Inclusive and Semi–Inclusive Double Spin Asymmetries at COMPASS

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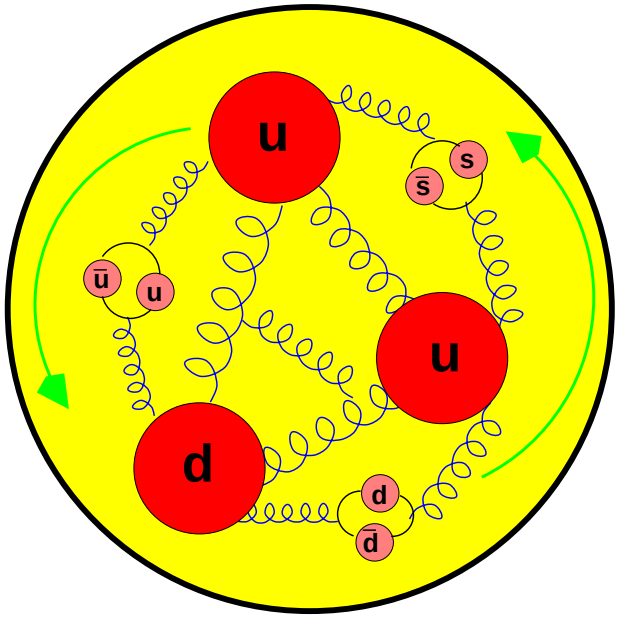
on behalf of the COMPASS Collaboration

Outline of the Talk

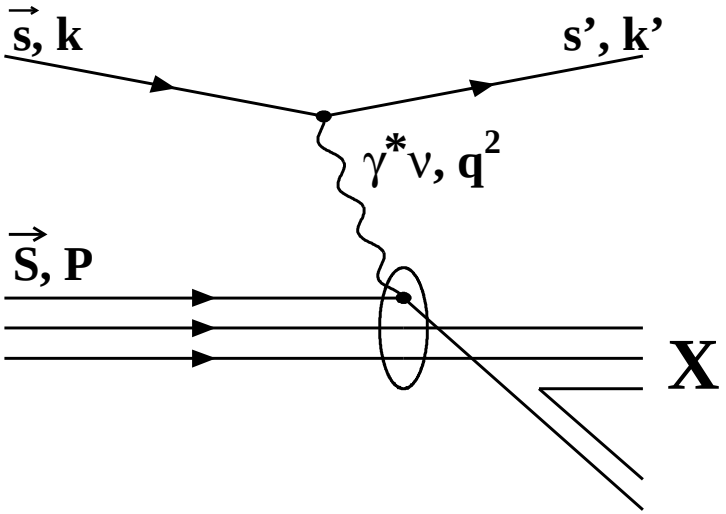
- Double spin asymmetries and quark helicities
- The COMPASS–experiment
- The measurement of the inclusive asymmetry A_1
- The status of analysis of the semi-inclusive asymmetry
- Summary

The Spin of the Nucleon

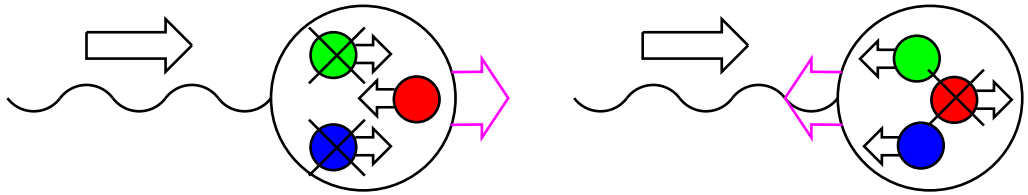


$$
\begin{aligned}
S_N &= \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g \\
\Delta\Sigma &= \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s} \\
\Delta q &:= q^{\uparrow\uparrow} - q^{\uparrow\downarrow} \qquad q := q^{\uparrow\uparrow} + q^{\uparrow\downarrow}
\end{aligned}
$$

Polarised deep inelastic scattering



- **Photoabsorbtion:**



$$\sigma^{\uparrow\uparrow} = \sum_q e_q^2 (q^{\uparrow\downarrow} + \bar{q}^{\uparrow\downarrow}) \qquad \sigma^{\uparrow\downarrow} = \sum_q e_q^2 (q^{\uparrow\uparrow} + \bar{q}^{\uparrow\uparrow})$$

- **γ–nucleon asymmetry:**

$$A_1 = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}} = \frac{\sum_q e_q^2 \left(q^{\uparrow\uparrow} - q^{\uparrow\downarrow} + \bar{q}^{\uparrow\uparrow} - \bar{q}^{\uparrow\downarrow}\right)}{\sum_q e_q^2 \left(q^{\uparrow\uparrow} + q^{\uparrow\downarrow} + \bar{q}^{\uparrow\uparrow} + \bar{q}^{\uparrow\downarrow}\right)} = \frac{\sum_q e_q^2 (\Delta q + \Delta \bar{q})}{\sum_q e_q^2 (q + \bar{q})}$$

The Inclusive Asymmetry A_1

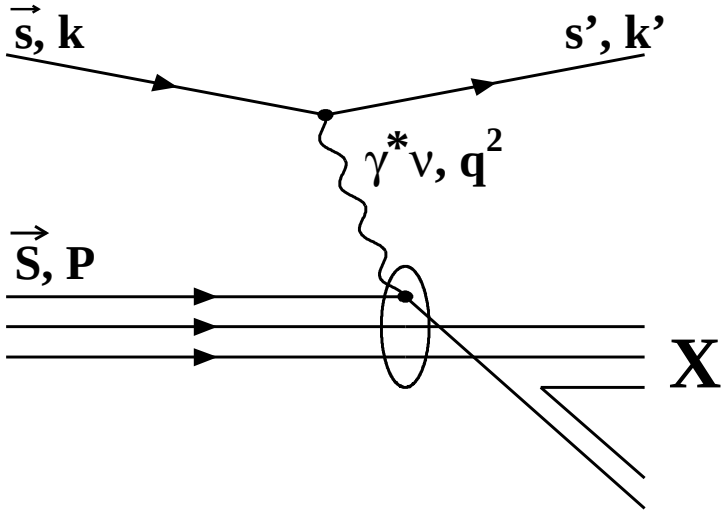
- **Inclusive DIS:**
  - Detection of μ and μ'
  - Hadronic final state unobserved

