Direct Photon Production with Meson Beams

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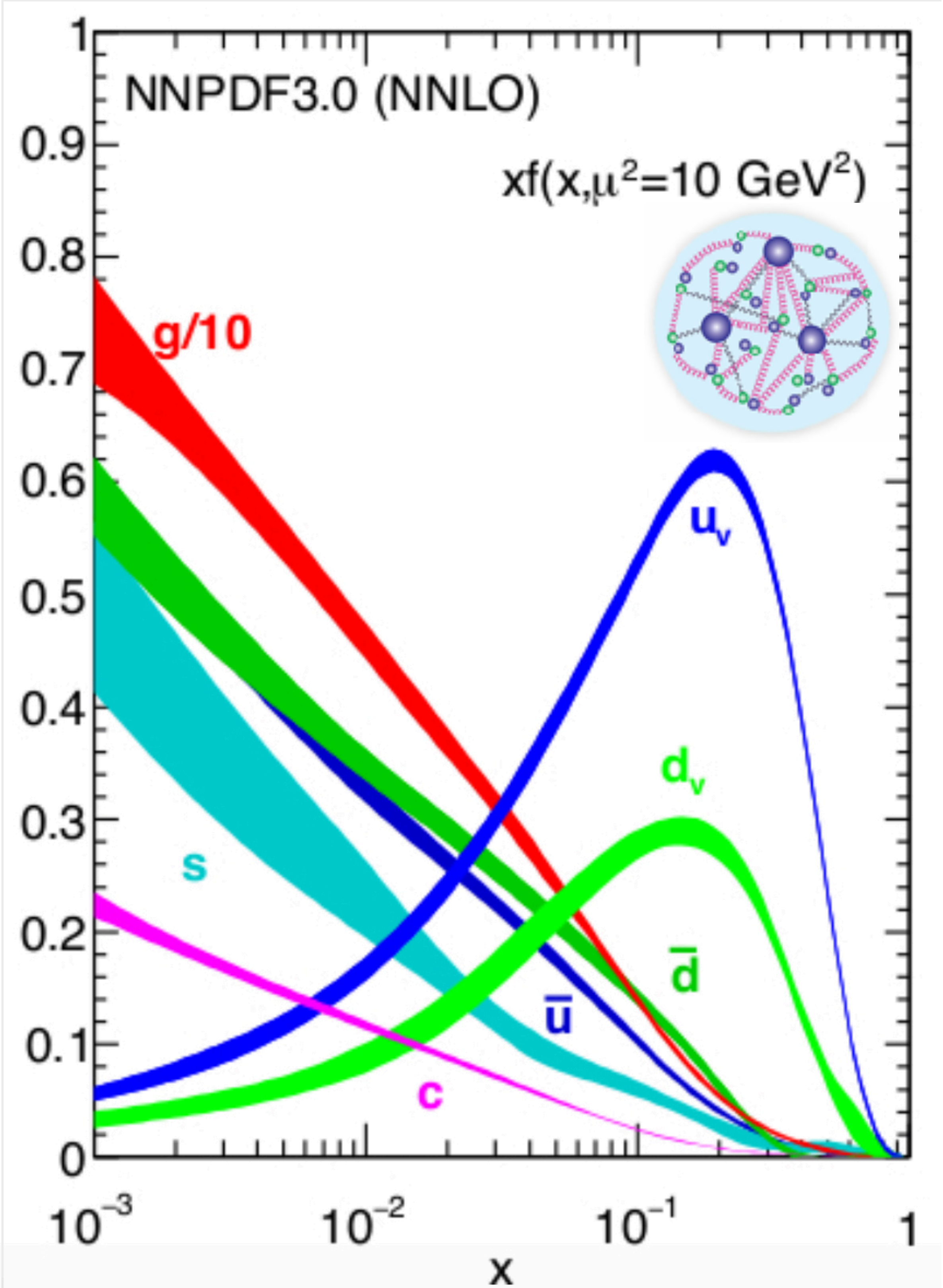
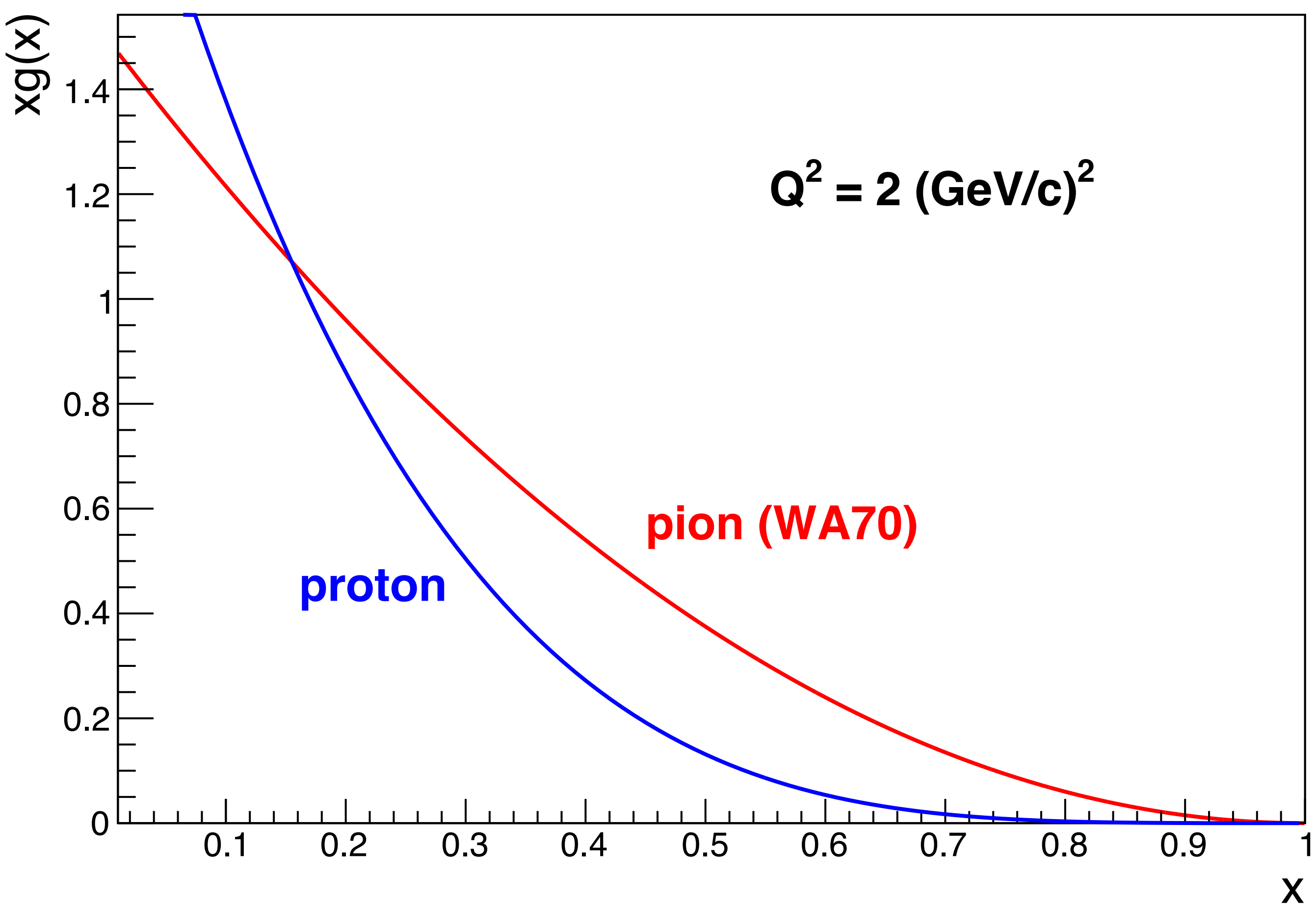
Outline

- Gluon structure of hadrons
- Photons in hadron collisions
- Prompt photons
- Previous prompt photon experiments with pion beams
- Possible future measurements with kaon beam
- Summary

