Selected Aspects of Baryon Spectroscopy

in the light Quark Sector

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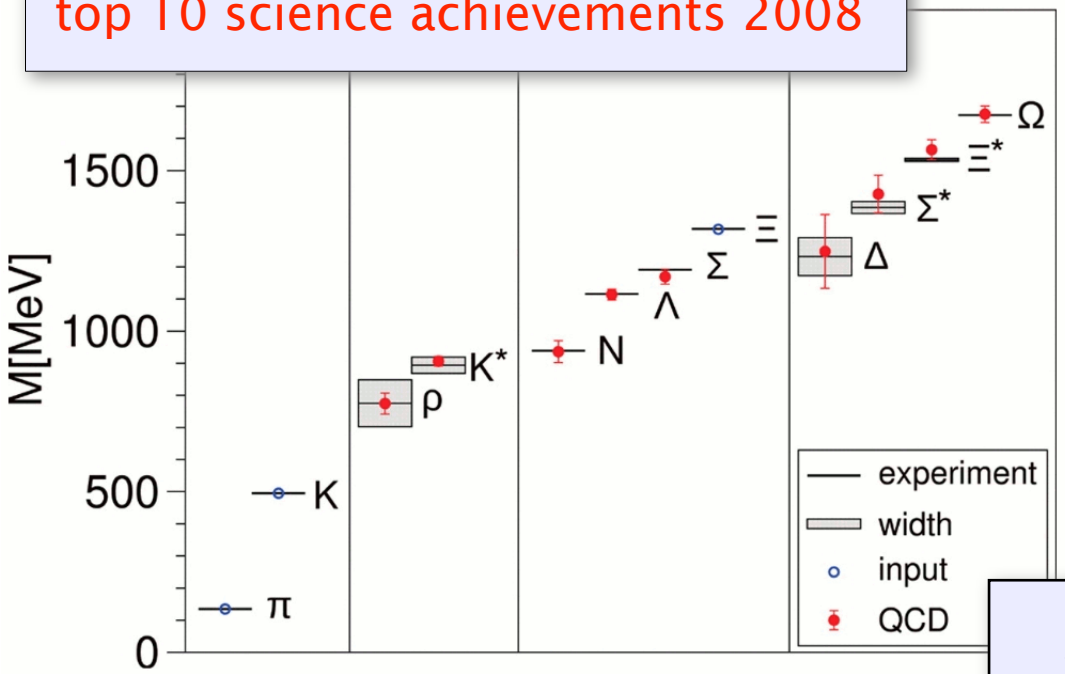
Outline

- introduction
- status baryon spectroscopy
- context heavy quarks
- ELSA experiments
- summary

Physics Motivation

Lattice QCD – ground states

top 10 science achievements 2008

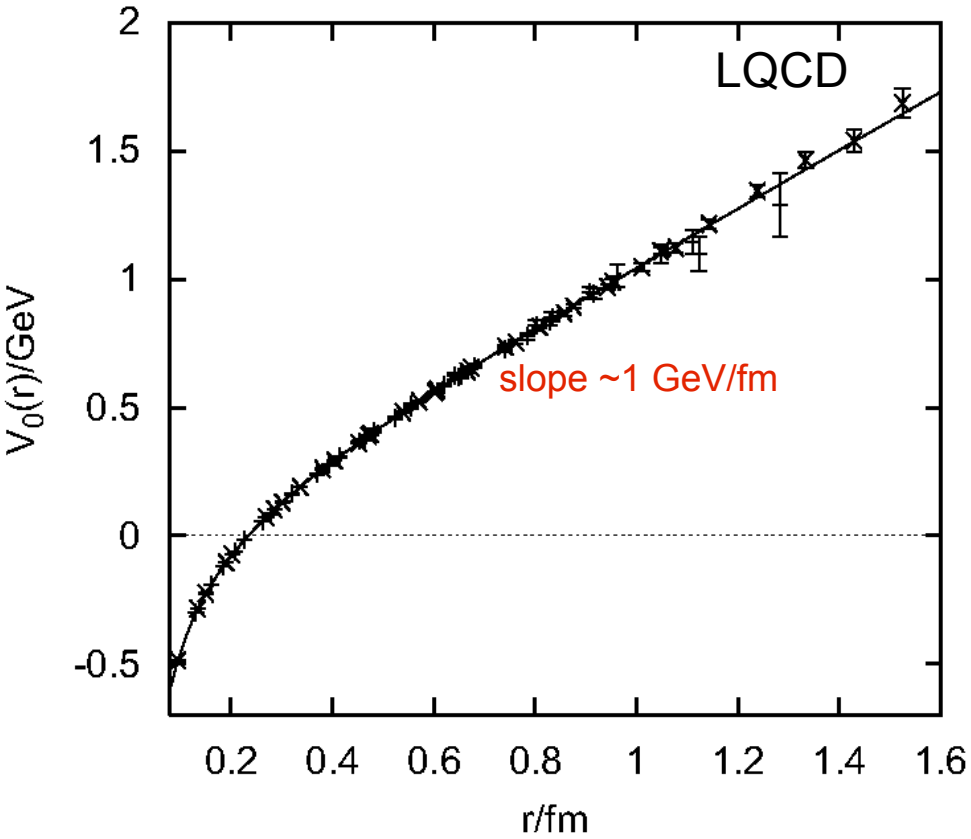


S. Dürr et al. (BMW-collaboration), Science 322 (2008) 1224

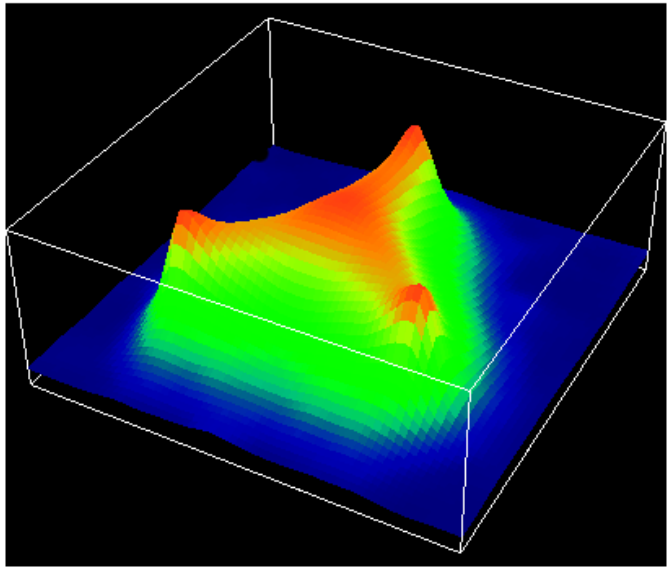
- "unquenched" calculation
- realistic quark masses

Physics Motivation

hadronic resonances



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

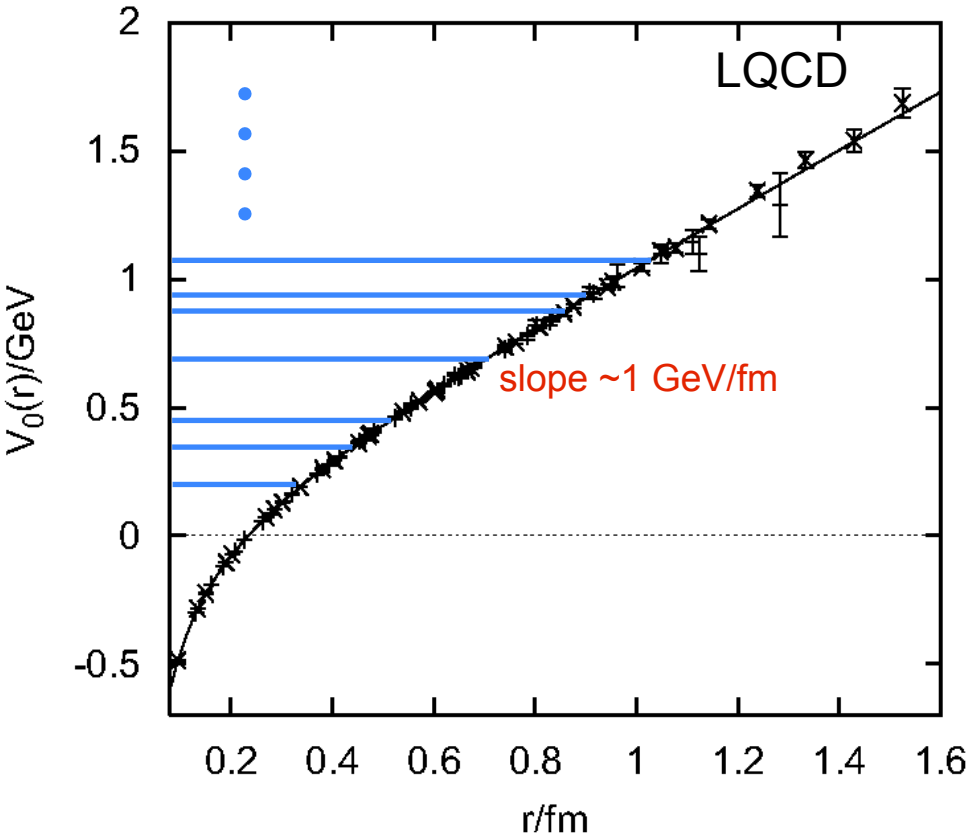


Energy density distribution
inside nucleon in LQCD simulation
(F. Wilczek, Physics today 11/99 & 1/00)

Physics Motivation

hadronic resonances

models: excitation in mutual potential



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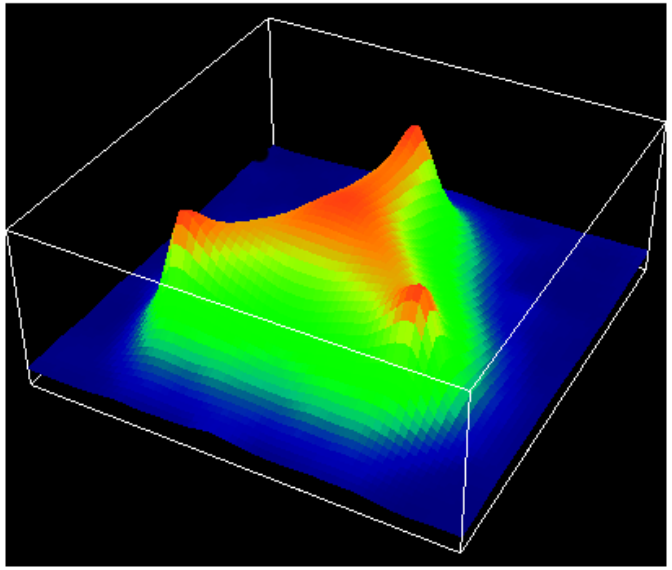

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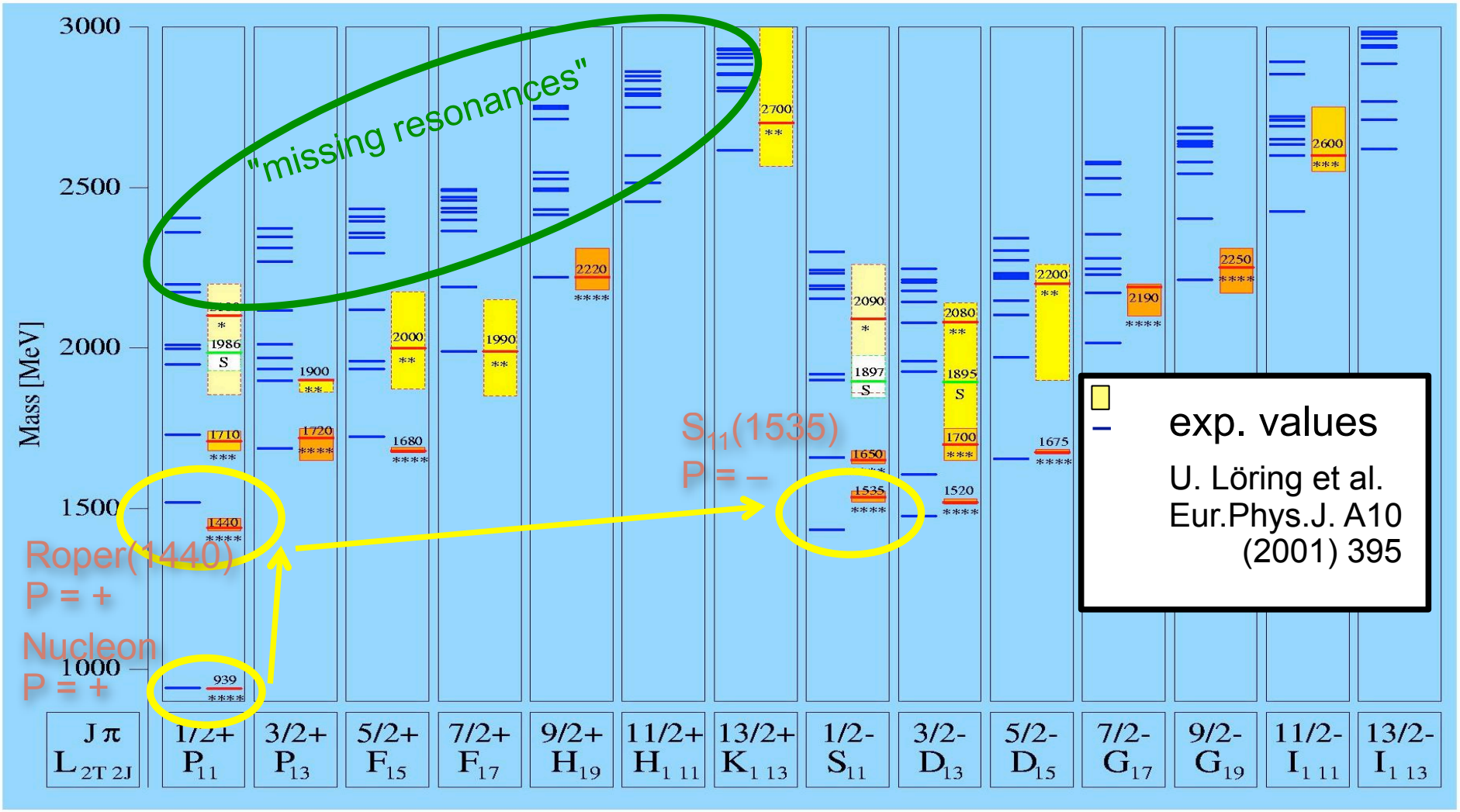
Excited states: quark model

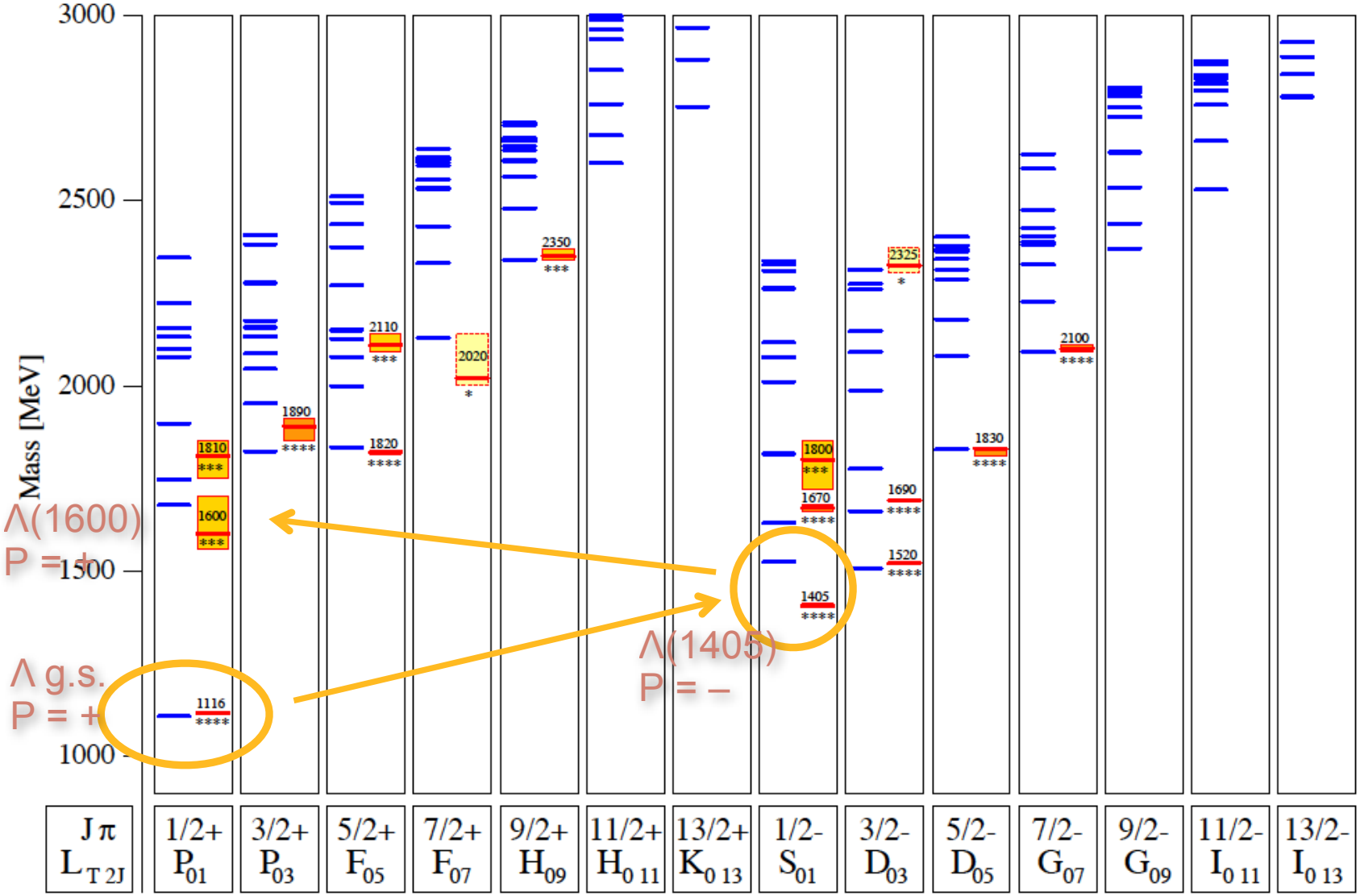
N* resonances



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

Excited states: quark model

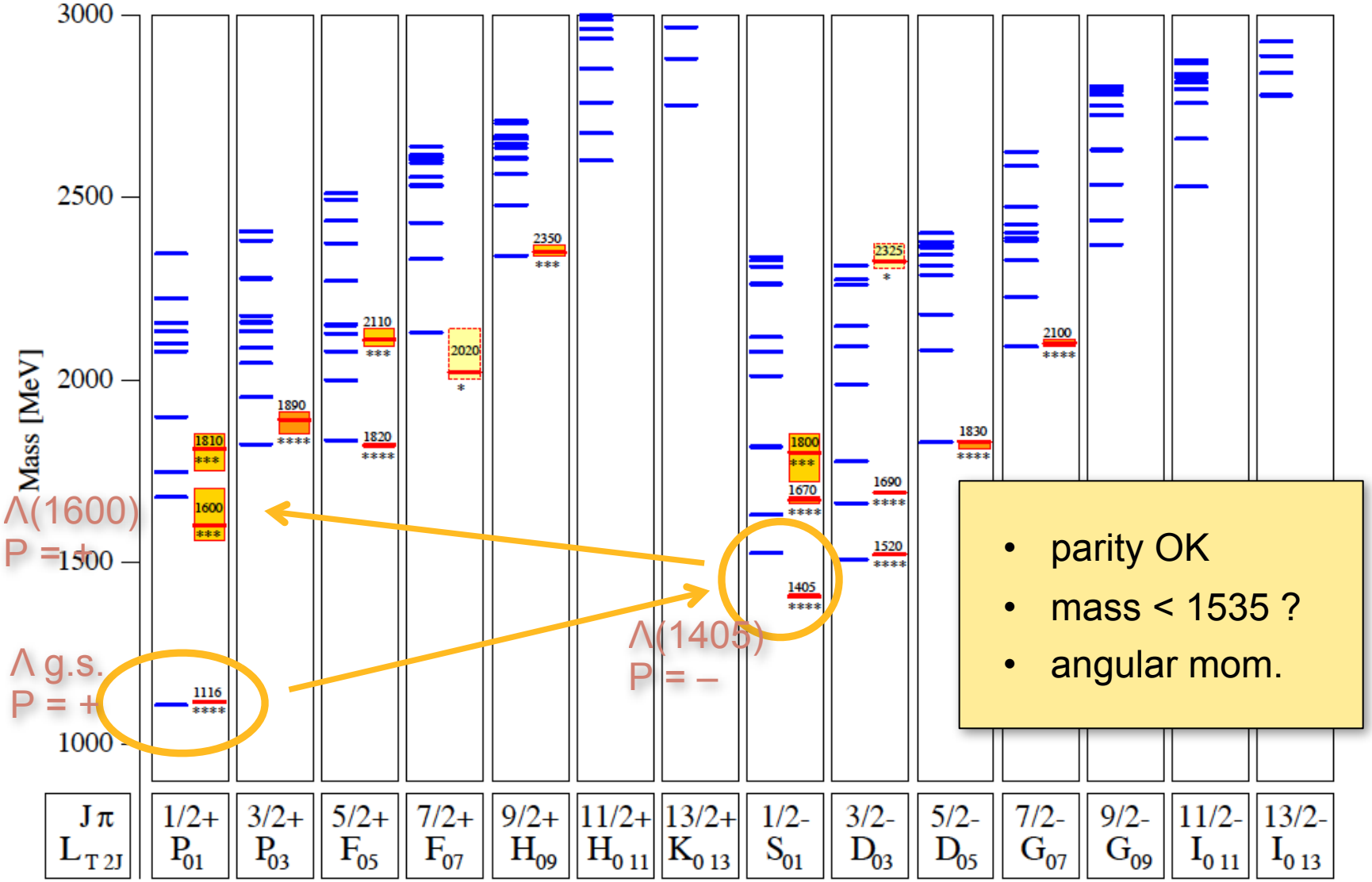
Λ* resonances



- parity pattern OK
- masses reversed ??

