COMPASS++

Physics opportunities for a future COMPASS-like experiment

G.K. Mallot for COMPASS
EP-SME-CO

many slides from Oleg Denisov

Outline

- Introduction
- Physics with RF-separated beams (kaons, antiprotons)
  - Spectroscopy
  - Drell-Yan
- Physics with existing muons and hadron beams
  - SIDIS, DVCS, DVMP
  - DY
- Outlook

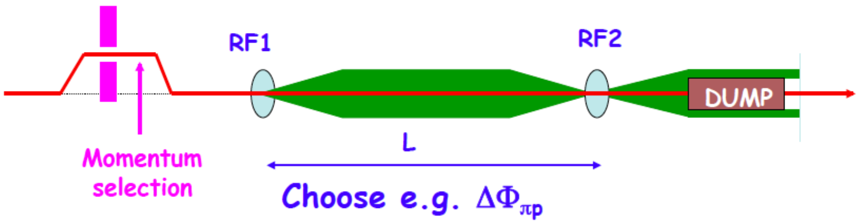
QCD Questions

- How in detail hadrons are made up by quarks and gluons
- What are the correlations, e.g. between transverse and spatial degrees of freedom (TMD, GPD, tomography)
- Are time-reversal-odd TMD PDFs universal?
- What is the structure of kaons (kaon DY, direct photons)
- Kaon excitation spectrum and decay modes $> 1.5\ \mathrm{GeV}/c^2$
- Charmonium hybrids and exotics
- chiral dynamics – kaon polarisability

- add-on: Dark matter, supporting measurements

Future plans

- COMPASS is preparing a Letter of Intent for a new round of experiments beyond 2020
- Open to new groups and ideas
- Starting point: [Beyond 2020 workshop]March 2016 at CERN
- Unique opportunity: RF separated kaon and antiproton beams (in M2)



$\Delta\Phi = 2\pi\,(L\,f\,/\,c)\,(\beta_1^{-1} - \beta_2^{-1})$ with $\beta_1^{-1} - \beta_2^{-1} = (m_1^2 - m_2^2)/2p^2$

- Goals: LoI in 2017, proposal in 2018
- Likely a 7-8 year endeavour

Ideas for a LoI

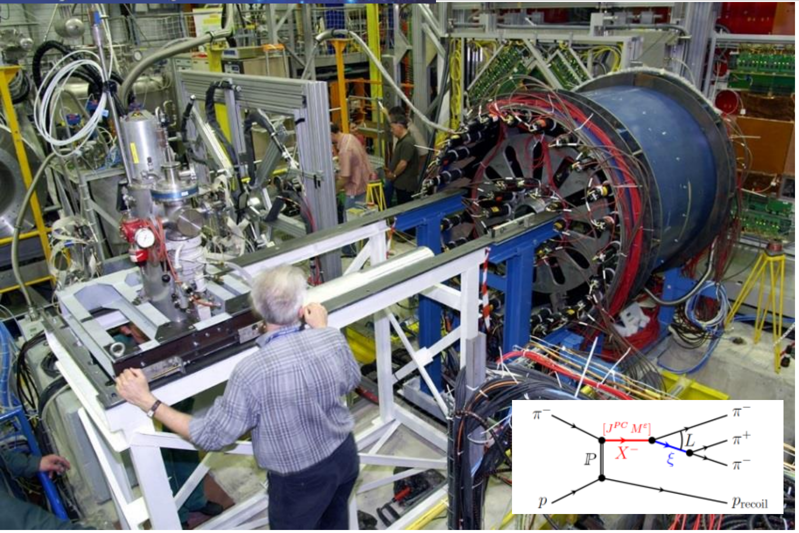
- **Spectroscopy with RF-separated beams**
  - Kaon: Hadron spectroscopy and diffraction
  - Kaon: polarisability
  - Kaon: gluon distribution with prompt photons
  - Antiproton: Charmonium hybrids and exotics (low p-bar energy)
- **Drell-Yan with RF-separated beams**
  - Kaon: DY with both polarised and unpolarised targets, kaon structure
  - Antiproton: DY, both polarised and unpolarised, TMDs

LoI (cont'd)

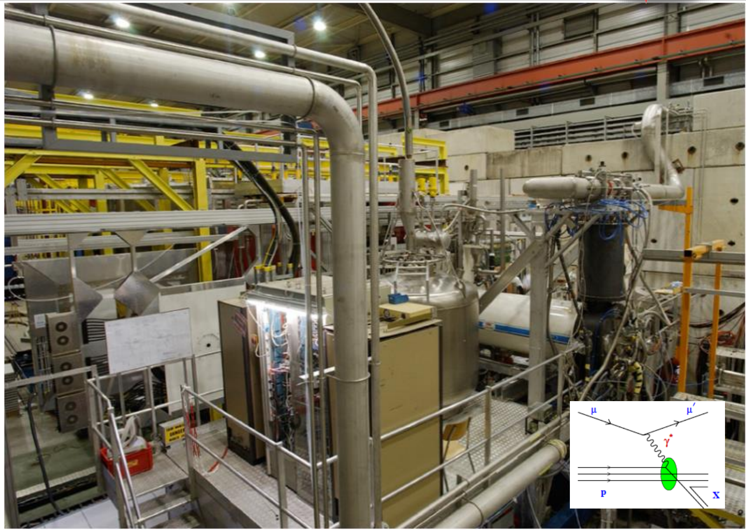
- **Physics with existing muon beam**
  - SIDIS with transverse polarised deuteron target
  - DVCS with transverse polarised proton target
- **Physics with existing pion/proton beam**
  - Pol. DY with deuteron target – flavour separation
  - Unpol. DY with various targets
  - x-section $p + \mathrm{He} \rightarrow \bar{p}\, X$ for dark matter

