JÜLICH
FORSCHUNGSZENTRUM

Final State Interactions and Polarization Observables in the Process $\vec{p}p \longrightarrow pK^{+}\Lambda$

BEACH 2012 | Matthias Röder for the COSY-TOF Collaboration

Motivation

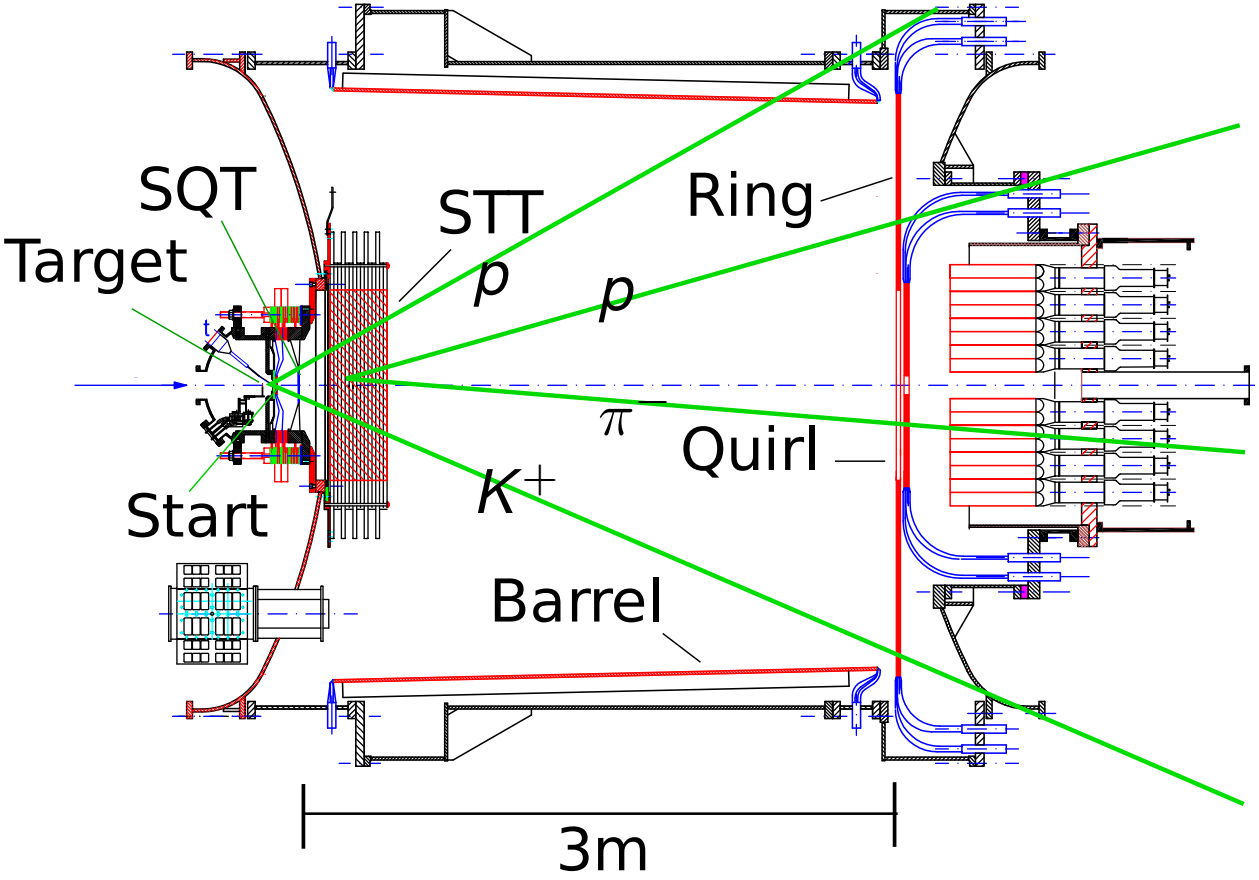
pΛ Final State Interactions

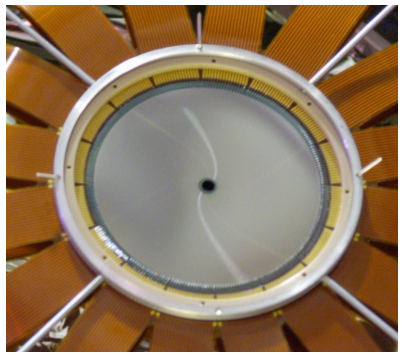
- Study Hyperon-Nukleon Interactions:
  - Role of strangeness in hadron physics
  - Test SU(3) flavour symmetry in interactions
  - Prequisite sudies for hypernuclei
  - Astrophysics: Hyperon stars, stability of neutron stars
- Described by potential models
  and chiral effective field theory
- Polarized beam allows us the determination
  of the spin triplet scattering length (a_t)

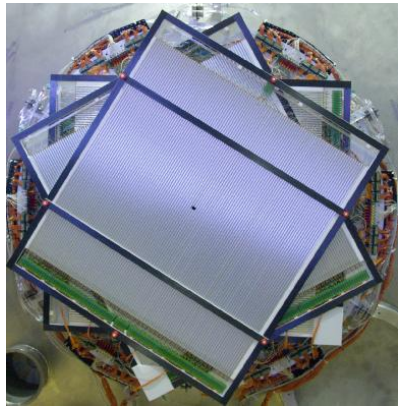
Λ Polarization Observables

- Study the $pK^+\Lambda$ production mechanism
- Example: Polarized beam and self analyzing Λ decay
  allow to determine the Λ-depolarization $\Rightarrow \pi$ or K exchange

