COMPASS++/AMBER long-term plans

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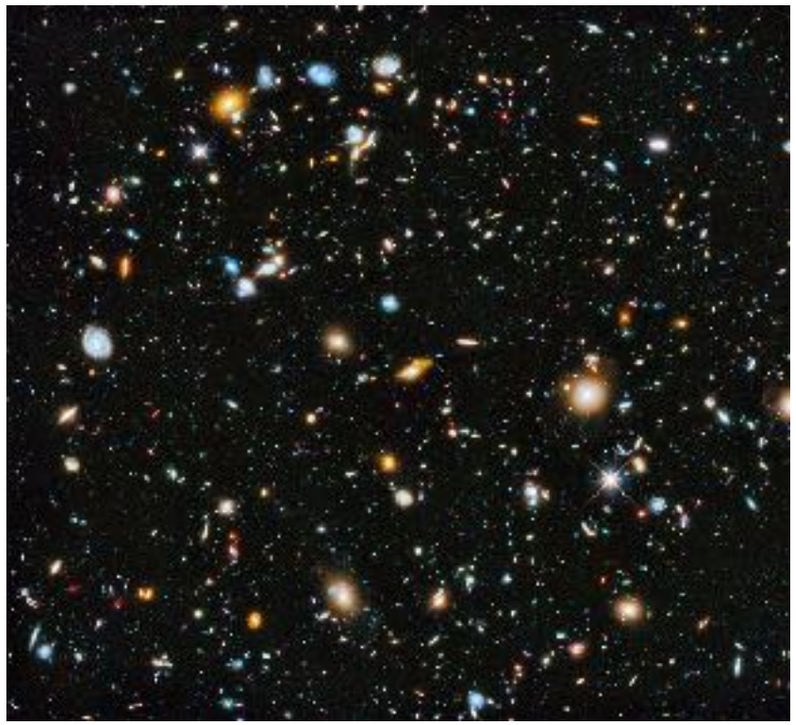
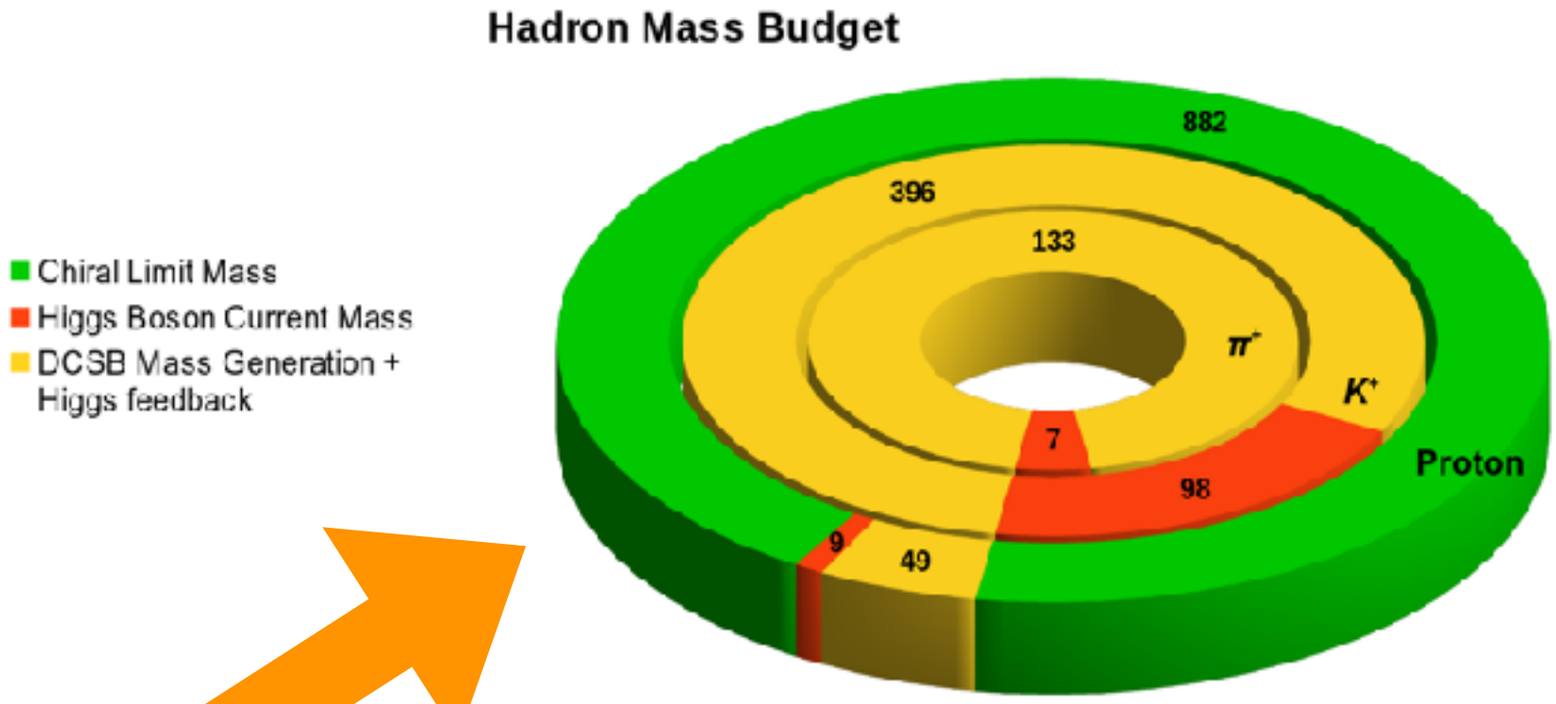
on behalf of the COMPASS++/AMBER collaboration

