The BGOOD experiment at ELSA

- multi-quark structures in the uds sector ?

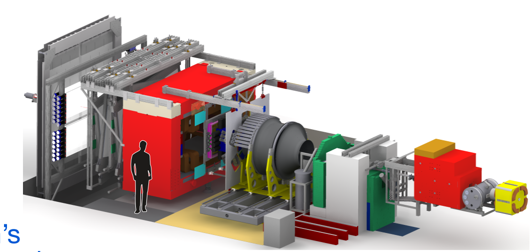
Hartmut Schmieden
Physikalisches Institut
Universität Bonn

Outline

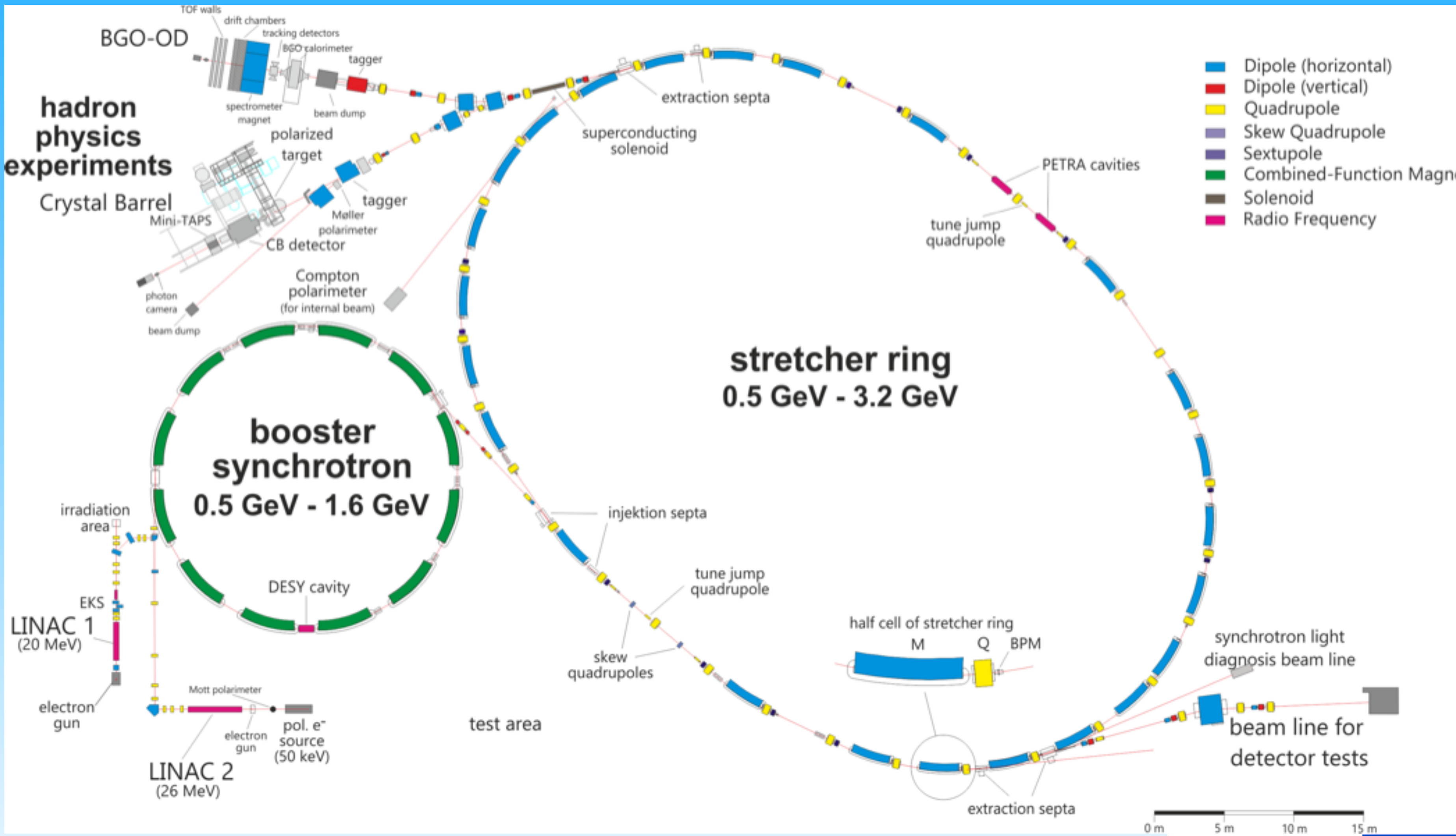
- BGOOD experiment
- physics case
- selected results
- conclusions

supported by DFG
PN 50165297 and
PN 405882627

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093



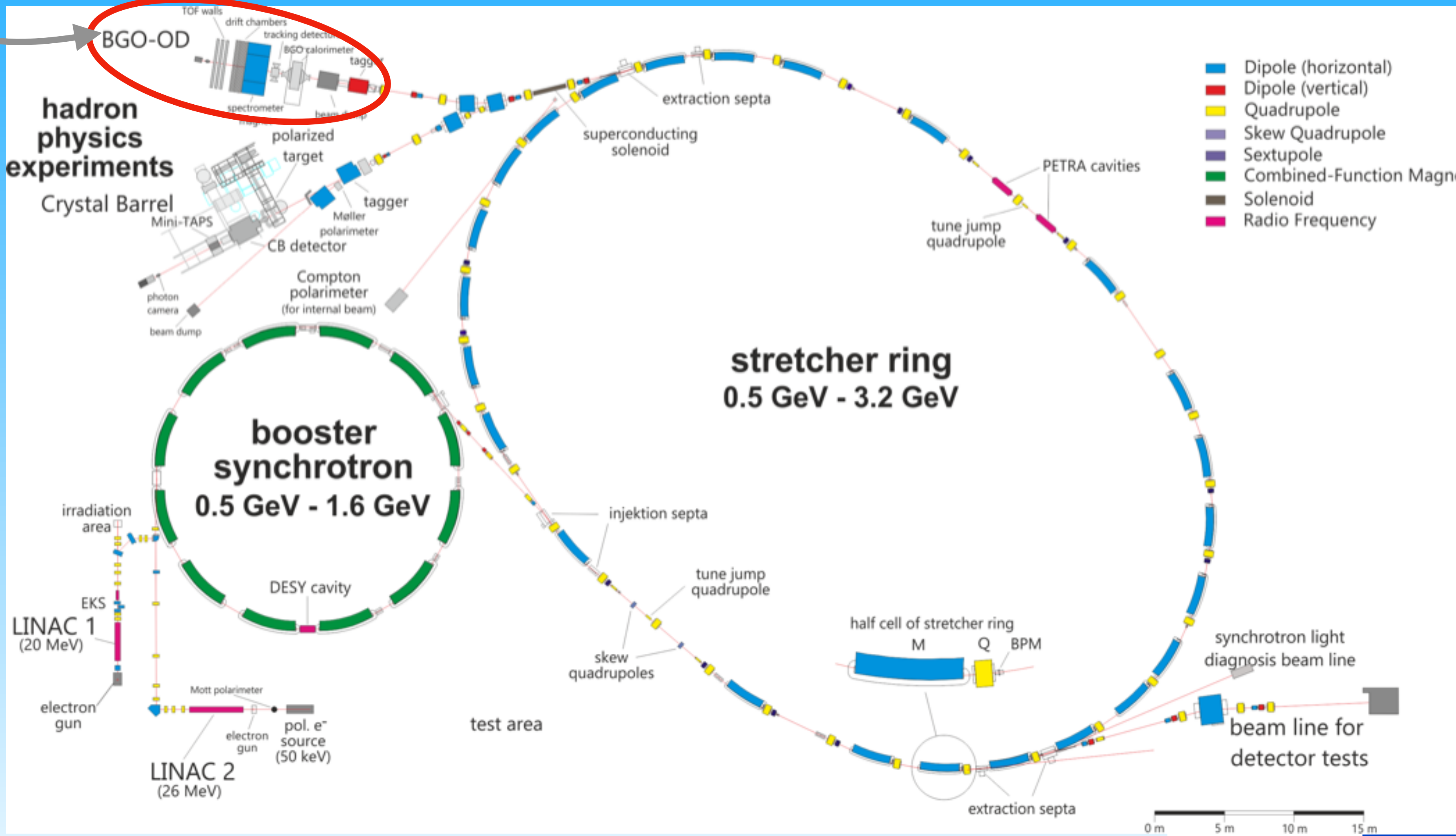
located at ELSA
electron accelerator
Physikalisches Institut
University of Bonn



universitätbonn

BGOOD experiment

located at ELSA
electron accelerator
Physikalisches Institut
University of Bonn



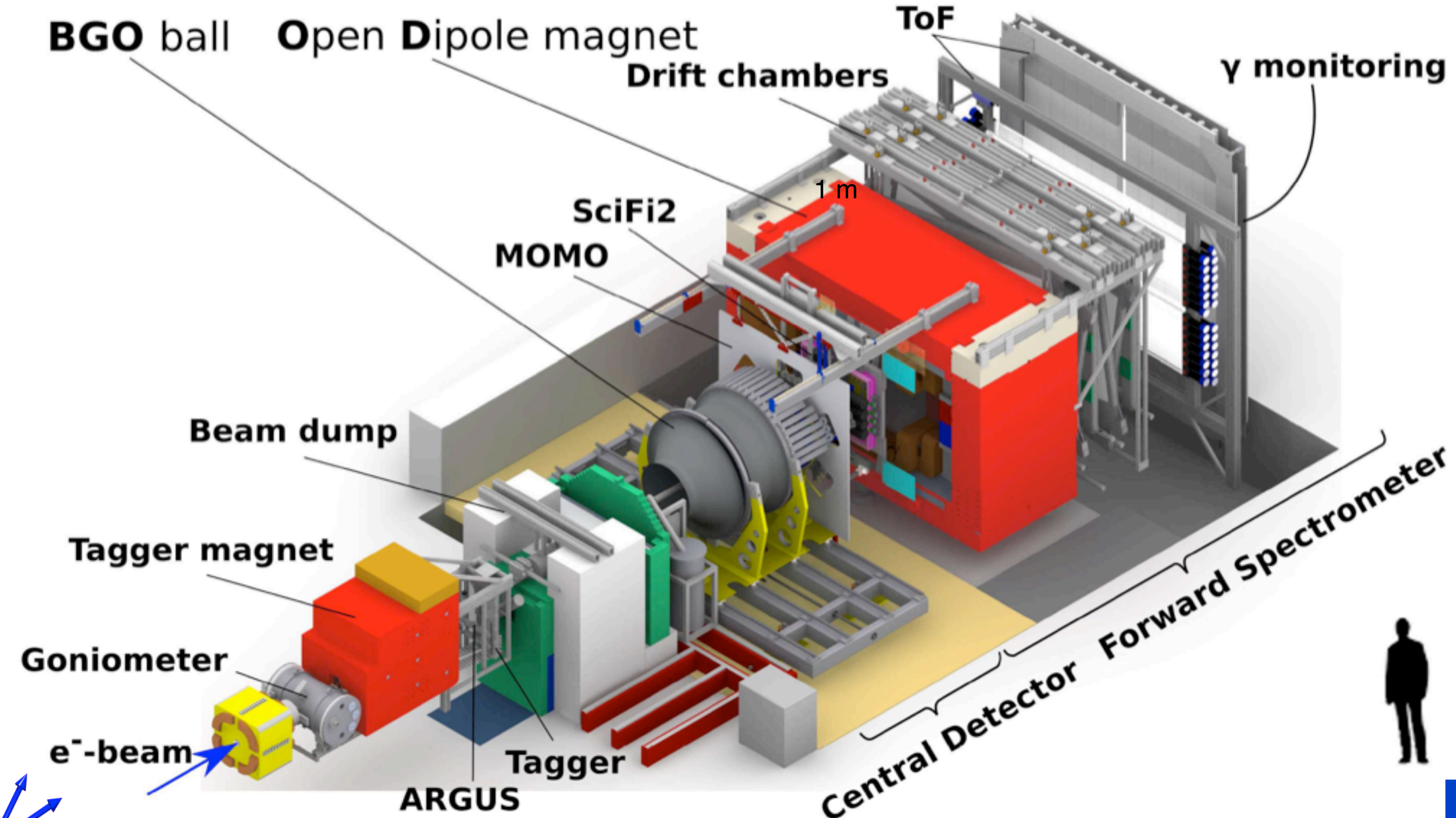
universität bonn

BGOOD experiment

S. Alef et al. [BGOOD collab.], EPJ A 56 (2020) 104

spokespersons: P. Levi Sandri (Frascati) & H.Schmieden (Bonn)

- combination of BGO central calorimeter & forward spectrometer
- high momentum resolution, excellent neutral & charged particle id

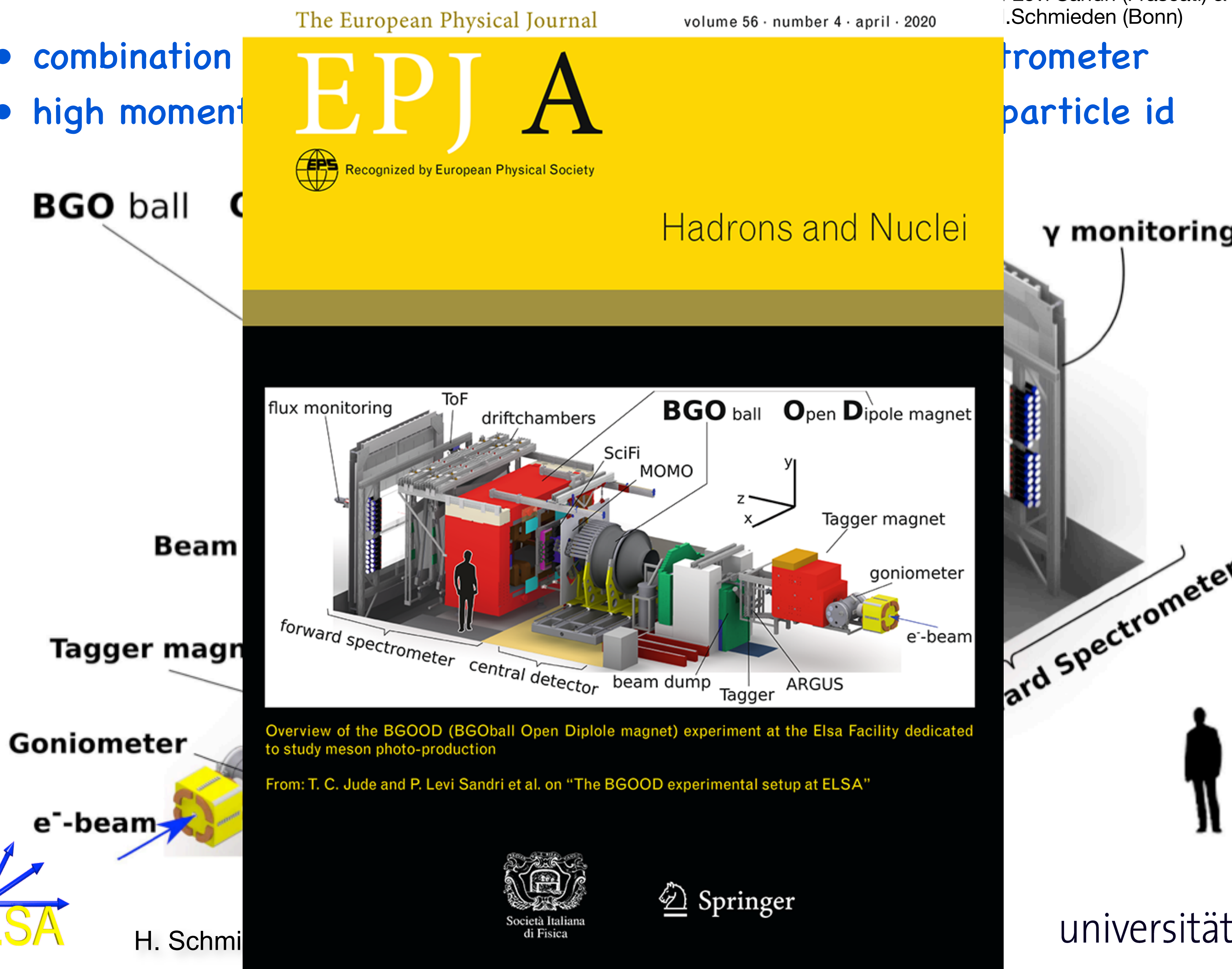


BGOOD experiment

S. Alef et al. [BGOOD collab.], EPJ A 56 (2020) 104

. Levi Sandri (Frascati) &
.Schmieden (Bonn)

- combination ... trometer
- high moment ... particle id

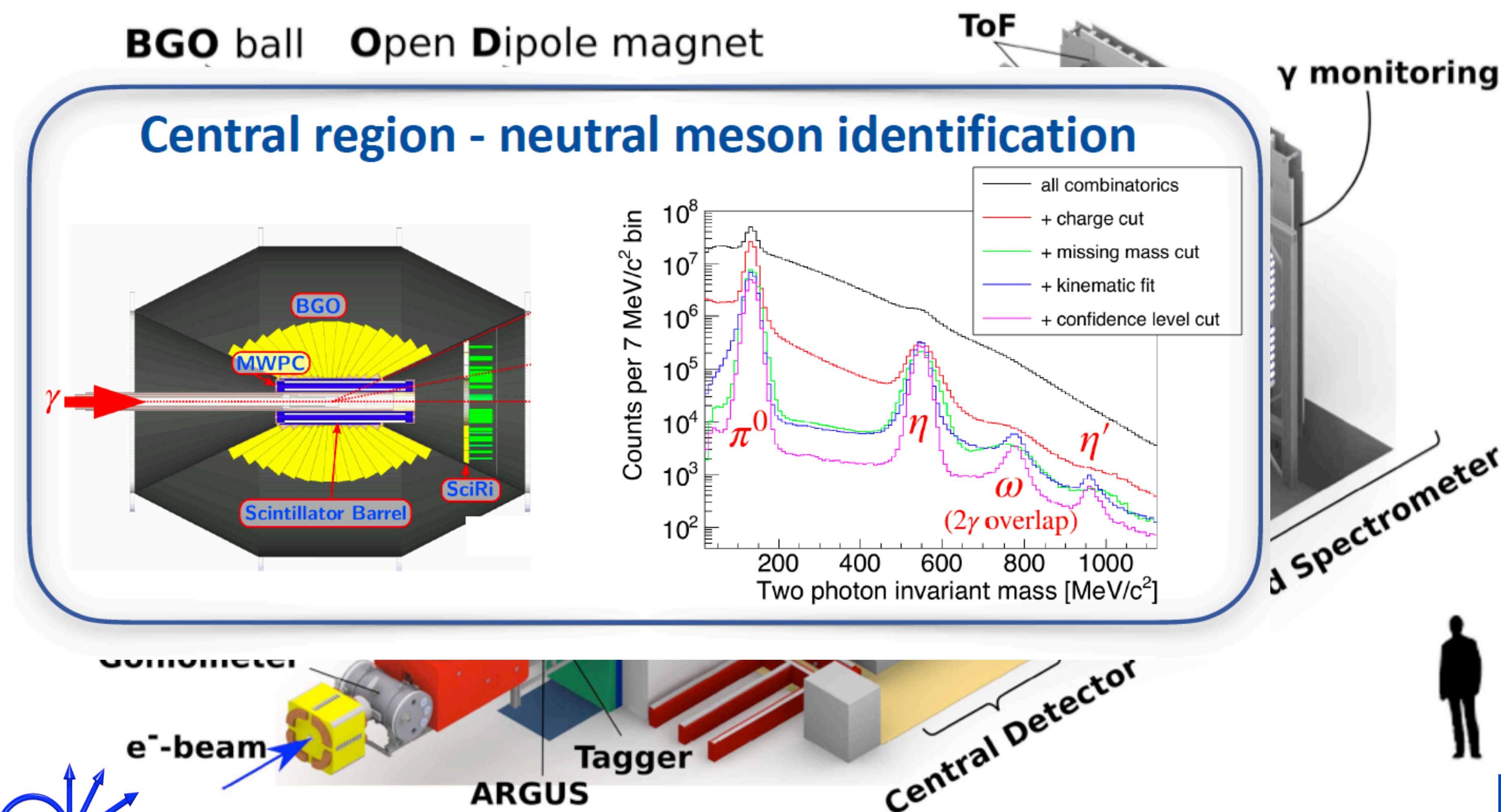


BGOOD experiment

S. Alef et al. [BGOOD collab.], EPJ A 56 (2020) 104

spokespersons: P. Levi Sandri (Frascati) & H.S. (Bonn)

- combination of BGO central calorimeter & forward spectrometer
- high momentum resolution, excellent neutral & charged particle id

