COMPASS and AMBER experiments at CERN

Partons and QCD group

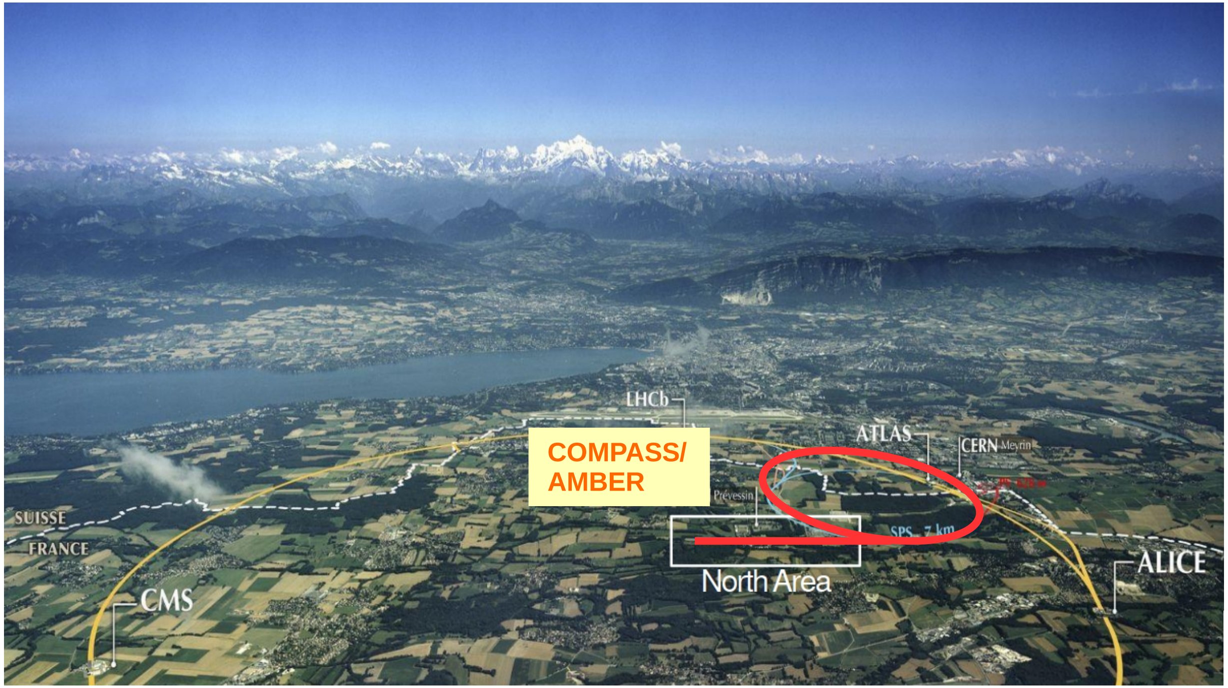
Apparatus for Meson and Baryon Experimental Research

C. Quintans, M. Stolarski, P. Faccioli, C. Pires
R. Silva, C. Corte-Real, G. Almeida

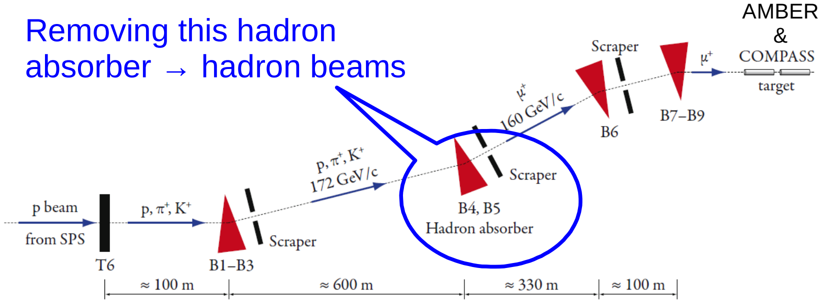
9 July 2022, Jornadas LIP 2022

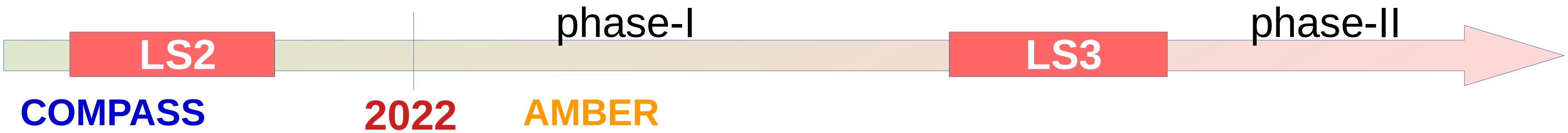
LABORATÓRIO DE INSTRUMENTAÇÃO E FÍSICA EXPERIMENTAL DE PARTÍCULAS
FCT Fundação para a Ciência e a Tecnologia

COMPASS & AMBER: at the North Area of the CERN-SPS



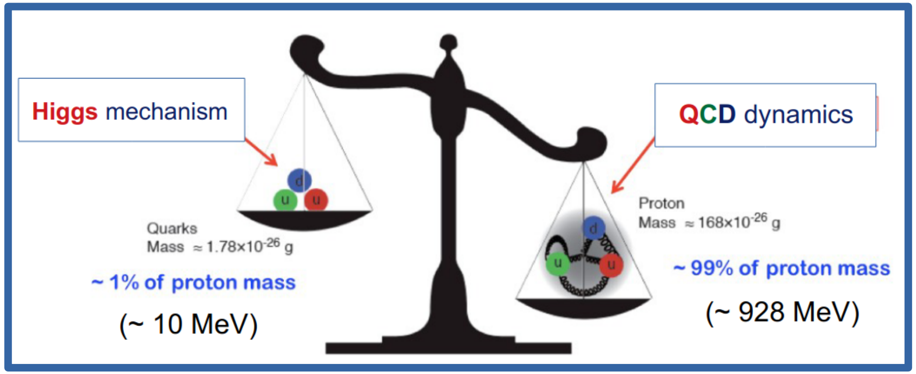
M2 beamline:
The same beamline can provide muon and hadron beams



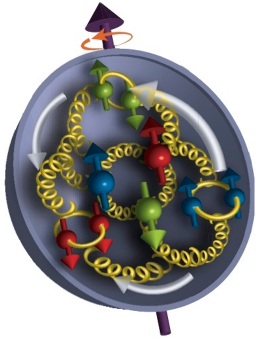


QCD: still a lot of questions to answer

How hadrons acquire mass?



Where is the spin of the proton coming from?