Gluon component: π vs. p

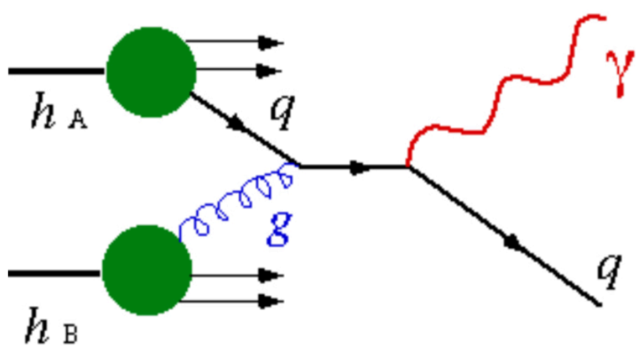


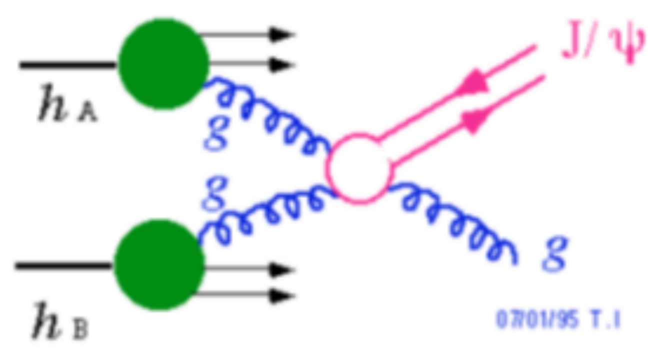


Gluon contribution at high x in pion is much larger than in proton

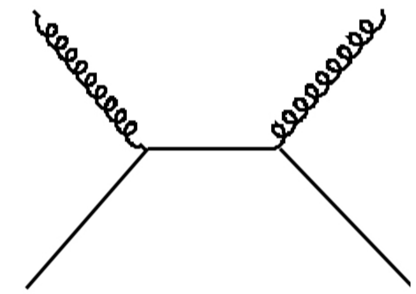
g(x) for pion

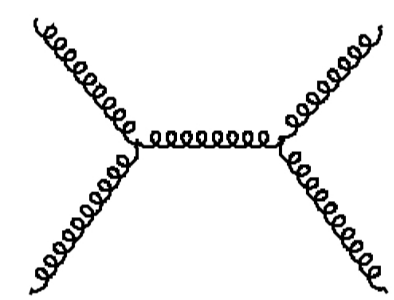
prompt photons





quarconia production





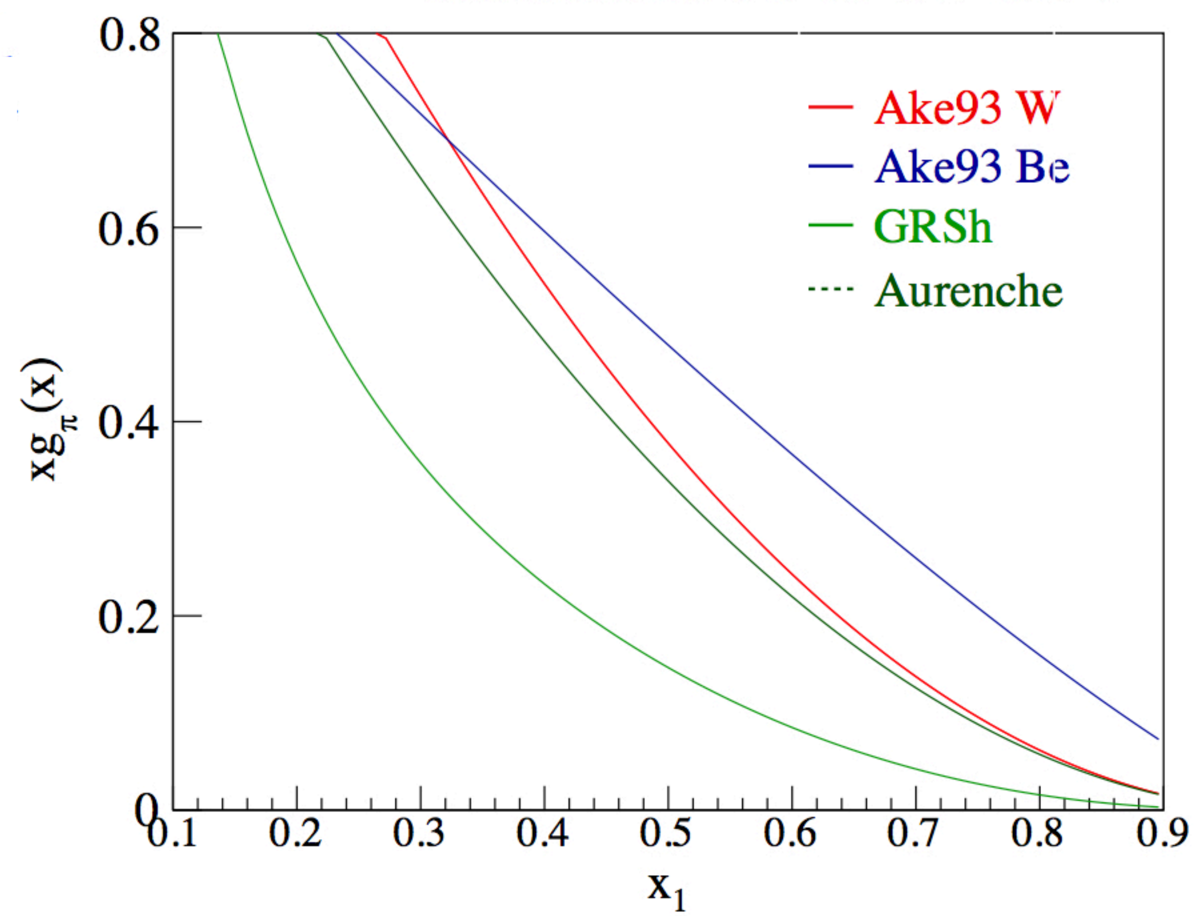
jet production

Z. Phys. C 72, 249–254 (1996)

$xG(x)$	Reactions	Subprocess	Reference
$(1-x)^3$	$\pi N \to \psi$	$GG \to c\bar{c}$	[4], (1980)
$(1-x)^{1.9\pm0.3}$	$\pi^- Be \to \psi$	$GG \to c\bar{c}$	[5],(1983), WA11
$(1-x)^{2.38\pm0.06\pm0.1}$	$\pi^\pm Pt \to \psi$	$GG \to c\bar{c}$	[6], (1983)
$\sim(1-x)^{3.1}$, evolves with Q^2	$\pi p \to \psi, \pi^\pm X$	$GG \to c\bar{c}$	[7], (1984)
$(1-x)^{2.3^{+0.4+0.1}_{-0.3-0.5}}$	$\pi^- W \to \Upsilon$	$GG \to b\bar{b}$	[8], (1986) NA10
$(1-x)^{1.94^{+0.39}_{-0.17}}$	$\pi^\pm p \to \gamma X$	$QG \to \gamma Q$	[10], (1989) WA70
$(1-x)^{2.1\pm0.4}$	$\pi^+ p \to \gamma X$	$QG \to \gamma Q$	[11], (1991)
$(1-x)^{2.75\pm0.40\pm0.75}$	$\pi^- p \to dijets$	$QG, GG \to dijets$	This paper

$$xg(x) \sim (1-x)^\eta, \eta \approx 2$$

Gluon PDFs at 10 GeV^2



G(x) for kaon

No direct experimental data!

Not too many theoretical works

Gluon content of kaon is ~1.5 larger in respect to pion)!

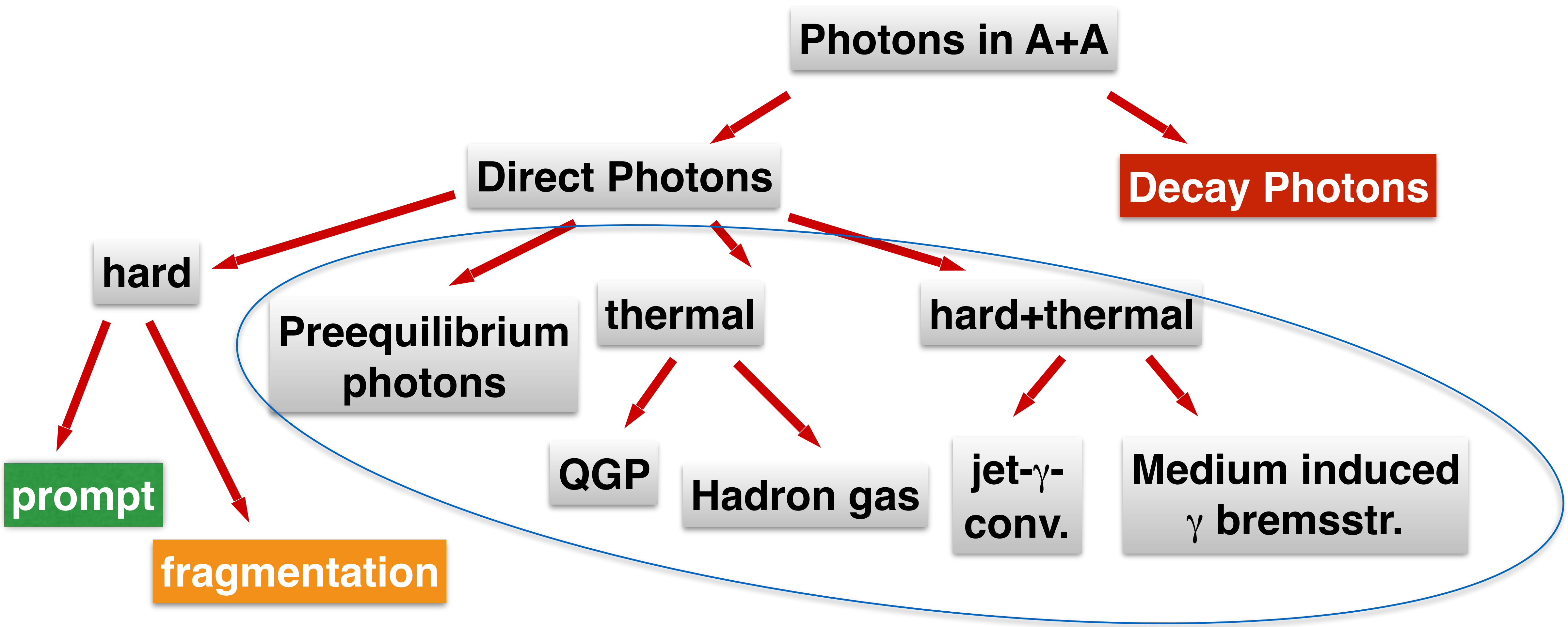
(based on yield of D-mesons in NA32)

Sov.J.Nucl.Phys. 49 (1989) 346
Yad.Fiz. 49 (1989) 554-558
IFVE-88-67

Gluon content of kaon is ~1/6 in respect to pion)!

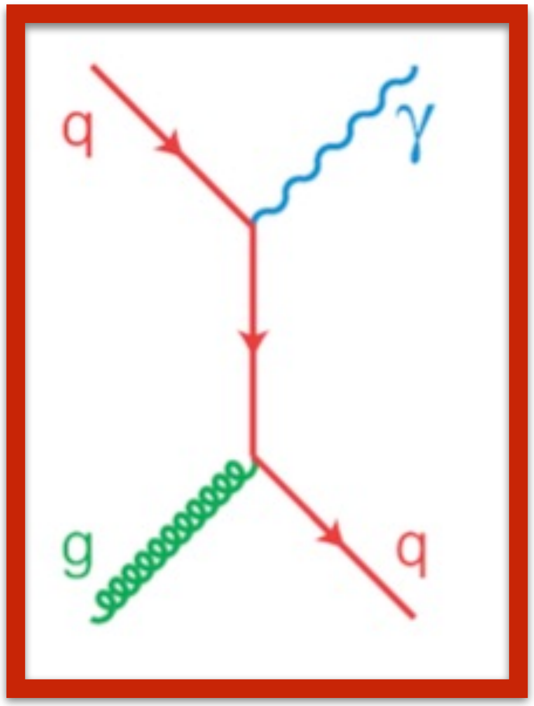
Phys. Rev. D93 (7) (2016) 074021

Production of photons in hadron collisions

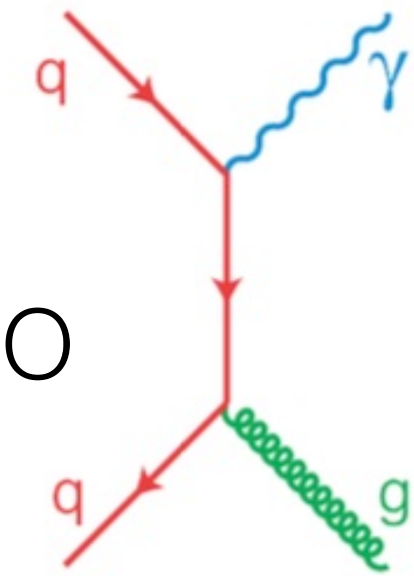


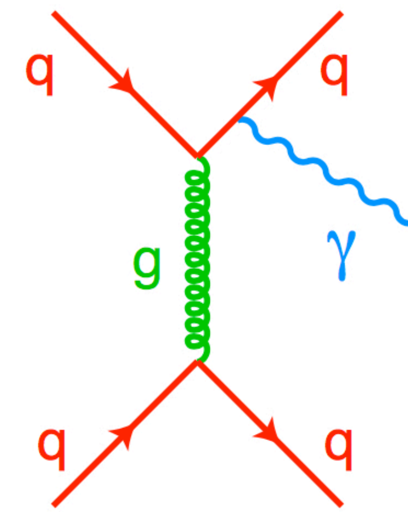
collective effects,
not important for hA collisions

