# Electroproduction of Strangeness on $^{3,4}$He

Ê Motivation

Ë $^{1}$H(e,e'K)L

Ì A(e,e'K), A=2,3,4

Í Bound $\Lambda$ Hypernuclei: $^{3}_{\Lambda}$H, $^{4}_{\Lambda}$H

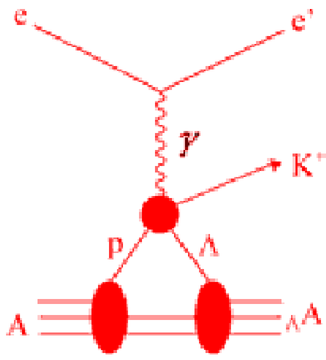
Î Outlook

HYP2003, Jefferson Lab

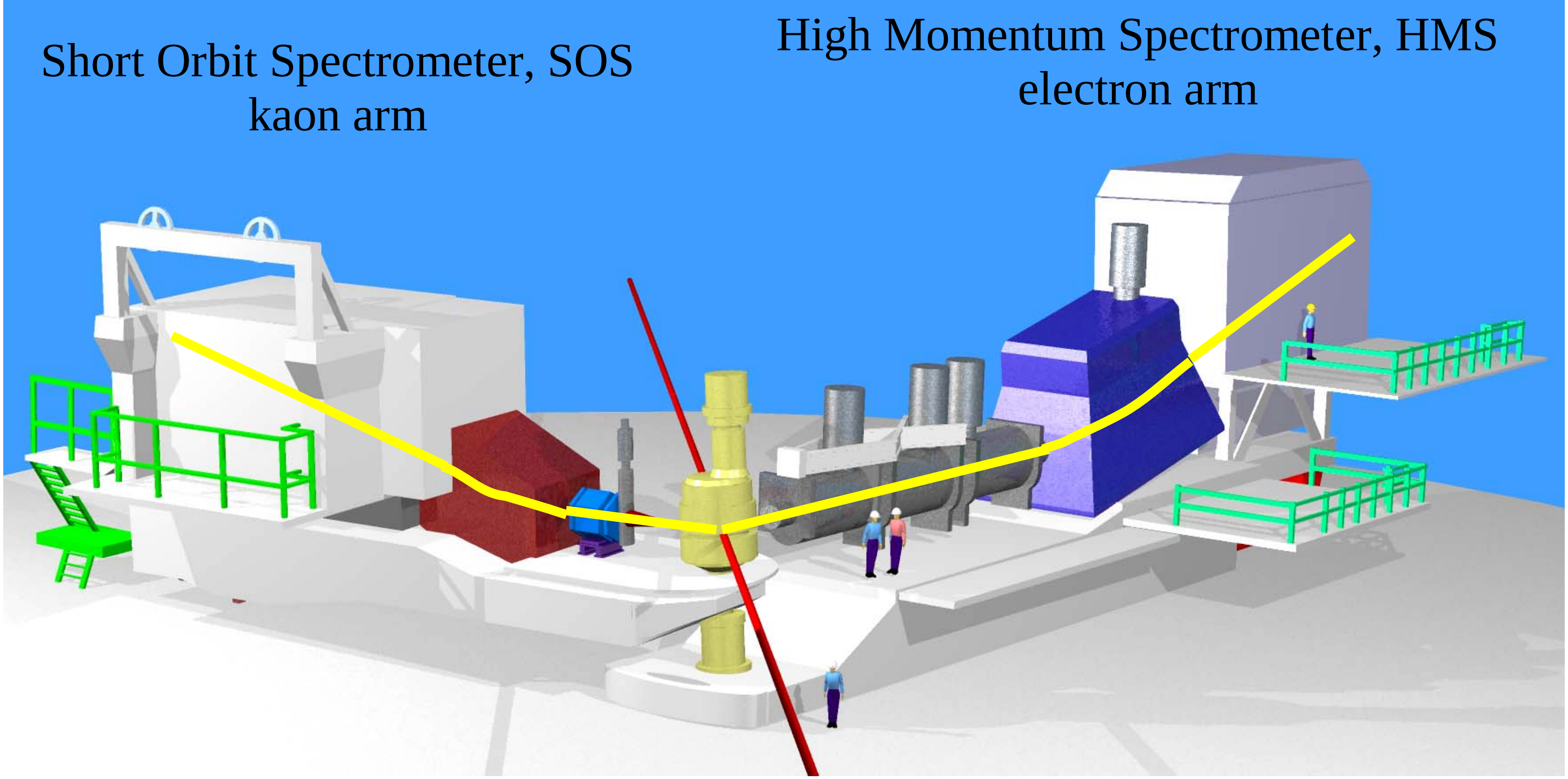
Frank Dohrmann, Forschungszentrum Rossendorf, Dresden

# Motivation

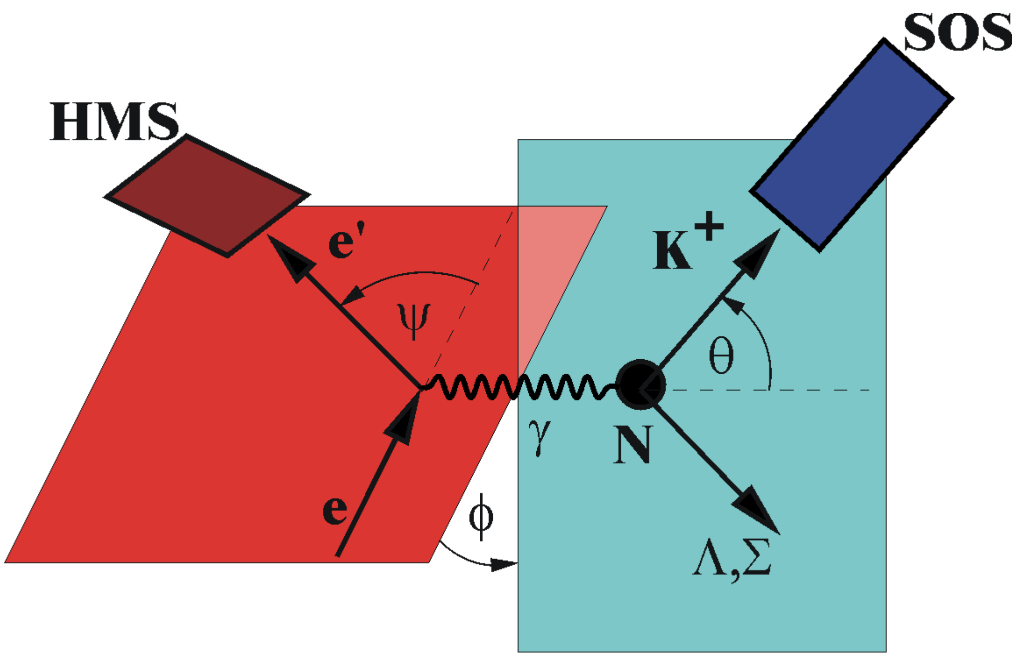
- Electroproduction of kaons is an efficient tool for investigating fundamental baryonic interactions in the nuclear medium
- New $^{1}H(e,e'K)Y$ data for new, improved models
- No data for electroproduction on $^{3}He$, $^{4}He$ exists
- $A(e,e'K)Y$ for $^{1}H$, $^{2}H$, $^{3}He$, $^{4}He$
  - A-dependence of kaon electroproduction cross section
- Bound hypernuclear states for A=3,4, è lightest hypernuclei



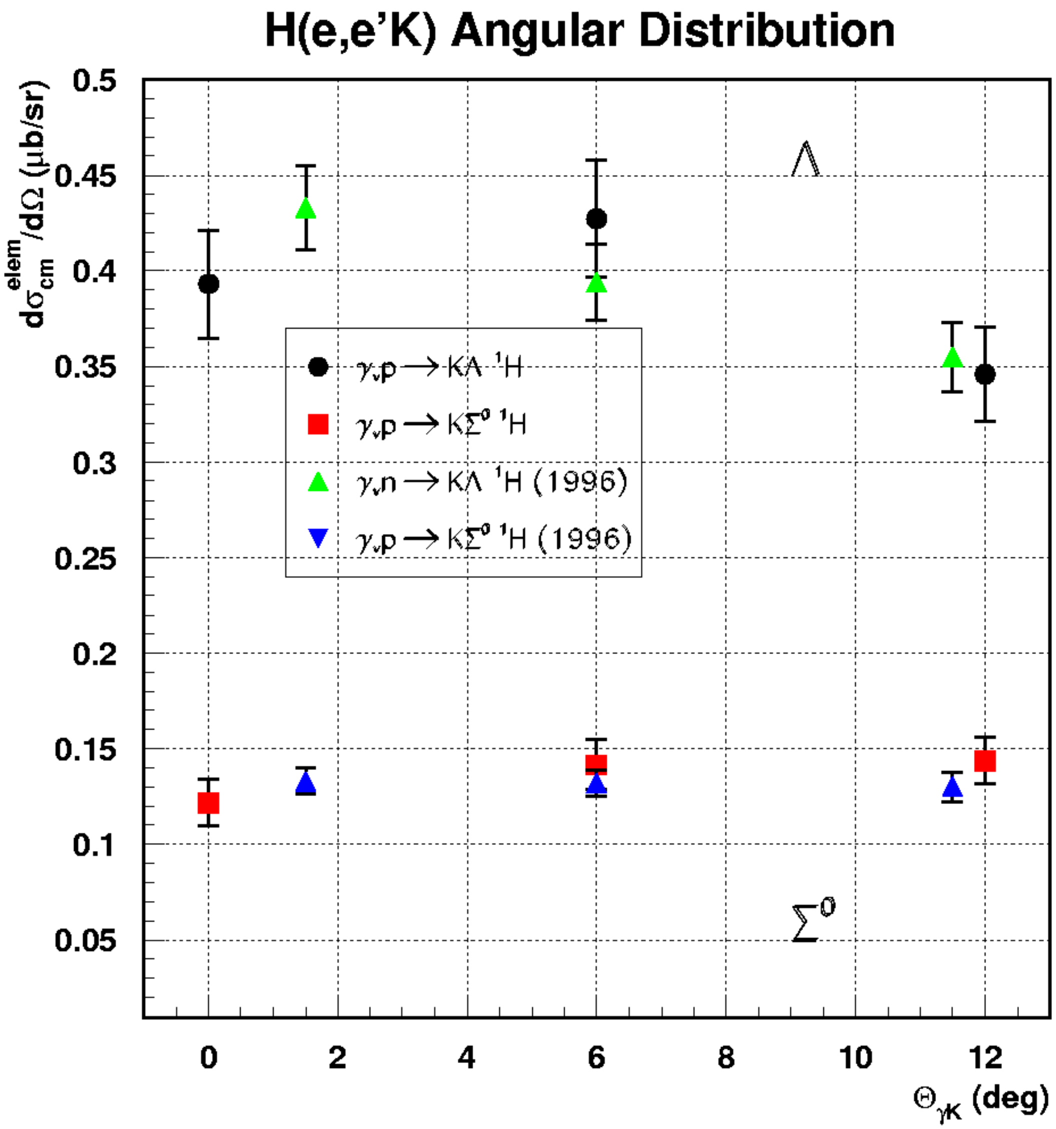
# Hall C Spectrometers



# Experimental Program

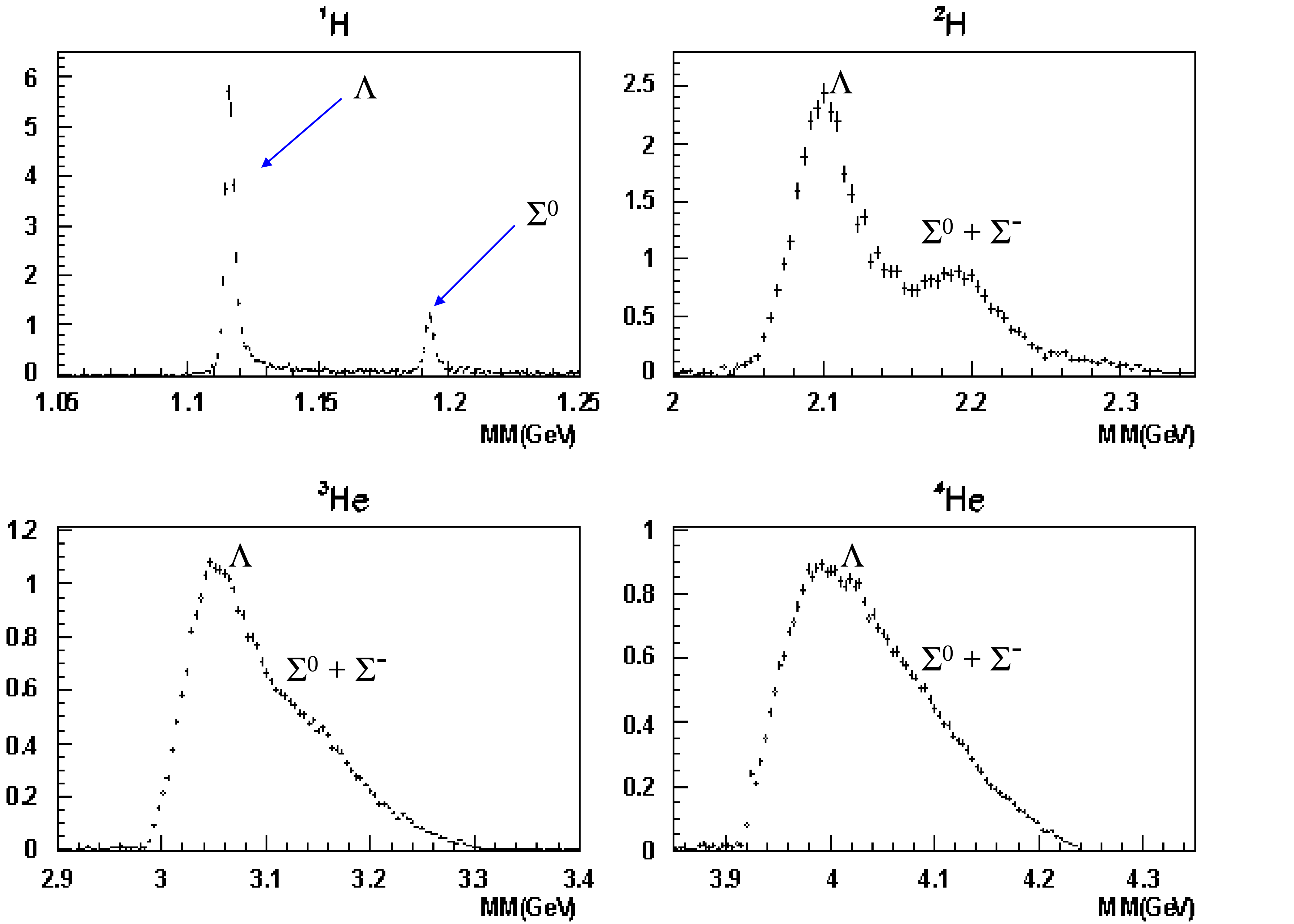



| | Kinematics | |
|---|---|---|
| ***Targets 1996*** | **$^{1}$H, $^{2}$H, C, Al** | |
| | ($Q^2$($GeV^2$), W(GeV)) | $\theta_{\gamma K}$,lab ($^{o}$) |
| Ebeam=3.245 GeV | (0.38,1.90) | (1.5, 6.0, 11.5) |
| ***Targets 1999*** | **$^{1}$H, $^{2}$H, $^{3}$He, $^{4}$He, C, Al** | |
| | ($Q^2$($GeV^2$), W(GeV)) | $\theta_{\gamma K}$,lab ($^{o}$) |
| Ebeam=3.245 GeV | (0.35, 1.91) | (0.0, 6.0, 12.0) |




Hydrogen Data ´96 and ´99

- Good agreement between independent measurements
- He(e,e'K) data is used for
  - own model development
  - normalization
  - calibration
- Data represents high statistics and high quality electro- production data on hydrogen.



$^1$H
Λ
$\Sigma^0$
MM(GeV)
$^2$H
Λ
$\Sigma^0 + \Sigma^-$
MM(GeV)
$^3$He
Λ
$\Sigma^0 + \Sigma^-$
MM(GeV)
$^4$He
Λ
$\Sigma^0 + \Sigma^-$
MM(GeV)

# Effective Range Ansatz

For A(e,e'K), A=2,3,4:

Effective range Ansatz

$$k \cdot \cot d^{0} = \frac{1}{a} + r_e \cdot \frac{k^2}{2} + O(k^4) \qquad k = k_{\mathrm{YN}}$$

Calculate singlett and triplett s-wave enhancement factor I using inverse Jost Function

$$s = I \cdot s_0 \quad I = \frac{1}{J^* J} = \frac{k^2 + a^2}{k^2 + b^2} \quad J = \frac{k - ia}{k - ib}$$

$$\text{with } 0.5 \cdot r_e \cdot (b - a) = 1 \;,\; 0.5 \cdot r_e \cdot a \cdot b = \frac{1}{a}$$

Scattering length a and effective range $r_e$ are given by hypernuclear potential such as Nijmegen 97f or Jülich A

# Simulation of Production off Nuclear Targets (SIMC)

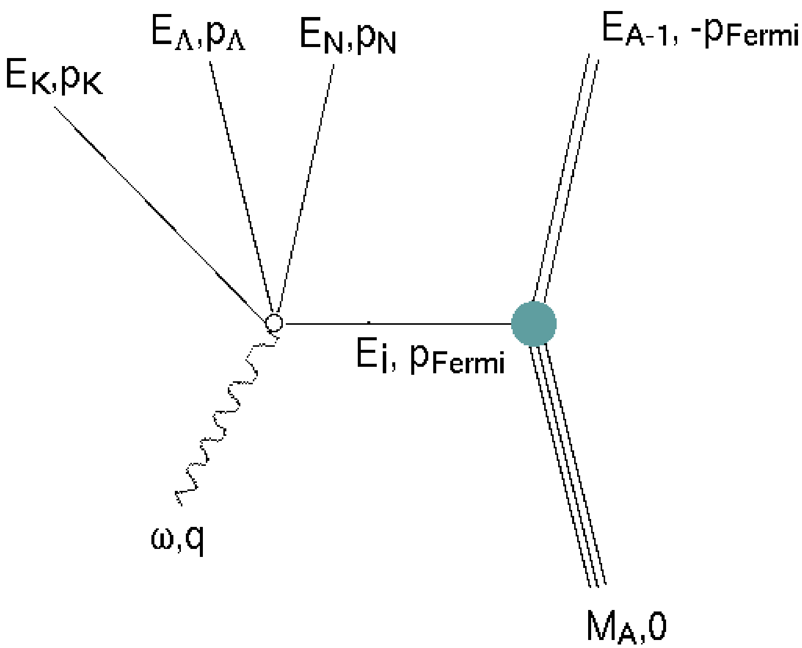
- Beam energy fixed (allow smearing)
- e' quantitites and $K^+$ angles are thrown flat
- production on free proton:
- $|p_K|$ fixed by E and p conserv.
- production on nuclear target: A=2
- assume production on a single nucleon while the others are fixed (impulse approx.)
- throw $p_{Fermi}$ using momentum space wave function (Bonn potential)

$$E_t = M_d - \sqrt{m^2{}_{spectator} + p^2{}_{Fermi}}$$

- For A>2: How to treat relative momentum of spectators ?
- Use spectral function P(k,E):
- P(k,E) represents the probability to find in a nucleus a nucleon of momentum k and removal energy E
- Use spectral function by Benhar et al (NPA 579(1994) 493)
- also tried Atti et al (PRC 53(1996) 1689) with similar results.

