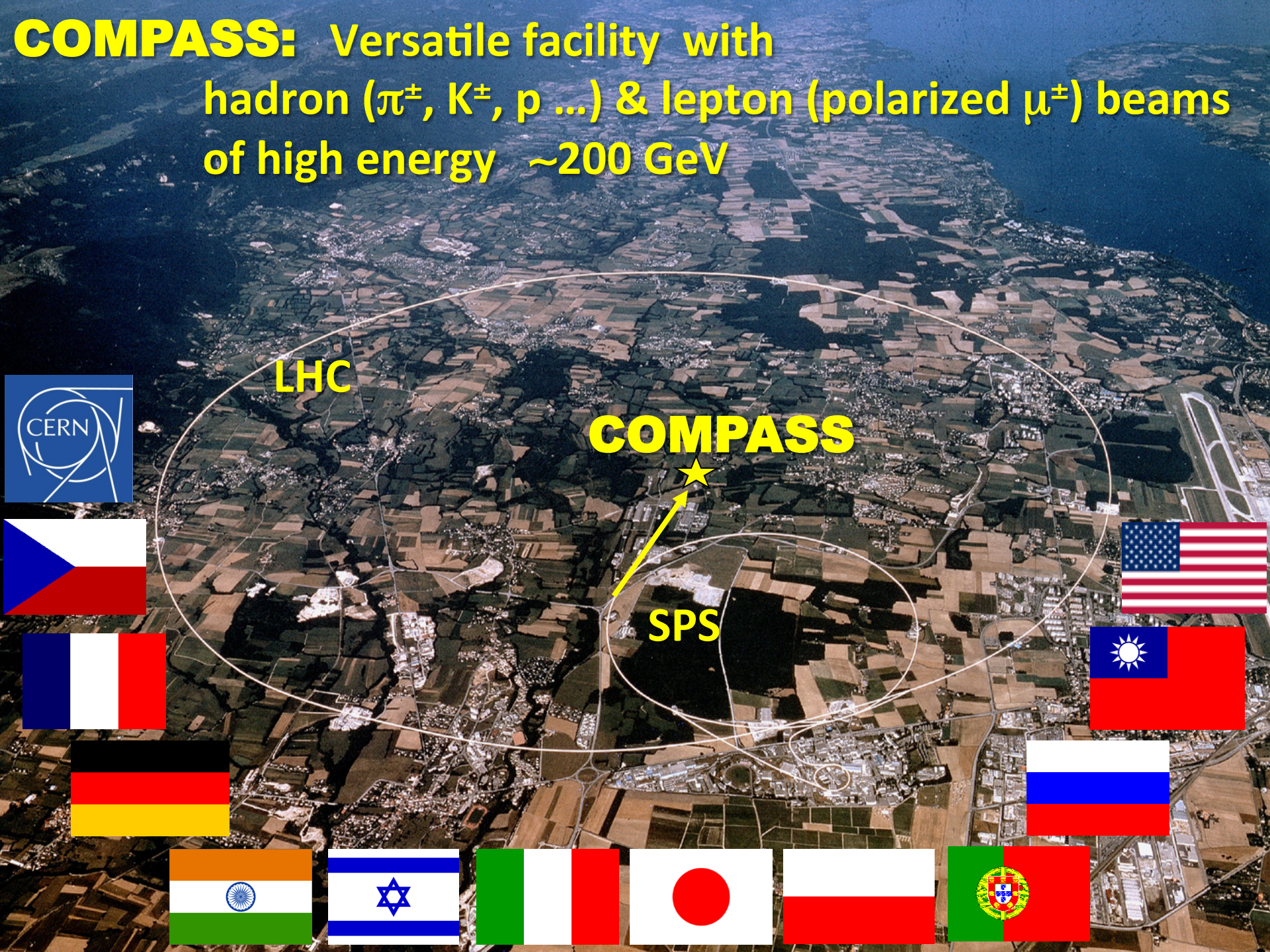
Physics Opportunities for a Future COMPASS-like Experiment

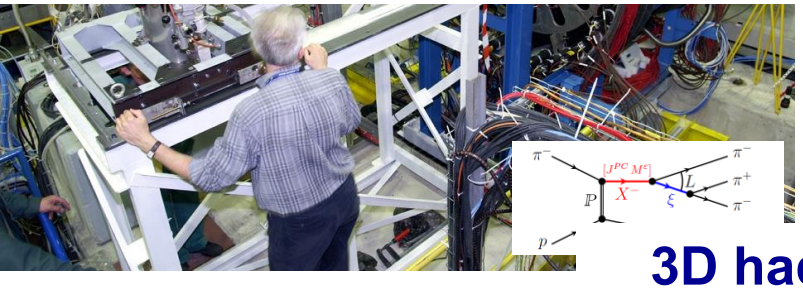
A. Ferrero for COMPASS
CEA-Saclay/IRFU/SPhN

DIS2017 – University of Birmingham – April 4 2017


COMPASS: Versatile facility with
hadron ($\pi^{\pm}$, $K^{\pm}$, p ...) & lepton (polarized $\mu^{\pm}$) beams
of high energy ~200 GeV
LHC
COMPASS
SPS
CERN

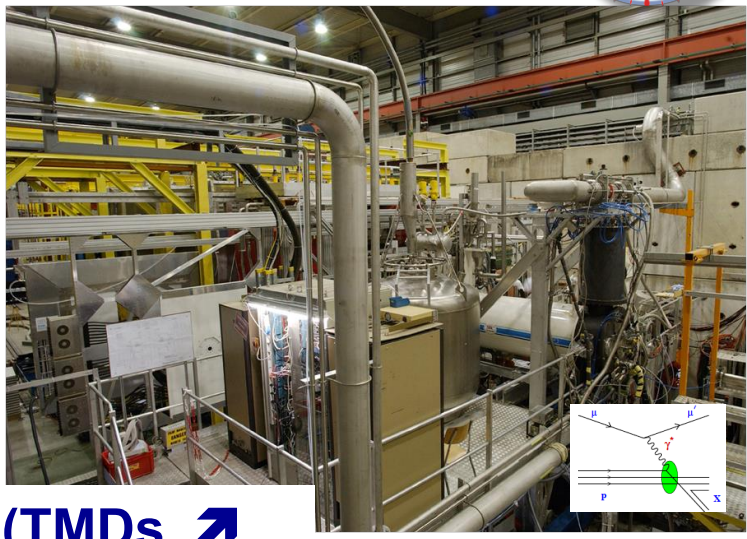
COMPASS QCD facility at SPS M2 beam line (CERN) (secondary hadron and lepton beams)