Prompt photons



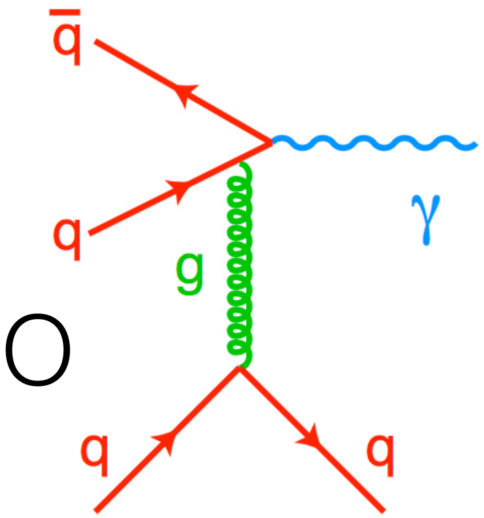
LO





Bremsstrahlung

NLO



annihilation with scattering

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

access to gluon distributions in hadrons

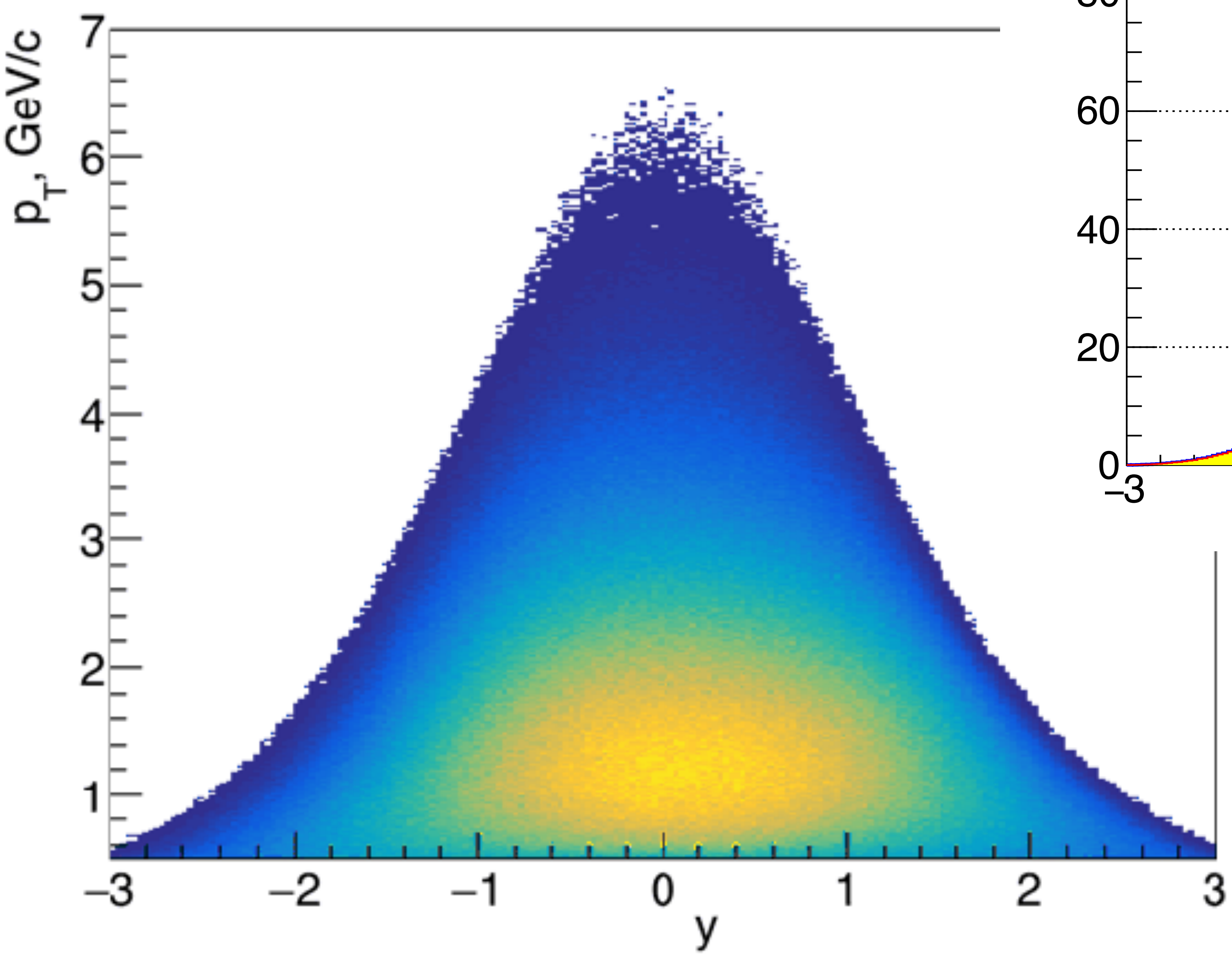
$$\sigma \sim (\mathbf{g_B} \cdot \mathbf{q(\bar{q})_T} + \mathbf{g_T} \cdot \mathbf{q(\bar{q})_B} + \mathbf{q(\bar{q})_B} \cdot \mathbf{\bar{q}(q)_T} + \mathbf{NLO}) \times \text{K-factor}$$

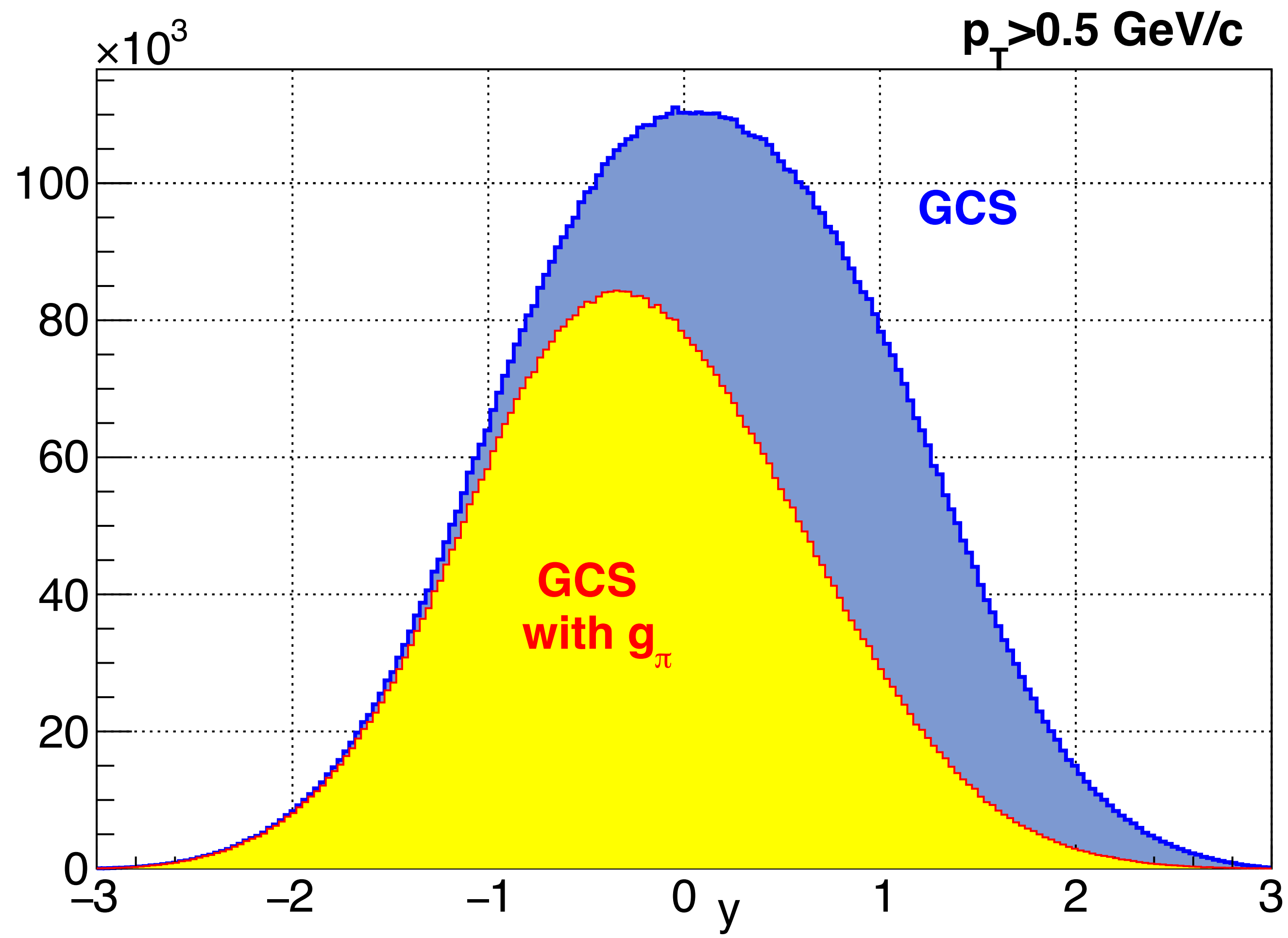
signal

Gluon Compton Scattering (GCS)

$\pi^+ p \to \gamma X$

$E_\pi = 100$ GeV

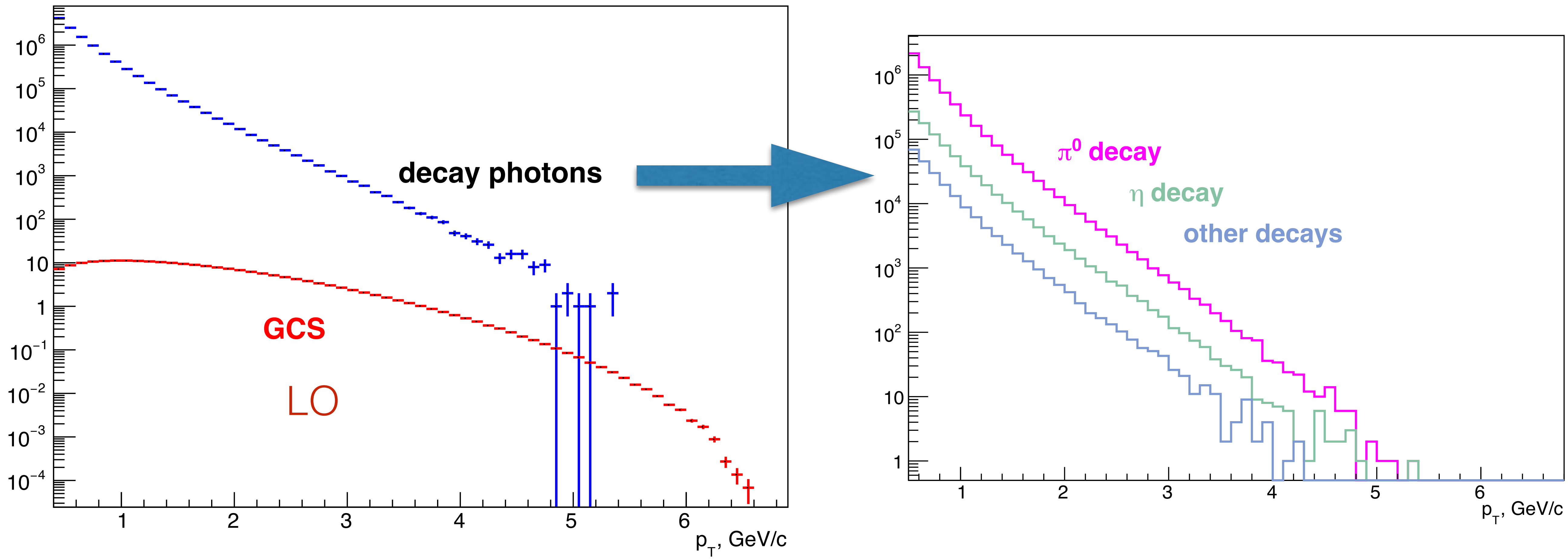




The region of **negative y** (or **x_F**) is the most sensitive for gluon content of beam meson

