Meson-induced prompt photon production and diffractive scattering at AMBER

Perceiving of the Emergence of Hadron Mass through AMBER@CERN

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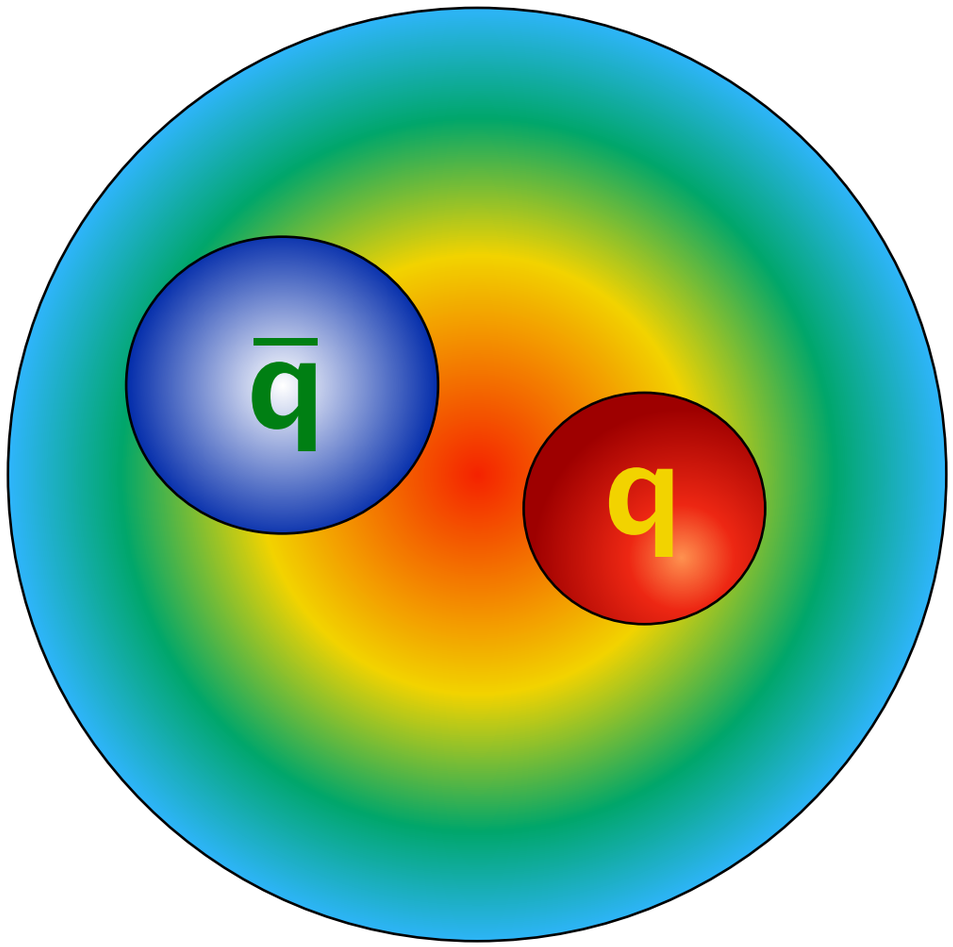
Meson as a complex QCD system



Emergence of hadronic mass

Partonic structure

Drell-Yan

Charmonia

Prompt photons

π K

π K

π K

Resonant and dynamical properties of mesons

Spectroscopy

COMPASS π K

"Rigidity" of the meson as a complex system

Polarisability

COMPASS π K

Pion and kaon as Nambu-Goldstone bosons

Low-t (Primakoff) reactions

COMPASS π K

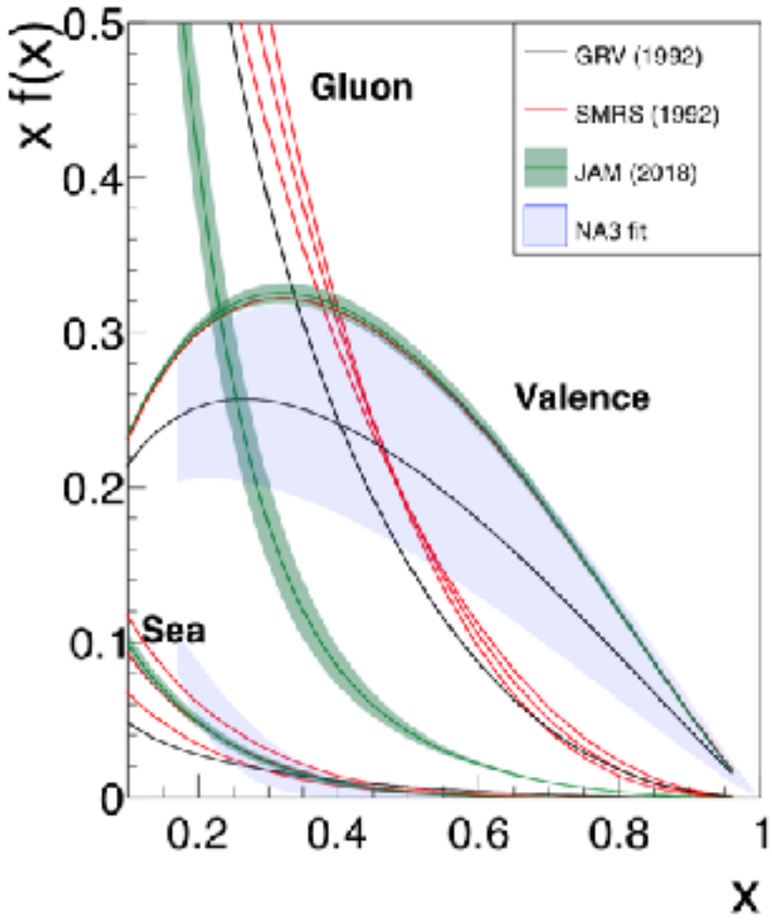
Meson PDFs

Theory

Meson mass

Meson wave function

Meson PDFs

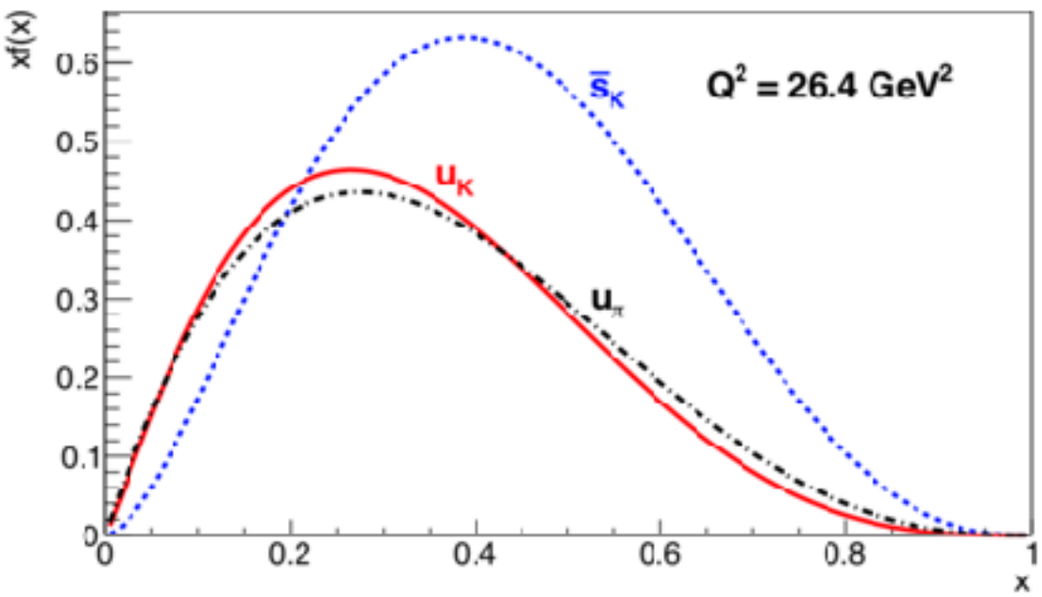


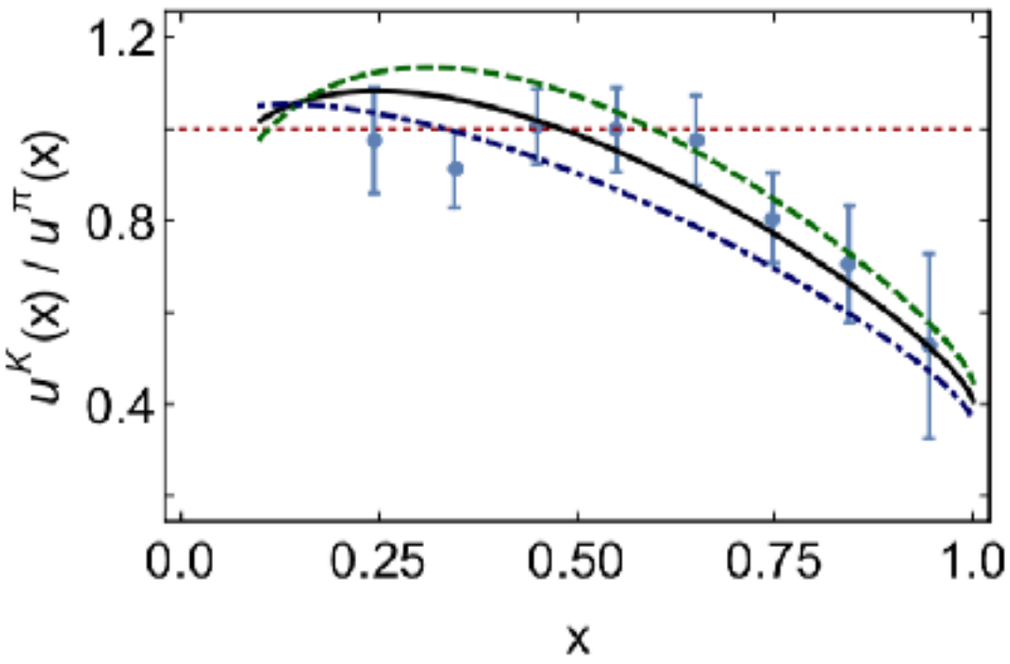
*GRV (1992) set of pion PDFs: Drell-Yan, charmonia and prompt photon production experiments (**E615, NA10, WA70, NA24**).*

SMRS (1992): basically the same old data.

