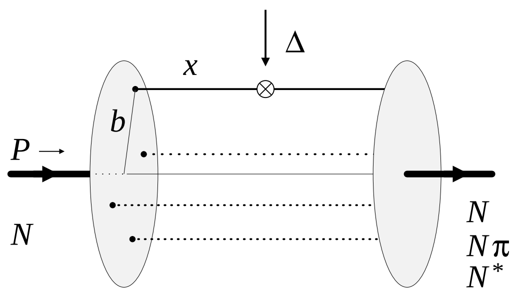
High–Q^2 resonance production in QCD

C. Weiss (JLab), EmNN∗2012 Workshop, U. South Carolina, 13–Aug–12



Correct high–Q^2 asymptotics
QCD DOF, light–front formulation

Non–perturbative interactions
Chiral symmetry–breaking forces → SDE

Clean interface quarks–hadrons
Wave functions, distribution amplitudes

Meson–baryon interactions parametrically controlled
Large–N_c, χEFT

- Transition form factors at high Q^2

  Wave function description

  Selection of configurations

  Small–size vs. end–point configurations

  Dynamical origin: pQCD, non–perturbative interactions

- Lessons from elastic form factors

  Pion FF: Model–independent analysis
  LCWF ↔ large–x PDFs. Miller, Strikman, CW 11

  Nucleon FF: Light–cone sum rules → Talk Braun

- Toward N^* transition FFs in QCD

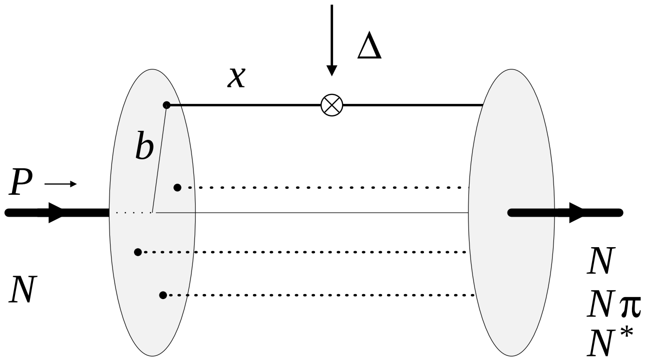
  πN near threshold: Chiral LETs

  N^* DAs from large–N_c limit (Δ)

  Dynamical resonances from χEFT (S_{11})

  Lattice QCD (N^*1535)

Transition FF: Wave function description



- Wave function description

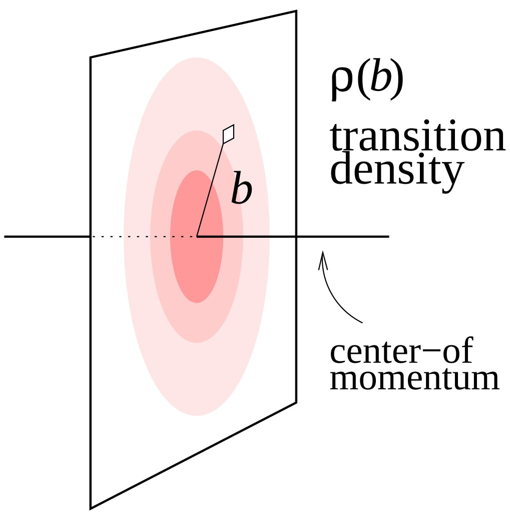
  A) Infinite–momentum frame $P \to \infty$
  Gribov, Feynman; Bjorken, Kogut

  B) Light–front quantization time $= x^+$
  WFs universal, frame–independent. Brodsky et al.

  Momentum transfer transverse $t = -\boldsymbol{\Delta}^2$
  Frame appropriate for $t \to \infty$, masses fixed

  Hadron resolved in pointlike constituents with momentum fraction x_i, transv. position $\boldsymbol{r}_i$

  Quantum–mechanical superposition: Configs with different particle number, spatial size



- Current operator sees transition density

$$F(t) \;=\; \int d^2b\; e^{i\boldsymbol{\Delta b}}\; \rho(b) \qquad \text{2D Fourier}$$

