Outline

1. **Intro: COMPASS – QCD facility at CERN SPS**

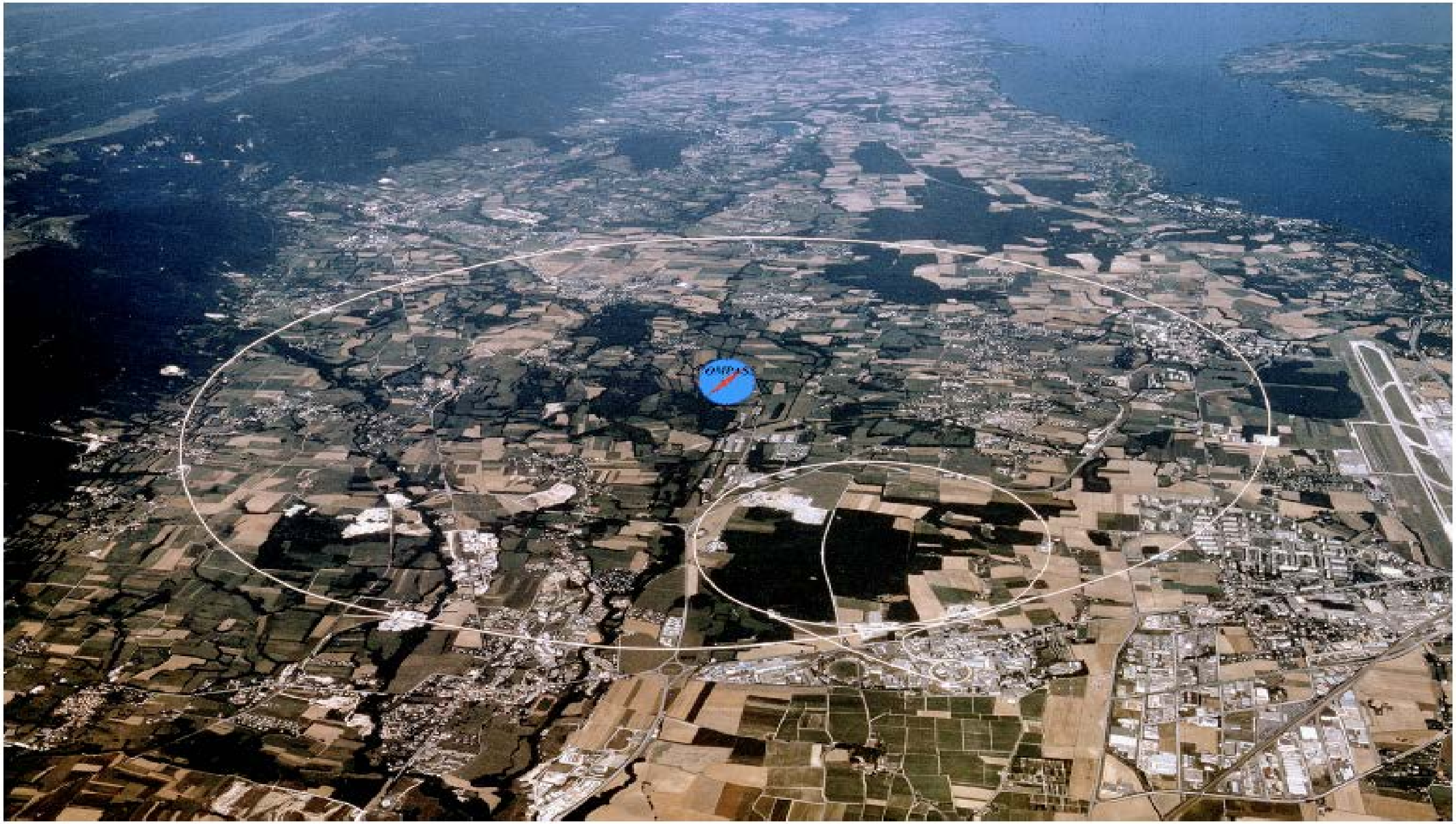
2. **A new QCD facility at SPS (CERN) M2 beamline**
    - Hadron structure study in DY, DPP and DVCS
    - Hadron spectroscopy (strange sector)
    - Hadron spectroscopy with low energy antiproton beam
    - Absolute antimatter production cross-section measurements

3. **New hardware**
4. **Time-lines and LoI status**
5. **Summary**

Materials are provided by: C. Roberts, V. Andrieux, M. Chiosso, C. Riedl, B. Grube, J. Friedrich, A. Guskov, S. Wallner, B. Ketzer etc.

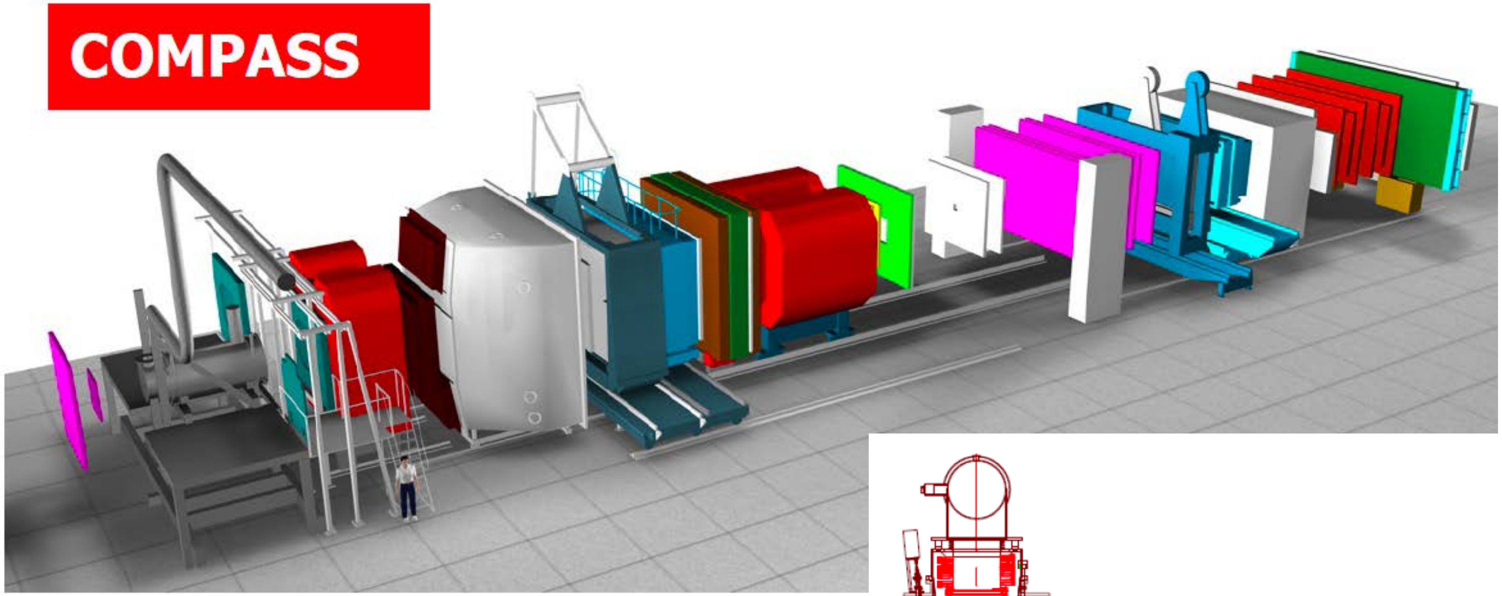
COMPASS QCD facility at CERN (SPS)

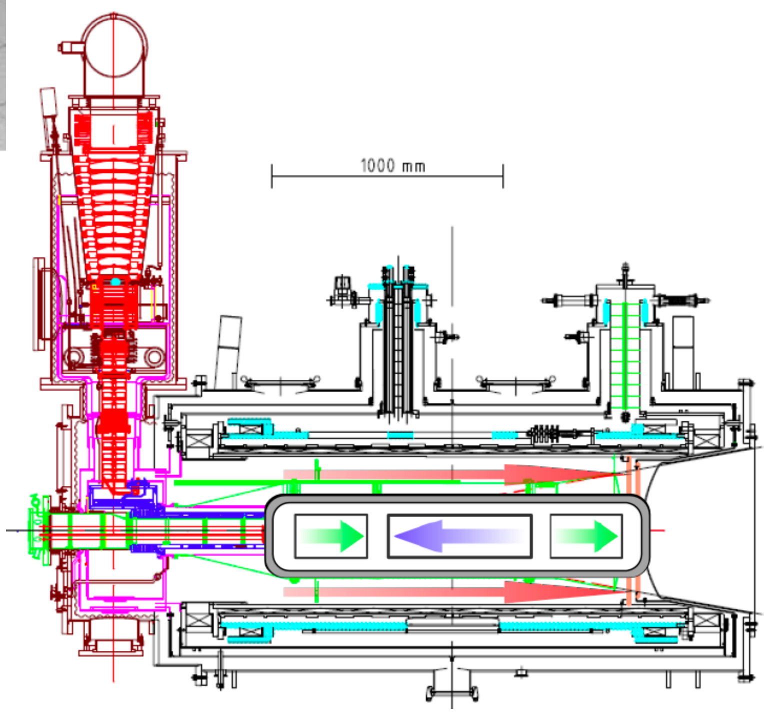
COmmon Muon Proton Apparatus for Structure and Spectroscopy



~240 physicists, 12 countries + CERN, 24 institutions

COMPASS Spectrometer at SPS M2 beam line (CERN)



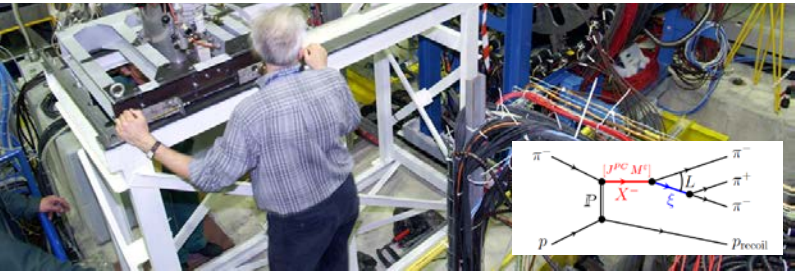


Universal and flexible apparatus.
Most important features of the two-stage COMPASS Spectrometer:

1. Muon, electron or hadron beams with the momentum range 20-250 GeV and intensities up to 10^8 particles per second
2. Solid state polarised targets (NH_3 or ^6LiD) as well as liquid hydrogen target and nuclear targets
3. Powerful tracking (350 planes) and PiD systems (Muon Walls, Calorimeters, RICH)

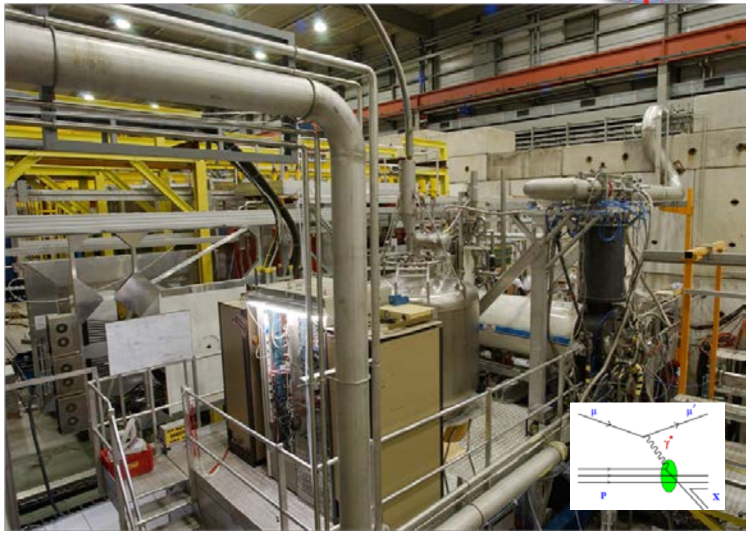
COMPASS QCD facility at SPS M2 beam line (CERN)
(secondary hadron and lepton beams)

Exotic states, chiral dynamics



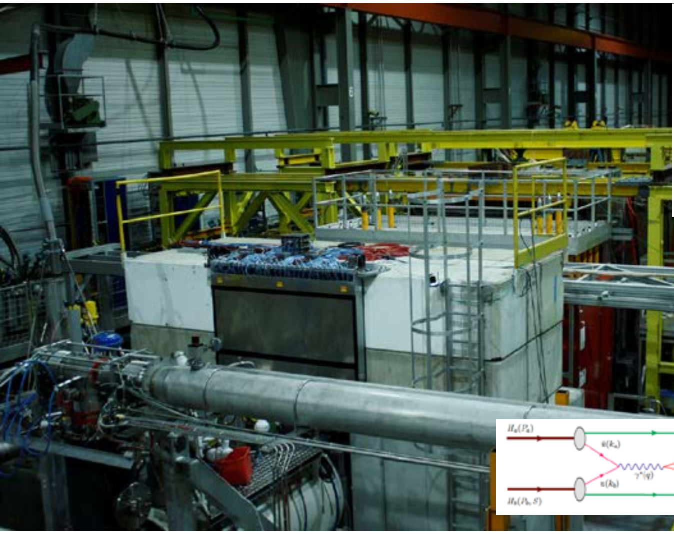
Hadron Spectroscopy & Polarisability

COMPASS-I
1997-2011



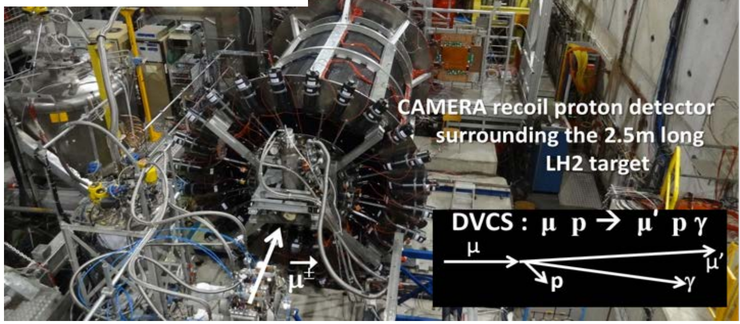
Polarised SIDIS

3D hadron structure,
Proton spin decomposition
(spin crisis)



Polarised Drell-Yan

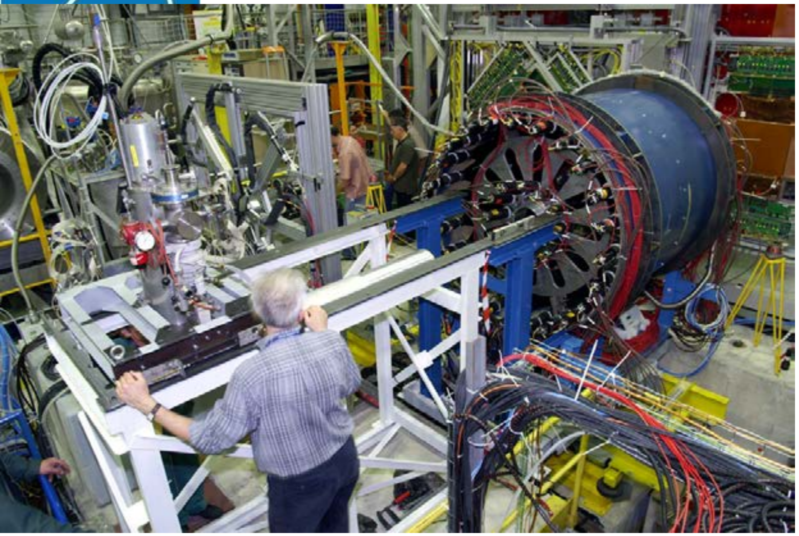
COMPASS-II
2012-2020

DVCS (GPDs) + unp. SIDIS

Diffractive dissociation I

main results



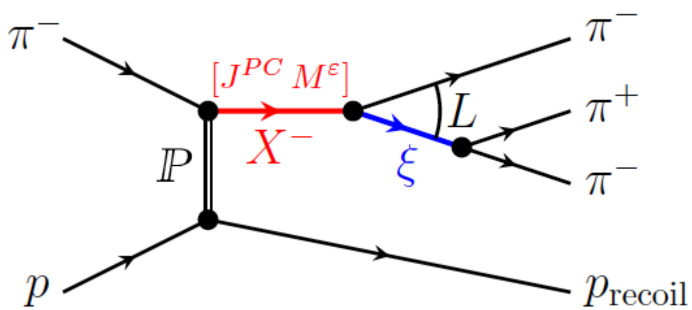
2008-2009 data taking, 190 GeV/c hadron beam on a hydrogen target.

3π data sample ~50x10^{6} exclusive events – factor 10 to 100 to previous experiment

Potential illustration – discovery of a new axial-vector meson $a_1(1420)$ in $1^{++}0^{+}$ $f_0(980)\pi$ *P* wave (PRL).

