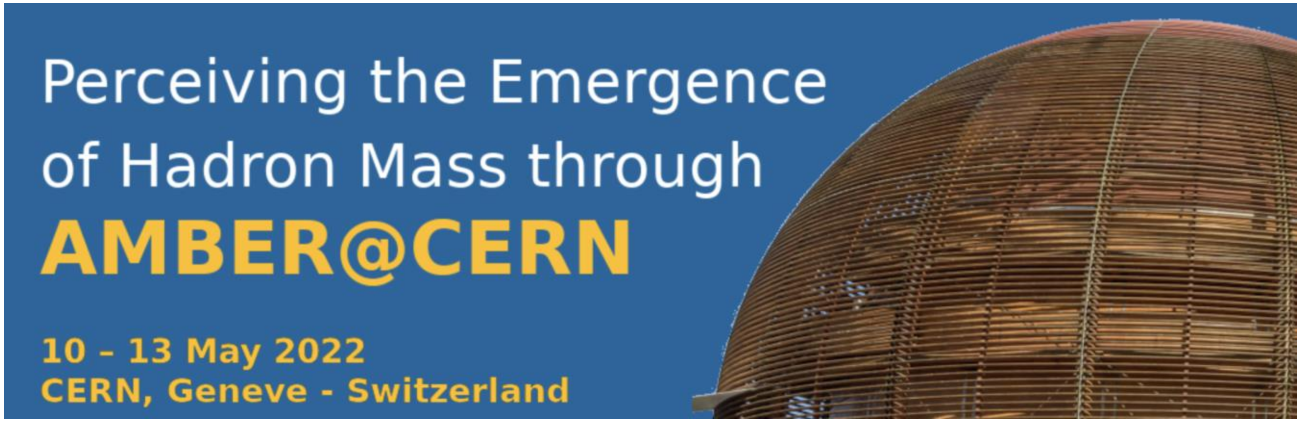
Kaon Primakoff reactions: Polarisability, $F_{KK\pi}$, Radius

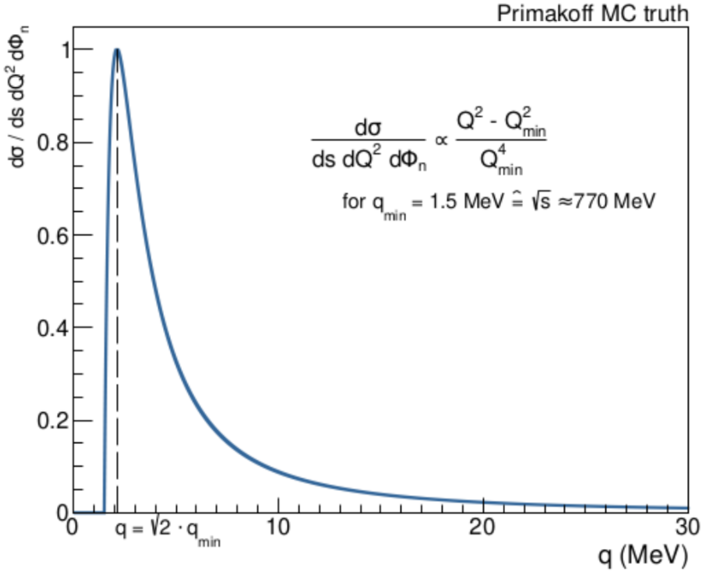


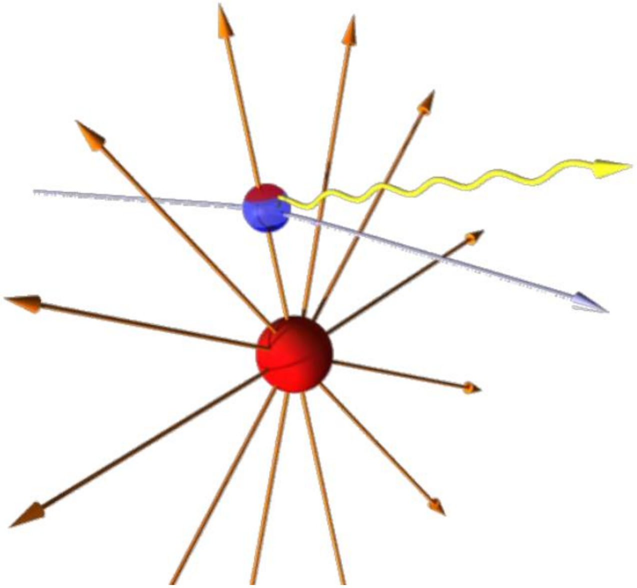
Perceiving the Emergence
of Hadron Mass through
AMBER@CERN

