The BGOOD experiment at ELSA

- parallels between multi-quark states in c & s quark sectors ?

Hartmut Schmieden
Physikalisches Institut
Universität Bonn

Outline

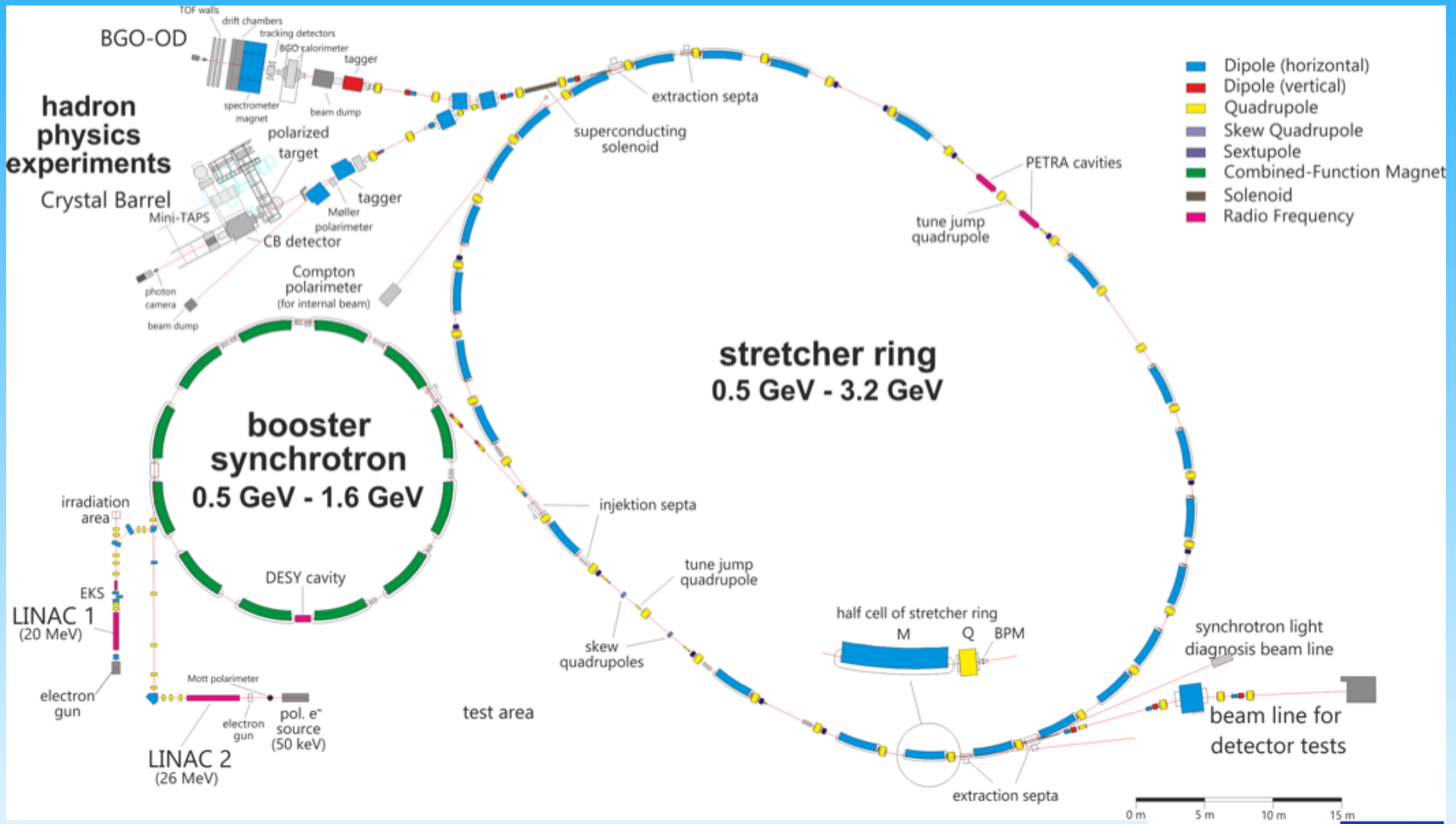
- BGOOD experiment
- why? - physics case
- what? - (preliminary) results
- summary

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

BGOOD experiment

located at ELSA
electron accelerator
Physikalisches Institut
University of Bonn



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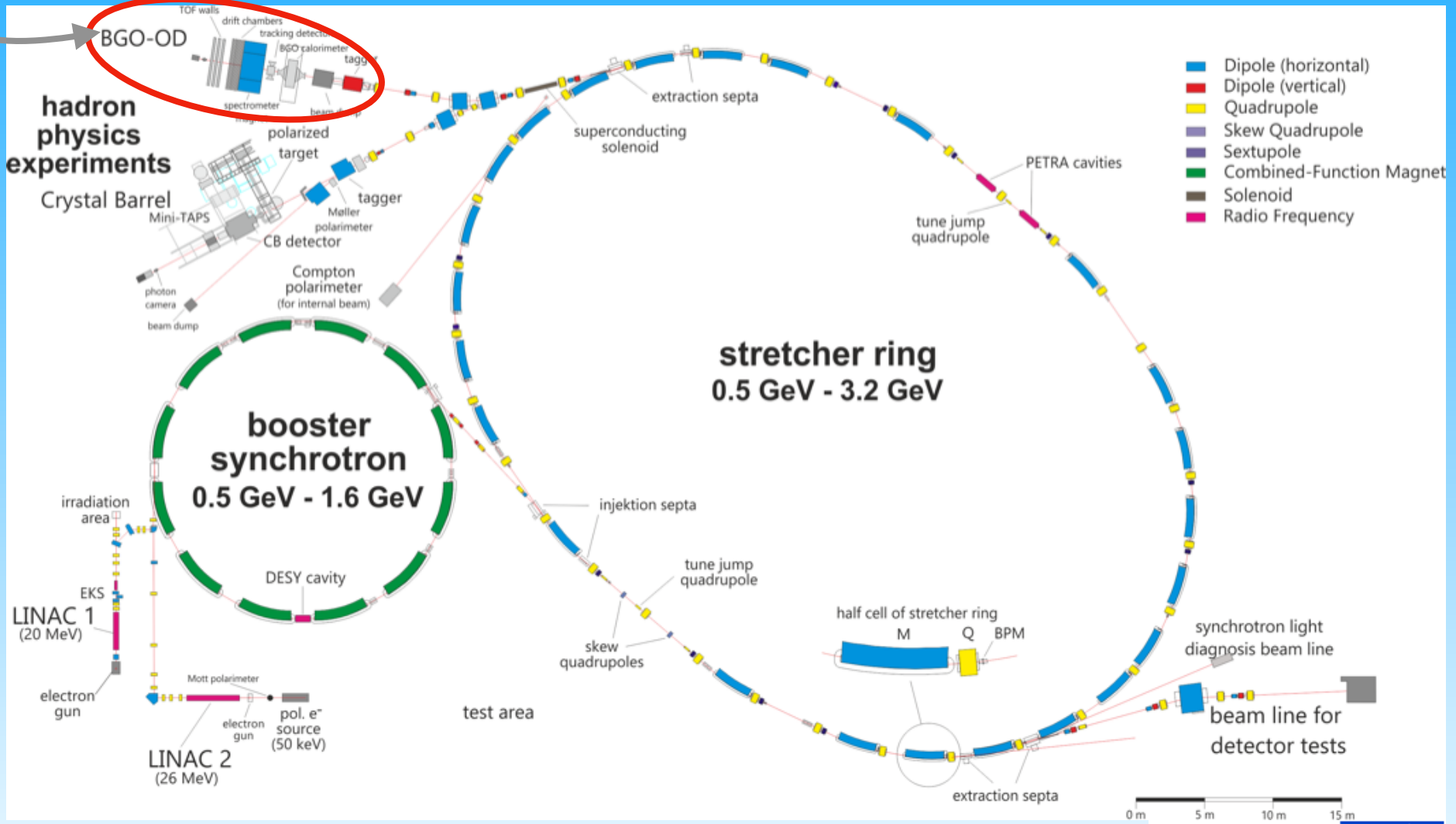

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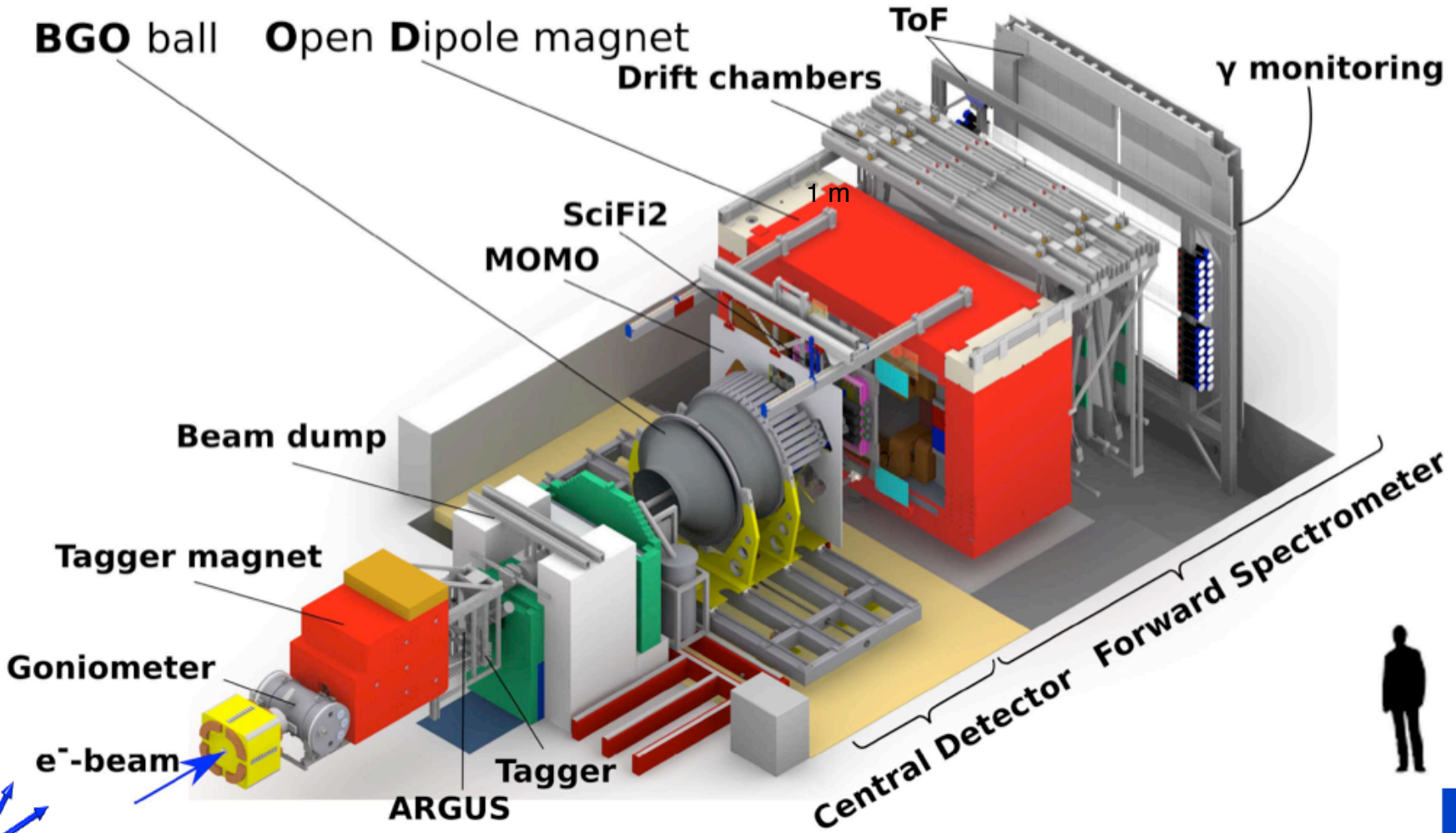
BGOOD experiment

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



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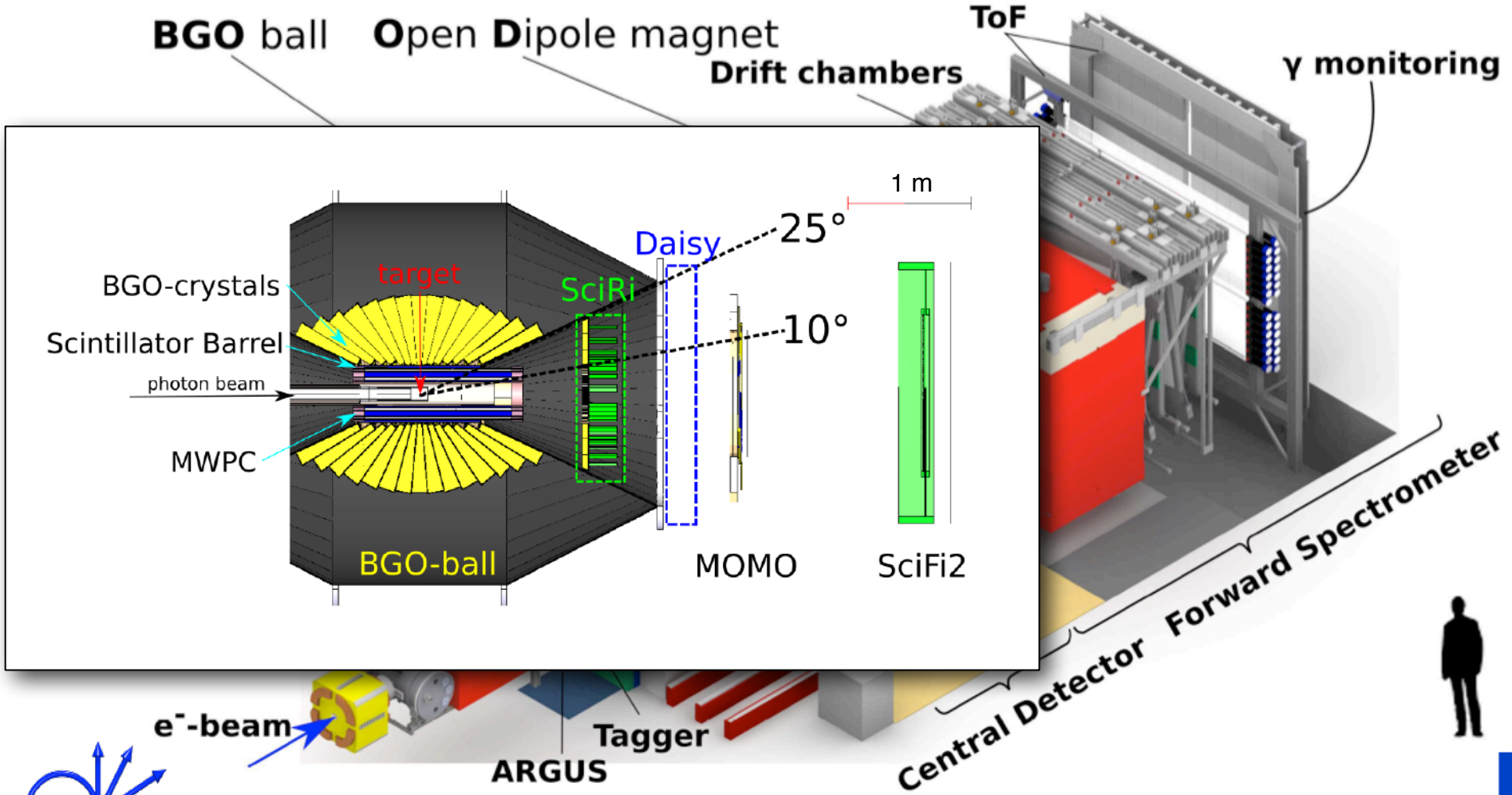

ELSA

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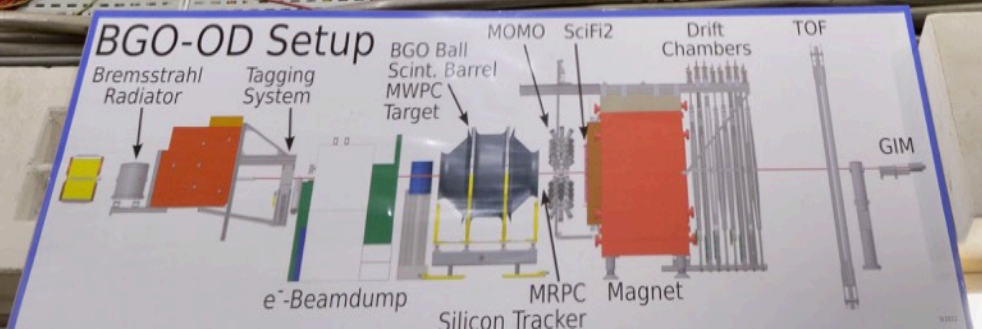
BGO-OD experiment at ELSA

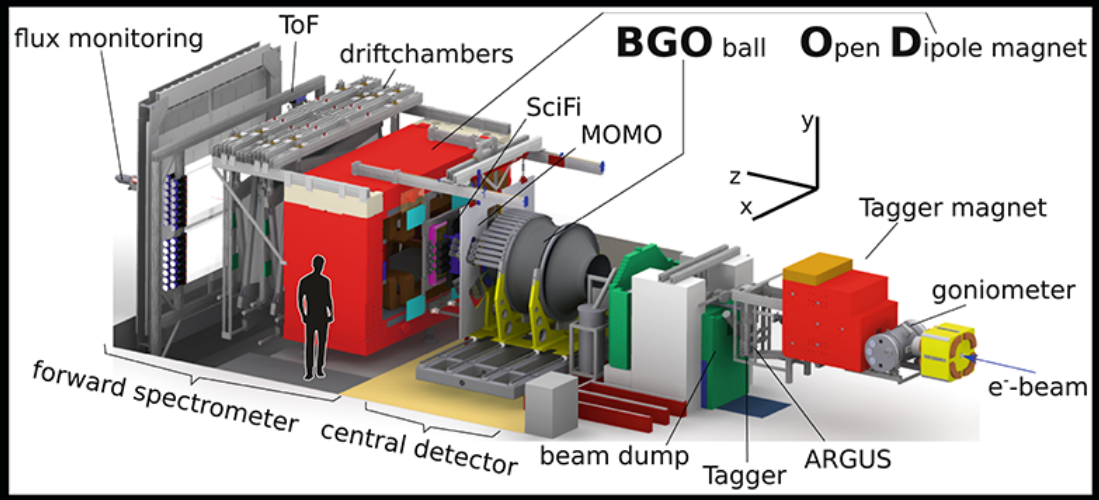


The European Physical Journal volume 56 · number 4 · april · 2020

EPJ A

Recognized by European Physical Society

Hadrons and Nuclei



Overview of the BGOOD (BGOball Open Diplole magnet) experiment at the Elsa Facility dedicated to study meson photo-production

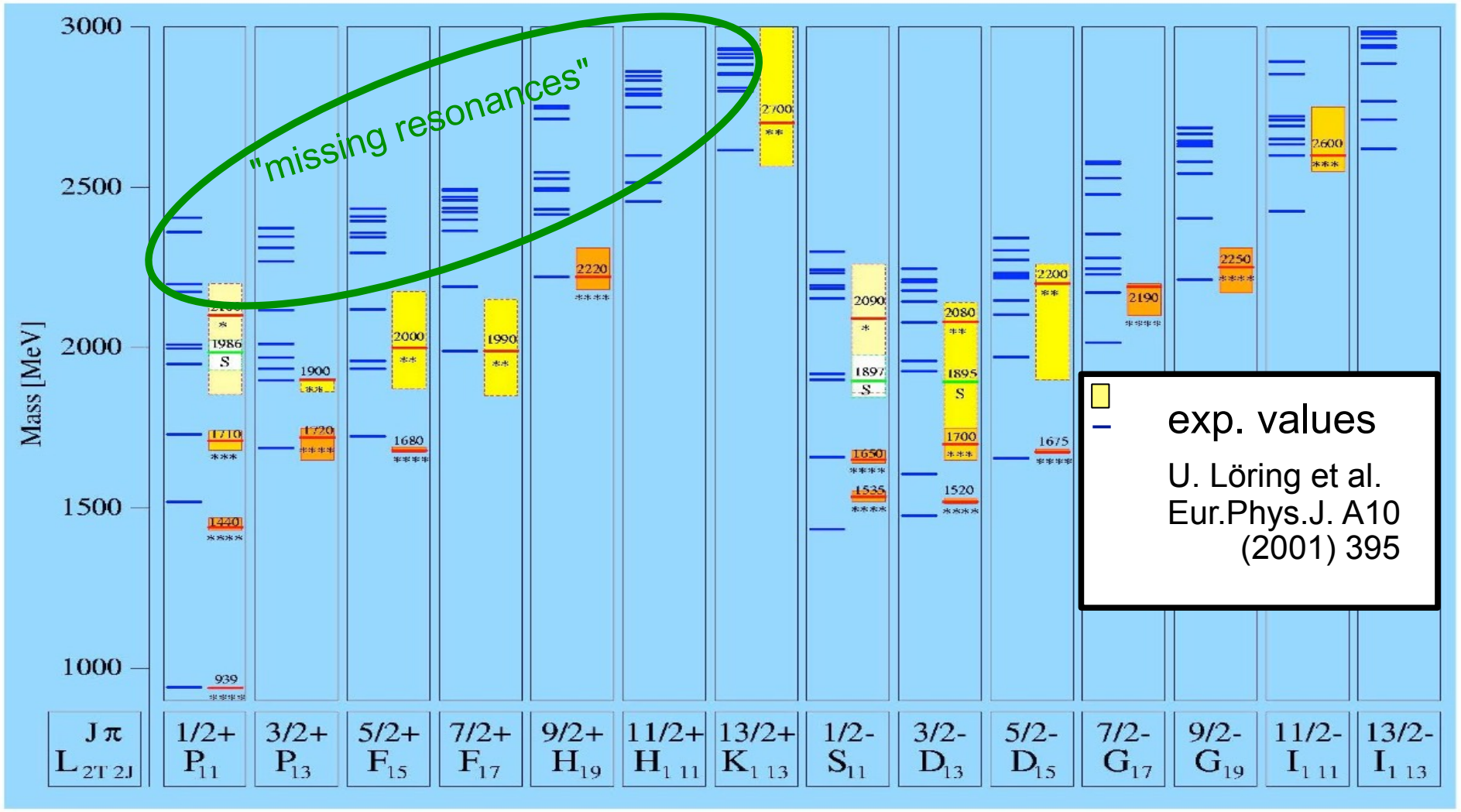
From: T. C. Jude and P. Levi Sandri et al. on "The BGOOD experimental setup at ELSA"

Società Italiana di Fisica

Springer

why? - physics case

Excited states: quark model



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.