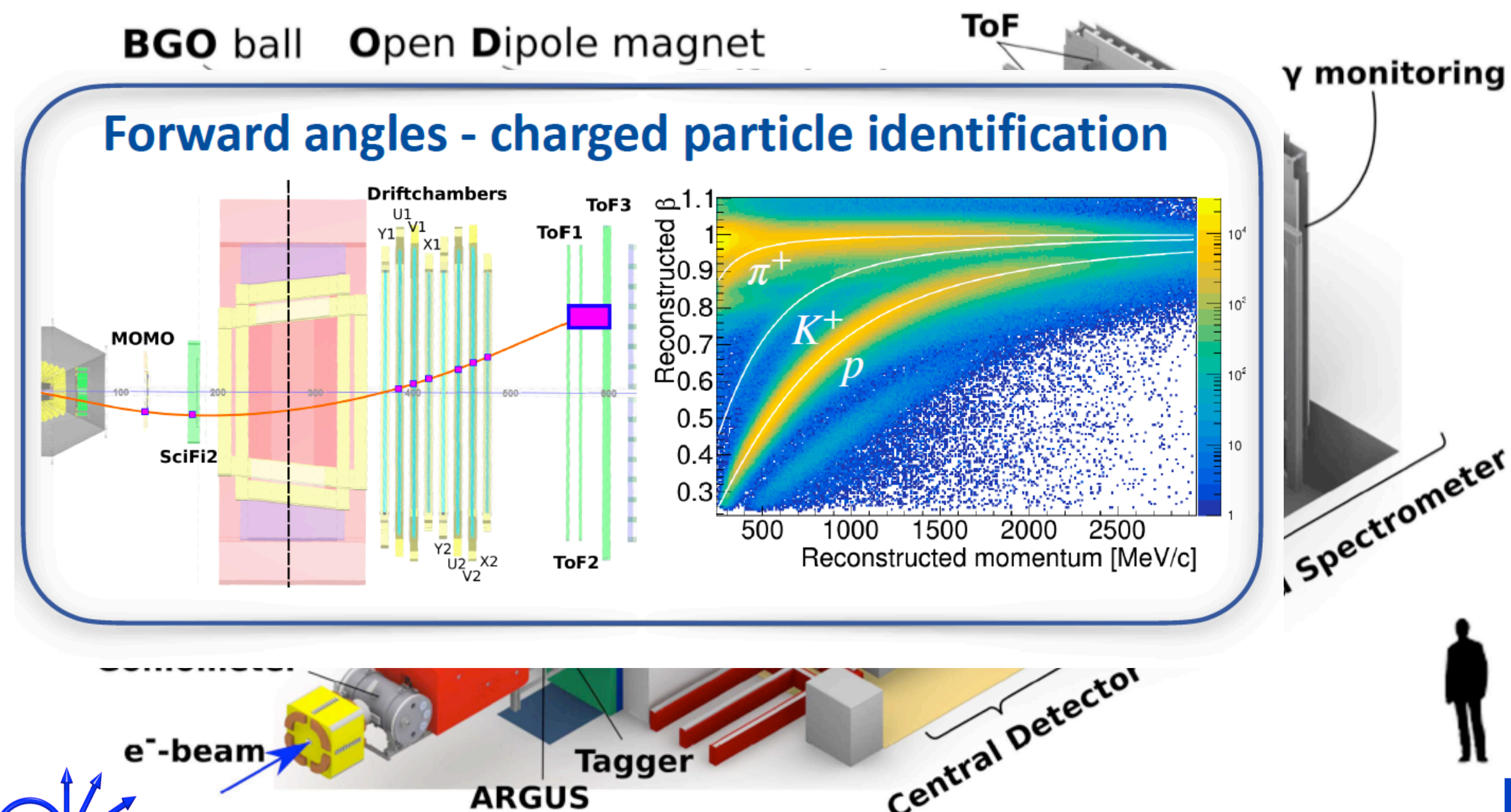


BGOOD experiment

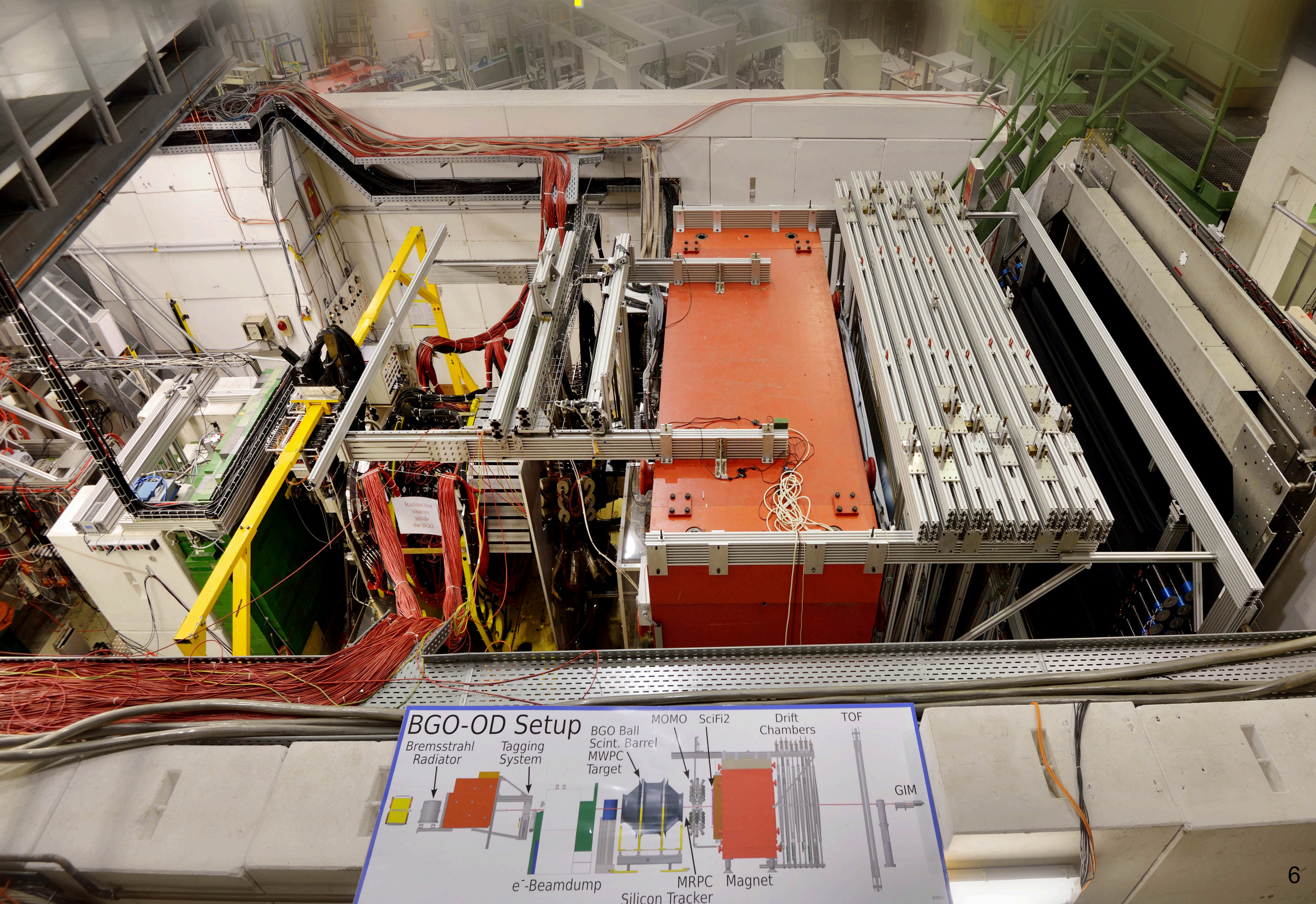
S. Alef et al. [BGOOD collab.], EPJ A 56 (2020) 104

spokespersons: P. Levi Sandri (Frascati) & H.S. (Bonn)

- combination of BGO central calorimeter & forward spectrometer
- high momentum resolution, excellent neutral & charged particle id



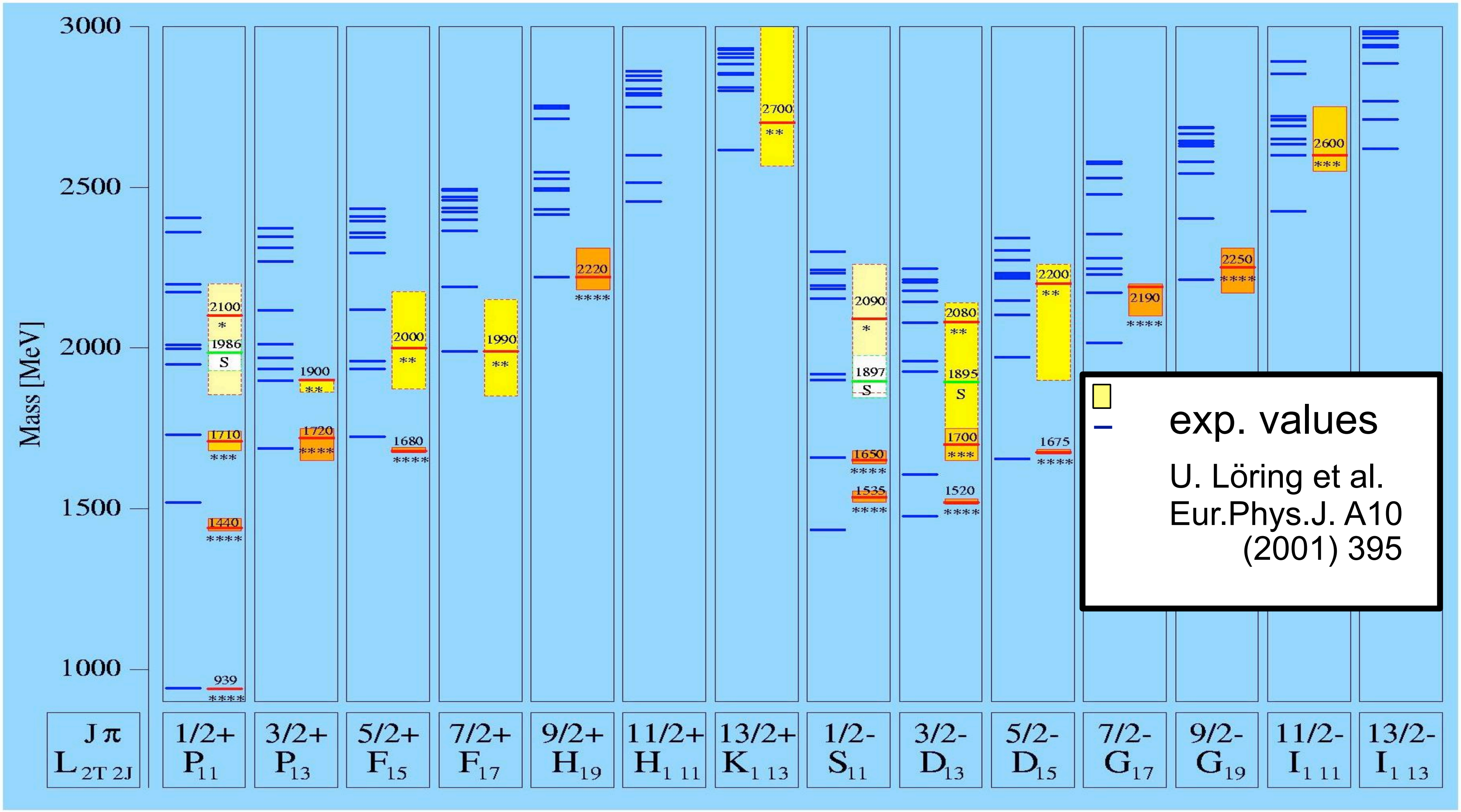
BGOOD experiment at ELSA



physics case

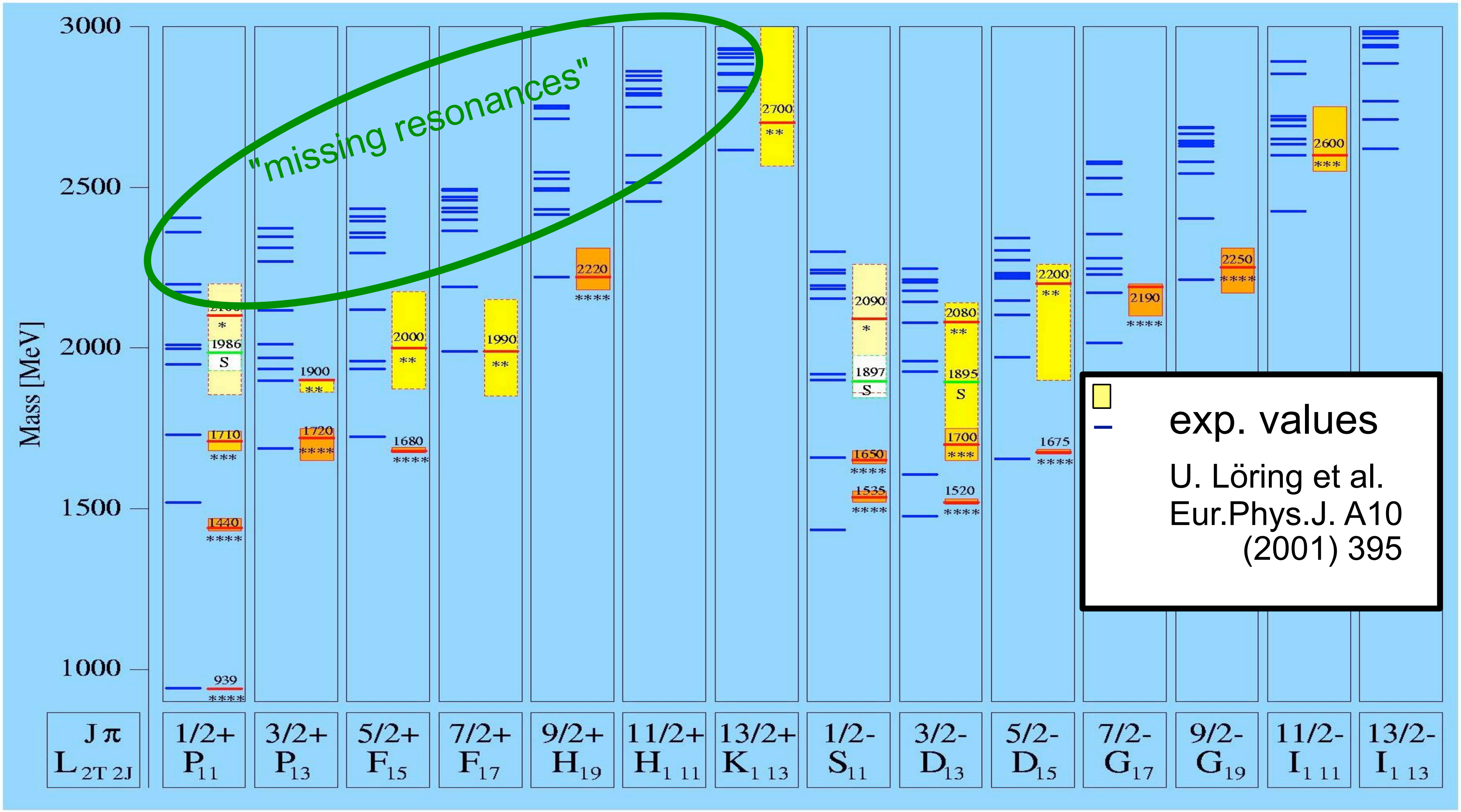
Excited states: quark model

N* resonances

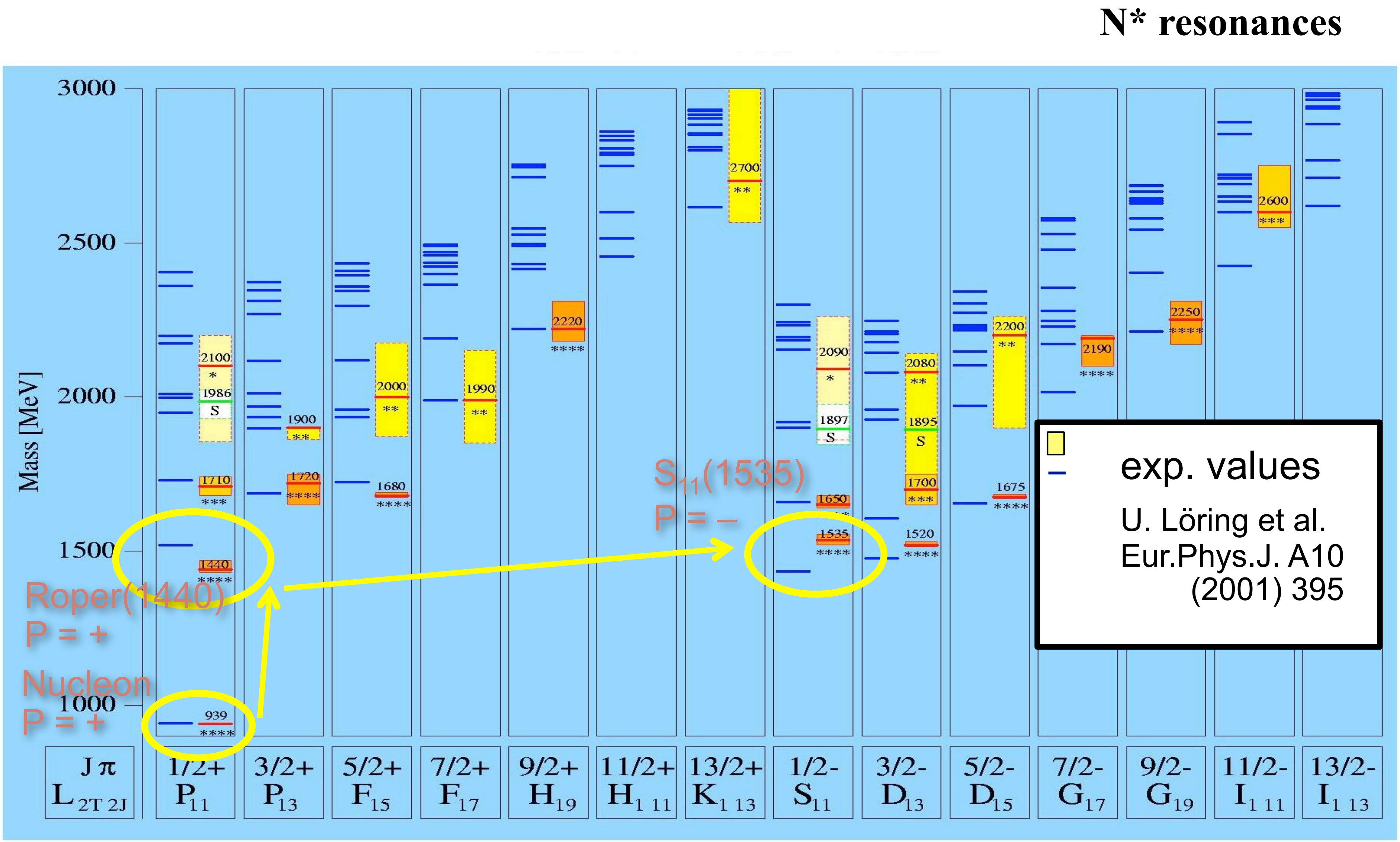


Excited states: quark model

N* resonances

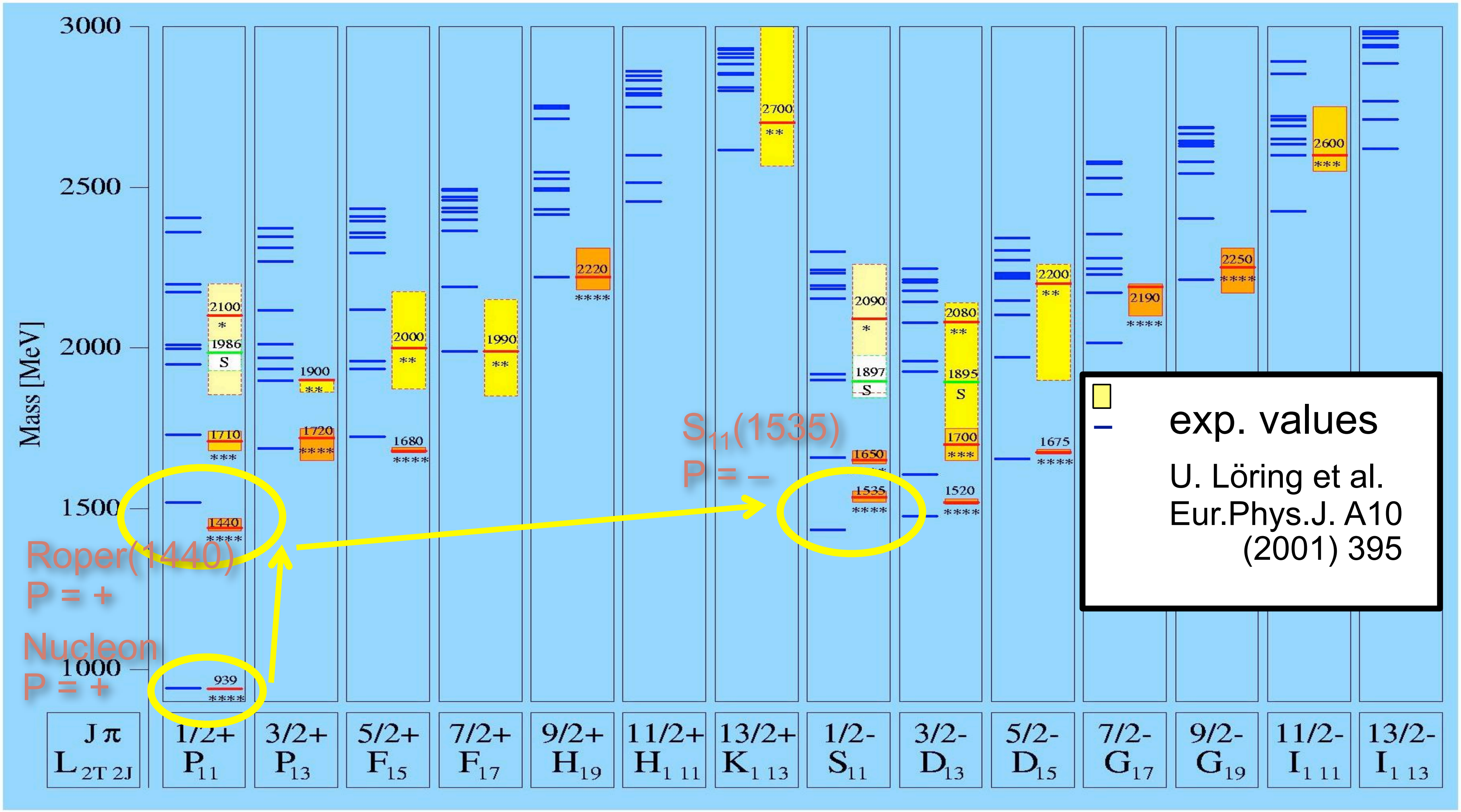


Excited states: quark model



Excited states: quark model

N* resonances



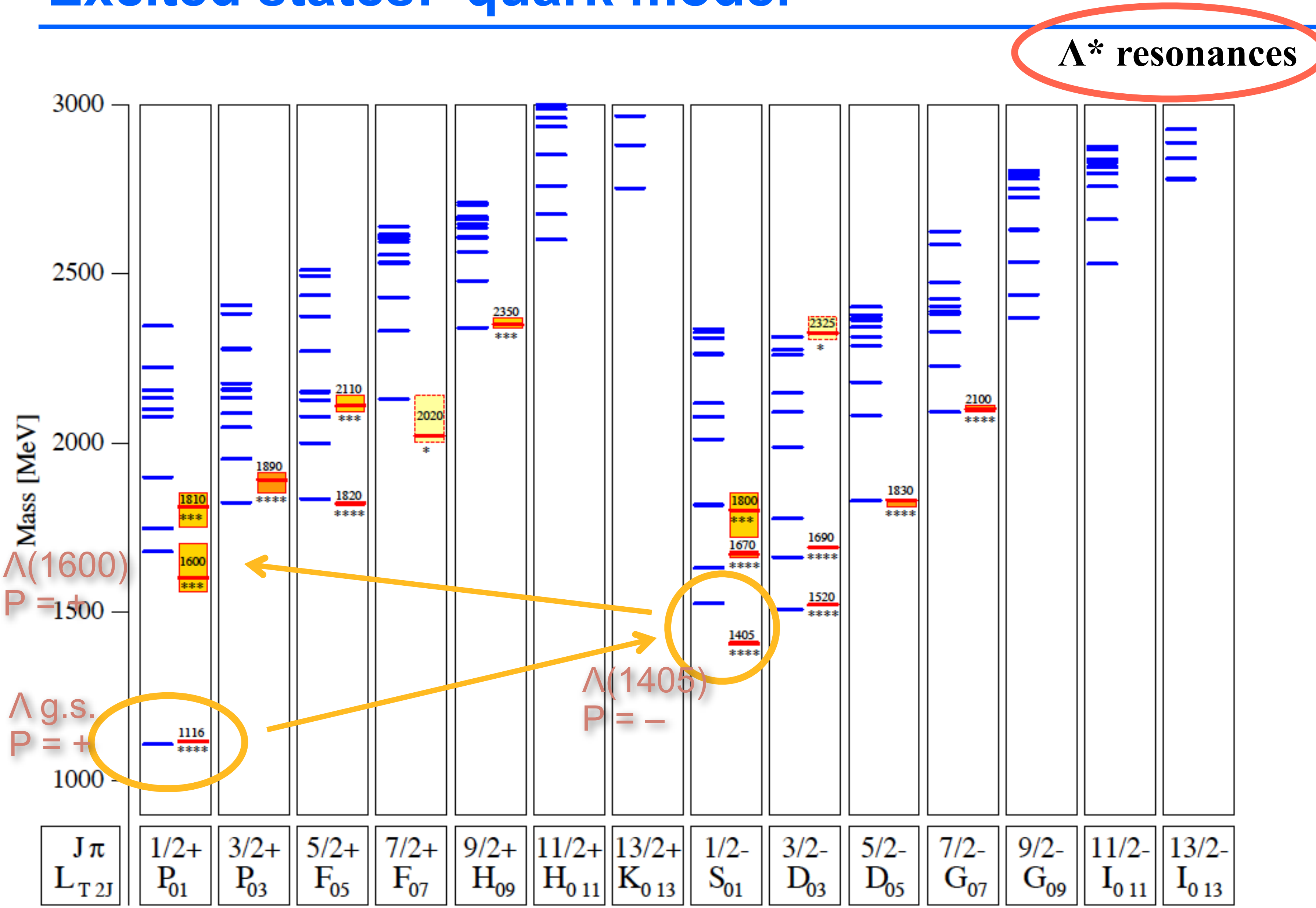
- parity pattern lowest states + → + → – !?!
- effective degrees of freedom ??

