Strangeness Production

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Strangeness Production - Why?

- u,d quarks light
  → dynamics described by low energy EFTs (ChPT)
- c, b, t quarks heavy
  → non-relativistic potential theories (HQET)
- s quarks are neither light nor heavy (or both)

- baryon spectroscopy: missing resonances

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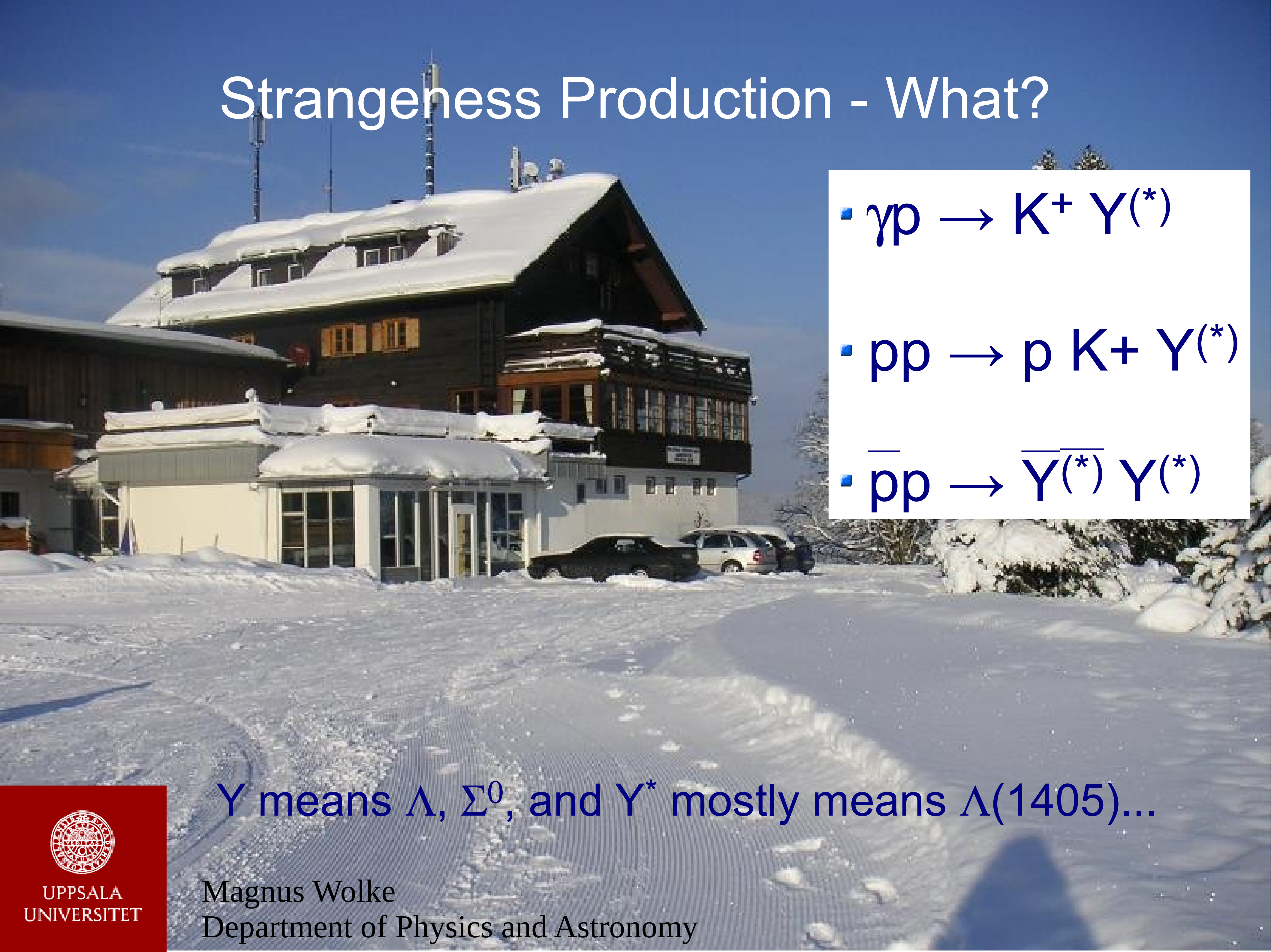
Strangeness Production - What?



- $\gamma p \rightarrow K^+ Y^{(*)}$
- $pp \rightarrow p K+ Y^{(*)}$
- $\bar{p}p \rightarrow \overline{Y^{(*)}} Y^{(*)}$

Y means Λ, Σ^0, and Y^* mostly means $\Lambda(1405)$...

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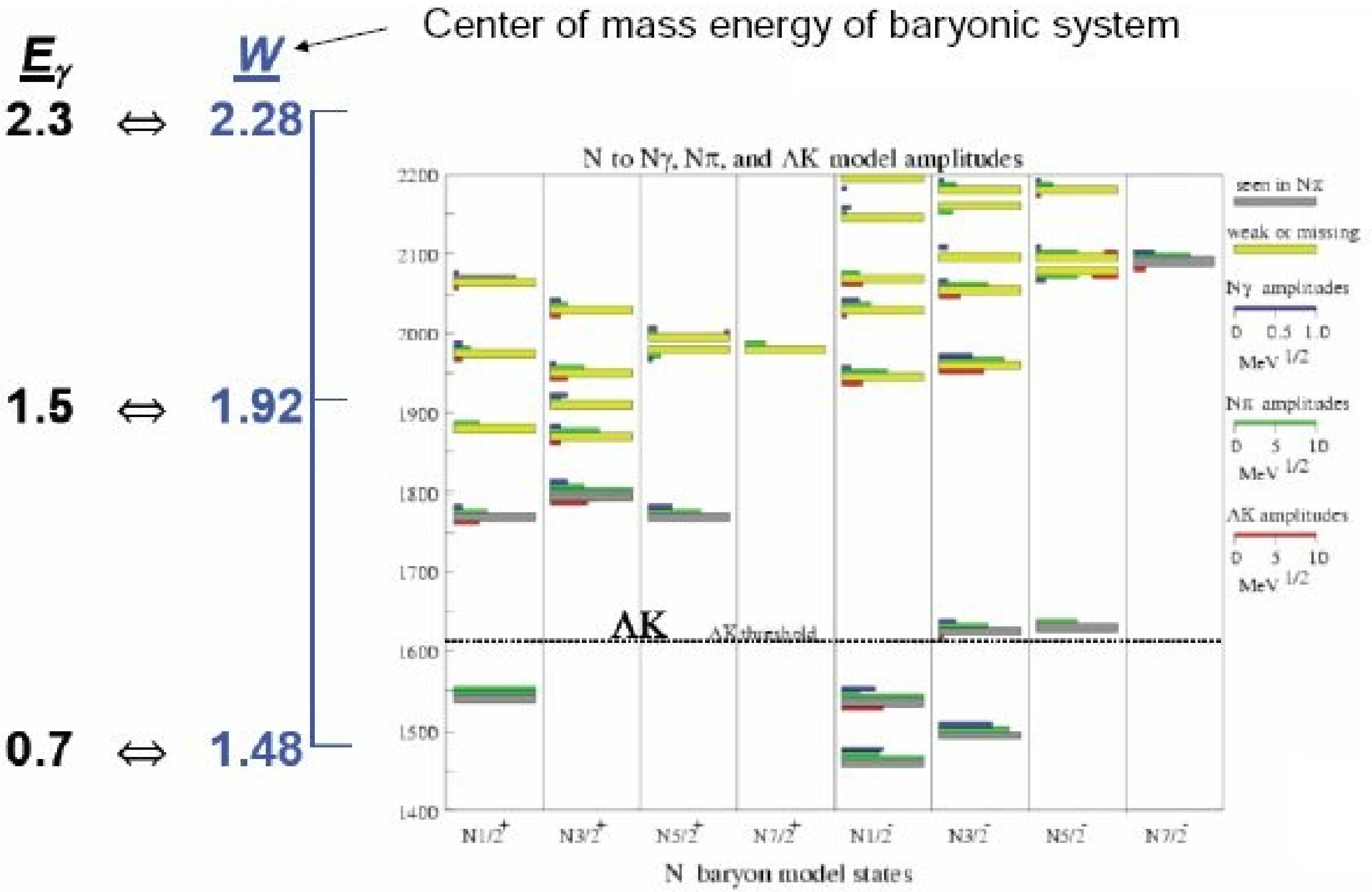
Missing Resonances



S.Capstick, W.Roberts, PRD 58 (98) 074011

Photoproduction of 0^- Mesons

R.Schumacher, MENU 2010

- Photoproduction described by **4 complex amplitudes**
- Bilinear combinations define **16 observables**
- **8 measurements needed** to separate amplitudes at any given energy

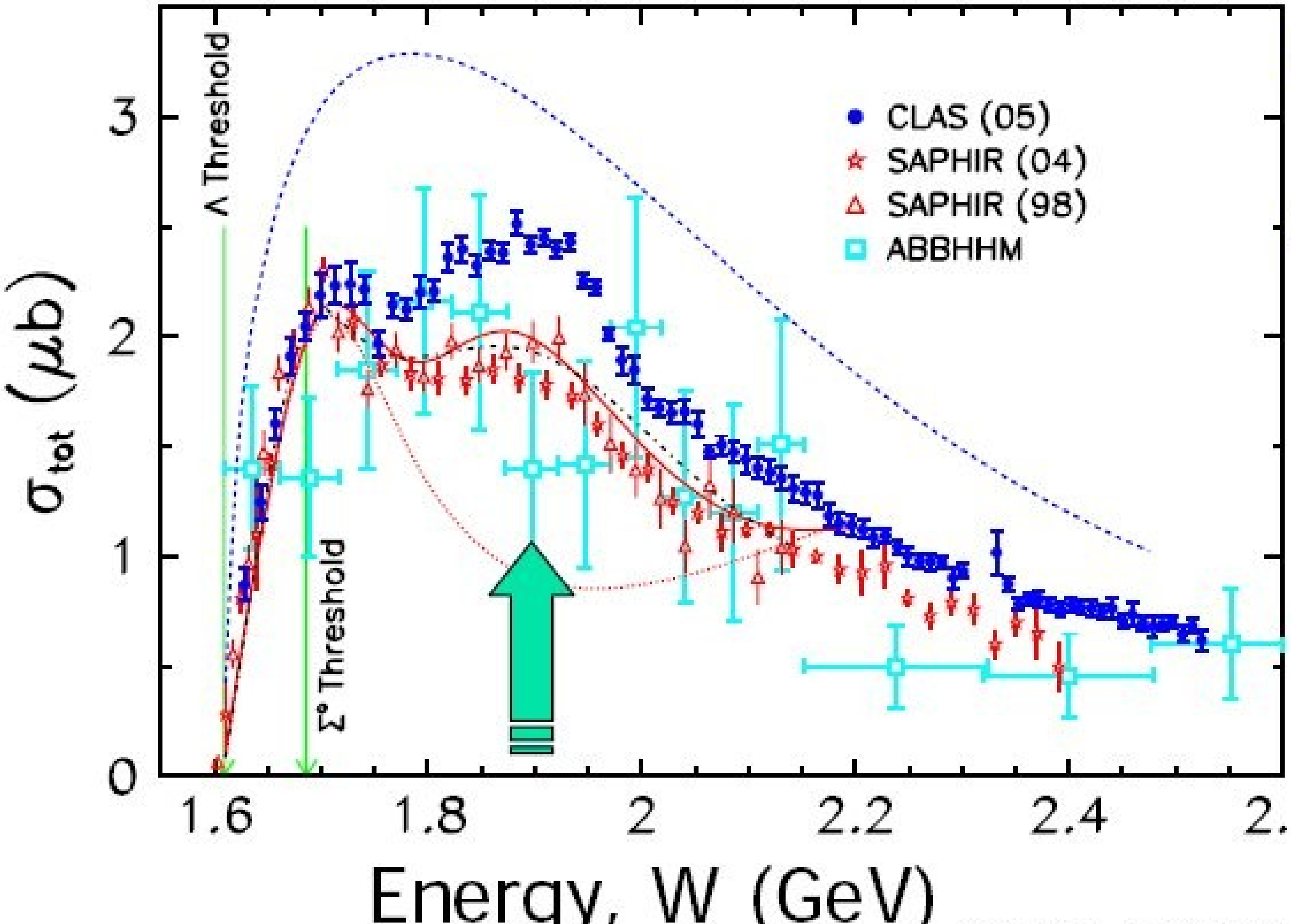
W.T.Chiang, F.Tabakin, PRC 55 (1997) 2054

  - differential cross section: **$d\sigma/d\Omega$**
  - 3 single polarization observables: **P, T, Σ**
  - 4 **double polarization observables**

Complete measurements essential
to fully define the reaction amplitude

$\gamma p \rightarrow K^+\Lambda$ Cross Sections

R.Schumacher, MENU 2010



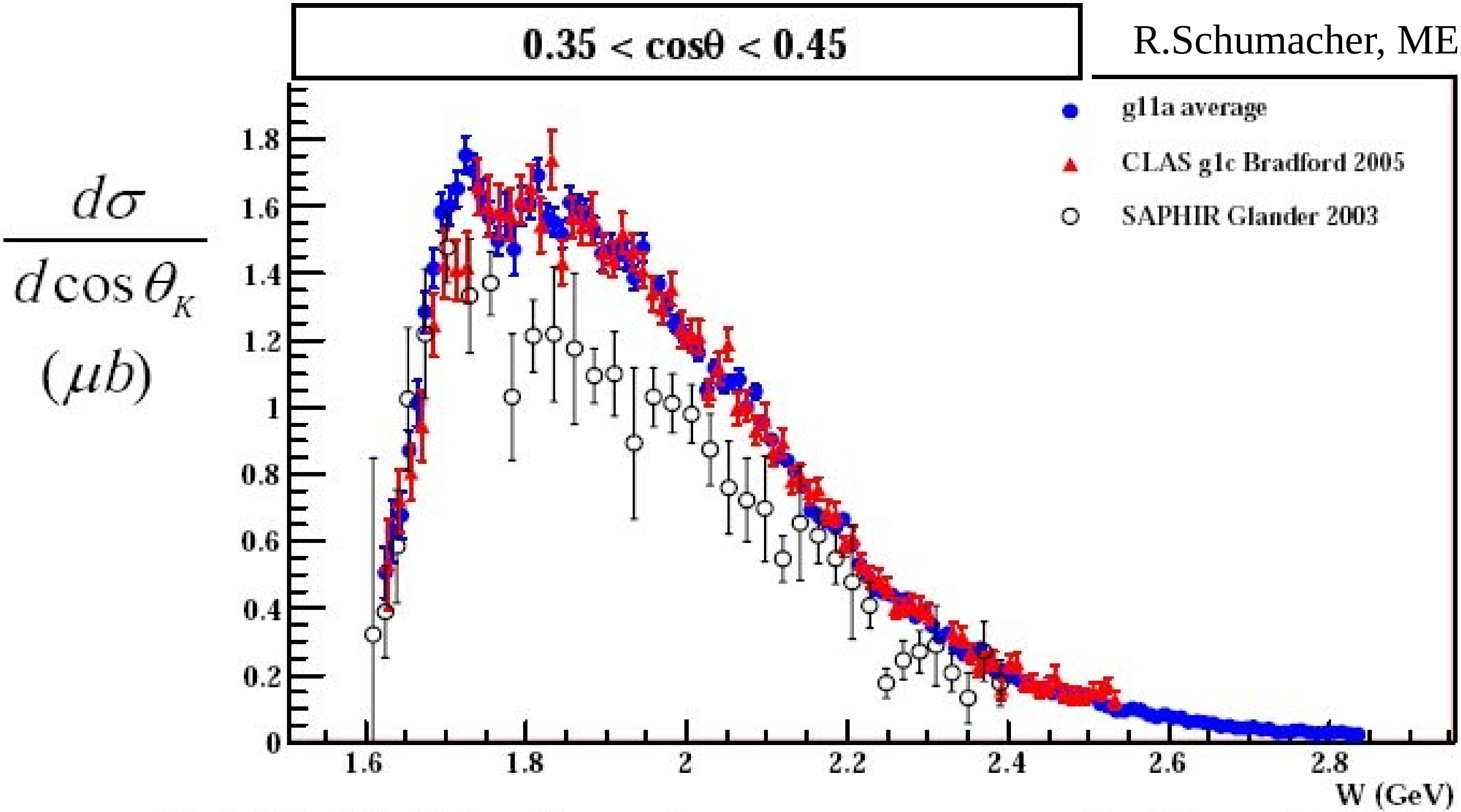
- Two-bump structure seen
- Resonance-like structure at 1.9 GeV:
  - D_{13} (Bennhold & Mart)[a]
  - P_{13} (Bonn-Gachina)[b]
  - P_{11} (Ghent "RPR" model)[c]
  - $\overline{K}KN$ bound state (Valencia model)[d]
  - Coupled-channel effects (Giessen)[e]

R. Bradford *et al.* Phys. Rev. C**73** 035202 (2006)
K. H. Glander *et al.* Eur. Phys. J. A**19** 251 (2004)

a) T. Mart, C. Bennhold, Phys Rev C **61**, 012201(R) (1999).
b) V. Nikanov et al, Phys Lett B **662**, 245 (2008).
c) T. Corthals, et al., PRC **73**, 045207 (2006).
d) A. MartinezTorres, et al., Eur. Phys J. A 41, **361** (2009).
e) R. Shyam, O.Scholten & H.Lenske, PRC **81**, 015204 (2010).