Excited states: quark model

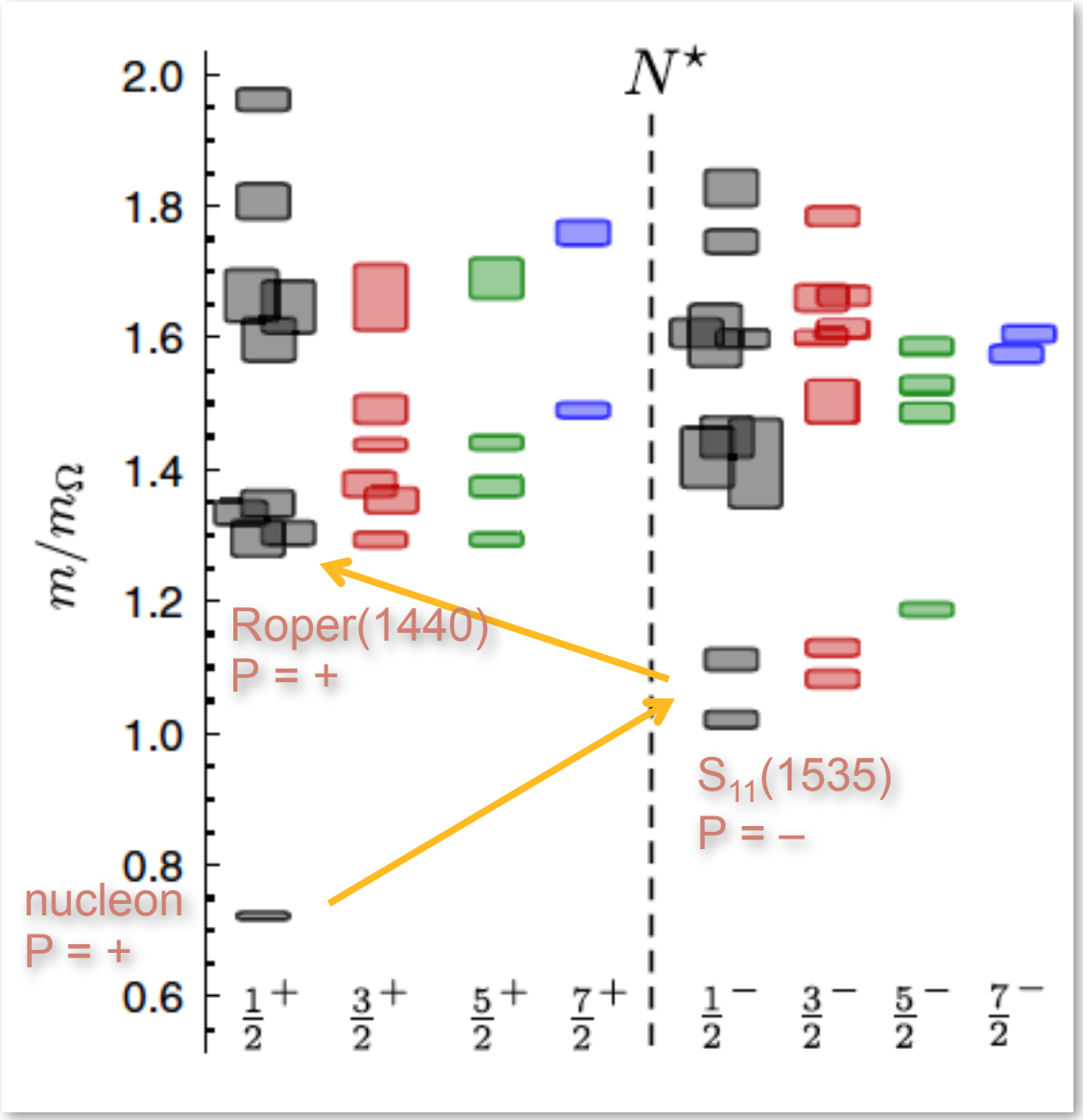
Λ* resonances



- parity OK
- mass < 1535 ?
- angular mom.

- parity pattern OK
- masses reversed ??

Excited states: Lattice QCD

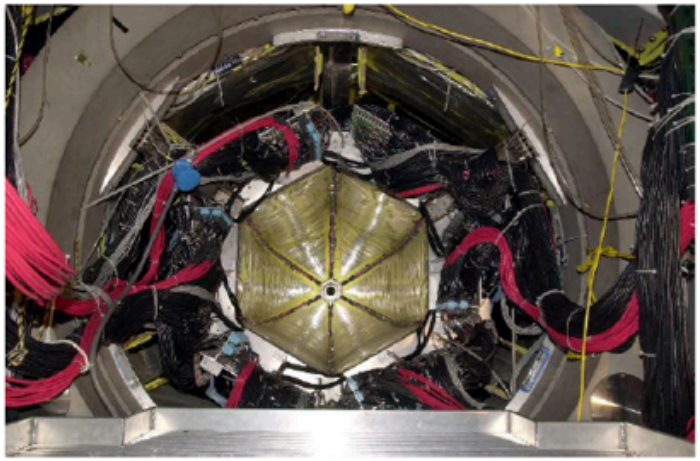


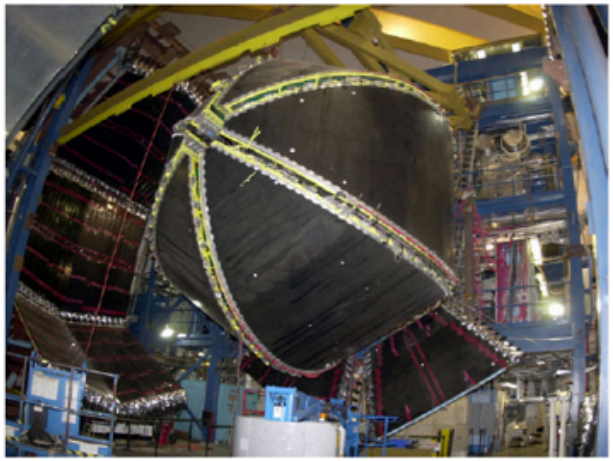
Excited states: LQCD

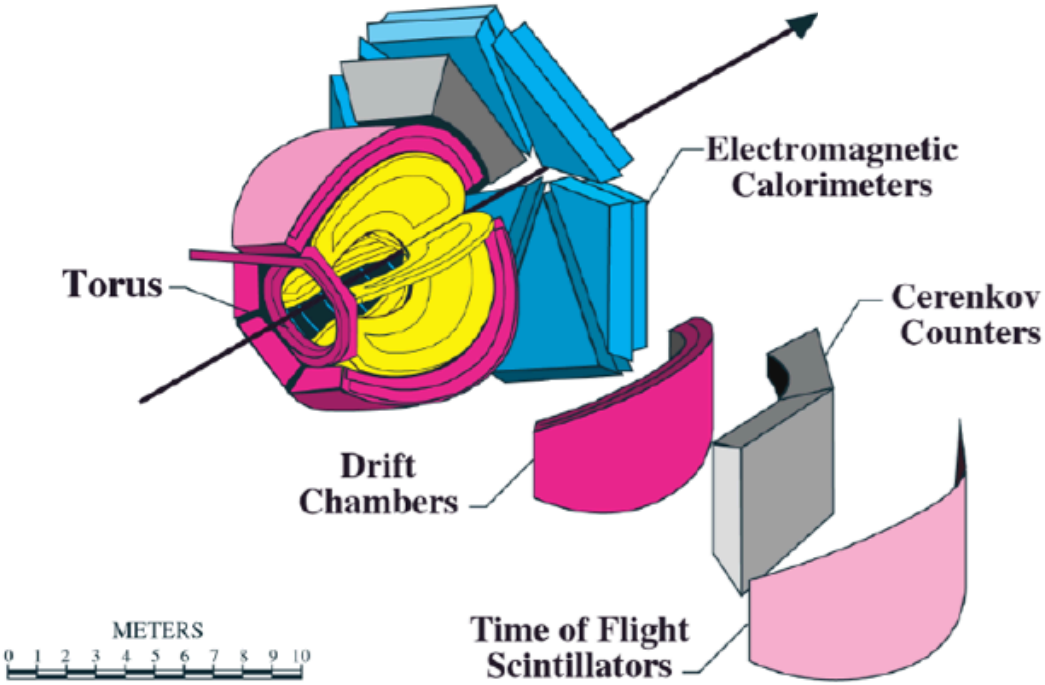
- m_π = 396 MeV
- reproduces q-models
- wrong parity pattern
- but: no decays !

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

CLAS @ JLab







courtesy: V. Credé

CLAS @ JLab

✓ - *data acquired* ✓ - *analyzed/published*

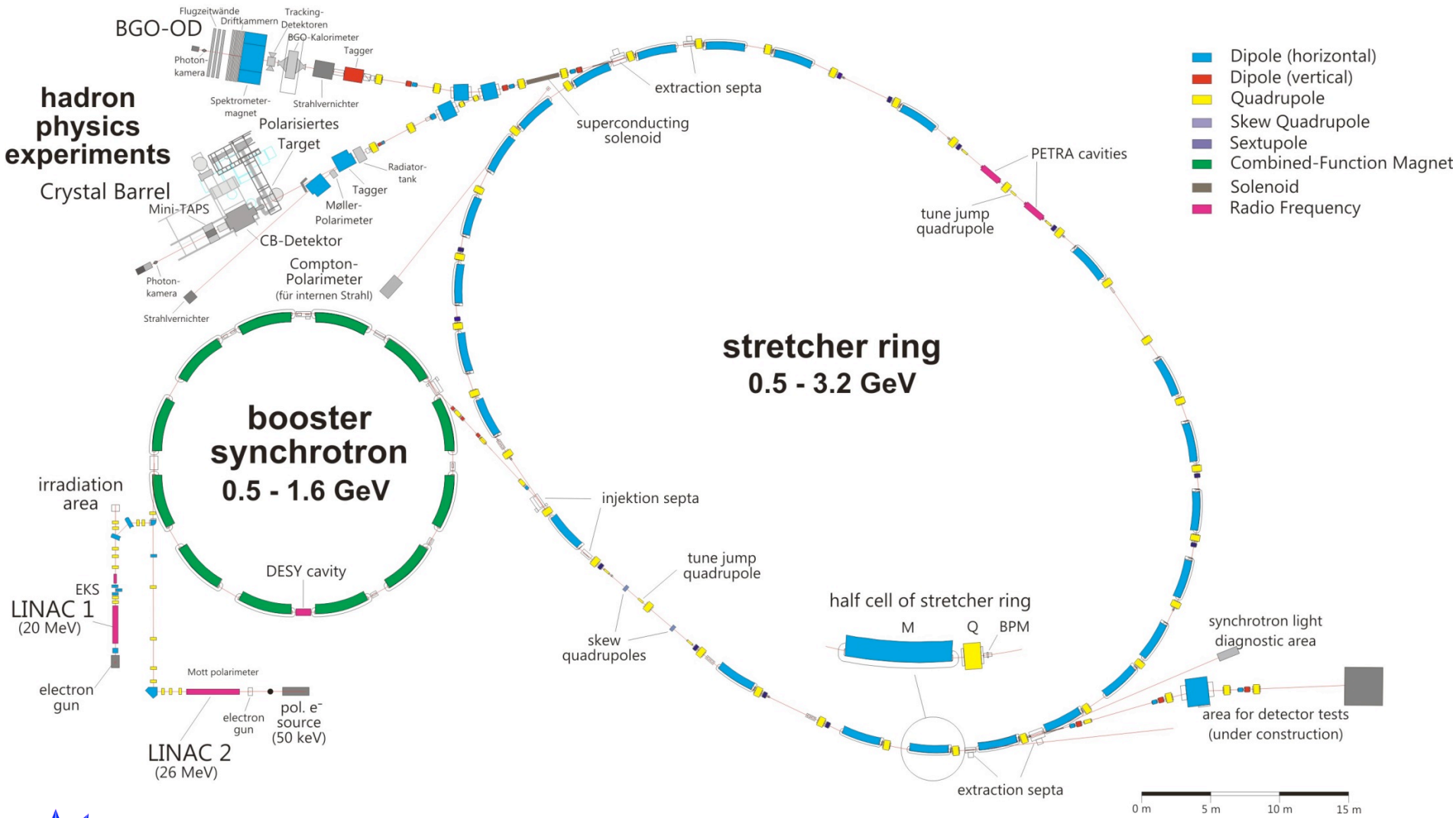
Observable	σ	Σ	T	P	E	F	G	H	T_x	T_z	L_x	L_z	O_x	O_z	C_x	C_z
$p\pi^0$	✓	✓	✓		✓	✓	✓	✓								
$n\pi^+$	✓	✓	✓		✓	✓	✓	✓								
$p\eta$	✓	✓	✓		✓	✓	✓	✓								
$p\eta'$	✓	✓	✓		✓	✓	✓	✓								
$K^+\Lambda$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$K^+\Sigma^0$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$p\omega/\phi$	✓	✓	✓		✓	✓	✓	✓	✓ SDME							
$K^{+*}\Lambda$	✓			✓					SDME							
$K^{0*}\Sigma^+$	✓	✓									✓	✓	SDME			
$p\pi^-$	✓	✓			✓	✓	✓									
$p\rho^-$	✓	✓			✓	✓	✓									
$K^-\Sigma^+$	✓	✓			✓	✓	✓									
$K^0\Lambda$	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
$K^0\Sigma^0$	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
$K^{0*}\Sigma^0$	✓	✓									✓	✓				

$\gamma p \rightarrow X$

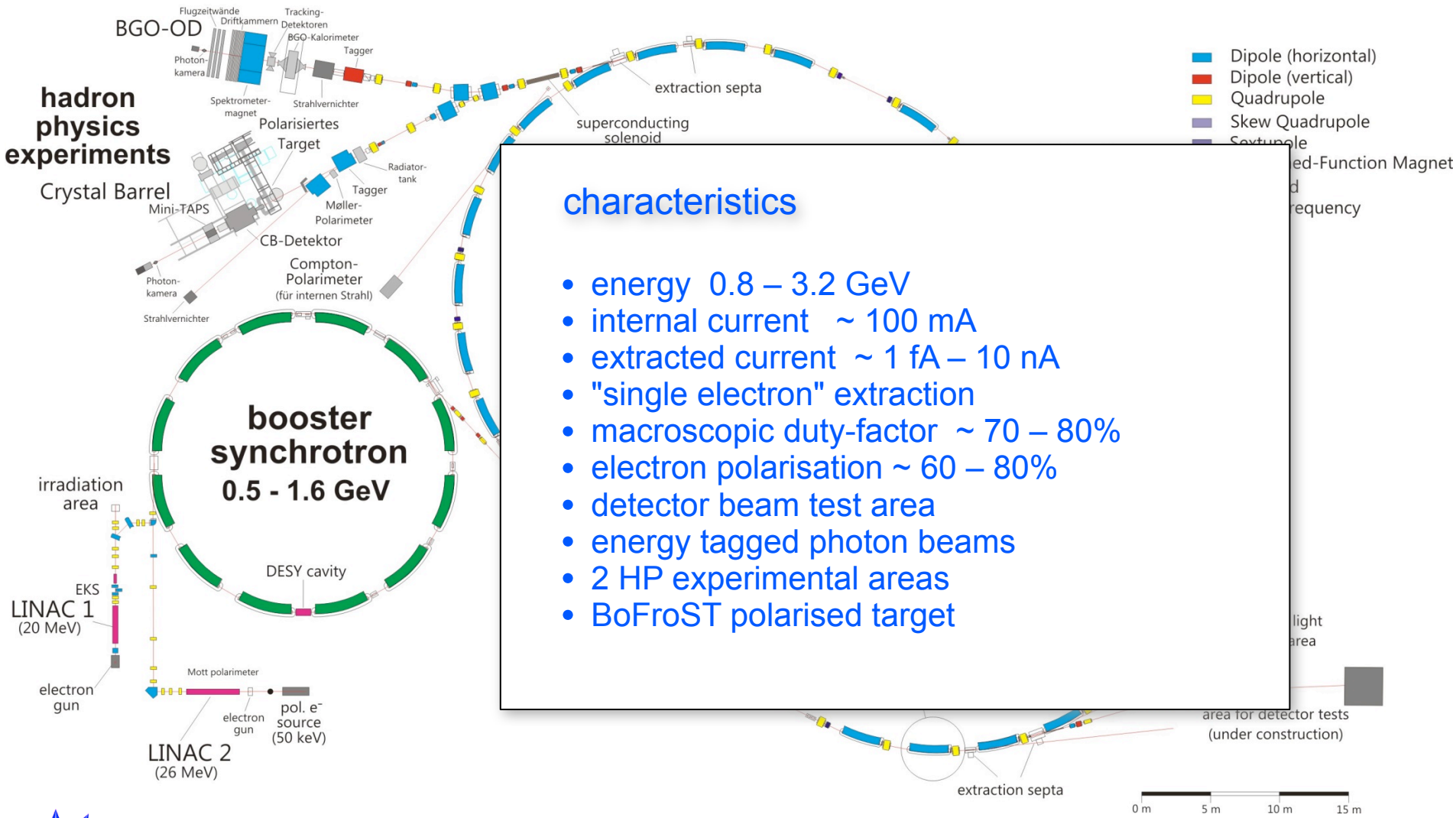
$\gamma n \rightarrow X$

courtesy: V. Burkert

ELSA accelerator



ELSA accelerator

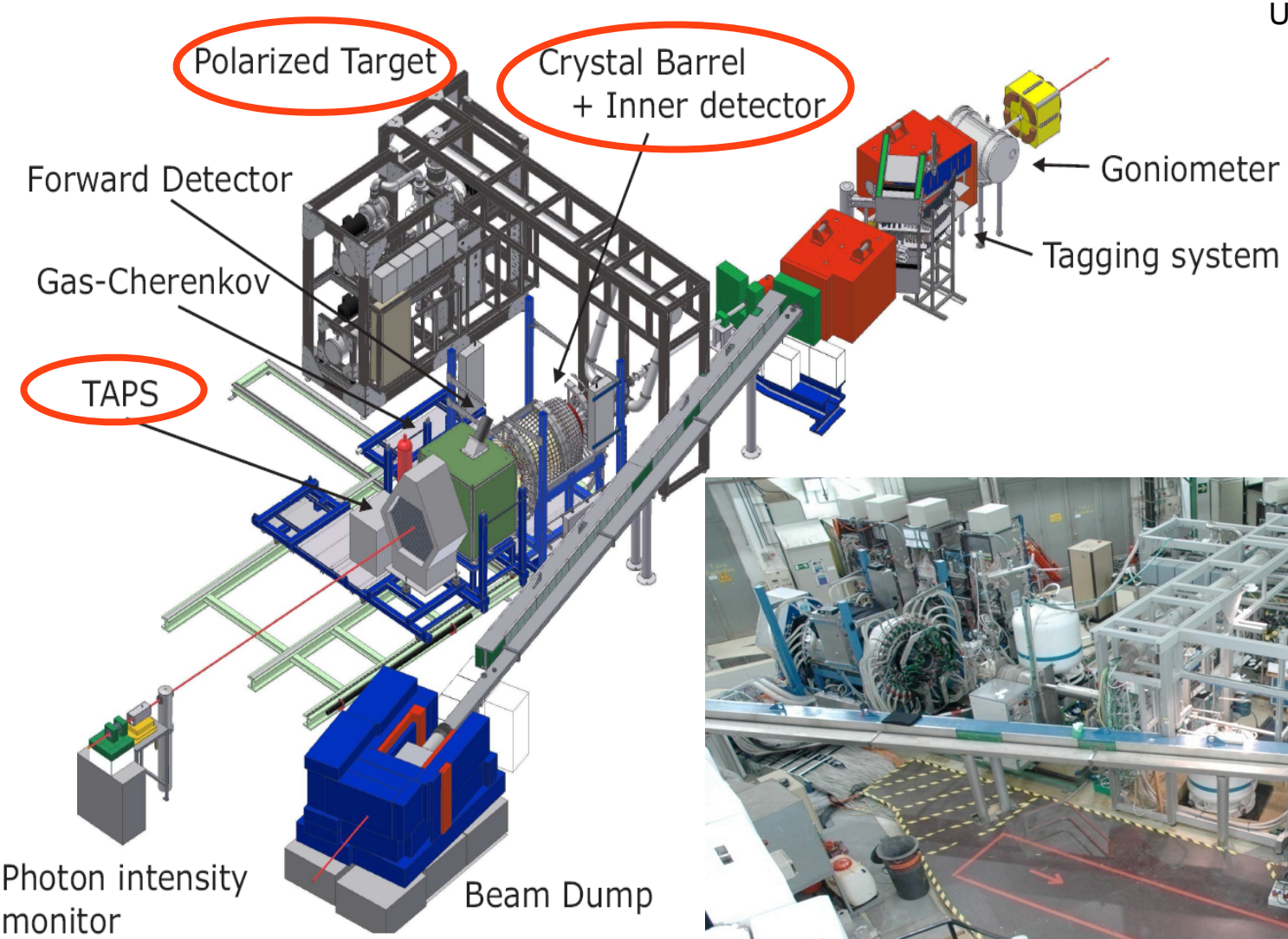


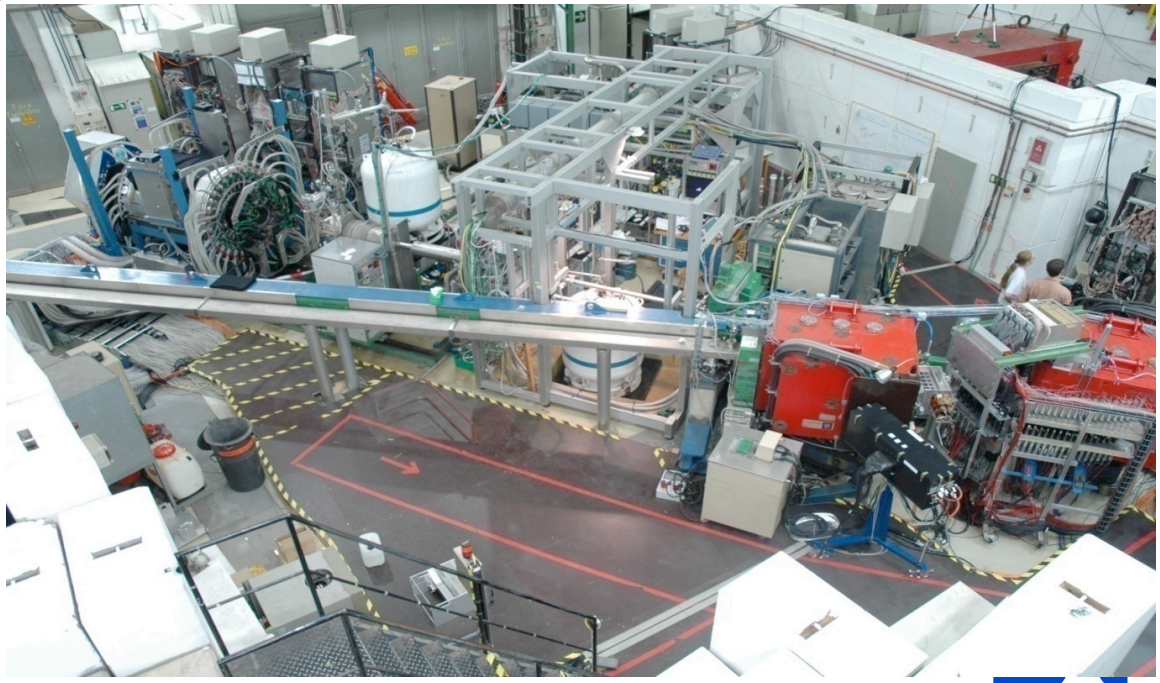
characteristics

- 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
- BoFroST polarised target

