Why ALICE FoCal may be interesting: Some loose thoughts of a theorist

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Contents, list of possible problems

- Introduction
- Topics of potential interest
  - $pp \to pp\gamma$, different mechanisms
    with Piotr Lebiedowicz
  - $pp \to \gamma X$, saturation effects. k_t-factorization approach.
    with Rafal Maciula
  - $PbPb \to \gamma$, but more mechanisms than binary NN interactions.
  - $pPb \to \gamma$, better for saturation studies.
  - $\gamma\gamma \to \gamma\gamma$ scattering in $PbPb \to PbPb\gamma\gamma$.
    with Mariola Klusek-Gawenda
  - Production of charged leptons ($e^{\pm}$, $\mu^{\pm}$) from semileptonic decays of charmed mesons in forward directions - testing forward charm production.
  - Production of J/ψ in forward directions.
  - Production of π^0 and η in FoCal.
- Results
- Conclusions and outlook

Introduction

- FOCAL can measure photons (main focus here)
- FOCAL can measure leptons (future studies)

$pp \to pp\gamma$, diffractive bremsstrahlung

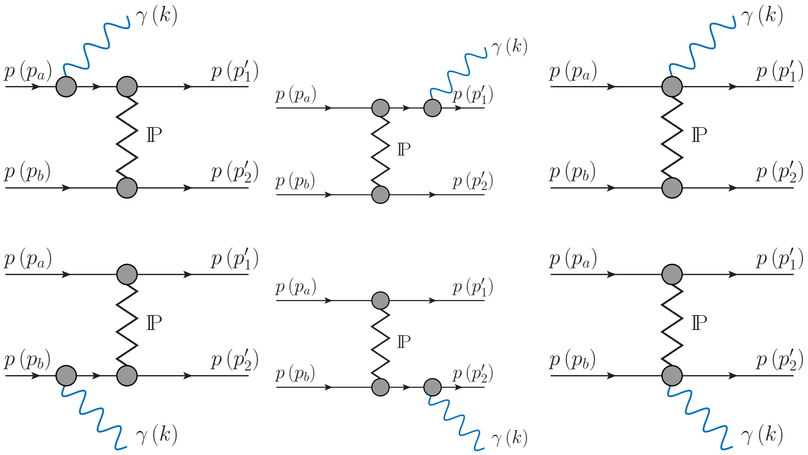


Figure: Lebiedowicz, Nachtmann, Szczurek, arXiv:2206.03411

$pp \to pp\gamma$, photoproduction

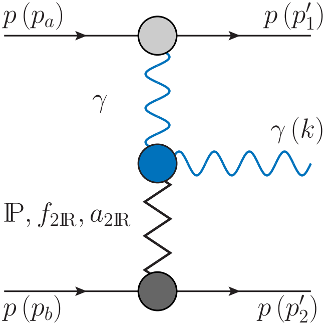
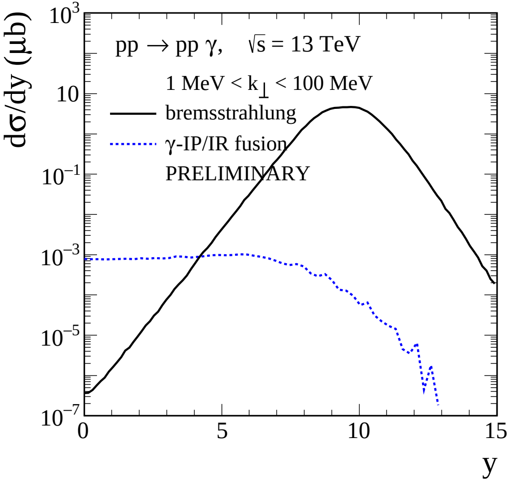


Figure: Diagrams for photoproduction.

