NANJING UNIVERSITY

Craig Roberts … http://inp.nju.edu.cn/

Discussion III

… Next Meetings

Public | Europe/Zurich | C. Roberts

Perceiving the Emergence of Hadron Mass through AMBER@CERN

27 - 29 September 2021
CERN, Geneve - Switzerland

27-29 September 2021
Europe/Zurich timezone

Enter your search term

The 2021 School on the Physics of Baryons (Baryons-21_School)

Oct 18, 2021, 1:00 PM → Oct 22, 2021, 5:00 PM Europe/Madrid

Virtual (Seville)

Jorge Segovia (Pablo de Olavide U., Seville), Juan Antonio Caballero (Universidad de Sevilla), Feliciano de Soto (Pablo de Olavide University), Teresa Peña, Craig D. Roberts (Nanjing University), José Rodriguez Quintero (University of Huelva), Daria Sokhan (University of Glasgow, UK)

Description

Pion charge radius

Pion charge radius from pion+electron elastic scattering data,
Zhu-Fang Cui (崔著钫), Daniele Binosi, Craig D. Roberts and Sebastian M. Schmidt,
NJU-INP 047/21, arXiv:2108.04948 [hep-ph], Phys. Lett. B **822** (2021) 136631/1-5

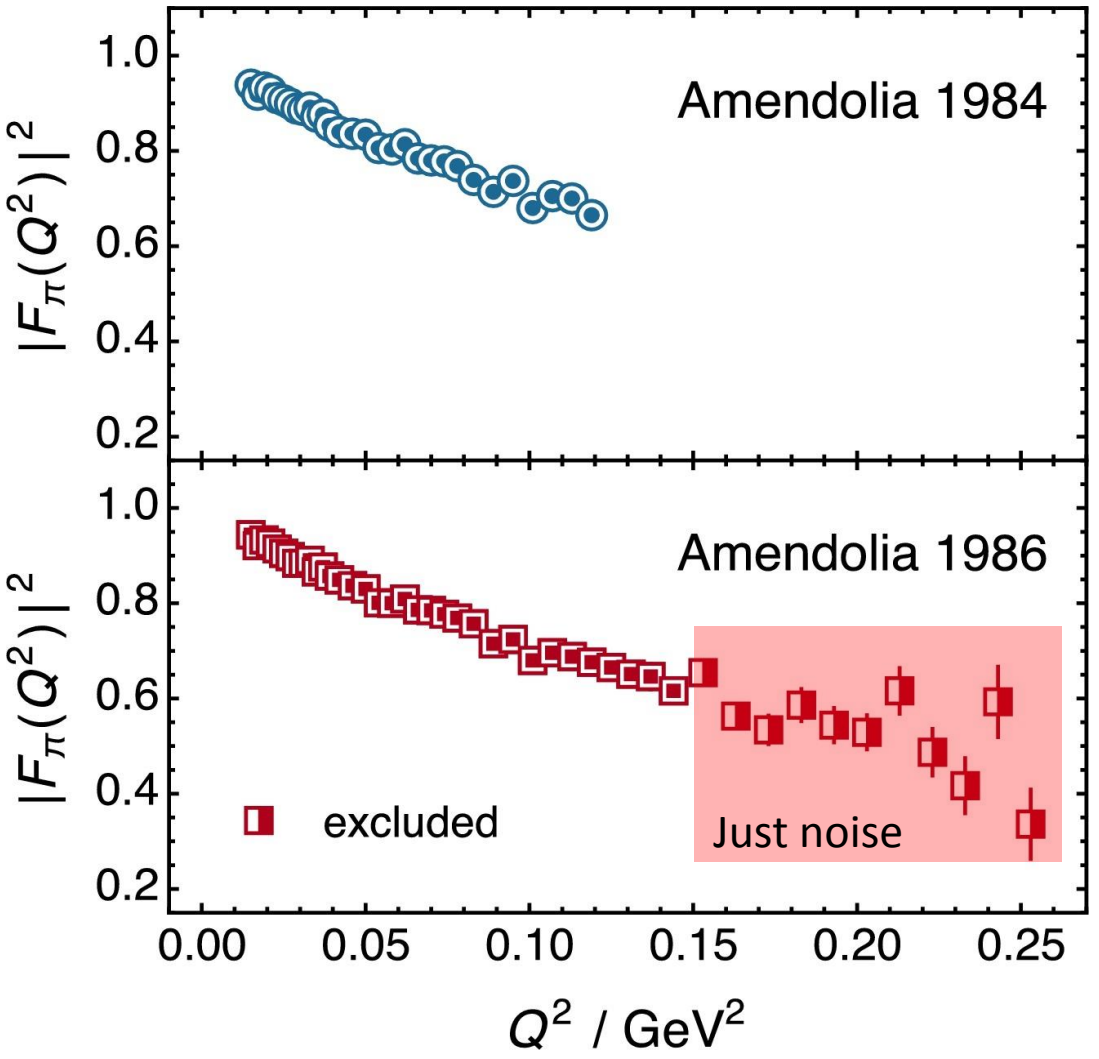
- 1984 NA7 data set has N=30 elements on $0.015 \leq Q^2/\mathrm{GeV}^2 \leq 0.119$
- 1986 NA7 set has N=45 elements on $0.015 \leq Q^2/\mathrm{GeV}^2 \leq 0.253$

