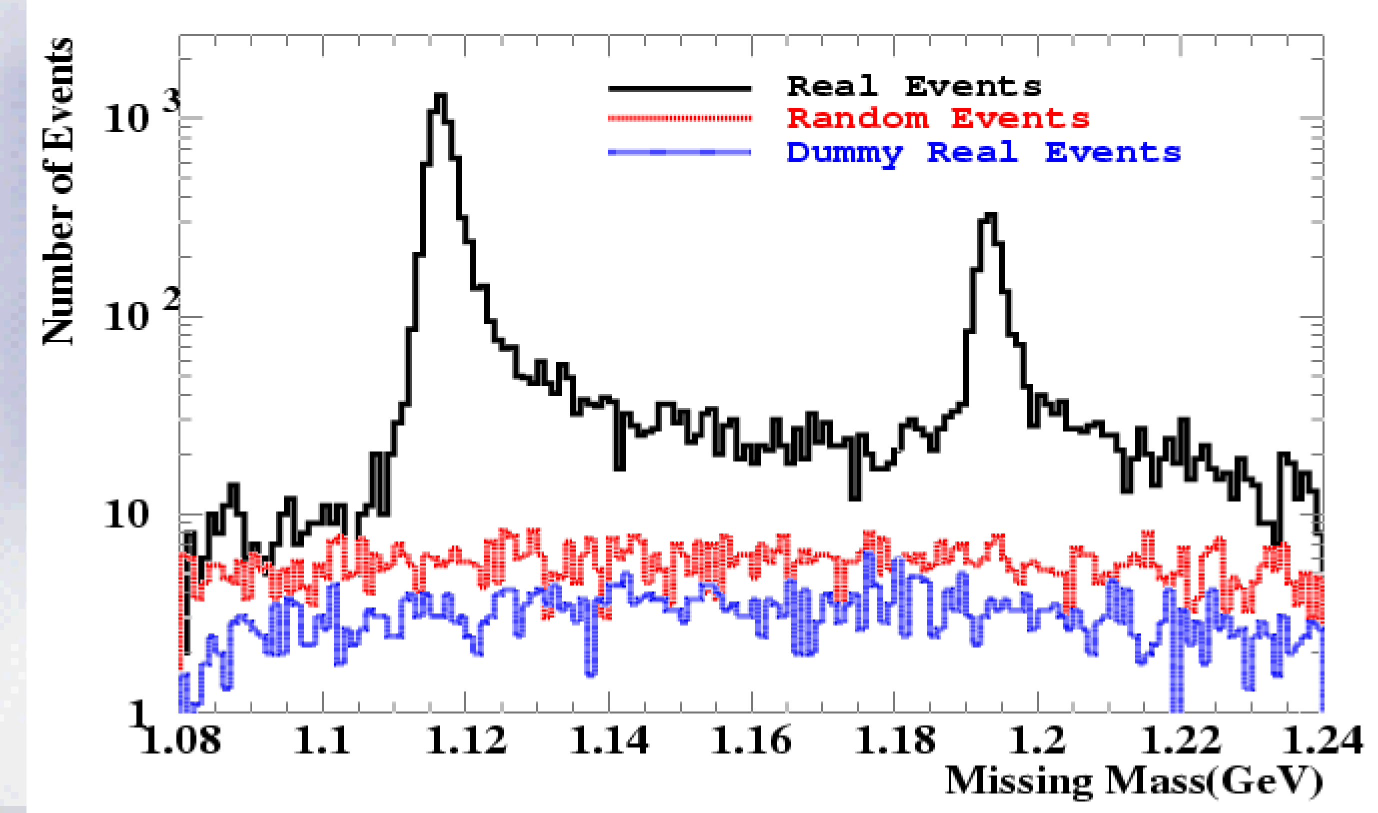


e‘ PID

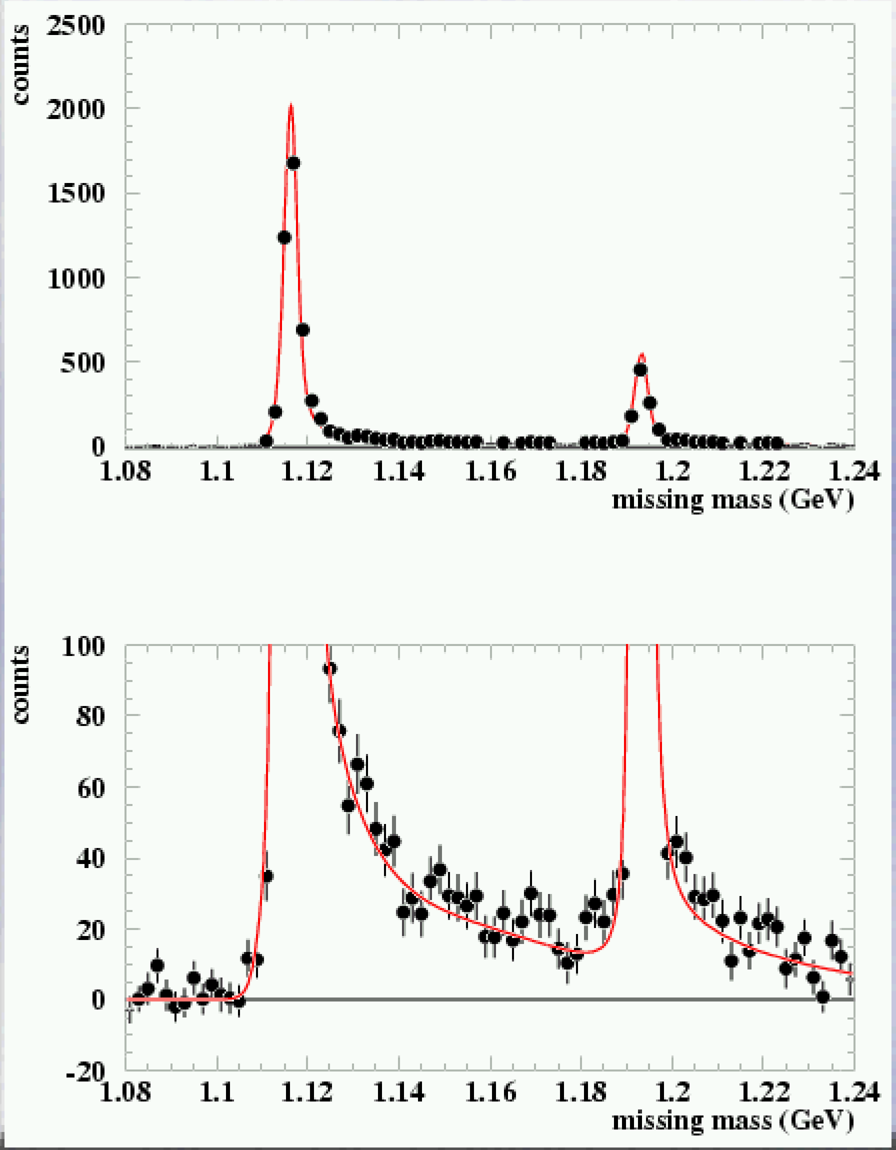
Cerenkov and calorimeter have ~ 99.8 % efficiency for electron PID

Missing Mass Analysis for p(e,e'K+)X

$$\left.\begin{aligned}\tilde{p}_e \, f \, \underbrace{\tilde{p}_p}_{0} &= \tilde{p}_e{}' \, f \, \tilde{p}_K \, f \, \tilde{p}_{miss} \\ E_e \, f \, \underbrace{E_p}_{M_p} &= E_e{}' \, f \, E_K \, f \, E_{miss}\end{aligned}\right\} m_{miss}^2 = E_{miss}^2 \, \square \, p_{miss}^2$$



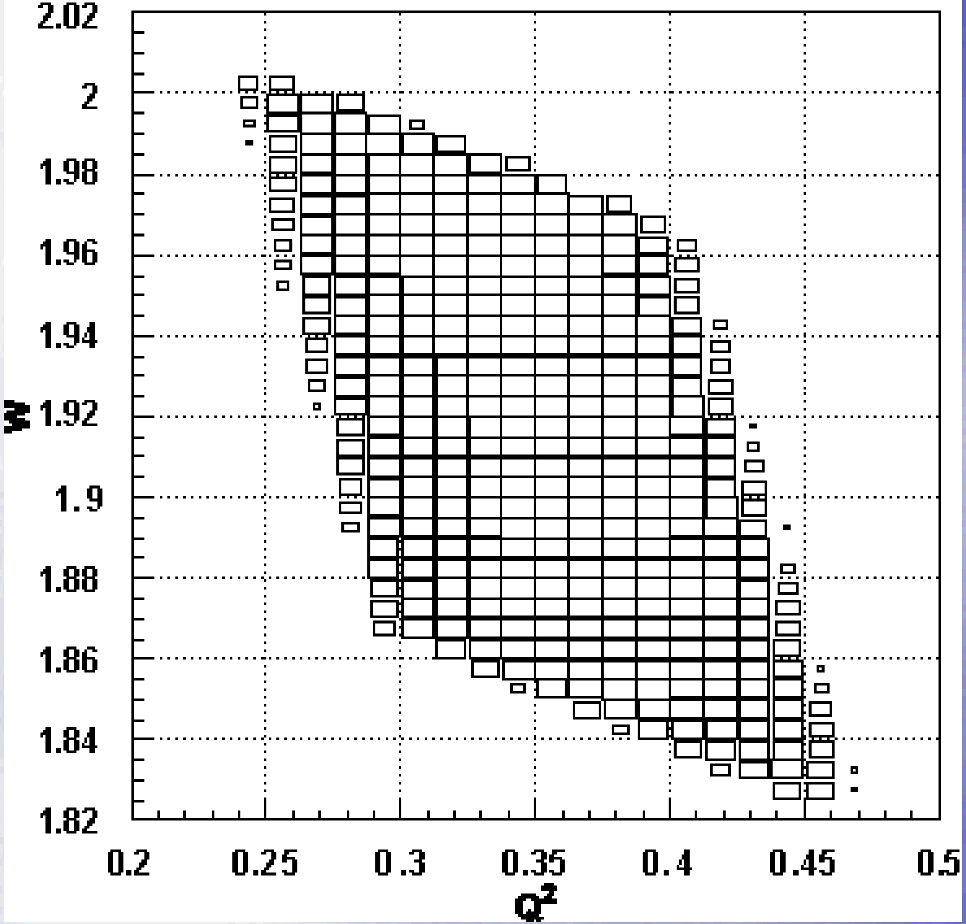
H(e,eK) Monte Carlo: SIMC



- Generate $\mathbf{p}_e$ and $\hat{\mathbf{p}}_K$
- mY determines $|p_K|$
- use reasonable model for ds/dW
- radiate event
- transport through spectrometers
- reconstruct
- compare with data
- iterate ds/dW until data and MC agree

Simple Model for Hydrogen Data

$$\frac{d\,sigma}{d\,Omega} = f\left(Q^2\right) g\left(W\right) h\left(t\right) i\left(phi\right)$$



