

COMPASS - a facility to study QCD

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bmb+f - Förderschwerpunkt
COMPASS
Großgeräte der physikalischen
Grundlagenforschung



JOHANNES GUTENBERG
UNIVERSITÄT MAINZ



Physics program: QCD at different scales

COMMON MUON AND PROTON APPARATUS FOR STRUCTURE AND SPECTROSCOPY

Bochum, Bonn, Burdwan/Calcutta, CERN, Dubna, Erlangen, Freiburg, Illinois,
Lissabon, Mainz, Moscow, Munich, Prague, Protvino, Saclay, Taipei, Tel Aviv,
Turino, Trieste, Warsaw, Yamagata
(30 institutes, 225 physicists)

Chiral dynamics

- ▶ $\pi\gamma$ and $K\gamma$ reactions
- ▶ π and K polarisabilities
- ▶ Radiative decay width

Hadron spectroscopy

- ▶ Mass spectrum of hadrons
- ▶ Gluonic excitations
- ▶ Exotics

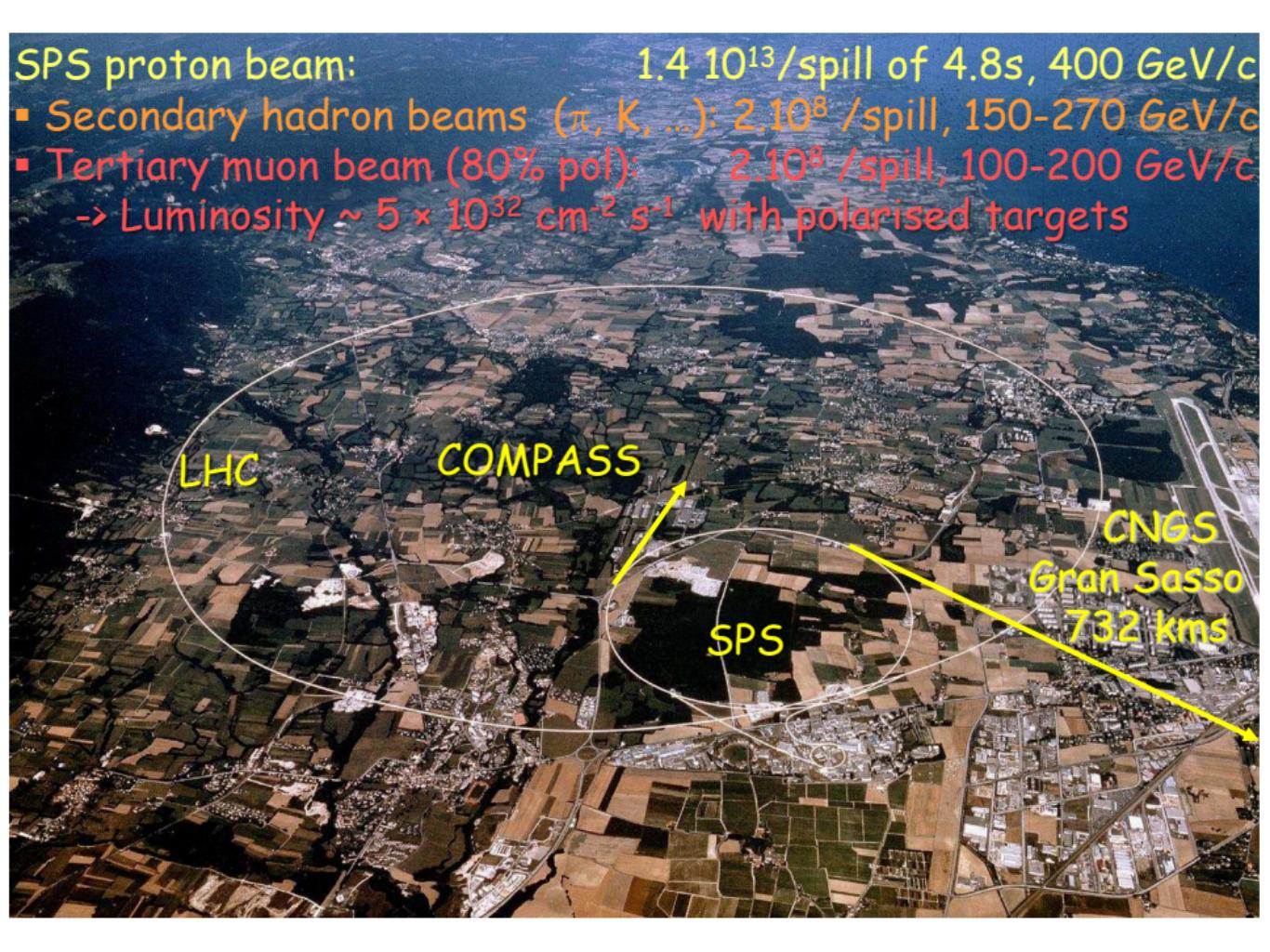
Nucleon structure

- ▶ Gluon polarisation
- ▶ Helicity and transversity PDFs
- ▶ Transverse mom. dep. distributions
- ▶ Generalised PDFs