- **Measure μ–nucleon asymmetry:**

$$A_{\mu N} = \frac{1}{P_t f P_b}\left(\frac{N_{\uparrow\downarrow} - N_{\uparrow\uparrow}}{N_{\uparrow\downarrow} + N_{\uparrow\uparrow}}\right)$$

- **γ–nucleon asymmetry:**

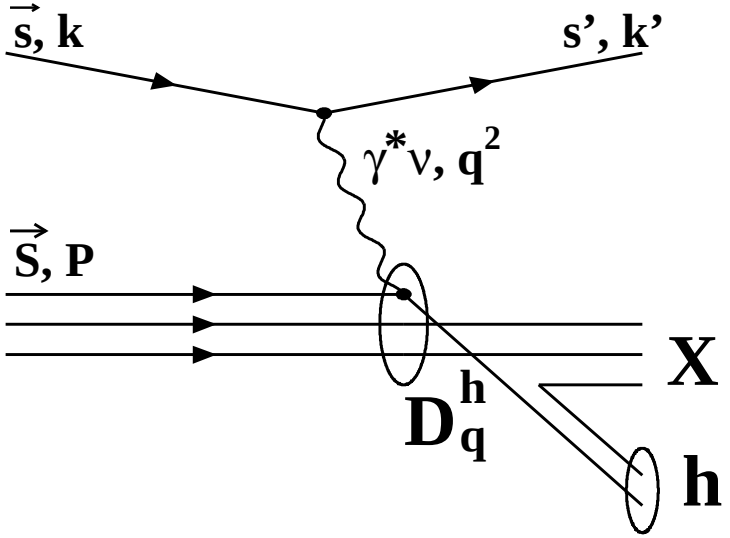
$$A_1 = \frac{A_{\mu N}}{D} = \frac{\Sigma e_q^2 \left(\Delta q + \Delta\bar{q}\right)}{\Sigma e_q^2 \left(q + \bar{q}\right)}$$



- Δq and $\Delta\bar{q}$ can not be separated
- with hyperon decay data:
  $\Delta u + \Delta\bar{u}$, $\Delta d + \Delta\bar{d}$ and $\Delta s + \Delta\bar{s}$
  can be determined

Semi–inclusive Asymmetries

- **Semi–inclusive Measurement:**
  - Detection of μ and μ'
  - Plus at least one hadron h
  - Fragmentation independent of scattering
  - Fragmentation function: $D_q^h(z)$ with $z = \frac{E_h}{\nu}$



- **Asymmetries:**

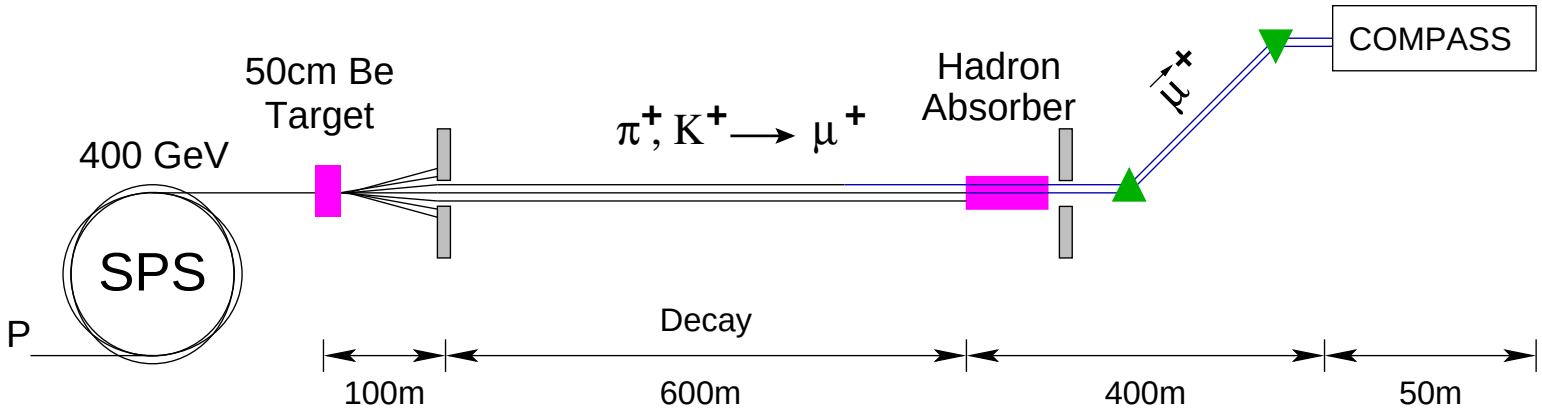
$$A_1^h = \frac{1}{P_t f P_b D}\left(\frac{N^h_{\uparrow\downarrow} - N^h_{\uparrow\uparrow}}{N^h_{\uparrow\downarrow} + N^h_{\uparrow\uparrow}}\right) = \frac{\sum_q e_q^2\left(\Delta q(x)\int D_q^h(z)dz + \Delta\bar{q}(x)\int D_{\bar{q}}^h(z)dz\right)}{\sum_q e_q^2\left(q(x)\int D_q^h(z)dz + \bar{q}(x)\int D_{\bar{q}}^h(z)dz\right)}$$

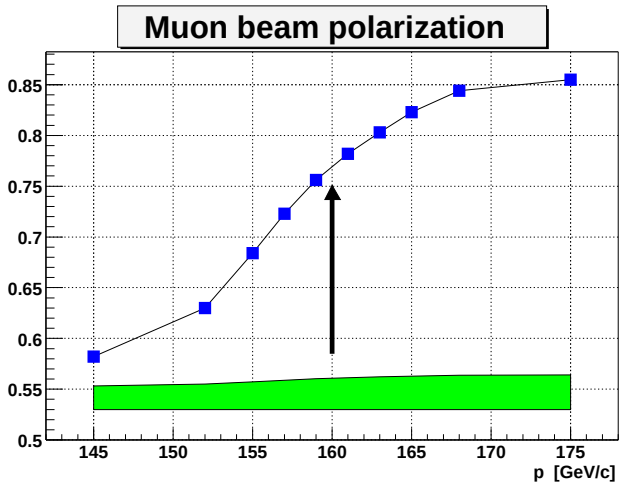
  since $D_q^h \neq D_{\bar{q}}^h$ separation of quarks and anti-quarks