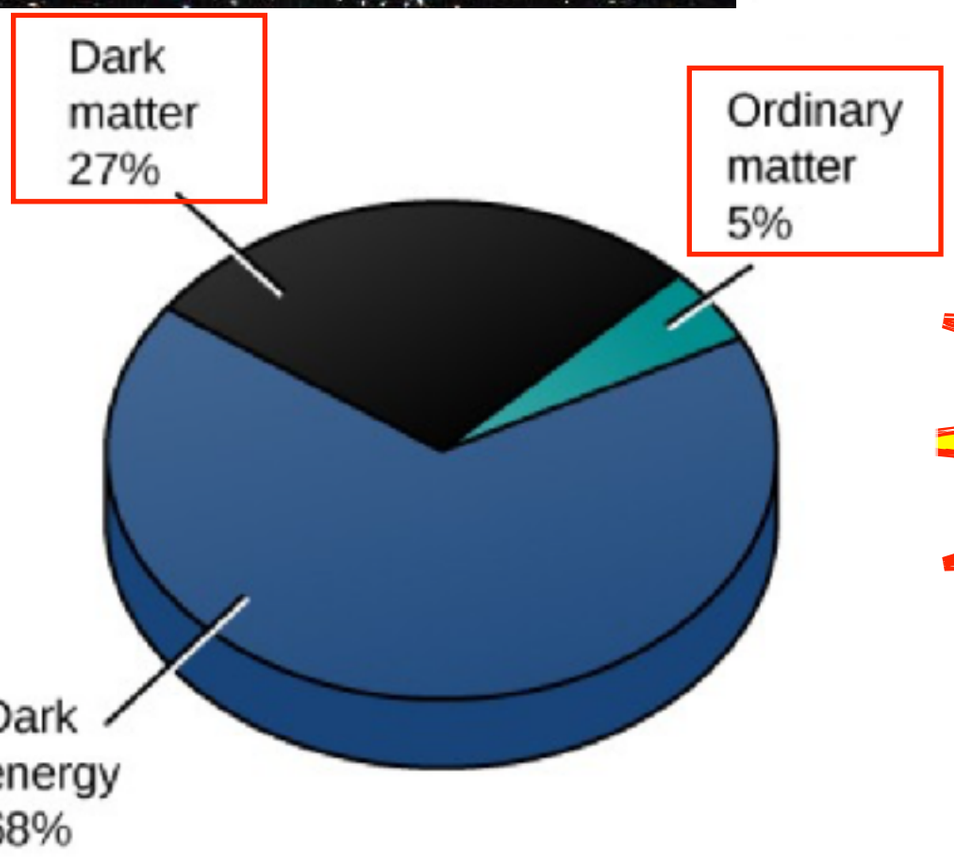
1.3.2021

Physics Beyond Collider Working Group meeting

MASS IN THE UNIVERSE

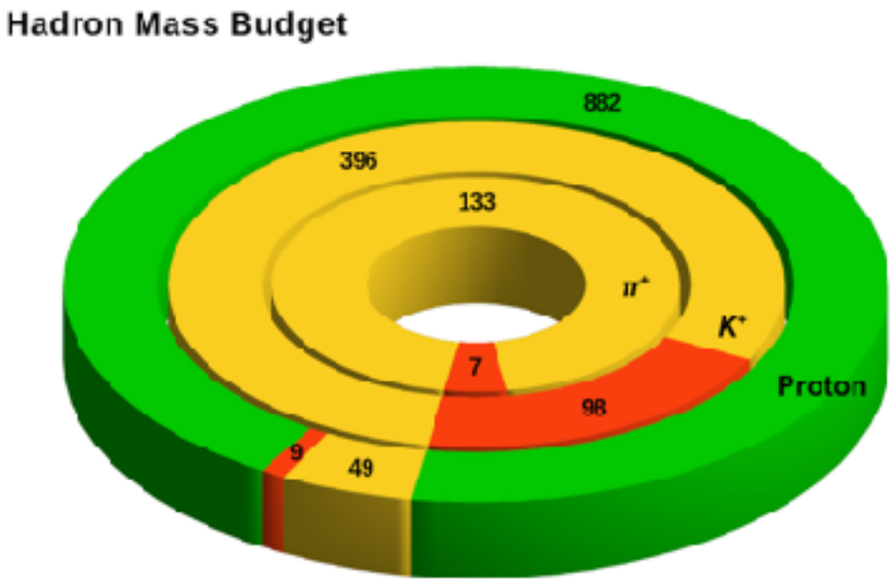






COMPASS++/AMBER

EMERGENCE OF HADRON MASS



Higgs mechanism is a minor contributor to the mass of hadrons!

- Chiral Limit Mass
- Higgs Boson Current Mass
- DCSB Mass Generation + Higgs feedback

➢ What is the origin of EHM?

➢ Does it lie within the Standard Model, i.e., within QCD?

➢ What are the connections with …
- Gluon and quark confinement?
- Dynamical chiral symmetry breaking (DCSB)?
- Nambu-Goldstone modes = π & K?

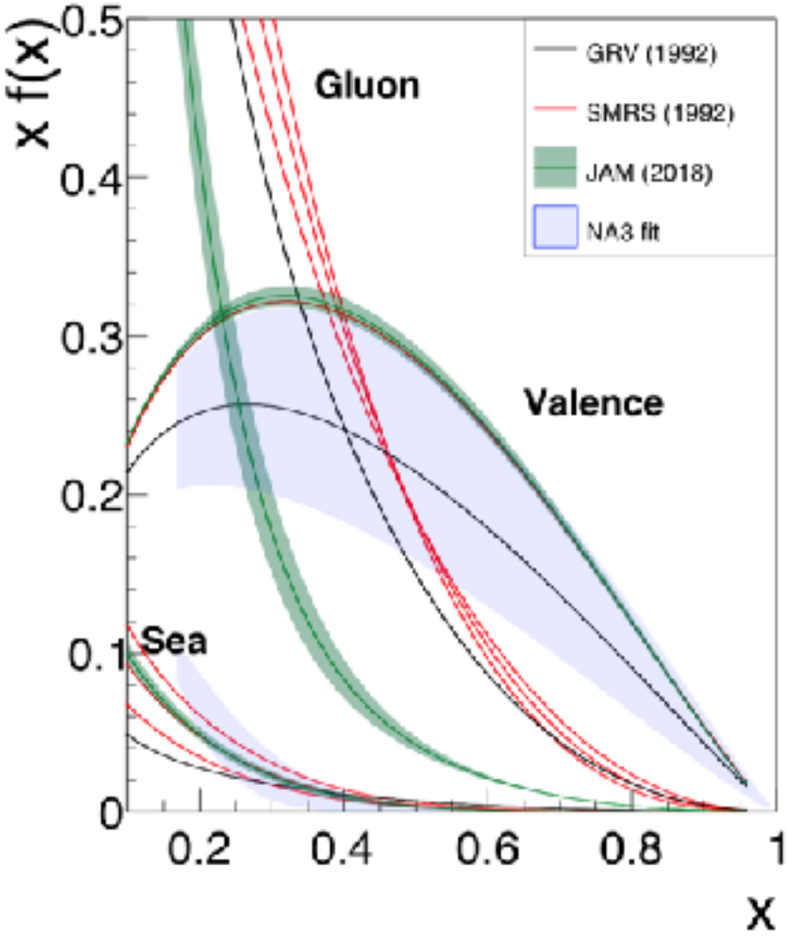
➢ What is the role of Higgs in modulating observable properties of hadrons?
- Critically, without Higgs mechanism of mass generation, π and K would be indistinguishable

➢ What is and wherefrom mass?

Experiment:

PDFs
Form-factors and radii
Polarizabilities
Hadronic spectra
…

STATUS OF MESON PDFs



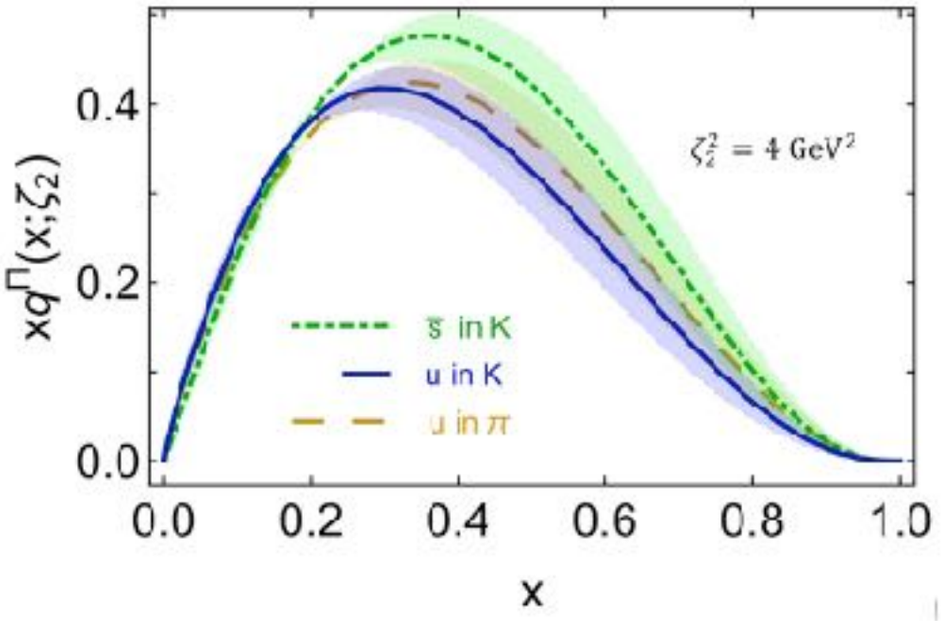
GRV (1992) *set of pion PDFs: Drell-Yan, charmonia and prompt photon production experiments (**E615, NA10, WA70, NA24**).*

