Prospects of DIS with fixed targets

Ewa Rondio,
IPJ, Warsaw, Poland

- Nucleon structure road map
- Options for additional information (A_{PV})
- GPD and DVCS measurements

→ high intensity proton beam at Cern

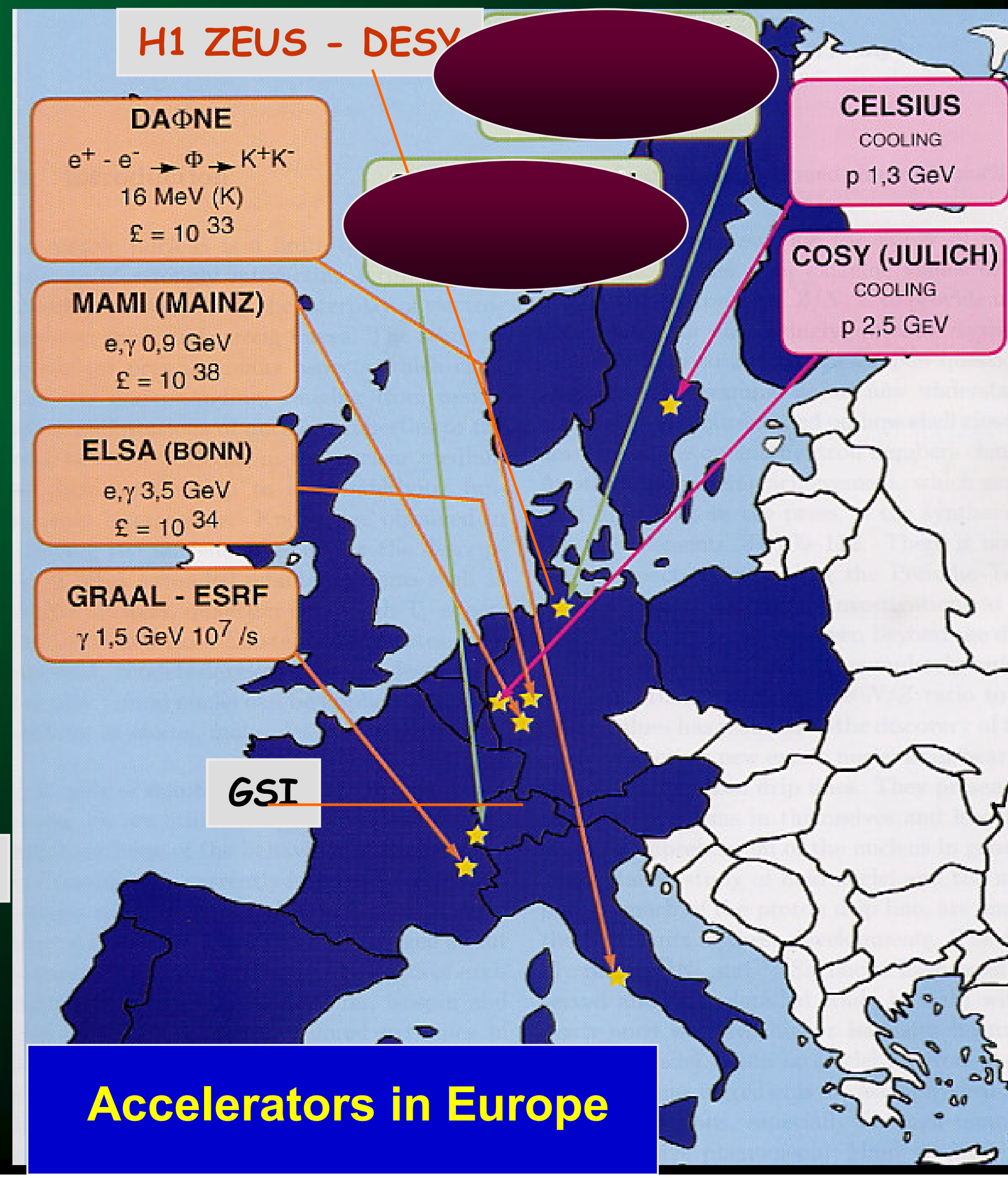
DIS2005, Madison 30.04.2005

Lepton-Hadron and Hadron Physics

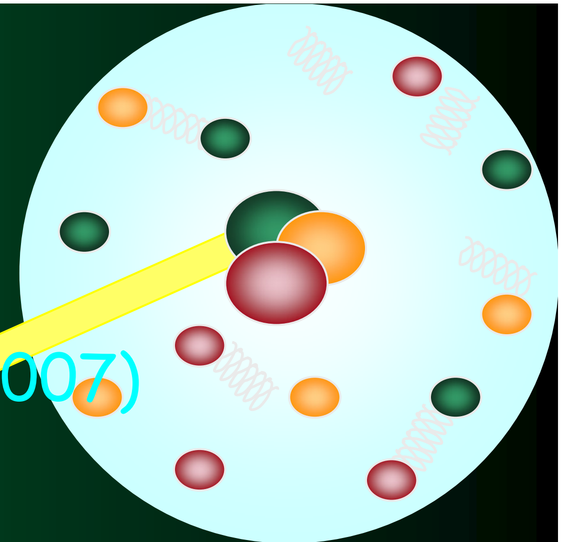
- presently available accelerators
- marked places where FT DIS physics

in USA

← CDF D0 - FNAL



Present situation



Spin averaged:

- High luminosity running with HERA (till 2007)
- High x at JLab

Spin dependent:

- Statistics accumulation and analysis of Hermes data (DESY) (till 2007)
- Many precise data from JLab
- High intensity, high energy muon beam at CERN – Compass – more running: 2006 – 2009

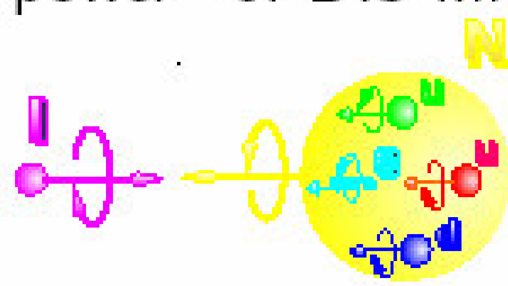
many new results presented at this conference,

→ more to come from present experiments in the neast future → not discussed here

- Neutrino beams → talk by J. Morfin

Main goal of DIS for long time was bringing data for determination of Parton Distribution Functions (PDF)

"resolving power" of DIS microscope



$\leftrightarrow$ virtuality Q^2 of γ^*: $R \simeq 1/\sqrt{Q^2}$

→Shape of quark and gluon distributions at fixed value of Q^2

→Evolution in Q^2 described with evolution equations

→Test of QCD

This is still valid

- where is the place for FT?

