The Pion Form Facto

Present status and future outlook

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European Research Conference

on

Jefferson Lab, Newport News, VA , USA

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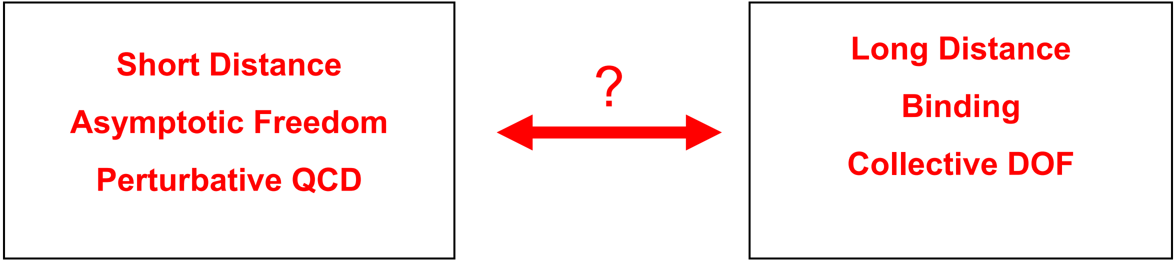
- BUT, we are unable to construct a quantitative description of hadrons in terms of the underlying constituents, quarks and gluons.
  – We know that there is an asymptotic limit, but how do we get ther and what governs the transition?



dies for understanding hadronic structure

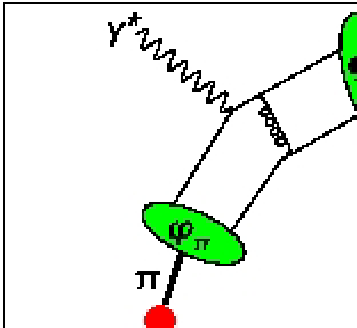
Simple qq valence structure of π^+

The pQCD description is expected to be valid at much lower values
Q^2 compared to the nucleon

very large Q^2 one can calculate F_π in pQCD, which reduces to
torized form as $Q^2 \rightarrow \infty$

$$F_\pi(Q^2) \rightarrow 16\pi \frac{\alpha_s f_\pi^2}{Q^2}$$

where $f^2\pi = 93$ MeV is the
$\pi^+ \rightarrow \mu^+\nu$ decay constant



This asymptotic normalization does

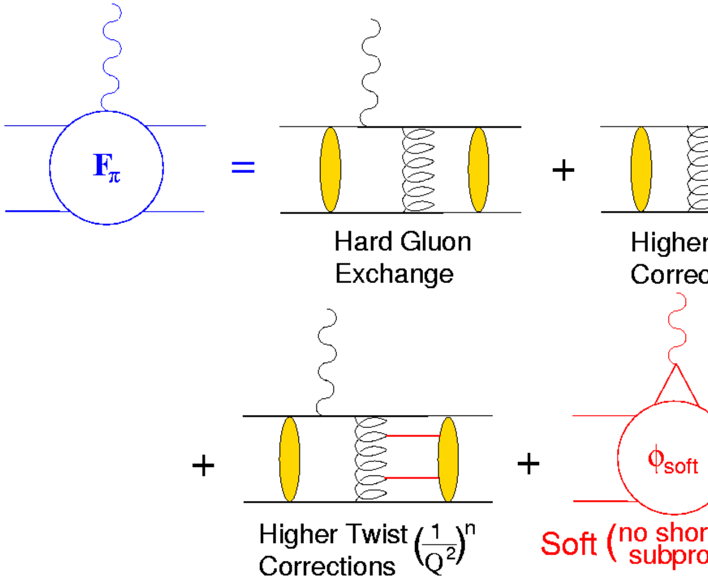
xperimentally accessible Q
hard and soft components
ibute

ransverse momentum effects

nterplay of hard and soft
ponents is not well
rstood

lon-perturbative hard
omponents of higher twist cancel
oft components *[V. Braun et al.,
PRD* ***61*** *(2000) 07300]*

rent theoretical perspectives
e dominance of higher twist



- he charged pion presents a clean test case for our understand
ound quark systems
  - Structure of pion at all Q^2 values

- what value of Q^2 will hard pQCD contributions dominate?
  - Perturbative QCD(LO) hard calculations under-predict experimenta
    by a factor of 2-3

- any studies of F_π, but the interplay of hard and soft contributio
t well understood
  - Constraints on theoretical models require high precision data
  - JLab is the only experimental facility capable of the necessary
    measurements

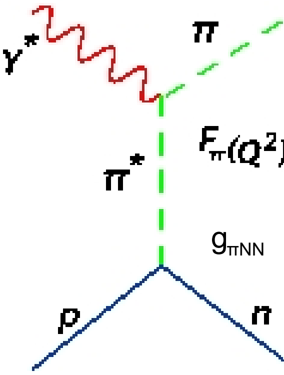
– Accurate measure of the π^+ charge radius, r_π=0.657 ± 0.012 fm

At larger Q^2 values, one must use the “virtual pion cloud” of th
proton to extend the F_π measurement

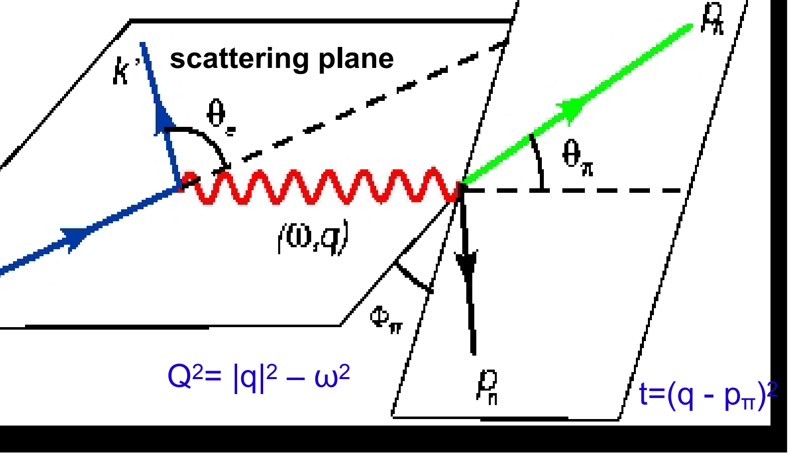
– t-channel diagram dominates σ_L at small –t