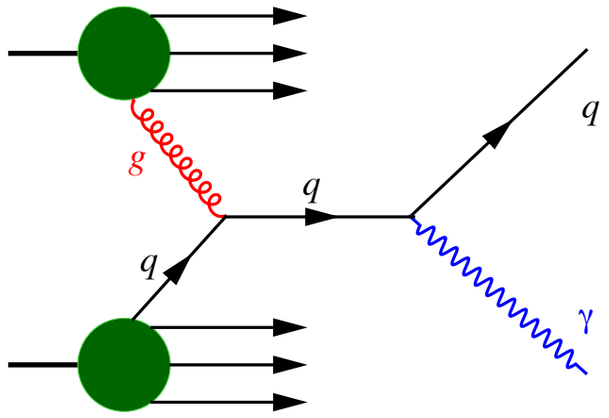
*JAM (2018) set: production of leading neutrons in DIS at HERA (**ZEUS, H1**).*

*Kaon PDFs: just 700 kaon-induced DY events at **NA3***





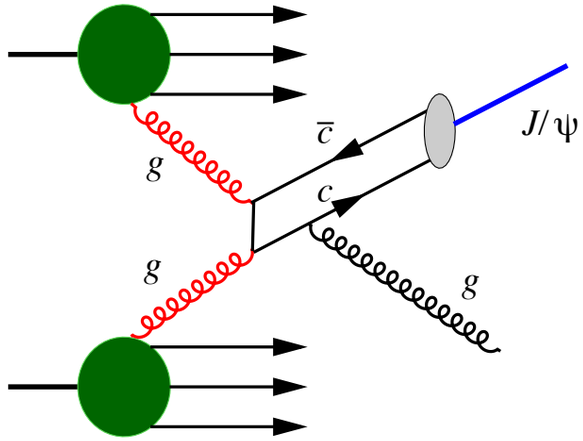
Ways to access gluon structure of hadron at low energies



- **prompt-photon production**

The most direct way

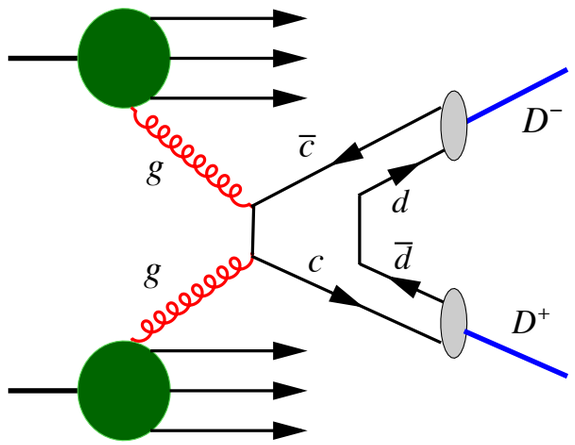
Hard background



- **charmonia production**

Nice signal

Model-dependent treatment

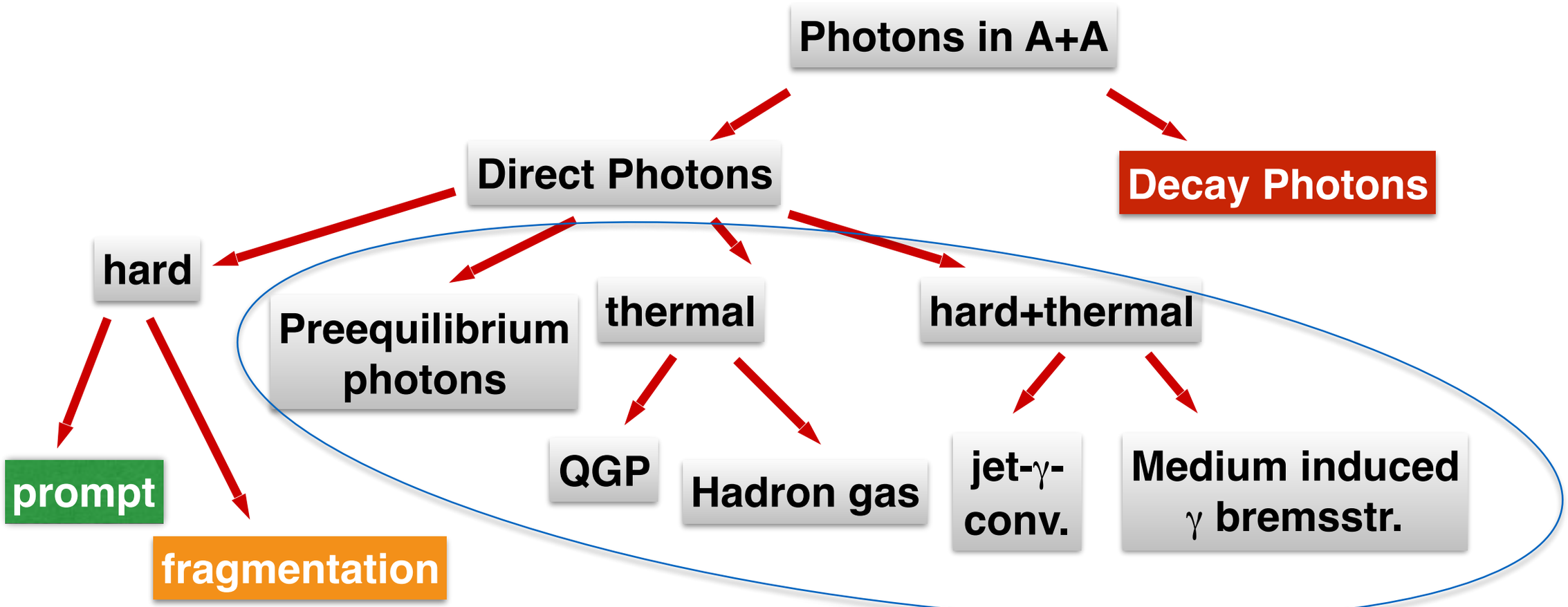


- **open-charm production**

Rather simple treatment

Problematic signal

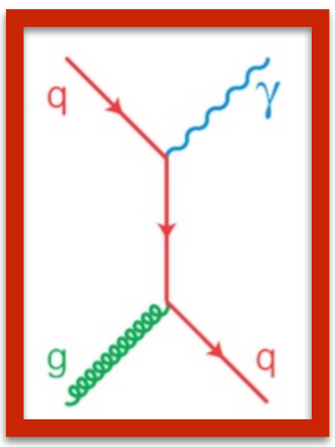
Production of photons in hadron collisions



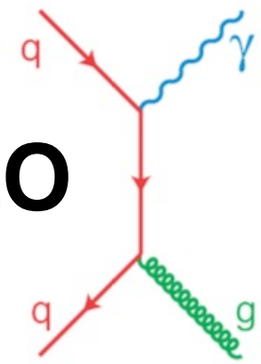
~10% at our energies

collective effects, not important for hA collisions

Physics goal



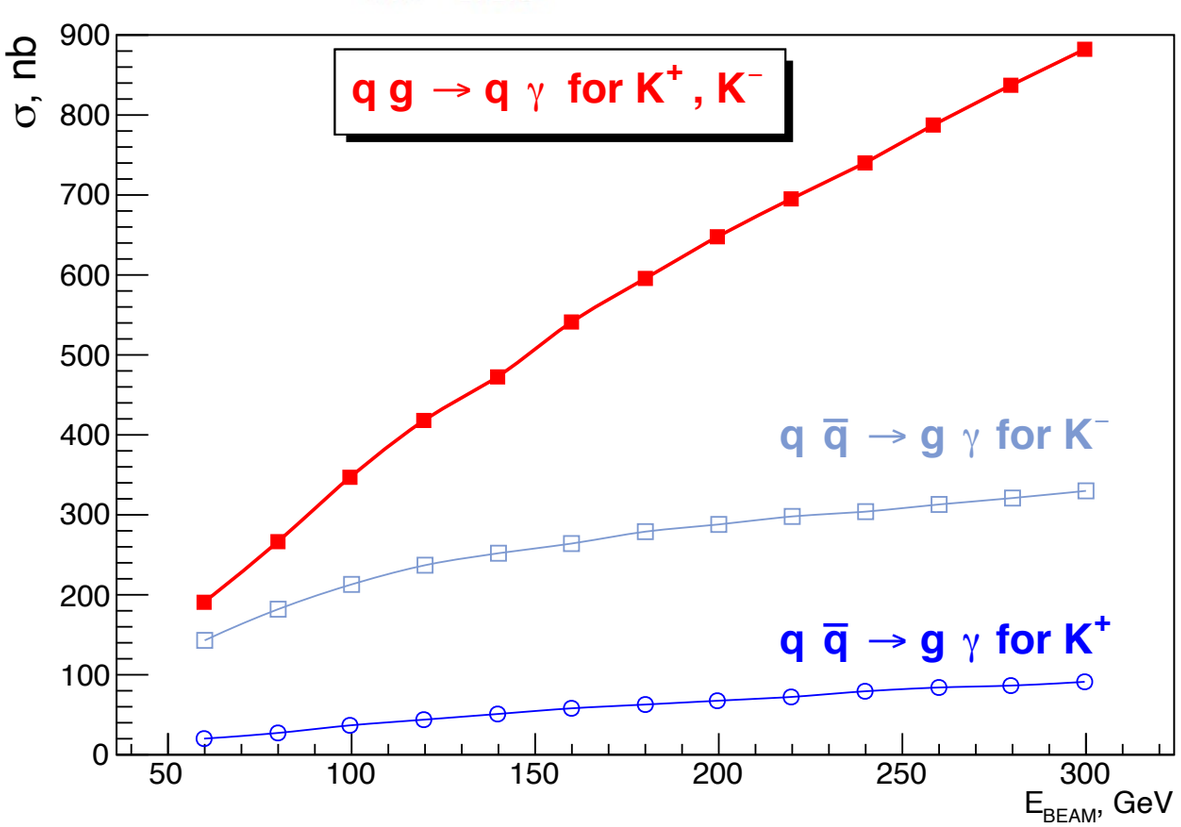
LO



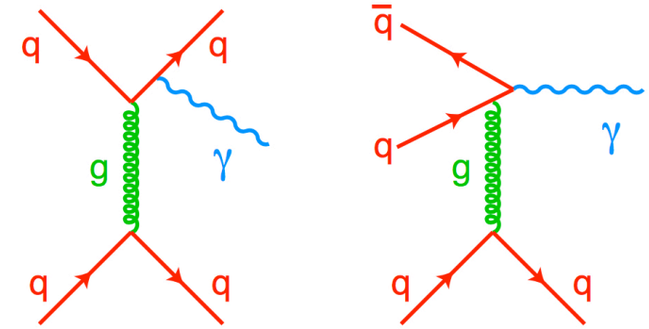
$$data \rightarrow \sigma_{inclusive\ \gamma}(p_T, x_F) \rightarrow g_K(x_K)$$

Gluon Compton scattering

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



NLO



Bremsstrahlung

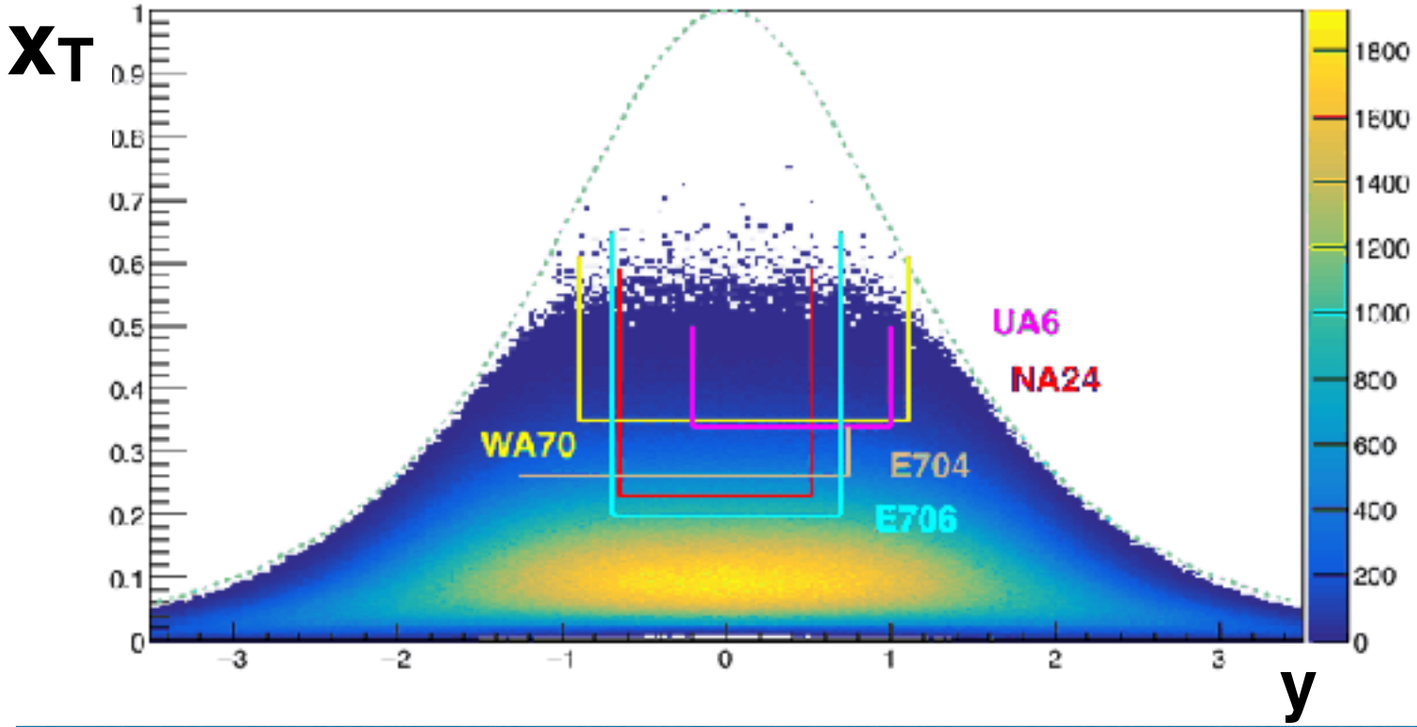
annihilation with scattering

- **separation of quark/gluon contribution in kaon (K+ vs K–)**
- **semi-inclusive reactions (?)**

