Fixed target physics at CERN SPS

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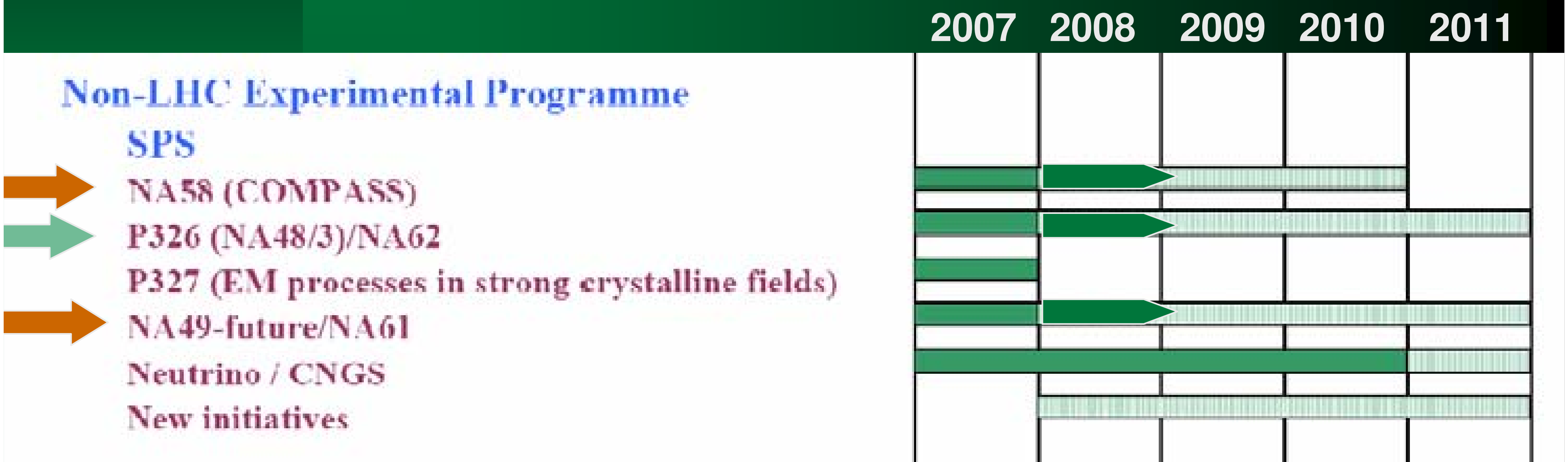
- Why fixed targets
- Compass and spin structure of the nucleon
- SHINE – cross sections and energy scan with heavy ions
- Rare K decays – search for New Physics
- Future: GPD and DVCS measurements

Why fixed target ?

- Study of the structure of composed object by scattering on it elementary projectiles:
  - Rutherford like experiment
  - charged leptons and neutrinos as projectiles
- Requirements on target
  - polarization
  - matherial
- Study of decays (particle production)

Present and near future experiments on SPS

What is the CERN - SPS fixed target program ?

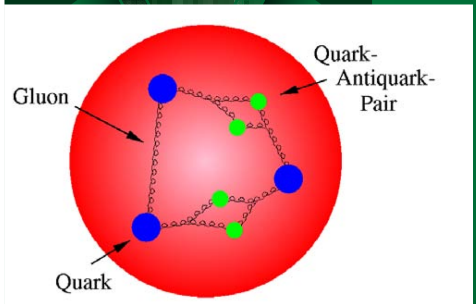


from CERN Council 142'th session in 21'st June 2007

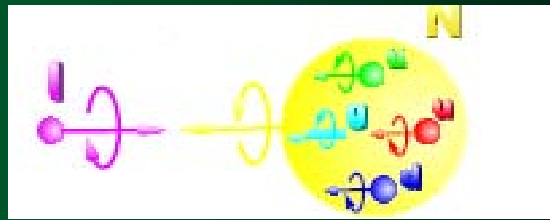
Experiments with strong polish participation

Experiment without polish participation

Resolution of the „DIS microscope"

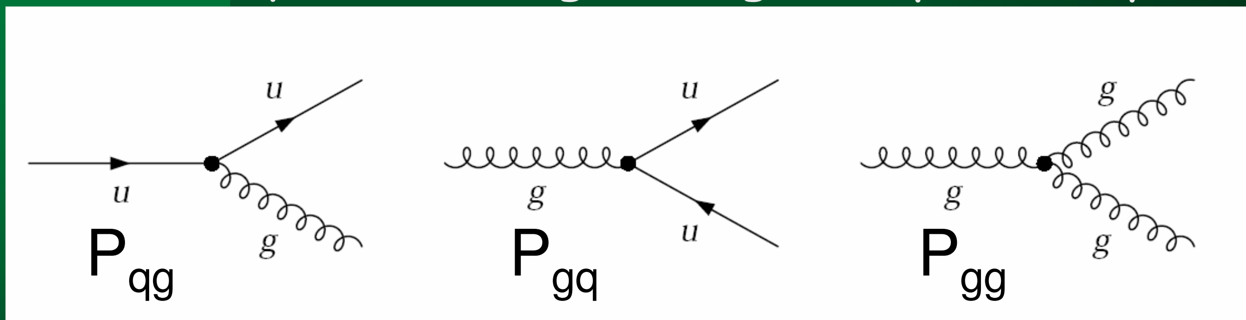


This is what we know:
quarks
pairs quark-antiquark
gluons



$$R \sim \frac{1}{\sqrt{Q^2}}$$

Deeper we look inside → more quark-antiquark pairs we see ...
Mechanism: quarks emit gluons, gluons produce pairs ...



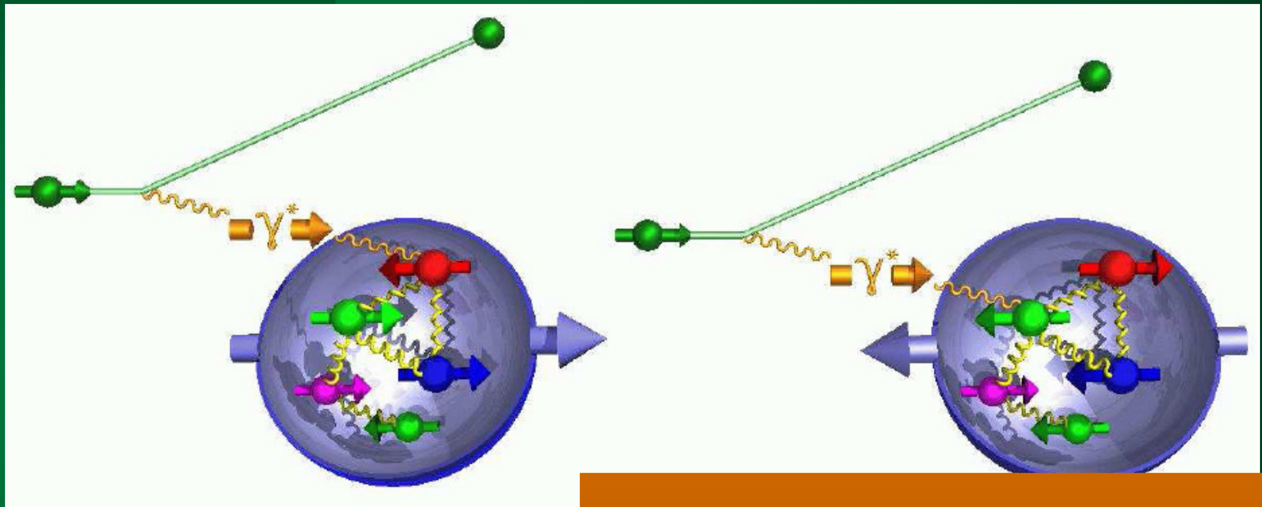
$$\mathcal{P}_{qq/qg} \sim \log \frac{Q^2}{\mu^2}$$

emision probability depends on Q^2,
splitting functions, Pij, describe how the momentum is divided

$$\mu \frac{d}{d\mu} \begin{pmatrix} \Delta q(x,\mu) \\ \Delta g(x,\mu) \end{pmatrix} = \int_x^1 \frac{dz}{z} \begin{pmatrix} \Delta\mathcal{P}_{qq} & \Delta\mathcal{P}_{qg} \\ \Delta\mathcal{P}_{gq} & \Delta\mathcal{P}_{gg} \end{pmatrix}_{(z,\alpha_S(\mu))} \cdot \begin{pmatrix} \Delta q \\ \Delta g \end{pmatrix} \left(\frac{x}{z}, \mu\right)$$

Scale μ
Replaced by Q^2

Determination of quark polarization inside nucleon



Photon spin = 1
Quark spin = 1/2 } photon can be absorbed only by quark of opposite polarization

$$\Delta\Sigma\left(\overline{\mathrm{MS}}\right) = 0.33 \pm 0.03(\mathrm{stat}) \pm 0.05(\mathrm{syst})$$

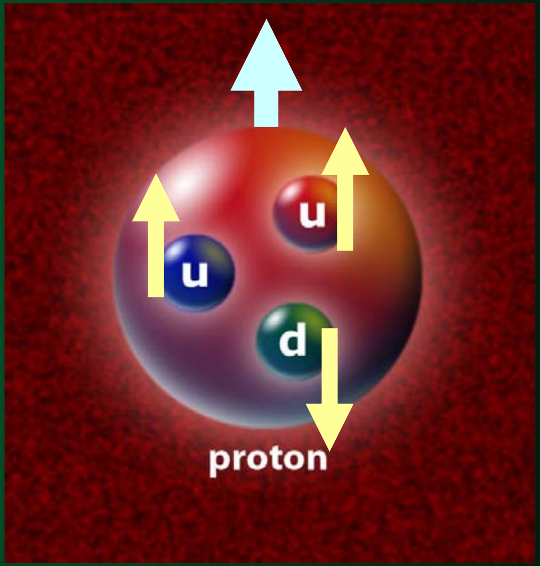
From naive expectation it should be +1, after relativistic correction about 0.66
So half is missing !!!

Spin goals

How is the proton built from its known quark and gluon constituents?