SIMC created by Tom O'Neill, Naomi Makins, John Arrington and many others.

M.Debowski et al: ZPA 356 (1996) 315



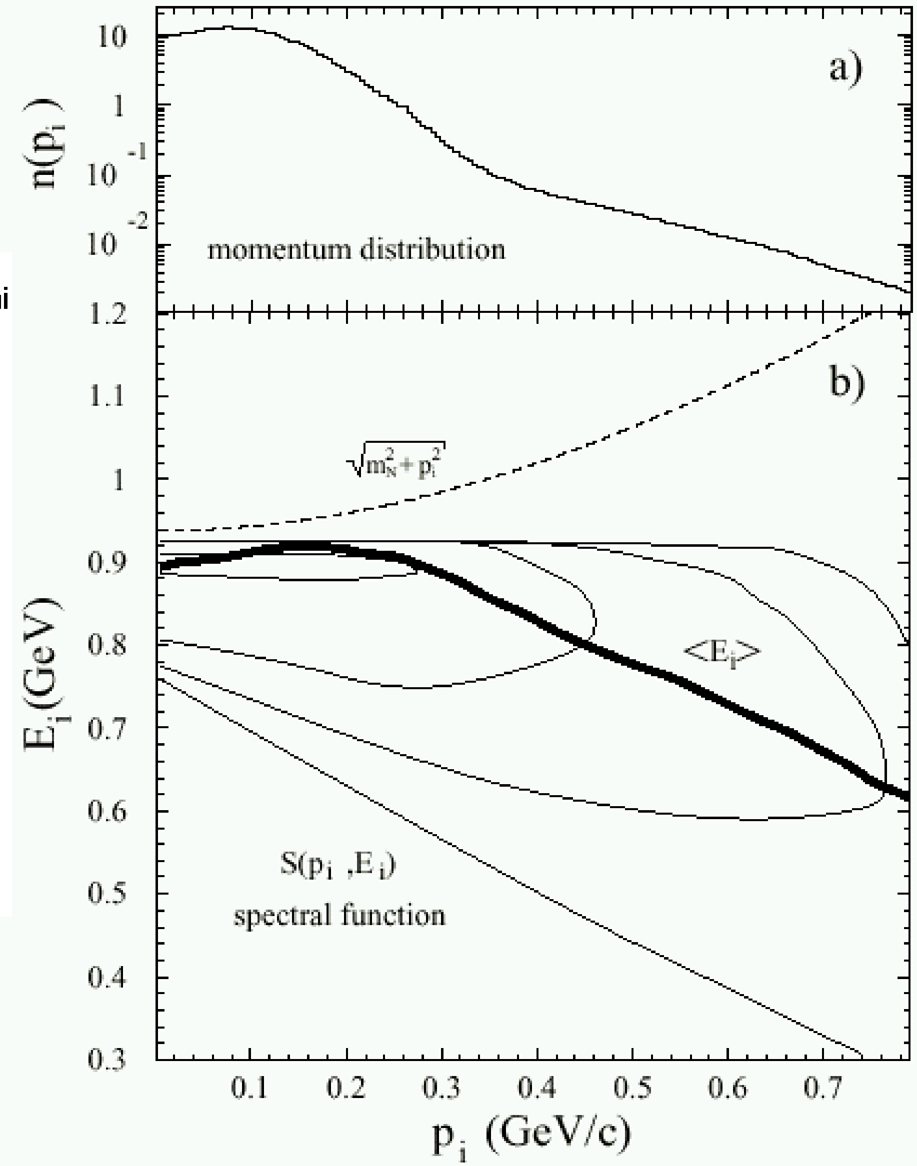
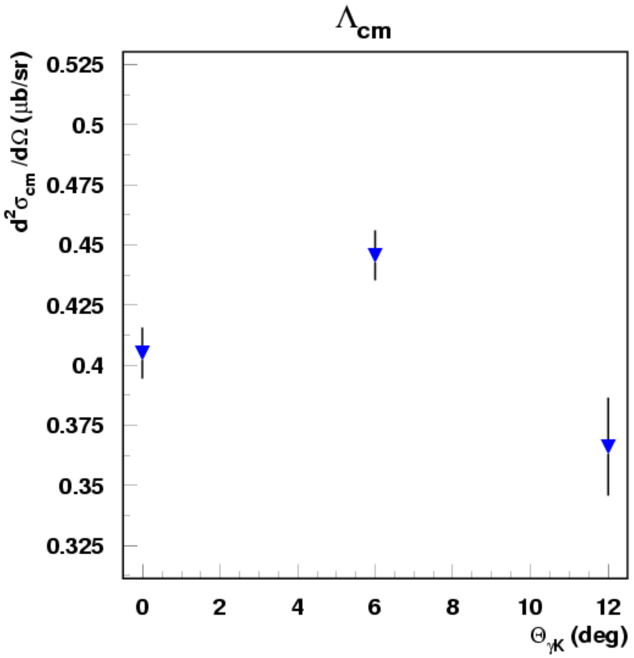
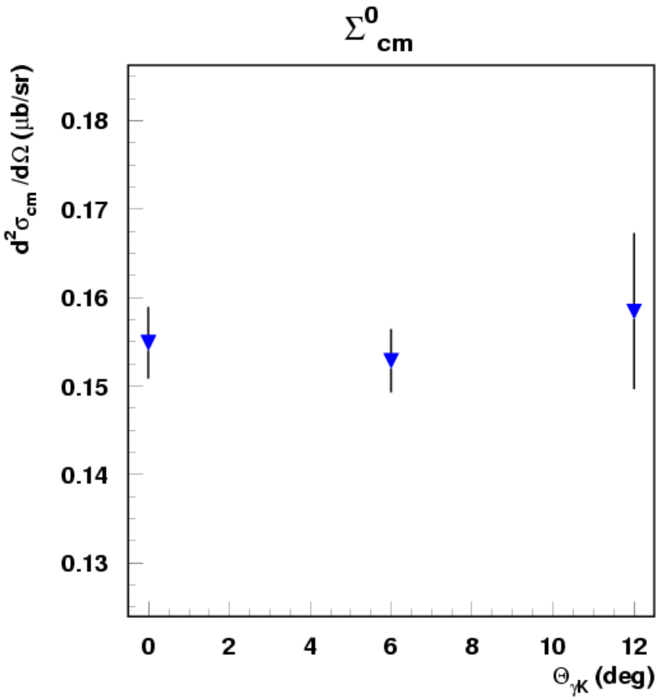
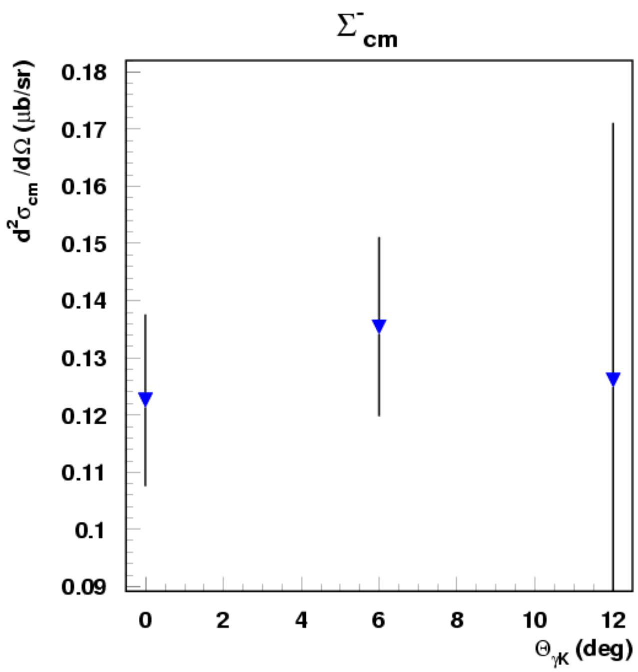




**Fig. 16.** Momentum distribution of nucleons in the nucleus **(a)** and the spectral function for the same nucleus **(b)**, as calculated by Sick *et al.* [35]. The thick solid line is the ridge of the distribution. The dashed line correspond to the free space energy

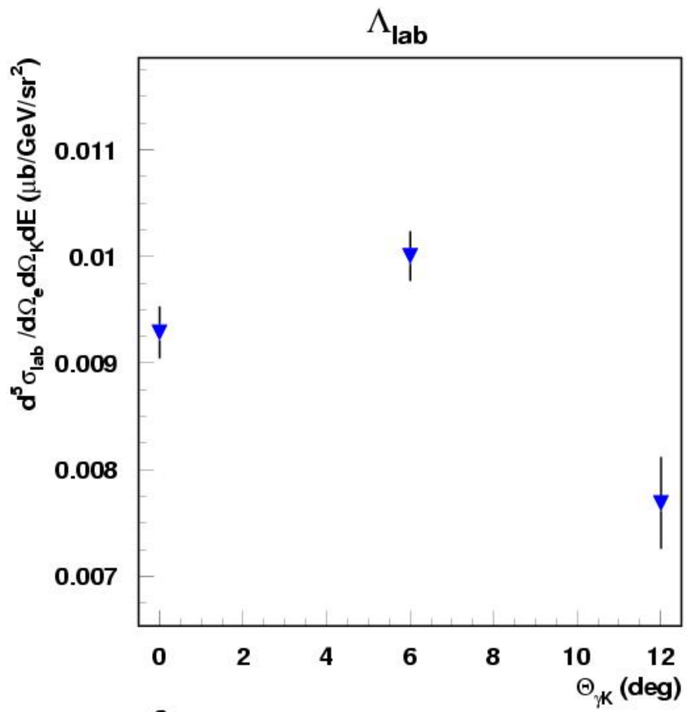
# Elementary Cross Sections for $^3$He

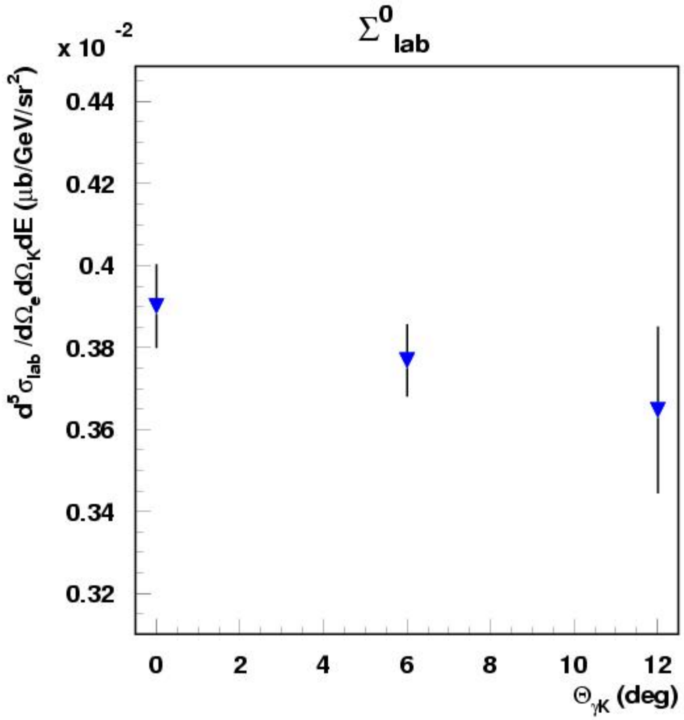


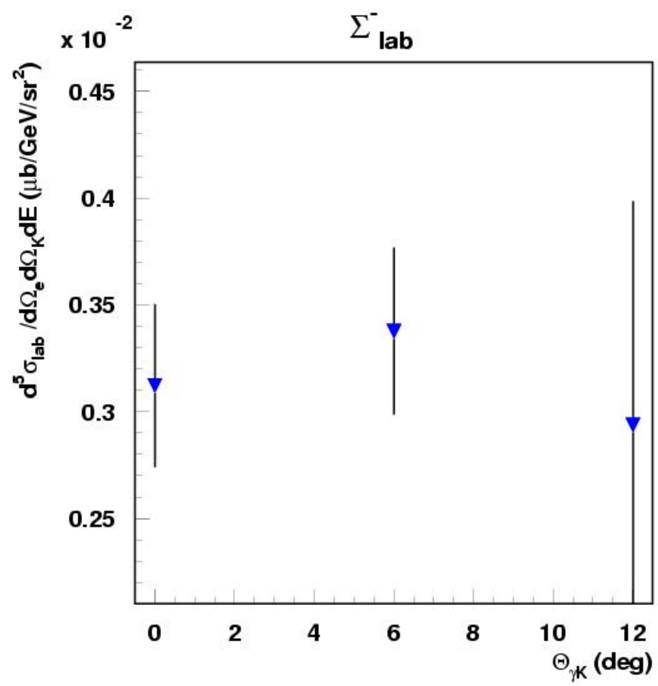



# Elementary Cross Sections for $^3$He



# Bound L-Hypernuclear States for He

**A=3**

$^{3}{}_{L}$**H** ***(Hypertriton)*** **B (1/2)$^{+}$ =130 keV**

**A=4**

$^{4}{}_{L}$**H** **$B_{ground}$ (0$^{+}$)= 2.04 ± 0.04 MeV**

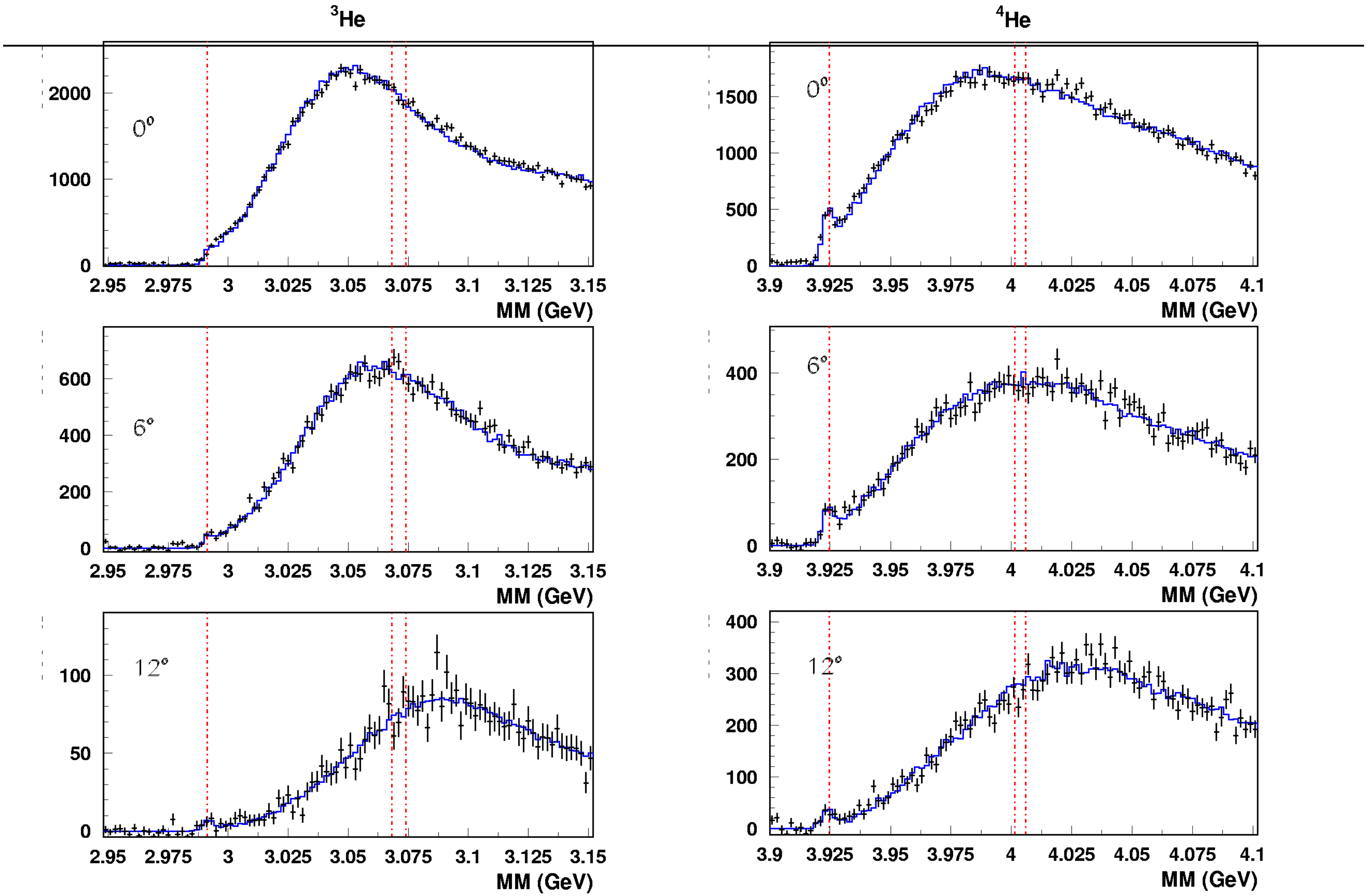
**$B_{excited}$ (1$^{+}$)= 1.00 ± 0.06 MeV**

