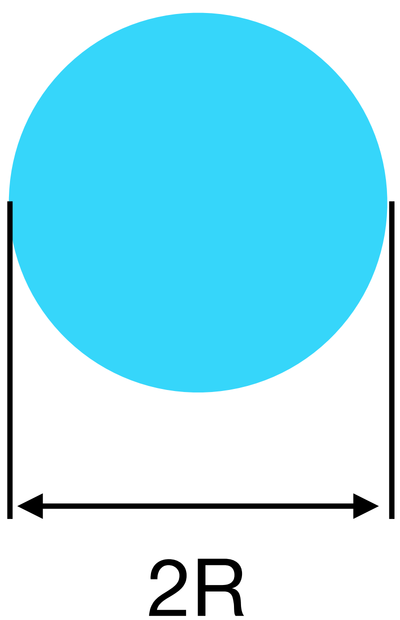
Apparatus for Meson and Baryon Experimental Research

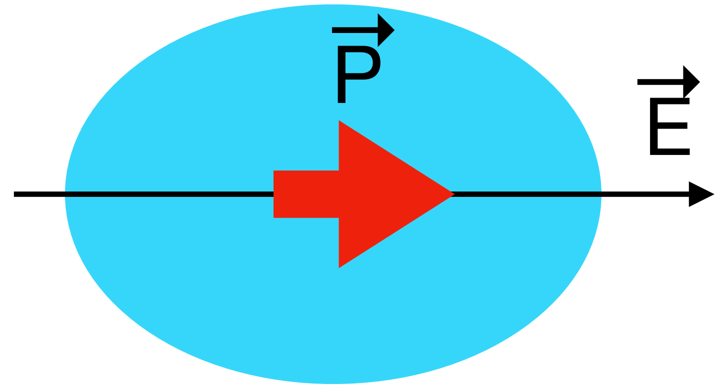
Primakoff Reactions and Prompt Photons Production with AMBER

A. Guskov , JINR **19.3.2024** **aguskov@jinr.int**

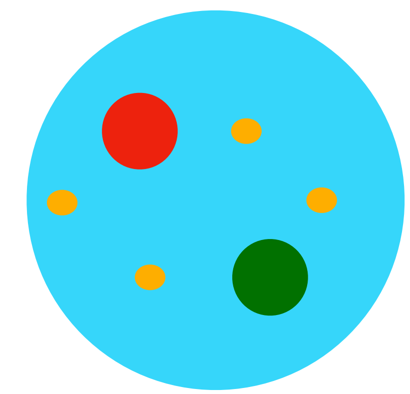
Hadronic matter



Existence
of nuclear matter
and its
self-organizatioin



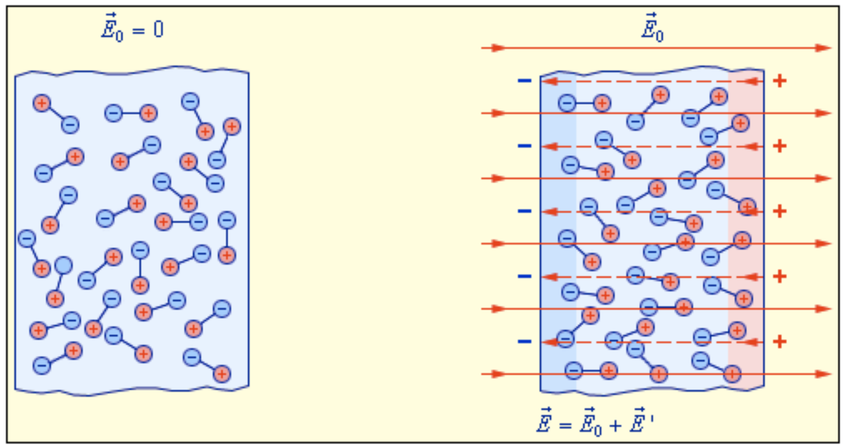
Rigidity
of nuclear matter



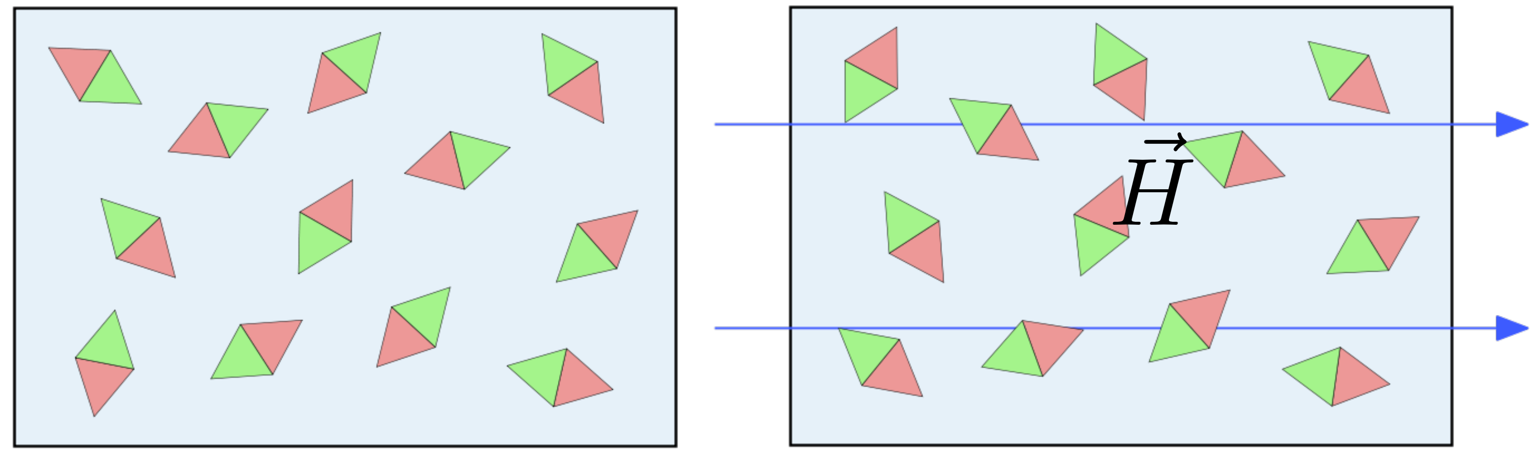
Structure
of nuclear matter

Polarizabilities: from medium to particles

Electric



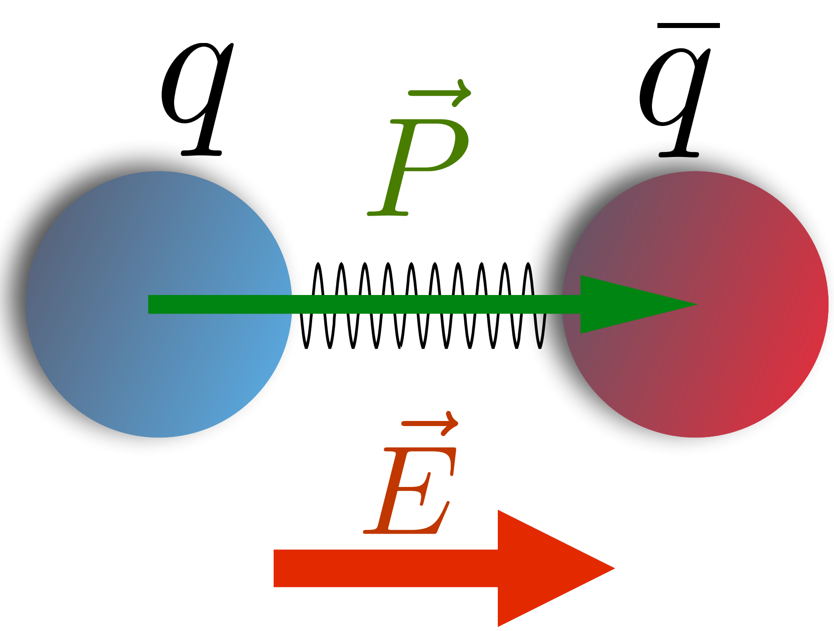
Magnetic



Polarizabilities:

$$\vec{P} = \alpha_X \vec{E}$$

$$\vec{\mu} = \beta_X \vec{H}$$



Compton amplitude:

$$A(\gamma X \to \gamma X) =$$

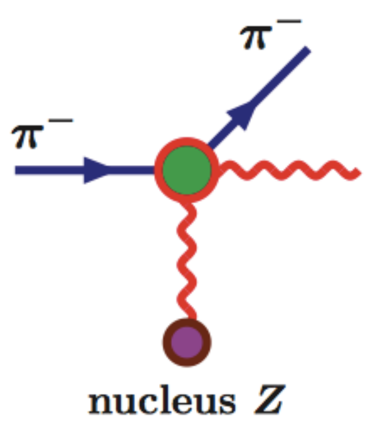
$$(-\frac{\alpha}{m}\delta_{o\pm} + \alpha_X \omega_1 \omega_2)\hat{e}_1 \cdot \hat{e}_2 +$$

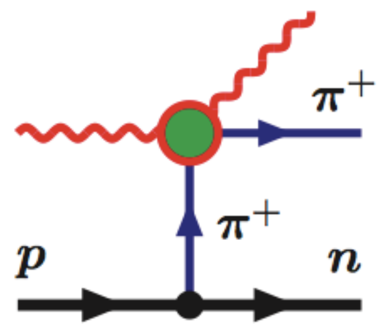
$$+\beta_X \omega_1 \omega_2 (\hat{e}_1 \times \hat{q}_1)(\hat{e}_2 \times \hat{q}_2) + \ldots$$

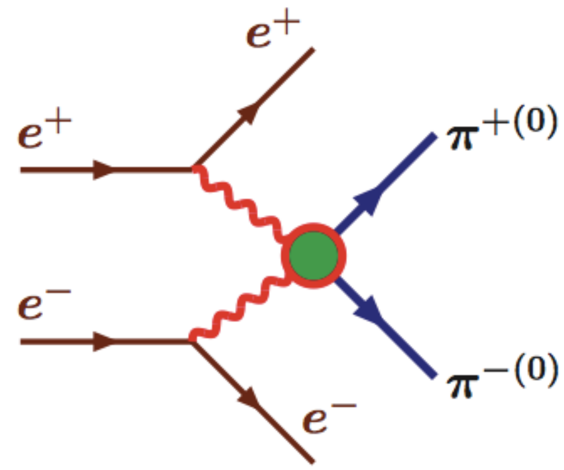
$$H = \ldots -(\alpha_X E^2 + \beta_X H^2)/2$$

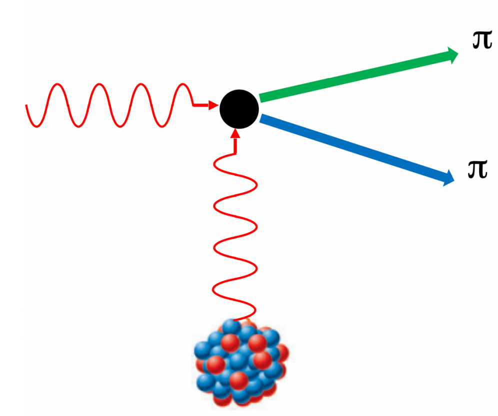
The electric and magnetic polarizabilities of a hadron are the quantities characterizing the rigidity of QCD system

Polarizability of hadrons





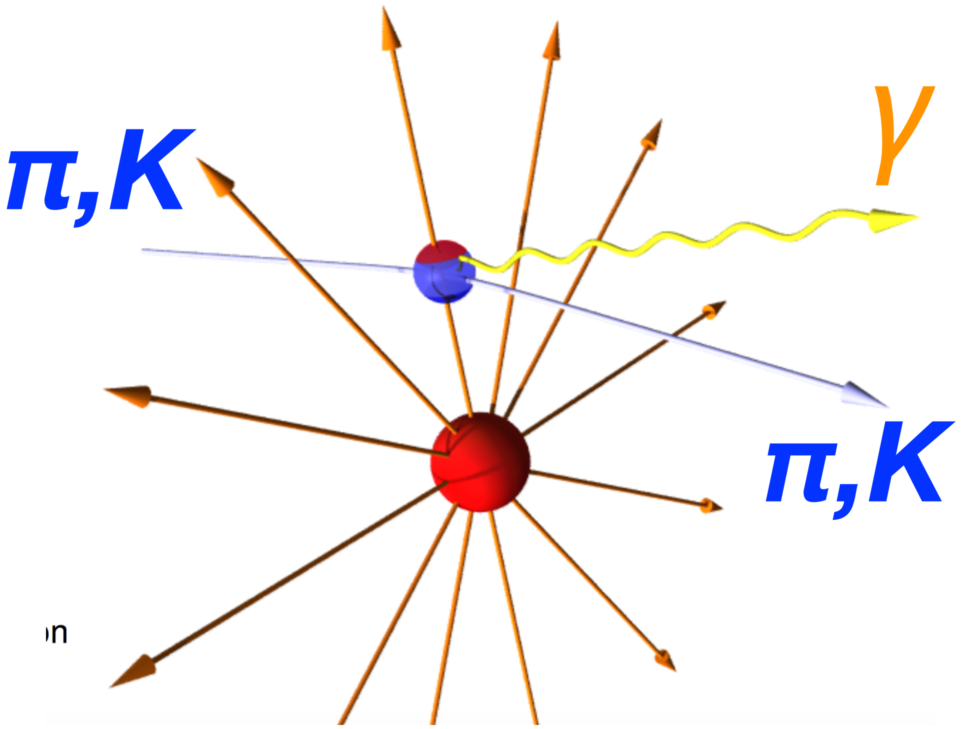




	α_X, 10^{-4} fm^3	β_X, 10^{-4} fm^3	Comments	Chiral theory	α_X/r^3_X, 10^{-3}
p	**11.2±0.4**	**2.5±0.4**		α=10.8 , β=4.0 (±0.7)	1.9
n	**11.8±1.1**	**3.7±1.2**			
$\pi^\pm$	**2.0±0.9**	**-2.0∓0.9**	assuming α= -β	α=2.9 , β=2.7 (±0.5)	1
π^0	0±2	1∓2		α=−0.4 , β=1.5 (±0.3)	
$K^\pm$	**<200**		from kaonic atom spectra	α= −β = 0.6	0.34
Hydrogen atom					4 500

