Feasibility Studies for the ENC@FAIR Project

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Outline

- The ENC fair project
  Potential compared to running fixed target experiment (COMPASS)

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    quark helicity, structure functions g_1, g_2

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  - Transversity & Transverse Momentum Distributions (TMD)

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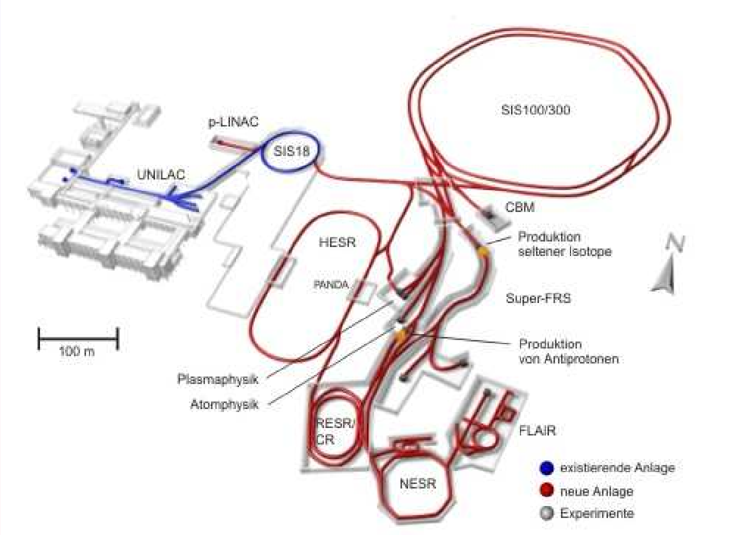
  - Factorization in hadronization process
- Summary & Outlook

ENC @ FAIR project

FAIR-Facility & PANDA detector



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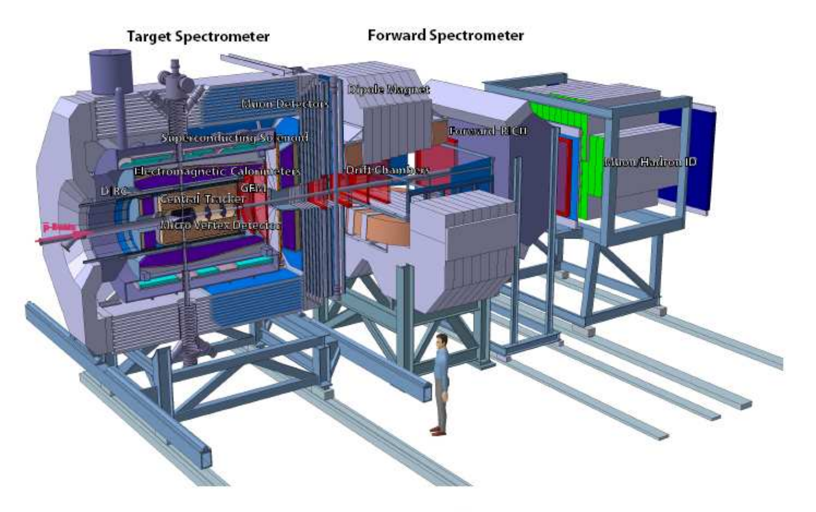

The ENC@FAIR project

- add a 3 GeV e^+/e^- accelerator to the already planed 15 GeV HESR (High Energy Storage Ring) for $\bar{p}$, p
- e^- and p polarized ($P \approx 80\%$)
- $\mathcal{L} > 10^{32}/\mathrm{cm}^2/\mathrm{s}$
- Use (modified) PANDA detector
- Constraints from accelerator side:
  no acceptance from 5 to 25 and 155 to 175 degrees

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Experiment	JLab(12 GeV)	HERMES	ENC	COMPASS
s/GeV^2	23	50	180	300
$\mathcal{L}/(1/\mathrm{cm}^2/\mathrm{s})$	$\approx 10^{38}$	$\approx 10^{32}$	$\approx 10^{32}$	$\approx 10^{32}$

Luminosity $\rightarrow$ FOM

More interesting FOM:

$$\boxed{\text{FOM} = (\text{diluting factors})^2\,\mathcal{L}}$$

diluting factors:	beam polarization	P_B
	target polarization	P_T
	target dilution factor	f
	reconstruction efficiency and purity	r

