

Aspects of Baryon Spectroscopy at ELSA

– opportunities with new BGO-OD experiment

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Outline

- physics motivation
- status baryon spectroscopy
- context c-quark sector
- BGO-OD experiment @ ELSA
- summary

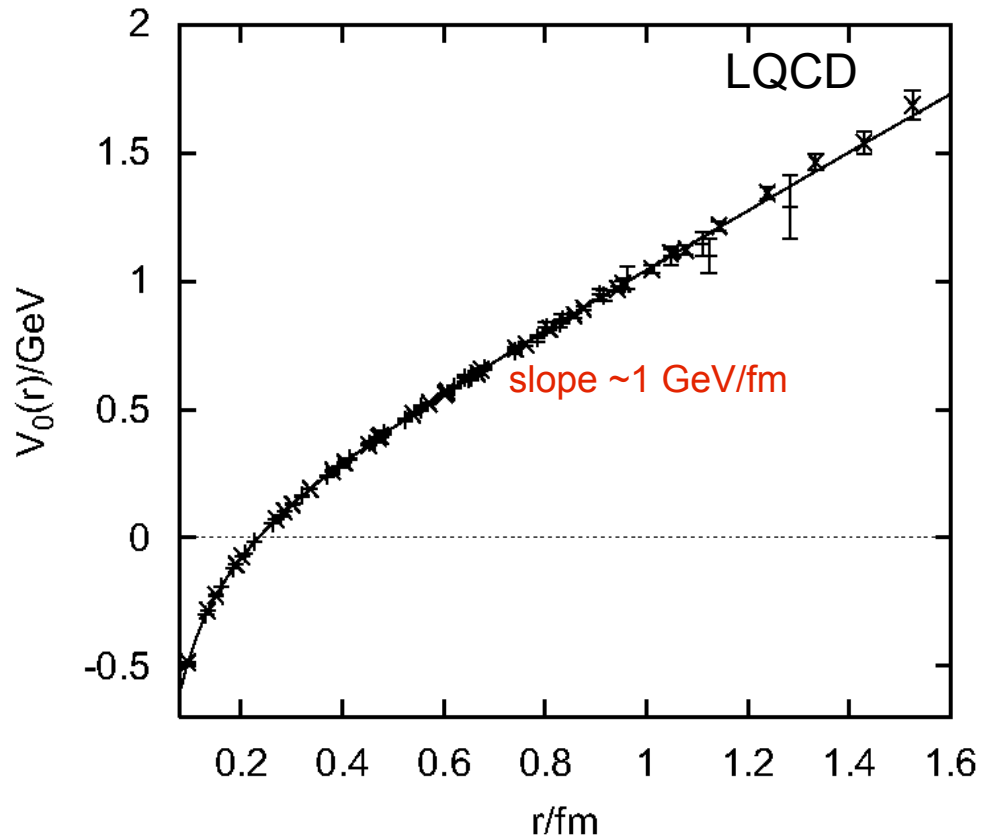
supported by DFG
PN 50165297



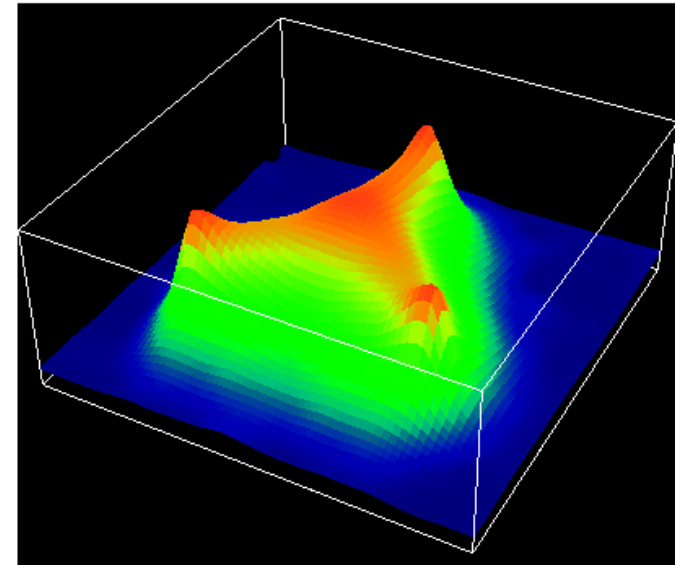
M E S O N 2 0 1 8

Physics Motivation

hadronic resonances



G.S. Bali,
Phys. Rep. 343 (2001) 1

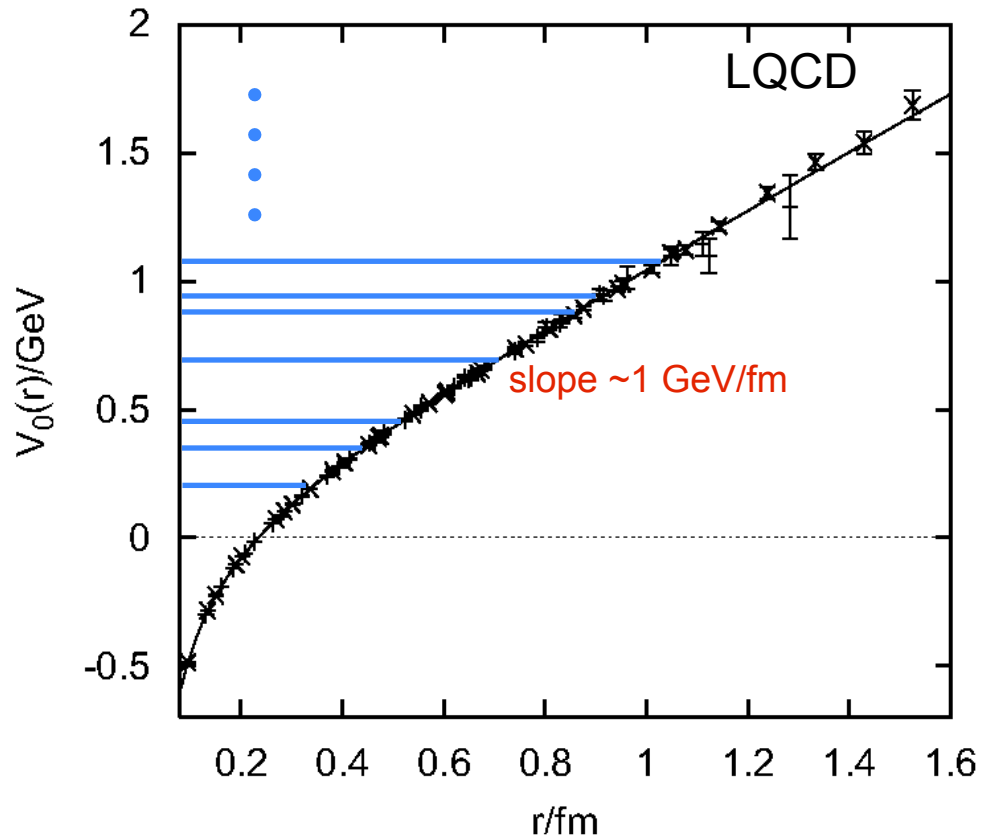


Energy density distribution
inside nucleon in LQCD simulation
(F. Wilczek, Physics today 11/99 & 1/00)

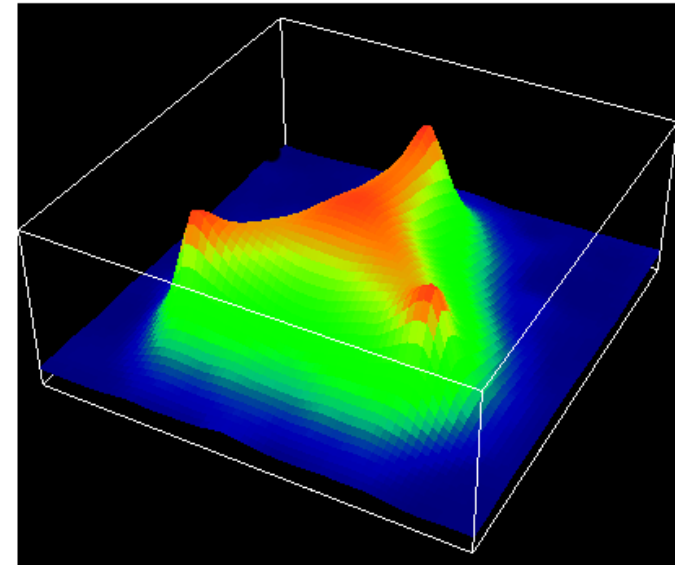
Physics Motivation

hadronic resonances

models: excitation in mutual potential



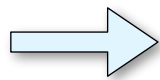
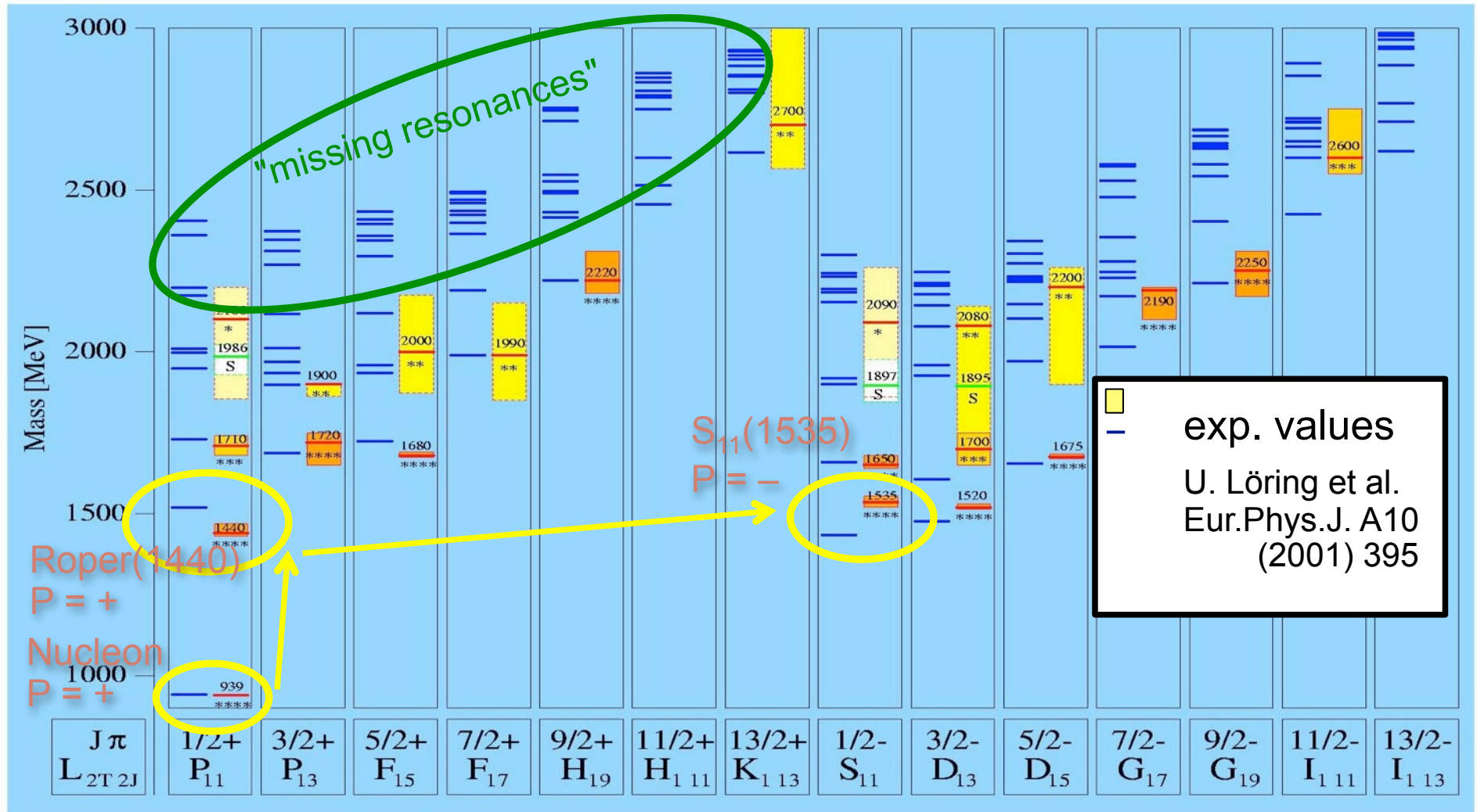
G.S. Bali,
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Energy density distribution
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Excited states: quark model

N^* resonances

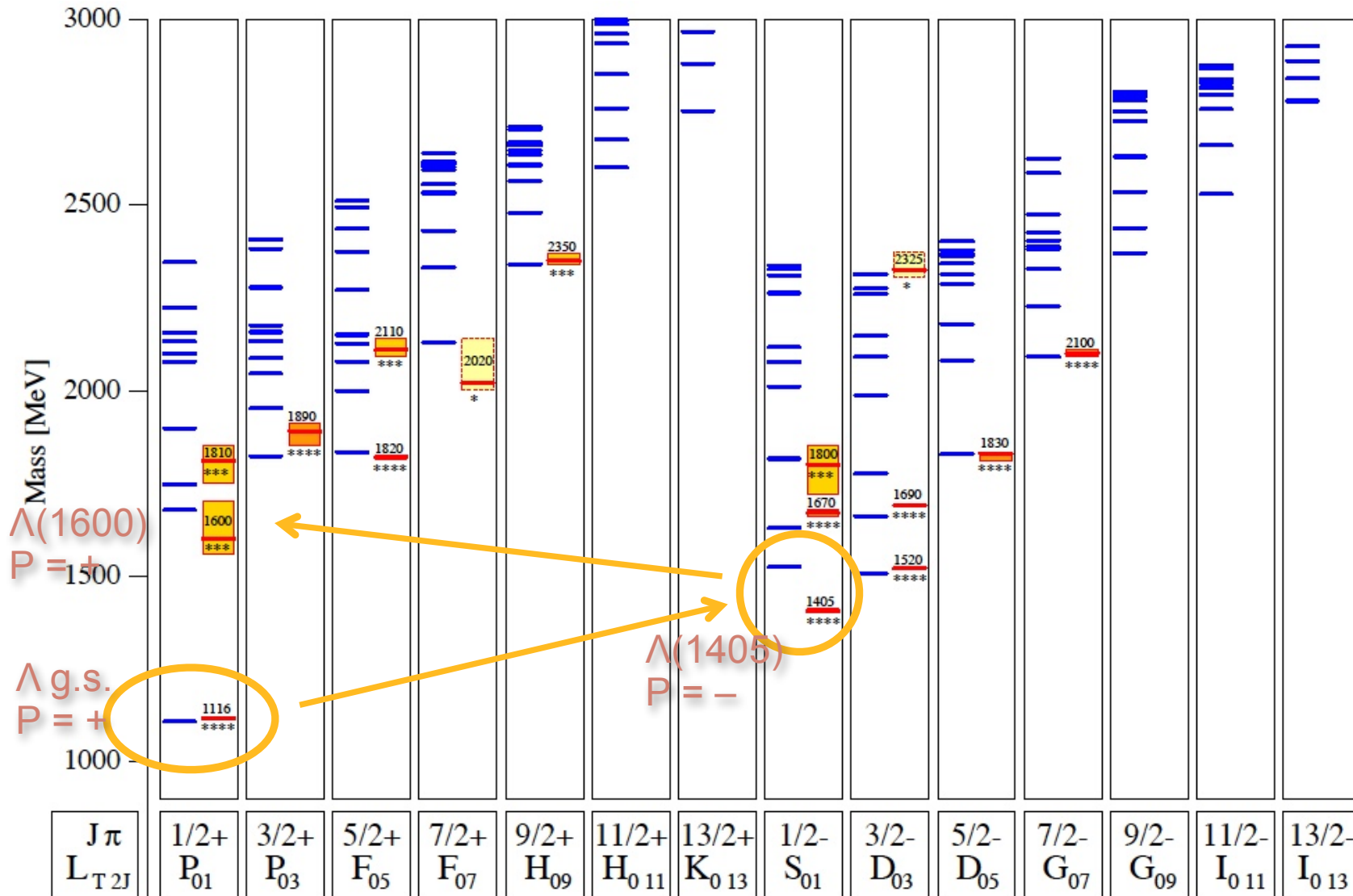


- parity pattern $+ \rightarrow + \rightarrow -$!?!
- effective degrees of freedom ??

H. Schmieden

Excited states: quark model

Λ^* resonances

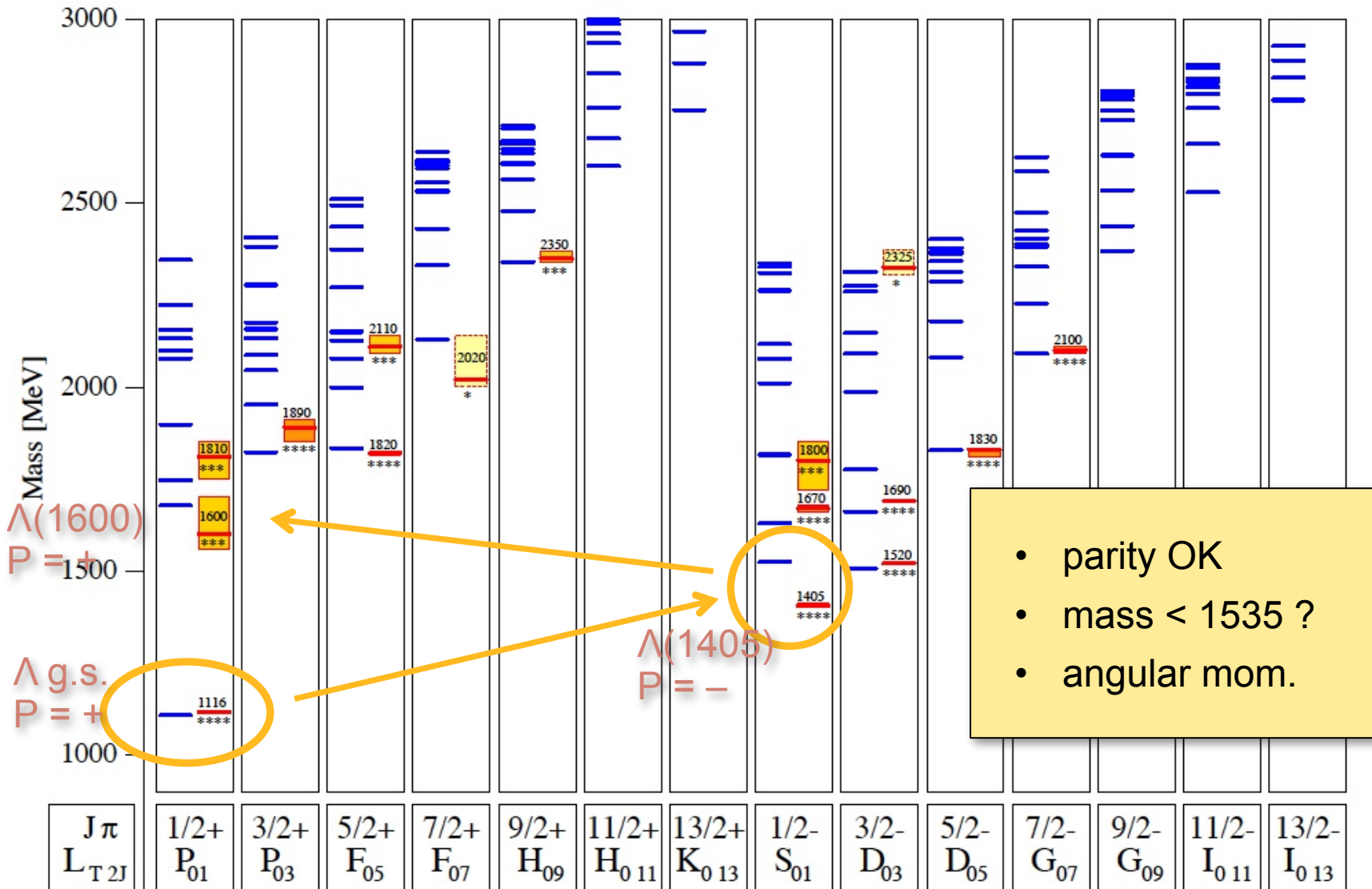


H. Schmieden

- parity pattern OK
- masses reversed ??