The COSY-TOF Experiment

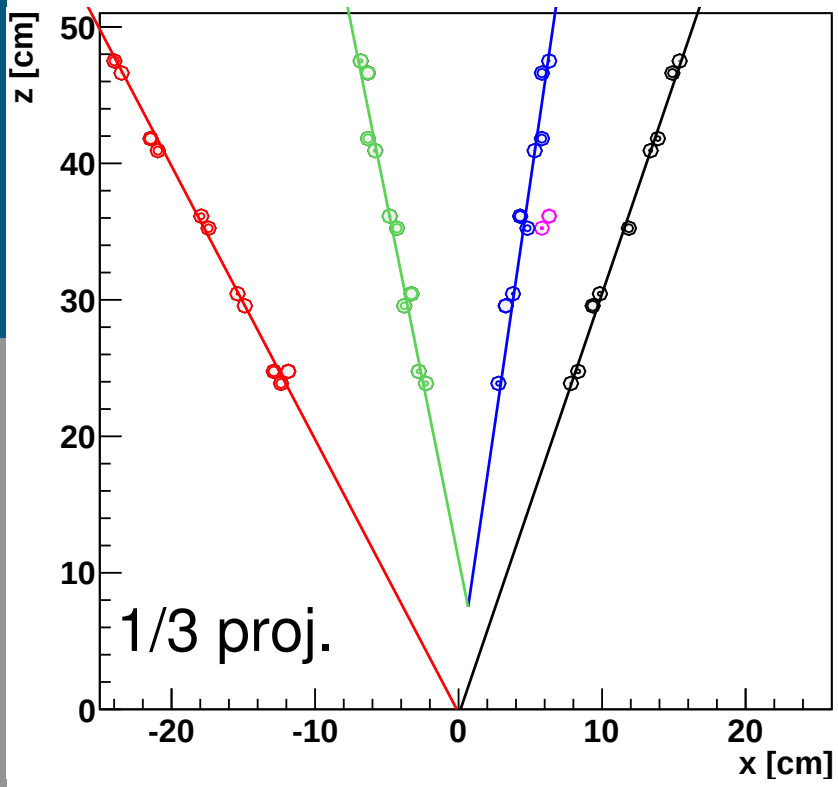


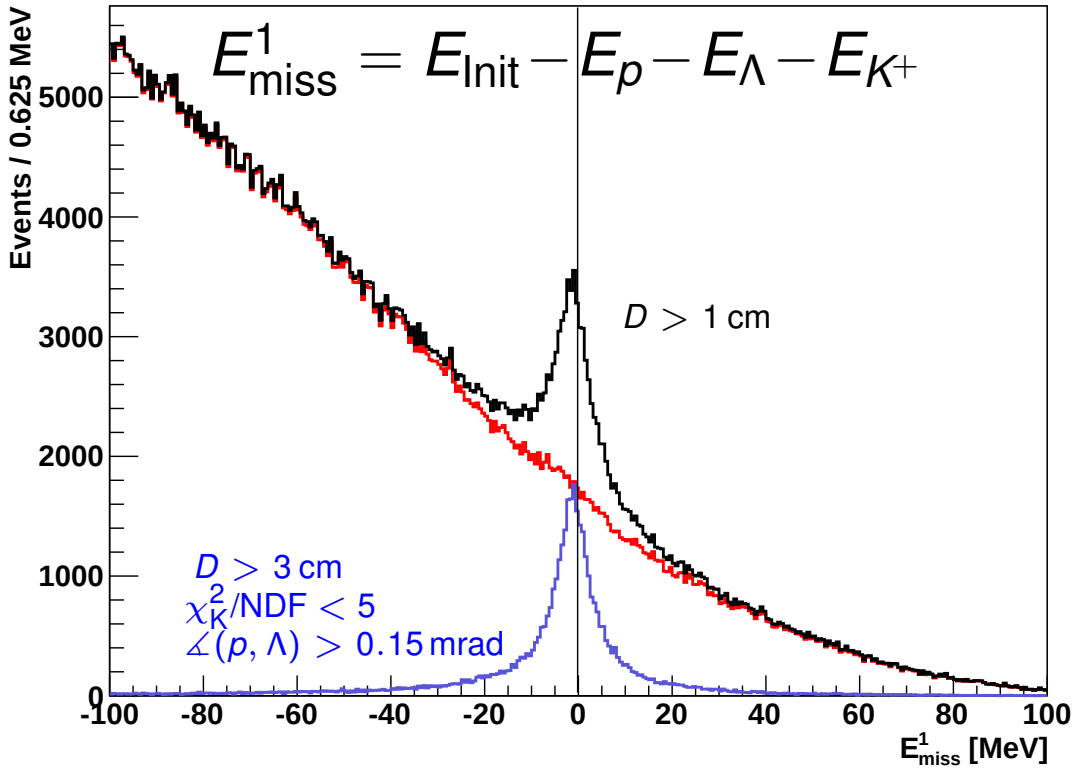




- Low mass: $X/X_0 \approx 0.02$ before stop detectors
- Scintillators for timing and dE/dx measurement
- Straw Tube Tracker (STT) and Silicon Quirl (SQT) for precise track reconstruction

$pK^+\Lambda$ Event Reconstruction and Selection

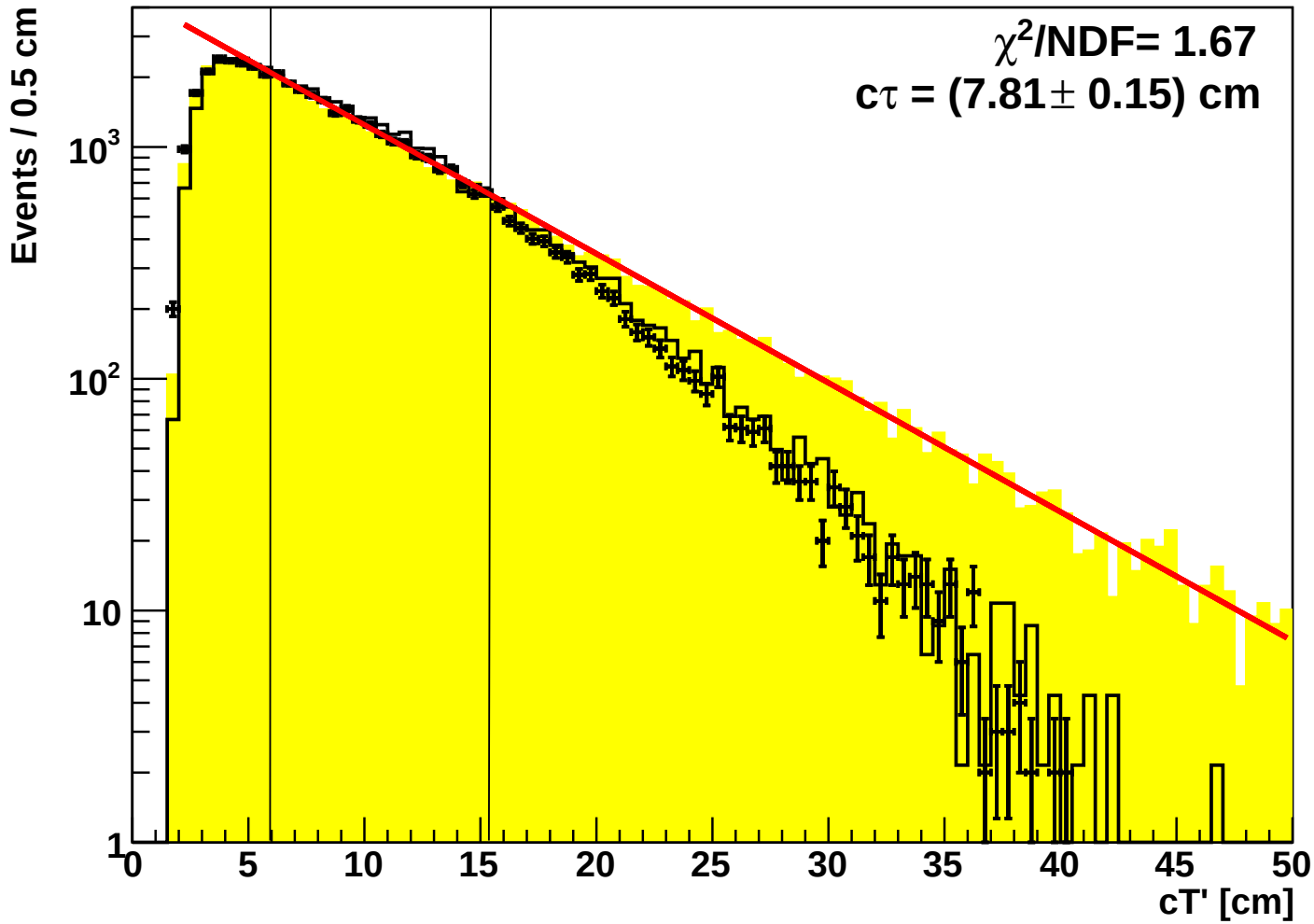




- Straw drift times $\xrightarrow{\textit{calibration}}$ track-wire distances
- Delayed vertex with primary vertex in decay plane
- Complete kinematic fit to track-wire distances

