Results and Future Plans of the COMPASS Experiment

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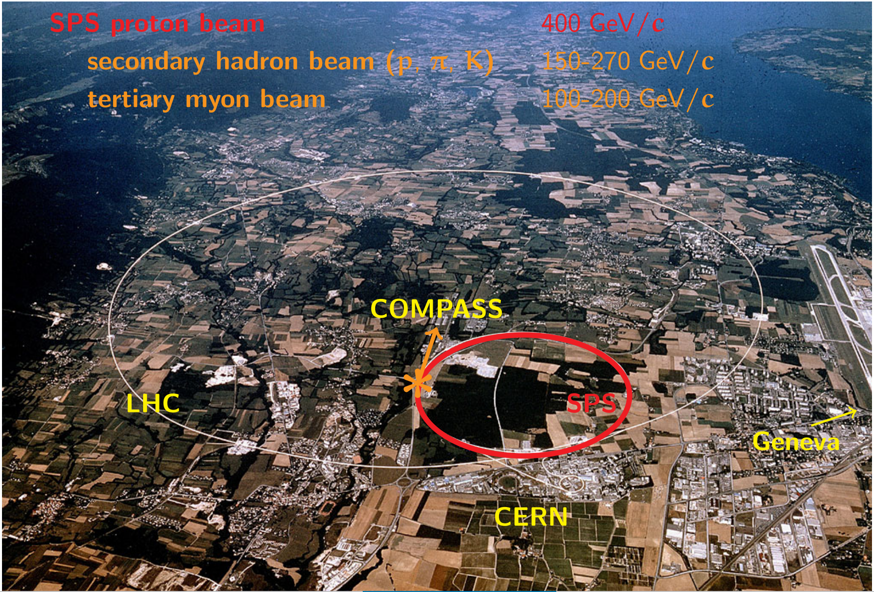
bmb+f - Förderschwerpunkt
COMPASS
Großgeräte der physikalischen Grundlagenforschung

COMPASS

Outline

The COMPASS Experiment

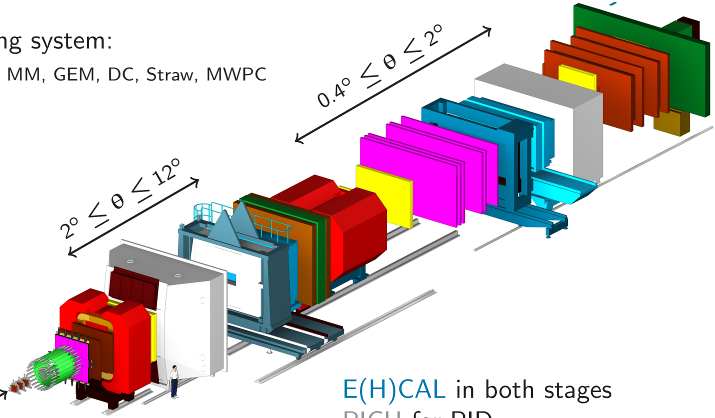


The COMPASS Experiment

COmmon Muon and Proton Apparatus for Structure and Spectroscopy

Tracking system:

SciFi, Si, MM, GEM, DC, Straw, MWPC



beam ($\mu^{\pm}/h^{\pm}$)

E(H)CAL in both stages

RICH for PID

Recoil Proton Detector

Hodoscope trigger system for μ beam

Beam PID for h beam

The COMPASS Physics Program

Goal: Study QCD in a large range of $\mathbf{Q}^2$

Hadron Beam

- Spectroscopy
- OZI violation and spin alignment
- Chiral dynamics
- Pion polarisability
- Radiative widths

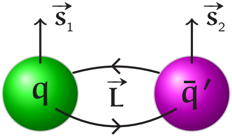
Muon Beam

- Parton distribution functions
- Fragmentation functions
- Nucleon spin structure
- Search for $\boldsymbol{Z_c}(3900)$

Physics with Hadron Beam

Mesons in the Constituent Quark Model

- Intrinsic spin $S = 0$ or $S = 1$
- Total angular momentum $\vec{J} = \vec{L} + \vec{S}$
- Parity $P = (-1)^{L+1}$
- Charge conjugation $C = (-1)^{L+S}$



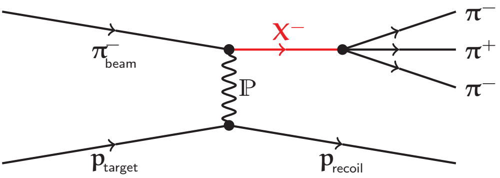
$\Rightarrow$ Forbidden J^{PC}: 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, 3^{-+}, ...