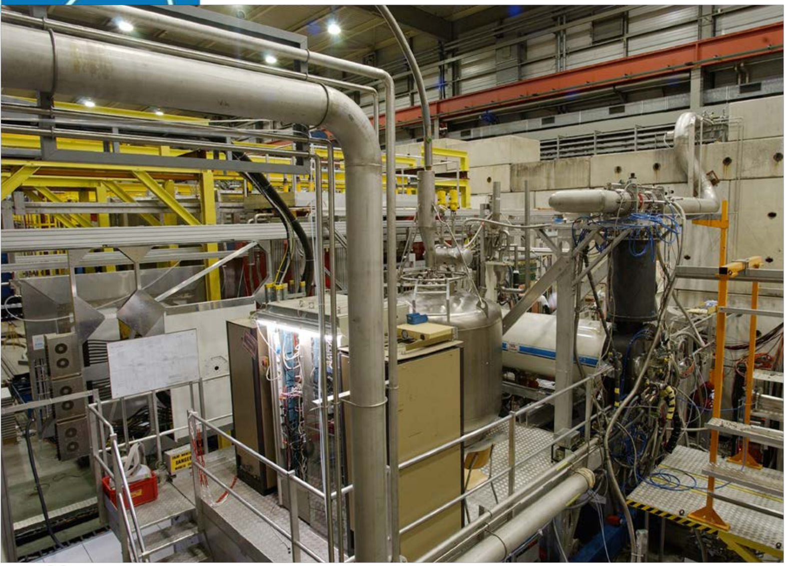
A lot of work has been invested to develop new methods in order to cope with huge data sample.

An extensive papers that describes the PWA method and the results from this analysis has recently been published (PRD 95 (2017) 032004, arXiv:1802.05913, sub. PRD). Major step forward in the field: 100 bins in $m_{3\pi}$ (0.5 to 2.5 GeV/c^{2}) and 11 in *t'* (0.1 to 1.0 (GeV/*c*)^{2}), 88 waves up to spin 6.

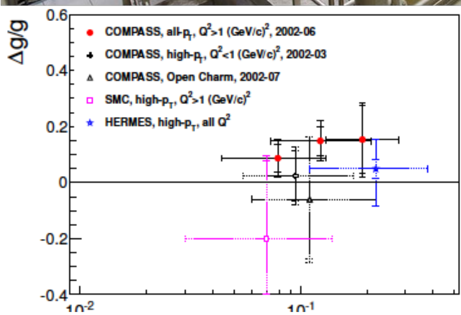


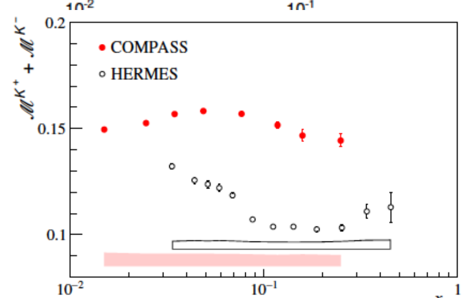
Analysis steps:
1. p-w decomposition: 88x88 spin-density matrix for each *t'* (f.-m. transfer squared) and $m_{3\pi}$ bin (mass-independent fit)
2. For selected wave set (14 waves, 60% of total intensity) fit of the spin-density matrix by a resonance models (B.-W. + coherent non-resonant term)

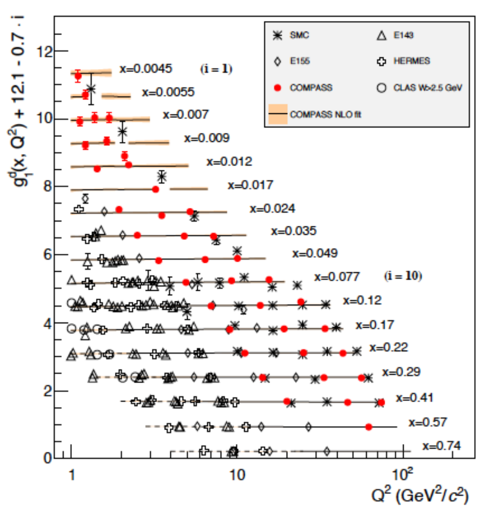
(SI)DIS longitudinal/transverse

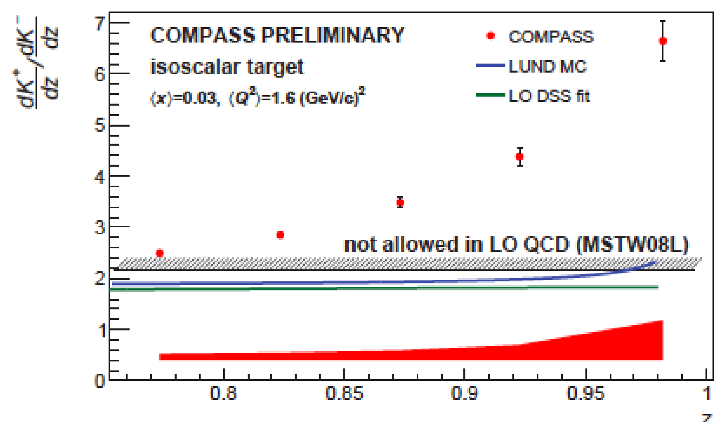


- g_1^d (PLB 769 (2017) 034, together with the results on the proton spin structure function g^p_1 , this results constitute the COMPASS legacy on the measurements of g_1 structure function.
- Δg/g final result PJC 77 (2017) 209
- Charged kaon multiplicities (2006 160 GeV ^{6}LiD) – published in PLB 767 (2017) 133
- Recently new results were produced on the kaon multiplicity ratio K^+/K^-, at high z, 0.75 < z < 1 (hep-ex/1802.00584, sub. PLB)

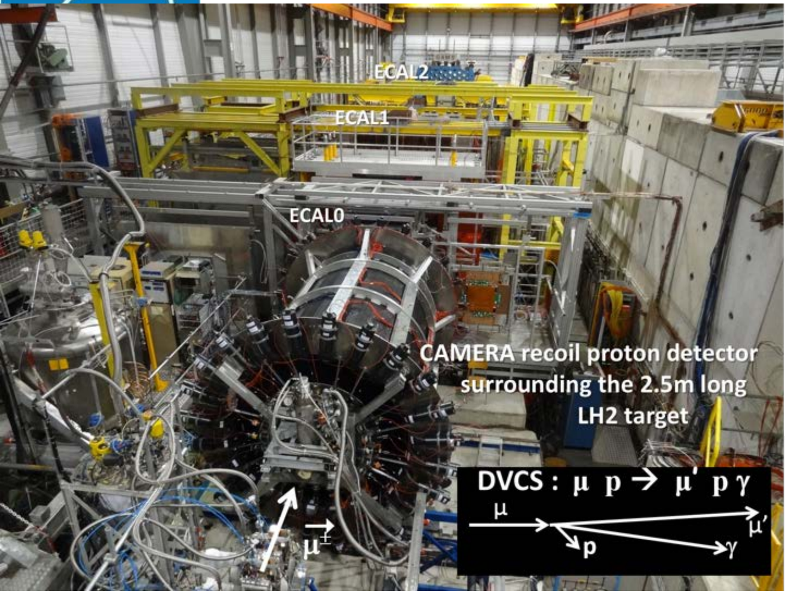


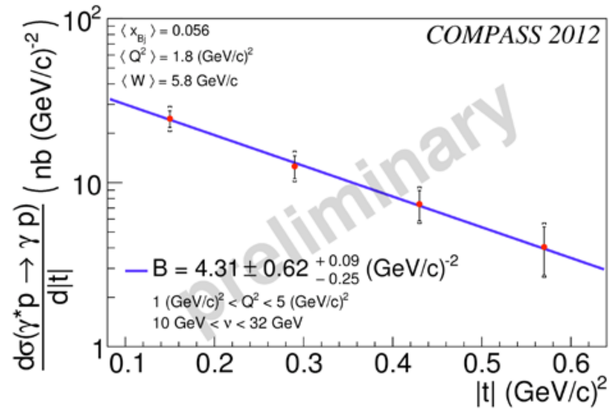


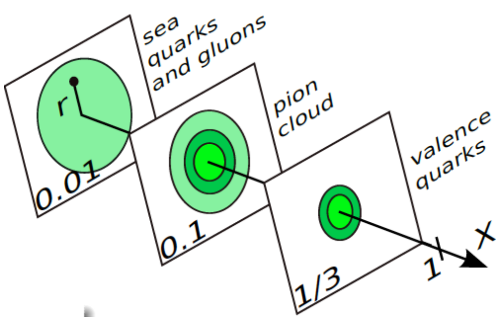




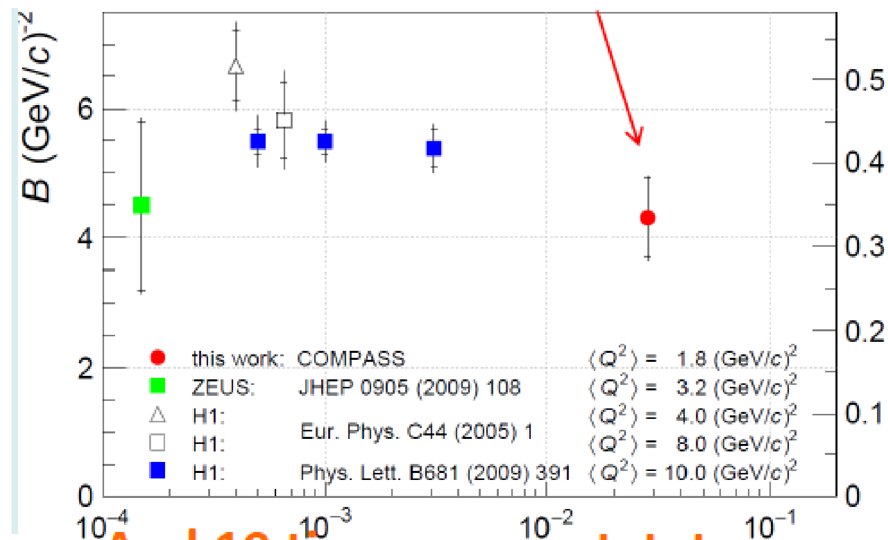
GPD 2012 results
(first DVCS results were published this year)

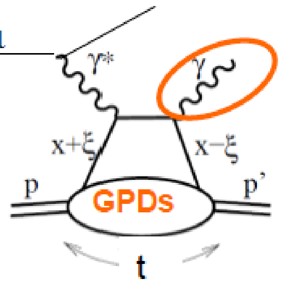






NEW, from 2012 pilot run





$$\sigma^{DVCS}/dt \sim \exp^{-B|t|}$$

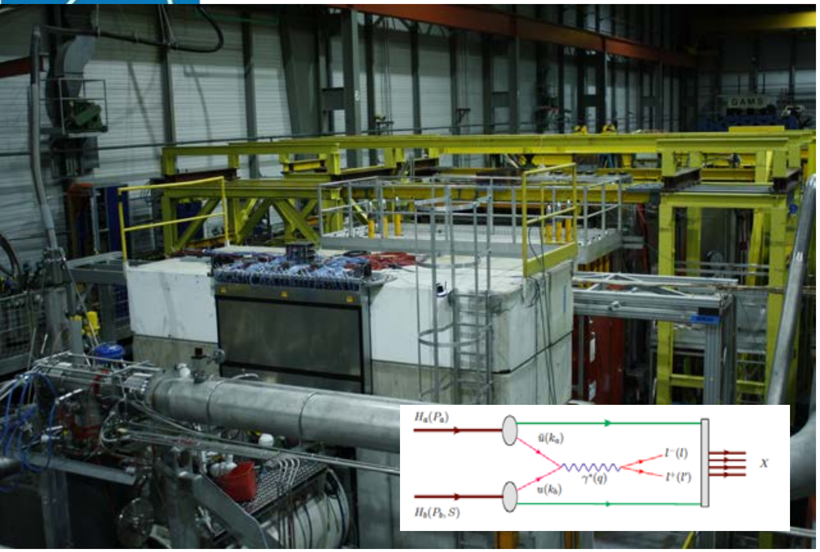
$$B(x_B) = ½ \langle r_\perp^2(x_B) \rangle$$

And 10 times more stat. to come with 2016/2017 data

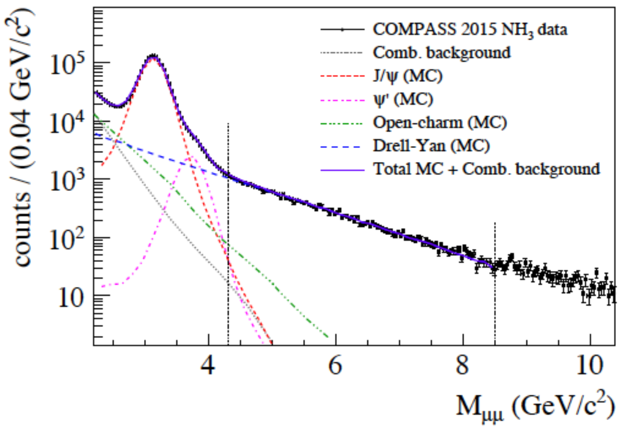
Ref: hep-ex/1802.02739, sub. PRL

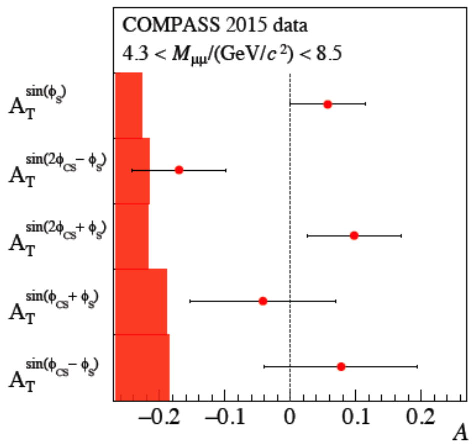
COMPASS Drell-Yan Run 2015 results I

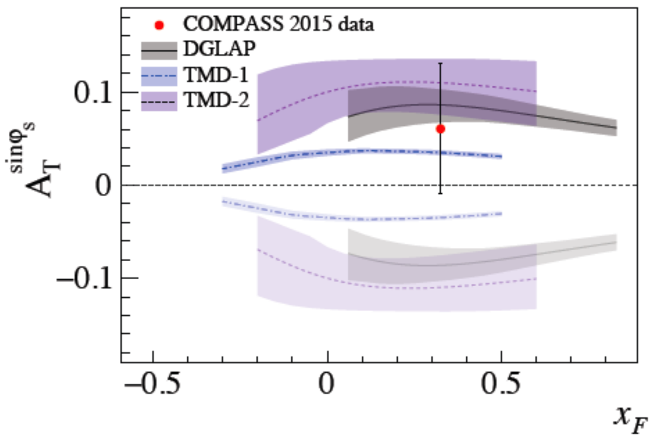
First ever polarised Drell-Yan data



First ever polarised Drell-Yan paper
(PRL 119 (2017) 112002)



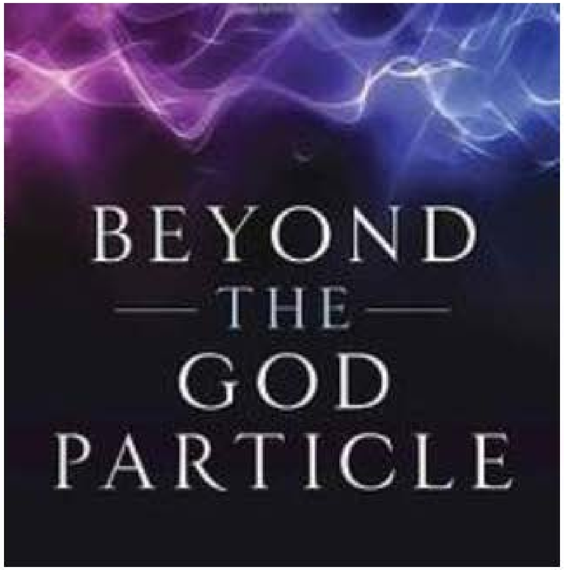




Overture

- LHC has NOT found the "God Particle" because the Higgs boson is NOT the origin of mass
  - Higgs-boson only produces a little bit of mass
  - Higgs-generated mass-scales explain neither the proton's mass nor the pion's (*near*-)masslessness
  - Hence LHC has, as yet, taught us very little about
    - Origin Nature Structure

    of the nuclei whose existence support the Cosmos



- Strong interaction sector of the Standard Model, *i.e*. QCD, is the key to understanding the
  origin, existence and properties
  of (almost) all known matter
- Answers are in sight
  - Theoretical tools are reaching point where sound QCD predictions can be made
  - New facilities – in operation or being planned – can validate those predictions

M2 Fixed Target QCD Facility Beyond 2020 I

COMPASS beyond 2020 Workshop

21 Mar 2016, 08:05 → 22 Mar 2016, 17:10 Europe/Zurich

222-R-001 (CERN)

Description The goal of the workshop is to explore hadron physics opportunities for fixed-target COMPASS-like experiments at CERN beyond 2020 (CERN Long Shutdown 2 2019-2020). The programme comprises

- Reviews of the various physics domains: TMDs, GPDs, FFs, spectroscopy, exotics, tests of ChPT, astrophysics

- Reviews of physics results expected in the next 10 years from major labs around the world

- Good attendance (>100 physicists), large interest
- 11 "outside" review talks – Jefferson Lab, RHIC, Fermilab, KEK (Japan) BEPC II (IHEP, Beijing), NICA (JINR, Dubna), CERN (After, LHCb), GSI (Panda), J-PARC (Japan), EIC – China;
- 7 COMPASS talks (chronol.) – SIDIS, GPDs, Chiral Dynamics, astrophysics (dark matter), Drell-Yan, hadron spectroscopy;
- 2 "round-table"-like discussions on possible future with hadron and muon beams;
- Outcome of the Workshop:
    - **RF Separated antiproton/kaon beam would provide a unique opportunity for future fixed target COMPASS-like program at CERN**
    - **Existing muon and hadron beam allows to extend current COMPASS program by doing unique or first class measurements of exclusive processes, SIDIS and Drell-Yan**

M2 Fixed Target QCD Facility Beyond 2020 II

The outcome of the COMPASS Beyond 2020 Workshop was used as a basis for a talks given at Physics Beyond Collider workshops in September 2016, March and November 2017 (see for more details PBC web page: http://pbc.web.cern.ch/)

Possible physics program for the fixed target experiment at M2 line was extensively discussed then at the COMPASS-organized International workshop In Cortona, Italy:
http://iwhss17.to.infn.it/

As a result of these discussions we decide to proceed in two steps:
- First to ask for short extension of the COMPASS-II experiment (~1 year)
- Second is to start preparation of the New Long Term Future Physics Program and to initiate creation of a new Collaboration

Short term COMPASS future

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN–SPSC–2017–XXX
SPSC-X-XXX
October 2, 2017

d-Quark Transversity

and

Proton Radius

Addendum to the COMPASS-II Proposal

The COMPASS Collaboration
and
PNPI

v2.1 3.10.2017 9:17

)34 / SPSC-P-340-ADD-1

COMPASS-II ➔A new QCD facility at SPS

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

July 5, 2018

Letter of Intent:

A new QCD facility at SPS (CERN) M2 beam line

LoI content: Physics

The content of the LoI has been reported at several PBC meetings in 2016 and 2017.