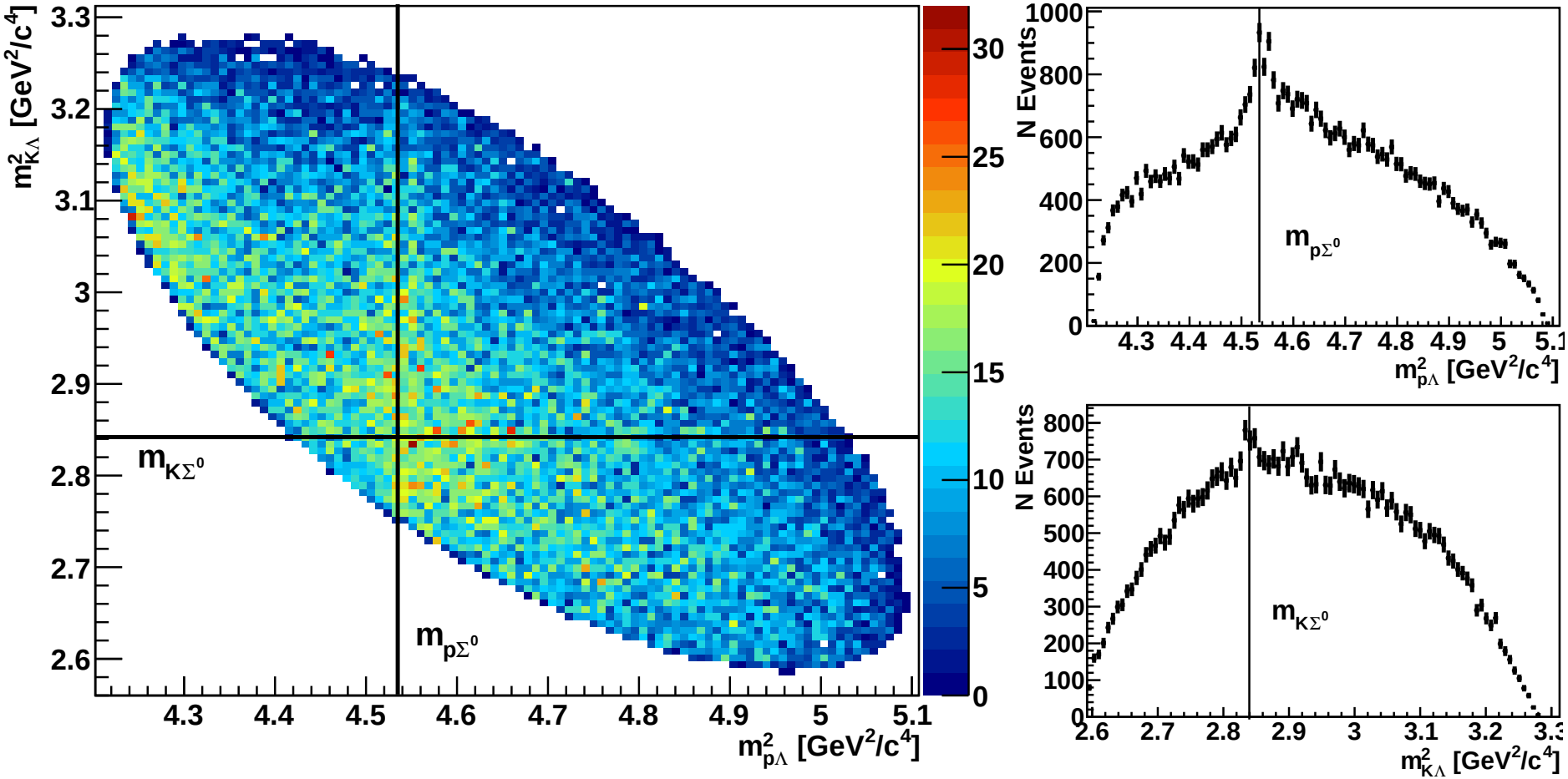
$\Rightarrow$ 42 000 events from 6 days beam time
(MC study: 20% reconstruction efficiency)

Event Sample Check: Λ Decay Length



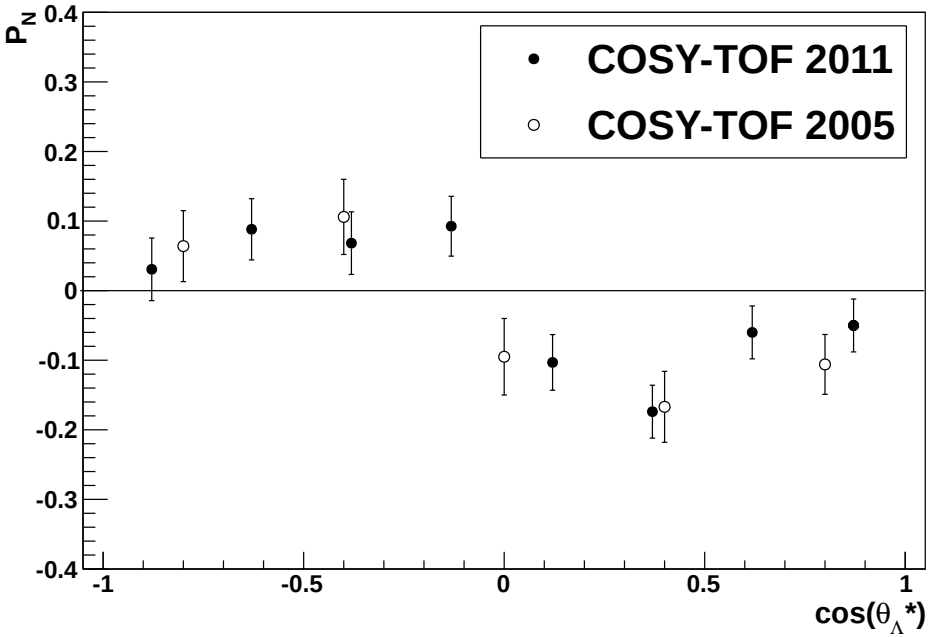
- Data and MC in good quantitative agreement
- 100% acceptance marked with black lines
- Correct lambda lifetime ⇒ ”low” background contamination

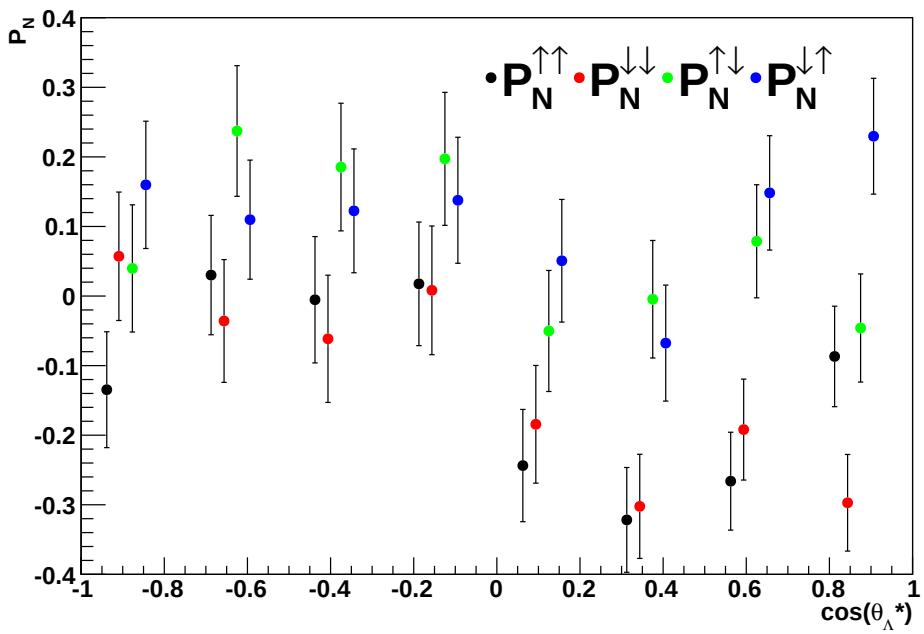
$pK^+\Lambda$ Dalitz Plot $p_{beam} = 2.95\,\mathrm{GeV}/c$



