COMPASS++/AMBER project: common topics with SPD

A. Guskov, JINR, DLNP

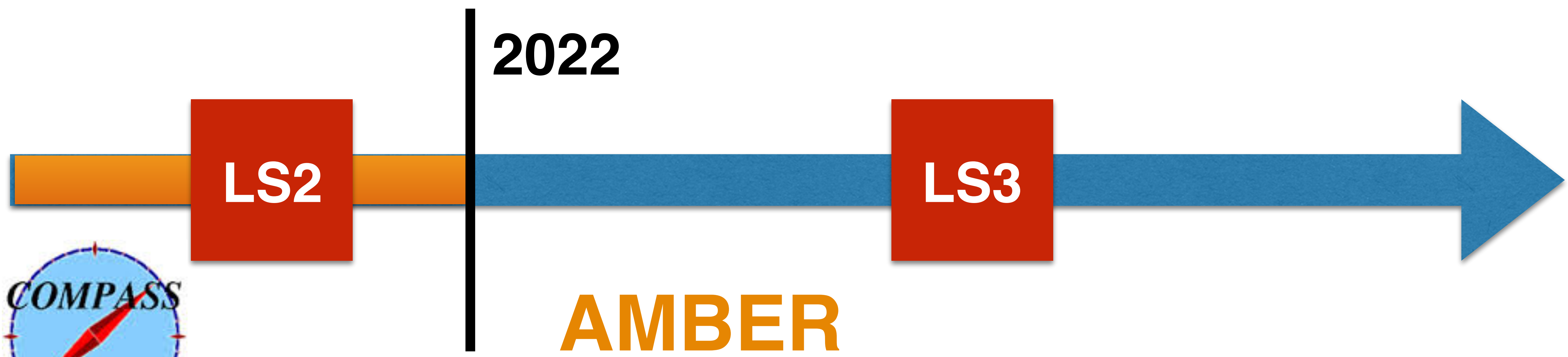
avg@jinr.ru

5.06.2019

COMPASS→AMBER

Apparatus for Meson and Baryon Experimental Research

— a new QCD facility at the M2 beam line of the CERN SPS



COMPASS

AMBER physics program

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Letter of Intent:

A New QCD facility at the M2 beam line of the CERN SPS[*]

COMPASS++[†]/AMBER[‡]

CERN-SPSC-2019–003
SPSC-I-250
January 28, 2019

arXiv:1808.00848

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal for Measurements at the M2 beam line of the CERN SPS

Phase-1: 2022-2024

COMPASS++[*]/AMBER[†]

SPSC-2019–022
SPSC-P-360
May 31, 2019

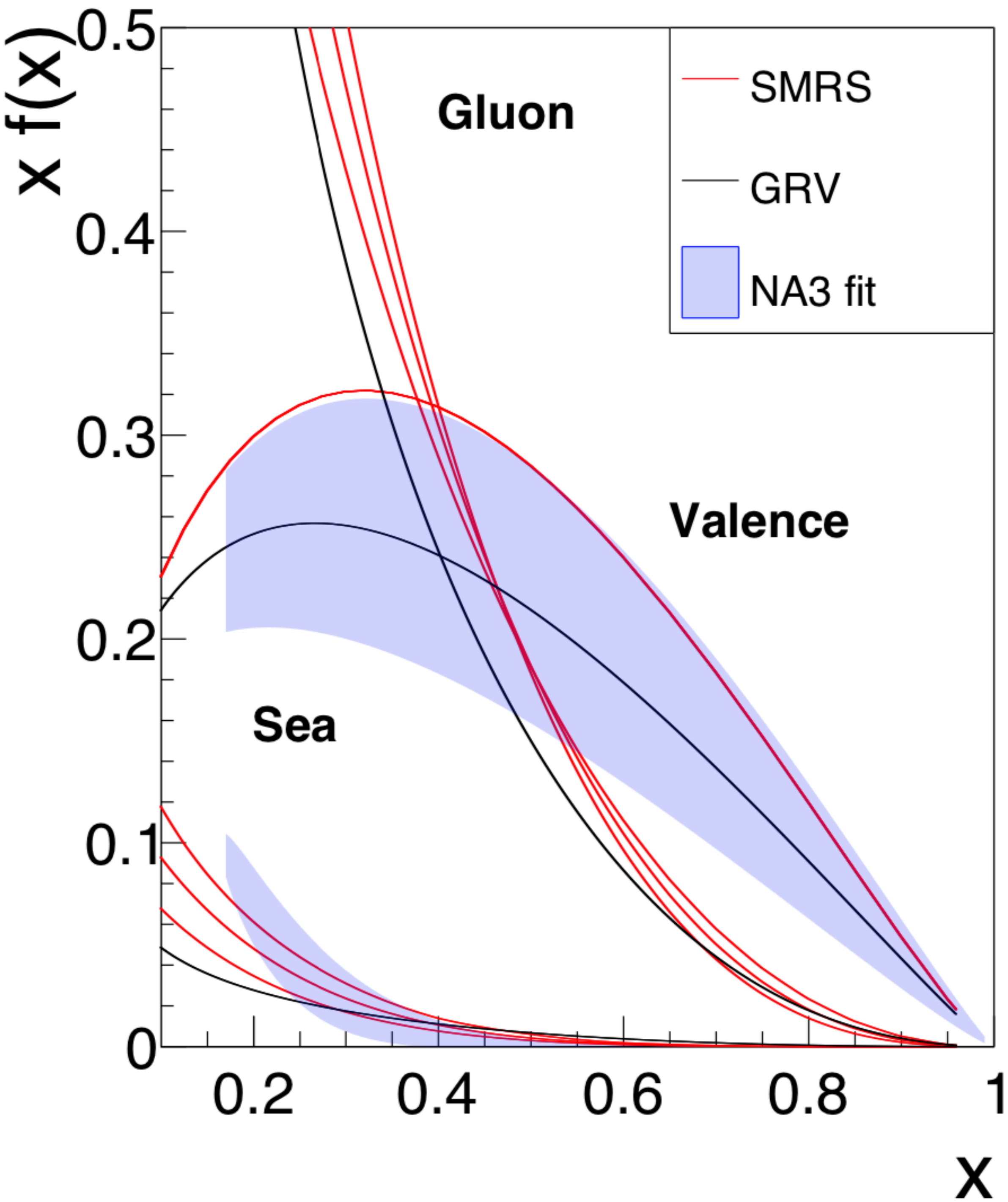
AMBER physics program

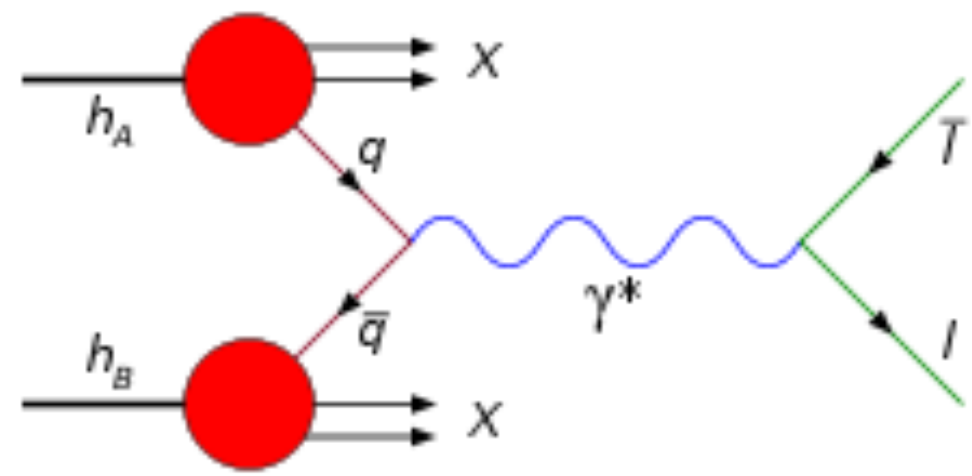
- Proton radius measurement in μ-p elastic scattering
- Drell-Yan and charmonium production using conventional hadron beams
- Hard exclusive reactions with muon beam and transversely polarised target
- Spectroscopy with low-energy antiproton beam
- Measurement of antiproton production cross section for dark matter search

RF-separated beam

- Vector-meson production in nuclear matter
- Spectroscopy of kaons
- Drell-Yan and charmonium production using kaon and antiproton beams
- Study of gluon content of kaons with prompt photons
- Low-energy QCD with kaon beam

Sea/valence quarks in pion via DY

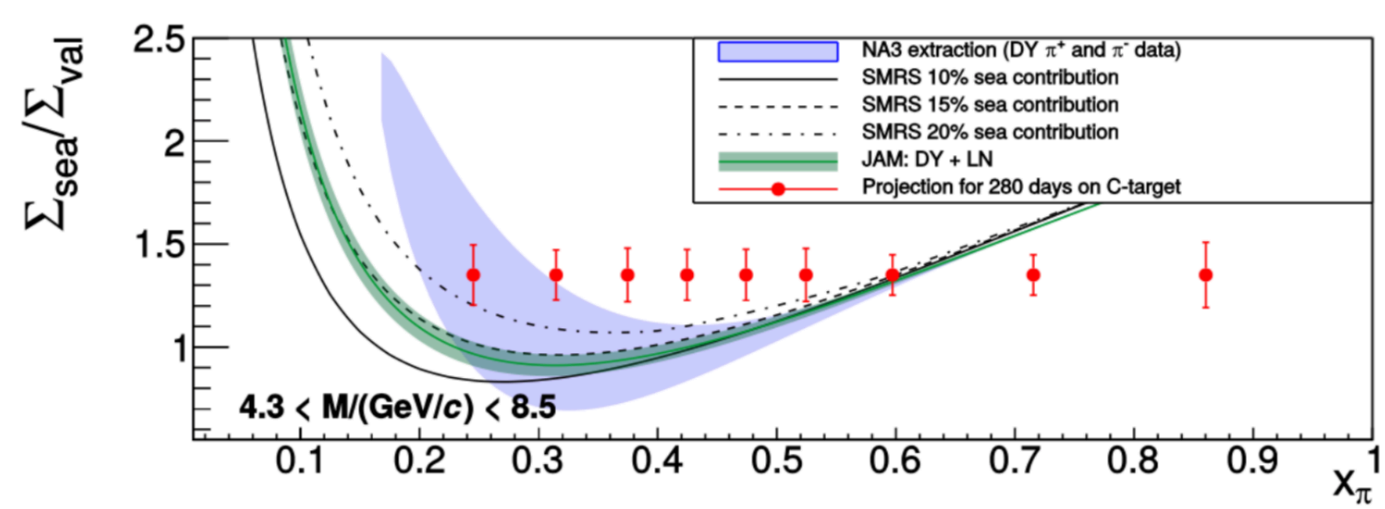




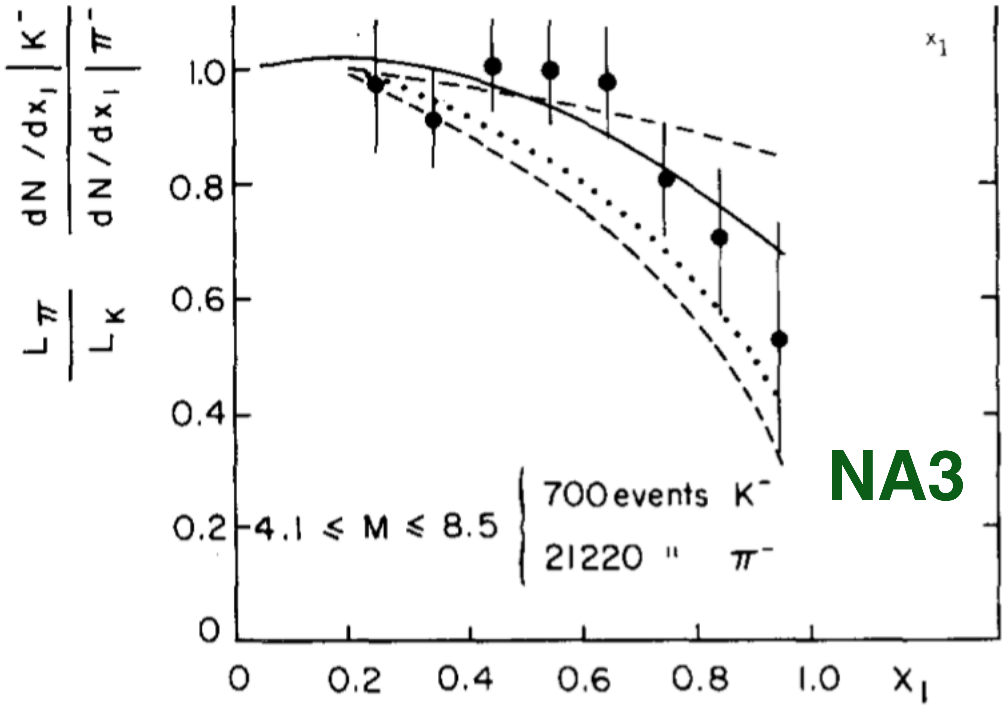
Sea/valence separation

$$\Sigma_{val}^{\pi D} = -\sigma^{\pi^+ D} + \sigma^{\pi^- D}$$

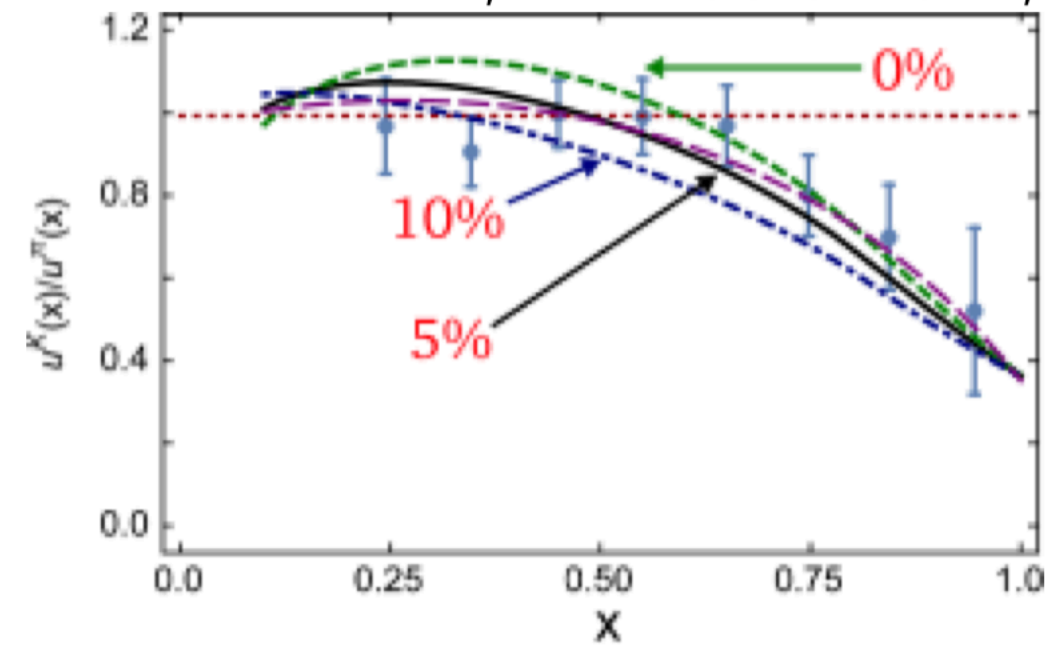
$$\Sigma_{sea}^{\pi D} = 4\sigma^{\pi^+ D} - \sigma^{\pi^- D}$$



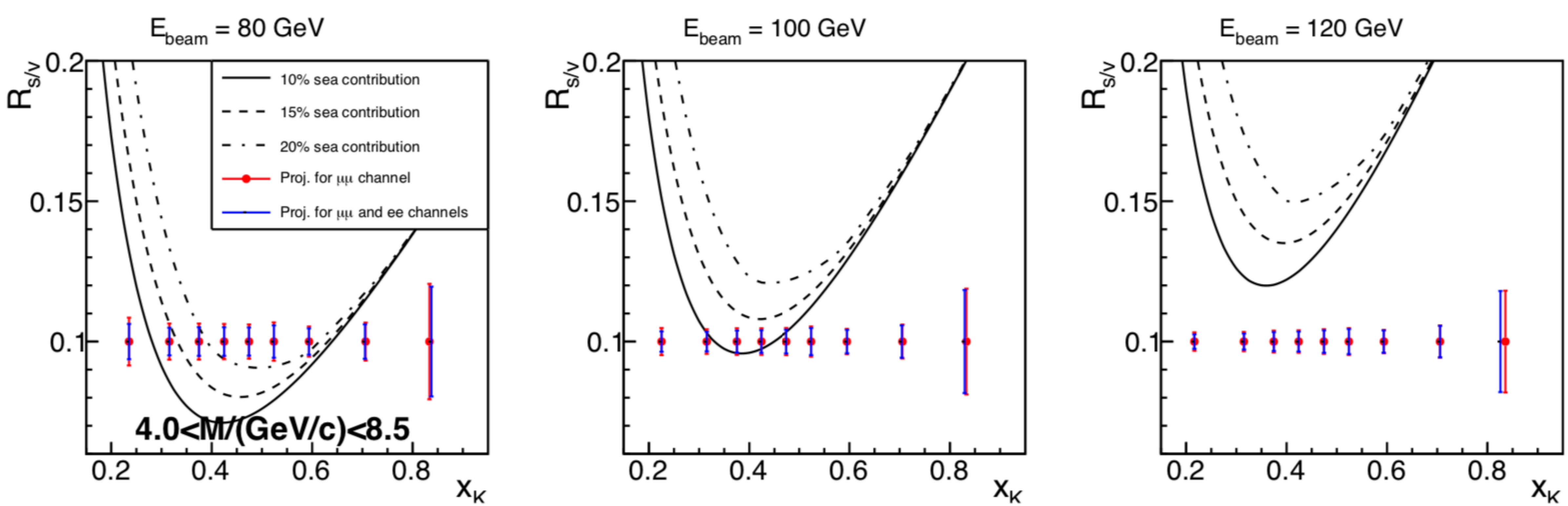
Sea/valence quarks in kaon



C. Chen *et al.*, PRD 93 074021, 2016



Poor knowledge of kaon valence PDFs, no info about sea



Gluon PDFs of mesons

Z. Phys. C 72, 249–254 (1996)

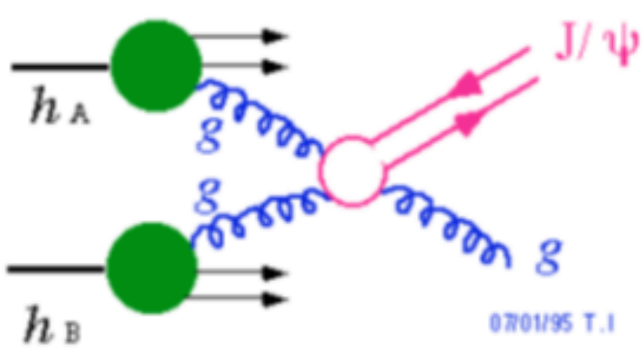
$xG(x)$	Reactions	Subprocess	Reference
$(1-x)^3$	$\pi N \to \psi$	$GG \to c\bar{c}$	[4], (1980)
$(1-x)^{1.9\pm0.3}$	$\pi^- Be \to \psi$	$GG \to c\bar{c}$	[5],(1983), WA11
$(1-x)^{2.38\pm0.06\pm0.1}$	$\pi^\pm Pt \to \psi$	$GG \to c\bar{c}$	[6], (1983)
$\sim(1-x)^{3.1}$, evolves with Q^2	$\pi p \to \psi, \pi^\pm X$	$GG \to c\bar{c}$	[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

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

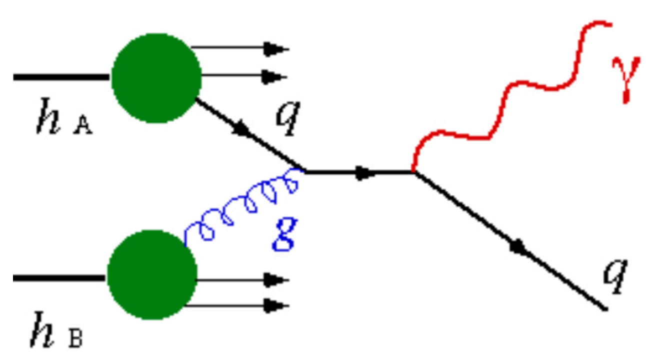
We have some minimal data for pion, for kaon there is no any experimental results!

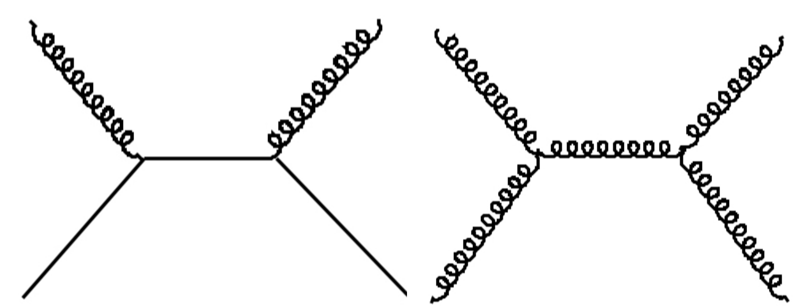
While there is a prediction that gluon content of kaon at hadronic scale is ~1/6 in respect to pion.

quarkonia production



prompt photons



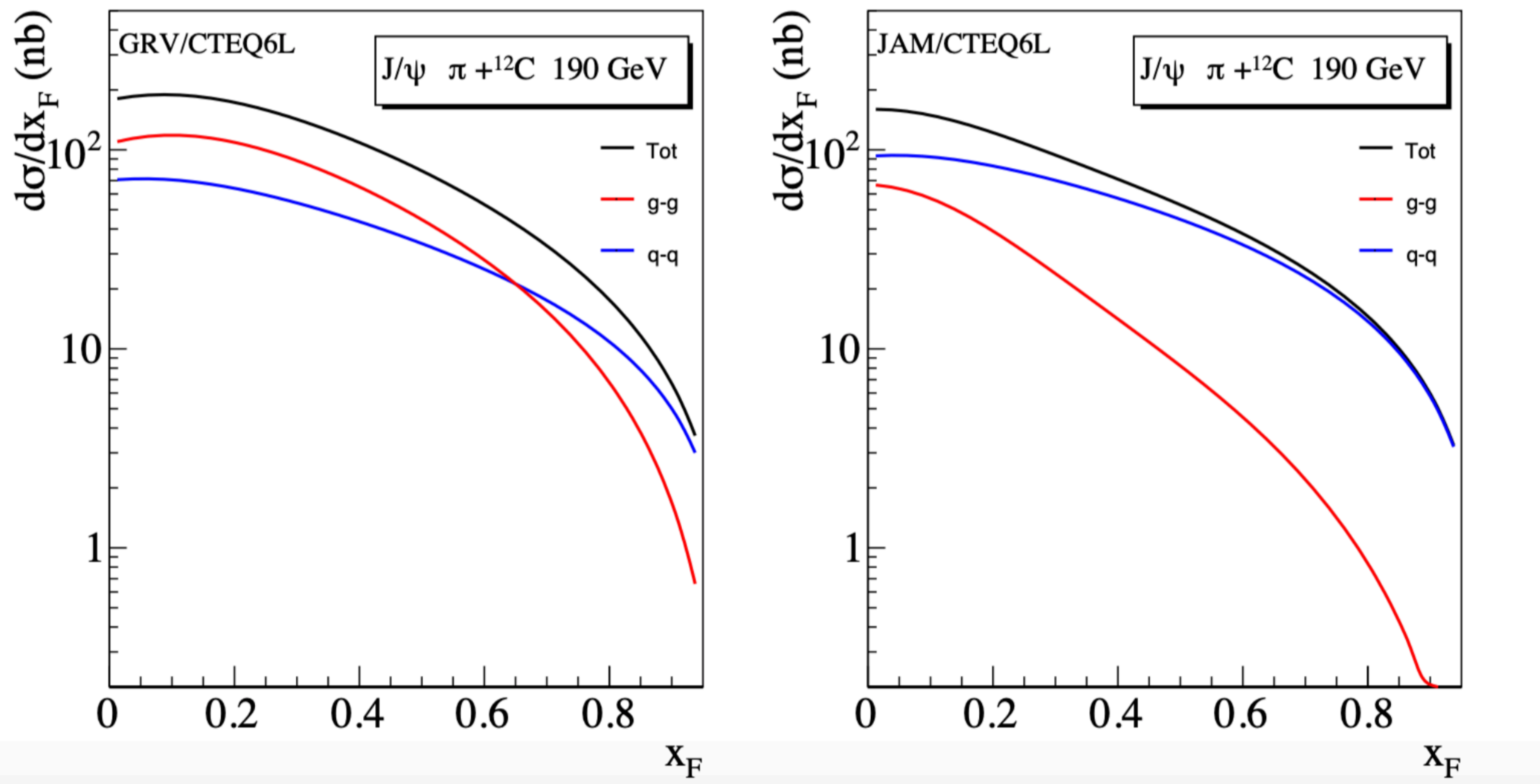


jet production

Complimentary approaches!

Gluon content of pion & J/ψ

CEM



Two main mechanisms of J/ψ production in hadron collisions:

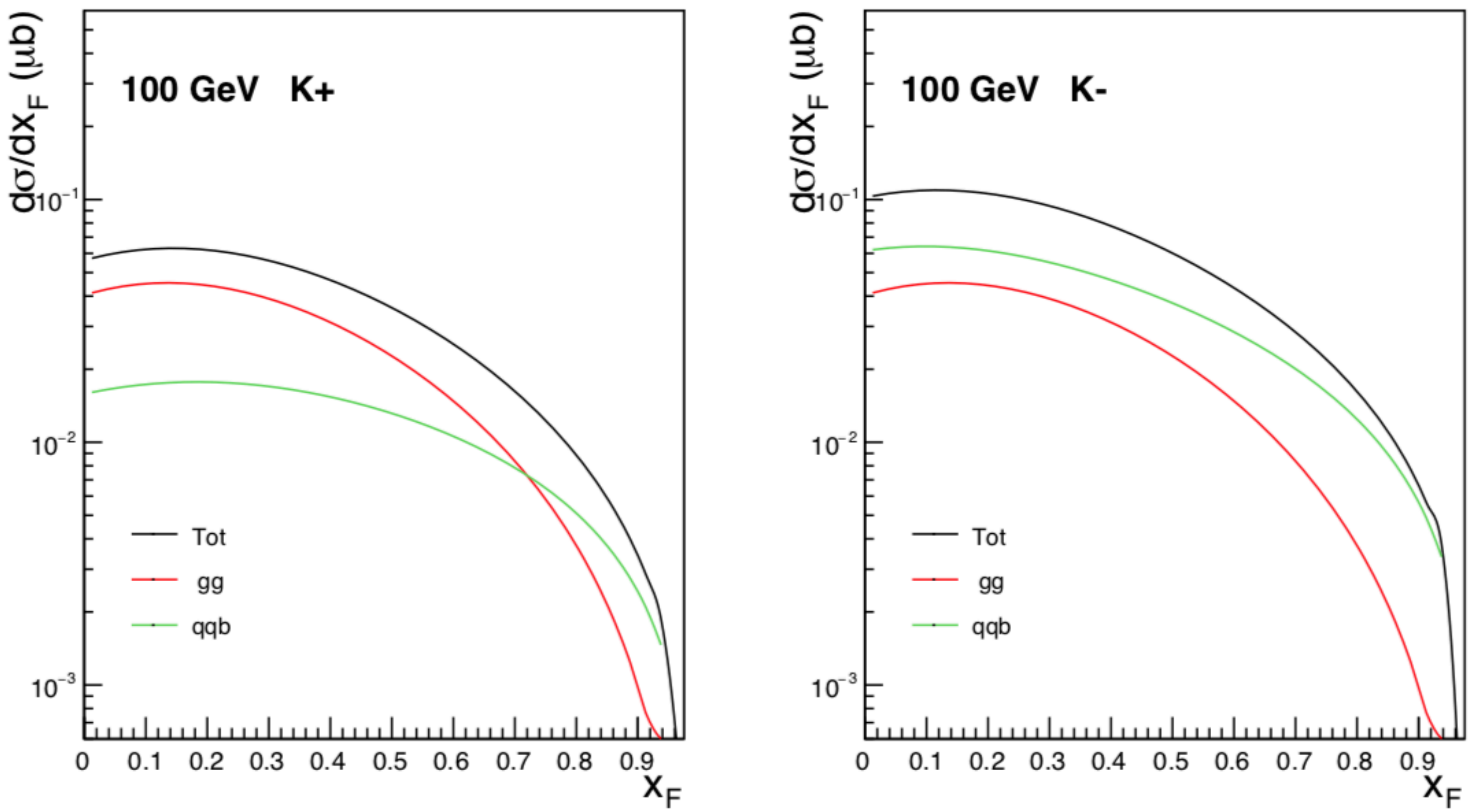
gg→J/ψ+…

$q\bar{q}$→J/ψ+…

Model-dependent separation of gg and $q\bar{q}$ contributions

Gluon PDFs of kaon & J/ψ

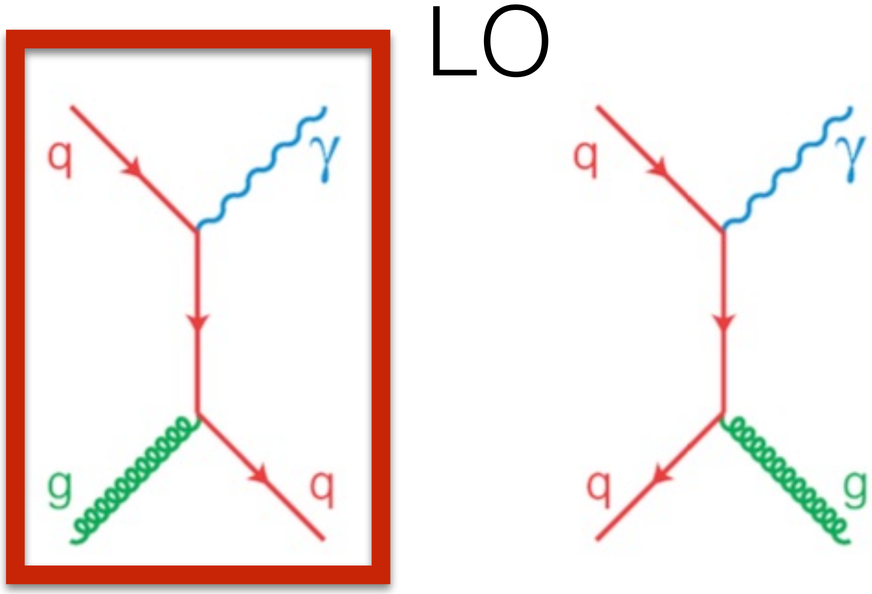
CEM



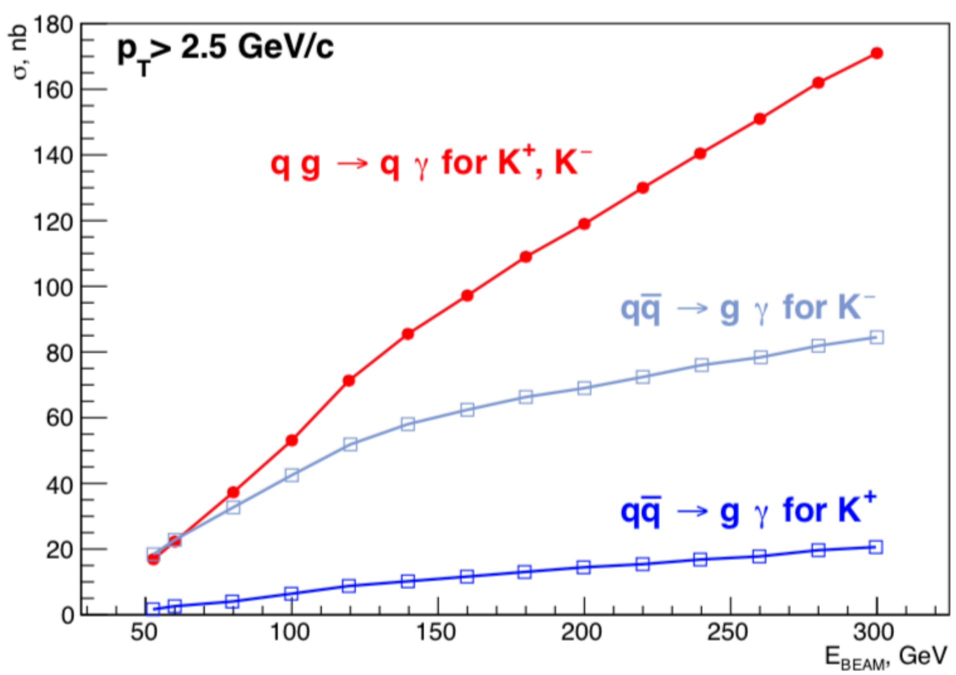
$$\sigma_{J/\psi}^{K^-} - \sigma_{J/\psi}^{K^+} \propto \bar{u}^{K^-} u^N$$

Gluon PDFs of kaon via prompt γ

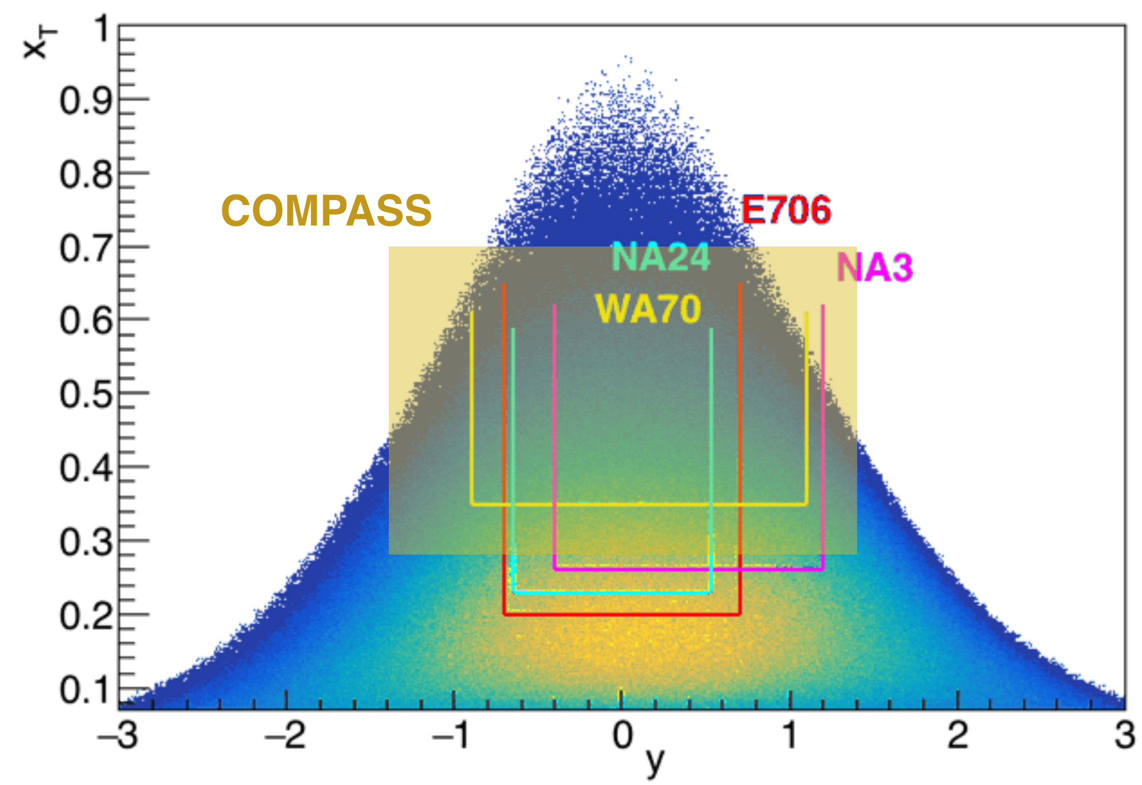
LO

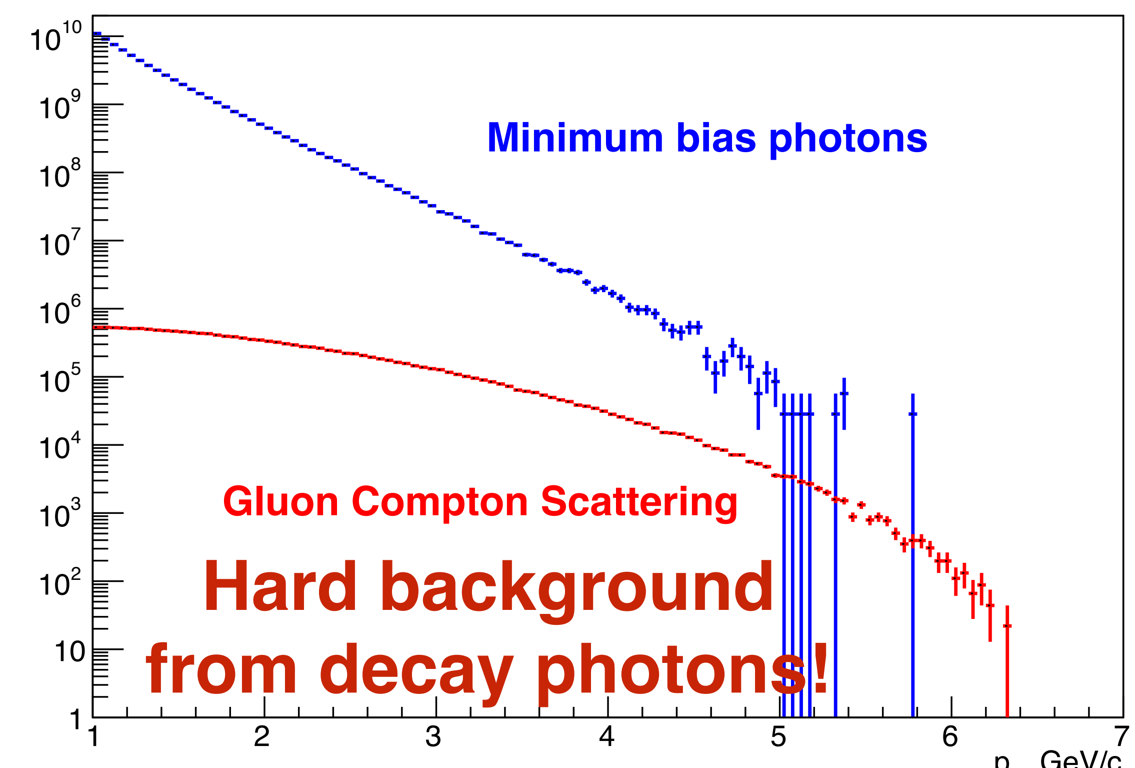


$$d\sigma_{AB} = \sum_{a,b=q,\bar{q},g} \int dx_a dx_b f_a^A(x_a,\mu^2) f_b^B(x_b,\mu^2) d\sigma_{ab\to\gamma X}(x_a,x_b,\mu^2).$$



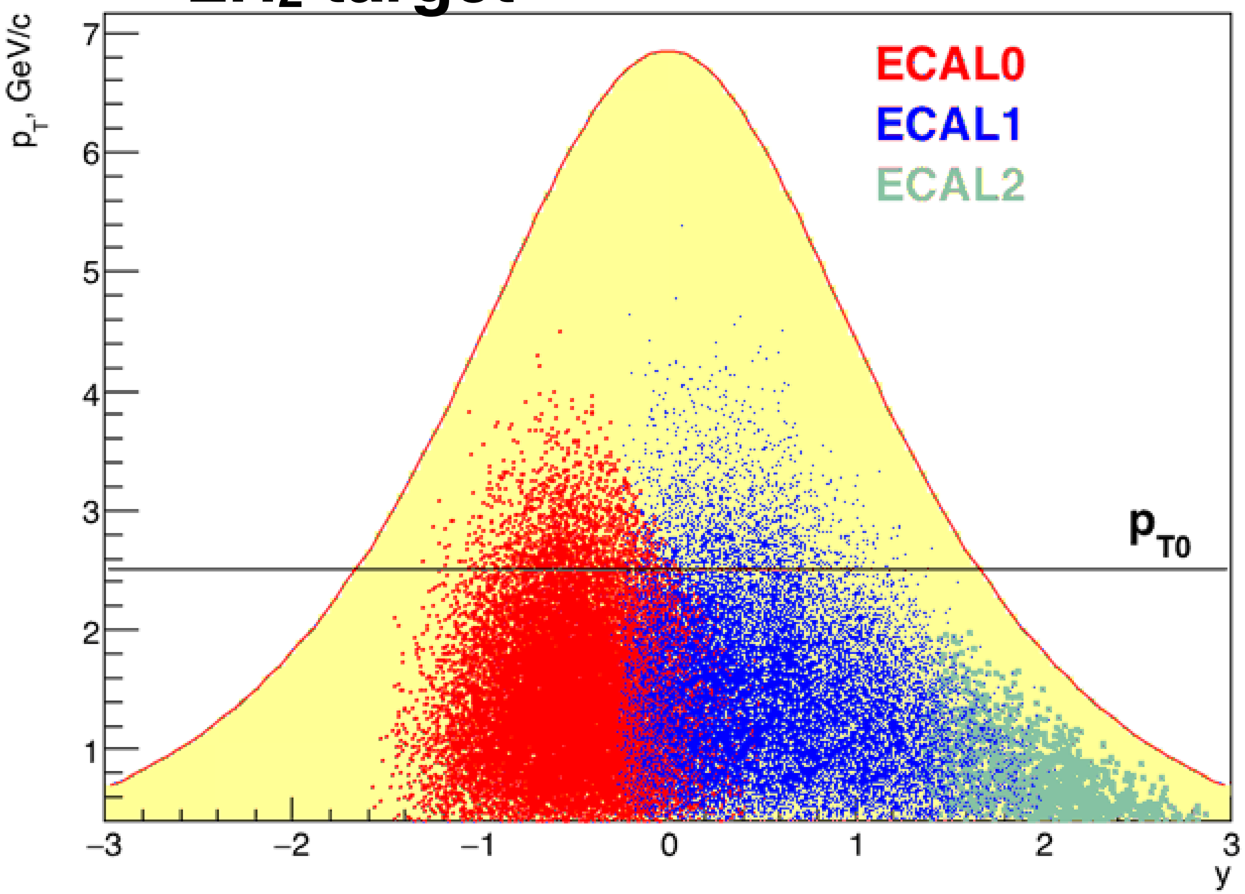
K+ for main sample, K–,π+,π– for reference and systematic studies.



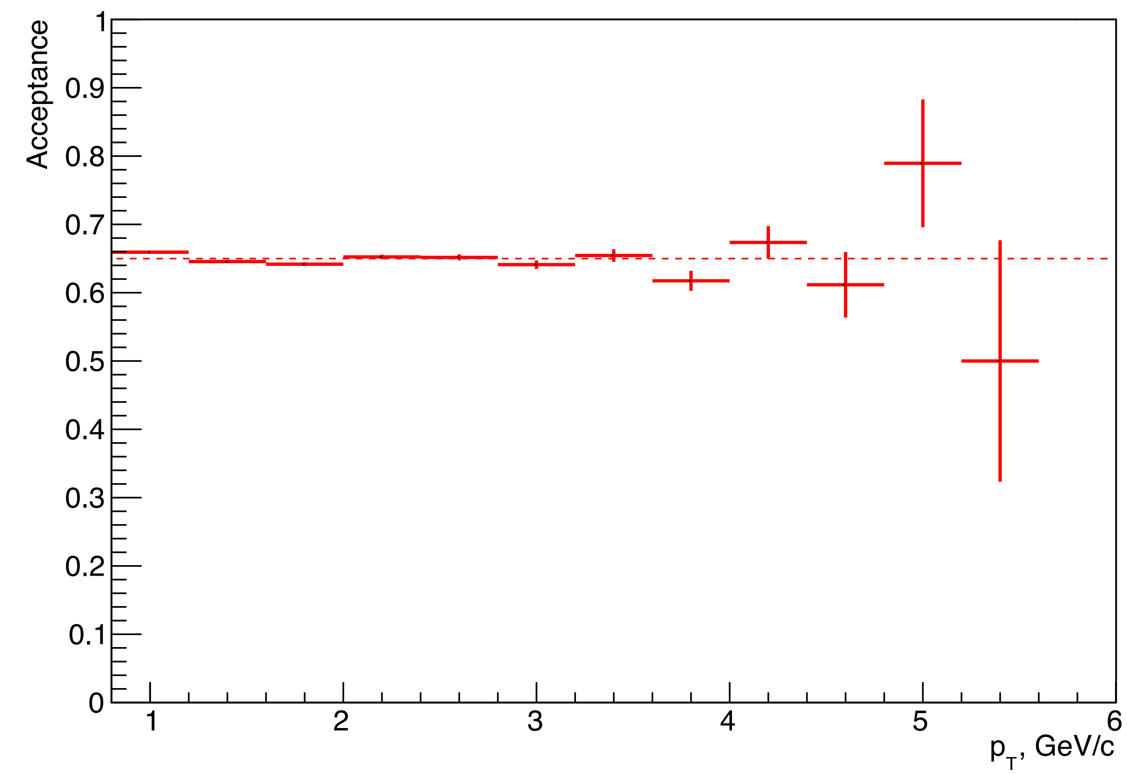


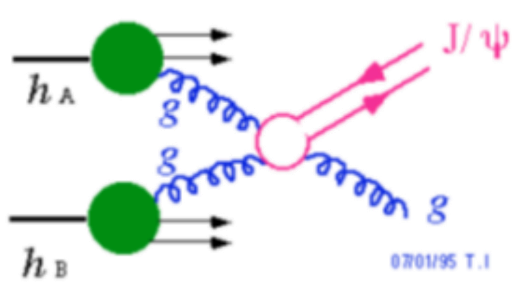
Gluon PDFs of kaon via prompt γ

LH_2 target

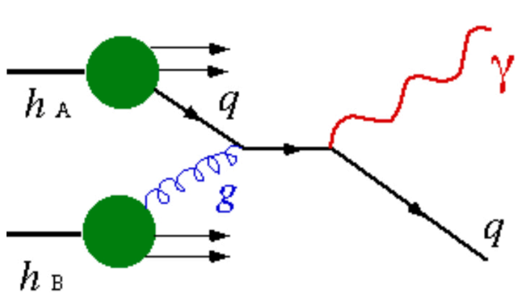


Flat acceptance in p_T





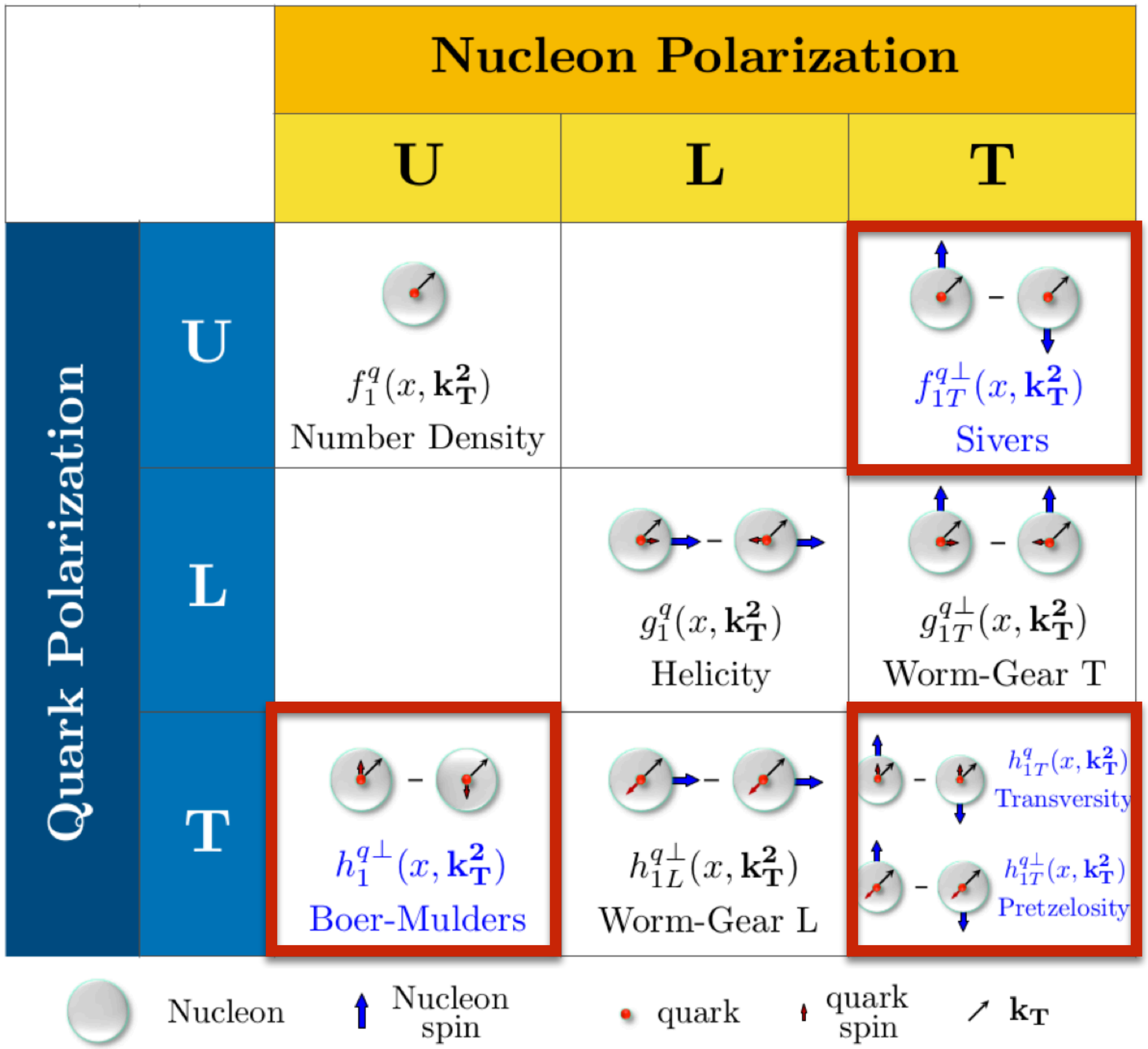
$x_{\pi,K} > 0.2$



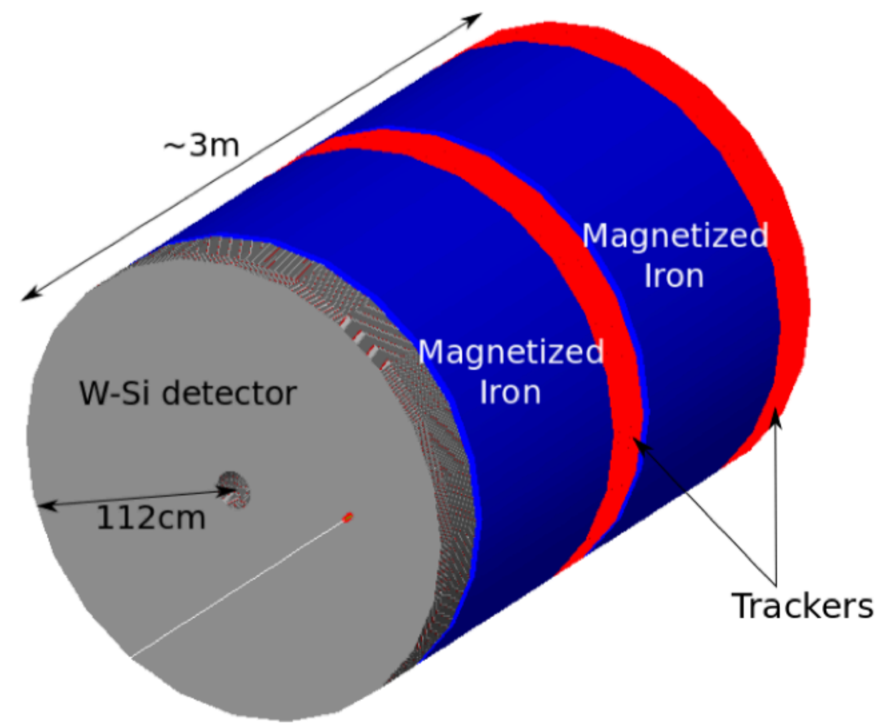
$x_{\pi,K} > 0.05$

Two different methods to touch g(x) — different systematics, different kinematic ranges.

Spin physics with antiproton beam



Antiproton beam and transversely polarised NH_3 target



Active absorber

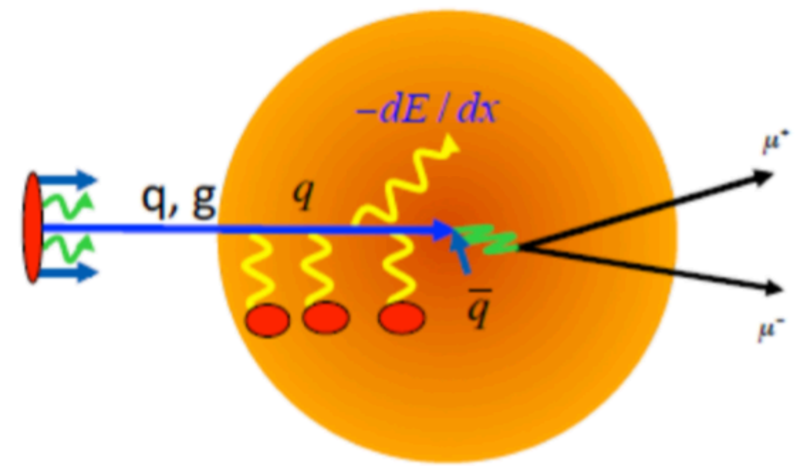
Experiment	Target type	Beam type	Beam intensity (part/sec)	Beam energy (GeV)	DY mass (GeV/c^2)	DY events $\mu^+\mu^-$	DY events e^+e^-
This exp.	110cm NH_3	$\bar{p}$	3.5×10^7	100	4.0 – 8.5	28,000	21,000
				120	4.0 – 8.5	40,000	27,300
				140	4.0 – 8.5	52,000	32,500

Nuclear effects in DY

Energy loss:

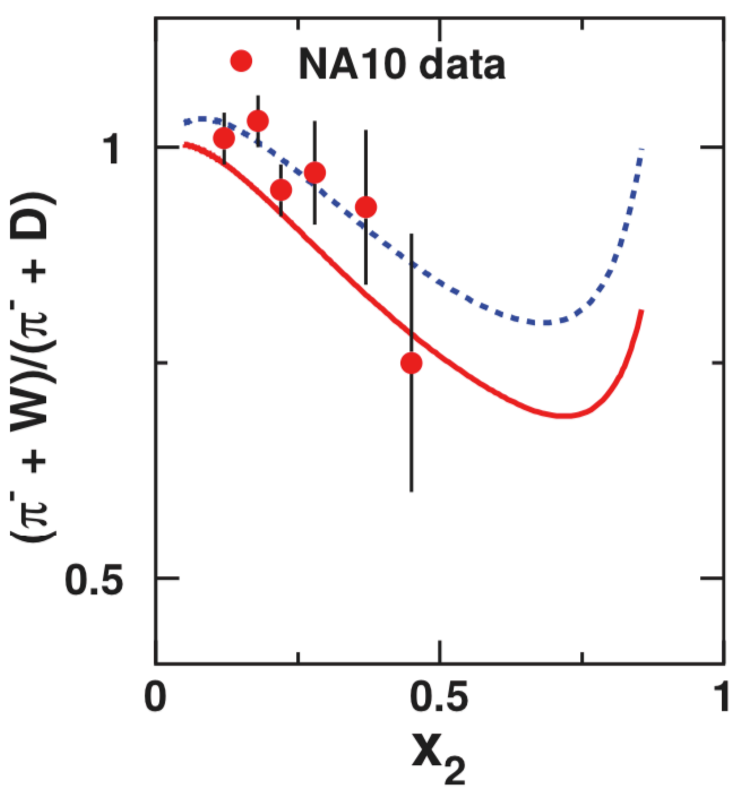
- Multiple scattering of incoming quark in large nuclei
- No energy loss in the final state

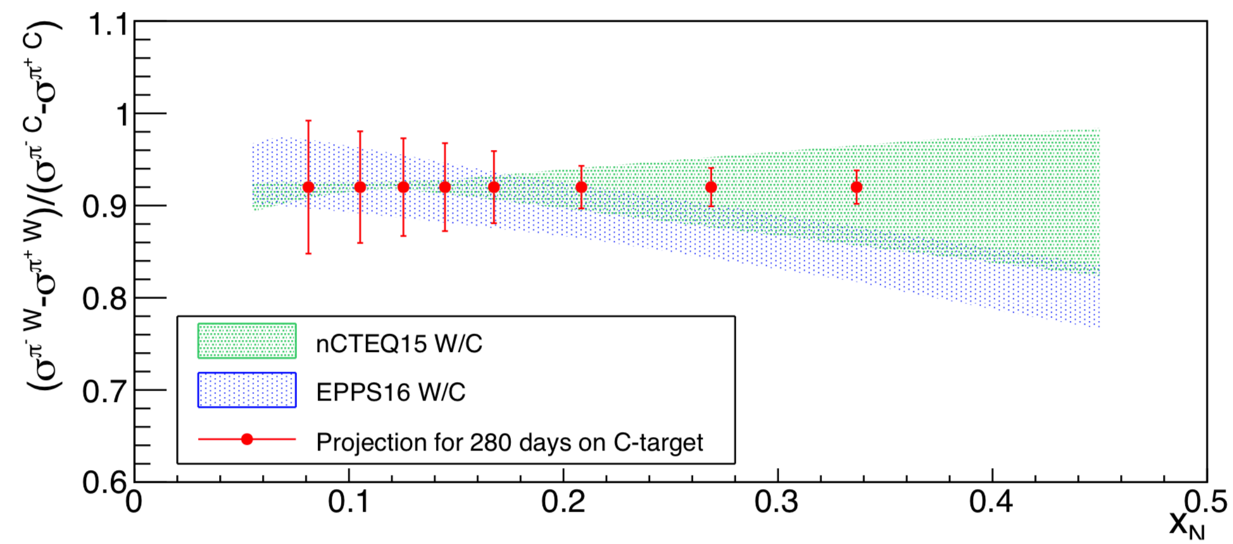
→ Comparison between DY and J/ψ complementary information



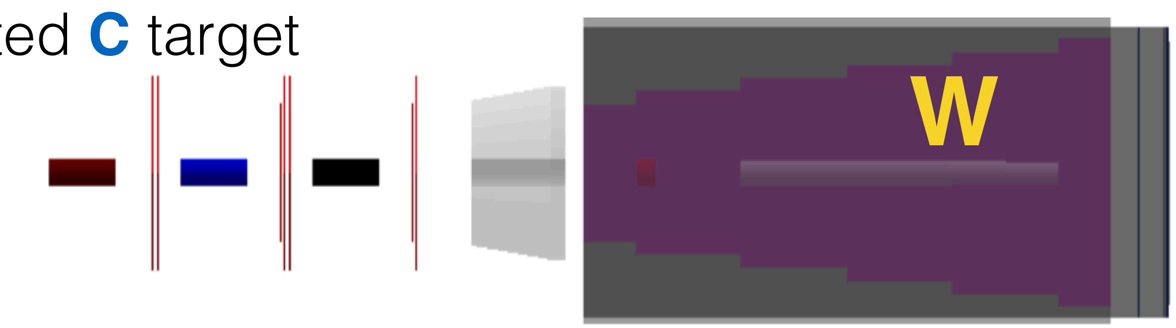
Flavour dependent EMC effect: Meson induced Drell-Yan process tags flavours

Using two π beam charges and two targets, one can add constraints on the EMC flavour dependence





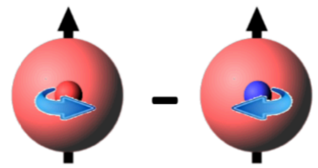
segmented **C** target



GPD E via DVCS and DVMP

$\mathbf{H}(x, \xi, t) \xrightarrow{t\to 0} q(x)$ or $f_1(x)$

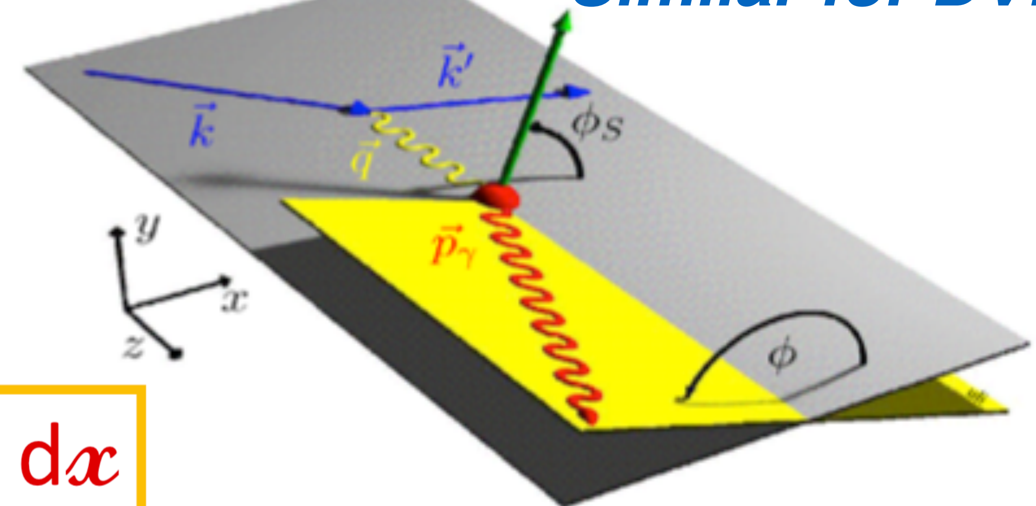
"Elusive"
$\mathbf{E}(x, \xi, t) \longleftrightarrow f_{1T}^{\perp}(x, k_T)$



Ji sum rule

$$J^q = \frac{1}{2} \lim_{t\to 0} \int \left(\mathbf{H}^q(x,\xi,t) + \mathbf{E}^q(x,\xi,t) \right) x\, dx$$

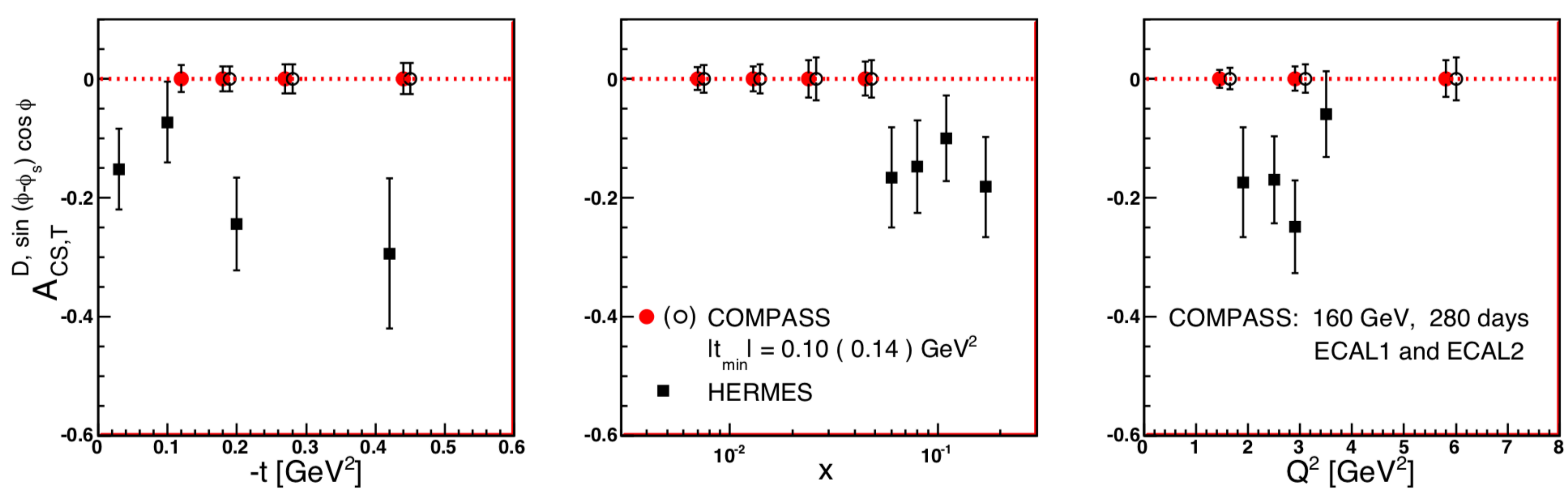
Similar for DVMP



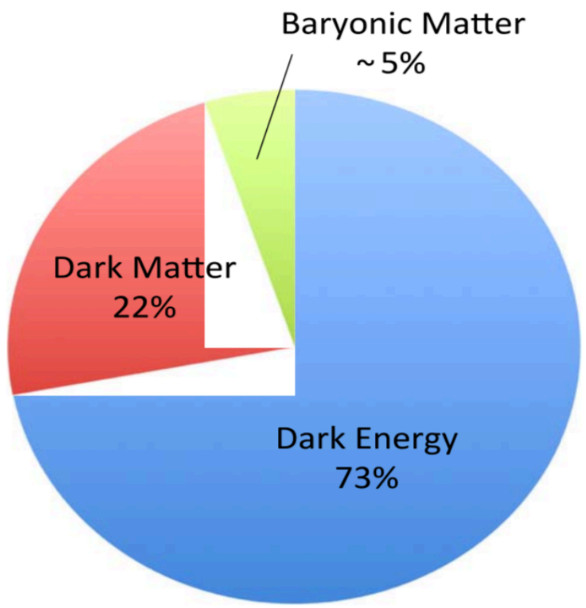
$$\mathcal{D}_{CS,T} \equiv \Delta\sigma_T(\mu^{+\downarrow}) - \Delta\sigma_T(\mu^{-\uparrow})$$
$$\rightarrow Im(F_2\mathcal{H} - F_1\mathcal{E}) \sin(\phi - \phi_s) \cos\phi$$

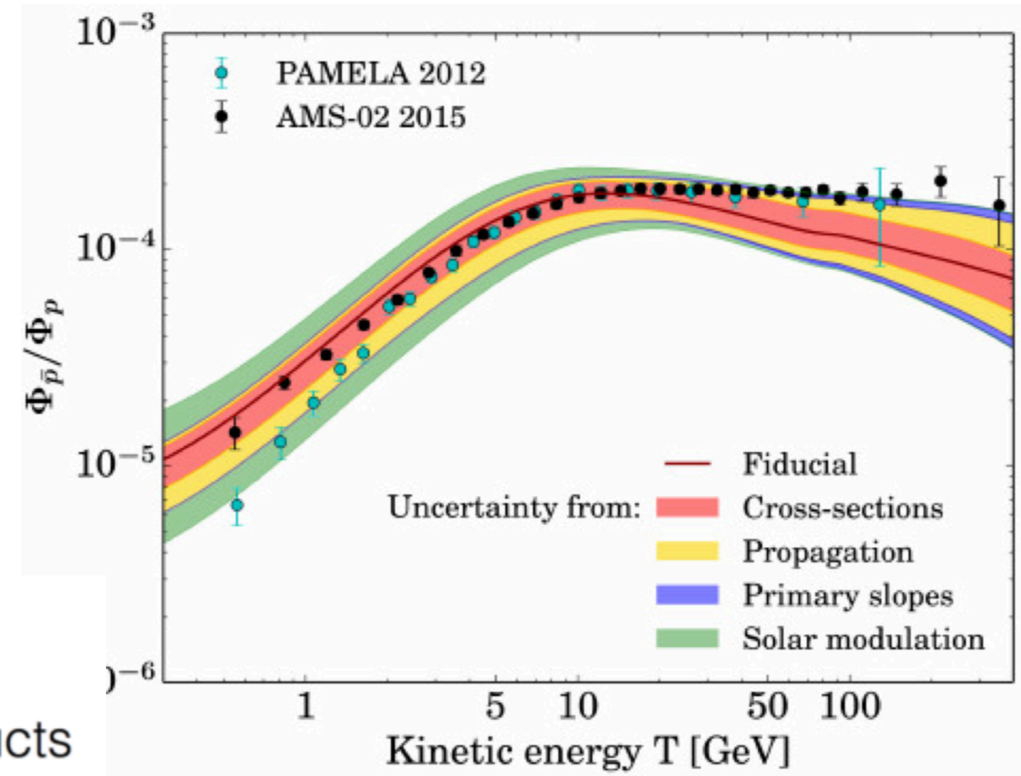
μ± beams
Transversely polarised NH_3 target
2 year of data taking

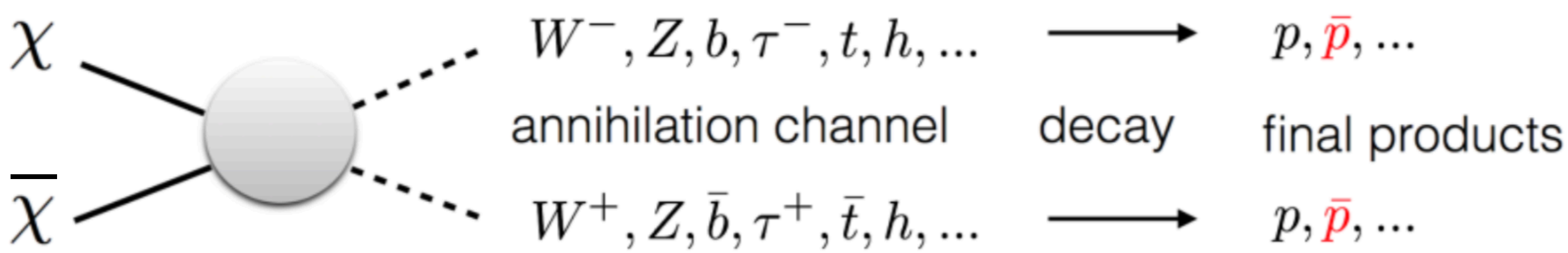
$$\mathcal{A}^{\sin(\phi-\phi_s)\cos\phi}_{\mathcal{D}_{CS,T}}$$



$\overline{p}$-yields for astrophysical dark matter search

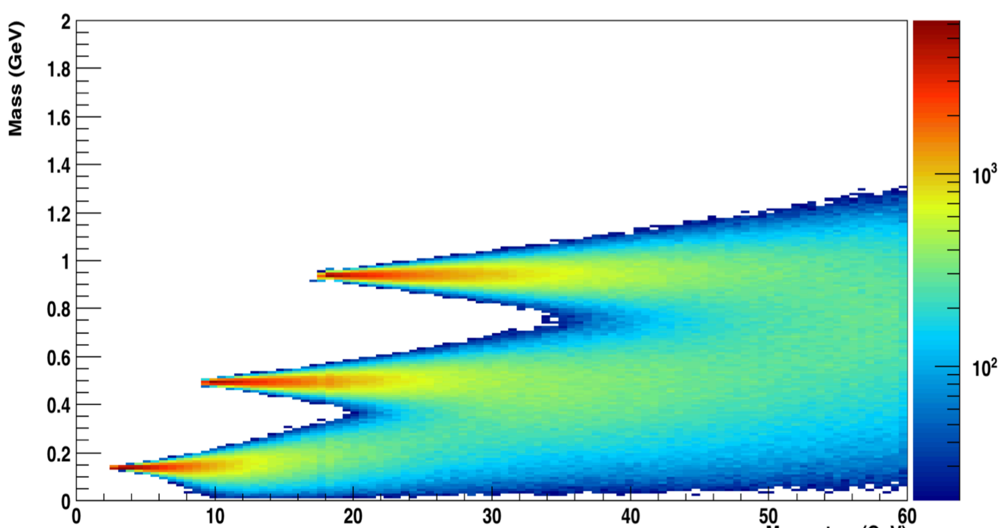






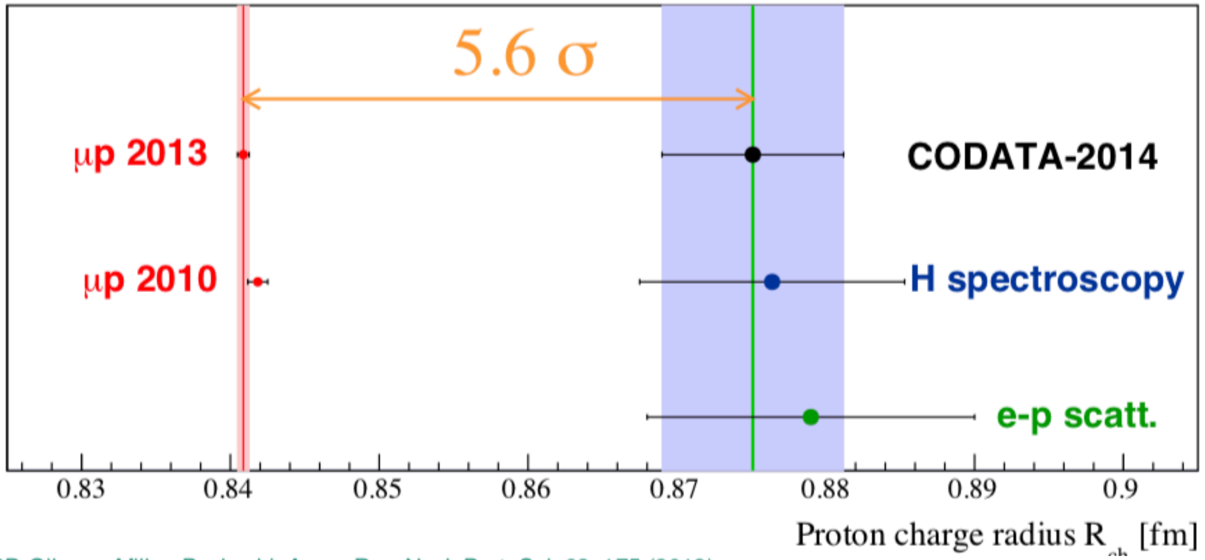
But the most of antiprotons are produced in interaction of primary CR with interstellar matter

$$\begin{cases} p + H \to \bar{p} + X & \sim 70\% \\ \alpha + H \to \bar{p} + X & \sim 25\% \\ p + He \to \bar{p} + X & \sim 4\% \\ \alpha + He \to \bar{p} + X & \sim 1\% \end{cases}$$

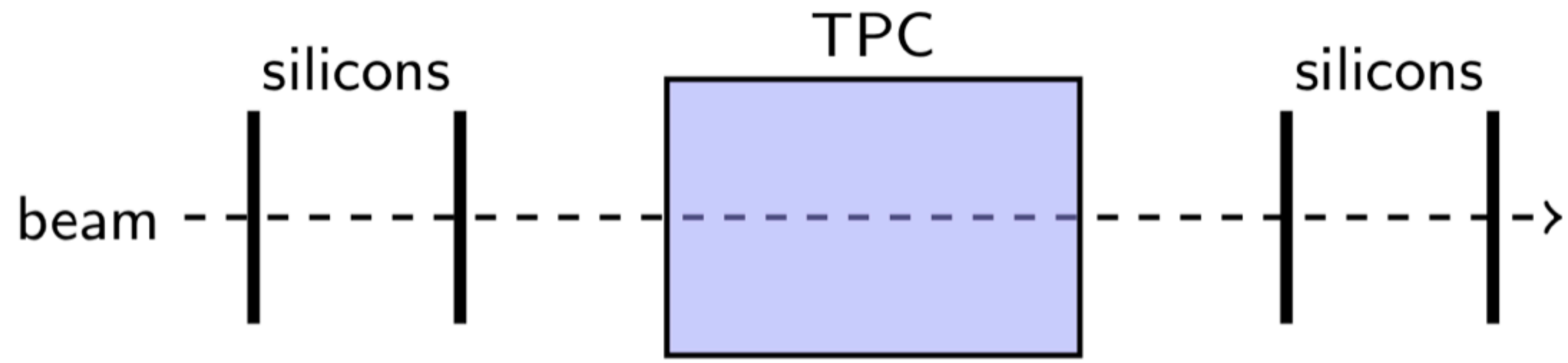


	pbar(18-45 GeV/c)	pbar (5-18 GeV/c)
p-p @ 0-280GeV/c	OK 2009 data @190GeV	RICH veto or RICH0
p-He @0-280GeV/c	new LHe target	RICH veto or RICH0

Proton radius measurement



RP, Gilman, Miller, Pachucki, Annu. Rev. Nucl. Part. Sci. 63, 175 (2013).

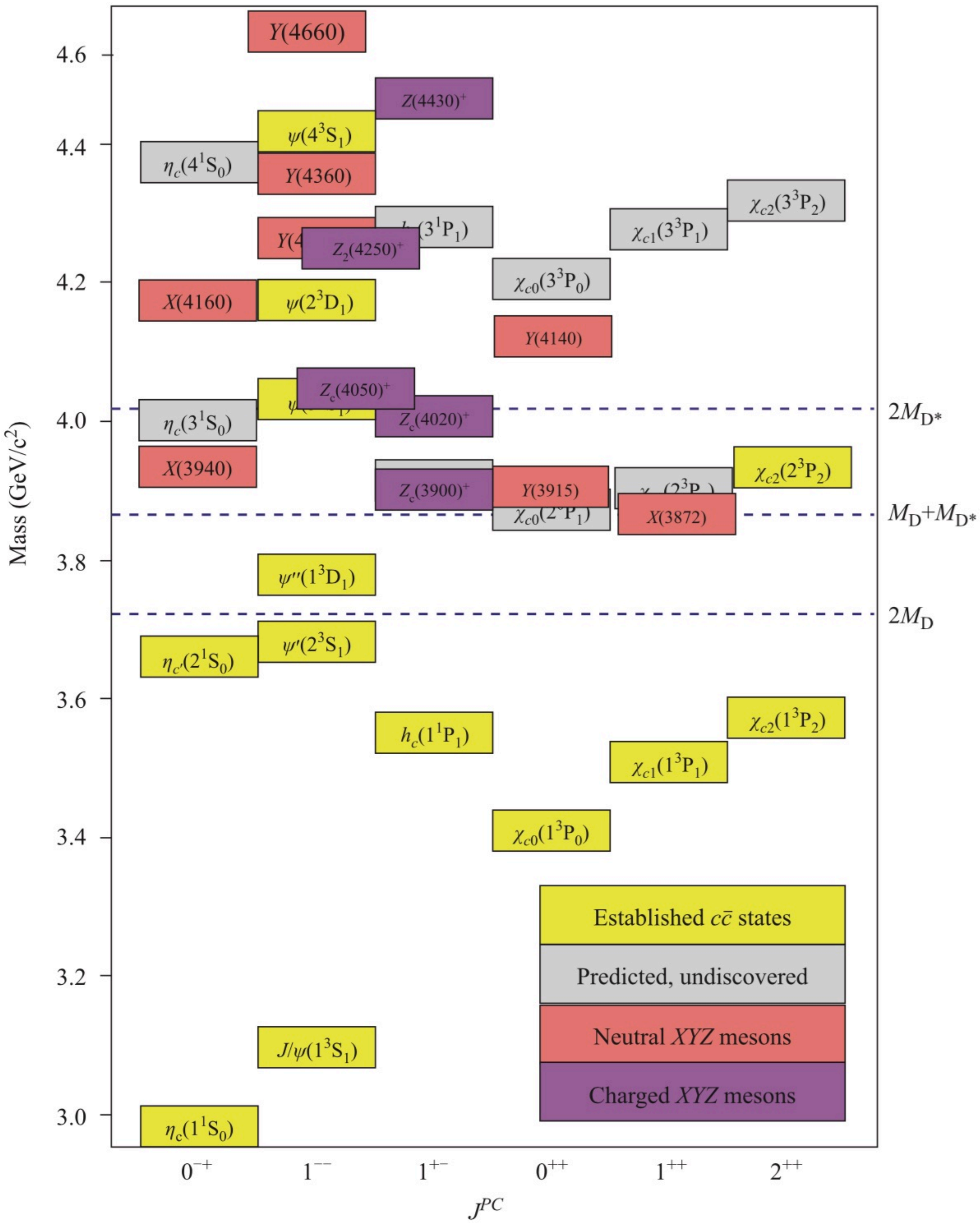


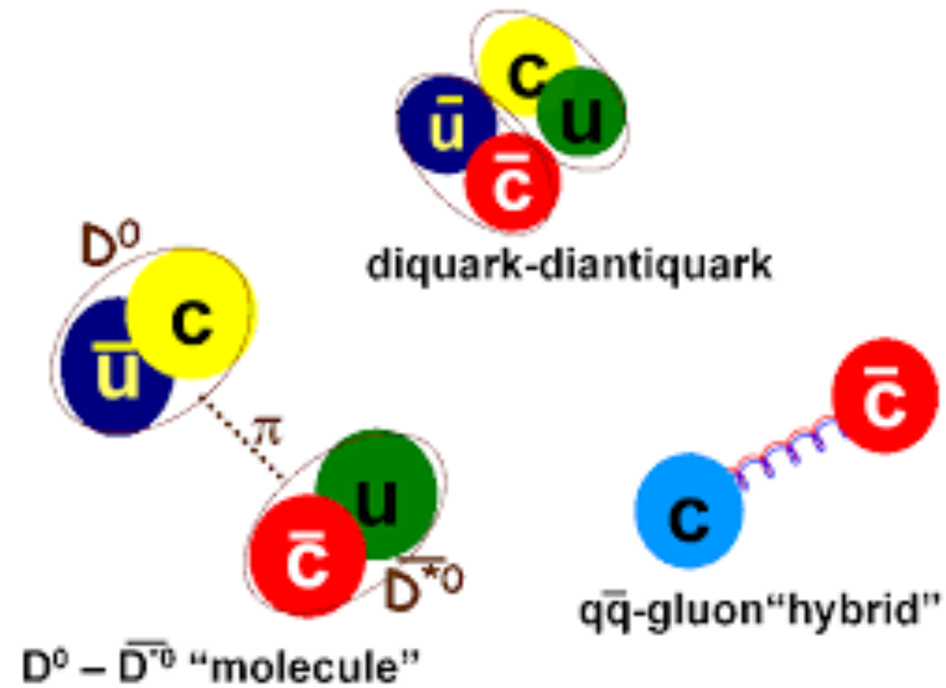
proposed set-up

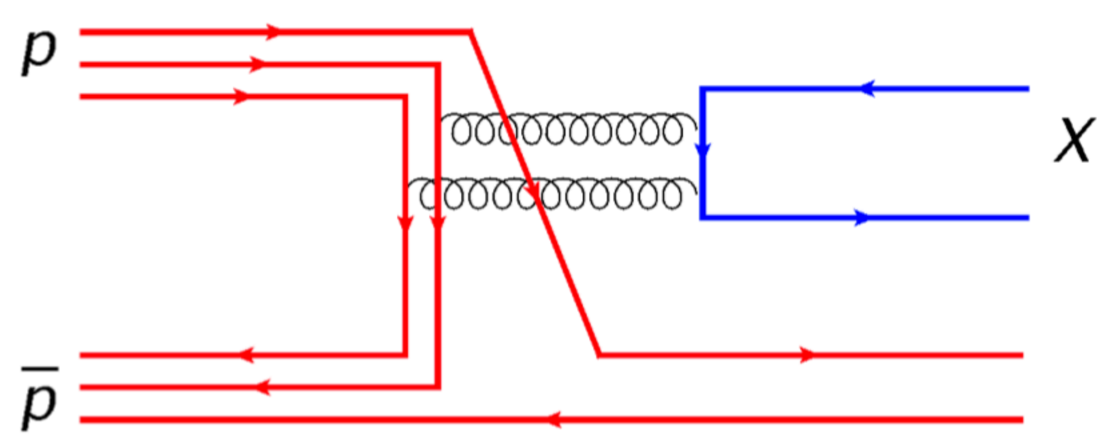
- hydrogen TPC acting as active target
  - measurement of energy of recoil proton
  - between 0.5 and 100 MeV
  - required resolution: $\Delta \approx 60$ keV)
- silicon telescopes up- and downstream of target
  - measurement of muon scattering angles
  - 300 μrad at $Q^2 \approx 10^{-3}$ $(\mathrm{GeV}/c)^2$
  - required resolution $\sigma \lessapprox 100$ μrad

uncertainty on $\sqrt{\langle r_E^2 \rangle} \approx 0.01$ fm

Charmonia via $p\bar{p}$ annihilation







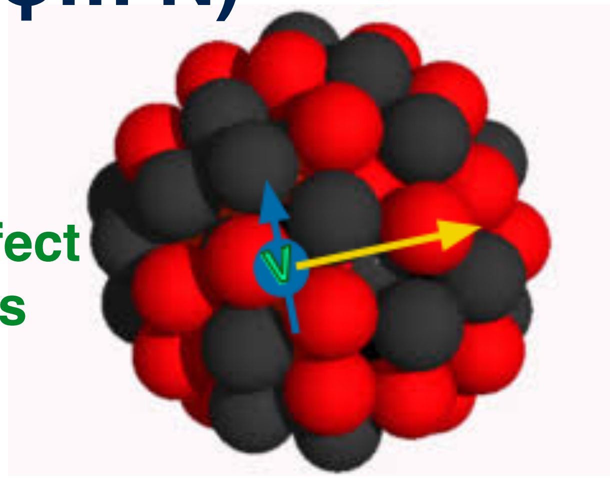
Wide spectrum of quantum numbers!

Vector mesons in nuclear matter

$\sigma_{L,T}=\sigma(V_{L,T}:\rho,\omega,\phi\ldots\ N)$

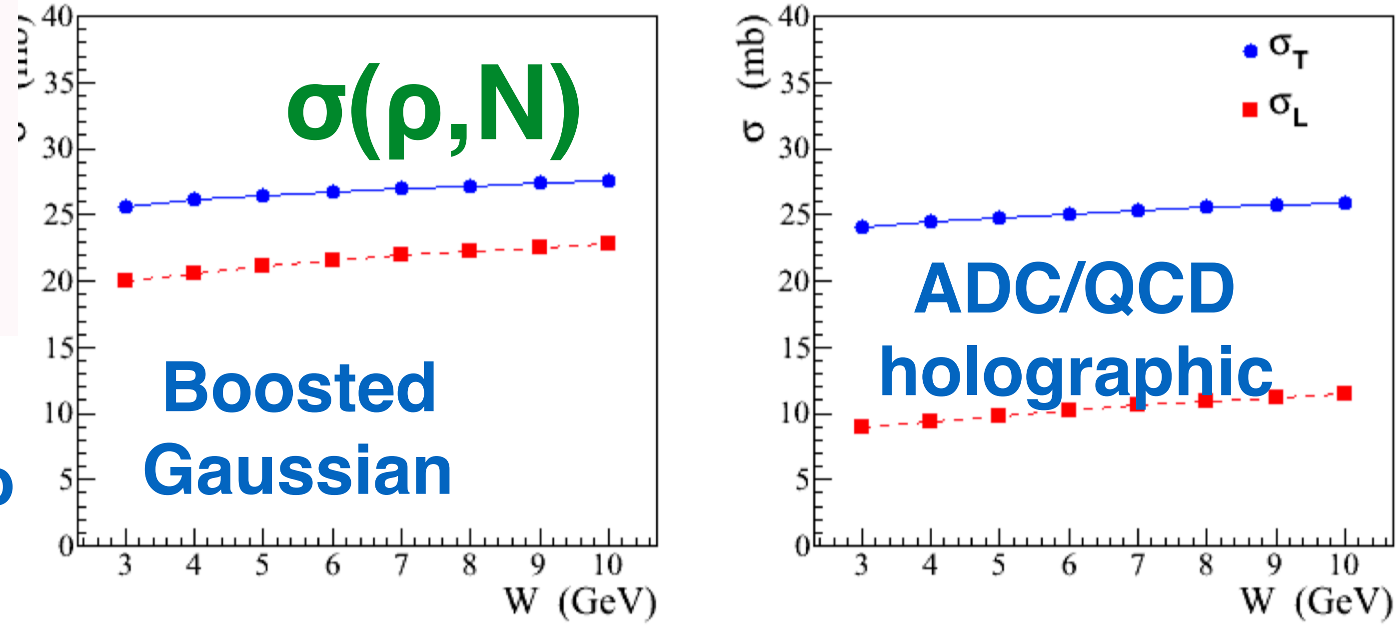
Important for:

- treating of the CT effect
- heavy ion collisions



Naive quark model: $\sigma_L=\sigma_T$

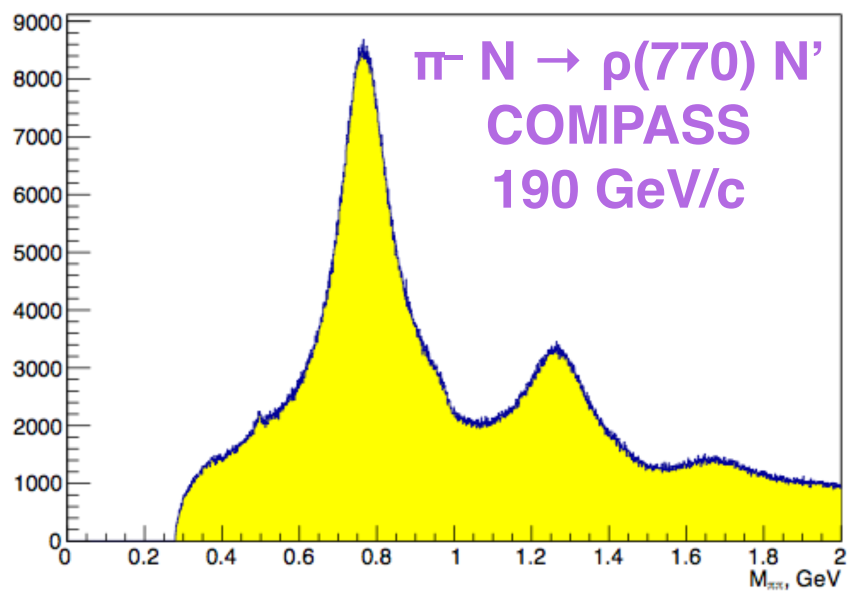
Color dipole model:



$\gamma A \rightarrow V A$ (coherent) – σ_T (proposed to be precisely measured at JLab)

$\pi^- A \rightarrow V A'$ – σ_L dominates (AMBER)

Running with the set of different nuclear targets (Be - Pb). No special requirement for the spectrometer. Running in parasitic mode is also possible.



xclusive charge exchange reactions:

$K^- A \rightarrow K^*(892) A'$

$\pi^- A \rightarrow \rho(770) A'$

$\pi^- A \rightarrow f_2(1270) A'$

…

Low-energy QCD with RF-separated hadron beam

Kaon polarizability

$_\chi$PT prediction $O(p^4)$:

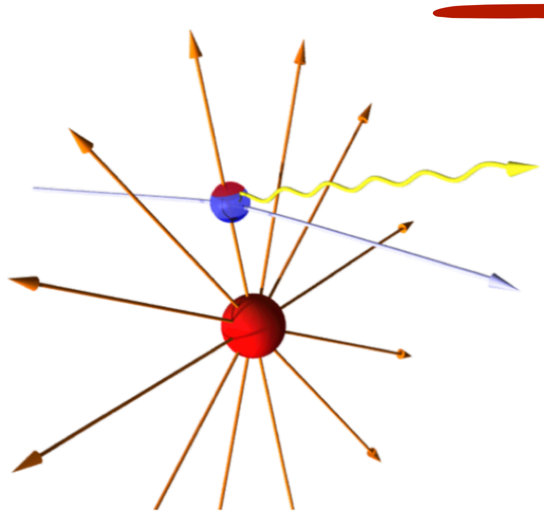
$$\alpha_K + \beta_K = 0$$

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

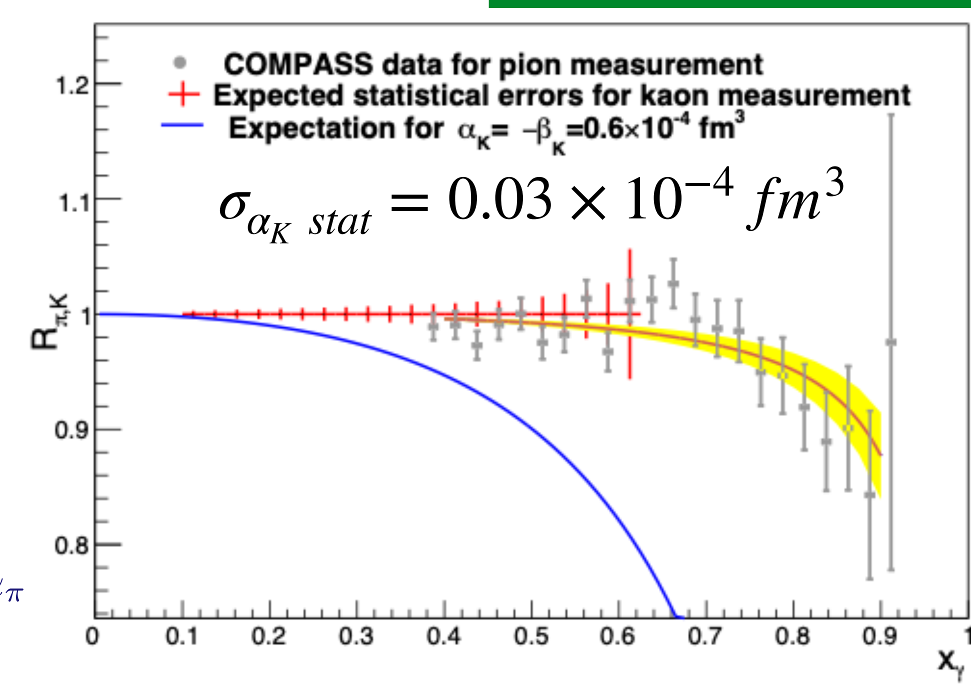
Quark confinement model:

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

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

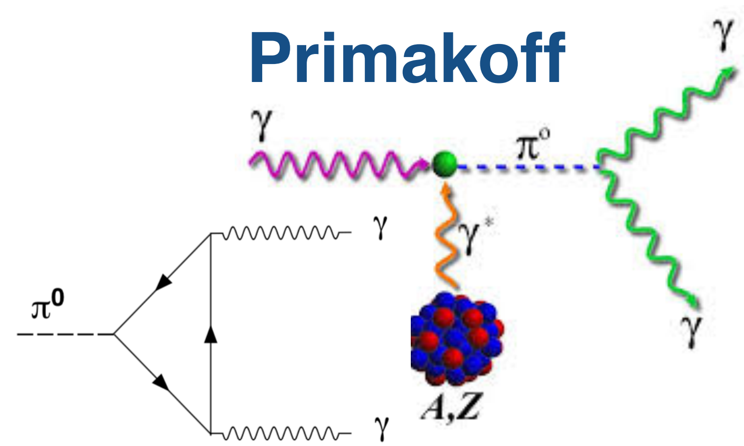


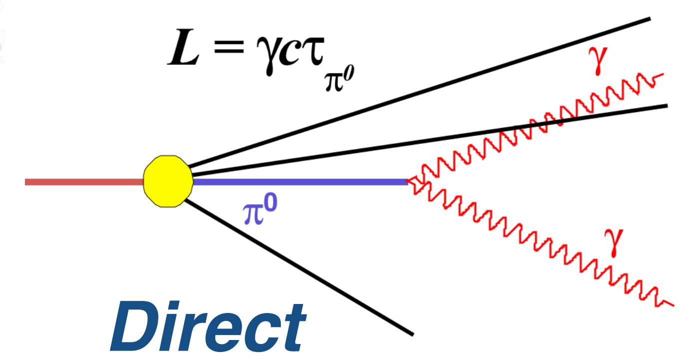
$$\mathrm{R} = \frac{\sigma}{\sigma_{\mathrm{p.l.}}} \approx 1 - \frac{3}{2} \cdot \frac{\mathrm{x}_\gamma^2}{1 - \mathrm{x}_\gamma} \cdot \frac{\mathrm{m}_\pi^3}{\alpha} \cdot \alpha_\pi$$

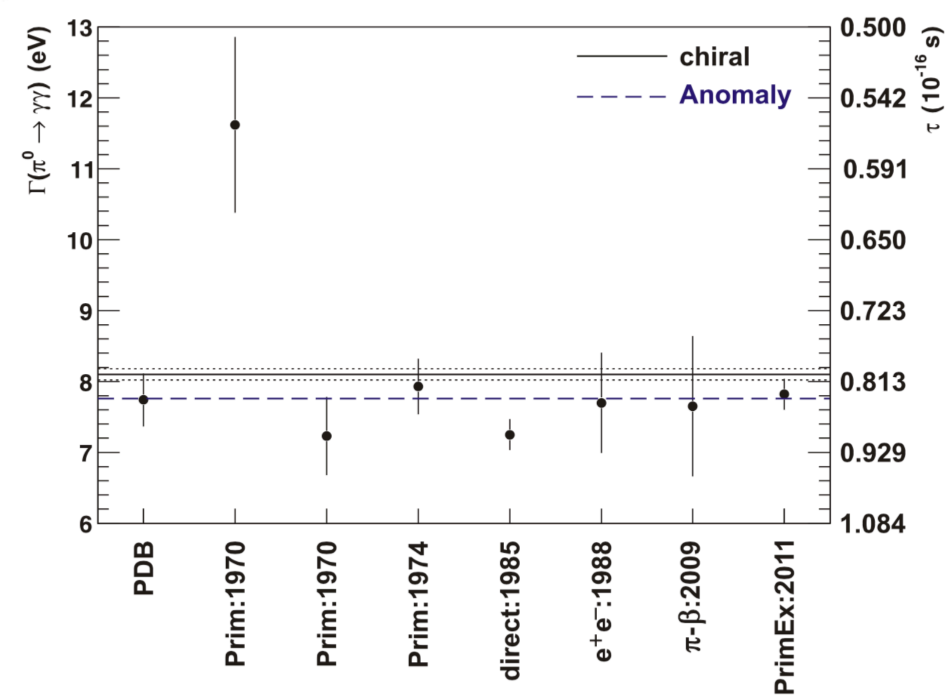


π^0 lifetime

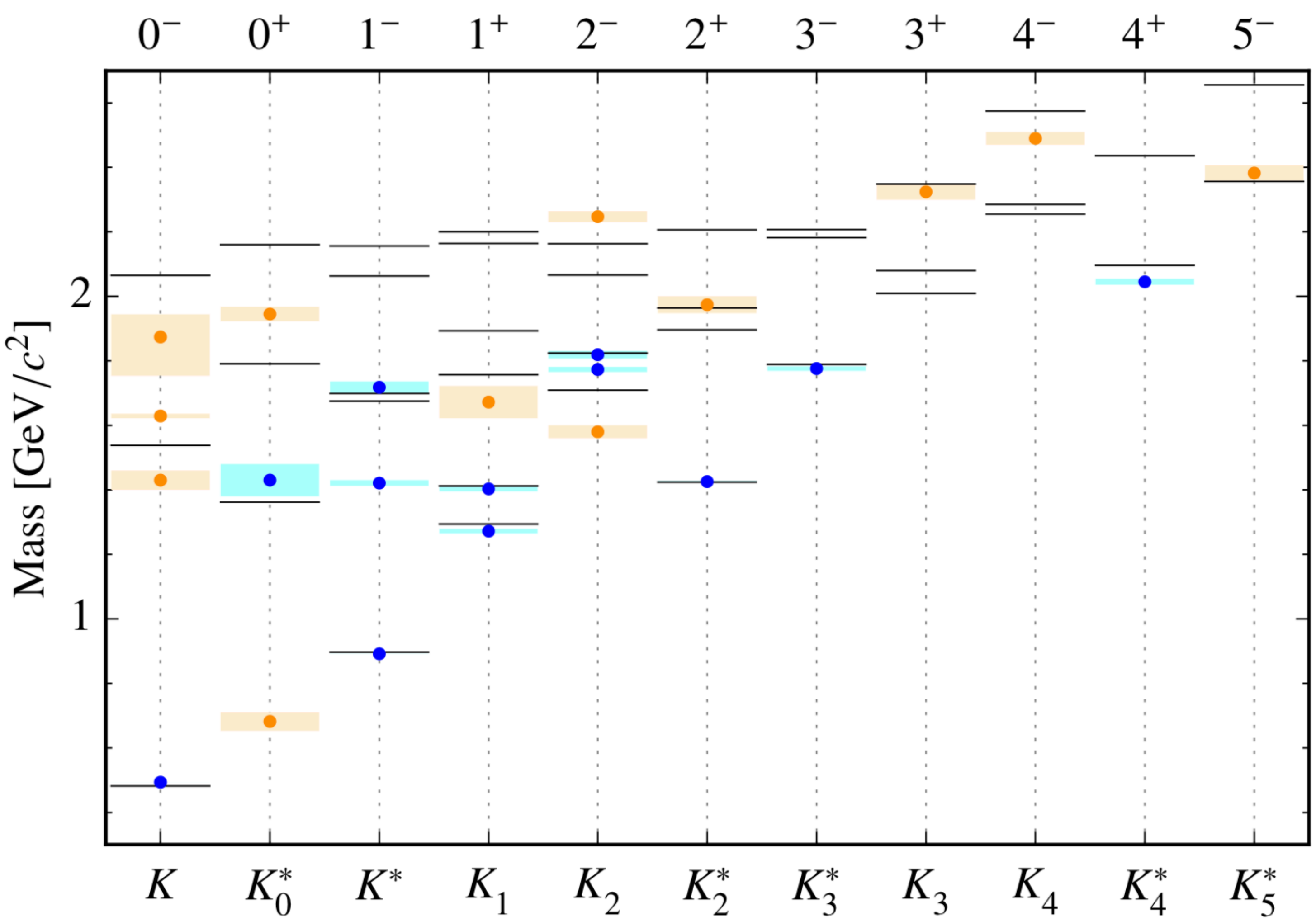
VALUE (10^{-17} s)	EVTS	DOCUMENT ID		TECN	COMMENT
8.52±0.18 OUR AVERAGE		Error includes scale factor of 1.2.			
8.32±0.15±0.18		[1] LARIN	11	PRMX	Primakoff effect
8.5 ±1.1		[2] BYCHKOV	09	PIBE	$\pi^+ \rightarrow e^+ \nu \gamma$ at rest
8.4 ±0.5 ±0.5	1182	[3] WILLIAMS	88	CBAL	$e^+ e^- \rightarrow e^+ e^- \pi^0$
8.97±0.22±0.17		ATHERTON	85	CNTR	Direct measurement
8.2 ±0.4		[4] BROWMAN	74	CNTR	Primakoff effect

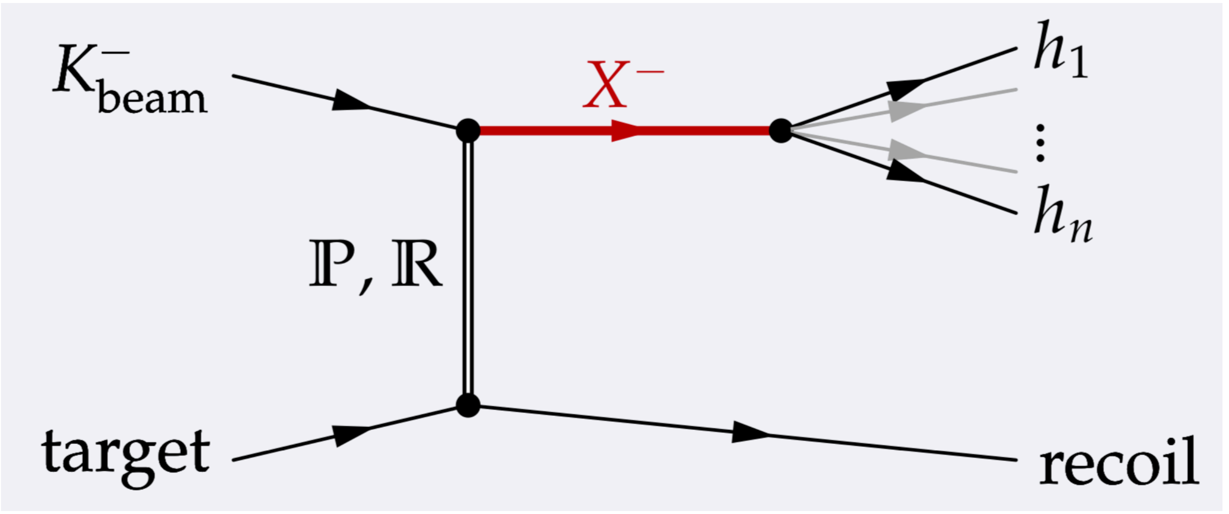






Kaon spectroscopy with kaon beam





- Most PDG entries more than 30 years old
- Since 1990 only 4 kaon states added to PDG

We intend to rewrite completely the kaon section of PDG

SUMMARY

COMPASS++/AMBER is a planned fixed-target facility at CERN with an extended physics program which partially overlaps with the SPD physics program.

Experience of the COMPASS++/AMBER project could be used by the SPD project