Ø **Production Mechanism are different:**

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

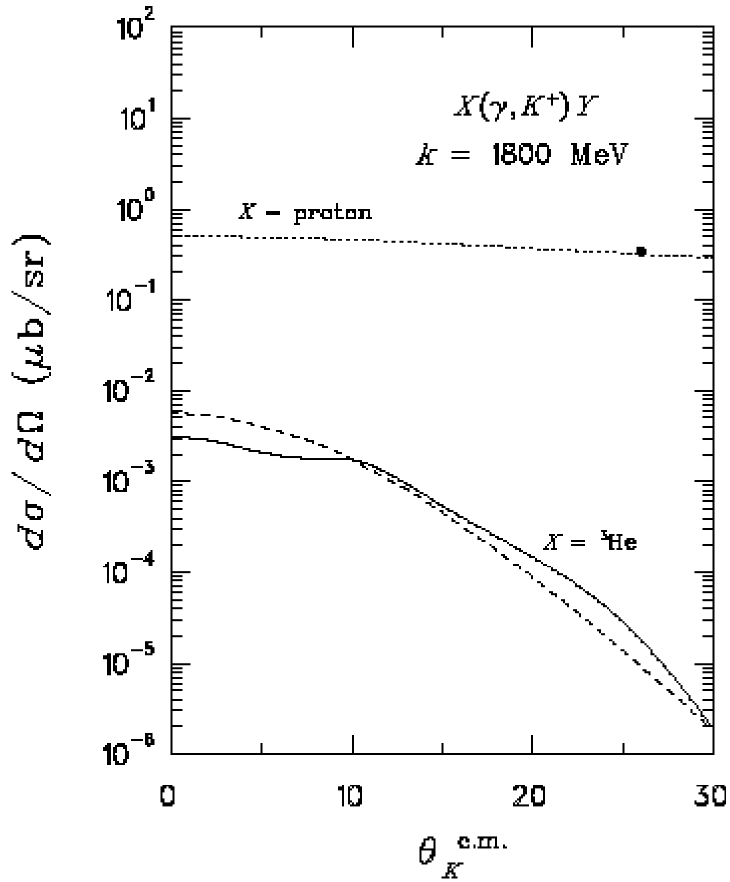
**(p,K)** **substantial momentum transfer,**
**may excite higher spin states,**
**medium spin flip strength**

Ø **(g$^{*}$,K)** **Large momentum transfer,**
**large spin flip strength**



$^3$He
$^4$He
0°
6°
12°
0
1000
2000
200
400
600
50
100
500
1500
300
2.95
2.975
3
3.025
3.05
3.075
3.1
3.125
3.15
3.9
3.925
3.95
3.975
4
4.025
4.05
4.075
4.1
MM (GeV)

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




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

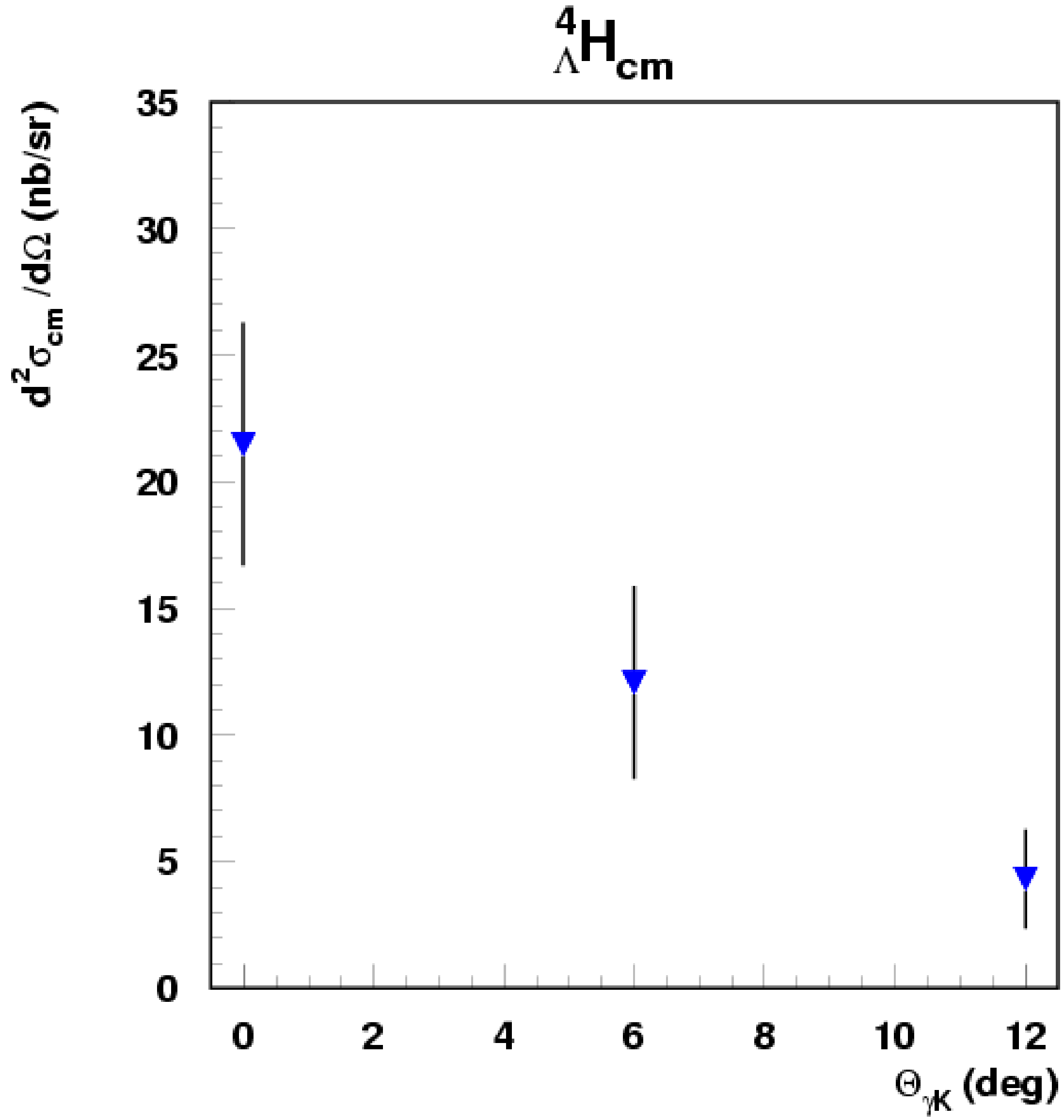
$$F(Q) = \int d^3\boldsymbol{q}\, d^3\boldsymbol{p}\, \Psi_{{}^3_\Lambda{\rm H}}(\boldsymbol{p}, \boldsymbol{q} + \tfrac{2}{3}\boldsymbol{Q}) \Psi_{{}^3{\rm He}}(\boldsymbol{p}, \boldsymbol{q})$$

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

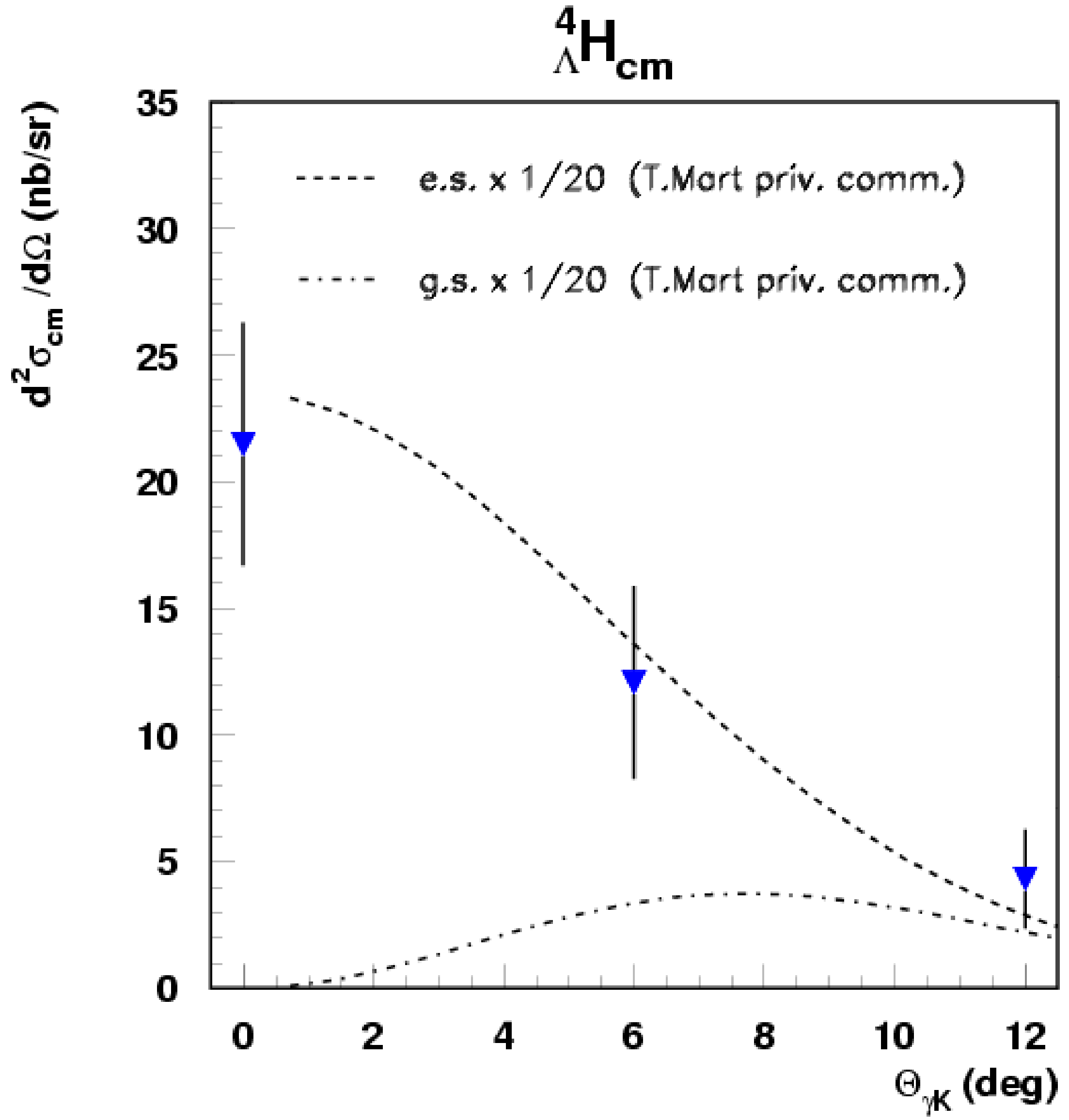
*Cross section is kinematic factor times overlap integral times elementary cross section*

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.