10 projects for the moment, at first stage we are going to use available hadron/muon beam, at the second – RF separated kaon and antiproton beam.

All beams we are going to use are unique worldwide

LoI content: Instrumentation

It is difficult to give exact cost estimate right now: it stays in the range 10-20 MCHF

Summary table – beam requirements

Program	Physics Goals	Beam Energy [GeV]	Beam Intensity [s^{-1}]	Trigger Rate [kHz]	Beam Type	Target	Earliest start time, duration	Hardware Additions
μp elastic scattering	Precision proton-radius measurement	100	$4 \cdot 10^6$	100	$\mu^\pm$	high-pr. H2	2022 1 year	active TPC SciFi trigger silicon veto
Hard exclusive reactions	GPD E	160	10^7	10	$\mu^\pm$	$NH_3^\uparrow$	2022 2 years	recoil silicon, modified PT magnet
Input for DMS	$\overline{p}$ production cross-section	20-280	$5 \cdot 10^5$	25	p	LH2, LHe	2022 1 month	LHe target
$\overline{p}$-induced Spectroscopy	Heavy quark exotics	12, 20	$5 \cdot 10^7$	25	$\overline{p}$	LH2	2022 2 years	target spectr.: tracking, calorimetry
Drell-Yan	Pion PDFs	190	$7 \cdot 10^7$	25	$\pi^\pm$	C/W	2022 1-2 years	
Drell-Yan (RF)	Kaon PDFs Nucleon TMDs	~100	10^8	25-50	$K^\pm, \overline{p}$	$NH_3^\uparrow$, C/W	2026 2-3 years	"active absorber", vertex det.
Primakoff (RF)	Kaon polarizi-bility & pion life time	~100	$5 \cdot 10^6$	> 10	K^-	Ni	n/e 2026 1 year	
Prompt Photons (RF)	Meson gluon PDFs	≥ 100	$5 \cdot 10^6$	10-100	$K^\pm$ $\pi^\pm$	LH2, Ni	n/e 2026 1-2 years	hodoscope
K-induced Spectroscopy (RF)	High-precision strange-meson spectrum	50-100	$5 \cdot 10^6$	25	K^-	LH2	2026 1 year	recoil TOF forward PID
Vector mesons (RF)	Spin Density Matrix Elements	50-100	$5 \cdot 10^6$	10-100	$K^\pm, \pi^\pm$	from H to Pb	2026 1 year	

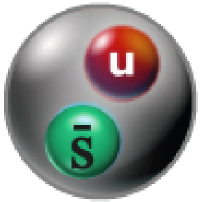
Table 5: Requirements for future programs at the M2 beam line after 2021. Standard muon beams are in blue, standard hadron beams in green, and RF-separated hadron beams in red.

Motivations

Pion

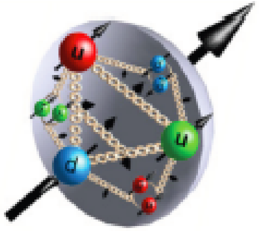
- $M_\pi \sim 140$MeV
- Spin 0
- 2 light valence quarks
- 2 TMD PDFs at LT.

Kaon



- $M_K \sim 490$MeV
- Spin 0
- 1 light and 1 "heavy" valence quarks
- 2 TMD PDFs at LT.

Proton



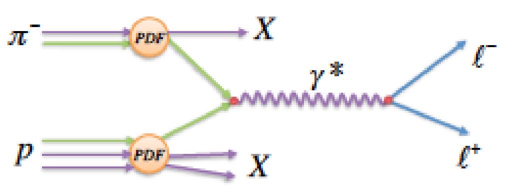
- $M_p \sim 940$MeV
- Spin 1/2
- 3 light valence quarks
- 8 TMD PDFs at LT.

3 QCD objects, different structures, different properties, understanding differences and similarities teaches us about QCD

Existing hadron beam
We learned very little so far about meson structure

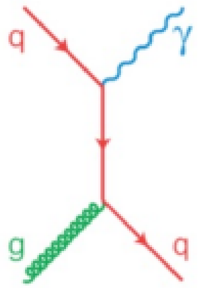
How to access meson structure

Drell-Yan:



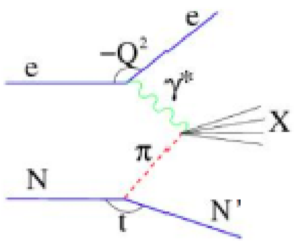
- 90's: NA3, NA10, E615
- 10's: COMPASS-II
- 20's: New Experiment

Prompt photon production:



- 90's NA24, W70
- 20's New experiment

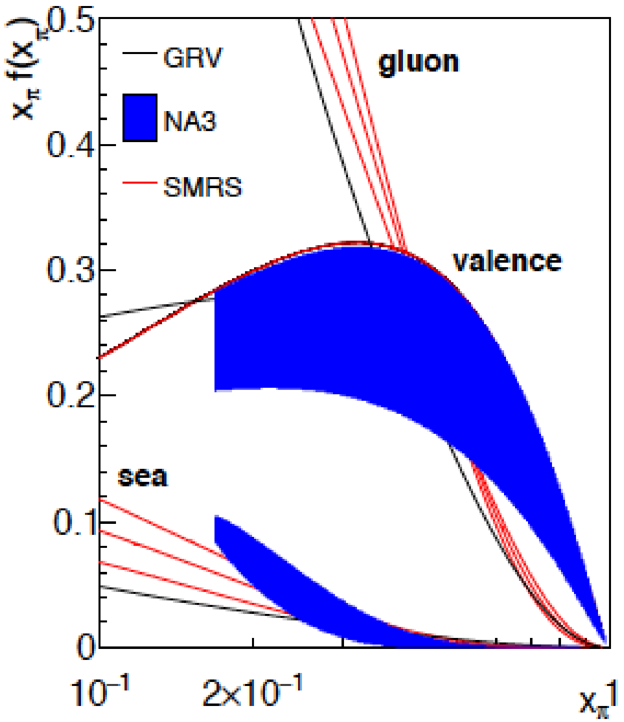
DIS with leading N:



- 90's: H1, ZEUS
- 10's: JLAB TDIS
- 30's: EIC

Existing hadron beam
Drell-Yan (I): pion structure

Pion Structure Function: $F_\pi(x_1)$

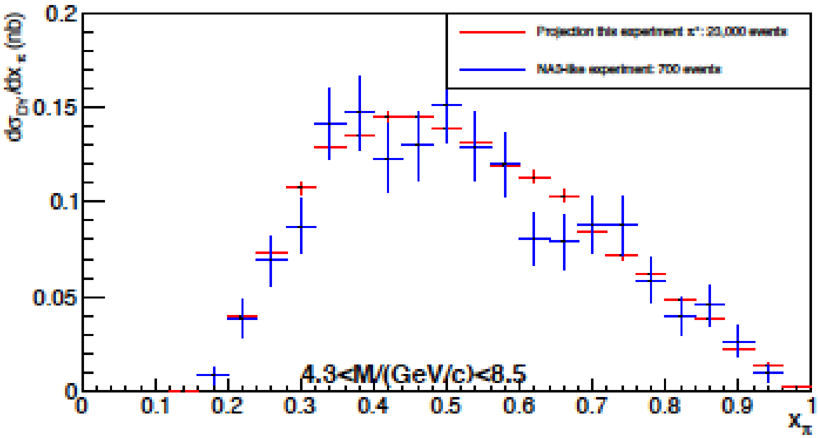


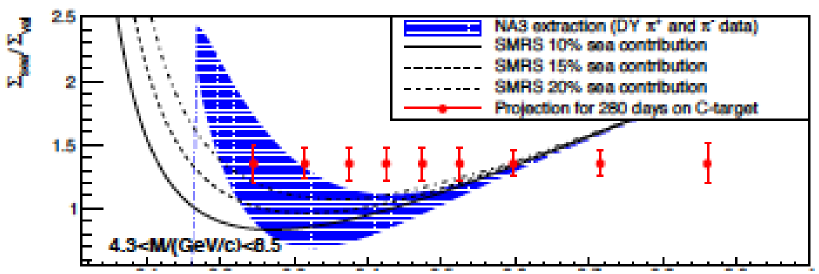
GRV: M. Gluck et al, Z.Phys.C **53** (1992) 651-655

SMRS: P.J. Sutton et al, Phys.Rev.D **45** (1992) 2349–2359

- SMRS did not use NA3 data. Instead, they assume 3 levels of sea: 10%, 15% or 20%.
- GRV neither. They constrain the pion gluon distribution from pion-induced direct photon production (NA24, WA70)
- The available pion PDF sets differ a lot. More data is needed, with better control of uncertainties, and full error treatment.
- Include Drell-Yan data with both pion beam charges **and** direct photon data in future global fits.

Existing hadron beam
Drell-Yan (II): competitiveness

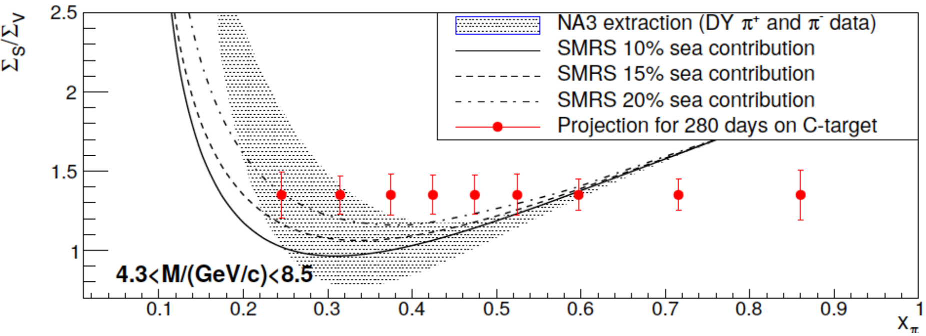




Expected accuracy compared to NA3 result

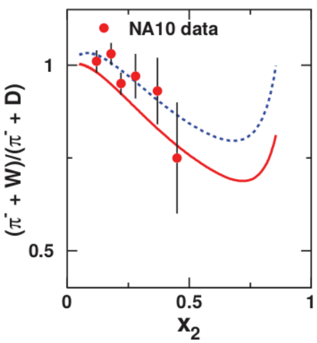
- $\Sigma_V = \sigma^{\pi^- C} - \sigma^{\pi^+ C}$: only valence-valence
- $\Sigma_S = 4\sigma^{\pi^+ C} - \sigma^{\pi^- C}$: no valence-valence
- Collect at least a **factor 10 more statistics** than presently available
- Minimize nuclear effects on target side
  - Projection for 2×140 days of Drell-Yan data taking
  - π^+ to π^- 10:1 time sharing
  - 190 GeV beams on Carbon target ($1.9\lambda^{\pi}_{int}$)
  - Improvement of shielding to double the intensity is under investigation

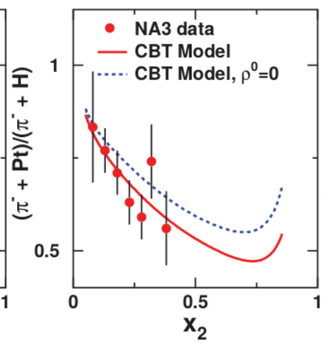
Existing hadron beam Drell-Yan (III)

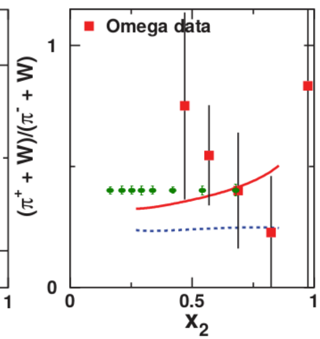


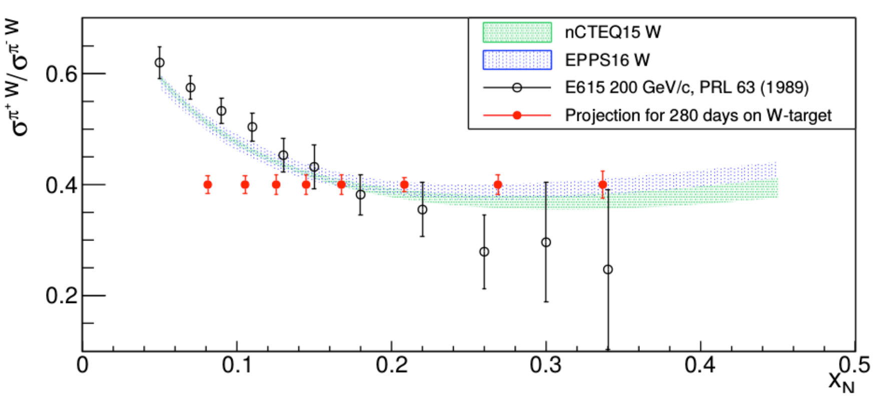
- Statistical uncertainties projections for COMPASS-like experiment (1 or 2 years of running depending on beam intensity: 7×10^7 or 1.4×10^8 /s)
- Time sharing 1:10 h^-/h^+ beam

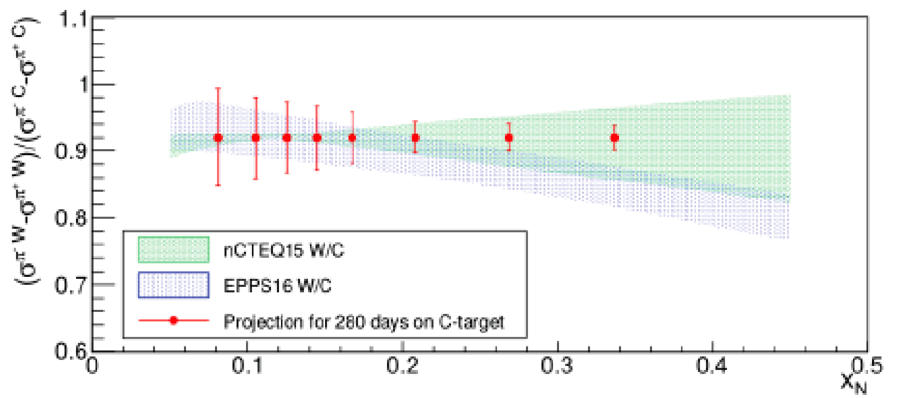
1. sea/valence ratio in pion
2. EMC effect pion projectile (red - flavour dep.)
3. Nuclear PDFs (existing DY data already in)
4. Nuclear PDFs (valence)