Road maps in studying nucleon structure

Fixed target data — Parton distributions fits

Spin dependent physics →

Collider: high $\sqrt{s}$
extended Q^2 range
low x

Better constrained functional forms
Test with wide range of Q_0^2

Low x extrapolation, behaviour

→ Spin independent physics

Very high precision
High luminosity measuremets
→ Back to fixed target

Checking assumed symmetries as: $q_{sea} = \bar{q}_{sea}$ $u_p = d_n$

GPD's

High x bahaviour
and parton fractions for x→1

Additional information from parity violating asymmetries A_{PV}

- beams with spin parallel or antiparallel to momentum

$$Q^2 = M_Z^2$$

$$A_{PV} \equiv \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \approx \frac{|A_Z|}{|A_\gamma|} \approx \frac{G_F Q^2}{4\sqrt{2}\pi\alpha}$$

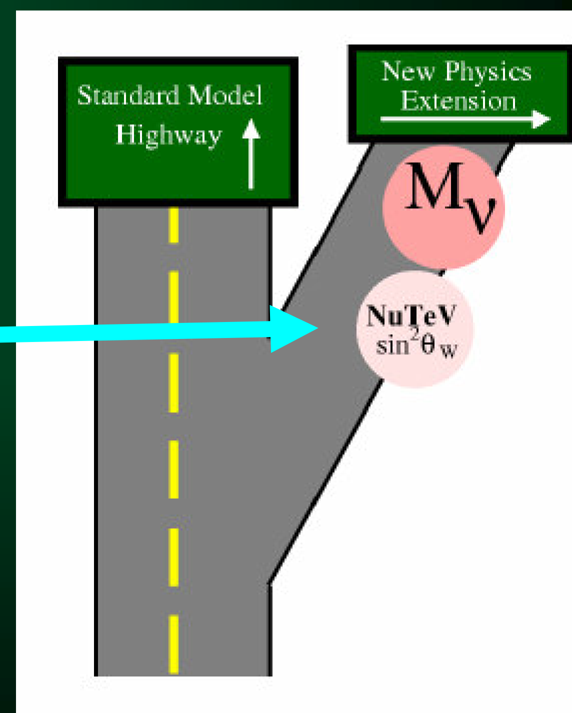
- presently experimental developements allow measurements of asymmetries at **parts per milion level and fractionaly %**
- **spin flip and intensity conditions → electron beam**

Weak neutral current interactions

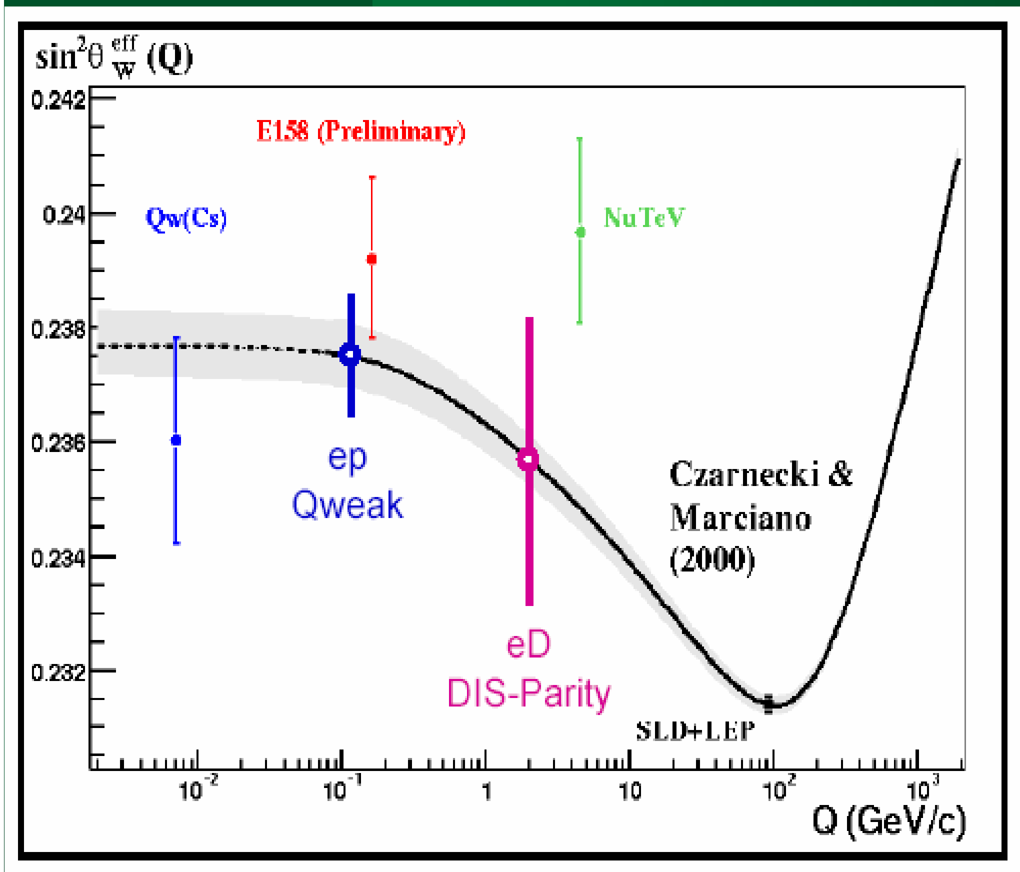
- amplitudes from electron axial vector coupling and vector coupling of target particle
  → probing nucleon structure

- when vector coupling very well known or ratio of weak and electromagnetic amplitude insensitive to hadron structure
  → probe of new physics

- amplitudes from electron vector coupling and target axial-vector coupling product
  → probing axial nucleon current



problem waiting for solution/explanation
→ NuTeV anomaly



From talk by Y. Kolomensky
At SLAC summer institute, August 2004

$\sin^2\theta_W$ determined from the ratio:

$$R = \frac{\sigma^{\nu}_{NC} - \sigma^{\bar{\nu}}_{NC}}{\sigma^{\nu}_{CC} - \sigma^{\bar{\nu}}_{CC}}$$

Assumptions:

- Isospin symmetry ie. $u_p(x)=d_n(x)$ (u in proton as d in neutron)
- Sea momentum symmetry: $s=\bar{s}$ and $c=\bar{c}$
- Nuclear effects common in W and Z exchange

DIS at high x - A_{PV}

→ on isoscalar targets brings ratio of weak to electromagnetic amplitudes

→ on proton target brings u and d contribution

- Deviation form charge symmetry in nucleon

$$u_p - d_n = \delta u$$

Possible explanation of the NuTeV anomaly

d/u at high x

- Asymmetries sensitive to d/u as x→1
  accuracy of 1-2% required

  → PDF → **More constrains for distributions at high x**
  → nucleon wave function

- Suppression of d/u expected,
  → SU(6) d/u ~ 0.5 for x=1
  → simple SU(6) breaking d/u→0 as x→1
  → QCD d/u=0.2 as x→1

- at low energy →higher twist, (JLab)
  can be used to search signal from diqarks

A_{PV} measurements with electron beams – where?