Experiments with prompt photons at low 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$\uparrow$	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

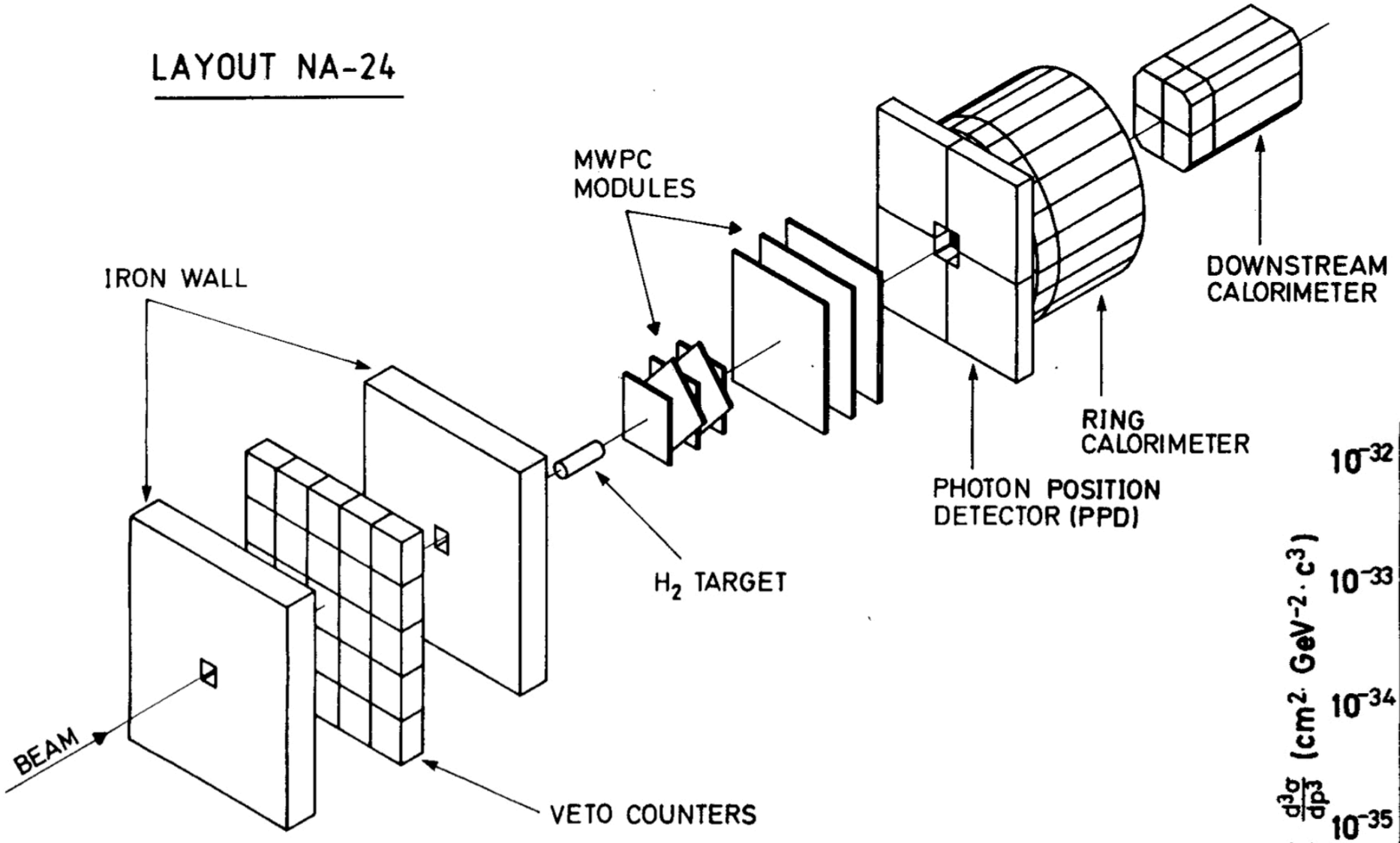


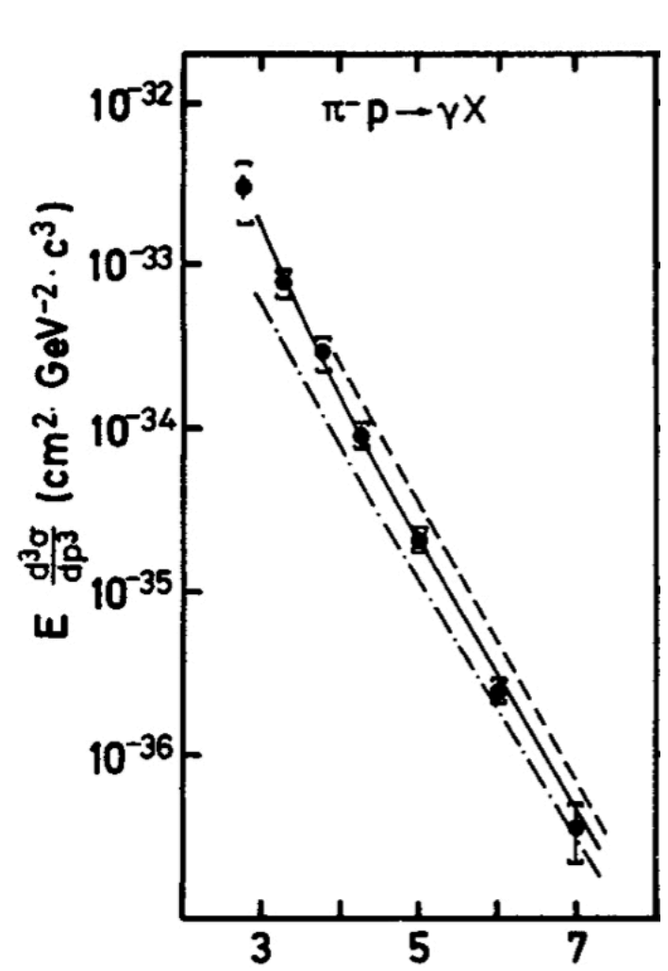
$$x_T = \frac{2p_T}{\sqrt{s}}$$

COMPASS++/AMBER $K^{\pm}, \pi^{\pm}$ **13.7 GeV 2025+**

New project

NA24 — typical fixed-target experiment for prompt photon studies





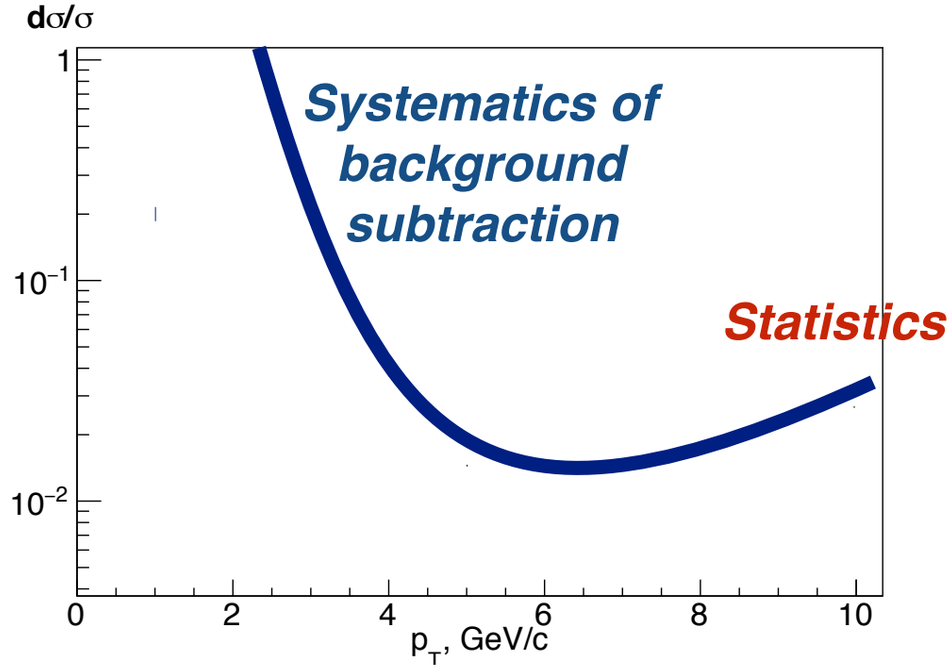
300 GeV beam

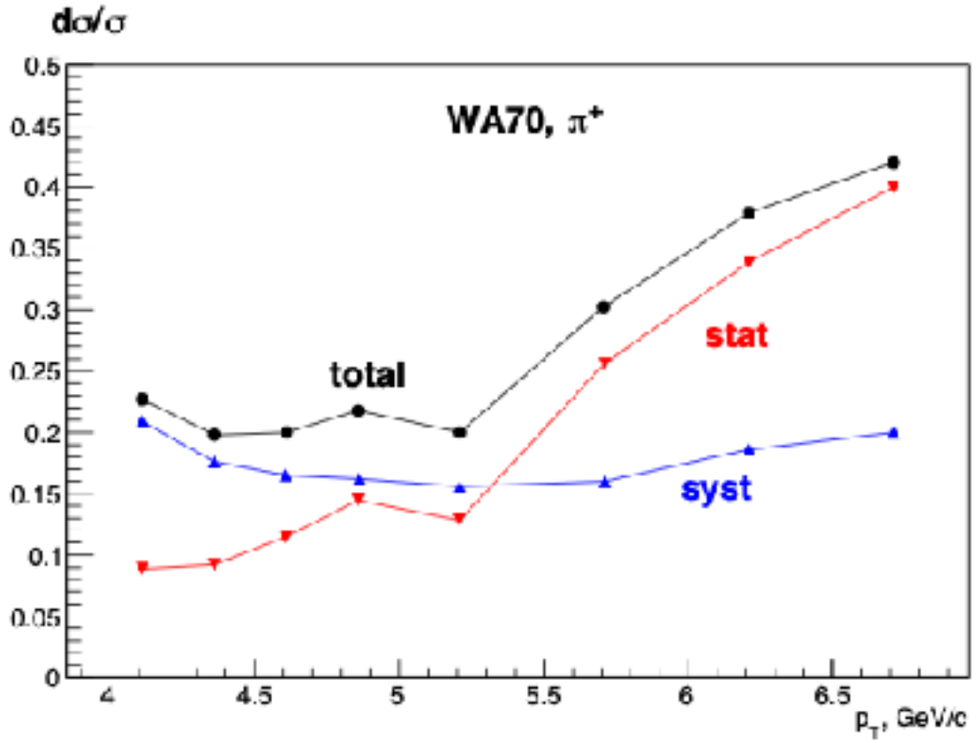
Experimental problem

Huge background from $\pi^0 \to 2\gamma$ and $\eta \to 2\gamma$ decays.