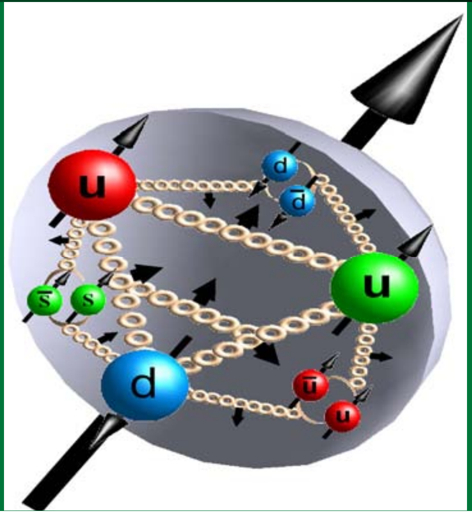
As with atomic and nuclear structure, this is an evolving understanding

Recall:
simple quark model

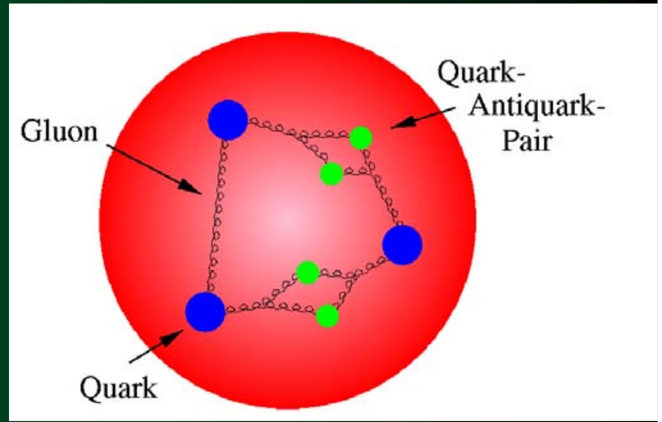


In QCD: proton is not just 3 quarks !

Rich structure of quarks anti-quarks, gluons



„spin crisis"



$$S_N = \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

Orbital angular momentum:

- contribution from quarks
- and from gluons

Presently unknown, goal for next generation experiments

Missing contribution can be carried by gluons

→ Goal for present experiments

Quark contribution is not enough

To undestand spin structure we have to measure ΔG and ΔL

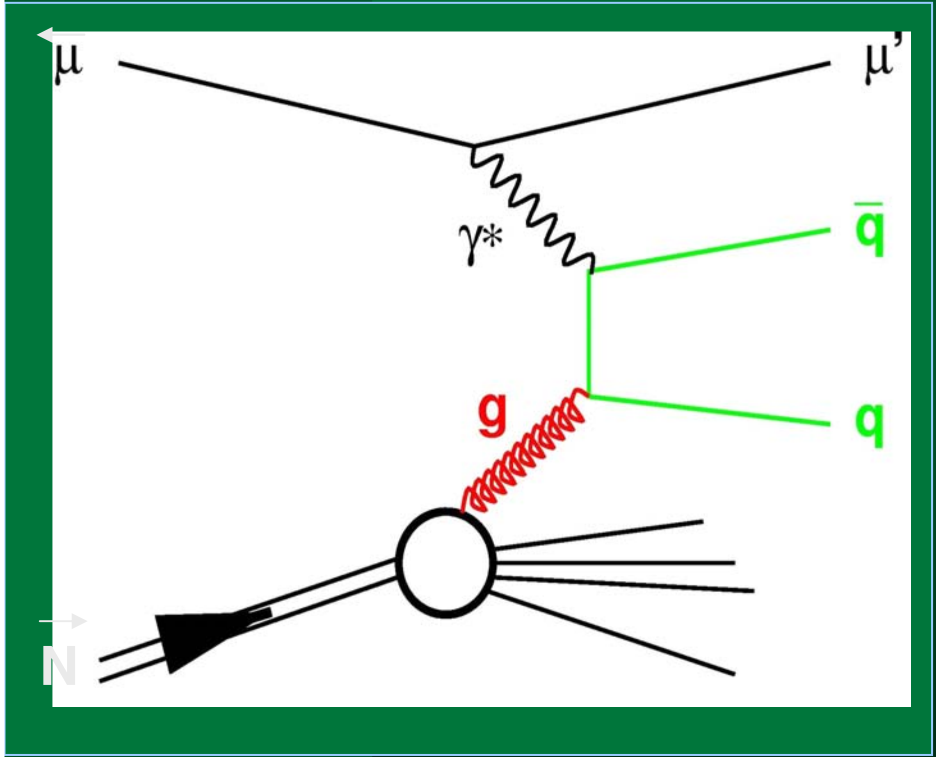
- First look at ΔG
  - in lepton nucleon scattering gluon does not couple to virtual photon (or intermediate boson)
  - selection of Photon Gluon Fusion needed
  - gluon polarization related to measured asymmetry

- Competition –

  →polarized proton-proton collider RHIC
  - here measured asymmetries compared with expected asymmetries for specific model for the gluon polarization

ΔG/G at COMPASS

Photon Gluon Fusion



Selection of events where underlying process involved **gluon**
→sensitivity to gluon parameters including **spin orientation**

q = c cross section difference in **charmed meson production**

→ ***simple theoretical description in LO***

→ ***experiment challenging***

q= u,d,s cross section difference in 2+1 jet production in COMPASS: **events with 2 hadrons with high p_T**

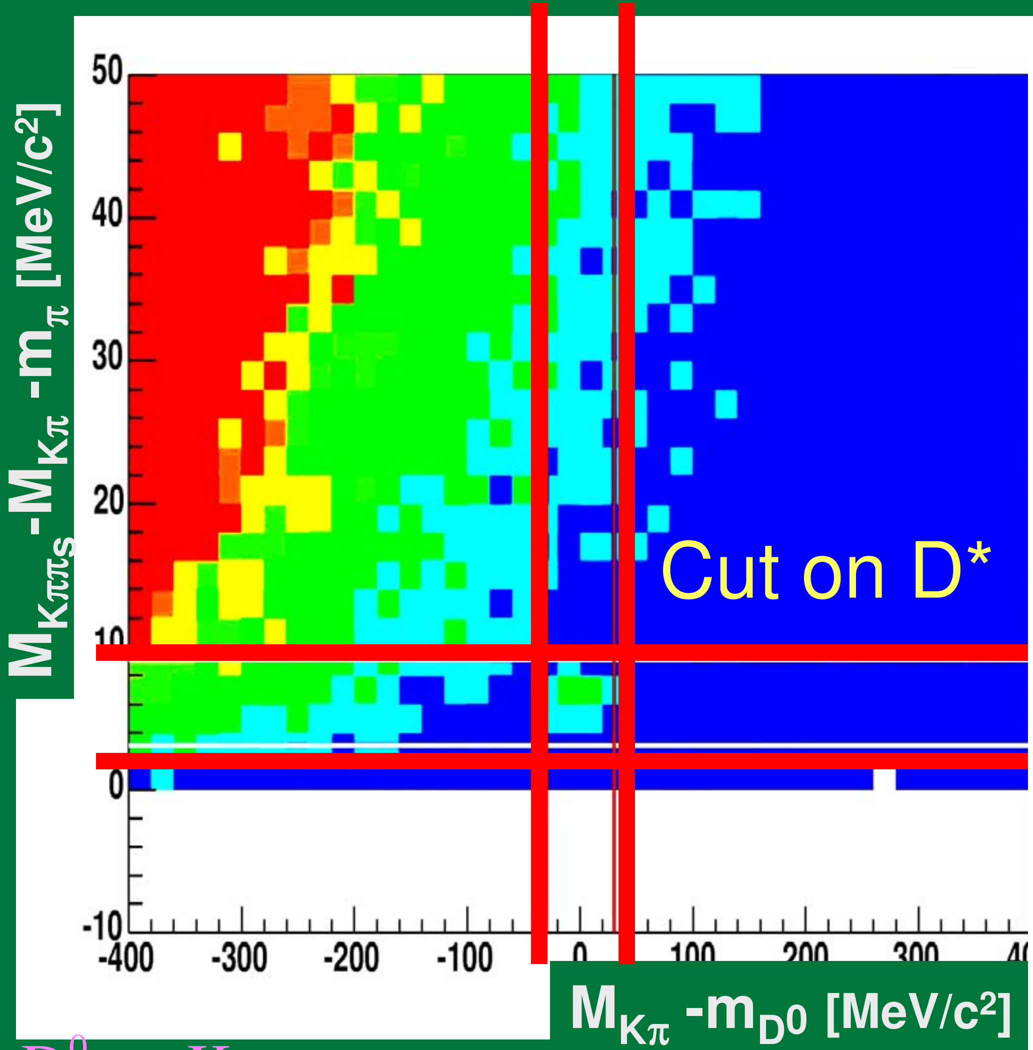
→ ***experimentally easier***

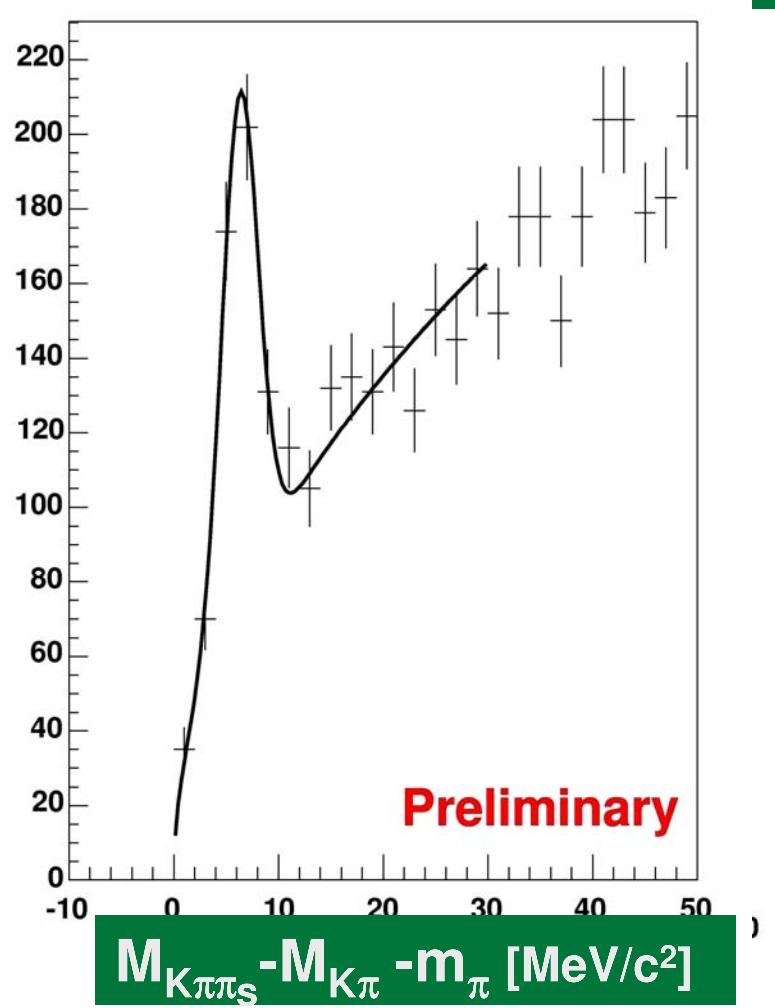
→ ***theoretical description more complicated***