SPS proton beam:

1.4×10^{13} /spill of 4.8s, 400 GeV/c

- Secondary hadron beams (π , K, ...): 2×10^8 /spill, 150-270 GeV/c
- Tertiary muon beam (80% pol): 2×10^8 /spill, 100-200 GeV/c
→ Luminosity $\sim 5 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ with polarised targets



LHC

COMPASS

SPS

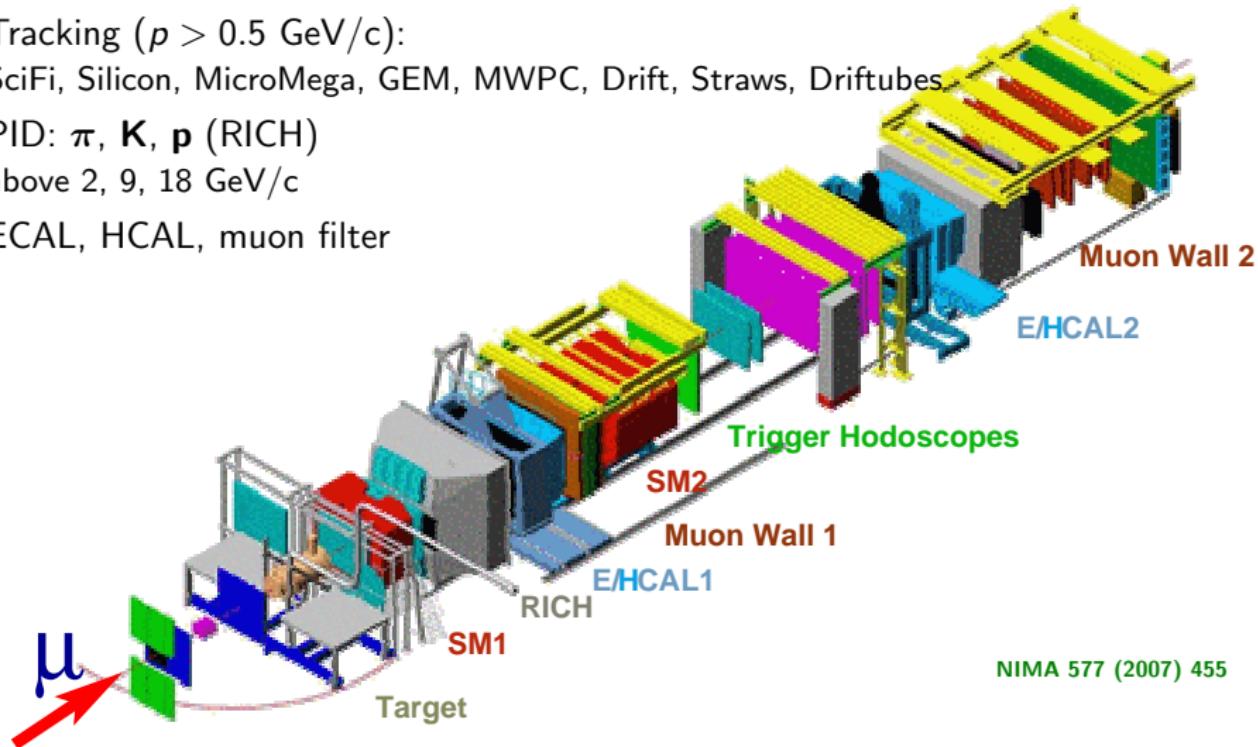
CNGS

Gran Sasso
732 kms

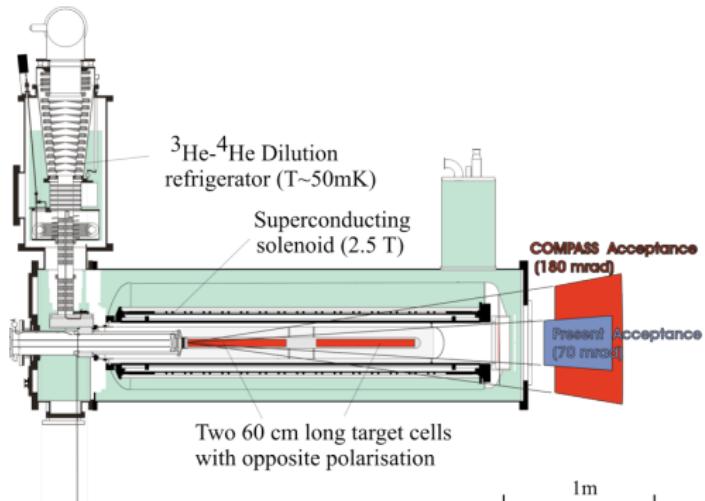
COMPASS experiment - Phase 1

Spectrometer

- ▶ Two magnets (1 Tm, 4.5 Tm)
- ▶ Tracking ($p > 0.5 \text{ GeV}/c$):
SciFi, Silicon, MicroMega, GEM, MWPC, Drift, Straws, Driftubes
- ▶ PID: π , K , p (RICH)
above 2, 9, 18 GeV/c
- ▶ ECAL, HCAL, muon filter



