Study of the K^+K^- FSI in proton – proton and electron - positron collisions

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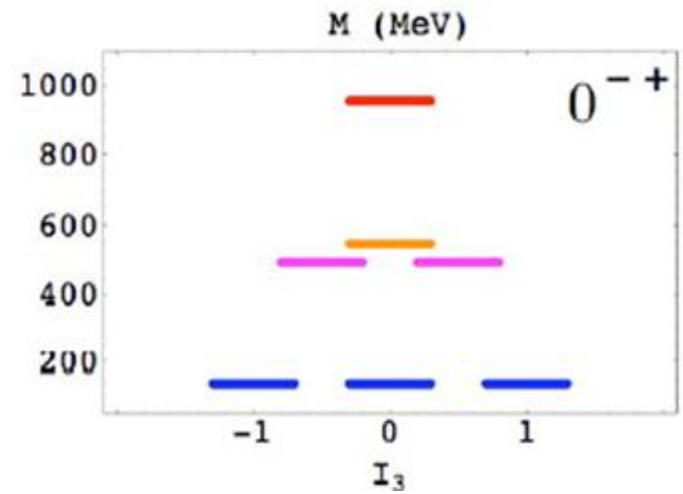
- Motivation
- Proton-proton collisions at K^+K^- threshold: COSY
- Near future: KLOE-2 @ DAΦNE

3-9 February 2013 Bjelasnica Mountain, Sarajevo

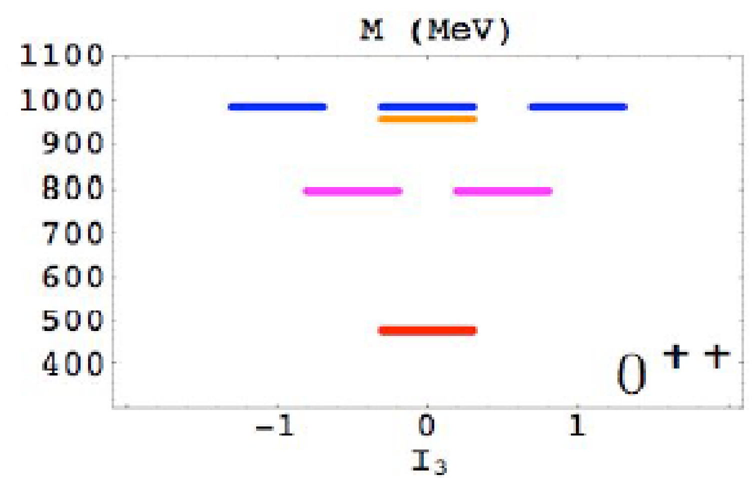
Motivation

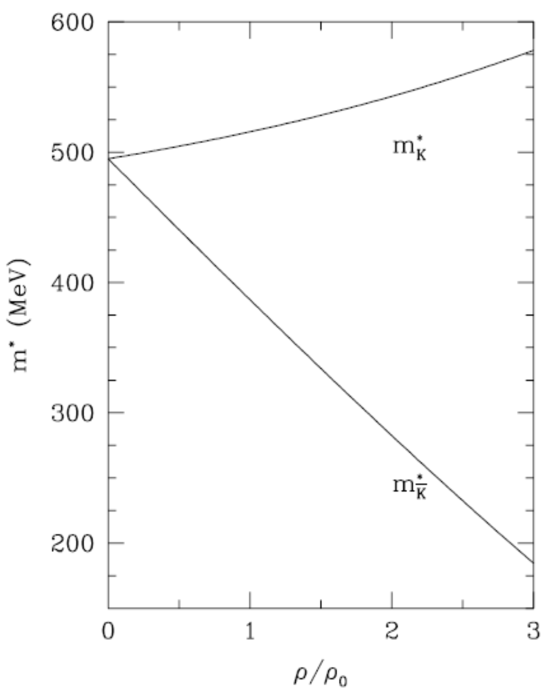
- a_0 and f_0 mesons as a K^+K^- molecules
- Physics of neutron stars: kaon condensates

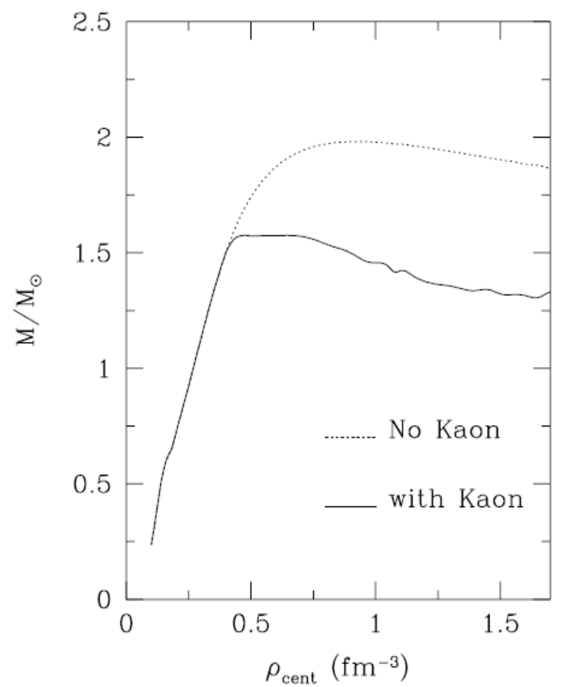
Pseudoscalar mesons



Scalar multiplet:
σ(500), κ(700), f_0(980), a_0(980)

