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Hyperon Dynamics with PANDA from Day One

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for the Hyperon Physics Working Group

PANDA collaboration meeting, December 2016

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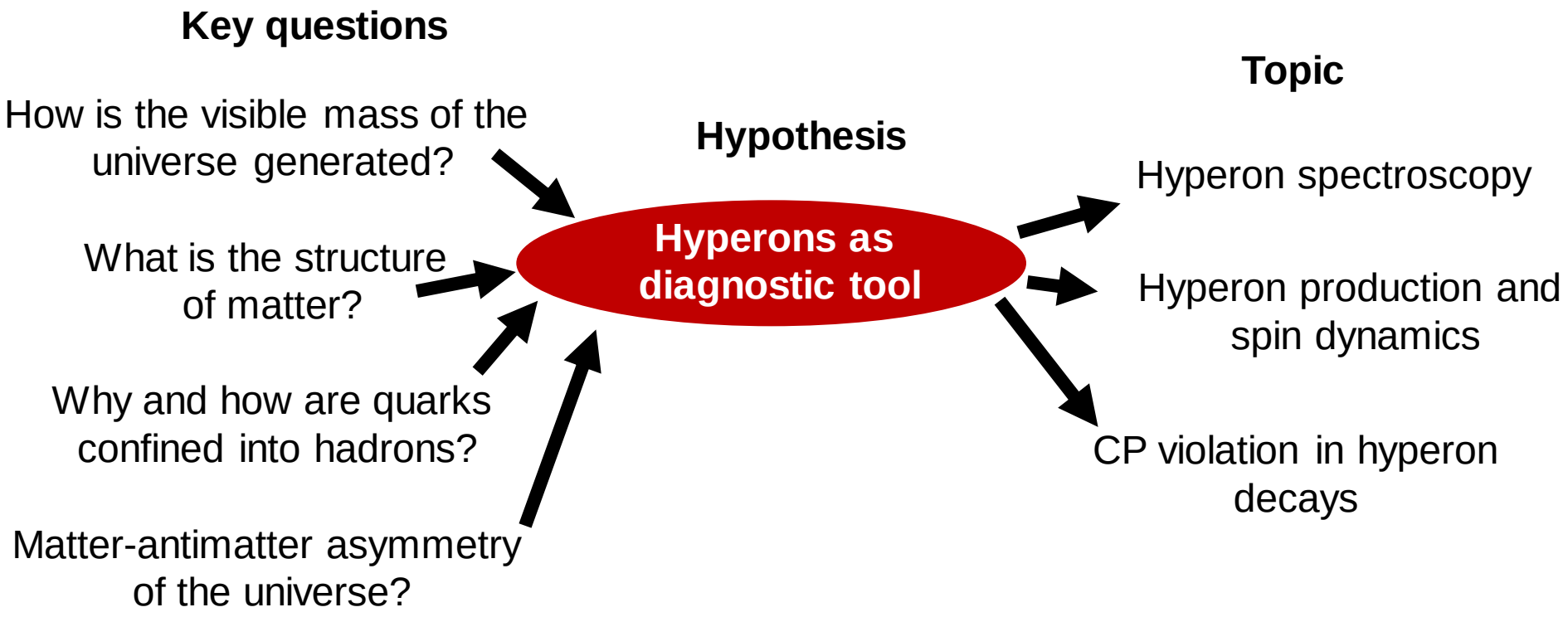
Introduction



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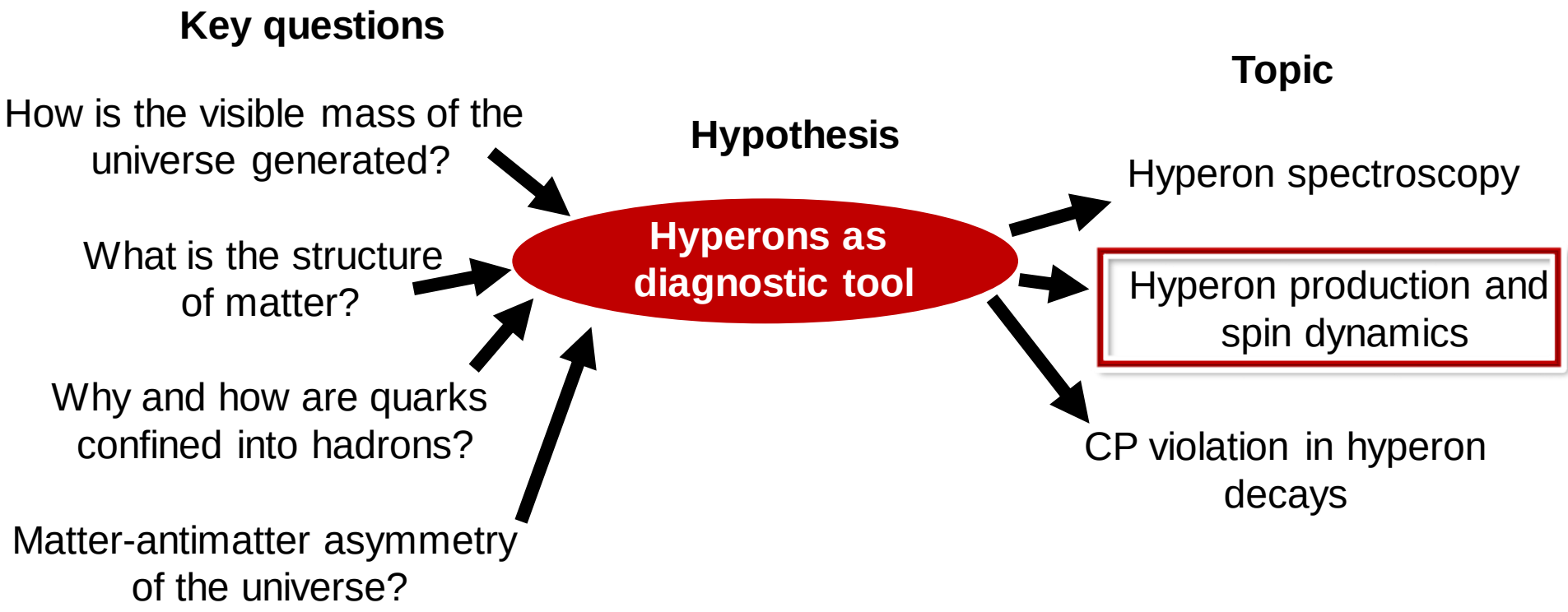
Introduction



