Study of polarised gluon structure of proton via prompt photon production in the SPD experiment at the NICA collider.

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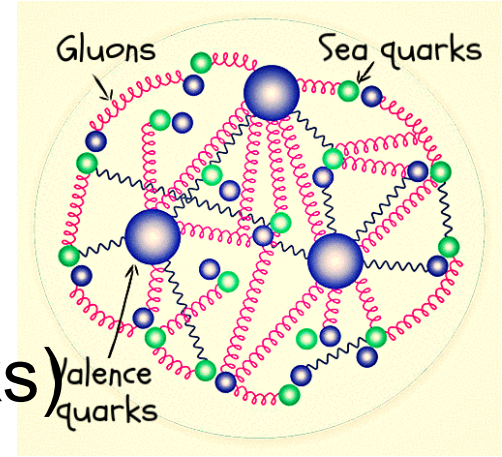
On behalf of the SPD working group

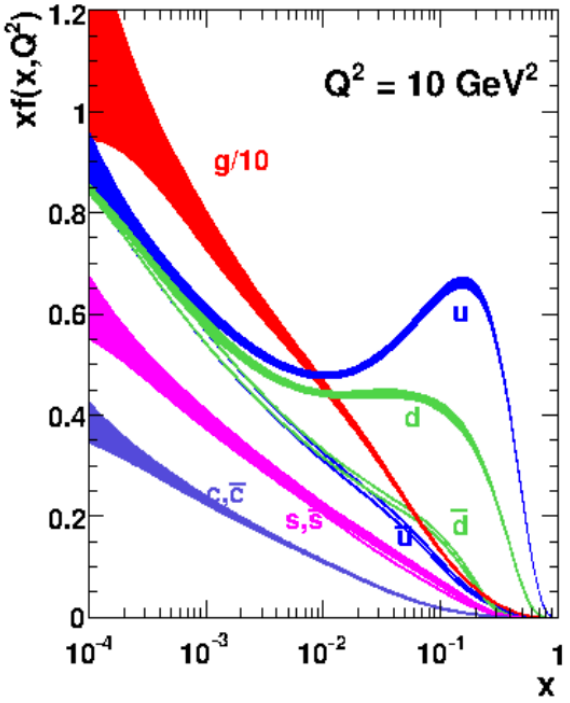
June 11, 2019

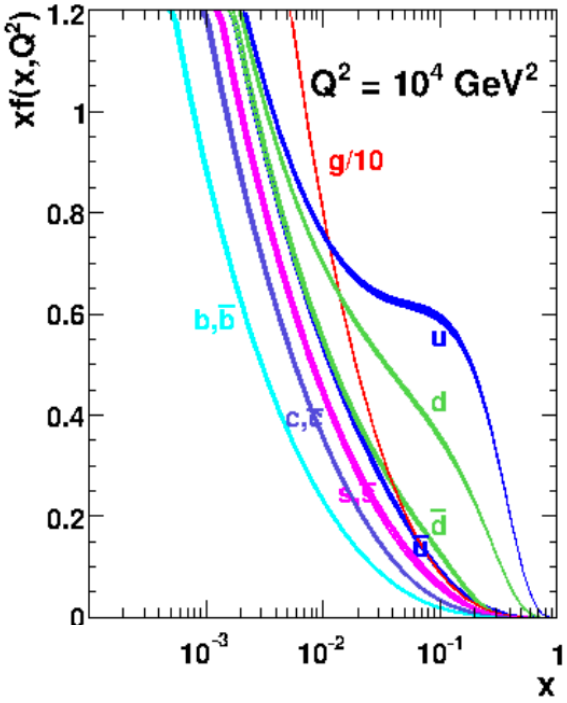
Nucleon structure

Nucleon consist of **partons** (3 valence quarks, gluons and sea quarks)



3 PDFs are needed to describe nucleon structure in collinear approximation





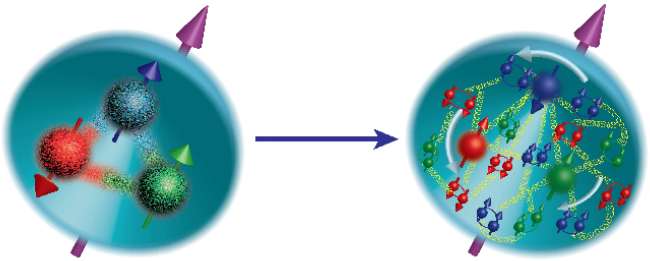
$$q(x,Q^2),$$
$$\bar{q}(x,Q^2),$$
$$g(x,Q^2)$$

Spin crysis and TMD PDFs

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma \qquad \Delta u = \frac{2}{3}, \Delta d = -\frac{1}{3}$$

For proton $\Delta\Sigma = \frac{4}{3} - \frac{1}{3} = 1$

1988 EMC: $\Delta\Sigma \approx 0.12$



$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_g + L_q$$

$\Delta\Sigma \approx 0.30 \quad \Delta G \approx 0.10$

Orbital momentum - ?