D* tagging: $D^* \to D^0 \pi$

$D^* \to (K\pi)\pi$

$D^0 \to K\pi$



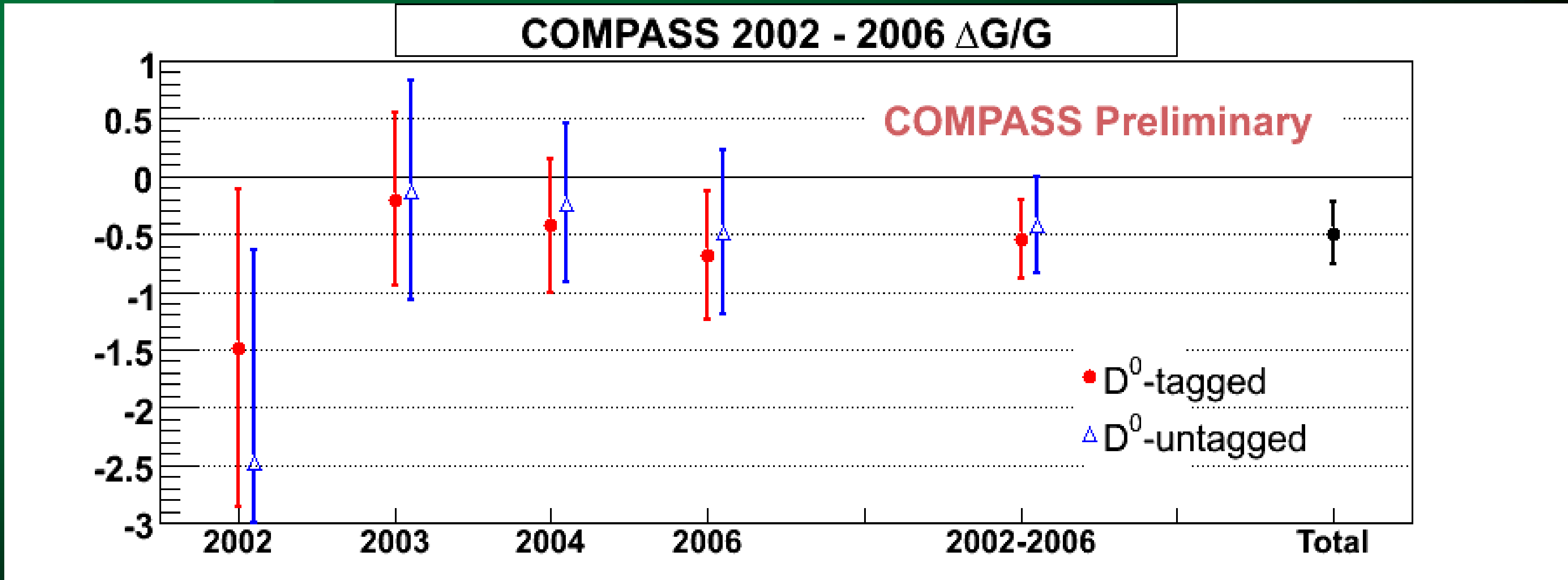


$D^0 \to K\pi$

Improved result for all data on deuteron (2002-2006)

Analysis in two channels:
tagged for D* production
untagged – only D^0 observed

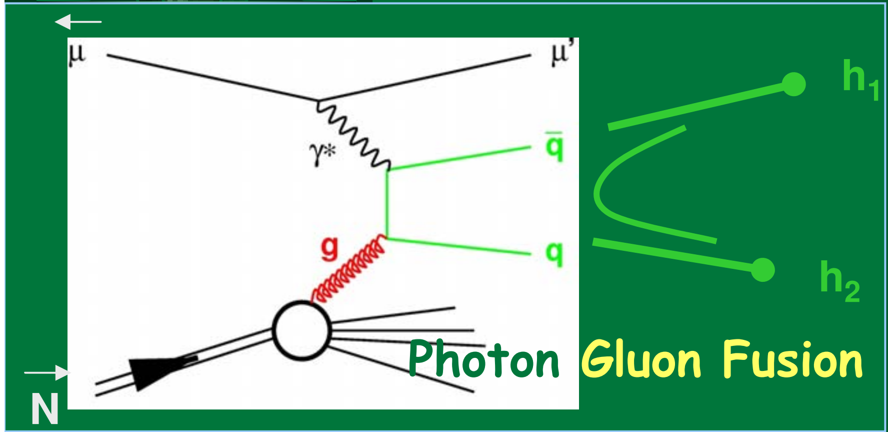
stat. error: 0.44 → 0.27

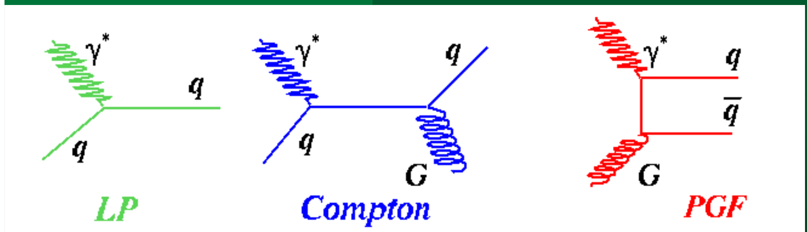


$\Delta G/G = -0.49 \pm 0.27$ (stat) ± 0.11 (syst)

$< x_g > = 0.11$, scale: $\mu^2 = 13$ GeV^2

$\Delta G/G$: pairs of high p_T hadrons





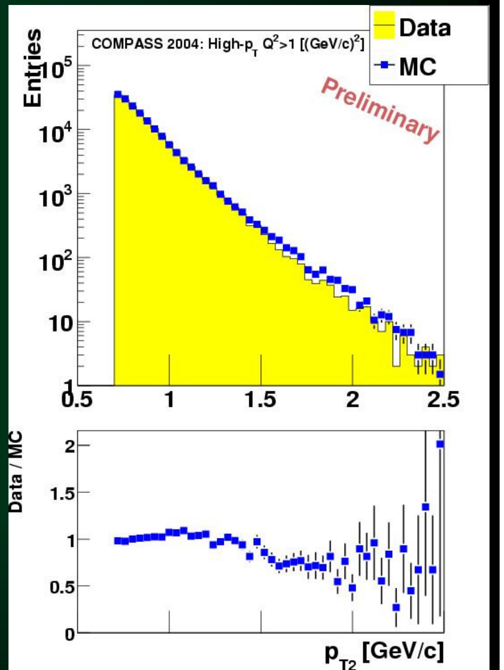
- Current fragmentation
- 2 high p_T hadrons
- p_T > 0.7 GeV/c

Two saples analyzed: Q2<1 GeV2
Photoproduction region

Q2>1 GeV2
DIS region

Contribution from other processes estimated from MC simulations

→ it has to agree very well with data



$$A_{LL}^{2h}(x_{Bj}) = R_{PGF}\, a_{LL}^{PGF} \frac{\Delta G}{G}(x_G) + R_{LO}\, D\, A_1^{LO}(x_{Bj}) + R_{QCDC}\, a_{LL}^{QCDC}\, A_1^{LO}(x_C)$$

