Physics with prompt photons at SPD

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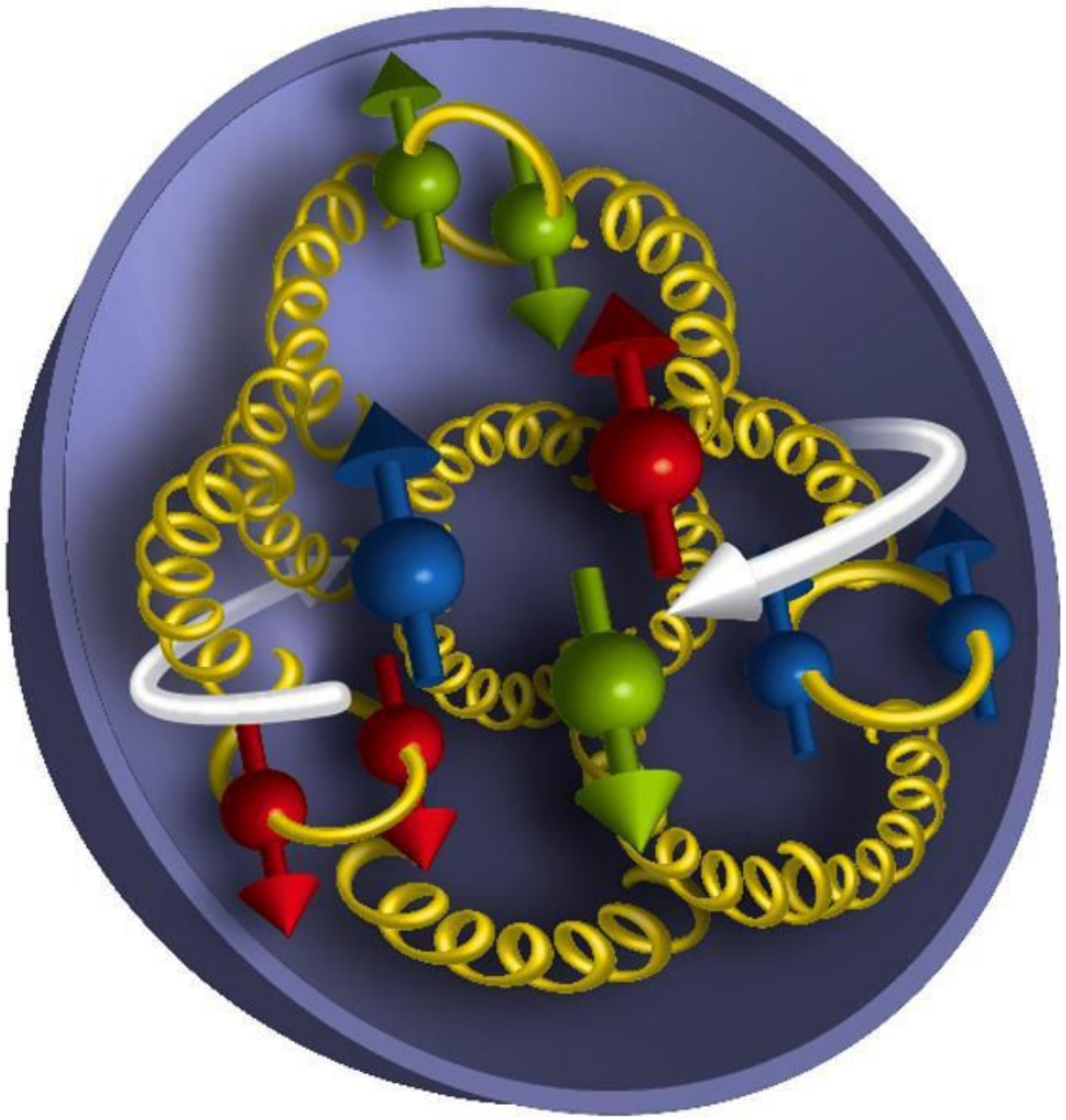
on behalf of
the SPD working group

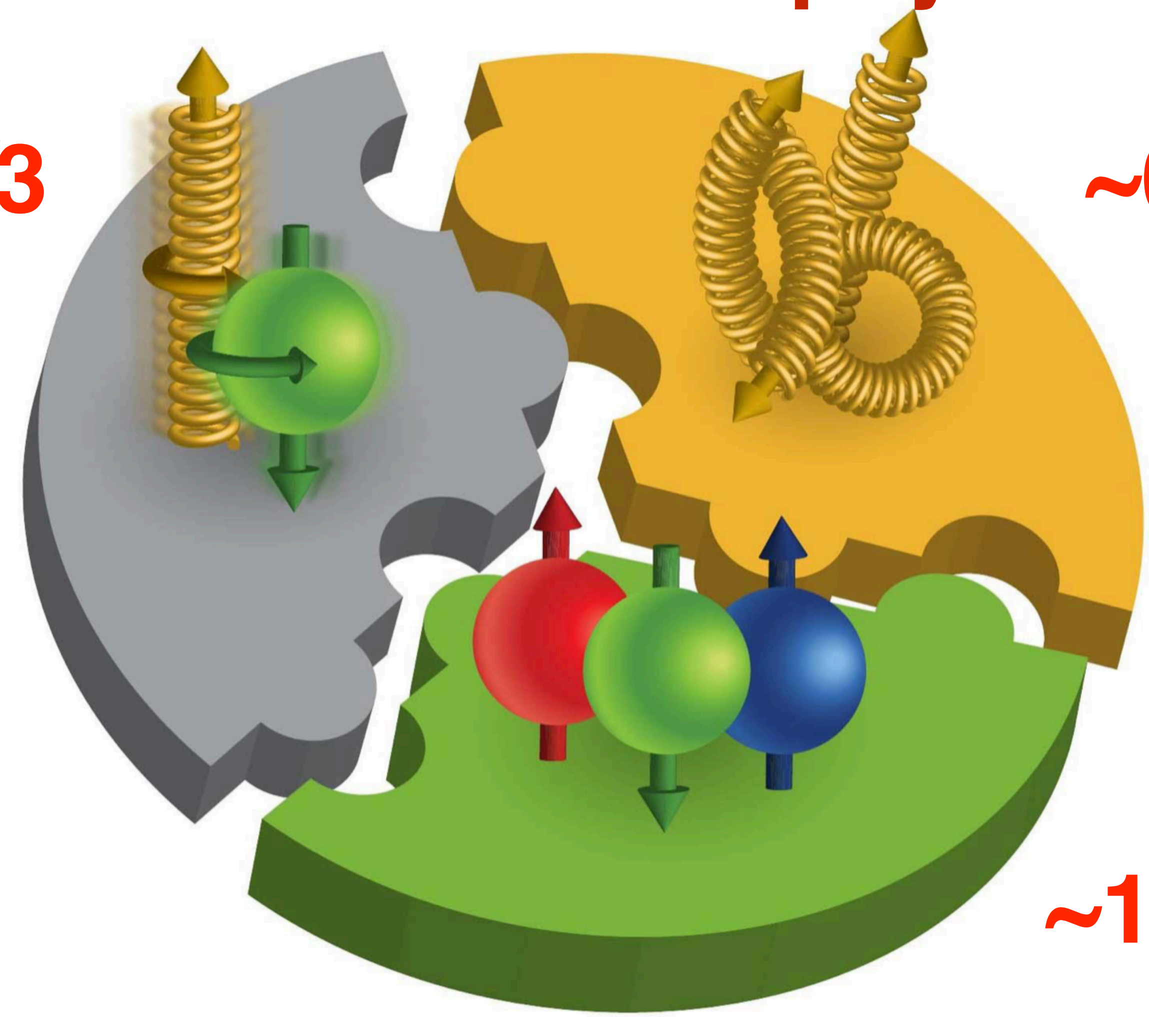
2.9.2019

DSPIN-19

Gluon content of nucleon

Gluon contribution to spin of nucleon is an actual question of hadron physics

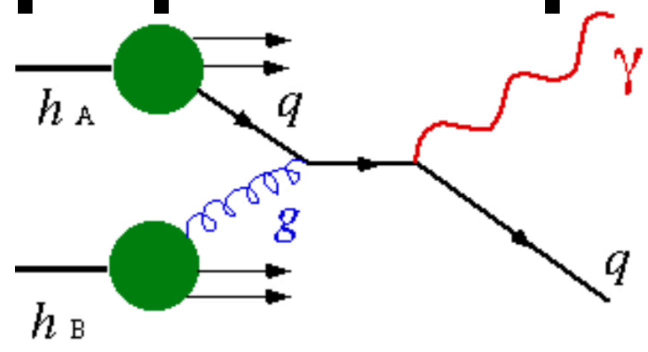




$$S_N = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L$$

Ways to access gluon structure of nucleon at low energies

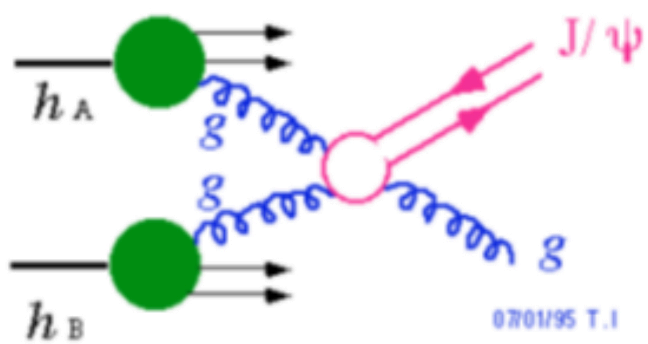
- prompt-photon production



The most direct way

Hard background

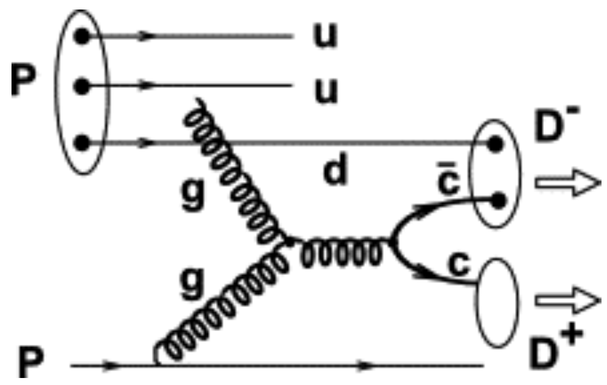
- charmonia production



Nice signal

Model-dependent treatment

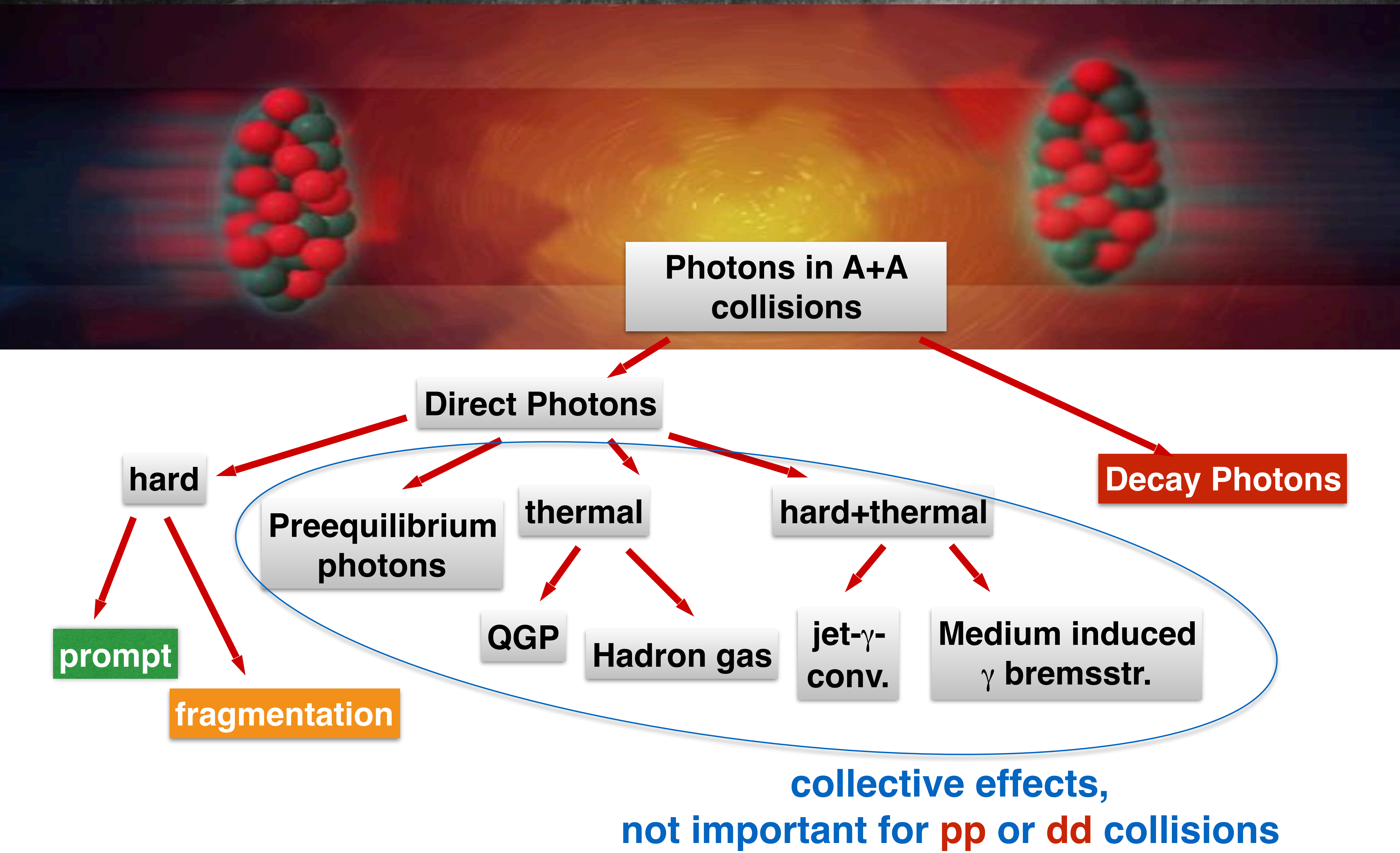
- open-charm production



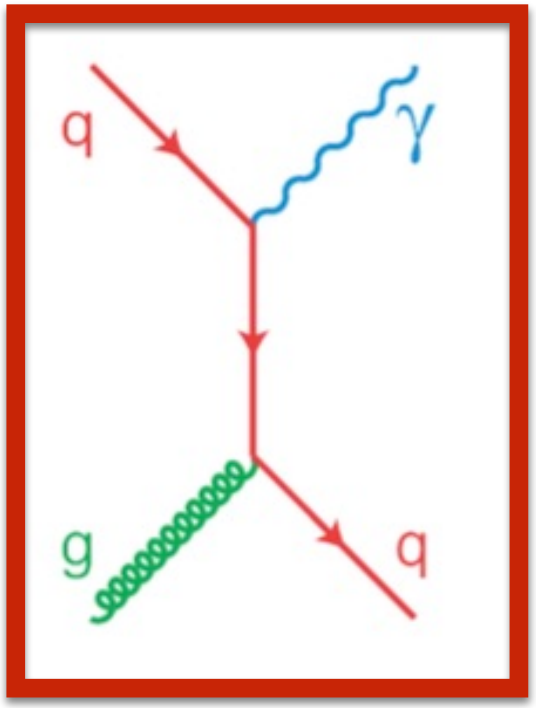
Rather simple treatment

Problematic signal

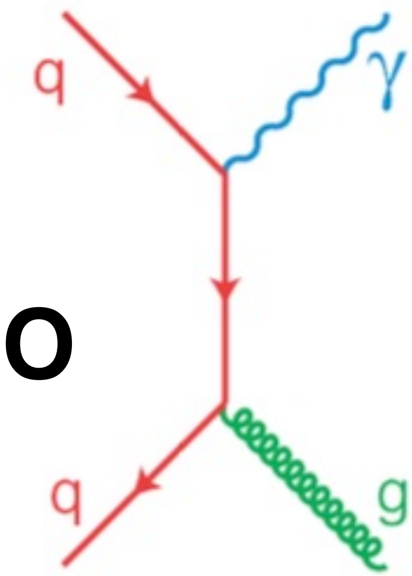
Production of photons in hadron collisions



Prompt photons

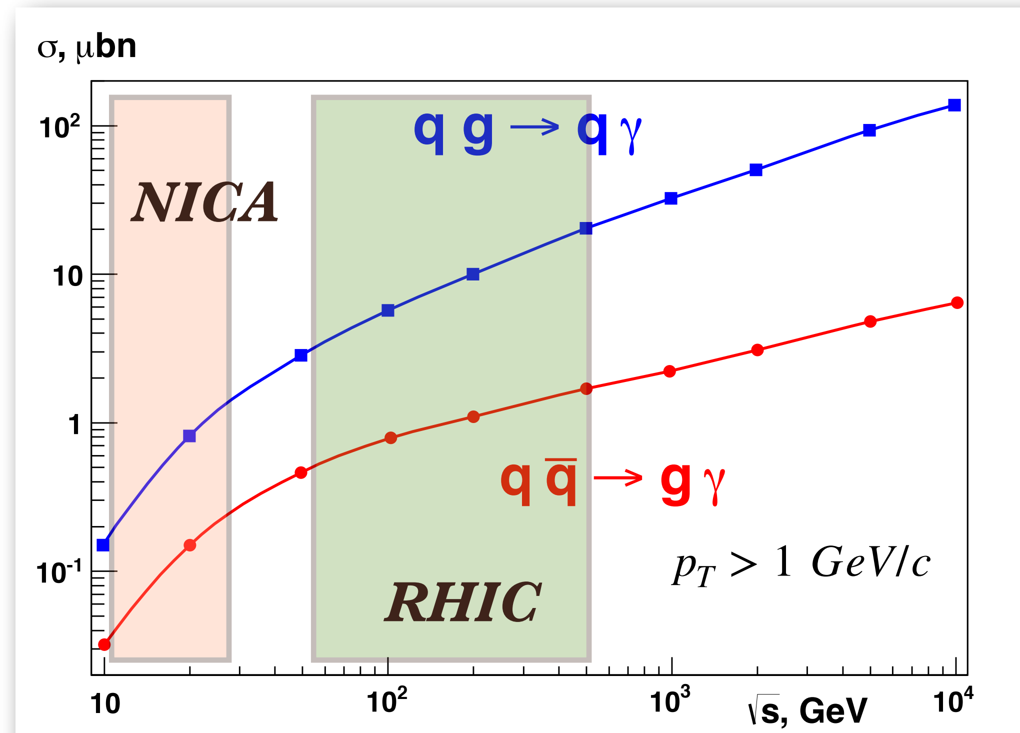


LO

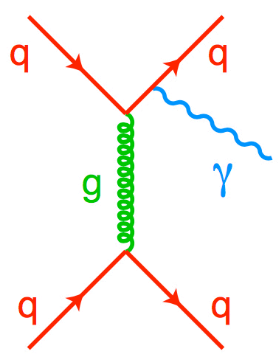


$$\hat{\sigma}_{qg\to q\gamma} = \frac{\pi\alpha_s\alpha}{3\hat{s}}\left(\frac{\hat{u}}{\hat{s}} + \frac{\hat{s}}{\hat{u}}\right)$$

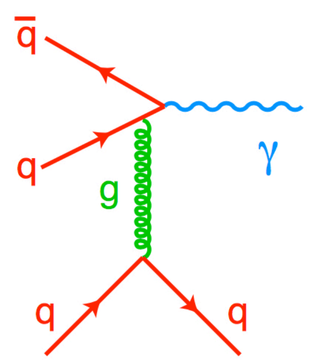
$$\hat{\sigma}_{q\bar{q}\to g\gamma} = \frac{8\pi\alpha_s\alpha}{9\hat{s}}\left(\frac{\hat{u}}{\hat{t}} + \frac{\hat{t}}{\hat{u}}\right)$$