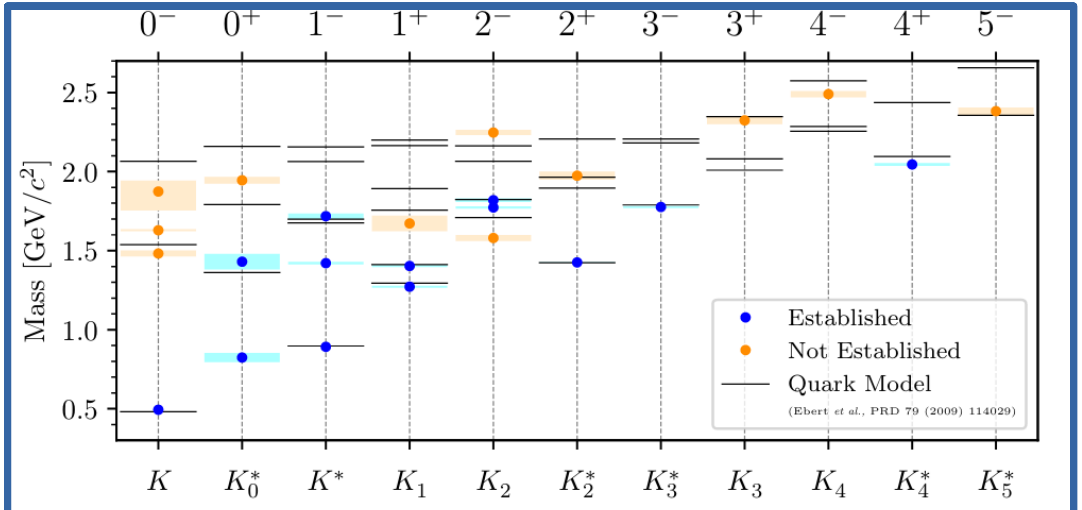


$$\textbf{Nucleon spin: } \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_Z$$

quarks spin

gluons spin

orbital ang. mom.



Meson spectroscopy: strange sector

Exploring the particles zoo

Hadron structure

Parton Distribution Function
PDF

Probability to find a parton with given
fraction of longitudinal momentum (x)
In the parent hadron

Transverse momentum dependent
TMD PDF

Dependence on (x,kT)

Fragmentation Functions
FF

Probability that a given parton hadronizes
To a hadron type with given fraction of energy z

Generalized Parton distributions
GPD

Spatial distribution. Dependence on x and on
impact parameter (x,bT)

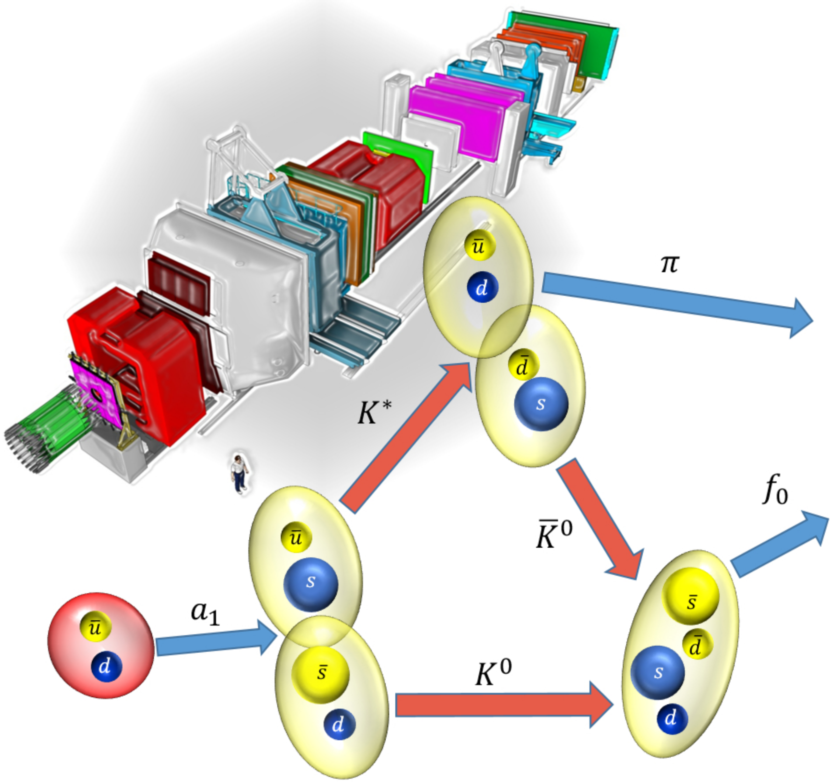
Form factors

At very low momentum transfer,
provide a link to hadron charge radii

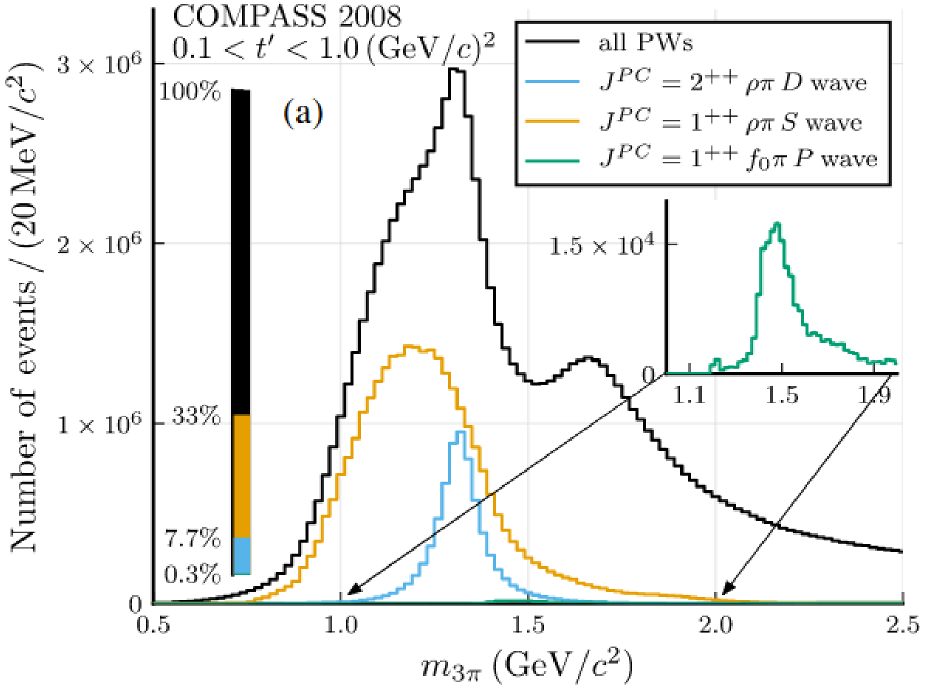
Tetraquark? No… observation of a triangle singularity

$\pi^- + p \rightarrow \pi^- \pi^- \pi^+ + p$

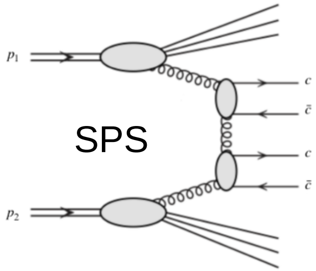
COMPASS, PRL 127, 082501 (2021)