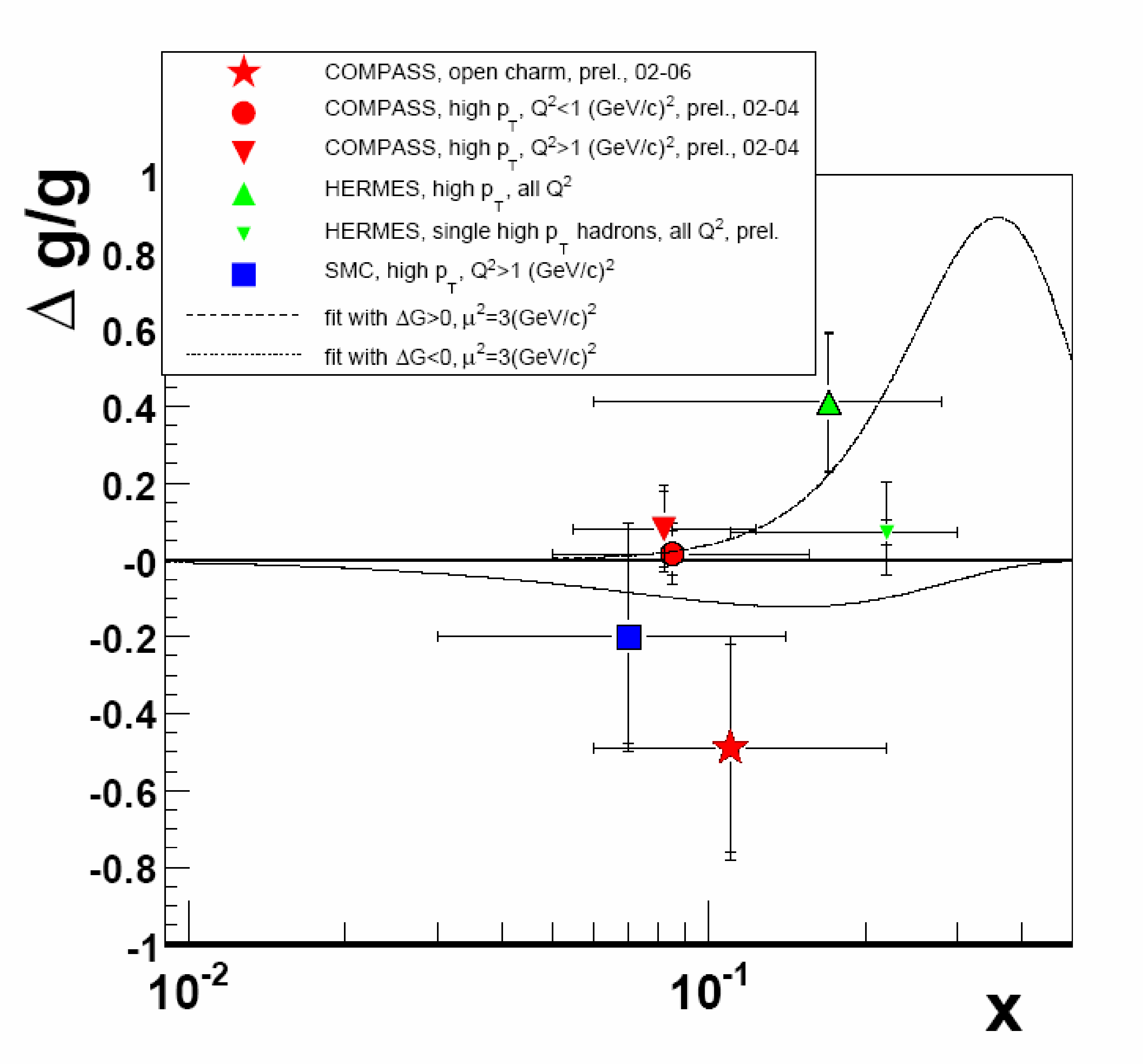
$$\Delta G/G = 0.08 \pm 0.01 \pm 0.05 \text{ at averaged } x_G = 0.082^{+0.041}_{-0.027}$$

results

Best present knowledge from „direct measurements"

Compass →most precise

ΔG/G small

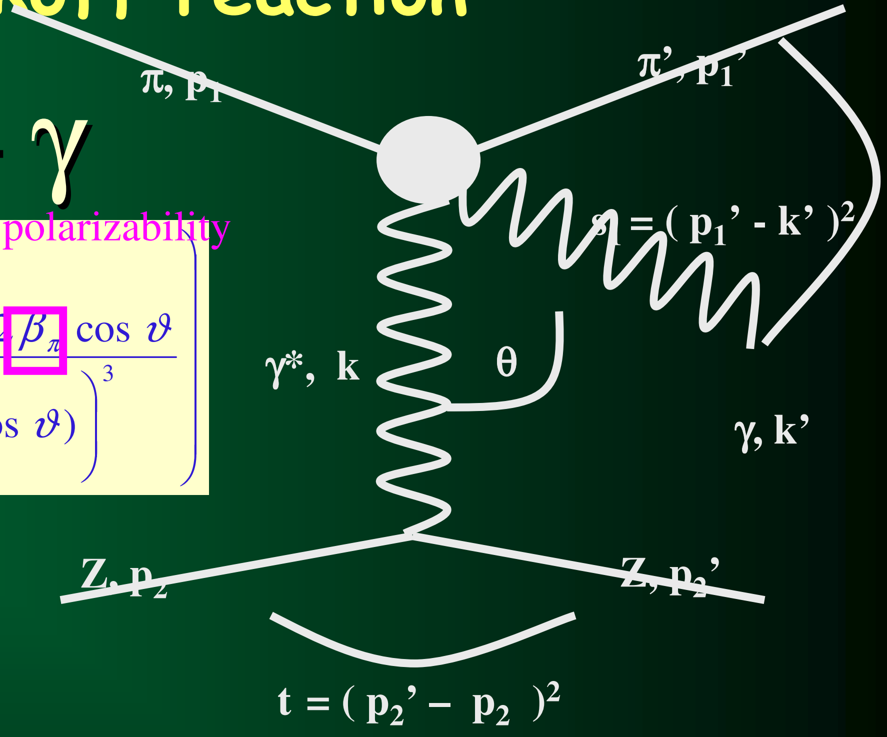


Hadron beams in Compass: The Primakoff reaction

$$\pi + Z \rightarrow \pi' + Z + \gamma$$

Electric & Magnetic polarizability

$$\frac{d\sigma_{\pi\gamma}(\omega,\vartheta)}{d\cos\vartheta} = \frac{2\pi\alpha_f^2}{m_\pi^2}\cdot\left(F_{\pi\gamma}^{Th} + \frac{m_\pi \omega^2}{\alpha_f}\,\frac{\alpha_\pi(1+\cos^2\vartheta) + 2\beta_\pi \cos\vartheta}{\left(1+\frac{\omega}{m_\pi}(1-\cos\vartheta)\right)^3}\right)$$



first data taken in 2004
expected ~30k events

nucleon spectroscopy

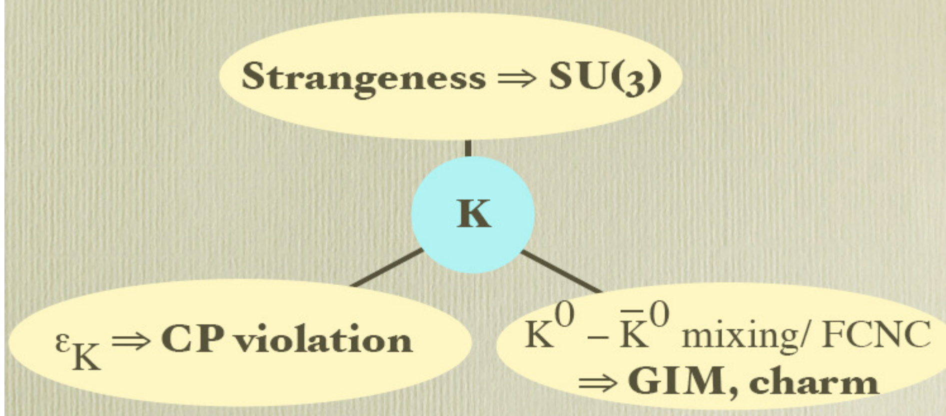
glue balls and hybrids

charmed mesons and baryons
- semi-leptonic decays
- double-charmed baryons
- Central production

Long run with hadron beam this year

II. Very rare decays - possible signal of new physics

K decays



More: ε'/ε, CKM parameters, CPT tests (m(K) vs m(Kbar)), etc.etc.

New frontier: very rare decays, O($10^{-10\div-11}$)

NA62 – P326

"New physics" decays (SM = 0):

$LFV : K_L^0 \to \mu e, K_L^0, K^\pm \to \pi\mu e$

Precision measurements (SM/NP window):

Transverse μ polar. $K^+ \to \pi\mu\nu, K^+ \to \mu\nu\gamma$

Short-distance modes (SM = precise)

$K_L \to \pi^0 l^+ l^-, K_L \to \pi^0 \nu\bar{\nu}, K^\pm \to \pi^\pm \nu\bar{\nu}$

CP, CPT measurements (well known decays)

$K^\pm \to \pi^\pm\pi^\pm\pi^\pm$ $\quad K_S^0 \to 3\pi^0$

$K^\pm \to \pi^\pm\pi^0\pi^0$ $\quad K_S^0 \to \pi l \nu$

$K^\pm \to \pi^\pm\pi^0\gamma$ $\quad \phi^\pm, \phi^{00}$

Long-distance modes

(tests of low-energy effective theory)

$K^\pm \to \pi^\pm l^+ l^-, K_L \to l^+ l^-$

A measurement of the 4 decay modes

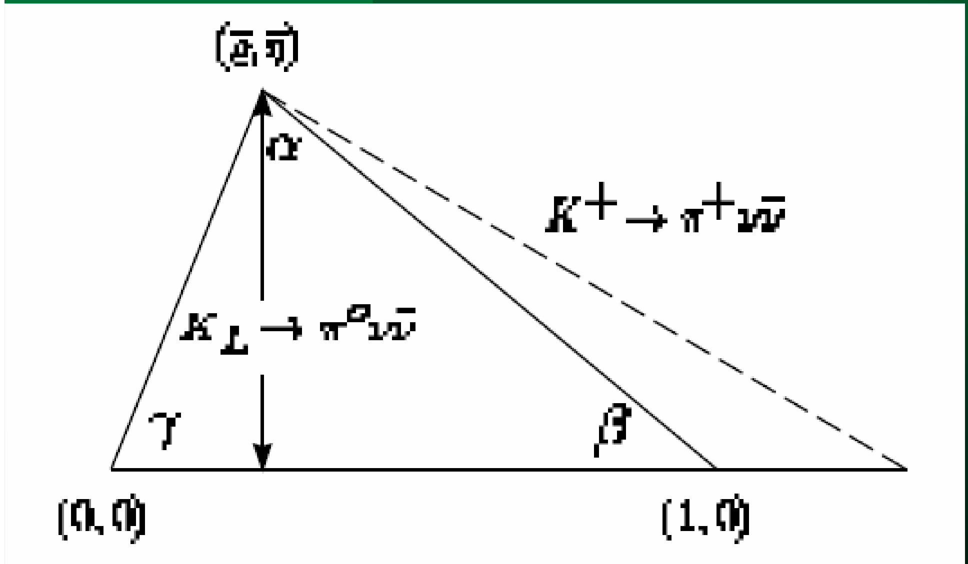
$K^+ \to \pi^+ \nu \nu$ $\quad K^0_L \to \pi^0 \nu \nu$

$K^0_L \to \pi^0 e^+ e^-$ $\quad K^0_L \to \pi^0 \mu^+ \mu^-$

is a crucial element in the exploration of the new physics discovered at the LHC.