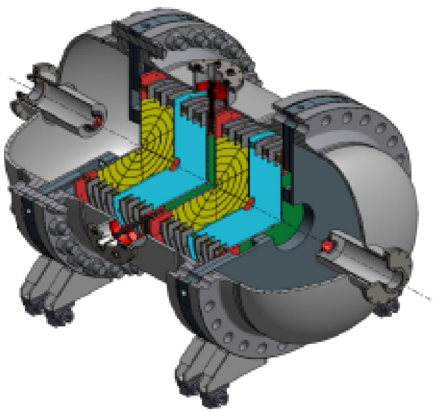


Existing muon beam:
Proton radius measurement in elastic mu-p scattering

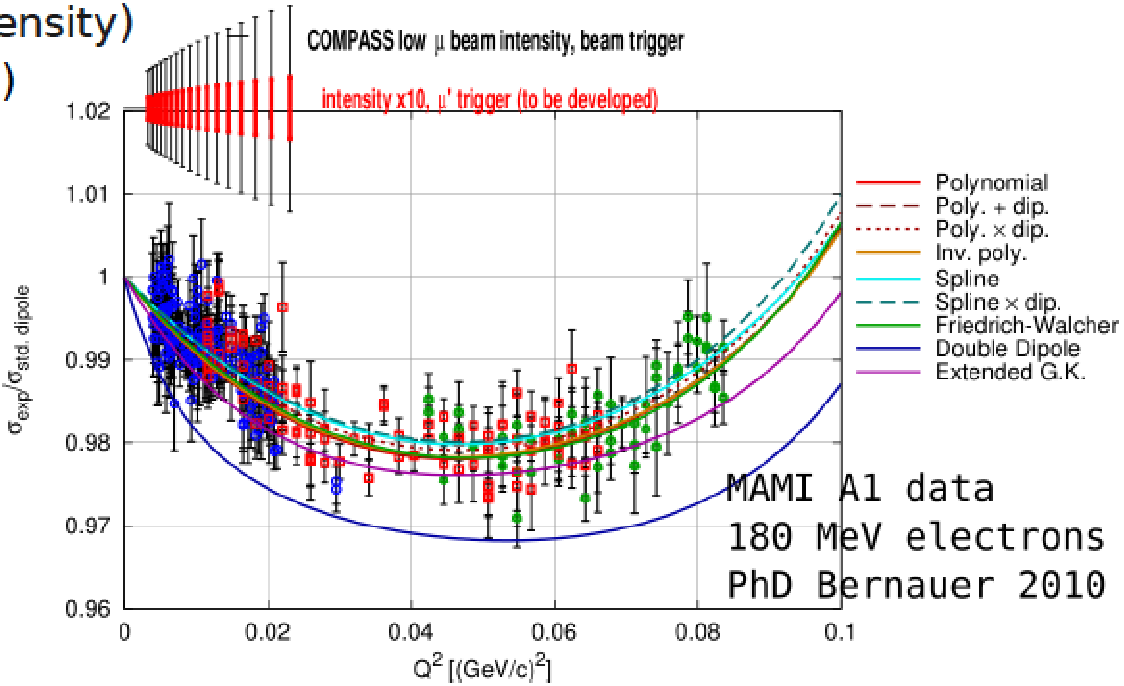
- 100 GeV SPS muon beam (M2)
- Hydrogen high-pressure active TPC target cell (PNPI development)
- Measure the cross-section (shape) over broad Q^2 range 10^{-4} … 10^{-1}
- From 10^{-3} … $2*10^{-2}$ fit the proton radius (slope of electric form factor)
  - Precision 0.03 fm with conservative beam trigger (0.5% beam intensity)
  - Goal: 0.01 fm (from 180 days) trigger concept to be solved

unique because…

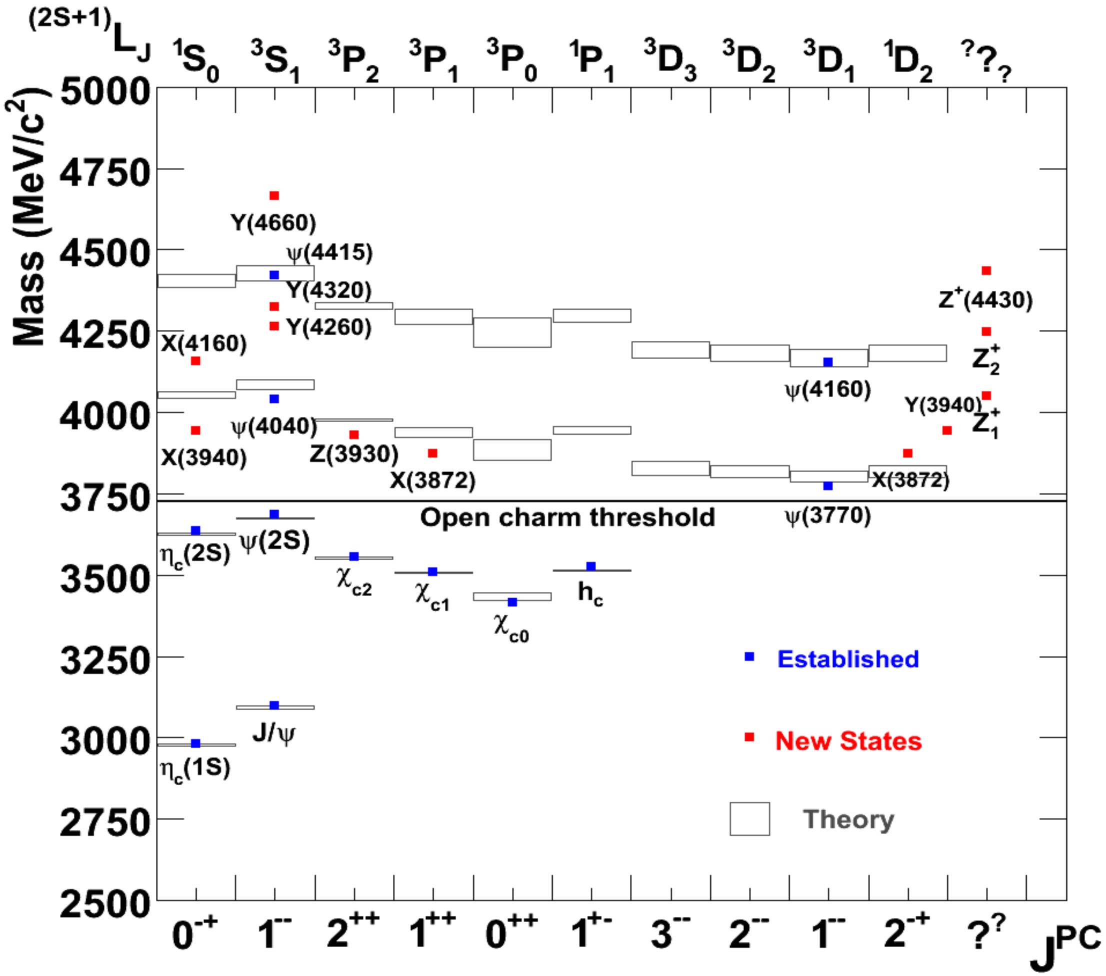
- muon beam requires a factor 10 smaller radiative corrections than e^- beams (vs. Mainz, Jlab)
- high-energy muon beam, very small scattering angles: practically no Coulomb correction (vs. MUSE)
- *best systematics control*



IKAR active target cell
A. Vorobyev, St. Petersburg



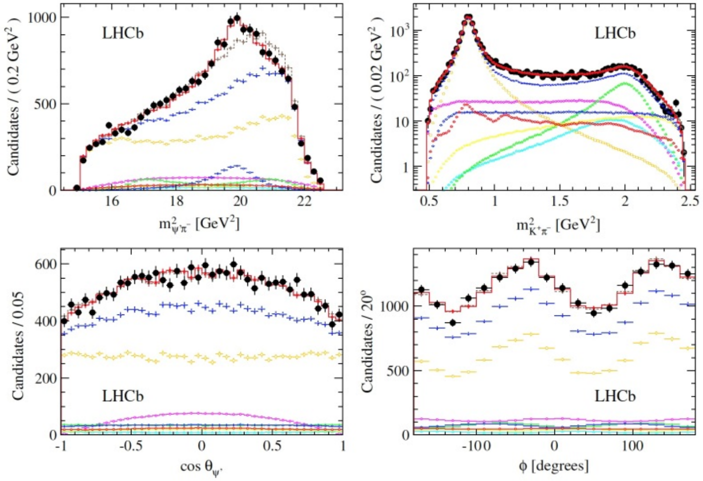
Existing beam line, antiproton-enriched beam
Charmonium spectra



[V. Santoro, Hadron 2015]

- Many new (narrow) states discovered in recent years
- Assignment not clear
- Some definitively not charmonium-like

LHCb: $Z(4430)^-$: 13.9 σ



[LHCb, PRL 112, 222002 (2014)]

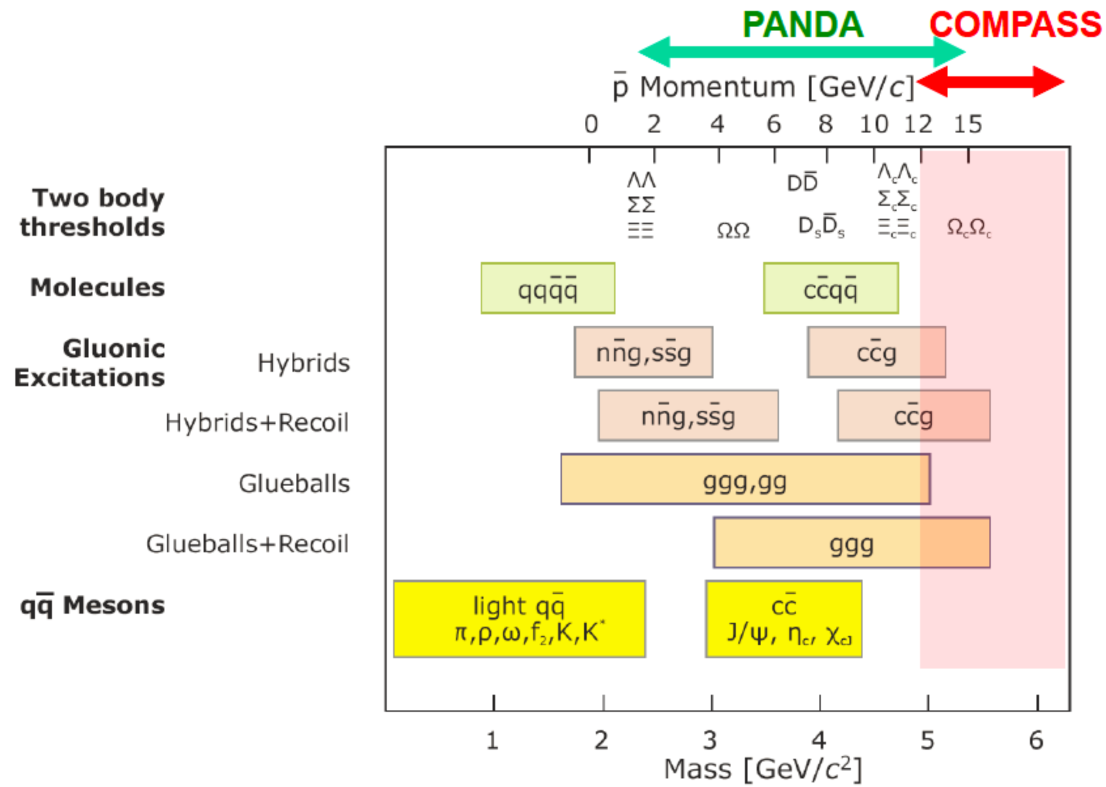
Existing beam line, antiproton-enriched beam
Charmonium-like mesons

M2 SPS beam line has to be retuned to extract Antiproton beam (momentum ~ 20 GeV)

Method: antiproton-proton annihilation

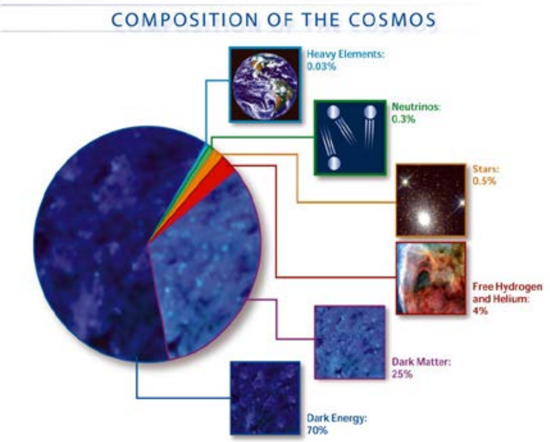
Goal: charmed hybrids and exotics study in the mass range higher than reachable in PANDA

Complementary to LHCb
(p-pbar annihilation – gluon rich environment and it allows high spin states)
Otherwise no competitors for the next at least 10 years



Existing proton beam: Search for Dark Matter

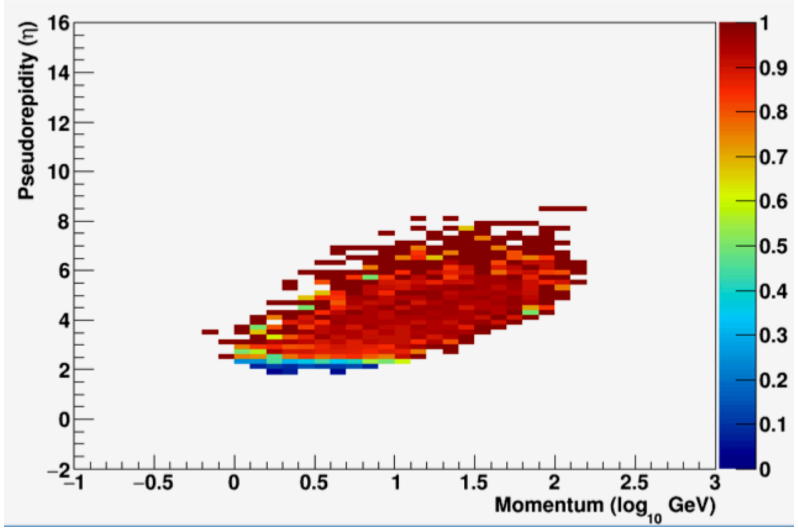
Absolute cross section measurement p+He--> pbar+X



-New AMS(2) data – the antiparticle flux is well known now (few % pres.) (http://dx.doi.org/10.1103/PhysRevLett.117.091103)
- Two type of processes contribute – SM interactions (proton on the ISM with the production for example antiprotons in the f.s.) and contribution from dark particle – antiparticle annihilation;
- In order to detect a possible excess in the antiparticles flux a good knowledge of inclusive cross sections of p-He interaction with antiparticles in the f.s. is a must, currently the typical precision is of 30-50%.

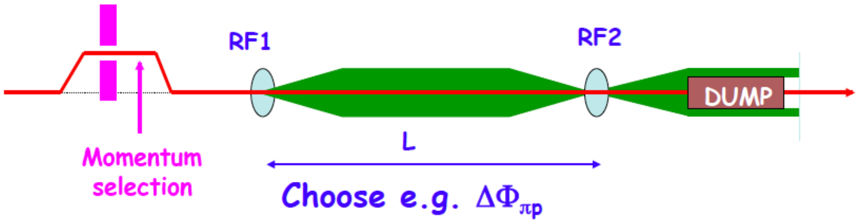
COMPASS++ from a few tens of GeV/c up to 250 GeV/c, in the pseudorapidity range 2.4 < h < 8.
We performed simulation with TGEANT (GEANT4 based COMPASS MC), using FLUKA generator or the internal TGEANT generator:
2009 COMPASS hadron setup, 190 GeV beam.

New tCOMPASS associated members
for this project:
AMS: Paolo Zuccon (MIT), Nicolò Masi (Bologna)
Theoretical Physicist: Fiorenza Donato (Torino)



Goal is to measure the double differential (momentum and pseudorapidity) anti-p cross production from p+p and p+He at different proton momenta (50, 100, 190, 250 GeV/c).

RF separated antiproton/kaon beam



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

"Normal" h^- beam composition:
~97% (π) ~2.5%(K) ~0.5% (pbar)

Assumptions:

– 8 x 10^7 antiprotons for 10^{13} ppp (10 seconds) (optimistic estimate by Lau Gatignon);
– we assume here 4 x 10^{13} protons.