Programme with present beams, likely to start right after LS2 (unless separated beams would be available already)

Versatile COMPASS in EHN2

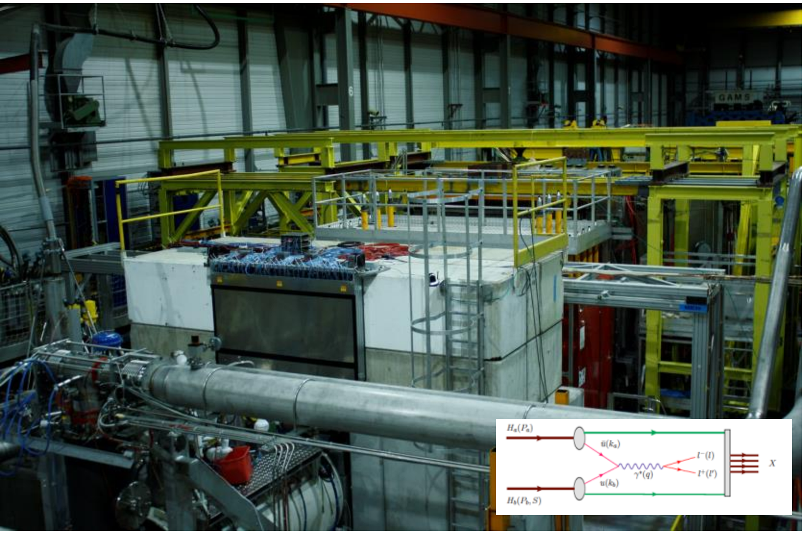


COMPASS-I
1997-2011

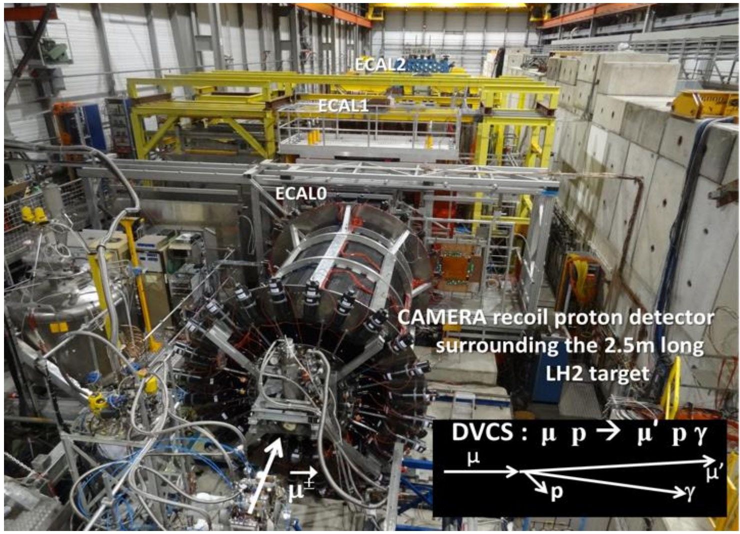


Hadron Spectroscopy & Polarisability

Polarised SIDIS



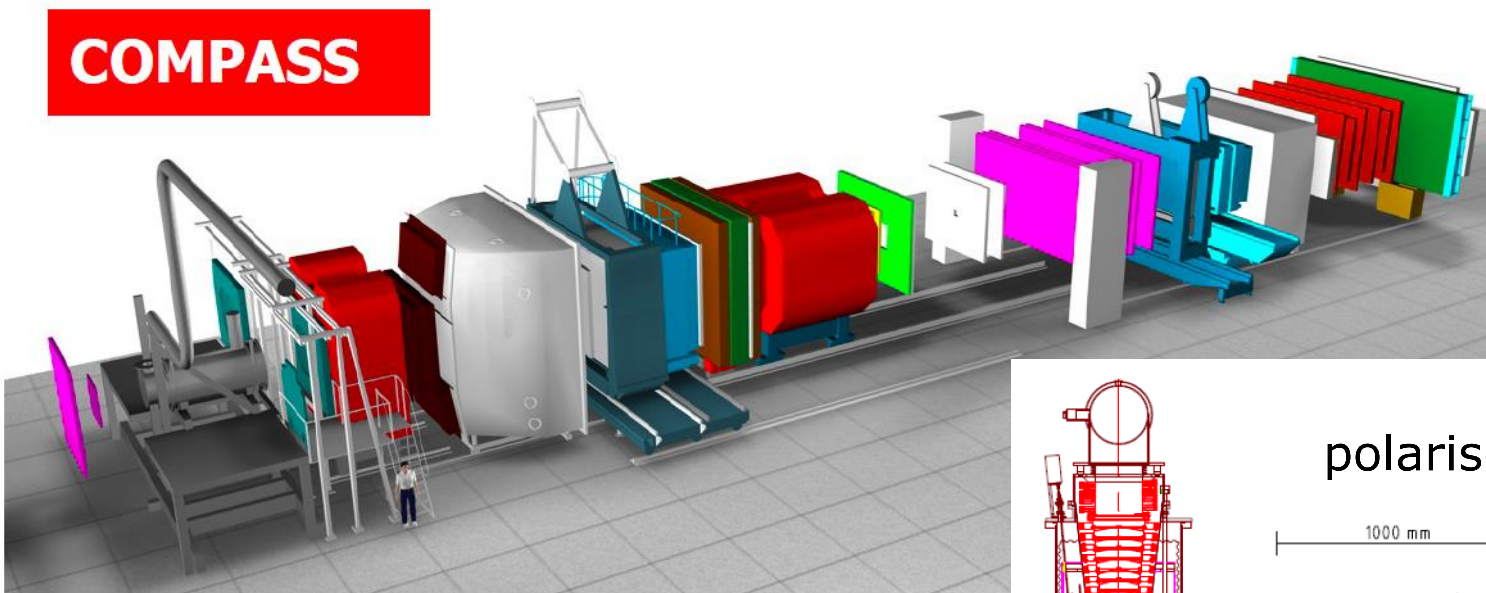
COMPASS-II
2012-2018

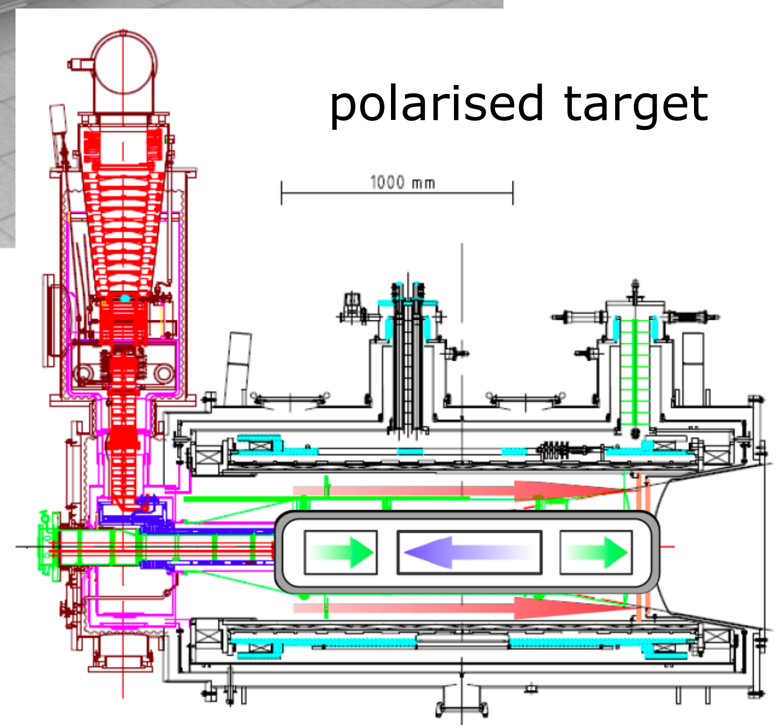


Polarised Drell-Yan

