Loose thoughts on possible proton-proton collisions program with SIS100

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Contents

Introduction

- PANDA difficult to realize soon.
- Do we have an alternative program for hadron community ?
- $p + p$ collisions is an option. Also reference for AA collisions.
- I (we) will talk about some options.

Open charm production, midrapidities

At high energies and midrapidities the dominant production mechanism is:

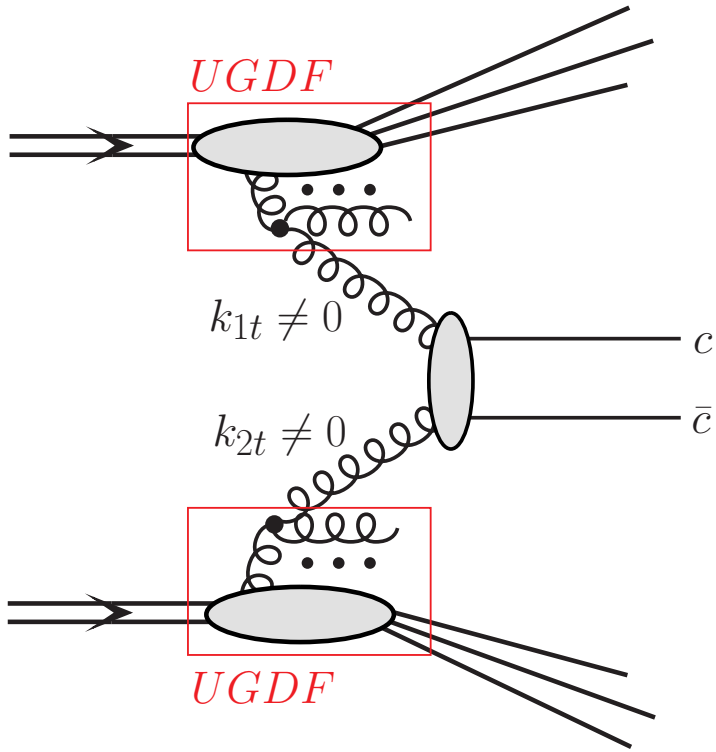


Figure: The dominant mechanism of charm production at high energies and midrapidities.

We have made with Rafal Maciula detailed studies for the LHC

Open charm production, forward directions

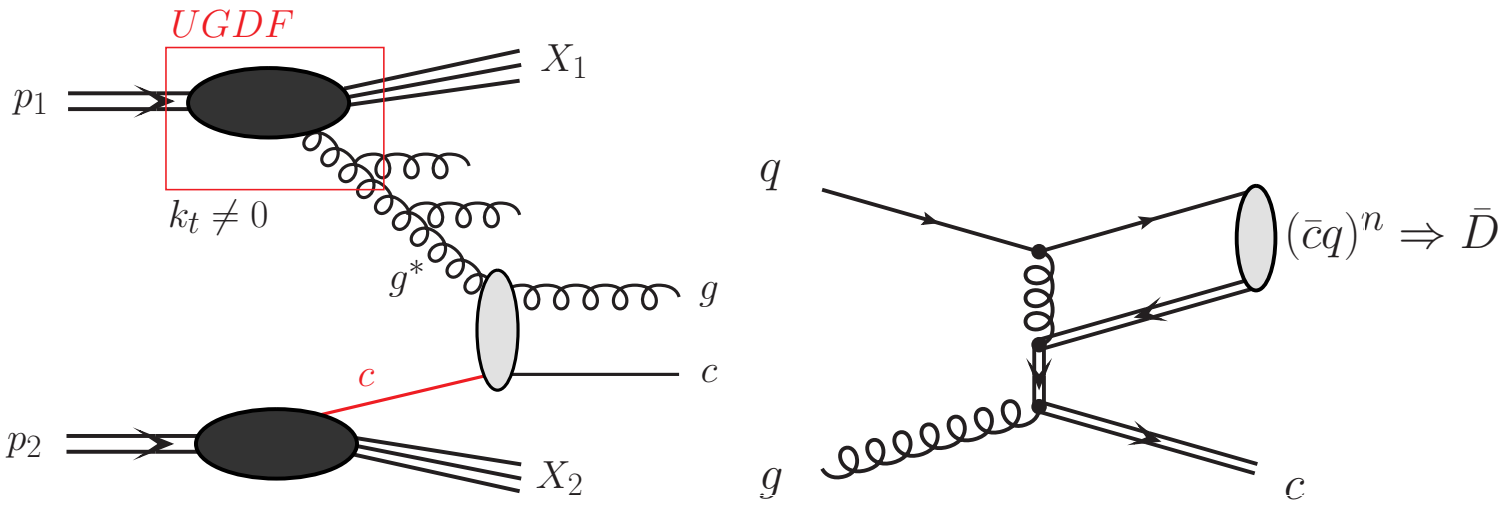


Figure: The mechanisms of charm production at high energies and forward rapidities.

There are a few models of intrinsic charm.
How big is the intrinsic charm component ?

