Probing short-range structure of hadrons and nuclei with high energy hadron beams at J-PARC

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Future prospects of hadron physics at J-PARC

J-PARC, February 10, 2012

Key questions

Understanding microscopic structure of hadrons beyond single parton distributions:

3D structure, correlations, bound state structure with heavy quarks [baryons, exotics, admixture in light hadrons]

Tools - fixed target experiments at Jlab, FAIR (PANDA), CERN (COMPASS) - J-PARC has complementary options

Spinoff of pp collider experiments LHC & RHIC

Understanding dynamics of strong interactions - transition from well understood hard inclusive QCD to hard exclusive processes and to soft QCD

Current focus -- understanding dynamics of the simplest hard two body reactions

Rationals:

- color transparency feature of hard coherent interactions as an effective diagnostic tool
- testing multiparton structure of hadrons

Mostly fixed target experiments

J-PARC could nicely complement Jlab and PANDA.

Understanding short-range structure of nuclei - mapping short-range NN correlations, nonnucleonic degrees of freedom in correlations - link to dynamics of high density cold baryon matter - neutron stars.

Tools

Large Q^2 e- A scattering - Jlab - active program

Hard (large t) hadron induced quasielastic reactions off nuclei

very important complementary tool - number of advantages as compared to eA

Deep inelastic scattering allowed to resolve quarks and gluons in nucleons due to

* well understood point-like interaction, * large energy & momentum, * reduction of final state interaction

Large angle two body processes is a good candidate for serving the same function in reactions initiated by hadrons: removing in a controlled way color singlet clusters.

Possible to form an experimental program around studies of large angle (semi) exclusive reactions initiated by protons and pions with a strong potential for discoveries and leading to progress in the understanding QCD & nuclei

Parallel program (same time frame) with antiproton beams - PANDA - comparison would be very helpful

large angle two body processes with proton/neutrons

color transparency phenomena

study of the properties of cold dense nuclear matter - structure of the short-range correlations

Main focus of the talk

branching processes and GPDs

pion induced reactions with dilepton productions

Briefly in the end

Large angle two body processes

So far we do not understand the origin of one of **the most fundamental hadronic processes in pQCD -large angle two body reactions** (-t/s=const, $s \to \infty$)

$\pi + p \to \pi + p$, $p + p \to p + p$,...

Summary: reactions are dominated by quark exchanges with

$$\frac{d\sigma}{d\theta_{c.m.}} = f(\theta_{c.m.}) s^{(-\sum n_{q_i} - \sum n_{q_f} + 2)}$$

Indicates dominance of minimal Fock components of small size

Most extensive set of processes was studied by the BNL experiments at 5.9 and 9.9 GeV/c

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Comparison of 20 exclusive reactions at large t

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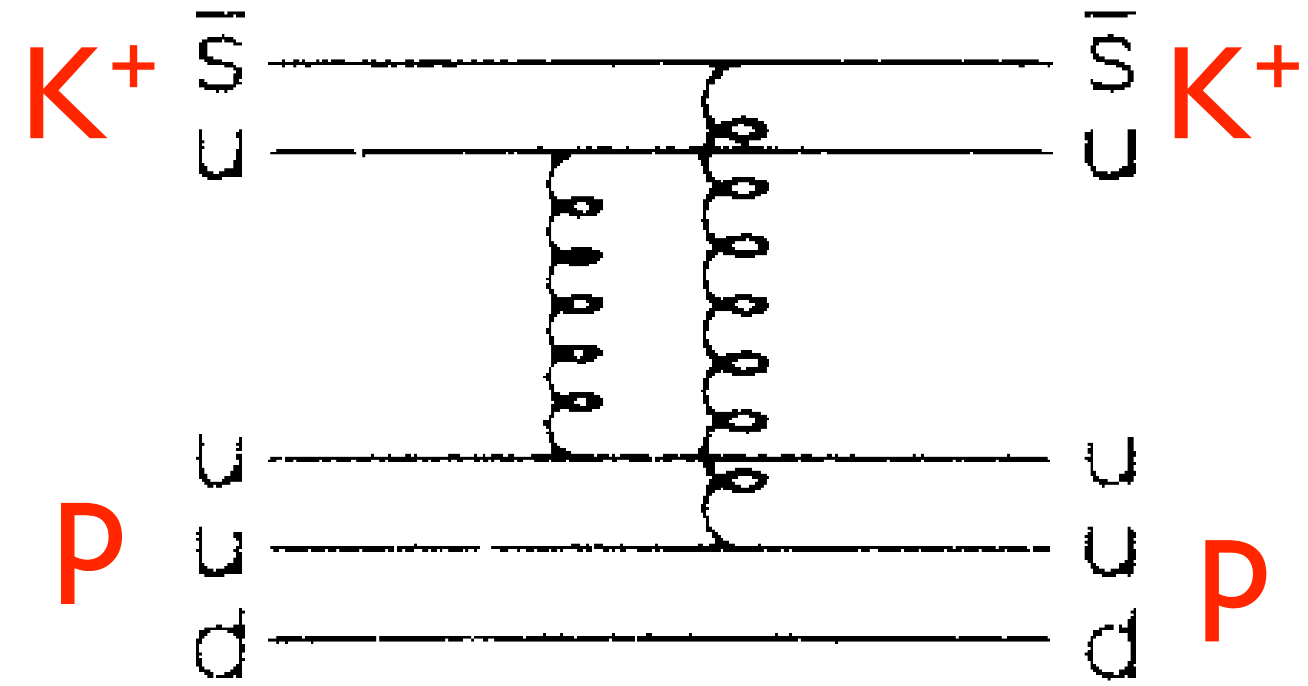
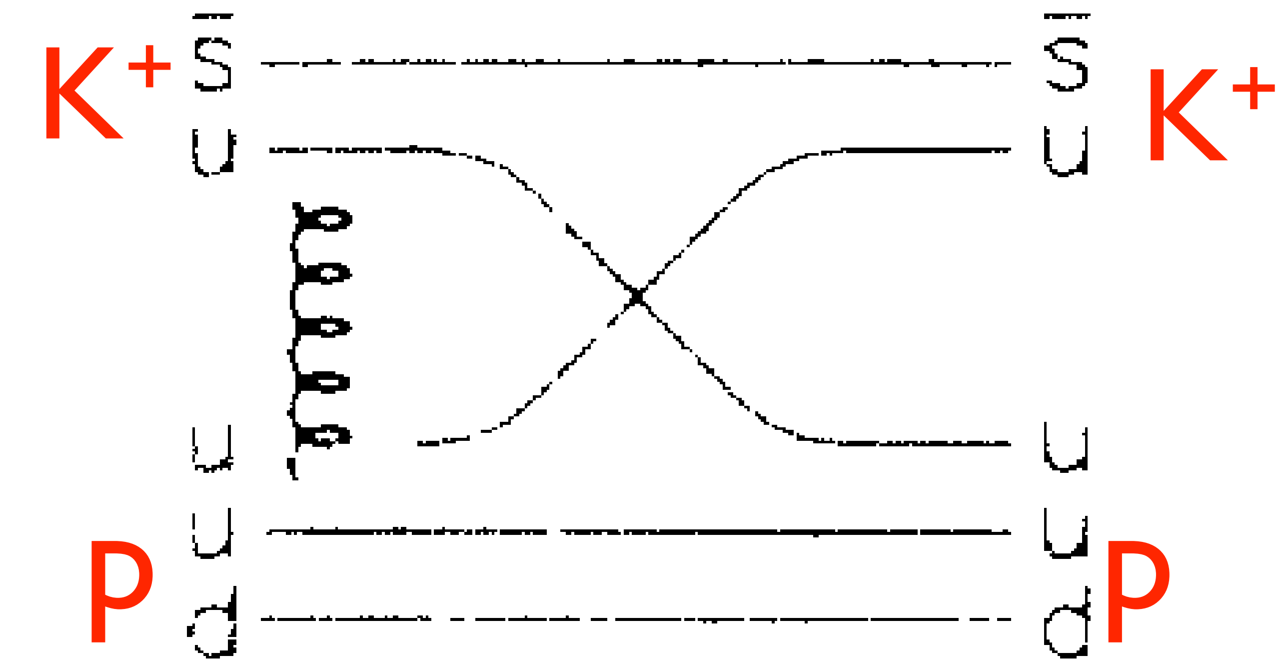
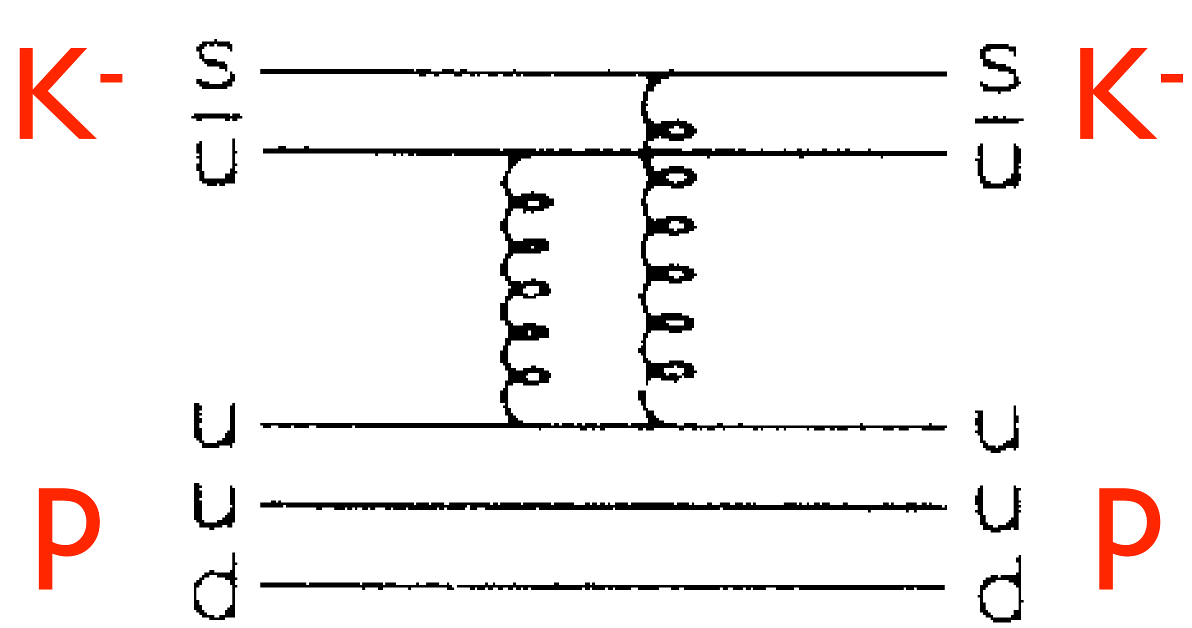
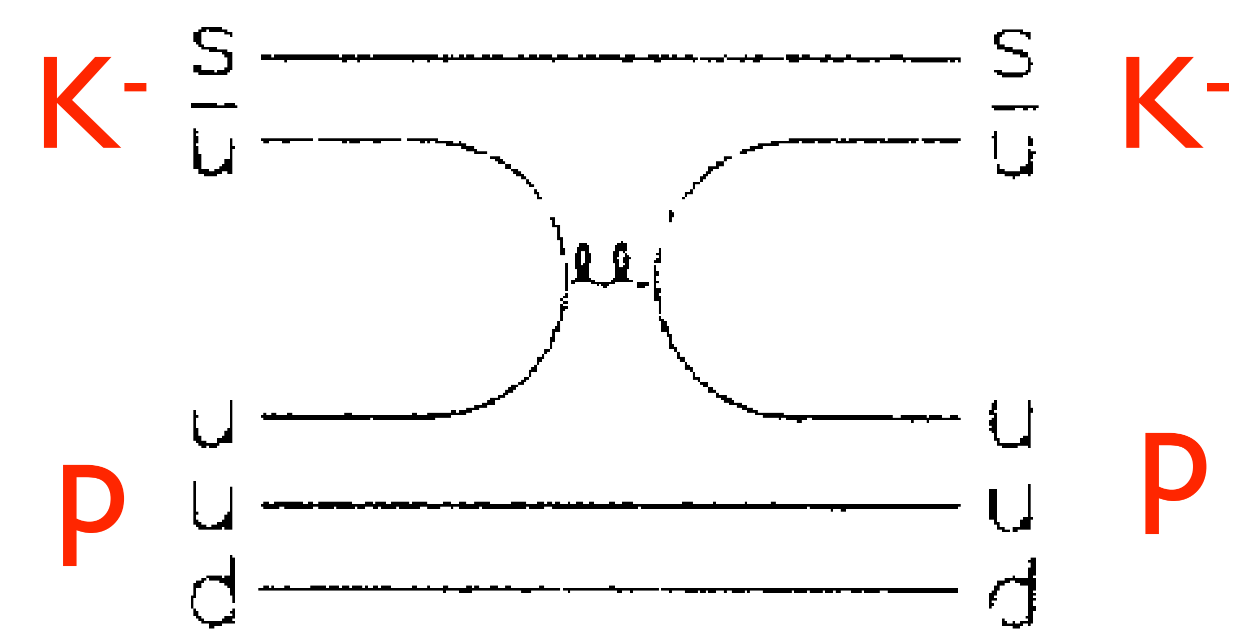
Meson-baryon reactions	
1	$\pi^+ p \to p\pi^+$
2	$\pi^- p \to p\pi^-$
3	$K^+ p \to pK^+$
4	$K^- p \to pK^-$
5	$\pi^+ p \to p\rho^+$
6	$\pi^- p \to p\rho^-$
7	$K^+ p \to pK^{*+}$
8	$K^- p \to pK^{*-}$
9	$K^- p \to \pi^-\Sigma^+$
10	$K^- p \to \pi^+\Sigma^-$
11	$K^- p \to \Lambda\pi^0$
12	$\pi^- p \to \Lambda K^0$
13	$\pi^+ p \to \pi^+\Delta^+$
14	$\pi^- p \to \pi^-\Delta^+$
15	$\pi^- p \to \pi^+\Delta^-$
16	$K^+ p \to K^+\Delta^+$
Baryon-baryon reactions	
17	$pp \to pp$
18	$\bar{p}p \to p\bar{p}$
19	$\bar{p}p \to \pi^+\pi^-$
20	$\bar{p}p \to K^+K^-$



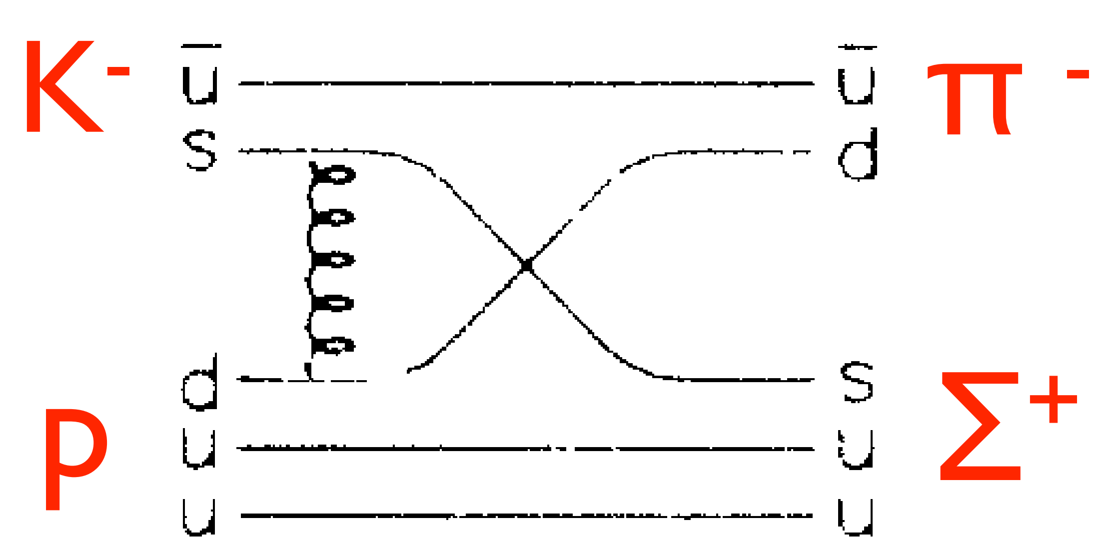


$K^+p \to K^+p$





$K^-p \to K^-p$



Examples of the simplest pQCD diagrams for large angle exclusive processes

Quark counting expectations

$$\frac{d\sigma^{a+b\to c+d}}{dt} \propto \frac{1}{s^{q_a+q_b+q_c+q_d-2}}$$

TABLE V. The scaling between E755 and E838 has been measured for eight meson-baryon and 2 baryon-baryon interactions at $\theta_{\text{c.m.}} = 90°$. The nominal beam momentum was 5.9 GeV/c and 9.9 GeV/c for E838 and E755, respectively. There is also an overall systematic error of $\Delta n_{\text{syst}} = \pm 0.3$ from systematic errors of $\pm 13\%$ for E838 and $\pm 9\%$ for E755.