Excited states: quark model

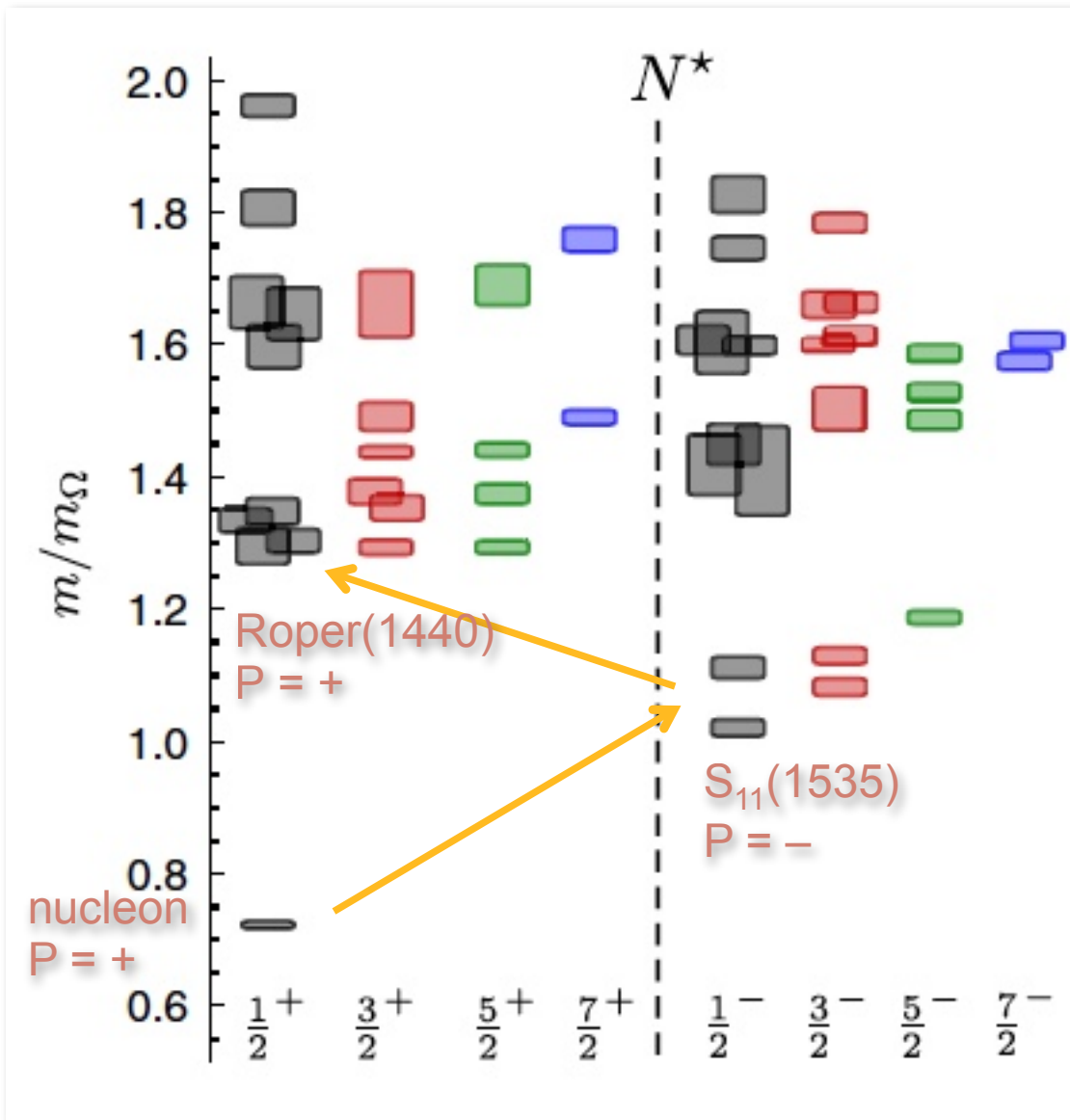
Λ^* resonances



H. Schmieden

- parity pattern OK
- masses reversed ??

Excited states: Lattice QCD



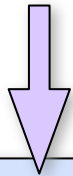
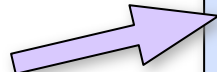
Excited states: LQCD

- $m_\pi = 396$ MeV
- reproduces q-models
- wrong parity pattern
- but: no decays !

R.G. Edwards et al.,
 Phys. Rev. D84 (2011) 074508

Status spectroscopy

- missing resonances ?
- relevant degrees of freedom ?



- 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

H. Schmitt

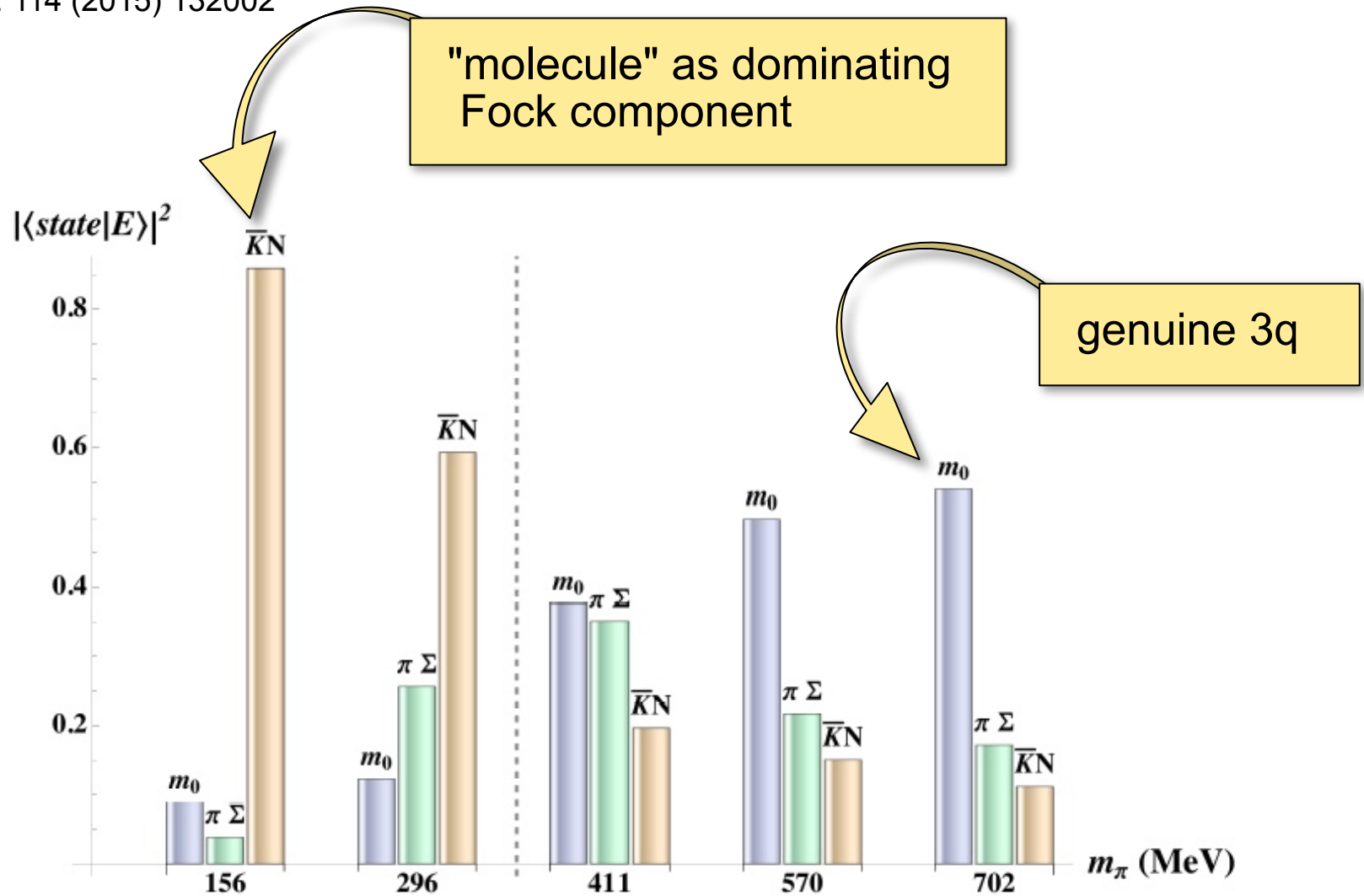
E. Klempt, A. Sarantsev,
U. Thoma et al.

State	PDG 2010	BnGa PWA	PDG 2012	SAID PWA
N(1860) 5/2+		*	**	
N(1875) 3/2-		***	***	
N(1880) 1/2+		**	**	
N(1895) 1/2-		**	**	
N(1900) 3/2+	**	***	***	no evidence
N(2060) 5/2-		***	**	
N(2150) 3/2-		**	**	
$\Delta(1940)$ 3/2-	*	*	**	no evidence

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

Status spectroscopy: $\Lambda(1405)$ L-QCD

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



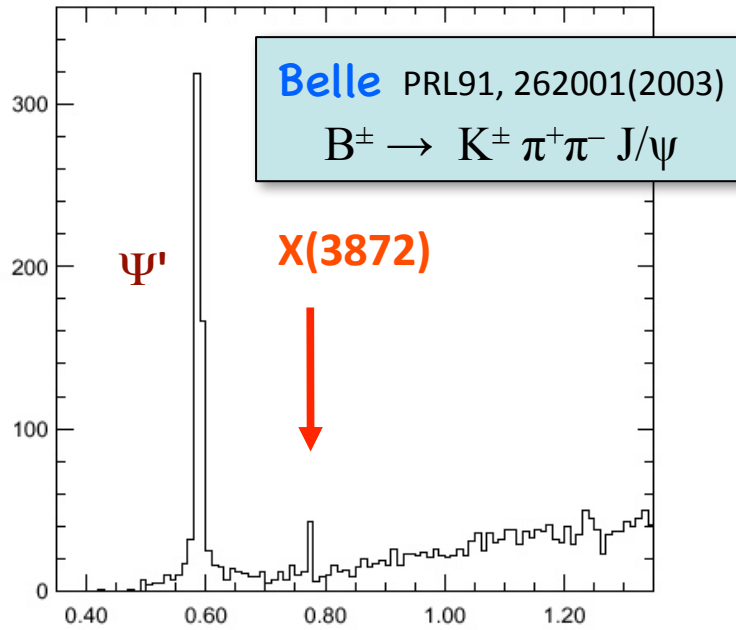
context c-quark sector



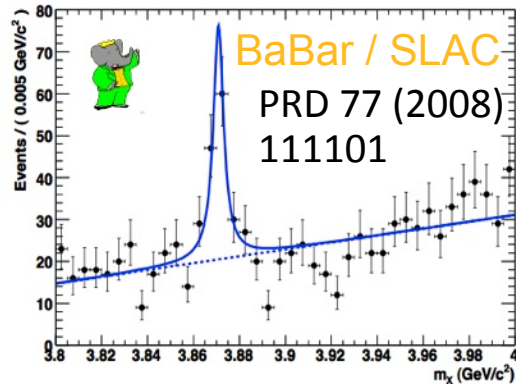
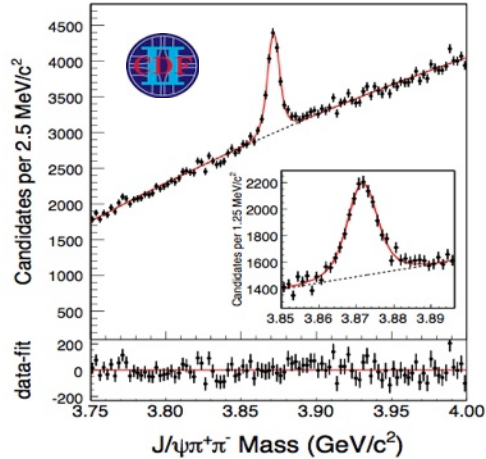
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context c-quark sector

X(3872)



$M(\pi^+ \pi^- 1^+ 1^-) - M(1^+ 1^-)$



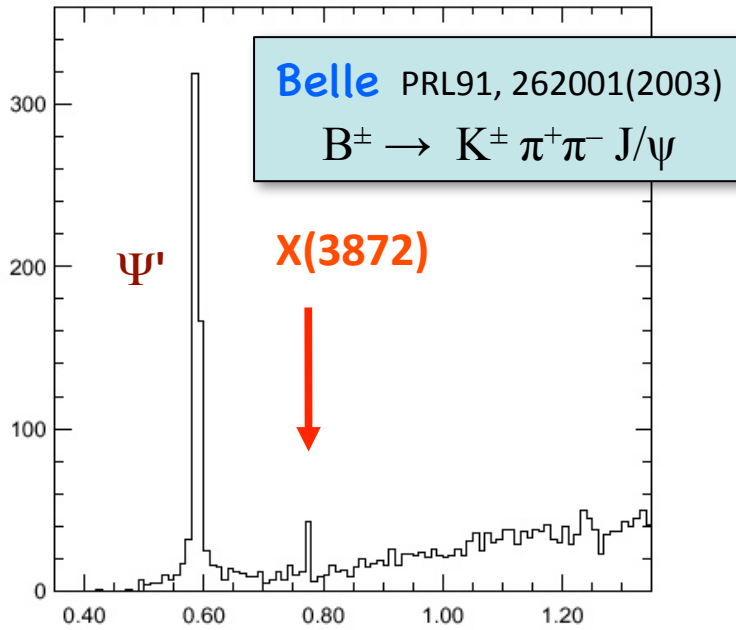
CDF / Tevatron

PRL 103 (2009) 152001

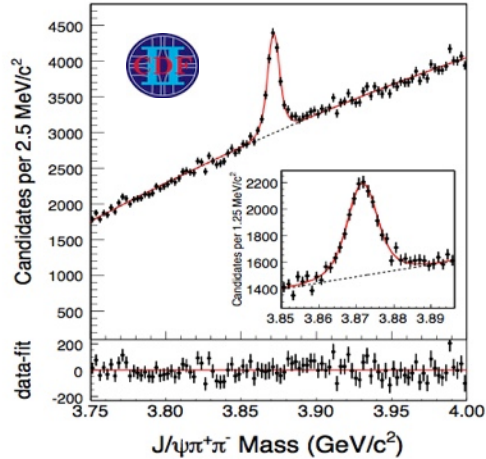
context c-quark sector



X(3872)

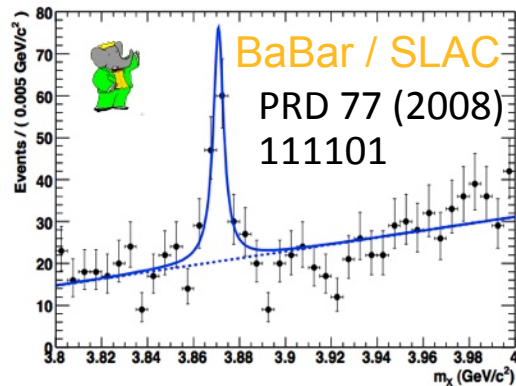


$$M(\pi^+\pi^-\psi(2S)) - M(\psi(2S))$$



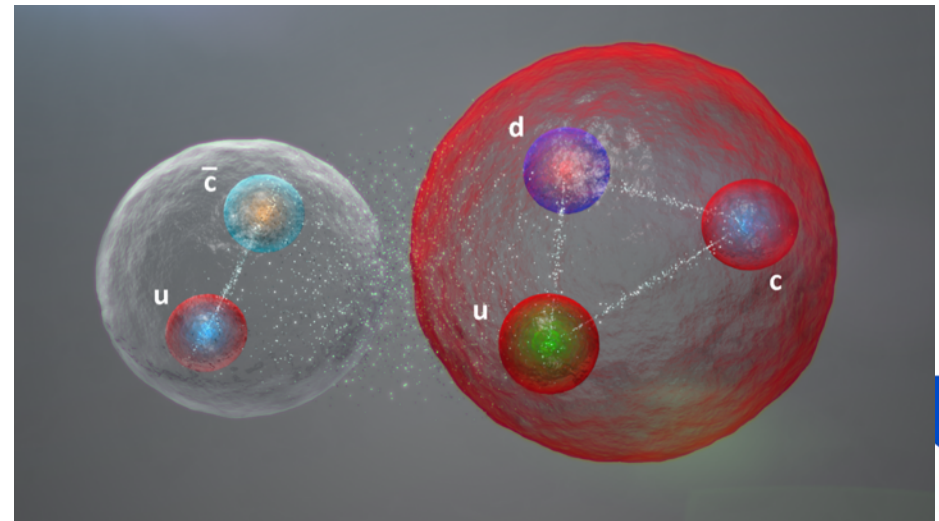
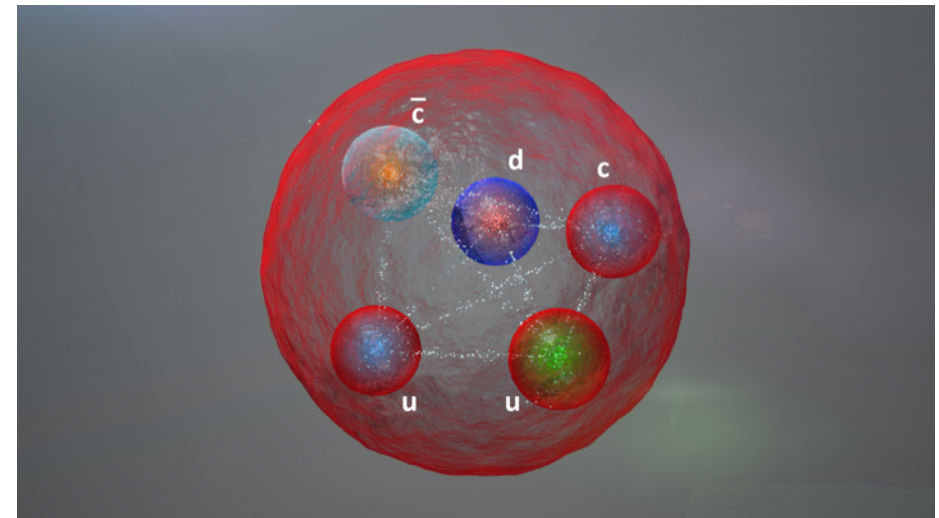
CDF / Tevatron

PRL 103 (2009) 152001



Forsaken pentaquark particle spotted at CERN

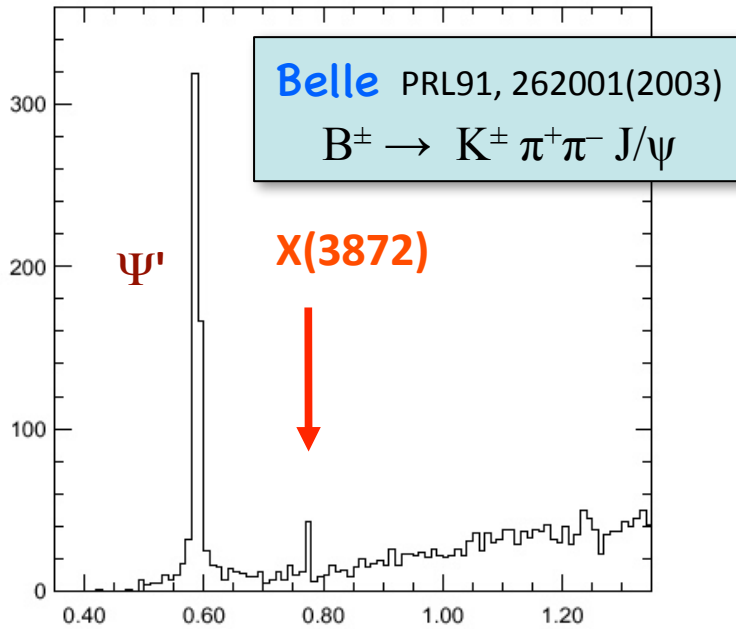
Exotic subatomic species confirmed at Large Hadron Collider after earlier false sightings.