Tentative calculation for SIS100

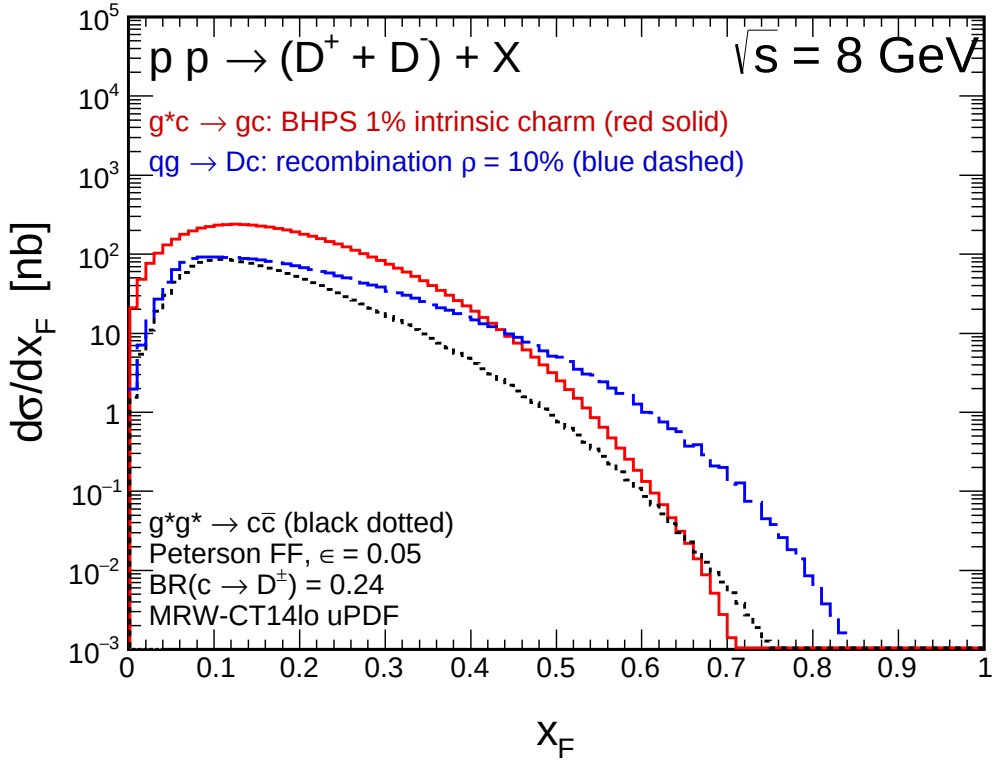


Figure: First result for $\sqrt{s} = 8$ GeV.

Rafal Maciula will talk more about the formalism.

Gluon longitudinal momentum fractions

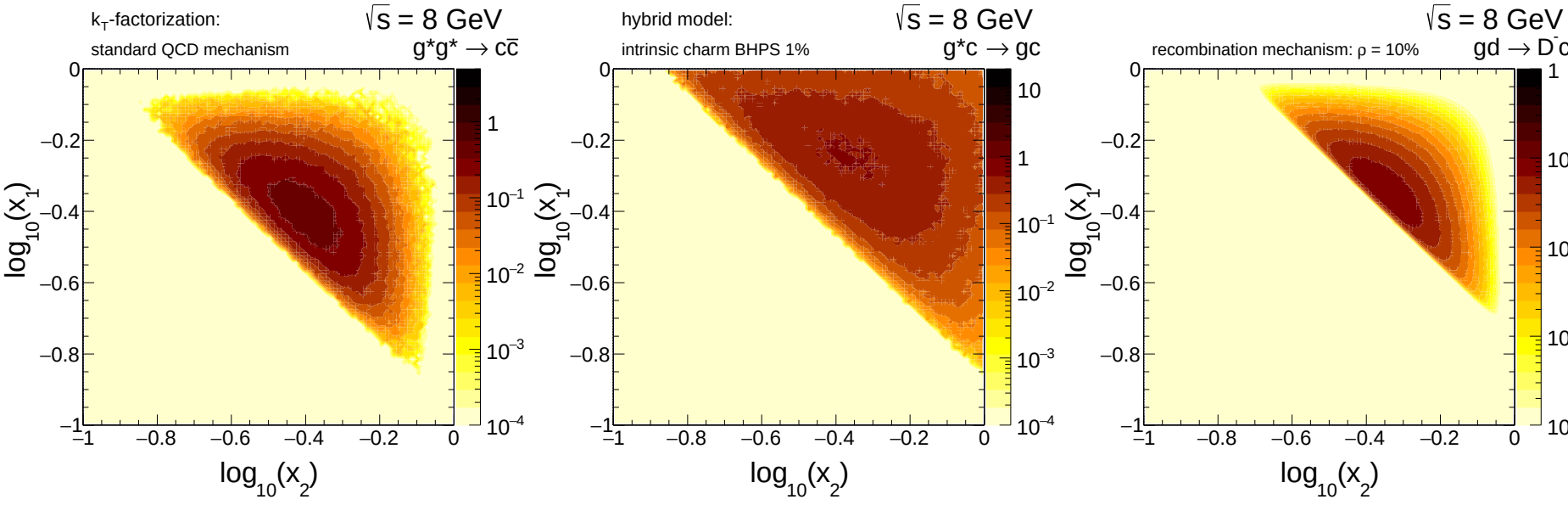


Figure: Longitudinal momentum fractions.

large x gluon distribution $\longrightarrow$ new regime.

Exclusive channels with charm mesons/baryons

So far we have considered only partonic processes which are supplemented by hadronization.
One could consider also the following exclusive hadronic reactions:

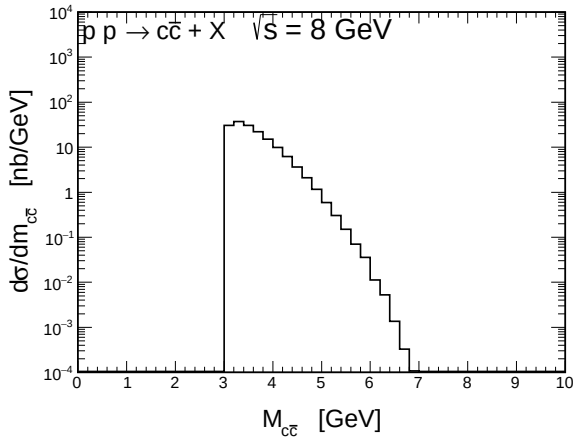
- $pp \to p\Lambda_c^+ D^0$
- $pp \to p\Lambda_c^+ D^{*,0}$