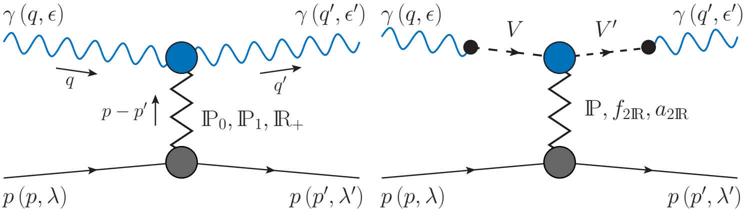
Lebiedowicz, Nachtmann, Szczurek, a paper in preparation

Window for photoproduction



There seem to be a window at midrapidity where the photoproduction may win with the bremsstrahlung

$\gamma^* p \to \gamma p$



Two tensor pomeron model, vertex coupling

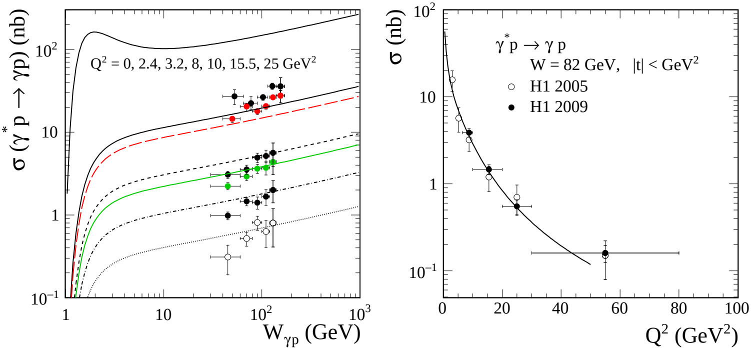
In the tensor pomeron model two couplings for the $\gamma^* \gamma \mathbb{P}$ vertex:

$$\Gamma_{\mu\nu\kappa\rho}(q', q) = 2a(q^2, q'^2, t)\Gamma^0_{\mu\nu\kappa\rho}(\dots) - b(q^2, q'^2, t)\Gamma^2_{\mu\nu\kappa\rho}(\dots) \quad (1)$$

Britzger, Ewerz, Glazov, Nachtmann, Schmitt fitted the coupling parameters. $a = a(Q^2), b = b(Q^2)$ to DIS data
There two virtual photons with identical virtuality.

We (Lebiedowicz, Nachtmann, Szczurek) try to use the same model to DVCS.
Here one photon virtual, one photon real.

2TPM, $\gamma^* p \to \gamma p$

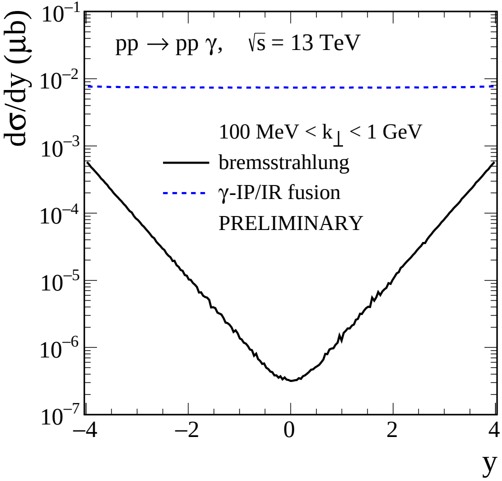


For pomeron exchange: $F(t) = exp(-B/2t)$, $B = 4$ GeV^{-2}

$a/b = \sqrt{a/b(0)a/b(Q^2)}$

quite reasonable description in a broad range of Q^2

2TPM, $pp \to pp\gamma$, general situation



There is a window where the photoproduction dominates over bremsstrahlung.

Dipole approach

In the color dipole approach the corresponding amplitude for the process can be written as:

$$\mathcal{M}^{TT}_{\gamma^* p \to \gamma^* p}(W; Q_1^2, Q_2^2) = \int d^2\rho dz\, \Psi_T(\rho, z, Q_1^2)\Psi_T^*(\rho, z, Q_2^2)\, \sigma(\rho, z, W, Q_1^2, Q_2^2)\ . \tag{2}$$

$$\mathcal{M}^{LL}_{\gamma^* p \to \gamma^* p}(W; Q_1^2, Q_2^2) = \int d^2\rho dz\, \Psi_L(\rho, z, Q_1^2)\Psi_L^*(\rho, z, Q_2^2)\, \sigma(\rho, z, W, Q_1^2, Q_2^2)\ . \tag{3}$$

Above Ψ_T / Ψ_L are so-called transverse/longitudinal virtual photon wave functions (see e.g. Nikolaev-Zakharov) and σ is color dipole - proton cross section.