NLO



Bremsstrahlung

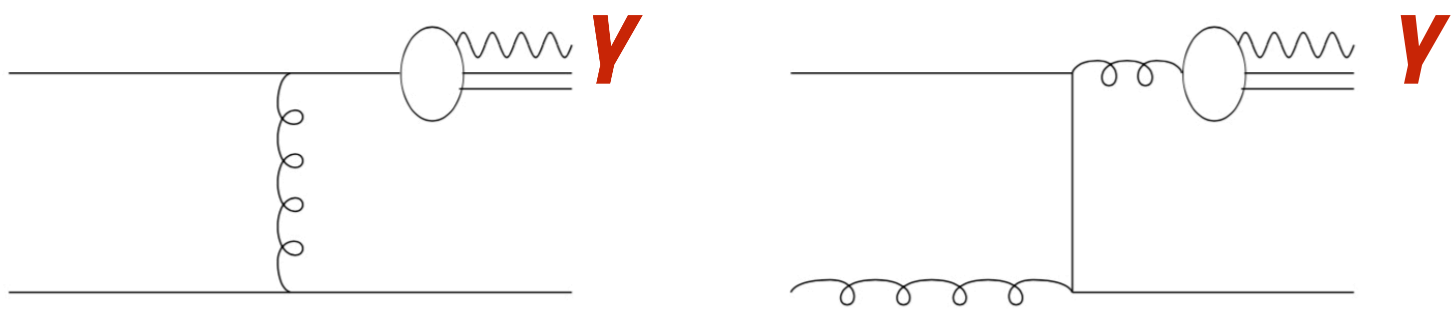


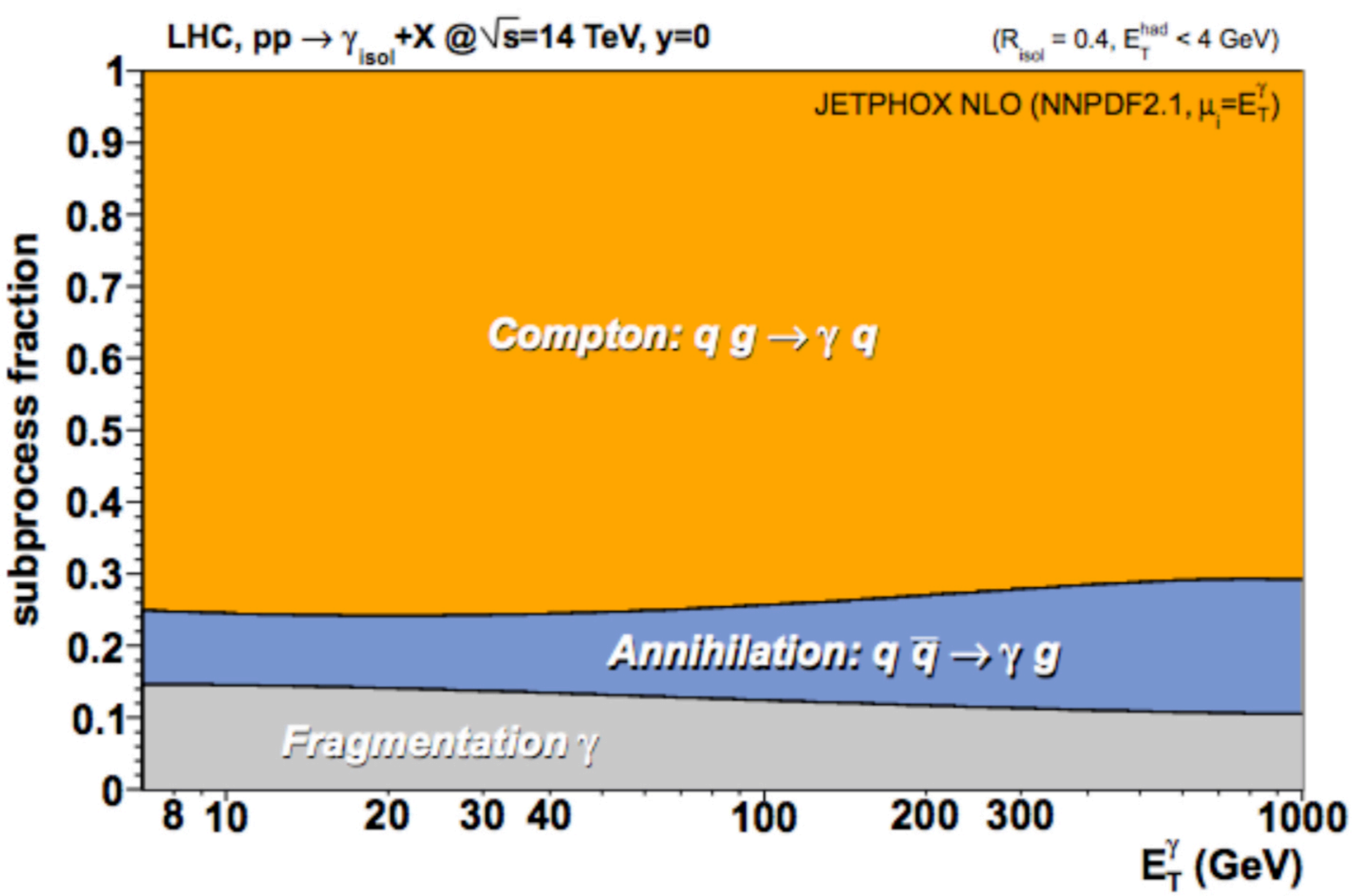
annihilation with scattering

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

$$\mu \sim \frac{p_T}{2}$$

Fragmentation photons





Relative contribution of fragmentation photons is below 15% even at much higher energies.

It can be calculated in LO and NLO

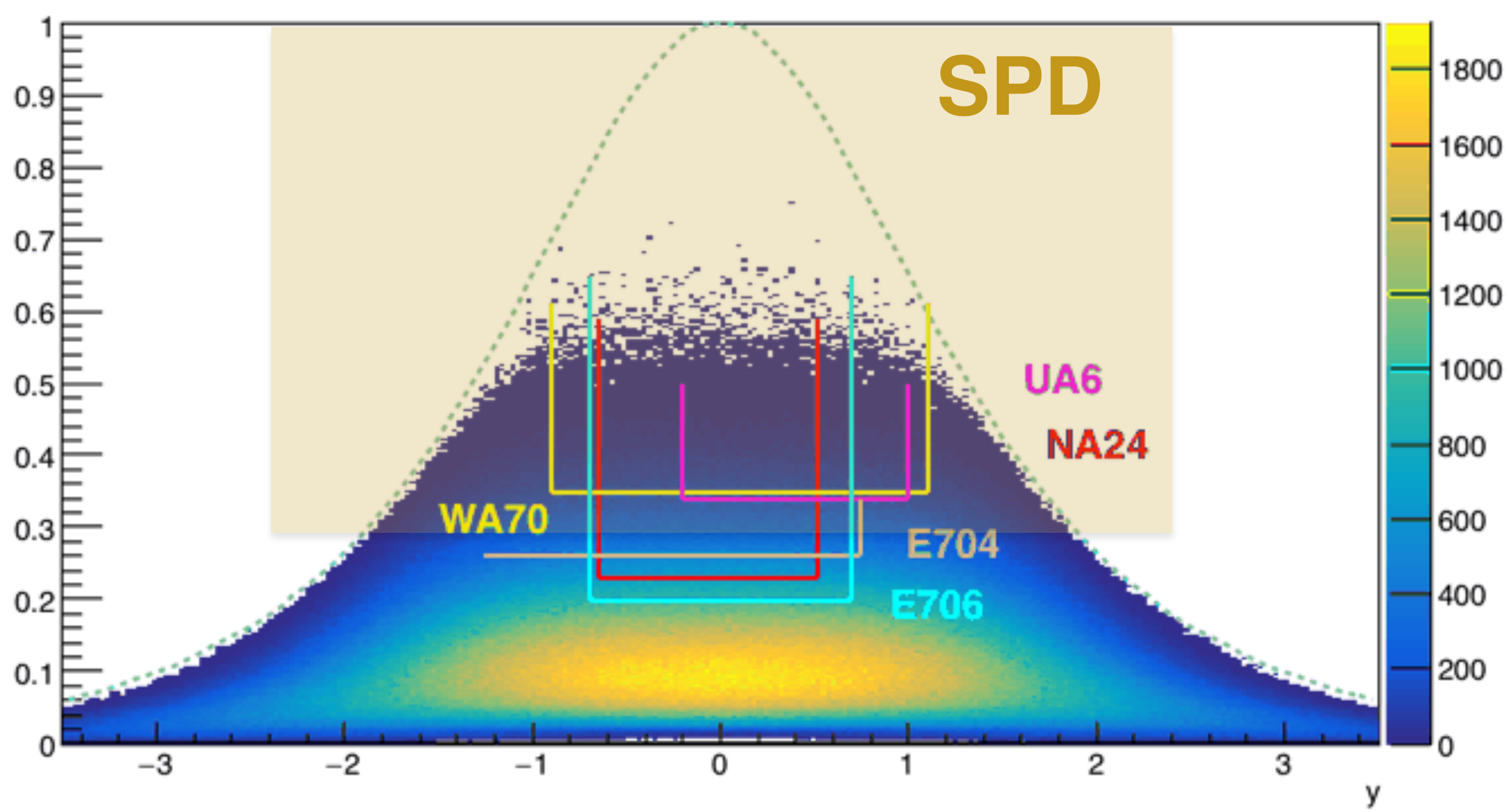
Previous studies at our energies

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

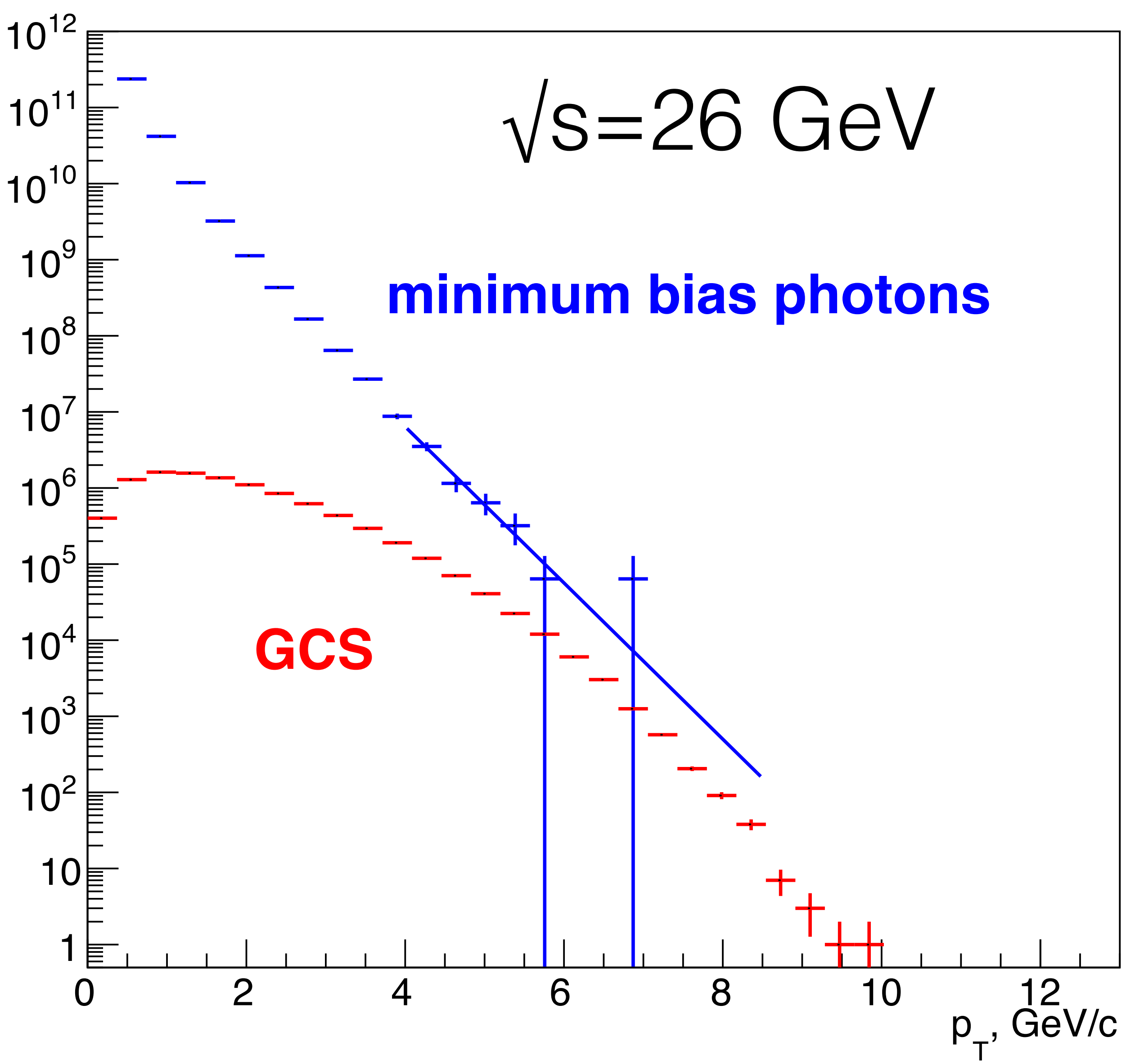
Fixed target experiments

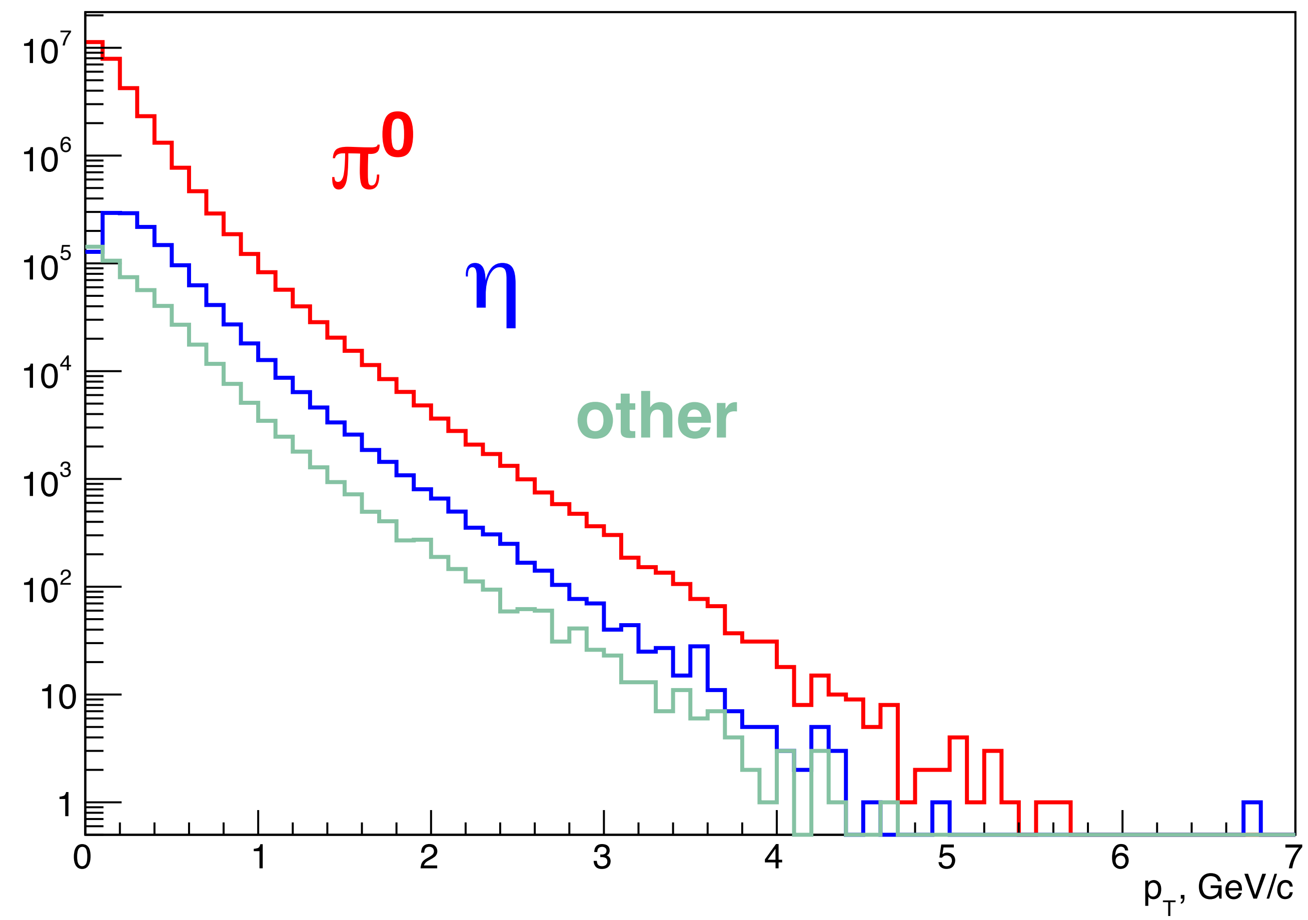
—polarised

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



Decay photons



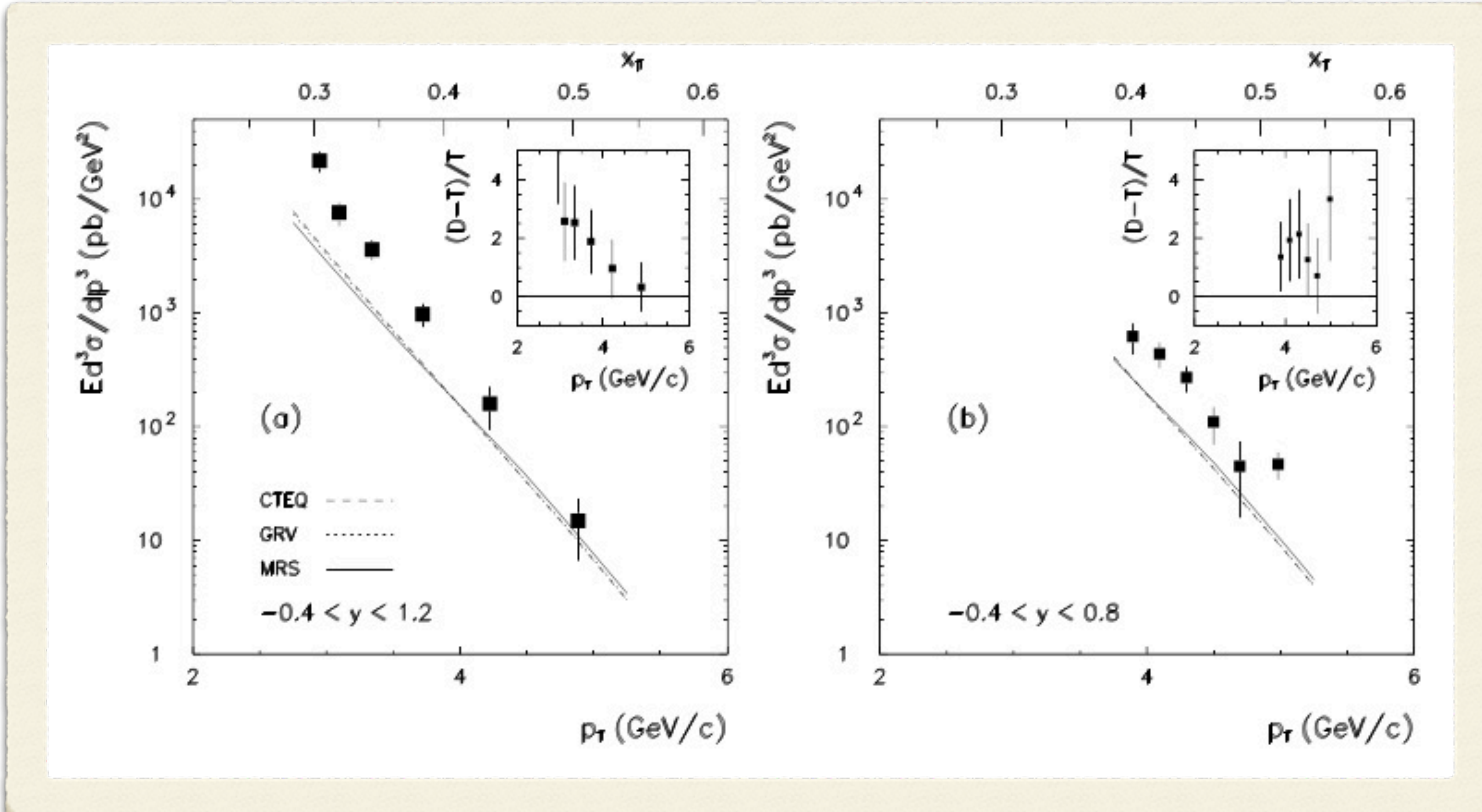


Even at very high p_T signal dominates over background !