Polarised target for muon beam



- ▶ target material: **$^6\text{LiD}, \text{NH}_3$**
- ▶ polarisation: **50%, 90%**
- ▶ dilution factor: **0.4, 0.15**
- ▶ longitudinal, transverse pol.
- ▶ set-up optimised for asymmetry measurements

Measurements 2002-07, 2010-11

- ▶ muon scattering on polarised p(NH_3) and d(^6LiD) with longitudinal and transverse target polarisation (2002 - 2007)
- ▶ addendum in 2010 (transv. p) and 2011 (long. p)
- ▶ all three leading twist PDFs investigated ($f_1(x), g_1(x), h_1(x)$)

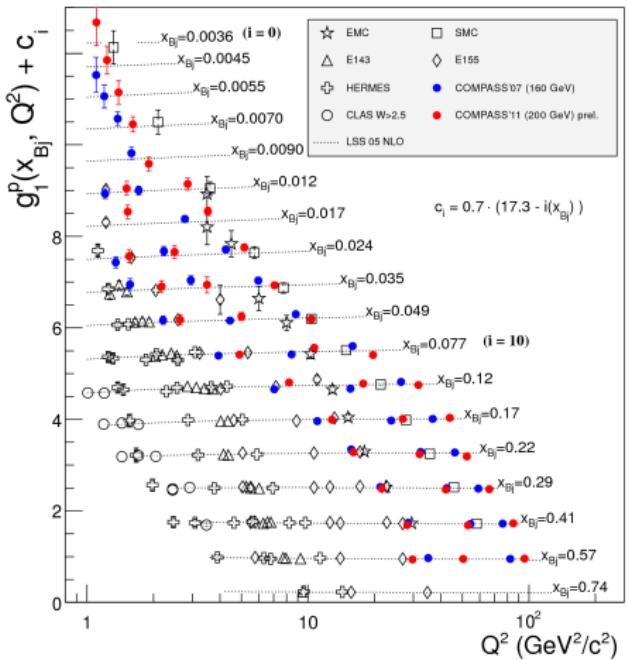
Nucleon structure: Results

Longitudinal polarisation

- quarks carry 30% of nucleon spin
- gluon contribution small
(in x range covered)
- quark helicities distributions

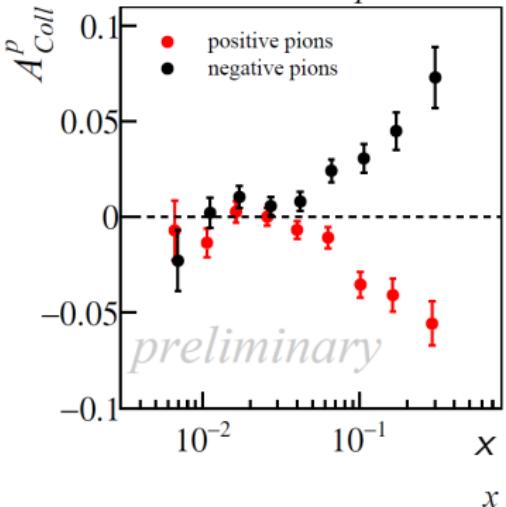
Unpolarised

- charm production
- Multiplicities: p_T dependence
- Fragmentation functions for pion and kaons (ongoing work)



Results for transverse target polarisation

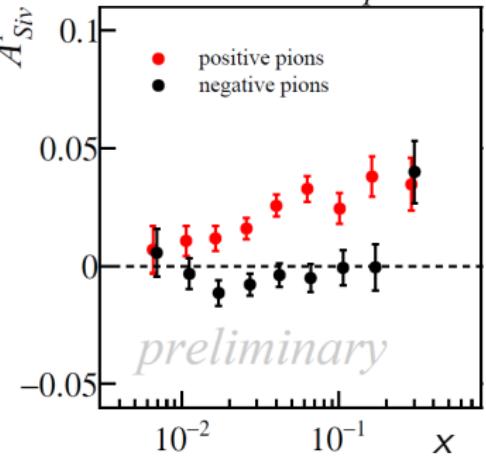
COMPASS 2007 and 2010 proton data



- ▶ sizeable transverse effect observed (for proton)
- ▶ transverse quark distributions accessible
- ▶ u- and d-quark transversity similar to helicity distributions, but about factor 2 smaller