10 – 13 May 2022
CERN, Geneve - Switzerland

Physics with Primakoff reactions

- Charged particles passing by nuclei at high momentum and large distance interact predominantly by one-photon exchange
- Primakoff reactions at COMPASS: **Pions on nickel**
- Typical field strength: 300 kV/fm at $d = 5\, r_{\mathrm{Ni}}$

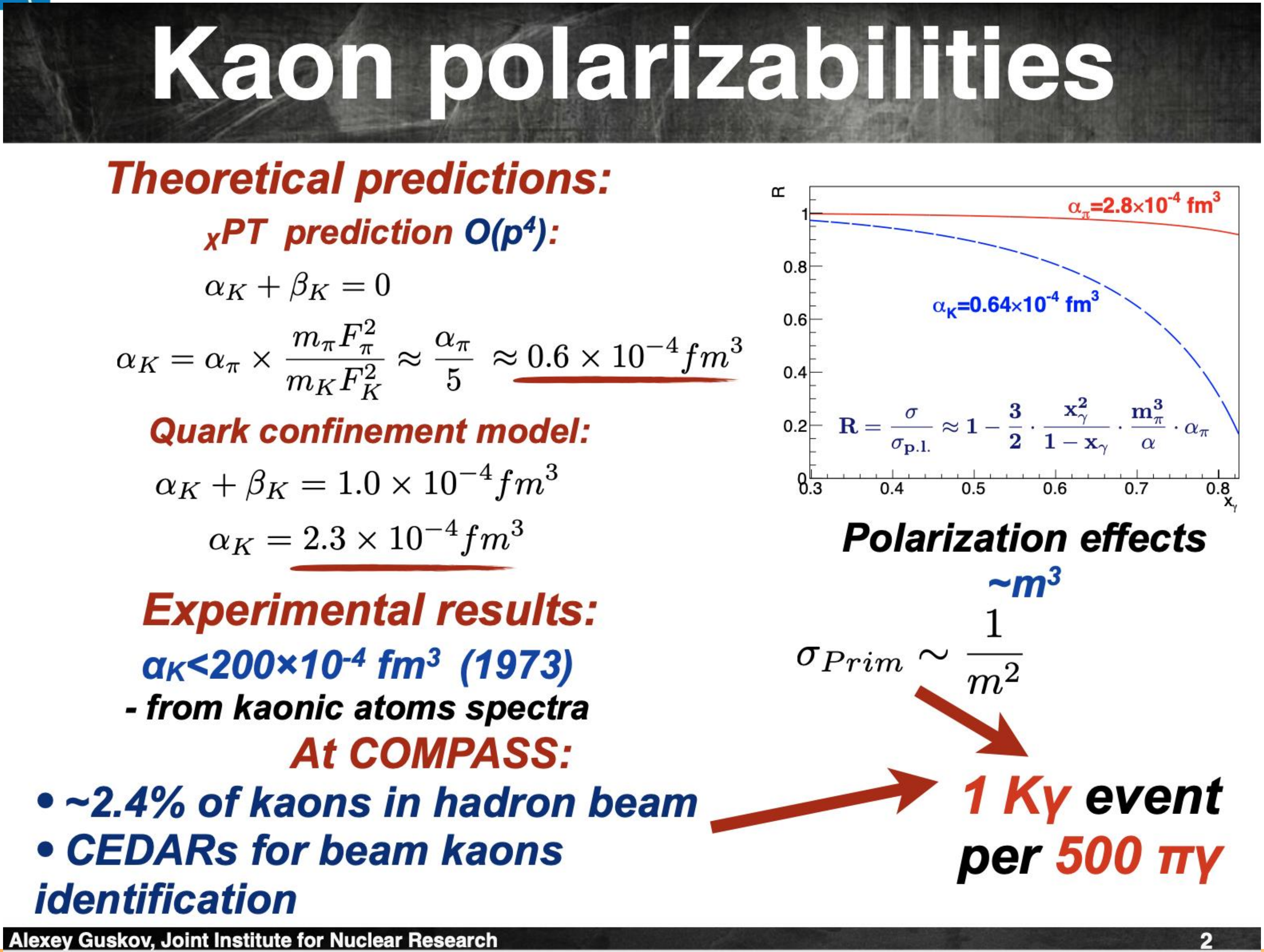




- Weizsäcker-Williams approximation for the quasi-real photon exchange and the embedded pion-photon reaction:

$$\boxed{\frac{d\sigma}{ds\, dQ^2\, d\phi_n} = \frac{Z^2\alpha}{\pi(s - m_\pi^2)}\, F^2(Q^2)\, \frac{Q^2 - Q^2_{min}}{Q^4} \cdot \frac{d\sigma(\pi\gamma \longrightarrow X)}{d\phi_n}}$$

