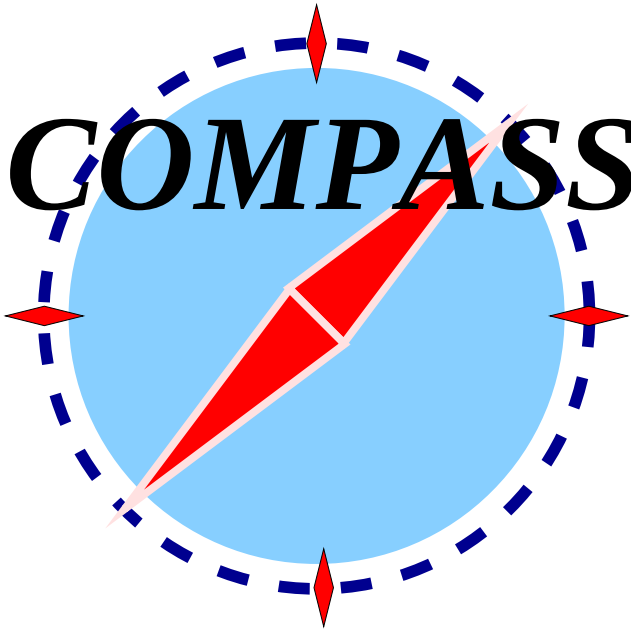


Spin physics in COMPASS.

A.Korzenev[a]

Mainz University

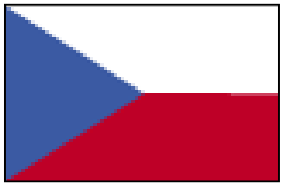
January 19, 2004

- Introduction.
- Spectrometer.
- Event reconstruction.
- Physics analysis.

[a] on leave from JINR

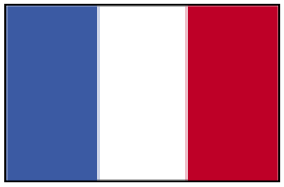
INTRODUCTION

More than 220 physicists from 30 institutes



Prague(CU,CUT, TUL)

Helsinki



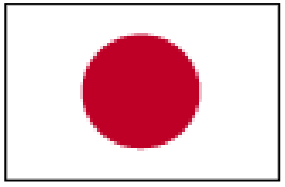
Saclay

Bielefeld
Bochum
Bonn(ISKP&PI)
Erlangen
Freiburg
Heidelberg
Mainz
Munchen(LMU,TU)

Burdwan
Calcutta

TelAviv

Torino (University & INFN)
Trieste (University & INFN)

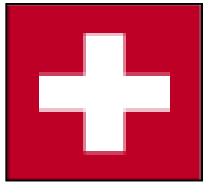


Nagoya

Warsaw (SINS & TU

Lisbon

Dubna
Moscow(INR,LPI, State University)
Protvino

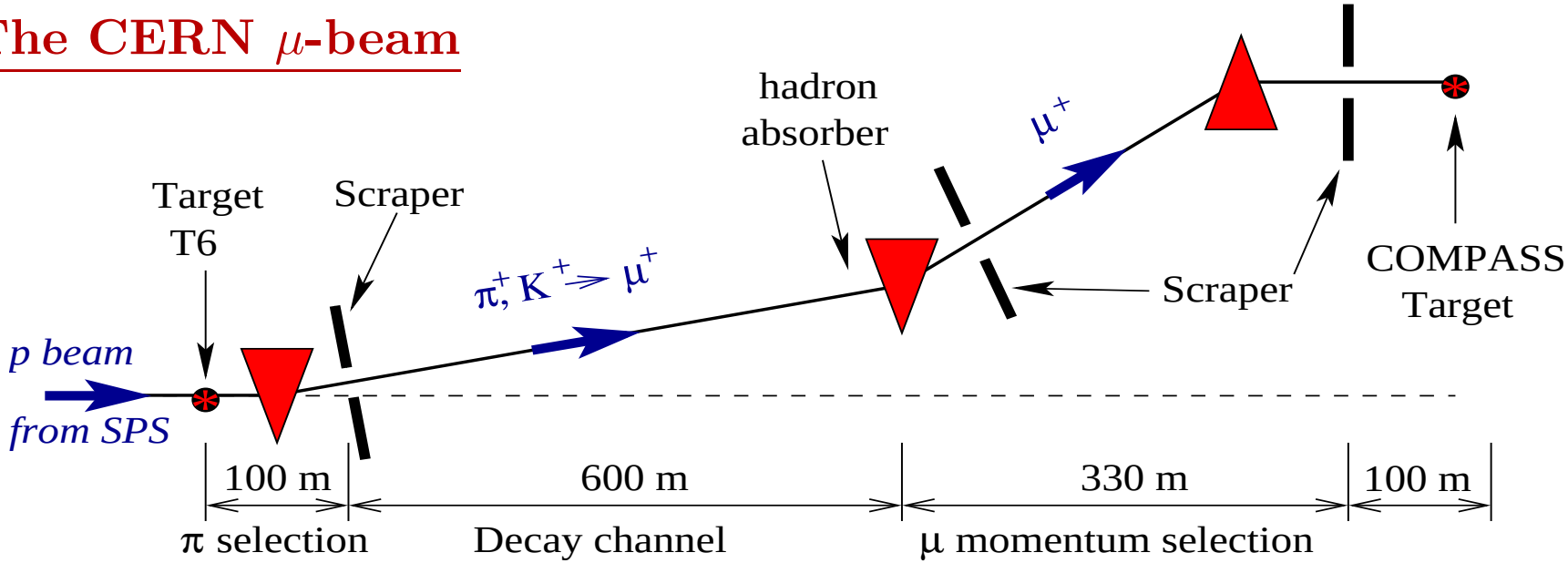


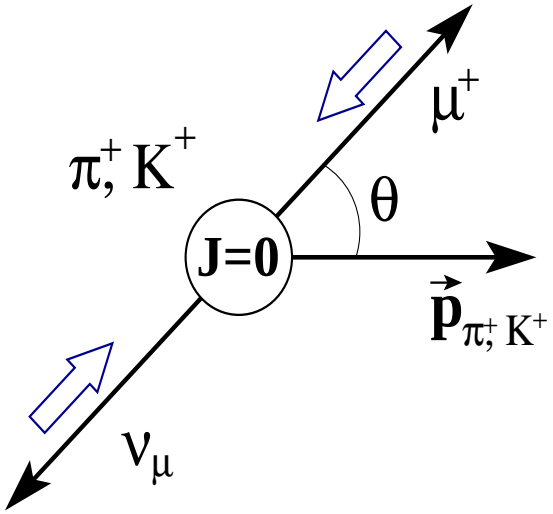
CERN

Physics goals

- Spin physics with muon beam
  - $\Delta G/G$ from high p_T hadrons and open charm production
  - Quark flavor separation via semi-inclusive analysis
  - Transverse quark distribution $\Delta_T q$ via single spin asymmetry
  - Λ and $\bar{\Lambda}$ polarization
  - Exclusive vector meson production
- Physics with hadron beam
  - Primakoff effect
  - Exotic QCD states (glueballs, hybrids)
  - Doubly charmed baryons

The CERN μ-beam

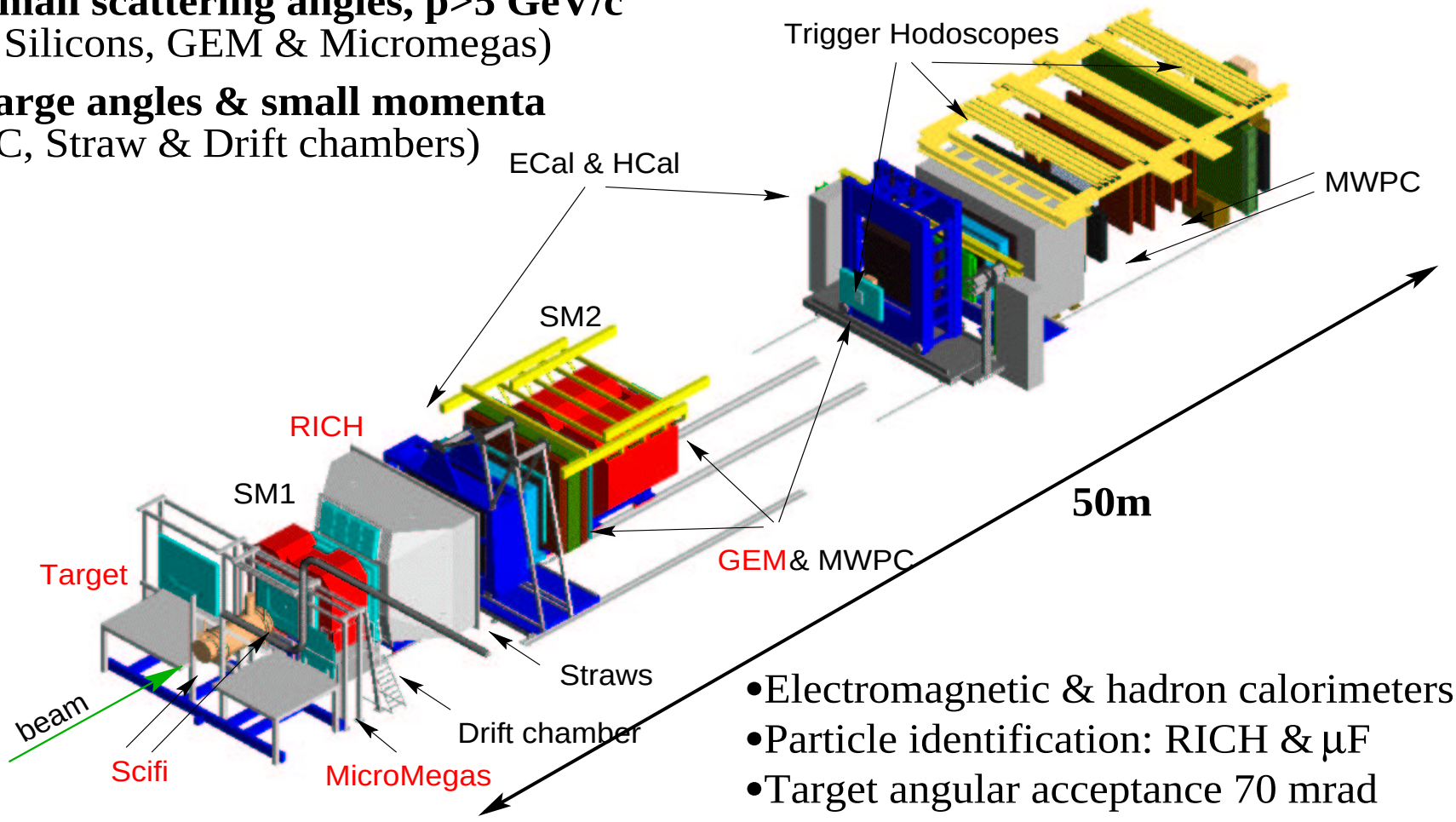




- Energy 160 GeV
- 5s spill every 14.4s
- Intensity $2 \cdot 10^8$ μ/spill
- Natural polarization due to parity violation in the week decay of parent hadrons P_μ =-76%