DVCS (GPDs) + unp. SIDIS

COMPASS



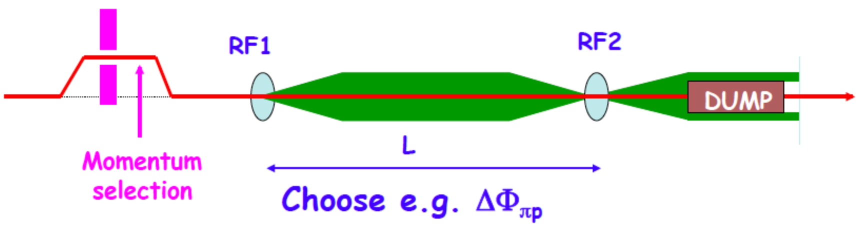


240 physicists from
12 countries + CERN,
24 institutions

RF-separated kaon beam

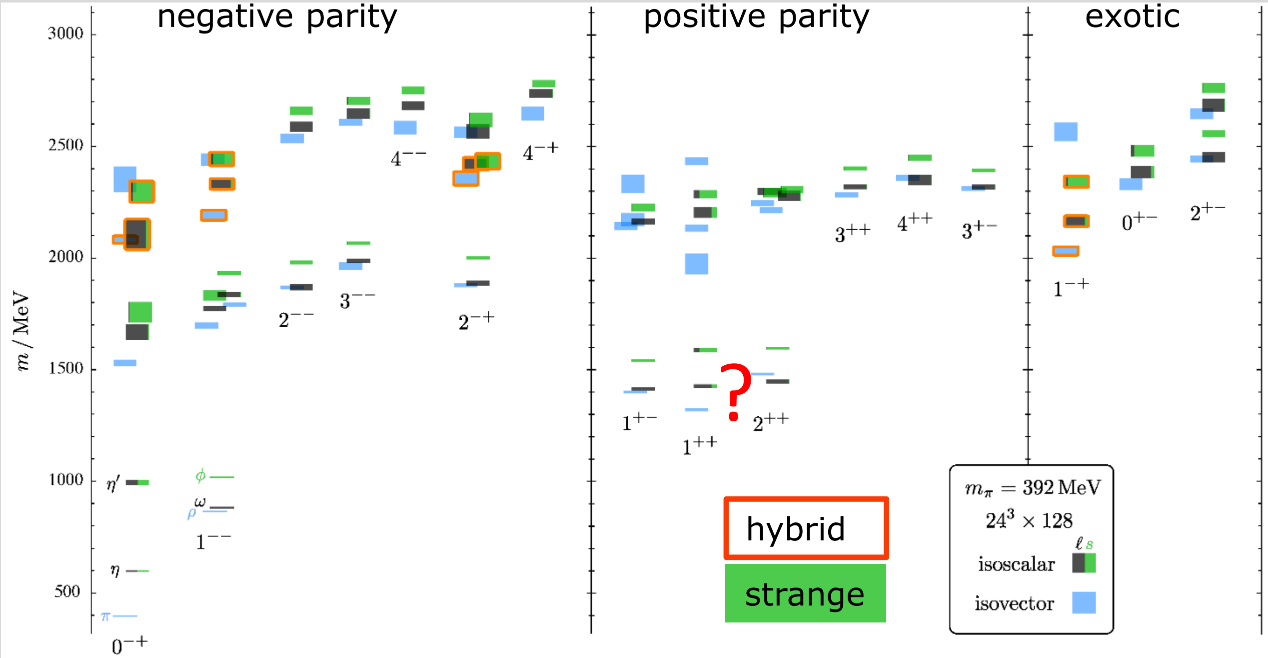
Hadron spectroscopy

($\sim 10^8/s$ in spill, $\sim 100\ \mathrm{GeV}$)



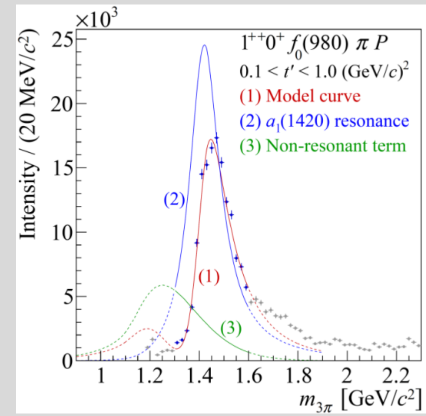
$$\Delta\Phi = 2\pi\,(L\,f\,/\,c)\,(\beta_1^{-1} - \beta_2^{-1}) \text{ with } \beta_1^{-1} - \beta_2^{-1} = (m_1^2 - m_2^2)/2p^2$$

Light and strange meson sector



Lattice, J. Dudek et al., PRD 88 (2013) 094505

COMPASS: $a_1(1420)$

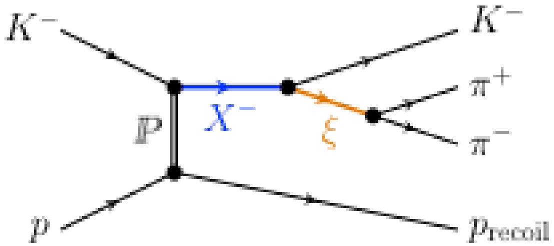


COMPASS:

3π data sample ~50x10^6 exclusive events – factor 10 to 100 more than previous experiments, advanced analysis (88 waves) PRD 95 (2017) 032004

Illustration or our potential: discovery of a new axial-vector meson $a_1(1420)$ in $1^{++}0^{+}$ $f_0(980)\pi$ *P* wave. PRL 115 (2015) 082001