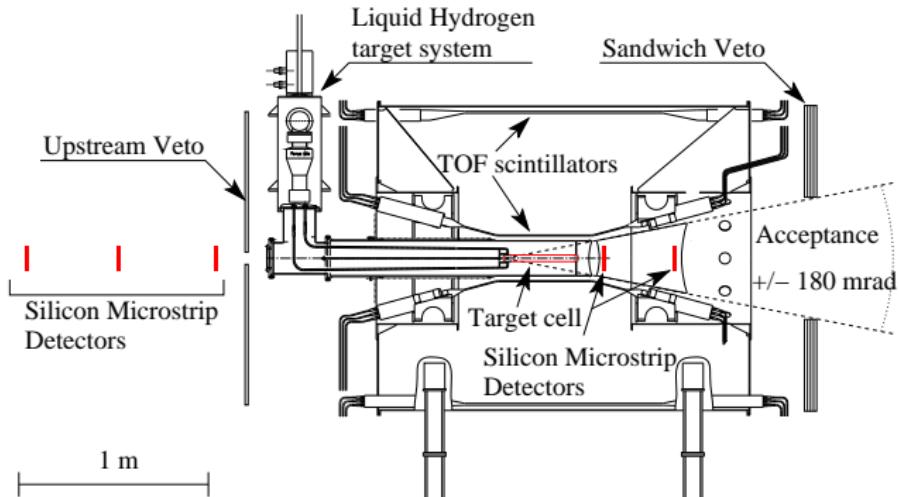
- ▶ first look on transverse momentum dependent distributions
- ▶ clear effects observed for transverse polarisation (Sivers function) and unpol. target (Boer-Mulders function)
- ▶ hints for quark orbital angular momentum

COMPASS 2007 and 2010 proton data



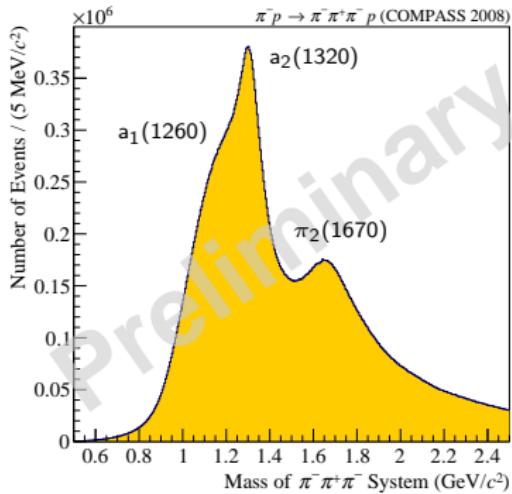
Targetregion for hadron beam

- ▶ diffractive and central production with 190 GeV/c π and p beam
- ▶ target recoil detection to ensure exclusivity

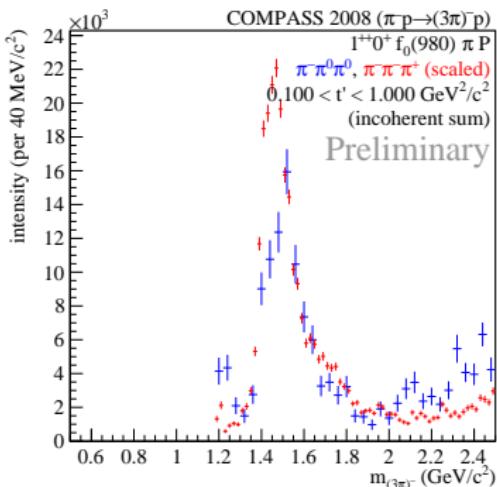


- ▶ target material: unpolarised **IH₂, Pb, Ni, Cu ,W**
- ▶ Si microstrip detector telescope around target (vertex resolution)
- ▶ recoil proton detector for PID and momentum measurement (TOF)
- ▶ setup optimised for exclusive channels (sandwich veto)

Example for Hadron spectroscopy



- ▶ data taking for spectroscopy 2008 and 2009, pilot run in 2004
- ▶ diffractive $\pi^- p \longrightarrow \pi^- \pi^+ \pi^- p_{slow}$
- ▶ $50 \cdot 10^6$ events: world largest data set → very challenging analysis



- ▶ PWA with isobar modell
- ▶ analysis in mass and momentum transfer bins
- ▶ new resonance $a_1(1420)$ observed
- ▶ similar analysis for $\pi^- p \longrightarrow \pi^- \pi^0 \pi^0 p_{slow}$

Status - Phase 1

Spectroscopy - analysis ongoing

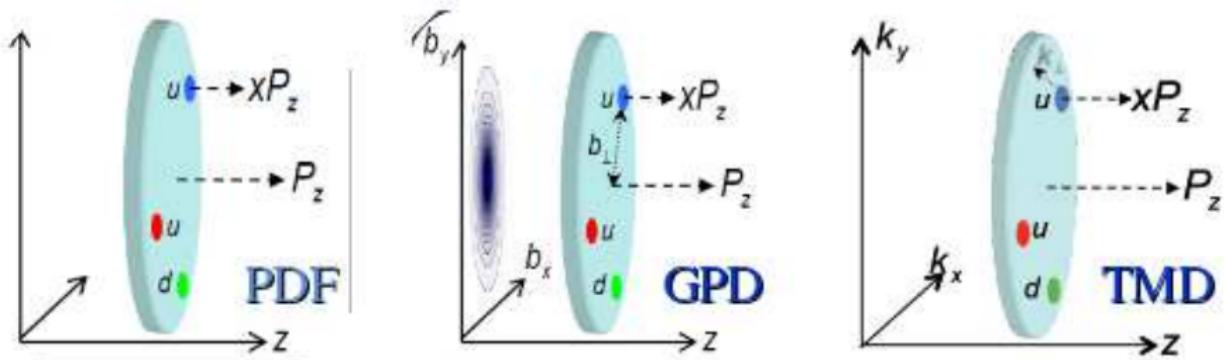
- ▶ Many different channels analysed
- ▶ Meson and baryon spectroscopy
- ▶ Search for exotics and glueballs
- ▶ Tests of chiral pert. theory

Nucleon structure - open questions

- ▶ Strange quark momentum distribution?
- ▶ Fragmentation of strange quarks?
- ▶ Strange quark helicity distribution?
- ▶ Transverse momentum dependent distributions
- ▶ Orbital angular momentum of quarks and gluons?