No.	Interaction	Cross section E838	Cross section E755		n-2 $(\frac{d\sigma}{dt} \sim 1/s^{n-2})$
1	$\pi^+ p \to p\pi^+$	132 ± 10	4.6 ± 0.3	n=8	6.7 ± 0.2
2	$\pi^- p \to p\pi^-$	73 ± 5	1.7 ± 0.2	n=8	7.5 ± 0.3
3	$K^+ p \to pK^+$	219 ± 30	3.4 ± 1.4	n=8	$8.3^{+0.6}_{-1.0}$
4	$K^- p \to pK^-$	18 ± 6	0.9 ± 0.9		≥ 3.9
5	$\pi^+ p \to p\rho^+$	214 ± 30	3.4 ± 0.7	n=8	8.3 ± 0.5
6	$\pi^- p \to p\rho^-$	99 ± 13	1.3 ± 0.6	n=8	8.7 ± 1.0
13	$\pi^+ p \to \pi^+ \Delta^+$	45 ± 10	2.0 ± 0.6	n=8	6.2 ± 0.8
15	$\pi^- p \to \pi^+ \Delta^-$	24 ± 5	≤ 0.12		≥ 10.1
17	$pp \to pp$	3300 ± 40	48 ± 5	n=10	9.1 ± 0.2
18	$\bar{p}p \to p\bar{p}$	75 ± 8	≤ 2.1	n=10	≥ 7.5

Interesting regularity:

$$\frac{d\sigma^{K^+p\to K^+p}}{d\theta_{c.m.}}(\theta=90^o) > \frac{d\sigma^{\pi^+p\to\pi^+p}}{d\theta_{c.m.}}(\theta=90^o) > \frac{d\sigma^{\pi^-p\to\pi^-p}}{d\theta_{c.m.}}(\theta=90^o)$$

while at t=0 the cross sections are 1/2:1:1

If quark exchanges dominates we expect if contribution of the wave function in the origin gives dominates

$$\frac{d\sigma^{K^+p\to K^+p}}{d\theta_{c.m.}}(\theta=90^o)/\frac{d\sigma^{\pi^+p\to\pi^+p}}{d\theta_{c.m.}}(\theta=90^o) \sim (f_K/f_\pi)^2 \sim 1.4$$

data ~1.69 (1 ±15%)

$$\frac{d\sigma^{\pi^+p\to\pi^+p}}{d\theta_{c.m.}}(\theta=90^o)/\frac{d\sigma^{\pi^-p\to\pi^-p}}{d\theta_{c.m.}}(\theta=90^o) \sim u(x)/d(x) \sim 2$$

data ~1.76 (elastic); 2.15 (for ρ-meson production; error 10-15%

Similar pattern is observed at 9.9 GeV. There is an evidence of the change of the pattern at p=20 GeV but errors are too large. Overall it appears likely that these processes are dominated by short distances for -t> 5 GeV^2. Clearly new experiments are necessary to determine details of the dynamics. J-PARC is in the optimal energy range.

Baryon final states

Two of the biggest mysteries are

Why $$\frac{d\sigma(\bar{p}p \to \bar{p}p)}{d\theta_{c.m.}} \leq \frac{1}{50}\frac{d\sigma(pp \to pp)}{d\theta_{c.m.}}$$ for $\vartheta_{cm}=90^\circ$, $E_{inc} \geq 6$ GeV

Is it due to lack of quark exchanges in the antiproton case?

What is the origin of oscillations in pp elastic scattering at for $\vartheta_{cm}=90^\circ$? Are they present in other reactions?

Example of discriminative power of comparing two reactions:

$$\frac{d\sigma(pp \to pp)}{d\theta_{c.m.}} / \frac{d\sigma(pn \to pn)}{d\theta_{c.m.}}$$ very sensitive to the reaction mechanism

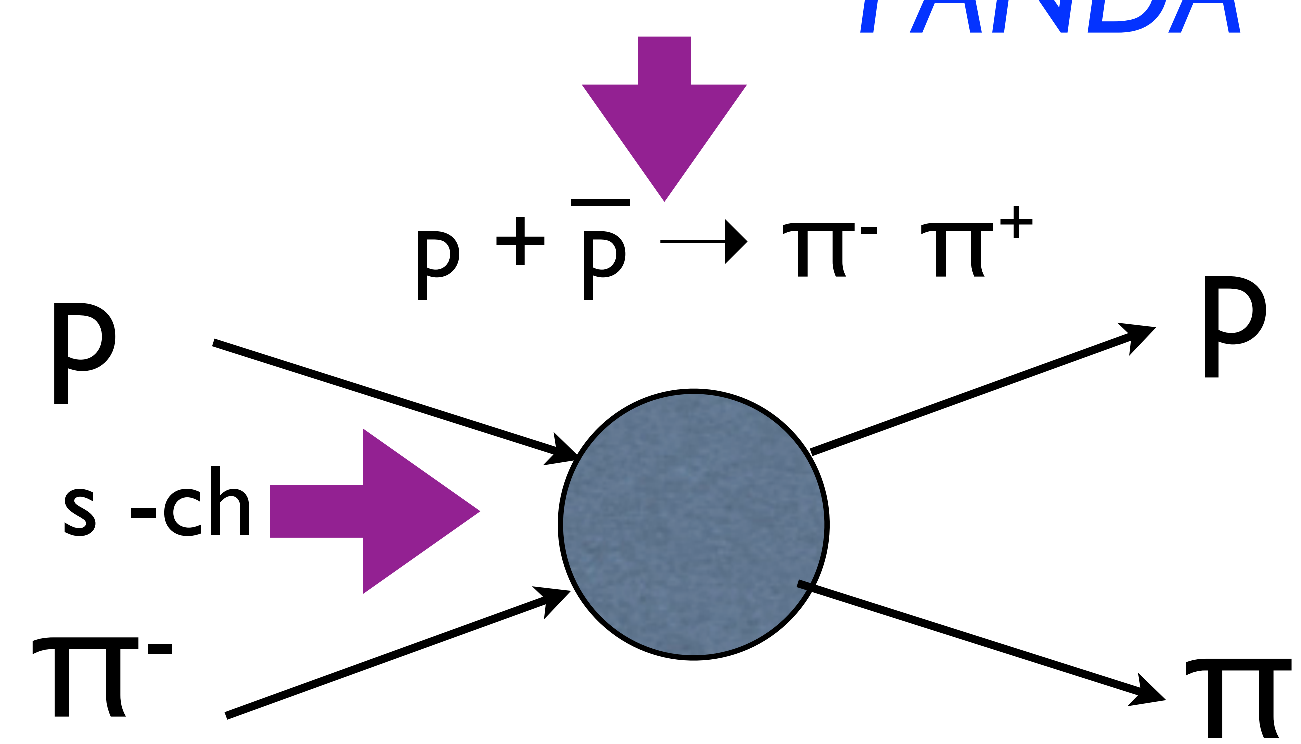
C. Granados & M.Sargsian 2010

Fruitful to study s and t channel of the same amplitude:

t -channel *PANDA*

$p + \bar{p} \to \pi^- \pi^+$

π^- (π^+) $p \to \pi^-$ (π^+) p s -ch

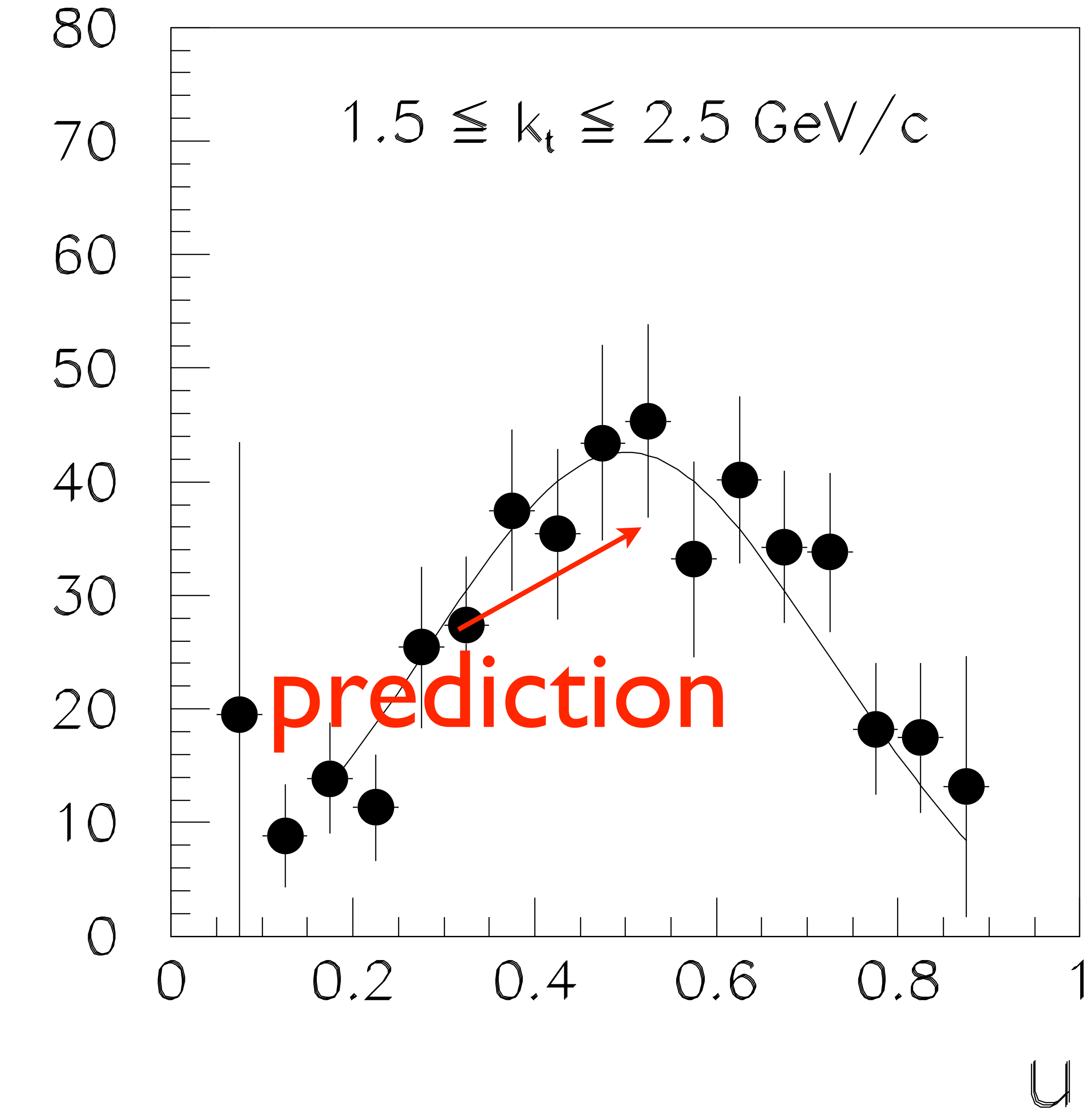


Color transparency phenomena

At high energies weakness of interaction of point-like configurations with nucleons - is routinely used for explanation of DIS phenomena at HERA.