ELSA

H. Schmieden

universitätbonn

Excited states: quark model



ELSA

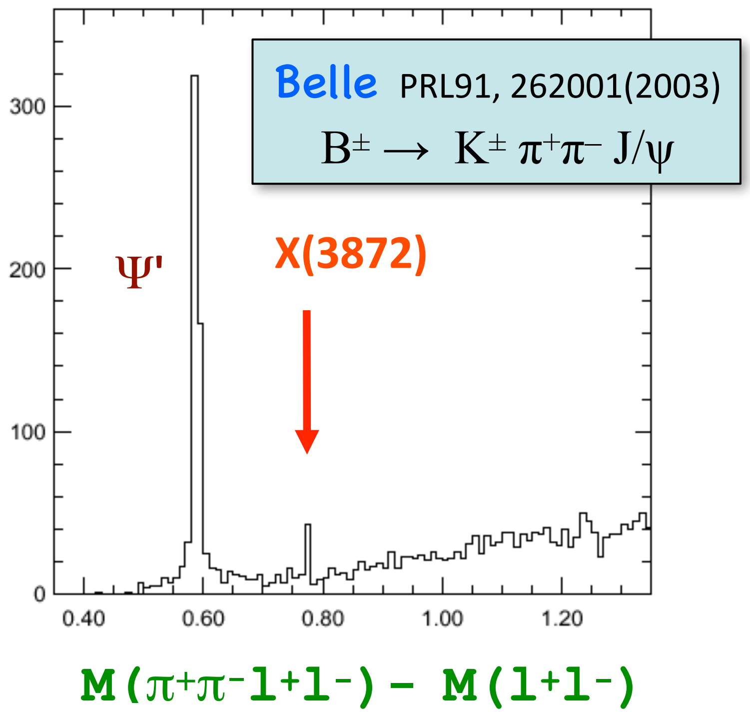
H. Schmieden

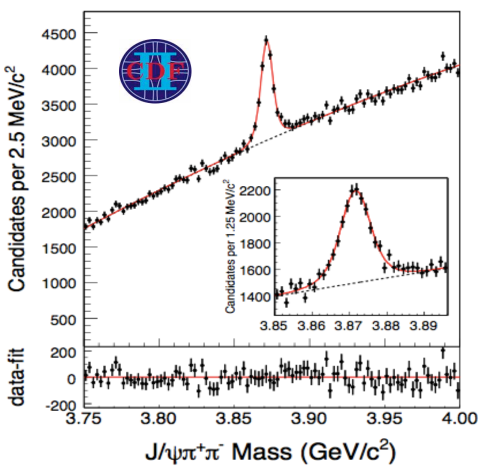
- parity pattern OK
- masses reversed ??

universität**bonn**

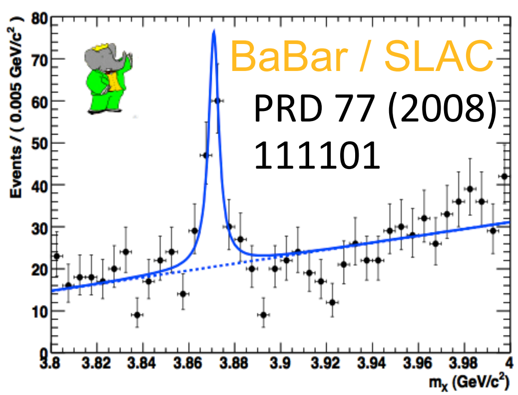
context c-quark sector

X(3872)





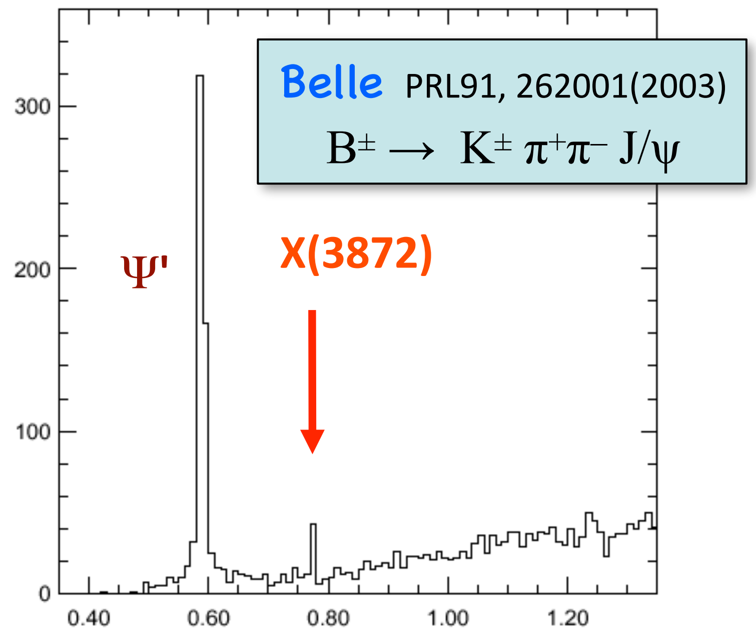
CDF / Tevatron
PRL 103 (2009) 152001



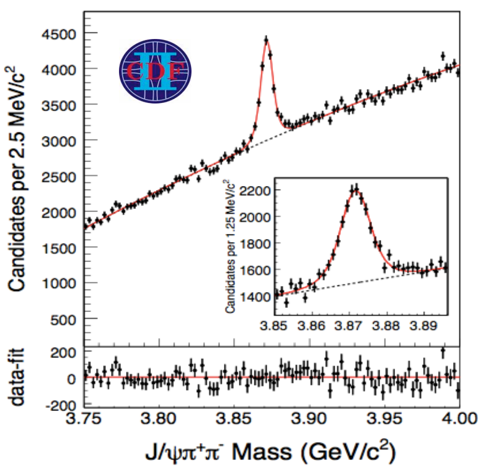
universitätbonn

context c-quark sector

X(3872)

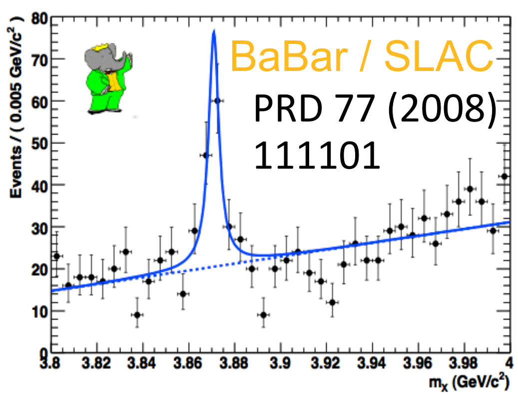


$M(\pi^+\pi^- l^+ l^-) - M(l^+ l^-)$



CDF / Tevatron

PRL 103 (2009) 152001



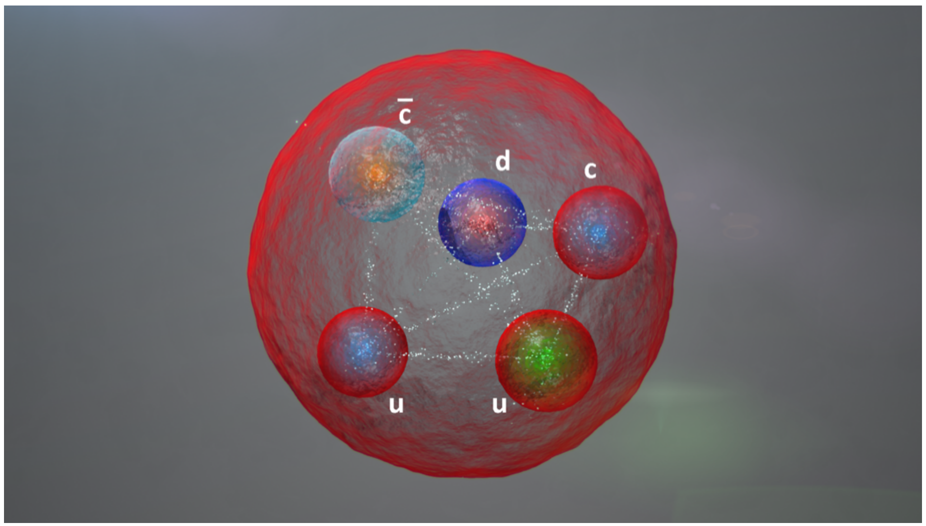
BaBar / SLAC

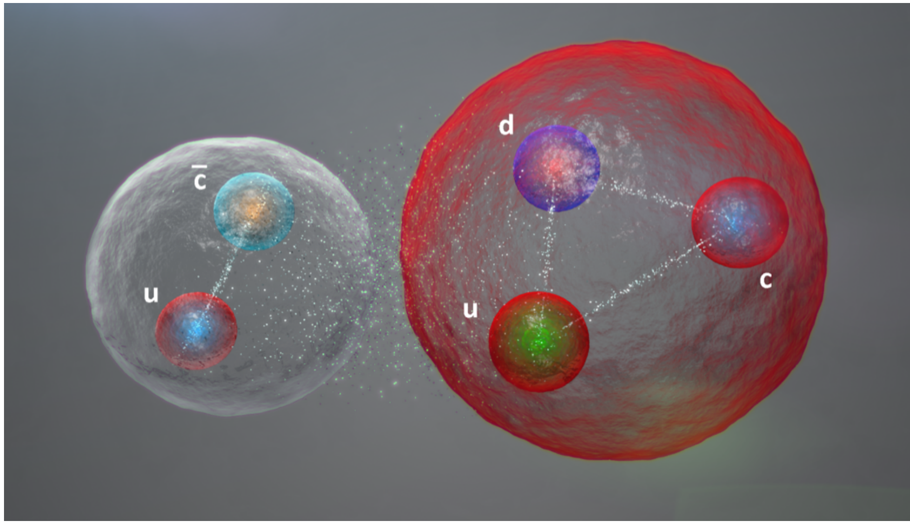
PRD 77 (2008) 111101

PARTICLE PHYSICS

Forsaken pentaquark particle spotted at CERN

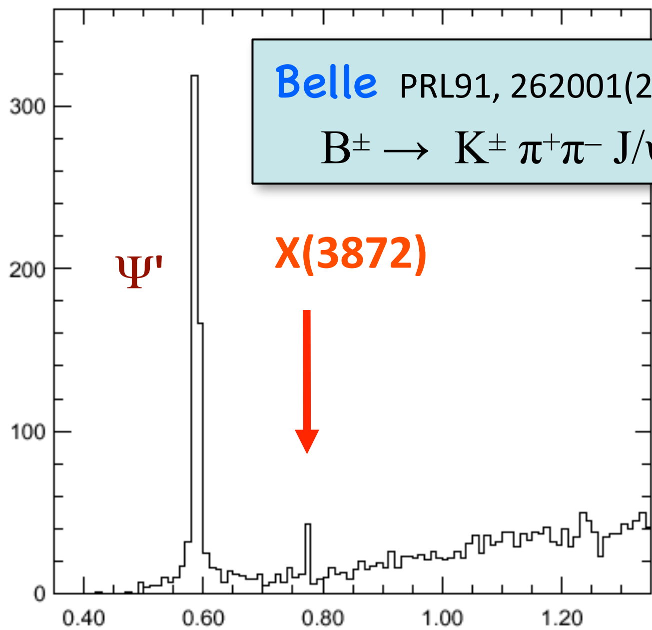
Exotic subatomic species confirmed at Large Hadron Collider after earlier false sightings.





context c-quark sector

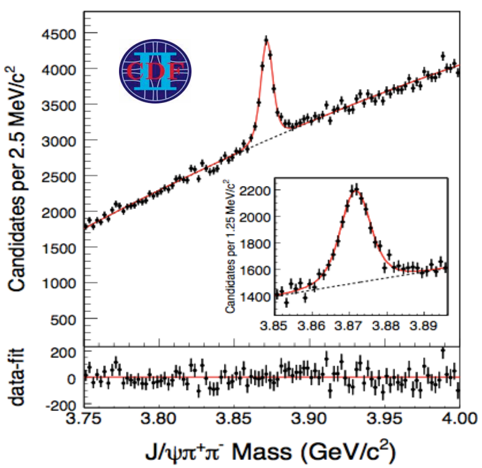
X(3872)



Belle PRL91, 262001(2003)

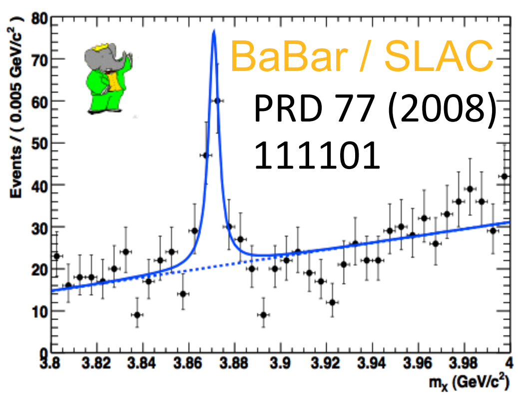
$B^{\pm} \rightarrow K^{\pm} \pi^{+}\pi^{-} J/\psi$

$M(\pi^{+}\pi^{-}l^{+}l^{-}) - M(l^{+}l^{-})$



CDF / Tevatron

PRL 103 (2009) 152001



BaBar / SLAC

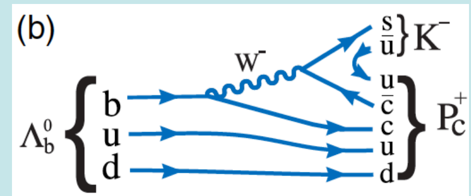
PRD 77 (2008) 111101

$P_C^{+}(4380, 4450)$

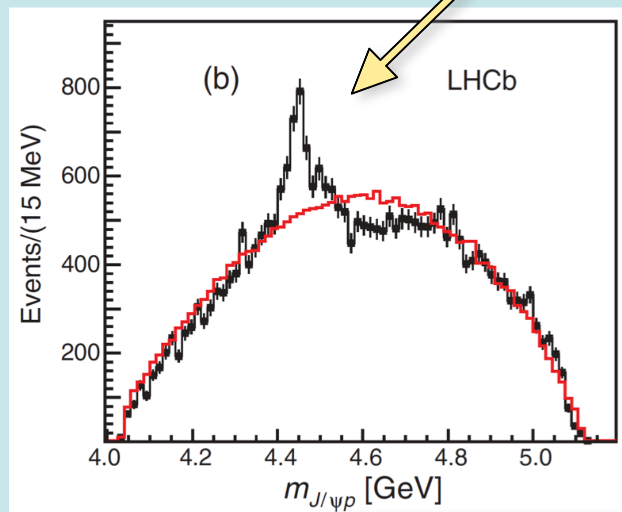
PARTICLE PHYSICS

Forsaken pentaquark

R. Aaij et al., PRL 115 (2015) 072001



p J/ψ

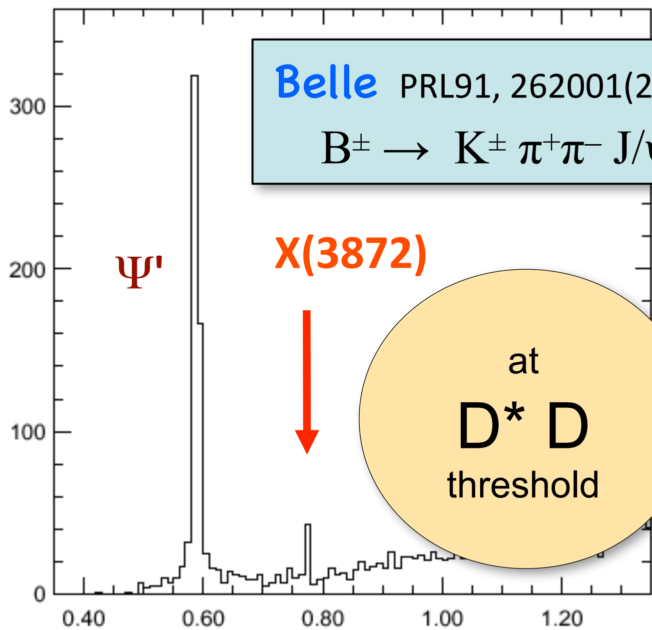


PB / VB hidden c predicted from meson-baryon interactions:
Oset, Zou et al., PRL 105 (2010)

"new N^*_{cc} states are simply brothers or sisters of the well known N*(1535) and Λ*(1405) ... and many other dynamically generated states ..."

context c-quark sector

X(3872)

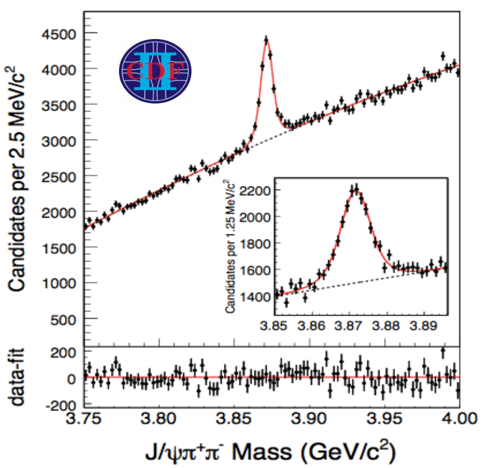


Belle PRL91, 262001(2003)

$B^{\pm} \rightarrow K^{\pm} \pi^{+}\pi^{-} J/\psi$

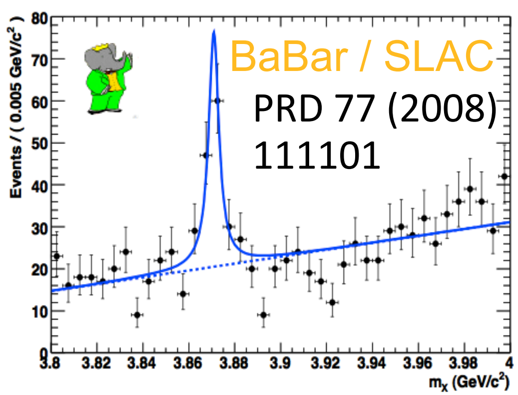
at
D* D
threshold

$M(\pi^{+}\pi^{-}l^{+}l^{-}) - M(l^{+}l^{-})$



CDF / Tevatron

PRL 103 (2009) 152001



BaBar / SLAC

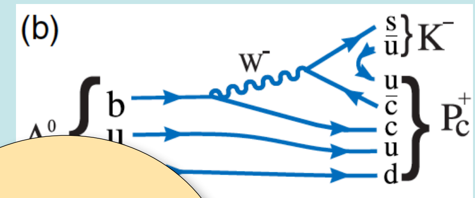
PRD 77 (2008) 111101

P_c^+(4380, 4450)

PARTICLE PHYSICS

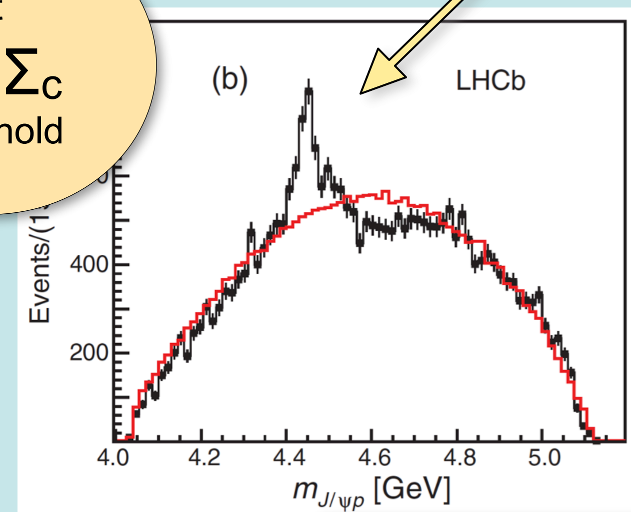
Forsaken pentaquark

R. Aaij et al., PRL 115 (2015) 072001



p J/ψ

at
D* Σ_c
threshold



PB / VB hidden c predicted from meson-baryon interactions:
Oset, Zou et al., PRL 105 (2010)

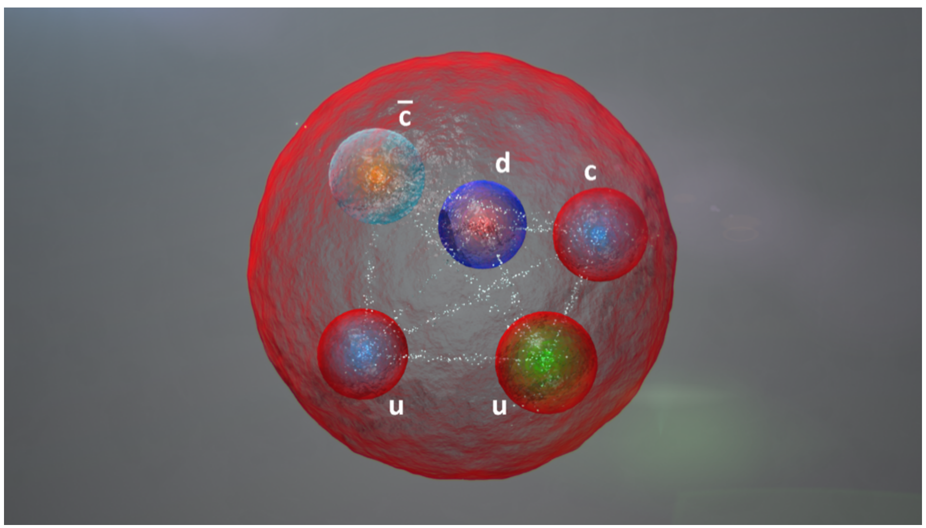
"new N^*_{cc} states are simply brothers or sisters of the well known N*(1535) and Λ*(1405) ... and many other dynamically generated states ..."

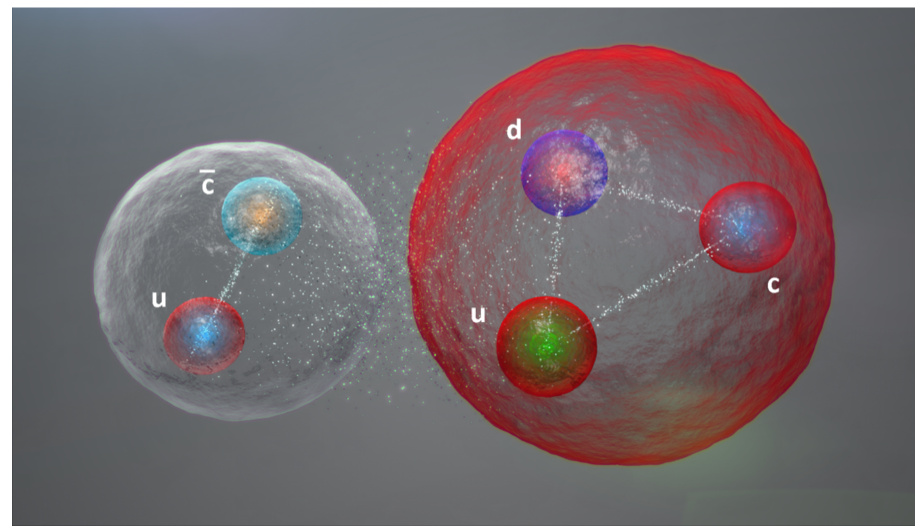
PARTICLE PHYSICS

Forsaken pentaquark particle spotted at CERN

Exotic subatomic species confirmed at Large Hadron Collider after earlier false sightings.

Parallels in s-quark sector ?





$D^{(*)}\ \Sigma_c$

thresholds

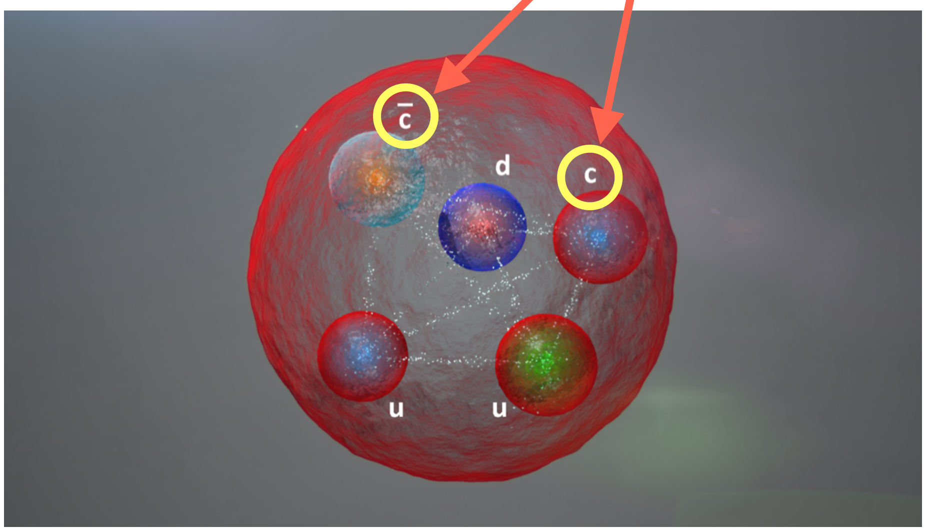
PARTICLE PHYSICS

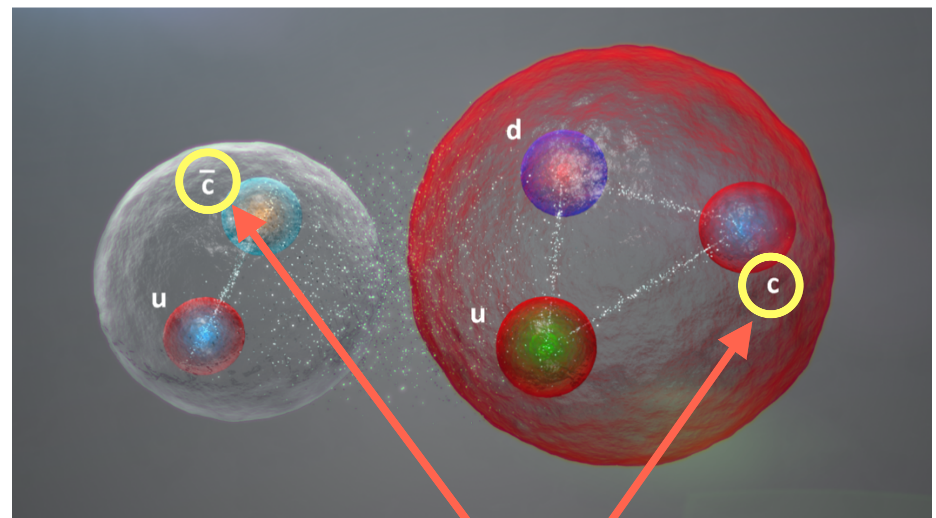
Forsaken pentaquark particle spotted at CERN

Exotic subatomic species confirmed at Large Hadron Collider after earlier false sightings.