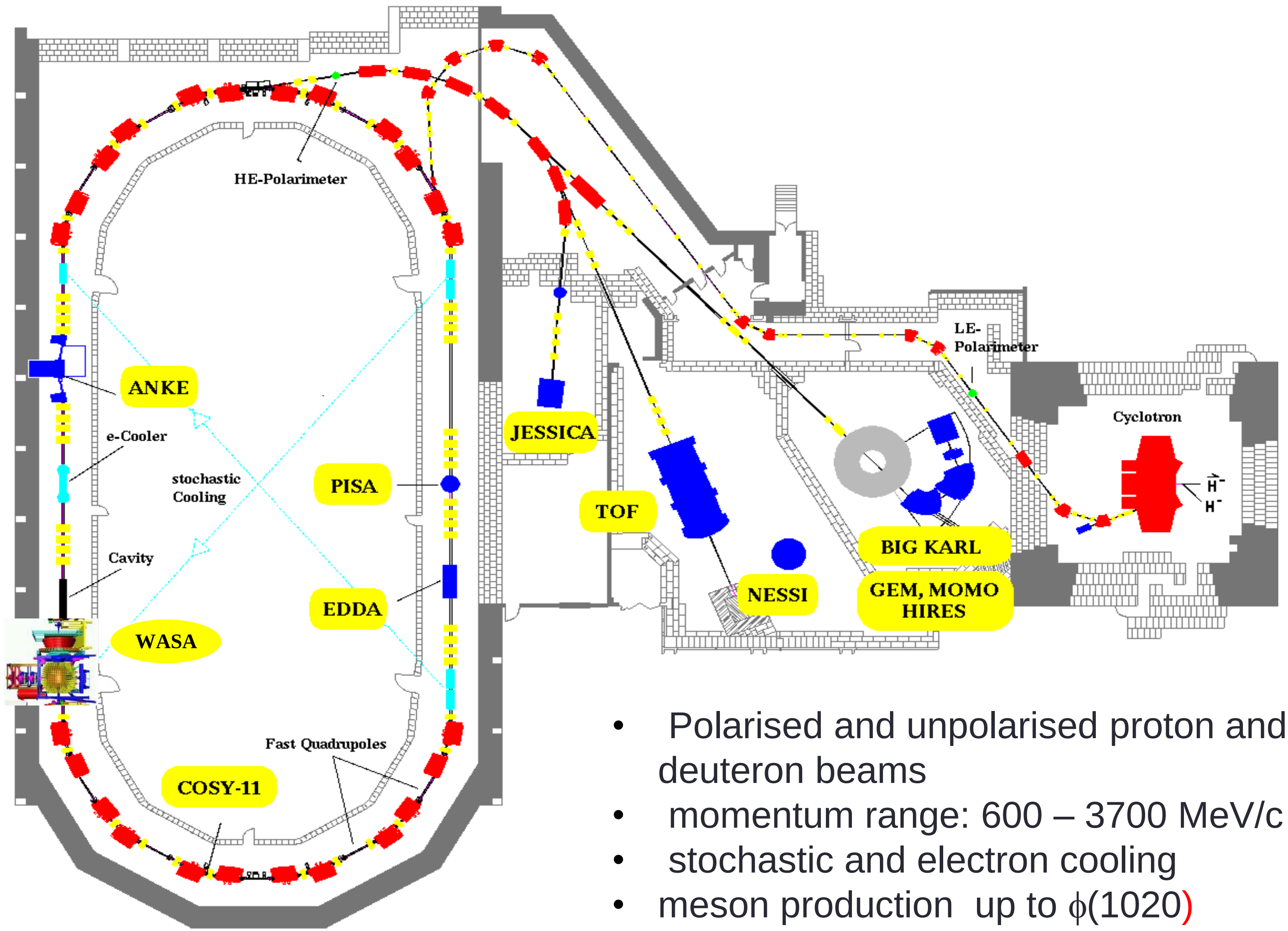






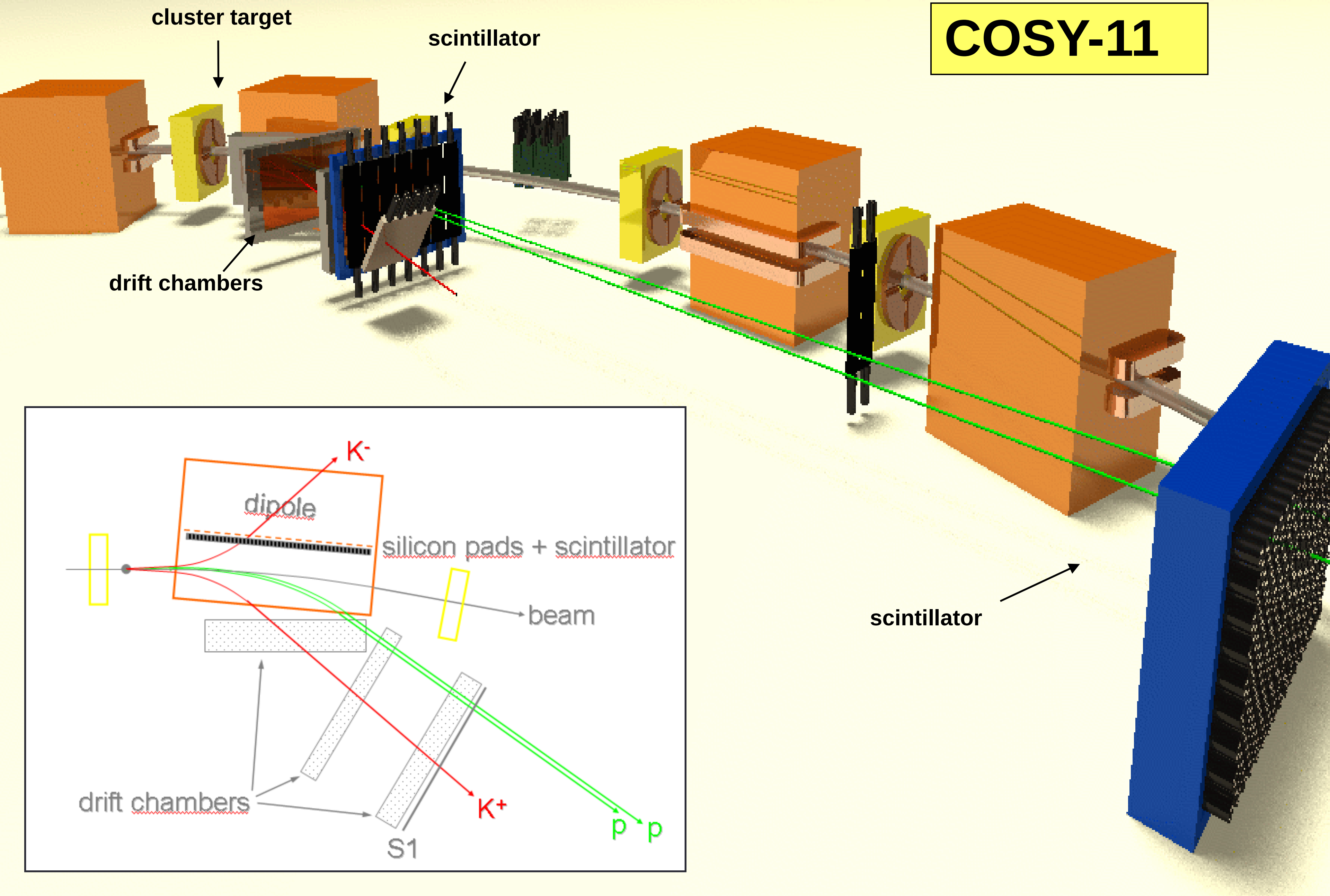
proton-proton collisions at K^+K^- threshold: COSY