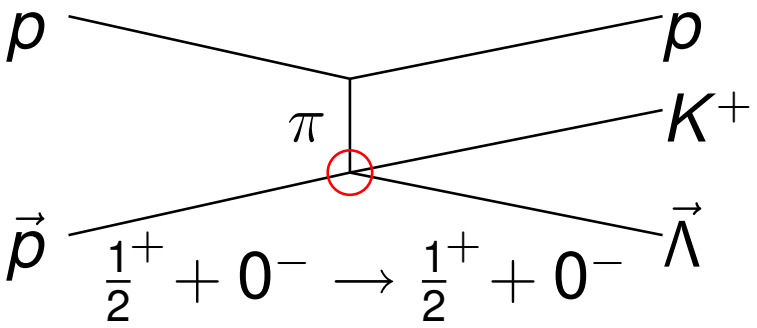
- Full kinematic acceptance and $\sigma_m \approx 1\,\mathrm{MeV}/c^2$ resolution
- Cusp structure at $p\Sigma^0$ threshold in $m_{p\Lambda}$! ($p\Lambda$-$p\Sigma$ coupling)
- Cusp structure at $K\Sigma^0$ threshold in $m_{K\Lambda}$?!
- FSI and N^*-resonances can explain structure underneath

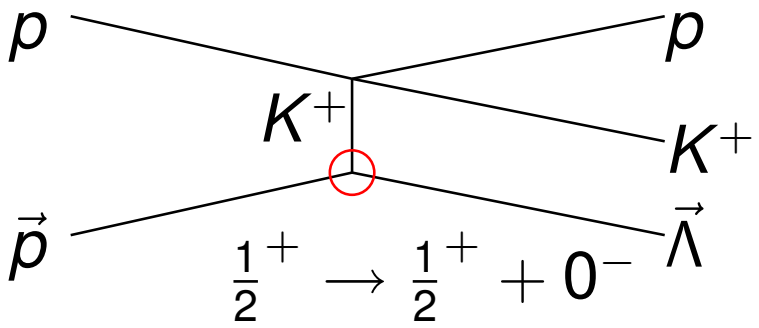
Λ Polarization P_N





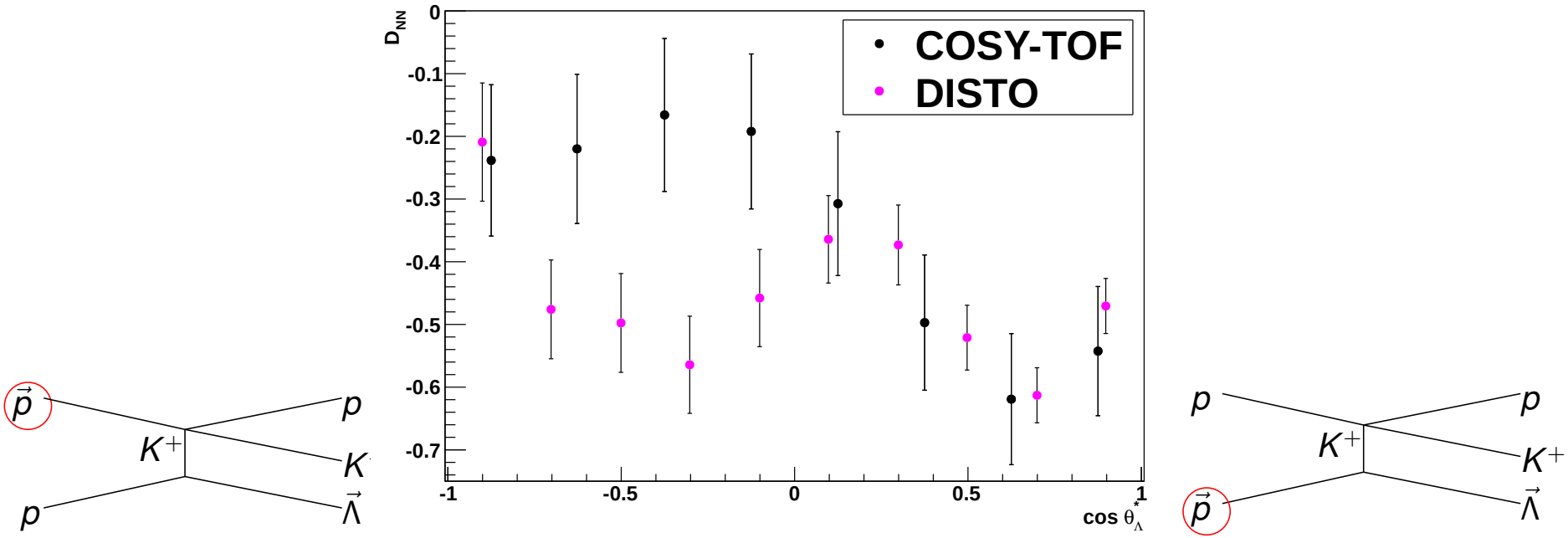
- Self analyzing Λ decay ⇒ Λ polarization (P_N)
- 61% polarized beam ⇒ Λ depolarization (D_{NN}):