Magnetic moment of proton induced by atomic magnetic fields is ~ 10^{-14} μ_N

Primakoff reactions



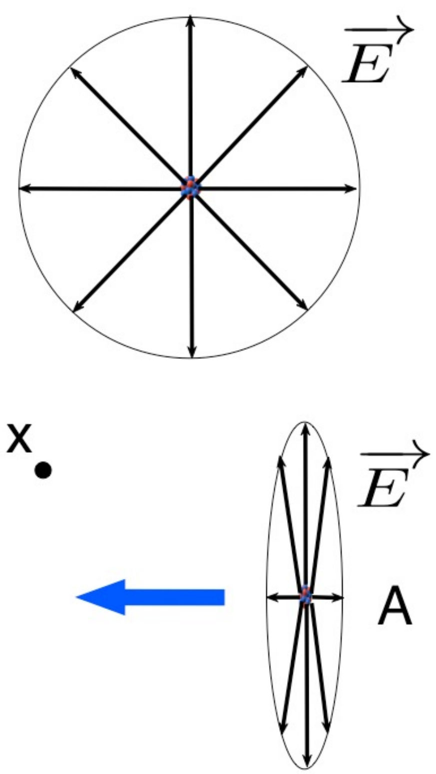
$$\sigma_{x\gamma} \sim 1/m_x^2$$

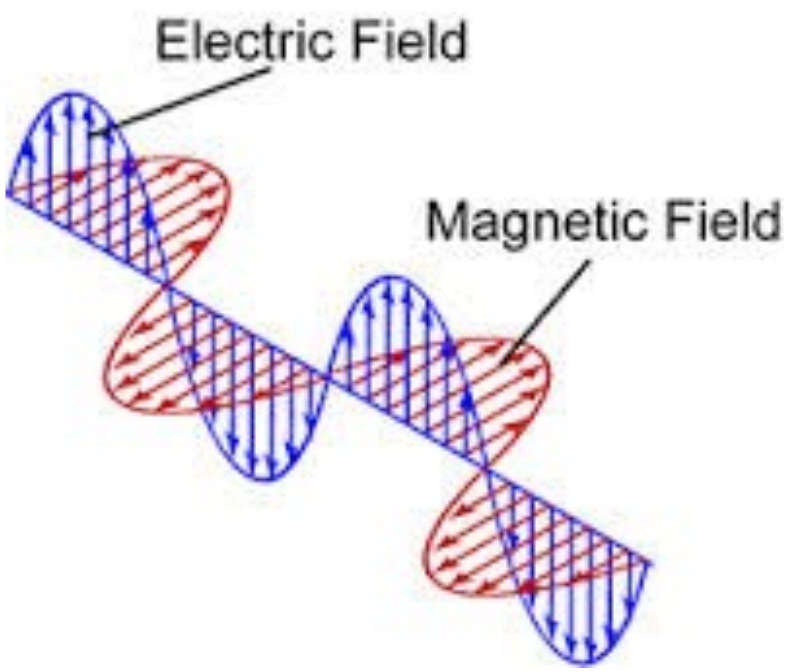
$$\sigma_{x\gamma}(\omega, Q^2) \rightarrow \sigma_{x\gamma}(\omega, 0)$$

$$d\sigma_{xZ} = \int n_\gamma(\omega) d\sigma_{x\gamma}(\omega) d\omega$$

$$n_\gamma(\omega) \sim \frac{Z^2\alpha}{\omega} ln \frac{E}{\omega}$$

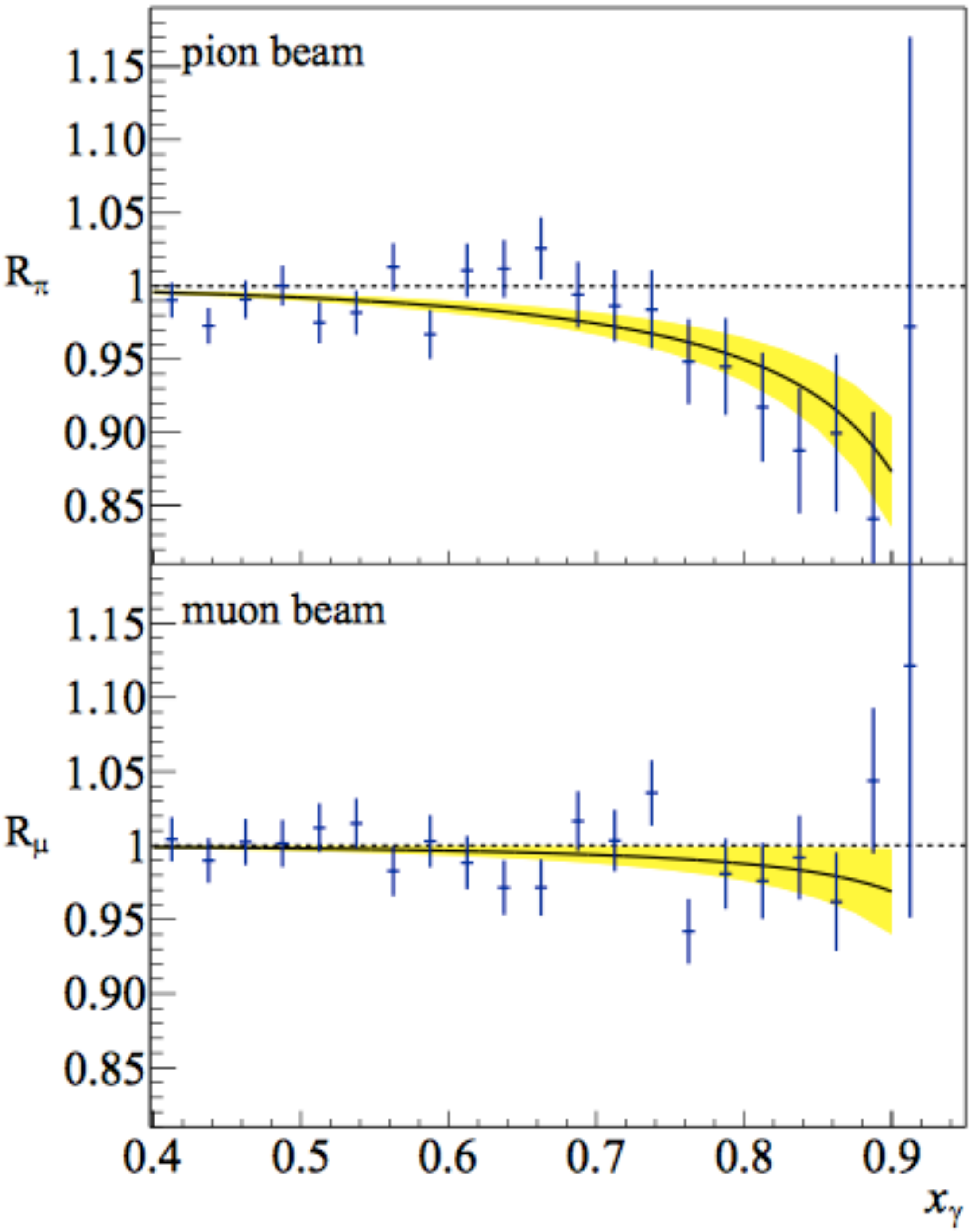
density of equivalent photons





Pion polarizability at COMPASS

$$R_X = \frac{\sigma}{\sigma_{p.l.}} = 1 - \frac{3}{2} \times \frac{x_\gamma^2}{1 - x_\gamma} \times \frac{m_X^3}{\alpha} \times \alpha_X$$



Source of uncertainty	Estimated magnitude $[10^{-4}\,\mathrm{fm}^3]$
Determination of tracking detector efficiency	0.5
Treatment of radiative corrections	0.3
Subtraction of π^0 background	0.2
Strong interaction background	0.2
Pion-electron elastic scattering	0.2
Contribution of muons in the beam	0.05
Quadratic sum	0.7

Under assumption $\alpha_\pi = -\beta_\pi$:

$\alpha_\pi = (2.0 \pm 0.6_{stat} \pm 0.7_{syst}) \times 10^{-4}\ \mathrm{fm}^3$

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Kaon polarisability via Primakoff scattering

Theoretical predictions:

χPT prediction $O(p^4)$:

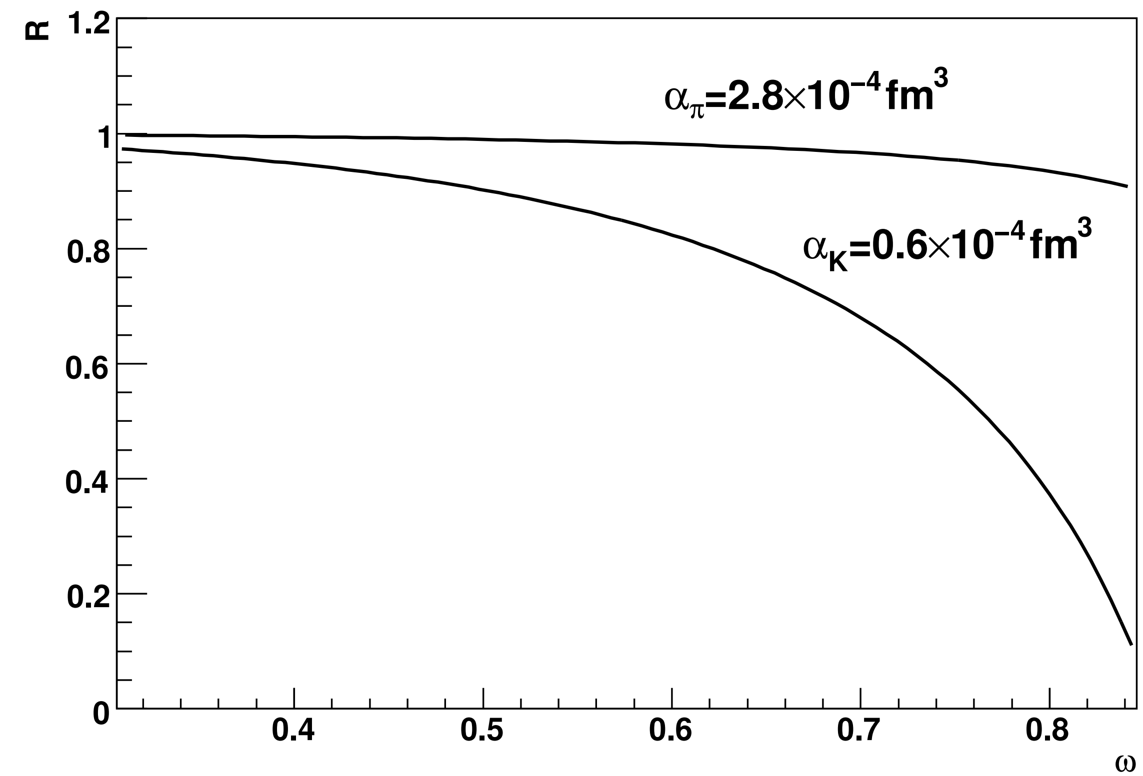
$$\alpha_K + \beta_K = 0$$

$$\alpha_K = \alpha_\pi \times \frac{m_\pi F_\pi^2}{m_K F_K^2} \approx \frac{\alpha_\pi}{5} \approx 0.6 \times 10^{-4} fm^3$$