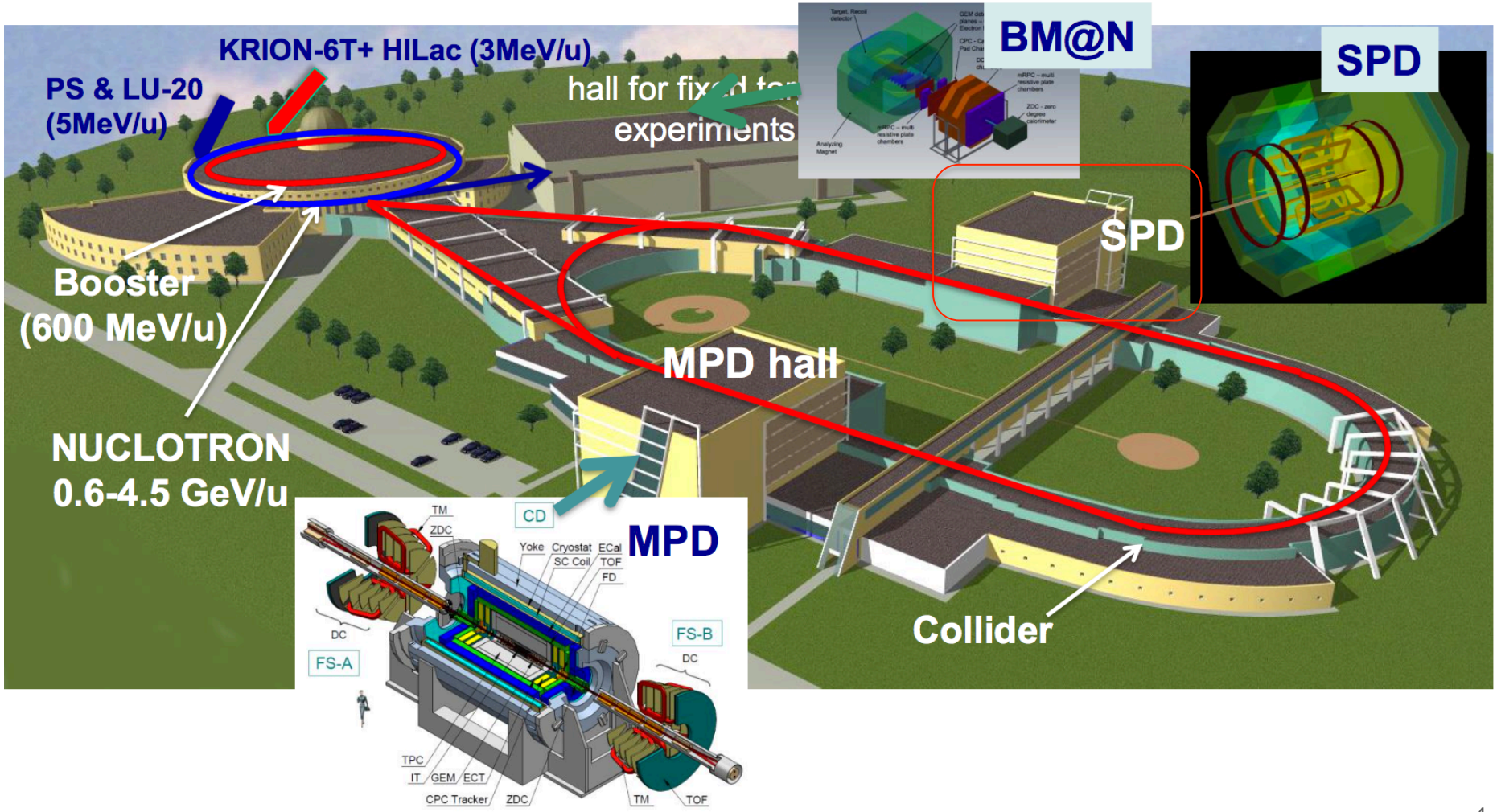
Gluon polarization

Gluon Sivers function

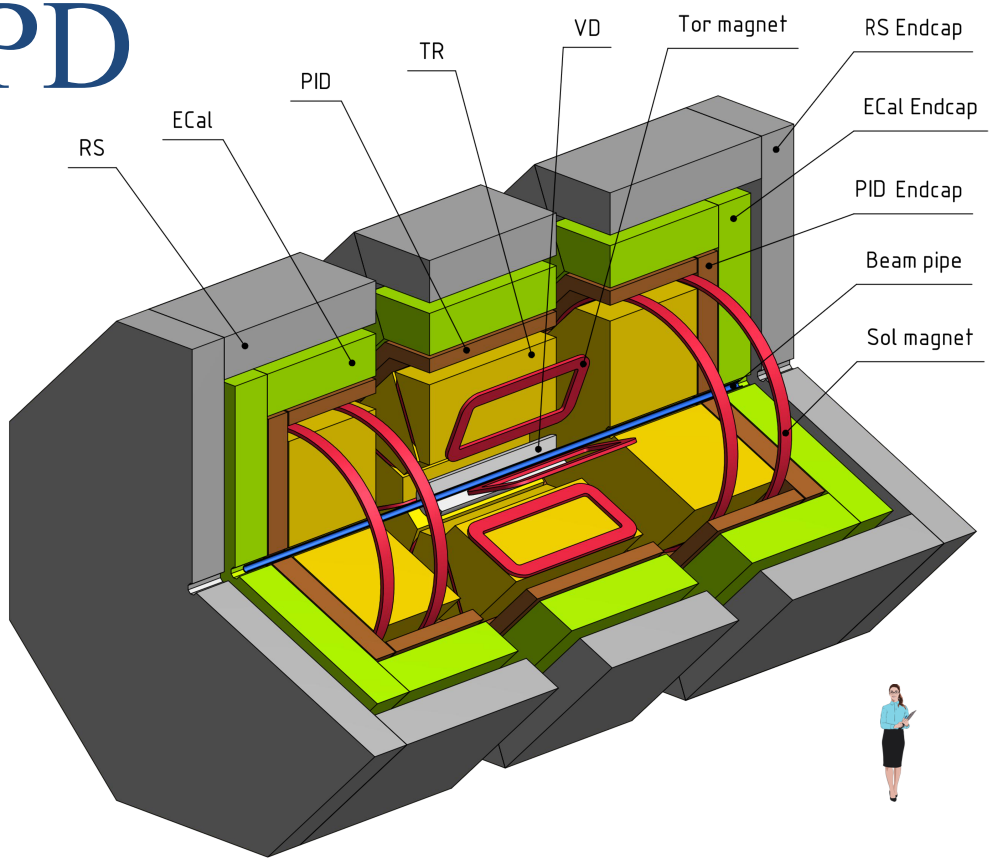
Quark / Nucleon	U	L	T
U	number density		Boer-Mulders
L		helicity	worm-gear L
T	Sivers	Kotzinian-Mulders worm-gear T	transversity, pretzelosity

spin of the nucleon spin of the quark k_T

NICA (Nuclotron based Ion Collider fAcility)



SPD

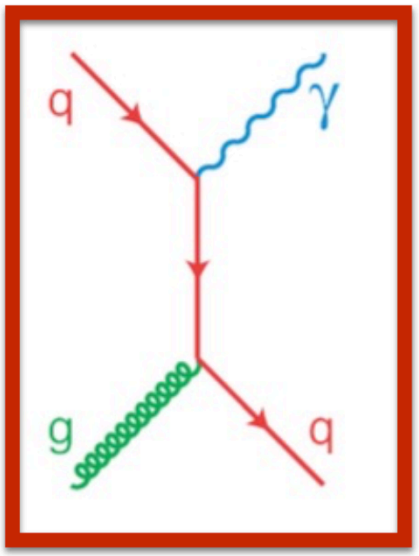


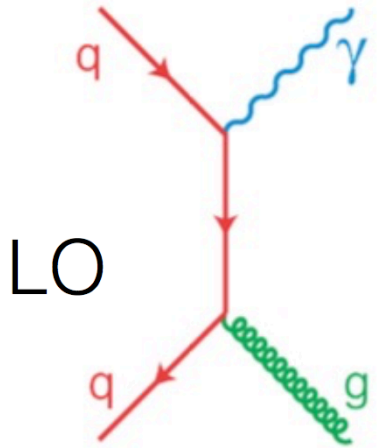
It consists of the 3 parts: 2 endcaps and central one.
Each part has individual magnet system, the endcaps - solenoidal coils, central part - toroidal.