"Exotic Mesons"

QCD allows also for states with J^{PC} forbidden in $|q\bar{q}\rangle$ systems:

- Hybrids $|q\bar{q}g\rangle$
- Glueballs $|gg\rangle$
- Tetraquarks/Molecules

Production of Mesons in Diffractive Dissociation

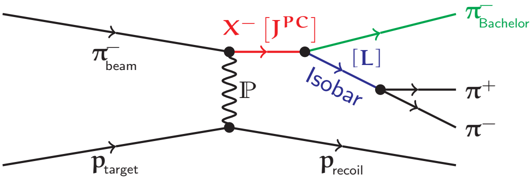


- Soft scattering (target proton remains intact)
  - Beam particle is excited into intermediate state X^-
  - X^- decays into n particles
- Large $\sqrt{s}$ and low t
  - Pomeron exchange
- Goal: Use kinematic distributions of final state particles to
  - Disentangle resonances X^-
  - Determine mass, width and quantum numbers
- Method: partial wave analysis (PWA)

Partial Wave Analysis

Isobar Model:

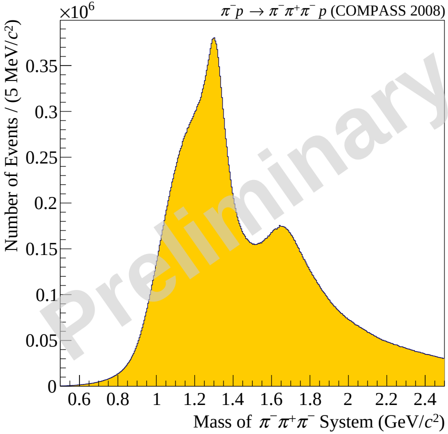
- X^- decays via successive two-body decays
- "Wave": Unique combination of quantum numbers and isobar J^{PC}[isobar bachelor]L



Analysis done in two steps:

1. Fit to spin-density matrix in independent bins of 3π-mass and t' to obtain intensities and phase correlations of single waves ("Mass-independent fit")
2. Breit-Wigner fit to extract resonance parameters ("Mass-dependent fit")

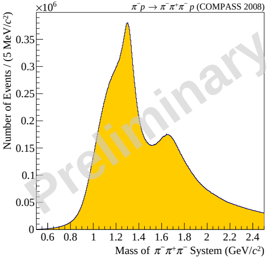
$\pi^- p \to \pi^- \pi^+ \pi^- p$



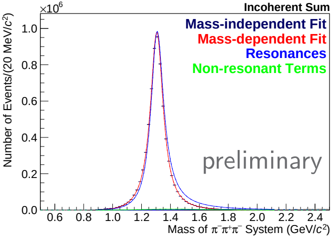
- 96M 3π events on liquid hydrogen target (world's largest dataset)
- PWA in 100 bins of $M_{3\pi}$ and 11 bins of t' with 88 waves
- Results will be published soon

PWA of $\pi^- p \to \pi^-\pi^+\pi^- p$

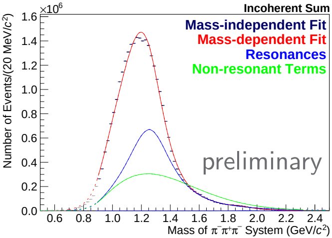
Invariant $\pi^-\pi^+\pi^-$ mass spectrum



