JÜLICH FORSCHUNGSZENTRUM

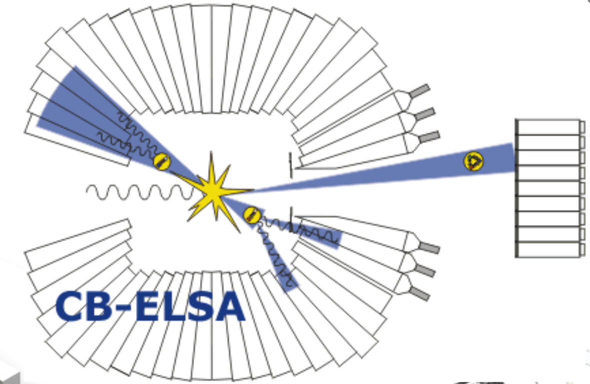
Baryon Spectroscopy

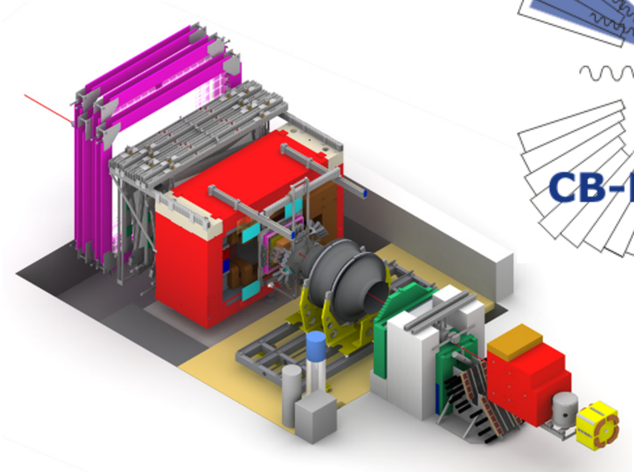
Dec 2, 2015 | Albrecht Gillitzer, IKP Forschungszentrum Jülich

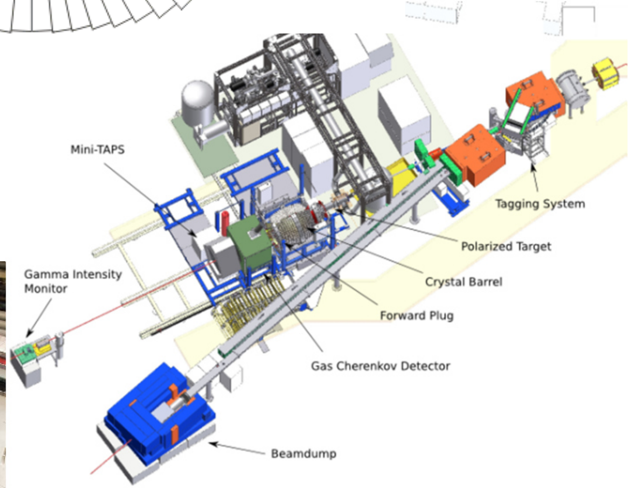
PANDA LV Collaboration Meeting, Vienna, Nov 30 – Dec 4, 2015

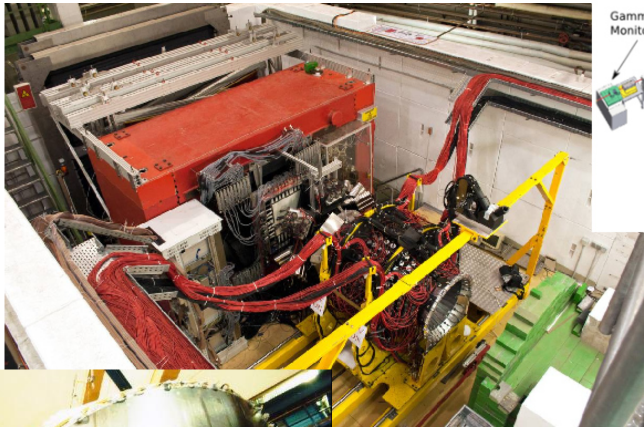
Why to be Interested in Baryons?

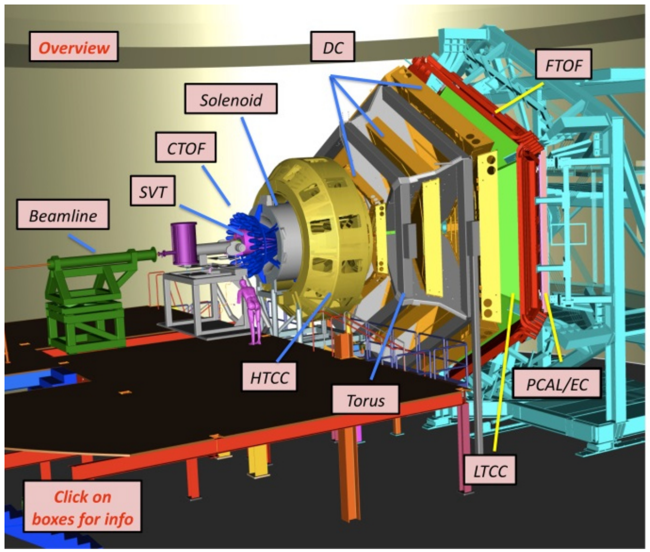
- No understanding of strong interaction without under-standing the excitation pattern of baryons!
- Strong worldwide activity in „Baryon Spectroscopy“ with photo-induced reactions