First experimental observation of high energy CT for pion interaction (Ashery 2000): $\pi + A \rightarrow$ "jet"+"jet" $+ A$. Confirmed predictions of pQCD (Frankfurt ,Miller, MS93) for *A-dependence, distribution over energy fraction, u carried by one jet, dependence on p_t(jet), etc*

(π wave funct)^2



Overall, presence of small $q\bar{q}$ configurations in $\pi,\rho,\ldots$ mesons is now well established

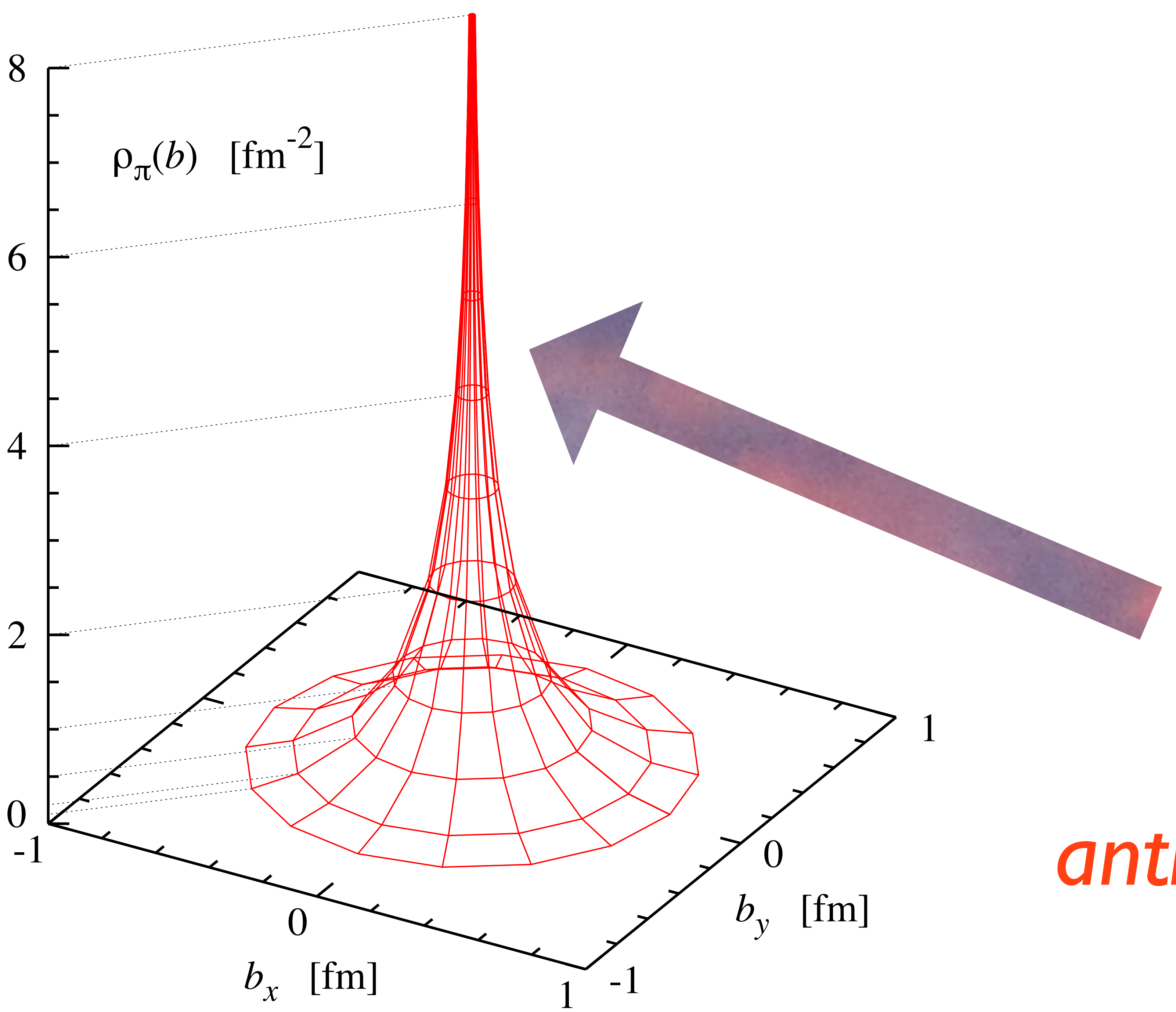
New evidence for PLCs in pion from e.m. form factors - Miller, MS, Weiss (2010)

Consistent with singular structure of the transverse charge density in the pion extracted from the data using dispersion technique

$$\rho_\pi(b) = \int_0^\infty \frac{dQ}{2\pi} Q\, J_0(Qb)\, F_\pi(t = -Q^2)$$

$$\rho_\pi(b) = \int_{4m_\pi^2}^\infty \frac{dt}{2\pi} K_0(\sqrt{t}b) \frac{\mathrm{Im}\, F_\pi(t + i0)}{\pi} \quad ☀$$

dispersion representation of transverse density



Contribution of small transverse size quark-antiquark component in pion

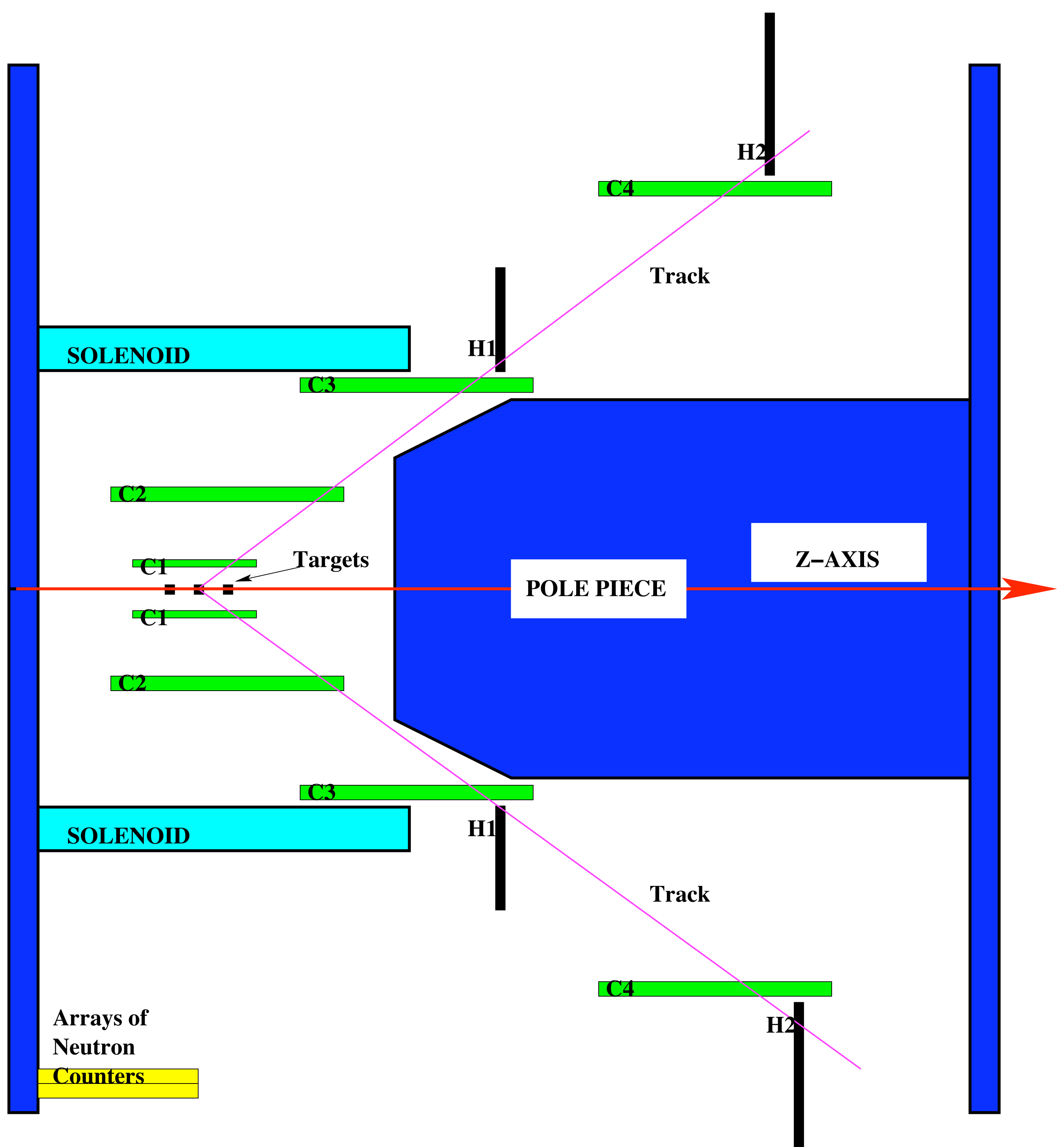
Three–dimensional rendering of the transverse charge density in the pion, as obtained from the dispersion integral ☀ evaluated with the Gounaris-Sakurai form factor parametrization of Brush et al.

CT - Intermediate energies

At high energies A(p,2p)(A-1), A(π,πp)(A-1) reactions were suggested by A.Mueller and S.Brodsky in 82 to look for Color Transparency (CT) as a way to understand the origin of **large angle two body reactions** check :

$$\sigma(pA \to pp(A-1)) = Z\sigma(pp \to pp)$$

At intermediate energies (E_p~ 1 GeV) A(p,2p)(A-1) was used for many years for study of the nuclear structure - Glauber model based approximation works within 10%.



Most extensive studies at $p_N \geq 5.9$ GeV/c were performed by EVA collaboration at BNL.

Main issues to be addressed in CT studies

- ☛ At what Q^2 / t particular processes select point-like configurations - for example interplay of the feynman mechanism and LT contributions

- ☛ If the point-like configuration is formed - they are not frozen - - how long it will remain smaller than average configuration? They evolve with time - expand after interaction to average configurations and contract before interaction from average configurations (Frankfurt, Farrar, Liu, Strikman88)

Freezing: ***Main challenge:*** |qqq> (|q$\bar{q}$>) is not an eigenstate of the QCD Hamiltonian. So even if we find an elementary process in which interaction is dominated by small size configurations - they are not frozen. They evolve with time - expand after interaction to average configurations and contract before interaction from average configurations (FFLS88)

$$|\Psi_{PLC}(t)\rangle = \sum_{i=1}^{\infty} a_i \exp(iE_i t)\, |\Psi_i t)\rangle = \exp(iE_1 t) \sum_{i=1}^{\infty} a_i \exp\left(\frac{i(m_i^2 - m_1^2)t}{2P}\right) |\Psi_i t)\rangle$$

$$\sigma^{PLC}(z) = \left(\sigma_{hard} + \frac{z}{l_{coh}}\left[\sigma - \sigma_{hard}\right]\right)\theta(l_{coh} - z) + \sigma\theta(z - l_{coh})$$

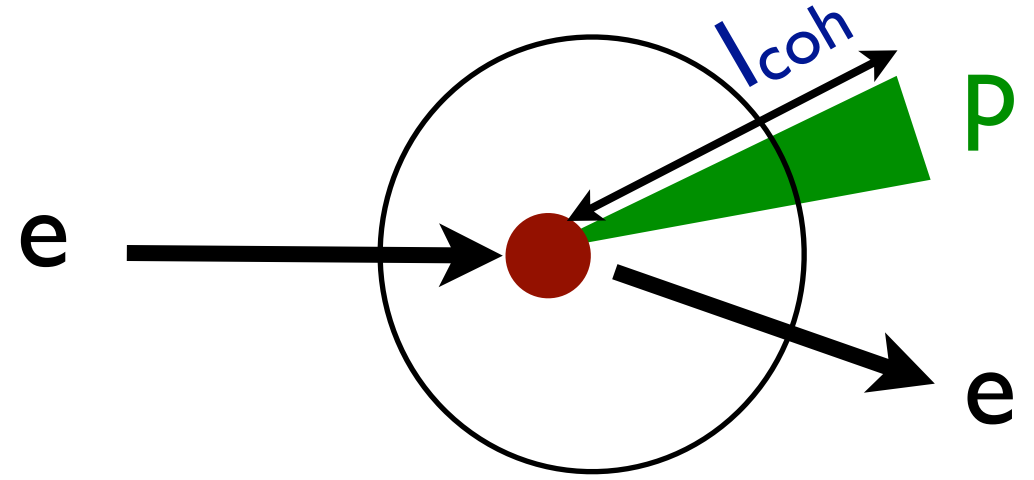
Quantum Diffusion model of expansion (FFLS88)

$$l_{coh} = \frac{2P_h}{\underbrace{m_{h*}^2 - m_h^2}_{0.6 \div 1.1\ \mathrm{GeV}^2}}$$

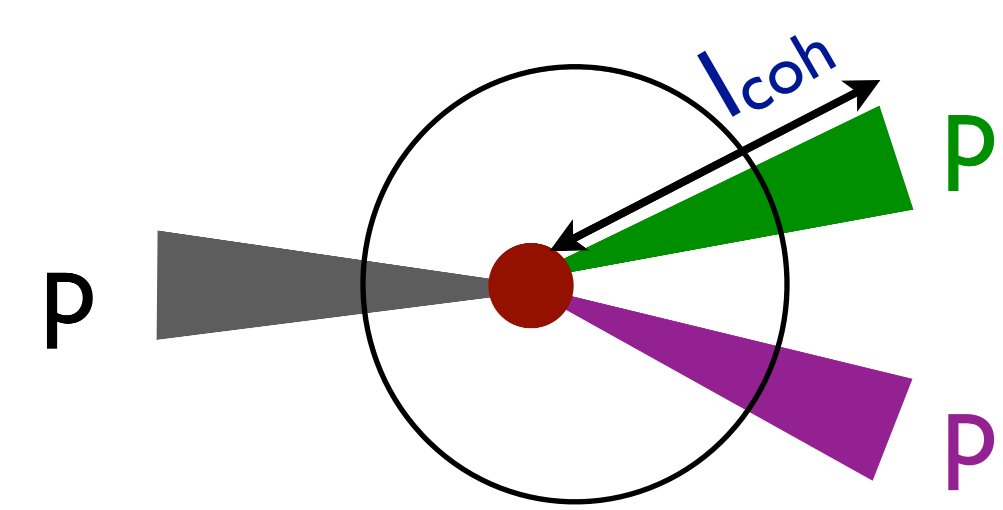
light hadrons

l_{coh}~ (0.5- 0.8) fm E_h[GeV]

actually incoherence length



eA→ ep (A-1) at large Q



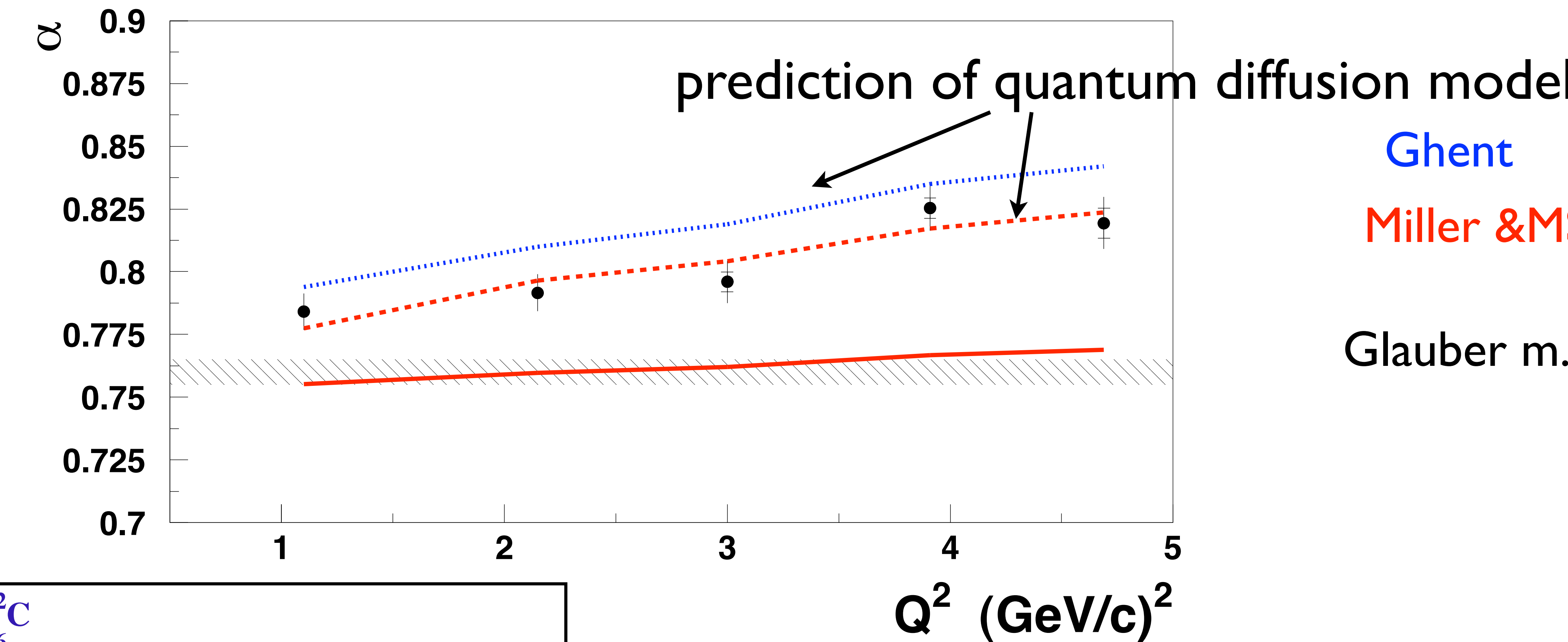
pA→ pp (A-1) at large t and intermediate energies