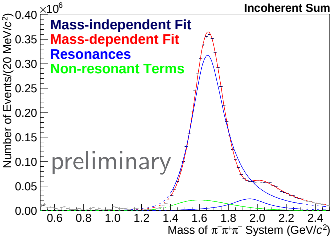
$a_2(1320)$ in $2^{++}[\rho\pi]D$



$a_1(1260)$ in $1^{++}[\rho\pi]S$

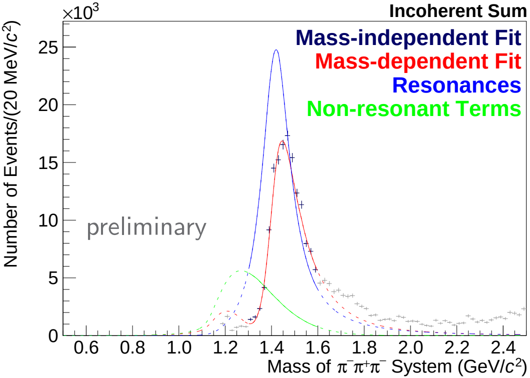


$\pi_2(1670)$ in $2^{-+}[f_2(1270)\pi]S$



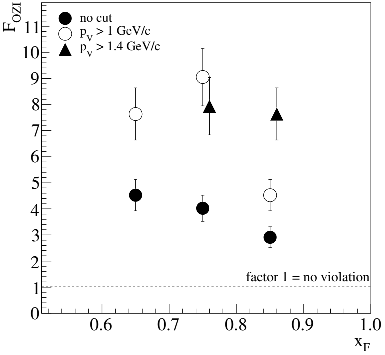
New axial resonance $a_1(1420)$

- $1^{++}[f_0(980)\pi]P$ wave shows resonant structure
- Can be explained by new resonance
- Mass: 1412-1422 MeV/c^2
- Width: 130-150 MeV/c^2



Measurement of OZI Violation

- Compare ω and ϕ production
- $F_{OZI} \propto \frac{d\sigma(pp\to p\phi p)/dx_F}{d\sigma(pp\to p\omega p)/dx_F}$



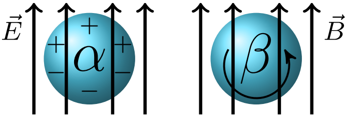
- OZI violation observed
  - factor 4, x_F dependence
- Larger F_{OZI} found by other experiments
  - ω production resonantly enhanced
  - → different production mechanisms
  - cut on ω/ϕ momentum to remove resonances

⇒ OZI violation factor 8 observed
  - no x_F dependence
  - in agreement with SPHINX results at low energy
- Study of spin alignment and production mechanisms

[NPB 886 (2014) 1078, hep-ex/1405.6376]

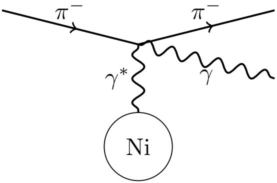
Measurement of Pion Polarisability

Polarisability = “Reaction” of pion to external electromagnetic field



χPT prediction:
$2\alpha_\pi = \alpha_\pi - \beta_\pi = (5.7 \pm 1.0) \times 10^{-4}\ \mathrm{fm}^3$

COMPASS: Primakoff reaction



[hep-ex/1405.6377, submitted to PRL]

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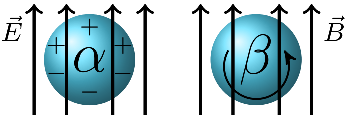

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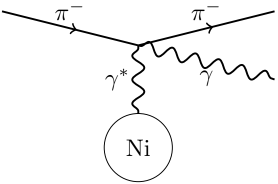


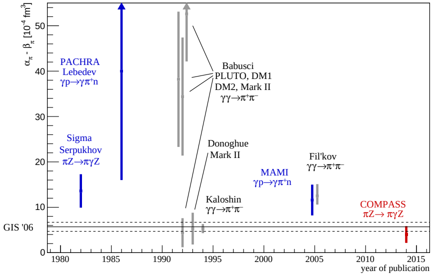
[hep-ex/1405.6377, submitted to PRL]

Measurement:

- Deviation from point-like cross section
- Assume $\alpha_\pi = -\beta_\pi$
- Measure muon fake-polarisability

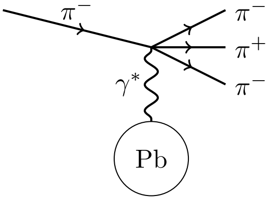
Result:

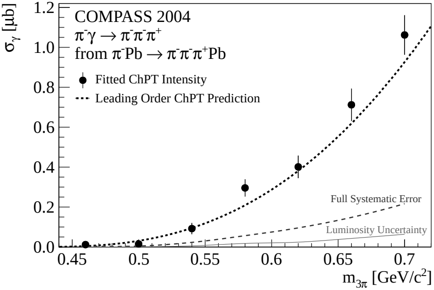
$\alpha_\pi = (2.0 \pm 0.6 \pm 0.7) \times 10^{-4}\ \mathrm{fm}^3$



