Introduction to Round Table Discussion

02 April 2020

With contribution from many colleagues: Craig Roberts, Oleg Denisov, Wolf-Dieter Novak, Boris Grube, Alexey Guskov, Vincent Andrieux, Márcia Quaresma, Wen-Chen Chang, Stephane Platchkov, ...

On the way for a COMPASS++/AMBER Phase-II Proposal

- pion valence PDF
- Sea-valence separation in the pion
- kaon valence PDF
- Ratio of Kaon to pion valence: u_{K}/u_{π}
- Sea-valence separation in the kaon
- gluons in pion (phase-I)
- gluons in kaon (phase-II)
- Kaon spectroscopy

From meson structure to the EHM problem

Connection between the knowledge of meson structure and the more general problem of emergence of hadron mass in QCD: talks by Craig Roberts and Cédric Lorcé.

In the non-perturbative regime, gluons acquire a running mass – due to dynamic chiral symmetry breaking. The so-called **"trace anomaly"** for the gluon term in the **QCD energy-momentum tensor** leads to expectation value $\propto M^2$ for the proton, and zero for the pion (relation to spin).

Mass, spin and pressure, all encoded in the QCD Energy-Momentum Tensor.

The Higgs mechanism becomes relevant for hadron mass generation at the transition boundary of strange quark mass – kaon structure.

Hadron Structure – Theory approaches

What theorist colleagues tell us – several **different approaches**:

- Dyson-Schwinger Equation based

  Minghui Ding, Fei Gao, Shu-Sheng Xu

- Light-front wave function

  Cédric Mezrag, José Rodriguez-Quintero, Khépani Raya-Montaño, Chao Shi, Xingbo Zhao

- Nambu-Jona-Lasinio model

  Aurore Courtoy, Xingbo Zhao

- Covariant Spectator Theory

  Elmar Biernat

- Continuum functional approach

  Jorge Segovia

- Lattice QCD

  Huey-Wen Lin, David Richards

- Global fits to data: parametrizations based on models, or from NN

Lei Chang compared several of these approaches.

Wen-Chen Chang compared different Global Fit approaches to the pion PDFs.

Hadron Structure – theory approaches

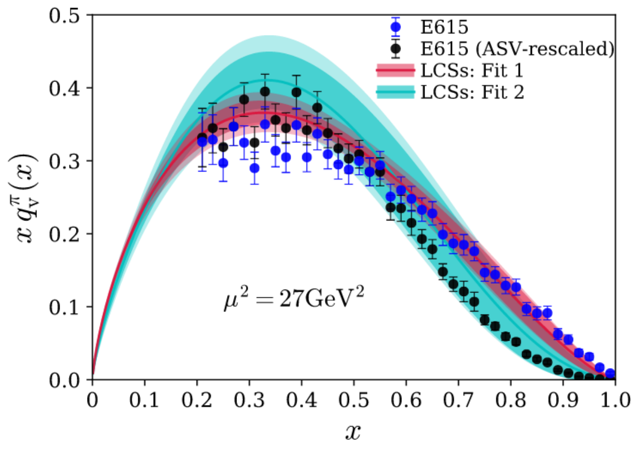
These can extract/calculate all sorts of objects related to hadron structure:

- Distribution amplitudes
- Generalized parton Distributions
- Light front wave functions
- Parton Distribution Functions
- Transverse-momentum-dependent PDFs
- Form factors
- Fragmentation functions

Pion valence PDF

And what data is used to compare with: **pion-induced DY**, **leading-neutron DIS**, **direct photon** production.

- E615, NA10, NA3 – DY
- WA70, NA24 – direct photons
- ZEUS, H1 – LN-DIS



from David Richards talk

From Craig Roberts: when comparing to data, one must always **include soft gluon resummation**, or the large-x_π region cannot be correctly described.