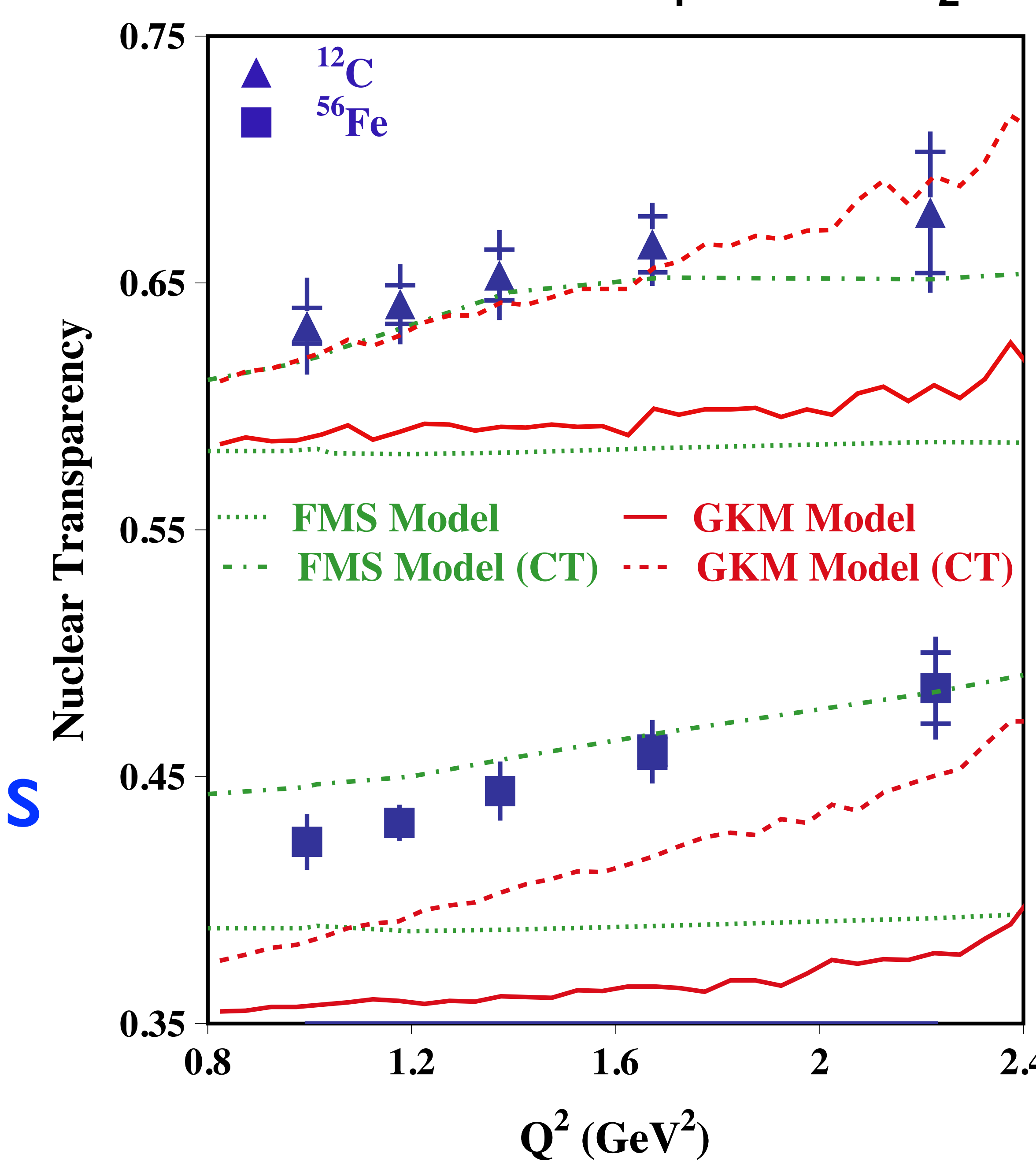
Experimental situation

- Energy dependence of transparency in (p,2p) is observed for energies corresponding to $l_{coh} \geq$ 2 fm. Such dependence is impossible without freezing. But not clear whether effect is CT or something else? Needs independent study.

- $\gamma^* + A \to \pi A^*$ evidence for increase of transparency with Q (Dutta et al 07)

A- dependence checks not only squeezing but **small** l_{coh} as well



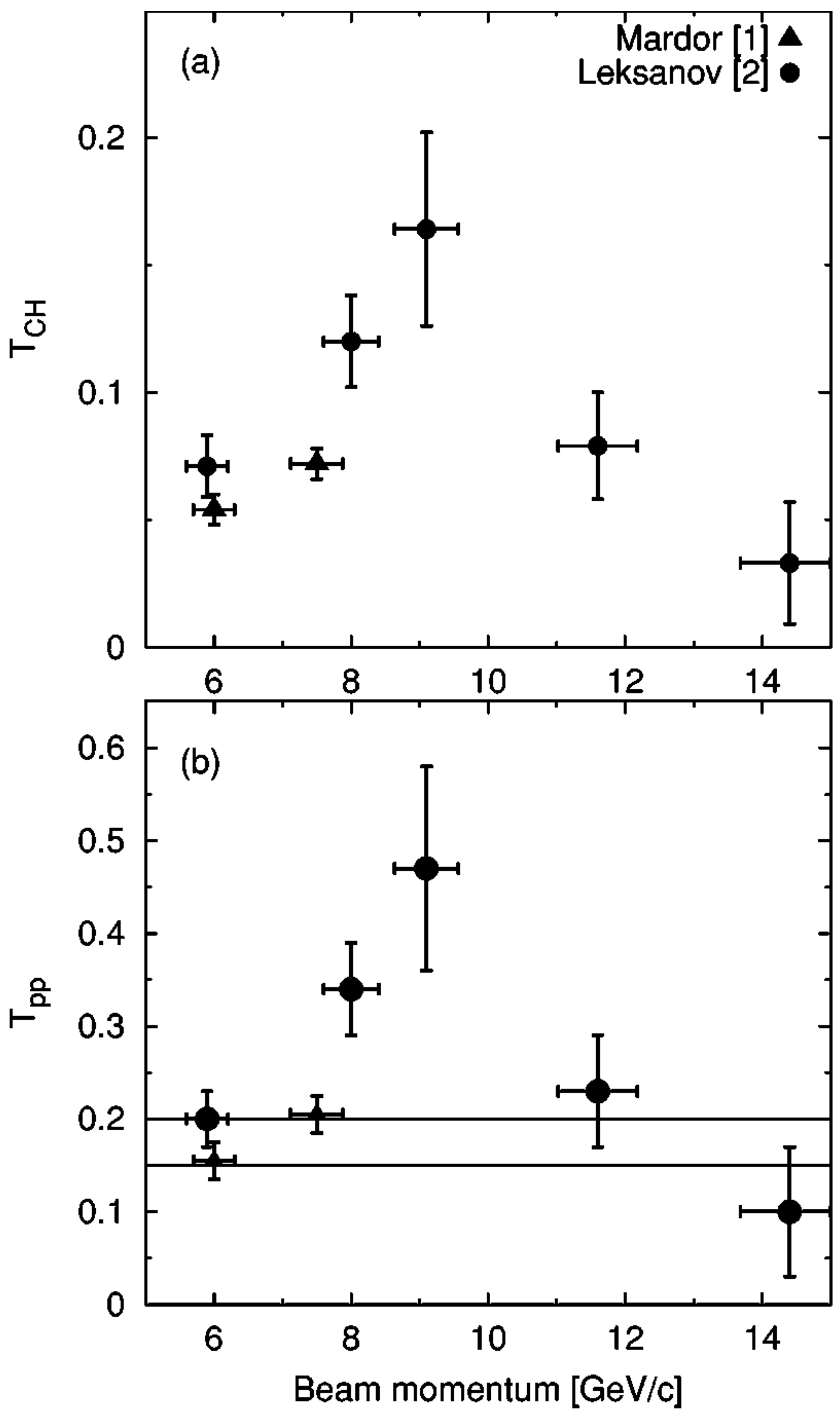


- ☺ $\gamma^* + A \to \rho A^*$ data are also consistent with our predictions

El Fassi et al , 2012

The Jlab π,ρ data seem to be consistent with CT predictions with coherence length $l_{coh} \sim 0.6\text{fm}\ p_h$ [GeV]

In spite of progress with studies of CT with virtual photons, investigation of CT for the hadronic projectile remains a challenge. Very limited data on $\pi + A \rightarrow \pi + p + (A-1)$, $p + A \rightarrow p + p + (A-1)$,... All comes from BNL EVA experiment. Mostly *p+A → pp (A-1)*



Nuclear transparency T_{CH} as a function of beam momentum (experiment used CH target)

Nuclear transparency T_{pp} as a function of beam momentum (defined so $T_{pp}=1$ - corresponds to the impulse approximation). Errors shown are statistical which dominate for these measurements

- Eikonal approximation with proper normalization of the wave function agrees well the 5.9 GeV data.
- Significant increase of T for p= 9 GeV where l_{coh}= 3.6 fm (assuming $l_{coh} = 0.6\, p_h$ as for pions) is sufficient to reduce expansion effects. Magnitude of the enhancement expected in CT models is consistent with the data.
- Glauber level transparency for 11.5 -14.2 GeV a problem for all models as it is observed in a wide energy range $24\ \mathrm{GeV}^2 \leq s' \leq 30\ \mathrm{GeV}^2$.
  Challenge for QCD theory !!!

Critical to perform new studies of CT phenomenon in hadronic reactions at energies above 10 GeV where expansion effects are moderate to determine interplay between pQCD and nonpert. QCD for 2 → 2 reactions. WIll complement the program of CT in eA scattering at Jlab at 12 GeV.

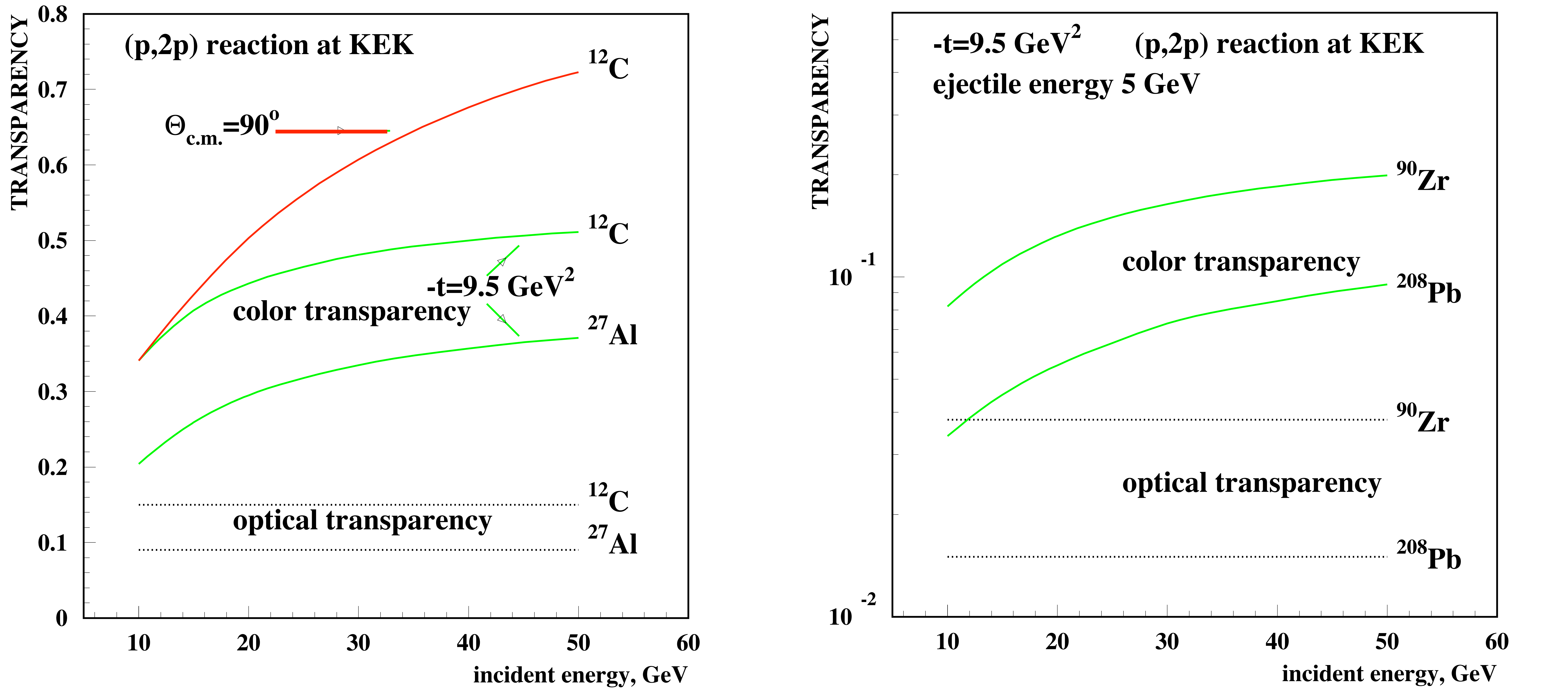
J-PARC & GSI(PANDA)

Advantages as compared to EVA - progress in electronics leading to a possibility to work at higher luminosity, wider range of hadron beams including antiprotons at GSI. (I am listing below the simplest channels - no time to talk about chiral transparency, Δ production,...)

☛ (p,2p) at the range of 10-20 GeV for all angles including those close to $\theta_{c.m.} \sim 90^0$

☛ (π,pπ) for E_π= 6 --14 GeV. Benefit - knowledge of pion expansion rates from 6 GeV and future 12 GeV Jlab experiments

☛ E_p>20 GeV (p,2p) rates for $\theta_{c.m.} \sim 90^0$ are probably too low. Different strategy - T (E_p) for large but fixed t. In this case l_{coh} for initial and the fastest of two final nucleons is very large. Only the slow nucleon has time to expand leading to transparency very similar to the one in A(e,e'p). (Zhalov &MS 89)



Energy dependence of the nuclear transparency calculated in the quantum diffusion model with l_{coh} = 0.4 fm p_N[GeV] ~ as compared to the expectations of the Glauber model.