$\gamma p \rightarrow K^+\Lambda$: CLAS'05, CLAS'09 and SAPHIR

R.Schumacher, MENU 2010

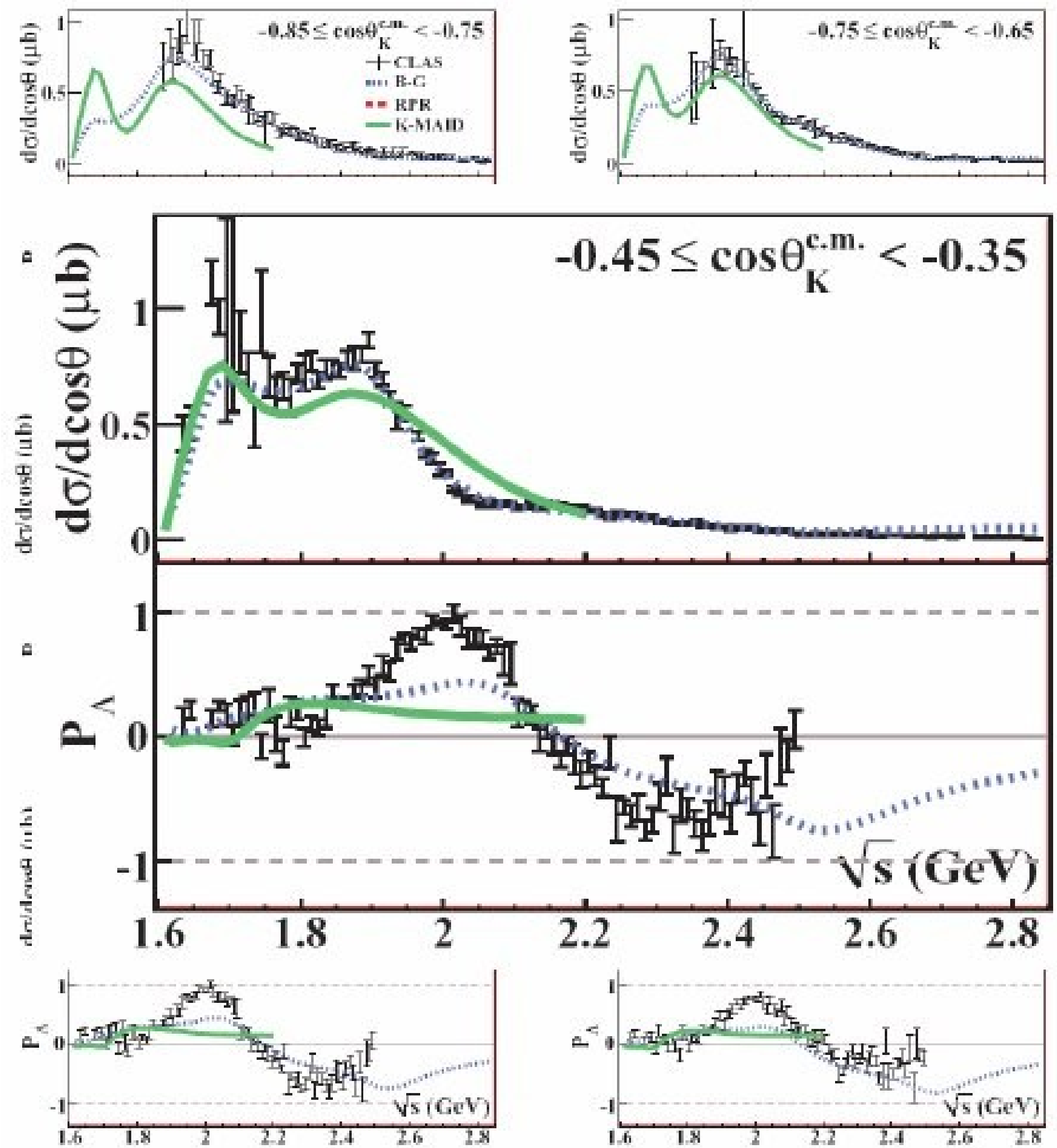


- CLAS 'g11' data: broader energy range, better statistics, good agreement with 'g1c' (Bradford *et al.*)
  - Different data set, different trigger, different analysis chain
  - M. McCracken et al. Phys. Rev. C **81**, 025201 (2010).
  - PWA analysis underway

$\gamma p \rightarrow K^+\Lambda$: Data and Models

R.Schumacher, MENU 2010

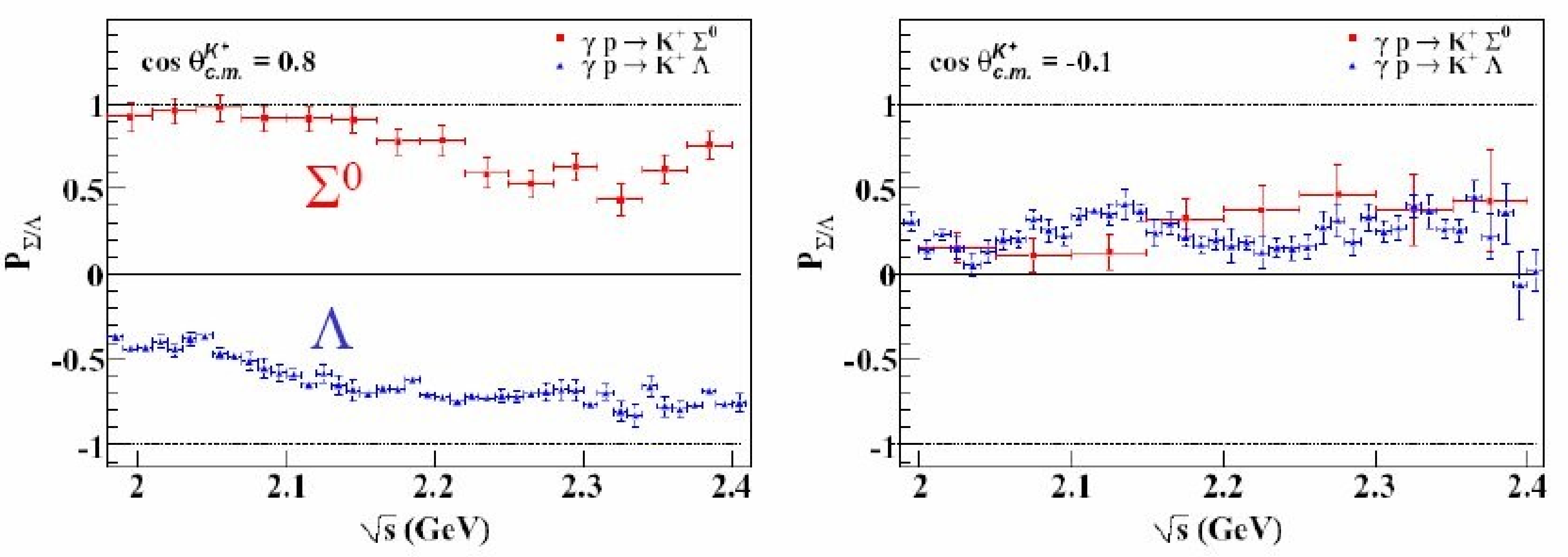
M.McCracken et al., PRC 81 (10) 025201



- Kaon-MAID model (green)
  - F.X.Lee et al., Nucl. Phys. **A695**, 237 (2001).
  - Single-channel BW resonance fits
  - No longer up-to-date
- Bonn-Gachina model (blue)
  - A.V. Sarantsev et al., Eur. Phys. J., A **25**, 441 (2005).
  - Multi-channel, unitary, BW resonance fit
  - Large suite of N* contributions
  - Was not predictive for recoil polarization

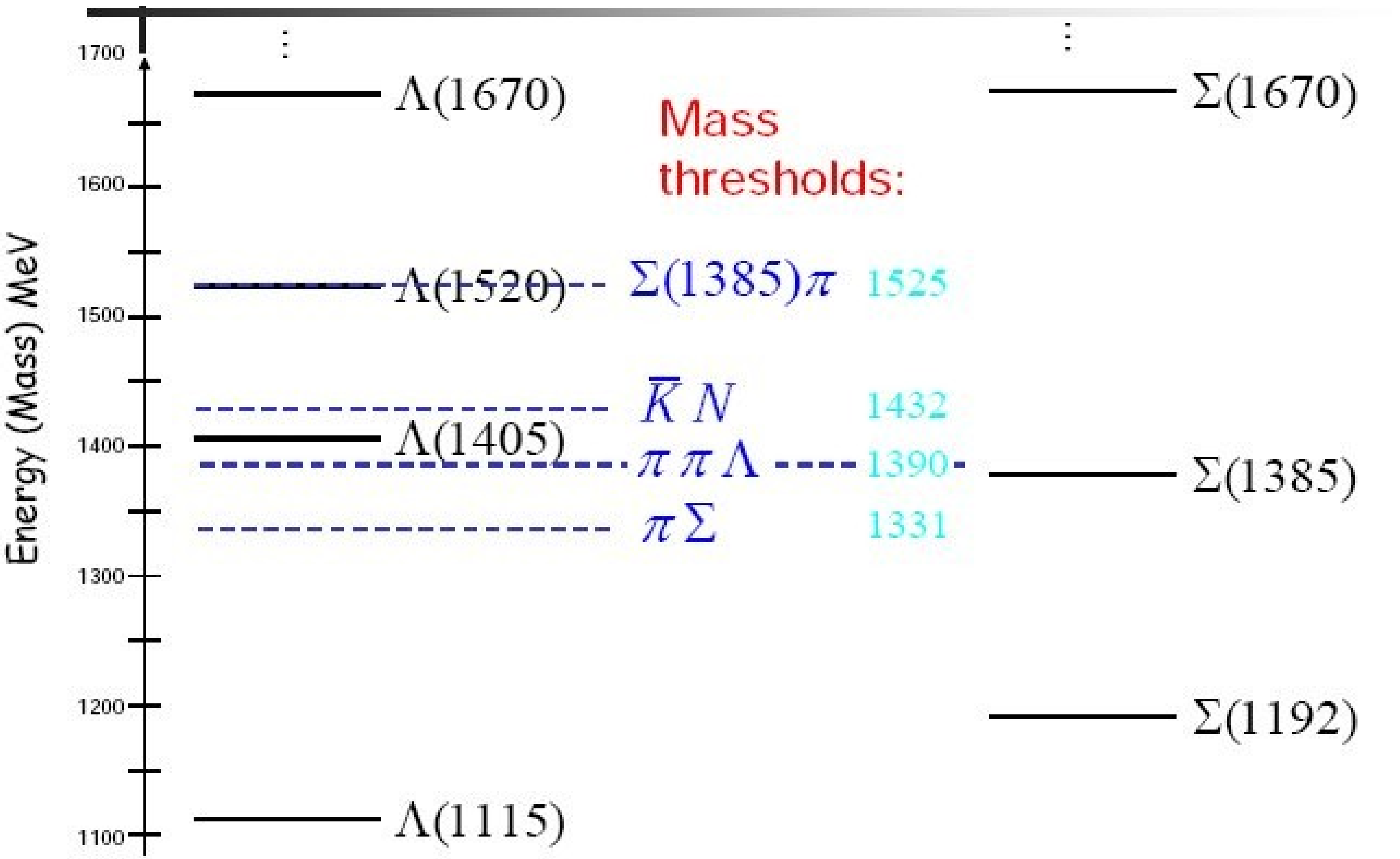
Λ, Σ^0 Recoil Polarisation

R.Schumacher, MENU 2010 B.Dey et al., PRC 82 (10) 025202



- naïve SU(6) expectation: $\mathbf{P_\Lambda \approx -P_\Sigma}$
- **True** in **forward** direction
- **False** in **backward** direction

Low-Mass S = -1 Hyperons



R.Schumacher, MENU 2010

Spectroscopy of cryptoexotic states: Λ(1405)

QMs: isospin singlet, excited state,
but: mass difficult to reproduce

N.Isgur, G.Karl, PRD 18 (78) 4187
U.Löring, B.C.Metsch, H.R.Petry, EPJA 10 (01) 395

$\overline{K}$N bound state

R.C.Arnold, J.J.Sakurai, PR 128 (62) 2808
N.Kaiser, P.B.Siegel, W.Weise, NPA 594 (95) 325

Chiral EFTs:

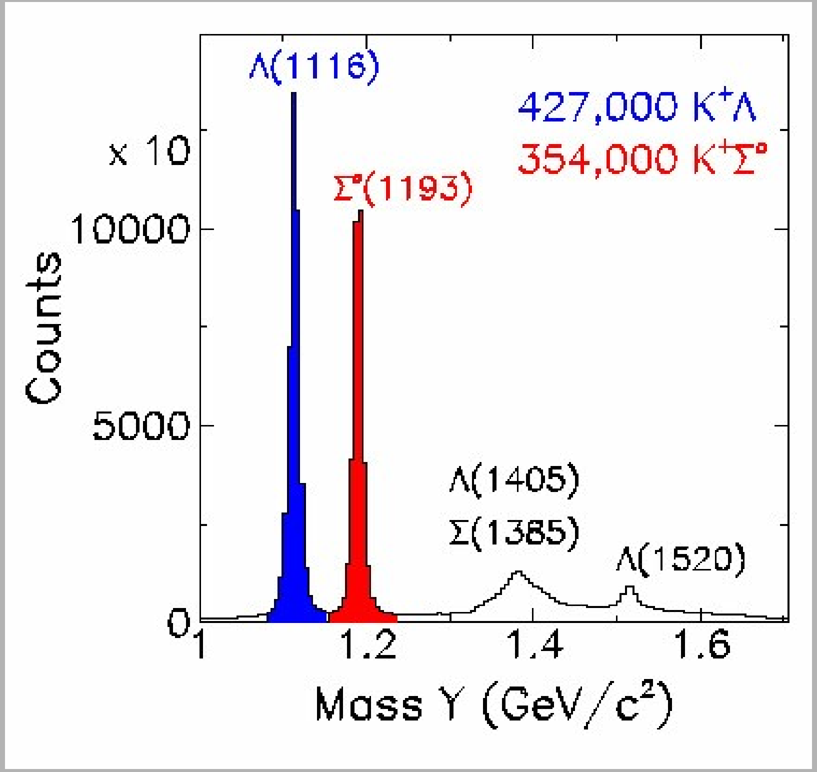
two pole structure close to Λ(1405)
different coupling to $\overline{K}$N, Σπ
different mass distributions in
hadron and γ induced reactions

D.Jido, NPA 725 (03) 181

experimental difficulty:

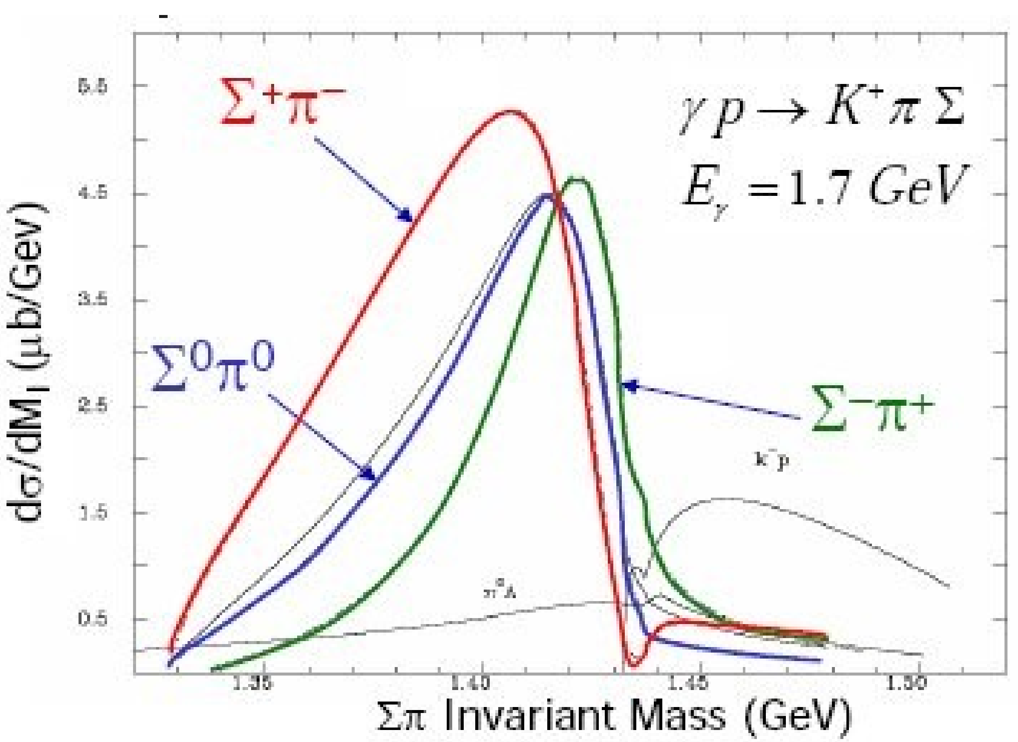
separation of Λ(1405) and Σ(1385)

(early) K+ missing mass analysis CLAS



➡ Goal: resonance line shape with high statistics, angular distributions

Chiral Unitary Model: $\gamma p \to K^+\Lambda(1405)$



J.C.Nacher, E.Oset, H.Toki, A.Ramos, PLB 455 (99) 55

$$\frac{d\sigma(\pi^+\Sigma^-)}{dM_I} \propto \frac{1}{2}|T^{(1)}|^2 + \frac{1}{3}|T^{(0)}|^2 + \frac{2}{\sqrt{6}}\mathrm{Re}\left(T^{(0)}T^{(1)*}\right) + O\left(T^{(2)}\right)$$

$$\frac{d\sigma(\pi^-\Sigma^+)}{dM_I} \propto \frac{1}{2}|T^{(1)}|^2 + \frac{1}{3}|T^{(0)}|^2 - \frac{2}{\sqrt{6}}\mathrm{Re}\left(T^{(0)}T^{(1)*}\right) + O\left(T^{(2)}\right)$$

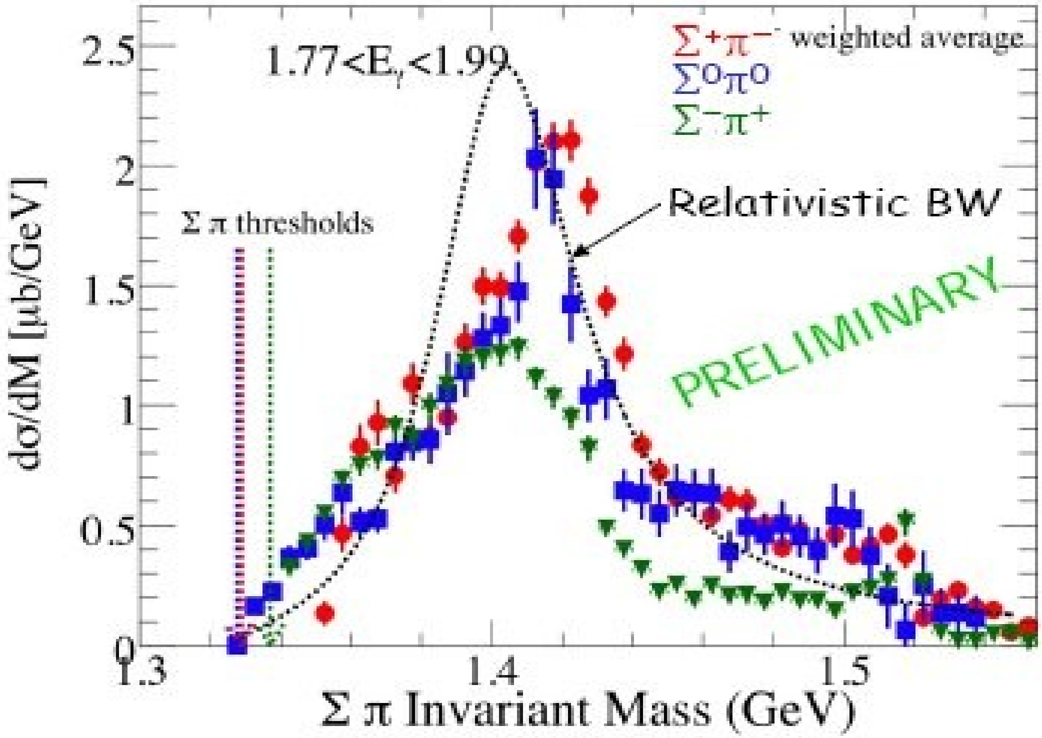
$$\frac{d\sigma(\pi^0\Sigma^0)}{dM_I} \propto \frac{1}{3}|T^{(0)}|^2 + O\left(T^{(2)}\right)$$