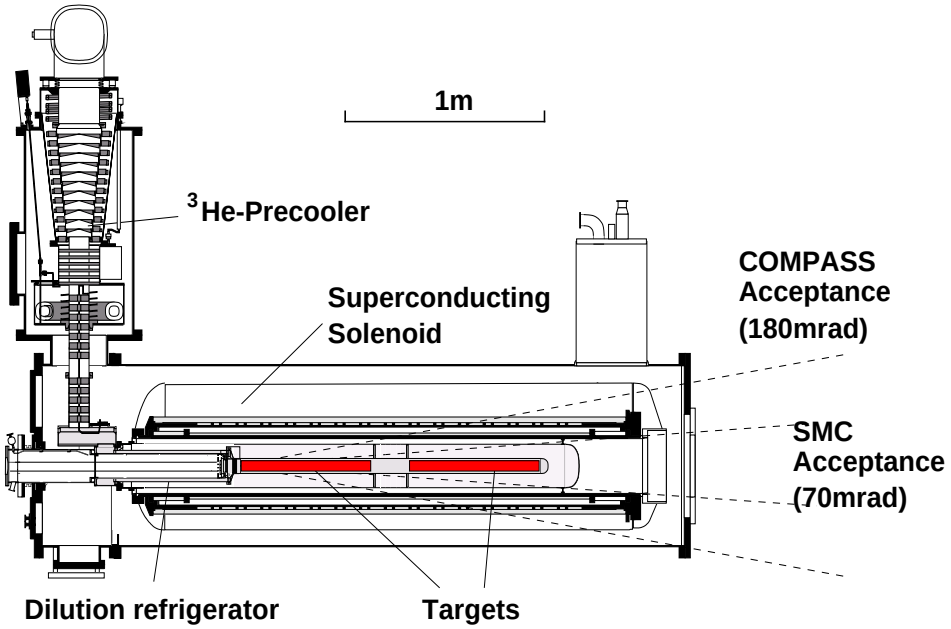
COMPASS SPECTROMETER

- **Spectrometer with 2 stages**
  (SM1: 1Tm, SM2: 4.4 Tm)
- **SAS: small scattering angles, p>5 GeV/c**
  (SciFi, Silicons, GEM & Micromegas)
- **SAS: large angles & small momenta**
  (MWPC, Straw & Drift chambers)



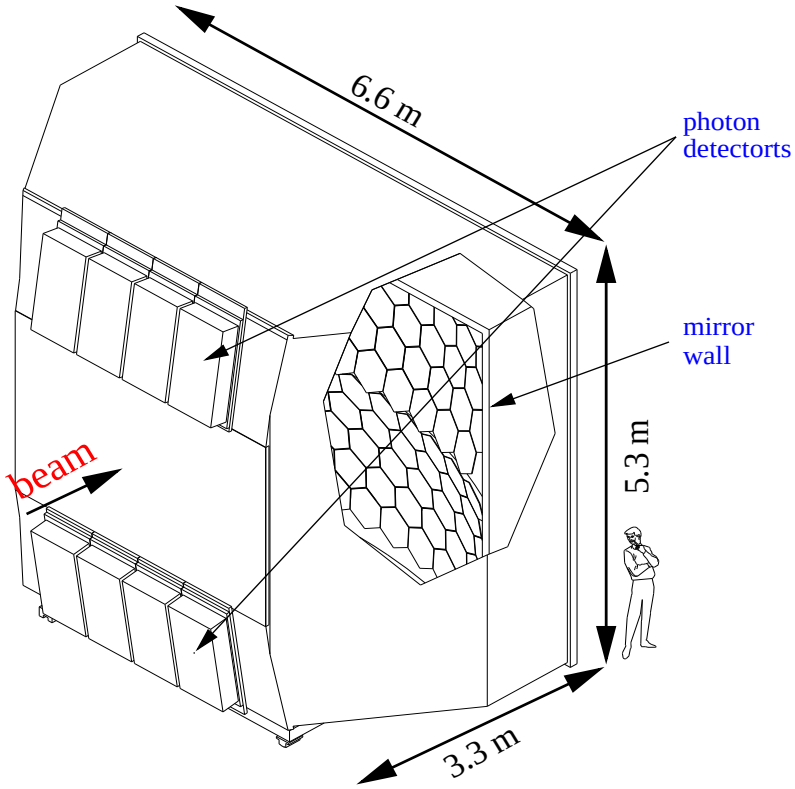
- Electromagnetic & hadron calorimeters
- Particle identification: RICH & μF
- Target angular acceptance 70 mrad

The Polarized Target

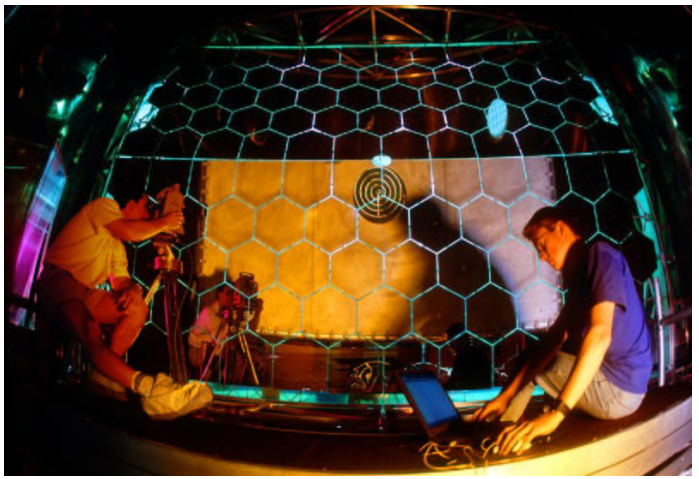


- Two 60 cm long target cells with opposite polarization
- Target material ^{6}LiD
  - Maximum polarization: 57%
  - Dilution factor: $\sim$50%
- 2.5 T solenoid field (homogeneity: $\pm 1.5 \cdot 10^{-5}$)
- ^{3}He/^{4}He dilution refrigerator ($T_{min} \approx$50 mK)
- SMC magnet is currently used
  - Hadron acceptance: 70 mrad

RICH characteristics



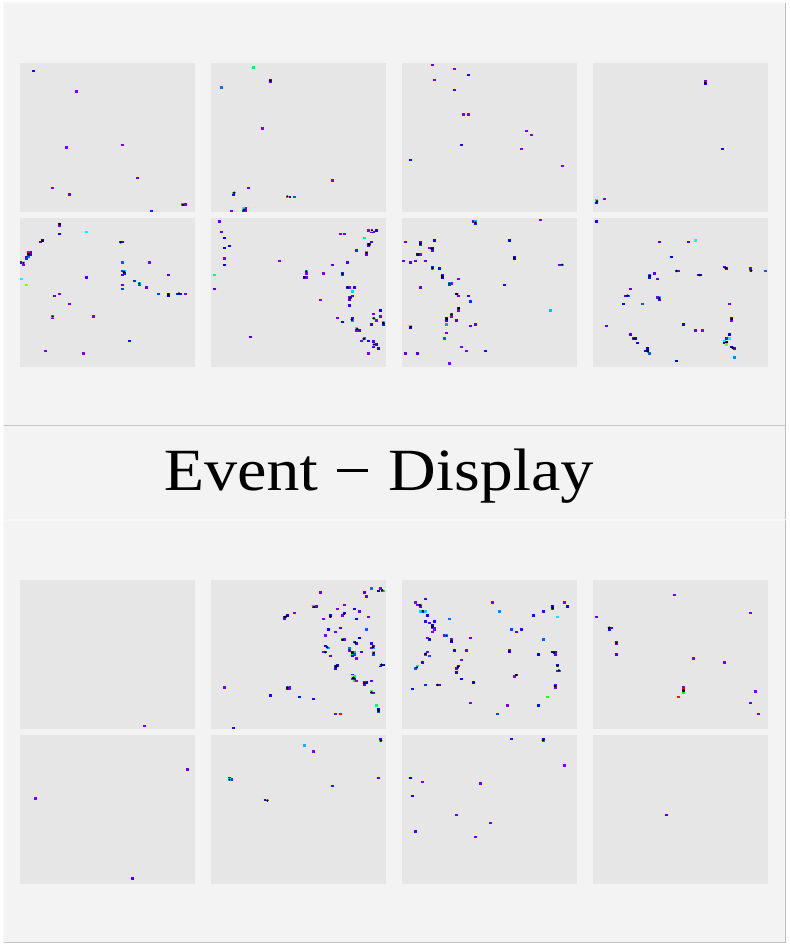
- Two segmented spherical mirrors.
- Photon detectors are MWPC's with CsI photocathodes. Total active surface 5.3 m^2. Pad size 8×8 mm^2.
- Analog 2D read-out.
- Radiator gas C_4F_{10} for momenta 3-65 GeV.

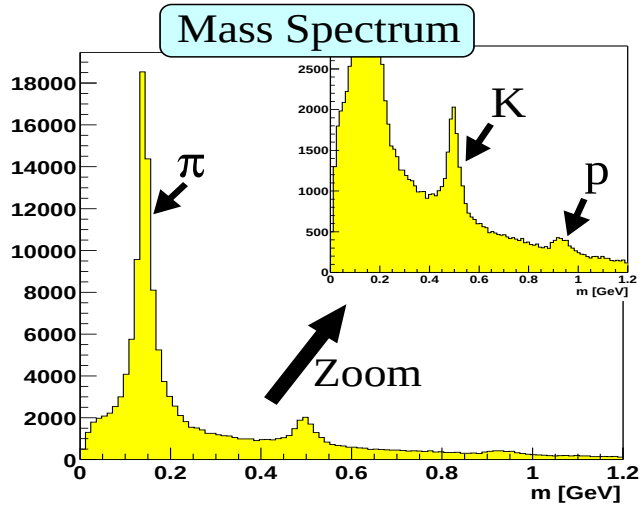


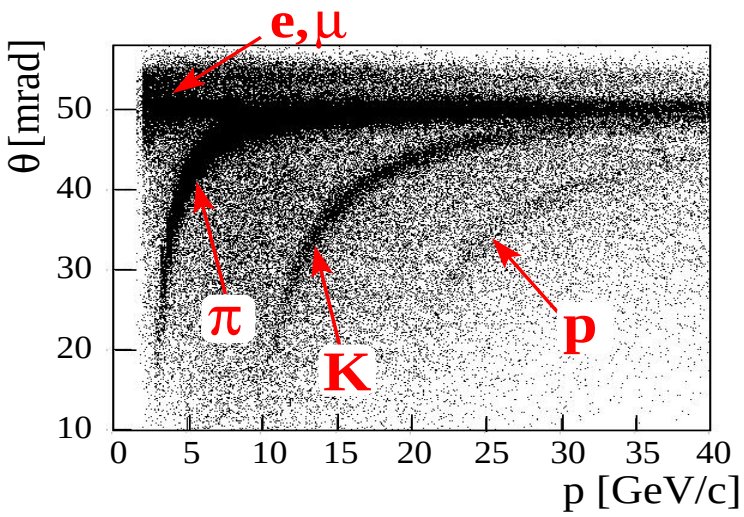
Performance:

- Angular resolution $\sigma_{1\gamma}$=1.4 mrad.
- Photons per ring $\langle n_\gamma \rangle = 14$

RICH PID performance



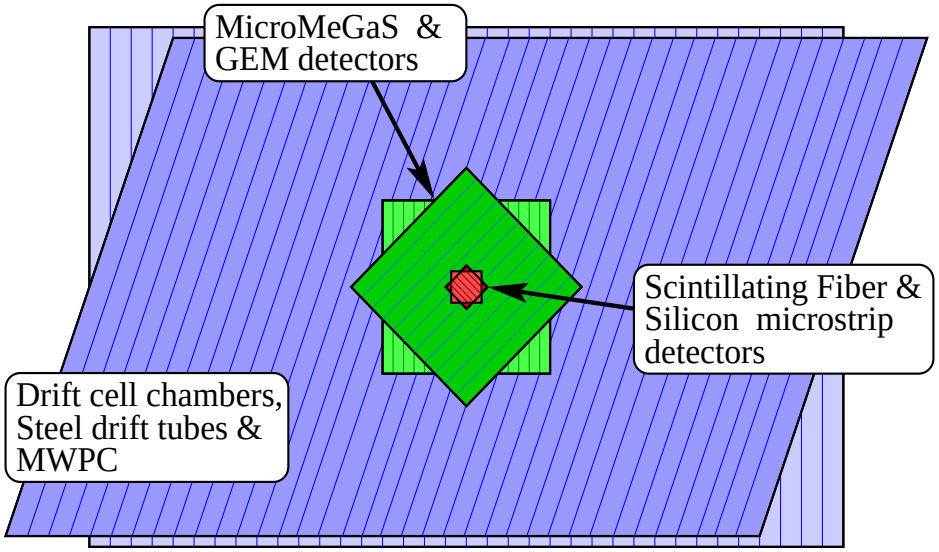




Detectors positioning

Particle rate is highest on the beam axis and decreases outward ⇒

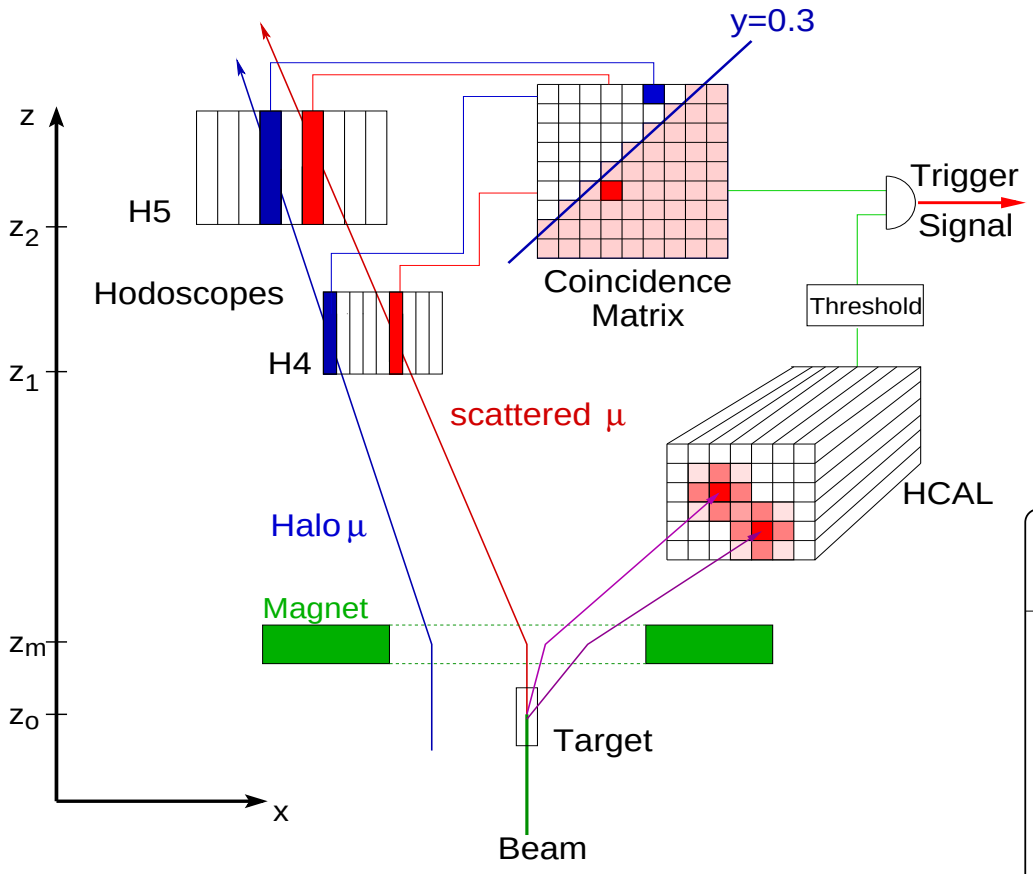
- Tracking system is subdivided into a set of nested detectors of increasing rate capabilities.
- Large aperture detectors are protected against high rate either by physical hole or by deactivation of the central region.



	Silicon microstrips	Scintillating Fibers	Micro-MeGas	GEM	Drift chambers	Straw
resolution	15 μm	150 μm	70 μm	70 μm	170 μm	270 μm

Size →

Trigger concept



- hodoscope time resolution 130 ps.
- 32x32 coincidence matrix.
- coincidence width < 3ns.

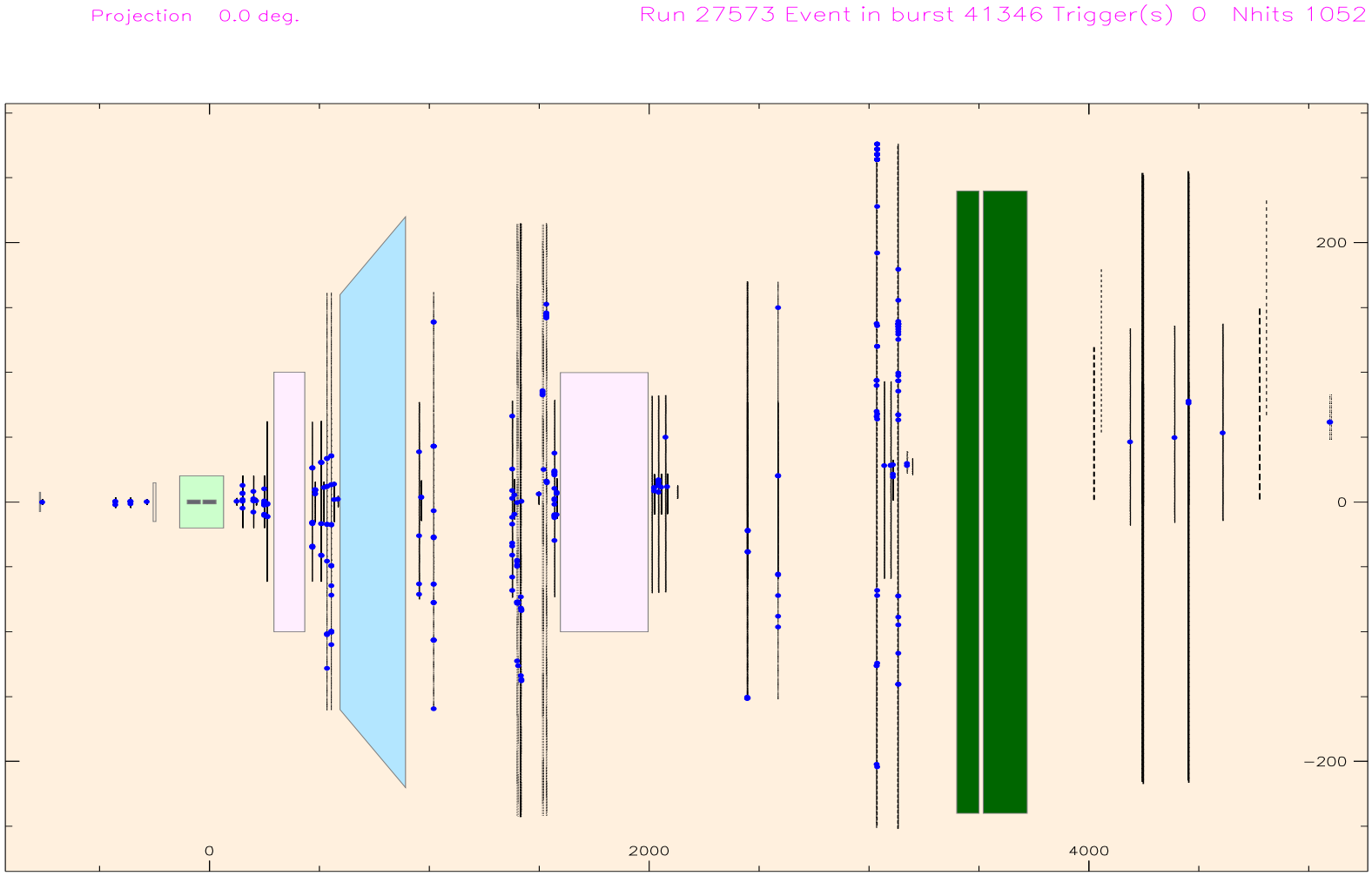
Inclusive triggers ($Q^2 > 0.5$ (GeV/c)^2)

- geometric property of scattered μ

Semi−inclusive triggers ($Q^2 < 5$ (GeV/c)^2)

- geometric property of scattered μ
- minimal energy deposition in hadron calorimeter to reject
  1. radiative events
  2. μ *e* scattering
  3. events with low energy halo tracks

EVENT RECONSTRUCTION



TRAFFIC (version 1.71) event display

(071)

Track finding program

Pattern Recognition

Selection of group of clusters which seems consistent with belonging to a straight line

1. reconstruction in projections.
2. reconstruction in space.
3. straight line fit of track segments without multiple scattering.