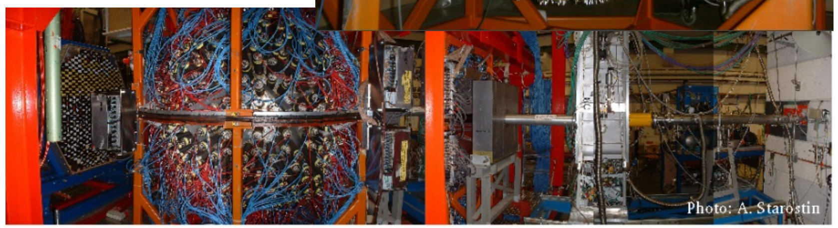






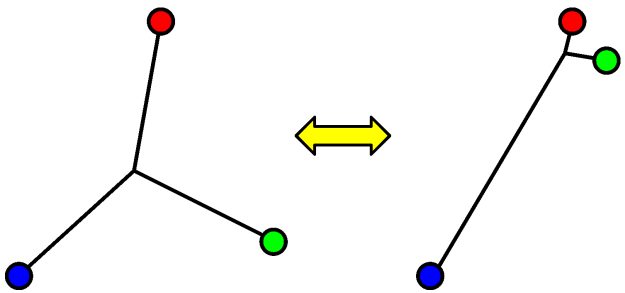


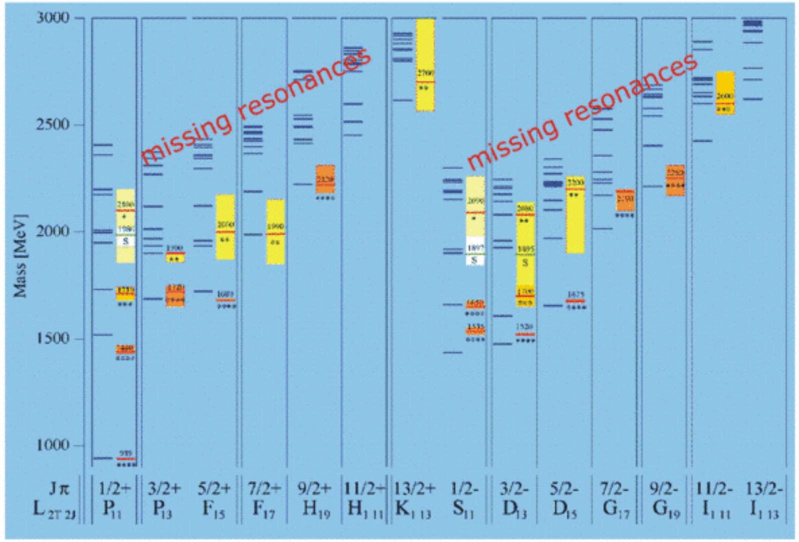


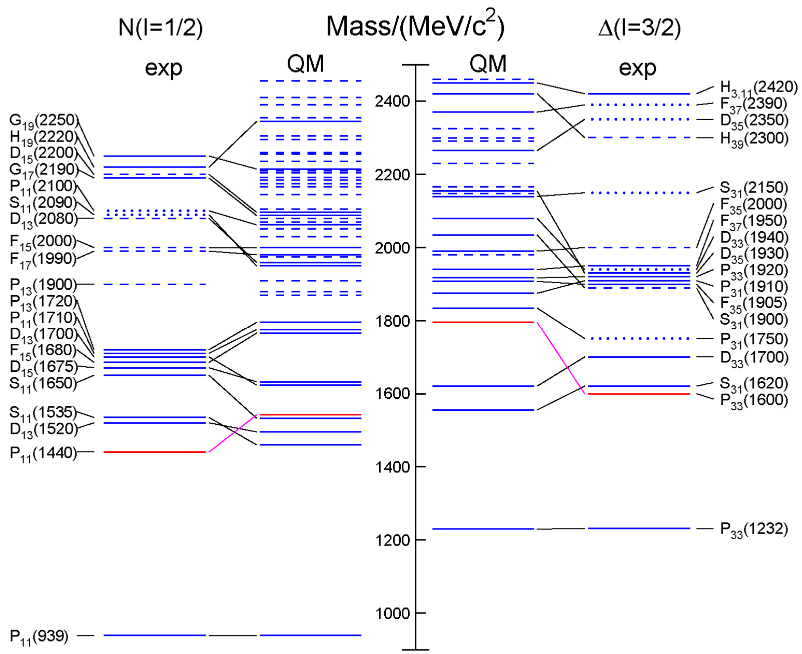


Open Questions

- Missing resonances
- Wrong masses, wrong sequence
- Relevant degrees of freedom?
  - 3-quark or quark-diquark structure?
  - single particle excitation modes
  - meson-baryon dynamics

