

TA4 – Transnational Access to FTD/ELSA



STRONG-2020 ANNUAL MEETING (2022)



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

TA4 – Transnational Access to FTD/ELSA

- 1) Scientific results obtained since the last year
- 2) ~~Modifications of the scientific Work Plan (as compared to the initial plan in the Grant Agreement)~~
- 3) Possibilities/needs of another request for the extension of the project (beyond 30 November 2023)

(We kindly ask to focus on the scientific aspects of the work carried out without administrative issues or timeline questions for deliverables and milestones)

TA4 – Transnational Access to FTD/ELSA

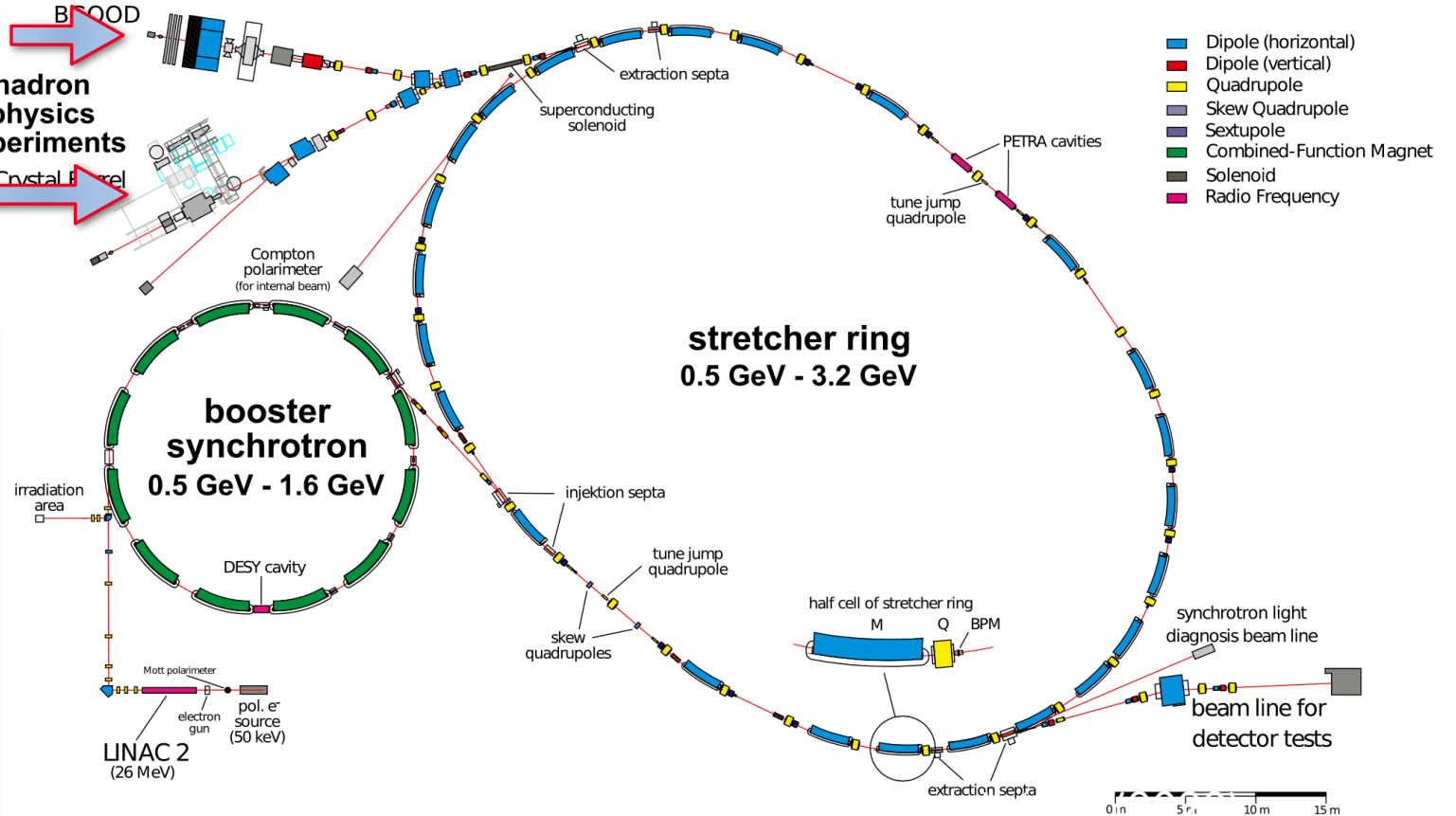
Projects

TA2-4..6 projects @BGOOD

hadron physics experiments

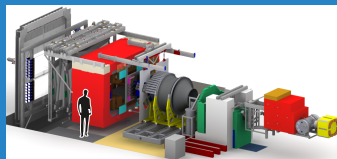
TA2-7 & 8 projects @CB

Crystal Ball



- 3 projects detector development
- 3 projects baryon spectroscopy
- 3 projects multi-quark states

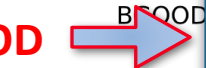
➔ **BGOOD**



TA4 – Transnational Access to FTD/ELSA

Projects

TA2-4..6 projects @BGOOD



hadron physics experiments

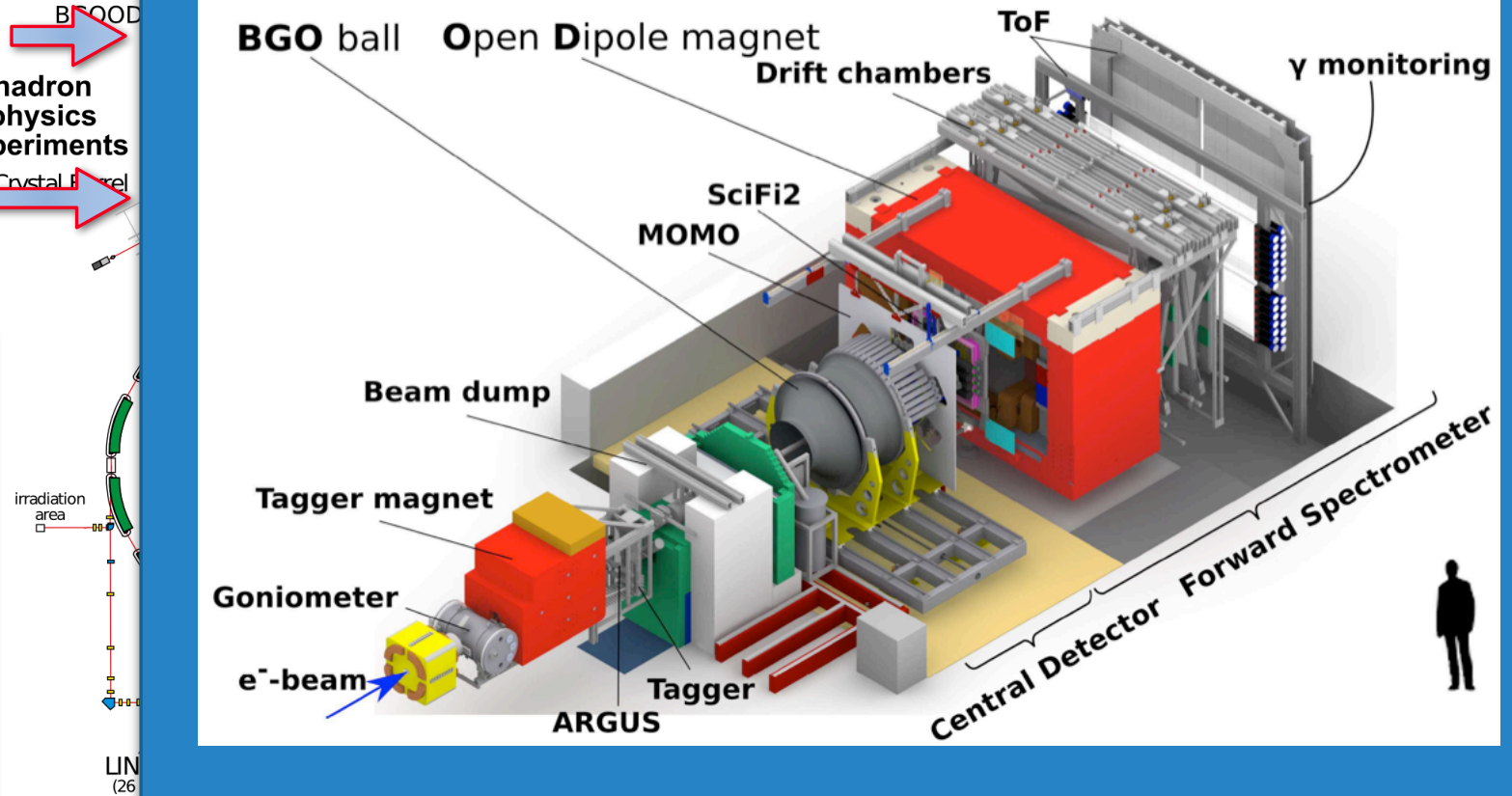
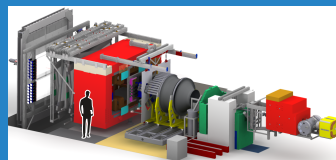
TA2-7 & 8 projects @CB



- 3 projects detector development
- 3 projects baryon spectroscopy
- 3 projects multi-quark states



BGOOD



S. Aef et al. [BGOOD collab.], Eur. Phys. J. A 56 (2020)

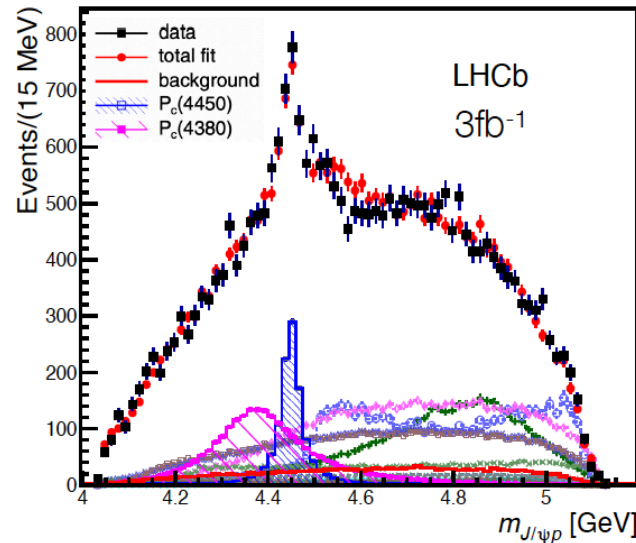
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Multi-quark states

