MEASUREMENT OF TRANSVERSITY AT COMPASS

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- **THE COMPASS EXPERIMENT**
  - **physics programme and apparatus**
- **TRANSVERSITY**
  - **pion asymmetry**
  - **data collected and expected statistical precision**

COmmon Muon and Proton Apparatus for Structure and Spectroscopy

a new fixed target experiment at CERN (NA58)

data taking started in 2002, will continue in 2004 and after 2006

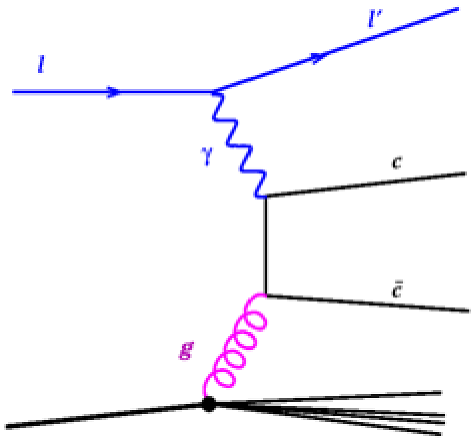
28 Institutes, more than 200 physicists

Finland, France, Germany, India, Israel, Italy, Japan, Poland, Portugal, Russia, Switzerland

Bielefeld, Bochum, Bonn, Burdwan, Calcutta, CERN, Dubna, Erlangen, Freiburg, Heidelberg, Helsinki, Lisbon, Mainz, Miyazaky, Moscow, Munich, Nagoya, Protvino, Saclay, Tel Aviv, Torino, Trieste, Warsaw

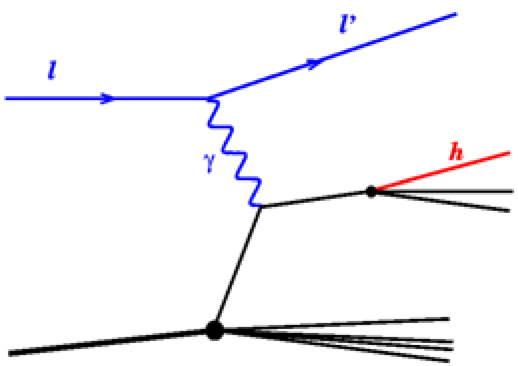
Physics Programme with the Muon Beam

to determine the polarized parton density functions in a polarized nucleon from measurements of hadron asymmetries in semi-inclusive polarized DIS, both longitudinal and transverse



specifically,

- to measure the gluon polarization ΔG through open charm (Gluck and Reya, Altarelli and Stirling, 1988)



- flavour decomposition of g_1 from identified hadron asymmetries: Δu, Δd, Δs

- to measure the spin transfer in fragmentation from Λ production
- to remeasure with high statistics g_1 and g_2
- …new ideas …

- <u>to measure h_1, the new territory…</u>

Physics Programme with Hadron Beams

- hadron structure
  - polarizability in Primakoff reactions
- gluonic states
  - search for glueballs in Pomeron-Pomeron scattering
  - search for exotic states
- charmed hadrons
  - production phenomena (p, π, K)
  - leptonic decays
  - semi-leptonic decays
  - precision measurements of c-baryon lifetimes
  - production and spectroscopy of cc-baryons

2002, 2003, 2004: data taking with muon beam
$\geq$ 2006 : data taking with hadron beams and muon beam

2002 - 2003 apparatus

μ beam energy 160 GeV [100-200 GeV] - longitudinally polarized (80%)

μ beam intensity ~ 2 • 10^8 μ/spill [4 s]

Polarized target 2 oppositely polarized cells, 60 cm long

neutron: ^{6}LiD, P_T ~50%, f ~50% as in Proposal!

[proton: NH_3, P_T ~90 %, f ~17%]

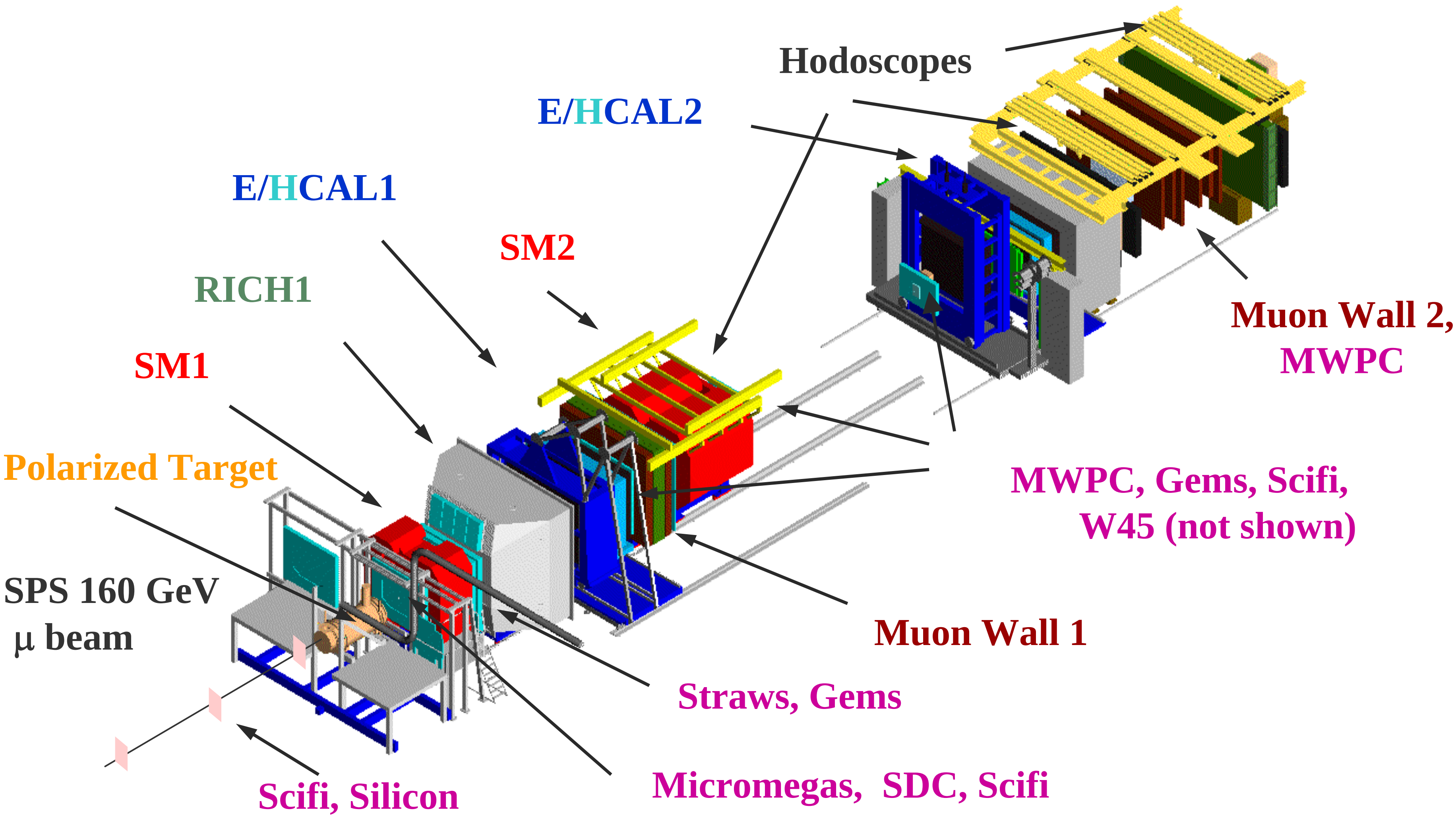
~80% longitudinal polarization, 20% transverse polarization