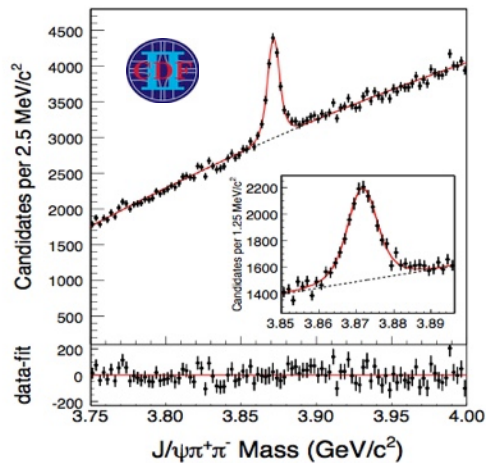
context c-quark sector



X(3872)

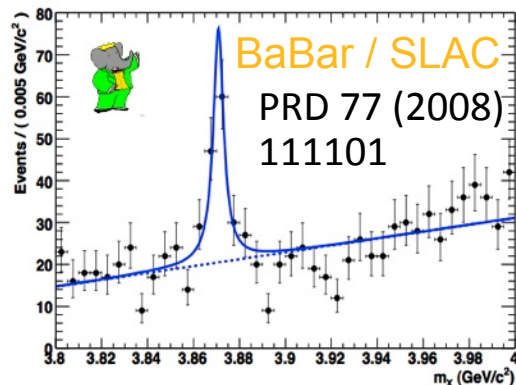


$$M(\pi^+\pi^-\mathbf{1}^+\mathbf{1}^-) - M(\mathbf{1}^+\mathbf{1}^-)$$



CDF / Tevatron

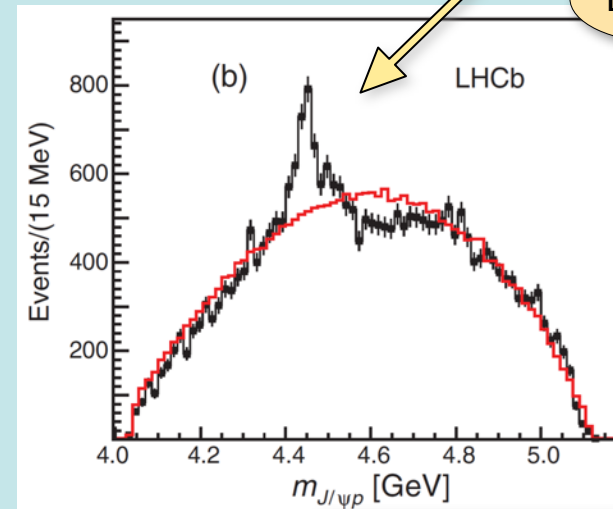
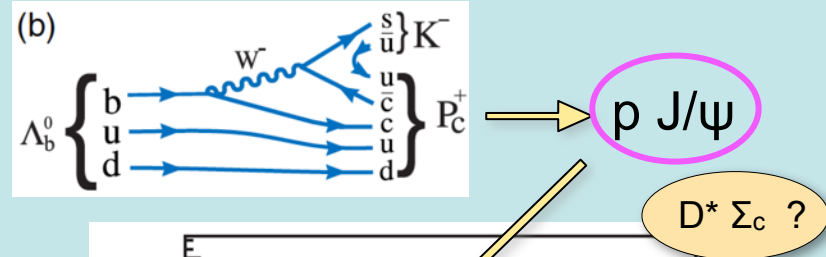
PRL 103 (2009) 152001



P_C⁺(4380, 4450)

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)

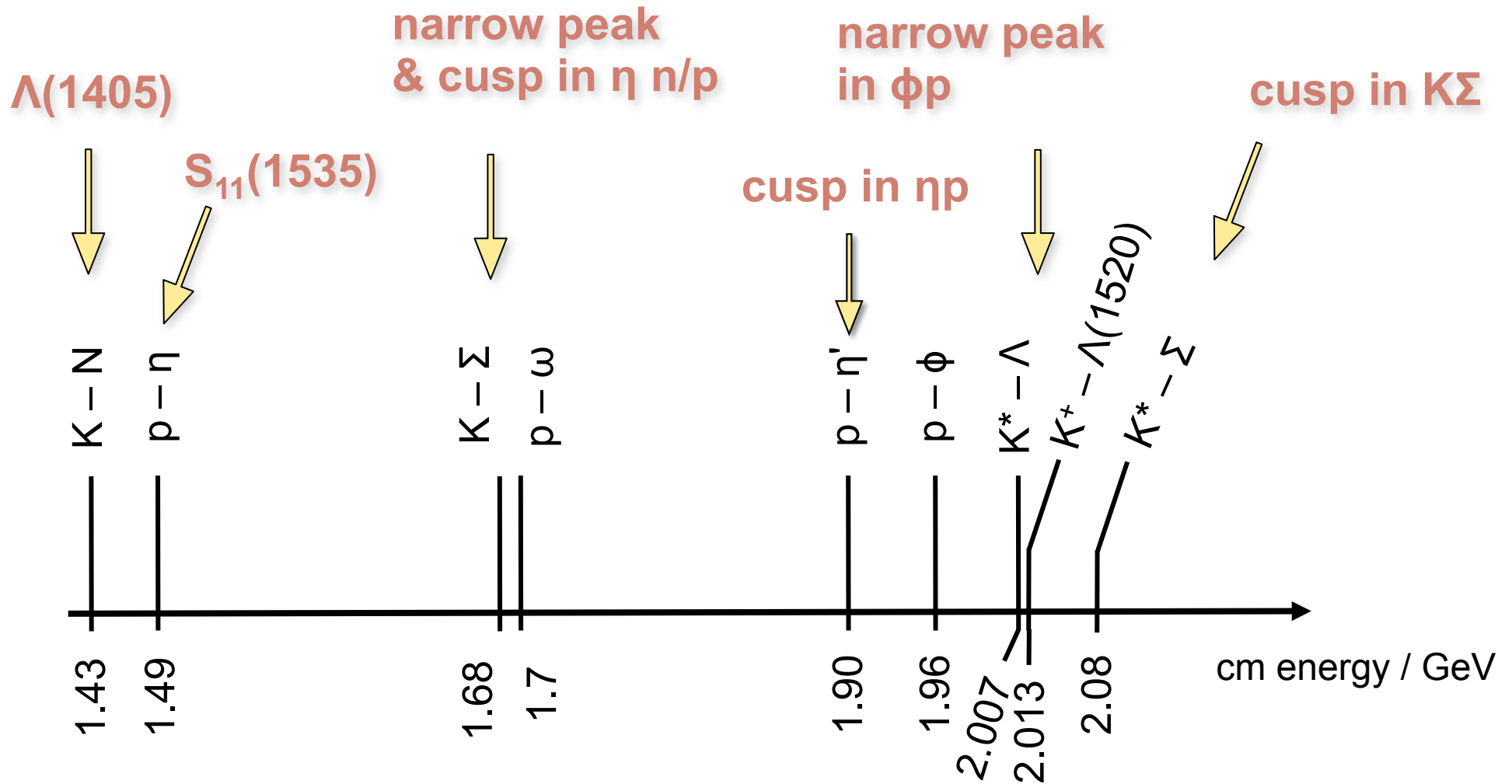
"new N_{cc}^{*} states are simply brothers or sisters of the well known N^{*}(1535) and Λ^{*}(1405) ... and many other dynamically generated states ..."

uds sector ?



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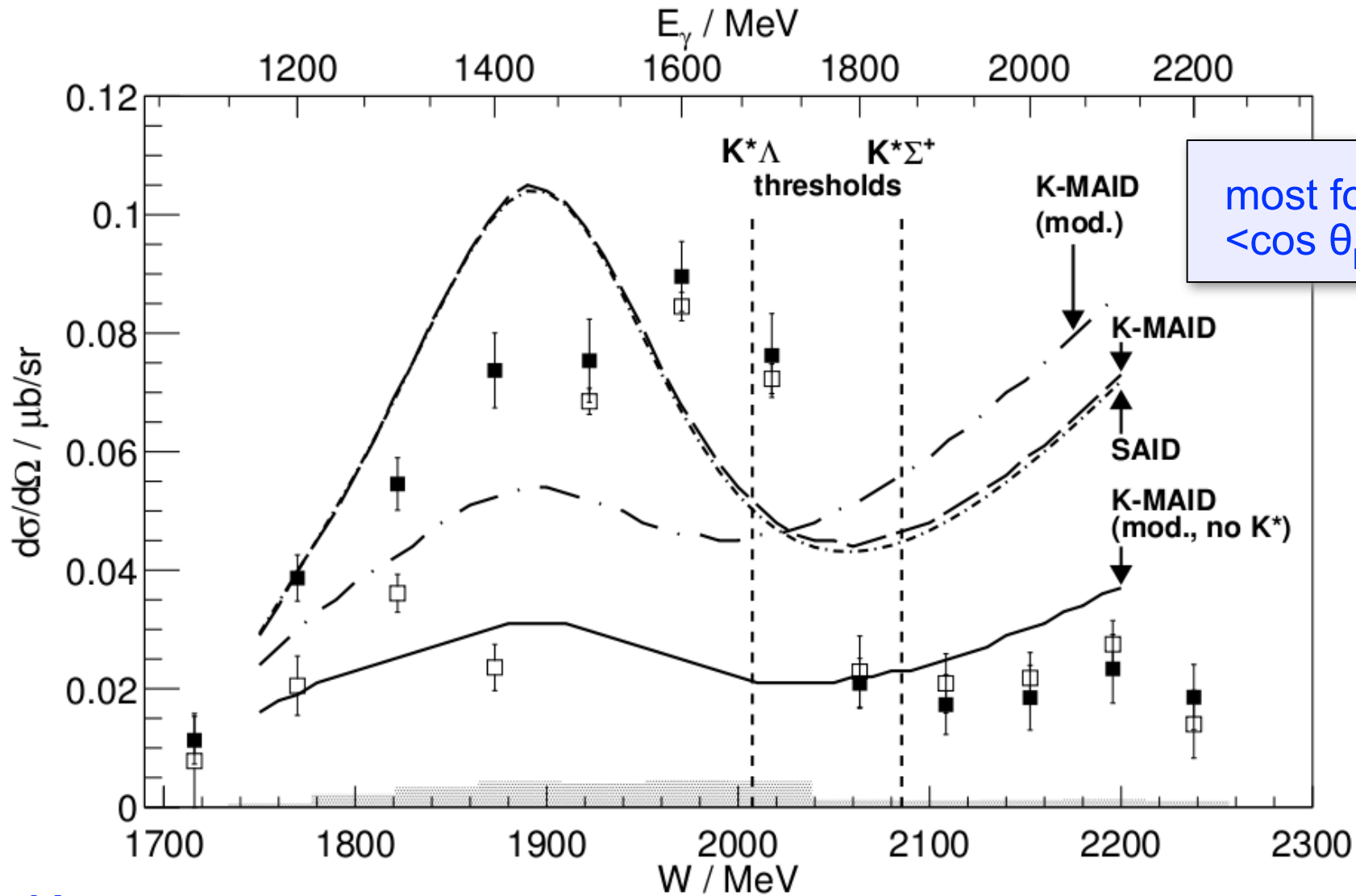
uds sector – threshold dynamics



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

anomaly @ K^* threshold

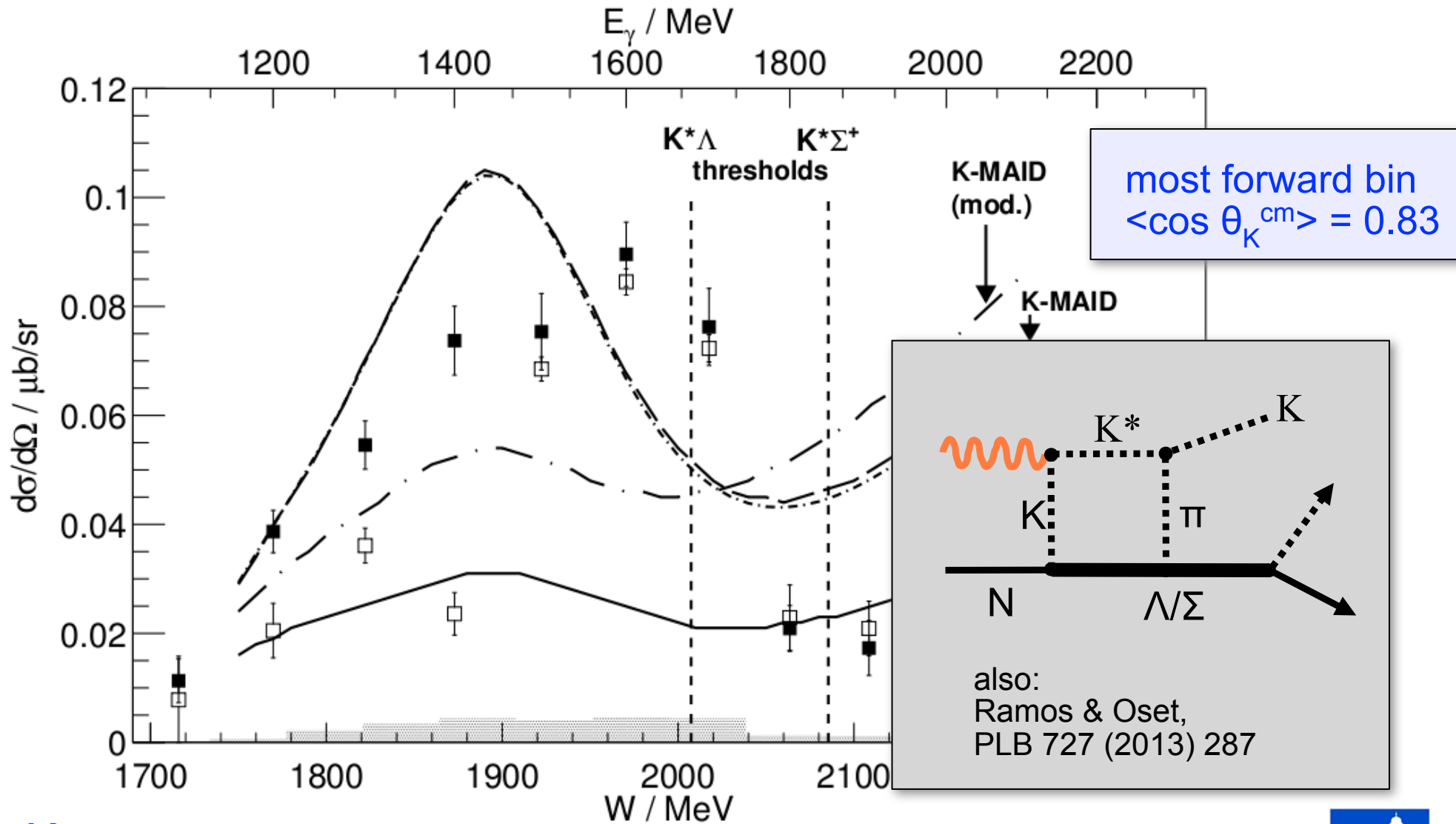
R. Ewald et al. (CB/TAPS), PLB 713 (2012)



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

anomaly @ K^* threshold

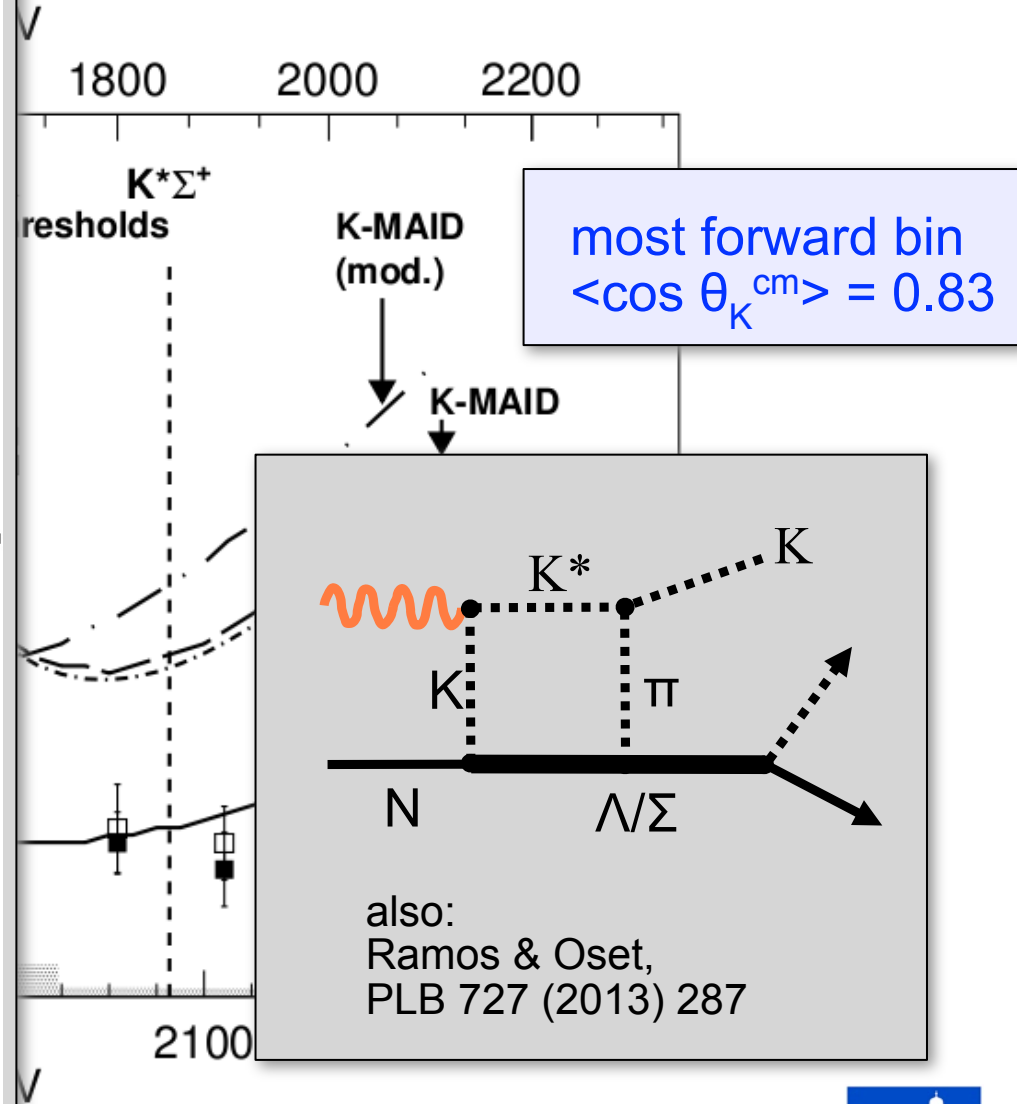
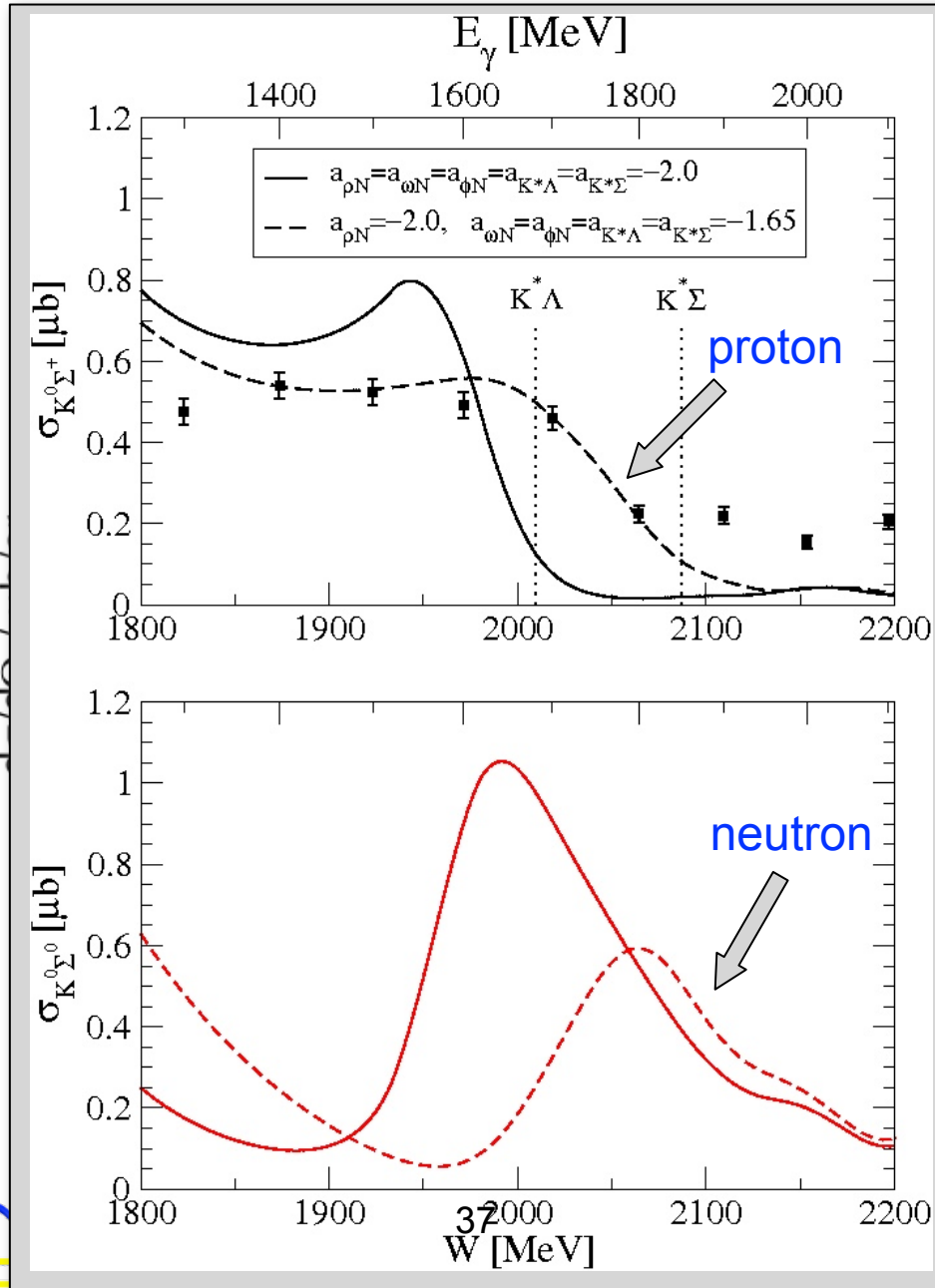
R. Ewald et al. (CB/TAPS), PLB 713 (2012)



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uds sector ?

