# Fixed target physics at CERN SPS

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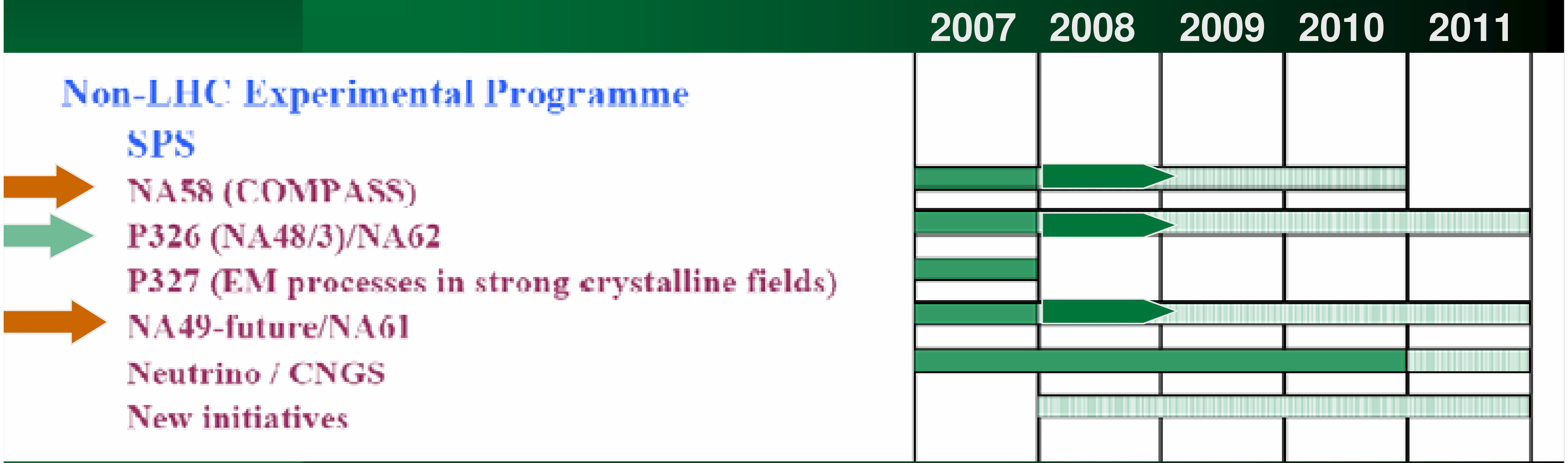
- Why fixed targets
- Compass and spin structure of the nucleon
- SHINE – cross sections and energy scan with heavy ions
- Rare K decays – search for New Physics
- Future: GPD and DVCS measurements

# 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 ?

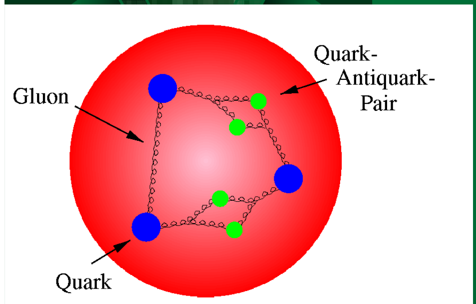



from CERN Council 142'th session in 21'st June 2007

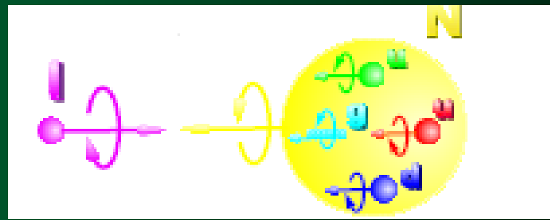
Experiments with strong polish participation

Experiment without polish participation

# Resolution of the „DIS microscope"

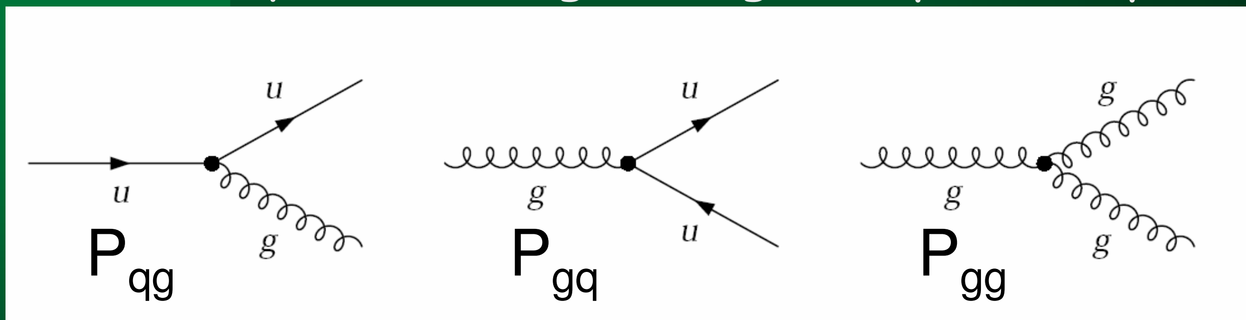



This is what we know:
quarks
pairs quark-antiquark
gluons



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

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



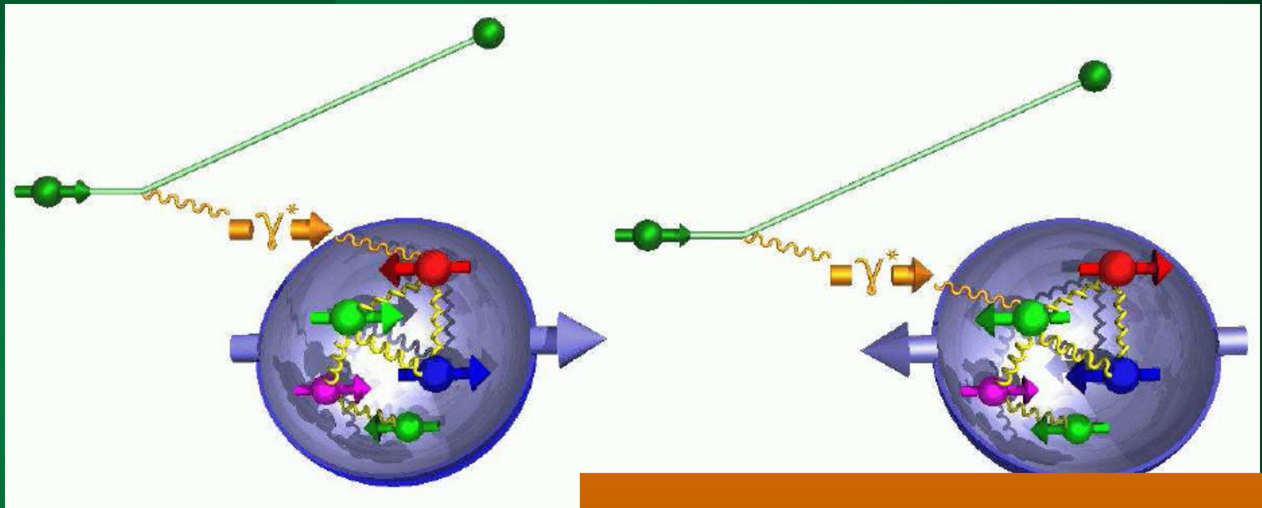

$$\mathcal{P}_{qq/qg} \sim \log \frac{Q^2}{\mu^2}$$

**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 $\mu$**
**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

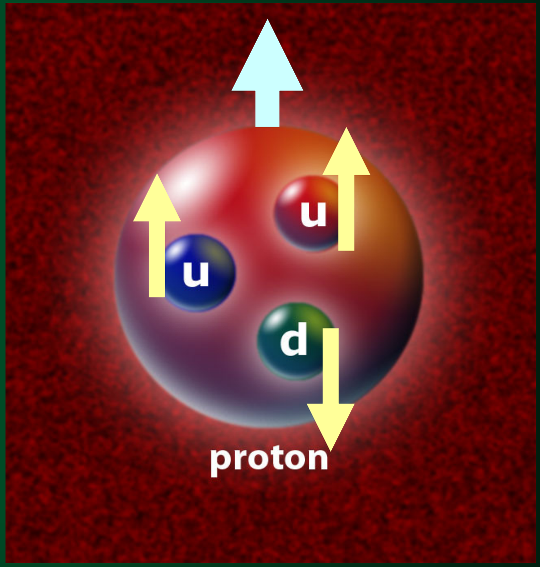
**So half is missing !!!**

# Spin goals

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

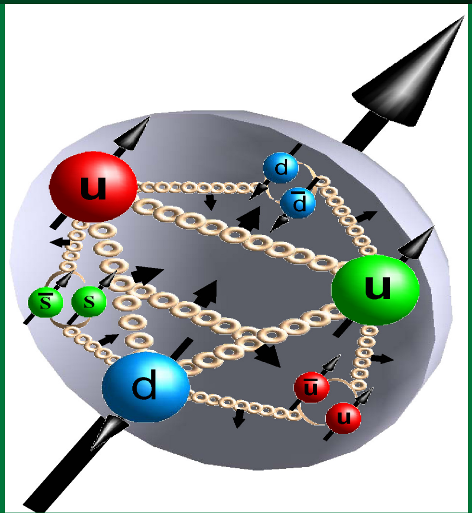
As with atomic and nuclear structure, this is an evolving understanding