What we will do

Improve the 1-dimensional picture of the nucleon



Study generalised parton distributions and
transverse momentum dependent distributions



COMPASS - Phase 2 Proposal

submitted in May 2010 for 5 years of data taking in the first phase
approved in December 2010 for *initially* 3 years of data taking in 2015-2017

Generalized parton distribution (GPD)

longitudinal momentum structure plus transverse spatial structure
accessible in exclusive reaction like DVCS or DVMP

Flavour separation and fragmentation in SIDIS

strange quark distribution and fragmentation functions

Transverse momentum dependent distributions (TMD)

dynamic picture using intrinsic transverse momenta of partons
accessible in SIDIS and Drell-Yan processes

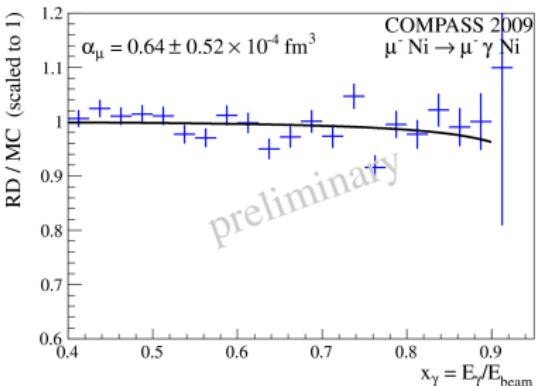
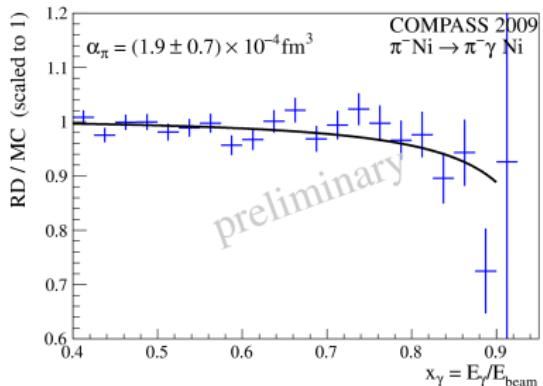
QCD at very low momentum transfers

pion/kaon polarisabilities, testing chiral perturbation theory

Polarisabilities using



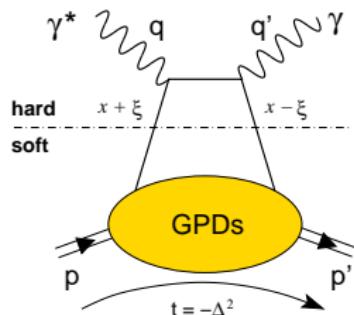
- ▶ measurement of deviation from pointlike behaviour due to pion structure
- ▶ unique at COMPASS: comparison with muon
- ▶ prediction of low energy behaviour from chiral pert. theory
- ▶ first measurement with Ni target in 2009 → preliminary value for α_π



- ▶ COMPASS phase 2:
 - measurement of electric α_π and magnetic β_π polarisabilities separately
 - first look of kaon polarisability
 - data already taken in 2012

Generalised parton distributions

Access GPD through DVCS mechanism



- ▶ generalised parton distributions for quarks and gluons $H^f, E^f, \tilde{H}^f, \tilde{E}^f(x, \xi, t)$
- ▶ limits: $q(x) = H(x, 0, 0)$
 $F(t) = \int dx H(x, \xi, t)$
- ▶ GPDs contained in Compton form factors

► Ji's sumrule

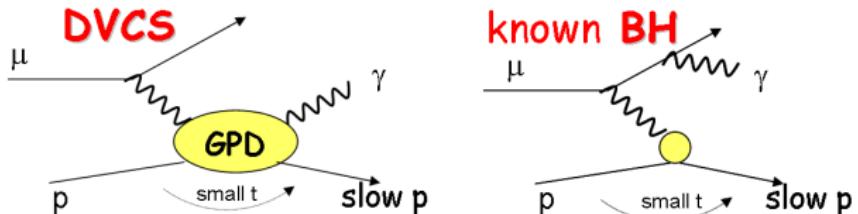
$$J^f = \frac{1}{2} \lim_{t \rightarrow 0} \int_{-1}^1 dx x [H^f(x, \xi, t) + E^f(x, \xi, t)]$$

