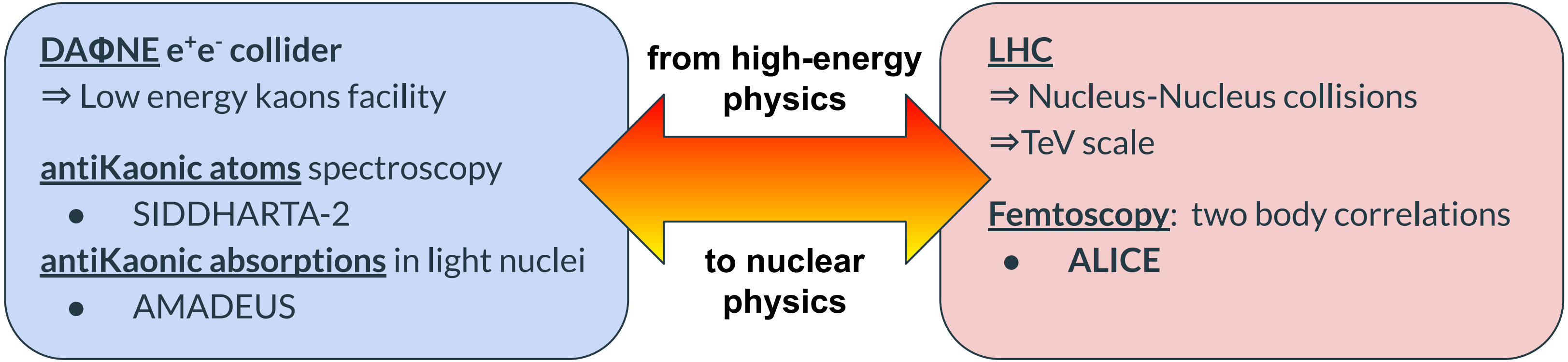
A new era of hadron physics measurements

Otón Vázquez Doce
Frascati, December 1st, 2022

A combined effort…



DAΦNE e^+e^- **collider**

⇒ Low energy kaons facility

antiKaonic atoms spectroscopy

- SIDDHARTA-2

antiKaonic absorptions in light nuclei

- AMADEUS

from high-energy physics

to nuclear physics

LHC

⇒ Nucleus-Nucleus collisions

⇒TeV scale

Femtoscopy: two body correlations

- ALICE

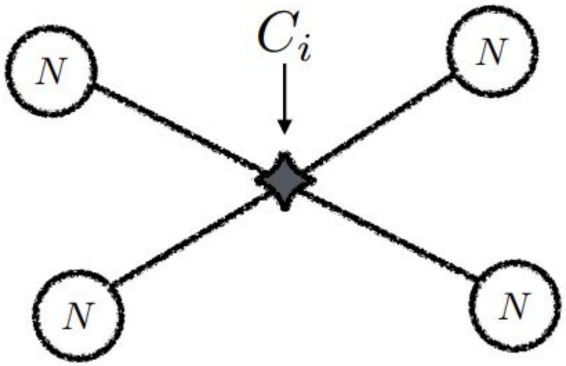
…with a great opportunity

Unprecedented precise data to constraint of state of the art models (EFT) and…

- Study **coupled-channel systems** **and new molecular states**
- **Constraint the Equation of State** of neutron stars
- **Test** **first principle calculations** in their preferred framework
- **Search for new bound states:** 2-baryon systems beyond the deuteron and more

Hadron-hadron strong interactions

Residual strong interaction among hadrons



$$\mathcal{L}_{EFT}[\pi, N, \ldots; m_\pi, m_N, \ldots, C_i]$$

Effective theories (EFT)

- **Hadrons as degrees of freedom**
- **Low-energy EFT coefficients constraint by data**

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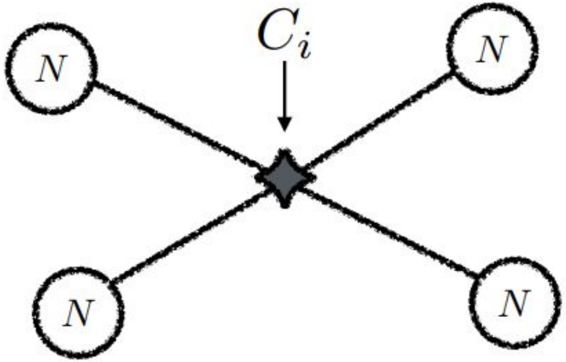

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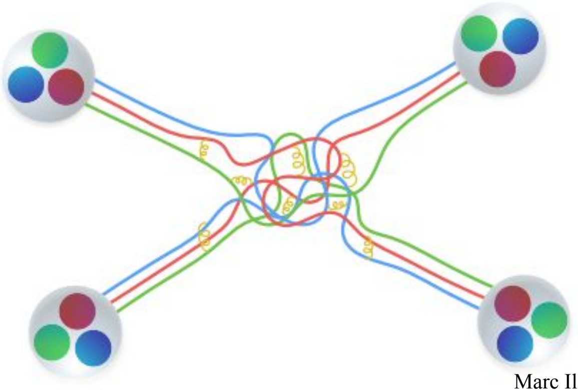


Marc Illa
THEIA-STRONG2020

$$\mathcal{L}_{QCD}[q, \bar{q}, A; m_q, \alpha_s]$$

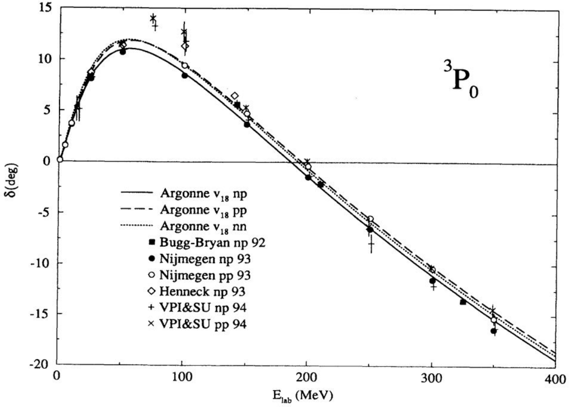
Lattice QCD

- Understanding of the interaction starting from **quark and gluons**

Hadron-hadron interactions (with strangeness)

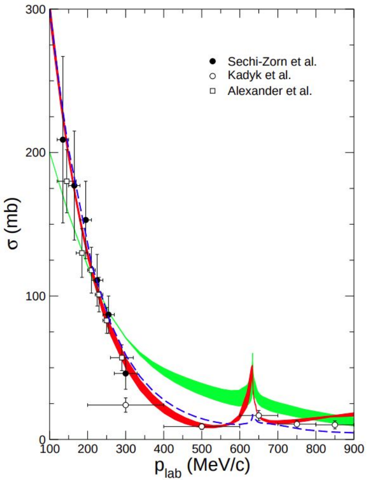
S=0 *S*=-1 *S*=-2

NN → NN



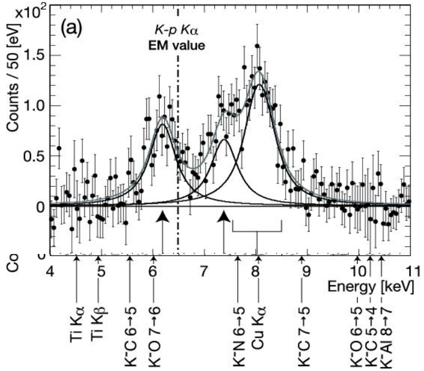
R. B. Wiringa, V. G. J. Stoks, R. Schiavilla Phys. Rev. C 51, 38 (1995)

Λp → Λp



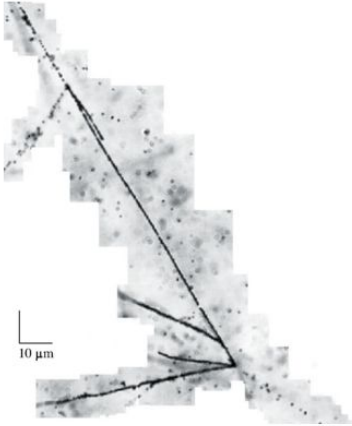
LO: H. Polinder, J. Haidenbauer, U. Meißner, Nucl. Phys. A779 (2006) 244.
NLO: J. Haidenbauer et al., Nucl. Phys. A915 (2013) 24.

Kaonic atoms



SIDDHARTA Coll. Phys.Lett.B 704 (2011) 113

ΛΛ, Ξ hypernuclei



KISO event: K. Nakazawa et al., Prog. Theor. Exp. Phys. 2015, 033D02
IBUKI event J-PARC E07 Coll., Phys. Rev. Lett. 126, 062501 (2021)

The case of the antiKaon-Nucleon interaction

Kaon and antiKaon interactions with nucleons are <u>totally different</u>

Chiral Perturbation Theory (Weinberg, Gasser, Leutwyler) is not applicable

- mass of the strange quark: **$m_s > m_u, m_d$**
- appearance of the **Λ(1405) below** (and close to) **threshold**

Theoretical models should:

- make <u>predictions below threshold</u>
- <u>describe</u> (the nature of) <u>the Λ(1405)</u>

Connected many hot topics:

- Strong coupled channel dynamics $\bar{K}N$-$\Sigma\pi$
  [Y. Kamiya et al., Phys. Rev. Lett. 124, 132501 (2020)]
- Kaonic bound states (case of $\bar{K}NN$)
  [JPARC E15, PLB 789 (2019) 620]
- Strangeness in NS: kaon condensate
  [D.Logoteta Universe 2021, 7(11), 408]
- Enhanced production of strangeness with multiplicity [T. Song @ SQM2021]

Theoretical approaches to antiK-N

- Lattice QCD… in the near future!
- meson exchange
- phenomenological
- **chiral SU(3) dynamical**

Data is crucial to test (+feed) this approaches.

Data fitting by Chiral SU(3).