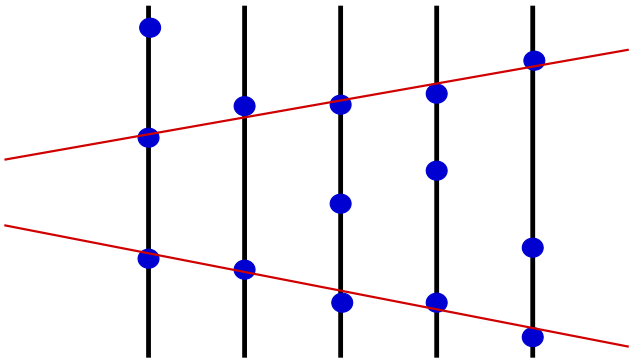
Track Bridging

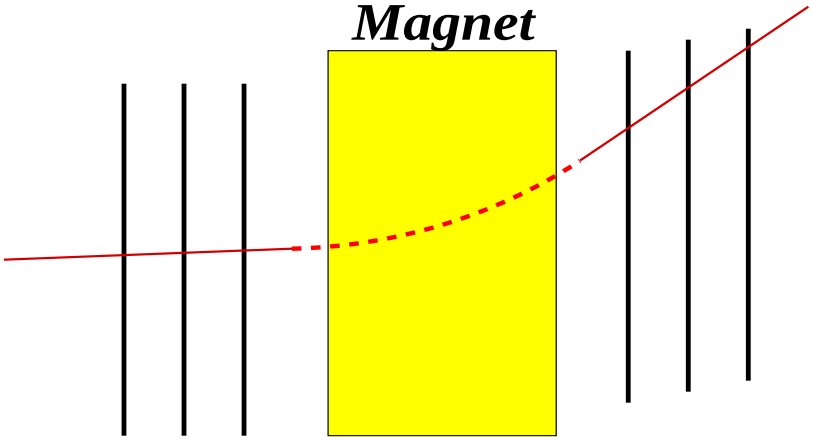
Joining of track segments from different zones into one track

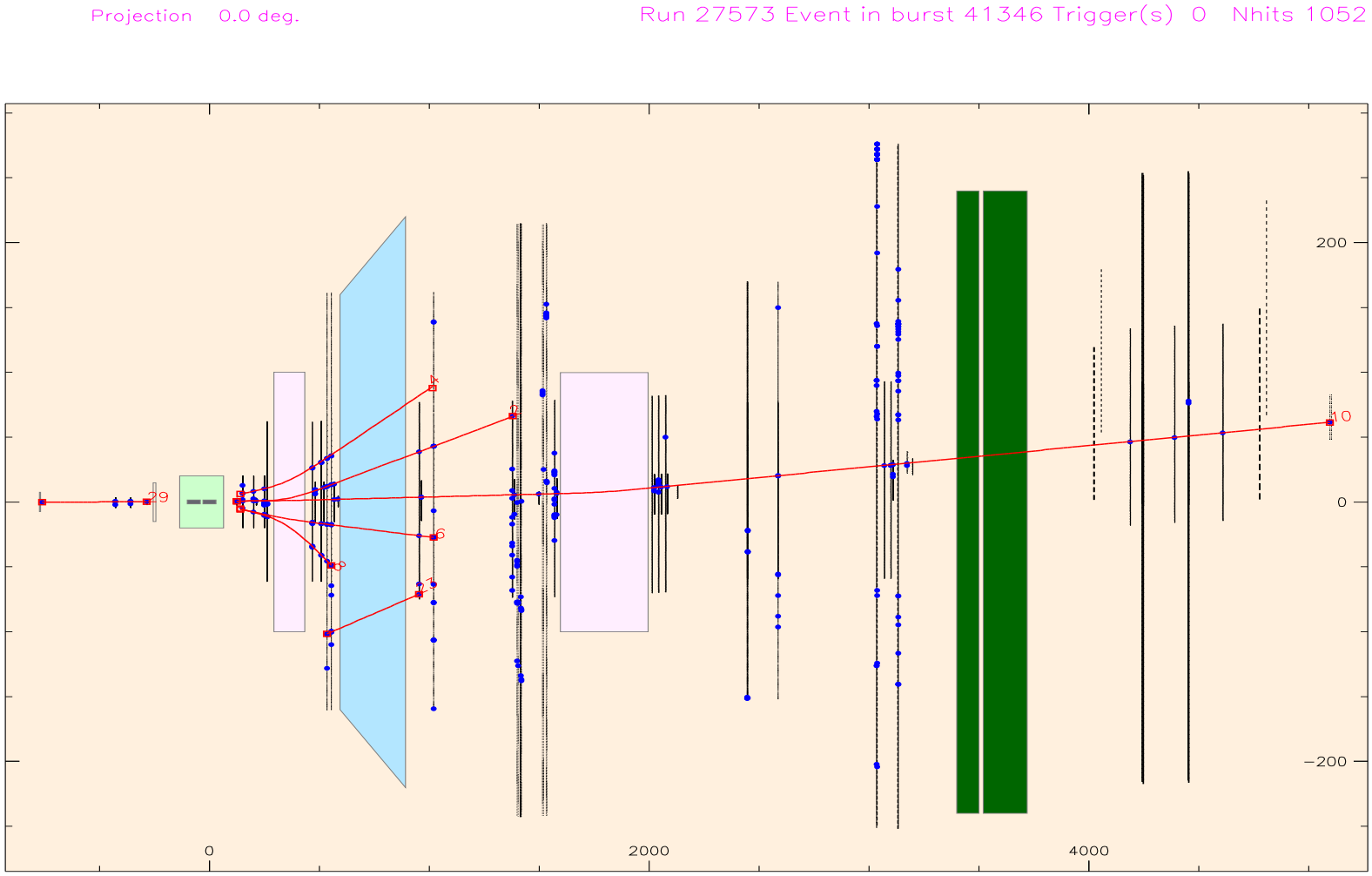
1. bridging through magnets
2. bridging through thick material (hadron absorber).

Track Fitting

Final fit of tracks in mag− netic field taking into account multiple scattering.



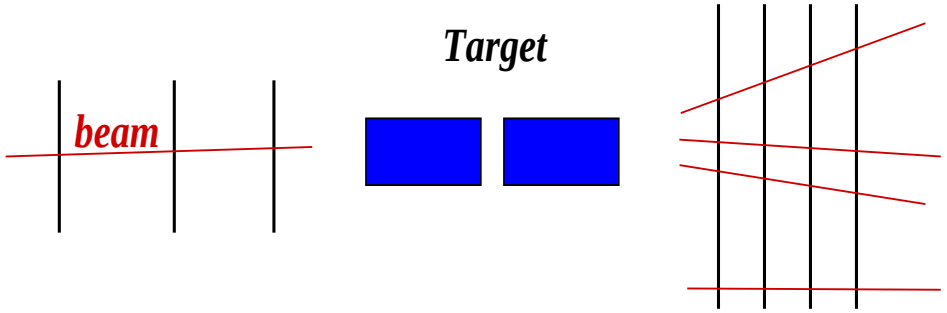




TRAFFIC (version 1.71) event display

(071)

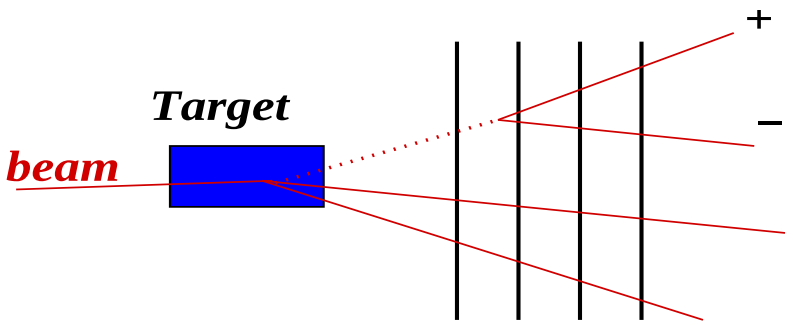
Search for primary interaction and V0 decay points



- Fit with constraint on intersection of all tracks in one point is used.
- V0 is a neutral particle which decay into to charged.

$$K_S^0 \rightarrow \pi^+ \pi^-$$
$$\Lambda \rightarrow p \pi^-$$

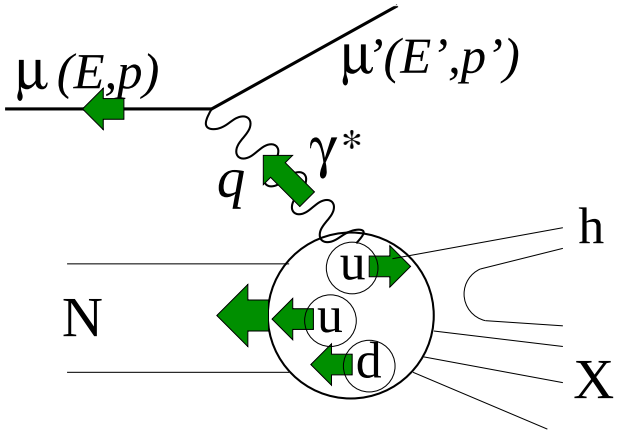
- Estimation of the vertex position.
- Estimation of momentum of all tracks at the vertex.
- Rejection of tracks belonging to another vertices or to background.



PHYSICS ANALYSIS

- $\Delta G/G$ from high p_T hadrons
- Open charm production
- Quark flavor separation via semi-inclusive analysis
- Transversity
- Λ and $\bar{\Lambda}$ polarization
- Exclusive vector meson production

Nucleon Spin Puzzle



Static Quark Model	$\Delta\Sigma = 1$
Baryons week decays	$\Delta\Sigma = 0.58 \pm 0.03$ assuming $\Delta s = 0$
DIS	$\Delta\Sigma = 0.24 \pm 0.03$ $\Delta s = -0.11 \pm 0.01$

Due to axial anomaly $\Delta\Sigma$ interpretation is difficult: $\Delta\Sigma \to \Delta\Sigma - \frac{3\alpha_s}{2\pi}\Delta G$

- Nucleon Spin

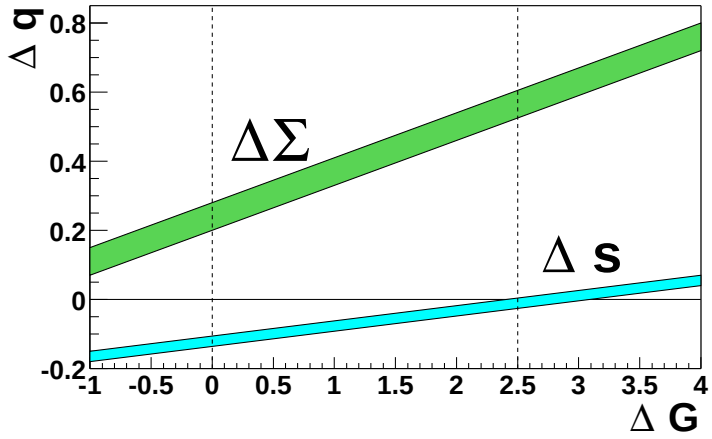
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \langle L_z \rangle$$

ΔG - gluon contribution.

$\langle L_z \rangle$ - orbital angular momentum of q and G.