$$\mathrm{SPM}\, r_\pi^{\mathrm{NA7}} = 0.640 \pm 0.007_{\mathrm{stat}}\ \mathrm{fm}$$

$$\mathrm{PDG}\, r_\pi = 0.659 \pm 0.004\ \mathrm{fm}$$

2.4 σ discrepancy

- PDG value is likely an overestimate
- Value has been reduced in recent years, with inclusion of timelike data – but that introduced model/theory bias
- NEED objective determination from definitive experiment = slope of form factor at $Q^2=0$



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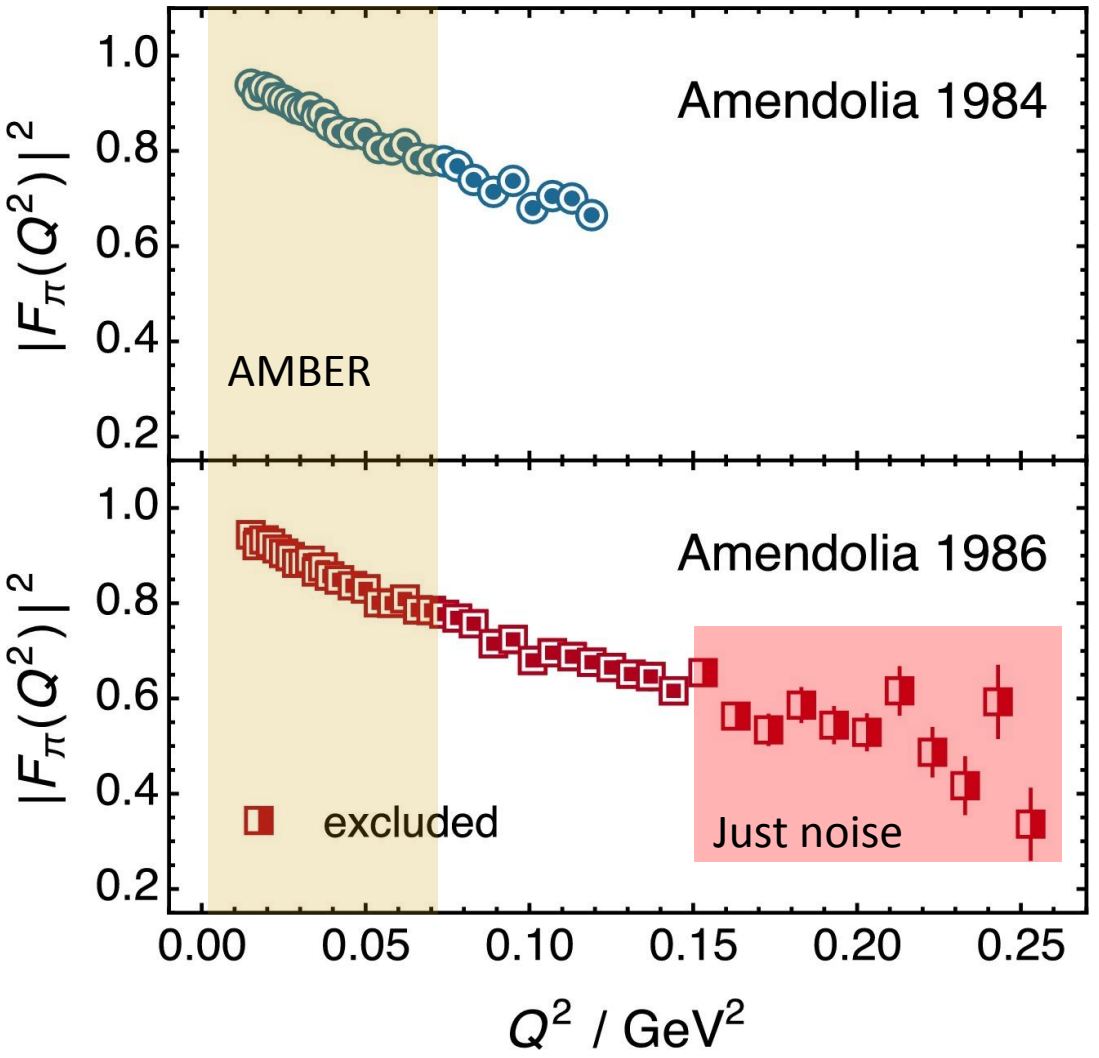
$$_{\mathrm{SPM}}r_\pi^{\mathrm{NA7}} = 0.640 \pm 0.007_{\mathrm{stat}}\ \mathrm{fm}$$