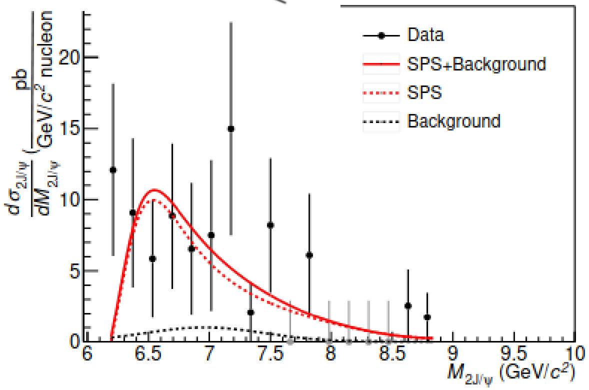
(by Bernhard Ketzer / Uni Bonn)



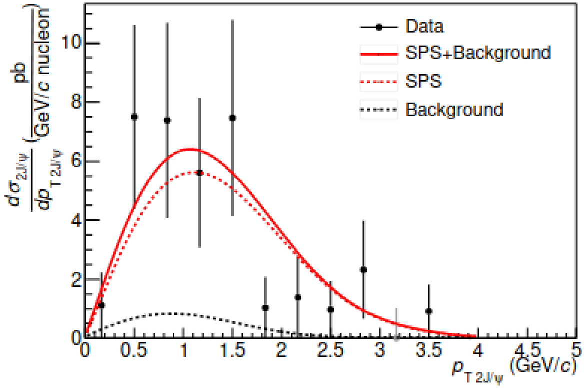
Double J/psi production at COMPASS



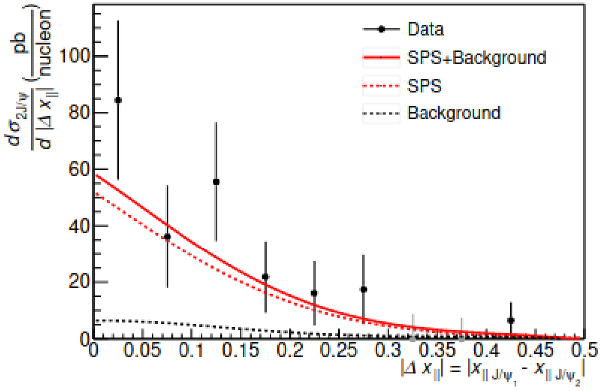
COMPASS, hep-ex 2204.01817



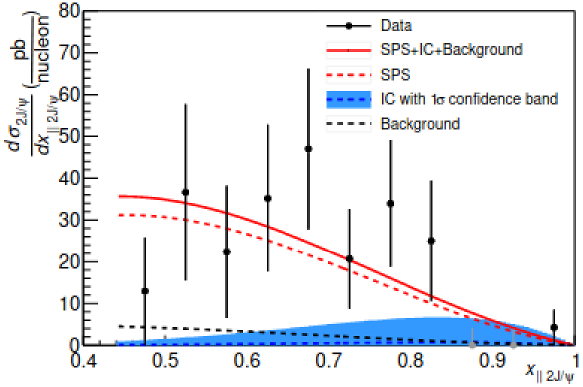
(a)



(b)



(c)



(d)

Single-Parton Scattering is enough to explain COMPASS data

Different from LHC, where DPS is very important

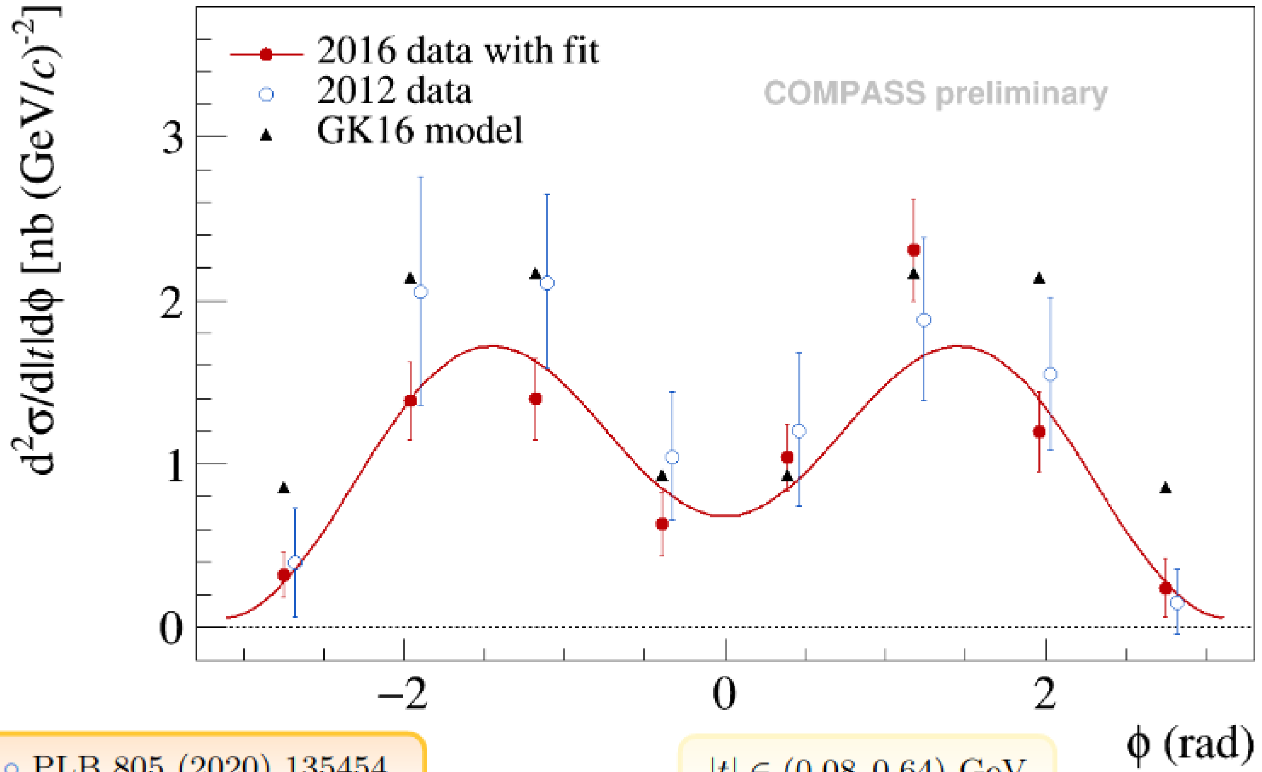
Data does not support previous explanations where intrinsic charm was dominant.