Study with COMPASS data, in preparing LoI



Kaon polarizabilities

Theoretical predictions:

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

$$\alpha_K + \beta_K = 0$$

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

Quark confinement model:

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

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

Experimental results:

$\alpha_K < 200 \times 10^{-4}$ fm^3 (1973)

- from kaonic atoms spectra

At COMPASS:

- ***~2.4% of kaons in hadron beam***
- ***CEDARs for beam kaons identification***

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

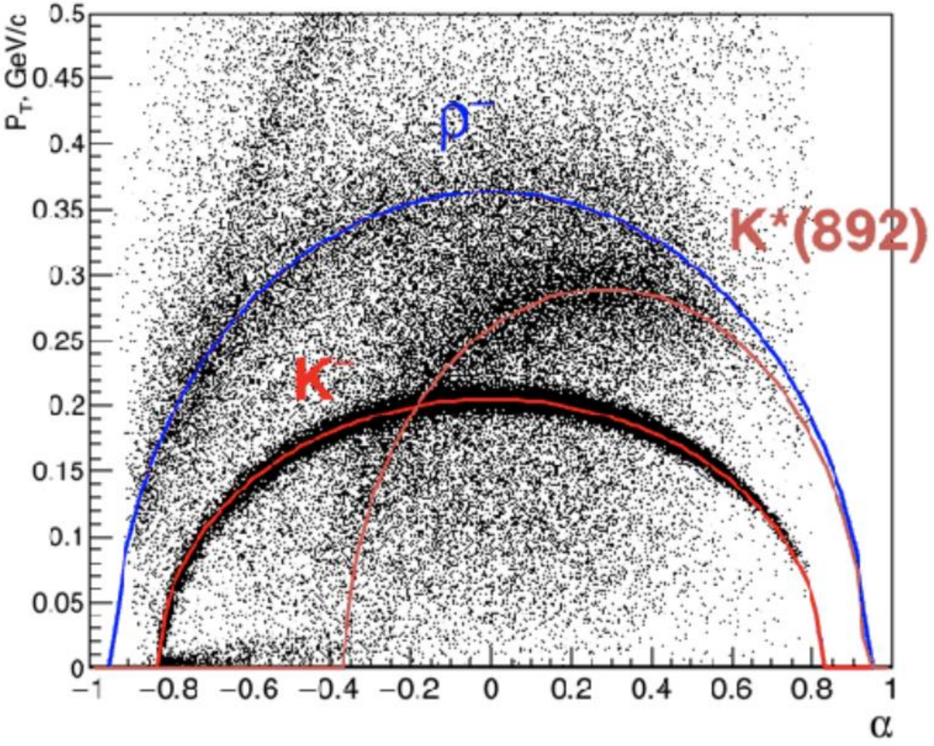
Polarization effects ~m^3

$$\sigma_{Prim} \sim \frac{1}{m^2}$$