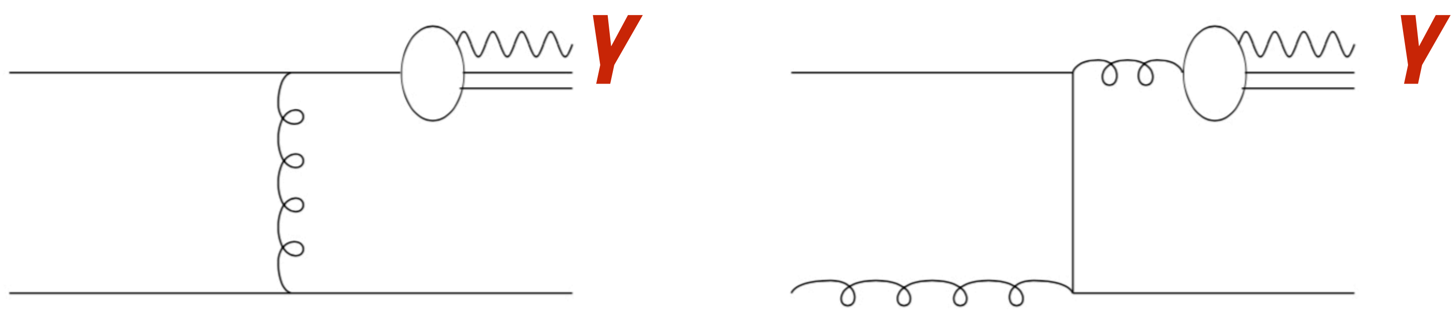
Decay photons

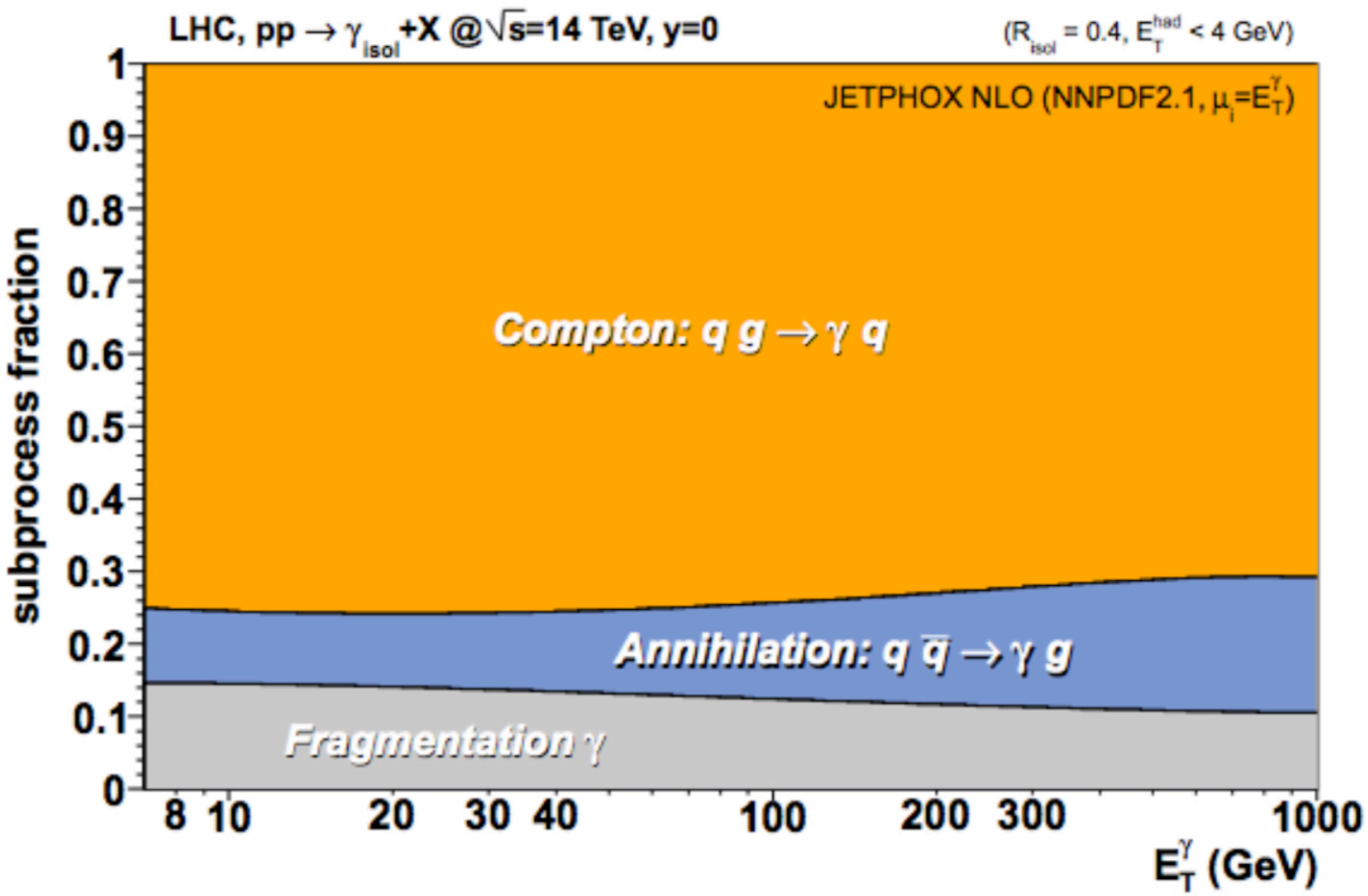
$\pi^+ p \rightarrow \gamma X$ $E_\pi = 100$ GeV



Decay photons dominate over prompt photons in the full range of transverse momentum p_T. Even at high p_T signal-to-background ratio in much below 1