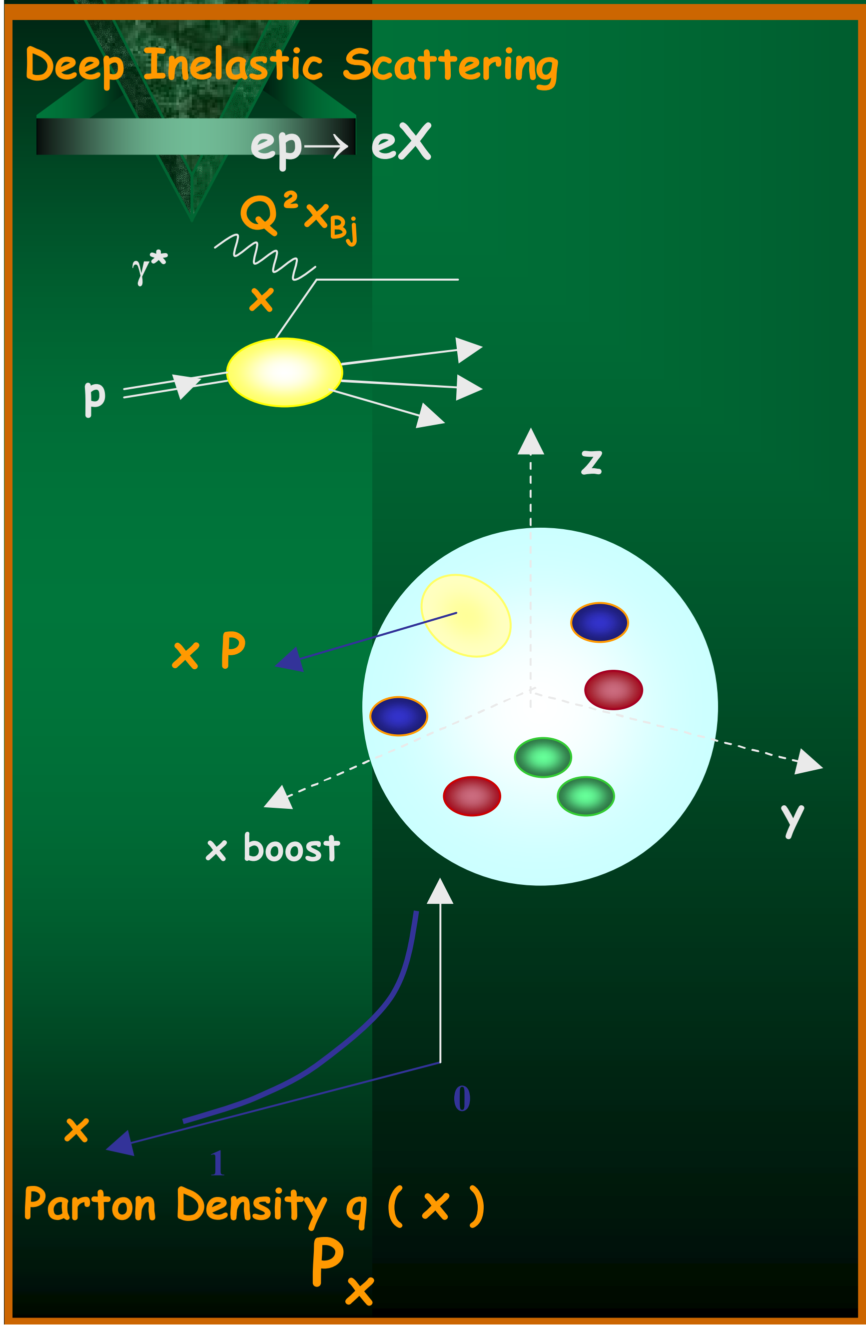
- A lot will be done at JLab

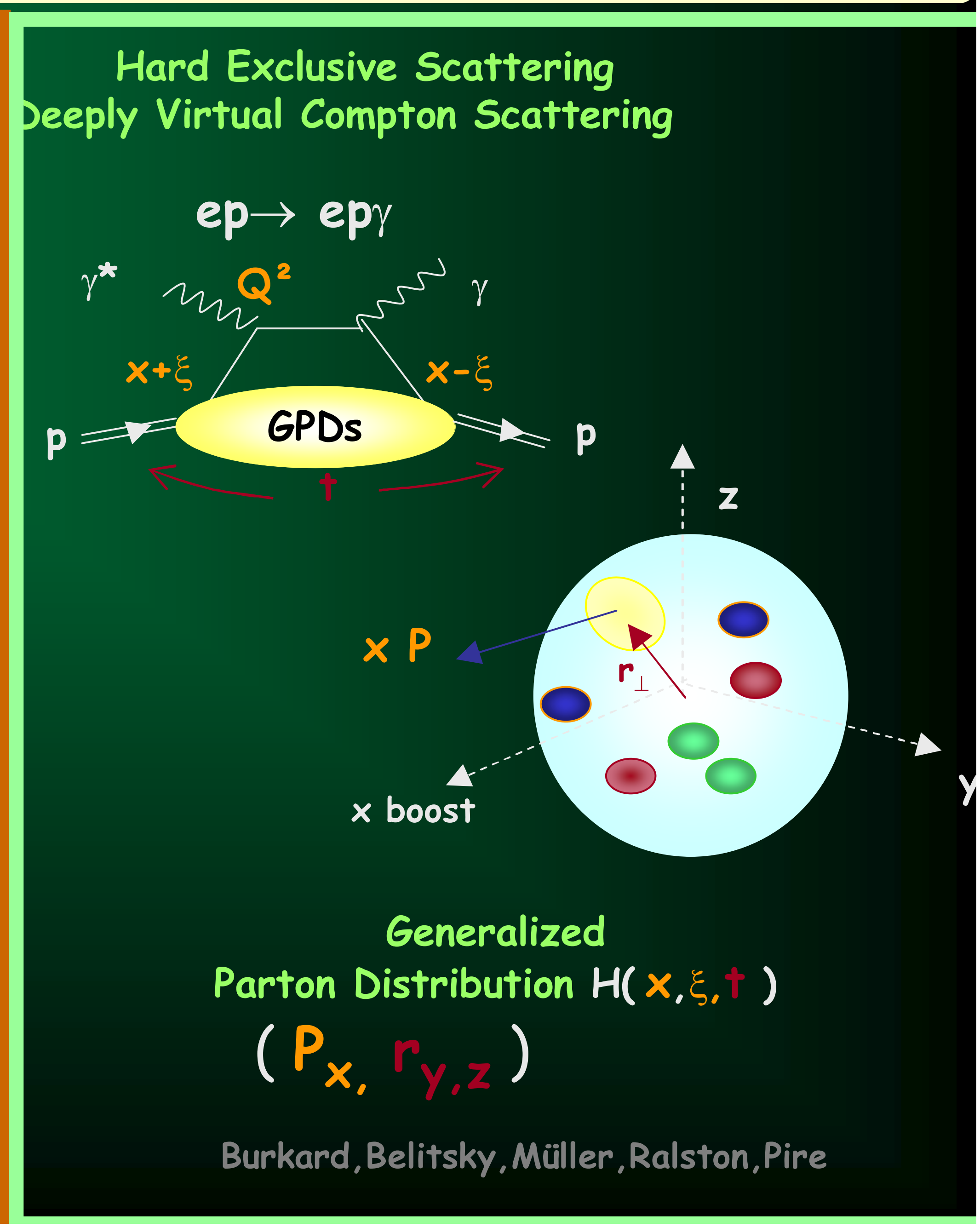
  -- very important – extention of kinematics with 12 GeV upgrade

- Higher energy possible at SLAC

  -- but no plans for such measurements

NEW : 3-dimensional picture of the partonic nucleon structure





Deeply Virtual Compton Scattering – tool to study nucleon

Forward amplitude of Compton scattering is related to DIS

$$2MW_{\mu\nu} = \frac{1}{\pi}\,\mathrm{Im}\,T_{\mu\nu} \qquad t=0$$

DVCS :

$$\gamma^{*} h \to \gamma\, h$$

Measures „off-forward" („squed") parton distributions,

structure functions and form factors are their limits

Relation with nucleon spin

$$J^i = \frac{1}{2}\varepsilon^{ijk}\int d^3x\, M^{0jk}$$

Where M^{0jk} is the angular momentum density, which can be expressed

in terms of energy momentum tensor: $M^{\alpha\mu\nu} = T^{\alpha\nu}x^{\mu} - T^{\alpha\mu}x^{\nu}$

and $T^{\mu\nu}$ can be separated into quark and gluon contributions (gauge invariant

