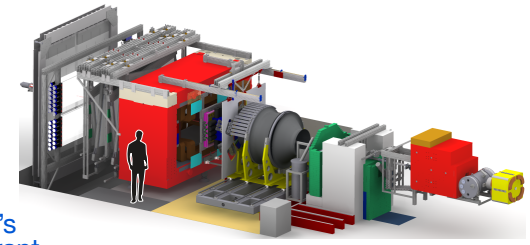
The BGOOD experiment at ELSA

- multi-quark structures in the baryon uds sector ?

Hartmut Schmieden
Physikalisches Institut
Universität Bonn

Outline

- motivation
- BGOOD experiment
- recent results
- summary

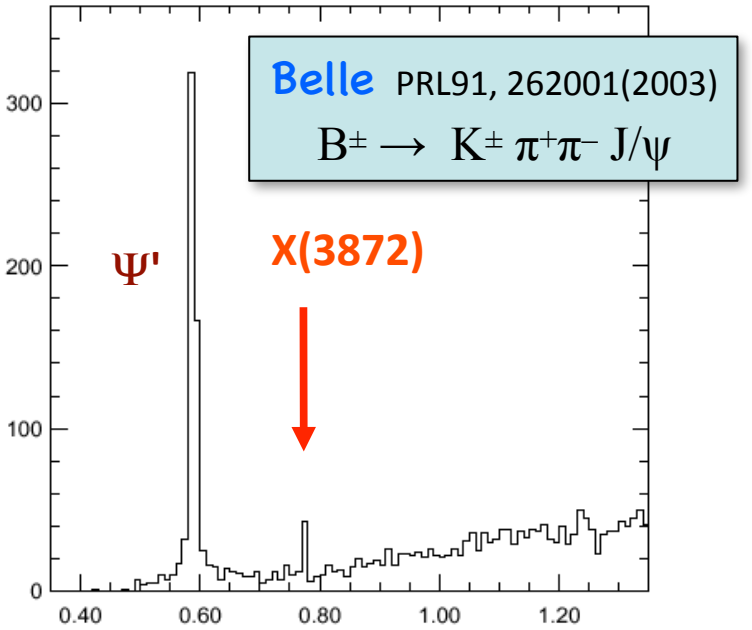


supported by DFG
PN 50165297 and
PN 405882627

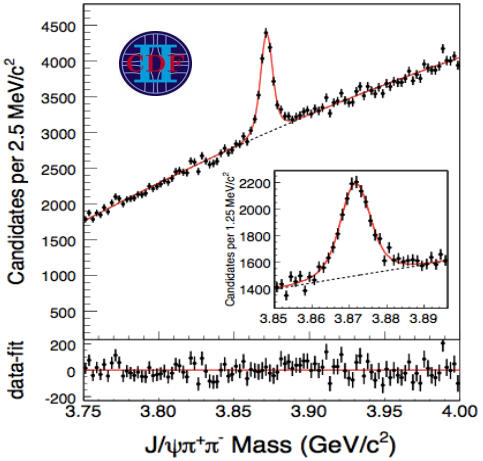
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093

Motivation: c-quark sector

X(3872)

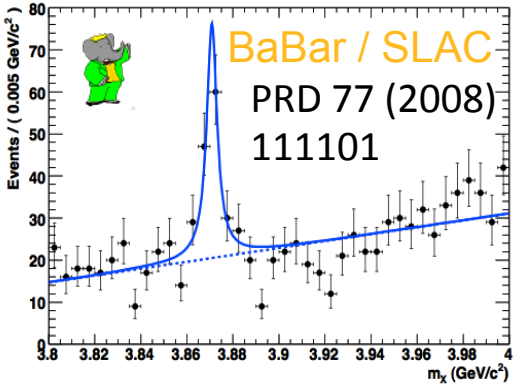


M(π⁺π⁻l⁺l⁻) – M(l⁺l⁻)



CDF / Tevatron

PRL 103 (2009) 152001



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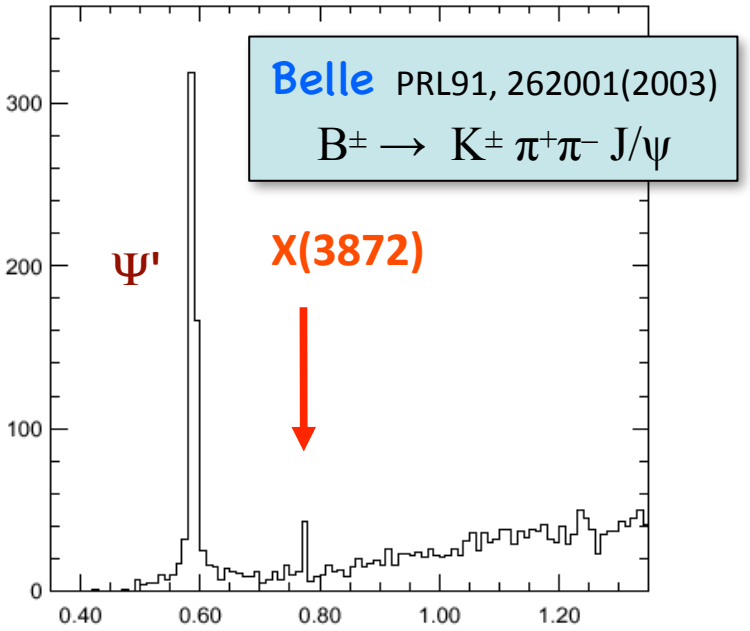
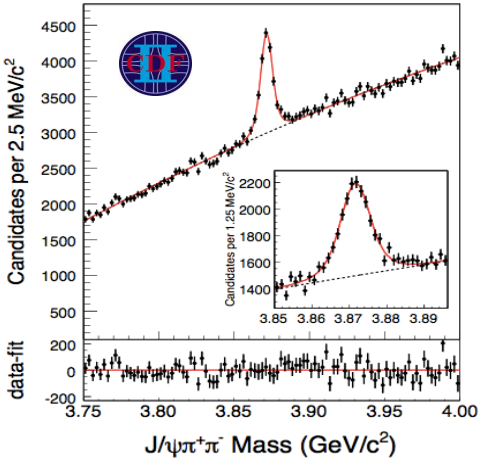


$M(\pi^+\pi^- l^+ l^-) - M(l^+ l^-)$



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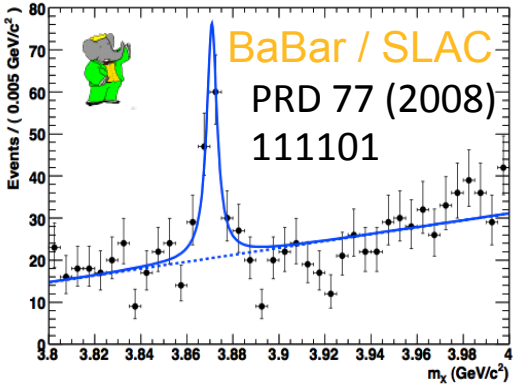
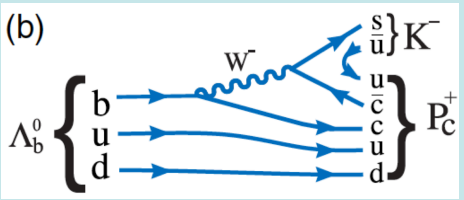


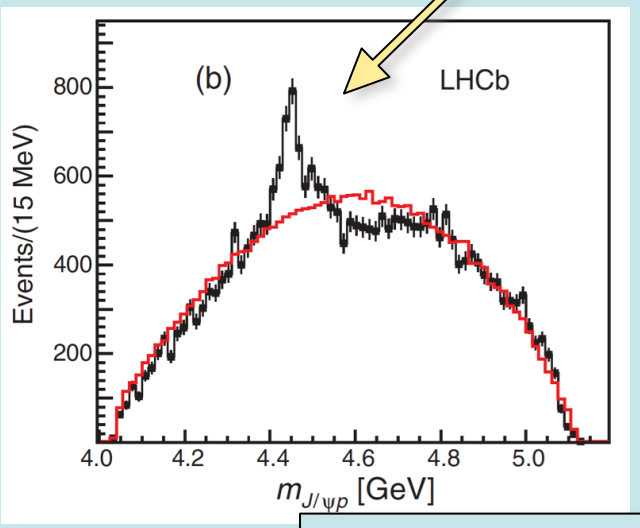
$P_c^+(4380, 4450)$

PARTICLE PHYSICS

Forsaken pentaquark

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





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 ..."

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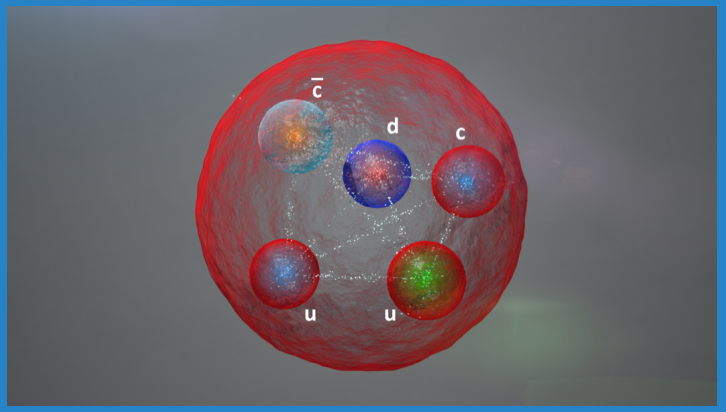
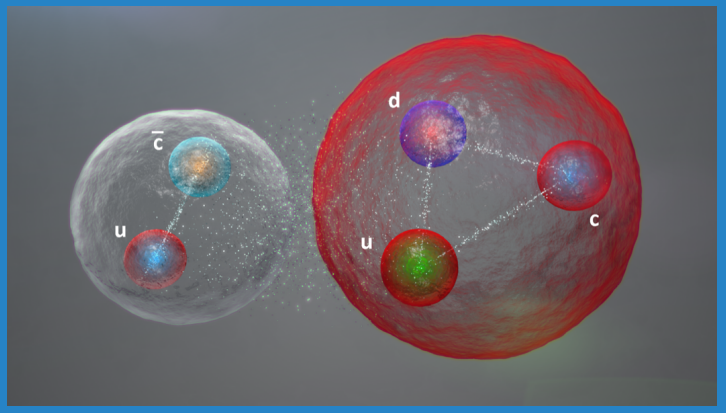




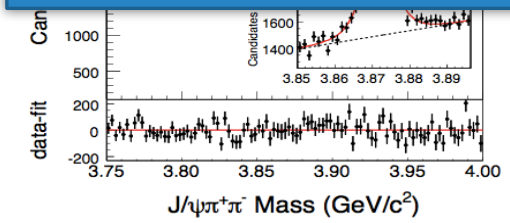
- 5-quark structures definitely observed
- (hidden) c-quark sector
- similar 4-quark states in meson sector
- structure/binding mechanism under debate

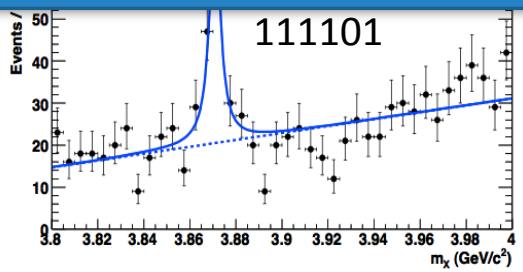
→ paradigm change in hadron physics

→ general feature of structure formation in QCD ?