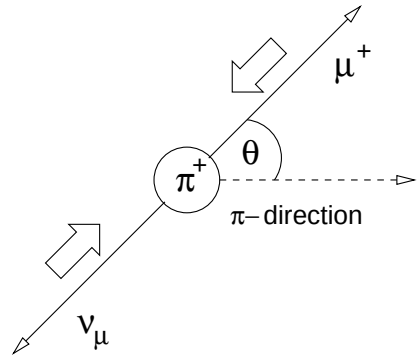
- in principle full flavour separation possible (Δu, $\Delta\bar{u}$, Δd, $\Delta\bar{d}$, Δs, $\Delta\bar{s}$)

The Experimental Setup

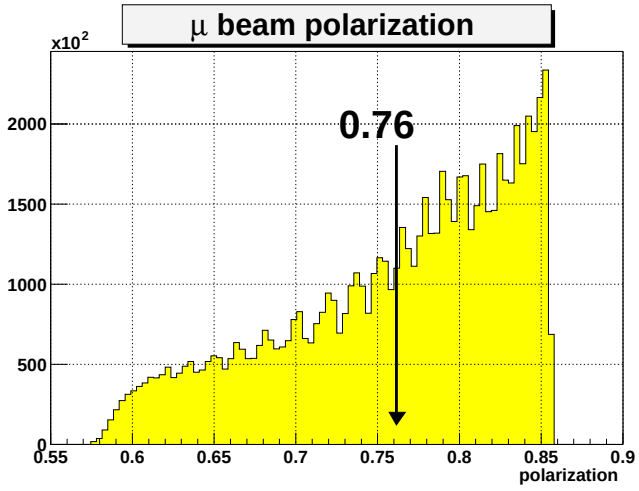
The Polarised Muon Beam



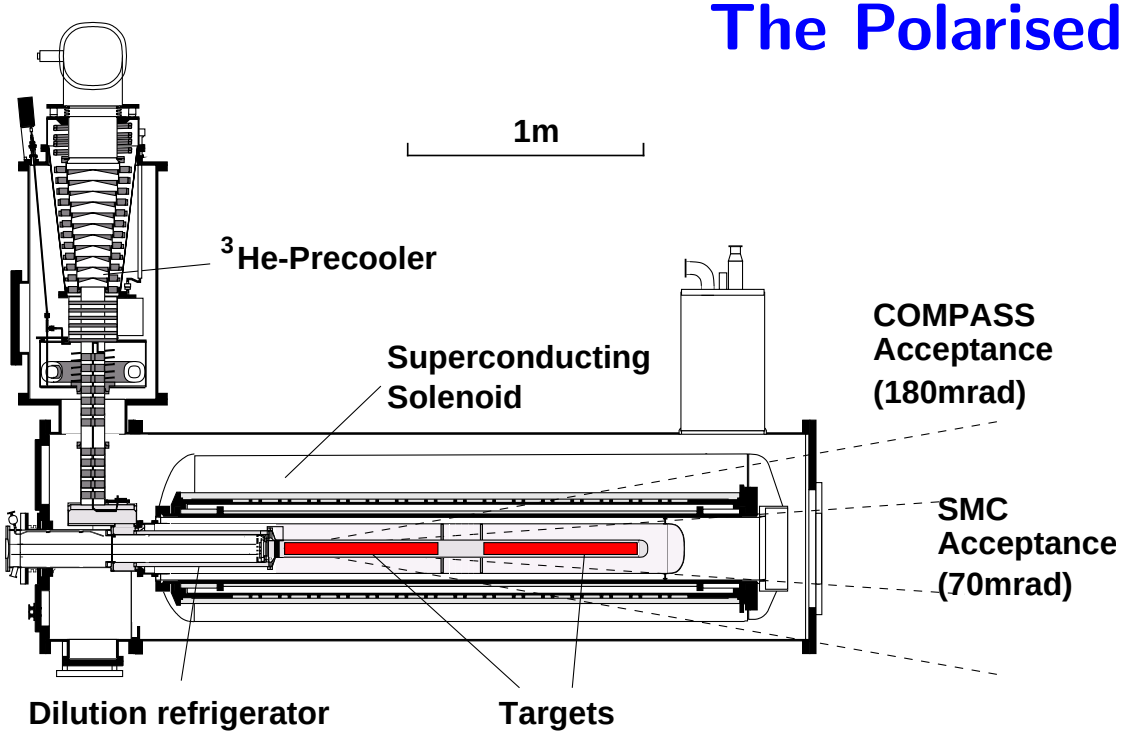


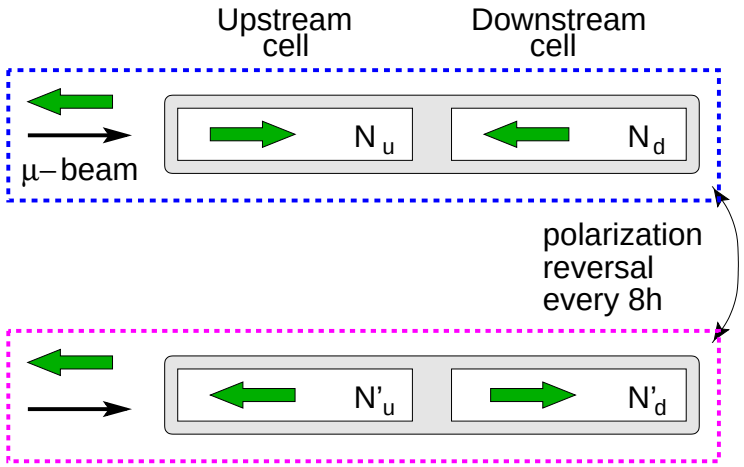


Energy	160 GeV
Intensity	$2 \cdot 10^8 \mu$/Spill
Polarisation	$\approx 76\,\%$



The Polarised Target





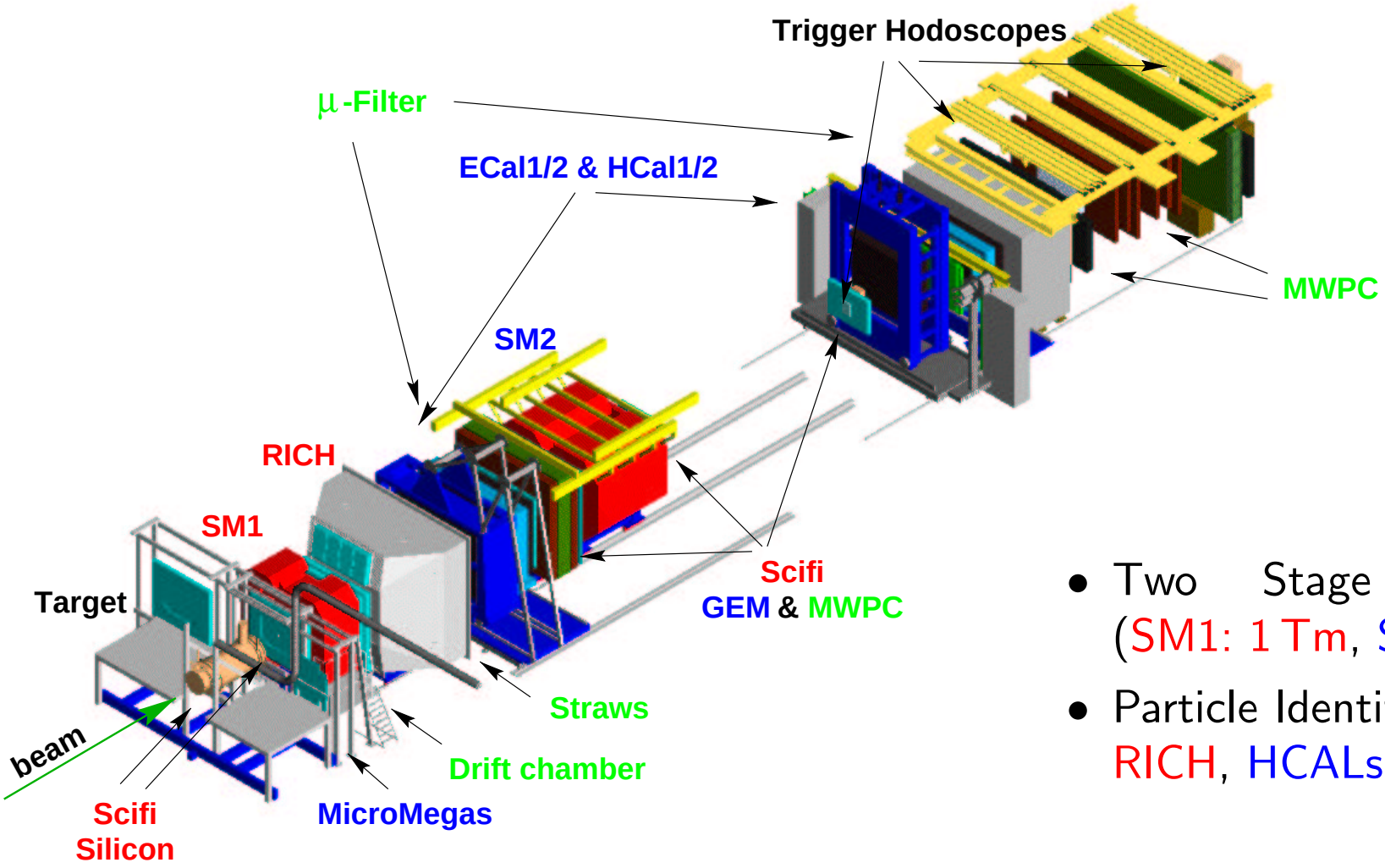