Parallels in s-quark sector ?

$s\ \bar{s}$





$s\ \bar{s}$

$D^{(*)}\ \Sigma_c$
thresholds

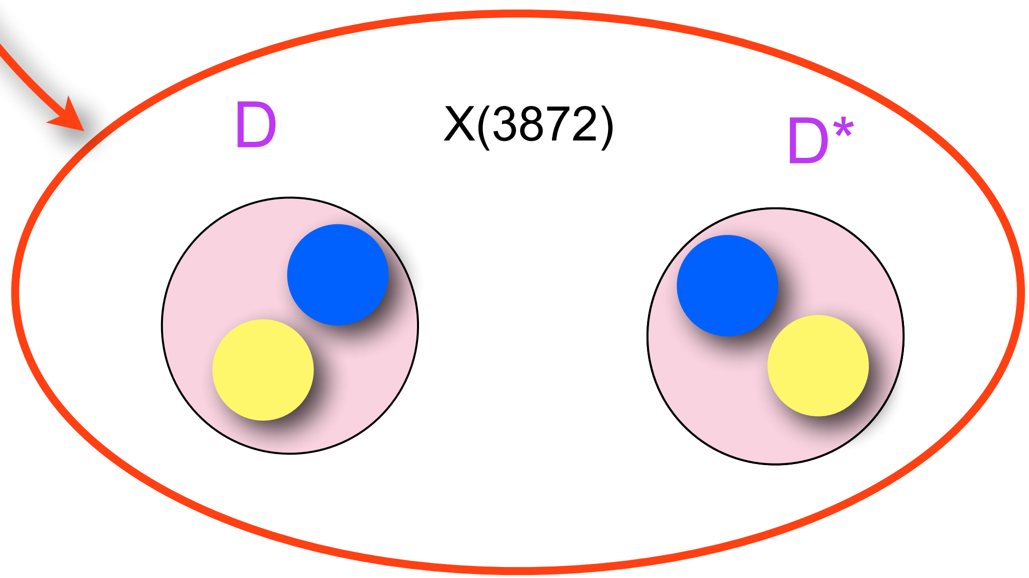
$K^{(*)}\ \Sigma$
thresholds

parallels between c and s sector ?

	c-sector		s-sector	
	meson	baryon(s)	meson	baryon(s)
state(s)	$X(3872)$	$P_c^*(4380/4450)$	$f_1(1420)$	$N^*(2030/2080)$
π-exchange transition	$D^{*0}\bar{D}^0 + D^0\bar{D}^{*0}$	$\Lambda_c^*\bar{D} + \Sigma_c\bar{D}^*$	$K^*\bar{K} + K\bar{K}^*$	$\Lambda^*\bar{K} + \Sigma\bar{K}^*$
quantum nos.	$J^{PC} = 1^{++}$	$J^P = (3/2)^-$	$J^{PC} = 1^{++}$	$J^P = (3/2)^-$
3-body threshold	$D^0\bar{D}^0\pi^0$	$\Sigma_c^+\bar{D}^0\pi^0$	$K\bar{K}\pi$	$\Sigma\bar{K}\pi^0$
closed flavour channel	$J/\psi\ \omega$	$\chi_{c1}p$	$\phi f_0(500)$	ϕp

parallels between c and s sector ?

	c-sector		s-sector	
	meson	baryon(s)	meson	baryon(s)
state(s)	$X(3872)$	$P_c^*(4380/4450)$	$f_1(1420)$	$N^*(2030/2080)$
π-exchange transition	$D^{*0}\bar{D}^0 + D^0\bar{D}^{*0}$	$\Lambda_c^*\bar{D} + \Sigma_c\bar{D}^*$	$K^*\bar{K} + K\bar{K}^*$	$\Lambda^*\bar{K} + \Sigma\bar{K}^*$
quantum nos.	$J^{PC} = 1^{++}$	$J^P = (3/2)^-$	$J^{PC} = 1^{++}$	$J^P = (3/2)^-$
3-body threshold	$D^0\bar{D}^0\pi^0$	$\Sigma_c^+\bar{D}^0\pi^0$	$K\bar{K}\pi$	$\Sigma\bar{K}\pi^0$
closed flavour channel	$J/\psi\ \omega$	$\chi_{c1}p$	$\phi f_0(500)$	ϕp

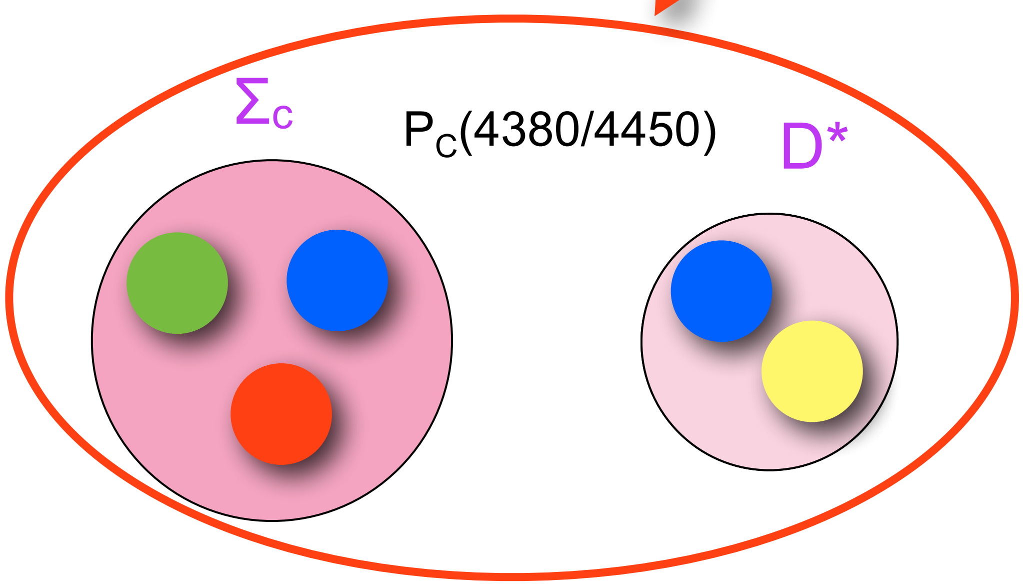


parallels between c and s sector ?

	c-sector		s-sector	
	meson	baryon(s)	meson	baryon(s)
state(s)	$X(3872)$	$P_c^*(4380/4450)$	$f_1(1420)$	$N^*(2030/2080)$
π-exchange transition	$D^{*0}\bar{D}^0 + D^0\bar{D}^{*0}$	$\Lambda_c^* D + \Sigma_c \bar{D}^*$	$K^*\bar{K} + K\bar{K}^*$	$\Lambda^*\bar{K} + \Sigma\bar{K}^*$
quantum nos.	$J^{PC} = 1^{++}$	$J^P = (3/2)^-$	$J^{PC} = 1^{++}$	$J^P = (3/2)^-$
3-body threshold	$D^0\bar{D}^0\pi^0$	$\Sigma_c^+\bar{D}^0\pi^0$	$K\bar{K}\pi$	$\Sigma\bar{K}\pi^0$
closed flavour channel	$J/\psi\ \omega$	$\chi_{c1}p$	$\phi f_0(500)$	ϕp

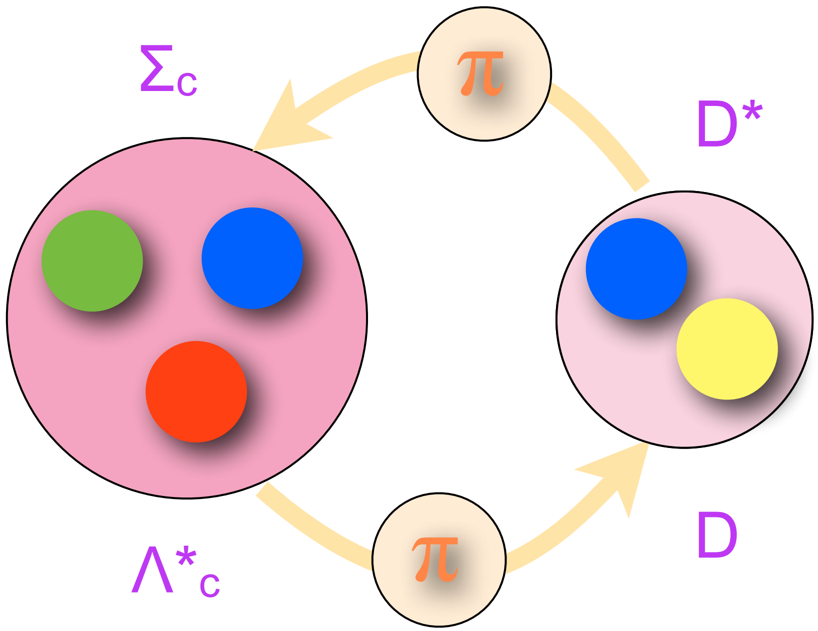
$\bar{3} \leftrightarrow \bar{3}$

$\bar{q} \rightarrow [qq]$



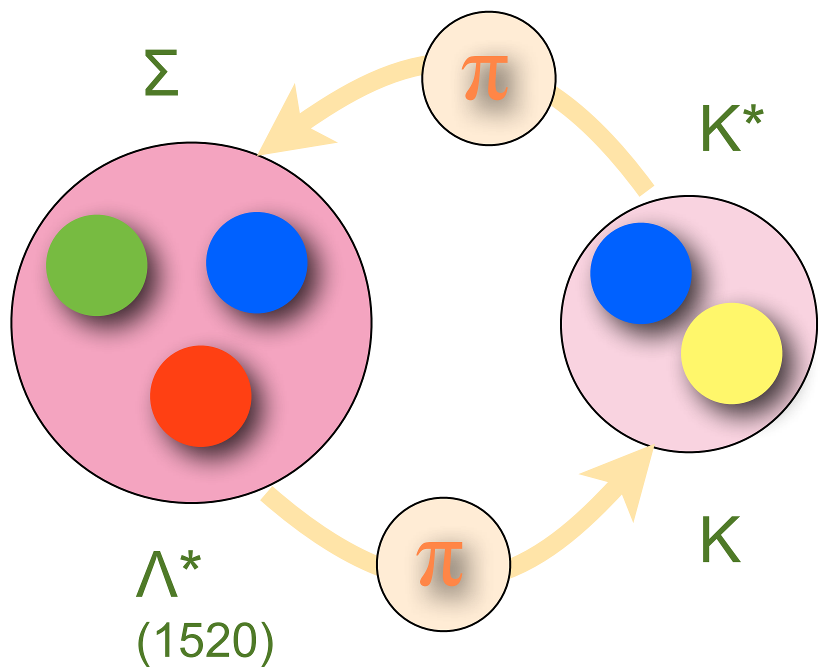
parallels between c and s sector ?

	c-sector		s-sector	
	meson	baryon(s)	meson	baryon(s)
state(s)	$X(3872)$	$P_c^*(4380/4450)$	$f_1(1420)$	$N^*(2030/2080)$
π-exchange transition	$D^{*0}\bar{D}^0 + D^0\bar{D}^{*0}$	$\Lambda_c^*\bar{D} + \Sigma_c\bar{D}^*$	$K^*\bar{K} + K\bar{K}^*$	$\Lambda^*\bar{K} + \Sigma\bar{K}^*$
quantum nos.	$J^{PC} = 1^{++}$	$J^P = (3/2)^-$	$J^{PC} = 1^{++}$	$J^P = (3/2)^-$
3-body threshold	$D^0\bar{D}^0\pi^0$	$\Sigma_c^+\bar{D}^0\pi^0$	$K\bar{K}\pi$	$\Sigma\bar{K}\pi^0$
closed flavour channel	$J/\psi\ \omega$	$\chi_{c1}p$	$\phi f_0(500)$	ϕp



parallels between c and s sector ?

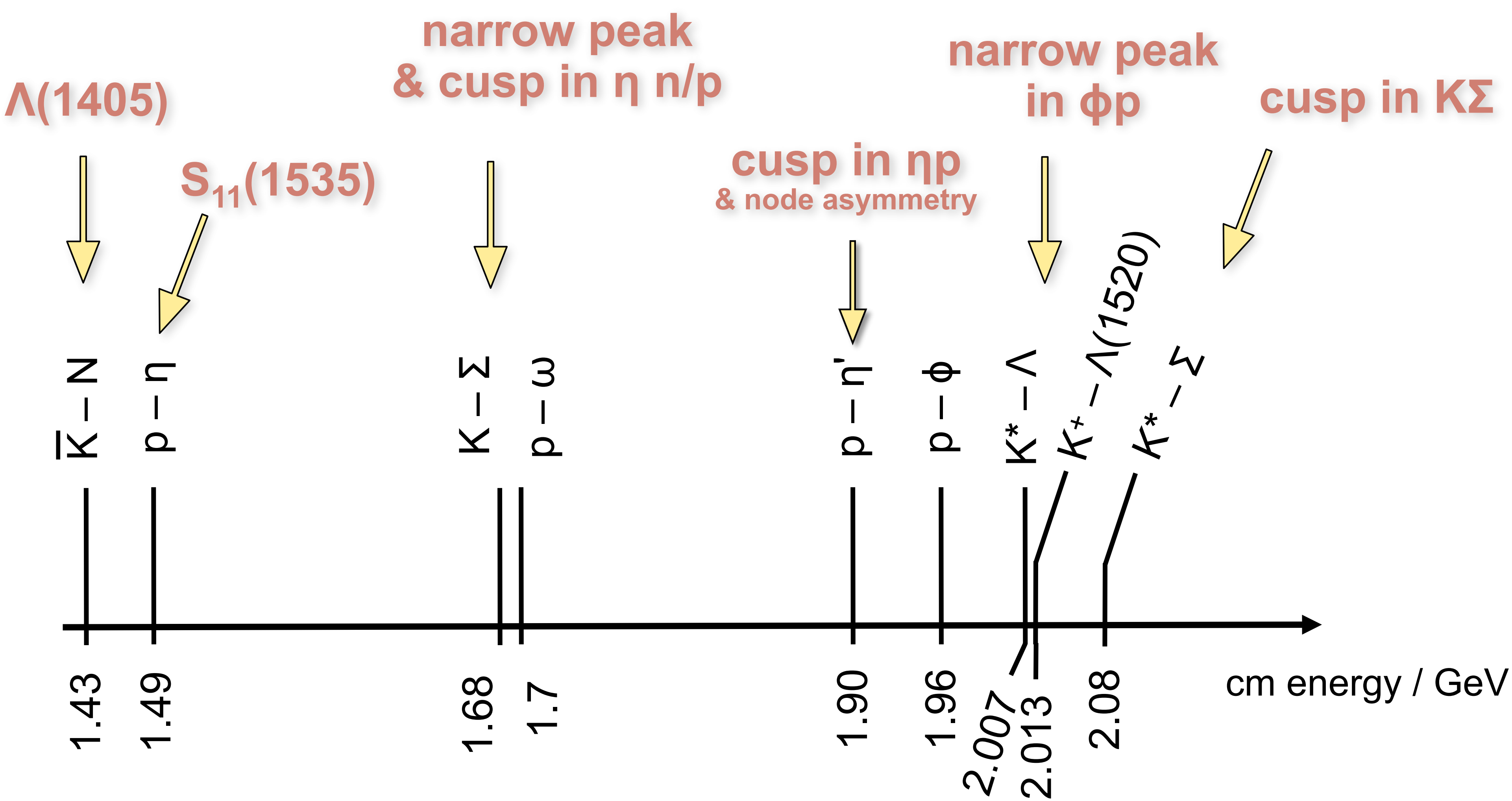
	c-sector		s-sector	
	meson	baryon(s)	meson	baryon(s)
state(s)	$X(3872)$	$P_c^*(4380/4450)$	$f_1(1420)$	$N^*(2030/2080)$
π-exchange transition	$D^{*0}\bar{D}^0 + D^0\bar{D}^{*0}$	$\Lambda_c^*\bar{D} + \Sigma_c\bar{D}^*$	$K^*\bar{K} + K\bar{K}^*$	$\Lambda^*\bar{K} + \Sigma\bar{K}^*$
quantum nos.	$J^{PC} = 1^{++}$	$J^P = (3/2)^-$	$J^{PC} = 1^{++}$	$J^P = (3/2)^-$
3-body threshold	$D^0\bar{D}^0\pi^0$	$\Sigma_c^+\bar{D}^0\pi^0$	$K\bar{K}\pi$	$\Sigma\bar{K}\pi^0$
closed flavour channel	$J/\psi\ \omega$	$\chi_{c1}p$	$\phi f_0(500)$	ϕp



uds sector ?

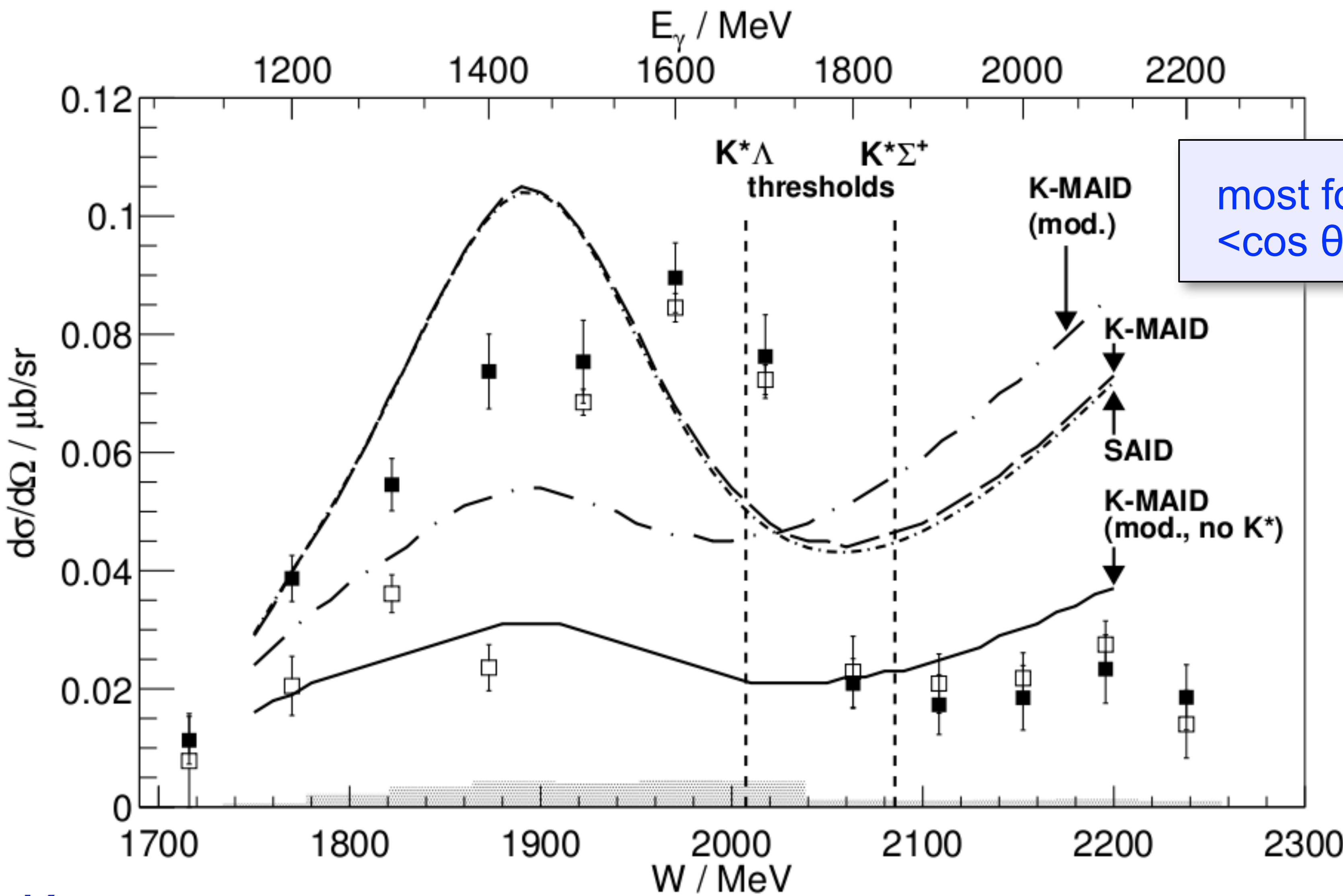
selected results of BGOOD

uds sector – threshold dynamics



$\gamma + p \rightarrow K^0 + \Sigma^+$ anomaly @ K^* threshold

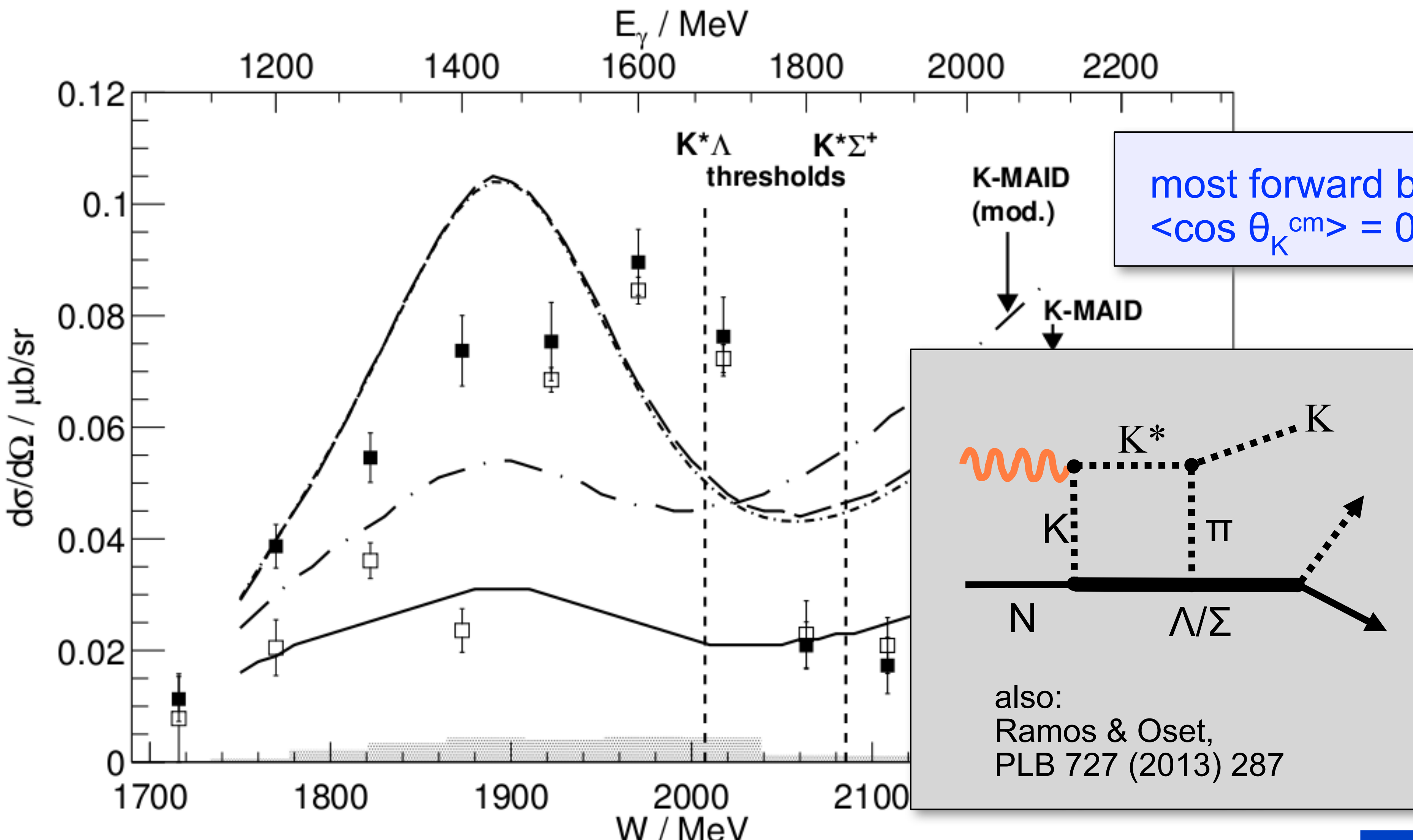
R. Ewald et al. (CB/TAPS), PLB 713 (2012)