- Jan Friedrich:
  - ✓ Kaon form factor knowledge in the range $0.001 < Q^2/\mathrm{GeV}^2 < 0.07$ appears in reach with AMBER using an 80 GeV rf-separated kaon beam
  - ✓ Pion form factor with similar coverage
- ✓ This factor of 15 deeper reach and anticipated density of coverage will make a world of difference



Kaon charge radius

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Zhu-Fang Cui (崔著钫), Daniele Binosi, Craig D. Roberts and Sebastian M. Schmidt,
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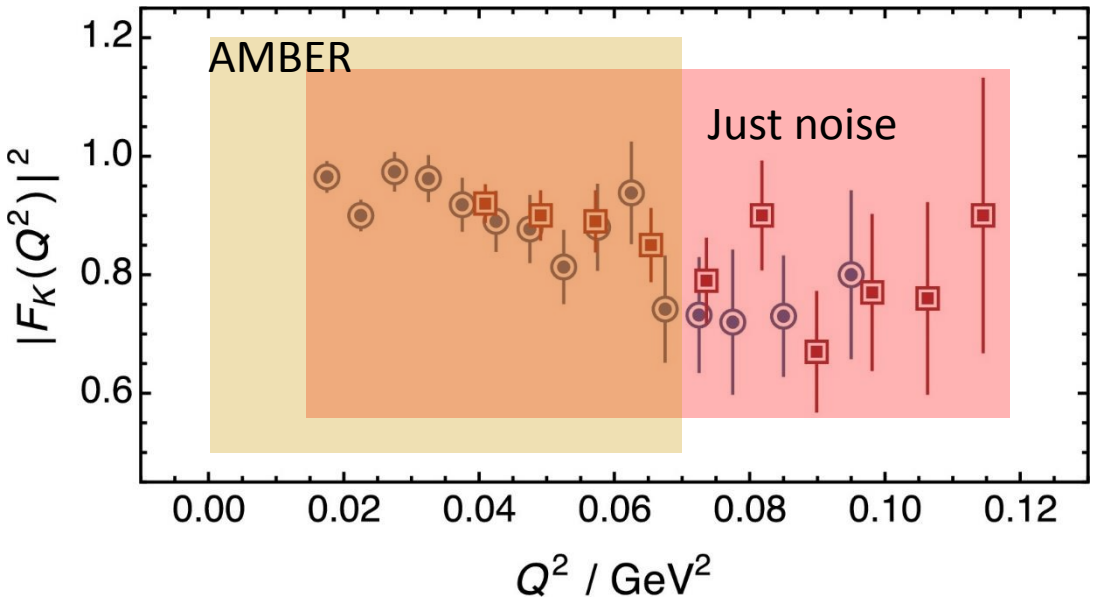
- FermiLab (1980) 10 points
- CERN (1986) 15 points
  - Evidently, just noise
- Assume dipole for $|F_K|^2$:

$$_{PDG}r_K = 0.560 \pm 0.031 \text{ fm}$$

- Mathematically rigorous analysis via SPM
- Data contains ZERO information beyond that obtained using a least-squares fit
- Anything else is human-induced bias

$$_{SPM}r_K = 0.53\text{fm} \text{ with } \frac{\chi^2}{\text{datum}} = 0.68$$



Kaon form factor knowledge in the range $0.001 < Q^2/\text{GeV}^2 < 0.07$ appears in reach with AMBER using an 80 GeV rf-separated kaon beam

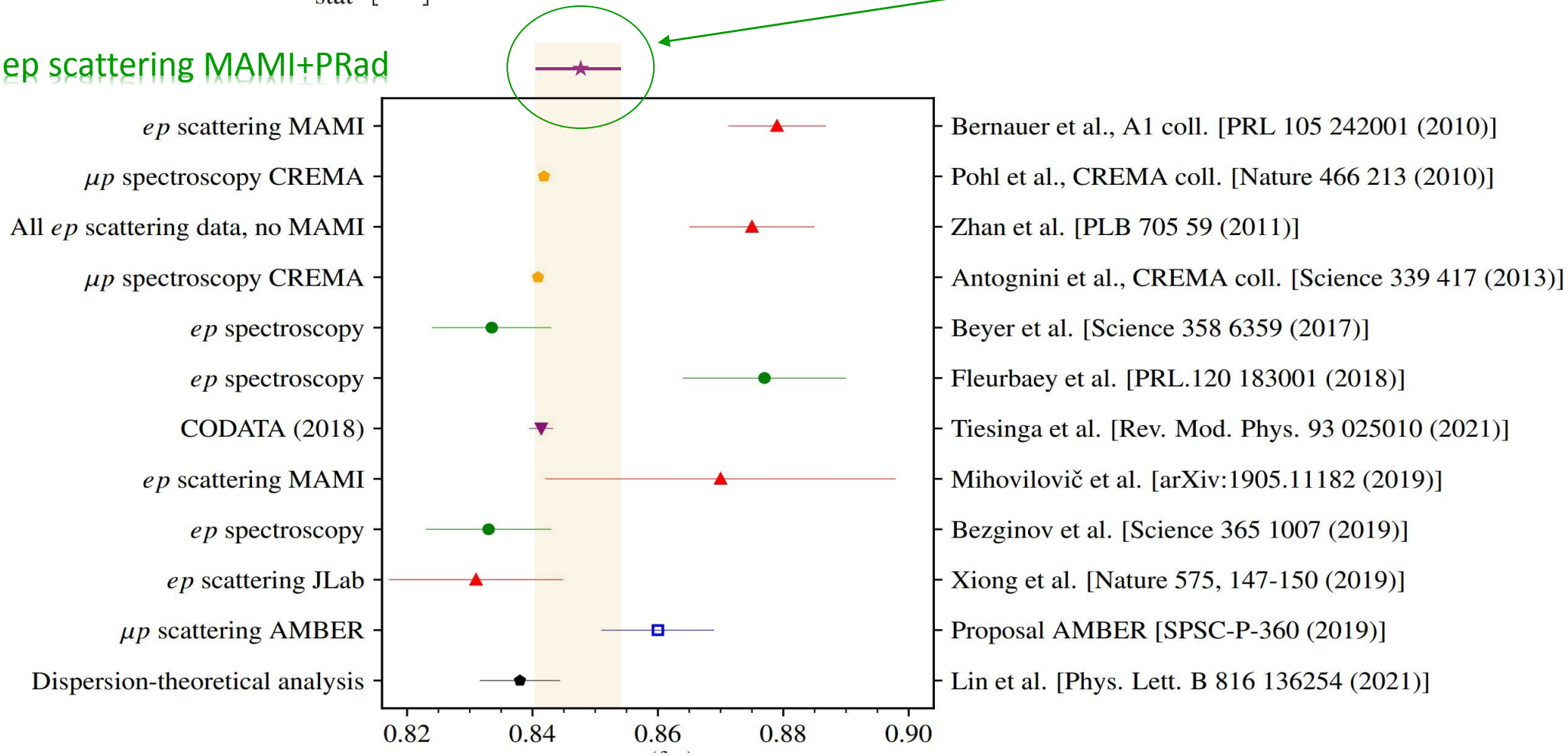
This factor of 15 deeper reach will enable 1st objective determination of kaon radius