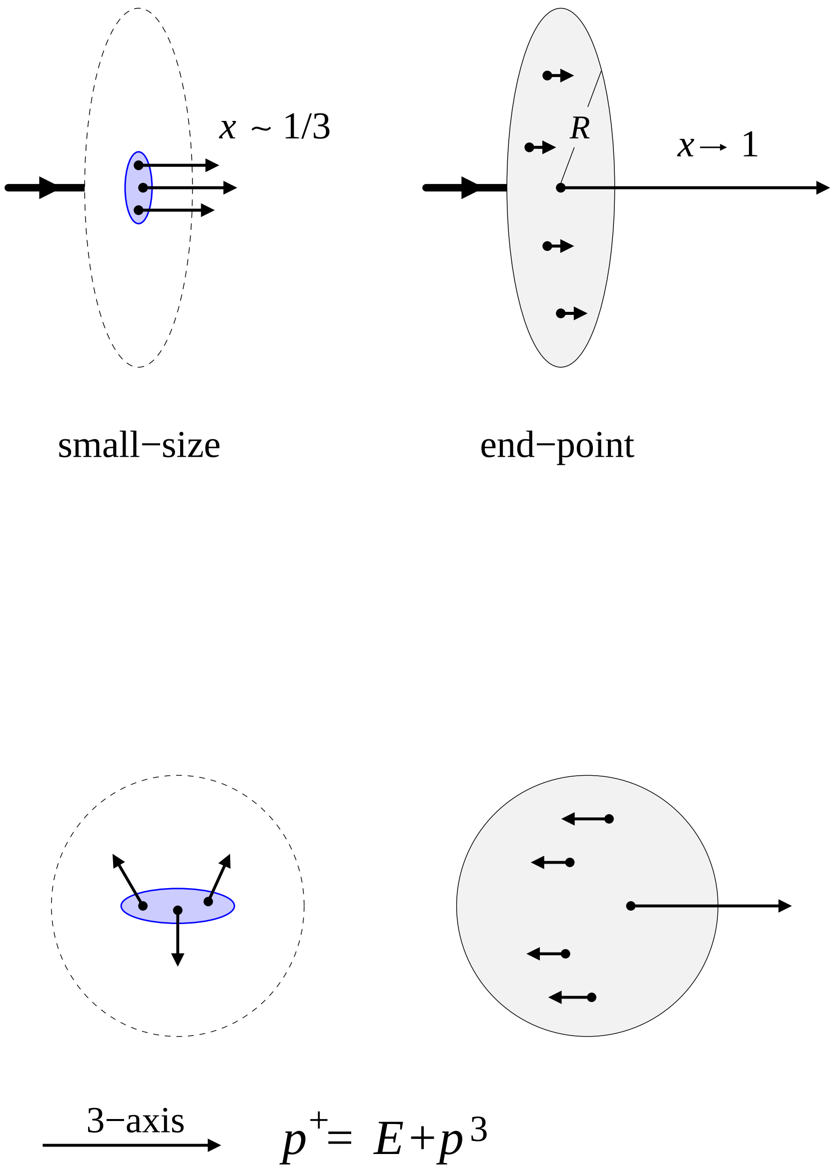
$$\rho(b) = \sum_{\text{configs}} \int dx\; \psi^*(x, \boldsymbol{r}, ..)\psi(x, \boldsymbol{r}, ..)$$

- Selection of configurations

  Large $|t| \longleftrightarrow$ Small b Singularity?

  What kind of configurations contribute to density at small b?

Transition FF: Small–size configurations



- Two types of configurations contribute to small–b density

$x \sim \frac{1}{3}$	size $\ll R$	small–size	mostly qqq
$x \to 1$	size $\sim R$	end–point	multiparticle, soft gluons

- Basic questions

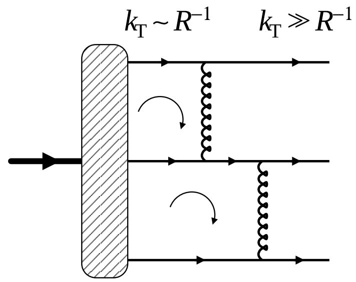
  What is their relative importance?
  Probability of end–point configurations constrained by quark PDF at $x \to 1$

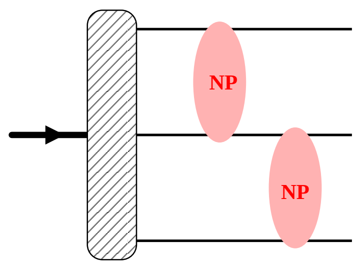
  How do they arise dynamically?
  Perturbative vs. non–perturbative interactions?
  Correlations in light–front wave function?