- Going to NLO (N^2LO?), s+p waves ⇒ more parameters to be fixed (by data)
- Adding **new data** helps to improve the model
- Adding **more precise data** helps to improve the model
- Adding **data at different energies** helps to improve the model

Theoretical a

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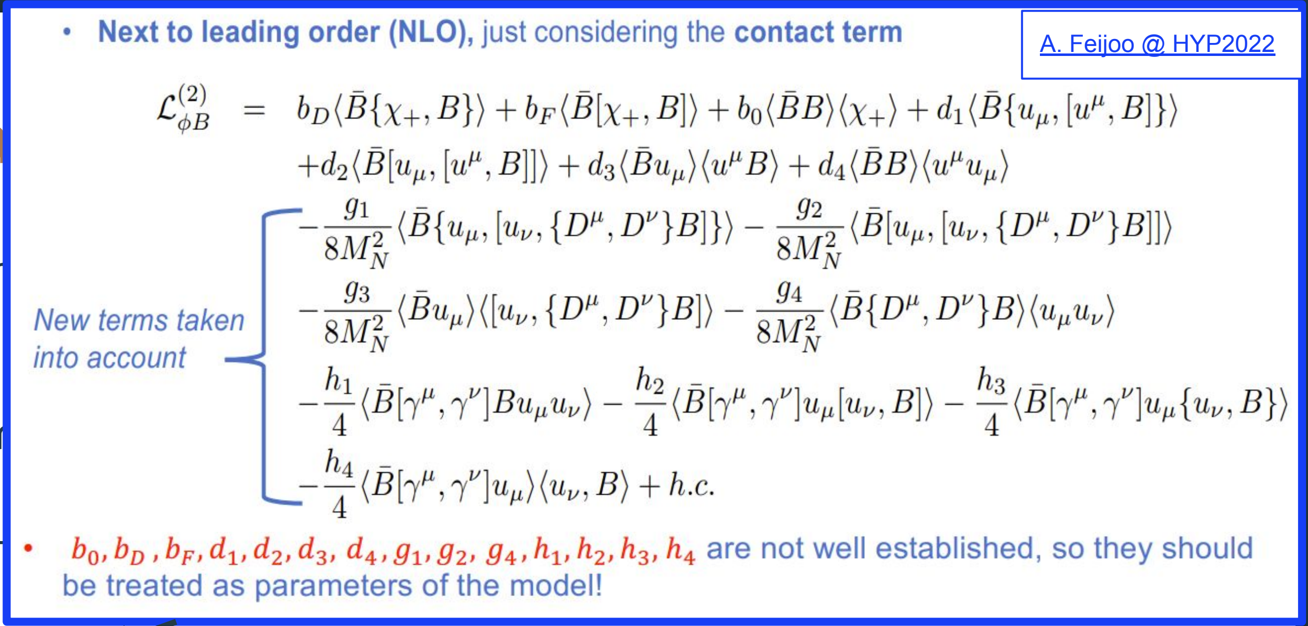

- **Next to leading order (NLO),** just considering the **contact term**

A. Feijoo @ HYP2022

$$\begin{aligned}\mathcal{L}^{(2)}_{\phi B} = {} & b_D\langle\bar{B}\{\chi_+,B\}\rangle + b_F\langle\bar{B}[\chi_+,B]\rangle + b_0\langle\bar{B}B\rangle\langle\chi_+\rangle + d_1\langle\bar{B}\{u_\mu,[u^\mu,B]\}\rangle \\ & + d_2\langle\bar{B}[u_\mu,[u^\mu,B]]\rangle + d_3\langle\bar{B}u_\mu\rangle\langle u^\mu B\rangle + d_4\langle\bar{B}B\rangle\langle u^\mu u_\mu\rangle \\ & \left\{\begin{array}{l} -\dfrac{g_1}{8M_N^2}\langle\bar{B}\{u_\mu,[u_\nu,\{D^\mu,D^\nu\}B]\}\rangle - \dfrac{g_2}{8M_N^2}\langle\bar{B}[u_\mu,[u_\nu,\{D^\mu,D^\nu\}B]]\rangle \\ -\dfrac{g_3}{8M_N^2}\langle\bar{B}u_\mu\rangle\langle[u_\nu,\{D^\mu,D^\nu\}B]\rangle - \dfrac{g_4}{8M_N^2}\langle\bar{B}\{D^\mu,D^\nu\}B\rangle\langle u_\mu u_\nu\rangle \\ -\dfrac{h_1}{4}\langle\bar{B}[\gamma^\mu,\gamma^\nu]Bu_\mu u_\nu\rangle - \dfrac{h_2}{4}\langle\bar{B}[\gamma^\mu,\gamma^\nu]u_\mu[u_\nu,B]\rangle - \dfrac{h_3}{4}\langle\bar{B}[\gamma^\mu,\gamma^\nu]u_\mu\{u_\nu,B\}\rangle \\ -\dfrac{h_4}{4}\langle\bar{B}[\gamma^\mu,\gamma^\nu]u_\mu\rangle\langle u_\nu,B\rangle + h.c. \end{array}\right.\end{aligned}$$

New terms taken into account

- $b_0, b_D, b_F, d_1, d_2, d_3, d_4, g_1, g_2, g_4, h_1, h_2, h_3, h_4$ are not well established, so they should be treated as parameters of the model!

[Data fitting by Chiral SU(3).](#)

- Going to NLO (N^{2}LO?), s+p waves ⇒ more parameters to be fixed (by data)
- Adding **new data** helps to improve the model
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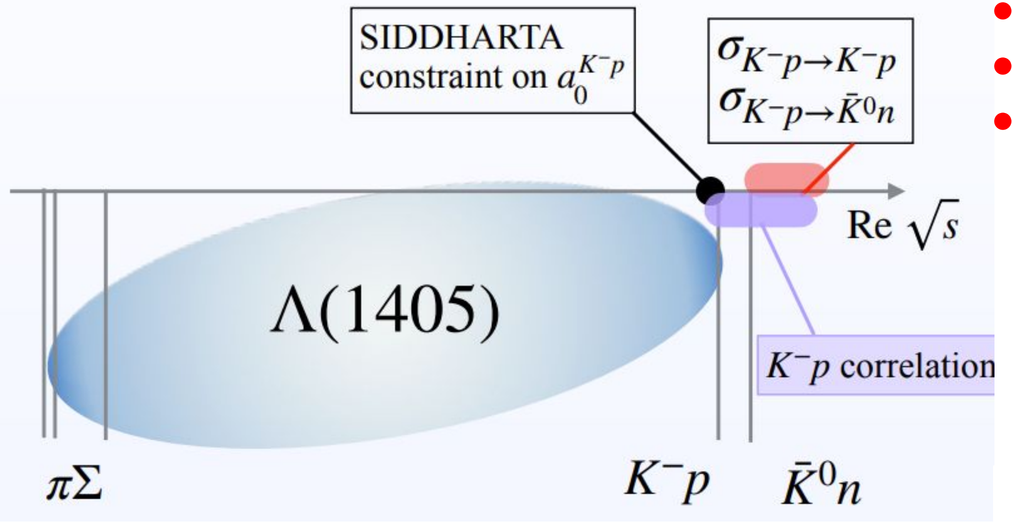
Available experimental data

Antikaonic atoms

Scattering data



- **Yield, B and Γ of kaonic nuclear states**
- **Single vs Multi-nucleonic absorption rates**
- **K-pp three body femtoscopy**

⇐ **Femtoscopy**

image courtesy of Y. Kamiya

⇧

Scattering amplitudes below threshold

⇧

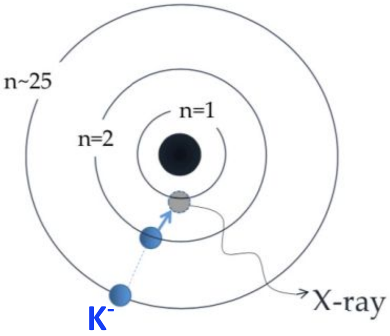
Threshold branching ratios

⇧

Λ(1405) mass shape in different channels

antikaonic hydrogen: SIDDHARTA

antikaonic hydrogen: SIDDHARTA



2p → 1s
K_α transition

shift(ε), width(Γ) with respect to e.m. value caused by attractive/repulsive strong interaction and the presence of inelastic channels

Measurement of the **shift(ε) and width(Γ) induced by the strong interaction** in the lowest level atomic transition.

SIDDHARTA Coll., PLB 704 (2011) 113

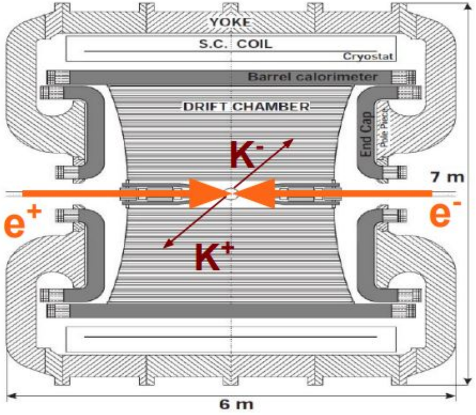
$$\epsilon_{1s} = -283 \pm 36(\mathrm{stat}) \pm 6(\mathrm{syst})\ \mathrm{eV}$$
$$\Gamma_{1s} = 541 \pm 89(\mathrm{stat}) \pm 22(\mathrm{syst})\ \mathrm{eV},$$

Translated via Desser-type Formula into a **K$^-$p scattering length** that is an average of the KbarN scattering lengths for I=0 and I=1

$$\epsilon_{1s} - \frac{i}{2}\Gamma_{1s} = -2\alpha^3\mu_c^2 a_p\left(1 - 2\alpha\mu_c(\ln\alpha - 1)a_p\right)$$

$$a_{K^-p} = \frac{a_0(I=0) + a_1(I=1)}{2}$$

AMADEUS: K^- absorption in ^{4}He and ^{12}C



KLOE used as an active target

- DC wall (750 μm C foil , 150 μm Al foil);
- DC gas (90% He, 10% C_4H_{10}).