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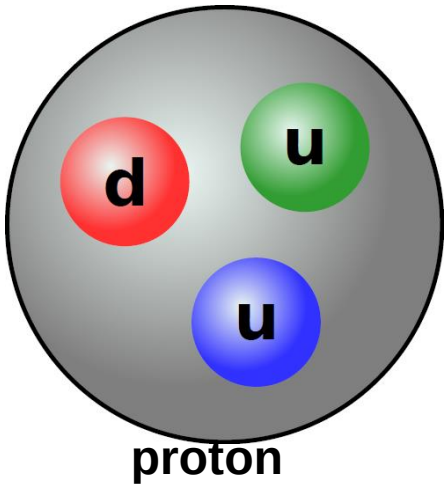
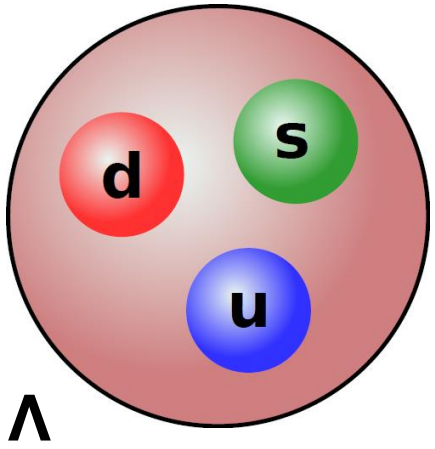
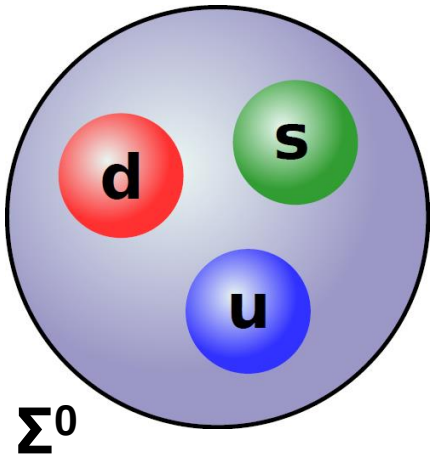
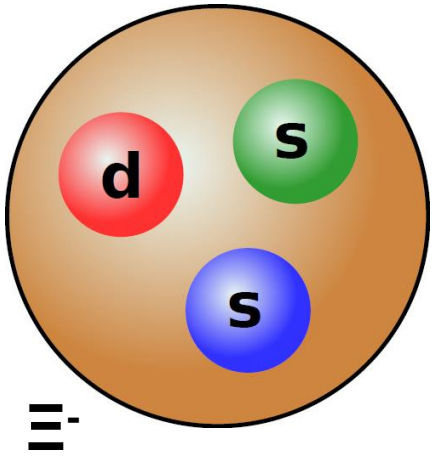
Strange and charmed hyperons

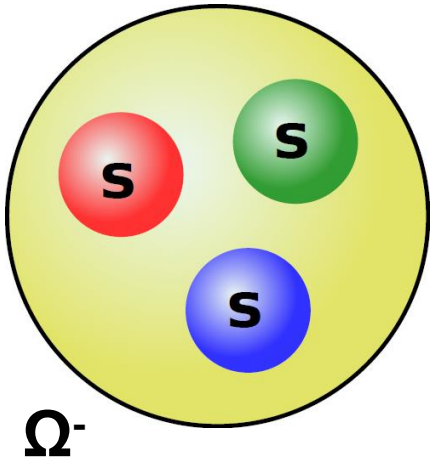
What happens if we replace one of the light quarks in the proton with one - or many - heavier quark(s)?











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Introduction

- Light quark (*u, d*) systems:
  - Highly non-perturbative interactions.
  - Relevant degrees of freedom are hadrons.
- Systems with strangeness
  - Scale: $m_s \approx 100$ MeV ~ $\Lambda_{QCD} \approx 200$ MeV.
  - Relevant degrees of freedom?
  - **Probes QCD in the confinement domain.**
- Systems with charm
  - Scale: $m_c \approx 1300$ MeV.
  - Quark and gluon degrees of freedom more relevant.
  - **By comparing strange and charmed hyperons we learn about QCD at two different energy scales.**

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Why hyperons spin dynamics?