**Recall:**
**simple quark model**

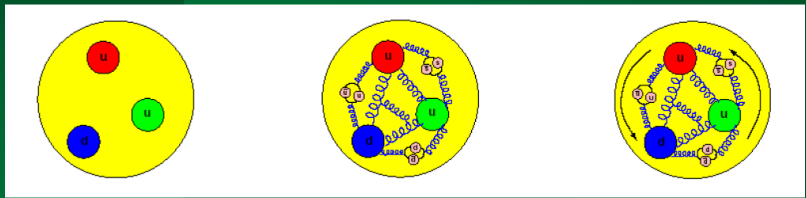


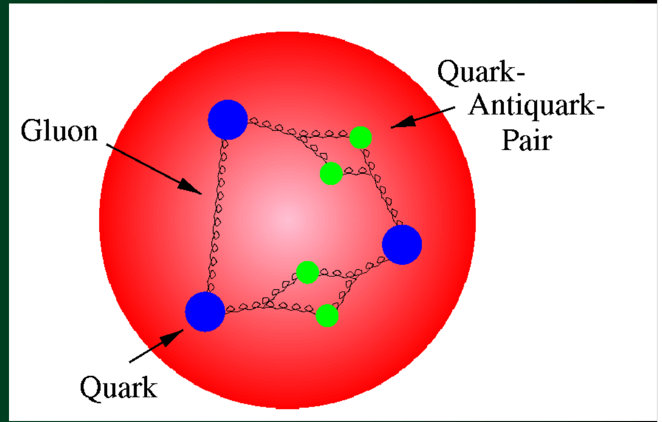

**In QCD: proton is not just 3 quarks !**

**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

Quark contribution is not enough

Missing contribution can be carried by gluons
→ Goal for present experiments

# To undestand spin structure we have to measure $\Delta G$ and $\Delta L$

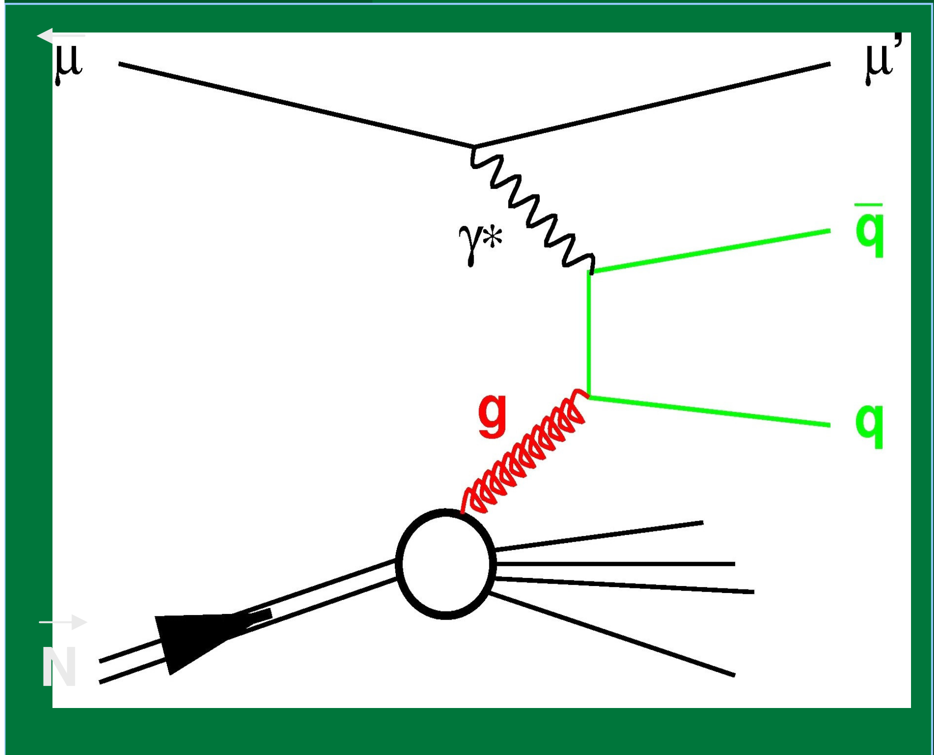
- First look at $\Delta G$
  - in lepton nucleon scattering gluon does not couple to virtual photon (or intermediate boson)
  - selection of Photon Gluon Fusion needed
  - gluon polarization related to measured asymmetry