most forward bin
$\langle\cos\theta_K^{cm}\rangle = 0.83$

$\gamma + p \rightarrow K^0 + \Sigma^+$ anomaly @ K^* threshold

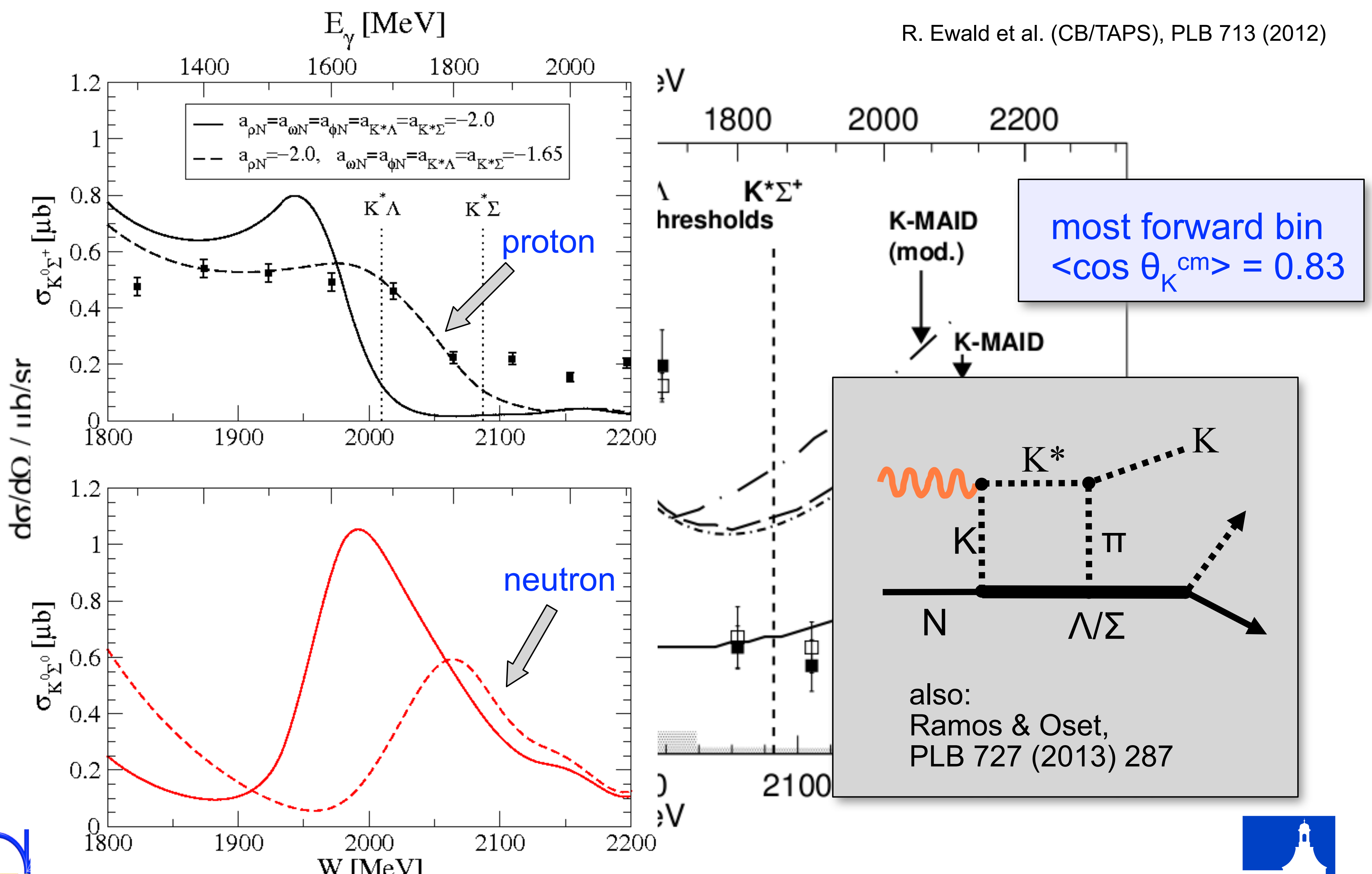
R. Ewald et al. (CB/TAPS), PLB 713 (2012)



most forward bin
$\langle \cos\theta_K^{cm} \rangle = 0.83$

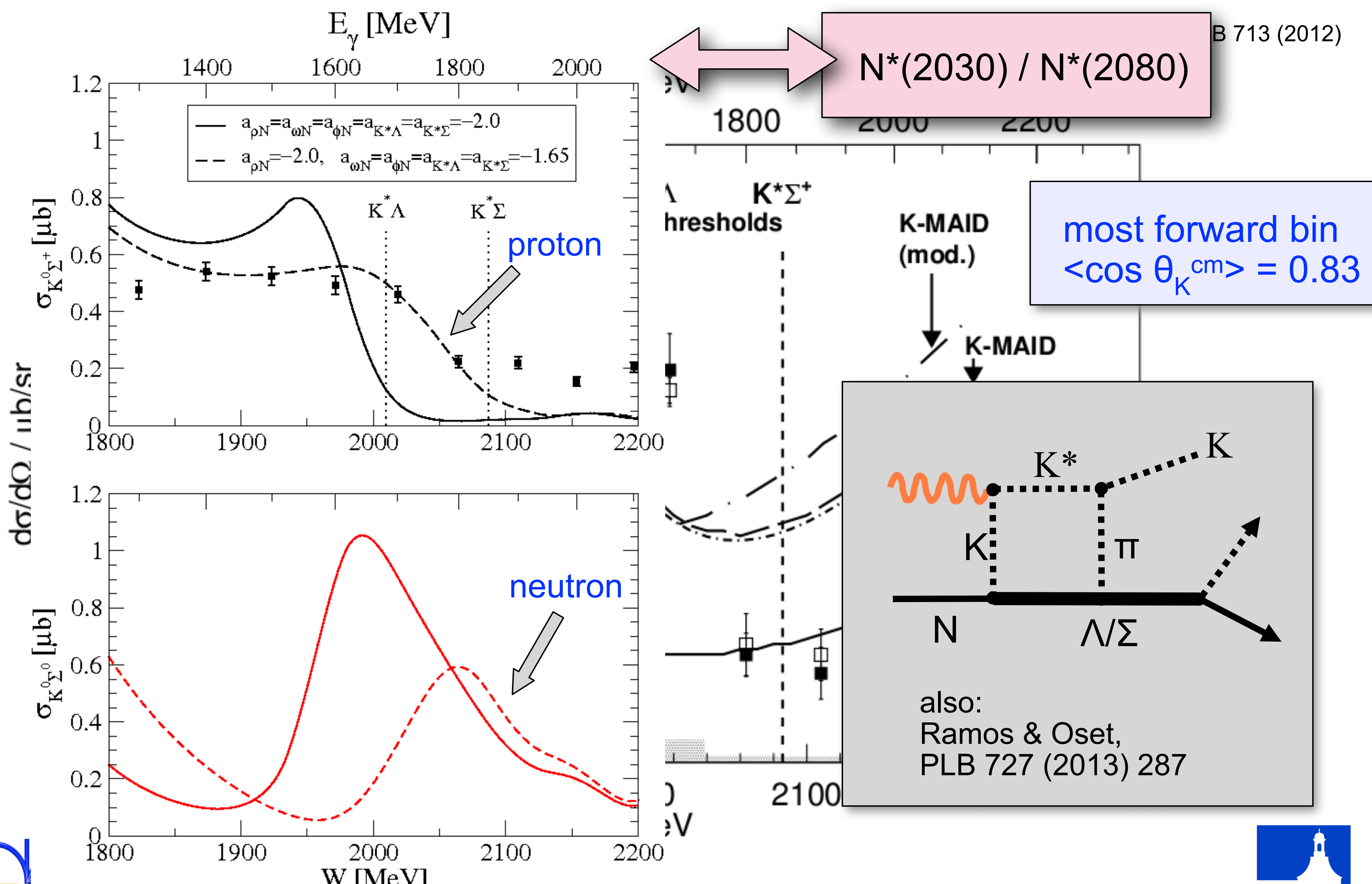
$\gamma + p \to K^0 + \Sigma^+$ anomaly @ K* threshold

R. Ewald et al. (CB/TAPS), PLB 713 (2012)

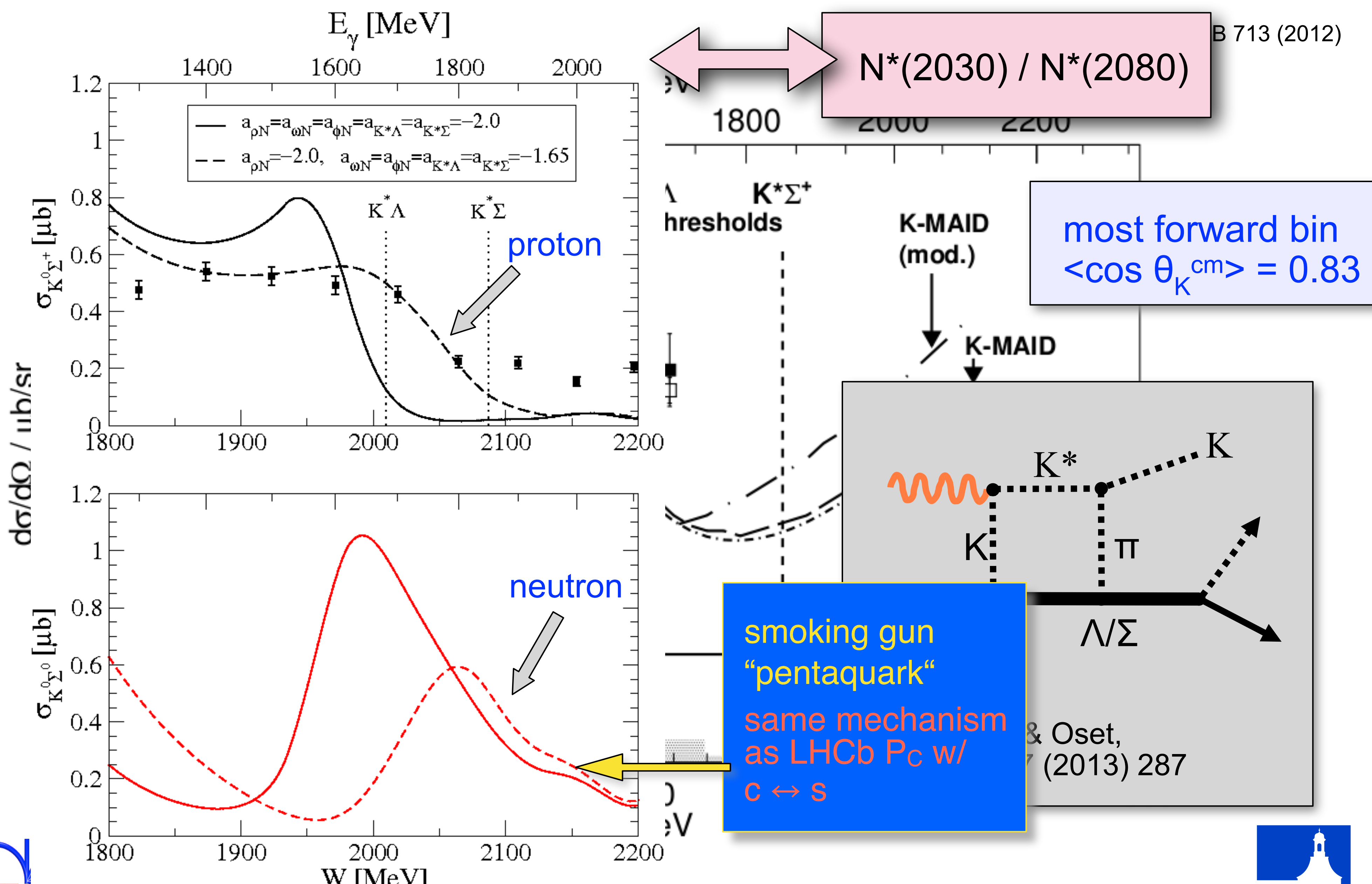


H. Schmieden

$\gamma + p \to K^0 + \Sigma^+$ anomaly @ K* threshold



γ + p -> $K^0 + \Sigma^+$ anomaly @ K^* threshold



N*(2030) / N*(2080)

most forward bin
$<\cos\theta_K^{cm}> = 0.83$

smoking gun
“pentaquark“

same mechanism as LHCb P_C w/
$c \leftrightarrow s$

ELSA

H. Schmieden

universitätbonn

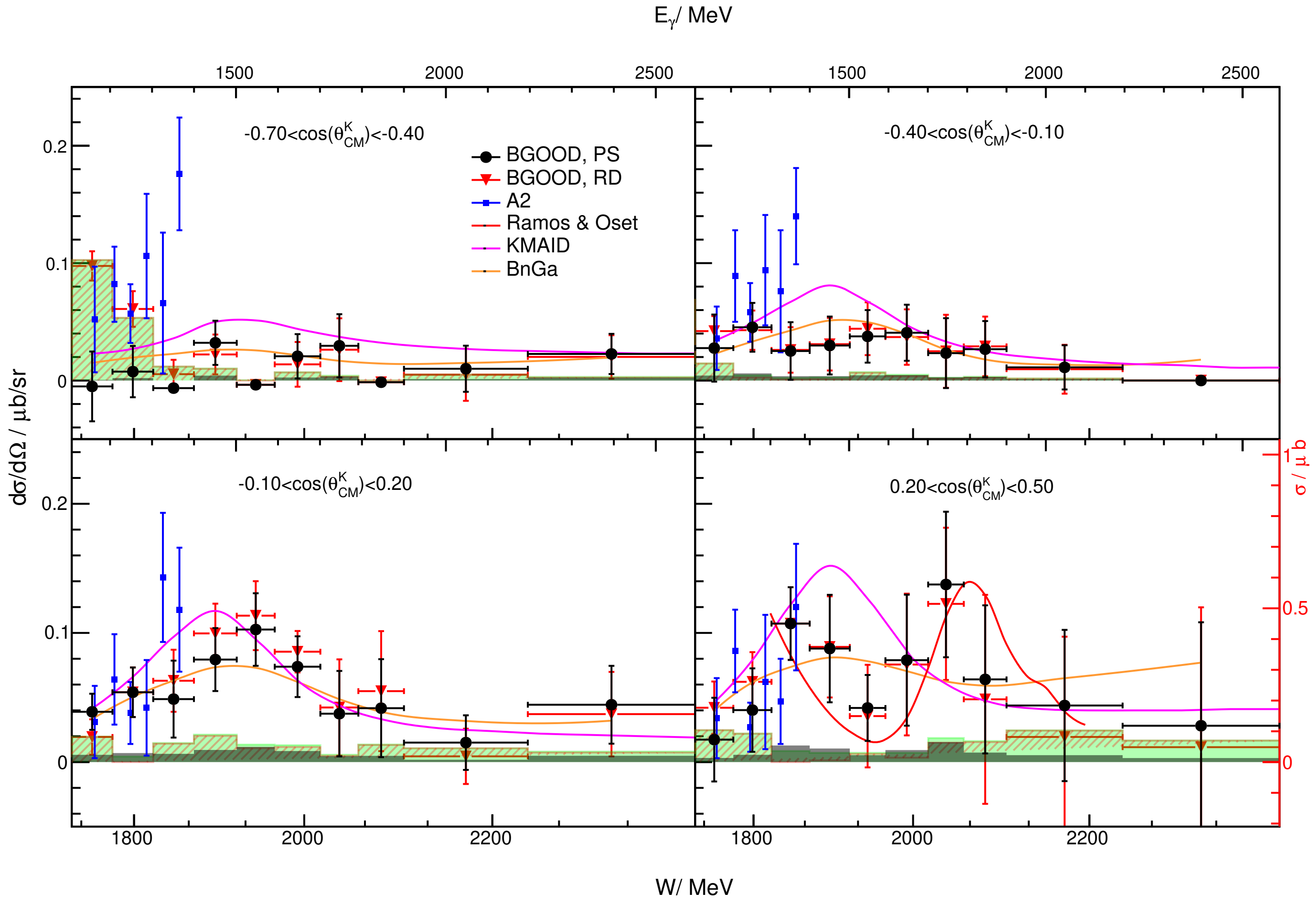
$\gamma\, n \rightarrow K^0\, \Sigma^0$

PhD thesis K. Kohl (Bonn 2021)
arXiv:2108.13319

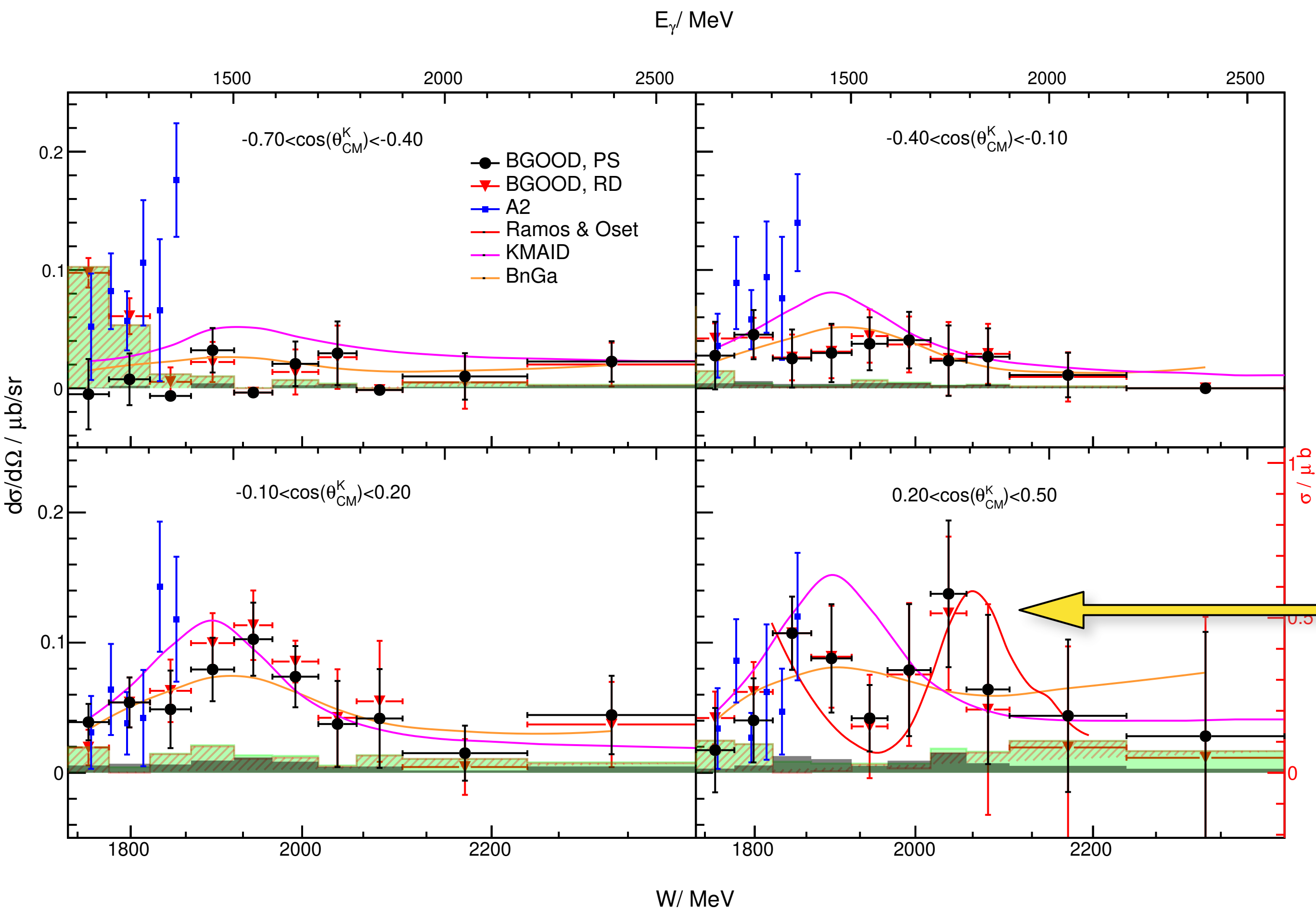
C. Akondi et al. [MAMI-A2]
EPJ A 55 (2019) 202

BGOOD simulated bg fit

BGOOD real bg fit



$\gamma\, n \rightarrow K^0\, \Sigma^0$



PhD thesis K. Kohl (Bonn 2021)
arXiv:2108.13319

C. Akondi et al. [MAMI-A2]
EPJ A 55 (2019) 202

BGOOD simulated bg fit

BGOOD real bg fit

see also:
“The molecular nature of some exotic hadrons“
Ramos, Feijoo, Llorens, Montaña
Few Body Sys. 61 (2020) 4, 34
arXiv:2009.04367 (2020)

smoking gun
“pentaquark“

same mechanism as LHCb P_C w/
$c \leftrightarrow s$

$\gamma\, n \rightarrow K^0\, \Sigma^0$

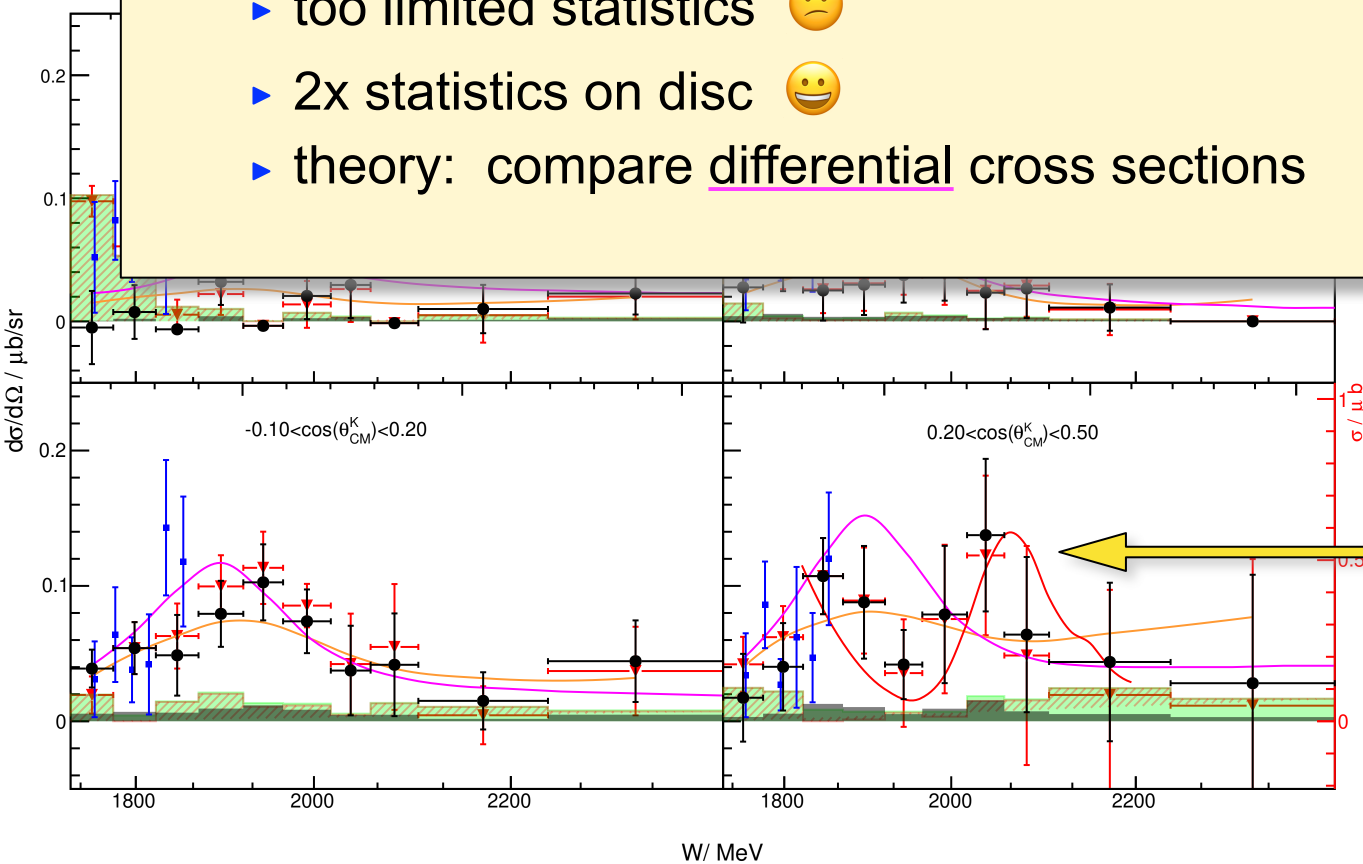
PhD thesis K. Kohl (Bonn 2021)
arXiv:2108.13319

C. Akondi et al. [MAMI-A2]
EPJ A 55 (2019) 202

BGOOD simulated bg fit

BGOOD real bg fit

- too limited statistics 😕
- 2x statistics on disc 😀
- theory: compare differential cross sections



see also:
“The molecular nature of some exotic hadrons“
Ramos, Feijoo, Llorens, Montaña
Few Body Sys. 61 (2020) 4, 34
arXiv:2009.04367 (2020)

smoking gun
“pentaquark“
same mechanism as LHCb P_C w/
$c \leftrightarrow s$

Λ(1405)

Historic remark

- → Λ(1405) predicted by Dalitz & Tuan as composed of Kaon-Nucleon
  R.H. Dalitz & S.F. Tuan, PRL 2 (1959) 425
- → discovered 1961 in Kp → $\Sigma\pi\pi\pi$
  M.H. Alston et al., PRL 4 (1961) 698
- → probably first “exotic“ hadron

ttle the decades-long
-quark state or mere
ne first interpretation.

yon scattering amplitude
with the strangeness $S = -1$ and isospin $I = 0$. It is the *archetype* of what is called a dynamically generated resonance, as pioneered by Dalitz and Tuan.