→ similiar structures in (hidden) s-quark sector ??

but: – mass pattern D – D* / K – K* and
– widths D* – K* different





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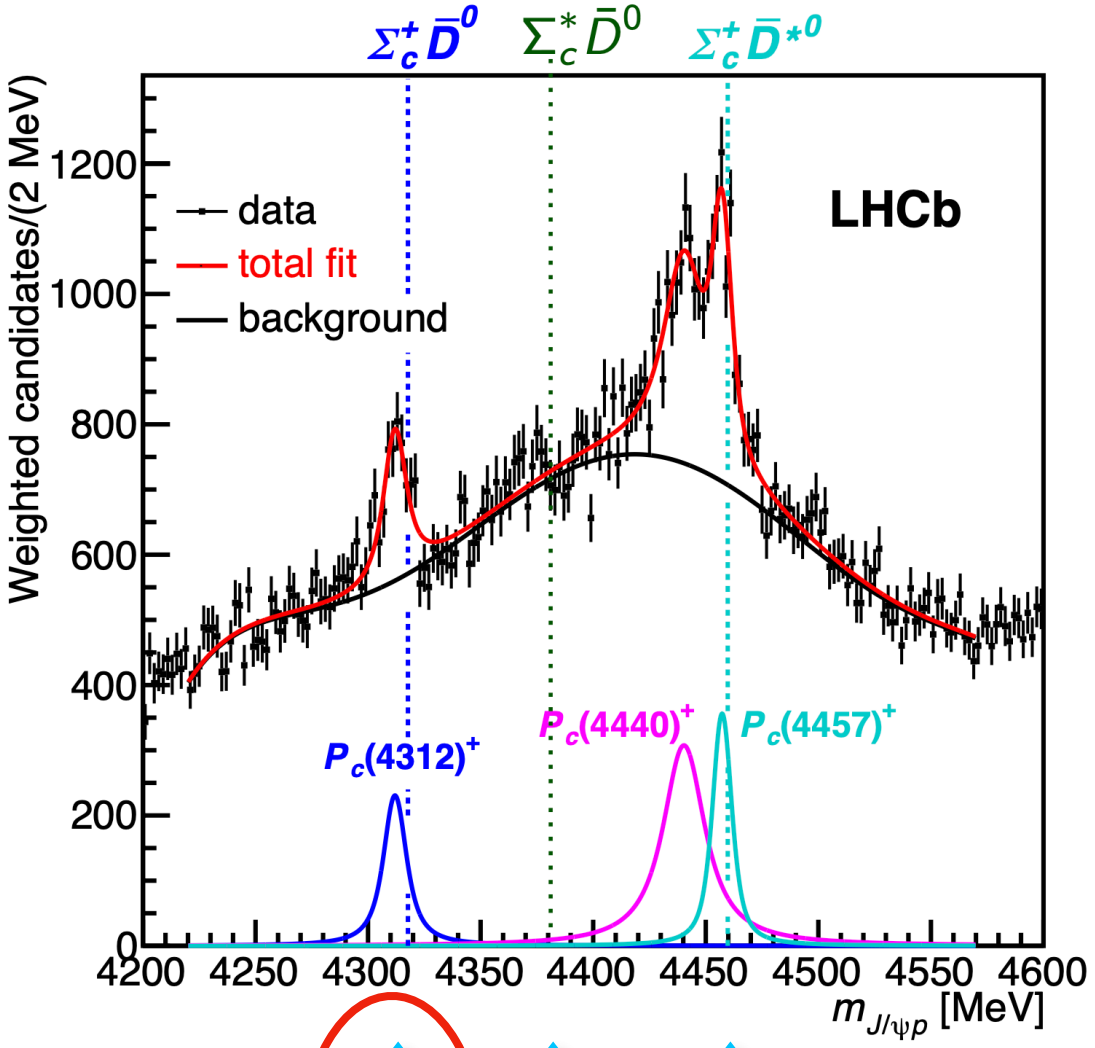

Meng-Lin Du et al.,
PRL 124 (2020) 072001

Hadronic molecules & HQSS

LHCb data: PRL 122 (2019) 222001

uds sector N*(1535) Σ K Σ* K Σ K*

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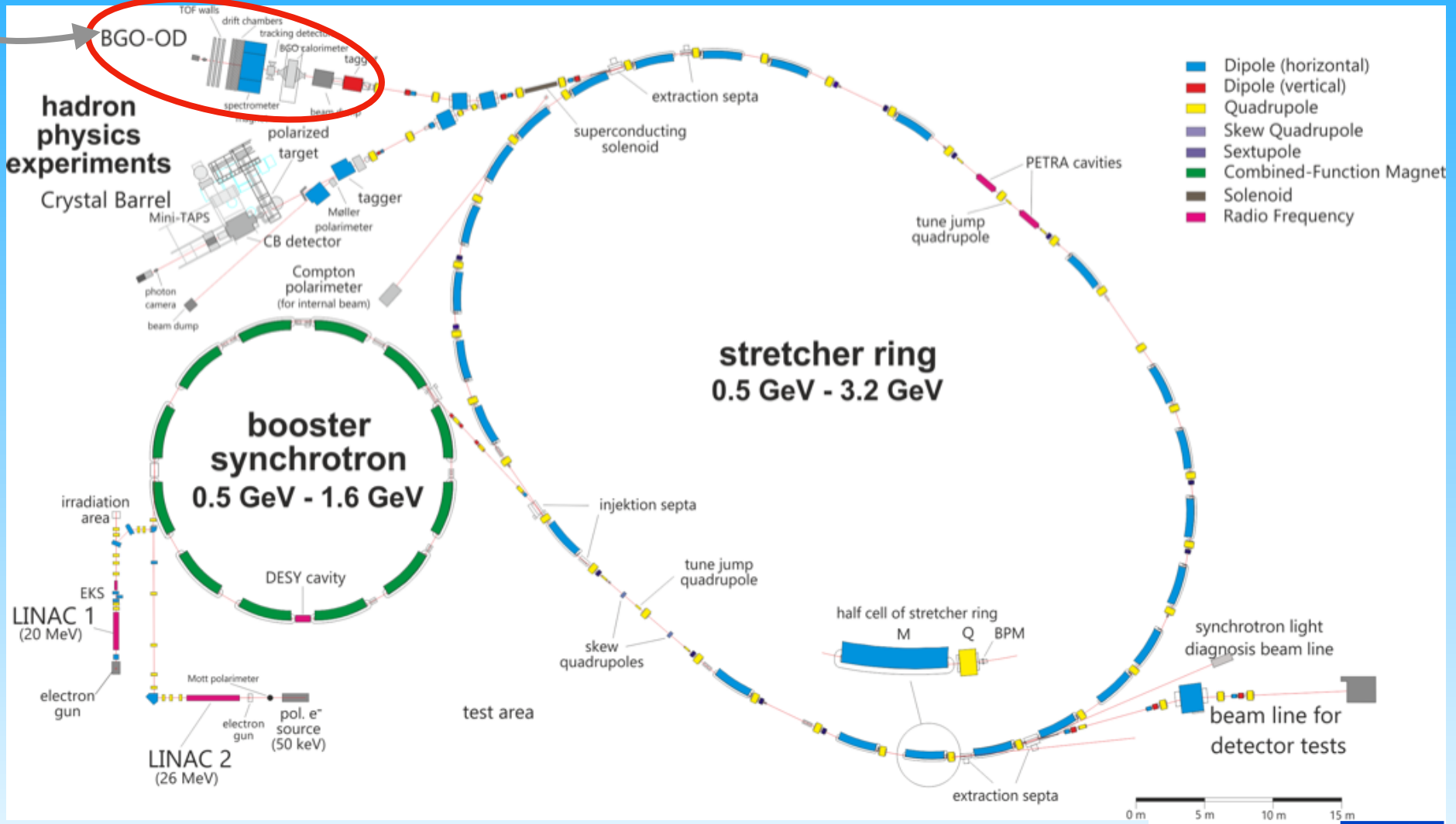
BGOOD experiment

located at ELSA
electron accelerator
Physikalisches Institut
Universität Bonn



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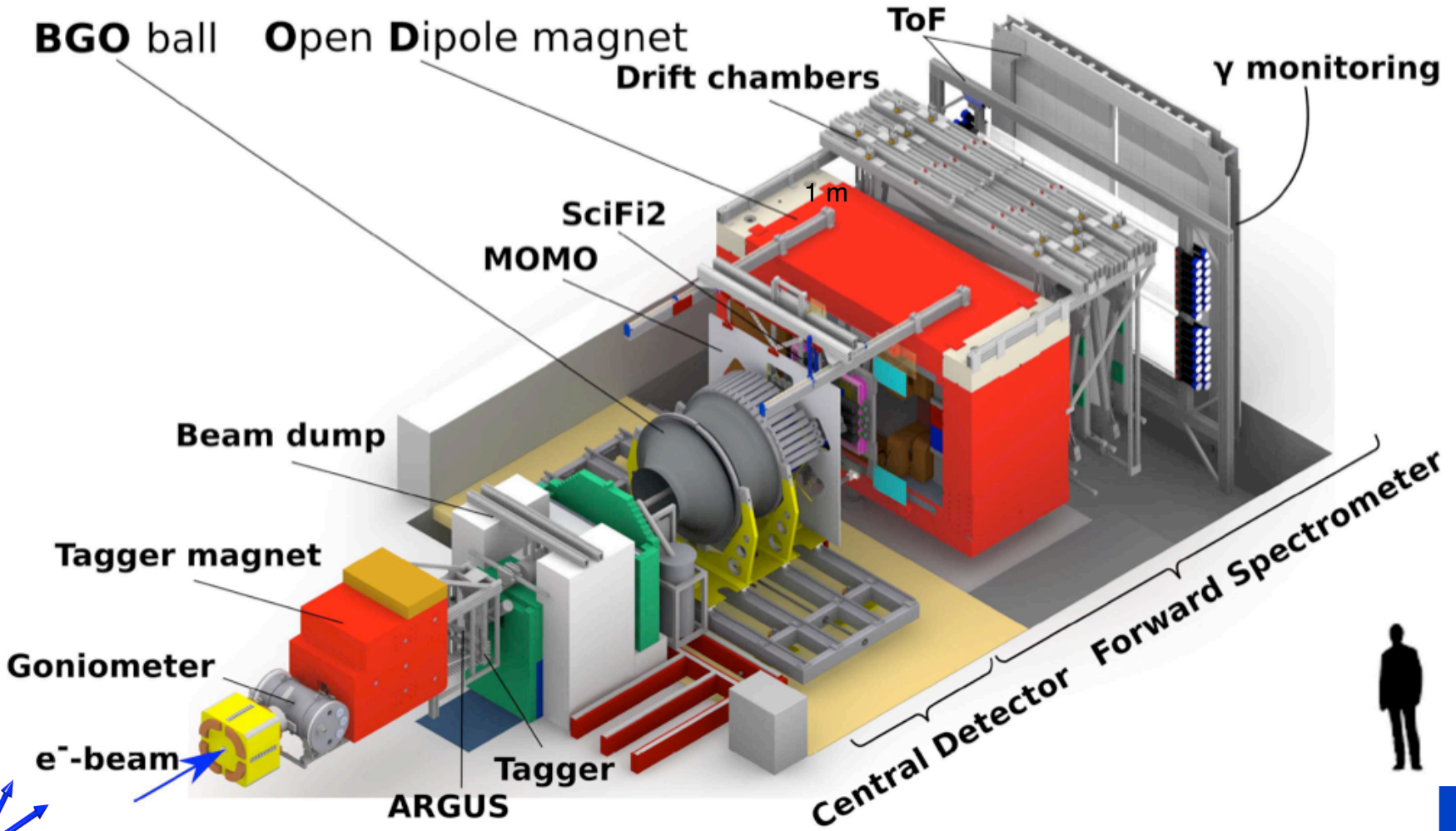
BGOOD experiment