- 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***

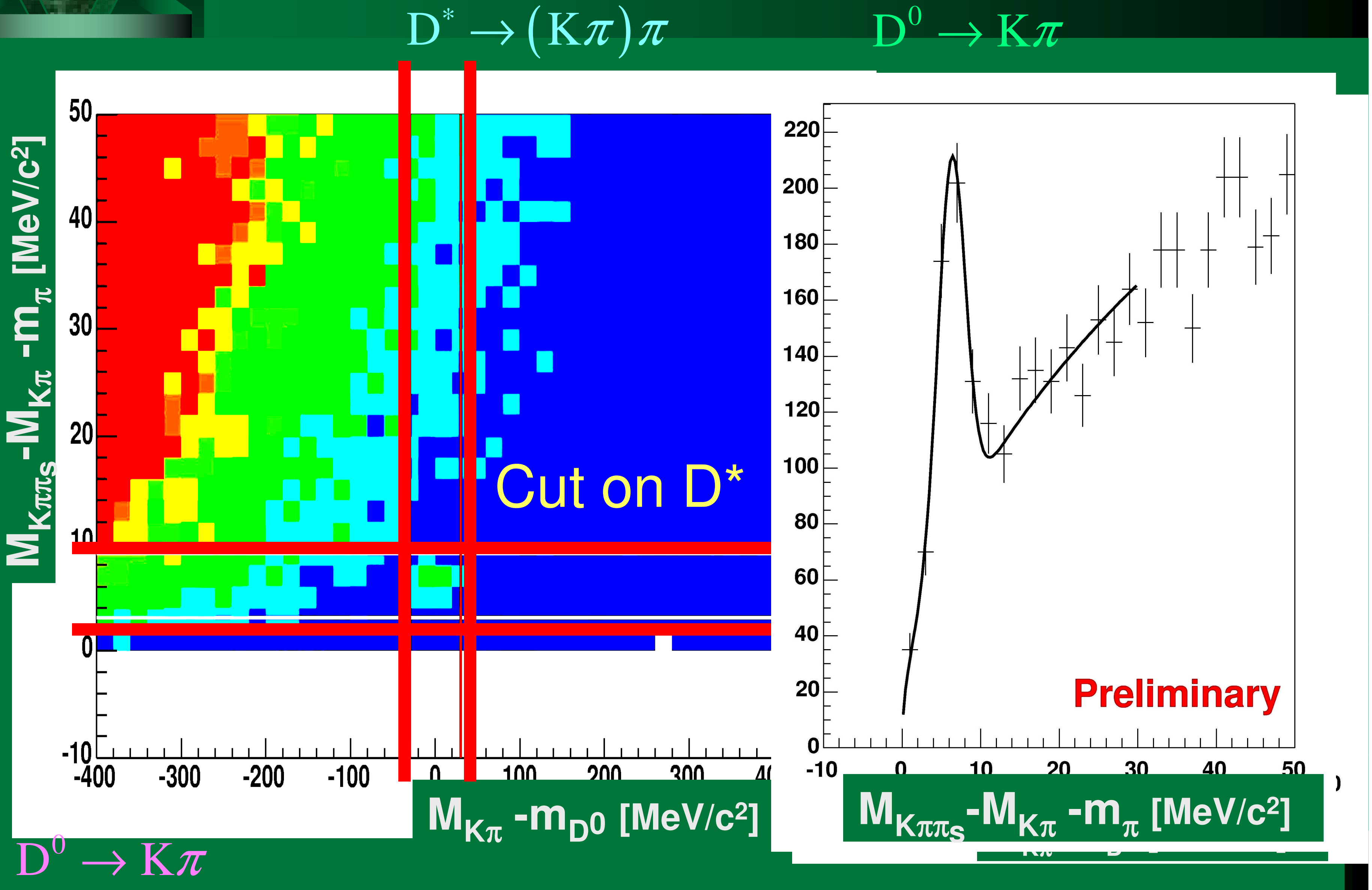
→ ***experiment challenging***

**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***

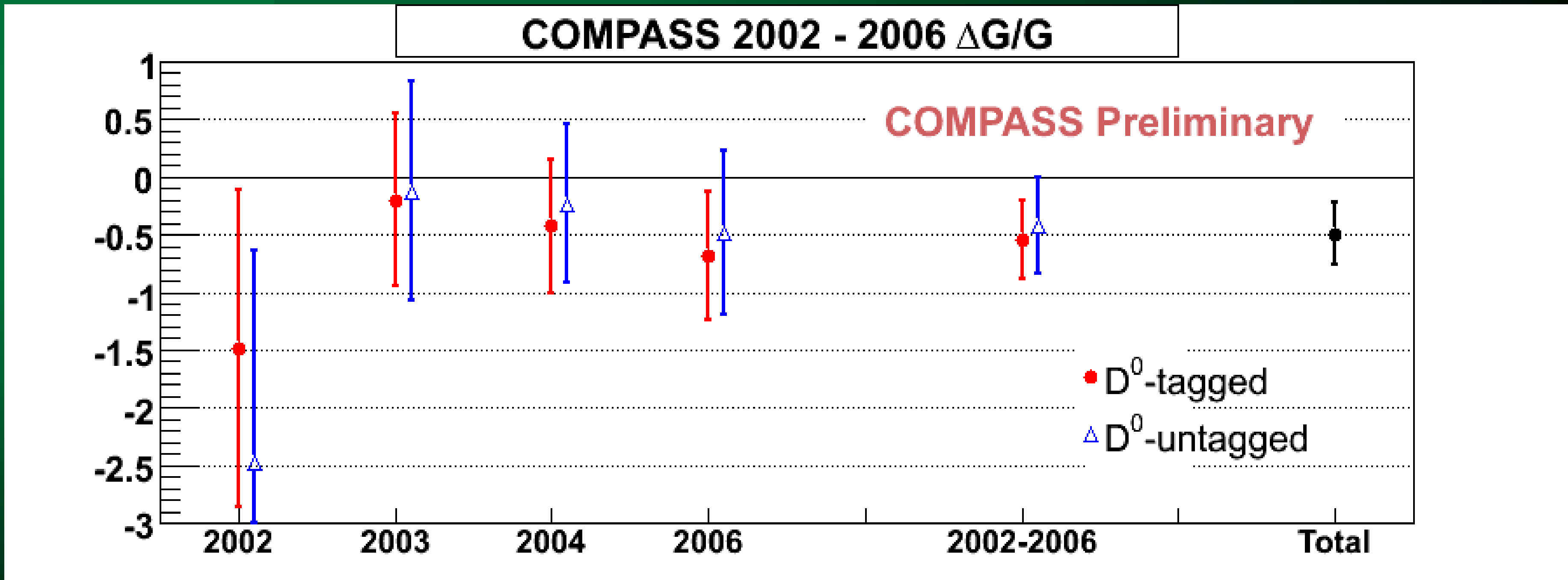
# D* tagging: $D^* \to D^0\,\pi$



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

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

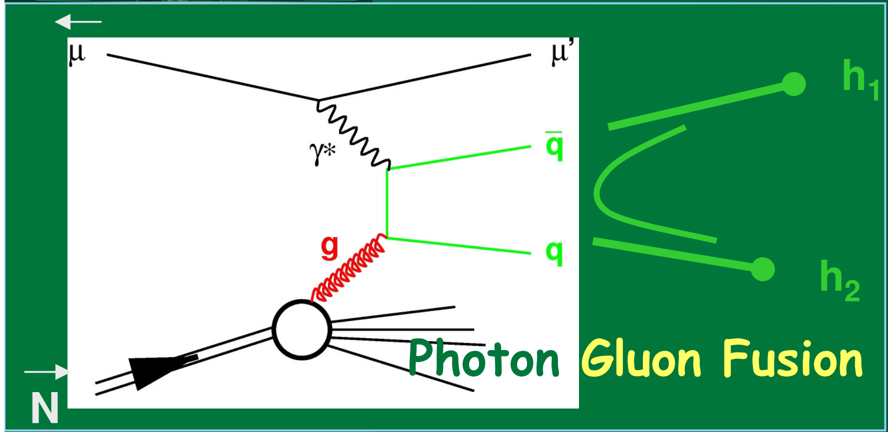
stat. error: 0.44 → 0.27

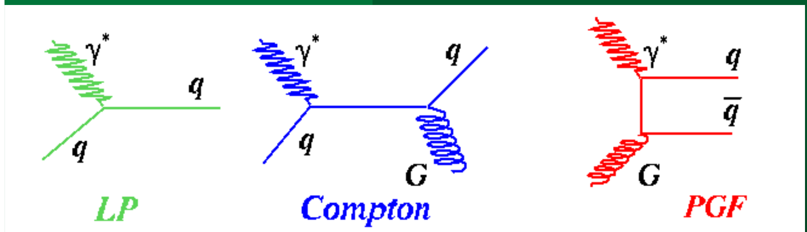



$$\Delta G/G = -0.49 \pm 0.27\ (\text{stat}) \pm 0.11\ (\text{syst})$$

$$\langle x_g \rangle = 0.11, \quad \text{scale: } \mu^2 = 13\ \text{GeV}^2$$

# ΔG/G: pairs of high $p_T$ hadrons



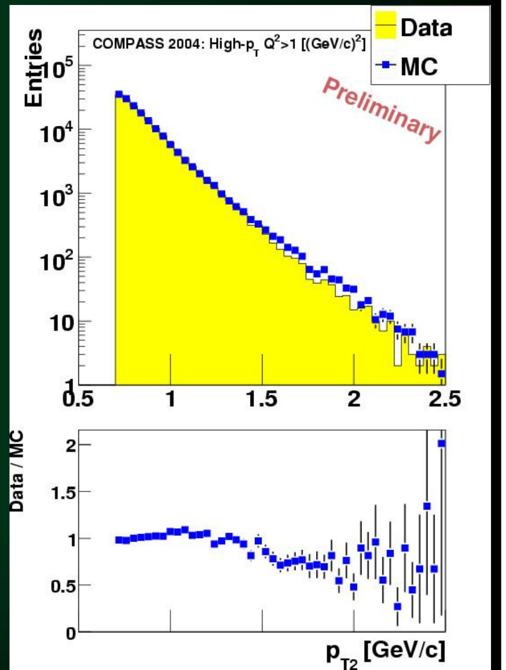

- Current fragmentation
- 2 high $p_T$ hadrons
- $p_T$ > 0.7 GeV/c

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




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

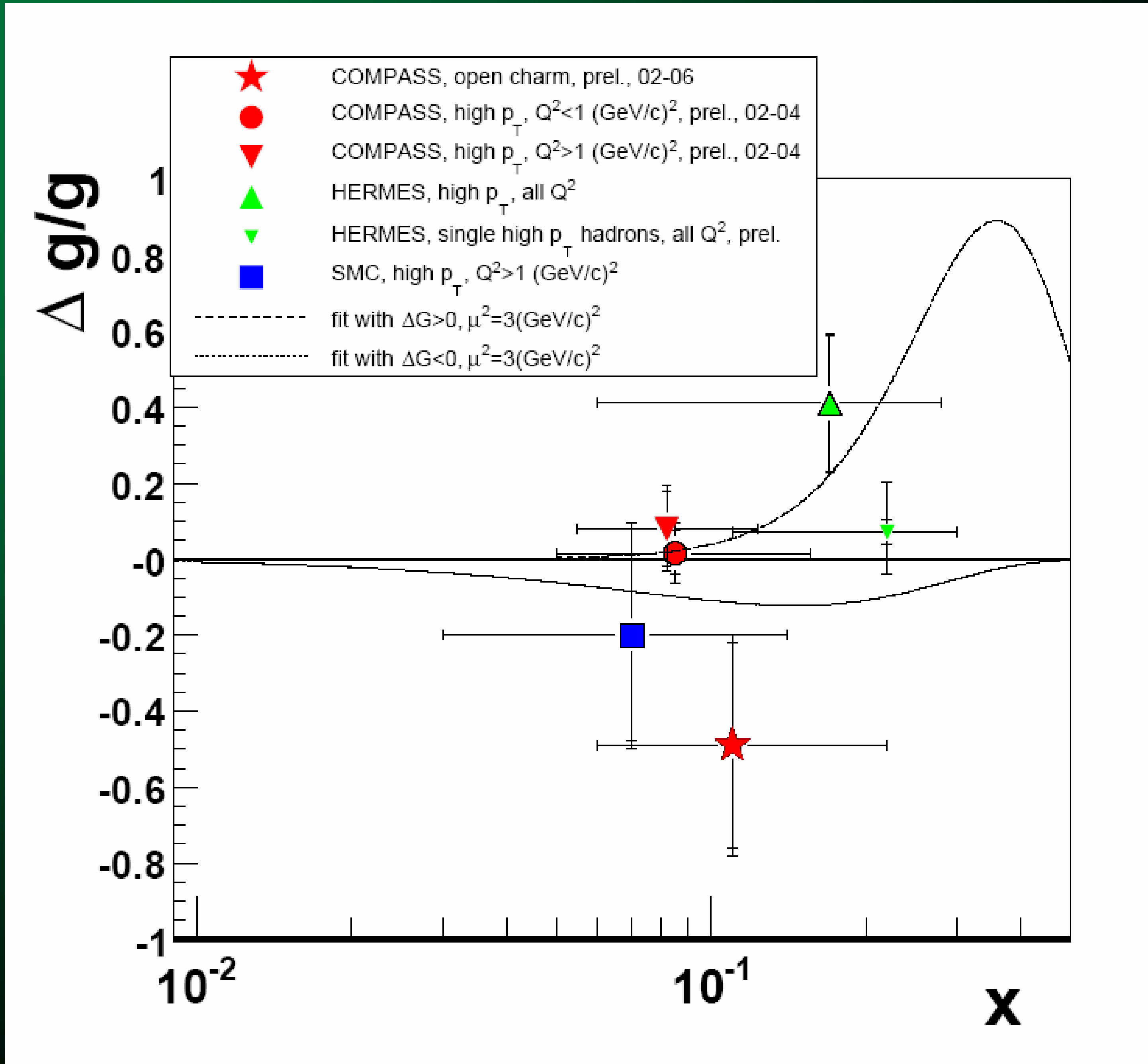
$$\Delta G/G = 0.08 \pm 0.01 \pm 0.05 \text{ at averaged } x_G = 0.082^{+0.041}_{-0.027}$$