Proton Radius

Fresh extraction of the proton charge radius from electron scattering,
Zhu-Fang Cui, Daniele Binosi, Craig D. Roberts and Sebastian M Schmidt,
NJU-INP 033/21, arXiv: 2102.01180 [hep-ph], Phys. Rev. Lett. **127** (2021) **092001**

$$r_p^{\mathrm{SPM}} = 0.847 \pm 0.008_{\mathrm{stat}}\ [\mathrm{fm}]$$

- SPM ep scattering MAMI+PRad



Process-independent Effective Charge

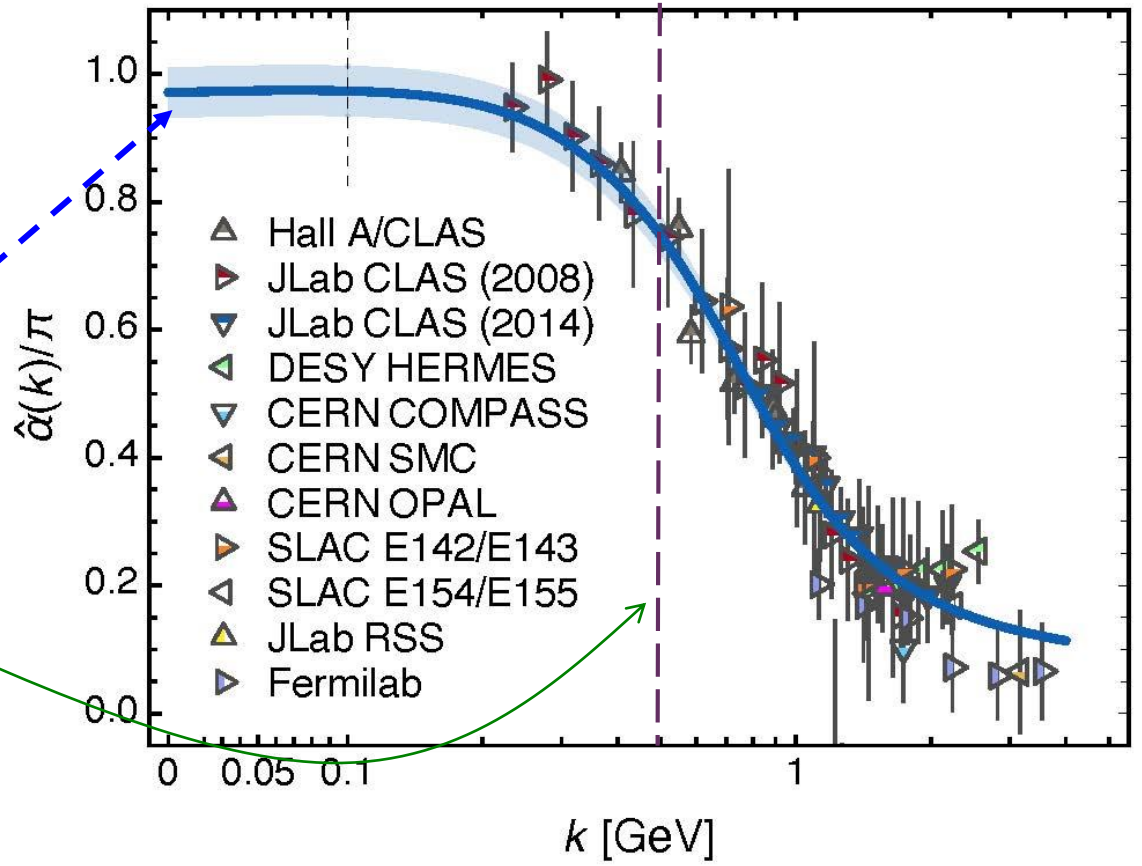
- 3 key references
  - *Bridging a gap between continuum-QCD and ab initio predictions of hadron observables,* Daniele Binosi, Lei Chang, Joannis Papavassiliou, Craig D. Roberts, arXiv:1412.4782 [nucl-th], Phys. Lett. B **742** (2015) pp. 183-188
    - Proved that such a charge could both exist and explain scattering processes between ALL QCD degrees-of-freedom
  - *Process-independent strong running coupling,* Daniele Binosi, Cédric Mezrag, Joannis Papavassiliou, Craig D. Roberts and Jose Rodríguez-Quintero, arXiv:1612.04835 [nucl-th], Phys. Rev. D **96** (2017) 054026/1-7
    - Delivered unique definition of PI charge – clear analogue of QED Gell-Mann/ Low charge – using background field method and pinch technique to reorder and recombine resummations of diagrams in QCD's gauge sector to arrive at renormalization group invariant running coupling defined at all Q^2, matching perturbative QCD coupling on $Q^2 \geq 1\mathrm{GeV}^2$
  - *Effective charge from lattice QCD*, Zhu-Fang Cui, Jin-Li Zhang, Daniele Binosi, Feliciano De Soto, Cédric Mezrag, Joannis Papavassiliou, Craig D. Roberts, José Rodríguez-Quintero, Jorge Segovia, NJU-INP 014/19, arXiv:1912.08232 [hep-ph], Chin. Phys. C **44** (2020) 083102/1-10
    - Parameter free calculation of effective charge by combining best of continuum and lattice results, including better-than 4% precision on RGI gluon mass and coupling saturation value