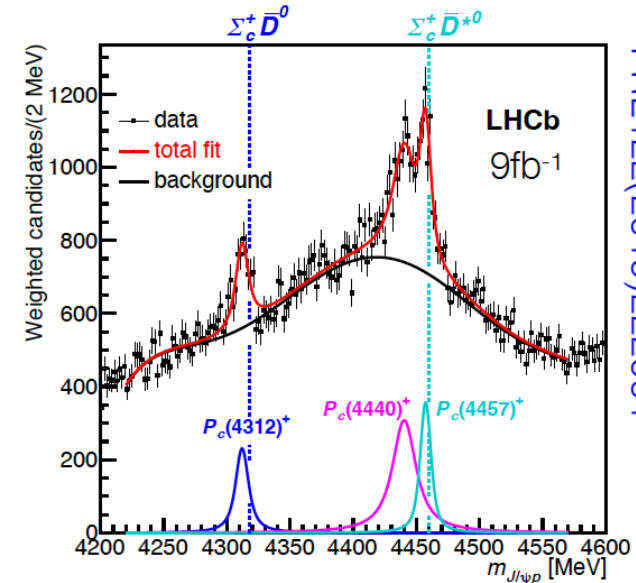
First observation of P_{ψ}^{N+} s in $\Lambda_b^0 \rightarrow J/\psi p K^-$ decays

In 2015, 26k signal yield,
6D amplitude analysis

In 2019, 246k signal yield,
1D mass fit



PRL 115(2015)072001



PRL 122(2019)222001

taken from
Jinlin Fu's talk
@ HaSP general
meeting (Munich 22)

pentaquark candidates:

$P_{\psi}^{N+}(4450)^+$

$P_{\psi}^{N+}(4380)^+$

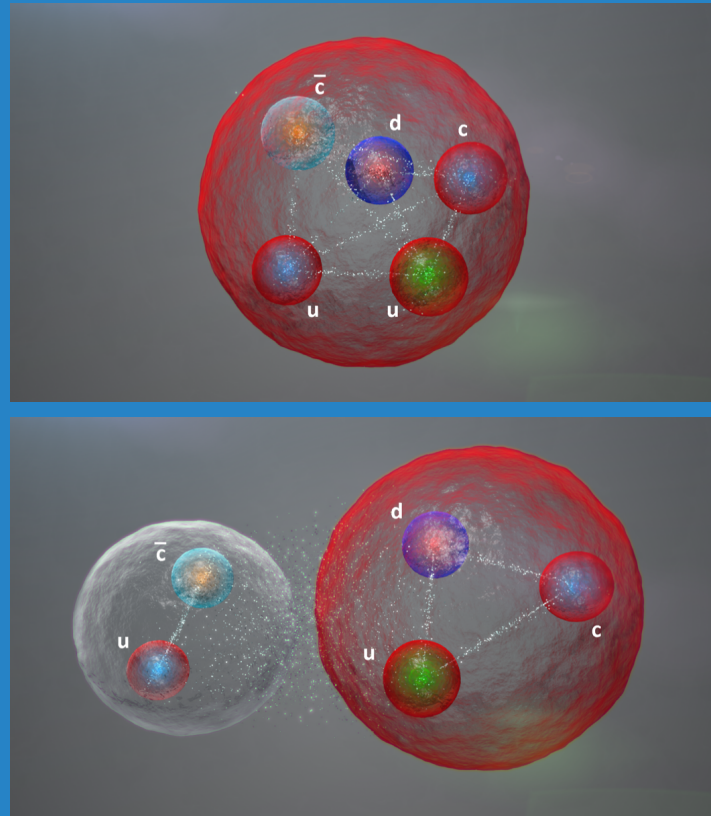
Fine structures $P_{\psi}^{N+}(4440)^+$, $P_{\psi}^{N+}(4457)^+$

New pentaquark state $P_{\psi}^{N+}(4312)^+$

Not sensitive to broad state $P_{\psi}^{N+}(4380)^+$

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Multi-



- 5-quark structures definitely observed
- (hidden) c-quark sector
- similar 4-quark states in meson sector
- structure/binding mechanism under debate

- ➔ paradigm change in hadron physics
- ➔ general feature of structure formation in QCD ?
- ➔ similar structures in (hidden) s-quark sector ??



taken from
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@ HaSP general
meeting (Munich 22)

pentaquark candidates:

$$P_{\psi}^N(4450)^+$$

$$P_{\psi}^N(4380)^+$$

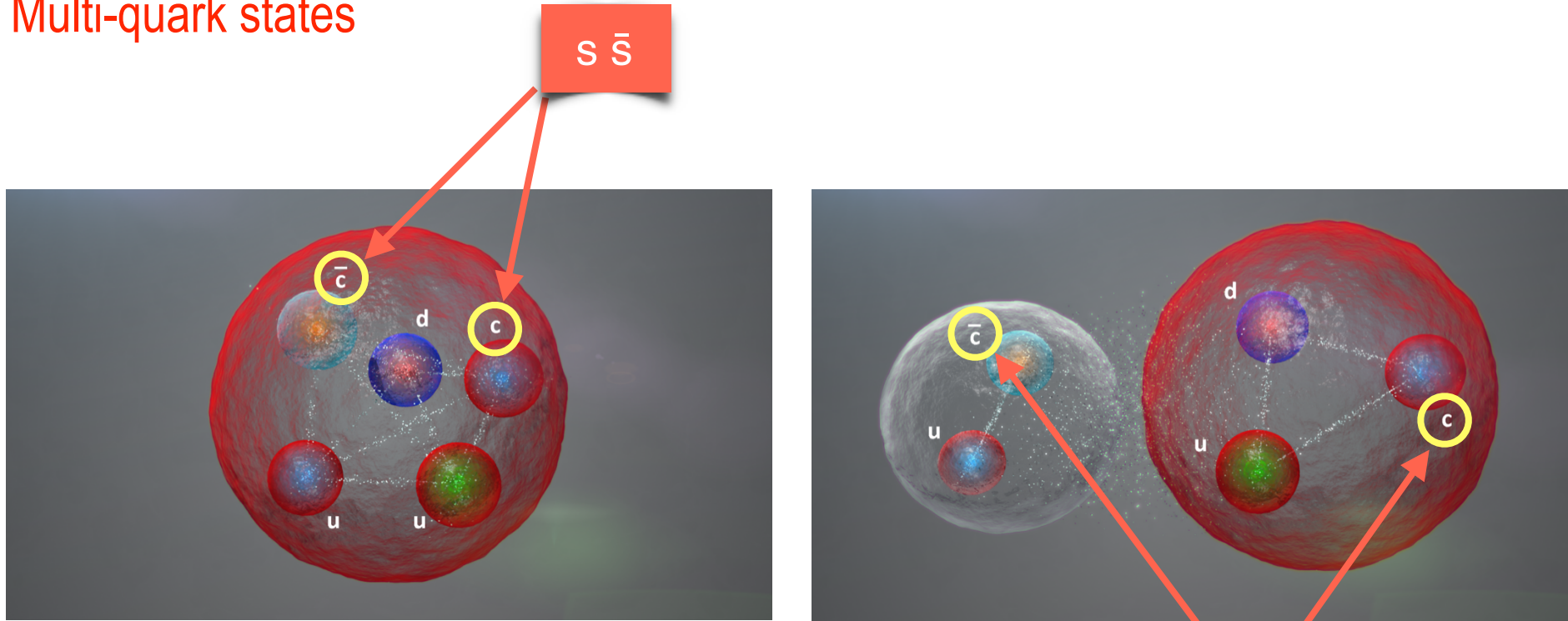
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Multi-quark states