Luminosity ~ 5 • 10^{32} $cm^{-2}s^{-1}$

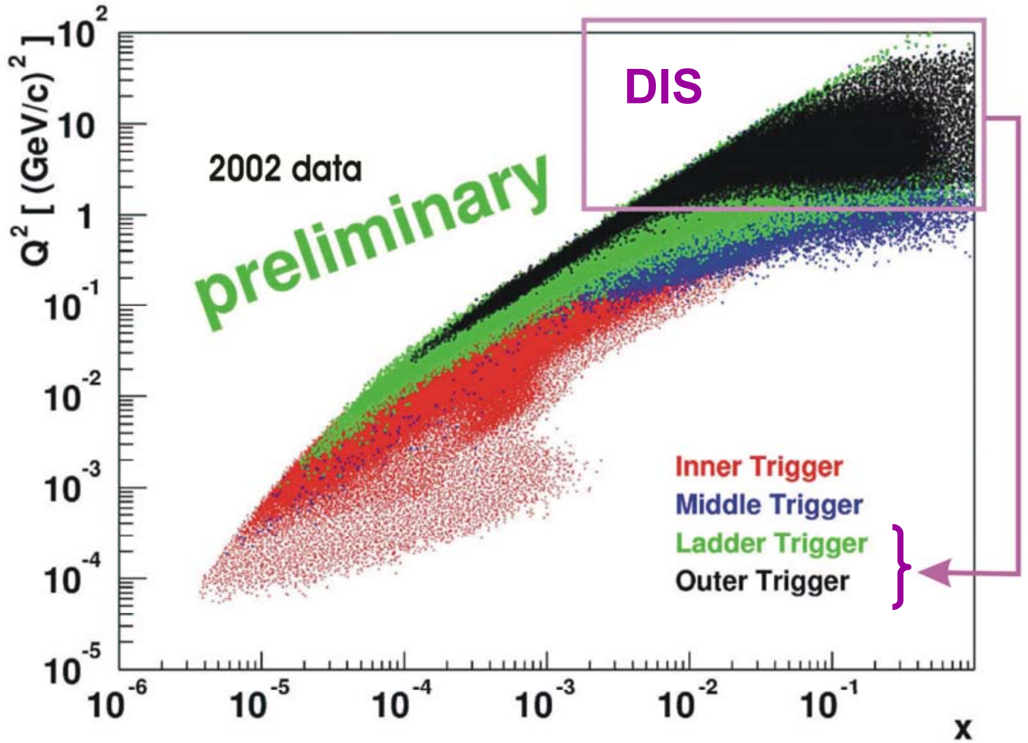
Spectrometer tracking down to 0°

2 stages	Large Angle	Small Angle
	1.5 T•m	5 T•m
	RICH1, HCAL1, μ-Wall1	HCAL2, μ-Wall2
	180 mrad → 80 mrad	40 mrad,

The Spectrometer



x - Q^2 acceptance in 2002 and 2003



Trigger efficiency:

	2002	➔	2003
Inner	96%	➔	99%
Middle	67%	➔	95%
Ladder	**86%**	➔	**97%**
Outer	**67%**	➔	**95%**

The structure function h_1

at leading order in 1/Q, the quark structure of the nucleons is described by three structure functions, all equally important for the nucleon structure:

$$F_1(x) = \frac{1}{2}\sum_a e_a^2 [q_a(x) + \bar{q}_a(x)] \qquad q_a(x) = q_a^+(x) + q_a^-(x)$$

$$g_1(x) = \frac{1}{2}\sum_a e_a^2 [\Delta_L q_a(x) + \Delta_L \bar{q}_a(x)] \qquad \Delta_L q_a(x) = q_a^+(x) - q_a^-(x)$$

measures the distribution of quarks polarized along or against the spin of a nucleon polarized parallel to its momentum

$$h_1(x) = \frac{1}{2}\sum_a e_a^2 [\Delta_T q_a(x) + \Delta_T \bar{q}_a(x)] \qquad \Delta_T q_a(x) = q_a^{\uparrow\uparrow}(x) - q_a^{\uparrow\downarrow}(x)$$

transverse polarization of quarks in a transversely polarized nucleon

measures the distribution of quarks polarized along or against the spin of a nucleon polarized transverse to its momentum

In a non relativistic system $h_1 = g_1$

h_1 tells us how relativistic the quarks in the nucleon are ….

[R.L.Jaffe and X.D.Ji, PRL 67(1991)552]

Measurement of the
transverse spin distribution functions

h_1 can be obtained in SIDIS because the cross-section depends on

$\underline{h_1}$ x <u>fragmentation function</u>

both chirally odd

Collins effect

At leading twist with a transversely polarized target promising channels are:

- **production of unpolarized hadrons**
- **production of two hadrons** (the next step …)