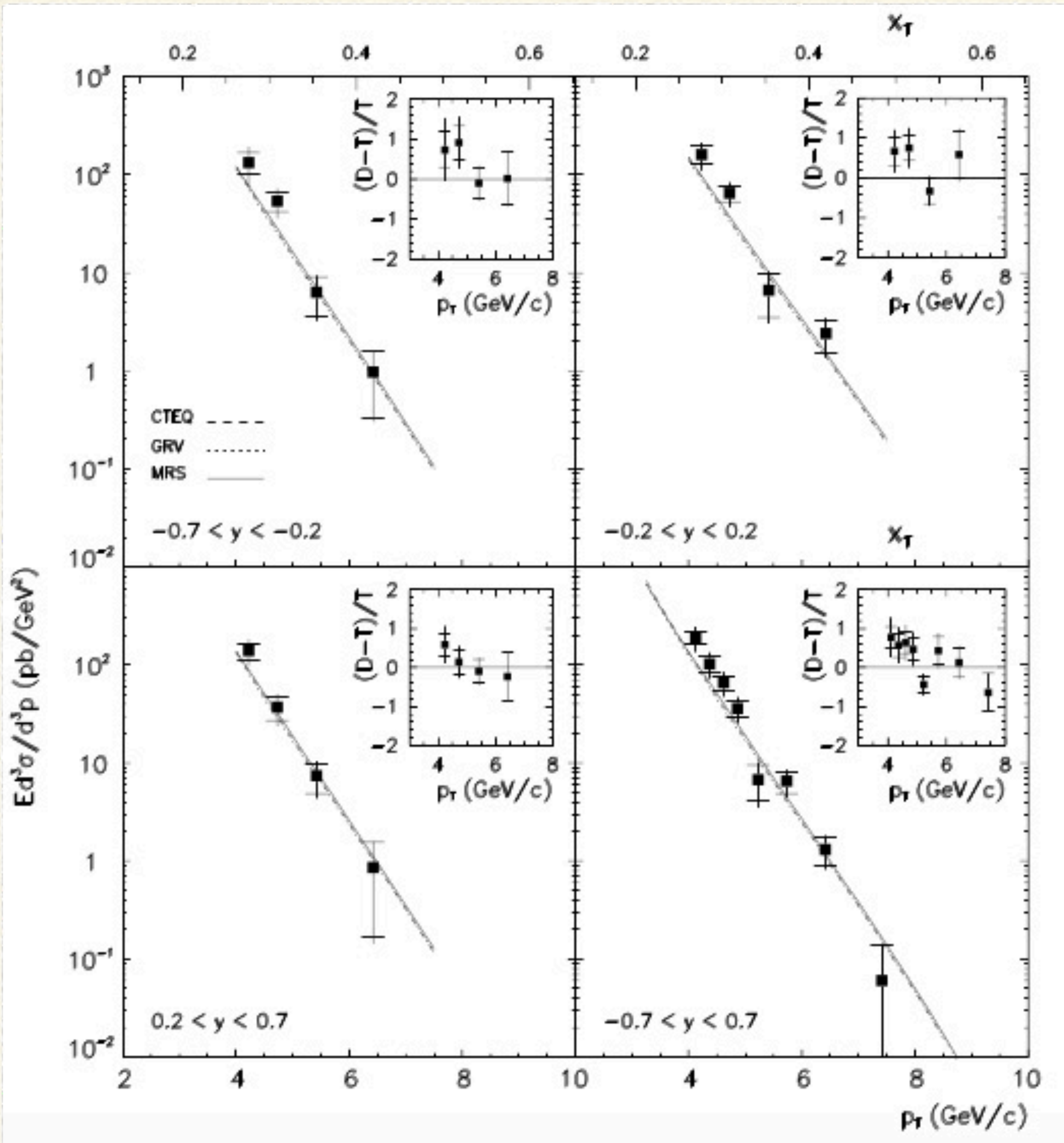
Previous results: pA

J. Phys. G: Nucl. Part. Phys. **23** (1997) A1–A69.

NA3 (1987) $p\,C \rightarrow \gamma\,X$



Previous results: pA



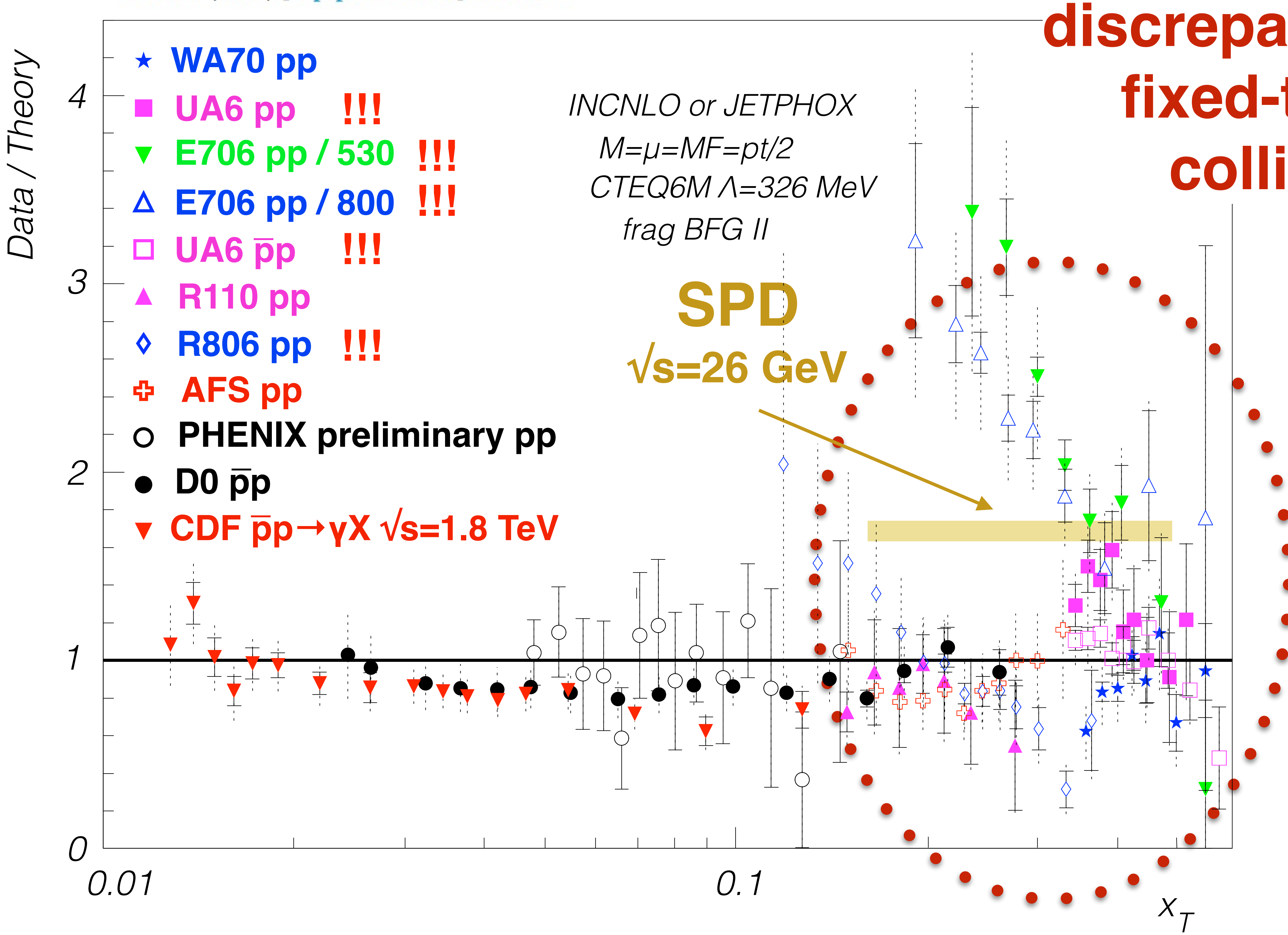
E706 (1993)

$p\,Be \rightarrow \gamma\ X$

Previous results: pp(pbar)

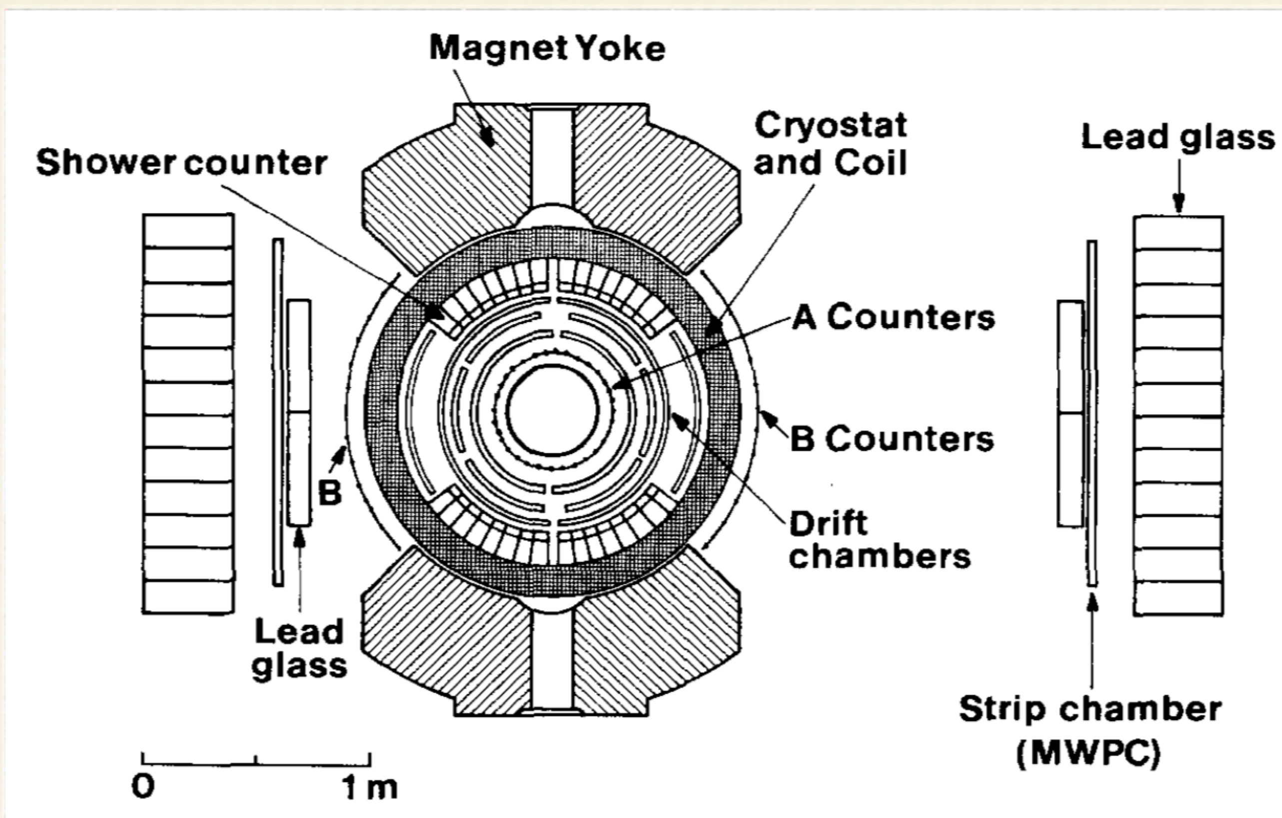
P. Aurenche, M. Fontannaz, J.-P. Guillet, E. Pilon, and M. Werlen, *A New critical study of photon production in hadronic collisions*, Phys. Rev. **D73**, 094007 (2006) [hep-ph/0602133]. xi, 70, 71

Longstanding discrepancy between fixed-target and collider data

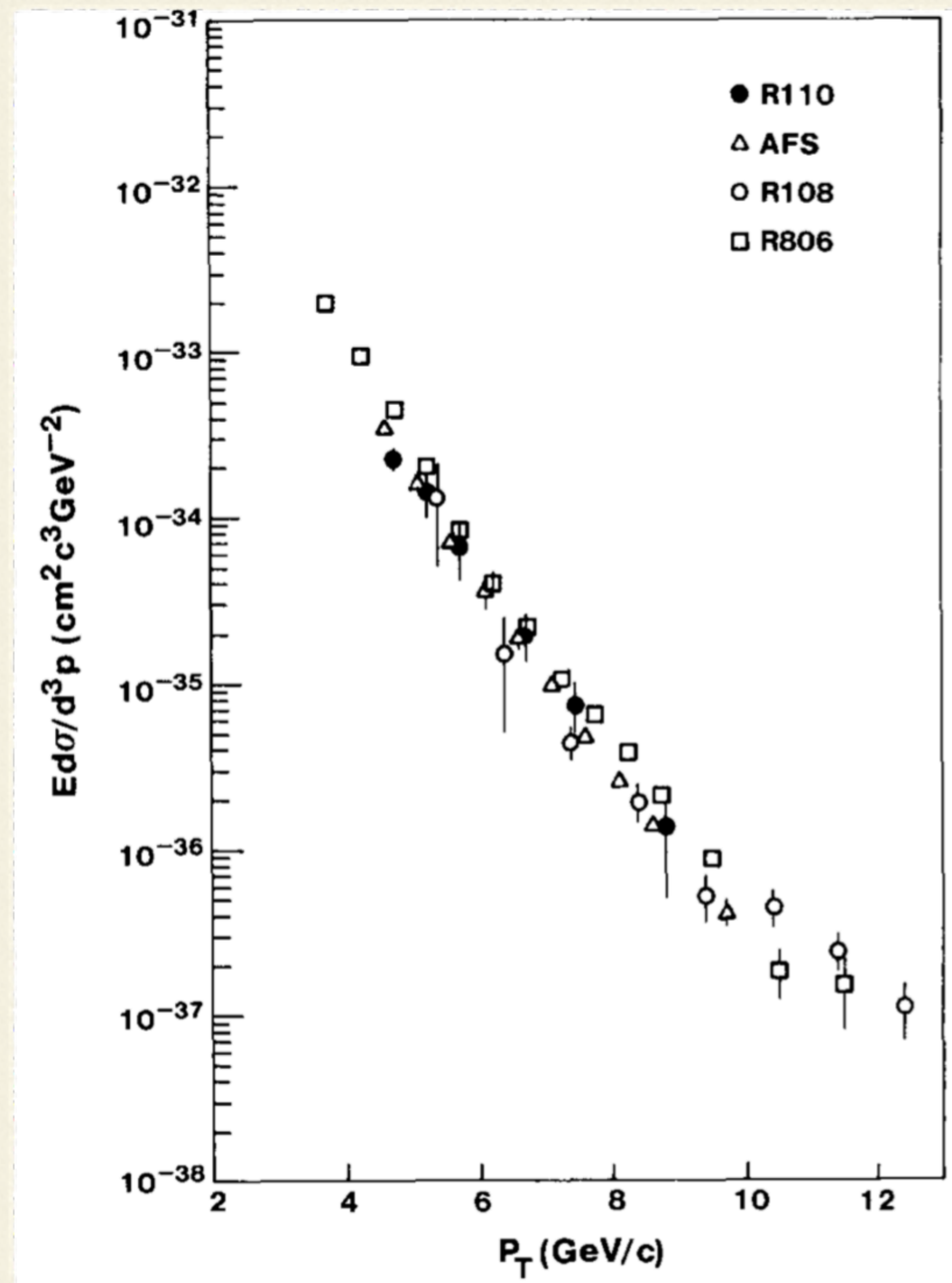


Prompt photons at low-energy colliders

ISR: $\sqrt{s} = 63\ GeV$ ***R806 (1982), R110 (1989), R807(1990)***



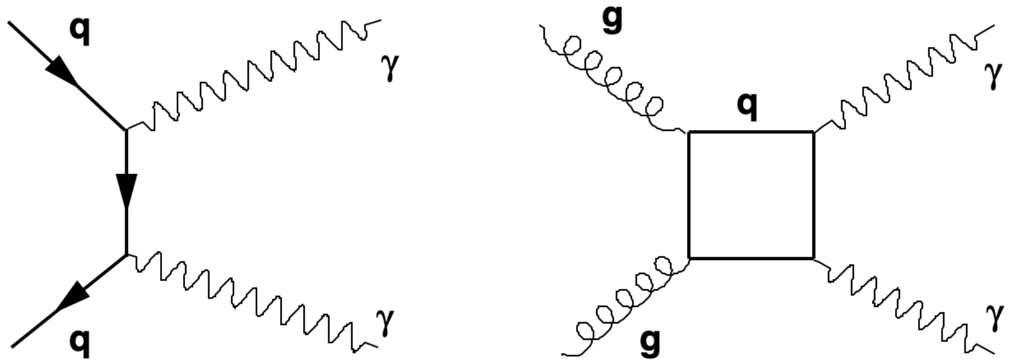
Particle	Mass (GeV)	Prod. σ/π^0	Decay	# of photons	Branching ratio (BR)	$\sigma \times BR/\pi^0$	% in sample
π^0	0.135	1.0	$\gamma\gamma$	2	1.0	1.0	61.4
η^0	0.549	0.55	$\gamma\gamma$	2	0.38	0.209	12.8
η^0	0.549	0.55	$\pi\pi\pi$	6	0.30	0.165	10.1
K_s^0	0.498	0.40	$\pi\pi$	4	0.31	0.124	7.6
ω^0	0.783	0.50	$\pi\gamma$	3	0.09	0.045	2.8
η'	0.957	1.0	$\eta\pi\pi$	6	0.084	0.084	5.2



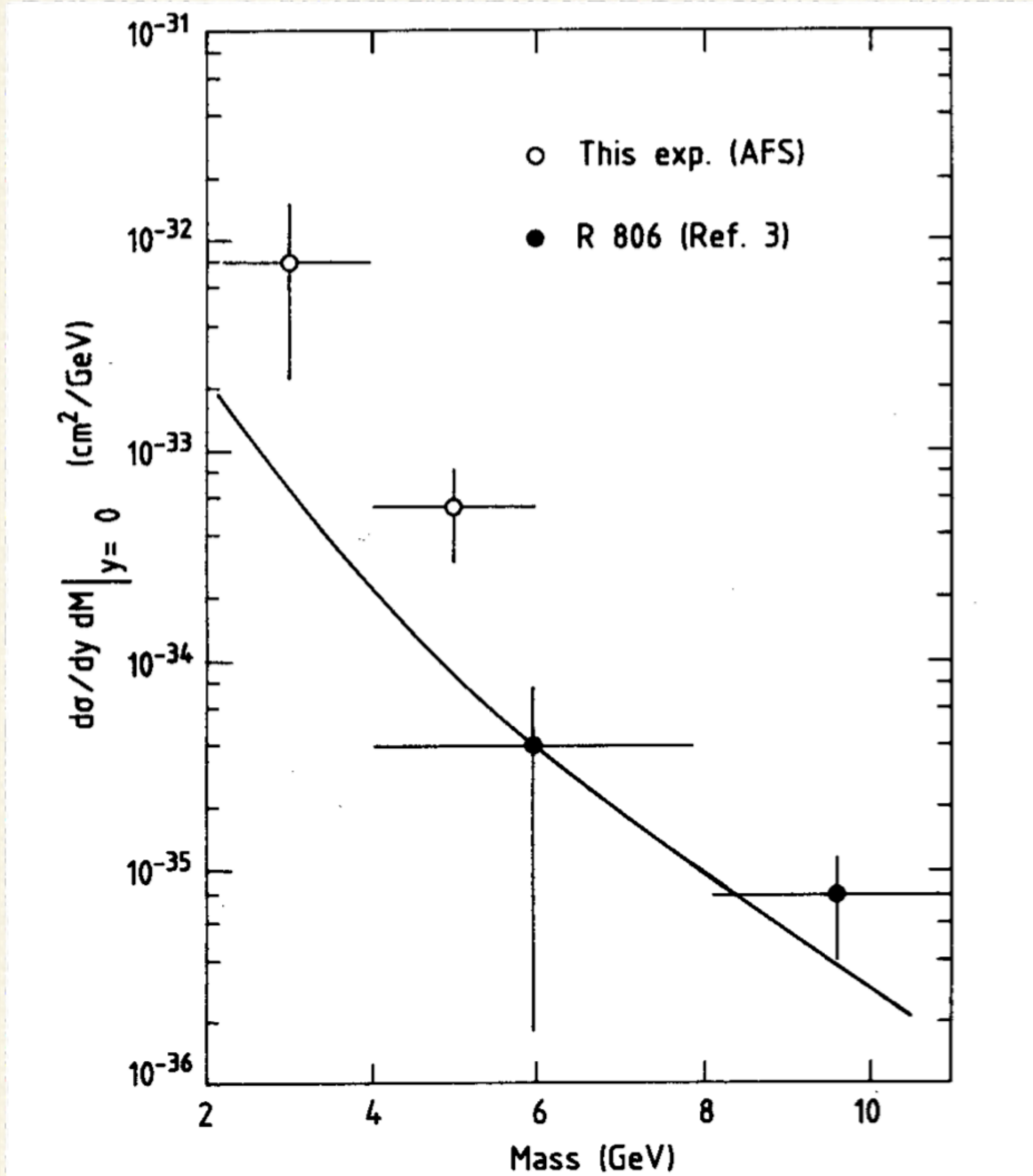
Also at RHIC down to 62.4 GeV

Production of double photons

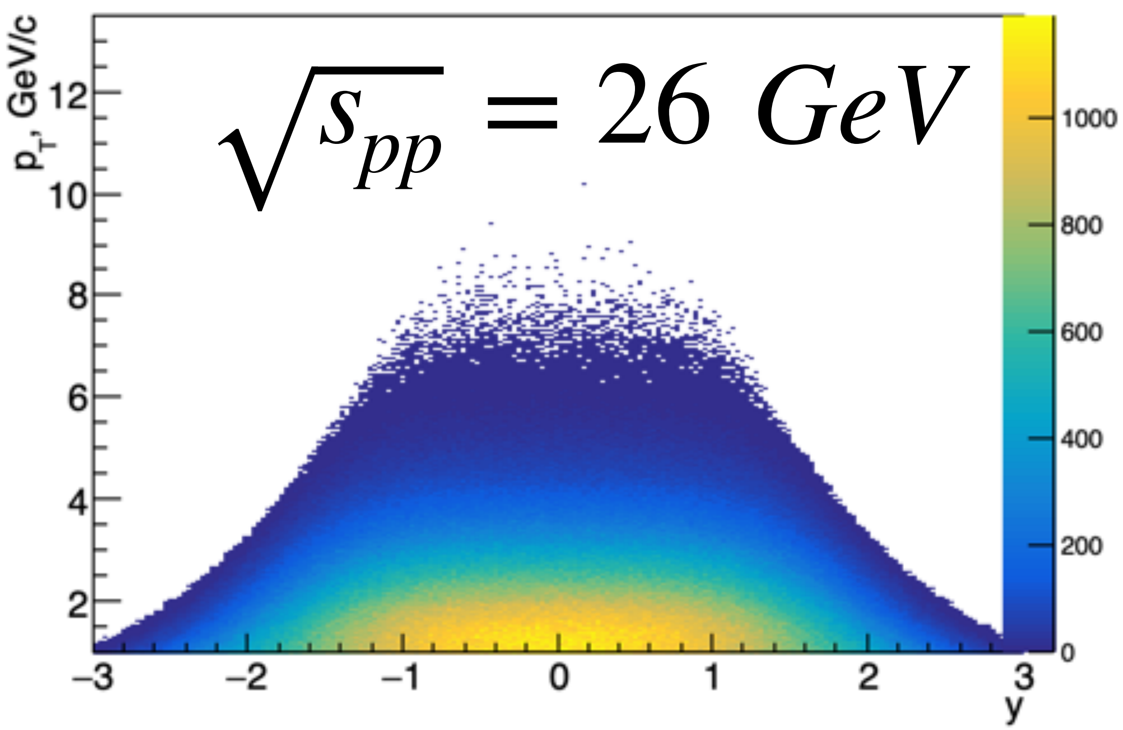
Much smaller cross section but rather high masses