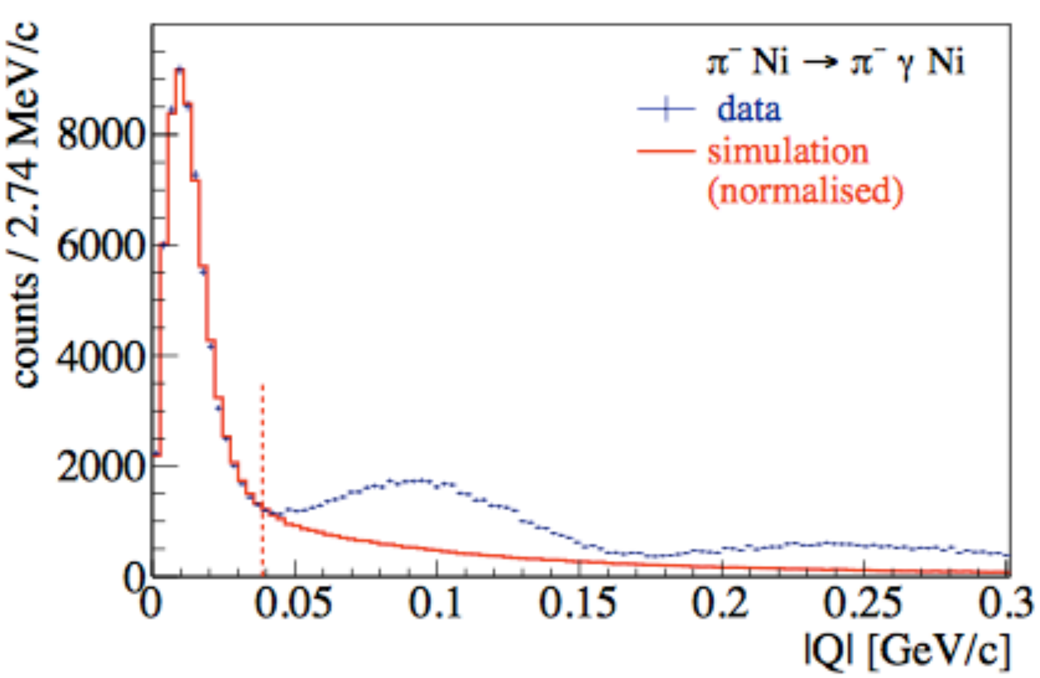
Quark confinement model:

$$\alpha_K + \beta_K = 1.0 \times 10^{-4} fm^3$$

$$\alpha_K = 2.3 \times 10^{-4} fm^3$$



$$R_K \approx \frac{\sigma}{\sigma_{p.l.}} = 1 - \frac{3}{2} \cdot \frac{x_\gamma^2}{1 - x_\gamma} \cdot \frac{m_K^3}{\alpha} \cdot \alpha_K$$



1-st experimental problem:

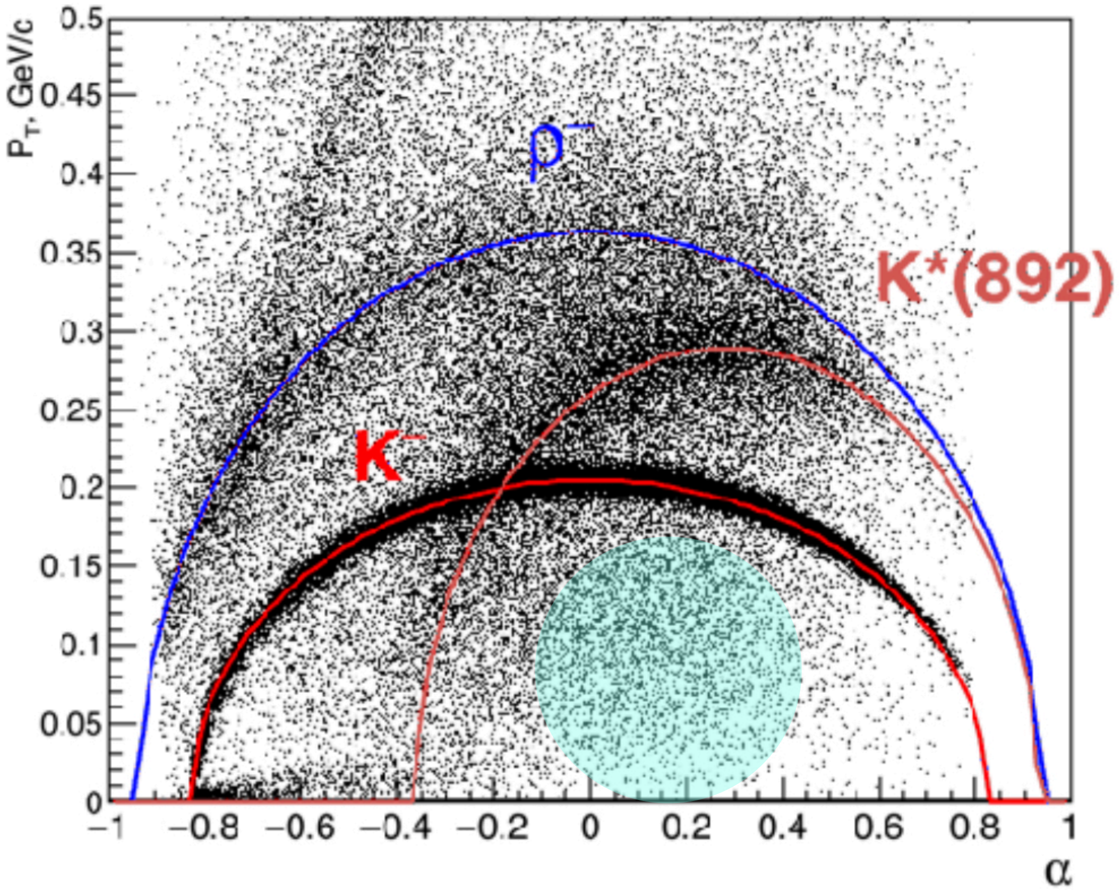
$$\sigma_{x\gamma} \sim 1/m_x^2$$

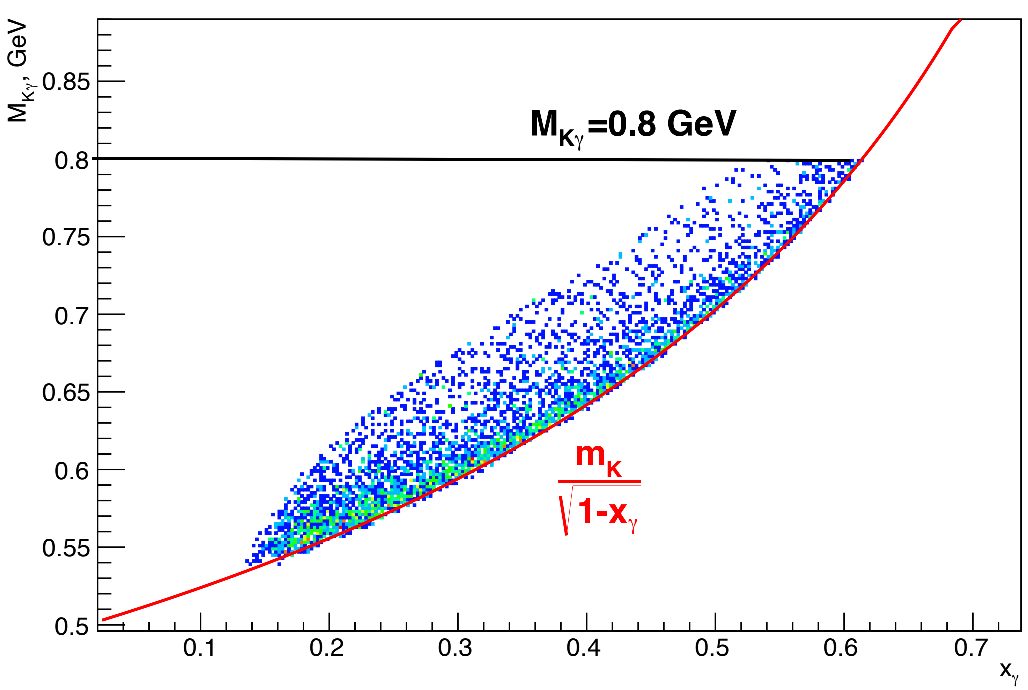
Primakoff peak for kaon is 10 times lower than for pion

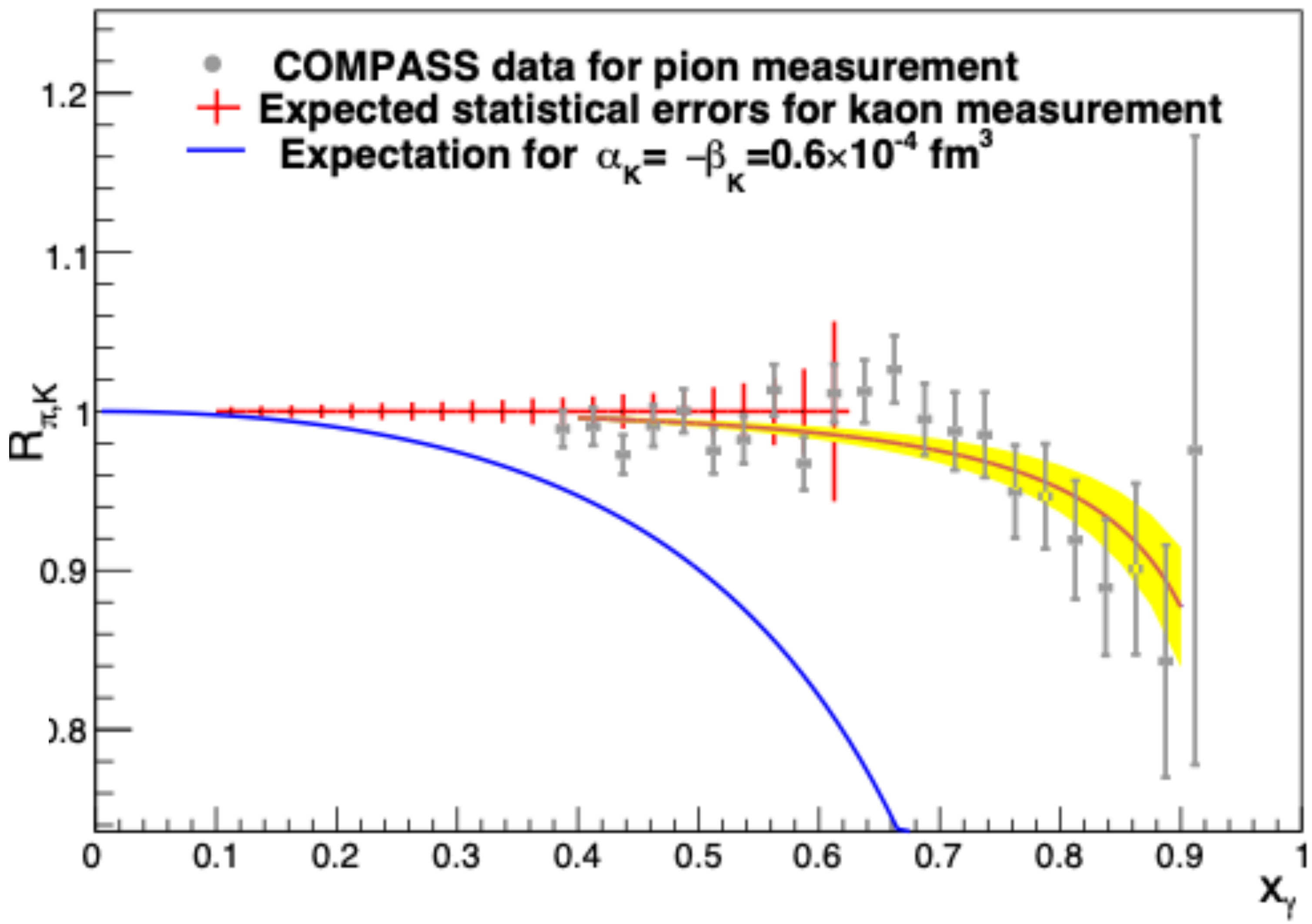
Higher Z for target?