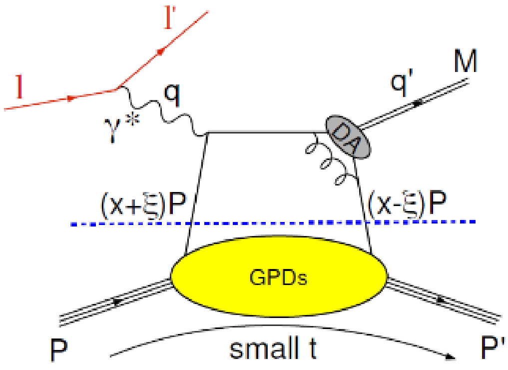
Exotic tetraquark states not observed at COMPASS(c.f. LHCb)

Exclusive π⁰ cross section: an access to GPDs $\tilde{H}$ & $\tilde{E}$

@ ICHEP 2022

$$\frac{d^2\sigma_{\gamma^* p}}{dt d\phi} = \frac{1}{2\pi}\left[\frac{d\sigma_T}{dt} + \epsilon\frac{d\sigma_L}{dt} + \epsilon\cos(2\phi)\frac{d\sigma_{TT}}{dt} + \sqrt{\epsilon(1+\epsilon)}\cos\phi\frac{d\sigma_{LT}}{dt}\right]$$





Hard Exclusive (pseudoscalar) Meson Production

○ PLB 805 (2020) 135454

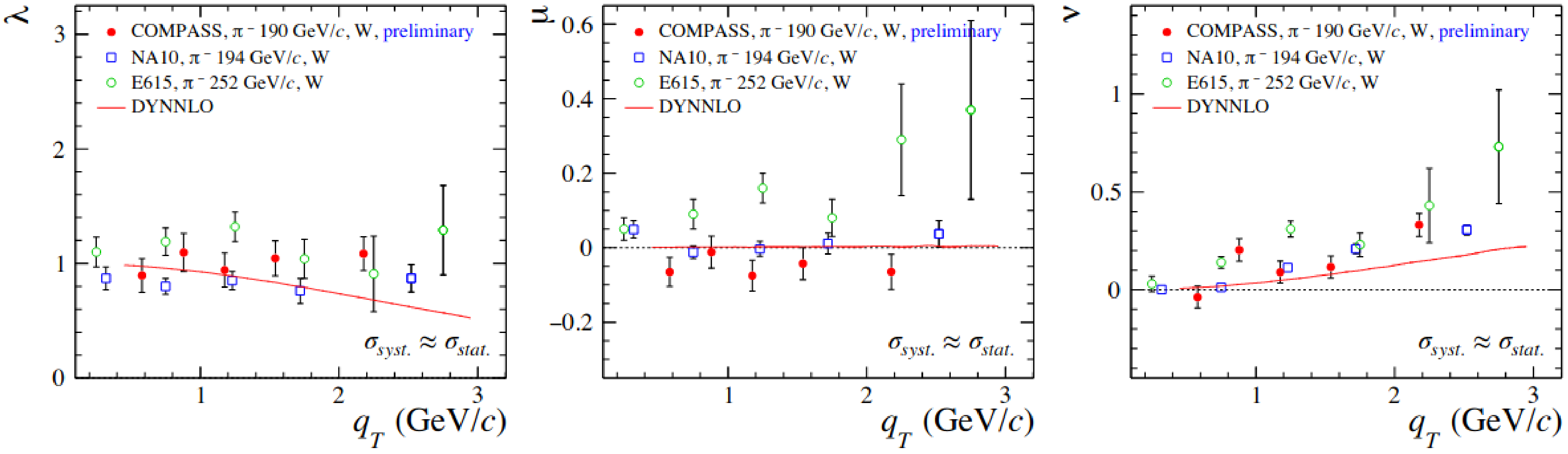
$|t| \in (0.08, 0.64)$ GeV

Goloskokov&Kroll model EPJ A47 (2011) 112

Unpolarized Drell-Yan cross section: access to Boer-Mulders TMD PDF

@ DIS 2021

$$\frac{d\sigma}{d\Omega} \propto \frac{3}{4\pi}\frac{1}{\lambda+3}\left[1+\lambda\cos^2\theta_{CS}+\mu\sin 2\theta_{CS}\cos\varphi_{CS}+\frac{\nu}{2}\sin^2\theta_{CS}\cos 2\varphi_{CS}\right]$$

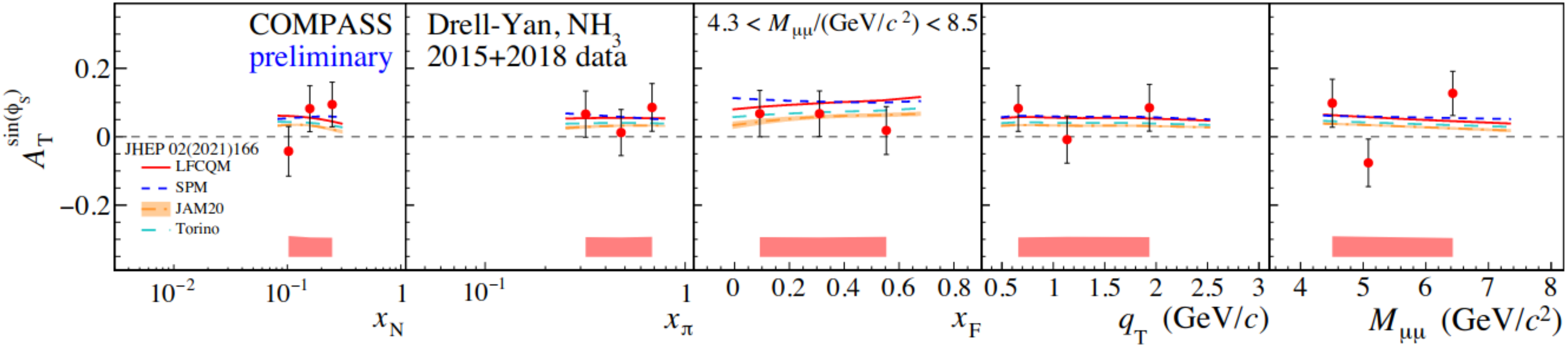


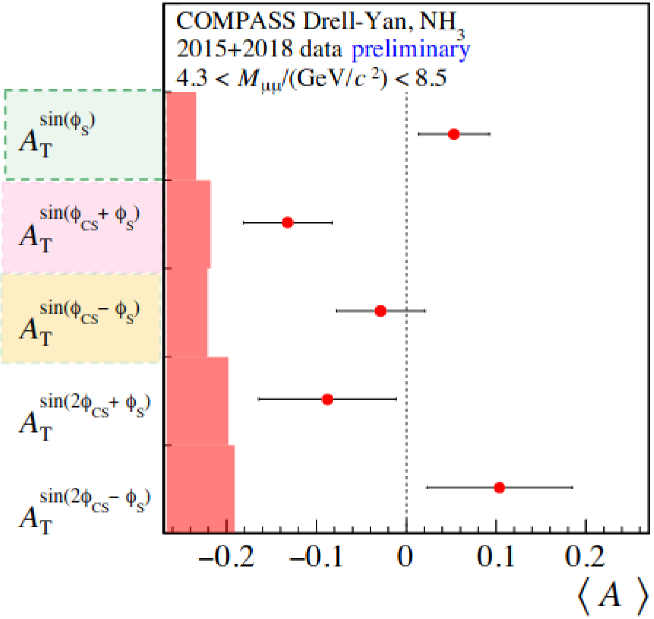
Compatibility with past experiments.
An indication of non-zero Boer-Mulders effect.