Dipole approach

σ is color dipole - proton cross section is parametrized using GBW type of parametrization.
Consistent with their fit to DIS the crucial parameter is:

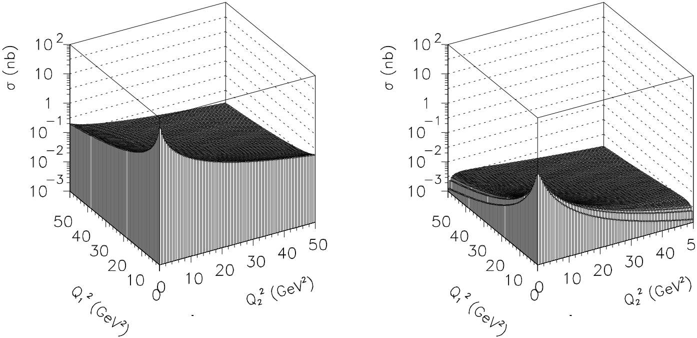
$$x_{eff} = \frac{Q^2 + M_{q\bar{q}}^2}{Q^2 + W^2} \,, \tag{4}$$

where $Q^2 = (Q_1^2 + Q_2^2)/2$ and

$$\sigma_{\gamma^* p \to \gamma^* p}(W; Q_1^2, Q_2^2) = |\mathcal{M}_{\gamma^* p \to \gamma^* p}|^2/(16\pi B) \,, \tag{5}$$

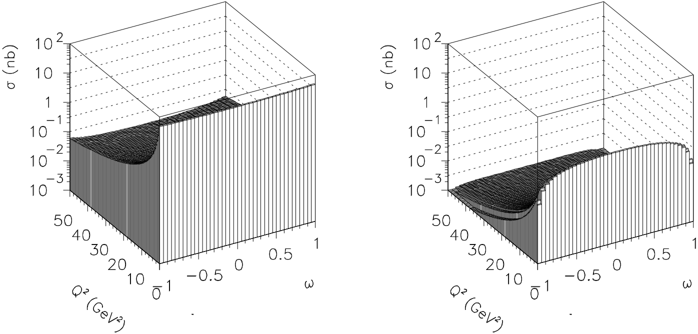
In general slope parameter B may depend on W and even Q^2.
In the dipole approach I use $B = B(Q^2)$ proposed by Machado.

Dipole approach, $\gamma^* p \to \gamma^* p$



LL $<$ *TT*

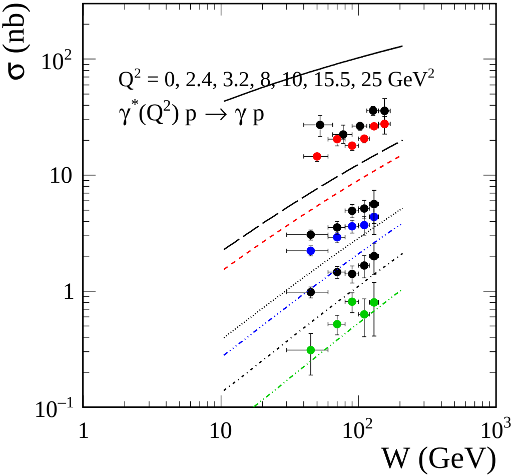
Dipole approach, $\gamma^* p \to \gamma^* p$



weak dependence on asymmetry parameter omega $\omega = \frac{Q_1^2 - Q_2^2}{Q_1^2 + Q_2^2}$

$\overline{Q^2} = (Q_1^2 + Q_2^2)/2$

Dipole approach, $\gamma^* p \to \gamma p$ vs data



Below the experimental data but:

(a) no real part of the amplitude,

(b) no skwedness enhancement factor,

$pp \longrightarrow pp\gamma$

Here we first calculate:
(a) $M^a_{pp\to pp\gamma}$ for $\gamma\mathbb{P}$
(b) $M^b_{pp\to pp\gamma}$ for $\mathbb{P}\gamma$.
Then the total amplitude is obtained by adding the two components:

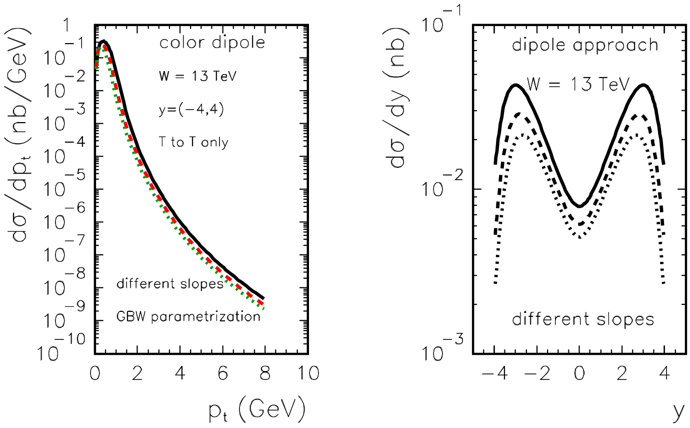
$$M_{pp\to pp\gamma} = M^a_{pp\to pp\gamma} + M^b_{pp\to pp\gamma} \tag{6}$$

In the dipole picture the amplitude is calculated using $\gamma^* p \to \gamma p$ amplitude (Schäfer-Szczurek 2007).
Differential distributions for $pp \to pp\gamma$ are calculated as:

$$\frac{d\sigma}{dt_1 dt_2 dy d\phi} = \frac{1}{512\pi^2 s^2}\overline{|M|^2} \tag{7}$$

Careful treatment of conventions is required.

Dipole approach, B-slopes



The dipole model considered is missing quarkish components (is not complete)

Dipole approach, subsystem energies

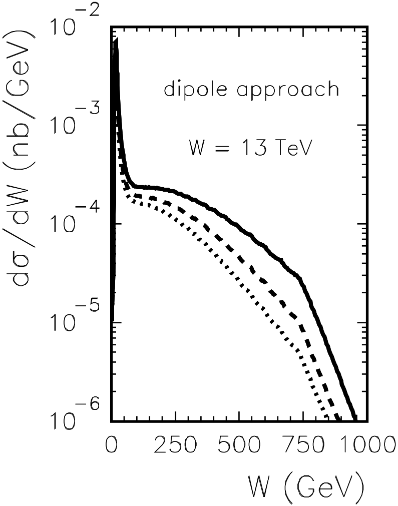
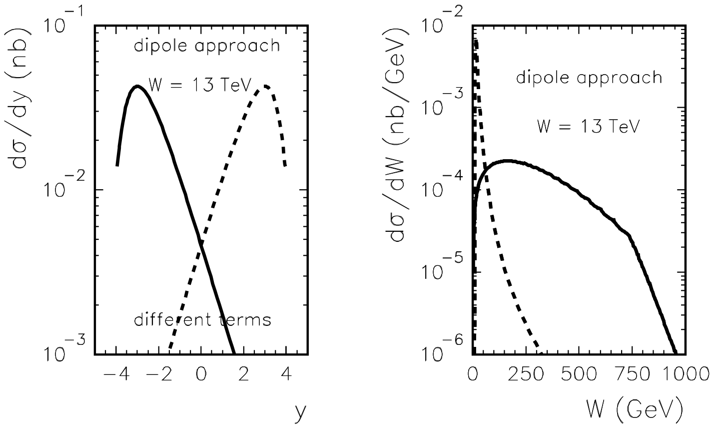


Figure: $B = 4, 6, 8$ GeV^{-2}.

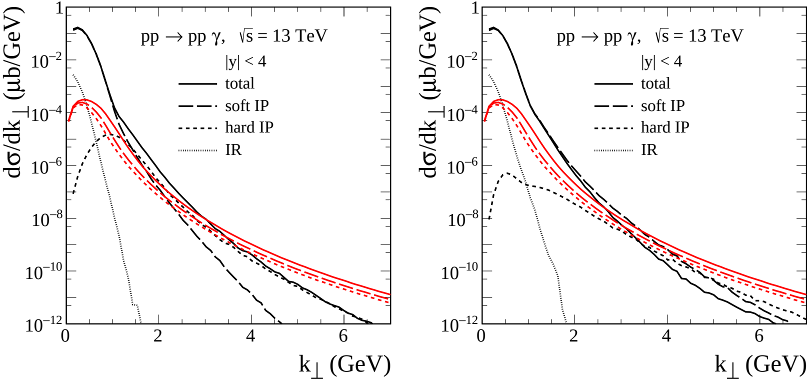
Dipole approach, terms



The two contributions are almost separated.