COoler SYnchrotron COSY

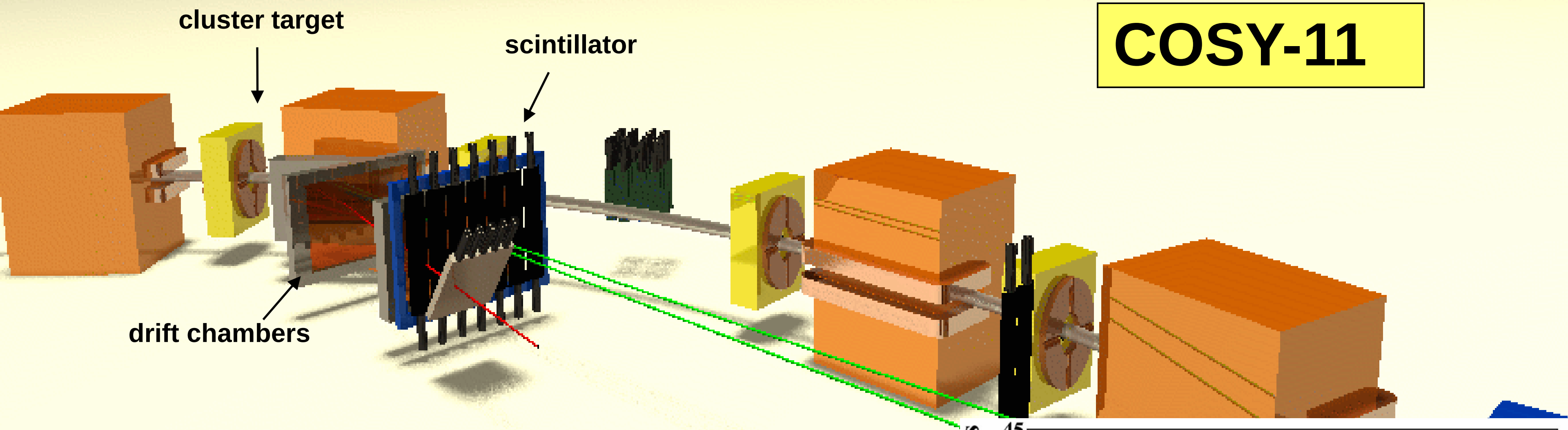


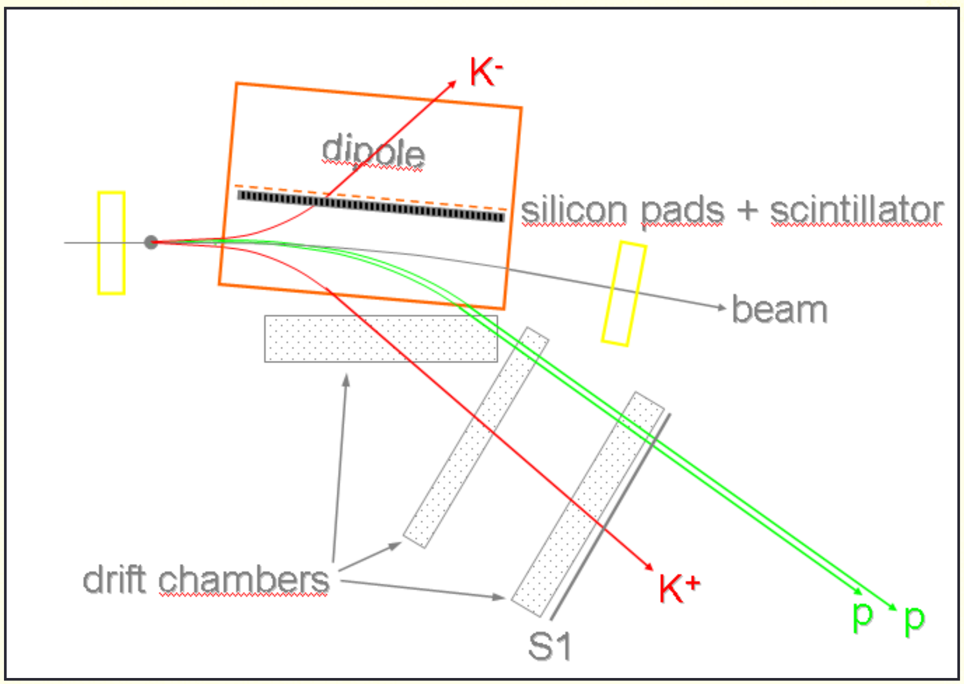
- Polarised and unpolarised proton and deuteron beams
- momentum range: 600 – 3700 MeV/c
- stochastic and electron cooling
- meson production up to ϕ(1020)

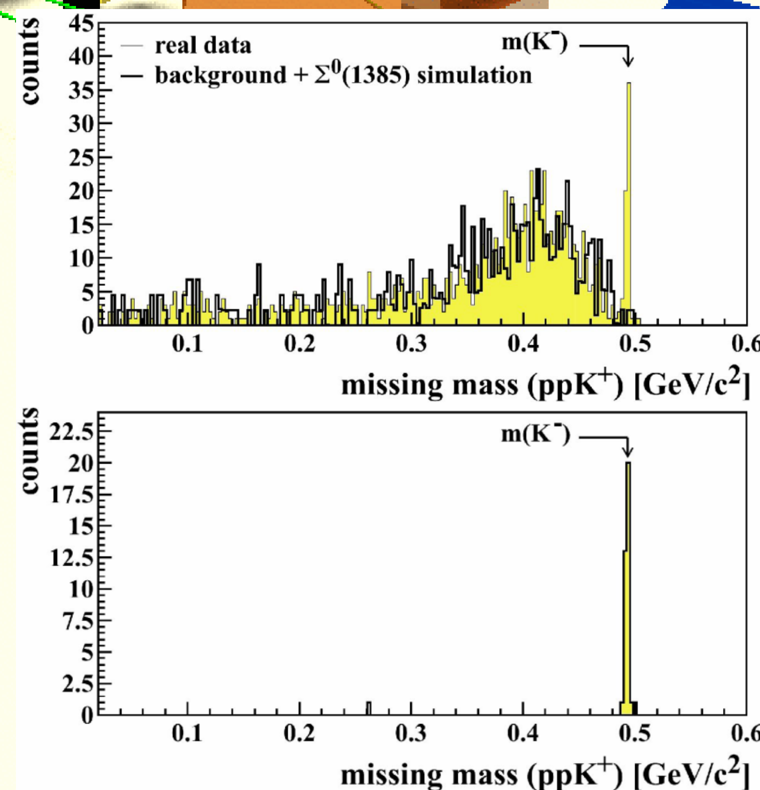
COSY-11


cluster target
scintillator
drift chambers
scintillator
K-
dipole
silicon pads + scintillator
beam
drift chambers
S1
K+
p
p

COSY-11


cluster target
scintillator
drift chambers


K-
dipole
silicon pads + scintillator
beam
drift chambers
S1
K+
p
p


counts
real data
background + Σ0(1385) simulation
m(K-)
0
5
10
15
20
25
30
35
40
45
0.1
0.2
0.3
0.4
0.5
0.6
missing mass (ppK+) [GeV/c2]
counts
m(K-)
0
2.5
5
7.5
10
12.5
15
17.5
20
22.5
0.1
0.2
0.3
0.4
0.5
0.6
missing mass (ppK+) [GeV/c2]

Excitation function

- FSI indication in both total and differential cross sections at K^+K^- threshold

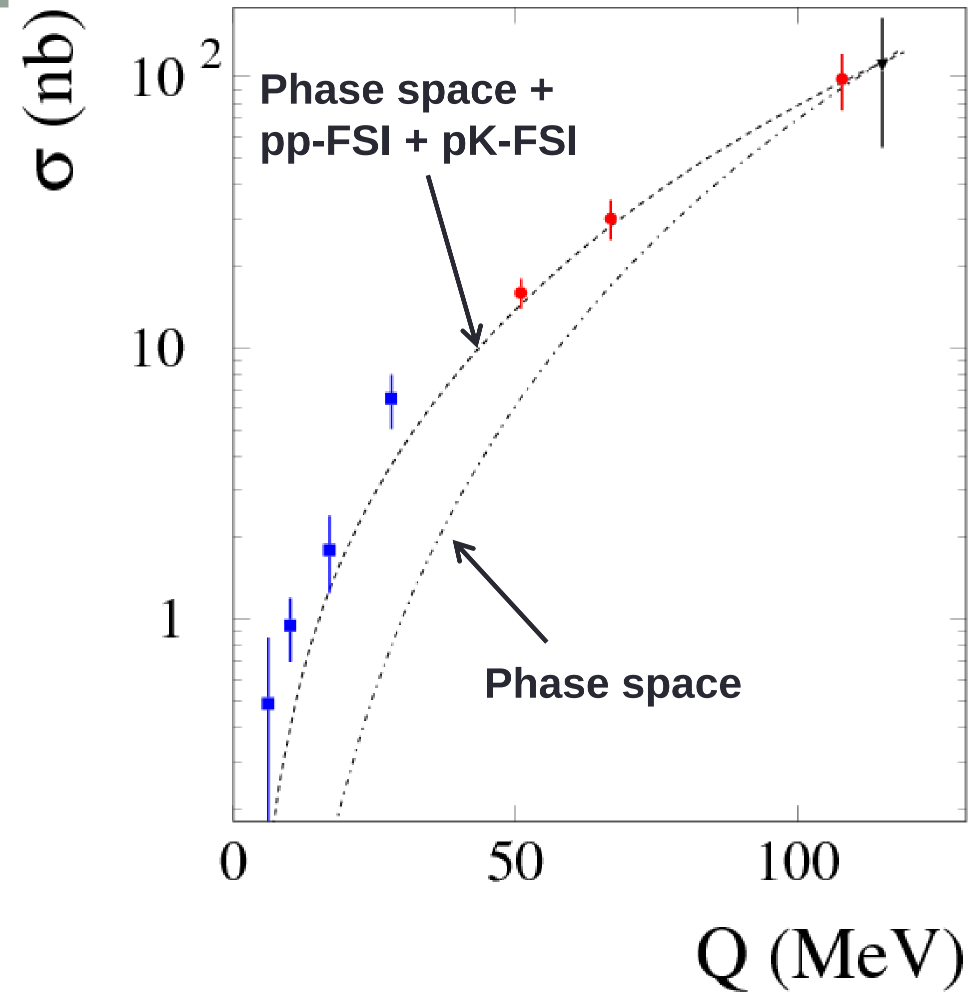
$$\left|M_{pp\to ppK^+K^-}\right|^2 \approx \left|M_0\right|^2 \left|F_{FSI}\right|^2$$

$$F_{FSI} = F_{pp}(q) \times F_{p_1K^-}(k_1) \times F_{p_2K^-}(k_2)$$

$$F_{pp}(q) = \frac{e^{i\delta_{pp}(^1S_0)} \times \sin\delta_{pp}(^1S_0)}{C \times q}$$

$$F_{pK^-}(k) = \frac{1}{1 - ika}$$

$$a = (0 + i1.5)[\mathrm{fm}]$$



DISTO: F. Balestra et al.., Phys. Rev. C 63, 024004 (2001)