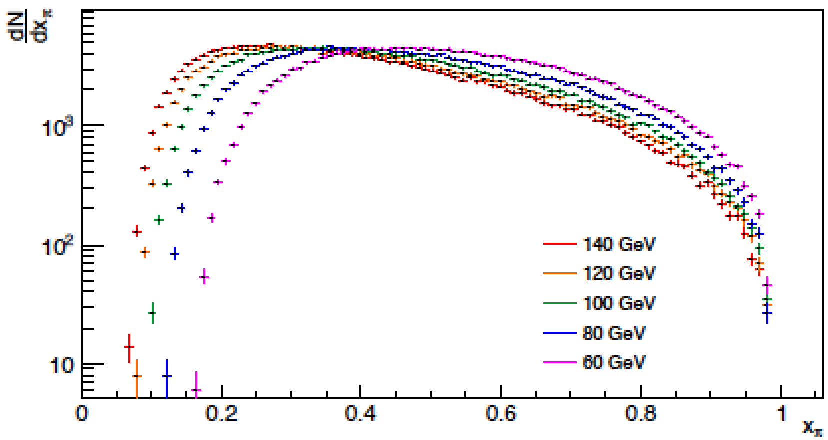
Antiprotons RF separated beam: 3.2 x 10^7 /s - Gain is a factor of 50 compared to the standard h^- beam for Drell-Yan experiment (~1% of h^- beam 6x10^7 /s dominated by π^-)

Using the same assumption for RF separated kaon beam, possible kaon beam intensity is 8 x 10^6 /s - Gain is a factor of 80 compared to to the standard "spectroscopy" h^- beam

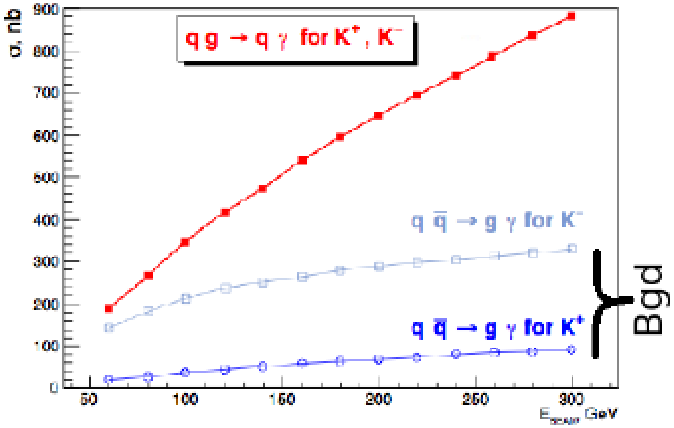
High intensity RF separated beam will provide unique opportunities for Hadron Spectroscopy and Drell-Yan physics

RF separated hadron beam
Meson structure study in DY and PP processes

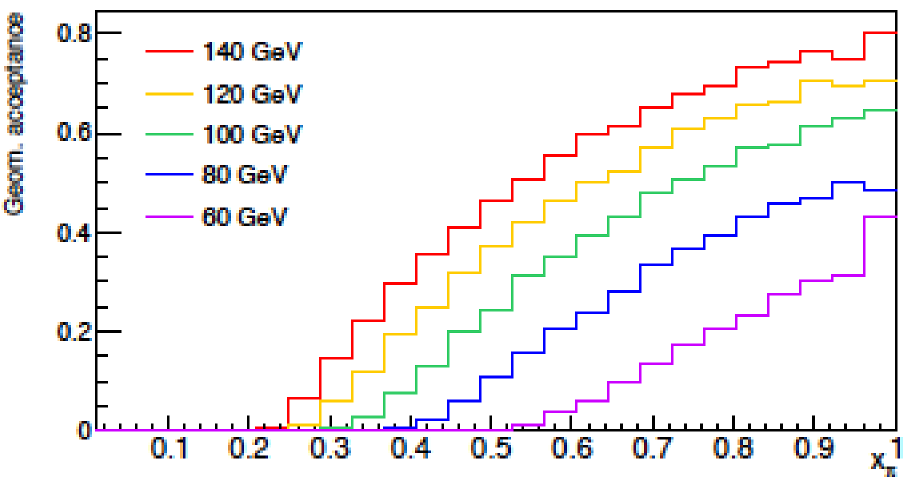
DY cross-section



Prompt photon cross-section



Highest possible beam momentum is Essential for both Drell-Yan and Prompt Photons program

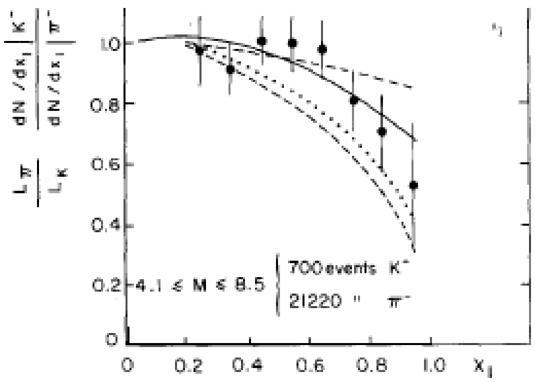


What do we know about kaon structure?

Sole measurement from NA3

J. Badier *et al.*, PLB93 354 (1984)

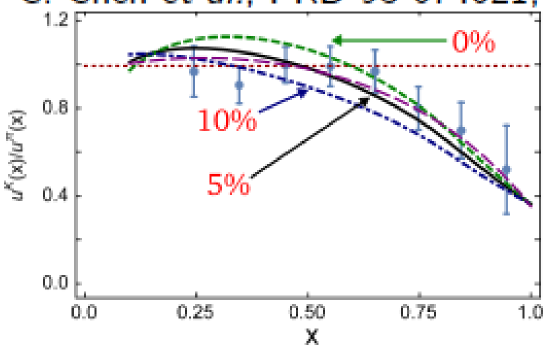
- Limited statistics: 700 events with K^-
- Sensitivity to $SU(3)_f$ breaking
- Mostly only model predictions
- No predictions from lattice - waiting for data!



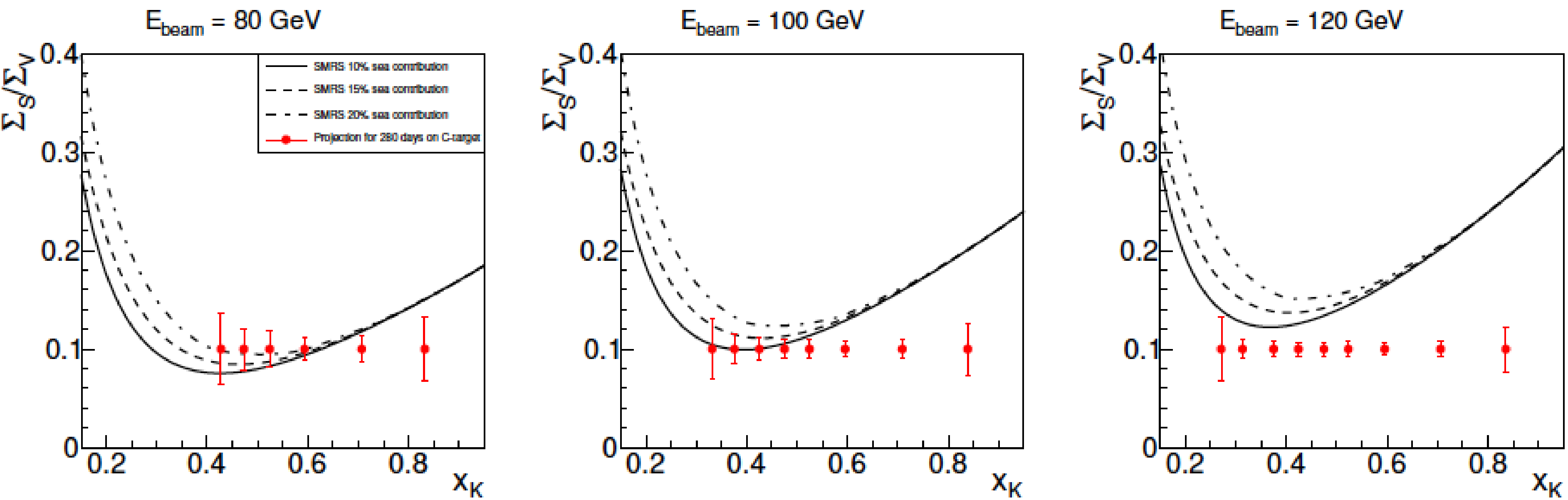
Interesting observation: At hadronic scale gluons carry only 5% of K's momentum *vs* ~30% in π

- Scarce data on *u*-valence
- No measurements on gluons
- No measurements on sea quarks

C. Chen *et al.*, PRD 93 074021, 2016

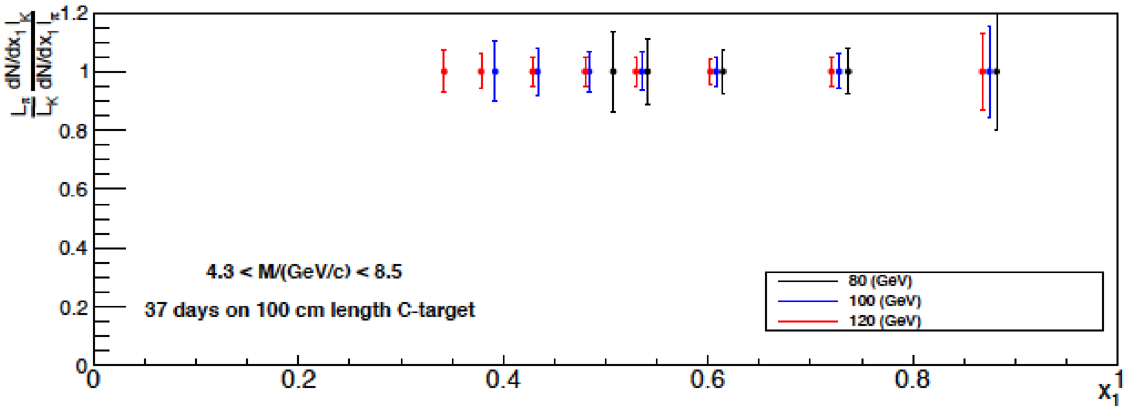


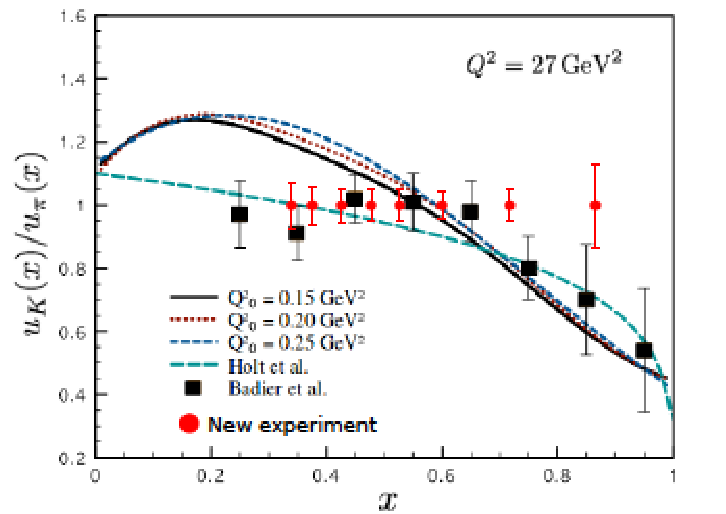
RF separated hadron beam
Meson structure study in DY and PP processes
Projection for valence/sea quarks separation in Kaon



- First measurement of sea in Kaon
- There is still a room for optimization
- Assumed K^+/K^- beam intensity $2x10^7$ /s
- 280 days of running

RF separated hadron beam
Meson structure study in DY and PP processes
Valence u-quark quarks in Kaon compared to pion





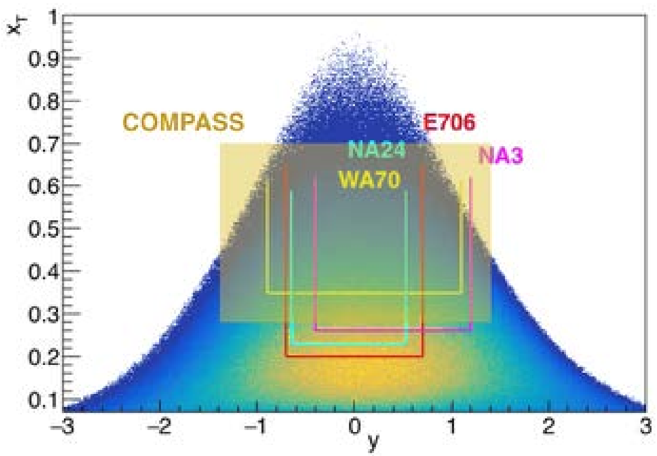
Experiment	Beam type (GeV)	Intensity (/s)	Target	DY events
NA3	K^- (150) K^- (200) K^+ (200)	0.25×10^7 0.93×10^7 0.22×10^7	Pt	688 90 170
This exp	K^- (80) K^- (100) K^- (120)	1.9×10^7 2.3×10^7 2.5×10^7	C	593 1,800 3,600
This exp	K^+ (80) K^+ (100) K^+ (120)	1.7×10^7 2.1×10^7 2.3×10^7	C	482 1,700 3,700

- Statistics with 280 days with a sharing K^-:K^+ $\sim$ 1:7
- Purity of the beam is around 30%, can it be better?
- Obvious gain in intensity with RF separated beam compared to NA3

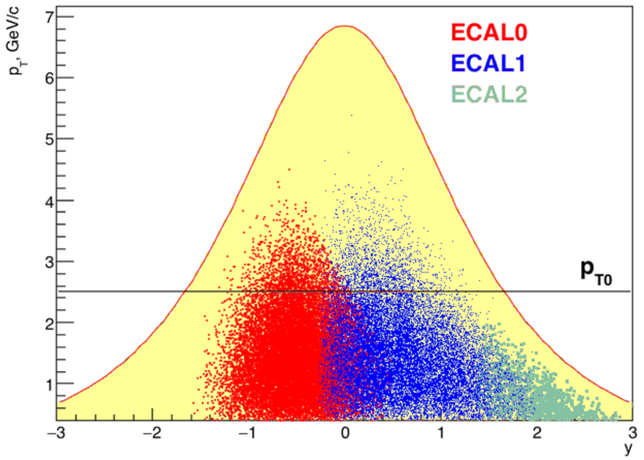
RF separated hadron beam
Meson structure study in DY and PP processes

At the moment there is no experimental information about gluon contribution in kaon. Calculations based on Dyson-Schwinger equations predict 6 times smaller contribution at hadronic scale in respect to pion (Phys. Rev. D93 (7) (2016) 074021)

Pythia-based MC simulation for prompt photons production was used for preliminary estimation of kinematic range accessible at COMPASS. It was compared with corresponding ranges accessible by previous experiments with pion beams.



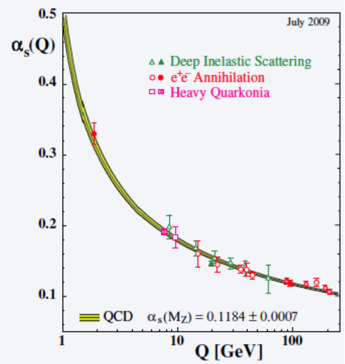
Full MC simulation for prompt photons and minimum bias events was performed for K+ beam of 100 GeV/c and the COMPASS setup configuration of 2017 DVCS run. Possibilities to identify signal and reject background were tested. Some optimization of the setup from point of the material budget was tested.