- polarised (longitudinal and transverse) and non-polarised p –; d – collisions;
- polarisation $\simeq 70\%$;
- $p \uparrow p \uparrow \sqrt{s} = 12 \div 27$ GeV;
- $d \uparrow d \uparrow \sqrt{s} = 4 \div 13.8$ GeV;
- $L_{average} \geq 10^{32} cm^{-2} s^{-1}$(at $\sqrt{s} = 27$ GeV).

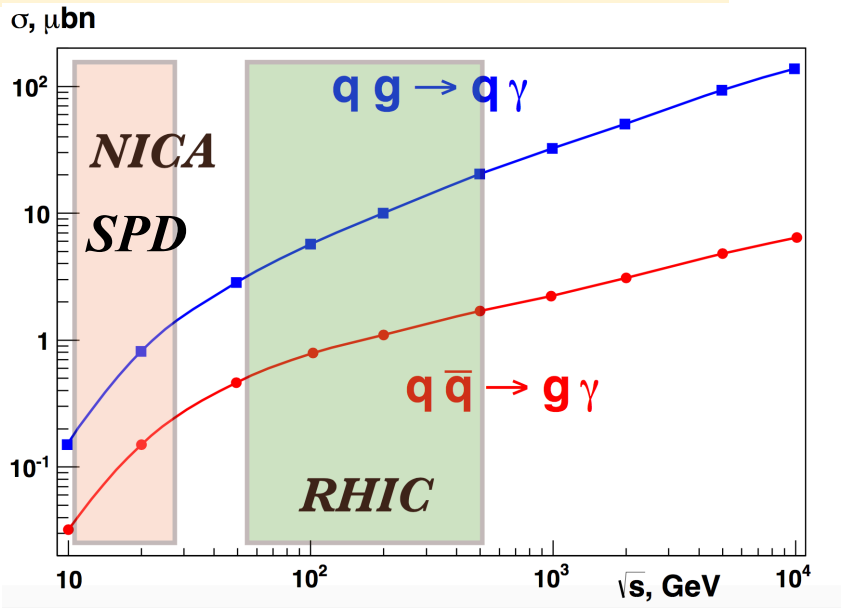
Prompt photons

Photons produced in the hard scattering, named the **prompt photons**, provide information about gluon component of the proton.





LO

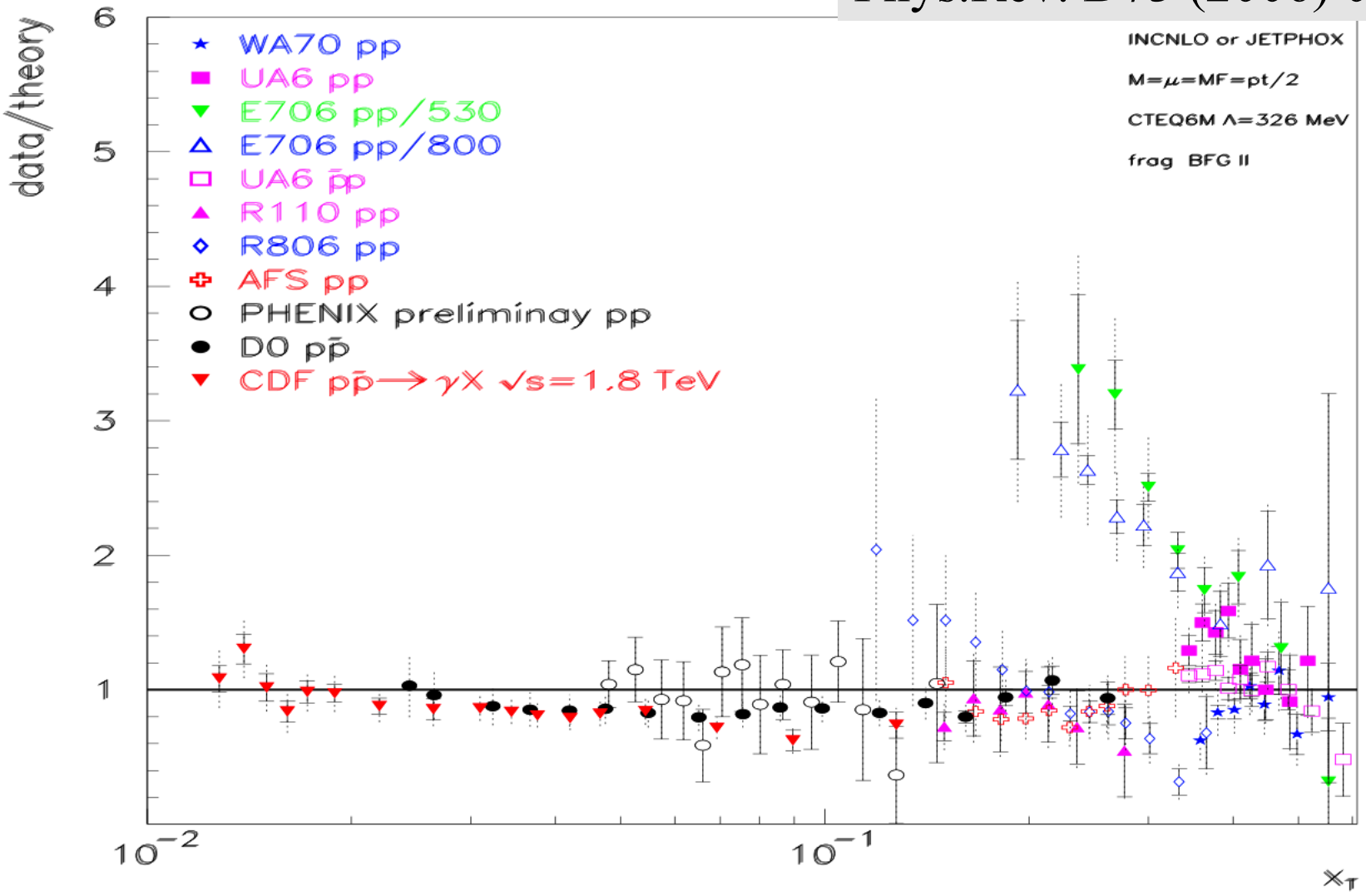


$$d\sigma_{AB} = \sum_{a,b=q,\bar{q},g} \int dx_a dx_b f_a^A(x_a,\mu^2) f_b^B(x_b,\mu^2) d\sigma_{ab\to\gamma X}(x_a,x_b,\mu^2).$$

One of the instrument to study gluon component of proton – prompt photons

Previous studies (data/theory)