This is due to steep energy dependence in the dipole model.

2TPM versus color dipole

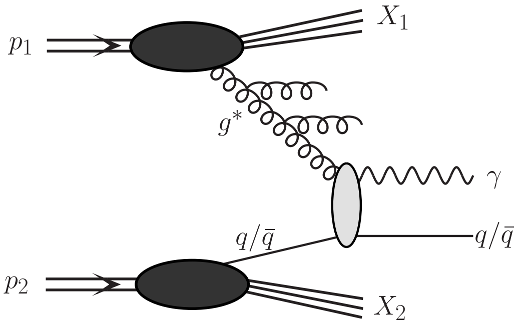


1) coupling constants from a fit to DIS data (BEGNS)

2) interpolation of coupling constants:

$a/b = \sqrt{a/b(0)a/b(Q^2)}$

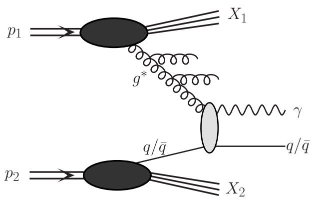
$pp \to \gamma X$, process considered



dominant mechanism for FOCAL

with Rafal Maciula

Hybrid high-energy factorization



The hybrid approach for far-forward production $\Rightarrow$

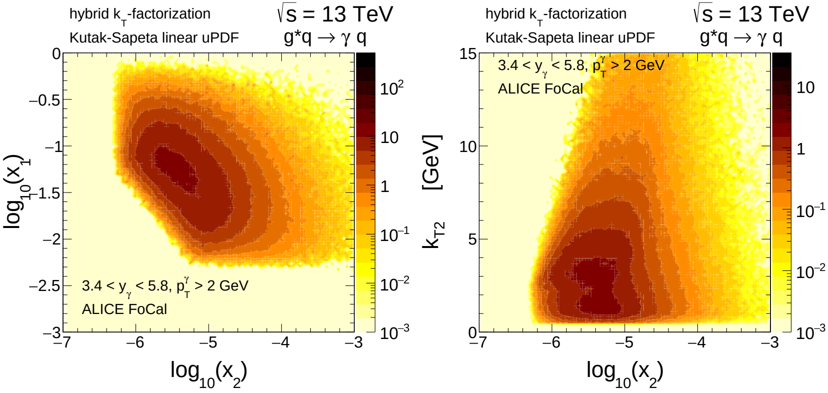
- combined collinear- and k_T-factorization
- used in many phenomenological studies
- the differential cross section for $g^*q \to \gamma q$ mechanism:

$$d\sigma_{pp\to photon}(g^*q \to \gamma q) = \sum_f \int dx_1 \int \frac{dx_2}{x_2} \int d^2k_t$$

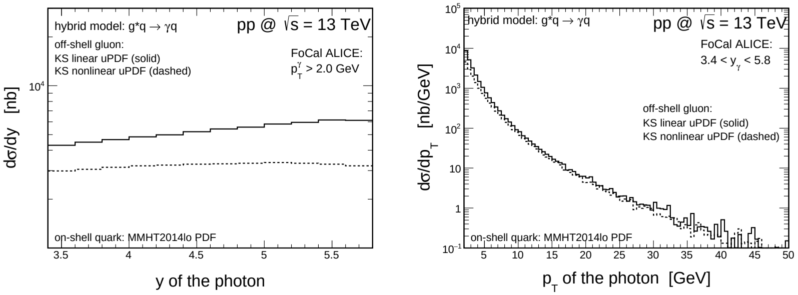
$$\times\ q_f(x_1, \mu^2) \cdot \mathcal{F}_g(x_2, k_t^2, \mu^2) \cdot d\hat{\sigma}_{g^*q\to\gamma q}$$