Fragmentation photons





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

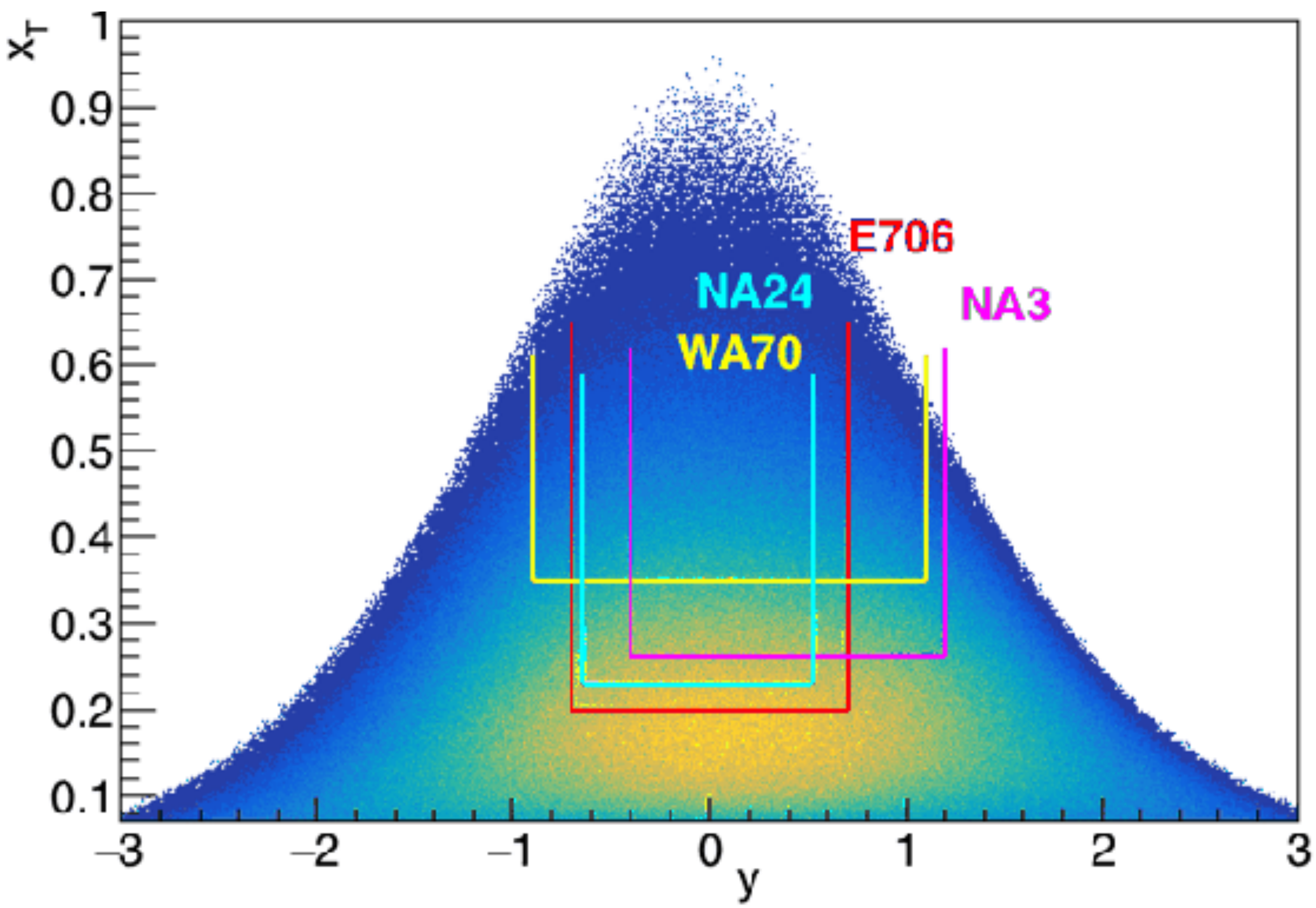
It can be calculated in LO and NLO

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

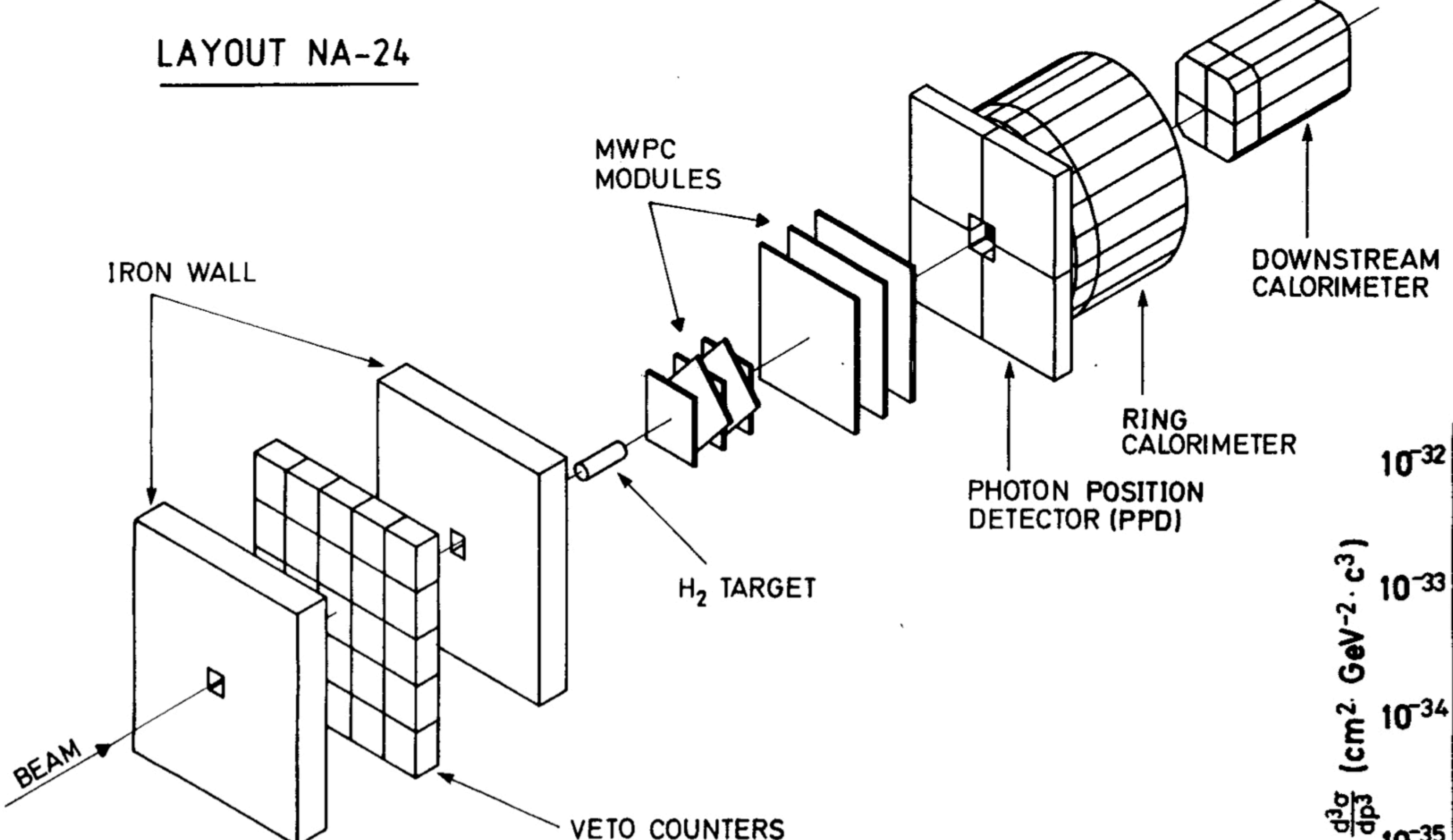
$x_T=2p_T/\sqrt{s}$

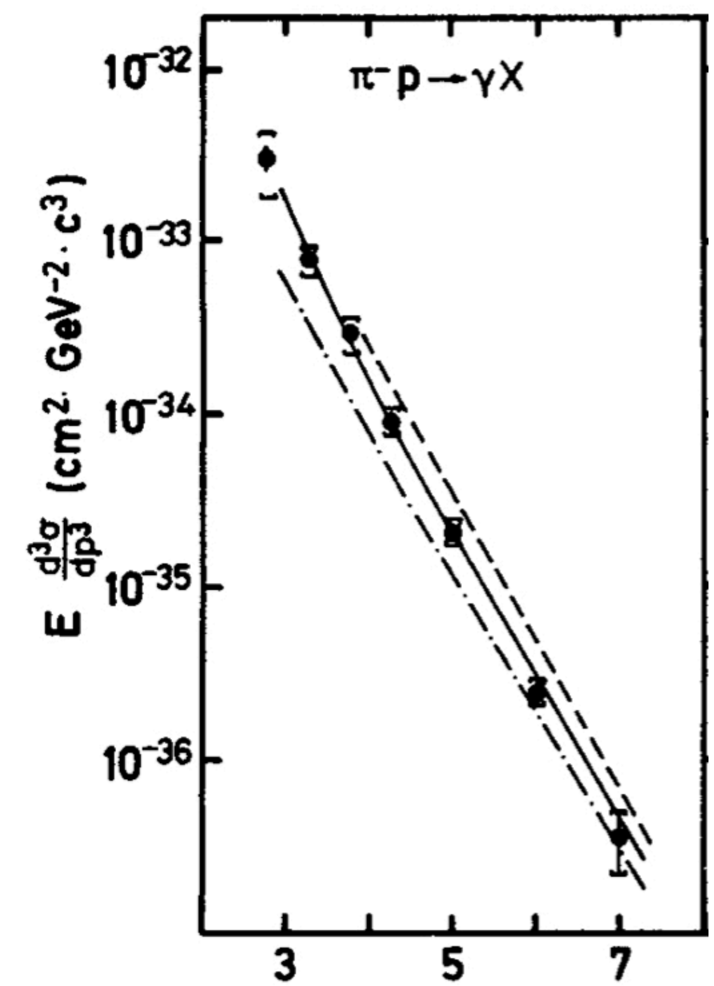
Fixed target measurements



A lot of measurements with proton beams at much higher energies (Tevatron, LHC)

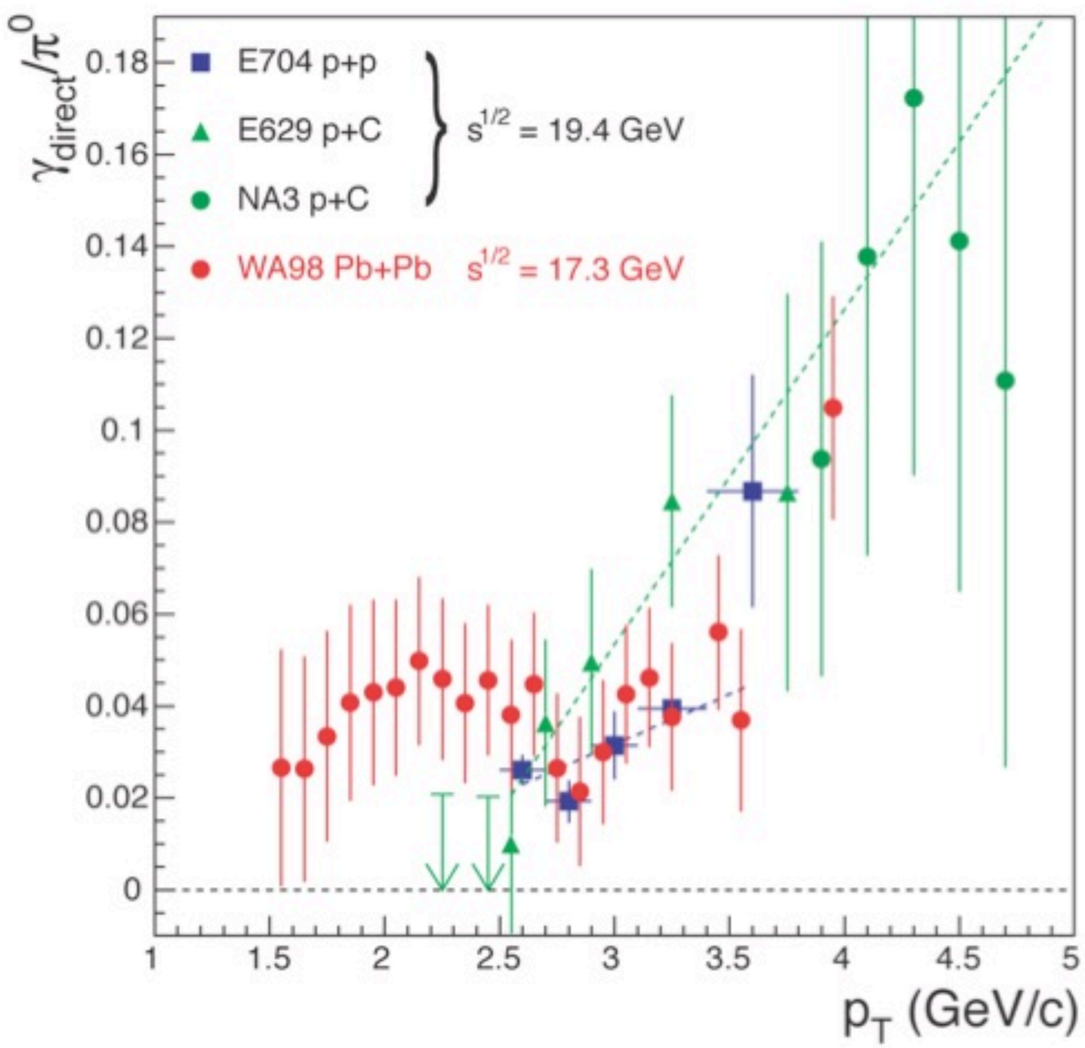
NA24 — typical fixed-target experiment for prompt photon studies

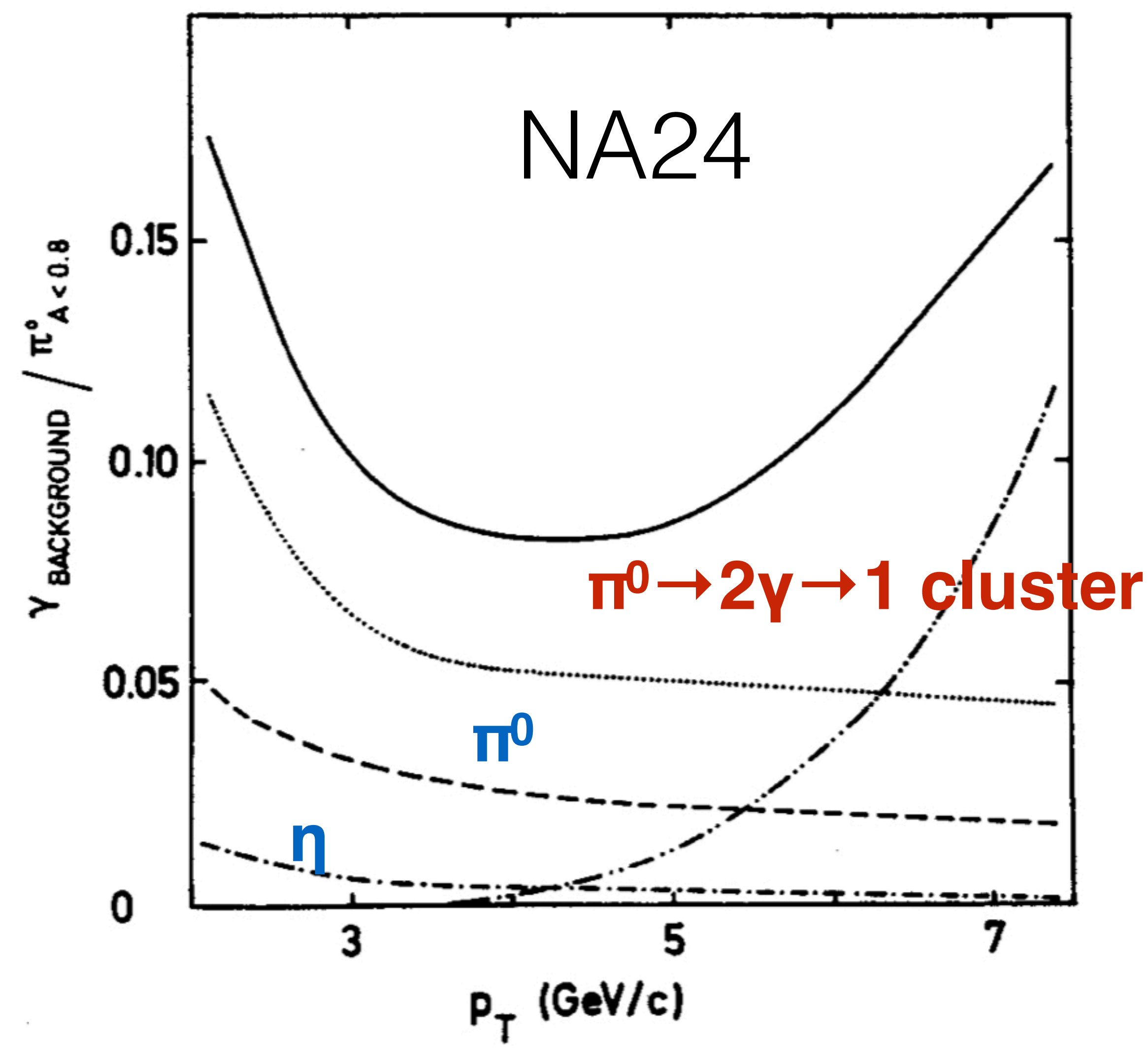




300 GeV beam

Signal vs background





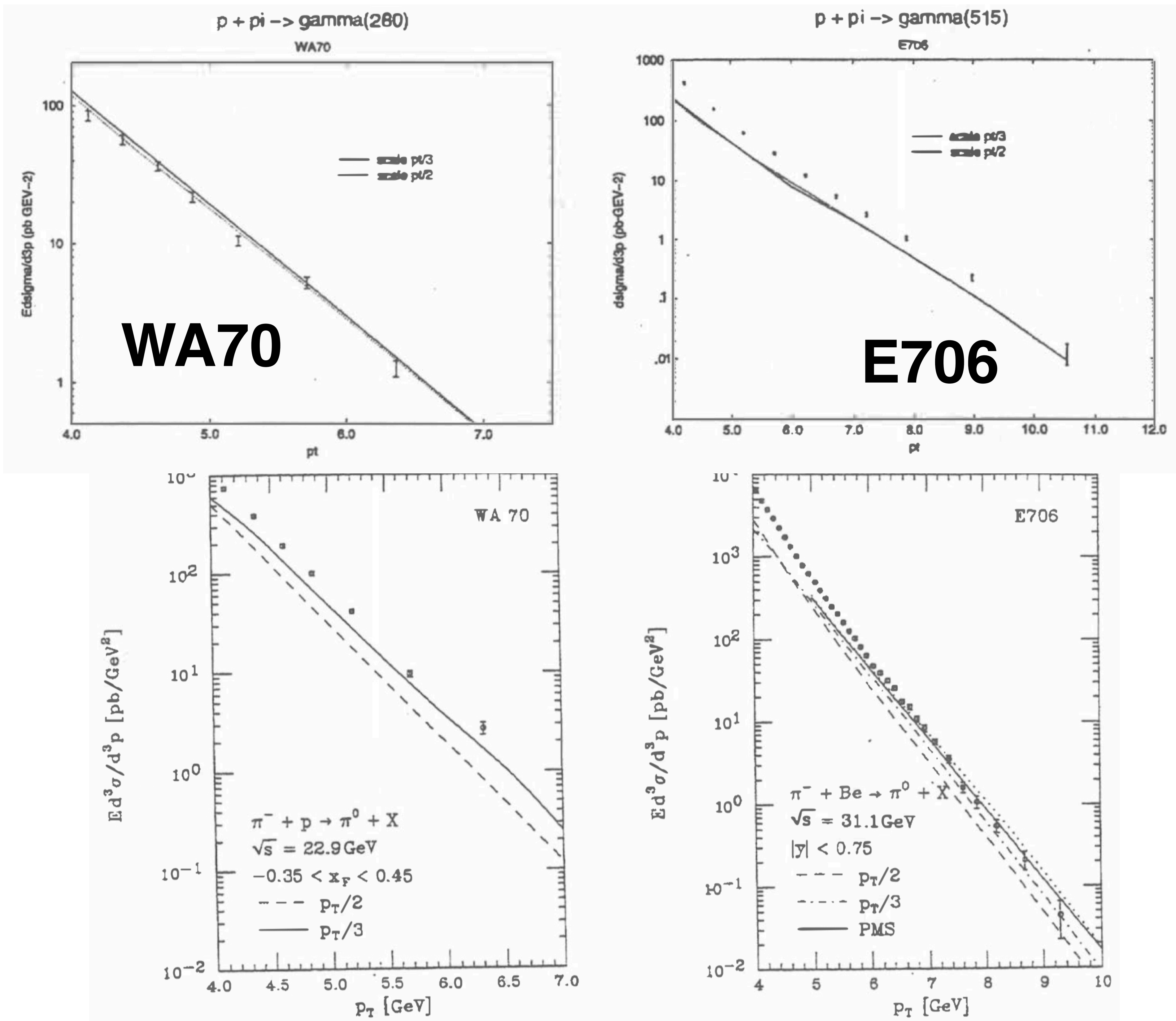
Much higher rate of background photons mainly from π^0 and η mesons decay!