- Reaction mechanism at different energy scales.
- The role of spin in the strong interaction.
- CP violation

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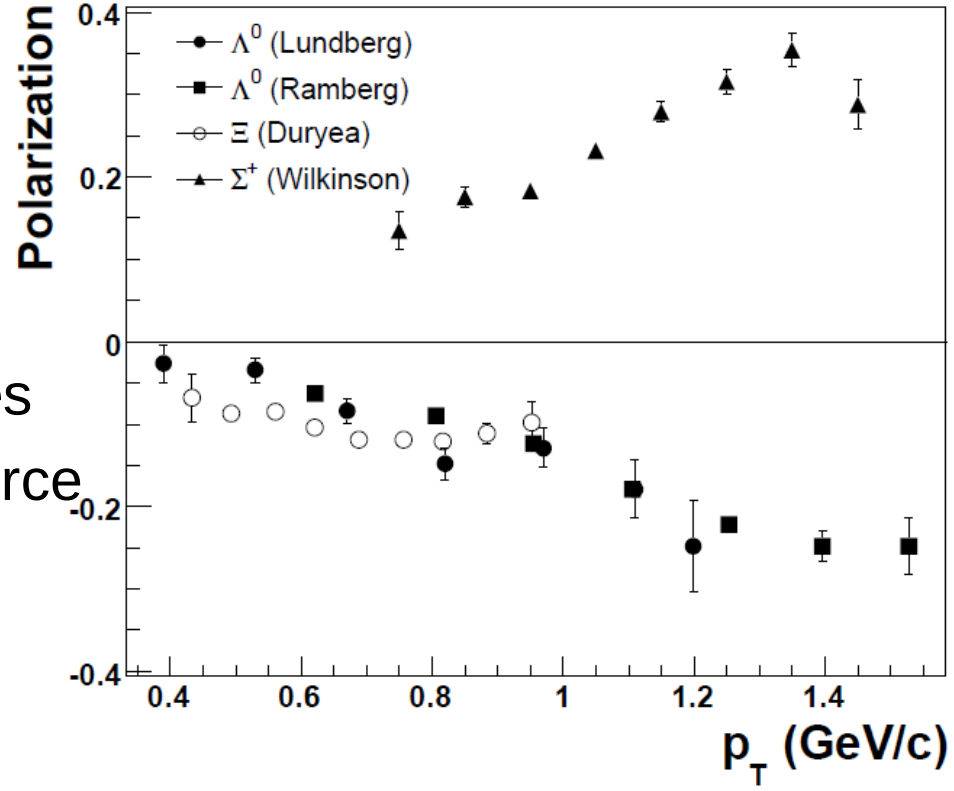
Hyperons from *pp* and *pA* reactions

- Polarization a result of interfering amplitudes.
- In hadronic reactions, many contributing sub-processes.
- High energies: total polarization should be 0.
- Data: hyperons produced polarized at high energies
  → contrast to naïve expectations.
- Many contributing amplitudes
  → difficult to pinpoint the source of polarization.



K. Heller, Colloque de Physique C6 (1990) 163

Hyperons from $\bar{p}p$ reactions

- Hyperons and anti-hyperons can be produced at low energies → fewer amplitudes contributing.
- Symmetry in hyperon and anti-hyperon observables.
- Polarization + other spin observables powerful tools for testing models of production dynamics and structure.

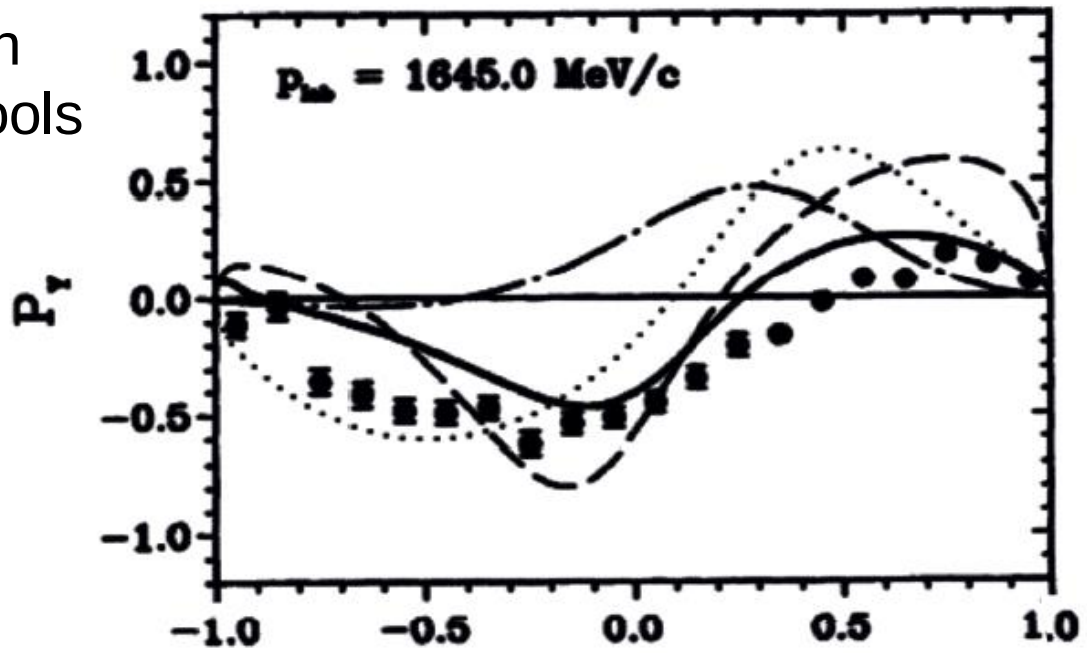


Figure from Phys. Rep. 368 (2002) 119.