<u>Collins Effect</u>

the fragmentation function can be written as

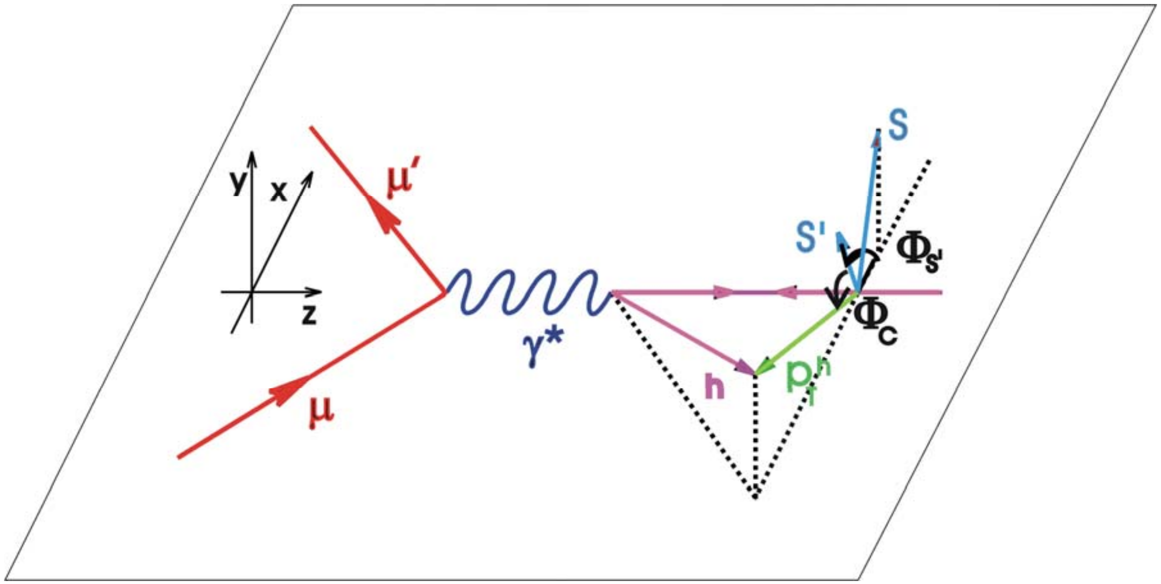
$$D_a^h(z,\vec{p}_a^{\,h}) = D_a^h(z,p_a^h) + \Delta D_a^h(z,p_a^h) \cdot \sin\Phi_C$$

spin dependent part

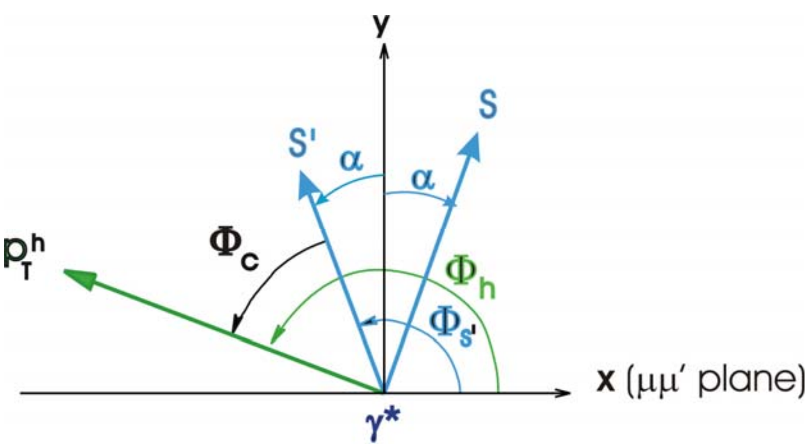
where

- $\vec{p}_a^{\,h}$ is the final **leading hadron** transverse momentum with respect to the quark direction (the virtual photon direction) and $z=E_h/(E-E')$
- $\Phi_C = \Phi_h - \Phi_{s'} = \Phi_h + \Phi_s - \pi$ is the **"Collins angle"**

Collins angle $\Phi_C = \Phi_h - \Phi_{s'} = \Phi_h + \Phi_s - \pi$



Φ_h final leading hadron azimuthal angle around the quark direction



$\Phi_{s'}$ azimuthal angle of the final quark spin around the quark direction

$\Phi_{s'} = \pi - \Phi_s$

Φ_s is the azimuthal angle of the final quark spin in a ref. System with z axis defined by γ direction and x-z plane defined by the scattering plane

Hadron asymmetry

Given the fragmentation function $D_a^h(z,\vec{p}_a^{\,h}) = D_a^h(z,p_a^h) + \Delta D_a^h(z,p_a^h)\cdot \sin\Phi_c$

and $\Delta_T q_a(x) = q_a^{\uparrow\uparrow}(x) - q_a^{\uparrow\downarrow}(x)$, $q_a(x) = q_a^{\uparrow\uparrow}(x) + q_a^{\uparrow\downarrow}(x)$

with target polarization direction in the lab system “up” (+) and “down” (–):

$$N_{h,a}^{\pm} \propto q_a^{\uparrow\uparrow}(D_a^h \pm \Delta D_a^h \cdot \sin\Phi_C) + q_a^{\uparrow\downarrow}(D_a^h \mp \Delta D_a^h \cdot \sin\Phi_C) = q_a \cdot D_a^h \pm \Delta_T q_a \cdot \Delta D_a^h \cdot \sin\Phi_C$$

Summing on quark flavors

and introducing f = polarized target dilution factor,

P_T = target nucleon polarization, $D_{nn} = (1-y)/(1-y-y^2/2)$

we have

$$N_h^{\pm} = N_h^0 \cdot [1 \pm \varepsilon \cdot \sin\Phi_C]$$

with

$$\varepsilon = f \cdot P_T \cdot D_{nn} \cdot \frac{\sum_a e_a^2 \cdot \Delta_T q_a \cdot \Delta D_a^h}{\sum_a e_a^2 \cdot q_a \cdot D_a^h}$$

to be estimated from $\dfrac{N_h^+ - N_h^-}{N_h^+ + N_h^-}$ or from $< \sin\Phi_C >$

Pion asymmetries

from the previous relations

neglecting the contributions of s quarks

and assuming $D_1 = D_u^{\pi^+} = D_d^{\pi^-} = D_{\bar{u}}^{\pi^-} = D_{\bar{d}}^{\pi^+}\,,\quad D_2 = D_u^{\pi^-} = D_d^{\pi^+} = D_{\bar{u}}^{\pi^+} = D_{\bar{d}}^{\pi^-}$

1. with a proton polarized target

$$\frac{(N^{p+}_{\pi^+} + N^{p+}_{\pi^-}) - (N^{p-}_{\pi^+} + N^{p-}_{\pi^-})}{(N^{p+}_{\pi^+} + N^{p+}_{\pi^-}) + (N^{p-}_{\pi^+} + N^{p-}_{\pi^-})} \rightarrow$$

$$\varepsilon_{p1} = f_p \cdot P_T^p \cdot D_{nn} \cdot \underbrace{\frac{4\Delta_T u + \Delta_T \bar{d} + 4\Delta_T \bar{u} + \Delta_T d}{4u + \bar{d} + 4\bar{u} + d}}_{2x \cdot h_1(x) / F_2(x)} \cdot \frac{\Delta D_1 + \Delta D_2}{D_1 + D_2}$$

$$\frac{(N^{p+}_{\pi^+} + N^{p-}_{\pi^-}) - (N^{p-}_{\pi^+} + N^{p+}_{\pi^-})}{(N^{p+}_{\pi^+} + N^{p-}_{\pi^-}) + (N^{p-}_{\pi^+} + N^{p+}_{\pi^-})} \rightarrow$$

$$\varepsilon_{p2} = f_p \cdot P_T^p \cdot D_{nn} \cdot \frac{4\Delta_T u_v - \Delta_T d_v}{4u + \bar{d} + 4\bar{u} + d} \cdot \frac{\Delta D_1 - \Delta D_2}{D_1 + D_2}$$

Pion asymmetries (cont.)

