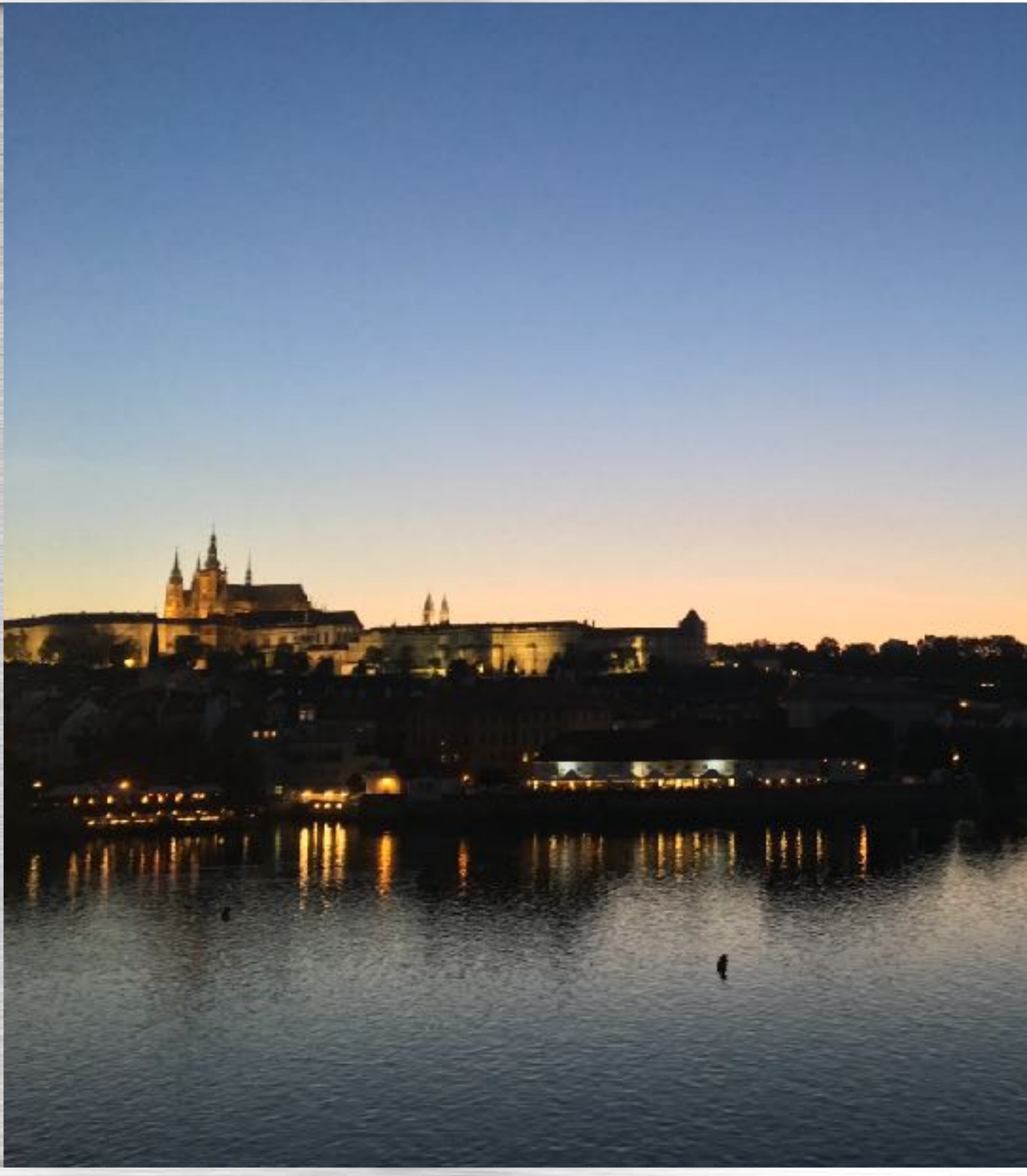
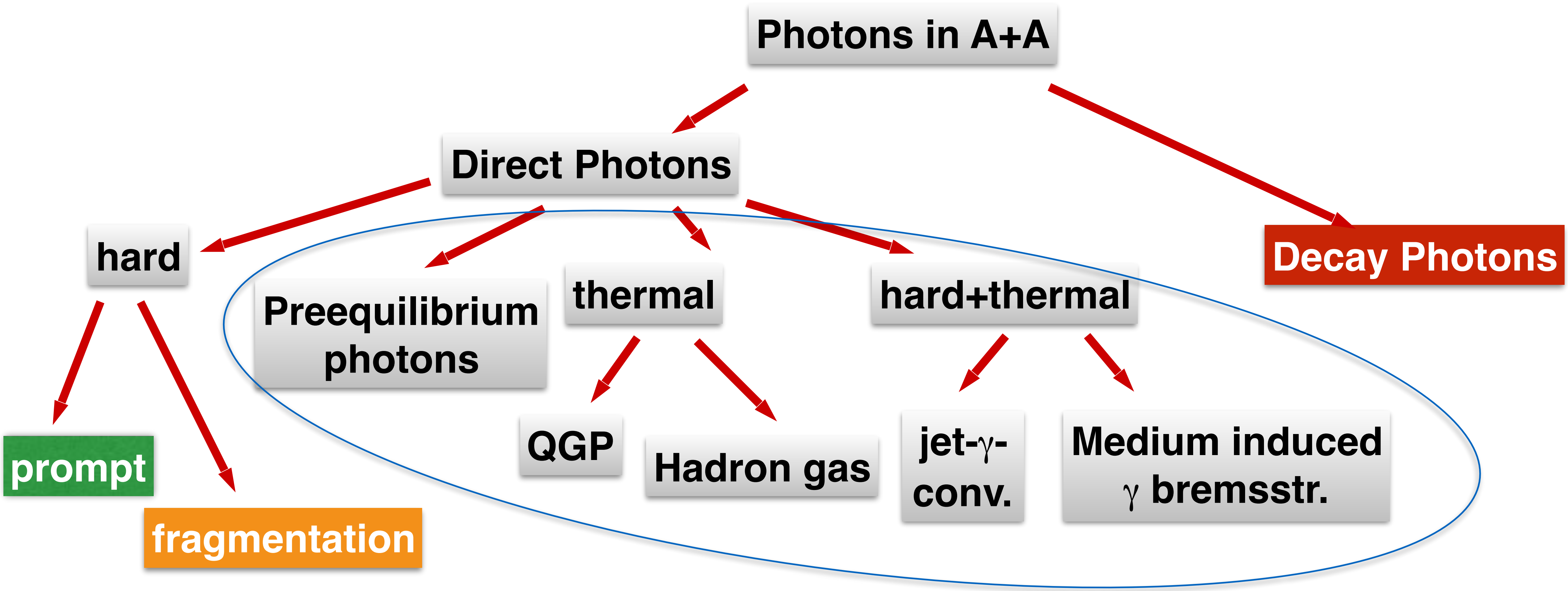
Physics with prompt photons at SPD

Alexey Guskov, JINR
avg@jinr.ru
11.07.2018

JINR



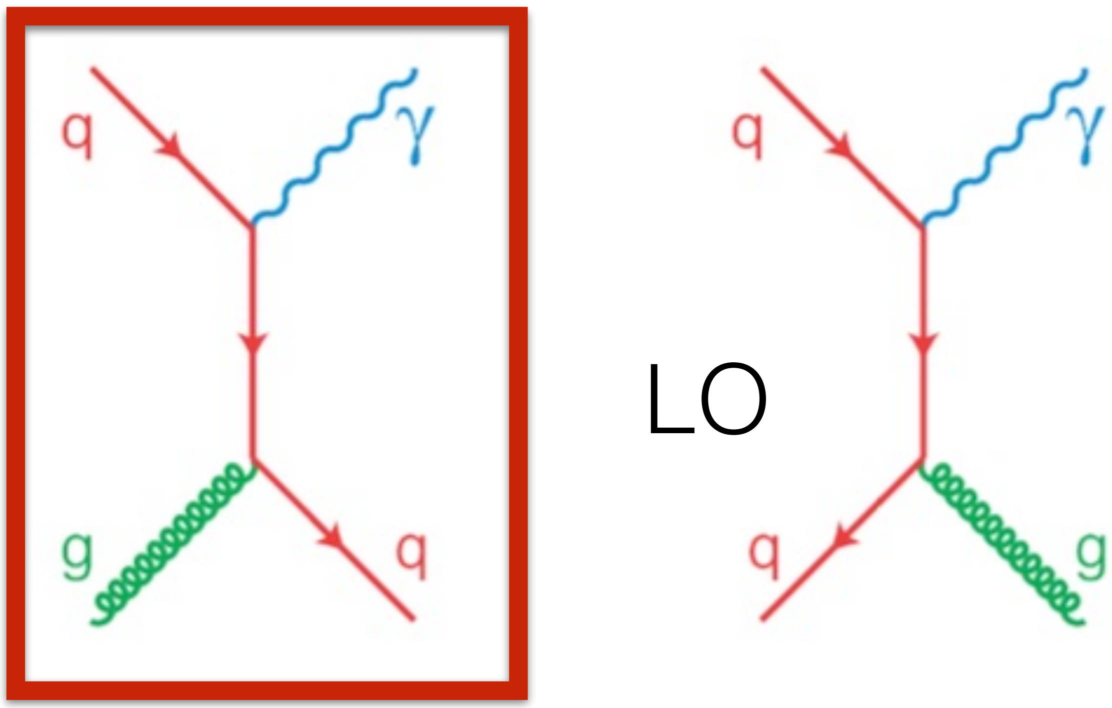
Production of photons in hadron collisions

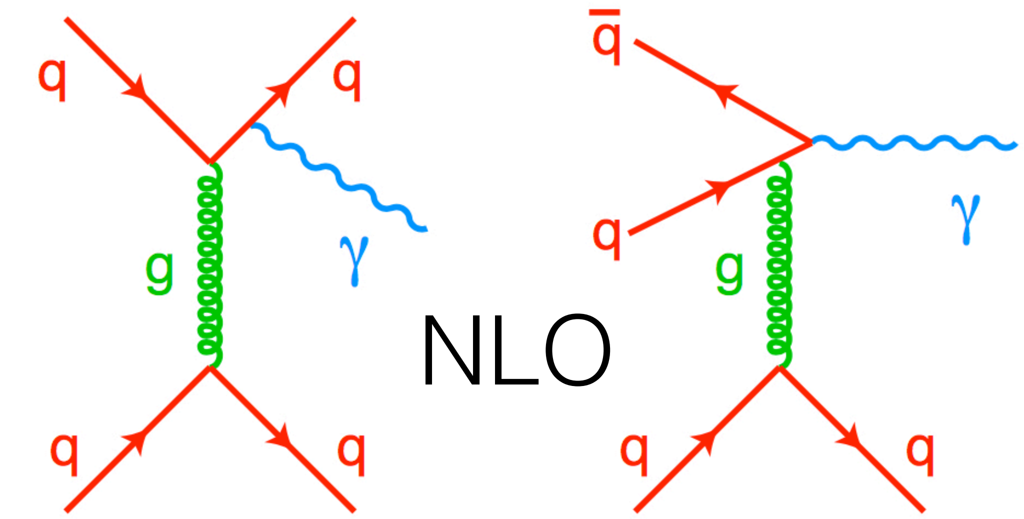


collective effects,
not important for pp or dd collisions

Please note, direct photons at MPD and SPD are different things!

Prompt photons





Bremsstrahlung

annihilation with scattering

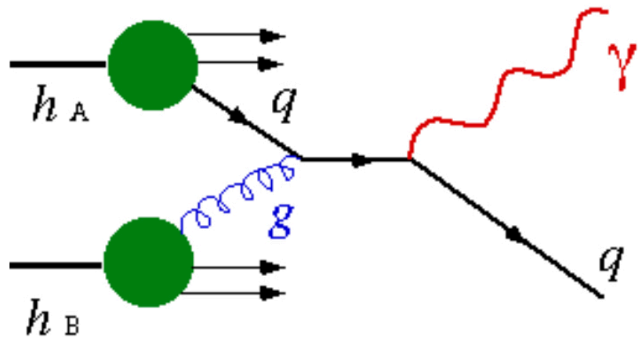
$$d\sigma_{AB} = \sum_{a,b=q,\bar{q},g} \int dx_a dx_b f_a^A(x_a,\mu^2) f_b^B(x_b,\mu^2) d\sigma_{ab\to\gamma X}(x_a,x_b,\mu^2).$$

$\mu \sim p_T/2$

Measurement with prompt photons is direct access to gluon distributions in nucleon