$\Lambda(1405)$ lineshape depends on $\Sigma\pi$ decay mode

$\Sigma^-\pi^+$ peaks at highest mass, higher than $\Sigma^+\pi^-$

Interference between I = 0,1 amplitudes modifies mass distribution

$\gamma p \rightarrow K^+\Lambda(1405)$ with CLAS



K.Moriya, R.Schumacher,
Hadron 2009

different Λ(1405) lineshape for different decay mode

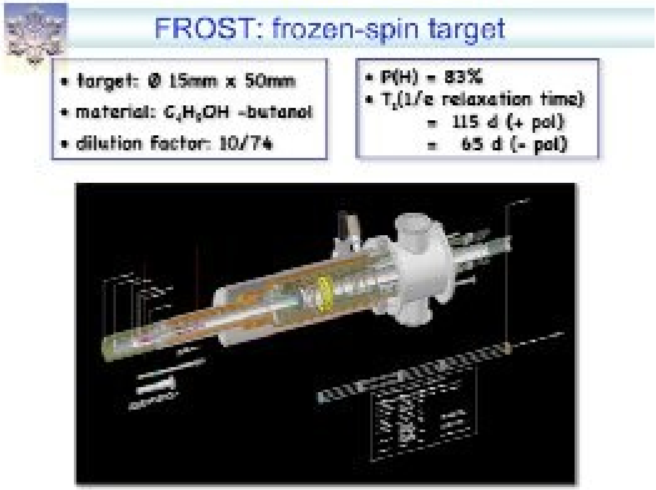
direct spin-parity measurement: $J^P = ½^-$

$\Sigma^+\pi^-$ peaks at highest mass, higher than $\Sigma^-\pi^+$, **opposite to chiral unitary model prediction (not yet understood)**

CLAS future prospects

R.Schumacher, MENU 2010

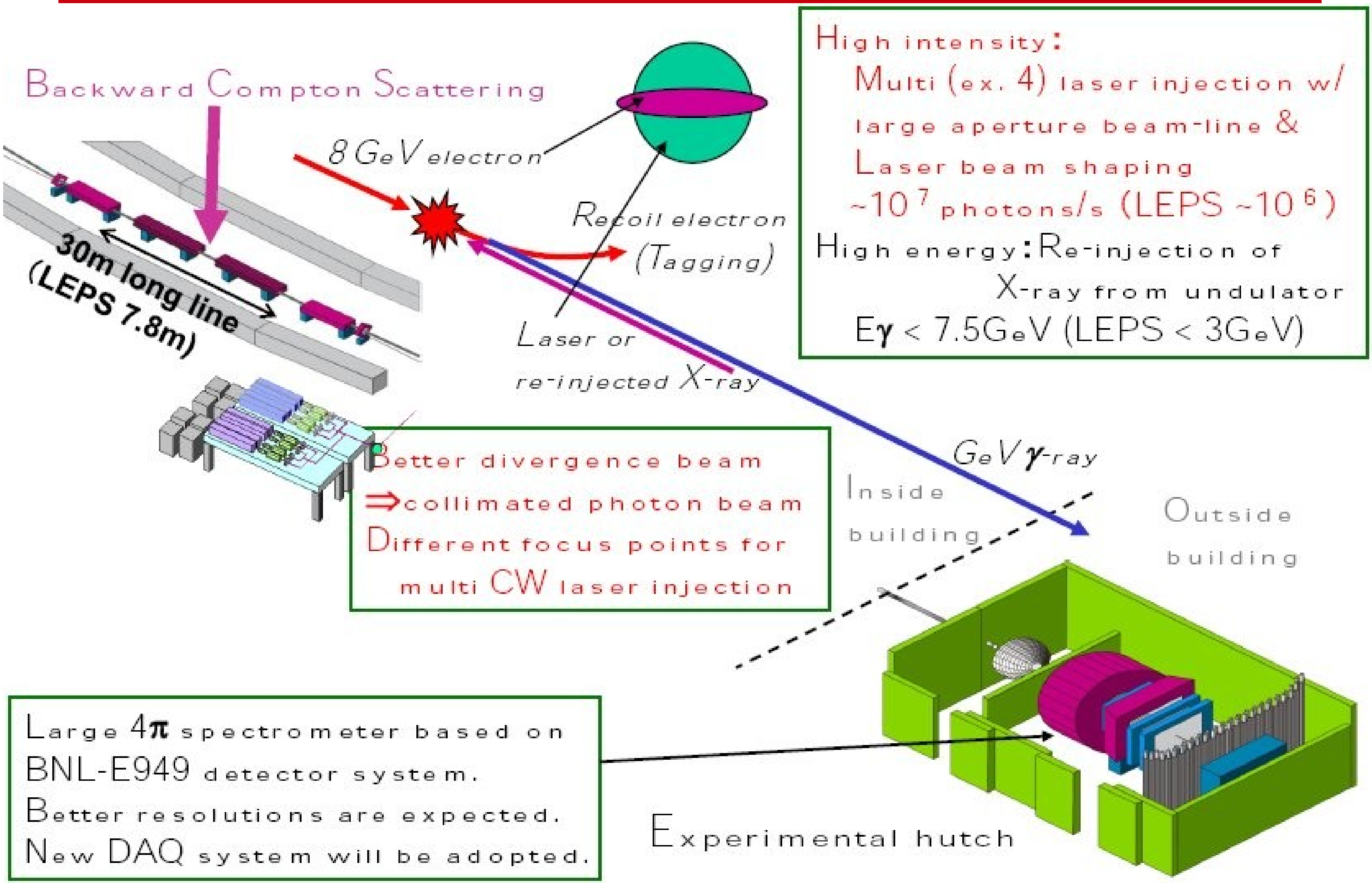
- **CLAS "g13" data set** – analysis in progress
  deuteron target
  $\gamma n(p) \rightarrow K^0\{\Lambda,\Sigma^0\}(p)$ neutron cross sections,
  spin observables



- **FroST** polarized target
  polarized photon beams → $\vec{\gamma}\,\vec{p}$
  complete experiments
  data taken Mar-Jul 2010

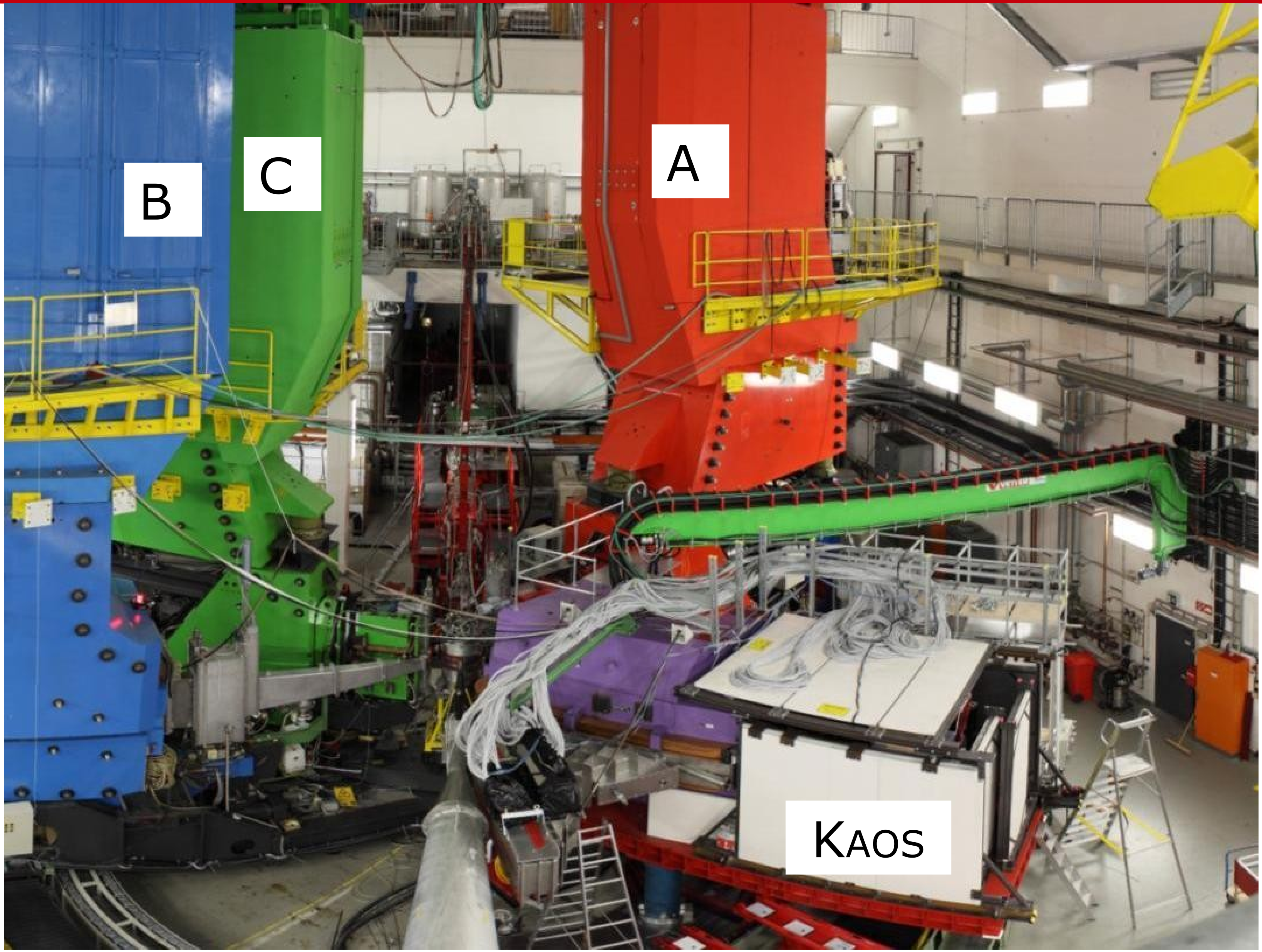
- **CLAS 12**

LEPS2 Project at SPring-8



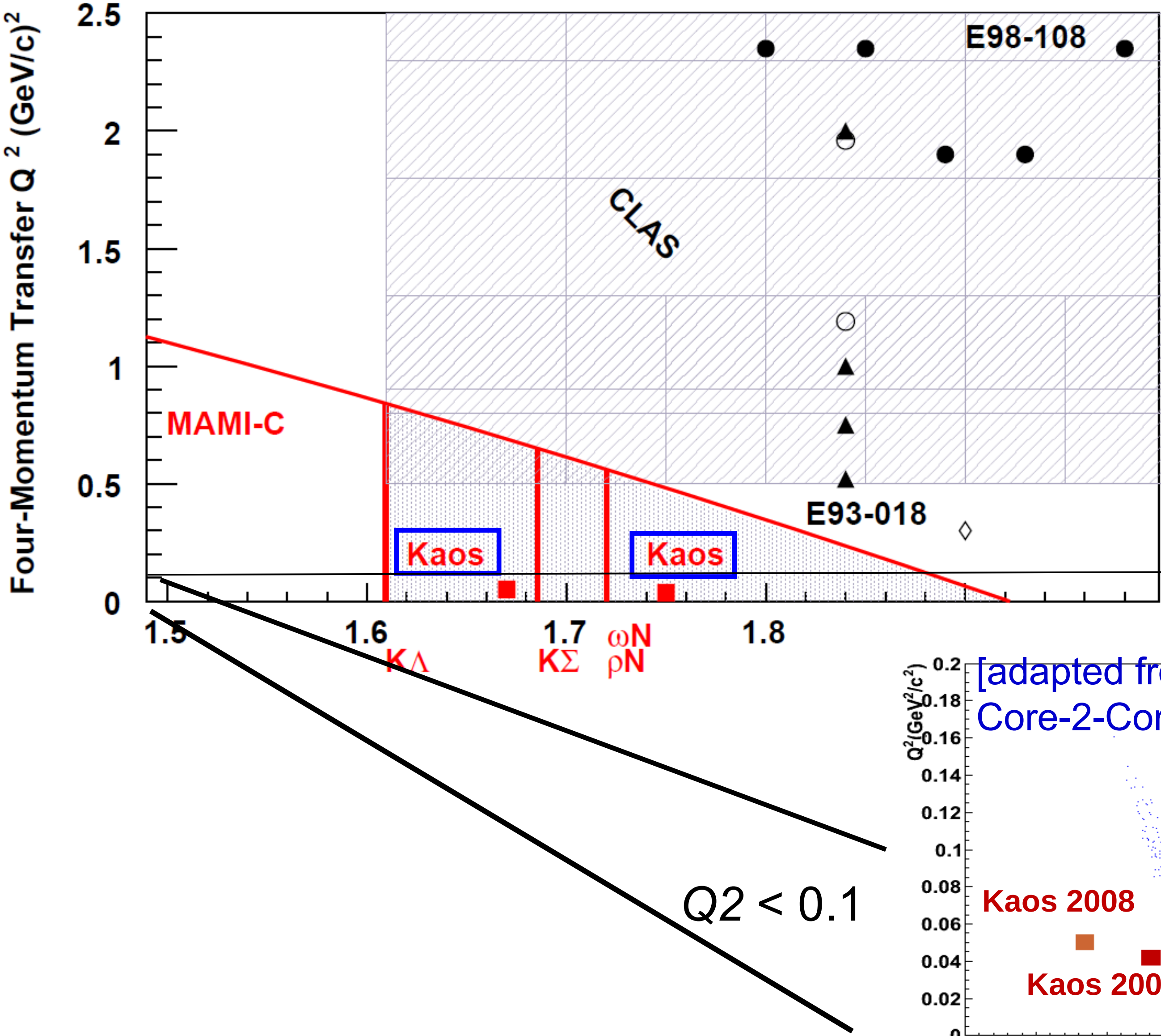
T.Nakano, Chiral10

Open Strangeness Detection at MAMI: KAOS



P.Achenbach

Kinematics of Strangeness Electroproduction

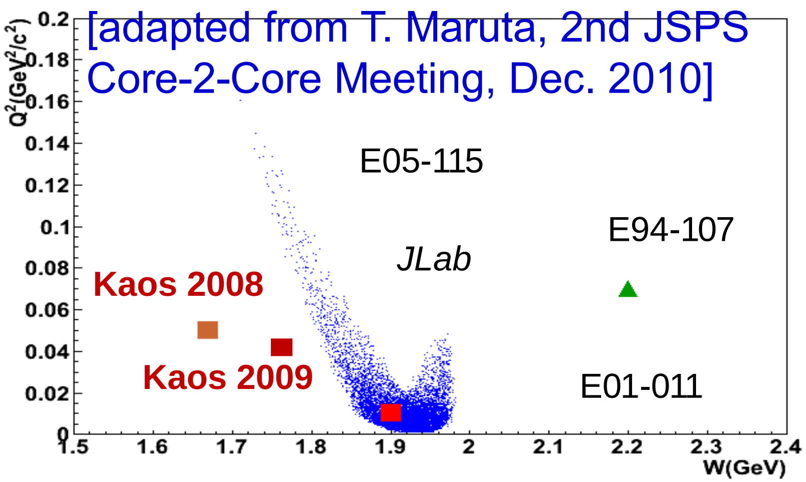


← **Hadronic Energy W (GeV)**

[E93-018: R. M. Mohring *et al.*, *Phys. Rev. C 67*, 055205 (2003); reanalysis in G. Niculescu *et al.*, *Phys. Rev. Lett. 81*, 1805 (1998).

E98-108: M. Coman, PhD thesis, Florida International University, 2005 (unpublished).

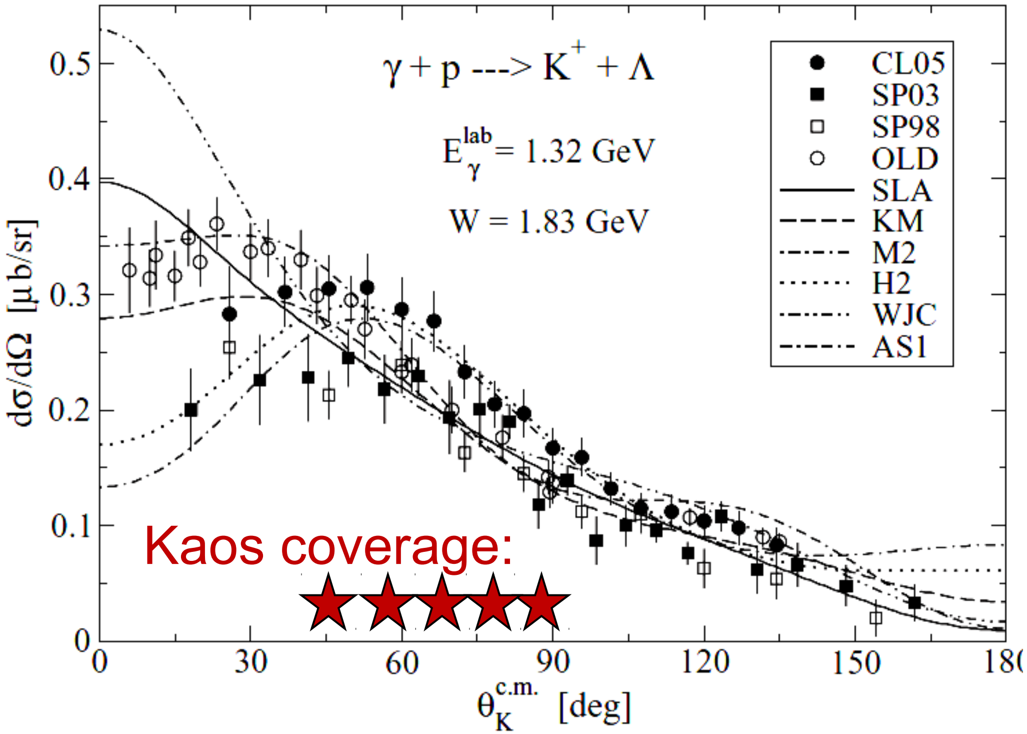
CLAS: Ambrozewicz *et al.*, *Phys. Rev. C 75*, 045203 (2007).]