+

pure sample of K^- ^{12}C absorptions at-rest

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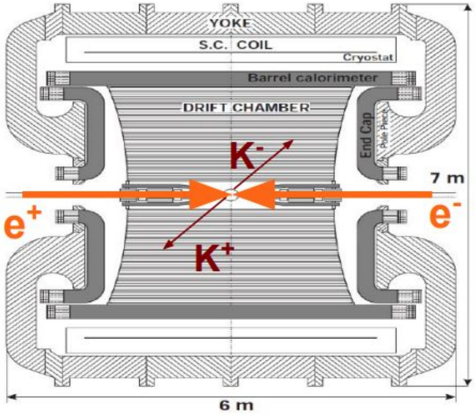

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+

pure sample of K^- ^{12}C absorptions at-rest

K^- + A → Yp + A'

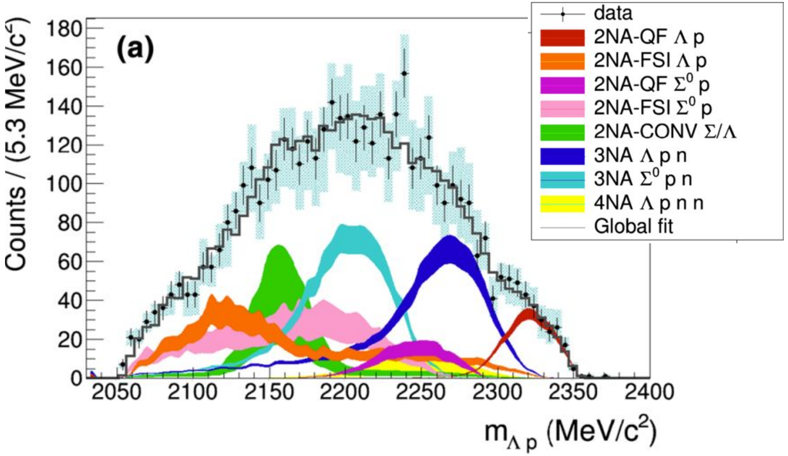
Multi-nucleon absorption processes dominate

AMADEUS Coll. PLB 758 (2016) 134
AMADEUS Coll. PLB 782 (2018) 339
AMADEUS Coll. FBS 62 (2021) 7.

Below threshold (-33 MeV) **$K^-n \rightarrow \pi^-\Lambda$ (I=1 non resonant)**

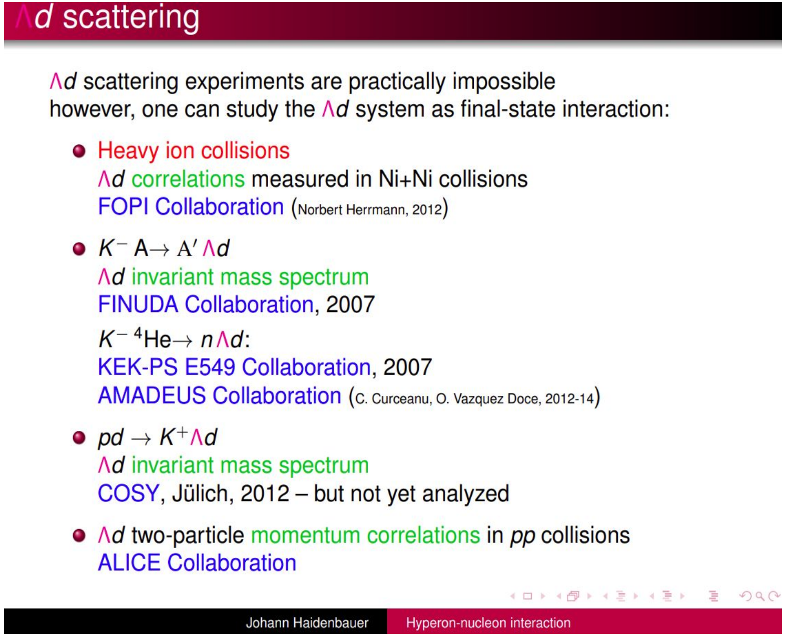
$$|A_{K^-n\rightarrow\Lambda\pi^-}| = (0.334 \pm 0.018\,\mathrm{stat}^{+0.034}_{-0.058}\,\mathrm{syst})\ \mathrm{fm}.$$

AMADEUS Coll., PLB 782 (2018) 339-345]



AMADEUS-type data is a hot topic

J. Haidenbauer @ FemTUM 2022



Λ*d* scattering

Λ*d* scattering experiments are practically impossible
however, one can study the Λ*d* system as final-state interaction:

- Heavy ion collisions
  Λ*d* correlations measured in Ni+Ni collisions
  FOPI Collaboration (Norbert Herrmann, 2012)
- K^- A→ A′ Λ*d*
  Λ*d* invariant mass spectrum
  FINUDA Collaboration, 2007
  $K^-\,{}^4$He→ *n*Λ*d*:
  KEK-PS E549 Collaboration, 2007
  AMADEUS Collaboration (C. Curceanu, O. Vazquez Doce, 2012-14)
- $pd \to K^+\Lambda d$
  Λ*d* invariant mass spectrum
  COSY, Jülich, 2012 – but not yet analyzed
- Λ*d* two-particle momentum correlations in *pp* collisions
  ALICE Collaboration

Johann Haidenbauer | Hyperon-nucleon interaction

E. Oset @ HYP 2022

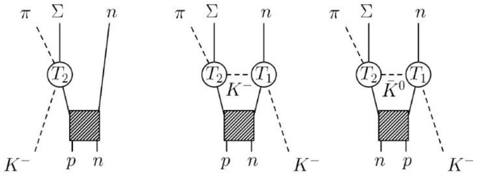
How to learn about the Kbar N amplitude below threshold and the Λ(1405)?

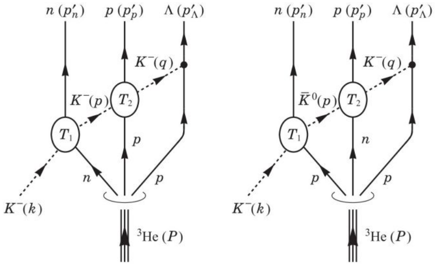
The photonuclear data provides information.

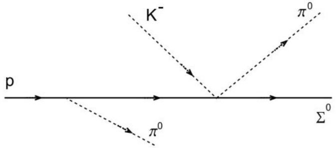
The K^- d → π n Σ reaction

K- 3He → Λ p n

$K^- p \to \pi^0\pi^0\Sigma^0$

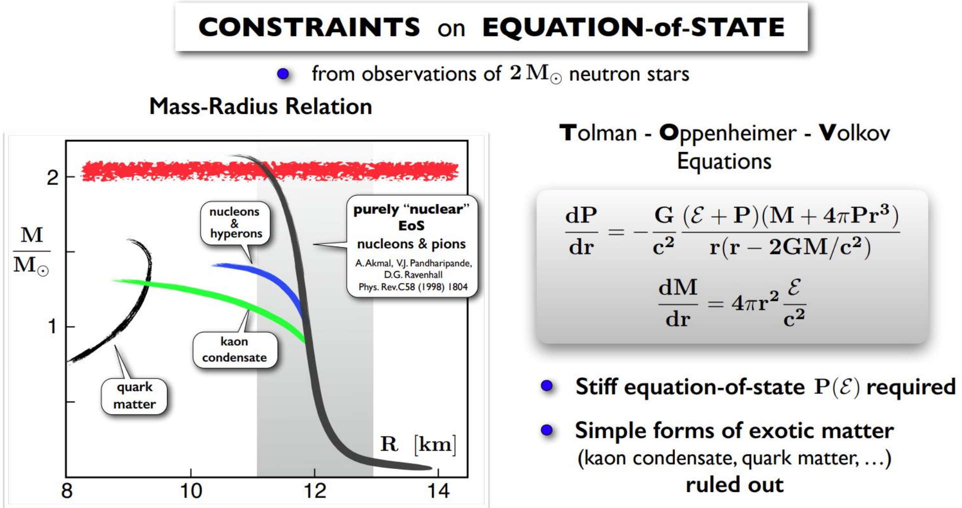






EoS of dense symmetric nuclear matter

W. Weise @ HYP 2022



CONSTRAINTS on EQUATION-of-STATE

- from observations of $2\,M_\odot$ neutron stars

Mass-Radius Relation

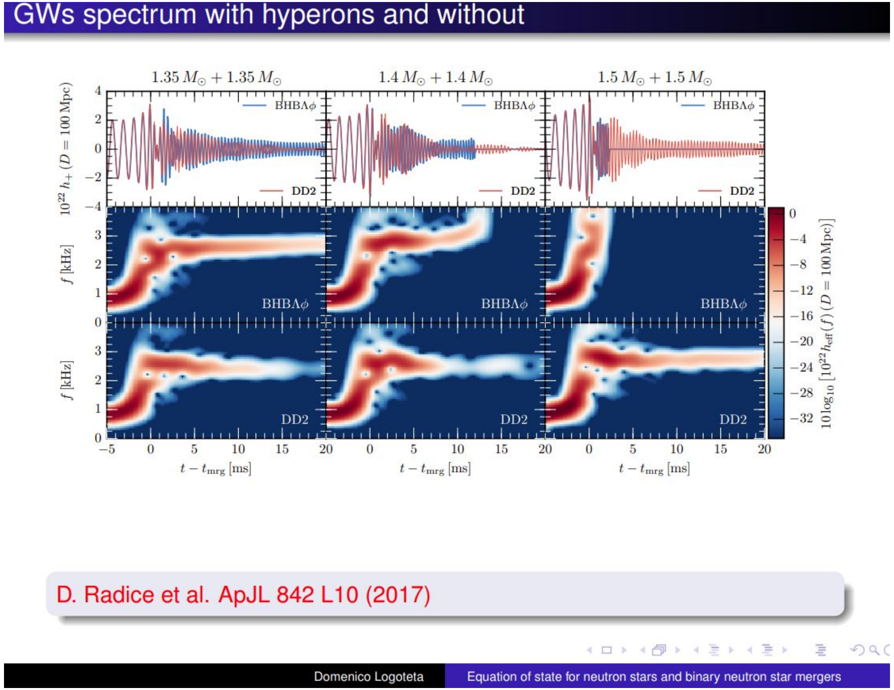
Tolman - **O**ppenheimer - **V**olkov Equations

$$\frac{dP}{dr} = -\frac{G}{c^2}\frac{(\mathcal{E}+P)(M+4\pi P r^3)}{r(r-2GM/c^2)}$$

$$\frac{dM}{dr} = 4\pi r^2 \frac{\mathcal{E}}{c^2}$$

- **Stiff equation-of-state $P(\mathcal{E})$ required**
- **Simple forms of exotic matter** (kaon condensate, quark matter, …) **ruled out**