2. with a deuteron polarized target

$$\frac{(N_{\pi^+}^{d+}+N_{\pi^-}^{d+})-(N_{\pi^+}^{d-}+N_{\pi^-}^{d-})}{(N_{\pi^+}^{d+}+N_{\pi^-}^{d+})+(N_{\pi^+}^{d-}+N_{\pi^-}^{d-})}\rightarrow \quad \varepsilon_{d1}=f_d\cdot P_T^d\cdot D_{nn}\cdot\frac{\Delta_T u+\Delta_T\bar{d}+\Delta_T\bar{u}+\Delta_T d}{u+\bar{d}+\bar{u}+d}\cdot\frac{\Delta D_1+\Delta D_2}{D_1+D_2}$$

$$\frac{(N_{\pi^+}^{d+}+N_{\pi^-}^{d-})-(N_{\pi^+}^{d-}+N_{\pi^-}^{d+})}{(N_{\pi^+}^{d+}+N_{\pi^-}^{d-})+(N_{\pi^+}^{d-}+N_{\pi^-}^{d+})}\rightarrow \quad \varepsilon_{d2}=f_d\cdot P_T^d\cdot D_{nn}\cdot\frac{3(\Delta_T u_v+\Delta_T d_v)}{5(u+\bar{d}+\bar{u}+d)}\cdot\frac{\Delta D_1-\Delta D_2}{D_1+D_2}$$

3. combining the p and d data

$$\frac{(N_{\pi^+}^{d+}+N_{\pi^-}^{d-})-(N_{\pi^+}^{d-}+N_{\pi^-}^{d+})}{(N_{\pi^+}^{p+}+N_{\pi^-}^{p-})+(N_{\pi^+}^{p-}+N_{\pi^-}^{p+})}\rightarrow$$

$$\boxed{\varepsilon=\frac{f_d\cdot P_T^d}{f_p\cdot P_T^p}\cdot\frac{3(\Delta_T u_v+\Delta_T d_v)}{4\Delta_T u_v-\Delta_T d_v}}$$

independent from the analyzing power of the FF

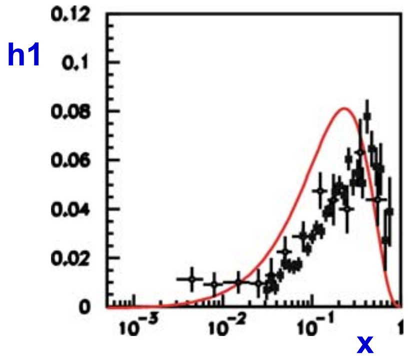
Statistical errors (Proposal)

estimates for the asymmetry on a proton polarized target:

$$\varepsilon_{p1} = f_p \cdot P_T^p \cdot D_{nn} \cdot \frac{2x \cdot h_1(x)}{F_2(x)} \cdot \frac{\Delta D_1 + \Delta D_2}{D_1 + D_2}$$

Assuming $$\frac{\Delta D_1 + \Delta D_2}{D_1 + D_2} = z \cdot p_a^h \cdot \frac{\sqrt{(p_a^h)^2 + M^2}}{M^2 + p_a^h \cdot \sqrt{(p_a^h)^2 + M^2}}$$

[X. Artru…,1994], M=0.3GeV - tuned on E704 and DELPHI

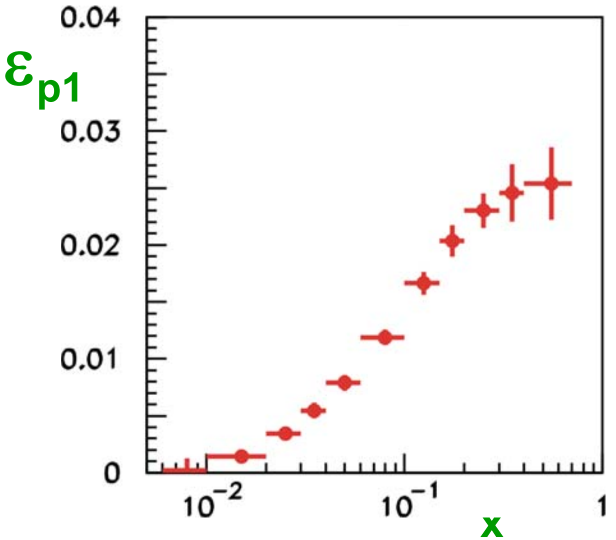


and $h_1(x) \cong g_1(x)$**, with:**

- **the foreseen experimental conditions** (luminosity, acceptance, multiple scatt., efficiency, dilution factor)
- **standard kinematical cuts**
  $Q^2 > 1$, $\nu > 15$ GeV, E'>5 GeV
  z > 0.3 and Berger criterion
- **one month of data taking**
- E_μ **= 100 GeV**

we obtained:

ε between 0.005 and 0.026
in the range 0.03 < x < 0.40, and
small statistical errors



Collected statistics

2002 run   **19 days (+;-;+,-), ~25 TB of useful raw data (~19%),**
~ 3 months   **~10^9 events on tape, useful beam ~ 5×10^{12}, ^{6}LiD**

Expected statistical error

(A. Magnon -Workshop on Future Physics @ COMPASS - 26-27 Sept. 2002)

with

- the same assumptions of the proposal (global efficiency ~25%, trigger and rec. included) **,**

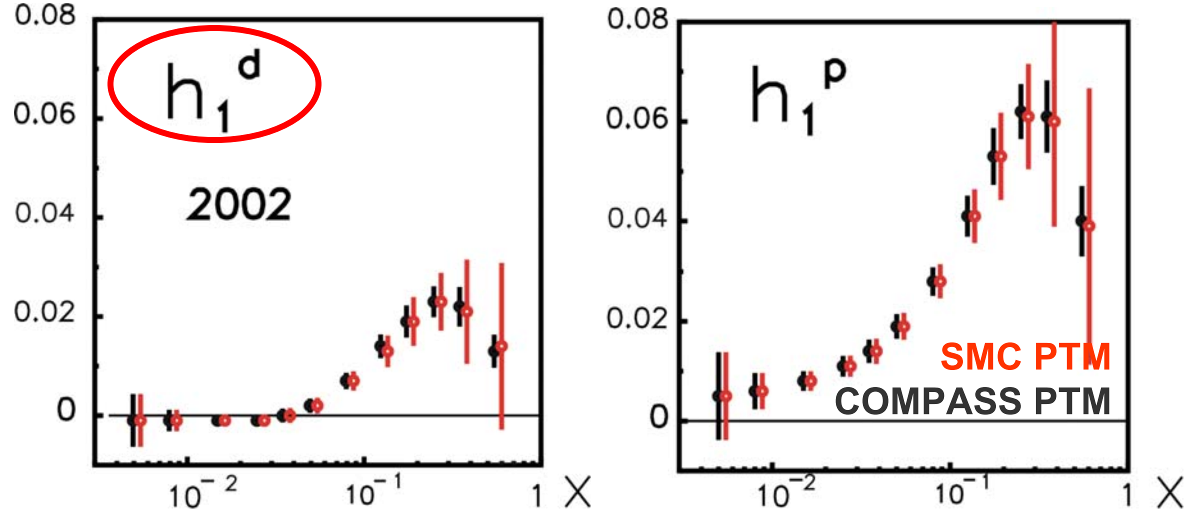
- at 160 GeV/c

- with the deuterium target,

- with the real acceptance,

integrating over x, a

5σ signal
was expected



Collected statistics (cont.)