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

spokespersons: P. Levi Sandri (Frascati) & T. Jude (Bonn)

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



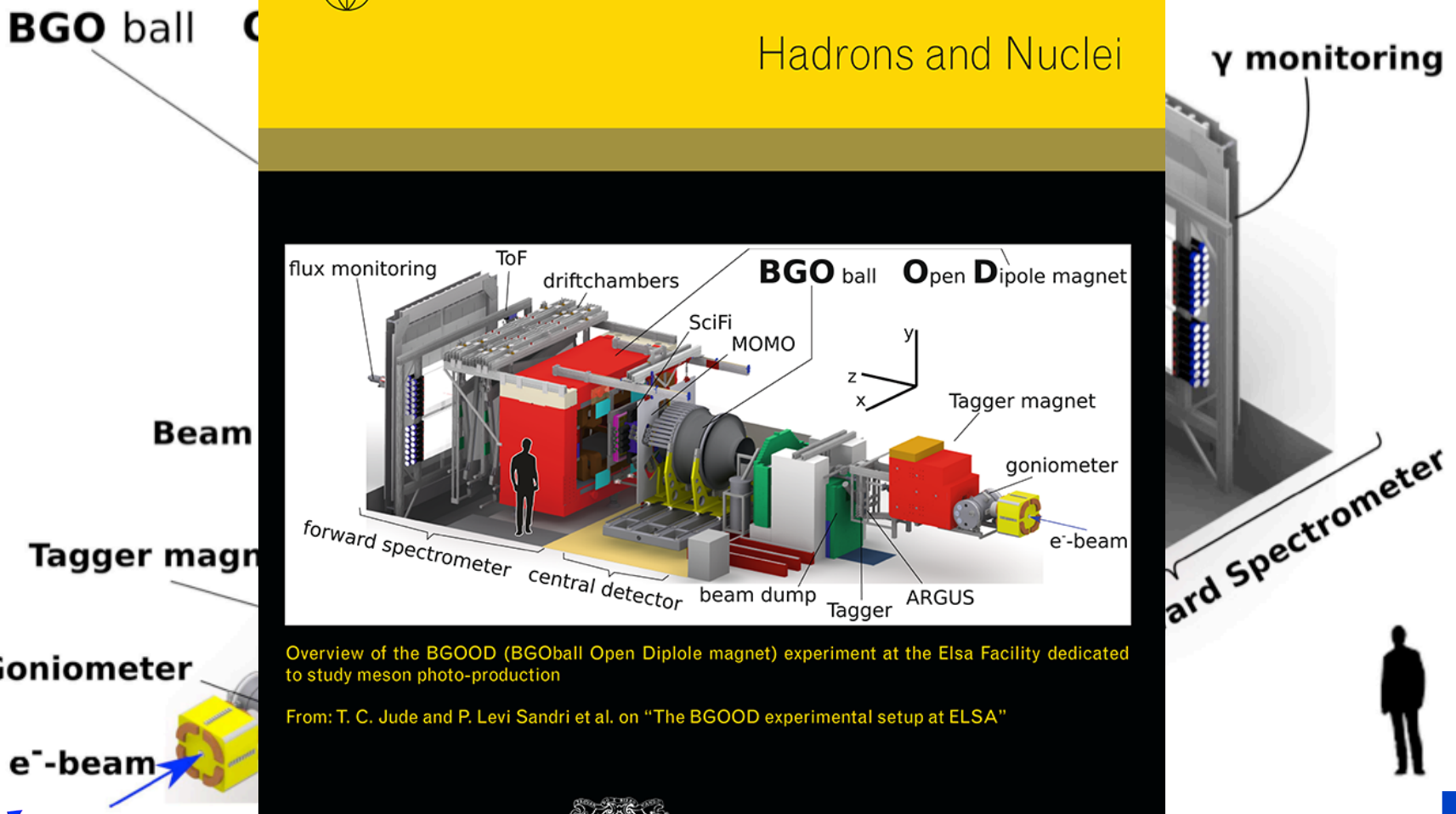
BGOOD experiment

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

P. Levi Sandri (Frascati) &
T. Jude (Bonn)

- combination
- high moment

trometer
particle id



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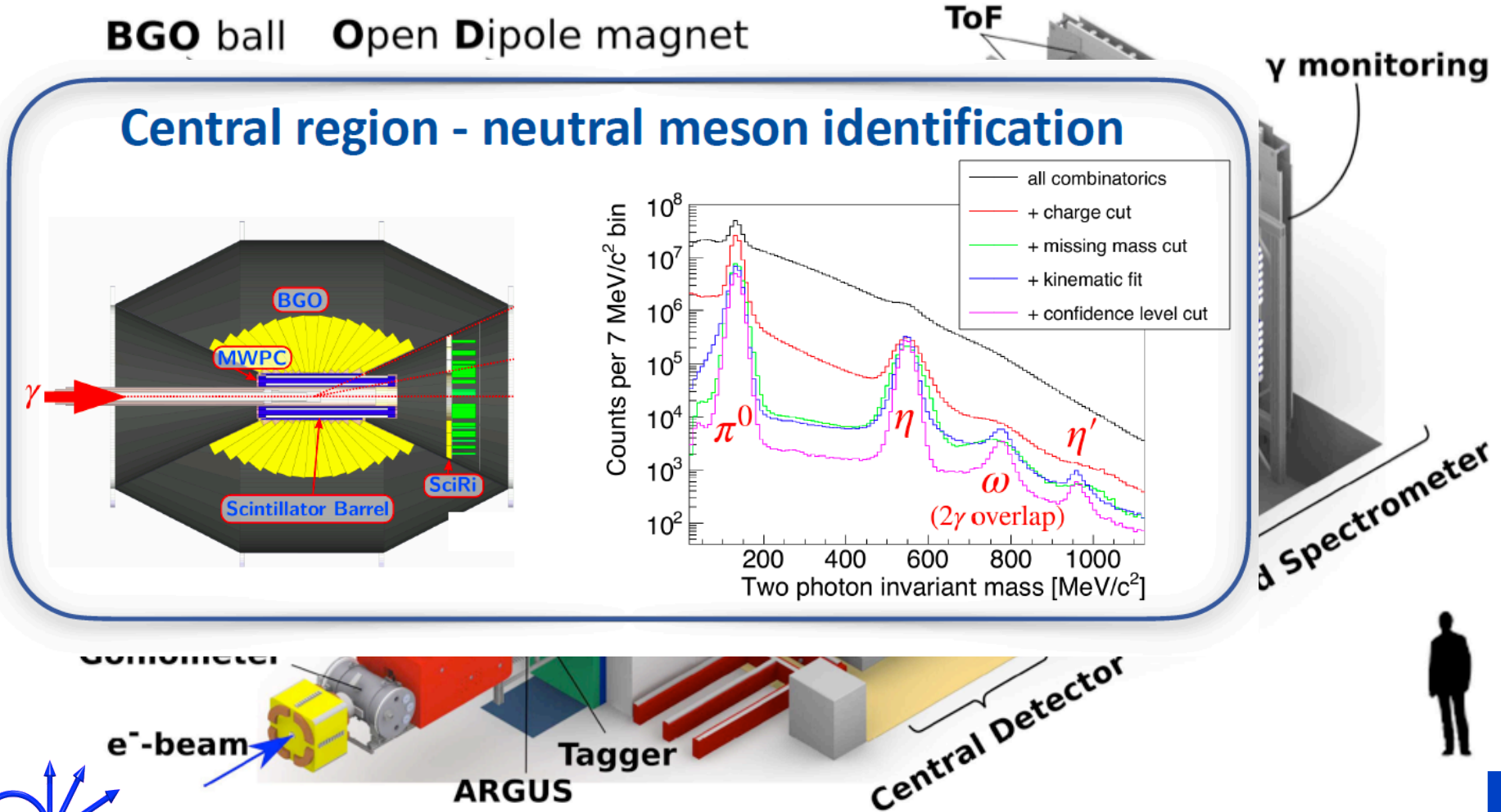

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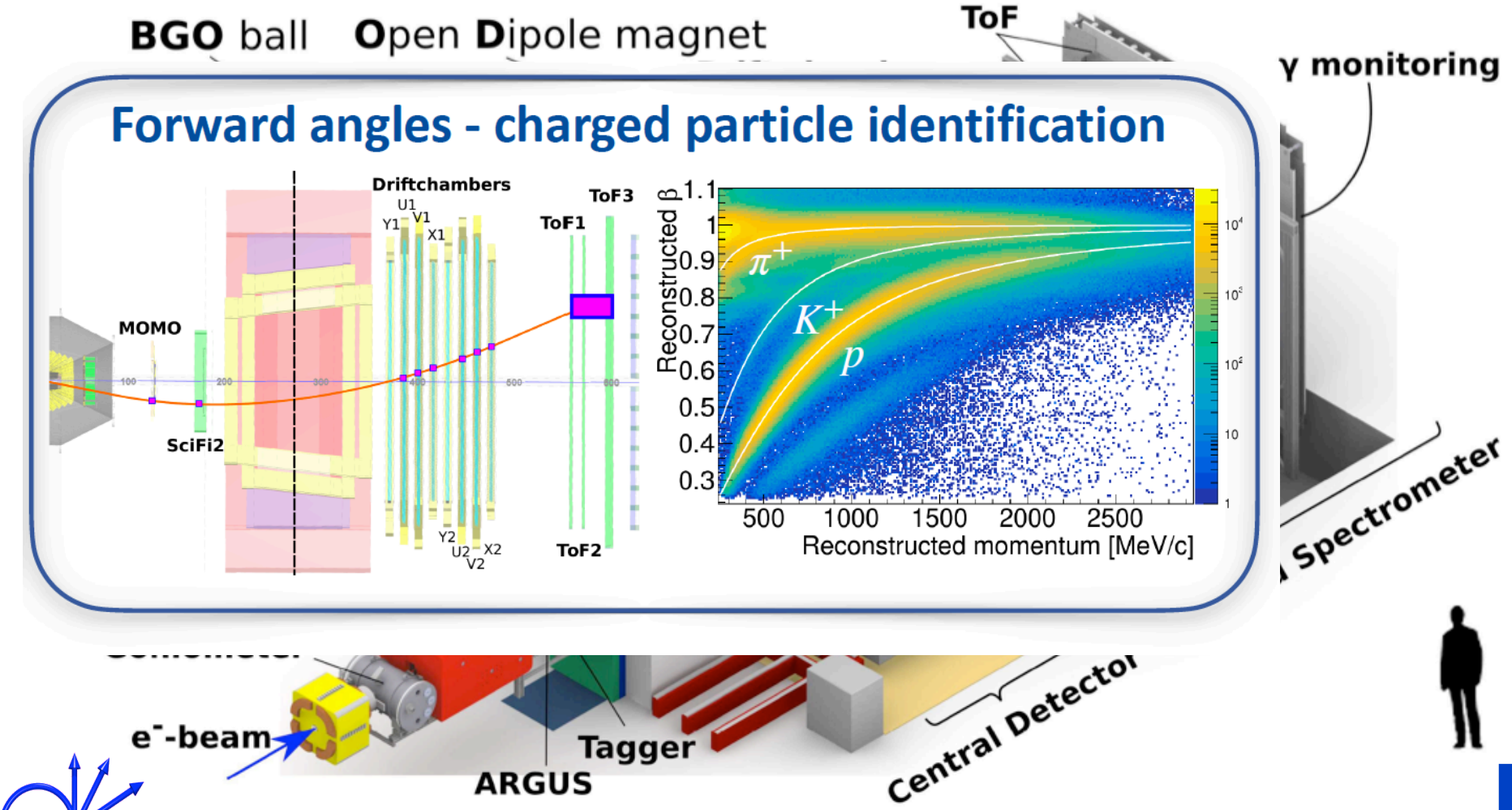
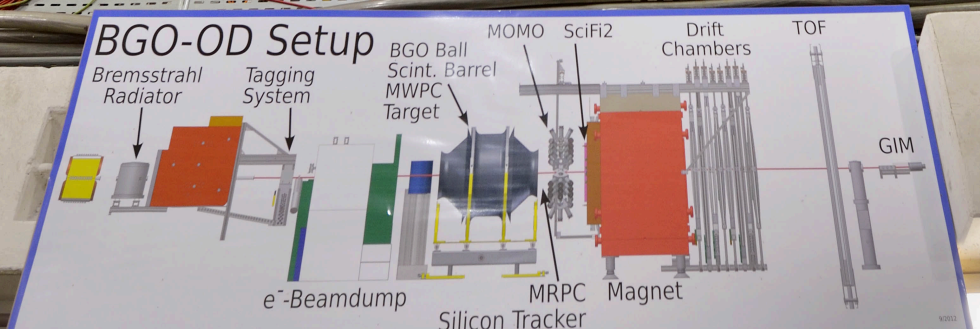