Polarized Drell-Yan: access to TMD PDFs

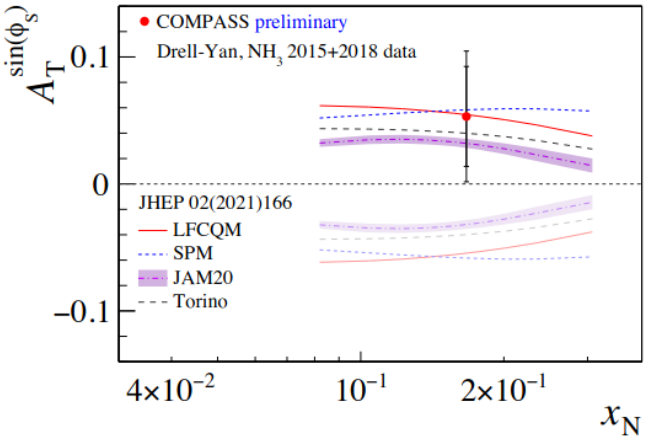
@ CPHI 2022

Curves from JHEP 02, 166 (2021)





$$A_T^{\sin\varphi_S} \propto f_{1,\pi}^{q} \otimes f_{1T,p}^{\perp q}$$



Sivers TMD prediction:

$$f_{1T,p}^{\perp q}|_{SIDIS} = -f_{1T,p}^{\perp q}|_{DY}$$

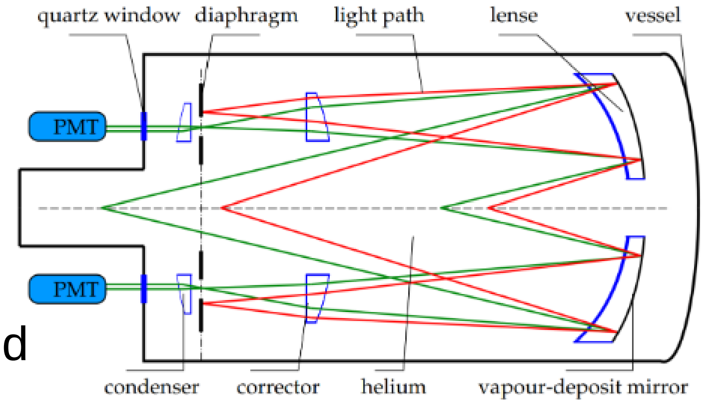
sign change

no sign change

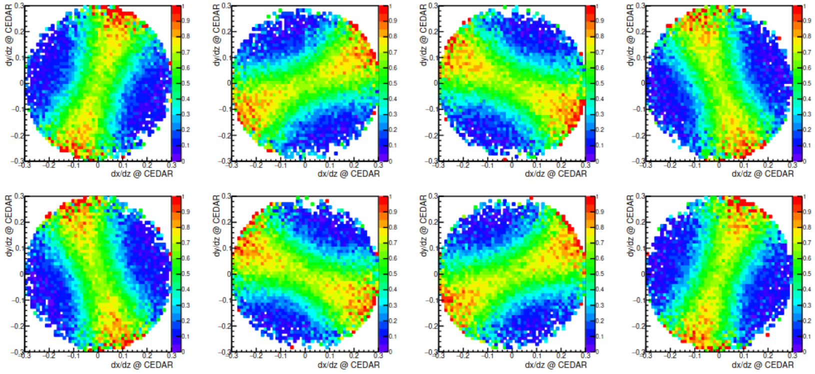
CEDARs – beam particle identification

@ ICHEP 2022

CEDAR: Cherenkov Differential Counter with Achromatic Ring Focus

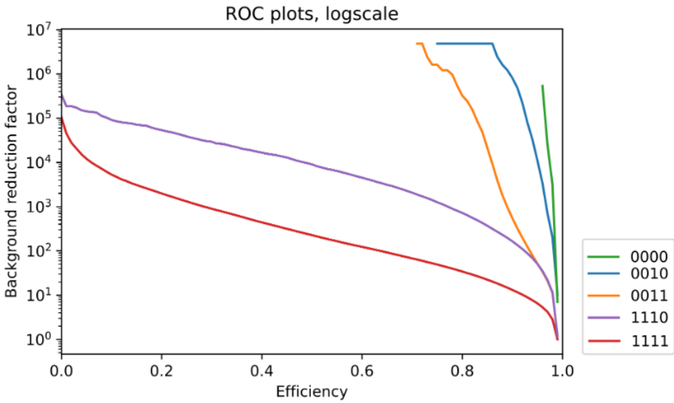


PMTs response for kaons (MC)



Hadron PID (π, K, p) is essential for Drell-Yan and spectroscopy at AMBER.

In DY @ COMPASS: beam intensity of 10^8/sec makes PID very challenging.



Developing a method of artificial neural networks for CEDAR PID: NN as a direct binary classifier is showing promissing results.