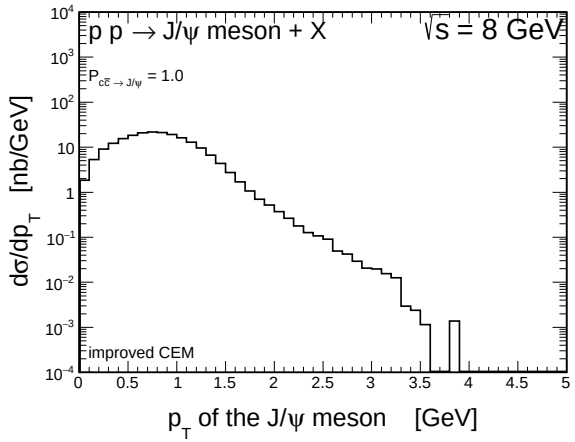
which involve meson/baryon degrees of freedom.
The underlying mechanisms are then

- $M^* p \to D^0 \Lambda_c^+$
- $M^* p \to D^{*,0} \Lambda_c^+$

where $M = \pi^0, V, \gamma$.

$pp \to J/\psi$ (inclusive production)





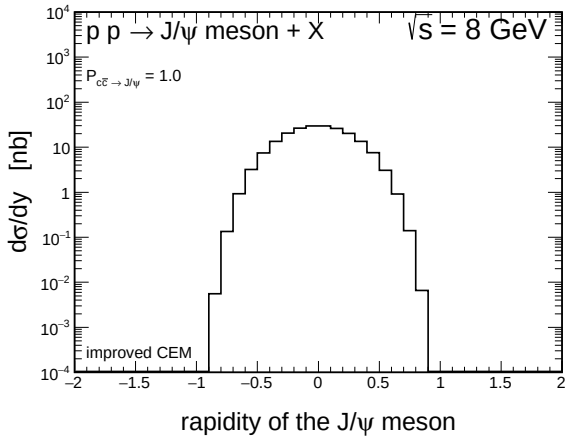


Figure: First results in the improved color evaporation model.
This numbers should be multiplied by 0.02

A fraction of nb. in addition it must be multiplied by 0.06 (J/ψ decay branching fraction).
There is also k_t-factorization approach (Cisek-Szczurek).

$pp \to ppJ\psi$ (exclusive production)

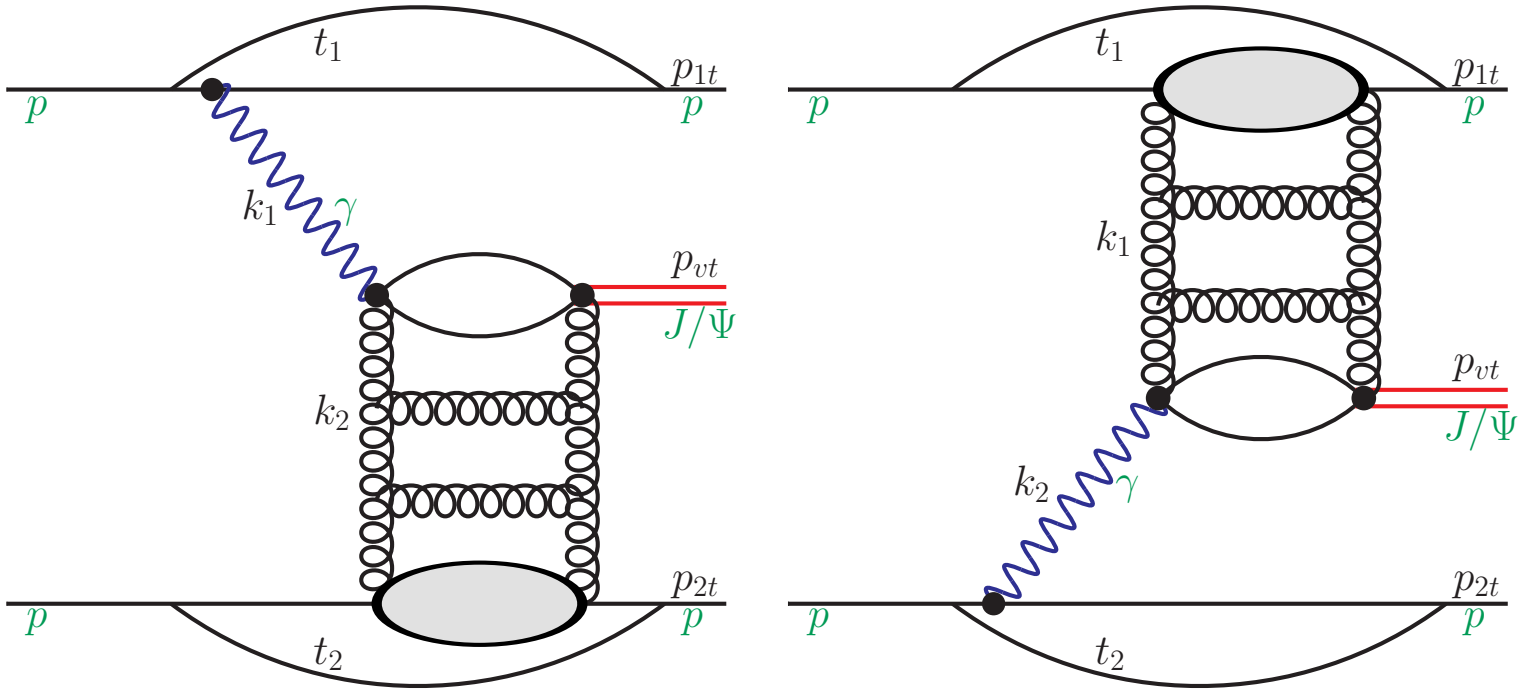


Figure: Two possible contributions.

Coherent sum of both processes

Not yet calculated. One has to understand first $\gamma p \to J/\psi p$.