Ways to access gluon structure of nucleon at low energies

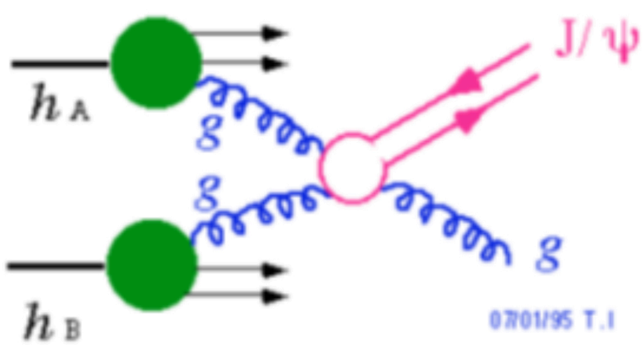
- **prompt-photon production**



The most direct way

Strong background

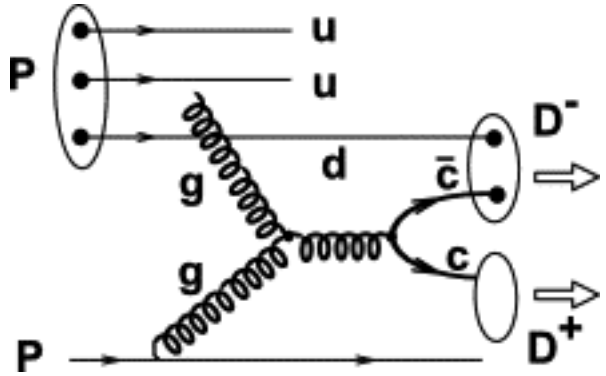
- **charmonia production**



Nice signal

Model-dependent treatment

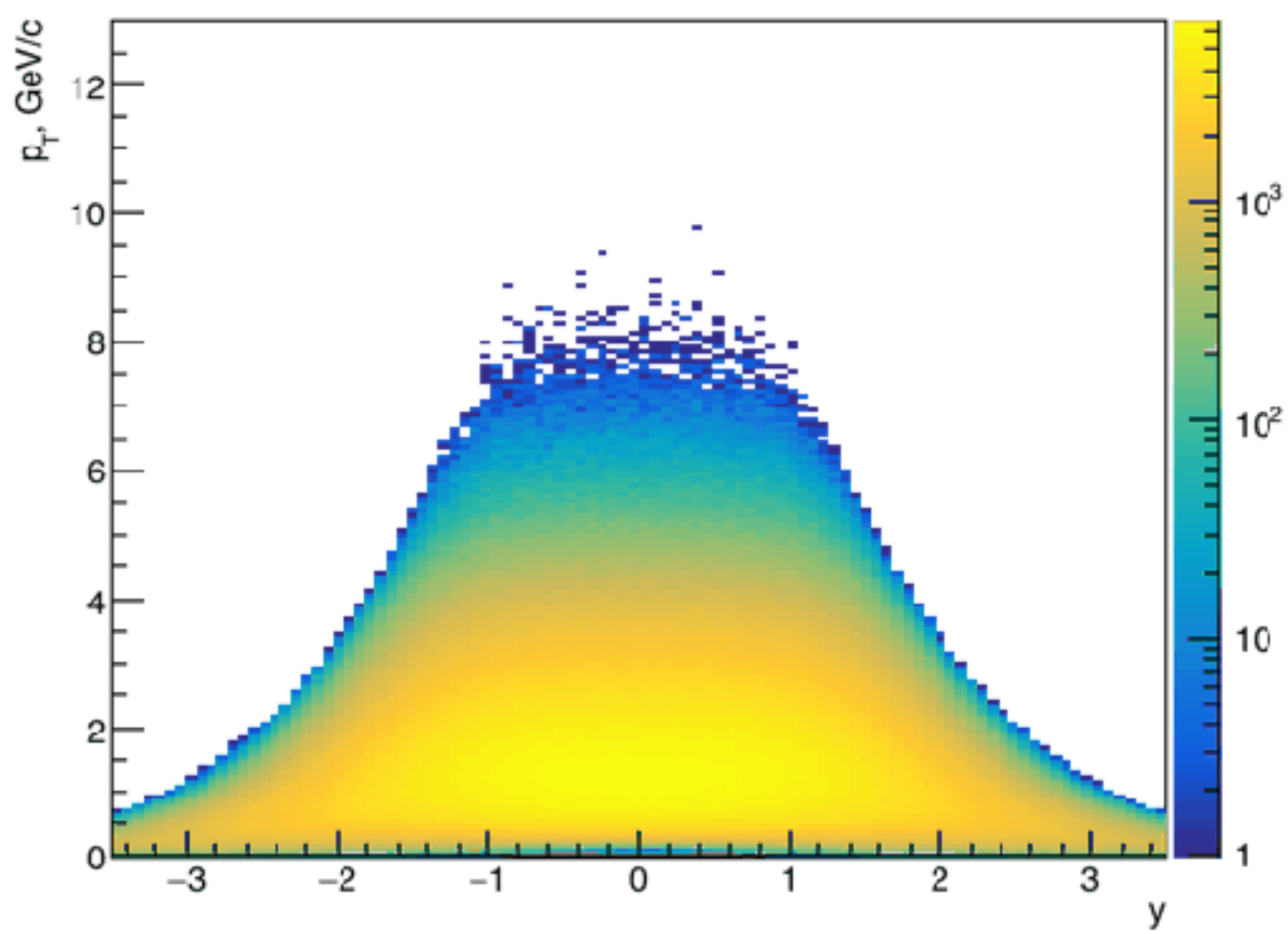
- **open-charm production**

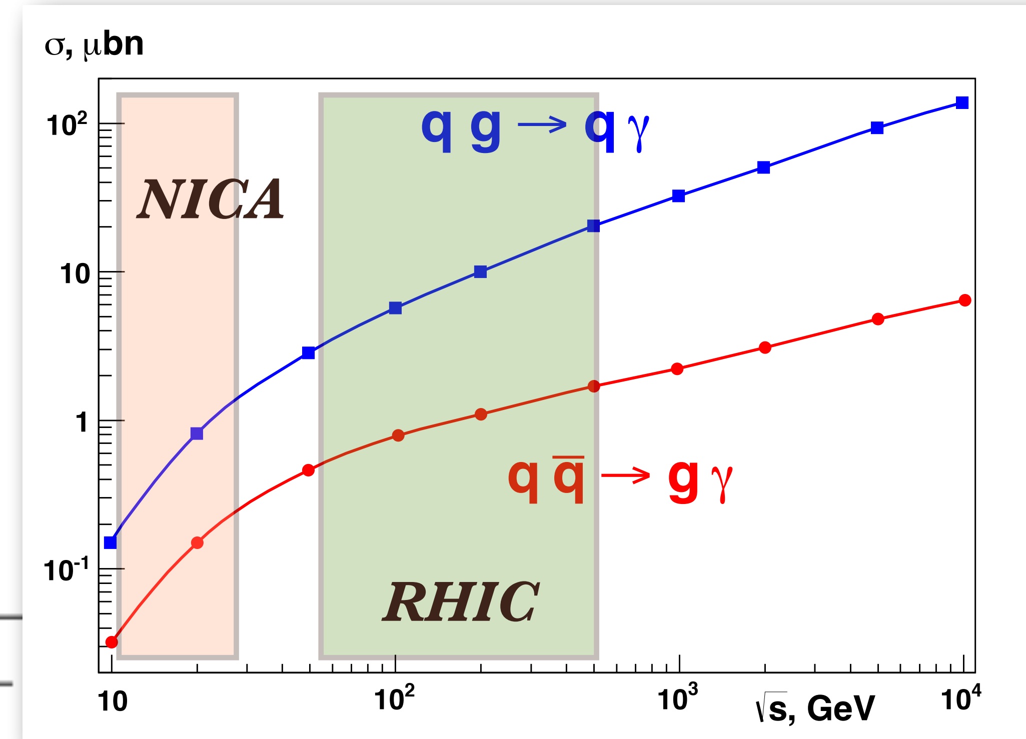


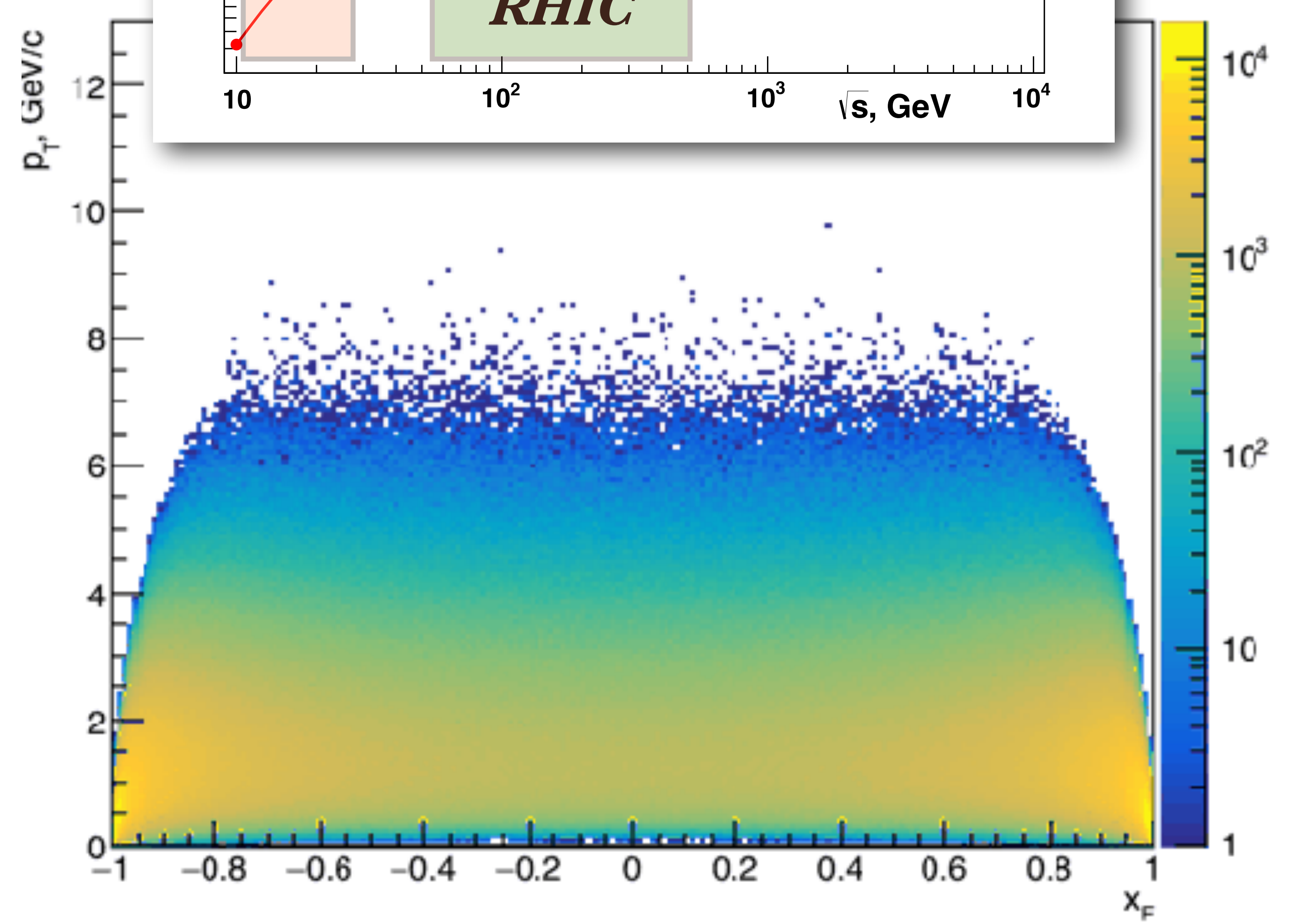
Rather simple treatment

Problematic signal

Gluon Compton Scattering (GCS)

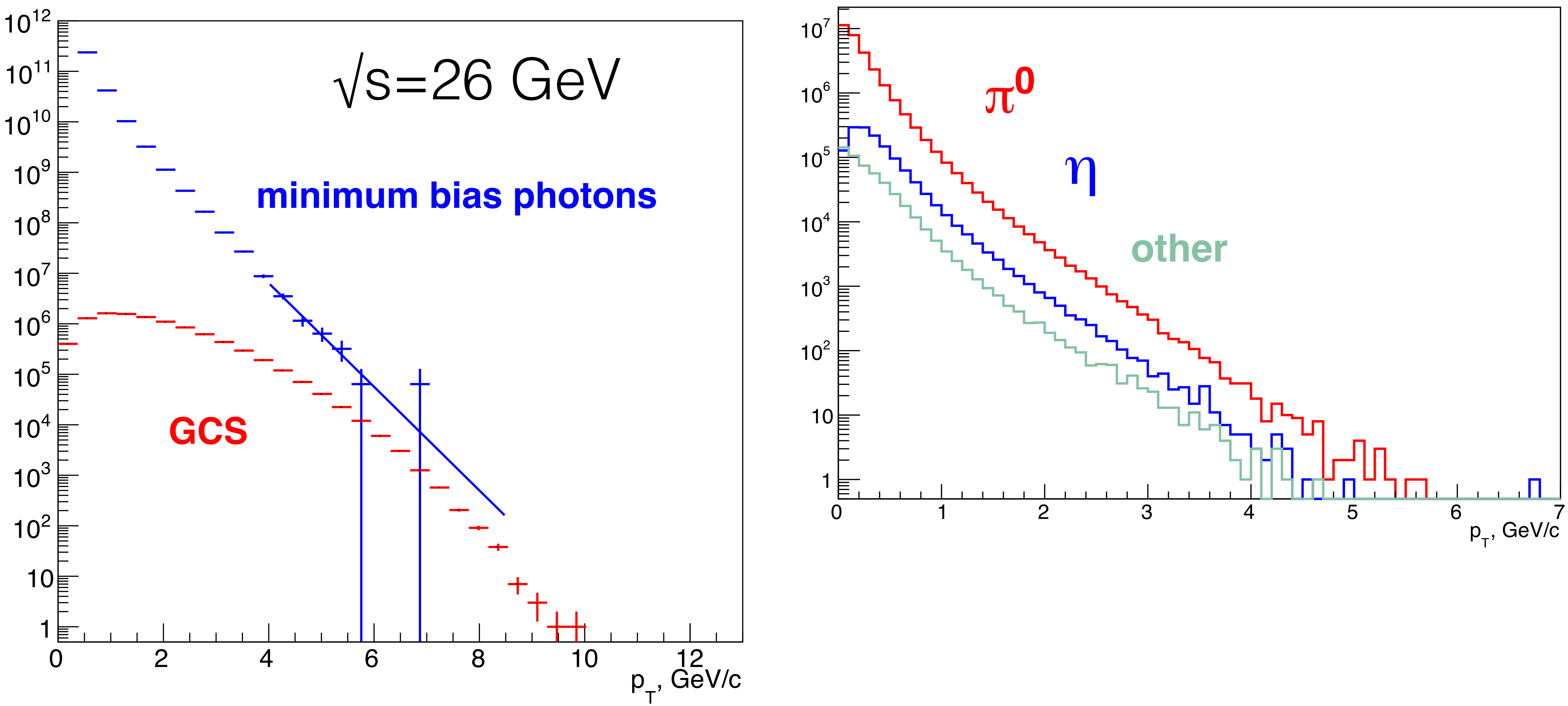






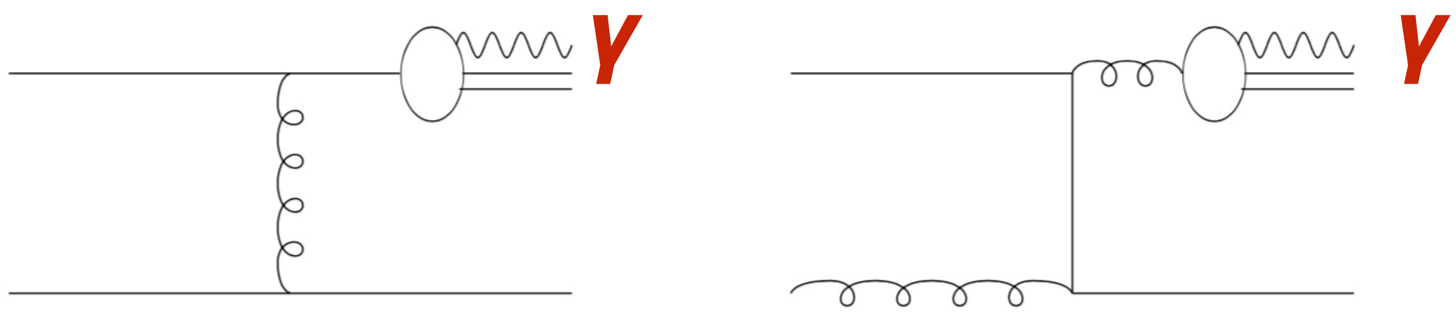
The region of **negative y** (or $\mathbf{x_F}$) is the most sensitive for gluon content of beam meson