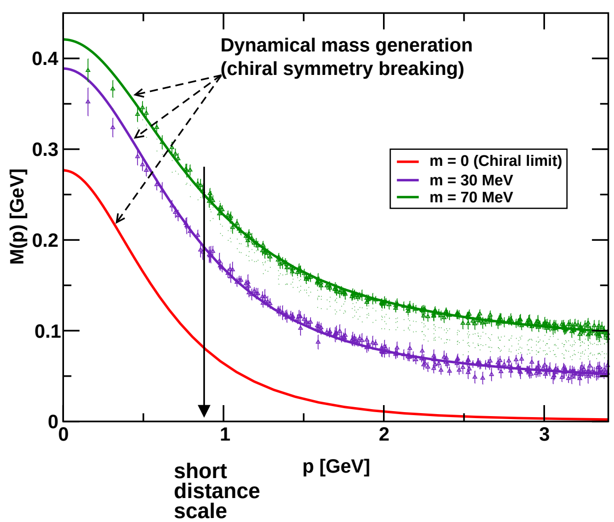
- Rest frame picture

  Can be rigorously discussed in light–front quantization
  Intuition from non–relativistic systems:
  Angular momentum, orbital motion, etc.

Transition FF: Dynamical origin of small–size confs







- Perturbative interactions

  High–momentum component of wave function built up by pQCD interactions

  "Soft" wave function $k_T \sim R^{-1}$ as source

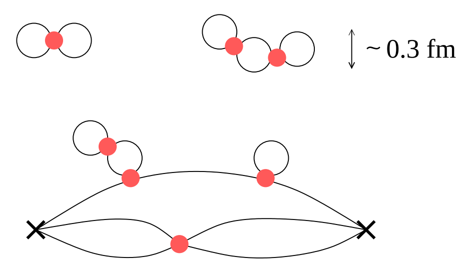
  $$\Phi(x_i|\mu^2) = \int^{\mu^2} d^2 k_{Ti}\, \psi(x_i, \boldsymbol{k}_{Ti})$$ distribution amplitude

  Responsible for leading $|t| \to \infty$ asymptotics of pion FF Brodsky Lepage; Efremov, Radyushkin: pion

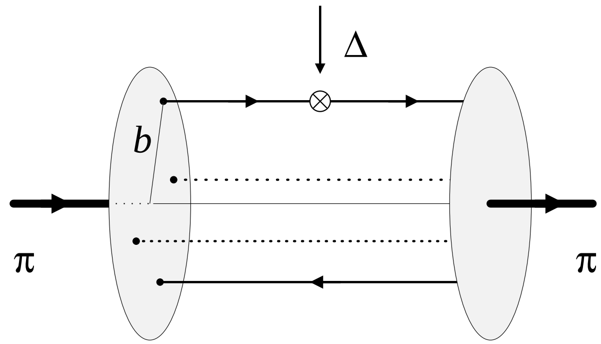
- Non–perturbative interactions

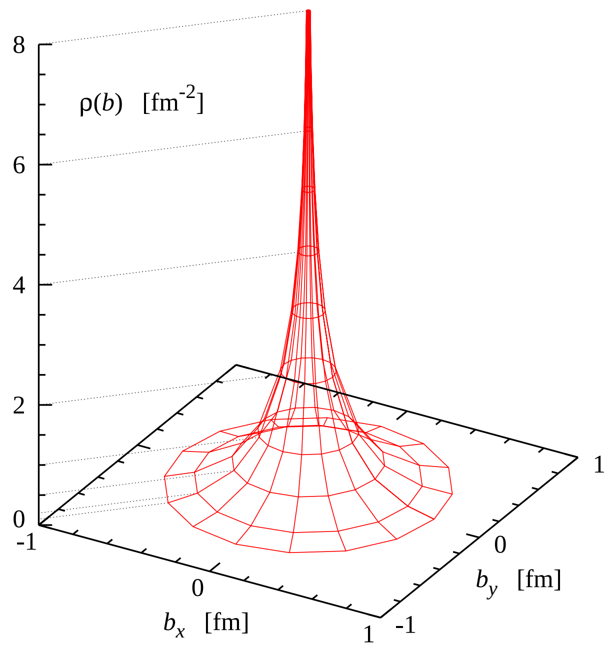
  Chiral symmetry breaking in QCD induced by short–range non–perturbative forces