Diluting Factors

	COMPASS	collider
P_T	$0.5^{a)}$ $(0.8)^{b)}$	0.8
f	$0.4^{a)}$ $(0.17)^{b)}$	1
P_B	0.8	0.8

$^{a)}$ for ^{6}LID target

$^{b)}$ for NH_3 target

Diluting Factors

	diluting factor		ratio
	COMPASS	ENC	
unpolarized	1	1	1
single spin target $(P_T f)^2$	0.04	0.64	$16^{a)}$ $(32^{b)})$
double spin asymmetries $(P_T f P_B)^2$	0.026	0.41	$16^{a)}$ $(32^{b)})$
reconstruction of hadronic final state			?
mass resolution	☹	☺	
displaced vertices	☹	☺	
target fragmentation	☹	☺	

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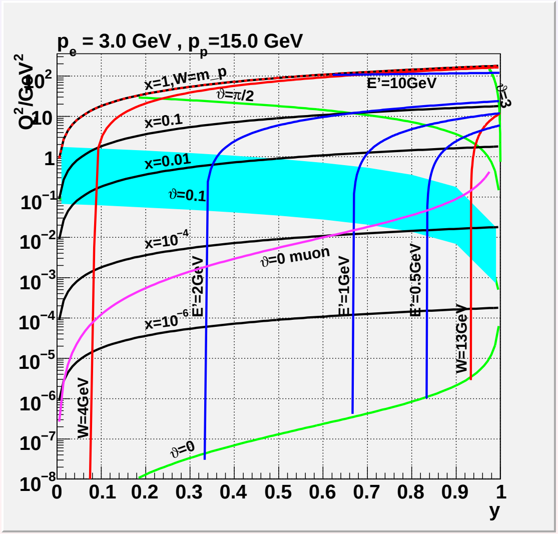
Huge potential for polarization observables!

Kinematic region covered



- Playground in $Q^2 - y$ plane $(\mathrm{Pol}(\gamma^*) \approx \mathrm{y})$

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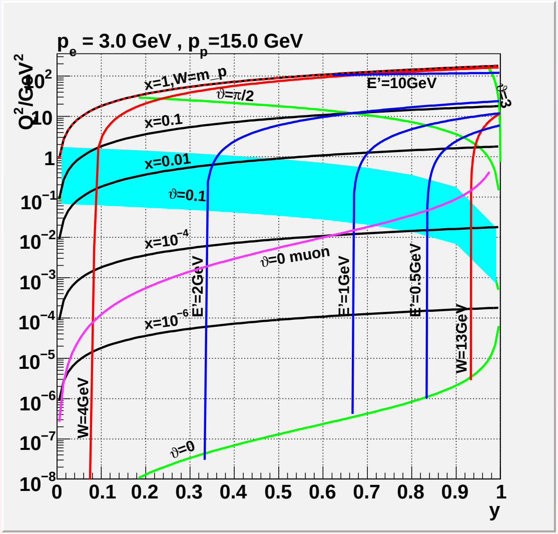

- Playground in $Q^2 - y$ plane $(\mathrm{Pol}(\gamma^*) \approx \mathrm{y})$
- Blue band: acceptance hole from 5-25 $^\circ$

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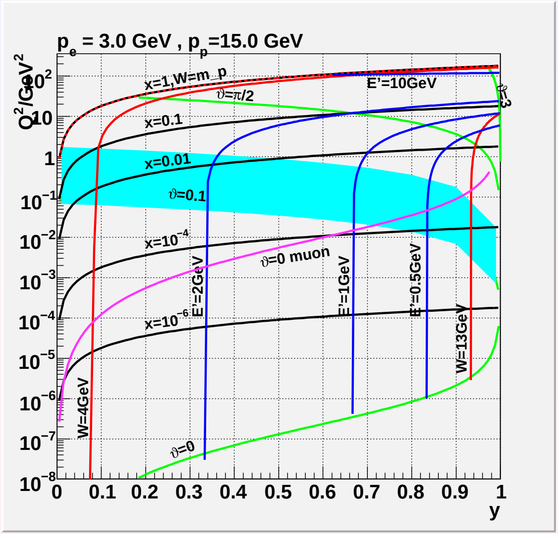


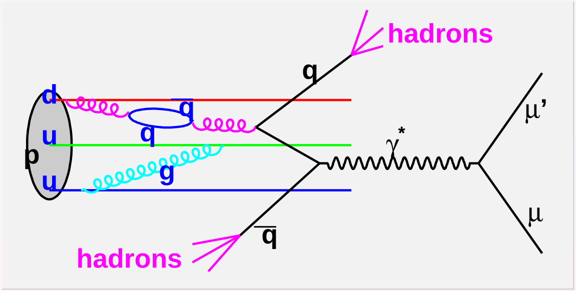
- Playground in $Q^2 - y$ plane $(\mathrm{Pol}(\gamma^*) \approx \mathrm{y})$
- Blue band: acceptance hole from 5-25°
- Higher Q^2_{min} for μ

Gluon Helicity

How to access the gluon distribution?