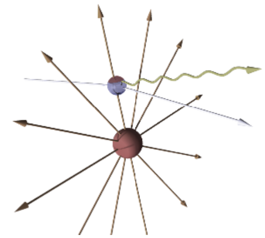
Kaon states



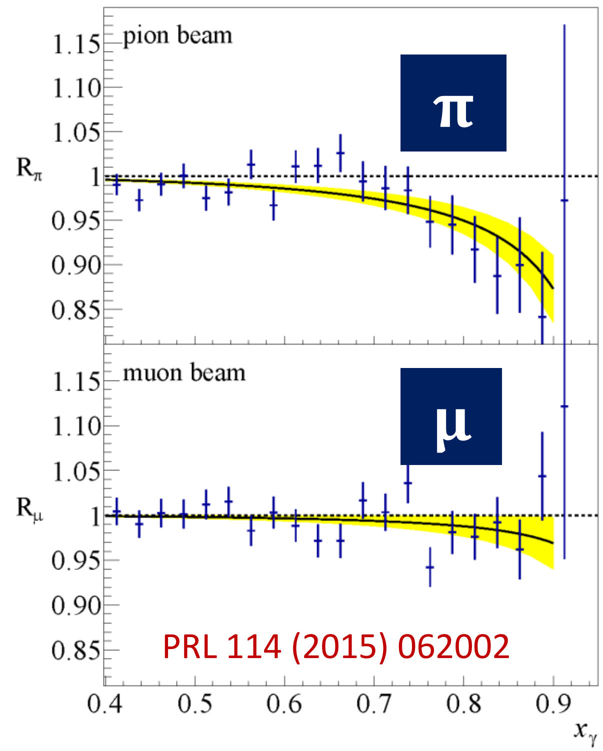
- PDG lists in total 25 kaon states
  - 17 kaon states above $1450\ \mathrm{MeV}/c^2$
  - 12 are omitted from summary tables
  - 8 need confirmation, for 2 states J^P is unknown
- All entries are older than 20 – 30 years
- Mapping out the kaon excitation spectrum and decay modes helps understanding light-meson spectrum by completing SU(3) flavour multiplets
- With an RF-separated kaon beam COMPASS++ could increase the global data set by a factor 10 and rewrite PDG for strange mesons for masses $> 1.5\ \mathrm{GeV}/c^2$
- Unique opportunity, no real competitors

B. Grube, Beyond 2020 WS

Chiral dynamics – e.g. kaon polarisability

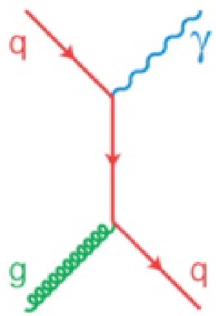


- Primakoff reaction
  $\pi\gamma \rightarrow \pi\gamma$ in nuclear field
- El. & magn. polarisabilities (α, β) are fundamental properties, predictable in χPT
- COMPASS measured α for π assuming $[\alpha + \beta = 0]$
- With RF-separated beam kaon measurement possible
- Further measurements for other processes $\pi\gamma \rightarrow \ldots$ in parallel



Direct photons from kaons (& pions)

Production of direct photons $hN \rightarrow X\gamma$



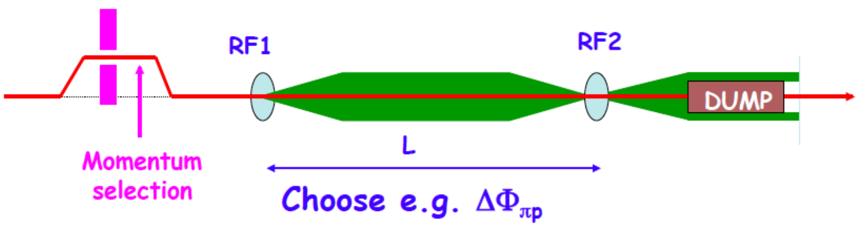
gluon PDFs
of hadrons

- Under study, maybe tests during 2017 GPD run
- First observation of direct photon production with a kaon beam could be an important direct measurement of gluon contribution in kaons
- No data existing

RF-separated(?) antiproton beam

Hadron spectroscopy

($\sim 5 \times 10^6/s$ in spill, ~ 20 GeV or lower)



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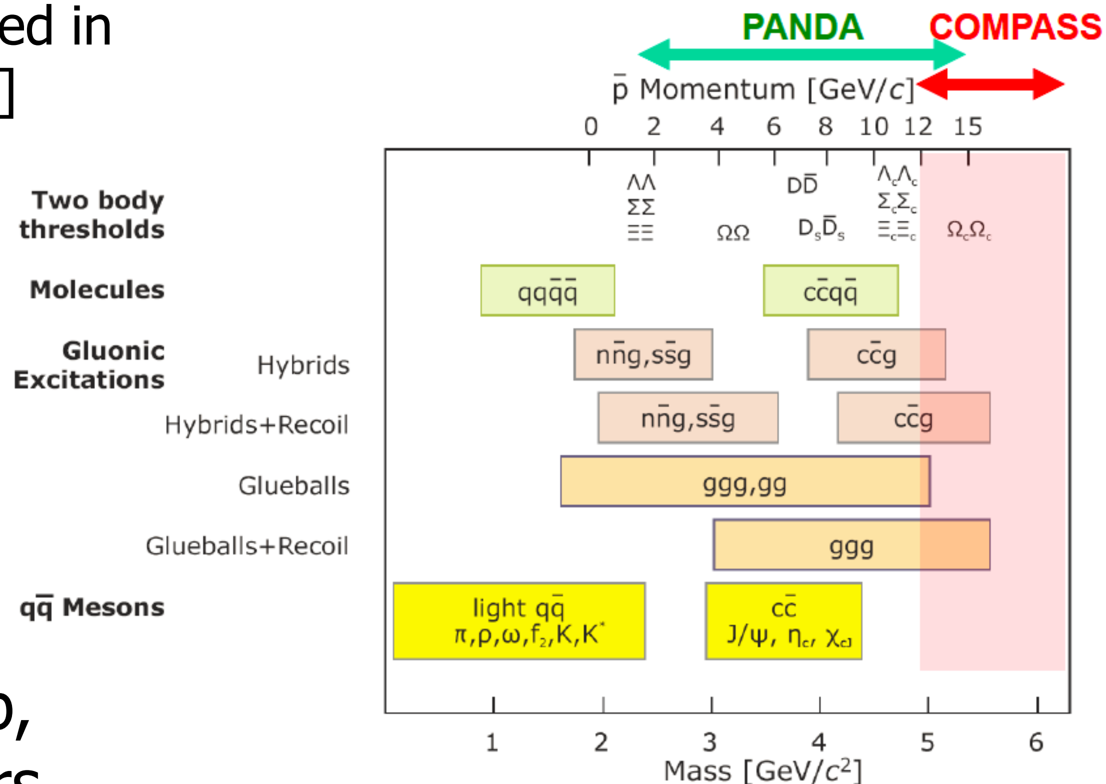
`Charmonium-like' mesons