$\Delta\Sigma$ - quarks spin.

$$\Delta\Sigma = \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}$$



Double-Spin asymmetry

- Polarized DIS cross section in one-photon exchange approximation

$$\sigma = \bar{\sigma} \pm \frac{1}{2}\Delta\sigma$$

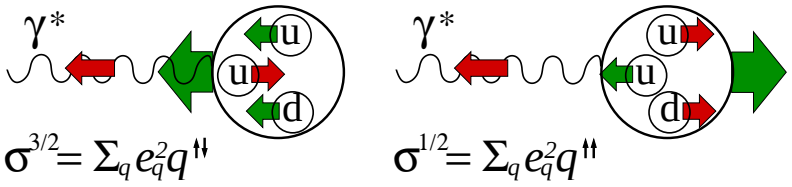
- Structure functions

$$\begin{aligned} \bar{\sigma} &= aF_1(x,Q^2) + bF_2(x,Q^2) \\ \Delta\sigma &= \alpha g_1(x,Q^2) + \beta g_2(x,Q^2) \end{aligned}$$

- Double spin asymmetry in case of longitudinally polarized beam and target

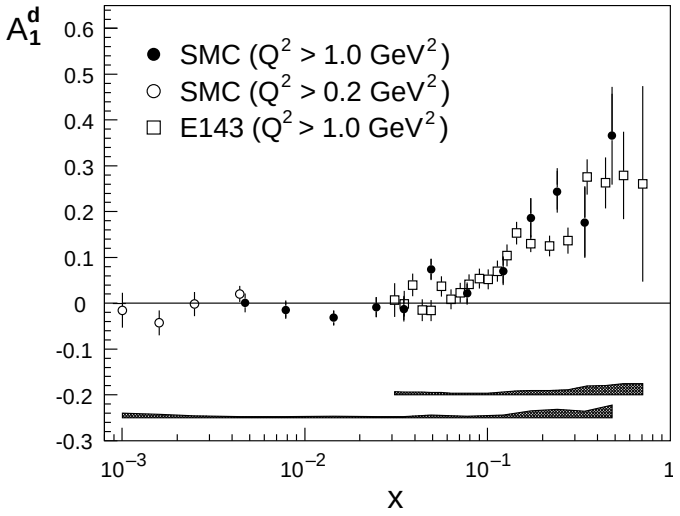
$$A_{||} = \frac{\Delta\sigma_{||}}{2\bar{\sigma}}, \qquad A_1 \simeq D A_{||}$$

- Virtual photon - proton asymmetry A_1:



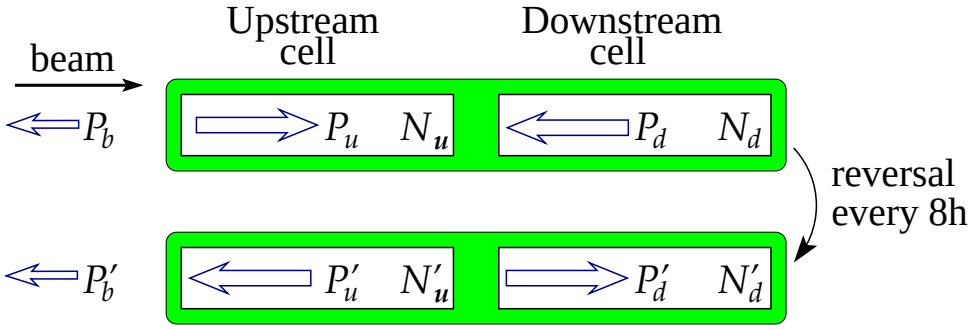
$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{\sum_q e_q^2 \Delta q}{\sum_q e_q^2 q}$$

- Measured in many experiments



Asymmetry extraction

$$N_u = a_u \Phi n_u \bar{\sigma}(1 + f P_b P_u A_{||})$$
$$N_d = a_d \Phi n_d \bar{\sigma}(1 - f P_b P_d A_{||})$$
$$N'_u = a'_u \Phi' n_u \bar{\sigma}(1 - f P_b P'_u A_{||})$$
$$N'_d = a'_d \Phi' n_d \bar{\sigma}(1 + f P_b P'_d A_{||})$$



$$A_{raw} = \frac{N_u - N_d}{N_u + N_d} = \frac{a_u n_u - a_d n_d + f P_b (a_u n_u P_u + a_d n_d P_d) A_{||}}{a_u n_u + a_d n_d + f P_b (a_u n_u P_u - a_d n_d P_d) A_{||}}$$

$$A'_{raw} = \frac{N'_u - N'_d}{N'_u + N'_d} = \frac{a'_u n_u - a'_d n_d - f P_b (a'_u n_u P'_u + a'_d n_d P'_d) A_{||}}{a'_u n_u + a'_d n_d - f P_b (a'_u n_u P'_u - a'_d n_d P'_d) A_{||}}$$

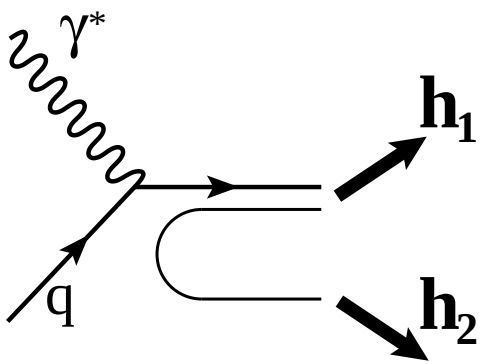
can be neglected assuming $a_u \approx a_d$

$$A_{||} = \frac{1}{f P_b P_t} \frac{1}{2} (A_{raw} - A'_{raw}) - A_{||}^{false}$$

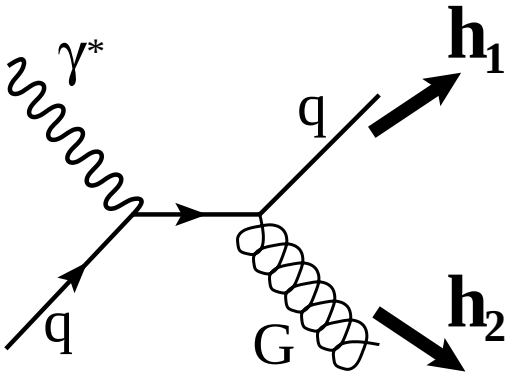
$$A_{||}^{false} = \frac{1}{f P_b P_t} \frac{1}{2} \left(\frac{r-1}{r+1} - \frac{r'-1}{r'+1} \right)$$

$$r = \frac{a_u n_u}{a_d n_d}$$

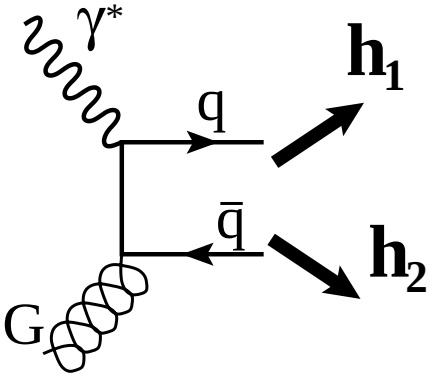
$\Delta G/G$ from high p_t pairs



Leading process



Gluon radiation (Compton)



Photon Gluon Fusion

Measured asymmetry:

$$A = \frac{N_{\uparrow\downarrow} - N_{\uparrow\uparrow}}{N_{\uparrow\downarrow} + N_{\uparrow\uparrow}} = P_\mu P_T f A^{\mu N \to hhN}$$

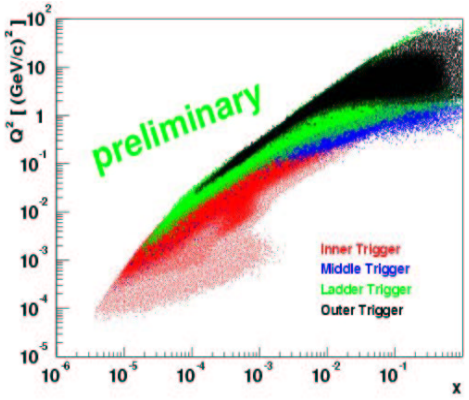
$$A^{\mu N \to hhN} = A_1 \langle a_{LL} \rangle^{LP} R_{LP} + A_1 \langle a_{LL} \rangle^{GR} R_{GR} + \frac{\Delta G}{G} \langle a_{LL} \rangle^{PGF} R_{PGF}$$

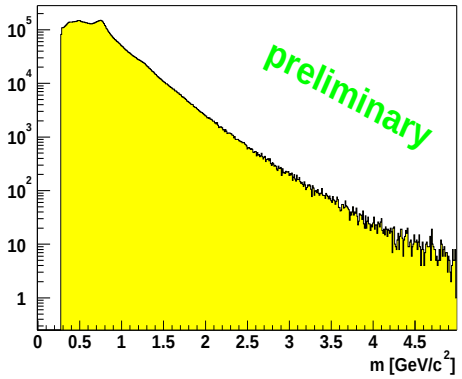
$\langle a_{LL} \rangle^{process}$ is analyzing power of process.

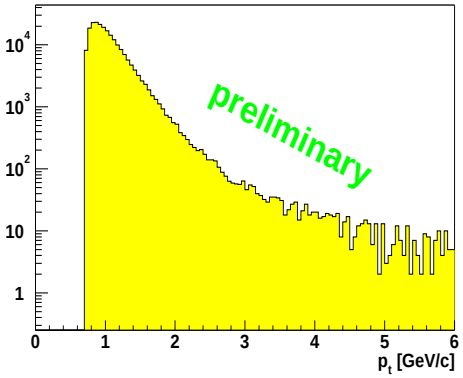
$$A_1 = g_1/F_1$$

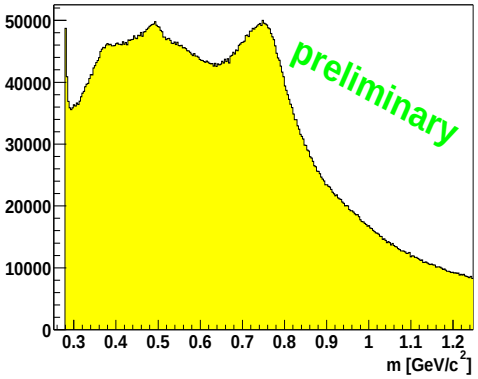
$$R_{process} = \sigma_{process}/\sigma_{total}$$

$\Delta G/G$ from high p_t pairs









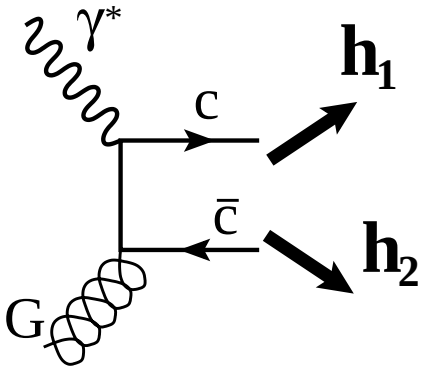
- μ, μ'+2 hadrons
- in plots only 5% of 2002
- Statistics of 2002 data:

$Q^2 > 1$ GeV^2	18K ev
all Q^2	160K ev

- Accuracy:

$Q^2 > 1$ GeV^2	$\delta(\frac{\Delta G}{G}) \approx 0.3$
all Q^2	$\delta(\frac{\Delta G}{G}) \approx 0.1$

Open charm production



$$D^{*+} \to D^0 \pi_s^+ \quad \hookrightarrow K^-\pi^+$$

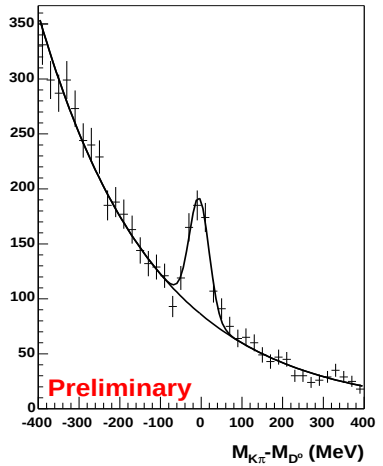
$$D^{*-} \to \bar{D}^0 \pi_s^- \quad \hookrightarrow K^+\pi^-$$