J^f : total angular momentum contribution of quark f

- ▶ unpolarised hydrogen target \Rightarrow **GPD H**
- ▶ transversely polarised target \Rightarrow **GPD E**

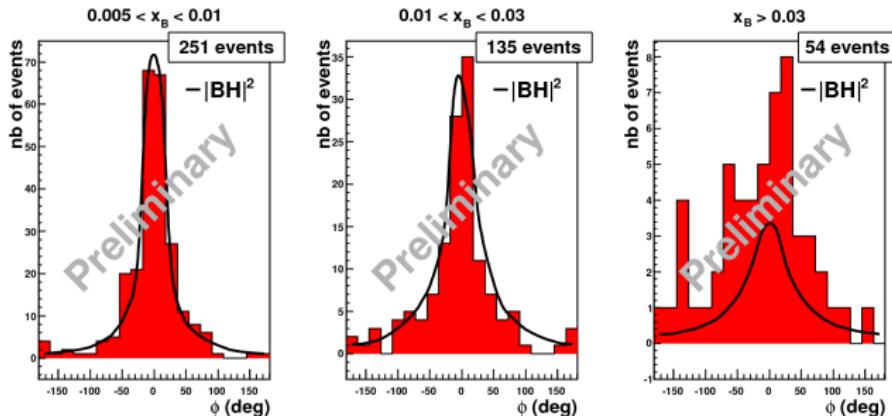
What we do measure

$$\mu^\pm p \rightarrow \mu^\pm \gamma p$$



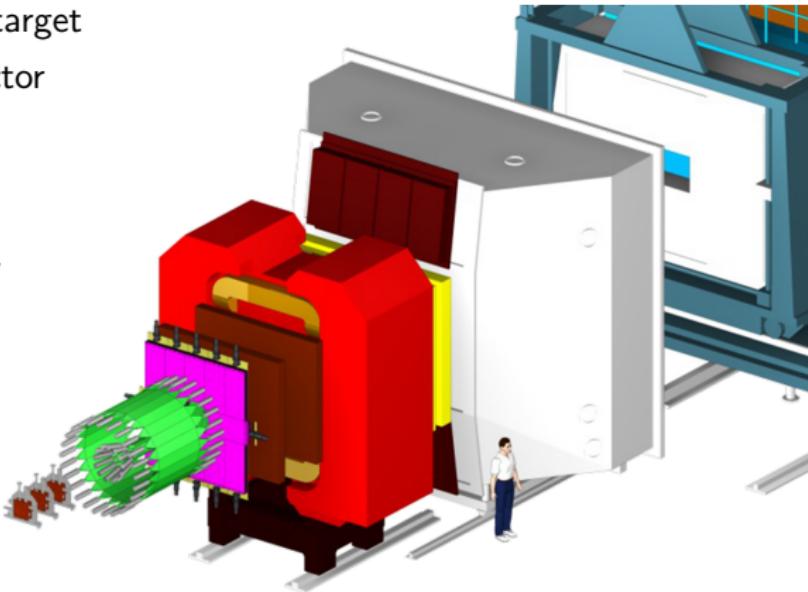
- competing: DVCS and BH \rightarrow measurement with μ^+ and μ^-
- yields $\text{Re}(H)$ and $\text{Im}(H)$