Low p_T — no chance!

High p_T — reconstruction of the decays and MC-based subtraction





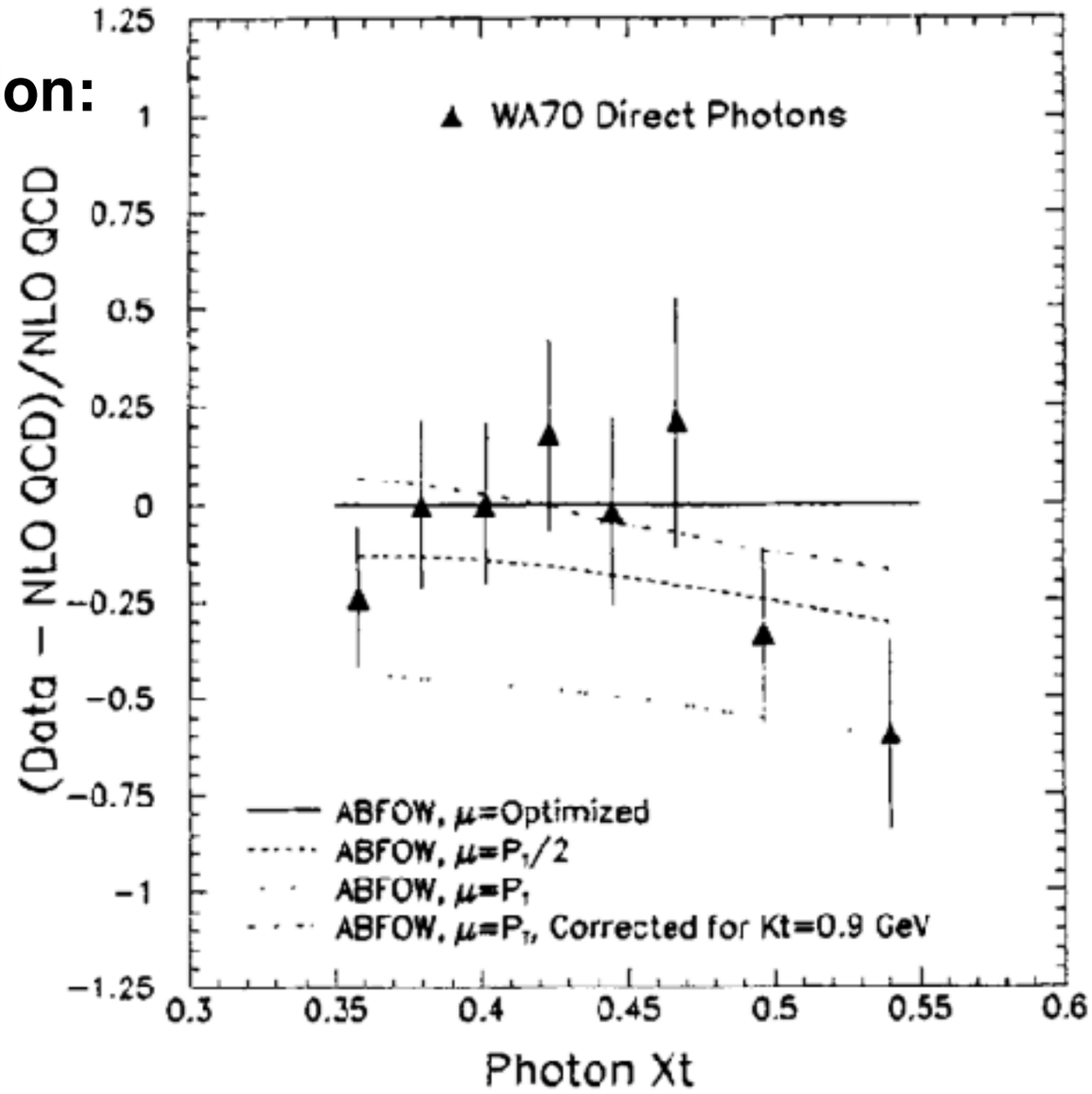
Theoretical problems

Scale problem

Usually two scales are used for calculation:

1) **renormalization scale μ for $\alpha_s(\mu)$**
2) **factorization scale M for PDFs**

In case of prompt photons there is just one - p_T of the photon



Primordial k_T problem

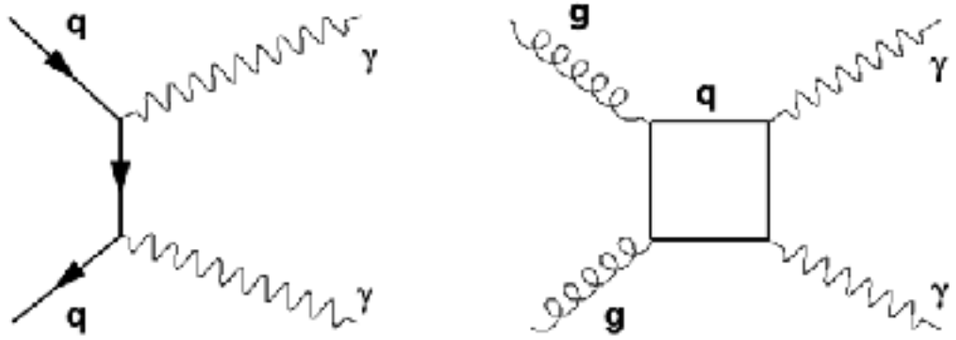
everything works great on case

$$\langle k_T \rangle \sim 1\ GeV/c \ll p_T \ll \sqrt{s}/2$$

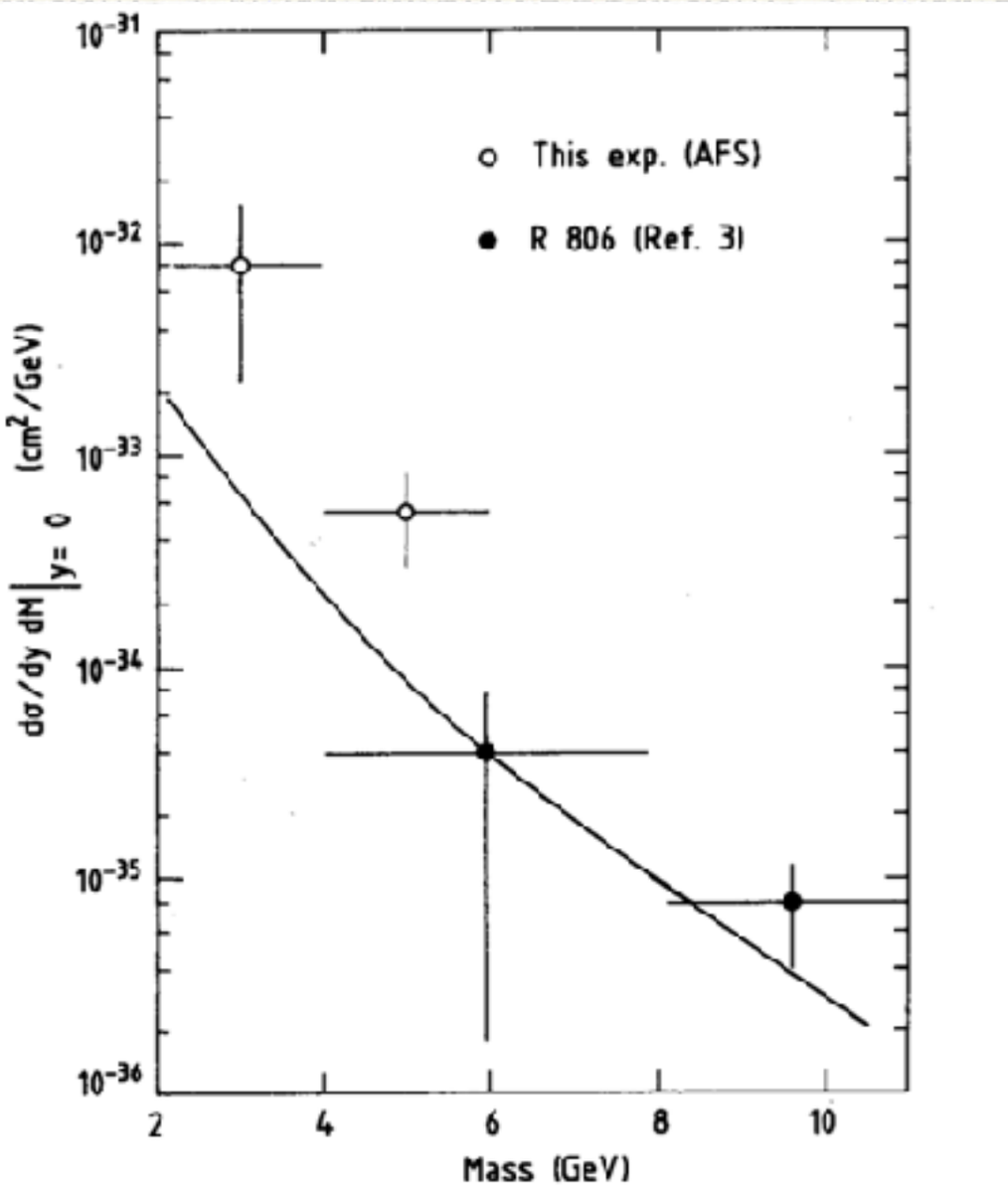
but it is not a case of low-energy fixed-target experiments

Production of double photons

Much smaller cross section but rather high masses

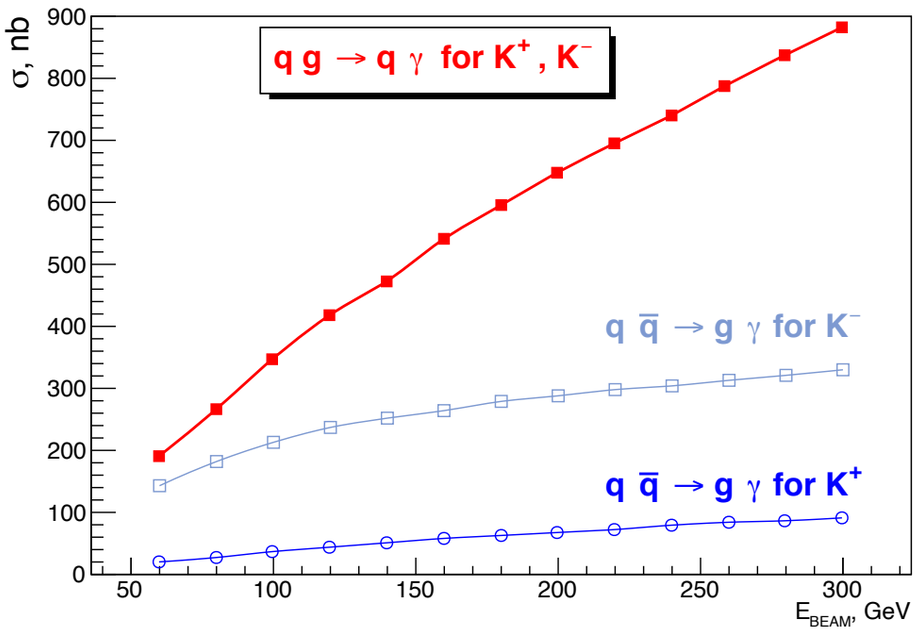


Collaboration	$\sqrt{s}$	Beam	Target	Measurement
R806 [16]	63	p	p	$d^2\sigma/dydm_{\gamma\gamma}$
R807 [19]	63	p	p	$d^2\sigma/dydm_{\gamma\gamma}$
UA2 [20]	630	$\bar{p}$	p	$d\sigma/dp_T$
UA2 [21]	630	$\bar{p}$	p	$d^2\sigma/d\eta_1/d\eta_2$
UA1 [22]	630	$\bar{p}$	p	σ $Ed^3\sigma/dp^3$
E741(CDF) [24]	1800	$\bar{p}$	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