Exotic state, chiral dynamics



Hadron Spectroscopy &

COMPASS-I
1997-2011

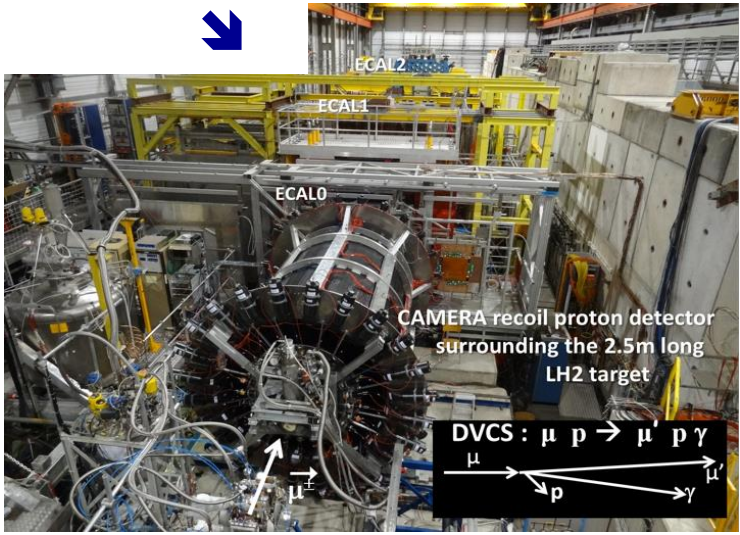


sed SIDIS

3D hadron structure (TMDs, GPDs), spin decomposition

Polarised Drell-Yan

COMPASS-II
2012-2018



DVCS (GPDs) + unp. SIDIS

COMPASS Physics Opportunities Beyond 2020

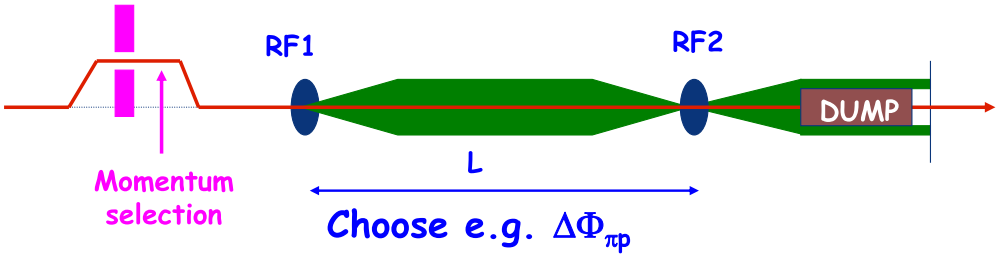
- **Spectroscopy with RF-separated beams**
  - Kaon: Hadron spectroscopy and diffraction
  - Kaon: polarisability
  - Kaon: gluon distribution with prompt photons
  - Antiproton: Charmonium hybrids and exotics (low p-bar energy)
- **Drell-Yan with RF-separated beams**
  - Kaon: DY with both polarised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

COMPASS Physics Opportunities Beyond 2020

- **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 $p+He \rightarrow p\ X$ for dark matter

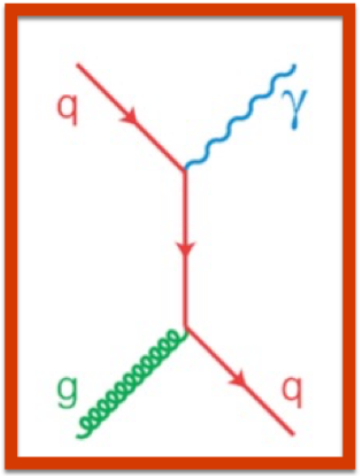
Programme with present beams, likely to start right after LS2 (unless separated beams would be available already)

RF-separated beams

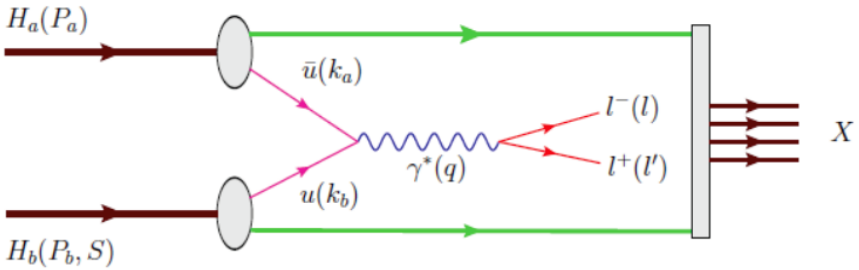


K- and anti-protons @ ~10^7/s

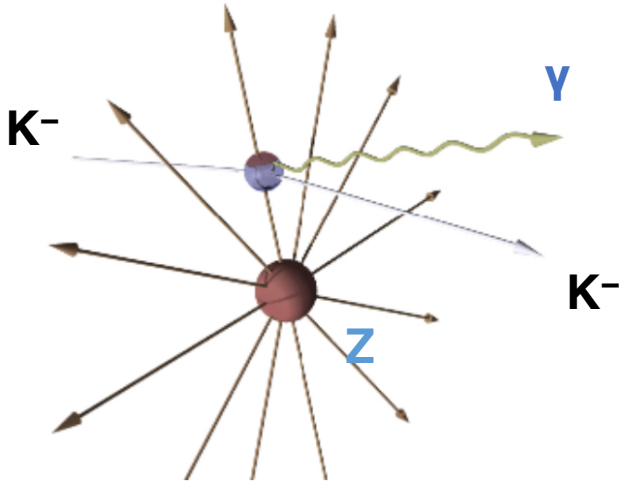
Kaon gluon structure



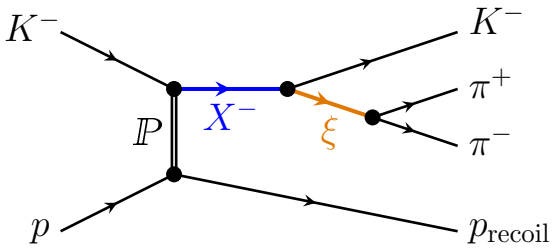
Drell-Yan



Kaon polarizabilities



Hadron spectroscopy



Drell-Yan measurements with K- and anti-protons

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 1×10^7 /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
- The overall gain for RF-separated beams wrt previous experiments is a factor 50 to 100