Nearly free lunch - possibility of detailed studies of the short-range correlations (SRC) in nuclei with the same experimental setup (FFLS89) (the same detector as for CT but with backward neutron detector). First I need to summarize recent developments in the field of strudies of SRCs.

*Driving idea -- Use **hard =multiGeV momentum transfer** nuclear phenomena to answer fundamental questions of microscopic quark-gluon structure of nuclei and nuclear forces*

- Are nucleons good nuclear quasiparticles?
- Microscopic origin of intermediate and short-range nuclear forces
- Probability and structure of the short-range correlations in nuclei
- What are the most important non-nucleonic degrees of freedom in nuclei?

Best chance to find new physics is to focus on the studies of configuration in nuclei where nucleons nucleons are close together and have large momenta - short-range correlations (SRC)

Popular perceptions about SRC:

- SRC is elusive feature of nuclei - cannot be observed

✔ Wrong - problem was due to use of low energy probes

- SRC small correction to any characteristic of nuclei - exotic feature - of no importance

✔ Wrong - >70% of kinetic energy of nucleons for $A \geq 50$ is due to SRC, strong influence on the nucleus excitation spectrum (more examples in the end of the talk)

- Can predict properties of the core of neutron stars based on studies of nuclei using mean field

✔ Wrong - Very different strength of pp and pn SRC, practical disappearance of the Fermi step for protons for ρ(neutron star) $>\rho$ (nuclear matter)

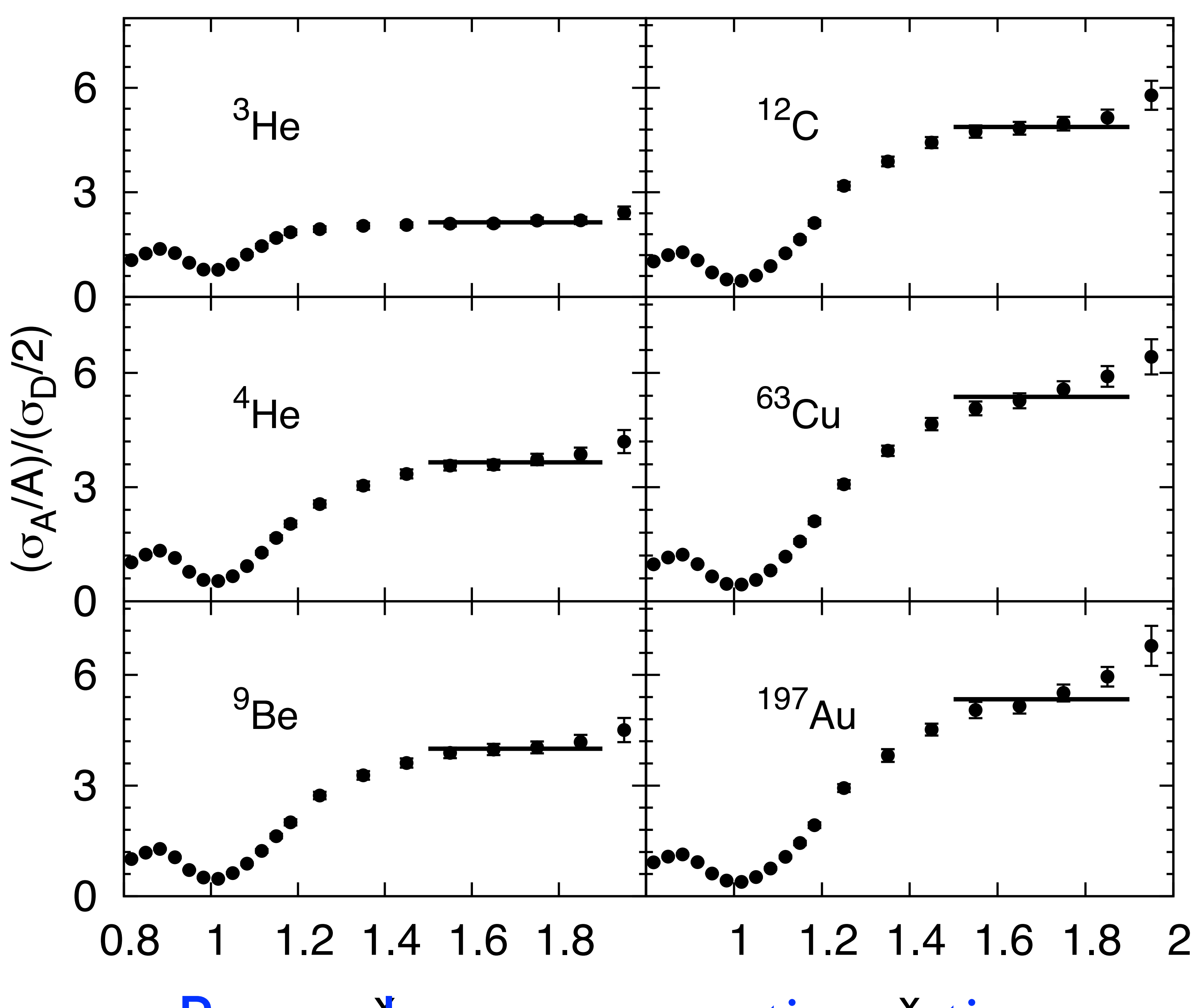
Progress in the study of SRCs of the last 5 years is due to analysis of two classes of hard processes we suggested in the 80's: inclusive scattering in the kinematics forbidden for scattering off free nucleon & nucleus decay after removal of fast nucleus.

One group of processes which led to the progress in the studies of SRC at high momentum is A(e,e') at x> 1, Q^2 > 1.5 GeV^2

Closure approximation for A(e,e') at $x=AQ^2/2q_0m_A > 1, Q^2 > 1.5$ GeV^2 up to final state interaction (fsi) between constituents of the SRC

Singular short-range NN interaction→ universality of SRC → *Prediction of the scaling of the ratios of A(e,e') at x> 1, Q^2 > 1.5 GeV^2*

Frankfurt & MS 81



Per nucleon cross section ratio at Q^2=2.7 GeV^2 - E2-019-2011

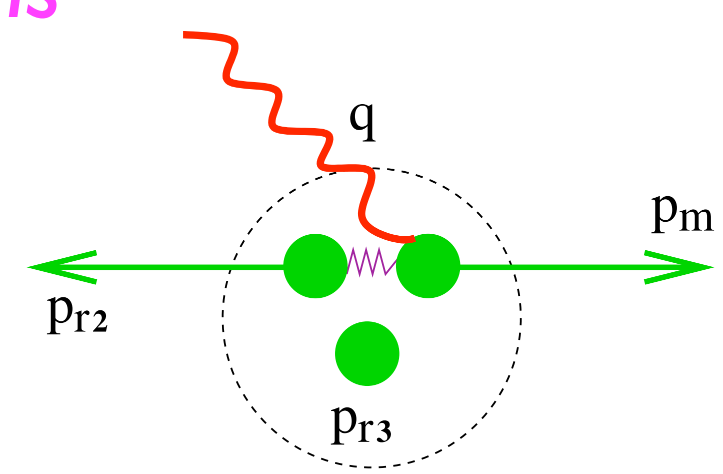
Very good agreement between SLAC and two Jlab (e,e') analyses of the A/D ratios

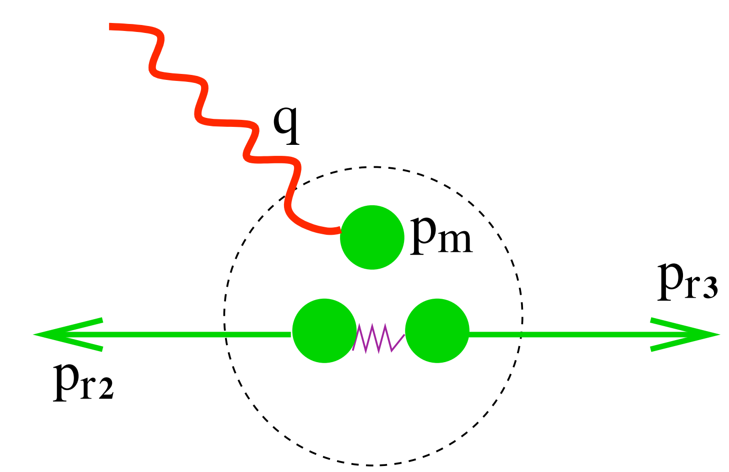
The second group of processes (both lepton and hadron induced) which led to the progress in the studies of SRC is investigation of the decay of SRC after one of its nucleons is removed via large energy- momentum transfer process.

Idea: typical 2 nucleon NN SRC = two nearby nucleons with momenta k and -k (k> 300 MeV/c)

Instantaneous removal of nucleon belongs to SRCs leads to emission of second nucleon which balances its momentum:

Spectator is released



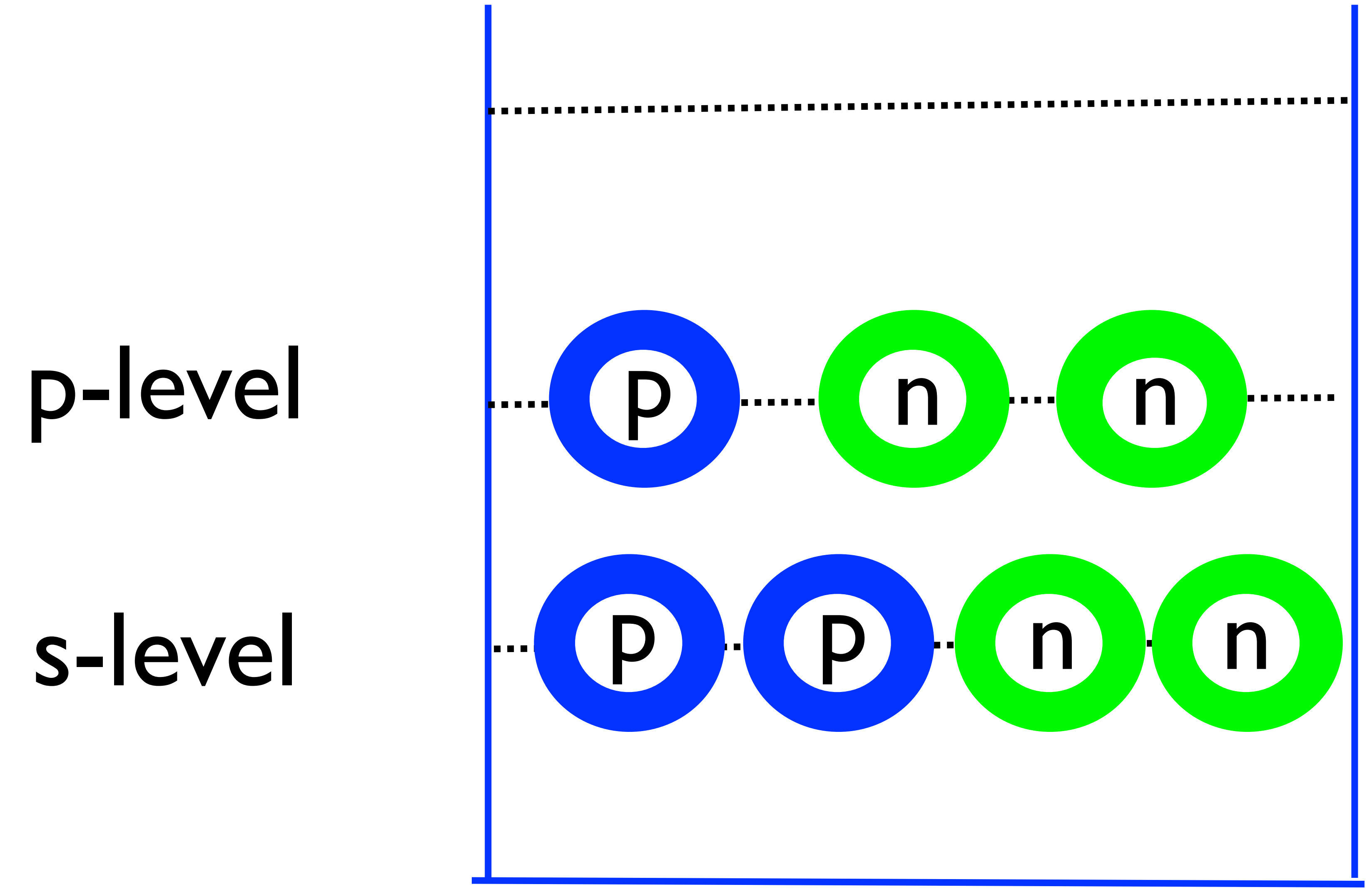


Emission of fast nucleons "2" and "3" is <u>strongly suppressed due to FSI</u>

resembles 2N momentum distribution

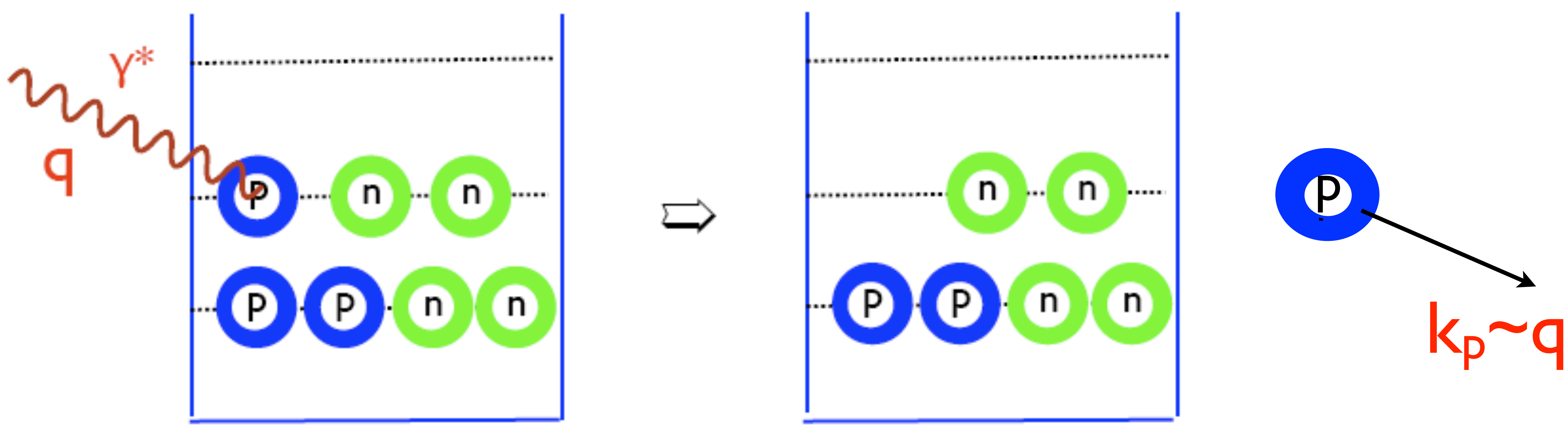
does not resemble 2N momentum distribution -