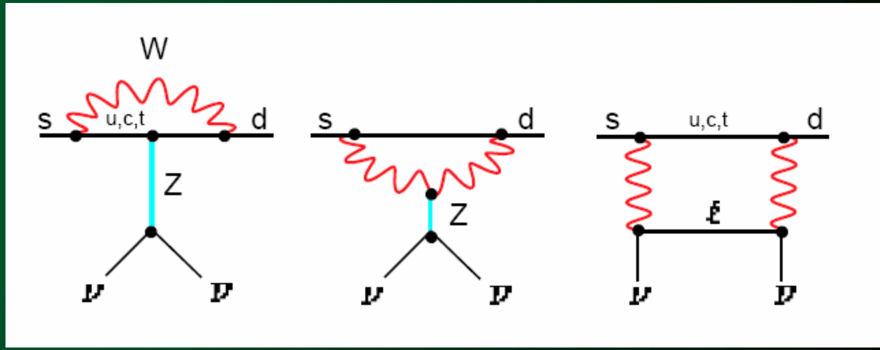
Physics motivation

Acurate determination of the universality triangle

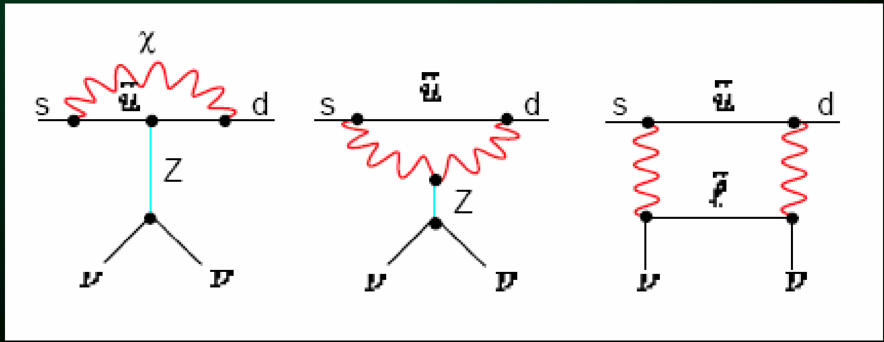


Independent of the B-system

Probes short distance behaviour of the Standard Model



Extremely sensitive to possible **new degrees of freedom beyond the Standard Model**

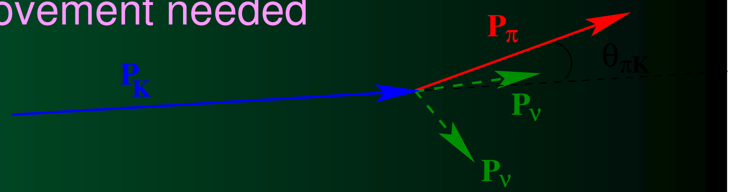


measurement of $K^+ \to \pi^+ \nu\bar{\nu}$

Branching ratio measured by E787/E949

$$BR(K^+ \to \pi^+ \nu\bar{\nu}) = 1.47^{+1.30}_{-0.89}\ 10^{-10}\ s$$

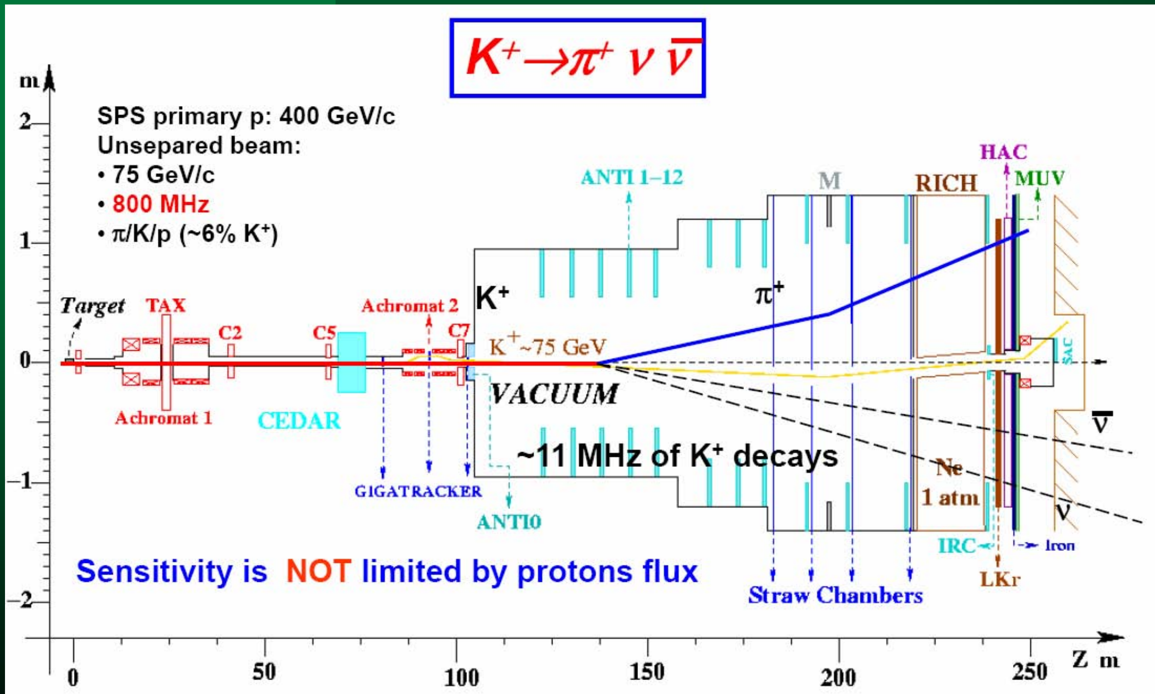
significant improvement needed

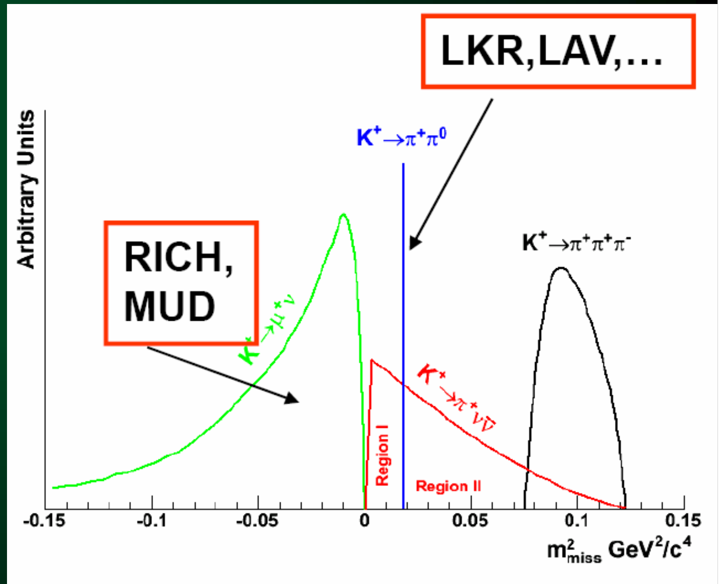


Kinematical rejection

SM prediction to be tested:

$$BR(K^+ \to \pi^+ \nu\bar{\nu}) = (0.8 \pm 0.1)\ 10^{-10}$$

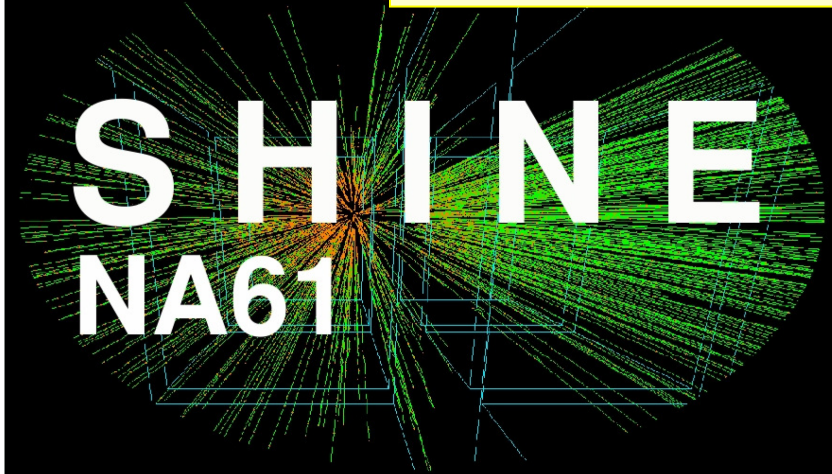




+ veto on photons to remove $K^+ \to \pi^+\pi^0$ background

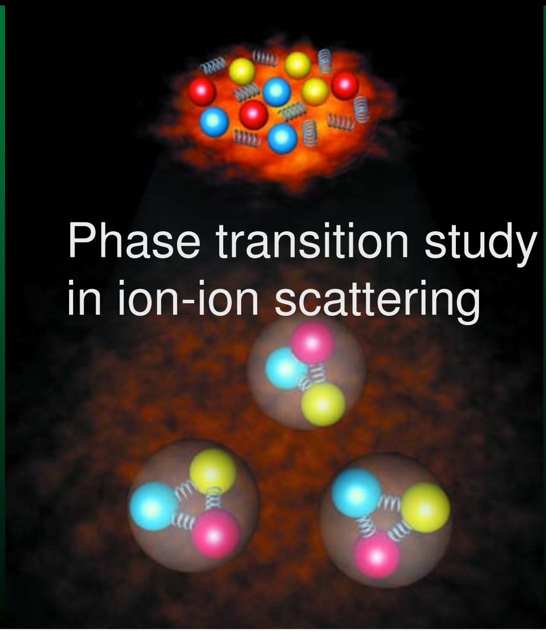
III. Hadron-hadron, hadron-ion, ion-ion

(SHINE – SPS Heavy Ion and Neutrino Experiment)



Experiment running,
(after first year of data taking)