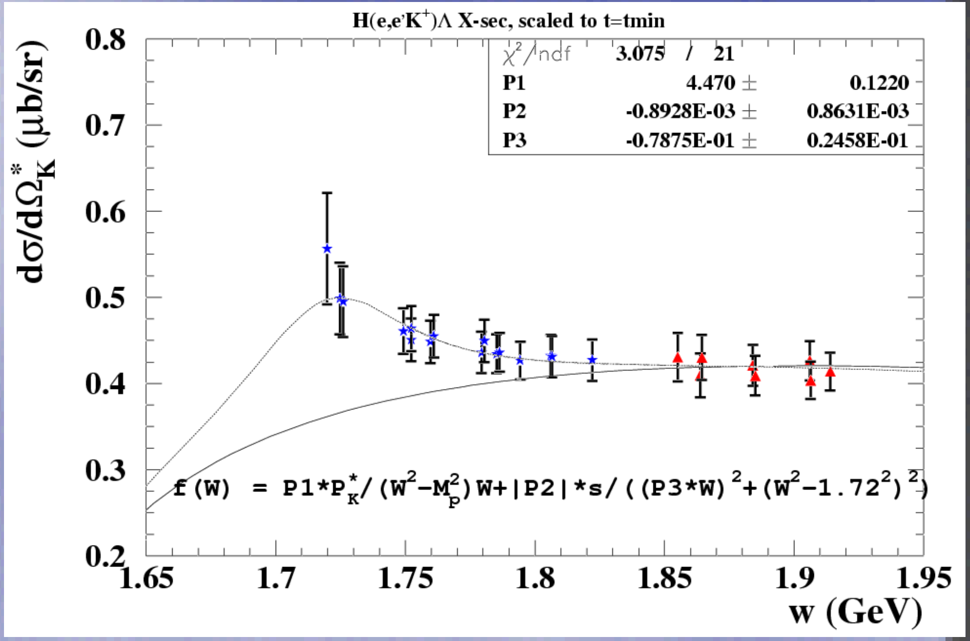
X-section parametrization

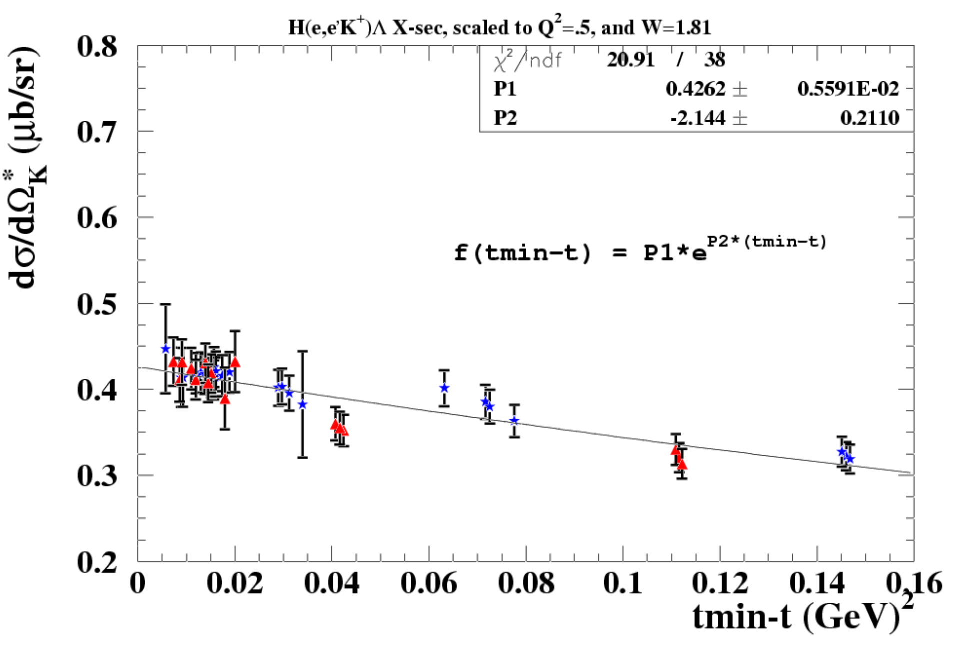
$$f(Q^2) = Constant \tag{5.2}$$

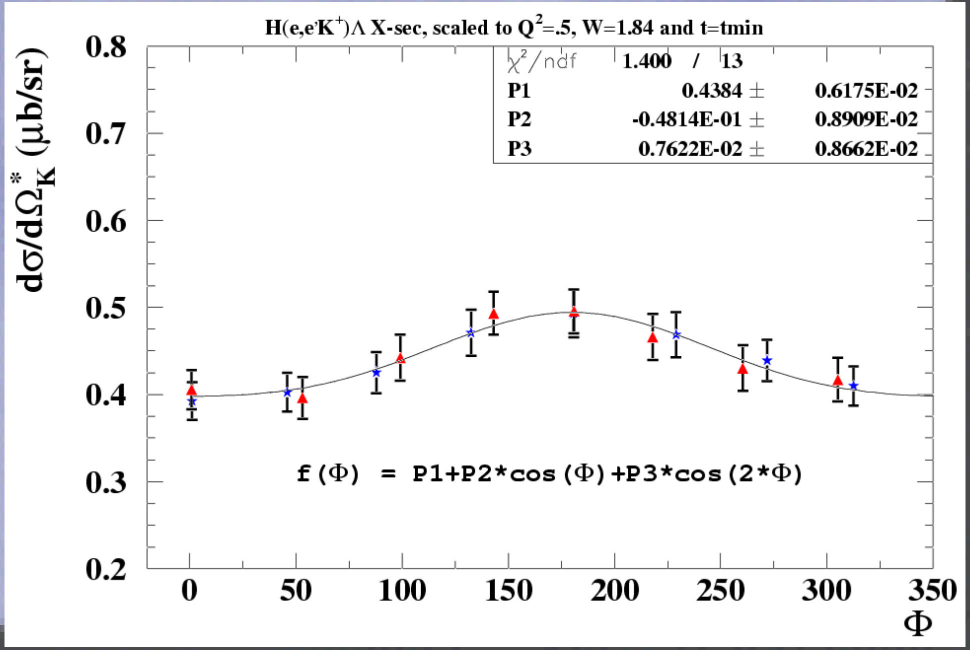
$$g(W) = \frac{P_1 P_k^{CM}}{(W^2 - M_p^2)W} + \frac{P_2 W^2}{(P_3 W)^2 + (W^2 - P_4^2)^2} \tag{5.3}$$

$$h(t_{min} - t) = P_1 e^{P_2 (t_{min} - t)} \tag{5.4}$$

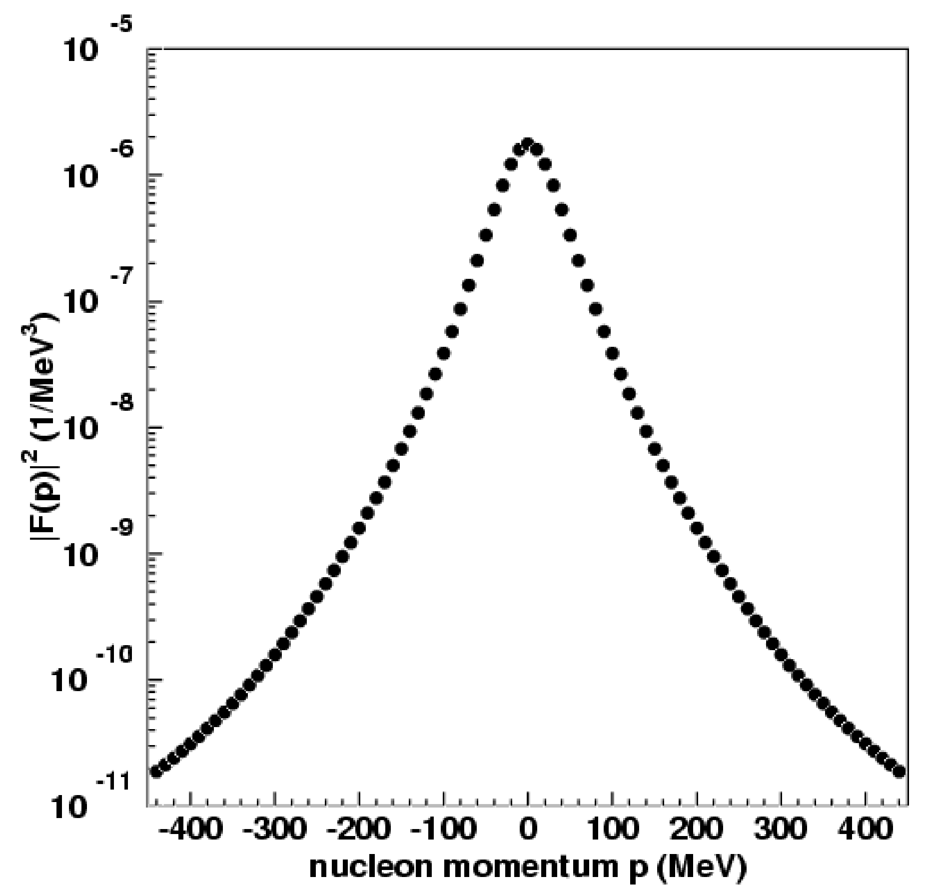
$$i(\phi) = P_1 + P_2 \cos(\phi) + P_3 \cos(2\phi) \tag{5.5}$$