BGOOD experiment at ELSA

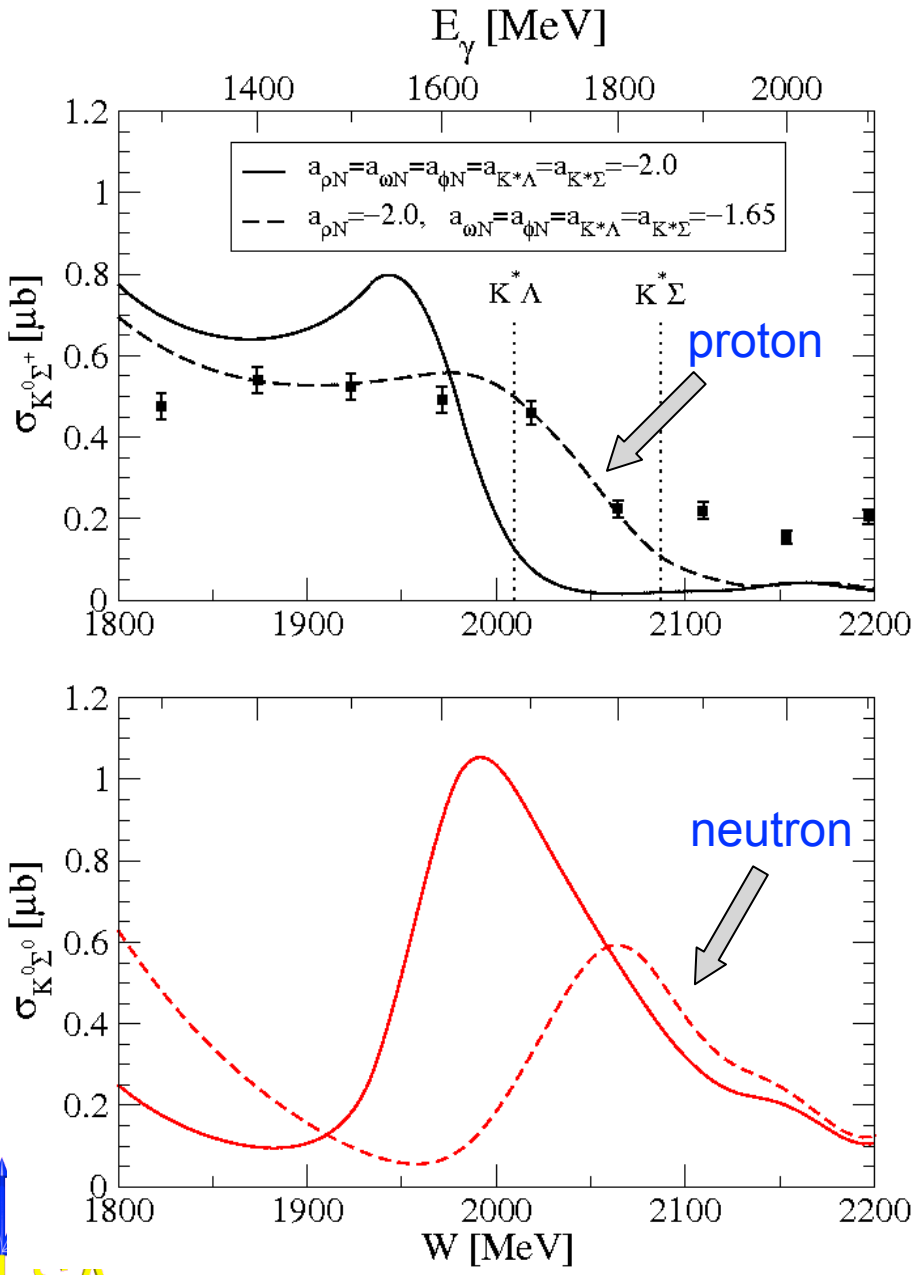


BGOOD

BGOOD experiment

- recent results

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

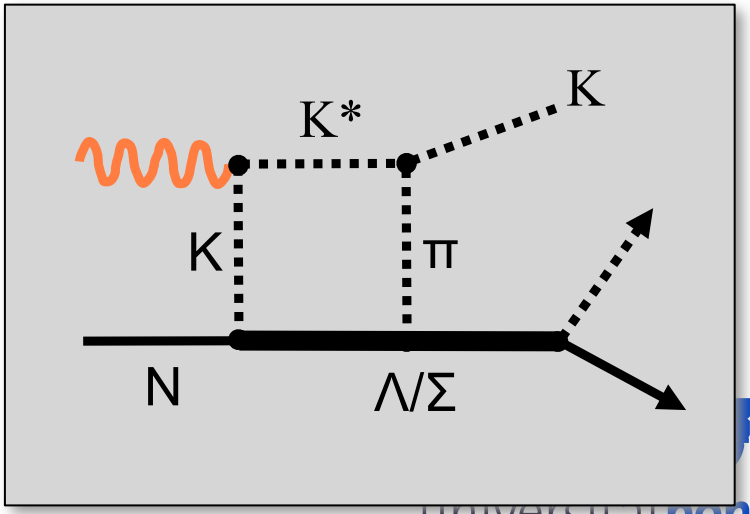


data:
R. Ewald et al. (CB/TAPS), PLB 713 (2012)

Ramos & Oset,
PLB 727 (2013) 287

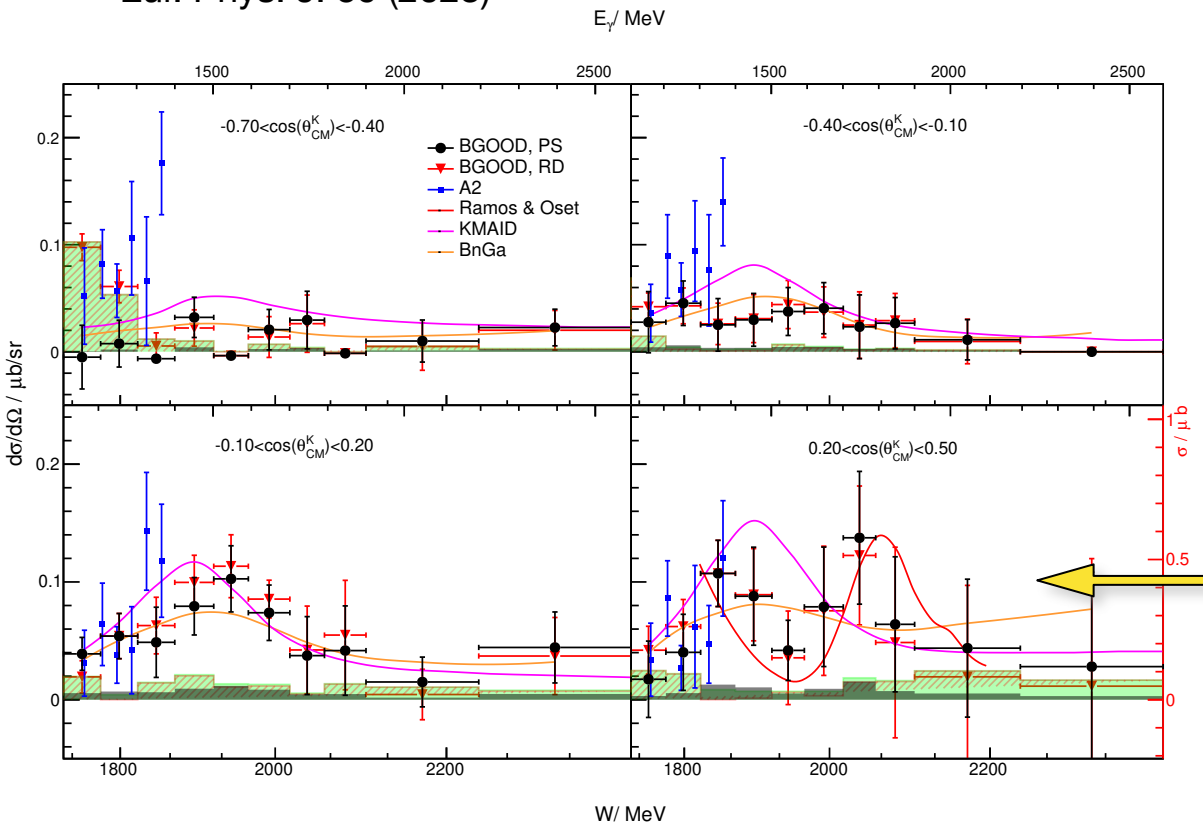
same model as LHCb P_c w/ c ↔ s

N*(2030) / N*(2080)