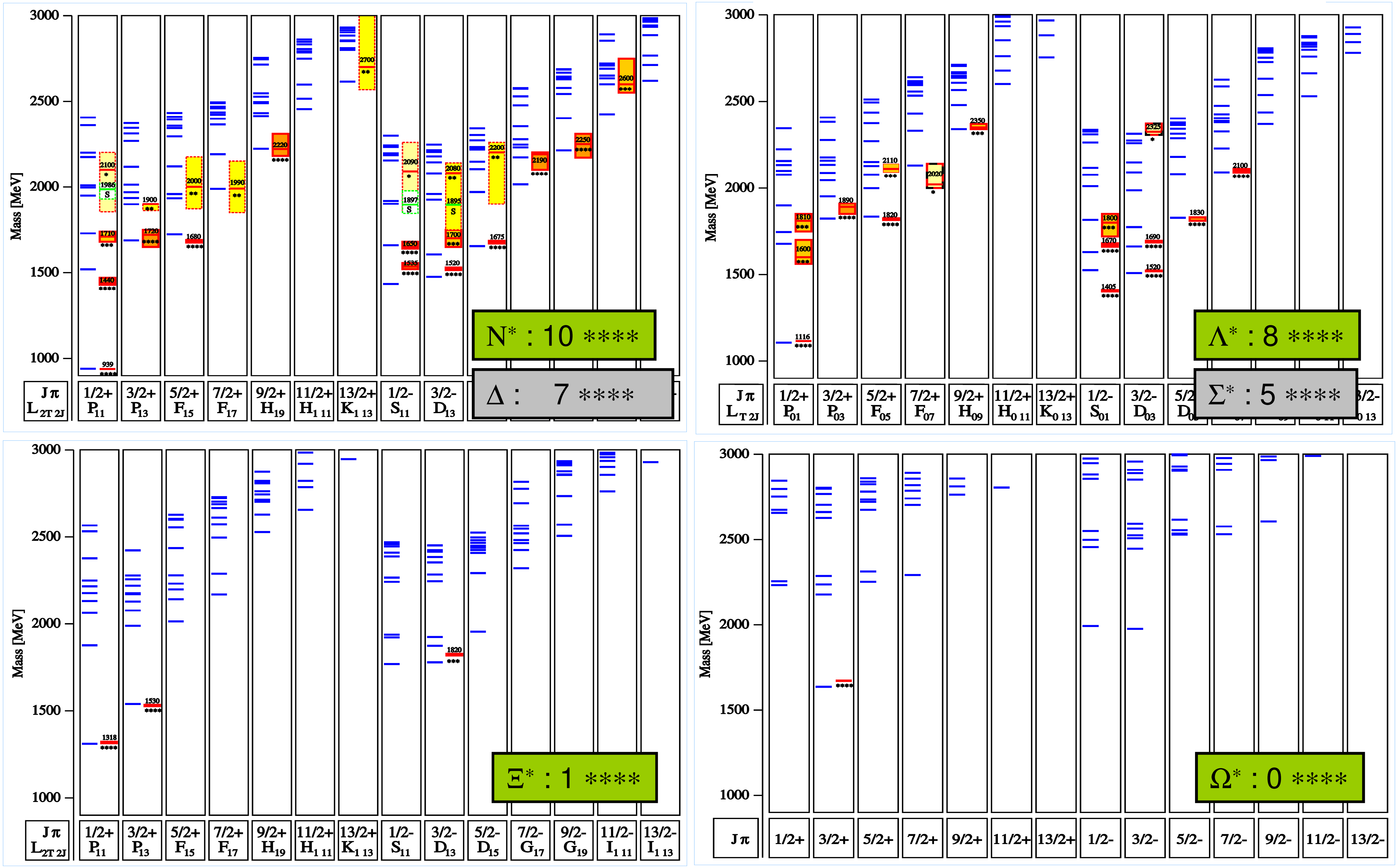






Excited Hyperon States?

U. Löring, B.Ch. Metsch, H.R. Petry,
Eur. Phys. J A 10 (2001) 309, 395,447



SU(6) x O(3) Classification

PDG:

- octet Ξ states: no partner states of most known N* states
- Ξ(1820) and Ξ(2030) "educated guess"
- decuplet Ξ and Ω states: no Δ* partner state
- note on Ξ resonances:

"… nothing of significance on Ξ resonances has been added since our 1988 edition."