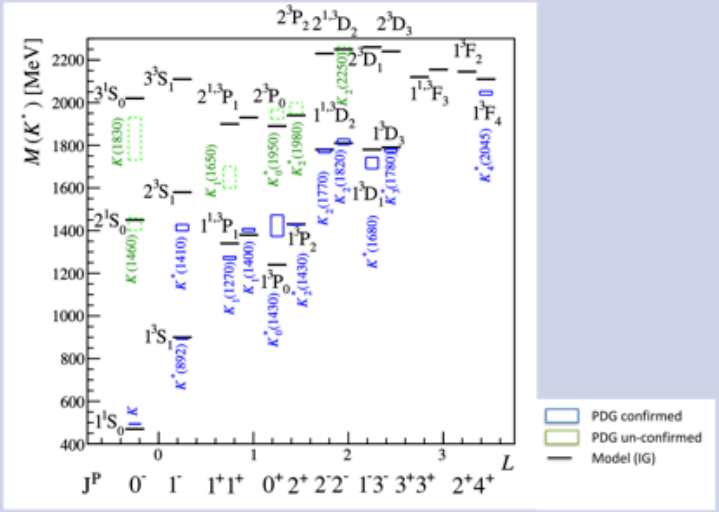
Beam	COMPASS++ (proj.)			NA3	E537
	NH3	Al	W		
	14’000	2’800	29’600	700	
	15’750	2’750	22’500		387

Kaon spectroscopy and polarisabilities

Known kaonic states

arXiv:1606.07895v2

- PDG lists 28 strange mesons

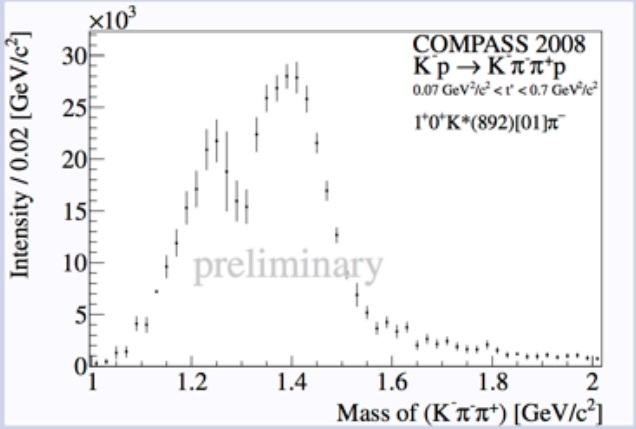


Previous measurements

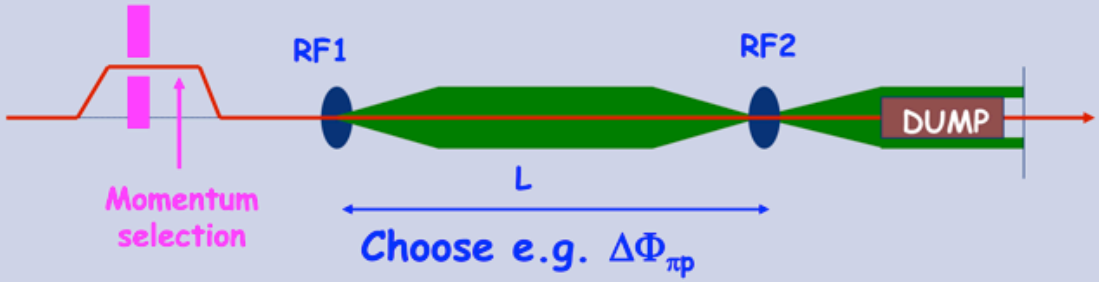
- ACCMOR [Daum, Nucl.Phys.B 1981]
  - 200 000 events
    $K^- + p \to K^-\pi^-\pi^+ + p_{\text{recoil}}$
- LASS [Aston, Nucl.Phys.B 1993]
  - 100 000 $K^- p \to K^-\omega p$ events
- τ or heavy-meson decays

COMPASS analysis

- $\approx 2\,\%$ K^- fraction in 190 GeV/c beam
- 270 000 exclusive
  $K^- + p \to K^-\pi^-\pi^+ + p_{\text{recoil}}$ events
- Partial wave analysis including 19 waves
- At most 1 M events in current data set



RF separated beam



- Enrich beam kaon contribution
- Aim for $8 \times 10^6\,\mathrm{s}^{-1}$ kaons @ $100\,\mathrm{GeV}/c$
- Allows to collect 30 M to 50 M $K^- + p \to K^-\pi^-\pi^+ + p_{\mathrm{recoil}}$ events per year
- Uniform detector acceptance over broad kinematic range for charged and neutral final states required
- No direct competitors at the moment

Spectroscopy with antiprotons

- $\lesssim 20\,\mathrm{GeV}/c$ hadron beam
  - $\Rightarrow$ Enriched beam antiproton contribution
  - $\Rightarrow$ No RF separation needed
- Spectroscopy in the energy region of charmonium
- Using Panda (-like) barrel detector and COMPASS as forward spectrometer

Kaon polarizability

Theoretical predictions:

χPT prediction $O(p^4)$:

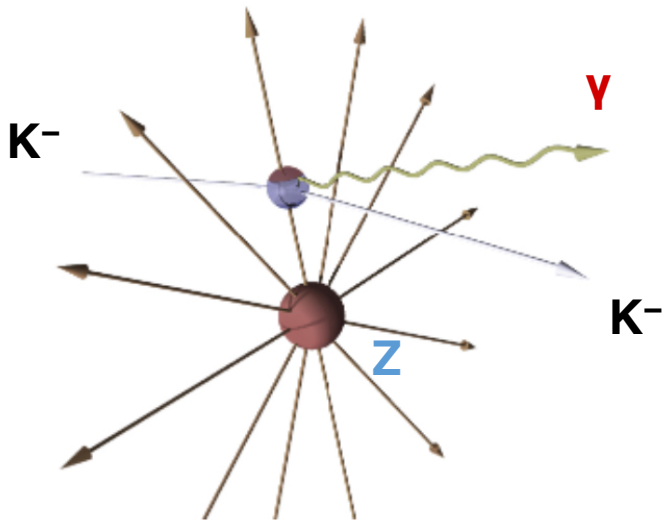
$$\alpha_K + \beta_K = 0$$

$$\alpha_K = \alpha_\pi \times \frac{m_\pi F_\pi^2}{m_K F_K^2} \approx \frac{\alpha_\pi}{5} \approx 0.6 \times 10^{-4} fm^3$$

Quark confinement model:

$$\alpha_K + \beta_K = 1.0 \times 10^{-4} fm^3$$

$$\alpha_K = 2.3 \times 10^{-4} fm^3$$



Experimental results:

α_K<200×10^{-4} fm^3 (1973)

- from kaonic atoms spectra

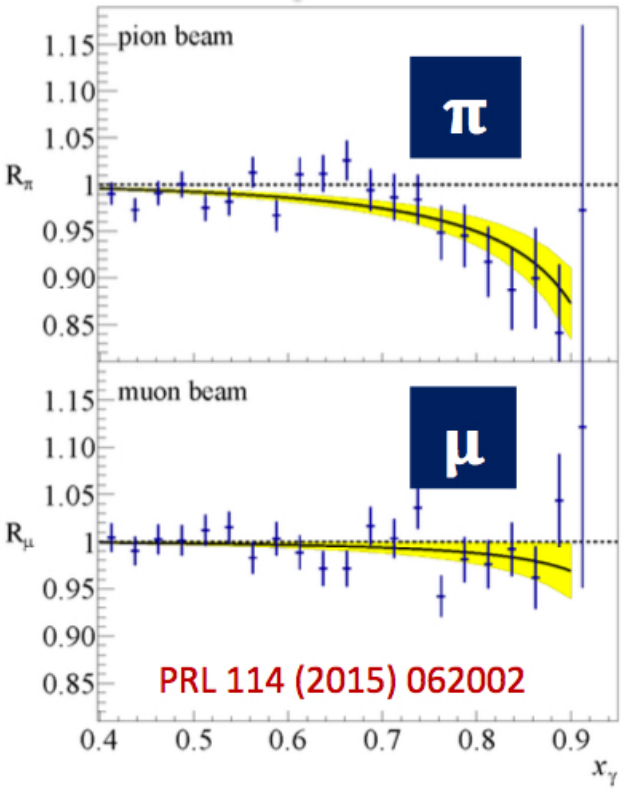
Standard COMPASS hadron beam

Particles	Positive beam	Negative beam
π	0.240	0.968
K	0.014	0.024
p	0.746	0.008

1 Kγ event per 500 πγ

Test of low-energy QCD models like the Chiral Perturbation theory in Kγ interaction

Primakoff 2009



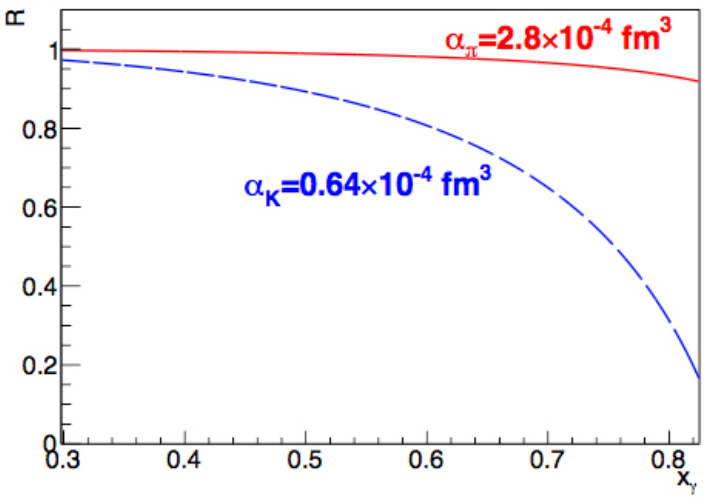
$\alpha_\pi = (2.0 \pm 0.6_{stat} \pm 0.7_{syst}) \times 10^{-4}$ fm^3

Primakoff 2012

Precise result for pion polarizabilities

First glimpse of Compton scattering off kaon

Primakoff with kaon beam (2020+)



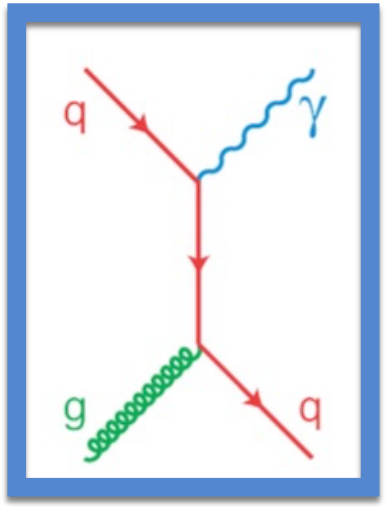
First measurement of kaon polarizability

Study of kaon-induced exclusive Primakoff reactions like

K^- (A,Z) → K^- (A,Z) π^0
K^- (A,Z) → K^- (A,Z) η
K^- (A,Z) → K^- (A,Z) π^0 π^0
K^- (A,Z) → K^0 (A,Z) π^-
…

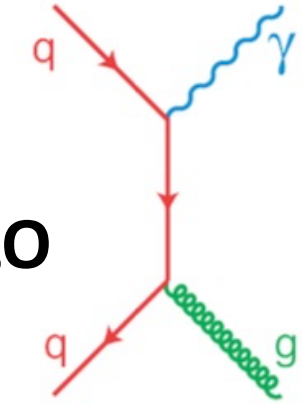
Gluon structure of kaon with prompt photons