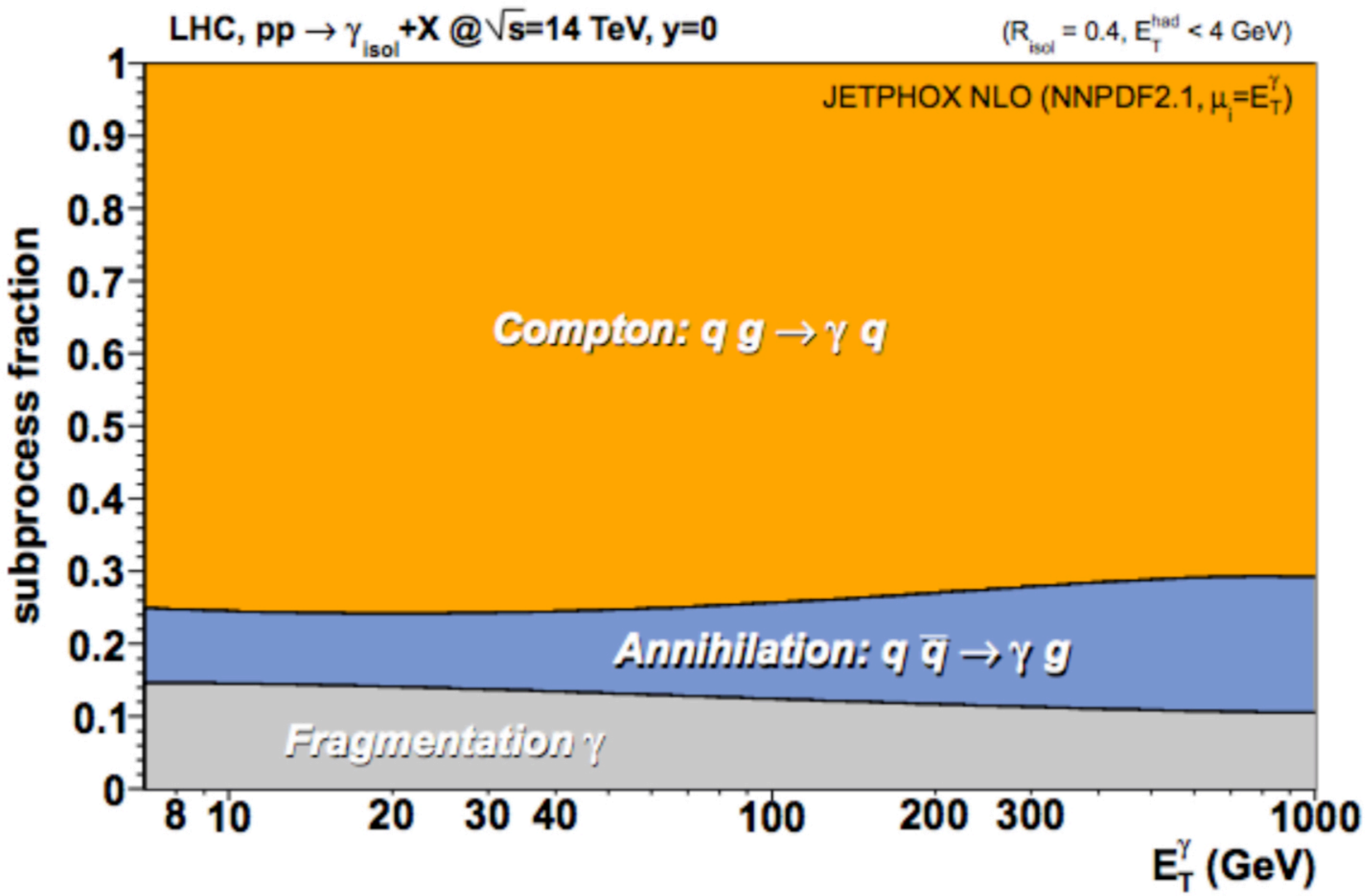
Decay photons



Even at very high p_T signal will dominate over background !