PDG 2008

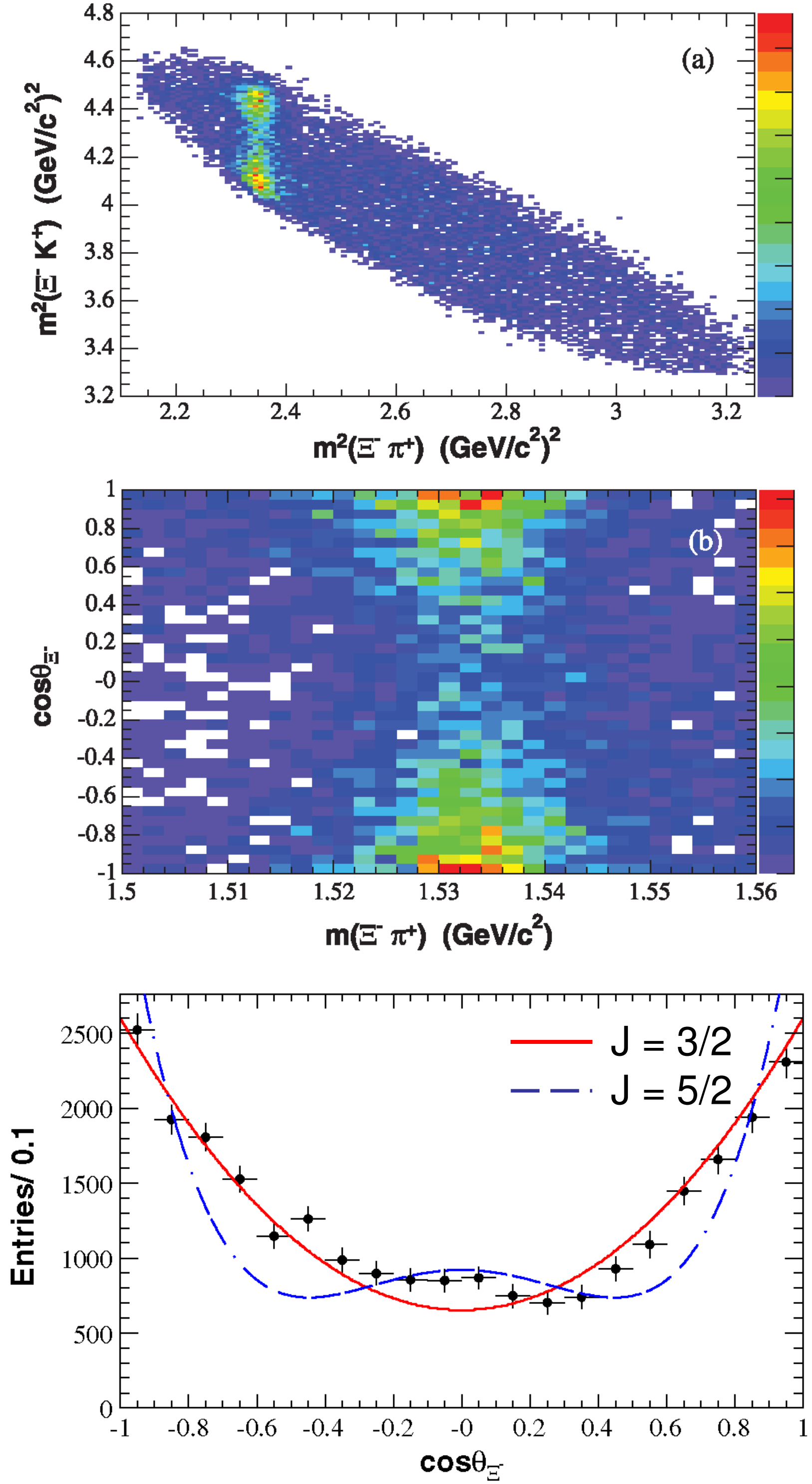
J^P	(D, L^P_N)	S	Octet members				Singlets
1/2⁺	$(56,0^+_0)$	1/2	$N(939)$	$\Lambda(1116)$	$\Sigma(1193)$	$\Xi(1318)$	
1/2⁺	$(56,0^+_2)$	1/2	$N(1440)$	$\Lambda(1600)$	$\Sigma(1660)$	$\Xi(?)$	
1/2⁻	$(70,1^-_1)$	1/2	$N(1535)$	$\Lambda(1670)$	$\Sigma(1620)$	$\Xi(?)$	$\Lambda(1405)$
3/2⁻	$(70,1^-_1)$	1/2	$N(1520)$	$\Lambda(1690)$	$\Sigma(1670)$	$\Xi(1820)$	$\Lambda(1520)$
1/2⁻	$(70,1^-_1)$	3/2	$N(1650)$	$\Lambda(1800)$	$\Sigma(1750)$	$\Xi(?)$	
3/2⁻	$(70,1^-_1)$	3/2	$N(1700)$	$\Lambda(?)$	$\Sigma(?)$	$\Xi(?)$	
5/2⁻	$(70,1^-_1)$	3/2	$N(1675)$	$\Lambda(1830)$	$\Sigma(1775)$	$\Xi(?)$	
1/2⁺	$(70,0^+_2)$	1/2	$N(1710)$	$\Lambda(1810)$	$\Sigma(1880)$	$\Xi(?)$	$\Lambda(?)$
3/2⁺	$(56,2^+_2)$	1/2	$N(1720)$	$\Lambda(1890)$	$\Sigma(?)$	$\Xi(?)$	
5/2⁺	$(56,2^+_2)$	1/2	$N(1680)$	$\Lambda(1820)$	$\Sigma(1915)$	$\Xi(2030)$	
7/2⁻	$(70,3^-_3)$	1/2	$N(2190)$	$\Lambda(?)$	$\Sigma(?)$	$\Xi(?)$	$\Lambda(2100)$
9/2⁻	$(70,3^-_3)$	3/2	$N(2250)$	$\Lambda(?)$	$\Sigma(?)$	$\Xi(?)$	
9/2⁺	$(56,4^+_4)$	1/2	$N(2220)$	$\Lambda(2350)$	$\Sigma(?)$	$\Xi(?)$	
			Decuplet members				
3/2⁺	$(56,0^+_0)$	3/2	$\Delta(1232)$	$\Sigma(1385)$	$\Xi(1530)$	$\Omega(1672)$	
3/2⁺	$(56,0^+_2)$	3/2	$\Delta(1600)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$	
1/2⁻	$(70,1^-_1)$	1/2	$\Delta(1620)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$	
3/2⁻	$(70,1^-_1)$	1/2	$\Delta(1700)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$	
5/2⁺	$(56,2^+_2)$	3/2	$\Delta(1905)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$	
7/2⁺	$(56,2^+_2)$	3/2	$\Delta(1950)$	$\Sigma(2030)$	$\Xi(?)$	$\Omega(?)$	
11/2⁺	$(56,4^+_4)$	3/2	$\Delta(2420)$	$\Sigma(?)$	$\Xi(?)$	$\Omega(?)$	

Data on Ξ States: Ξ(1530)

- The only reasonably well studied Ξ resonance:
- Ξ(1530) - decuplet g.s. $J^P = 3/2^+$
- Γ = 9…10 MeV *Compare to Δ!!*
- decay: ~100% Ξπ
- BaBar measured the $\Xi(1530)^0$ spin J = 3/2 in $\Lambda_c^+ \rightarrow \Xi^- \pi^+ K^+$

BaBar 2008

B. Aubert *et al.*,
PRD 78 (2008) 034008



Why to Study Excited Baryons with $\bar{\text{P}}$ANDA?

- Large cross sections for $\bar{p}\,p \rightarrow \bar{B}\,B^*$
  - $\sigma(\bar{p}p \rightarrow \bar{\Xi}\Xi) \approx \mu b$
  - $\sigma(\bar{p}p \rightarrow \bar{\Omega}\Omega) \approx 0.03 \ldots 0.1 \mu b$ (prediction)
- No extra mesons to balance strangeness or charm
- Symmetry in baryon and antibaryon observables
- Capabilities of the PANDA detector
- ***$\bar{\text{P}}$ANDA is particularly suited for double & triple strange baryon spectroscopy !!***

Physics Subtopics in Baryon Spectroscopy at PANDA

Study excited states of

- double-strange hyperons (Ξ^*)
- triple-strange hyperons (Ω^*)
- charmed hyperons (Λ_c^*, Σ_c^*)
- hidden-charm nucleons ($N_{c\bar{c}}$)

- non-strange baryons (N^*)
- single-strange hyperons (Λ^*, Σ^*)