[adapted from T. Maruta, 2nd JSPS Core-2-Core Meeting, Dec. 2010]

P.Achenbach

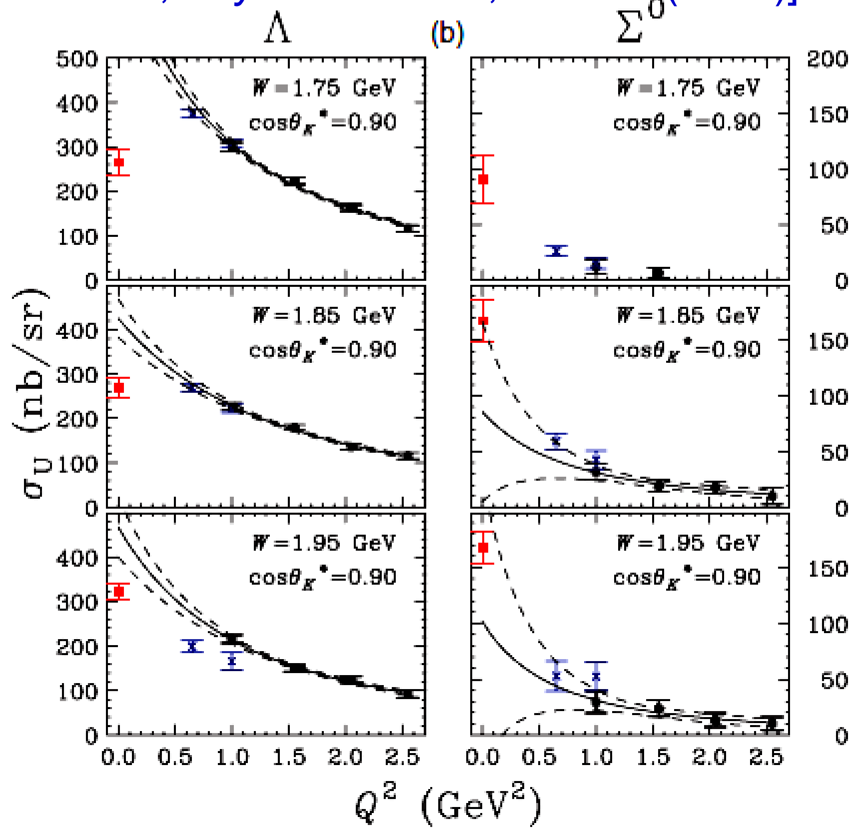
Elementary cross section



[T. Mart and A. Sulaksono, *Phys. Rev. C 74,* 055203 (2006)]

[Data:
K. H. Glander *et al., Eur. Phys. J. A 19,* 251 (2004)
R. Bradford *et al. (CLAS), Phys. Rev. C 73,* 035202 (2006)
M. Sumihama *et al. (LEPS), Phys. Rev. C 73,* 035214 (2006)
K. H. Althoff *et al., Nucl. Phys. B 137*, 269 (1978)
M. Q. Tran *et al. (SAPHIR), Phys. Lett. B 445,* 20 (1998)]

[Ambrozewicz *et al.*, *Phys. Rev. C 75*, 045203 (2007)]

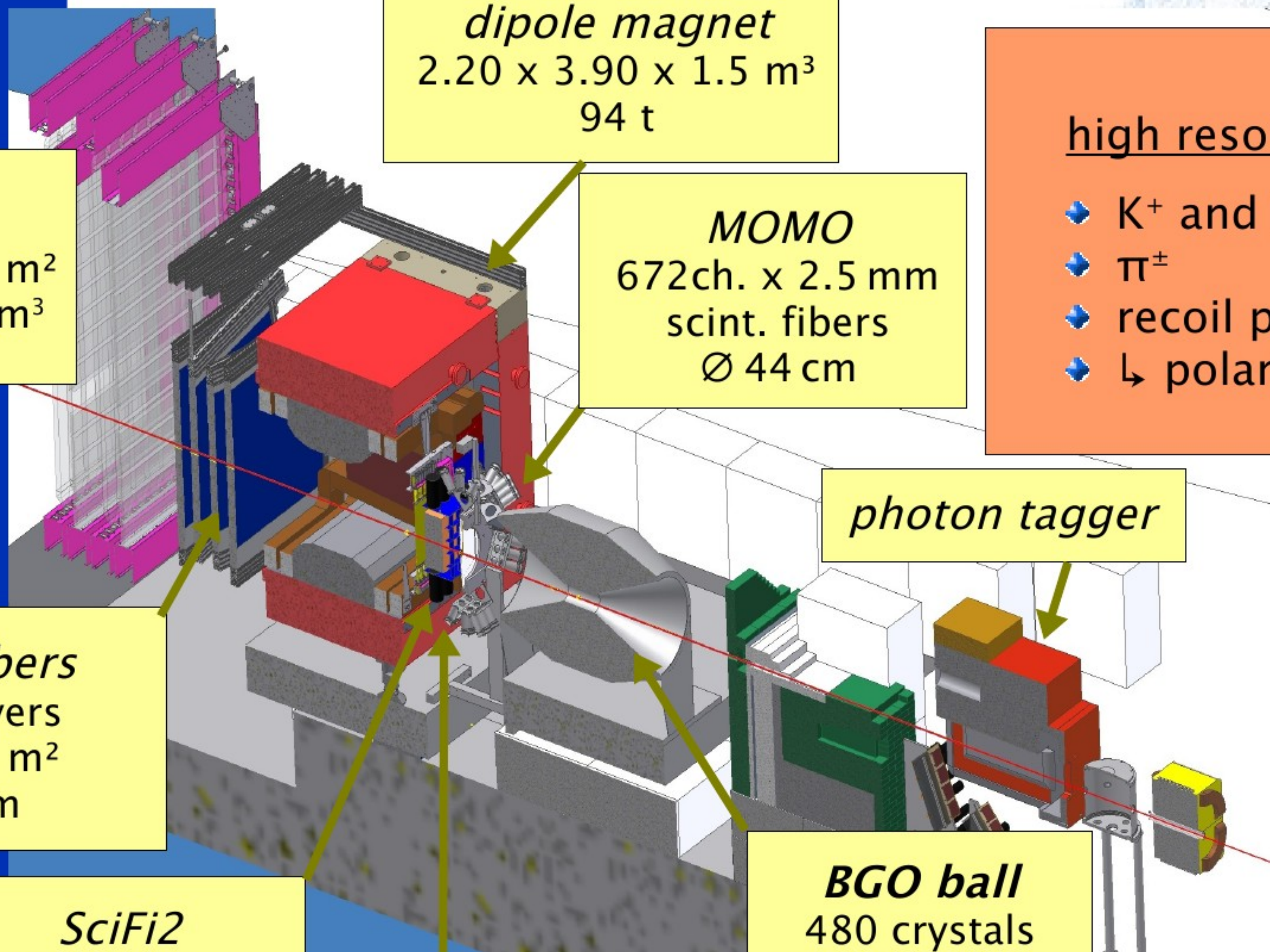


Σ cross section falls faster with Q^2 than Λ cross section
→ strong longitudinal contributions

P.Achenbach

BGO-OpenDipole setup

H.Schmieden



<u>high resolution det. of</u>

- K^+ and K^- (⇨ Φ)
- $\pi^\pm$
- recoil p (& n)
- ↳ polarimetry

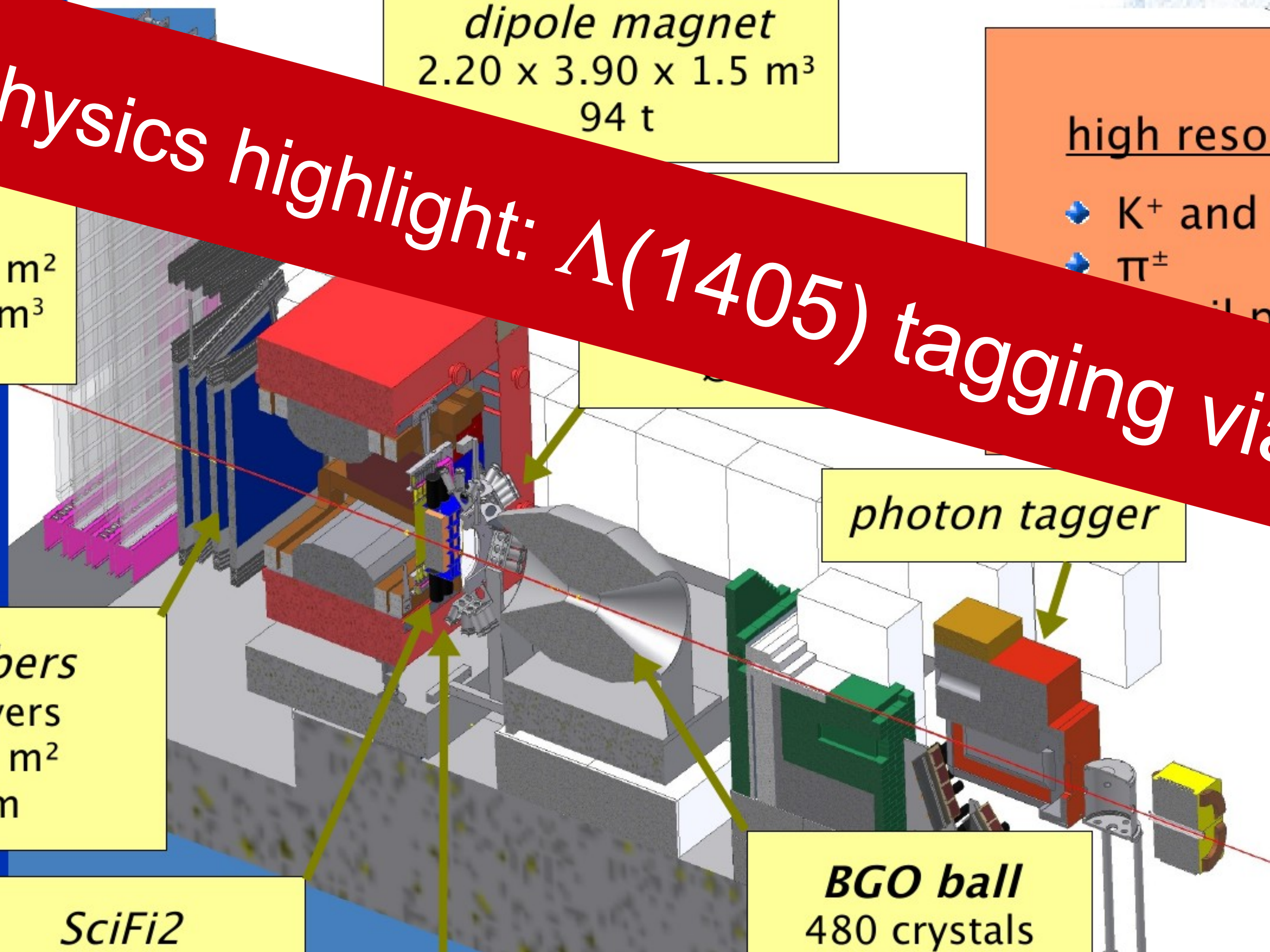
SFB/TR-16

universitätbonn

BGO-OpenDipole setup

H.Schmieden

(one) physics highlight: $\Lambda(1405)$ tagging via $\Sigma^0\pi^0$



dipole magnet
2.20 x 3.90 x 1.5 m³
94 t

TOF
4 layers à 3x3 m²
5 x 20 x 300 cm³

high resolution det. of
- K^+ and K^- (⇨ Φ)
- $\pi^\pm$
- p (& n)

photon tagger

drift chambers
8 double layers
2.46 x 1.23 m²
δ < 300 μm

SciFi2
640ch. x 3.0 mm
scint. fibers
66 x 51 cm²

aerogel-Č
46 x 46 cm²
n = 1.05

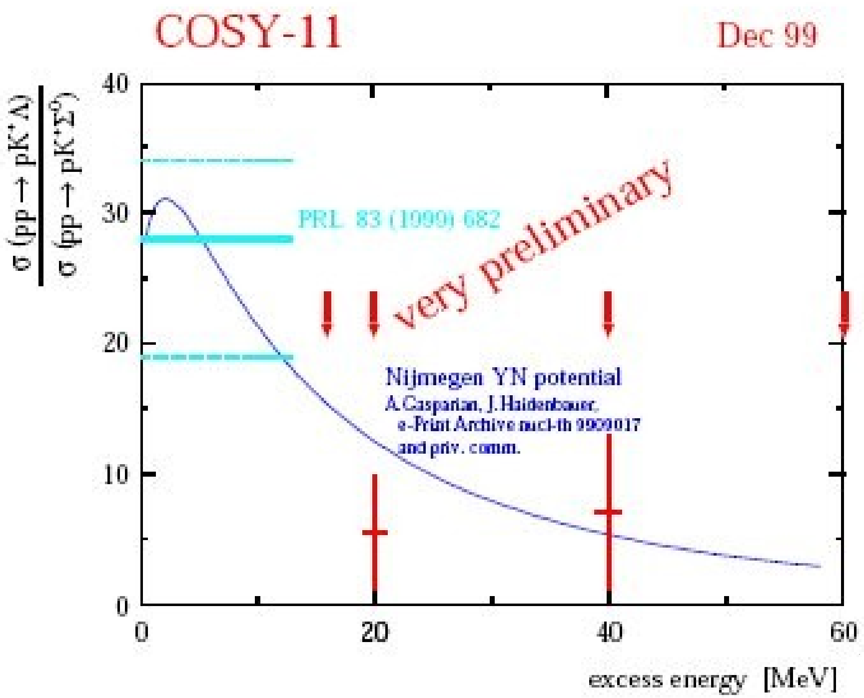
BGO ball
480 crystals
21 rad lengths
25-155 deg

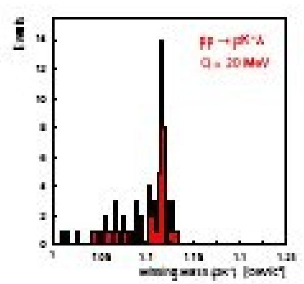
SFB/TR-16

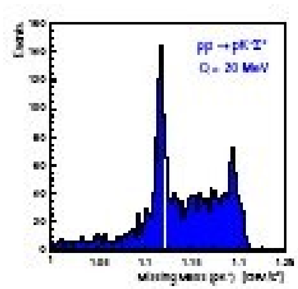
pp → pK⁺Y 11 years ago...

The Λ/Σ⁰ Ratio

Energy Dependence

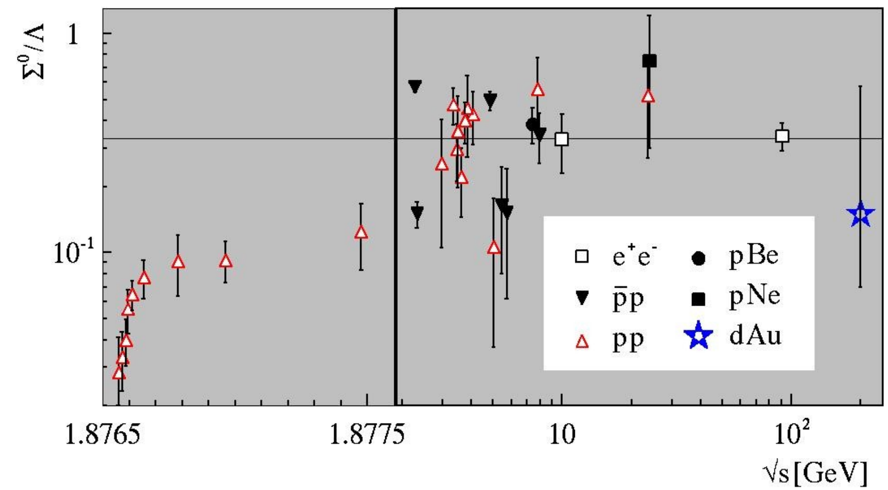






MW, Hirschegg 2000

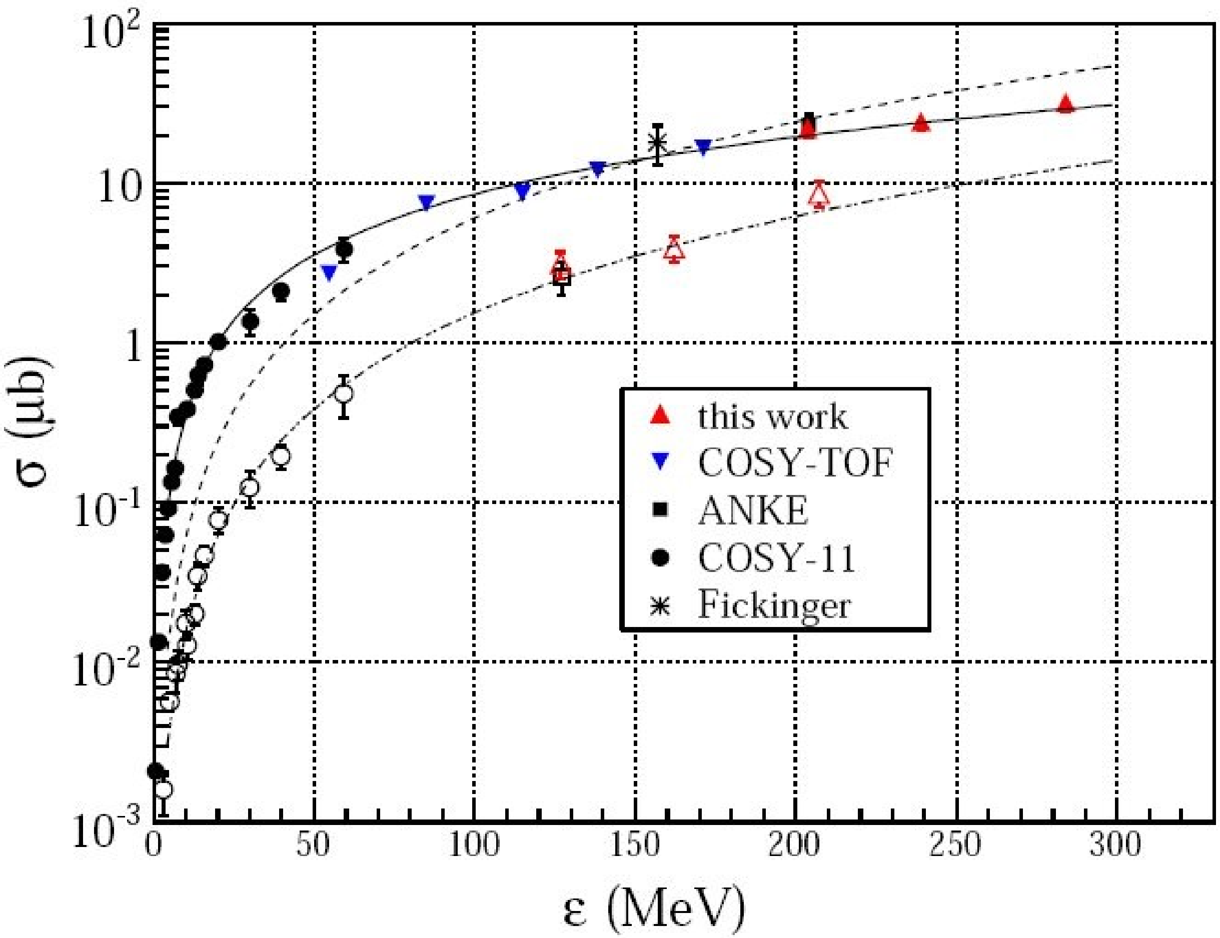
Λ/Σ^0 ratio at high energies: R ≈ 2.2



G. Van Buren (STAR Collaboration),
QM 2005, nucl-ex/0512018

Λ/Σ^0 ratio at threshold: **R** $\approx 28^{+6}_{-9}$

and pp → pK⁺Y today...