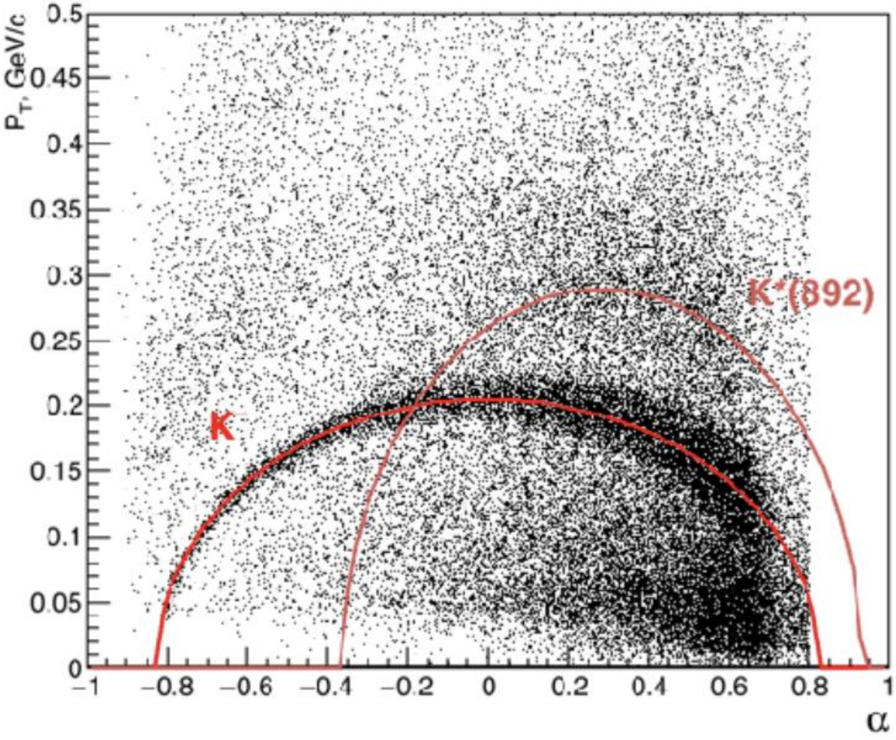
1 Kγ event per 500 πγ

Study with COMPASS data: Armenteros plots

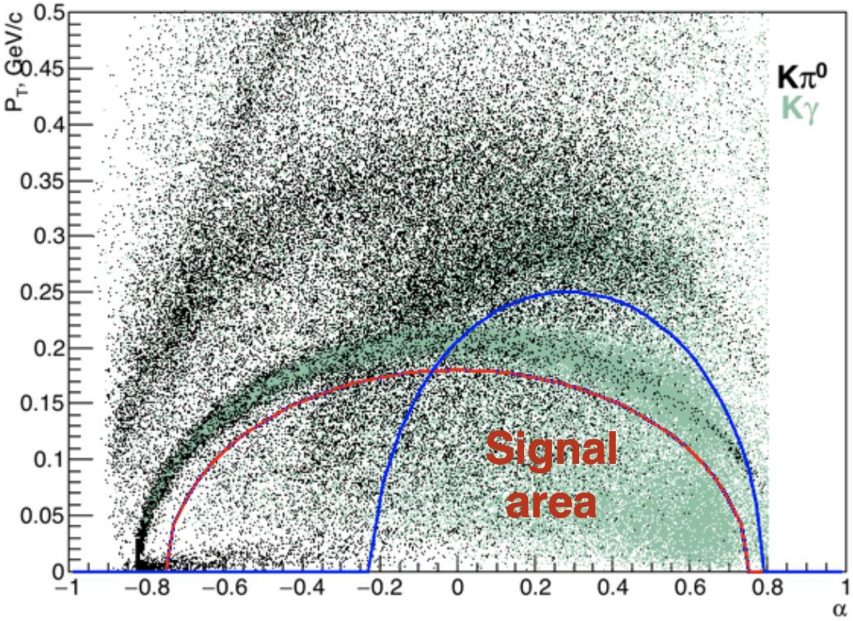
$K\pi^0$



$K\gamma$



Study with COMPASS data: Armenteros plots



- Challenge of the kaon polarisability measurement:

The first resonance $K^*(892)$ **is very close to threshold, especially expressed in terms of the meson mass:**

$m_{K^*} \approx 1.8\, m_K$ compared to $m_\rho \approx 5.5\, m_\pi$

Important question to theoreticians:
Can this kinematic limitation be overcome by including the resonance in an extended fit?

Chiral anomaly for pions – COMPASS analysis

- Dispersive framework to deduce $F_{3\pi}$ from a fit to the full data set up to 1.2 GeV including the $\rho(770)$-resonance:

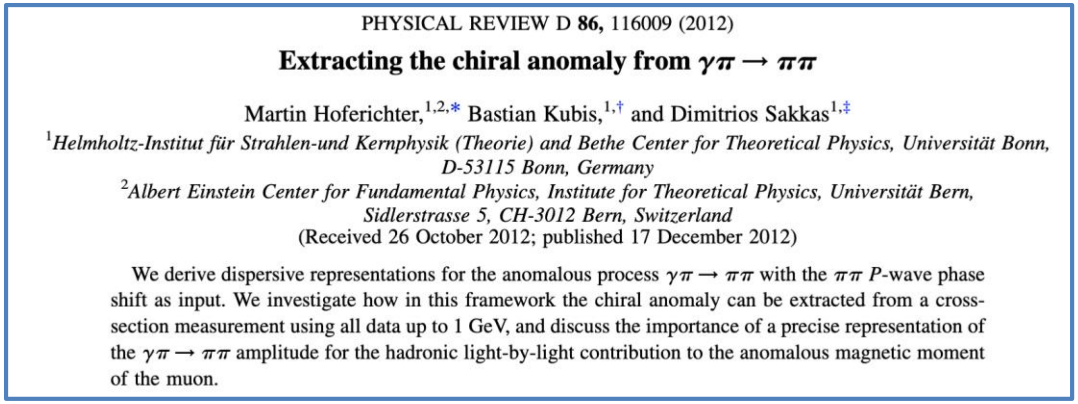
$$\sigma(s)=\frac{(s-4m_\pi^2)^{3/2}(s-m_\pi^2)}{1024\pi\sqrt{s}}\int_{-1}^{1}\mathrm{d}z(1-z^2)|\mathcal{F}(s,t,u)|^2$$

With

$$\mathcal{F}(s,t,u)=C_2^{(1)}\mathcal{F}_2^{(1)}(s,t,u)+C_2^{(2)}\mathcal{F}_2^{(2)}(s,t,u)-\frac{2e^2F_\pi^2F_{3\pi}}{t}$$

$C_2^{(1)}, C_2^{(2)}$: fit parameters

$\mathcal{F}_2^{(1)}(s,t,u)$, $\mathcal{F}_2^{(2)}(s,t,u)$: provided by theory colleagues (Kubis, Hoferichter)



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Extracting the chiral anomaly from $\gamma\pi \to \pi\pi$

Martin Hoferichter,[1,2,*] Bastian Kubis,[1,†] and Dimitrios Sakkas[1,‡]

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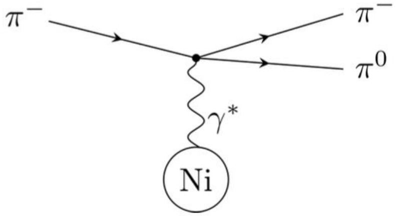
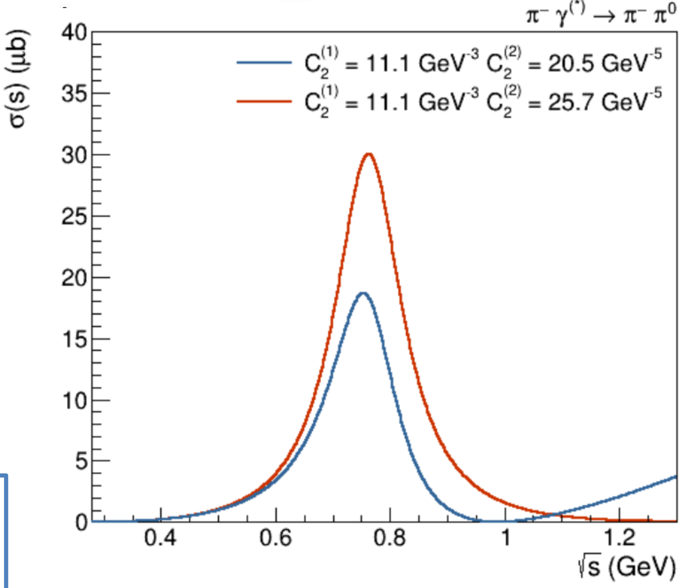
We derive dispersive representations for the anomalous process $\gamma\pi \to \pi\pi$ with the $\pi\pi$ *P*-wave phase shift as input. We investigate how in this framework the chiral anomaly can be extracted from a cross-section measurement using all data up to 1 GeV, and discuss the importance of a precise representation of the $\gamma\pi \to \pi\pi$ amplitude for the hadronic light-by-light contribution to the anomalous magnetic moment of the muon.





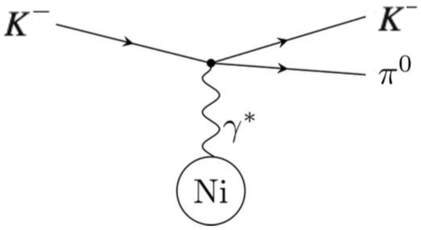
- Theory expectation:

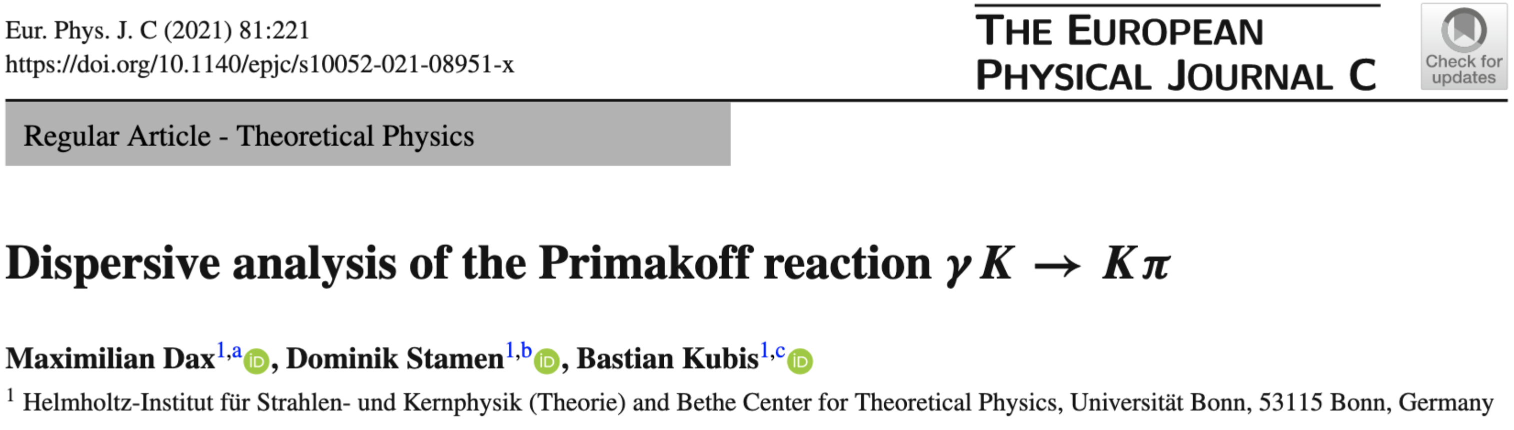
$$F_{3\pi}=\frac{eN_c}{12\pi^2F_\pi^3}=(9.78\pm0.05)\ \mathrm{GeV}^{-3}$$

COMPASS analysis close to finalization

ChPT coupling for the kaon

- A similar process exists for the kaon




Eur. Phys. J. C (2021) 81:221
https://doi.org/10.1140/epjc/s10052-021-08951-x

THE EUROPEAN PHYSICAL JOURNAL C

Check for updates

Regular Article - Theoretical Physics

Dispersive analysis of the Primakoff reaction $\gamma K \rightarrow K\pi$

Maximilian Dax[1,a], **Dominik Stamen**[1,b], **Bastian Kubis**[1,c]

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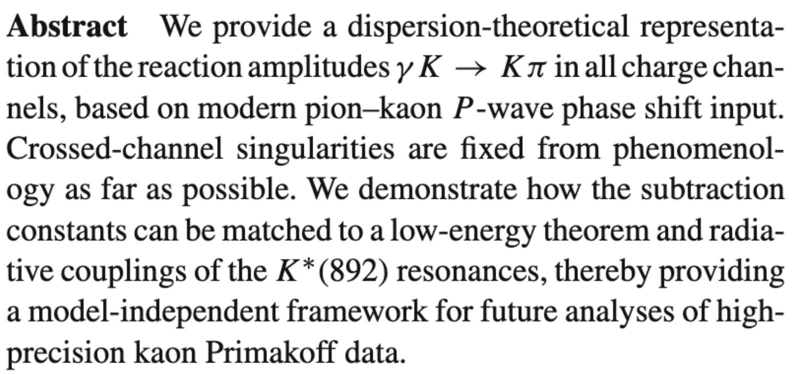

Abstract We provide a dispersion-theoretical representation of the reaction amplitudes $\gamma K \rightarrow K\pi$ in all charge channels, based on modern pion–kaon P-wave phase shift input. Crossed-channel singularities are fixed from phenomenology as far as possible. We demonstrate how the subtraction constants can be matched to a low-energy theorem and radiative couplings of the $K^*(892)$ resonances, thereby providing a model-independent framework for future analyses of high-precision kaon Primakoff data.