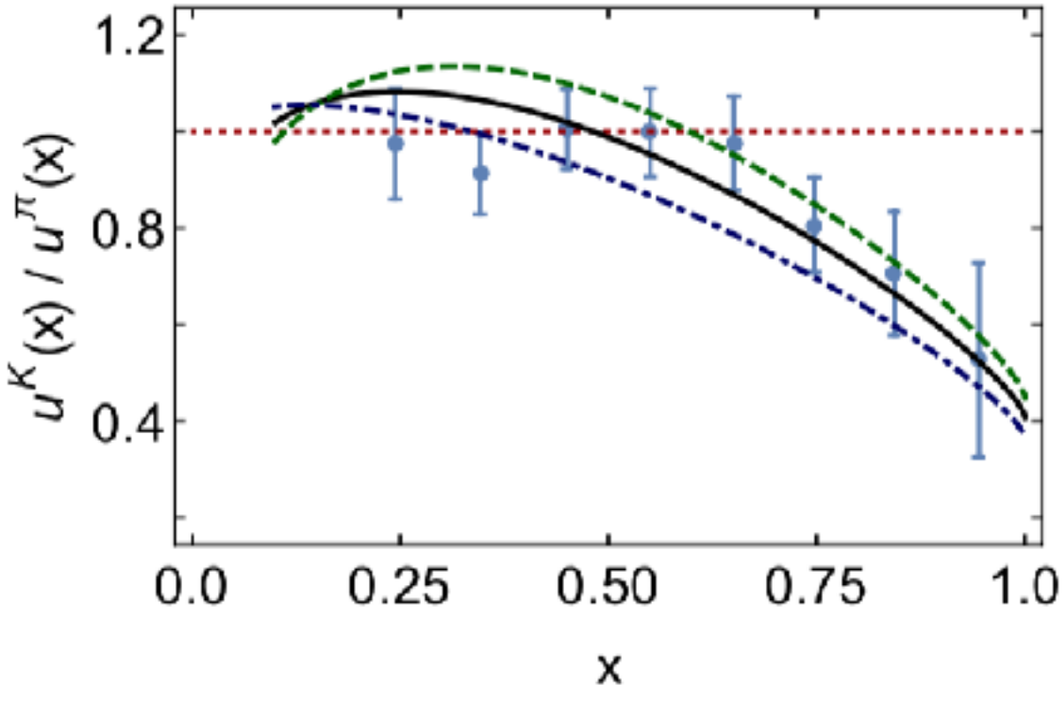
SMRS (1992)*: basically the same old data.*

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

XFITTER (2020) - reanalysis of existing data

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

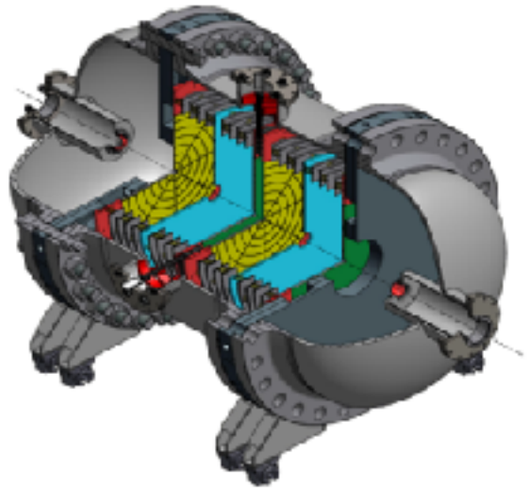


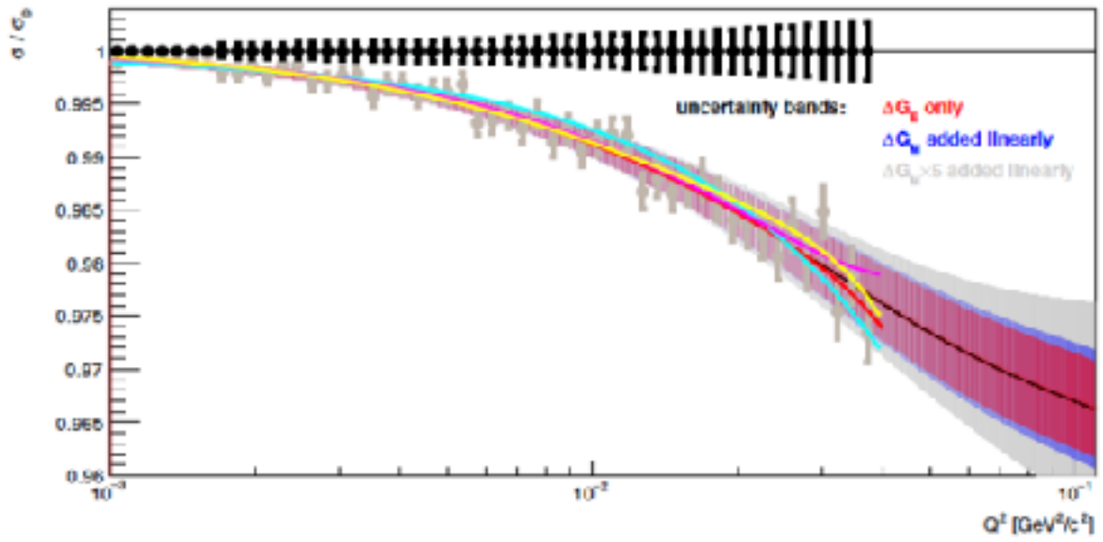


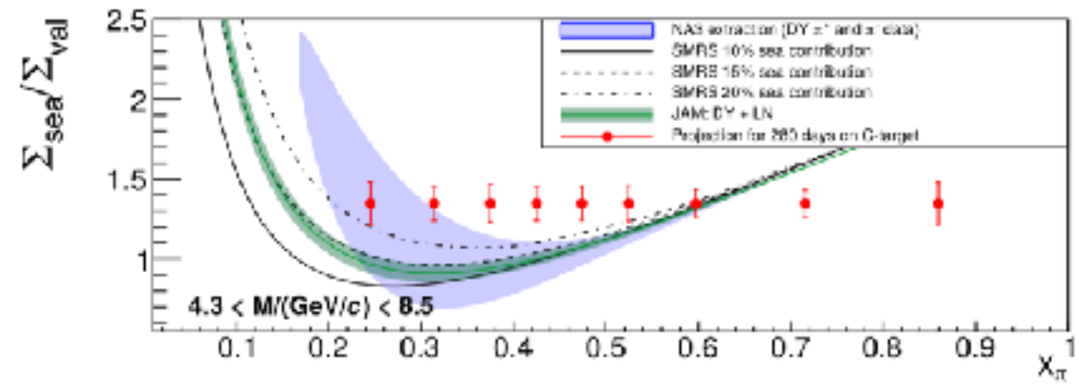
Apparatus for Meson and Baryon Experimental Research — a new QCD facility at the M2 beam line of the CERN SPS

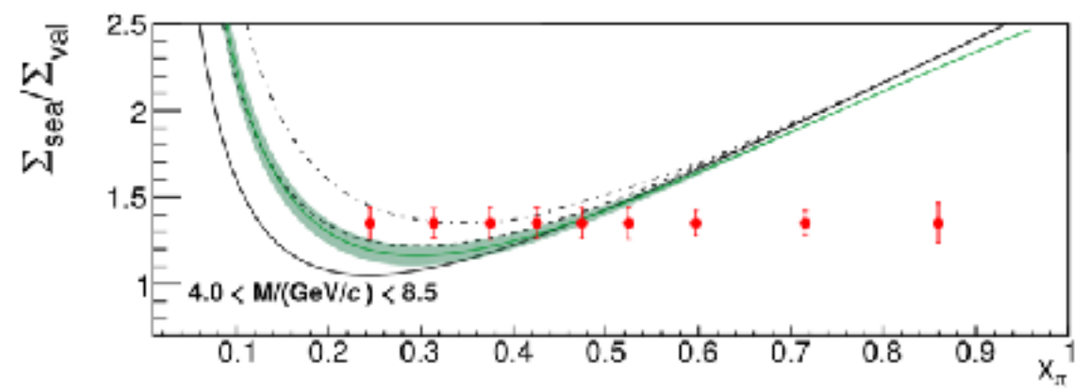
PHASE-1 (APPROVED)