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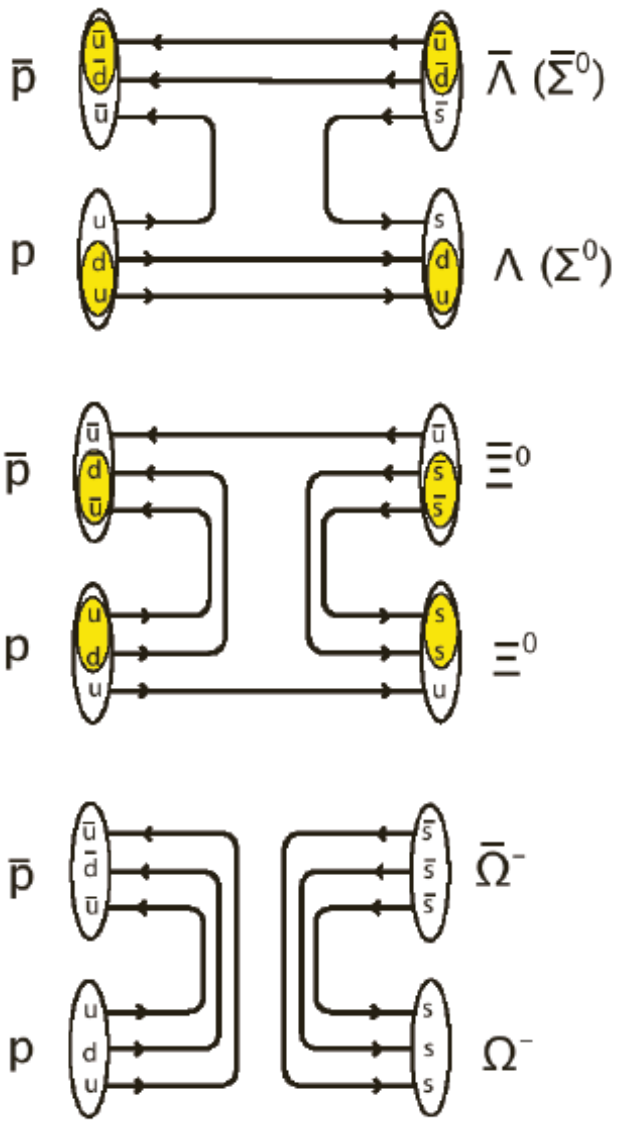
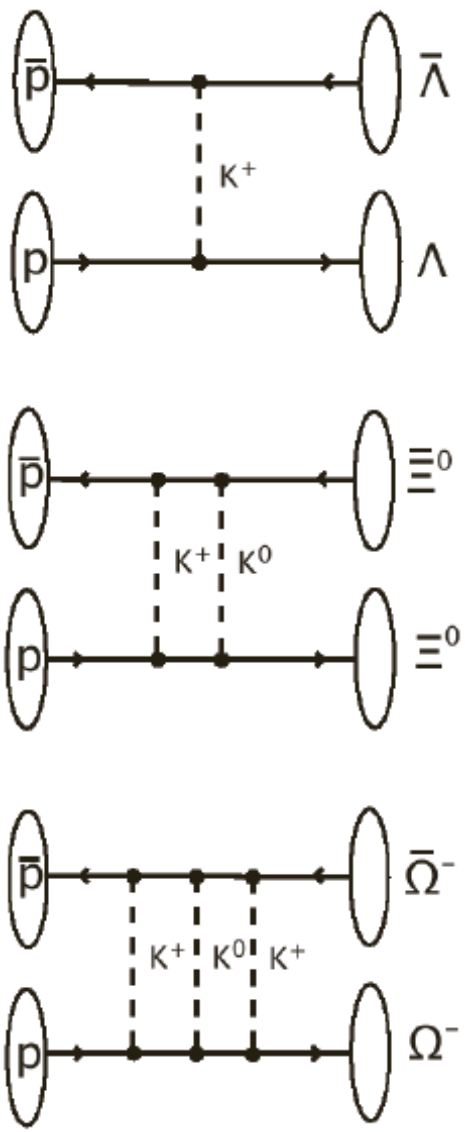
Hyperons from $\bar{p}p$ reactions