Use hadronic final state in deep inelastic scattering:

$$\vec{\mu} + \vec{N} \rightarrow \mu' + \text{hadrons} + X$$



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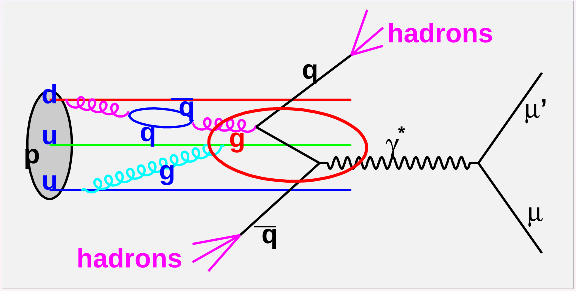
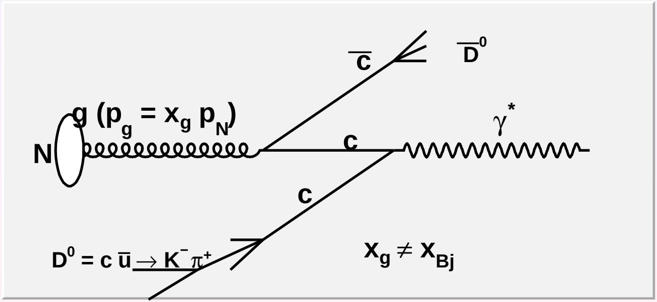


How to tag Photon -Gluon- Fusion sub-process

$$\gamma^* g \rightarrow q\bar{q} \text{ ?}$$

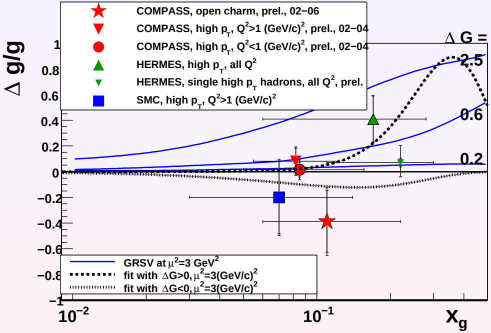
How to tag $\gamma^* g \to q\bar{q}$?

Cleanest way: Look at charmed particles resulting from the fragmentation of the process $\gamma^* g \to c\bar{c}$:



- no intrinsic charm,
- no charm quarks in string fragmentation
- If both charmed particles are reconstructed, one has access to x_g

Results on Δg from DIS



- Data show small values of $\Delta g/g$ at $x_g \approx 0.1$
- confirmed by indirect measurements
  - Scaling violation of $g_1^{p,n,d}$ structure function
  - $\vec{p}\vec{p}$ scattering at RHIC
- all measurements are concentrated around $x_g = 0.1$, little is known about $\Delta g(x_g)$

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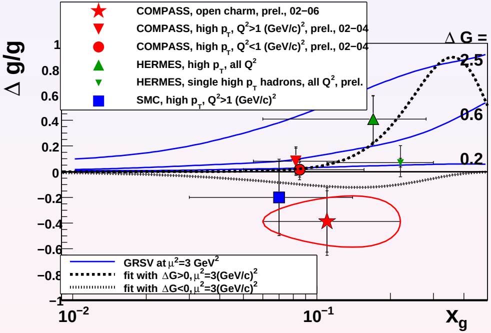