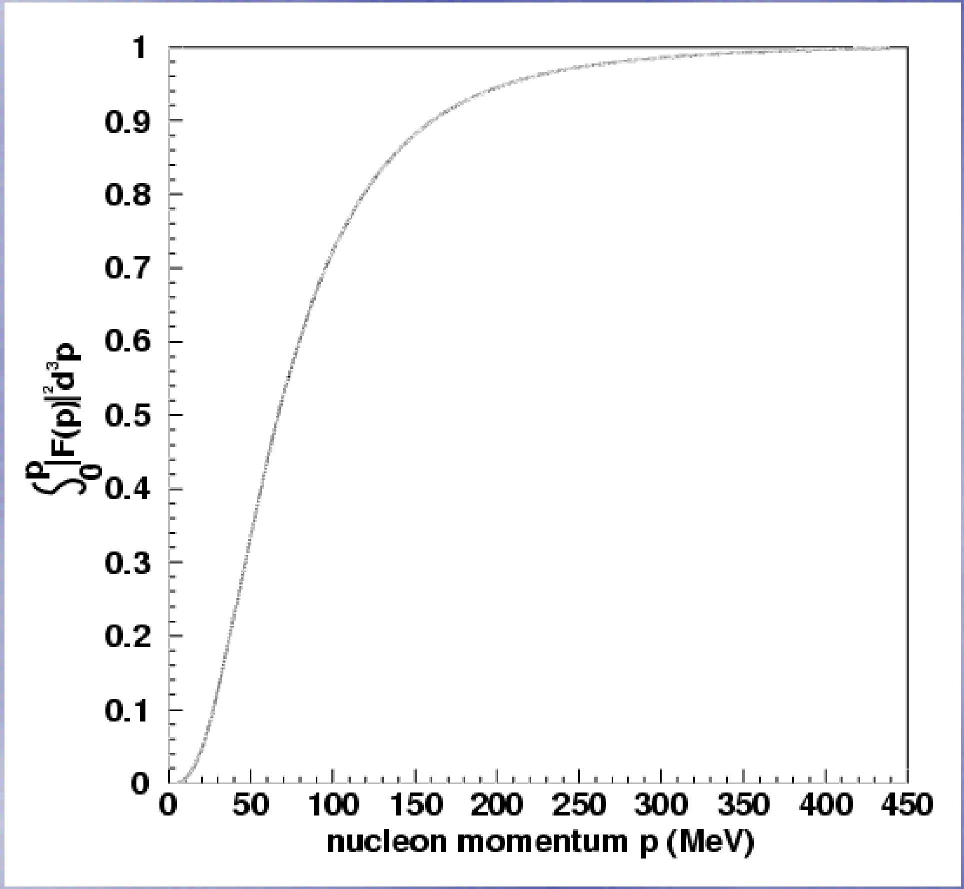




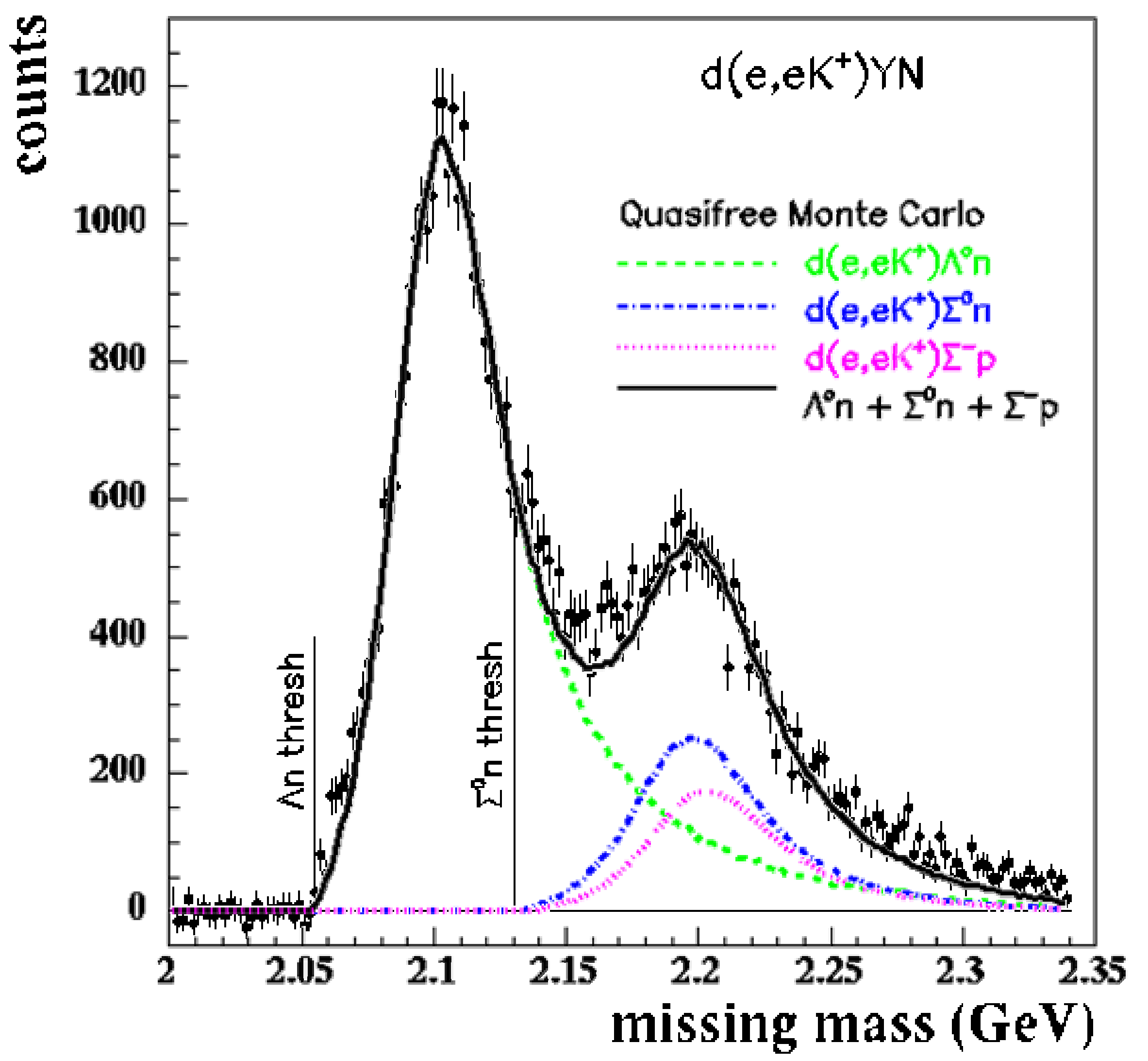


Momentum Wavefunction (Bonn potential)





$^{2}H(e,e'K^{+})$


counts
1200
1000
800
600
400
200
0
2
2.05
2.1
2.15
2.2
2.25
2.3
2.35
missing mass (GeV)
d(e,eK⁺)YN
Quasifree Monte Carlo
d(e,eK⁺)Λ°n
d(e,eK⁺)Σ°n
d(e,eK⁺)Σ⁻p
Λ°n + Σ°n + Σ⁻p
Λn thresh
Σ°n thresh

Modeling of FSI

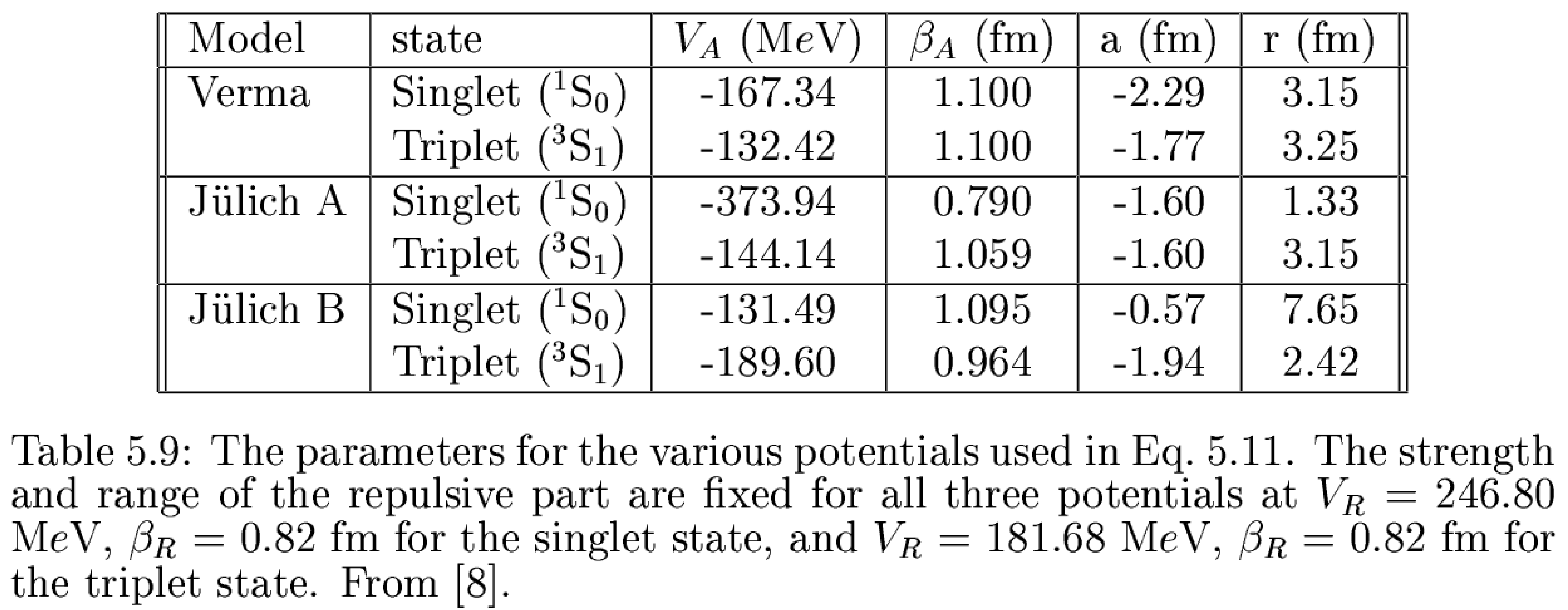
$$\tilde{M}_{fi} = \frac{\psi(kr+\delta)}{\psi(kr)} M_{fi},$$

$$(\frac{d\sigma}{d\Omega})_{FSI} = f_{P.S.}|\tilde{M}_{fi}|^2 = f_{P.S.}|\frac{\psi(kr+\delta)}{\psi(kr)}|^2|M_{fi}|^2$$

$$I = |\frac{\psi^*(kr+\delta)}{\psi(kr)}|^2$$

Ln Potential Parametrization

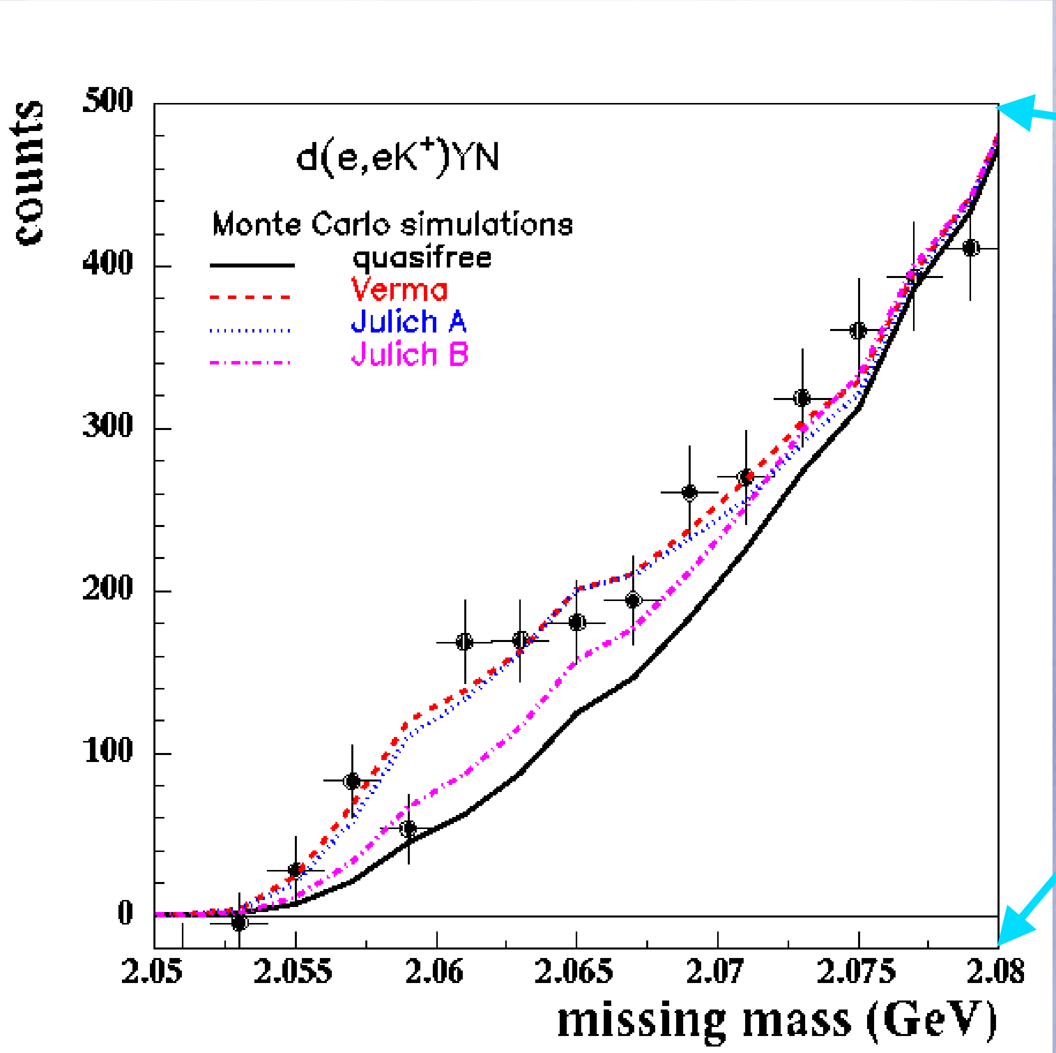
$$V(r) = V_A e^{r^2/{\beta_A}^2} + V_R e^{r^2/{\beta_R}^2}$$

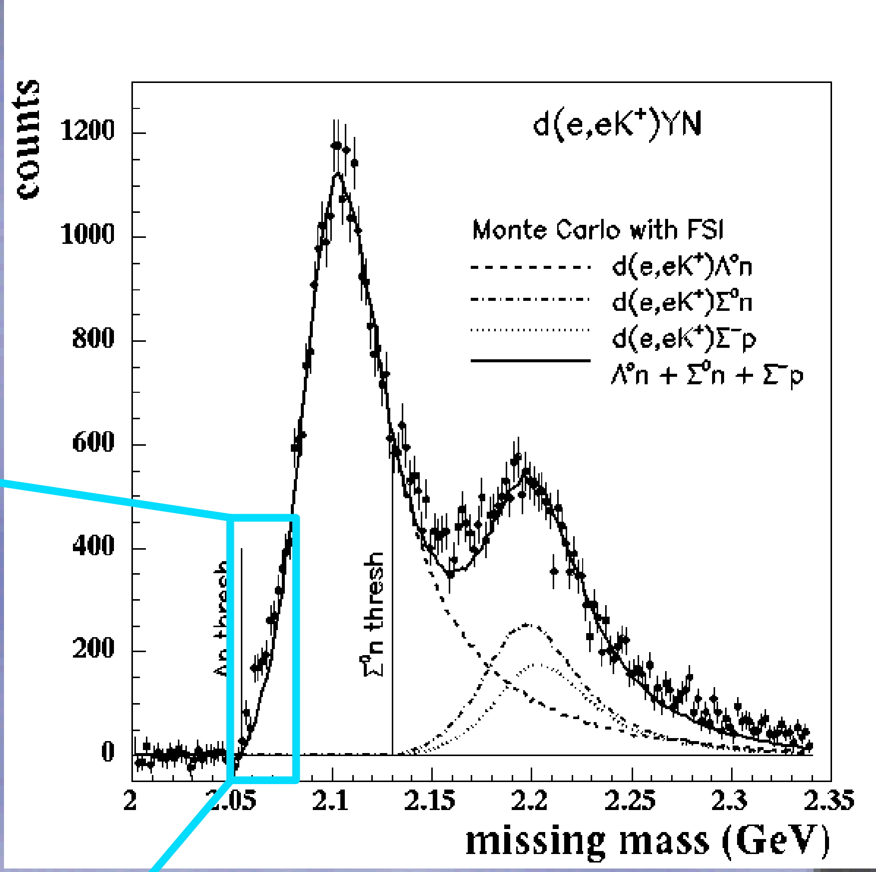


Model	state	V_A (MeV)	β_A (fm)	a (fm)	r (fm)
Verma	Singlet (^{1}S$_0$)	-167.34	1.100	-2.29	3.15
	Triplet (^{3}S$_1$)	-132.42	1.100	-1.77	3.25
Jülich A	Singlet (^{1}S$_0$)	-373.94	0.790	-1.60	1.33
	Triplet (^{3}S$_1$)	-144.14	1.059	-1.60	3.15
Jülich B	Singlet (^{1}S$_0$)	-131.49	1.095	-0.57	7.65
	Triplet (^{3}S$_1$)	-189.60	0.964	-1.94	2.42

Table 5.9: The parameters for the various potentials used in Eq. 5.11. The strength and range of the repulsive part are fixed for all three potentials at $V_R = 246.80$ MeV, $\beta_R = 0.82$ fm for the singlet state, and $V_R = 181.68$ MeV, $\beta_R = 0.82$ fm for the triplet state. From [8].