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

K. Kohl et al. [BGOOD]
Eur. Phys. J. 59 (2023)



BGOOD simulated bg fit

BGOOD real bg fit

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

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

same model as LHCb P_C w/ c ↔ s

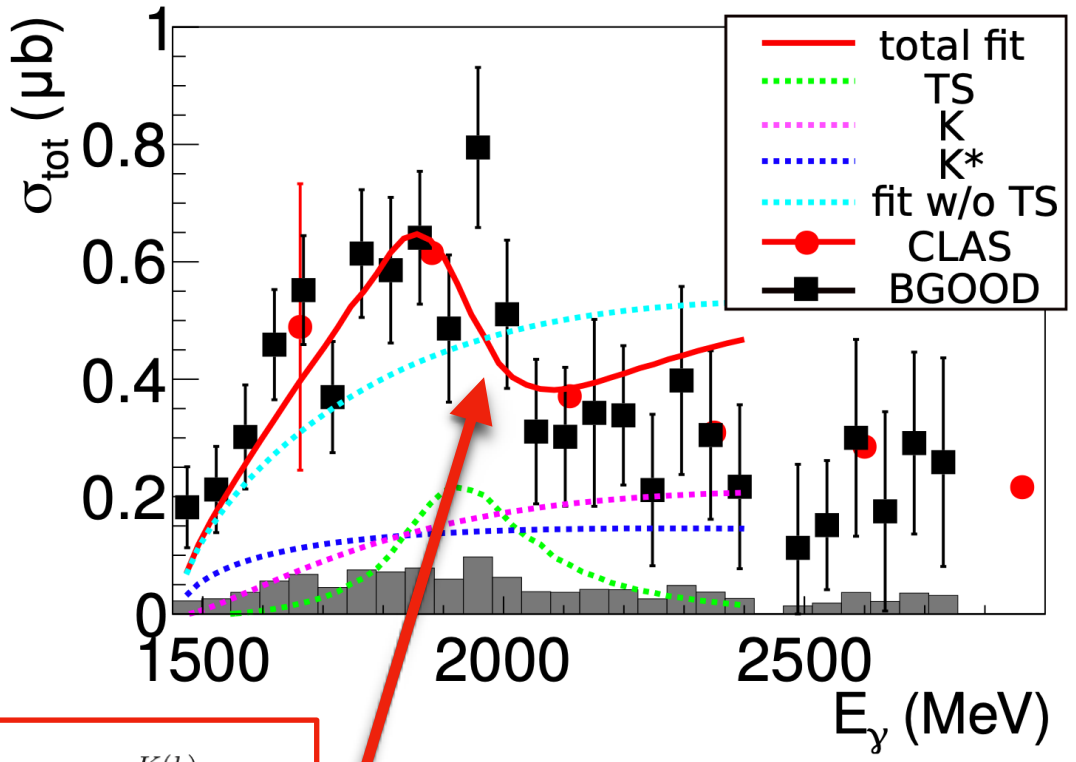
smoking gun "pentaquark", if …

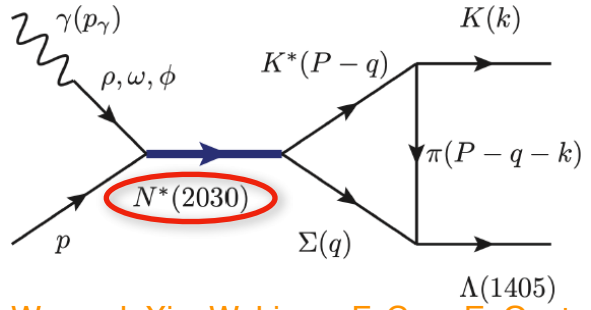
meanwhile: 2x statistics availabe & under analysis

$K^+ \Lambda(1405)$ – photoproduction mechanism

$K^+ \Lambda(1405)$ photoproduction – total x-sec

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

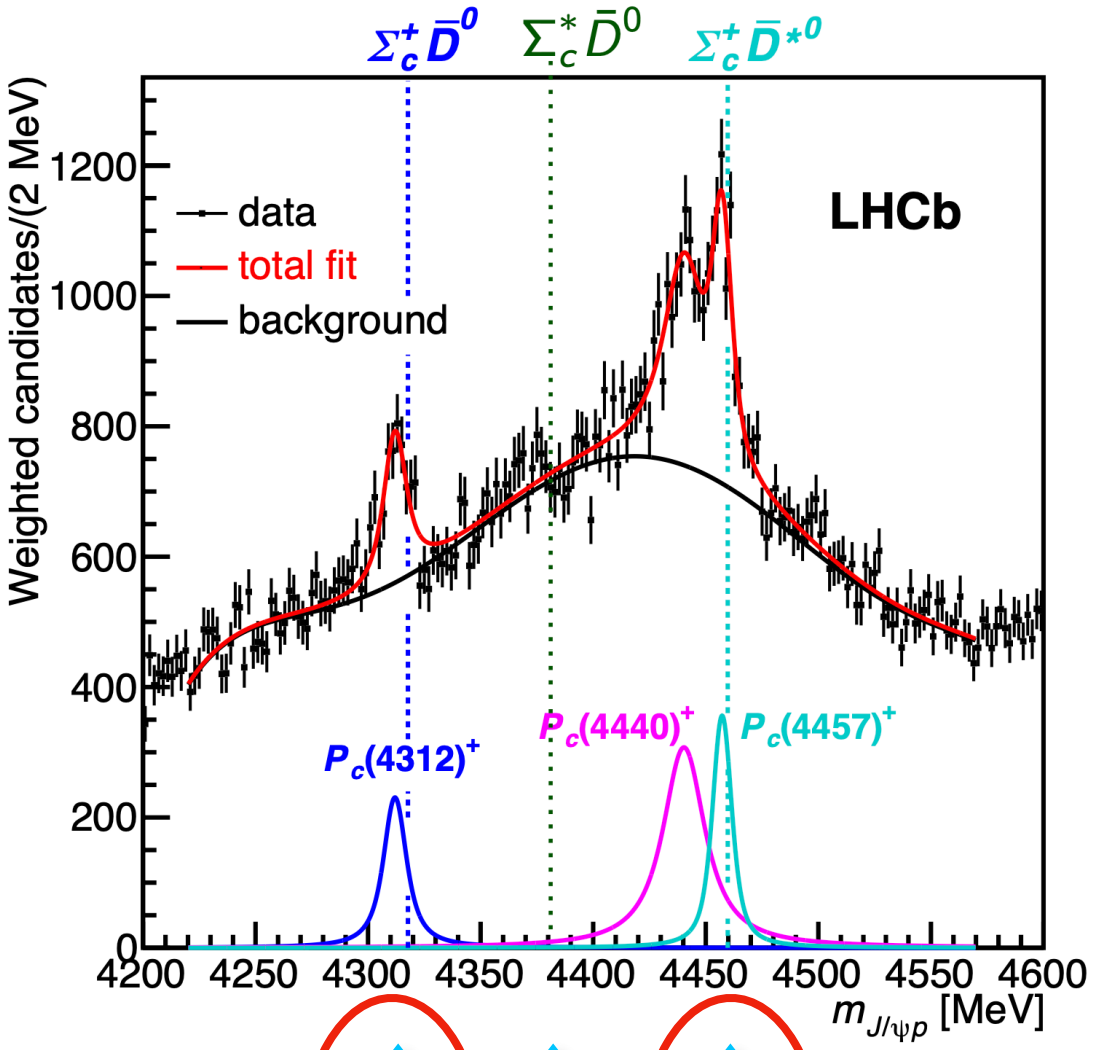




E. Wang, J. Xie, W. Liang, F. Guo, E. Oset,
PR C 95 (2017) 015205

cusp: triangle meachanism significant

reminder: LHCb



Meng-Lin Du et al.,
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LHCb data: PRL 122 (2019) 222001

uds sector N*(1535) Σ K Σ* K Σ K* N*(2030/80)

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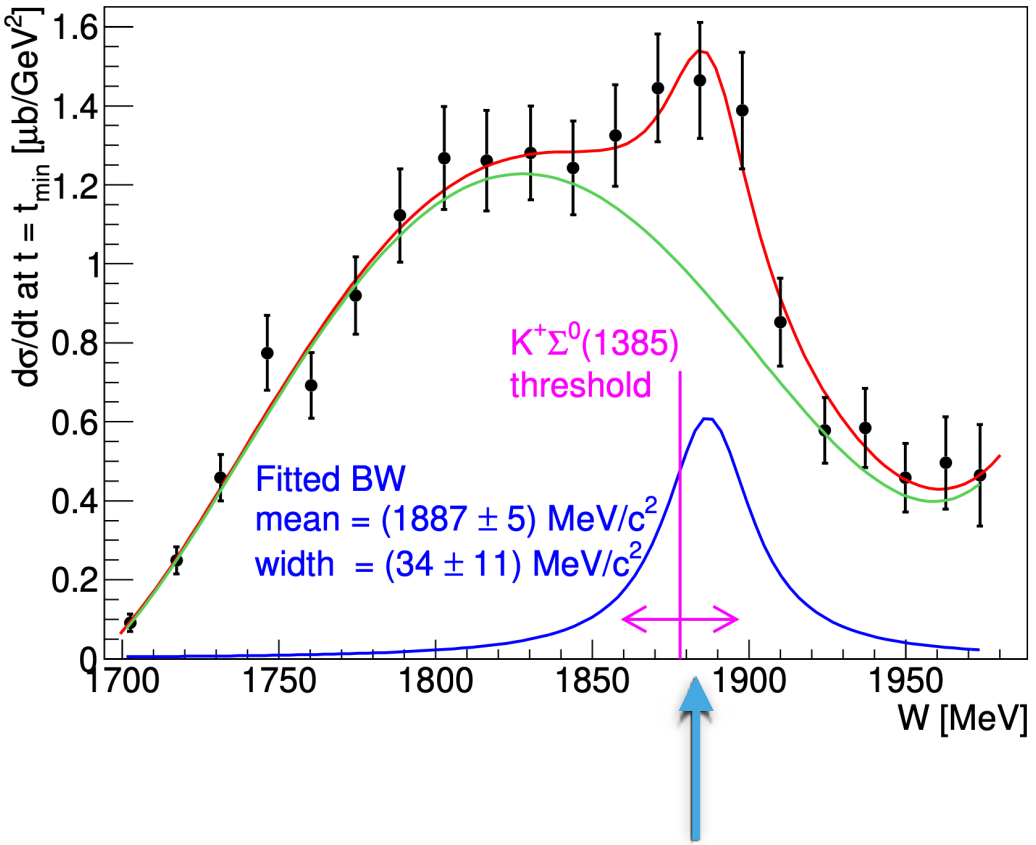
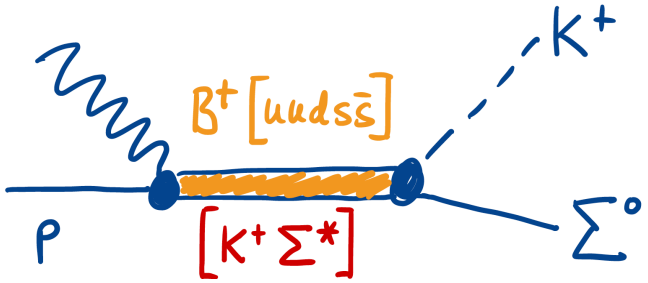
$\gamma p \rightarrow K^+ \Sigma^0$ photoproduction