CBELSA/TAPS experiment

spokespersons: B. Krusche (Basel)
U. Thoma (Bonn)





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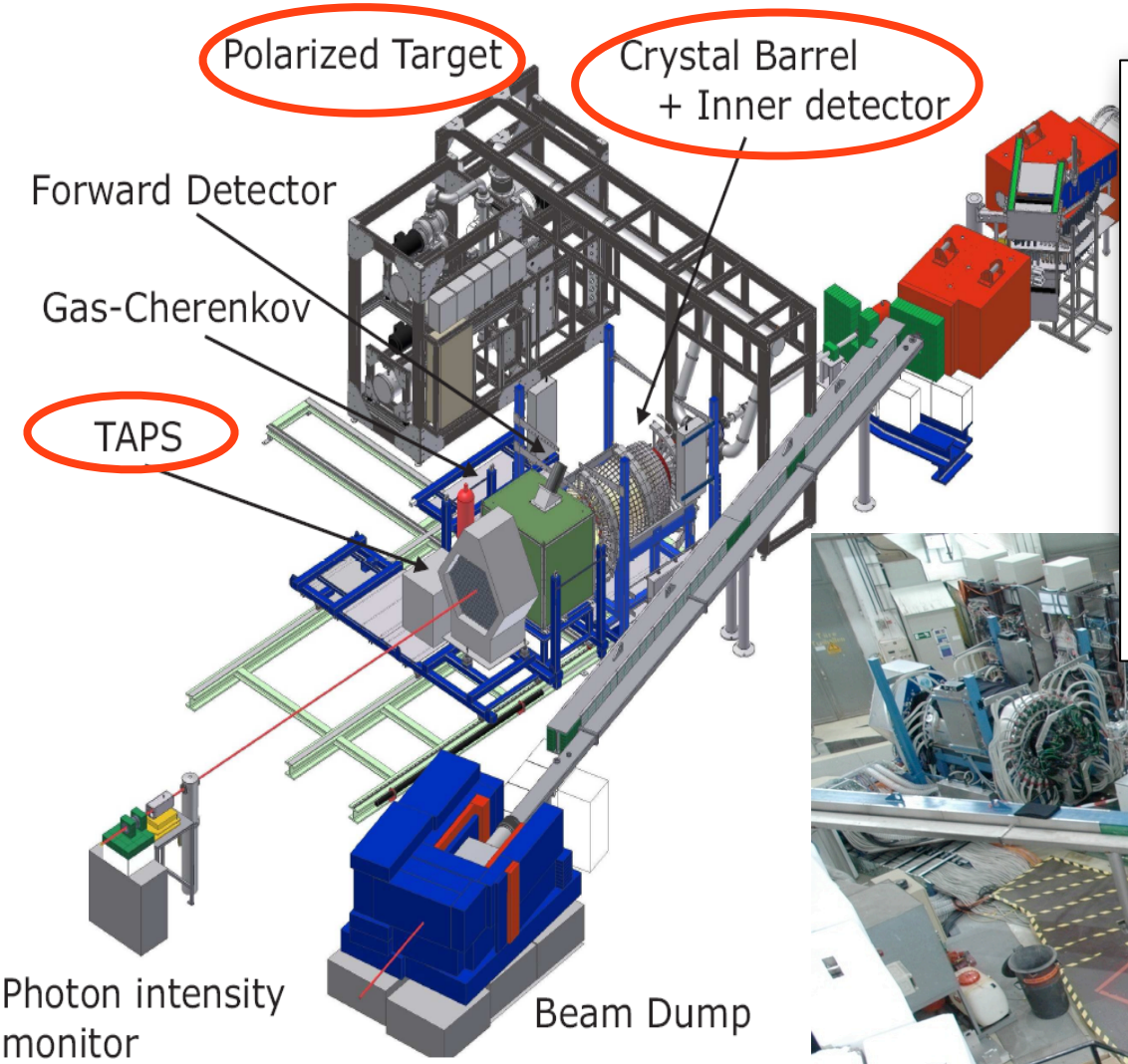
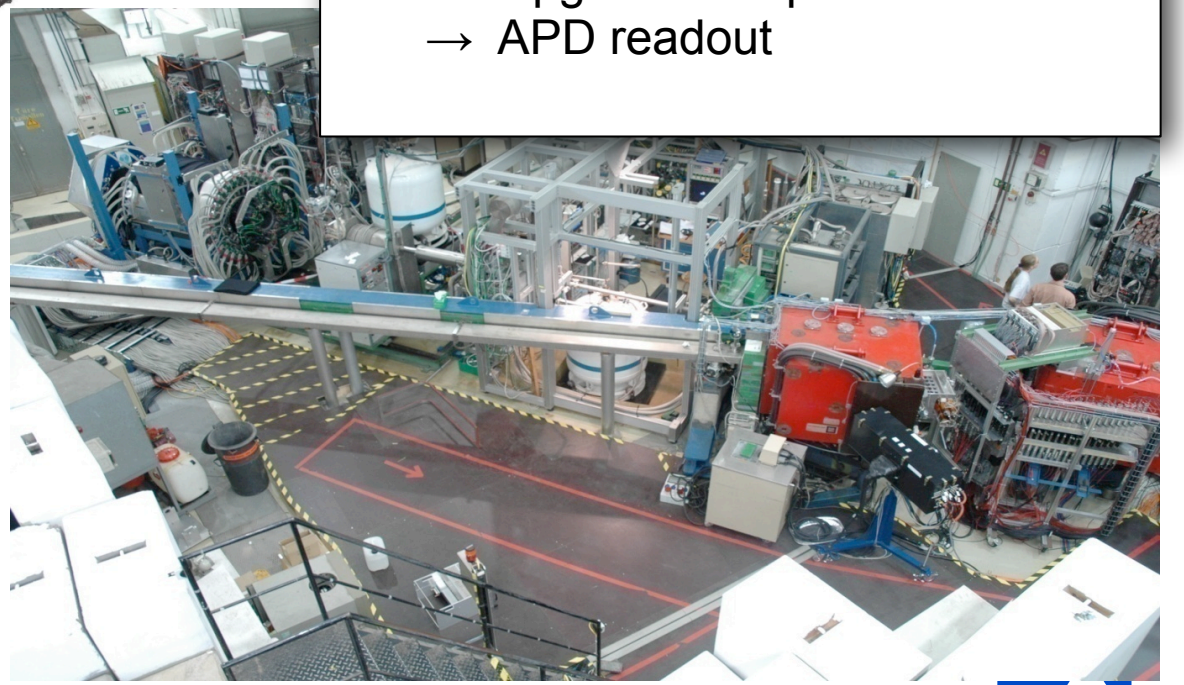


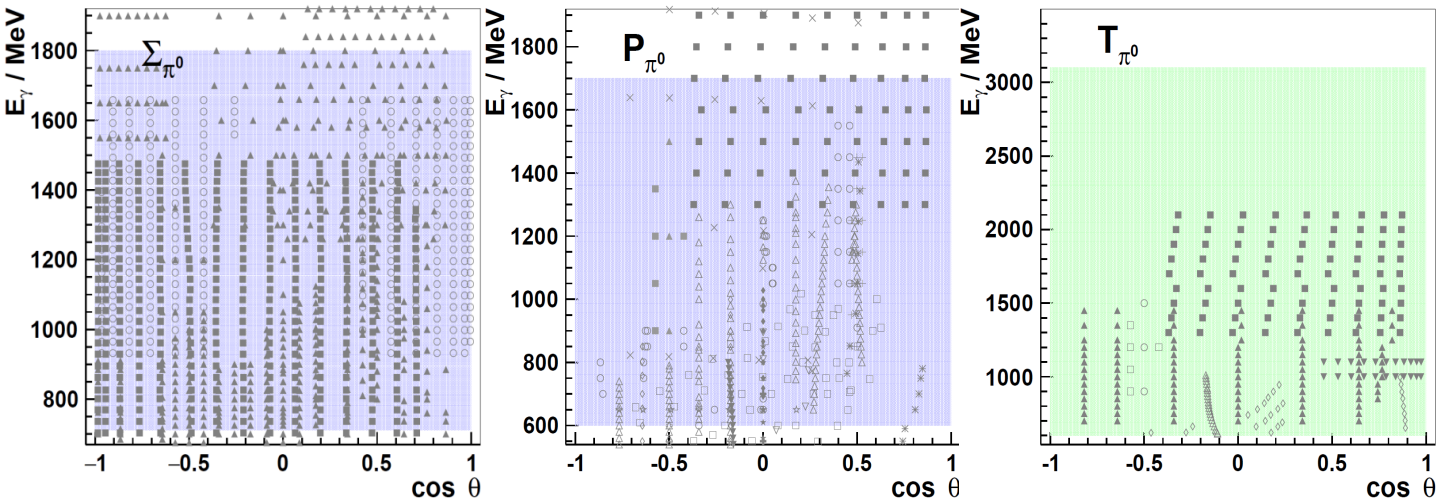
- lin./circ. polarised beam
  & long./transv. polarised target
- central calorimeter combined with forward calorimeter
- ideal for multi photon final states
- CB upgrade completed
  → APD readout