  Range $\rho \sim 0.2 - 0.3\,\mathrm{fm} \ll R$
  Instanton vacuum model: Shuryak; Diakonov, Petrov
  Schwinger–Dyson equations $\rightarrow$ Talk Roberts



Pion form factor: Transition density





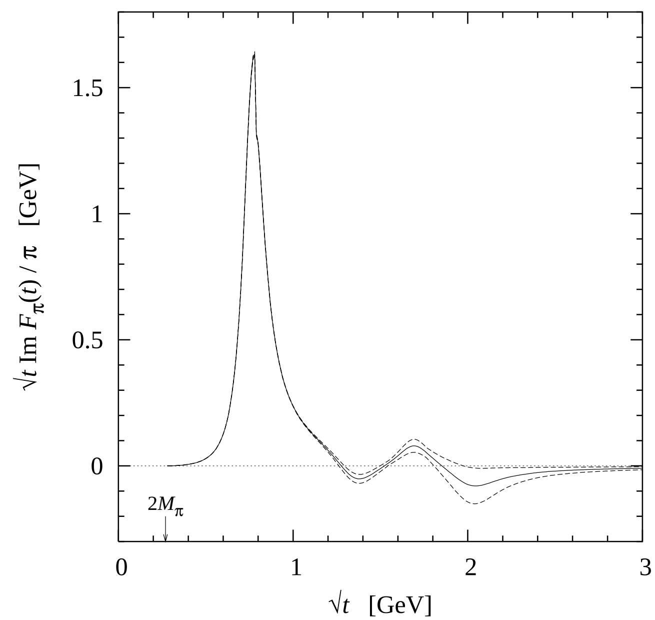
- Pion form factor $F_\pi(t)$

- Transition density $\rho(b)$

  Calculated from dispersion integral over timelike FF from e^+e^- data
  Miller, Strikman, CW 11

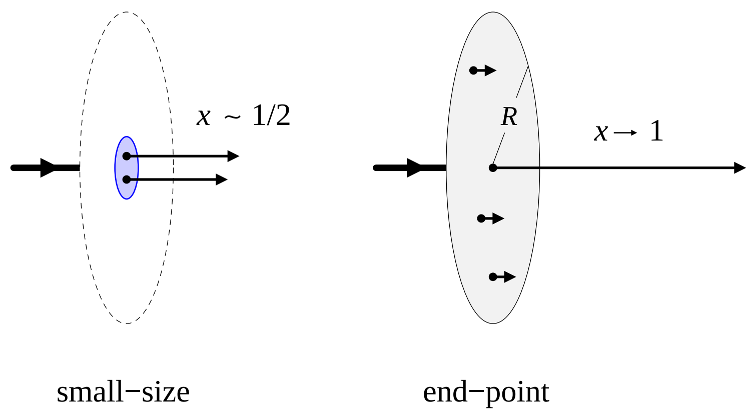
  Model–independent, controlled accuracy

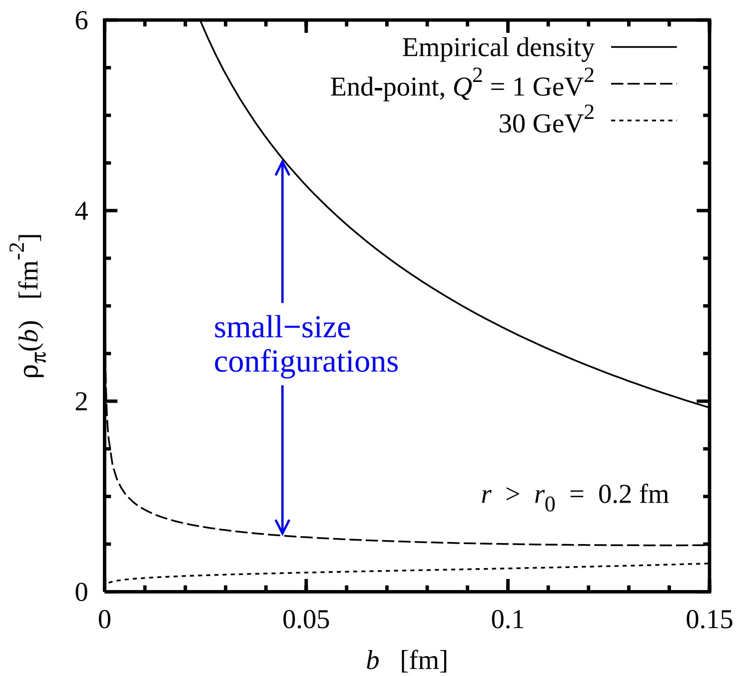
  High density at center $b \to 0$



$\mathrm{Im} F_\pi(t)$ from analysis of e^+e^- data. Bruch et al. 05

Pion form factor: Small–size configurations





- Is density in center due to small–size or end–point configurations?