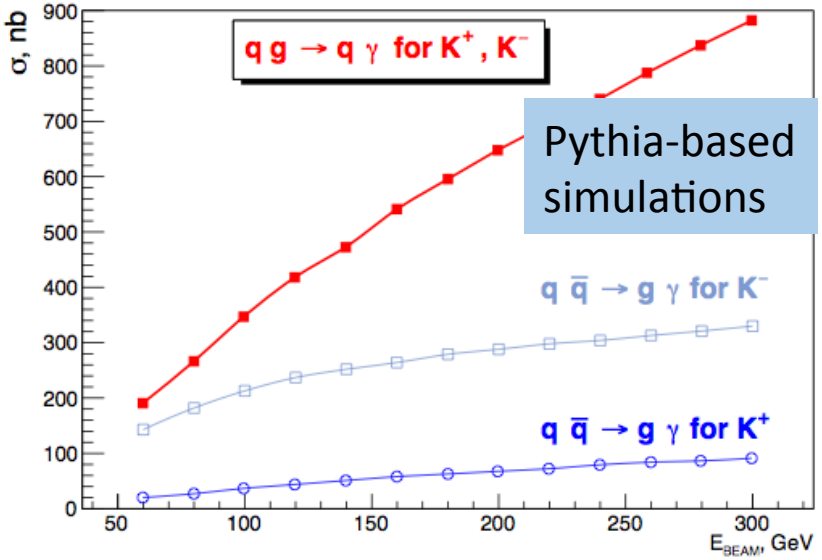
At the moment there is no experimental data on G(x) of kaon!



LO

High pT





$$d\sigma_{AB} = \sum_{a,b=q,\bar{q},g} \int dx_a dx_b f_a^A(x_a,\mu^2) f_b^B(x_b,\mu^2) d\sigma_{ab\to\gamma X}(x_a,x_b,\mu^2).$$

K^+ beam of 100+ GeV/c and nuclear target

High aperture system of 3 precise electromagnetic calorimeters

First observation of kaon-induced prompt photons, first measurement of kaon G(x)

Existing muon beams

Exclusive processes (GPD)

SIDIS with deuteron target

Existing hadron beams

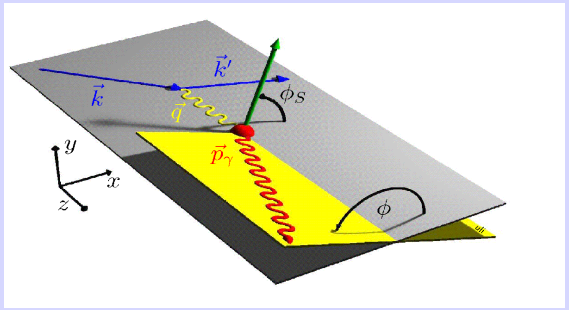
pol. DY with deuteron target

Contribution to dark matter searches

COMPASS + Transv. Pol. Target to constrain GPD E

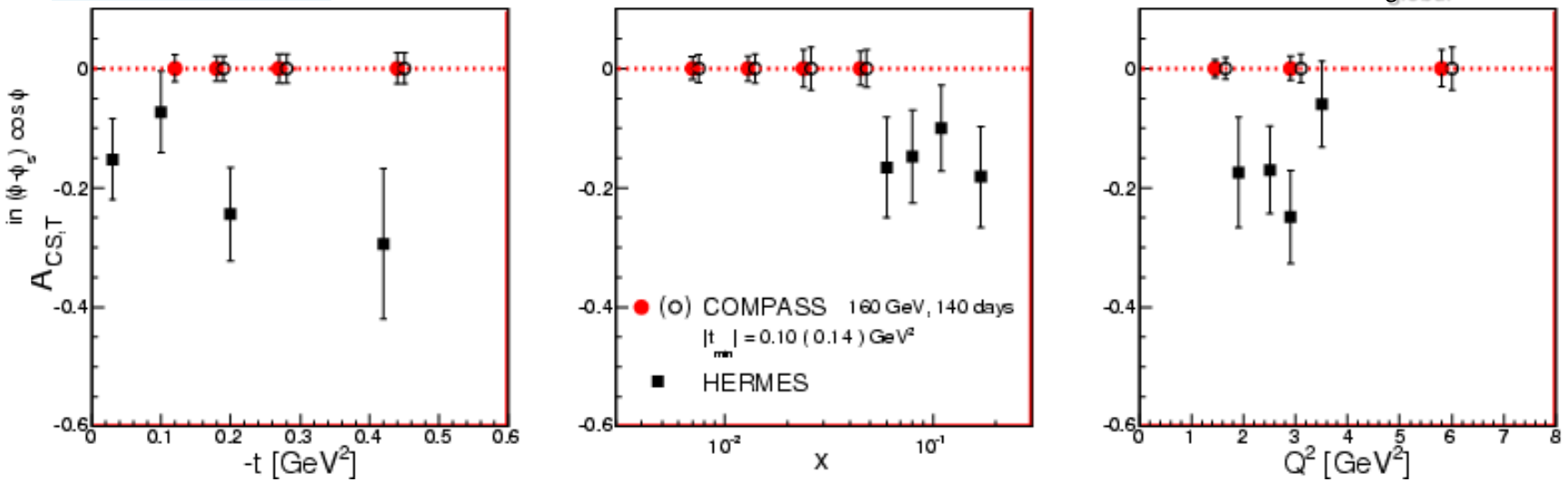
with $\mu^{+\downarrow}$, $\mu^{-\uparrow}$ beam and **transversely** polarized NH3 (proton) target

$$\mathcal{D}_{CS,T} \equiv d\sigma_T(\mu^{+\downarrow}) - d\sigma_T(\mu^{-\uparrow}) \propto Im(F_2\mathcal{H} - F_1\mathcal{E})\sin(\phi-\phi_s)\cos\phi$$