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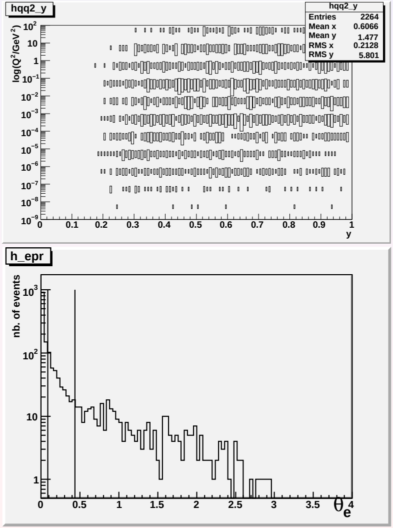
- only COMPASS point is obtained with the (least model dependent) open charm method
- this result is obtained in $\approx$ 200 days of running

kinematic distributions $ep \to e'D^0X$

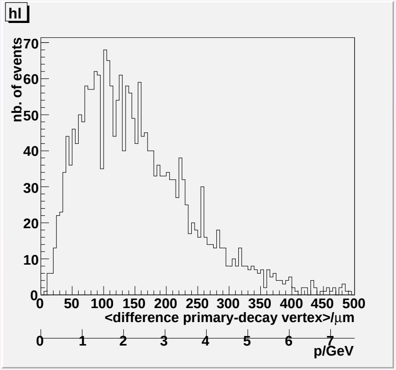


distribution of events in $Q^2 - y$ plane from PYTHIA MC

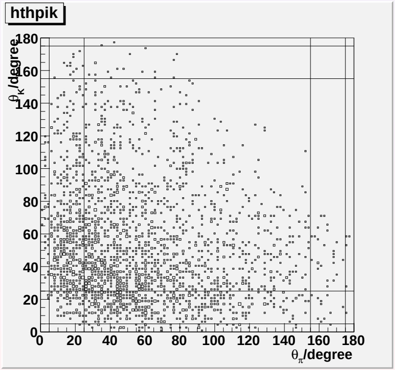
scattered electron: θ_e

loss due to angle cut $\approx 20\%$

kinematic distributions



momentum/average decay path of D^0



$D^0 \to K^-\pi+$

polar angles θ_K vs. θ_π

bands: acceptance cuts

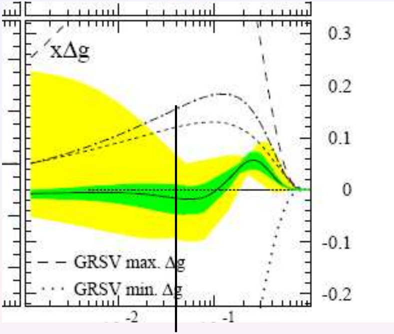
gluon momentum fraction range covered

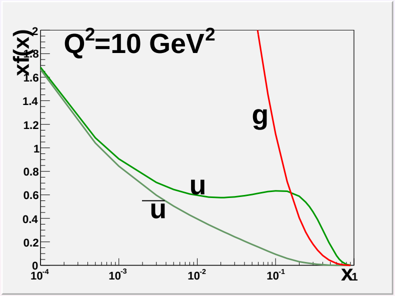
Lower limit:

$$\boxed{x_g(min) = \frac{4m_c^2}{s}}$$

COMPASS $E = 160$ GeV	pol eNC $E_p = 15$ GeV, $E_e = 3$ GeV
s/GeV^2	
300	180
$x_g(min)$	
0.02	**0.038**

QCD analysis on $\Delta g(x)$



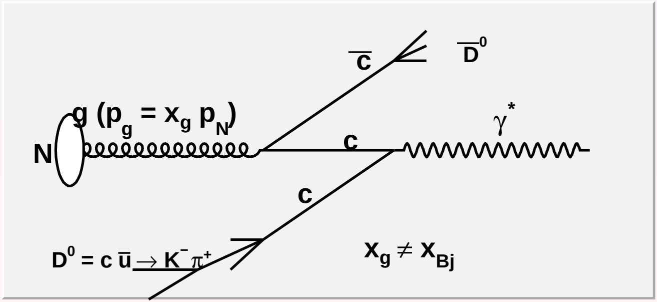


de Florian, Sassot, Stratmann, Vogelsang

- largest error in the region $x_g < 0.1$
- RHIC covers and will cover $0.01 < x_g < 0.2$
- on the other hand: all spin effects are observed at large x

