Physics with prompt photons at SPD.

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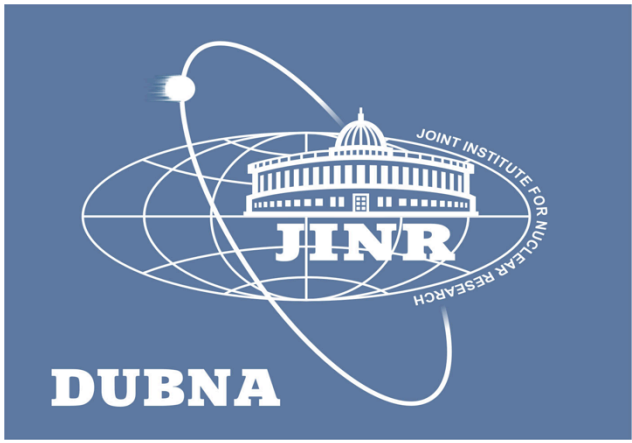
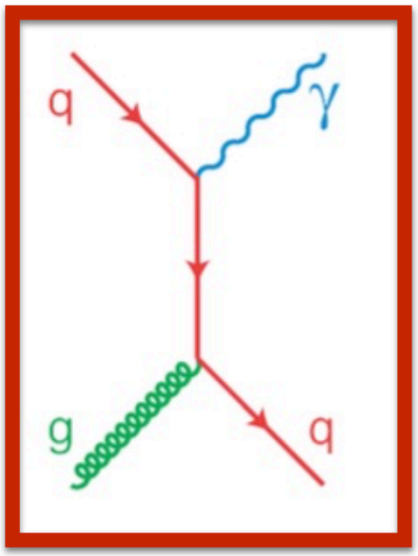
June 5, 2019

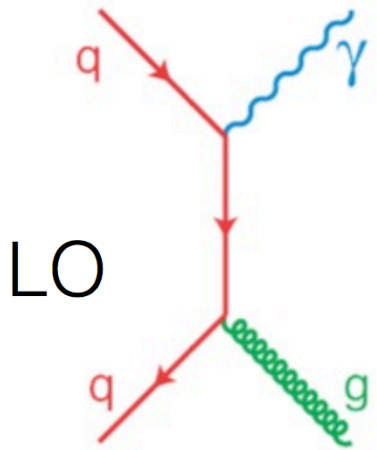


SPD at NICA - 2019

Prompt photons

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





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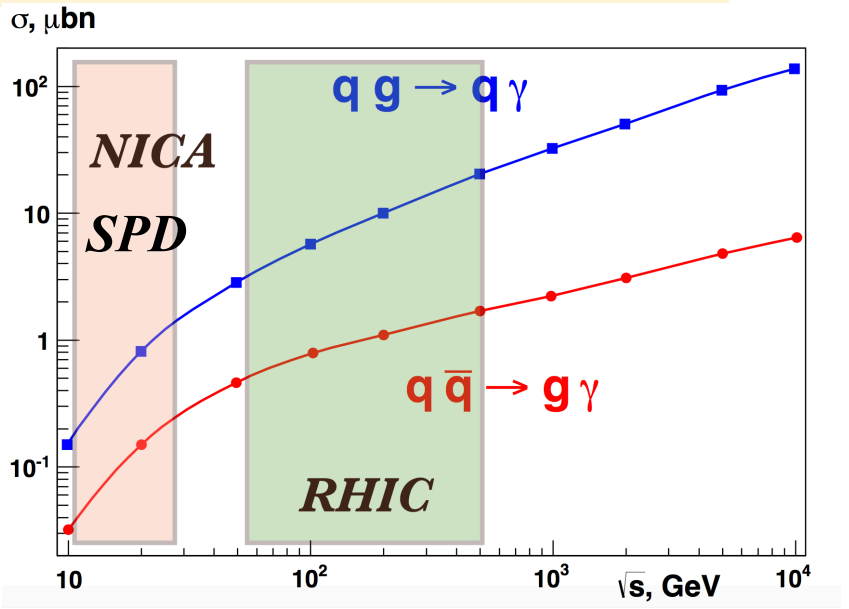


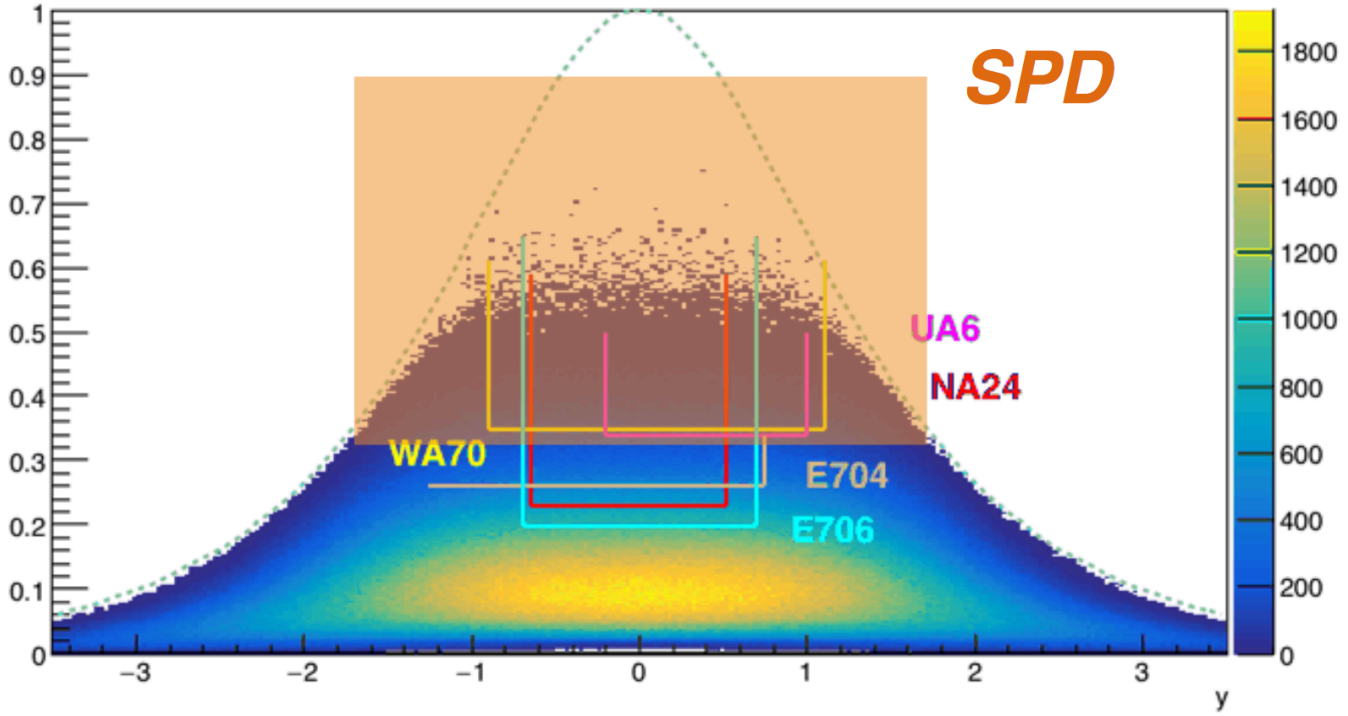
$$d\sigma_{AB} = \sum_{a,b=q,\bar{q},g} \int dx_a dx_b f_a^A(x_a,\mu^2) f_b^B(x_b,\mu^2) d\sigma_{ab\to\gamma X}(x_a,x_b,\mu^2).$$