- **Target material:** ^{6}LiD
- **Polarisation:** above 50 %
- **Flux Variation:** 2 target cells
- **Acceptance Difference:** Reversal

- **Take average Asymmetry:**

$$\Rightarrow A = \frac{A_1 + A_2}{2} = \frac{1}{2}\left(\frac{N_u - N_d}{N_u + N_d} - \frac{N'_u - N'_d}{N'_u + N'_d}\right)$$

$\Rightarrow$ Minimization of false asymmetries

The COMPASS Spectrometer



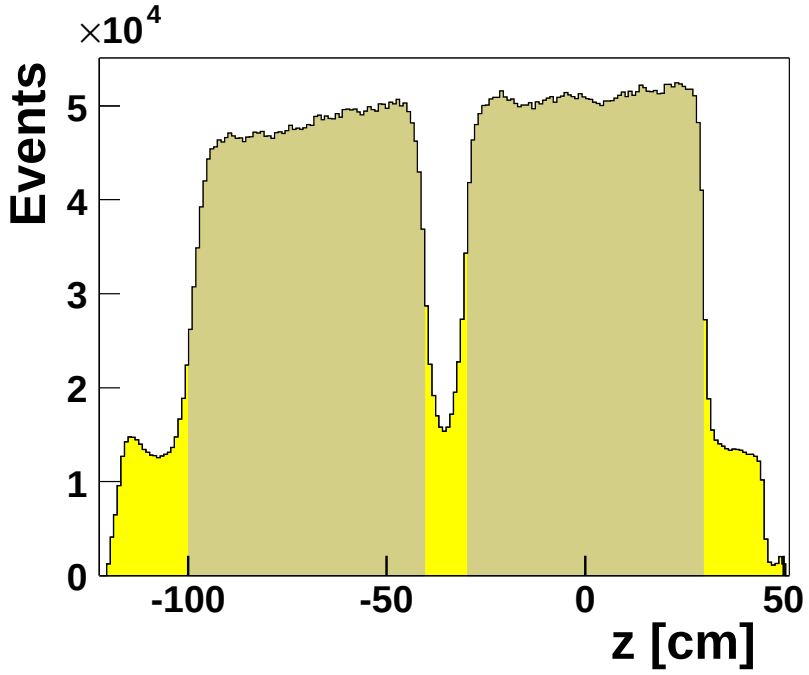
- Two Stage Spectrometer (SM1: 1 Tm, SM2: 5.2 Tm)
- Particle Identification RICH, HCALs, μF