Qualitative differences

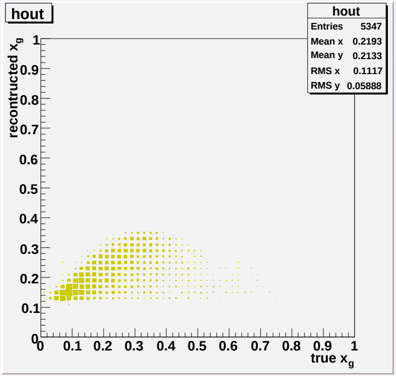
- In COMPASS only one of the two D mesons produced in a event is reconstructed
  $\Rightarrow$ momentum fraction x_g of gluon cannot be reconstructed
- Collider: Possibility to reconstruct both D mesons in one event
  $\Rightarrow$ better access to gluon momentum fraction x_g
- $\Rightarrow$ measurement of $\Delta g/g(\mathbf{x_g})$ is possible and not only $< \Delta g/g >_{x_g}$



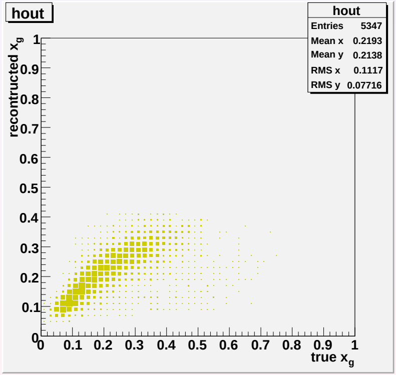
Better Reconstruction of x_g

using information of …

… one D^0 (52% corr.)



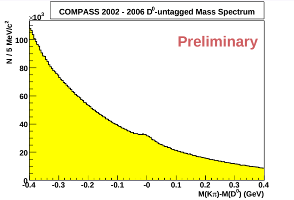
… both D^0 (70% corr.)



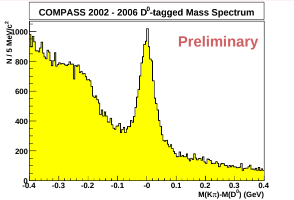
D^0 reconstruction

COMPASS

$D^0 \to K^-\pi^+ + c.c \quad (37\mathrm{k}\ D^0)$



D^0 from $D^{*+} \to D^0 + \pi^+$
$\to K^-\pi^+\pi^+ \quad (9\mathrm{k}\ D^0)$



collider

S:B = 4:1

(expected for PANDA)

assume B=0

D^0 reconstruction

	COMPASS S:B	collider S:B	
D^0	1:10	4:1	
D^*	1:1	1:0	

D^0 reconstruction

	COMPASS S:B	collider S:B	Gain in FOM*
D^0	1:10	4:1	11
D^*	1:1	1:0	2.6

In COMPASS D^0 and D^* have approximately the same FOM:
$\Rightarrow$ total gain $\approx \frac{11+2.6}{2} =$ **7**

* for the same number of signal events

D^0 reconstruction

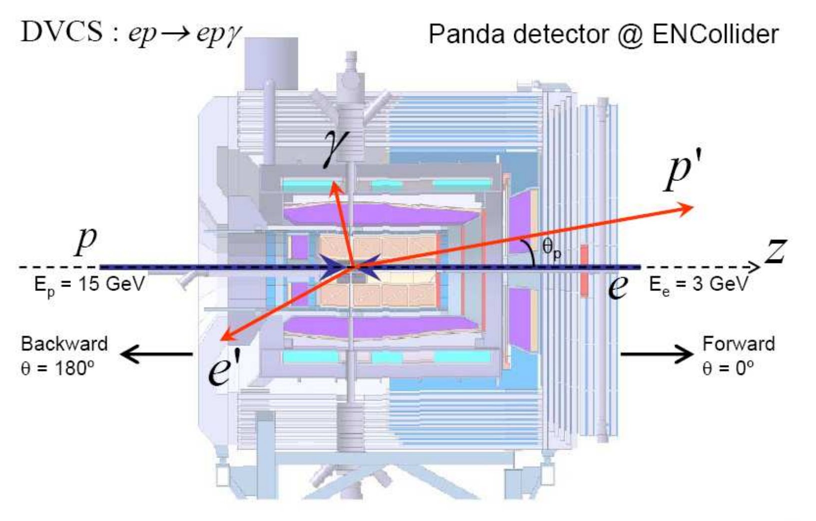
- COMPASS has a solid state target:
  - $\Rightarrow$ D^0 decay vertex cannot be resolved from main vertex
  - $\Rightarrow$ mass resolution deteriorated due to multiple scattering
- Additional gains at collider:
  - from number of reconstructed D mesons (COMPASS target has ≈ 1 nuclear interaction length)
  - considering more decay channels ($D^0 \rightarrow K^-\pi^+$ has only 4% BR)