- Many narrow states discovered in recent years [LHCb, Belle, …]
- Assignment not clear, hybrids and exotics
- Study states in $p\bar{p}$ annihilation, gluon rich
- ass range beyond PANDA



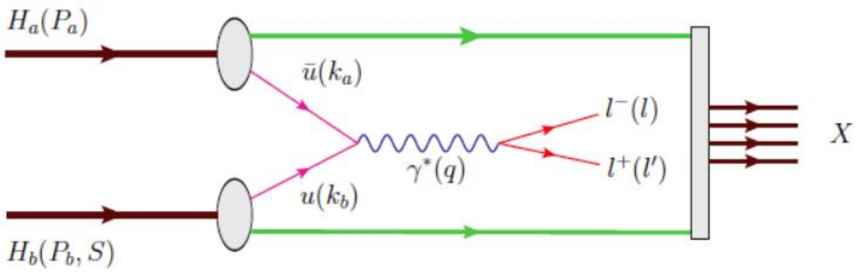
- Complementary to LHCb, otherwise no competitors for the next at least 10 years

RF-separated beams (>120 GeV)

neg. kaons ($\sim 8 \times 10^6/s$ in spill)

antiprotons ($\sim 4 \times 10^7/s$ in spill)

Drell-Yan



Kaon-induced DY

- Kaon-induced DY is the only source of information on kaon structure
- Compare pion and kaon-induced DY x-sections

$$\frac{d\sigma^{K^-}/dx_1}{d\sigma^{\pi^-}/dx_1} = \frac{\overline{u}_K}{\overline{u}_\pi}(x_1)$$

- Unpolarised case, possibility to use different nuclear targets (like LH_2, Al, W, Cu):
  1. Kaon structure functions (PDFs)
  2. Nucleon strange quark structure
  3. Fundamental Lam-Tung relation for the kaon
  4. Boer-Mulders TMDs (quark-spin – quark-k_T correl.) for kaons
  5. …
- Unique opportunity

Antiproton-induced Drell-Yan

Model-independent TMD extraction

- TMD (restricted) universality
- TMD-induced asymmetries in both High-Mass and J/Ψ regions:
  1. Boer-Mulders (quark-spin – quark-k_T correl.) extraction (CPT)
  2. Transversity extraction
  3. Lam-Tung relation for antiprotons (QCD effects)
  4. Sivers asymmetry (nucleon-spin–quark-k_T correlations) without uncertainty from pion PDFs
  5. Sivers function for gluons (J/Ψ regions)
  6. …
- Unique data

Drell-Yan rates

- Assuming flux of $1x10^7$ /s for kaon/antiproton,
- High mass range $4 < M_{\mu\mu} < 9$ GeV/c^2
- 140 days of data taking with the efficiency of 2015 Drell-Yan run assuming a flux of $1x10^7$ /s for kaons/antiprotons
- The overall gain for RF-separated beams wrt previous experiments is a factor 50 to 100

Beam	COMPASS++ (proj.)			NA3	E537
	NH3	Al	W		
K^-	14’000	2’800	29’600	700	
$\bar{p}$	15’750	2’750	22’500		387

Existing muon beams

Exclusive processes (GPD)

SIDIS with deuteron target

Existing hadron beams

pol. DY with deuteron target

- Generalised Parton Distribution (GPD) *E* and access to Orbital Angular Momentum
  - DVCS (μ p↑ → μ p γ)
  - DVMP (μ p↑ → μ ρ (ω) γ)
- Recoil detector to be inserted into the PT magnet
  - Several options being studied
- unique kinematic range, small x