D. Logoteta @ EXOTICO 2022



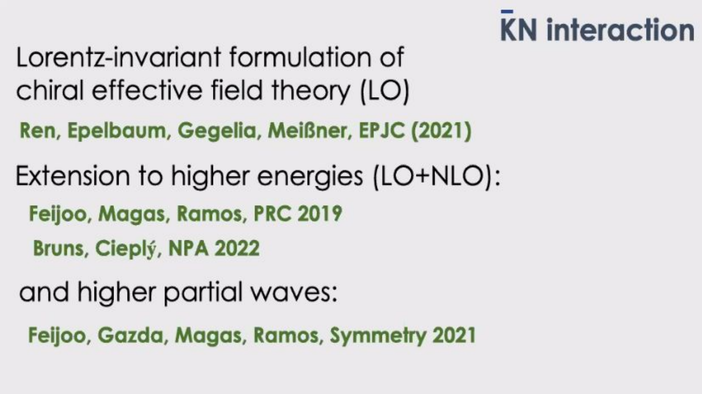
GWs spectrum with hyperons and without

D. Radice et al. ApJL 842 L10 (2017)

Domenico Logoteta | Equation of state for neutron stars and binary neutron star mergers

Avaliable KbarN scattering data

A. Ramos @ QNP2022



$\bar{K}$N interaction

Lorentz-invariant formulation of chiral effective field theory (LO)

Ren, Epelbaum, Gegelia, Meißner, EPJC (2021)

Extension to higher energies (LO+NLO):

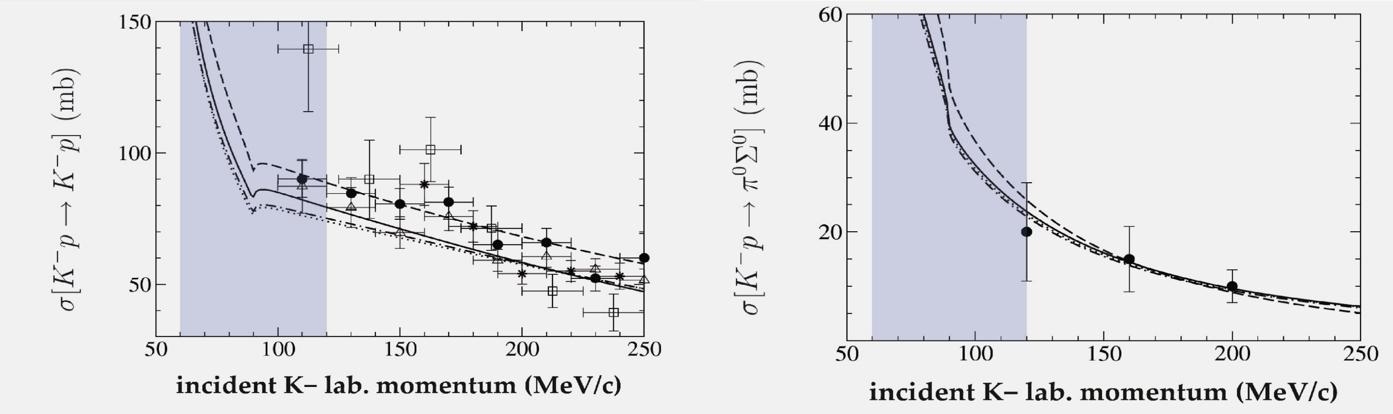
Feijoo, Magas, Ramos, PRC 2019

Bruns, Cieplý, NPA 2022

and higher partial waves:

Feijoo, Gazda, Magas, Ramos, Symmetry 2021

- The present knowledge of total and differential cross sections of low energy kaon-nucleon reactions is very limited.
- Below 150 MeV/c the experimental data are very scarce and with large errors and practically no data exist below 100 MeV/c.

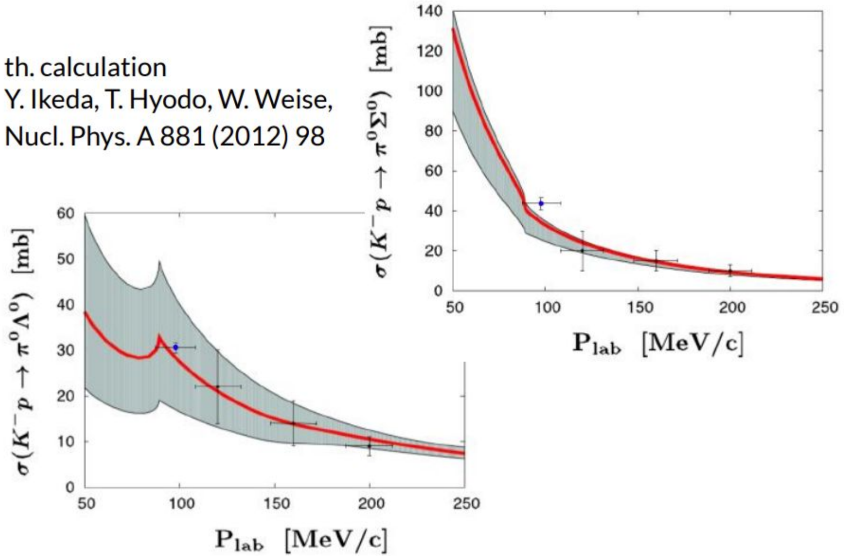


AMADEUS KbarN inelastic scattering

⇒ The most recent AMADEUS result has been submitted to PRL. **arXiv:2210.10342 [nucl-ex]**

First Simultaneous $K^-p \to (\Sigma^0/\Lambda)\,\pi^0$ Cross Sections Measurements at 98 MeV/c

th. calculation
Y. Ikeda, T. Hyodo, W. Weise,
Nucl. Phys. A 881 (2012) 98



$$\sigma_{K^-p\to\Sigma^0\pi^0} = 42.8 \pm 1.5(stat.)^{+2.4}_{-2.0}(syst.)\ \text{mb}$$

$$\sigma_{K^-p\to\Lambda\pi^0} = 31.0 \pm 0.5(stat.)^{+1.2}_{-1.2}(syst.)\ \text{mb}\,,$$

KNscat - KNint @ DAΦNE:

Kbar-N scattering and interaction

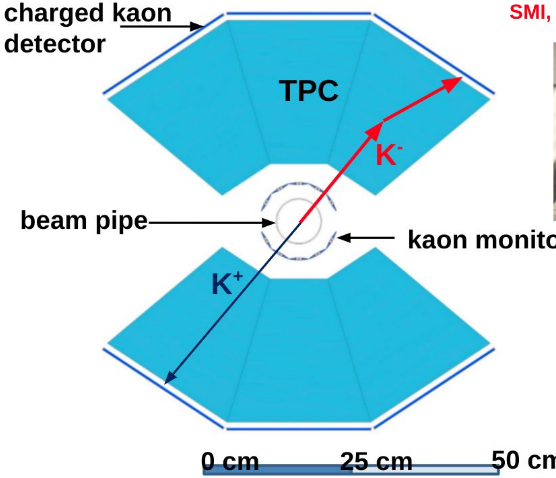
As presented to the Sci. Com. 2021:

https://arxiv.org/pdf/2104.06076.pdf

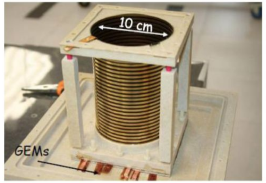
Fundamental physics at the strangeness frontier at DAΦNE.
Outline of a proposal for future measurements.