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

Previous studies

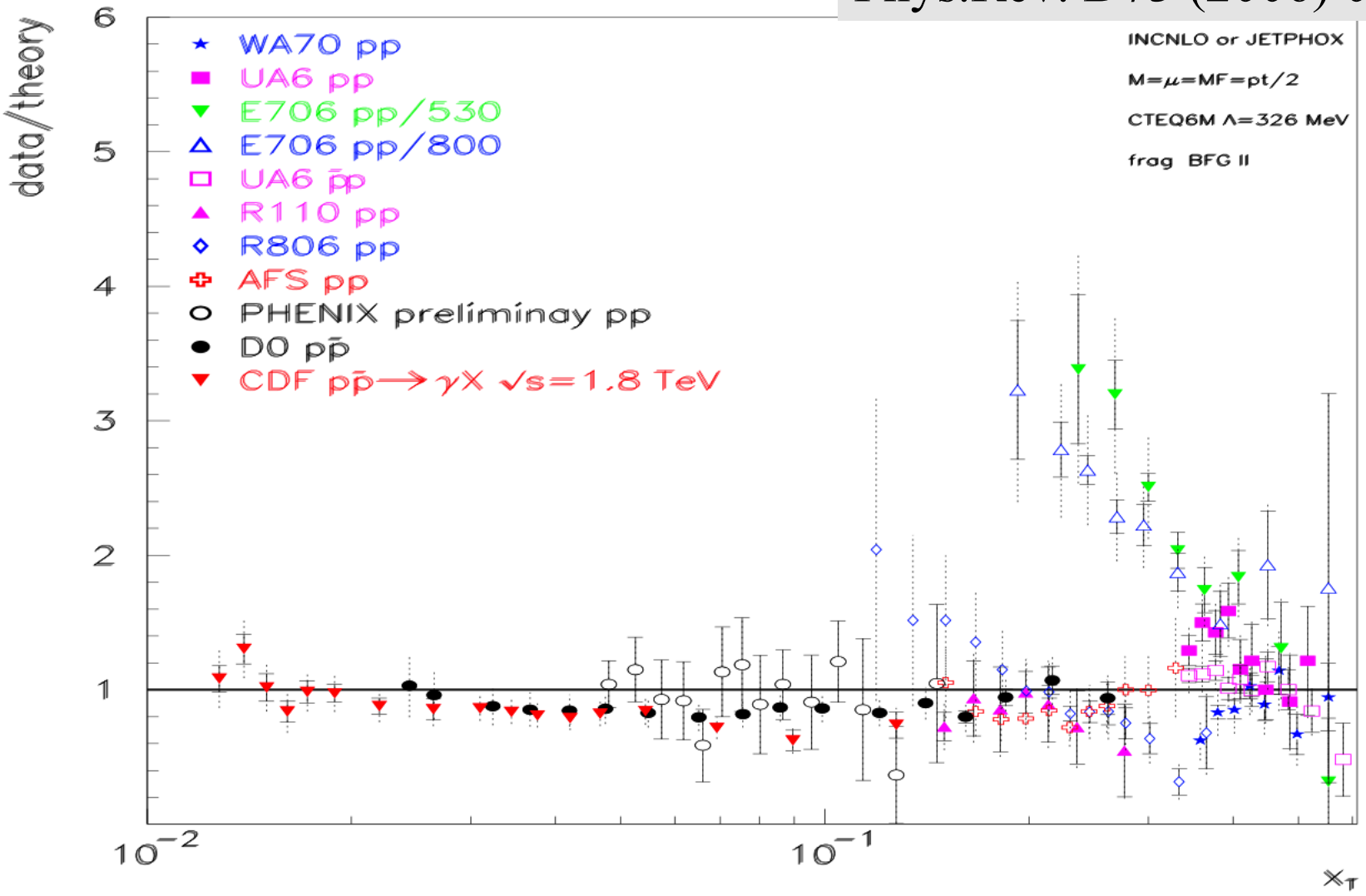
Experiment	Beam and target	$\sqrt{s}$, GeV	y range	x_T range
E95 (1979)	p; Be	19.4, 23.75	-0.7 – 0.7	0.15 – 0.45
E629 (1983)	p, π^+; C	19.4	-0.75 – 0.2	0.22 – 0.52
NA3 (1986)	p, π^+, π^-; C	19.4	-0.4 – 1.2	0.26 – 0.62
NA24 (1987)	p, π^+, π^-; p	23.75	-0.65 – 0.52	0.23 – 0.59
WA70 (1988)	p, π^+, π^-; p	22.96	-0.9 – 1.1	0.35 – 0.61
E706 (1993)	p, π^-; Be	30.63	-0.7 – 0.7	0.20 – 0.65
E704 (1995)	p; p	19.4	<0.74	0.26 – 0.39
UA6 (1993,1998)	$\bar{p}$; p	24.3	-0.2 – 1.0	0.34 – 0.50

$$x_T = \frac{2p_T}{\sqrt{s}}$$

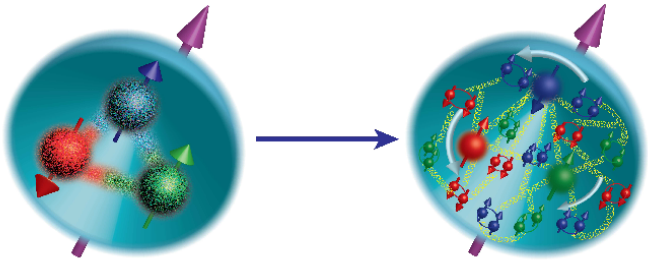


Previous studies (data/theory)

Phys.Rev. D73 (2006) 094007



TMD PDFs



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

Gluon Sivers function

Gluon polarization

3 PDFs are needed to describe nucleon structure in collinear approximation

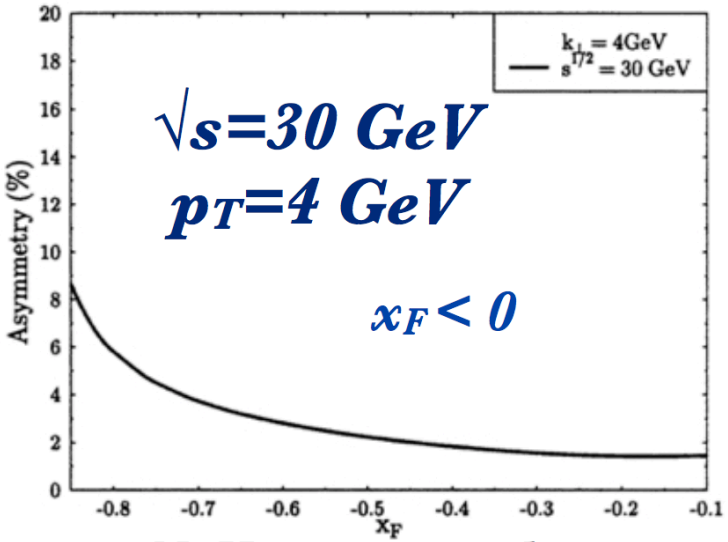
8 PDFs are needed if we want to take into account intrinsic transverse momentum k_T of partons (LO)

Transverse single spin asymmetry

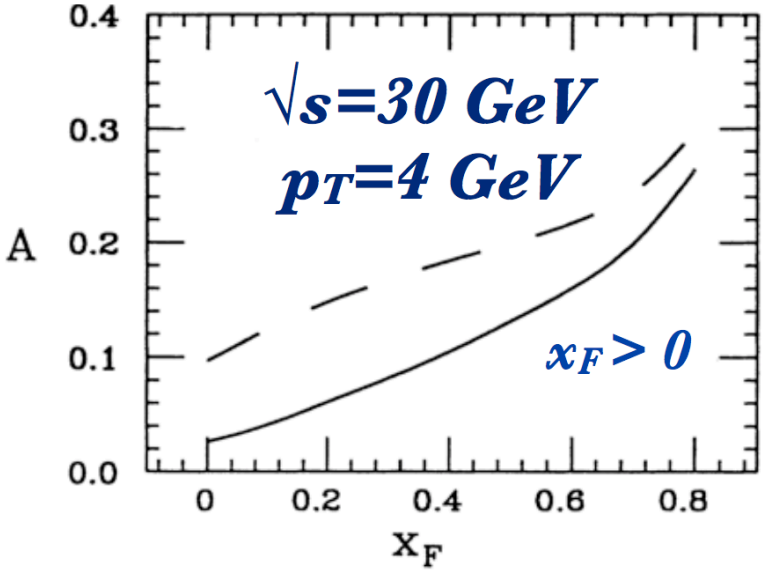
$$A_N = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