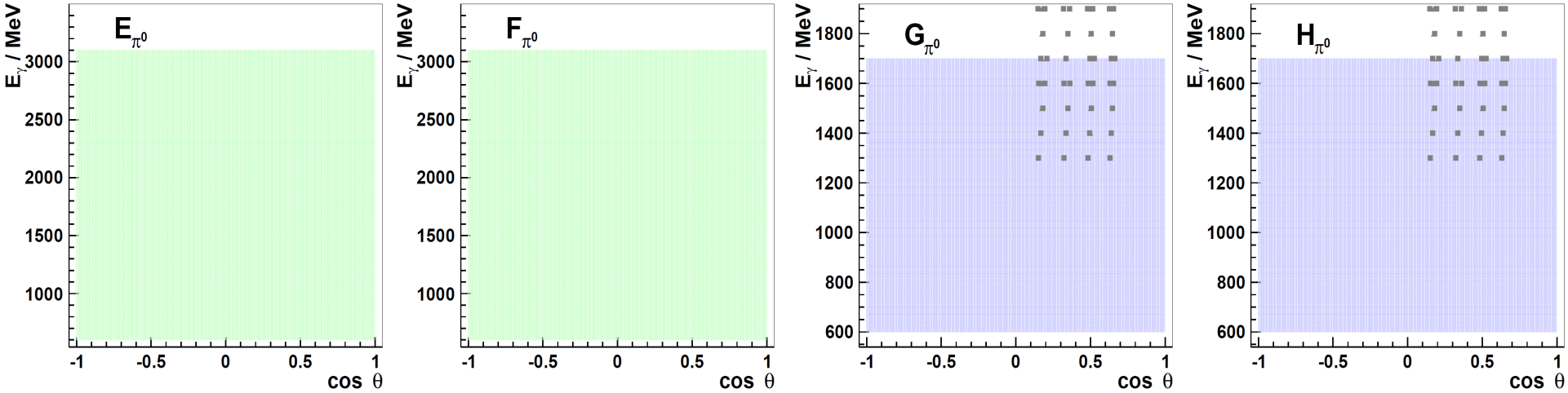


Overview measurements

$$\vec{\gamma}\ \vec{p} \rightarrow p\,\pi^0$$

data base **before** CBELSA/TAPS

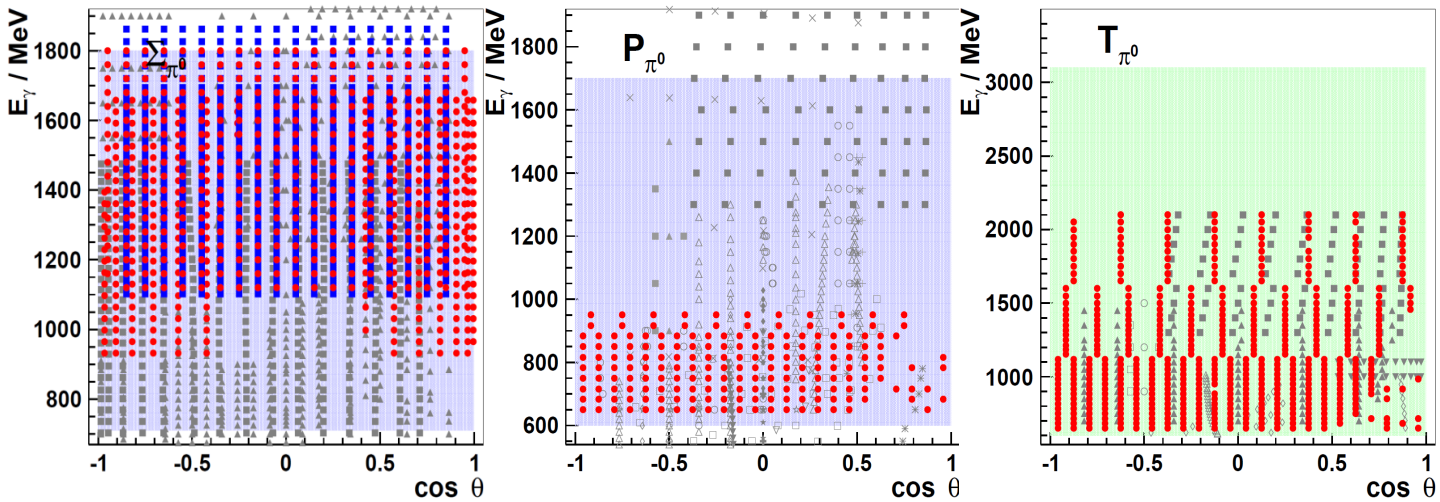


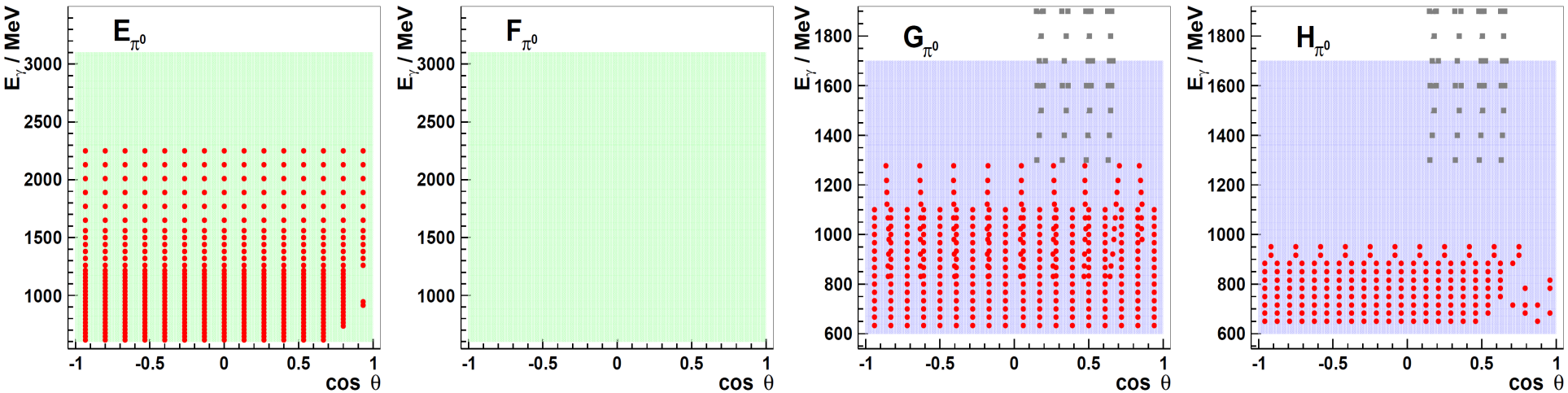


Overview measurements

$$\vec{\gamma}\ \vec{p} \rightarrow p\,\pi^0$$

- data base **after** CBELSA/TAPS
- JLab

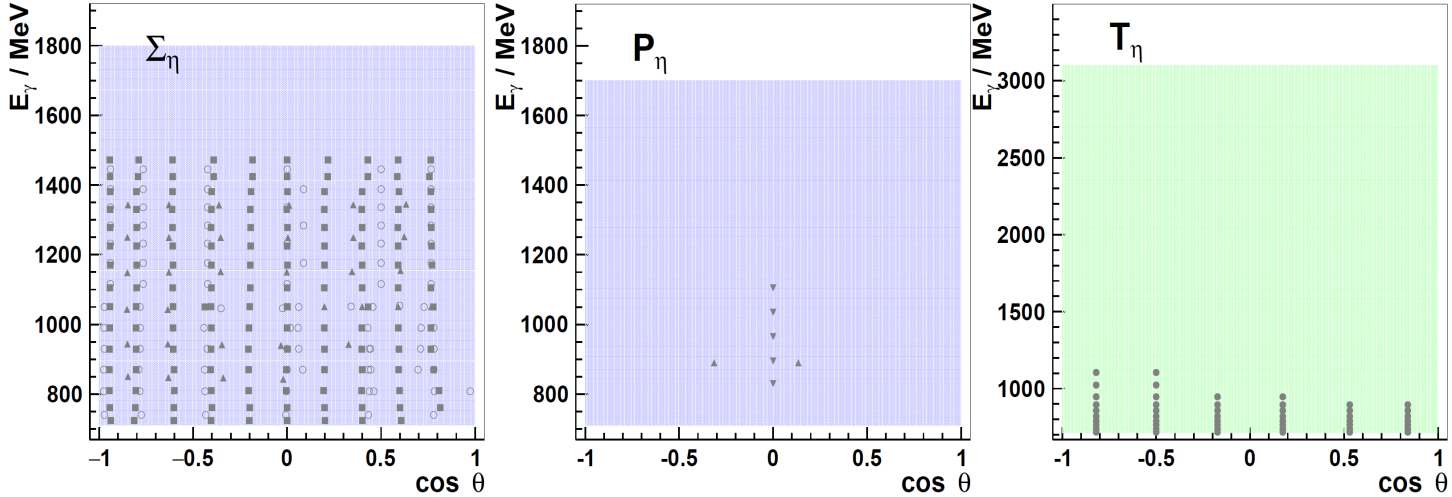


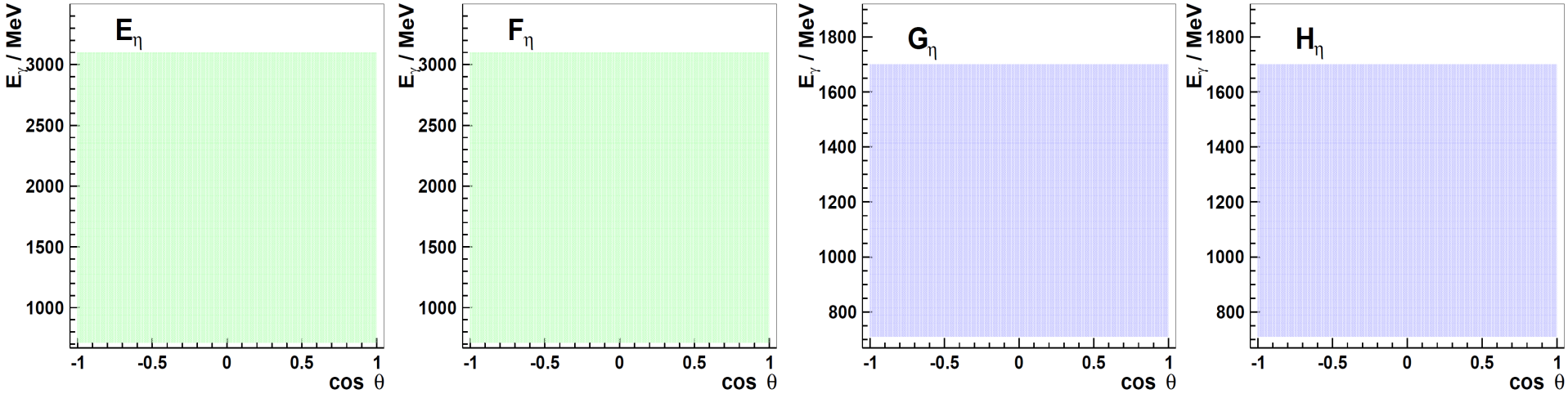


Overview measurements

$$\vec{\gamma}\ \vec{p} \rightarrow p\eta$$

data base **before** CBELSA/TAPS

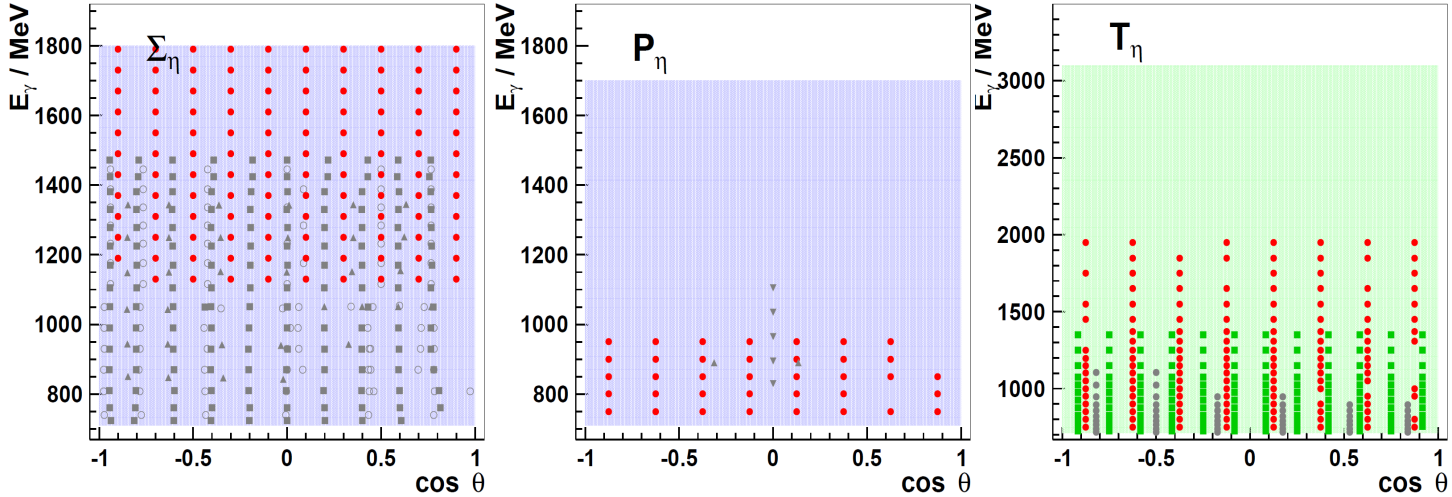


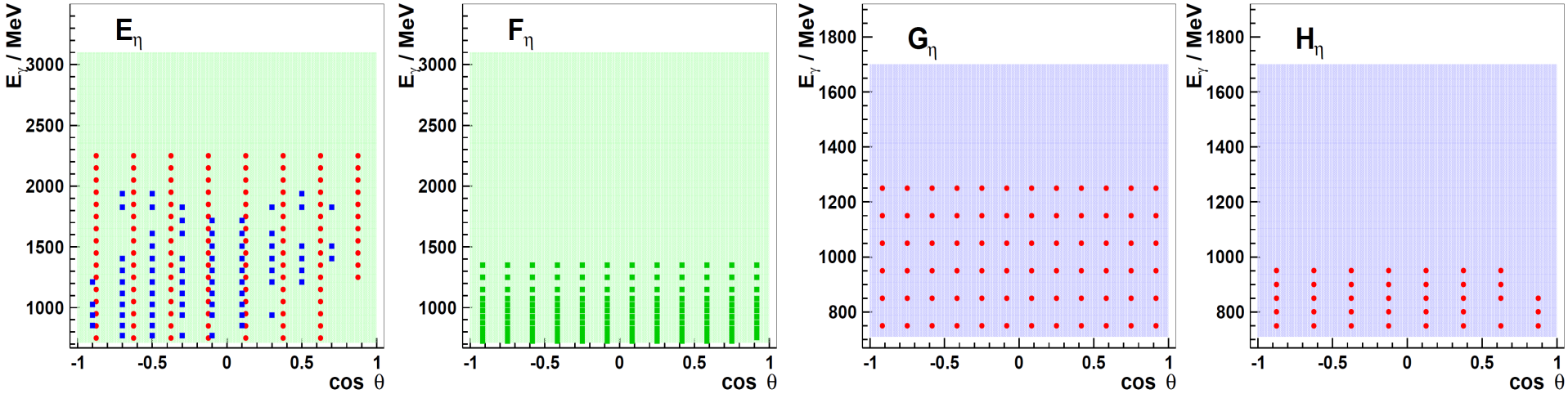


Overview measurements

$$\vec{\gamma}\ \vec{p} \rightarrow p\eta$$

- data base **after** CBELSA/TAPS
- JLab
- MAMI





Nucleon excitation spectrum

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-		**	**	
Δ(1940) 3/2-	*	*	**	no evidence

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

Nucleon excitation spectrum

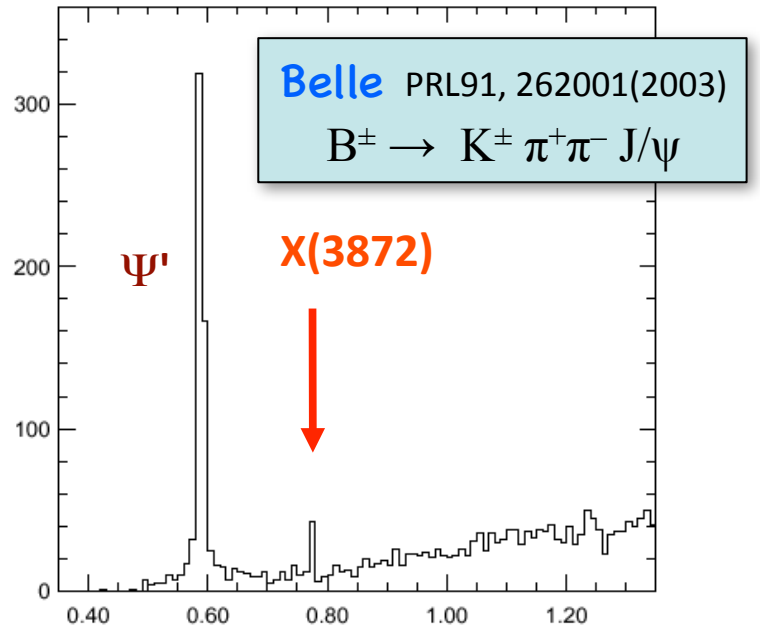
- N* spectrum → endeavor since over 50 years
- near "complete" experiments in meson photoproduction
- single & double polarisation observables
- identification of "missing" states

- ... some at least, but total number ??
- low lying states ??

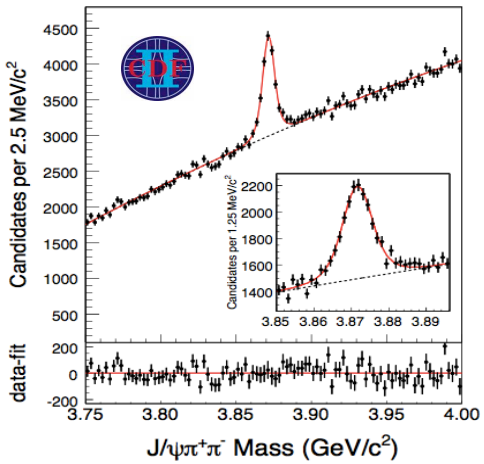
La "Belle" Révolution 2003

c-sector

X(3872)

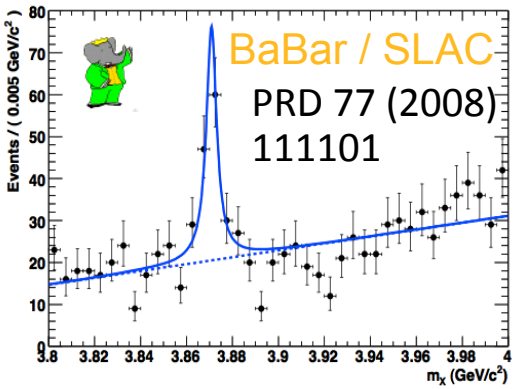


$M(\pi^+\pi^- l^+ l^-) - M(l^+ l^-)$

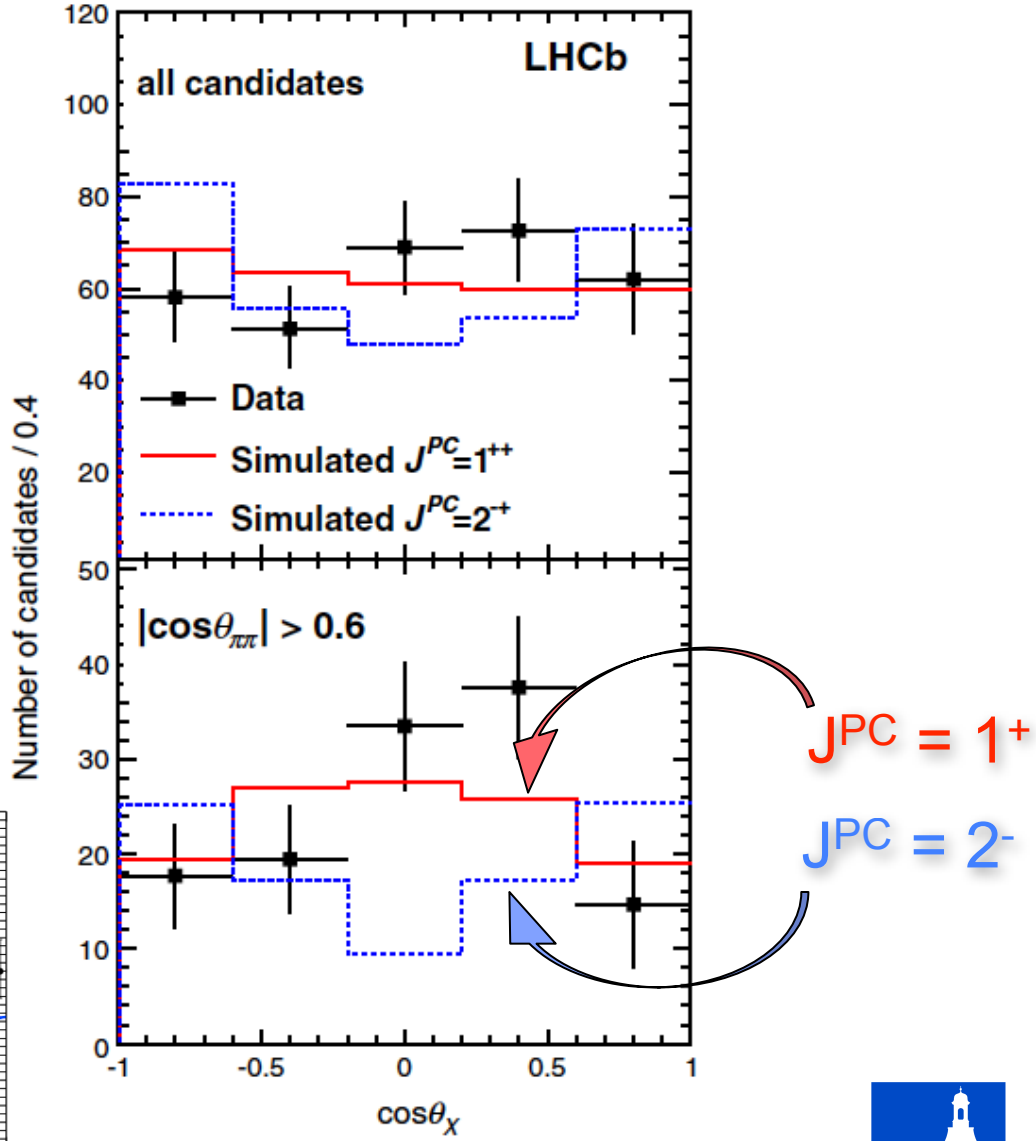


CDF / Tevatron

PRL 103 (2009) 152001



PRL 110 (2013)



universitätbonn

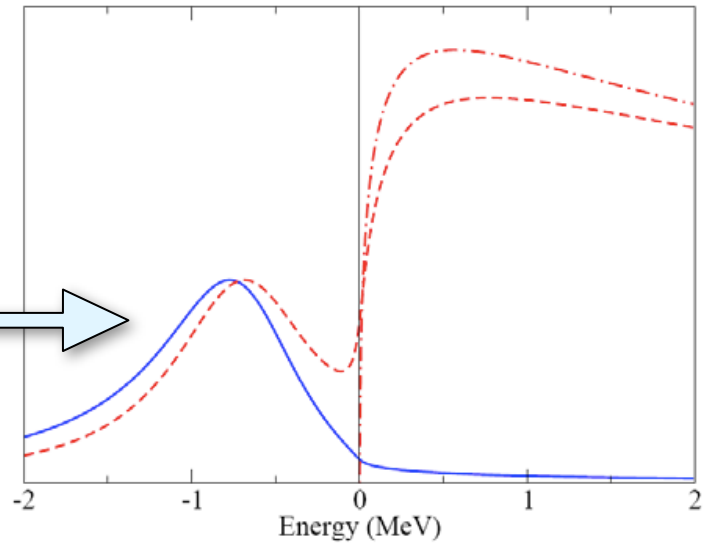
X(3872)

	M(X(3872)), MeV/c^2	Γ(X(3872)), MeV/c^2
B→XK	3871.46±0.37±0.07	<2.3 @ 90% C.L. (2003)
B→XK	3871.4±0.6±0.1	<3.3 @ 90% C.L. (2008)
$X \to J/\psi \pi^+ \pi^-$	3871.61±0.16±0.19	1.34 (fixed from first two)
average	3871.50±0.19	
$M(D^0)+M(D^{*0})$	3871.81±0.36	

"molecule"

possible bound state of D^0 D^{*0}

$J^P = 0^-$ 1^-



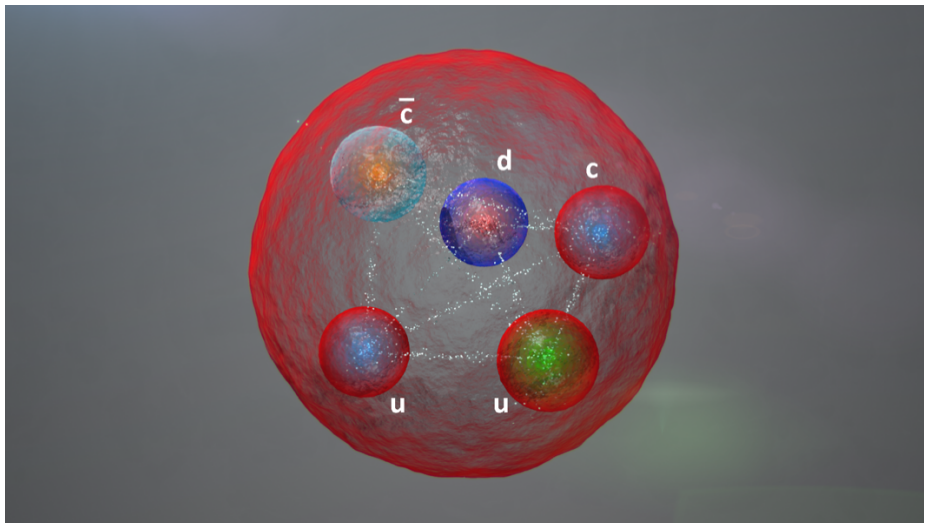
Hidden charm *baryon* sector

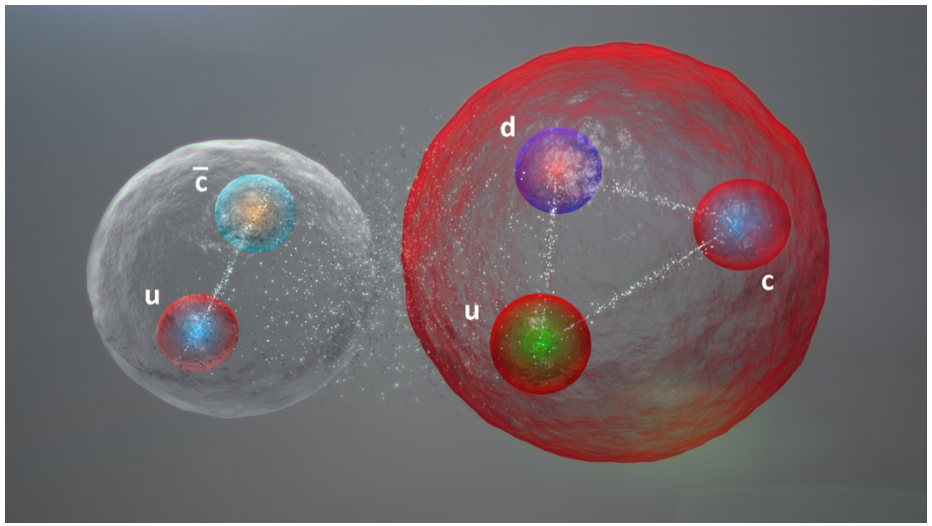
LHCb 2015

PARTICLE PHYSICS

Forsaken pentaquark particle spotted at CERN

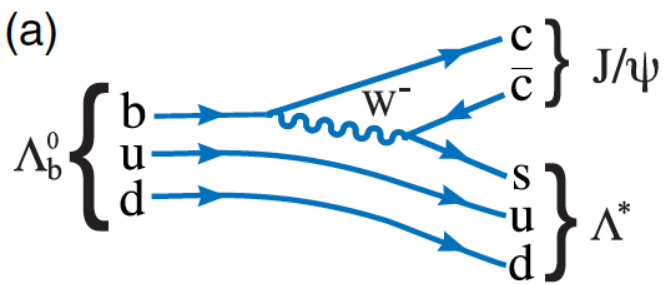
Exotic subatomic species confirmed at Large Hadron Collider after earlier false sightings.

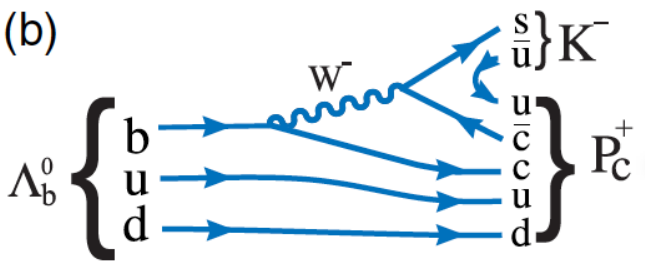




LHCb: $P_c^+(4380, 4450)$

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





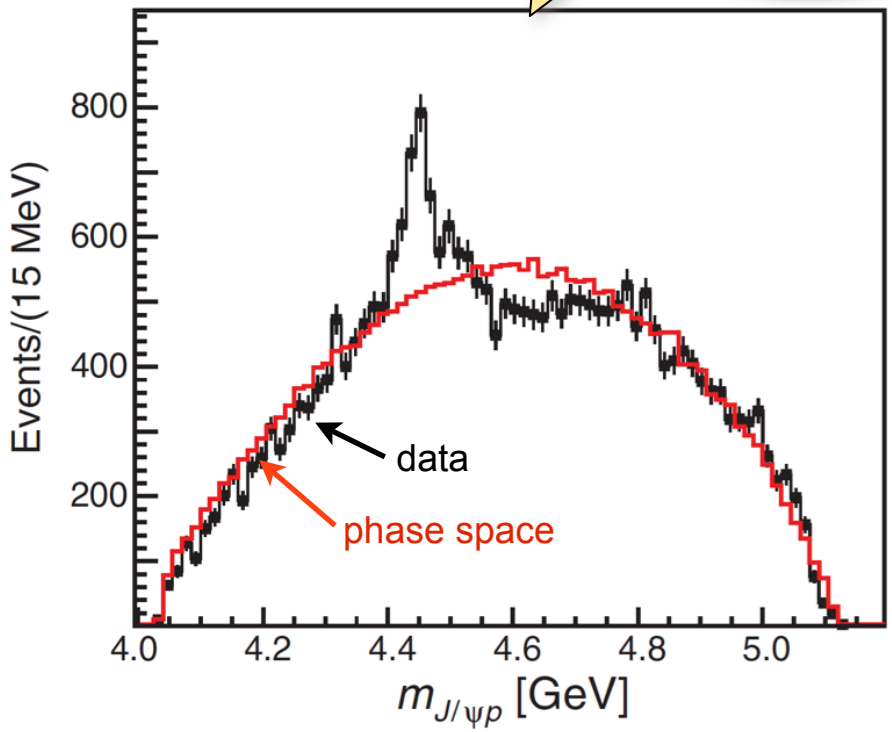
$J^P = 3/2^-, 5/2^+$

p J/ψ

D* Σ_c ?

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 ..."



χ_{c1}p threshold dynamics?