therefore: $\vec{J}_{QCD} = \vec{J}_q + \vec{J}_g$ where quark and gluon contribution is interaction dependent

$$J^i_{\ q,g} = \frac{1}{2}\varepsilon^{ijk}\int d^3x\ (T^{0k}_{\ \ q,g}x^j - T^{0j}_{\ \ q,g}x^k)$$

processes $\gamma^*\gamma \to hh$

Related with DVCS by crossing relations

Experimentaly - measurements in e^+e^-

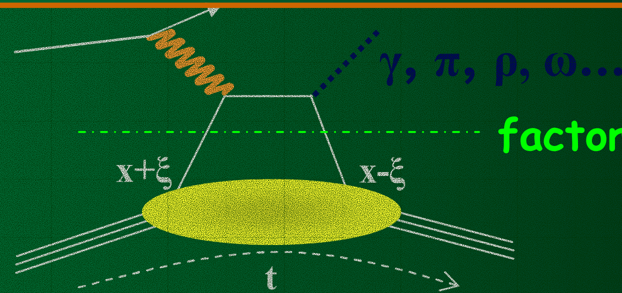
Exclusive vector meson production

Related by quark-parton duality

What does it bring ?

- Exclusive processes bear qualitatively new information on the nucleon structure
- Their dependence on momentum transfer give acess to transverse to the direction of motion distributions → 3 dimentional picture of the nucleon
- Second moments of PDG's (for $t \to 0$) allow determination of angular momentum carried by quarks

GPDs and relations to the physical observables



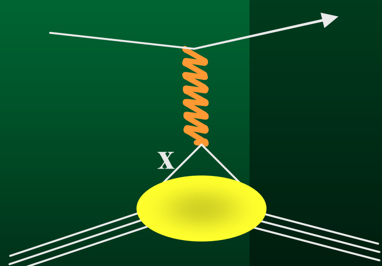
The observables are some integrals of GPDs over x