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)



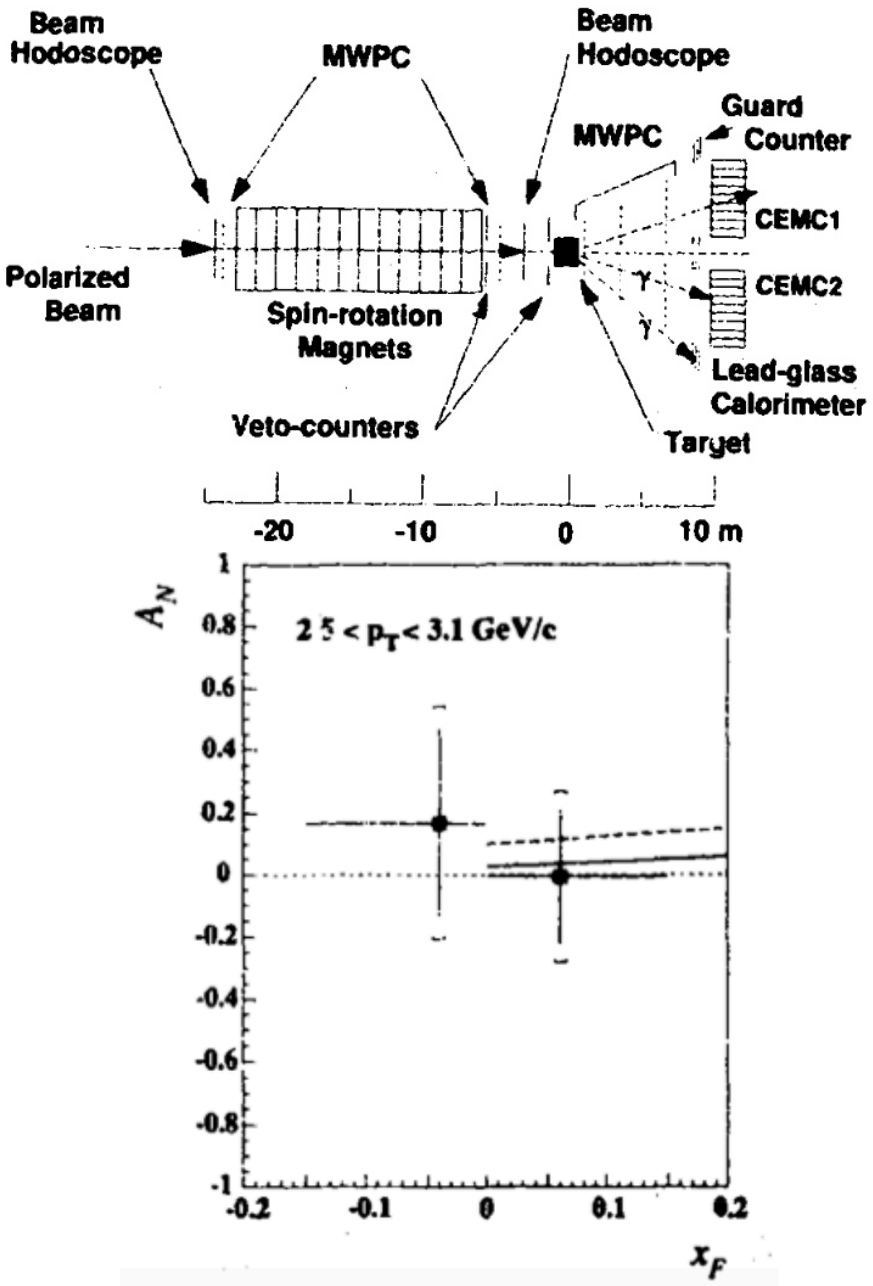
J. Qui and G. Sterman, Phys. Rev. Lett. 67 (1991) 2264

E704 Fermilab

First ever polarised beam

$\sqrt{S} = 19.4$ GeV

- Fixed-target experiment
- pp 200 GeV/c
- Polarized proton beam at 200 GeV/c originated from the decays of Λ-hyperons produced by an incident 800 GeV/c proton beam from the TEVATRON on a Be target



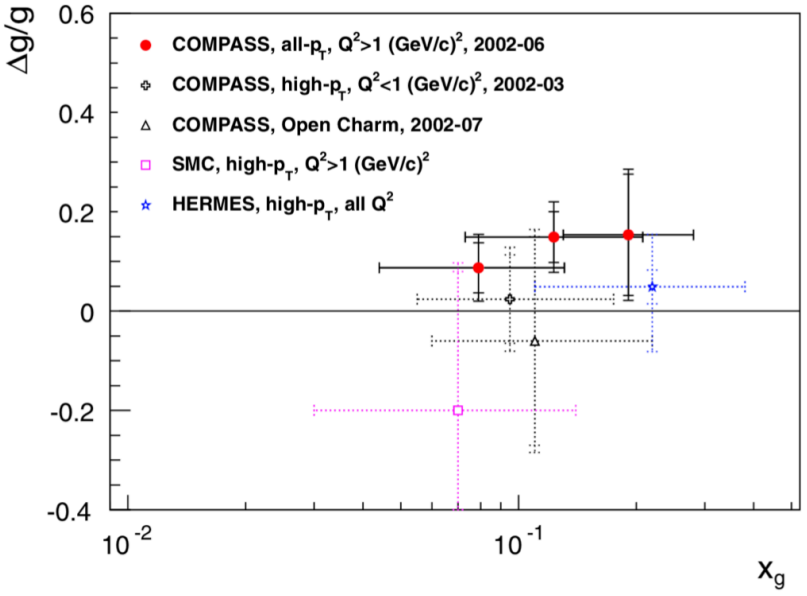
Phys. Lett. B345 (1995) 569 - 575

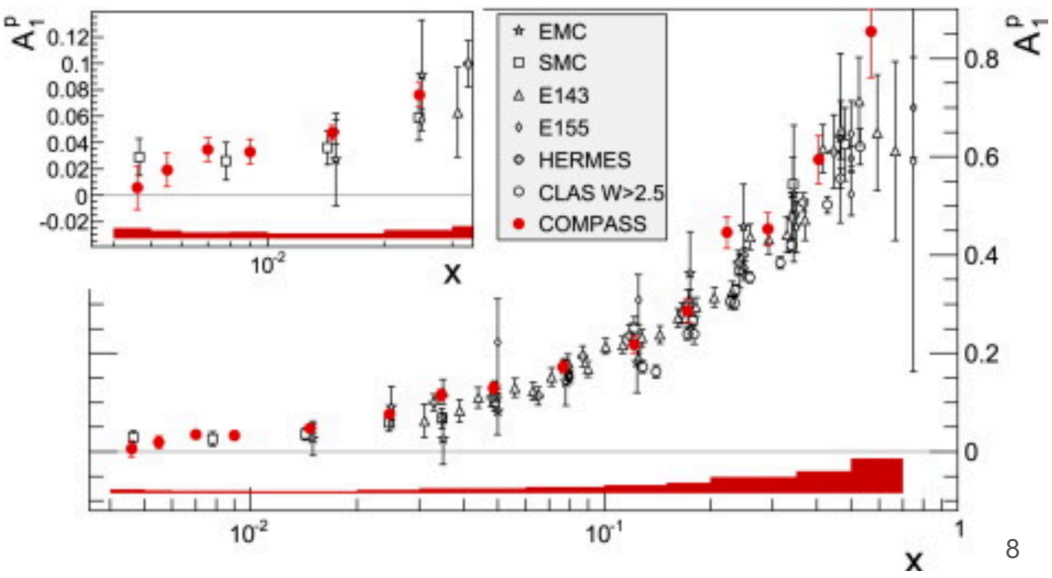
Longitudinal double spin asymmetry

Production of prompt photons at large transverse momentum with longitudinally polarised proton beams is a very promising method to measure gluon polarisation Δg from measurement of the Longitudinal double spin asymmetry A_{LL}, defined as:

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

Gluon polarization

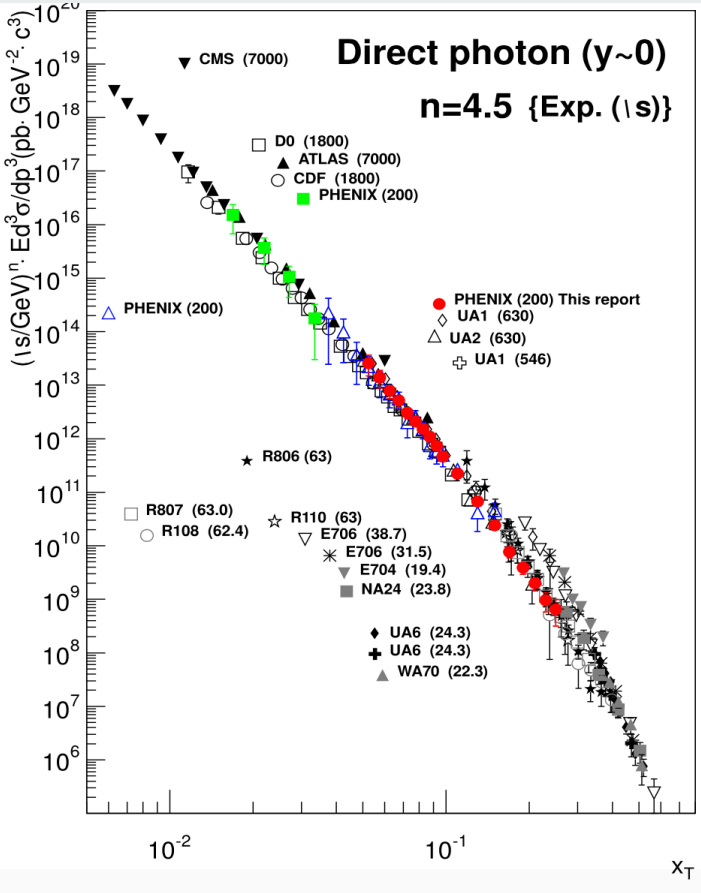




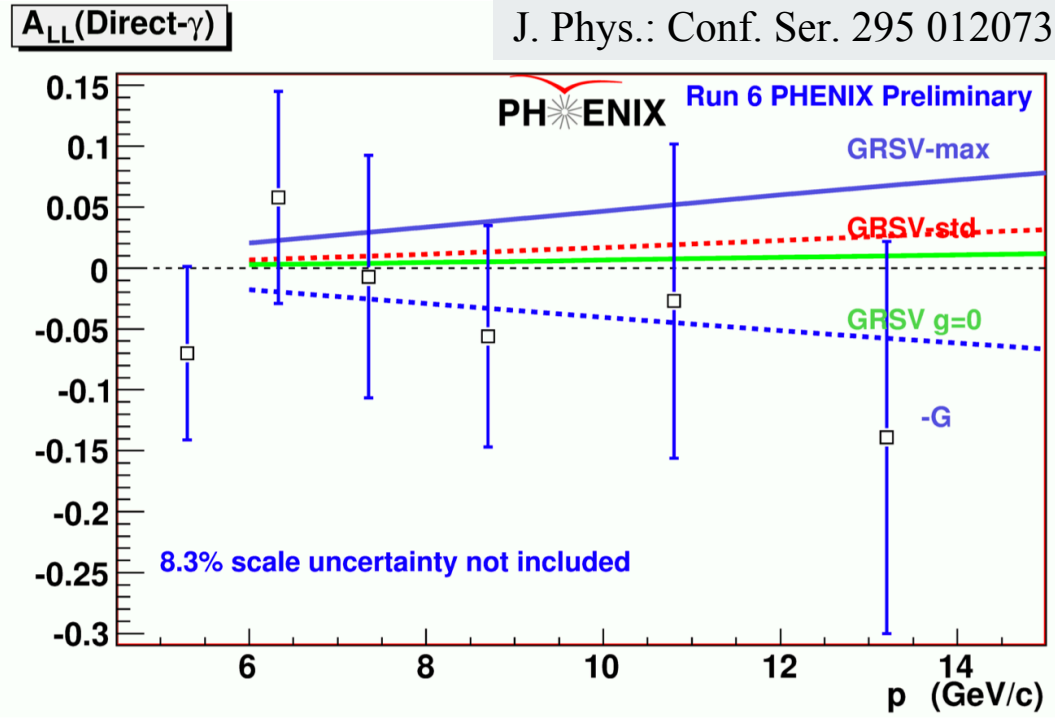
PHENIX

- Collider experiment
- pp $\sqrt{S} = 200$ GeV/c

Nuclear Physics A 910–911 (2013) 209–210



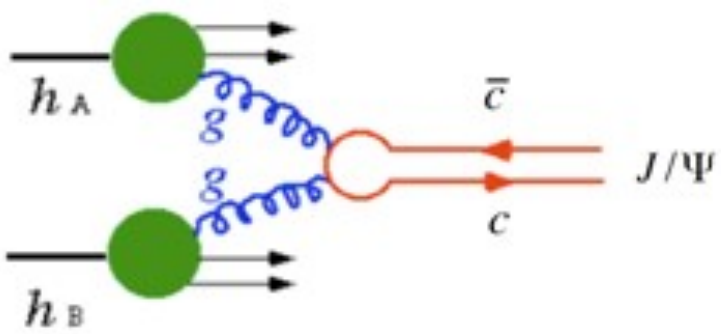
J. Phys.: Conf. Ser. 295 012073



Statistics is limited and it's very difficult to make any conclusions

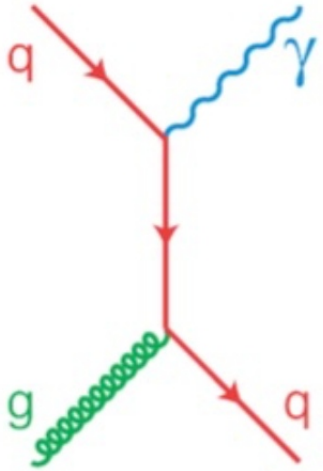
Two ways to study gluon structure

- ❑ J/ψ mesons production



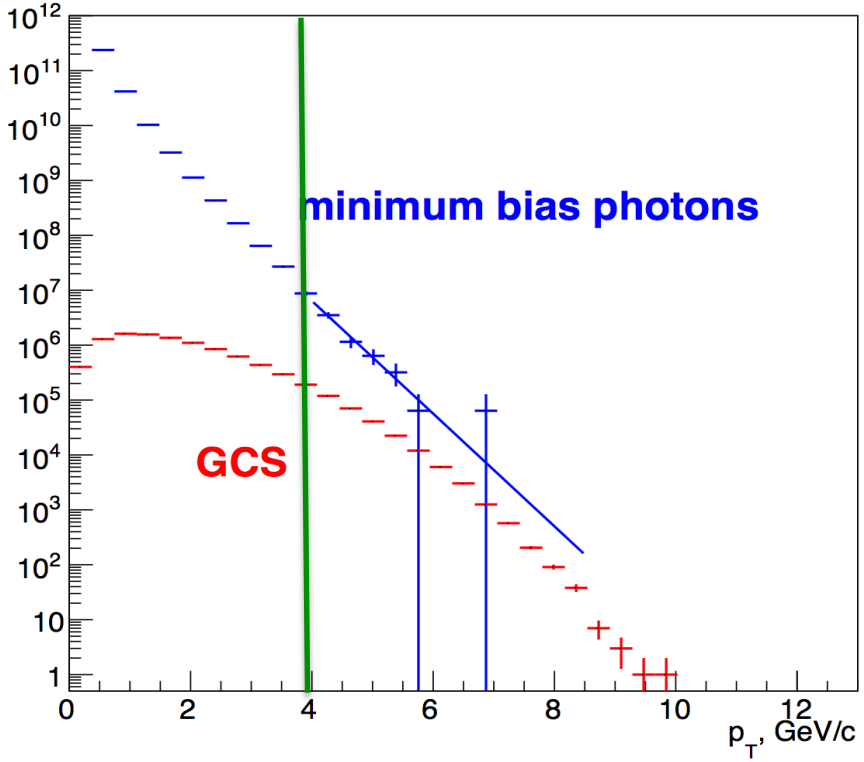
- Good signal
- **Hard to interpret (model dependent)**