The prediction of back - to - back correlation differs from the expectations based on the textbook picture of nuclei:



Nucleons occupy the lowest levels given by the shell model

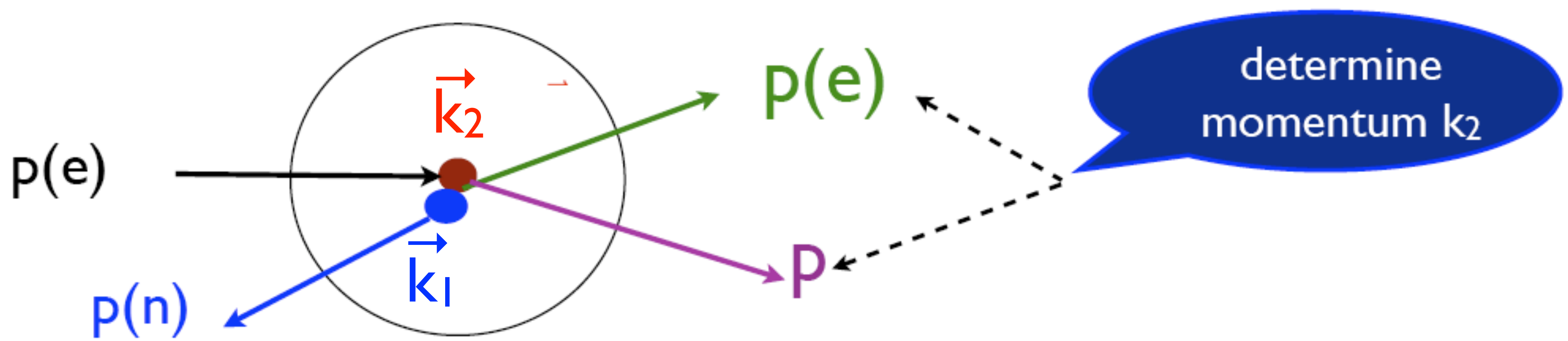
What happens if a nucleon is removed from the nucleus?



removal of a nucleon

residual nucleus in ground or excited state of the shell model Hamiltonian - decay product practically do not remember direction of momentum of struck proton

To observe SRC directly it is far better to consider semi-exclusive processes
e(p) +A → e(p) + p + " nucleon from decay" +(A-2) since it measures
both momentum of struck nucleon and decay of the nucleus

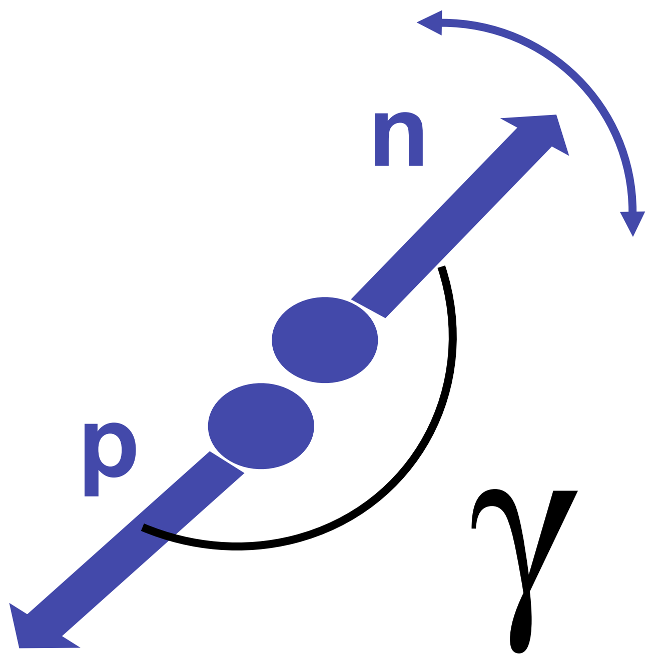


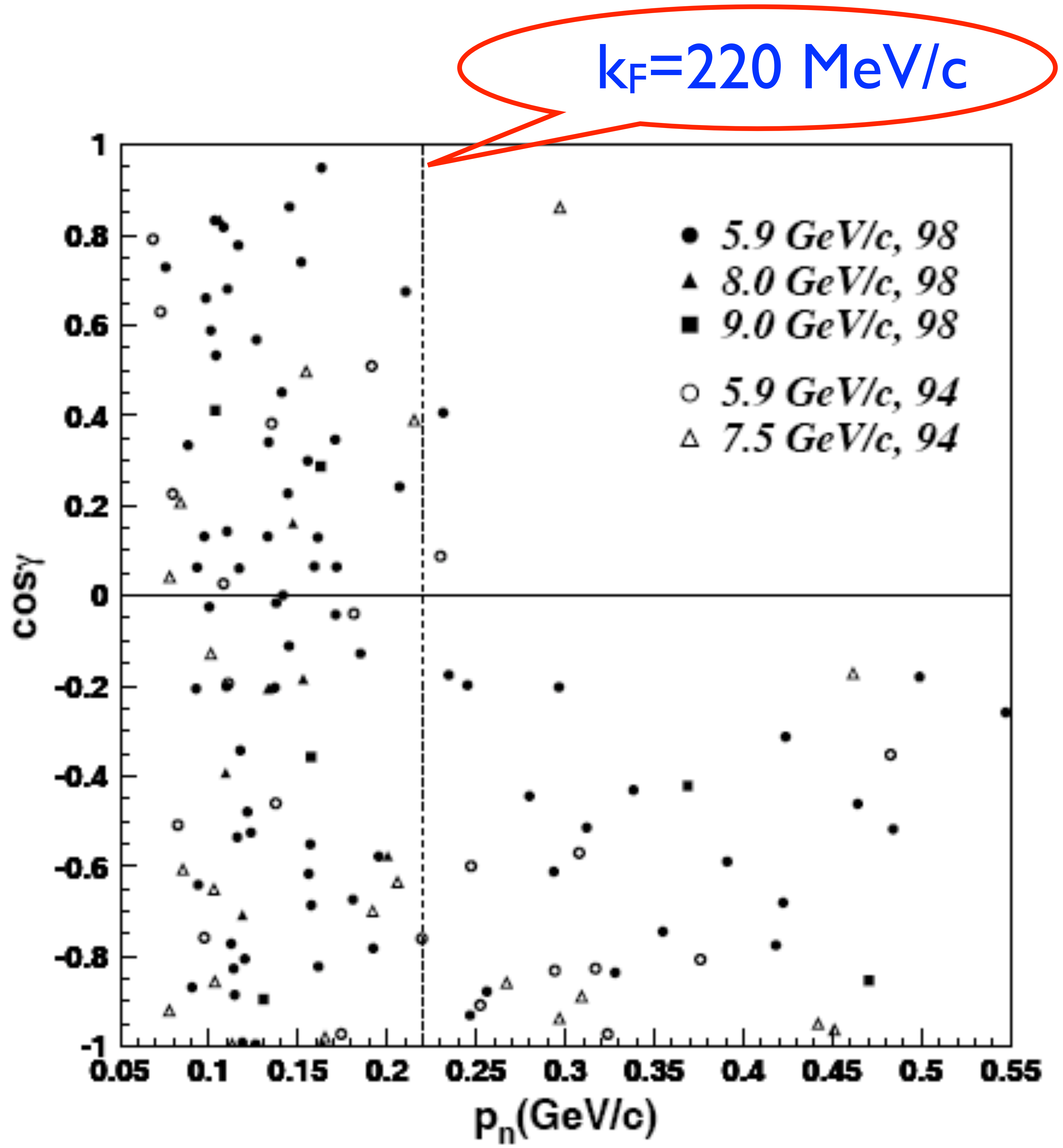
Two novel experiments reported results in the last 5 years:

- *EVA BNL 5.9 GeV protons (p,2p)n* $-t = 5\ \mathrm{GeV}^2;\ t=(p_{in}-p_{fin})^2$

Based on our proposal of 88-89 (strong enhancement of scattering off fast forward nucleons due to s^{-10} dependence of the elementary cross section)

- *(e,e' pp), (e,e'pn) Jlab* $Q^2 = 2\mathrm{GeV}^2$

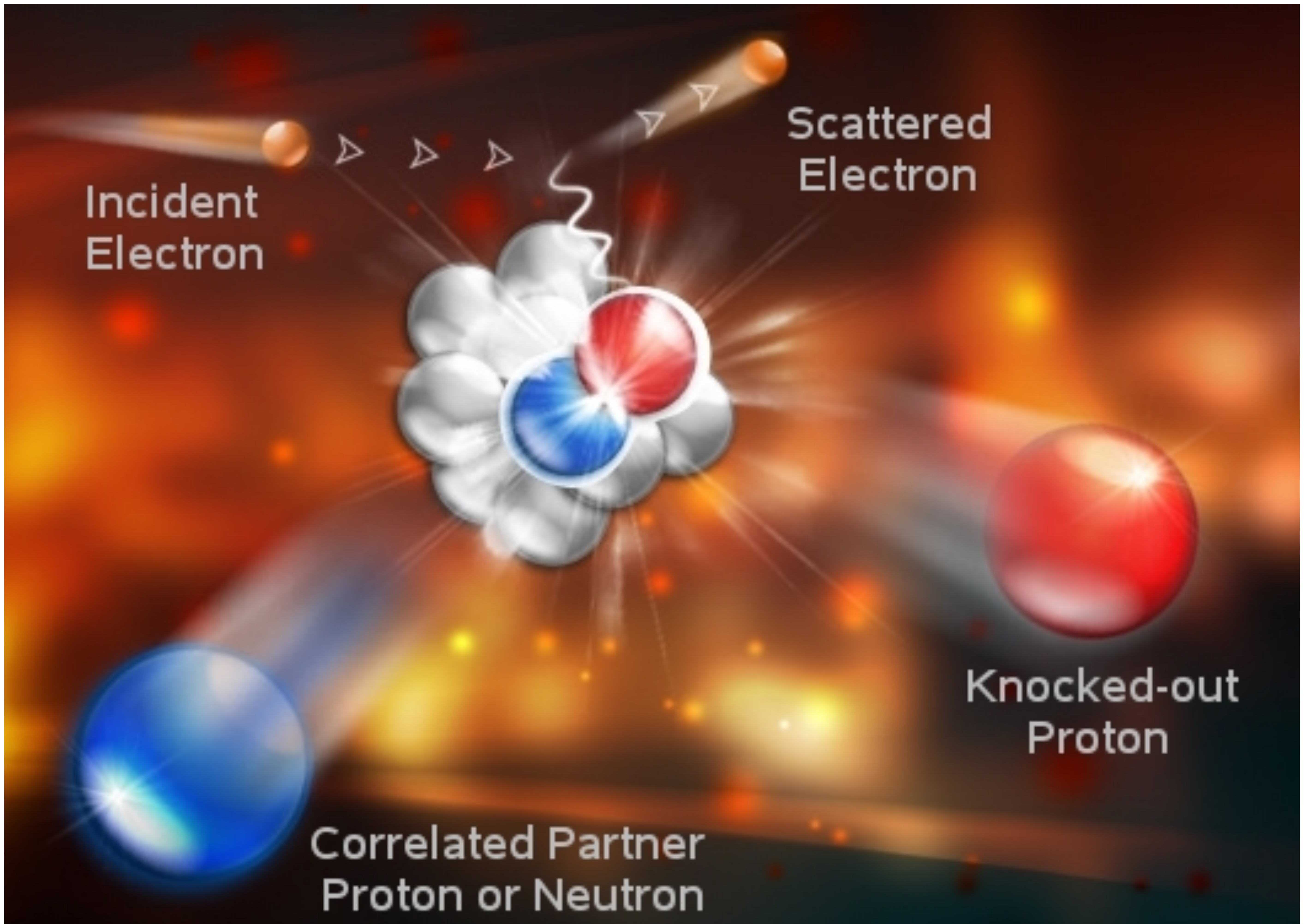




BNL Carbon data of 94-98. The correlation between p_n and its direction γ relative to p_i. The momenta on the labels are the beam momenta. The dotted vertical line corresponds to k_F=220 MeV/c.

SRC appear to dominate at momenta k> 250 MeV/c - very close to k_F. *A bit of surprise* - we expected dominance for k> 300 - 350 MeV/c. Naive inspection of the realistic model predictions for $n_A(k)$ clearly shows dominance only for k > 350 MeV/c. Important to check a.s.p. - Data mining collboration + new Jlab experiment with ^{4}He.

Jlab: from study of (e,e'pp), (e,e'pn)~10% probability of proton emission, strong enhancement of pn vs pp. The rate of pn coincidences is similar to the one inferred from the BNL data providing highly nontrivial test of the dynamic mechanism.



T-shirt of Jlab 09

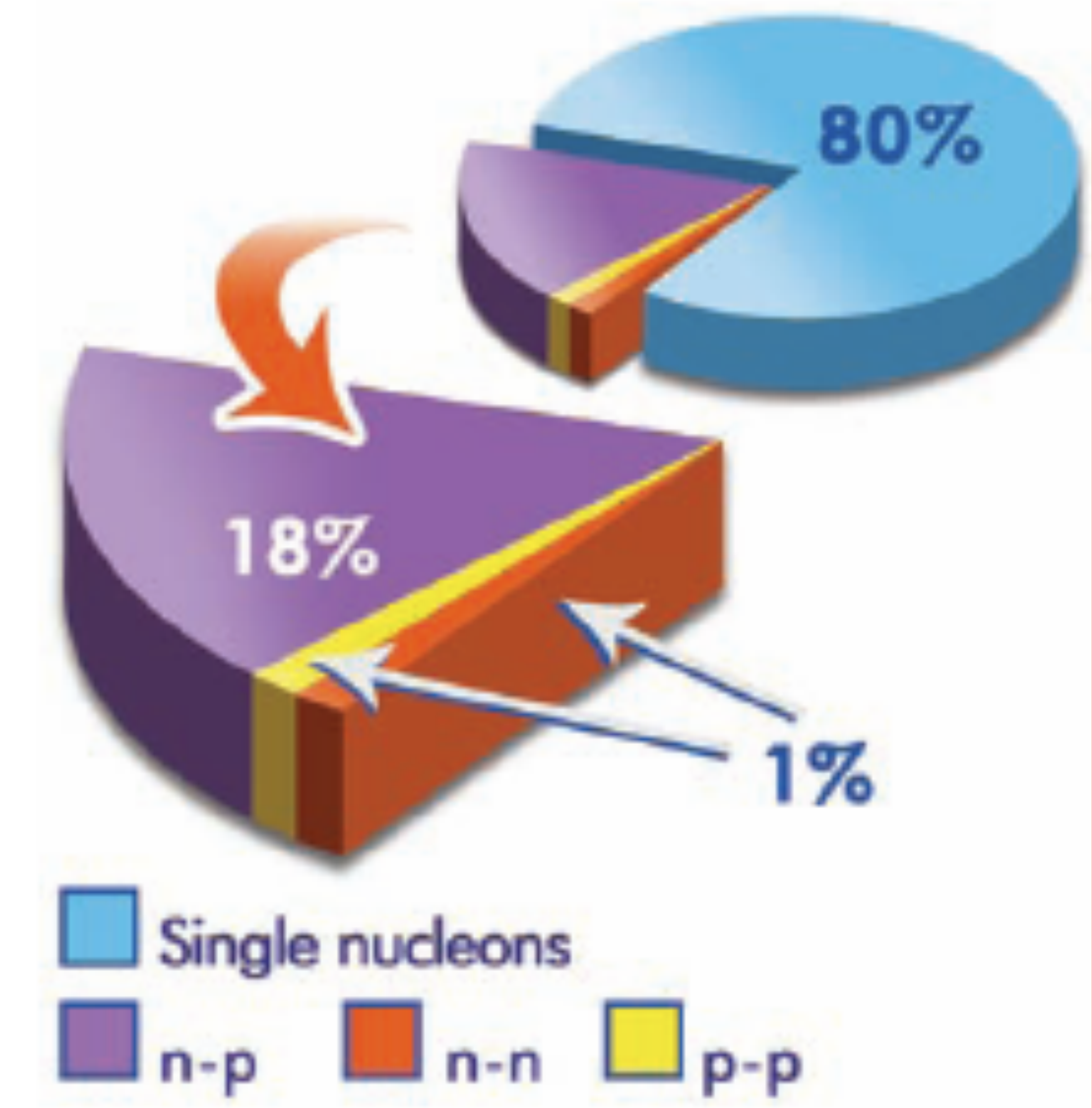
Due to the findings of the last 5 years at Jlab and BNL SRC are not anymore an elusive property of nuclei !!