Dynamics of partons
in the Nucleon Models:
Parametrization

Fit of Parameters to the data

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

Elastic Form Factors



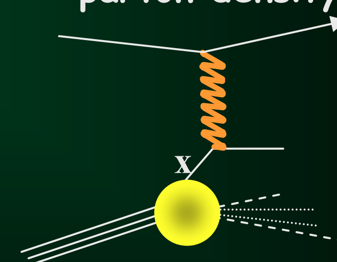
$\int \mathbf{H}(x,\xi,t)dx = F(t)$

Ji's sum rule

$2\mathbf{J_q} = \int x\left[\mathbf{H}+\mathbf{E}\right](x,\xi,0)\,dx$

$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + Lq + \Delta G + Lg$

parton density



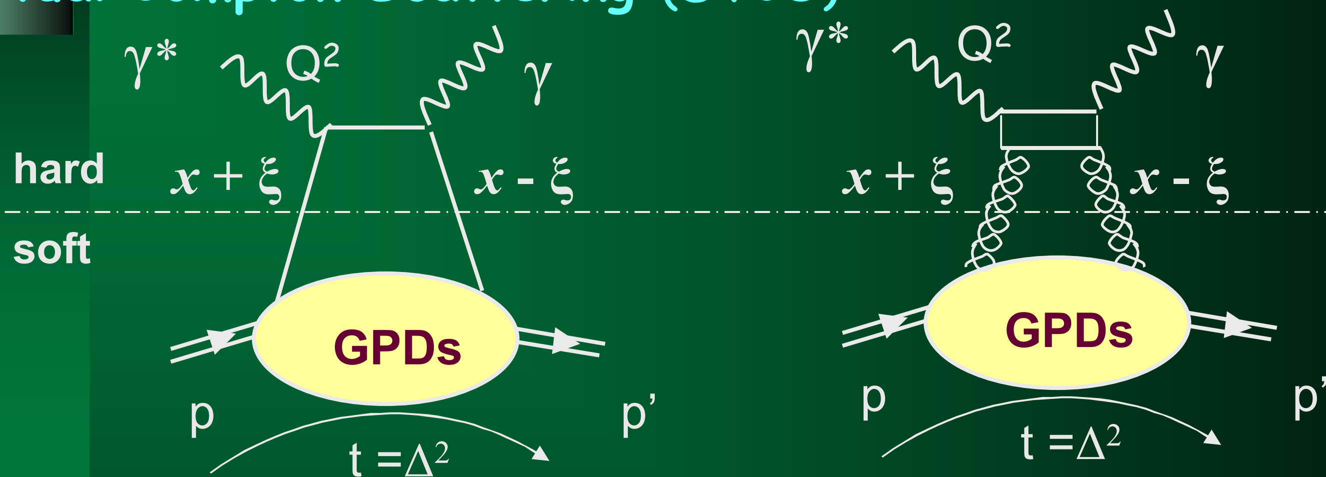
$\mathbf{H}(x,0,0) = \mathbf{q}(x)$

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

Necessity of factorization to access GPDs

Collins et al.

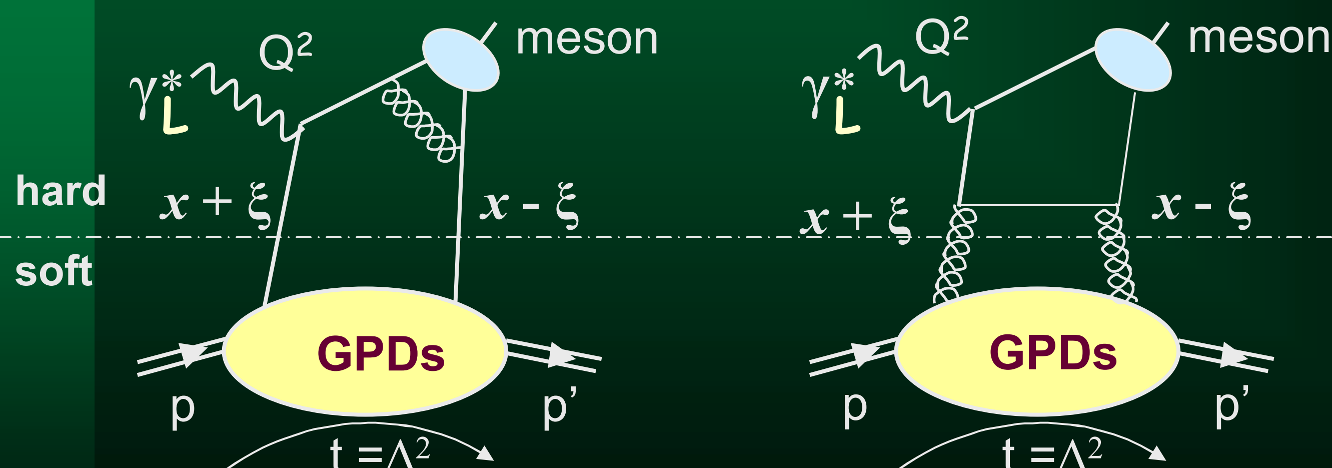
Deeply Virtual Compton Scattering (DVCS):



Q² large

$t \ll Q^2$

Hard Exclusive Meson Production (HEMP):



+ γ^*_L

Quark contribution

Gluon contribution

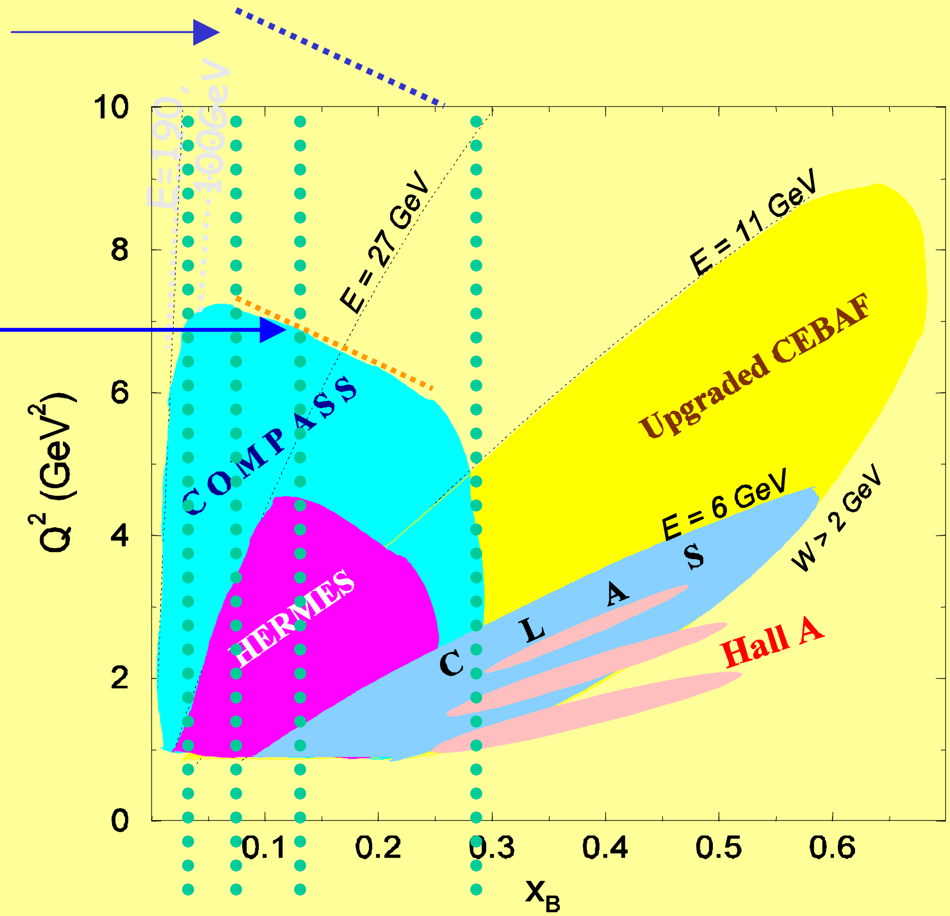
Complementarity of the experiments in the world

if Nμ × 2 $\Longrightarrow$ $Q^2 < 11$ GeV^2
for DVCS

Limitation by luminosity

now Nμ= 2.10^{8}μ per SPS spill
for DVCS
$\Longrightarrow$ $Q^2 < 7.5$ GeV^2

At fixed x_{Bj}, study in Q^2



$0.0001 < x_{Bj} < 0.01$ Gluons	Valence and sea quarks And Gluons	Valence quarks
H1 and ZEUS PLB517(2001) PLB573(2003)	**Hermes** PRL87(2001) **COMPASS** - plans	**JLab** PRL87(2001)