Fragmentation photons





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

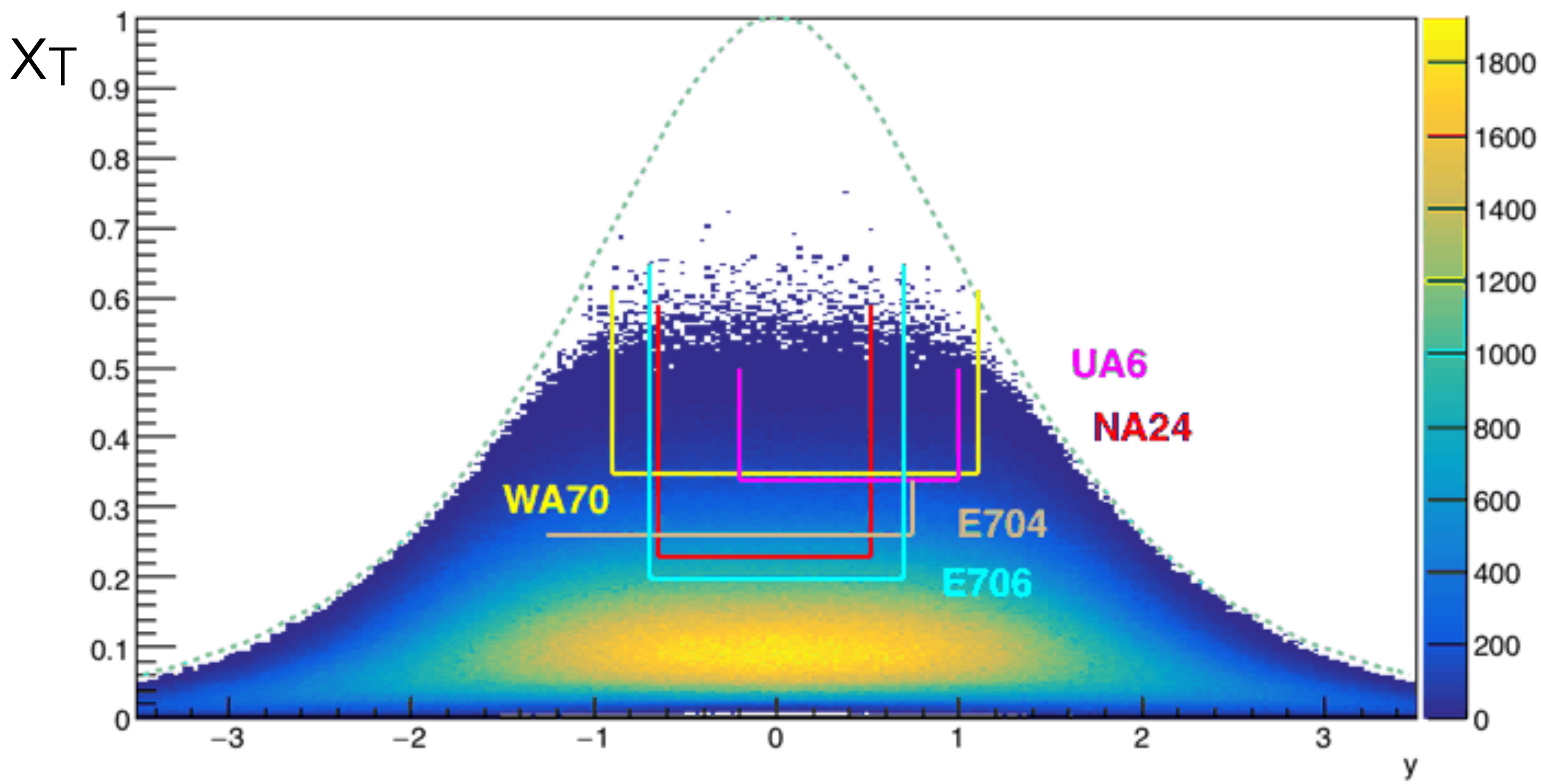
It can be calculated in LO and NLO

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

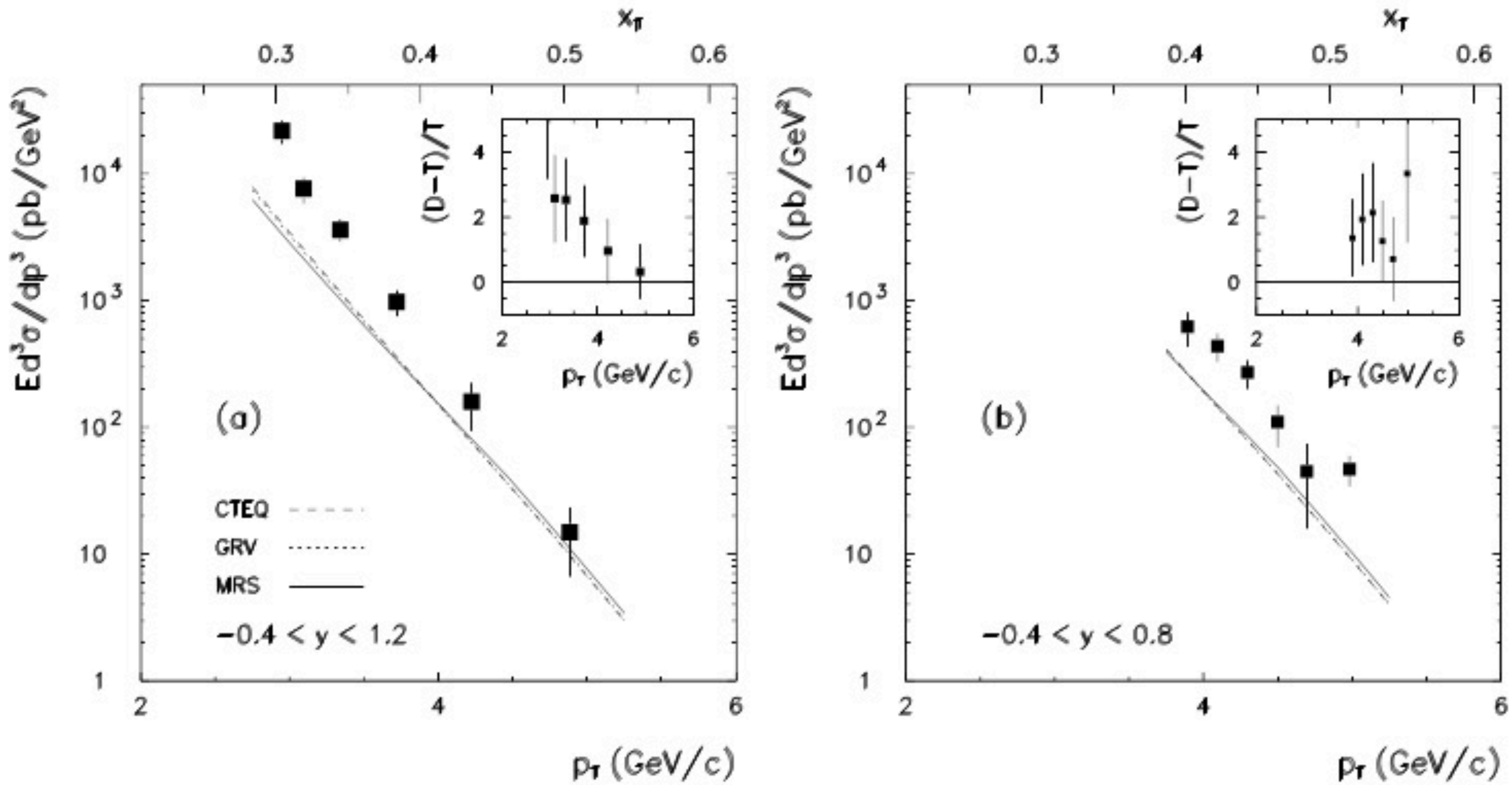
$x_T=2p_T/\sqrt{s}$

Low-energy measurements



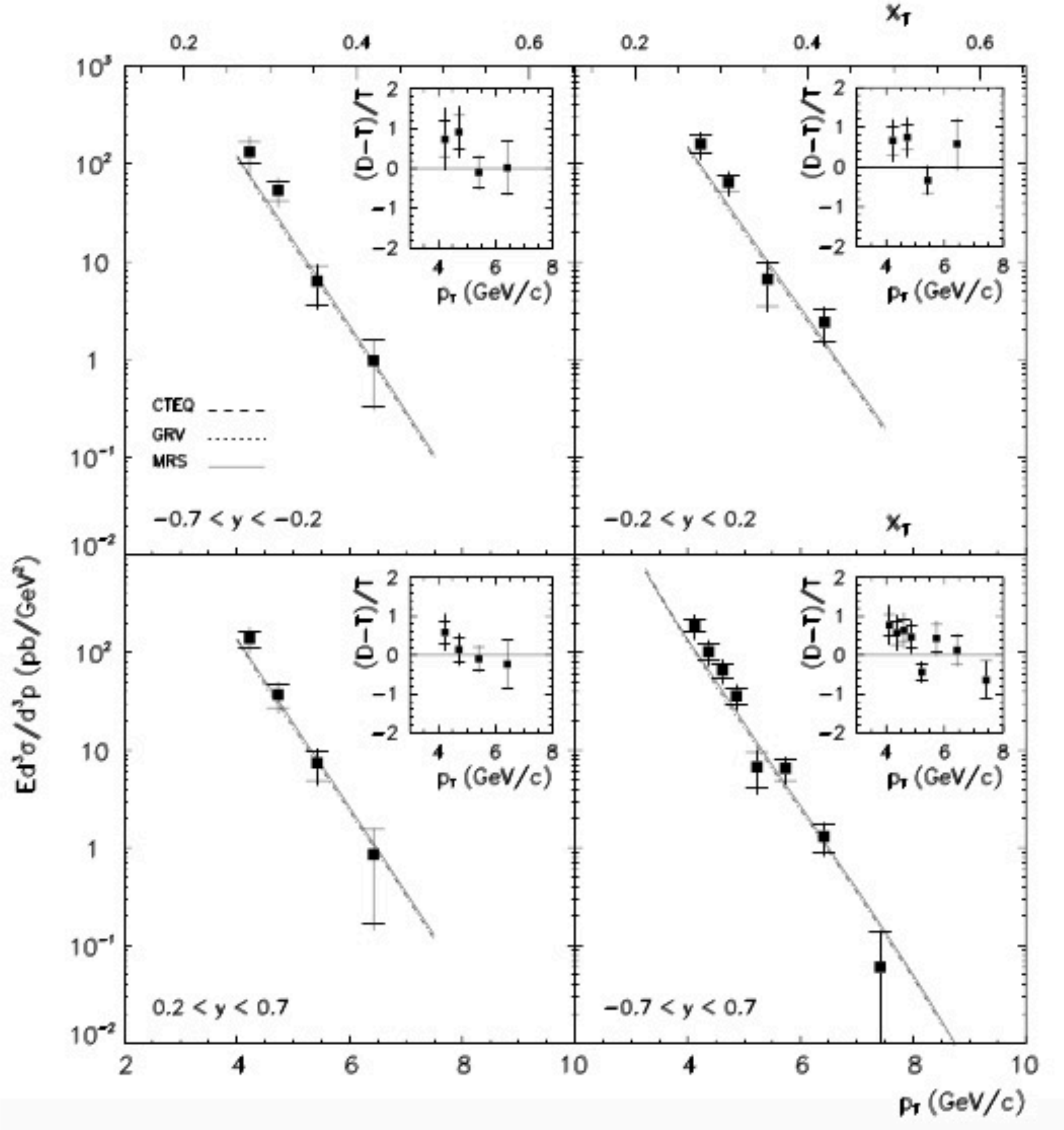
Previous results: pA

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



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

Previous results: pA

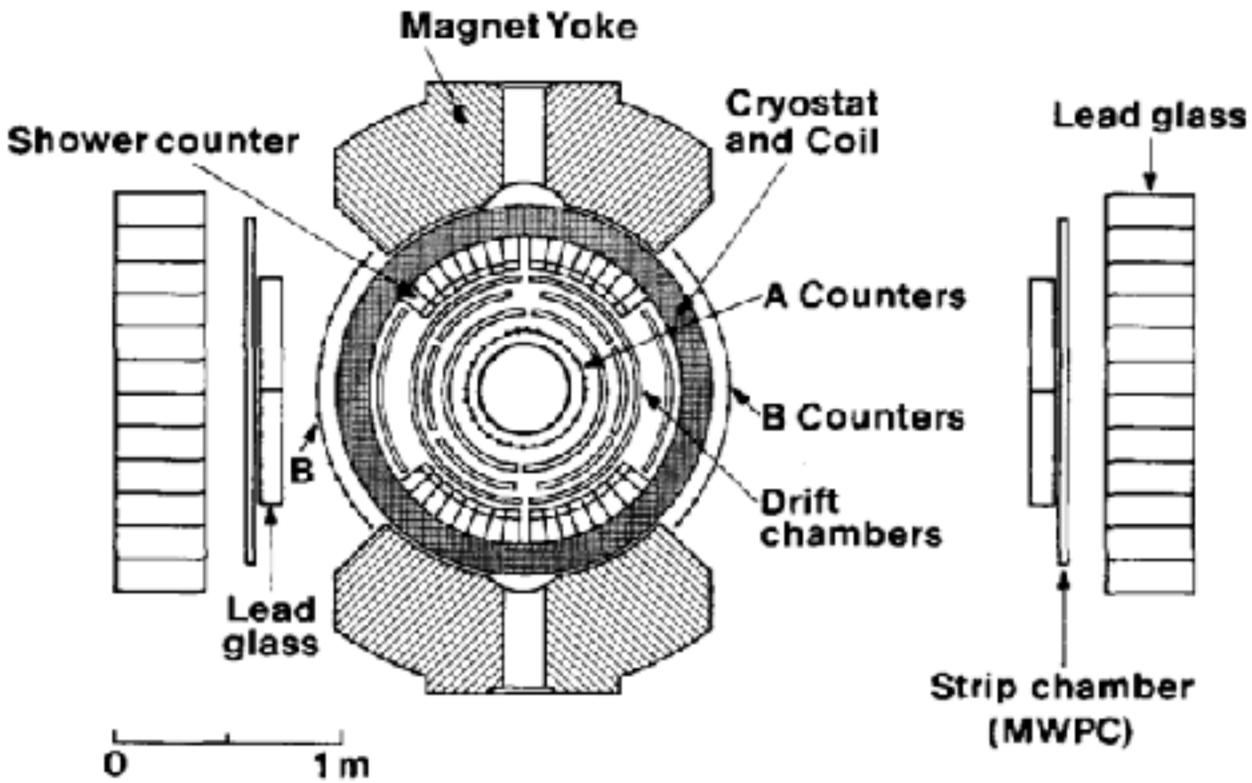


E706 (1993)

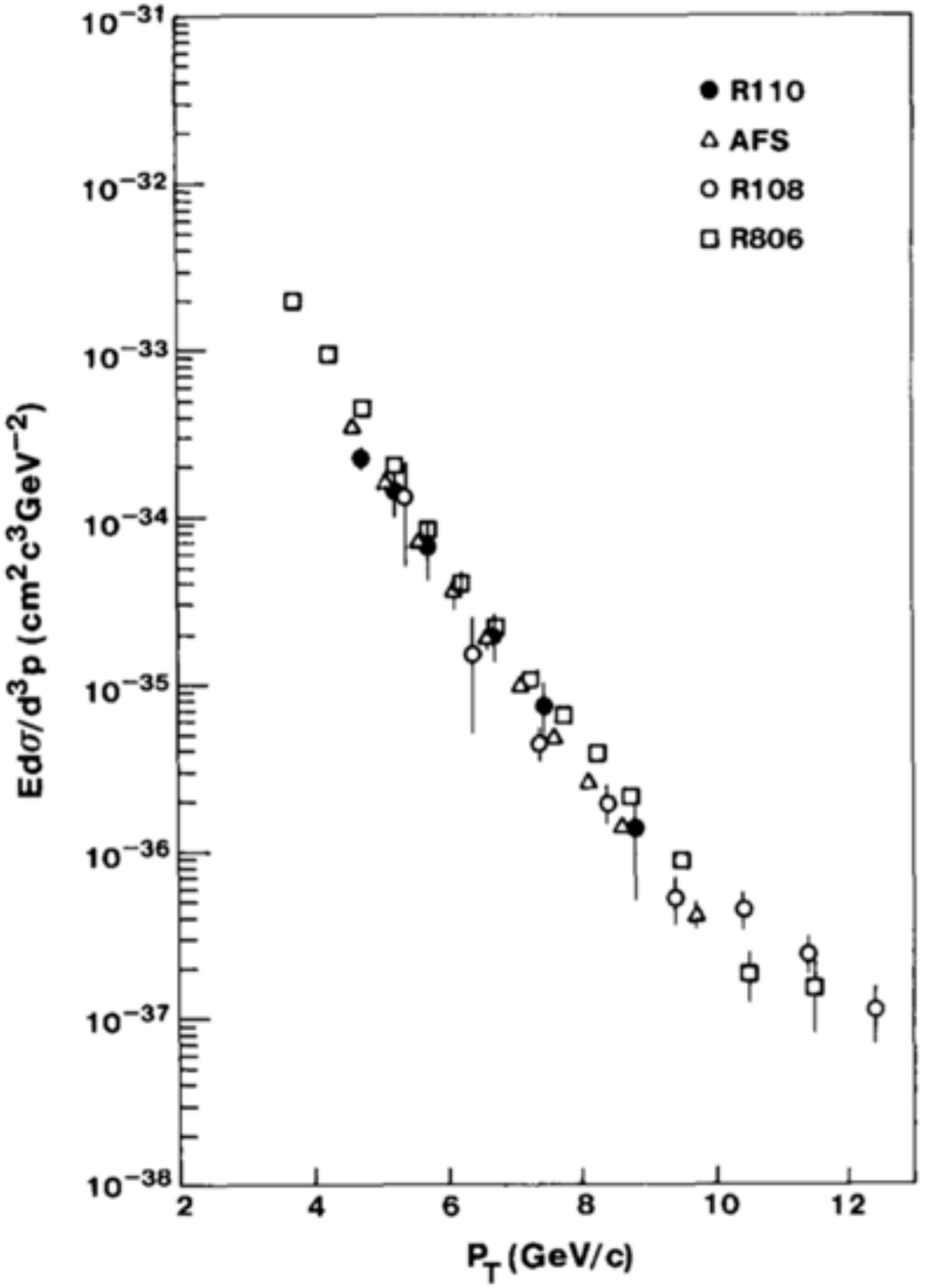
$p\ Be \rightarrow \gamma\ X$

Prompt photons at low-energy colliders

ISR: √s=63 GeV R806 (1982), R110 (1989), R807(1990)



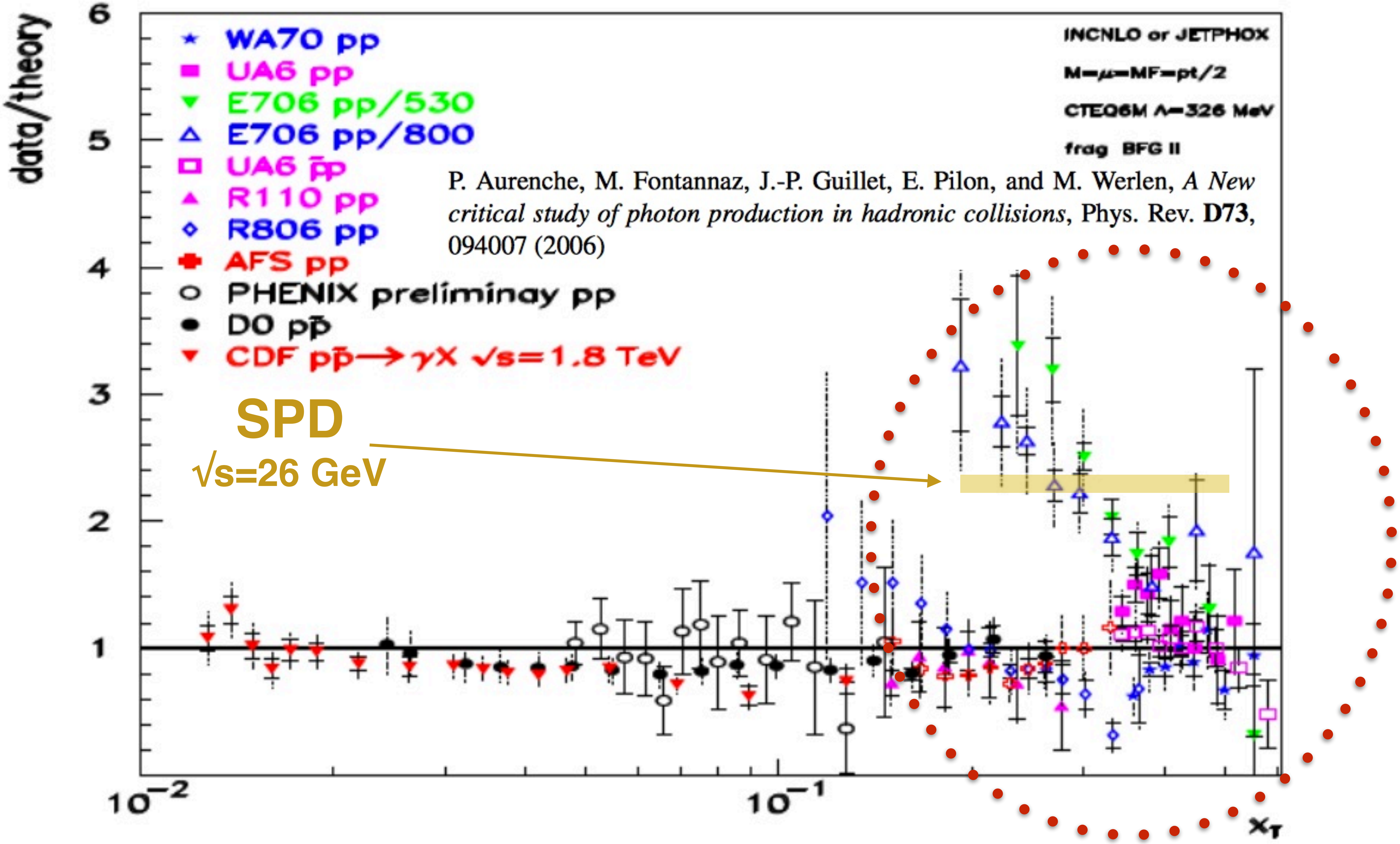
Particle	Mass (GeV)	Prod. σ/π^0	Decay	# of photons	Branching ratio (BR)	$\sigma \times BR/\pi^0$	% in sample
π^0	0.135	1.0	$\gamma\gamma$	2	1.0	1.0	61.4
η^0	0.549	0.55	$\gamma\gamma$	2	0.38	0.209	12.8
η^0	0.549	0.55	$\pi\pi\pi$	6	0.30	0.165	10.1
K_s^0	0.498	0.40	$\pi\pi$	4	0.31	0.124	7.6
ω^0	0.783	0.50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