# results

Best present knowledge from „direct measurements”

Compass →most precise

**ΔG/G small**

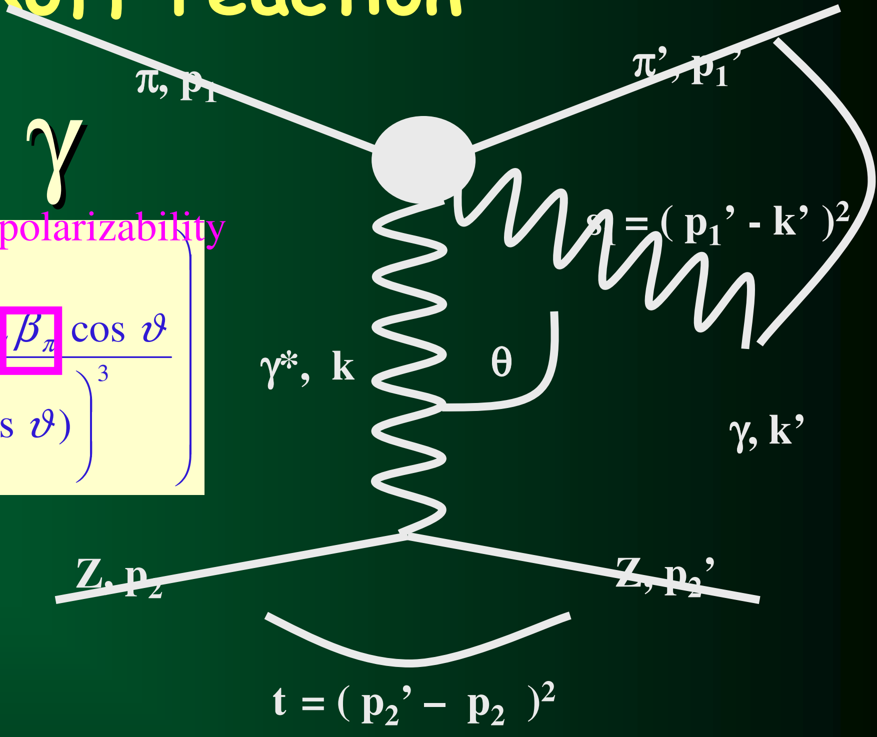


# Hadron beams in Compass: The Primakoff reaction

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

Electric & Magnetic polarizability

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




**first data taken in 2004**
**expected ~30k events**

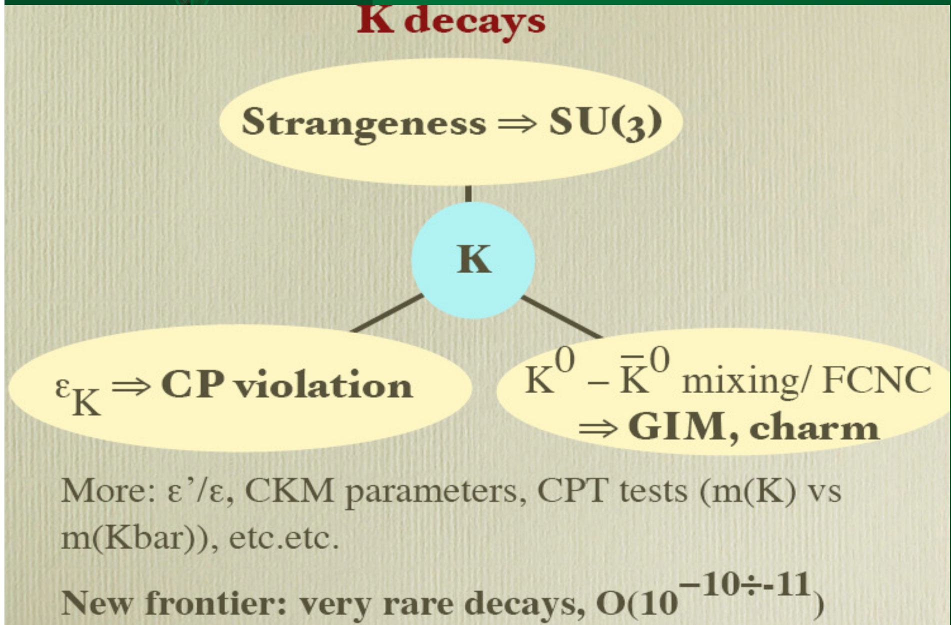
***nucleon spectroscopy***

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




## 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)

| | |
|---|---|
| $K^{\pm} \to \pi^{\pm}\pi^{\pm}\pi^{\pm}$ | $K_S^0 \to 3\pi^0$ |
| $K^{\pm} \to \pi^{\pm}\pi^0\pi^0$ | $K_S^0 \to \pi l \nu$ |
| $K^{\pm} \to \pi^{\pm}\pi^0\gamma$ | $\phi^{\pm}, \phi^{00}$ |

Long-distance modes

(tests of low-energy effective theory)

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

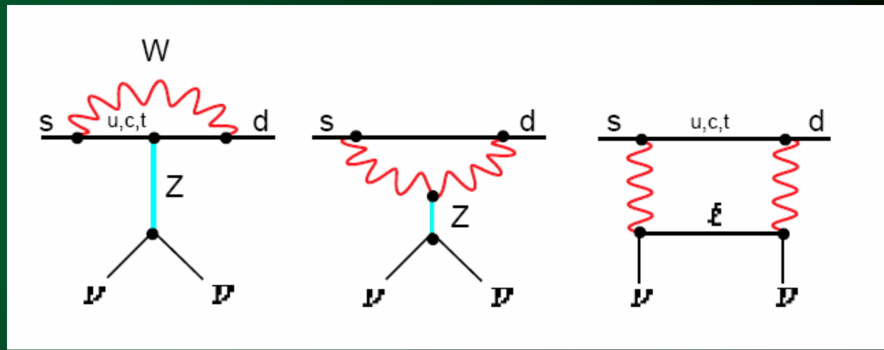
A measurement of the 4 decay modes

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

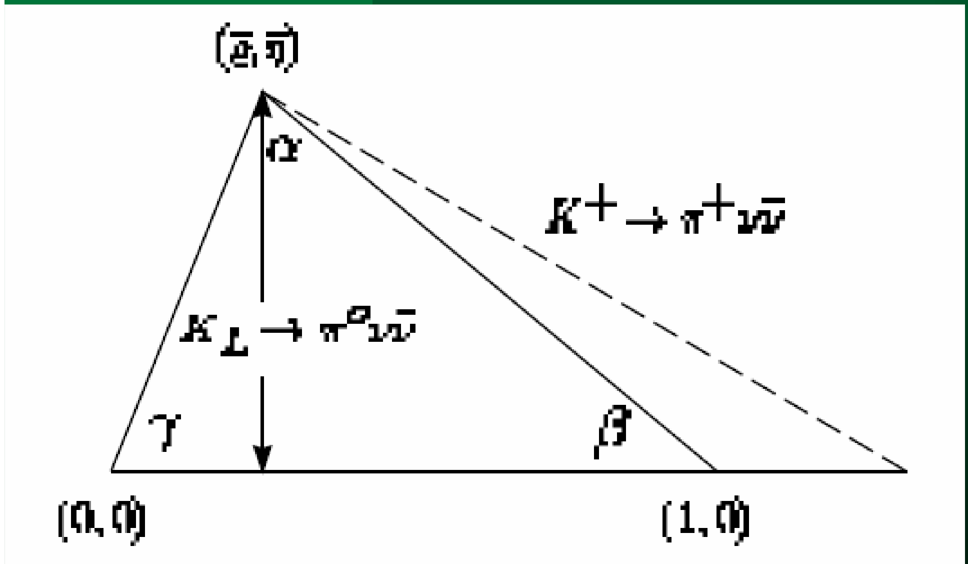
is a crucial element in the exploration of the new physics discovered at the LHC.