- Proton radius measurement with muon beam and TPC as active target





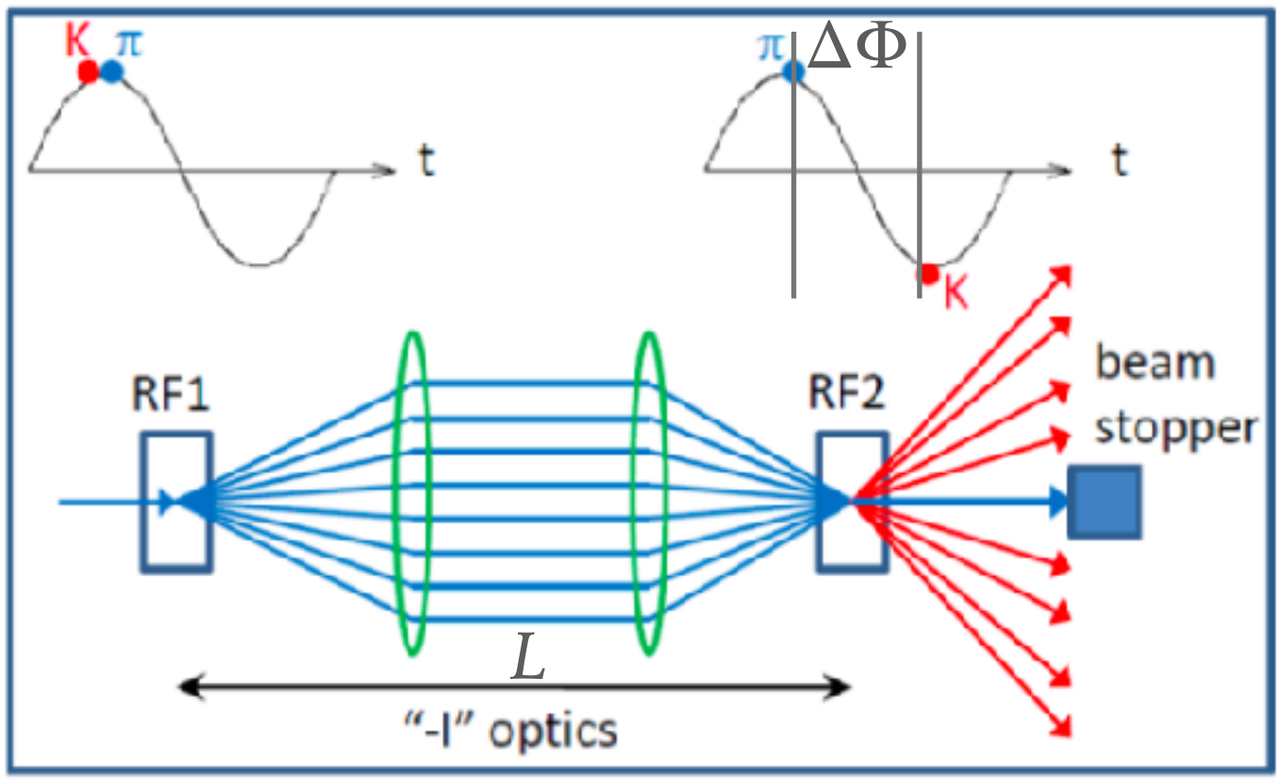


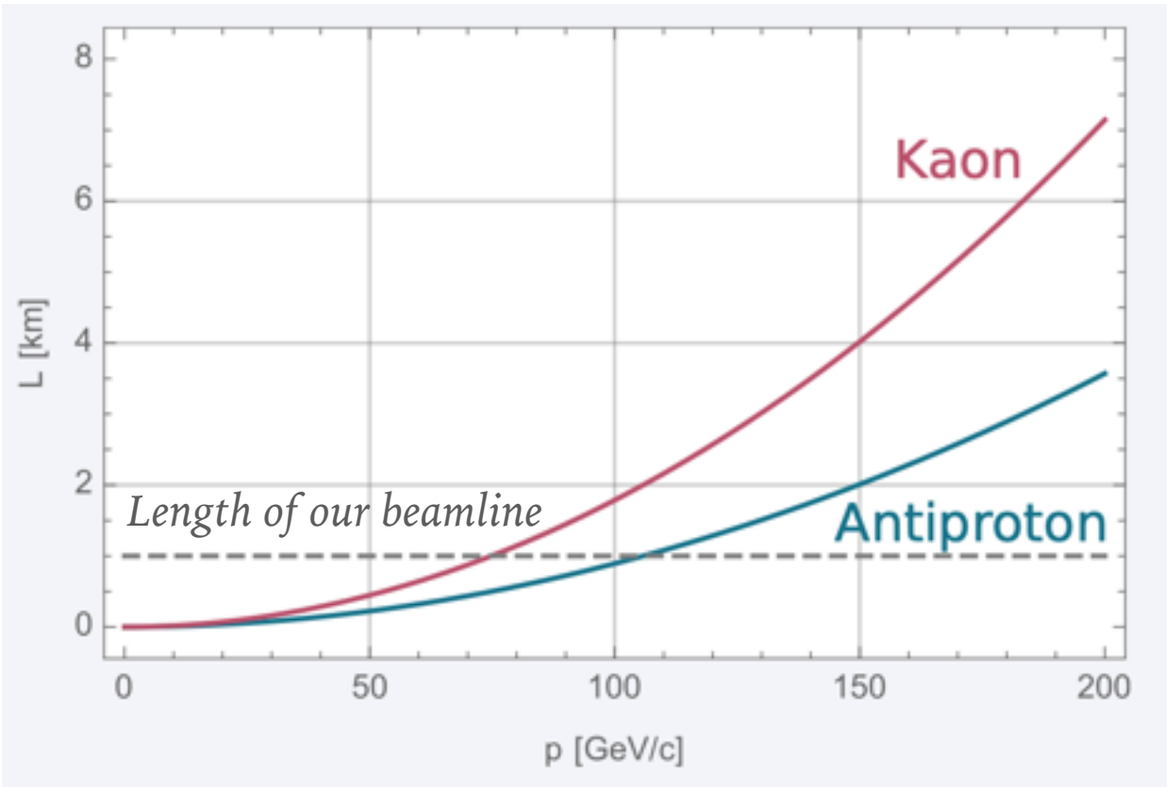


- Pion-induced Drell-Yan and charmonia production with both π^+ and π^-

- Antiproton production yield — input for astrophysical search for Dark Matter

RF-SEPARATED HADRON BEAM FOR AMBER





$$\Delta\Phi = 2\pi(Lf/c)\frac{m_1^2 - m_2^2}{2p^2}$$

It would be the only O(100) GeV beam in the world that delivers high-energy (charged) kaons AND anti-protons with high intensity. It would be the world-highest energy kaon beam used for a fixed-target experiment.

Program	Physics Goals	Beam Energy [GeV]	Beam Intensity [s^{-1}]	Trigger Rate [kHz]	Beam Type	Target	
Drell-Yan (RF)	Kaon PDFs & Nucleon TMDs	~100	10^8	25-50	$K^{\pm}$, $\bar{p}$	$NH_3^{\uparrow}$, C/W
Primakoff (RF)	Kaon polarisability & pion life time	~100	$5 \cdot 10^6$	> 10	K^-	Ni
Prompt Photons (RF)	Meson gluon PDFs	≥ 100	$5 \cdot 10^6$	10-100	K^- $\pi^{\pm}$	LH2, Ni
K-induced Spectroscopy (RF)	High-precision strange-meson spectrum	50-100	$5 \cdot 10^6$	25	K^-	LH2