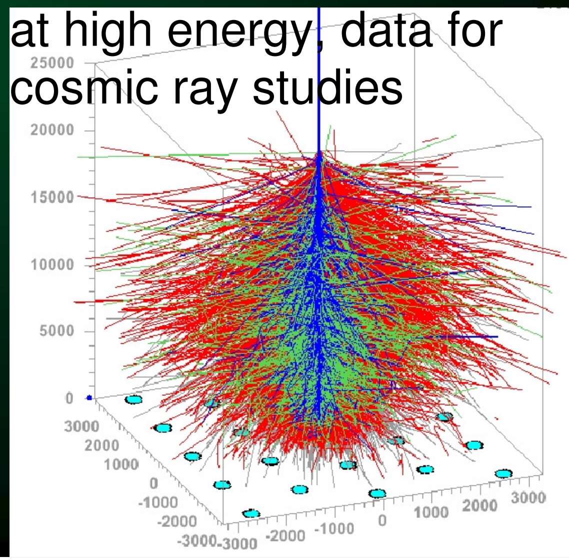
Three subjects combined around detector with high acceptance and good particle identification: NA49 detector

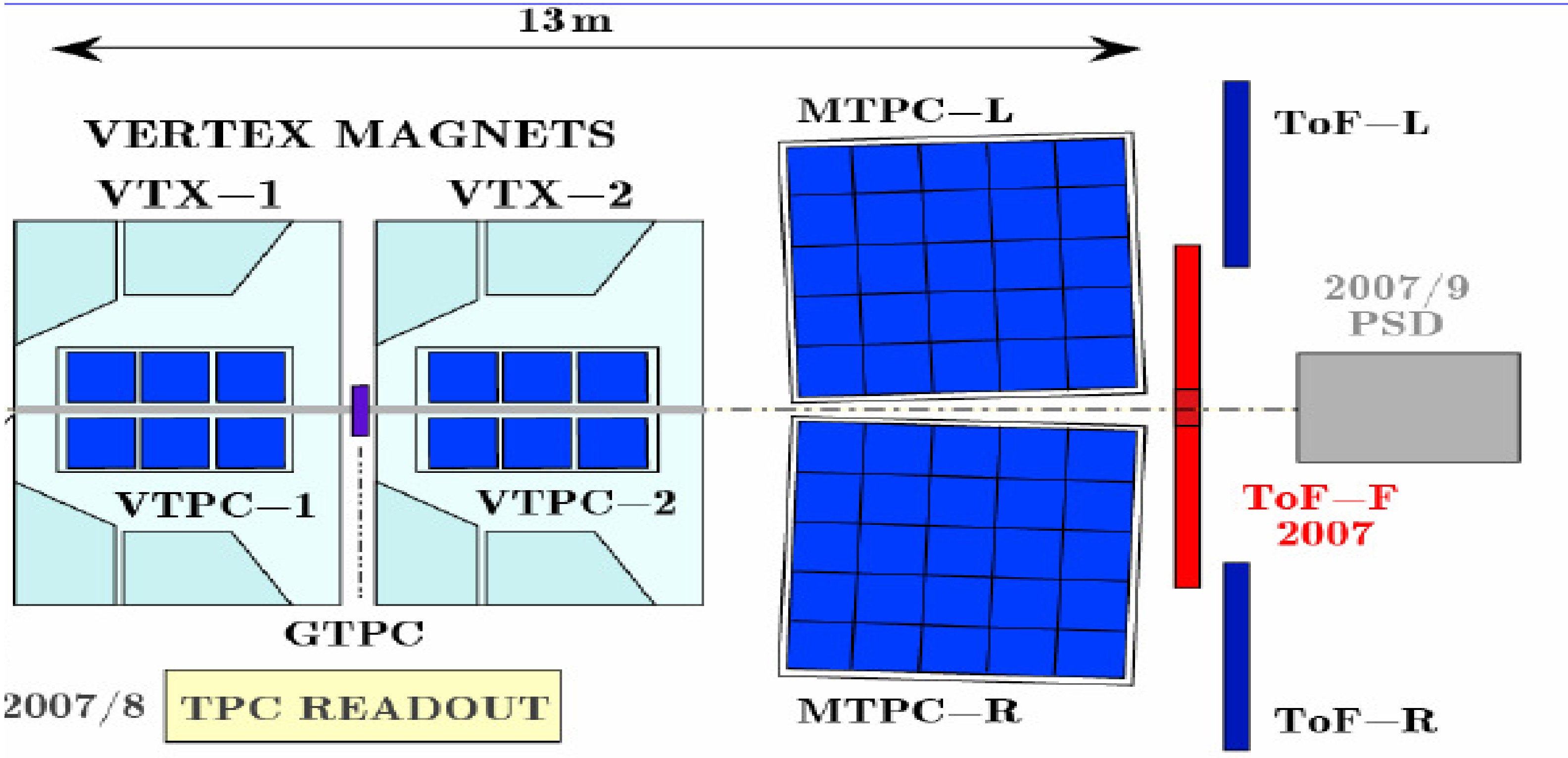


Phase transition study in ion-ion scattering

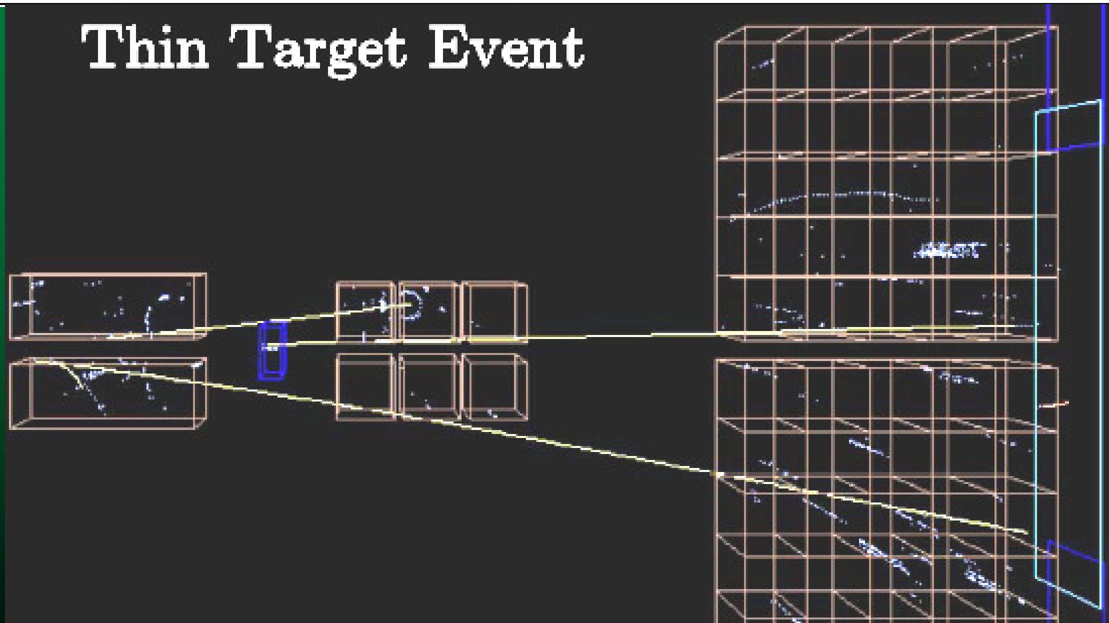
Precise measuremen of hadron production in pC scattering
→input for neutrino beam simulations (T2K)

Proton nucleus scattering at high energy, data for cosmic ray studies





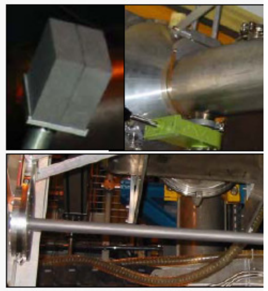
2007 run



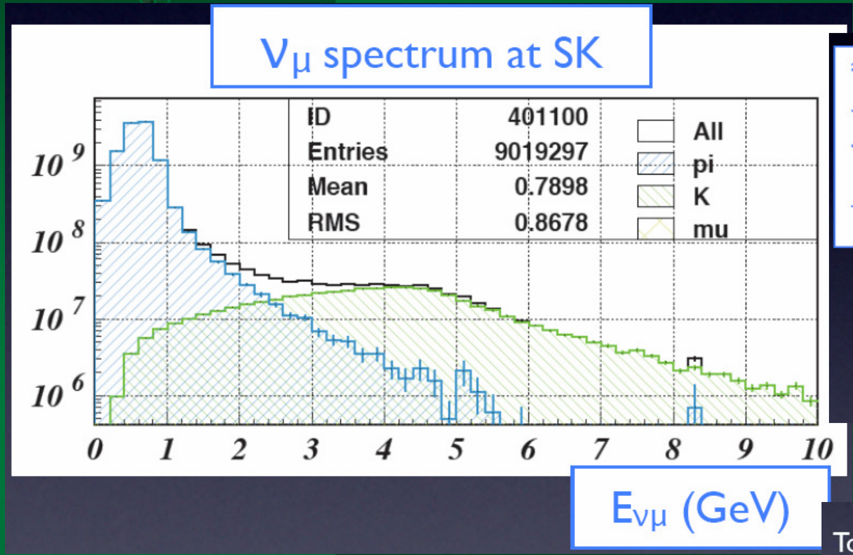
Information for neutrino beam in T2K experiment

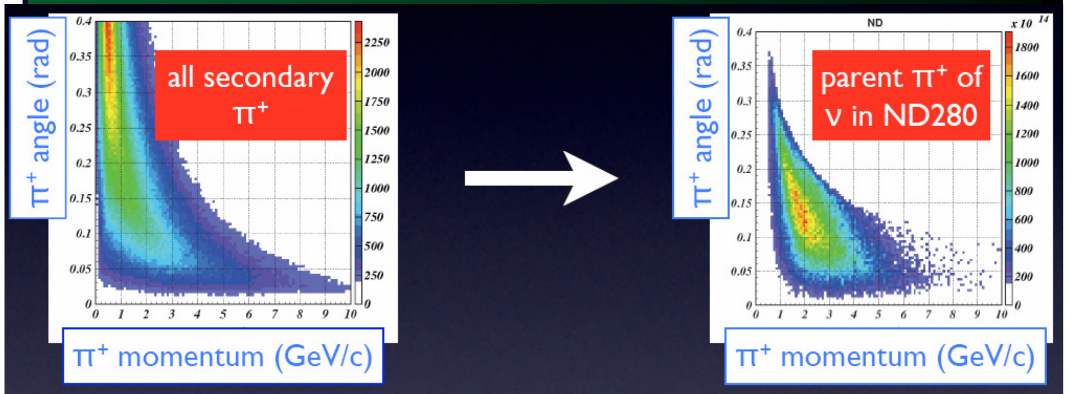
data with 30 GeV protons on two targets:

- 2 different carbon targets (isotropic graphite, $\rho = 1.84$ g/cm³):
  - Thin Carbon Target: 2.5 x 2.5 x 2cm³, int. length ~0.04
  - T2K Replica Target: Ø=2.6cm x 90cm, int. length ~1.9

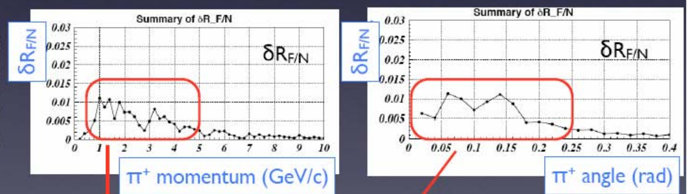


Why production of π and K have to be knows better?