In the Born term model:

$$\frac{d\sigma_L}{dt} \propto \frac{-tQ^2}{(t-m_\pi^2)} g_{\pi NN}^2(t) F_\pi^2(Q^2,t)$$



Pion electroprod



dominance of σ_L

- For maximum contributi
  the π^+ pole to σ_L, need d
  smallest possible –t
- At fixed Q^2, a higher val
  allows for smaller $-t_{min}$

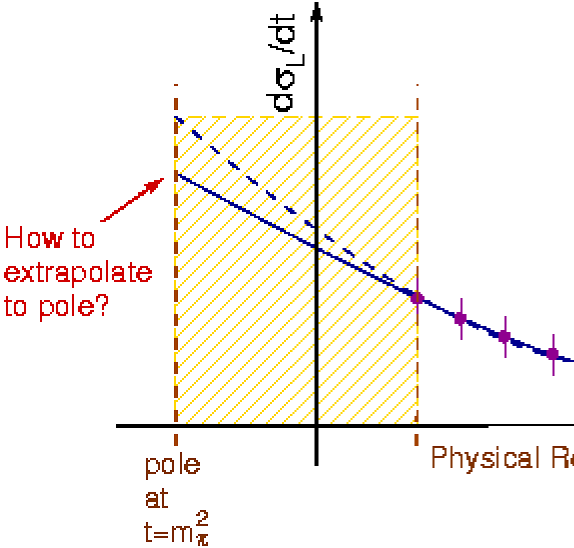
xtraction of F_π requires knowledge of the -t dependence of σ_L

- Only three of Q^2, W, t, and θ_π are independent
- Must vary θ_π to measure the -t dependence (off-parallel)
- In off-parallel kinematics, LT and TT must also be determined

–t>0 (away from the -t=m_π^2
e)

rly experiments used "Chew-
w" extrapolation technique

- Need to know the *–t* dependence through the unphysical region
- A reliable extrapolation is not possible



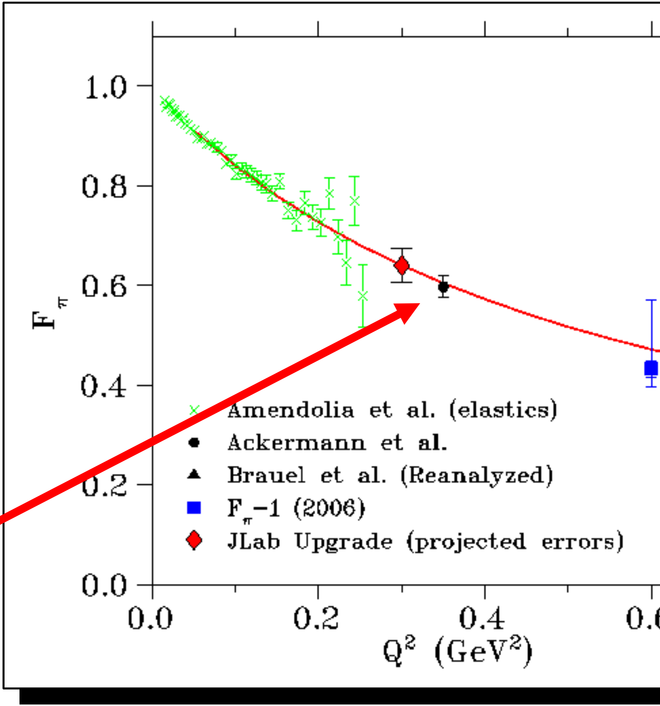
re reliable technique is to use a model including the

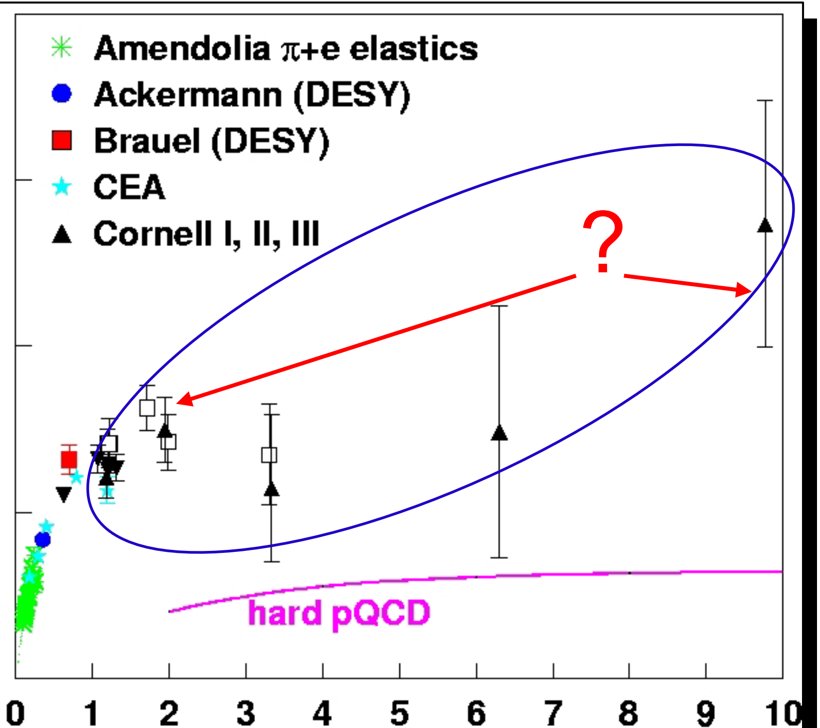
Can this method yield the physical form-factor?

st the method by comparing F_π ues extracted from *p(e,e'π^+)*n data h those obtained from π+e elastic ttering at the same kinematics

SY electroproduction data at Q^2 = 5 GeV^2 consistent with rapolation of elastic data