At high E (and pT) we should expect background from merging of 2γ into a single cluster!

$$N\gamma_{prompt} = N\gamma_{detected} - \frac{N\gamma_{bkg.\ found}}{\epsilon}$$

from MC!

WA70-E706 puzzle

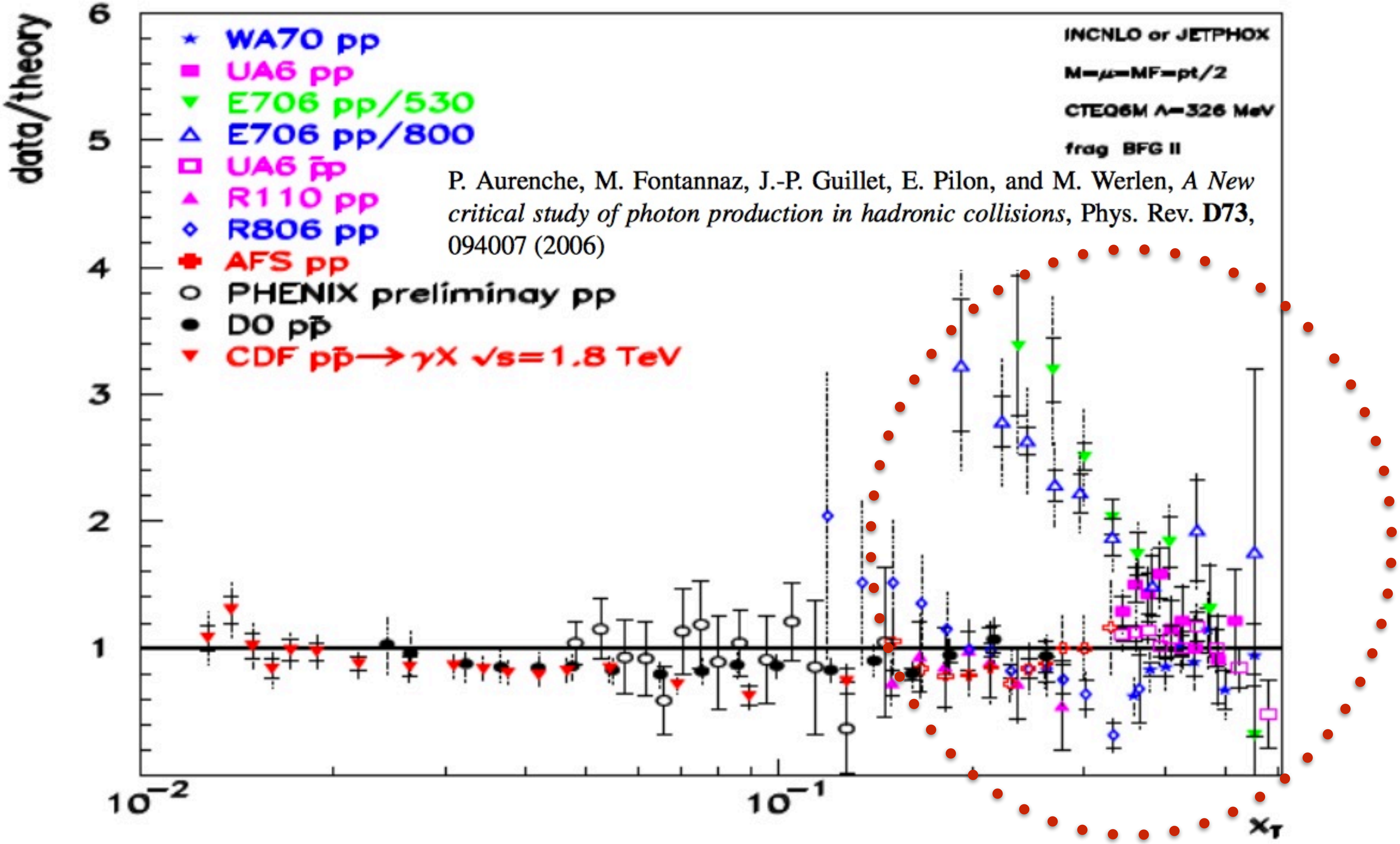


π/p ratio for **γ**

production of π^0

Previous results: pp(pbar)

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)

WA70-E706 puzzle

Two approaches were proposed to fix disagreement between data ant predictions:

k_T- smearing:

$$\phi(x,Q^2) \to f(k_T)\,\phi(x,Q^2)$$

$$f(k_T) = \frac{e^{-k_T^2/\langle k_T^2 \rangle}}{\pi \langle k_T^2 \rangle}$$

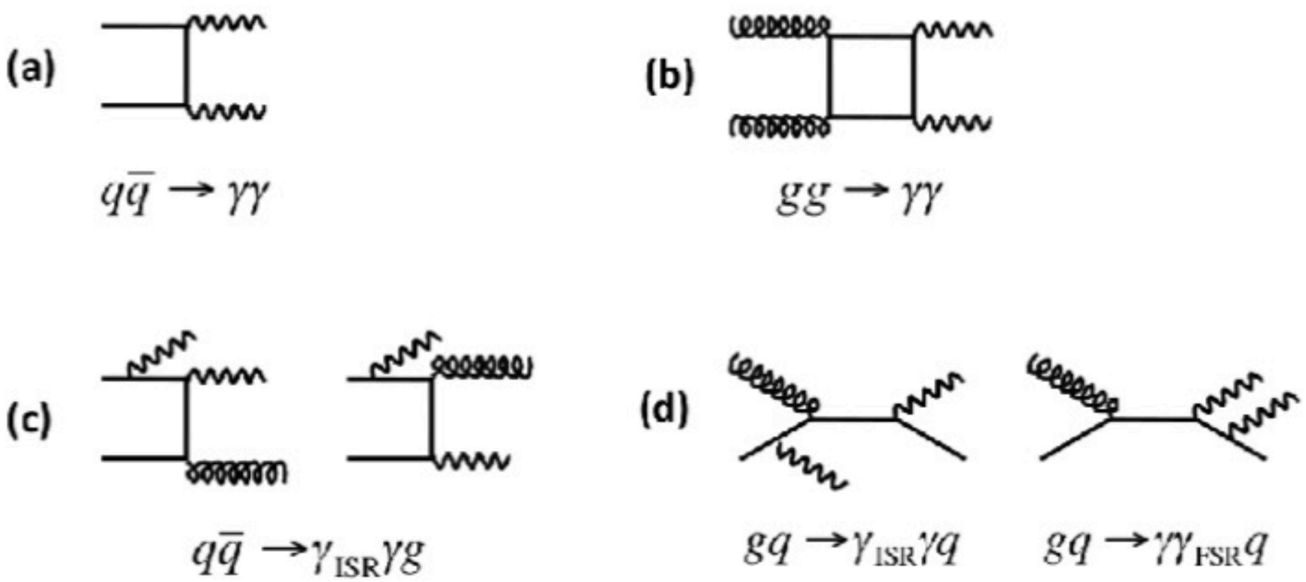
$\langle k_T \rangle$ =1.5 GeV for E706 and up to 3-4 GeV for ~ $\sqrt{s}$~1 TeV

This approach modifies only low-p_T part

ISR of soft gluons:

also an impact to transverse momenta of partons

2γ data



CERN WA70 — $\pi^- \, p \to \gamma\gamma \, X$ — $\sqrt{s} = 22.96$ GeV
Bonvin *et al* 1989 — *Z. Phys.* **C41** 591

y	p_{T1} (GeV/c)	p_{T2} (GeV/c)	σ (pb)
−1.0–1.25	>3.0	>2.75	54 ± 9

y	p_T (GeV/c)	$z_{\min}$	$d\sigma/dp_T$ (pb/GeV)
−1.0–1.25	3.0–3.5	2.75/3.0	70.0 ± 17.2
	3.5–4.0	2.75/3.5	25.0 ± 8.6
	4.0–4.5	2.75/4.0	17.0 ± 5.2
	4.5–5.0	2.75/4.5	10.0 ± 3.4
	5.0–6.0	2.75/5.0	4.7 ± 1.4
	6.0–7.0	2.75/5.5	1.0 ± 0.6

y	p_T (GeV/c)	$z_{\min}$	σ (pb)
−1.0–1.25	>3.0	2.75/3.0	69 ± 11.5

CERN NA24 — $\pi^- \, p \to \gamma\gamma \, X$ — $\sqrt{s} = 23.7$ GeV
De Marzo *et al* 1990 — *Phys. Rev.* **D42** 748

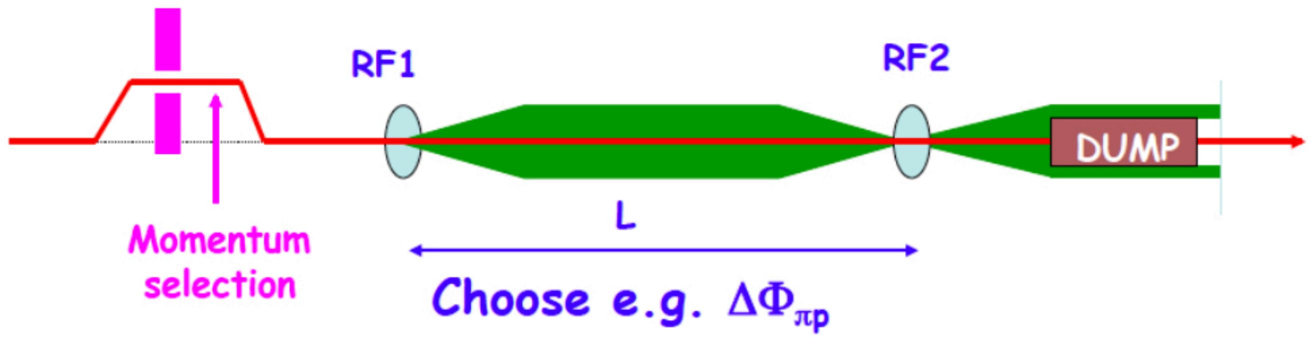
p_{T1} (GeV/c)	p_{T1}^{mid} (GeV/c)	$z^{\min}$	$E d^3\sigma/dp^3$ (pb/GeV^2)
2.5–3.0	2.75	0.80	$2.07^{+0.53}_{-0.92}$
3.0–4.0	3.50	0.67	$0.70^{+0.23}_{-0.36}$
4.0–5.0	4.50	0.50	$0.093^{+0.133}_{-0.093}$