Summary of the findings

- Practically all nucleons with momenta k≥300 MeV belong to two nucleon SRC correlations BNL + Jlab +SLAC

- Probability for a given proton with momenta 600> k > 300 MeV/c to belong to pn correlation is ~ 18 times larger than for pp correlation BNL + Jlab

- Probability for a nucleon to have momentum > 300 MeV/c in medium nuclei is ~25% BNL + Jlab 04 +SLAC 93



The average fraction of nucleons in the various initial-state configurations of ^{12}C.

- Three nucleon SRC are present in nuclei with a significant probability Jlab 05

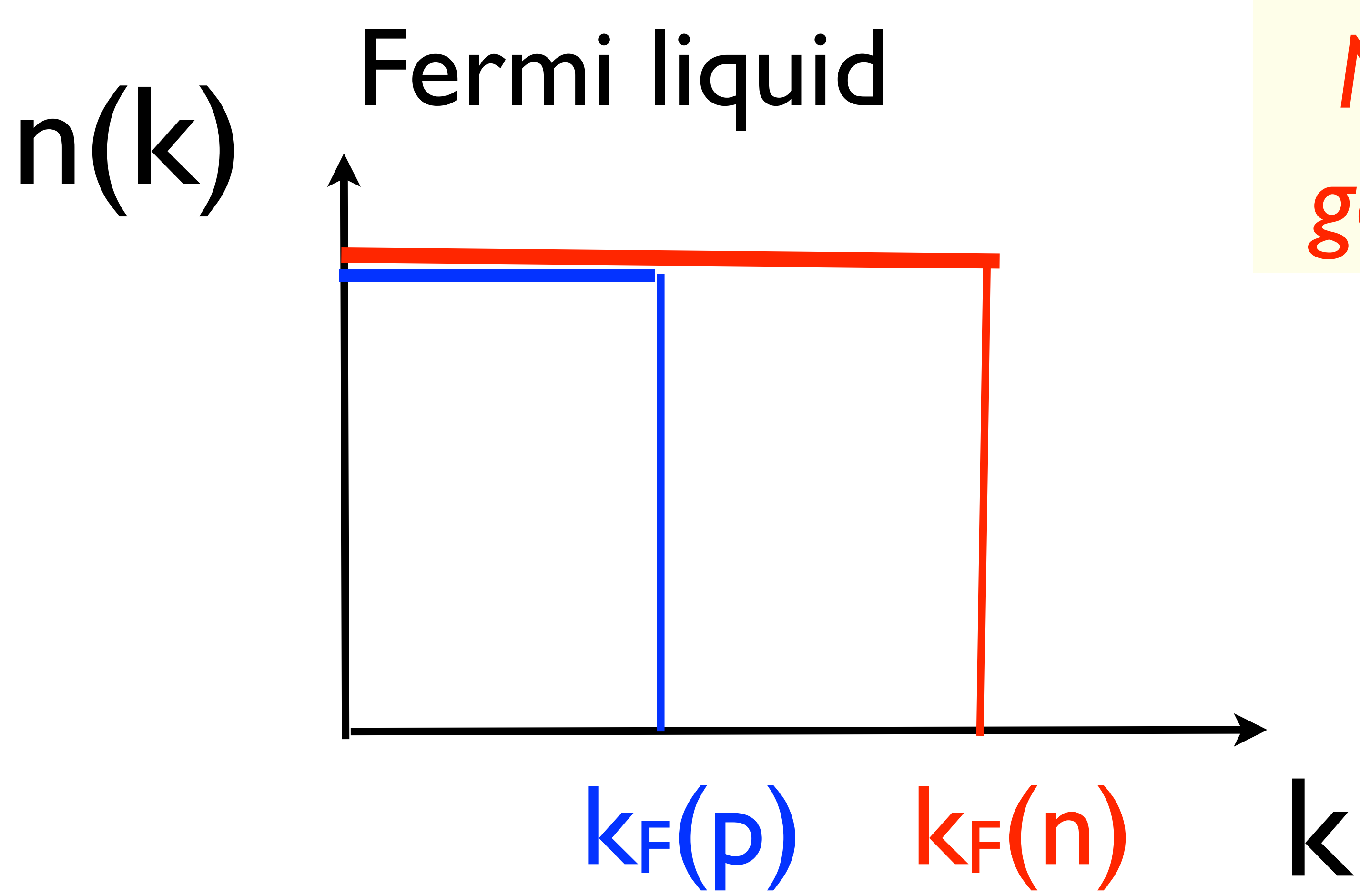
The findings confirm our predictions based on the study of the structure of SRC in nuclei (77-93), add new information about isotopic structure of SRC.

Confirm also small probability of nonnucleonic degrees of freedom even in SRCs

matches well discovery of a neutron star of mass = two Solar masses

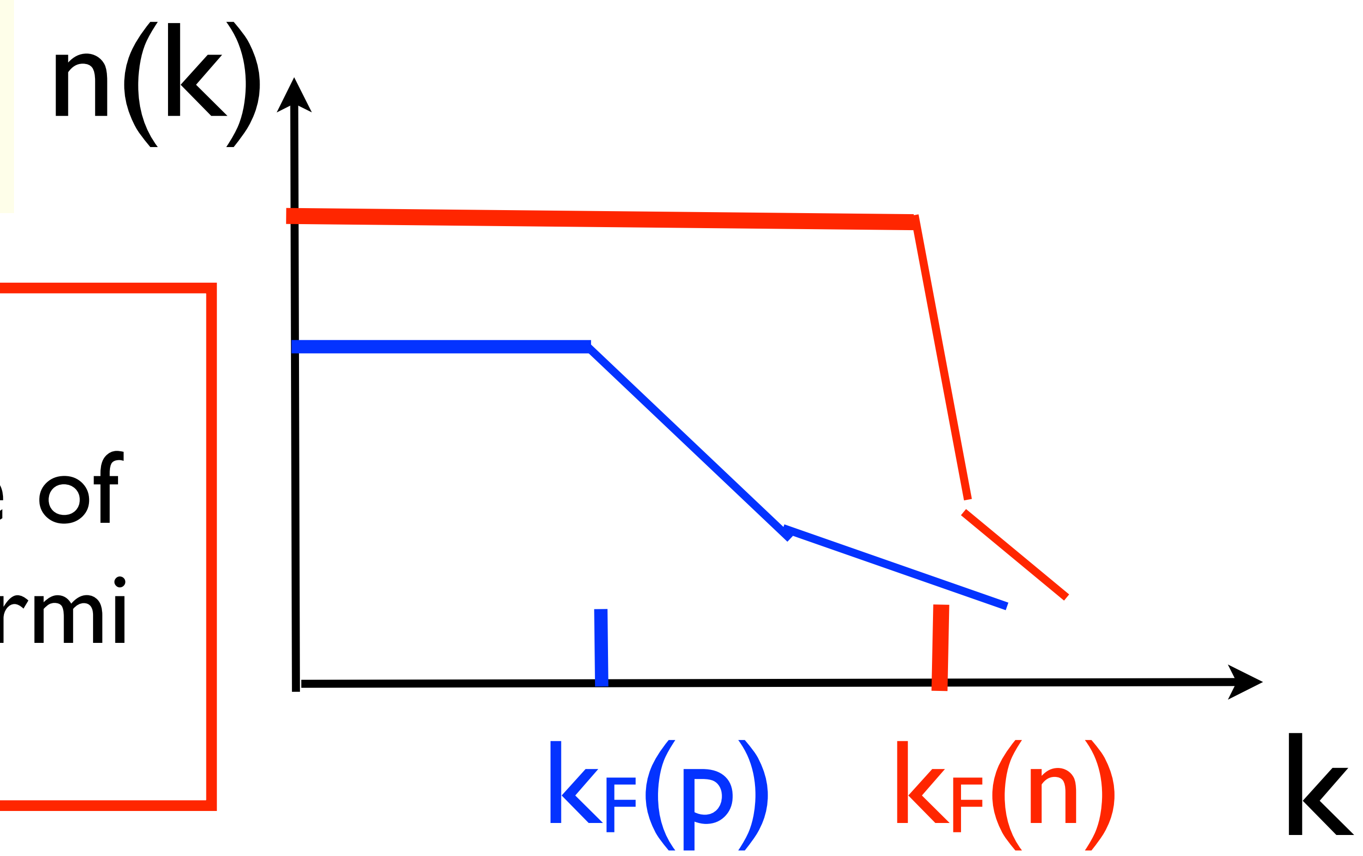
Some implications for neutron stars

- Our focus is on the outer core where nucleon density is close to nuclear one: $\rho \sim (2 \div 3)\ \rho_0$; $\rho_0 \approx 0.16$ nucleon/fm^3 and p/n ~ 1/10



Neutron gas heats proton gas due to large pn SRC

⇒ practical disappearance of the proton Fermi surface



Large enhancement of neutrino cooling of the neutron stars at finite temperatures FS08

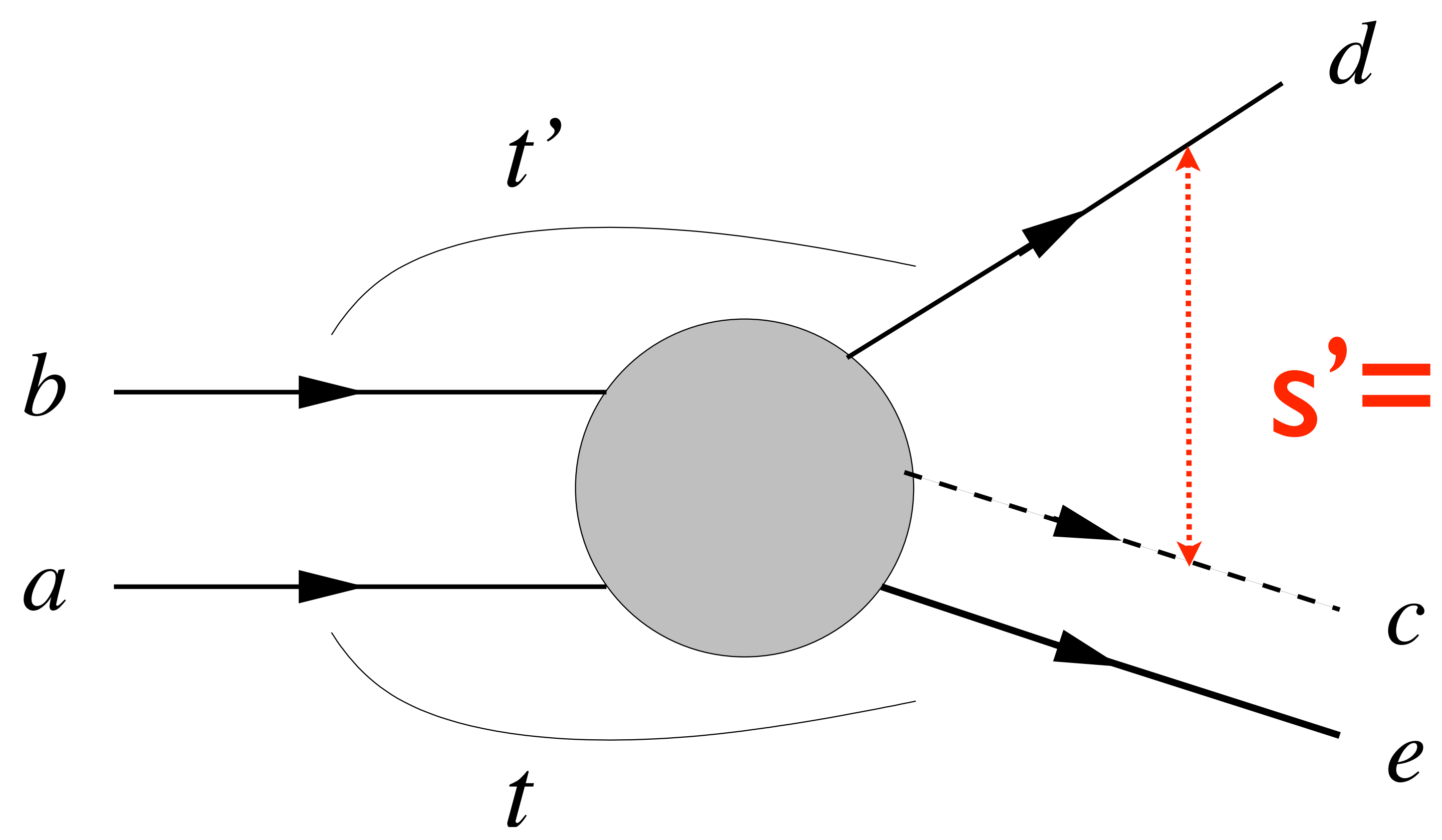
Suppression of the proton Fermi surface leads to the suppression of proton superconductivity, etc

Future studies of SRC with proton beams (E_p~8 GeV is probably optimal for most of the tasks). Advantages as compared to Jlab: (i) much larger t, (2) better kinematics (backward spectators).