*ckerman et al., NP **B277** (1986) 168]*



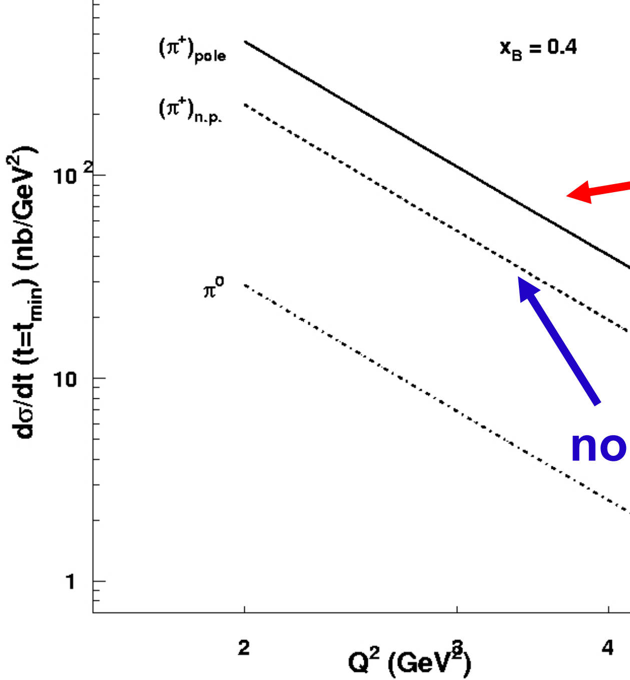


- Large Q^2 data from C
  - Use extrapolation o low Q^2 to isolate σ_L
  - Extract F_π from uns cross sections
- Largest Q^2 points als at large –t
  - Carlson&Milana pr M_{pQCD}/M_{pole} grows significantly for $-t_m$

ch of F_π measurements

asurement of σ_L for π^0 could help
strain pQCD backgrounds

GPD framework, π^+ and π^0 cross
ions involve different combinations
ame GPDs – ***but π^0 has no pole***
tribution



$$A \sim (\widetilde{H}^u - \widetilde{H}^d)(e_u + e_d)$$

$$A \sim (e_u\widetilde{H}^u - e_d\widetilde{H}^d)$$

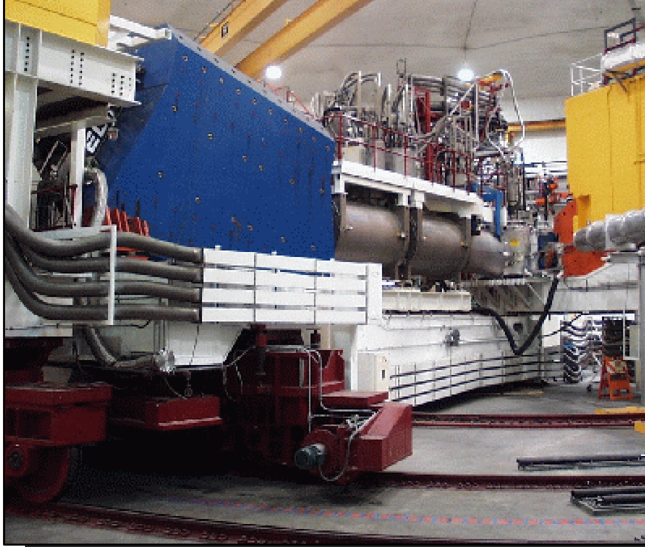
to the highest possible
e of Q² with 6 GeV beam
Lab

Fpi2 data at higher W,
smaller -t

Repeat Q^2=1.60 GeV^2 closer
o $t=m^2_\pi$ to study model
uncertainties

L/T/TT/LT separation in
roduction

surement of separated



Exp	Q^2 (GeV^2)	W (GeV)	|t| $(Gev)^2$	

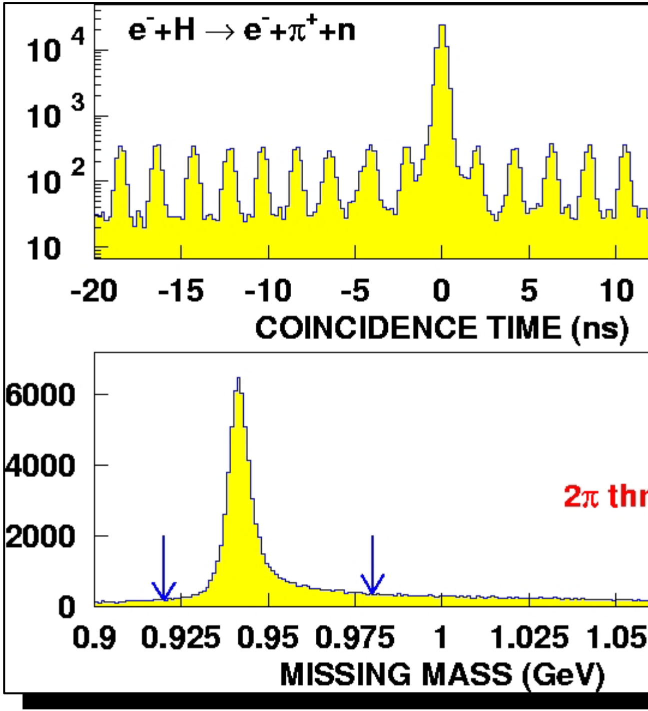
etween charged pions in HMS nd electrons in SOS