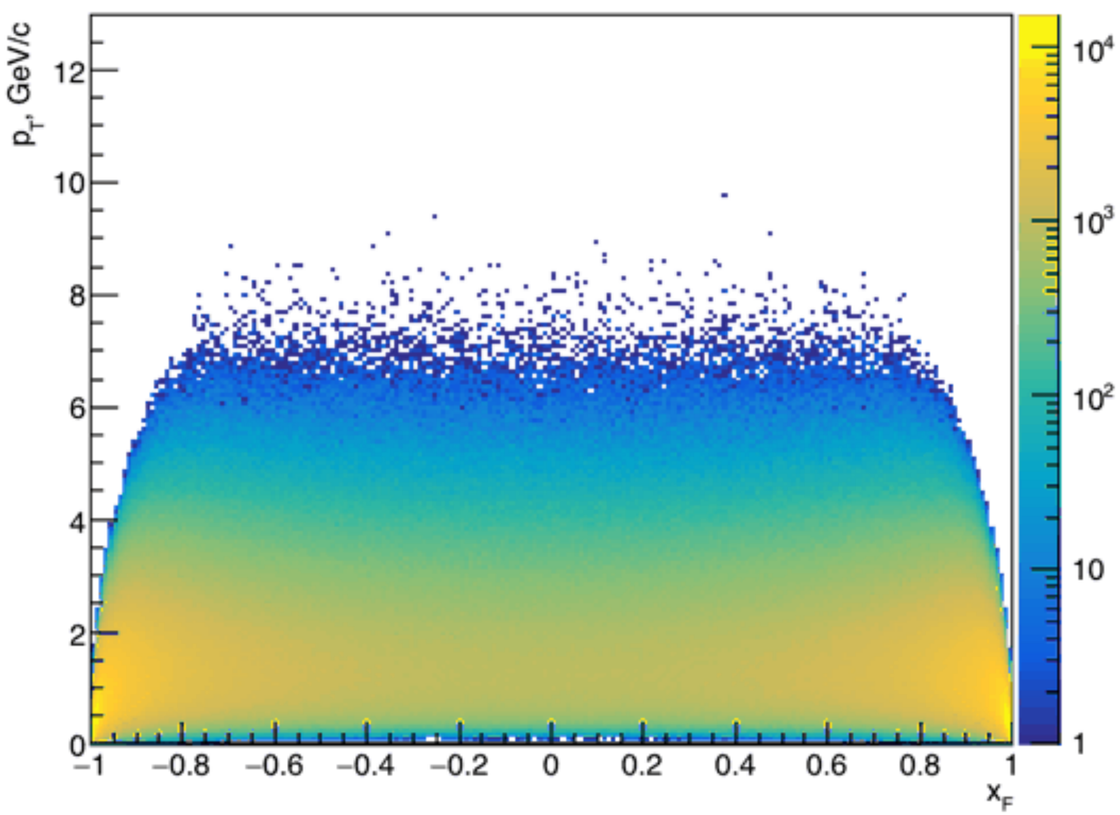


Collaboration	$\sqrt{s}$	Beam	Target	Measurement
R806 [16]	63	p	p	$d^2\sigma/dydm_{\gamma\gamma}$
R807 [19]	63	p	p	$d^2\sigma/dydm_{\gamma\gamma}$
UA2 [20]	630	$\bar{p}$	p	$d\sigma/dp_T$
UA2 [21]	630	$\bar{p}$	p	$d^2\sigma/d\eta_1/d\eta_2$
UA1 [22]	630	$\bar{p}$	p	σ $Ed^3\sigma/dp^3$
E741(CDF) [24]	1800	$\bar{p}$	p	σ $d\sigma/dp_T$
NA24 [6]	23.7	π^-	p	$Ed^3\sigma/dp^3$
WA70 [9]	22.96	π^-	p	σ $d\sigma/dp_T$
NA3 [4]	19.4	p	C	σ



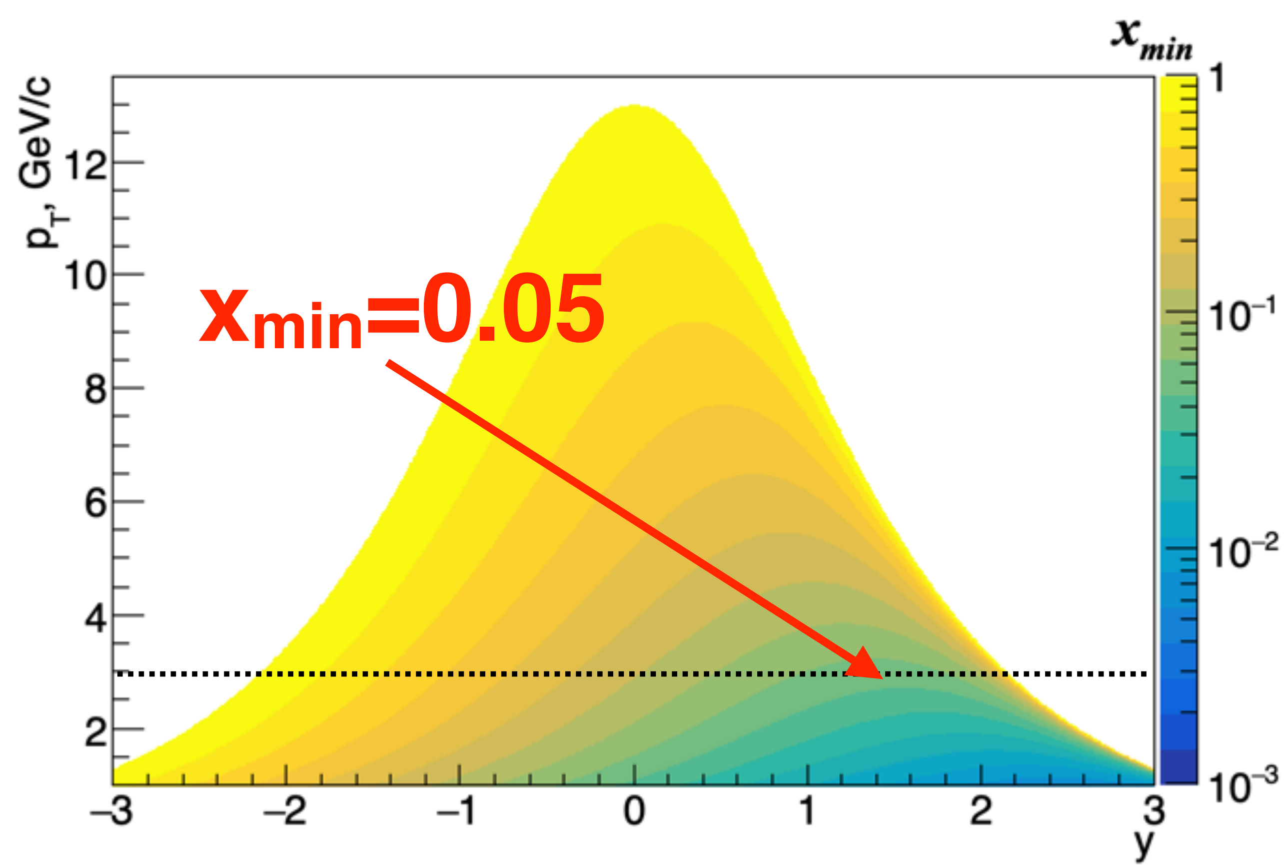
A bit more kinematics



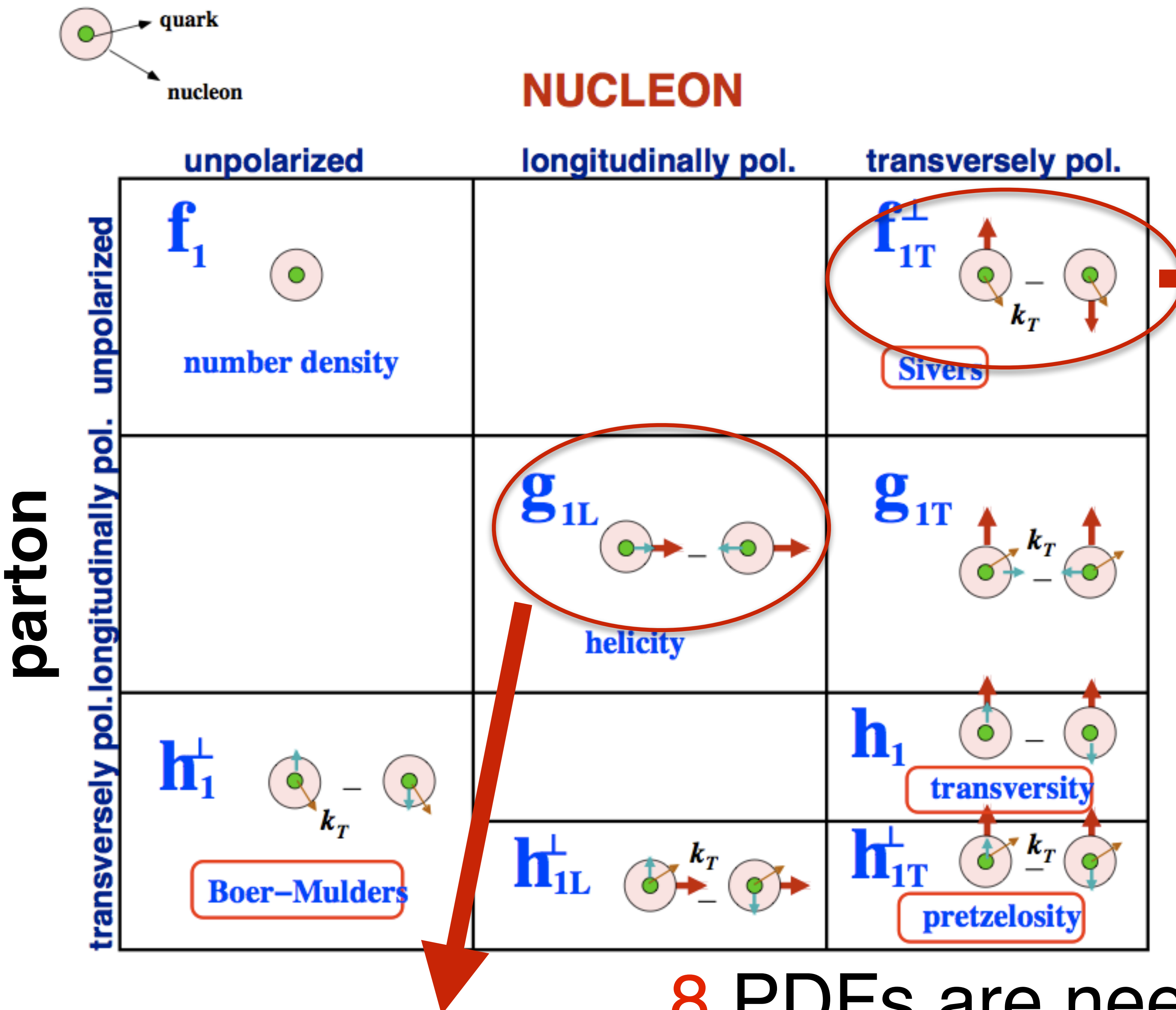


$$x_{min} = \frac{x_T e^{-y}}{1 - 2x_T e^{y}}$$

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



Nucleon PDFs



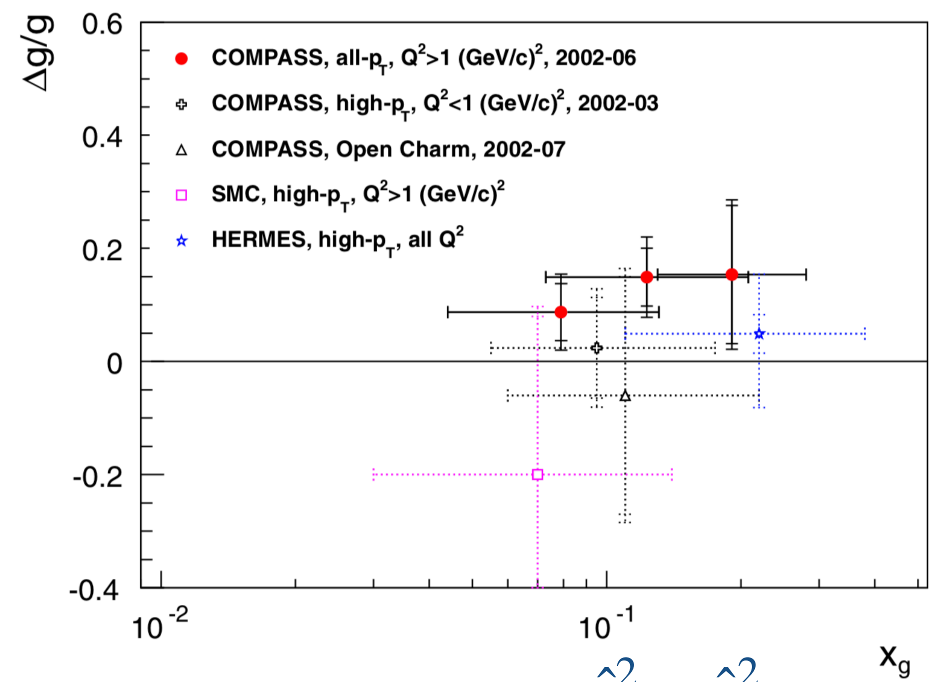
Gluon Sivers function

3 PDFs are needed to describe nucleon structure in collinear approximation

Gluon polarization

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

DSA with longitudinally polarised beams

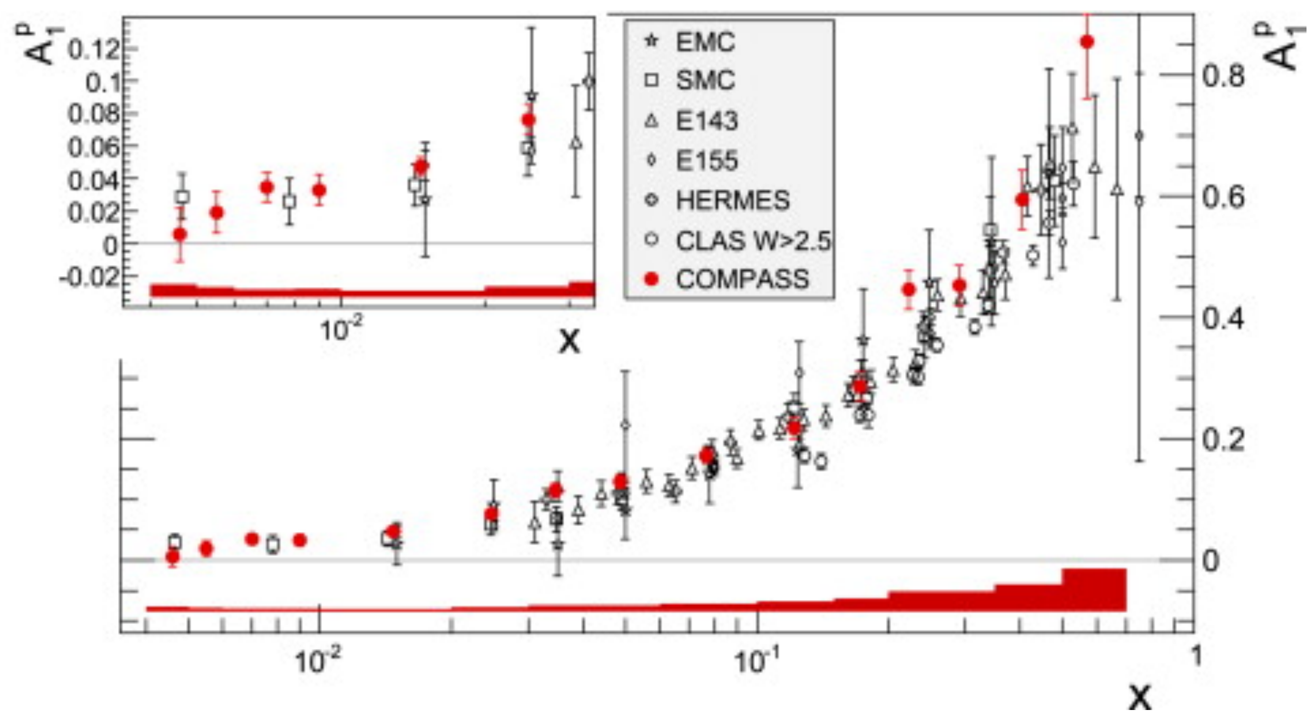


$$A_{LL} = \frac{(\sigma_{++} + \sigma_{--}) - (\sigma_{+-} + \sigma_{-+})}{(\sigma_{++} + \sigma_{--}) + (\sigma_{+-} + \sigma_{-+})}$$

$$A_{LL} \approx \frac{\Delta g(x_1)}{g(x_1)} \cdot \left[\frac{\sum_q e_q^2 \left[\Delta q(x_2) + \Delta \bar{q}(x_2)\right]}{\sum_q e_q^2 \left[q(x_2) + \bar{q}(x_2)\right]} \right] \times \hat{a}_{LL} + (1 \leftrightarrow 2)$$