$A^{\sin(\phi-\phi_s)\cos\phi}_{CS,T}$ **related to H and E**

2 years of data 160 GeV muon beam
1.2 m polarised NH_3 target ε_{global} = 10%



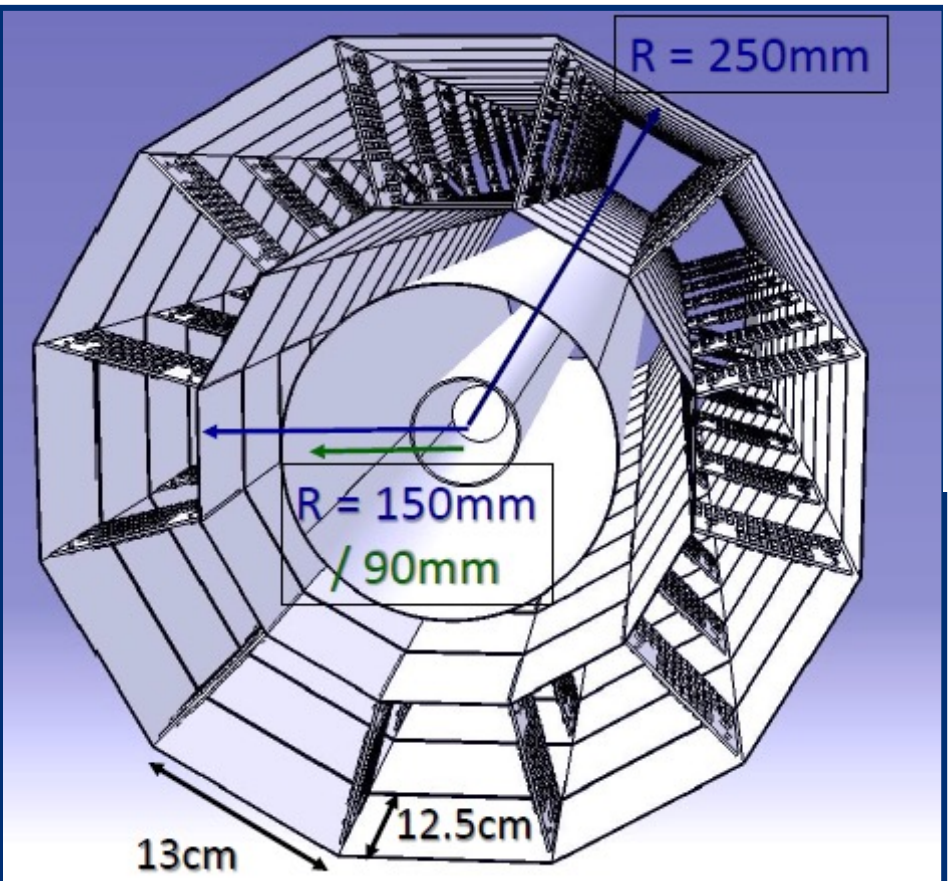
Impact on AOM of valence and sea quarks to be evaluated

Challenge: couple NH3 pol. target and recoil detector

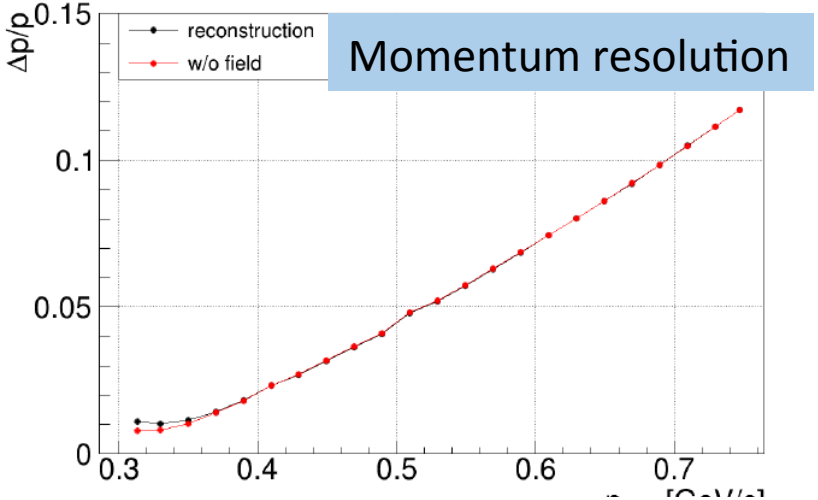
How to realize such an experiment?

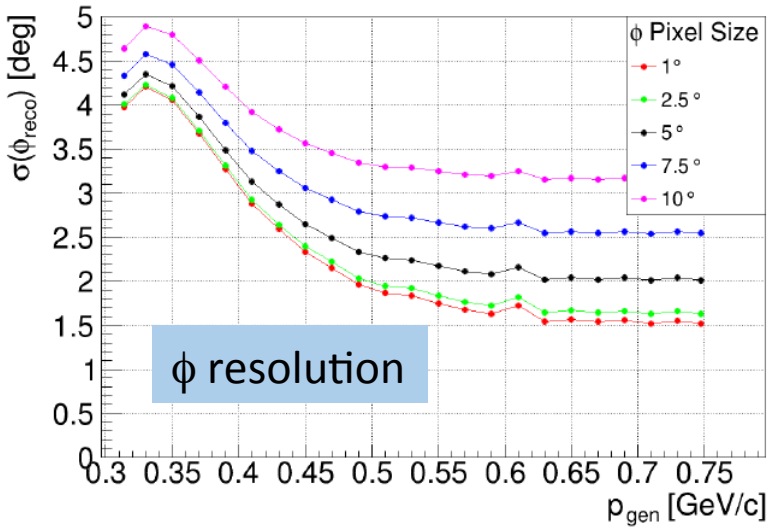
Two or three layers of **Si detectors** inside COMPASS **polarized target**

Working group from Dubna, Munich, Illinois, Freiburg…



$P_{min} \approx 300$ MeV/c





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
- Need equal statistics for optimal flavour separation:

Transversity distributons

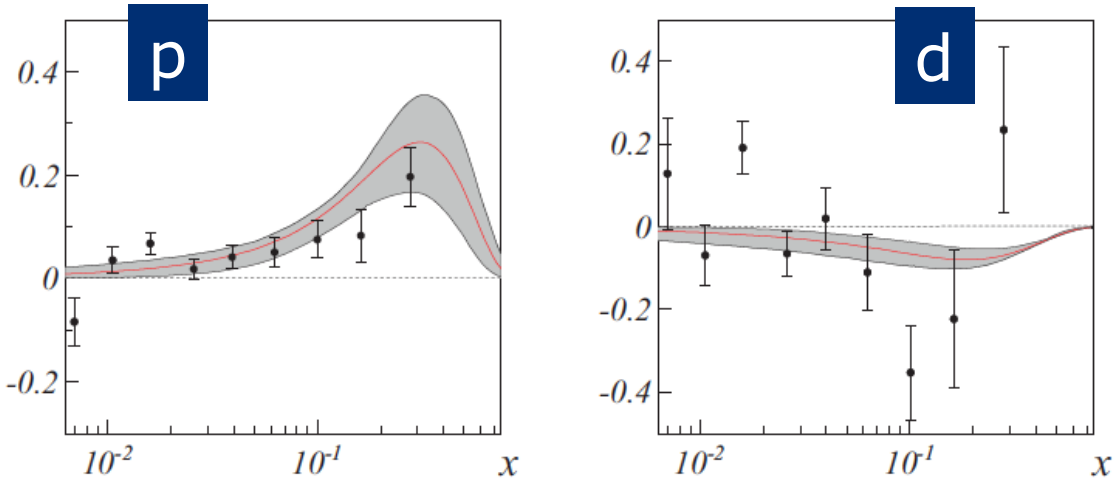
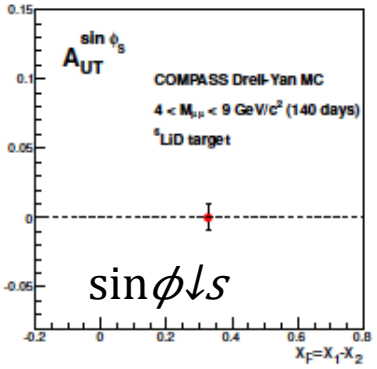


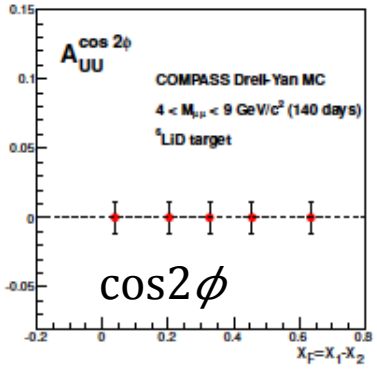
Fig. 6: $xh_1^u(x)$ (left) and $xh_1^d(x)$ (right) from the 'two hadron' asymmetries of 2010 proton and of 2002-2004 deuteron data (from[30]). The curves show the transversity PDFs obtained from a fit of Collins asymmetries [29]

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

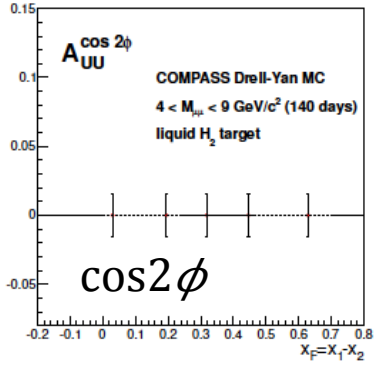
- Pol. proton DY data in 2015/2018
- Pol. deuteron DY data needed for flavour separation of PDFs
- Shorter run with unpolarised LH2 target is required
  - to test fundamental Lam-Tung relation
  - to extract Boer-Mulders TMD using “clean” (no nuclear effects) LH target – complementary to SIDIS.
- Simulation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

^{6}LiD





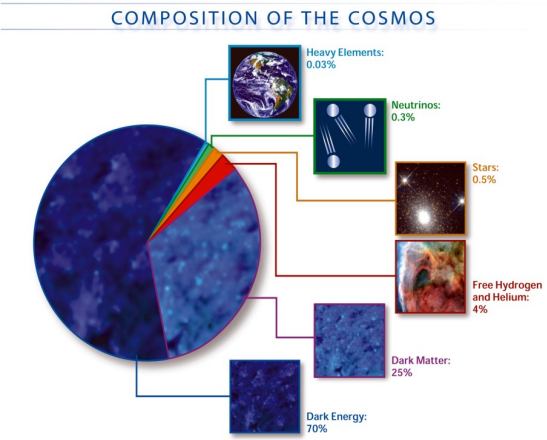
LH_2



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 kin.range with a precision <10%. Compared to NA49 COMPASS has factor ~1000 in luminosity.

COMPASS advantages:

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

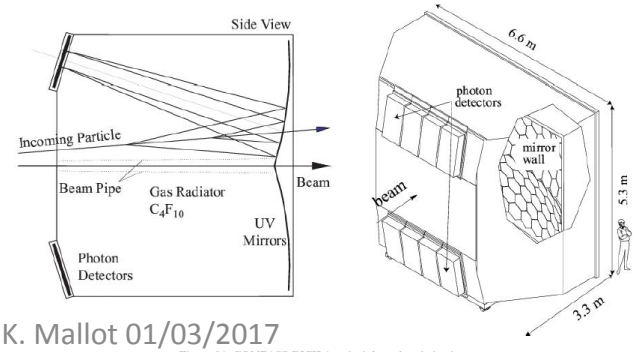
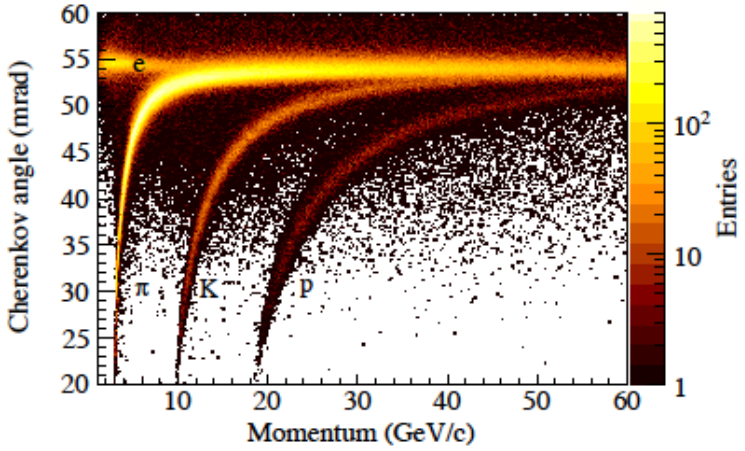


Figure 34. COMPASS RICH-1: principle and artistic view.