Summary $\Delta g(x)$

- Increase of FOM compared to fixed target experiment by two orders of magnitude possible (16 from $f\,P_T\,P_B$, > 7 from D^0 reconstruction)!
- Not only increase in FOM but also qualitative improvements (reconstruction of x_g)
- in parallel measurement of helicity distributions

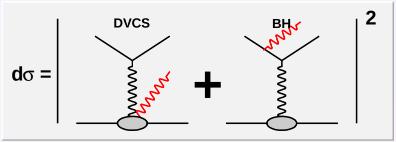
Deep Virtual Compton Scattering

Deep Virtual Compton Scattering



Studies done by D. Kang, W. Gradl & M. Fritsch

Cross Section



Bethe-Heitler (BH) contributes as background

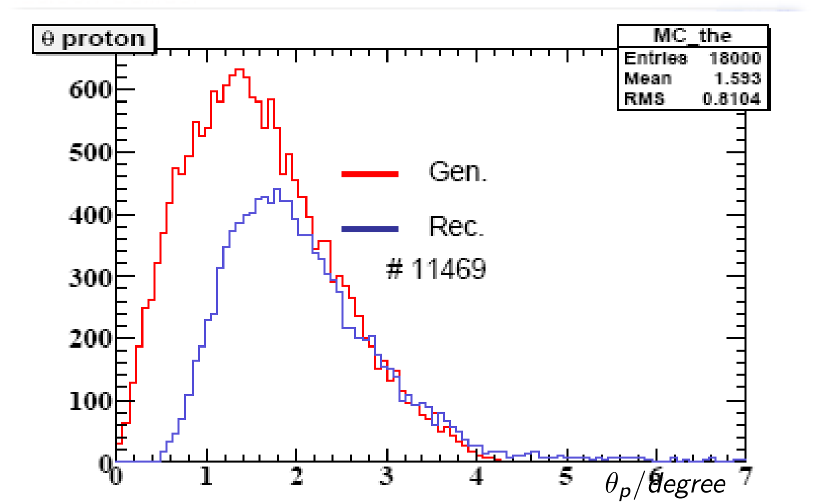
$$\begin{aligned} d\sigma &= (d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + e_\mu a^{BH}\,\mathcal{R}e(A^{DVCS})) \times \cos(n\Phi) \\ &+(P_\mu d\sigma^{DVCS}_{pol} + e_\mu P_\mu a^{BH}\,\mathcal{I}m(A^{DVCS})) \times \sin(n\Phi) \end{aligned}$$

e_μ: lepton charge, P_μ : lepton polarization, $A \propto \int_{-1}^{1} dx\, \frac{H(x,\xi,t)}{x-\xi+i\epsilon}$,
Φ : $\angle(l, l' - \text{plane}, \gamma, p - \text{plane})$

Exploit angular dependence, $\sigma^{e^+} - \sigma^{e^-}$, $\sigma^{\uparrow} - \sigma^{\downarrow}$, ...

$\Rightarrow$ access to various contributions

Deep Virtual Compton Scattering



using PANDA setup

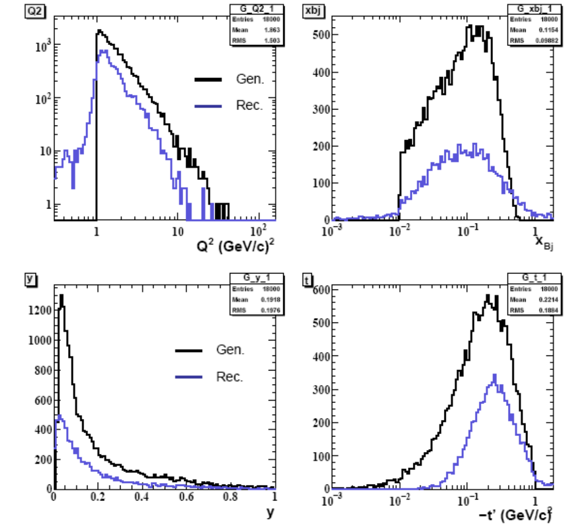
Reconstruction efficiency

using PANDA setup

particle	efficiency	resolution $\delta p/p$	resolution $\delta\theta/\theta$
e	83%	$< 2\%$	$< 2\%$
γ	93%	$< 2\%$	$< 5\%$
p	64%	$< 1\%$	$< 10\%$

combined efficiency 43%

Kinematic range



Kinematic

$$Q^2 = -(k - k')^2$$

$$x_{Bj} = Q^2 / p \cdot q$$

$$y = p \cdot q / p \cdot k$$

$$-t = (p' - p)^2$$

Generated MC

$Q^2 > 1\ (\mathrm{GeV/c^2})^2$,
$0.01 < x_{Bj} < 0.99$,
$0.0 < |t| < 1.0\ (\mathrm{GeV/c^2})^2$