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

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

$s \bar{s}$



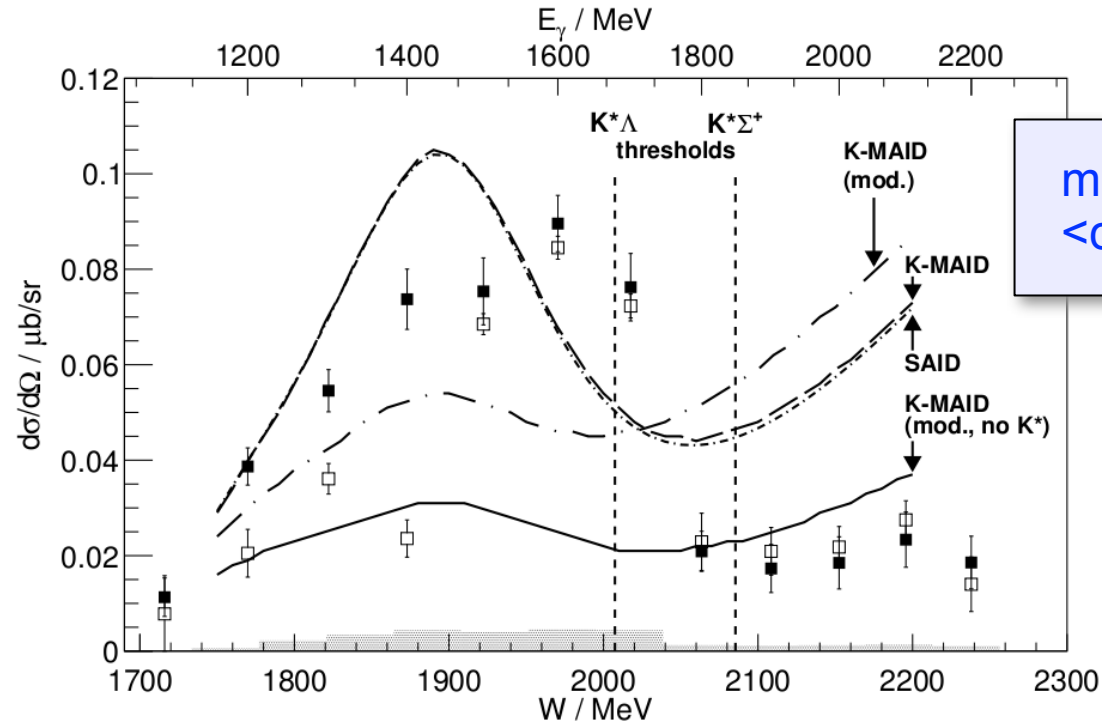
TA4 projects
@ BGOOD

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

anomaly @ K^* threshold

Multi-quark states

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



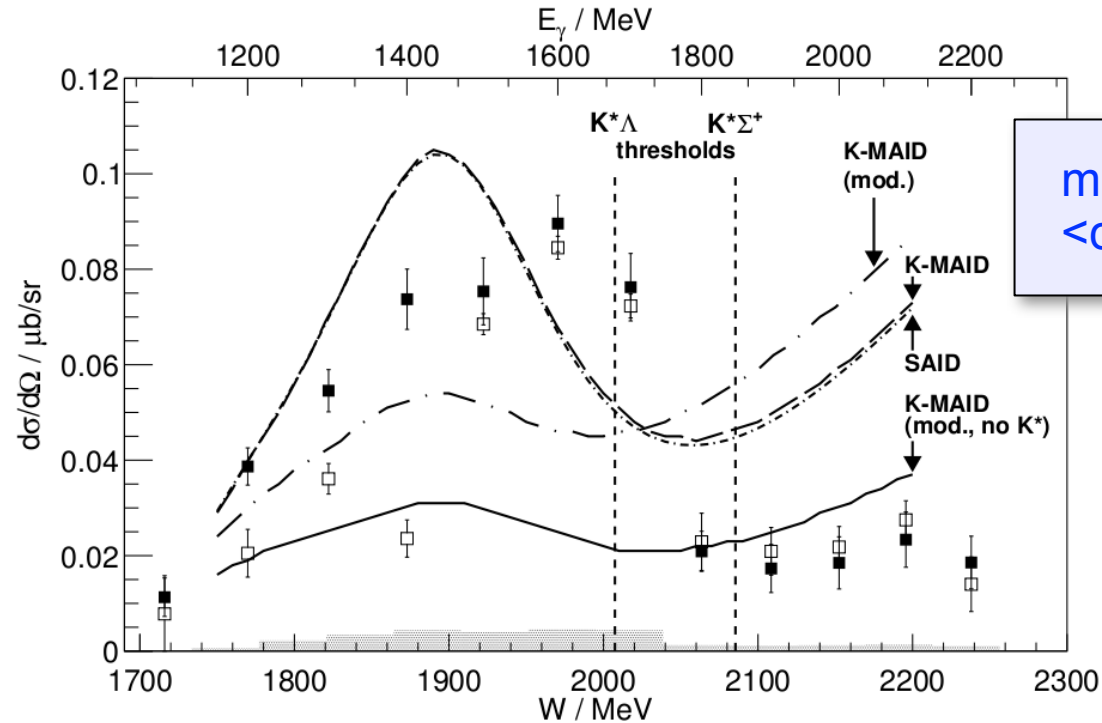
most forward bin
 $\langle \cos \theta_K^{cm} \rangle = 0.83$

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

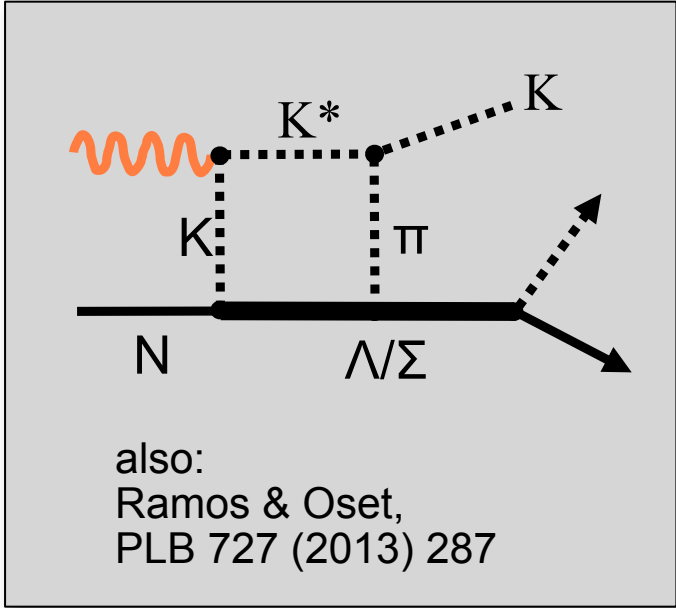
anomaly @ K^* threshold

Multi-quark states

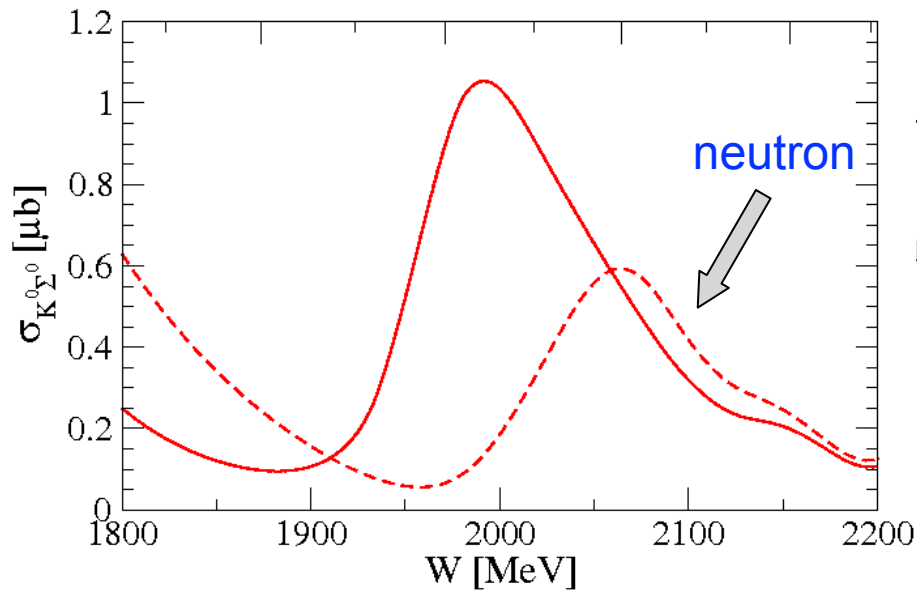
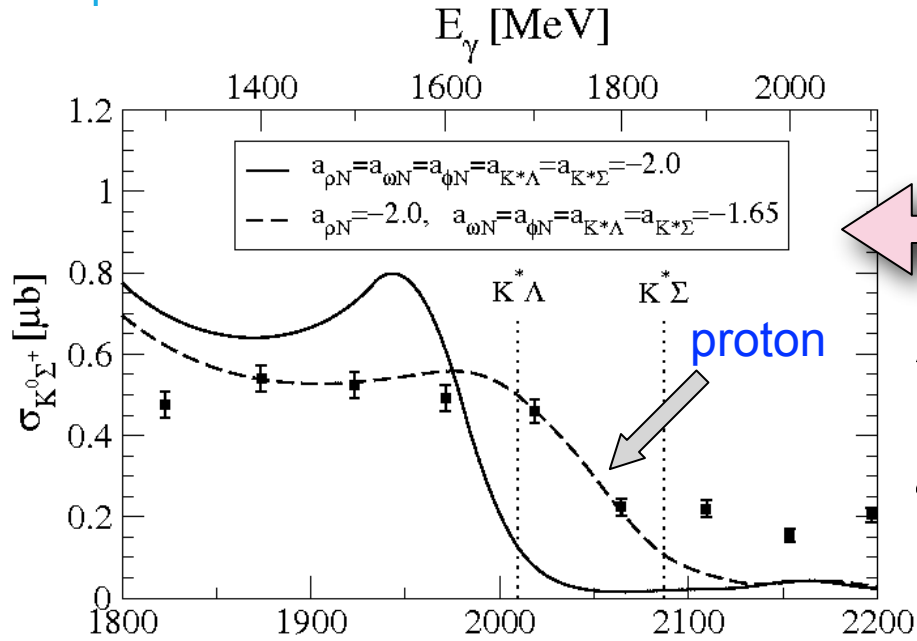
R. Ewald et al. (CB/TAPS), PLB 713 (2012)



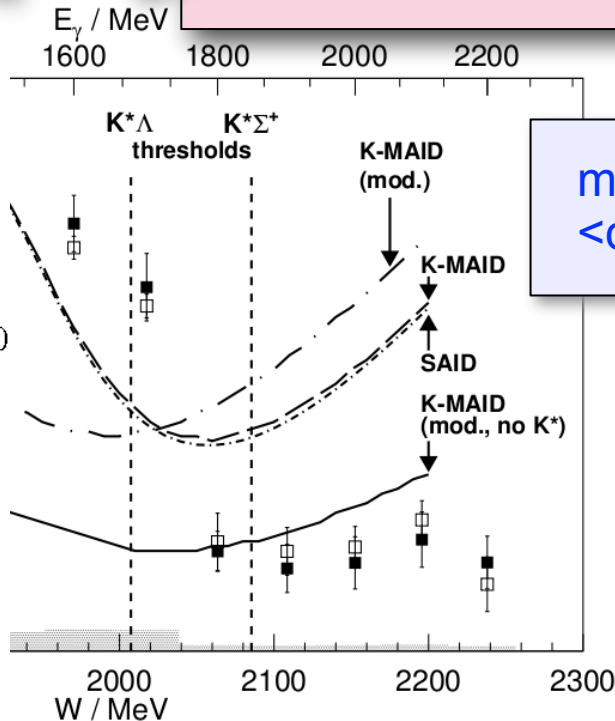
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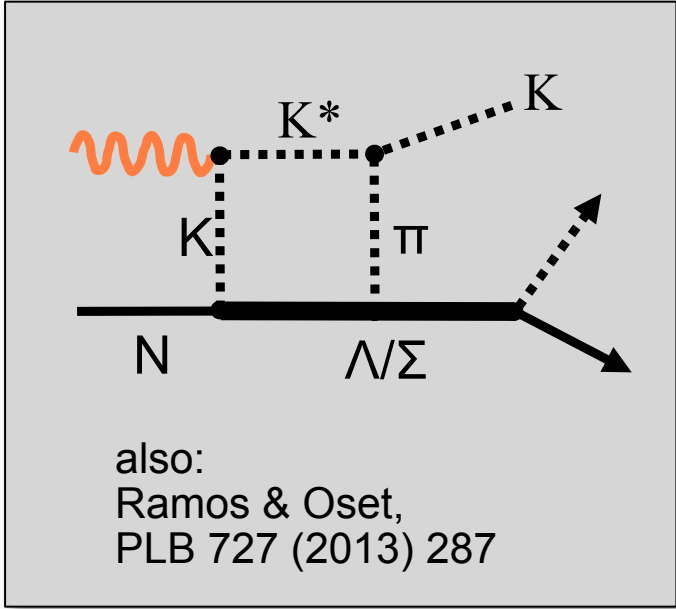
anomaly @ K^* threshold



$N^*(2030) / N^*(2080)$ in analogy to P_C states @ D^* thresh.