- ☻ Detailed mapping of pn and pp correlations using light nuclei
- ☻ Look for effects of SRCs including 3N correlations - comparison on pn, pp channels,...
- ☻ non-nucleonic degrees of freedom - discover Δ's?.

Briefly about two other interesting directions of studies

New type of hard hadronic processes - *branching exclusive processes* of large c.m.angle scattering on a "cluster" in a target/projectile (MS94)



$s' = (p_d + p_c)^2$

Limit:

-t' > few GeV^2, -t'/ s' ~1/2

-t=const ~ 0

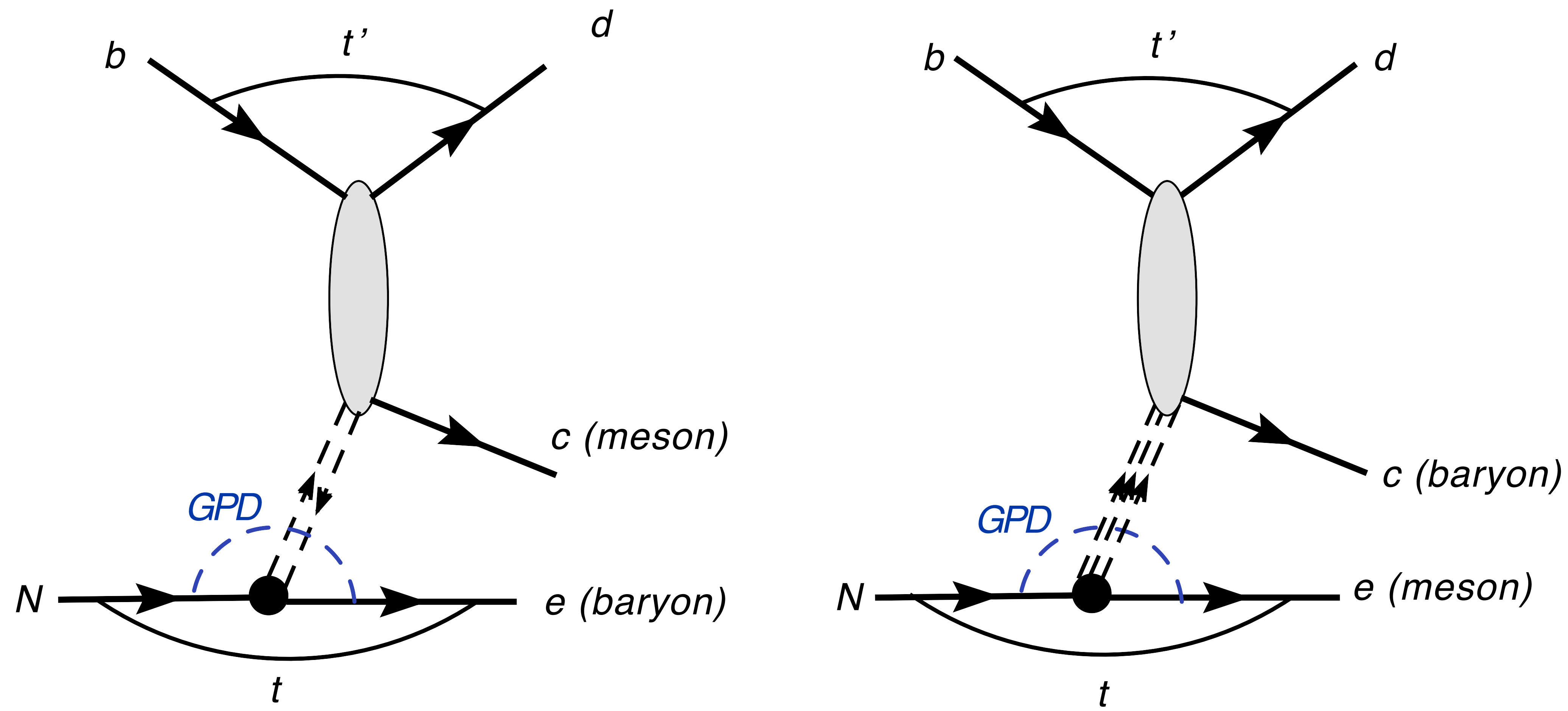
➠ s'/s<<1

Two recent papers: Kumano, MS, and Sudoh PRD 09; Kumano &MS Phys.Lett. 10

2 →3 branching processes:

- test onset of CT for 2 →2 avoiding freezing effects
- measure transverse sizes of b, d,c
- measure cross sections of large angle pion - pion (kaon) scattering
- probe 5q in nucleon and 3q+\bar q in mesons
- measure generalized parton distributions GPDs of nucleons, mesons and photons(!)

Factorization:

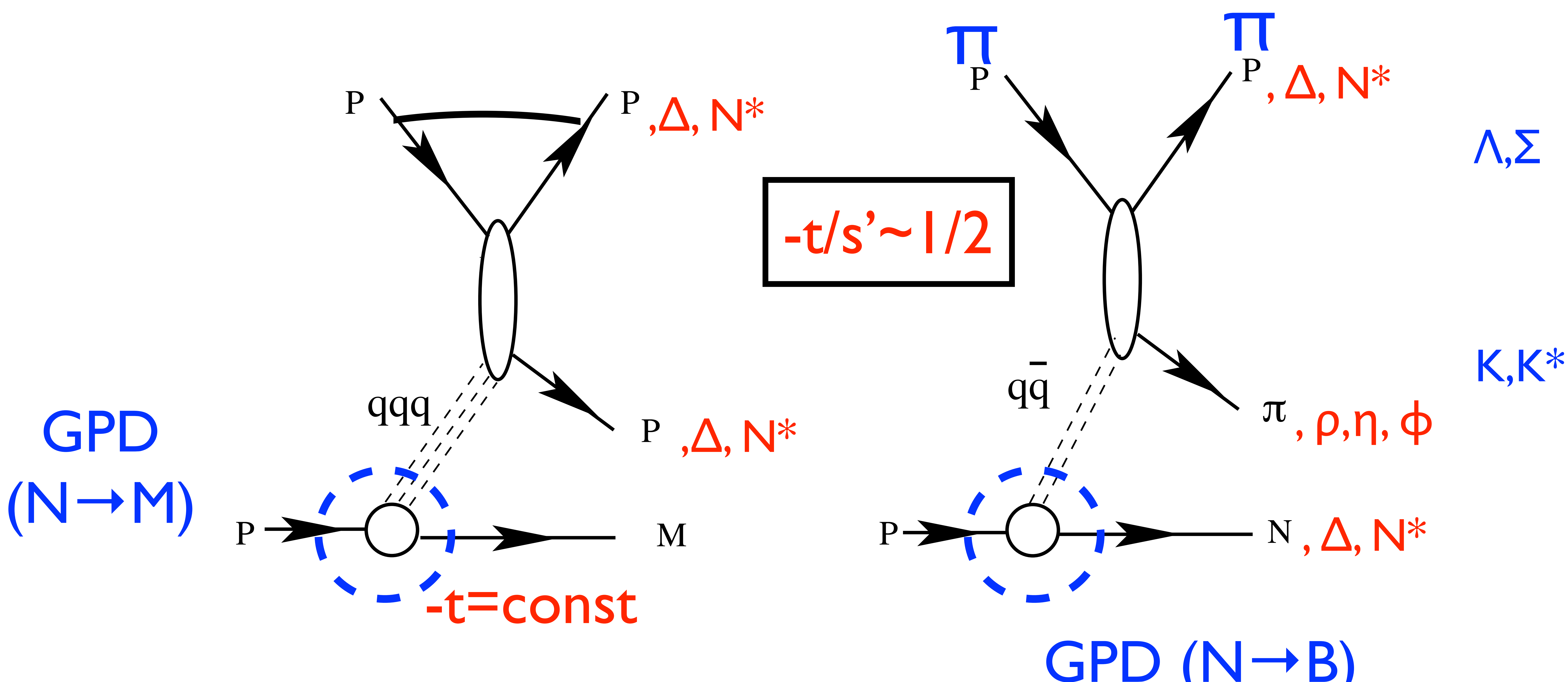


If the upper block is a hard (2 →2) process, "b", "d", "c" are in small size configurations as well as exchange system ($q\bar{q}$, qqq). Can use CT argument as in the proof of QCD factorization of meson exclusive production in DIS (Collins, LF, MS 97)

$$\Downarrow$$

$$\mathcal{M}_{NN\to N\pi B} = GPD(N \to B) \otimes \psi_b^i \otimes H \otimes \psi_d \otimes \psi_c$$

Many interesting channels, for example



Large mass dilepton production with pion beams

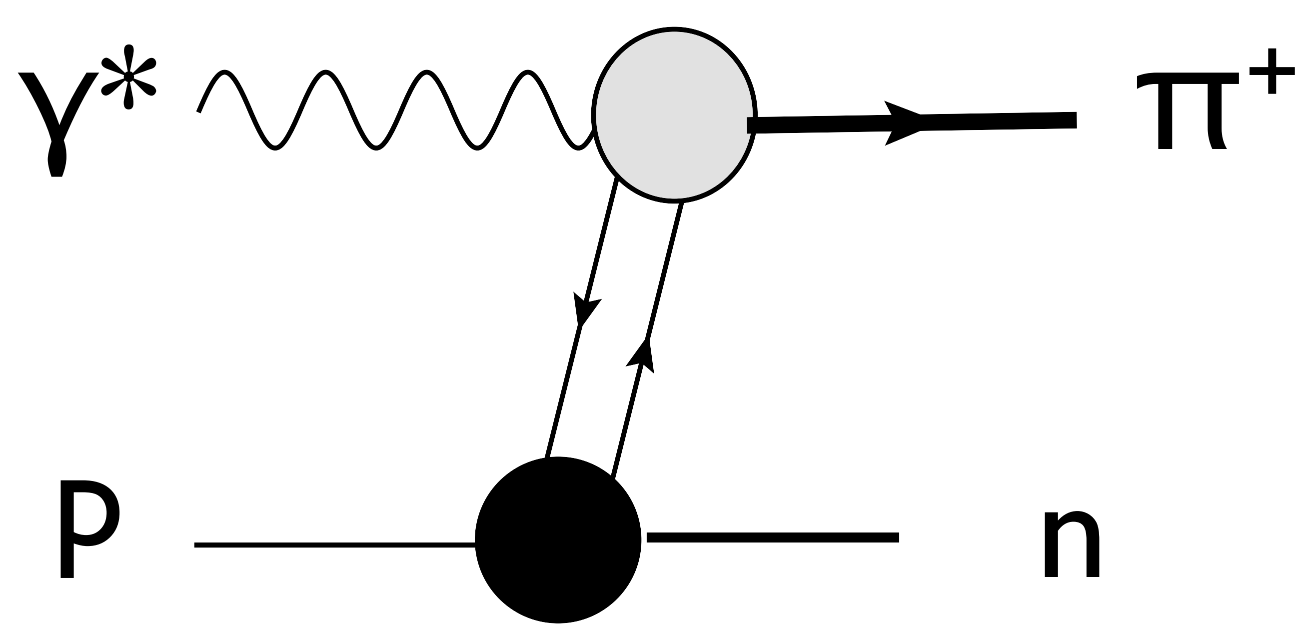
* $$\frac{d\sigma(\pi^+ C \to l\bar{l} + X)}{dx_F dM^2_{l\bar{l}}} - \frac{d\sigma(\pi^- C \to l\bar{l} + X)}{dx_F dM^2_{l\bar{l}}}$$

strong interaction contribution cancels out (SU(2))

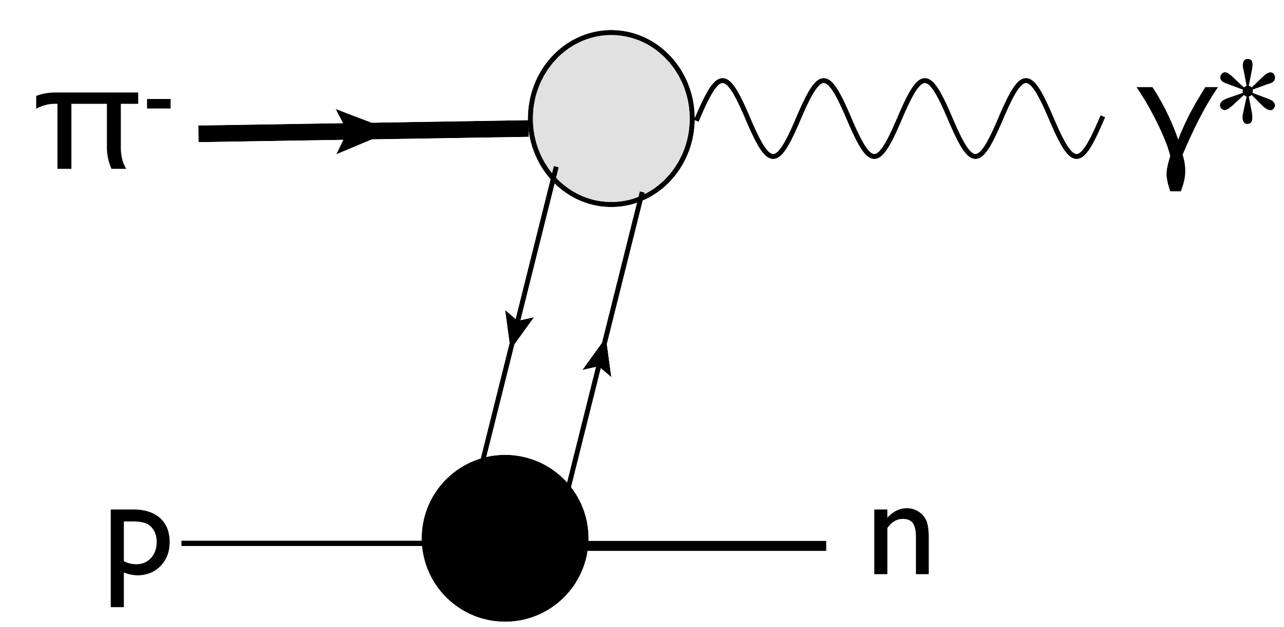
Objectives Measure virtual photon production over broad range of masses - determine onset of the Drell-Yan mechanism, study pion pdf at large x.

* $$\frac{d\sigma(\pi^- p \to l\bar{l} + n)}{dt dM^2_{l\bar{l}}}$$ study of the generalized parton dsitributions in nucleon

$M^2(\gamma^*) < 0$



Jlab



$M^2(\gamma^*) > 0$

J-PARC

Summary

Study of the discussed processes which is feasible at J-PARC would allow

- to discover pattern of interplay of hard and soft physics in one of the most fundamental hadronic processes of large angle $2 \to 2$ scattering
- compare wave function of different mesons and baryons
- map the space-time evolution of small wave packets at distances $1 < z < 6$ fm
- test the role of chiral degrees of freedom in hard interactions
- Structure of SRC in nuclei: pn vs pp

  NNN

  NΔ

  ....