Some processes in the Regge framework

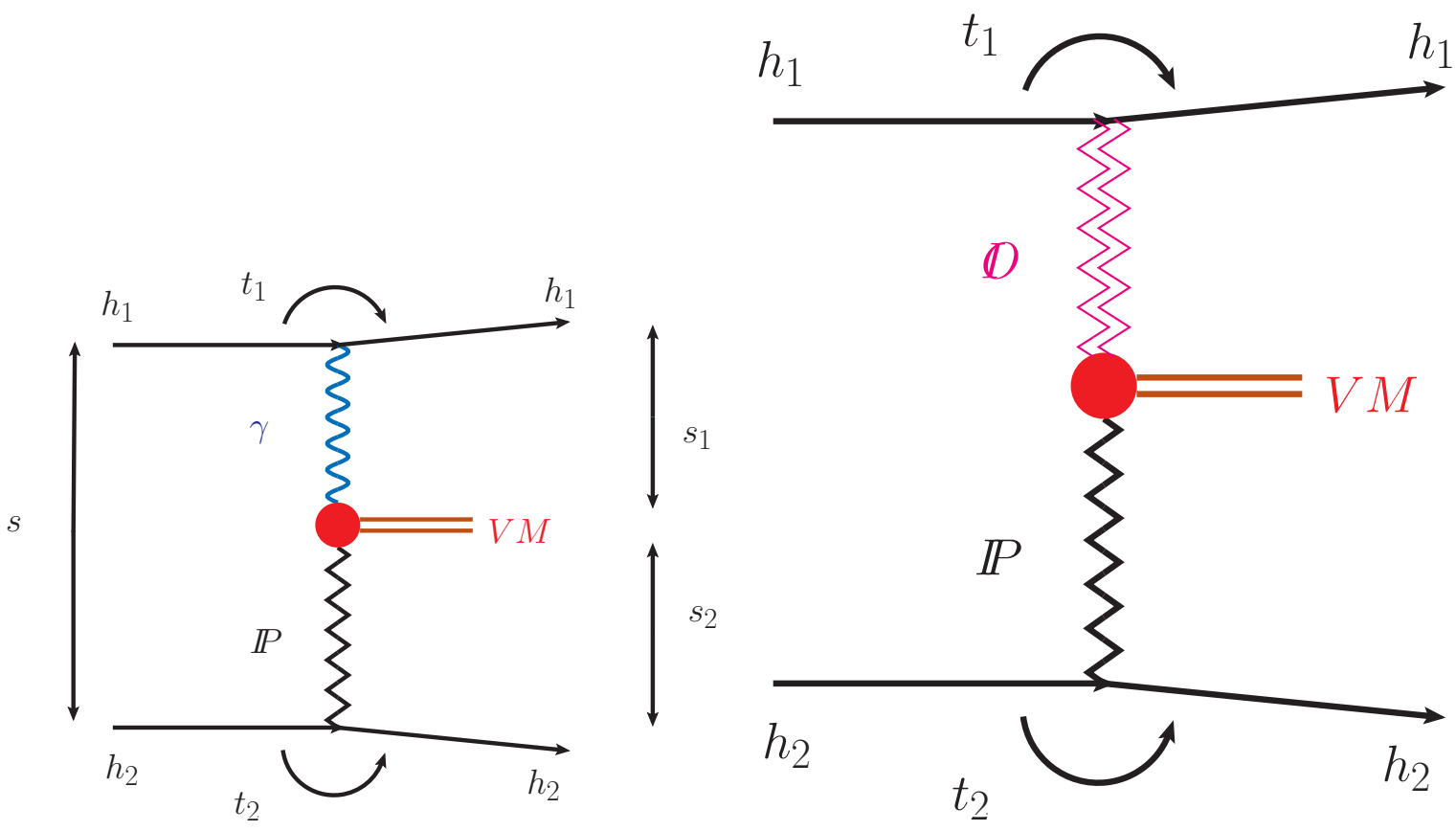
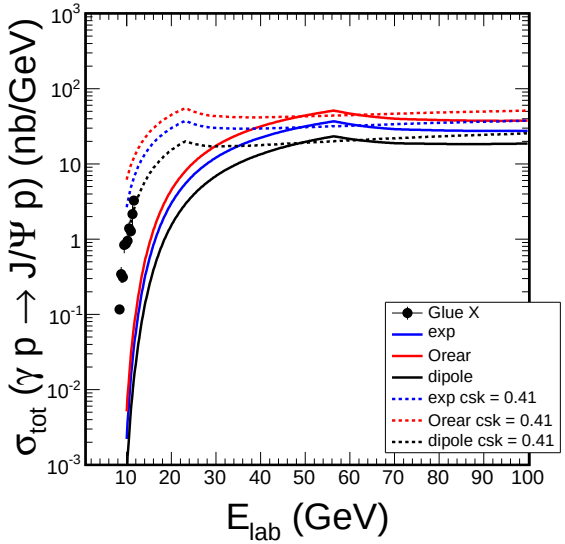
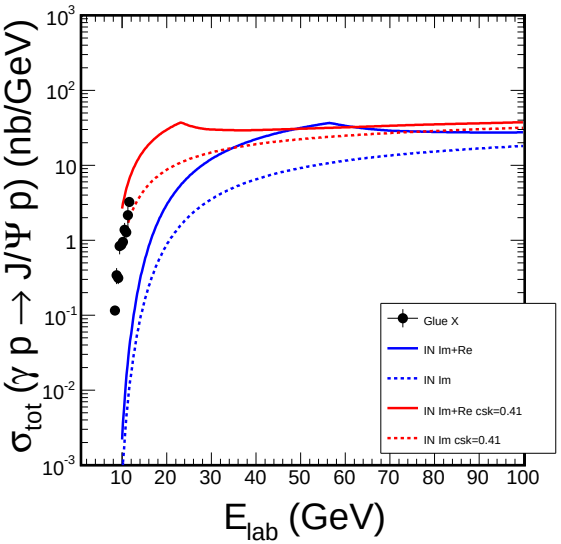