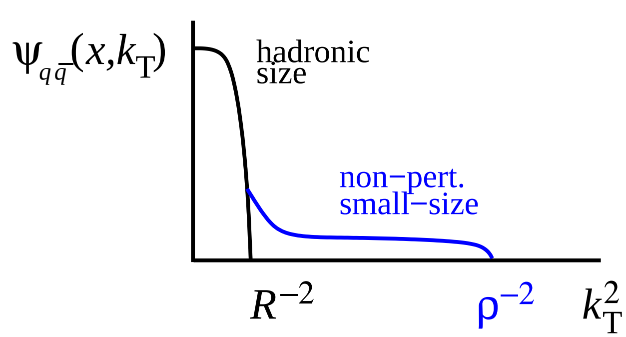
- Model–independent assessment
  Miller, Strikman, CW 10

  End–point contribution constrained by quark density in pion at $x \rightarrow 1$
  πA Drell–Yan data

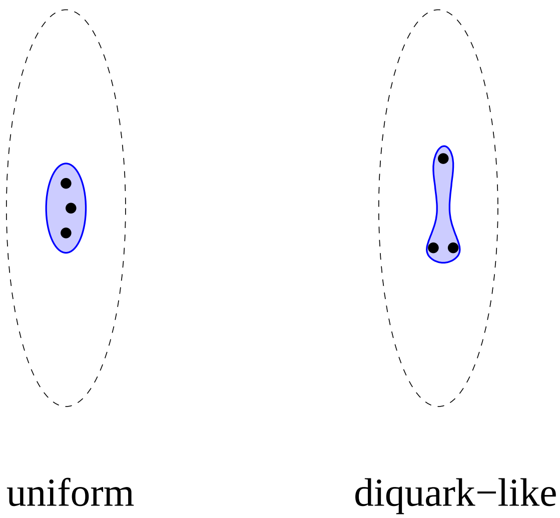
  Density in center of pion mostly from small–size configurations!

- Dynamical explanation

  Small–size configurations in pion WF from chiral symmetry–breaking interactions



Nucleon FF: Configurations



- Transition densities known from FF data
- More complex system, more possibilities

  Uniform squeezing or diquark–like configurations?

  Contribution of end-point configurations $x \to 1$?
  Related to large–x parton densities JLab 12 GeV

  Mean–field picture generally successful:
  Quark model, chiral soliton $N_c \to \infty$
  Nature of dynamical correlations?

- Spin and orbital angular momentum

  $Q^2 F_2/F_1$ suggests important role
  of orbital angular momentum Belitsky, Ji, Yuan 03

- Systematic approach: Light–cone sum rules
  Balitsky, Braun, Kolesnichenko 89; Braun et al. 02+

  pQCD–generated small–size configurations give leading asymptotic contribution

  End–point contributions reformulated as higher twist

  Can results be explained/reproduced in simple terms?

Nucleon FF: Key issues

- What is the relative importance of small–size and end–point configurations?

  Can be investigated in quasi–model independent manner!

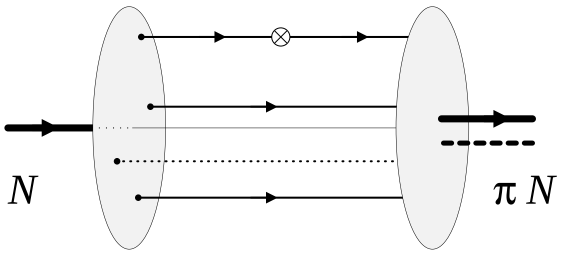
- What is the role of non–perturbative short–distance interactions responsible for χSB in QCD

  Think of them as *correlations* between elementary QCD degrees of freedom

  Correlation length $\rho \sim 0.2 - 0.3\,\mathrm{fm}\ \ll$ hadronic size

  Express in language of light–front wave function
  Schweitzer, Strikman, CW 12: $q\bar{q}$ correlations