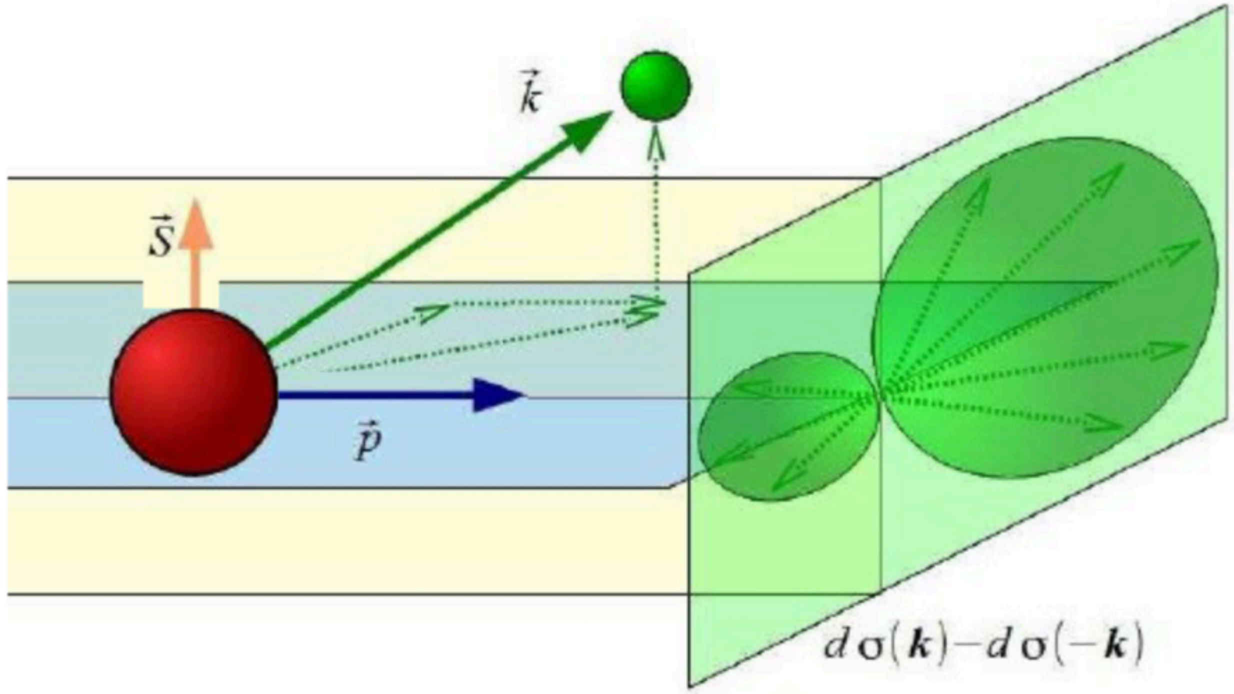
$$\hat{a}_{LL} = \frac{\hat{s}^2 - \hat{u}^2}{\hat{s}^2 + \hat{u}^2} \quad \textit{for GCS}$$

A_1^P is well-known from DIS

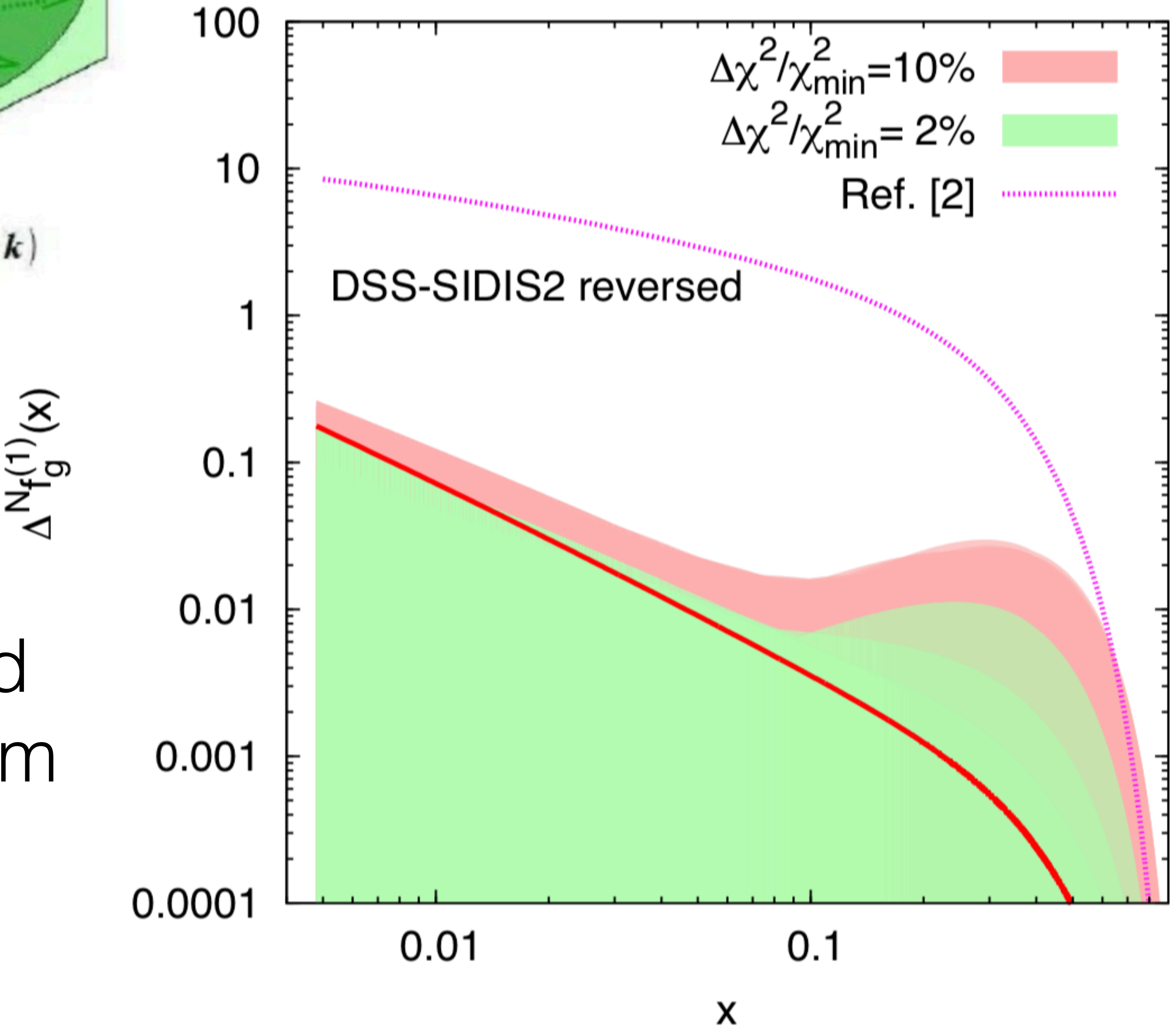


$A_{LL} < 10\%$

Gluon Sivers function



Some estimations
from RHIC data (Q^2=2 GeV^2/c^2)



Many theoretical models and just very rough estimation from experimental data

SSA with prompt photons

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

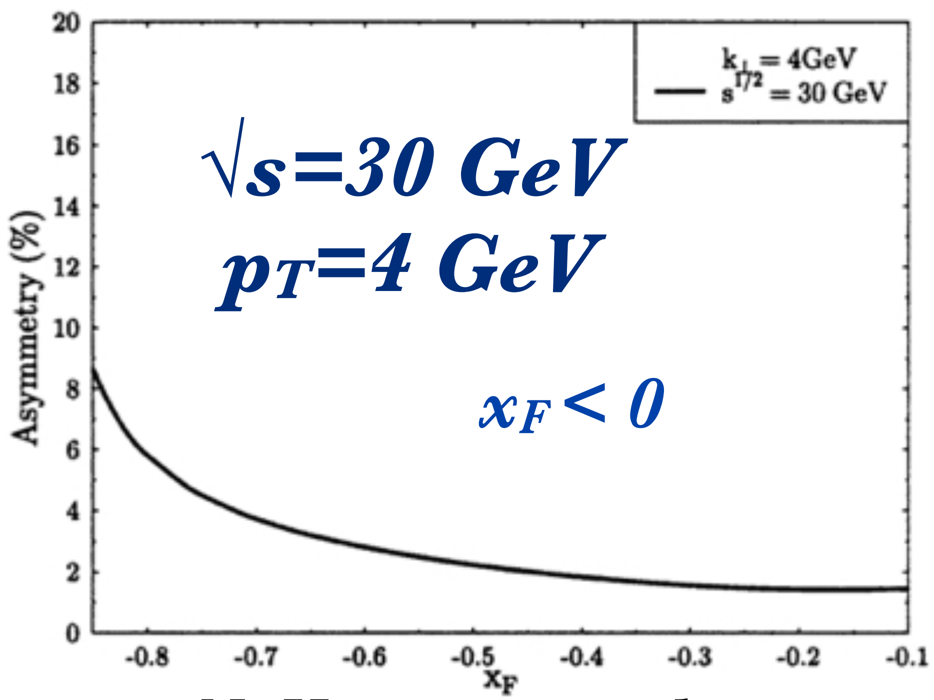
Single transverse spin asymmetry

I. Shmidt, J. Soffer, J.J. Yang, Phys. Lett. B 612 (2005)

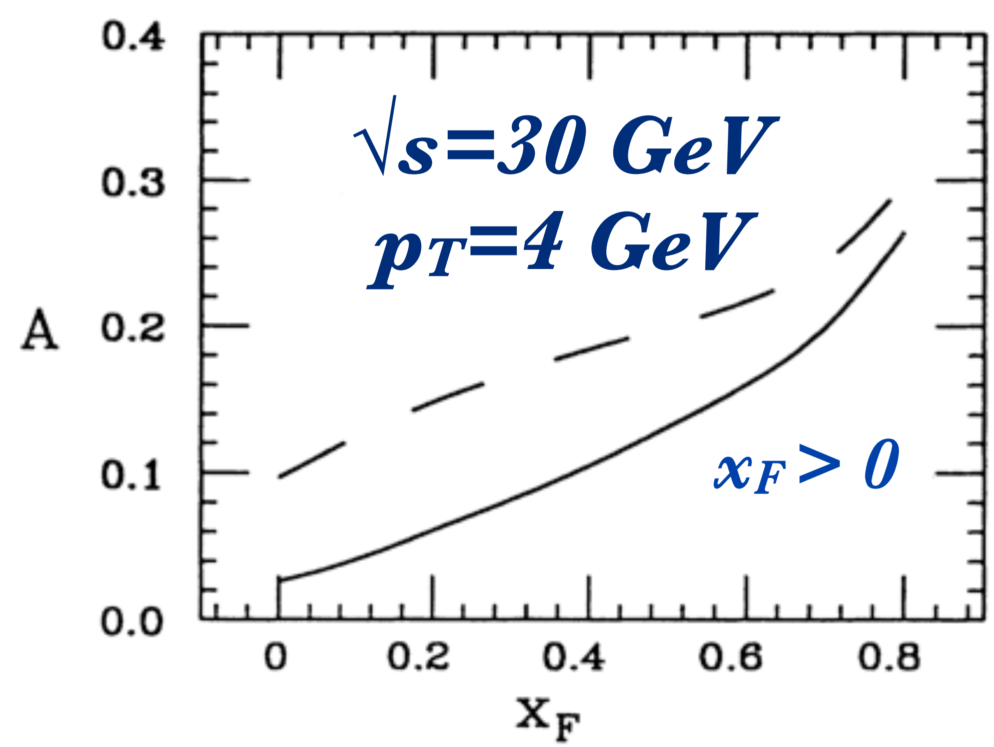
gluon Sivers function

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

where $q(x_{a,b}, k_{Ta,b})$ and $G(x_{a,b}, k_{Ta,b})$ are quark and gluon distribution functions and $\Delta_N q(x_{a,b}, k_{Ta,b})$



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



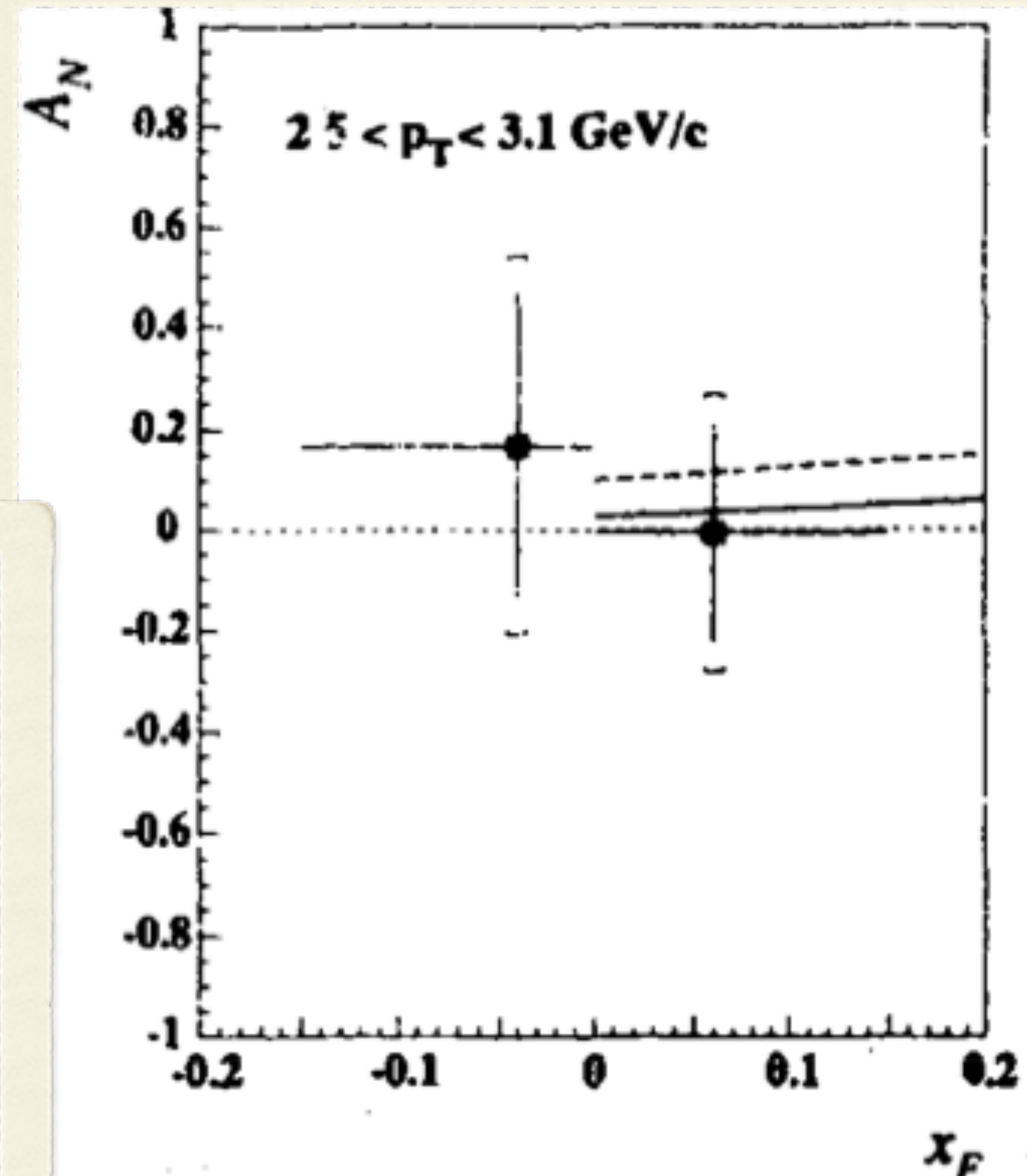
J. Qui and G. Sterman, Phys. Rev. Lett. 67 (1991) 2264

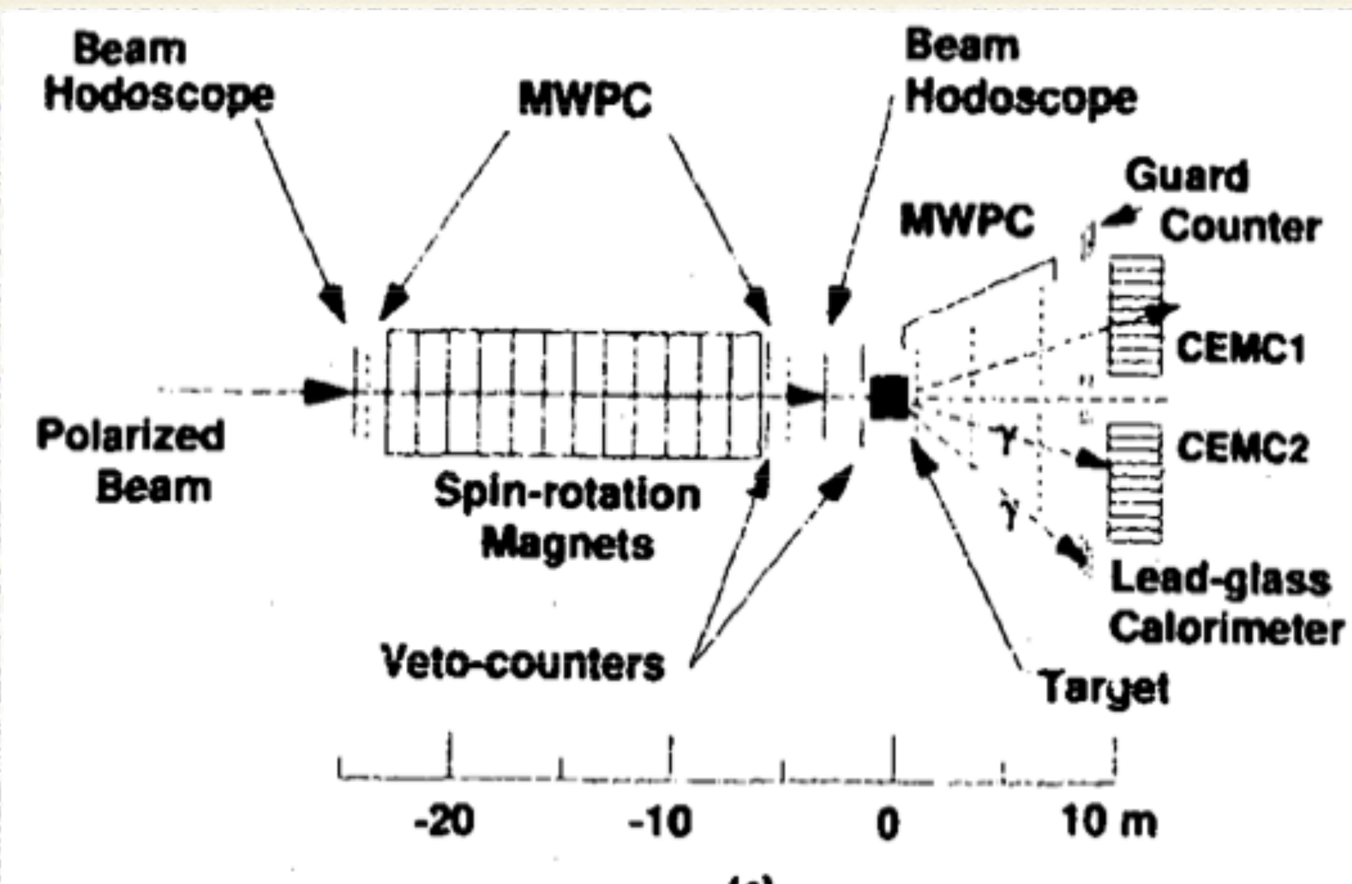
Single spin asymmetries at √s=19.4 GeV

Polarized measurement at FNAL E704

Phys. Lett. B 345 (1995)

- *Fixed target.*
- *Polarized proton beam from Λ decay*
- *2.5 GeV/c < p_T < 3.1 GeV/c*
- *π^0 mass resolution - 10.5 MeV*
- *473 prompt photon candidates (including 220+-22 background events)*





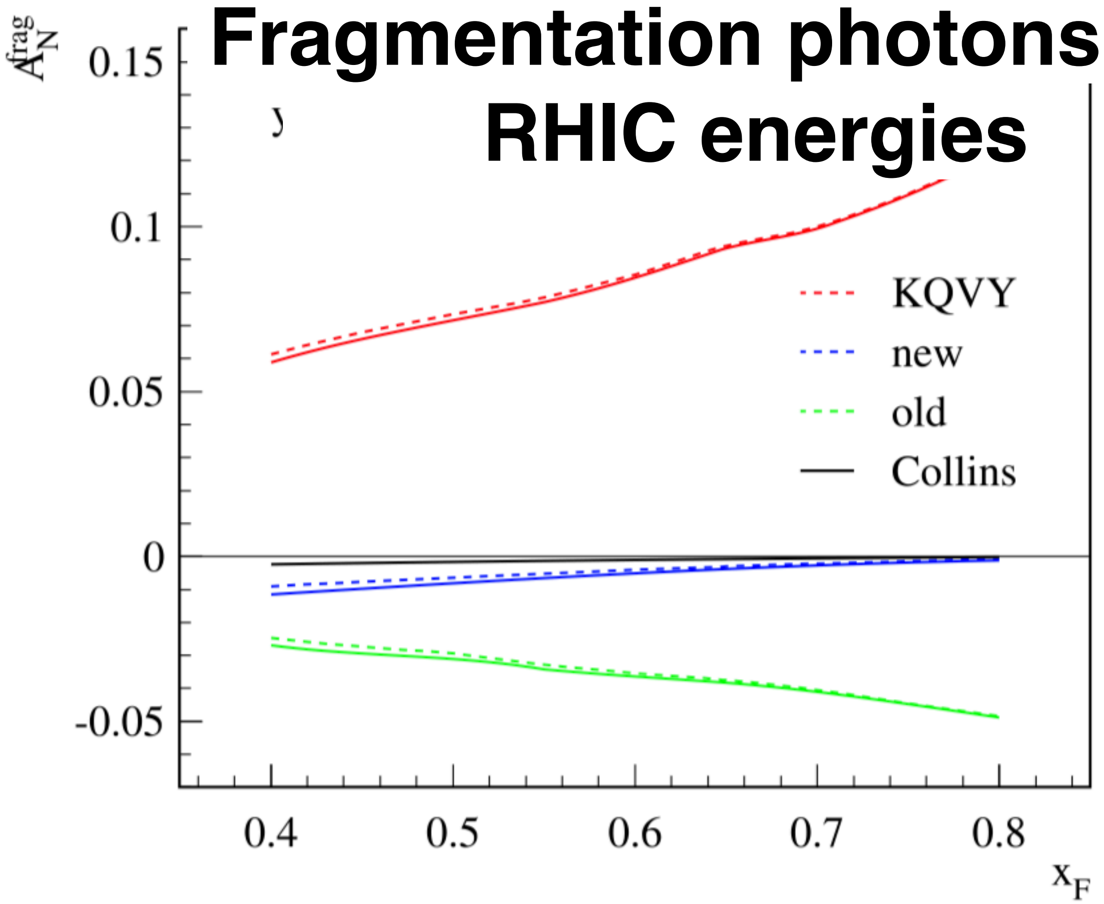
Our backgrounds are also spin-dependent !