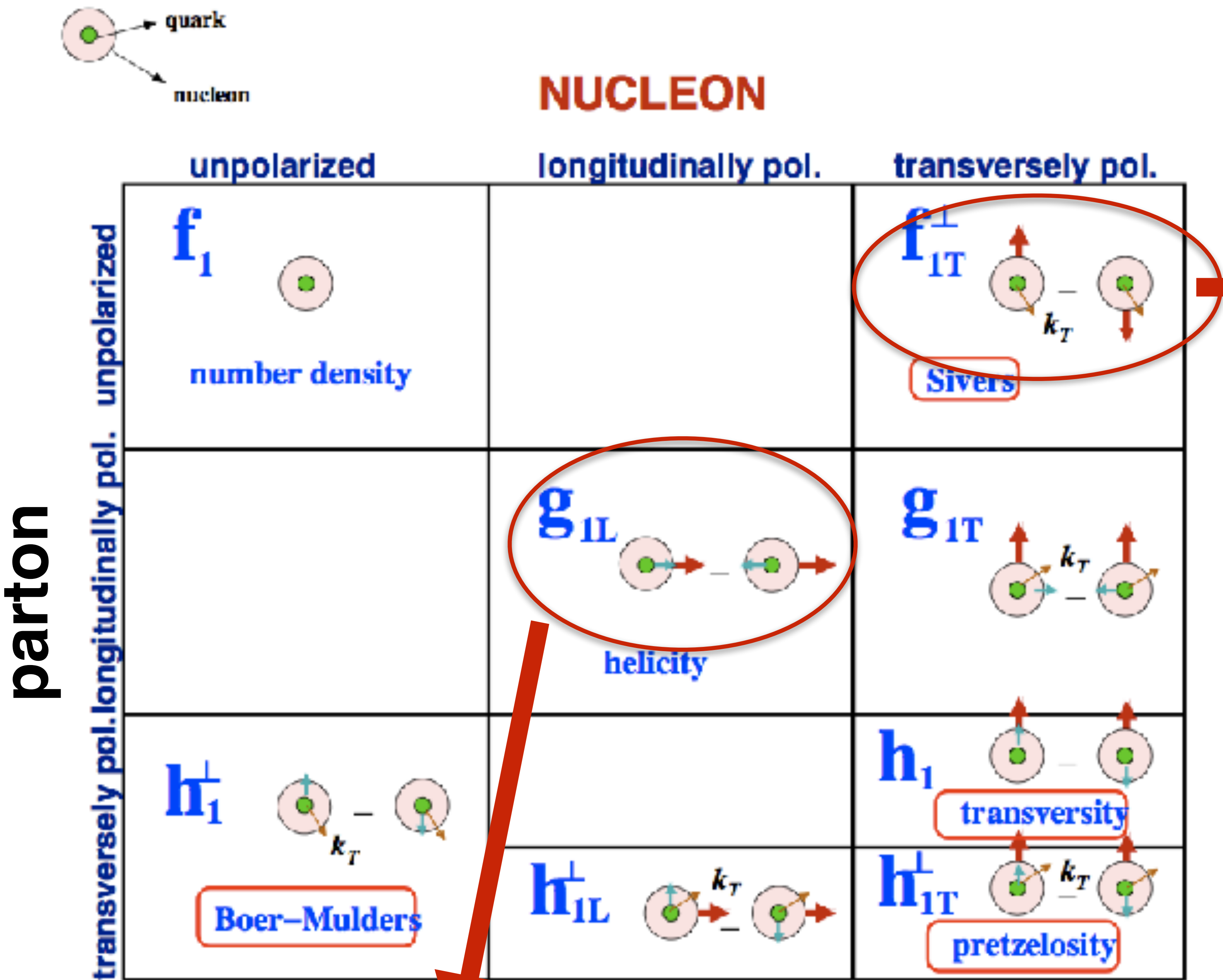
Also ar RHIC down to 62.4 GeV

Previous results: pp(pbar)

pp(pbar)



Nucleon PDFs



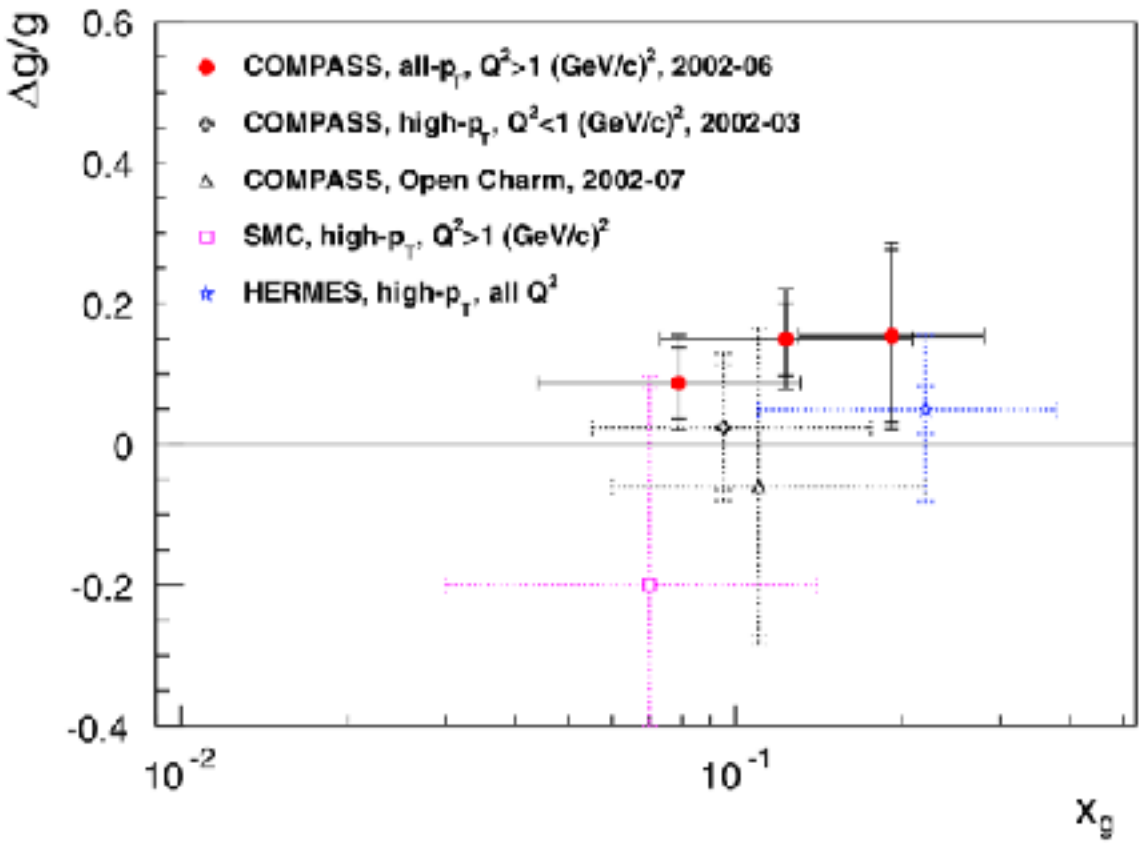
Gluon Sivers function

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 quarks (LO)

DSA with longitudinally polarised beams



Double longitudinal spin asymmetry

G. Bunce et. al. Ann.Rev.Nucl.Part.Sci. 50:525-575,2000

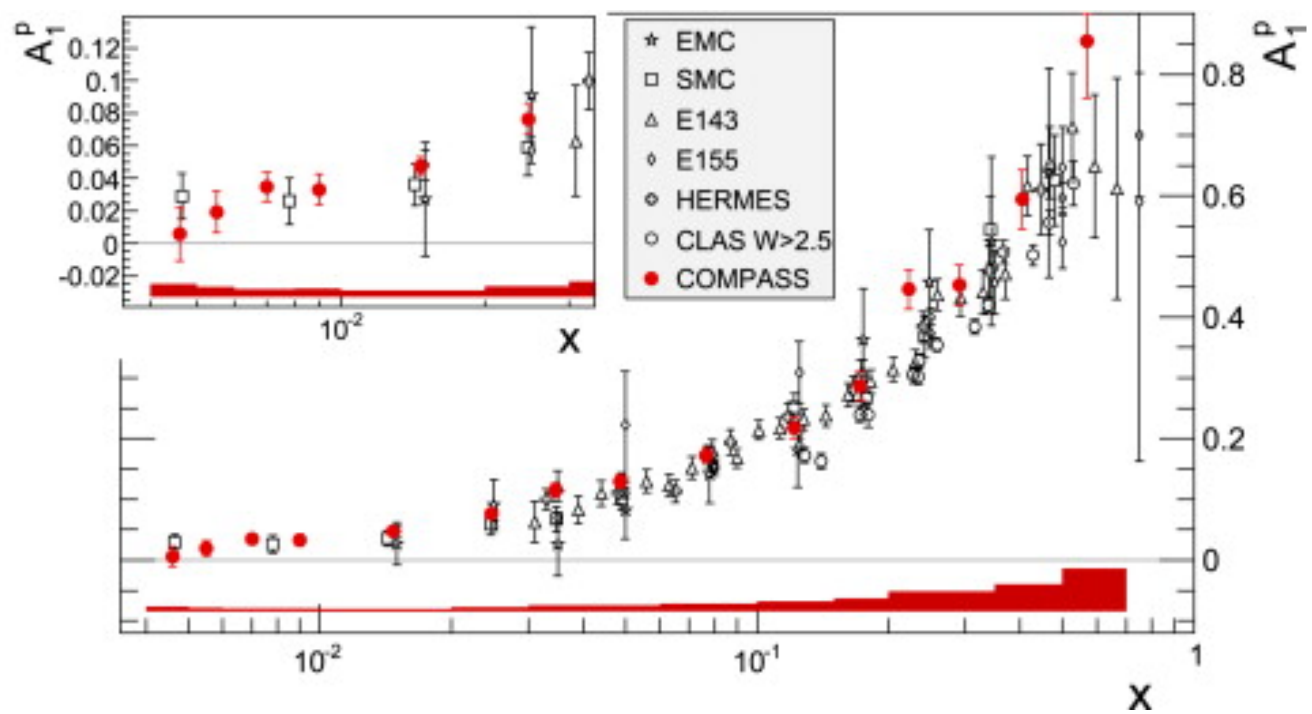
$$A_{LL} = \frac{(\sigma_{++} + \sigma_{--}) - (\sigma_{+-} + \sigma_{-+})}{(\sigma_{++} + \sigma_{--}) + (\sigma_{+-} + \sigma_{-+})}$$