Expectations

2-nd experimental problem: **π^0 - background**



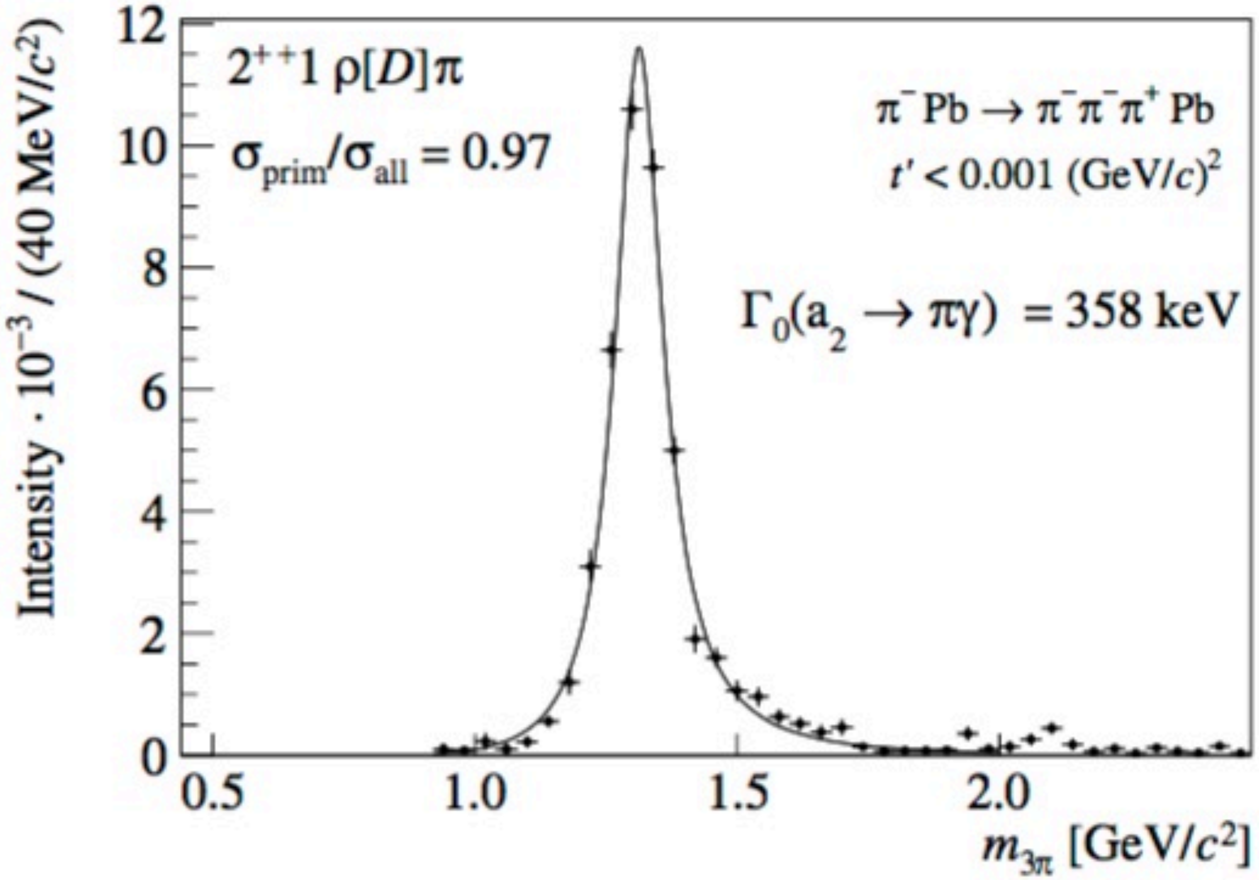


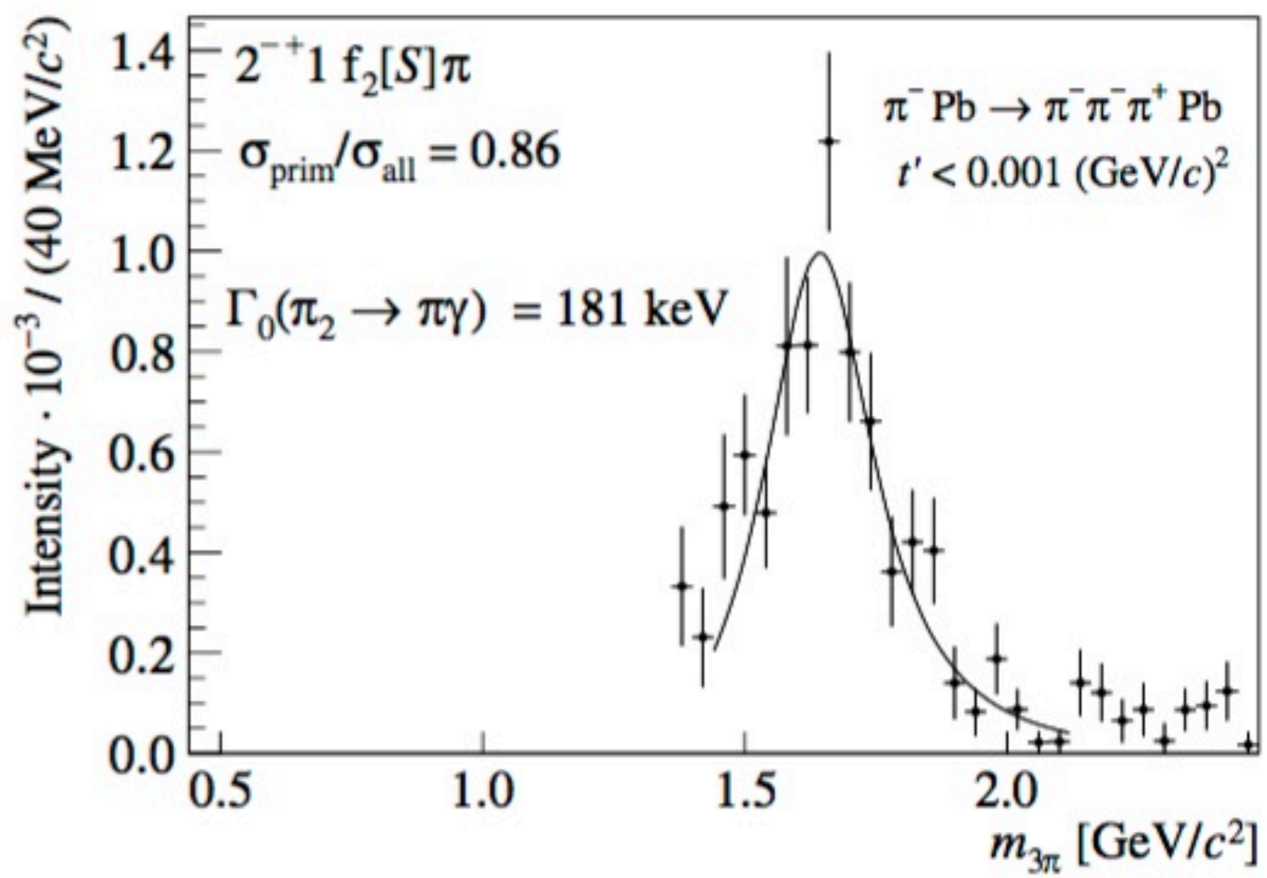


$$5\times10^{12}\ K^- \ \rightarrow\ 6\times10^5\ K\gamma\ events$$

$$\sigma_{\alpha_K\ stat} = 0.03\times10^{-4}\ fm^3$$

Radiative widths of mesons





	$a_2(1320)$	$\pi_2(1670)$
This measurement	$(358 \pm 6 \pm 42)$ keV	$(181 \pm 11 \pm 27)$ keV $\cdot$ $(0.56/\mathrm{BR}_{f_2\pi})$
SELEX [21]	$(284 \pm 25 \pm 25)$ keV	
S. Cihangir *et al.* [24]	(295 ± 60) keV	
E.N. May *et al.* [25]	(0.46 ± 0.11) MeV	
VMD model [1]	(375 ± 50) keV	
Relativ. Quark model [2]	324 keV	
Cov. Osc. Quark model [3]	235 keV	
Cov. Osc. Quark model [4]	237 keV	2 values: 335 keV and 521 keV

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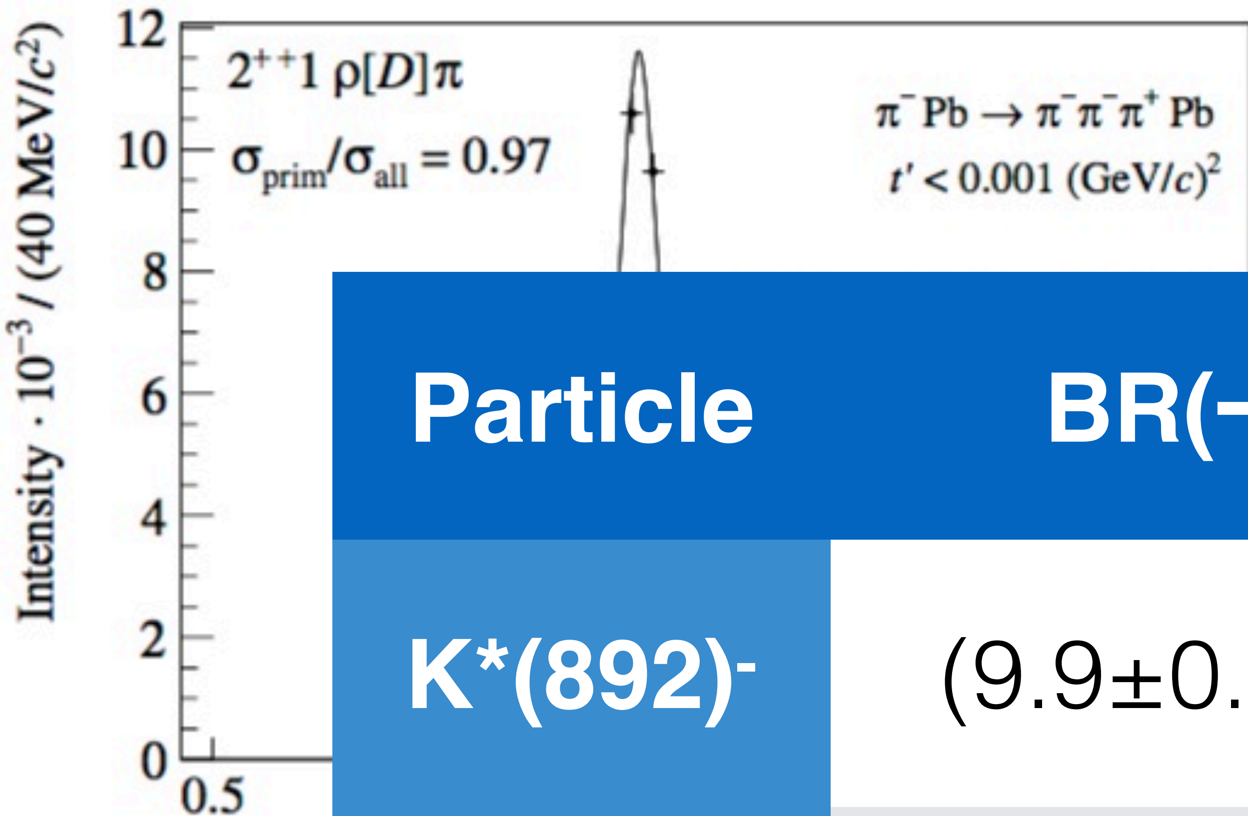
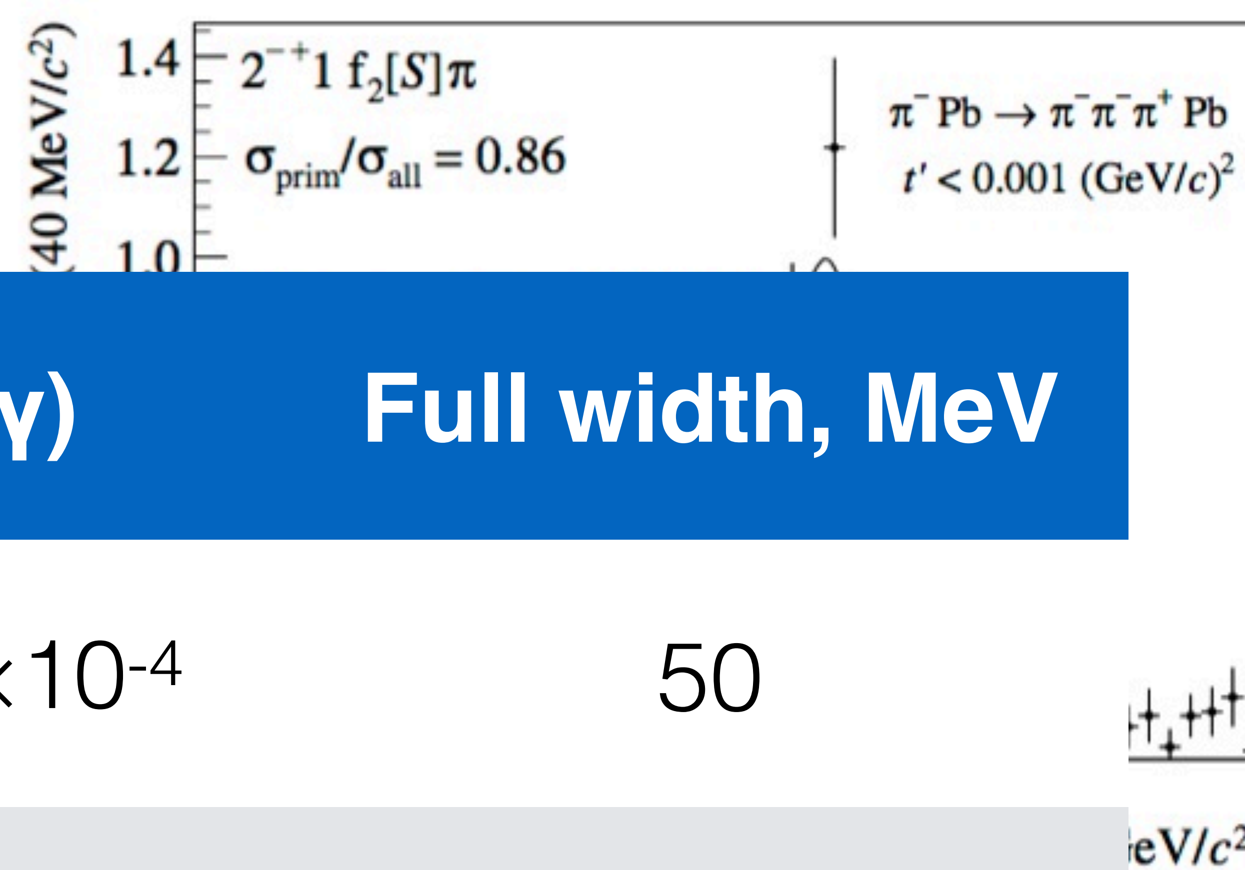
Radiative widths of mesons





Particle	BR(→Kγ)	Full width, MeV
$K^*(892)^-$	$(9.9\pm0.9)\times10^{-4}$	50
$K_2^*(1430)^-$	$(2.4\pm0.5)\times10^{-3}$	100
…		

AMBER could try to improve present result!