Towards a LOI (authors: Editorial Board only)

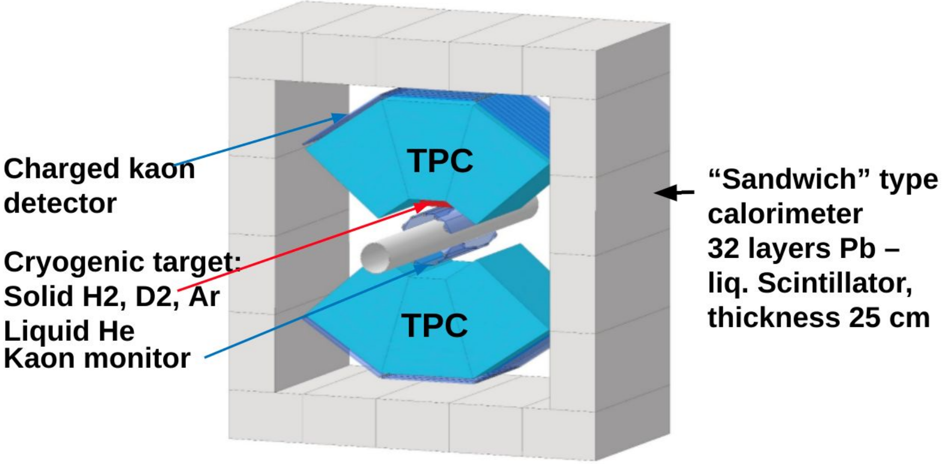
KN1: elastic scattering



TPC prototyping at:
Sendai Univ., Japan
SMI, Austria (EU-STRONG2020)



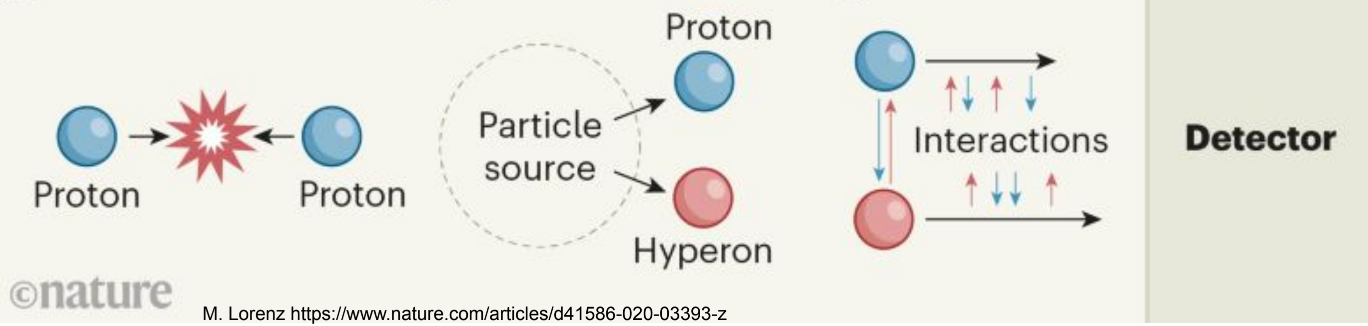
KN2 – inelastic scattering, nuclear interaction



Hadronic interactions via Femtoscopy at the LHC with ALICE

Hadronic interactions via Femtoscopy at the LHC with ALICE

Nucleus-Nucleus collisions at the LHC recorded by ALICE



M. Lorenz https://www.nature.com/articles/d41586-020-03393-z

Hadronic interactions via Femtoscopy at the LHC with ALICE

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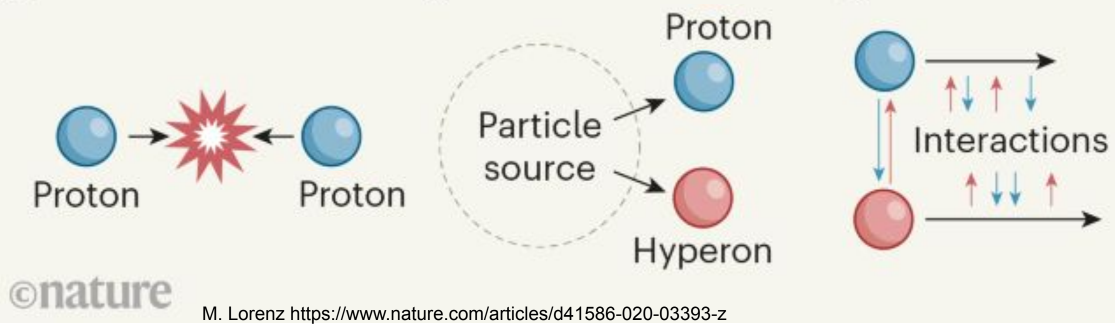

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LHC Run-2 data

- Charged particle tracking and PID
- Reconstruction of hyperons via weak decay

Hadronic interactions via Femtoscopy at the LHC with ALICE

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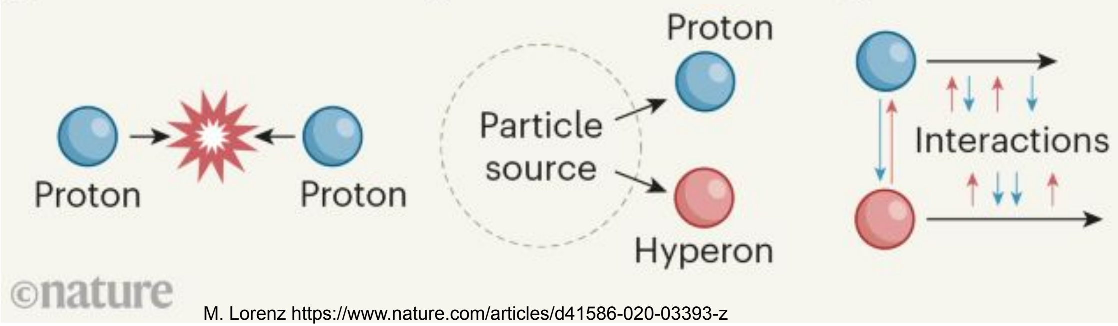


M. Lorenz https://www.nature.com/articles/d41586-020-03393-z

LHC Run-2 data

- Charged particle tracking and PID
- Reconstruction of hyperons via weak decay

Experimental observable: Correlation function of two final-state particles

$$C(k^*) = \frac{N_{\text{same}}(k^*)}{N_{\text{mixed}}(k^*)}$$

→ Pairs of particles from same collison

→ Particles produced in different collisions

$$k^* = \frac{|\vec{p_a^*} - \vec{p_b^*}|}{2}$$

relative momentum in pair rest frame

Theoretical correlation function

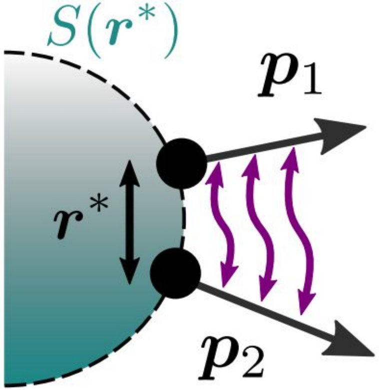
$$C(k^*) = \int \underset{\text{source}}{S(\boldsymbol{r}^*)} \, \underset{\text{wave function}}{|\psi(\boldsymbol{k}^*, \boldsymbol{r}^*)|^2} \, \mathrm{d}^3\boldsymbol{r}^*$$

Lisa, Pratt, Wiedemann, Solz, Ann. Rev. Nucl. Part. Sci. 55 (2005) 357

Theoretical correlation function

$$C(k^*) = \int \underbrace{S(\boldsymbol{r}^*)}_{\text{source}} \underbrace{|\psi(\boldsymbol{k}^*, \boldsymbol{r}^*)|^2}_{\text{wave function}} \, \mathrm{d}^3\boldsymbol{r}^*$$

Lisa, Pratt, Wiedemann, Solz, Ann. Rev. Nucl. Part. Sci. 55 (2005) 357



pp, p–Pb: r*~1fm
Pb–Pb: r*~3-10fm

Theoretical correlation function

$$C(k^*) = \int \underset{\text{source}}{S(\boldsymbol{r}^*)} \, \underset{\text{wave function}}{|\psi(\boldsymbol{k}^*, \boldsymbol{r}^*)|^2} \, \mathrm{d}^3\boldsymbol{r}^*$$

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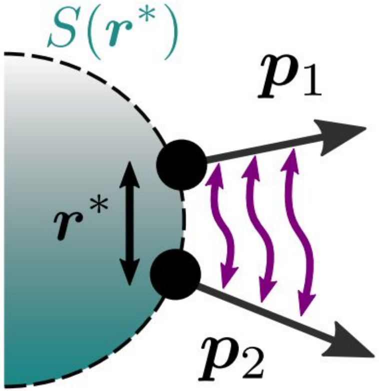
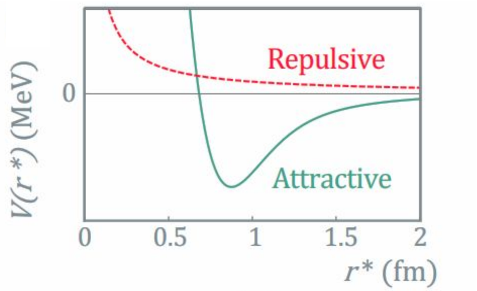


pp, p–Pb: r*~1fm
Pb–Pb: r*~3-10fm

Interaction



Schrödinger ⬇ equation

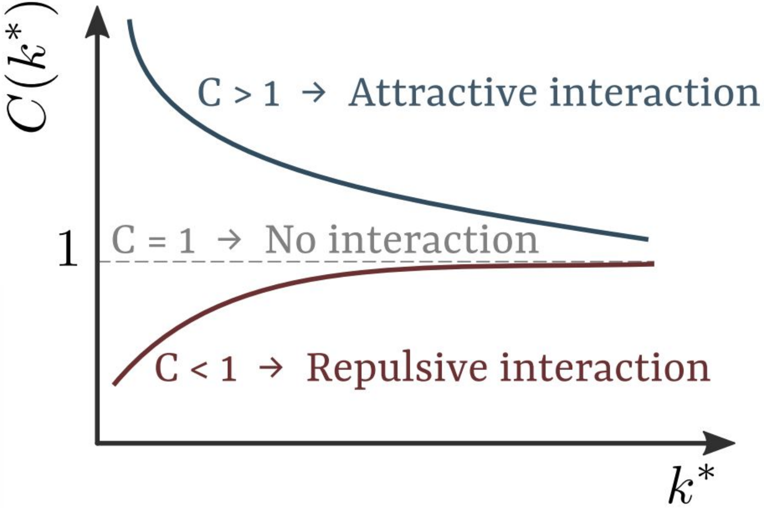
Two-particle wave function

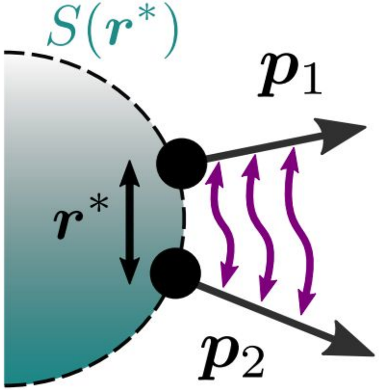
ψ(k*,r*)