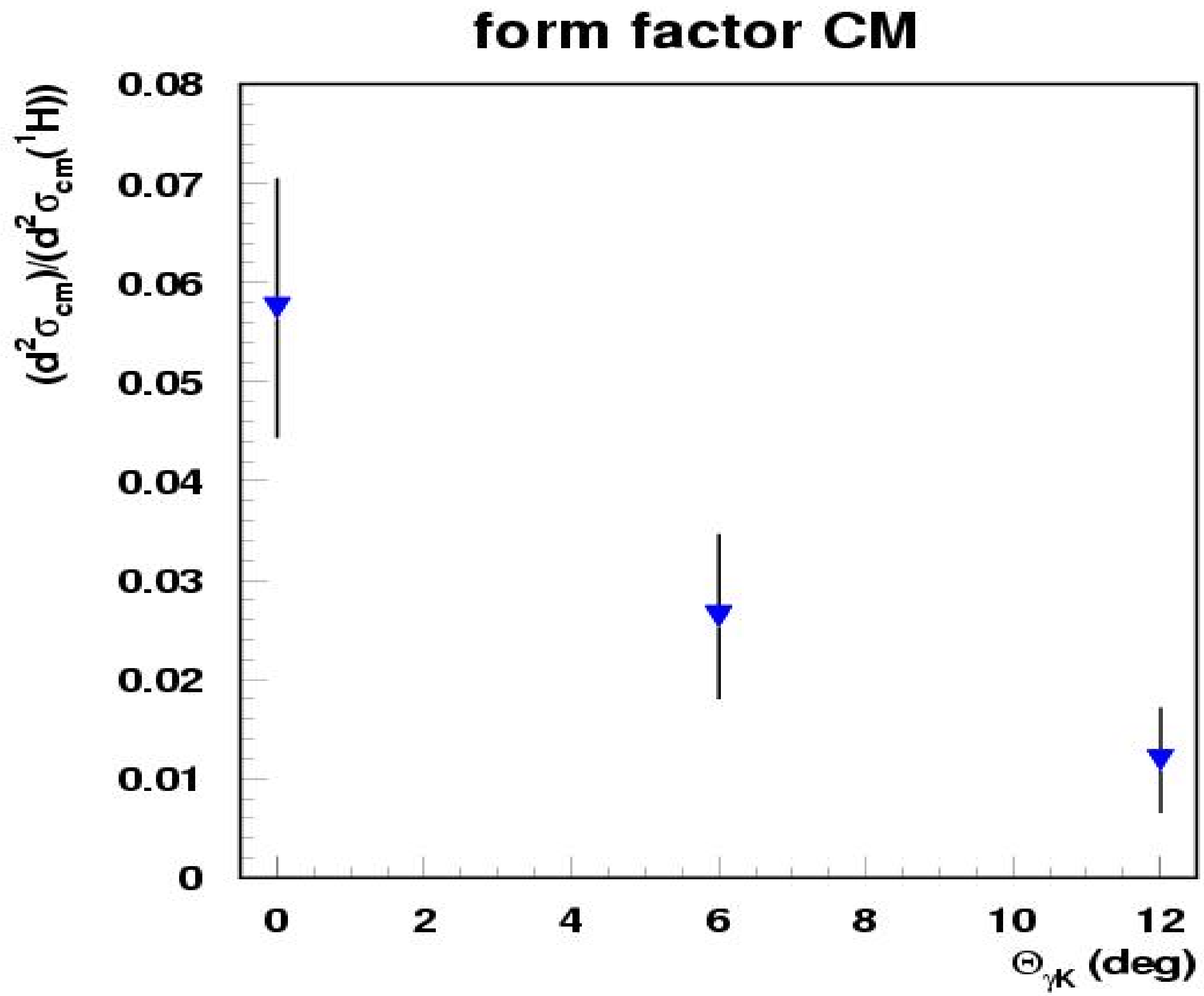
# Bound Λ-Hypernuclei A=4



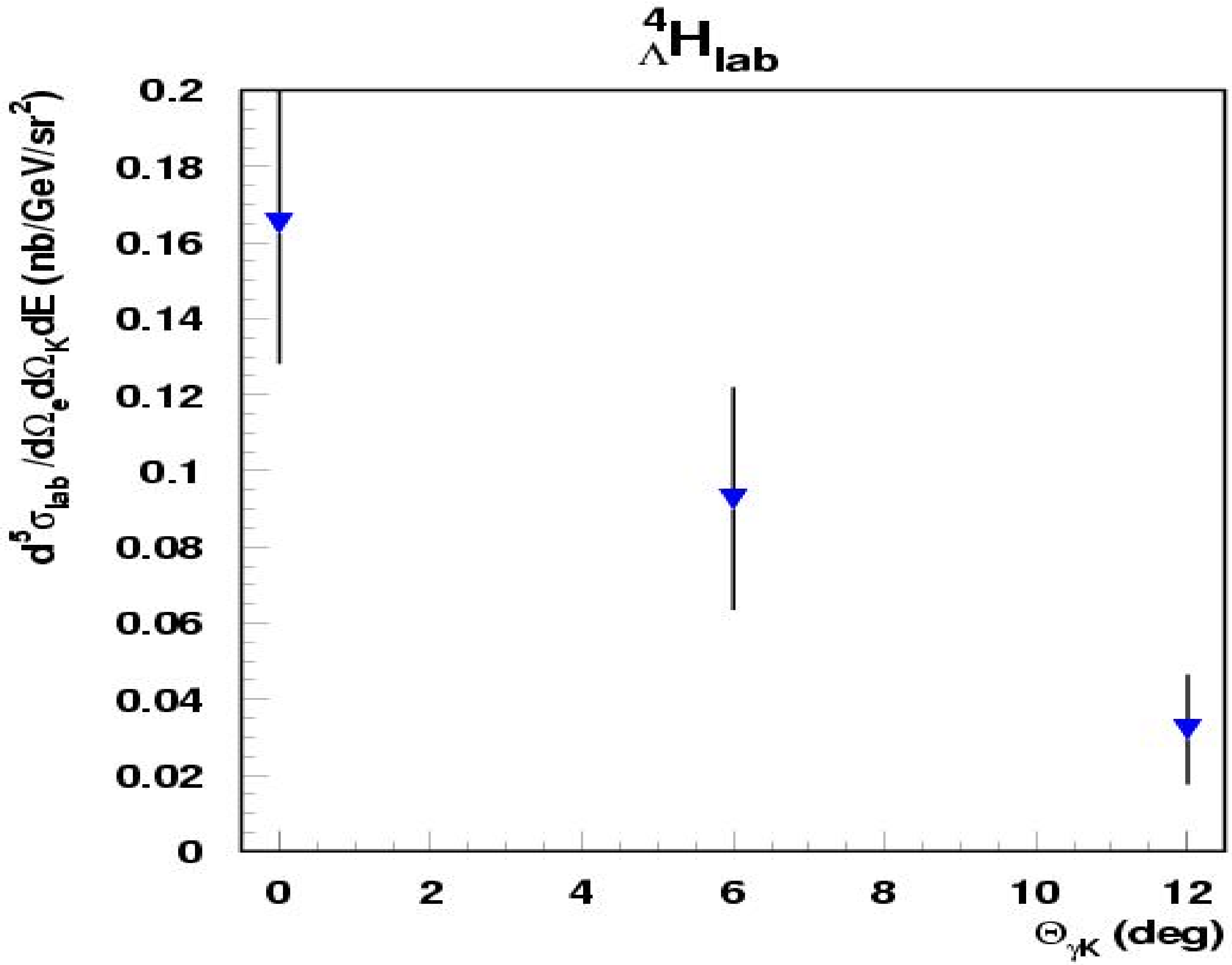
# Bound Λ-Hypernuclei A=4



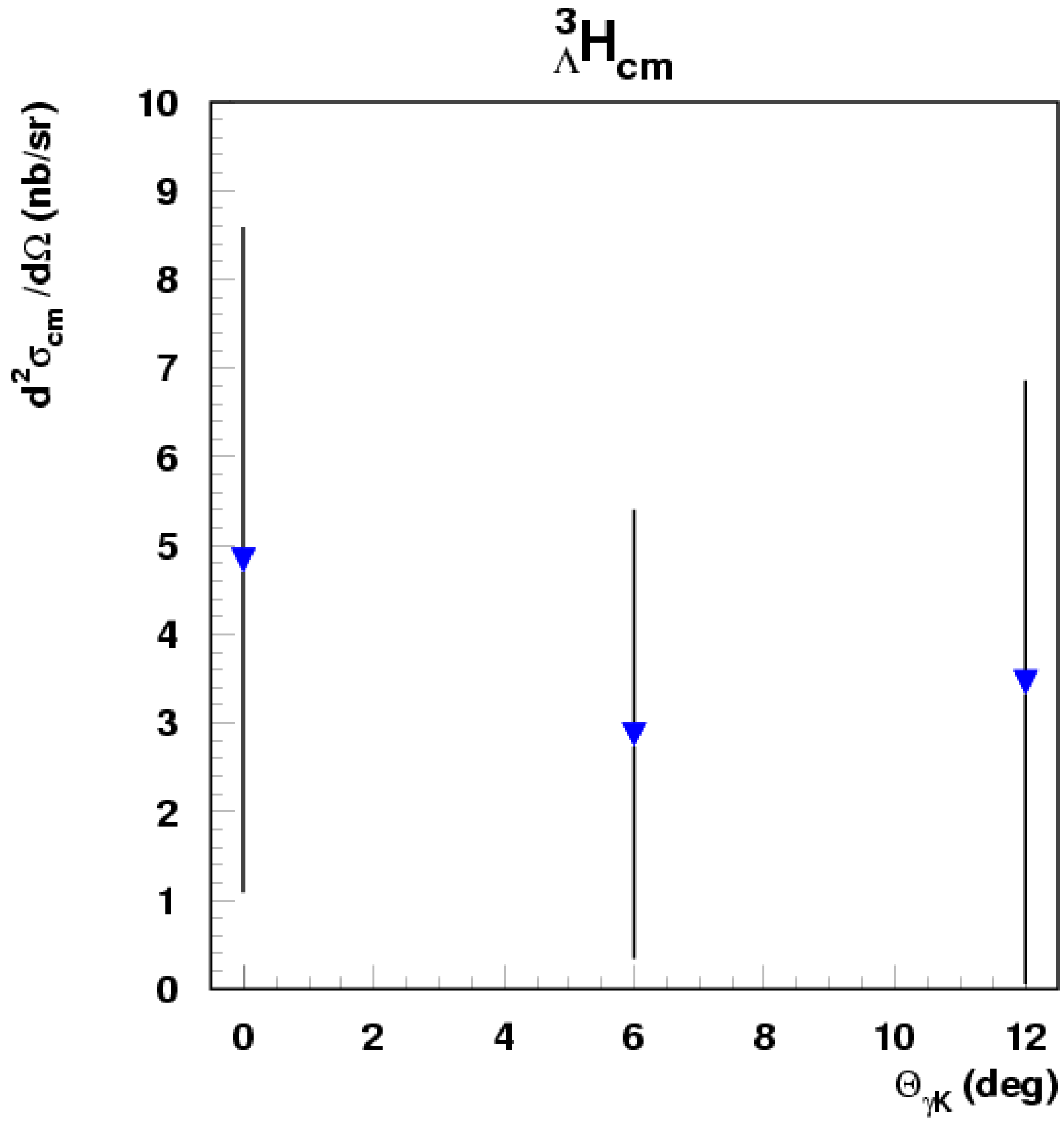
# Bound Λ-Hypernuclei A=4



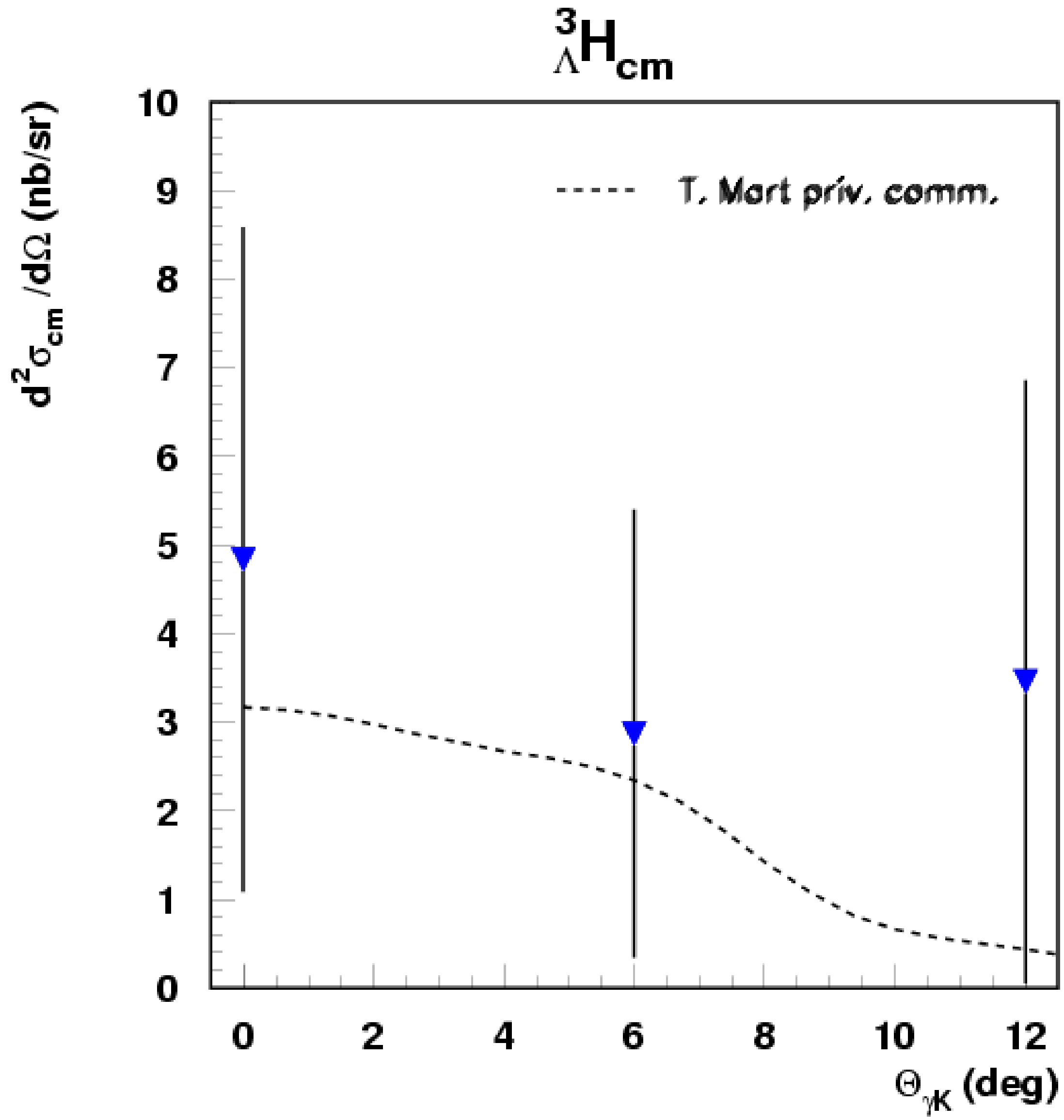
# Bound Λ-Hypernuclei A=4



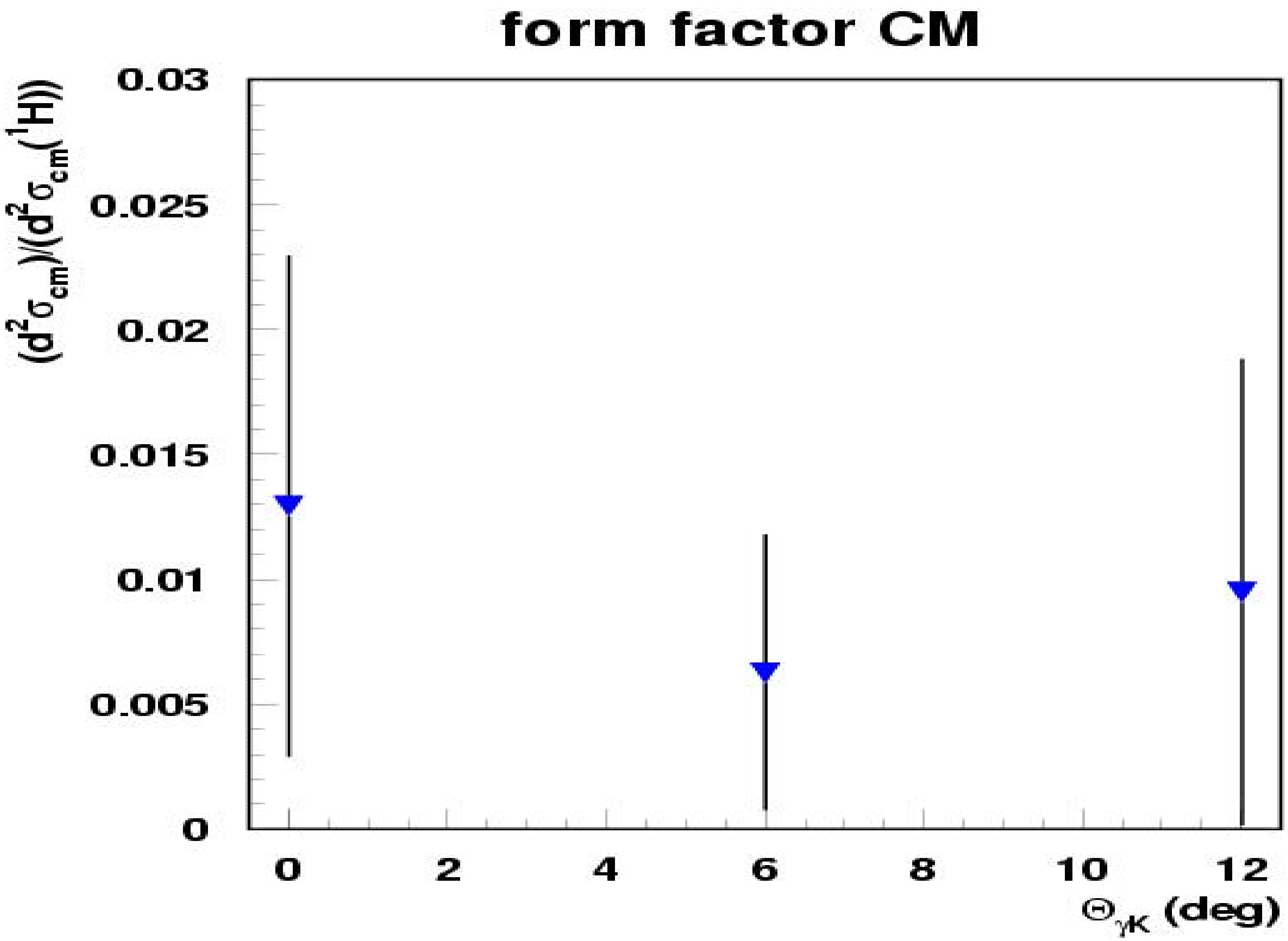
# Bound Λ-Hypernuclei A=3



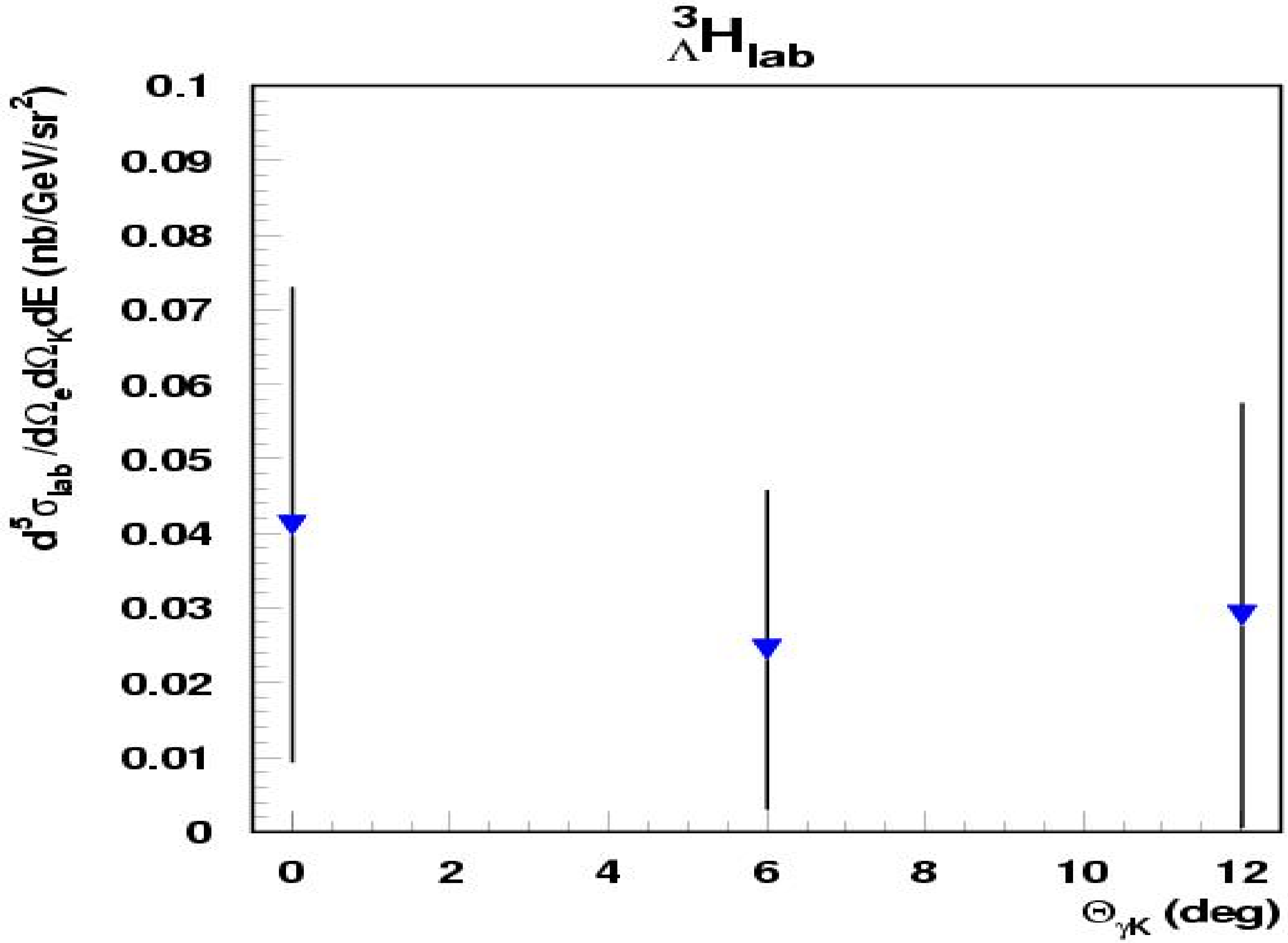
# Bound Λ-Hypernuclei A=3



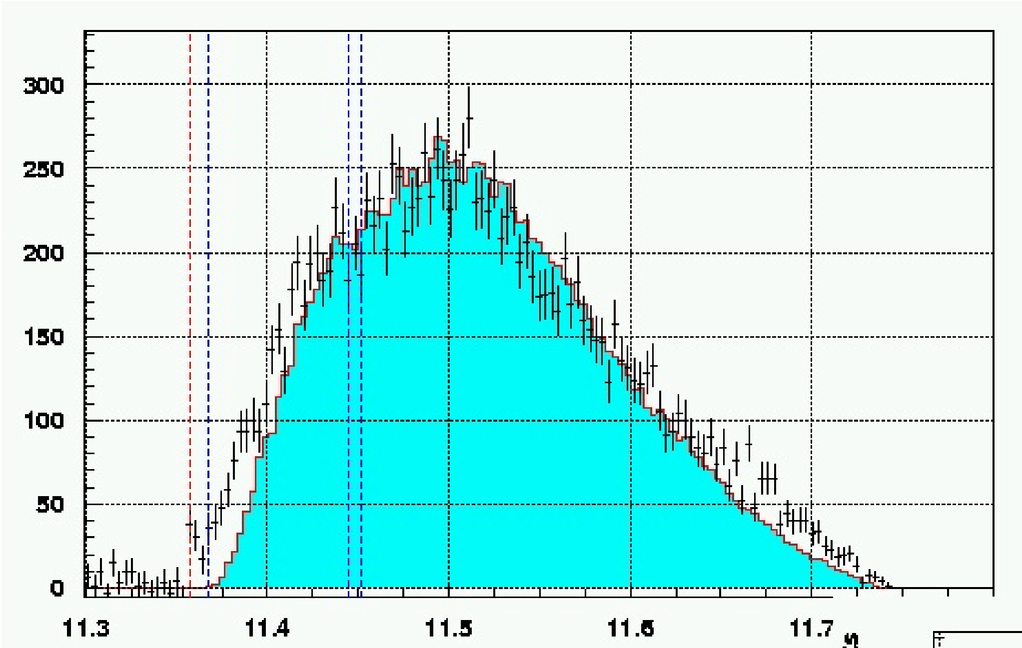
# Bound Λ-Hypernuclei A=3

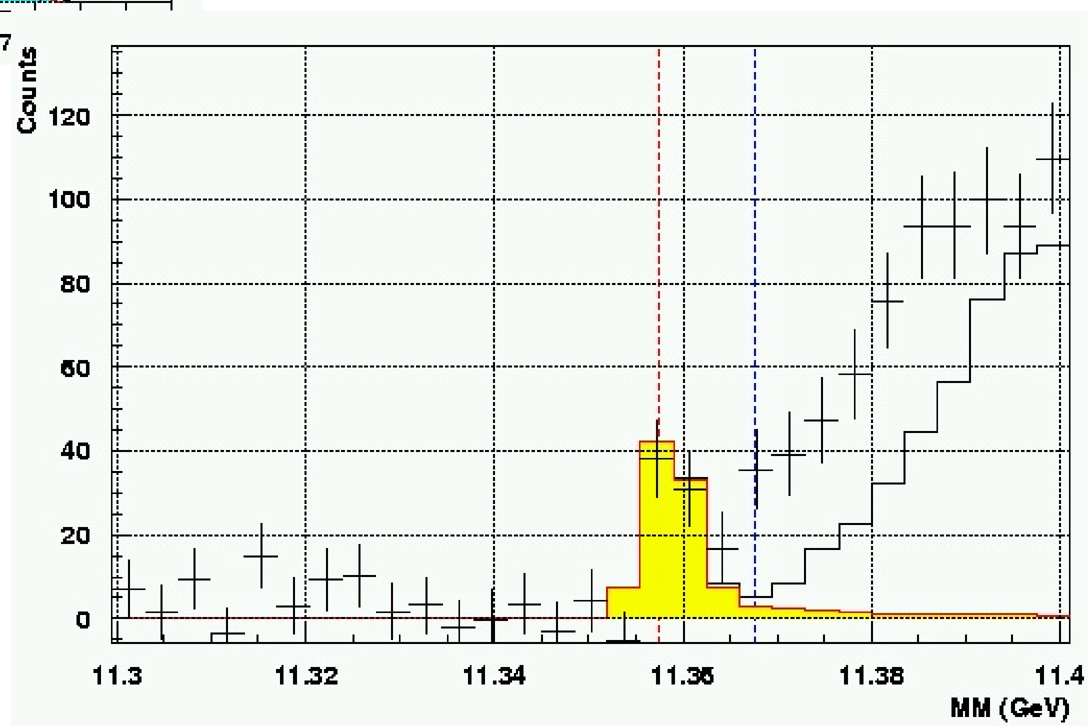


# Bound Λ-Hypernuclei A=3



# MMCarbon with ${}^{12}_{\Lambda}B$ Boundstate



Preliminary A-dependence for A(e,e'K)Y for different targets.