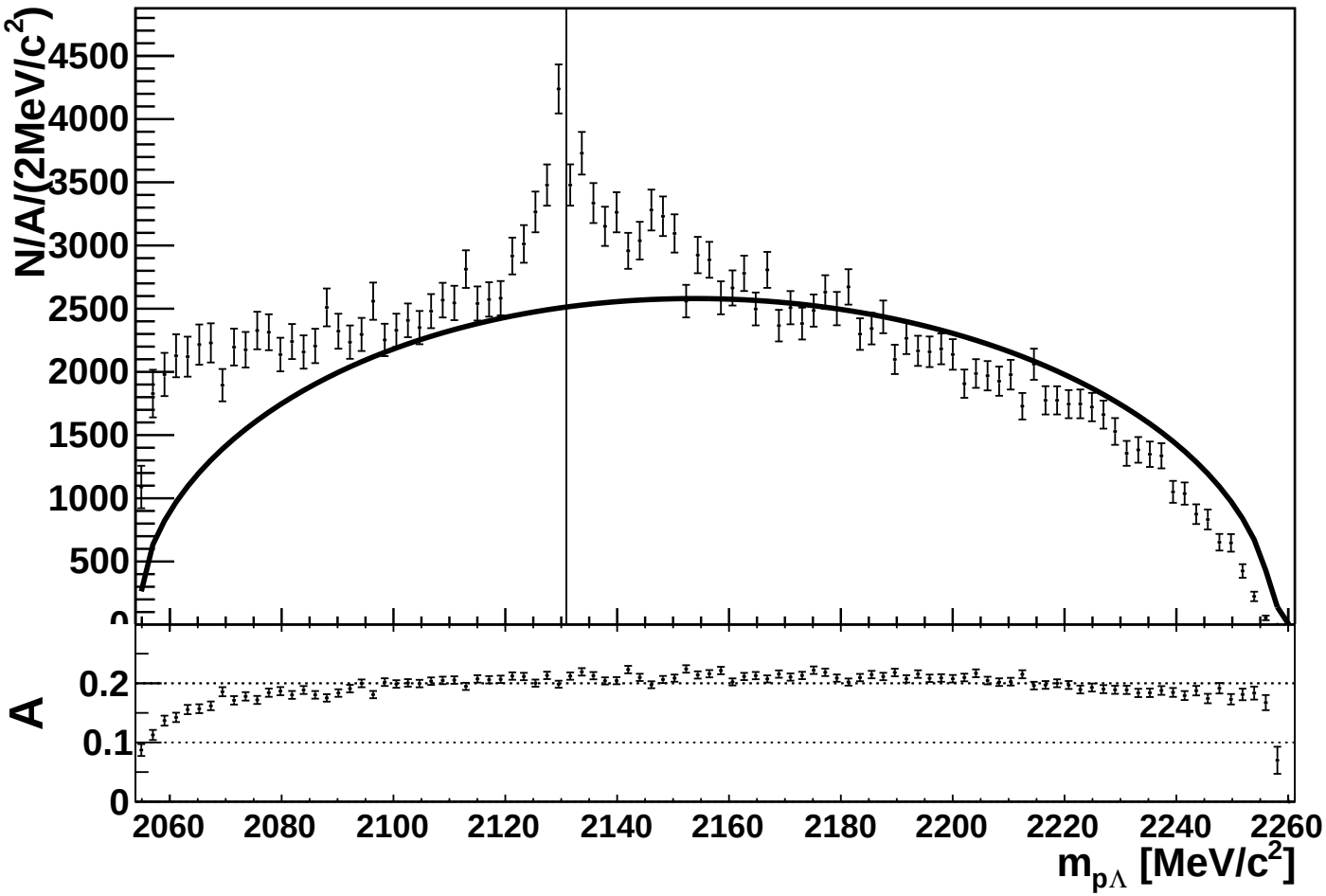
⇒ Spin-Flip

Λ Depolarization



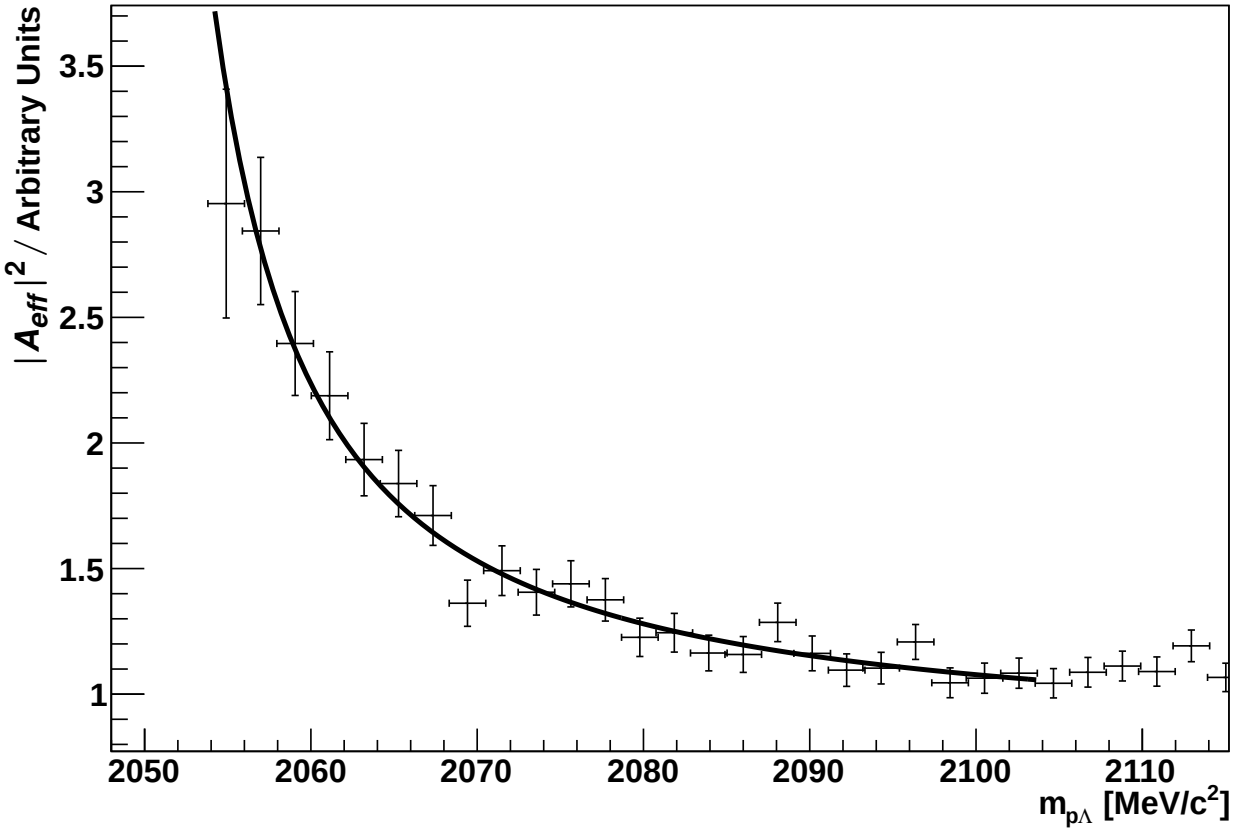
- D_{NN} forward agrees with DISTO M.Maggiora Nucl.Phys. A691
  - ⇒ Kaon exchange dominates production process in the Laget Model (N^*-Resonances neglected)
- Differences for backward Λs
  - Trend to zero expected from gluon-exchange models
- More data needed

pΛ Invariant Mass Spectrum



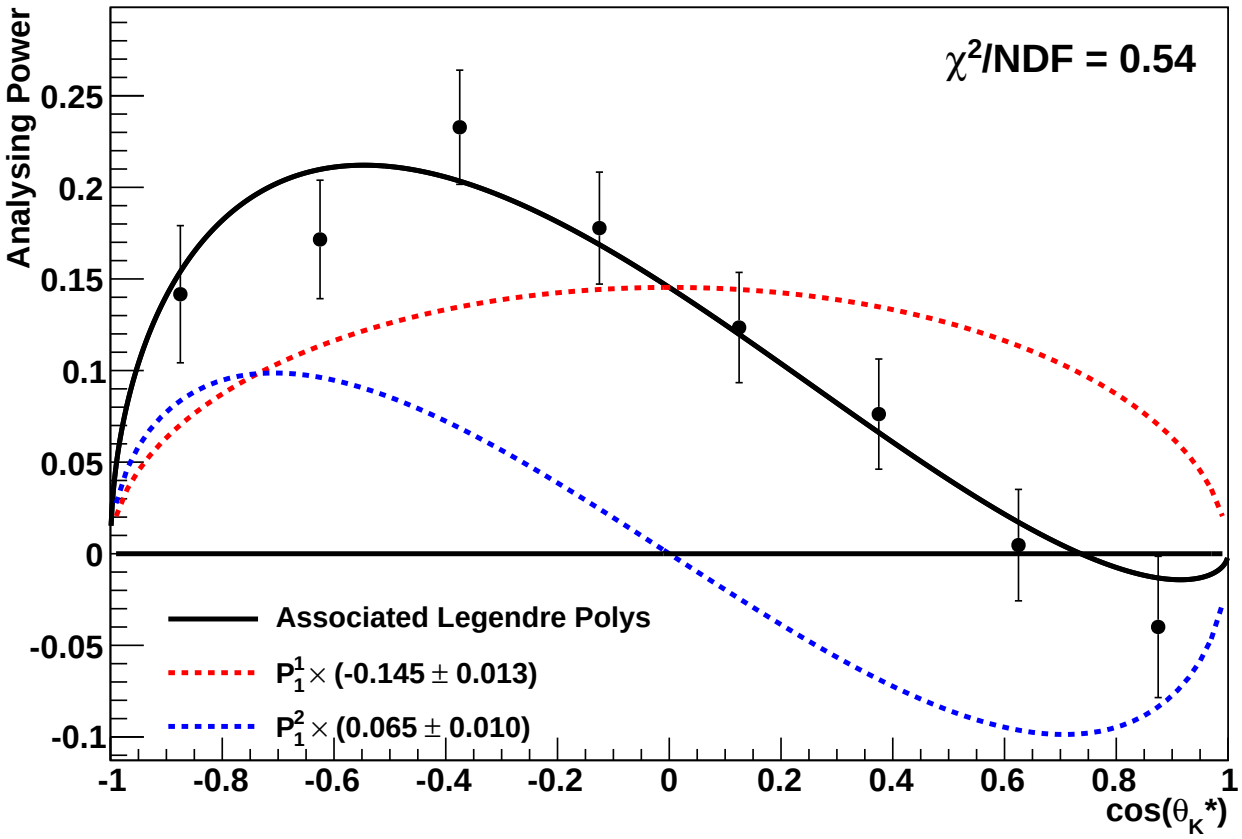
- Resolution $\sigma \approx 1.1\,\mathrm{MeV}/c^2$
- Cusp at $p\Sigma^0$ threshold (shape?, position?, strength?)
- pΛ final state interaction at low $m_{p\Lambda}$