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



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

@ K^* threshold

Multi-quark states

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

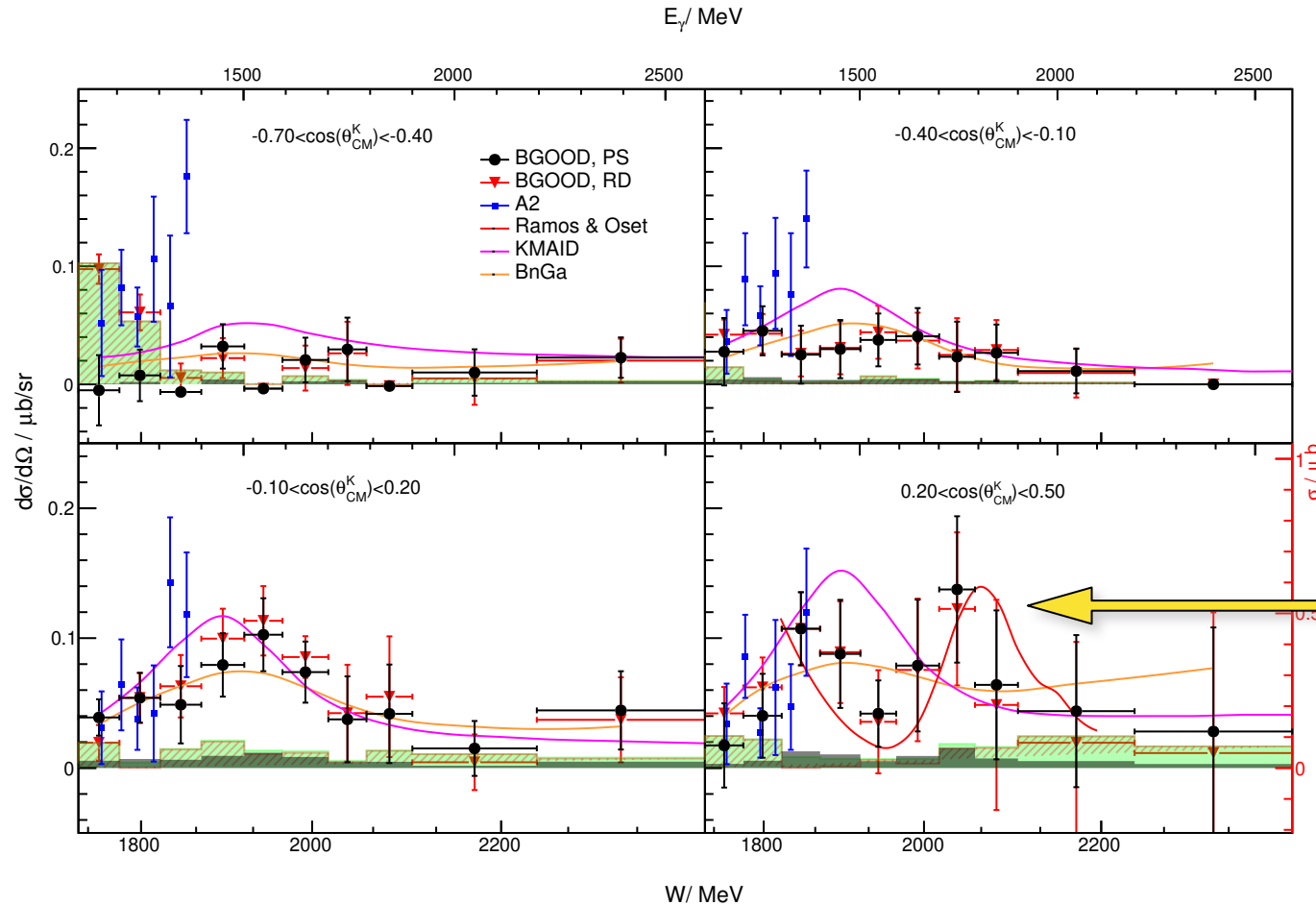
C. Akondi et al. [MAMI-A2]
EPJ A 55 (2019) 202

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/
 $c \leftrightarrow s$

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

@ K^* threshold

Multi-quark states

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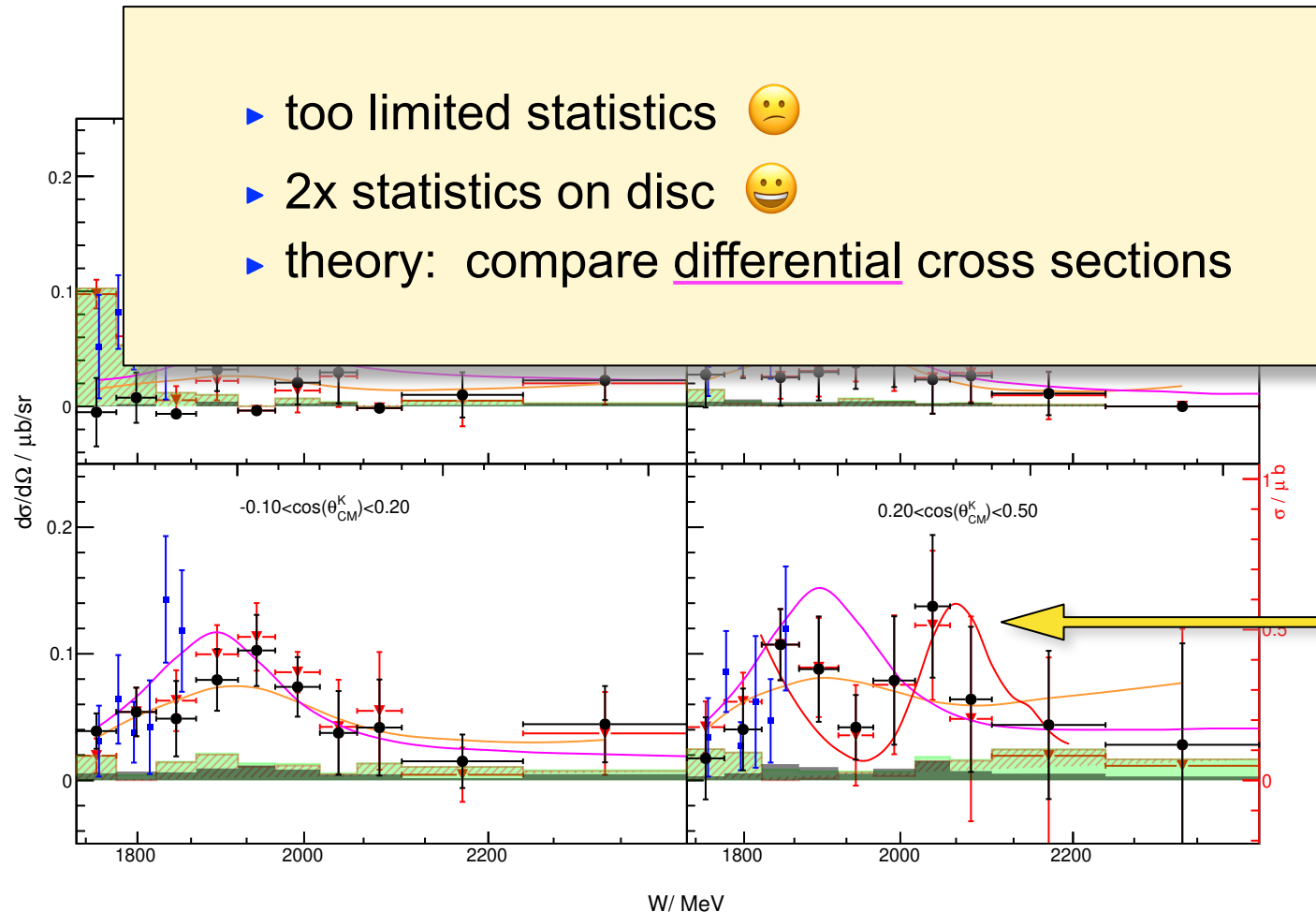
BGOOD simulated by fit

BGOOD real by 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)

- ▶ too limited statistics 😞
- ▶ 2x statistics on disc 😊
- ▶ theory: compare differential cross sections

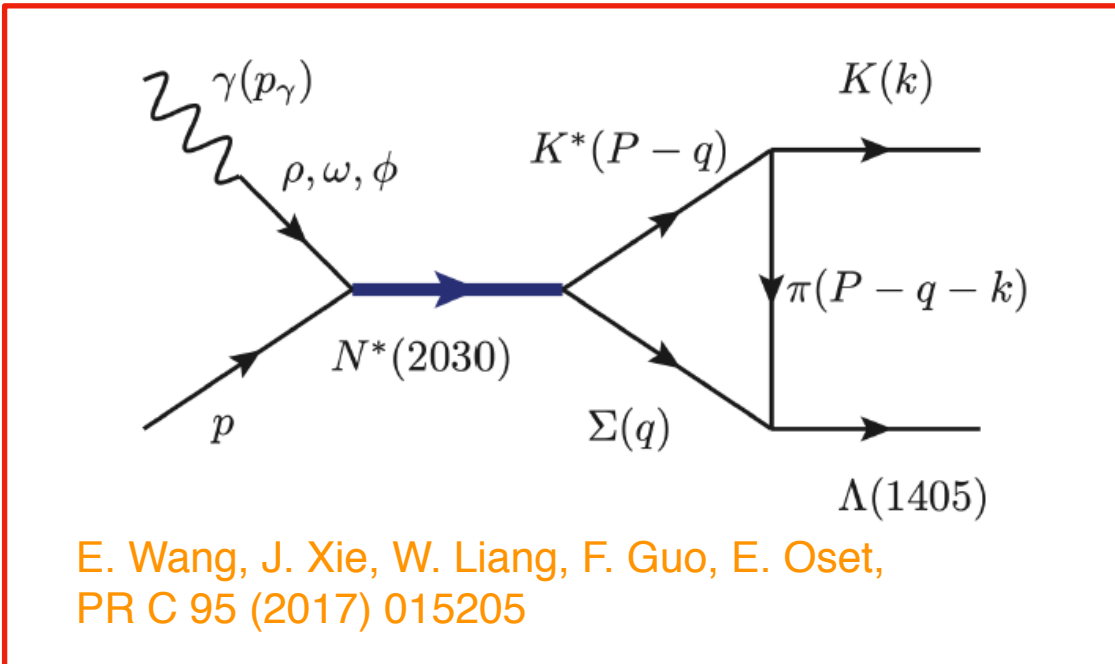


smoking gun
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same mechanism
as LHCb P_c w/
 $c \leftrightarrow s$