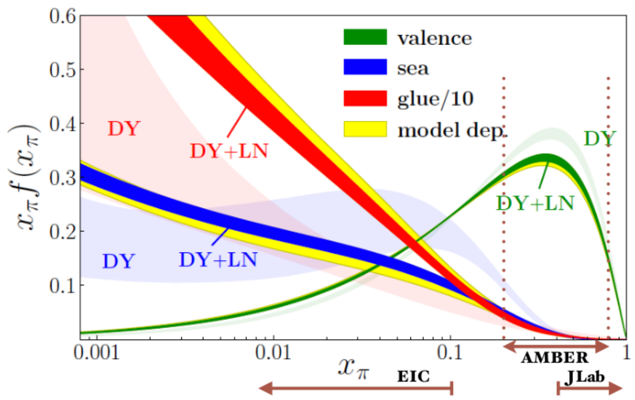
New data to come soon: **pion-induced DY COMPASS data**. 190 GeV/c π^- beam, NH_3 and W targets (60-80K DY events in the range 4.3 - 8.5 GeV/c^2 for each target)

Pion valence PDF

A word of caution: **what is valence, what is sea?**

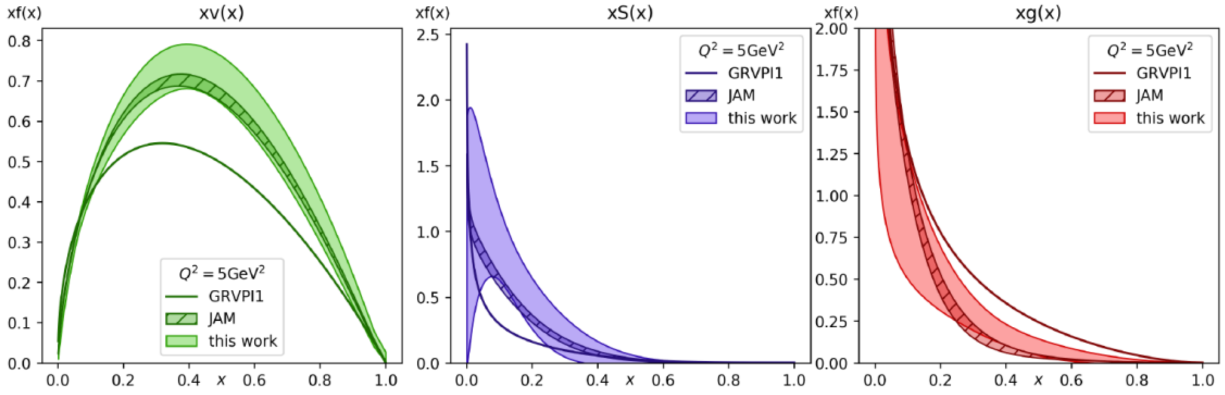
Craig Roberts: Conventions should be stated, not assumed.