- Coincidence time resolution ~200-230 ps
- Cut: ± 1ns

rotons in HMS rejected using oincidence time and aerogel erenkov

- Electrons in SOS identified by gas Cerenkov and Calorimeter

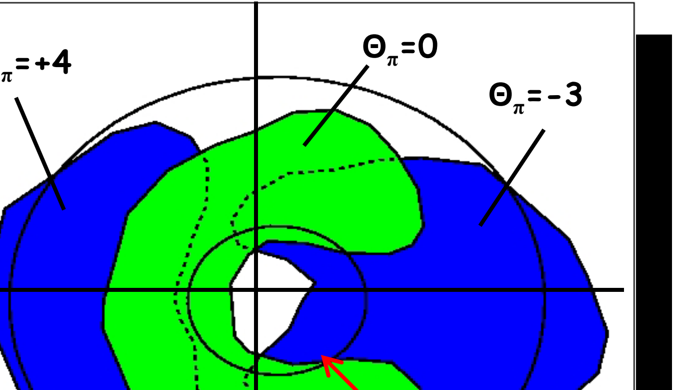
xclusive neutron final state elected with missing mass cut



cceptance not uniform

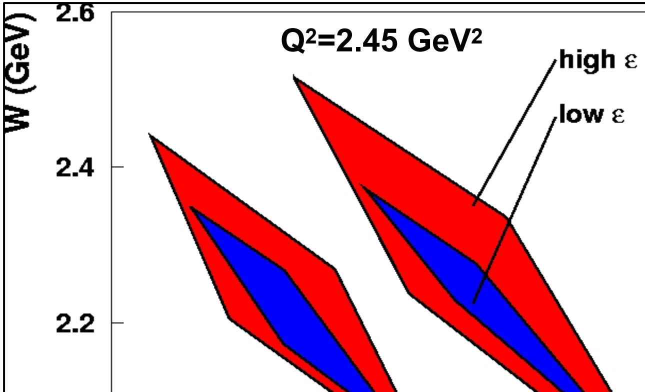
easure σ_{TT} and σ_{LT} by
king data at three angles:
=0, +4, -3 degrees

Radial coordinate: -t, azimuthal coordinate: φ



at low and high ε is diffe

- For L/T separation use c
to define common W/Q²
phase space

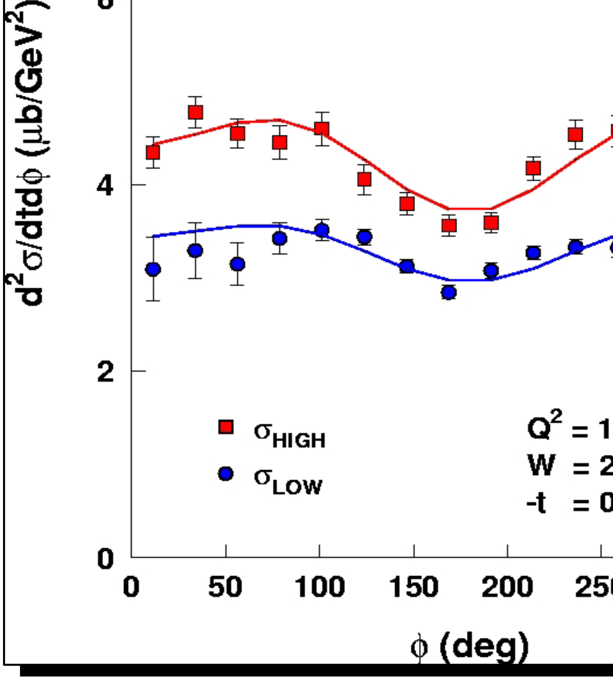


isolated using the Rosenbluth
aration technique

- Measure the cross section at two beam energies and fixed W, Q^2, -t
- Simultaneous fit using the measured azimuthal angle (φ_π) allows for extracting L, T, LT, and TT

eful evaluation of the systematic ertainties is important due to the amplification in the σ_L extraction

- Spectrometer acceptance, kinematics, and efficiencies

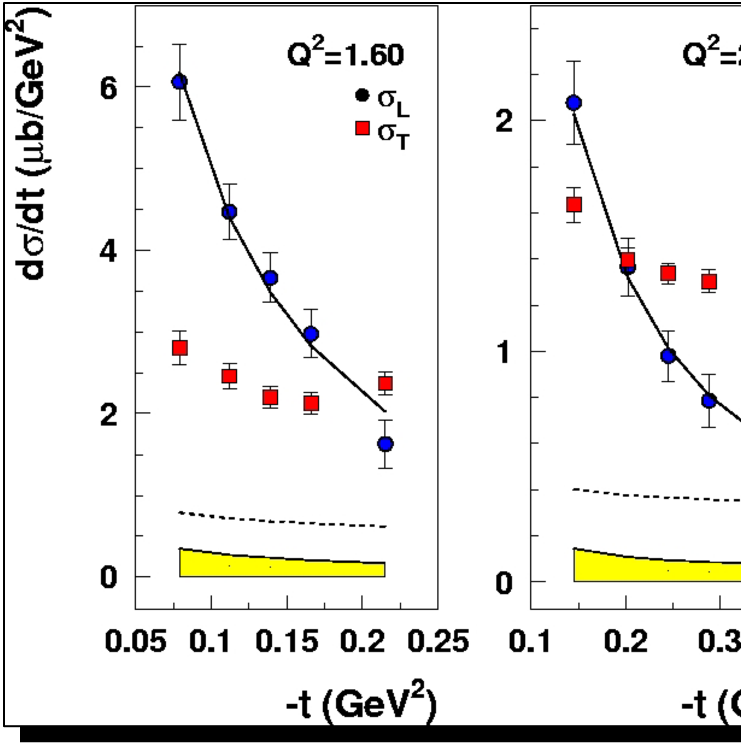


ch describes pion
troproduction in terms of
exchange of π and ρ like
cles *[Vanderhaeghen, Guidal,
t, PRC **57** (1998), 1454]*