- ✓ **Prompt photons production**



- Large background
- **Easy to interpret**
- **Possible to get soft gluons**

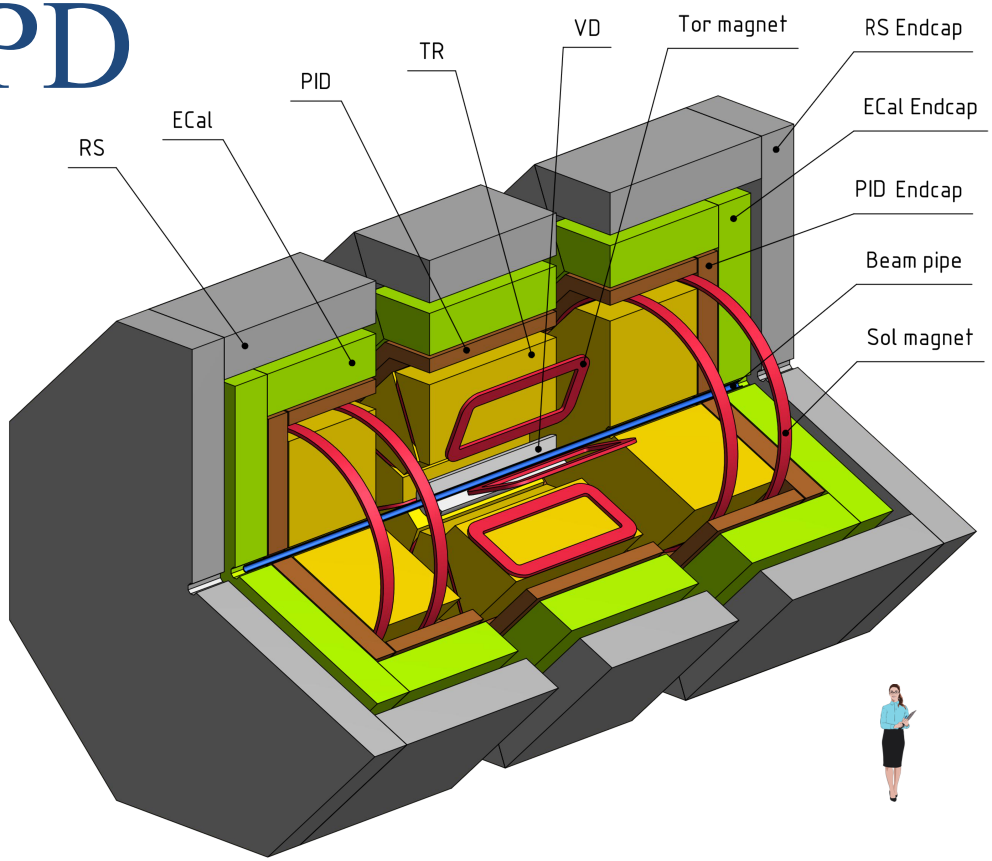
The main source of photons (almost 99%) in proton-proton collision is the production and decay of π^0 and η mesons



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.

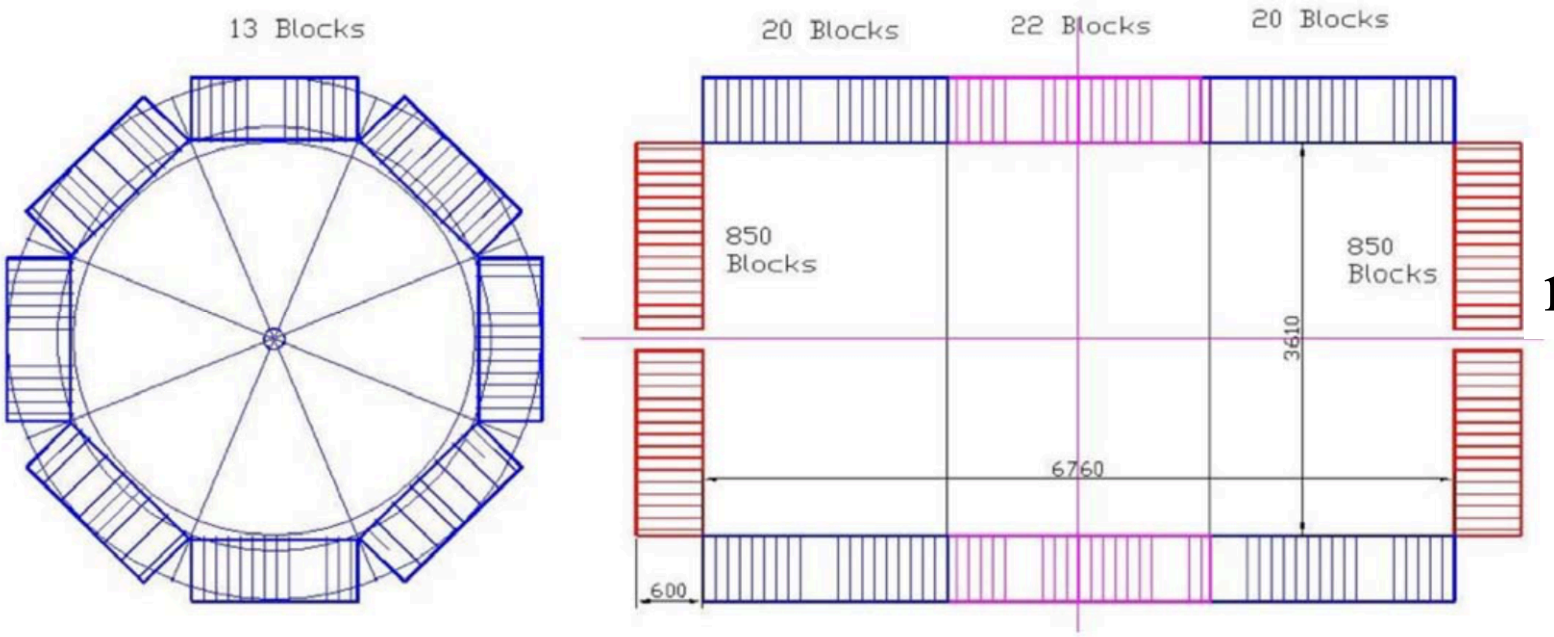
SPD



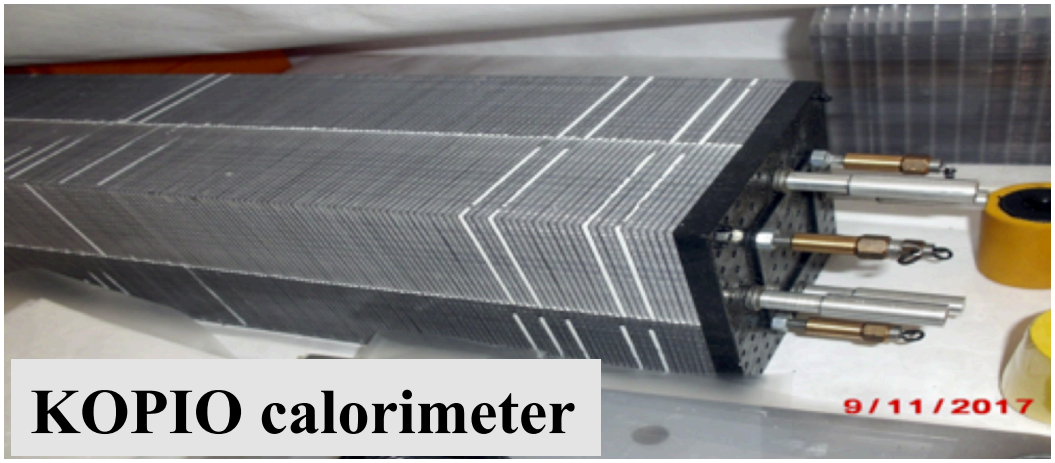
It consists of the 3 parts: 2 endcaps and central one.
Each part has individual magnet system, the endcaps - solenoidal coils, central part - toroidal.