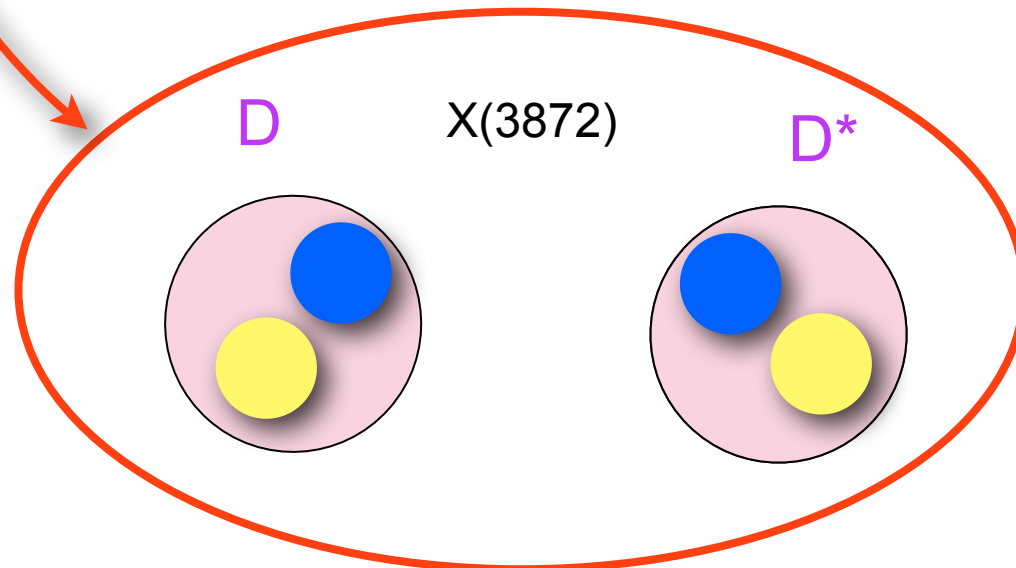
→ parallels between c and s sectors

	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 ?

→ parallels between c and s sectors

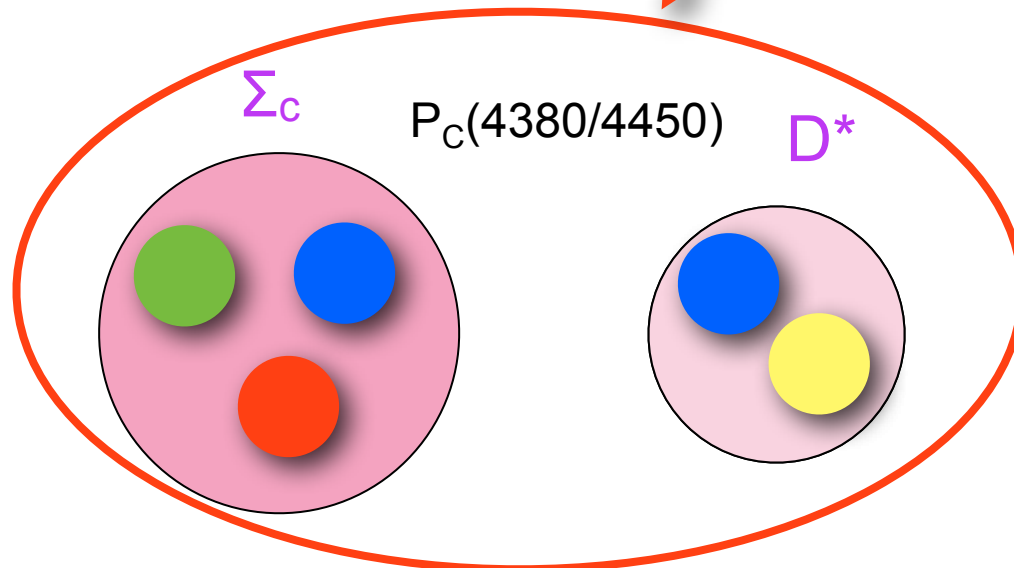
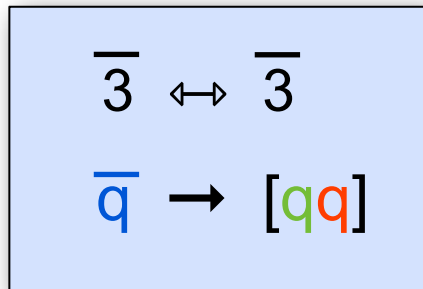
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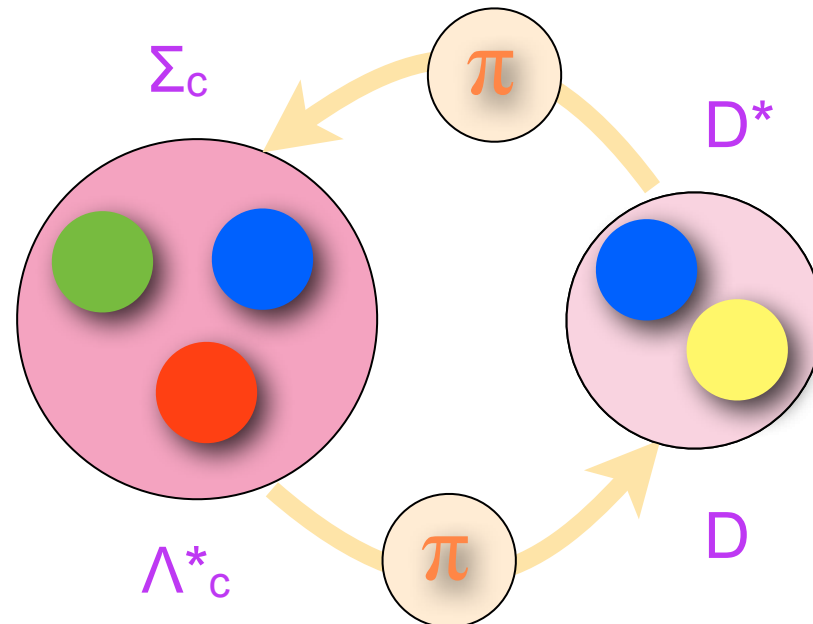
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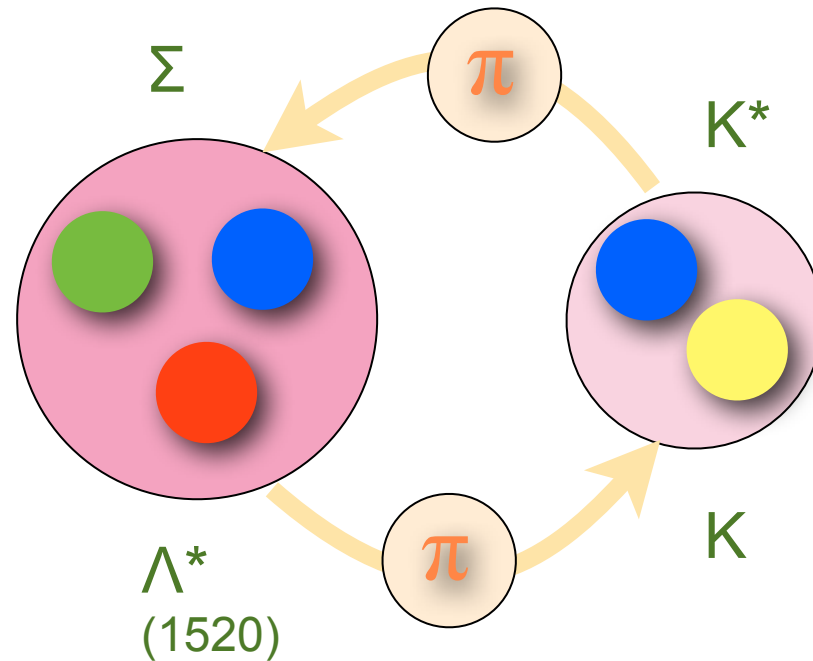
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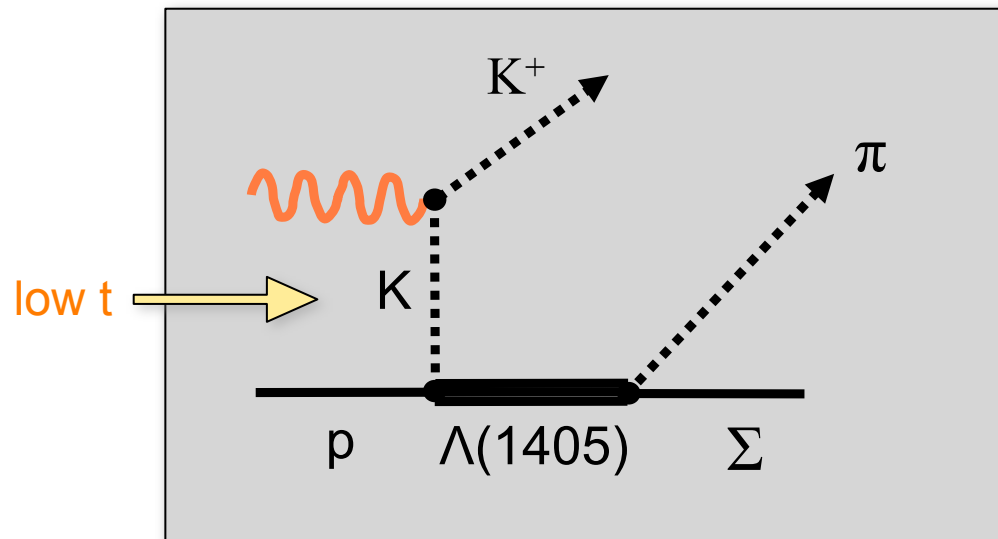
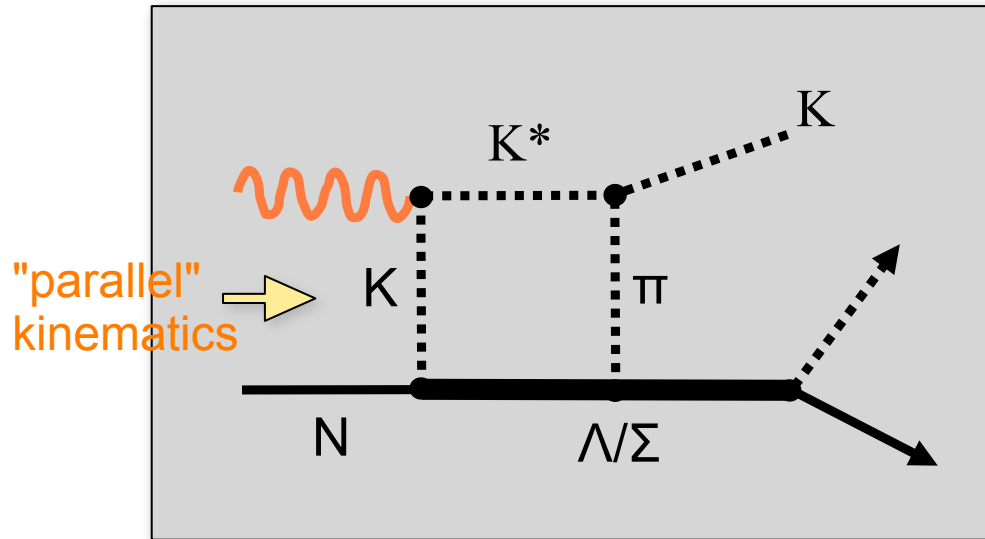
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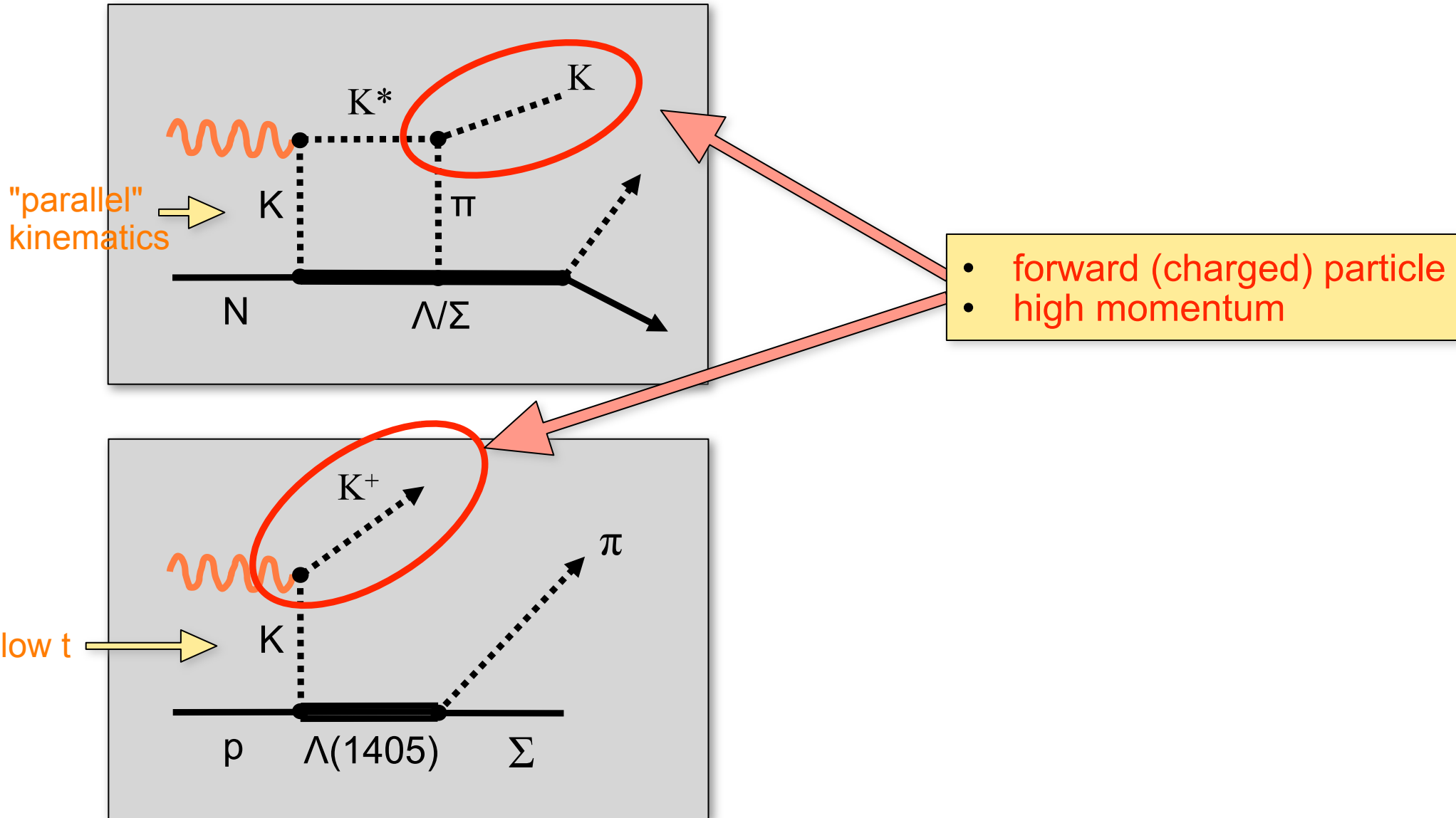
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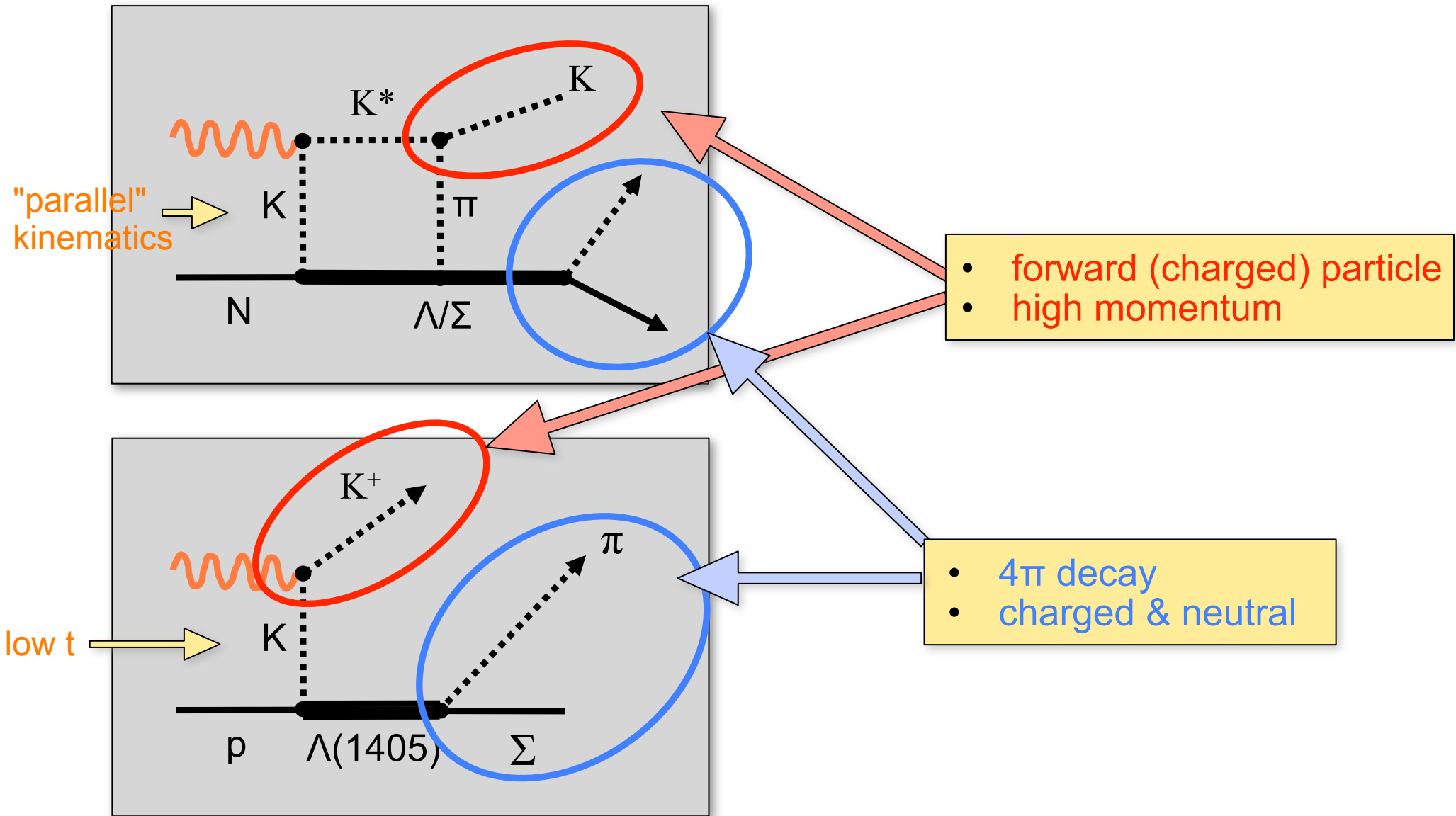
t-channel Kinematics