Model parameters fixed from
pion photoproduction

Free parameters: F_π and F_ρ

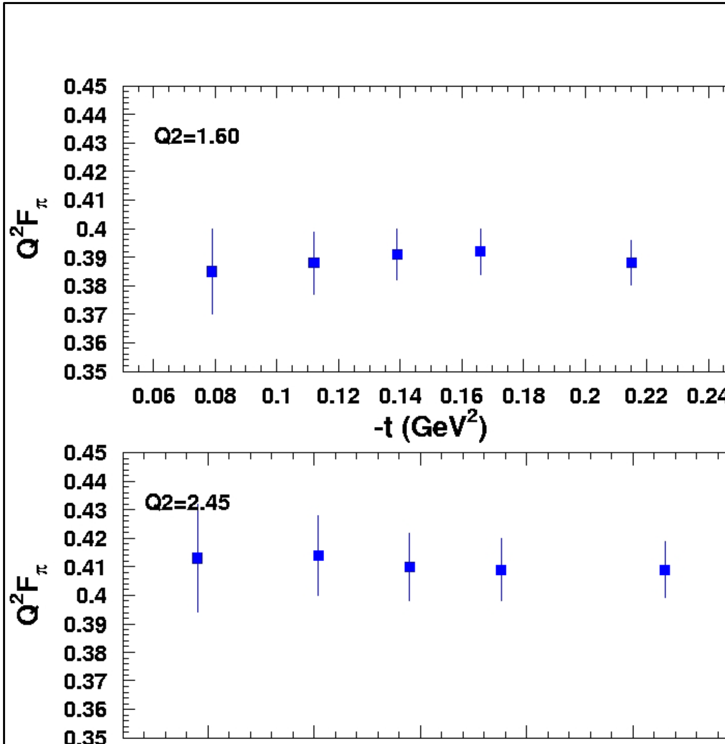
$$F_\pi = \frac{1}{1+Q^2/\Lambda_\pi^2}$$



ract F_π for each t-bin
arately

- F_π values are insensitive (<2%) to the t-bin used

s result gives confidence in
applicability of the VGL
gge model in the kinematic
ime of Fpi2 data

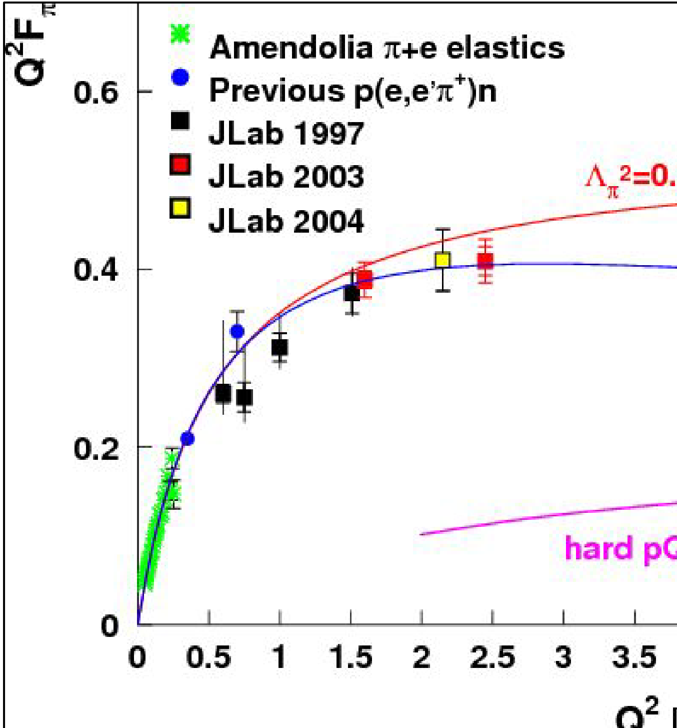


57 fm charge radius at Q^2=2.45
V^2 by ~1σ

- The monopole reflects the soft (VMD) physics at low Q^2
- The deviation suggests that the π+ “harder” at this Q^2

s still far from the pQCD
diction

- Including transverse momentum effects has no significant impact



Nesterenko and A.V. Radyushkin, Phys.
B115 *(1982)410]*

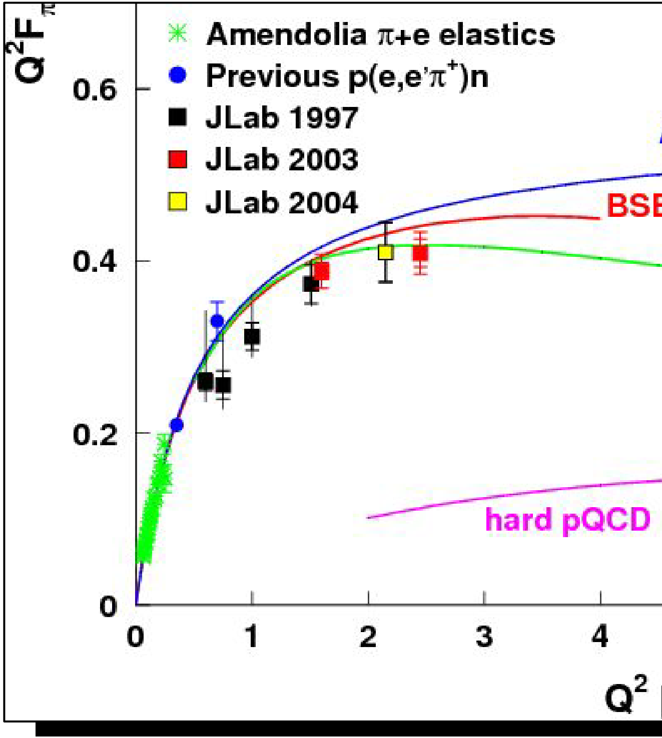
Use properties of Green functions –
spectral function contains pion pole

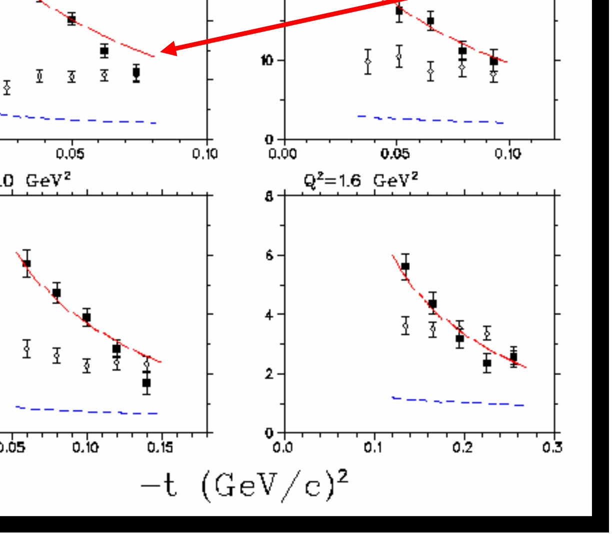
e-Salpeter/Dyson-Schwinger

*aris and P. Tandy, Phys.Rev.**C62***
)055204]