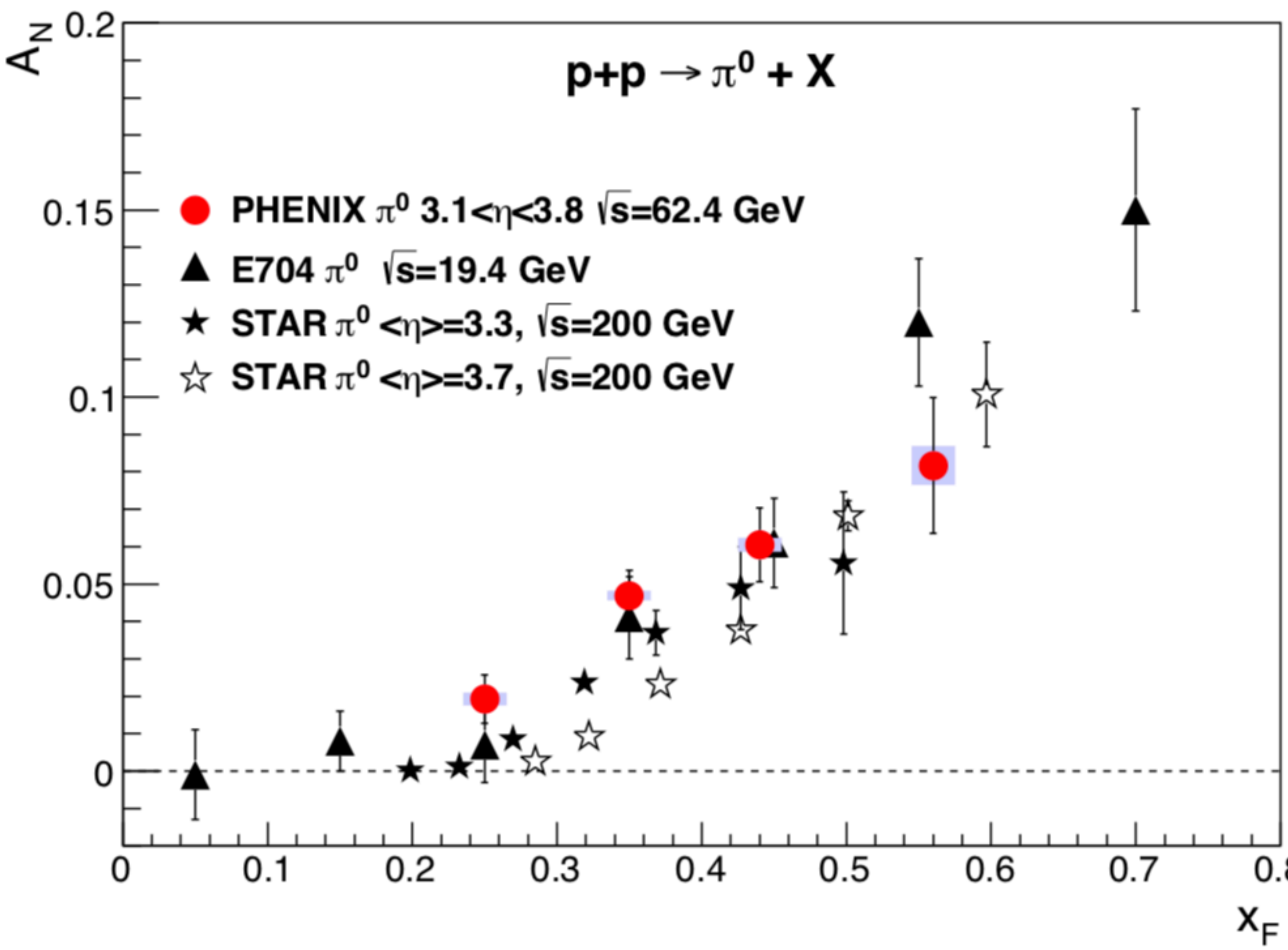
Leonard Gamberg, Zhong-Bo Kang

Phys.Lett.B696:109-118,2011

Phys.Rev. D90 (2014) no.1, 012006

Fragmentation photons, RHIC energies



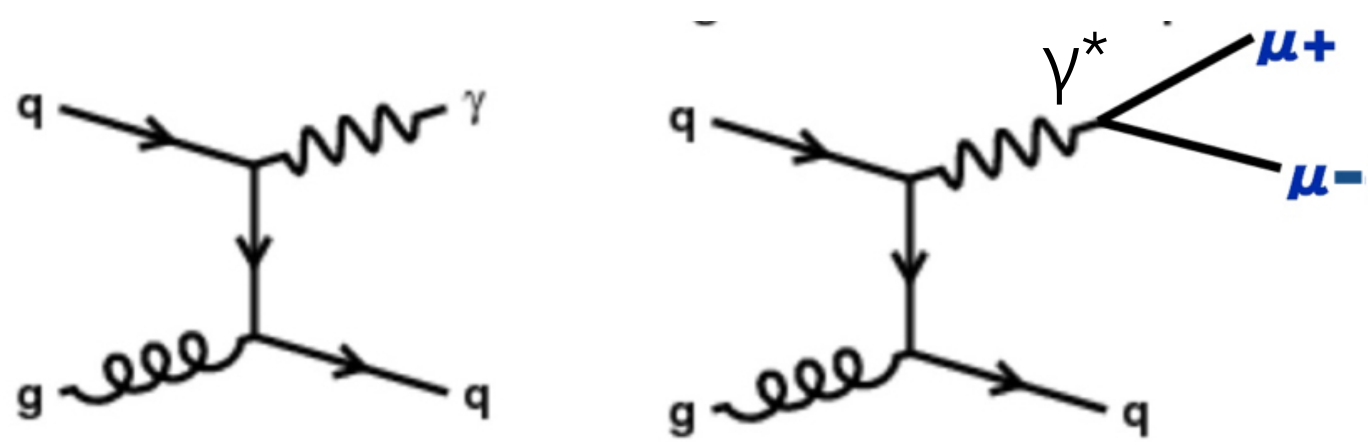


But they also contain info about spin structure of nucleon!

Prompt photons and DY

Phys.Lett. B209 (1988) 397-406 (1988)

Production of low-mass dimuon pairs is a process very similar to prompt photon production

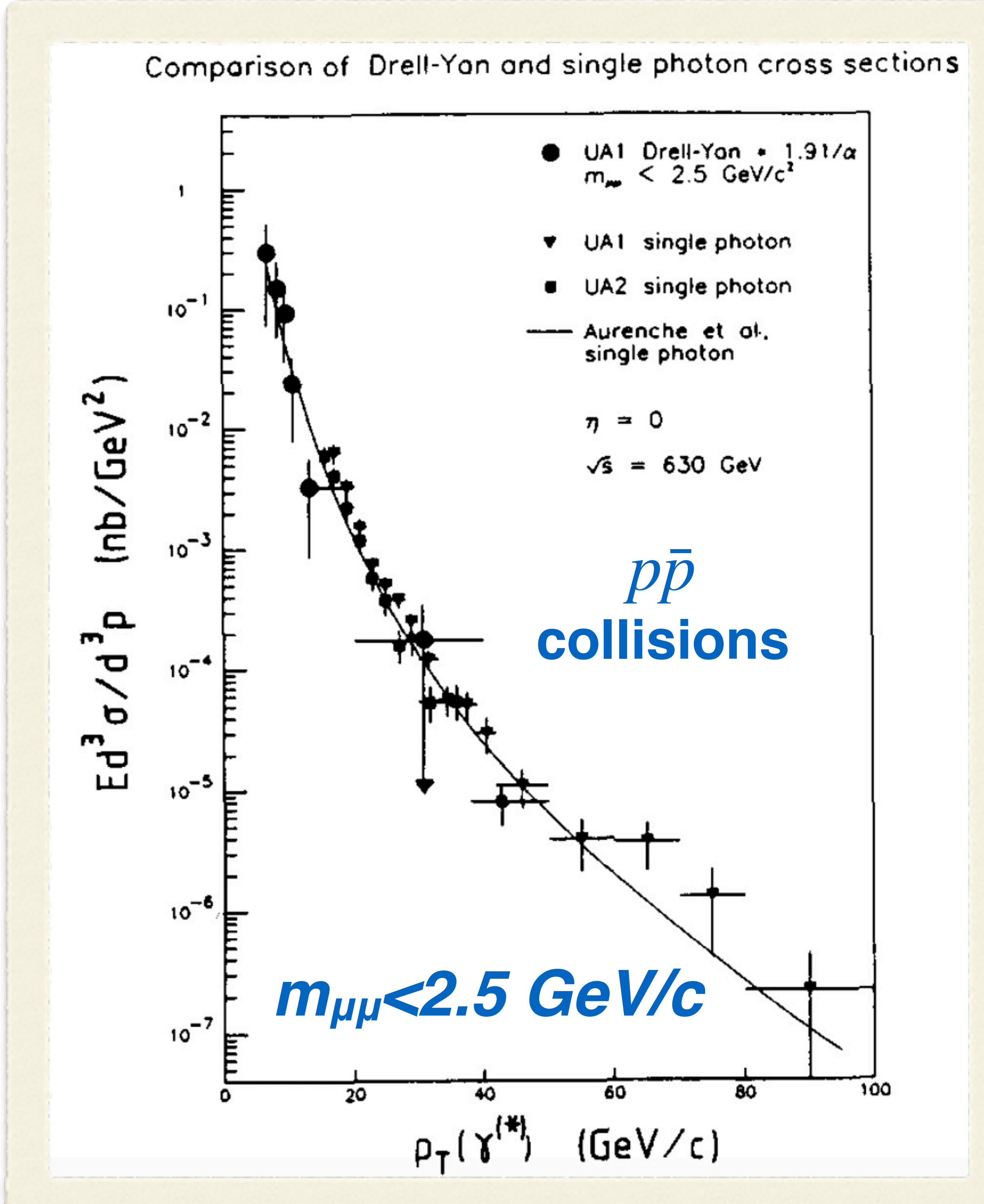


low-mass DY:

— two orders of magnitude smaller cross section

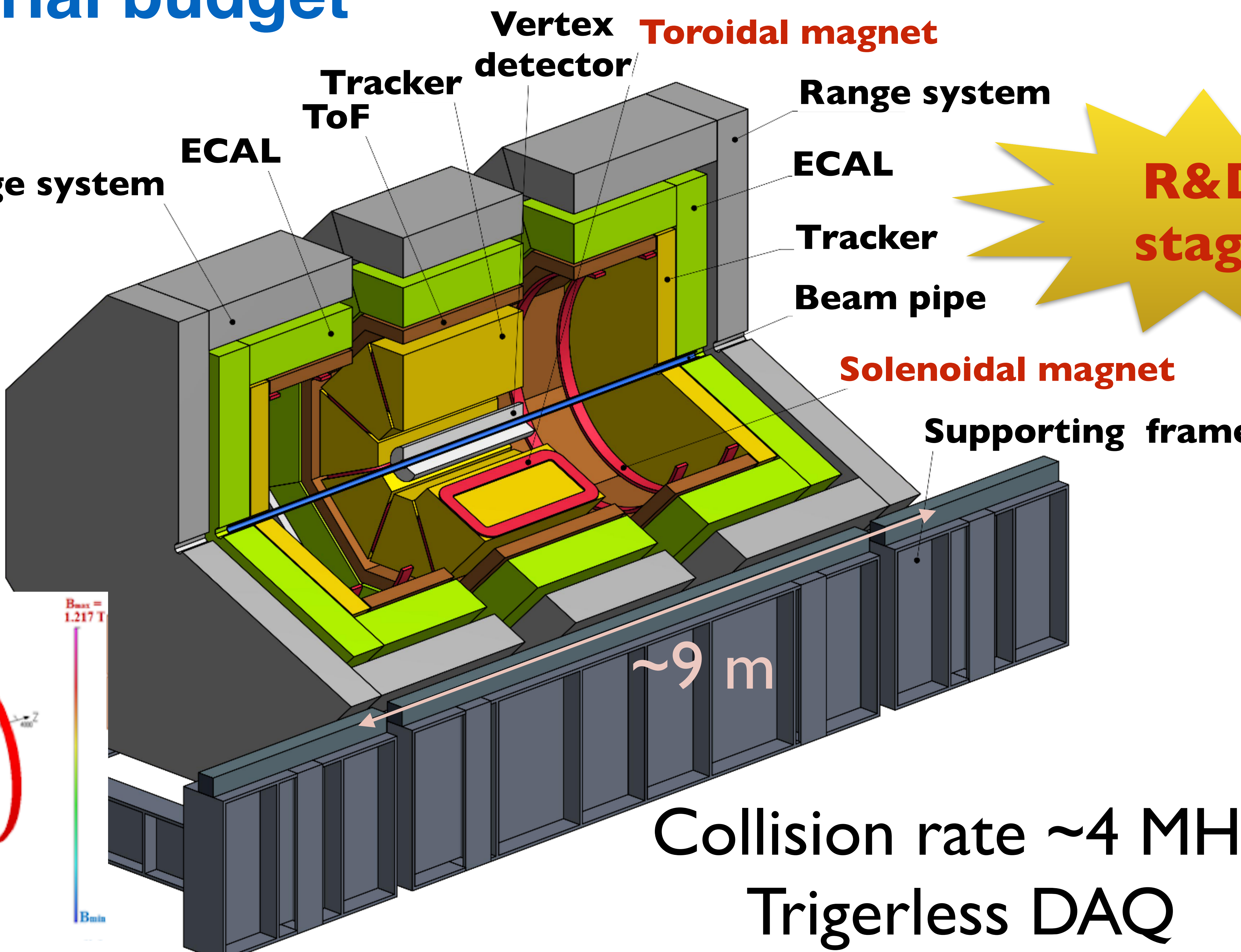
— possibility to achieve low-p_T region

This option is available only in the collider mode!



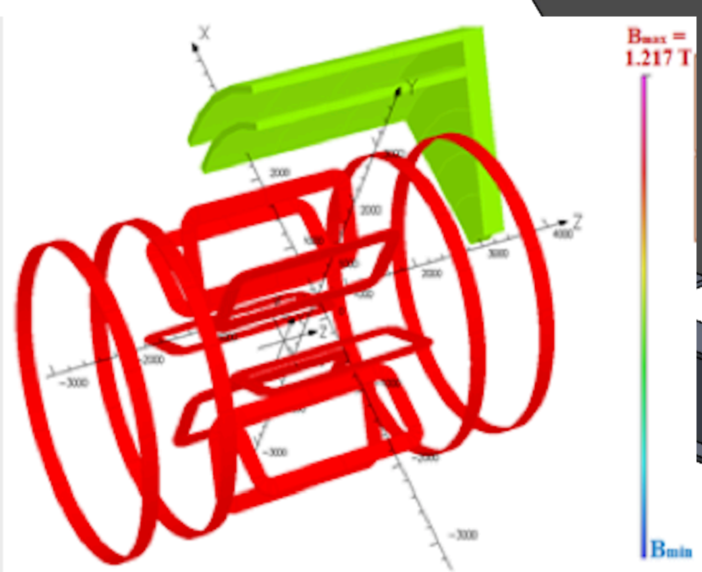
SPD detector

Low material budget



R&D stage

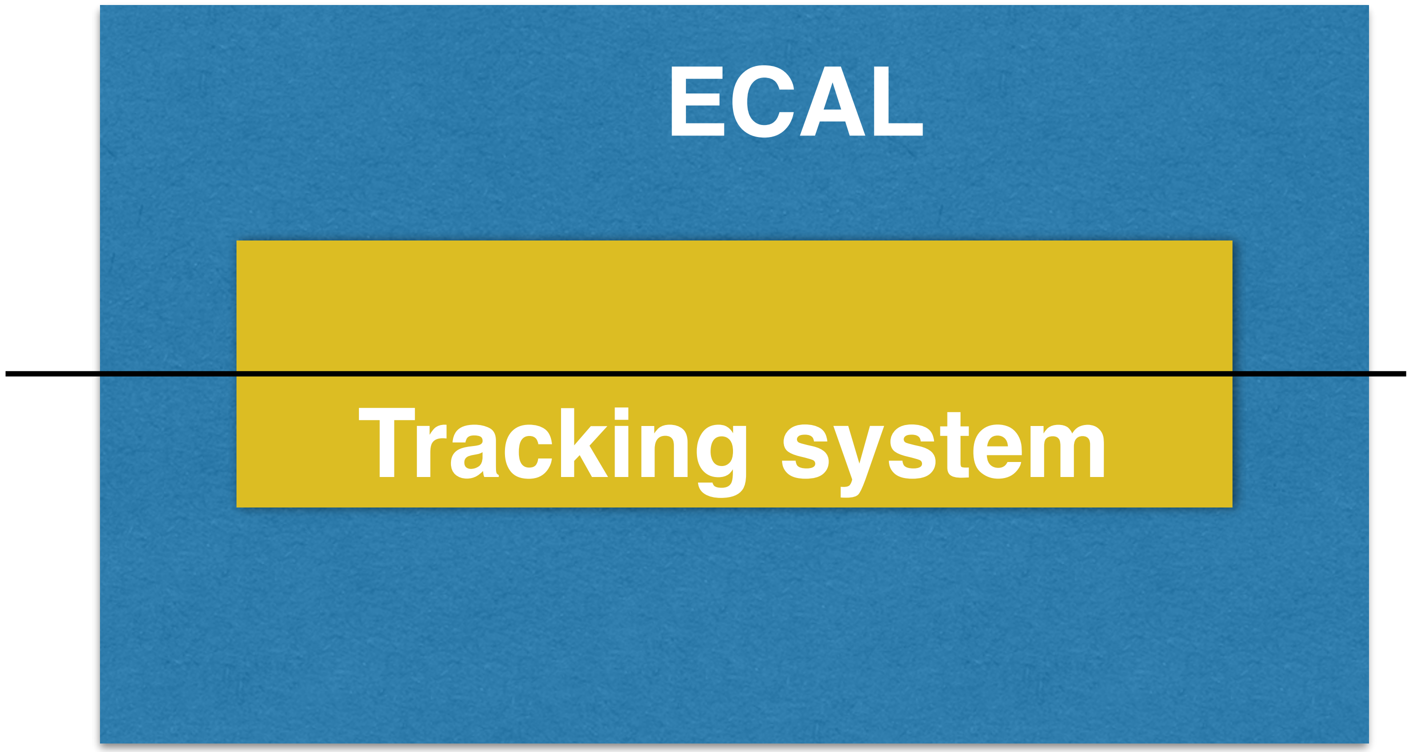
Magnetic system



Collision rate ~4 MHz

Trigerless DAQ

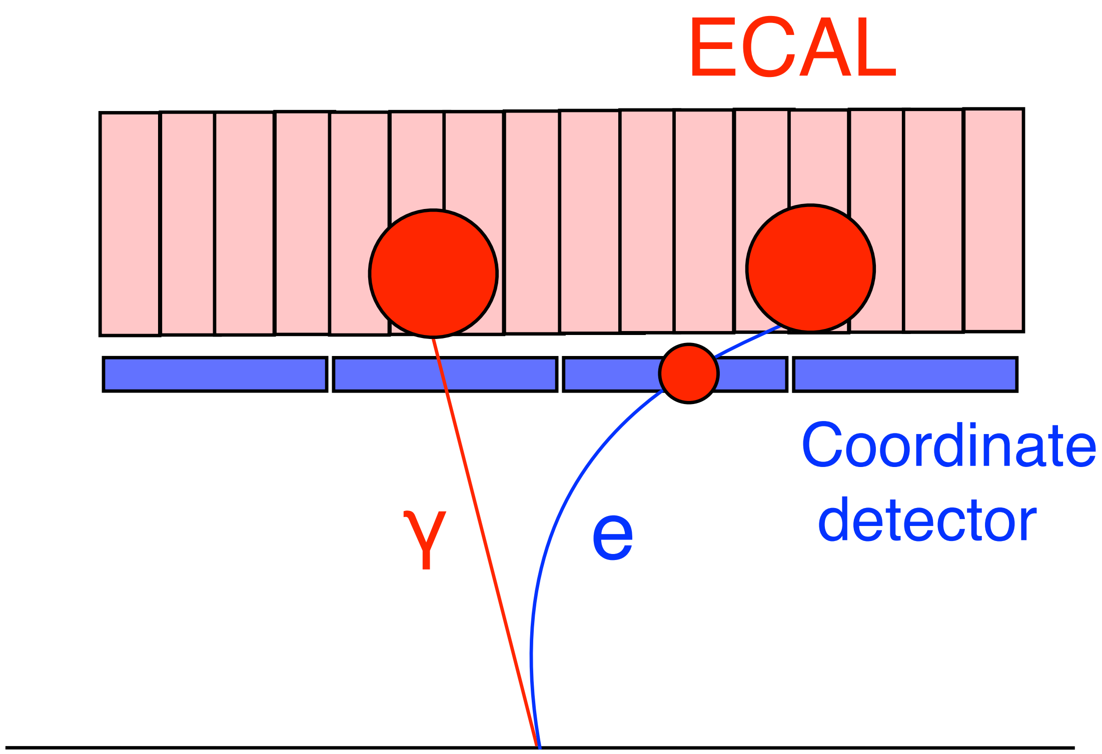
Prompt photons at SPD



Ideal setup:

- **4π ECAL**
- **minimal tracking system (vertexing, charged/neutral clusters separation)**

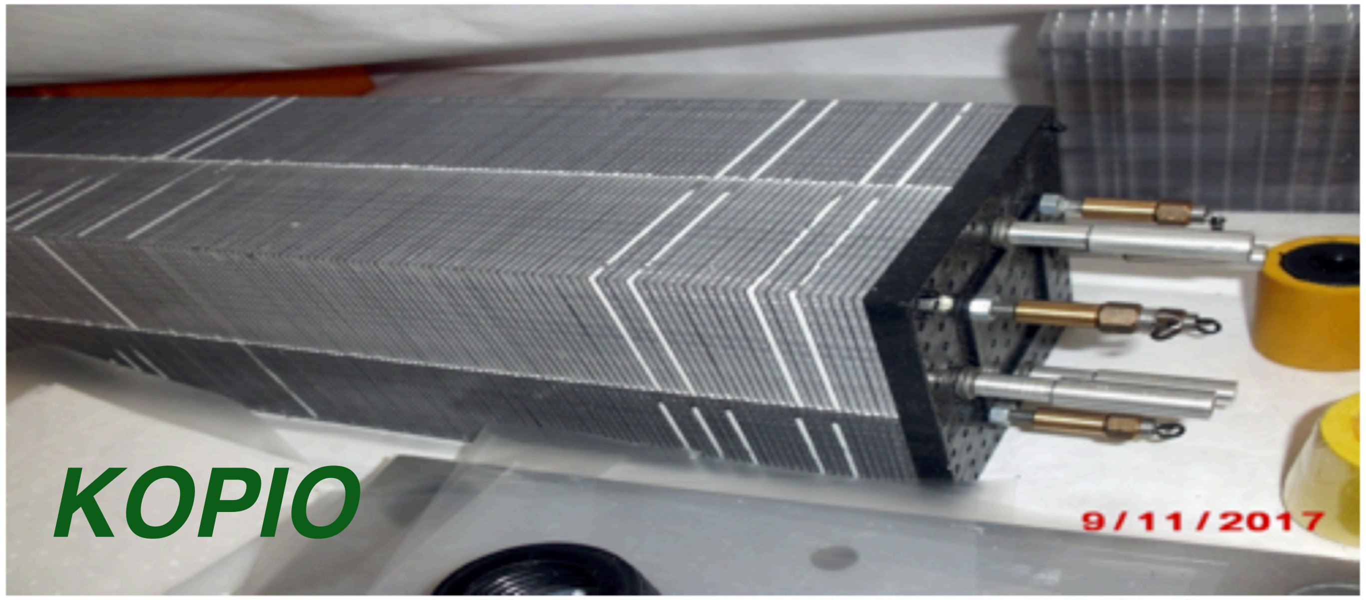
No need for magnetic field and muon system



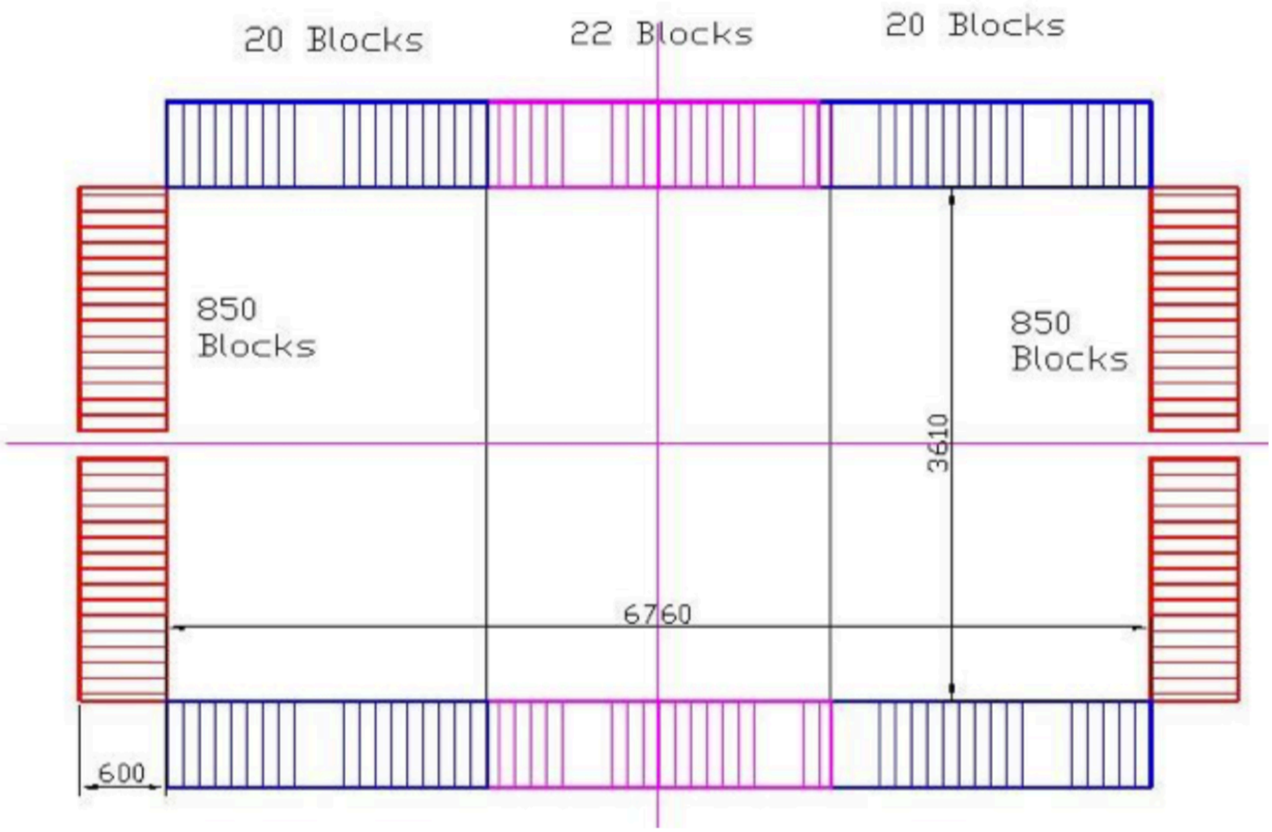
Measurements with prompt photons could be performed at the first stage of SPD operation

Electromagnetic calorimeter

Shashlyk-type sampling calorimeter



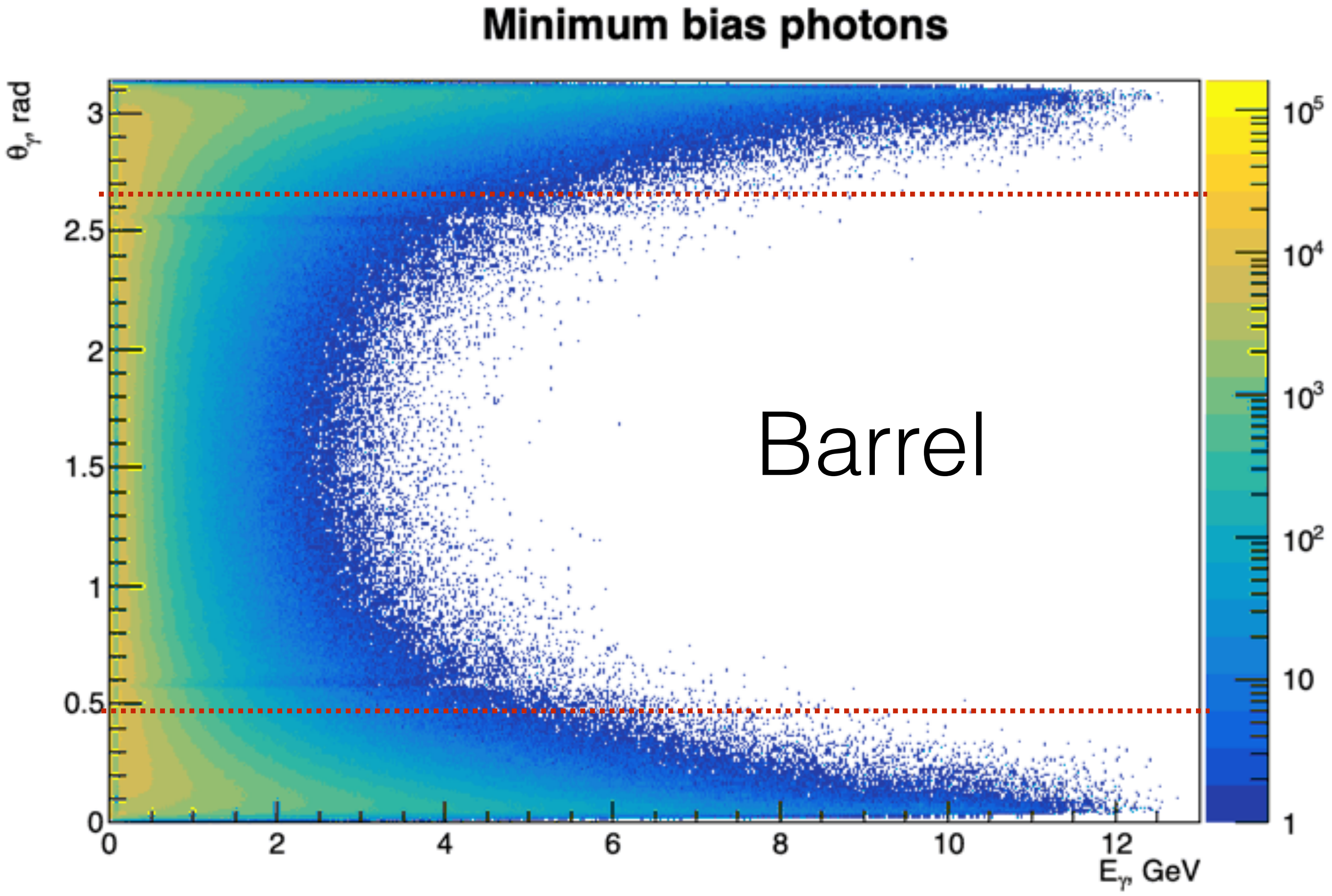
General requirements:



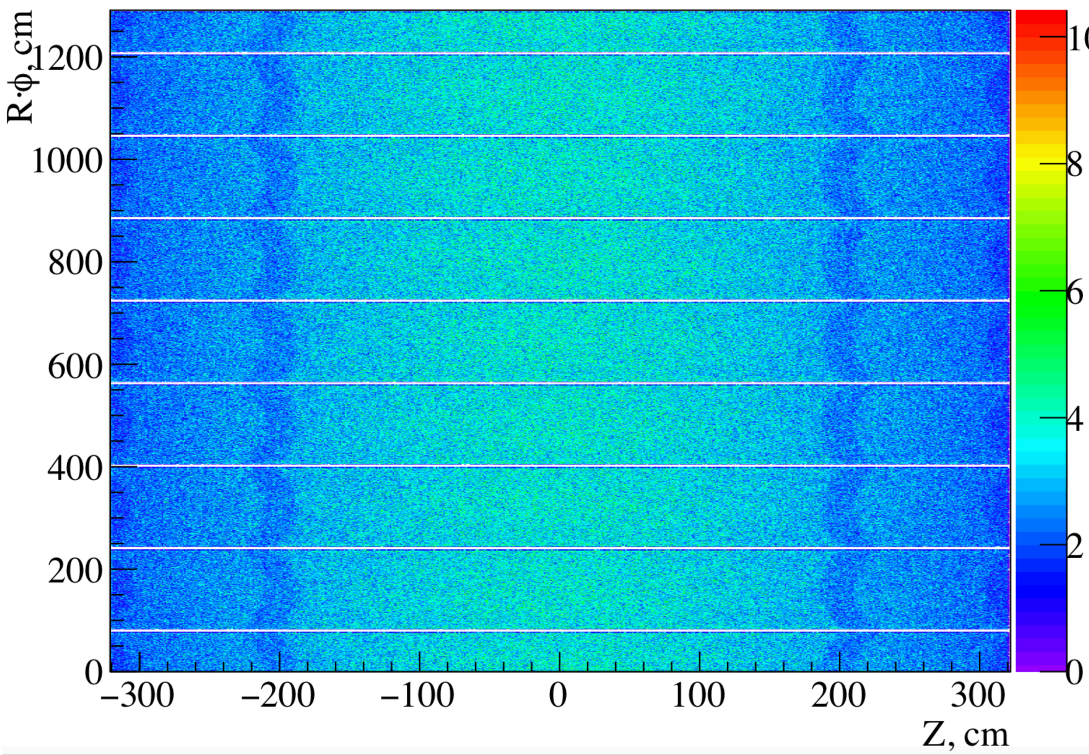
- energy range from 50 MeV to 10 GeV;
- energy resolution of about $5\%/\sqrt{E\ [GeV]}$;
- granularity ∼5 cm;
- time resolution ∼ 0.5 ns;
- operation in the magnetic field;
- long time stability of the basic parameters ±5%.