The Inclusive Measurement

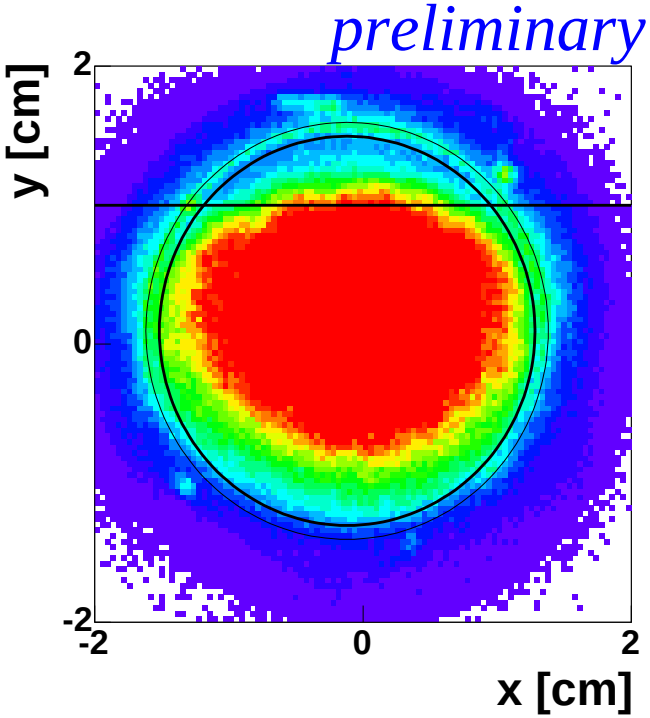
$$A_1 = \frac{1}{2} \quad \frac{1}{P_t f P_b D} \left(\frac{N_u - N_d}{N_u + N_d} - \frac{N'_u - N'_d}{N'_u + N'_d} \right)$$

Event Selection

- **Target Cuts:**
  - Primary Vertex in Target
  - μ would have passed both target cells



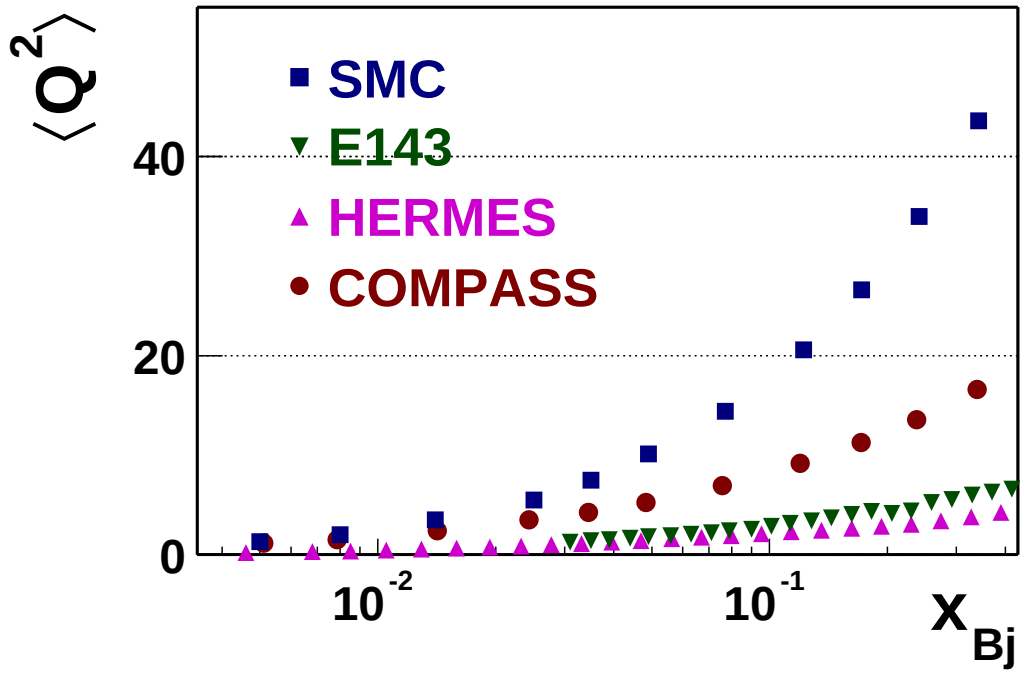
- **Target Description:**
  - $R < 1.4\,\mathrm{cm}$
  - $y < 1.0\,\mathrm{cm}$



Event Selection

- **Kinematic Cuts:**
  - $140\,\text{GeV} < E_\mu < 180\,\text{GeV}$
  - $Q^2 > 1\ \text{GeV}^2$
  - $0.1 < y < 0.9$

    $\Rightarrow x_{min} = 0.003$
    - Hermes: $x_{min} = 0.02$
    - SLAC: $x_{min} = 0.03$