N.d'Hose

if Nμ × 2 $\Longrightarrow$ $Q^2 < 11\ GeV^2$
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Limitation by luminosity

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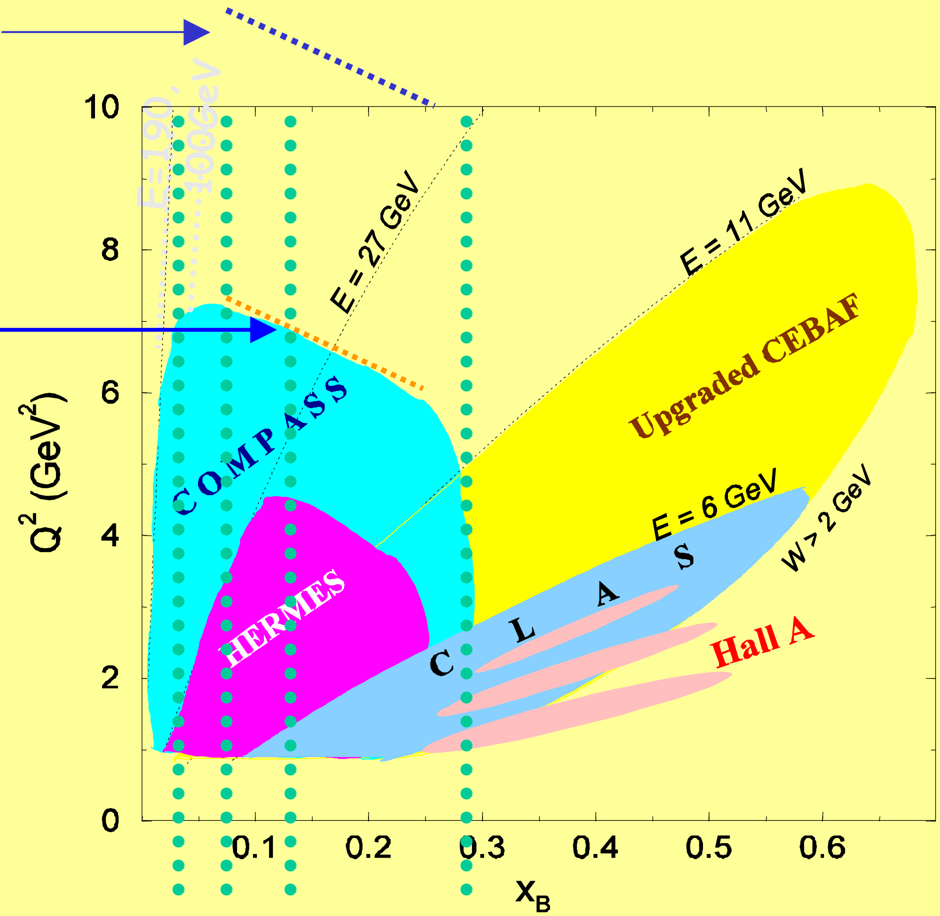