Available models based on

i) constituent quark-gluons*

ii) hadrons**

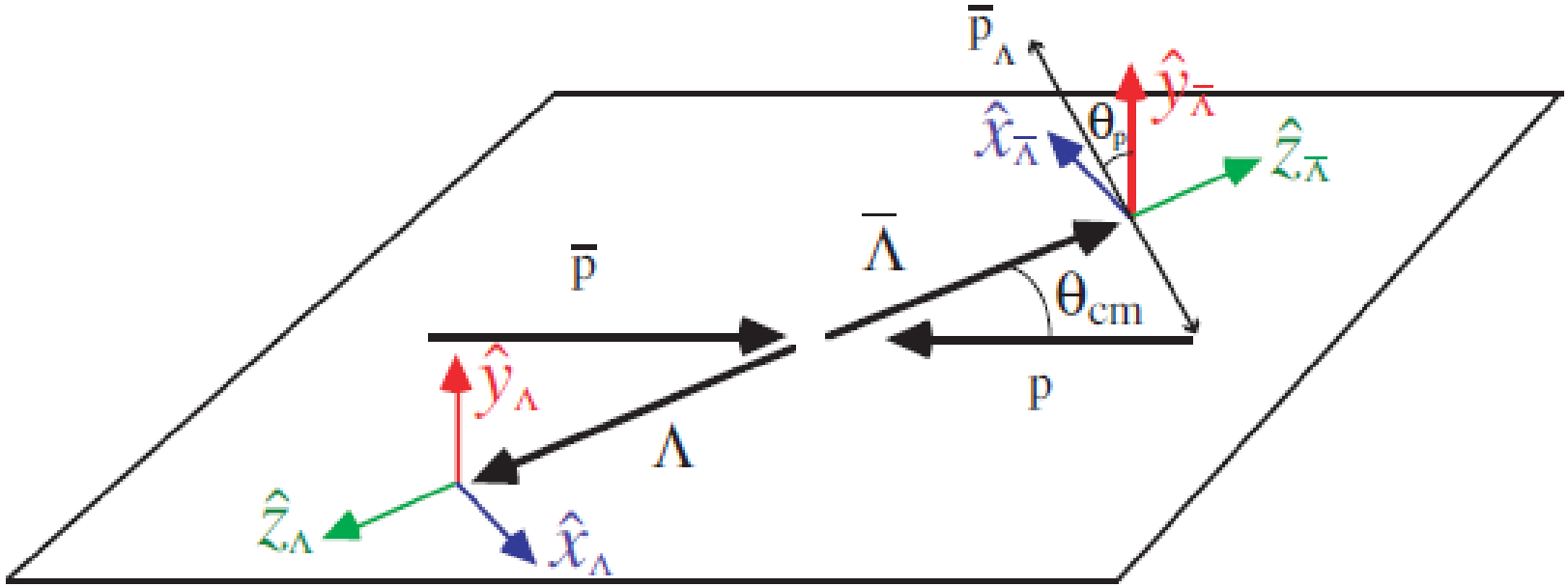
ii) a combination ***

*PLB 179 (1986) 15; PLB 165 (1985) 187; NPA 468 (1985) 669;
** PR**C** 31(1985) 1857; PLB179 (1986) 15; PLB 214 (1988) 317;
*** PLB 696 (2011) 352.

Spin observables in $\bar{p}p \rightarrow \bar{Y}Y$

- *Vector polarisation* P the most straight-forward observable for spin $\frac{1}{2}$ hyperons.

- Strong interactions: normal to the production plane (y-direction)



Spin observables in $\bar{p}p \rightarrow \bar{Y}Y$

Polarisation

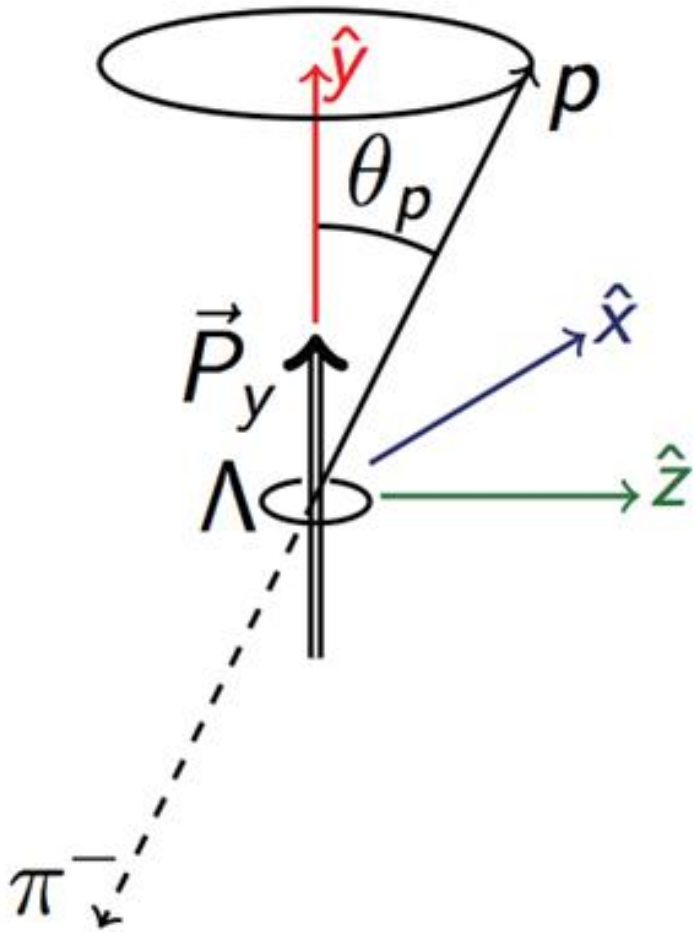
Accessible by the parity violating decay:
Decay products preferentially emitted along the spin of the hyperon.