Conclusions & Outlook

- The COMPASS Spectrometer has proven to be an excellent tool to study the structure and spectroscopy of hadrons
- New physics opportunities are being explored for a future experiment at the COMPASS facility
- **RF-separated kaon and antiproton beams would represent a unique opportunity for hadron structure and spectroscopy studies**
- An extended collaboration needs to be built on top of the existing COMPASS core

Backup Slides

COMPASS: a Facility to study QCD

a fixed target experiment at the CERN SPS

~ 220 physicists from 25 Institutes of 13 Countries

COMMON
MUON and
PROTON
APPARATUS for
STRUCTURE and
SPECTROSCOPY

Hadron Spectroscopy & **Test of ChPT** with **π, K, p** beams on nuclei **2008-9- 12**

Nucleon Structure

SIDIS with $\vec{\mu}$ beams with Long or Trans. Polarized Targets

Long. and Transv. Spin structure
PDFs, FFs and TMDs

	Polar. Deuteron (Li^6D)	Polar. Proton (NH_3)
Long.	**2002-3-4-6**	**2007-11**
Transv.	**2002-3-4**	**2007-10**

Drell-Yan with **π** beams with Transv. Pol. NH_3 target

TMDs **2009-12-14** (tests) and **2105-18**

Exclusive DVCS & DVMP +SIDIS with $\vec{\mu}$ beams with LH_2 target

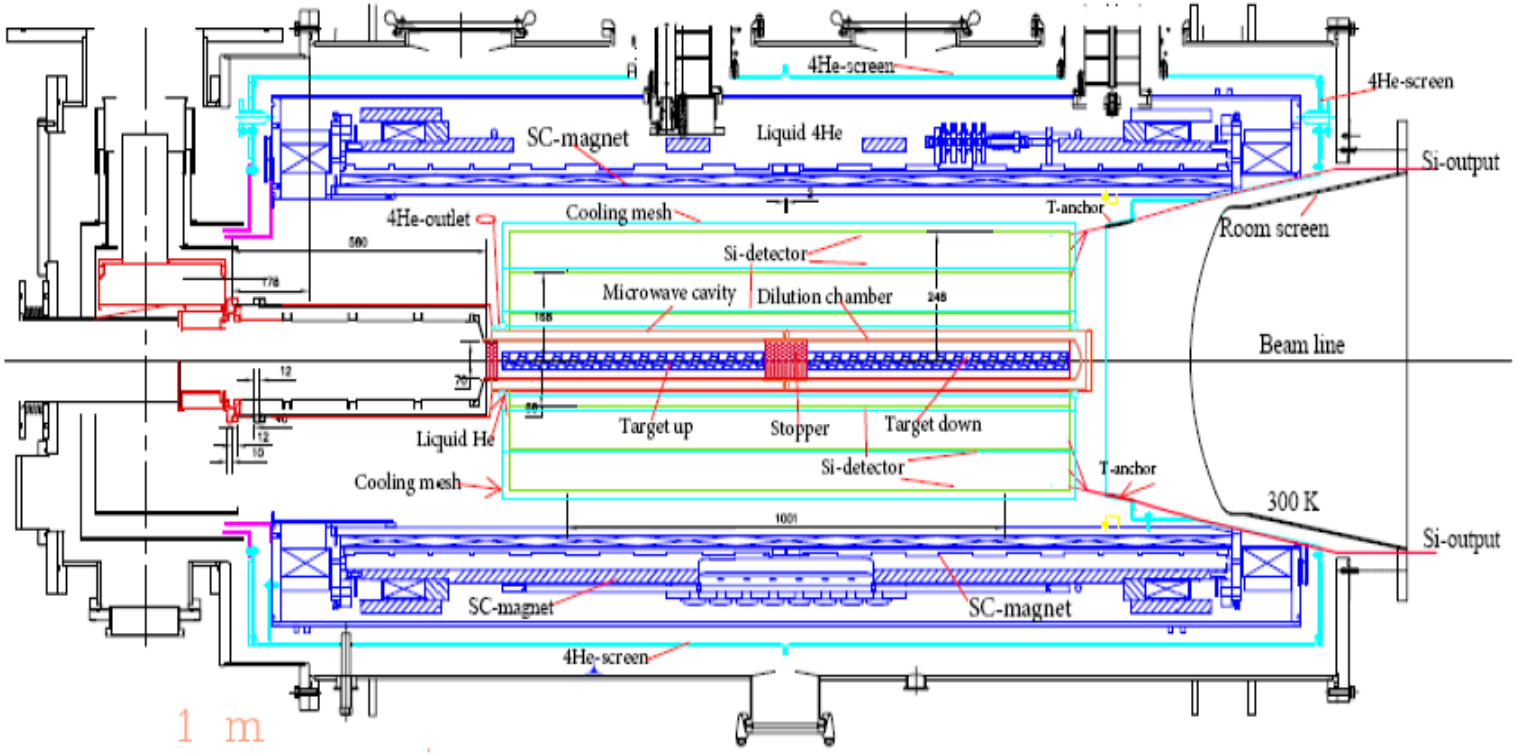
GPDs + TMDs, FFs **2008-9-2012** (tests) and **2016-17**

How to realize such and experiment?

New design of the MW cavity of the present NH3 polarized target

Radial dimension of the free space outside of the MW ~180mm

allow 3 concentric cylindrical layers of Silicon detectors (in green)



No possibility for ToF ➔ PID of protons/pions with dE/dx

momentum and coordinates (as for HERMES)

GPD studies at COMPASS
Exclusive measurements

Deeply Virtual Compton Scattering and Exclusive Meson Production with LH2 target and Recoil detection

- pilot runs (2008-9 and 2012) …… PRELIMINARY RESULTS **DVCS** and π^0
- 2 years (2016-17) …….. measurements ongoing

Transverse target asymetries without recoil detection for exclusive ρ and ω production

- with polarized Li_6D (2002-3-4)……..RESULTS for **ρ**
- with polarized NH_3 (2007-10) ……..RESULTS for **ρ and ω**

Plan/idea for Transverse target and recoil detection

- After 2020