- $q_f(x_1, \mu^2)$ $\Rightarrow$ collinear large-x quark/antiquark PDFs
  we use MMHT2014lo, MMHT2014nlo, CT14nlo, JR14NLO08FF, NNPDF23
- $\mathcal{F}_g(x_2, k_t^2, \mu^2)$ $\Rightarrow$ off-shell small-x gluon unintegrated PDFs (uPDFs)
  we use KMR/MRW, KS linear/nonlinear, PB-NLO-set1, JH2013set1 CCFM models
- $d\hat{\sigma}_{g^*q\to\gamma q}$ is the hard partonic cross section obtained from a gauge invariant off-shell tree-level amplitudes (available in KaTie Monte Carlo generator)
- regularization needed at $p_T \to 0$ $\Rightarrow$ we use PYTHIA prescription:
  $F_{sup}(p_T) = \frac{p_T^2}{p_{T0}^2 + p_T^2}$, $\alpha_S(\mu_R^2 + p_{T0}^2)$, where $p_{T0} = 1.0$ GeV (free parameter)
- a derivation of the hybrid factorization from the dilute limit of the Color Glass Condensate approach can be found in the literature

$pp \rightarrow \gamma X$, kinematics



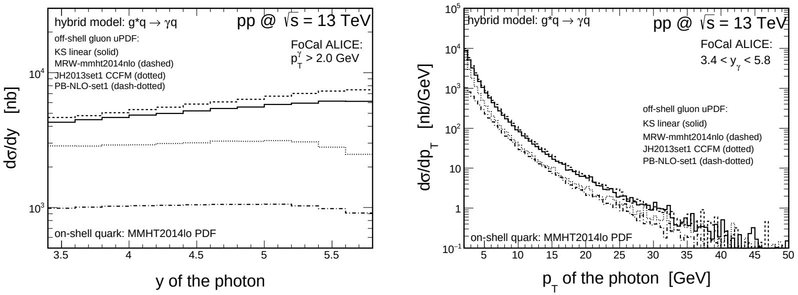
$pp \to \gamma X$, results



saturation vs no saturation

sizeable effect, especially at small transverse momenta

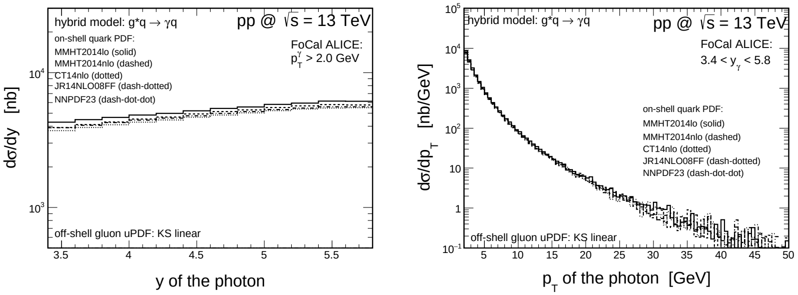
$pp \to \gamma X$, results



different UPDFs

sizeable effect

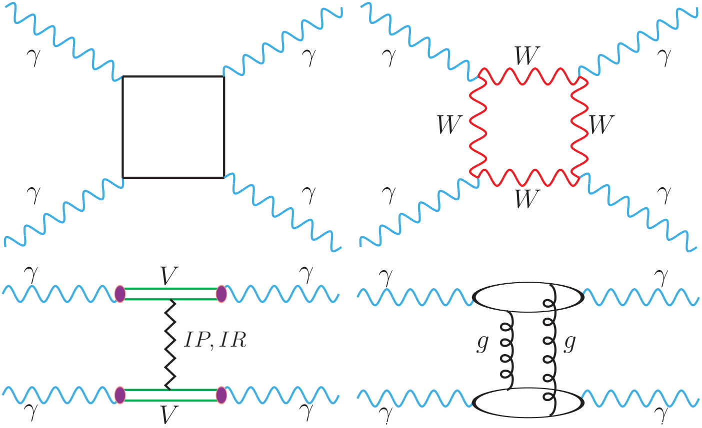
$pp \to \gamma X$, results