$\Lambda \rightarrow p\pi^-$:
Proton angular distribution

$I(\cos\theta_p) = N(1+\alpha P_\Lambda \cos\theta_p)$

P_Λ : polarisation

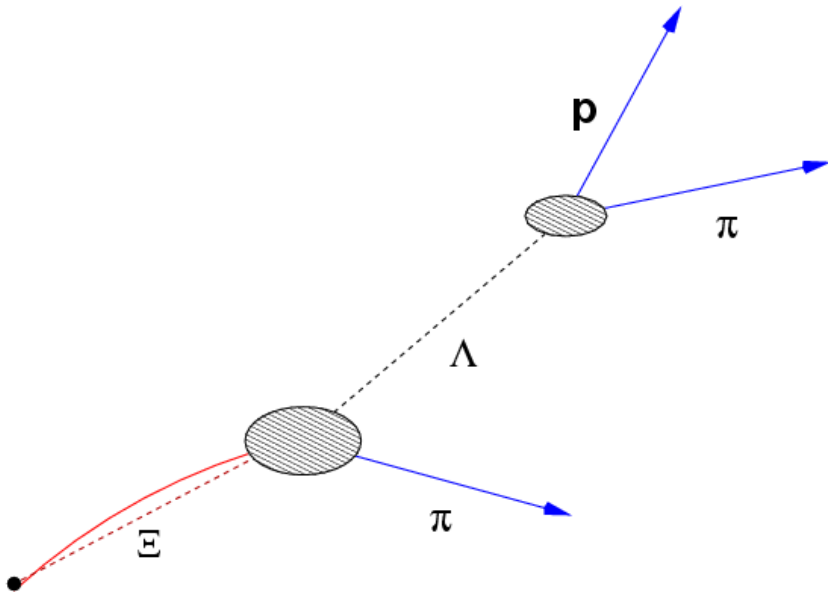
α = 0.64 asymmetry parameter



Spin observables for spin $\frac{1}{2}$ hyperons

If the decay product of the hyperon is a hyperon, *e.g.* $\Xi \rightarrow \Lambda\pi$, more information can be obtained from the decay protons of the Λ.

$$I(\theta_p, \phi_p) = \frac{1}{4\pi}\left[1 + \alpha_\Xi \alpha_\Lambda \cos\theta_p + \frac{\pi}{4}\alpha_\Lambda P \sin\theta_p (\beta_\Xi \sin\phi_p - \gamma_\Xi \cos\phi_p)\right]$$



α, β, γ decay parameters.
related to the decay amplitudes T_s and T_p

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Spin observables in $\bar{p}p \to \bar{Y}Y$

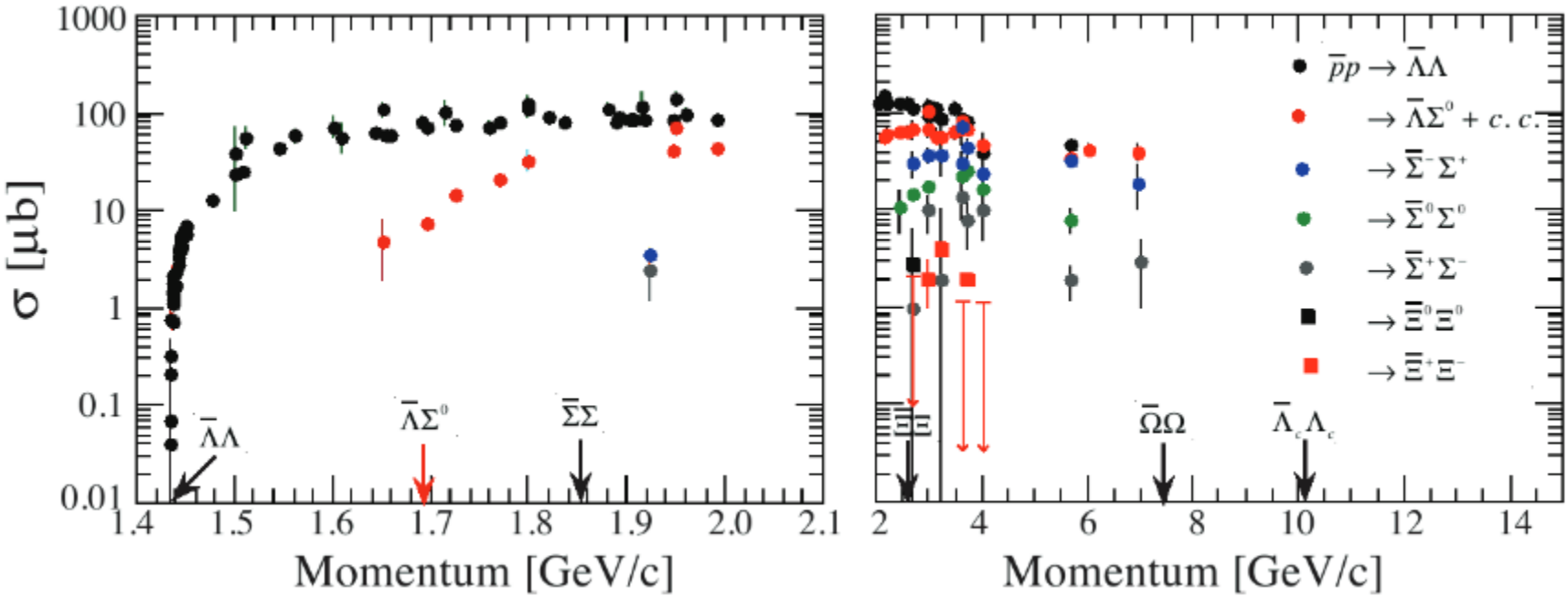
- Spin $\frac{1}{2}$ hyperons (Λ, Ξ, Λ_c) :
  - Polarisation.
  - Spin correlations and singlet fraction:

$$SF = \frac{1}{4}(1 + C_{xx} - C_{yy} + C_{zz})$$

- Spin $\frac{3}{2}$ hyperons into spin $\frac{1}{2}$ hyperons ($\Omega \to \Lambda K$):
  - 7 polarisation parameters + degree of polarisation.

$$d(\rho) = \sqrt{\sum_{L=1}^{2j} \sum_{M=-L}^{L} (r_M^L)^2}$$

Previous measurements of $\bar{p}p \to \bar{Y}Y$



- A lot of data on $\bar{p}p \to \bar{\Lambda}\Lambda$ near threshold, mainly from PS185 at LEAR*.
- Very scarce data bank above 4 GeV.
- Only a few bubble chamber events on $\bar{p}p \to \bar{\Xi}\Xi$
- No data on $\bar{p}p \to \bar{\Omega}\Omega$ nor $\bar{p}p \to \bar{\Lambda}_c\Lambda_c$

* See *e.g.* T. Johansson, AIP Conf. Proc. Of LEAP 2003, p. 95.