The QCD Running Coupling,
A. Deur, S. J. Brodsky and G. F. de Teramond, Prog. Part. Nucl. Phys. **90** (2016) 1-74
Process independent strong running coupling
Daniele Binosi *et al.*, arXiv:1612.04835 [nucl-th], Phys. Rev. D 96 (2017) 054026/1-7
Effective charge from lattice QCD, Zhu-Fang Cui et al., NJU-INP 014/19, arXiv:1912.08232 [hep-ph], Chin. Phys. C **44** (2020) 083102/1-10

Process-independent coupling in QCD

Saturation: $\hat{\alpha}_{PI}(0) = \pi \times 0.97(4)$
Conformal window extends to $\hat{m}_0$ =gluon mass

- Modern continuum & lattice methods for analysing gauge sector enable QCD analogue
  "Gell-Mann – Low"
  running charge to be defined and calculated
- Combined analysis of QCD's gauge sector
  yields a *parameter-free prediction*
- N.B. Qualitative change in $\hat{\alpha}_{PI}(k)$ at $k \approx ½\ m_p$
- No Landau Pole
- Below k ~ $\hat{m}_0$, interactions become scale independent, just as they were in the Lagrangian; so, QCD becomes practically conformal again
- Basis for all-orders DGLAP evolution described by many speakers



Data = process dependent effective charge
[Grunberg:1982fw]: α_{g1}, defined via Bjorken Sum Rule

Mass and Pressure Distributions

- Begin with QCD' stress-energy tensor: $T_{\mu\nu}$
- In meson, P: $\langle P(q')|T_{\mu\nu}|P(q)\rangle = -q'_\mu q_\nu\, \theta_2^P(\Delta^2) + \theta_1^P(\Delta^2)\,\frac{1}{4}[\Delta_\mu\Delta_\nu - \delta_{\mu\nu}\Delta^2]$