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

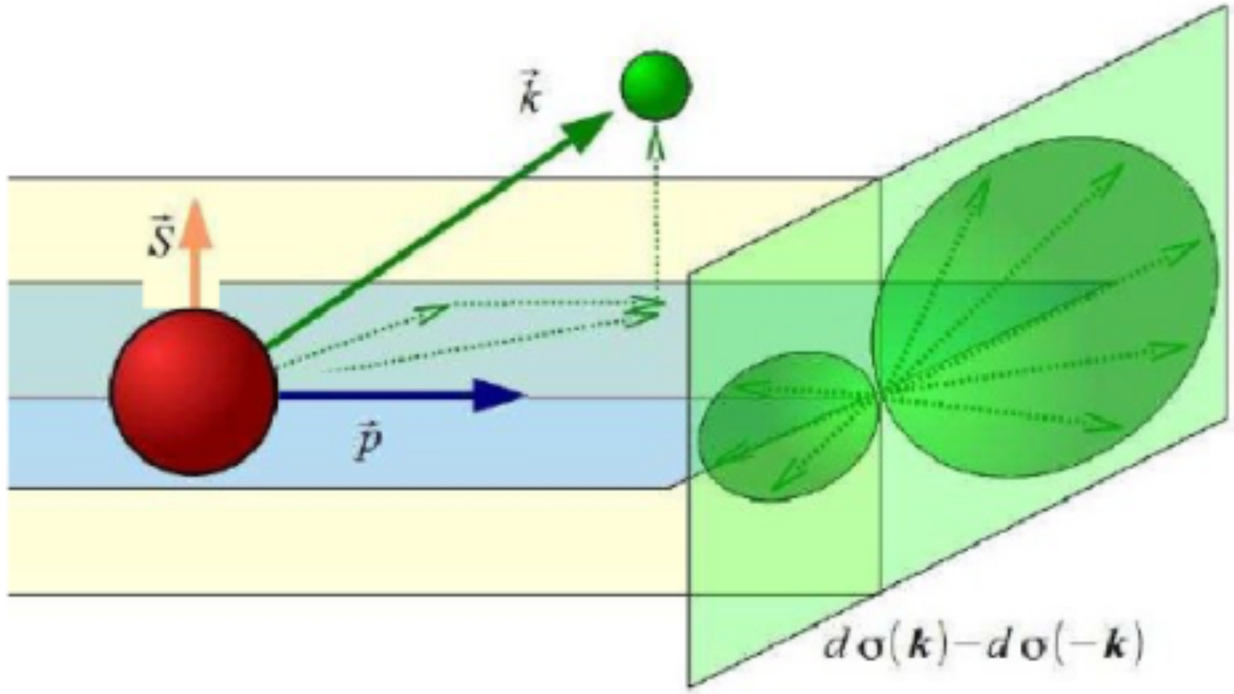
gluon polarization

***A_1^P* - known from DIS**

A_{LL} <3-5%

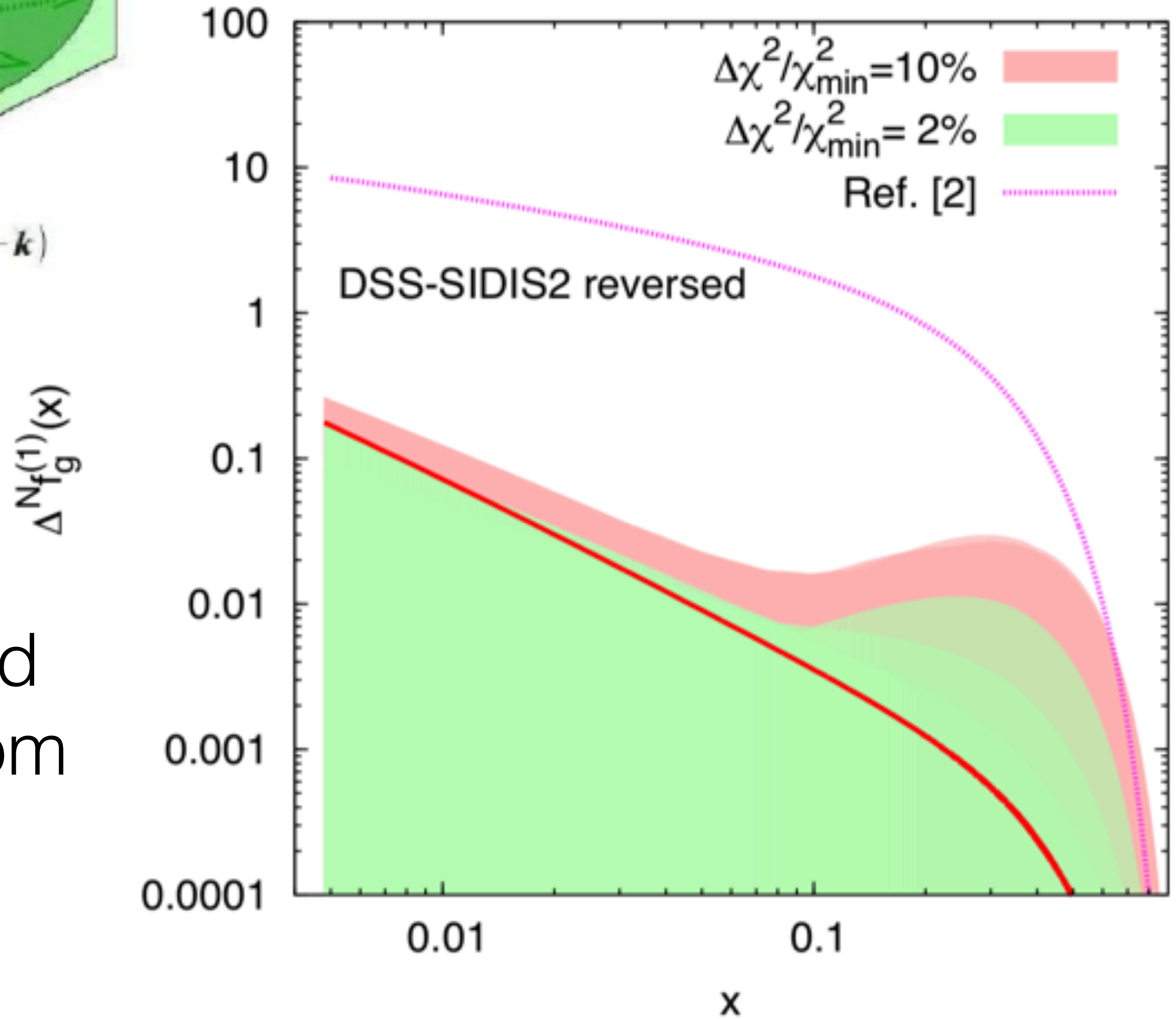


Gluon Sivers function



Many theoretical models and just very rough estimation from experimental data

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



SSA with prompt photons

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

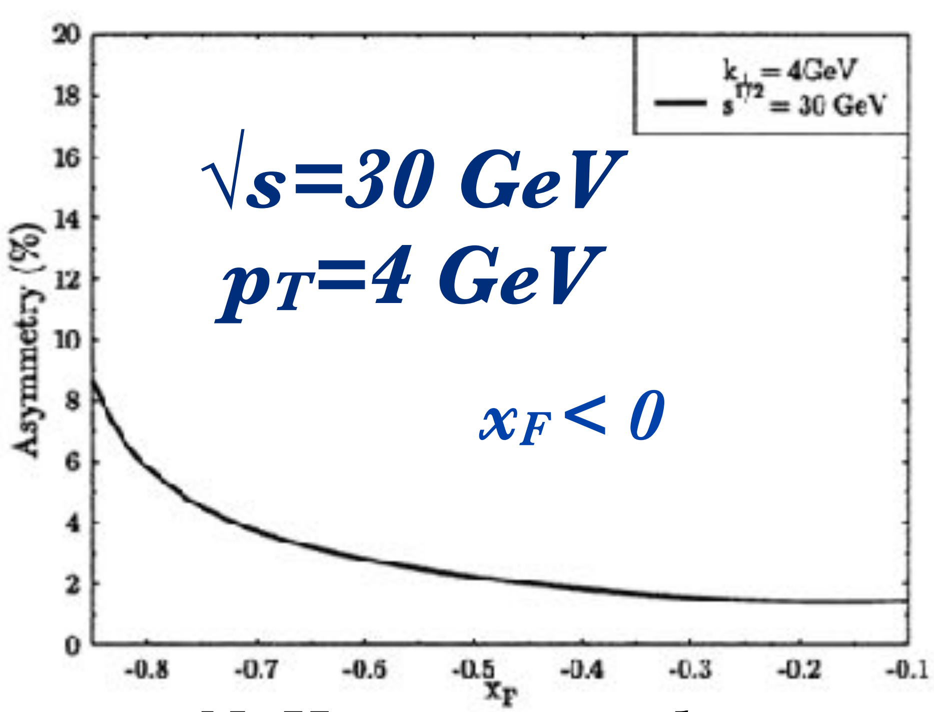
Single transverse spin asymmetry

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

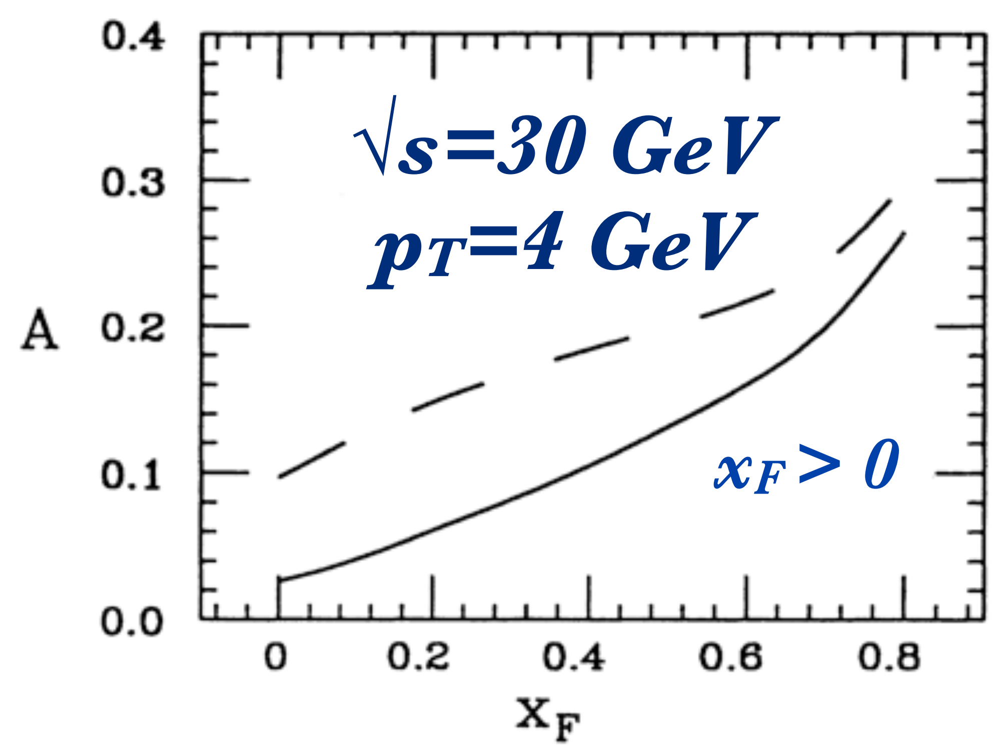
gluon Sivers function

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

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

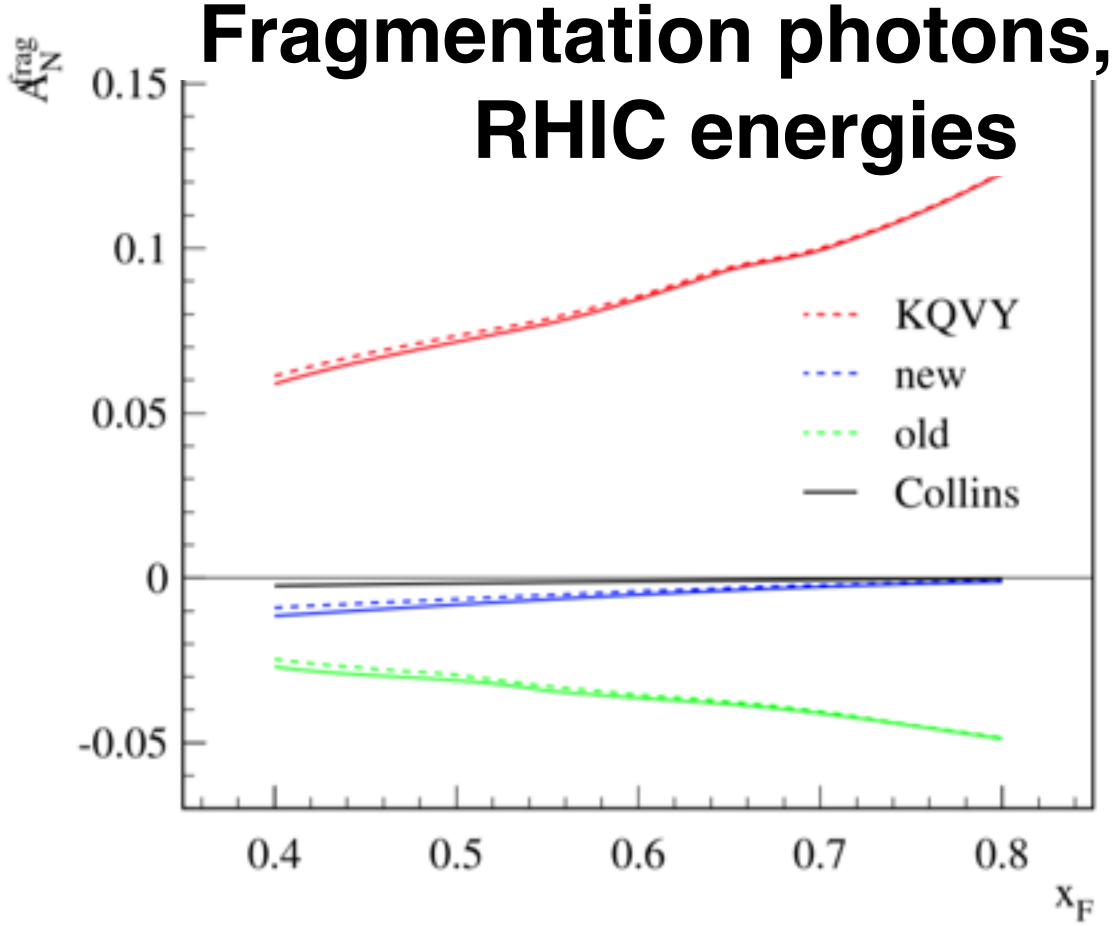
Our backgrounds are also spin-dependent !