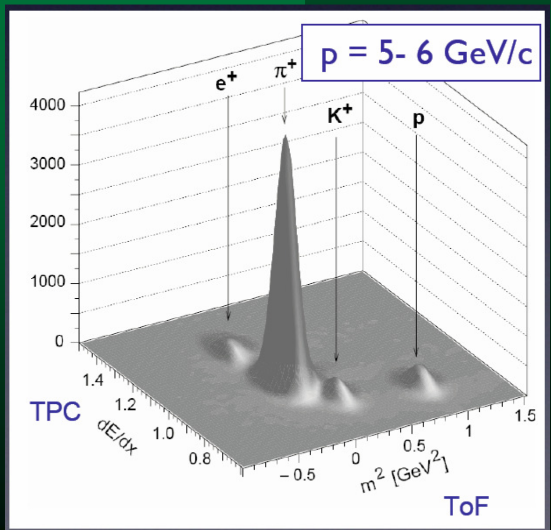




To define quantitatively the region of interest the particle yield has been increased by 30% independently in each momentum and angle bin.



Region of interest:
$0.5 < p < 5$ GeV/c ; $0 < \theta < 250$ mrad

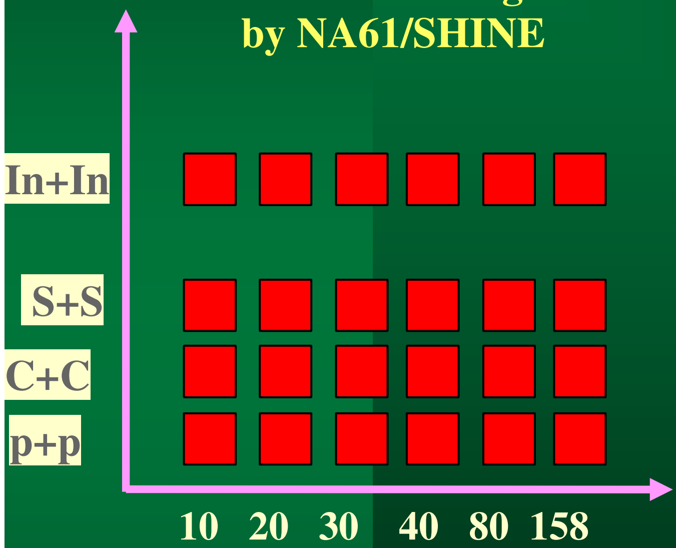


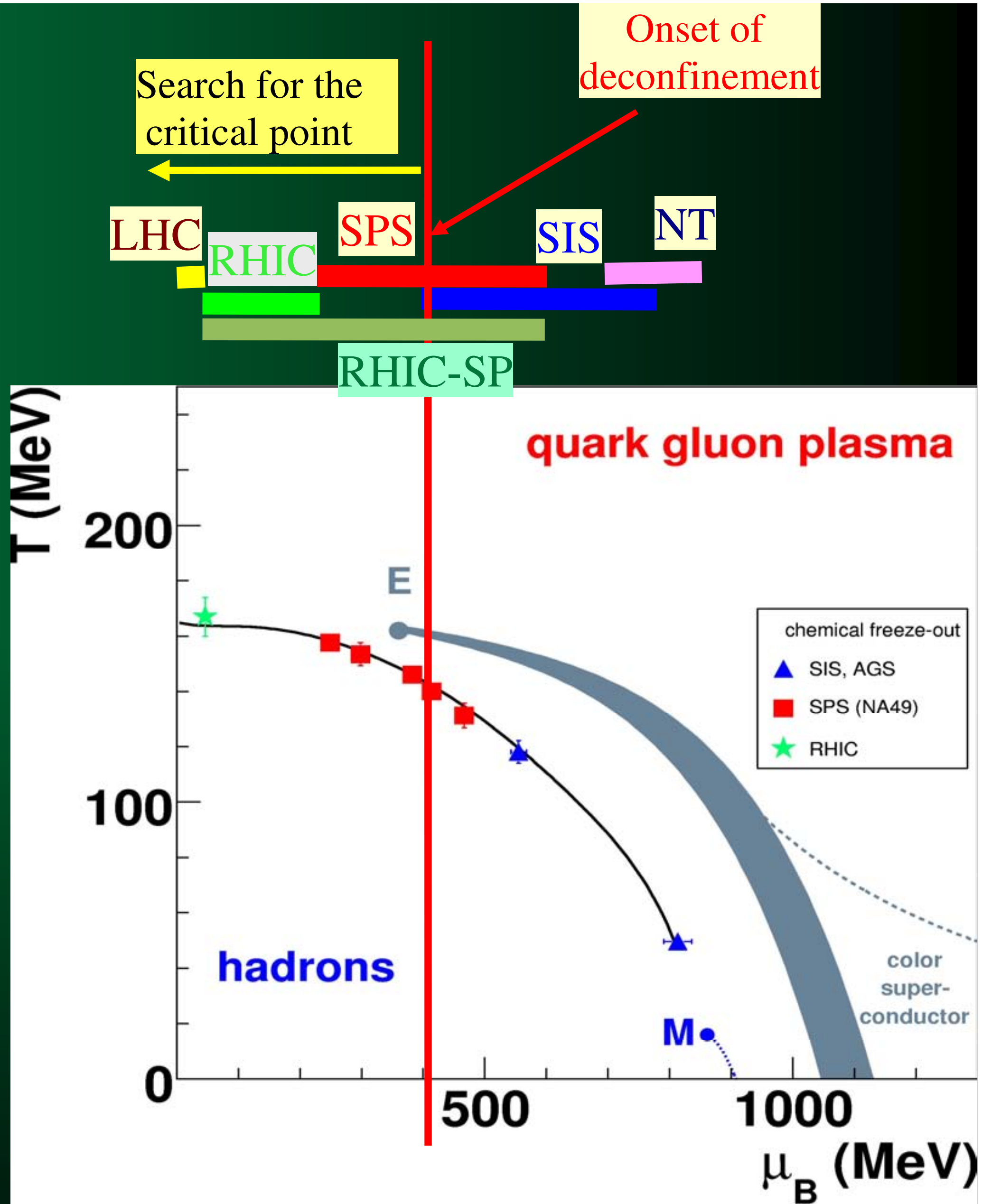
Needed statistics to improve knowledge about beam

~200k π^+ reconstructed tracks

ion-ion scattering

New data to be register by NA61/SHINE





may lead to discovery of the critical point of strongly interacting matter by an observation of a hill of fluctuations in two dimensional plane (energy)-(system size) or equivalently (temperature)-(baryo-chemical potential)

In particular the critical point should lead to an increase of multiplicity and transverse momentum fluctuations

Longer scale future (>2011)