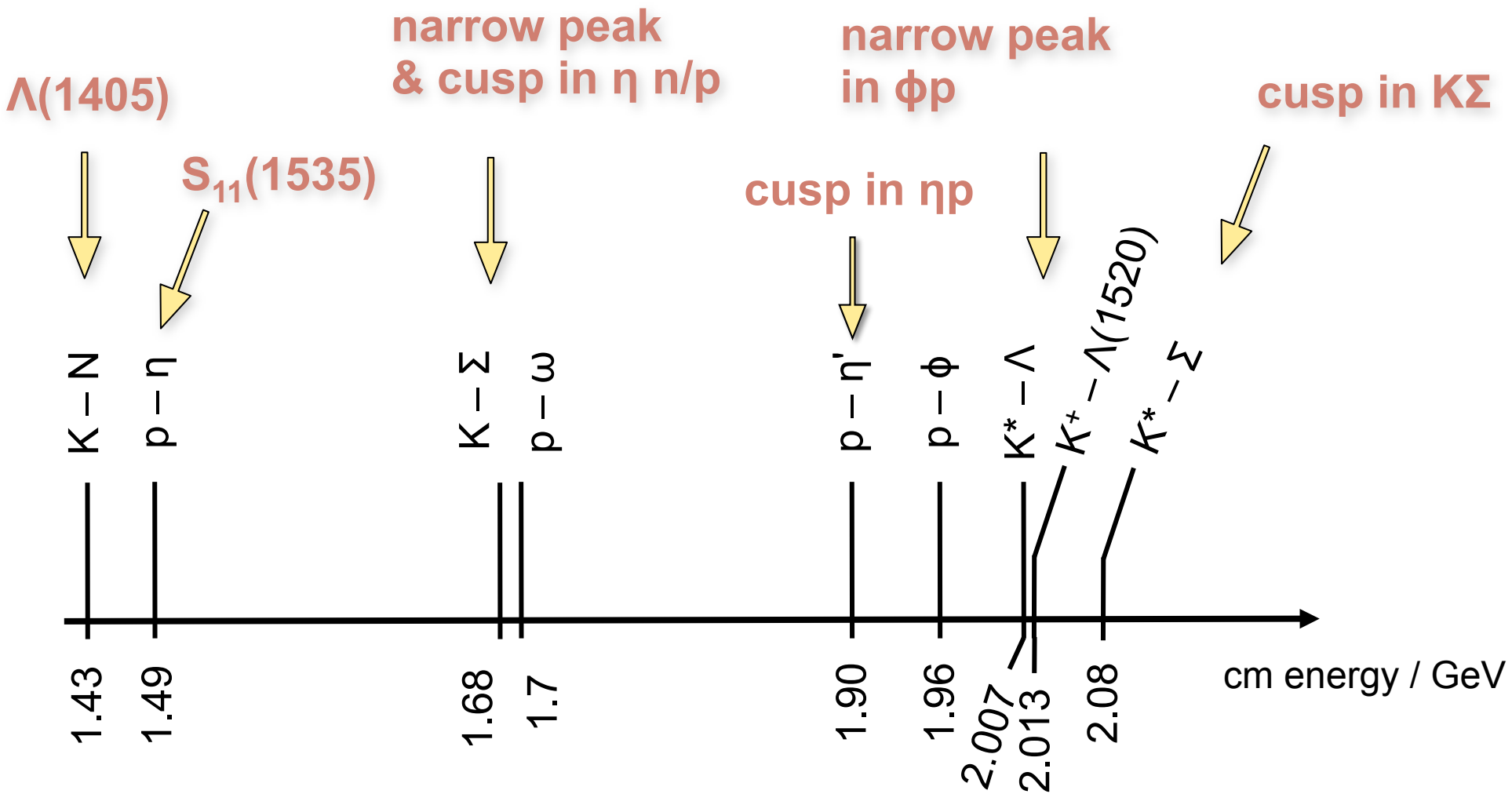
Guo, Meißner et al., PRD92 (2015) 071502

ELSA

universitätbonn

uds sector ?

uds sector – threshold dynamics

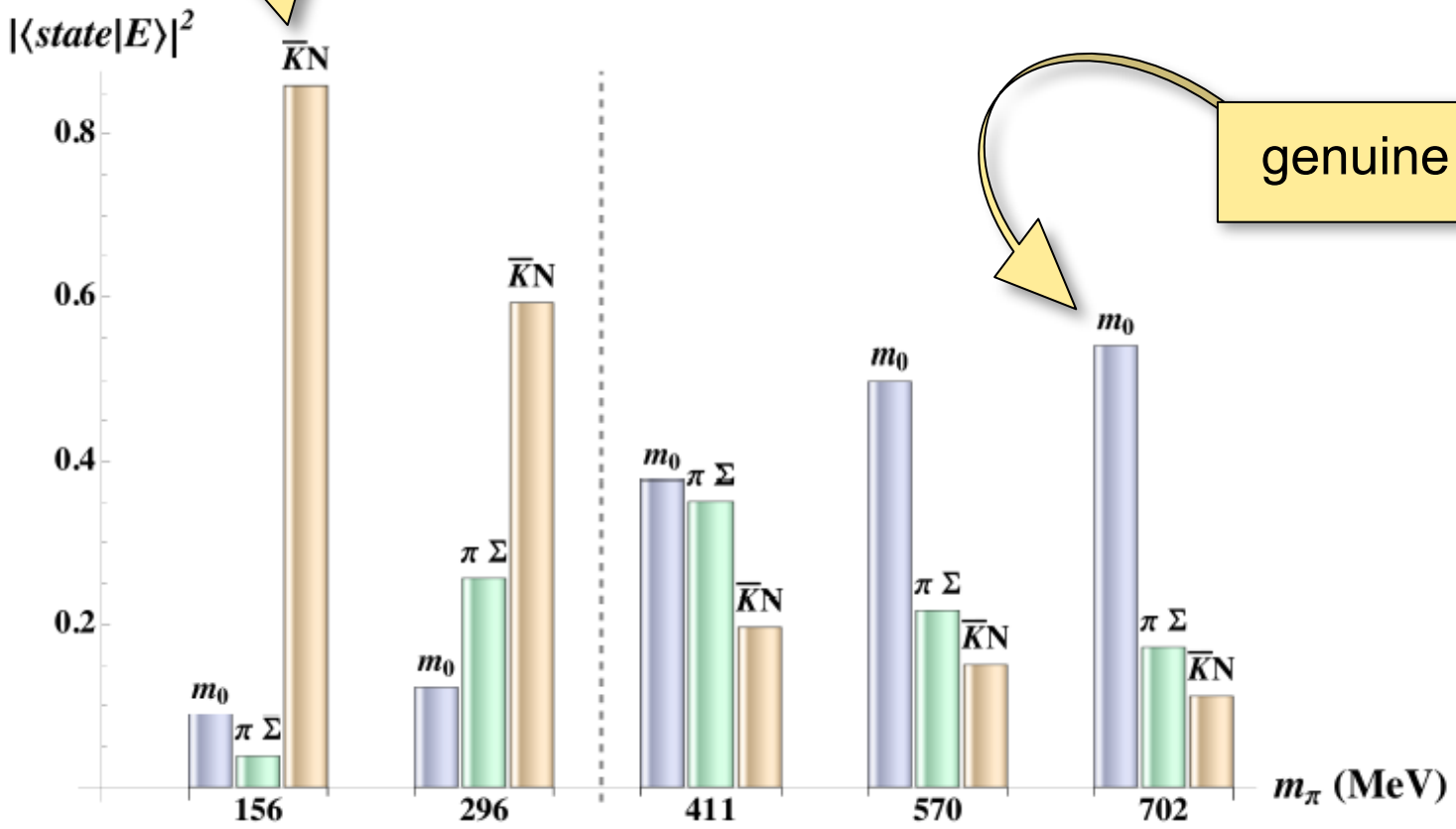


Λ(1405) – KN threshold

L-QCD

"molecule" as dominating Fock component

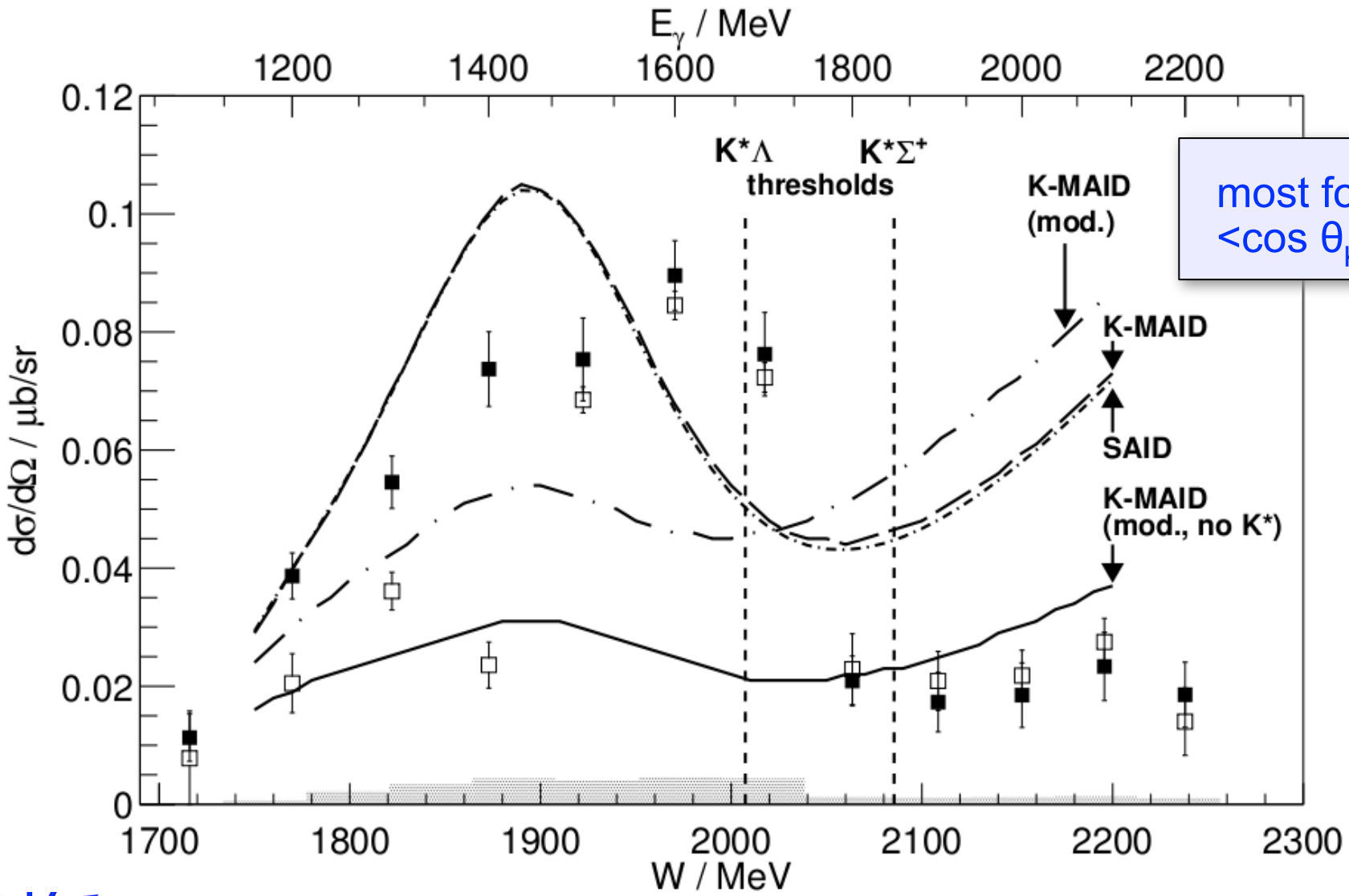
genuine 3q



J.M.M. Hall et al. [Adelaide group], Phys. Rev. Lett. 114 (2015) 132002
arXiv::1411.3402v2 (2015)

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

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



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

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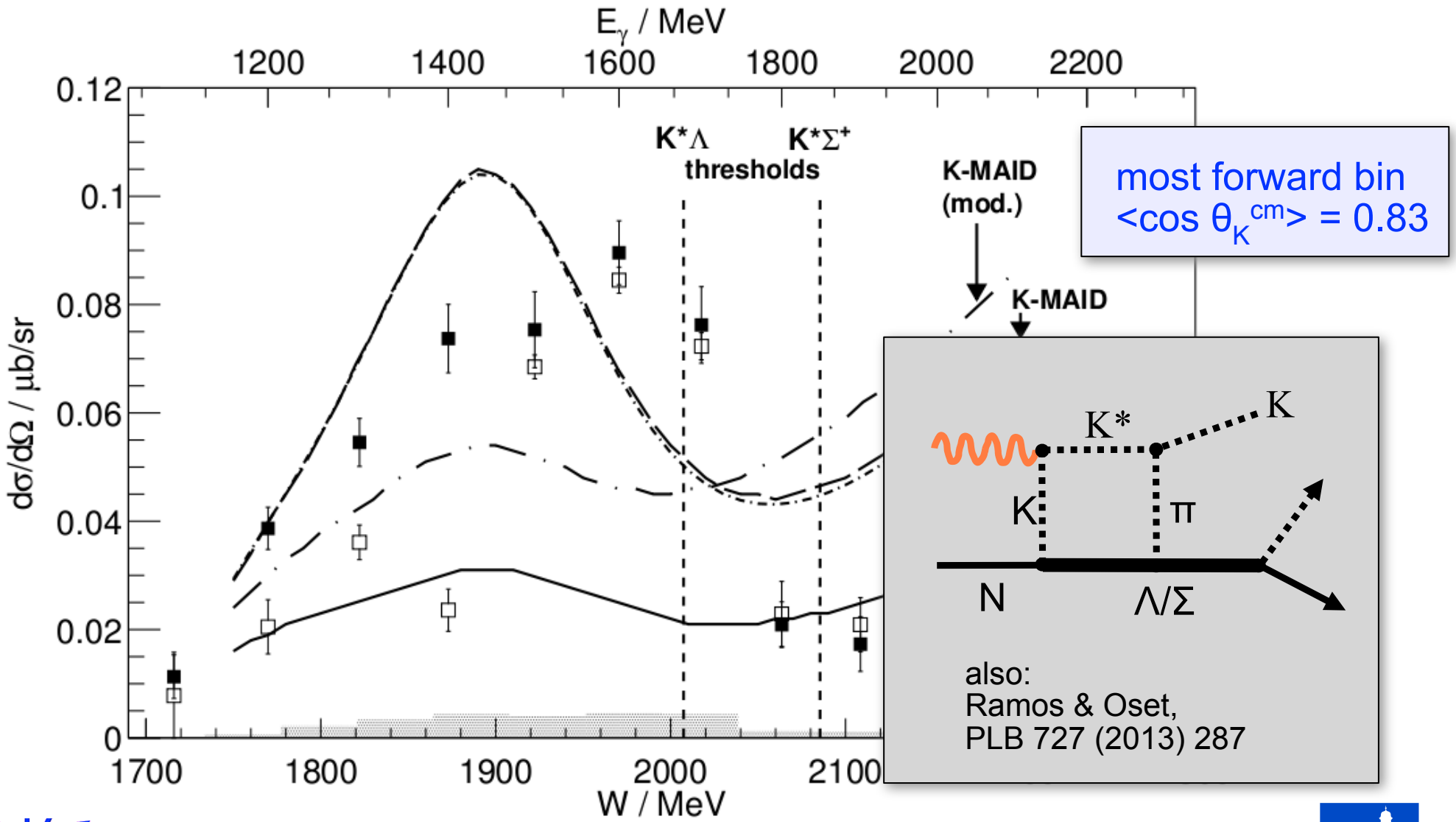

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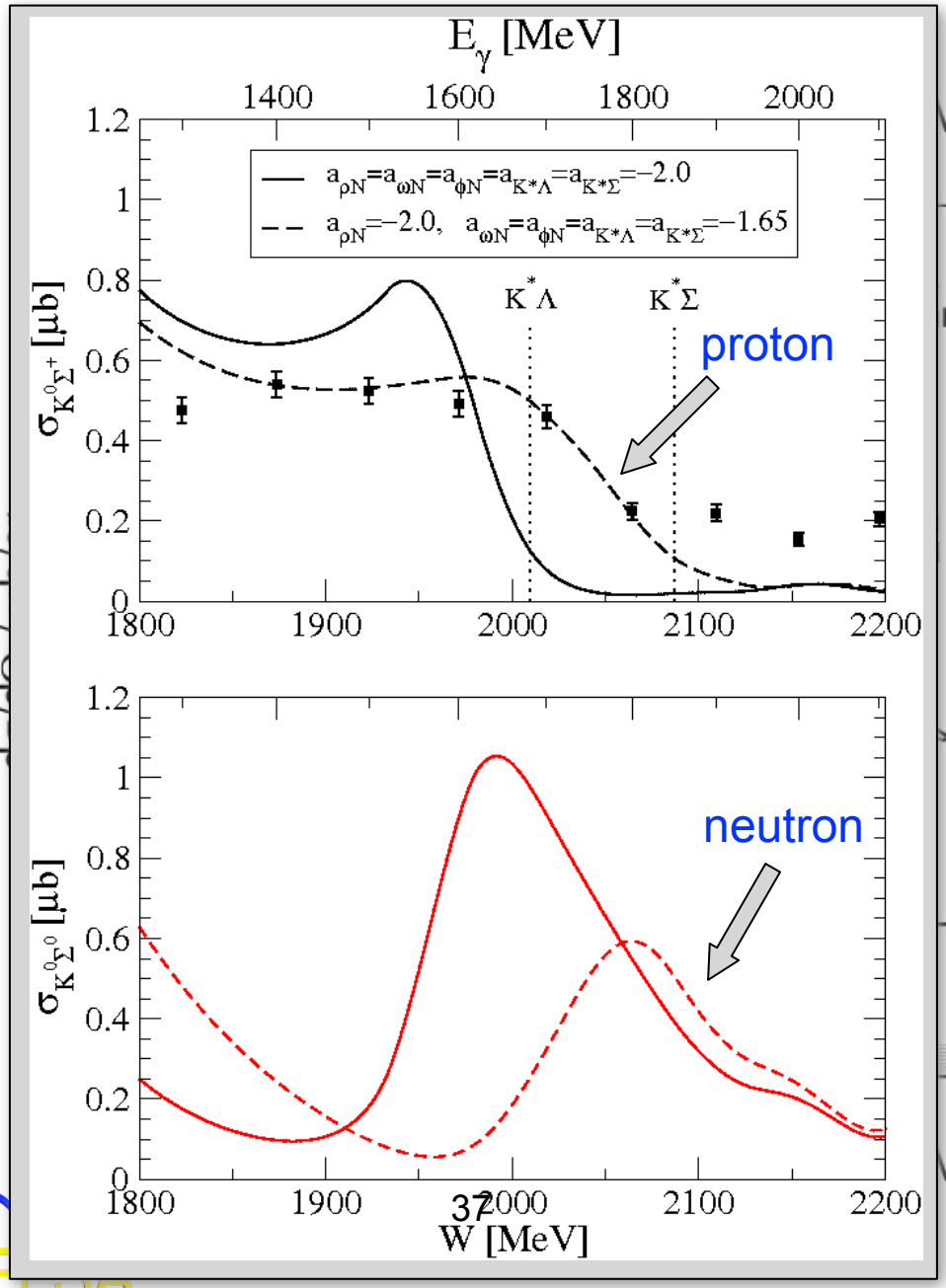

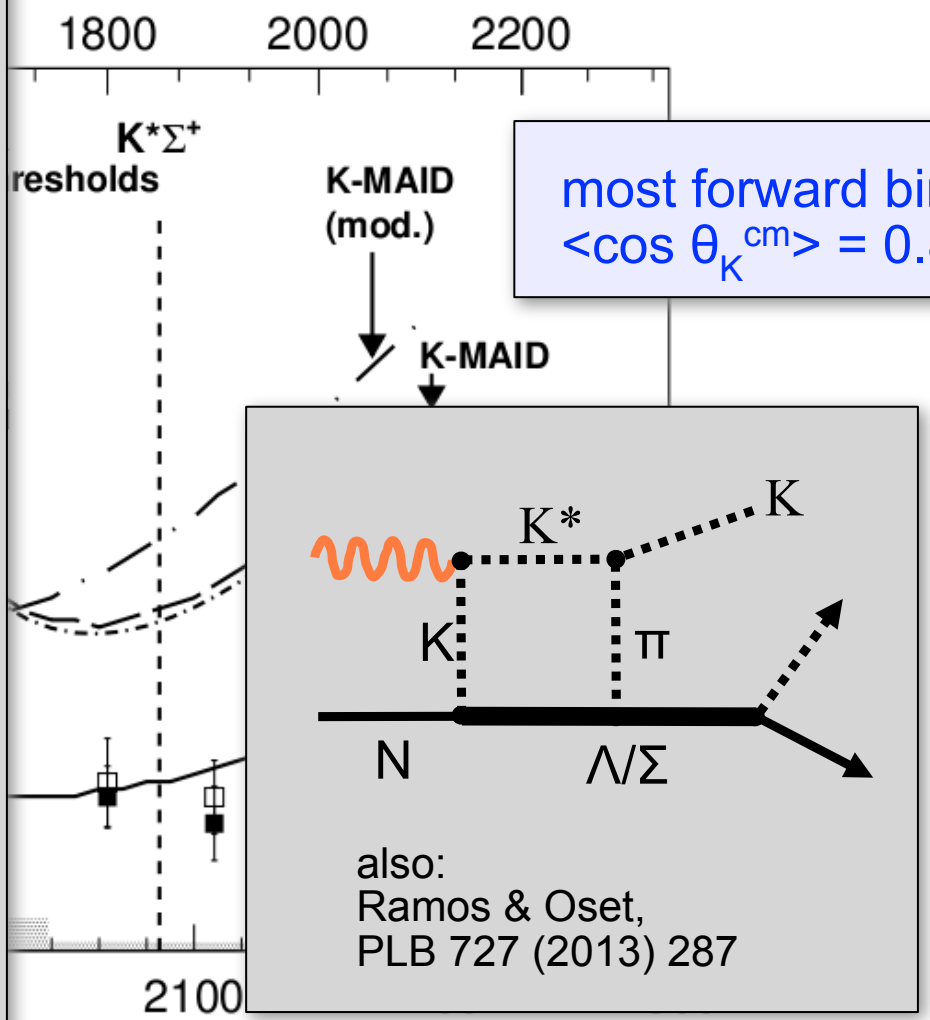

most forward bin
$\langle\cos\theta_K^{cm}\rangle = 0.83$

also:
Ramos & Oset,
PLB 727 (2013) 287

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

	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	$D^{*0}\bar{D}^0 + D^0\bar{D}^{*0}$	$\Lambda_c^*\bar{D} + \Sigma_c\bar{D}^*$	$K^*\bar{K} + K\bar{K}^*$	$\Lambda^*\bar{K} + \Sigma\bar{K}^*$
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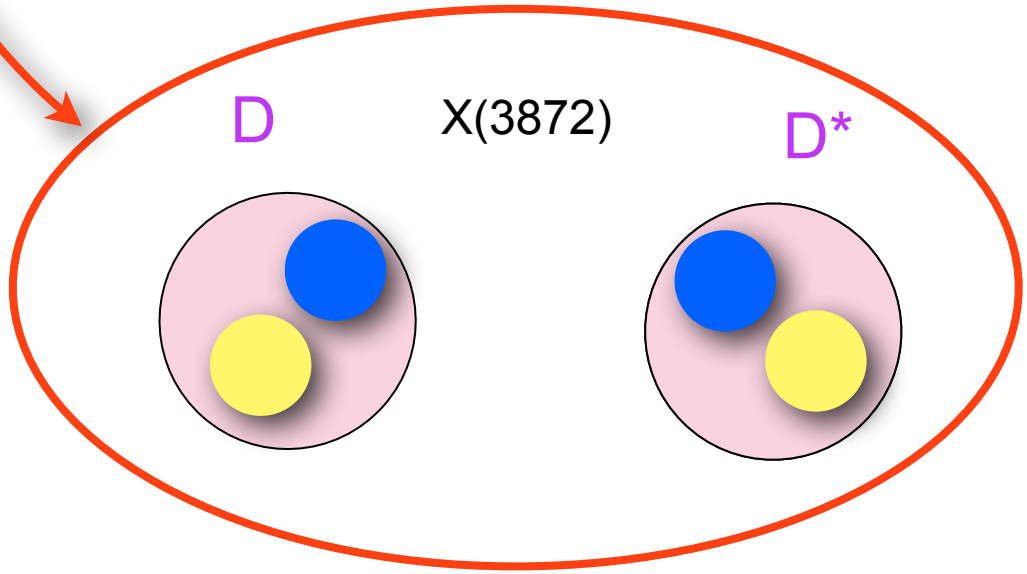