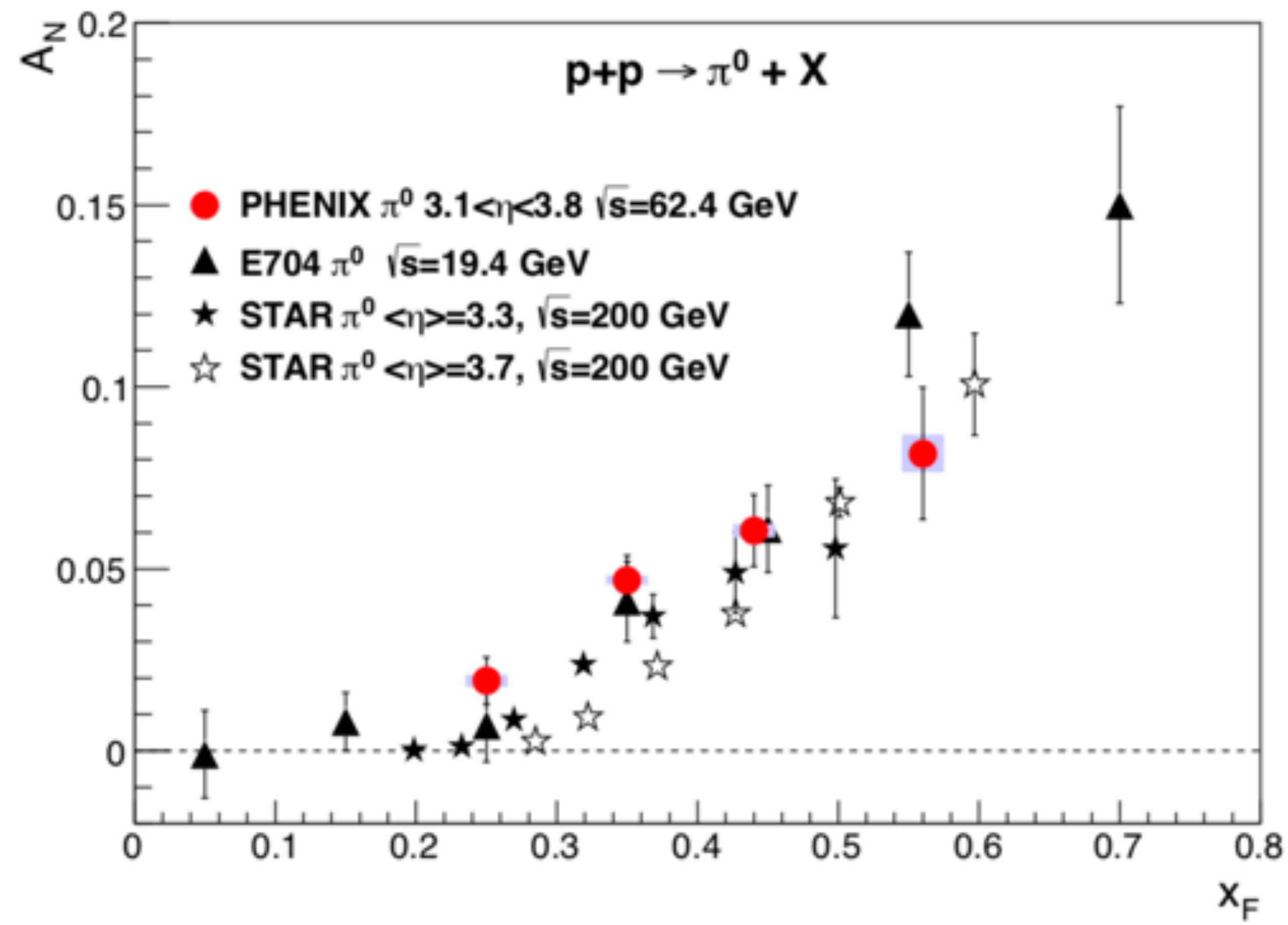
Leonard Gamberg, Zhong-Bo Kang

Phys.Lett.B696:109-118,2011

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

Fragmentation photons, RHIC energies



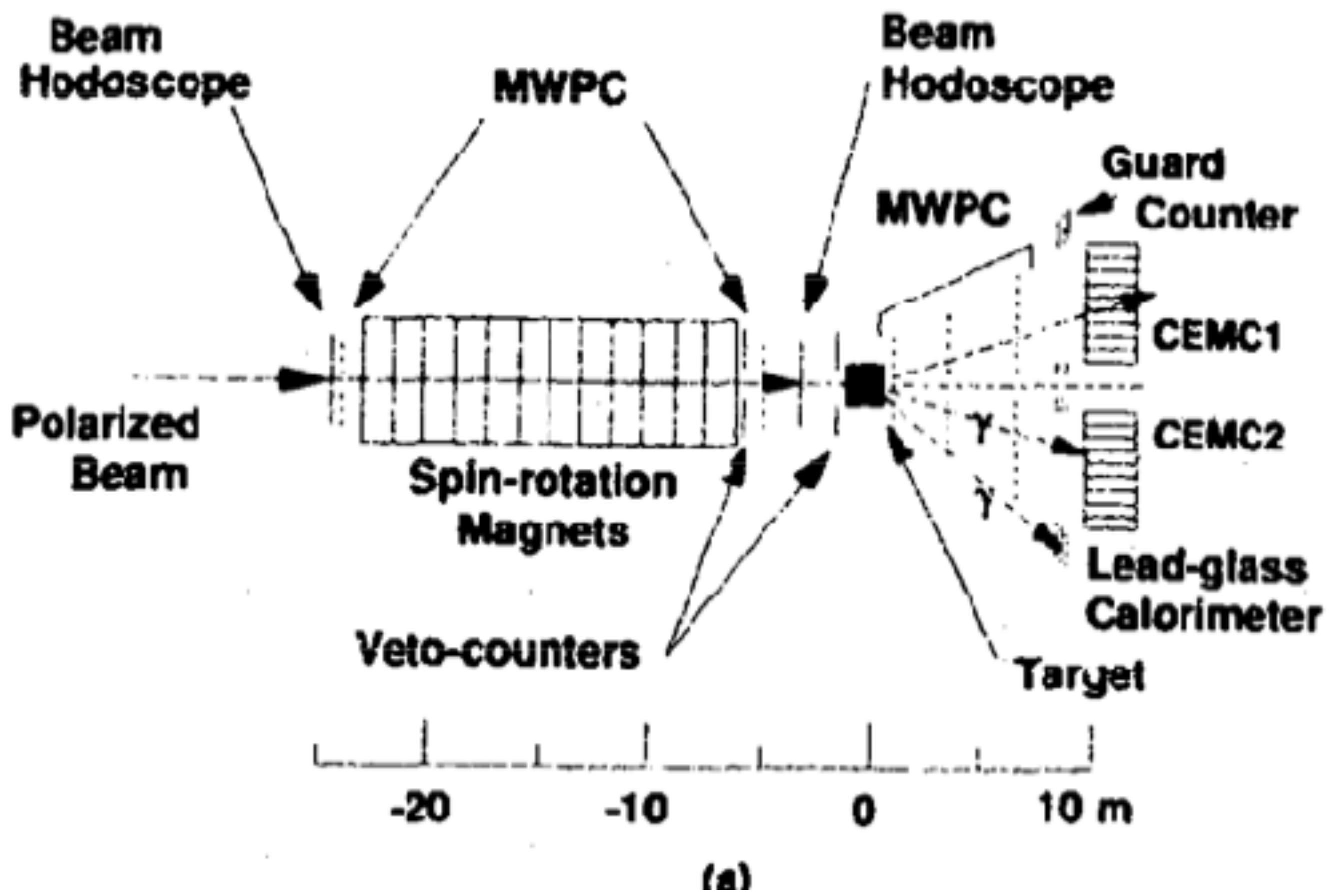


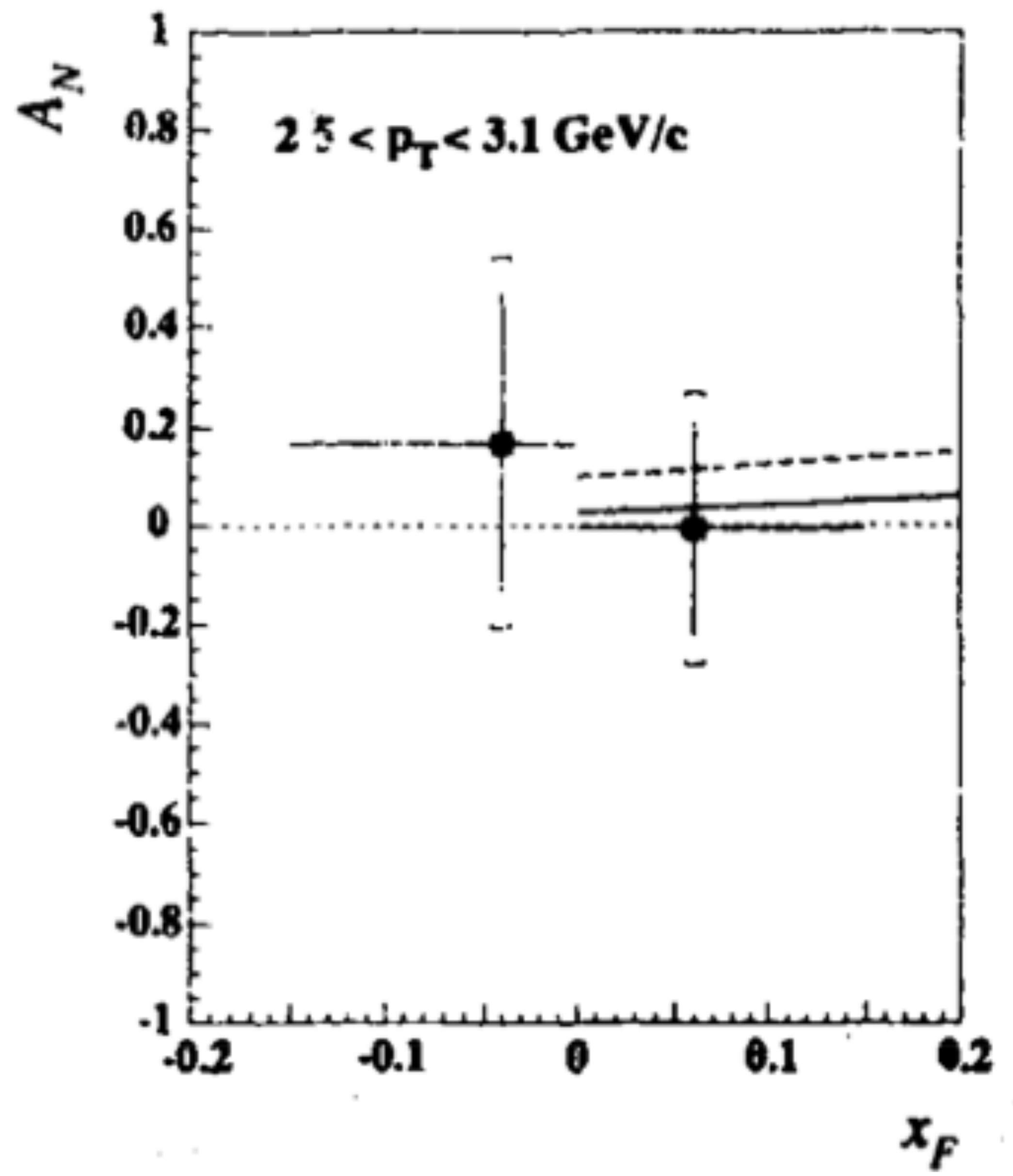
But they also contain info about spin structure of nucleon!

Single spin asymmetries at $\sqrt{s}$=19.4 GeV

Polarized measurement at FNAL E704 *Phys. Lett. B 345 (1995)*

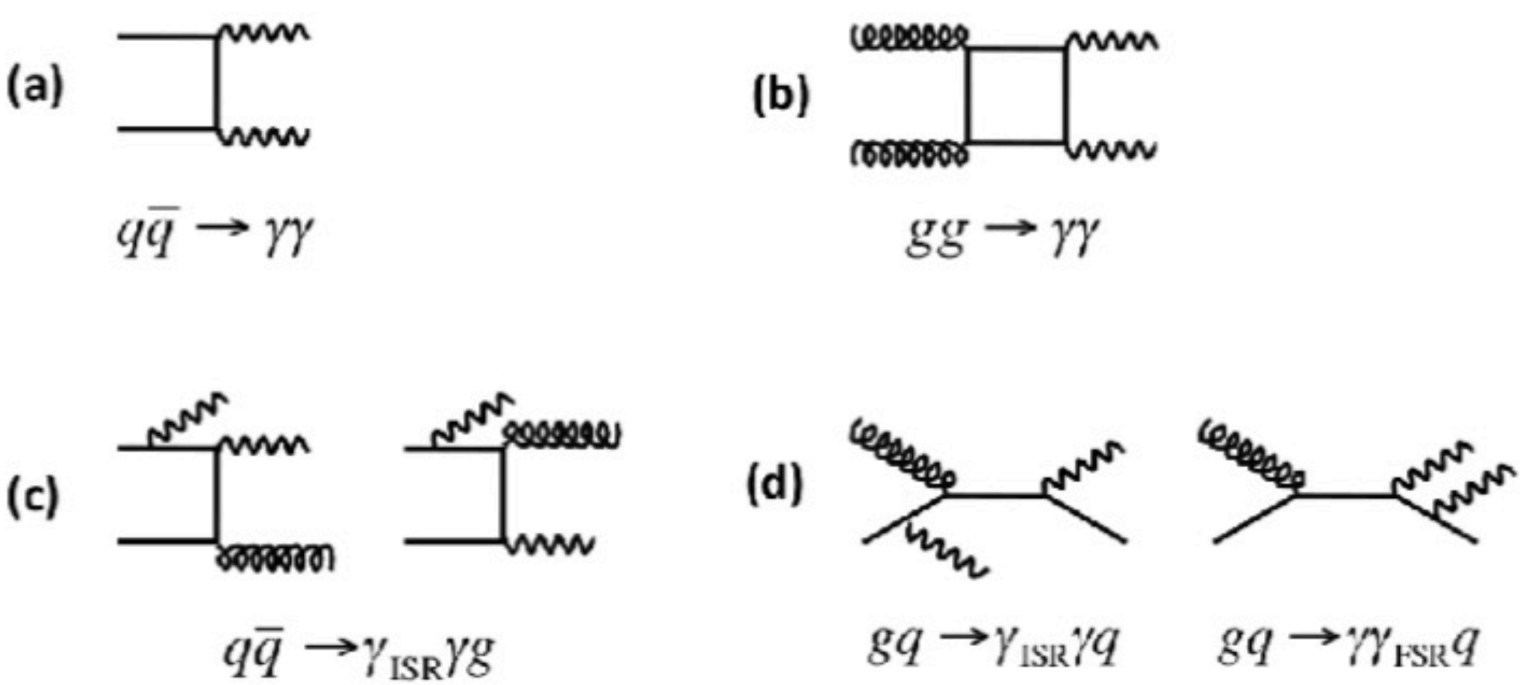
- *Fixed target.*
- *Polarized proton beam from Λ decay*
- *2.5 GeV/c $<p_T<$ 3.1 GeV/c*
- *π^0 mass resolution - 10.5 MeV*
- *473 prompt photon candidates (including 220+-22 background events)*