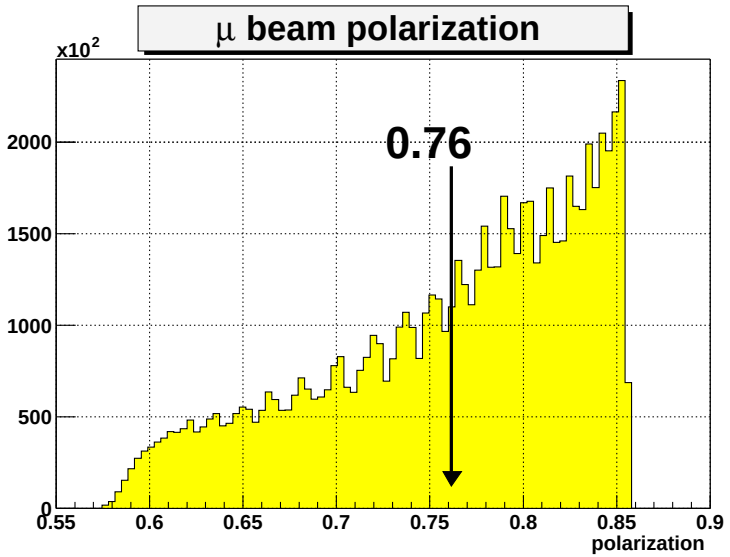


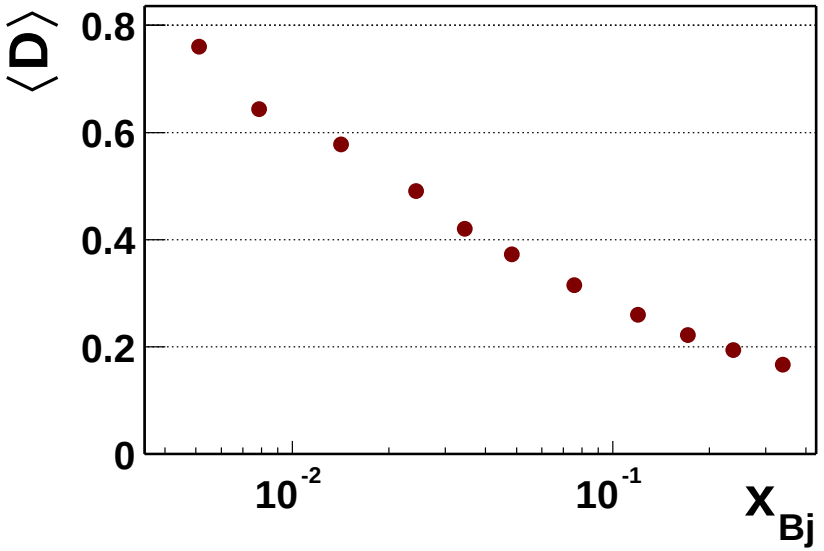
Period	P1C	P2A	P2D	P2E	P2F	P2G	total
# of runs	167	181	166	211	114	168	1007
Events after cuts $\times 10^6$	0.88	1.22	1.1	1.56	0.71	1	6.47

The Beam Factor $P_b D$

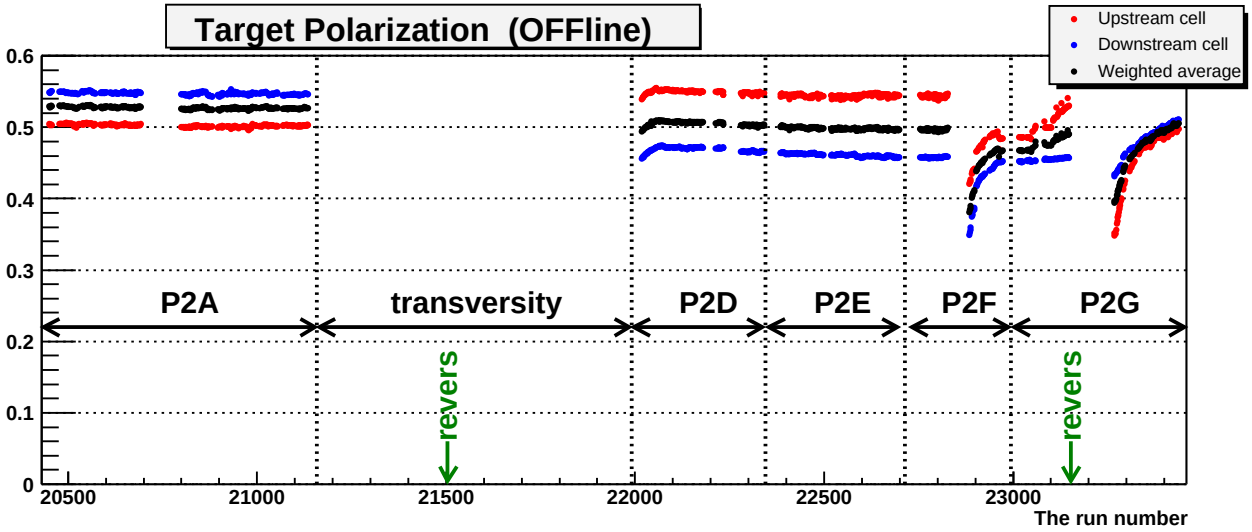
- Beam polarisation $P_b(E_\mu)$
- Depolarisation factor:

$$D \approx \frac{2y - y^2}{2 - 2y + y^2}$$





The Target Factor $P_t f$



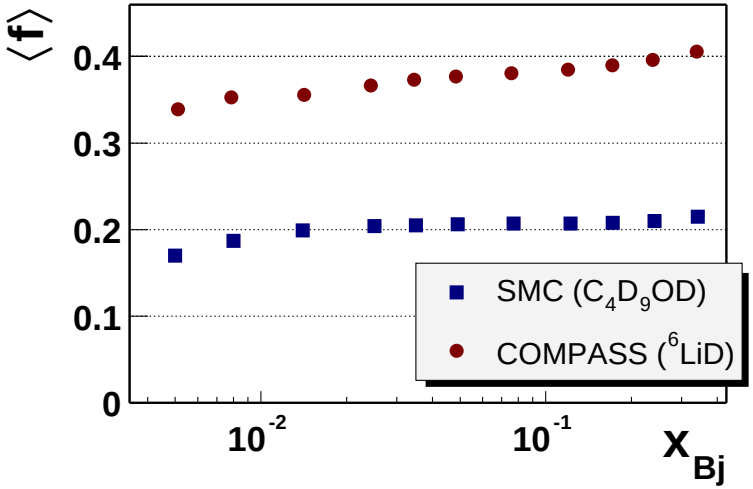
$$P_t = \frac{\sum^{runs} |P_u| N_u + \sum^{runs} |P_d| N_d}{\sum^{runs} N_u + \sum^{runs} N_d}$$

Dilution factor:

- Naive: ^{6}LiD $\approx 2D + 1\alpha \Rightarrow f \approx 0.5$
- ^{6}LiD in He bath (packing 50 %)

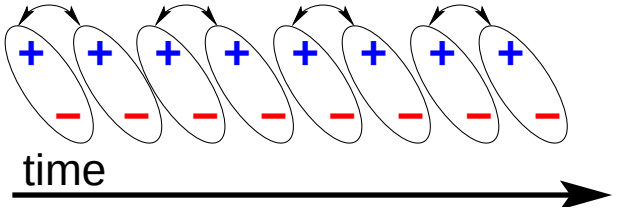
$$\Rightarrow f = \frac{n_d \sigma_d}{n_d \sigma_d + \sum_A n_A \sigma_A} \approx 0.4$$