$K^+ \Lambda(1405)$ photoproduction

– photoproduction mechanism

Multi-quark states



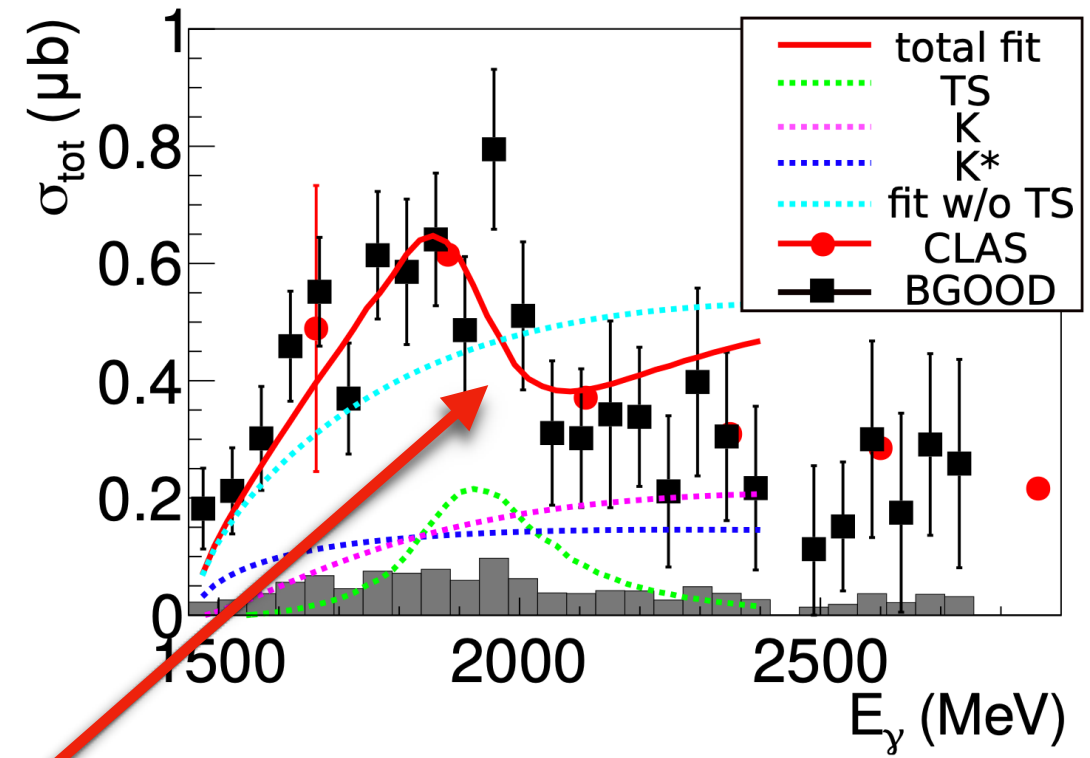
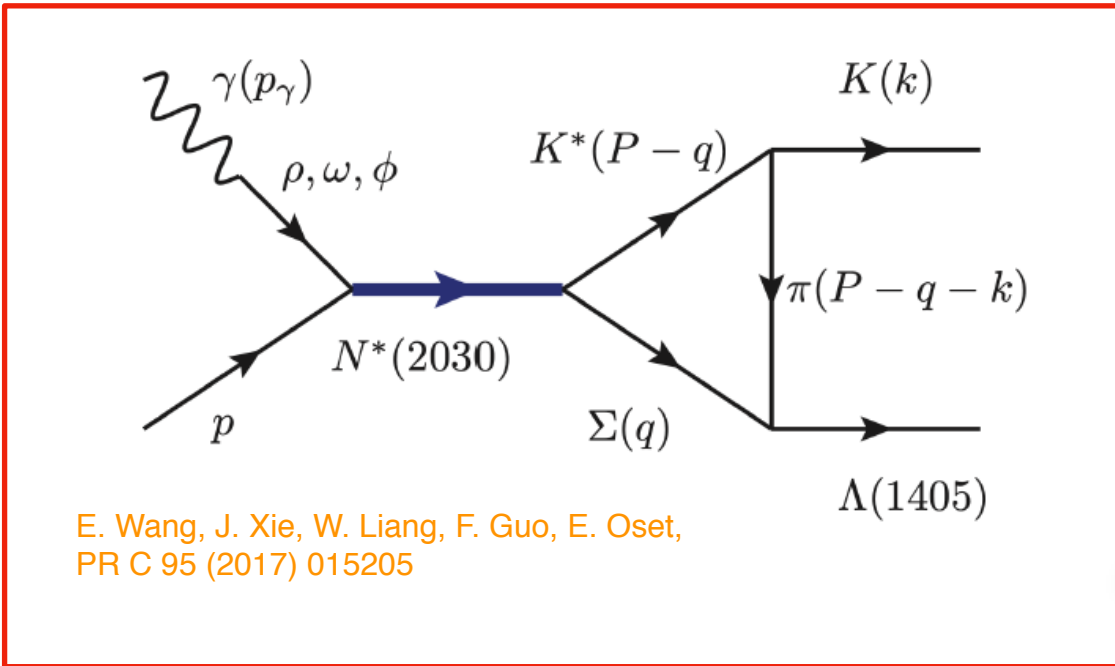
triangle singularity \Rightarrow **cusp**

K⁺ Λ(1405) photoproduction

– photoproduction mechanism

Multi-quark states

G. Scheluchin *et al.* [BGOOD collab.]
Phys. Lett B 833 (2022) 137375

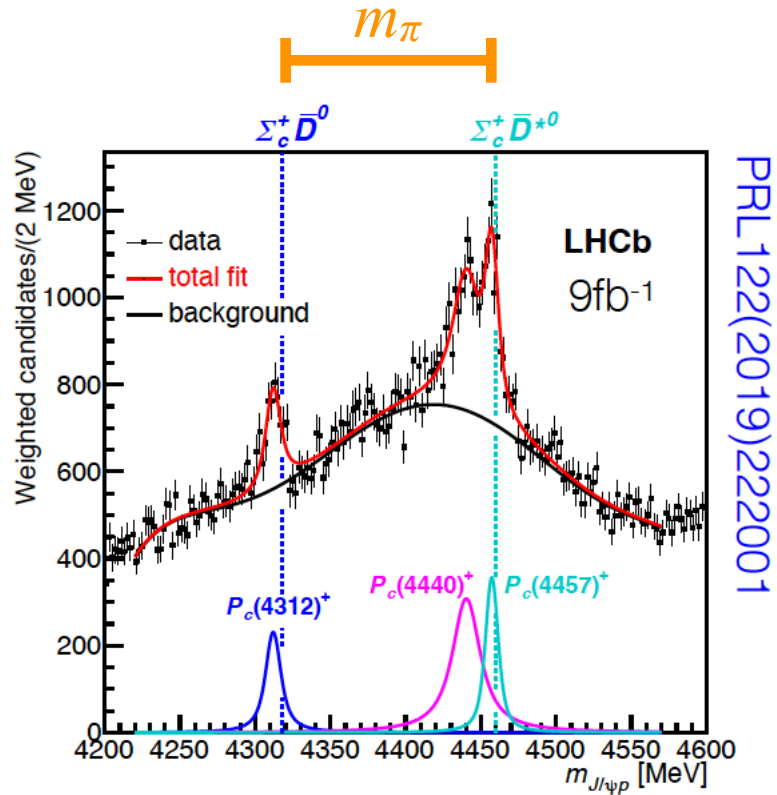


triangle singularity ⇒ cusp

$K^+ \Sigma_{g.s.}$ photoproduction

Multi-quark states

reminder



Fine structures $P_{\psi}^N(4440)^+$, $P_{\psi}^N(4457)^+$

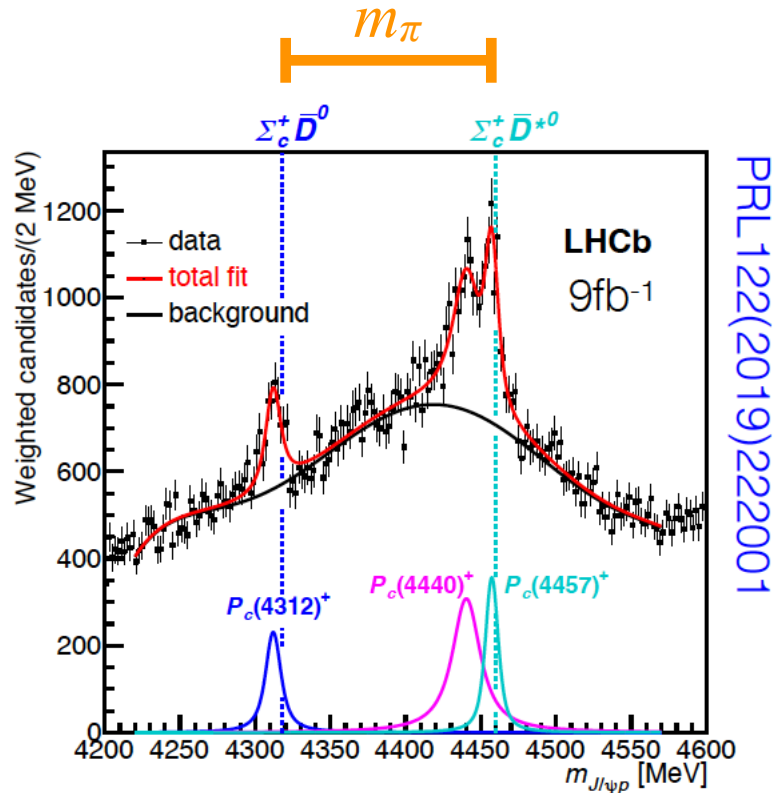
New pentaquark state $P_{\psi}^N(4312)^+$



K⁺ Σ_{g.s.} photoproduction

Multi-quark states

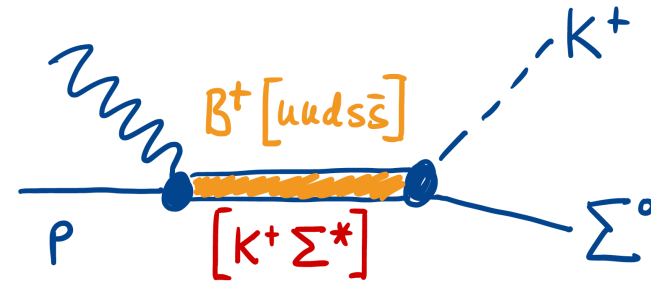
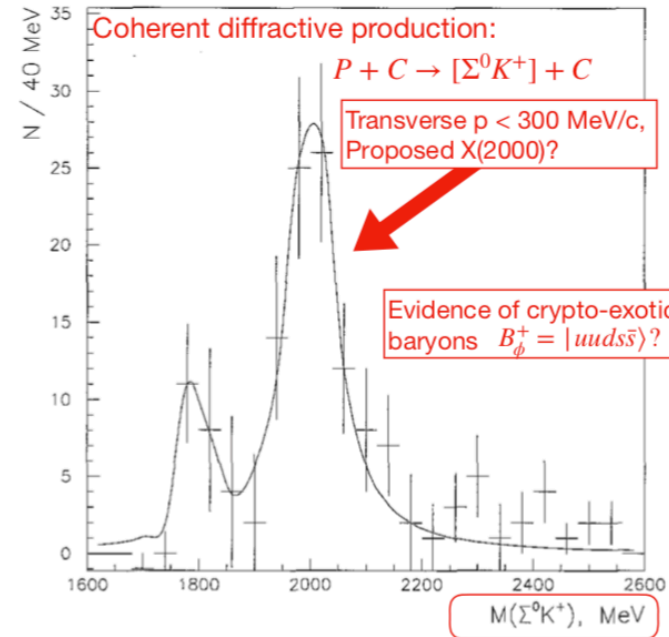
reminder