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

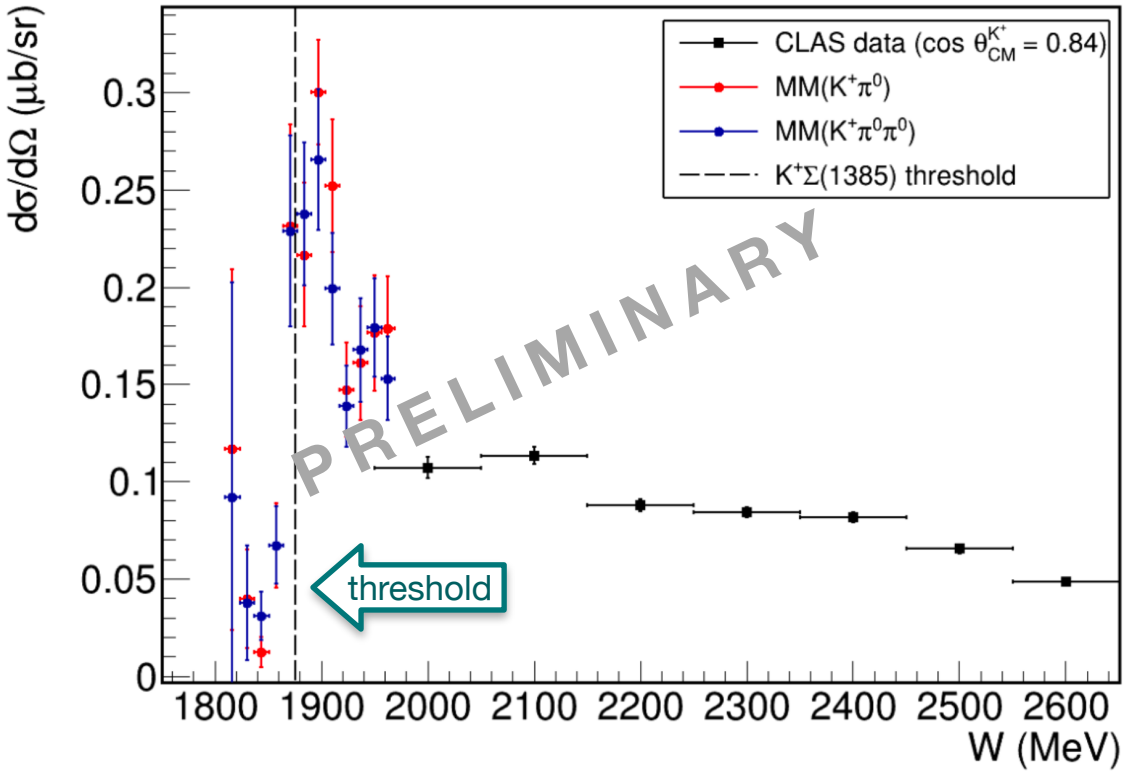


$\gamma p \rightarrow K^+ \Sigma^{0*}(1385)$ photoproduction

$\gamma p \rightarrow K^+ \Sigma^*(1385)$ at $\Sigma^*(1385)$ threshold

M. Jena Masters thesis (Bonn 2024), data preliminary

- Differential cross section for $\cos\theta^K_{\mathrm{CM}} > 0.9$
- First data from threshold
- large peak at $W \approx 1900\,\mathrm{MeV}$



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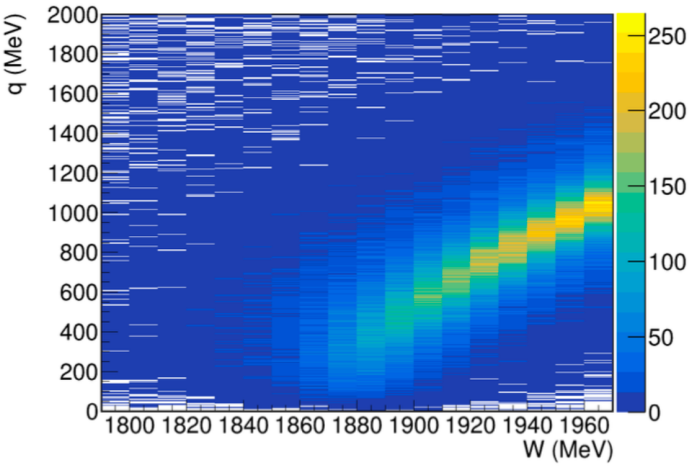
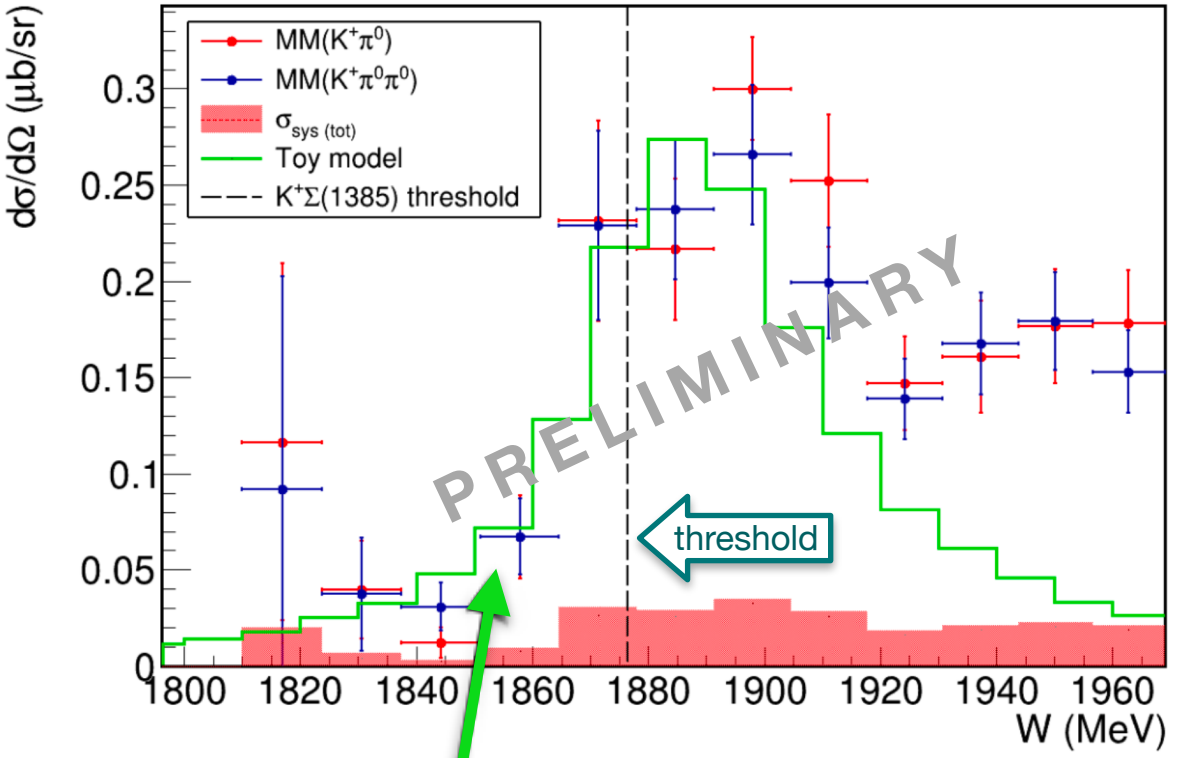
- Relative $K^+ - \Sigma(1385)$ momentum:



- Assume $\frac{d\sigma}{d\Omega} \propto \frac{1}{(m_\pi^2 + q^2)^2}$



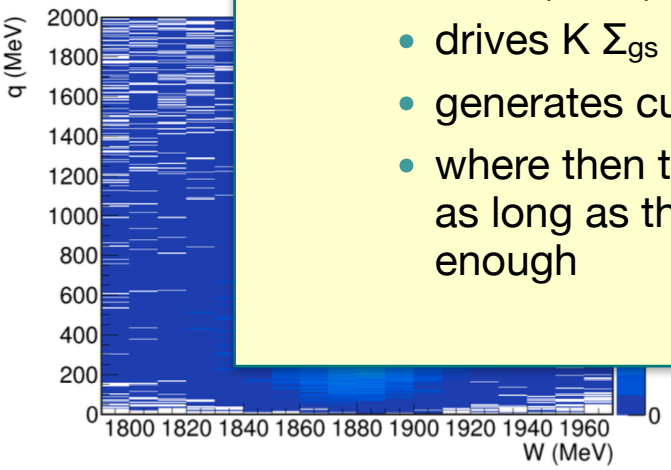
π-exchange toy model
$K^+ \leftrightarrow \Sigma^0(1385)$

$\gamma p \to K^+ \Sigma^{0*}(1385)$ photoproduction

$\gamma p \to K^+ \Sigma^*(1385)$ at $\Sigma^*(1385)$ threshold

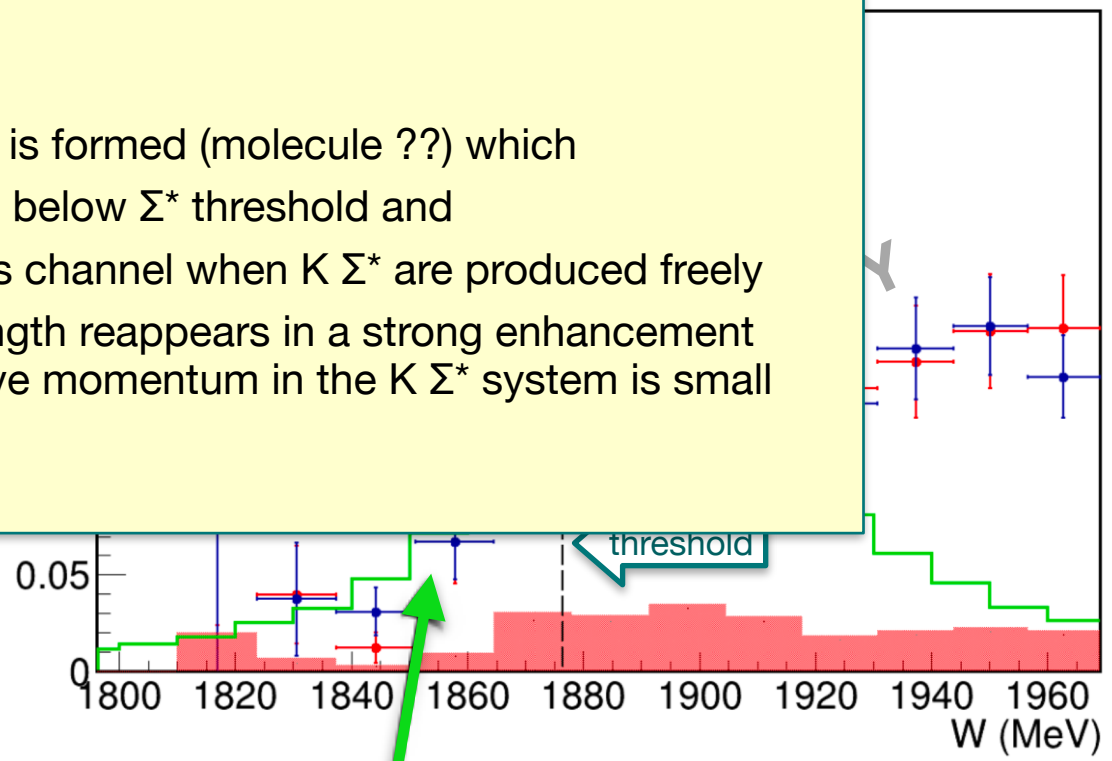
M. Jena Masters thesis (Bonn 2024), data preliminary

- Relativ
momen



this all looks as if

- [K Σ* (1385)] system is formed (molecule ??) which
- drives K Σ_{gs} channel below Σ* threshold and
- generates cusp in gs channel when K Σ* are produced freely
- where then the strength reappears in a strong enhancement as long as the relative momentum in the K Σ* system is small enough