Universität Mainz

Summary DVCS

- already with present PANDA setup good acceptance
- further studies needed (ensure exclusivity, ...)

Transversity & TMDs

Transversity & TMDs

- Same (or even less) requirements than for Δg measurements
- very active field (see parallel workshop)

quark \ nucleon	unpol.	long.	trans.
unpol.	f_1		$f_{1T}^{\perp}$
long.		g_1	g_{1T}
trans.	$h_1^{\perp}$	h_{1L}	$h_1, h_{1T}^{\perp}$

- Table shows all 8 twist 2 parton distributions
- 4 of them appear for transversally polarized nucleon

Side remark: TMDs

Sivers: $f_{1T}^{\perp}(DY) = -f_{1T}^{\perp}(SIDIS)$

Boer-Mulders: $h_1^{\perp}(DY) = -h_1^{\perp}(SIDIS)$

connection to Drell-Yan program at FAIR (PAX)

Factorization in fragmentation process

Fragmentation

Just two examples:

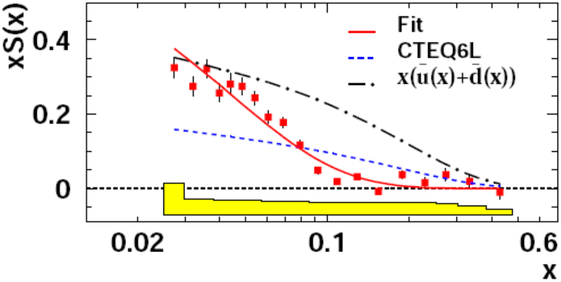
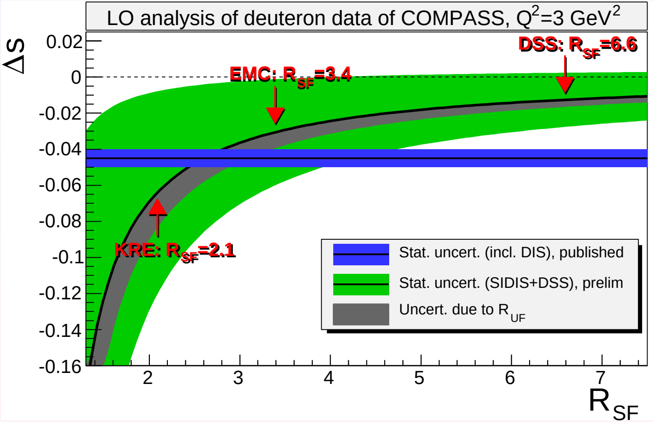


FIG. 3: The strange parton distribution $xS(x)$ from the measured HERMES multiplicity for charged kaons evolved to $Q_0^2 = 2.5$ GeV^2 assuming $\int \mathcal{D}_S^K(z)dz = 1.27 \pm 0.13$. The solid curve is a 3-parameter fit for $S(x) = x^{-0.924}e^{-x/0.0404}(1-x)$, the dashed curve gives $xS(x)$ from CTEQ6L, and the dot-dash curve is the sum of light antiquarks from CTEQ6L.

Fragmentation

Just two examples:



$$R_{SF} = \frac{\int D_s^{K^-} \mathrm{d}z}{\int D_u^{K^+} \mathrm{d}z} \qquad \Delta s = \int \Delta s(x) + \Delta \bar{s}(x) \mathrm{d}x$$

Spin dependence in Fragmentation process

$$A^h = \frac{\sum e_q^2 \Delta q(x) D_q^h(z)}{\sum e_q^2 q(x) D_q^h(z)}$$

Spin dependence in Fragmentation process

$$\boxed{A^h = \frac{\sum e_q^2 \Delta q(x) D_q^h(z) + q(x)\Delta D_q^h(z)}{\sum e_q^2 q(x) D_q^h(z) + \Delta q(x)\Delta D_q^h(z)}}$$

$$\Delta D_q^h(z) = D_{q\uparrow}^h(z) - D_{q\downarrow}^h(z)$$

- additional term in denominator can be neglected ($\Delta q \Delta D \ll qD$)
- term in numerator is dangerous because $\Delta q D$ maybe of same order as $q\Delta D$

- M. Glück & E. Reya hep-ph/0203063
- A. Kotzinian Eur.Phys.J.C44:211,2005 e-Print: hep-ph/0410093

Fragmentation

All this is best studied at a collider at moderate energy!