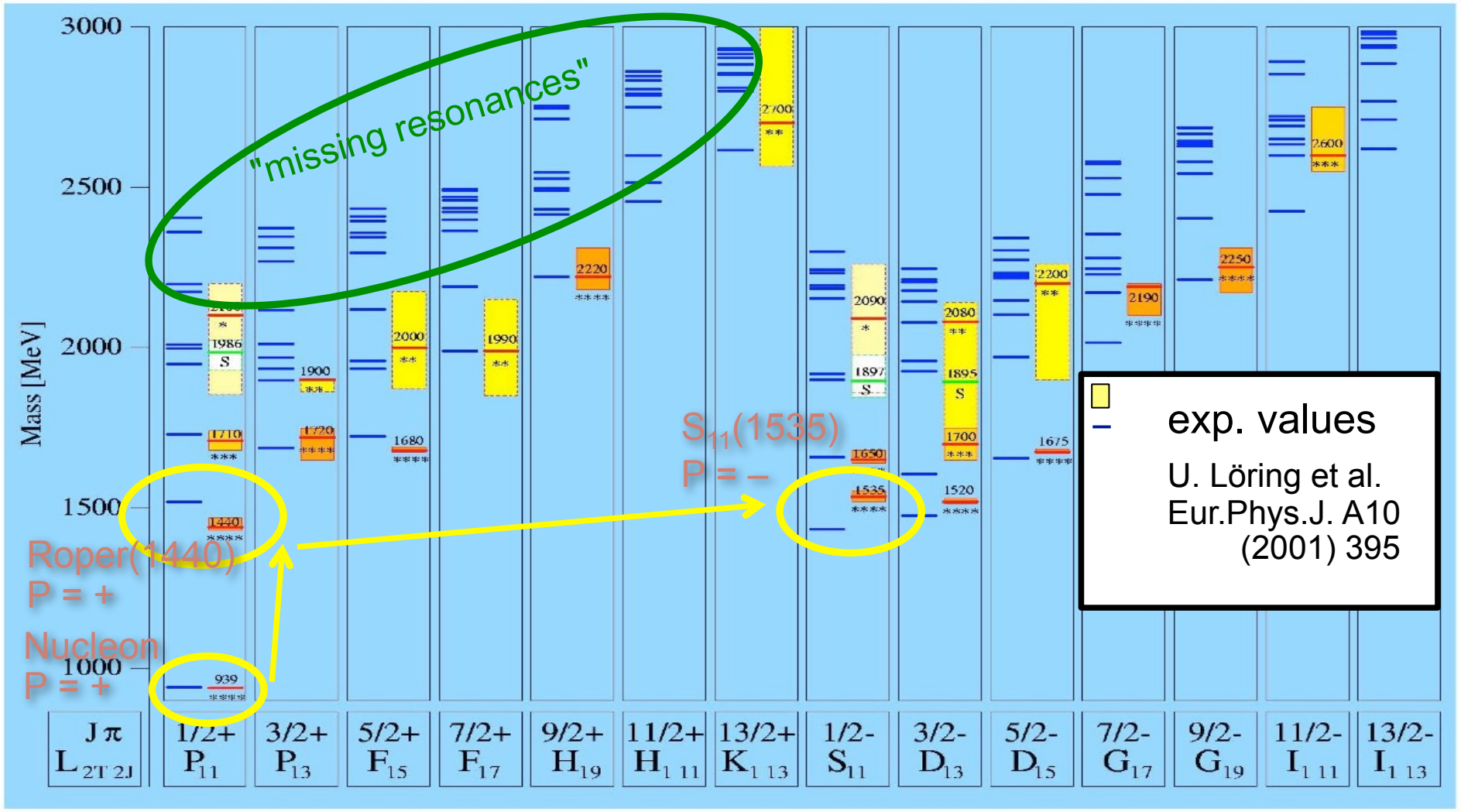
L.Ya. Glozman and D.O. Riska,
Phys. Rep. 268 (1996) 263

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

Excited states: quark model



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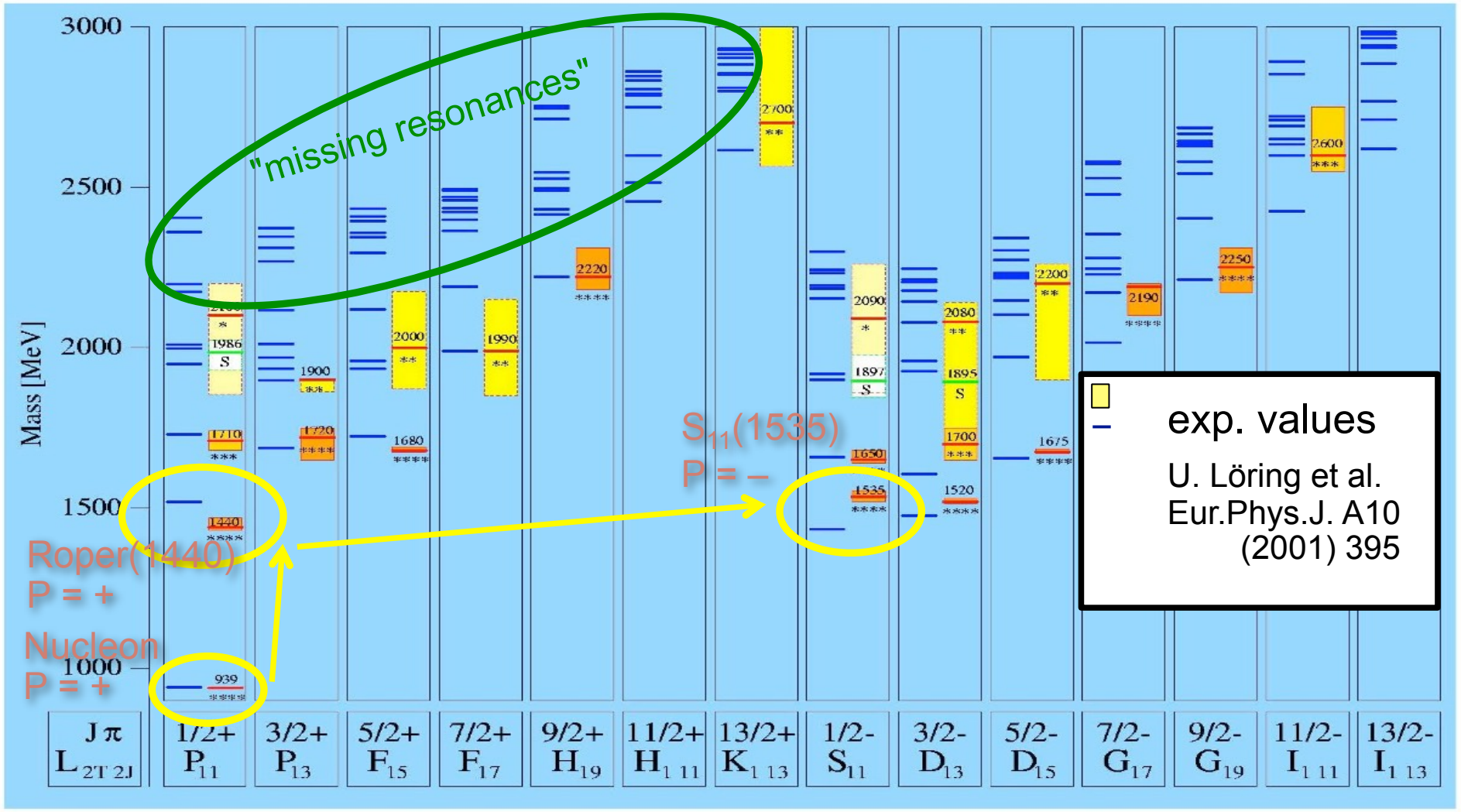
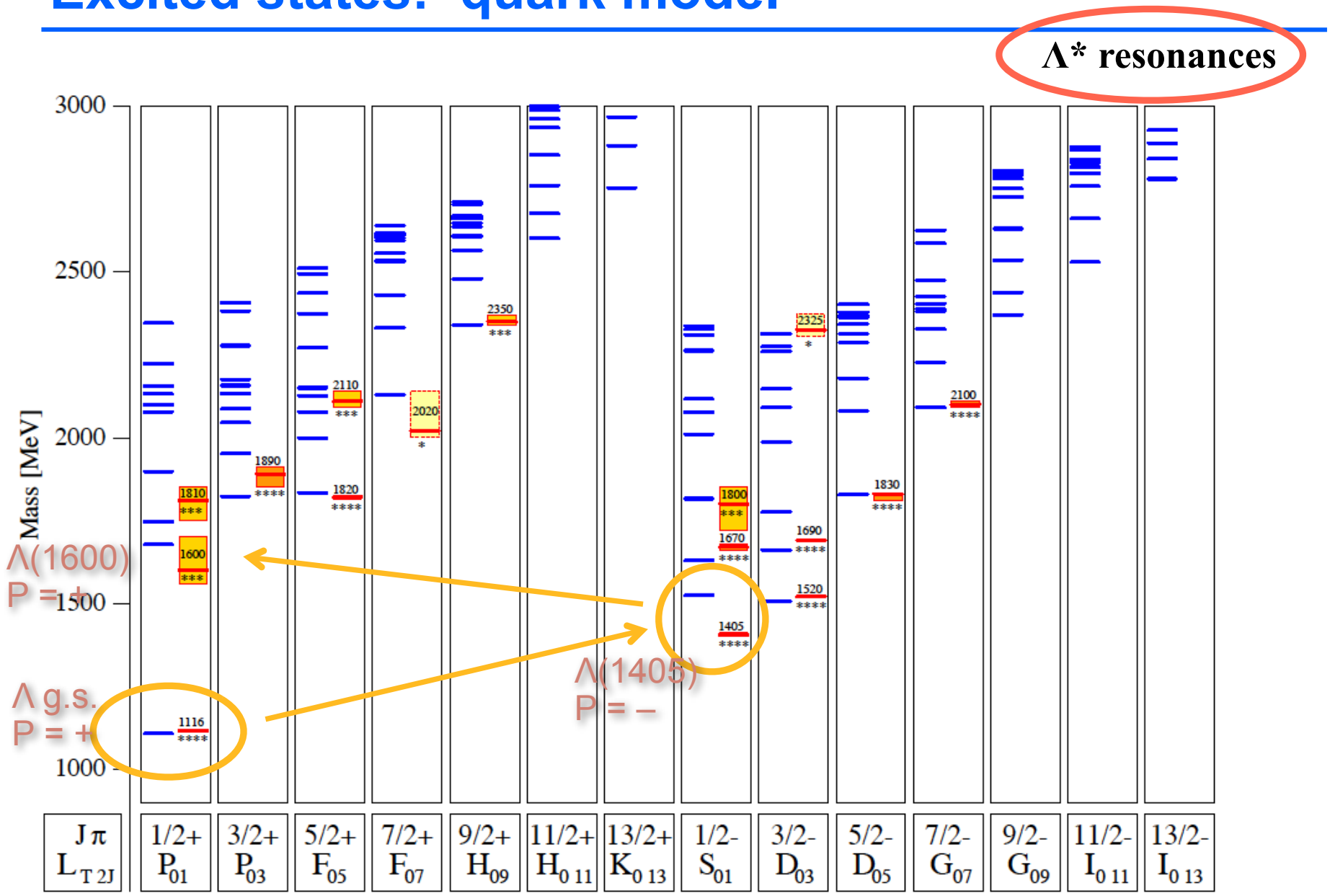


- parity pattern lowest states + → + → – !?!
- effective degrees of freedom ??

Excited states: quark model



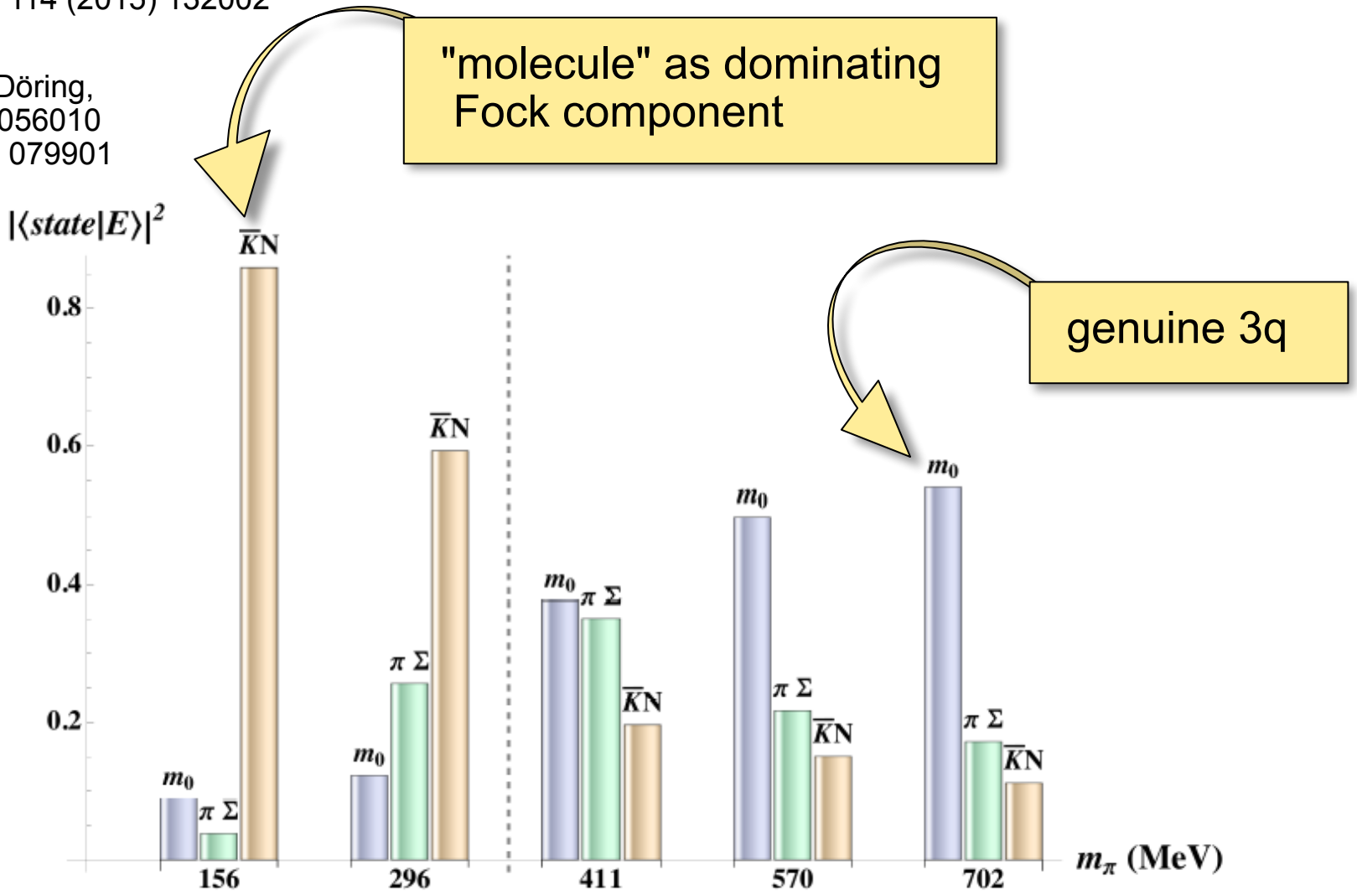
- parity pattern OK
- masses reversed ??