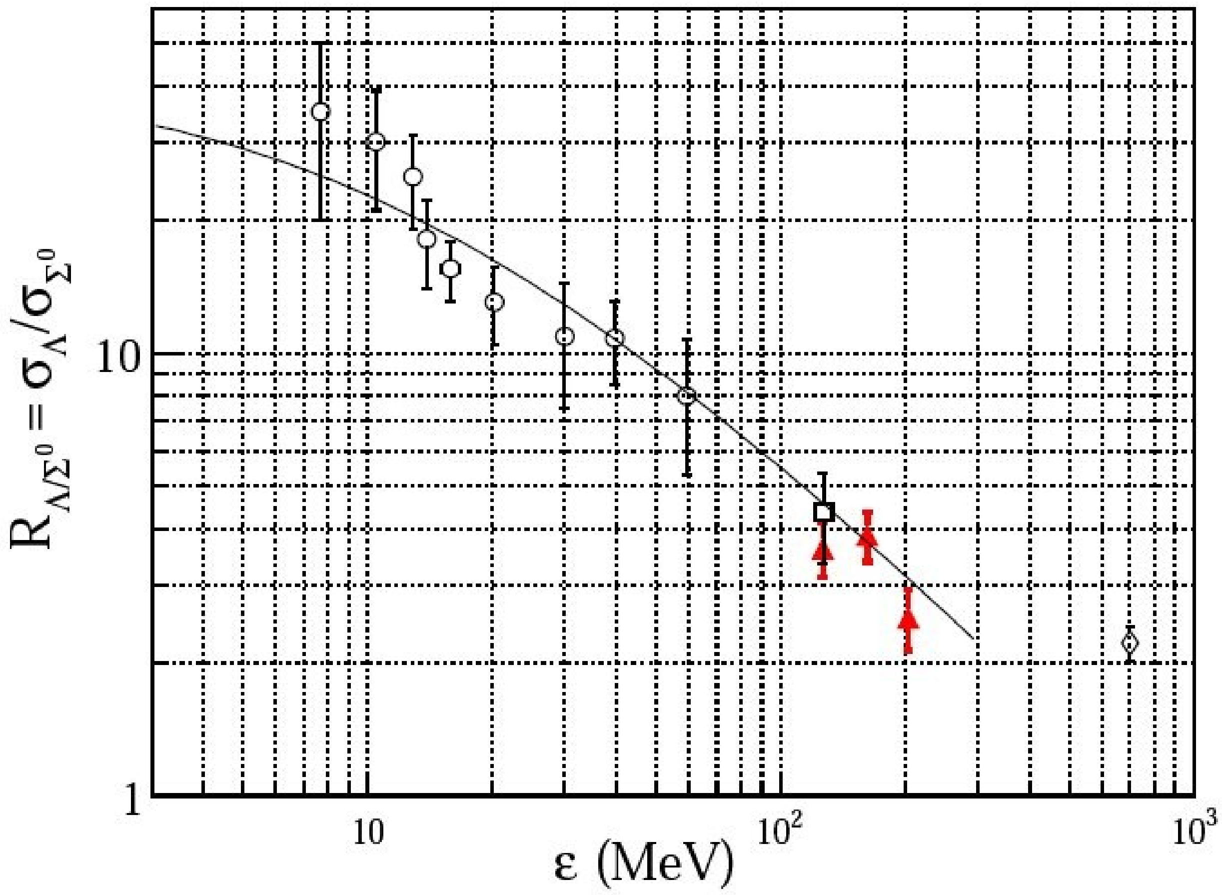
M. Abdel-Bary et al. (COSY-TOF Collaboration), EPJA 46 (2010) 27

solid symbols	$pK^+\Lambda$
open symbols	$pK^+\Sigma^0$
phase space	
G.Fäldt, C.Wilkin, ZPA 357 (97) 241	

Σ^0 excitation function described by phase space behaviour

Λ excitation function deviates from phase space behaviour

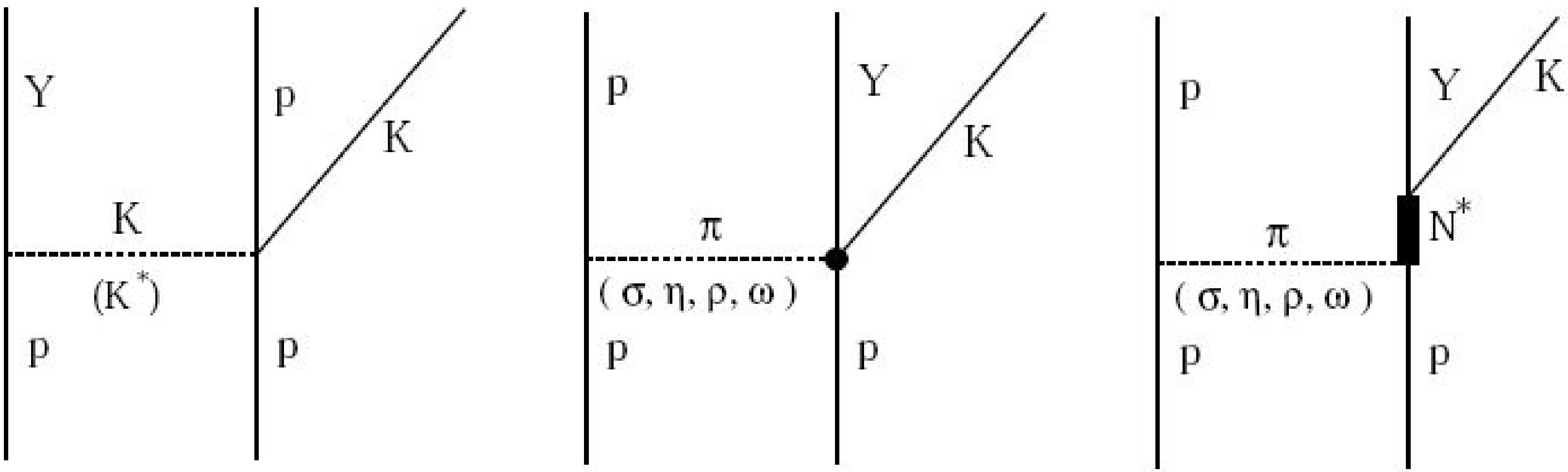
$R_{\Lambda/\Sigma} = \sigma(pK^+\Lambda) \,/\, \sigma(pK^+\Sigma^0)$



M. Abdel-Bary et al. (COSY-TOF Collaboration), EPJA 46 (2010) 27

Energy region of enhanced Λ over Σ^0 production ends slightly above 200 MeV excess energy

pp → $pK^+\Lambda/\Sigma^0$ reaction mechanism

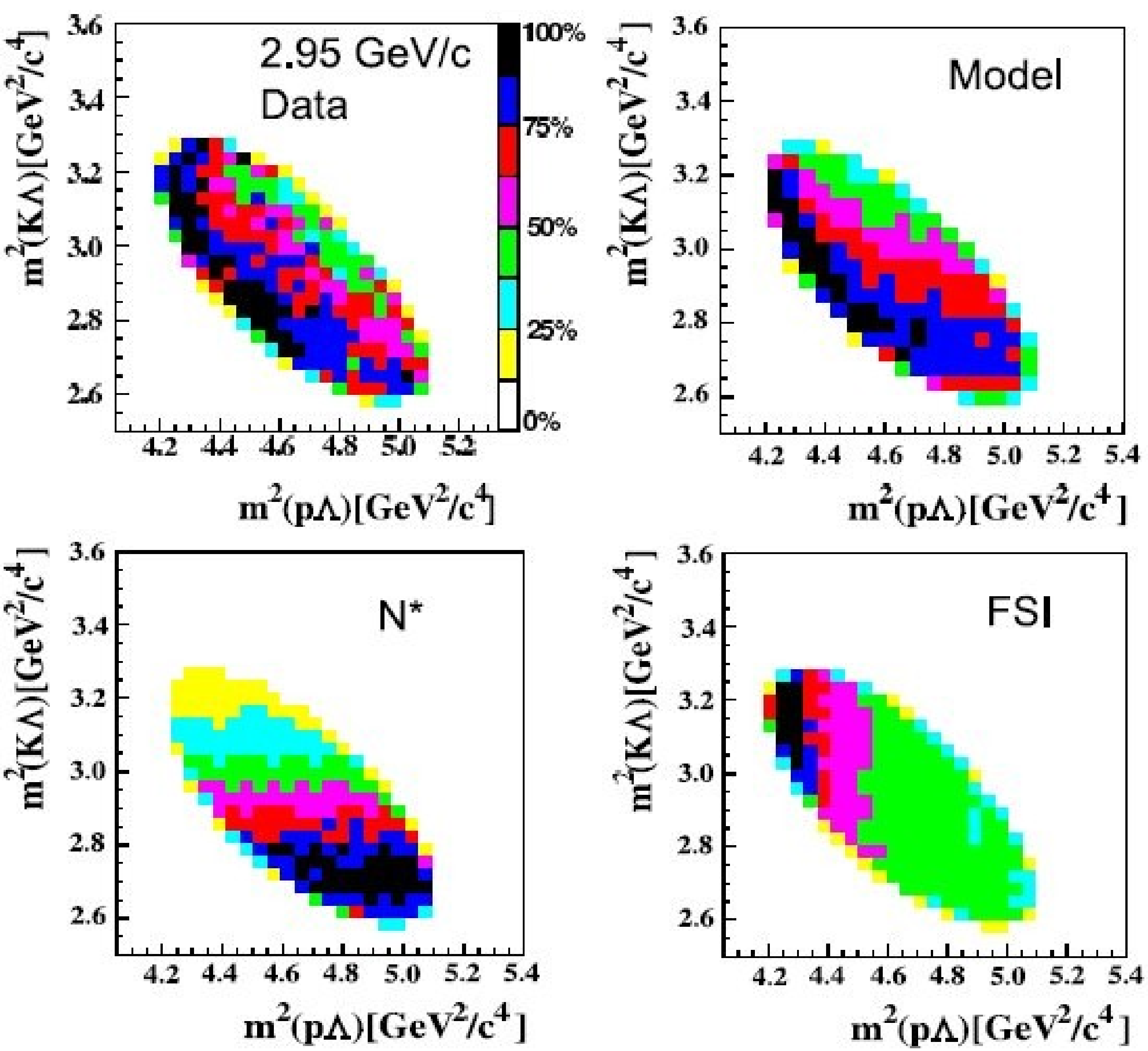


Model contents describing total cross section data and Λ/Σ^0 ratio:

- production via established nucleon resonances
- coherent interplay of resonances and final state interaction
- N(1535) without any FSI
- destructive interference of π and K exchange
- constituent quark-gluon model with resonances

⇒ Differential observables needed to constrain reaction mechanism

pp → pK⁺Λ Dalitz plot

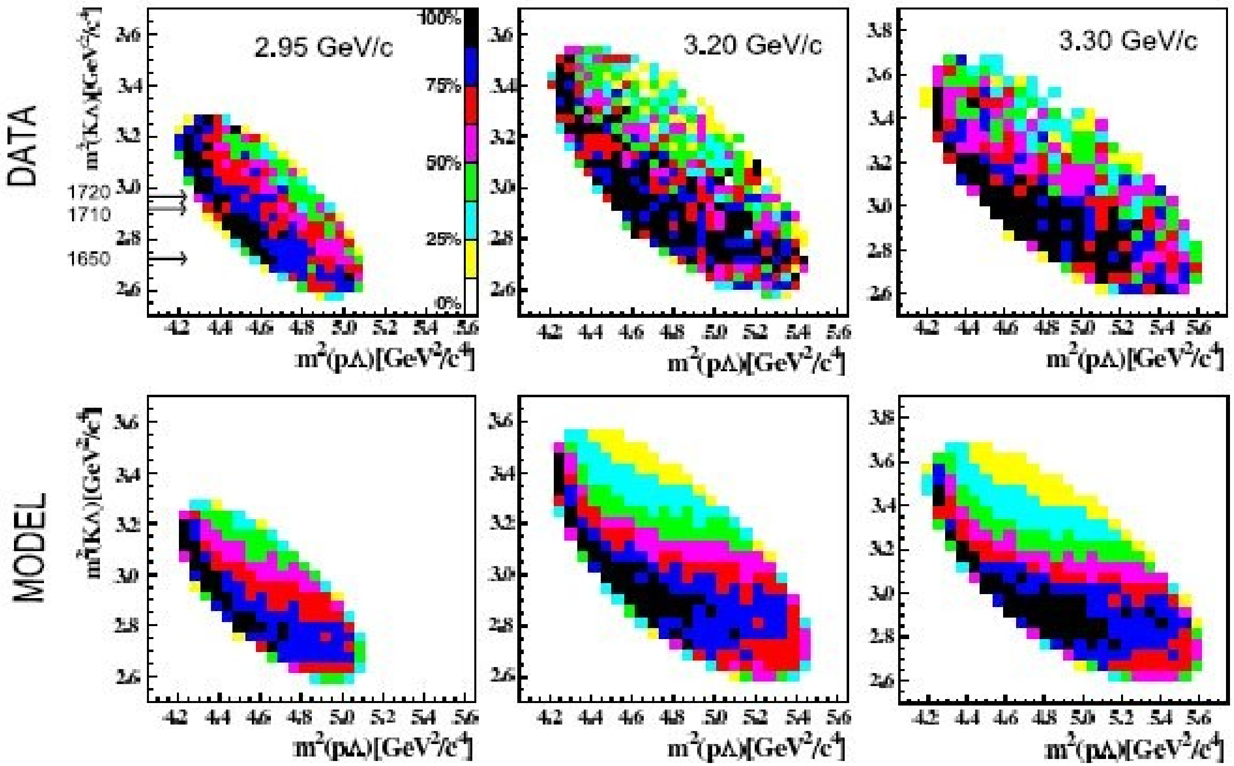


S. Abd El-Samad et al. (COSY-TOF Collaboration), PLB 688 (2010) 142

ISOBAR model, A. Sibirtsev: different N^* resonances, final state interaction

A.Sibirtsev, J.Haidenbauer, H.-W.Hammer, S.Krewald, EPJA 27 (2006) 269

pp → pK$^+$Λ Dalitz plot



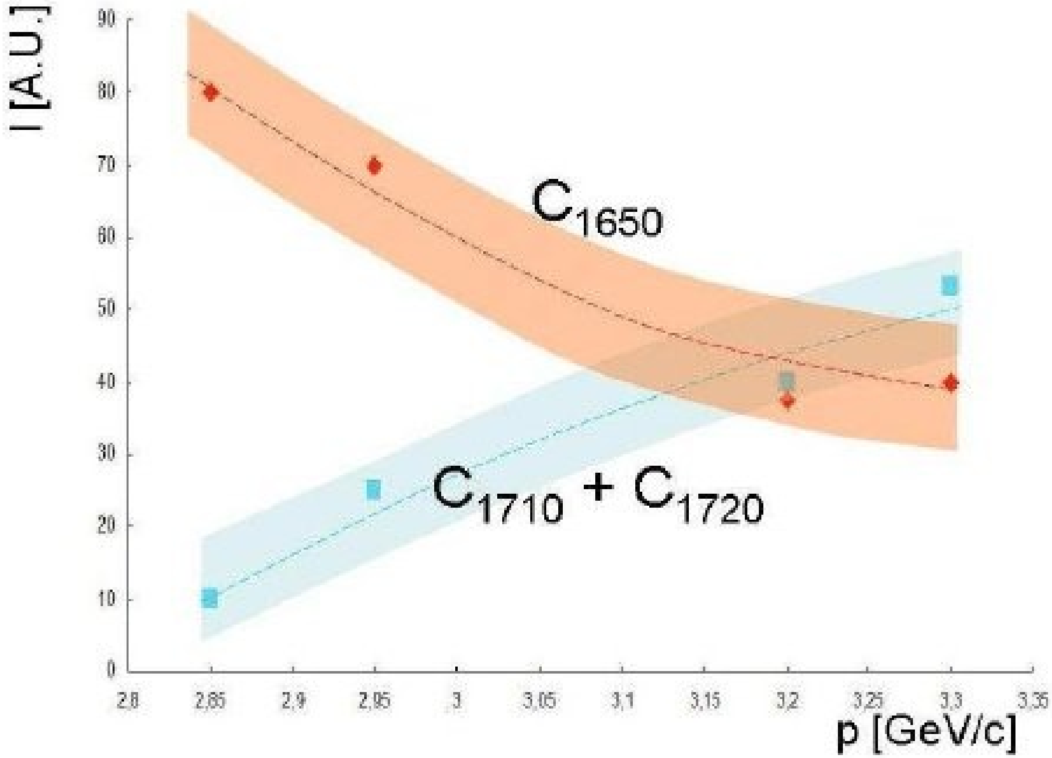
S. Abd El-Samad et al. (COSY-TOF Collaboration), PLB 688 (2010) 142

ISOBAR model, A. Sibirtsev: different N* resonances, final state interaction

$$\frac{\partial^2 \sigma}{\partial m_{K\Lambda}^2 \partial m_{p\Lambda}^2} = fl \cdot ps \cdot \left| \left(\sum_R (C_R \cdot A_R) + C_N \cdot A_N \right) \cdot (1 + C_{FSI} \cdot A_{FSI}) \right|^2$$

A_R = relativistic BW amplitudes of three N* resonances considered $\quad \sum_R C_R + C_N = 1$

pp → pK$^+$Λ Dalitz plot



S. Abd El-Samad et al. (COSY-TOF Collaboration), PLB 688 (2010) 142

leading mechanism: **N* resonance excitation**

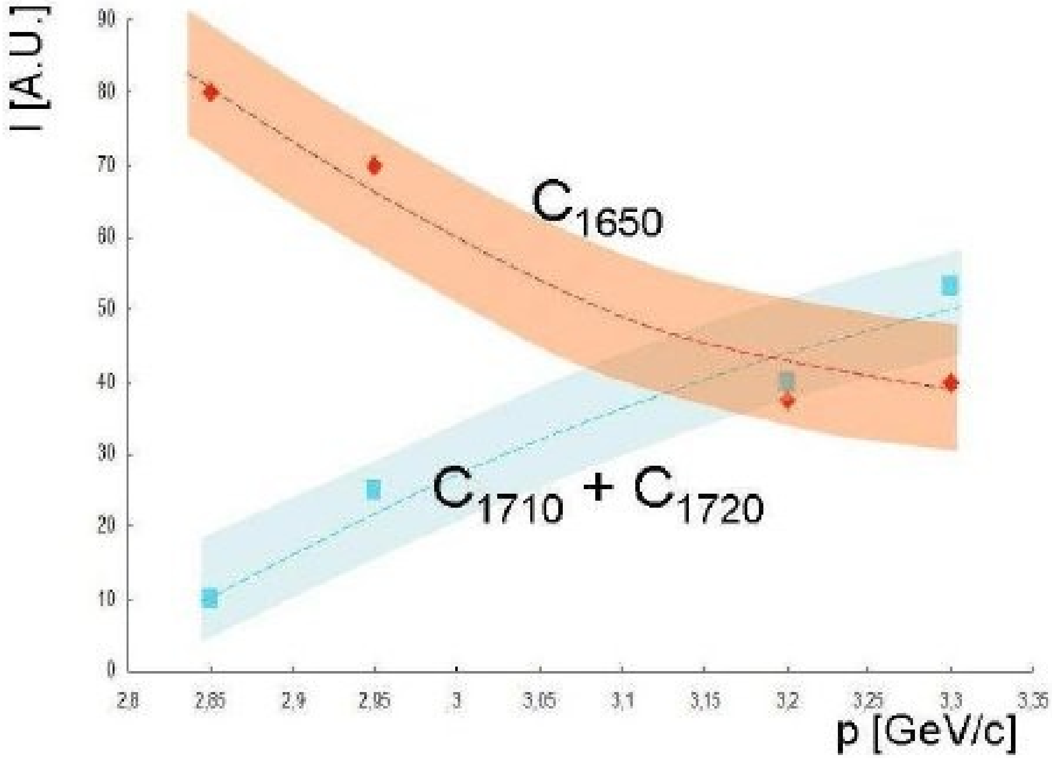
at ε ≈ 200 MeV: N(1650)S_{11} dominant,

comparable to N(1710)P_{11} + N(1720)P_{13} at ε ≈ 300 MeV

pΛ–FSI mandatory for appropriate description

nonresonant contribution small

pp → pK$^+$Λ Dalitz plot



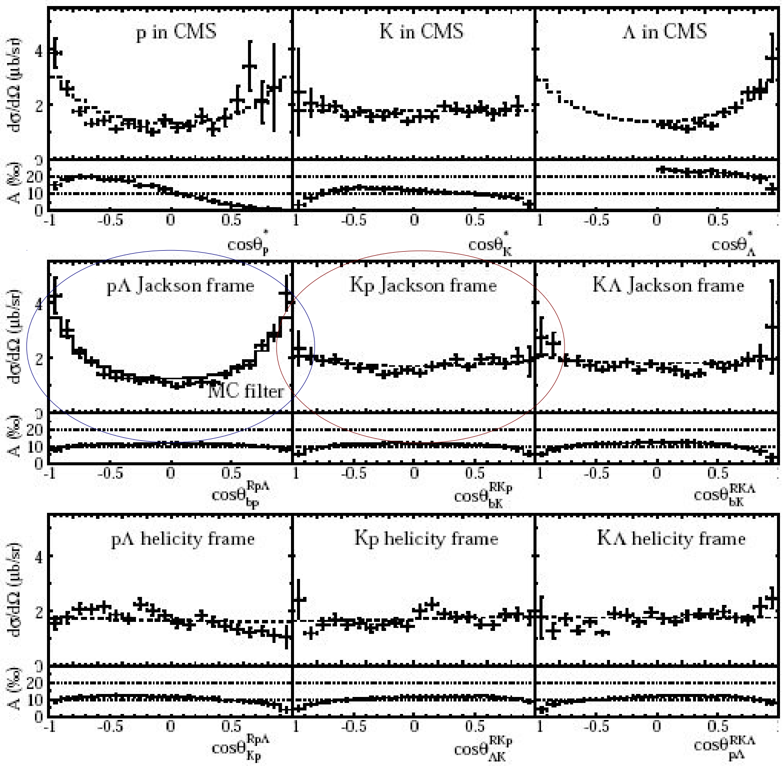
S. Abd El-Samad et al. (COSY-TOF Collaboration), PLB 688 (2010) 142

separation of N(1710)P_{11} and N(1720)P_{13} with **polarised beam (program started 2010)**