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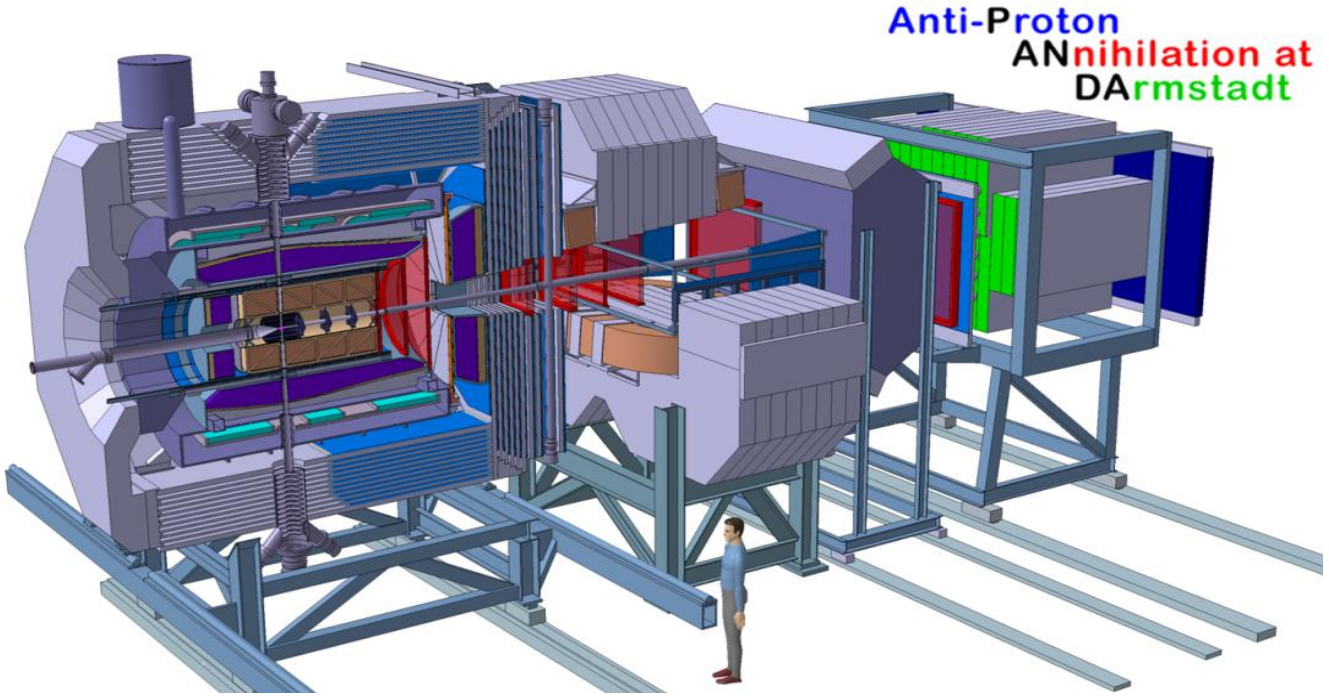
Simulations for Day One



$$\bar{p}p \rightarrow \bar{\Lambda}\Lambda,\ \bar{\Sigma}^{-}\Sigma^{+},\ \bar{\Sigma}^{0}\Sigma^{0},\ \bar{\Sigma}^{-}\Sigma^{+},\ \bar{\Xi}^{0}\Xi^{0},\ \bar{\Xi}^{+}\Xi^{-},\ \bar{\Omega}^{+}\Omega^{-},\ \bar{\Lambda}_{c}^{-}\Lambda_{c}^{+}$$

$p\pi^{-}$	$p\pi^{0}$	$\Lambda\gamma$	$n\pi$	$\Lambda\pi^{0}$	$\Lambda\pi$	ΛK	$\Lambda\pi$
64%	52%	$\approx 100\%$	$\approx 100\%$	$\approx 100\%$	$\approx 100\%$	68%	$\approx 1\%$

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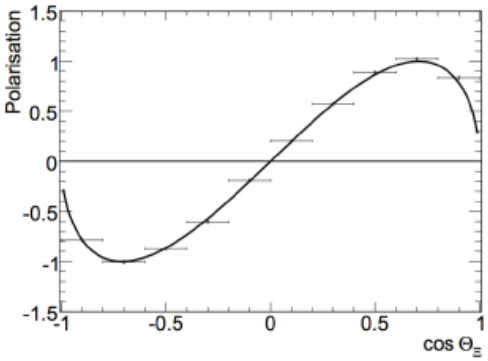
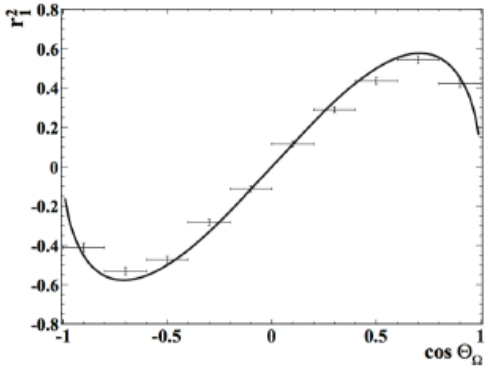
Previous results