} high rates already at 1% of design lumi

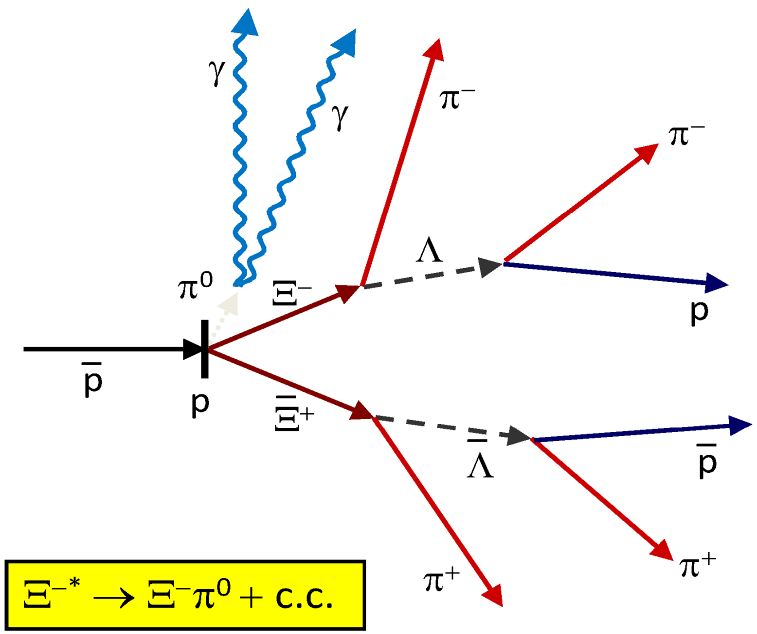
Expected Rates

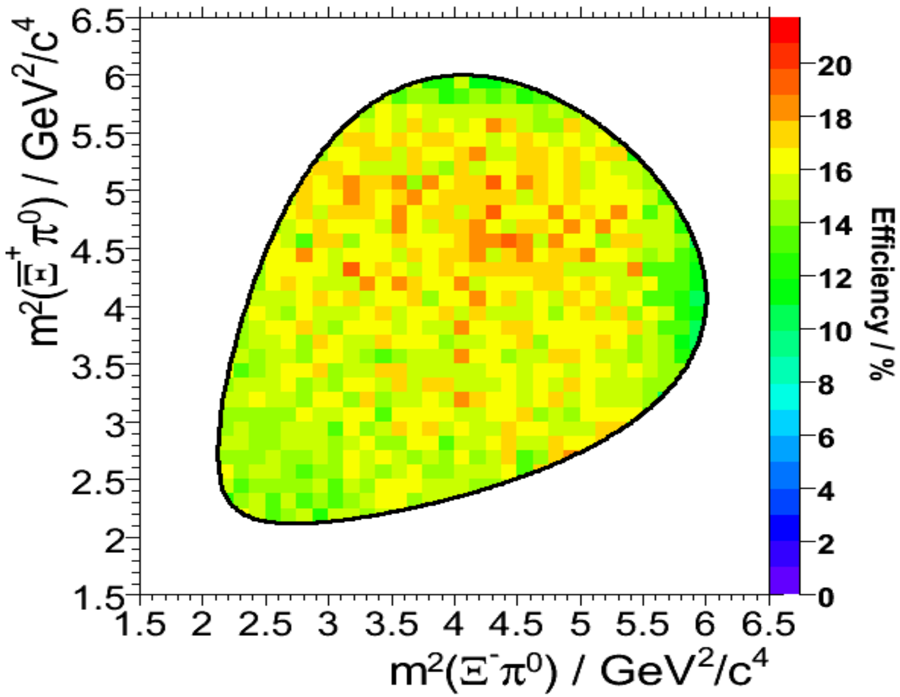
- initial phase: $L \cong 10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ instead of $L \cong 2 \cdot 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- nevertheless the $\Xi\bar{\Xi}$ production rate will be $R_{\Xi\bar{\Xi}} \cong 10/s \cong 10^6/\mathrm{d}$
- for $\Omega\bar{\Omega}$ production we expect $R_{\Omega\bar{\Omega}} \cong 0.3/s \cong 3 \cdot 10^4/\mathrm{d}$
- for excited states the cross section should be of the same order of magnitude as for the ground state for given $\sqrt{s} - \sqrt{s_{\mathrm{thr}}}$
- the *detected* rate depends on the specific decay mode (branching & reconstruction efficiency)
- e.g. $\bar{p}p \rightarrow \bar{\Xi}^+\Xi^{*-} \rightarrow \bar{\Xi}^+\Xi^-\pi^0 \rightarrow \bar{\Lambda}\pi^+\Lambda\pi^-\pi^0 \rightarrow \bar{p}\pi^+\pi^+p\pi^-\pi^-\pi^0$
  assume $b = 0.5 \cdot 0.64^2 = 0.2$ and $\epsilon = 5\%$ → $R_{det} \cong 10^4/\mathrm{d}$

$\bar{\text{P}}$ANDA Physics Book: $\Xi^* \rightarrow \Xi\pi$

- characteristic event topology
- σ ~ μb: ~10^7 Ξ /d produced
- final states to be studied:
  $\Xi^* \rightarrow \Xi\pi, \Xi\eta, \Lambda\bar{K}, \Sigma\bar{K},$
  $\Xi(1530)\pi, \Xi\pi\pi, \ldots$
- benchmark channel:
  6.57 GeV/c $\bar{p}p \rightarrow \Xi^- \bar{\Xi}^+ \pi^0$
- no empty regions or discontinuities in Dalitz plot
- $\Xi^-\pi^0$ mass resolution < 4 MeV; rec. eff. ~15%, S/B >19*

*DPM generated background





to be repeated with Pandaroot

Recent Simulation & Analysis Activities

- New subgroup on "Hyperon Physics" joining efforts related to reaction dynamics and spectroscopy

- $\bar{\Xi}^+\Xi^-$ (g.s.) at p = 4.0 GeV/c Karin Schönning / A.G. (completed)

- $\bar{\Xi}^+\Xi(1690)^-$, $\Xi(1690)^- \rightarrow \Lambda K^-$ at p = 4.1 GeV/c
  André Zambanini, analysis completed, PhD thesis handed in

- $\Lambda(1520) \rightarrow \Lambda e^+e^-$ Dalitz decay in $\Lambda^{(*)}\bar{\Lambda}^*$
  Jacek Biernat, on-going