Phys. Rev. Lett. 121 (2018) 152001



Márcia Quaresma talk, illustrating pion PDFs from JAM group

Here $V = u_v = \bar{d}_v$,
$S = u_s = d_s = \bar{u}_s = \bar{d}_s$



Wen-Chen Chang talk, xFitter (arXiv: 2002.02902) compared to JAM

Here $V = u_v + \bar{d}_v$,
$S = 2u_s + 2d_s + s + \bar{s} = 6u_s$

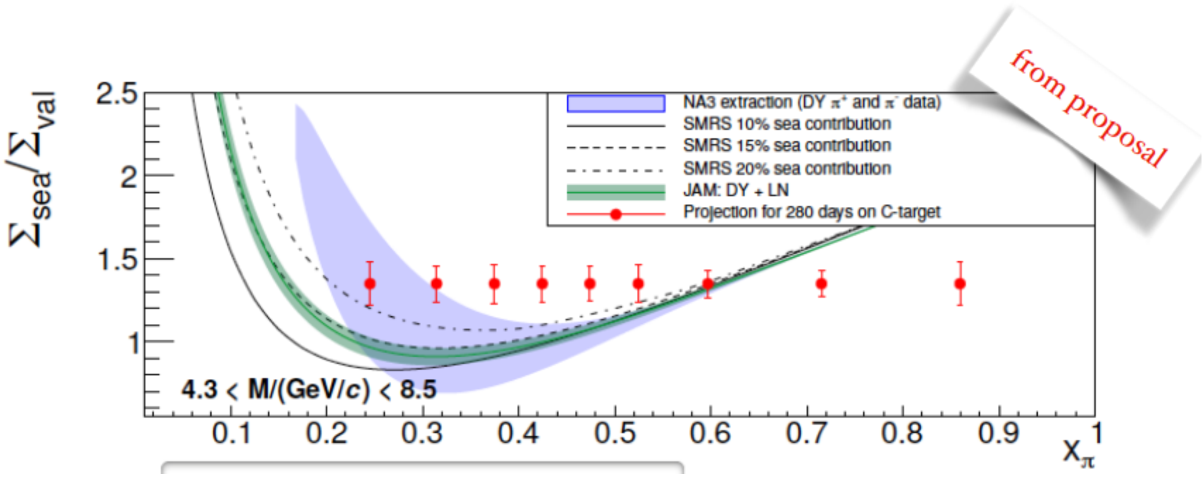
Sea-valence separation in the pion

COMPASS++/AMBER program: use **pion beams of both charges** to do sea - valence separation.

Observable: a ratio of cross-section differences. It is not the ratio of sea to valence PDFs in the pion!

Pion PDFs - sea/valence

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

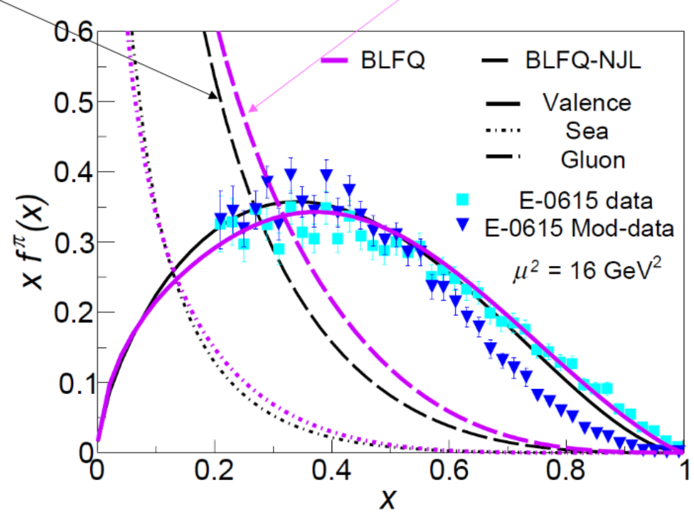


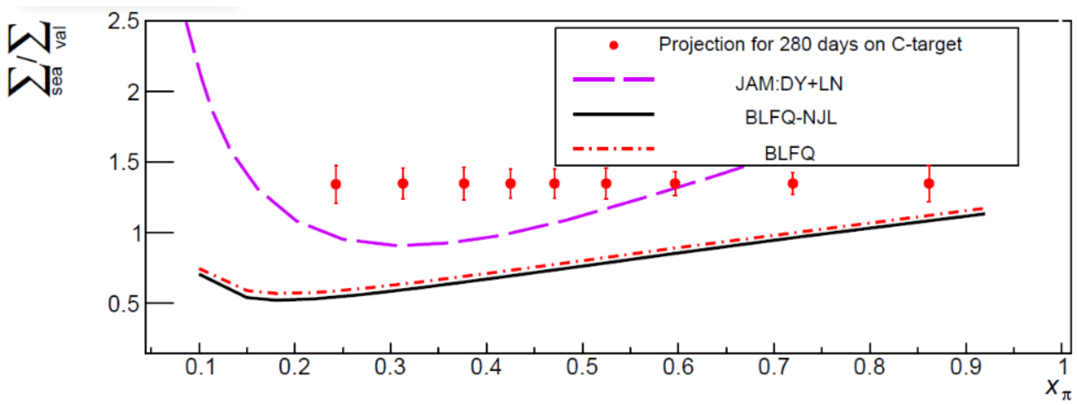
Both pion and nucleon contributions entering. In this observable, the numerator contains all combinations but valence-quark valence-quark terms, the denominator contains only valence-quark valence-quark terms.