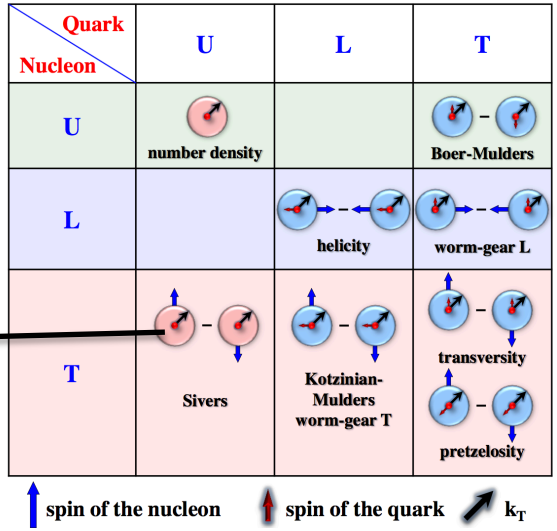
Phys.Rev. D73 (2006) 094007



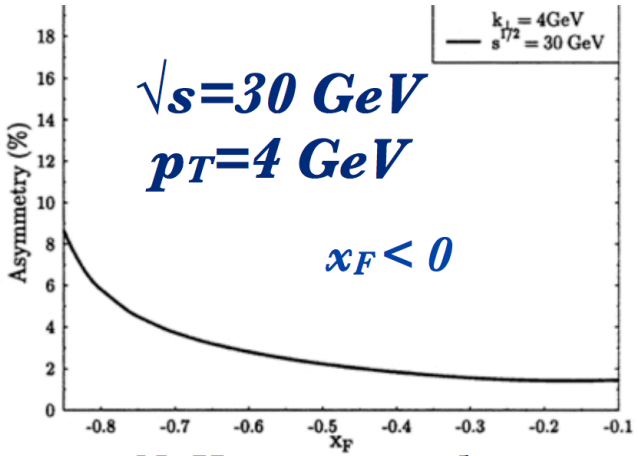
Transverse single spin asymmetry

$$A_N = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

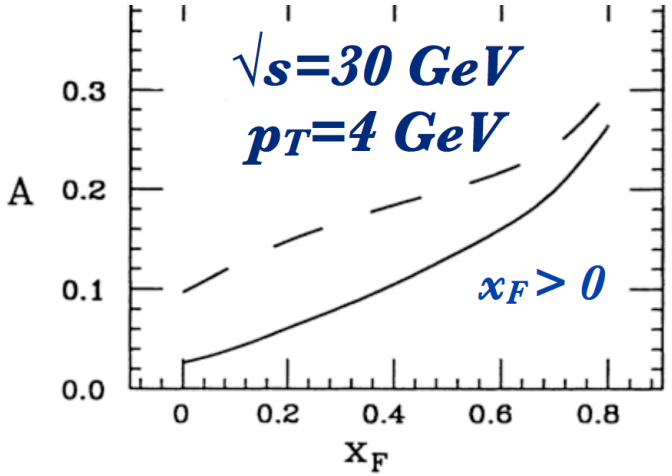
Gluon Sivers function



$$\sigma^{\uparrow} - \sigma^{\downarrow} = \sum_i \int_{x_{min}}^{1} dx_a \int d^2\mathbf{k}_{T_a} d^2\mathbf{k}_{T_b} \frac{x_a x_b}{x_a - (p_T/s)e^y} \left[q_i(x_a, \mathbf{k}_{T_a}) \Delta_N G(x_b, \mathbf{k}_{T_b}) \times \frac{d\hat{\sigma}}{d\hat{t}}(q_i G \to q_i \gamma) + G(x_a, \mathbf{k}_{T_a}) \Delta_N q_i(x_b, \mathbf{k}_{T_b}) \frac{d\hat{\sigma}}{d\hat{t}}(G q_i \to q_i \gamma) \right]$$

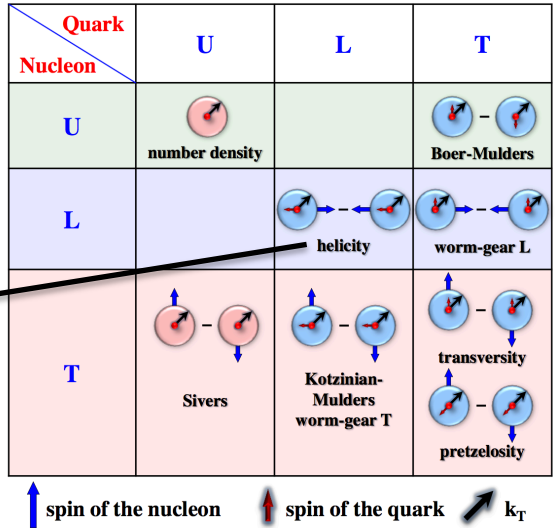


N. Hammon et al.
J. Phys. G: Nucl. Part. Phys. 24 991(1998)



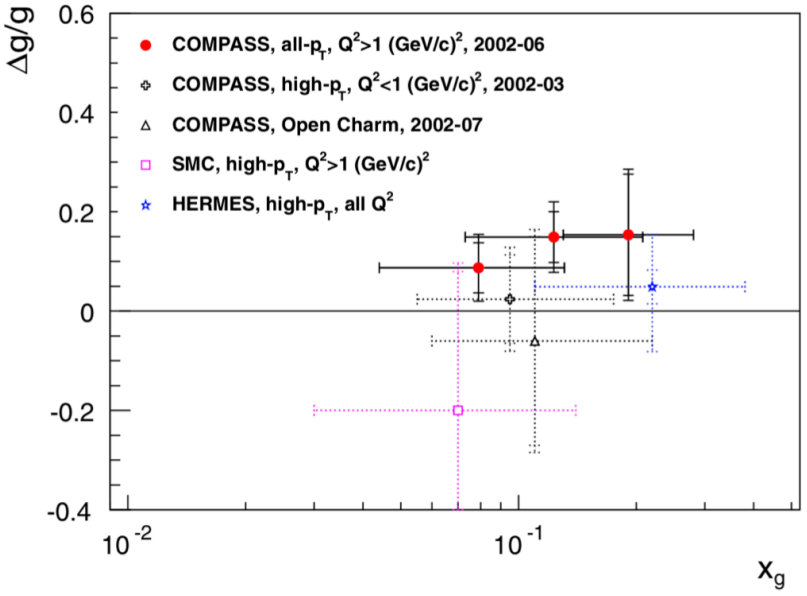
J. Qui and G. Sterman, Phys. Rev. Lett. 67 (1991) 2264