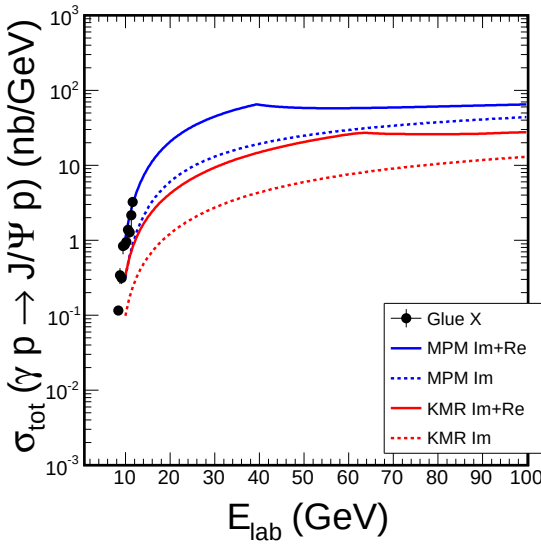
Figure: Other processes

$\gamma p \to J/\psi p$, QCD approach

according to Cisek, Schäfer, Szczurek







Imaginary part of the amplitude is almost sufficient at high energies.

Impossible to describe the Glue-X data without real part of the amplitude

Differential distributions

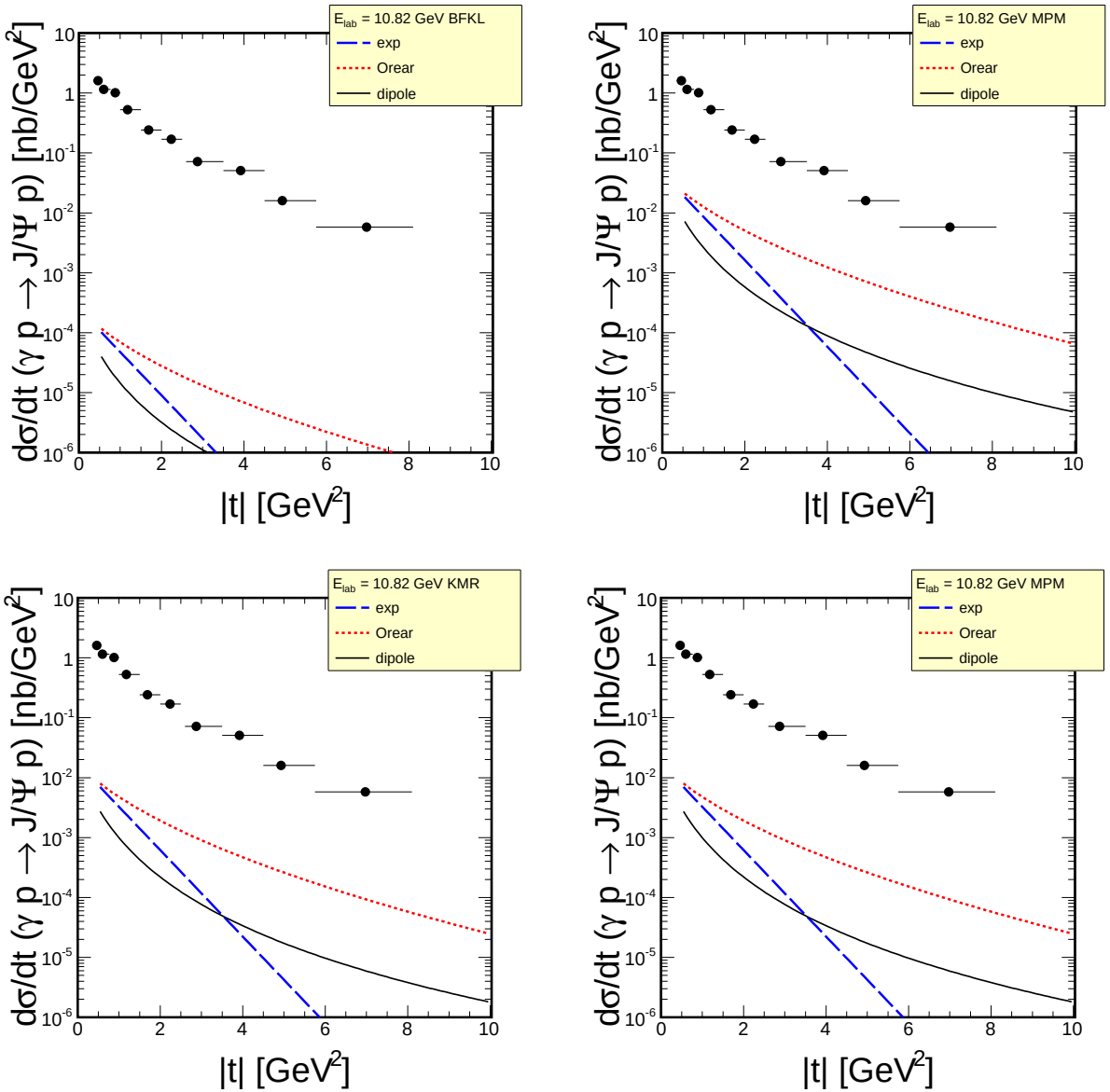


Figure: For BFKL, Ivanov-Nikolaev, KMR, MPM UGDFs.