# Physics motivation

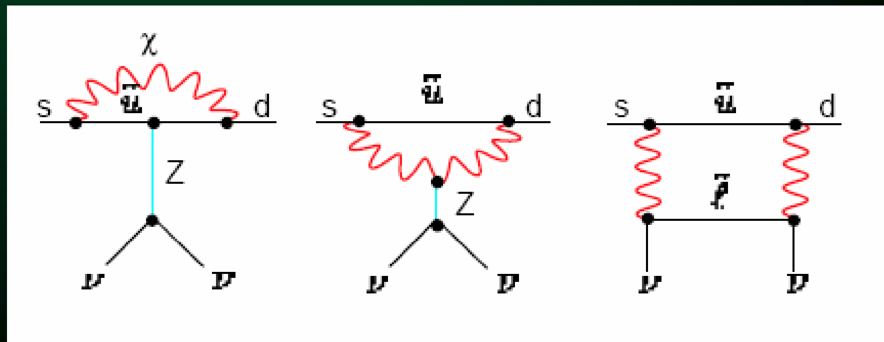
Probes short distance behaviour of the Standard Model




Acurate determination of the universality triangle




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



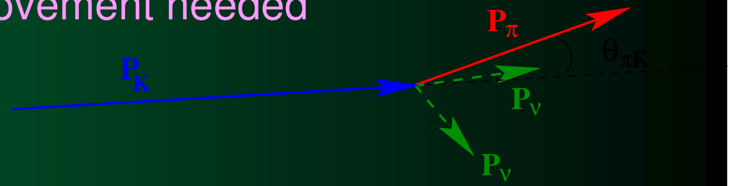

Independent of the B-system

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

Branching ratio measured by E787/E949

significant improvement needed

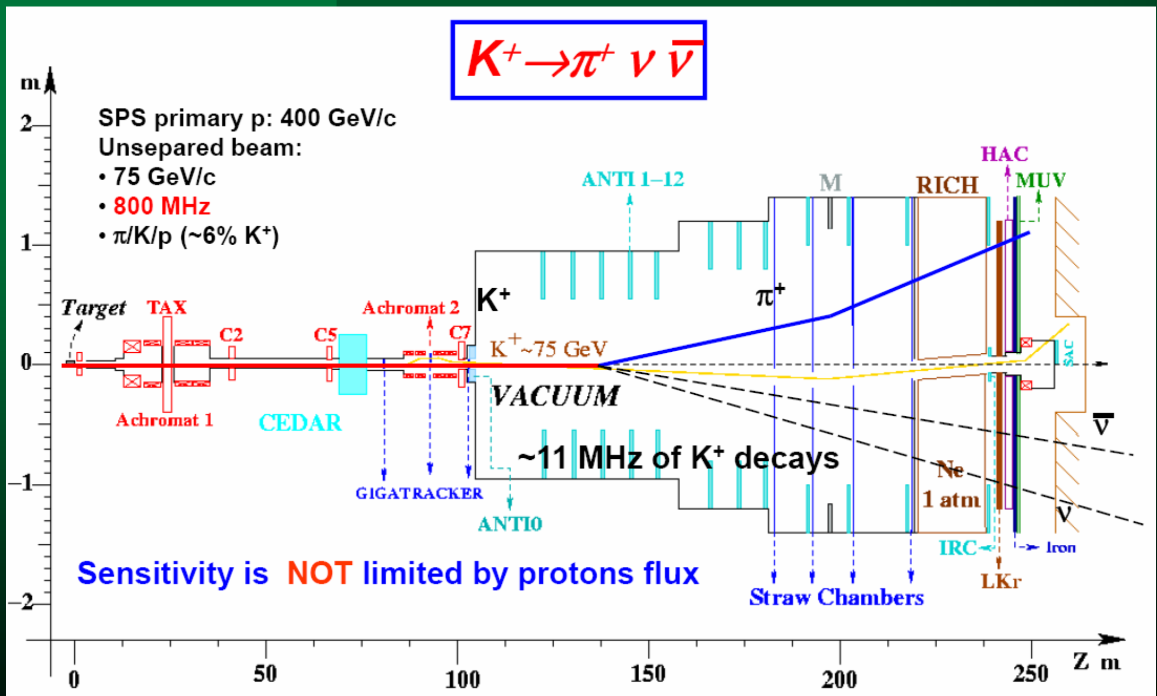
$$BR(K^+ \to \pi^+ \nu \bar{\nu}) = 1.47^{+1.30}_{-0.89}\ 10^{-10}\ s$$

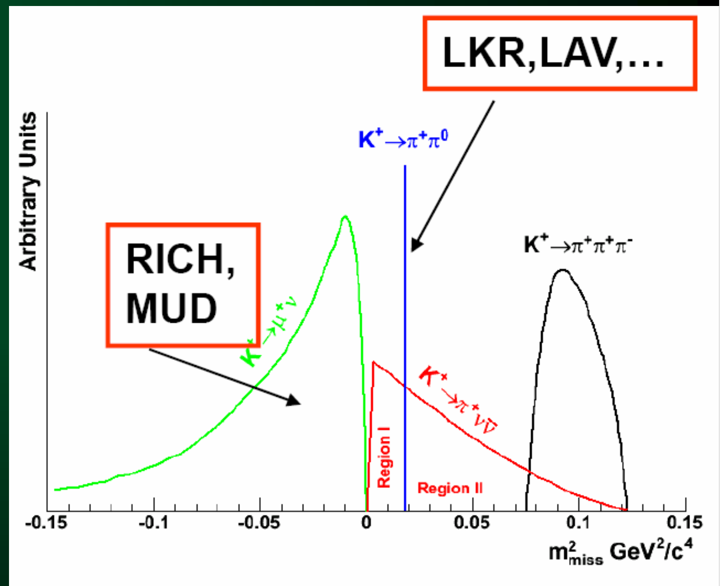



**SM prediction to be tested:**

Kinematical rejection

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



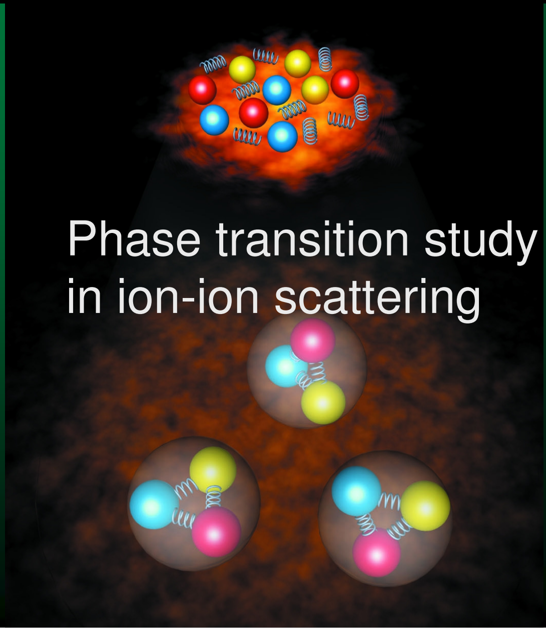

+ veto on photons to remove $K^+ \to \pi^+ \pi^0$ background

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

(**SHINE** – **S**PS **H**eavy **I**on and **N**eutrino **E**xperiment)


Experiment running,
(after first year of data taking)

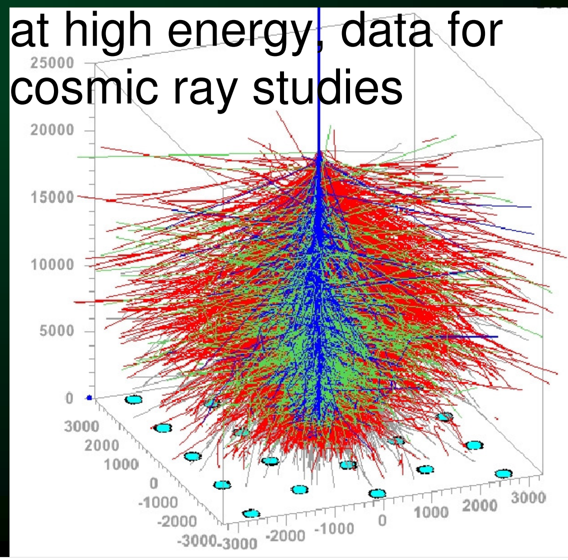
Three subjects combined around detector with high acceptance and good particle identification: NA49 detector