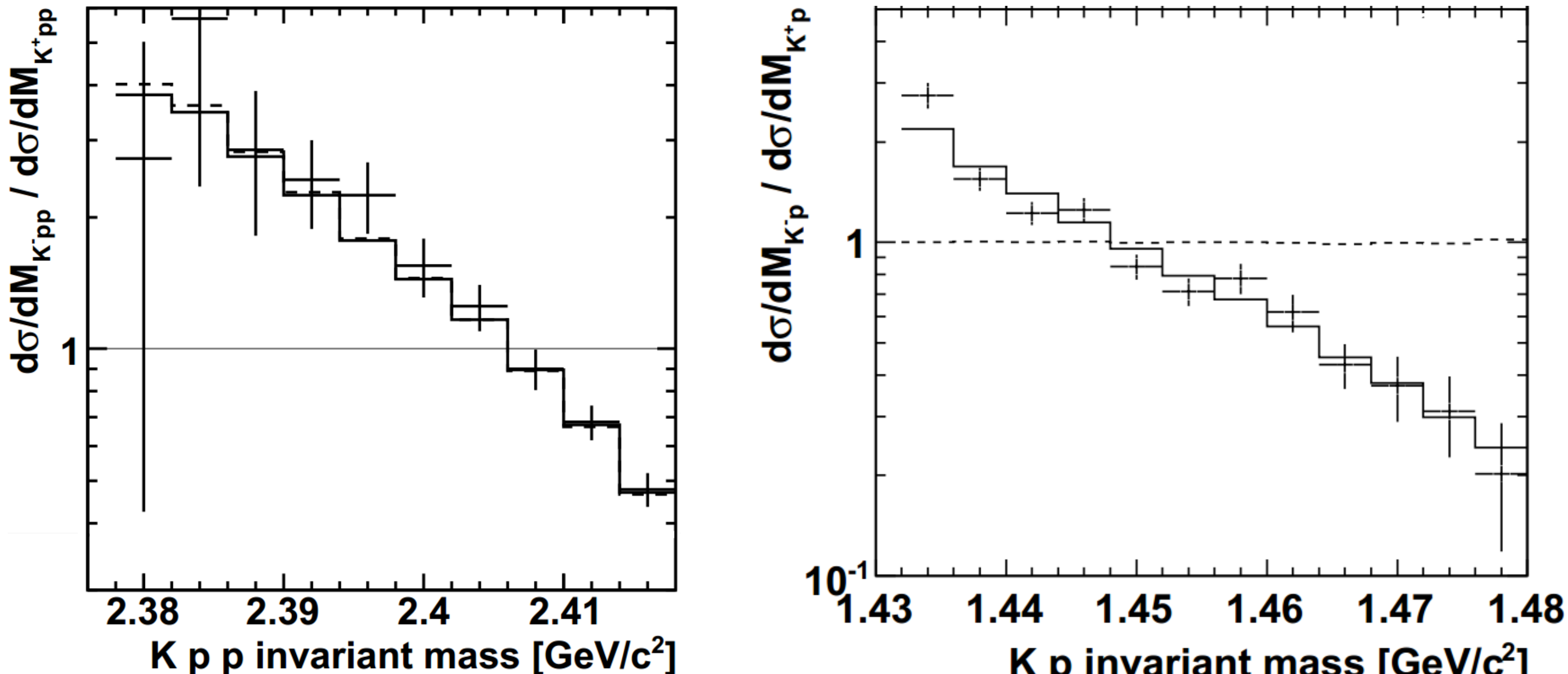
ANKE: Y.Maeda et al. Phys., Rev. C 77, 01524 (2008)

ANKE: Q. J. Ye et al., Phys. Rev. C 85, 035211 (2012)

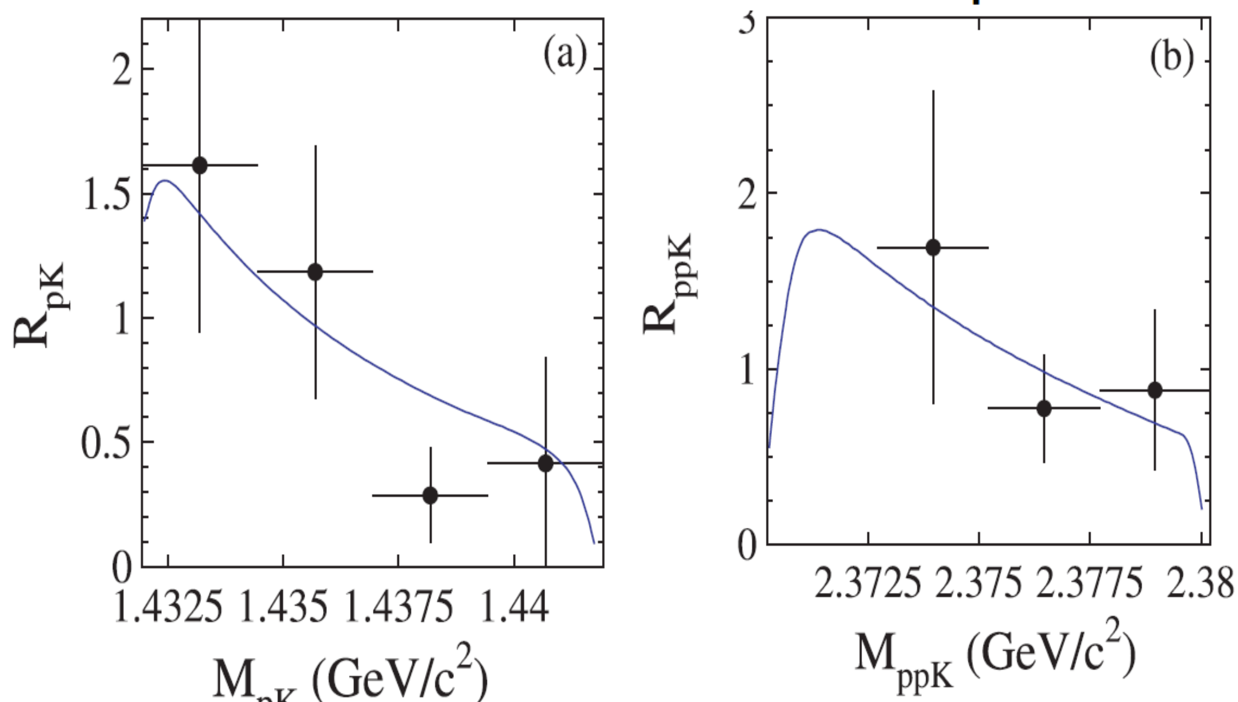
COSY-11: C. Quentmeier et al., Phys.Lett. B 515 (2001) 276-282

COSY-11: P. Winter et al., Phys. Lett. B 635 (2006) 23-29

COSY-11: M. Wolke, PhD thesis

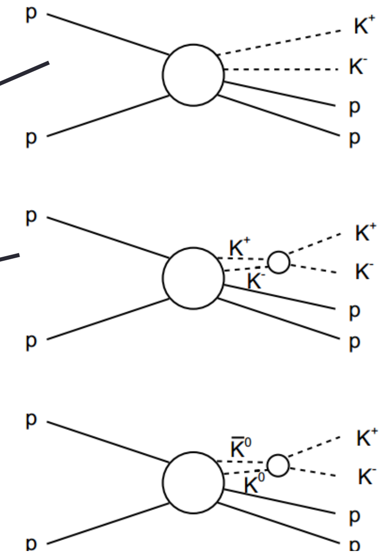


dσ/dM_{K⁻pp} / dσ/dM_{K⁺pp}
1
2.38
2.39
2.4
2.41
K p p invariant mass [GeV/c²]
dσ/dM_{K⁻p} / dσ/dM_{K⁺p}
1
10⁻¹
1.43
1.44
1.45
1.46
1.47
1.48
K p invariant mass [GeV/c²]



(a)
R_{pK}
0
0.5
1
1.5
2
1.4325
1.435
1.4375
1.44
M_{pK} (GeV/c²)
(b)
R_{ppK}
0
1
2
3
2.3725
2.375
2.3775
2.38
M_{ppK} (GeV/c²)