Gravitational form factors of the nucleon

Matrix element of the energy momentum tensor

$$< p', s' | T_{\mu\nu} | p, s > =$$
$$< \bar{u}(p', s')[A(t)A_{\mu\nu} + B(t)B_{\mu\nu} + C(t)C_{\mu\nu}]u(p, s) > .$$

Recently $A(t)$, $B(t)$ and $C(t)$ were calculated within lattice QCD.
$B(t)$ is rather small.
When combined with VDM they were used for the $\gamma p \to J/\psi p$ reaction.
It was argued that the form factors could be extracted from the $\gamma p \to J/\psi p$ reaction at the threshold.
Some trials were already performed.
Related to proton mass decomposition (X.Ji).

Extraction of GFF from the $\gamma p \to J/\psi p$ data

It is assumed:

$$\frac{d\sigma}{dt} \sim D^2(t) \, . \tag{1}$$

D assumed in the dipole or tripole form.
The results (m_D) for ϕ, J/ψ and DVCS are different.

$$m_D(J/\psi) > m_D(\phi) > m_D(DVCS) \tag{2}$$

and different than from LQCD.
This may show that the extraction is not fully reliable.

VDM + tensor Pomeron

Lebiedowicz+Nachtmann+Szczurek

In this approach the t-dependence of the amplitude is hidden in:

(a) $NN\mathbb{P}$ vertex (similar to the EMT ME),
(b) $\mathbb{P}$ propagator,
(c) $VV\mathbb{P}$ vertex (two tensorial components).

- In $pp \to pp$ at low energies both Pomeron and Reggeon exchanges.
- In $\gamma p \to Vp$, where $V = \phi, J/\psi, \upsilon$ only Pomeron exchange (OZI rule).

This is slightly different than in the fit(s) to the GlueX data.

Ingredients of the $V^*p \longrightarrow Vp$ amplitude

In the tensor pomeron model there are several tensorial components:

- $i\Gamma^{\mathbb{P}VV}_{\mu\nu\kappa\lambda}(k', k)$, two-couplings
- $i\Delta_{\mu\nu\kappa\lambda}(s, t)$
- $i\Gamma^{\mathbb{P}pp}_{\mu\nu}(p', p)$, similar to EMT ME

There are possible tests of the approach.
One could consider decays of J/ψ: $J/\psi \longrightarrow e^+e^-(\mu^+\mu^-)$
$\longrightarrow$ calculate distributions in the Gottfried-Jackson frame.

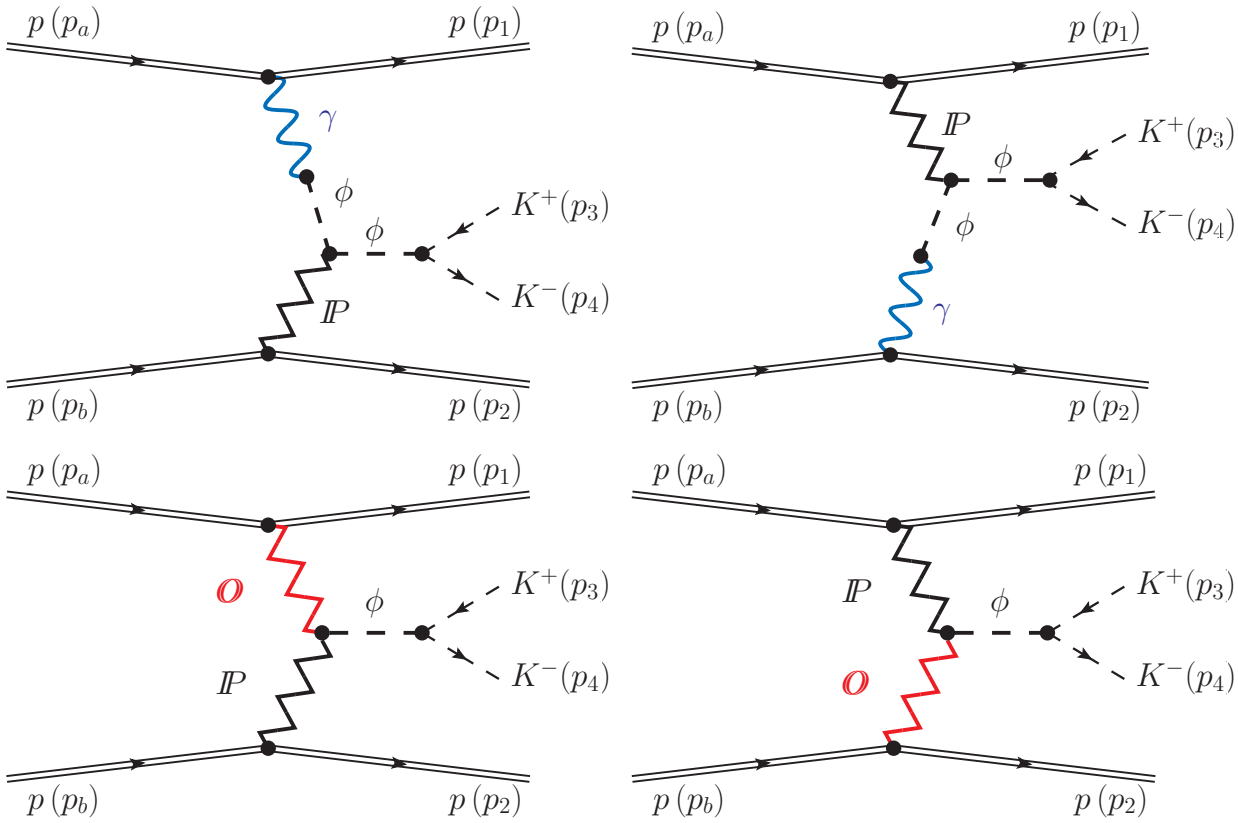
Remark:
Similar (not identical) structure in elastic proton-proton scattering (Liu, Xie, Watanabe, 2023)

A comment and a discussion

It was suggested to use the $\gamma p \to J/\psi p$ data at the threshold to extract gravitational form factor(s) or mass radius of the proton.
However:

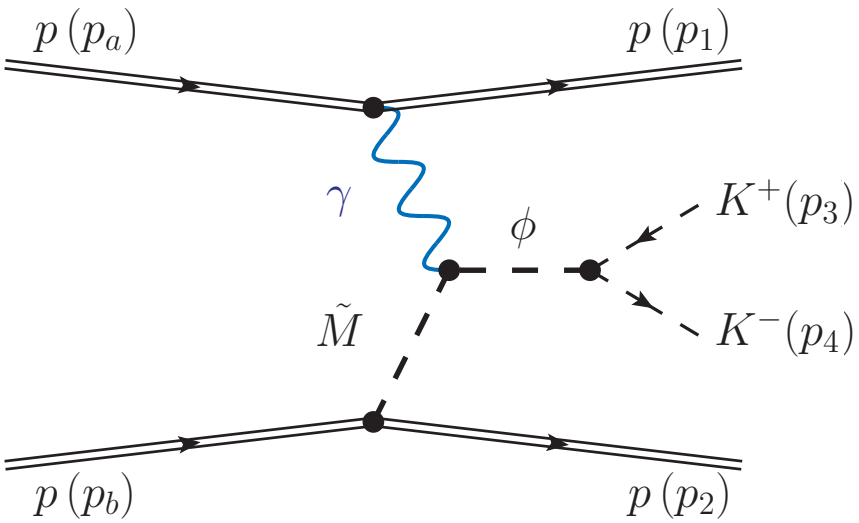
- The two-gluon exchange mechanism may be not the only mechanism at the threshold!
- Three gluon exchange mechanism was suggested by Brodsky et al.
- The coupling with $\Lambda_c, D^{(*)}$ channel(s) may be of importance at the threshold (Baru et al.).
- There is no explicit coupling of the EMT to J/ψ, which could change the extraction.

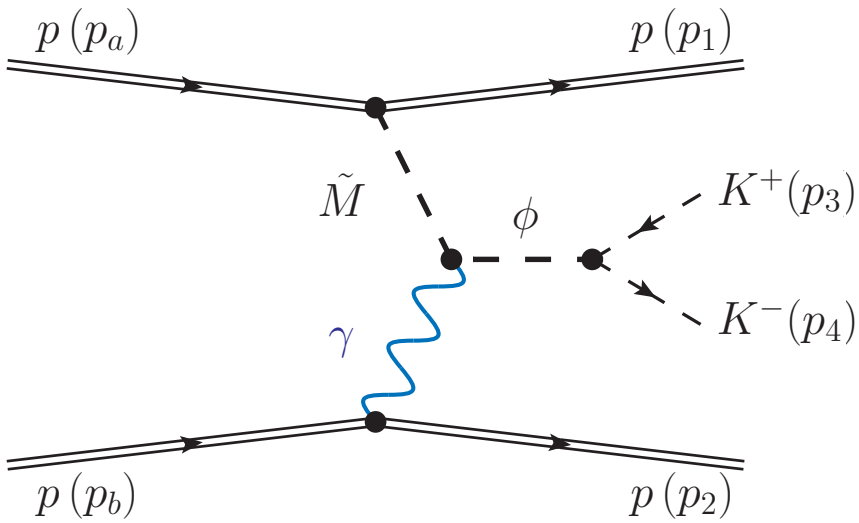
Single ϕ production



Odderon exchange contribution modifies the photon-exchange contribution

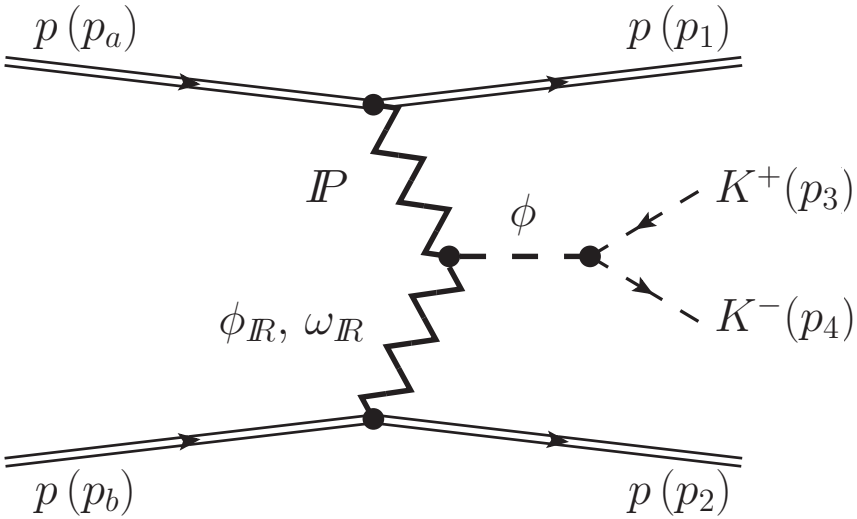
Meson exchanges

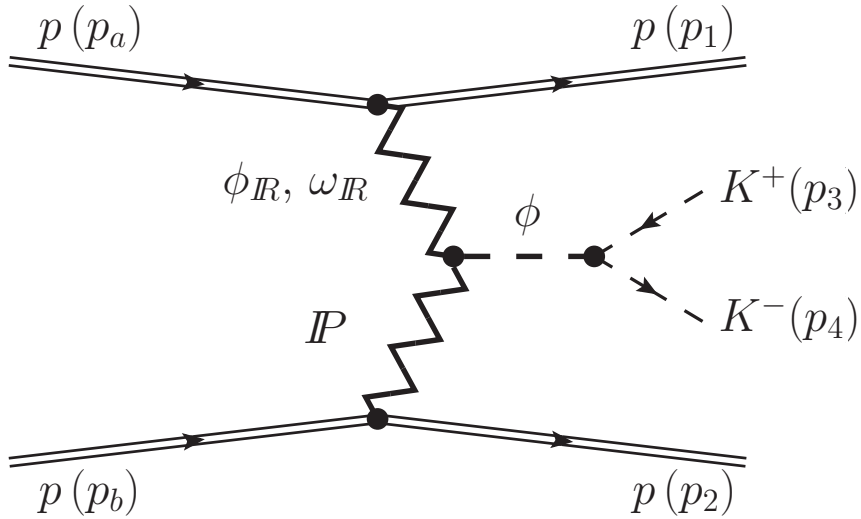




At low energies, as WA102, also pseudoscalar meson exchanges

Reggeon exchanges





New diagrams due to $\omega - \phi$ mixing

At present we think that:

ω exchange is larger than ϕ exchange.