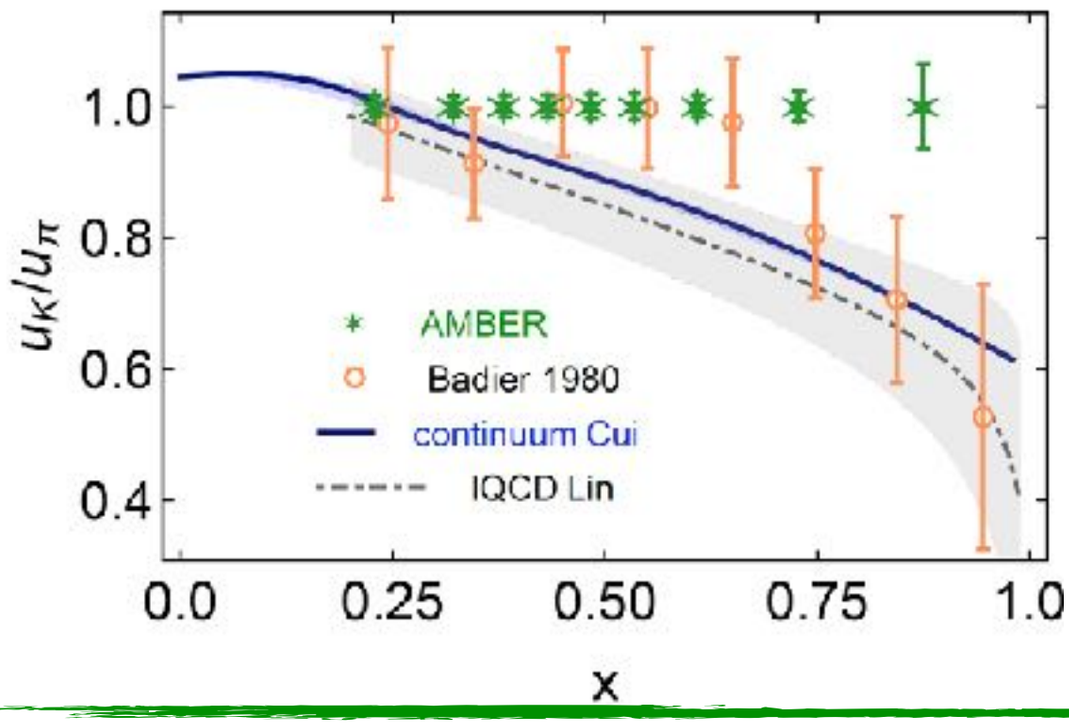
KAON-INDUCED DRELL-YAN & CHARMONIA PRODUCTION

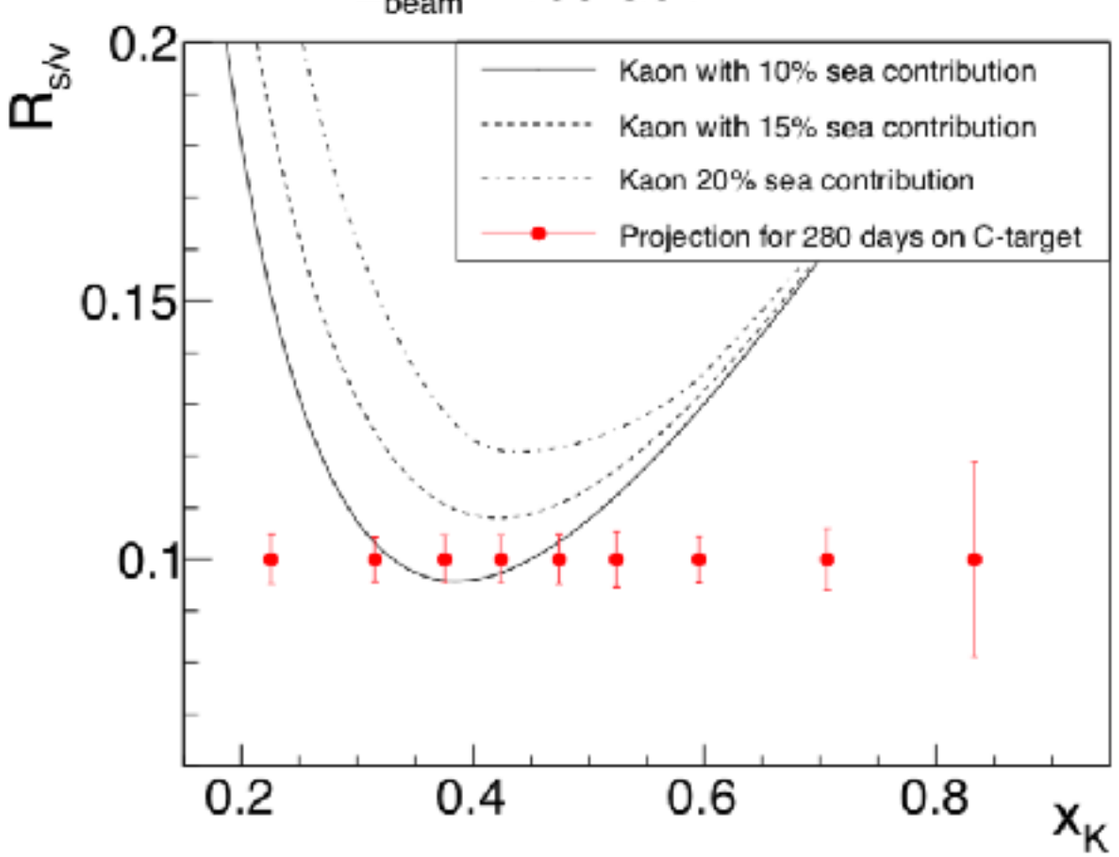
1) Valence/sea separation

$$R_{S/V} = \frac{\sigma_{K^+}}{\sigma_{K^-} - \sigma_{K^+}}$$

2) $u_K(x)/u_\pi(x)$ *- ratio*

DY





Model-dependent separation of gg ***and*** $q\bar{q}$ ***contributions using data collected with both positive and negative beams.***

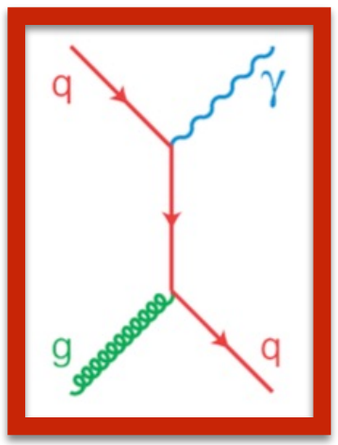
$$\sigma^{K^-}_{J/\psi} - \sigma^{K^+}_{J/\psi} \propto \bar{u}^{K^-} u^N$$

J/ψ

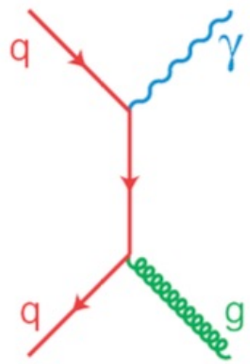
$\psi(2S)$ ***production*** *- free of feed-down effect from* χ_{c1} *and* χ_{c2}