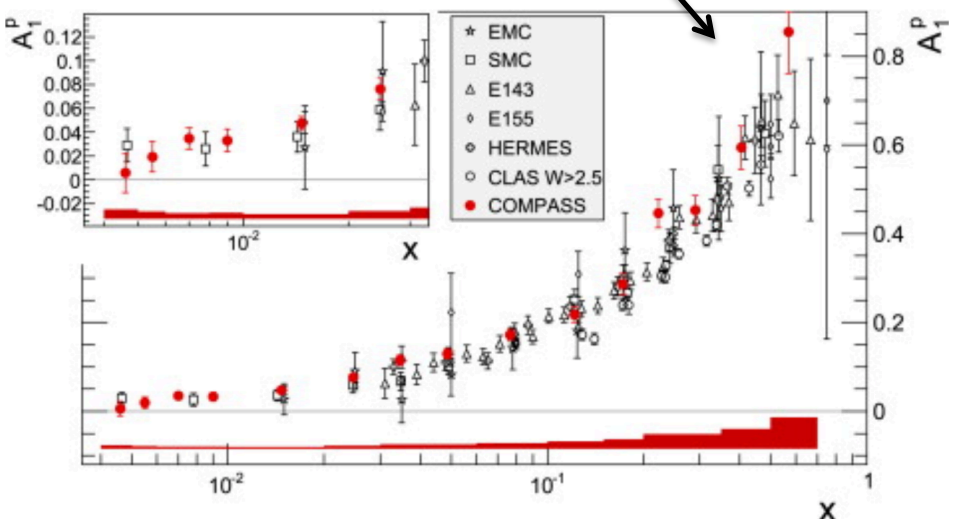
Longitudinal double spin asymmetry



Gluon polarization

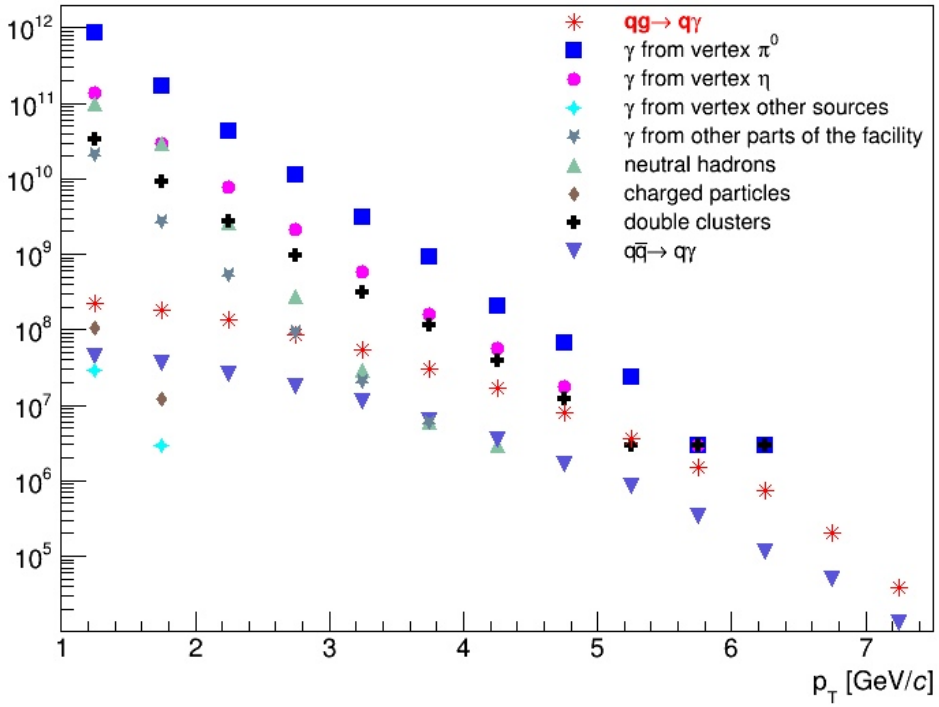
$$A_{LL} = \frac{(\sigma_{++} + \sigma_{--}) - (\sigma_{+-} + \sigma_{-+})}{(\sigma_{++} + \sigma_{--}) + (\sigma_{+-} + \sigma_{-+})} \approx \frac{\Delta g(x_1)}{g(x_1)} \times \left[\frac{\sum_q e_q^2 [\Delta q(x_2) + \Delta \bar{q}(x_2)]}{\sum_q e_q^2 [q(x_2) + \bar{q}(x_2)]} \right] + (x_1 \leftrightarrow x_2)$$

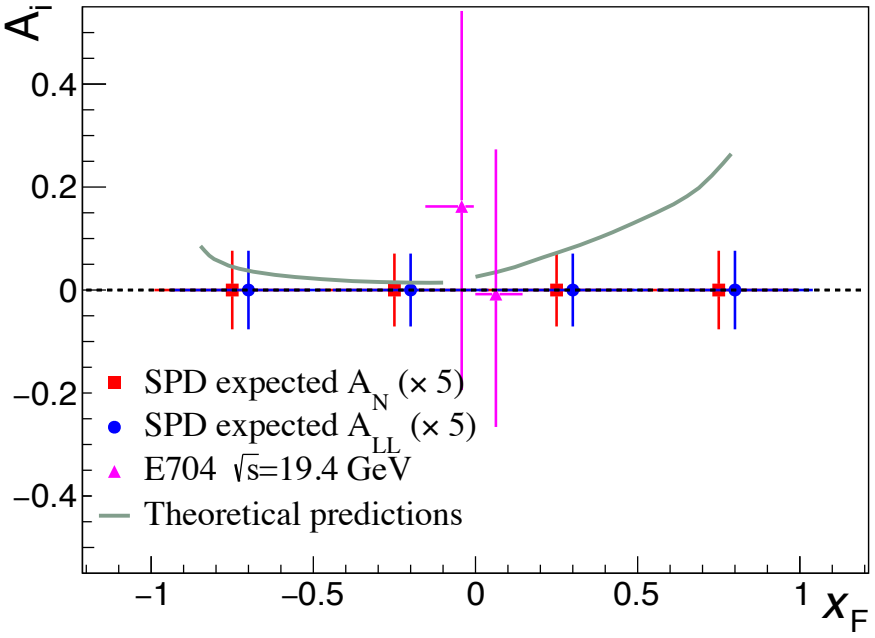




Expected accuracy

- Data sample corresponds to 10^7 s of data taking (about 100 days) with average luminosity $L = 10^{32} s^{-1} cm^{-2}$.
- Errors from polarisation and luminosity measurements are not taken into account.