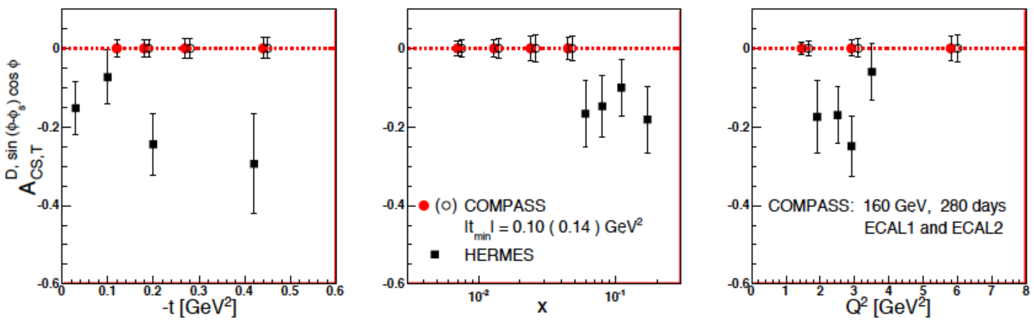


Figure 13: Expected statistical accuracy of $A_{CS,T}^{D,\sin(\phi-\phi_s)\cos\phi}$ as a function of $-t$, x_B and Q^2 from a measurement in 280 days, using a 160 GeV muon beam and ECAL1+ECAL2. Solid and open circles correspond to the simulations for the two hypothetical configurations of the target region (see text). Also shown is the asymmetry $A_{U,T}^{\sin(\phi-\phi_s)\cos\phi}$ measured at HERMES [41] with its statistical errors.

Deuteron transversity and TMDs (SIDIS)

- Only existing deuteron/neutron data sets:
  - COMPASS (^{6}LiD) and CLAS (^{3}He)
- COMPASS data only from 2002–2004
- Data set factor 4 smaller than proton set
- For flavour separation equal statistics is optimal

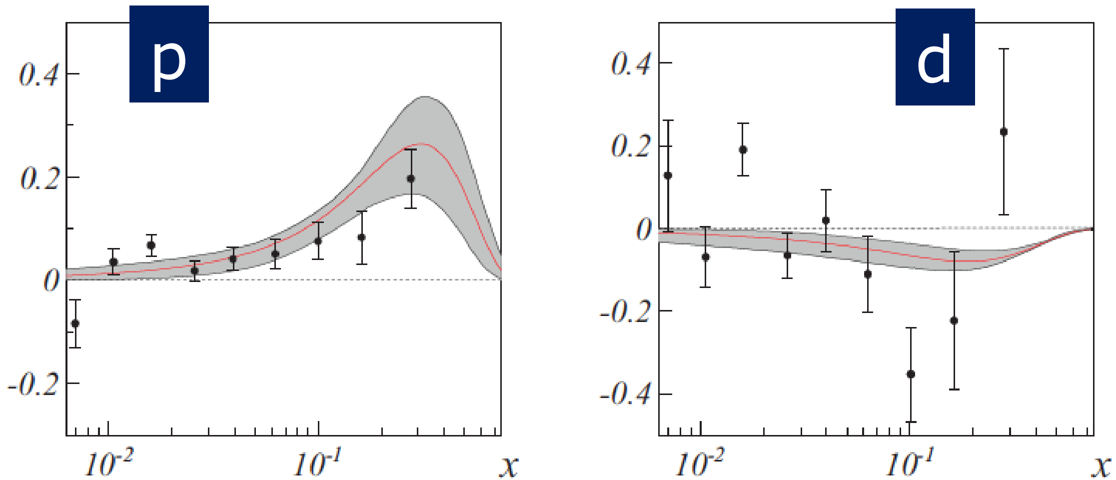
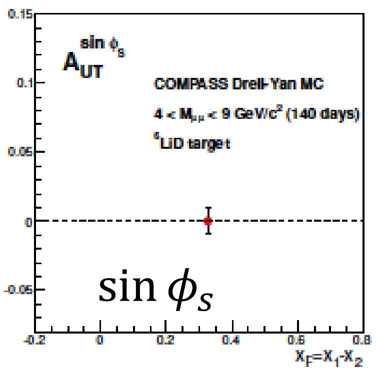


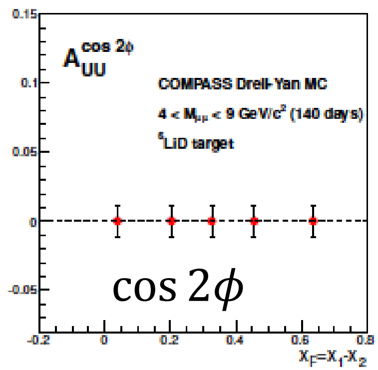
Fig. 6: $xh_1^u(x)$ (left) and $xh_1^d(x)$ (right) from the 'two hadron' asymmetries of 2010 proton and of 2002-2004 deuteron data (from[30]). The curves show the transversity PDFs obtained from a fit of Collins asymmetries [29]