H. Schmieden

Λ* Lattice QCD: Λ(1405)

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



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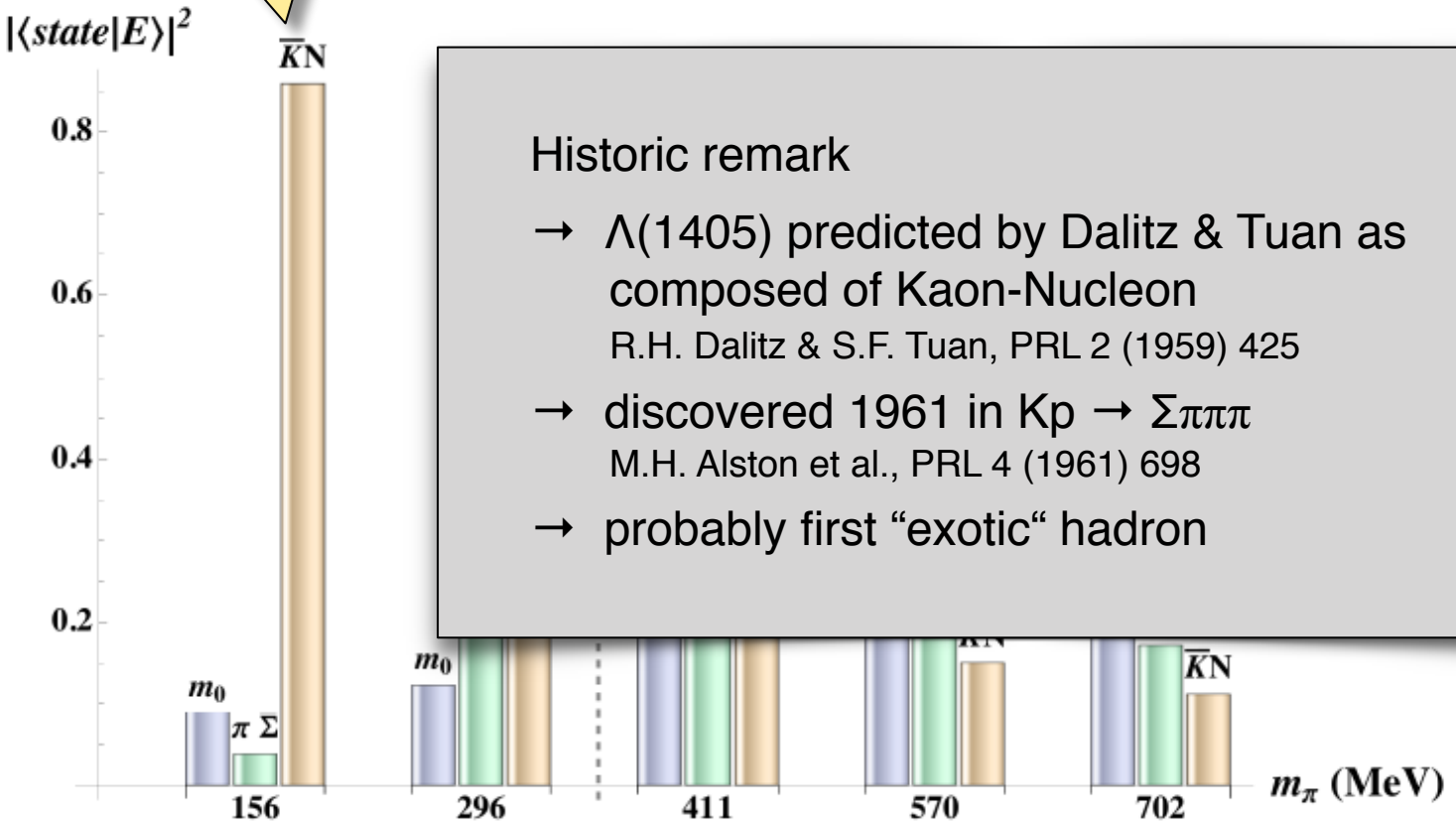
"molecule" as dominating Fock component



Historic remark

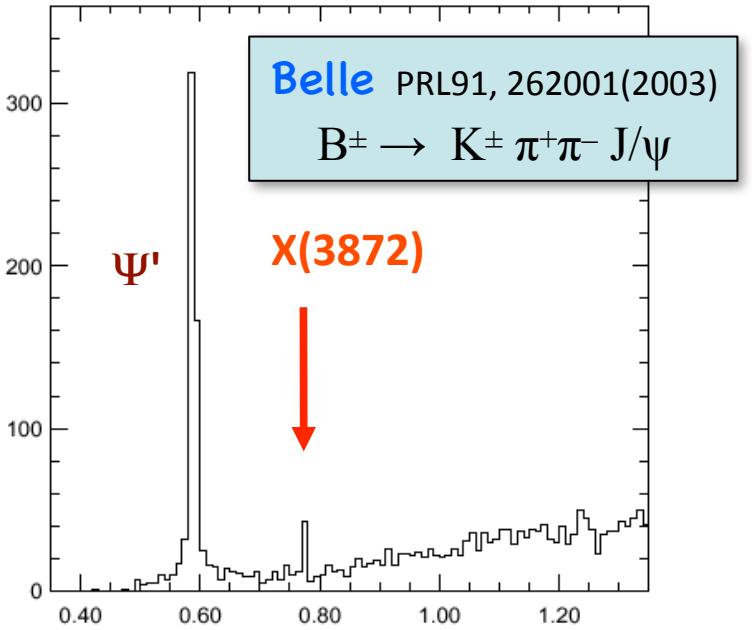
→ Λ(1405) predicted by Dalitz & Tuan as composed of Kaon-Nucleon
R.H. Dalitz & S.F. Tuan, PRL 2 (1959) 425

→ discovered 1961 in Kp → Σππ
M.H. Alston et al., PRL 4 (1961) 698

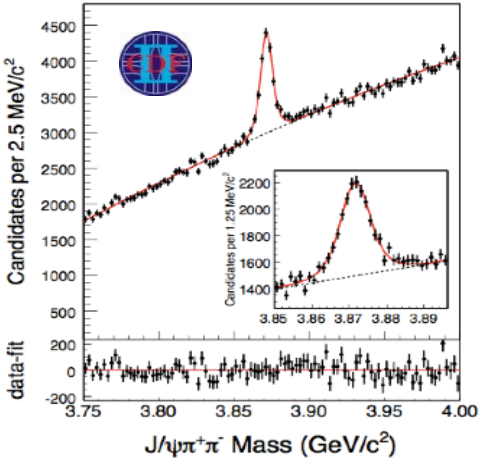
→ probably first "exotic" hadron

context c-quark sector

X(3872)

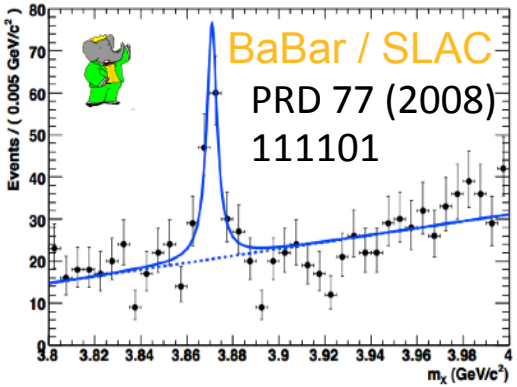


$M(\pi^{+}\pi^{-}l^{+}l^{-}) - M(l^{+}l^{-})$



CDF / Tevatron

PRL 103 (2009) 152001



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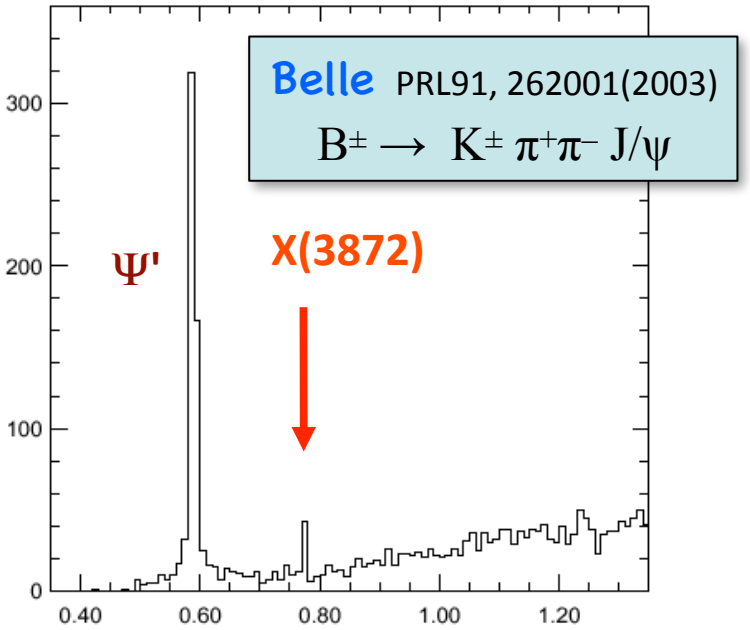

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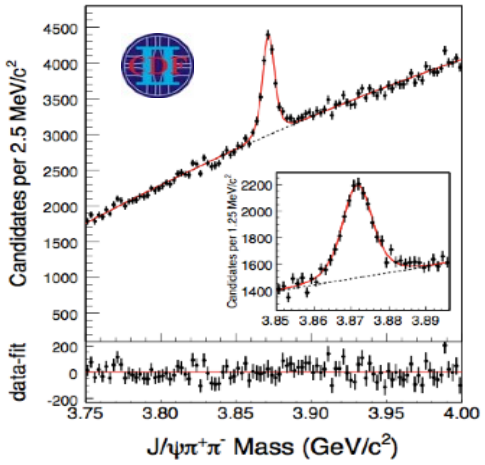

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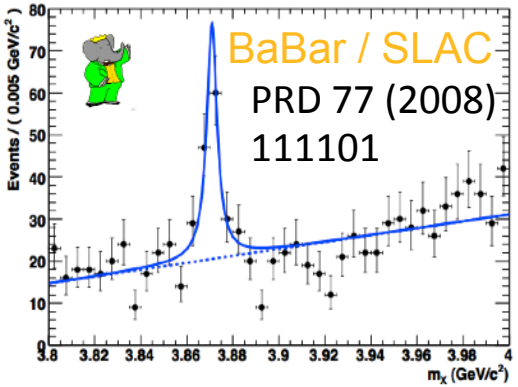
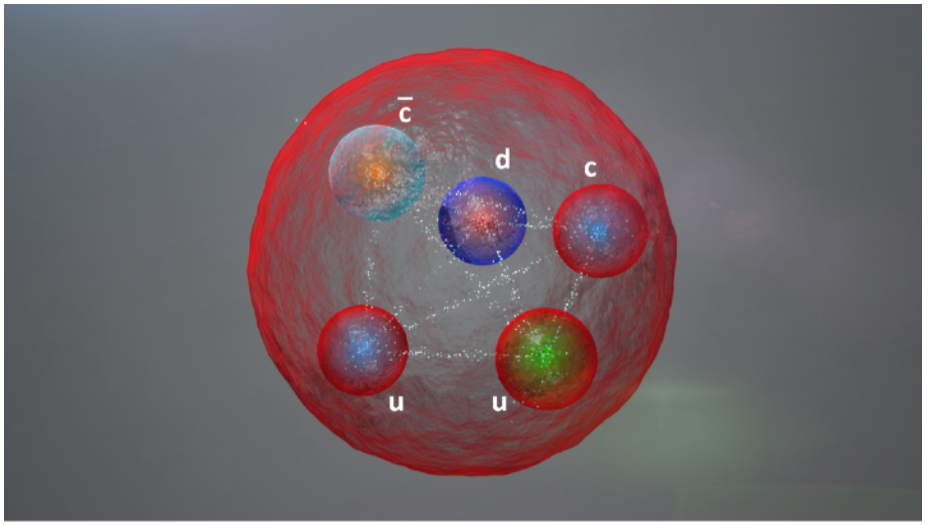


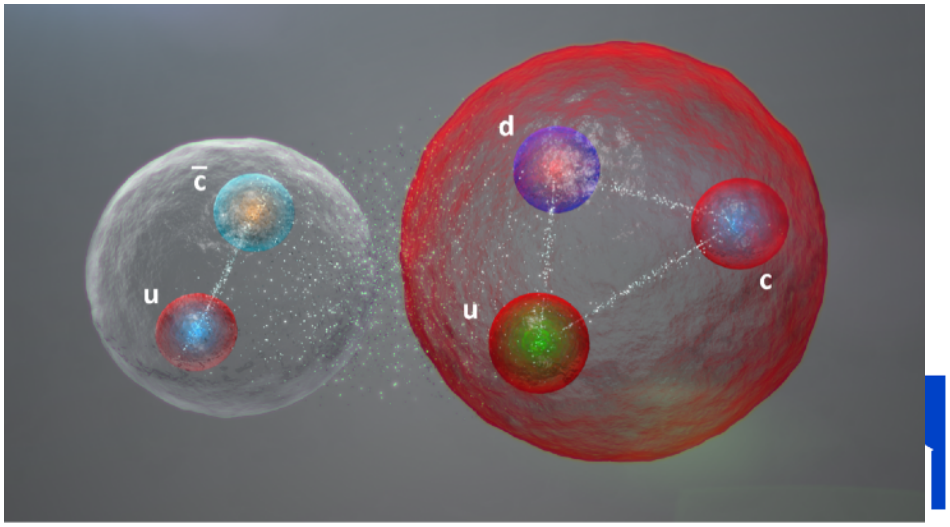
PRD 77 (2008) 111101

PARTICLE PHYSICS

Forsaken pentaquark particle spotted at CERN

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





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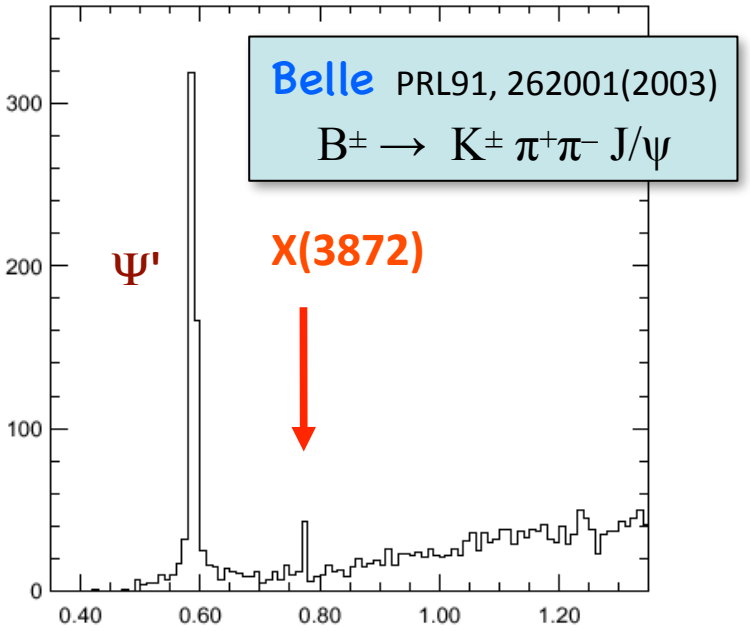
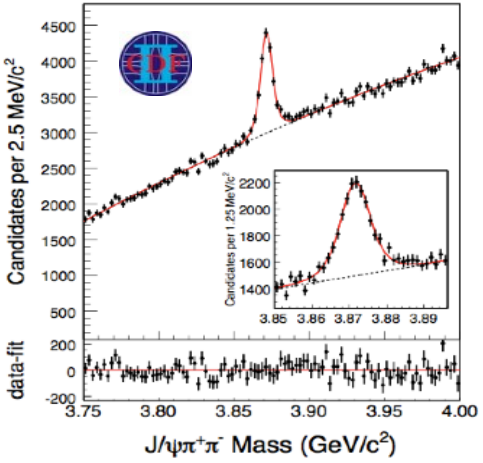


M(π+π-l+l-) - M(l+l-)



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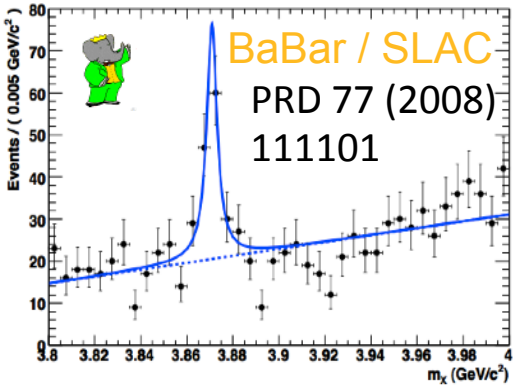
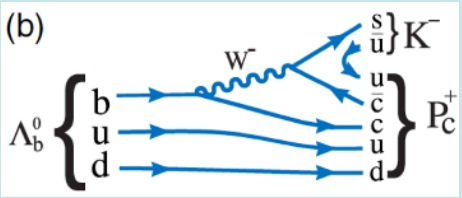


$P_c^+(4380, 4450)$

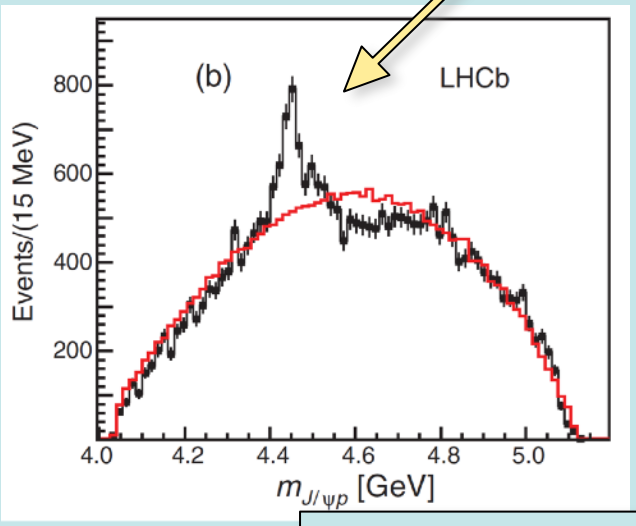
PARTICLE PHYSICS

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

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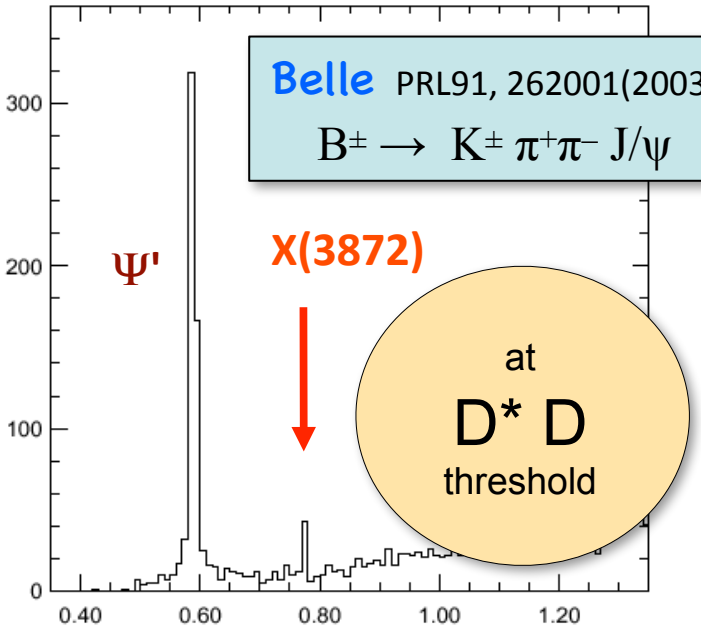

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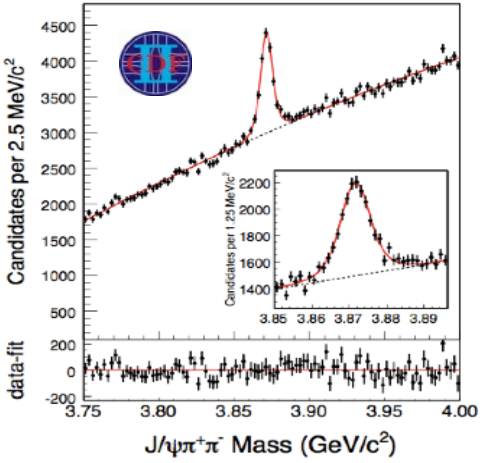

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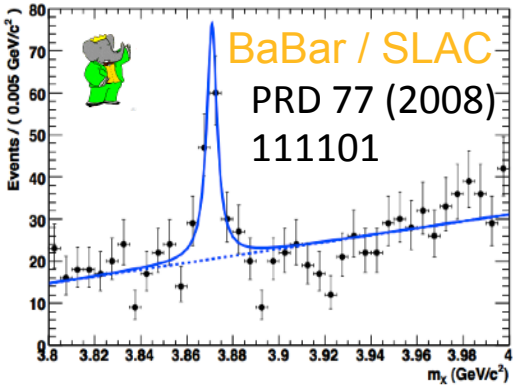