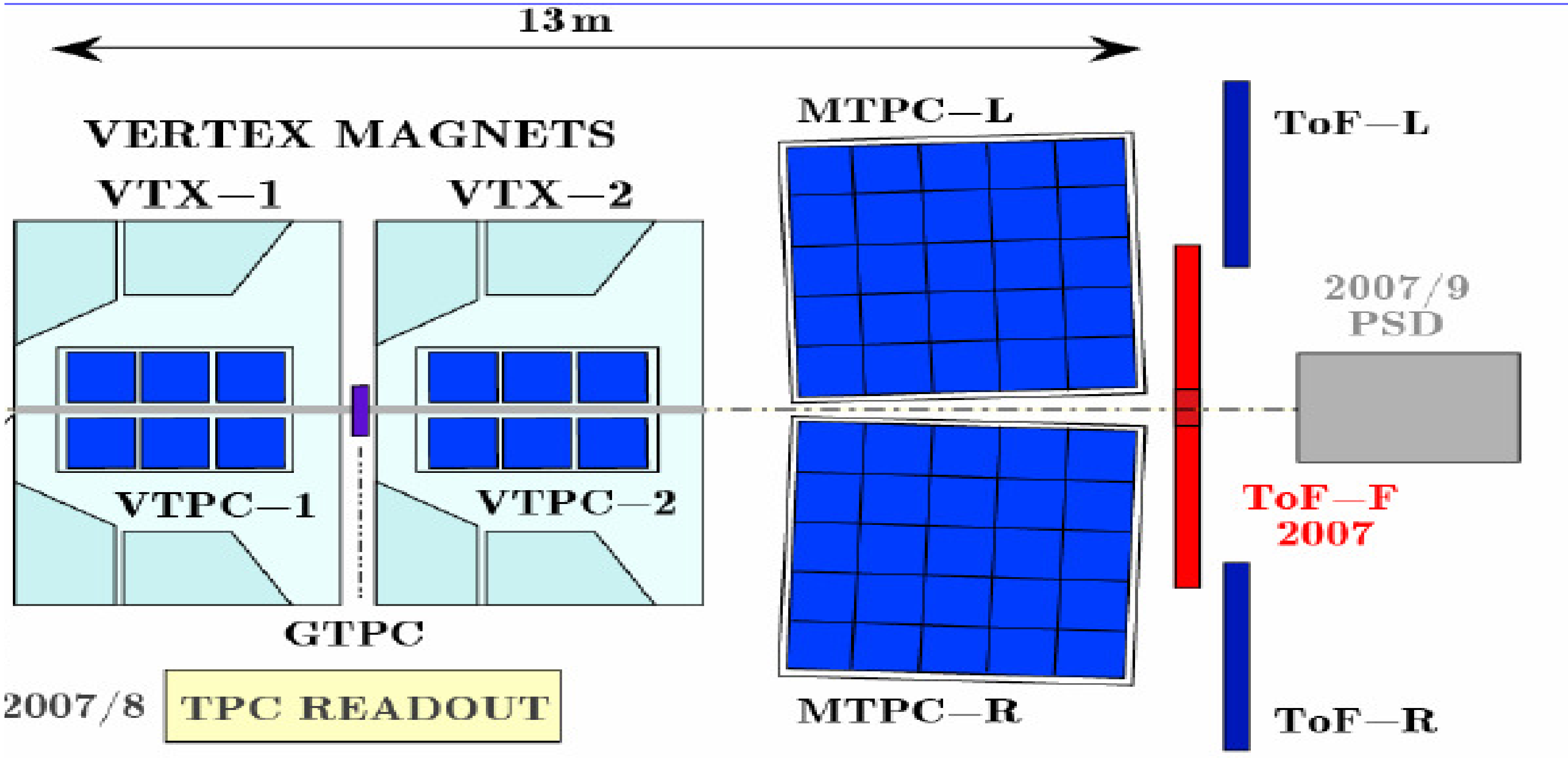


Phase transition study in ion-ion scattering

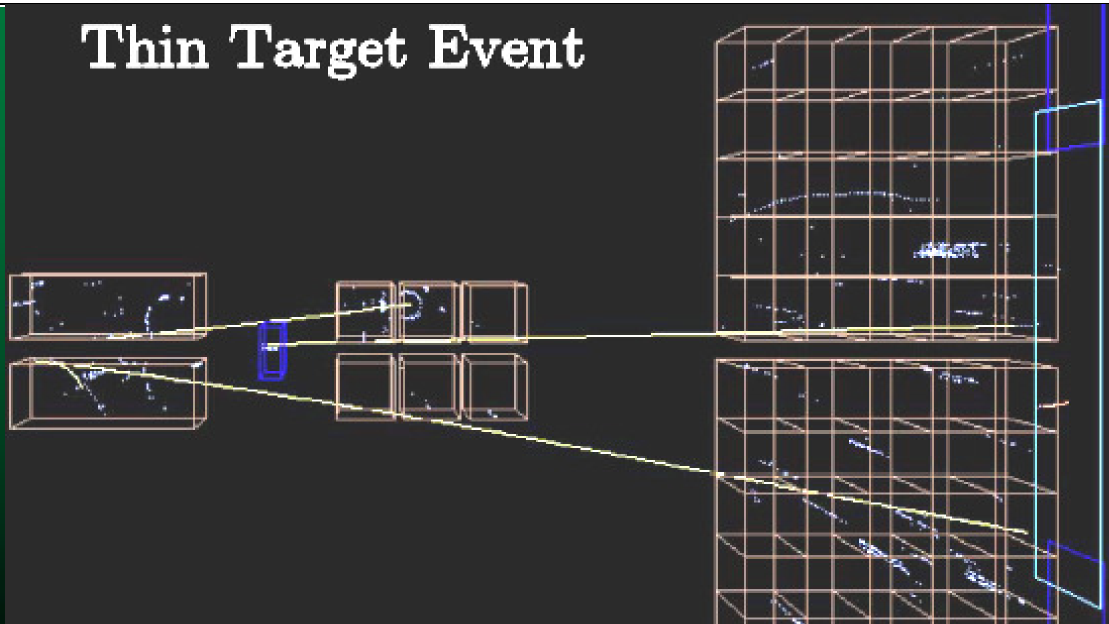
Precise measuremen of hadron production in pC scattering
→input for neutrino beam simulations (T2K)

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






# 2007 run

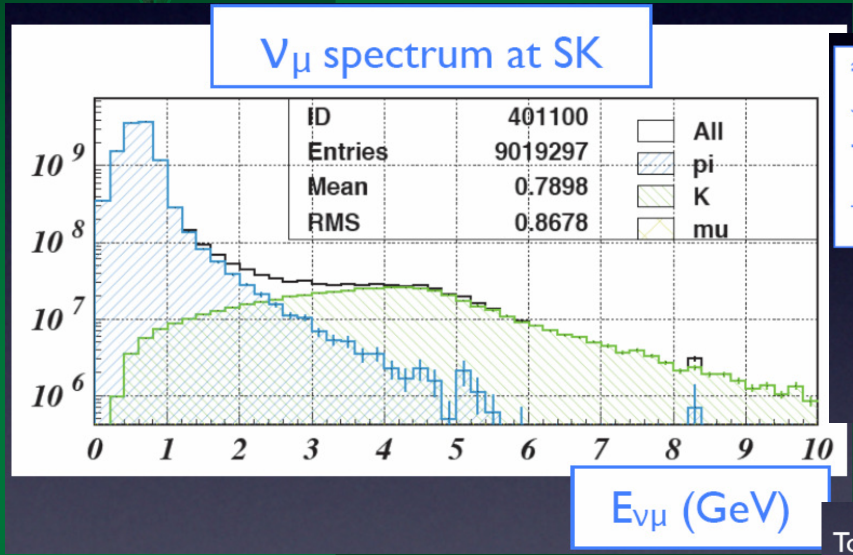


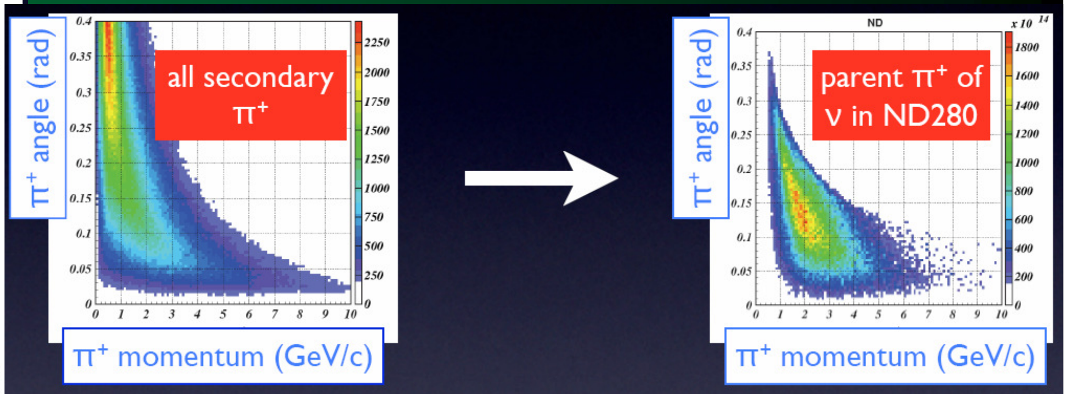

## Information for neutrino beam in T2K experiment

data with 30 GeV protons on two targets:

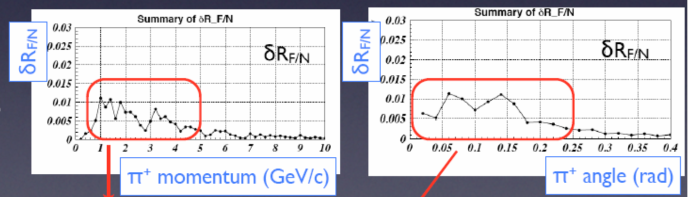
- 2 different carbon targets (isotropic graphite, $\rho = 1.84$ g/cm³):
  - Thin Carbon Target: 2.5 x 2.5 x 2cm³, int. length ~0.04
  - T2K Replica Target: Ø=2.6cm x 90cm, int. length ~1.9

# Why production of $\pi$ and K have to be knows better?

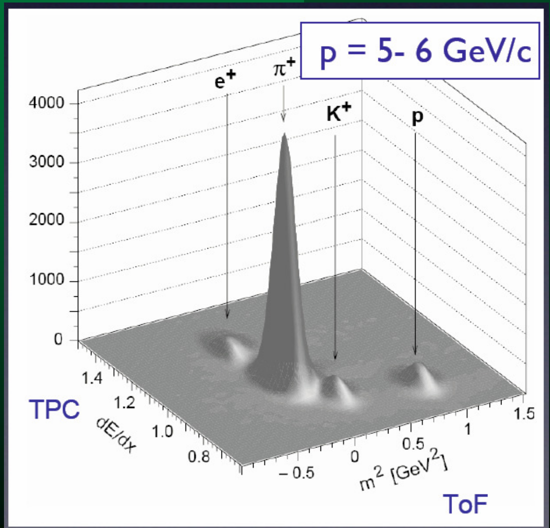



To define quantitatively the region of interest the particle yield has been increased by 30% independently in each momentum and angle bin.