Systematic expansion in terms of
dressed particle Schwinger equations

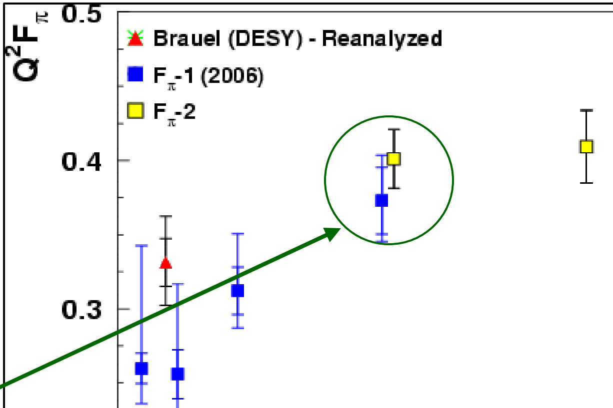
de Sitter/Conformal Field Thry





at the lowest Q^2

- May be due to resonance contributions not included in
- Linear fit to Λ_π^2 to t_{min} gives th estimate of F_π at each Q^2



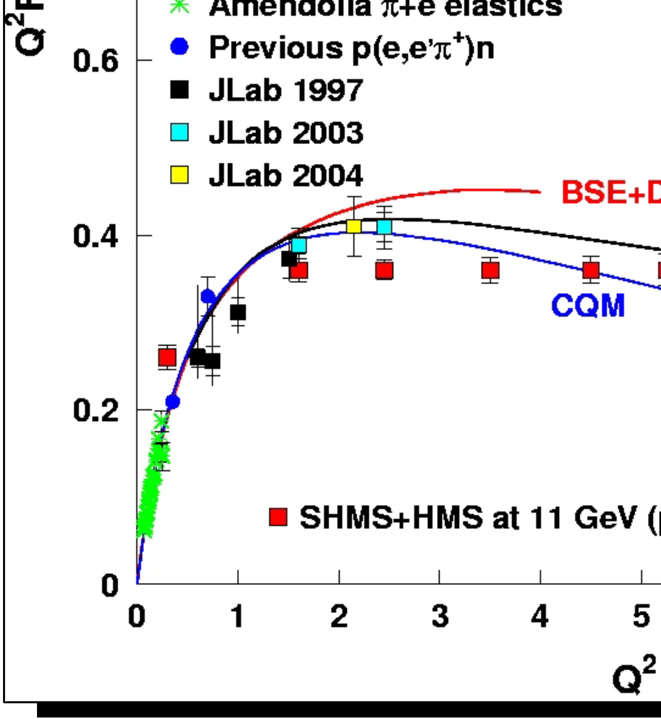
ck the model dependence of the s pole extrapolation

Good agreement between Fpi1

t expected in next 5 years
Lattice, GPDs etc.

11 GeV electron beam and the
MS in Hall C with θ=5.5º allows

- Precision data up tp Q^2=6 GeV^2 to study the transition to hard QCD
- Test of the electroproduction method at Q^2=0.3 GeV^2 with the upper limit of elastic scattering data
- Most stringent test of the model



dom to quarks and gluons

neasurements from JLab yield high quality data – in part due to

Continuous electron beam provided by JLab accelerator

Magnetic spectrometers and detectors with well-understood properties

highest Q^2 JLab results indicate that Q^2F_π is still increasing, but ~1
monopole parameterization of the charge radius

Still far from the QCD prediction

dies of F_π at higher electron beam energies will allow to reach the ki
ge where hard contributions are expected to dominate

Planned measurement of F_π at JLab after the upgrade to Q^2=6 GeV^2

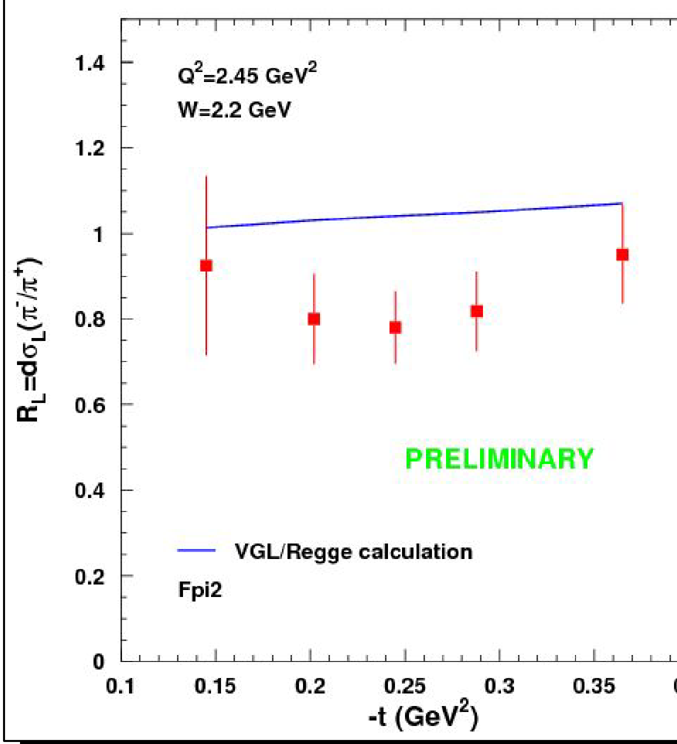
ninance of t-channel (pole ninance)

t-channel diagram is purely isovector

$$R = \frac{\sigma_L^{\pi^-}}{\sigma_L^{\pi^+}} = \frac{|A_v - A_s|^2}{|A_v + A_s|^2}$$

e dominance tested using + from D(e,e'p)