$\Lambda(1405)$

PDG 2010

The clean Λ_c spectrum has in fact been taken to settle the decades-long discussion about the nature of the $\Lambda(1405)$ – true 3-quark state or mere $\bar{K}N$ threshold effect? – unambiguously in favor of the first interpretation.

PDG 2016

The $\Lambda(1405)$ resonance emerges in the meson-baryon scattering amplitude with the strangeness $S = -1$ and isospin $I = 0$. It is the *archetype* of what is called a dynamically generated resonance, as pioneered by Dalitz and Tuan.

$\Lambda(1405)$

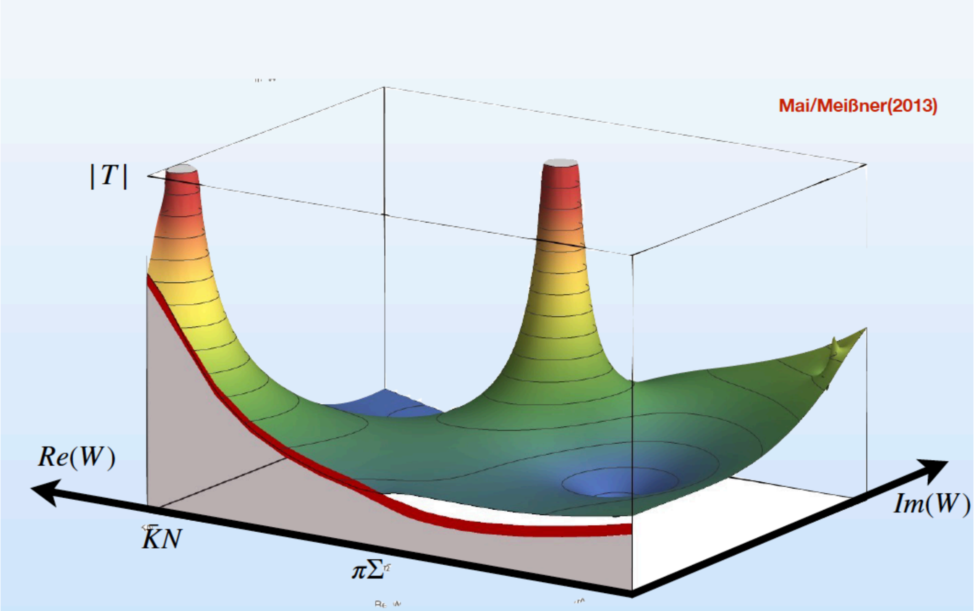
PDG 2010

The clean Λ_c spectrum has in fact been taken to settle the decades-long discussion about the nature of the $\Lambda(1405)$ – true 3-quark state or mere $\bar{K}N$ threshold effect? – unambiguously in favor of the first interpretation.

PDG 2016

The $\Lambda(1405)$ resonance emerges in the meson-baryon scattering amplitude with the strangeness $S = -1$ and isospin $I = 0$. It is the *archetype* of what is called a dynamically generated resonance, as pioneered by Dalitz and Tuan.

Λ(1405) 2-pole structure in χPT



taken from Maxim Mai's
talk at NSTAR 2019
(Baryon ChPT)

Oller/Meißner (2001)

- *Relativistic re-summation of chiral potential*
- *Two-poles on II Riemann Sheet* → **Now part of PDG**

Kaiser/Siegel/Weise (1995) Oset/Ramos (1998)

- *Lippmann-Schwinger equation for K⁻p,Σπ,Λπ*
- *Potential from Chiral Lagrangian*

"Thus, a potential derived from chiral dynamics with interaction ranges commensurate with the meson-baryon system necessarily produces a quasi-bound state or resonance below or near the K⁻p threshold"

universitätbonn

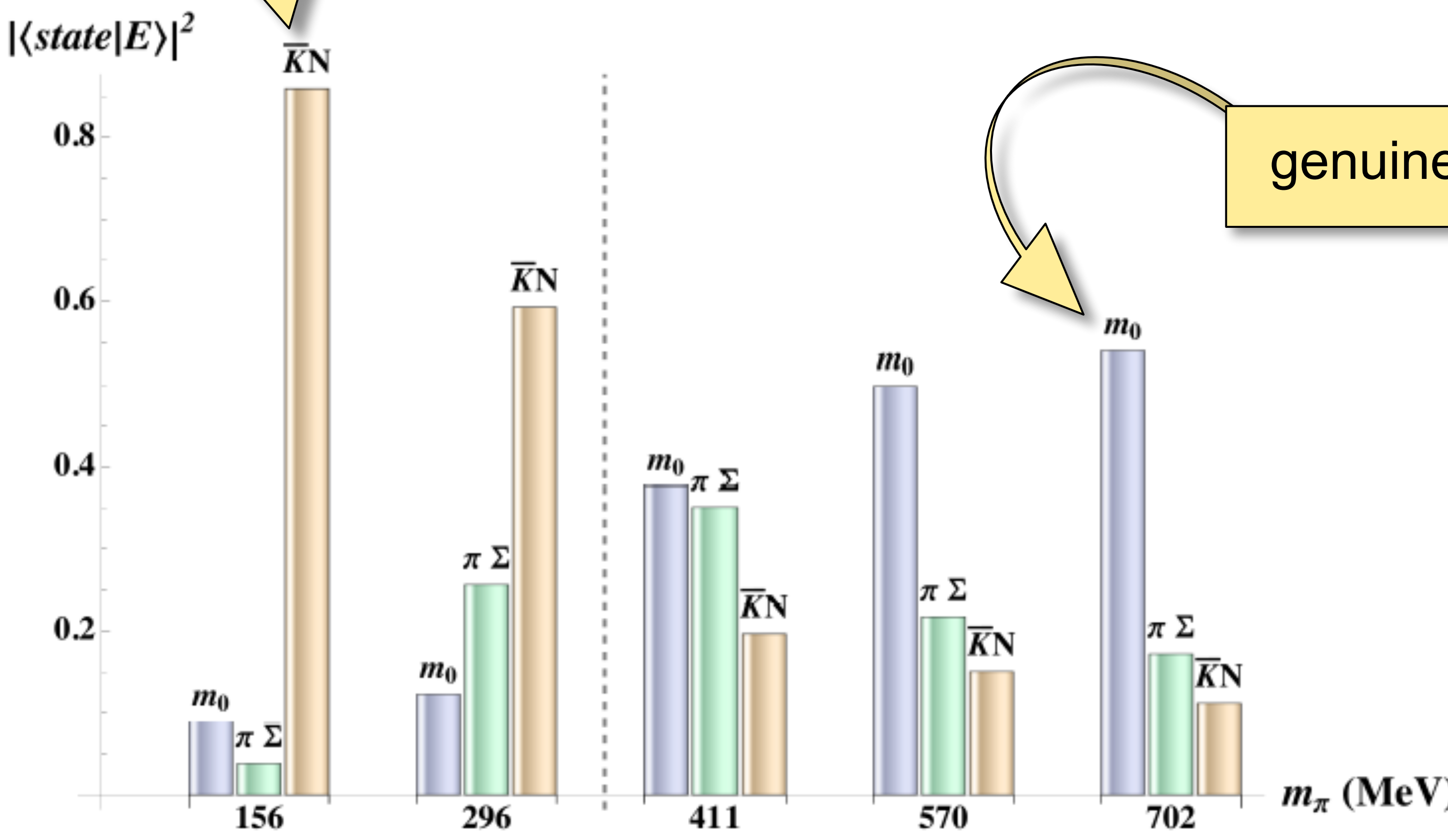
Λ(1405) Lattice QCD

J.M.M. Hall et al. [Adelaide group],
Phys. Rev. Lett. 114 (2015) 132002

UχPT see also:
R. Molina & M. Döring,
PR D94 (2016) 056010
& 079901

"molecule" as dominating Fock component

genuine 3q



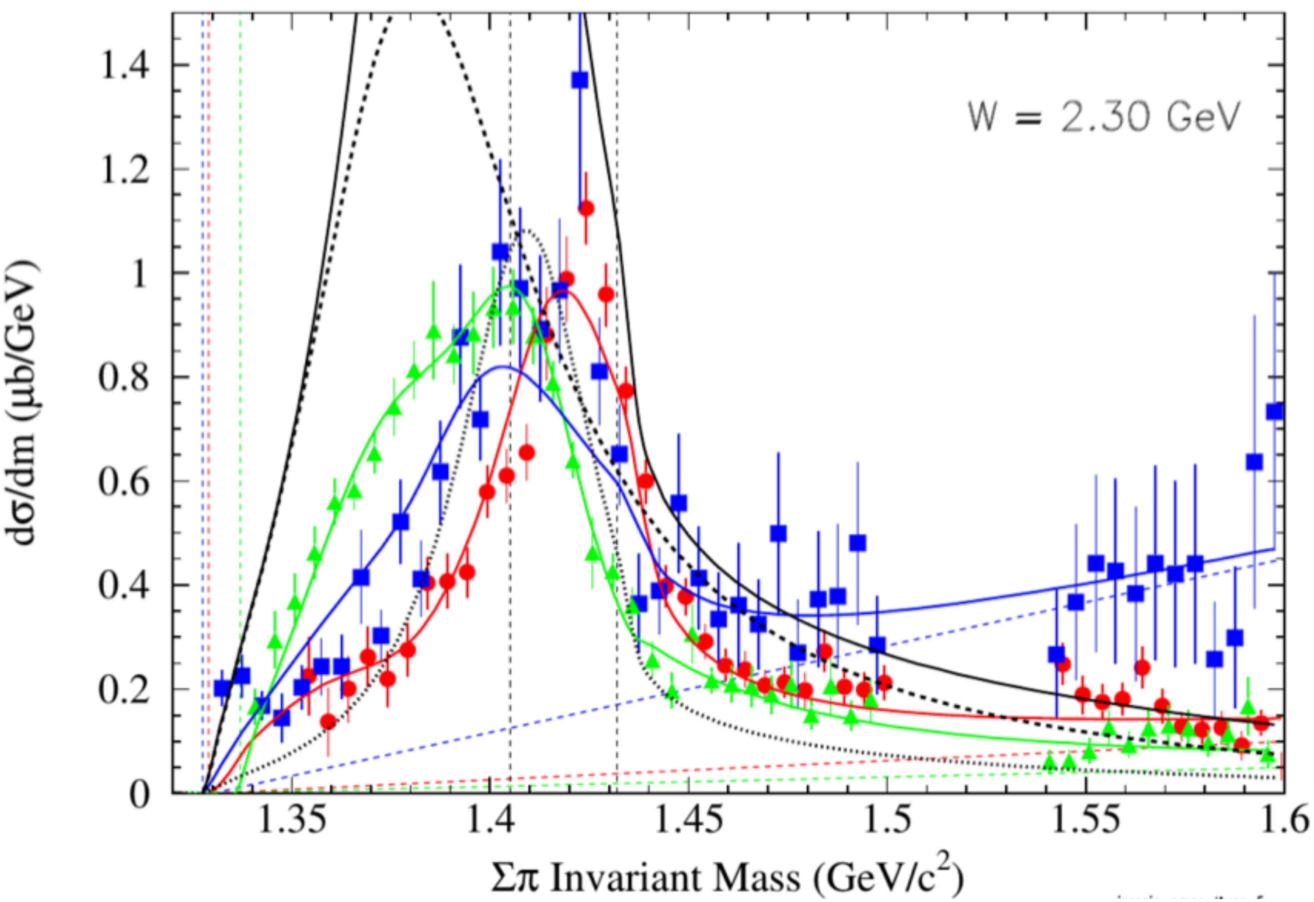
K⁺ Λ(1405) experimental status

Λ(1405) photoproduction – line shape

$\Lambda(1405) \rightarrow \Sigma^0\pi^0$

$\Sigma^+\pi^-$

$\Sigma^-\pi^+$



R.A.Schumacher et al. Nucl.Phys.A. 914,51–59 (2013)

K. Moriya et al., Phys. Rev. **C 88**, 045201 (2013)

theory: J.A. Oller & U.-G. Meißner, PLB 500 (2001) 263

- two pole structure predicted & confirmed
- different line shapes in $(\Sigma\pi)^0$ channels confirmed

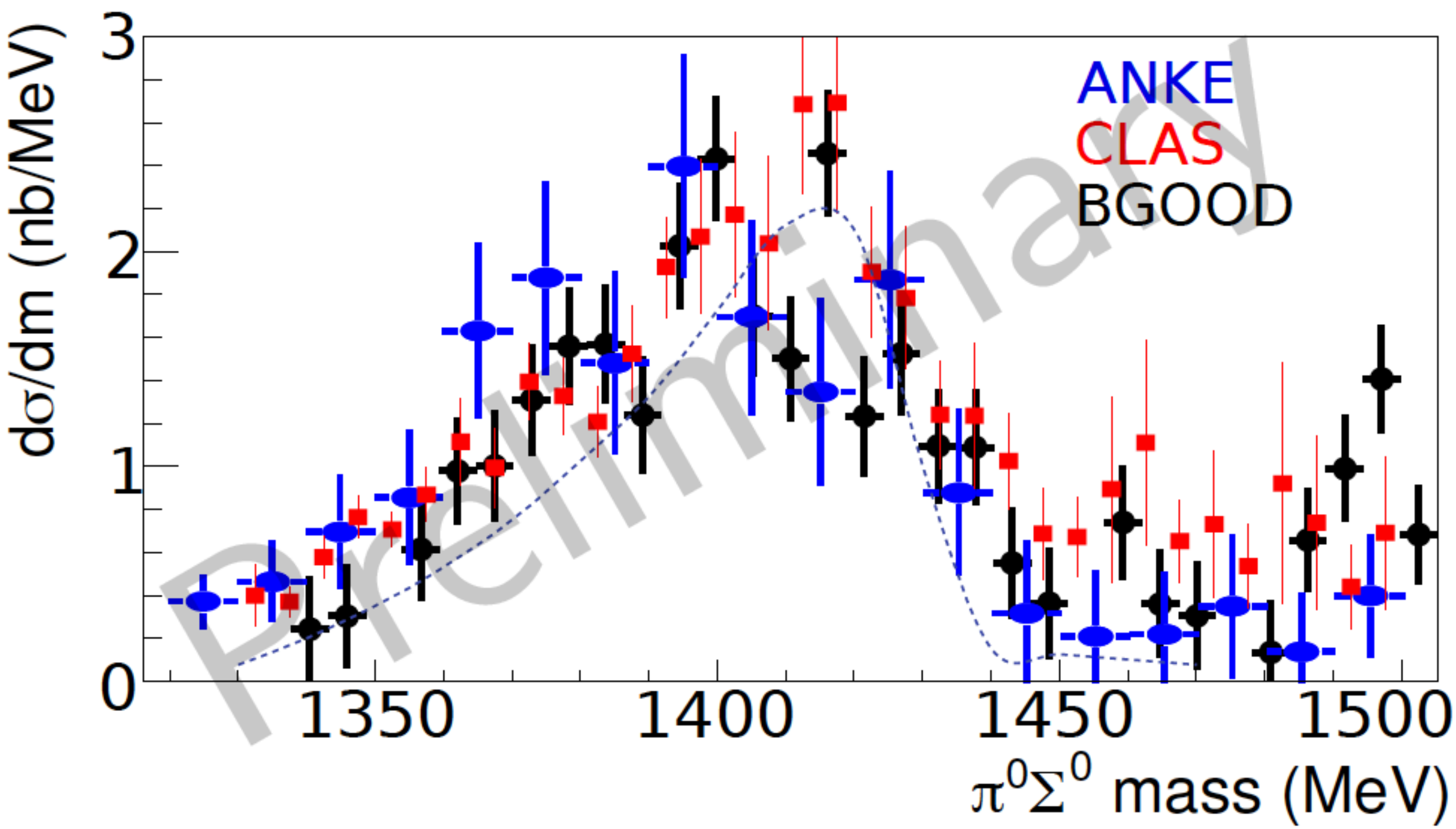
2-poles structure should be visible in pure I=0 channel $\Sigma^0\pi^0$

universitätbonn

K⁺ Λ(1405)

Λ(1405) photoproduction – line shape

G. Scheluchin *et al.* [BGOOD collab.]
arXiv:2108.12235 (2021)

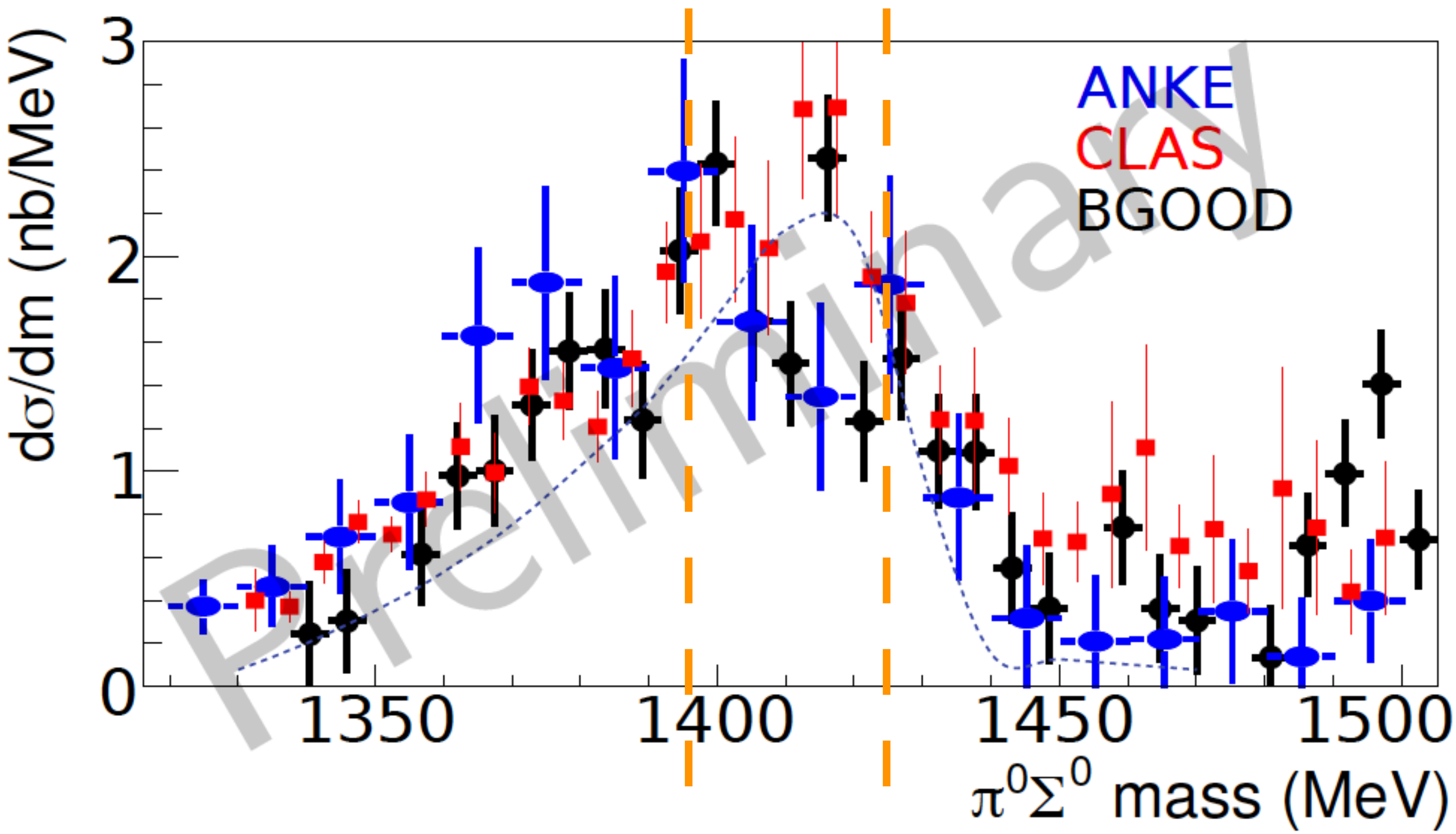


K⁺ Λ(1405)

Λ(1405) photoproduction – line shape

G. Scheluchin *et al.* [BGOOD collab.]
arXiv:2108.12235 (2021)

double peak strukture
@ 1395 / 1425 MeV ??