This		
SELE		
S. Ci		
E.N.		
VMD model [1]	(375 ± 50) keV	
Relativ. Quark model [2]	324 keV	
Cov. Osc. Quark model [3]	235 keV	
Cov. Osc. Quark model [4]	237 keV	2 values: 335 keV and 521 keV

Chiral anomaly and Primakoff cross sections near threshold

COMPASS → AMBER (Apparatus for Meson and Baryon Experimental Research)

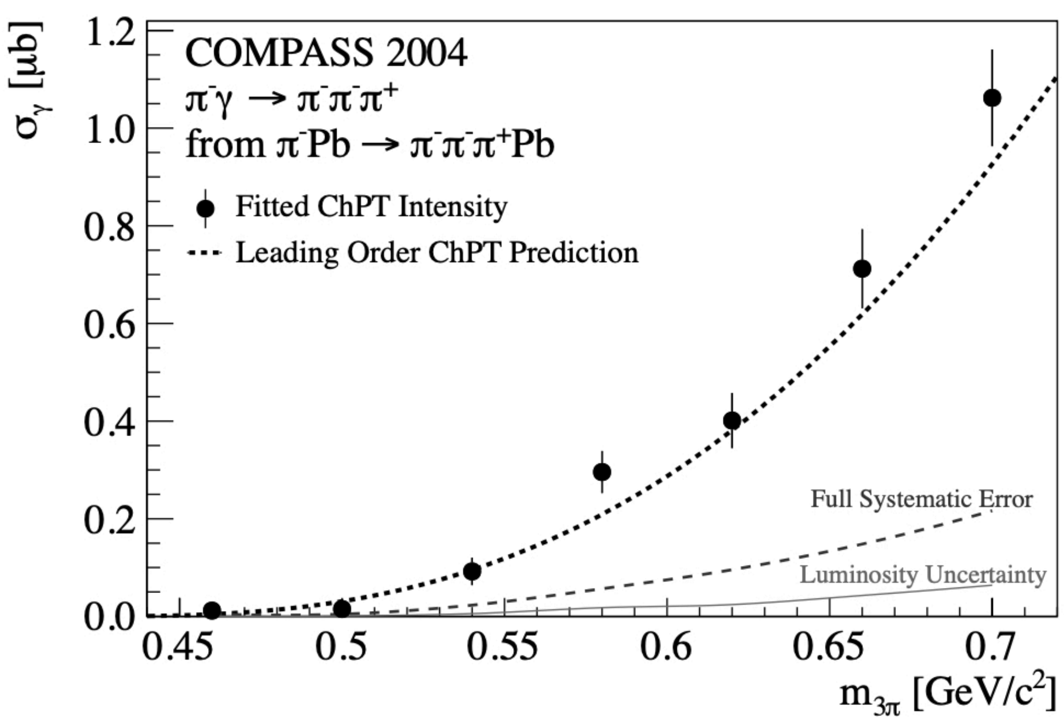
Chiral anomaly, $F_{3\pi}$ constant

$$\pi^- N \to \pi^- \pi^0 N$$

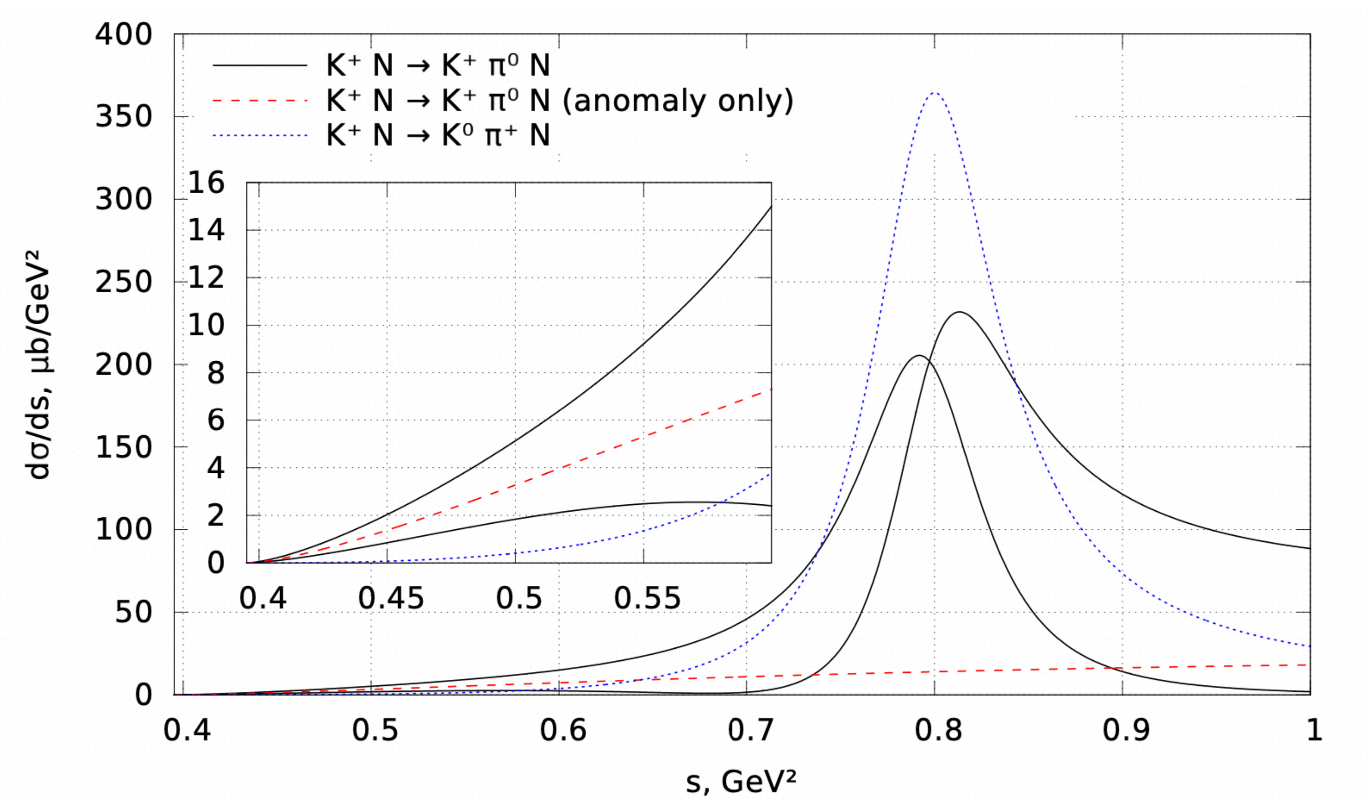
$$\pi^- N \to \pi^- \pi^0 \pi^0 N$$

$$\pi^- N \to \pi^- \pi^+ \pi^- N$$

$$\pi^- N \to \eta \pi^- N$$



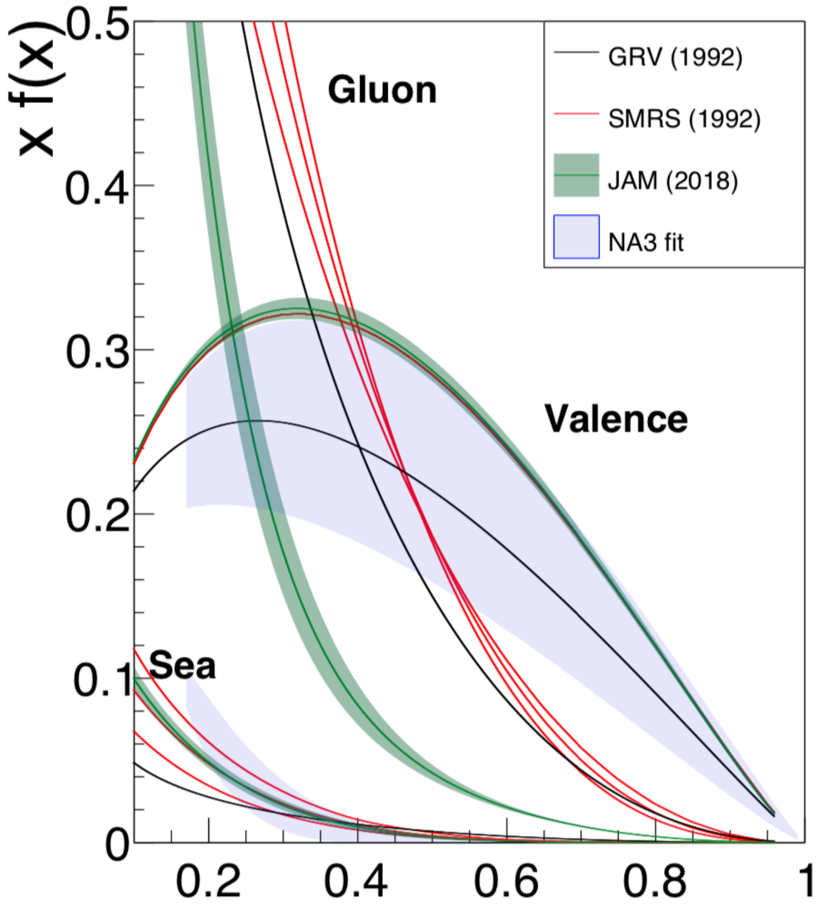
$$K^\pm N \to K^\pm \pi^0 N$$



$$K^\pm N \to K^0 \pi^\pm N$$

...

Meson PDFs

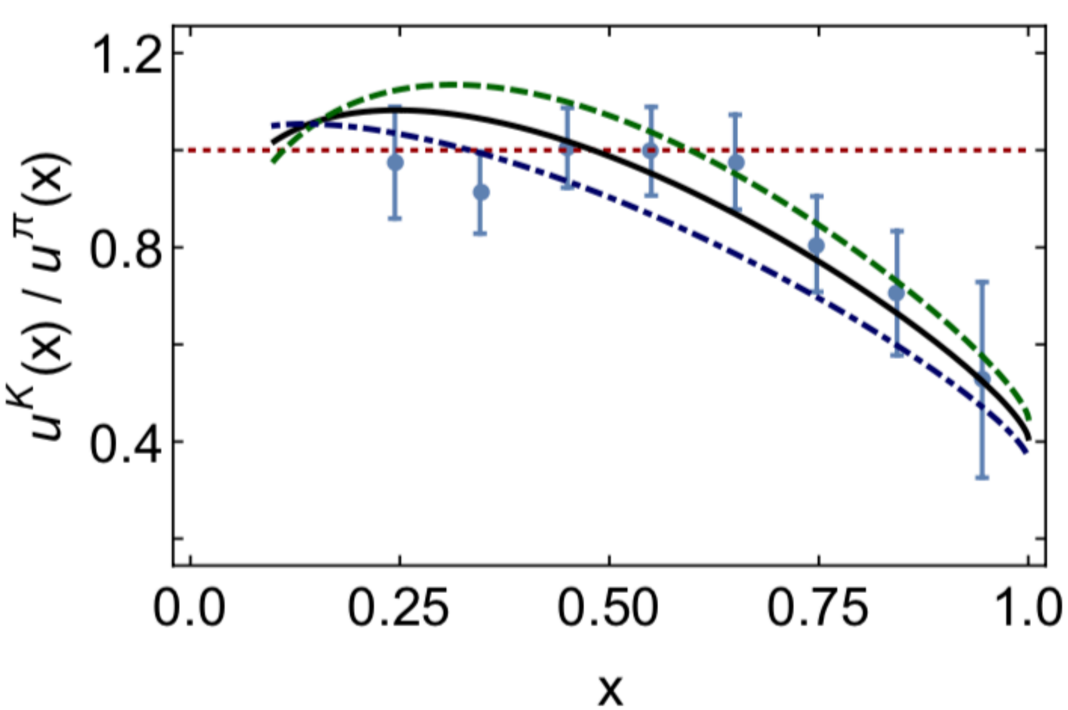


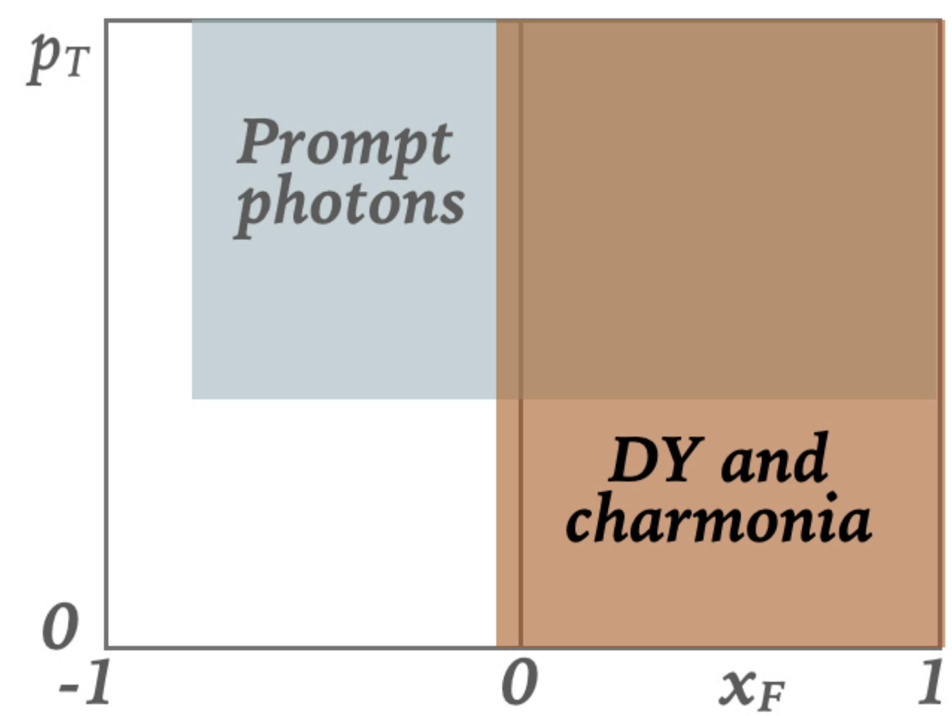
GRV (1992) *set of pion PDFs: Drell-Yan, charmonia and prompt photon production experiments (**E615, NA10, WA70, NA24**).*

SMRS (1992)*: basically the same old data.*

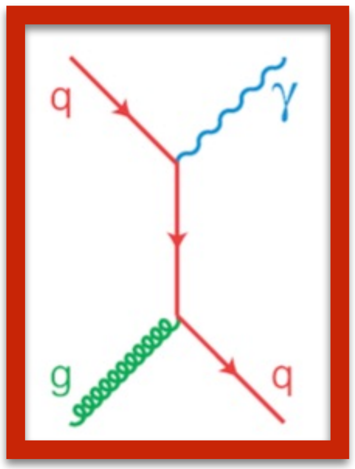
JAM (2018) *set: production of leading neutrons in DIS at HERA (**ZEUS, H1**).*

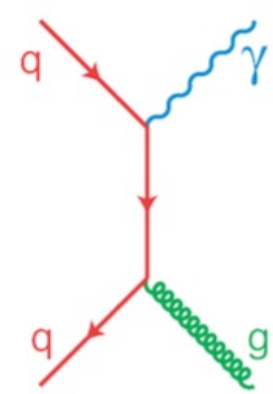
Kaon PDFs*: just 700 kaon-induced DY events at **NA3***





Prompt-photon production



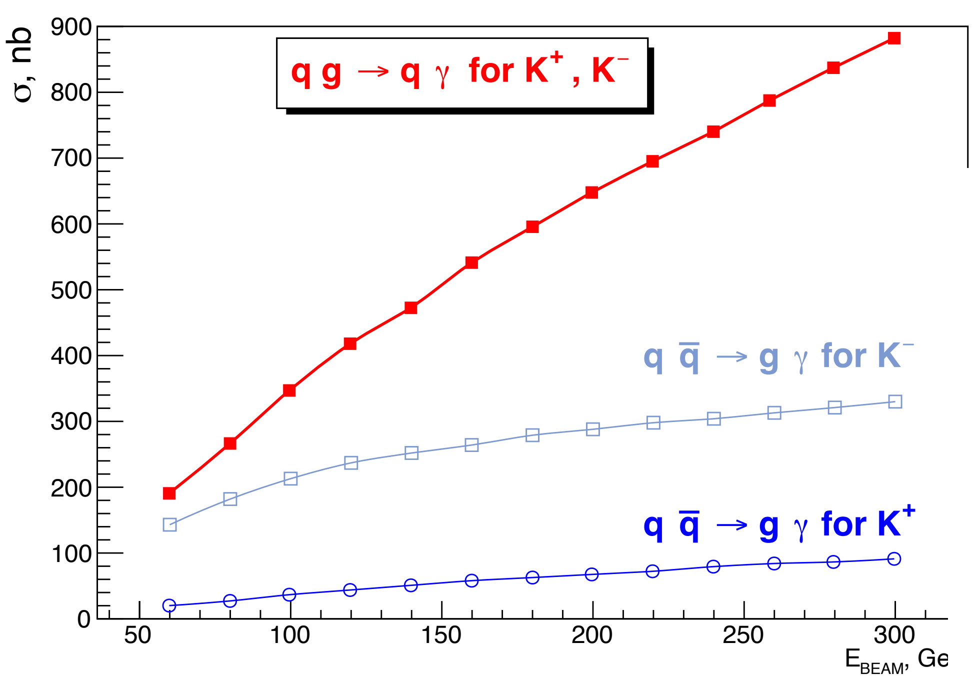


$$data \rightarrow \sigma_{inclusive\ \gamma}(p_T, x_F) \rightarrow g_K(x_K)$$

- **separation of quark/gluon contribution in kaon (K+ vs K–)**
- **pion as a reference!**

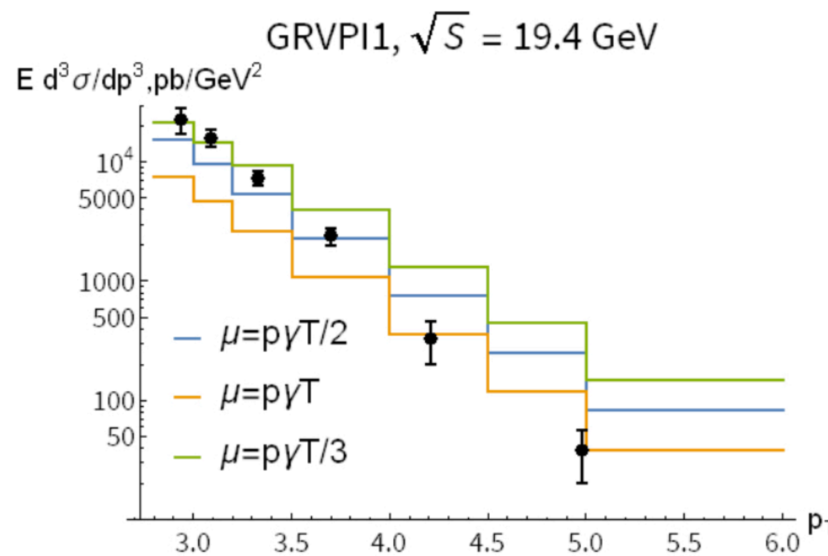
$$x_{g\ min} \approx x^2_{T\ min} = \frac{4p^2_{T\ min}}{s}$$

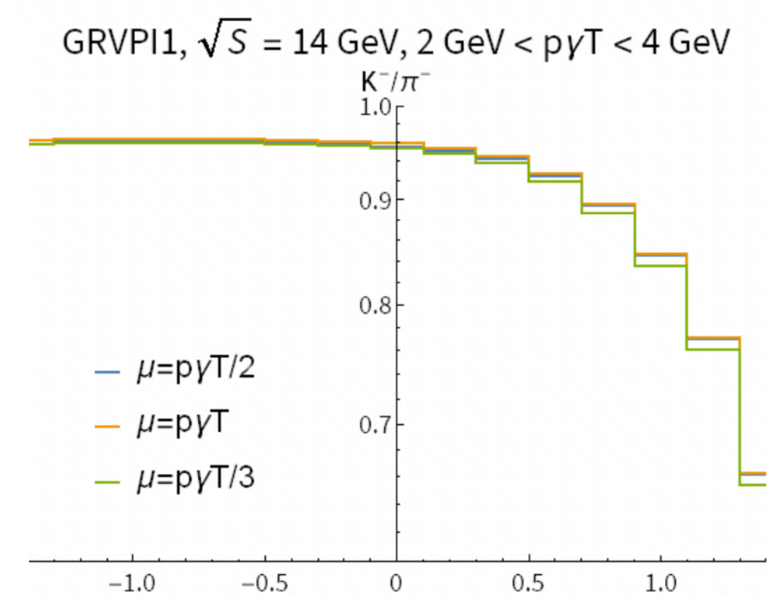
For $p_{T\ min} = 3\ GeV/c$ and $P_{beam} = 190\ GeV$: $x_{g\ min} = 0.1$



Observables:

$$\sigma_K, \sigma_{K+} - \sigma_{K-}, \sigma_K/\sigma_\pi, (\sigma_{K+} - \sigma_{K-})/\sigma_\pi, \ldots$$





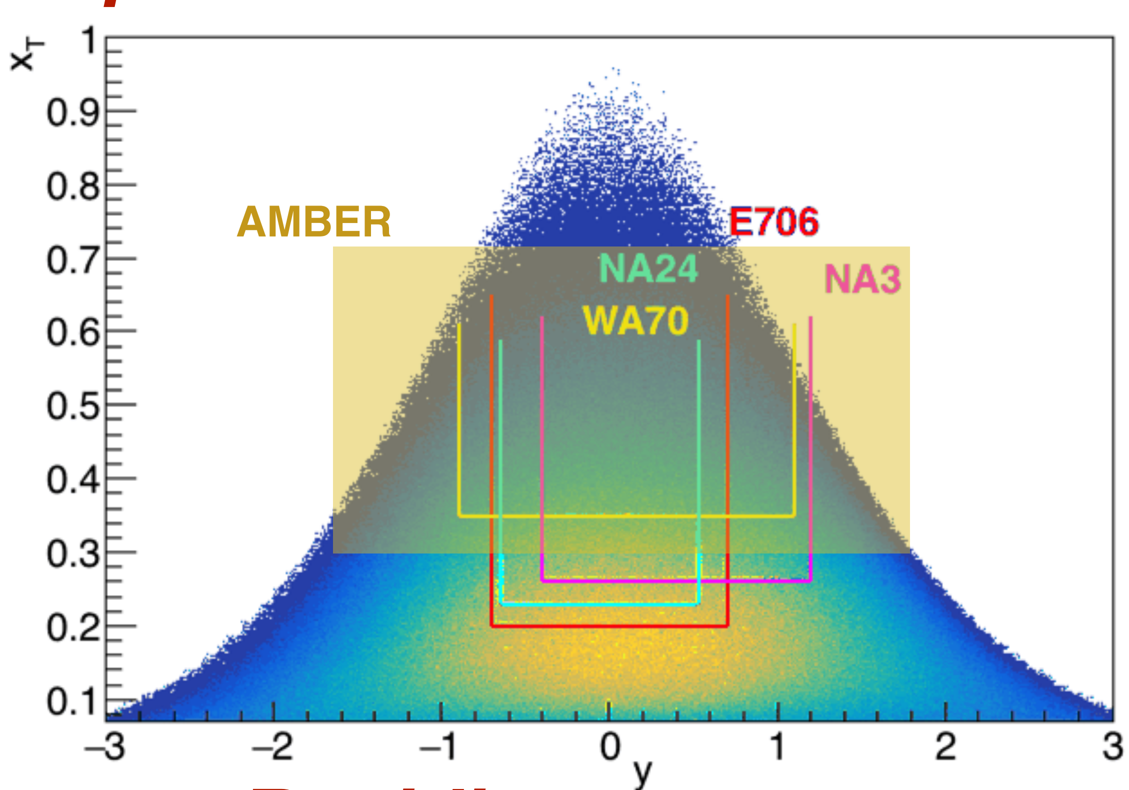
courtesy of A. Shipilova (Samara Univ.)

Previous measurements at low √s

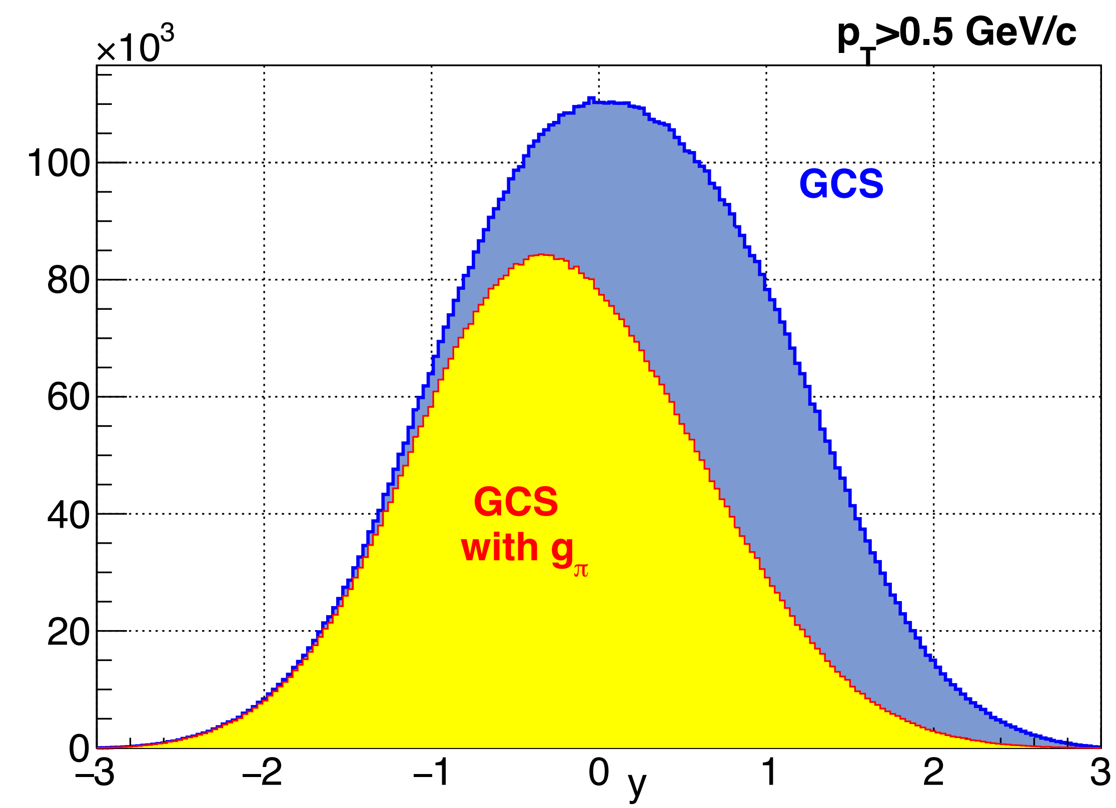
Experiment	Beam and target	$\sqrt{s}$, GeV	y range	x_T range
E95 (1979)	p; Be	19.4, 23.75	-0.7 – 0.7	0.15 – 0.45
E629 (1983)	p, π^+; C	19.4	-0.75 – 0.2	0.22 – 0.52
NA3 (1986)	p, π^+, π^-; C	19.4	-0.4 – 1.2	0.26 – 0.62
NA24 (1987)	p, π^+, π^-; p	23.75	-0.65 – 0.52	0.23 – 0.59
WA70 (1988)	p, π^+, π^-; 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 measurements

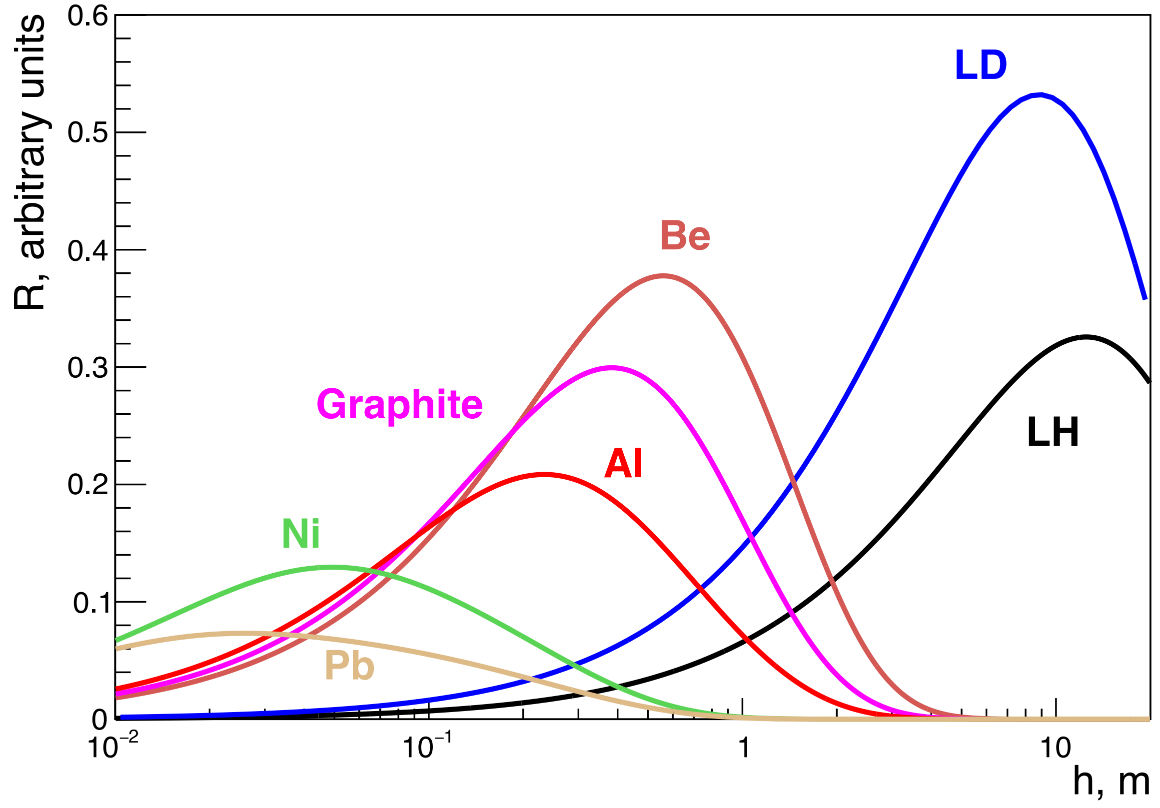
$x_T = 2p_T/\sqrt{s}$



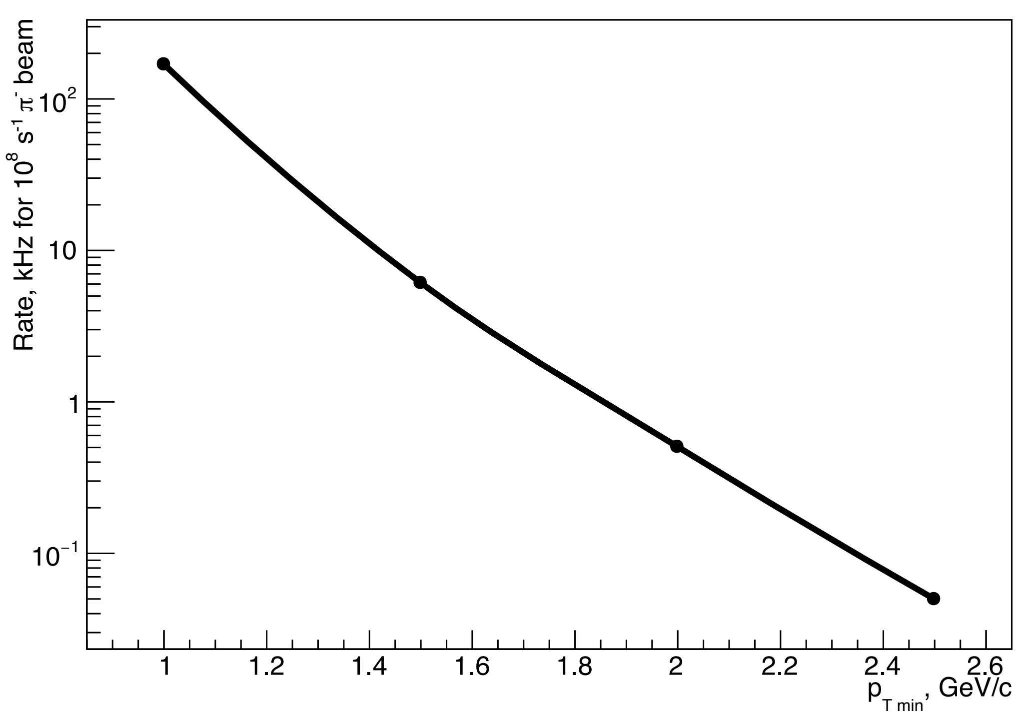
Rapidity

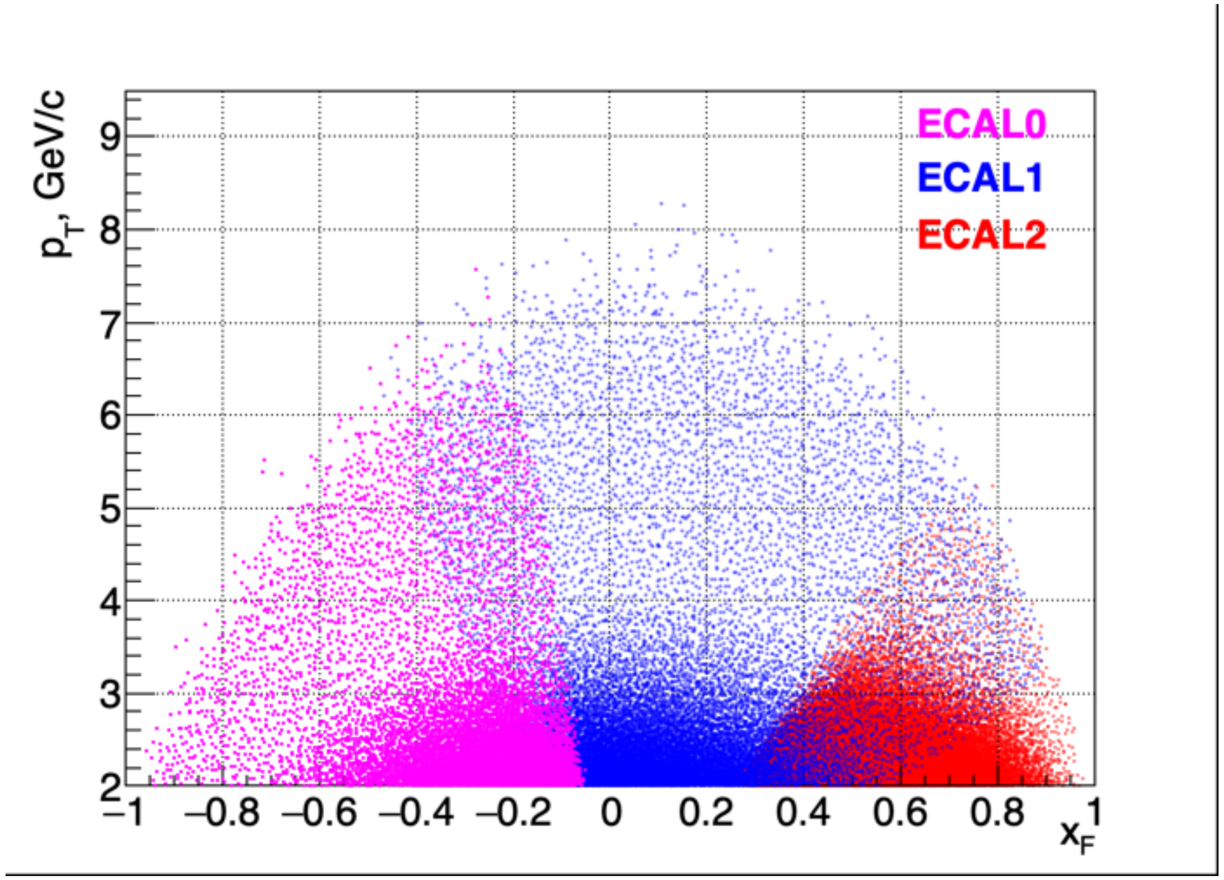


Photons at AMBER

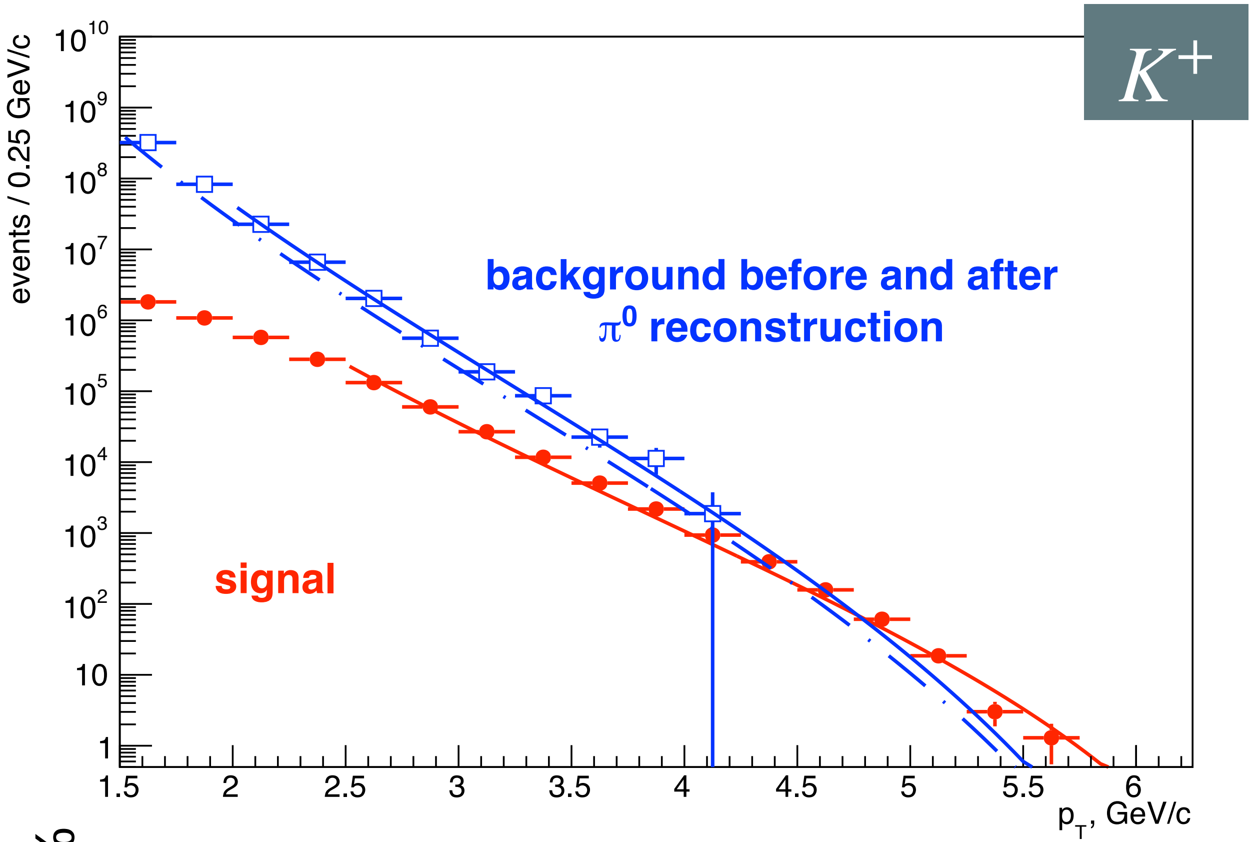


Target: 40 cm of graphite

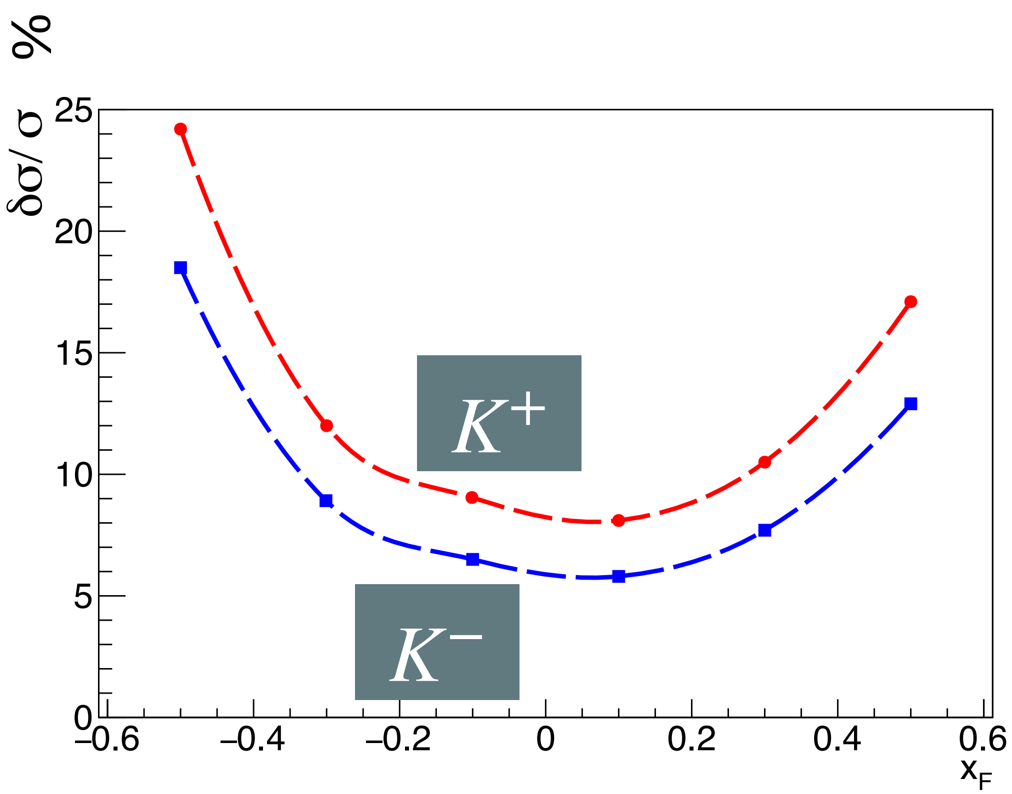


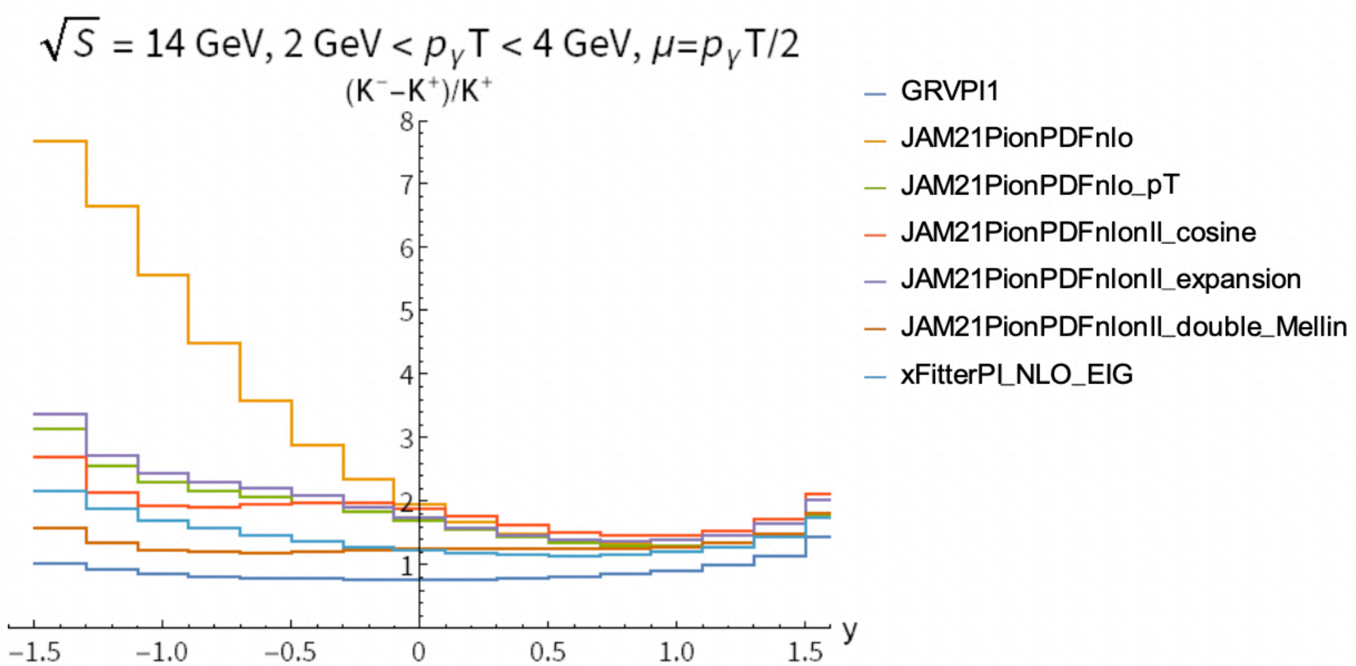


Expectations



Assuming the same gluon content for kaon as for pion





courtesy of A. Shipilova (Samara Univ.)

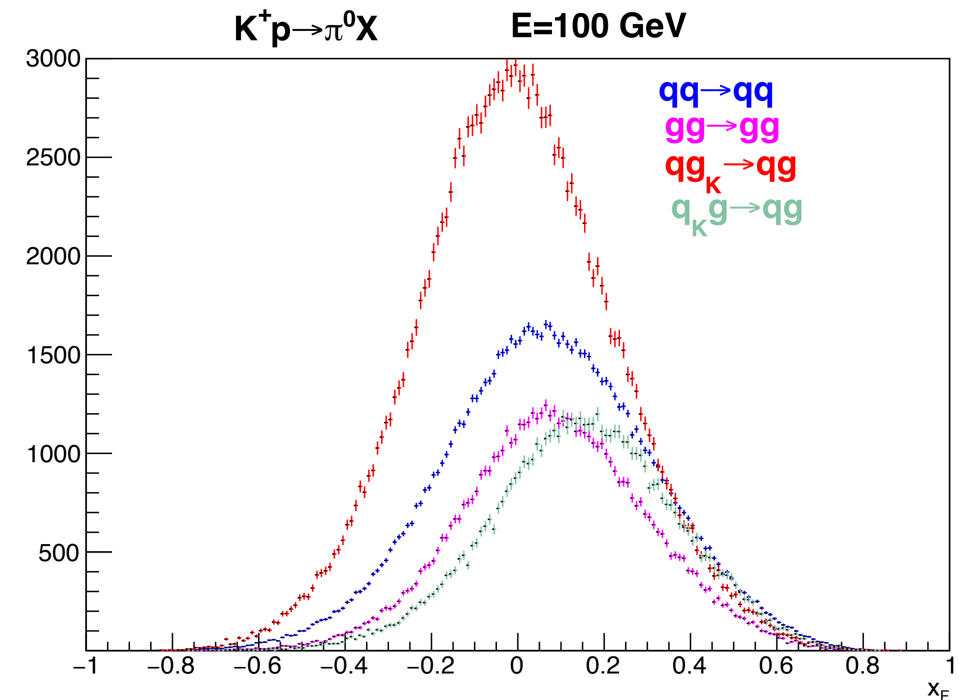
Kaon-induced high-pT π^0 production

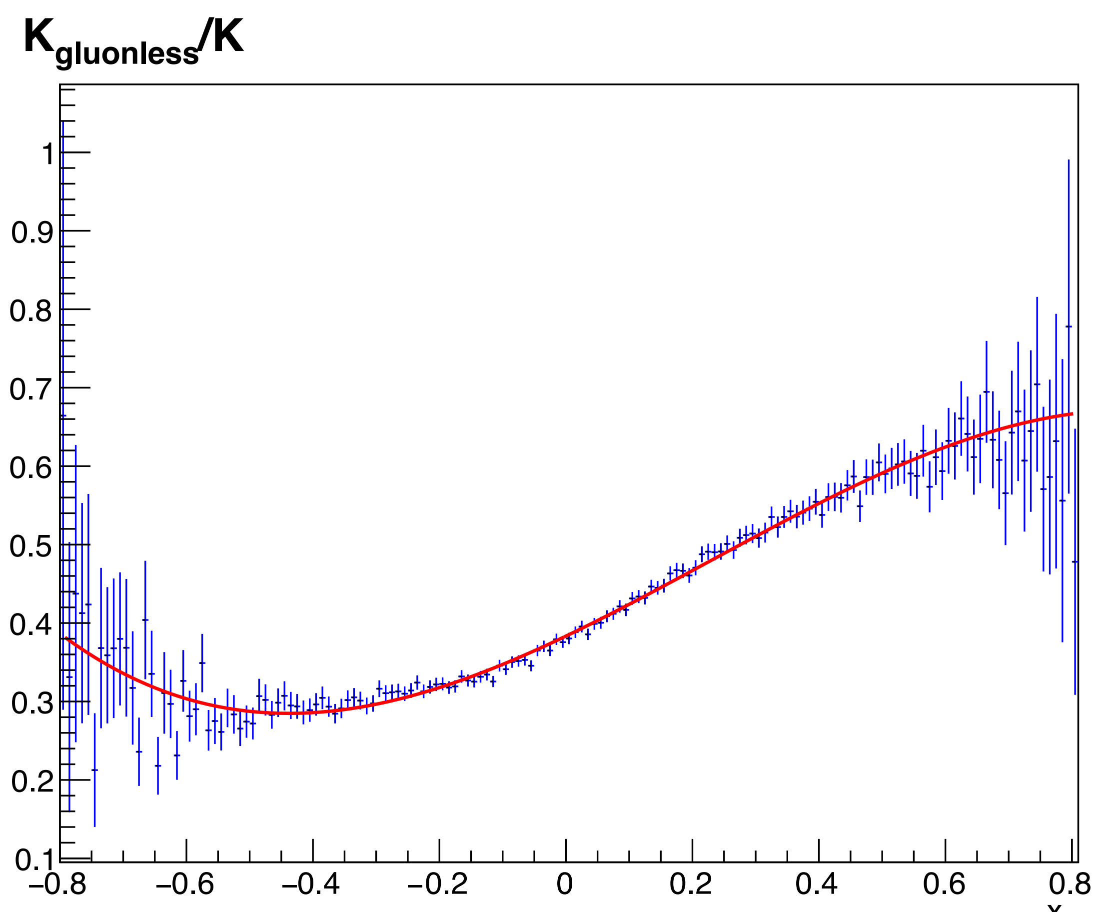
LO

qg→qg	51 %
gg→gg	33 %
qq→qq	15 %
qqbar	1 %
qqbar	
gg→qq	

p_T>2 GeV/c

p_T>2 GeV/c





Beam requirements

BEAM	Primakoff	High-pT photons
Beam particle	K-	K+/- , π+/-
Beam momentum	>40 GeV	190 GeV
dP/P	1 %	not critical
Beam intensity	~5e6 kaons s^{-1}	~5e6 kaons s^{-1}
Beam spot on target	~5x5 mm	~5x5 mm
Beam time request	1 year	1 year
Particle ID by CEDAR	**pion suppression ~10^4**	**pion suppression ~10^3**
TARGET	> Ni ~0.5 X_0	~ C ~ 2 X_0

Summary

- AMBER as successor of COMPASS with its three calorimeters is a unique facility for the study of processes with photons in the final state.
- AMBER can perform sophisticated test of low-energy QCD models via kaon-induced Primakoff reactions:
  - first measurement of kaon polarizability
  - update the estimation of radiation width of kaon states
  - chiral anomaly study
  - investigation of Primakoff cross sections dynamics near threshold
- Measurement of the kaon-induced high-pT prompt photon and π^0 production cross section can provide an important information about gluon content in kaon.