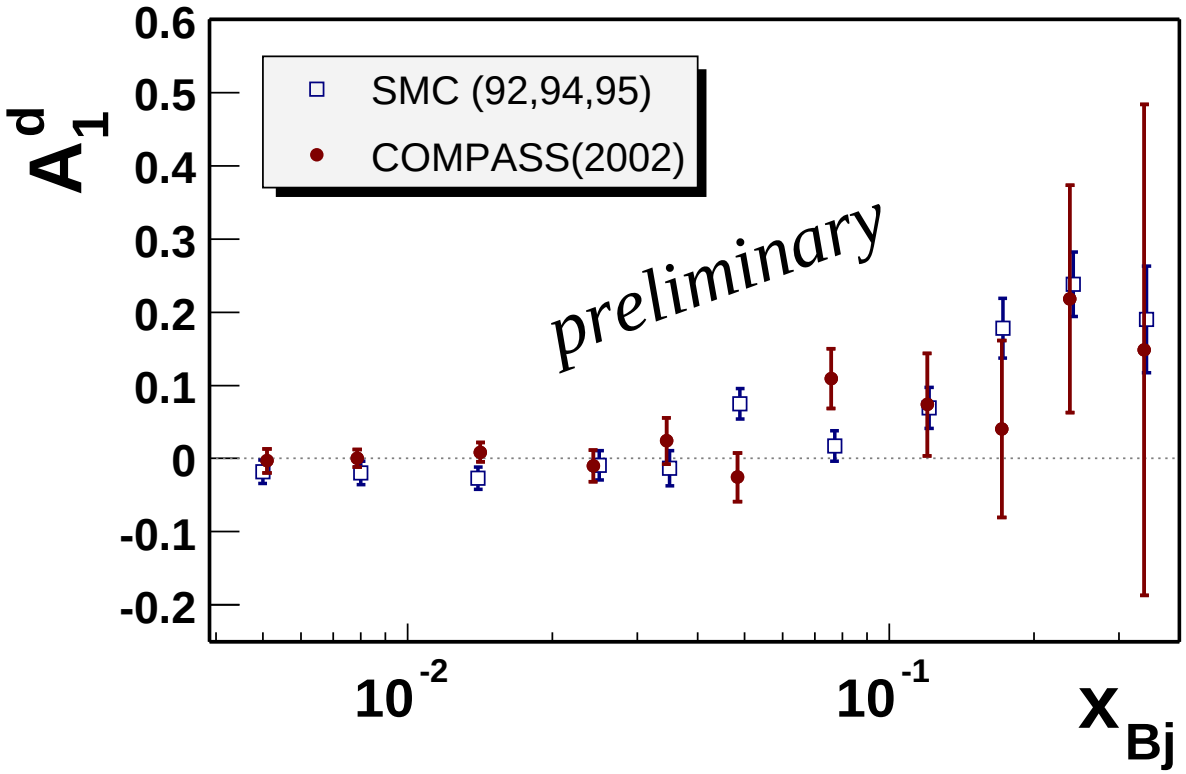
- Impurities (^{7}Li, H)



Inclusive Result A_1

- **Combine Configurations:**





- 1st year data taking

  $\approx$ 3 years of SMC for $x < 0.04$

  – 5 times higher beam rate
  – 2 times higher f

- large uncertainty for $x > 0.04$

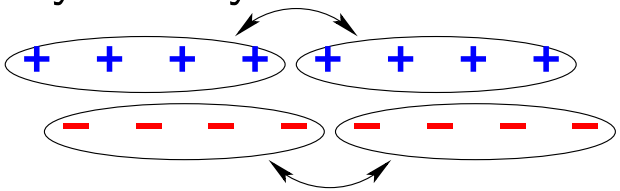
  $\Rightarrow$ trigger upgrade for 2003
  $\Rightarrow$ large Q^2

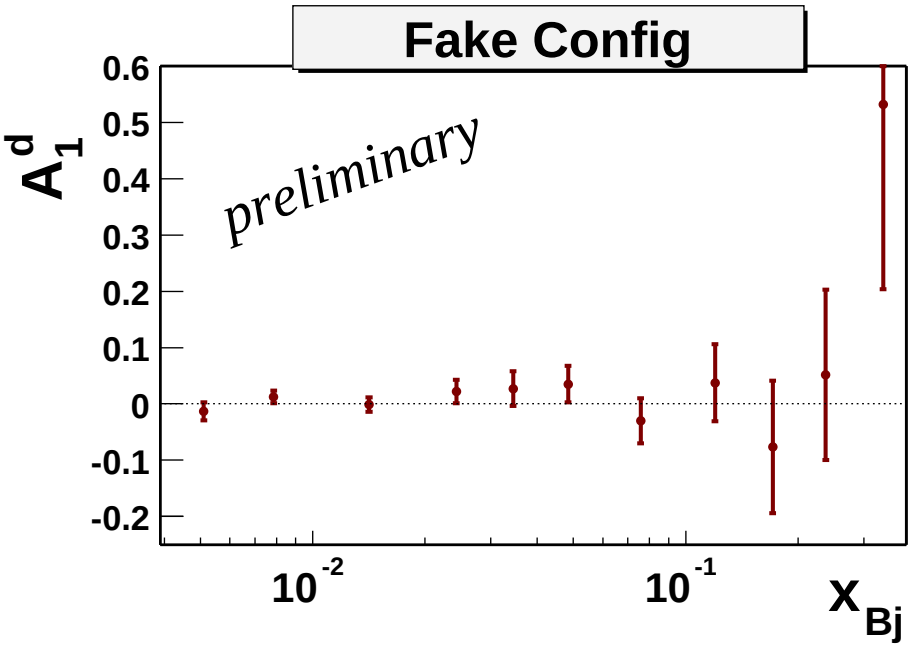
- 2003 + 2004 data $\Rightarrow$ four times the statistics

False Asymmetries

- False asymmetries can be determined from
  - Data: all sources but limited statistics
  - MC: infinite statistics but only known sources
- False asymmetry determination with MC is in progress

combine data w/o physical asymmetry





- Observed asymmetry compatible with 0–hypothesis
- Probability $\approx 70\,\%$
- Systematic error (without false asymmetries) $\approx 10\,\%$