Ln FSI from ^{2}H(e,e'K$^+$)





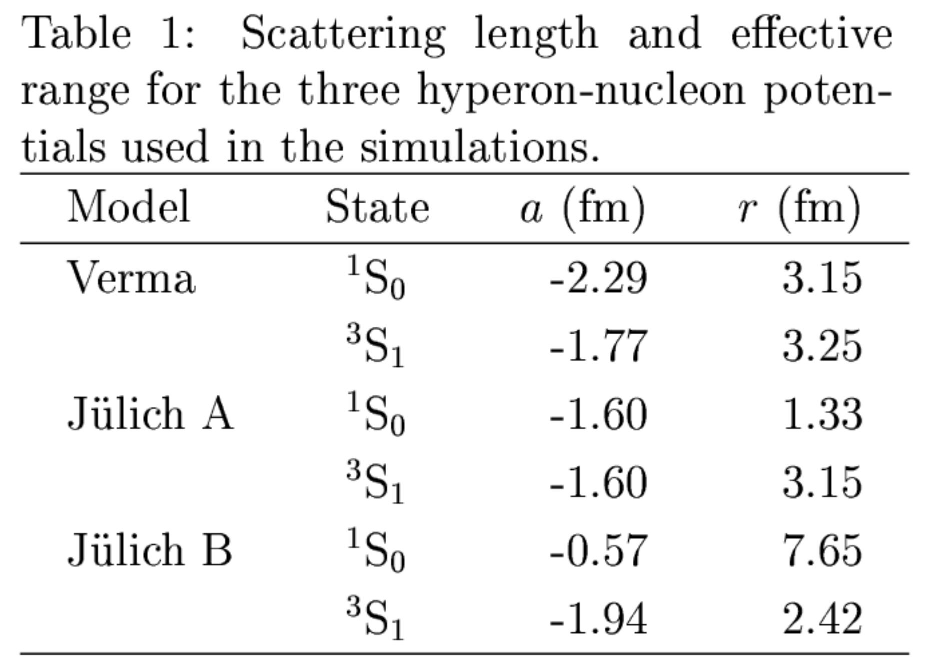
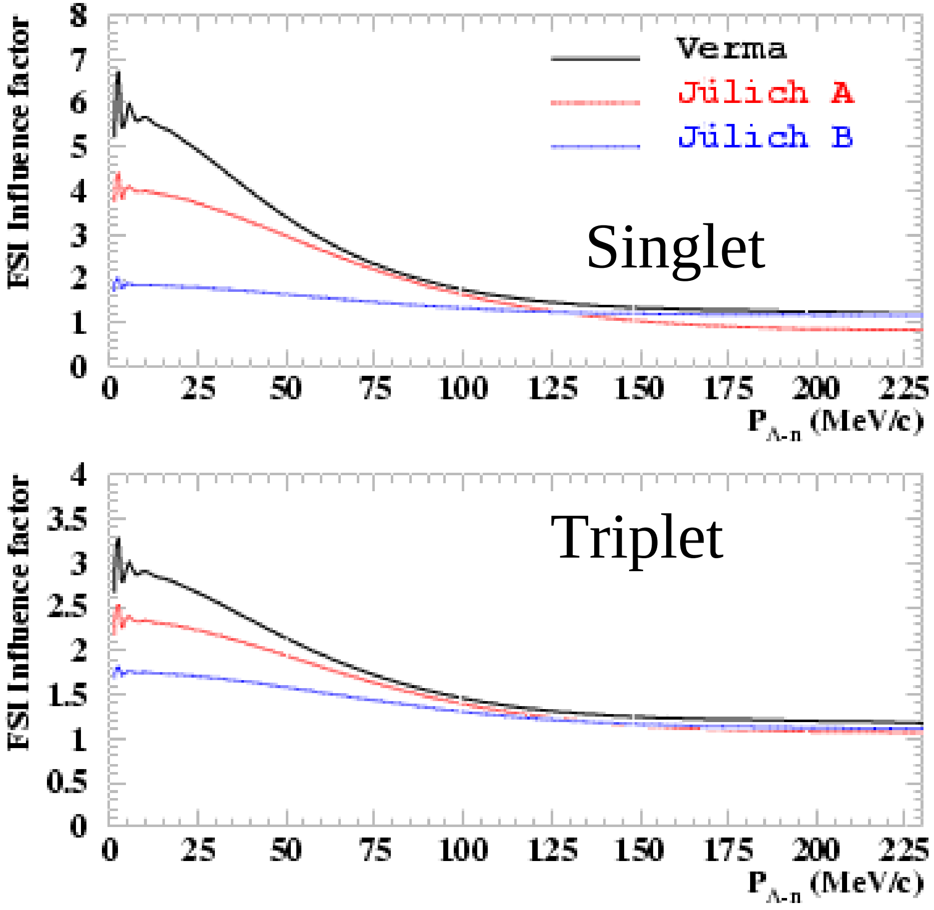
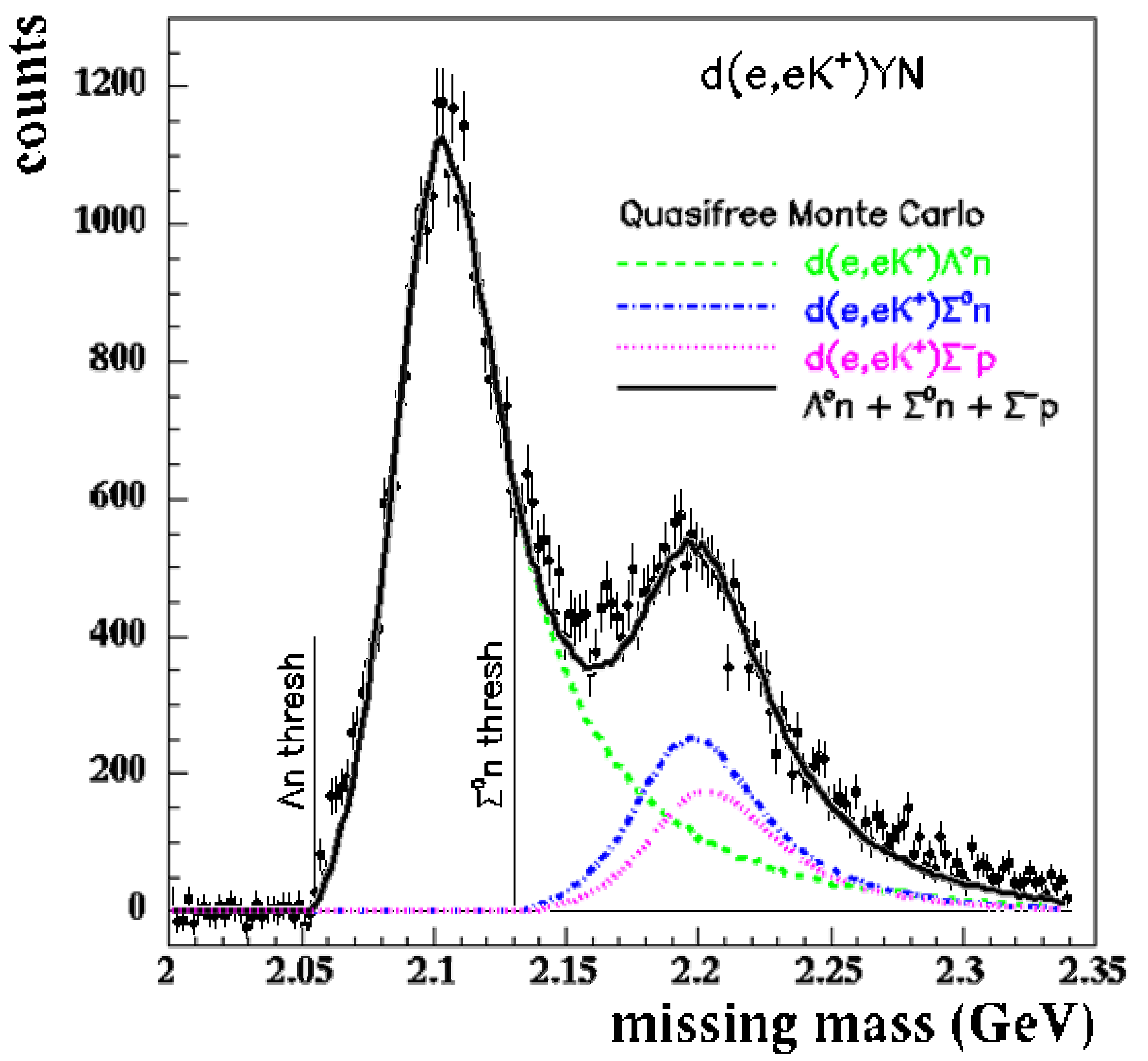


Table 1: Scattering length and effective range for the three hyperon-nucleon potentials used in the simulations.