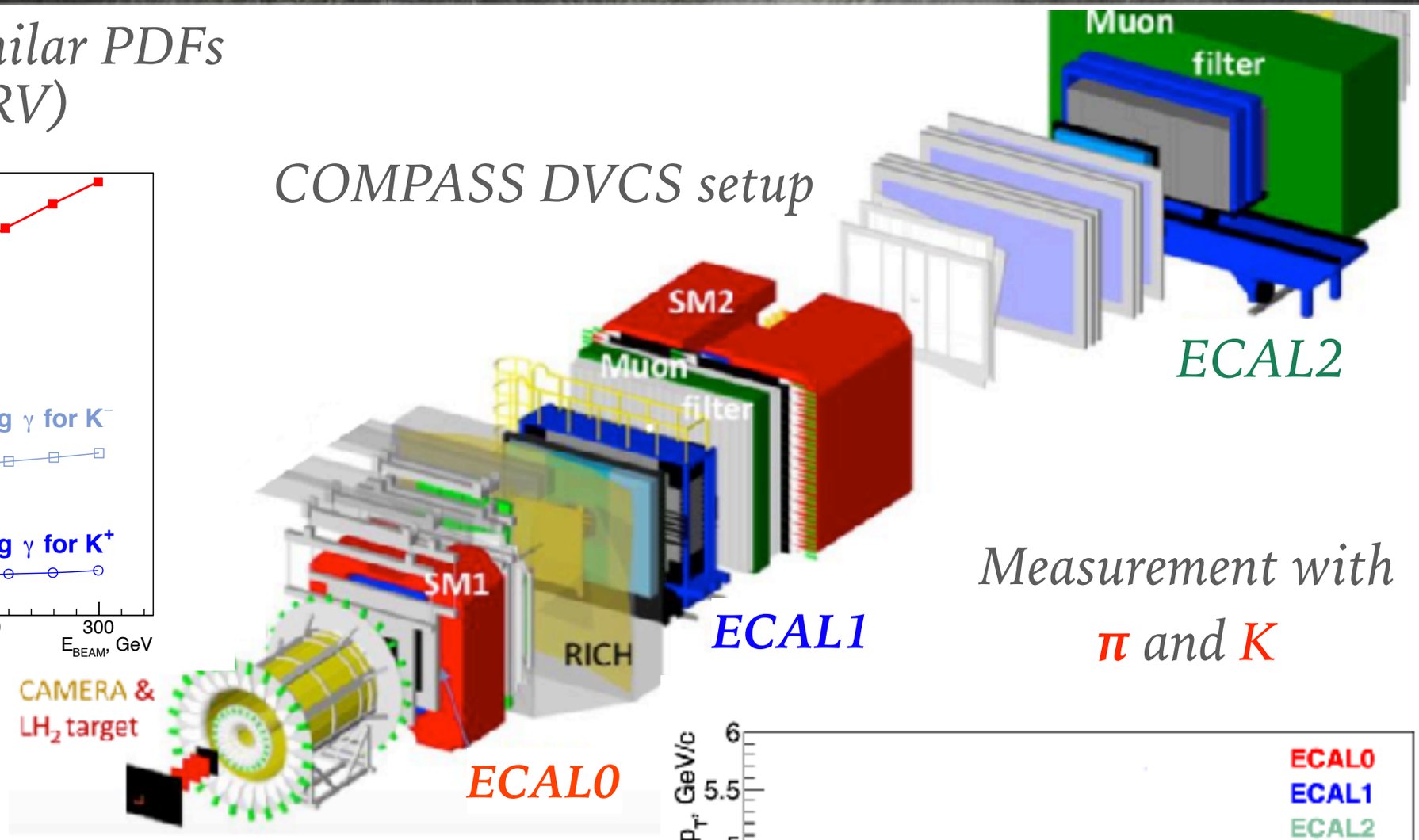
Prompt photons at COMPASS++/AMBER

Assumed for kaon similar PDFs as for pion (GRV)



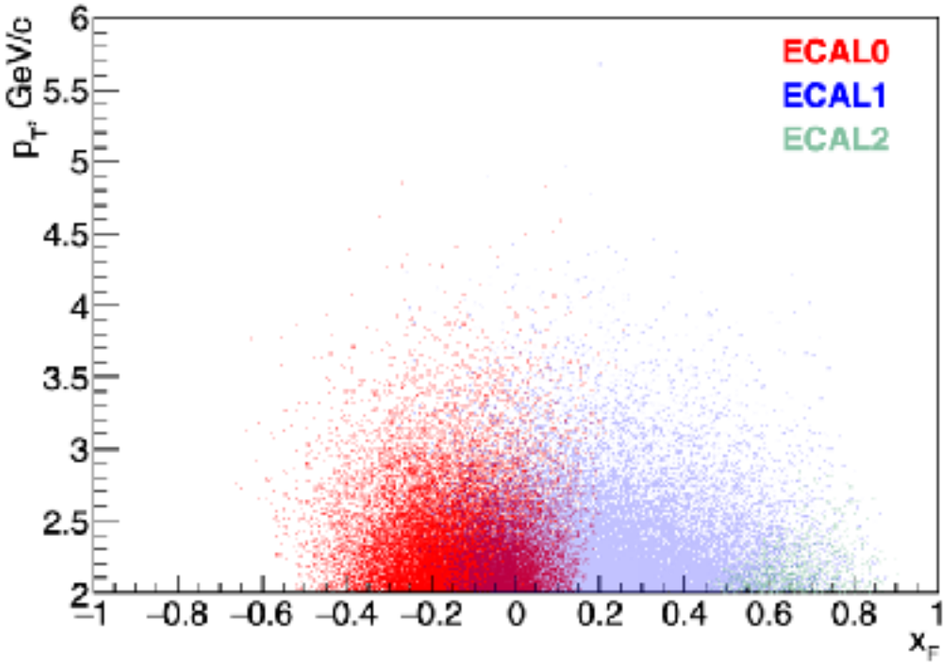
100 GeV kaon-enriched hadron beam!