Thesis: AliciaUzzle, Hampton Univ. 2001

...this is work in progress

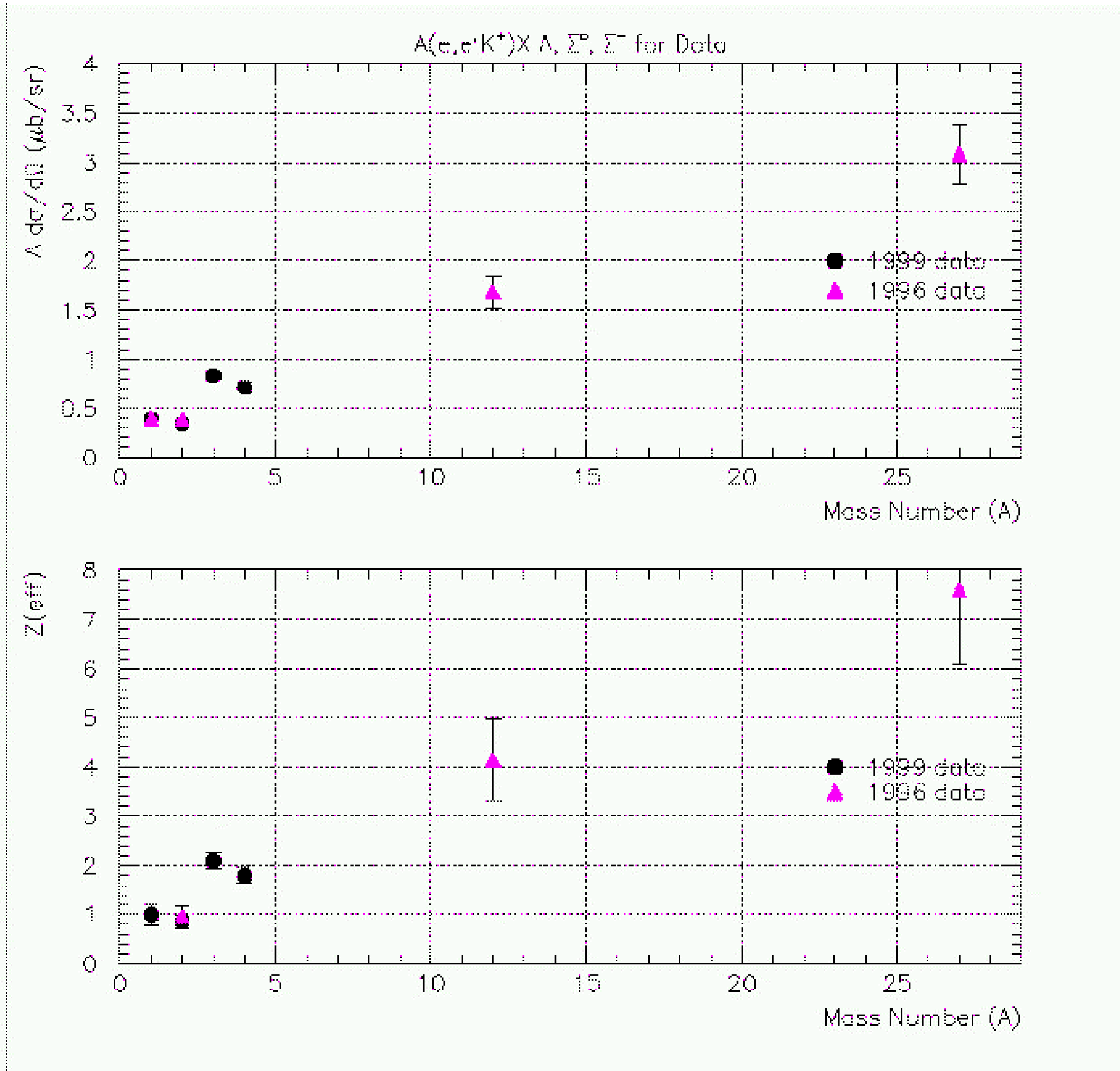



Figure 5.27: The $\Lambda$ cross section and effective proton number for $\theta_{\gamma K} = 0^o$. Shown are the present data and 1996 kaon electroproduction data which includes the aluminum and carbon targets.

# Summary and Outlook

- A(e,e'K) for A=3,4,(12) has been measured at low $Q^2$.
- FSI (effective range approx.) yields satisfactory description using Nijmegen YN 97f.
- Spectral functions (Benhar et al) are essential for the analysis of data on nuclear targets.
- Statements on separated quasifree $\Sigma^{0,-}$ contributions require strong assumptions.
- $^{4}He(e,e'K)\Lambda$ and $^{3}He(e,e'K)\Lambda$ data clearly indicate $^{4}H_{\Lambda}$ and $^{3}H_{\Lambda}$ bound states.
- First measurement in electroproduction.
- Indication of $^{12}B_{\Lambda}$ boundstate.

## Jefferson Lab E91-016 Collaboration: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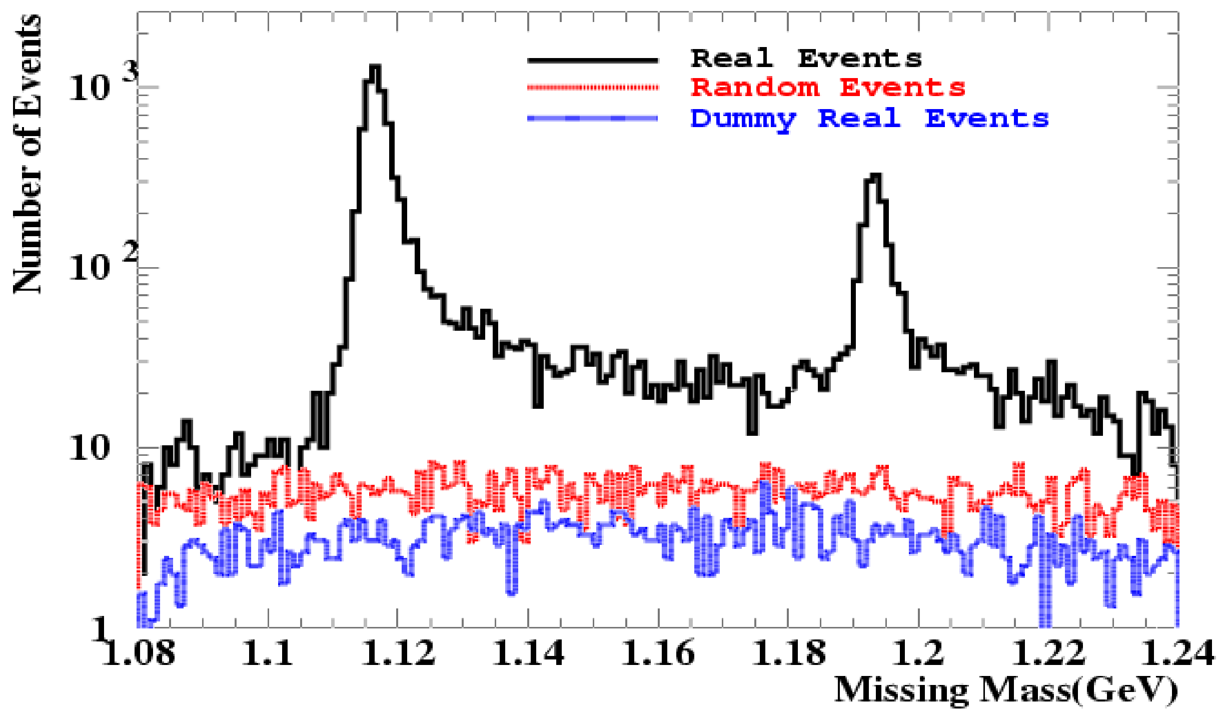
[a]Florida International University, [b]Thomas Jefferson National Accelerator Laboratory, [c]Argonne National Laboratory, [d]NC A&T State University, [e]Kent State University, [f]Hampton University, [g]Temple University, [h]College of William and Mary, [i]California Institute of Technology, [j]Yerevan Physics Institute, [k]University of Maryland, [l]University of Virginia, [m]Juniata College, [n]Forschungszentrum Rossendorf, [o]Northwestern University, [p]Southern University at New Orleans, [q]University of Pennsylvania, [r]Tohoku University, [s]University of Minnesota, [t]Old Dominion University, [u]American University, [v]Ohio University, [w]The George Washington University, [x]Rensselaer Polytechnic Institute, [y]University of Houston, [z]Duke University, [+]University of Illinois

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

$$\left.\begin{aligned} \vec{p}_e + \vec{p}_p &= \vec{p}_{e'} + \vec{p}_K + \vec{p}_{miss} \\ E_e + E_p^0 &= E_{e'} + E_K + E_{miss} \end{aligned}\right\} \quad m_{miss}^2 = E_{miss}^2 - p_{miss}^2$$



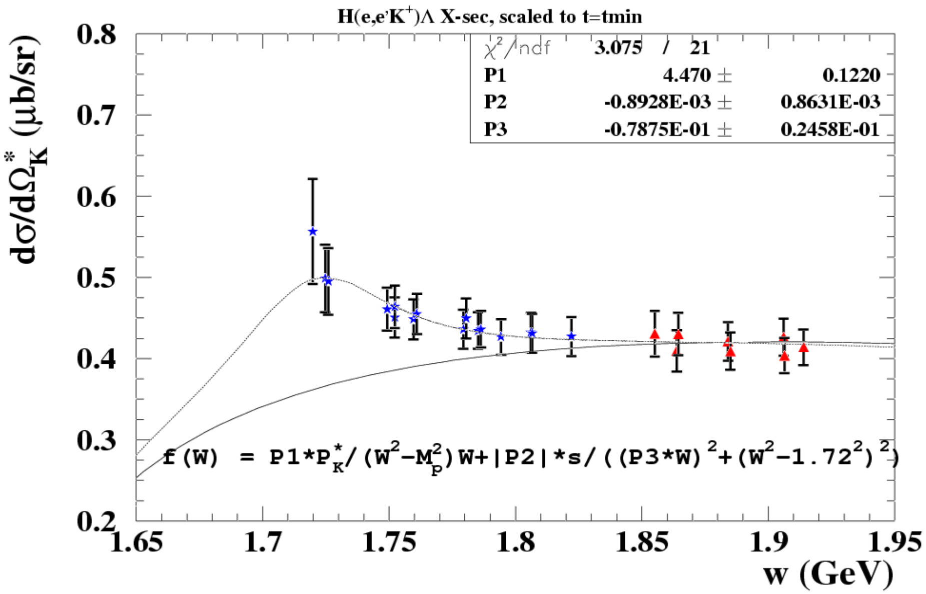
# Cross-Section Parametrization

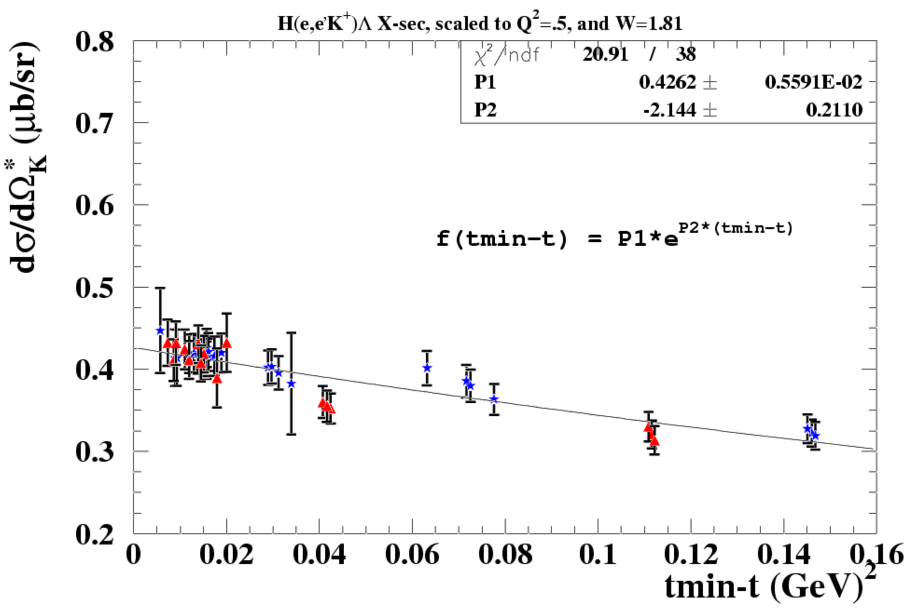
$$f(Q^2) = Constant$$

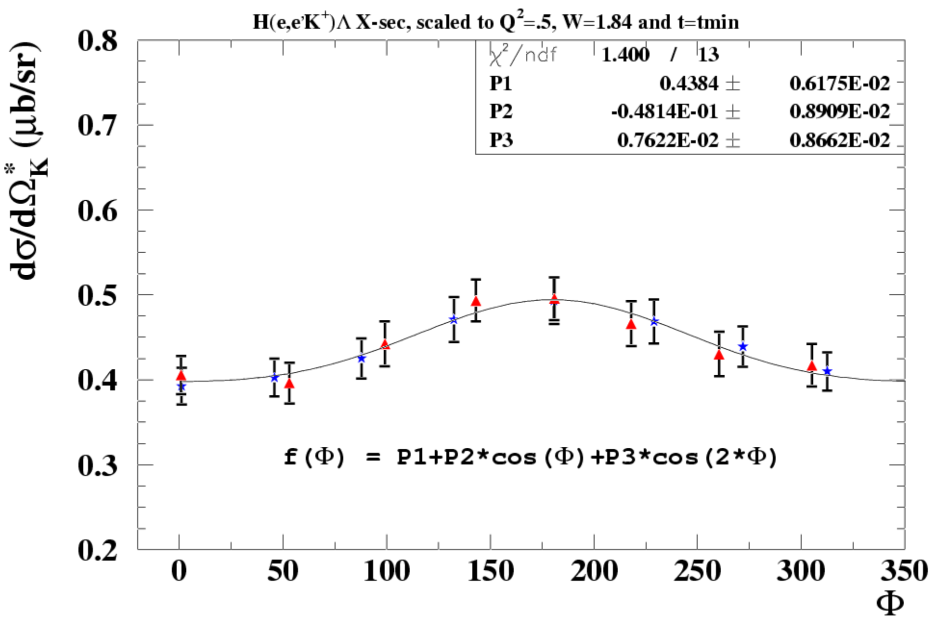
$$g(W) = \frac{P_1 P_k^{CM}}{(W^2 - M_p^2)W} + \frac{P_2 W^2}{(P_3 W)^2 + (W^2 - P_4^2)^2}$$

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

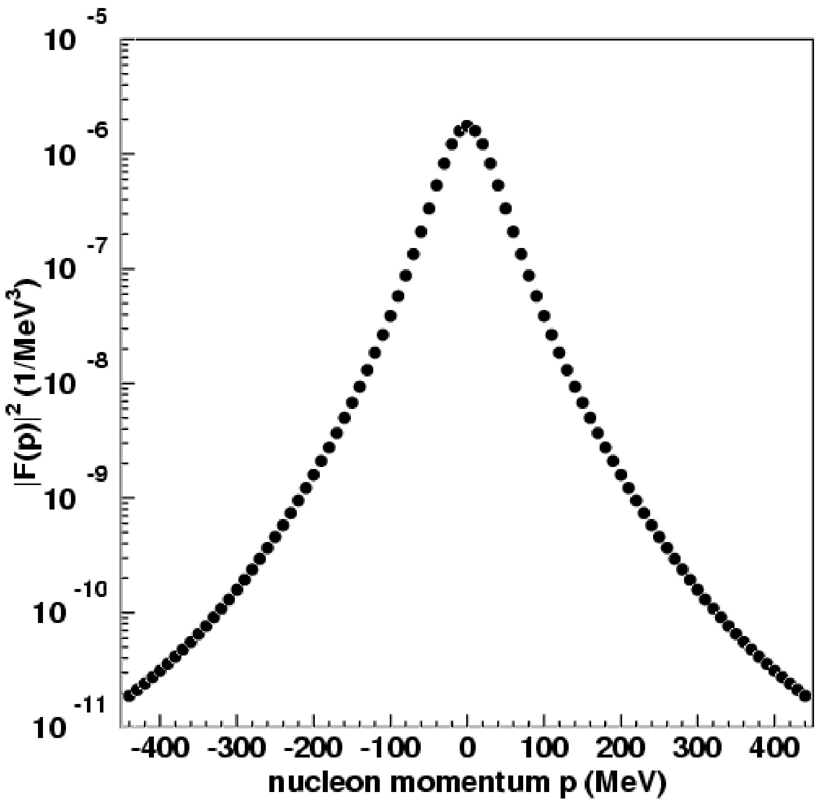
$$i(\phi) = P_1 + P_2\cos(\phi) + P_3\cos(2\phi)$$