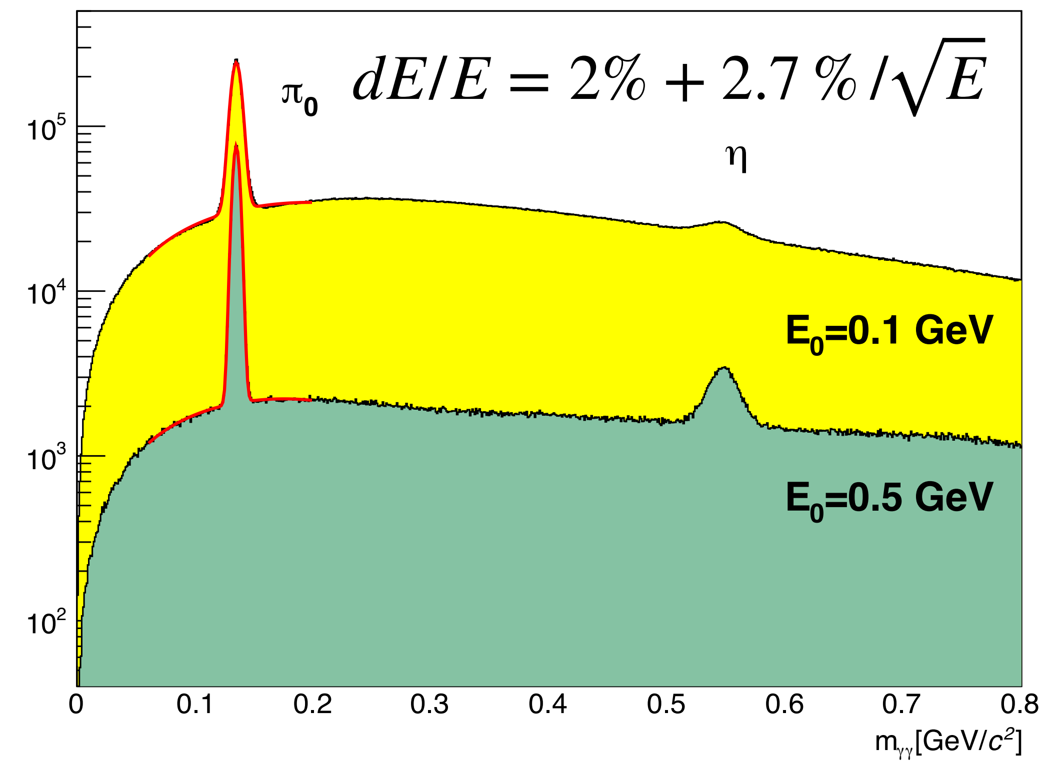
Photons in the SPD setup

Photons produced in primary vertex and reached the ECAL

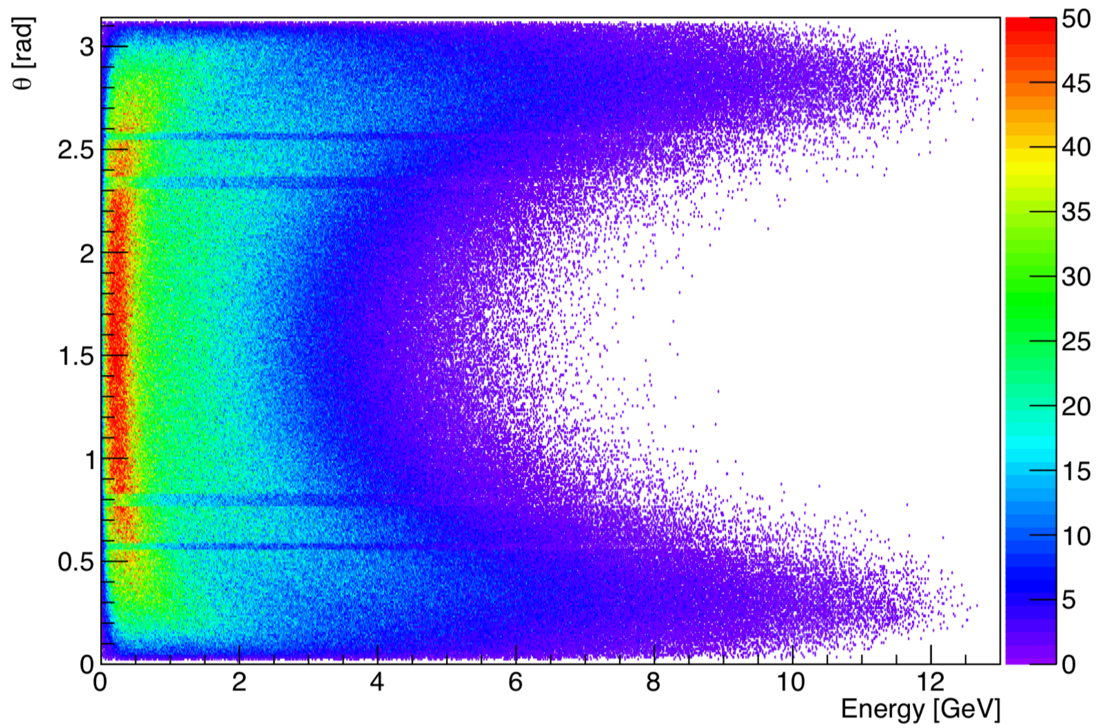


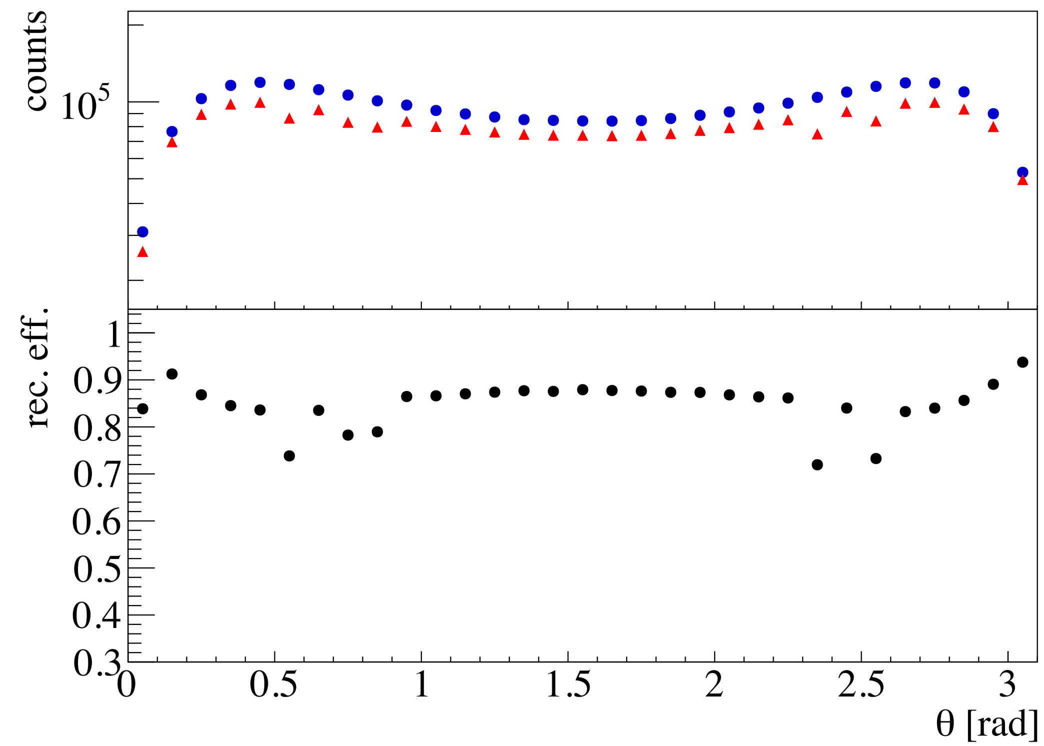
cm^{-1} per 10^6 events

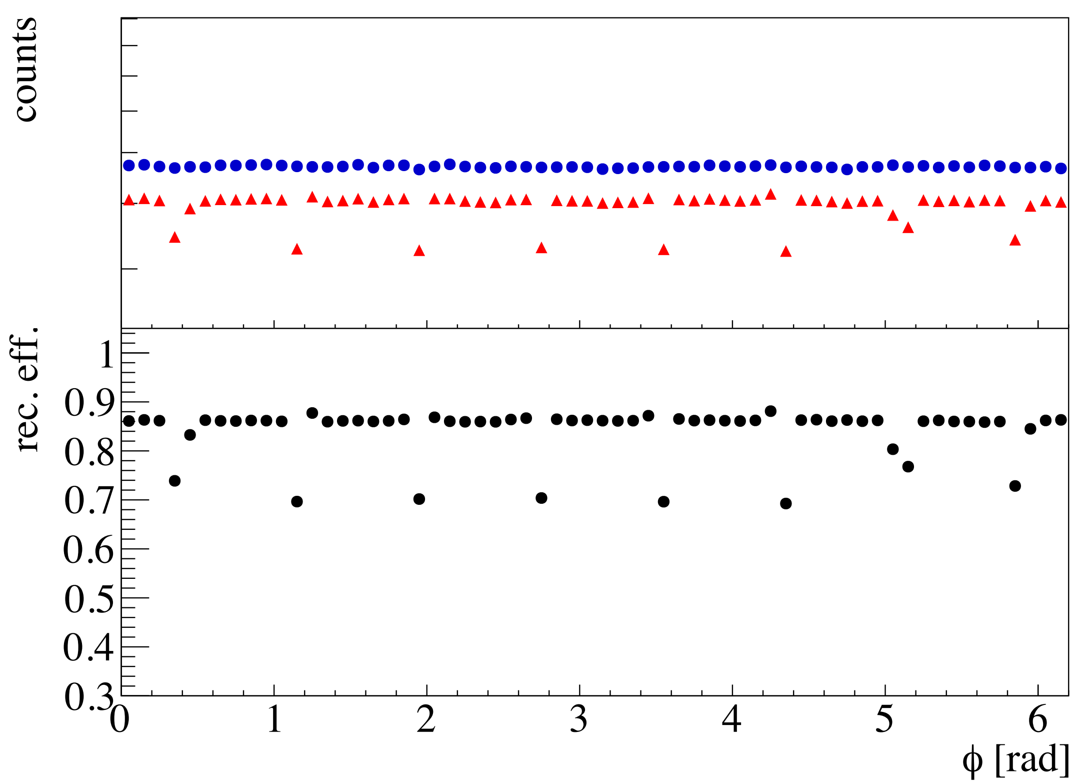


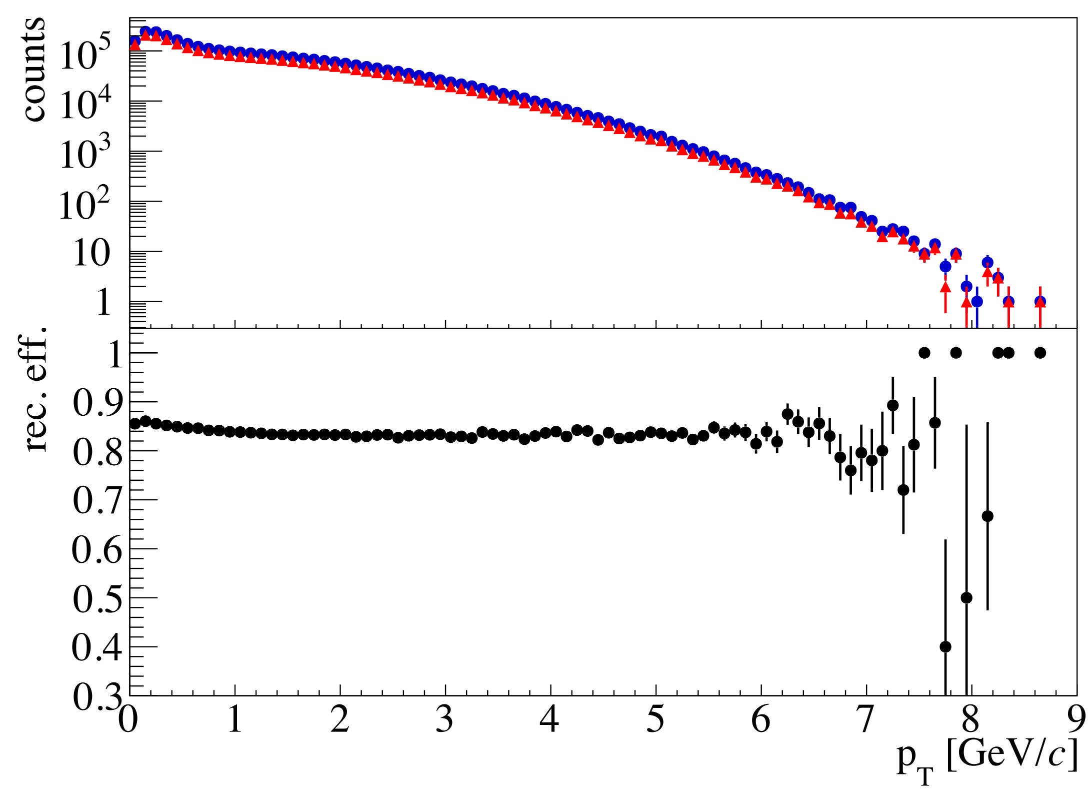


Prompt photons in the SPD setup

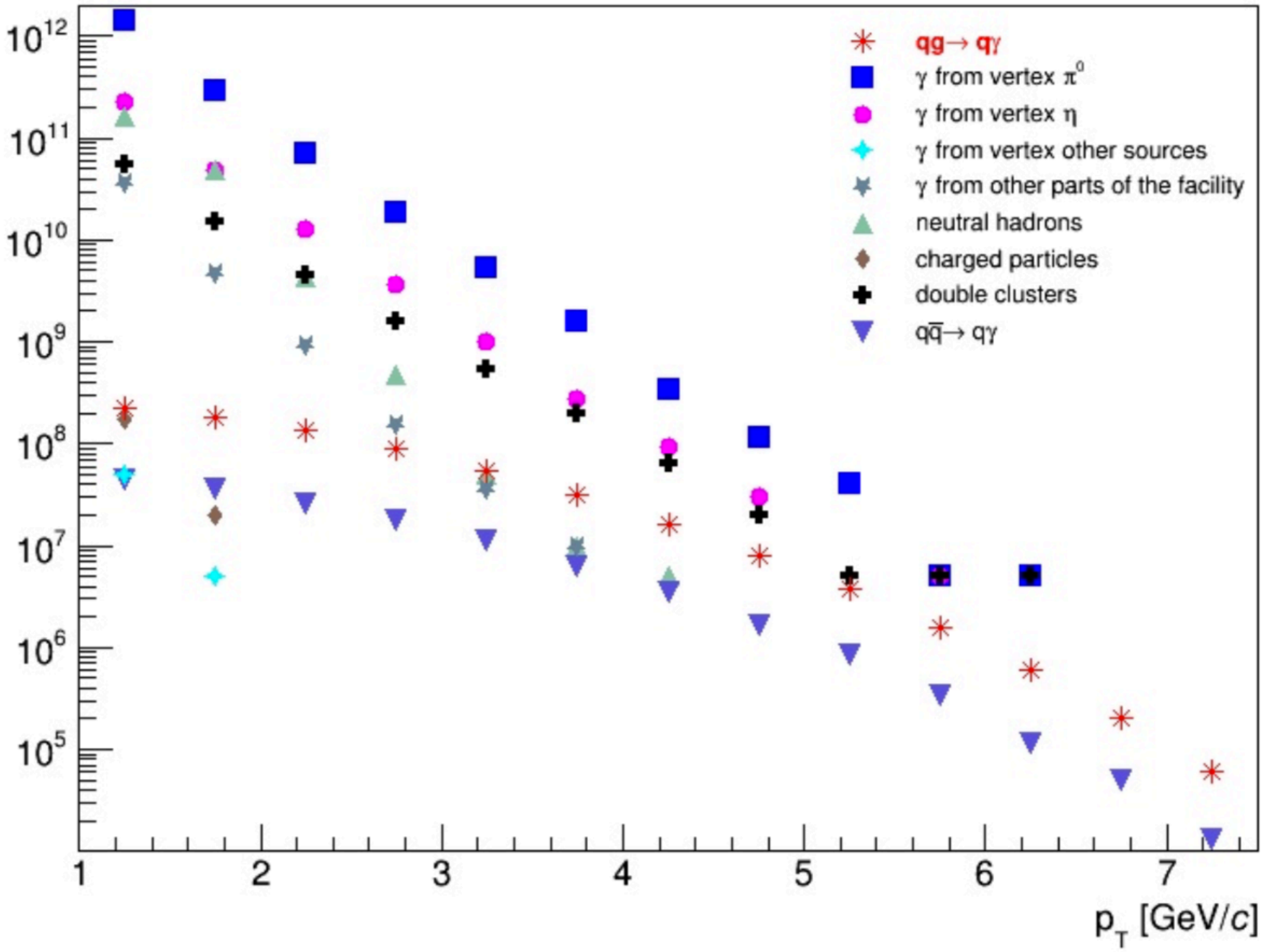








Main background sources



- decay photons from **π^0**, **η** and **other sources**

	π^0	η	others
γ per γ|π^0	1	0.18	0.03

- clusters from **neutral hadrons**
- **double clusters**
- clusters from **misidentified charged particles** (5%)
- clusters from **photons produced at the setup elements**

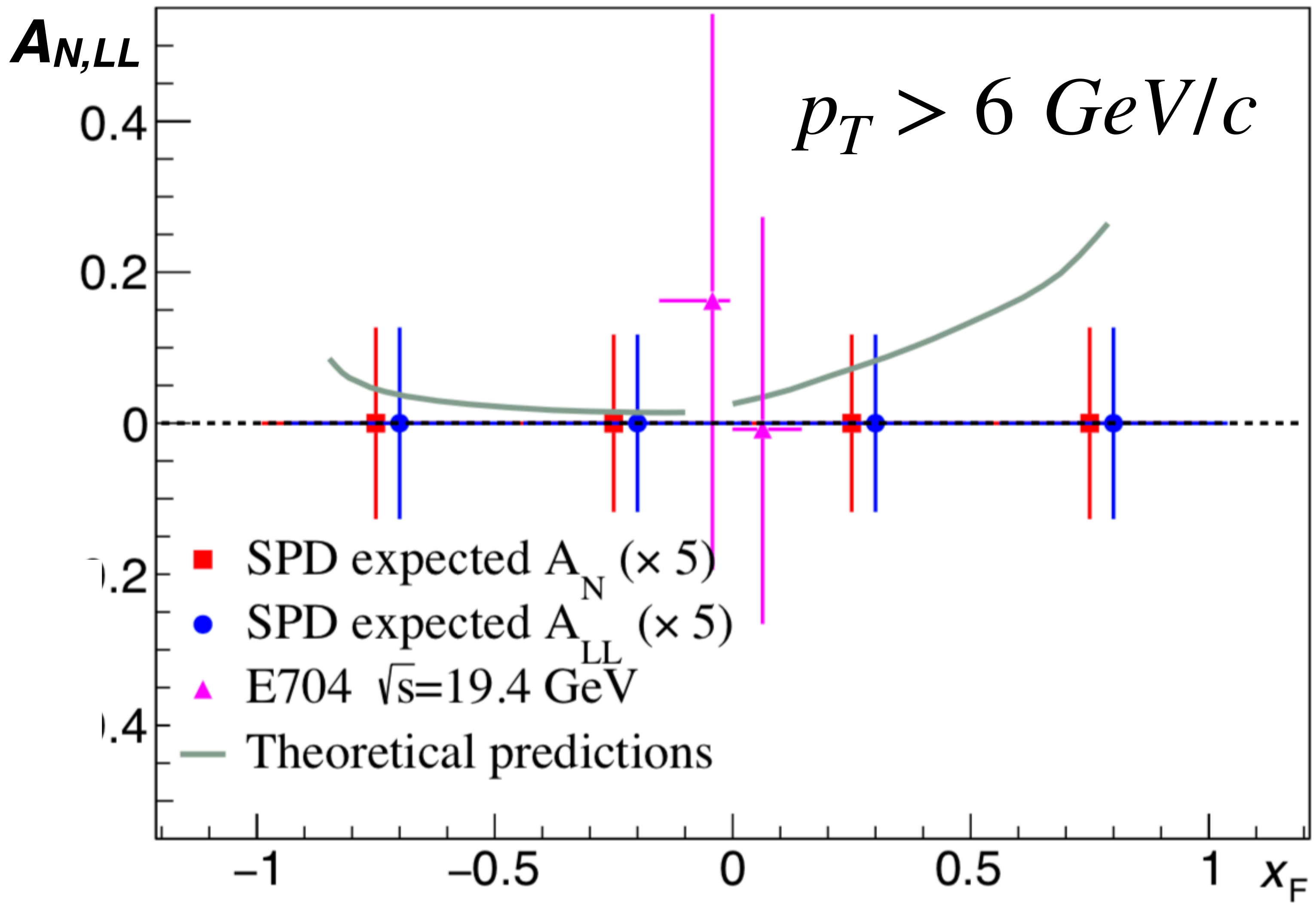
General strategy:

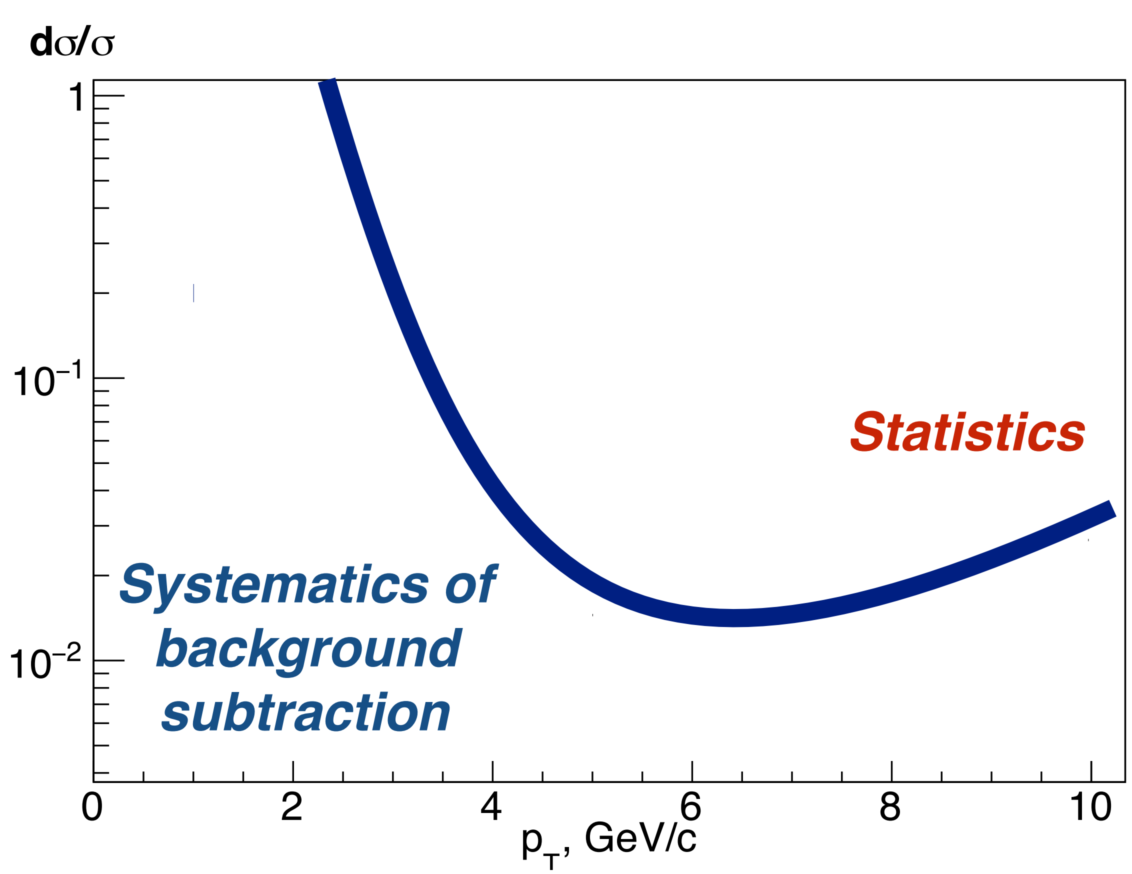
1) π^0 reconstruction and subtraction of photons from $\pi^0 \rightarrow \gamma\gamma$
2) Subtraction of residual background: $N_{prompt\ \gamma} = N_{\gamma} - \mathbf{k} N_{\pi^0}$

There **k**-factor is calculated from MC simulation $\mathbf{k} \approx 0.2$

Expected accuracy

- **1 year of data taking (10^7 s) with $L = 10^{32} cm^{-2} s^{-1}$**
- **Beam polarization $|P| = 1$**
- **Luminosity measurement uncertainty is ignored**
- $dk/k = 0.02$





Further optimisation of the setup and background subtraction algorithms is needed

Summary

- Unpolarized and polarized physics with prompt photons looks very attractive
- All the measurements at energy scale ~20 GeV were performed 20-30 years ago It is a good time to come back with new level of experimental techniques and theoretical understanding
- We have good chance to perform such kind of measurements at SPD detector
- Background conditions for studies with prompt photons are quite hard. So the SPD detector should be effectively optimized
- Nevertheless preliminary MC studies show that the measurement of the prompt-photon production cross section on the level of a few per cent is possible at the SPD conditions
- Measurement with prompt photons could be the first stage of the SPD operation

Thank you for your attention!