$$F_{KK\pi} = \frac{e}{4\pi^2 F_\pi^3} = 9.8\,\mathrm{GeV}^{-3}$$

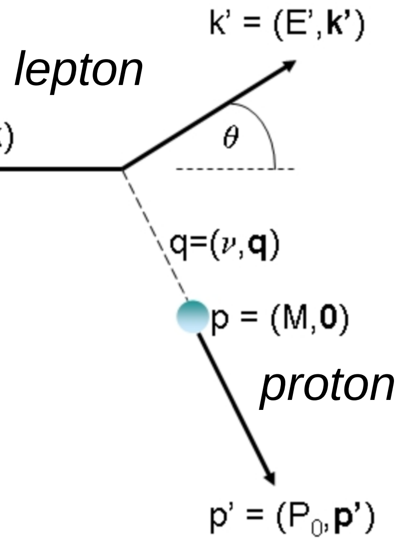
…however large corrections

Looking forward to the talk by Dominik Stamen tomorrow

Hadron charge radii through elastic lepton scattering at low Q^2

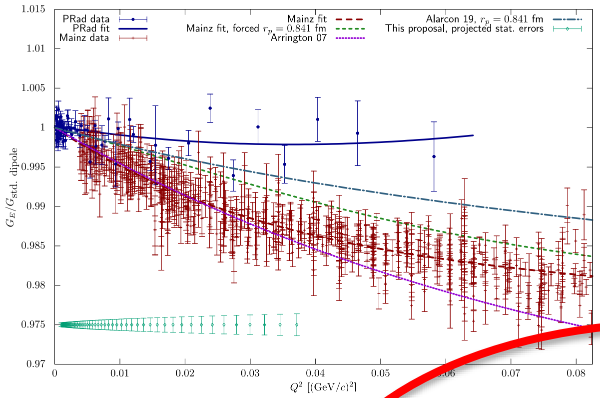
Protons in hydrogen target (or other stable nuclei):
Measurement via elastic electron or muon scattering
Cross section:

$$\boxed{\frac{d\sigma}{dQ^2} = \frac{4\pi\alpha^2}{Q^4} R \left(\varepsilon G_E^2 + \tau G_M^2\right)}$$

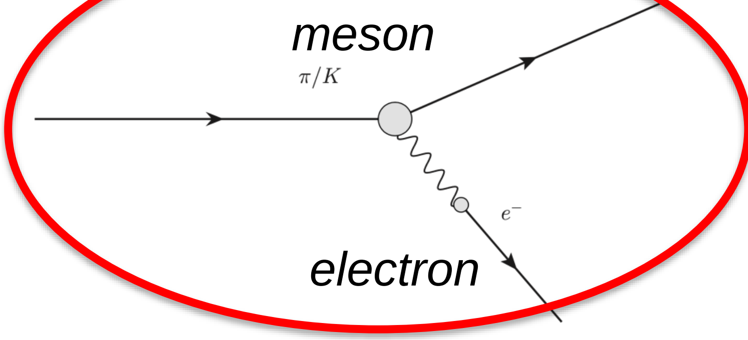


Charge radius from the slope of *G*$_E$

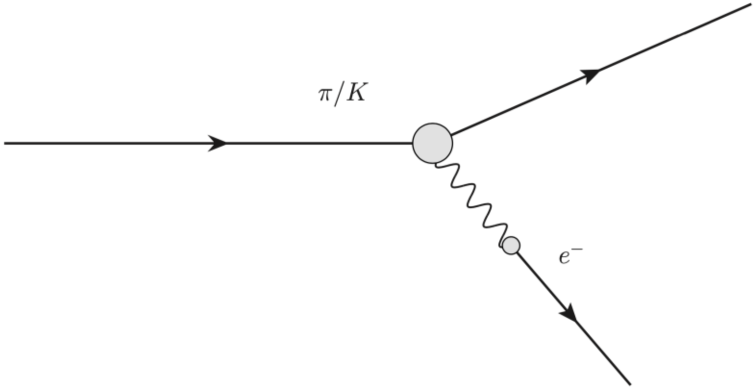
$$\langle r_E^2 \rangle = -6\hbar^2 \left.\frac{\mathrm{d}G_E(Q^2)}{\mathrm{d}Q^2}\right|_{Q^2\to 0}$$



For unstable particles, electron scattering can be realised in *inverse kinematics*



Kinematics



$$K^- \; e^-_{target} \rightarrow \; K^- \; e^-$$

$$s = 2E_b m_e + m_b^2 + m_e^2$$

$$Q^2_{max} = \frac{4p_b^2\, m_e^2}{s}$$

Beam	E_b [GeV]	Q^2_{max} [GeV²]	$E'_{b,min}$ [GeV]	Relative charge-radius effect on c.s. at Q^2_{max}
π	190	0.176	17.3	~40%
K	190	0.086	105.7	~20%
π	80	0.066	15.3	~15%
K	80	0.020	59.8	~6%
π	50	0.037	13.7	~8%
K	50	0.009	41.3	~3%

Kinematics

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K	80	0.020	59.8	$\sim$6%
π	50	0.037	13.7	$\sim$8%
K	50	0.009	41.3	$\sim$3%

New questions to investigate:

- Could we get sufficient statistical precision for a meaningful kaon radius measurement with beam energy 80 or 100 GeV? Which intensity and purity would be needed?
- Will a measurement with conventional 190 GeV beam be advantageous?