Ideal MC

MC reproducing COMPASS problems

EHM at AMBER

The Emergence of Hadron Mass is the leitmotiv for the various proposed measurements.
The experiment was approved in December 2020

Phase-I:

Proton charge radius, via muon-proton elastic scattering

Pion PDFs, via de $\pi^{\pm}$-induced Drell-Yan

Antiproton production cross section, an input to Dark Matter searches

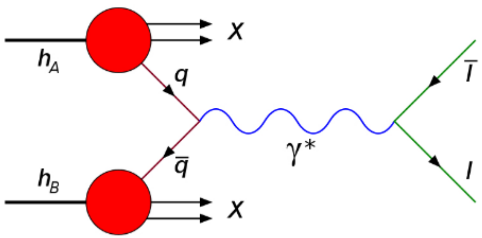
AMBER
Apparatus for Meson and Baryon Experimental Research

Phase-II:

- **Kaon structure**, via $K^{\pm}$-induced Drell-Yan
- **Pion and Kaon radii**, via meson-electron elastic scattering
- **Kaon polarizability**, via Primakoff reaction
- Strange-sector meson **spectroscopy**

Phase-I: Drell-Yan, an access to pion structure

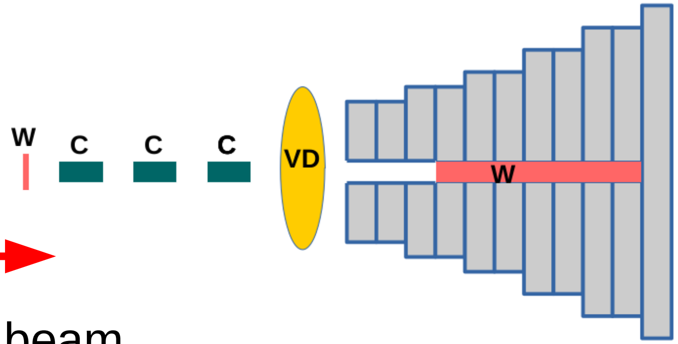
Apparatus for Meson and Baryon Experimental Research



$$\frac{\Sigma_{sea}}{\Sigma_{valence}} = \frac{4\sigma^{\pi^+C} - \sigma^{\pi^-C}}{-\sigma^{\pi^+C} + \sigma^{\pi^-C}}$$

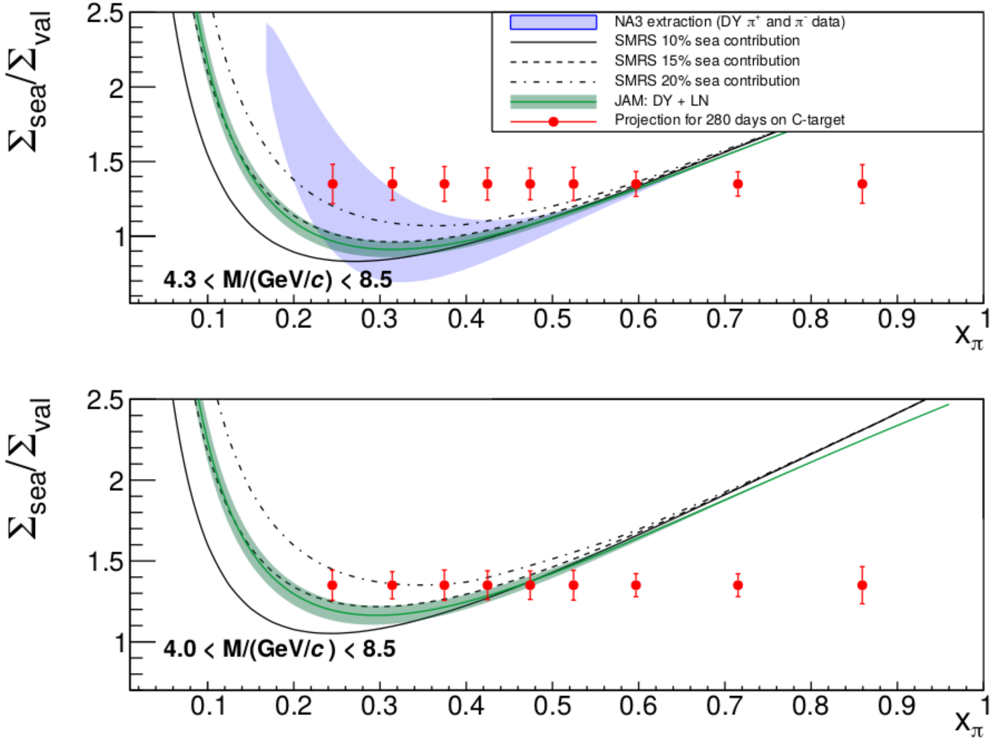
LO: only sea-val and val-sea terms

LO: only val-val terms



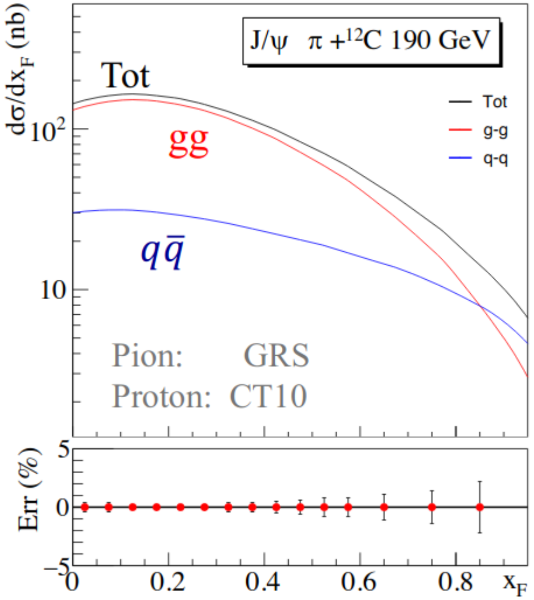
$\pi^{\pm}$ beam

Hadron absorber

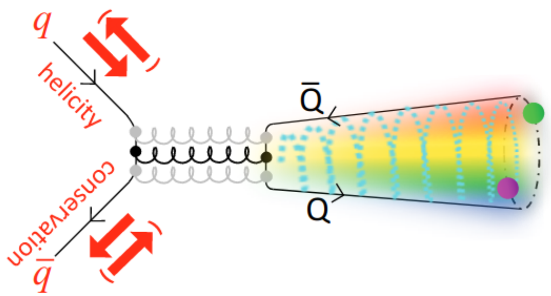


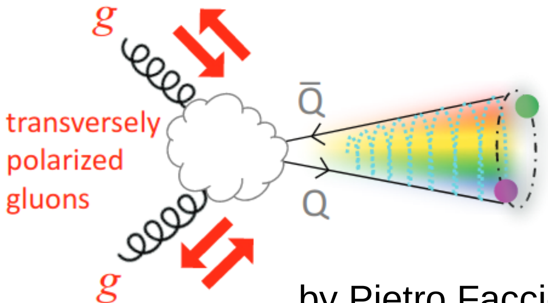
See the poster by
R. Silva and G. Almeida