Theoretical correlation function

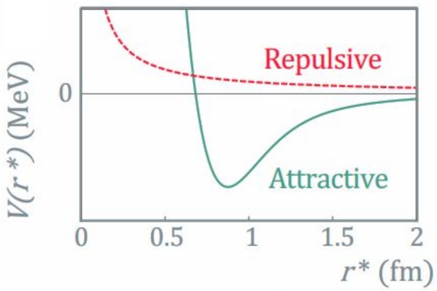
$$C(k^*) = \int \underset{\text{source}}{S(\boldsymbol{r}^*)}\,\underset{\text{wave function}}{|\psi(\boldsymbol{k}^*, \boldsymbol{r}^*)|^2}\, \mathrm{d}^3\boldsymbol{r}^*$$

Lisa, Pratt, Wiedemann, Solz, Ann. Rev. Nucl. Part. Sci. 55 (2005) 357





Interaction



Schrödinger equation

Two-particle wave function

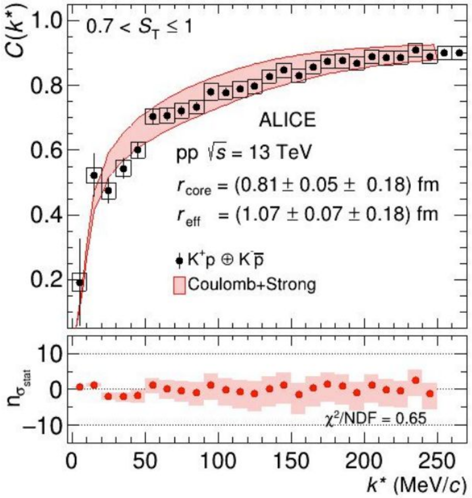
$\psi(k^*, r^*)$

pp, p–Pb: r*~1fm
Pb–Pb: r*~3-10fm

KbarN Femtoscopy with ALICE

Well known $K^{+}p$ interaction

⇒ experimental determination of the source size



Jülich meson exchange model Eur. Phys. J. A47, 18 (2011)

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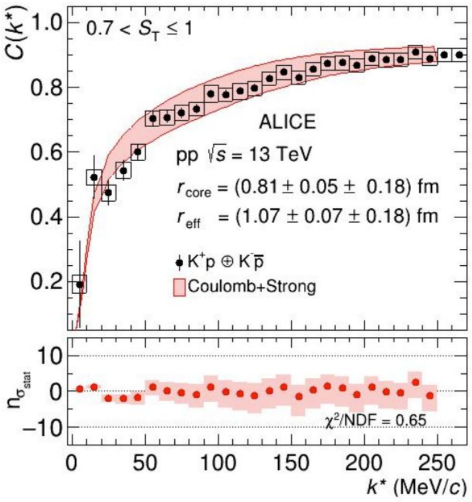
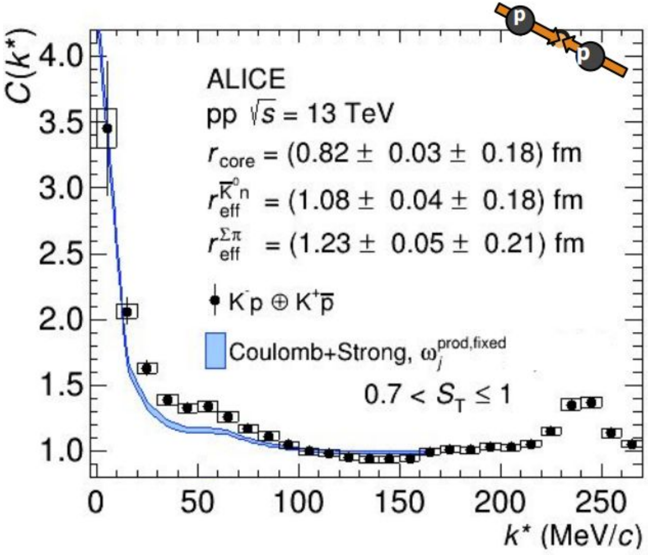


Jülich meson exchange model Eur. Phys. J. A47, 18 (2011)

K$^-$p femtoscopy:

Test of Kyoto potential anchored to SIDDHARTA result



Strong interaction: Kyoto model
K. Miyahara, T. Hyodo, W. Weise, Phys. Rev. C98, 2, (2018) 025201

Small systems: pp collisions r~1fm

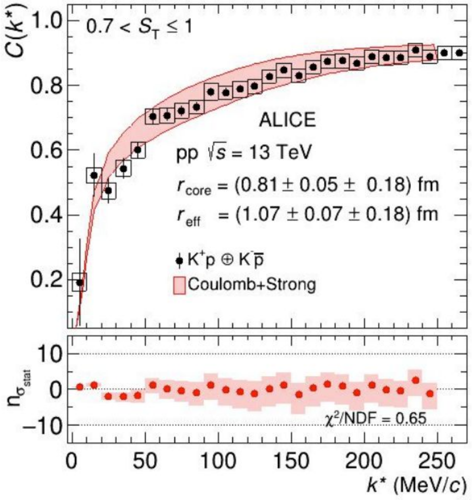
⇒ Provides a **quantitative test of coupled channels in the theory**

Effects of coupled channels enhanced by small source

KbarN Femtoscopy with ALICE

Well known K^+p interaction

⇒ experimental determination of the source size



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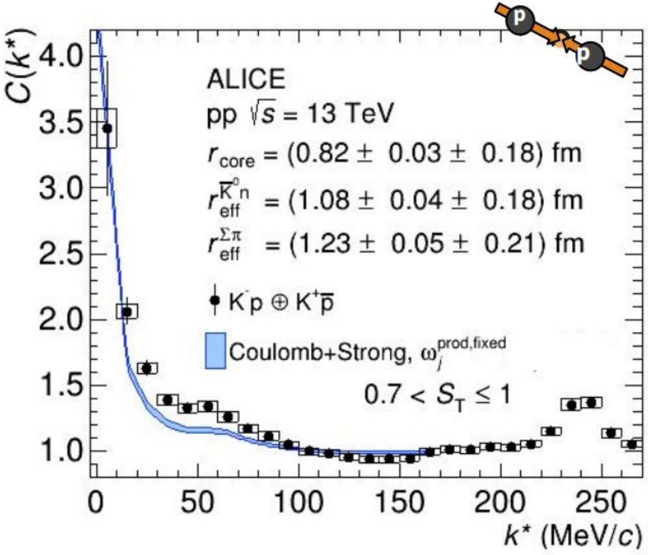

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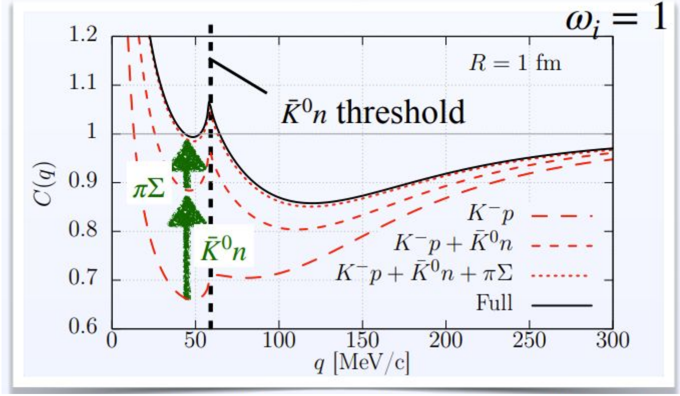
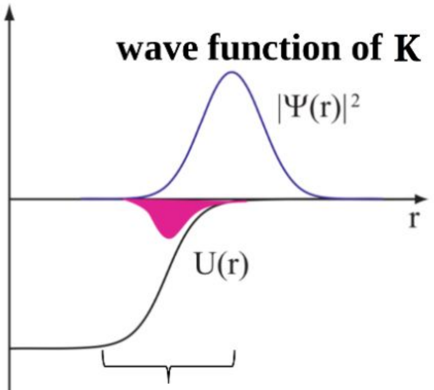
Y. Kamiya @ Baryons22



KbarN at threshold and low momentum

SIDDHARTA: antiKaonic Hydrogen

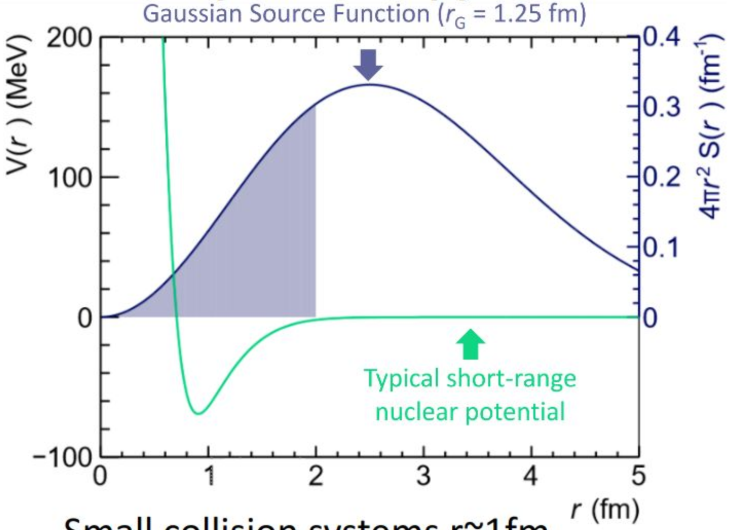


Sensitive to near surface potential shape

* for antikaonic hydrogen the K- p distance is ~100 times the Bohr radius

The overlap of the kaon wavefunction with the nucleon delivers insight into the effects of the strong interaction, competing with Coulomb effects