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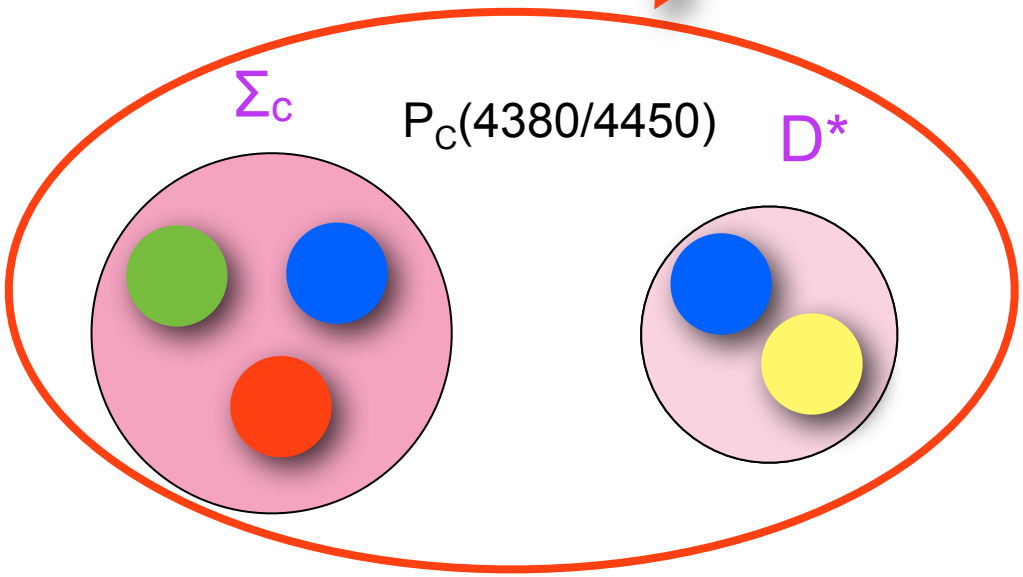
closed flavour channel	$J/\psi\ \omega$	$\chi_{c1}p$	$\phi f_0(500)$	ϕp

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

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



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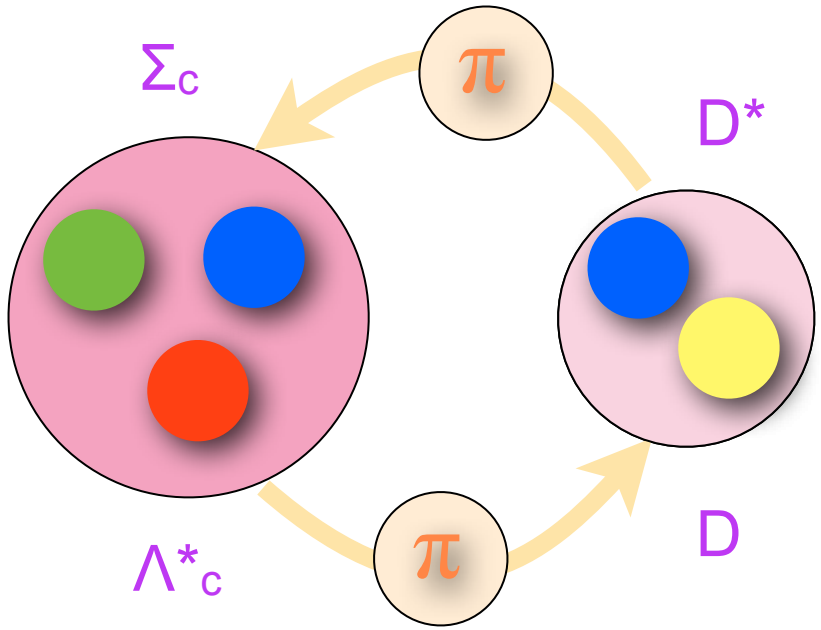

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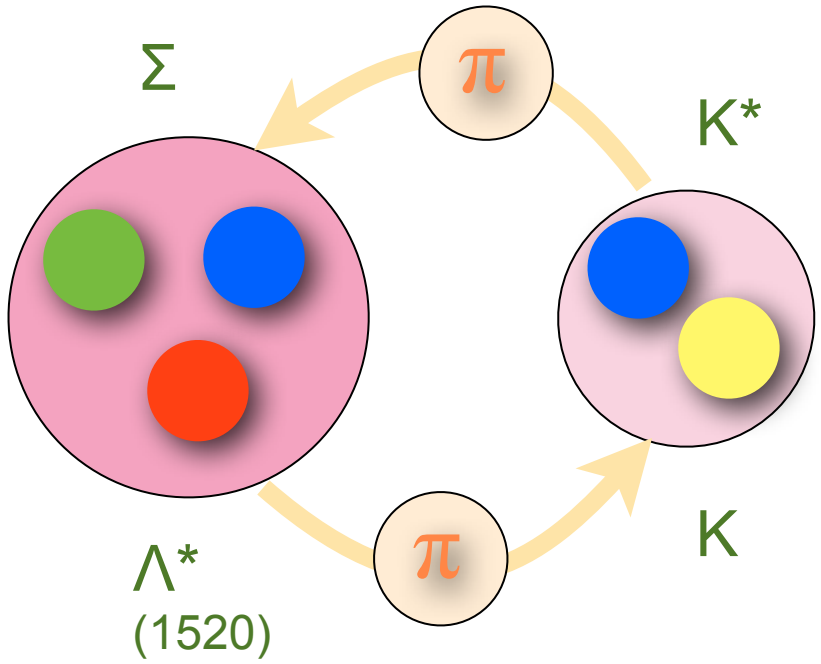
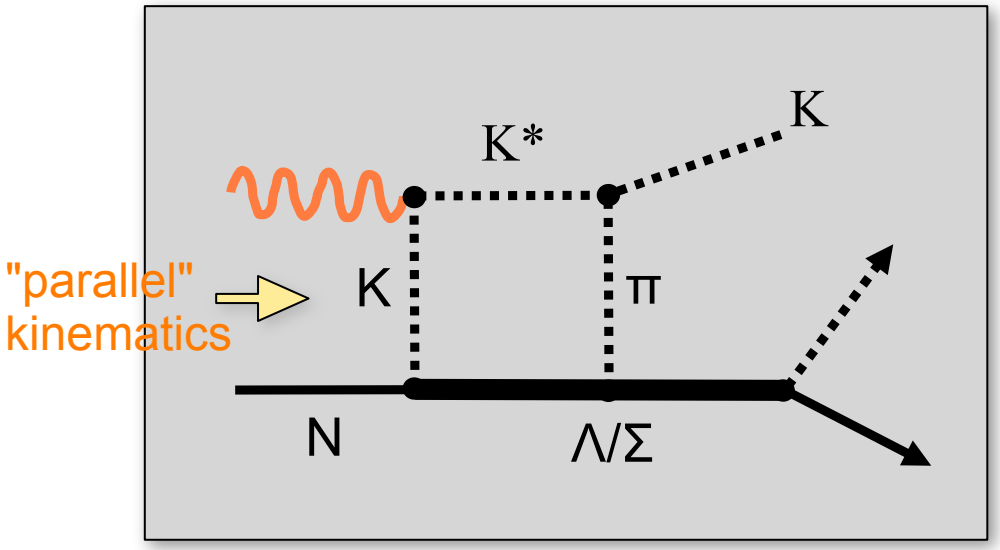
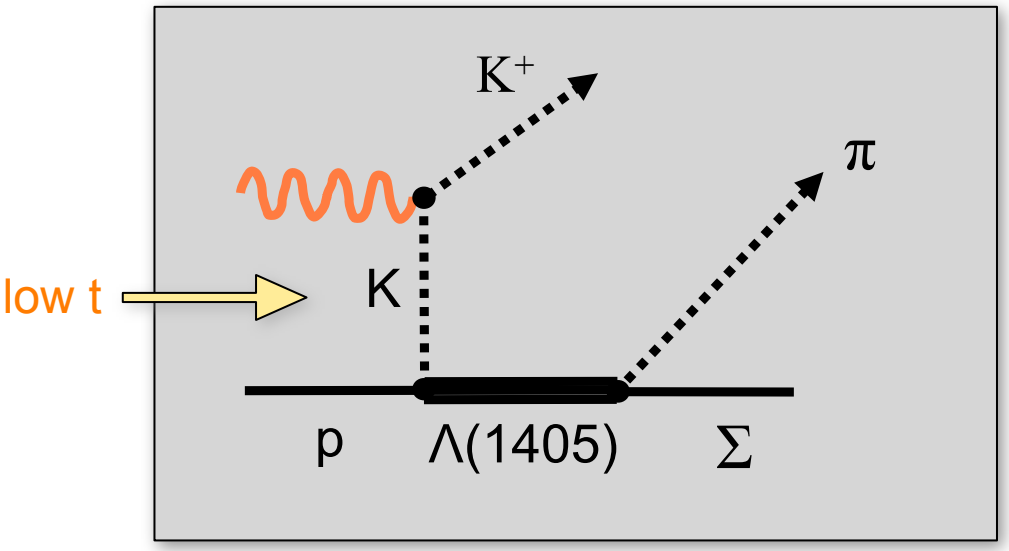
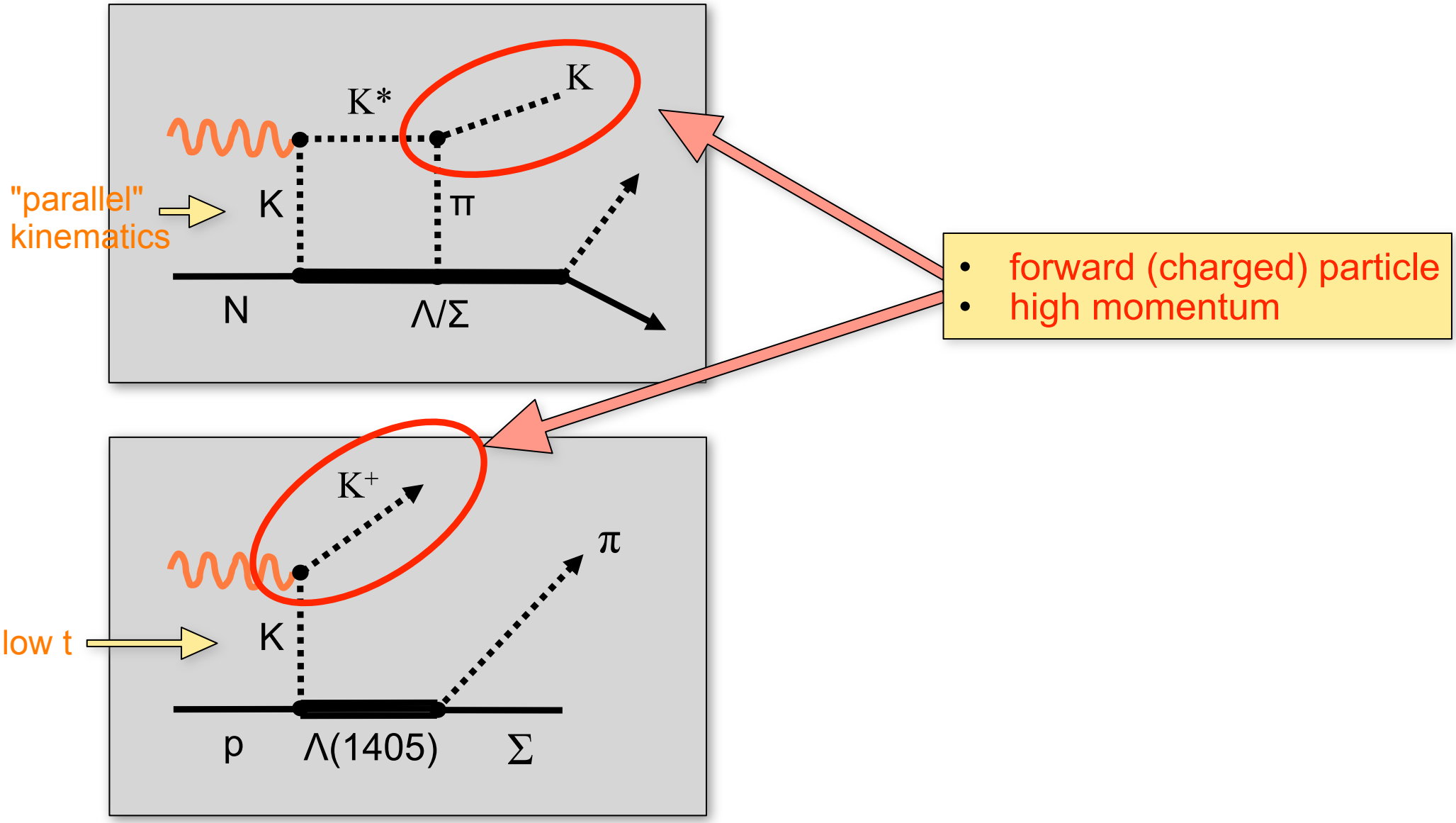