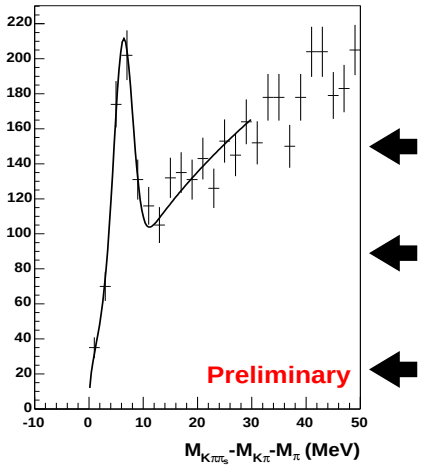
$$\Delta M_{K\pi\pi} = M_{K\pi\pi_s} - (M_{K\pi} + M_{\pi_s})$$

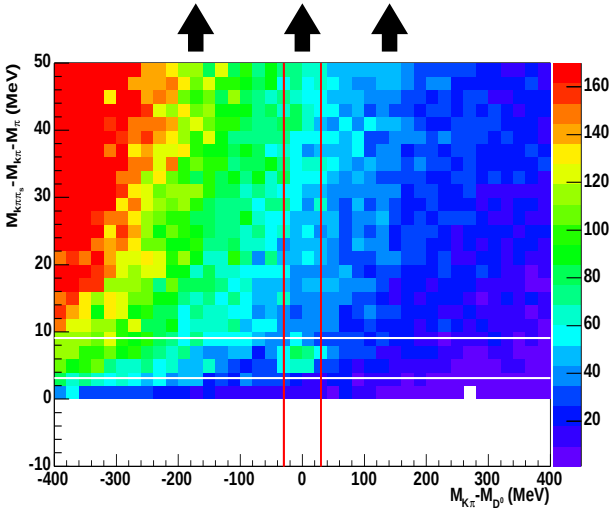
- $3.1 < \Delta M_{K\pi\pi} < 9.1$ MeV
- statistics: 317 D^0 tagged by D^*.

Data 2002. Selection cuts:

- $z_{D^0} > 0.2$.
- $|\cos(\theta^*)| < 0.85$
- $10 < p_k < 35$ GeV



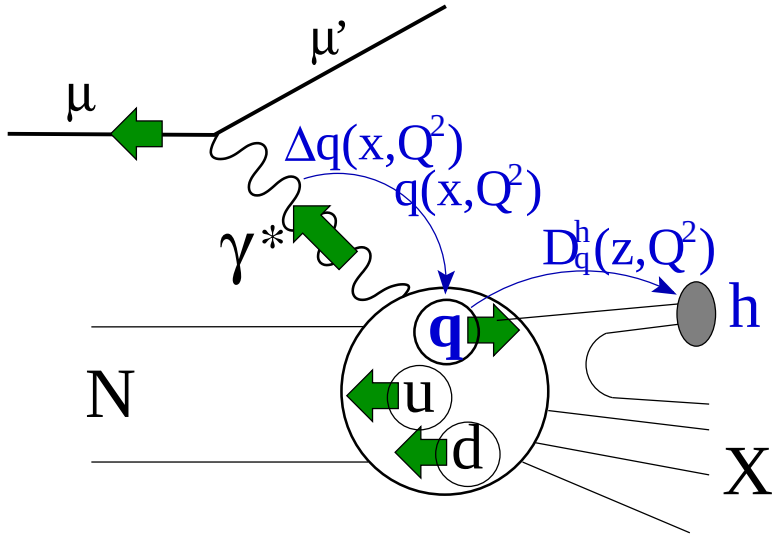




Flavor separation via semi-inclusive asymmetries

- Inclusive Asymmetry:

$$A_1 = \frac{\sigma_{\uparrow\downarrow} - \sigma_{\uparrow\uparrow}}{\sigma_{\uparrow\downarrow} + \sigma_{\uparrow\uparrow}} \overset{\mathbf{LO}}{=} \frac{\sum_q e_q^2(\mathbf{\Delta q(x)} + \mathbf{\Delta \bar{q}(x)})}{\sum_q e_q^2(q(x) + \bar{q}(x))}$$

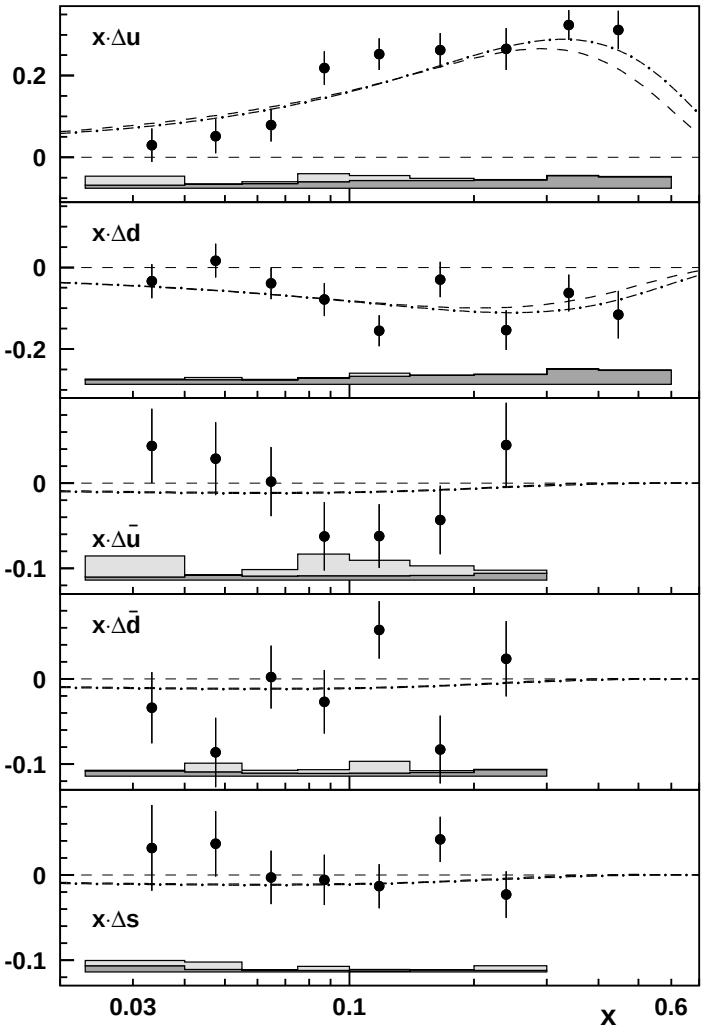


- Semi-Inclusive Asymmetry:

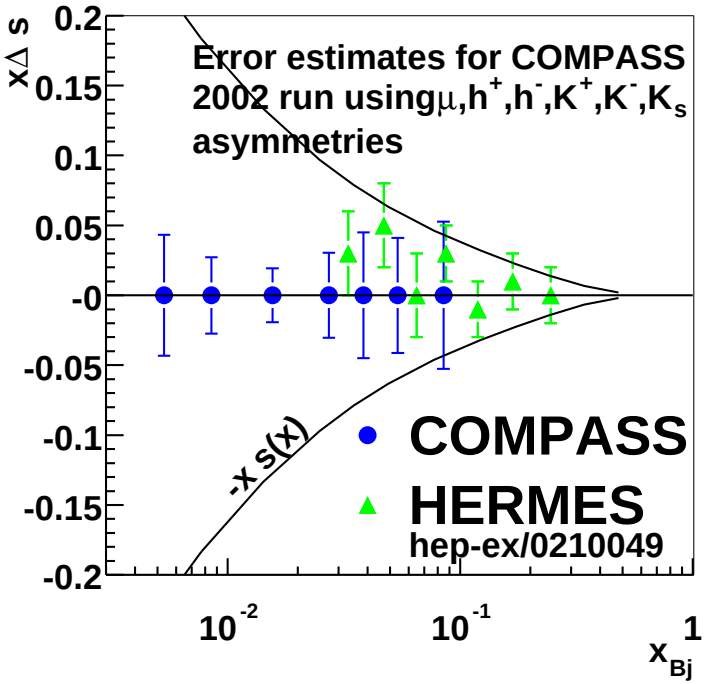
$$A_1^h = \frac{\sigma^h_{\uparrow\downarrow} - \sigma^h_{\uparrow\uparrow}}{\sigma^h_{\uparrow\downarrow} + \sigma^h_{\uparrow\uparrow}} \overset{\mathbf{LO}}{=} \frac{\sum_q e_q^2(\mathbf{\Delta q(x)} \int D_q^h dz + \mathbf{\Delta \bar{q}(x)} \int D_{\bar{q}}^h dz)}{\sum_q e_q^2(q(x) \int D_q^h dz + \bar{q}(x) \int D_{\bar{q}}^h dz)}$$

- Due to isospin symmetry of *deuteron* only $\{\Delta u + \Delta d, \Delta \bar{u} + \Delta \bar{d}, \Delta s\}$ can be extracted assuming $\Delta s = \Delta \bar{s}$.
- If combined with data from *proton* target full flavor separation is possible.

Quark flavors separation

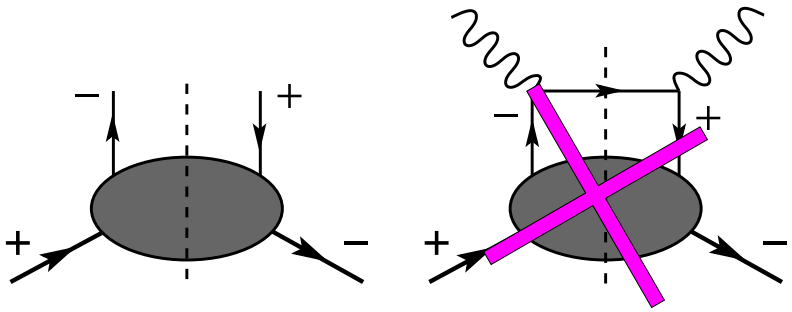


- HERMES: hep-ex/0307064
- Low x region is important
- COMPASS limit with $Q^2 > 1$ GeV^2 is $x_{min} = 0.003$

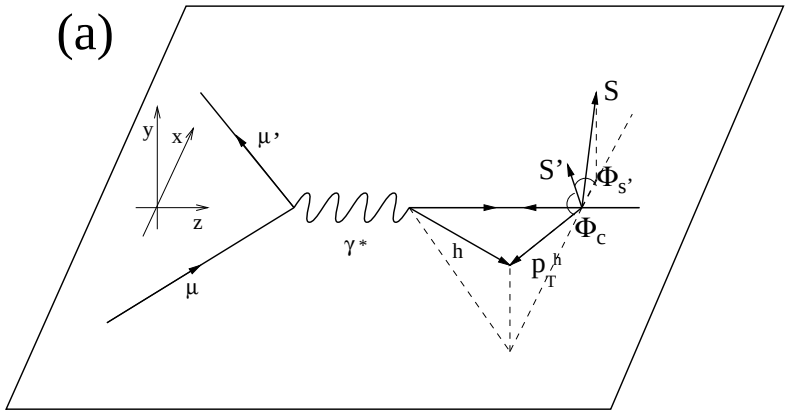


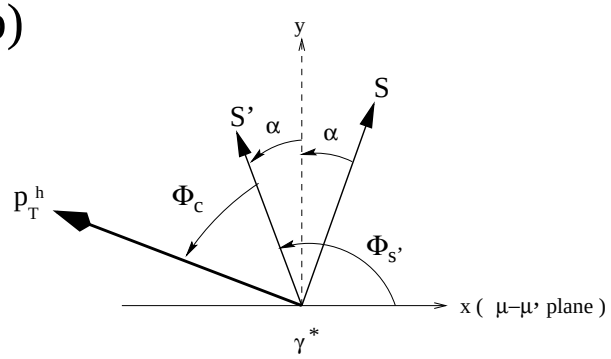
Transversity and Collins asymmetry

- PDF $q(x)$, $\Delta q(x)$, $\Delta_T q(x)$ ($f_1(x)$, $g_1(x)$, $h_1(x)$) fully describe the nucleon structure at twist-2 level.
- $f_1(x)$ and $g_1(x)$ are measured in inclusive DIS.
- $h_1(x)$ is chiral odd (helicity flip), so requires associative hadron production.