- extension of vertex fitters and

- $\bar{\Xi}^+\Xi(1820)^-$, $\Xi(1820)^- \rightarrow \Lambda K^-$ & c.c. (started recently)
  Jennifer Pütz, PhD thesis devoted to Ξ^* spectroscopy

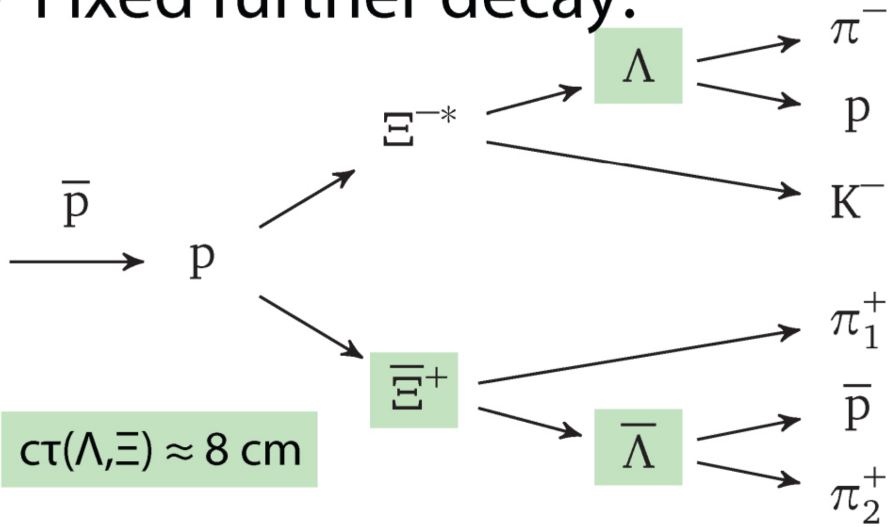
Investigated Channel

- Excited cascade: $\bar{\Xi}^{+}\Xi^{-}(1690)$
  - Not much is known for $\Xi^{-}(1690)$
  - Threshold at 3012 MeV
    (J/Ψ: 3097 MeV)
  - Beam momentum: 4.1 GeV/c
    ($\sqrt{s}$ = 3106 MeV)

$\Xi(1690)$	$I(J^P) = \frac{1}{2}(?^?)$	
Mass $m = 1690 \pm 10$ MeV [c]		
Full width $\Gamma < 30$ MeV		
$\Xi(1690)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$\Lambda\bar{K}$	seen	240
$\Sigma\bar{K}$	seen	70
$\Xi\pi$	seen	311
$\Xi^{-}\pi^{+}\pi^{-}$	possibly seen	213

http://pdg.lbl.gov/, summary tables, generated on 2015-02-24

- Fixed further decay:

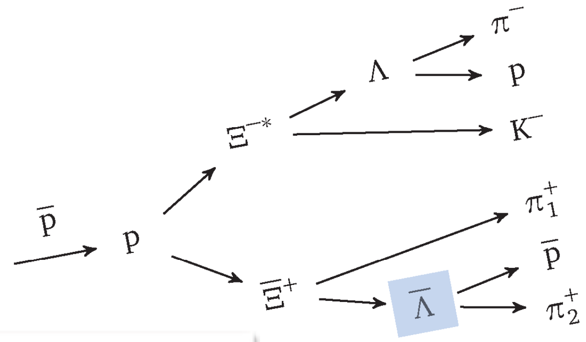


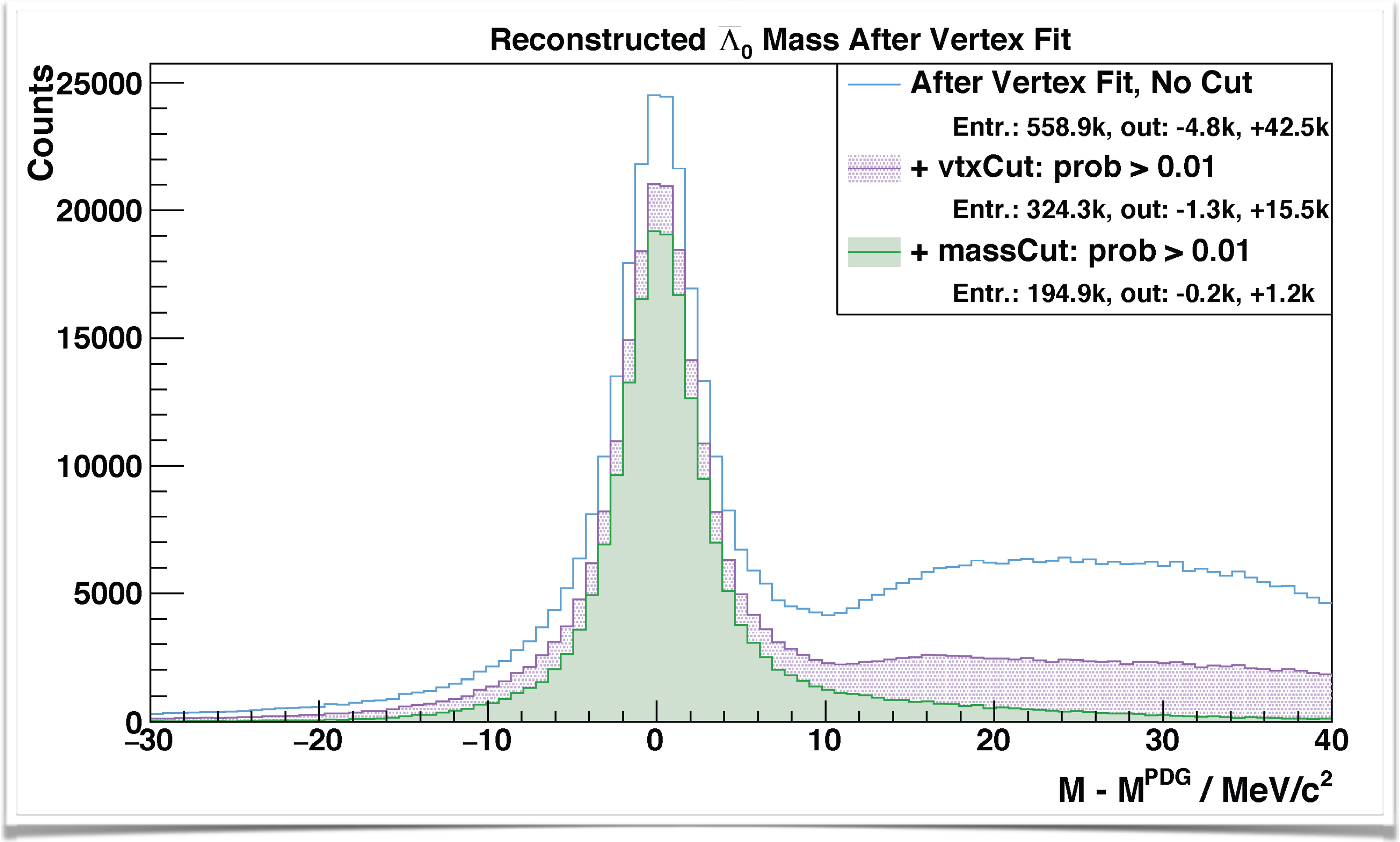
Note: Ξ^{-*} in my case always $\Xi^{-}(1690)$.