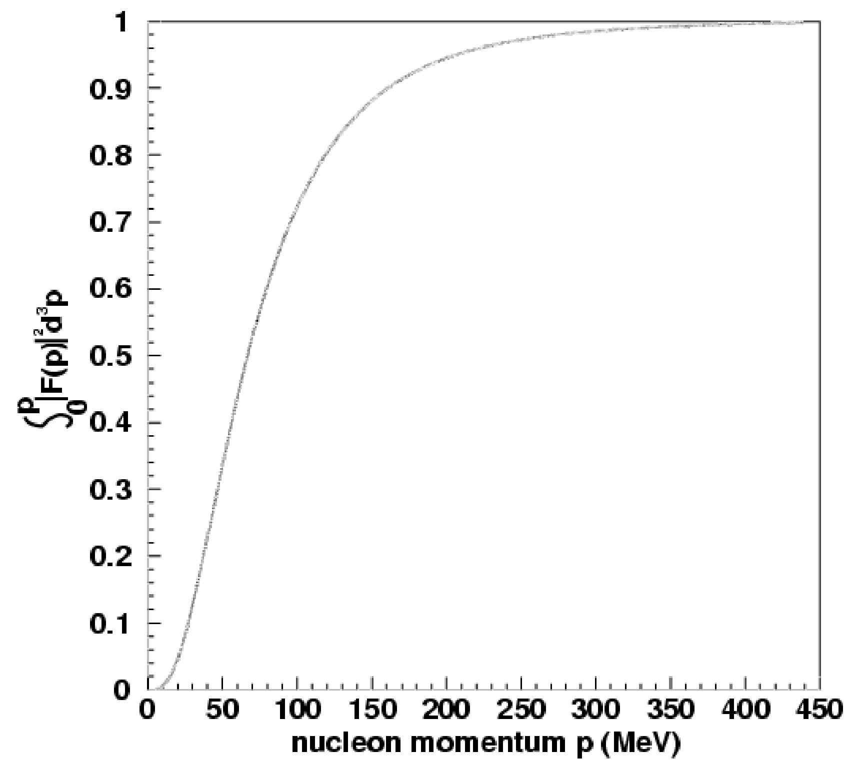


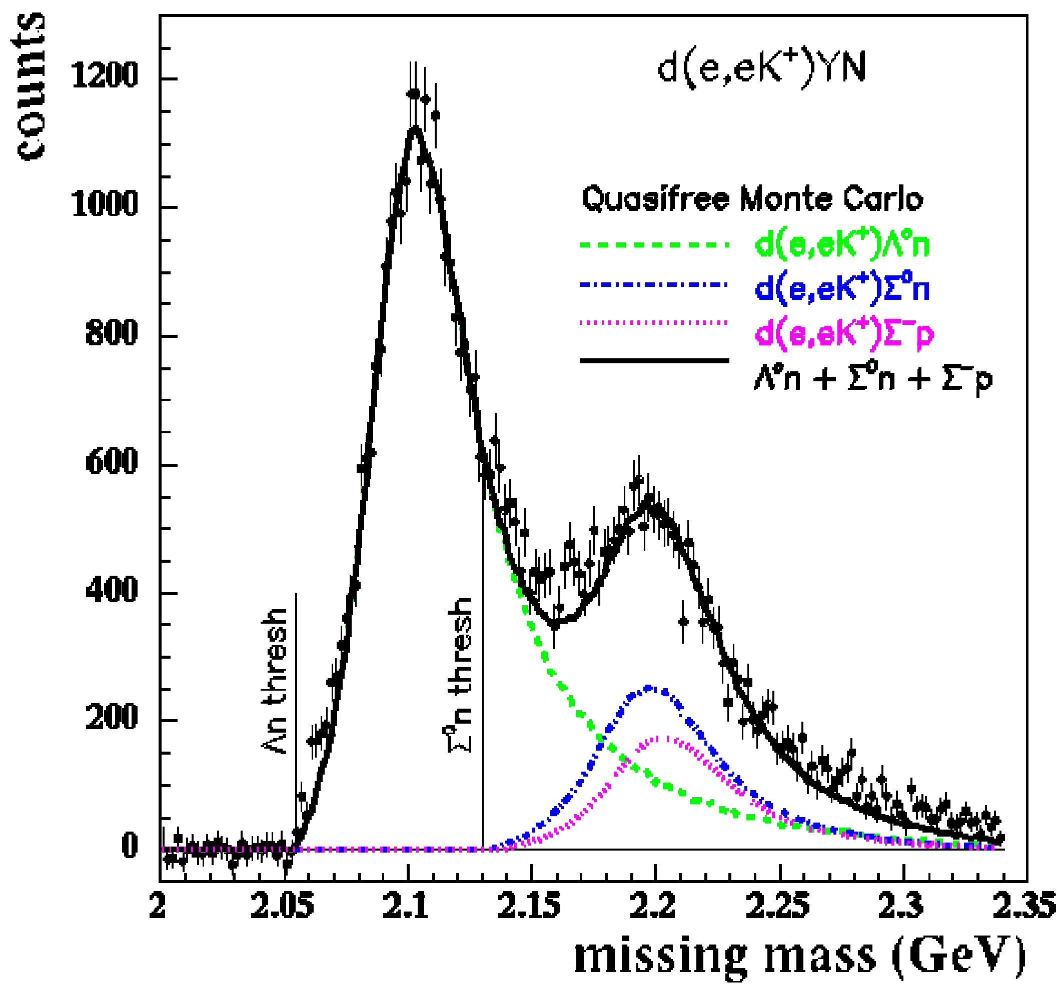



# Momentum Wavefunction (Bonn potential)



# $^2H(e,e'K^+)$



counts
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
0
200
400
600
800
1000
1200
2
2.05
2.1
2.15
2.2
2.25
2.3
2.35
missing mass (GeV)

# Modeling of FSI

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

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

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

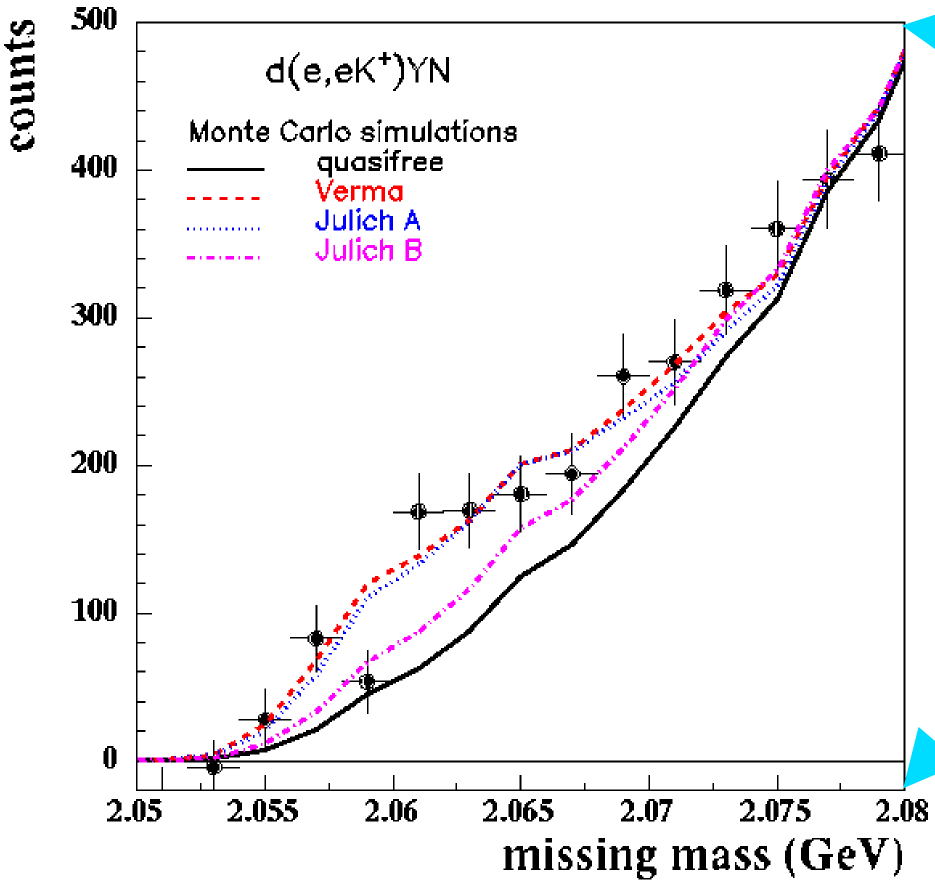
# Λn Potential Parametrization

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

| Model | state | $V_A$ (MeV) | $\beta_A$ (fm) | a (fm) | r (fm) |
|---|---|---|---|---|---|
| Verma | Singlet ($^1S_0$) | -167.34 | 1.100 | -2.29 | 3.15 |
| | Triplet ($^3S_1$) | -132.42 | 1.100 | -1.77 | 3.25 |
| Jülich A | Singlet ($^1S_0$) | -373.94 | 0.790 | -1.60 | 1.33 |
| | Triplet ($^3S_1$) | -144.14 | 1.059 | -1.60 | 3.15 |
| Jülich B | Singlet ($^1S_0$) | -131.49 | 1.095 | -0.57 | 7.65 |
| | Triplet ($^3S_1$) | -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].

# Λn FSI from $^2$H(e,e'K$^+$)



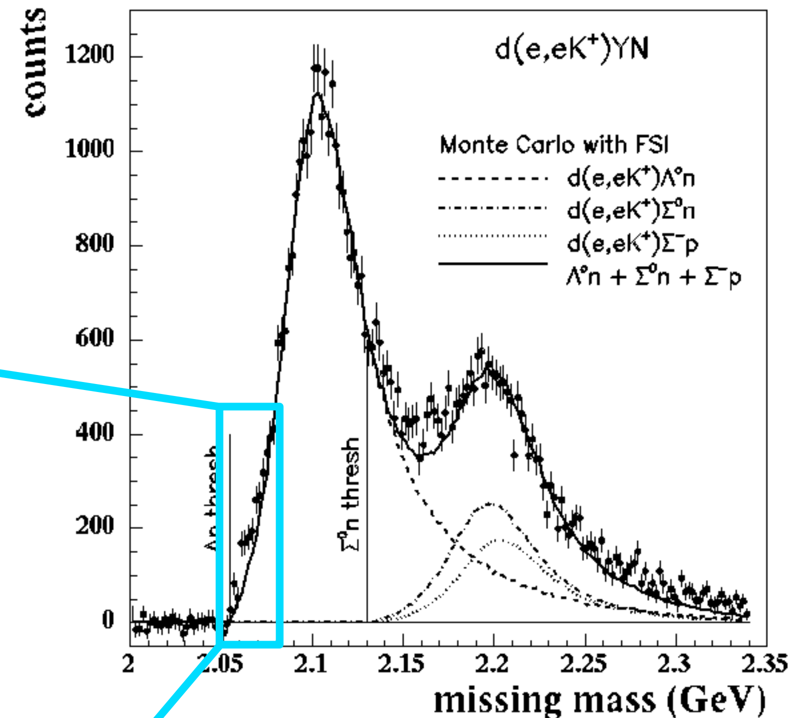
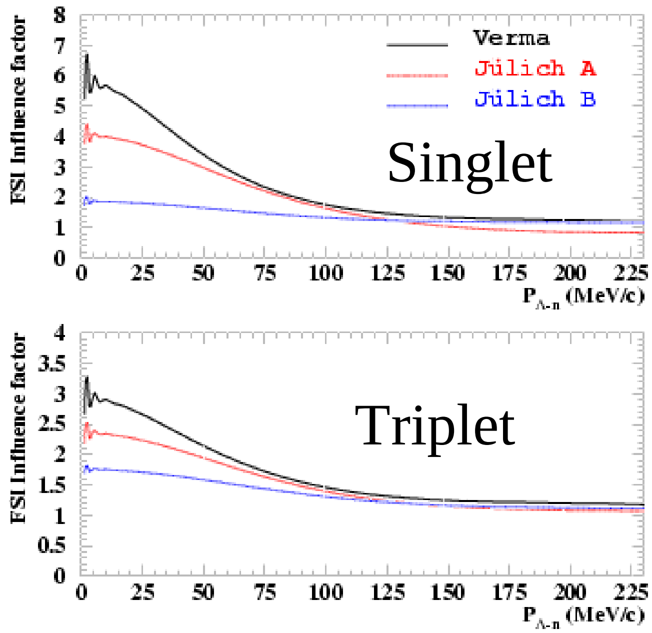



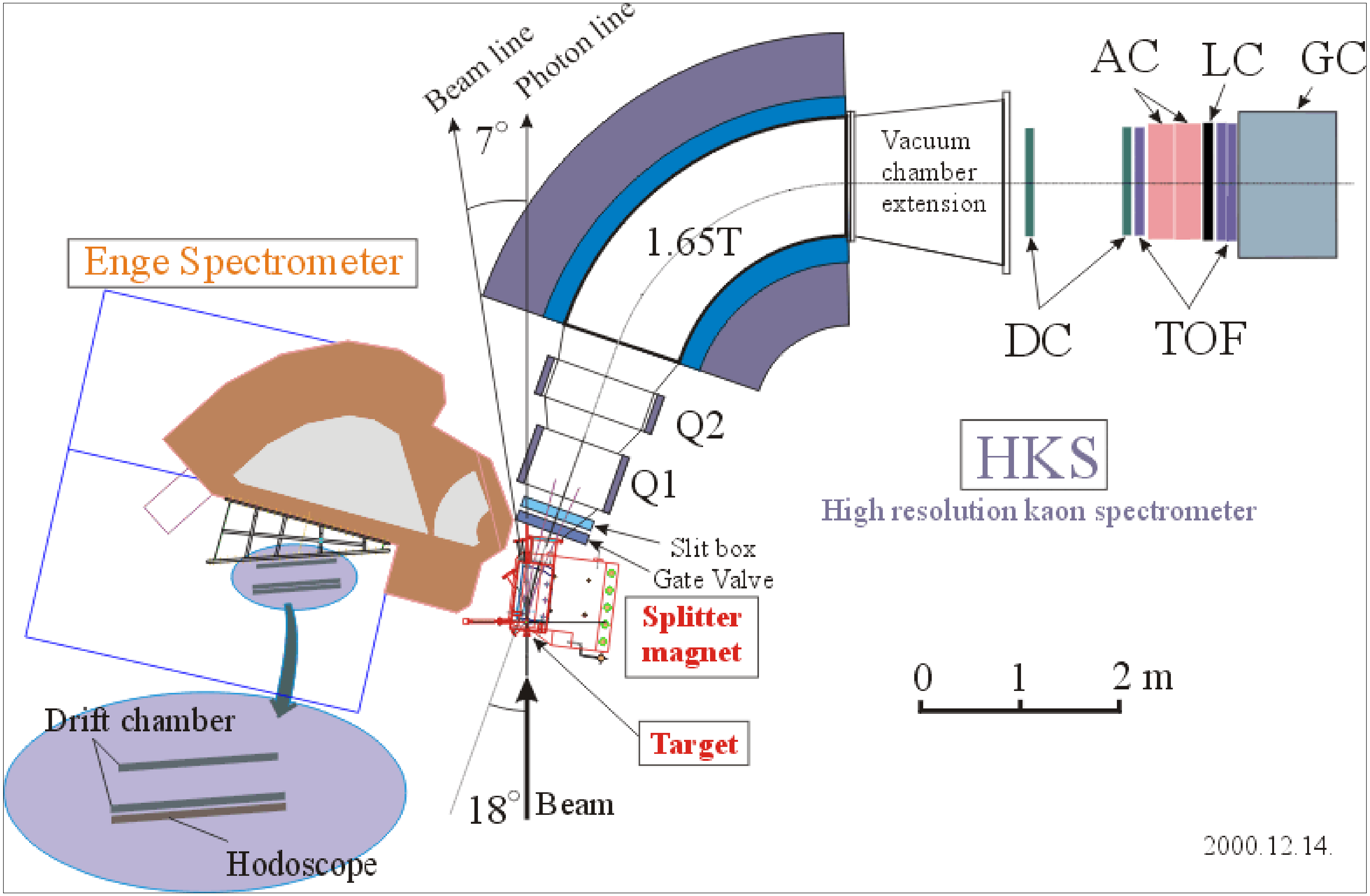

Table 1: Scattering length and effective range for the three hyperon-nucleon potentials used in the simulations.