pΛ Final State Interactions



- $\frac{1}{|\vec{p}_p - \vec{p}_\Lambda|} \frac{d\sigma^2}{dm_{p\Lambda} d\Omega} = |A_{eff}(m_{p\Lambda})|^2 \propto$ effective pΛ scattering length
- Fit the shape of the effective scattering amplitude
  $\Rightarrow$ Effective pΛ scattering length $a_{\text{eff}} = (-1.28 \pm 0.11 \pm 0.3)\ fm$,
- Idea: $|A_t|^2 \propto K^+$ P wave (in FSI region)

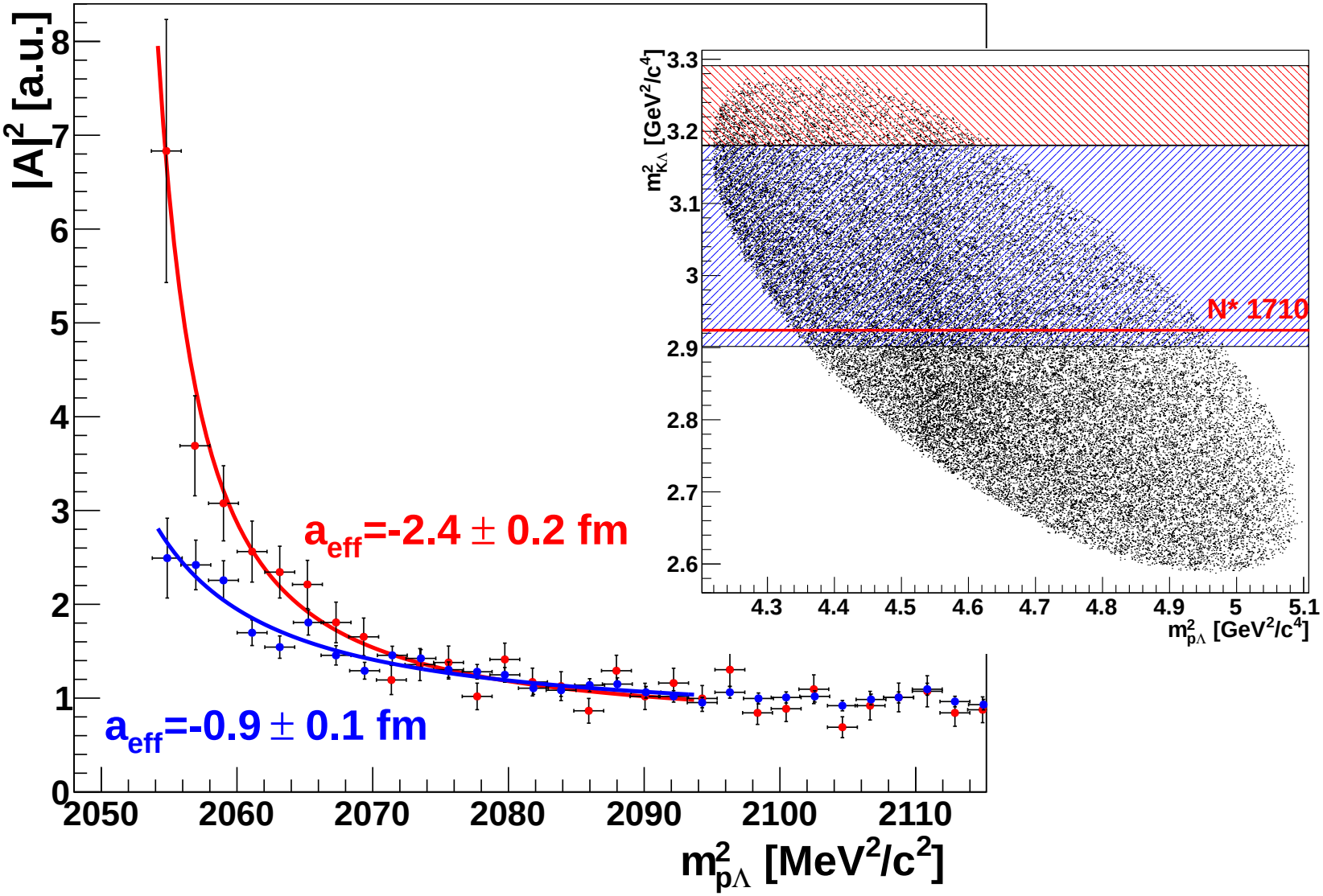
K^+ Analyzing Power



- Kaon analyzing power for full $m_{p\Lambda}$ range
- Partial wave analysis with symmetric (S*P waves) (red) and asymmetric (S*D waves) (blue) contributions
- Symmetric part only from $p\Lambda$ spin triplet scattering

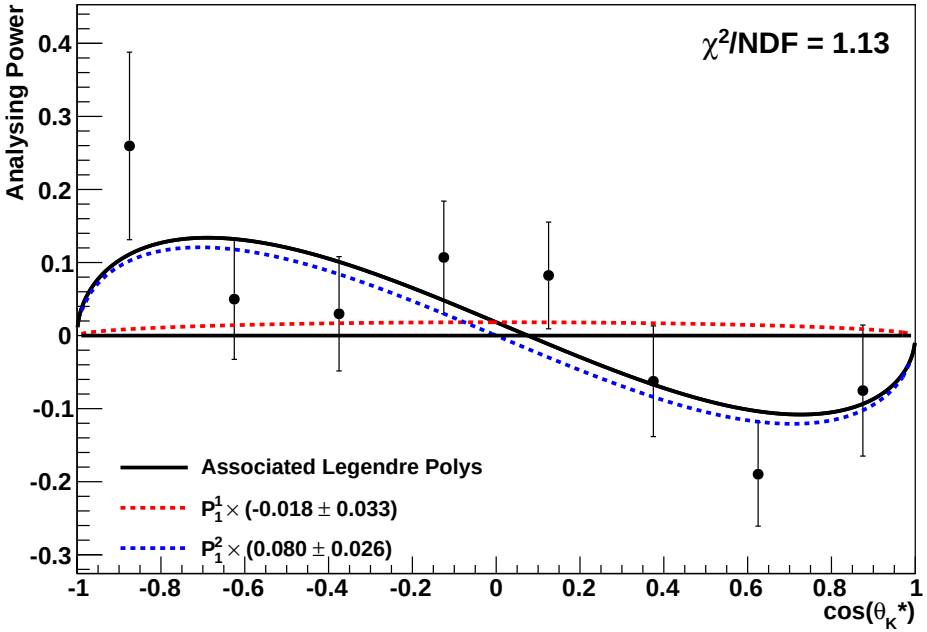
  $\Rightarrow$ Use for extraction of spin triplet scattering length