Model	State	a (fm)	r (fm)
Verma	$^1S_0$	-2.29	3.15
	$^3S_1$	-1.77	3.25
Jülich A	$^1S_0$	-1.60	1.33
	$^3S_1$	-1.60	3.15
Jülich B	$^1S_0$	-0.57	7.65
	$^3S_1$	-1.94	2.42

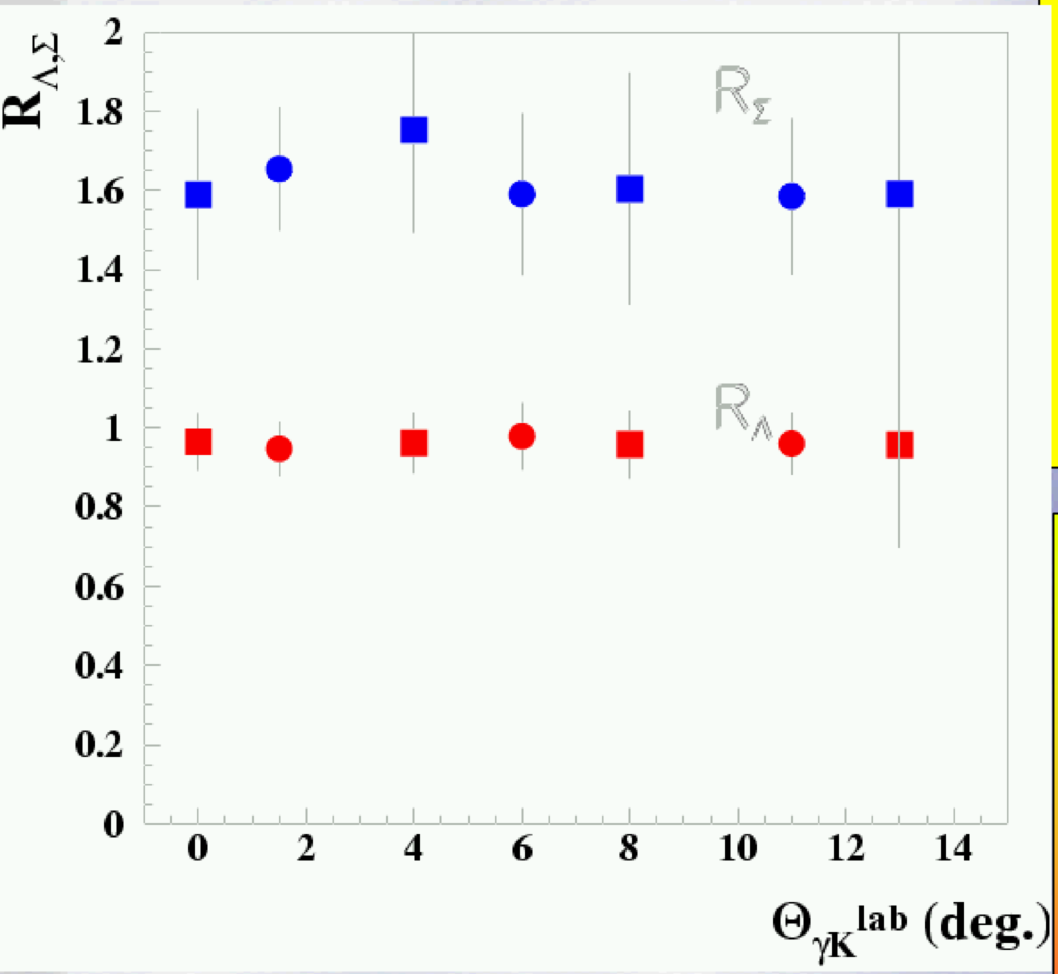

FSI Influence factor
Verma
Jülich A
Jülich B
Singlet
$P_{\Lambda-n}$ (MeV/c)
0
25
50
75
100
125
150
175
200
225
0
1
2
3
4
5
6
7
8
FSI Influence factor
Triplet
$P_{\Lambda-n}$ (MeV/c)
0
0.5
1
1.5
2
2.5
3
3.5
4

^{2}H(e,e'K$^+$)

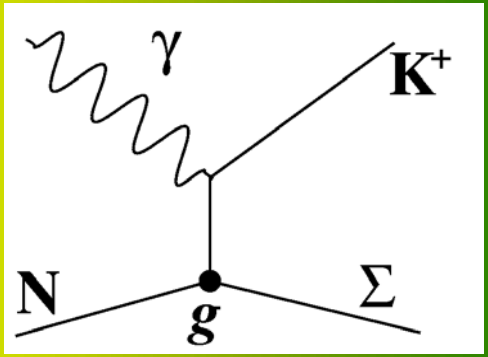

counts
1200
1000
800
600
400
200
0
2
2.05
2.1
2.15
2.2
2.25
2.3
2.35
missing mass (GeV)
d(e,eK$^+$)YN
Quasifree Monte Carlo
d(e,eK$^+$)Λ^0n
d(e,eK$^+$)Σ^0n
d(e,eK$^+$)Σ^-p
Λ^0n + Σ^0n + Σ^-p
Λn thresh
Σ^0n thresh

$$R_\Lambda = \frac{\frac{d\sigma}{d\Omega}(\gamma d \to K^+\Lambda)}{\frac{d\sigma}{d\Omega}(\gamma p \to K^+\Lambda)}$$

$$R_\Sigma = \frac{\frac{d\sigma}{d\Omega}(\gamma d \to K^+\Sigma)}{\frac{d\sigma}{d\Omega}(\gamma p \to K^+\Sigma^0)}$$



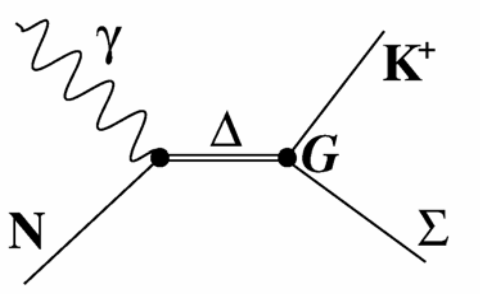
t-channel:



$$g_{K^+\Sigma^- n} = \sqrt{2} g_{K^+\Sigma^0 p}$$

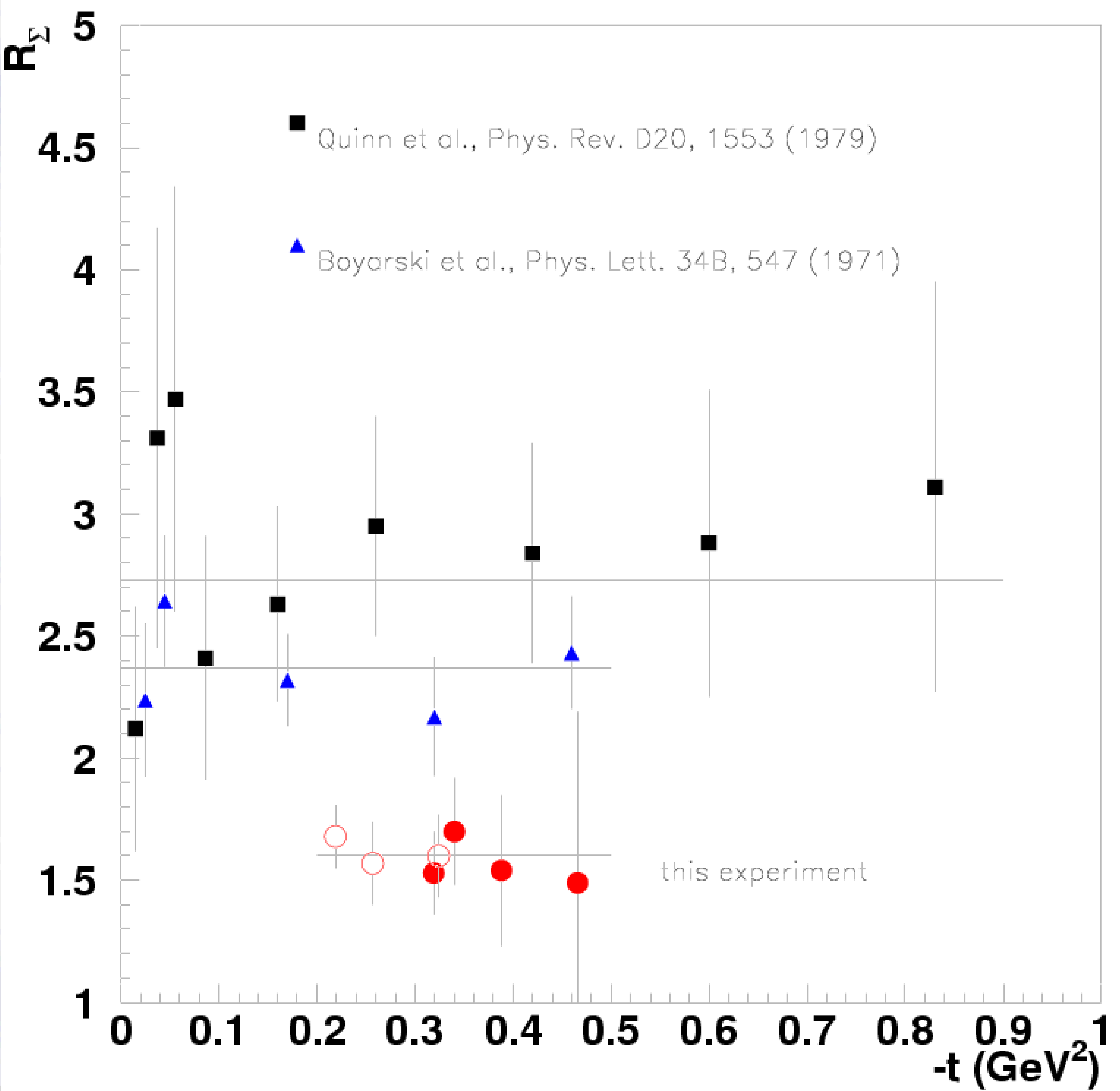
$$R_\Sigma = 3$$

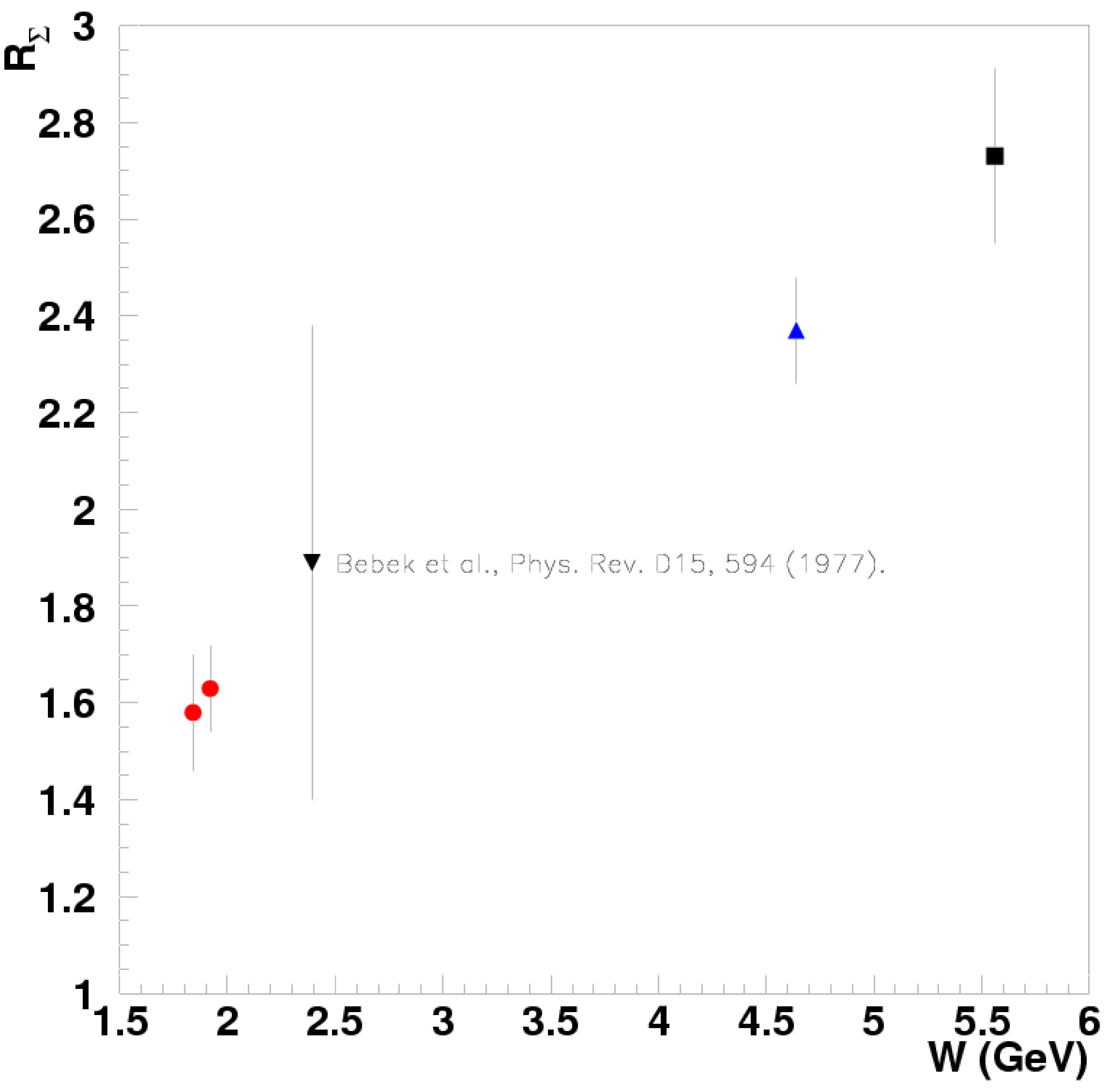
s-channel:



$$G_{K^+\Sigma^-\Delta^0} = G_{K^+\Sigma^0\Delta^+}/\sqrt{2}$$

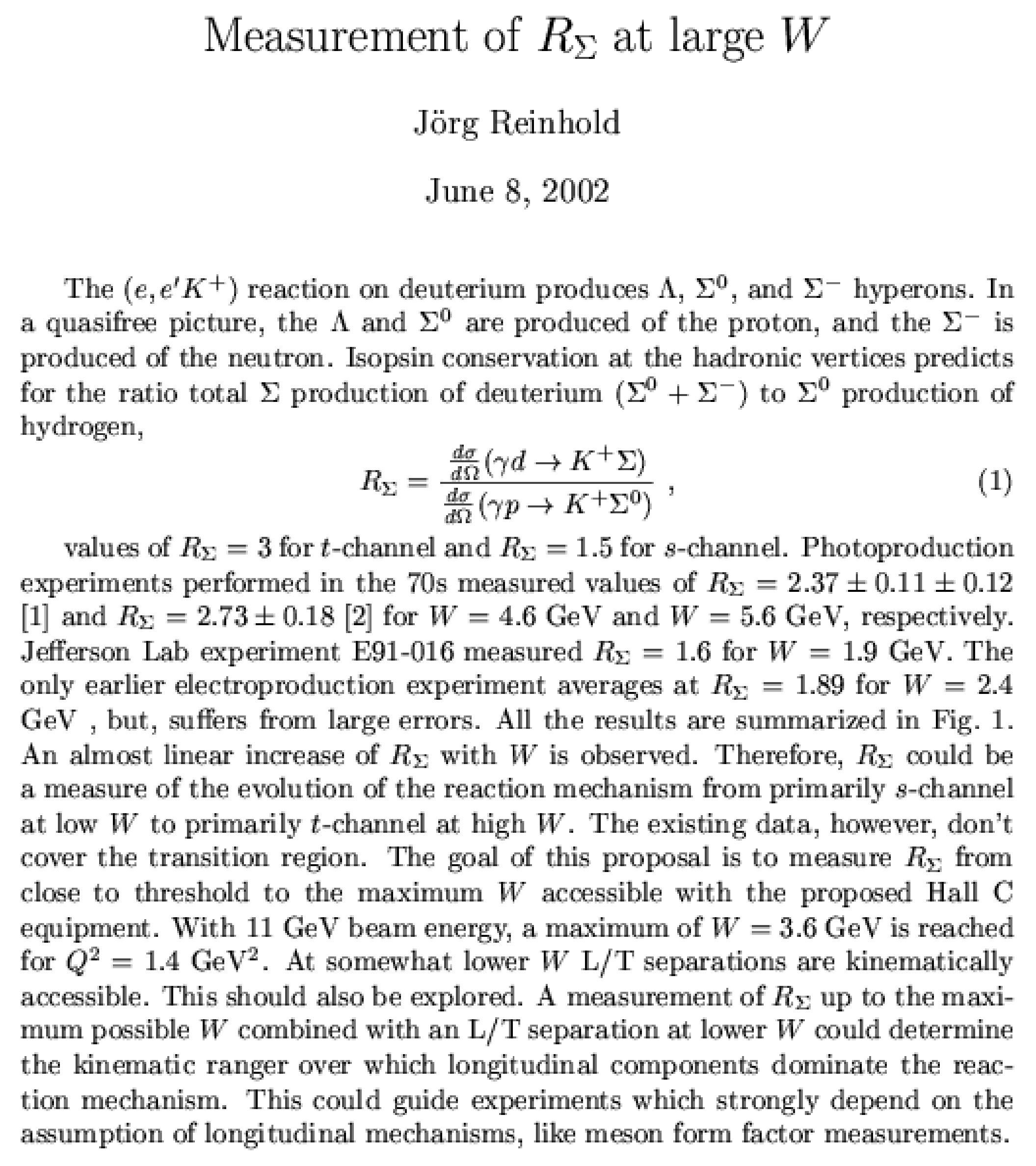
$$R_\Sigma = 1.5$$


R_Σ
5
4.5
4
3.5
3
2.5
2
1.5
1
■ Quinn et al., Phys. Rev. D20, 1553 (1979)
▲ Boyarski et al., Phys. Lett. 34B, 547 (1971)
this experiment
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
$-t$ (GeV^2)



▼ Bebek et al., Phys. Rev. D15, 594 (1977).

User Proposal to Hall C 12GeV Upgrade



Measurement of R_Σ at large W

Jörg Reinhold

June 8, 2002

The $(e, e'K^+)$ reaction on deuterium produces Λ, Σ^0, and Σ^- hyperons. In a quasifree picture, the Λ and Σ^0 are produced of the proton, and the Σ^- is produced of the neutron. Isopsin conservation at the hadronic vertices predicts for the ratio total Σ production of deuterium $(\Sigma^0 + \Sigma^-)$ to Σ^0 production of hydrogen,

$$R_\Sigma = \frac{\frac{d\sigma}{d\Omega}(\gamma d \rightarrow K^+\Sigma)}{\frac{d\sigma}{d\Omega}(\gamma p \rightarrow K^+\Sigma^0)} , \tag{1}$$

values of $R_\Sigma = 3$ for t-channel and $R_\Sigma = 1.5$ for s-channel. Photoproduction experiments performed in the 70s measured values of $R_\Sigma = 2.37 \pm 0.11 \pm 0.12$ [1] and $R_\Sigma = 2.73 \pm 0.18$ [2] for $W = 4.6$ GeV and $W = 5.6$ GeV, respectively. Jefferson Lab experiment E91-016 measured $R_\Sigma = 1.6$ for $W = 1.9$ GeV. The only earlier electroproduction experiment averages at $R_\Sigma = 1.89$ for $W = 2.4$ GeV , but, suffers from large errors. All the results are summarized in Fig. 1. An almost linear increase of R_Σ with W is observed. Therefore, R_Σ could be a measure of the evolution of the reaction mechanism from primarily s-channel at low W to primarily t-channel at high W. The existing data, however, don't cover the transition region. The goal of this proposal is to measure R_Σ from close to threshold to the maximum W accessible with the proposed Hall C equipment. With 11 GeV beam energy, a maximum of $W = 3.6$ GeV is reached for $Q^2 = 1.4$ GeV^2. At somewhat lower W L/T separations are kinematically accessible. This should also be explored. A measurement of R_Σ up to the maximum possible W combined with an L/T separation at lower W could determine the kinematic ranger over which longitudinal components dominate the reaction mechanism. This could guide experiments which strongly depend on the assumption of longitudinal mechanisms, like meson form factor measurements.

Bound Λ-Hypernuclear States for He

A=3

$^{3}_{\Lambda}$H B = 130 keV, $J^{\pi} = (1/2)^{+}$ (Hypertriton)

A=4

$^{4}_{\Lambda}$He $B_{ground}(0^{+}) = 2.93 \pm 0.03$ MeV $B_{excited}(1^{+}) = 1.24 \pm 0.06$ MeV

$^{4}_{\Lambda}$H $B_{ground}(0^{+}) = 2.04 \pm 0.04$ MeV $B_{excited}(1^{+}) = 1.00 \pm 0.06$ MeV

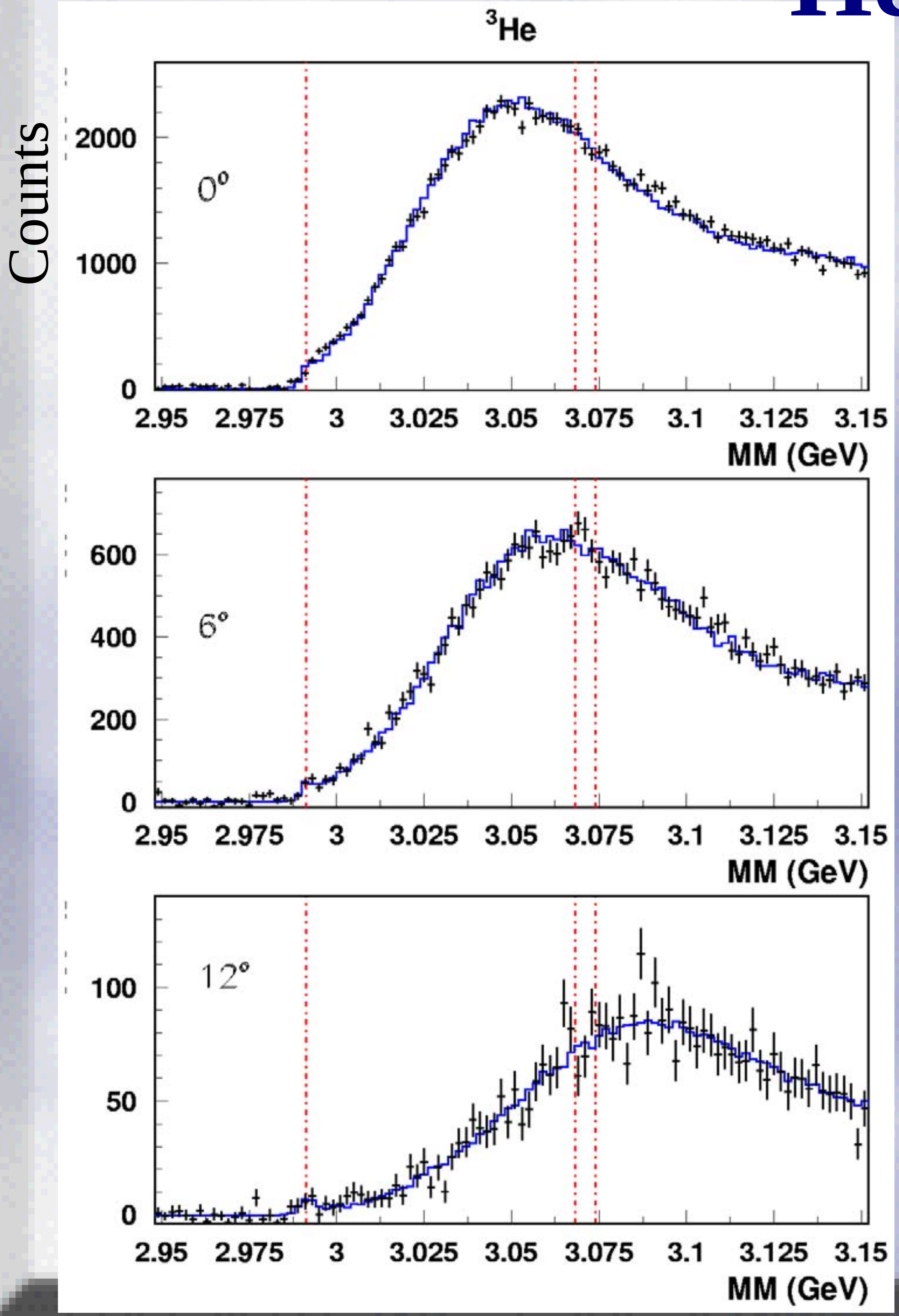
Different Production Mechanism:

(K,π) negligible spin flip strength, good momentum matching, may populate substitutional states