PRODUCTION OF PROMPT PHOTONS

Gluon Compton scattering



$qg \to q\gamma$



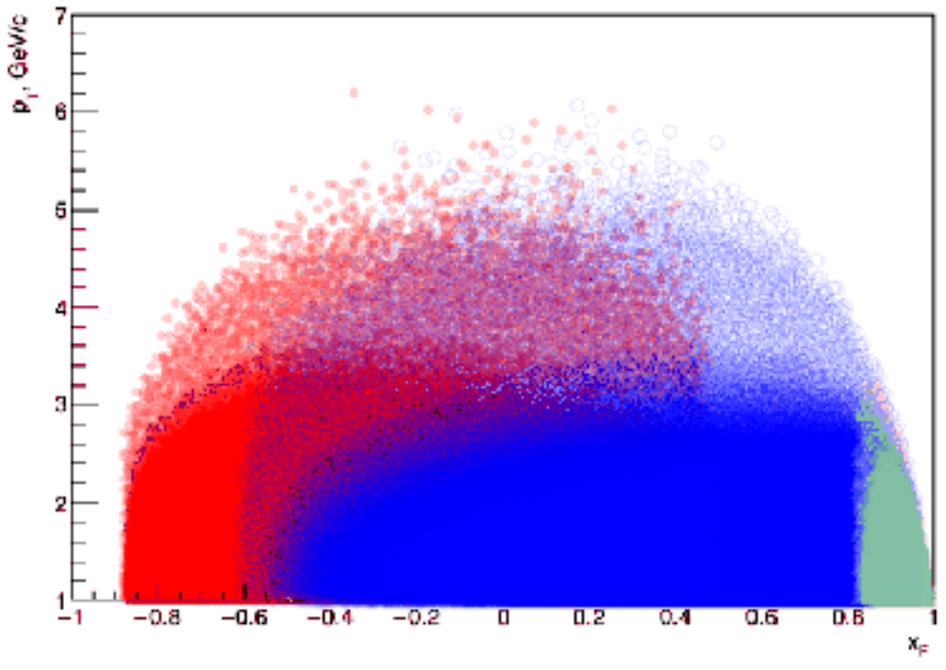
$q\bar{q} \to g\gamma$

ECAL0

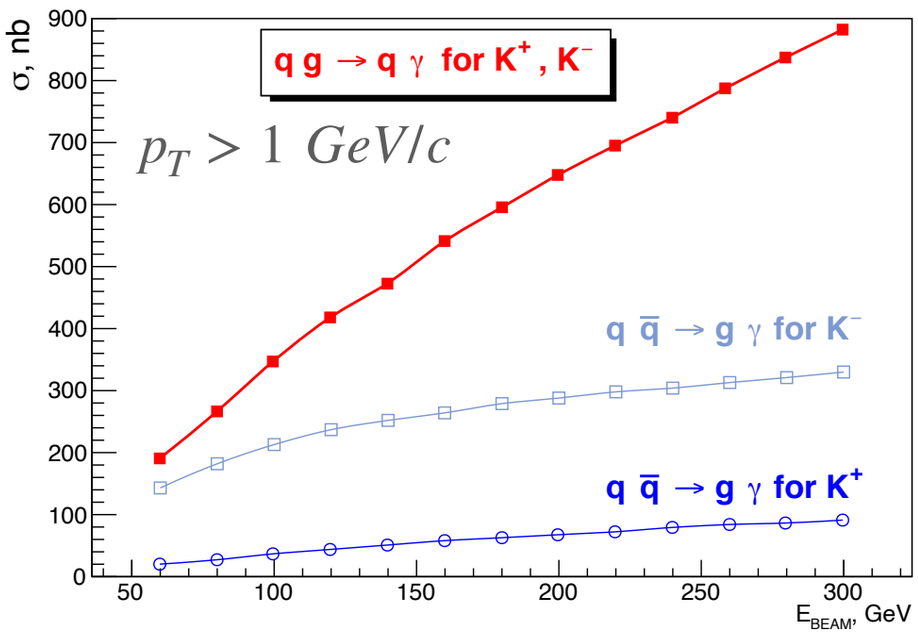
ECAL1

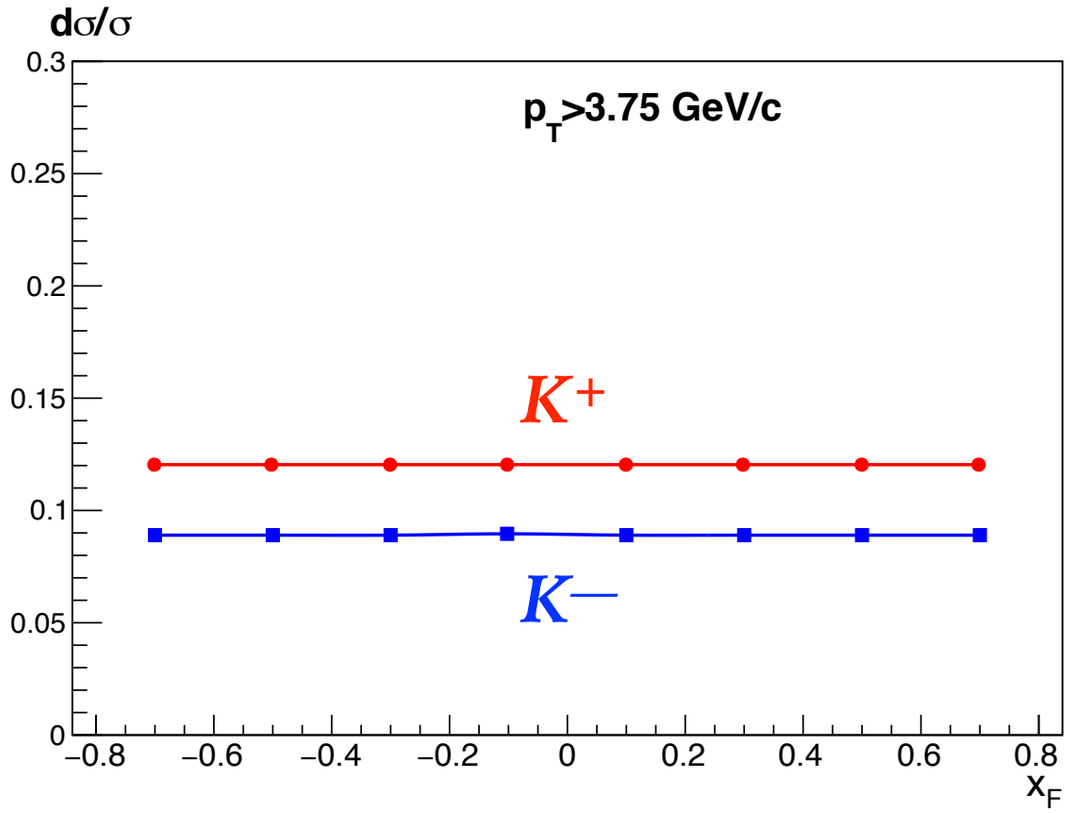
ECAL2

100 GeV kaon beam

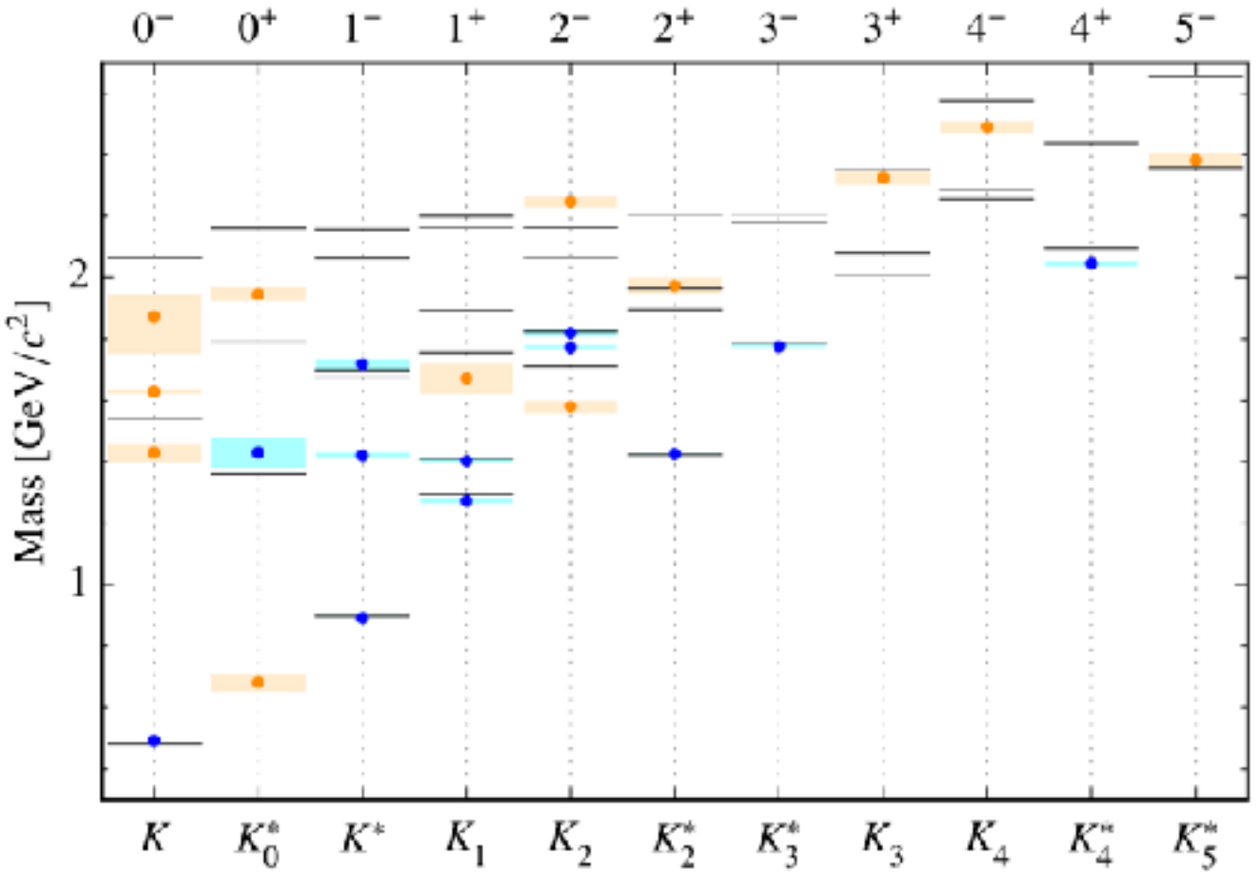


Assumed for kaon similar PDFs as for pion (GRV)