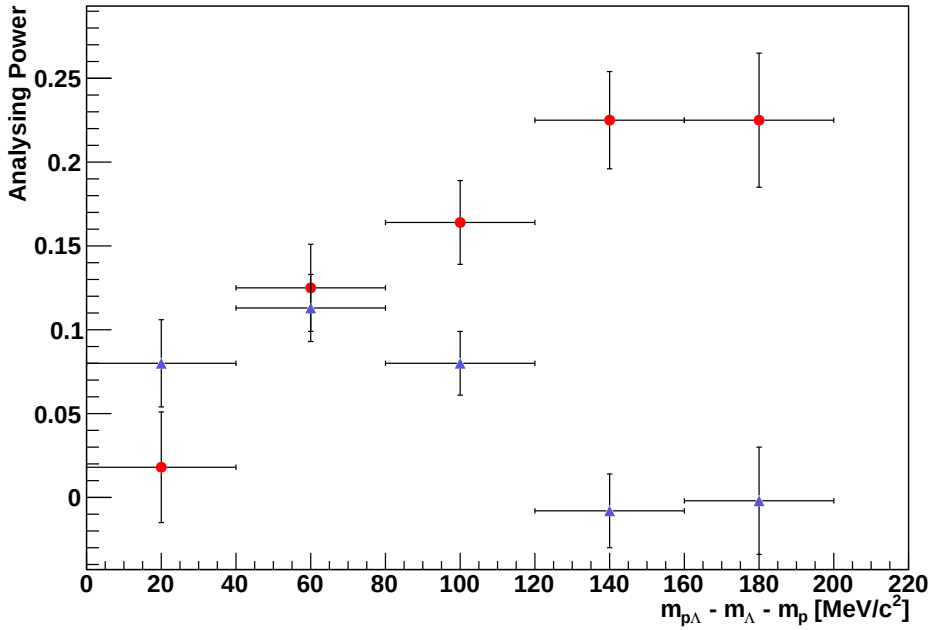
Systematic Effect of N^* Resonances



- Full kinematical acceptance reveals N^* effects
- Result matches predictions: $a_t \approx 1.8$ fm, $a_s \approx 2.4$ fm ($_\Lambda H^3$!)
- Next step: Model the $m^2_{k\Lambda}$ dependence of systematics

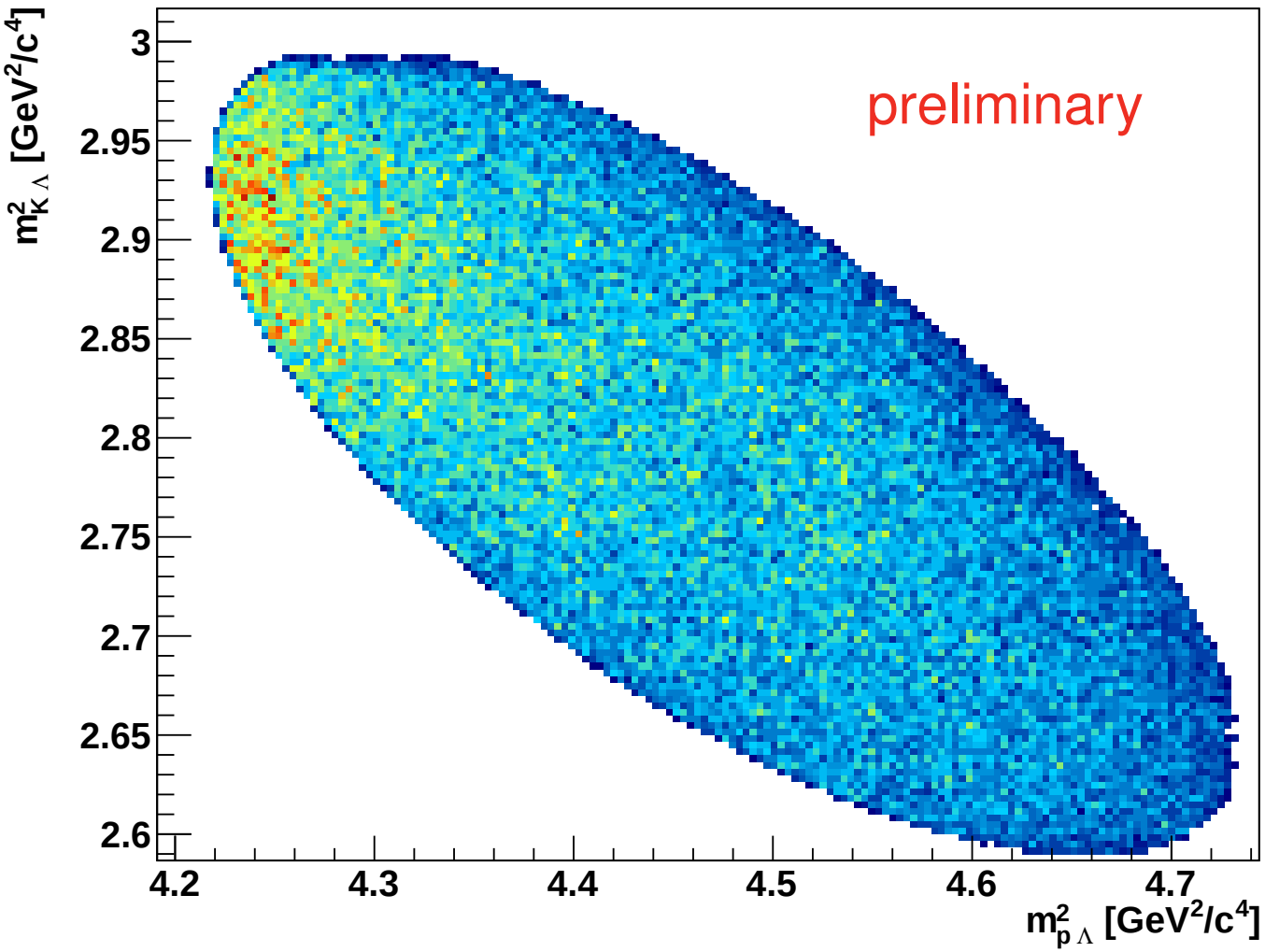
K^+ Analyzing Power: $m_{p\Lambda}$ Dependence





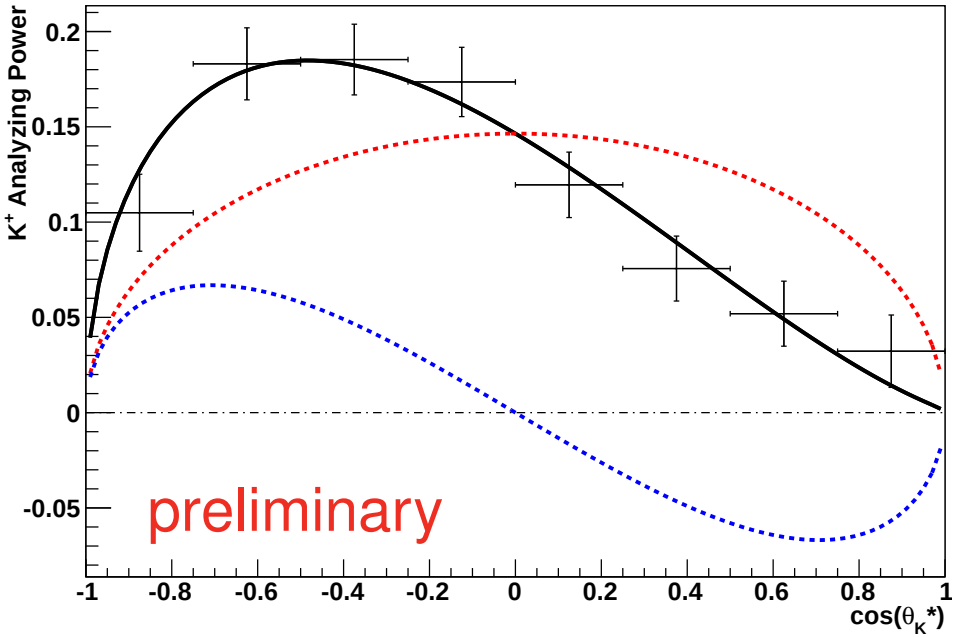
- $m_{p\Lambda} < m_0 + 40\,\mathrm{MeV}/c^2$: Analyzing power $< 11\%$ (3σ)
  - $\Rightarrow$ High statistics needed for scattering length determination
- This dependence on $m_{p\Lambda}$ is unexpected
  - Consistent with no spin triplet scattering at all [HIRES]
  - Other explanation: absence/cancellation of P wave
- Measurement with better statistics is important