Toward N^*: Near–threshold πN



- Same picture applies to high–Q^2 production of πN near threshold $W = M_N + M_\pi + \epsilon$

  $\Phi_{\pi N}(x_1 x_2 x_3; \zeta, W)$ distribution amplitude,

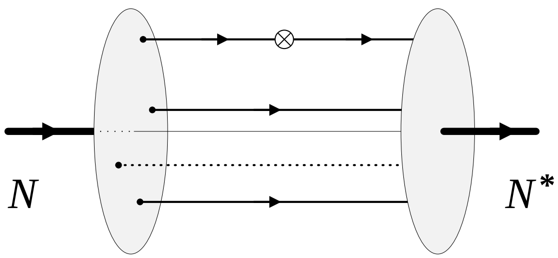
  $\zeta \leftrightarrow \cos\theta_{\mathrm{CM}}$, partial wave expansion possible

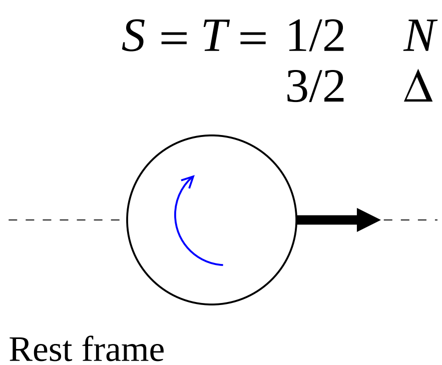
- Soft–pion theorem for πN DA

  $\langle \pi N | \psi\psi\psi | 0 \rangle \;\; \leftrightarrow \;\; \langle N | [Q_{\mathrm{axial}}, \psi\psi\psi] | 0 \rangle$
  chiral rotation of QCD quark operator

- CLAS 6 GeV data $\rightarrow$ Talk K. Park
  LC sum rule calculations $\rightarrow$ Talk Braun

Toward N^*: Resonances in QCD





- QCD description of high–Q^2 N^* production

  $\Phi_{N*}(x_1 x_2 x_3)$ resonance distribution amplitude

  How to define “resonance” in QCD?

  Need parametric control of hadronic FSI!
  Several possibilities

- Large–N_c limit of QCD   Semiclassical limit. ’tHooft, Witten

  N, Δ degenerate, mass splitting $\sim 1/N_c$

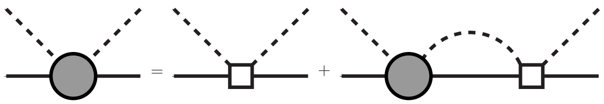
  N, Δ wave functions related: Rotational states

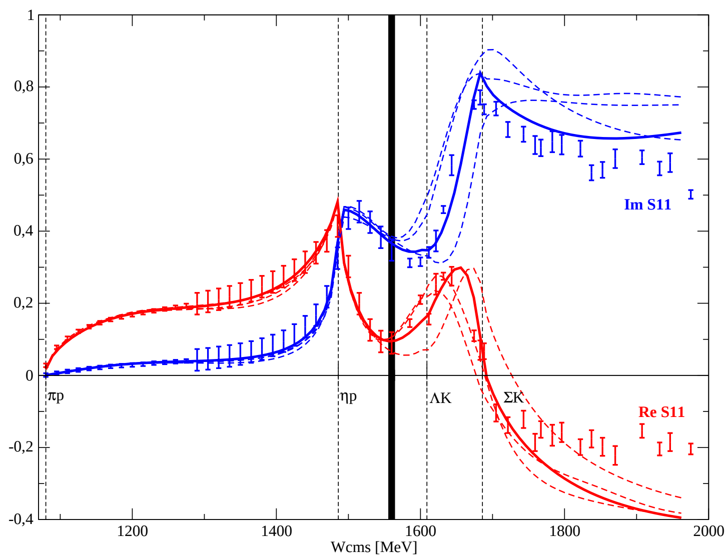
  Meson–meson interactions suppressed,
  meson–baryon interactions strong:
  $g_{MM} \sim 1/\sqrt{N_c} \quad \ll \quad g_{MBB} \sim \sqrt{N_c}$

  Guidance for phenomenology of MB
  and MM interactions

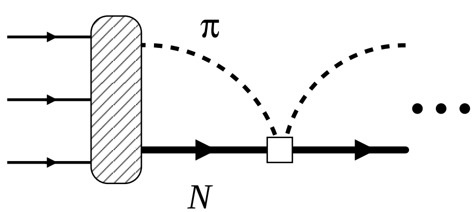
  Should be explored further!