The Semi–Inclusive Measurement

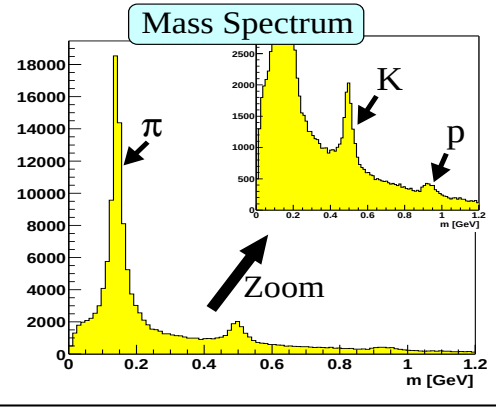
Asymmetries to be measured

$$\vec{A}_1 = \{ A_1, A_1^{h+}, A_1^{h-}, A_1^{K+}, A_1^{K-}, A_1^{K_S^0} \}$$

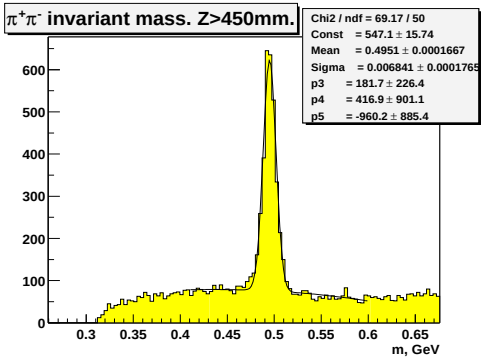
Inclusive Asymmetry

90% of hadrons are pions

RICH PID
Threshold: p_K>9 GeV



Secondary vertices produced by track coming from interac−tion point



Flavour Separation

- Measure Asymmetries and Correlations:

$$\vec{A}_1^d = \left(A_1, A_1^{h^+}, A_1^{h^-}, A_1^{K^+}, A_1^{K^-}, A_1^{K_s^0}\right)$$

- Fragmentation Functions:
  - EMC: $D_u^{\pi^+}$, $D_{\bar{u}}^{\pi^+}$, $D_u^{K^+}$, $D_{\bar{u}}^{K^+}$,D_u^p,$D_{\bar{u}}^p$
  - MC (Pythia): $D_q^{K_s^0}$

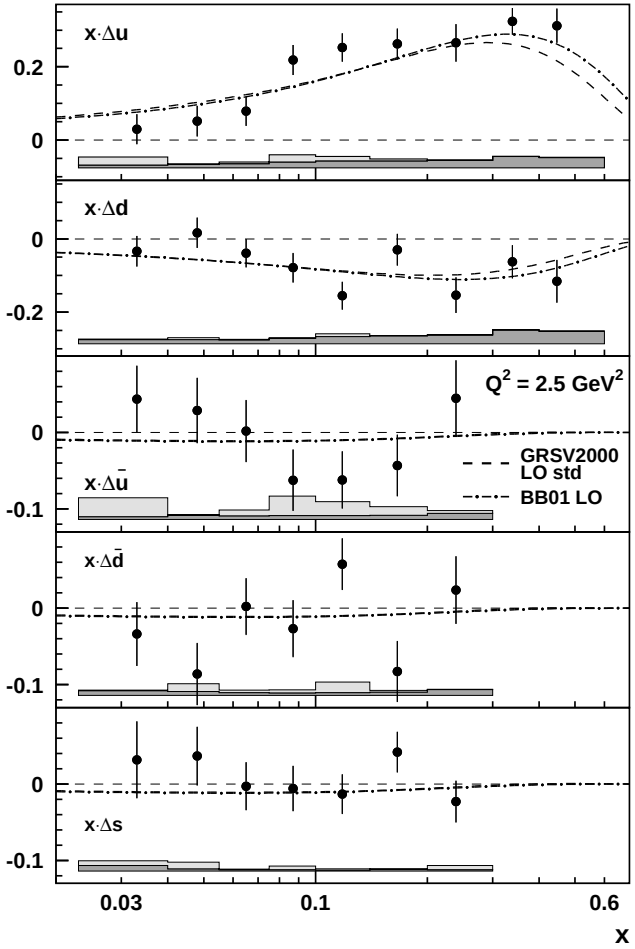
$$\vec{A}_1 = \mathcal{B}(q(x), D_q^h(z))\vec{\Delta q}$$

- Unpolarized quark distributions $q(x)$:
  - MRST, GRSV, ACC, BB, CTEQ

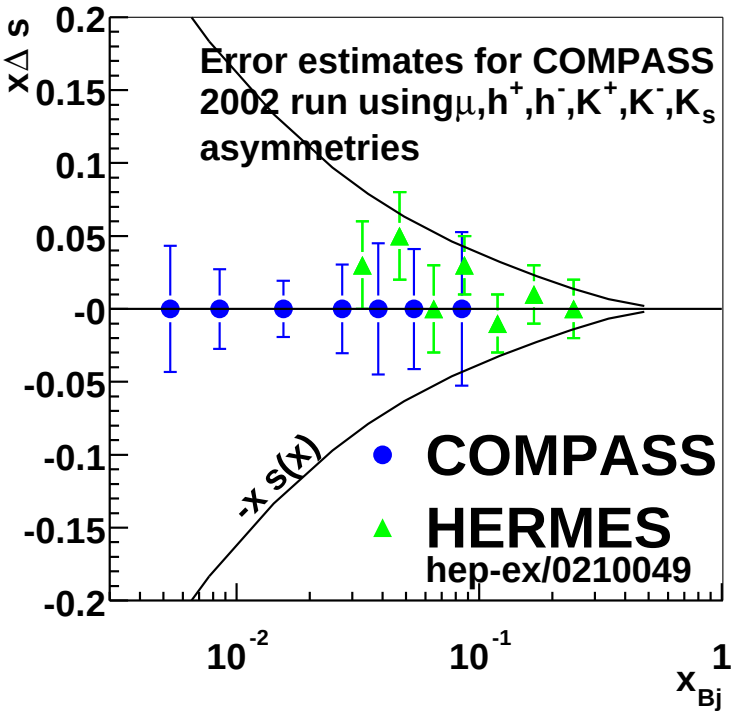
- Deuteron = isoscalar $\Rightarrow \vec{\Delta q} = \left(\Delta u + \Delta d, \Delta\bar{u} + \Delta\bar{d}, \Delta s = \Delta\bar{s}\right)$
- With proton data $\Rightarrow \vec{\Delta q} = \left(\Delta u, \Delta\bar{u}, \Delta d, \Delta\bar{d}, \Delta s, \Delta\bar{s}\right)$

Semi-inclusive Asymmetries

- Hermes: PRL 92 (2004) 012005



- COMPASS:
  - Contribution to Δs
  - Extension to-wards small x



Summary

- First results (A_1, high pt, transversity, ...)
- All results based on 2002 data
- A1 has been measured:
  - good accuracy for $x < 0.04$
  - Determination of systematic error and false asymmetries in progress
  - much more (at least factor 4) statistics to come
- The analysis of the semi-inclusive asymmetries is in progress:
  - Error projection for 2002 shown