$0.0001 < x_{Bj} < 0.01$
Gluons

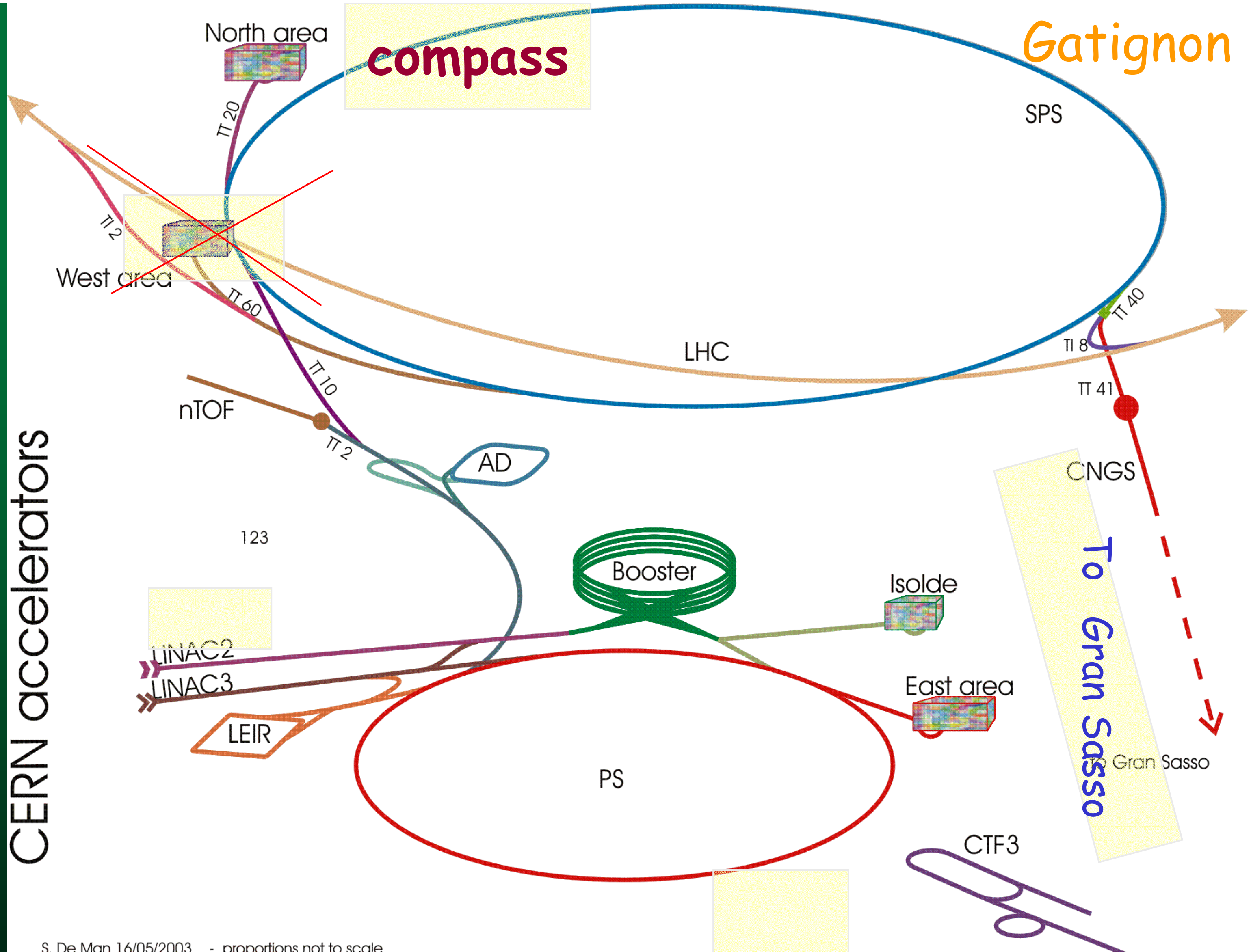
Valence and sea quarks
And Gluons

Valence quarks

H1 and ZEUS

Hermes
COMPASS

JLab

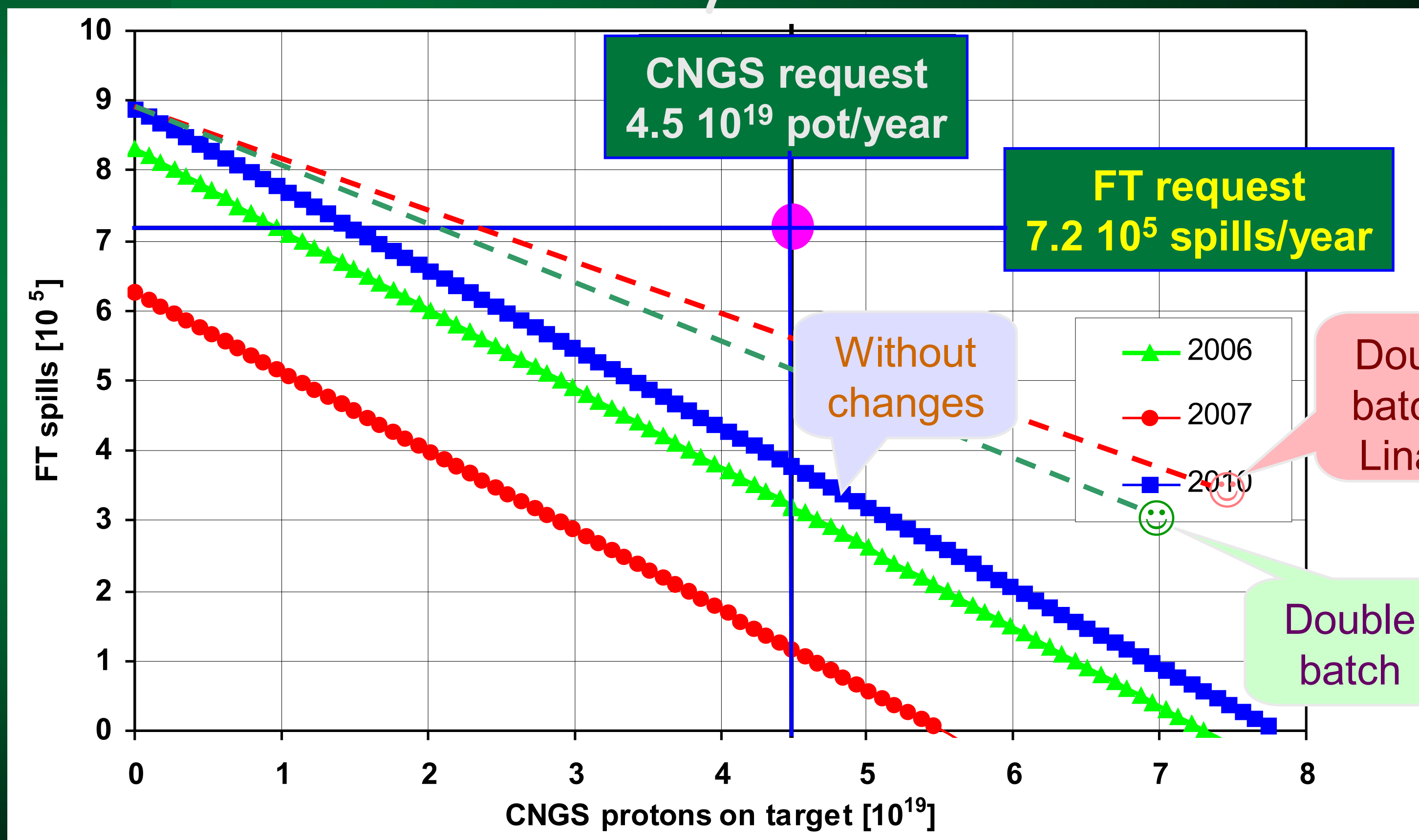


Proton luminosity upgrade at CERN

Proton intensity at CERN
Fixed target ↔ CNGS

Benedikt
Garoby

- FT + CNGS share SPS cycles

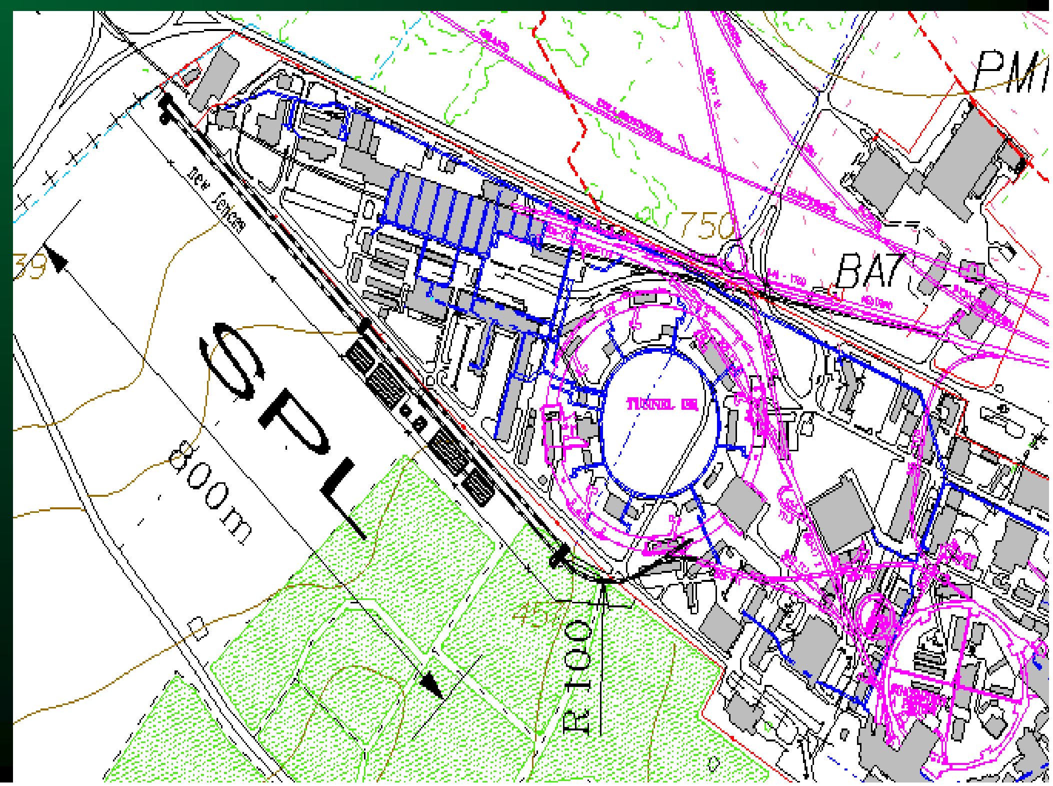


- impossible to meet FT + CNGS demands

Upgrades - plans

- started 2004/5:
  - PS: multi-turn ejection
  - increase SPS intensity (impacts all machines)
  - 0.9s PSB repetition
- Linac 4 design
  → construction decision
  @ end 2006

- prepare decision
  on optimum future
  accelerator
  - study of a
  Superconducting Proton Linac (SPL)
  - alternative scenarios
    for the LHC upgrade



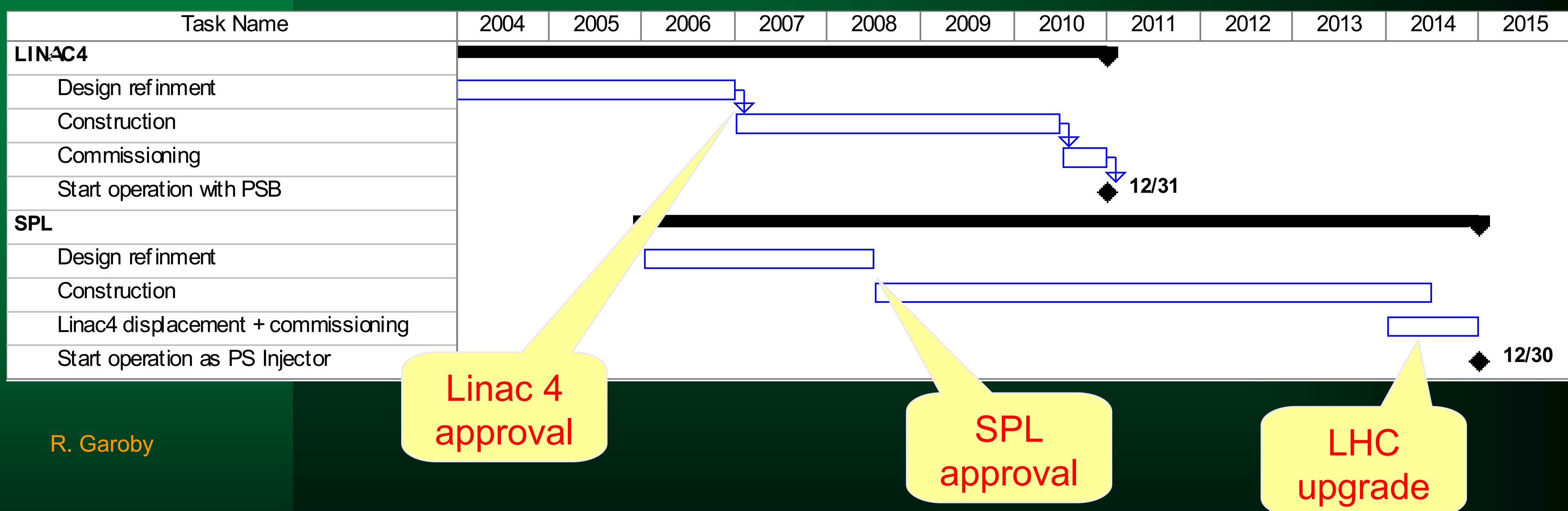
Gilardoni

SPL Proposed Roadmap

As in a talk by L. Maiani at the "Celebration of the Discovery of the W and Z bosons". ("CERN Future Projects and Associated R&D").