Coupled channel effects



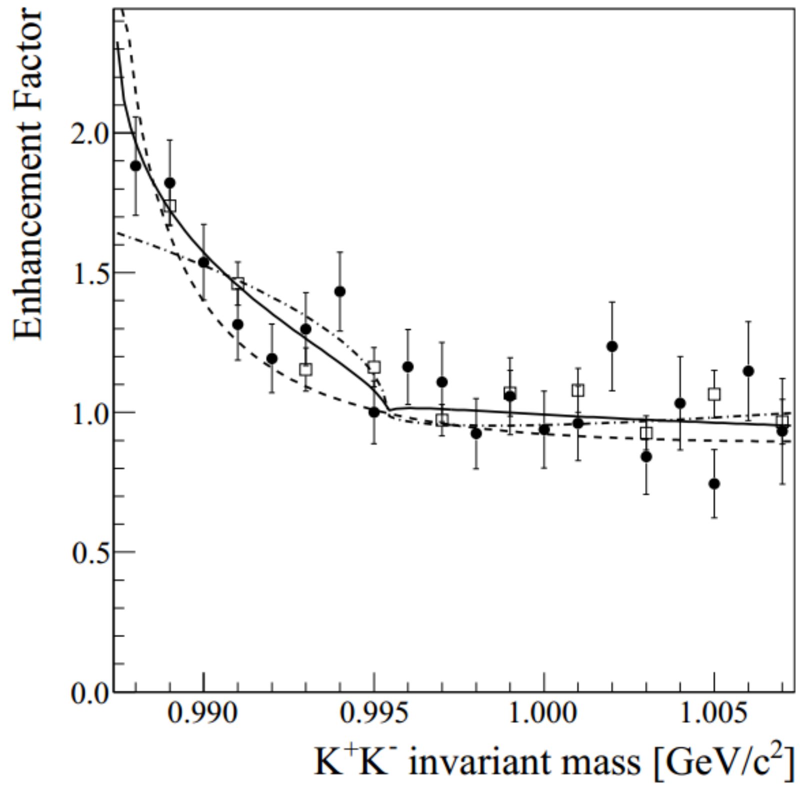
$$\mathcal{F} = \left| \frac{B_1/(B_1+B_0)}{\left(1 - i\frac{1}{2}q[A_1 - A_0]\right)(1 - ikA_1)} + \frac{B_0/(B_1+B_0)}{\left(1 - i\frac{1}{2}q[A_0 - A_1]\right)(1 - ikA_0)} \right|$$

ANKE: A. Dzyuba et al., Phys. Lett. B668, 315 (2008).

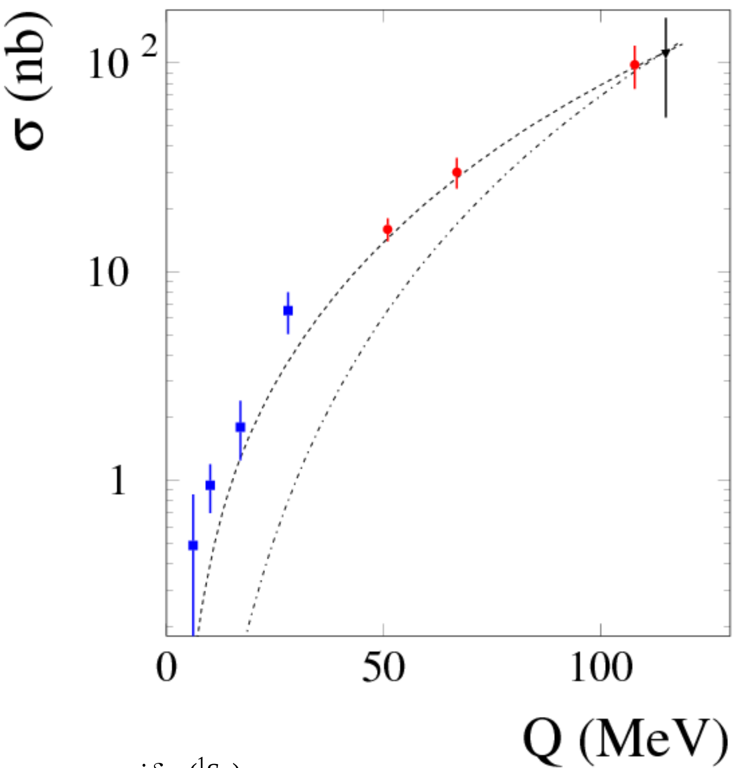
$A_0 = (-0.45 + i1.63)$ fm ; $A_1 = (0.1 + i0.7)$ fm

(M. Ablikim et al., Phys. Lett. B 607 (2005) 243;)

- With the ANKE statistics the expected cusp effects are not distinguishable from the elastic scattering of K^+ and K^-
- Izospin I= 0 state is favourable
- No indication of the $f_0(980)/a_0(980)$ influence
- More statics at lower excess energy needed