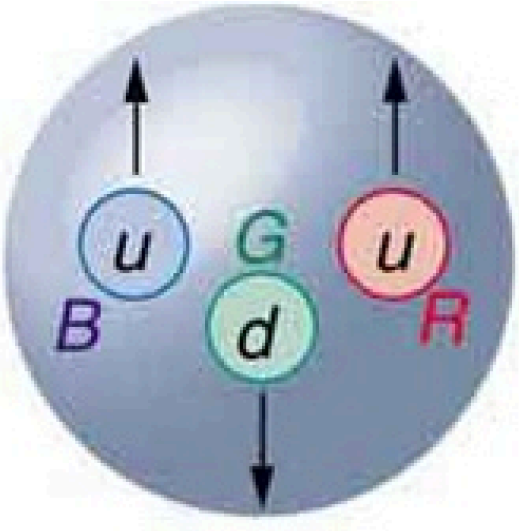
Summary

Prompt photons provide an information about polarased and non-polarised gluon component of the proton

Studies of gluon structure of nucleon with prompt photons – one of the main tasks of the SPD physics program

Backup

Nucleon structure

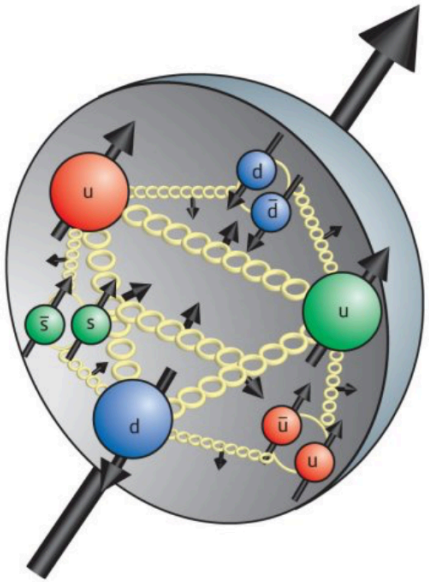


$$\frac{1}{2} = \Delta\Sigma = \frac{1}{2} + \frac{1}{2} - \frac{1}{2}$$

1988 EMC: $\Delta\Sigma \approx 0.12$

What else contribute?

$$\frac{1}{2} = \Delta\Sigma + \Delta G + L_g + L_q$$

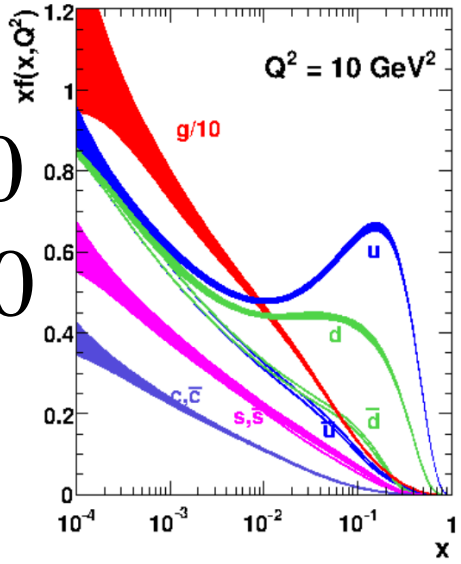


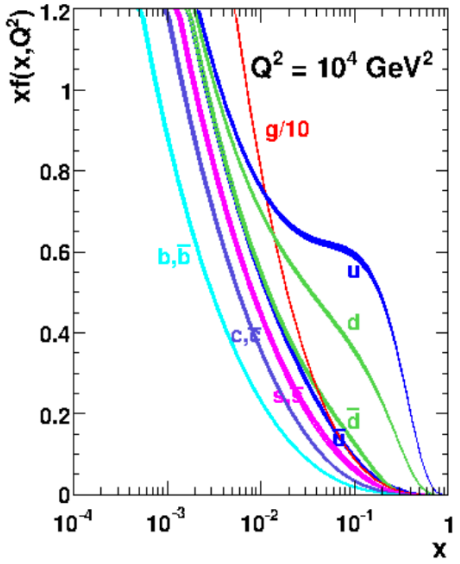
Now:

$\Delta\Sigma \approx 0.30$

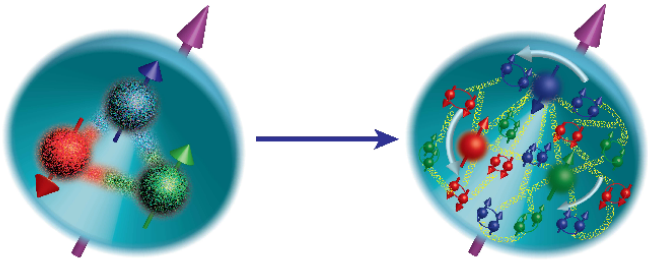
$\Delta G \approx 0.10$

$L_g, L_q - ?$





TMD PDFs



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U	number density		Boer-Mulders
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spin of the nucleon spin of the quark k_T