ALICE: K⁻p femtoscopy



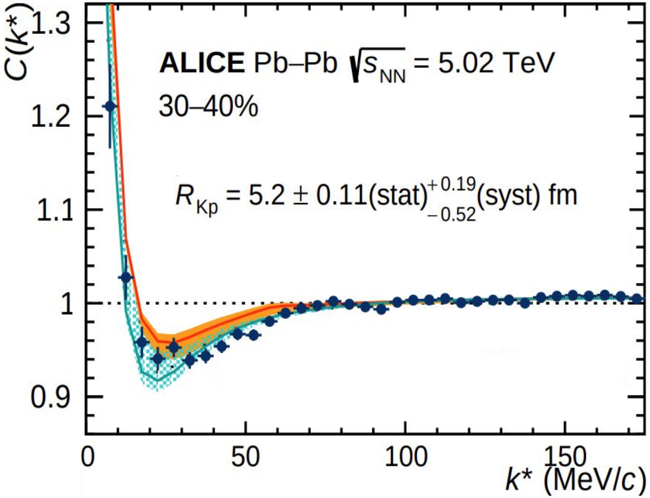
Small collision systems r~1fm
⇒ effect of the interaction is enhanced

$$C(k^*) = \int S(r^*)\,\left|\Psi(k^*,\vec{r^*})\right|^2 d^3r^*$$

Deliver different observables ⟸⟹ **scattering lengths can be obtained** from both (via Deser-type and Lednický–Lyuboshitz formulae)

K⁻p Femtoscopy with ALICE in Pb-Pb collisions

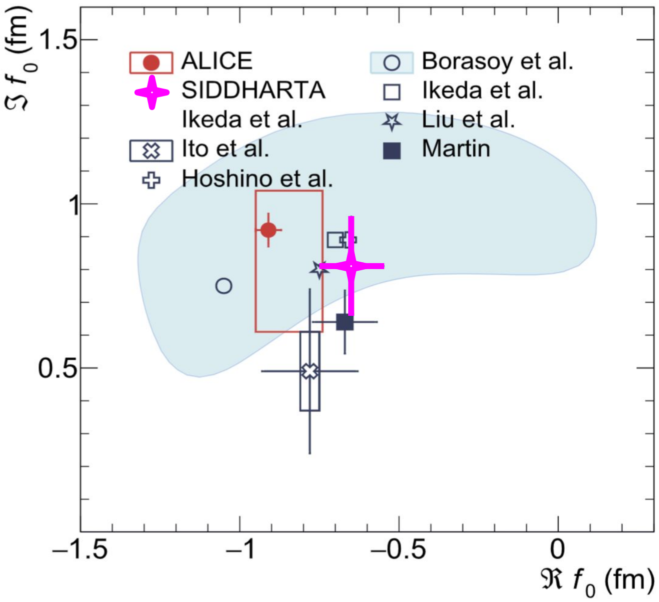
ALICE Coll., PLB 822 (2021) 136708



Large systems (HIC): Pb-Pb collisions, up to r~9fm

Strength of coupled channels significantly reduced

- Kyoto model
- Fit to the scattering parameters R. Lednický Phys. Atom. Nucl. 67 (2004) 72

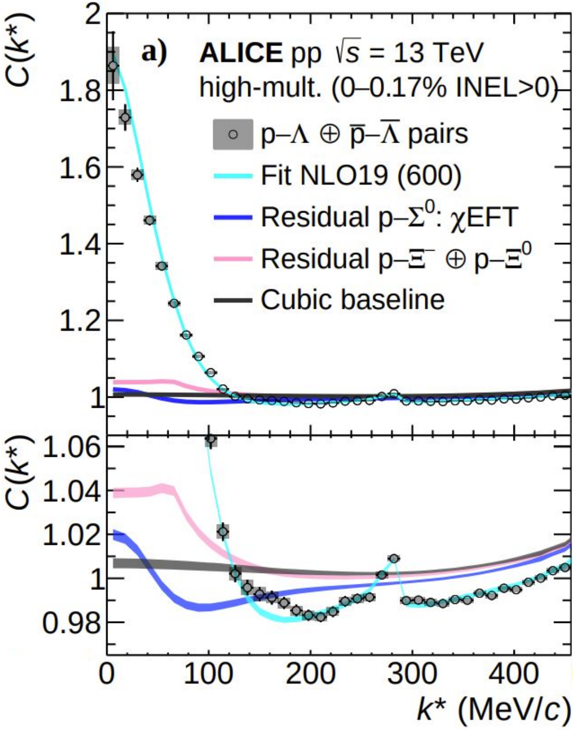


⇒ Antikaonic-hydrogen and K-p femtoscopy scattering parameters compatible

Femtoscopy results up to |S| = 3

S = -1, p-Λ Femtoscopy test Chiral SU(3)

ALICE Coll., Phys. Lett. B 833 (2022) 137272



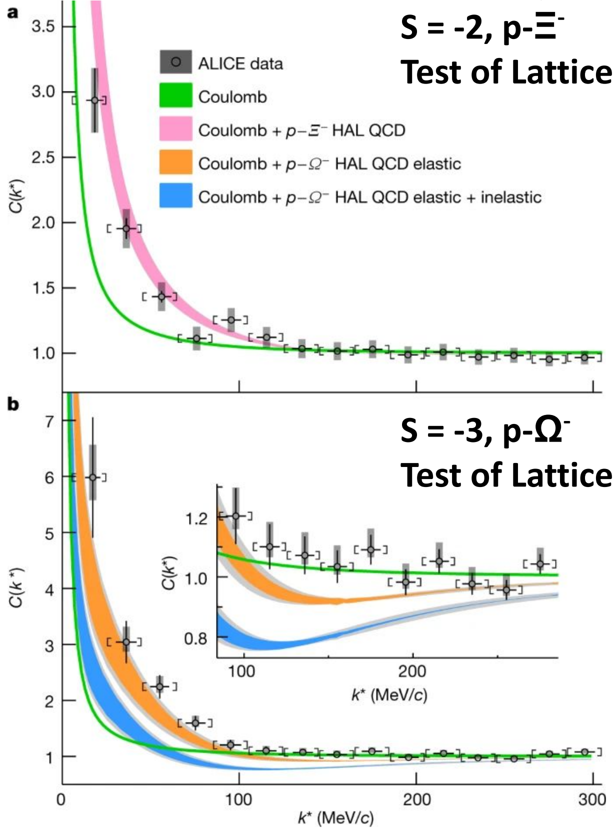
ALICE Coll., **Nature** 588, 232 (2020)

S = -2, p-Ξ^-

Test of Lattice QCD potentials

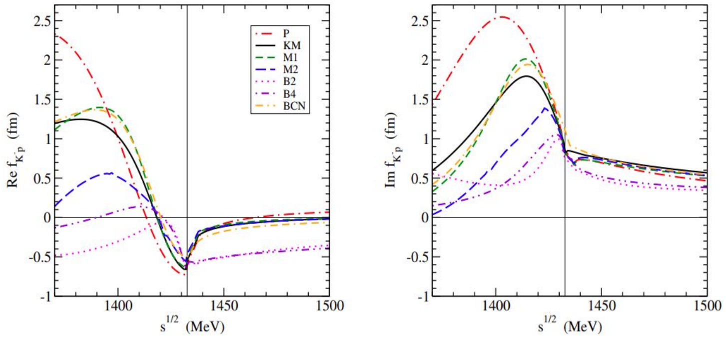
S = -3, p-Ω^-

Test of Lattice QCD potentials



Upcoming: Accessing KbarN I=1 interaction

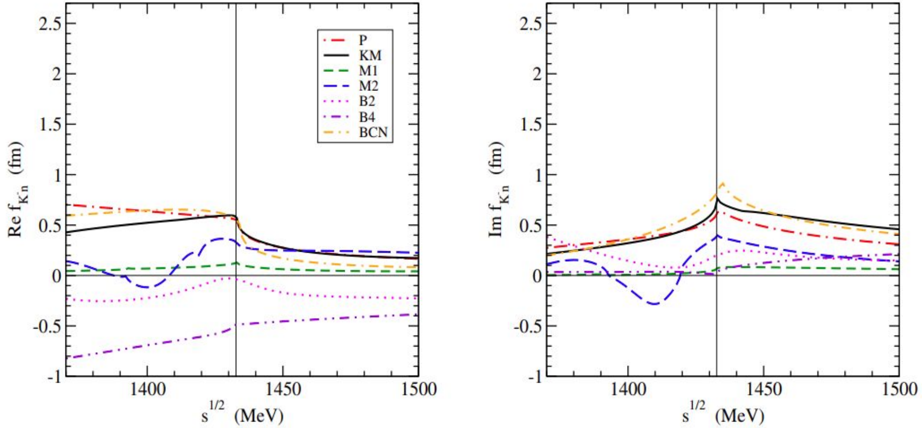
Free-space K^-p amplitudes in various chiral models



Prague (P)	*A. Cieply, J. Smejkal, Nucl. Phys. A 881 (2012) 115*
Kyoto-Munich (KM)	*Y. Ikeda, T. Hyodo, W. Weise, Nucl. Phys. A 881 (2012) 98*
Murcia (M1 and M2)	*Z. H. Guo, J. A. Oller, Phys. Rev. C 87 (2013) 035202*
Bonn (B2 and B4)	*M. Mai, U.-G. Meißner, Nucl. Phys. A 900 (2013) 51*
Barcelona (BCN)	*A. Feijoo, V. Magas, A. Ramos, Phys. Rev. C 99 (2019) 035211*

Free-space K^-n amplitudes

J. Obertova @ EXOTICO 2022



⇒ **Full isospin dependence** needs K⁻d interaction measurements:

SIDDHARTA2: $a_{K^-d} = \frac{1}{2}\frac{m_N + m_K}{m_N + \frac{m_K}{2}}(3a_1 + a_0) + C$

… and femtoscopy with deuterons with ALICE

K^-d femtoscopy with ALICE

Femtoscopy measurements with deuterons are indeed very **challenging**

- deuterons are expensive… penalty factor of 1/1000 w.r.t. protons
- K^+d correlation function to be used as reference