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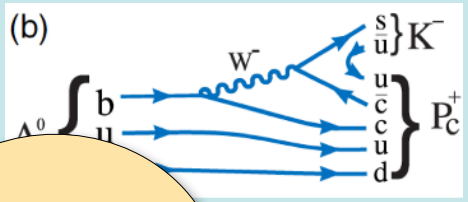
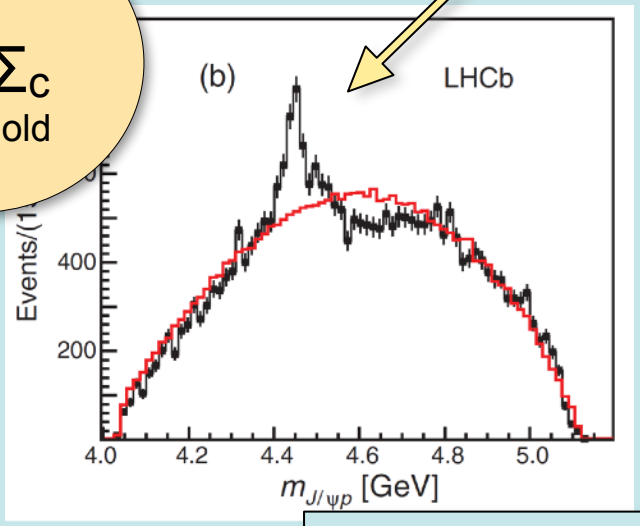


p J/ψ

at
D* Σ_c
threshold



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compact size vs. “molecule“

„Hadronic molecules"
Guo, Hanhart, Meißner, Wang, Zhao, Zou
Rev. Mod. Phys. 90 (2018) 1, 015004
arXiv:1705.00141

salient features “molecule“

- Weinberg’s compositeness criterion: $\lambda = 0$ (pure molecule) …. 1 (compact)

$$a = -2\frac{1-\lambda^2}{2-\lambda^2}\left(\frac{1}{\gamma}\right) + \mathcal{O}\left(\frac{1}{\beta}\right)$$

scattering length ↔ interaction probability, i.e. x-sec

$$r = -\frac{\lambda^2}{1-\lambda^2}\left(\frac{1}{\gamma}\right) + \mathcal{O}\left(\frac{1}{\beta}\right)$$

effective range ↔ distance between constituents

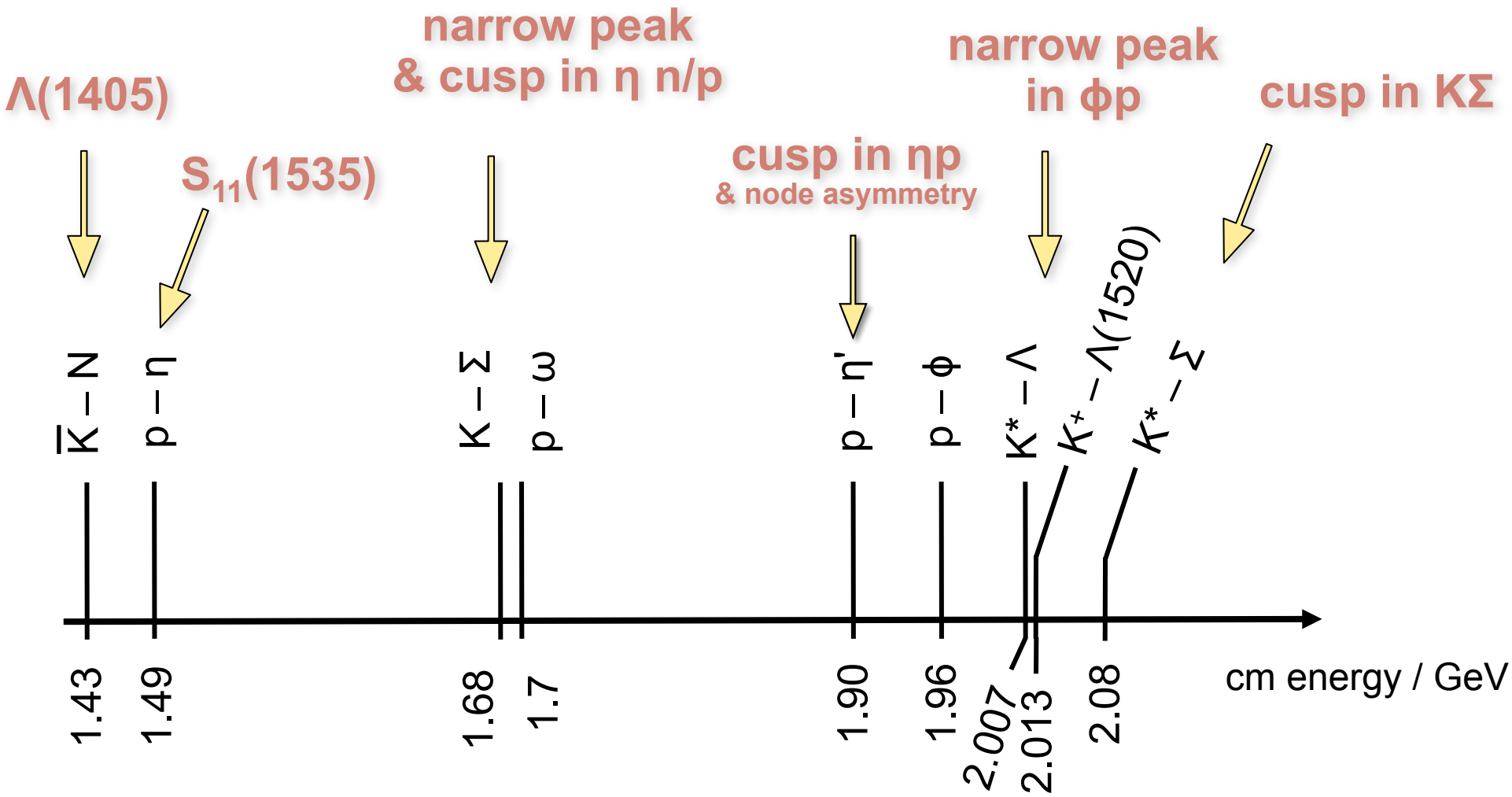
- γ ↔ momentum scale constituents:
- β ↔ momentum scale through forces, e.g. deuteron $1/\beta \sim 1/M_\pi \sim 1.4$ fm
- molecule natural near thresholds

$$\gamma = \sqrt{2\mu E_B} \rightarrow \frac{1}{\gamma} \sim R$$

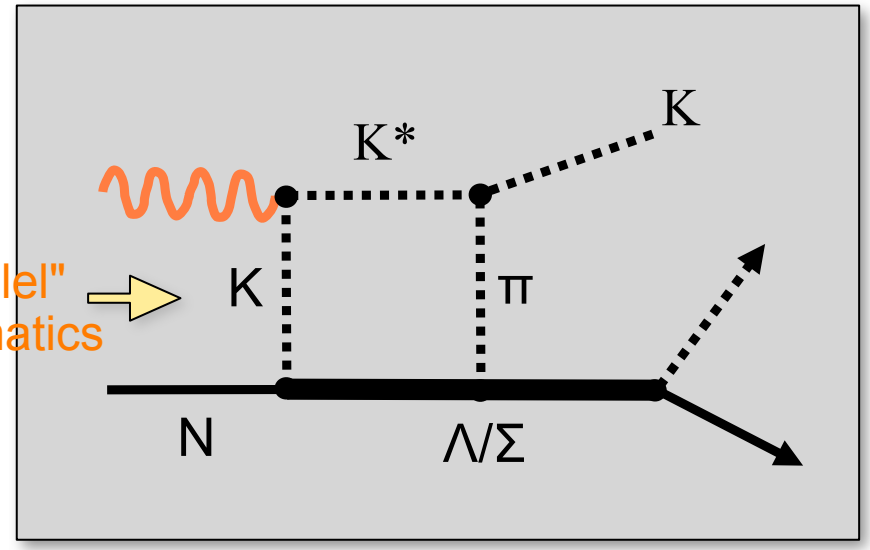
reduced mass; binding energy; composite size

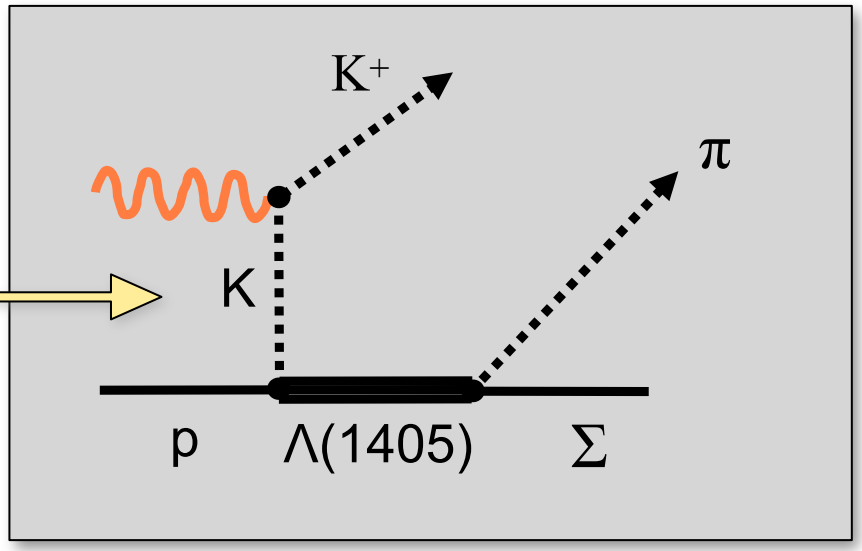
uds sector ?

uds sector – threshold dynamics



t-channel Kinematics





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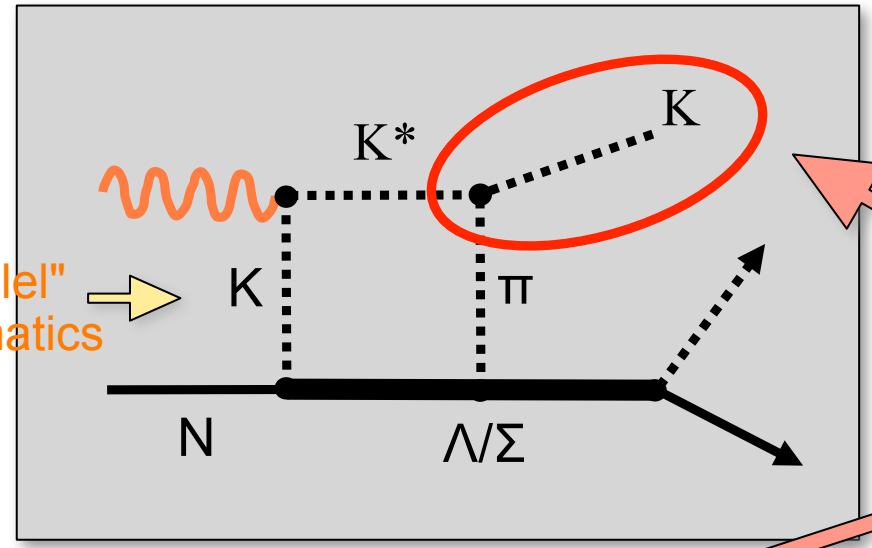
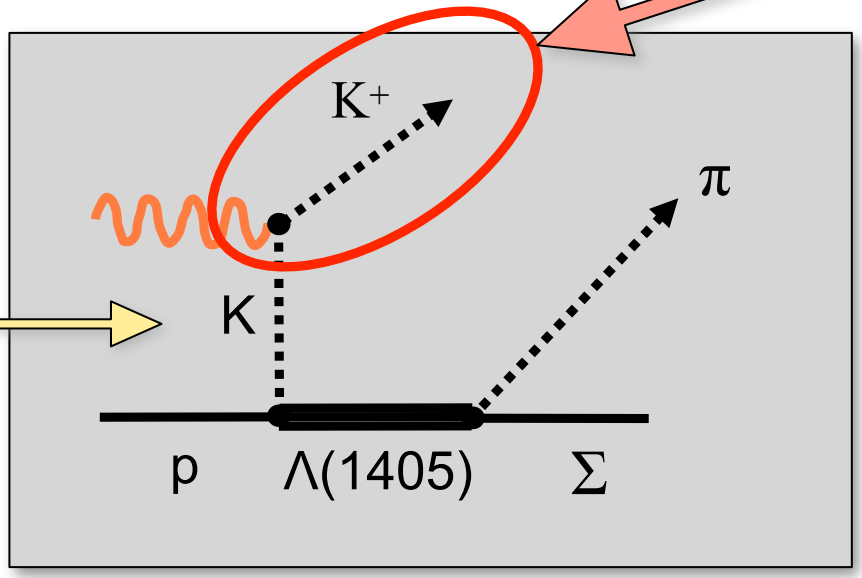


"parallel" kinematics

- forward (charged) particle
- high momentum



low t

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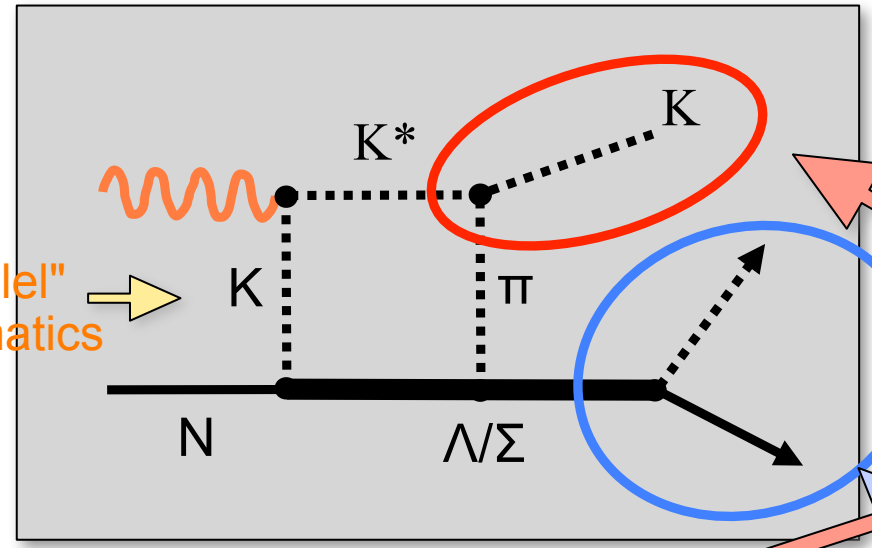

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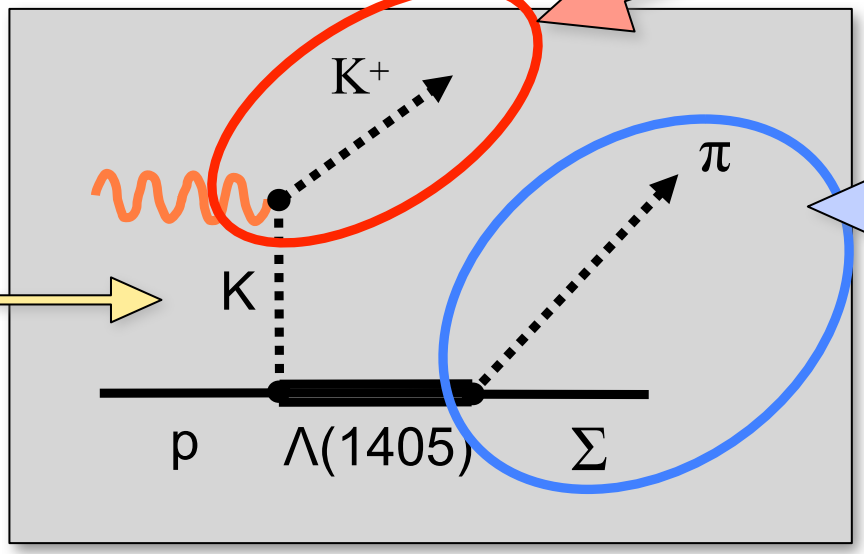
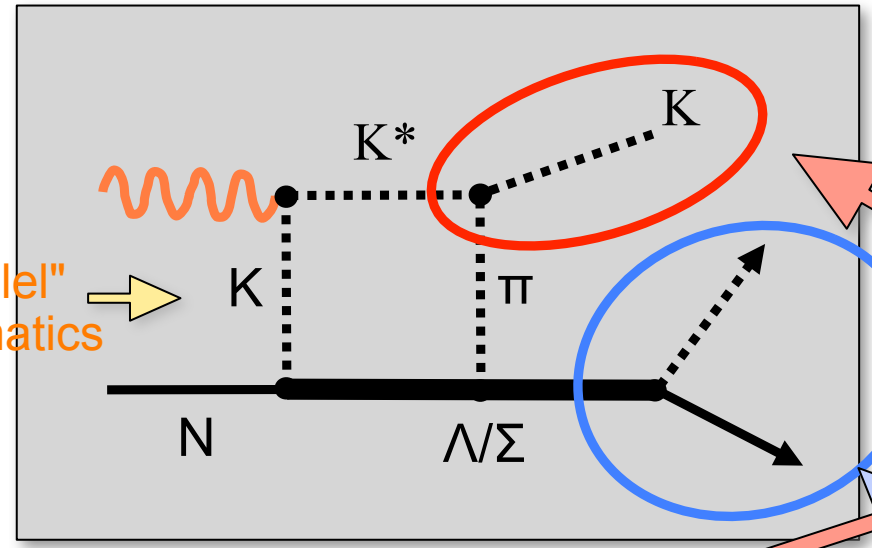


low t

- forward (charged) particle
- high momentum

- 4π decay
- charged & neutral

t-channel Kinematics



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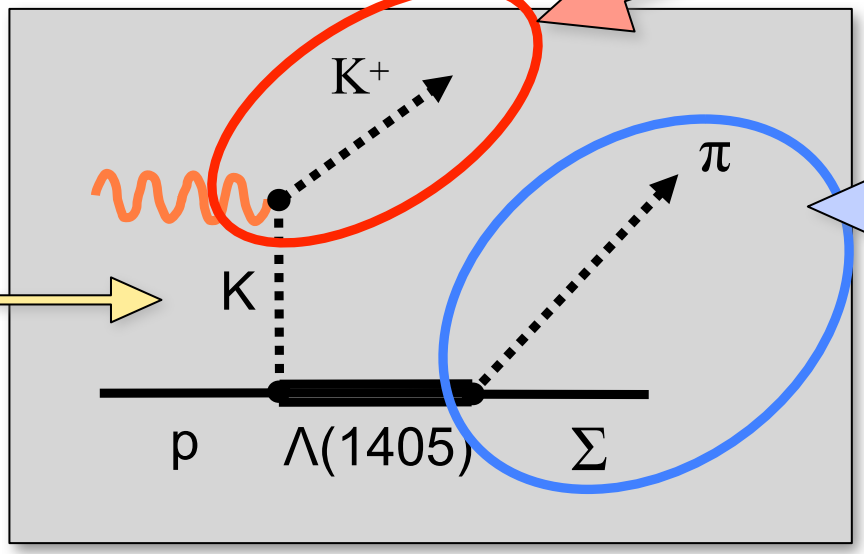

low t

BGO-OD !