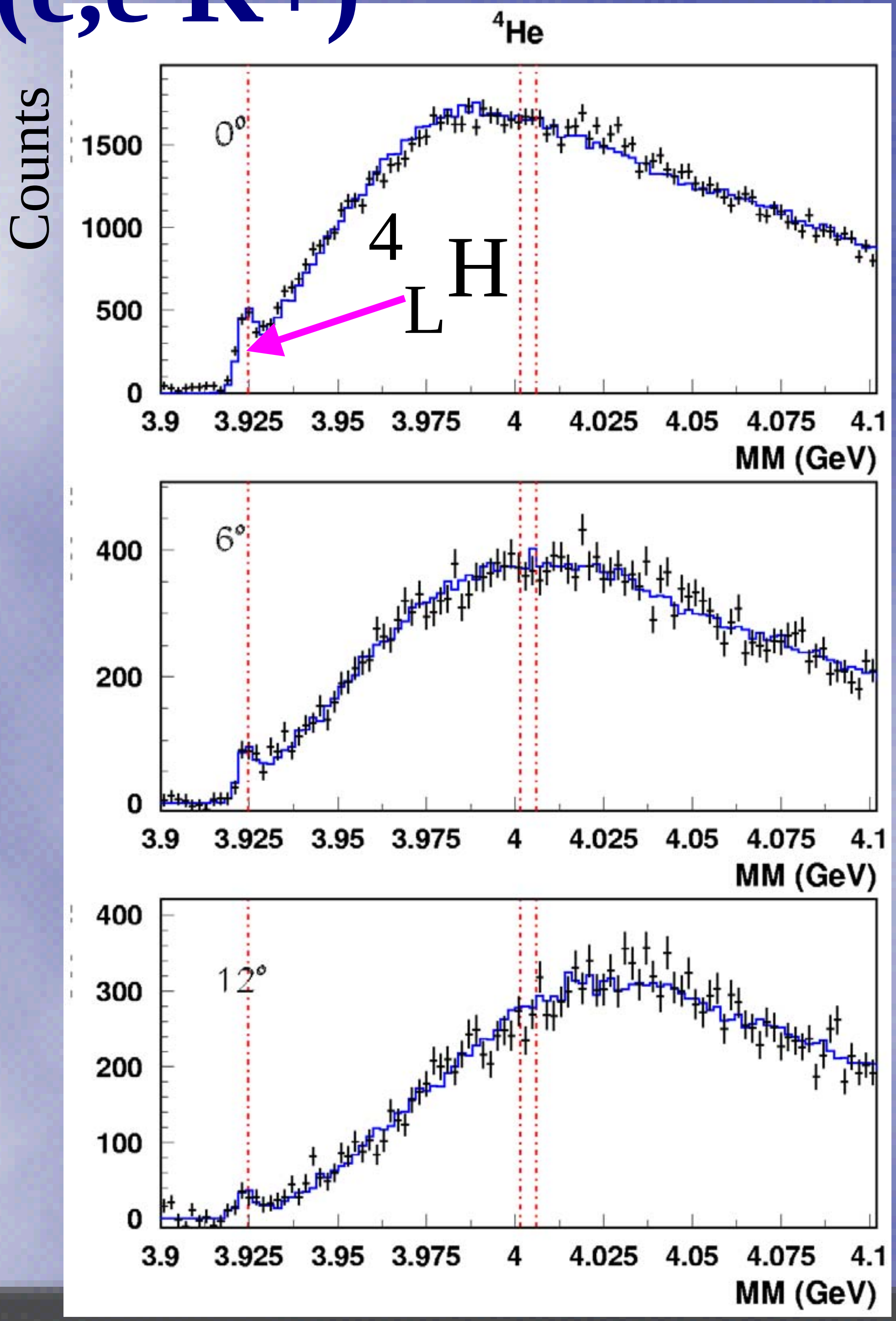
(π,K) substantial momentum transfer, may excite higher spin states, spin flip strength

(γ^{*},K) Electroproduction: Large momentum transfer, large spin flip strength

$^{3,4}He(e,e'K+)$

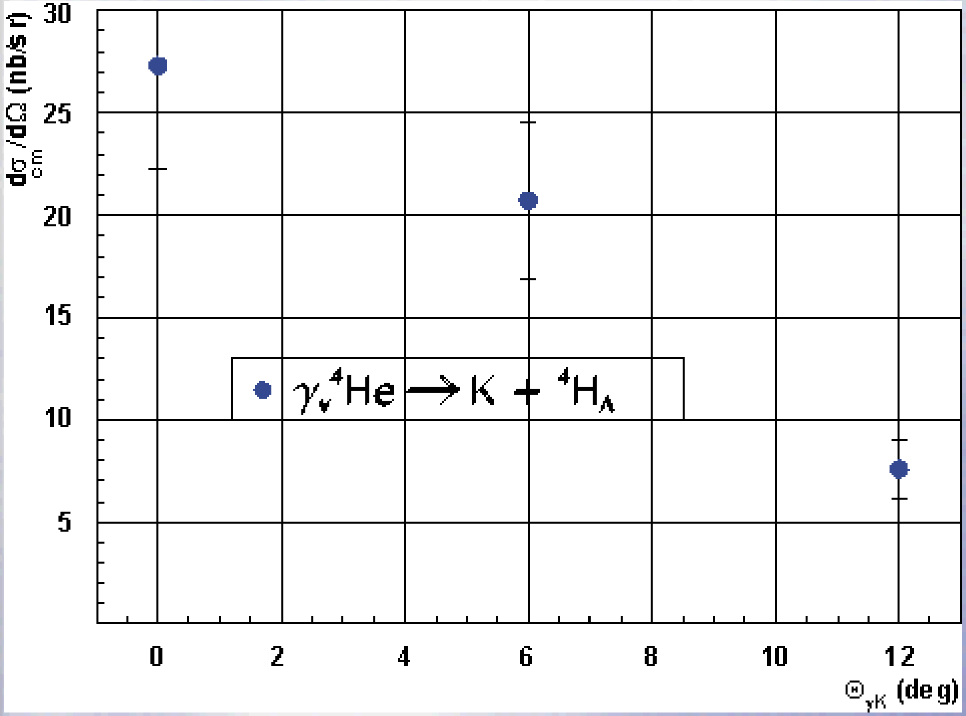


^{3}He
Counts
0°
6°
12°
2000
1000
0
600
400
200
100
50
2.95
2.975
3
3.025
3.05
3.075
3.1
3.125
3.15
MM (GeV)

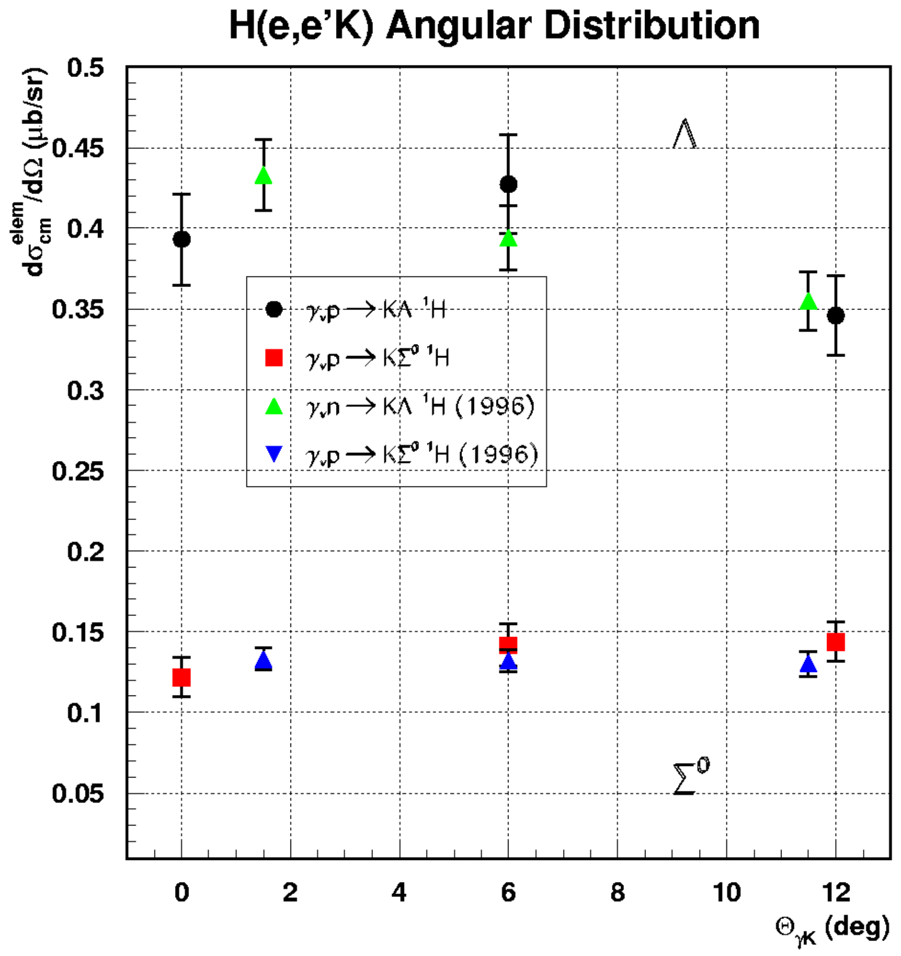


^{4}He
Counts
0°
6°
12°
$^4_\Lambda H$
1500
1000
500
400
300
200
100
0
3.9
3.925
3.95
3.975
4
4.025
4.05
4.075
4.1
MM (GeV)

Bound L-Hypernuclei A=4

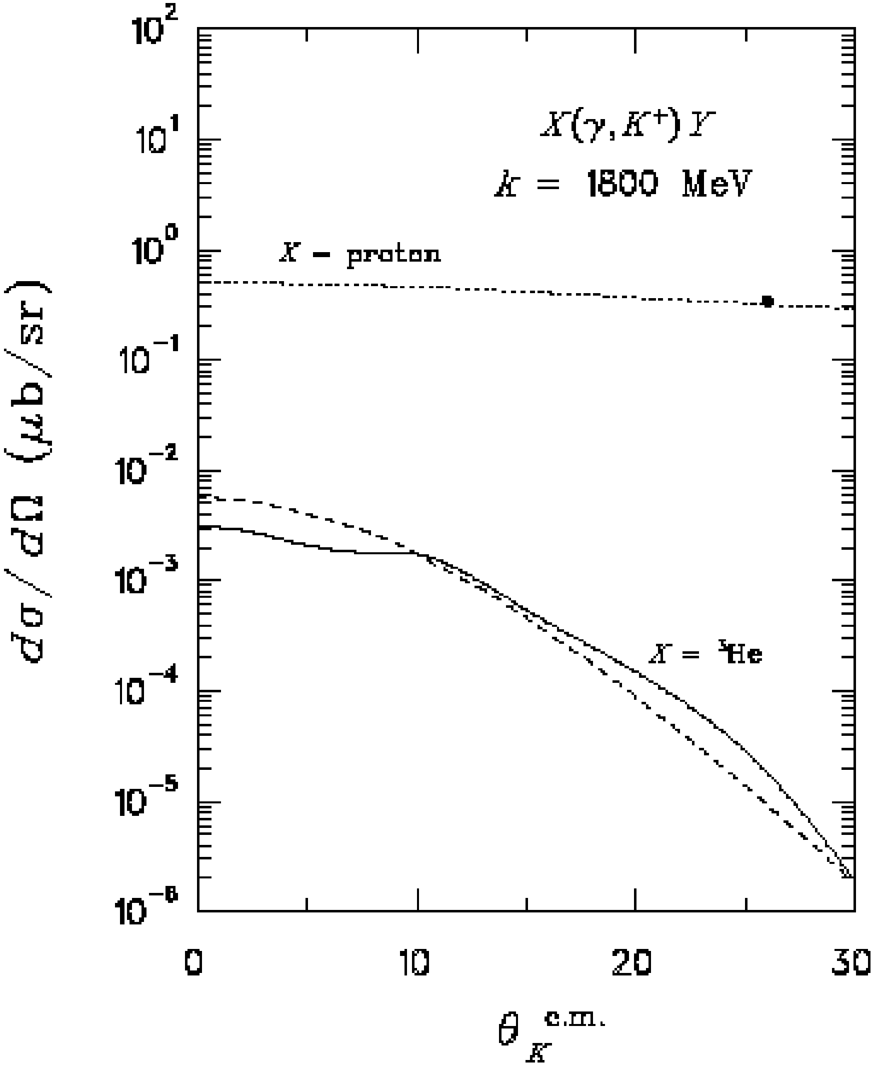


Kaon-photon angle



Kaon-photon angle

T.Mart et al, NPA 640 (1998) 235



$$\frac{d\sigma_{\rm T}}{d\Omega_K} = \tfrac{1}{6} W_A^2 |F(Q)|^2 \left(\frac{d\sigma_{\rm T}}{d\Omega_K}\right)_{\rm proton},$$