Production of double photons

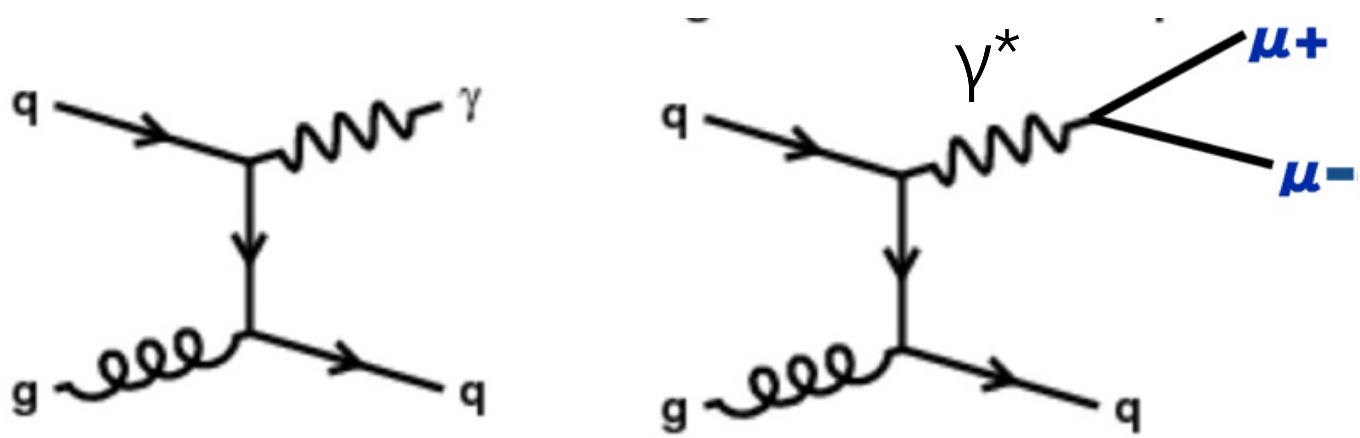
Much smaller cross section



Collaboration	$\sqrt{s}$	Beam	Target	Measurement
R806 [16]	63	p	p	$d^2\sigma/dy dm_{\gamma\gamma}$
R807 [19]	63	p	p	$d^2\sigma/dy dm_{\gamma\gamma}$
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

Prompt photons and DY

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

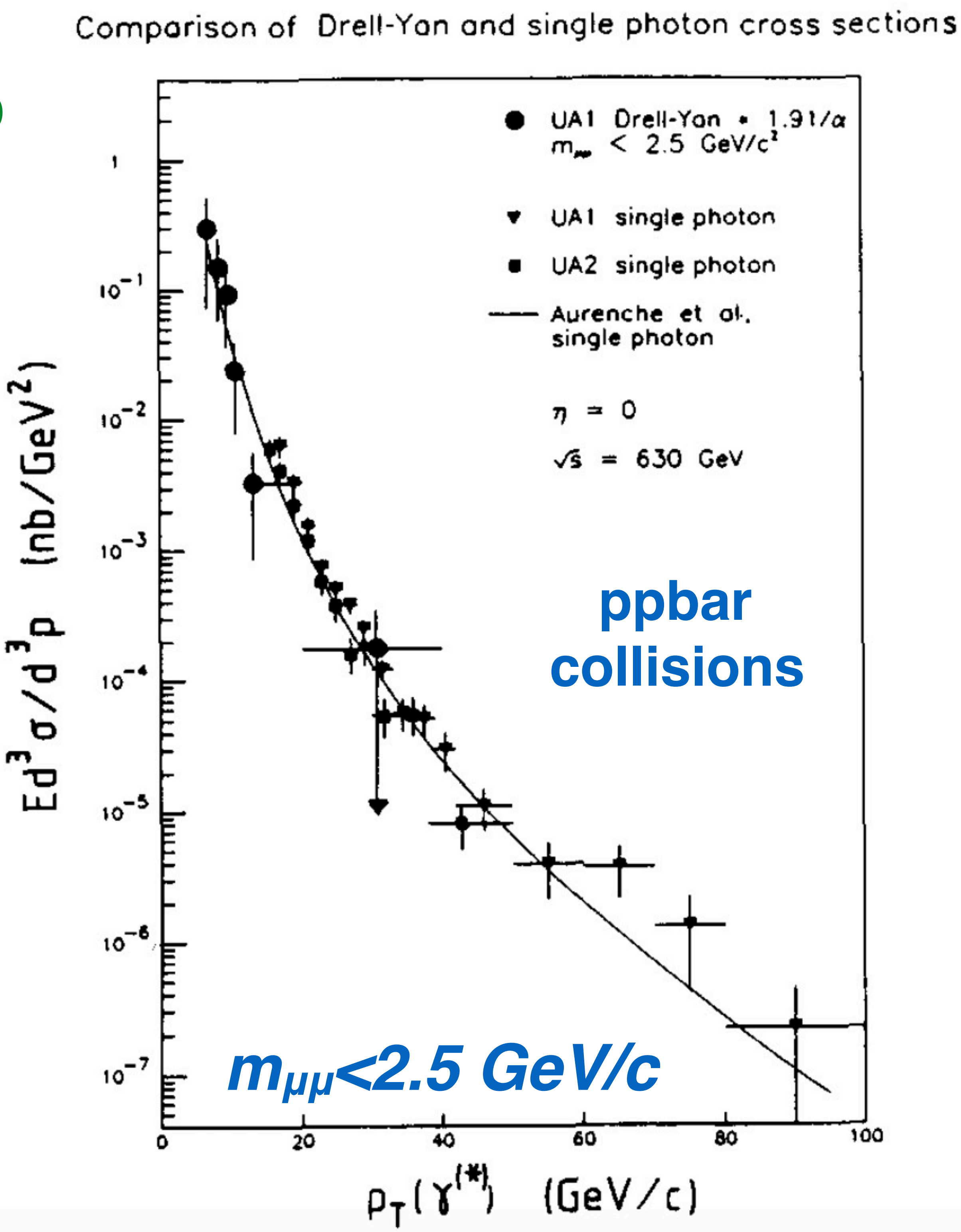


— two orders of magnitude smaller cross section

— possibility to achieve low-p_T region

This option is available only in the collider mode!

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

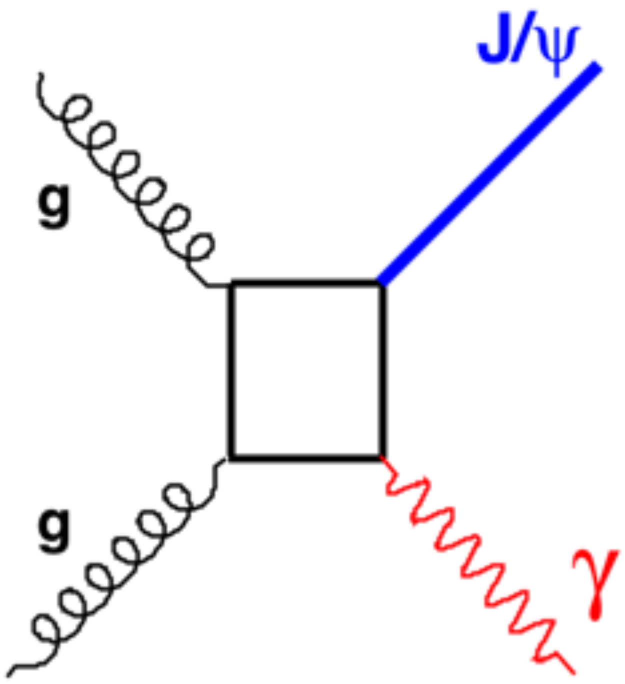


Associative production of prompt photons

One more mechanism to access gluon content of the proton: p p→γ J/ψ X

arXiv:1502.02263
PLB 672:51-55 (2009)

$$\sigma_{\gamma J/\psi} \sim 50\ nb\ at\ LHC\ energy\ scale$$

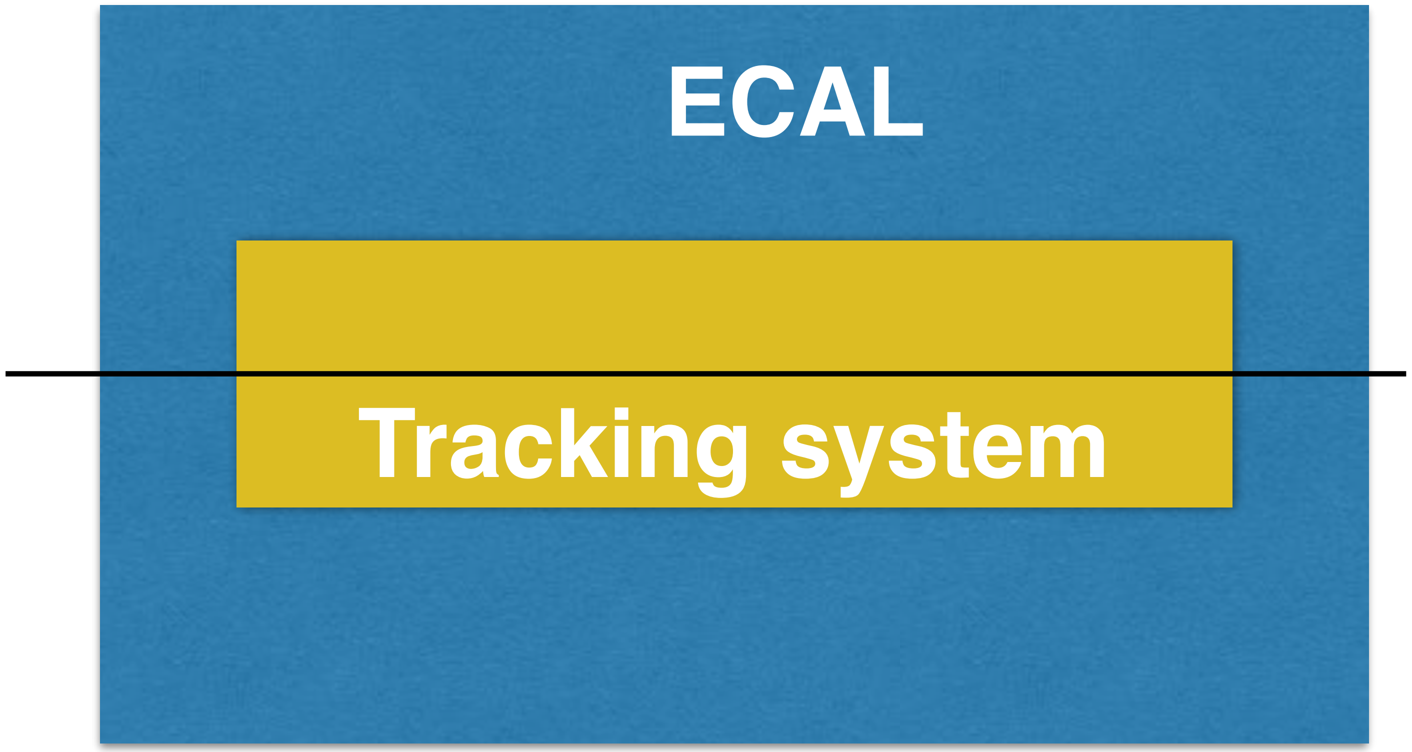


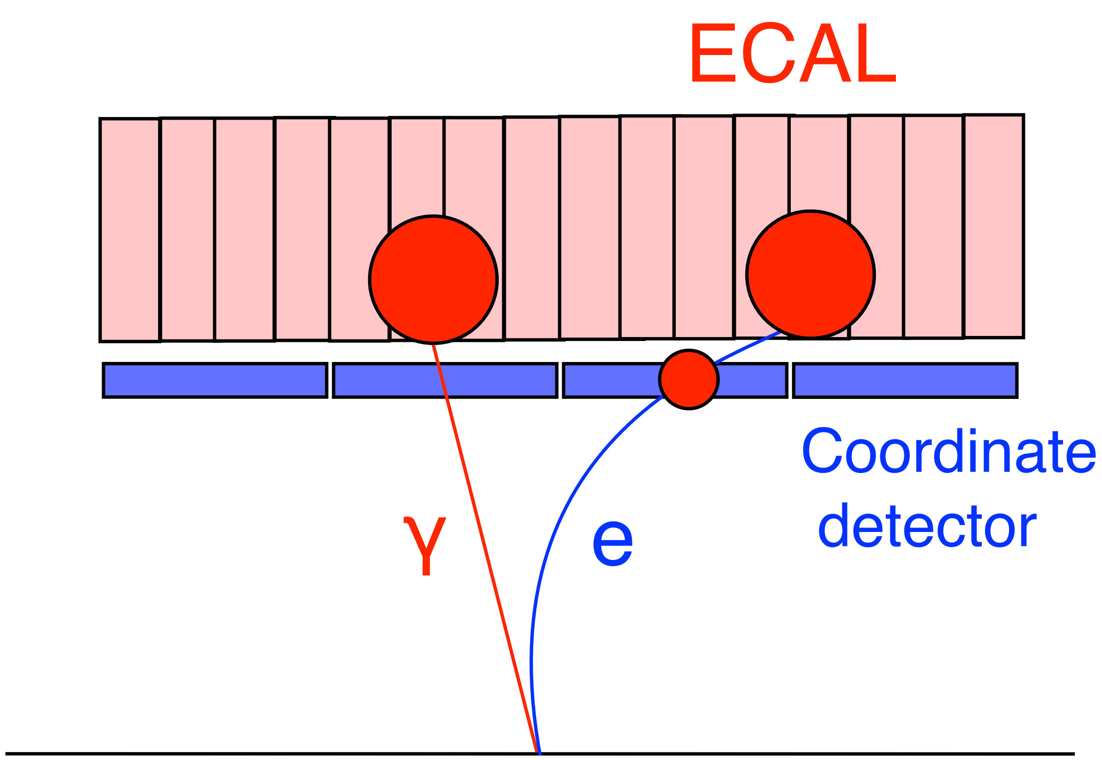
Nice signal definition!

How large is the cross section at our energy scale? ~100 pb?

Other processes?

Prompt photons at SPD





Ideal setup:

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

No need for magnetic field and muon system

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

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.
- Measurement with prompt photons could be the first stage of the SPD operation

Thank you for your attention!