COMPASS DVCS setup

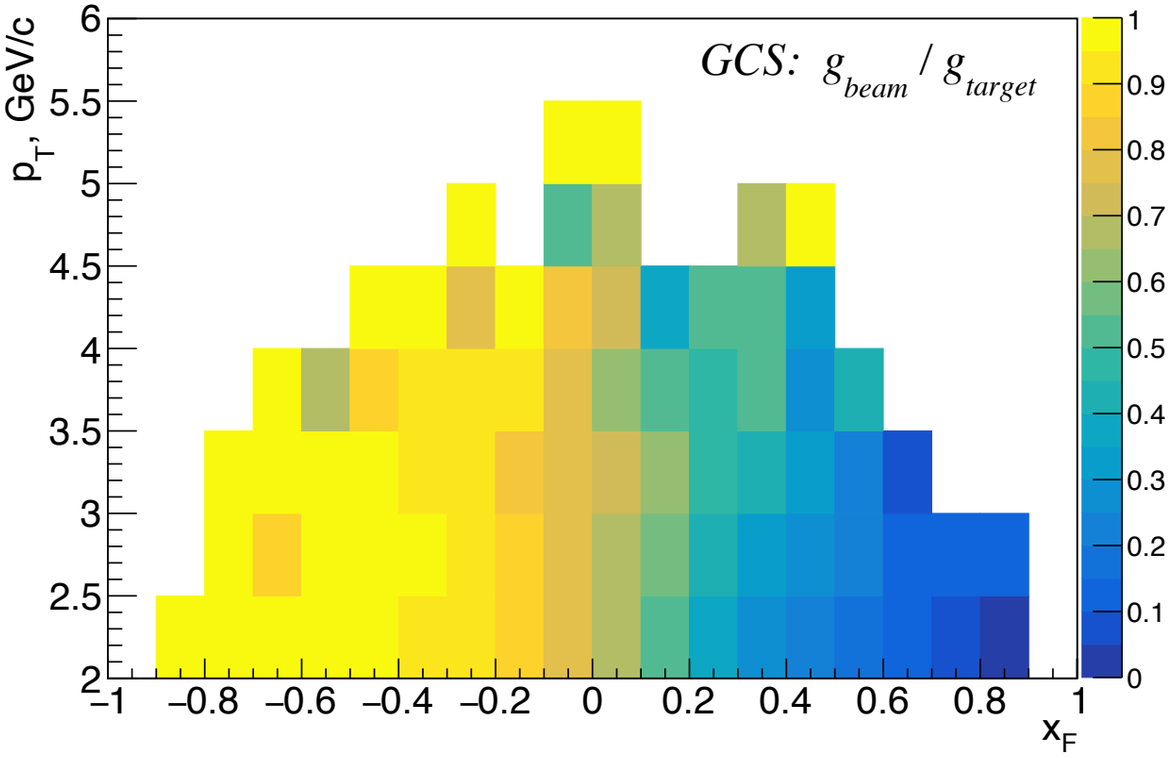


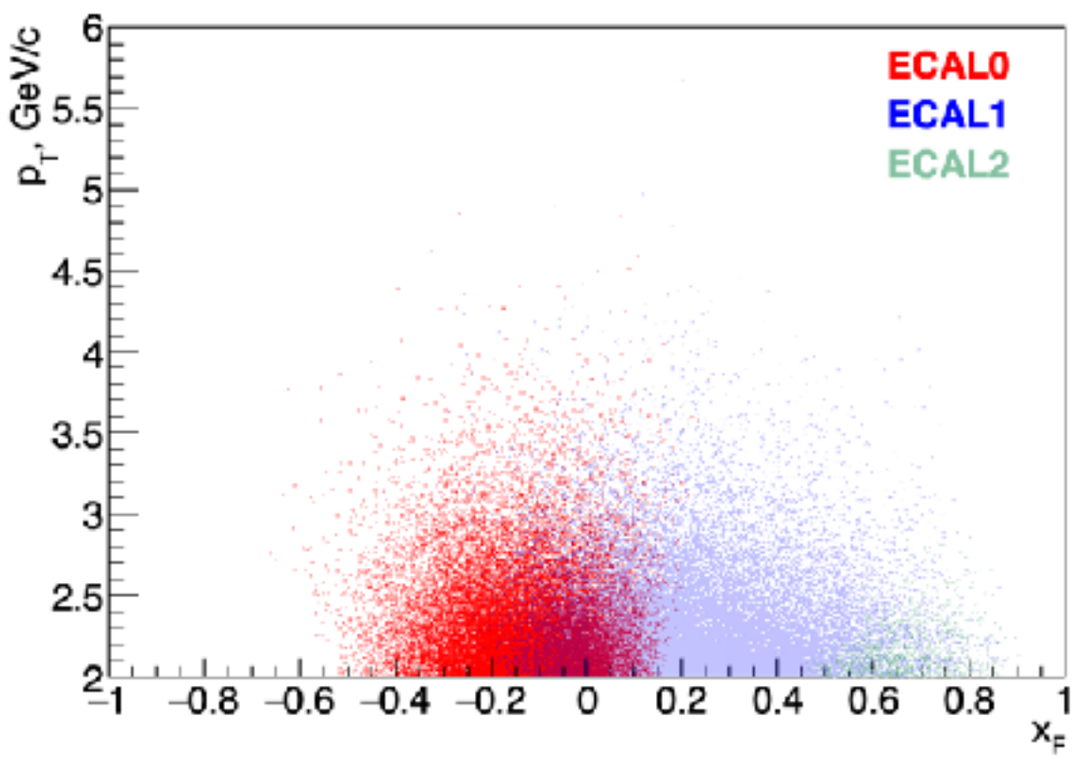
Measurement with π *and* K

Open setup *- possibility for semi-inclusive and exclusive reactions!*



x_g, x_F and p_T

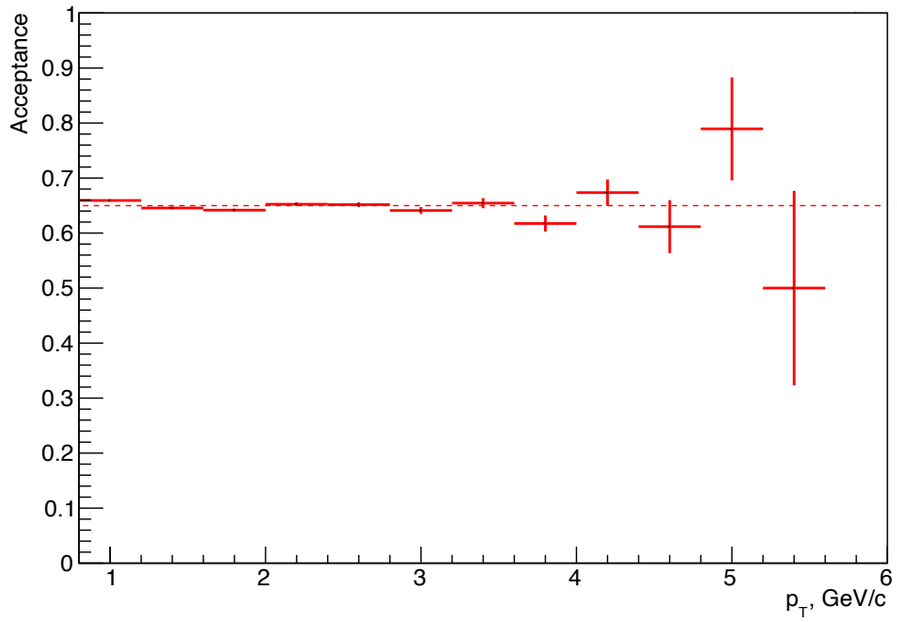




$$x_{K\ min} \approx \frac{4p_{T\ min}^2}{s}$$

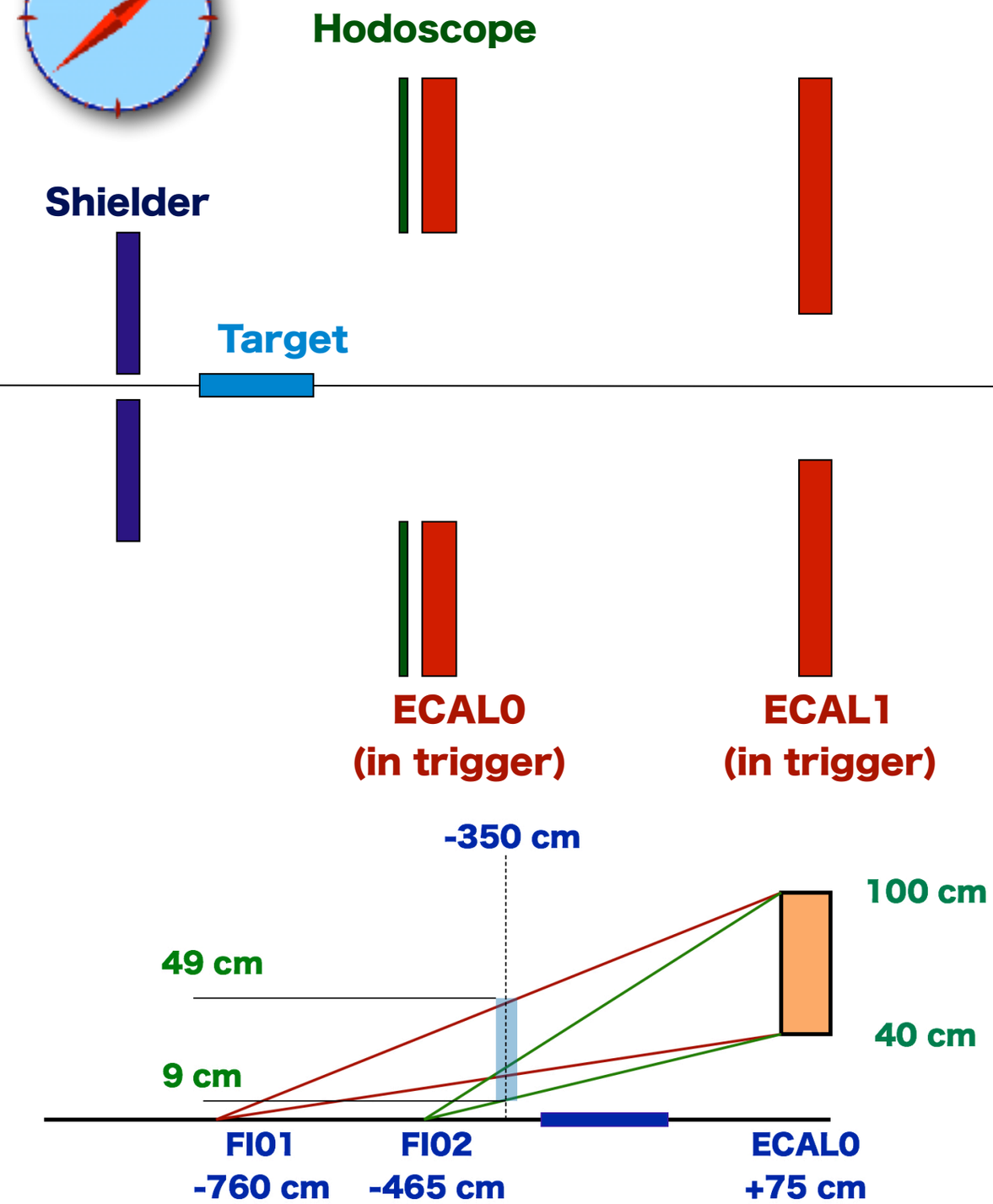
For $p_{T\ min}$ =2.5 GeV/c and E_K=100 GeV

$$x_{K\ min} \approx 0.13$$



Basic requirements

COMPASS DVCS-like setup



Stable performance

K^+ beam of $5*10^6$ s^{-1}

"Transparent" target
$\leq 0.3\ X_0$

ECALs at low threshold

ECAL0,1 in trigger

Hodoscope in front of ECAL0

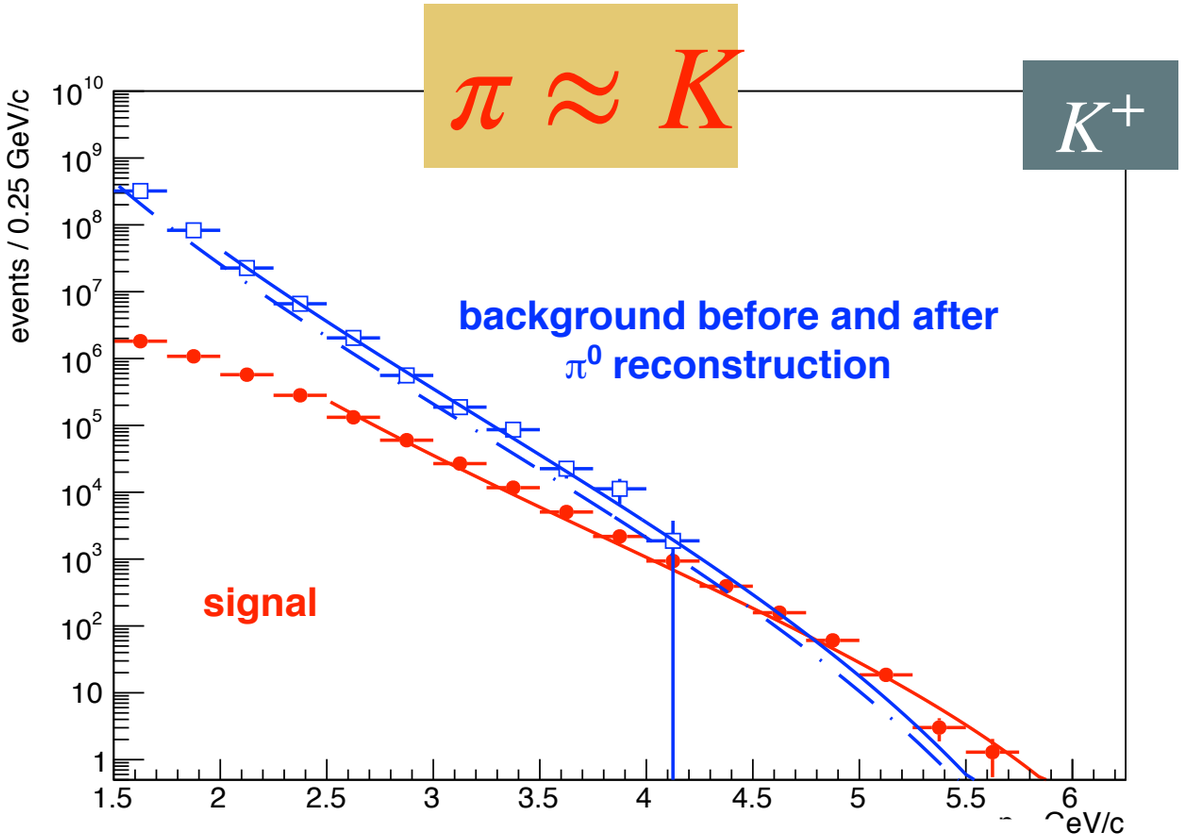
Preshower with coordinate detector in front of ECAL0