- 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).

Calorimeter



6500 modules

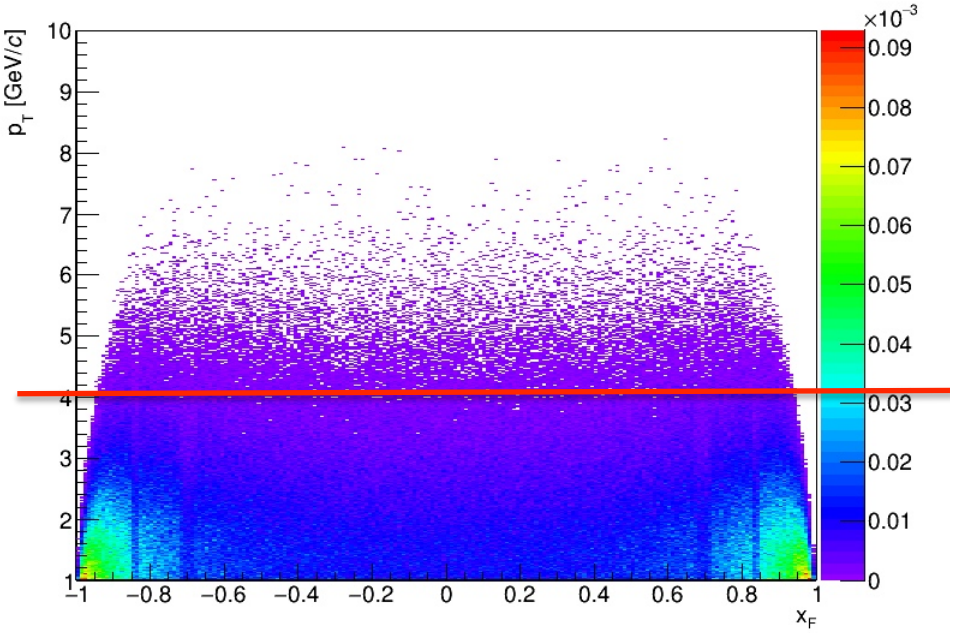


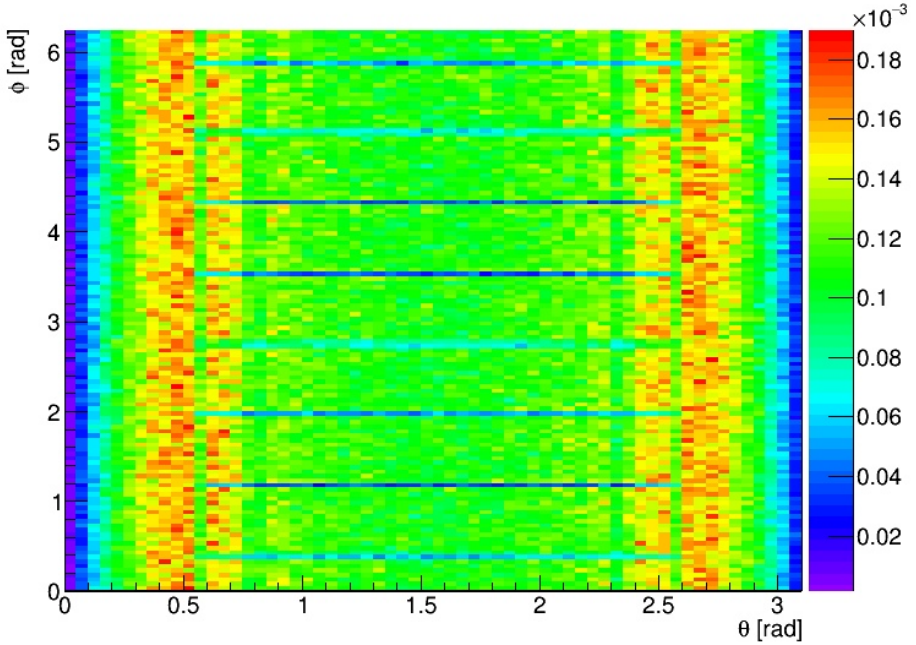
KOPIO calorimeter

- Energy resolution of about $5\%/\sqrt{E(GeV)}$
- Energy threshold below 100 MeV
- Granularity < 10 cm
- 12.5 X_0

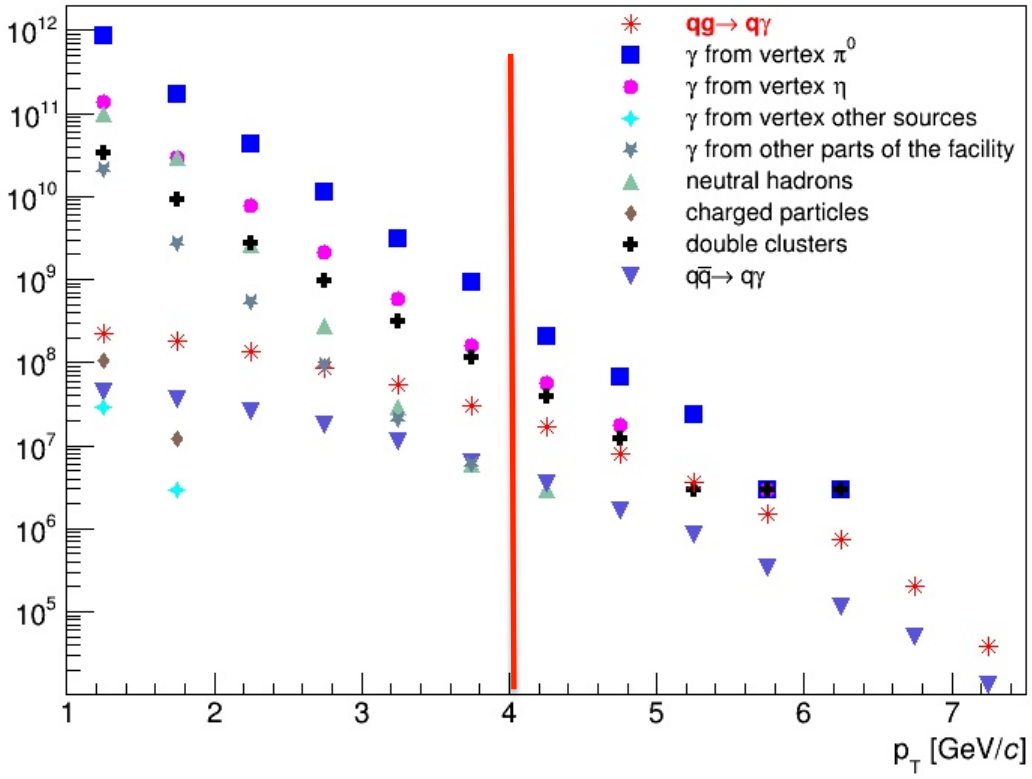
Prompt photons at SPD

Monte Carlo data using SPD root and Pythia 6 generator (GCS).





Main background sources

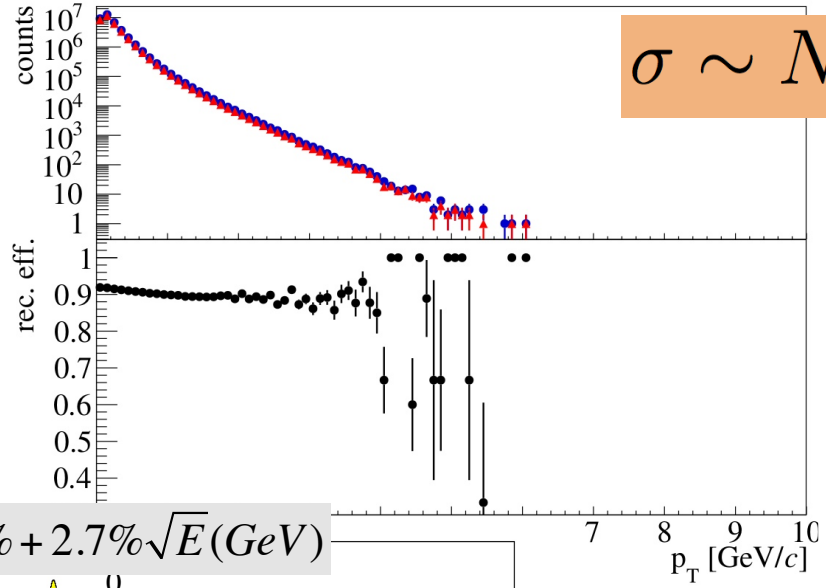


- **π° Decay**
- **η-meson decay**
- **double clusters**
- **neutral hadrons (n,K,Λ)**
- **charged particles**

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.