Pion and Kaon form factor measurements by NA7

S.R. Amendolia et al. / Pion electromagnetic form factor 193

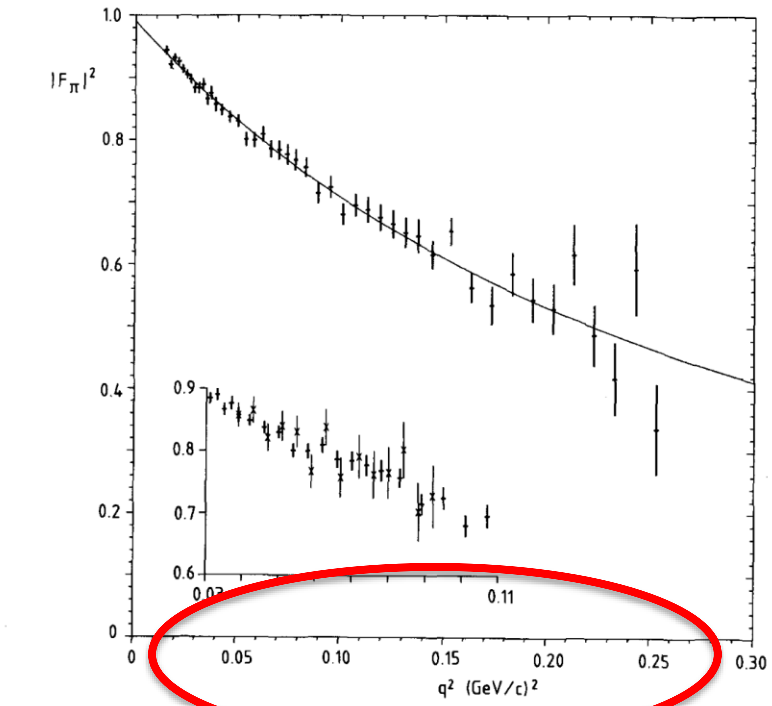

Fig. 17. The square of the pion form factor, $|F_\pi|^2$ versus q^2, with statistical error bars only. The line

S. R. Amendolia, et al. , Phys. Lett. B **178**, 435 (1986)

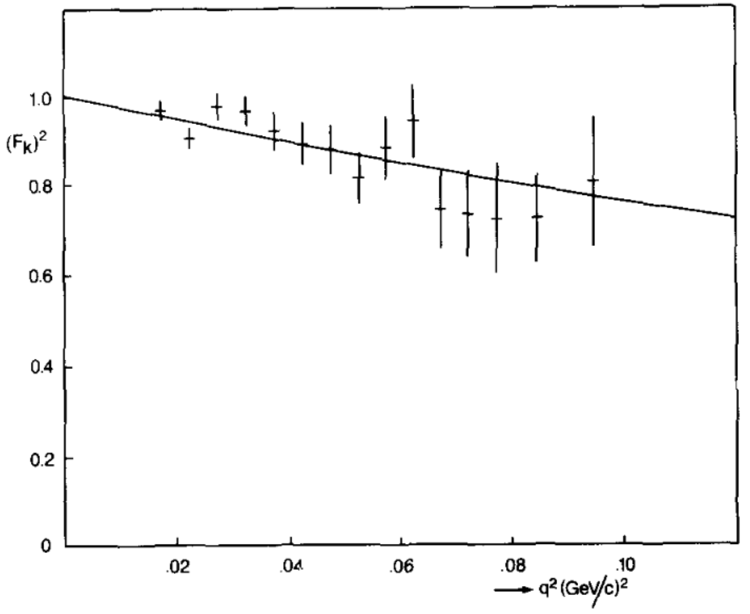

Fig. 3. The measured kaon form factor squared. The line corresponds to the pole fit with $\langle r^2 \rangle = 0.34$ fm^2.

~380,000 pion-electron scattering events

~400,000 kaon triggers
(~30,000 kaon-electron scatterings?)