Pion-induced Drell-Yan (^{6}LiD, LH_2)

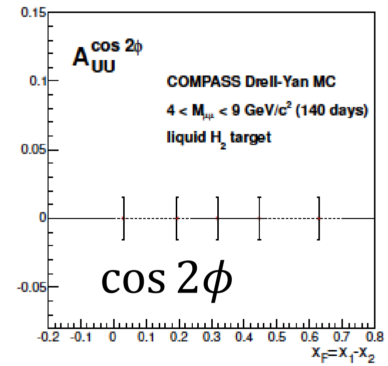
- Pol. proton DY data in 2015/2018
- Pol. deuteron DY data needed for flavour separation of PDFs
- Shorter run with unpolarised LH2 target is required
  - to test fundamental Lam-Tung relation
  - to extract Boer-Mulders TMD using “clean” (no nuclear effects) LH target – complementary to SIDIS.
- Simulation for 140 days of beam:

^{6}LiD



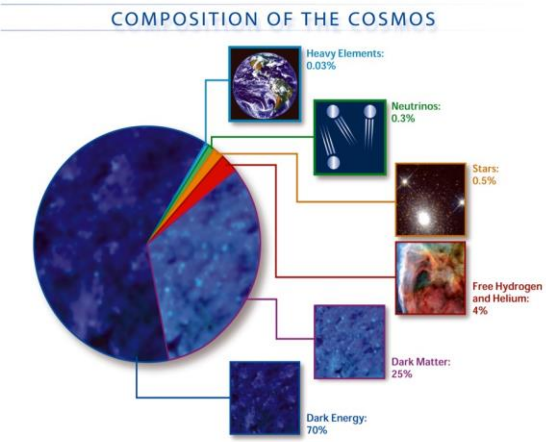


LH_2



Unique, no competitors

Astrophysics – search for dark matter,
possible contribution from COMPASS



- New AMS(2) data – the antiparticle flux is well known now (few % pres.);
- Two types of processes contribute – SM interactions (proton on the ISM with the production for example antiprotons in the FS.) and contribution from dark matter annihilation;
- In order to detect a possible excess in the antiparticle flux a good knowledge of inclusive cross sections of p-He interaction with antiparticles in the FS is a must, currently the typical precision is of 30-50%.

Thus the primary goal is to measure inclusive antiproton (positron, gamma) production cross section in a wide kinematical range with the precision <10%. **Compared to NA49 COMPASS has factor ~1000** in luminosity. COMPASS:

- Proton beam energy range 50-250 GeV
- Secondary particles identification:
  - Antiprotons (RICH)
  - Positrons and Gamma (ECals)

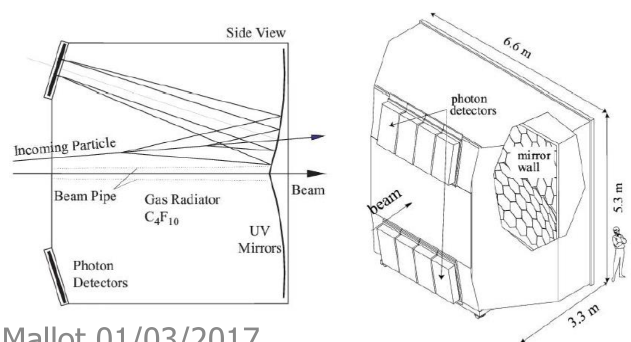
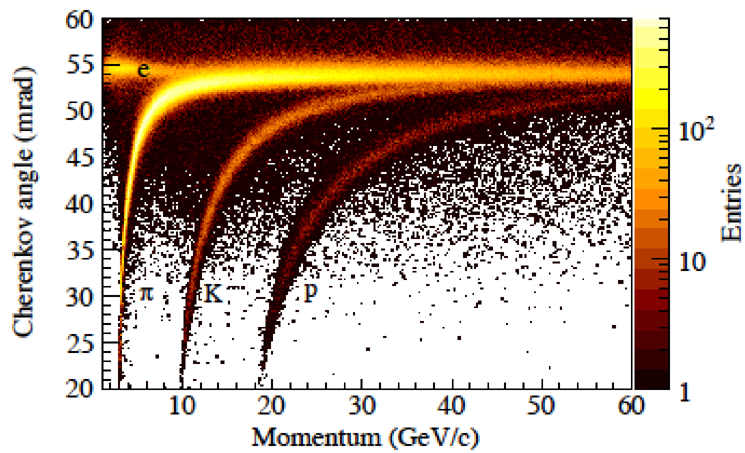


Figure 34. COMPASS RICH-1: principle and artistic view.



Outlook

- Many open questions and important measurements remain on hadron structure and spectroscopy
- The COMPASS spectrometer is a unique facility and well adapted to the proposed measurements
- Upgrades in various places are inevitable for a 7–8 year programme after 2020
- An extended collaboration has to be built on the COMPASS nucleus
- RF-separated kaon and antiproton beams would open a new chapter in structure and spectroscopy studies

M2 muon beam option should be kept if possible