NO competitors

RF separated hadron beam
Strange sector meson spectroscopy with Kaon beam

- Binding of quarks and gluons into hadrons governed by low-energy (long-distance) regime of QCD
- Least understood aspect of QCD
  - Perturbation expansion in α_s not applicable
  - Revert to models or numerical simulation of QCD (lattice QCD)
- Details of binding related to hadron masses
  - Only small fraction of proton mass explained by Higgs mechanism $\Rightarrow$ most generated dynamically

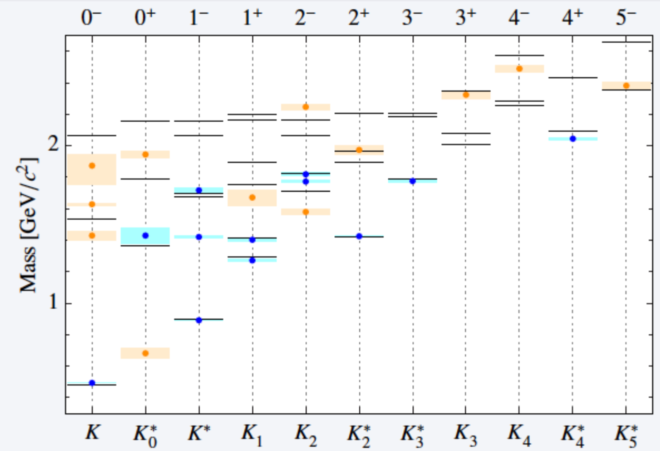


Hadrons reflect workings of QCD at low energies

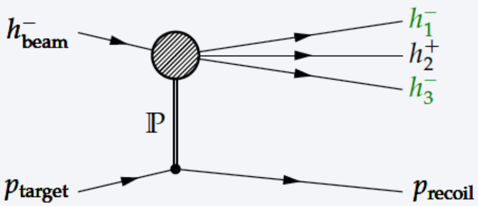
Measurement of **hadron spectra** and **hadron decays** gives valuable input to theory and phenomenology

PDG 2016: 25 kaon states below 3.1 GeV/c^2

- Only 12 kaon states in summary table, 13 need confirmation
- Many predicted quark-model states still missing
- Some hints for supernumerous states



[Courtesy S. Wallner, TUM]

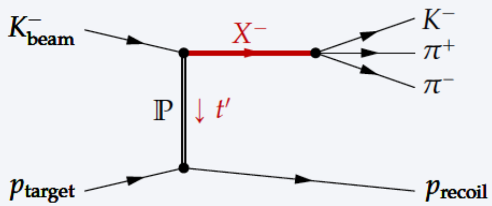


Many kaon states need confirmation

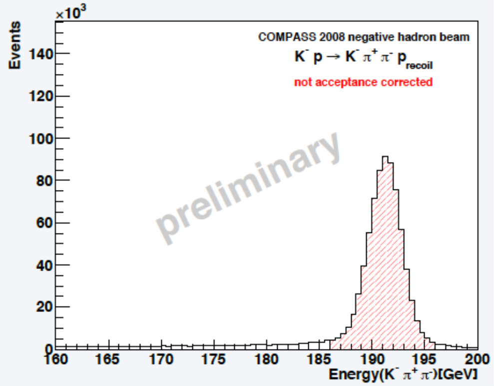
- Little progress in the past
  - Most PDG entries more than 30 years old
  - Since 1990 only 4 kaon states added to PDG (only 1 to summary table)

- Diffractive production of excited kaon states X^- that decay into $K^-\pi^+\pi^-$
- Beam-particle ID via Cherenkov detectors (CEDARs)
  - Ca. $50\times$ more π^- than K^- in beam
- Final-state PID via RICH detector
  - Distinguish K^- from π^- over wide momentum range

RF separated hadron beam
Strange sector meson spectroscopy with Kaon beam



- From 2008 data taking campaign
- 270 000 events
- $0.07 < t' < 0.7\ (\mathrm{GeV}/c)^2$
- Exclusivity ensured by measuring recoil proton
  - Also suppresses target excitations



Work in progress: improving analysis

- Improved beam PID + data sample from 2009 run
  $\Rightarrow$ ca. 8×10^5 $K^-\pi^+\pi^-$ events
  $\Rightarrow$ world's largest data set (4× WA03)
- Improved PWA model $\Rightarrow$ clearer resonance signals
- Resonance-model fit $\Rightarrow$ extraction of $K^-\pi^+\pi^-$ resonances and their parameters

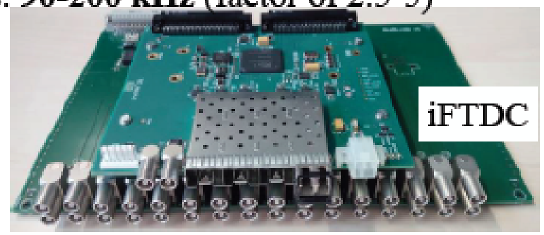
Future program

- *Goal:* collect 10 to 20 $\times 10^6$ $K^-\pi^+\pi^-$ events using high-intensity RF-separated kaon beam
  - Would exceed any existing data sample by at least factor 10
  - *High physics potential:* rewrite PDG for kaon states above 1.5 GeV/c^2 (like LASS and WA03 did 30 year ago)
  - Precision study of $K\pi$ S-wave
- Requires experimental setup with uniform acceptance over wide kinematic range (including PID and calorimeters)
- No direct competitors

Measurement of kaon Compton scattering via the Primakoff effect and an RF separated beam for determination of the kaon polarisability, and kaon-photon induced strange meson production

QCD facility – future fixed target experiment at M2
Spectrometer upgrades

- **New type of FEE and trigger logic compatible with trigger-less readout**
  - FPGA-based TDC with time resolution down to 100 ps (iFTDC)
- Higher trigger rates: **90-200 kHz** (factor of 2.5-5)
- Digital trigger
- First tests in 2018

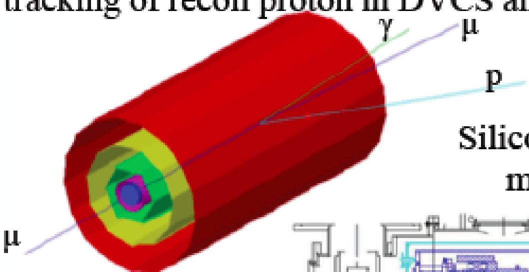


General upgrades of COMPASS-II apparatus:
- New large-size **PixelGEMs**
- **GEMs** or **Micromegas** to replace aging MWPCs
- High-aperture "**RICH0**" for some programs, $p <$ 10-15 GeV?

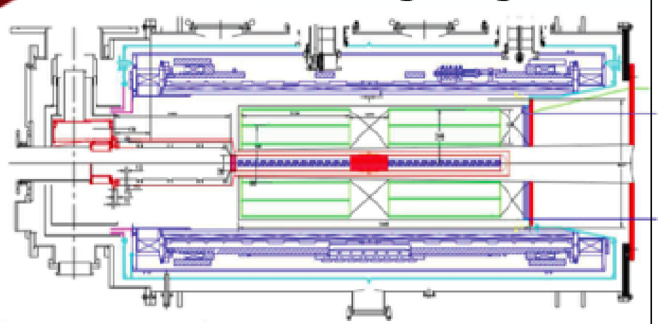
Could be Large-Area Picosecond Photo-Detectors based on micro-channel plates with time resolution < 50 ps, spatial resolution ~ 0.5 mm. LAPPD™ by IncomInc.

- High-rate-capable **CEDARs** for beam PID for all hadron programs.

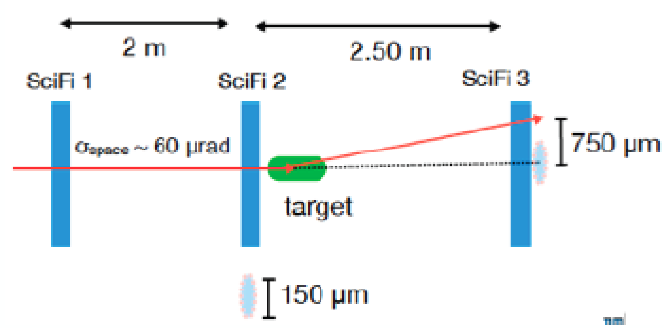
GPD E: 3-layer silicon detector at very low temperature for tracking of recoil proton in DVCS and PID via dE/dx.



Silicon detector inside existing modified target magnet.



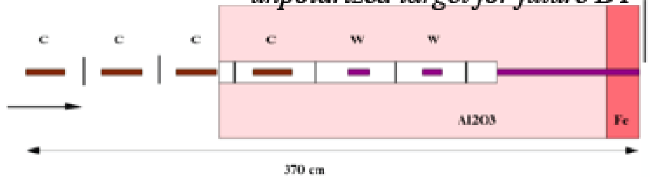
Proton radius:
- **High-pressure active TPC target or hydrogen tube** surrounded by SciFi, 4-8 layers with U/V projections
- **SciFi trigger system** on scattered muon
- Silicon trackers



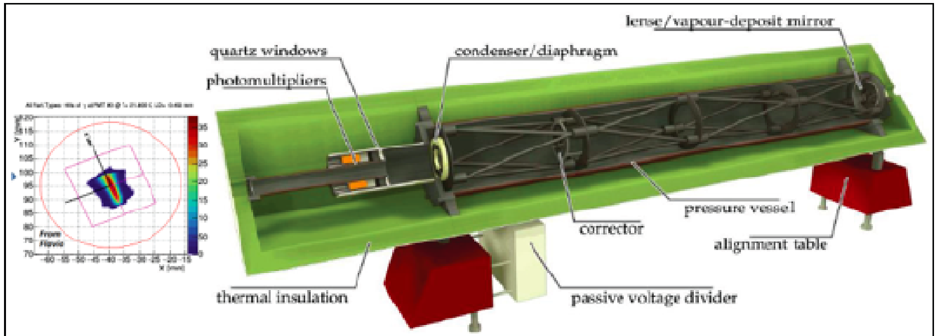
QCD facility – future fixed target experiment at M2
Spectrometer upgrades

Drell-Yan general:
- High-purity and efficiency di-muon trigger
- Dedicated precise luminosity measurement
- Dedicated vertex-detection system
- Beam trackers

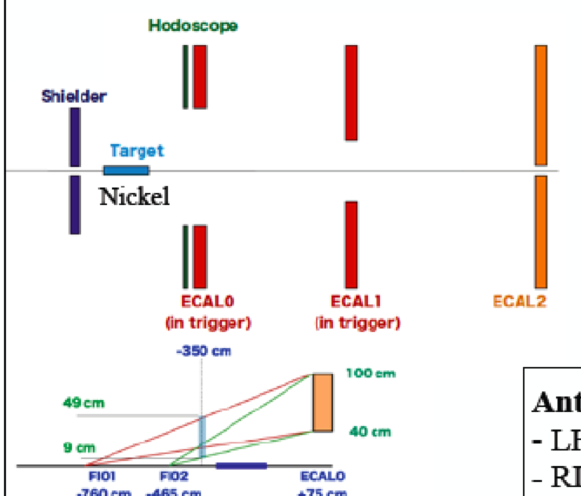
unpolarized target for future DY



Drell-Yan RF separated beams:
- Due to lower beam energy, need wide aperture ± 200 mrad
- High-rate and high-multiplicity capability
- Active absorber (magnetic field, calorimetry?)
- TPCs?
- GEMs?

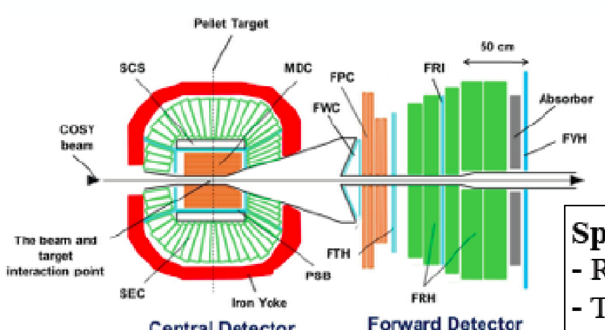


CEDAR upgrade 2018



Prompt Photons
- Shielder (20-30cm steel) upstream of target
- New hodoscope upstream of ECal0
- Transparent setup

Anti-matter cross section
- LH2 and LHe targets
- RICH0 for lower momentum to ID anti-protons?

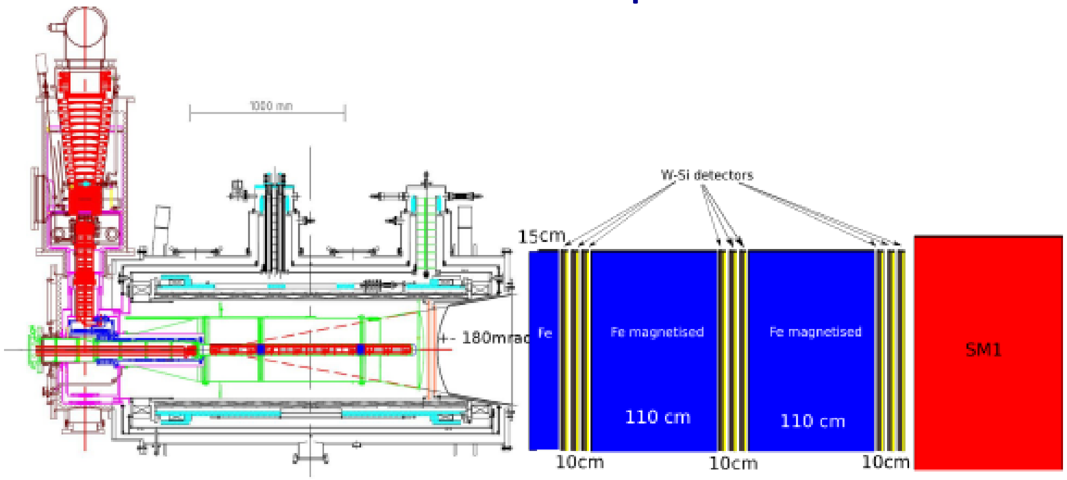


WASA detector with target spectrometer

Spectroscopy with low-anergy anti-p:
- RICH & CEDAR, RICH0 for low p?
- Target spectrometer (tracking, barrel calorimeter) similar to WASA

Spectroscopy with high-energy K—:
- RICH & CEDAR
- Uniform acceptance, ECals
- Good vertexing
- Recoil TOF detector

QCD facility – future fixed target experiment at M2
Spectrometer upgrades for Drell-Yan measurements with RF-separated beam



- Investigate the possibility to use W-Si detectors, a la PHENIX (NCC, MPC-EX)
- Dead zone with radius of 9 cm (12 cm) for angles below 90 mrad (120 mrad)
- Outter radius: 112 cm for angles up to 300 mrad

Initial detector consideration:

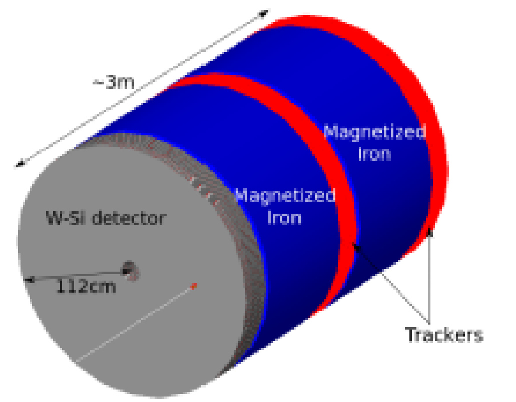
Combination of

- Baby-Mind detector

  M. Antonova *et al.* arXiv:1704.08079

- W-Si detectors, a la BNL

  AnDY | Phenix MPCEX | Phenix NCC



Current status & content of the LoI
LoI is open for new ideas and participants

~75 pages long document will be ready for distribution in the next 2 weeks

- We will leave it open for new ideas / participants for few months (do not exclude late new ideas/participants)
- We plan to submit it in the SPSC committee in September 2018
- In parallel we will go on with the Proposal preparation (submission is planned by the end of 2019)

Summary

- "Beyond 2020" workshop (CERN, March 2016) and IWHSS (Cortona, Italy, April 2017) ➔ success, strong interest in the hadron physics community

- RF separated antiproton/kaon beam will provide unique opportunity for meson spectroscopy and meson structure study

- Existing muon and hadron beams allows to enrich current COMPASS program

- New Collaboration should be founded in the next few years – JOIN!

- New QCD facility physics program is 100% complementary to NICA SPD (exclusive processes)

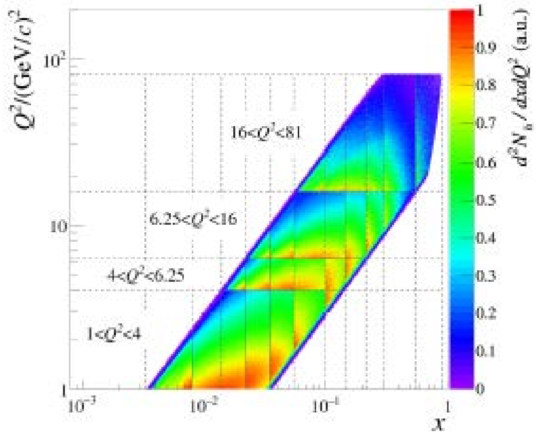
Thank you!

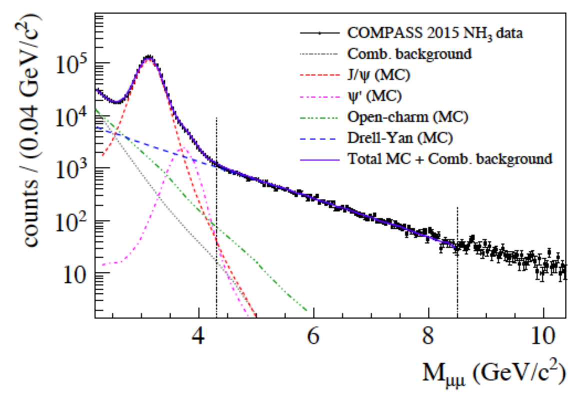
SPARES

SIDIS transverse

Sivers and TSA in the Drell-Yan Q^2 bins

Sivers TMD PDF has a very particular feature - it contributes with opposite sign to SIDIS and DY. It is considered to be an essential prediction of Quantum Chromodynamics (QCD) going to be tested by COMPASS. If Sivers function comparison SIDIS←→ DY is done at the same Q^2 we drop the uncertainties from the unknown QCD evolution of the Sivers TMD.