- forward (charged) particle
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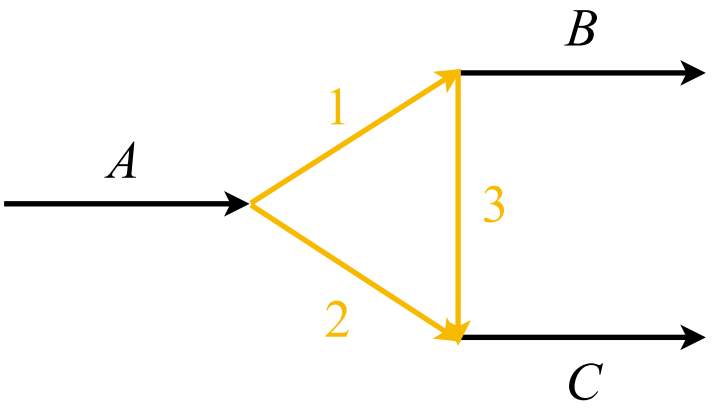
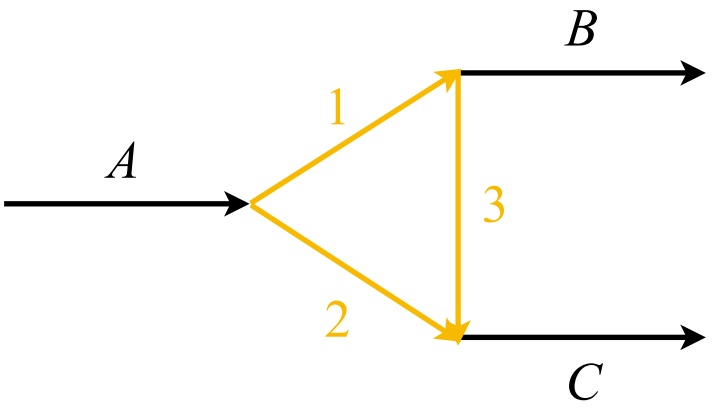
triangle singularities



Coleman-Norton theorem:
1, 2, 3 must be nearly on mass shell

can mimic resonance

triangle singularities



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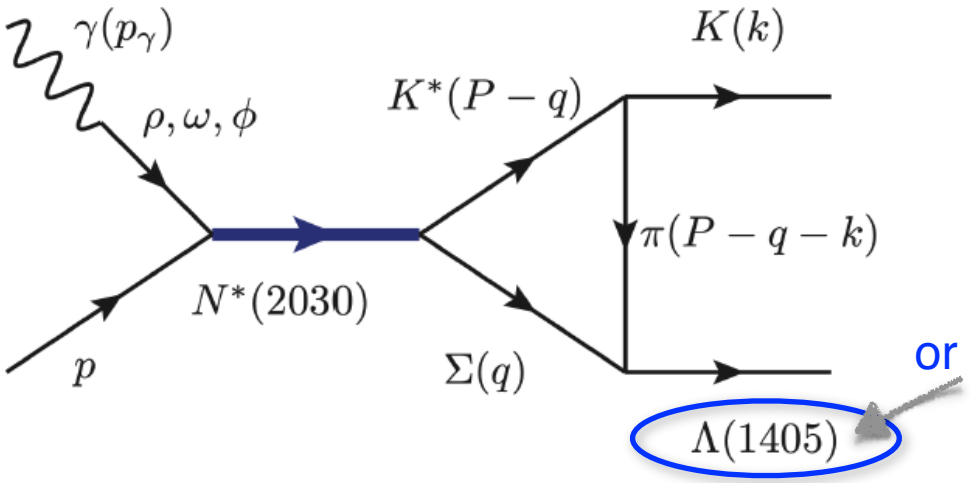


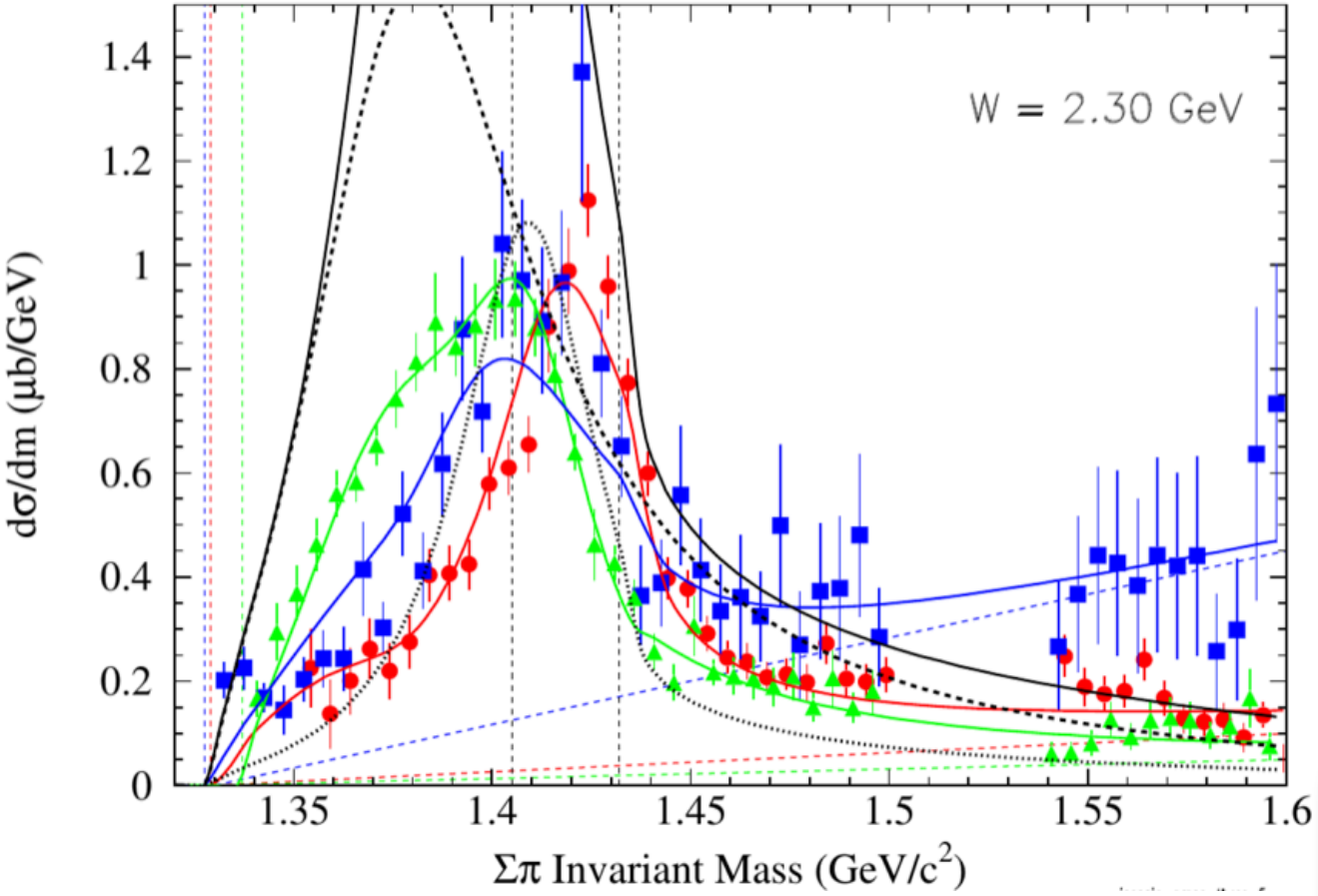
or drive (dynamically generated) resonance

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

$K^+ \Lambda(1405)$ status

Λ(1405) photoproduction – line shape

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



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

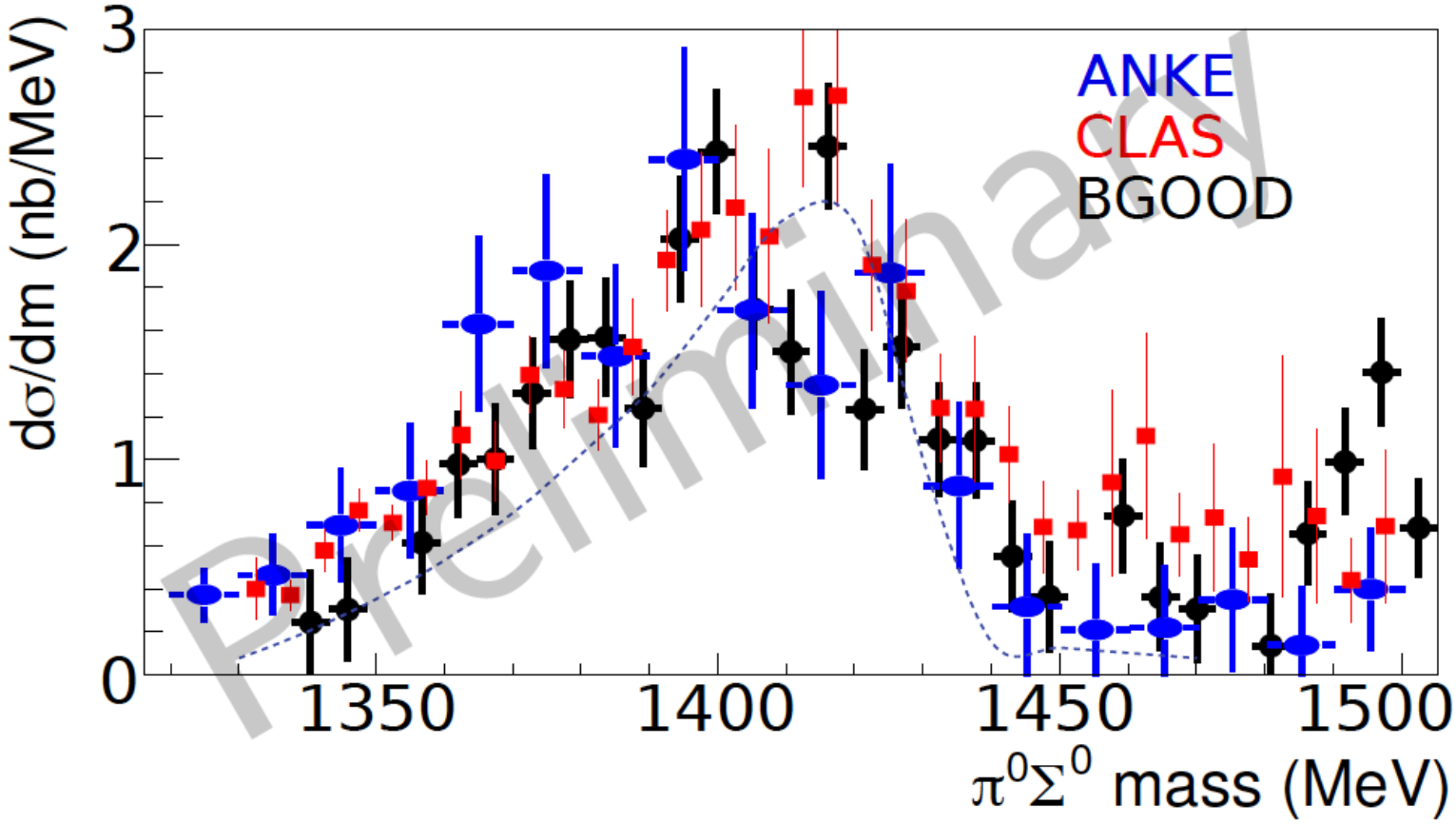
2-poles structure should be visible in pure I=0 channel $\Sigma^0\pi^0$

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

$K^+ \Lambda(1405)$

Λ(1405) photoproduction – line shape

work of G. Scheluchin
(paper in prepapartion)
see also:
arXiv:2007.08898
(NSTAR2019)

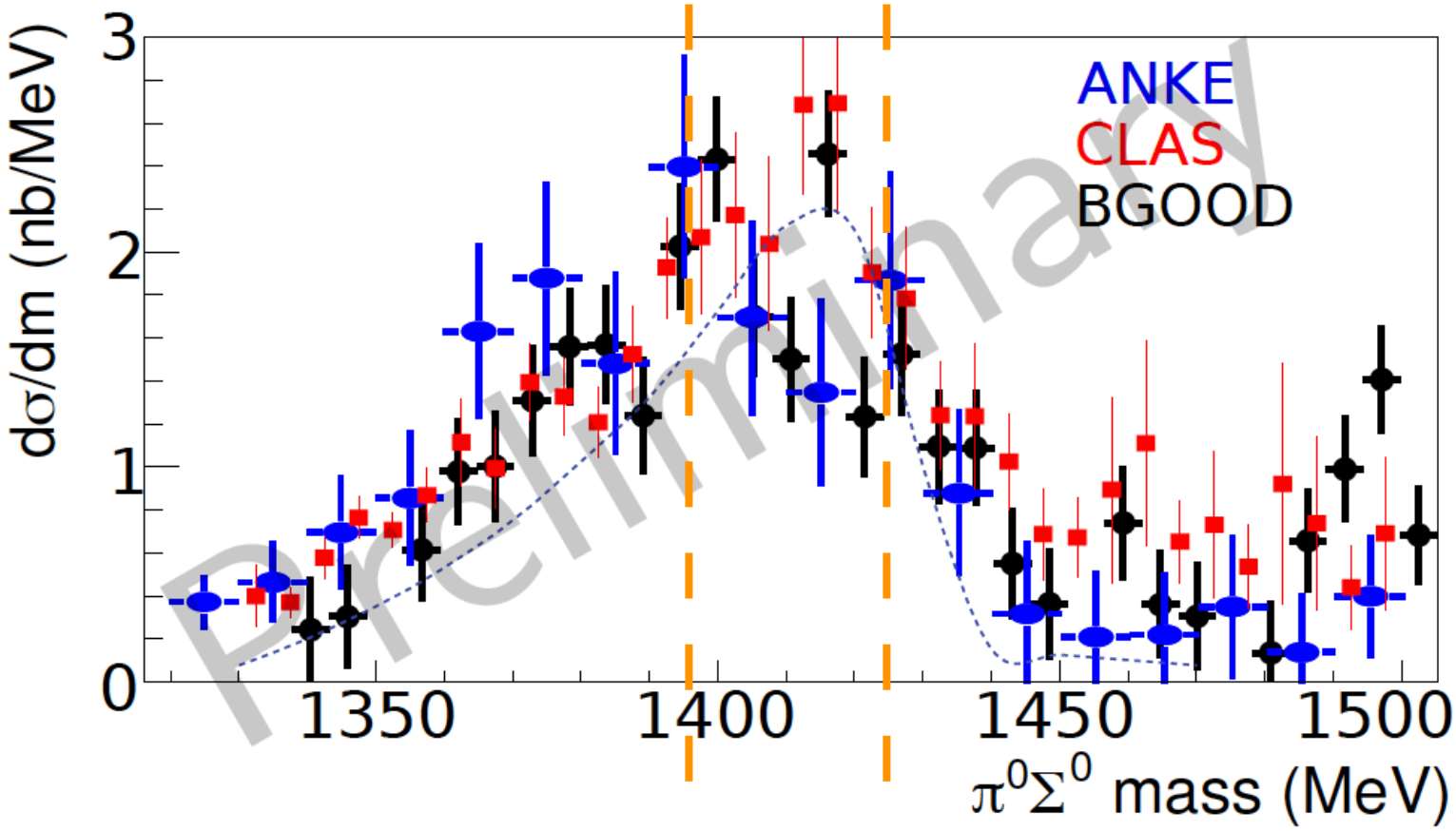


$K^+ \Lambda(1405)$

Λ(1405) photoproduction – line shape

work of G. Scheluchin
(paper in prepapartion)
see also:
arXiv:2007.08898
(NSTAR2019)

double peak strukture
@ 1395 / 1425 MeV ??



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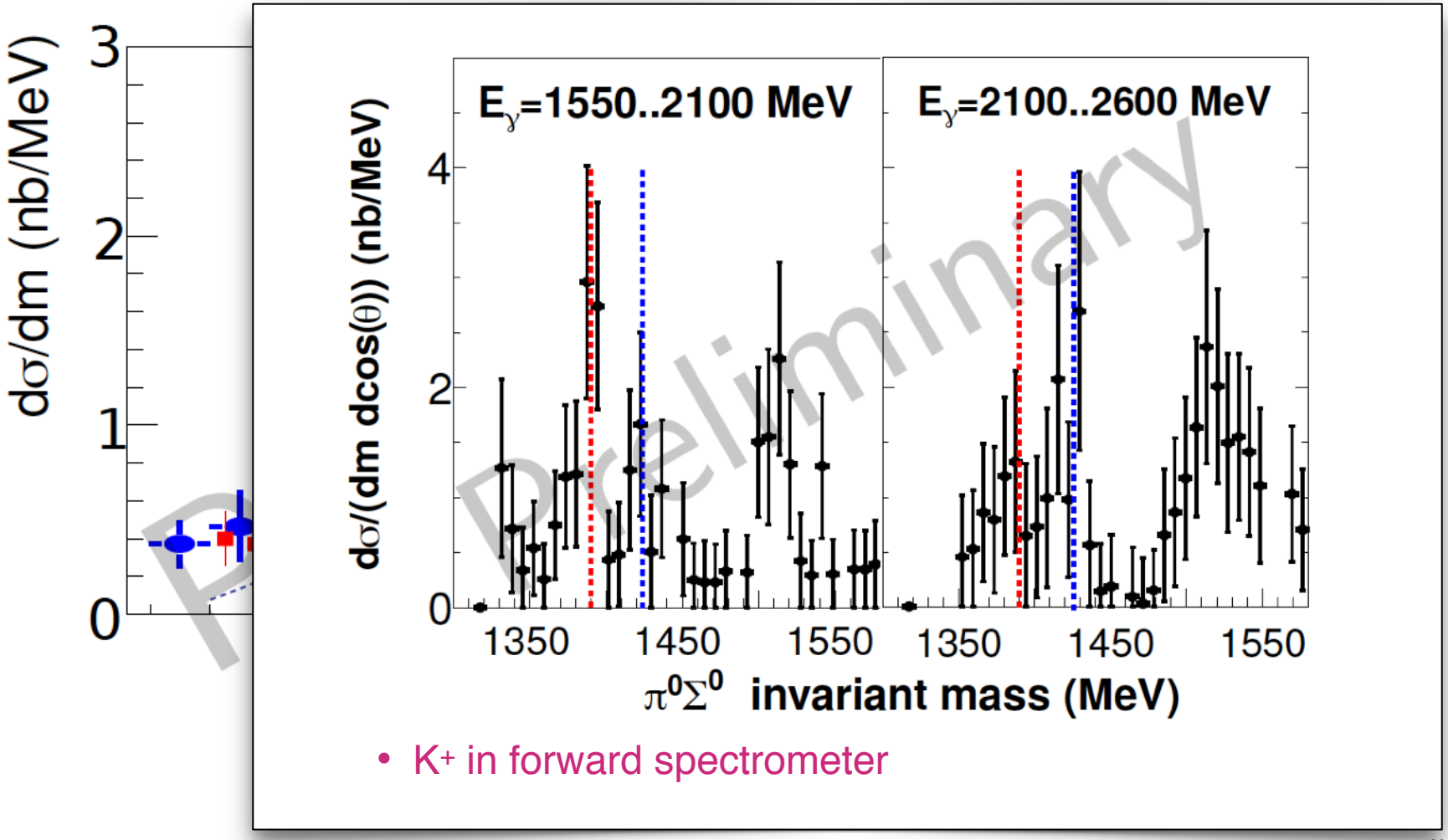

- K^+ in forward spectrometer

$K^+ \Lambda(1405)$

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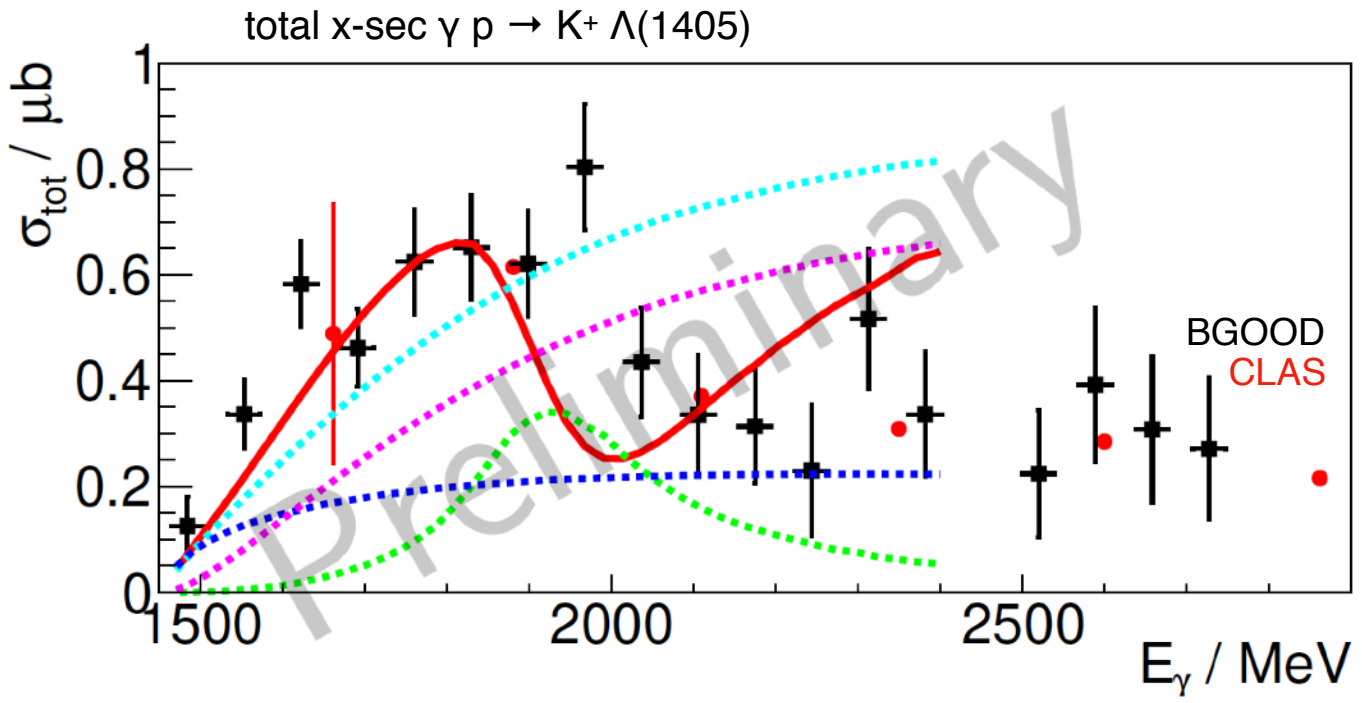