2003 run
~2.5 months

1 period of 14 days (+,-) , ~50 TB of raw data (~20%)
~200 good runs
~10^9 events on tape, useful beam ~ $5x10^{12}$, ^6LiD
as in 2002 but with a more efficient high Q^2 trigger

2004 run
~6 months

we expect to collect the same statistics of 2002+2003

Data Analysis

still ongoing

in particular

- the spectrometer was completely new: a lot of work was needed to study and calibrate the detectors and to improve track reconstruction
- we collected a very large amount of data (~250 TB/year): some technical problem like the change of the “event DB” at the end of 2002 …
- priority has been given to the handling of the data: work on the systematics lagging behind

The 2002 raw data processing has been finished in September

No preliminary result yet:

the study of data stability and systematic effects is ongoing…

MonteCarlo studies

to understand

1. **performance of the spectrometer and acceptance**
2. **extraction of Collins asymmetry from only one target polarization data**
3. **leading particle effects**

Some examples of preliminary results from events generated with

- beam momentum 160 GeV/c

- Lepto events with $Q^2 > 0.5$ GeV^2, $x > 0.006$, $0.05 < y < 0.95$

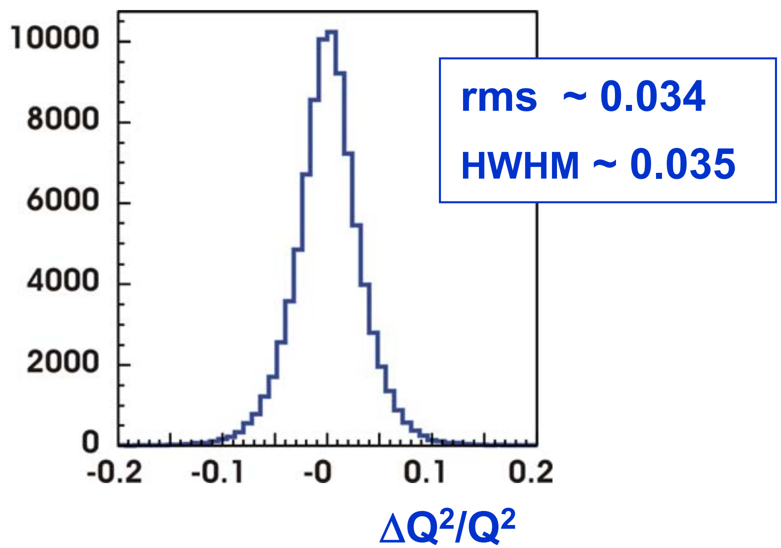
- 2002 apparatus

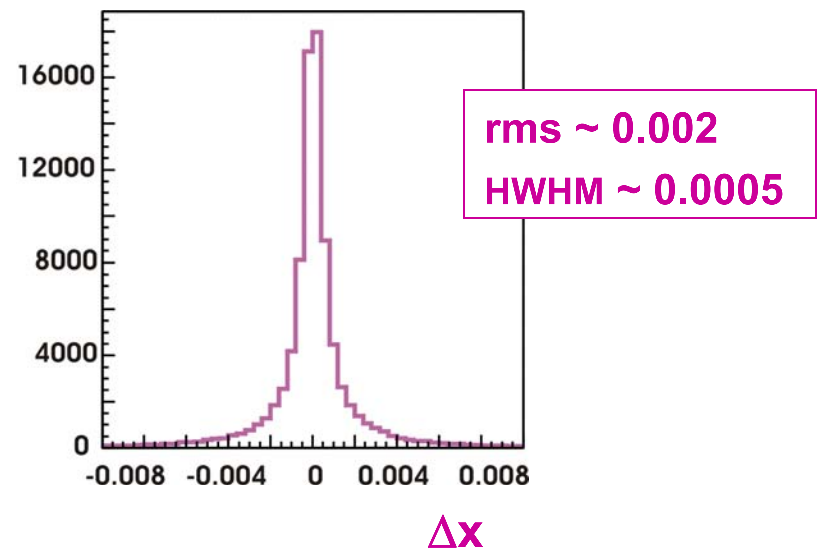
- detector resolution as from 2002 studies

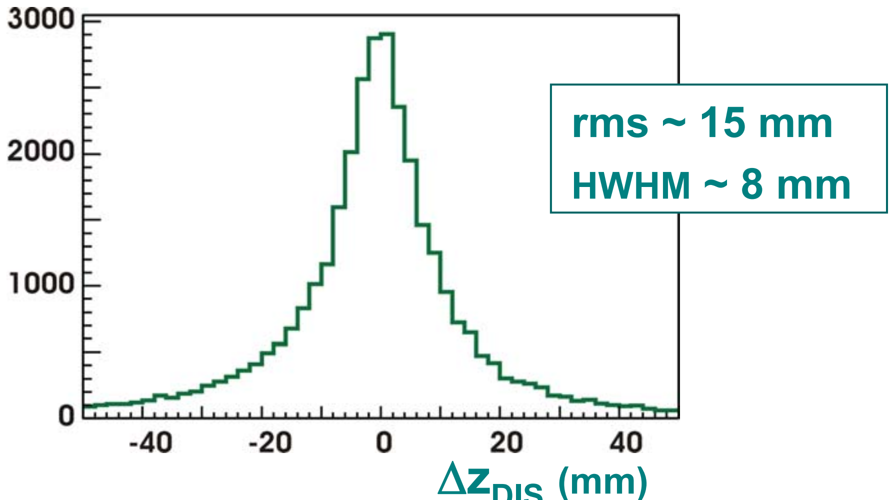
- detector efficiency 100%, no trigger simulation