Mass-squared distribution form factor because … $-q'_\mu q_\mu = m_P^2$

Pressure and shear-force distribution form factor

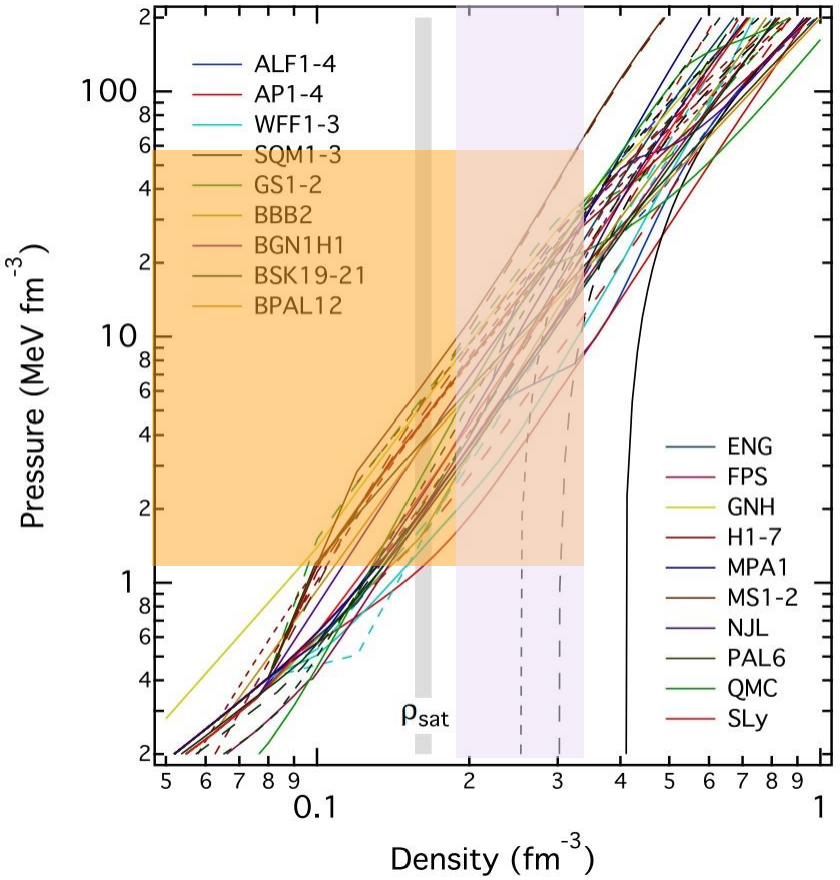
- Connection with GPDs via matrix values. 1st Mellin moment yields these form factors

$$\int_{-1}^{1} dx\, x\, H^q_{\mathsf{P}}(x,\xi,-\Delta^2;\zeta_{\mathcal{H}}) = \theta_2^{\mathsf{P}}(\Delta^2) - \xi^2\theta_1^{\mathsf{P}}(\Delta^2)$$