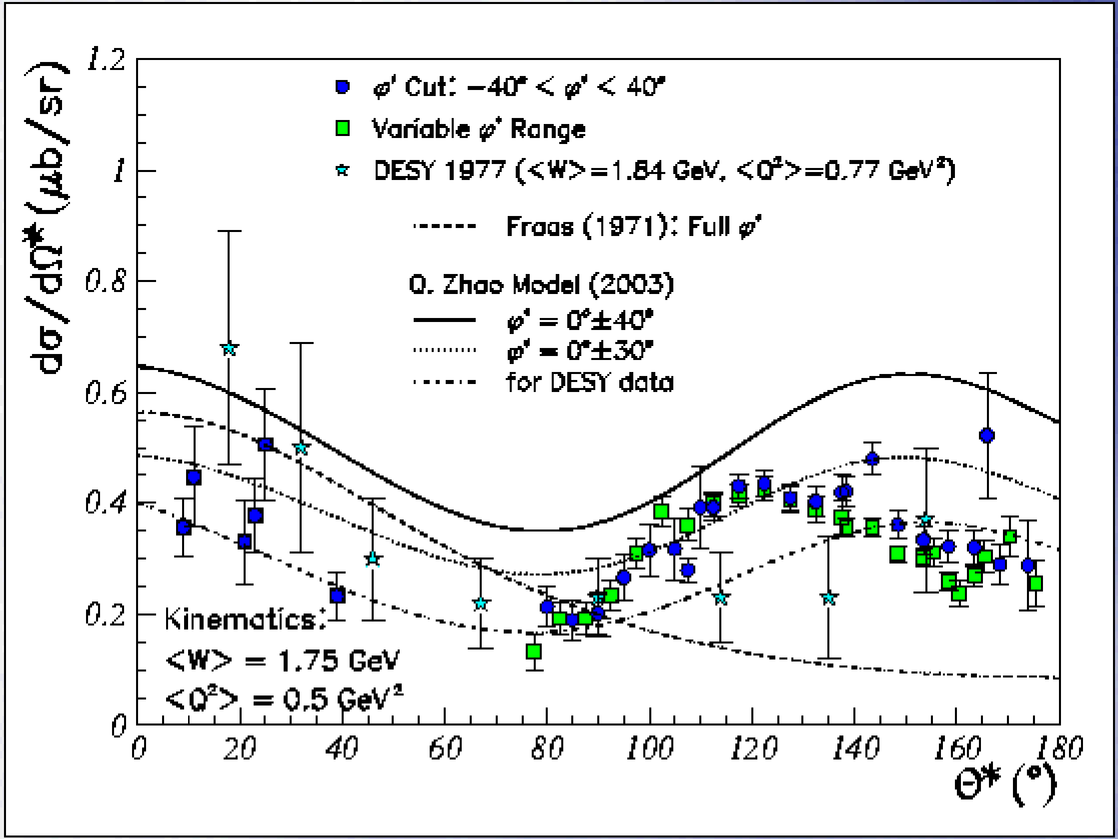
$$F(Q) = \int d^3\boldsymbol{q}\, d^3\boldsymbol{p}\, \Psi_{^3_\Lambda{\rm H}}(\boldsymbol{p}, \boldsymbol{q} + \tfrac{2}{3}\boldsymbol{Q})\, \Psi_{^3{\rm He}}(\boldsymbol{p}, \boldsymbol{q})$$

$$W_A = \sqrt{\frac{|\boldsymbol{q}_K^{\rm c.m.}|_{^3{\rm He}}}{|\boldsymbol{k}^{\rm c.m.}|_{^3{\rm He}}}\, \frac{|\boldsymbol{k}^{\rm c.m.}|_p}{|\boldsymbol{q}_K^{\rm c.m.}|_p}\, \frac{M_{^3{\rm He}} E_{^3_\Lambda{\rm H}} W_p^2}{m_p E_\Lambda W_{^3{\rm He}}^2}}.$$

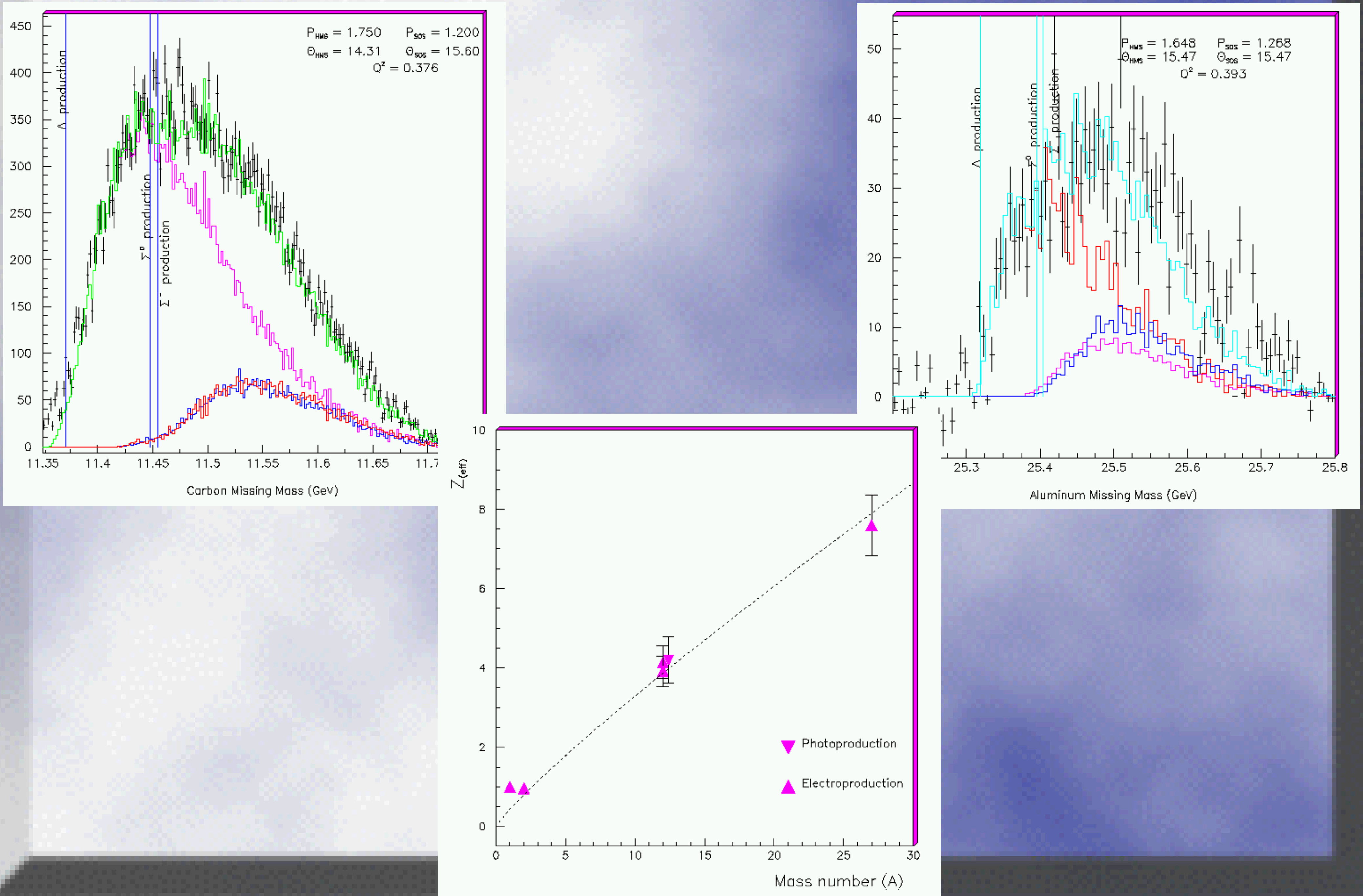
Cross section is kinematic factor times overlap integral times elementary cross section

Fig. 4. Differential cross section for kaon photoproduction off the proton and ^{3}He as function of kaon angle. The elementary reaction (dotted line) is taken from Ref. [32] and the corresponding experimental datum is from Ref. [35]. The dashed line shows the approximation for production off ^{3}He calculated from Eq. (32), the solid line represents the exact calculation using S-waves.

H(e,e'p)w: Pawel Ambozewicz



^{12}C,^{27}Al(e,e'K): Wendy Hinton's analysis



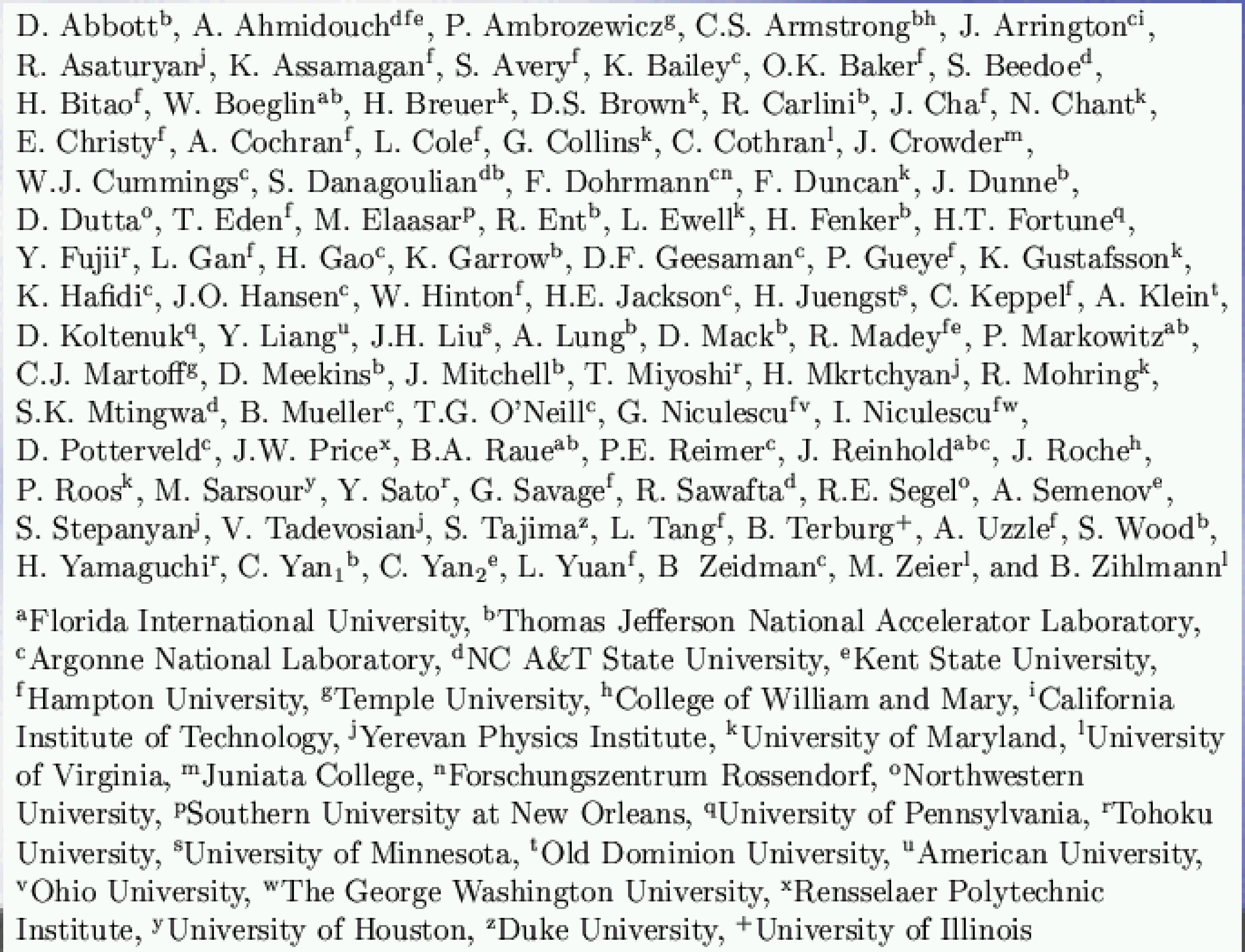
Summary

- First d(e,e'K) with good resolution
- R_L=1 ==> quasifree production mechanism
- R_S=1.6 ==> S production s-channel dominated
- First ever A(e,e'K) for A>2
- ^{4}He(e,e'K)$^4{}_L$H qualitatively shows formfactor

Outlook

- HNSS achieved 1 MeV resolution
- Hall A will take data early 2004 (Franco Garibaldi, Saturday)
- New hypernuclear spectrometer HKS will take data later in 2004 (S.N. Nakamura, Saturday)
- The HKS collaboration is considering the use of cryogenic targets for future few-body studies

E91-016 Collaboration



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