Measurement of Chiral Dynamics in 3π Final States

- $\pi^- \mathrm{Pb} \rightarrow \pi^-\pi^+\pi^- \mathrm{Pb}$
- Coulomb region, $t' < 0.001\,\mathrm{GeV}^2/c^2$
- Replace PWA amplitudes at low masses by "χPT-like" amplitude





First measurement of cross section:

- Results in agreement with LO χPT
- More data available (Ni target)

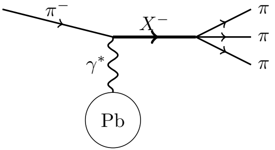
[PRL 108 (2012) 192001, hep-ex/1111.5954]

Radiative Widths of $a_2(1320)$ and $\pi_2(1670)$

$X \to \pi\gamma$

- Access to electromagnetic transitions
- Experimentally challenging

$\rightarrow$ Use inverse process



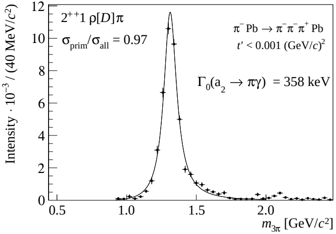
$$\sigma_{\text{Primakoff}} \propto \Gamma_0(X \to \pi\gamma)$$

- Primakoff contribution has $M = 1$
- $\sigma_{\text{diffractive}} \propto t'^M e^{-bt'}$

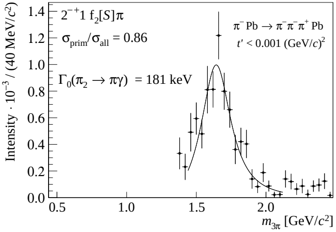
$\rightarrow$ Primakoff dominant at low t'

- Disentangle contributions via PWA

$a_2(1320)$: Good agreement



$\pi_2(1670)$: First measurement



[EPJA 50 (2014) 79, hep-ex/1403.2644]

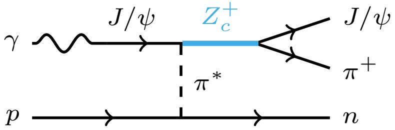
Physics with Muon Beam

Search for $Z_c(3900)$

2013: Discovery of charged charmonium state $Z_c(3900)$

COMPASS:

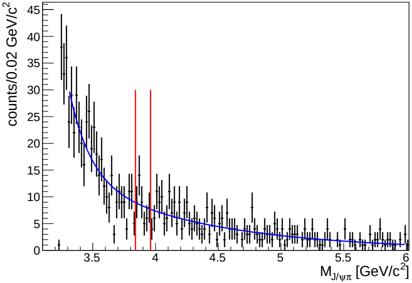
- virtual photon may behave like J/ψ (vector meson dominance)
- $Z_c(3900)$ production with virtual pion from nucleon target



- sizable production cross section

[Q.-Y. Lin et al, Phys. Rev. D 88, 114009 (2013)]

- no signal observed

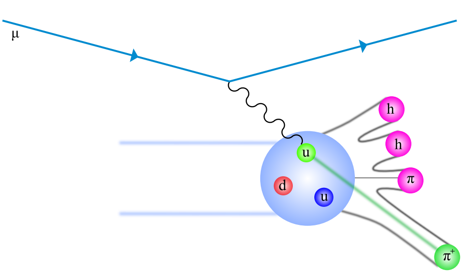


$\Rightarrow$ $BR(Z_c(3900) \rightarrow J/\psi\pi)$ seems to be small

[hep-ex/1407.6186, submitted to PLB]

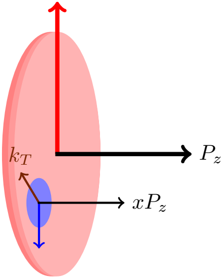
The Nucleon in the Quark Parton Model

Semi-Inclusive Deep Inelastic Scattering



- Muon scattering of polarised nuclear target
- Virtual photon interacts with single parton