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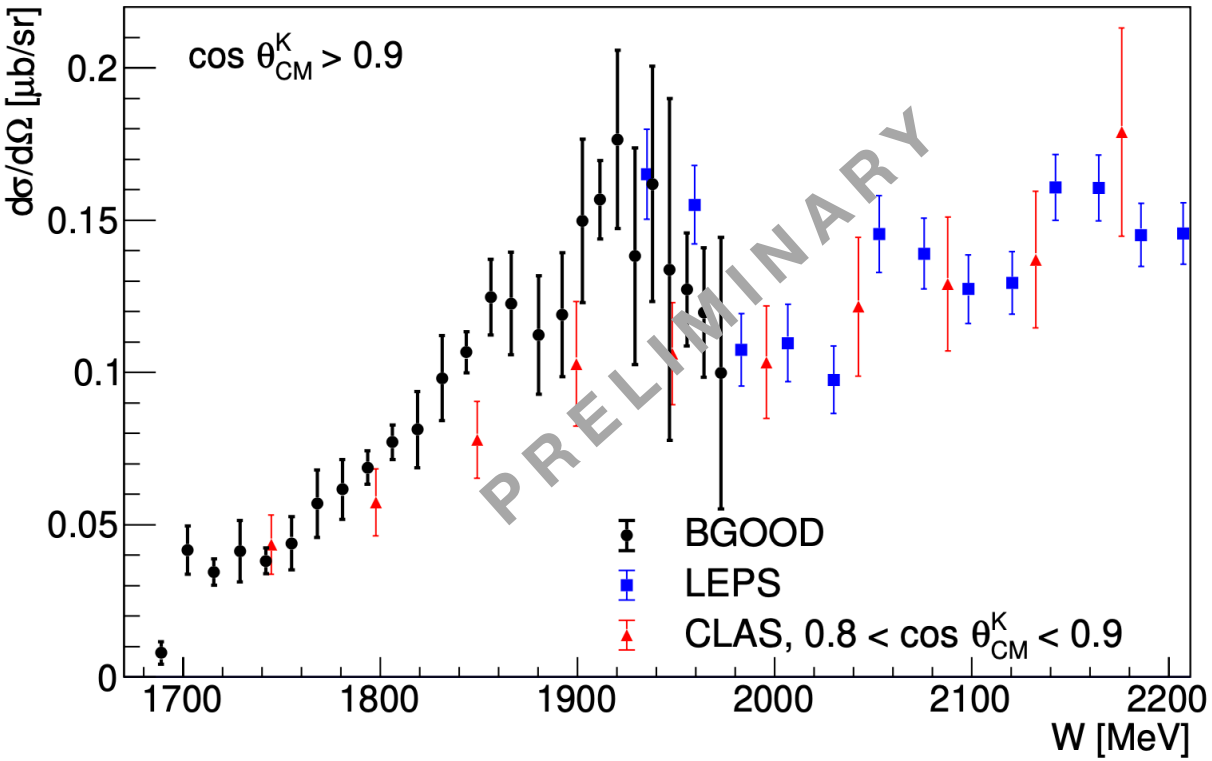
π-exchange toy model
$K^+ \leftrightarrow \Sigma^0(1385)$

charge conjugate channel: $\gamma\, n \rightarrow K^+\, \Sigma^-$

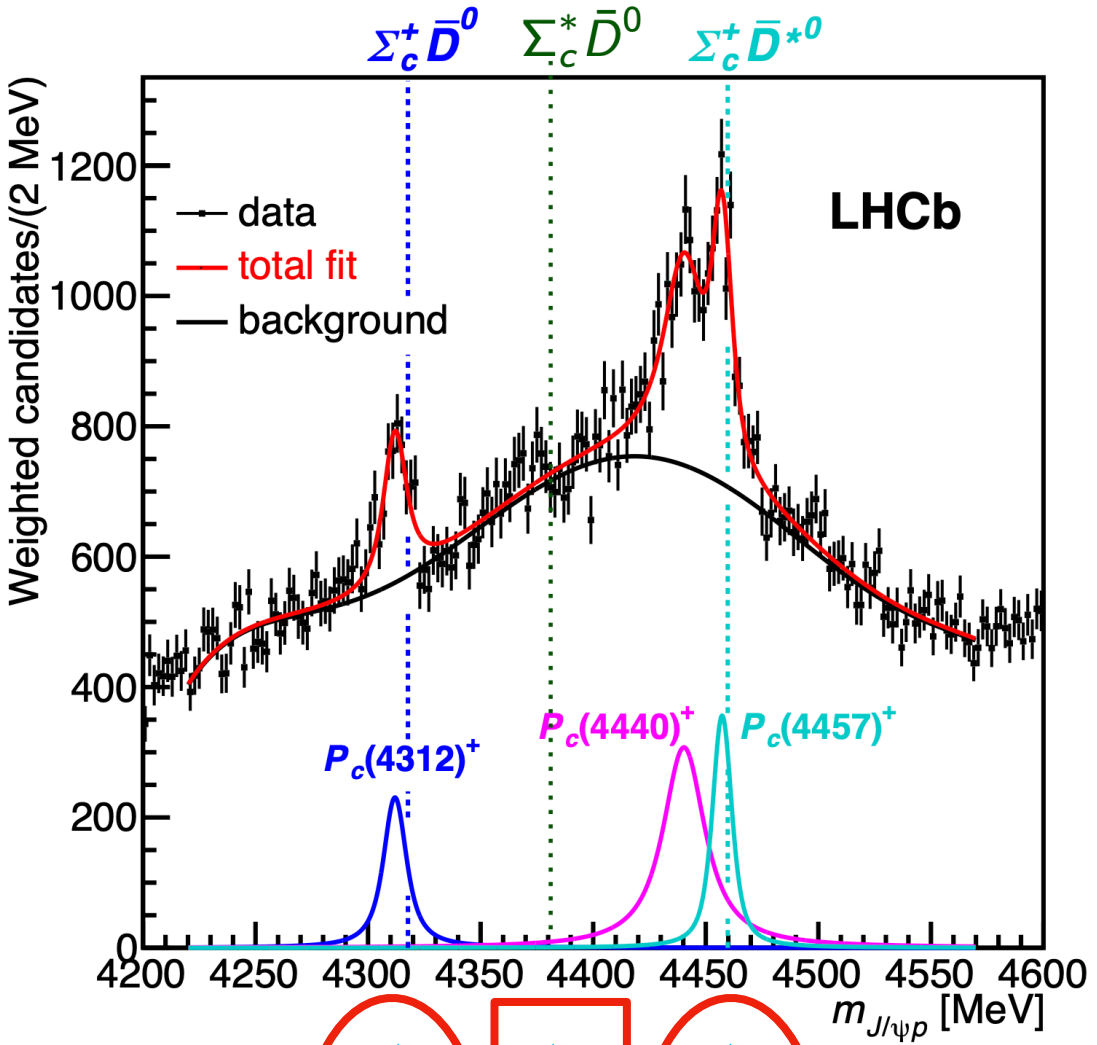
$\gamma\, n \rightarrow K^+\, \Sigma_{gs}$ at $\Sigma^*(1385)$ threshold

J. Groß, PhD thesis in preparation



- first data from threshold for $\cos\theta^K_{cm} > 0.9$
- good agreement w/ CLAS & LEPS where overlap
- enhancement in forward directions ↔ smallest $p_\perp$!

reminder: LHCb comparison



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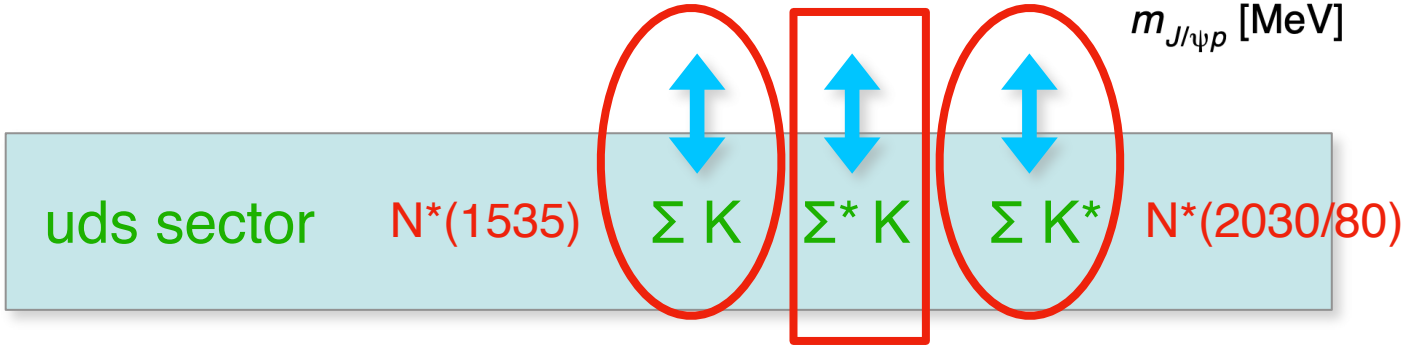

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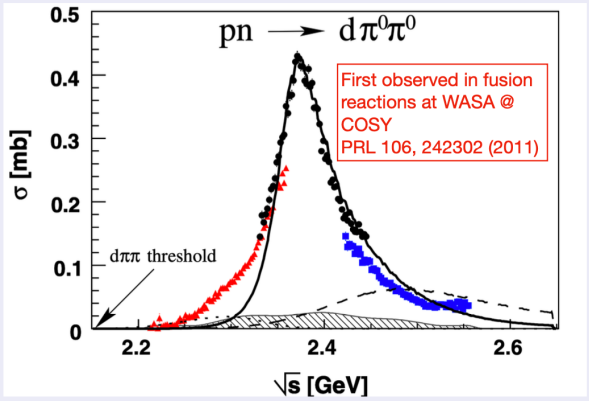
Hexa-quarks / Di-baryons ?

experimental context

coherent 2π photoproduction off deuteron

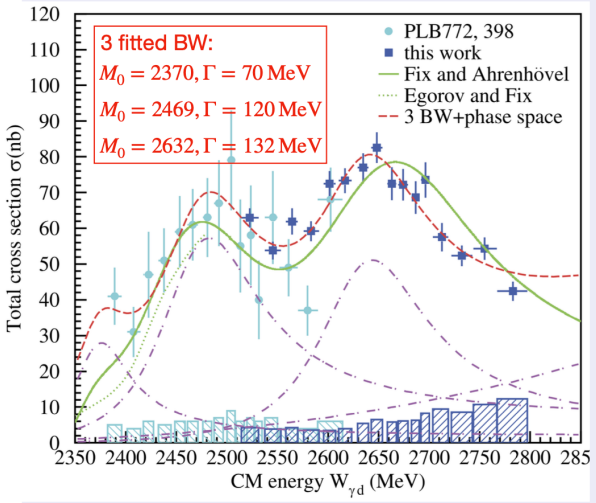
Evidence of the $d^*(2380)$

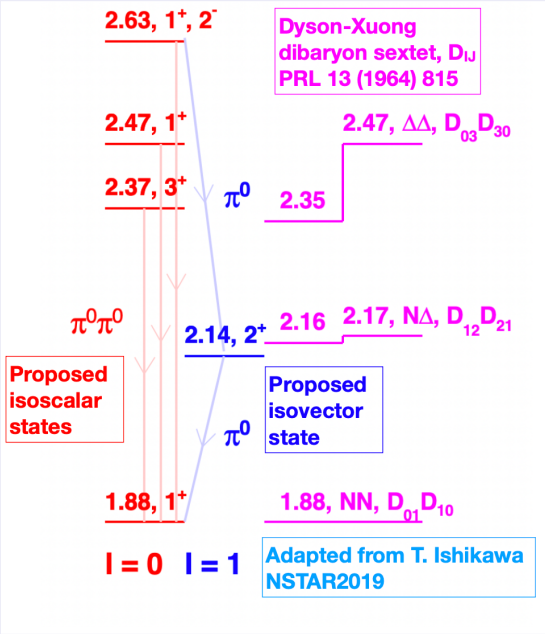
Adlarson et al PRL 106:242302, 2011
Bashkanov et al PRL 102:052301, 2009