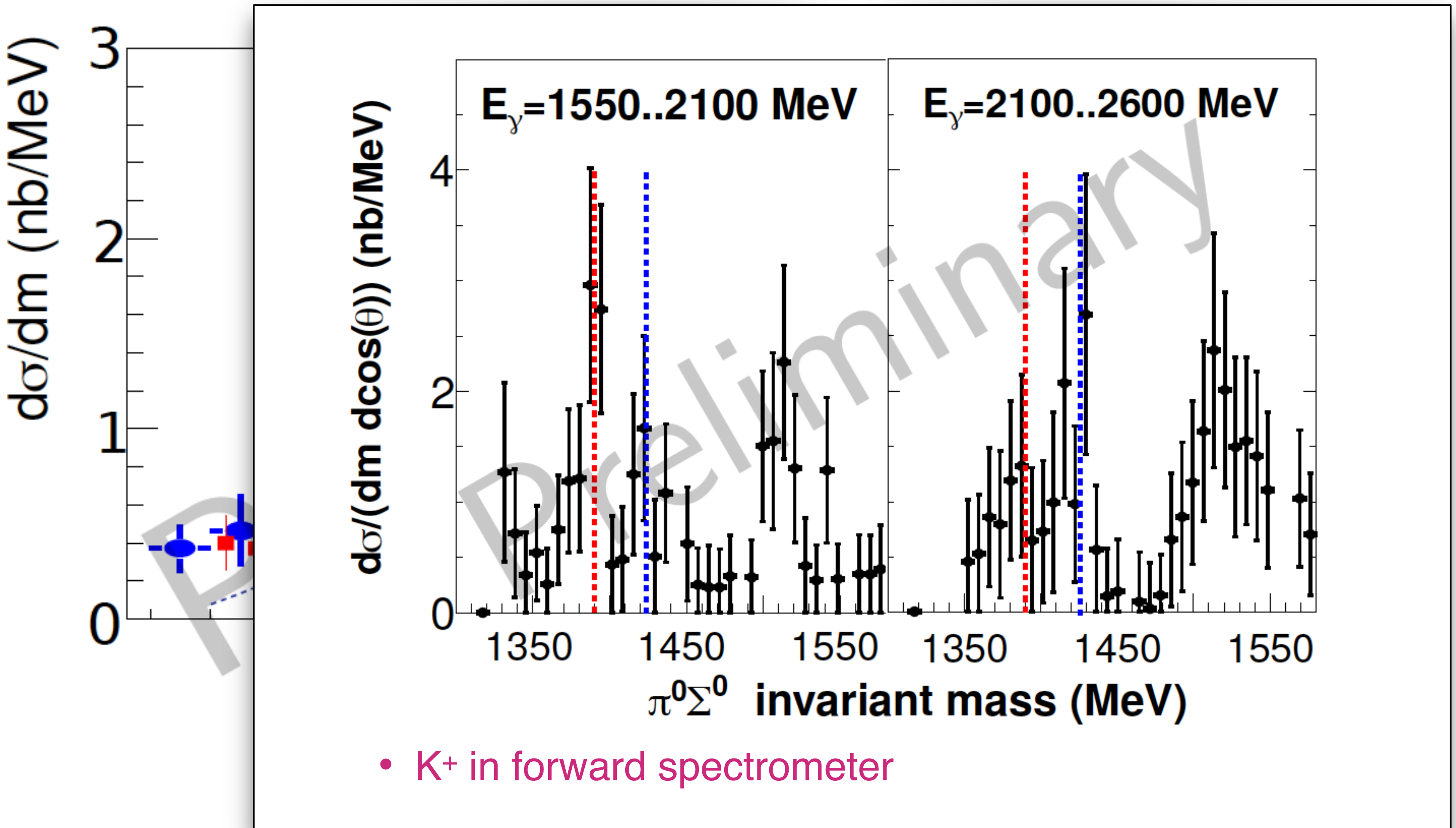


K^+ $\Lambda(1405)$

$\Lambda(1405)$ photoproduction – line shape

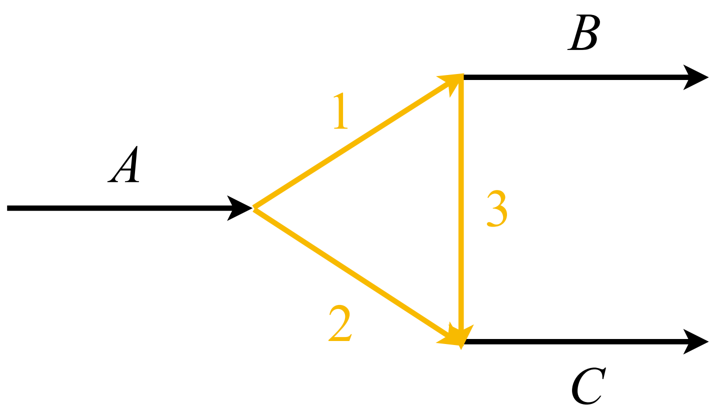
G. Scheluchin *et al.* [BGOOD collab.]
arXiv:2108.12235 (2021)

double peak strukture
@ 1395 / 1425 MeV ??



- K^+ in forward spectrometer

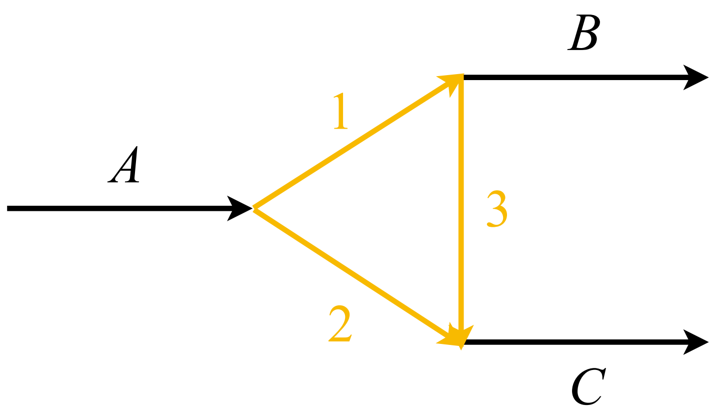
photoproduction mechanism – triangle singularity



Coleman-Norton theorem,
Il Nuovo Cimento 38 (1965) 438:
1, 2, 3 must be nearly on mass shell

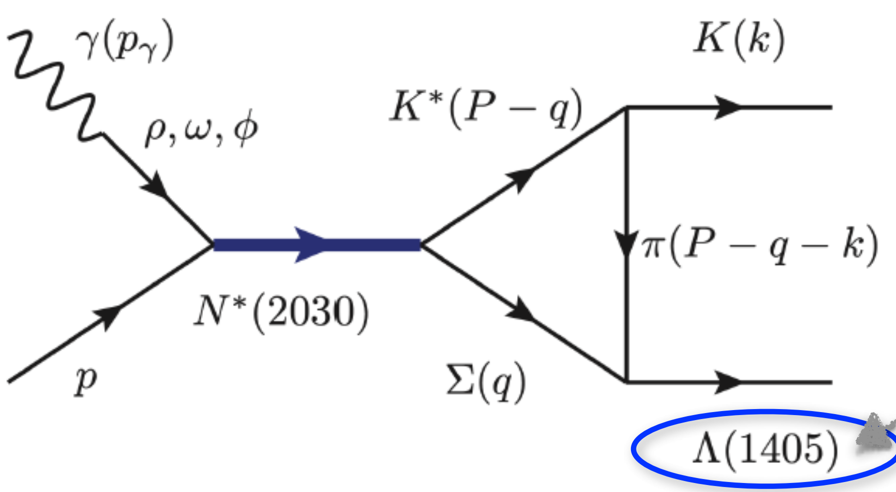
can mimic resonance

photoproduction mechanism – triangle singularity



Coleman-Norton theorem,
Il Nuovo Cimento 38 (1965) 438:
1, 2, 3 must be nearly on mass shell

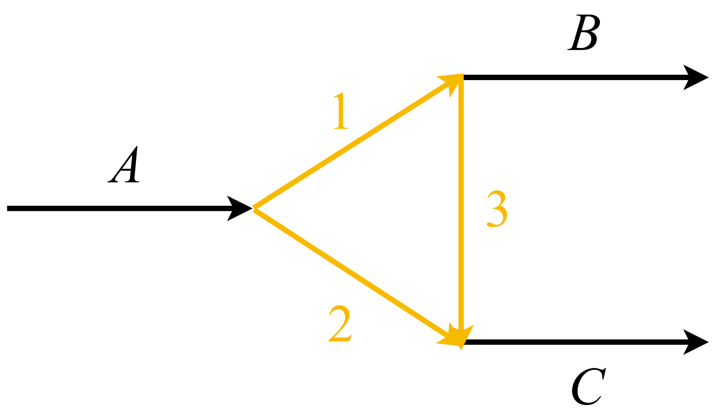
can mimic resonance



or drive (dynamically generated) resonance

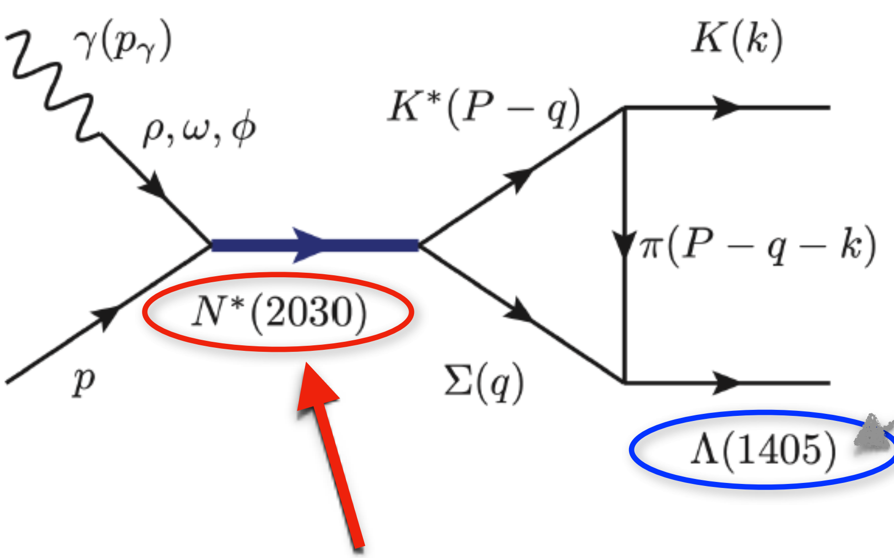
E. Wang, J. Xie, W. Liang, F. Guo, E. Oset,
PR C 95 (2017) 015205

photoproduction mechanism – triangle singularity



Coleman-Norton theorem,
Il Nuovo Cimento 38 (1965) 438:
1, 2, 3 must be nearly on mass shell

can mimic resonance



or drive (dynamically generated) resonance

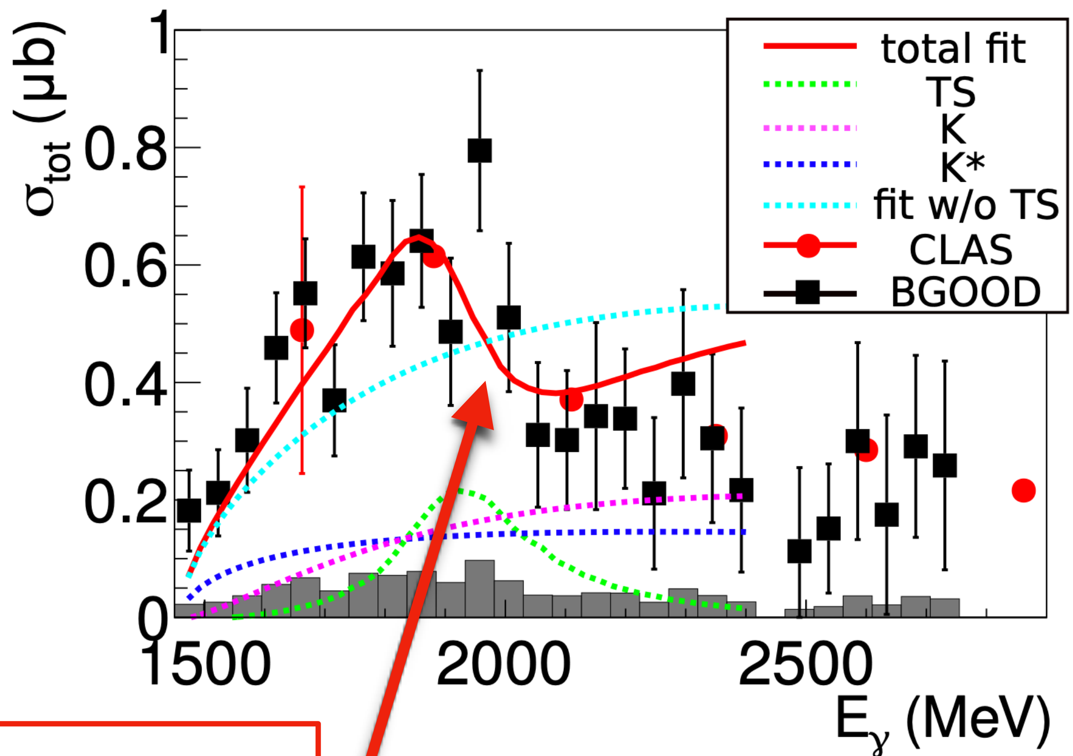
E. Wang, J. Xie, W. Liang, F. Guo, E. Oset,
PR C 95 (2017) 015205

$K^*\Sigma$ suspect in $K^0\Sigma^0$ channel

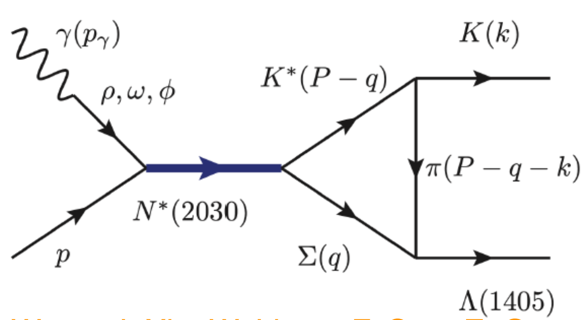
K⁺ Λ(1405) – photoproduction mechanism

K⁺ Λ(1405) photoproduction – total x-sec

G. Scheluchin *et al.* [BGOOD collab.]
arXiv:2108.12235 (2021)



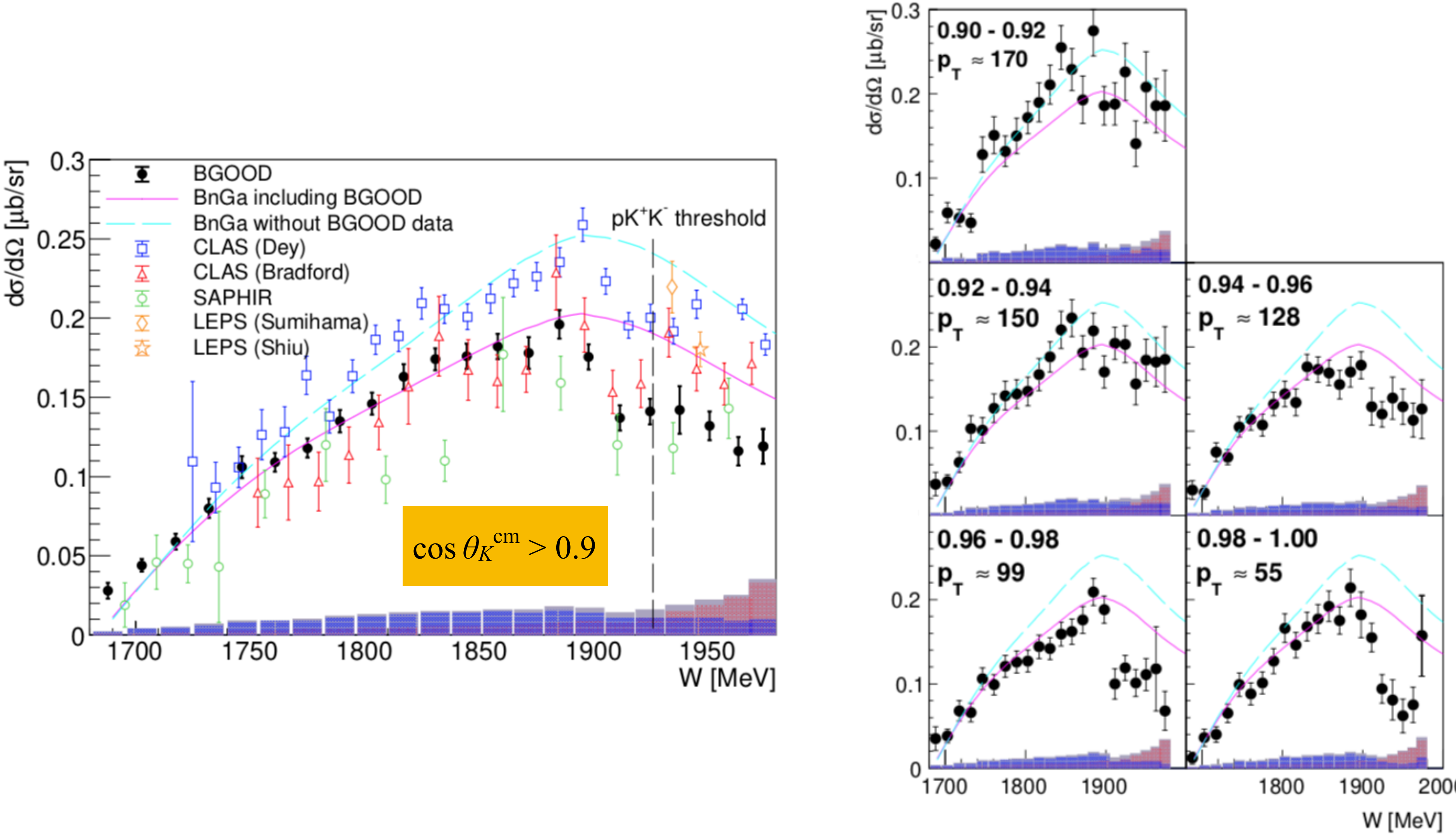
cusp: triangle meachanism significant



E. Wang, J. Xie, W. Liang, F. Guo, E. Oset,
PR C 95 (2017) 015205

$\gamma\, p \rightarrow K^+ \Sigma^0$ photoproduction

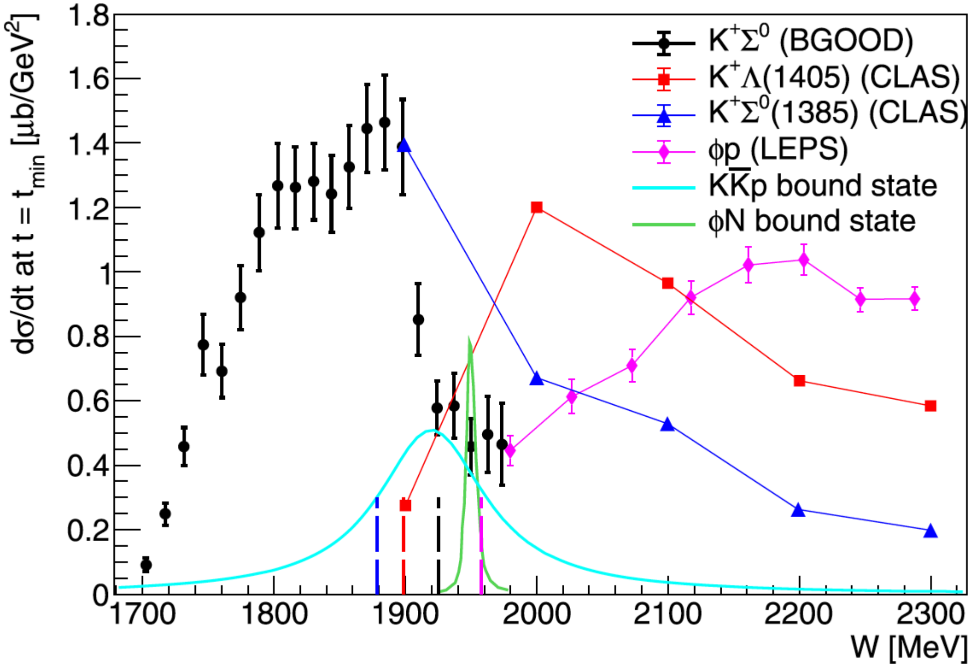
T. Jude *et al.* [BGOOD collab.]
Phys. Lett B 820 (2021) 136559



H. Schmieden

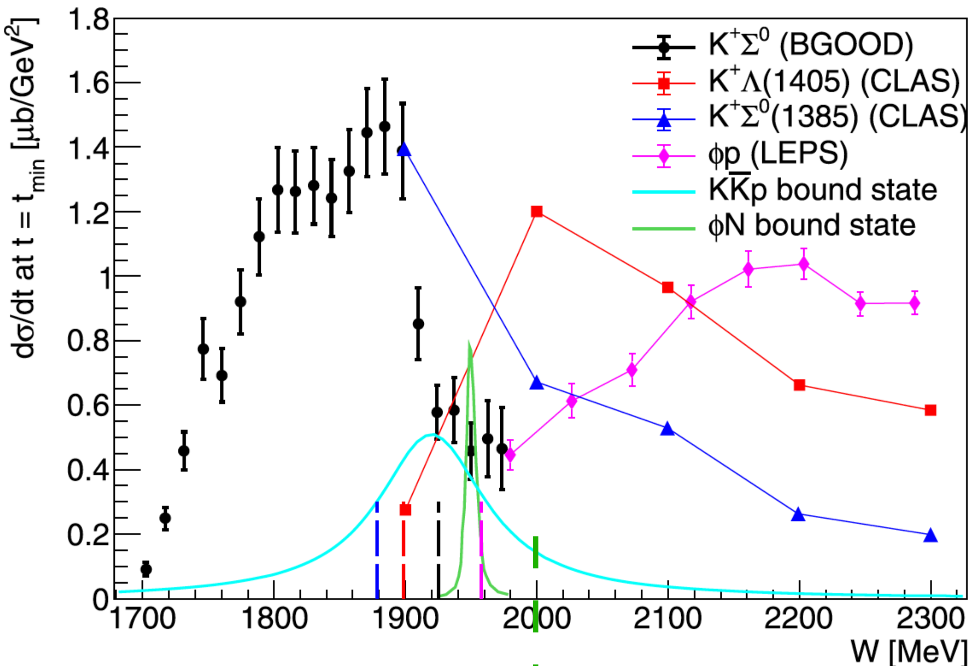
$\gamma p \rightarrow K^+ \Sigma^0$ photoproduction

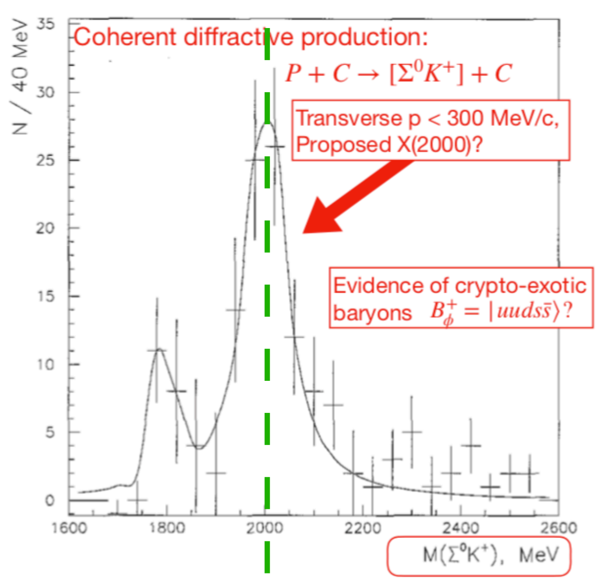
T. Jude *et al.* [BGOOD collab.]
Phys. Lett B 820 (2021) 136559

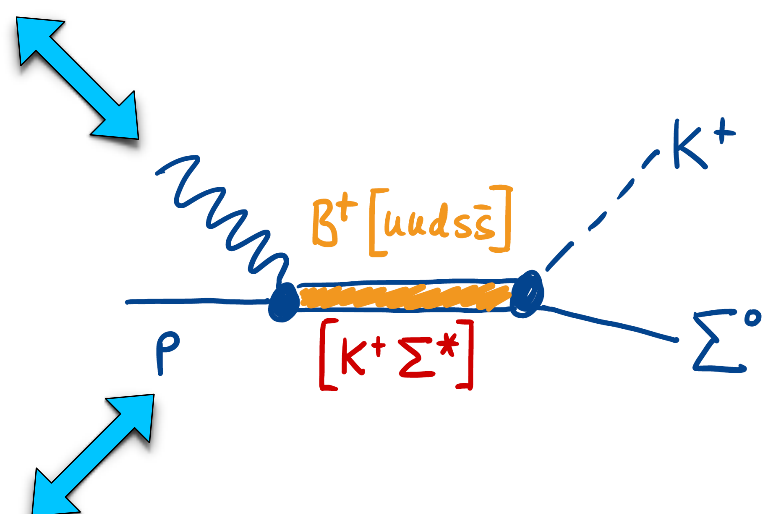


$\gamma\, p \rightarrow K^+\, \Sigma^0$ photoproduction

T. Jude *et al.* [BGOOD collab.]
Phys. Lett B 820 (2021) 136559







S.V. Golovkin *et al.* [SPHINX collab.]
Z. Phys. C 68 (1995) 585

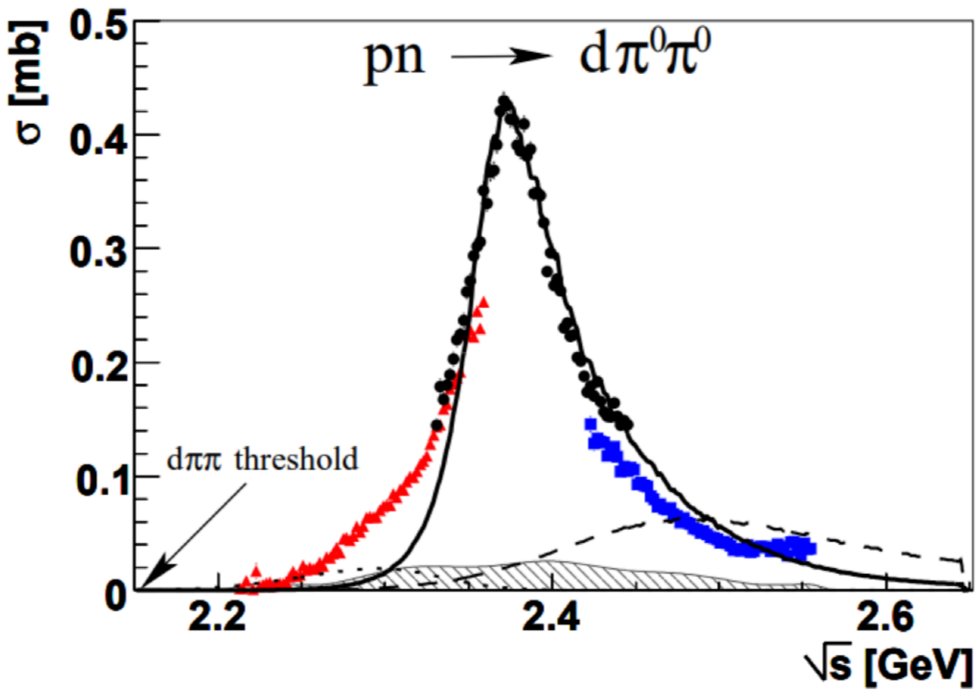
from penta to hexa ...