- 2009 Test measurement:**
clear DVCS signal

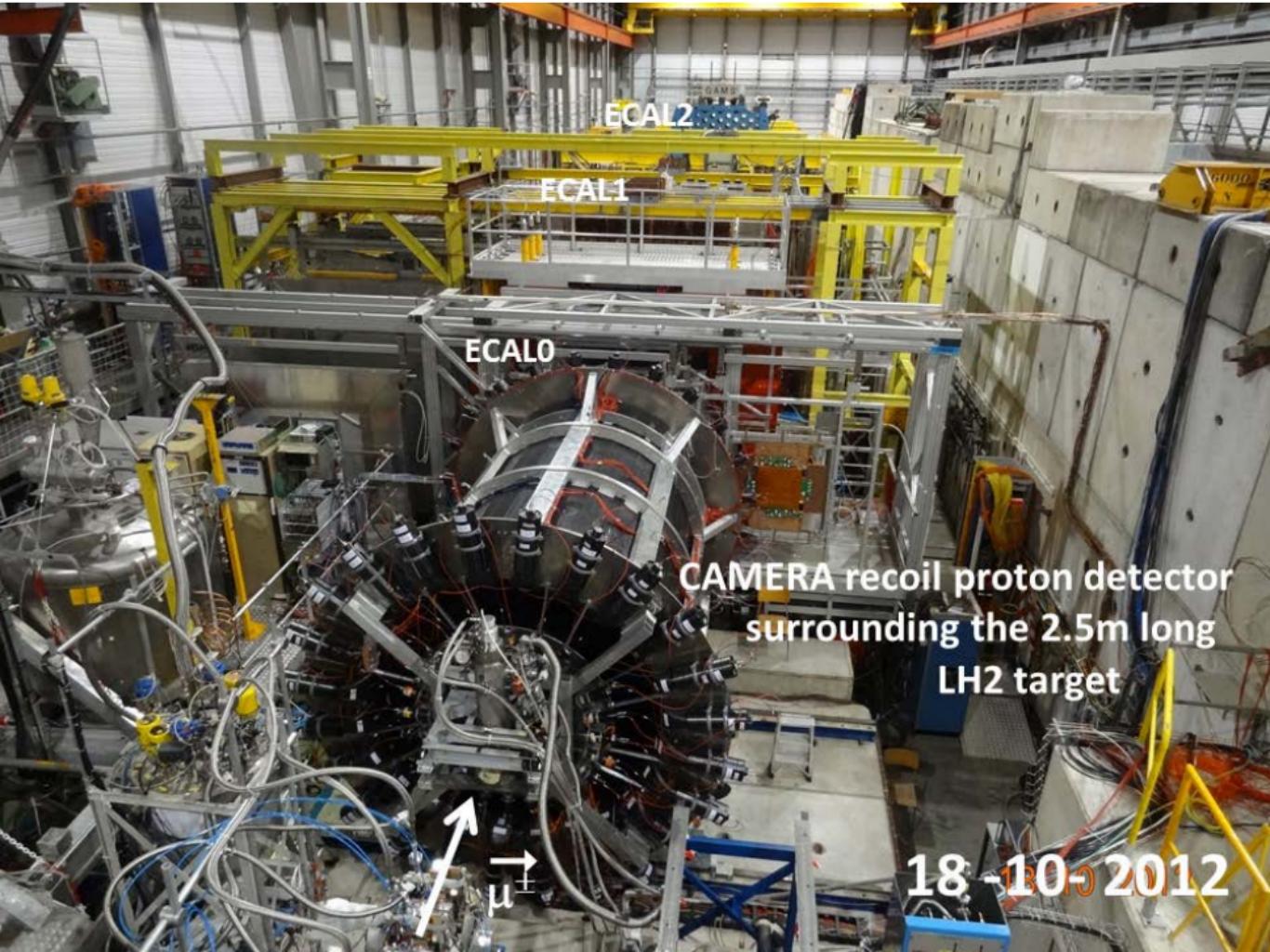


Target region for DVCS

- ▶ 2.5m long liquid hydrogen target
- ▶ 4m long recoil proton detector (CAMERA)
(Freiburg, Mainz)
- ▶ hermetic coverage with electromagnetic calorimetry
- ▶ new ECAL0 added READOUT (TUM)
- ▶ start counter (SciFi)
(Bonn HISKP, Erlangen)



- ▶ measurement with 160 GeV μ^+ (1/3) and μ^- (2/3)
- ▶ 2 years of data taking approved
- ▶ pilot run 2012



ECAL0

ECAL1

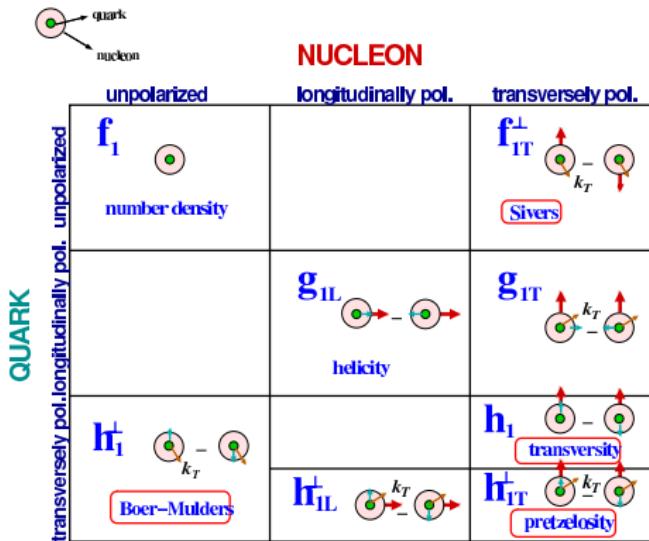
ECAL2

CAMERA recoil proton detector
surrounding the 2.5m long
LH₂ target

μ^-

18-10-2012

TMDs



- ▶ dynamic picture of the nucleon using intrinsic transverse momentum k_T of partons
- ▶ sensitivity to quark orbital angular momentum
- ▶ at leading twist:
full description with 8 TMDs
- ▶ 3 survive integration over k_T :
 f_1 , g_1 and h_1

- ▶ TMDs are accessed by azimuthal asymmetries in SIDIS and DY
- ▶ studied in SIDIS using unpolarised and transversely polarised target
- ▶ in SIDIS convolution with fragmentation function

TMDs

NUCLEON		
unpolarized	longitudinally pol.	transversely pol.
QUARK		
f_1 number density		f_{1T}^\perp Sivers
	g_{IL} helicity	g_{IT}
h_1^+ Boer-Mulders		h_1 transversity
	h_{IL}^+ 	h_{IT}^\perp pretzelosity

Sivers function f_{1T}^\perp :
correlation of quark k_T and nucleon transverse spin

Sivers and BM functions T-odd
→ process dependent

Prediction

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

Boer-Mulders function h_1^+ :