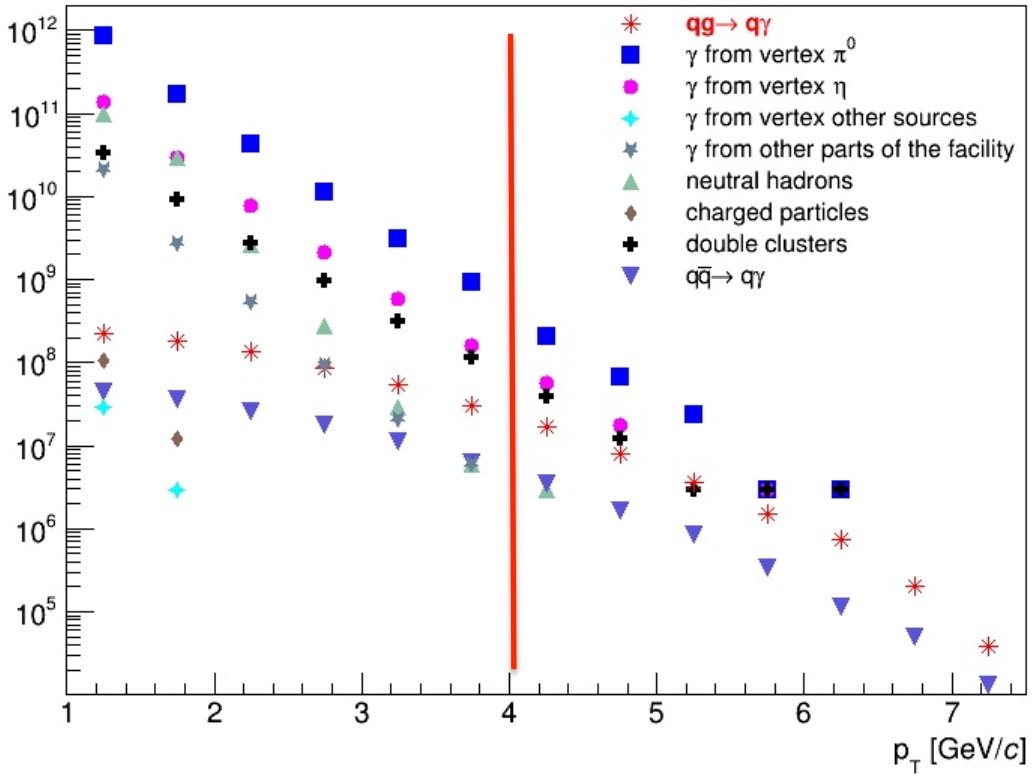
Gluon Sivers function

Gluon polarization

3 PDFs are needed to describe nucleon structure in collinear approximation

8 PDFs are needed if we want to take into account intrinsic transverse momentum k_T of partons (LO)

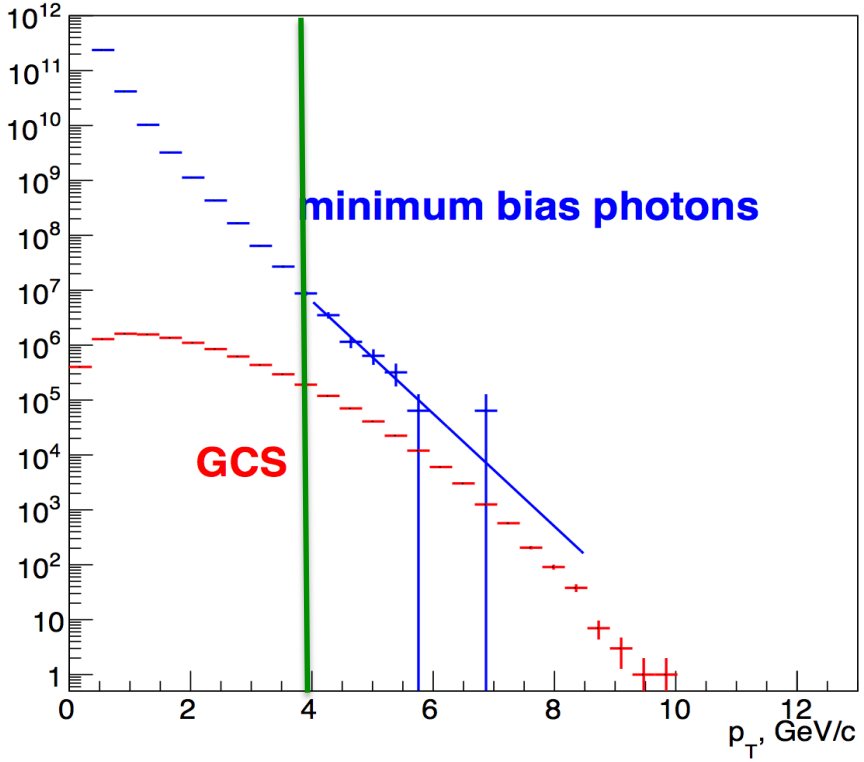
Main background sources



- **π° Decay**
- **η-meson decay**
- **double clusters**
- **neutral hadrons (n,K,Λ)**
- **charged particles**

A reasonable cut on transverse momentum (> 4 GeV/c) of photon has to be applied in order to maximize the accuracy of the planned measurements.

The main source of photons (almost 99%) in proton-proton collision is the production and decay of π^0 and η mesons

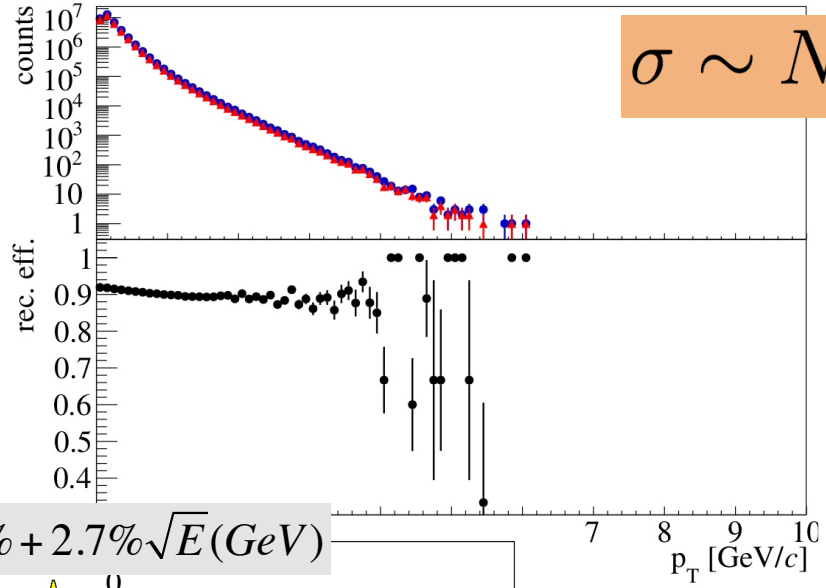


photons in 10^6-pp collisions	
π^0	$8.7 * 10^6$
η	400000
ω	59500
η'	46200
Σ^0	34500
Δ^+	1610
Δ^0	1130
ρ^0	743
K^{*0}	600
ρ^{+0}	570
ϕ	540
Λ	470
K^{*+}	370
γ_{direct}	30

- Low p_T region is useless for any studies of prompt photons due to huge background
- At high p_T statistics is very limited
- A reasonable cut on transverse momentum (> 4 GeV/c) of photon has to be applied in order to maximize the accuracy of the planned measurements.

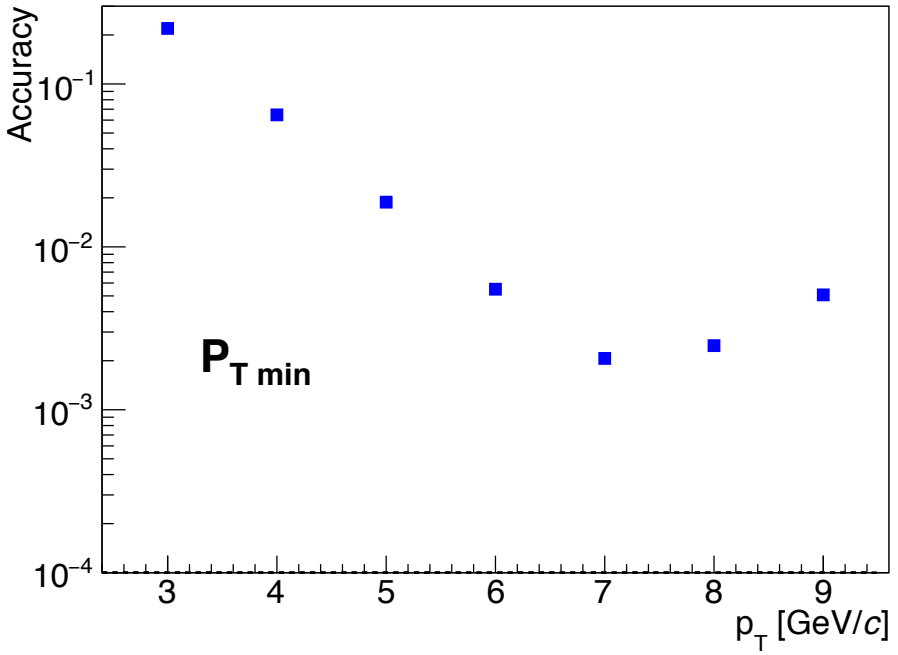
Expected accuracy

The main way to suppress the background is effective reconstruction of π^0 decays and an accurate simulation of setup behaviour.