$pp \longrightarrow pp\phi$, WA102 data

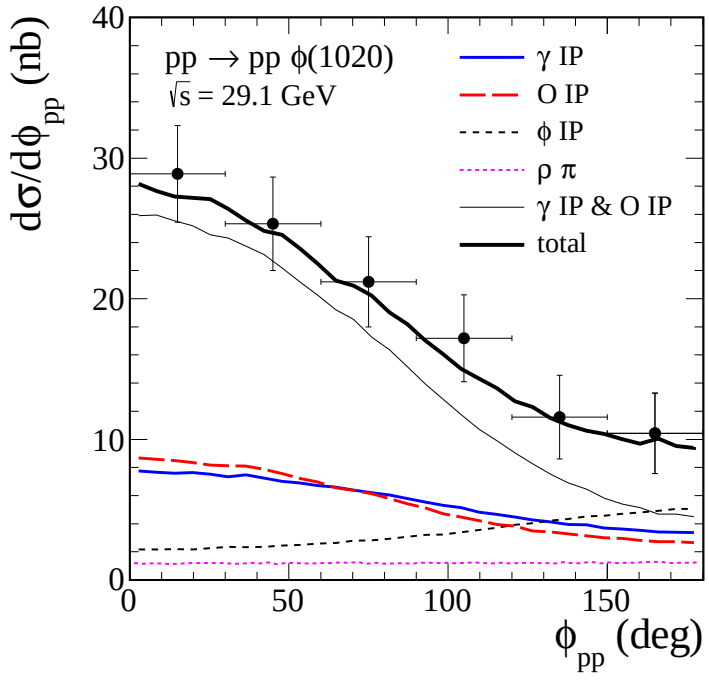


Figure: Azimuthal angle correlations between protons.

$g_{\mathbb{O}pp} = \frac{1}{10} g_{\mathbb{P}pp}$ (educated guess, TOTEM)
strong interference of $\gamma\mathbb{P}$ and $\mathbb{OP}$

$pp \longrightarrow pp\phi$, WA102 data

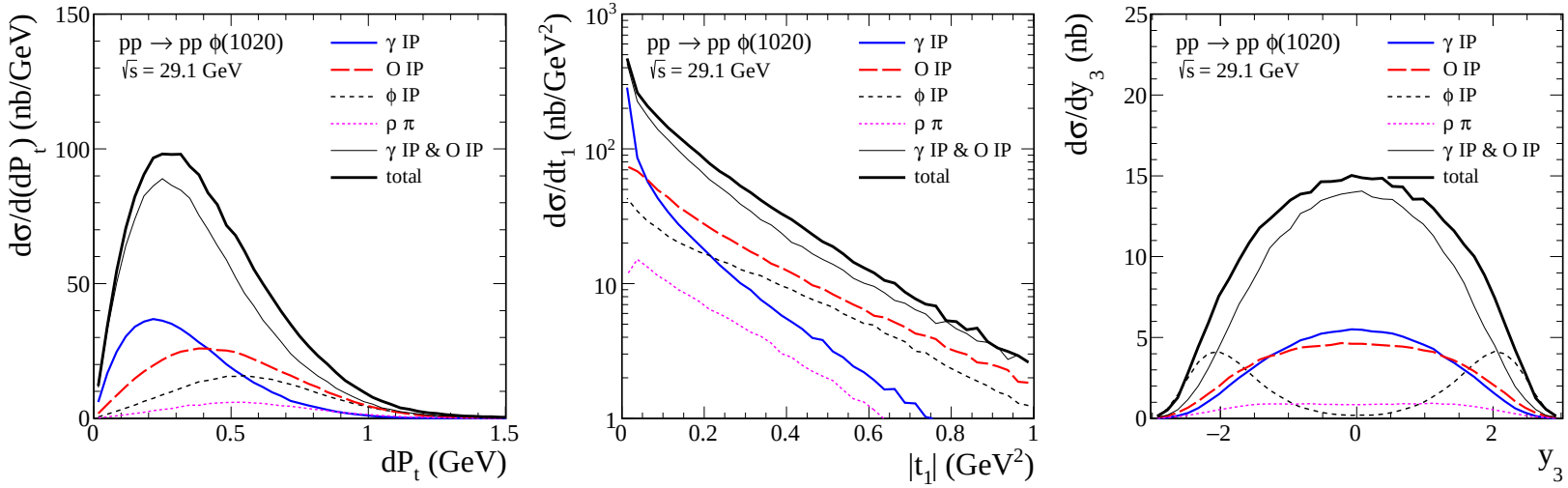


Figure: These distributions were not measured.

At the lower energies one could identify the other reactions. Lebiedowicz, Nachtmann, Szczurek, Phys. Rev. **D101** (2020) 094012.

Conclusions

- We just started to think about the program.
- The territory is new. Neither low nor high energy. Transition region.
- There are several possibilities inspired from:
  (a) high energies
  (b) low energies
- Degrees of freedom ? (hadronic vs partonic)
- More evaluations must be done.
  (e.g. for $pp \to ppJ/\psi$)