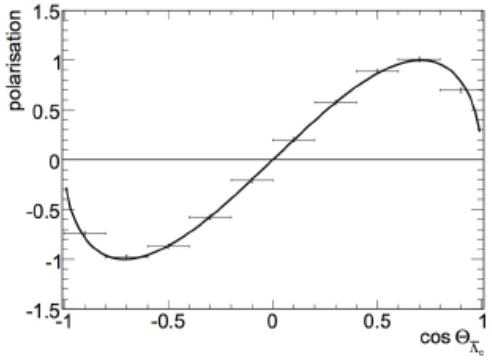
Using a simplified Monte Carlo framework:

$p_{\overline{p}}$ (GeV/c)	Reaction	σ (μb)	Eff (%)	Decay	BR (%)	Rate
1.64	$\overline{p}p \to \overline{\Lambda}\Lambda$	64	10	$\Lambda \to p\pi^-$	64	28 s^{-1}
4.0	$\overline{p}p \to \overline{\Xi}^+\Xi^-$	$\sim$2	20	$\Xi^- \to \Lambda\pi^-$	$\sim$ 100	2 s^{-1}
12.0	$\overline{p}p \to \overline{\Omega}^+\Omega^-$	$\sim$0.002*	$\sim$30	$\Omega^- \to \Lambda K^-$	68	$\sim$4 h^{-1}
12.0	$\overline{p}p \to \overline{\Lambda}_c\Lambda_c$	$\sim$0.1*	$\sim$30	$\Lambda_c \to \Lambda\pi^+$	$\sim$ 1	$\sim$2 d^{-1}

All measurements are exclusive!







Erik Thomé, PhD thesis, Uppsala University
Sophie Grape, PhD thesis, Uppsala University

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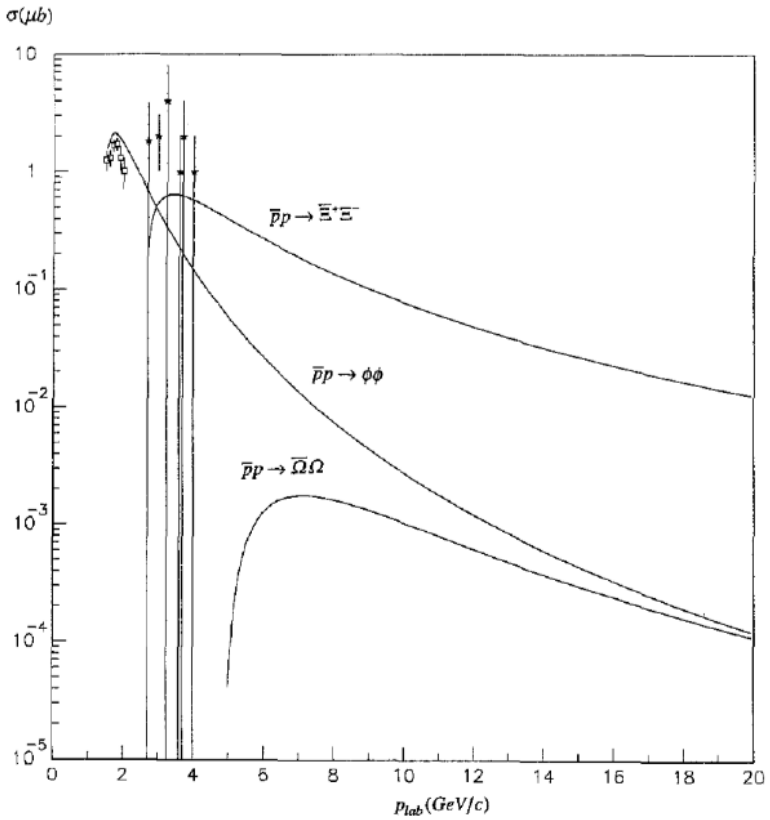
Ongoing simulations



During first two years of data taking: 80 days beam time to X(3872) scan

- X(3872) scan operate at $p_{\overline{p}} = 7.0$ GeV/c
- Above production threshold of $\overline{\Omega}\Omega$ and $\overline{\Xi}\Xi$

Theoretical prediction shows:

- Cross section of $\overline{\Omega}\Omega$ larger at 7.0 than 12.0 GeV/c
- Cross section of $\overline{\Xi}\Xi$ smaller

Work in progress by W. Ikegami-Andersson

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Ongoing simulations

- The $\bar{p}p \rightarrow \overline{\Lambda}\Lambda$ reaction at 1.64 GeV/c
  - Spin observables for PWA
- The $\bar{p}p \rightarrow \overline{\Xi^+}\Xi^-$ at 7 GeV/c
  - Total cross sections
  - Angular distributions
  - Polarisation and spin observables
- The $\bar{p}p \rightarrow \overline{\Omega^+}\Omega^-$ at 7 GeV/c
  - Total cross section
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  - Polarisation parameters
- Background studies

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For the Day One paper

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Ongoing simulations

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  - Spin observables for PWA
- The $\bar{p}p \rightarrow \overline{\Xi^+}\Xi^-$ at 7 GeV/c
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  - Angular distributions
  - Polarisation parameters **For separate paper**
- Background studies

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Summary and Outlook

- Production of strange and charmed hyperons probe QCD at two different energy scales.
- The role of spin in the strong interaction can be explored with hyperon spin observables.
- Ongoing simulation studies for verifying old results and testing new observables.