CERN NA3 — $p\,C \to \gamma\gamma\,X$, $\pi^+ C \to \gamma\gamma\,X$, $\pi^- C \to \gamma\gamma\,X$ — $\sqrt{s} = 19.4$ GeV
Badier *et al* 1985 — *Phys. Lett.* **164B** 184

	y	p_T (GeV/c)	σ (pb)
$p\,C \to \gamma\gamma\,X$	−0.4–1.0	> 1.8	1480 ± 380
		1.8–2.0	740 ± 250
		2.0–2.5	570 ± 230
		>2.5	170 ± 130
$\pi^+ C \to \gamma\gamma\,X$	−0.4–1.0	> 1.8	350 ± 640
$\pi^- C \to \gamma\gamma\,X$	−0.4–1.0	> 1.8	1220 ± 350
		1.8–2.0	610 ± 250
		2.0–2.5	430 ± 240
		>2.5	180 ± 140

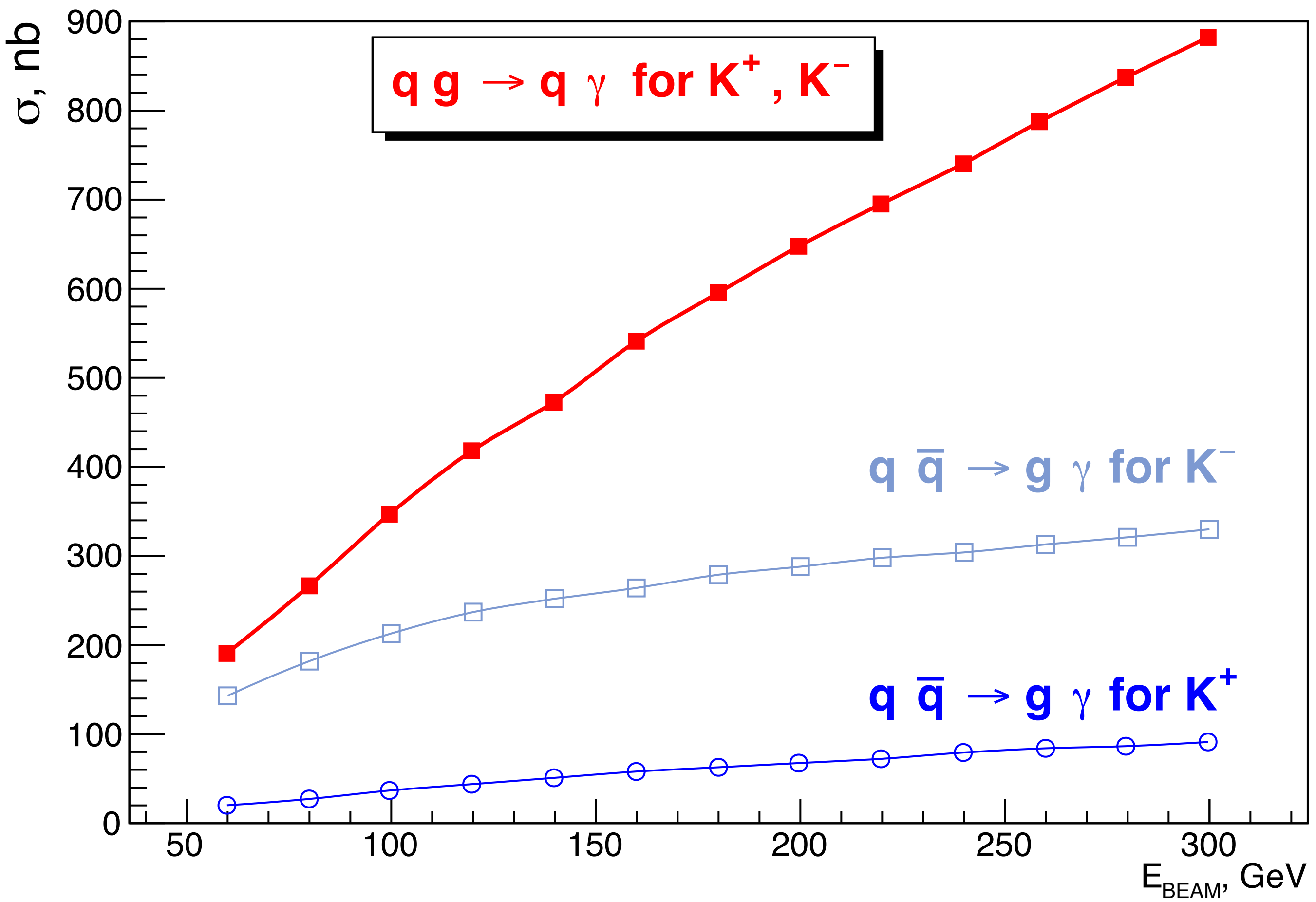
$g_K(x)$ with RF-separated kaon beam…

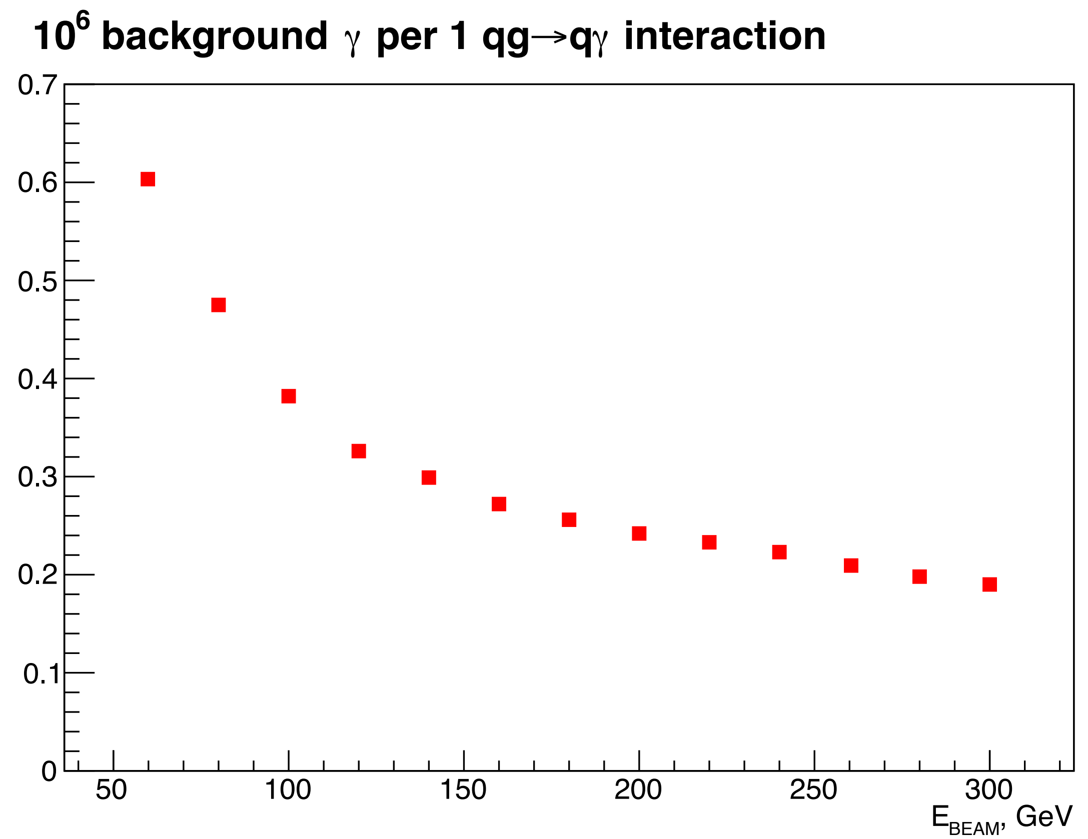
See Johannes's talk



K– would be nice for study of systematics

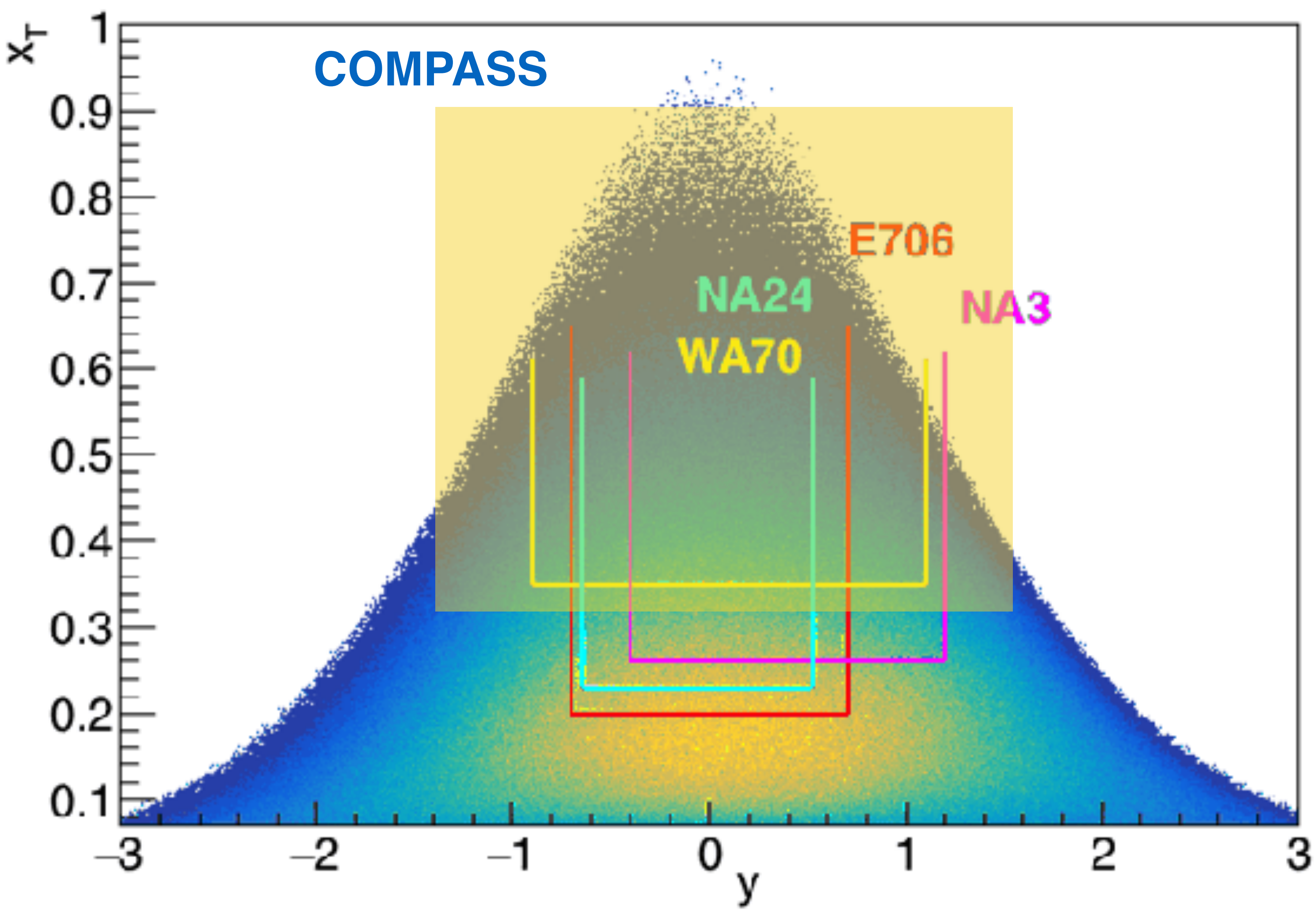
It would be nice to have **K+** beam with momentum as large as possible (**>100 GeV/c**) and intensity of about **~5e6 s⁻¹** **for 1 year**

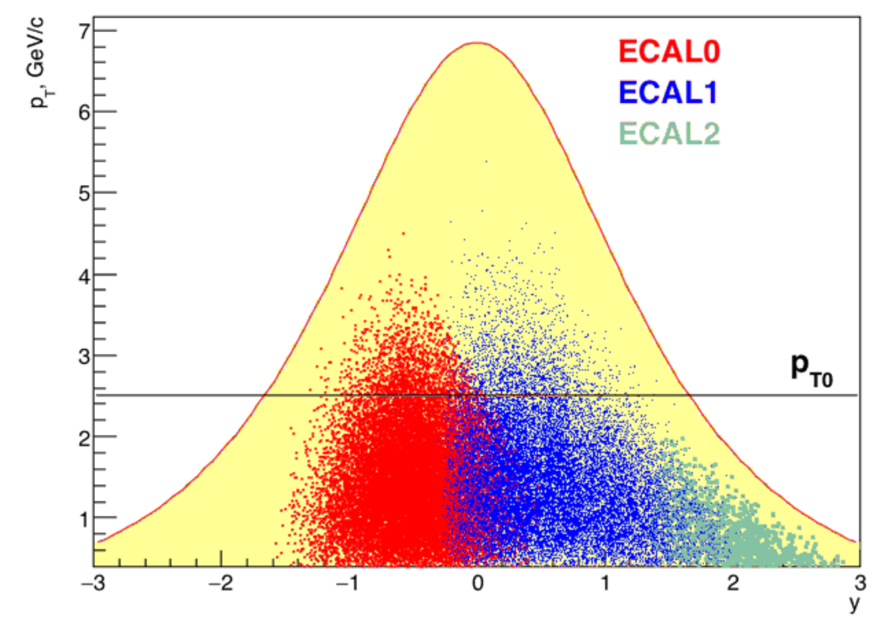




... at COMPASS ?