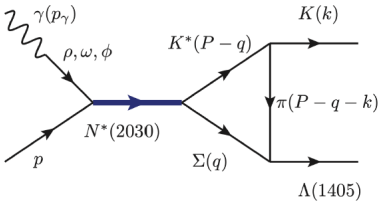

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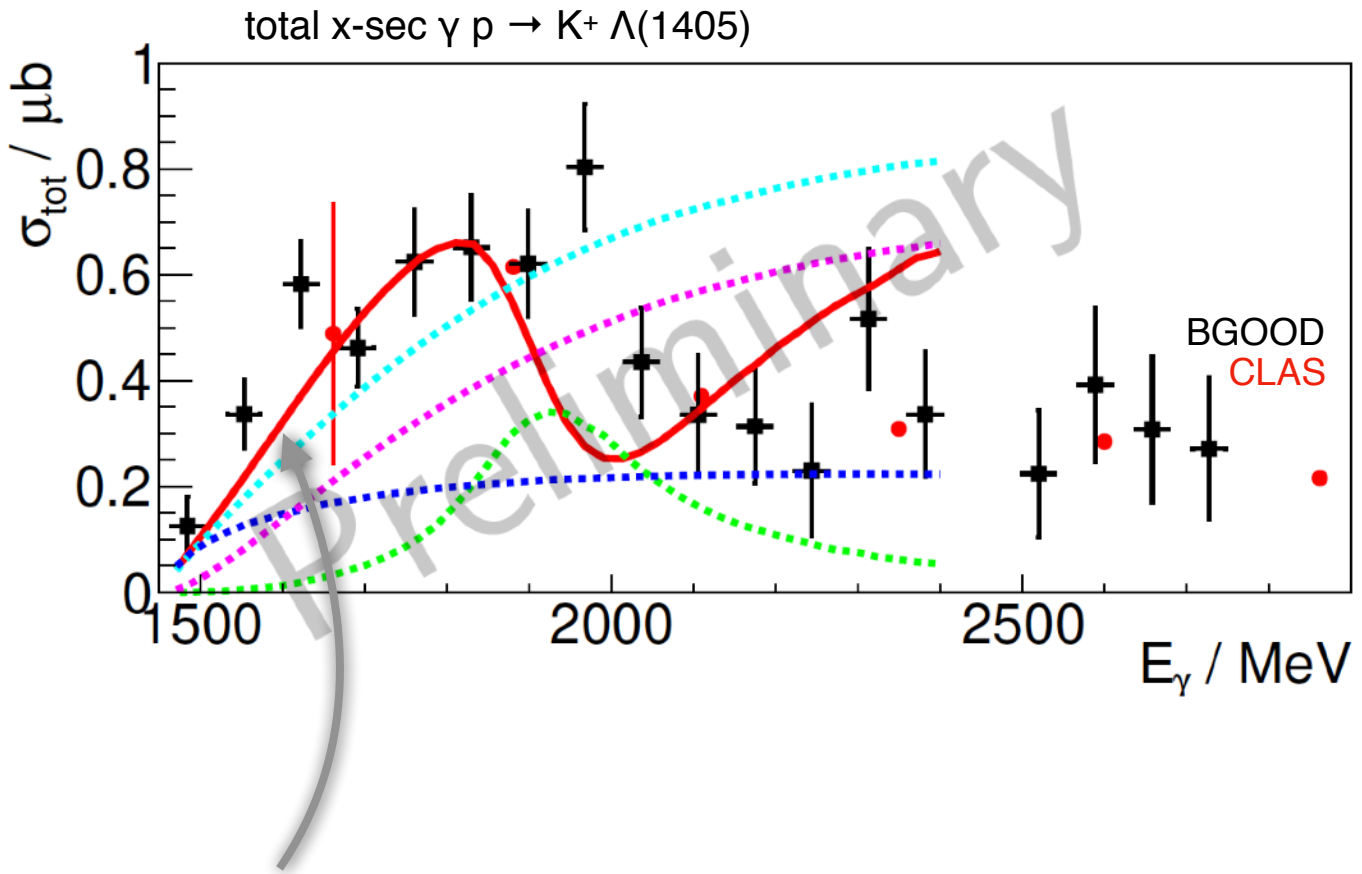

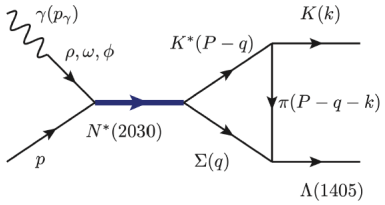

→ triangle meachanism significant

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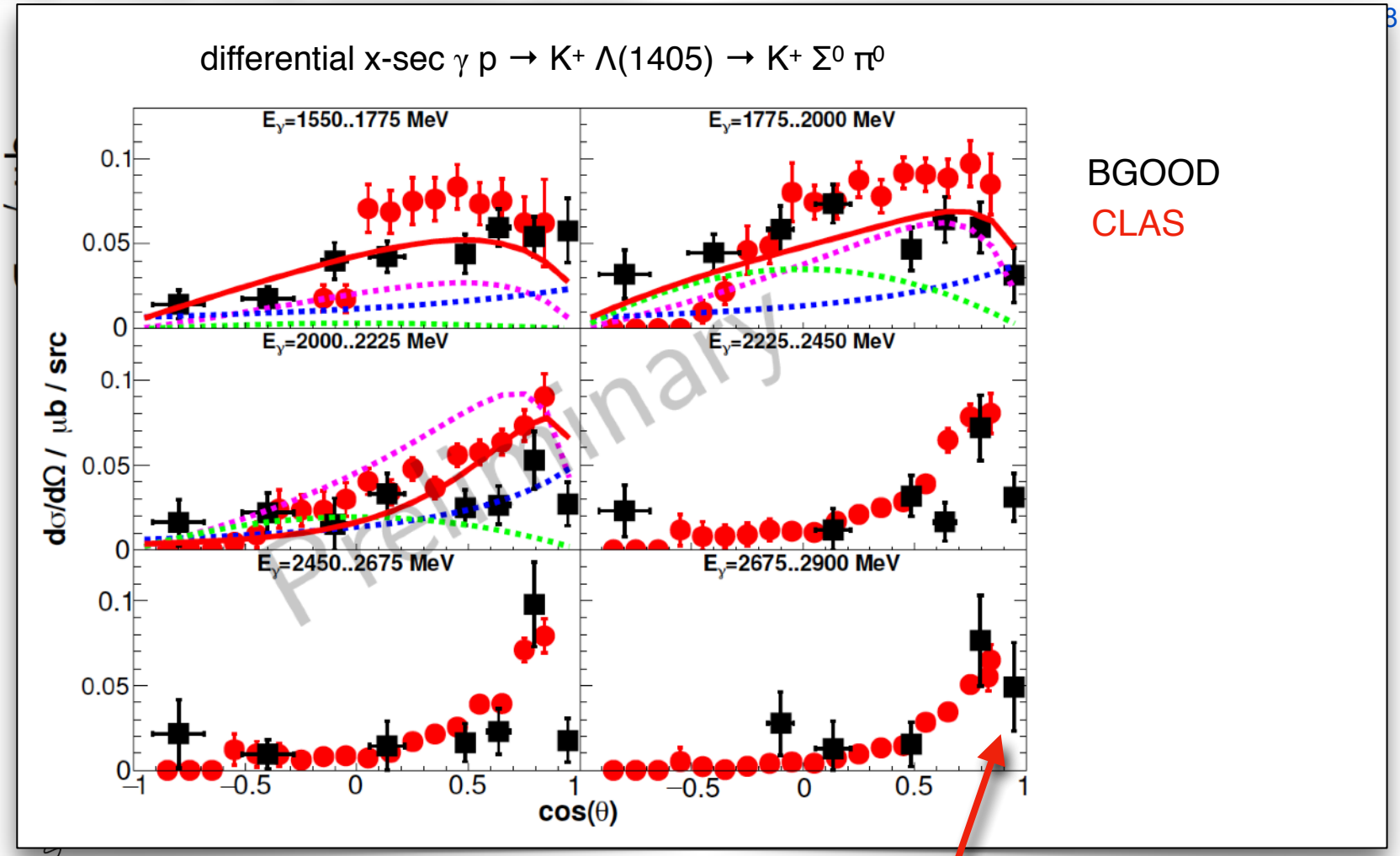
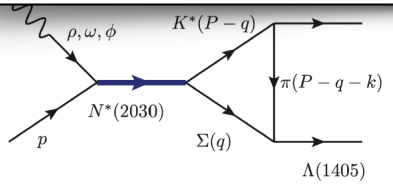


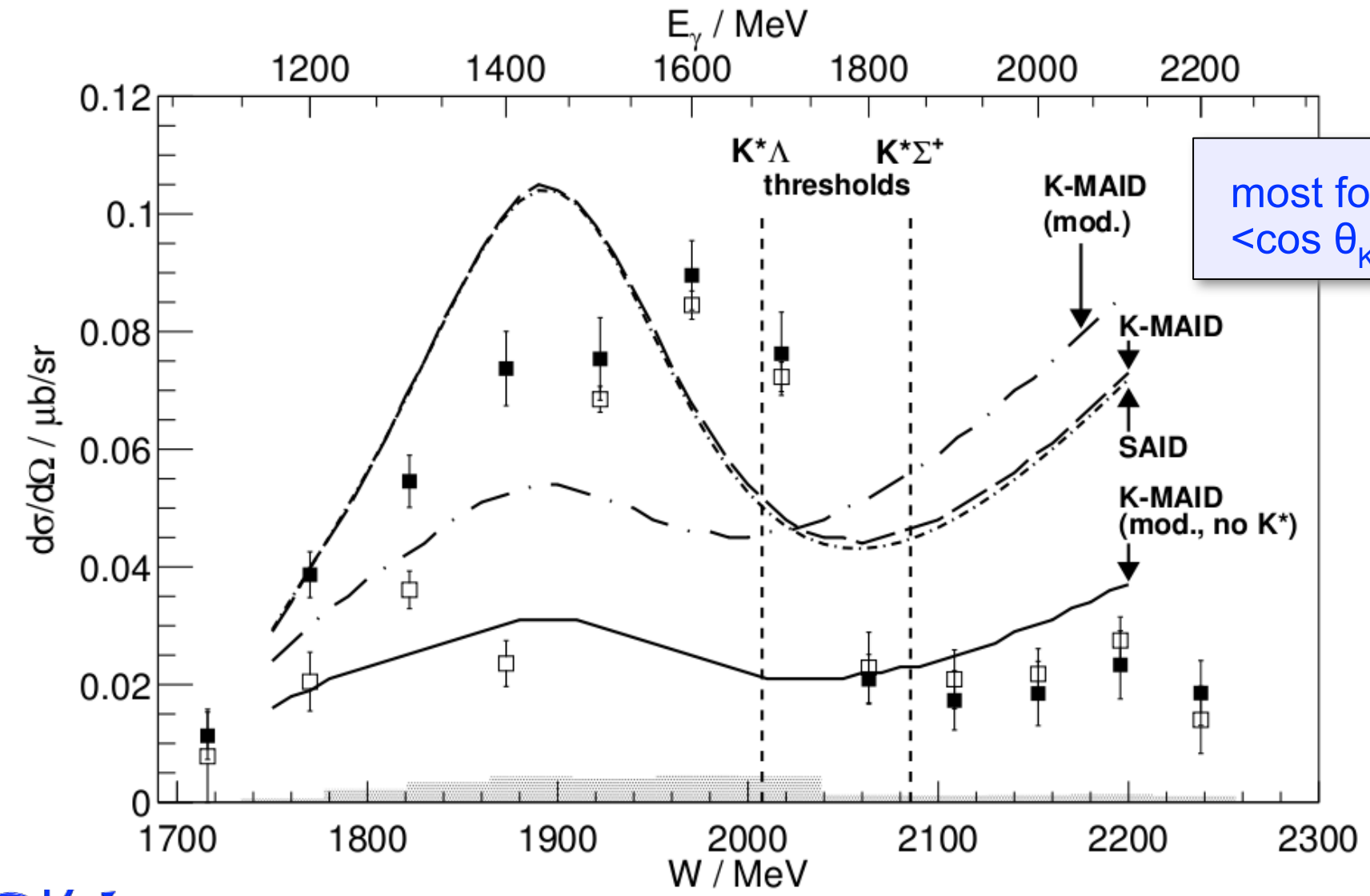
BGOOD
CLAS



→ triangle meachanism significant

γ + p -> K⁰ + Σ⁺ anomaly @ K* threshold

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



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

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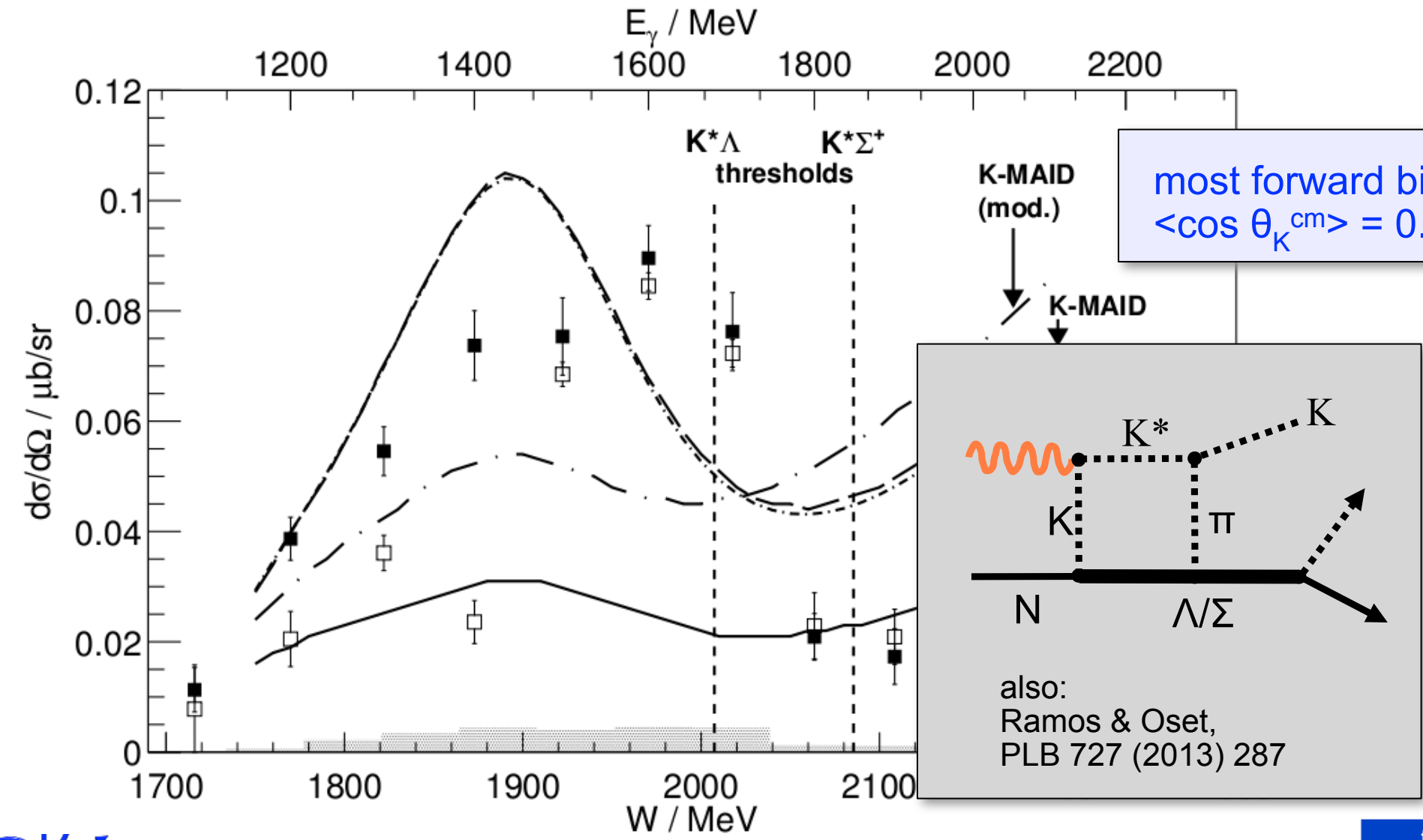

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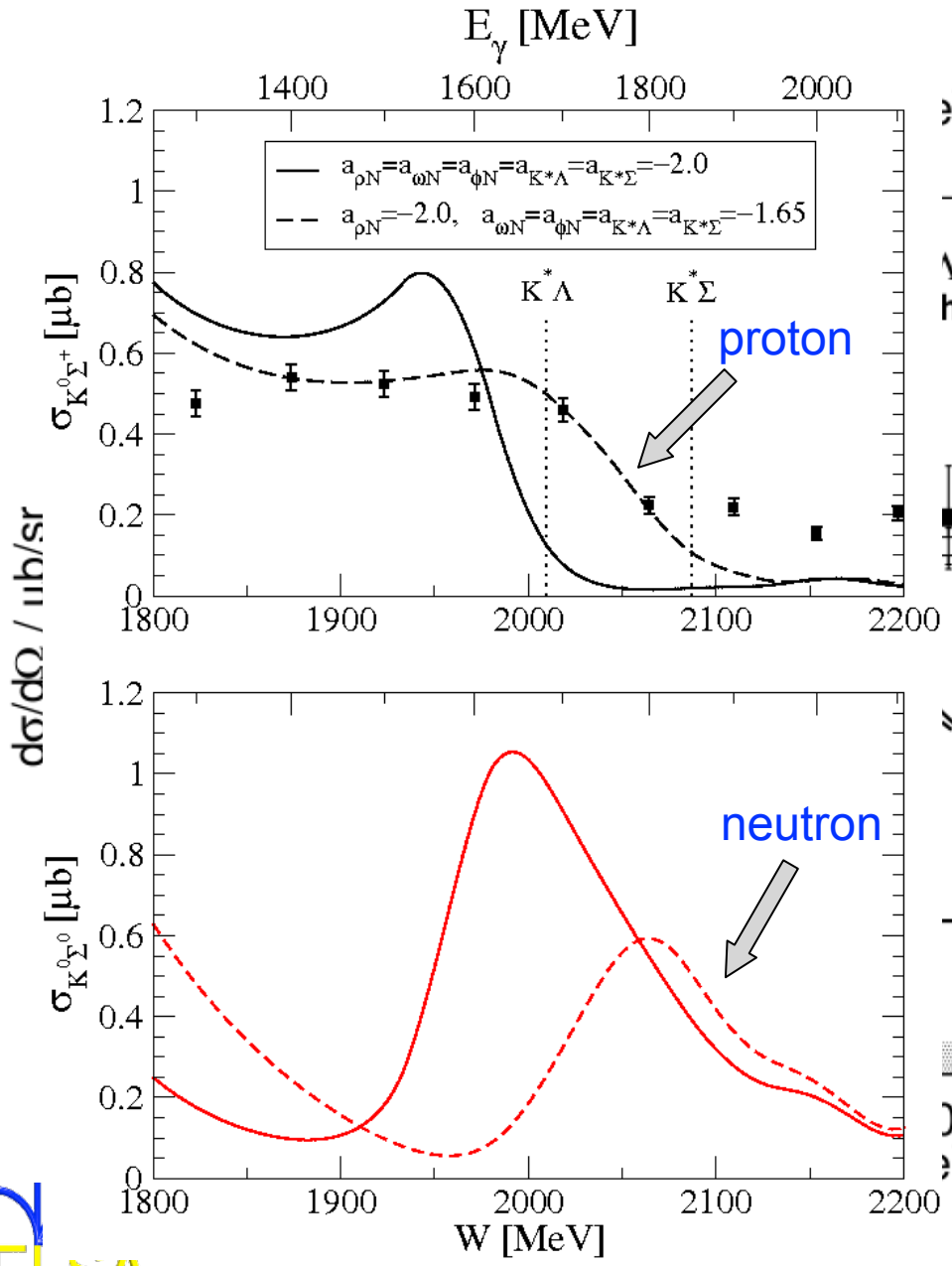