G-parity: If pure pole then necessary R=1



s	0.1%	2.0%	0.4%
rption	-	2.0%	0.1%
y	0.03%	1.0%	-
endence	0.2%	-	1.1(1.3)%
s	0.2%	-	1.0%
king	0.1%	1.0%	0.4%
	-	0.5%	0.3%
ckness	-	0.8%	0.2%
Efficiency	-	0.5%	0.3%

spectrometer quantit
parameterized using
constrained ^{1}H(e,e'p
reaction

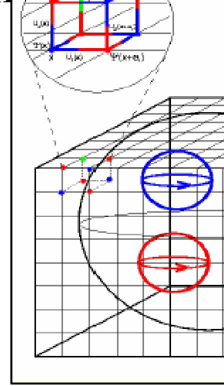
– Beam energy and r
to <0.1%

– Spectrometer angle
~0.5mrad

- Spectrometer accept
verified by comparing
elastic scattering dat
global parameterizat

– Agreement better t

This is different from QCD-inspired models where confin
must be put in by hand



T LQCD requires a number of approximations

Lattice discretization errors – improved LQCD action helps

Chiral extrapolation of LQCD is used to obtain the pion mass

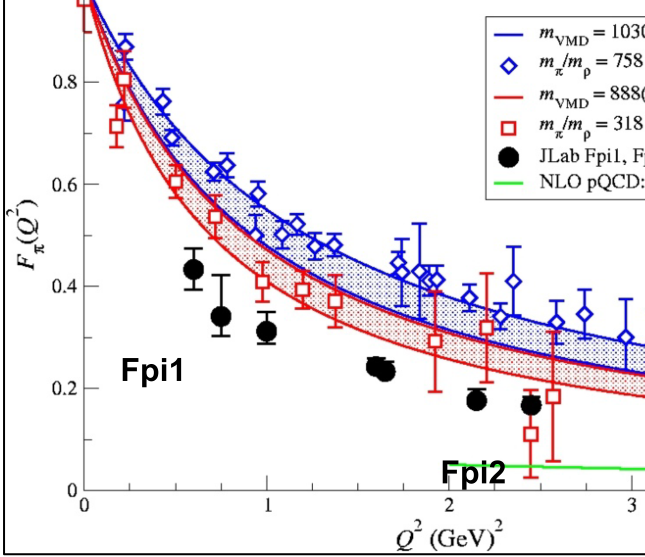
Quenching errors – need to include disconnected quark loops

vances in computational techniques have improved over the

quenched (dynamical)
main-wall action calculation

Lattice Hadron Physics Collaboration (Jefferson Lab, Regina, Yale)

F. Bonnet et al., hep-lat/0411028



tice calculations are consistent with experimental data within l
istical and systematic errors, dominated by chiral extrapolatio

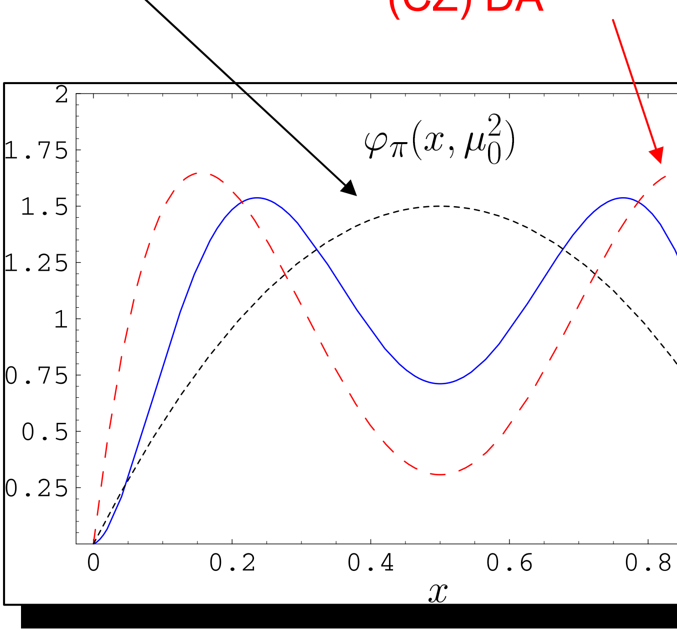
Primary goal is to test proof-of-principle of different technique

urbation theory at the parton
plitude level

τ DA is consistent to 1σ level
vith CLEO $\pi\gamma$ transition data

esults taken as evidence that
mptotic π DA appropriate as
as Q^2=*1* GeV^2

$F_{\pi+}$ soft contributions from
rk-hadron duality model need



A.P. Bakulev et al. Phys. Rev. **D70** (2004

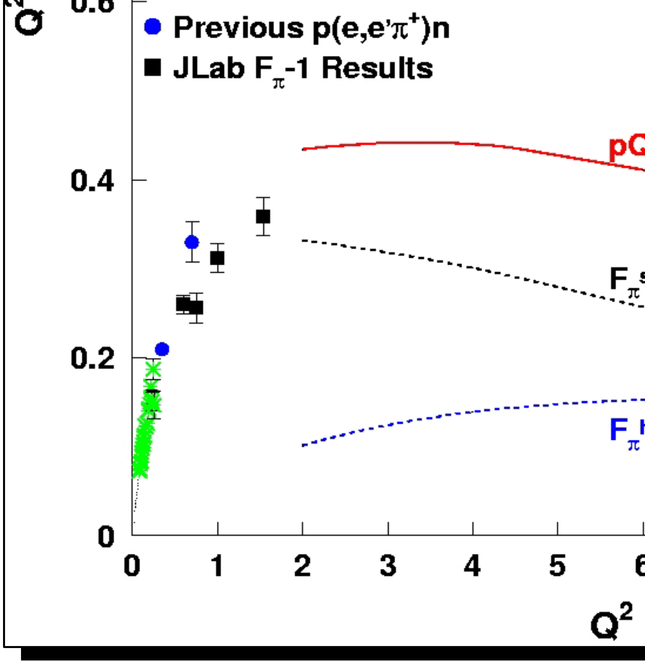
NLO

- Model φ_π using QCD Sum Rules prescription

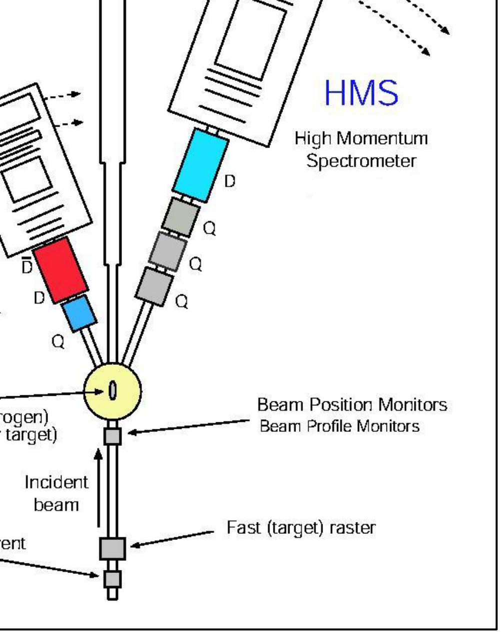
rd component significantly ler-predicts the data