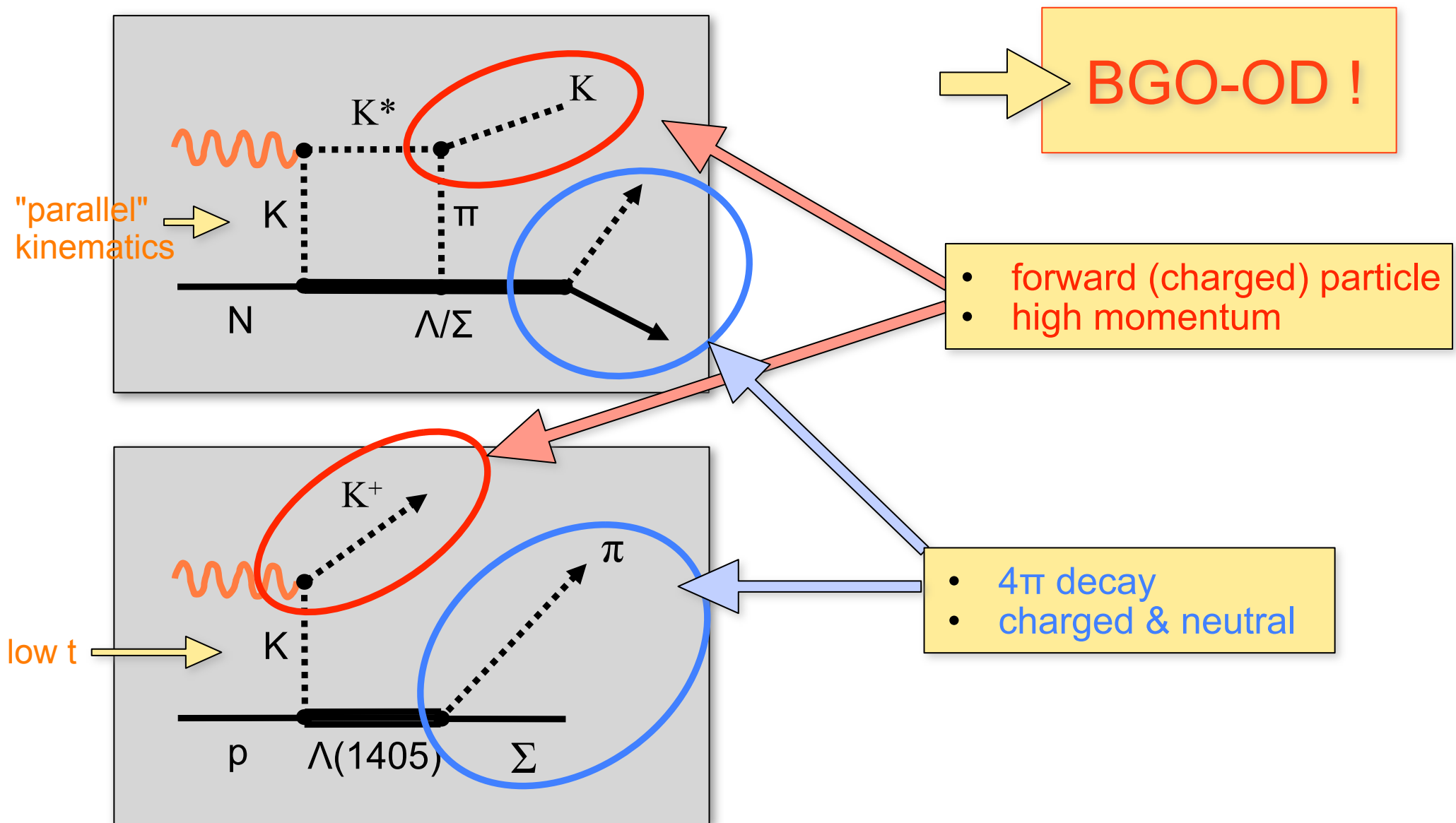
t-channel Kinematics



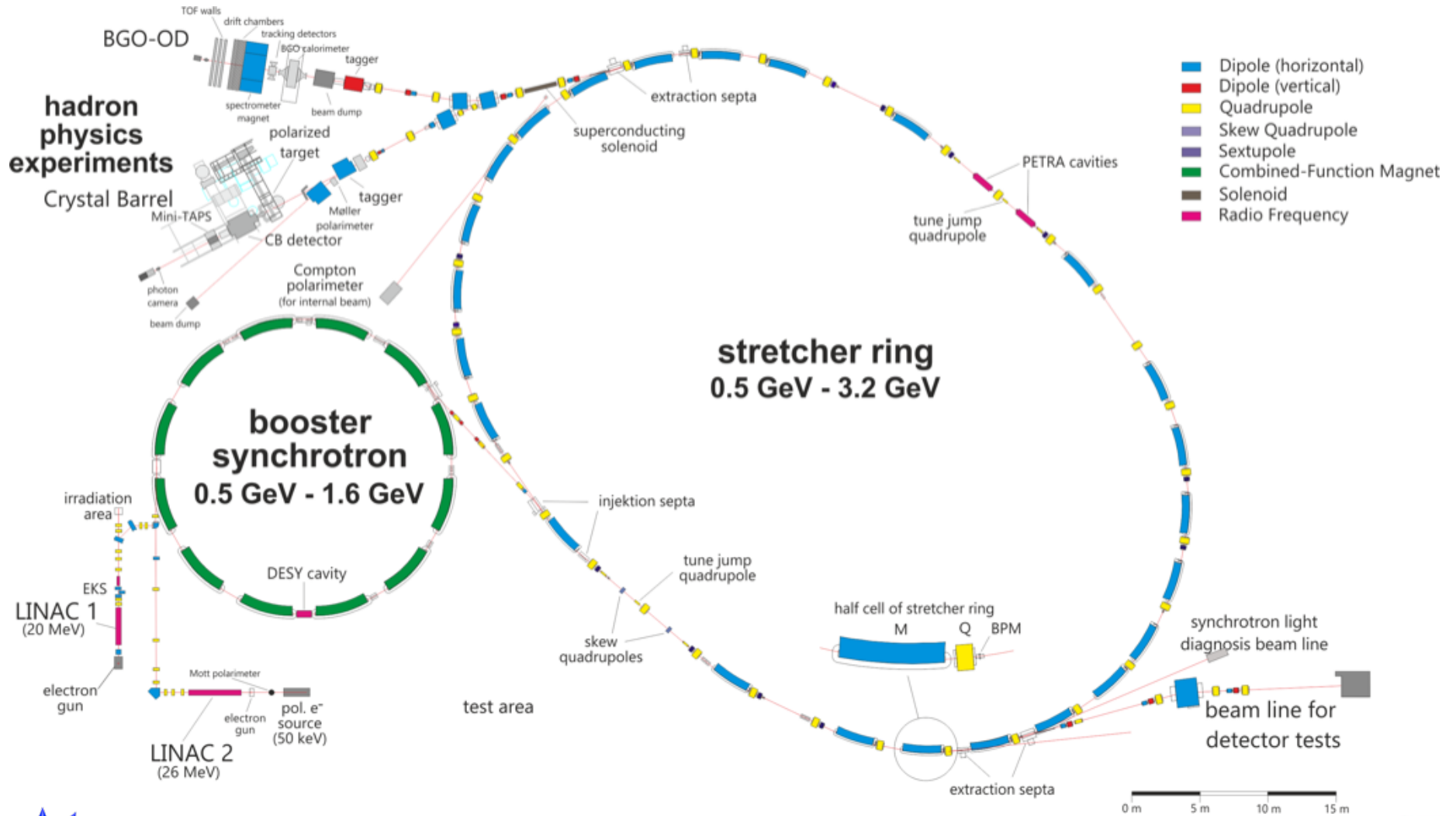
t-channel Kinematics



t-channel Kinematics



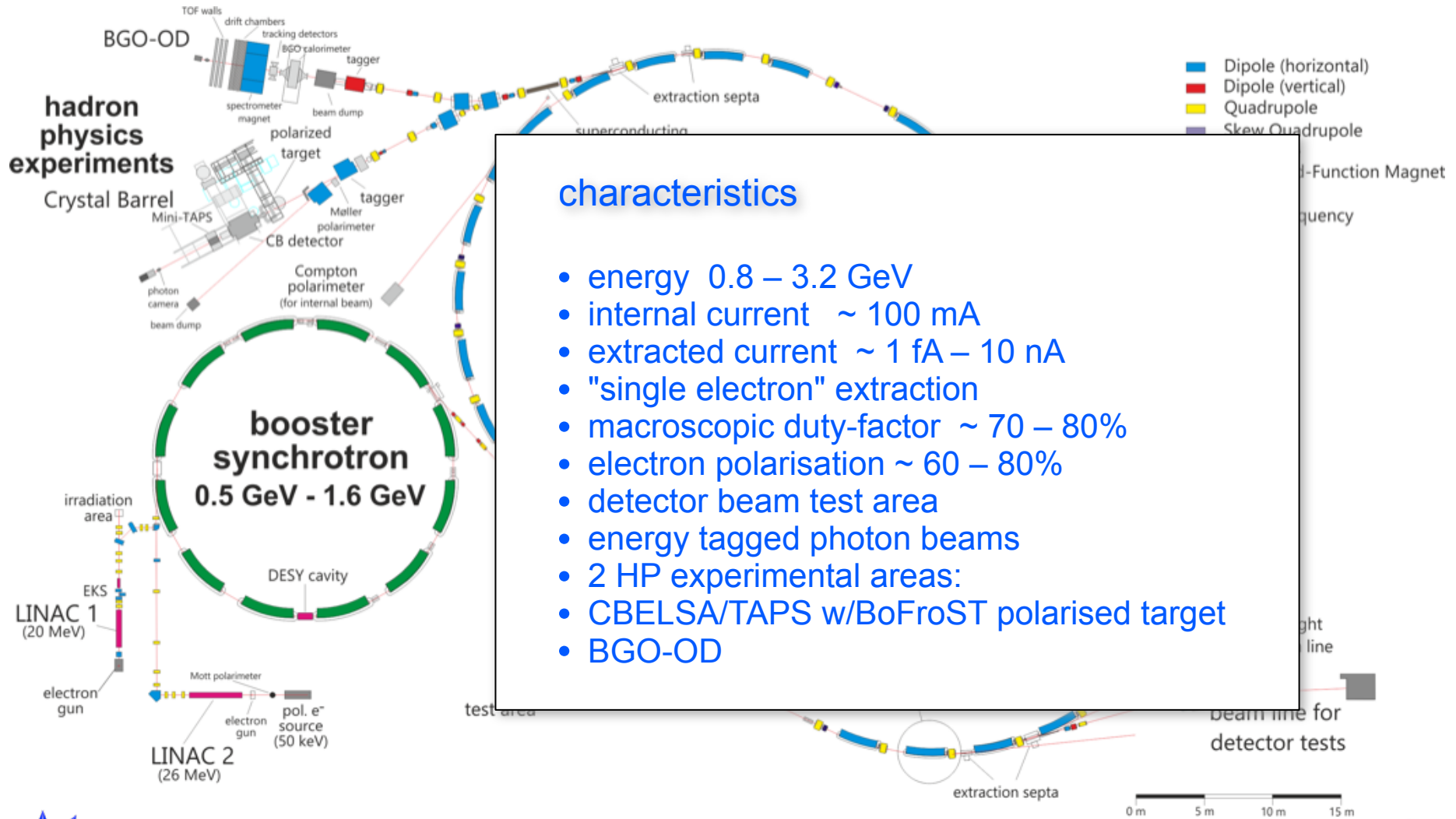
BGO-OD experiment @ELSA: accelerator



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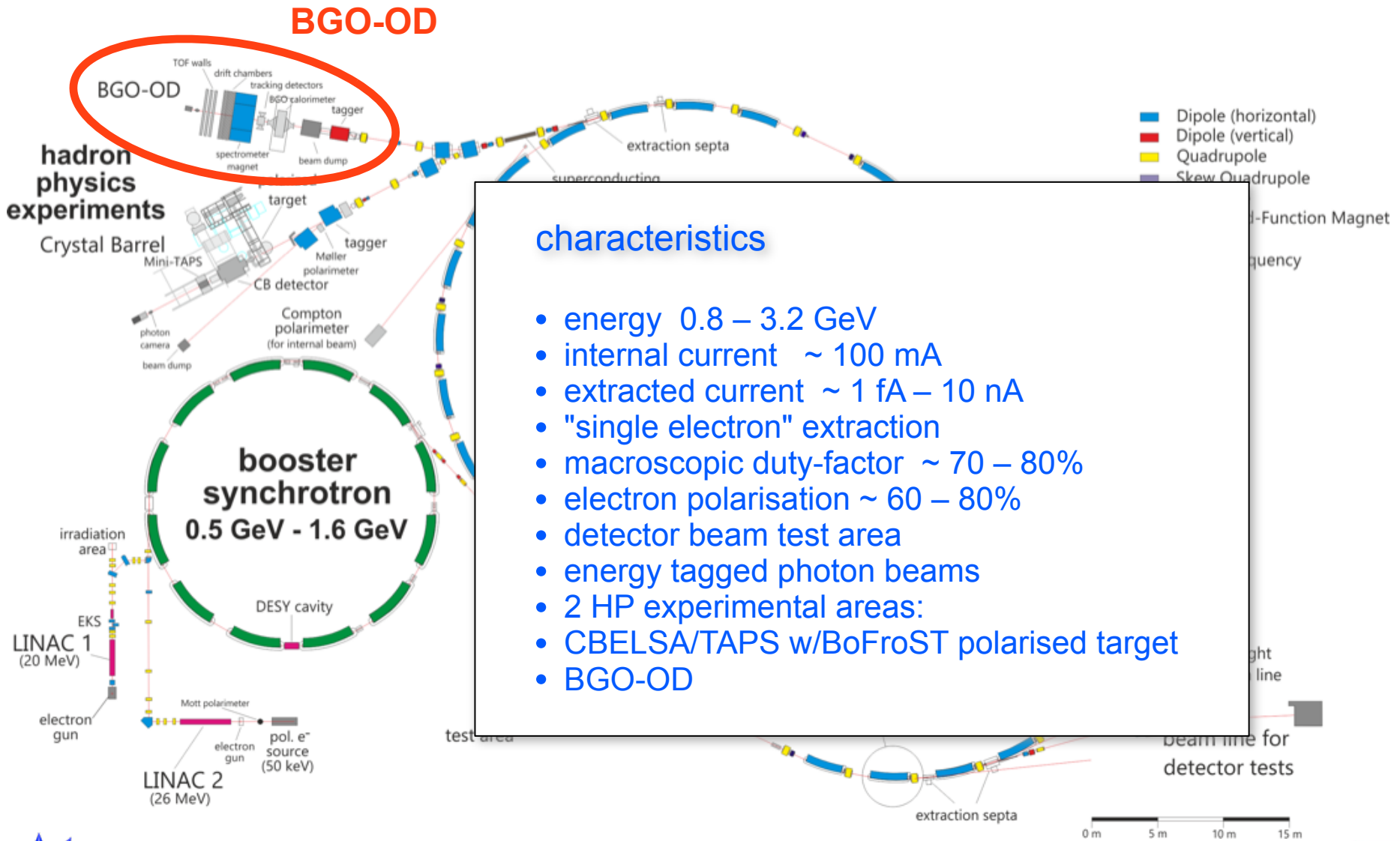
BGO-OD experiment @ELSA: accelerator



characteristics

- energy 0.8 – 3.2 GeV
- internal current ~ 100 mA
- extracted current ~ 1 fA – 10 nA
- "single electron" extraction
- macroscopic duty-factor ~ 70 – 80%
- electron polarisation ~ 60 – 80%
- detector beam test area
- energy tagged photon beams
- 2 HP experimental areas:
• CBELSA/TAPS w/BoFroST polarised target
• BGO-OD