and reconstructed with the last version of the reconstruction program

1. MonteCarlo - Performance of the spectrometer



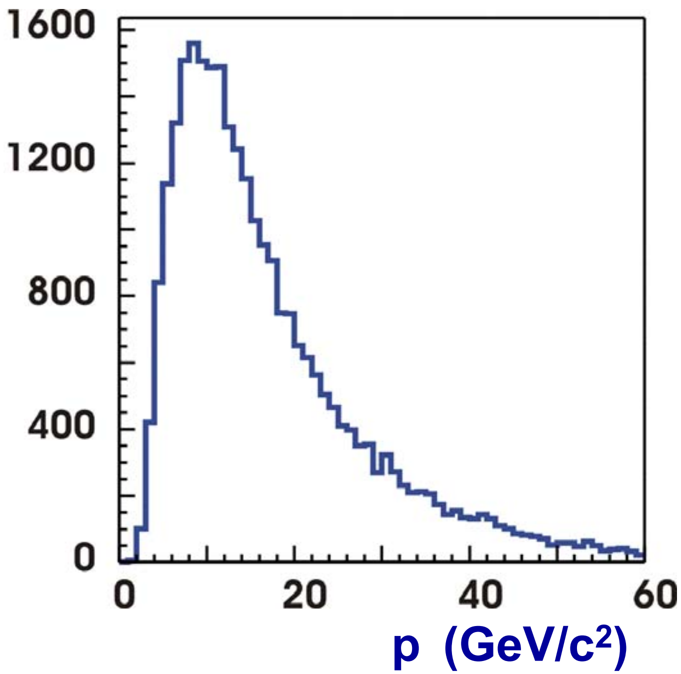


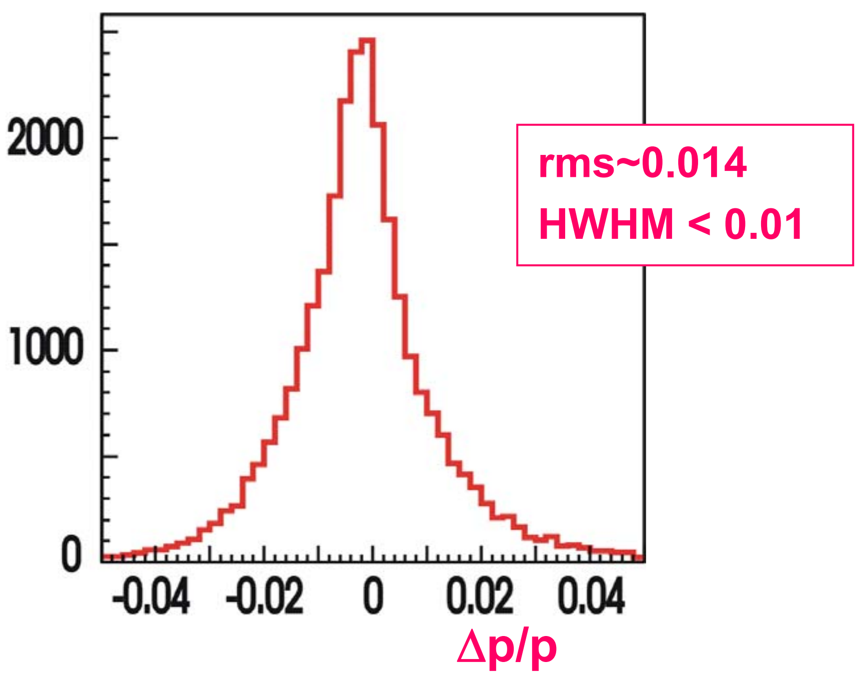


events with μ, μ' correctly reconstructed, $Q^2 > 1$ GeV^2

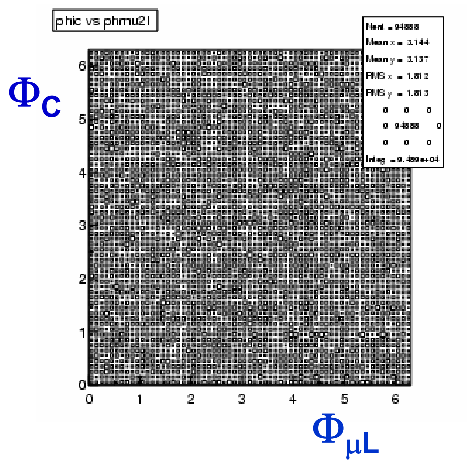
1. MonteCarlo - Performance of the spectrometer (cont.)

leading hadron distributions,
events with μ , μ' and l.h. correctly reconstructed





2. MonteCarlo - extraction of Collins asymmetry from only one target polarization data



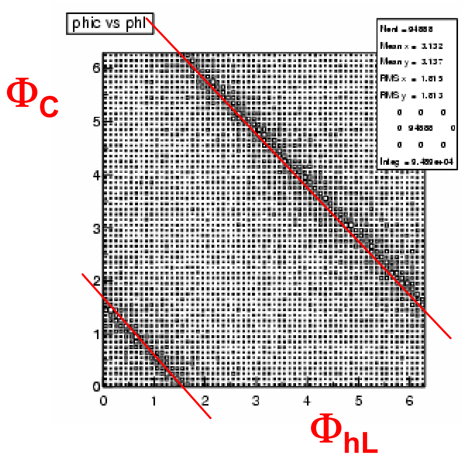
there is no correlation between the Collins angle Φ_C and $\Phi_{\mu L}$, the muon azimuthal angle in the laboratory

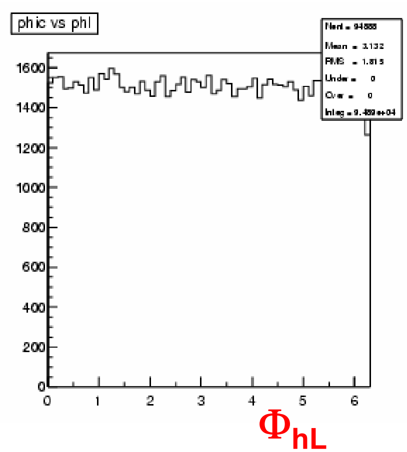
BUT

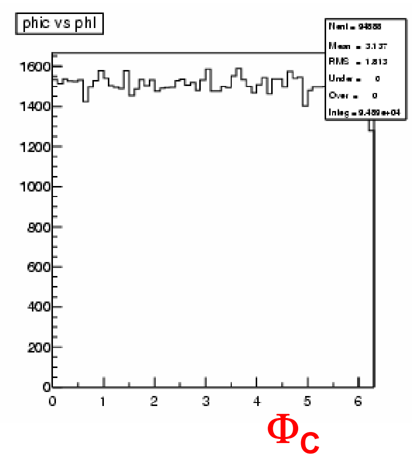
there is a clear correlation between the Collins angle Φ_C and Φ_{hL}, the muon azimuthal angle in the laboratory