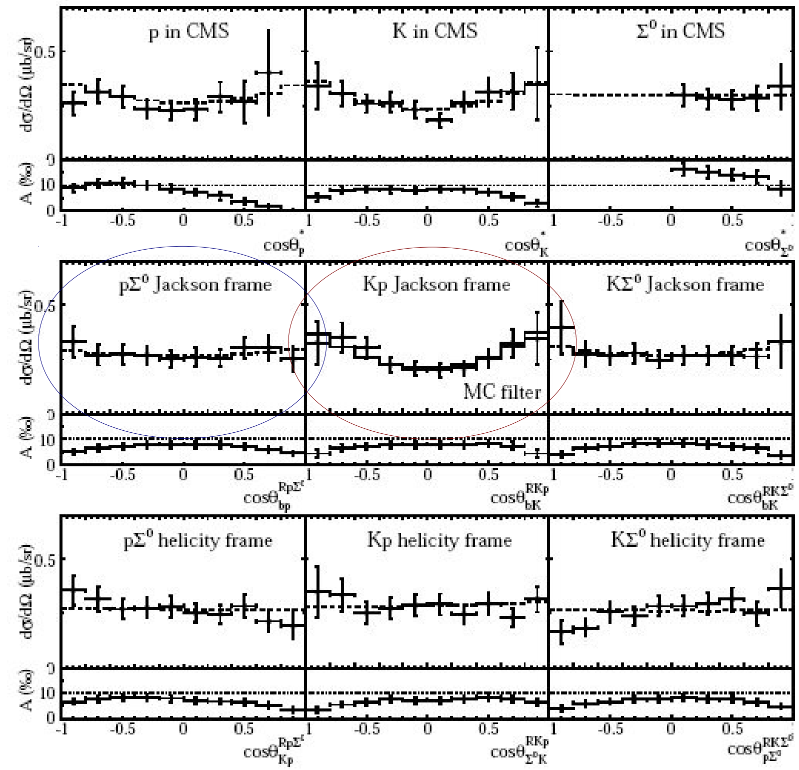
additional tool: **Partial Wave Analysis** as for γp (A.V.Sarantsev, V.A.Nikonov, A.V.Anisovich, E.Klempt, U.Thoma, EPJA 25 (05) 441)

pp → $pK^+\Lambda/\Sigma^0$ angular distributions

pp → $pK^+\Lambda$ Q = 204 MeV



pp → $pK^+\Sigma^0$ Q = 162 MeV



Λ: L=0 and L=1 resonances likely: S_{11}, P_{11}, P_{13}

Σ^0: intermediate resonances only occur with L=0 for p-N^* or p-Δ^*

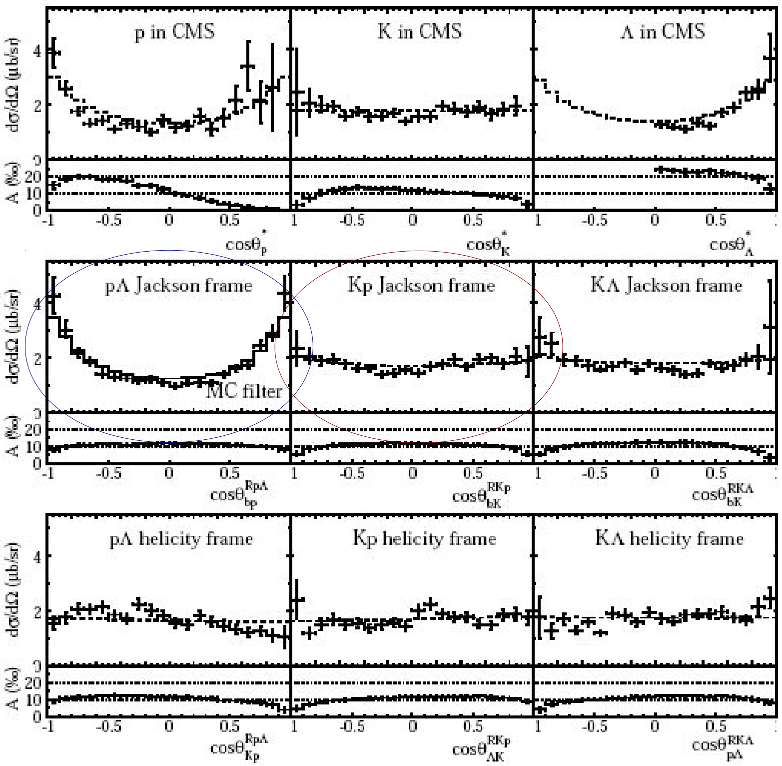
L in entrance or exit channel or total L must be 0!

Resonance contribution only likely from N(1650)S_{11}, Δ(1900)S_{31}

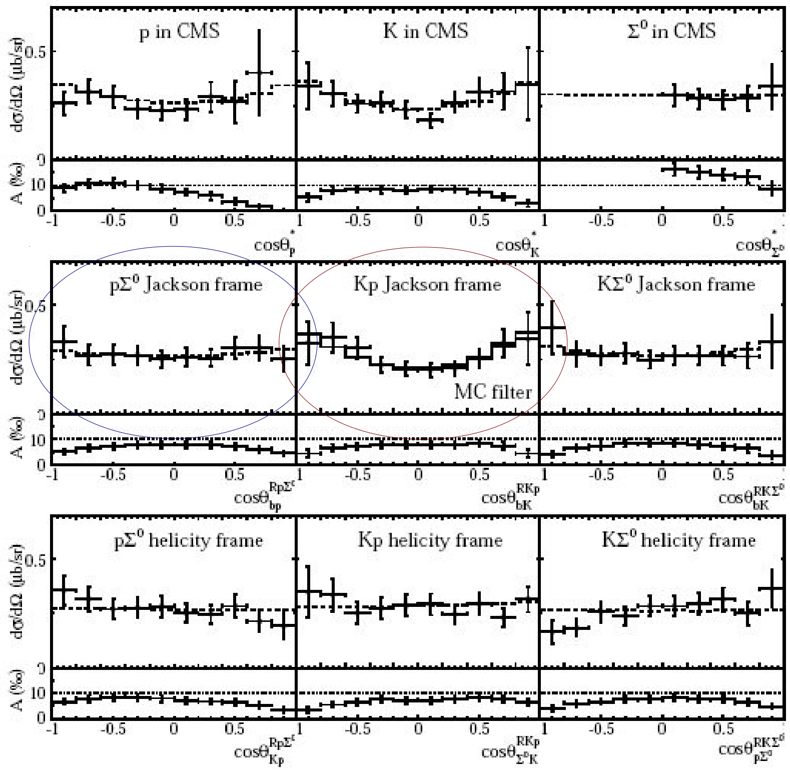
M. Abdel-Bary et al., EPJA 46 (2010) 27

pp → $pK^+\Lambda/\Sigma^0$ angular distributions

pp → $pK^+\Lambda$ Q = 204 MeV



pp → $pK^+\Sigma^0$ Q = 162 MeV



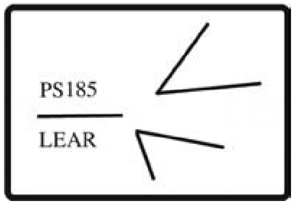
Λ: only small (L=0) contribution from K-exchange possible

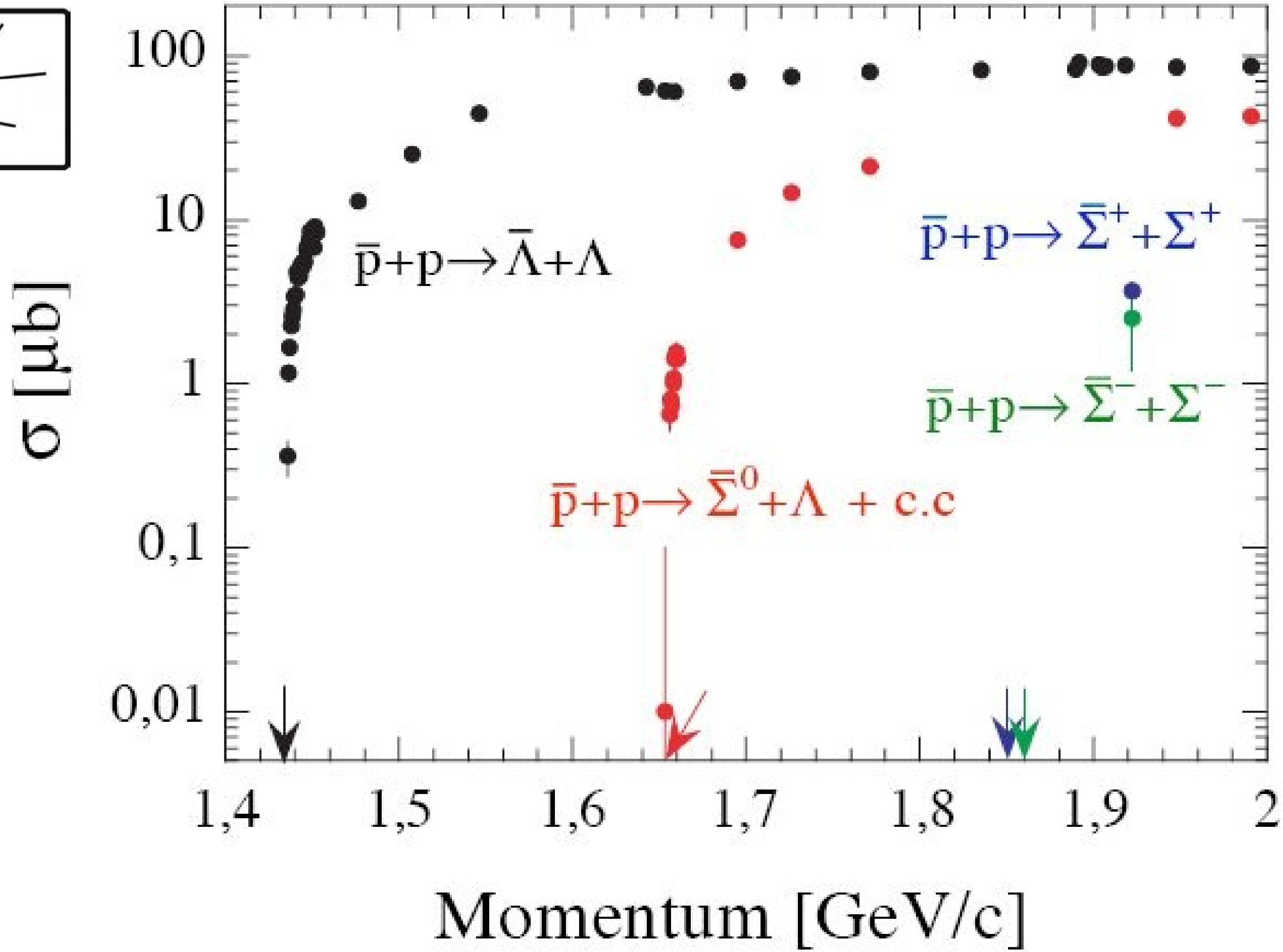
Σ^0: L=1 for p-K^+ subsystem strongly indicates significance of kaon exchange

Production mechanisms for Λ and Σ^0 differ decisively!

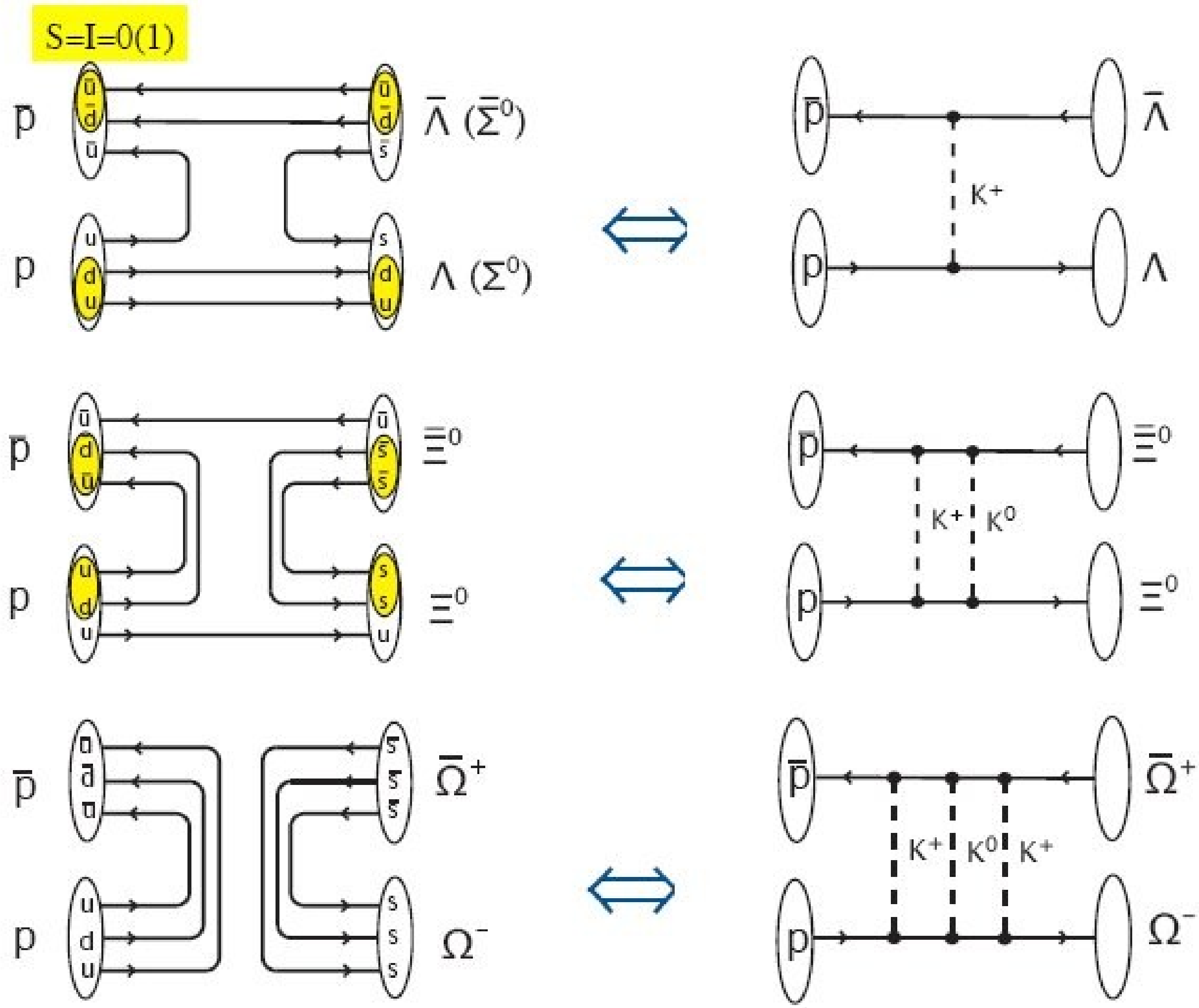
M. Abdel-Bary et al., EPJA 46 (2010) 27

$\bar{p}p \to Y\bar{Y}$ total cross sections





$\bar{p}p \rightarrow Y\bar{Y}$

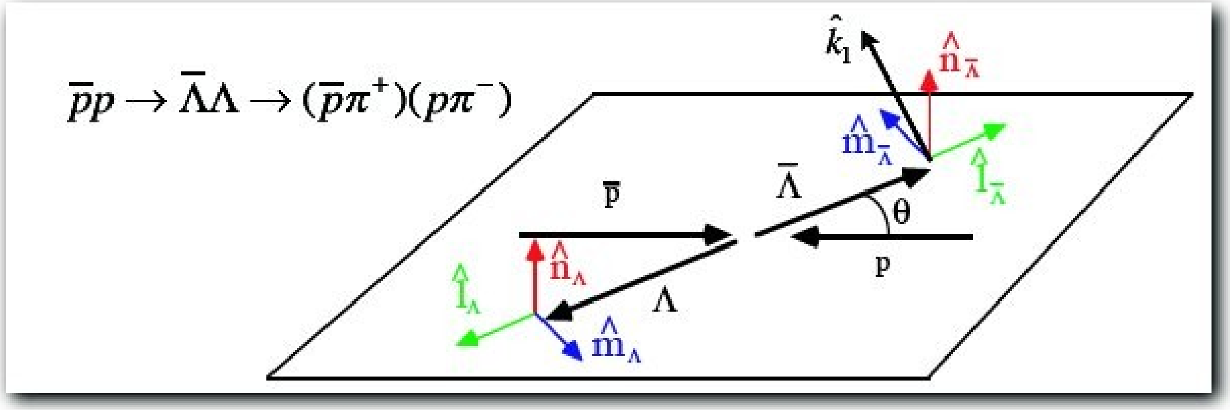


spin of the $\bar{\Lambda}/\Lambda$ is primarily carried by the $\bar{s}/s$ quark

$\bar{p}p \rightarrow \bar{\Lambda}\Lambda$

spin of the $\bar{\Lambda}/\Lambda$ is primarily carried by the $\bar{s}/s$ quark

➡ spin observables in $\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ give access to spin degreees of freedom in the $s\bar{s}$ creation process



$$I_{\bar{\Lambda}\Lambda}(\theta, \hat{k}_1, \hat{k}_2) = \frac{I_0^{\bar{\Lambda}\Lambda}}{64\pi^3}\left[\begin{array}{l} 1 \\ +P_n(\bar{\alpha}k_{1n} + \alpha k_{2n}) \\ +C_{nn}(\bar{\alpha}\alpha k_{1n}k_{2n}) \\ +C_{mm}(\bar{\alpha}\alpha k_{1m}k_{2m}) \\ +C_{ll}(\bar{\alpha}\alpha k_{1l}k_{2l}) \\ +C_{ml}(\bar{\alpha}\alpha(k_{1m}k_{2l} + k_{1l}k_{2m})) \end{array}\right]$$