| 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 |

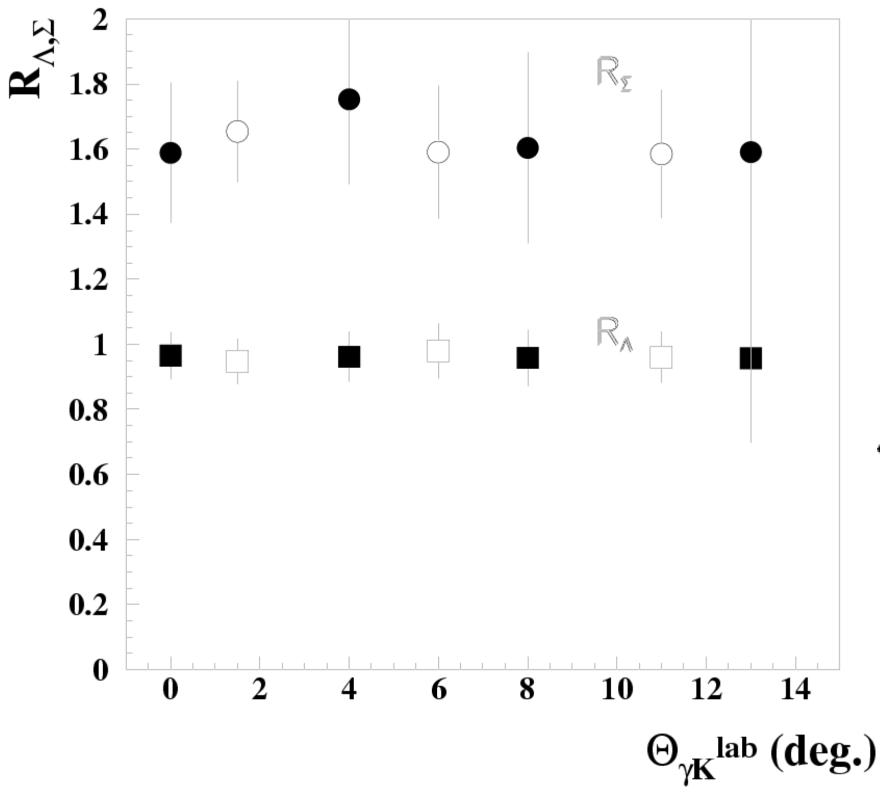


FSI Influence factor
Verma
Jülich A
Jülich B
Singlet
$P_{\Lambda-n}$ (MeV/c)
FSI Influence factor
Triplet
$P_{\Lambda-n}$ (MeV/c)

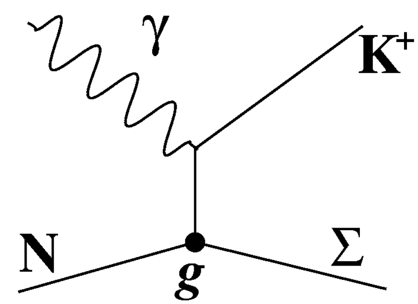
# High Resolution Kaon Spectrometer (HKS)



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

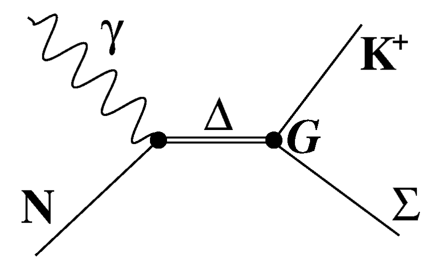



t-channel:

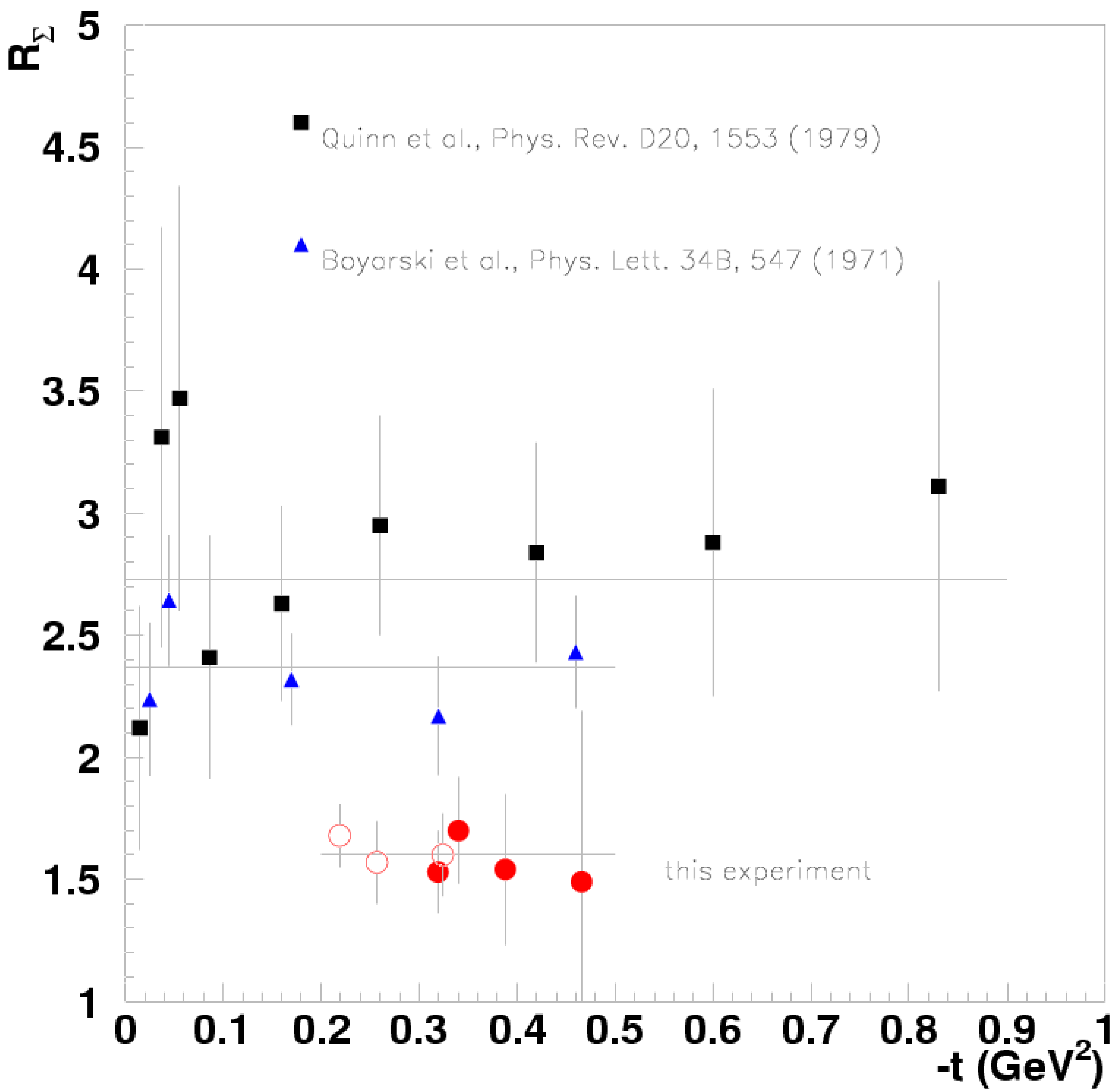



$$g_{K^+\Sigma^- n} = \sqrt{2} g_{K^+\Sigma^0 p} \qquad R_\Sigma = 3$$

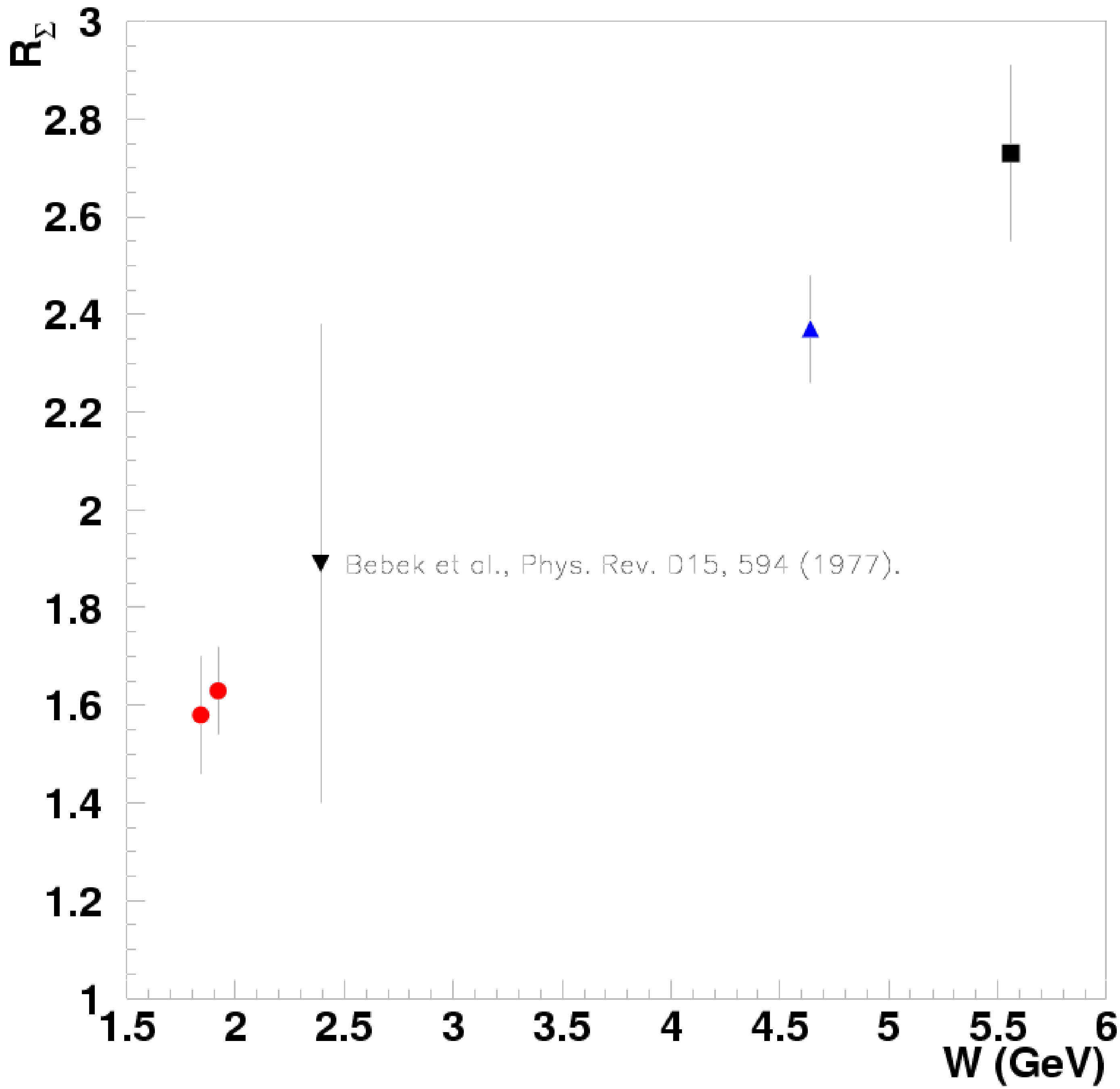
s-channel:




$$G_{K^+\Sigma^-\Delta^0} = G_{K^+\Sigma^0\Delta^+}/\sqrt{2} \qquad R_\Sigma = 1.5$$



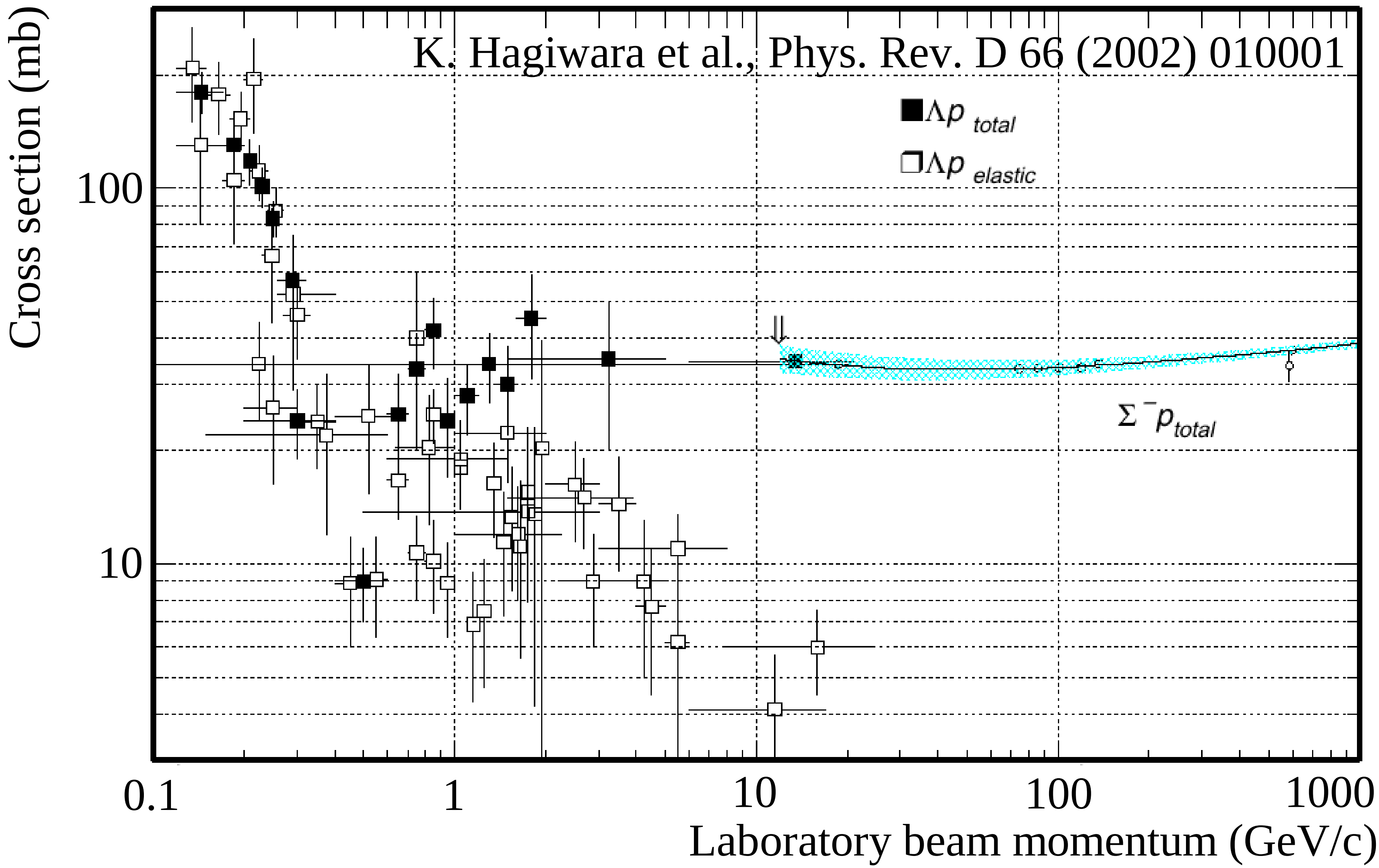
$R_\Sigma$
5
4.5
4
3.5
3
2.5
2
1.5
1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
-t (GeV$^2$)
Quinn et al., Phys. Rev. D20, 1553 (1979)
Boyarski et al., Phys. Lett. 34B, 547 (1971)
this experiment



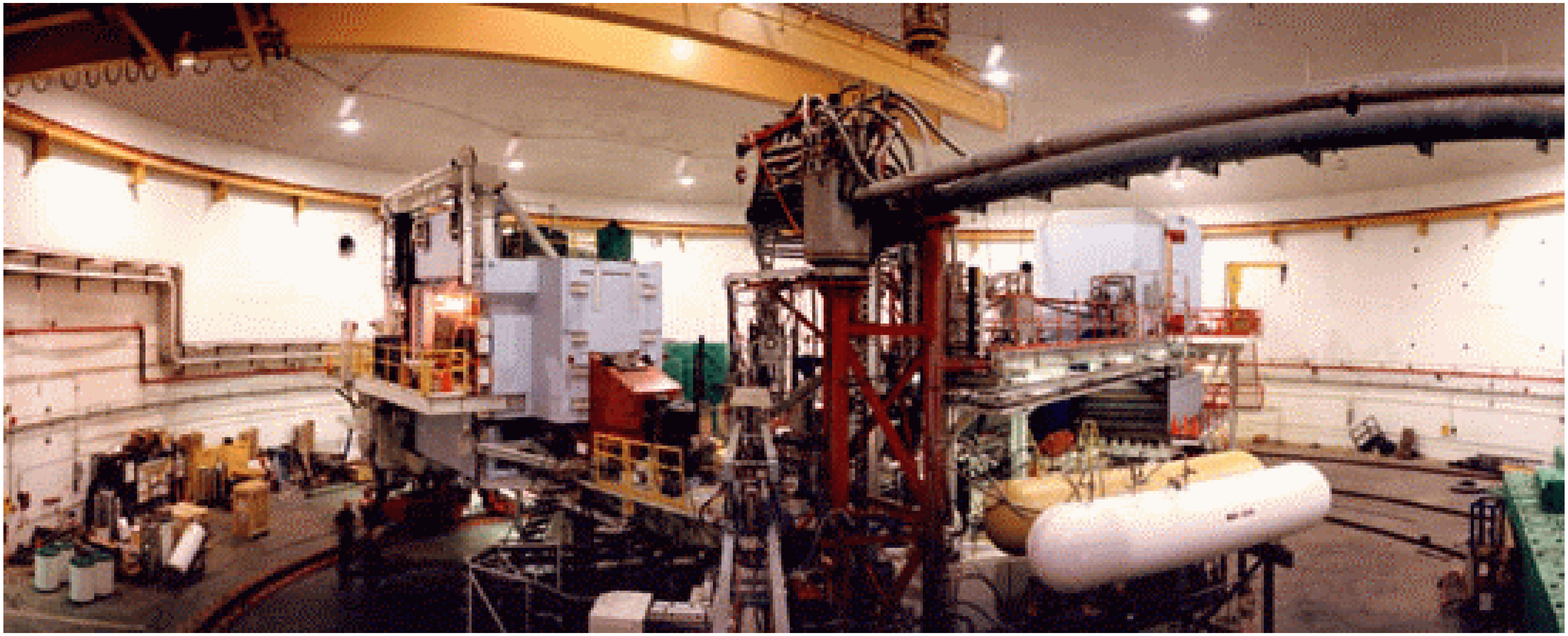
$R_\Sigma$
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
W (GeV)
Bebek et al., Phys. Rev. D15, 594 (1977).