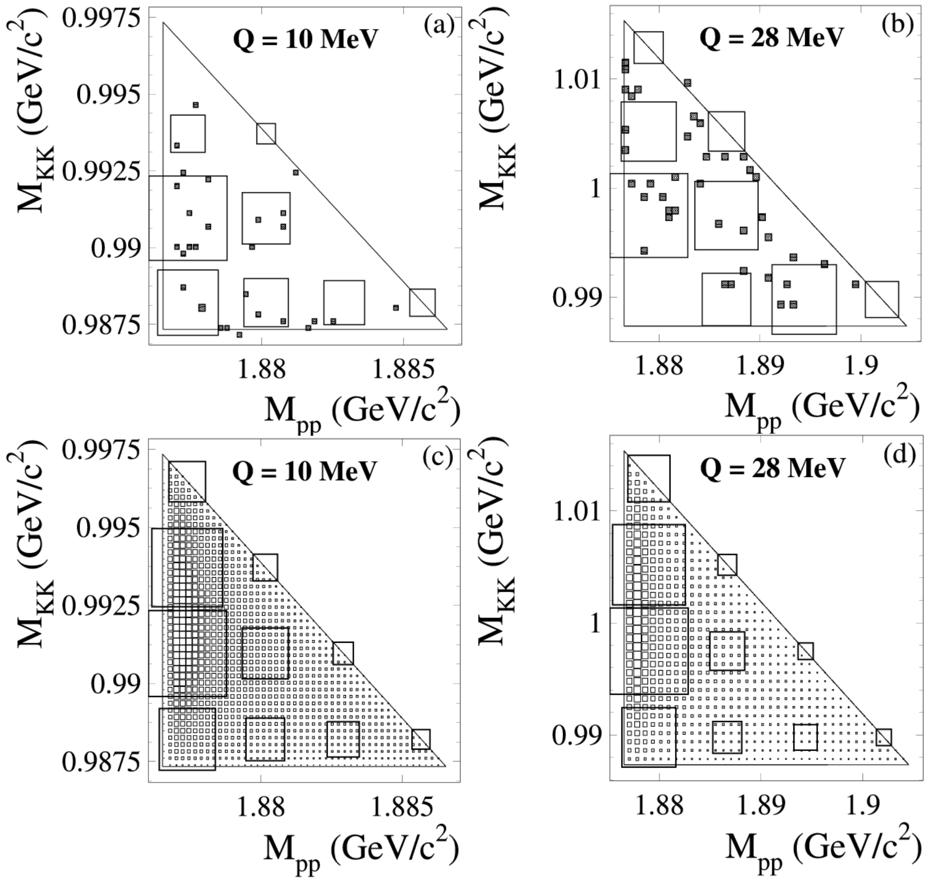
Analysis of the K⁺K⁻-FSI at COSY-11



$$F_{pp}(q) = \frac{e^{i\delta_{pp}(^1S_0)}\sin\delta_{pp}(^1S_0)}{Cq}$$

$$a_{pK^-} = (-0.65 + i0.78)[\text{fm}]$$

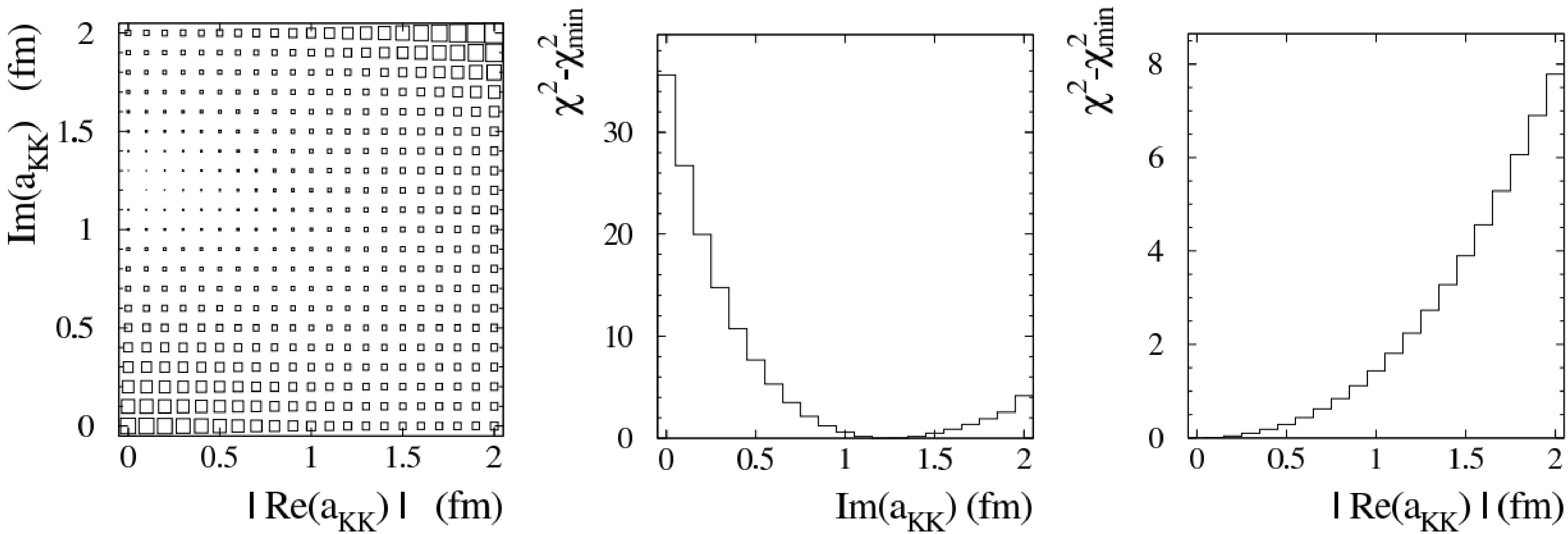
(Y. Yan, arXiv:0905.4818 [nucl-th])



M. Silarski, et al.,Phys. Rev. C 80, 045202 (2009)

- ❖ Analysis of the Goldhaber plots measured at Q = 10 MeV (27 events) and Q = 28 MeV (30 events) + near threshold excitation function

Analysis of the K^+K^--FSI at COSY-11



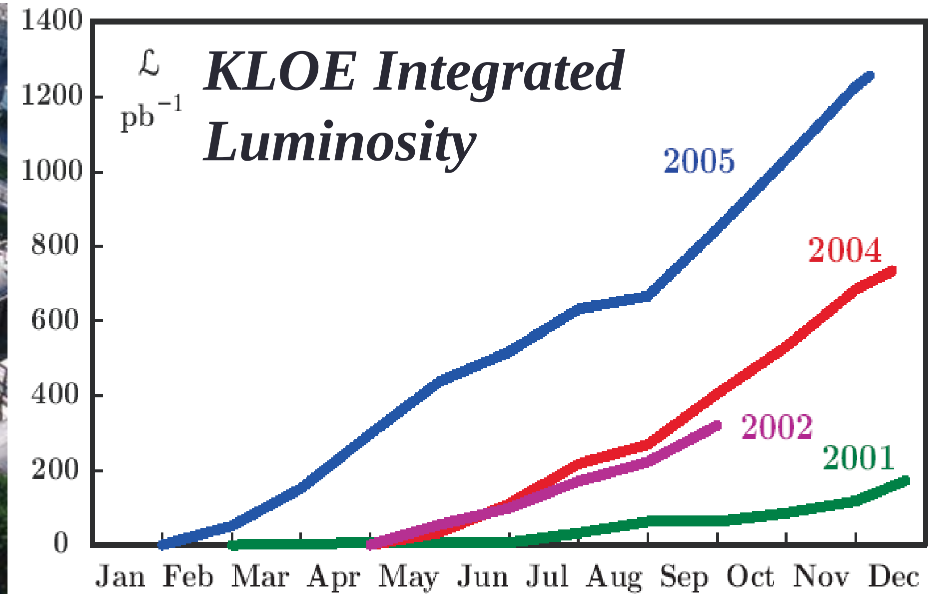
$$\chi^2\left(a_{K^+K^-},\alpha\right)=\sum_{i=1}^{8}\frac{\left(\sigma_i^{exp}-\alpha\sigma_i^{m}\right)^2}{\left(\Delta\sigma_i^{exp}\right)^2}+2\cdot\sum_{j=1}^{2}\sum_{k=1}^{10}\left[\beta_j N_{jk}^{s}-N_{jk}^{e}+N_{jk}^{e}\ln\left(\frac{N_{jk}^{e}}{\beta_j N_{jk}^{s}}\right)\right]$$

$$|\mathrm{Re}(a_{K^+K^-})|=0.0\,{}^{+1.1_{stat}}_{-0.0_{stat}}\ \mathrm{fm}$$

$$\mathrm{Im}(a_{K^+K^-})=1.1\,{}^{+0.6_{stat}}_{-0.5_{stat}}\,{}^{+0.9_{sys}}_{-0.6_{sys}}\ \mathrm{fm}$$

Near future:
KLOE-2 @ DAΦNE

DAΦNE Luminosity history



KLOE run:

- Daily performance: 7-8 pb^{-1}
- Best month $\int L\,dt \sim 200\ pb^{-1}$
- Total KLOE $\int L\,dt \sim 2400\ pb^{-1}$ at φ mass peak + 250 pb^{-1} off peak (@ 1 GeV)

BR's for selected Φ decays	
K^+K^-	49.1%
K_SK_L	**34.1%**
$\rho\pi + \pi^+\pi^-\pi^0$	15.5%

KLOE (K LOng Experiment)

Large cylindrical drift chamber

- Uniform tracking and vertexing in all volume
- Helium based gas mixture (90% He – 10% $IsoC_4H_{10}$)
- Stereo wire geometry