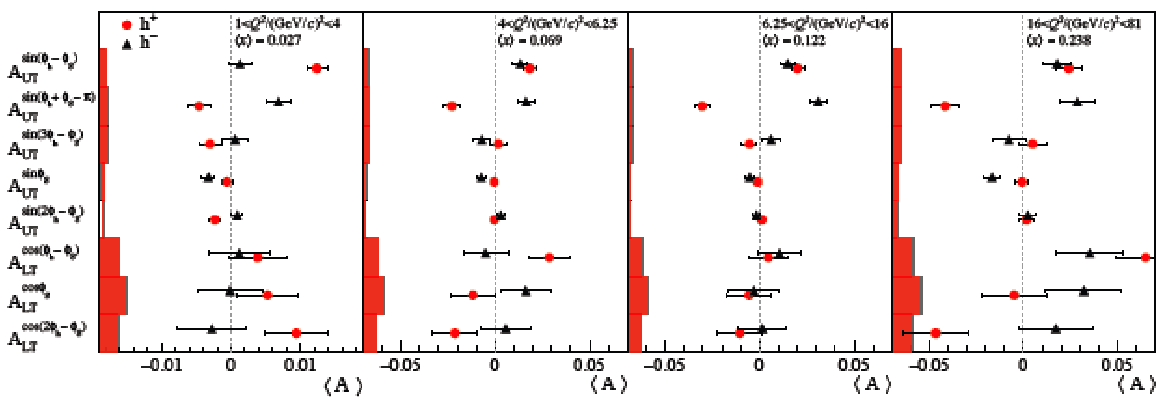
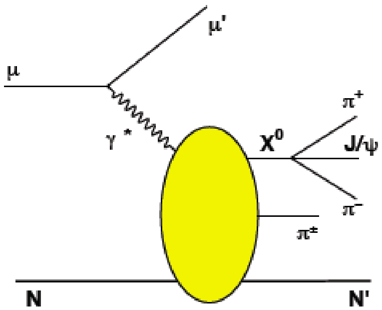


Fig. 2: Mean TSAs in the four DY Q^2-ranges. Systematic uncertainties are shown as error bands next to the vertical axis. For each Q^2-range also the average x-values are given.

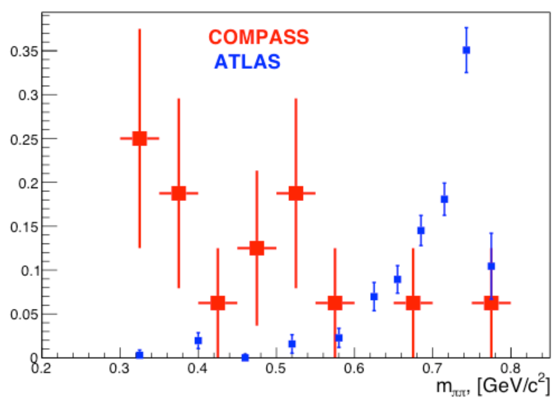
Exotic X(3872) lepto-production update

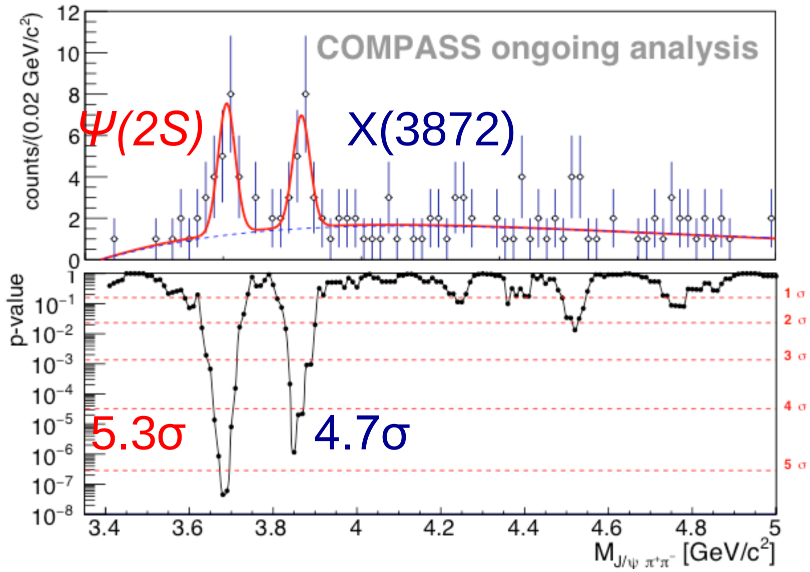
X(3872) is the first charmonium-like exotic hadron discovered by the Belle collaboration in 2003 and studied than in other experiments. Various interpretations exists: tetra-quark, *DD**-molecule, hybrid *ccg* state, glue-ball or else.
Additional information on its width would help to shed light on its nature.



COMPASS muon beam data 2003➔2010
Study $J/\psi\pi^+\pi^-$ subsystem of exclusive final state $J/\psi\pi^+\pi^-\pi^\pm$

COMPASS di-pion mass spectrum is different compared to the Atlas observation.

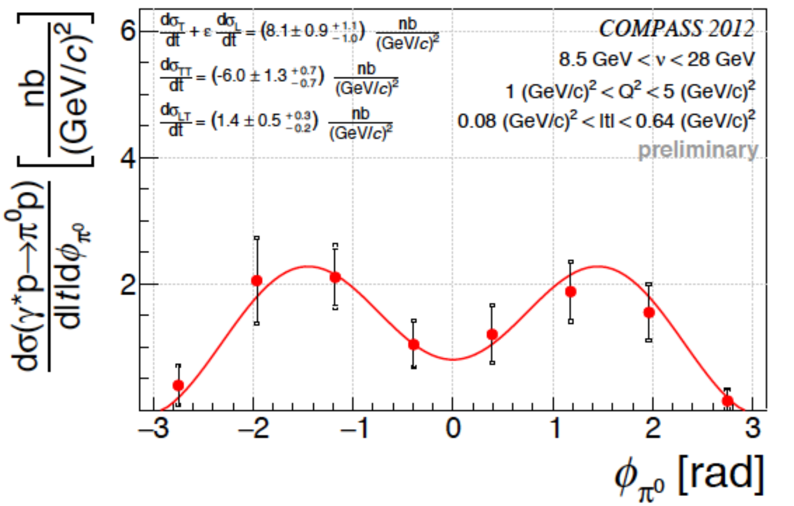




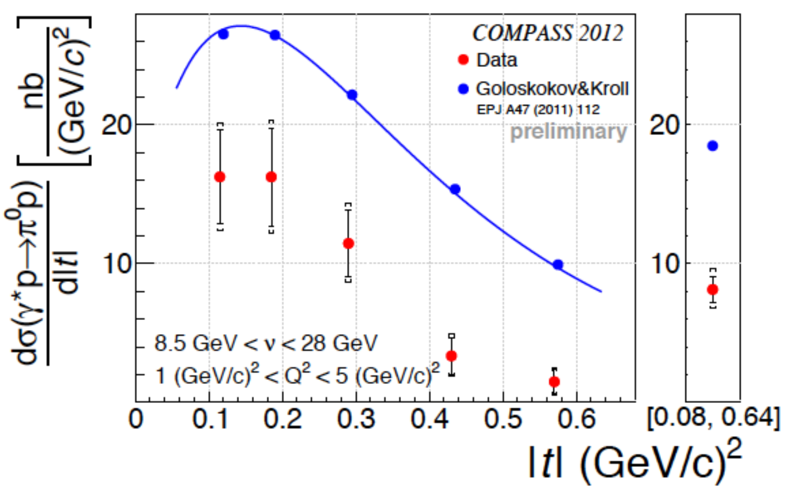
$$\sigma_{\gamma N\to X(3872)\,\pi^\pm N'} \times \mathcal{B}_{X(3872)\to J/\psi\pi\pi} = 71 \pm 28(\text{stat.}) \pm 39(\text{syst.})\ \text{pb}$$

Ref: hep-ex/1707.01796

DVCS 2012 results – exclusive π^0

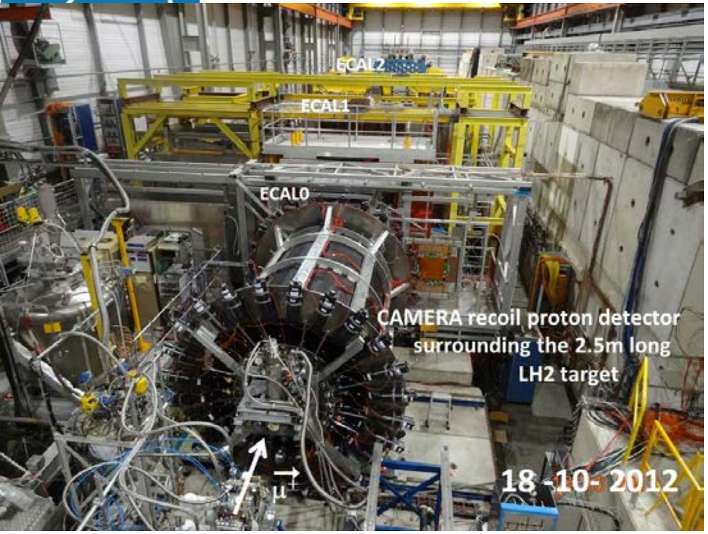


The exclusive meson production cross-section was extracted as a function of $\phi_{\pi 0}$ (8 equidistant bins) in a single bin of t and in five bins of t after integration in $\phi_{\pi 0}$.



Comparison to the Goloskokov and Kroll model shows a factor of approximately 2 lower cross-section as it is measured in experiment with respect to the model predictions.

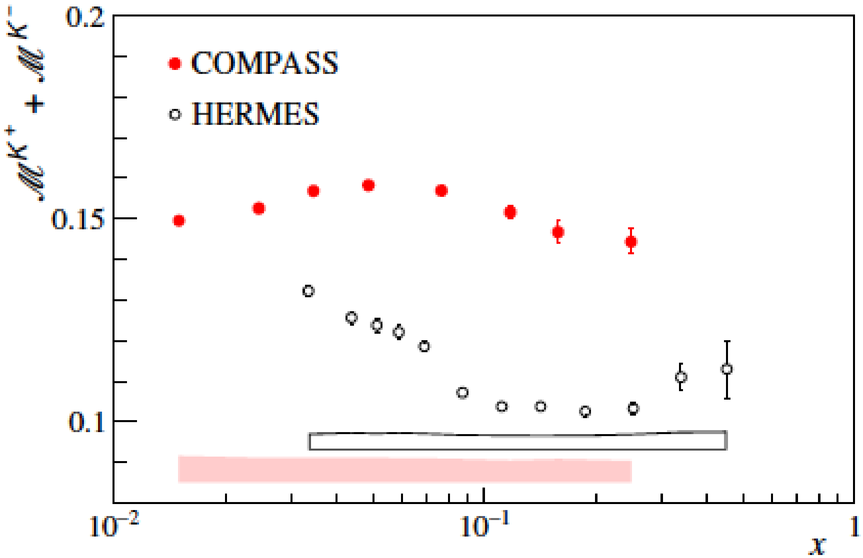
Change over for Polarised Drell-Yan run



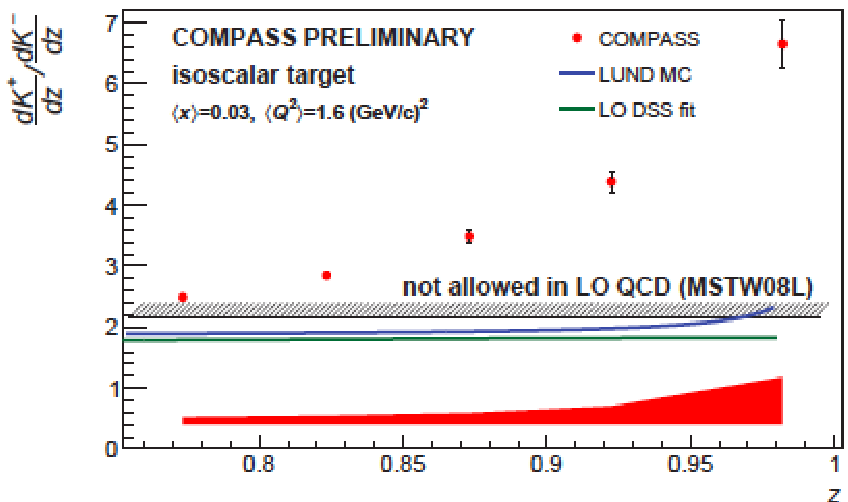
Group	function		comment	Contacted?
Various TE-CRG-ML	Helium, piping, magnets		Reserve people, Check availability	yes
EN-EL	Electricity, cabling		400V, 48V, AUL	yes
TE-EPC-LPC	Power supplies		Ready Jan. 2018	yes
DT-DI	Programming, connection			yes
EN-HE	Platform, rotation, shielding			yes
TE-CRG-OD	Helium consumption Cold box Dewar LN_2		Check for larger Dewar Check piquet service	yes
EN-EA	CEDAR/magnet support			Asking soon

SIDIS (kaon) multiplicities

Charged kaon multiplicities (2006 160 GeV ^{6}LiD) – published in PLB 767 (2017) 133
The 3-dimensional data set (*x, y* and *z)* ➔ an important input for future NLO pQCD analyses of world data in terms of FFs.

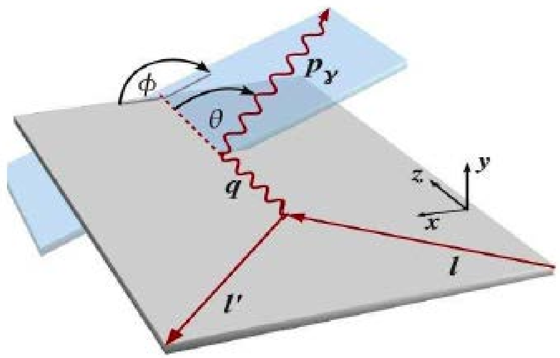


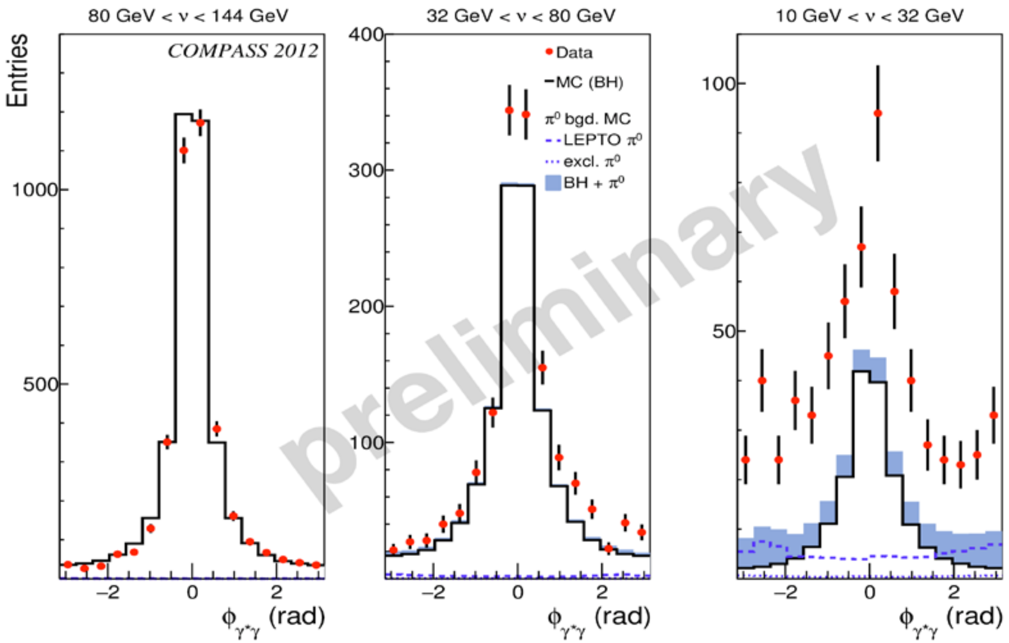
Important message – HERMES and COMPASS data are in tension.
Can not be explained only by different Q^2 range, the discussion is going on.