→ a non uniform acceptance in Φ_{hL} gives an asymmetry in the Φ_C distribution

→ the extraction of ε from $< \sin \Phi_C >$ can be affected by large systematic errors







Lepto events (no acceptance)

$$N_h^{\pm} = N_h^0 \cdot [1 \pm \varepsilon \cdot \sin \Phi_C]$$

a specific study was performed to understand the reason of the correlation and to single out the events not affected by this correlation

3. Leading particle effects

Present problems in COMPASS:

1. **π^0 not detected (known)**
2. **more limited angular acceptance (large x)**

⬇

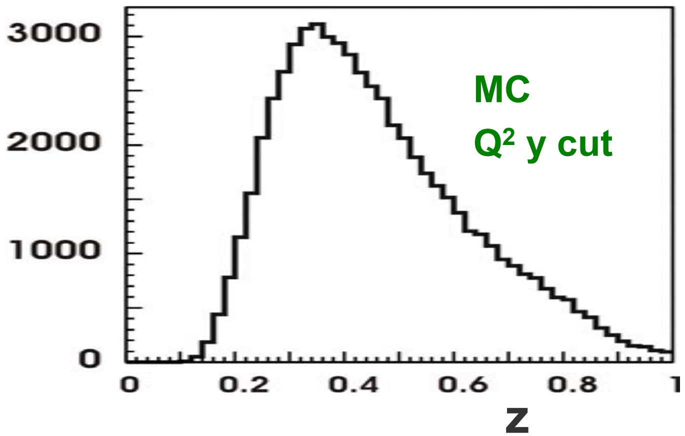
the most energetic reconstructed particle not necessarily is the leading particle

Collins asymmetry is expected to change sign when going from leading to subleading particle

NB possibility to distinguish from Sivers effect

3. MonteCarlo -
z distribution of the "leading" hadron

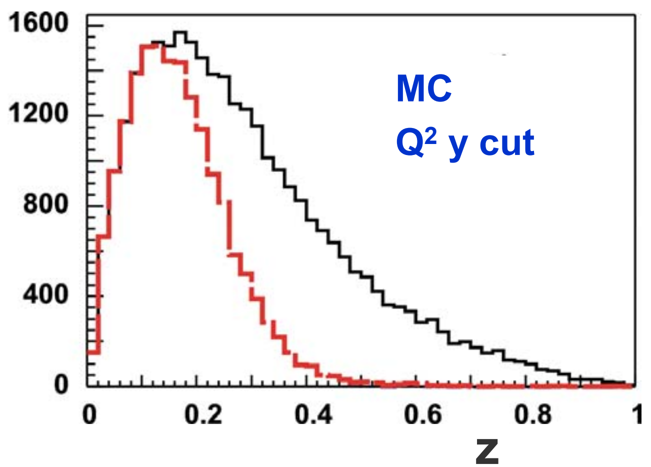
generated leading hadron



generated "leading" hadrons

- acceptance
- reconstruction efficiency
- leading π^0

reconstructed "leading" hadron

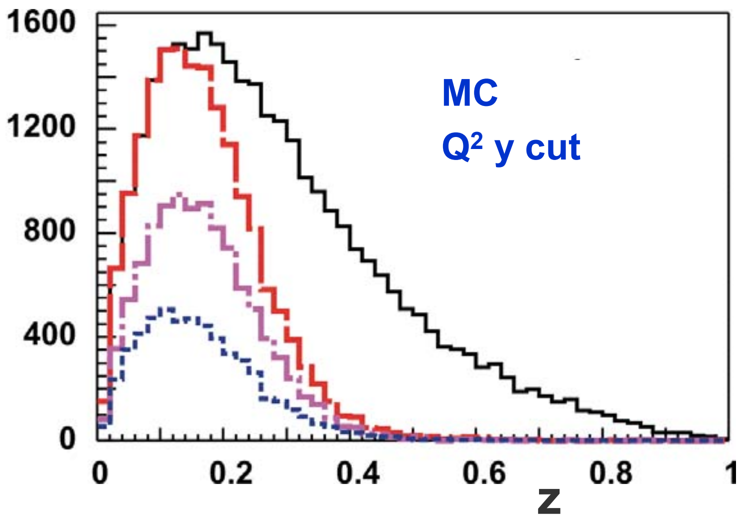


reconstructed "leading" hadrons

wrongly reconstructed "leading" hadron:

the reconstructed "leading" hadron is not the generated leading hadron

3. MonteCarlo - z distribution of the "leading" hadron (cont.)



reconstructed "leading" hadrons

wrongly reconstructed "leading" hadron: sum of

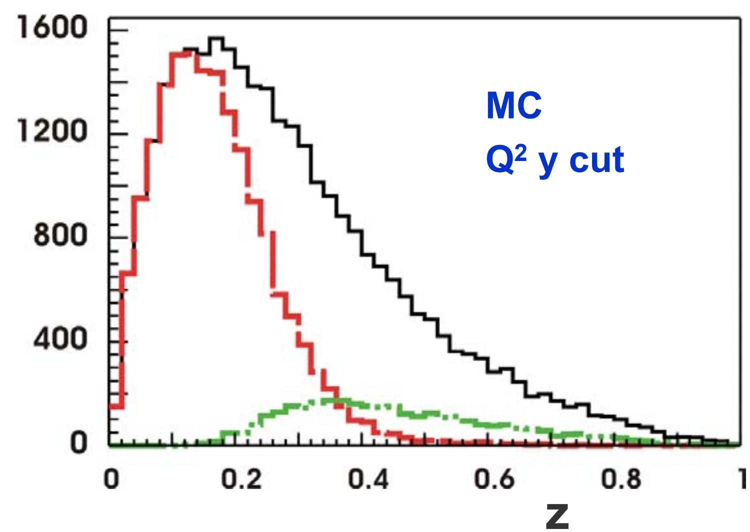
generated neutral leading particle (π^{0}: known problem since proposal)

generated charged leading hadron outside acceptance (SMC magnet)

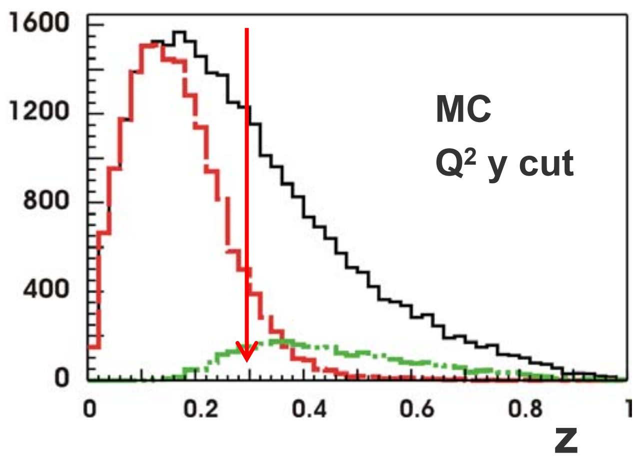
$\Delta\varepsilon_{syst} \sim N_w/N_{tot}$

also, there are events in which the leading hadron is correctly reconstructed but it is not a charged π