Phase-I: J/Ψ & Gluon content in the pion

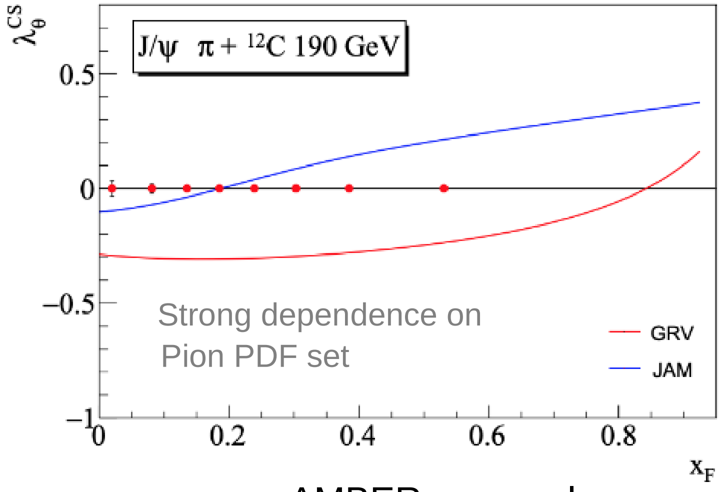


- Large statistics on J/ψ production at dimuon channel
- Inclusive: due to the hadron absorber, we cannot distinguish prompt production from the rest
- Expected significant feed-down: ψ(2S), χ_{c1}, χ_{c2}
- In the low-pT regime
- Expected to have dominant contribution from $2 \rightarrow 1$ processes
- Use J/ψ polarization to distinguish production mechanism:



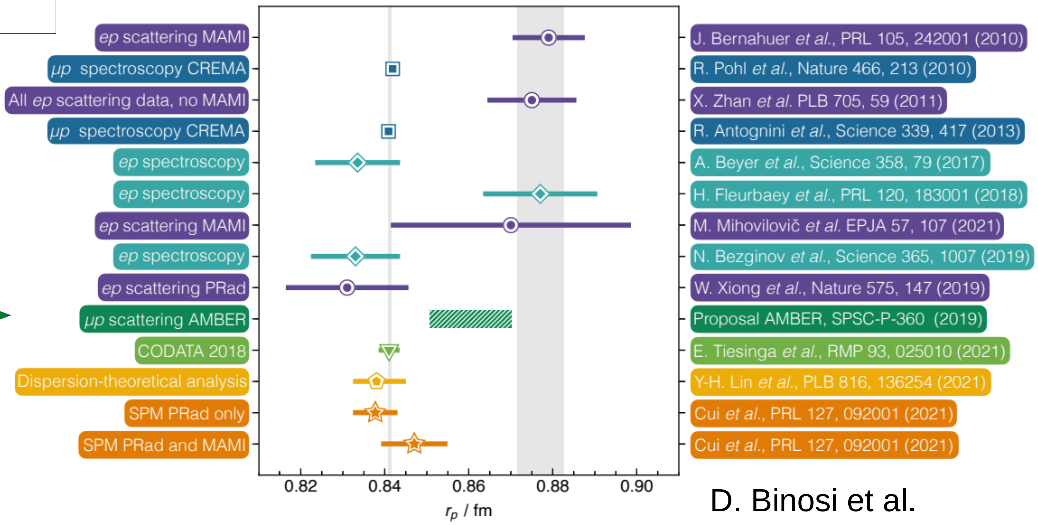


by Pietro Faccioli

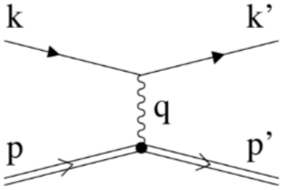


AMBER proposal

Phase-I: The proton charge radius



D. Binosi et al.



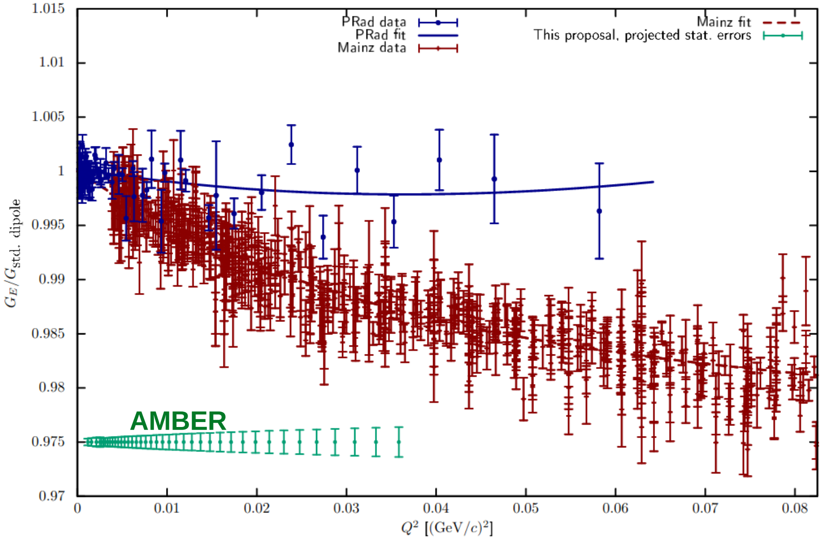
G_E, G_M

$$\langle r_E^2 \rangle = -6\hbar^2 \left. \frac{dG_E(Q^2)}{dQ^2} \right|_{Q^2 \to 0}$$

Two types of measurements, leading to discrepant results:

- **lepton-proton scattering**
- **hydrogen spectroscopy**

At AMBER: access via the electromagnetic form factors, measuring the **elastic muon-proton scattering**

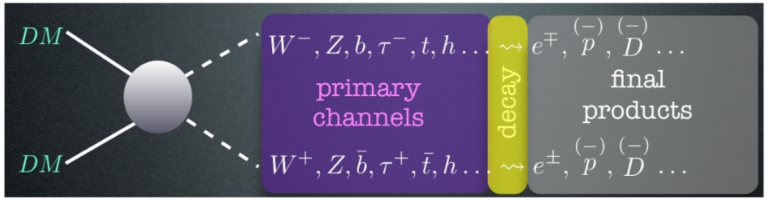


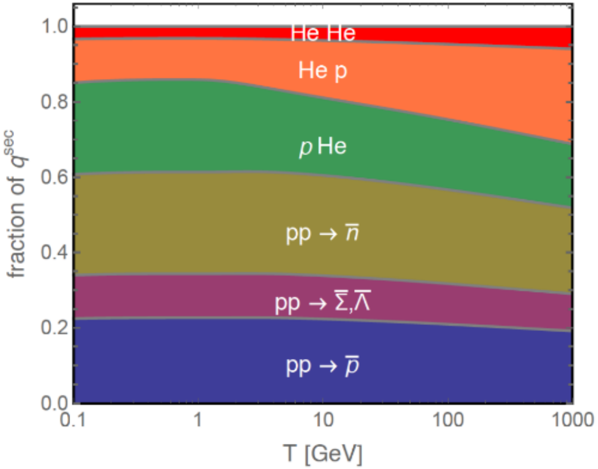
Phase-I: Antiproton production cross section

Dark Matter searches:
Search for products of DM annihilation or decay, as an excess in the spectra of rare cosmic ray components (like antiprotons)