Event Generator: EvtGen
Beam Momentum: 4.1 GeV/c
FairSoft/FairRoot: mar15
PandaRoot: trunk (r27694)
Track Finding/PID: ideal

André Zambanini

$\overline{\Lambda}$ Invariant Mass

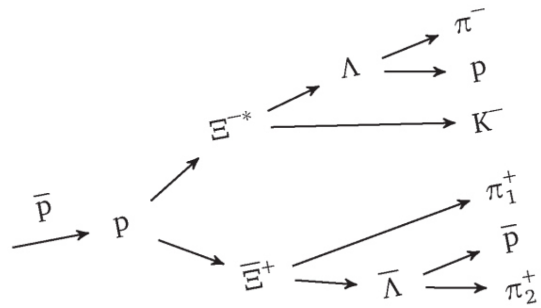




⇒ Good suppression of wrong combinations

André Zambanini

Reconstruction Summary

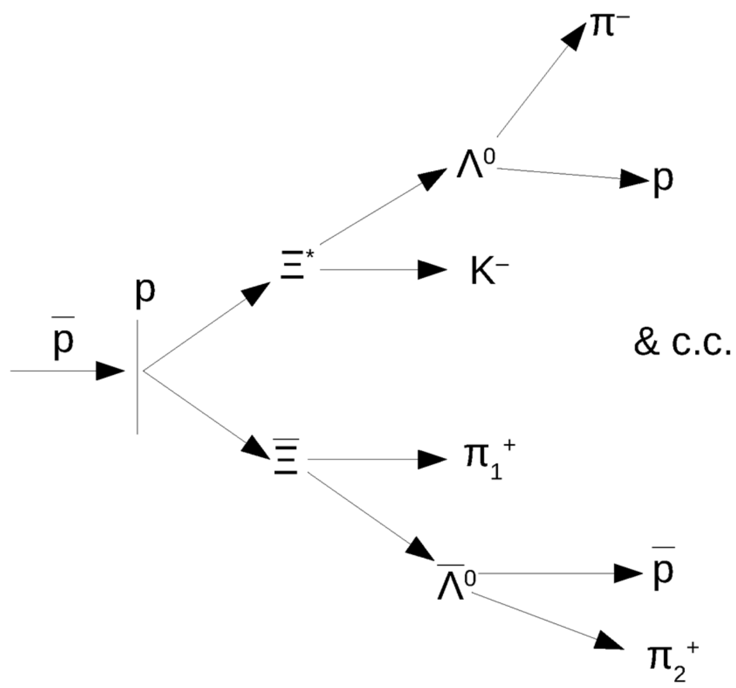


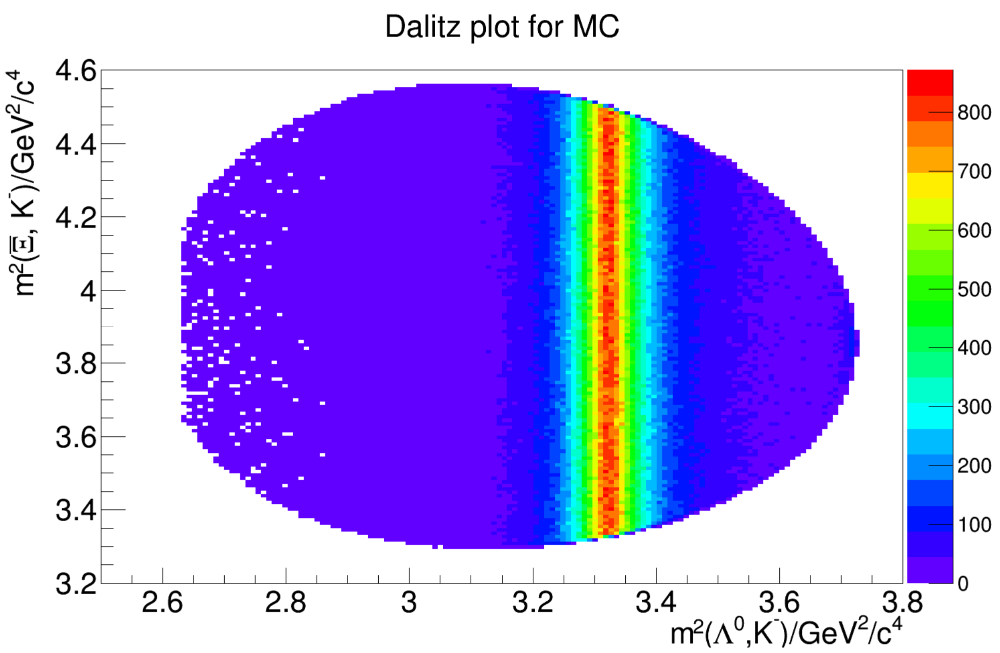
Particle	N_{sig} (ϵ_{sig})	N_{bkg} (ϵ_{bkg})	S
Generated	499,750 (100 %)	47,367,000 (100 %)	
Λ	210,761 (42.2 %)	270,433 (0.6 %)	199
$\bar{\Lambda}$	194,907 (39.0 %)	317,156 (0.7 %)	145
Ξ^{-*}	107,893 (21.6 %)	26 (5.5×10^{-7})	89,990
$\bar{\Xi}^+$	41,875 (8.4 %)	20 (4.2×10^{-7})	30,023
$\bar{\Xi}^+\Xi^{-*}$, only 4C cut	11,011 (2.2 %)	3 (0.6×10^{-7})	8142
$\bar{\Xi}^+\Xi^{-*}$, +$\bar{\Xi}^+$ cuts	4012 (0.8 %)	1 (0.2×10^{-7})	3034