t-channel Kinematics

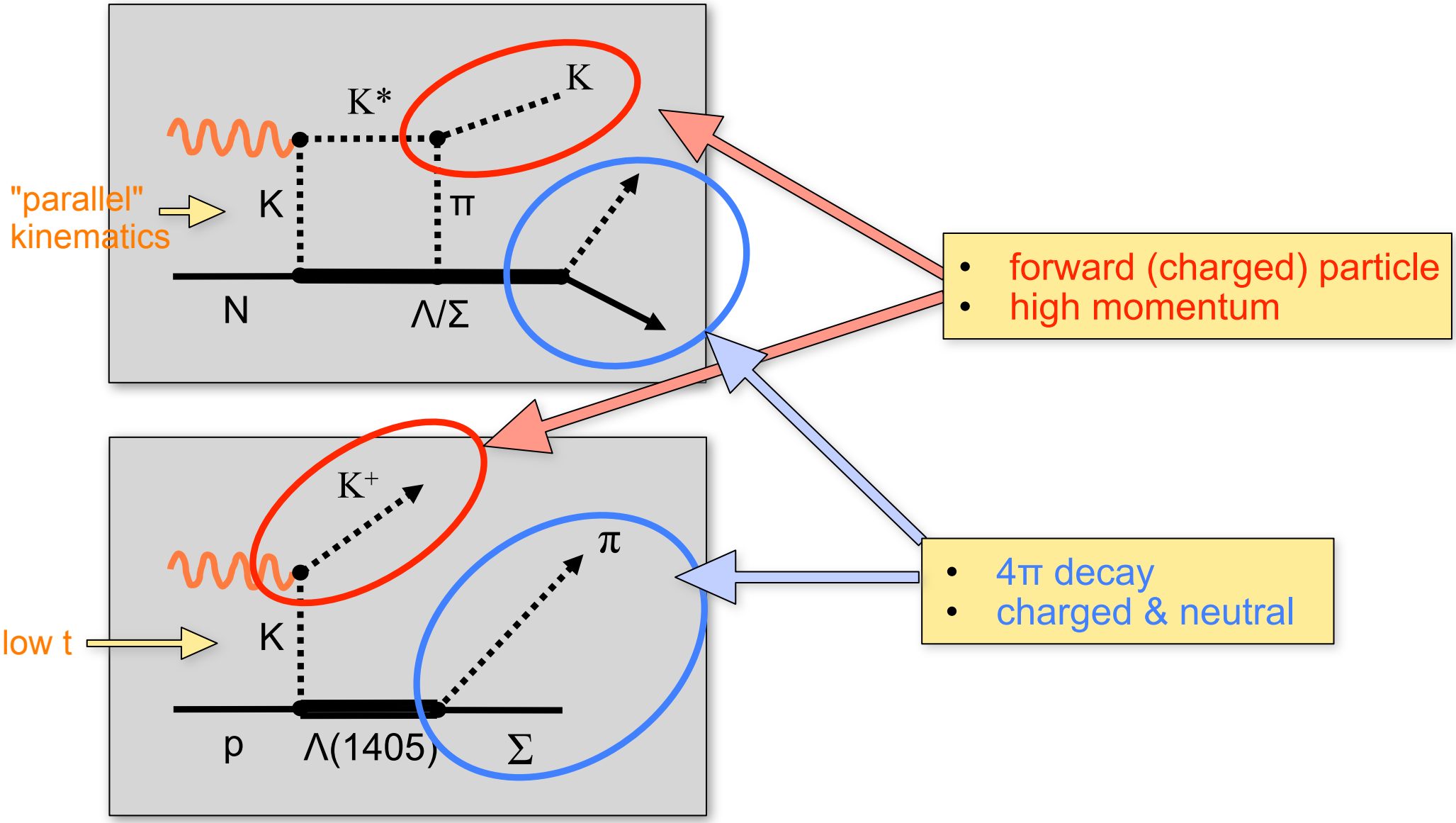




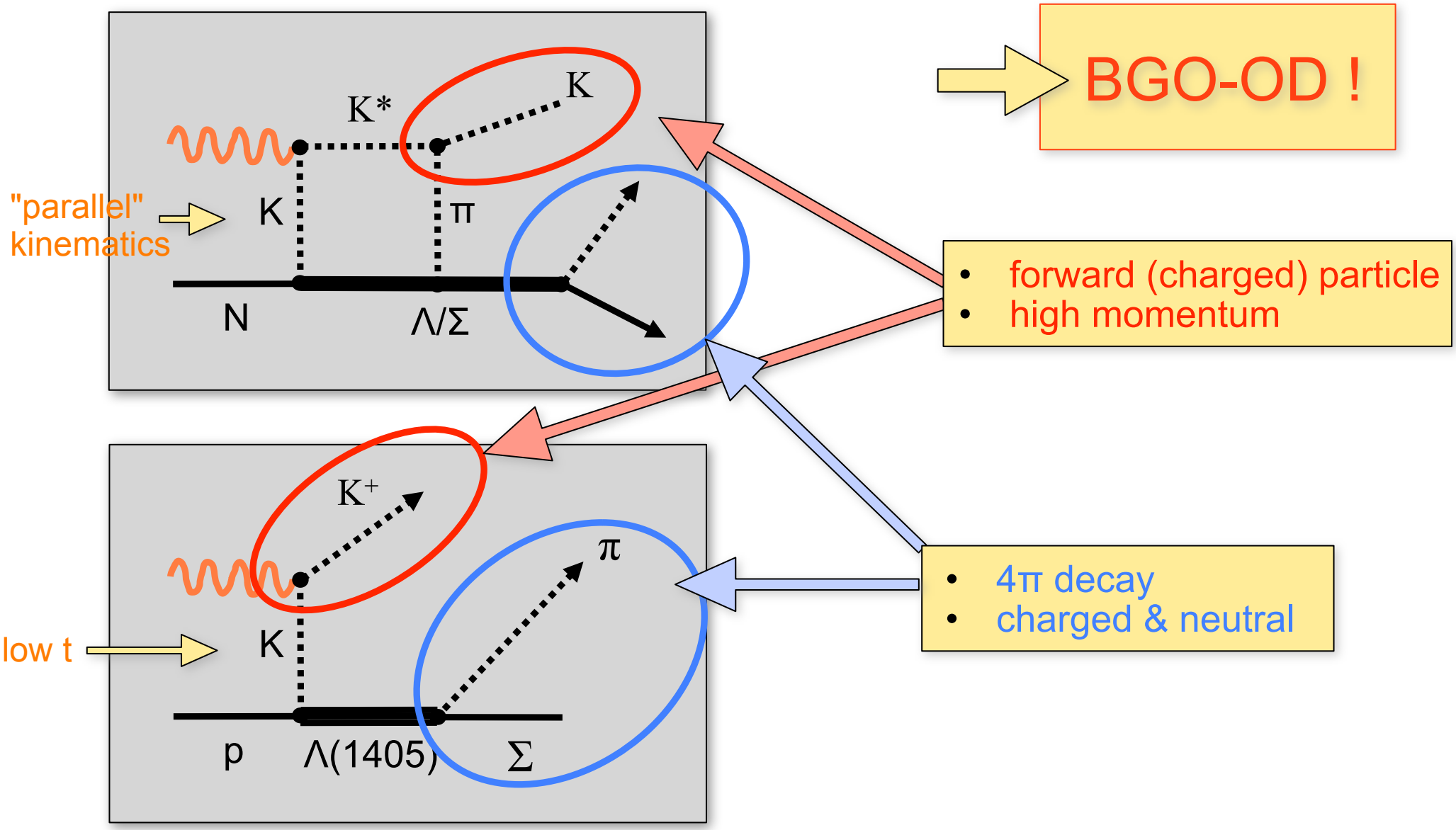
t-channel Kinematics



t-channel Kinematics



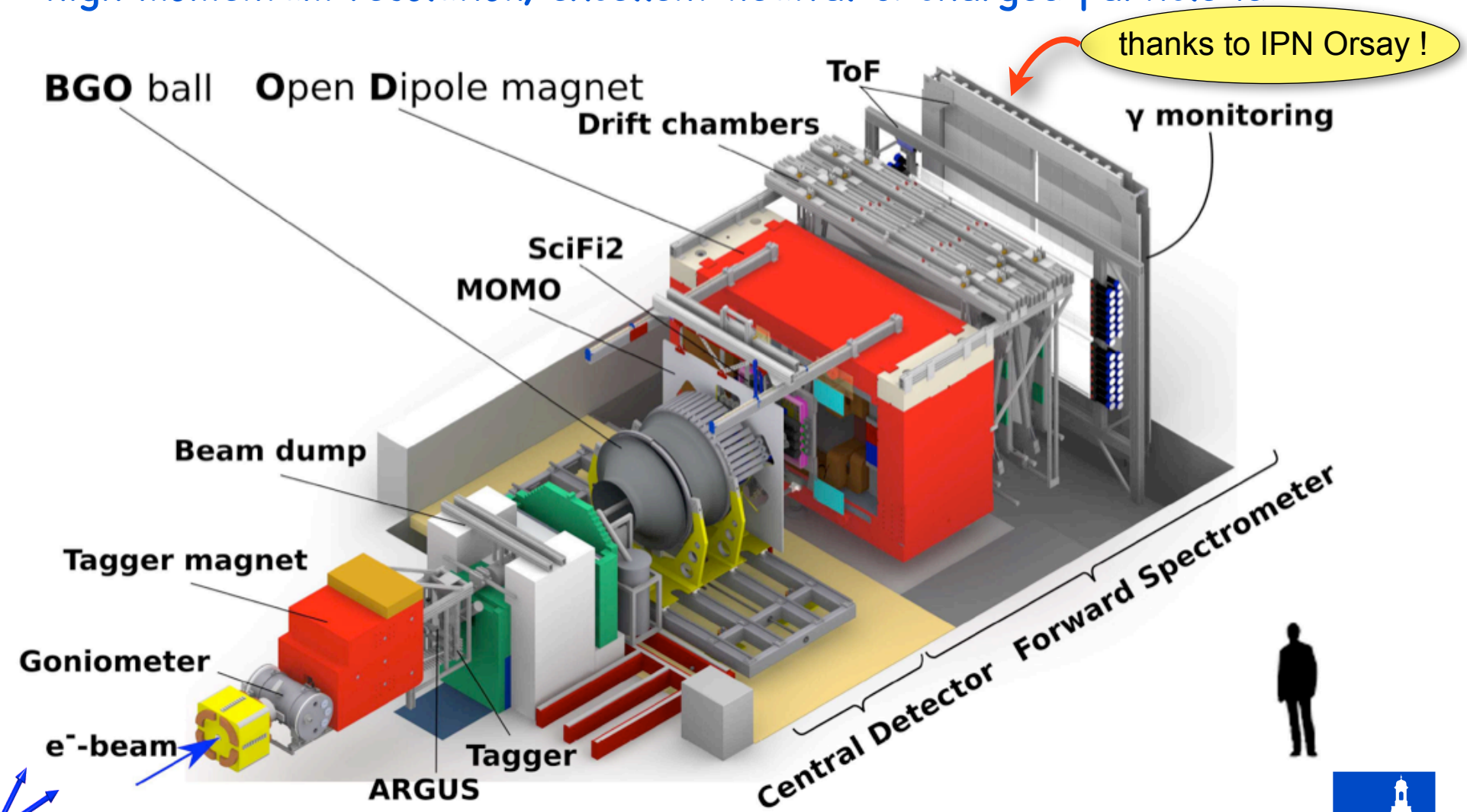
t-channel Kinematics



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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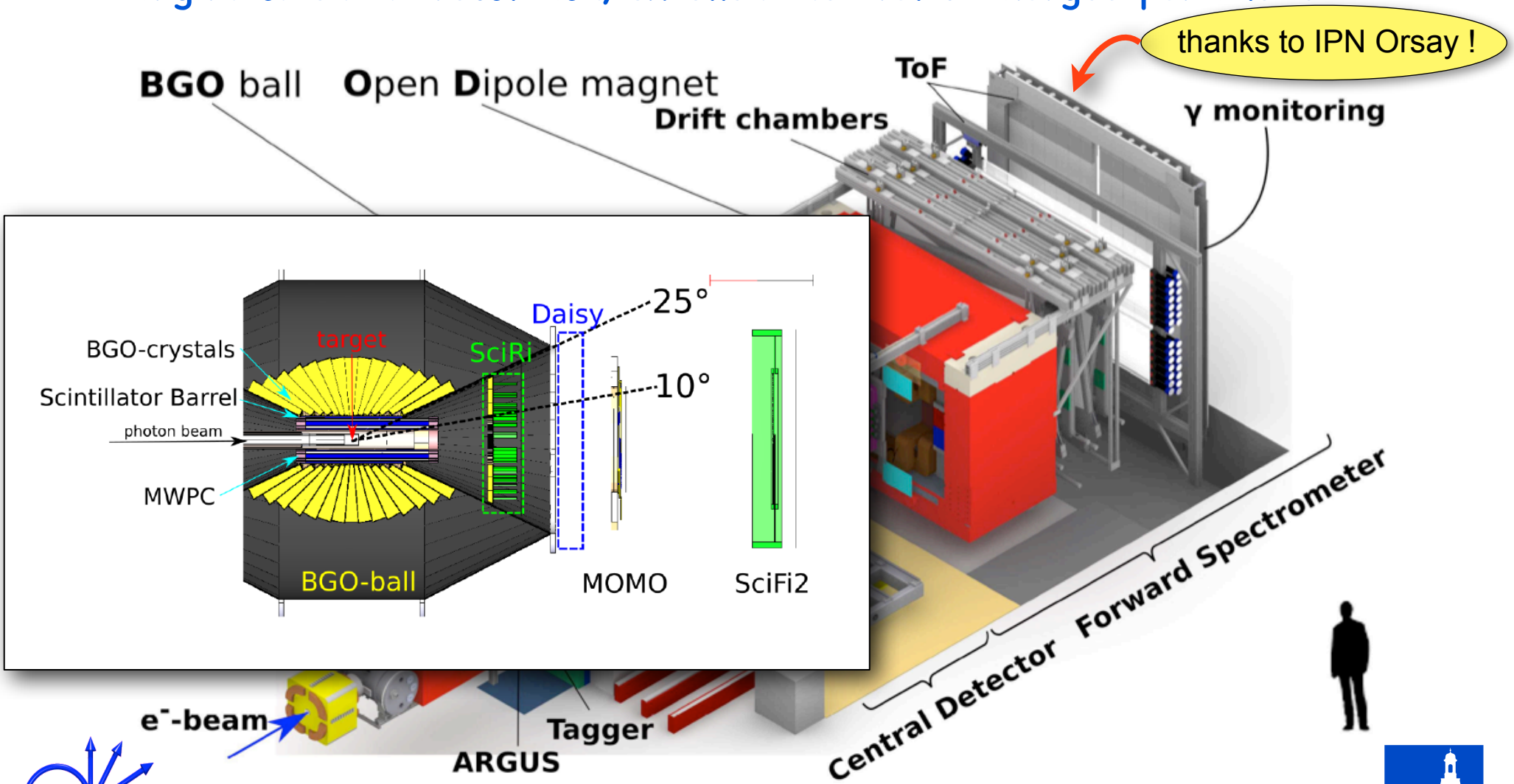


BGO-OD experiment at ELSA

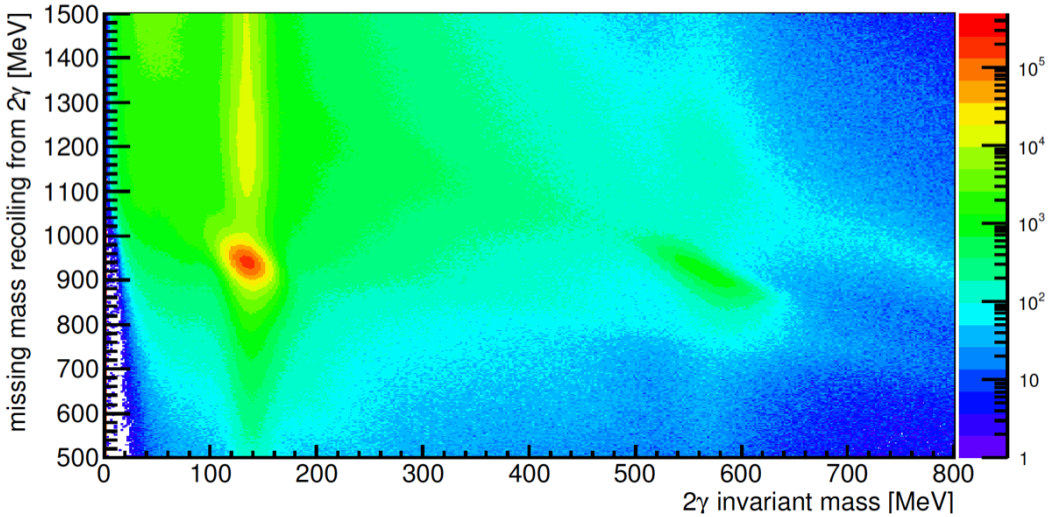
First Results from BGO-OD

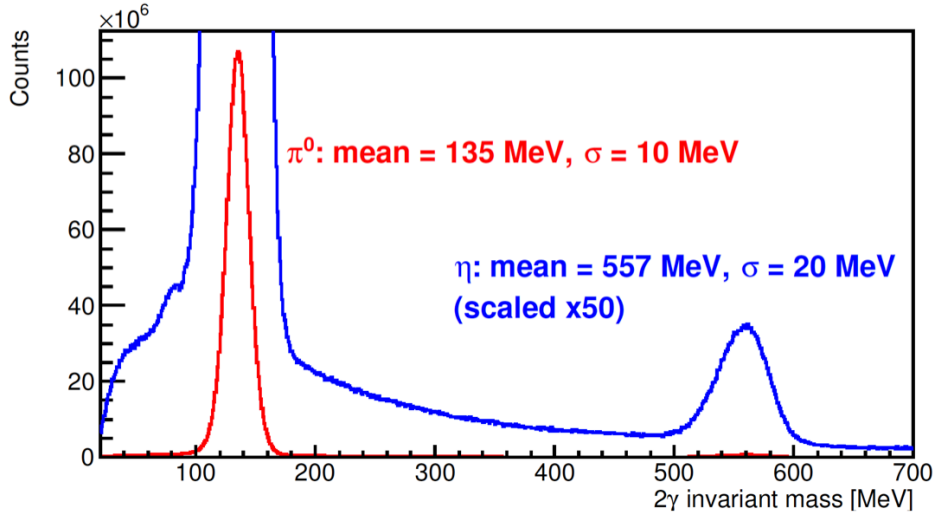
all preliminary

Particle ID & event reconstruction

central

BGO 2γ reconstruction

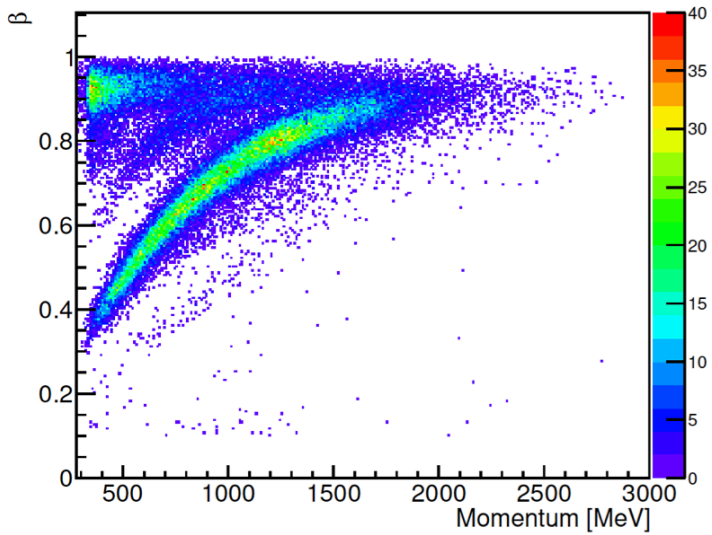


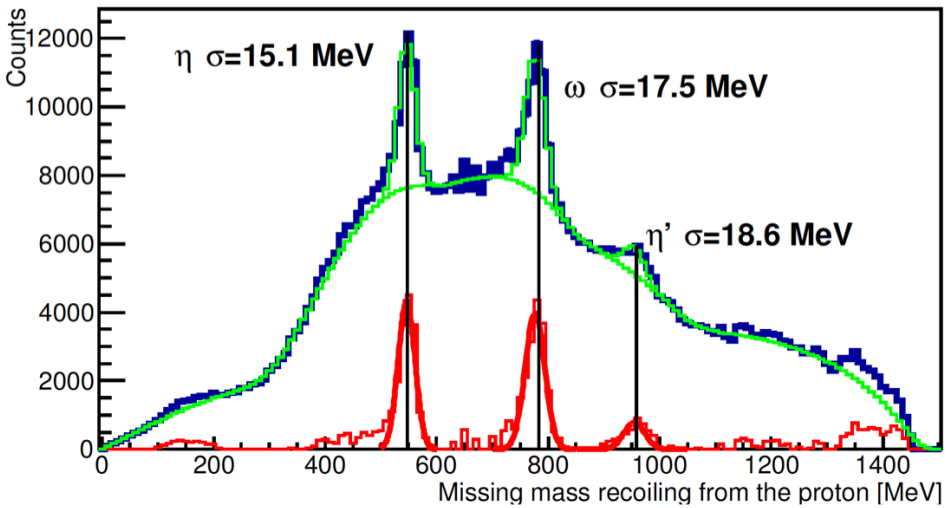


forward

few days of data

OD pos. charged particles



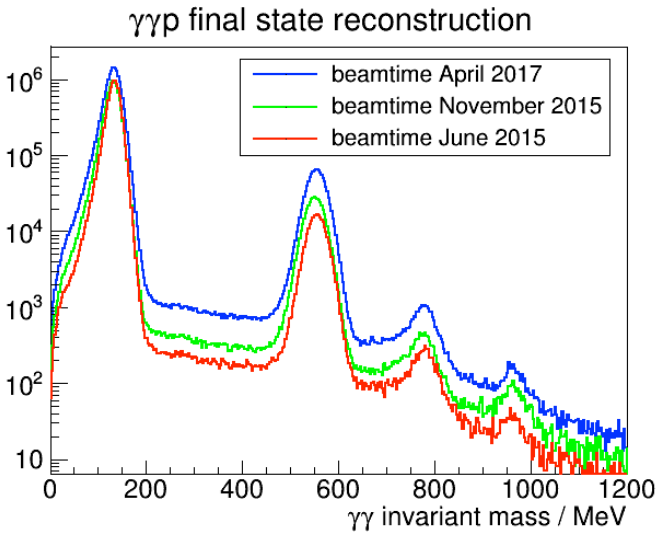


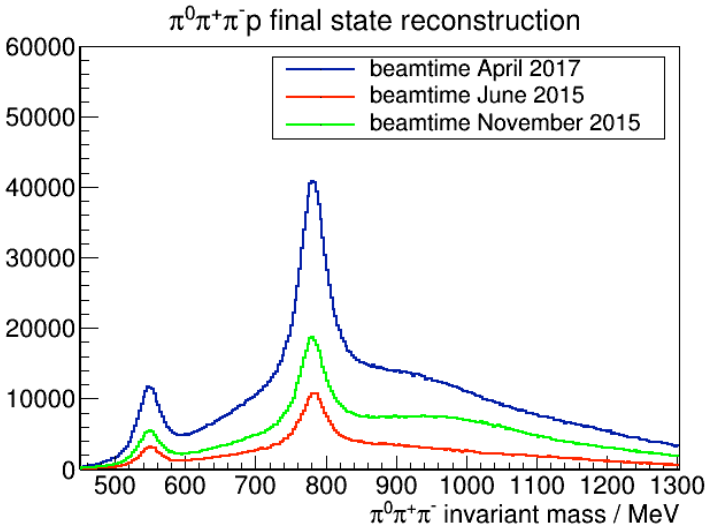
ELSA

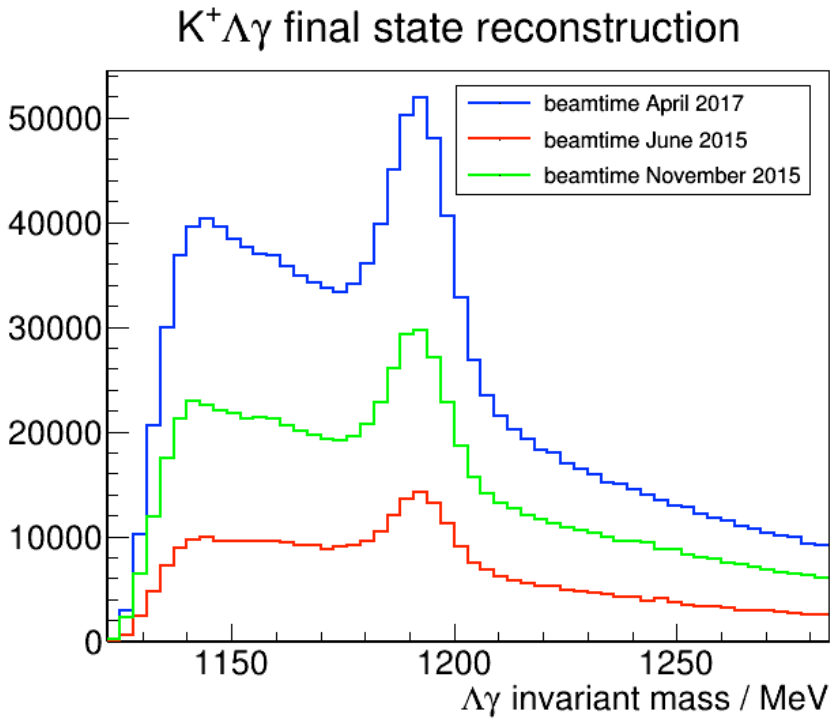
universitätbonn

event reconstruction

work of G. Scheluchin





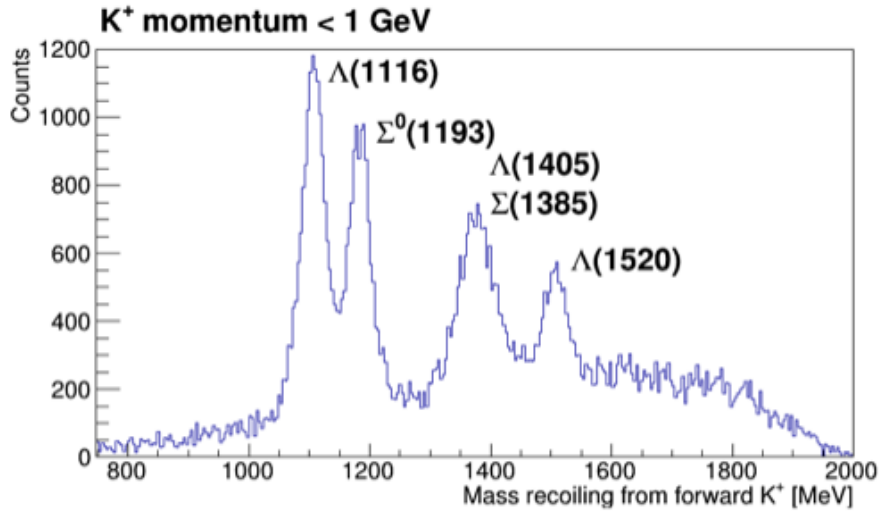


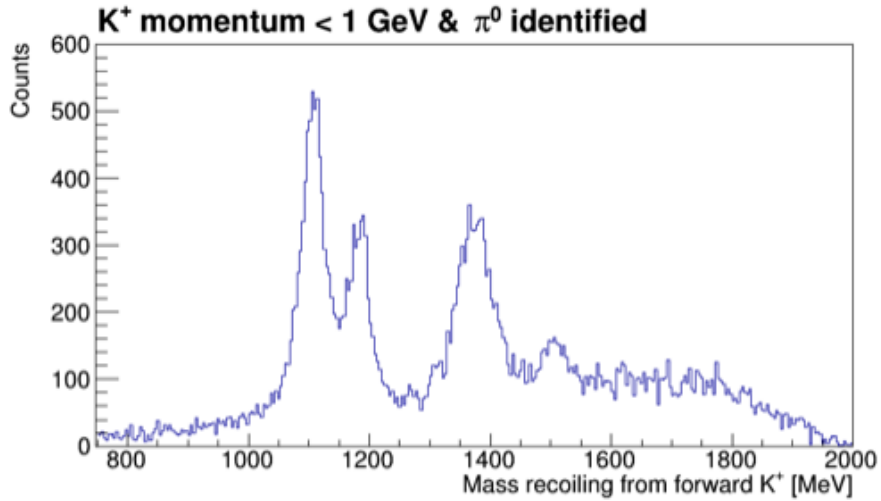
First Results from $\gamma + p \rightarrow K^+ + X$