Sea-valence separation in the pion

Shown in Xingbo Zhao talk on tuesday

$|\pi\rangle = |q\bar{q}\rangle + \cdots \quad \Rightarrow \quad |\pi\rangle = a|q\bar{q}\rangle + b|q\bar{q}g\rangle + \cdots$

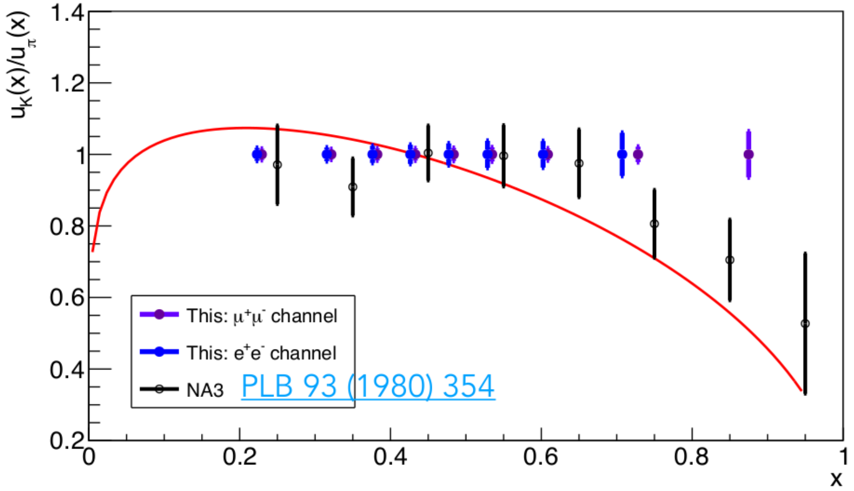




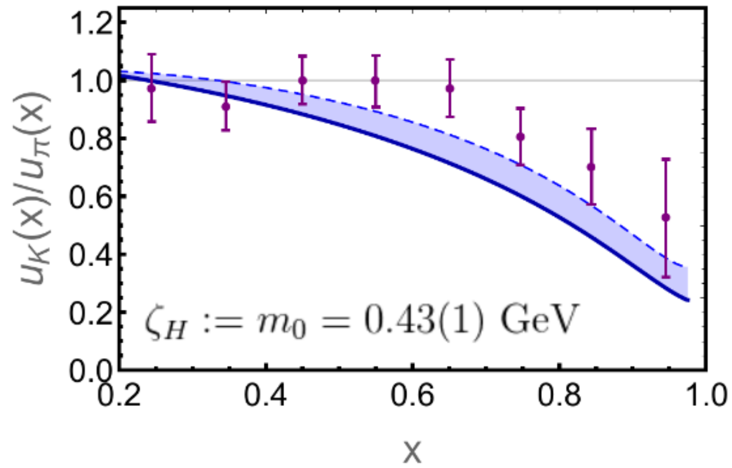
From Wen-Chen Chang: but how large is the systematic effect due to basis truncation on the predictions of pion PDFs?

Kaon to pion ratio

COMPASS++/AMBER statistical precision
2%, with time sharing 1:1 for K^-:K^-



Khépani Raya-Montaño talk,
exploratory DSE calculation



- **Momentum fractions:**

ζ	$\langle x \rangle_u$	$\langle x \rangle_s$	$\langle x \rangle_G$	$\langle x \rangle_S$
ζ_2	0.224(5)	0.302(5)	0.378(6)	0.096(4)
ζ_5	0.191(5)	0.269(5)	0.414(5)	0.126(5)

But what should be the experimental priority:

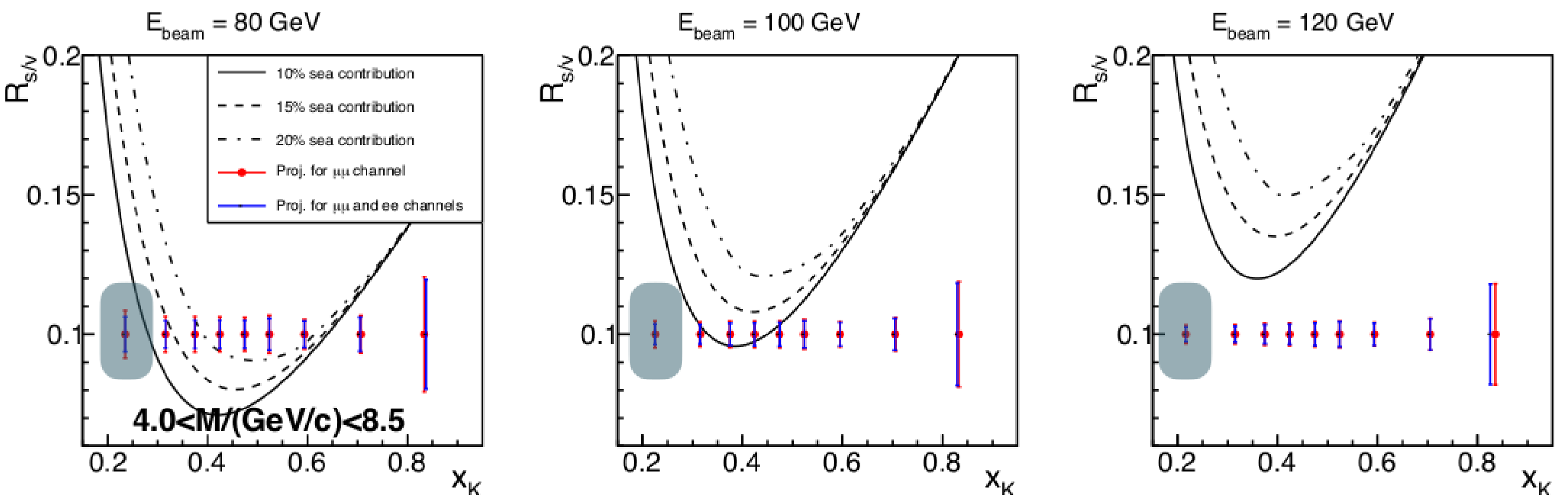
- Valence of kaon, with u_K/u_π ratio precision optimization, or
- Valence sea separation in the kaon?

Kaon sea and valence separation

Observable: a ratio of cross-sections, involving kaon and proton contributions. Again, not a ratio of kaon sea to valence PDFs!

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

Higher beam energies allows to access lower x_K values with a better precision



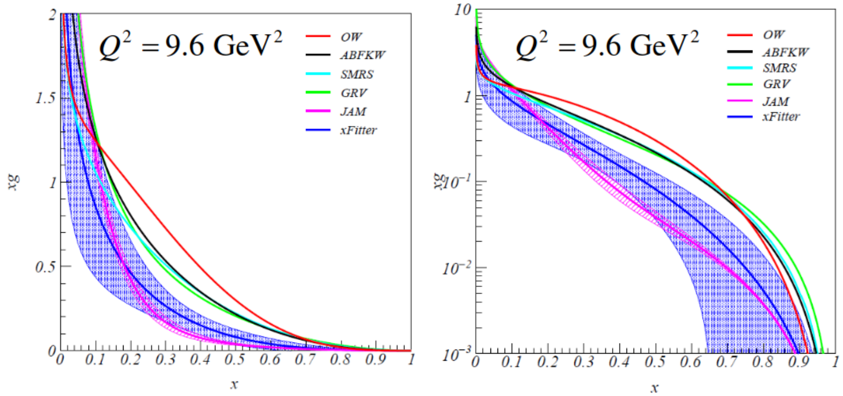
Here, the statistical precision reached is 10%, with a time sharing 1:1 for K^-:K^-

Can be optimized, changing this time sharing to 1:5 for K^-:K^-, but then reduce to 5% accuracy on u_K/u_π.