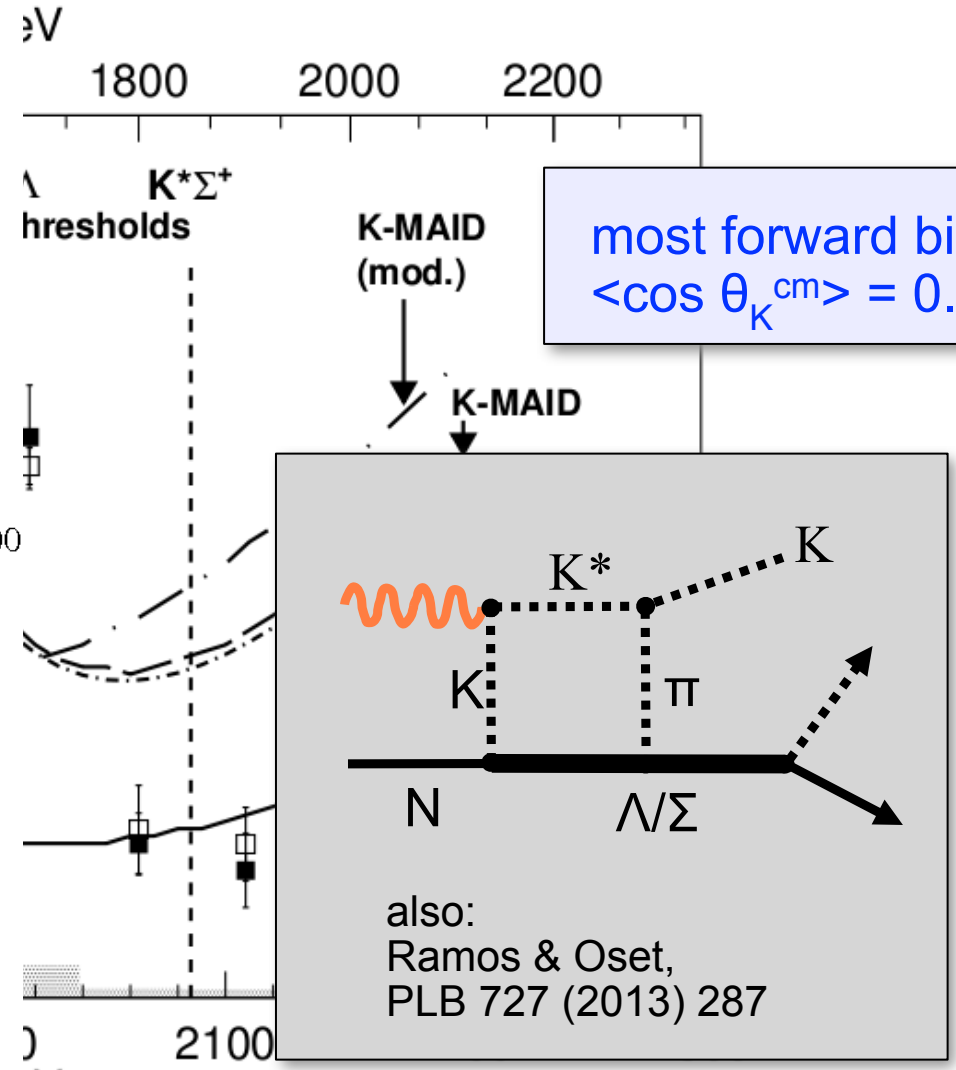

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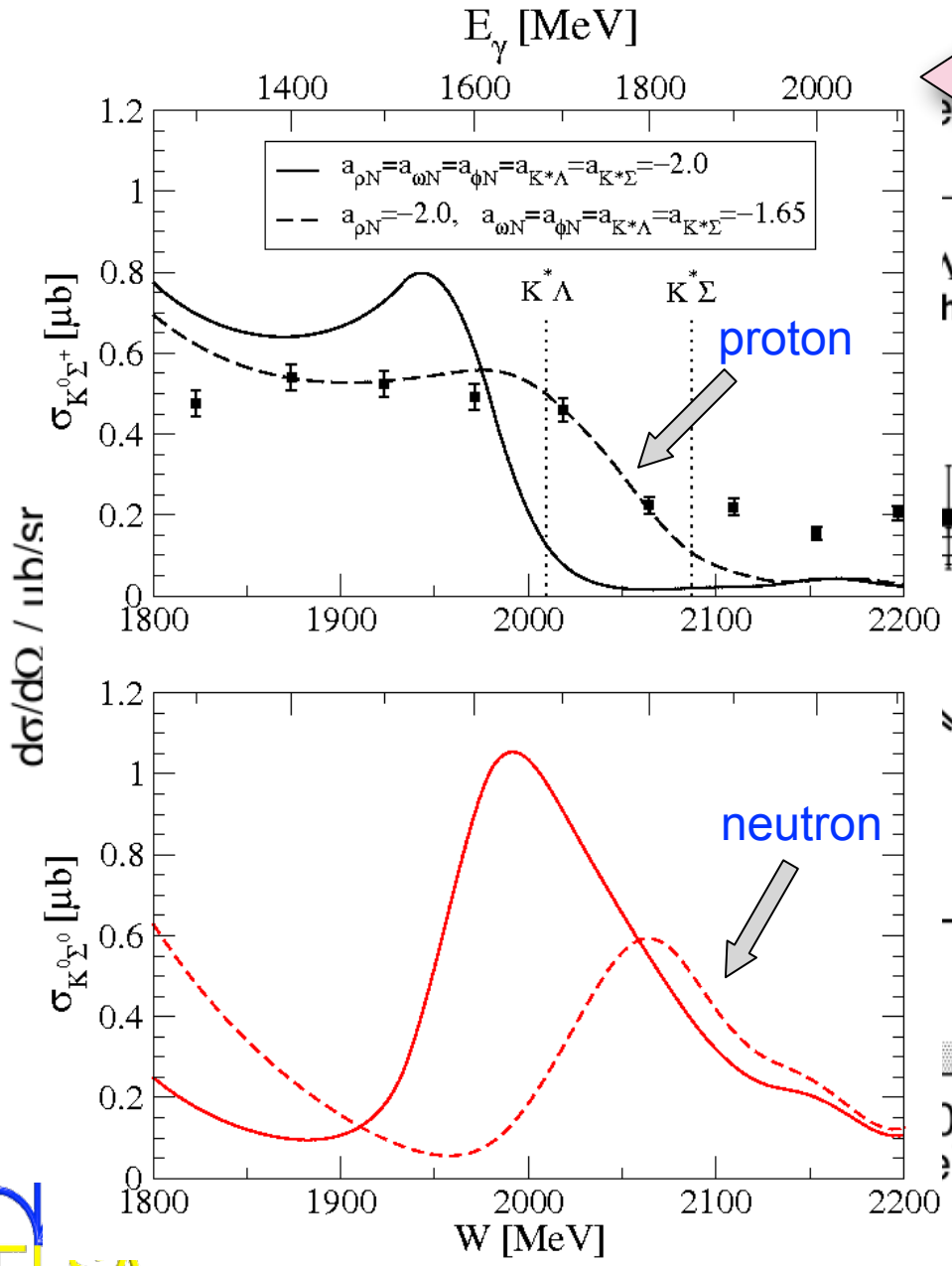

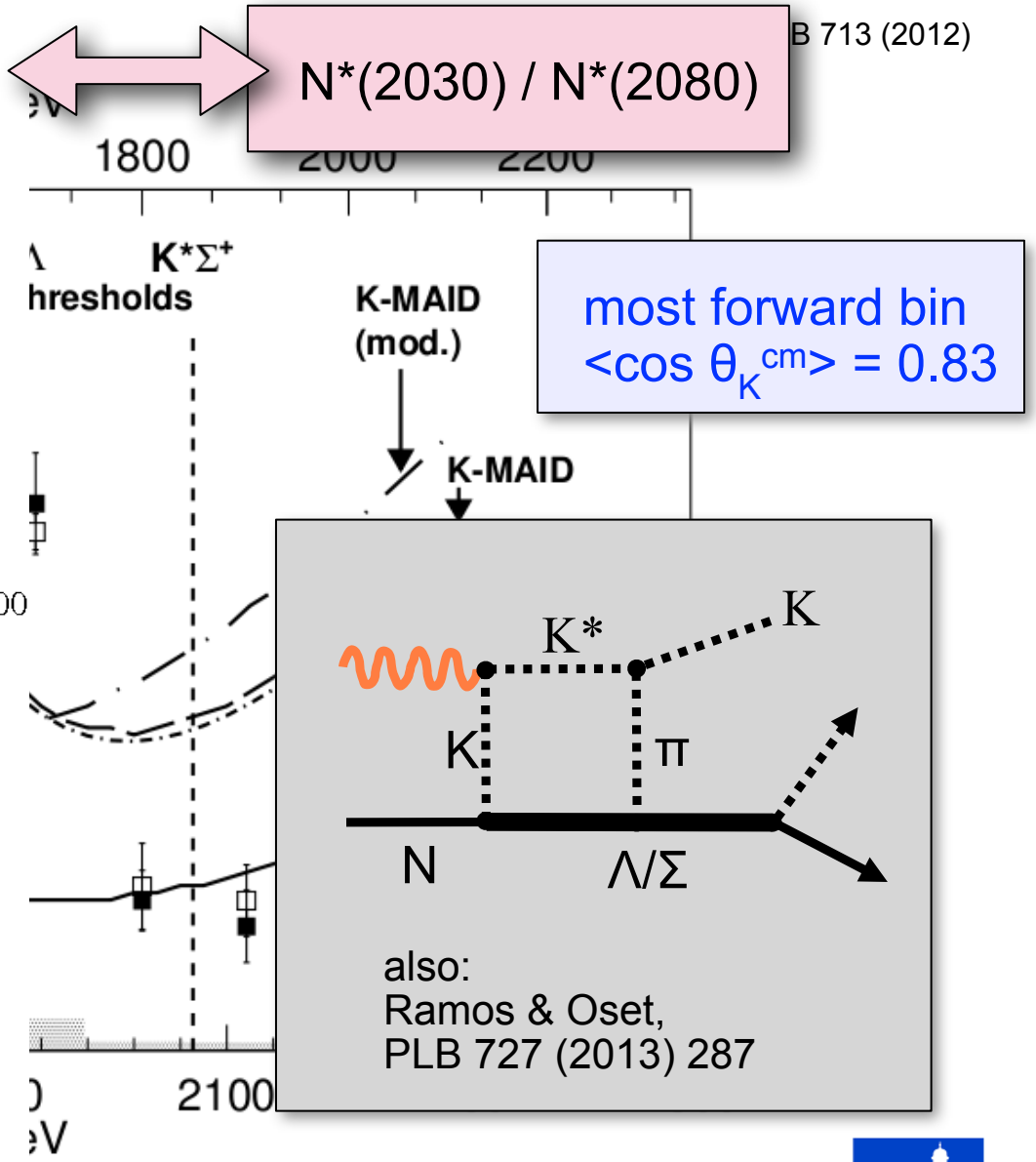

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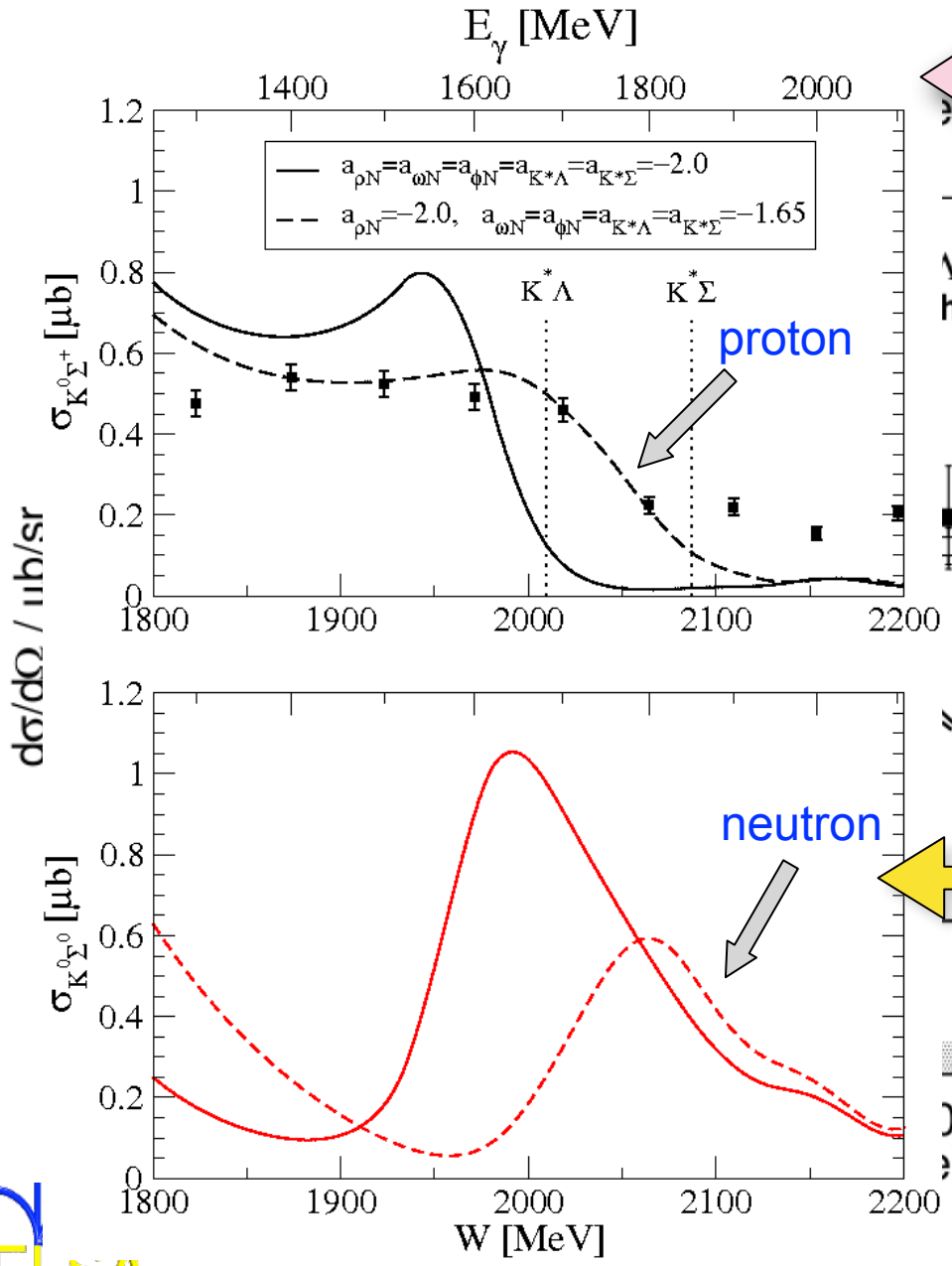