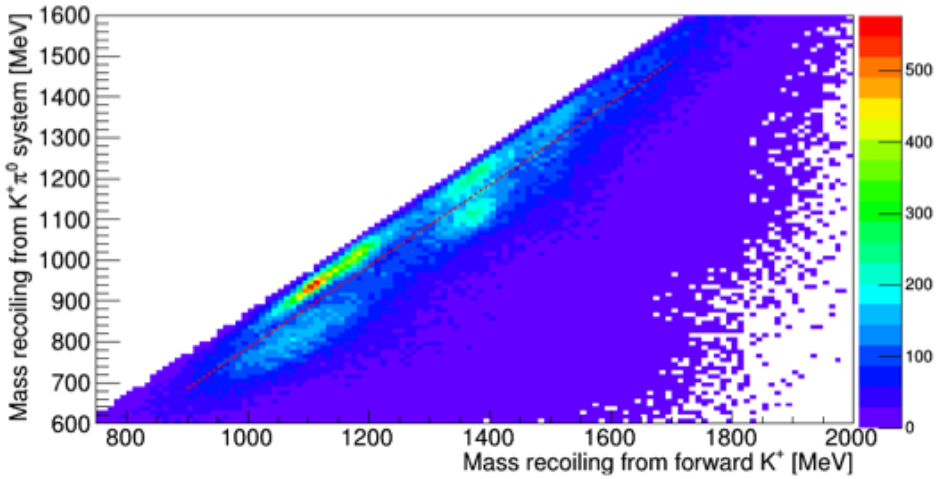
forward K^+ in spectrometer

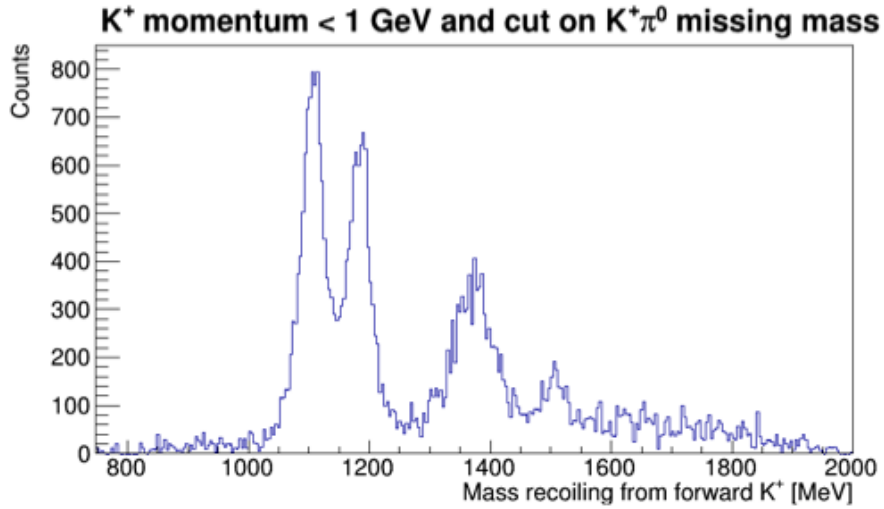
work of T. Jude

all data





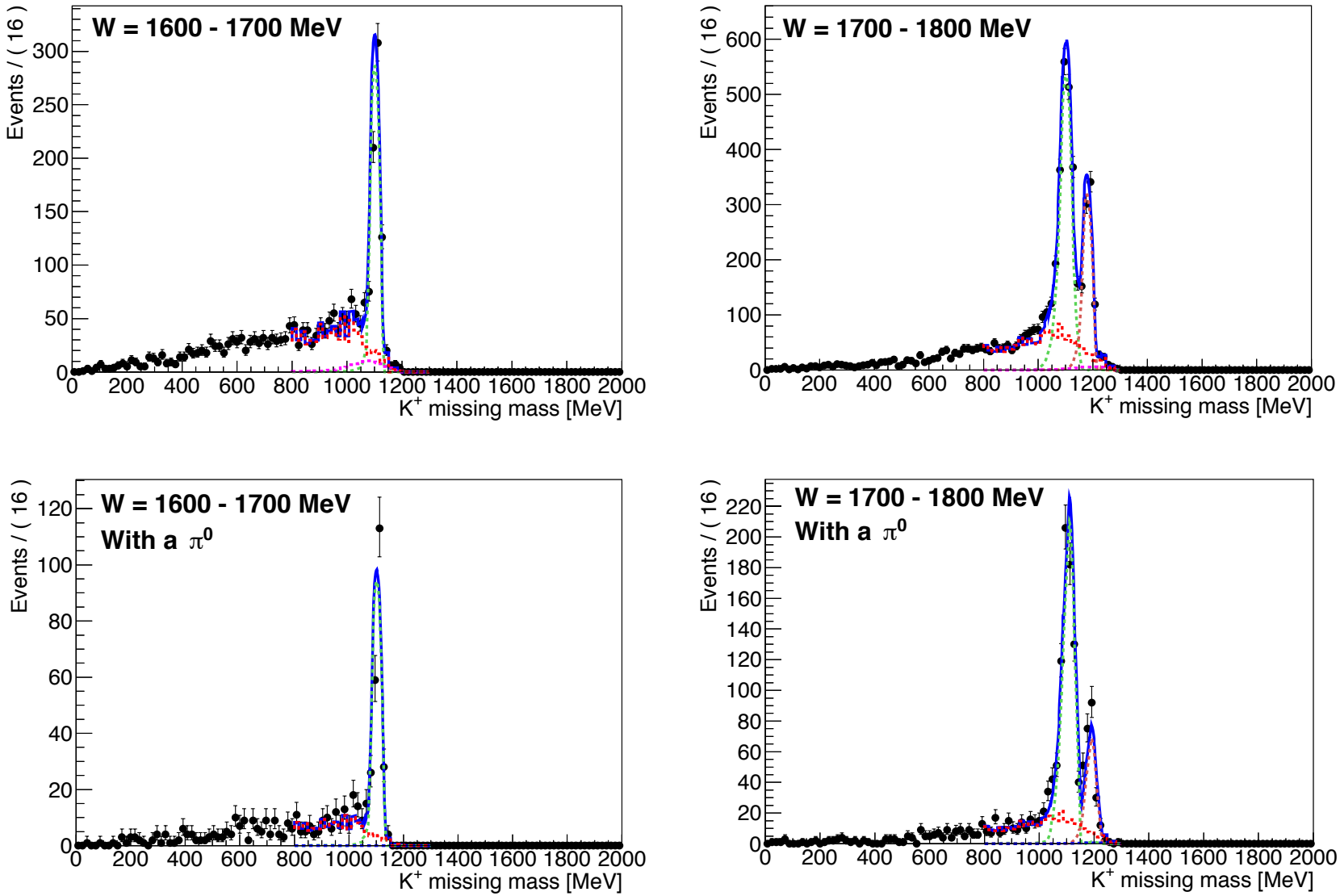




$\gamma + p \rightarrow K^+ + \Lambda(1116)$ @ forward angles

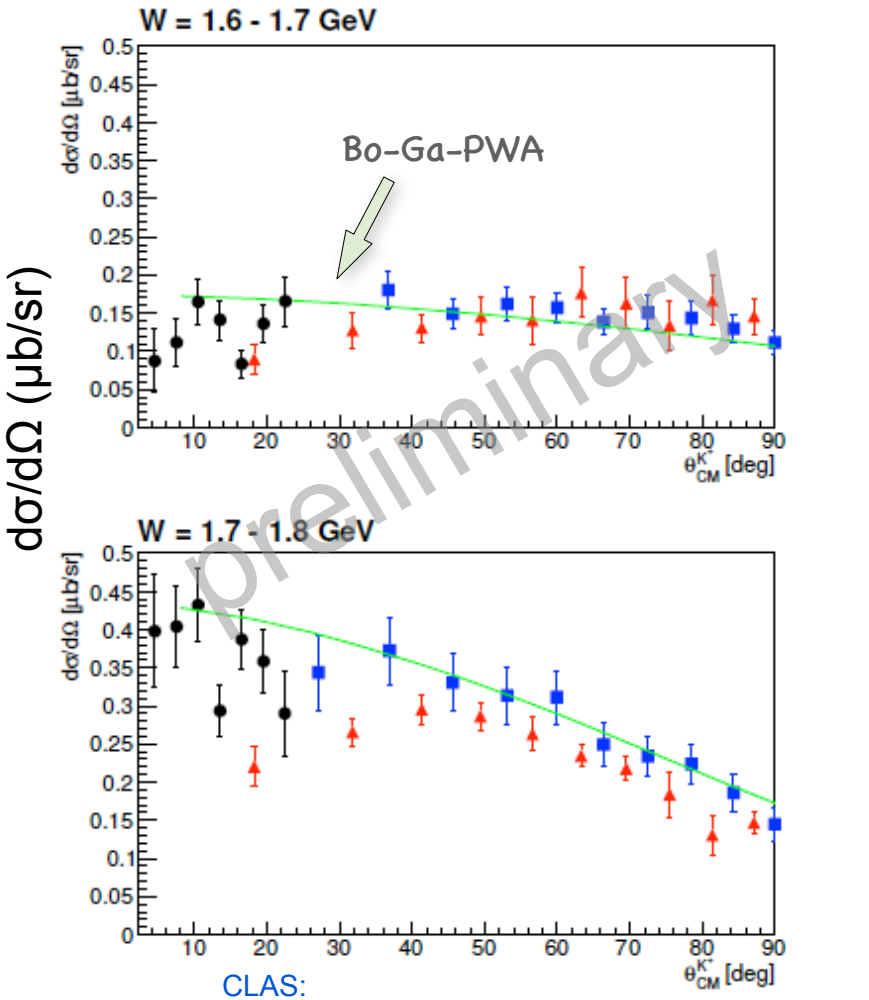
work of T. Jude

~1/3 subset of data



$\gamma + p \rightarrow K^+ + \Lambda(1116)$ @ forward angles

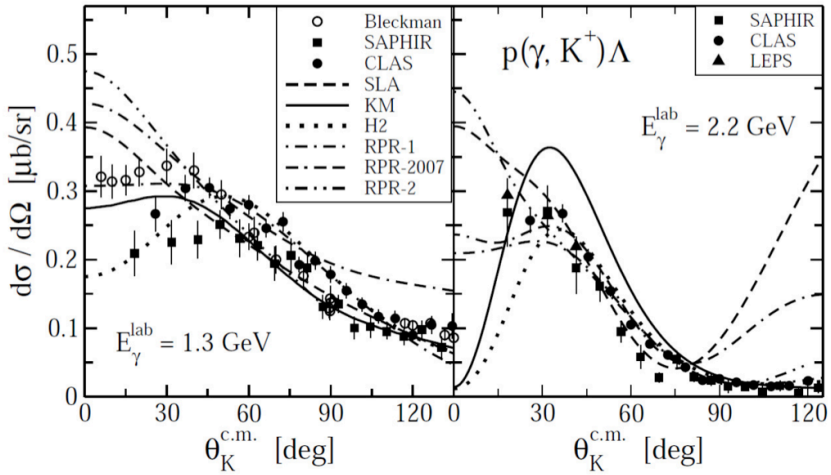
work of Th. Zimmermann & T. Jude



CLAS:
M.E. McCracken 2010
PRC 81

SAPHIR:
K.H. Glander 2004
EPJA 19

θ_K^{cm} (deg.)



Bydzovsky and Skoupil, arXiv:1211.2684
Proceedings SNP12

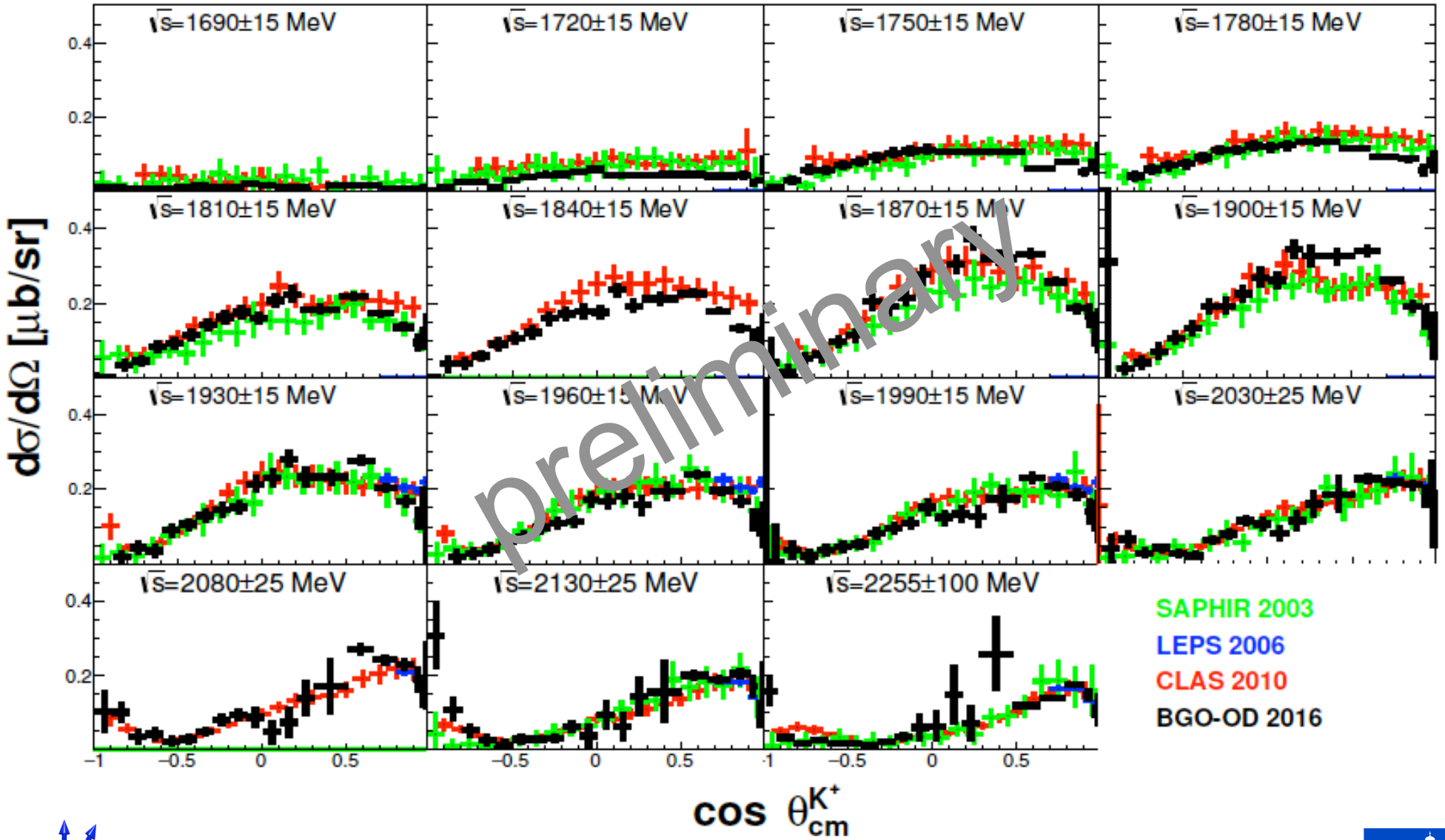
→ important constraint for hypernuclei production

10x event statistics available

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

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

work of G. Scheluchin



Λ(1405): initial tests – *very preliminary*

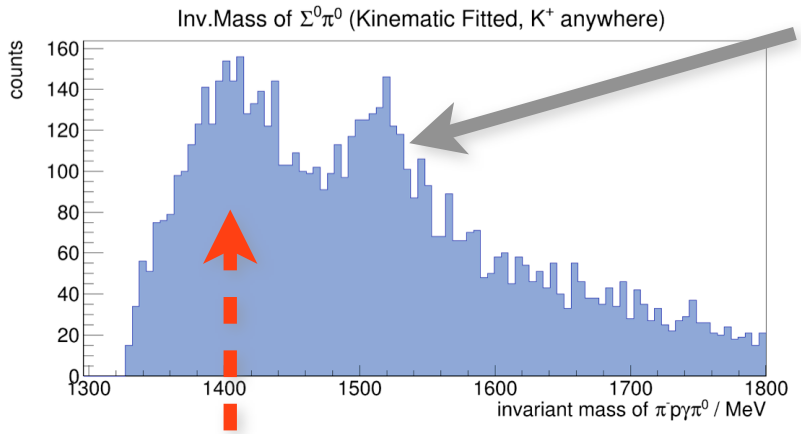
first results: $K^+\Lambda(1405)$

$\Lambda(1520) \rightarrow \Sigma\pi$ [42%]
$\Lambda\pi\pi$ [10%]

work of G. Scheluchin

~1/3 subset of data

- production at small t possible
- inaccessible to previous expts



$\gamma + p \rightarrow K^+ \Lambda(1405)$

$\Downarrow$

$(\pi\Sigma)^0$

isospin forbidden for Σ(1385)

$\Downarrow$

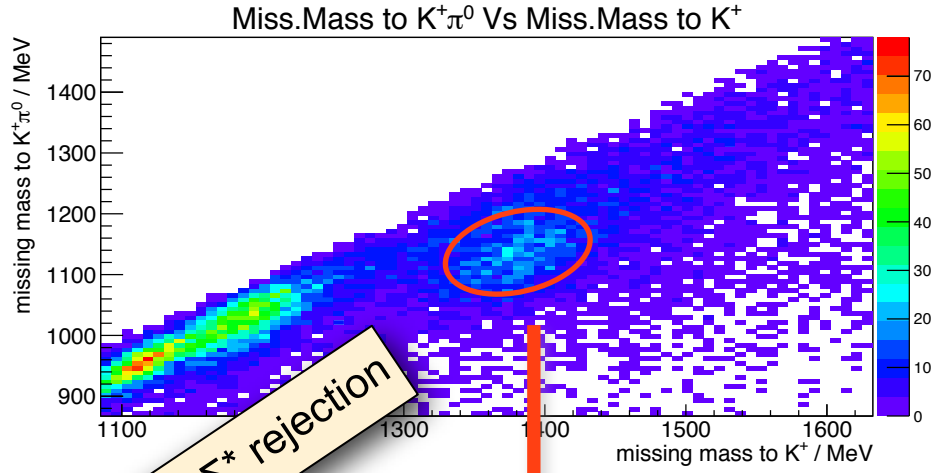
$\pi^0 \Sigma^0(1192)$

$\Downarrow$

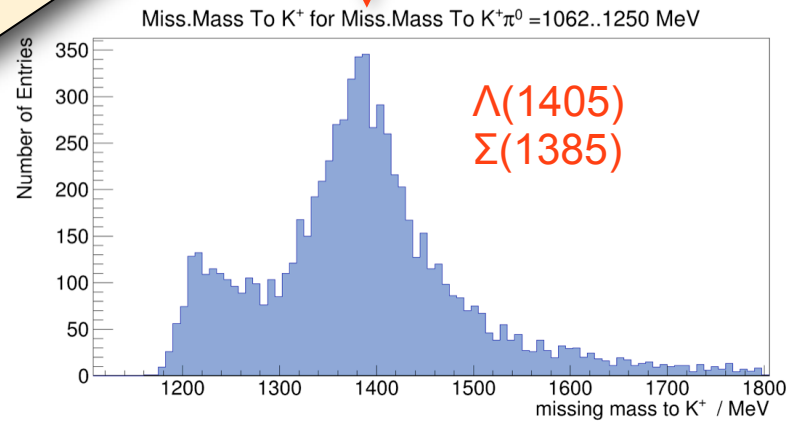
$\Lambda(1116) + \gamma$

$\Downarrow$

$\pi^- p$

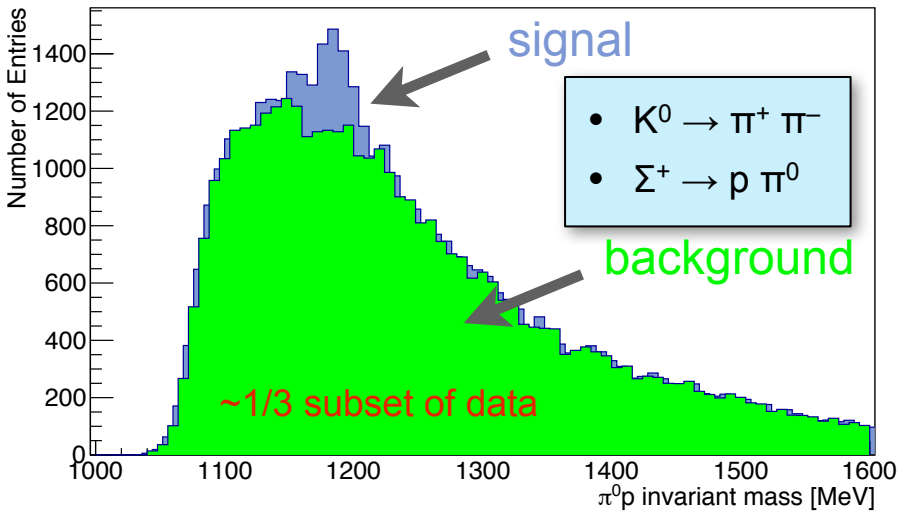


no explicit Σ* rejection



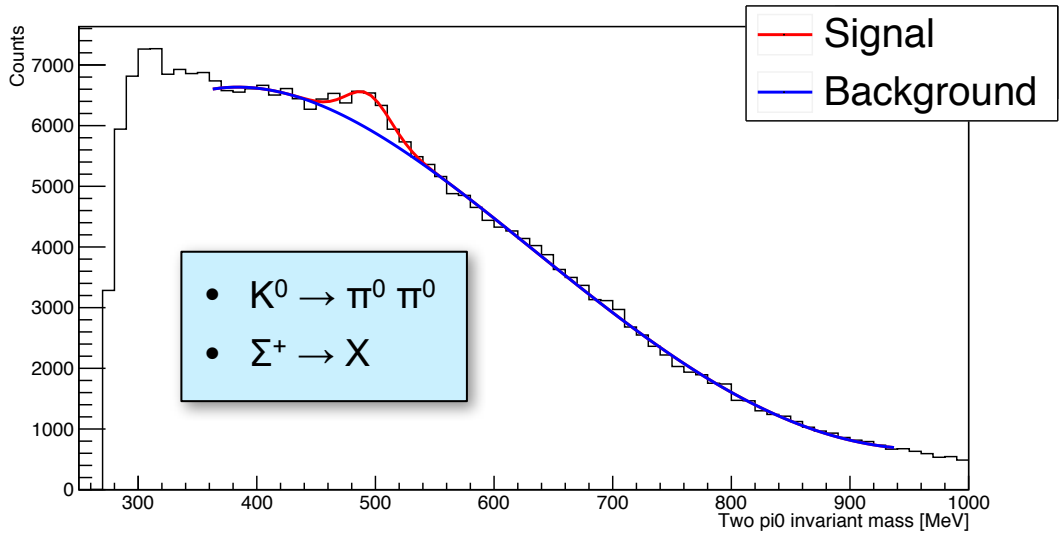
K^0 from *proton* target

work of B.-E. Reitz



w/ kinematic fit

work of S. Alef



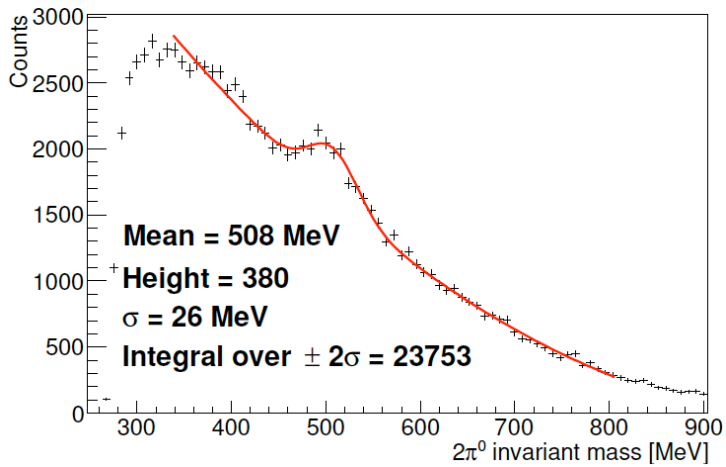
prior to kinematic fit

K^0 from *neutron* target

2 day test beam

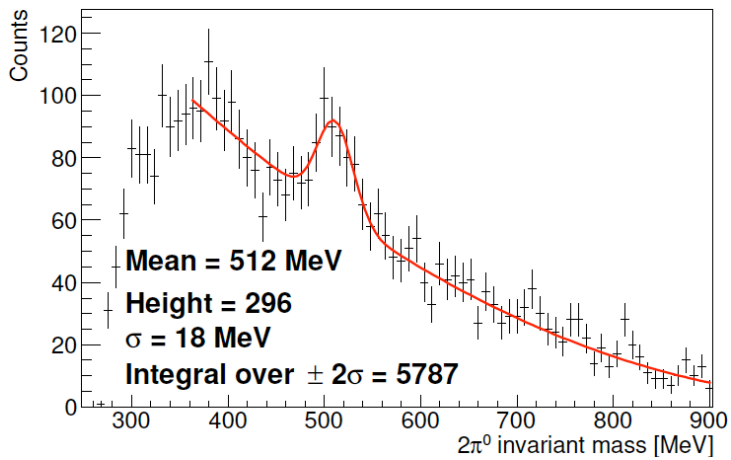
work of T. Jude

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



in addition:

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



Summary

- Baryon Spectrum long standing issue
- new insights through meson photoproduction,
- in particular w/ single & double polarisation
- "exotics" in charm sector
- uds sector → parallels ??
- threshold dynamics → (vector) meson-baryon
- low-t experiments → BGO-OD

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