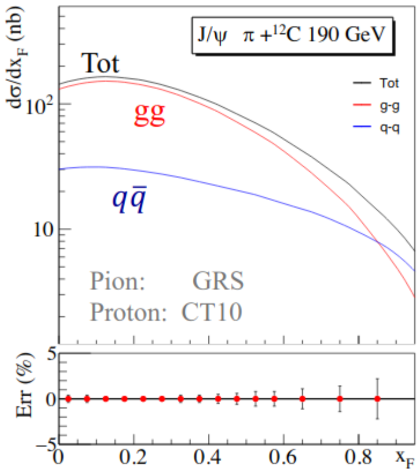
What is preferable?

Gluons in pion

Wen-Chen Chang: use J/ψ to access gluon distribution, poorly constrained.

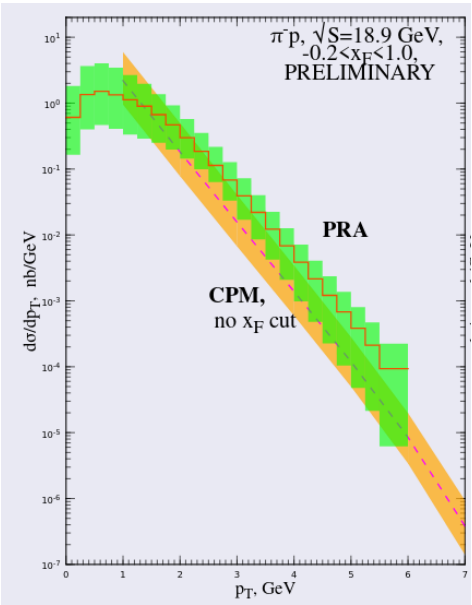


Stephane Platchkov:



Good statistical precision, but

- Model dependence – here, using ICEM model
- Use also the J/ψ polarization as relevant variable

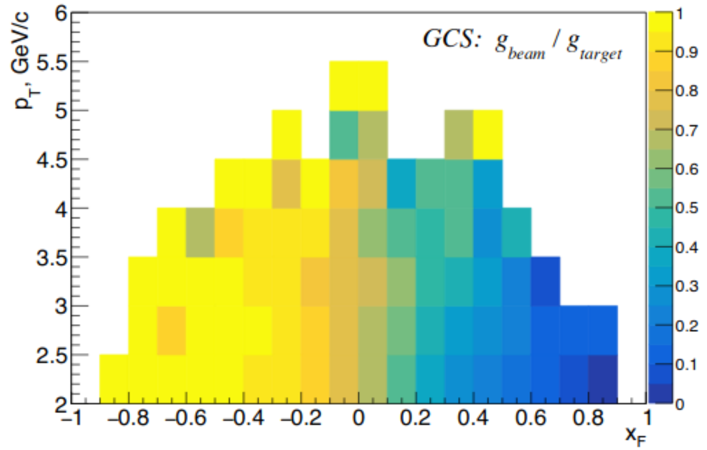


From Vladimir Saleev talk:
Using Parton Reggeization approach to describe the p_T behavior of prompt J/ψ production
(here compared to NLO CPM result by Mathias Butenschoen)
But: failing to describe NA3 data... (?)

Gluons in the kaon (and pion)

Alexey Guskov:
COMPASS++/AMBER measurement of **prompt photons** production, in **gluon Compton Scattering** induced by a K^+ beam ($\sqrt{s} = 13.7$ GeV).

- Experimentally challenging
- large background from minimum bias photons
- Does the concept work, at such low $\sqrt{s}$?