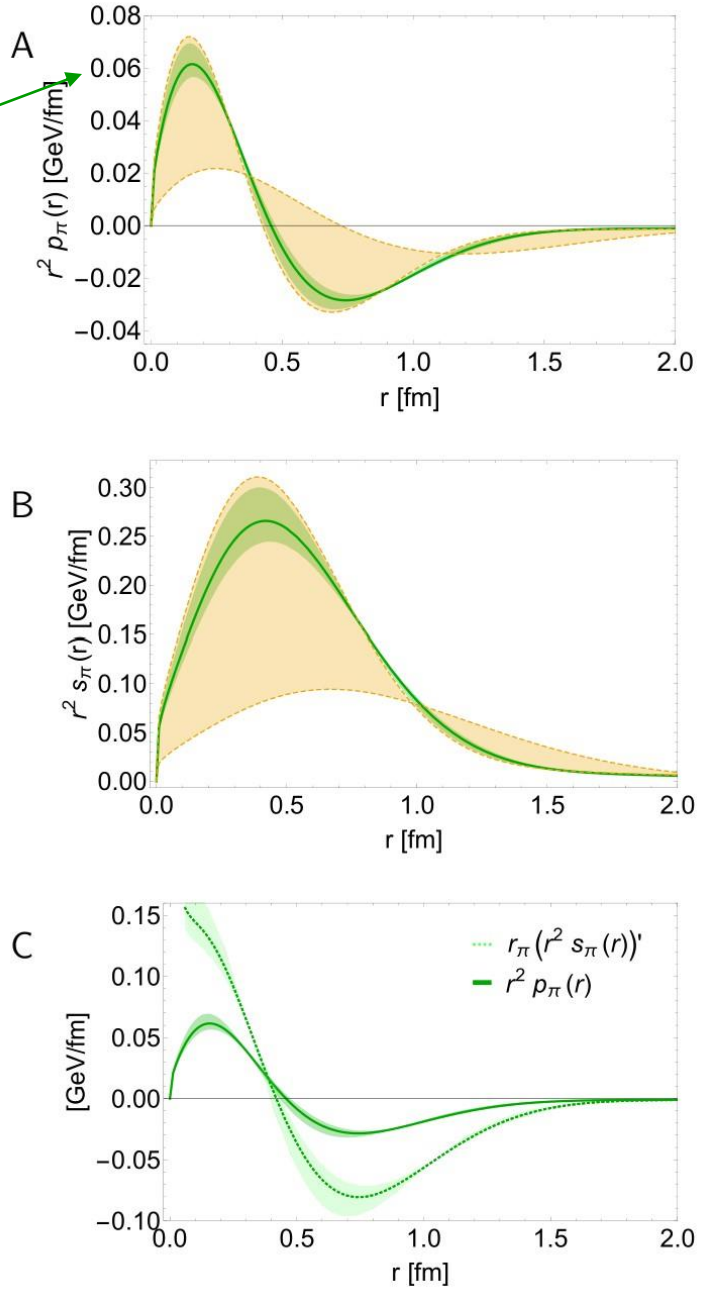
- In quantum field theory, on the mass-shell of any particular excitation, all interpolating fields are equivalent; so, if gravity is described by a J=2 quantum, then $\langle P(q')|T_{\mu\nu}|P(q)\rangle$ describes the meson's coupling to that excitation

Mass and Pressure Distributions

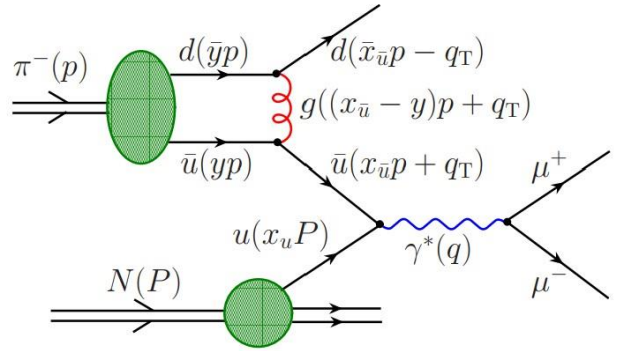
Neutron star core density
0.001 – 0.06 GeV/fm^3



- ✓ pion near-core pressure
  0.06 GeV/fm^3
- ✓ Similar for kaon
- ✓ "Little neutron stars" on Earth



Pion DA



- Alexandr Pimikov pointed us to

  Polarized and unpolarized mu-pair meson-induced Drell-Yan production and the pion distribution amplitude, A.P. Bakulev, N.G. Stefanis, O.V. Teryaev, Phys. Rev. D 76 (2007) 074032 • e-Print: 0706.4222 [hep-ph]

  "… we focus on the angular distribution of μ^+, which is sensitive to the shape of the pion distribution amplitude, the goal being to test corresponding results against available experimental data. Predictions are made, employing various pion distribution amplitudes, for the azimuthal angle dependence of the μ^+ distribution in the polarized case, relevant for the planned COMPASS experiment."

  "… detailed predictions for the angular distribution parameters for the hard-scattering of pions on longitudinally polarized protons. The single-spin asymmetry, predicted here for various pion distribution amplitudes, may soon become amenable to experimental check at COMPASS."

  "… one may hope that measuring the angular moment in the planned COMPASS experiment may lend quantitative support for one or the other proposed pion DA."


Let the games begin
KETELSTRAAT
ARNHEM
f 100.—