Toward N^*: Dynamical generation of resonances





Bruns, Mai, Meissner, PLB697 (2011) 254



- Can one generate resonances dynamically through hadronic FSI? . . . at least some?

- Chiral effective field theory

  Unitarized χEFT interactions, Bethe–Salpeter equation

  Constrained by chiral low–energy theorems

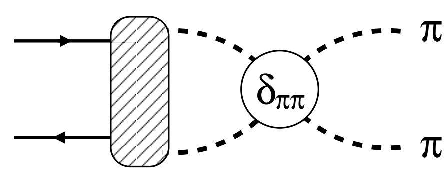
  Reasonable results for $S_{11}(1535, 1650)$
  Bruns, Mai, Meissner 11

  Could it be extended to πN DAs with near–threshold DAs as input?

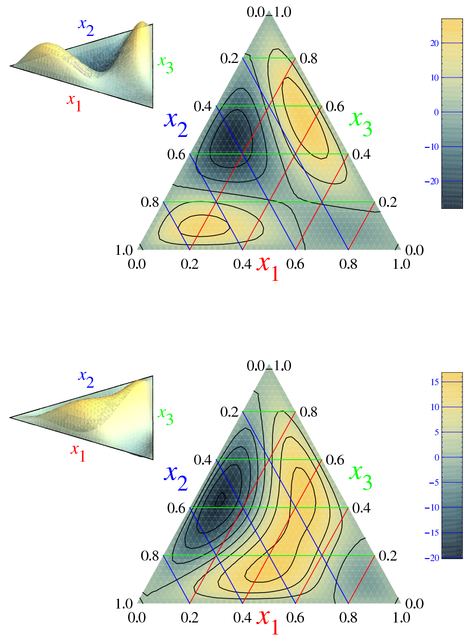
  χEFT guarantees universality, controlled accuracy

- Alt: Empirical phase shifts

  ρ, ρ' DAs from $\pi\pi$ near threshold
  M. Polyakov, NPB555 (1999) 231; applied at HERA



Toward N^*: DAs from Lattice QCD



- N^* distribution amplitudes from lattice
  → Talk Braun

  $N^*(1535)$ parity–partner of N,
  by–product of nucleon calculation

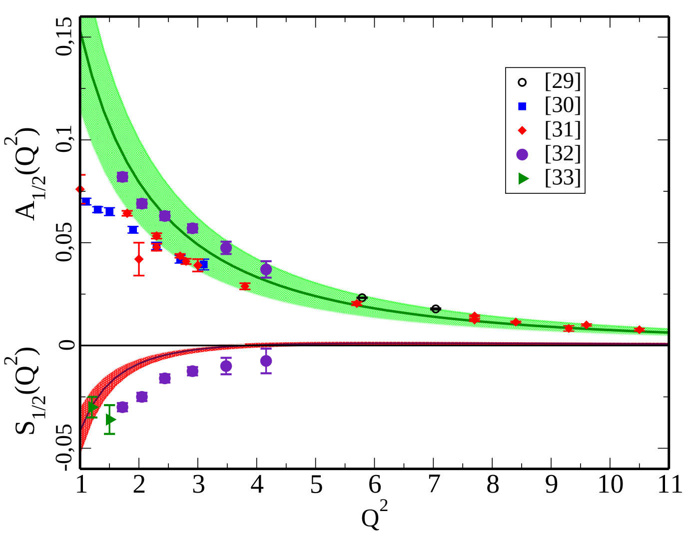
  First non–trivial moment determines
  distribution of bulk strength

- Transition FFs from light–cone sum rules

  Power corrections estimated using asymptotic DAs

  Promising "hybrid" approach

  Higher moments and "shape" of DA from Lattice?
  Higher–twist DAs for power corrections?



V. Braun et al., PRL 103 (2009) 072001.

Toward N^*: Key issues

- Explore regions where hadronic FSI is parametrically controlled

  Large–N_c limit of QCD

  Chiral near–threshold region $\rightarrow$ dynamically generated resonances

- Assess ratio non–resonant/resonant production in QCD

  Information from quark–hadron duality