$\sigma_p/p = 0.4\ \%$

$\sigma_{xy} = 150\ \mu m$; $\sigma_z = 2\ mm$

$\sigma_{vtx} \sim 3\ mm$

$\sigma(M_{\pi\pi}) \sim 1\ MeV$

Lead/scintillating-fiber calorimeter

- Hermetical coverage
- High efficiency for low energy photons

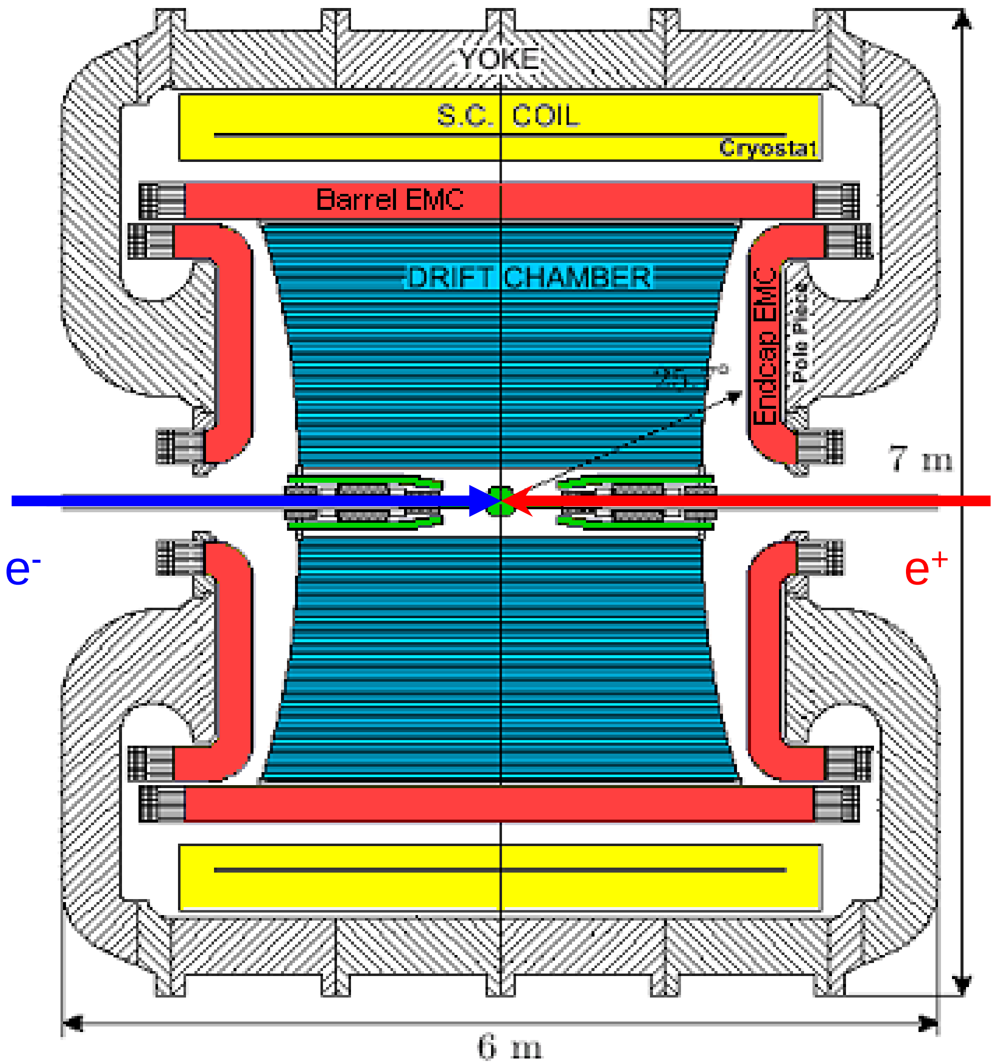
$\sigma_E/E = 5.7\% /\sqrt{E(GeV)}$

$\sigma_t = 57\ ps /\sqrt{E(GeV)} \oplus 140\ ps$

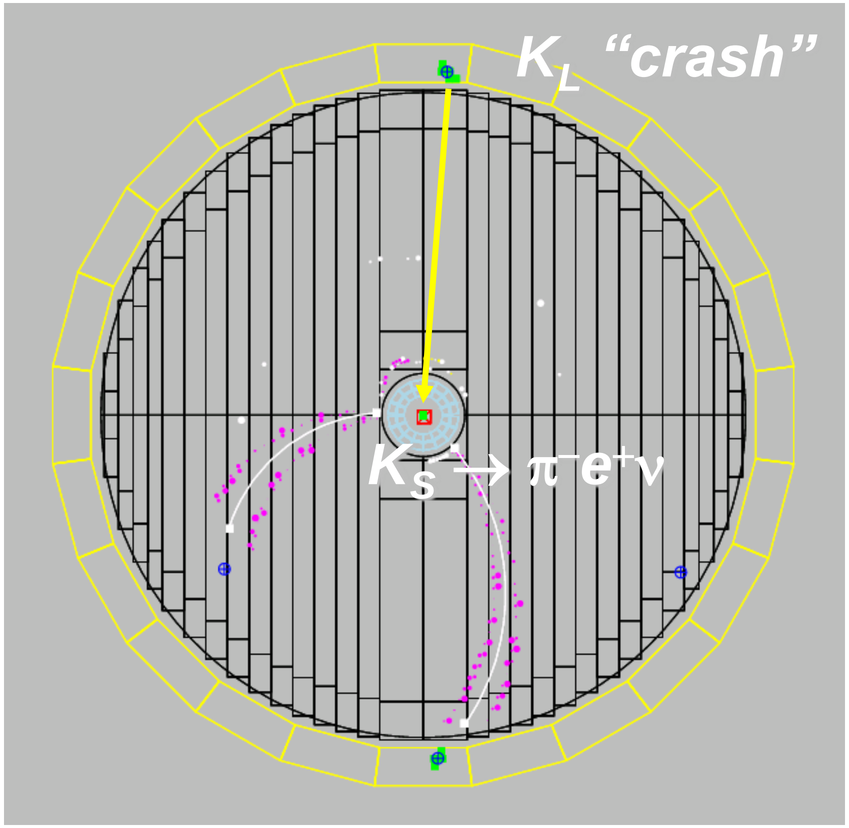
$\sigma_{vtx}(\gamma\gamma) \sim 1.5\ cm$

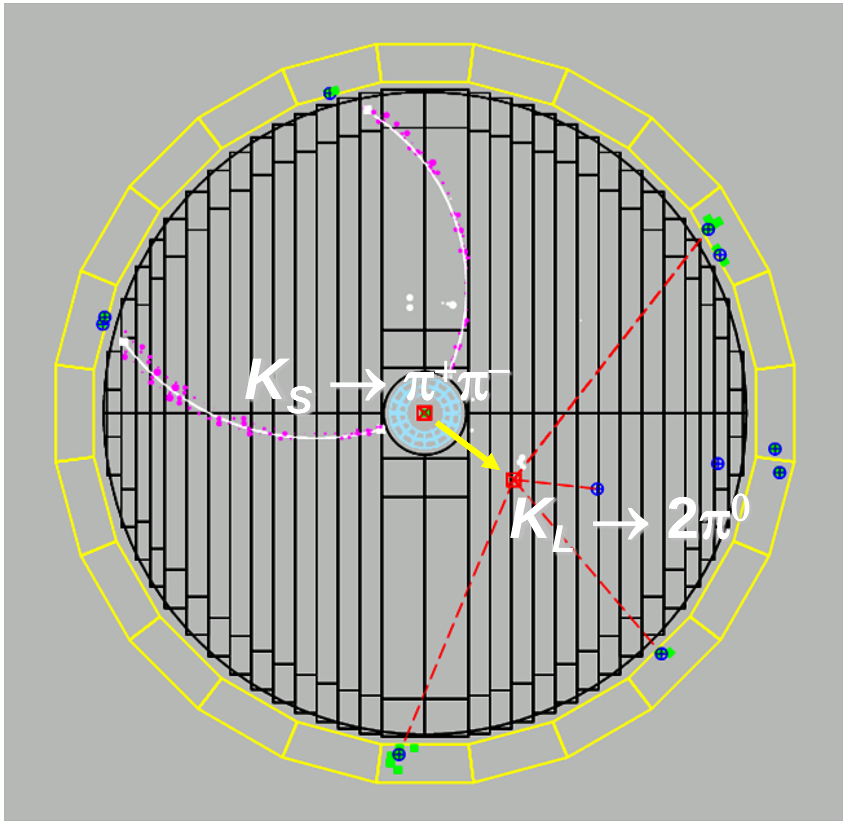
Superconducting coil

B = 0.52 T



A Φ-factory offers the possibility to select pure kaon beams:





K_S tagged by K_L interaction in EmC

Efficiency ~ 30%

K_S angular resolution: ~ 1°(0.3° in φ)

K_S momentum resolution: ~ 2 MeV

K_L tagged by $K_S \rightarrow \pi^+\pi^-$ vertex at IP

Efficiency ~ 70%

K_L angular resolution: ~ 1°

K_L momentum resolution: ~ 2 MeV

KK –FSI @ KLOE-2

$e^+e^- \rightarrow K^+K^-\gamma$

- **Advantage with respect to pp→ ppK^+K^- : only two interacting particles** (estimated scattering length independent from the FSI model)