Fine structures $P_{\psi}^N(4440)^+$, $P_{\psi}^N(4457)^+$

New pentaquark state $P_{\psi}^N(4312)^+$

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

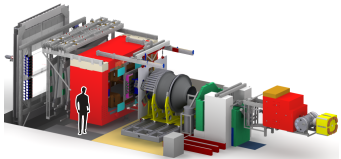
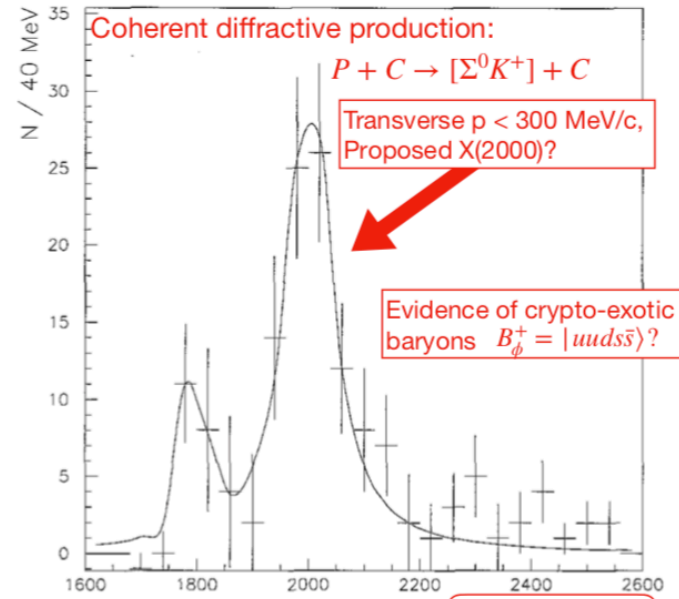
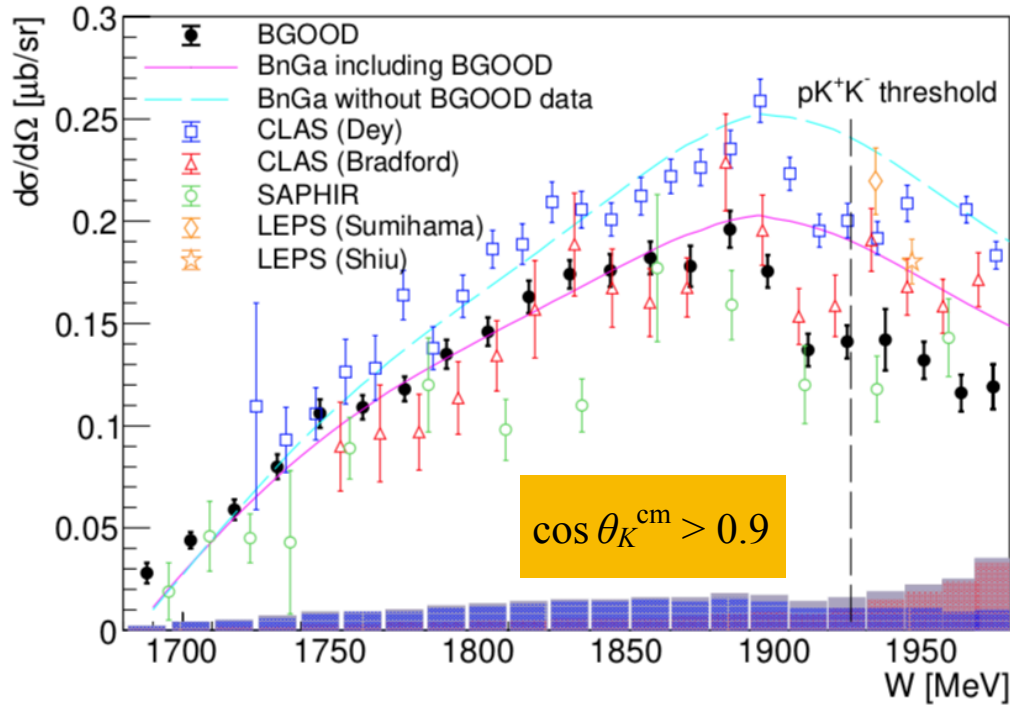


$K^+ \Sigma_{g.s.}$ photoproduction

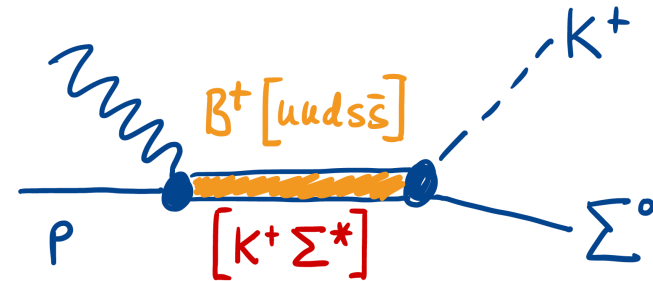
Multi-quark states

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

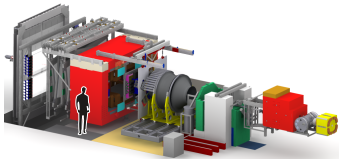
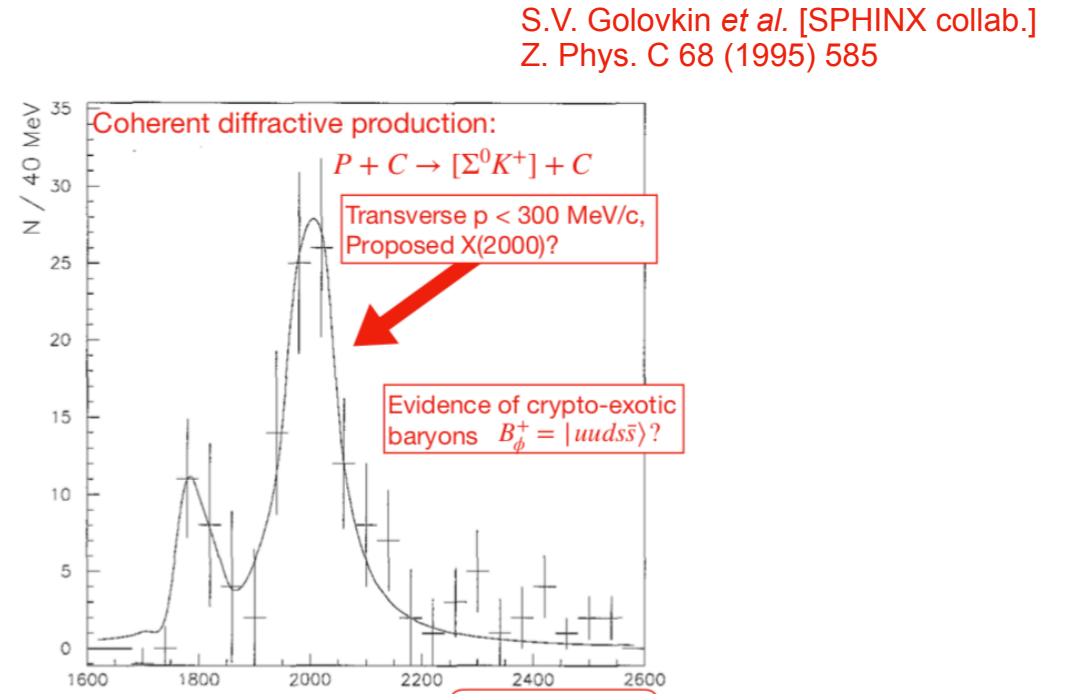
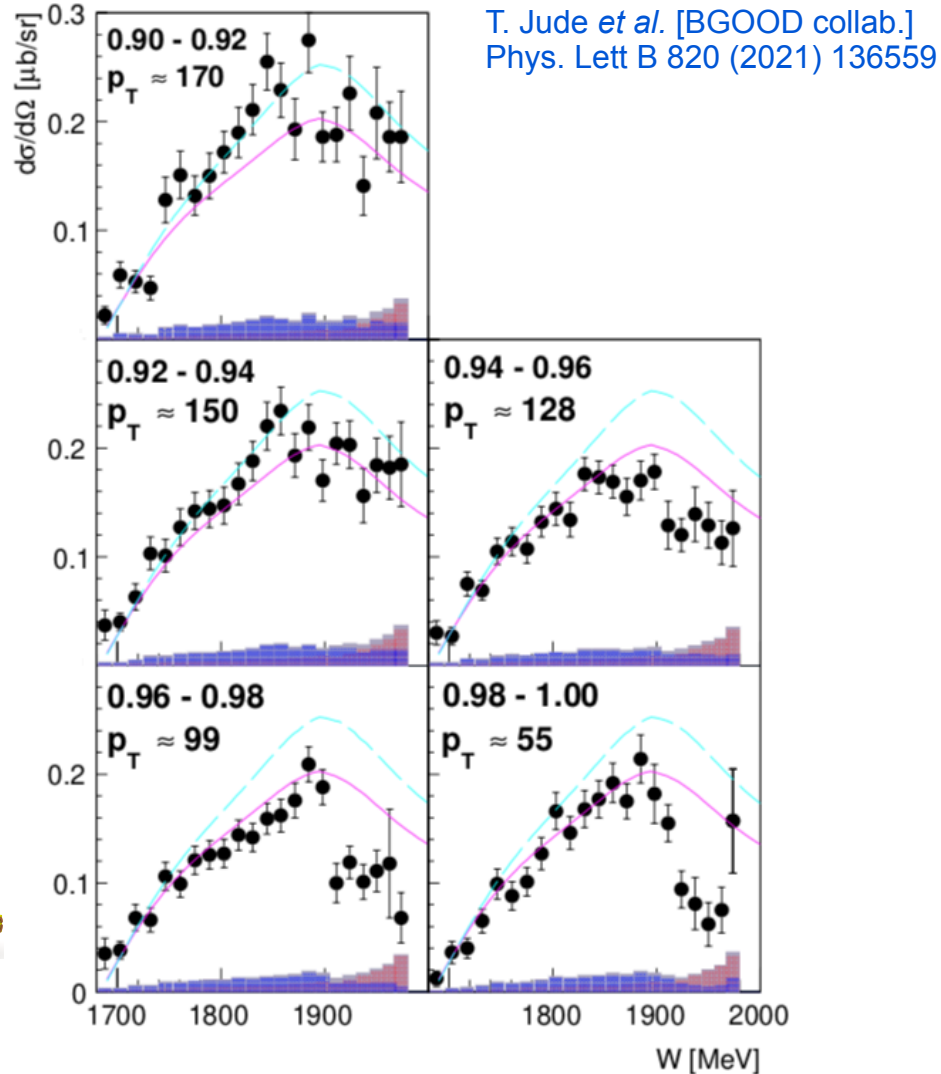