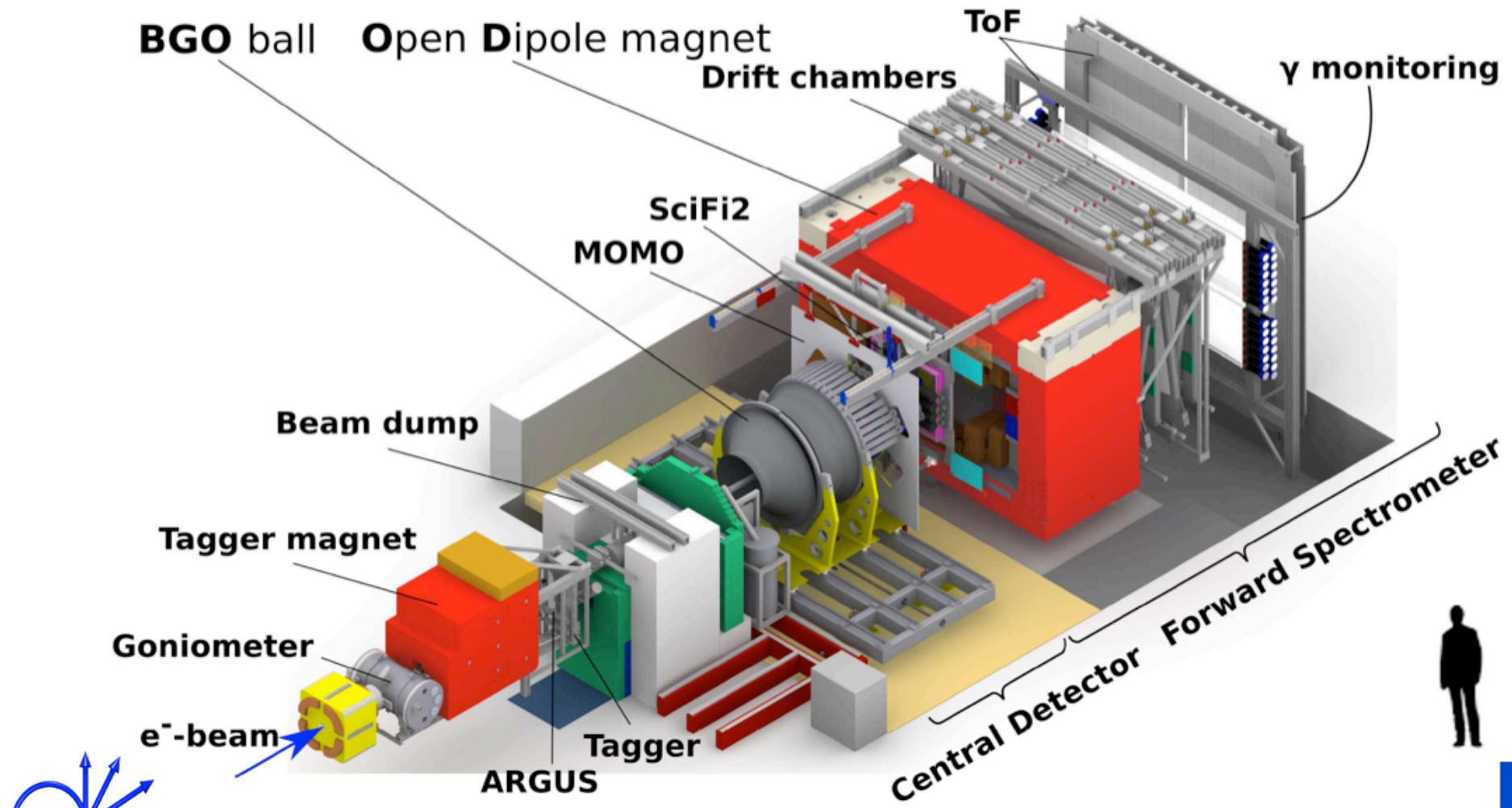
BGO-OD experiment @ELSA: accelerator



BGO-OD experiment

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

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

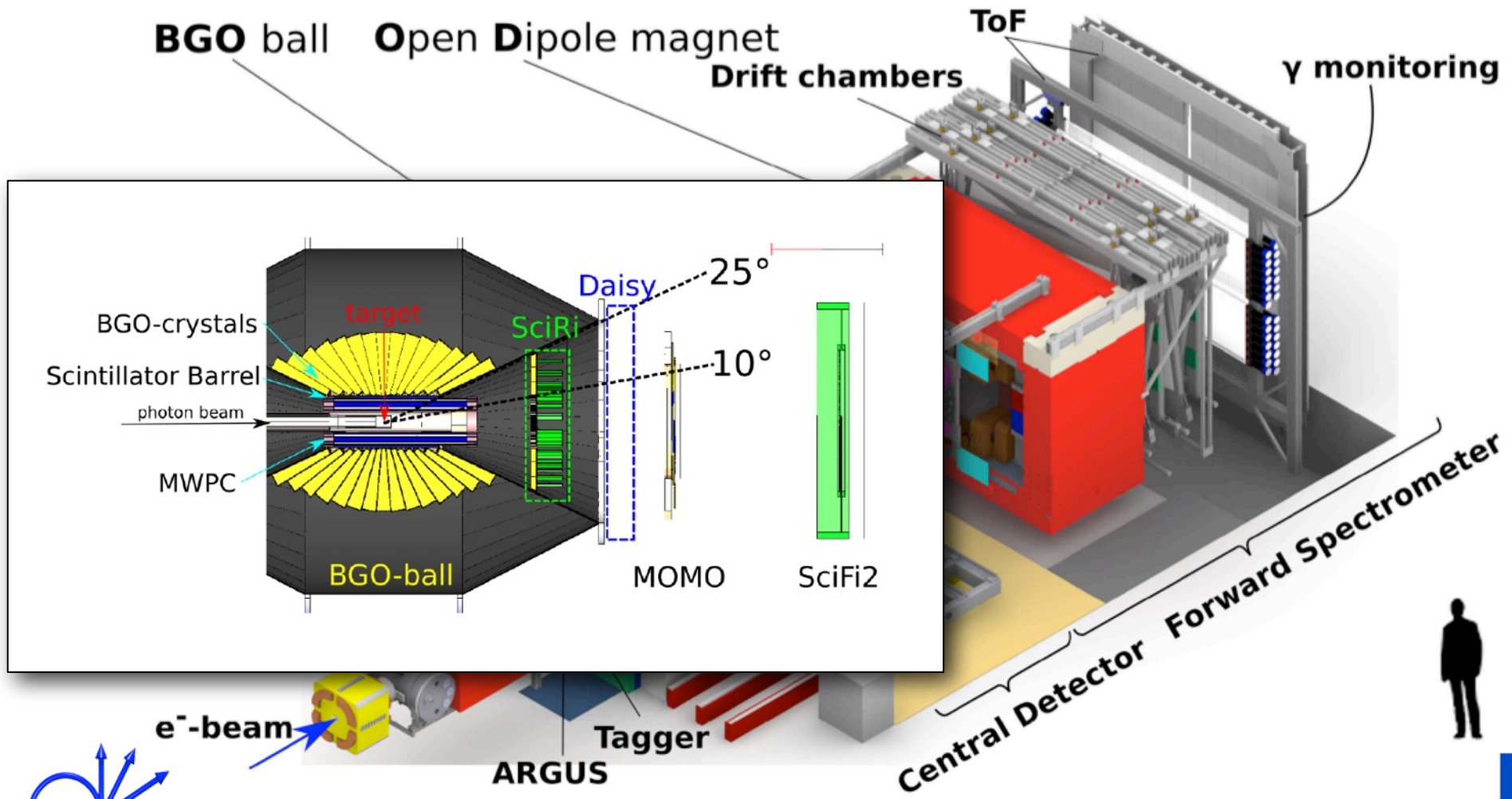


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BGO-OD experiment

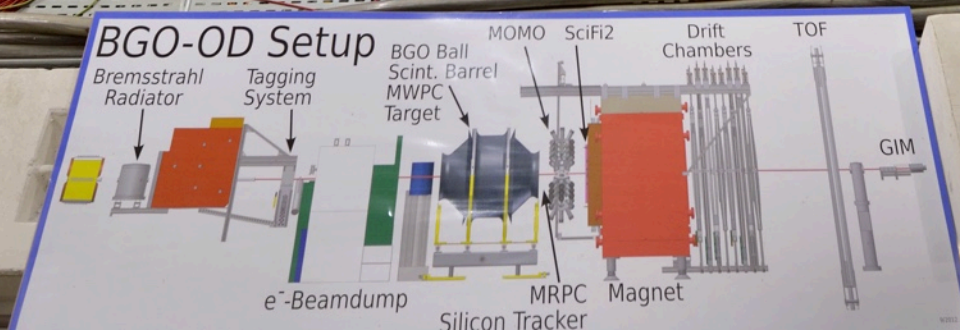
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BGO-OD experiment at ELSA



First Results from BGO-OD

all preliminary



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Particle ID & event reconstruction

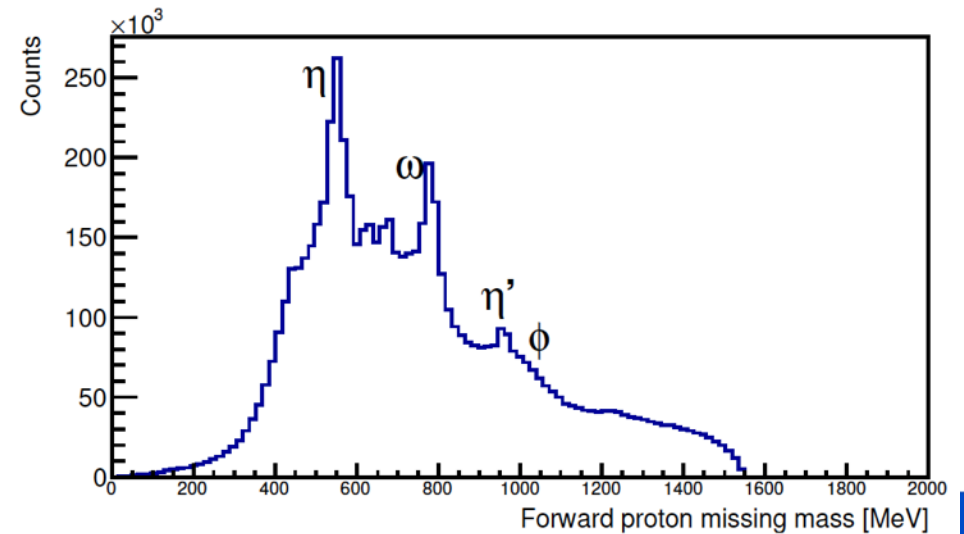
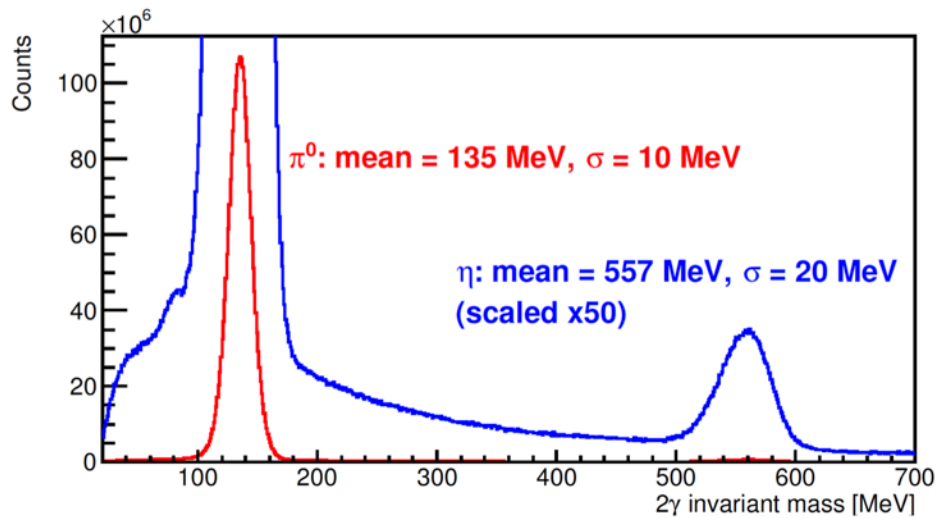
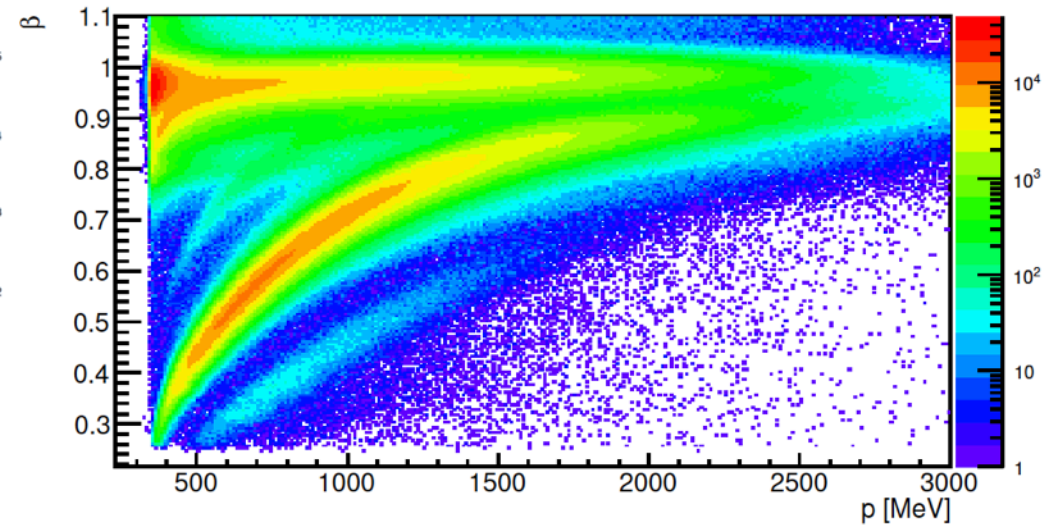
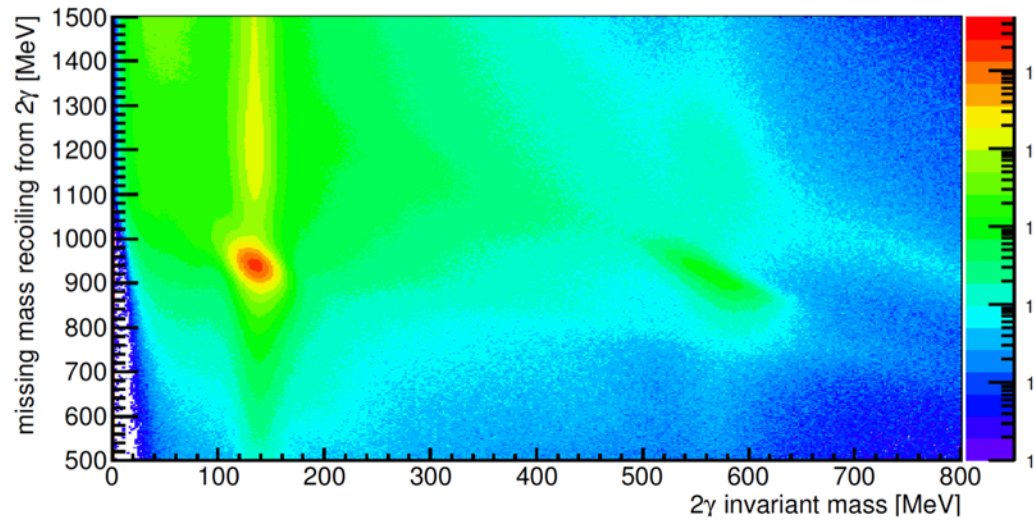
central

forward

few days of data

BGO 2 γ reconstruction

OD pos. charged particles

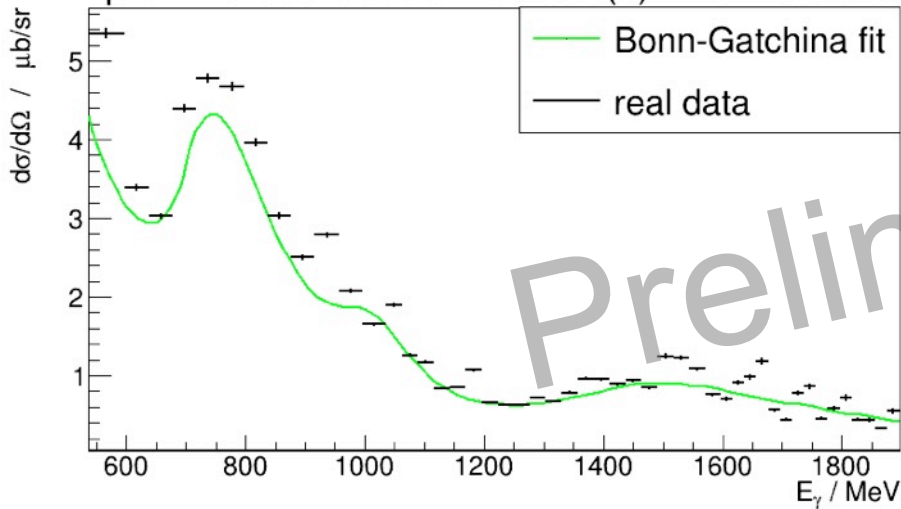


cross sections (bench marks)

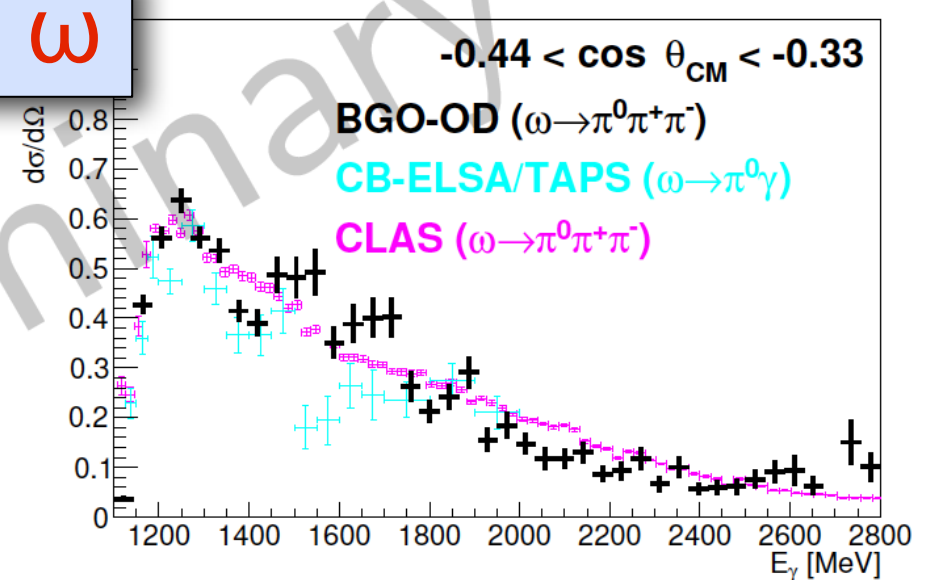
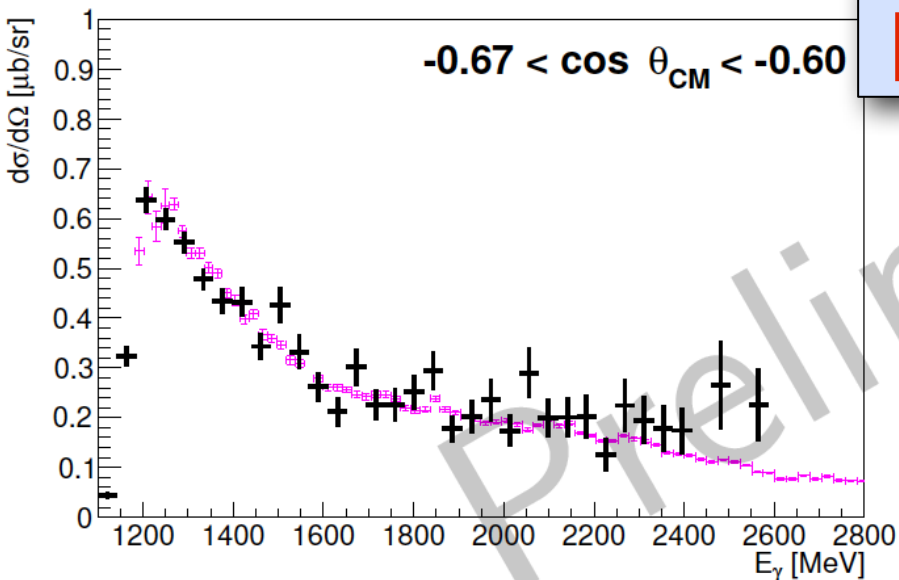
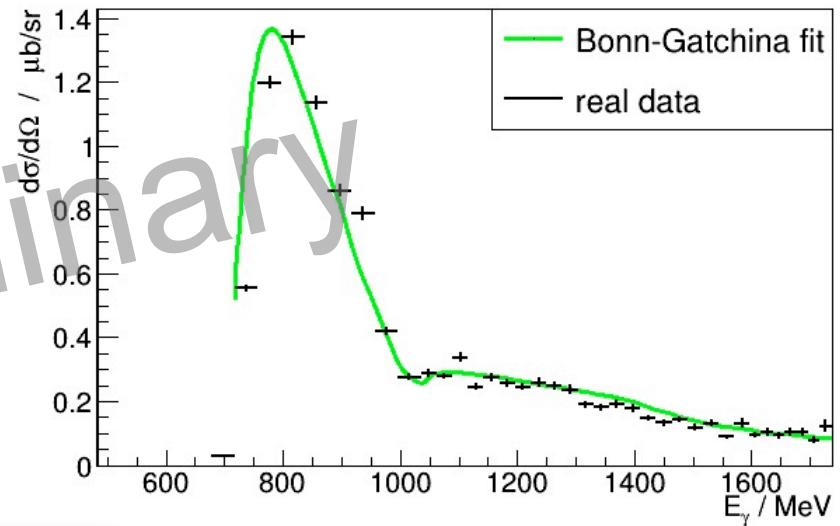
work of G. Scheluchin



$\pi^0 p$ diff. cross section for $\cos(\theta) = -0.2$ to 0.0



ηp diff. cross section for $\cos(\theta) = -0.2$ to 0.0



First Results strangeness photoproduction

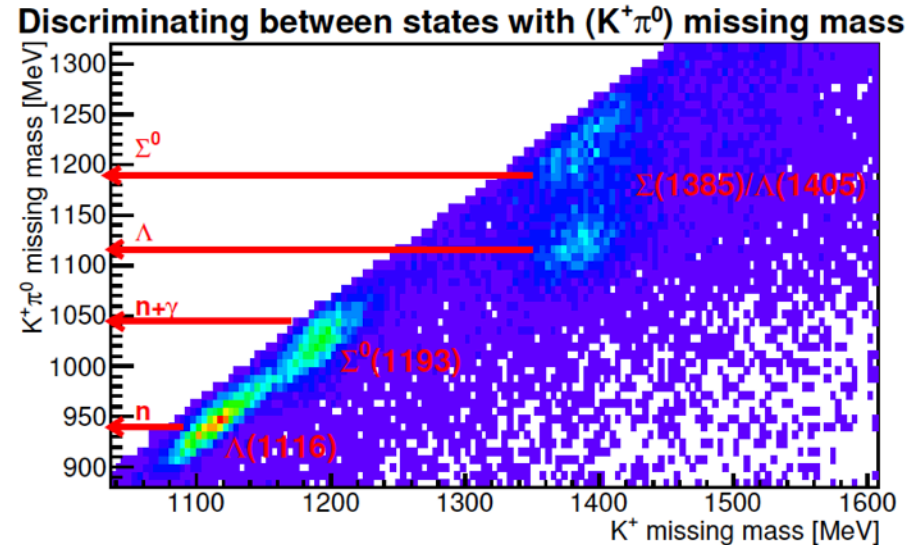
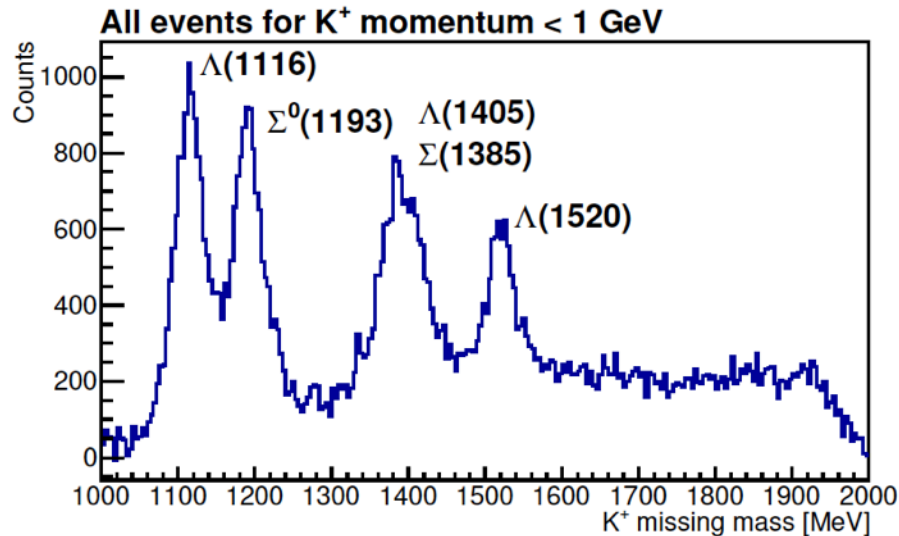
- overview – channel ID
- x-sec for (extreme forward) $K^+ Y_{g.s.}$
close to final
- $K^+ \Lambda(1405)$
preliminary
- $K^0 \Sigma^{+,0}$ off proton & neutron targets
event reconstruction