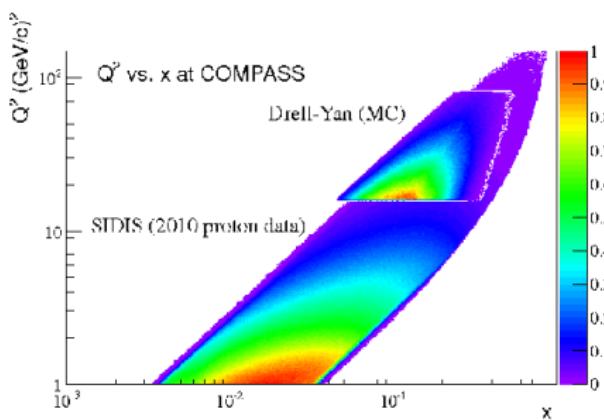
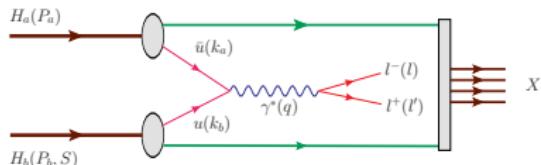
correlation of quark k_T and transverse quark spin in unpol. nucleons

$$h_1^+(SIDIS) = -h_1^+(DY)$$

→ Crucial test of non-perturbative QCD and of TMD approach

DY at COMPASS

$$\pi^- p^\uparrow \rightarrow \mu^+ \mu^- X$$

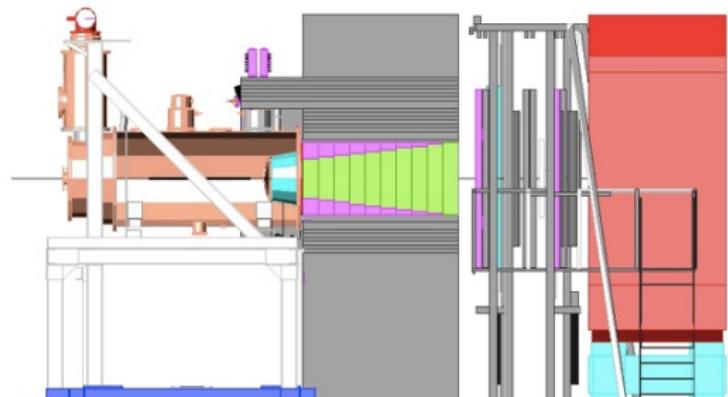
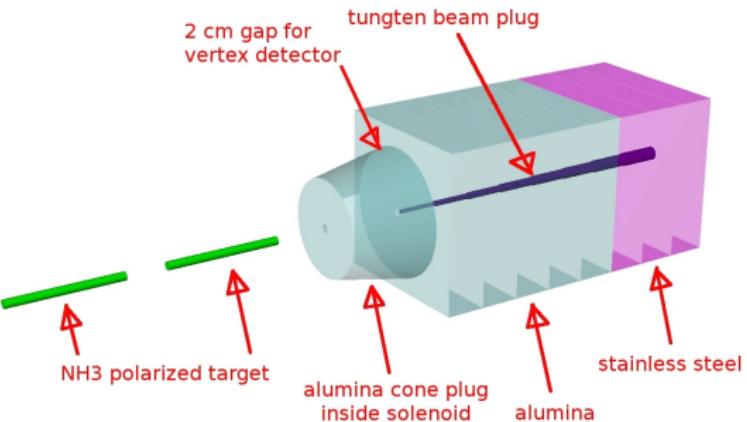


- ▶ convolution of two TMDs measured
- ▶ access to 4 azimuthal modulations: Boer-Mulders, Sivers, pretzelosity and transversity PDFs
- ▶ ideal DY measurement: $\bar{p}p$
- ▶ good compromise $\pi^- p$
- ▶ annihilation of valence anti-quark from π^- and valence quark from polarised proton
- ▶ large acceptance of COMPASS in the valence region

Target region for DY

- ▶ first DY measurement with pol. target
- ▶ high intensity 190 GeV/c pions
- ▶ transversely polarised NH₃ (Bochum)
- ▶ hadron absorber, beam plug
- ▶ vertex detector, beam telescope (Bonn HISKP, Erlangen)
- ▶ dimuon trigger system (Bonn PI, Mainz)
- ▶ DAQ upgrade (TUM)

- ▶ pilot run planned for 2014 (few weeks)
- ▶ 1 year of data taking approved



Outlook

Plans

- ▶ DY pilot run in 2014
- ▶ 2015 DY with transversely polarised NH₃
- ▶ 2016/7 DVCS with hydrogen target

Perspectives

- ▶ DVCS: Ji's sumrule →
measurement with transverse polarisation and recoil detector
- ▶ SIDIS: evolution of transversity and TMDs →
considerable increase of stat., transverse target pol.
- ▶ DY: precision, flavour separation →
deuteron target, exploit antiprotons in the beam
- ▶ Hadron spectroscopy: photoproduction
study of reaction mechanism