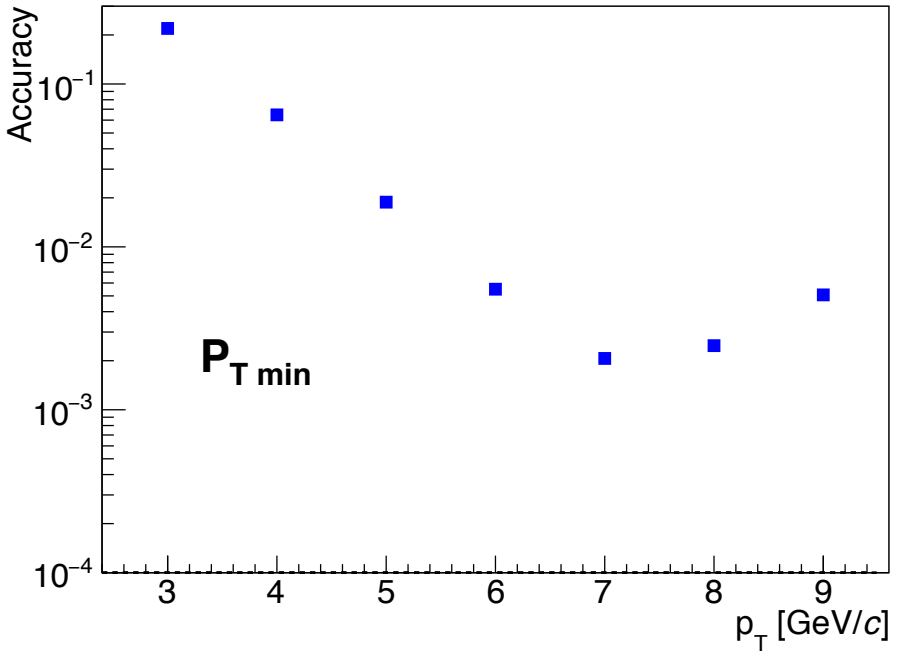
Expected accuracy

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

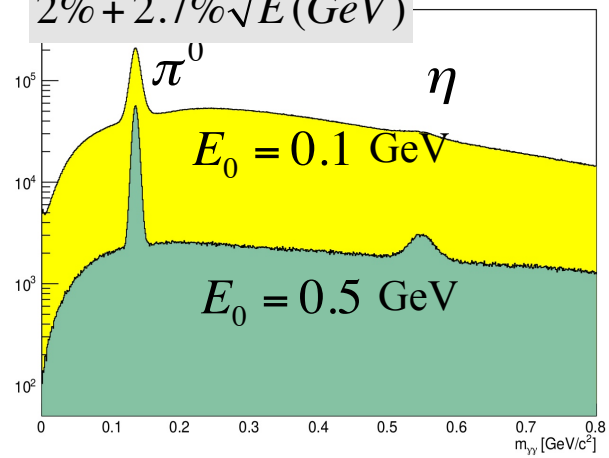


$$\sigma \sim N_{\text{direct}} = N_{\text{single }\gamma} - 2 \times N_{\pi^0} \times k$$

k - from MC data

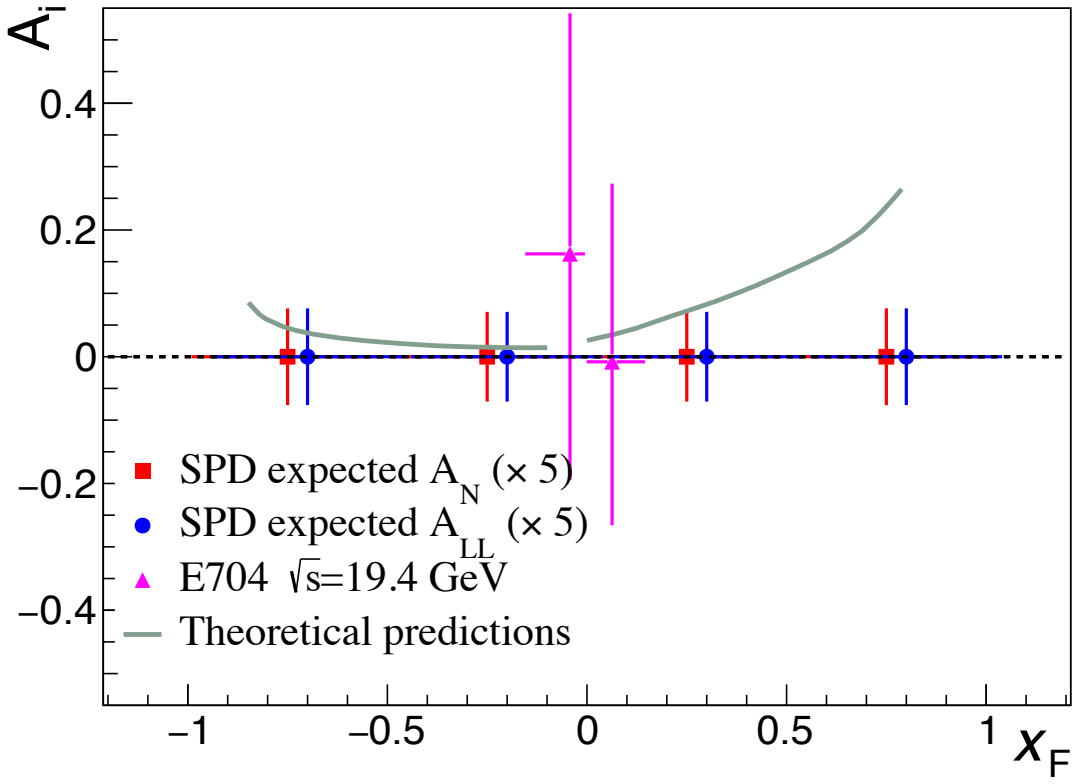


$2\% + 2.7\%\sqrt{E}(GeV)$



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.