- System of 3 precise electromagnetic calorimeters of high aperture for prompt photons detection in wide kinematic range. They can be used also in trigger.
- Threshold Cherenkov detectors on the beam line to identify incoming hadron.
- Nice tracking to separate neutral and charged clusters.
- Pions as a reference.



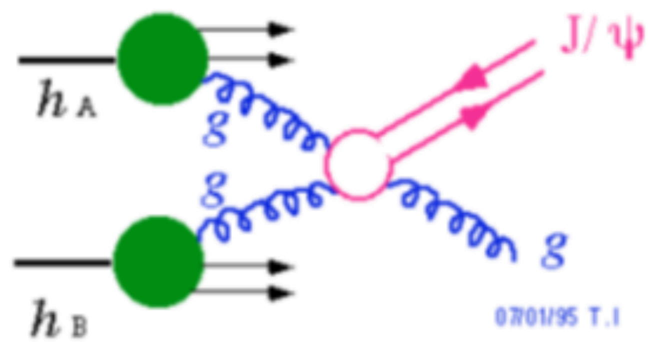


1 year of data taking with kaon beam — ~10^6 events with p_T>2.5 GeV/c, comparable with E706 ($g_K(x)=g_\pi(x)$)

Prompt photos vs quarkonia production

See Jen-Chieh's talk for more details

Different mechanisms of J/ψ production:



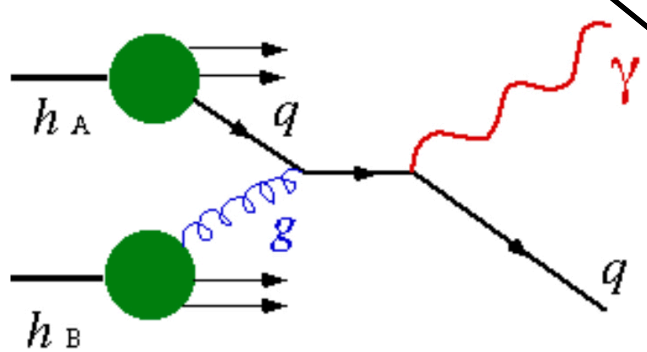
$gg \to J/\psi g$

$q\bar{q}$ (qqbar)$\to J/\psi$

$\ldots \to \chi_{c012} \to J/\psi \gamma$

diffractive production of J/ψ

…?



Transparent theory

Nice signal

Experimental difficulties with strong background subtraction

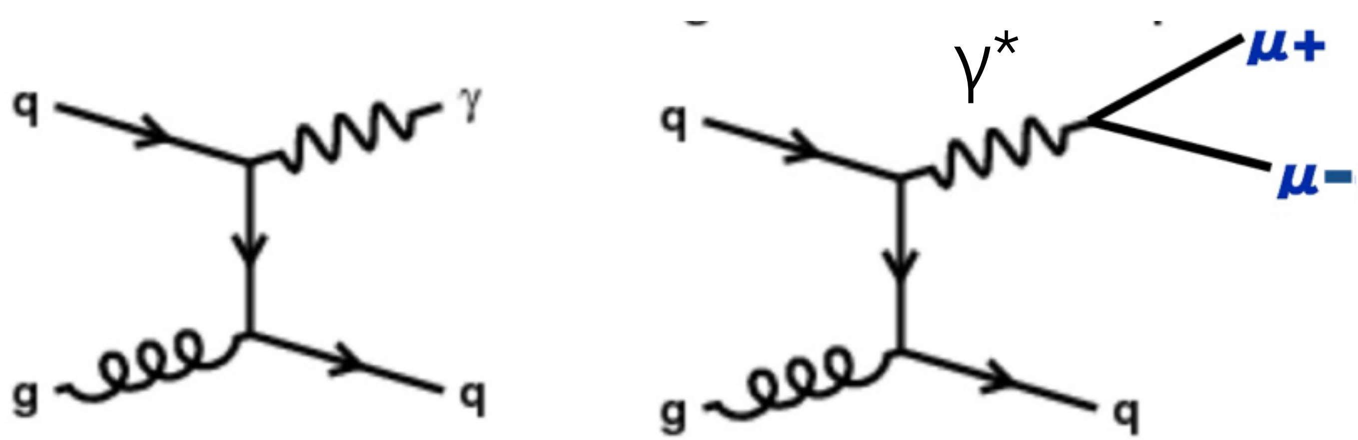
Difficulties to treat the signal

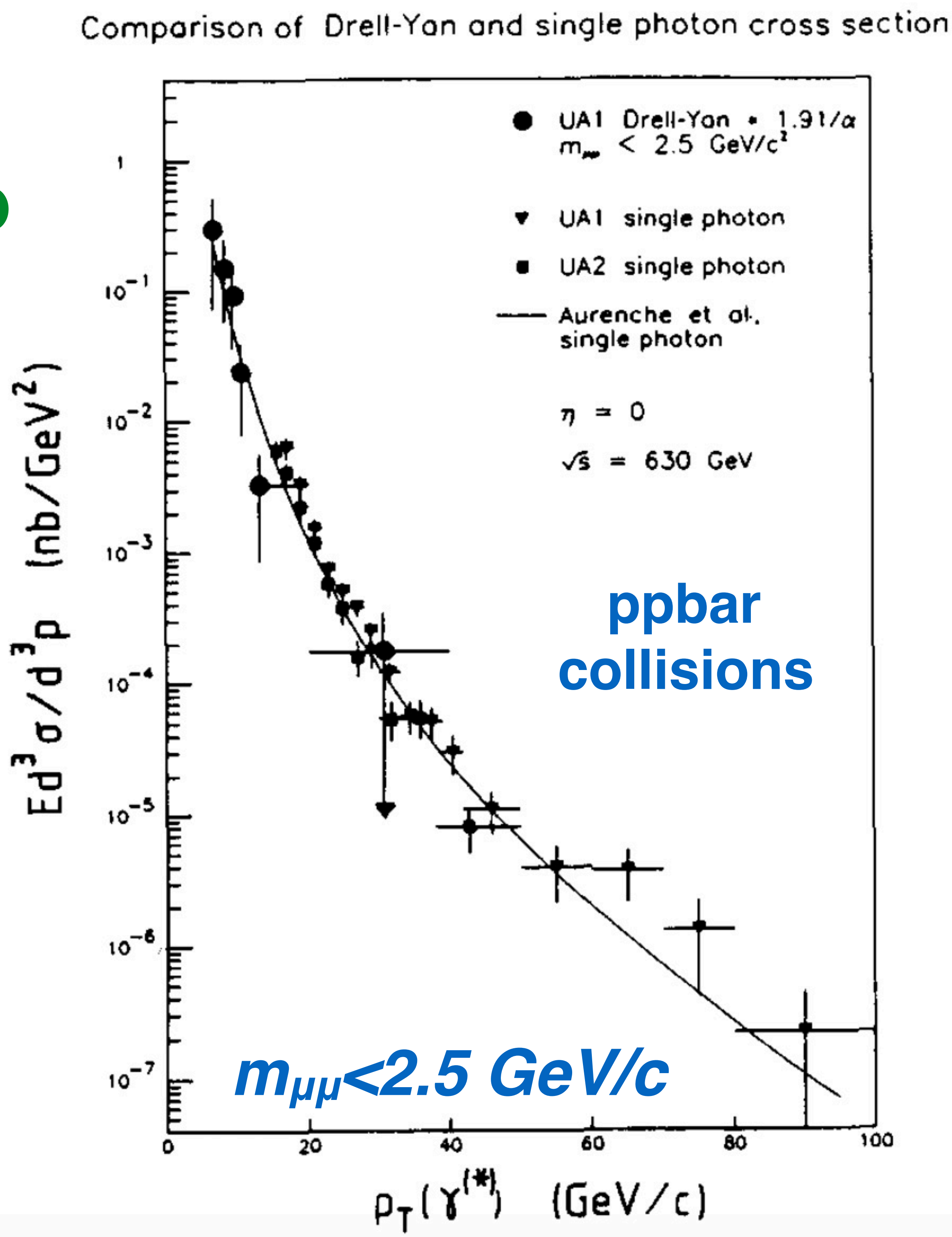
Complimentary approaches!

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





— two orders of magnitude smaller cross section

— possibility to achieve low-p_T region

γ→μ+μ− in matter

$$\sigma_{tot}(E_\gamma) = \int_{x_{min}}^{x_{max}} \frac{d\sigma}{dx_+} dx_+ = 4\,\alpha\, Z^2 r_c^2 \int_{x_{min}}^{x_{max}} \left(1 - \frac{4}{3} x_+ x_-\right) \log(W)\, dx_+ \,.$$

$$x_+ = \frac{E_\mu^+}{E_\gamma}$$

$\sigma_{N,E=10\text{-}100\ GeV} \simeq 5\ \mu b$

E_γ	σ_{tot}, H	σ_{tot}, Be	σ_{tot}, Cu	σ_{tot}, Pb
GeV	μbarn	μbarn	μbarn	μbarn
1	0.01559	0.1515	5.047	30.22
10	0.09720	1.209	49.56	334.6
100	0.1921	2.660	121.7	886.4
1000	0.2873	4.155	197.6	1476
10000	0.3715	5.392	253.7	1880
∞	0.4319	6.108	279.0	2042

For ~1m of the COMPASS ammonia target probability for secondary photon to convert into dimuon is $\sim 1\times10^{-5}$

So, the effective cross section of dimuon pair production via real secondary photons conversion in the target material is ~1 μb that is a few orders of magnitude larget than the cross section of low-mass dimuon production via virual photon.

Prompt photon - low-mass dimuons duality could be used in the collider experiments but not in the experiments with a thick fixed target

Summary

- Prompt photon production is a unique instrument for study of gluon content in hadrons.
- All the measurements at energy scale ~20 GeV were performed with pion and proton beams only 20-30 years ago It is a good time to come back with new level of experimental techniques and theoretical understanding
- Gluon structure of kaon is unknown. Prompt photon production with kaon beam could provide a unique opportunity to access it.
- Opportunity to have RF-separated kaon beam at CERN can be used to study of pion and kaon gluon structure at fixed target experiments like COMPASS.

Lets look inside kaon!