# Lambda-Proton Cross Section

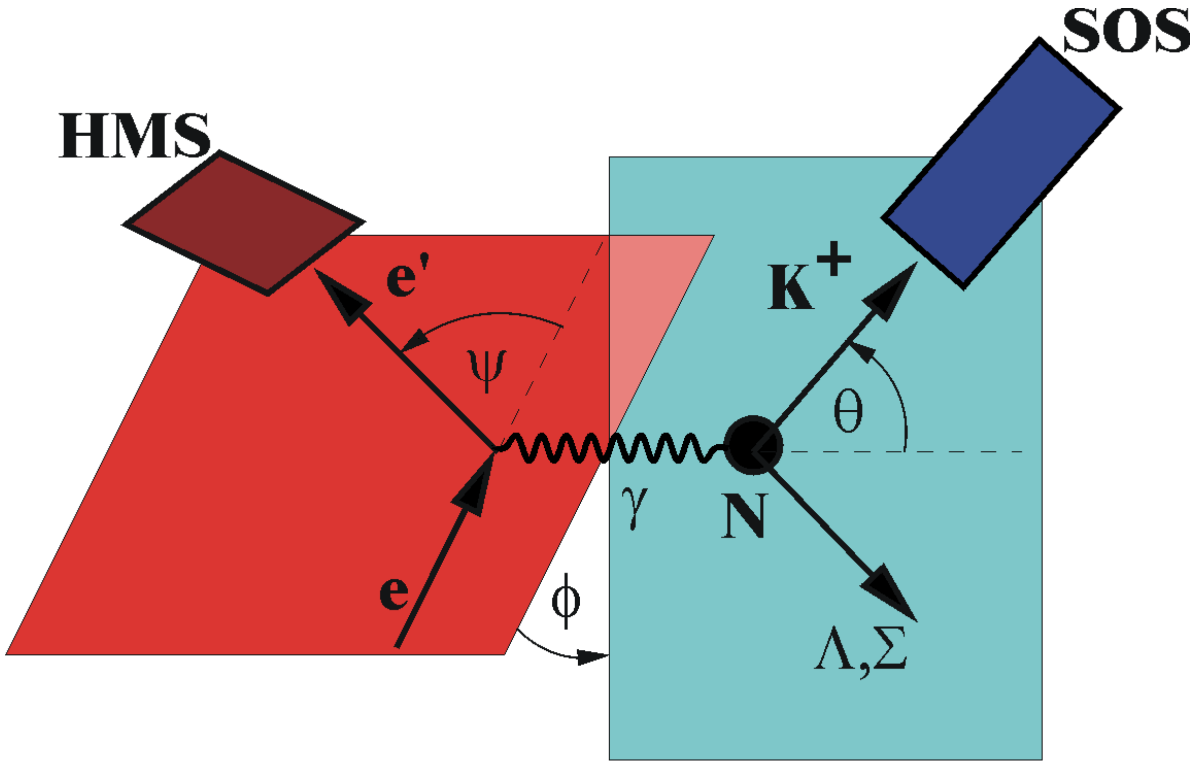
http://pdg.lbl.gov/



# TJNAF Hall C



# Kaon Electroproduction Cross Section




Virtual photon – nucleon CM cross section

$$\frac{d\bullet}{d\bullet_{CM}} = \bullet_T + \bullet\bullet_L + \bullet\bullet_{TT}\sin^2\bullet\cos(2\bullet) + \sqrt{\frac{\bullet(\bullet+1)}{2}}\,\bullet_{LT}\sin\bullet\cos\bullet$$

Virtual photon polarisation

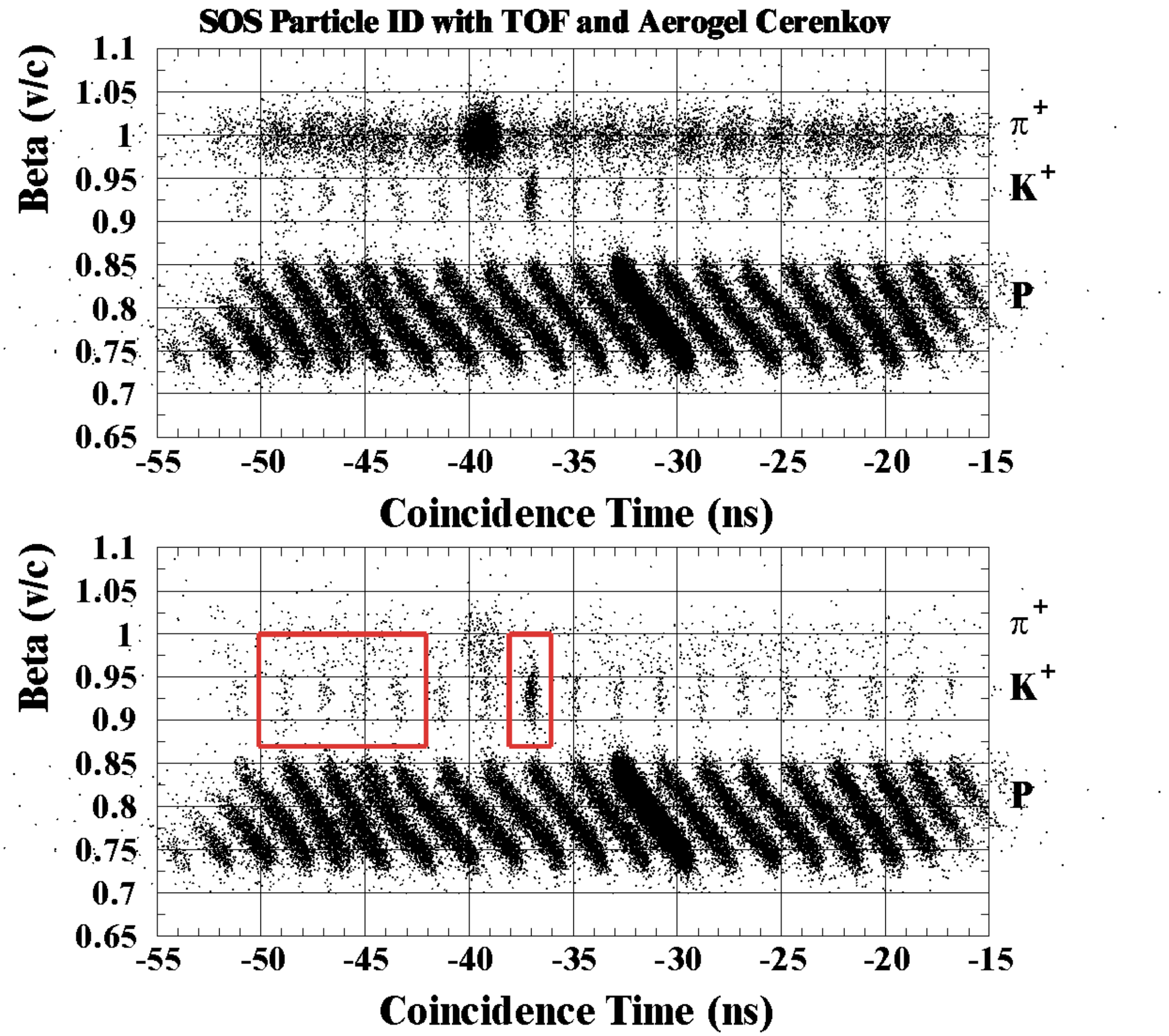
$$e = \left[1 + 2\frac{|\vec{q}|^2}{Q^2}\tan^2\left(\frac{y}{2}\right)\right]^{-1}$$

# Particle Identification

K+ PID:

Coincidence time cuts separate 99.9 % reak $K^+$, $\pi^+$,p

Aerogel cuts reject 98 % $\pi^+$
b cuts reject 99 % p




e' PID

Cerenkov and calorimeter have ~ 99.8 % efficiency for electron PID

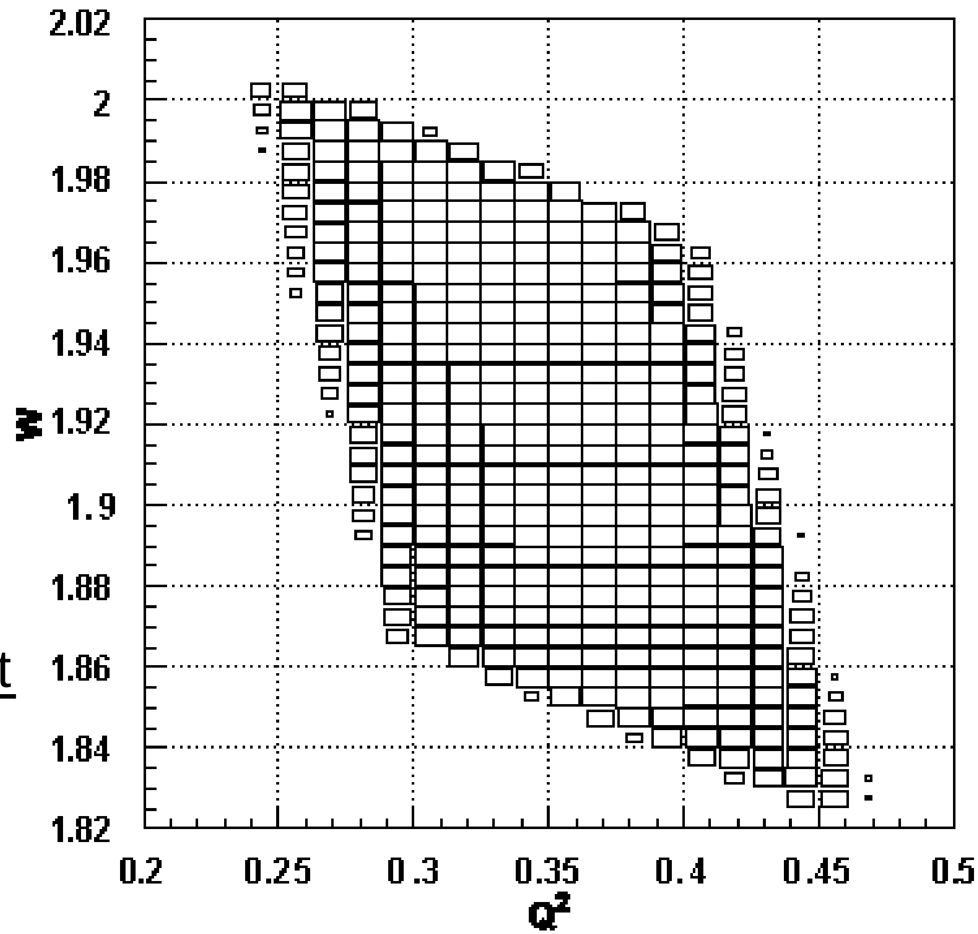
# Simple Model for Hydrogen Data

- Available models
  - Adelseck, Saghai PRC42 (1990) 108
  - Williams et al PRC46 (1992) 1617

  do not describe the data
- Use instead simple factorization Ansatz which describes the data over our acceptance

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

- Model describes 1996/1999 dat well and is also used for all nuclear targets



# W dependence of $^{1}H(e,e'K)\Lambda$ scaled to tmin

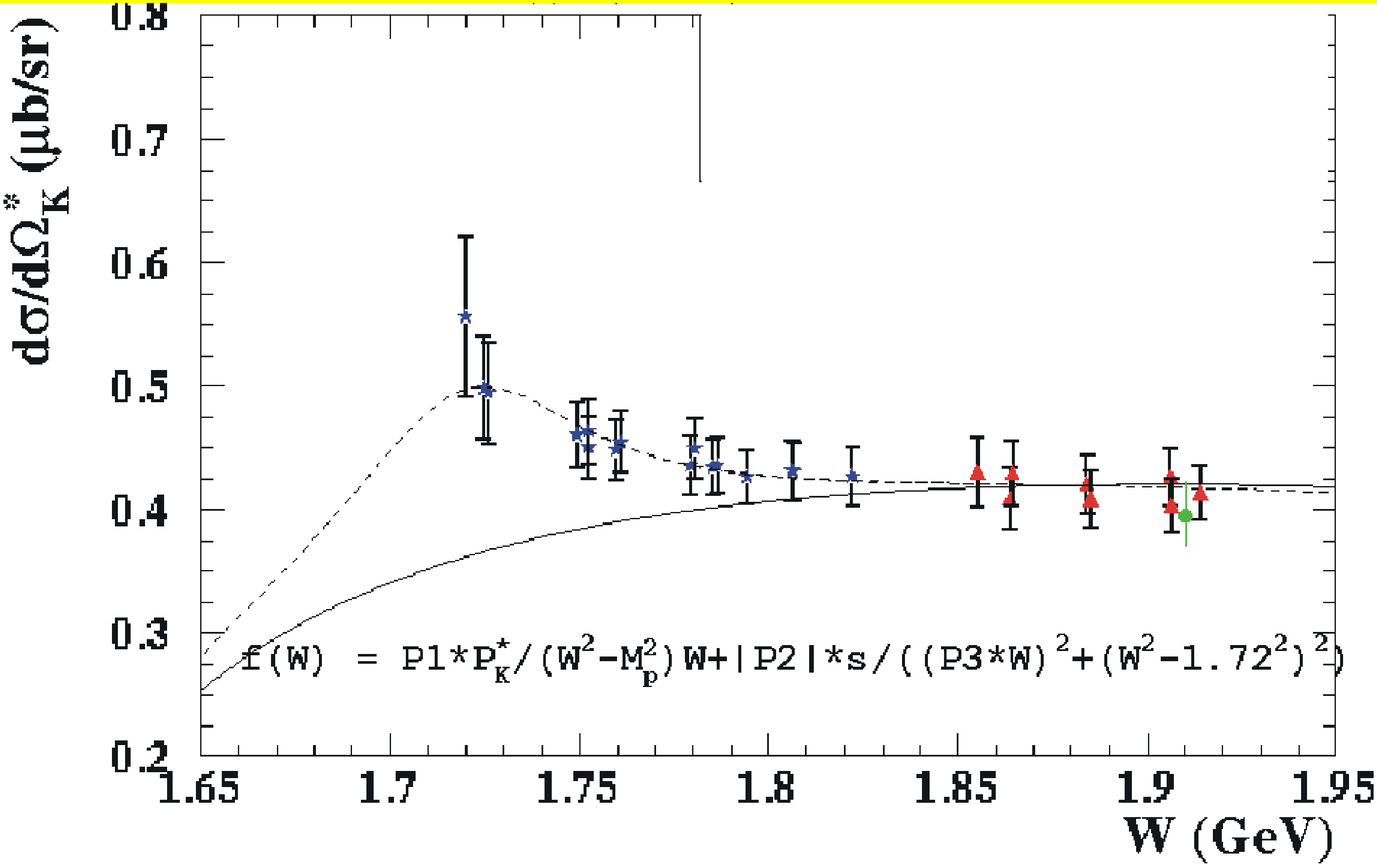
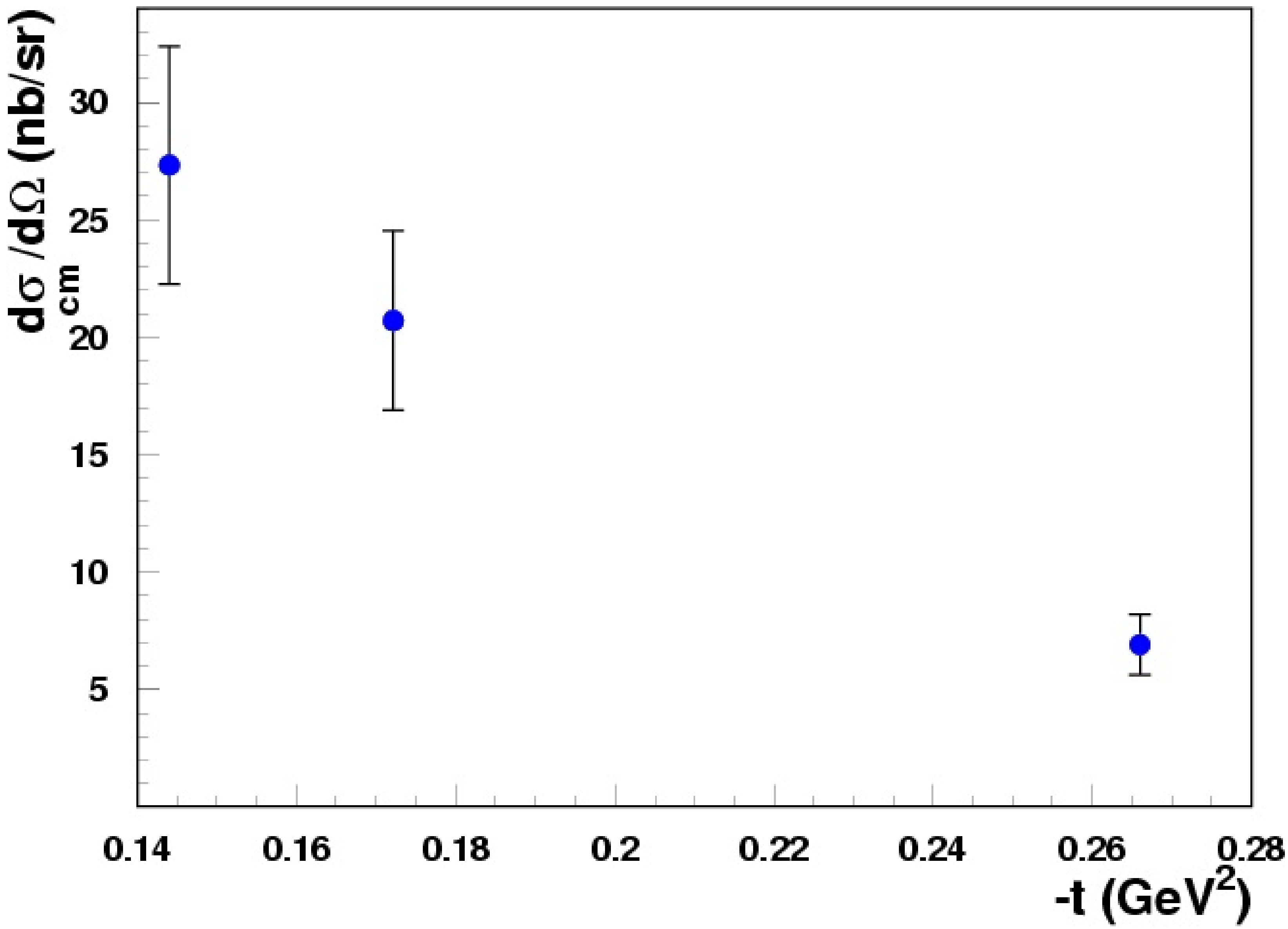



*Figure from J. Cha Hampton Univ. 2000.*

*The data are scaled in $\theta_{\gamma K.cm}$ and $Q^2$.*

# Bound Λ-Hypernuclei A=4



# Elementary Cross Sections for $^3$He