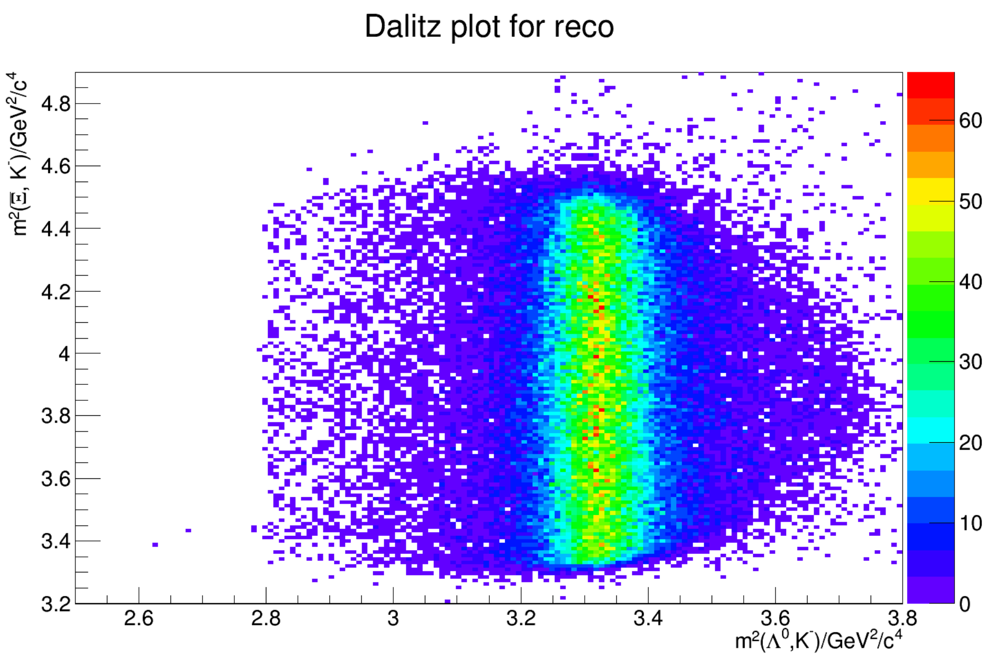
- Reconstruction efficiency: **2.2 %**
  - 6756 h^{-1} fully reconstructed signals at $L = 2 \times 10^{32}$ /(cm^2 s)
  - 338 h^{-1} fully reconstructed signals at $L = 1 \times 10^{31}$ /(cm^2 s)
- Very good background suppression possibilities
  - Conservative cuts: **3879** background events after scaling
  - Same time frame: **11,011** exclusive signal events
  - More optimizations possible (with final detector implementation?)

$\bar{p}p \rightarrow \bar{\Xi}^{+}\Xi(1820)^{-}$ & c.c.

- p = 4.6 GeV/c
- Used ideal tracking and „best“ particle id
- Selected only final state particles with $N_{\text{Hits}} \geq 4$ in any inner tracking detector (MVD, STT, GEM)







Jenny Pütz

$\bar{p}p \to \bar{\Xi}^{+}\Xi(1820)^{-}$ & c.c. Reconstruction Efficiencies

Reco efficiency $\bar{p}p \to \Xi^{*}\,\bar{\Xi}$	
Particle	Reco eff. in %
Λ^0	50.31
$\bar{\Lambda}^0$	41.61
$\bar{\Xi}$	18.39
$\Xi(1820)$	31.94
$\Xi(1820)\,\bar{\Xi}$ sys	4.67

Reco efficiency $\bar{p}p \to \Xi\,\bar{\Xi}^{*}$	
particle	Reco eff. in %
Λ^0	42.51
$\bar{\Lambda}^0$	49,03
Ξ	18.62
$\bar{\Xi}(1820)$	33.11
$\Xi\,\bar{\Xi}(1820)$ sys	4.86

Jenny Pütz

Ongoing & Future Simulation & Analysis Activities

- $\Lambda(1520) \rightarrow \Lambda e^+e^-$ Dalitz decay in $\overline{\Lambda}^{(*)}\Lambda^*$, Jacek Biernat (Cracow)
- $\overline{\Xi}^+\Xi(1820)^-$, $\Xi(1820)^- \rightarrow \Lambda K^-$ & c.c., Jenny Pütz (FZ Jülich)

not covered:

- single strange hyperons (Λ,Σ)
- triple strange hyperons (Ω)
- charmed baryons (Λ_c,Σ_c)
- hidden charm baryons (N^*_{cc})

Conclusion

- baryon spectroscopy group in much better shape
- further work needed on:
  - realistic pattern reconstruction for displaced tracks
  - tracking & PID in Forward Spectrometer
  - vertex fitters (decay trees, …) → Ralf Kliemt (Computing Session)
  - PWA
- only part of the physics program covered in simulation and analysis
- further participation highly welcome