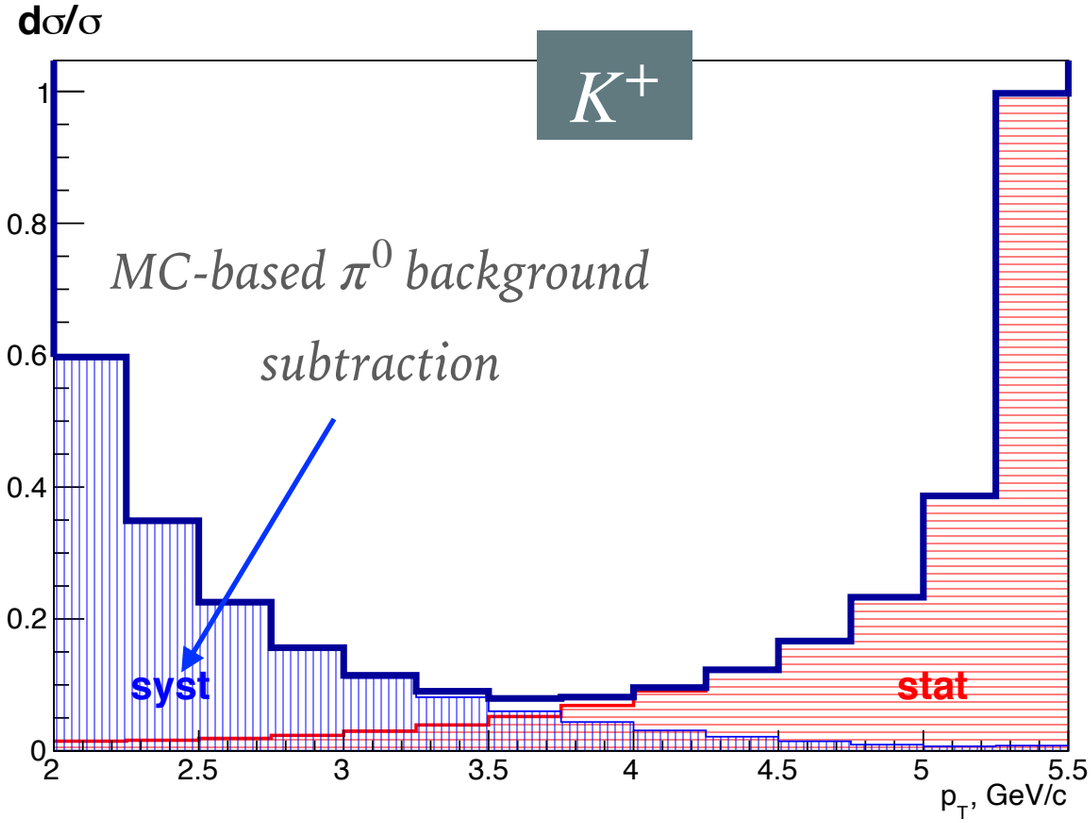
Reasonable amount of material

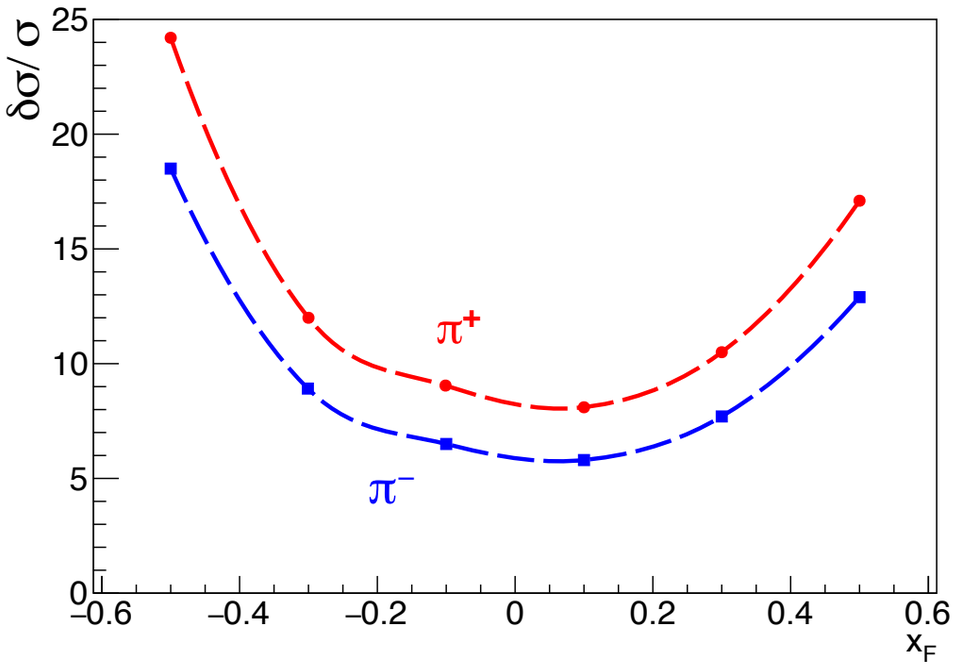
CEDARs

Shielder upstream the target (~20-30 cm of steel)

Expectations







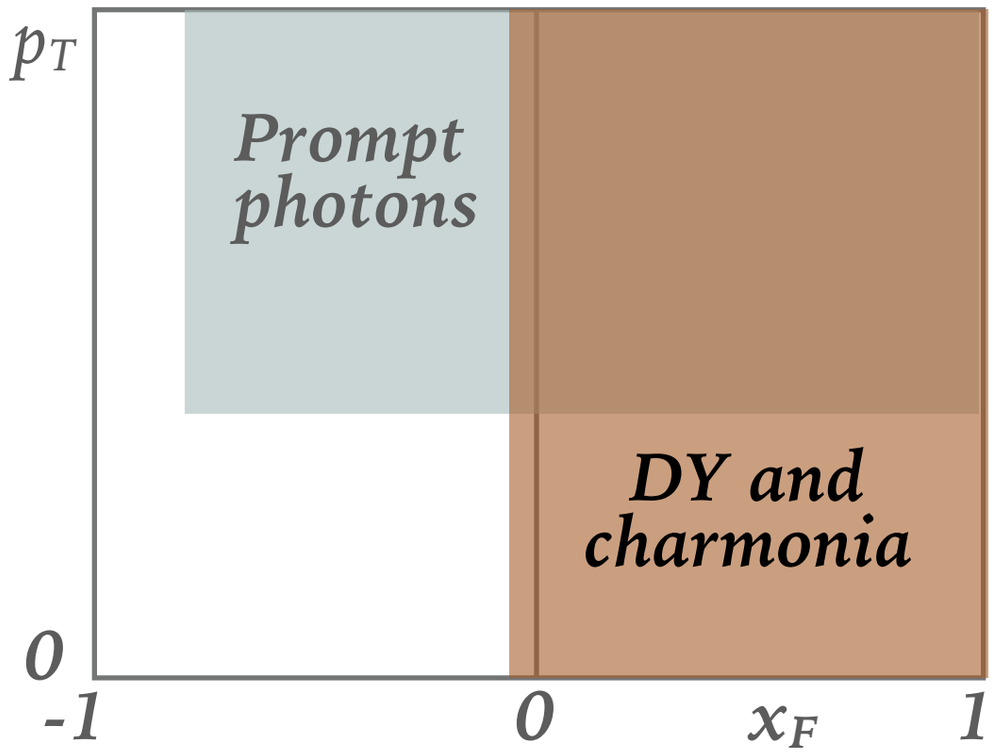
# of photons	p_T>2 GeV/c	p_T>3 GeV/c
π^- total	3.1×10^7	3.7×10^5
π^- prompt	1.3×10^6	6.8×10^4
π^+ total	3.3×10^7	3.6×10^5
π^+ prompt	1.1×10^6	4.7×10^4

This experiment (100 GeV): 50 pb^{-1} (1 year)

WA70 (280 GeV): *1.3 pb^{-1} for π^+ and 3.5 pb^{-1} for π^-*

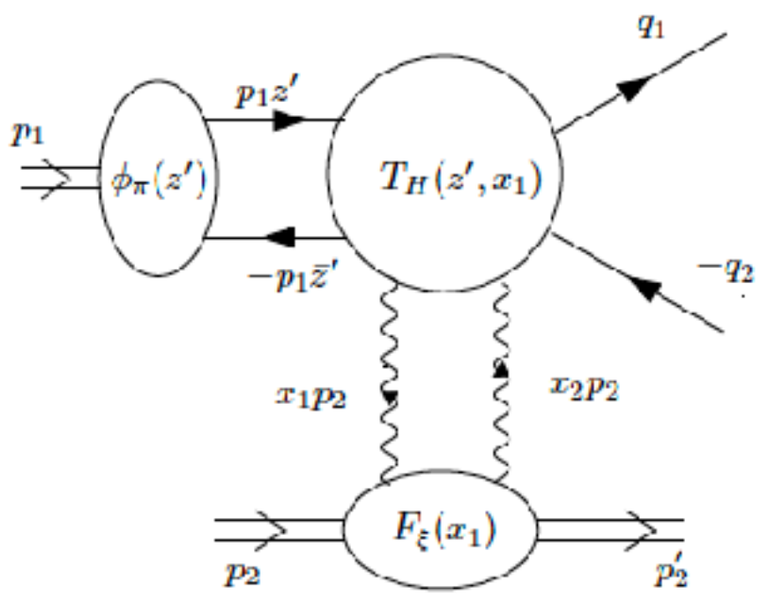
Prompt photons and other instruments at COMPASS++/AMBER

	Drell-Yan	Charmonia	Prompt photons
Main hard process (LO)	$q\bar{q} \to l^+l^-$	$gg \to J/\psi\ g$, $q\bar{q} \to J/\psi$	$q(\bar{q})g \to q(\bar{q})\gamma$, $q\bar{q} \to \gamma g$
Content to be tested	valence and sea quarks	gluons and quarks	gluons and quarks
Kinematic range	$x_F>0$	$x_F>0$	$p_T>2$ GeV/c
Main target	C	C	LH_2
Expected statistics, 10^6	π: ~0.1 (conv), K: ~0.06 (RF)	π: ~3 (conv), K: ~1 (RF)	π, K (RF) : ~10

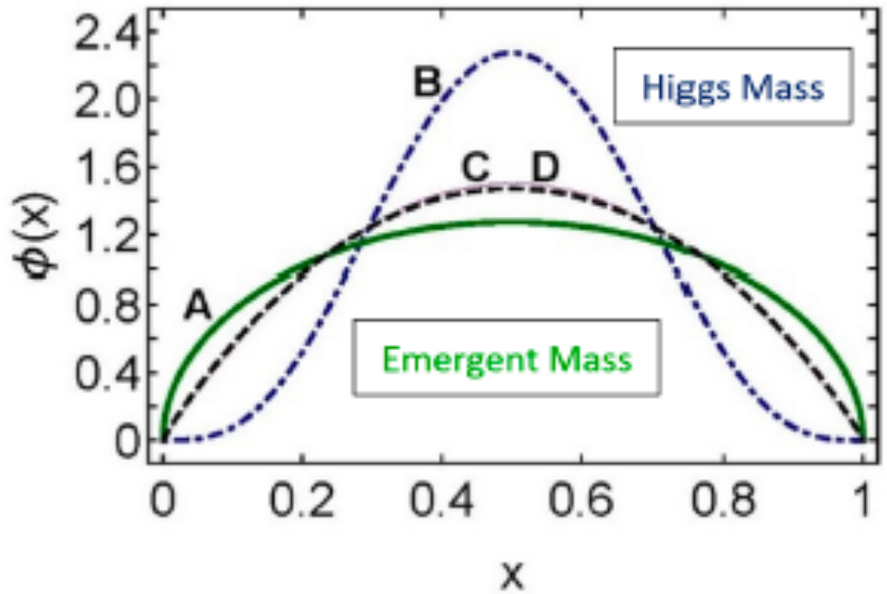


Different but overlapping kinematic ranges

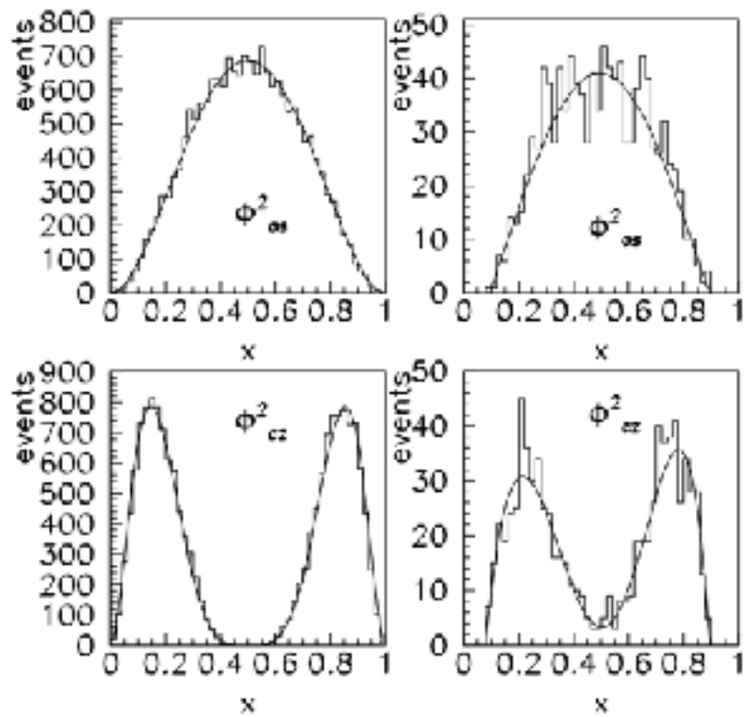
Diffractive meson dissociation & PDA



Probe: diffractive pion dissociation on a heavy target with very small *t'*. This is a coherent process where two quarks break apart producing iets/hadron in the final state



This kind of process is might give an access to the Pion light-cone wave function (squared), related to the Parton Distribution Amplitude (PDA).