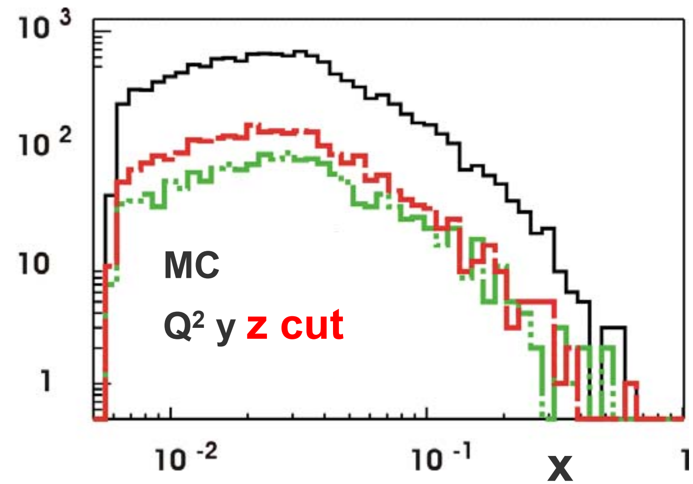
$\Delta\varepsilon_{syst} \sim N_{np}/N_{tot}$



3. MonteCarlo -
z distribution of the “leading” hadron (cont.)

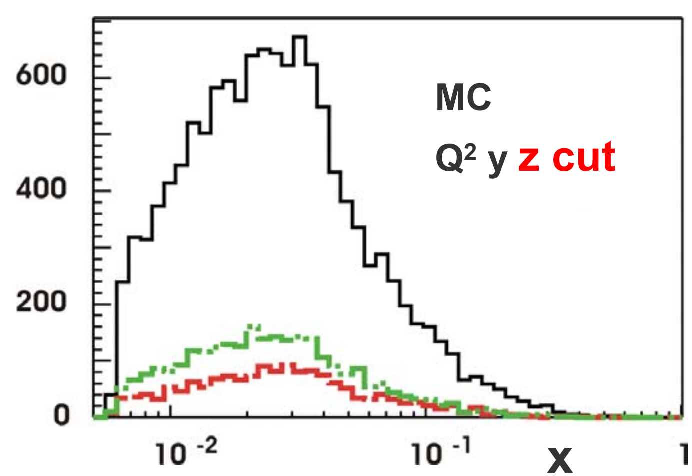


reconstructed“leading” hadrons
wrongly reconstructed “leading” hadron
leading hadron correctly reconstructed but not a charged π



a cut z > 0.3 reduces the contamination from wrongly reconstructed leading hadron (~55% → ~13%)

to indentify the events in which the correctly reconstructed leading hadron is not a pion (20%): **RICH1**



Status of the analysis

2002 data

November 2002: pre-processing of ~ 2/3 of the transverse target polarization data ("DST3")

→ preliminary distributions in agreement with MC

→ projected statistical errors

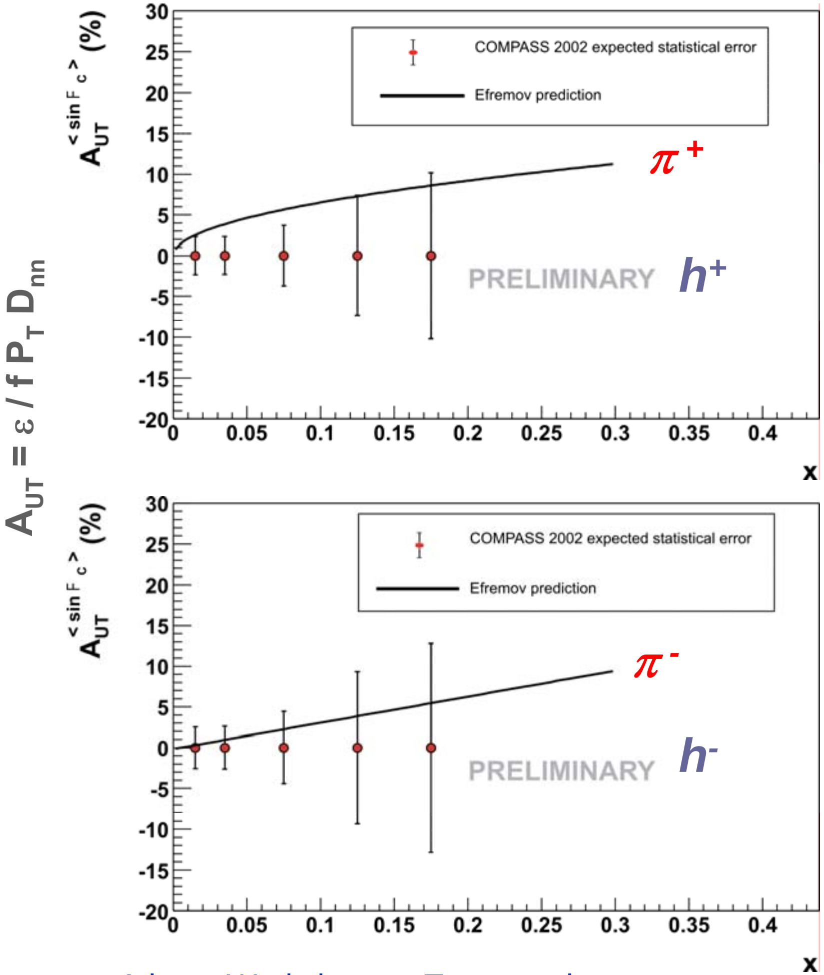
August-September 2003: all transverse target polarization data processed with a better version of the reconstruction program ("DST4")
→ no results yet

2003 data

only samples of data have been looked at in so far (the run is finished the 17th of September)

Hints from 2002 “DST3” analysis

Expected statistical errors for positive and negative hadron asymmetries from 2002 data compared with Efremov predictions



estimation based on the pre-processing of 2/3 of 2002 data

with:

- the higher reconstruction efficiency of the program used to produce the 2002 DST4
- the better trigger and PID performances during 2003 run

we can expect at least a factor of two in the statistical errors at larger x

Summarizing

- **from 2002 deuterium data a 5σ signal was expected**

  ANALYSIS: WORK IN PROGRESS

  RESULTS IN FEW MONTHS ….

- **in 2003 same statistics with better trigger and PID than in 2002**

- **in 2004**

  - COMPASS magnet (?) → large acceptance at large x

  - twice as much beam time

- **proton data probably only in 2007**