Recently new results were produced on the kaon multiplicity ratio K^+/K^-, at high z, $0.75 < z < 1$.
Surprisingly our data go far beyond the LO upper boundary value of (u+d)/(ū+đ) calculated at x=0.03 using MSTW08L as well as beyond the actual predictions of the K^+/K^- multiplicity ratio using Lund model or LO DSS fit (hep-ex/1802.00584)

DVCS 2012 results II



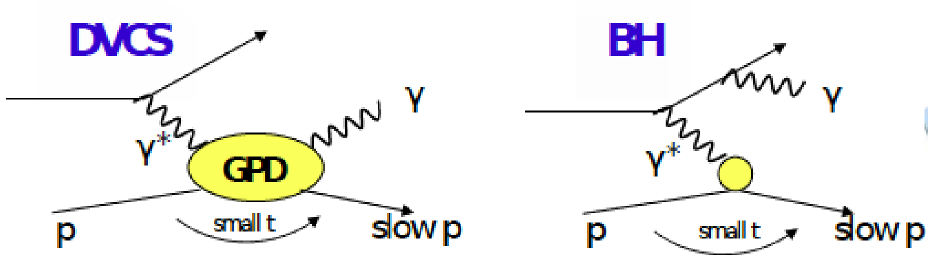


t-dependence of DVCS x-section

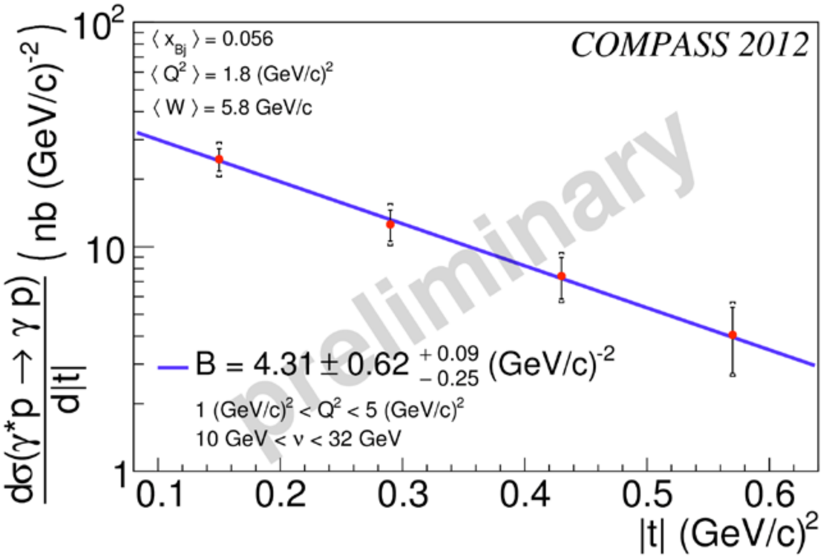
- Exclusive γ event selection
- π^0 bgd. estimation
- Kinematic fit
- Acceptance corrections
- Cross-section ($\gamma^* p \rightarrow \gamma p$)

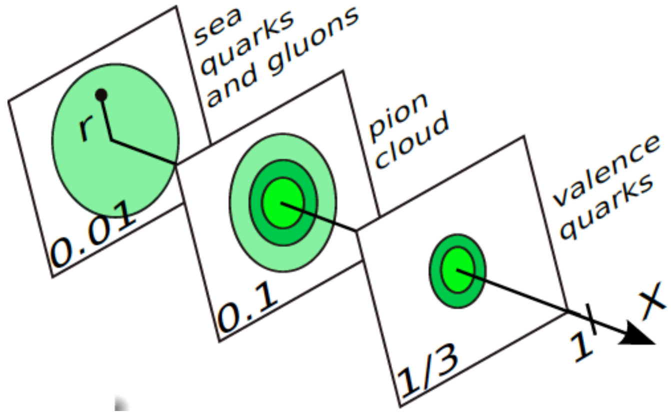
$\Downarrow$

Two competing processes (Bethe-Heitler and DVCS)
Contribute differently in the different *x(v)*-ranges

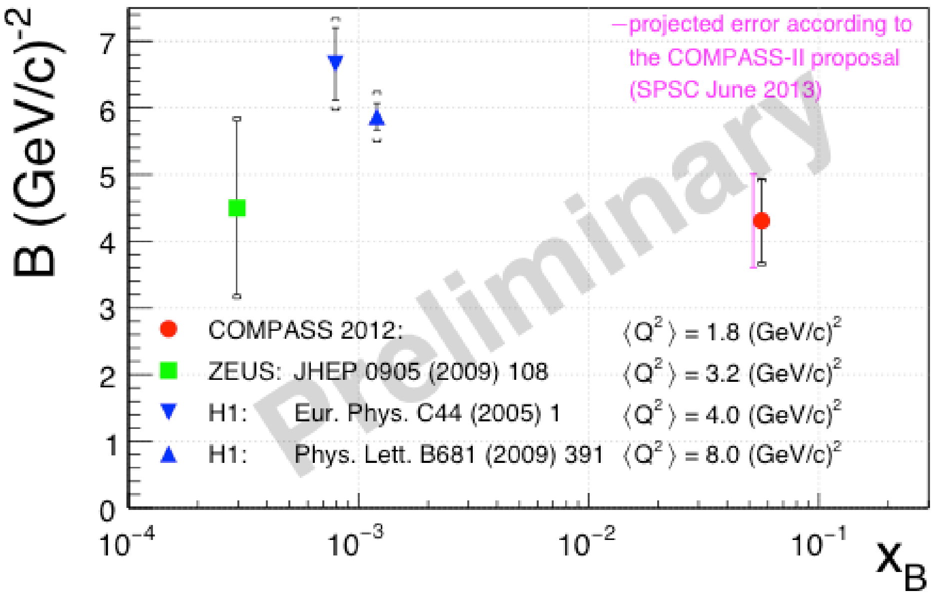


DVCS 2012 results V: *t*-slope





$$B = 4.31 \pm 0.62\,^{+0.09}_{-0.25}\,(\mathrm{GeV}/c)^{-2}$$



Ref: hep-ex/1802.02739

Existing muon beam
Polarised DVCS

Generalised Parton Distributions (GPD) *E* and access to Orbital Angular Momentum
Recoil detector to be inserted in the COMPASS PT magnet

- Muon beam, access to GPD *E* processes to be measured:

  ✓ DVCS (μ p↑ ➔ μ p γ)
  ✓ DVMP (μ p↑ ➔ μ ρ (ω) γ)

Projections: ➔

Competitors: No competitors in COMPASS kinematic range (small x_{Bj})

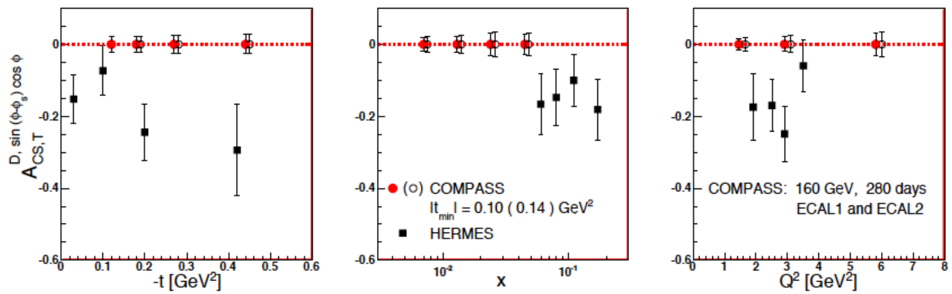
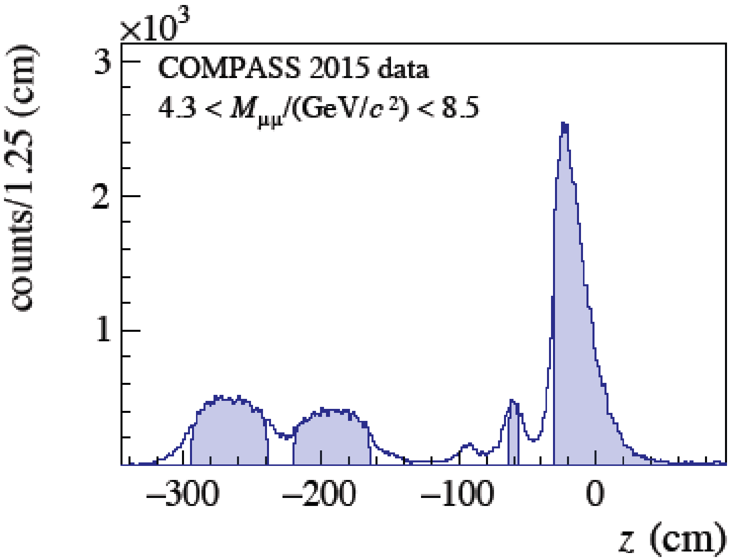
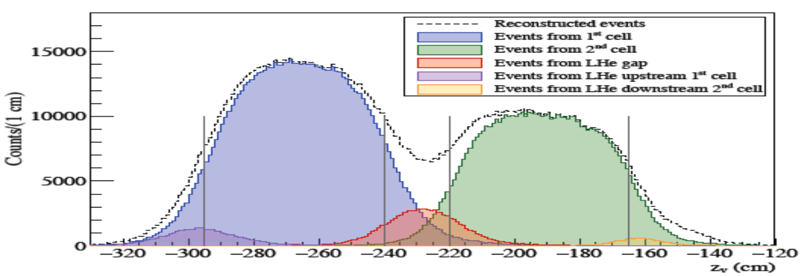


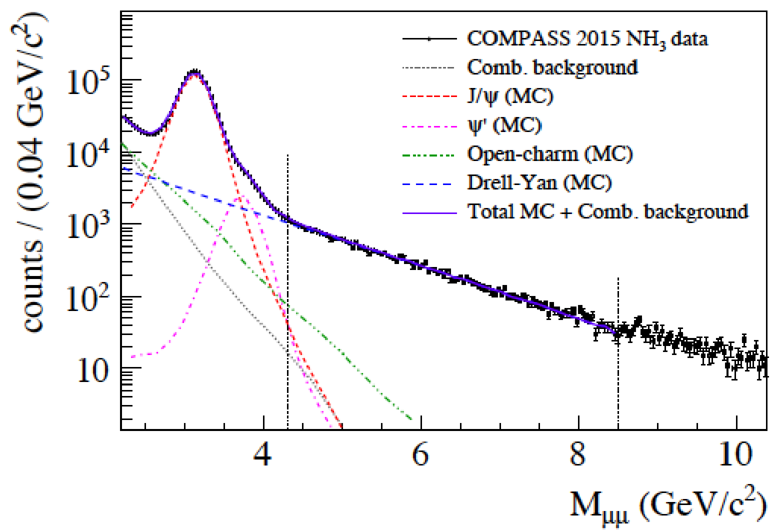
Figure 13: Expected statistical accuracy of $A_{CS,T}^{D,\sin(\phi-\phi_s)\cos\phi}$ as a function of $-t$, x_B and Q^2 from a measurement in 280 days, using a 160 GeV muon beam and ECAL1+ECAL2. Solid and open circles correspond to the simulations for the two hypothetical configurations of the target 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.

COMPASS Drell-Yan Run 2015 results II

First ever polarised Drell-Yan paper ([PRL 119 (2017) 112002](PRL 119 (2017) 112002))





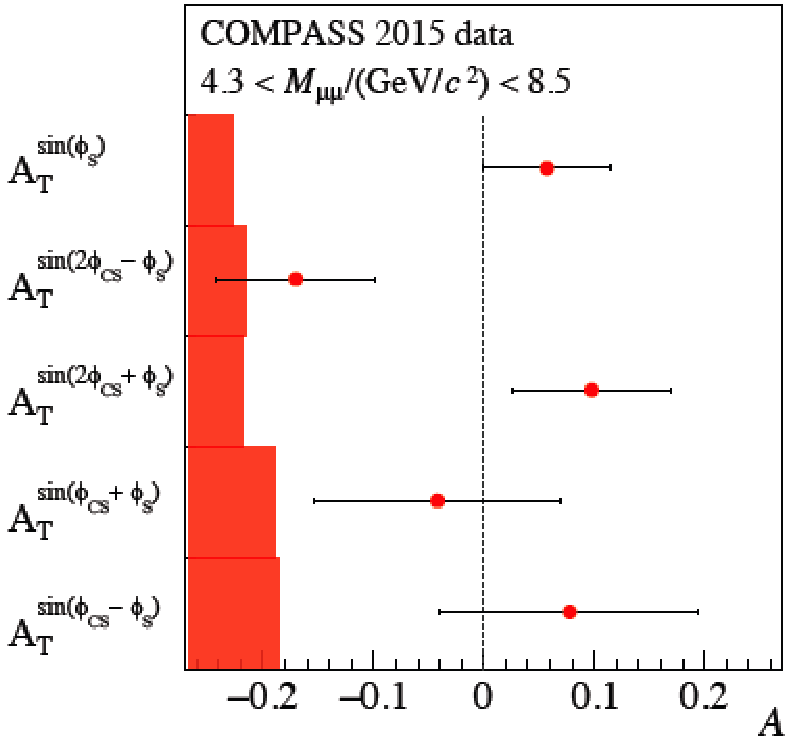


Total number of *J/ψ* (NH_3) is **~ 1.500.00**

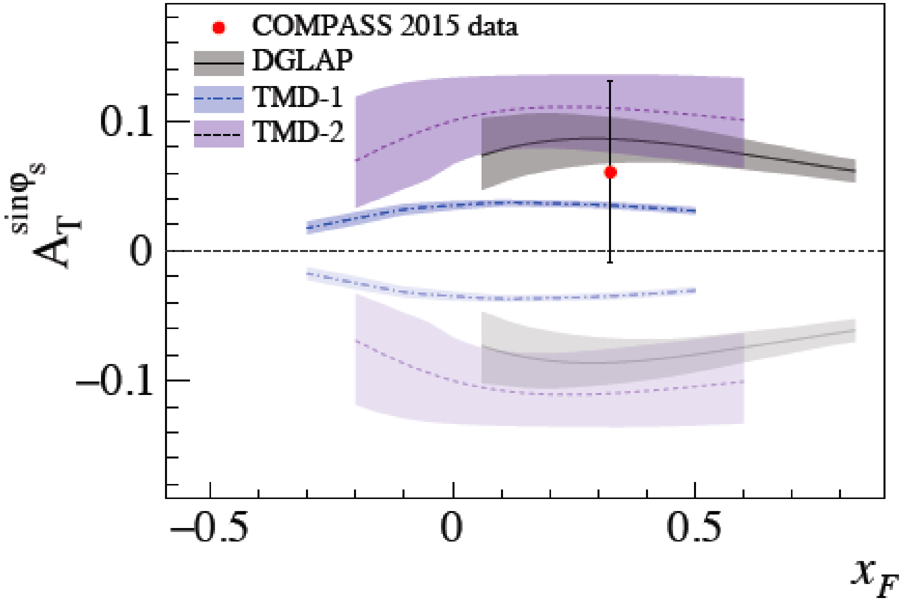
Total number of HM DY (4.3 GeV/c^2 < $M_{\mu\mu}$ < 8.5 GeV/ c^2) (NH_3) is **~35.000**

COMPASS Drell-Yan Run 2015 results V

Results on TSA & Sivers sign change



Mean TSAs. Systematic uncertainties are shown as error bands next to the vertical axis.



The measured mean Sivers asymmetry and the theoretical predictions for different Q^2 evolution schemes from Anselmino (DGLAP), Echevarria (TMD1) and Sun (TMD2). The dark-shaded (light-shaded) predictions are evaluated with (without) the sign-change hypothesis.

Polarised Drell-Yan data taking will be continued in 2018 with the goal to reduce an overall statistical error by a factor of 2

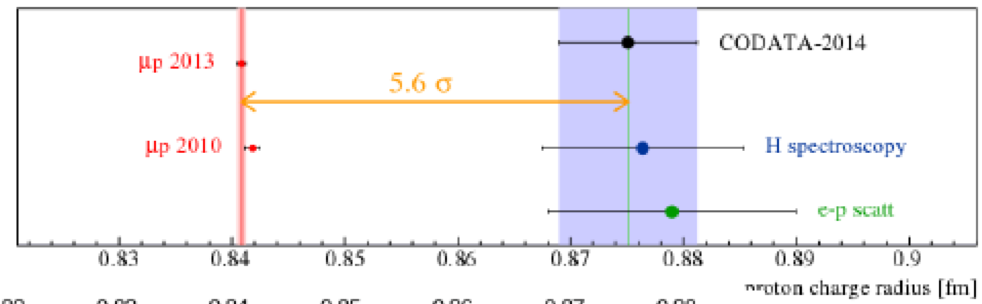
Existing muon beam:
Proton radius measurement in elastic mu-p scattering

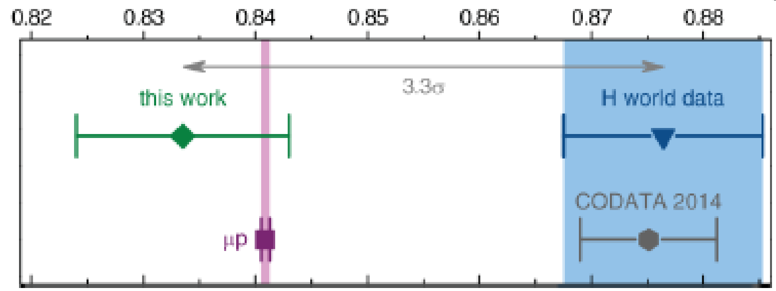
Proton radius puzzle since 2010
(Pohl et al, Nature 466, 213)

Laser spectroscopy of muonic hydrogen data are rather in agreement now with electronic hydrogen spectroscopy data (new determination of the Rydberg constant can be used to reinterpret all electronic hydrogen data) and e-p scattering data.

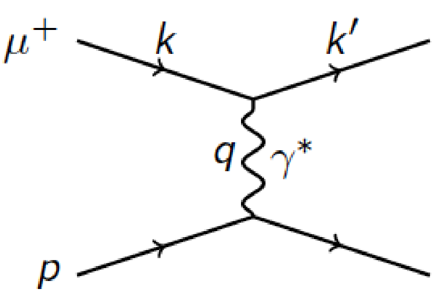
New experiment on μ-p scattering is a missing peace in proton radius puzzle

from: Krauth et.al. Arxiv:1706.00696





Science 358, 79 (October 2017)



$$Q^2 = -q^2$$

- elastic scattering of muons off a proton target
- measure Q^2 spectrum over wide range: 10^{-4} to 10^0 GeV^2/c^2
  - extract radius from its shape

challange: identify elastic reactions

- muon scattering angle between 100 μrad and 10 mrad
- recoil proton energy between 100 keV and 500 MeV

both information are required