For $|q\bar{q}>$ Fock state in pion:

$$\phi_{\rm cz}(x) = 5\sqrt{3}\,x(1-x)\,(1-2x)^2.$$

— Chernyak and Zhitnitsky from QCD sum rules

$$\phi_{\rm as}(x) = \sqrt{3}\,x(1-x)$$ ***— pQCD at high Q^2***

Diffractive meson dissociation & PDA

The only experiment with two jets in the final state which has been done so far is Fermilab experiment E791 (E791 Collaboration, E.M. Aitala et al., EPJ direct C4, 1 (1999)), recorded 2×10^{10} events from interactions of a 500 GeV/c π^- beam with carbon (C) and platinum (Pt) targets. The trigger included a loose requirement on transverse energy deposited in the calorimeters.

FERMILAB-Pub-00/221-E E791 October 2000

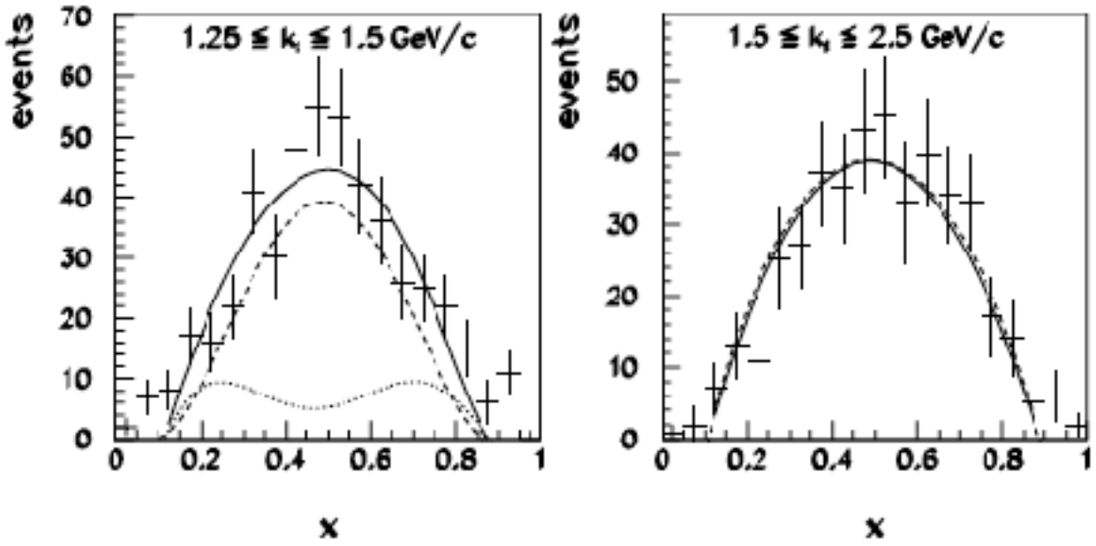


FIG. 3. The x distribution of diffractive di-jets from the platinum target for $1.25 \leq k_t \leq 1.5$ GeV/c (left) and for $1.5 \leq k_t \leq 2.5$ GeV/c (right). The solid line is a fit to a combination of the asymptotic and CZ wave functions. The dashed line shows the contribution from the asymptotic function and the dotted line that of the CZ function.

$$x_{\text{measured}} = \frac{p_{\text{jet1}}}{p_{\text{jet1}} + p_{\text{jet2}}}$$

Two-jet events were identified analysing by a number of selection criteria, for example all charged particles carried out 90% of beam particle momentum, cut on k_T, angular distributions analysis etc.

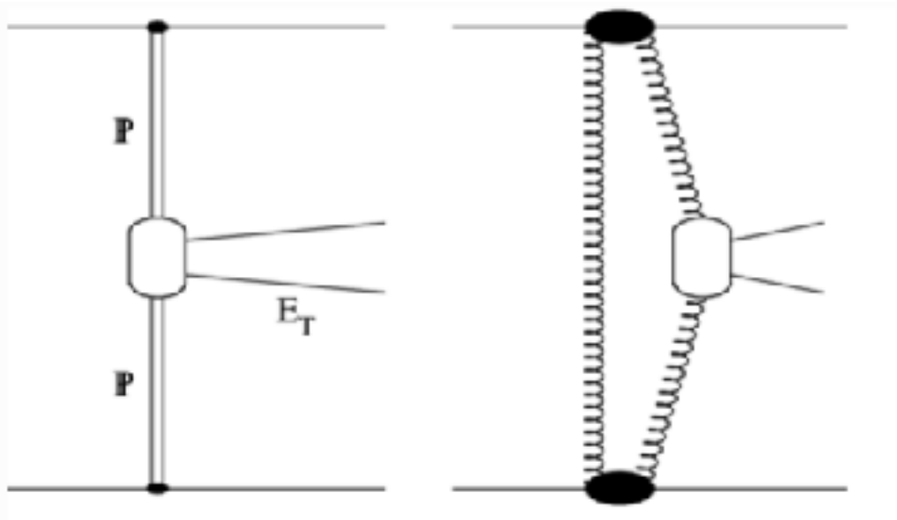
Diffractive meson dissociation & PDA

In case of COMPASS++/AMBER as our incoming beam energy is much smaller (typically 100— 200 GeV) the hadron multiplicities will be lower in the final state, on the other hand we can select for example events with 2 leading hadrons in the final state.

So we would like to know:

Whether such event topology can give an access to PDA?
Observable – (similar to two-jets) ?
The range in which observables has to be measured and reasonably treated ?

What about central production?



B Z Kopeliovich et. al. J.Phys. G34 (2007) 335

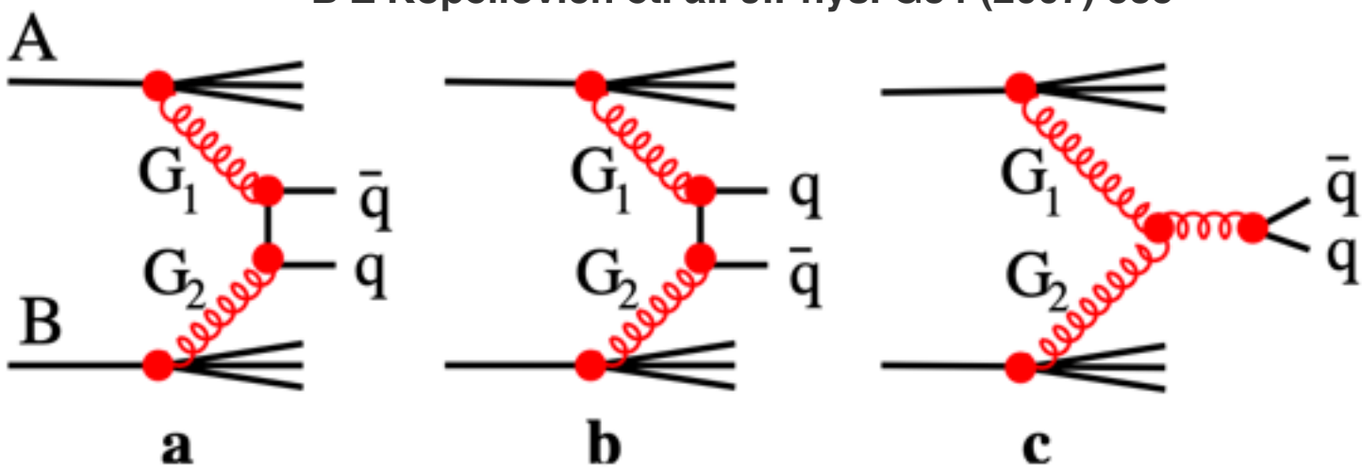
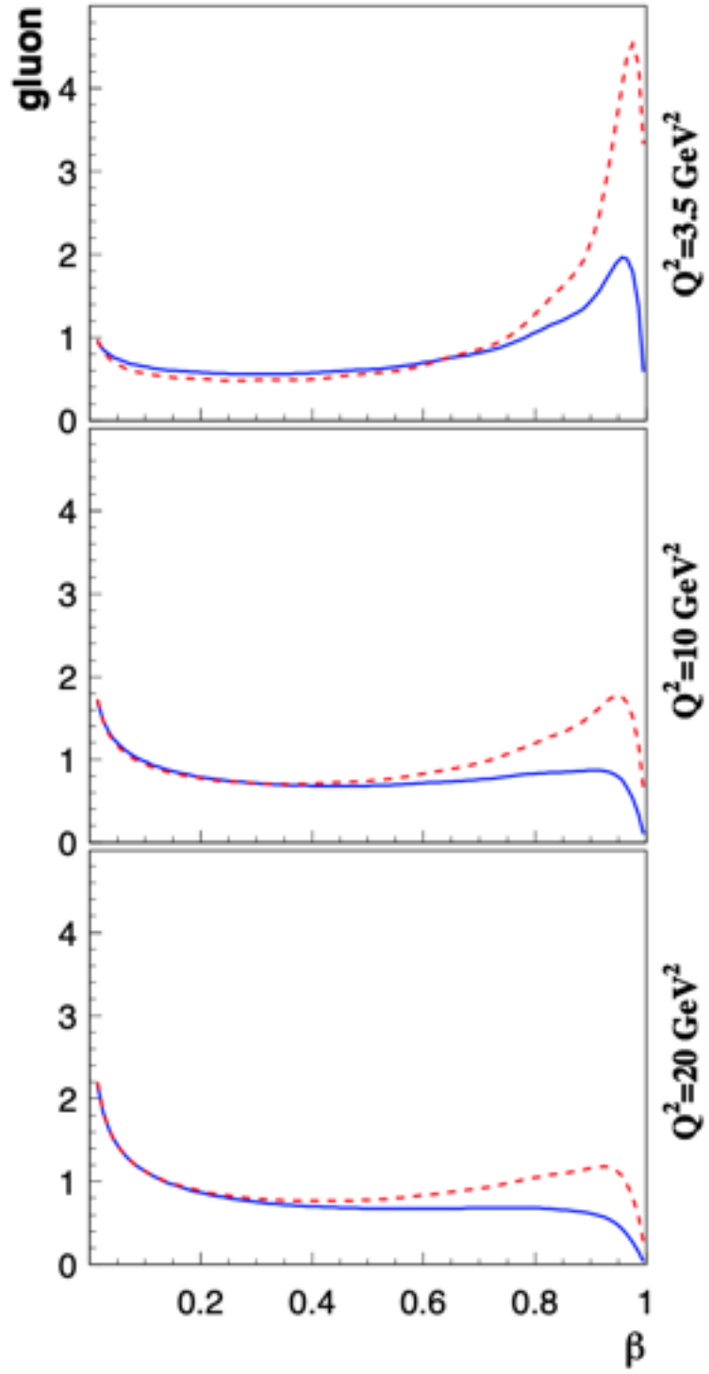


Figure 2: One gluon approximation to the central production of a $\bar{q}q$ pair.

Could we access the gluon content of mesons via central production at low energies?

gluon dPDFs from H1



Summary

- **Prompt-photon production is a proven instrument to access polarized and unpolarized gluon content of hadrons.**
- **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.**
- **Prompt-photon production is proposed for a first measurement of gluon distribution in kaon within the COMPASS++/AMBER project (CERN) with 100 GeV positive and negative RF-separated hadron beam. Due to the system of 3 electromagnetic calorimeters the measurement of the prompt-photon production production cross section could be performed in wide range of x_F and could be combined with the charmonia production results. New measurements for pion could be performed in parallel.**
- **Diffractive dissociation and central production could also be instruments to access the partonic structure of mesons.**
- **You are welcome with theoretical predictions and proposals to extend the experimental program with prompt photons of the COMPASS++/AMBER project.**