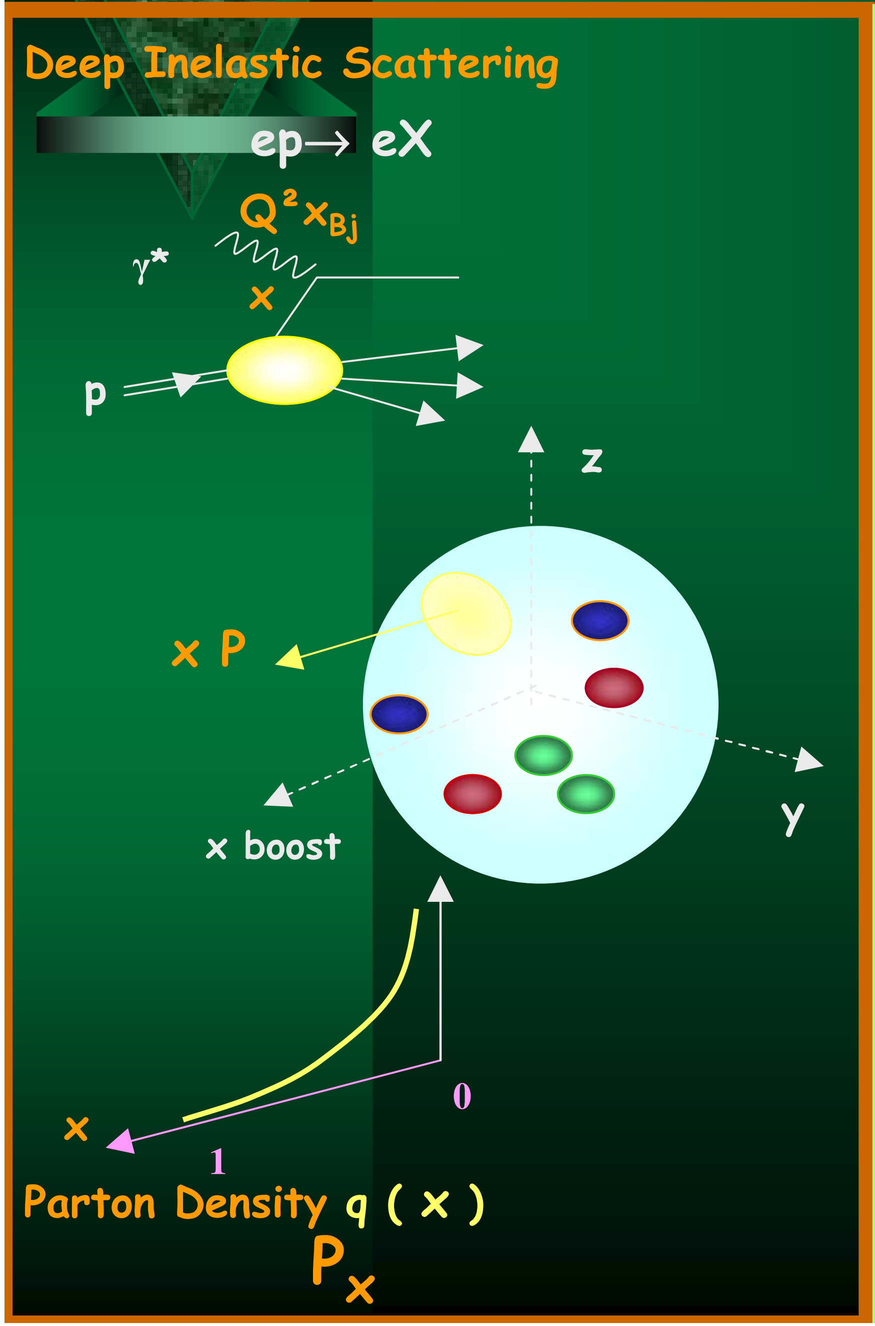
General Parton Distributions

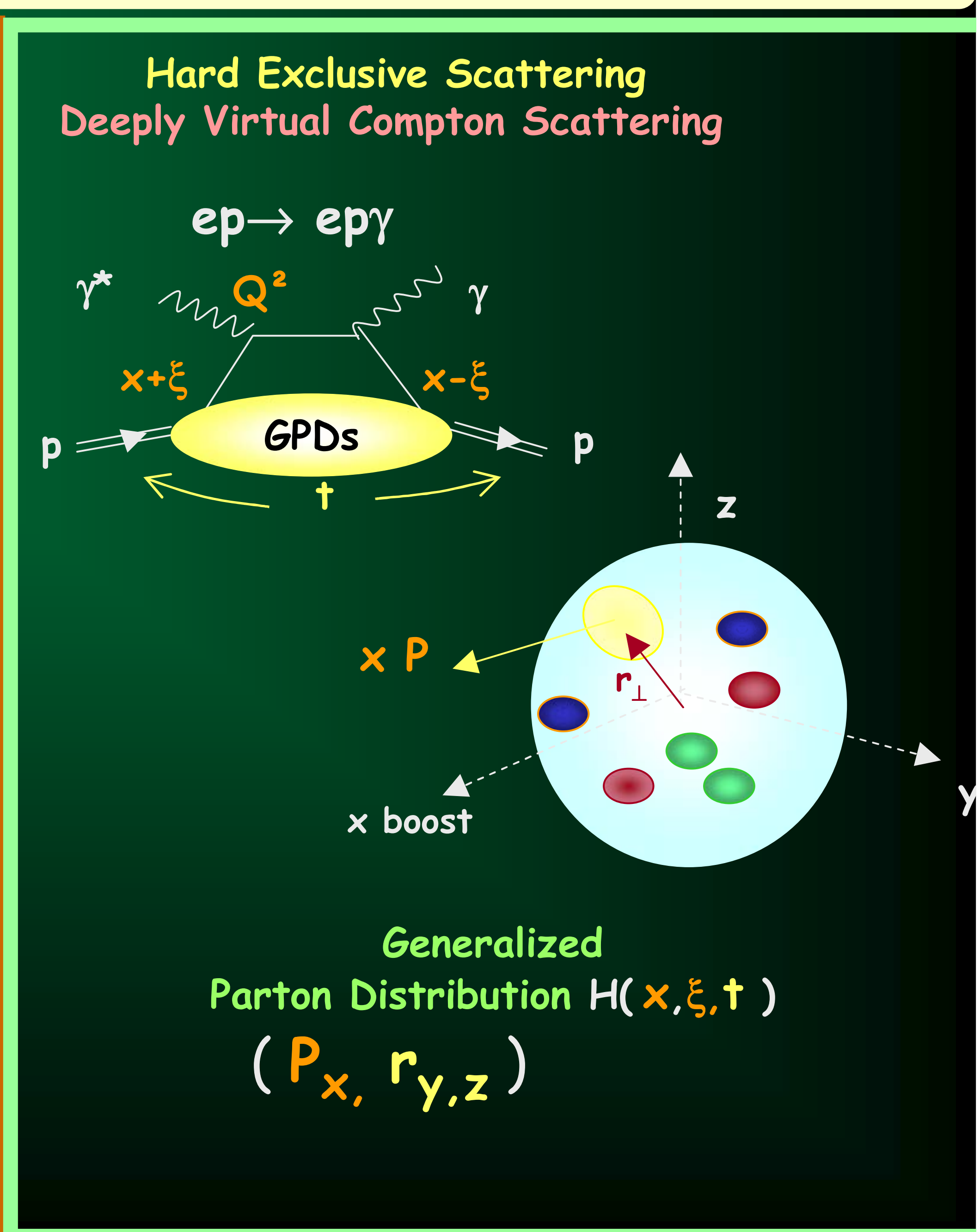
Next step – study 3D structure of the nucleon

→ additional transverse information

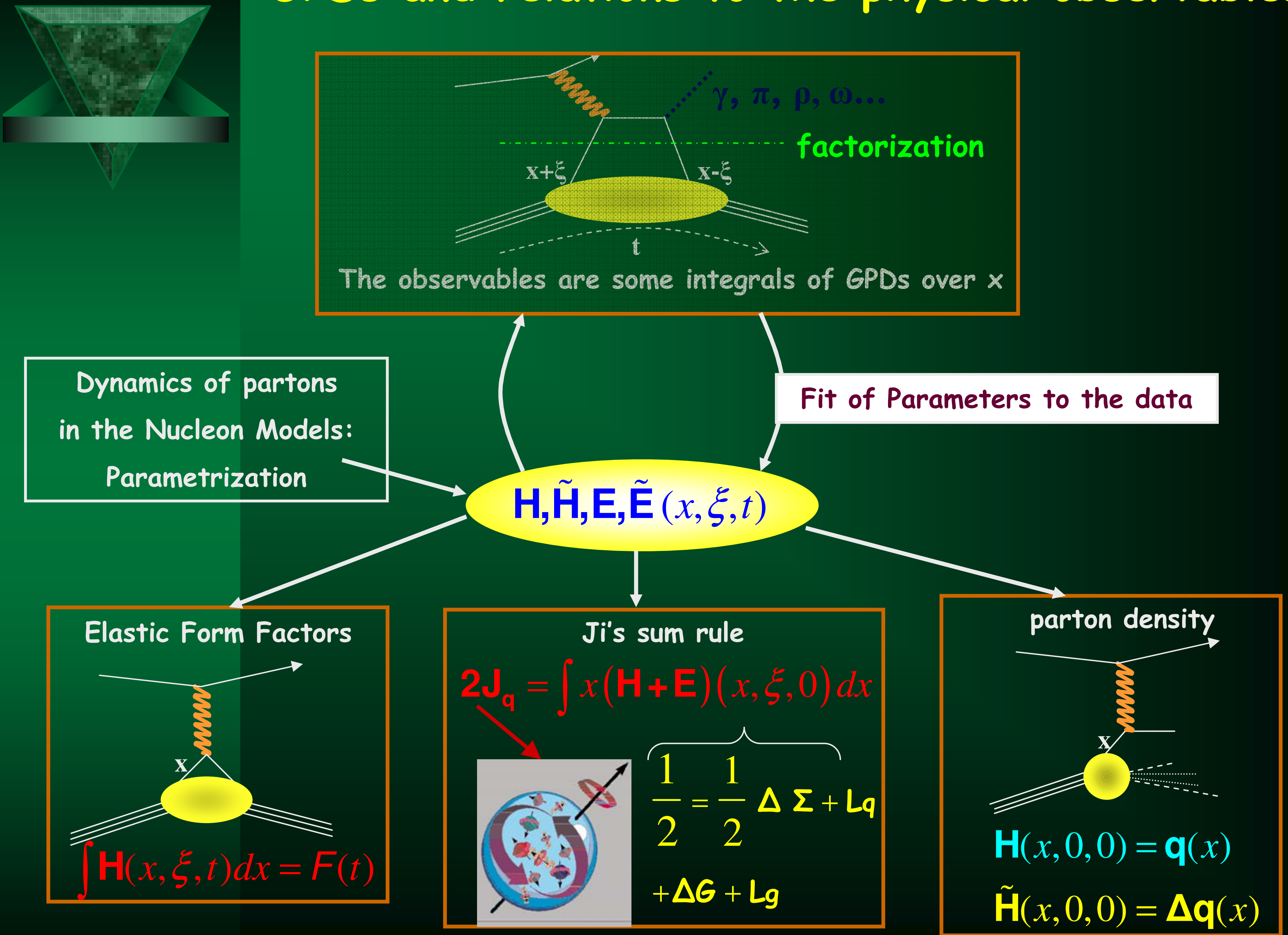
→ present structure functions – limit of 3D case

NEW : 3-dimensional picture of the partonic nucleon structure





GPDs and relations to the physical observables



Summary

- Still many fields for fixed target experiments
- Study of nucleon structure concentrated on spin puzzle, important role of μN data
- In future GPD is a very likely goal
- Rare decays of kaon can bring important information for flavour structure understanding
- Here there is also space for longer term plans
- Precise data with particle identification can contribute to other fields (neutrino physics, cosmic ray physics)
- Measurements with heavy ion beams can give input to critical point searches and deconfinement understanding