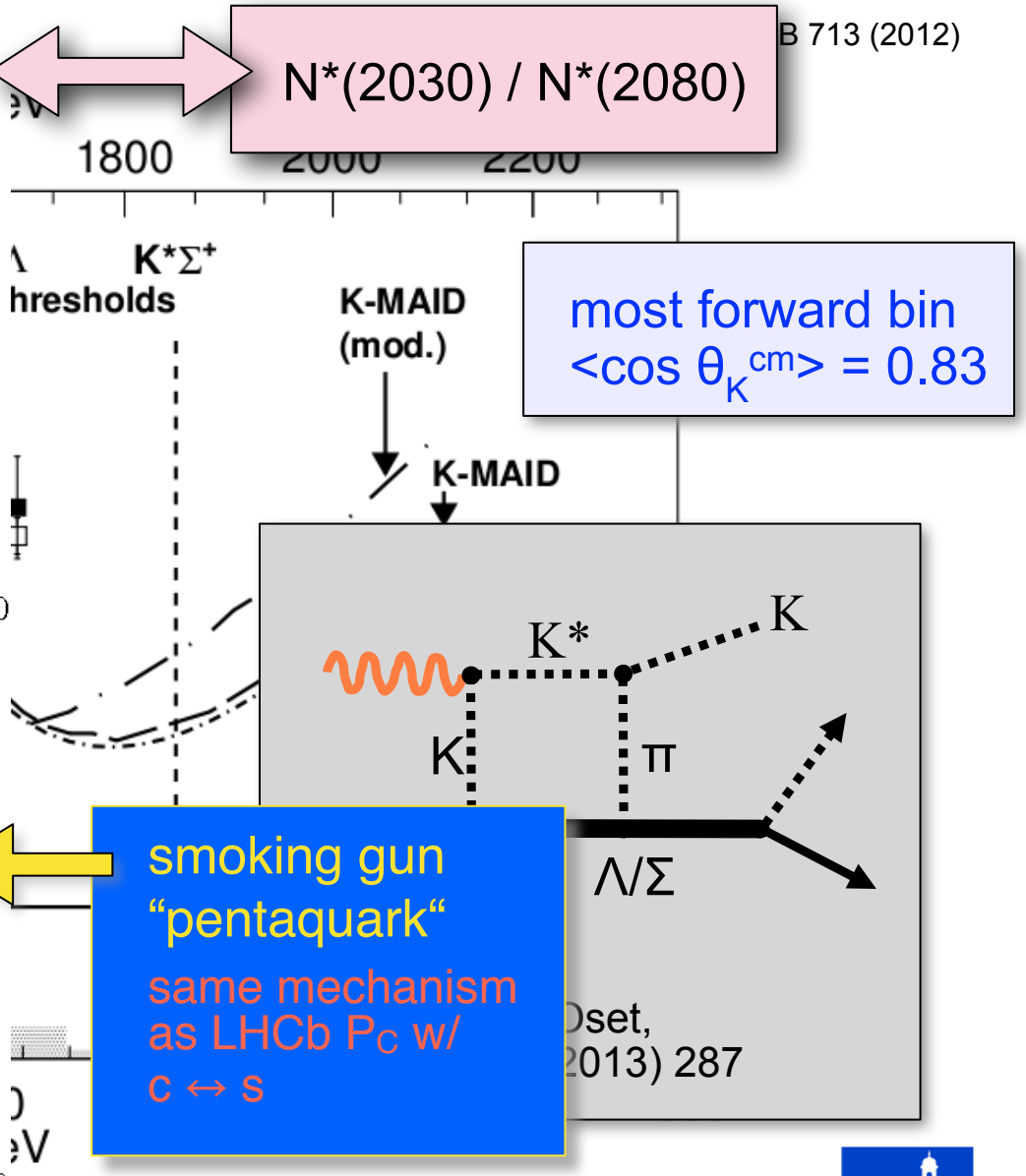

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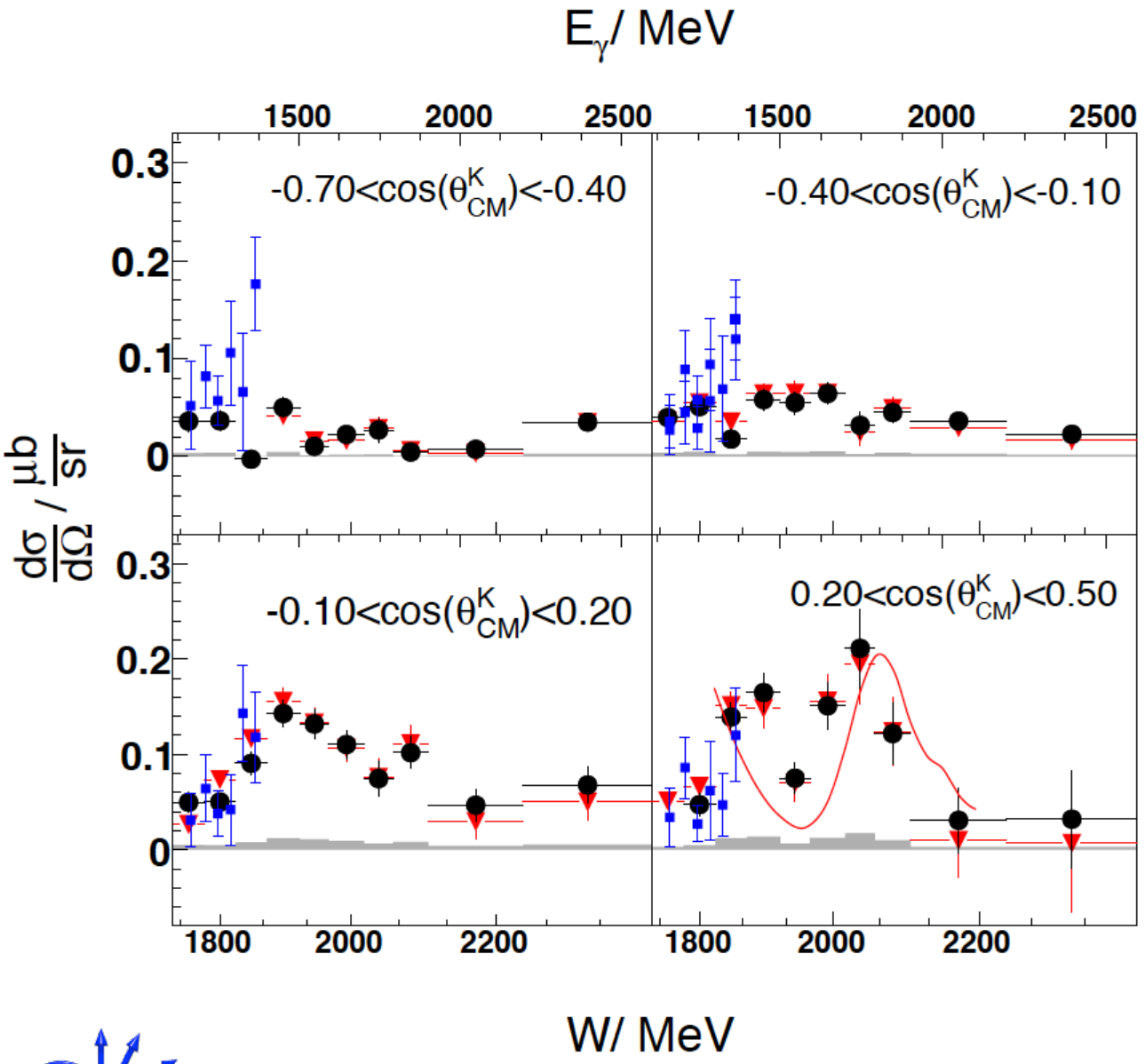
PhD thesis K. Kohl (in preparation)
see also:
arXiv:2007.08896 (NSTAR2019)



data:

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
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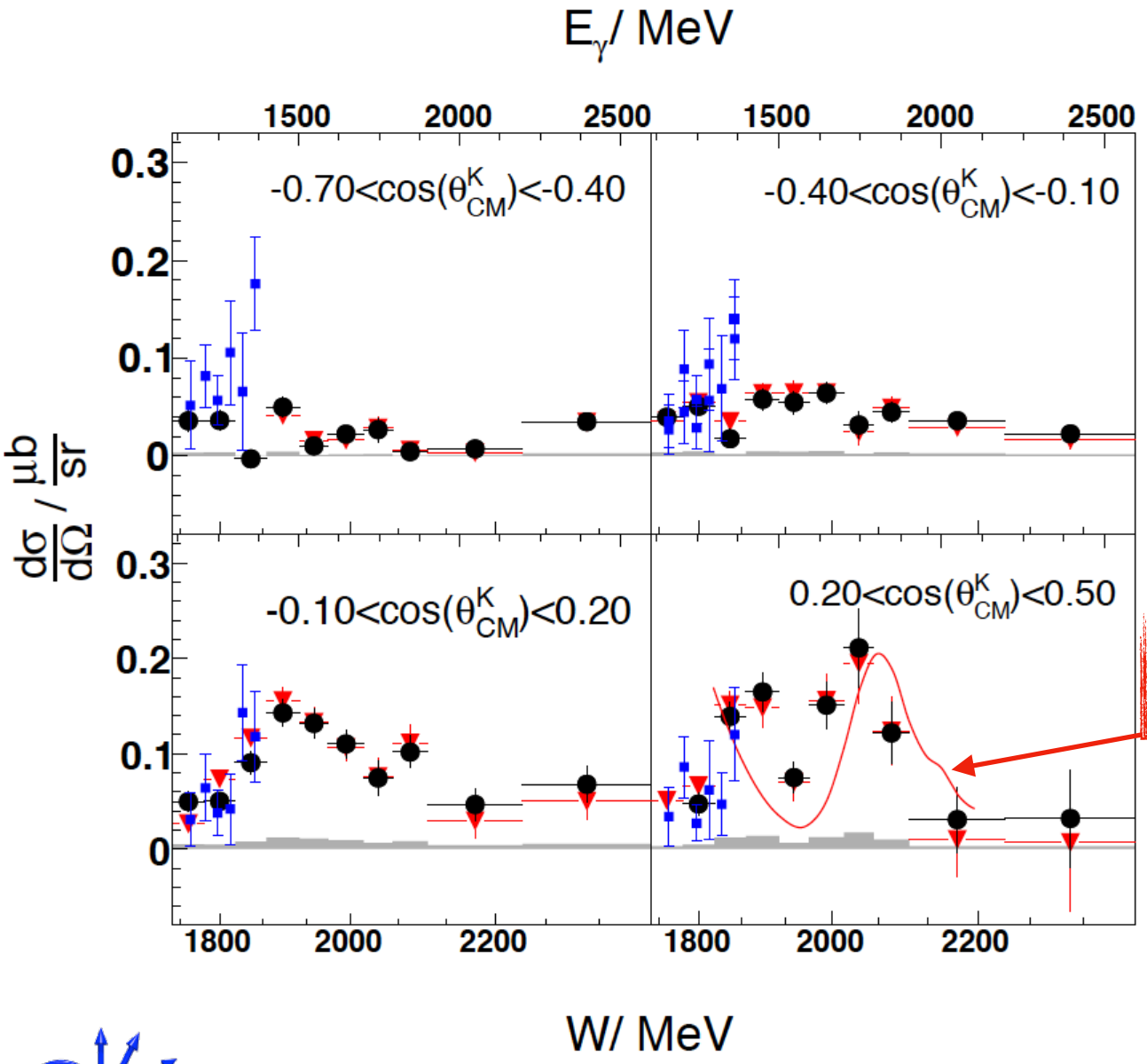

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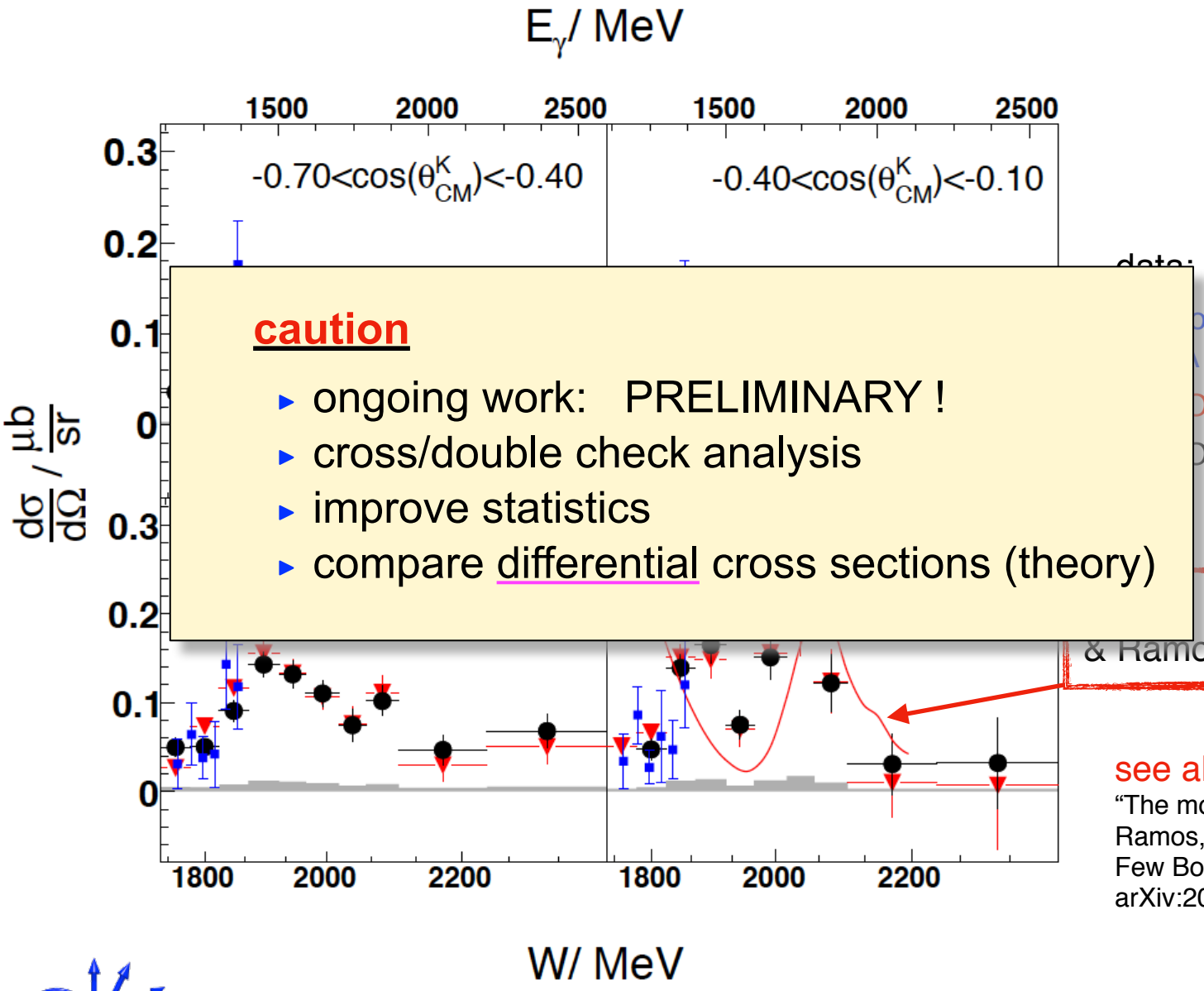

caution

- ongoing work: PRELIMINARY !
- cross/double check analysis
- improve statistics
- compare differential cross sections (theory)

ndi et al. [MAMI-A2]
55 (2019) 202
D simulated bg fit
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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

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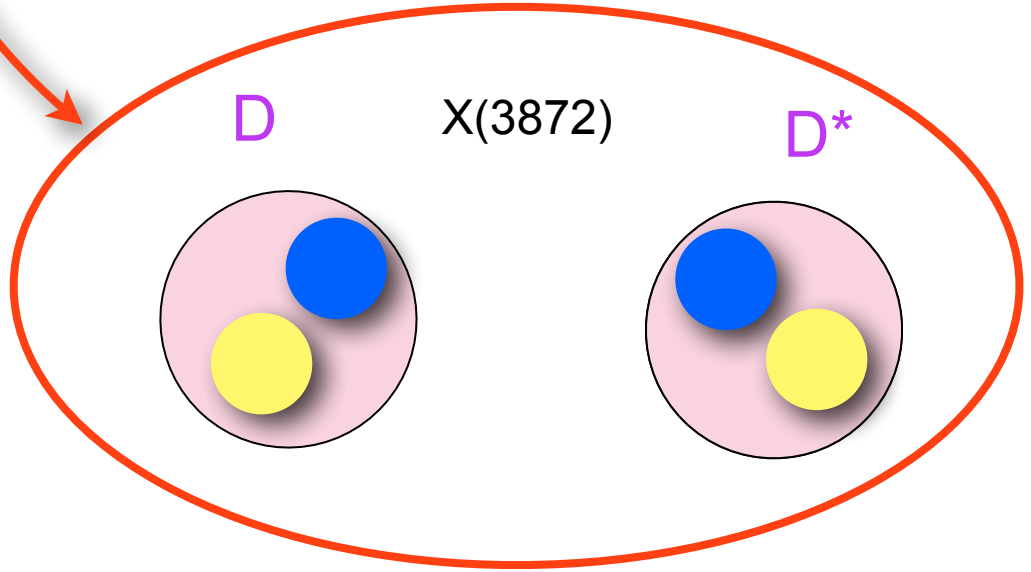

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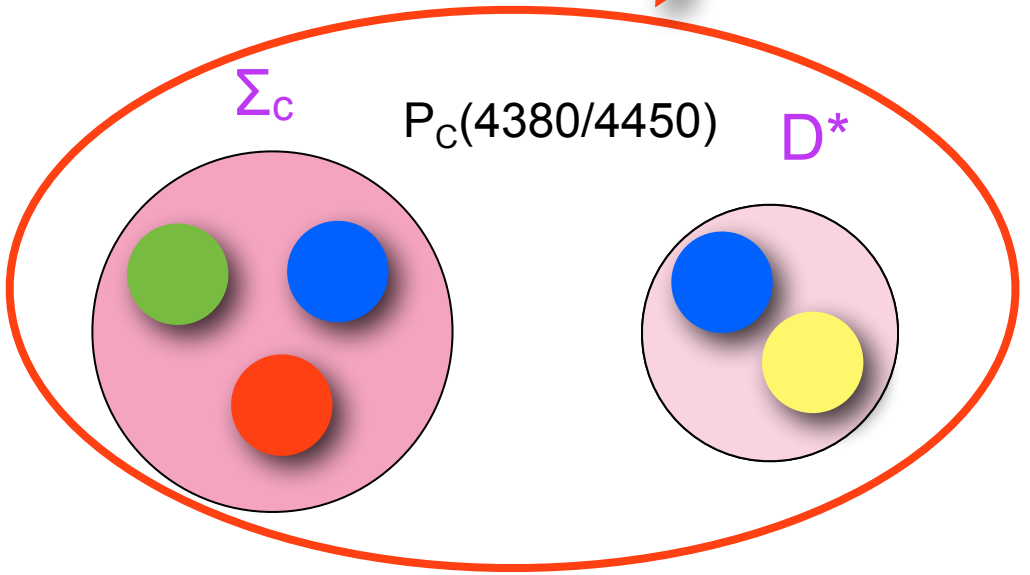
$\bar{3} \leftrightarrow \bar{3}$

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



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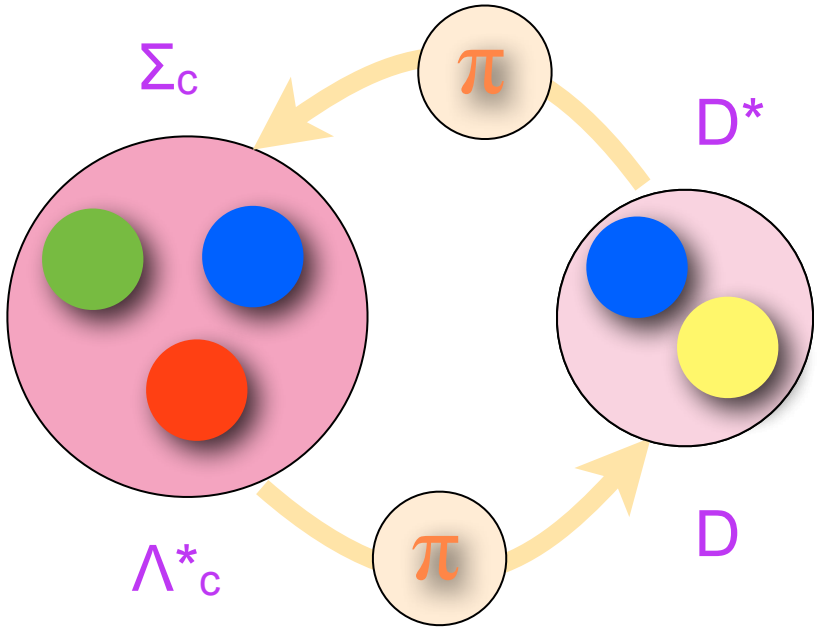

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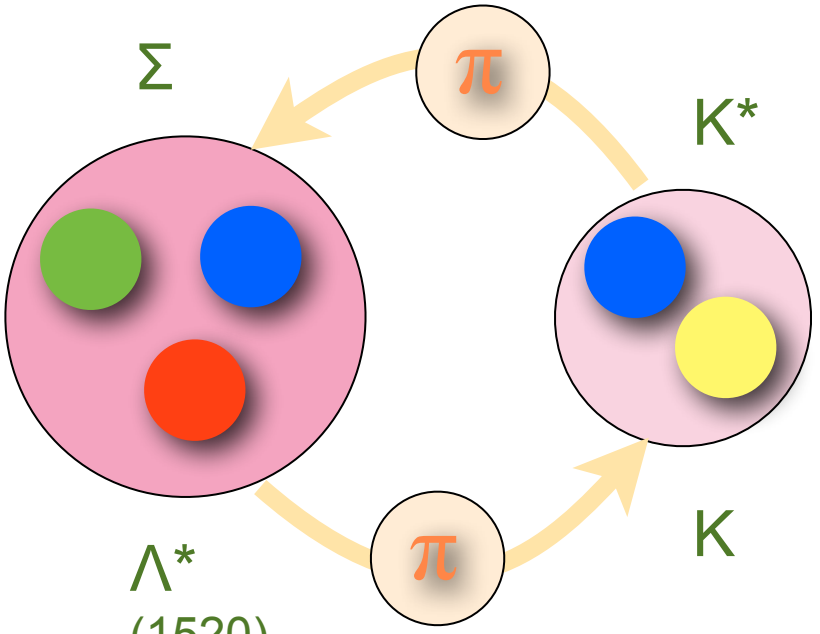
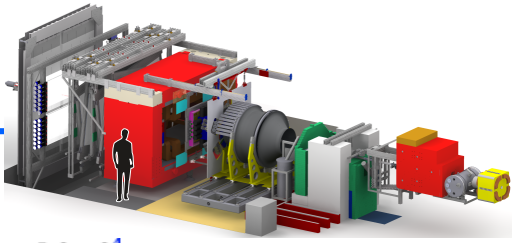


BGOOD collaboration



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

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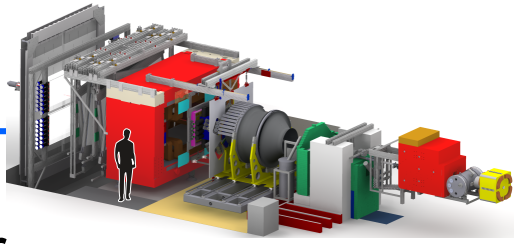
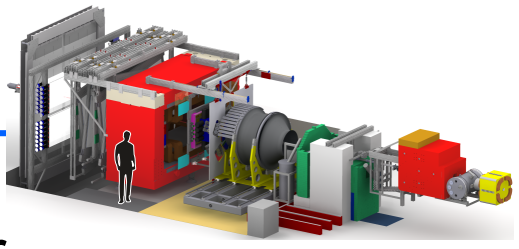
Summary



- multi-quark objects established in (hidden) c sector
- plausible parallels in (hidden) s sector
- BGOOD ideally suited to pursue this: thresholds & low t
- $K^+ \Lambda(1405)$
  - line shape in I = 0: double peak ??
  - photoproduction cross section: triangle driven
- $K^0 \Sigma^0 \rightarrow$ indication of LHCb analogous "multi-quark" ??
- not shown: $K^+\Lambda$, $K^+\Sigma$ & non-strange channels
- BGOOD debut results
  - overlap regions: on par with best to-date measurements
  - unique regions: qualitatively new effects
  - more to come …

Summary



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next:

improve statistics