BGOOD

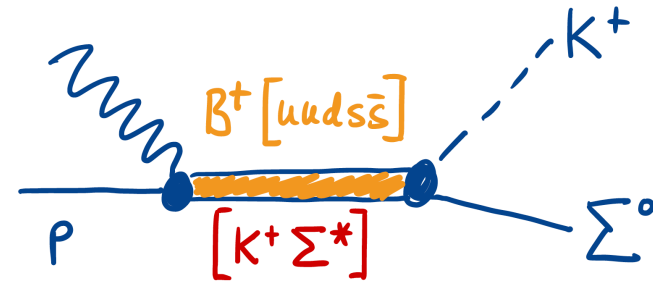


K⁺ Σ_{g.s.} photoproduction

Multi-quark states



BGOOD

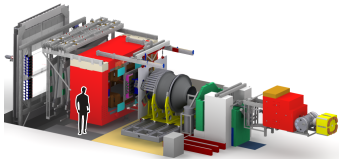
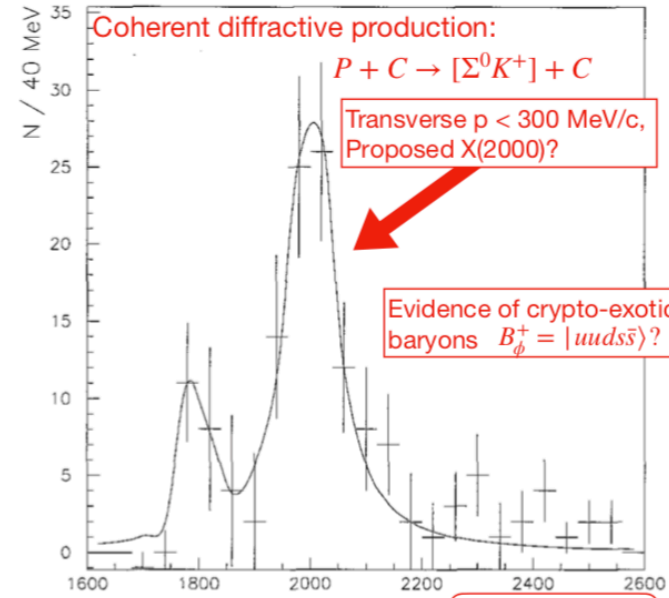
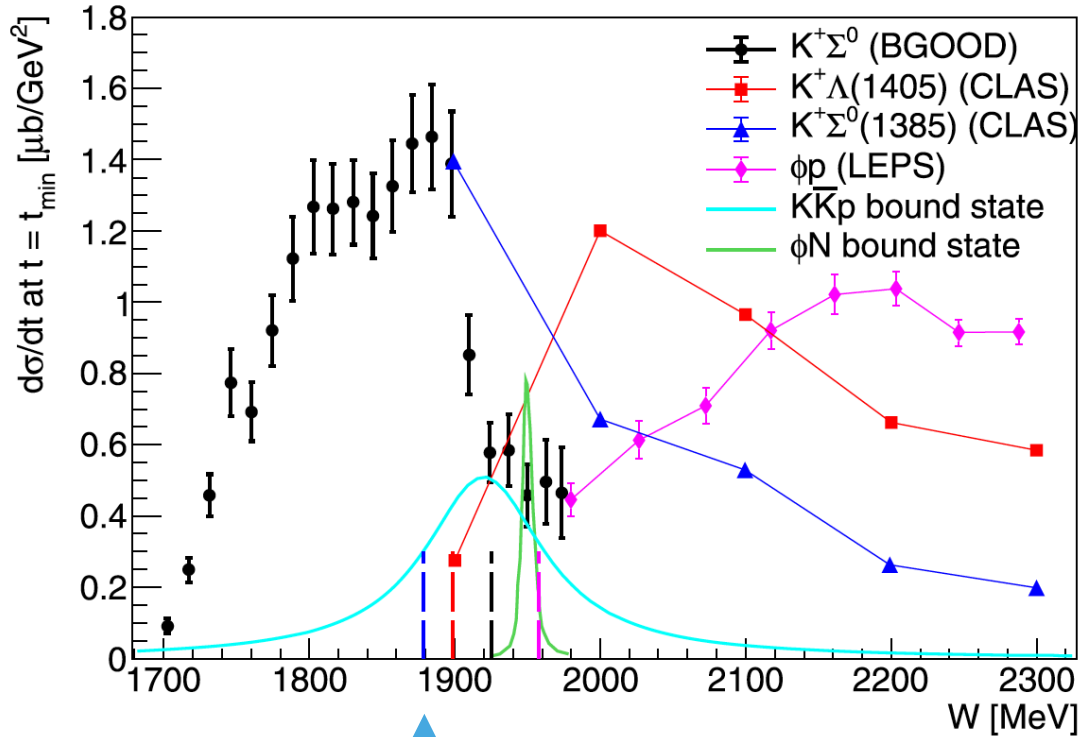


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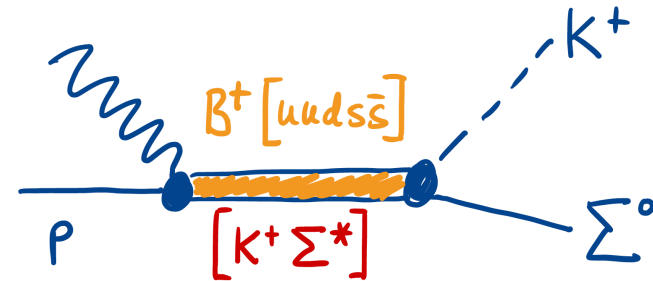
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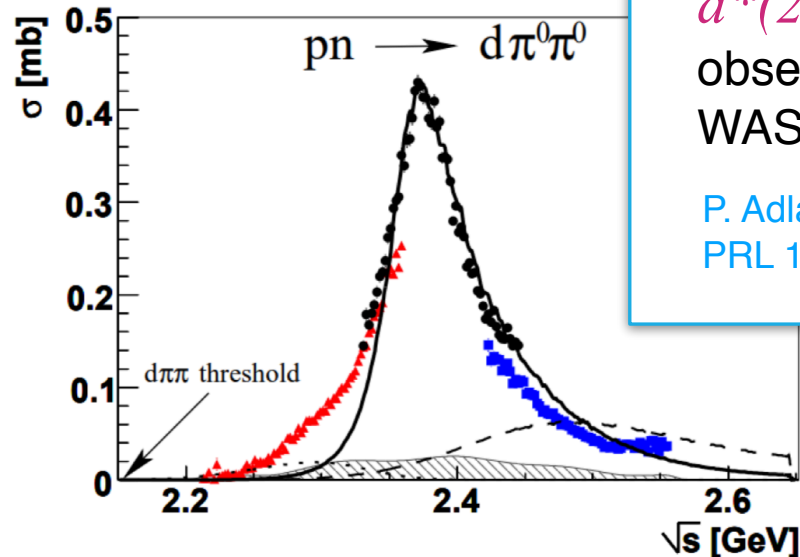
BGOOD



Dibaryons ?

Multi-quark states \rightarrow from penta to hexa ...

- early SU(6) predictions – NN, N Δ & $\Delta\Delta$ type dibaryon candidates
Dyson & Xuong, PRL 13 (1964) 815
- 3-body calculations N Δ & $\Delta\Delta$ 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

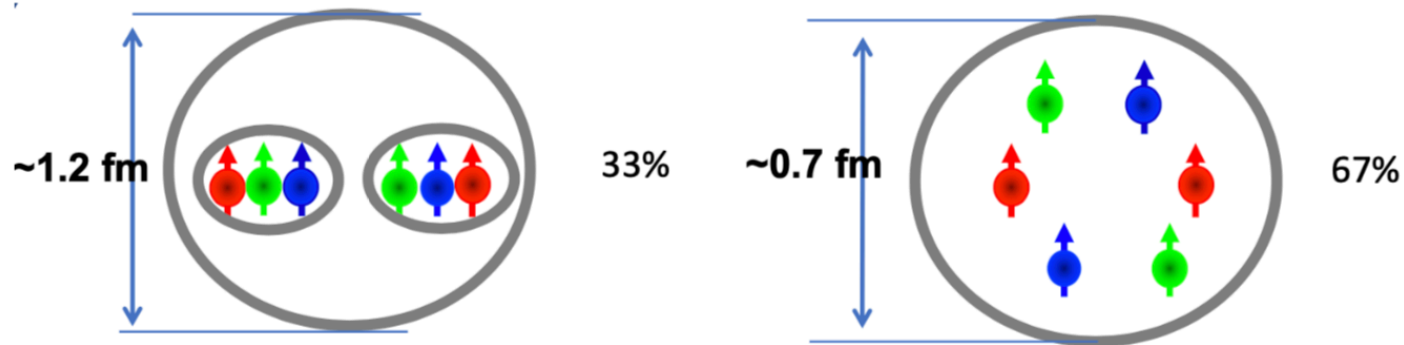
- $(I) J^P = (0) 3^+$
- $\Delta\Delta$ type object ?
- triangle singularity ?
- meanwhile observed in multiple final states in pn reactions

Dibaryons ?

Multi-quark states \rightarrow from penta to hexa ...

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

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

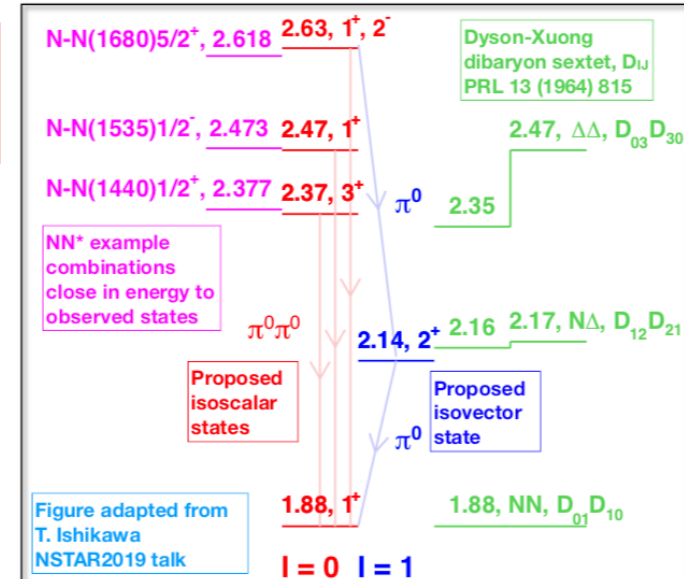
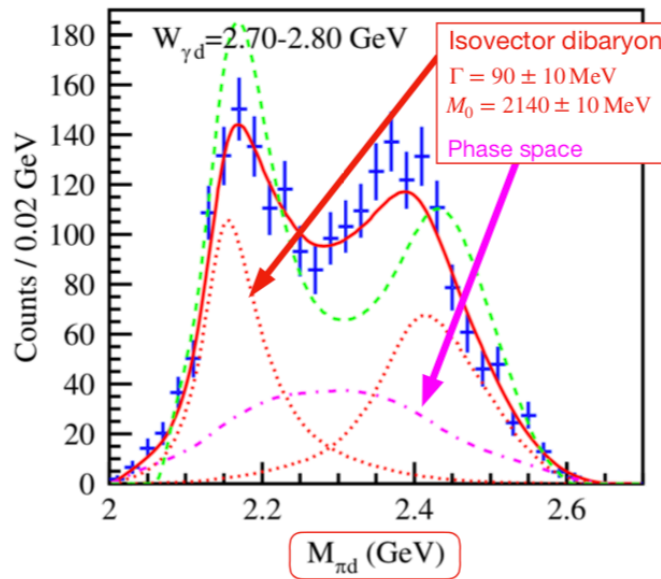
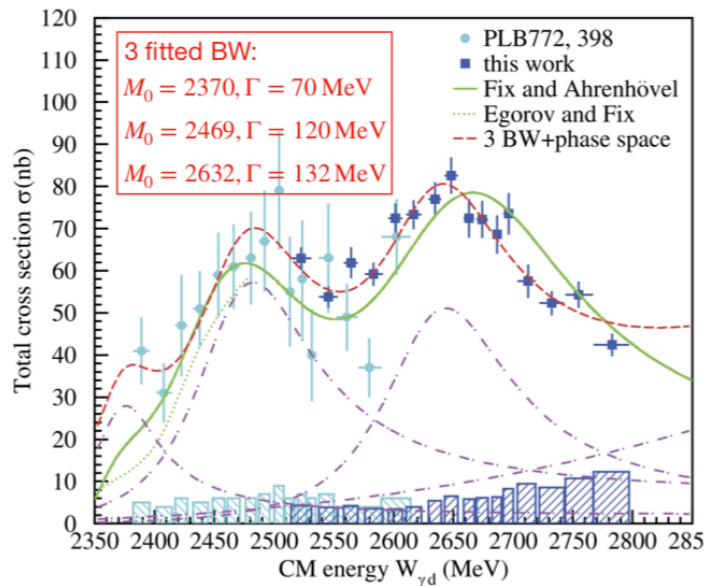


- $d^*(2380)$ in the centre of neutron stars
Vidana et al., PLB 781 (2018) 112
- Dark matter ?? – $d^*(2380)$ BEC formed in early universe ?
Bashkanov and Watts, J. Phys. G 47 (2020) 03LT01

Dibaryons ?

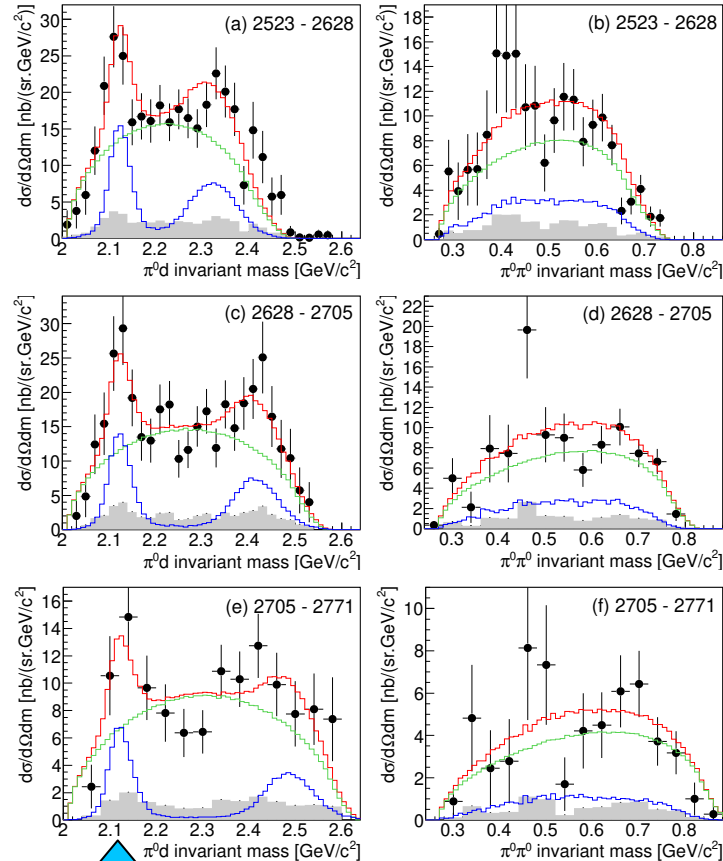
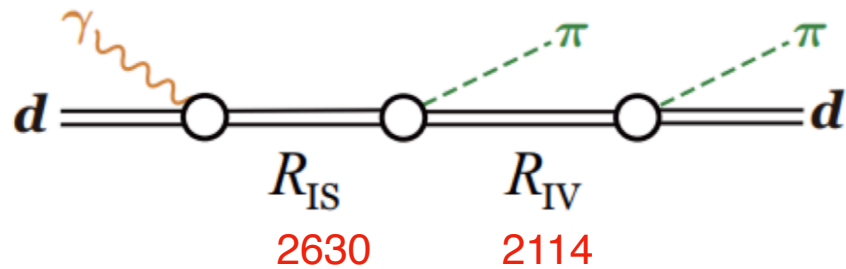
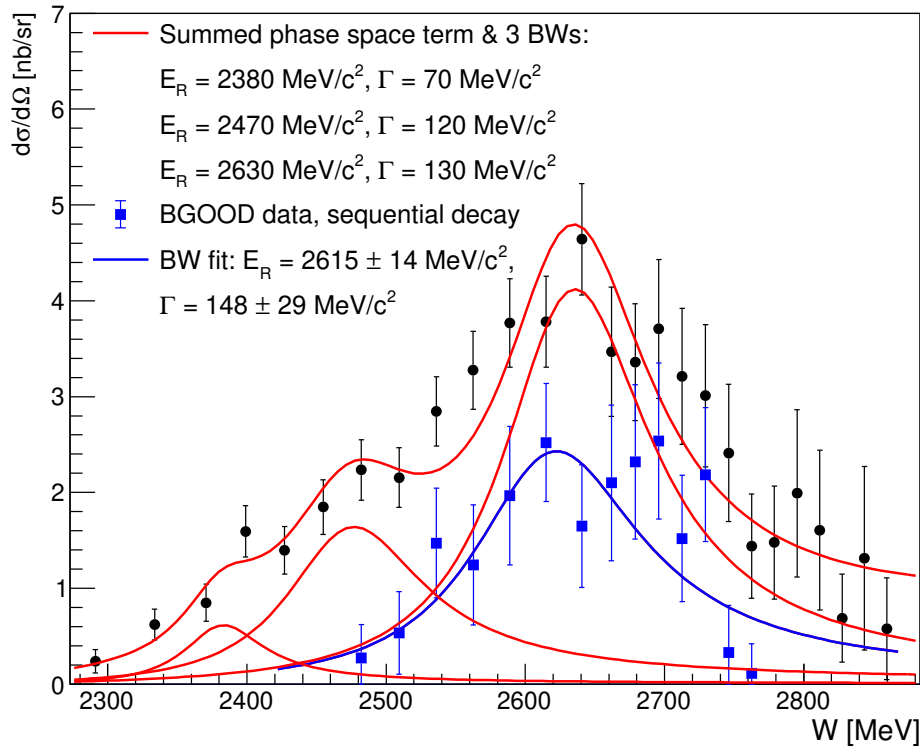
Multi-quark states \rightarrow from penta to hexa ...

- 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



$\gamma d \rightarrow d \pi^0 \pi^0$ coherent photoproduction @BGOOD

Multi-quark states \rightarrow from penta to hexa ...



$\pi^0 d$ isovector state: 2114 MeV, $\Gamma \approx 20 \text{ MeV}$

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

TA4 – Transnational Access to FTD/ELSA

Possibilities/needs of another request for the extension of the project (beyond 30 November 2023)

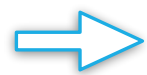
Aspects from TA4

- present limitations from Putin & his clique's war on Ukraine
- co-operation with Russian groups (Moscow & St. Petersburg) suspended
- detector developments (aerogel Cherenkov / drift chambers) halted
- lack of manpower for data taking (DFG helped!)
- power costs (offer for 2024: electricity cost up by factor 5 – 7)
- direct support possible from Strong-2020 for Ukrainian refugee ??
- ELSA planned LS-2023/24

TA4 – Transnational Access to FTD/ELSA

Summary

- multi-quark projects w/ BGOOD experiment
- forward acceptance \leftrightarrow meson-baryon dynamics @ thresholds & low t / p_T
- effects of multi-quark states in uds sector
- possible $[K^*-\Sigma]$ configuration $N^*(2030)$ in $K^0\Sigma^0$ and $K^+\Lambda(1405)$ photoproduction
- possible $[K-\Sigma^*(1385)]$ configuration in $K^+\Sigma^0$
- possible dibaryon transitions in coherent $2\pi^0 d$
- hadronic structure formation from basic QCD ?



meson-baryon & baryon-baryon interactions at thresholds do play a significant role in uds similar to c sector

TA4 – Transnational Access to FTD/ELSA

BACKUP



K⁺ Λ(1405) photoproduction – line shape

Multi-quark states

double peak structure
@ 1395 / 1425 MeV ??

G. Scheluchin *et al.* [BGOOD collab.]
Phys. Lett B 833 (2022) 137375