- $(I)J^P = (0)3^+$
- Observed in multiple final states

$\gamma d \to \pi^0\pi^0 d$ at ELPH PLB 789 (2019) 413 & PLB 772 (2017) 398

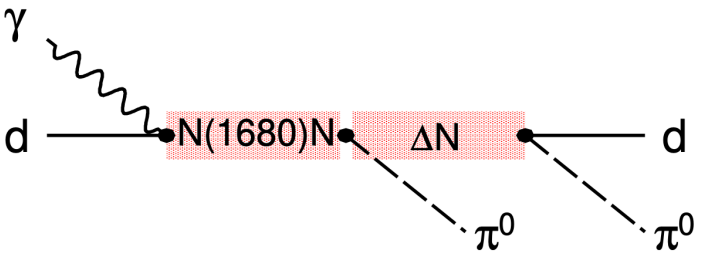


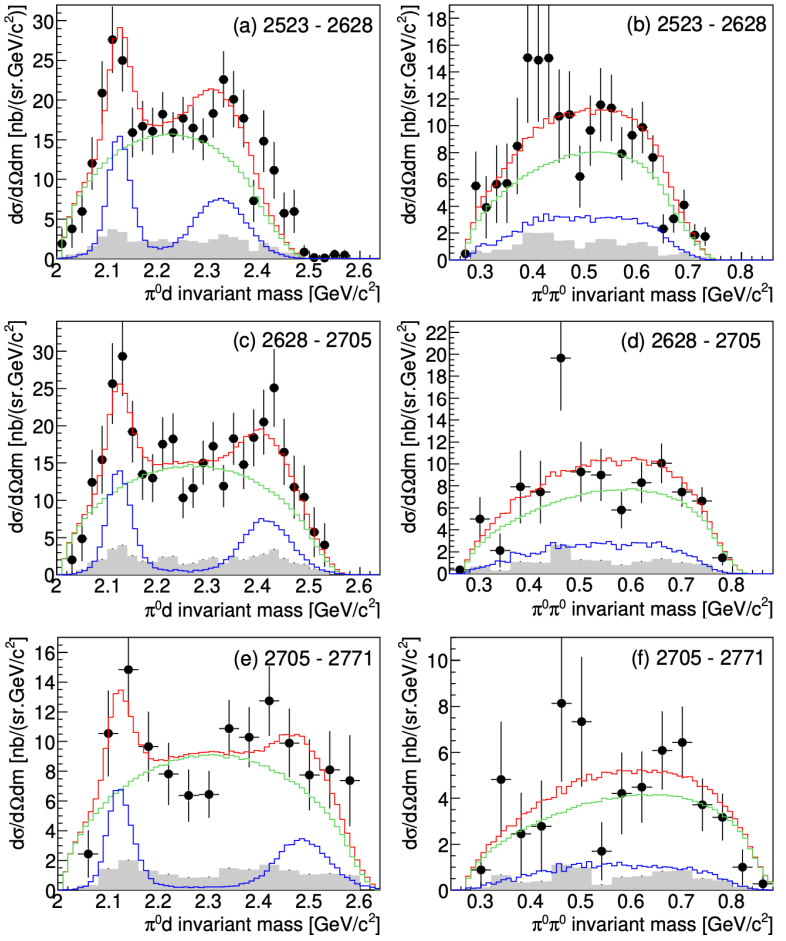


See also, preliminary data: M. Guenther et al (A2), PoS (Hadron 2017)051

Hexa-quarks ? – coherent photoproduction on d

- $\pi^0 d$ & $\pi^0\pi^0$ invariant mass distributions for higher W intervals
- Simulated sequential decay - different masses & widths of the first dibaryon
- Sequential decay + Phase space = sum
- Mass of 2114 MeV/c^2 and width $\sim$ 20 MeV/c^2 (exp. resolution!) proved optimal

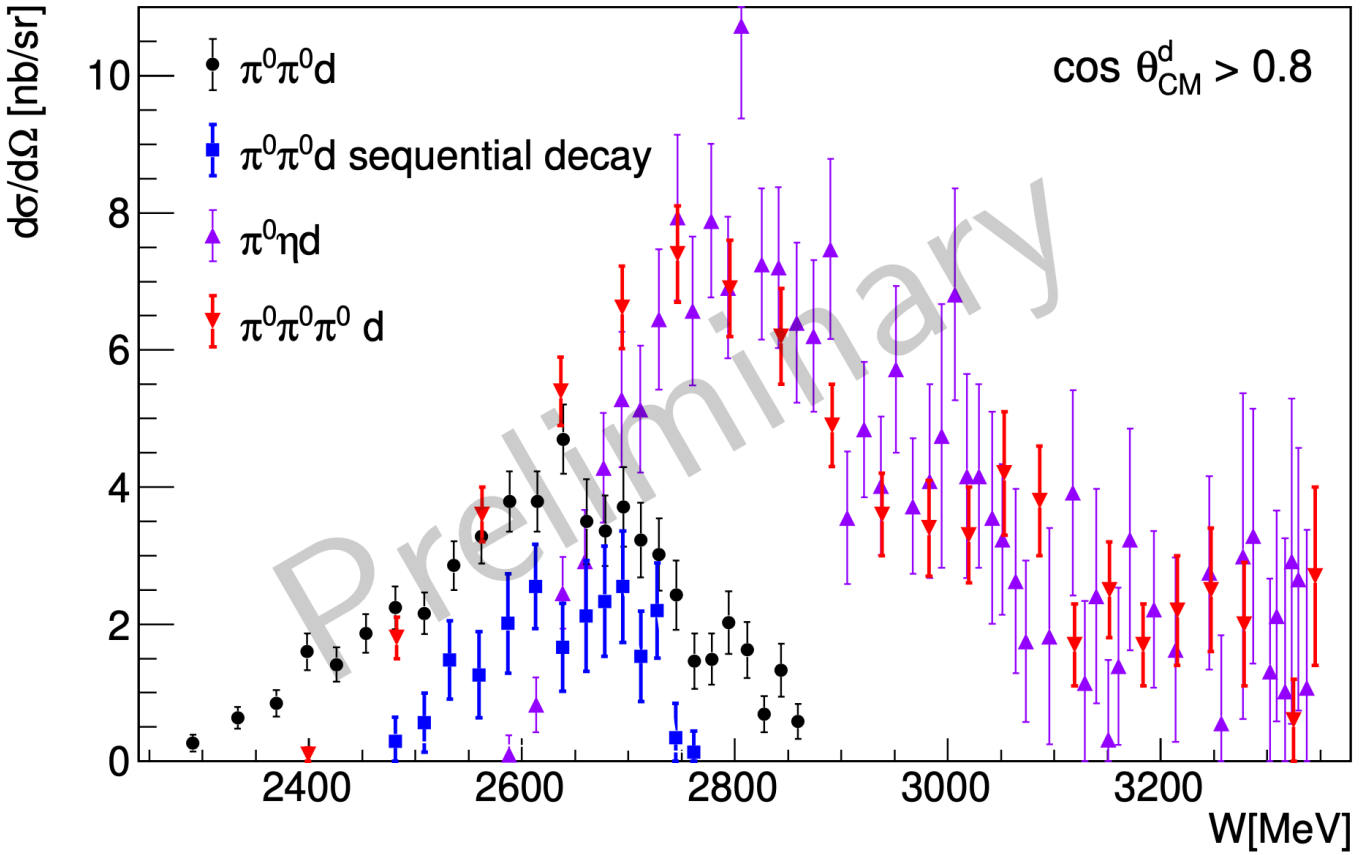




T.C. Jude et al [BGOOD], PLB 832 (2022) 137277 ⇨ mostly consistent w/ ELPH

Hexa-quarks ? – coherent photoproduction on d

further channels coherent photoproduction

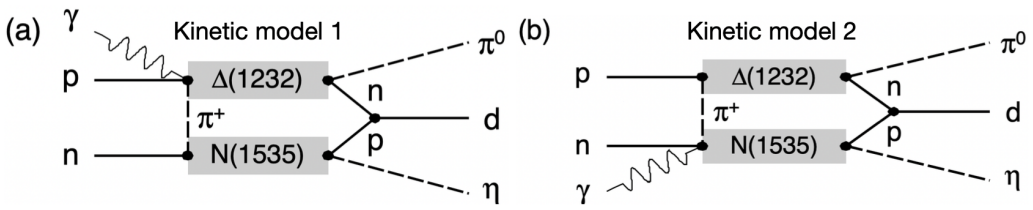


Hexa-quarks ? – coherent photoproduction on d

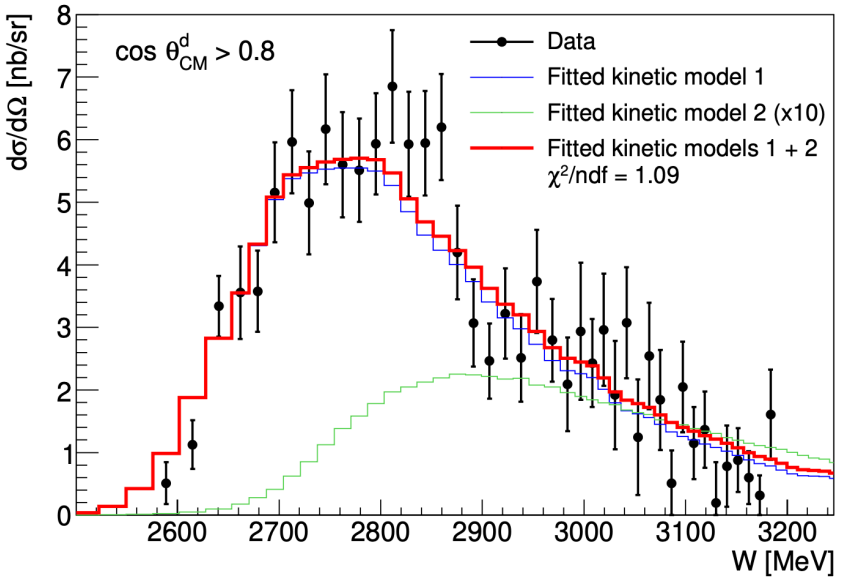
coherent $\pi^0 \eta d$ photoproduction

A. Figueiredo, T. C. Jude , et al. arXiv:2405.09392, submitted to PLB

- Distribution agrees well with models of pion re-scattering



- Similar strength of coherent channels could be explained by similar decay branching ratios::
  - $N(1535) \to \pi N$, $\Gamma_i/\Gamma = 32 - 53\,\%$
  - $N(1535) \to \pi\pi N$, $\Gamma_i/\Gamma = 4 - 31\,\%$
  - $N(1535) \to \pi\eta N$, $\Gamma_i/\Gamma = 30 - 55\,\%$



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