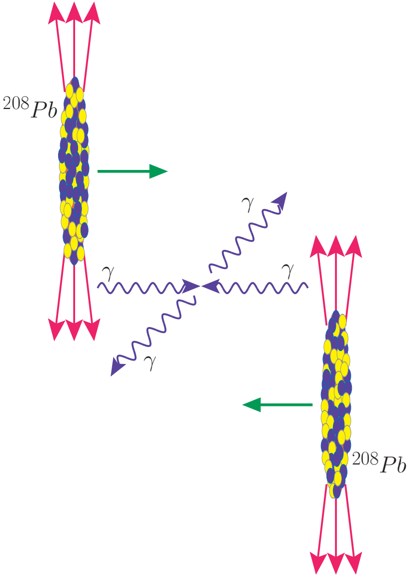
different PDFs

no large effect

Mechanisms of photon-photon scattering

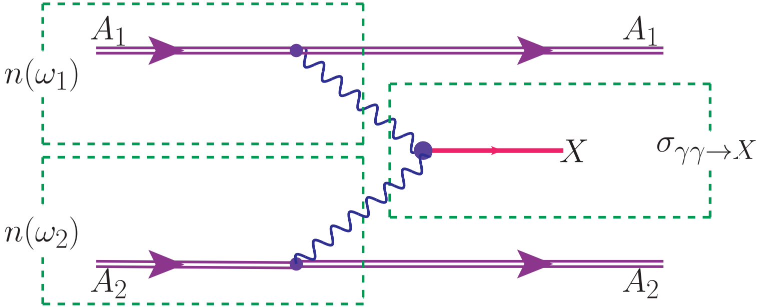


How to look at such a process ?



EM fields can be converted to photon fluxes

How to calculate cross secion ?



Equivalent photon approximation (EPA)

EPA in the impact parameter space

Ultraperipheral collisions: $b > R_{min} = R_1 + R_2 \approx 14$ fm

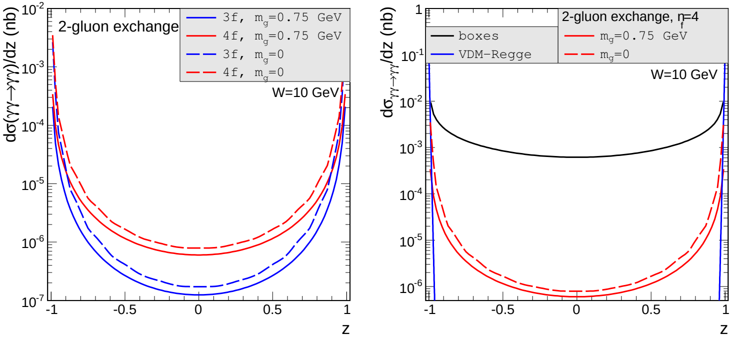
Consider reaction: $A_1 A_2 \to A_1 A_2 X_1 X_2$

$$
\begin{aligned}
& \sigma_{A_1 A_2 \to A_1 A_2 X_1 X_2} = \\
= \; & \int N(\omega_1, \mathbf{b_1}) \, N(\omega_2, \mathbf{b_2}) S^2_{abs}(\mathbf{b}) \\
\times \; & \sigma_{\gamma\gamma \to X_1 X_2}(W_{\gamma\gamma}) \\
\times \; & 2\pi b \mathrm{d}b \, \mathrm{d}\overline{b}_x \, \mathrm{d}\overline{b}_y \, \frac{W_{\gamma\gamma}}{2} \mathrm{d}W_{\gamma\gamma} \, \mathrm{d}Y_{X_1 X_2}
\end{aligned}
$$

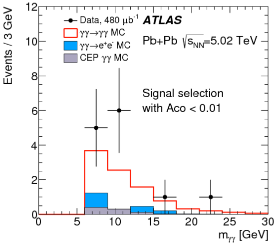
Ultraperipheral condition contained in S_{abs}

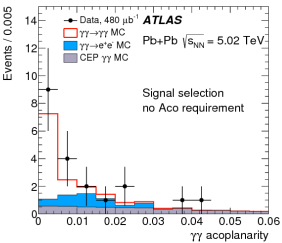
Can be generalized to calculate distributions

Elementary cross section



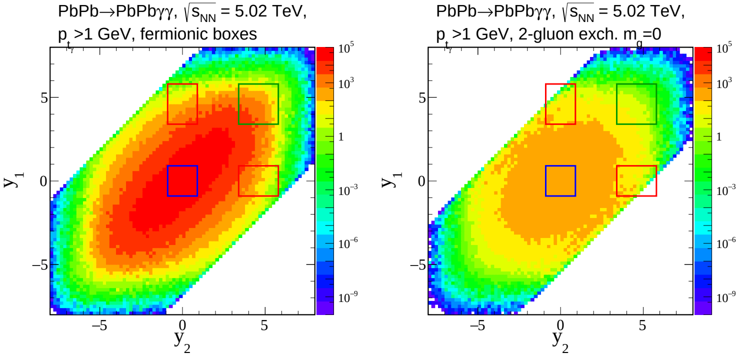
First observation of light-by-light scattering