- Polarisation = 100 %
- dk/k = 2%.
- $p_{T_{\min}} = 6$ GeV

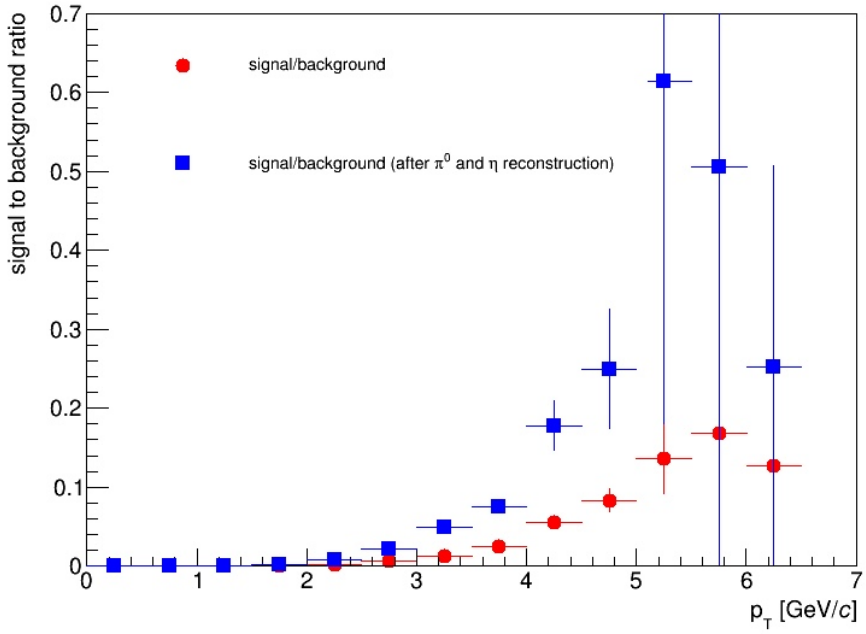
Summary

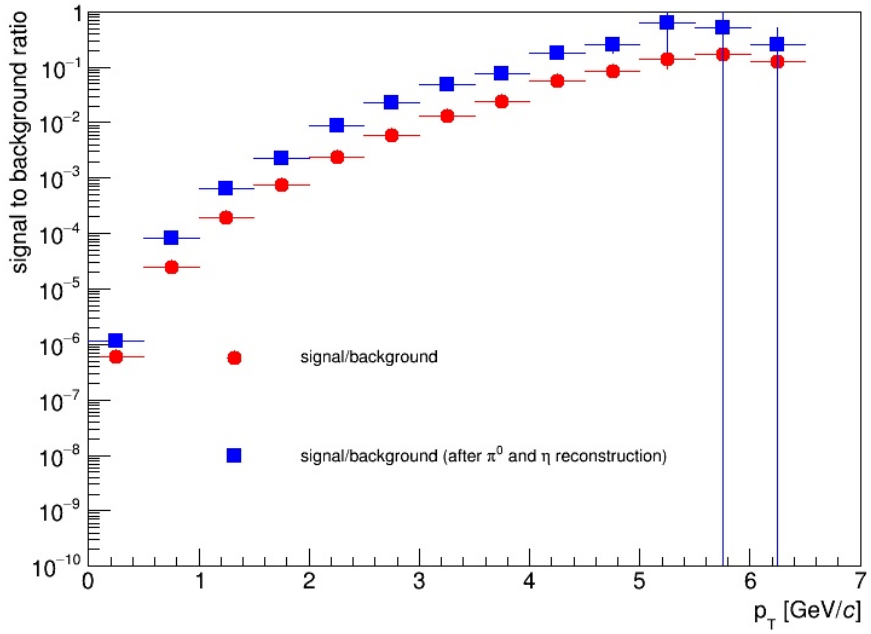
Prompt photons provide an information about polarased and non-polarised gluon component of the proton

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

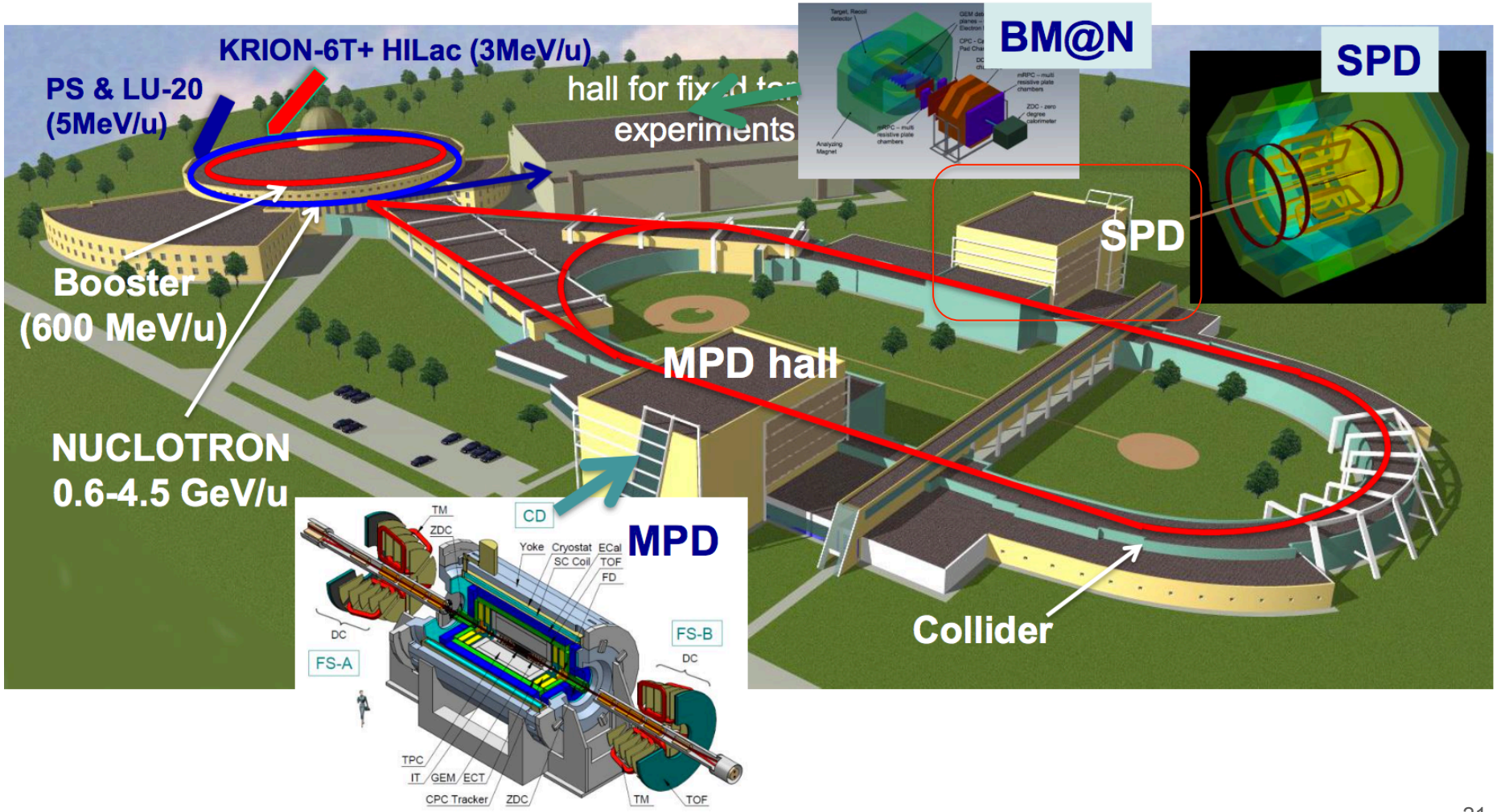
Backup

Signal to background ratio



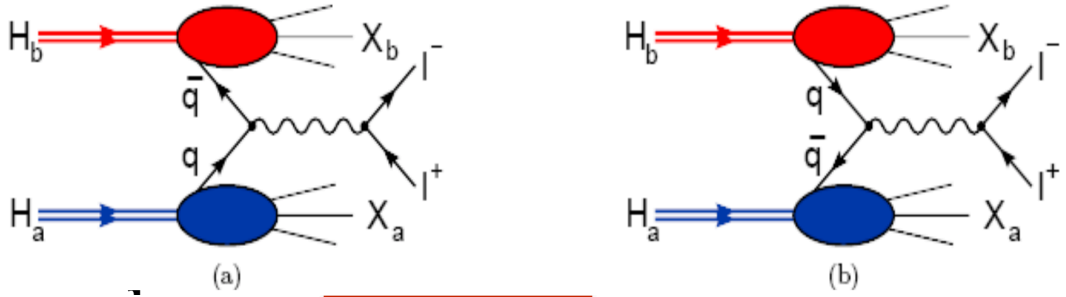


NICA (Nuclotron based Ion Collider fAcility)

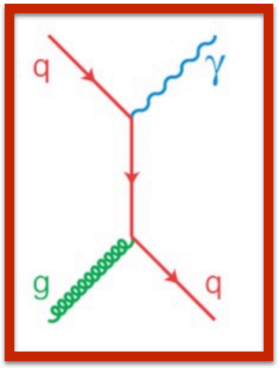


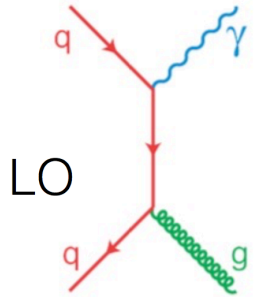
SPD physics tasks

- Drell-Yan pair production



- Direct photons





- Nucleon PDFs by J/psi production

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