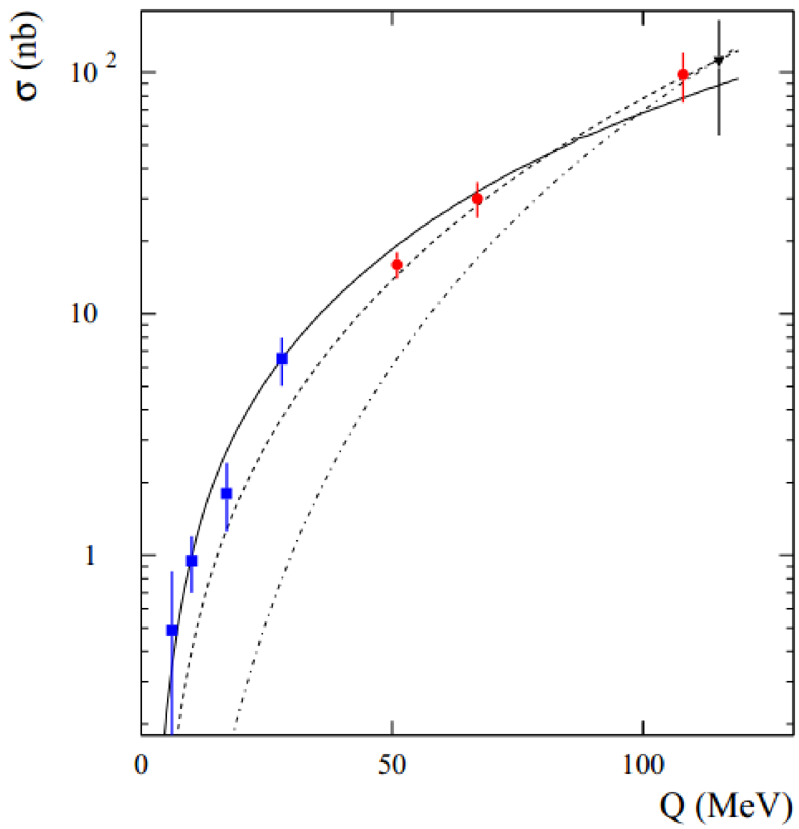
- The cross section including both ISR & FSR ~ 7nb (calculated with PHOKHARA at 1 GeV) ⇒ 200 pb^{-1} of integrated luminosity ~ $1.4 \cdot 10^6$ events (10^2 – 10^3 higher statistics than COSY-11)

- To fully describe the K^+K^- -FSI we need also to measure:

$e^+e^- \rightarrow \pi^0\pi^0\gamma$ [EPJC49(2007)473]
$e^+e^- \rightarrow \pi^+\pi^-\gamma$ [PLB606(2005)12, PLB670(2009)285, PLB700(2011)102]
$e^+e^- \rightarrow \pi^0\eta\gamma$ [PLB681(2009)5]
$e^+e^- \rightarrow K_S\, K_S\gamma$ [PLB679(2009)10]

Conclusions & outlook

- The excitation function for the pp→ppK+K- reaction reveal an enhancement which may be assigned to the influence of the pK- and K^+K^- interaction
- The ANKE factorization ansatz underestimates experimental data very close to threshold
- The coupled channel effects and production of $f_0(980)/a_0(980)$ are up to now not distinguishable even with high statistic measuremens
- We have estimated the K^+K^- scattering length based on the near threshold data independently from a_{pK^-} obtained by the ANKE group
- Rough estimates show that with KLOE-2 we could study the KK final state interaction with high precision



SPARES

$$\beta_j = \frac{L_j \alpha \sigma_j^m}{N_j^{gen}}$$

$$\sigma^m = \int \frac{\pi^2 \left|M\right|^2}{8s\sqrt{-B}} \, \mathrm{d}M_{pp}^2 \mathrm{d}M_{K^+K^-}^2 \mathrm{d}M_{pK^-}^2 \mathrm{d}M_{ppK^-}^2 \mathrm{d}M_{ppK^+}^2$$

$$\left|M_{pp \to ppK^+K^-}\right|^2 \approx \left|M_0\right|^2 \left|F_{FSI}\right|^2$$

$$F_{FSI} = F_{pp}(q) \times F_{p_1K^-}(k_1) \times$$
$$\times F_{p_2K^-}(k_2) \times F_{K^+K^-}(k_3)$$

$$F_{K^+K^-}(k_3) = \frac{1}{1 - ik_3 a_{K^+K^-}}$$

Generalization of the Dalitz Plot

- Probability of reaction yielding a state with the *i*-th particle in momentum range dp_i (in CM):

$$d^{12}R = d^3p_1 d^3p_2 d^3p_3 d^3p_4 \frac{1}{16E_1E_2E_3E_4}\delta^3\left(\sum_j \vec{p}_j\right)\delta\left(\sum_j E_j - \sqrt{s}\right) f^2$$

- Assuming that f depends only on invariant masses of the particles one obtains (**Nyborg et al. Phys. Rev. 140 922 (1965)**):

$$d^5R = f^2 \frac{\pi^2}{8s\sqrt{-B}} dM_{12}^2 dM_{14}^2 dM_{34}^2 dM_{124}^2 dM_{134}^2$$

[illegible]

$$\left| M_{pp \to ppK^+K^-} \right|^2 \approx \left| M_0 \right|^2 \left| F_{FSI} \right|^2$$

$$F_{FSI} = F_{pp}(q) \times F_{p_1K^-}(k_1) \times F_{p_2K^-}(k_2)$$

$$F_{pp}(q) = \frac{e^{-i\delta_{pp}(^1S_0)} \times \sin \delta_{pp}(^1S_0)}{C \times q}$$

$$F_{pK^-}(k) = \frac{1}{1 - ika}$$

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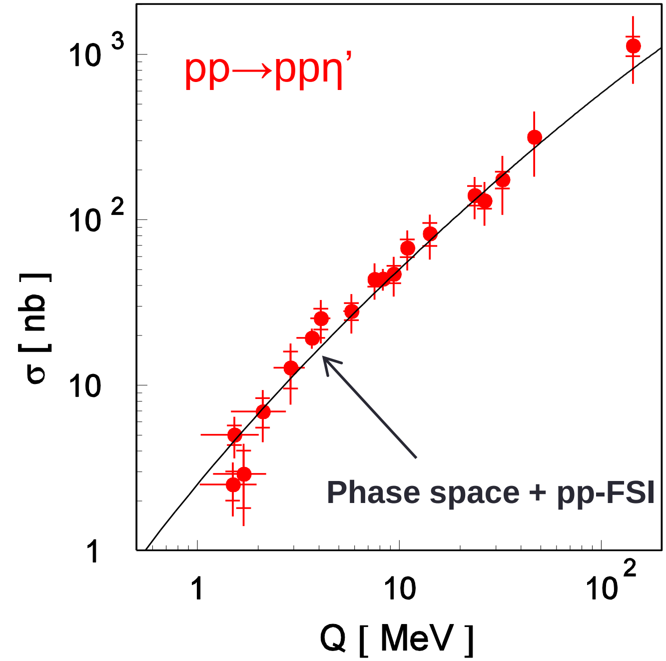

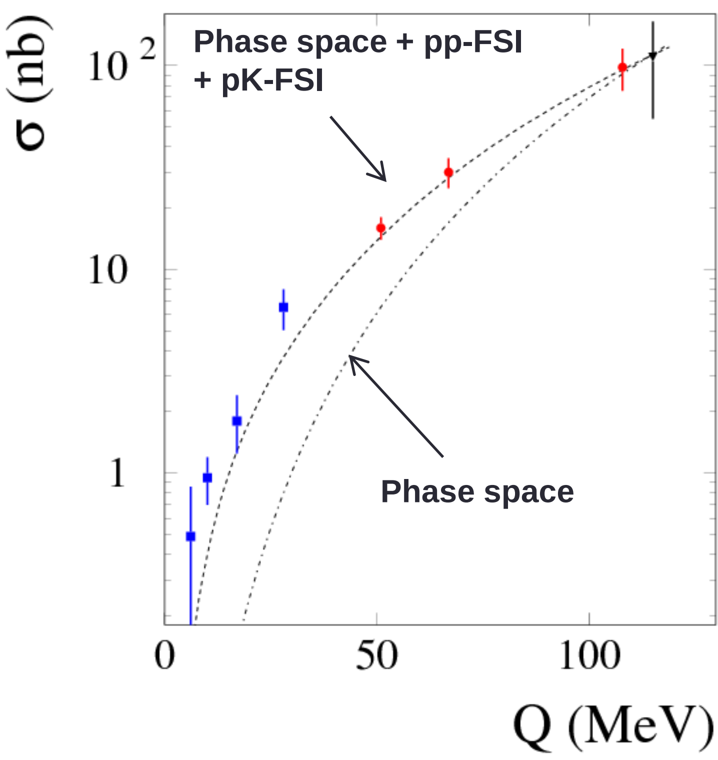

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