Could semi-inclusive meson-induced production of prompt photons (photon + leading hadron) be useful for understanding internal properties of pion and kaon and the origin of their mass **?**

Meson structure from diffractive meson dissociation

Mostly questions, here:

- Alexey Guskov: Can we access pion and kaon PDAs via diffractive dissociation of meson beams, if beam energies are ≤ 200 GeV ? Which observables should be used for that?
- Given the relatively low beam energies, not two jets, but 2 leading hadrons could be detected as final state. Would it work?
- Diffractive dissociation: low t' – access to **Distribution Amplitudes**. But how clear is the formalism to go from PDAs to PDFs?
- Oleg Denisov: Can the 3 different probes proposed – Drell-Yan, Charmonium, Diffractive Dissociation – provide independent input on the same physics object (the meson PDF) ?

Meson structure from Central Production?

From Alexey Guskov: Could we possibly use the central production of some final states **in meson-proton scattering** as a way to access the gluon content of meson?

B Z Kopeliovich et. al. J.Phys. G34 (2007) 335

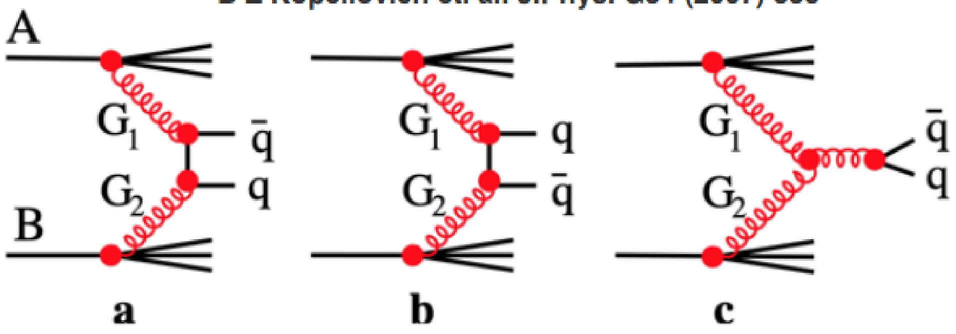


Figure 2: One gluon approximation to the central production of a $\bar{q}q$ pair.

Could we access the gluon content of mesons via central production at low energies?

Hadron structure studies using antiproton beam

Phase-II of COMPASS++/AMBER would bring the possibility of having **antiproton beam** (100 GeV) and high intensity.

As shown in Márcia Quaresma talk, the physics goal we envisage is study of **TMD PDFs of the proton**, with a transversely polarized proton target.

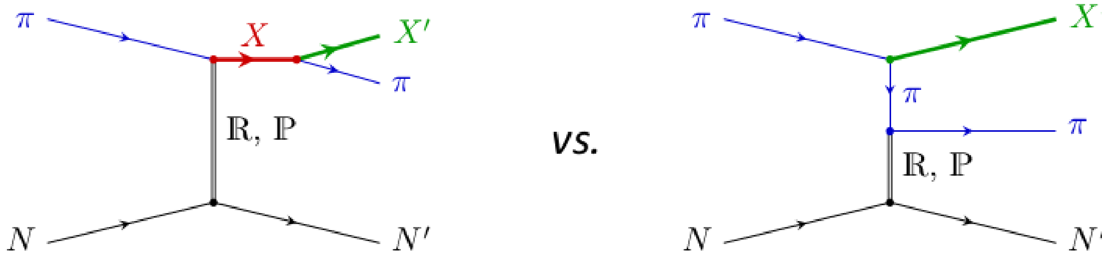
↪ Excellent, unique experimental opportunity. But the physics case here needs to be further explored and improved.

Your ideas and comments on this would be very very helpful!

Meson spectroscopy

From Boris Grube:

- Huge data sets of 10^7 to 10^8 events: analyses are limited by systematics
- Need to understand, quantify, and reduce systematic uncertainties
- The dominant systematic uncertainties are caused by assumptions in the analysis models
- Improvement of partial-wave analysis models relies heavily on theory input
  - How to correctly include knowledge about subsystem amplitudes, e.g. from $\pi\pi$ scattering?
  - How to take into account final-state interactions?
  - How to take into account non-resonant diagrams (multi-Regge exchange)? *Example:*



- *In summary:* How to construct 2 to *n* scattering amplitudes that fulfill *S*-matrix principles, i.e. analyticity, unitarity, and crossing?