→ Dibaryons ?

from penta to hexa ...

Dibaryons ?

- early SU(6) predictions – NN, NΔ & ΔΔ type dibaryon candidates
  Dyson & Xuong, PRL 13 (1964) 815
- 3-body calculations NΔ & ΔΔ in good agreement
  Gal & Garcilazo, NPA 928 (2014) 73



d(2380)*
observed in pn fusion reaction
at WASA experiment at COSY

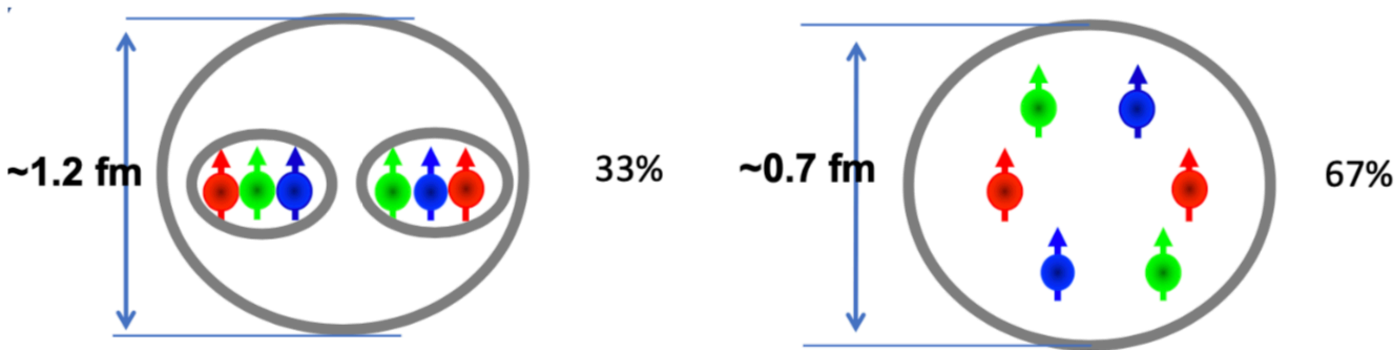
P. Adlarson et al. [WASA@COSY],
PRL 106 (2011) 242302

- $(I)\ J^P = (0)\ 3^+$
- ΔΔ type object ?
- meanwhile observed in multiple final states in pn reactions

Dibaryons ?

- Microscopic χ quark models:
  - 2/3 hidden color (compact) configuration
  - 1/3 molecular component

  Huang et al., Chin. Phys. C7 (2015) 071001



- *d*(2380)* in the centre of neutron stars

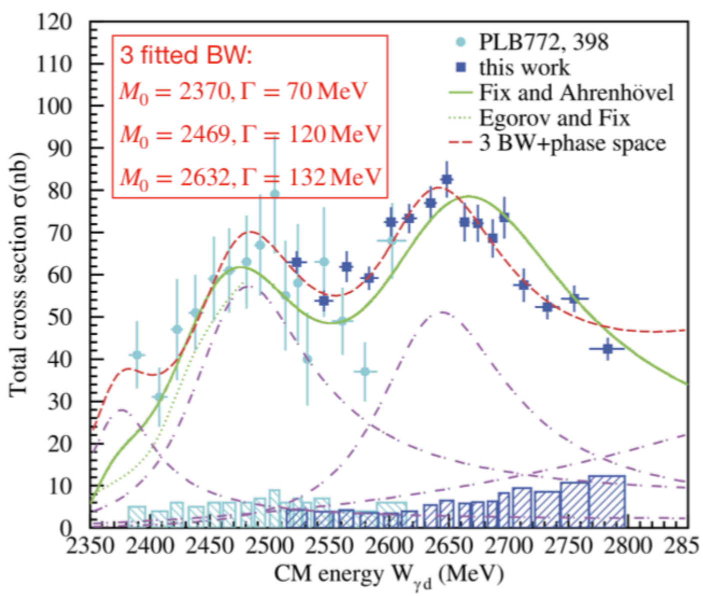
  Vidana et al., PLB 781 (2018) 112

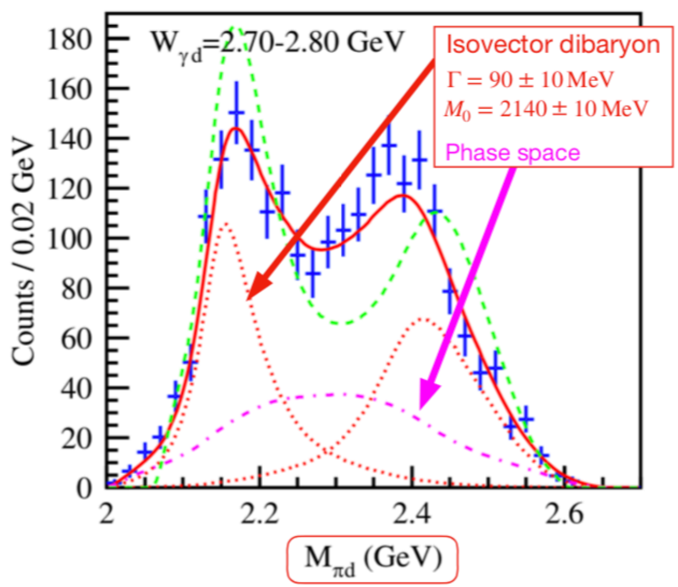
- Dark matter ?? – *d*(2380)* BEC formed in early universe ?

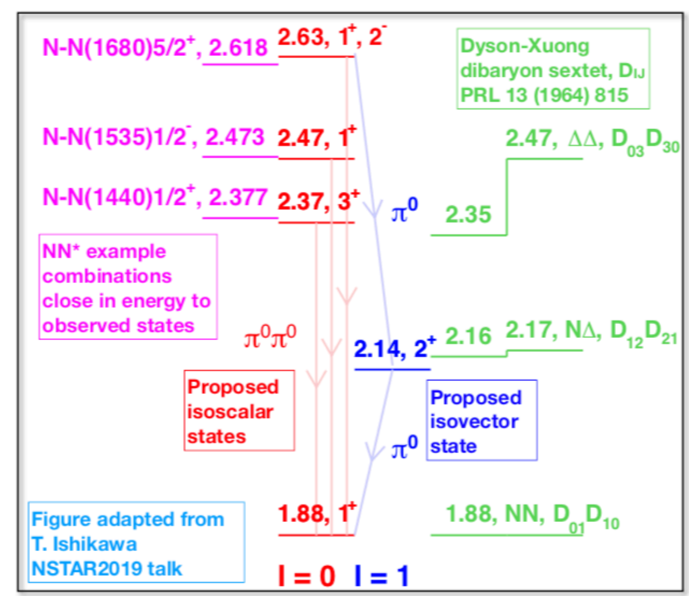
  Bashkanov and Watts, J. Phys. G 47 (2020) 03LT01

Dibaryons ?

- coherent photoproduction $\gamma\, d \rightarrow \pi\, \pi\, d$
  challenging: minimal momentum transfer to target deuteron, nbarn x-sec & large qf background
- previous data from ELPH
  Takatsuku Ishikawa et al., PLB 789 (2019) 413

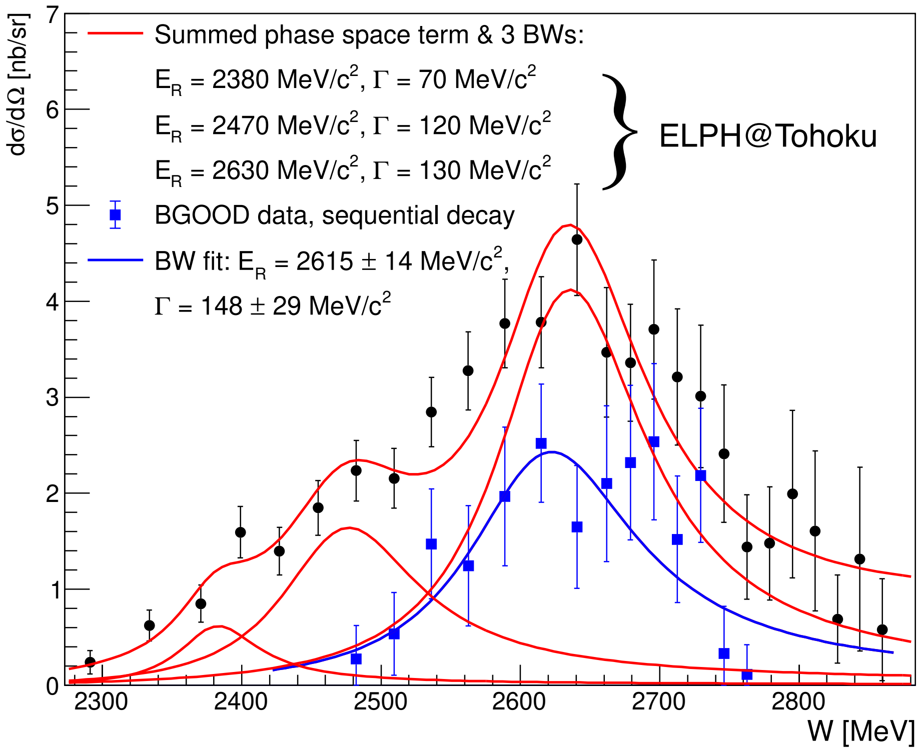


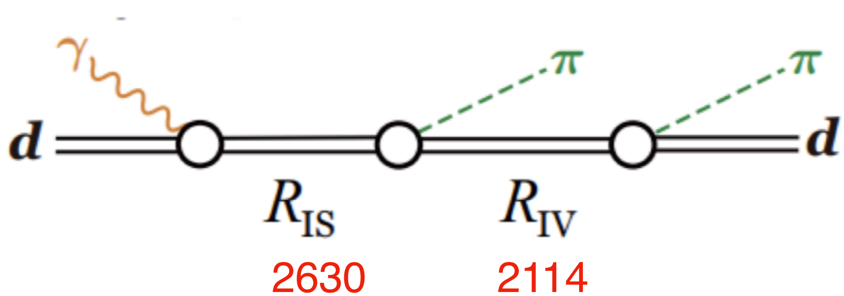


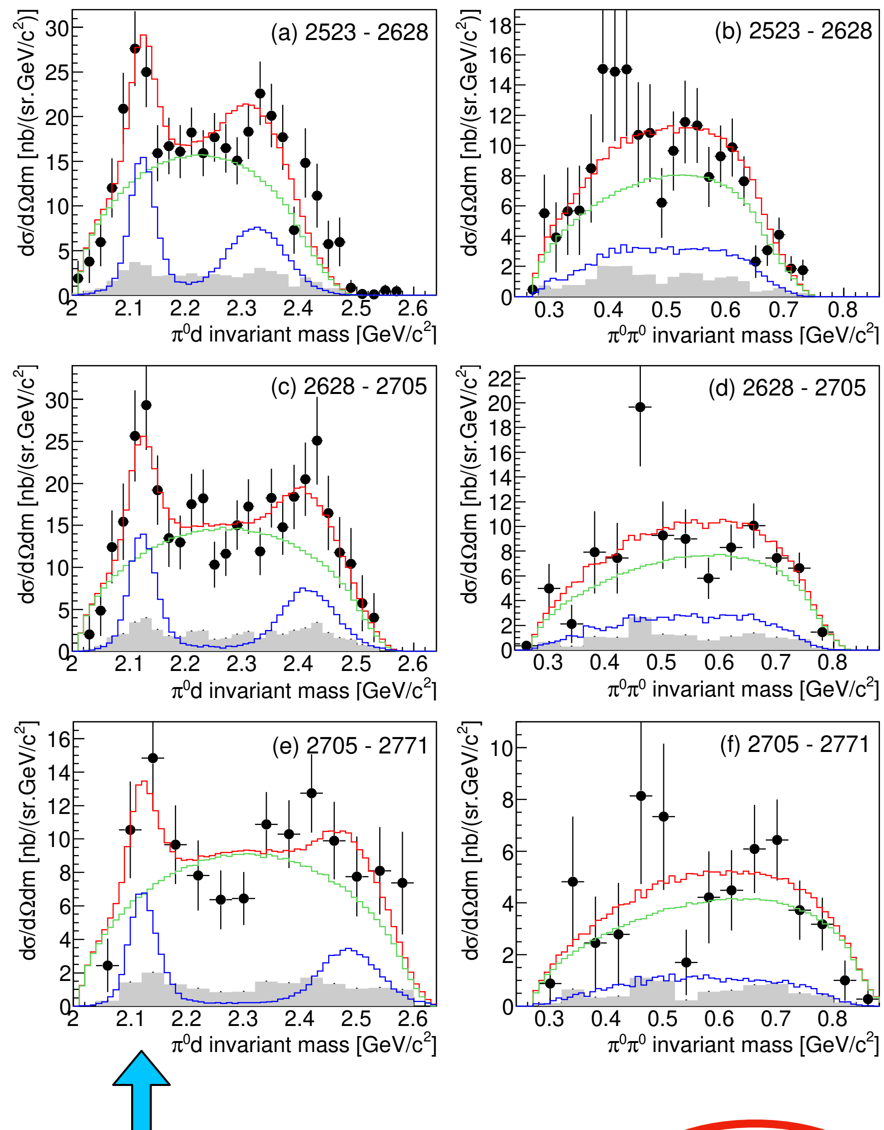


$\gamma\, d \to d\, \pi^0\, \pi^0$ coherent photoproduction @BGOOD

T.C. Jude et al. [BGOOD],
PLB 832 (2022) 137277
arXiv:2202.08594





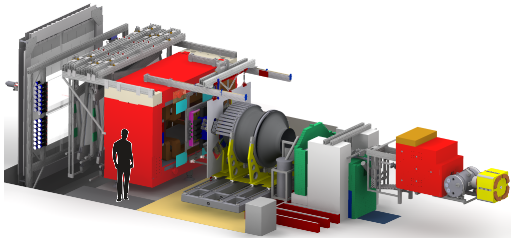


$\pi^0 d$ isovector state: 2114 MeV, $\Gamma \simeq 20$ MeV

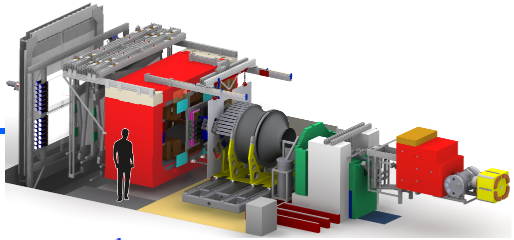
Conclusions

- BGOOD ideal for threshold physics in uds sector
- forward acceptance ↔ meson-baryon dynamics @ low t / p_T
- role of baryon type multi-quark states
- dibaryons
- hadronic structure formation from basic QCD

→ hadronic interactions DO play a significant role similar to the c sector also in the *uds* sector



BGOOD collaboration



S. Alef[1], P. Bauer[1] , D. Bayadilov[2,3] , R. Beck[2], M. Becker[2], A. Bella[1], J. Bieling[2], S. Böse[2], A. Braghieri[4], K.-Th. Brinkmann[5], P. L. Cole[6], R. Di Salvo[7], D. Elsner[1], A. Fantini[7,8], O. Freyermuth[1], F. Frommberger[1], G. Gervino[9,10], F. Ghio[11,12], S. Goertz[1], A. Gridnev[3], E. Gutz[5], D. Hammann[1], J. Hannappel[1,19], W. Hillert[1,19], O. Jahn[1], R. Jahn[2], J. R. Johnstone[1], R. Joosten[2], T. C. Jude[1,a], H. Kalinowsky[2], V. Kleber[1,20], F. Klein[1], K. Kohl[1], K. Koop[2], N. Kozlenko[3], B. Krusche[13], A. Lapik[14], P. Levi Sandri[15,b], V. Lisin[14], I. Lopatin[3], G. Mandaglio[16,17], M. Manganaro[16,17,21], F. Messi[1,22], R. Messi[7,8], D. Moricciani[7], A. Mushkarenkov[14], V. Nedorezov[14], D. Novinskiy[3], P. Pedroni[4], A. Polonskiy[14], B.-E. Reitz[1], M. Romaniuk[7,18], T. Rostomyan[13], G. Scheluchin[1], H. Schmieden[1], A. Stugelev[3], V. Sumachev[3], V. Tarakanov[3], V. Vegna[1], D. Walther[2], H.-G. Zaunick[2,5], T. Zimmermann[1]

[1] Rheinische Friedrich-Wilhelms-Universität Bonn, Physikalisches Institut, Nußallee 12, 53115 Bonn, Germany
[2] Rheinische Friedrich-Wilhelms-Universität Bonn, Helmholtz-Institut für Strahlen- und Kernphysik, Nußallee 14-16, 53115 Bonn, Germany
[3] Petersburg Nuclear Physics Institute, Gatchina, Leningrad District 188300, Russia
[4] INFN sezione di Pavia, Via Agostino Bassi, 6, 27100 Pavia, Italy
[5] Justus-Liebig-Universität Gießen, II. Physikalisches Institut, Heinrich-Buff-Ring 16, 35392 Gießen, Germany
[6] Department of Physics, Lamar University, Beaumont, TX 77710, USA
[7] INFN Roma “Tor Vergata”, Via della Ricerca Scientifica 1, 00133 Rome, Italy
[8] Dipartimento di Fisica, Università di Roma “Tor Vergata”, Via della Ricerca Scientifica 1, 00133 Rome, Italy
[9] INFN sezione di Torino, Via P.Giuria 1, 10125 Turin, Italy
[10] Dipartimento di Fisica,, Università di Torino, via P. Giuria 1, 10125 Turin, Italy
[11] INFN sezione di Roma La Sapienza, P.le Aldo Moro 2, 00185 Rome, Italy
[12] Istituto Superiore di Sanità, Viale Regina Elena 299, 00161 Rome, Italy
[13] Institut für Physik, Klingelbergstrasse 82, 4056 Basel, Switzerland
[14] Russian Academy of Sciences Institute for Nuclear Research, Prospekt 60-letiya Oktyabrya 7a, Moscow 117312, Russia
[15] INFN - Laboratori Nazionali di Frascati, Via E. Fermi 54, 00044 Frascati, Italy
[16] INFN sezione Catania, 95129 Catania, Italy
[17] Dipartimento MIFT, Università degli Studi di Messina, Via F. S. D’Alcontres 31, 98166 Messina, Italy
[18] Institute for Nuclear Research of NASU, 03028 Kiev, Ukraine
[19] *Present Address:* DESY Research Centre, Hamburg, Germany
[20] *Present Address:* Forschungszentrum Jülich, Jülich, Germany
[21] *Present Address:* University of Rijeka, Rijeka, Croatia
[22] *Present Address:* Lund University & ESS, Lund, Sweden

ELSA

universitätbonn

BACKUP

$\gamma\, p \rightarrow K^+ \Sigma^0$ photoproduction

T. Jude *et al.* [BGOOD collab.]
Phys. Lett B 820 (2021) 136559

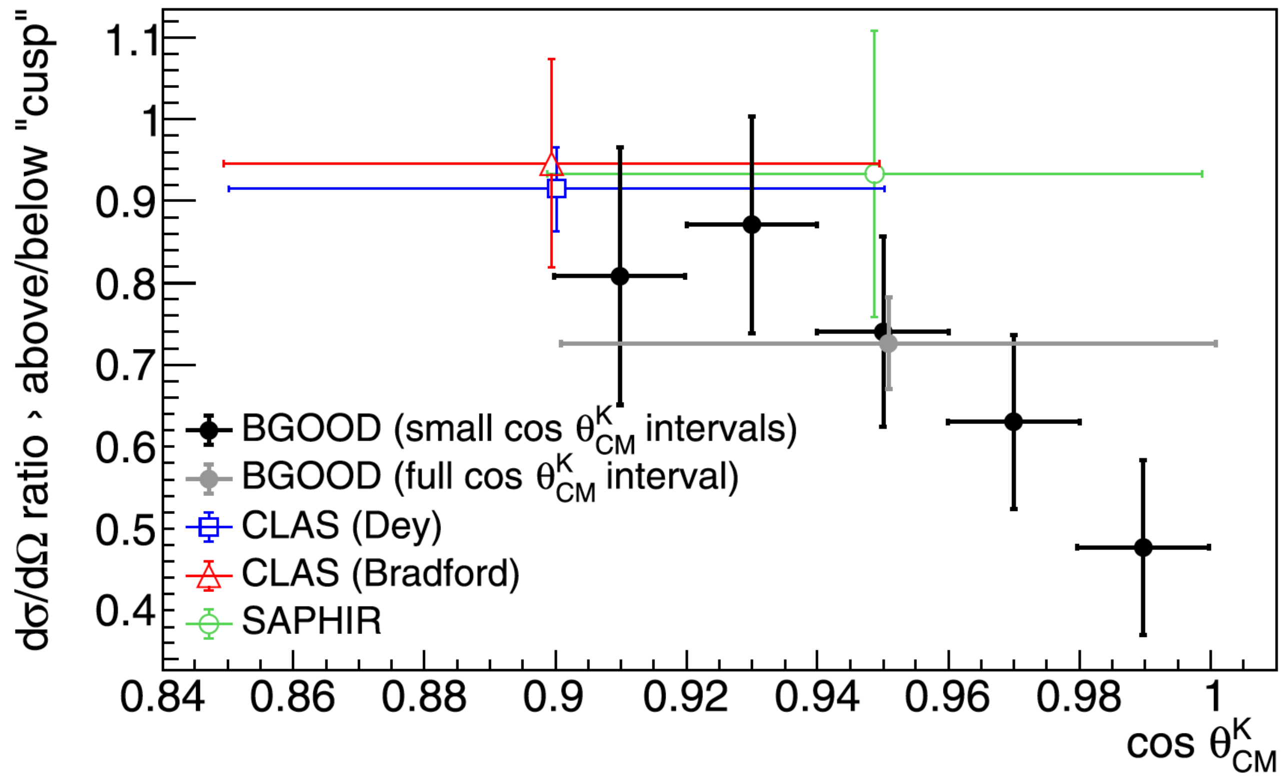


Fig. 7. The ratio of the differential cross section from $W = 1924$ to 1974 MeV compared to $W = 1831$ to 1885 MeV (above and below the cusp-like structure). The data are the average of the differential cross section over these intervals, weighted by the statistical and systematic error. The vertical error bars are the statistical uncertainties, the horizontal error bars are the interval in $\cos\theta^K_{CM}$ for the given dataset.

Status N* spectroscopy

- missing resonances ?
- relevant degrees of freedom ?

state	J^P	PDG status in 2010	PDG status in 2020 (Nγ)
N(1860)	$5/2^+$	*	*
N(1875)	$3/2^-$		**
N(1880)	$1/2^+$		**
N(1895)	$1/2^-$		****
N(1900)	$3/2^+$	****	****
N(1990)	$7/2^+$	**	**
N(2000)	$5/2^+$	**	**
N(2060)	$5/2^-$		***
N(2100)	$1/2^+$	*	**
N(2120)	$3/2^-$		***
N(2190)	$7/2^-$	****	**
N(2220)	$9/2^+$	****	**
N(2250)	$9/2^-$	****	**

- 3 const. quarks unlikely
- quark – diquark ??
- meson d.o.f. ?

e.g.

L.Ya. Glozman and D.O. Riska, Phys. Rep. 268 (1996) 263

C. Garcia-Recio et al., PLB 582 (2004) 49

M. Lutz, E. Kolomeitsev, PLB 585 (2004) 243

- inclusion of CLAS, GRAAL, MAMI, ELSA data
- confirmation of known resonances w/ improved parameters
- observation of few (!) new states