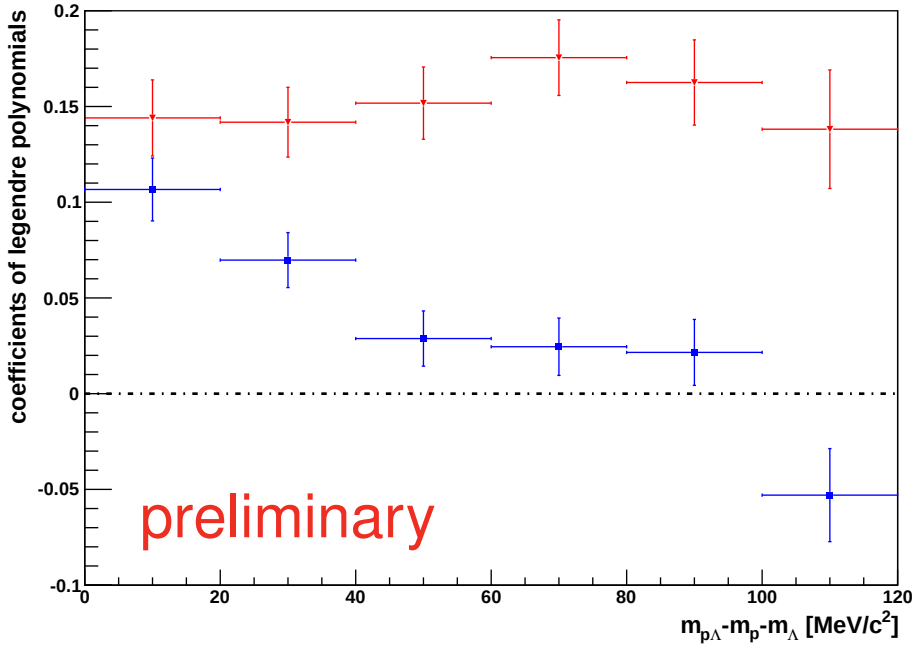
$pK^+\Lambda$ Dalitz Plot $p_{\text{beam}} = 2.70\,\text{GeV}/c$



- Measured at $p_{\text{beam}} = 2.70\,\text{GeV}/c$
- FSI and phasespace dominate
  - $\Rightarrow$ Cusp strength energy dependent (Not a phasespace effect)
  - $\Rightarrow$ Ideal beam momentum for FSI studies

K^+ Analyzing Power: $m_{p\Lambda}$ Dependence
$p_{\text{beam}} = 2.70\,\text{GeV}/c$





- $m_{p\Lambda} < m_0 + 20\,\text{MeV}/c^2$: Analyzing power $\approx 15\%$
  $\Rightarrow$ scattering length determination in progress
- Effect of N^* will be studied at different beam momenta

Conclusions and Outlook

Conclusions

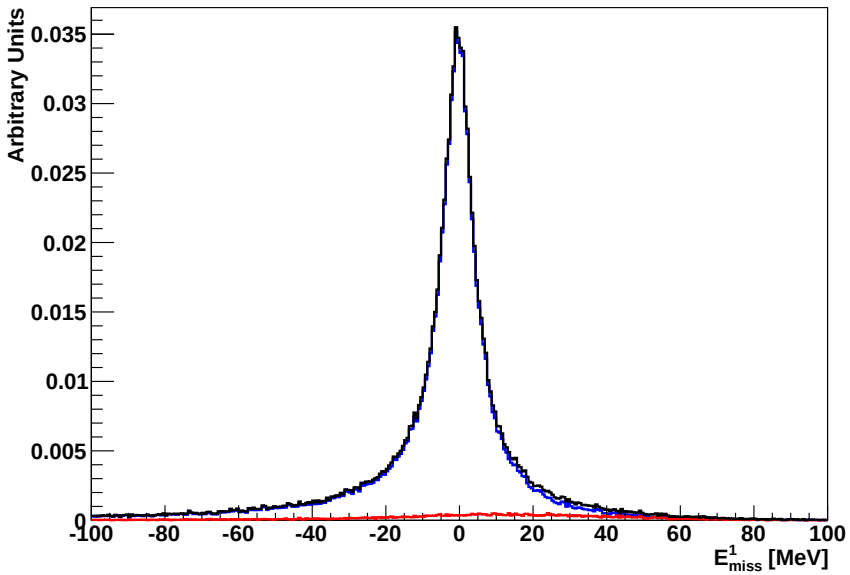
- COSY-TOF measures $\vec{p}p \rightarrow pK^+\Lambda$ kinematically complete with high precision and polarized beam
- Determined Λ polarization observables especially the Λ depolarization
- Determined the effective $p\Lambda$ scattering length
  - Studied systematic effects of N^* resonances
  - Discovered an unexpected behavior of K^+ analyzing power

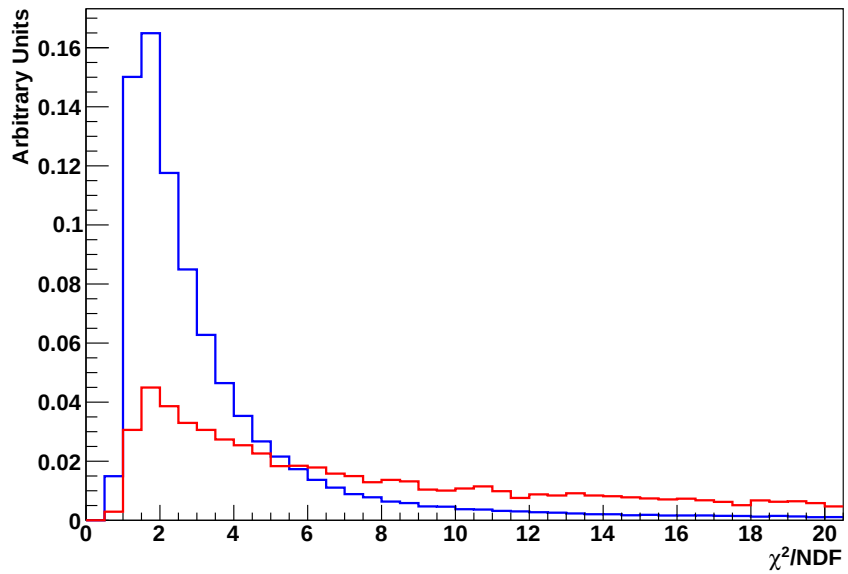
Outlook

- Upcoming: 6 weeks beam time at 2.95 and 3.3 GeV/c
  - Advanced studies of the cusp structures
  - Many more polarization observables available
- Determine the spin-triplet scattering length @2.7 GeV/c^2 with known systematic effect of N^* resonances

BACKUP

$pK^+\Sigma^0$ Background Study





- $pK^+\Sigma^0$ is broadly distributed under the signal peak
- χ^2 of kinematic fit reduces contamination to $< 5\%$