K$^-$d femtoscopy with ALICE

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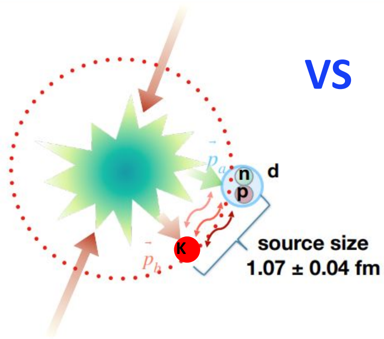
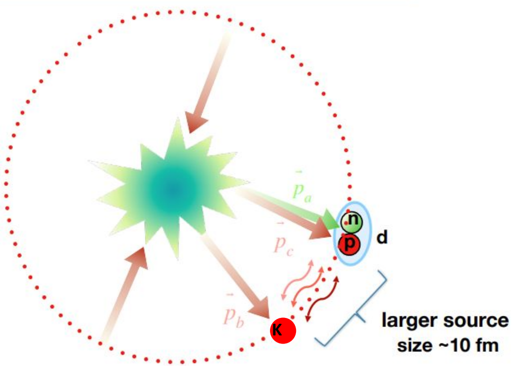
- deuterons are expensive… penalty factor of 1/1000 w.r.t. protons
- K$^+$d correlation function to be used as reference
- Enriched physics case: **formation of deuterons in hadronic collisions**

Thermal emission



VS

Coalesence

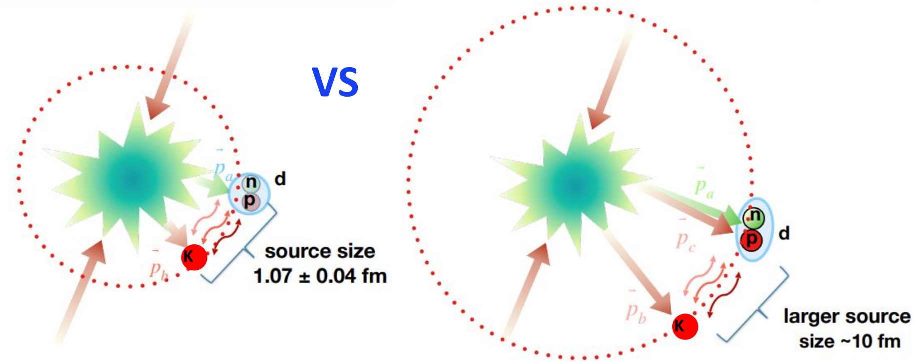


K$^-$d femtoscopy with ALICE

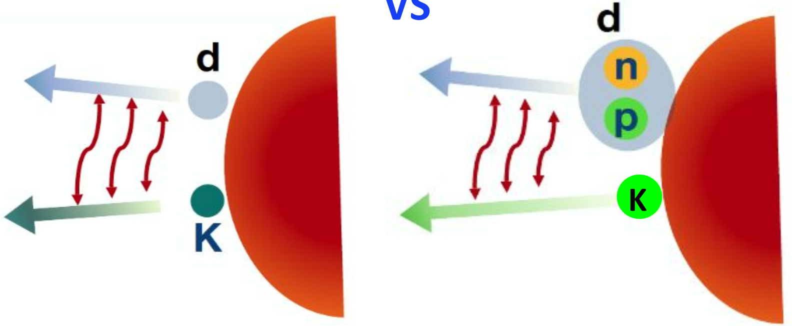
<u>Femtoscopy measurements with deuterons</u> are indeed very **challenging**

- deuterons are expensive… penalty factor of 1/1000 w.r.t. protons
- K$^+$d correlation function to be used as reference
- Enriched physics case: **formation of deuterons in hadronic collisions**
- Enriched physics case: **three-body interactions**

Thermal emission **VS** Coalescence



Two-body **VS** Three-body



PISA theory group (M. Viviani, A. Kievsky, L. Marcucci) developing three-body calculations for the correlation function

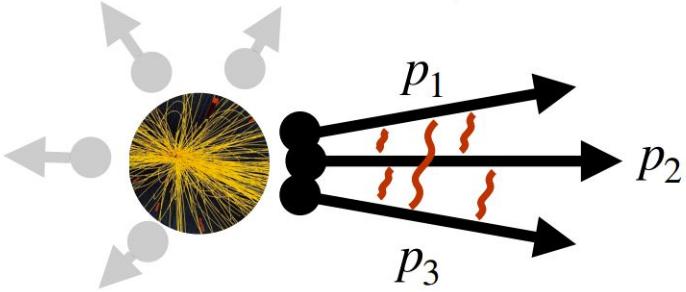
Three-body femtoscopy

Study of three-particle correlations

Three-particle correlation function:

$$C\left(\mathbf{p}_1, \mathbf{p}_2, \mathbf{p}_3\right) \equiv \frac{P\left(\mathbf{p}_1, \mathbf{p}_2, \mathbf{p}_3\right)}{P\left(\mathbf{p}_1\right) P\left(\mathbf{p}_2\right) P\left(\mathbf{p}_3\right)} = \frac{N_{\text{same}}\left(Q_3\right)}{N_{\text{mixed}}\left(Q_3\right)}$$

$$Q_3 = \sqrt{-q_{12}^2 - q_{23}^2 - q_{31}^2}$$



Three-body femtoscopy

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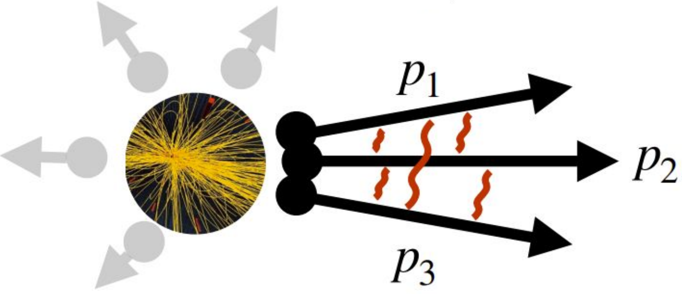


Study of three-particle correlations

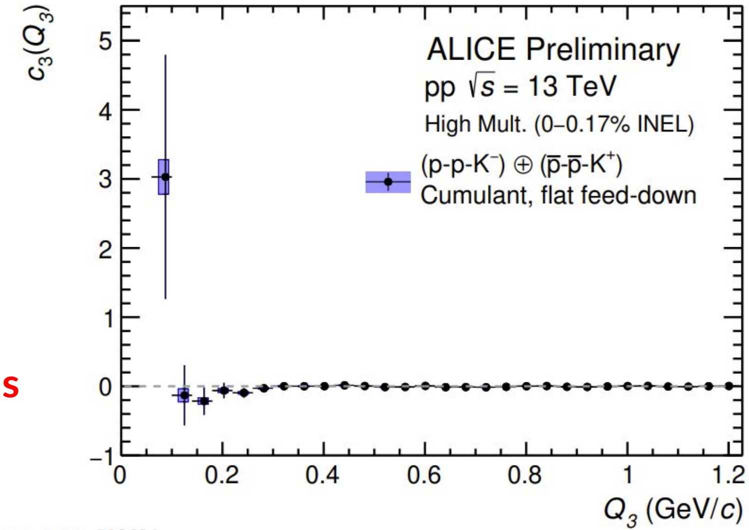
Three-particle correlation function:

$$C(\mathbf{p}_1,\mathbf{p}_2,\mathbf{p}_3) \equiv \frac{P(\mathbf{p}_1,\mathbf{p}_2,\mathbf{p}_3)}{P(\mathbf{p}_1)\,P(\mathbf{p}_2)\,P(\mathbf{p}_3)} = \frac{N_{\text{same}}(Q_3)}{N_{\text{mixed}}(Q_3)}$$

⇒ Direct access to the genuine three-body forces via Kubo cumulant method

R. del Grande et al., arXiv:2107.10227 [nucl-th]

Preliminary ALICE data ⇒



ALI-PREL-513634

Important constraints for the calculations of Kaonic nuclear states and multi-nucleonic absorptions

The Mid-term plan

	~ 1 year	~ 1-3 years	~ 3-5 years
DAPHNE: **Kaonic Atoms**	- SIDDHARTA2: kaonic deuterium - High Z kaonic atoms	- Light and Heavy Kaonic Atoms Measurements - Kaon Mass	- Intermediate + Ultra-high Kaonic Atoms Measurements
DAPHNE: **Kaon scattering**	- Publication of high impact results with KLOE data $K^-p \rightarrow \Sigma^0\pi^0 / \Lambda\pi^0$	- Additional channels and/or statistics from KLOE/KLOE-2 data?	- TPC setup to study elastic/inelastic scattering → beyond 5 years!
ALICE: **Femtoscopy**	- K^+d with Run2 as reference measurement	- K^-d with LHC Run-3 data - K^-p improved precision	- Full exploit of LHC Run-3 data with three-body femtoscopy

...and the competition / complementary approaches

JPARC: Ξ-atoms spectroscopy, $\Sigma^{\pm}p$ low E scattering, systematic studies on Kaonic Nuclei, etc.

KLong facility at Jefferson Lab: beam of K_L mesons + GlueX spectrometer

RHIC / STAR: Finalization of Femtoscopic analysis of Au-Au data.

Outlook

Precision studies of the strong interaction between hadrons at the LNF

- **Exotic atoms** experiments enter a **new era** with SIDDHARTA2 and the future plans at DAΦNE
- **Femtoscopy** studies at the LHC **updates the scenario of the experimental studies** on hadron-hadron interactions

⇒ The extension of the program for the hadron interaction with strangeness faces many challenges

- Very different experimental techniques will provide **complementary approaches**
- The expected results will **deliver a difficult test to the theoretical approaches**
- **The project is evolving and can be extended**

THANK YOU VERY MUCH!