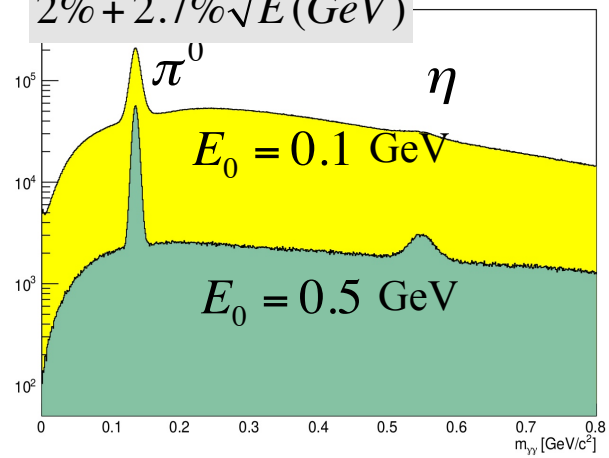


$$\sigma \sim N_{\text{direct}} = N_{\text{single }\gamma} - 2 \times N_{\pi^0} \times k$$

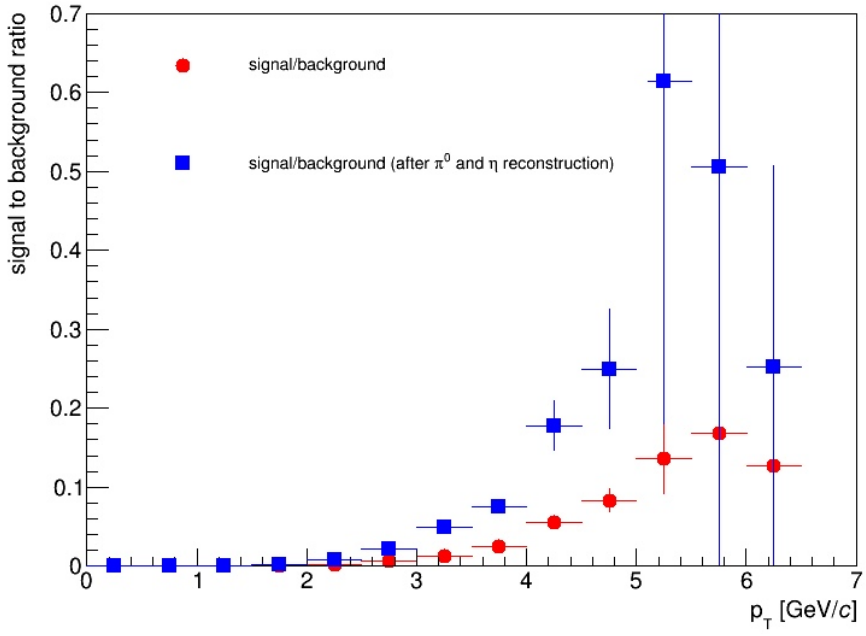
k - from MC data

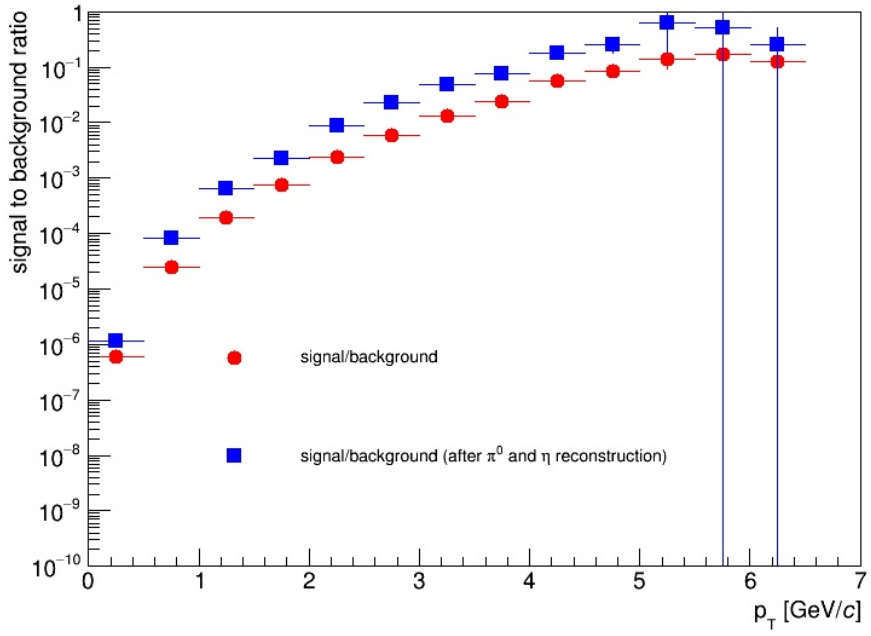


$2\% + 2.7\%\sqrt{E}(GeV)$



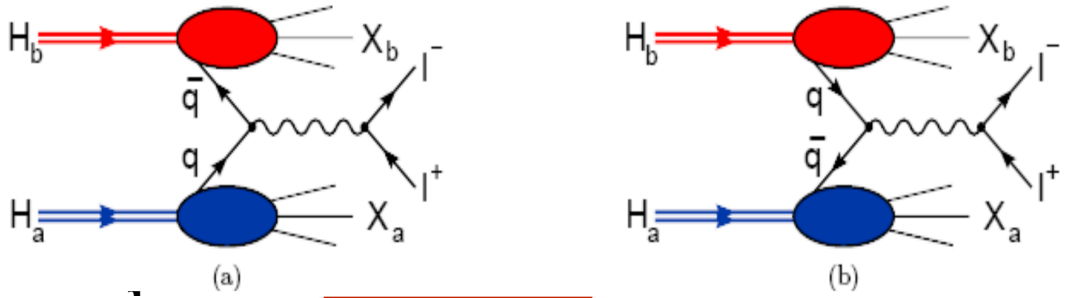
Signal to background ratio



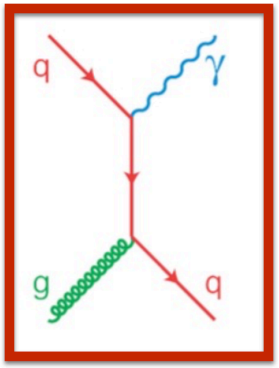


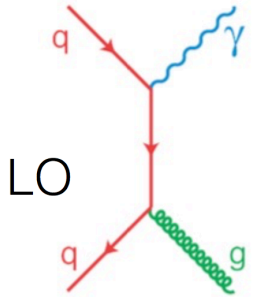
SPD physics tasks

- Drell-Yan pair production



- Direct photons





- Nucleon PDFs by J/psi production

LO $c\bar{c}$ production diagram: