Gluon structure of hadrons with prompt photons at COMPASS++/AMBER and NICA SPD

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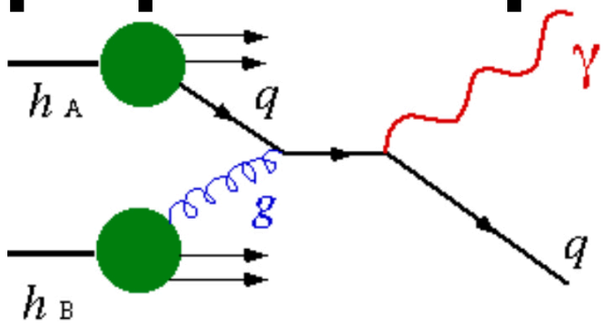
CERN

Ways to access gluon structure of hadron at low energies

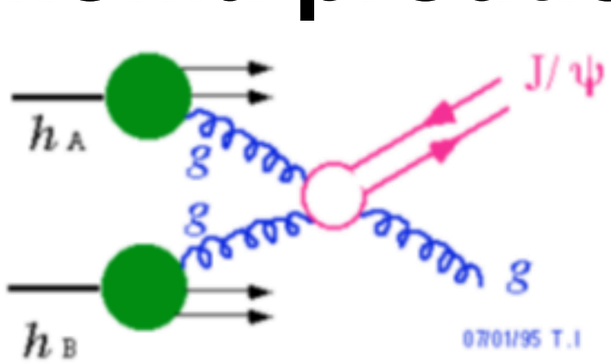
- **prompt-photon production**



The most direct way

Hard background

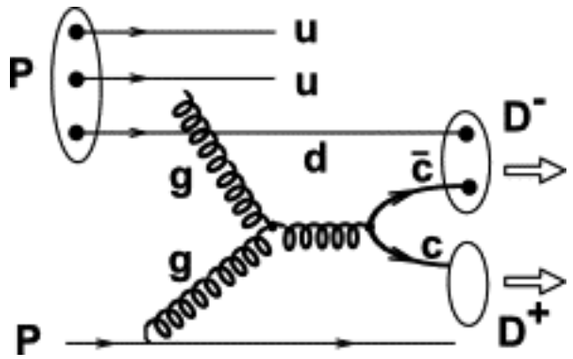
- **charmonia production**



Nice signal

Model-dependent treatment

- **open-charm production**



Rather simple treatment

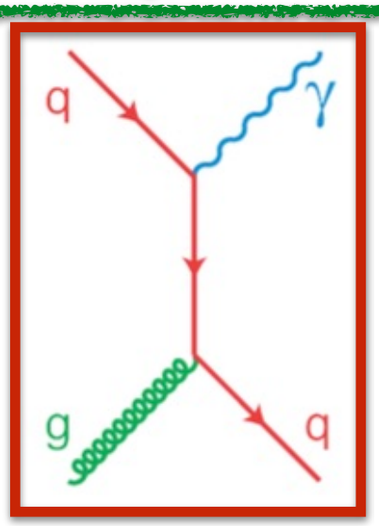
Problematic signal

Production of photons in hadron collisions

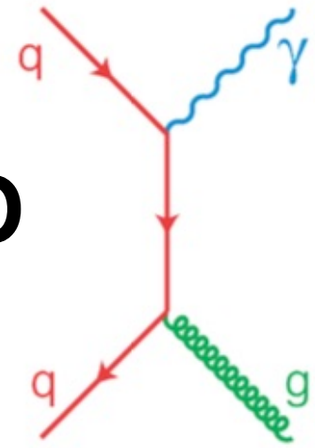
Photons in A+A collisions

- **Direct Photons**
  - **hard**
    - **prompt**
    - **fragmentation**
  - **Preequilibrium photons**
  - **thermal**
    - **QGP**
    - **Hadron gas**
  - **hard+thermal**
    - **jet-γ-conv.**
    - **Medium induced γ bremsstr.**
- **Decay Photons**

collective effects



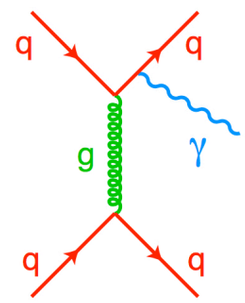
LO



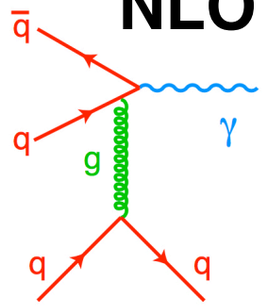
$$\hat{\sigma}_{qg\to q\gamma} = \frac{\pi\alpha_s\alpha}{3\hat{s}}\left(\frac{\hat{u}}{\hat{s}} + \frac{\hat{s}}{\hat{u}}\right)$$

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

NLO



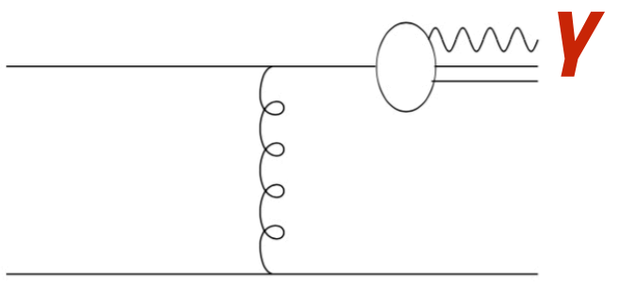
Bremsstrahlung

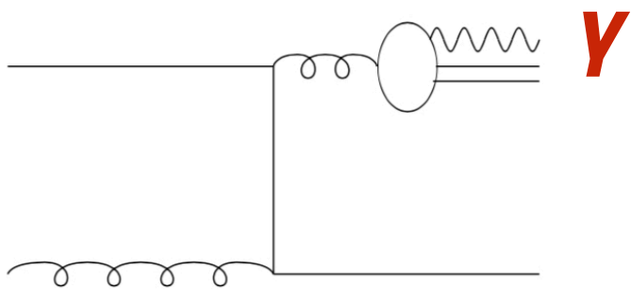


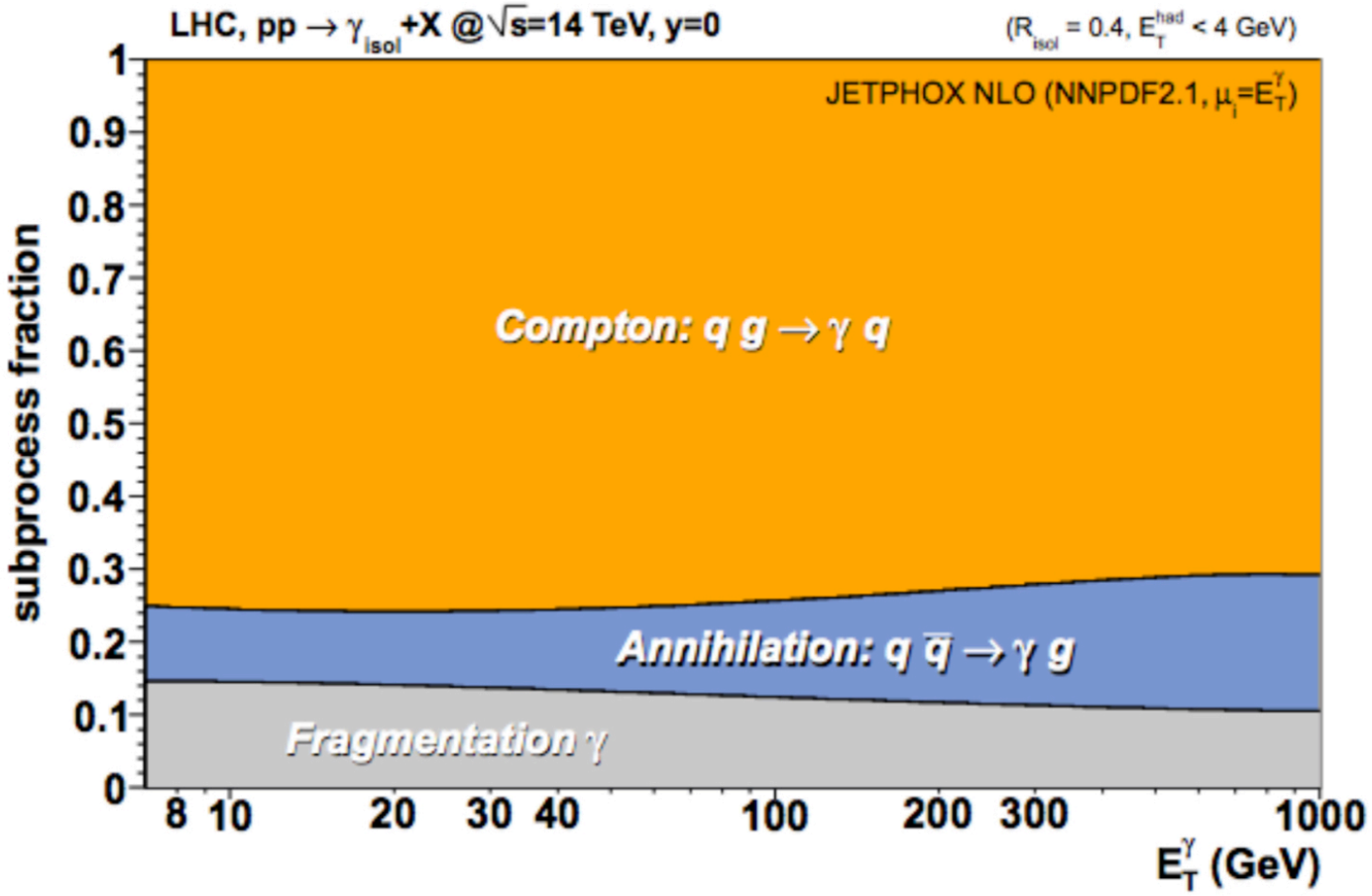
annihilation with scattering

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

Fragmentation photons







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

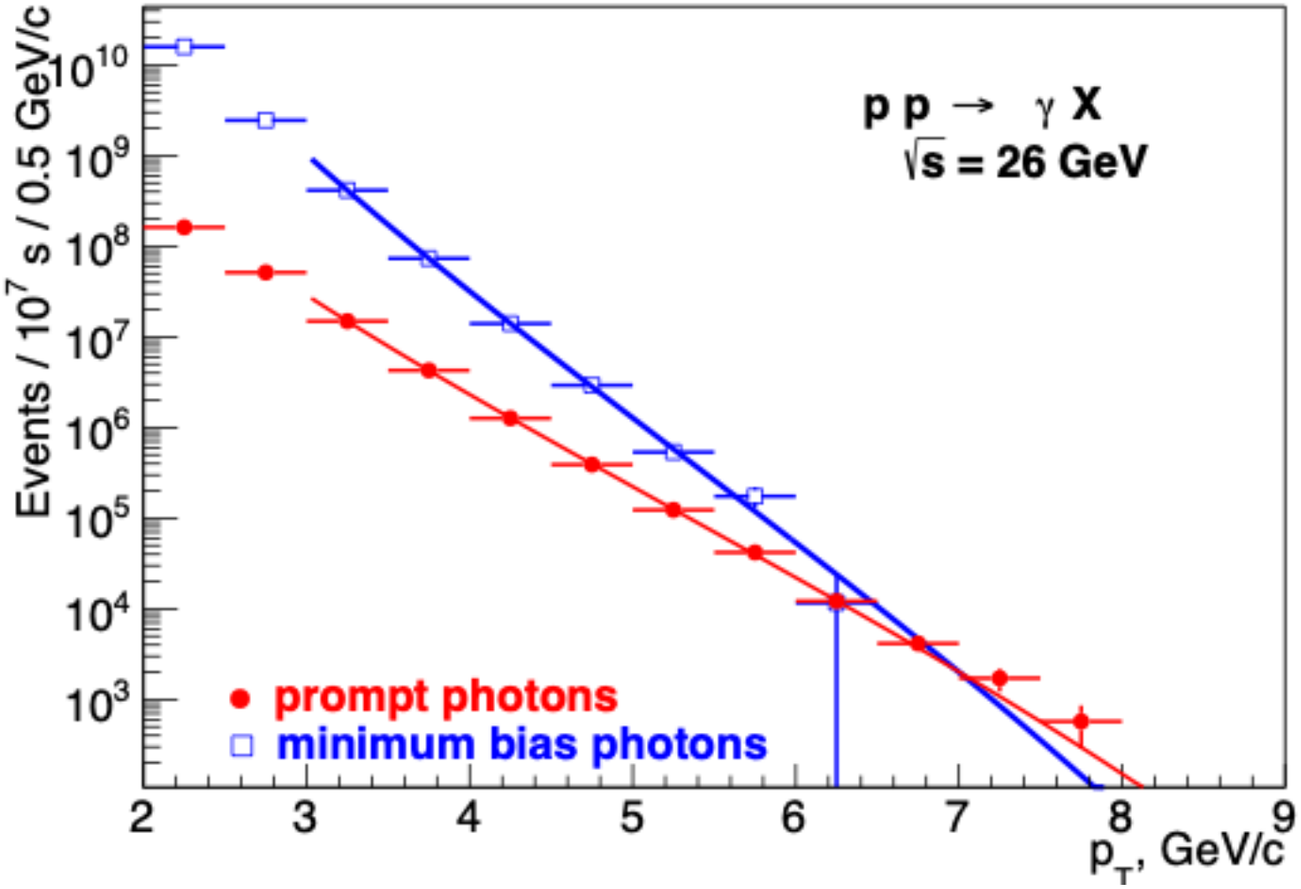
It can be calculated in LO and NLO

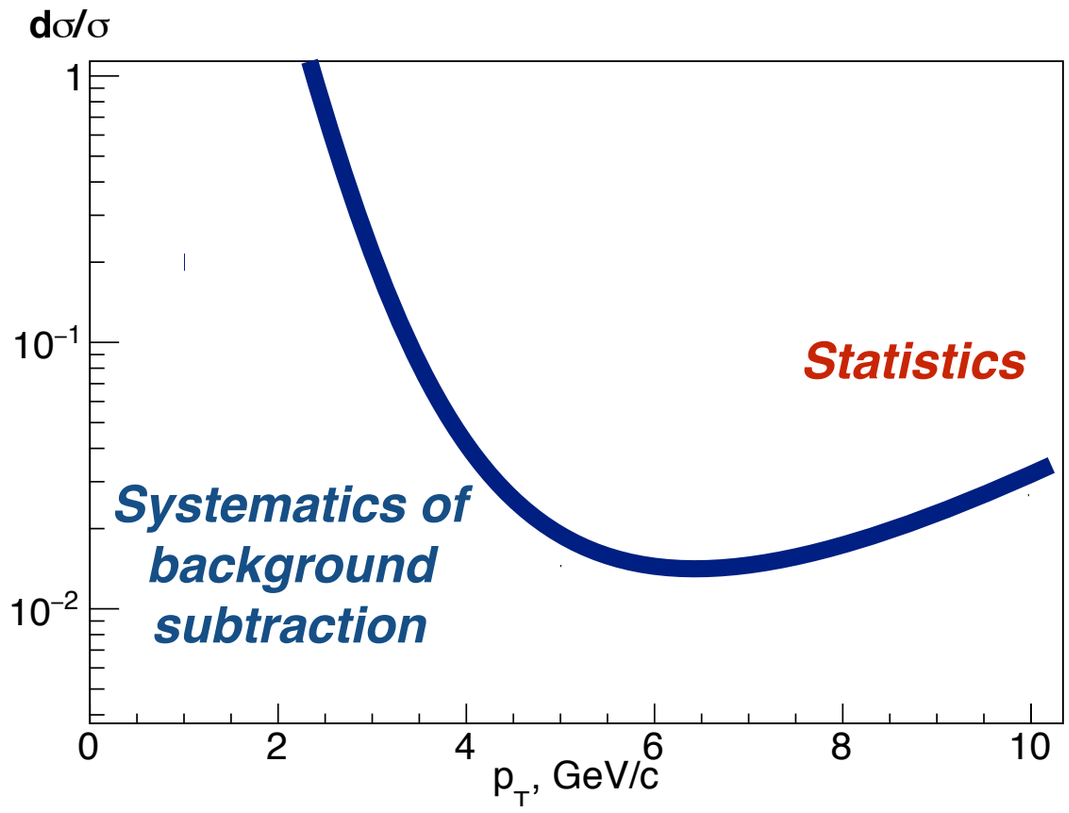
Decay photons

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

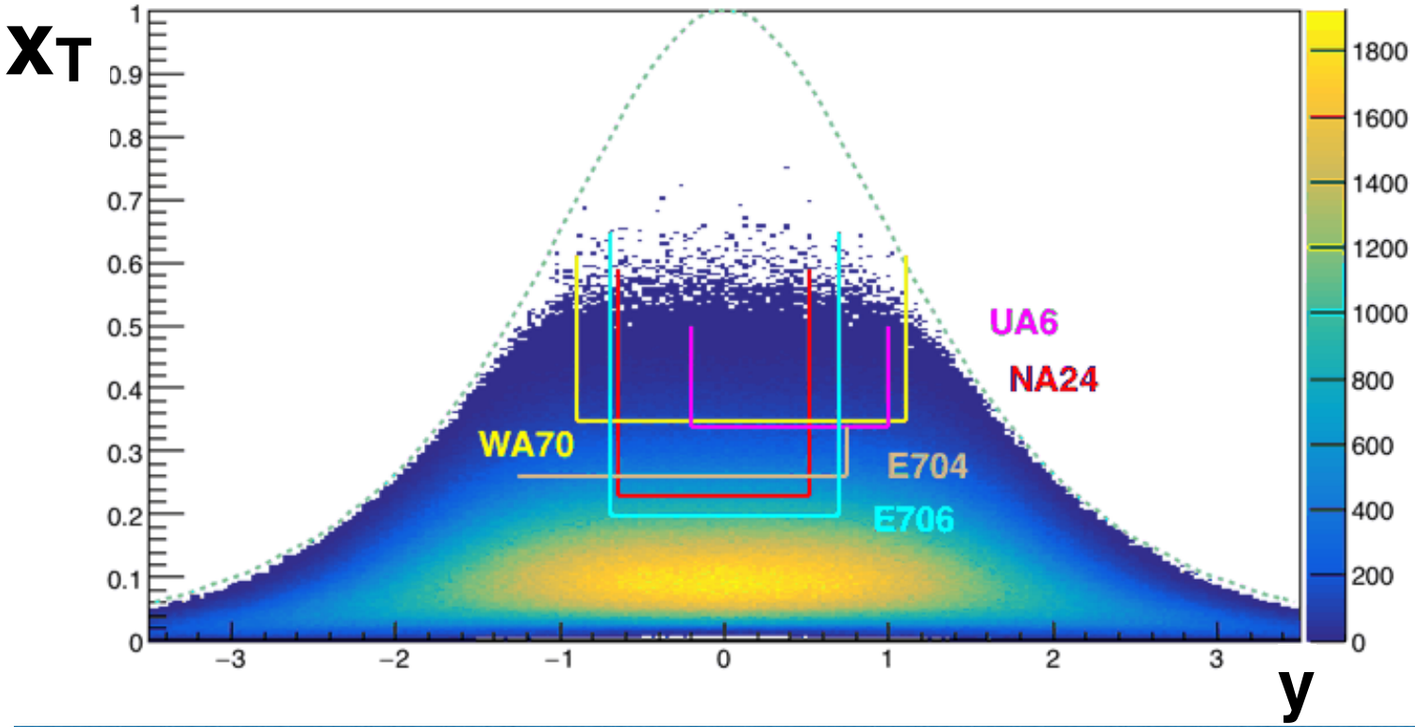




Experiments with prompt photons at low energies

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↑	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

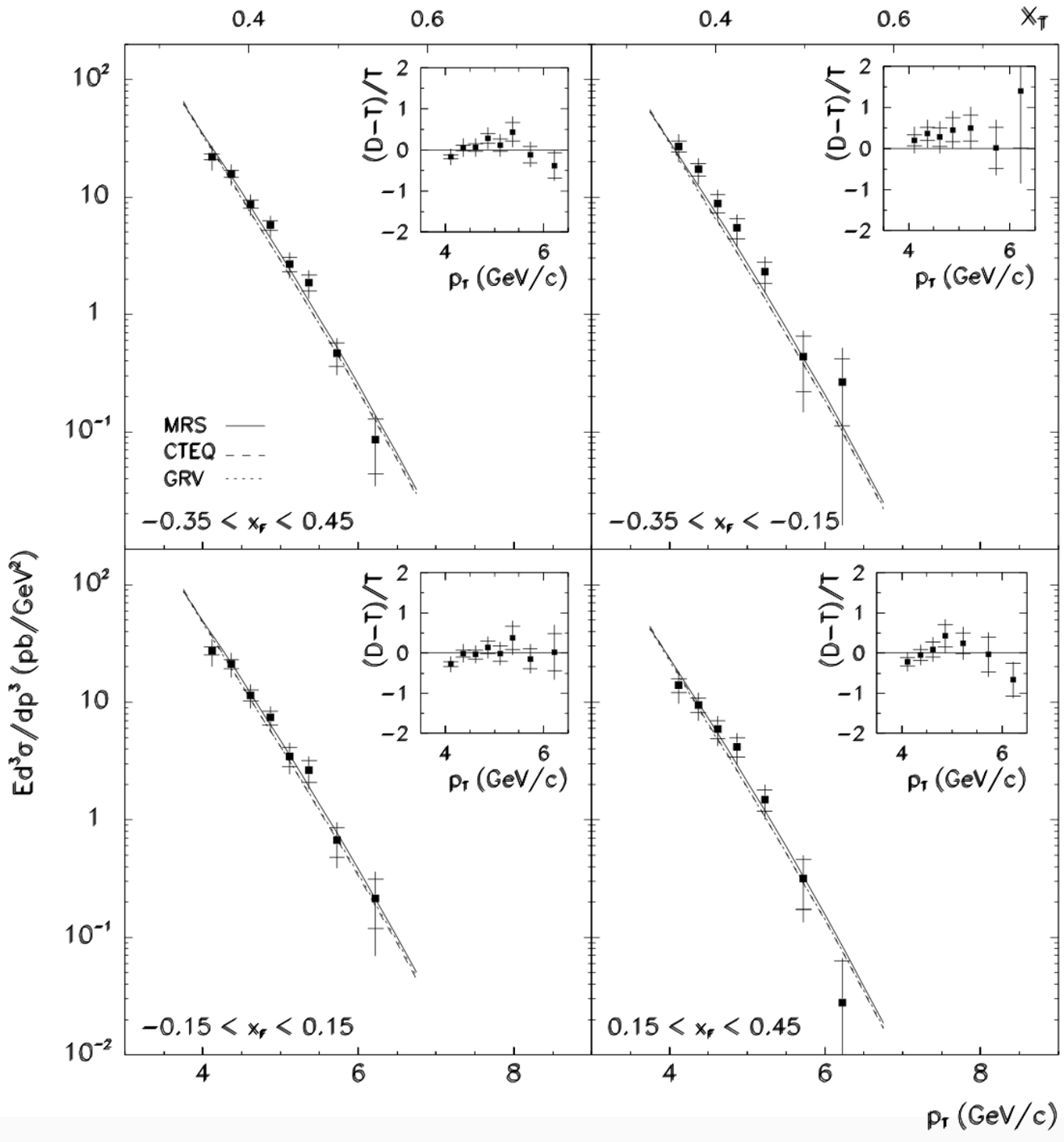


$$x_T = \frac{2p_T}{\sqrt{s}}$$

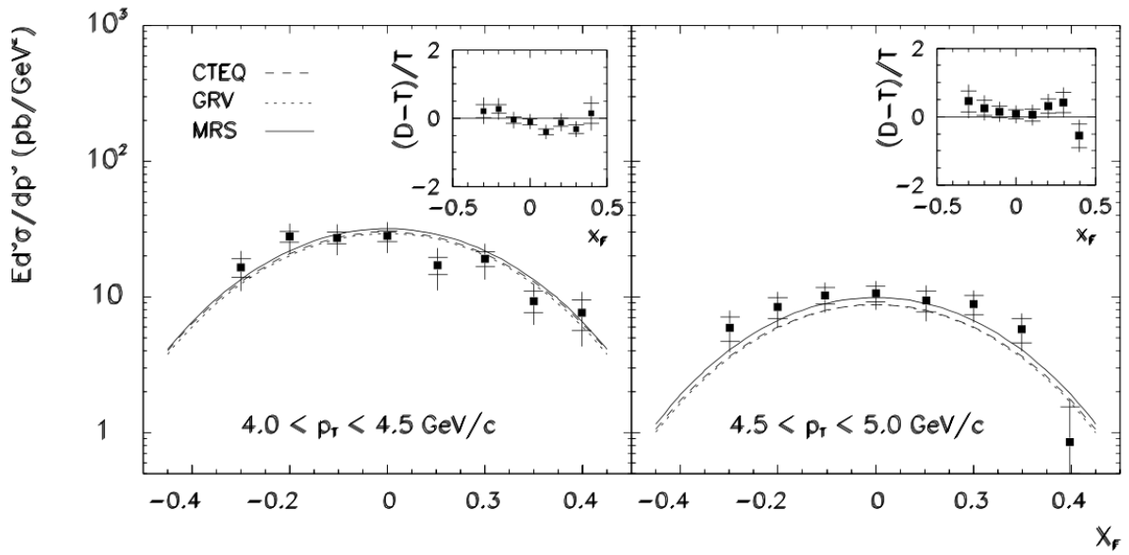
COMPASS++/AMBER	$K^{\pm}, \pi^{\pm}$	13.7 GeV	2025+
NICA SPD	p↑, d↑	up to 27 GeV	2025+

New projects

Previous results: p-p



WA70



COMPASS++/AMBER

2022

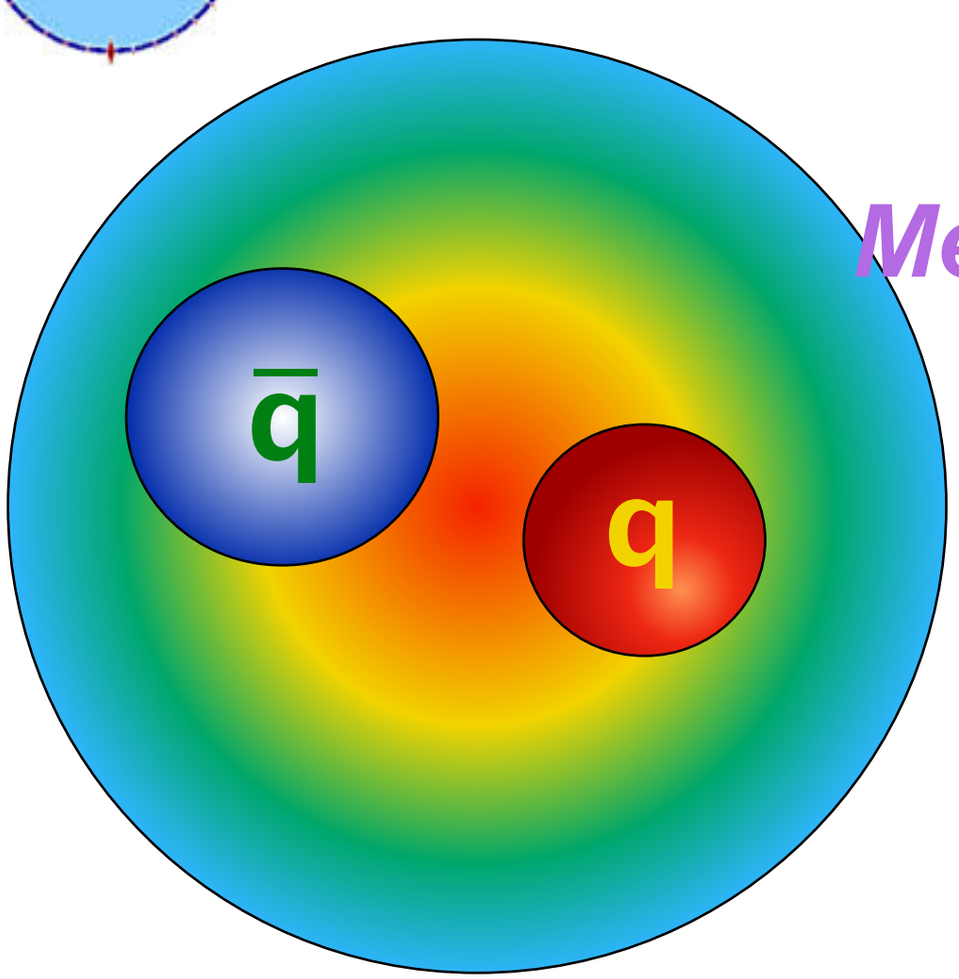
https://nqf-m2.web.cern.ch

LS2

LS3

COMPASS

AMBER — Apparatus for Meson and Baryon Experimental Research



Meson as a complex QCD system

Emergence of hadronic mass

Partonic structure

Drell-Yan

π K

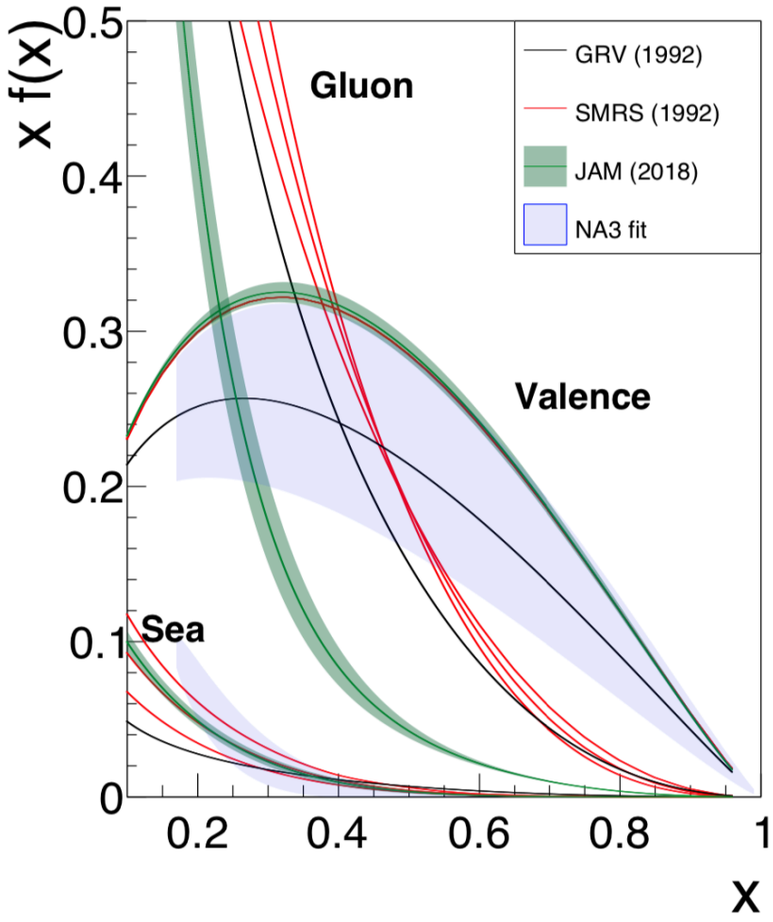
Charmonia

π K

Prompt photons

π K

Meson PDFs

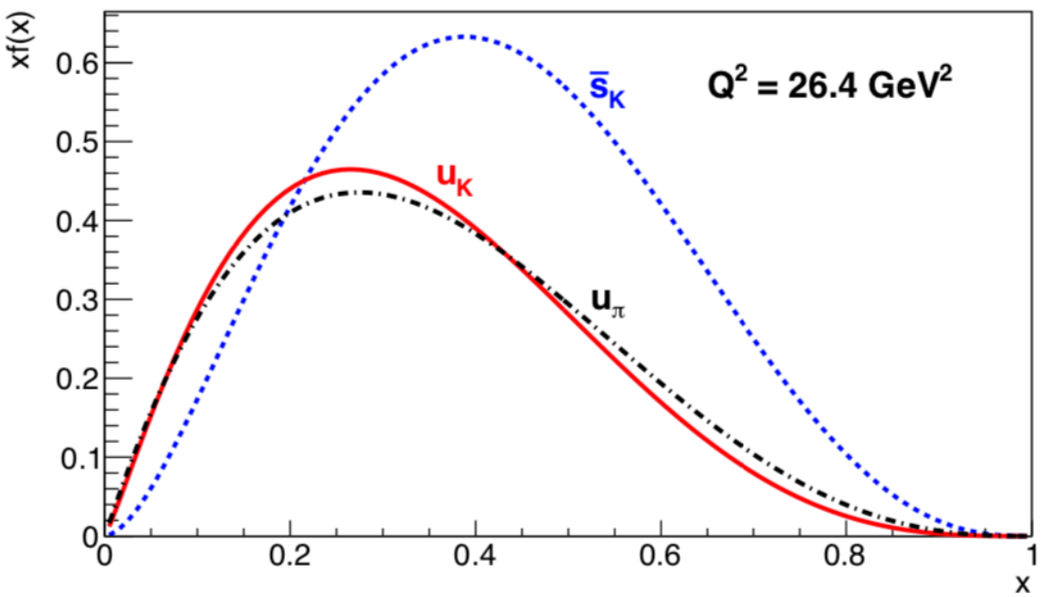


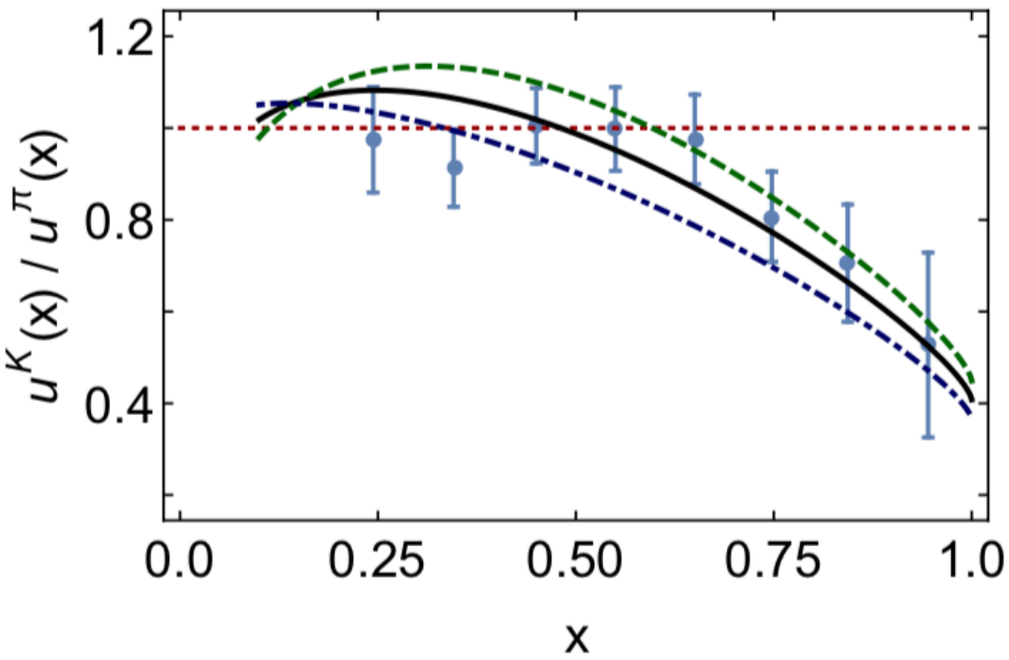
GRV (1992) *set of pion PDFs: Drell-Yan, charmonia and prompt photon production experiments (**E615, NA10, WA70, NA24**).*

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

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

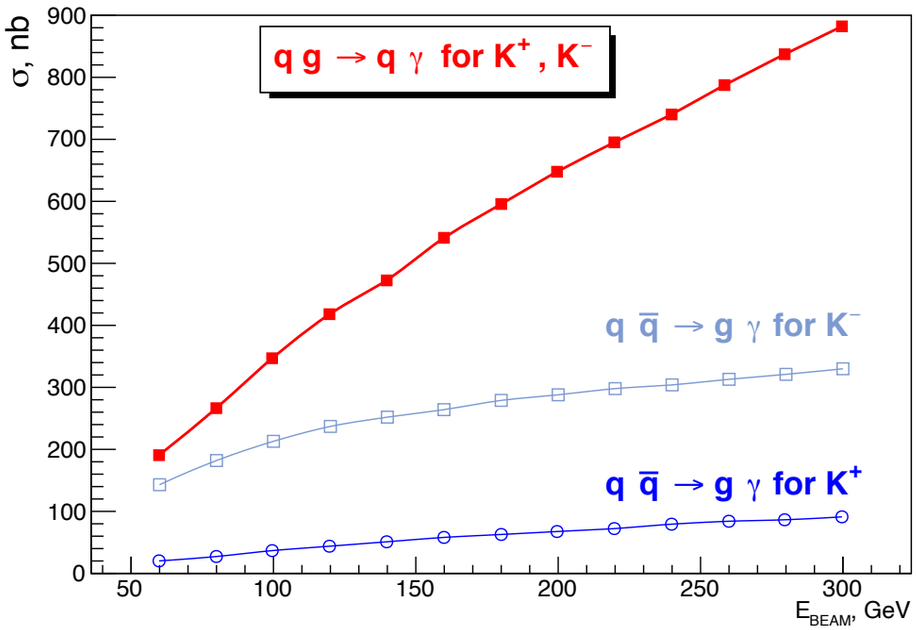
Kaon PDFs*: just 700 kaon-induced DY events at **NA3***



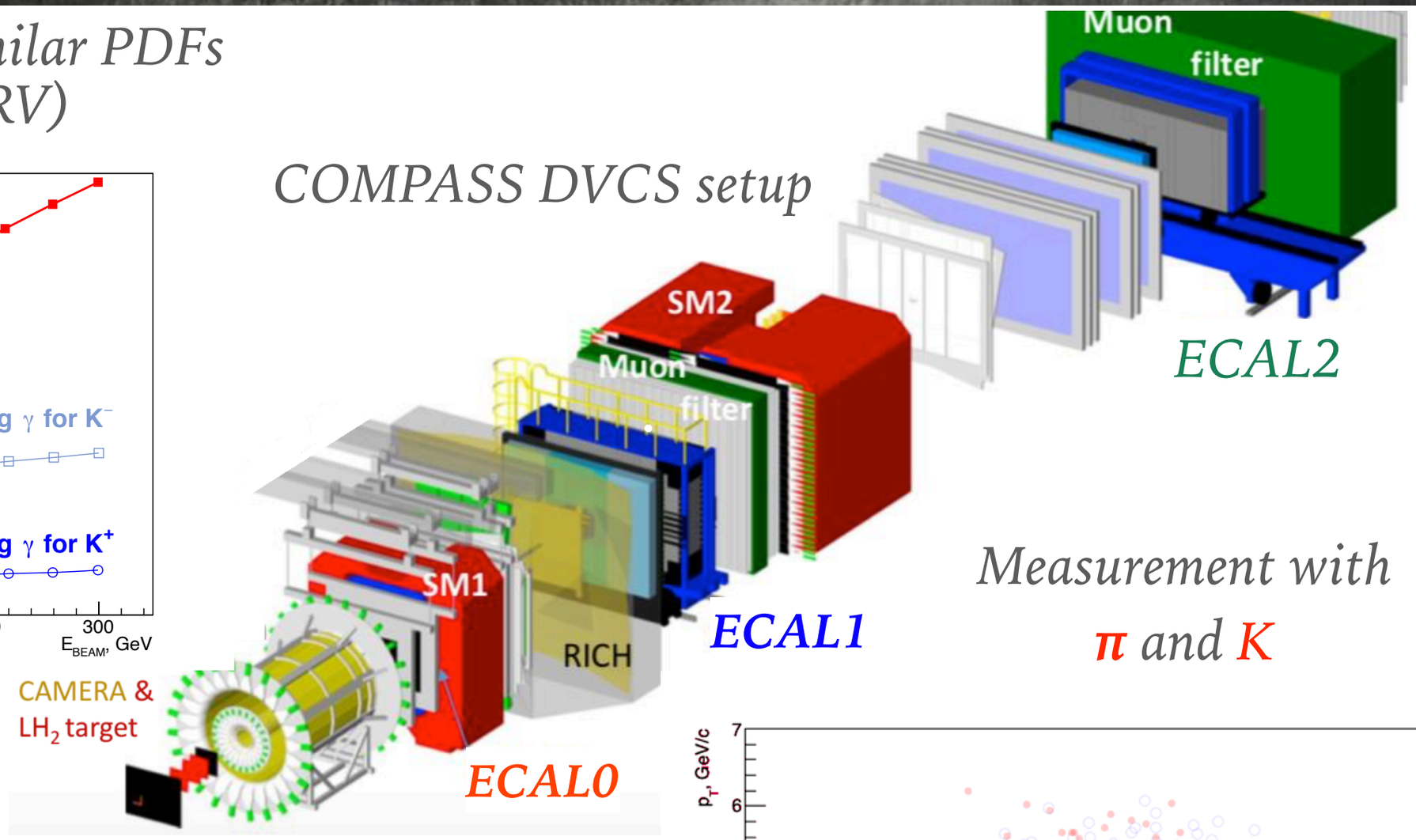


Prompt photons at COMPASS++/AMBER

Assumed for kaon similar PDFs as for pion (GRV)



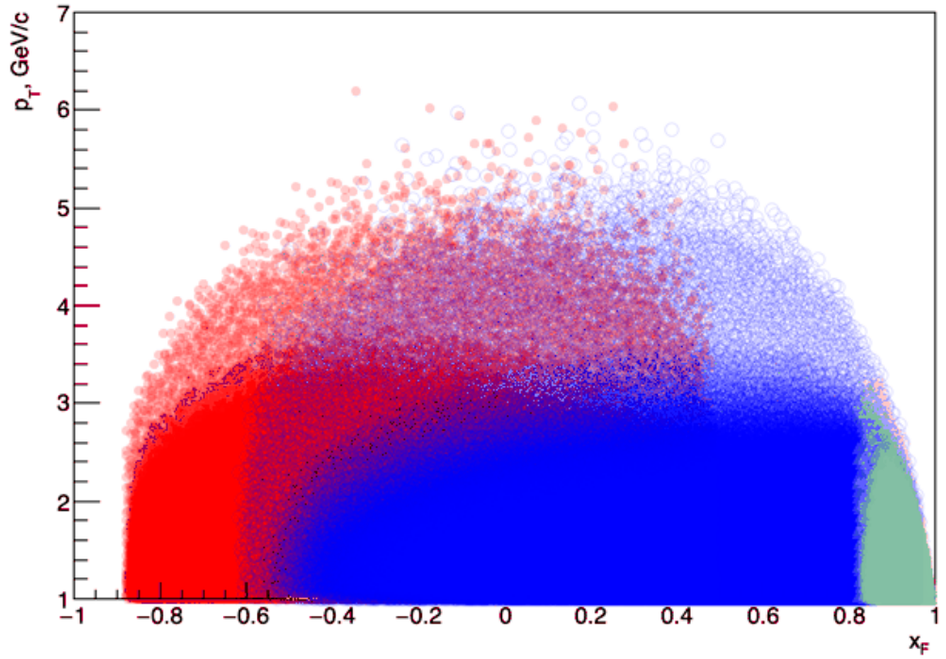
COMPASS DVCS setup



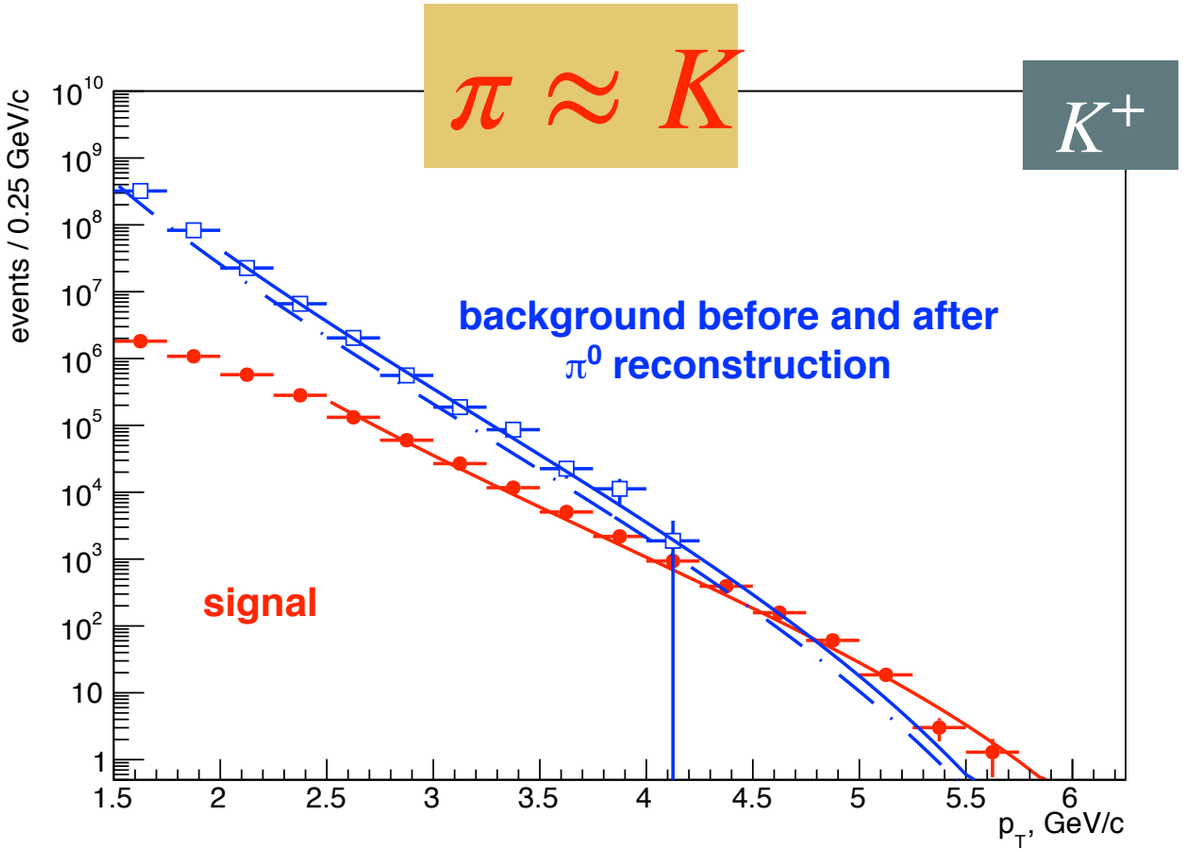
Measurement with π *and* K

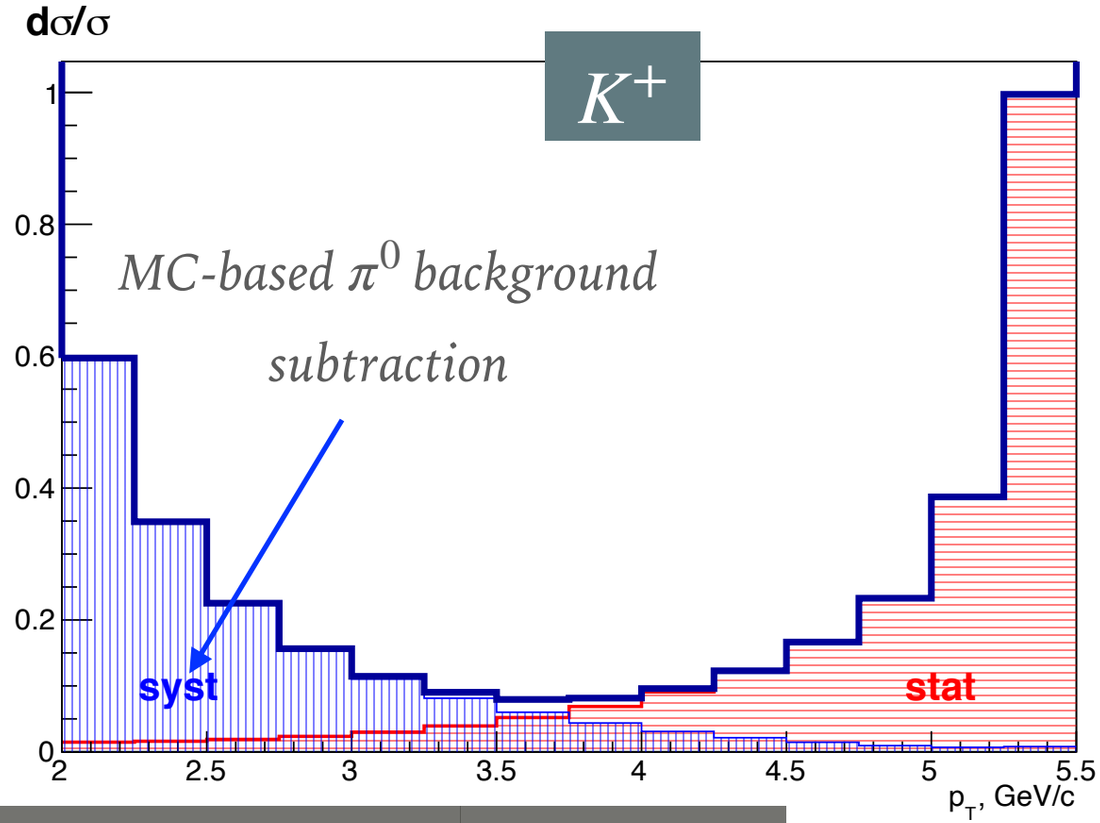
100 GeV kaon-enriched hadron beam!

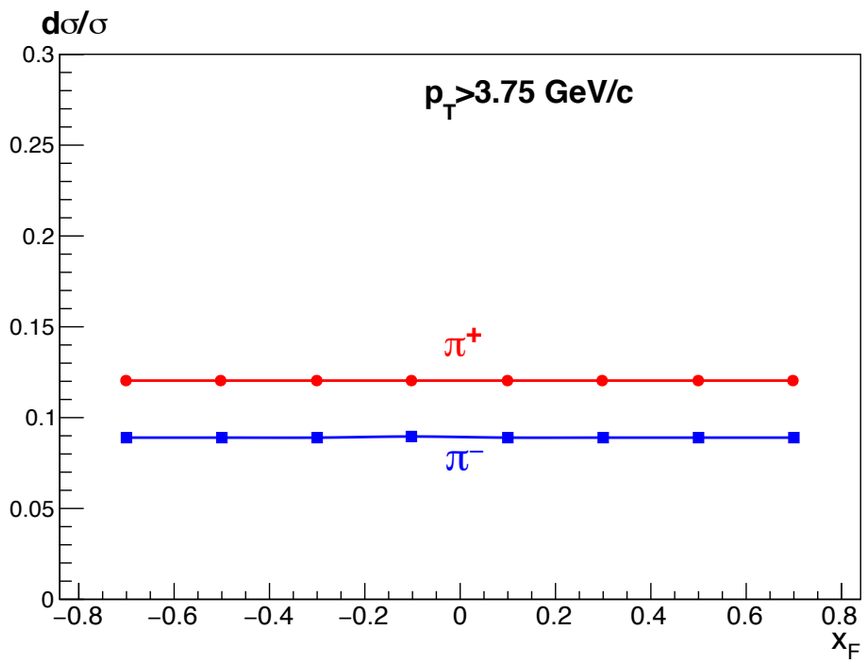
Open setup *- possibility for semi-inclusive and exclusive reactions!*



Expectations







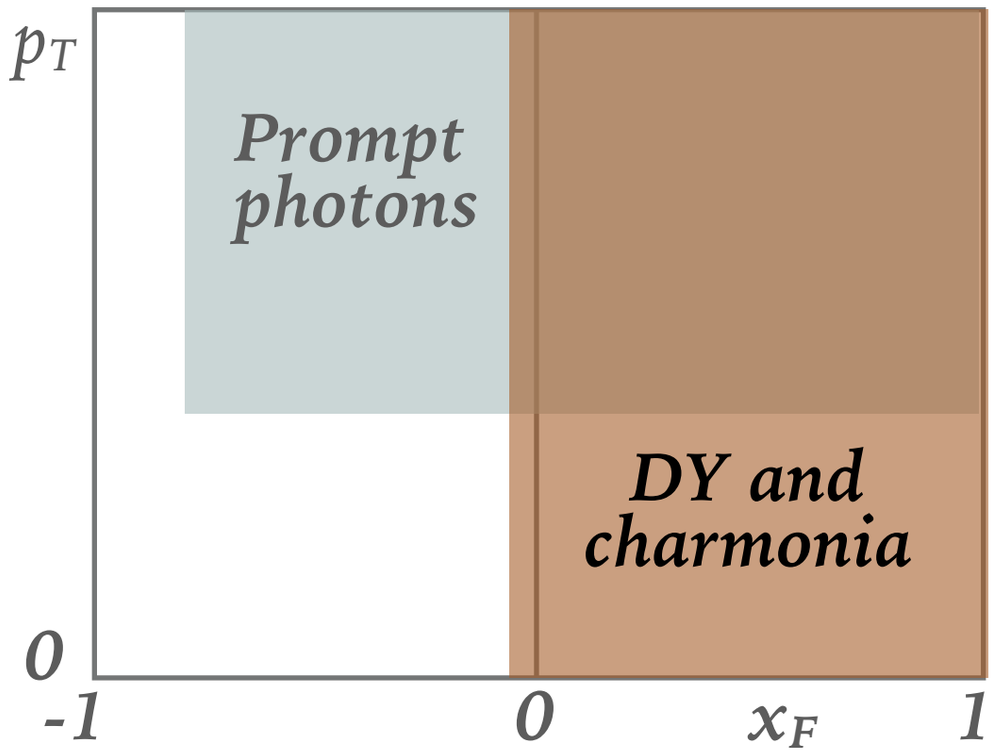
# of photons	p_T>2 GeV/c	p_T>3 GeV/c
π^- total	3.1×10^7	3.7×10^5
π^- prompt	1.3×10^6	6.8×10^4
π^+ total	3.3×10^7	3.6×10^5
π^+ prompt	1.1×10^6	4.7×10^4

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

The NICA collider at JINR, Dubna

Nuclotron-based
Ion **C**ollider f**A**cility
in the **Joint Institute for Nuclear Research** (JINR),
Dubna, Russia

A-A, **d↑-d↑, p↑-p↑ (L,T)**

$\sqrt{s_{pp}} \leq 27\ GeV$

L_{pp} **up to 10^{32} cm^{-2}s^{-2}**

Two interaction points:
MPD -Multi**P**urpose **D**etector
for heavy ion physics

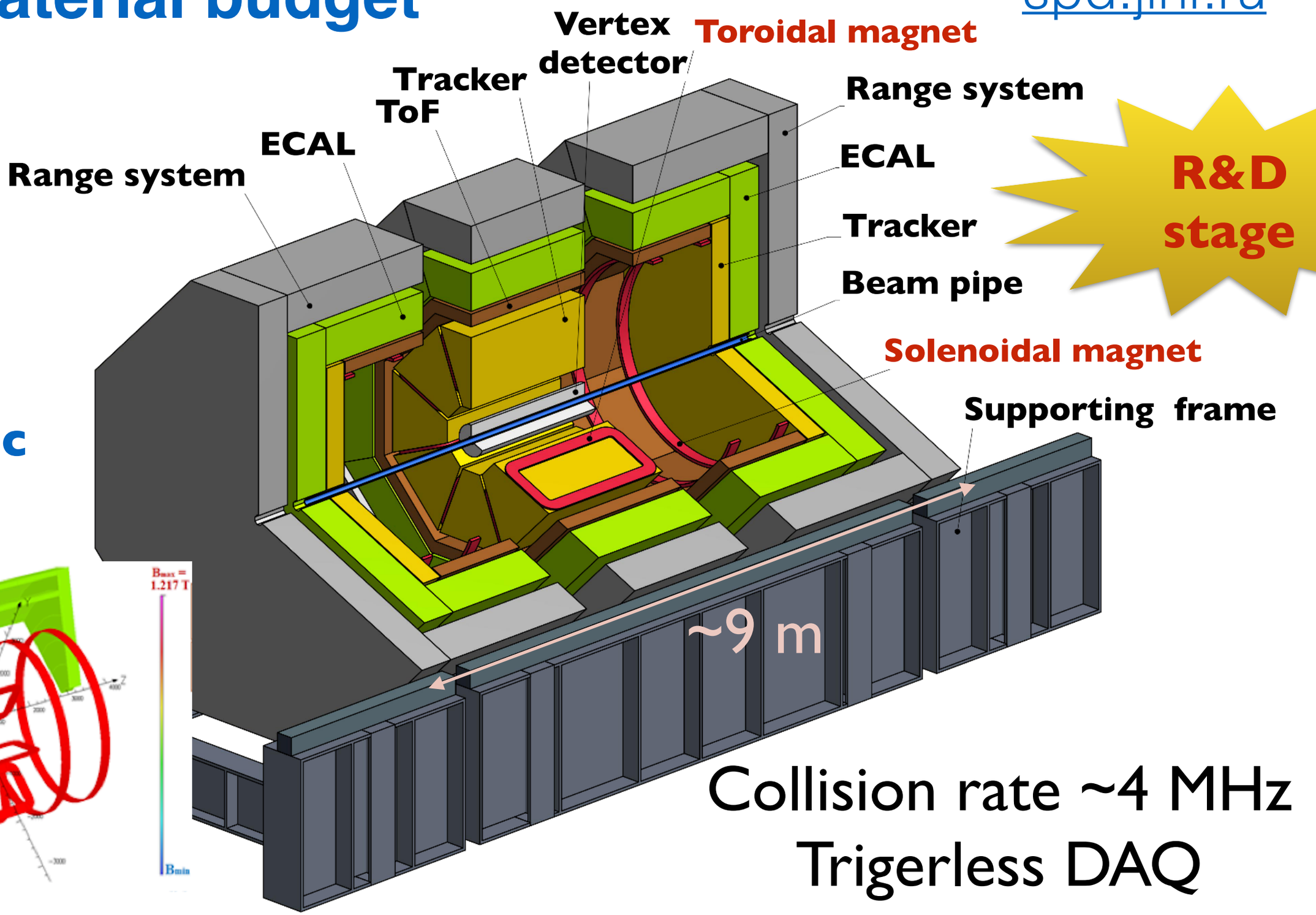
SPD - Spin **P**hysics **D**etector for
physics with polarized beams

NICA construction site

SPD detector (not fixed yet!)

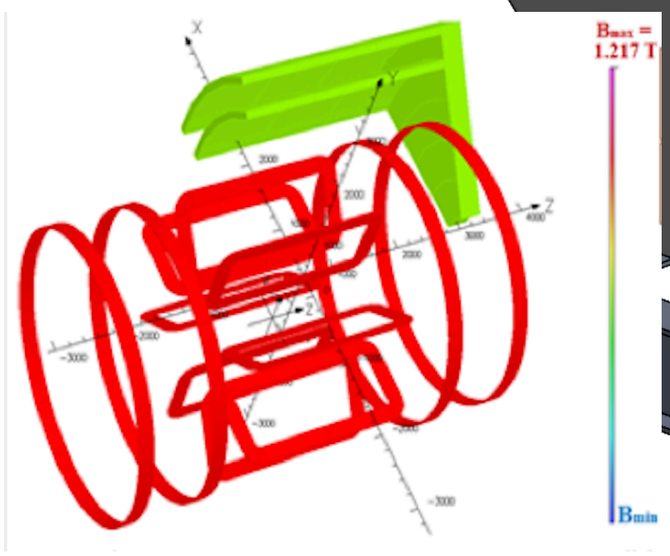
Low material budget

spd.jinr.ru



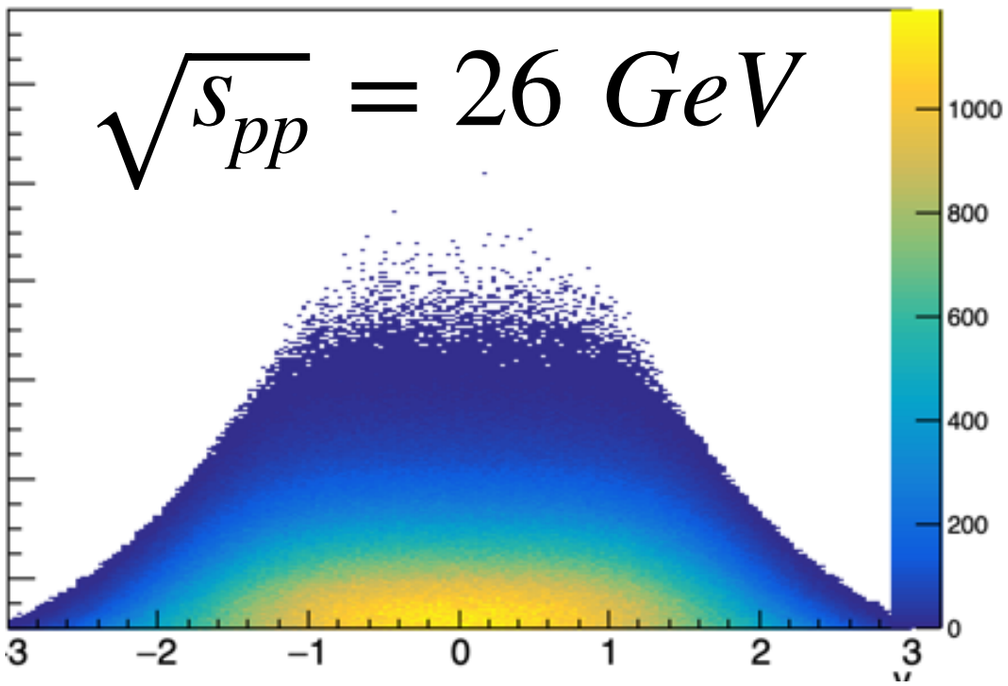
R&D stage

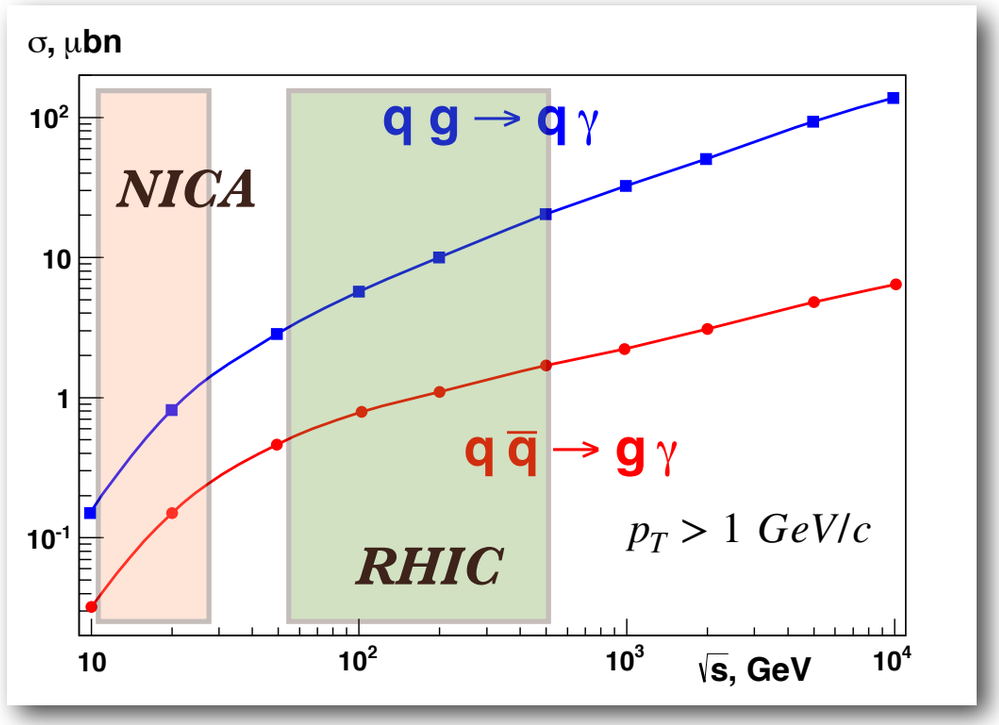
Magnetic system

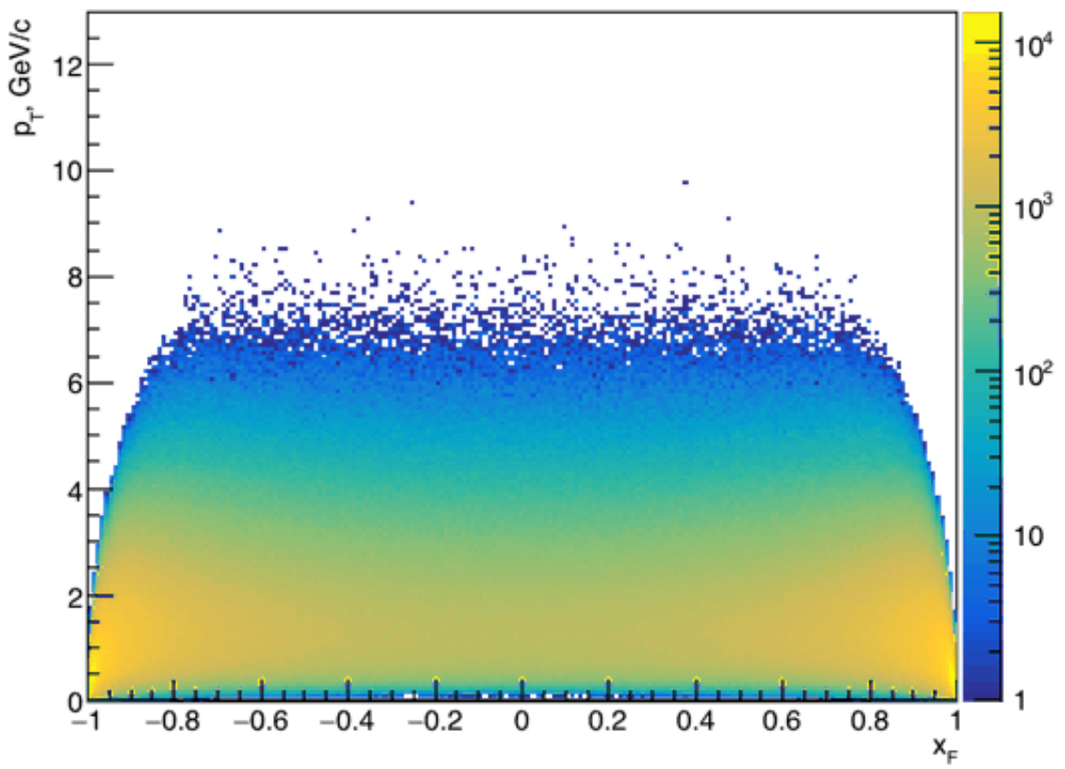


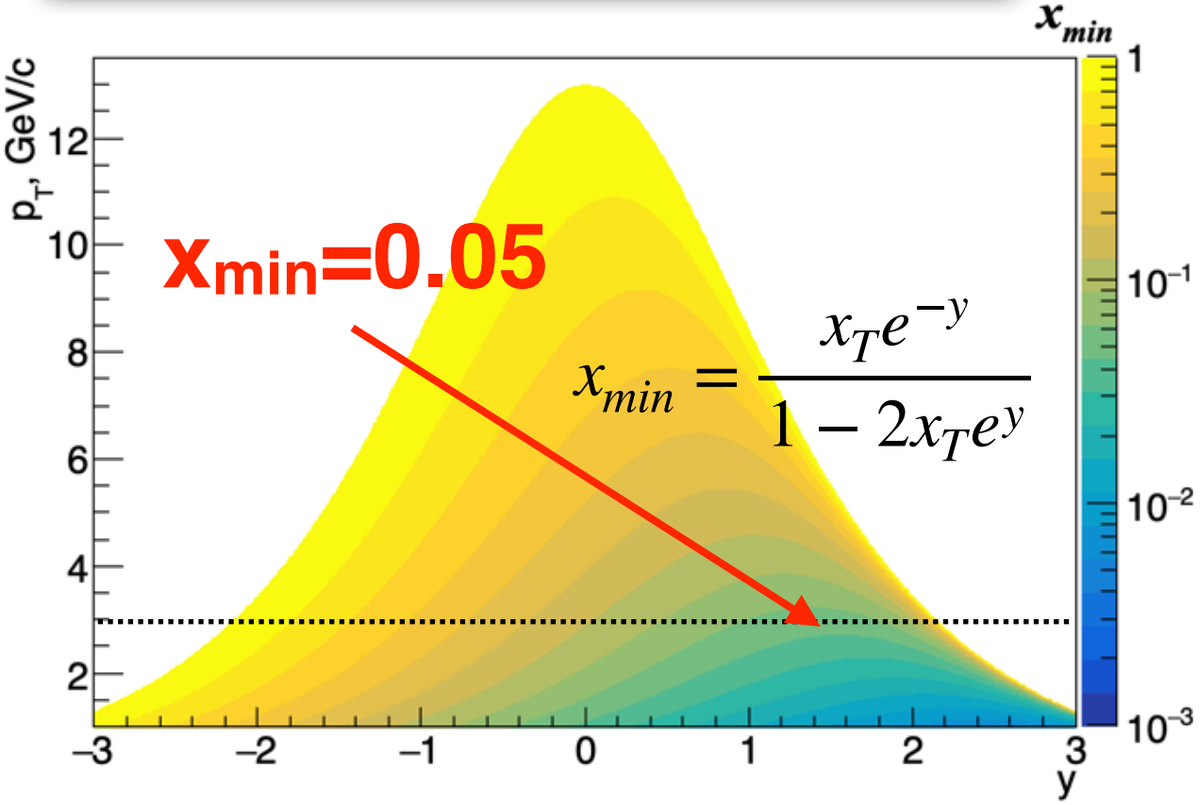
Collision rate ~4 MHz
Trigerless DAQ

A bit kinematics…



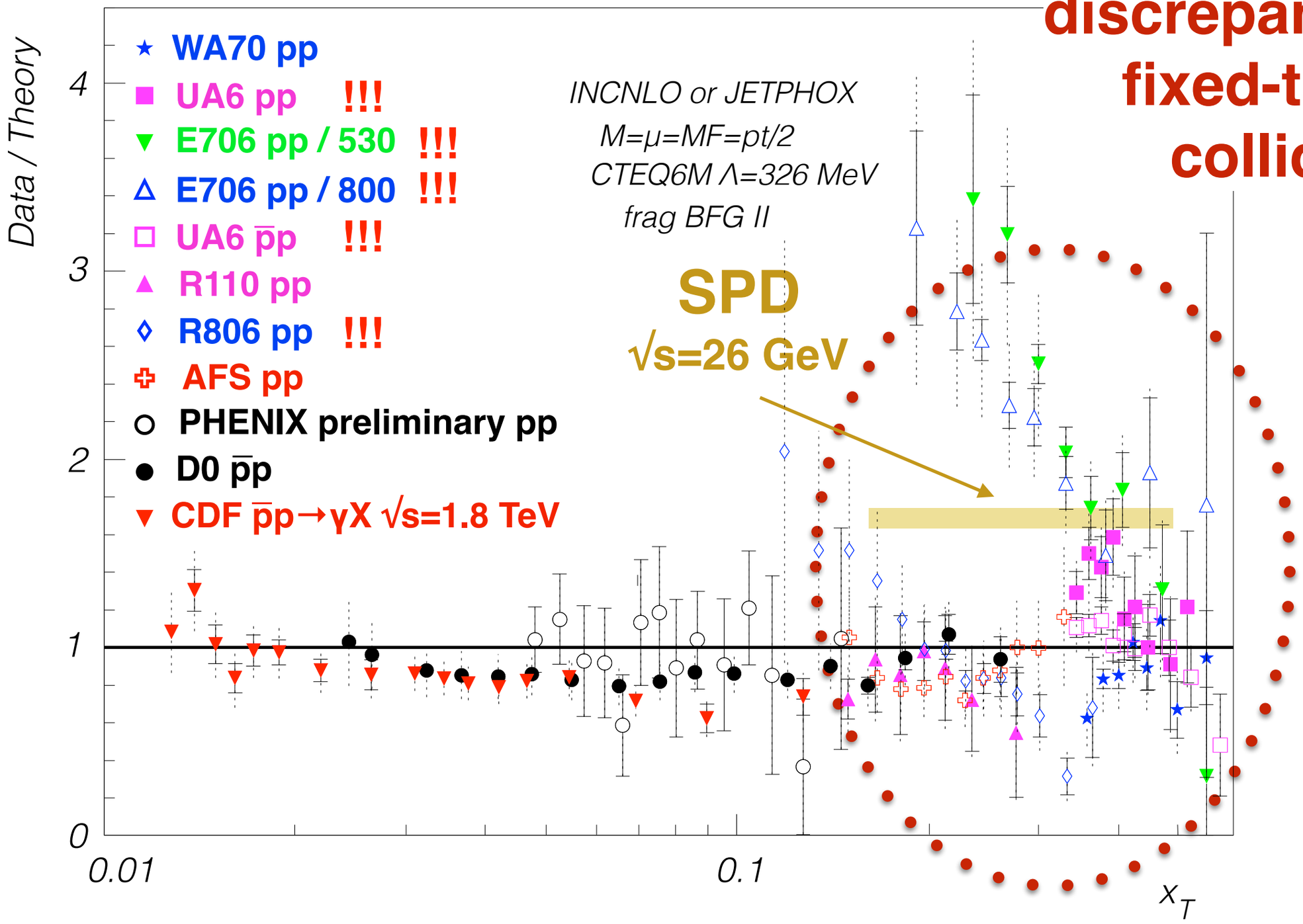






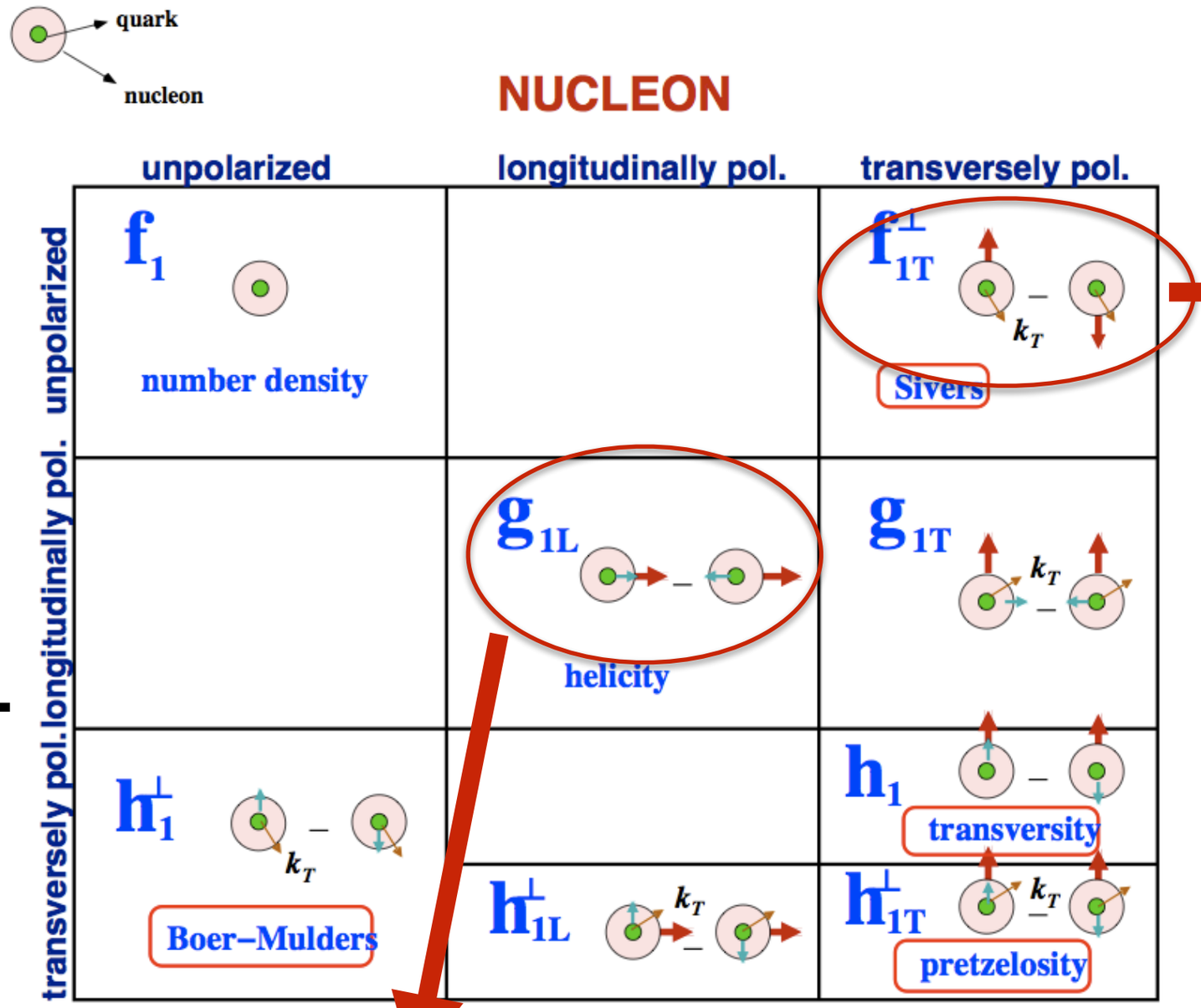
Previous results: pp(pbar)

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

Nucleon PDFs



Gluon Sivers function

Gluon polarization

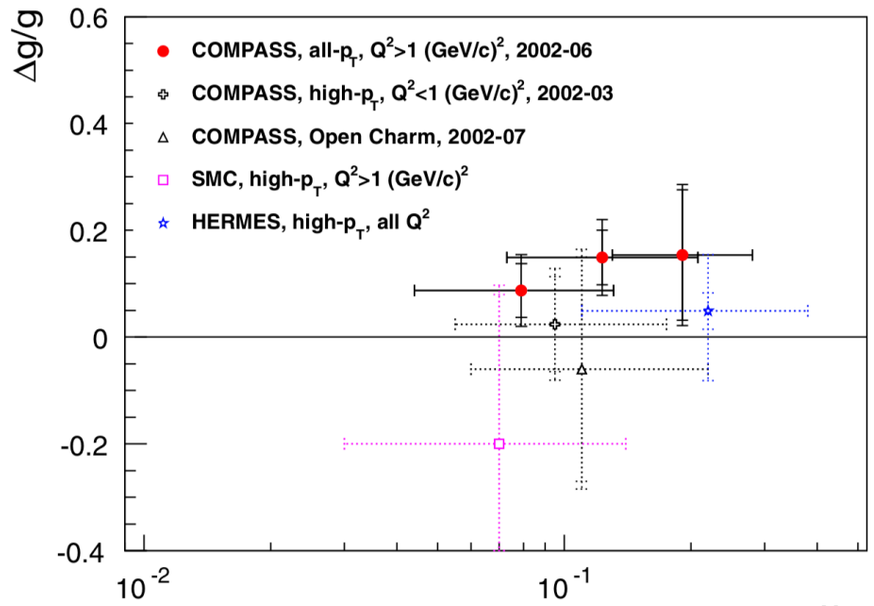
3 PDFs are needed to describe nucleon structure in collinear approximation

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

DSA with longitudinally polarised beams

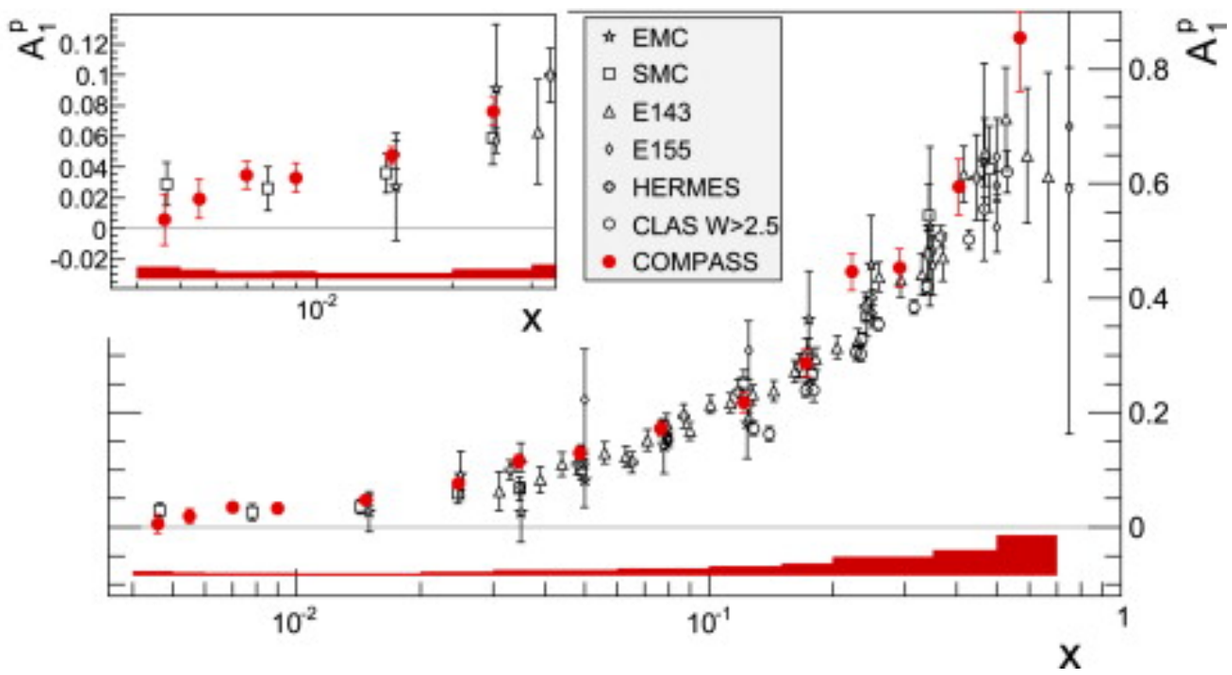
$$A_{LL} = \frac{(\sigma_{++} + \sigma_{--}) - (\sigma_{+-} + \sigma_{-+})}{(\sigma_{++} + \sigma_{--}) + (\sigma_{+-} + \sigma_{-+})}$$

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



A_1^P is well-known from DIS

$A_{LL} < 10\%$



SSA with prompt photons

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

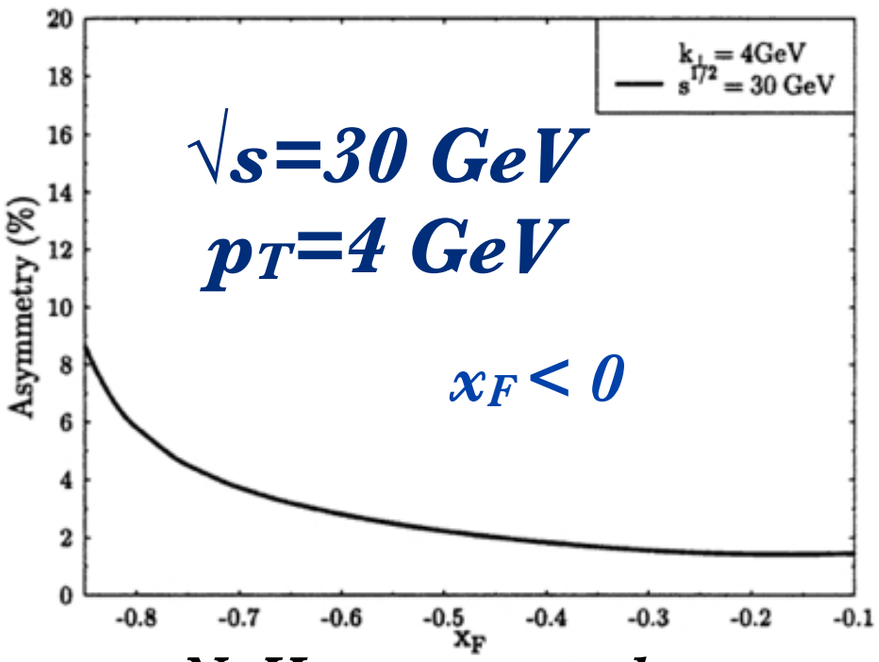
Single transverse spin asymmetry

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

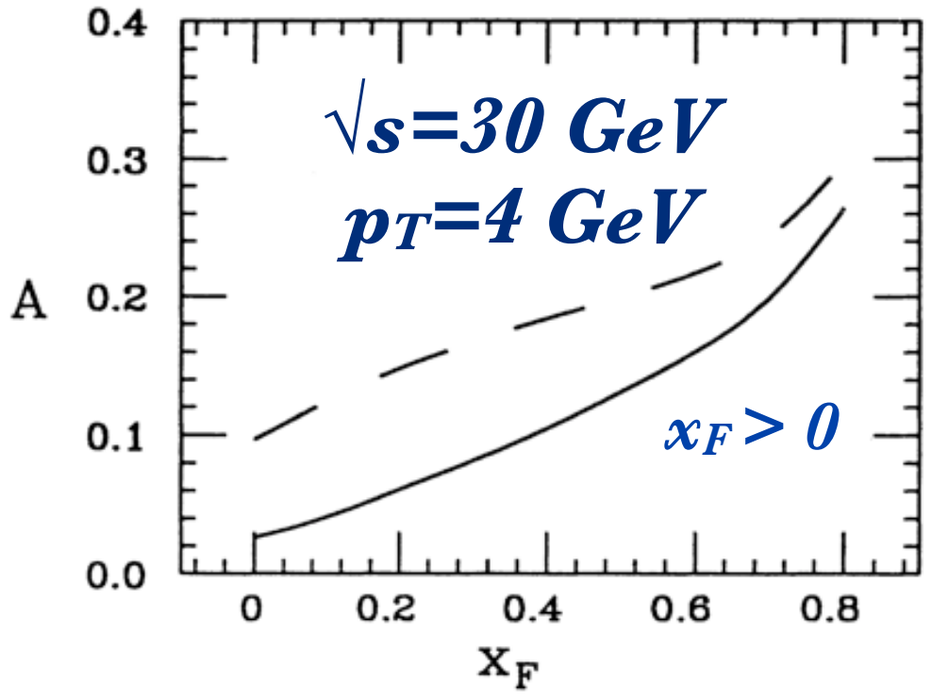
gluon Sivers function

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

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)



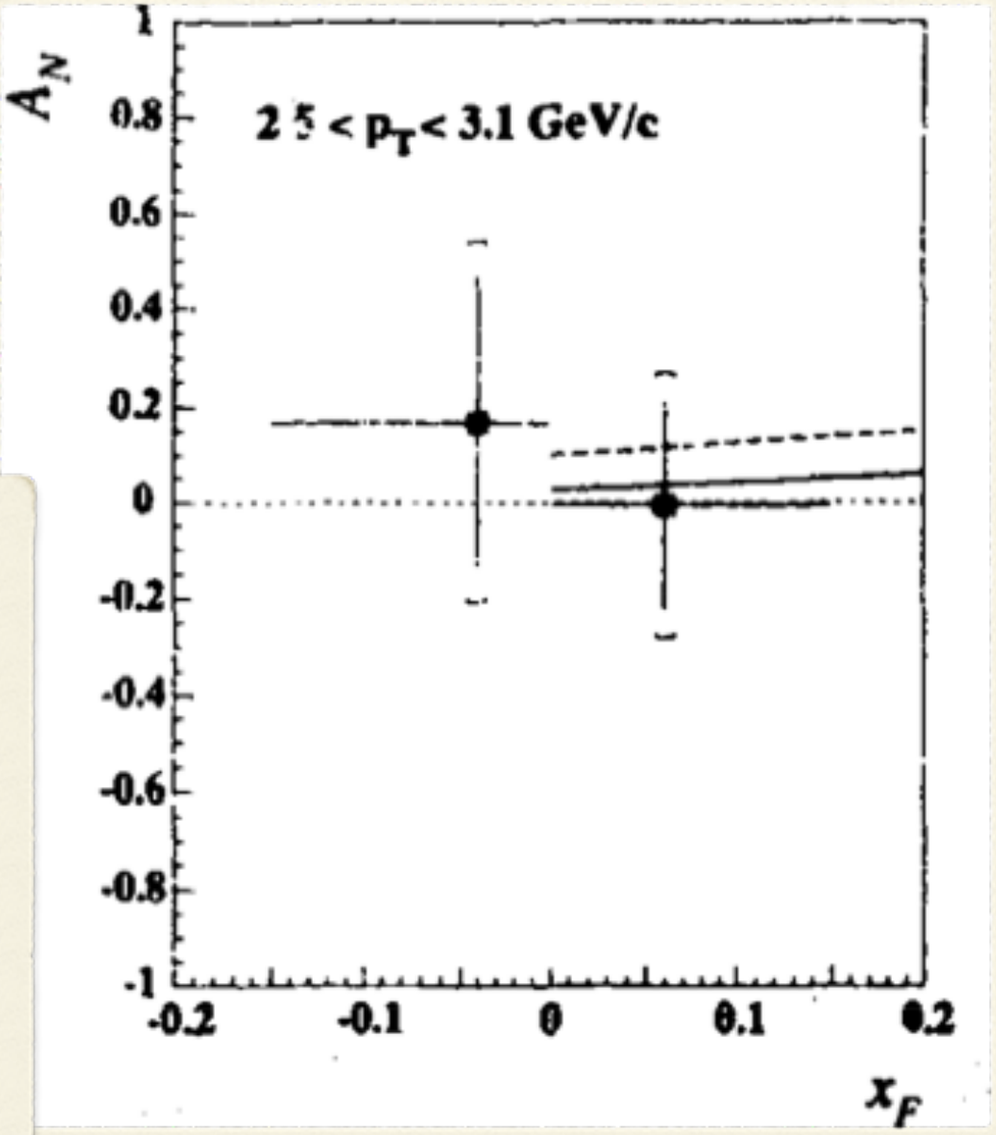
J. Qui and G. Sterman, Phys. Rev. Lett. 67 (1991) 2264

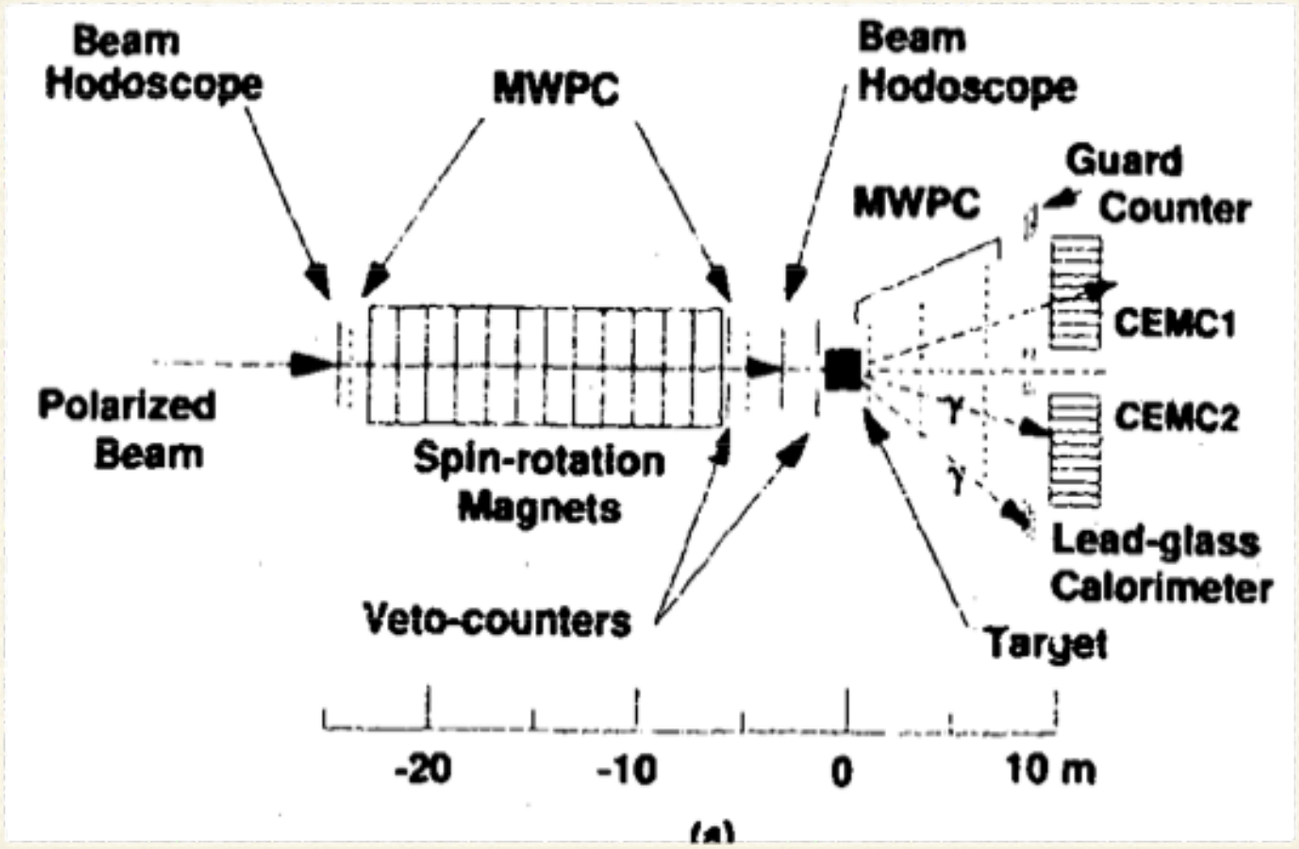
Single spin asymmetries at √s=19.4 GeV

Polarized measurement at FNAL E704

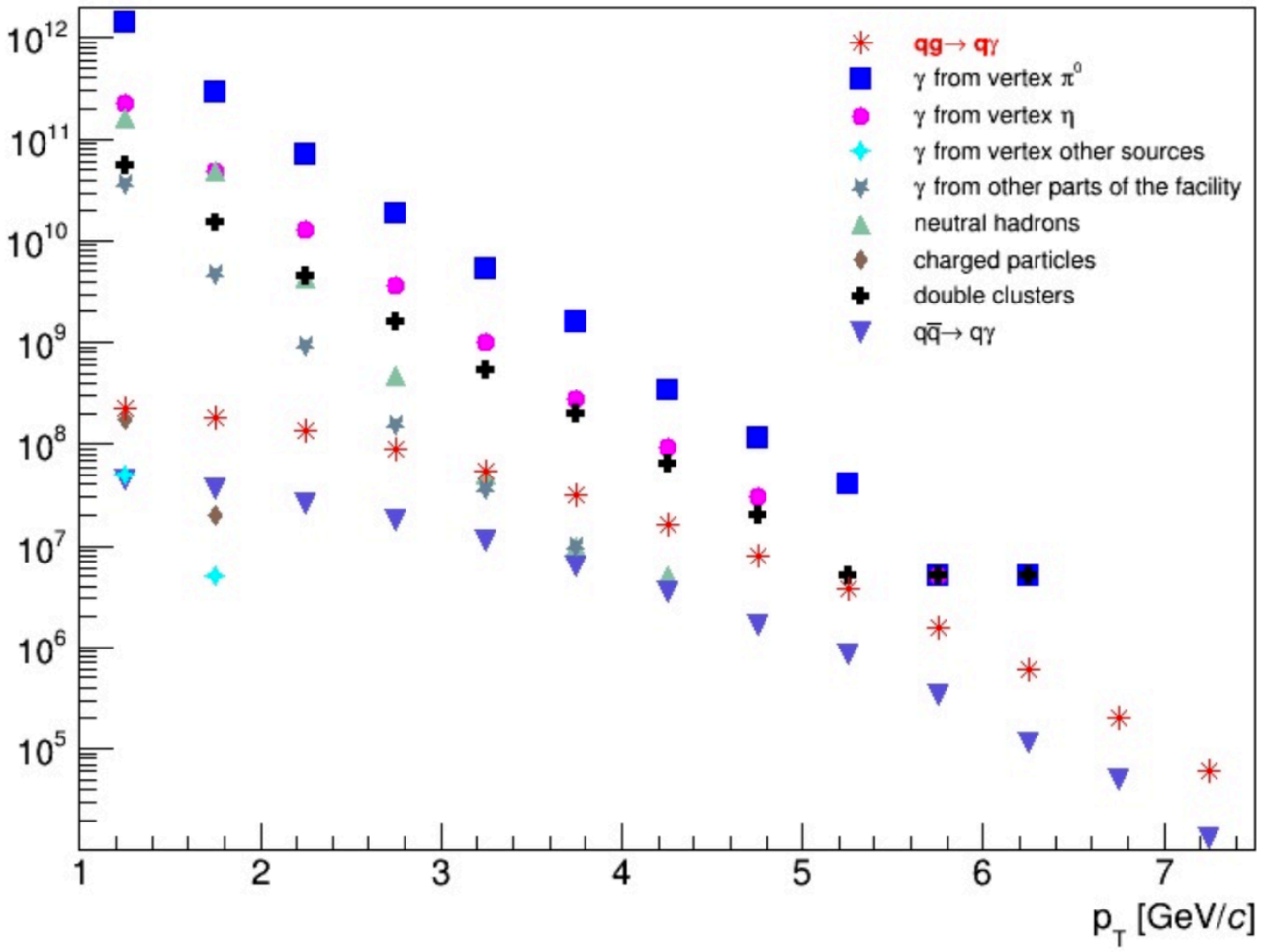
Phys. Lett. B 345 (1995)

- *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)*



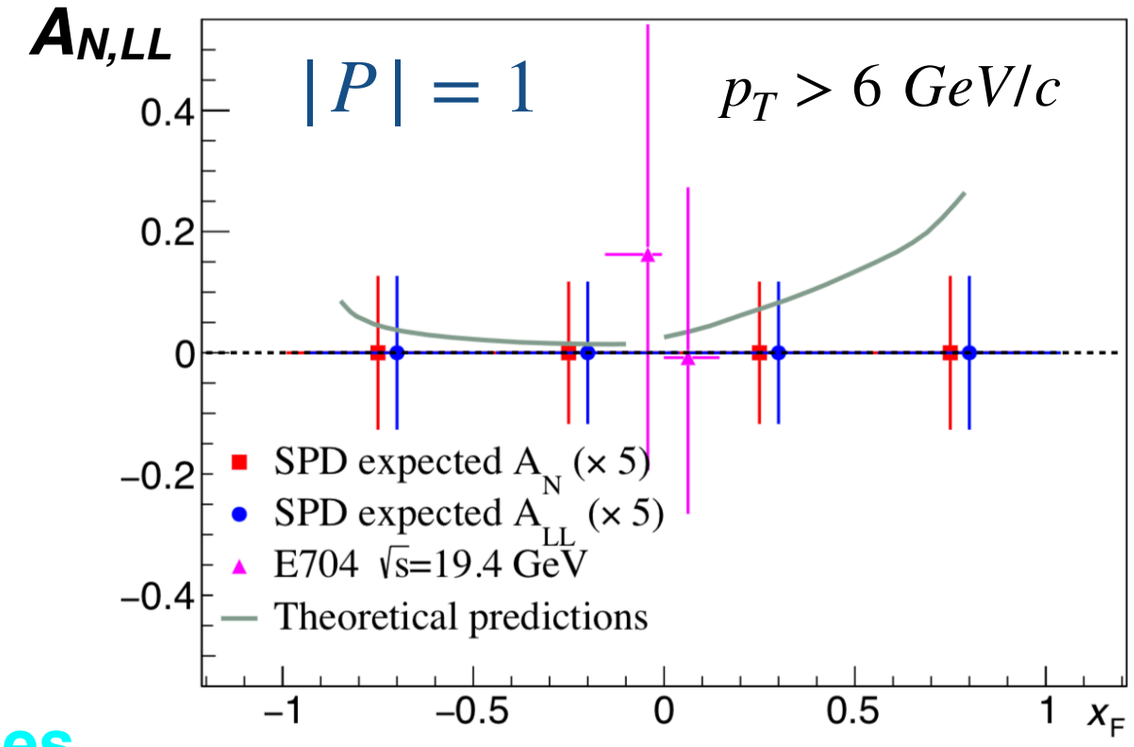


Accuracy expected for asymmetries



- decay photons from **π⁰**, **η** and **other sources**
- clusters from **neutral hadrons**
- **double clusters**
- clusters from **misidentified charged particles** (5%)
- clusters from **photons produced at the setup elements**

1 year of data taking (10^7 s) with $L = 10^{32} cm^{-2} s^{-1}$



No systematics related with luminosity and polarization measurement included.

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 to be used for the first measurement of gluon distribution in kaon within the COMPASS++/AMBER project (CERN) with 100 GeV positive and negative kaon beams. 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.**
- **Prompt-photon production will be used to access gluon polarization and gluon Sivers functions in polarized p↑-p↑ and d↑-d↑ collisions at the Spin Physics Detector (SPD) at the NICA collider (JINR, Dubna, Russia) at $\sqrt{s}$ up to 27 GeV. High luminosity, 4π acceptance of the SPD setup and controlled systematics will allow to access accuracy of A_N and A_{LL} measurement on the level of a few percent.**
- **You are welcome with theoretical predictions and proposals to extend the experimental program with prompt photons (and not only) of the COMPASS++/AMBER and NICA SPD projects.**

Input from theory for AMBER

Perceiving the Emergence of Hadron Mass through AMBER@CERN

kick-off meeting of the initiative took place 11/12/2019, very good attendance

COMPASS++
AMBER

Joint CERN TH department and AMBER event, web site will be open by the end of the week