Need good accuracy in their predicted/measured natural flux

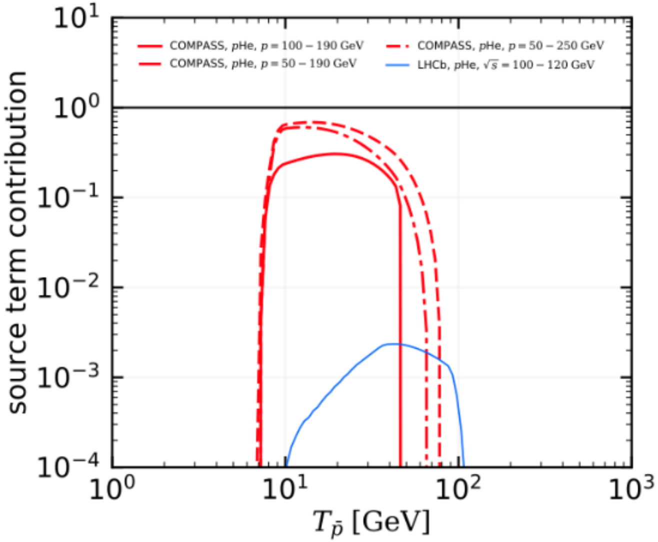
WIMP hypothesis

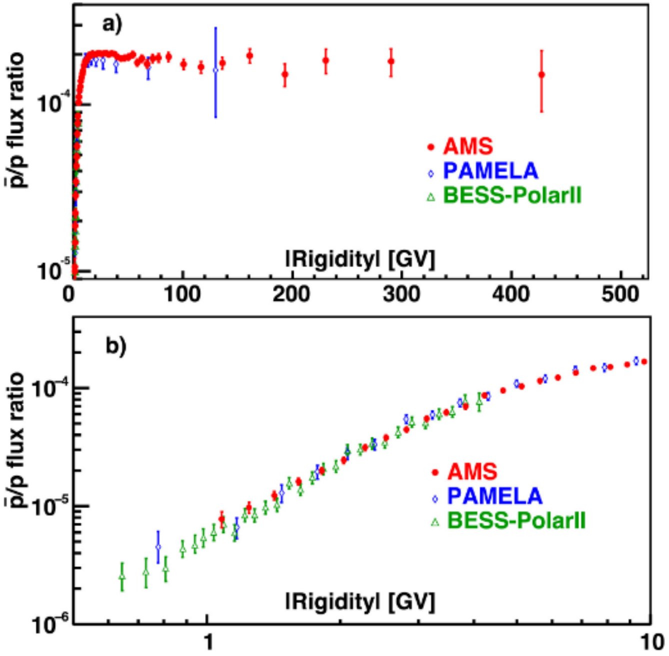




Martin W. Winkler (Stockholm University)

M. Korsmeier





M.Aguilar et al. (AMS02), Phys. Rep. 894, 1

Phase-II: Kaon structure

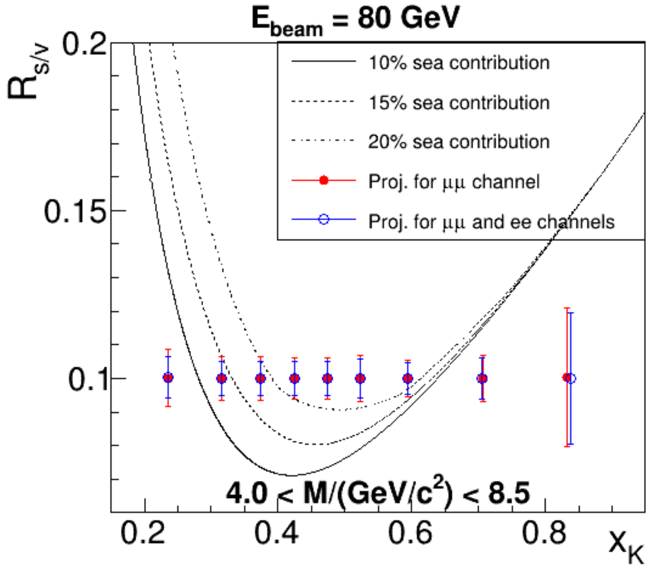
Kaon structure: a window to the region of interference between the Higgs mechanism and the EHM mechanism

Z-F. Cui, *et al.* EPJC80(2020)1064, H-W. Lin *et al.*, PRD103(2021)014516

The only available experimental data:

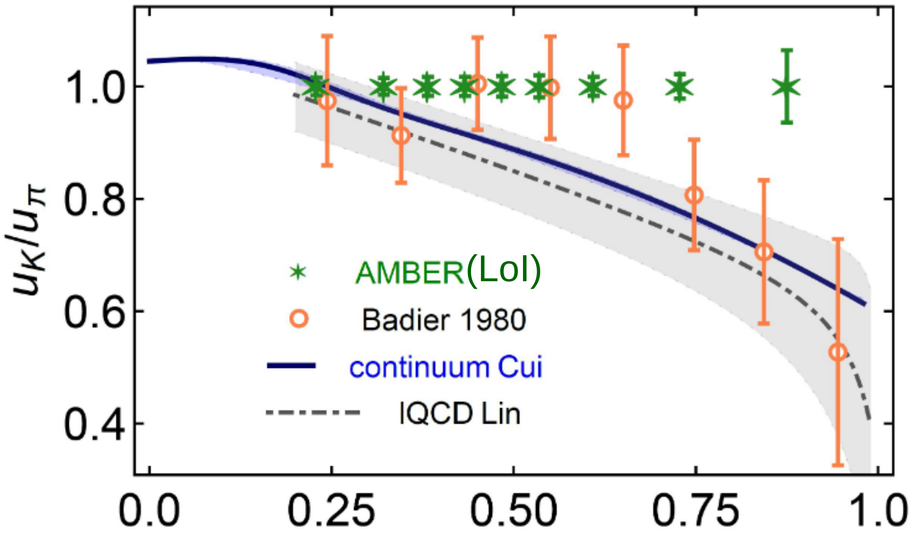
NA3 → 200 GeV K^- beam on 6 cm Pt target

700 kaon-induced Drell-Yan events



Kaon sea-valence separation using both charges kaon beams:

$$R_{s/v} = \frac{\sigma^{K^+C}}{\sigma^{K^-C} - \sigma^{K^+C}} \propto u_v^K u_v^p$$



* AMBER (LoI):
Assumed an RF-separated beam of 2 x 10⁷ kaons/second.

Summary

COMPASS completes 20 years of data taking, a long history of studies of hadron structure and Spectroscopy

The physics scope is now further enlarged by the QCD-related measurements proposed at AMBER

Smooth transition from COMPASS to AMBER experiments, during 2022

The LIP group has both technical (DCS) and physics analysis competences/responsabilities, in both experiments

The group welcomes both newcoming students and senior colleagues who would like to contribute.

Good time to join!