Overview $\gamma + p \rightarrow K^+ + X$

forward K^+ in spectrometer

work of T. Jude

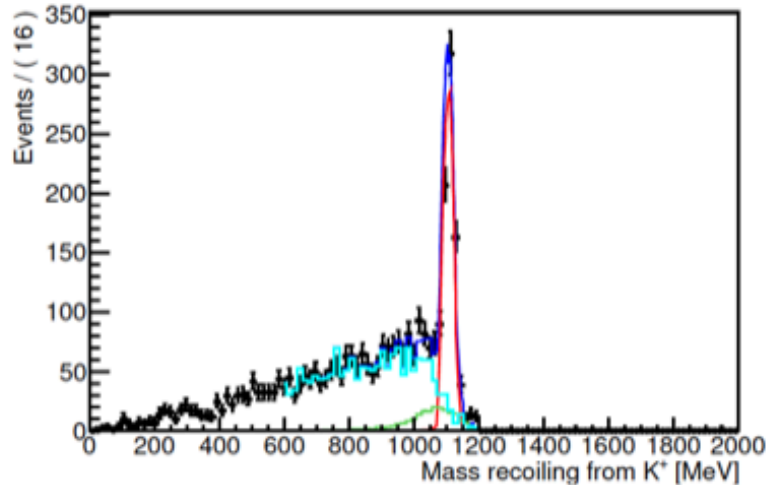


- Y^* at very low t
- Identify Y^* states from $(K^+ \pi^0)$ recoiling mass
 - ▶ $K^+ \Lambda \rightarrow K^+ \pi^0 n$ [missing neutron mass from $(K^+ \pi^0)$ system]
 - ▶ $K^+ \Lambda(1405) \rightarrow K^+ \pi^0 \Sigma^0$ [missing Σ^0 mass from $(K^+ \pi^0)$ system]
 - ▶ $K^+ \Sigma(1385) \rightarrow K^+ \pi^0 \Lambda$ [missing Λ mass from $(K^+ \pi^0)$ system]

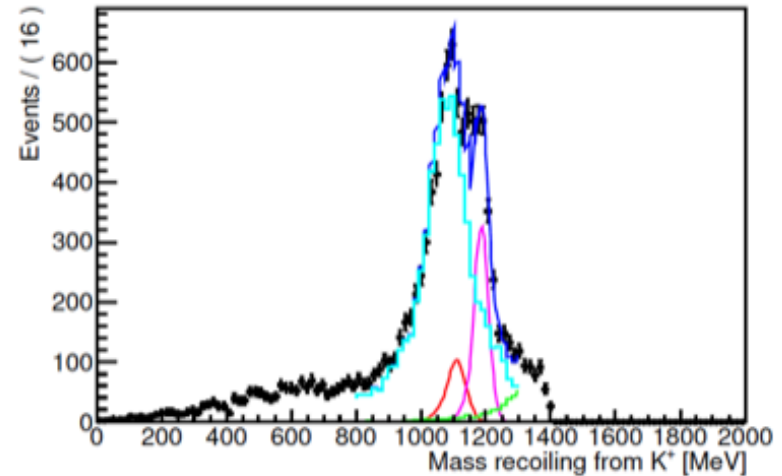
Extracting $K^+ \Lambda / \Sigma$ signals

work of T. Jude

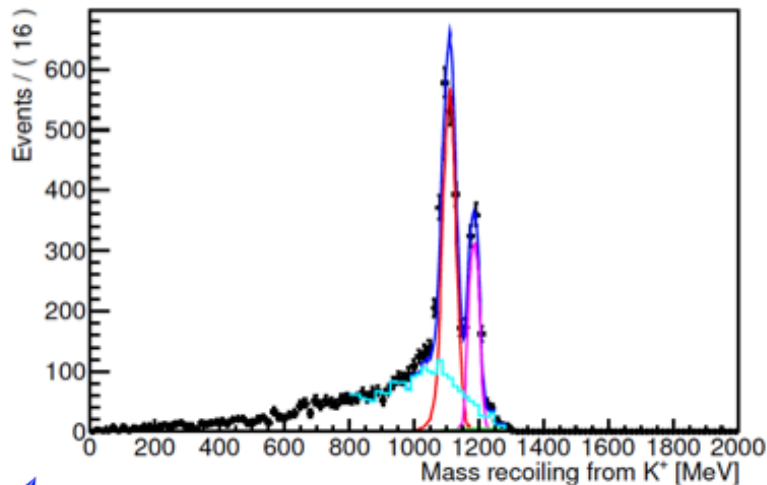
$W = 1600 - 1700$ MeV



$W = 1800 - 1900$ MeV



$W = 1700 - 1800$ MeV

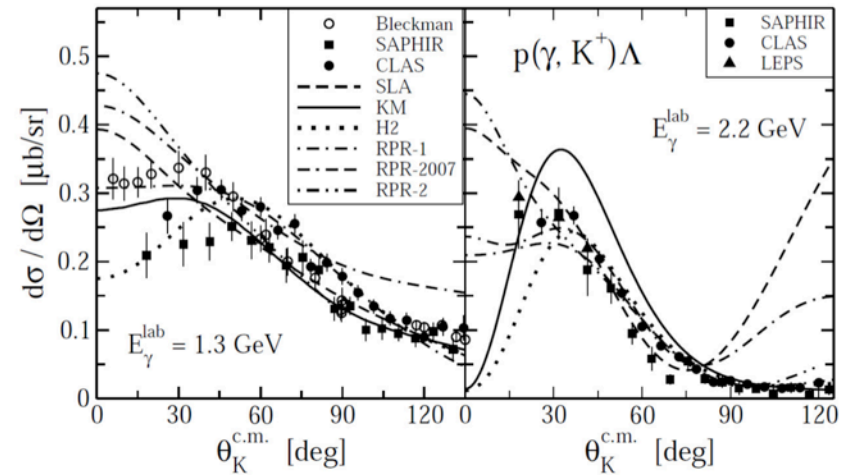
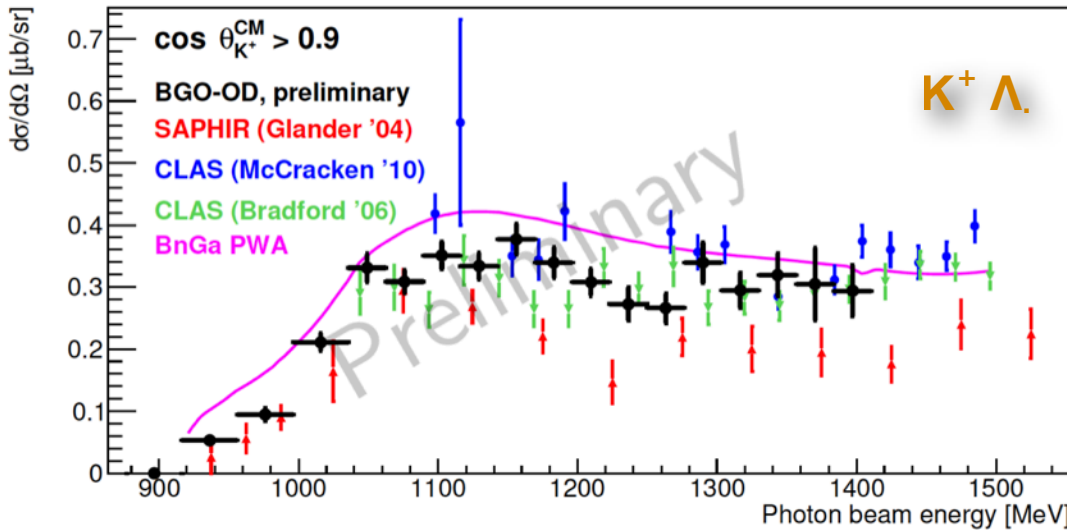
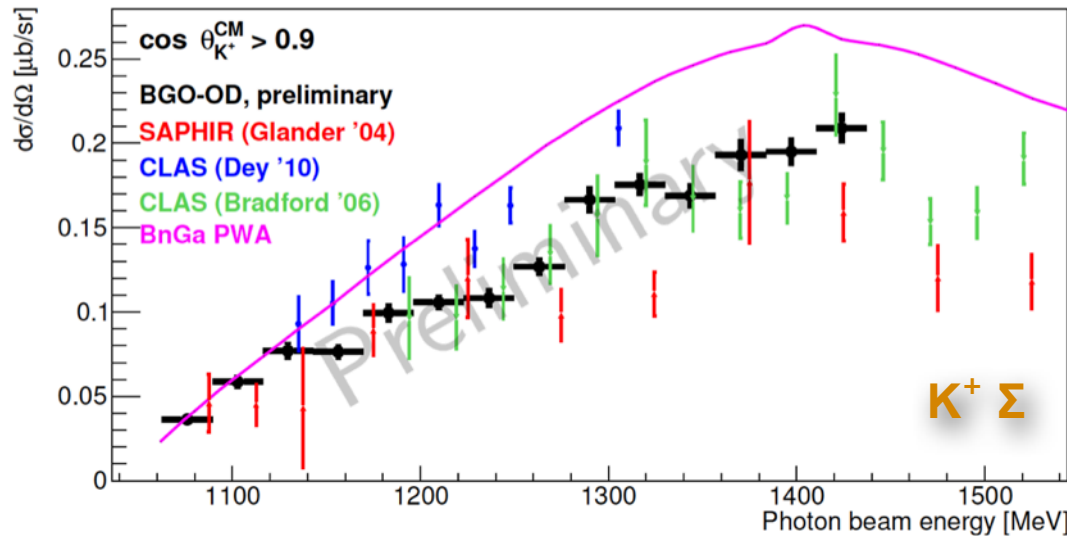


Fitting with *RooFit*

- Signal
- Simulated $K^+ \Lambda$ events
- Simulated $K^+ \Sigma^0$ events
- Background from pair production in the beam

$\gamma + p \rightarrow K^+ \Lambda_{g.s.} / \Sigma_{g.s.}$ @ forward angles

work of T. Jude



Bydzovsky and Skoupil, arXiv:1211.2684
Proceedings SNP12

- also $Y_{g.s.}$ almost unconstrained by data
- important constraint for hypernuclei production

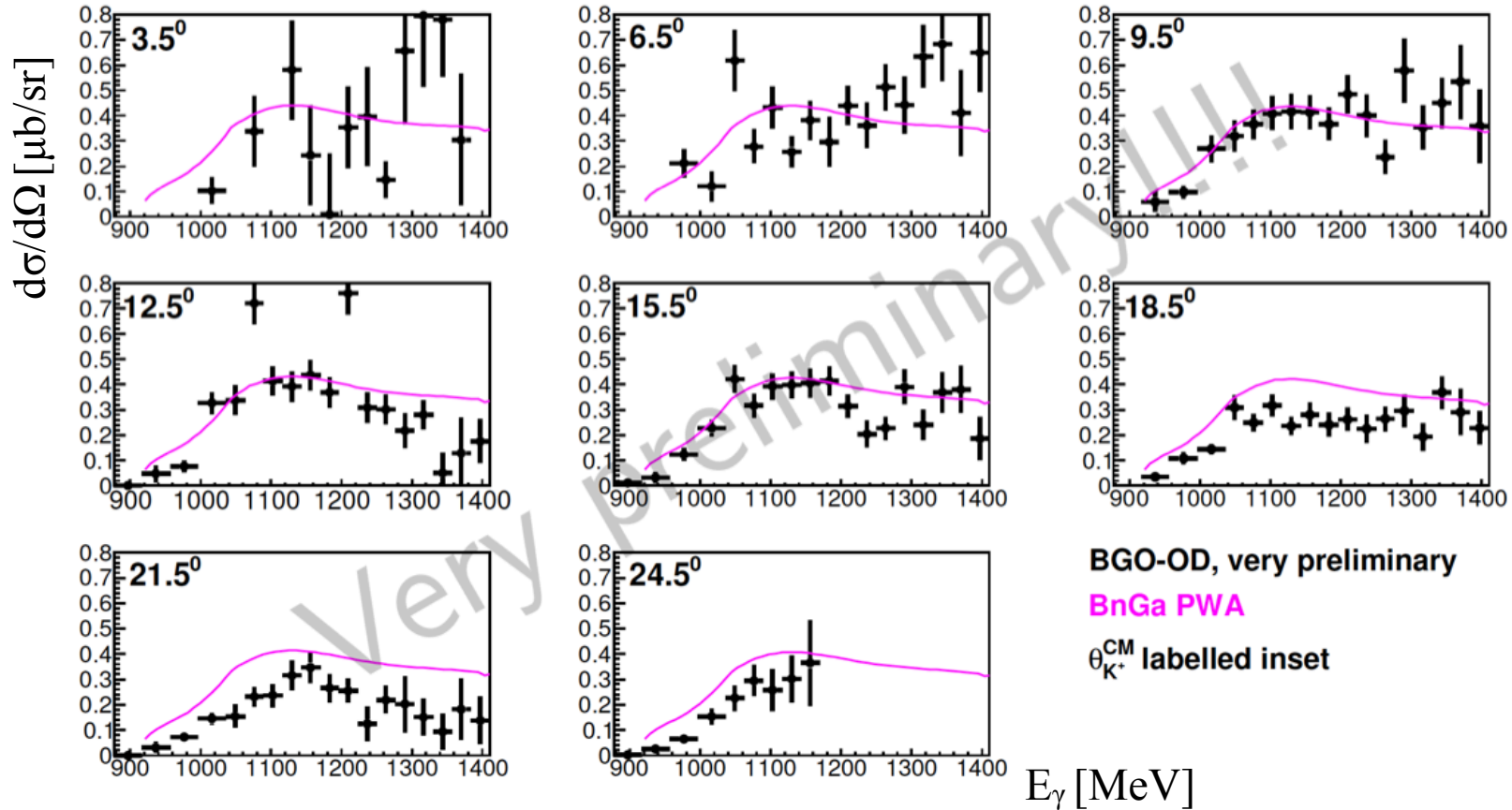
R. Bradford *et al.*, Phys. Rev. C73, 035202 (2006), M.E. McCracken *et al.*, Phys. Rev. C81, 025201 (2010),
K.H. Glander *et al.*, Eur. Phys. J. A19, 251 (2004), CLAS data in $\cos \theta_{K^+}^{CM}$ 0.85 to 0.95 interval



H. Schmieden



work of T. Jude

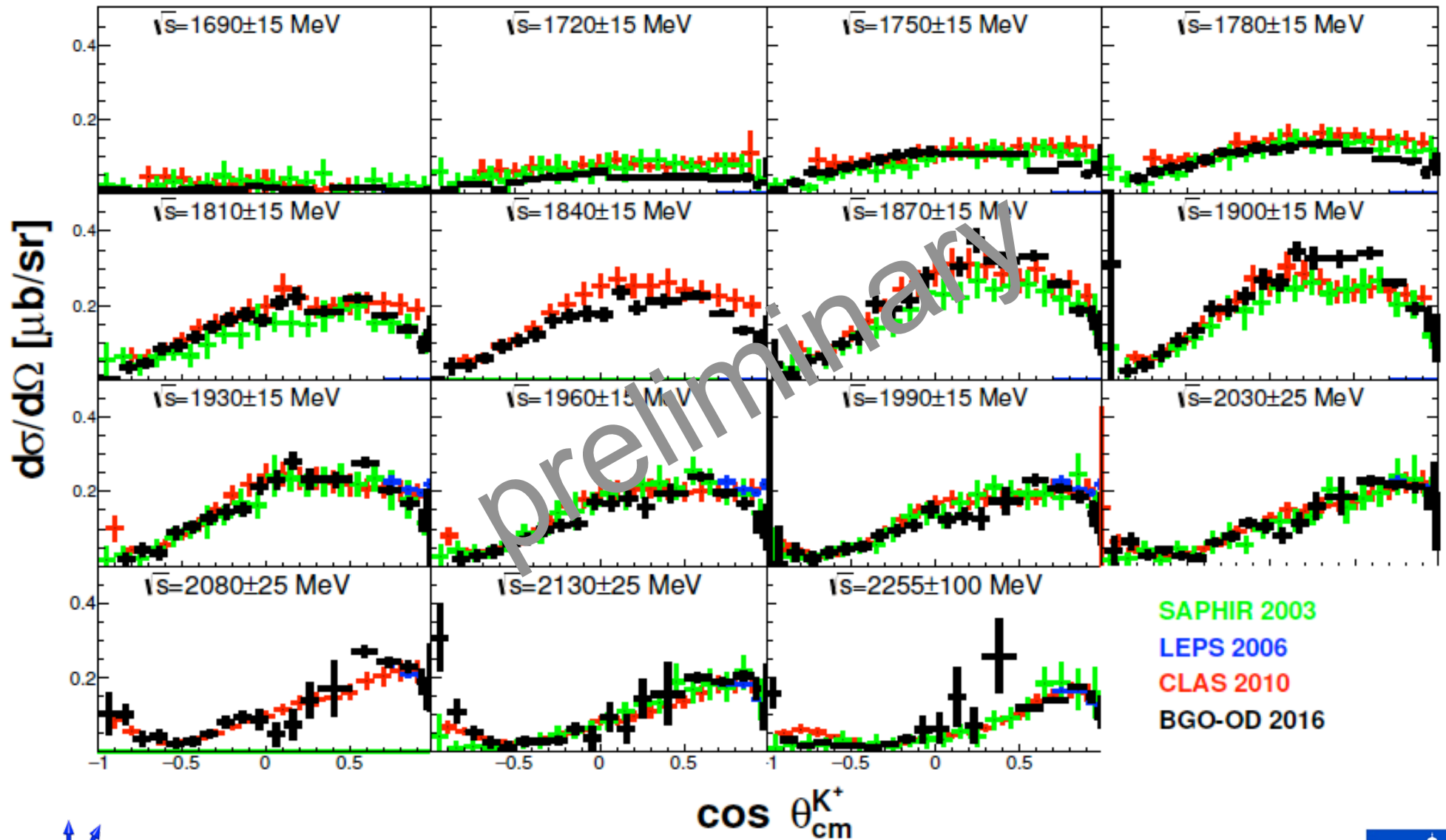


- unprecedented polar angular resolution
- ongoing analysis: statistical error to be reduced by 1/2
- more data to come