**Region of interest:**
**0.5 < p <5 GeV/c ; 0 < θ < 250 mrad**

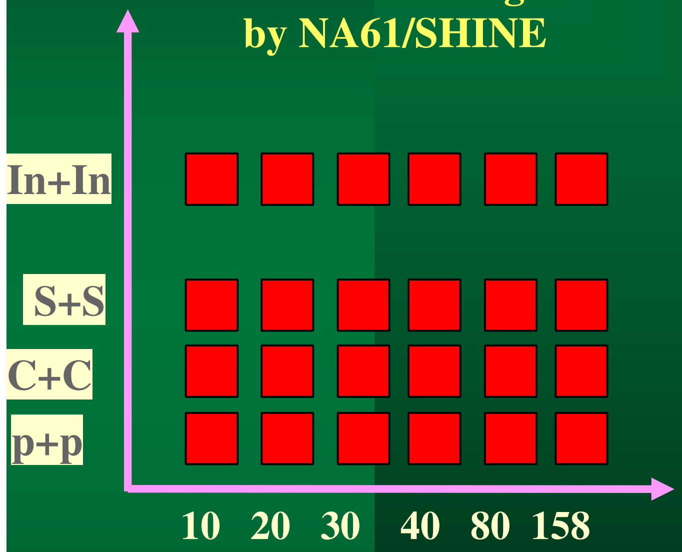


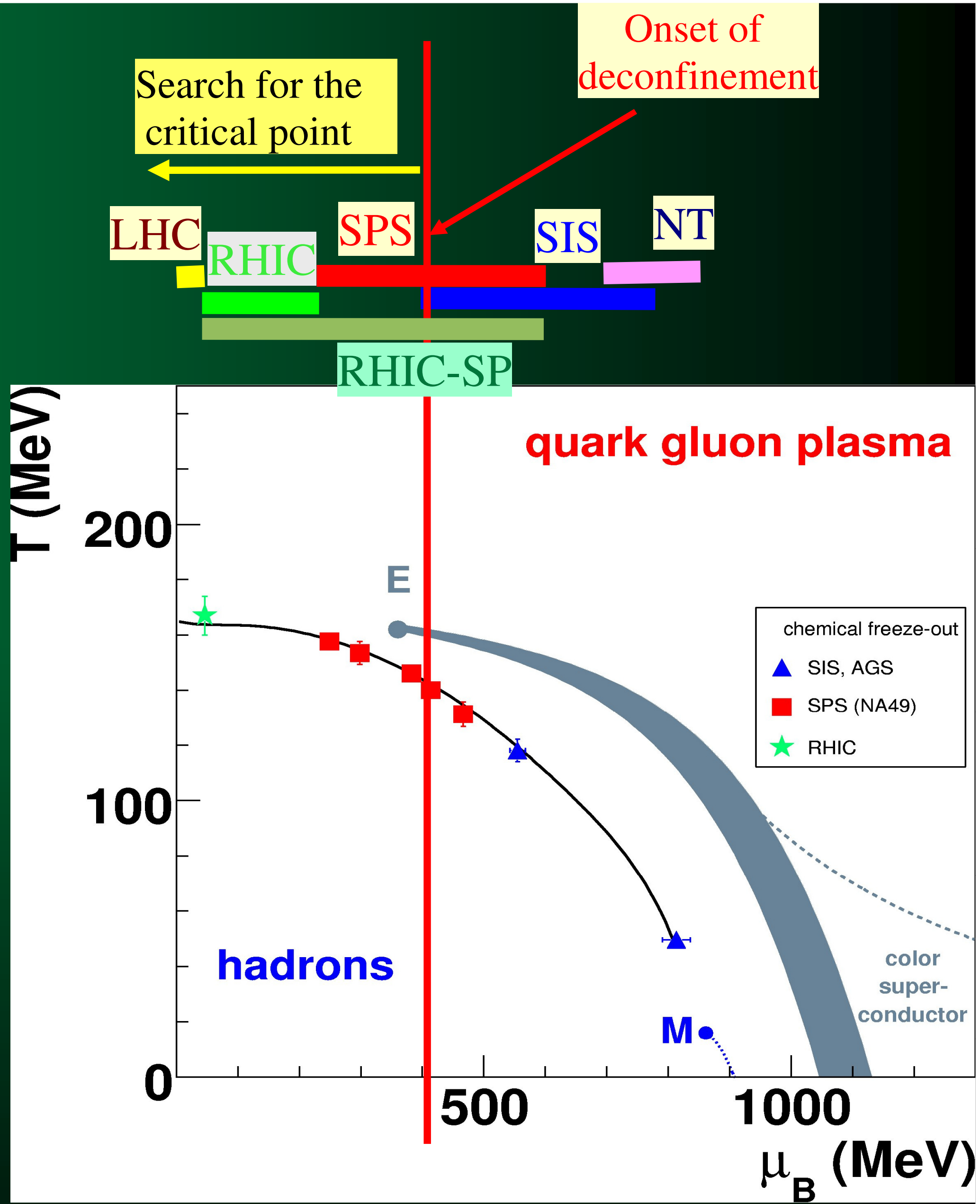

Needed statistics to improve knowledge about beam

**~200k $\pi^+$ 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)

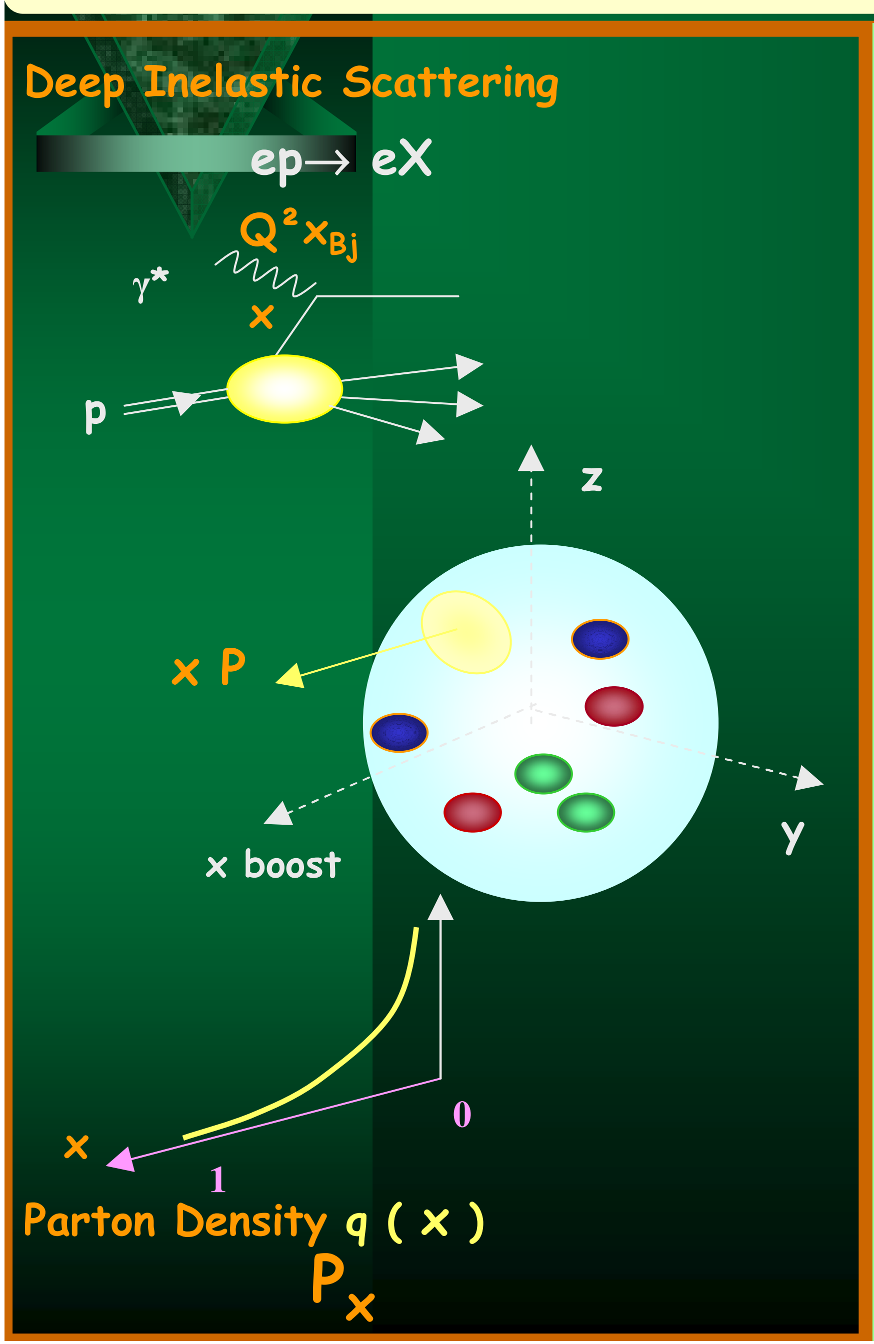
**General Parton Distributions**

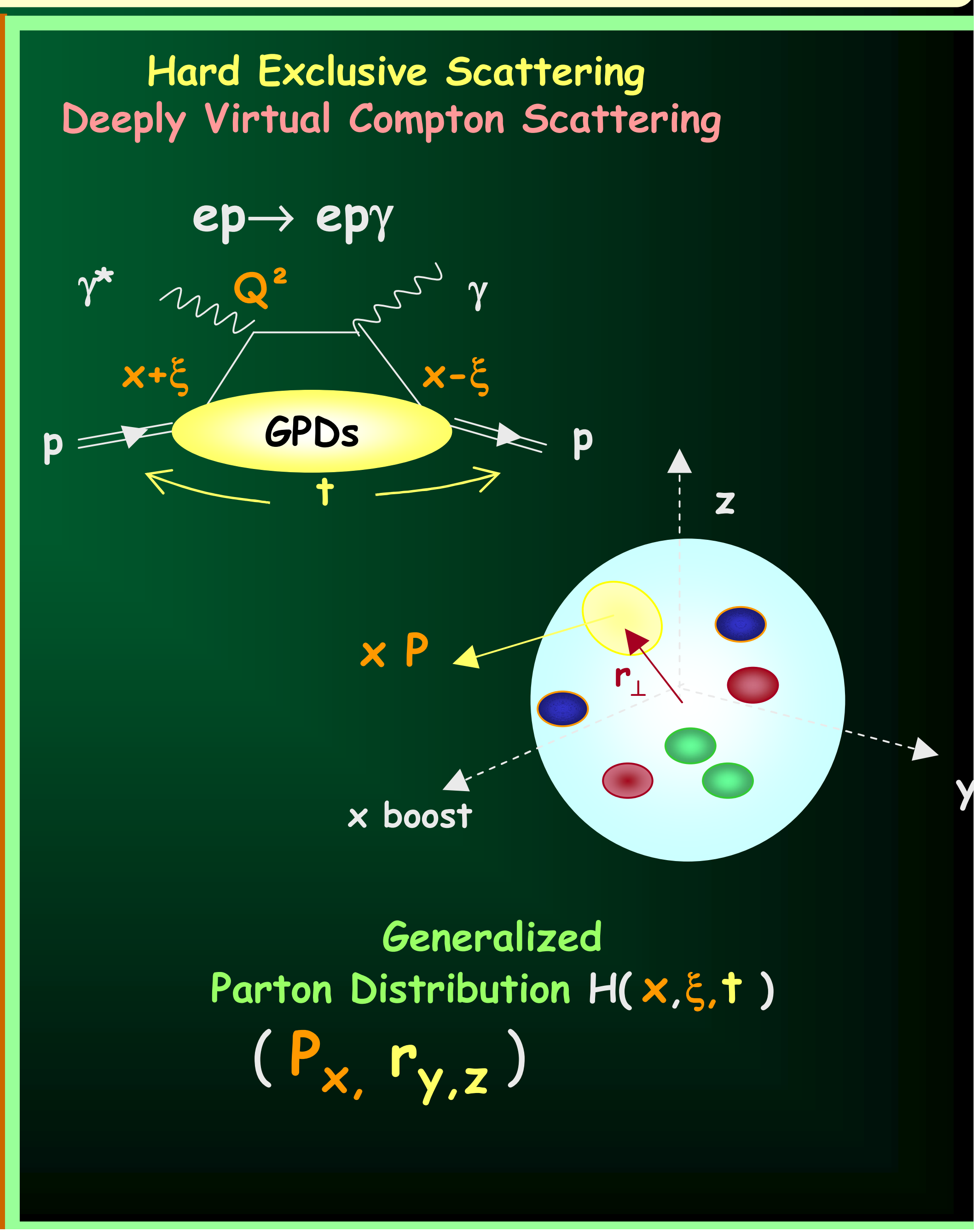
Next step – study 3D structure of the nucleon

→ additional transverse information

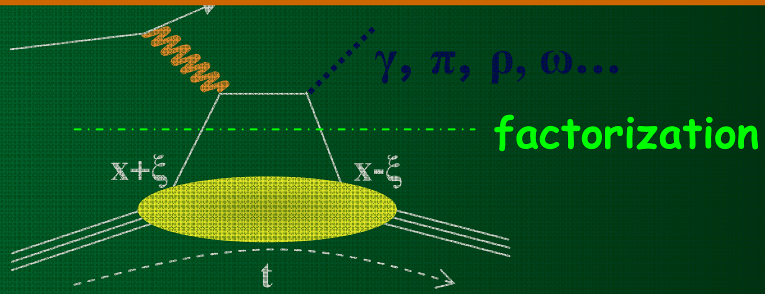
→ present structure functions – limit of 3D case

# NEW : 3-dimensional picture of the partonic nucleon structure



# GPDs and relations to the physical observables



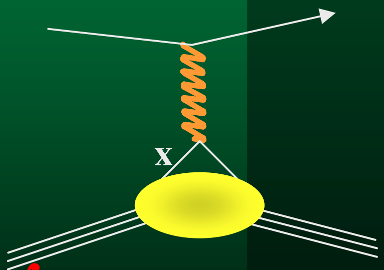

The observables are some integrals of GPDs over x

Dynamics of partons in the Nucleon Models: Parametrization

Fit of Parameters to the data

$$\mathbf{H},\tilde{\mathbf{H}},\mathbf{E},\tilde{\mathbf{E}}\,(x,\xi,t)$$

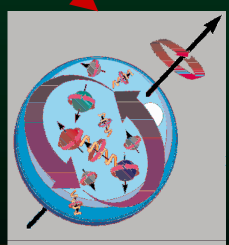
**Elastic Form Factors**




$$\int \mathbf{H}(x,\xi,t)\,dx = F(t)$$

**Ji's sum rule**

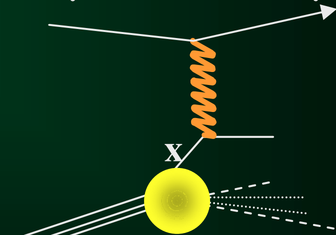
$$2\mathbf{J}_q = \int x\,(\mathbf{H}+\mathbf{E})(x,\xi,0)\,dx$$



$$\overbrace{\frac{1}{2} = \frac{1}{2}\,\Delta\Sigma + L_q}$$

$$+\Delta G + L_g$$

**parton density**




$$\mathbf{H}(x,0,0) = \mathbf{q}(x)$$

$$\tilde{\mathbf{H}}(x,0,0) = \Delta\mathbf{q}(x)$$

# 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