Parton Distribution Functions

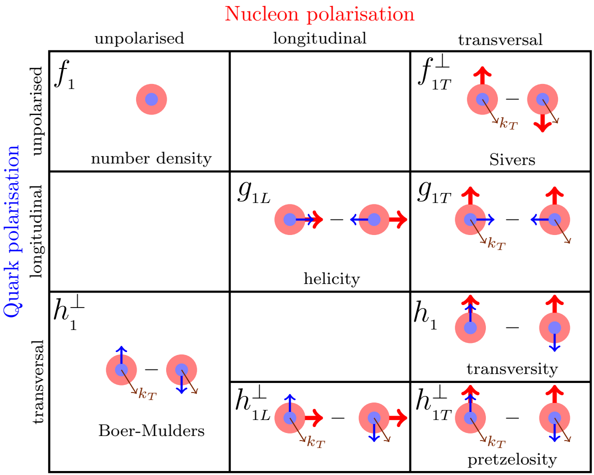


Accessible:

- Momentum fraction x of the parton
- Parton spin
- Transverse parton momentum $\mathbf{k_T}$

Parton Distribution Functions

Leading Order: 8 transverse momentum dependent PDFs



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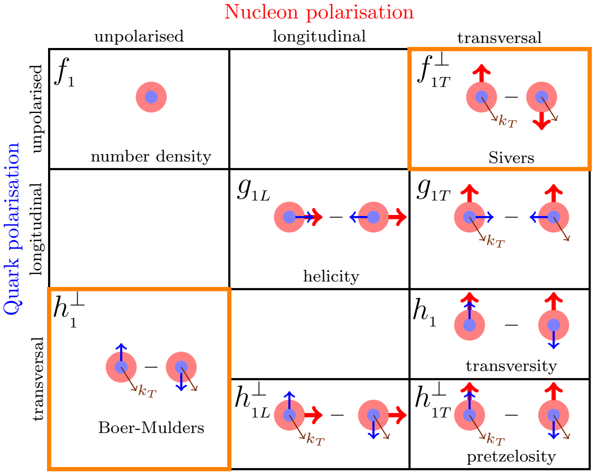


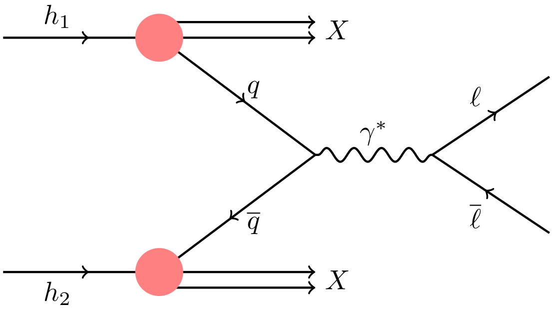
Sivers and Boer-Mulders: Process dependent

Future Physics at COMPASS

Drell-Yan at COMPASS

Goal: Measure sign flip: Sivers(DY) = −Sivers(SIDIS)

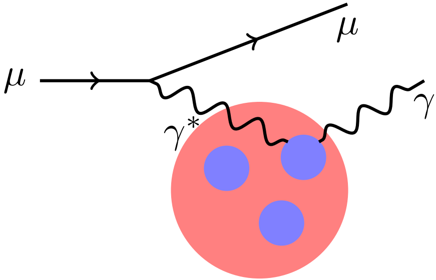
- Lepton pair production in hadron-hadron scattering



- $\boldsymbol{\pi^- p \to \mu^+ \mu^- + X}$
- Hadronic final state $\mathbf{X}$ absorbed

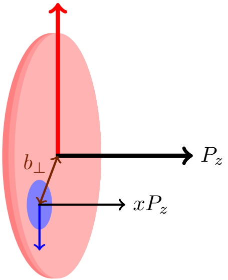
Generalised Parton Distributions

Deeply-Virtual Compton Scattering



- Compton scattering on single parton
- Real photon in final state
- Target remains intact

"Nucleon Tomography"



Accessible:

- Momentum fraction x of the parton
- Parton spin
- Transverse distance $\mathbf{b}_\perp$

Summary

- COMPASS studies QCD over a large range of $\mathbf{Q}^2$
- Only very selective highlights shown here

$\longrightarrow$ Many more analyses finished or ongoing

Future Plans

2014 Drell-Yan comissioning and first data taking

2015 Drell-Yan on transversely polarised target

16/17 DVCS to measure GPDs & SIDIS on unpolarised target

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Thank you for your attention

Further Analyses