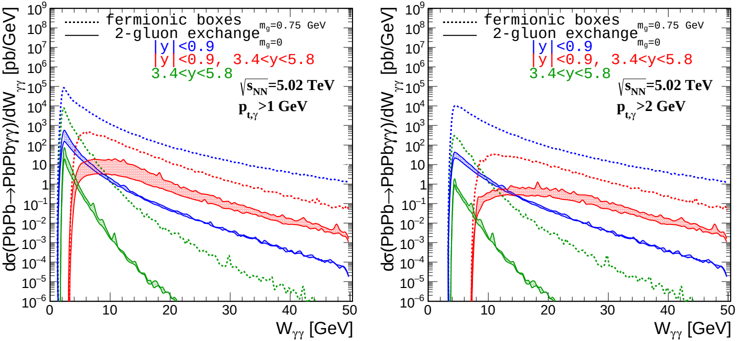
Our predictions vs ATLAS data.
Also CMS has similar data.

FoCal acceptance



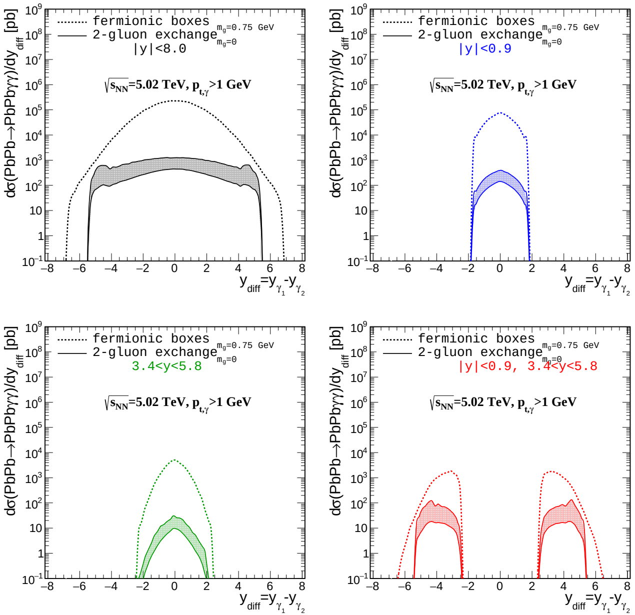
Shown are different possible combinations of measurements,
Photon can be measured in main detector and/or in FoCal.

Diphoton invariant mass distributions



$p_t > 1$ GeV (left) and $p_t > 2$ GeV (right)

y_{diff} distributions



Conclusions

- $pp \to pp\gamma$ at midrapidity never done, interesting. Photoproduction mechanism seems crucial.
- Two different approaches were used:
  (a) two tensor pomeron model
  (b) color dipole model
  The results are different.
  We are trying to understand the situation.
  Interesting to check experimentally.
- $pp \to \gamma X$ calculated in the k_t-factorization approach with different unintegrated gluon distributions.
- No dramatic saturation effect is predicted.
  The differences between different UGDFs much bigger.
- $PbPb \to PbPb\gamma\gamma$ was calculated for the FOCAL kinematics.
  Both boxes as well as two-gluon exchanges were included.
- There are some regions where two-gluon exchanges or improved two-gluon exchanges (resummation) may give visible contribution.
  One photon in central detector, one in FOCAL - the most interesting case.

Outlook, questions

- Separation of decay photons ? How precise ?
- Calculate photon production in nucleus-nucleus collisions. Plasma gives interesting contributions.
- Isospin effects in NN binary collisions.
- $\pi\pi \to \gamma M$ in A+A collisions in addition to binary collisions.
- How the leptons/dileptons measured in FOCAL depend on rapidity of charm.
- Calculation of J/ψ production in FOCAL (k_t-factorization, color evaporation)
- Calculate forward dijet (minijet) production and combine it with hadronization to get π^0 distributions.