Fragmentation

All this is best studied at a collider at moderate energy!

- possible violation of factorization
- detection of target fragmentation region

Summary & Outlook

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A polarized electron-nucleon-collider with
$\mathcal{L} > 10^{32}/\mathrm{cm}^2/\mathrm{s}$ and
$s \approx 200\ \mathrm{GeV}^2$
has great potential to make a big step in understanding the partonic structure of the nucleon.

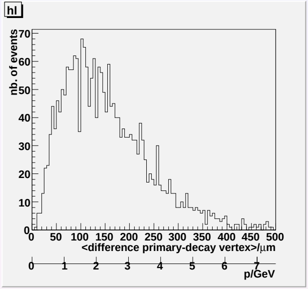
$\Delta g(x)$

$\Delta q(x)$ $\Delta q_T(x)$ TMDs ??? $q \rightarrow h$

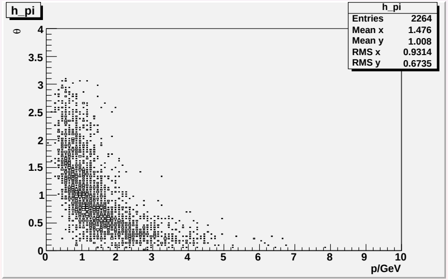
GPDs

Spare

D^0 momentum



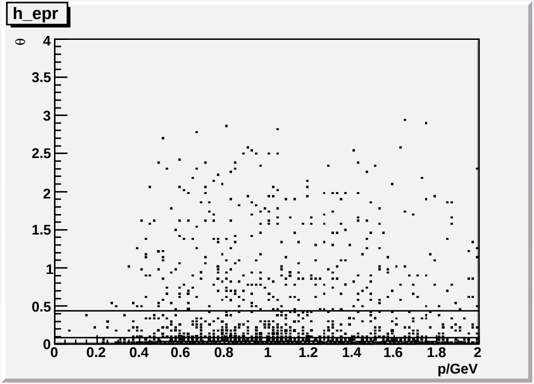
decay pion:
θ vs. p



$\theta_{e'}$

scattered electron

θ vs. p



Spin Dependence of Fragmentation Functions

$$D_q^h(z) \rightarrow D_q^h(z) + \Delta D_q^h(z)$$

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- one sums over spin states of hadron h

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- if fragmentation is independent of target remnant

Spin Dependence of Fragmentation Functions

$$D_q^h(z) \to D_q^h(z) + \Delta D_q^h(z)$$

$$\Delta D_q^h(z) = D_{q\uparrow}^h(z) - D_{q\downarrow}^h(z)$$

$D_{q\uparrow}^h(z) = D_{q\downarrow}^h(z)$, i.e. $\Delta D_q^h = 0$ if:

- one sums over spin states of hadron h ✓
- fragmentation process does not violate parity ✓
- if fragmentation is independent of target remnant ?

$$D_{q\uparrow}^h = \sum_{\lambda_h} \langle q, \uparrow \quad |T|h, \lambda_h \quad \rangle =$$
$$\sum_{\lambda_h} \langle q, \downarrow \quad |T|h, \lambda_h \quad \rangle = D_{q\downarrow}^h$$

Spin Dependence of Fragmentation Functions

$$D_q^h(z) \rightarrow D_q^h(z) + \Delta D_q^h(z)$$

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- one sums over spin states of hadron h ✓
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- if fragmentation is independent of target remnant ?

$$D_{q\uparrow}^h = \sum_{\lambda_h} \langle q, \uparrow, \text{tgt rem.} | T | h, \lambda_h, \text{hads.} \rangle = \sum_{\lambda_h} \langle q, \downarrow, \text{tgt rem.} | T | h, \lambda_h, \text{hads.} \rangle = D_{q\downarrow}^h ?$$