KAON SPECTROSCOPY

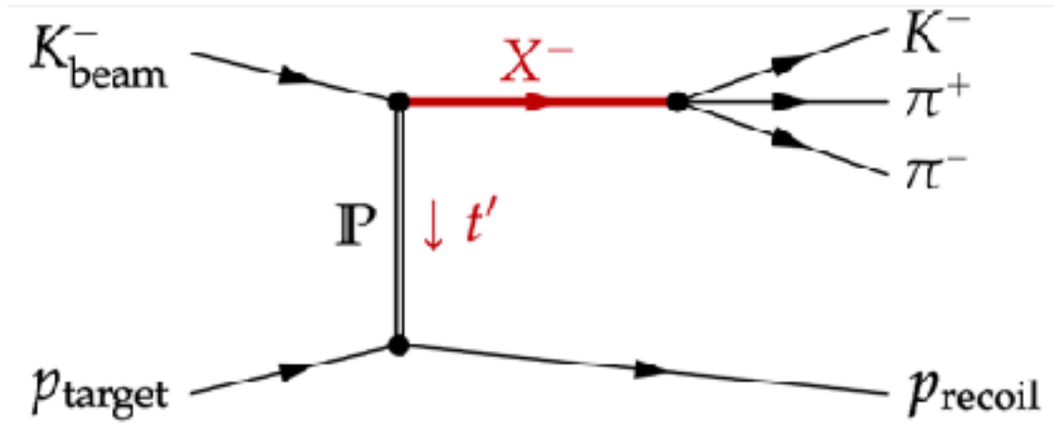


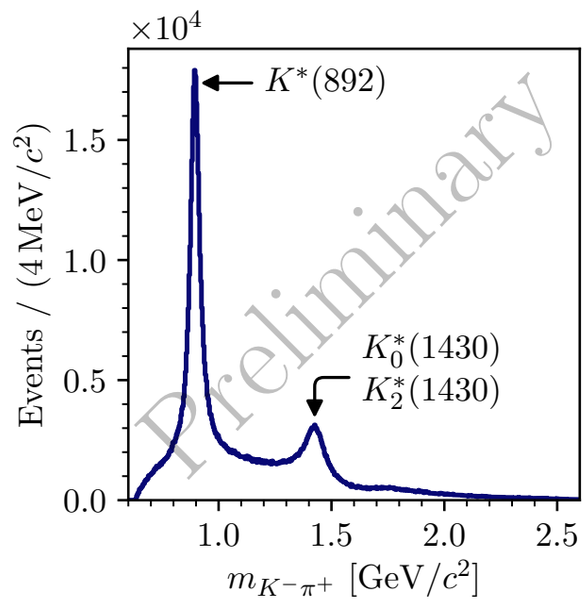
25 kaon states below 3.1 GeV can be found at PDG. But:

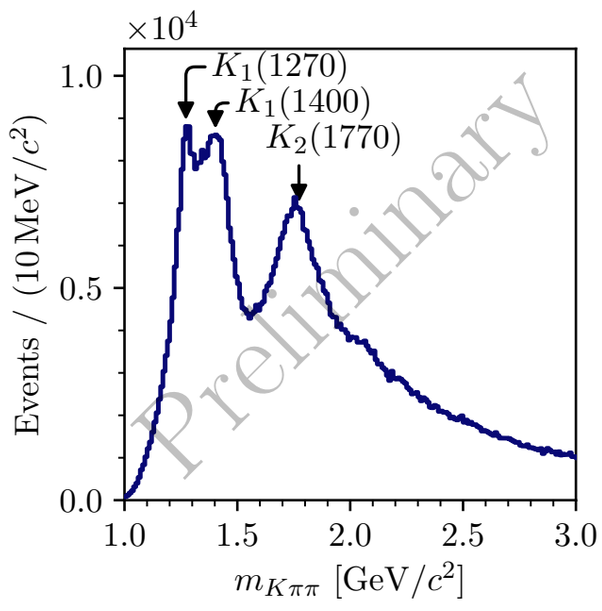
***only** 12 kaon states in summary table, 13 need confirmation;*

***most PDG entries** more than 30 years old;*

since 1990 only 4 kaon states added to PDG (only 1 to summary table)







***COMPASS**: 7×10^5 $K^-\pi^+\pi^-$ events*

AMBER: $> 1 \times 10^7$

We plan to rewrite completely the kaon part of PDG!

KAON POLARIZABILITY VIA PRIMAKOFF SCATTERING

Pion polarizability - *COMPASS, PRL 114, 062002 (2015)*

Theoretical predictions:

χPT prediction O(p⁴):

$$\alpha_K + \beta_K = 0$$

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

Quark confinement model:

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

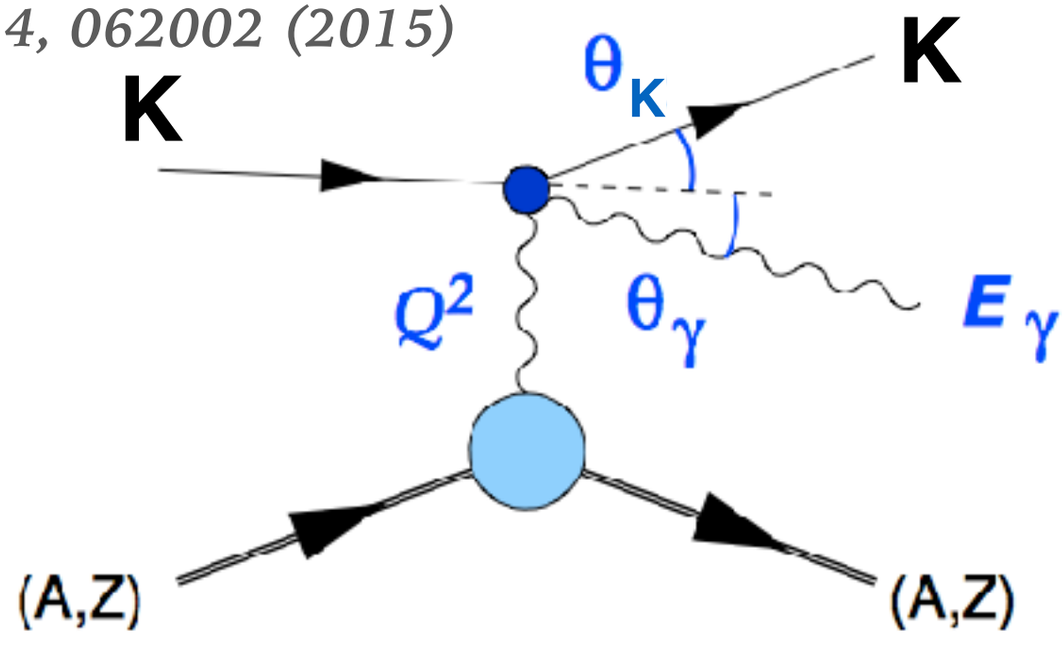
$$\alpha_K = 2.3 \times 10^{-4} fm^3$$

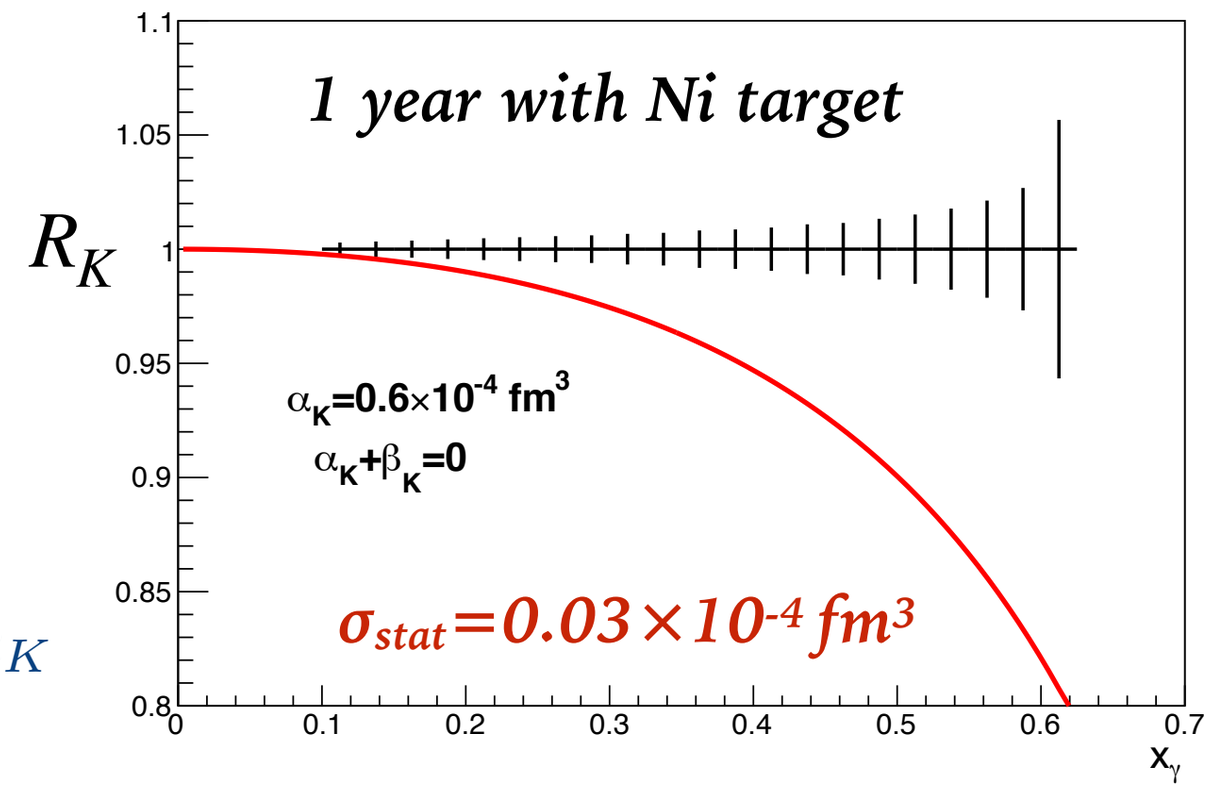
Experimental results:

a_K<200×10⁻⁴ fm³ (1973)

- from kaonic atoms spectra

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

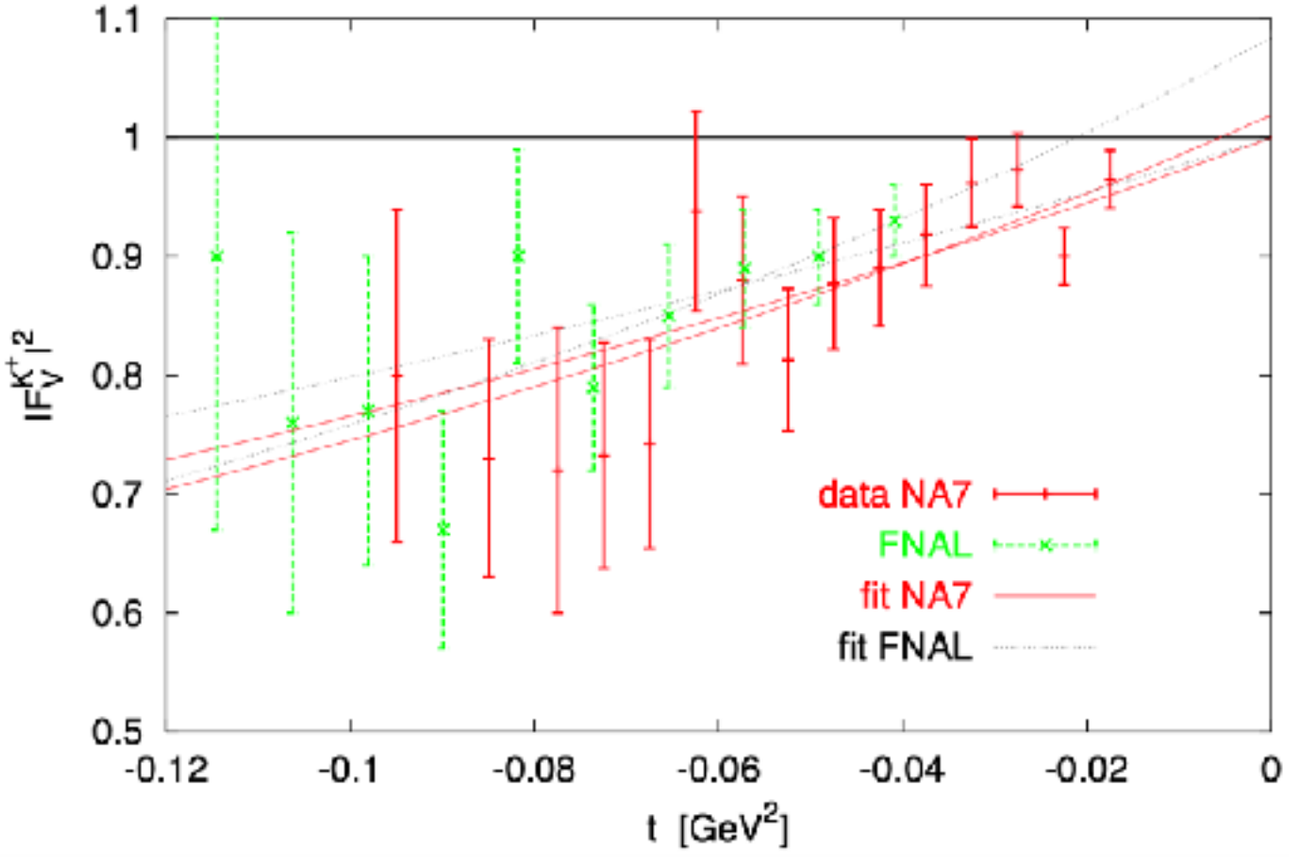




KAON FORM FACTOR & K-e ELASTIC SCATTERING

$K^{\pm}$ CHARGE RADIUS

VALUE (fm)		*DOCUMENT ID*		*COMMENT*
0.560±0.031 OUR AVERAGE				
0.580±0.040	$\sigma_{stat} \gg \sigma_{syst}$	AMENDOLIA	86B	$Ke \rightarrow Ke$
0.530±0.050		DALLY	80	$Ke \rightarrow Ke$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.620±0.037		BLATNIK	79	VMD + dispersion relations



SUMMARY

- ***No claim to have understood the Standard Model is supportable until an explanation is provided for the emergence and structure of Nambu-Goldstone modes.*** *The* ***emergence of hadron mass*** *is the central part of the proposed AMBER physics program with conventional pion and RF-separated beam, i.e. for both* ***Phase-1*** *and* ***Phase-2.*** *It will be attacked from several directions:*
  - *study of the parton structure of mesons via* ***Drell-Yan pair*** *production,* ***charmonia*** *and* ***prompt-photon*** *production;*
  - *investigation of resonant and dynamical properties in spectroscopy;*
  - *clarification of the Nambu-Goldstone nature of pion and kaon in low-t reactions.*
- ***AMBER at CERN is unique in providing real pion and kaon beams.***
- ***Phase-1*** *of the experiment is already approved.*
- ***Phase-2 proposal is under preparation!***