$I_0 = \sigma_{tot}$

$I(\theta) = d\sigma/d\Omega$

P_n = Polarisation

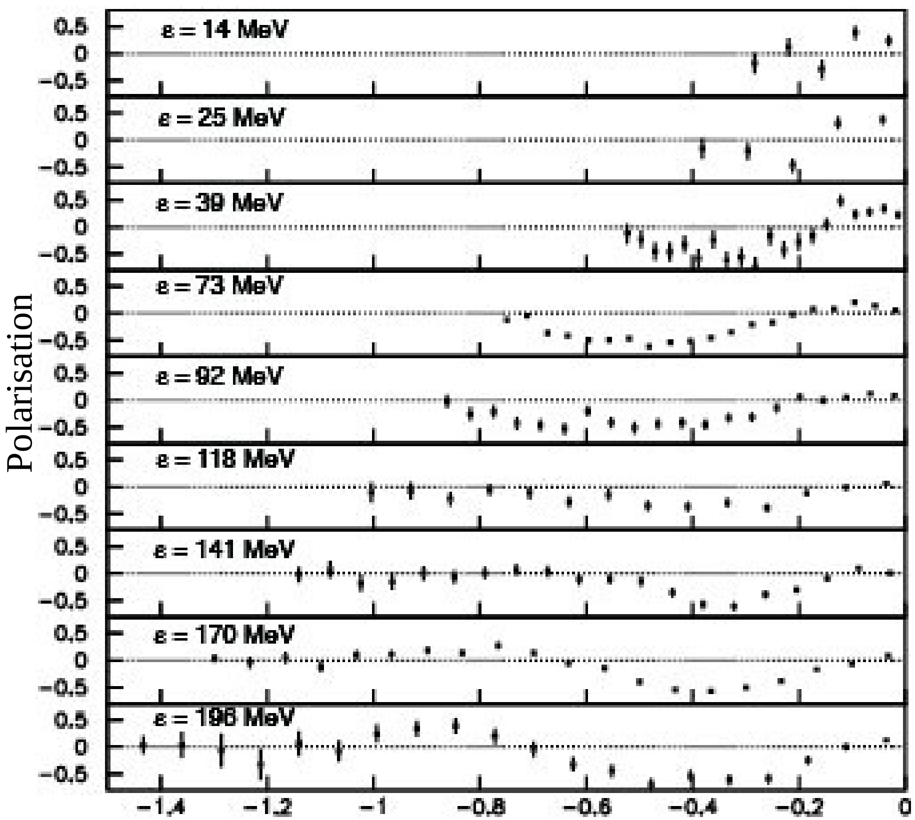
C_{ij} = Spin correlations

θ = C.M. scattering angle

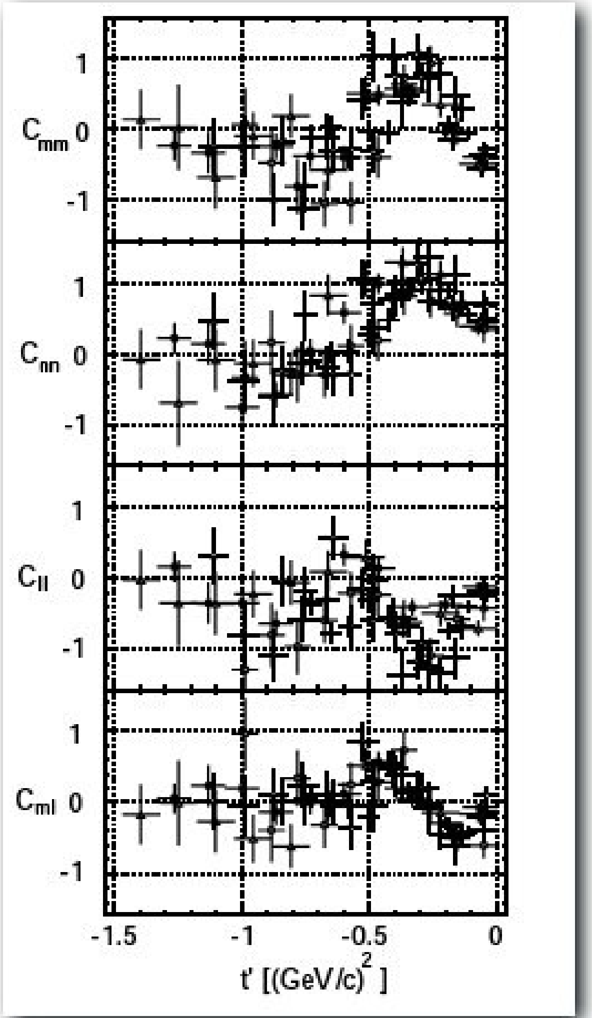
$\hat{k}_1, \hat{k}_2$ = directional vectors of decay baryons

Spin observables $\bar{p}p \rightarrow \Lambda\bar{\Lambda}$

Polarisation



Spin Correlations



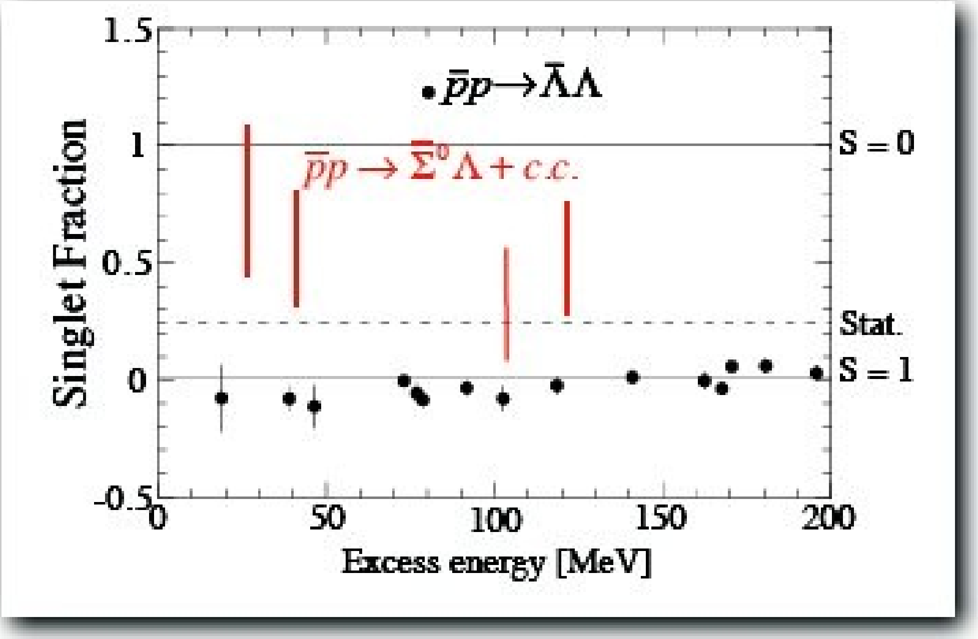
$t' = t - t_{min}$

= reduced four-momentum transfer squared

➡ interference between different amplitudes

Singlet Fraction F_s $\bar{p}p \rightarrow \Lambda\bar{\Lambda}$

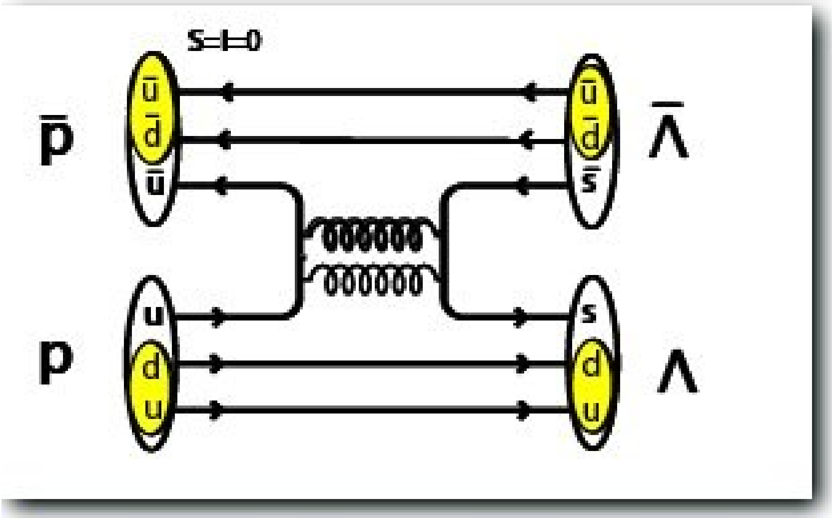
$$F_s = \frac{(1-\langle \vec{\sigma}_1 \cdot \vec{\sigma}_2 \rangle)}{4} = \begin{cases} 1 \textit{ if singlet} \\ 0 \textit{ if triplet} \\ 1/4 \textit{ if uncorrelated} \end{cases}$$



➡ $\Lambda\bar{\Lambda}$ pairs produced in triplet state!

➡ Triplet state reflects the $s\bar{s}$ production process

$\bar{p}p \rightarrow \bar{\Lambda}\Lambda$ production dynamics

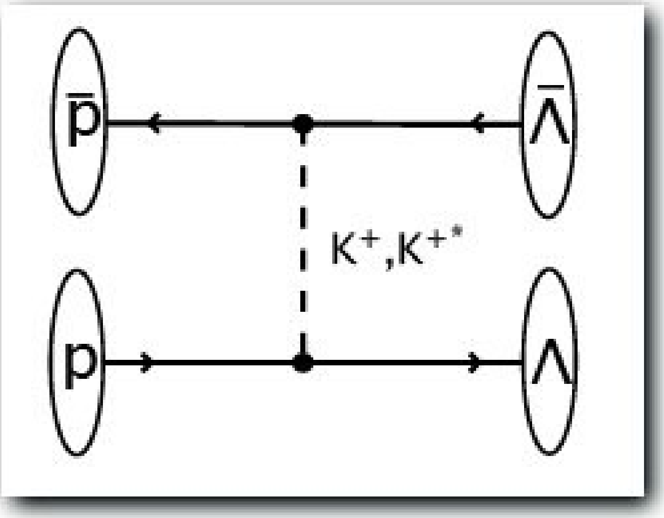


One gluon exchange: ${}^3S_{1^-}$ vertex

Two gluon exchange: ${}^3P_{0^+}$ vertex

➡ triplet $\bar{s}s$ spin

$D_{nn} > 0$

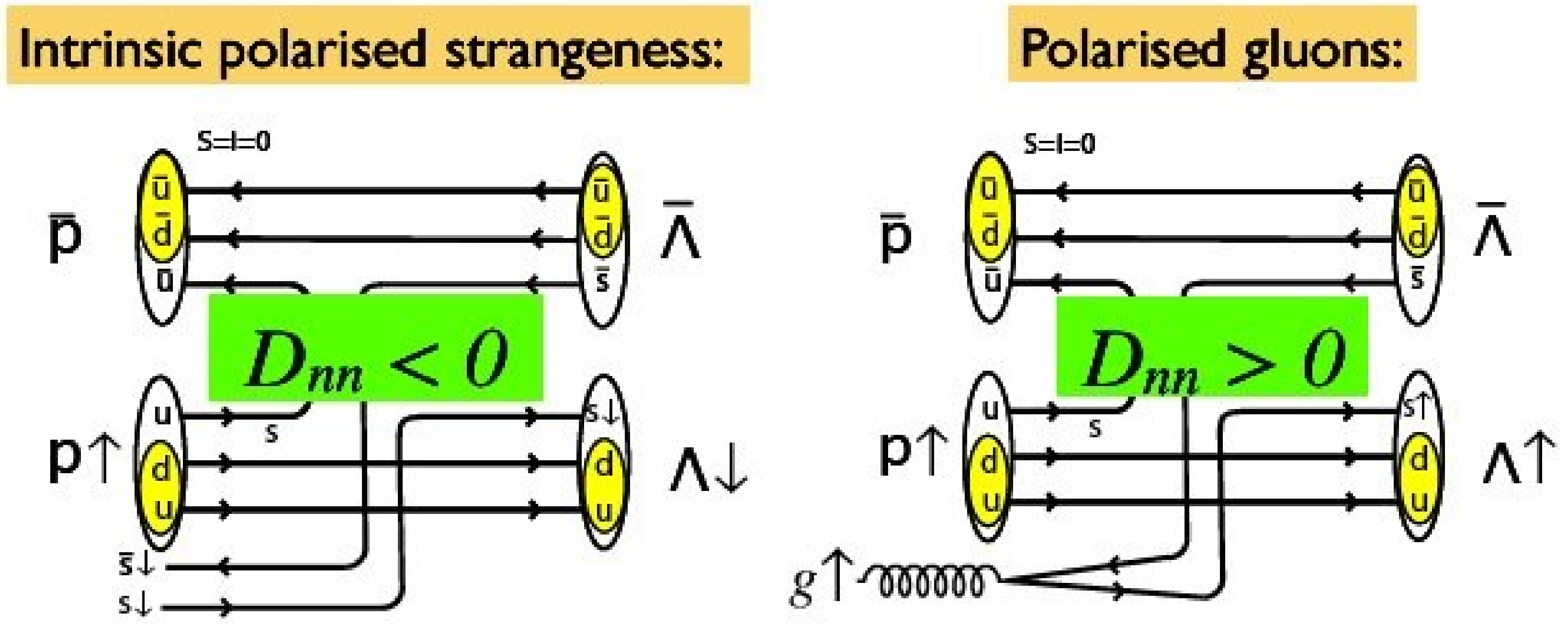


Including K_2^* allows for a $\Delta\ell = 2$ transition (spin flip)

➡ triplet $\bar{\Lambda}\Lambda$ spin

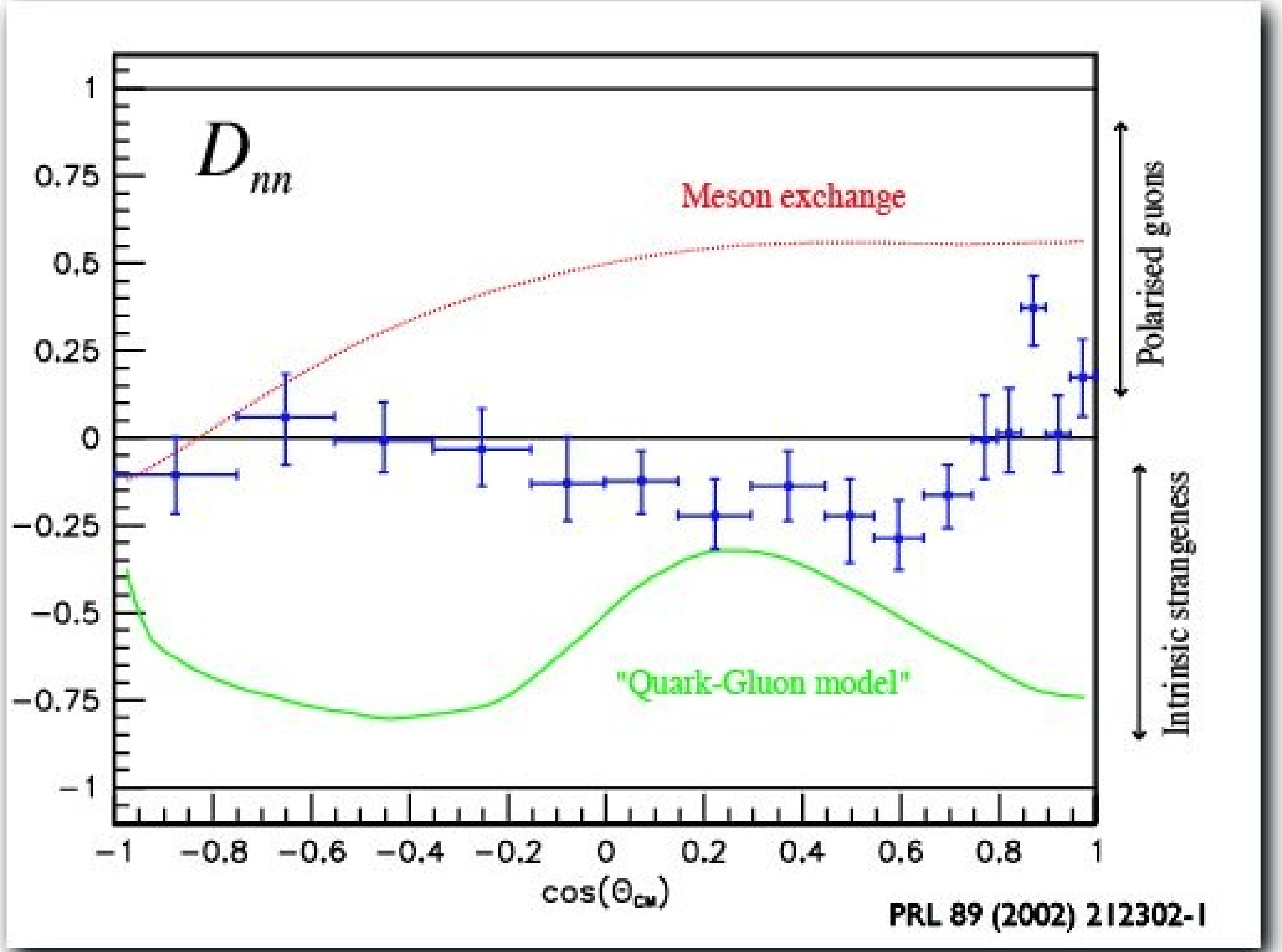
$D_{nn} < 0$

$\bar{p}p \rightarrow \Lambda\bar{\Lambda}$ production dynamics



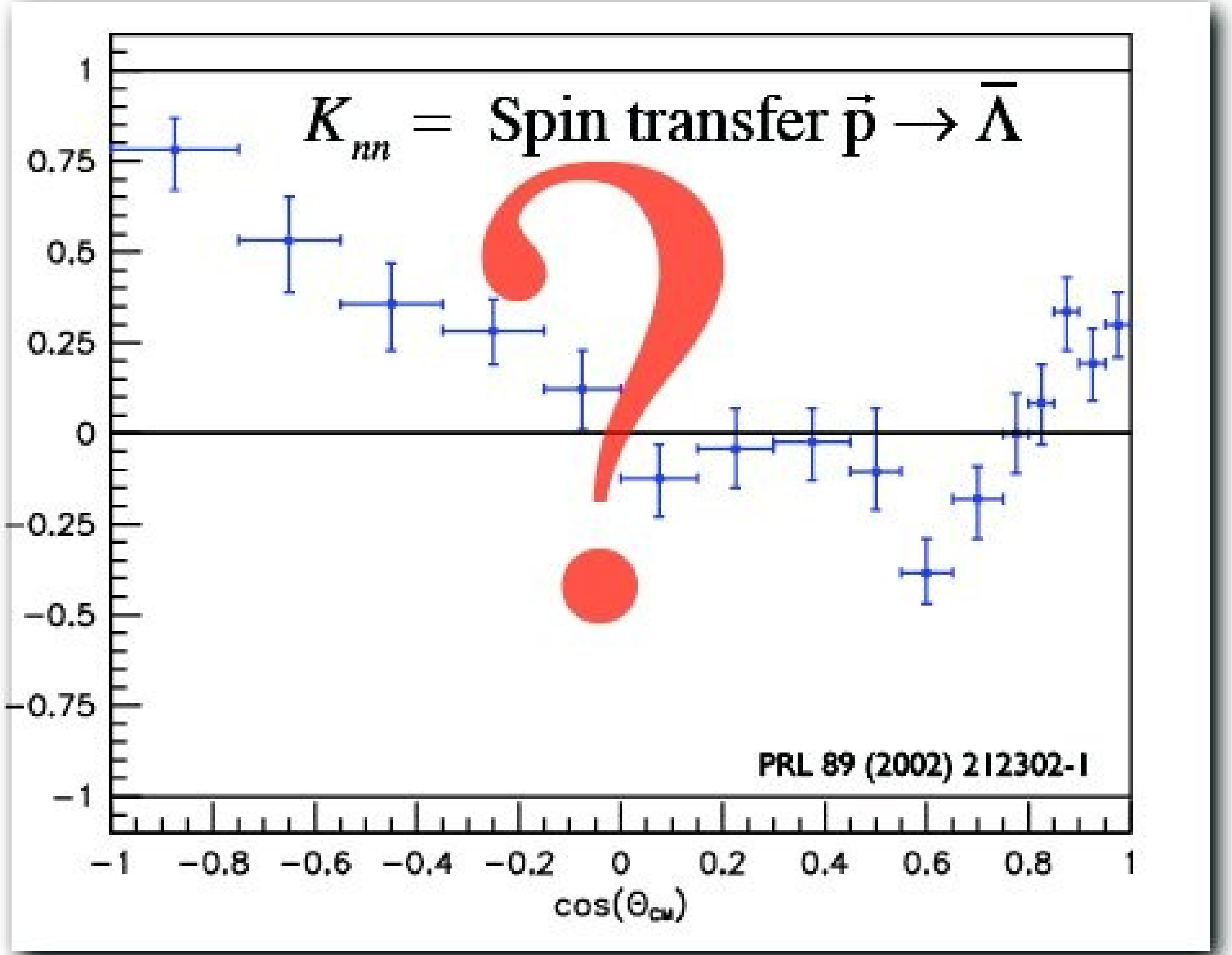
M.A. Alberg, J.R. Ellis, D. Kharzeev,
PLB 356 (1995) 113