- In polarized semi-inclusive DIS chiral odd $H_1^\perp$ is coupled to h_1. It affects azimuthal dependence of cross section.





Transversity and Collins asymmetry

- Experimental asymmetry

$$\frac{N_\uparrow - N_\downarrow}{N_\uparrow + N_\downarrow} = \epsilon \sin \Phi_C$$

$$\epsilon = A_{UT} \cdot P_T \cdot f \cdot D_{NN}$$

P_T - target polarization

D_{NN} - spin transfer coefficient

f - dilution factor

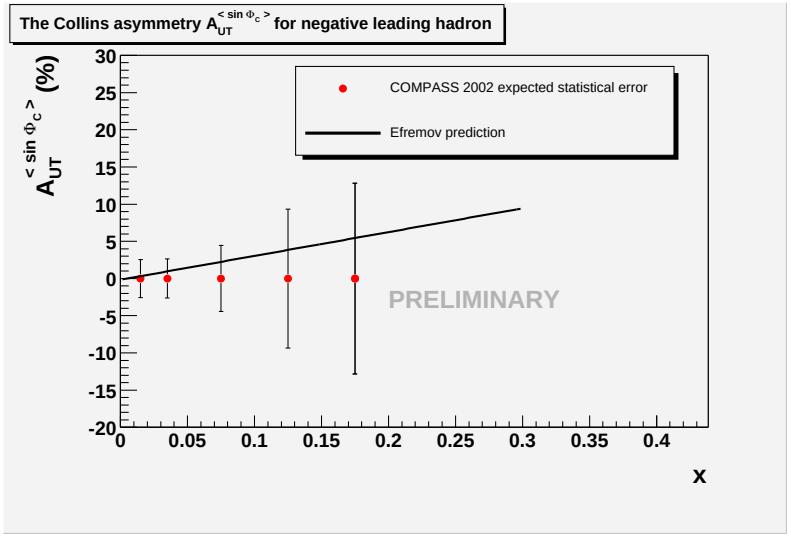
A_{UT} - Collins asymmetry

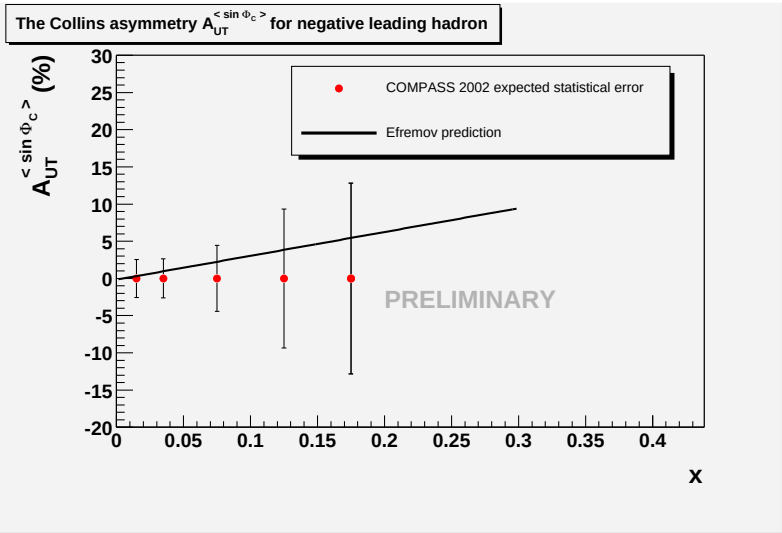
- Selection cuts

$Q^2 > 1 GeV^2/c^2 \qquad 0.1 < y < 0.9$

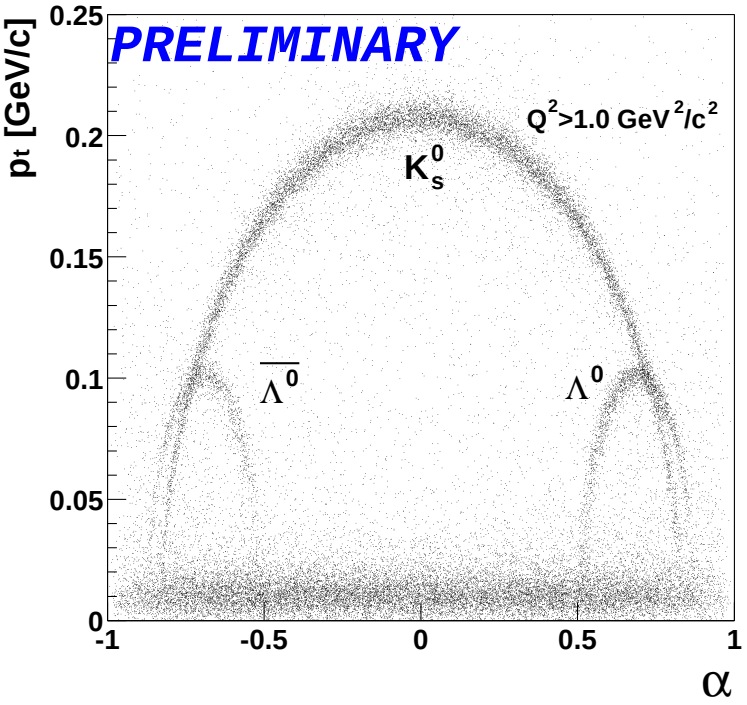
$z^h > 0.25 \qquad p_T^h > 0.1 GeV/c$

- 10^6 DIS events with transverse polarization (2002)



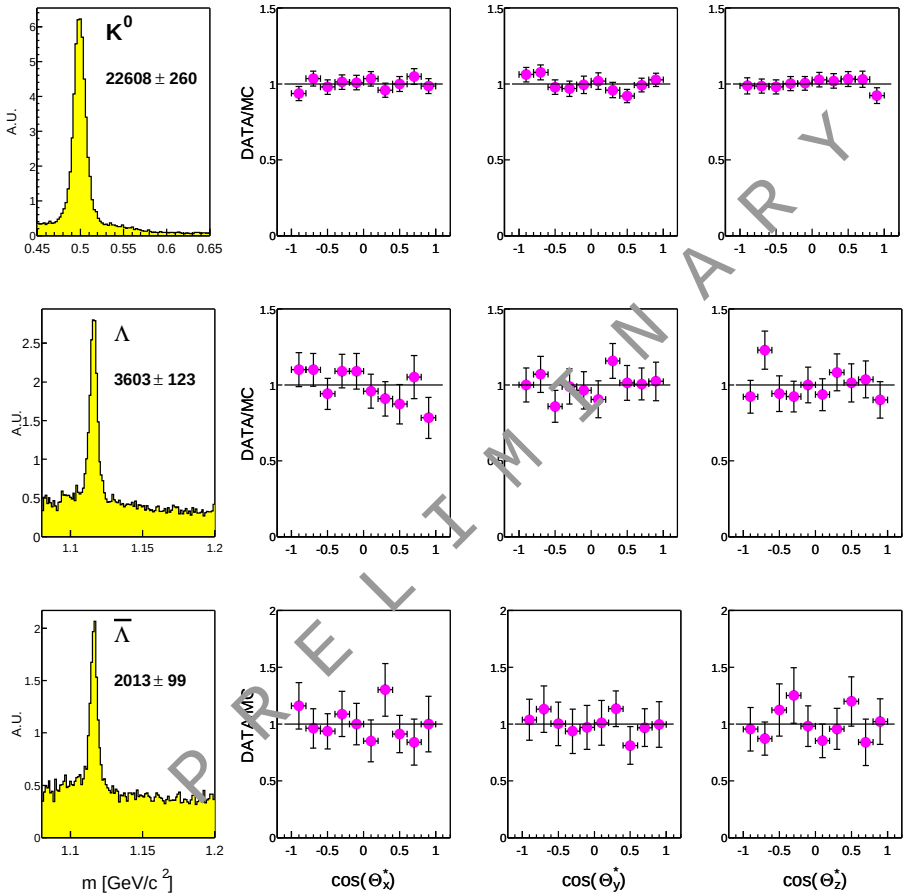


Λ and $\bar{\Lambda}$ production



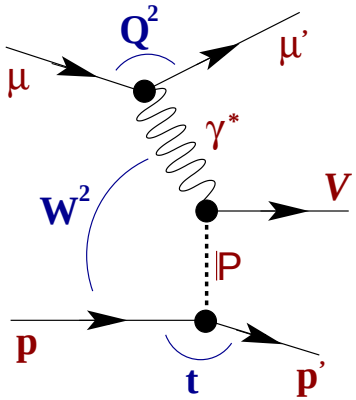
- Measure:
  - Longitudinal spin transfer in current fragmentation region.
  - Access to intrinsic strangeness of the nucleon in target fragmentation region.
- Selection criteria:
  - Decay vertex is outside of the target.
  - $p_t > 23$ MeV/c.
  - $Q^2 > 1$ GeV^2, $0.2 < y < 0.9$.

Λ and $\bar{\Lambda}$ production



- 1/6 of 2002 data.
- In total: 22K Λ and 12K $\bar{\Lambda}$.
- $\frac{dN}{d\cos\theta_i} = \frac{N_{tot}}{2}(1 + \alpha P_i \cos\theta_i)$
- Polarization seems consistent with 0.