- To describe the data must include soft contribution – here, via local duality

$$F_\pi = F_\pi^{soft} + F_\pi^{hard}$$



A.P. Bakulev et al. Phys. Rev. **D70** (

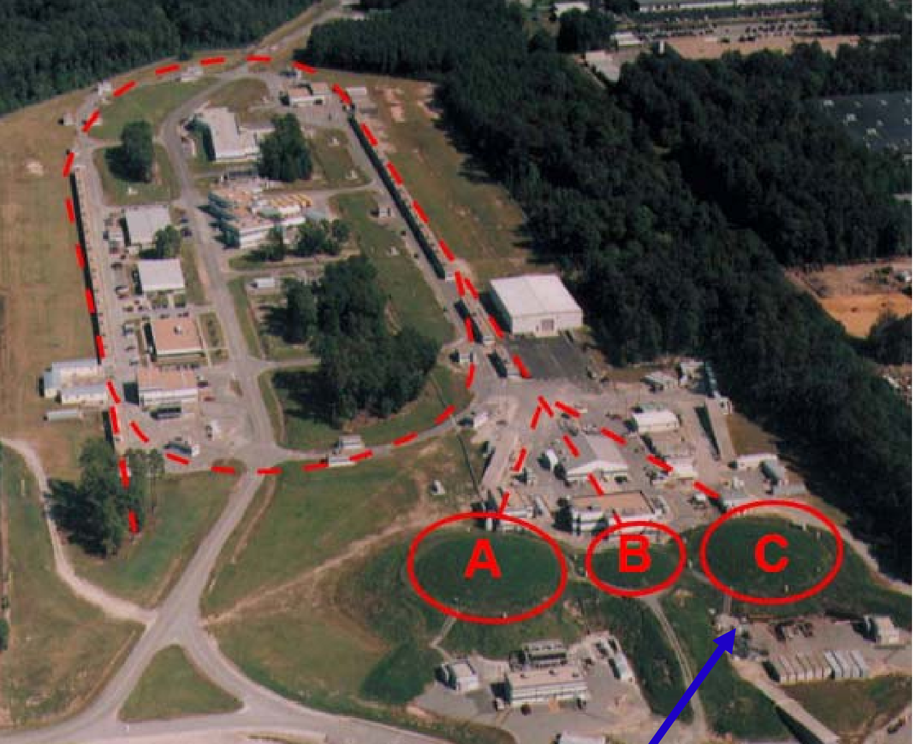


- SOS detects e^-
- HMS detects π^+

- Targets
  - Liquid 4-cm H/D cells
  - Al (dummy) target for backgroun
    measurement
  - ^{12}C solid targets for optics calibra

HMS Aerogel

- Improvement of $p/\pi^+/K^+$ PID
  momenta, first use in 2003
- Built by Yerevan group
  [*Nucl. Instrum. Meth.* ***A548***(2005

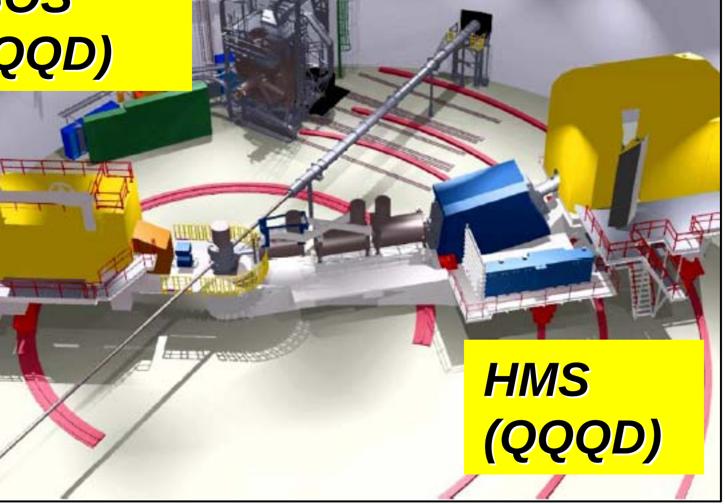


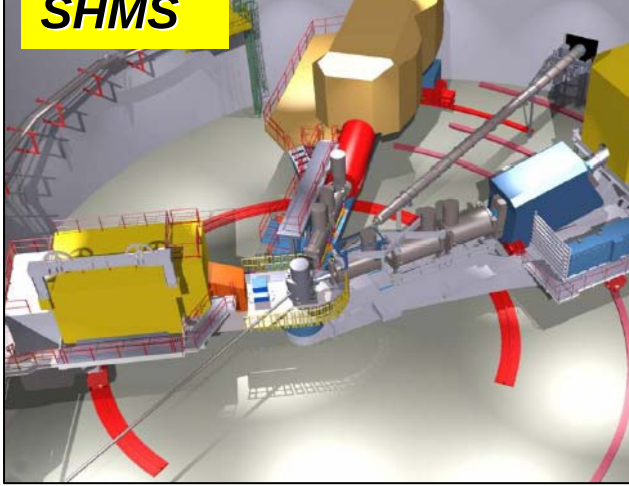
Linacs

– Three experin
Halls operatin
concurrently

- E<~ 5.7 GeV
  – Hadron-partor
  transition regi

- C.W. beam with c
of up to 100 uA





Hall C High Momentum Spectrometer and Short Orbit Spectrometer at present

- Add a Super-High Mom Spectrometer for studie
  - Form Factors and sim