$\overline{p}\vec{p} \rightarrow \Lambda\overline{\Lambda}$ depolarisation



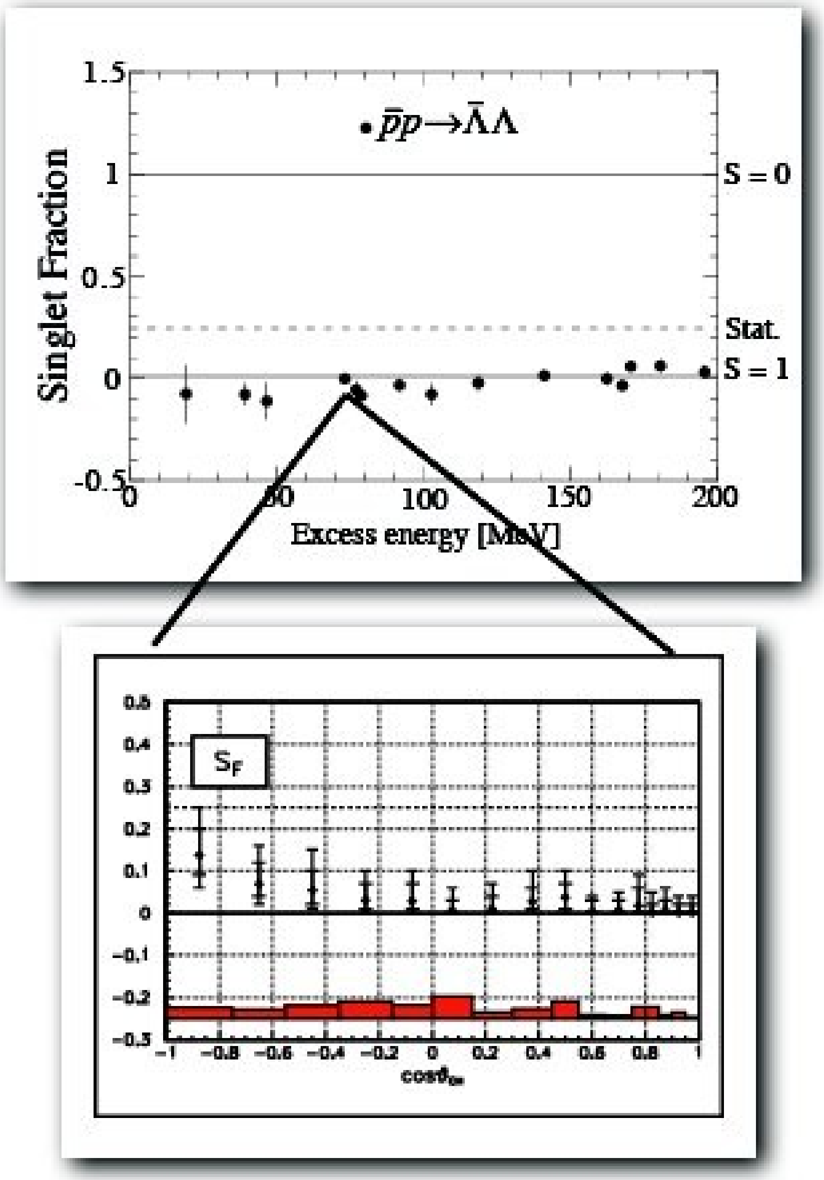
No transverse spin transfer from p to Λ!

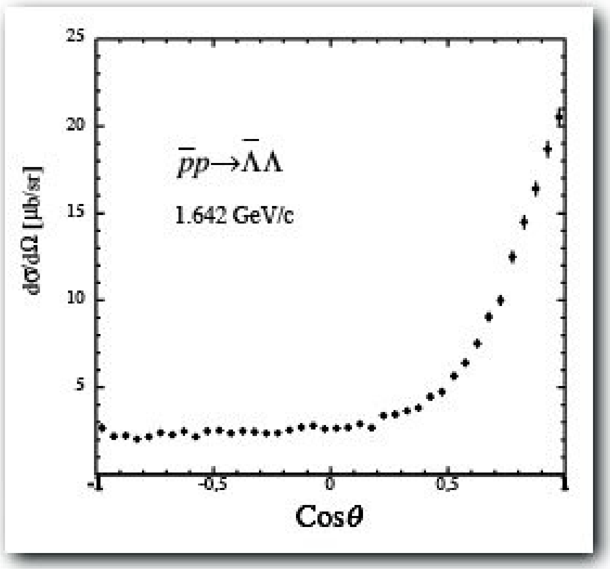
$\bar{p}\vec{p} \rightarrow \Lambda\bar{\Lambda}$ polarisation transfer



- Spin transfer from target p to $\bar{\Lambda}$!
- $\Lambda\bar{\Lambda}$ triplet state ⟷ $D_{nn} = K_{nn}$?

$\overline{p}\vec{p} \rightarrow \Lambda\overline{\Lambda}$ polarisation transfer



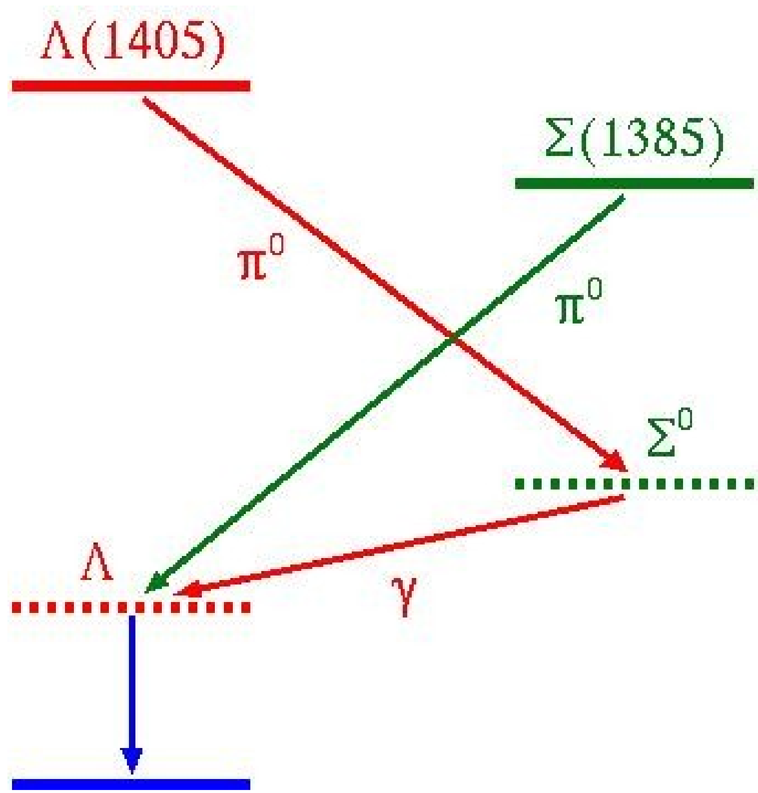


high statistical weight at forward angles → average FS ≈ 0

both depolarisation and polarisation transfer are so far not understood

Spectroscopy of cryptoexotic states: Λ(1405)

$pp \to pK^+Y^*$ $\bar{p}p \to \bar{Y}^*\Lambda\ (Y^*\bar{\Lambda})$ separation of Λ(1405) and Σ(1385)



by detection of...

...K^+ and/or $\Lambda \to p\pi^-$ (*strangeness tag*) and

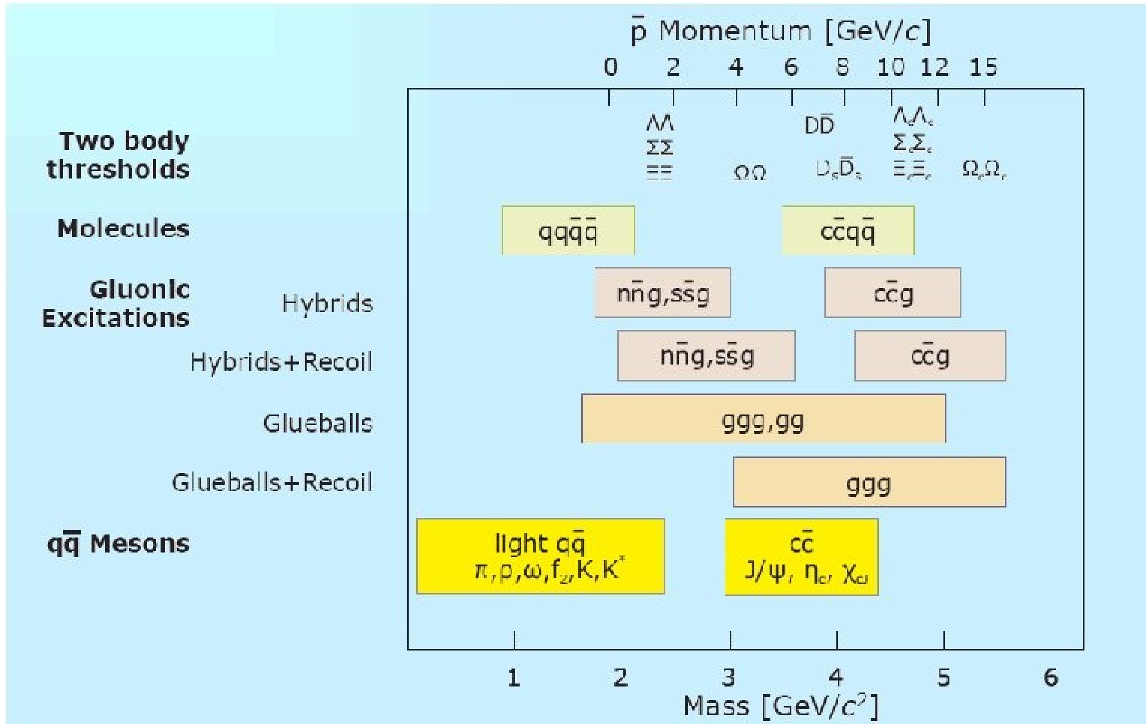
- $(p\pi^-)\pi^0$ 2γ for Σ(1385)
- $(p\pi^-)\pi^0\gamma$ 3γ for Λ(1405)

requires a detector with...

- (almost) full angular coverage
- detection of neutral and charged particles
- capability to run at high luminosity

⇨ Scan of $\bar{p}p \to \Lambda(1405)\bar{\Lambda}$ over $pK^-\bar{\Lambda}$ threshold
$\bar{p}p \to \bar{\Lambda}(1405)\Lambda$ over $\bar{p}K^+\Lambda$ threshold

Strangeness 2 and 3 with $\bar{p}$anda



$\bar{p}p \to \bar{\Xi}\Xi$ $\quad\alpha(\Xi^0) = -0.41$ polarisation, singlet fraction

How is the $\bar{q}\bar{q}qq \to \bar{s}\bar{s}ss$ creation reflected in spin observables?

$\bar{p}p \to \bar{\Omega}\Omega$ $\quad\alpha(\Omega^-) = -0.03$ differential cross section, spin observables difficult

And Charm? (not part of this talk)

Hyperon	Quarks	Mass [Mev/c^2]	cτ [cm]	α	Decay channel	B.R. [%]
Λ	uds	1116	8.0	+0.64	$p\pi^-$	64
Σ^+	uus	1189	2.4	-0.98	$p\pi^0$	52
Σ^0	uds	1193	2.2x10^{-9}	-	$\Lambda\gamma$	100
Σ^-	dds	1197	2.4	-0.07	$n\pi^-$	100
Ξ^0	uss	1315	8.7	-0.41	$\Lambda\pi^0$	99
Ξ^-	dss	1321	4.9	-0.46	$\Lambda\pi^-$	100
Ω^-	sss	1672	2.5	-0.03	ΛK^-	68
Λ_c^+	udc	2285	6.0x10^{-3}	-.98(19)	$\Lambda\pi^+$	1
Σ_c^{++}	uuc	2453	.		$\Lambda_c^+\pi^+$	100
Σ_c^+	udc	2455	.		$\Lambda_c^+\pi^0$	100
Σ_c^0	ddc	2452	.		$\Lambda_c^+\pi^-$	100
Ξ_c^+	usc	2466	1.3x10^{-2}			
Ξ_c^0	dsc	2472	2.9x10^{-3}	-0.6(4)	$\Xi^-\pi^+$	seen
Ω_c^0	ssc	2697	1.9x10^{-3}			

$$\bar{p}p \to \bar{\Lambda}_c^+ \Lambda_c^+$$

$$\alpha_{\Lambda_c^+} = -0.98 \pm 0.19$$

$$\Lambda\pi^+$$

$$\alpha_\Lambda = 0.64$$

$$p\pi^-$$

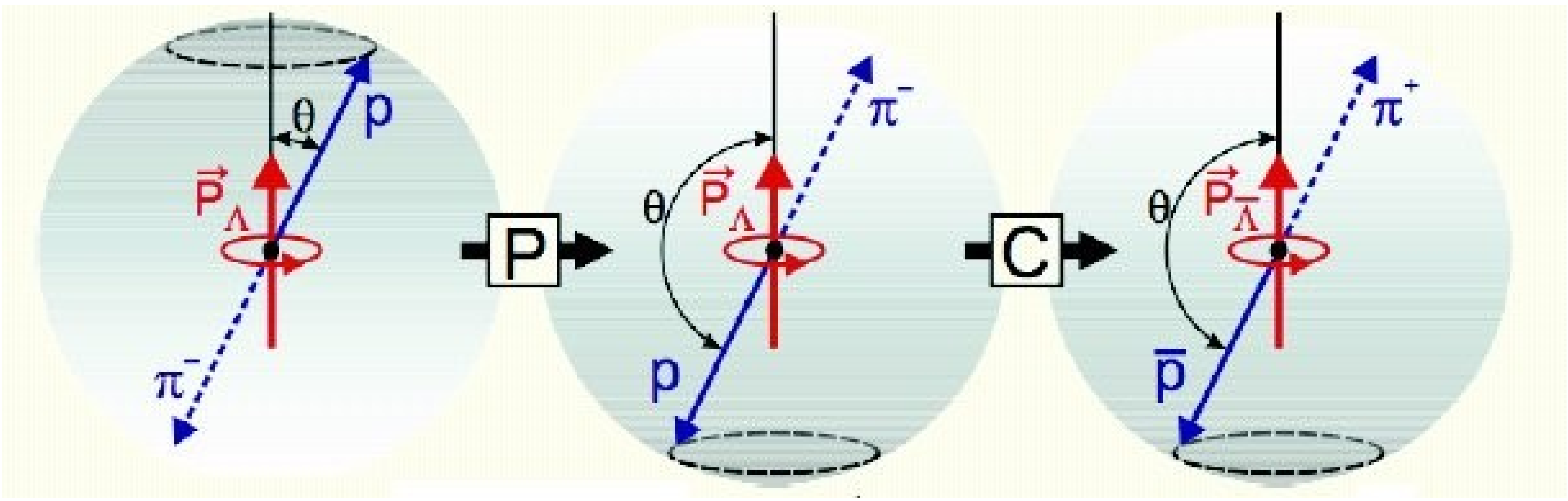
How does the $u\bar{u} \to c\bar{c}$ process compare to $u\bar{u} \to s\bar{s}$?

„Applied“ Strangeness Production

Angular distribution asymmetry: $A = \frac{\bar{\alpha} + \alpha}{\bar{\alpha} - \alpha}$

A = 0 if CP is conserved

α = weak decay asymmetry



Observation of CP violation in hyperon decay would be first observation of CP violation in baryon sector

Best experimental limit: $A_{\Lambda\bar{\Lambda}} = 0.006 \pm 0.014$

CP violation in hyperon decays

Angular distribution asymmetries

HyperCP statistics (expected): $\sigma(A_{\Xi\Lambda}) \leq 2 \times 10^{-4}$

Standard Model prediction: 1×10^{-5}

PANDA: 1×10^{-4} accuracy requires 1 year of running, hard to improve on HyperCP

Partial rate asymmetries

measure $$\Delta_{\Lambda K} = \frac{\Gamma(\Omega^- \rightarrow \Lambda K^-) - \Gamma(\bar{\Omega}^+ \rightarrow \bar{\Lambda} K^+)}{\Gamma(\Omega^- \rightarrow \Lambda K^-) + \Gamma(\bar{\Omega}^+ \rightarrow \bar{\Lambda} K^+)}$$

Standard Model prediction: $\Delta_{\Lambda K} = 2 \times 10^{-5}$; non-SM: 10^{-3} - 10^{-4}

PANDA: 1×10^{-4} accuracy in 1 year

Golden Book, 2nd Workshop on Physics with a High Intensity Proton Source at Fermilab (Draft, Feb 2008)

Strangeness Production

vivid field: direction towards differential observables,
polarisation data, and complete experiments,
which constantly provoque new questions and challenges

Photo-electroproduction:
CB-ELSA, CLAS, LEPS, KAOS@MAMI-C, NKS2/Tohoku

Hadronic production:
COSY

New facilities in future to meet present challenges:
BGO-OD, CLAS-12, LEPS2, PANDA

Strangeness Production

If you did not like the talk...
blame the speaker!

otherwise credits go to...

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