Exclusive ρ^0 and ϕ production



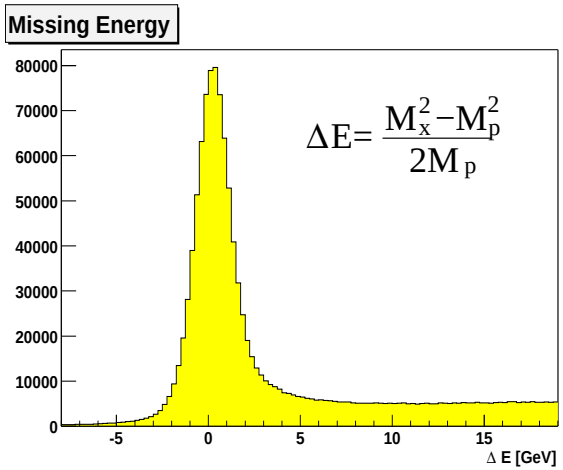
Cuts:

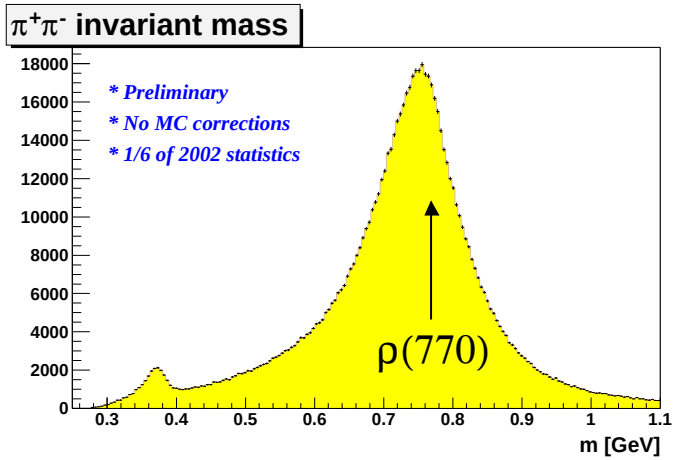
- 3 outgoing tracks in primary vertex: μ', h^+, h^-.
- $-2 < \Delta E < 2.5$ GeV
- $|t'| < 0.5$ GeV

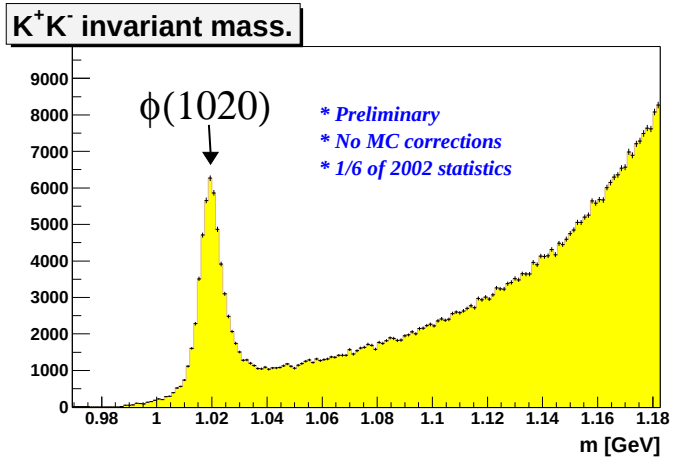
Kinematic range:

$$10^{-3} < Q^2 < 10\text{GeV}^2$$

$$7.5 < W < 16\text{GeV}$$

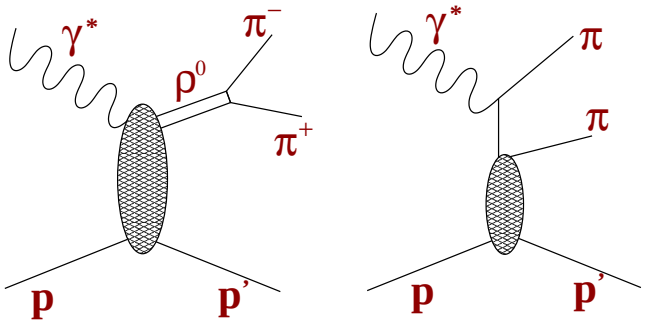






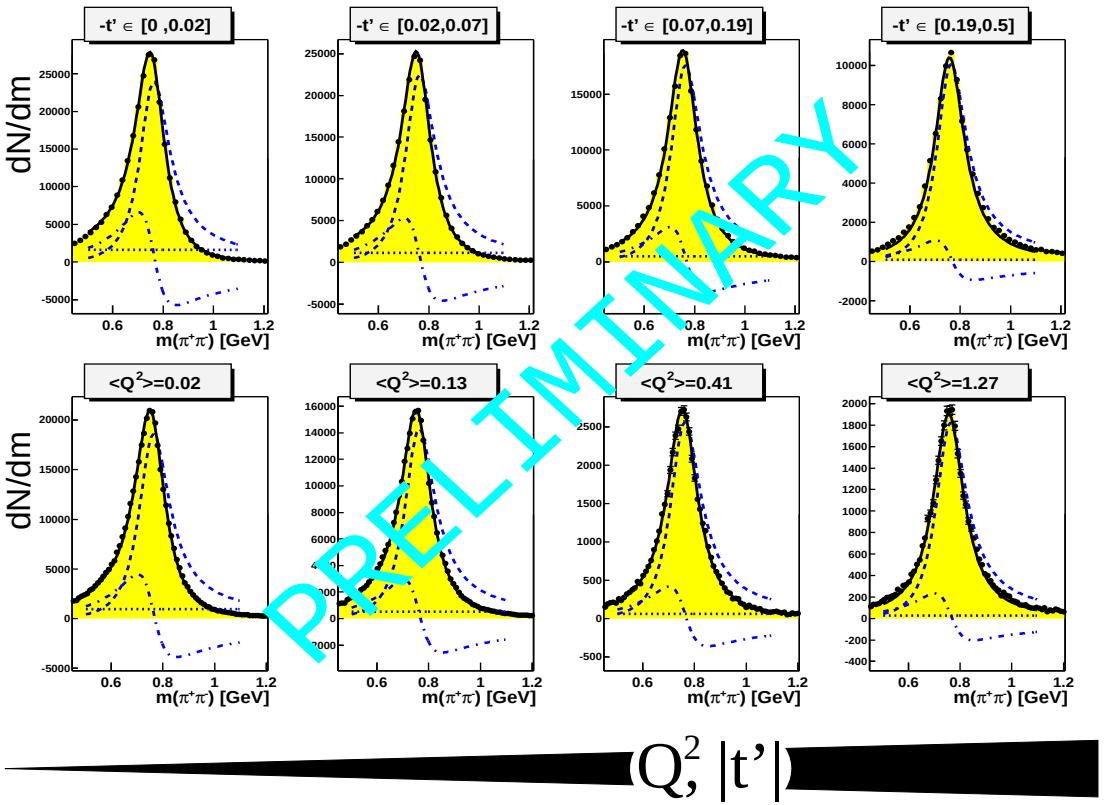
	mass cut	statistics (1/6 of 2002)
ρ^0	$0.5 < m_{\pi\pi} < 1$ GeV	$1.3 \cdot 10^6$
ϕ	$\lvert m_{KK} - m_\phi \rvert < 9$ MeV	$42 \cdot 10^3$

Exclusive ρ^0 production



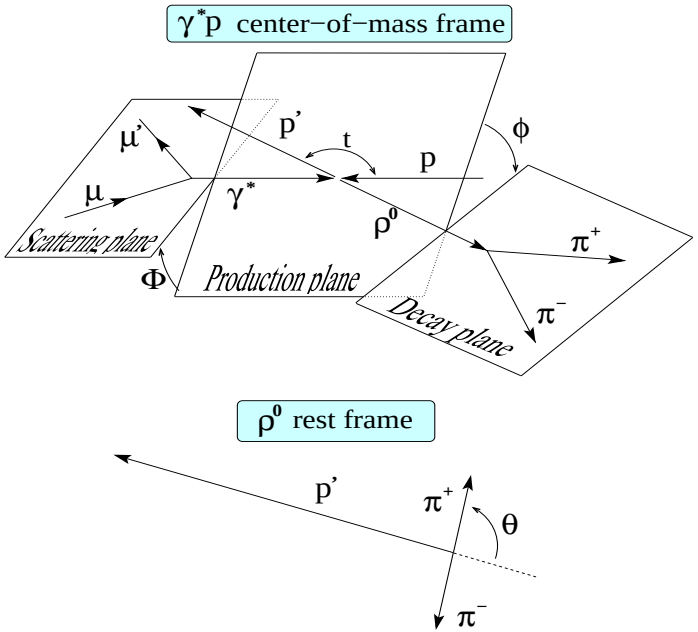
- No acceptance correction.
- Non-exlusive contribution is subtracted.
- Fit with Söding parameterization.
- Non-resonant contribution decreases with encrease of $|t'|$ or Q^2.

Interference between resonant and non-resonant $\pi^+\pi^-$ production.



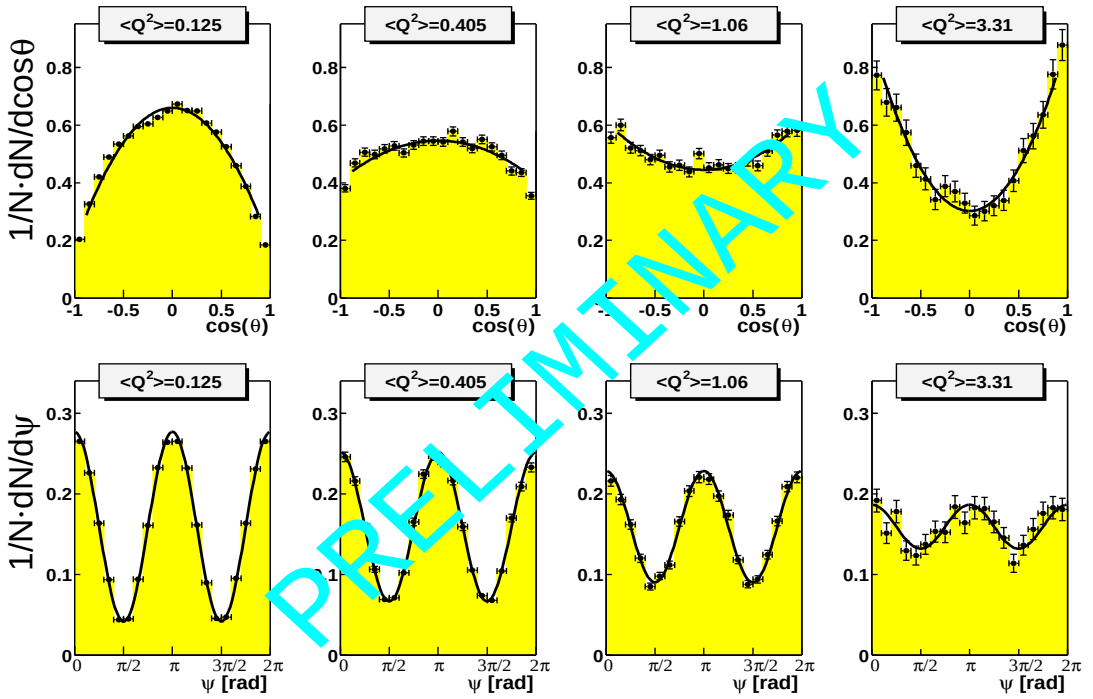
Angular distributions in ρ^0 production

- Test of SCHC at low Q^2.
- Access to GPD at high Q^2.



- Measurement of density matrix elements gives access to helicity transfer mechanism.

$$W(\cos\theta) = 3/4[(1 - r^{04}_{00}) + (3r^{04}_{00} - 1)\cos^2\theta]$$



- No acceptance correction.
- $p_t > 0.15$ GeV/c, $Q^2 > 0.05$ (GeV/c)^2

Summary and Outlook

- Very broad physics programme.
- A lot of data to be analyzed
  - collected data of 2002, 2003
  - Long run in 2004 (150 days)
- Physics analysis shows first results:
  - Photoproduction of vector mesons (ρ^0, ϕ, J/ψ)
  - Λ, $\bar{\Lambda}$ polarization
  - Quark flavor separation
  - $\Delta G/G$ from high p_t and open charm
  - Transversity
- Good perspective and upgrade of spectrometer after 2005.

Thank you for your attention