$\gamma + p \rightarrow K^+ + \Sigma(1193)$ full angular range

K^+ nearly 4π acceptance & kinematic fit / neural network analysis

work of G. Scheluchin

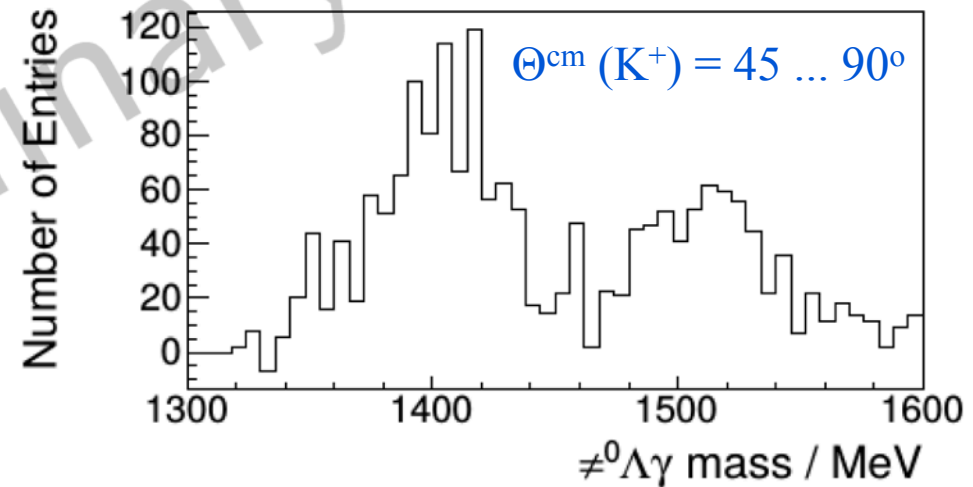
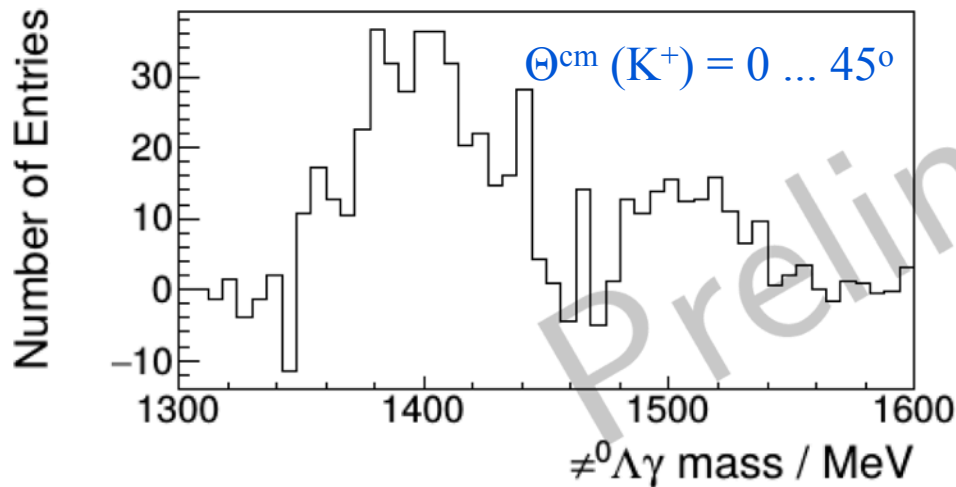
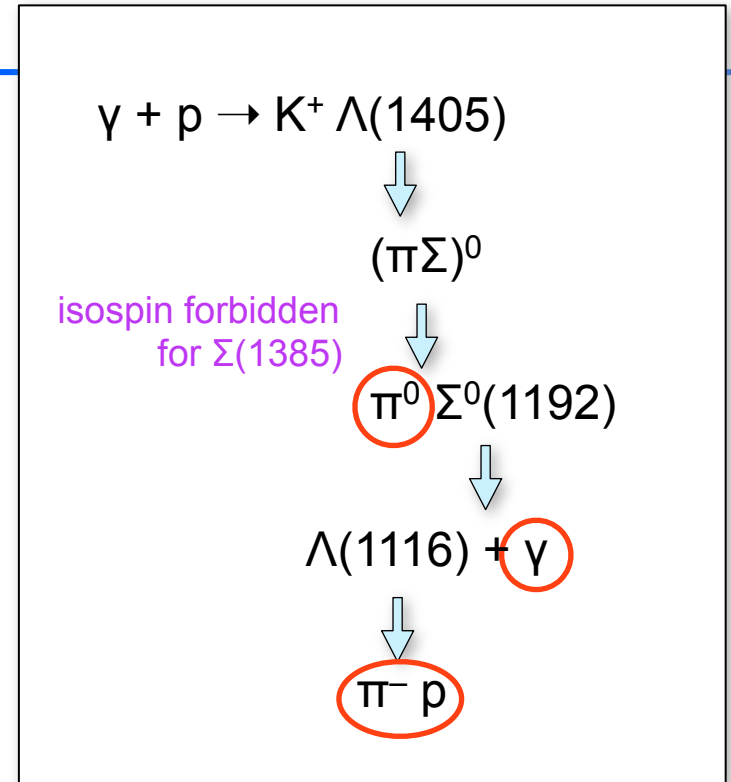


$\Lambda(1405)$: neutral decay mode

work of G. Scheluchin

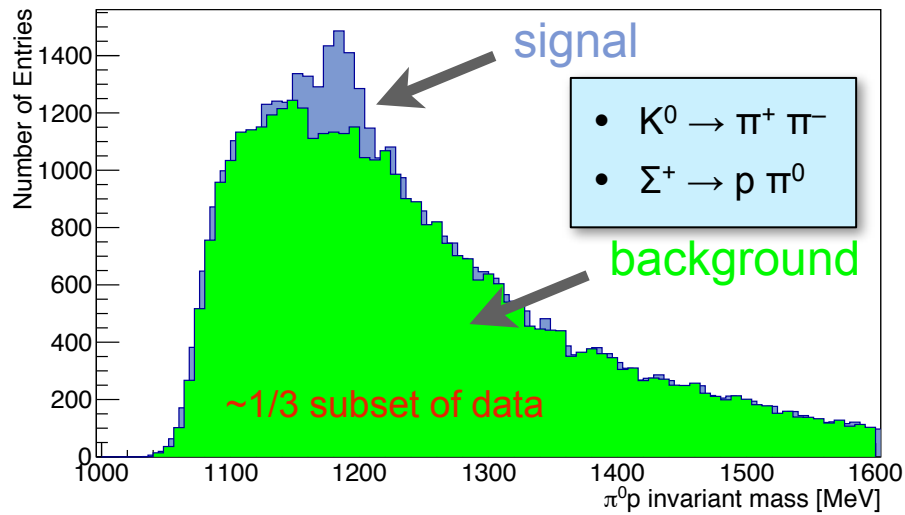
- full reconstruction of decay topology
- $K^+ \Lambda(1405) \rightarrow K^+ \pi^0 \Sigma^0 \rightarrow K^+ \gamma \gamma \gamma \pi^- p$
- complements CLAS data

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



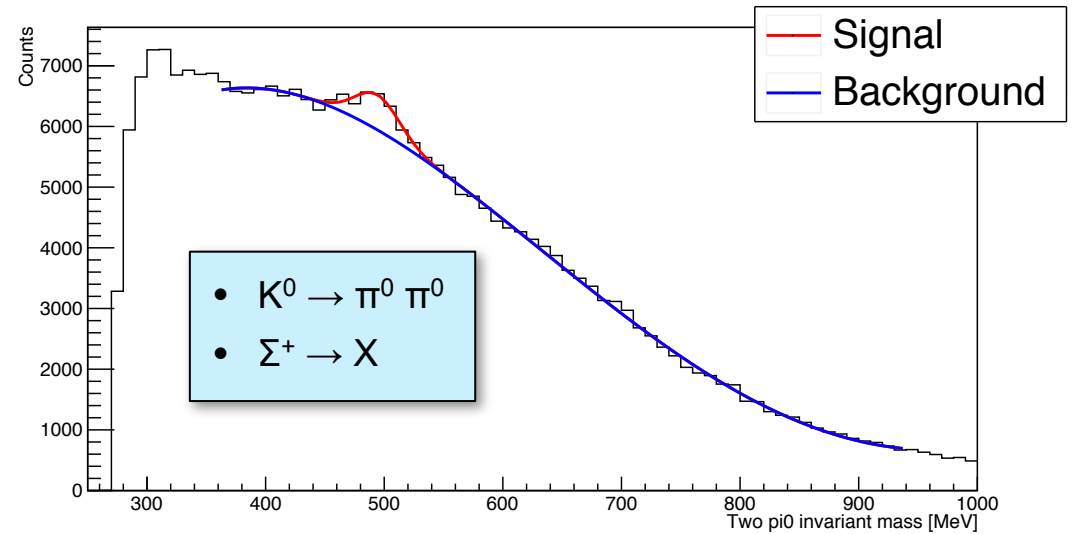
K^0 from *proton* target

work of B.-E. Reitz



w/ kinematic fit

work of S. Alef



prior to kinematic fit

K^0 from *neutron* target

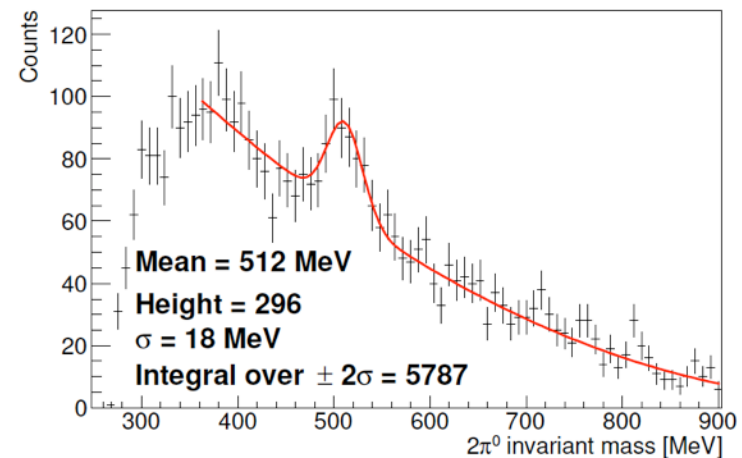
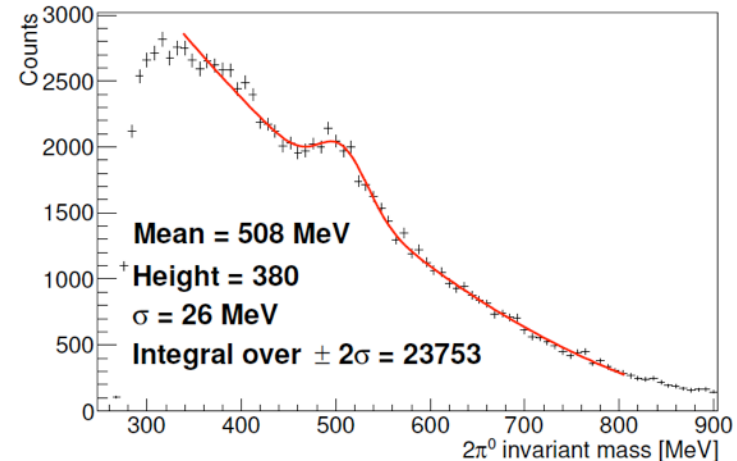
2 day test beam

work of T. Jude

- $K^0 \rightarrow 2\pi^0$ in BGO
- $n(\text{neutral}) < 6$
- $n(\text{charged}) < 3$

in addition:

- p from $\Sigma^0 \rightarrow p \pi^-$ in forward spectrometer



K^0 from *neutron* target

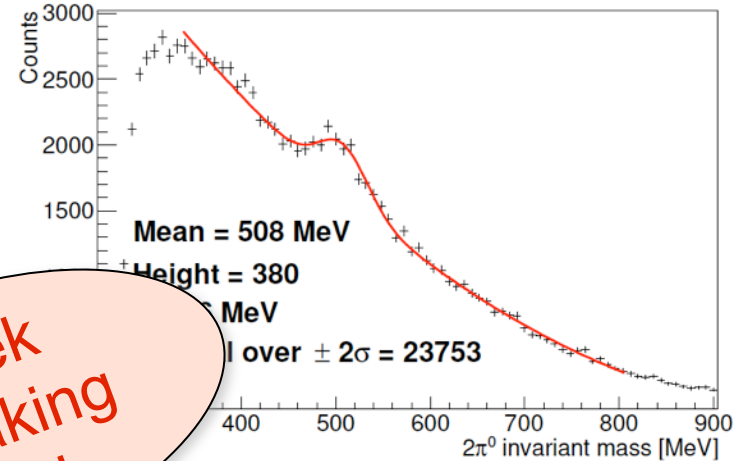
2 day test beam

work of T. Jude

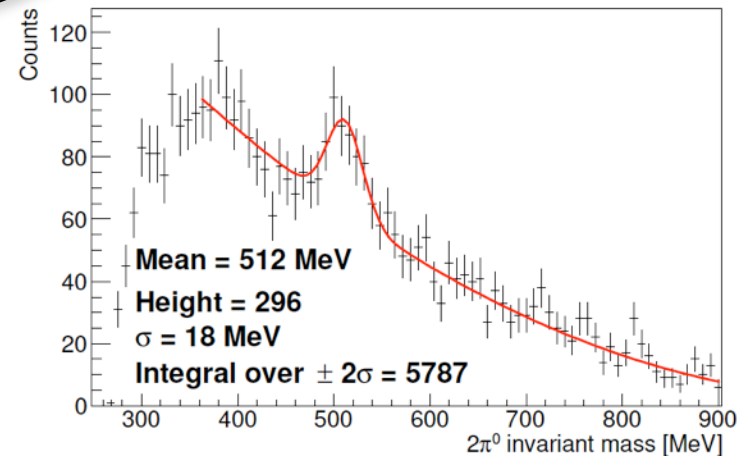
- $K^0 \rightarrow 2\pi^0$ in BGO
- $n(\text{neutral}) < 6$
- $n(\text{charged}) < 3$

in addition:

- p from $\Sigma^0 \rightarrow p \pi^-$ in forward spectrometer



3 week
data taking
ahead



Summary

- new BGO-OD experiment @ELSA
- unique for meson photoproduction
 - optimised for "forward kinematics" \leftrightarrow low- t processes
- first (very) preliminary results from s-sector
 - $K^+ \Lambda$ photoproduction at (very) forward angles
 - $K^+ \Sigma^0$ as check for Y^* production
 - $K^+ \Lambda(1405)$ line shape (& cross sections)
 - $K^0 \Sigma^+$ from proton target over K^* threshold
 - K^0 from neutron target (initial tests)
- open trigger: $KY^{(*)}$ data simultaneously, also η' etc.
- data taking ongoing



Summary

- new BGO-OD experiment @ELSA
- unique for meson photoproduction
 - optimised for "forward kinematics"
- first (very) preliminary results from 2018
 - $K^+ \Lambda$ photoproduction at (very) forward angles
 - $K^+ \Sigma^0$ as check for Y^* production
 - $K^+ \Lambda(1405)$ line shape (& cross-section)
 - $K^0 \Sigma^+$ from proton target over a wide range of angles
 - K^0 from neutron target (initially)
- open trigger: KY^* data simultaneous
- data taking ongoing

Thanks to:

- all collaborators in BGO-OD
- especially
S. Alef, P. Bauer, K. Kohl, B. Reitz,
G. Scheluchin, Ch. Tillmanns,
D. Spülbeck (present PhD, Master's
and Bachelor students), and
T. Jude (postdoc)
- ELSA crew for beam
- DFG for financial support

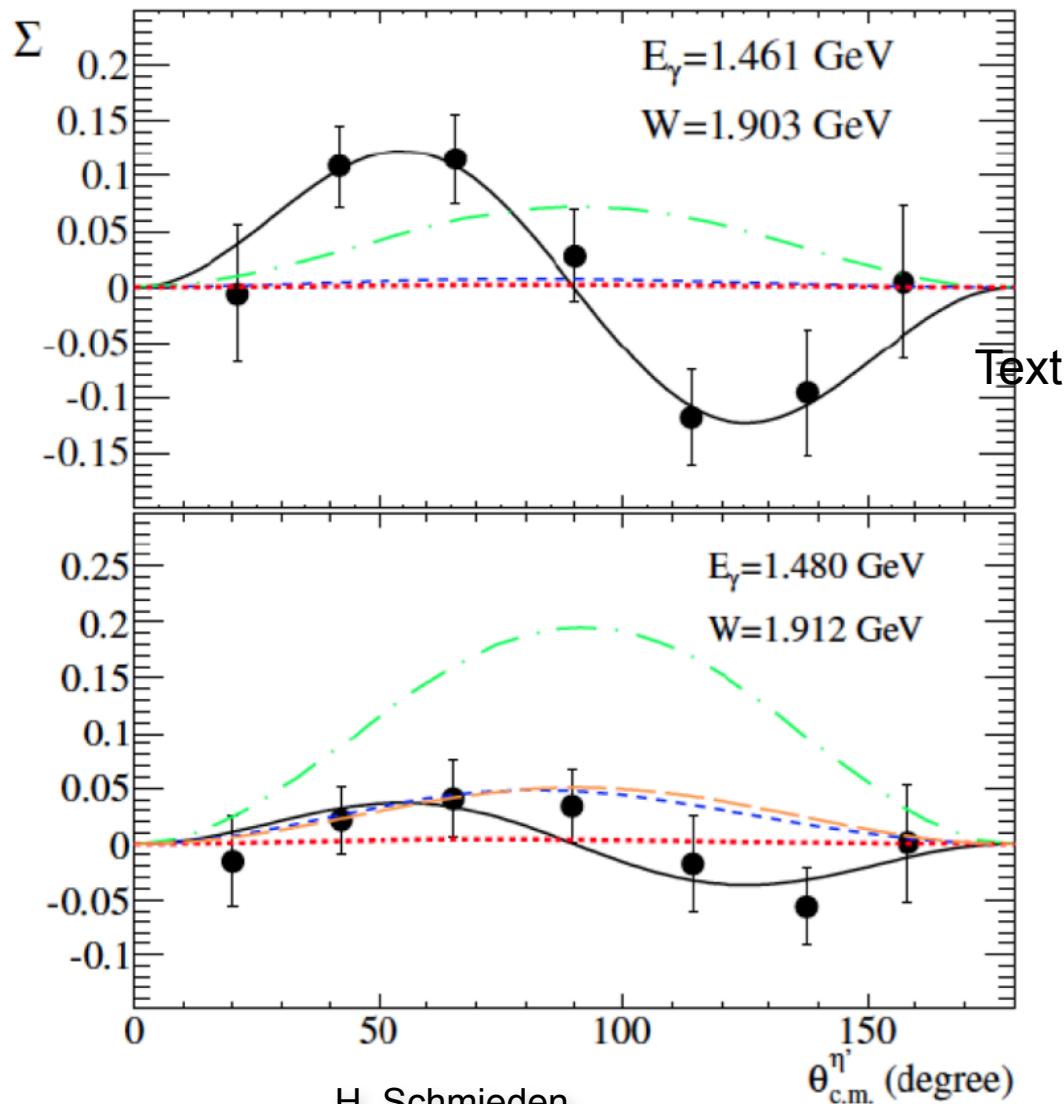
extra slides



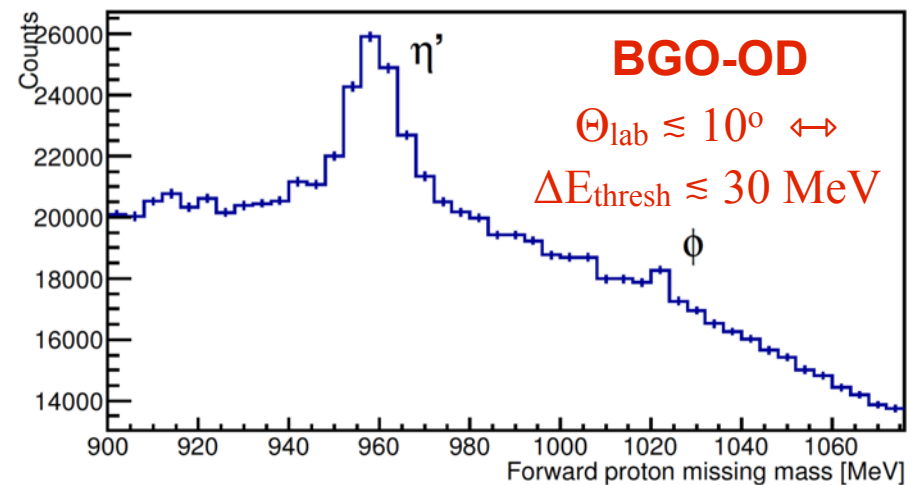
H. Schmieden

$\gamma p \rightarrow \eta' p$ @ threshold

all time **GRAAL** data



- nodal structure
→ interference w/ P/D-wave
- quickly decreasing w/ E_γ
→ narrow structure
- ideal for BGO-OD
→ recoil p in OD spectrometer



K⁺ ID in BGO Ball

T.C. Jude et al.,
PLB 735 (2014) 112