Assumptions:

- construction of **Linac4** in 2007/10 (with complementary resources, before end of LHC payment)
- construction of **SPL** in 2008/15 (after end of LHC payments)



R. Garoby

Warning: Compressor ring and detector (8 years) are not quoted
Protons from the SPL ready in 2015

Gatignon

North Area: μ & Hadrons

- M2 for COMPASS — increased intensity essential
  - primary p

- μ intensity ? — radiation limits ???

  option for μ^+ and μ^- -- with high intensity

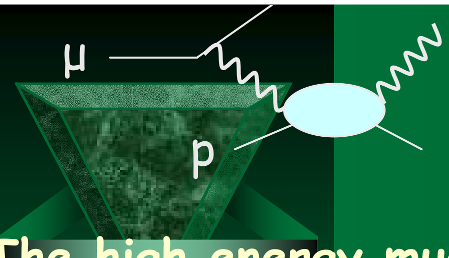
Based on 2004 beam characteristics

$N\mu = 2.10^8$ per SPS cycle duration 5.2s repetition each 16.8s

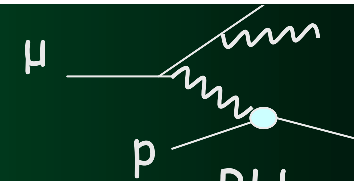
with a new 2.5m liquid hydrogen target $\Rightarrow$ $L = 1.3\ 10^{32}\ cm^{-2}s^{-1}$

with the 1.2m ^6LiD target $\Rightarrow$ $L = 4.2\ 10^{32}\ cm^{-2}s^{-1}$

one year of data taking $\equiv$ 150 days $\equiv$ $7.2\ 10^5$ spills/year



DVCS+ Bethe Heitler

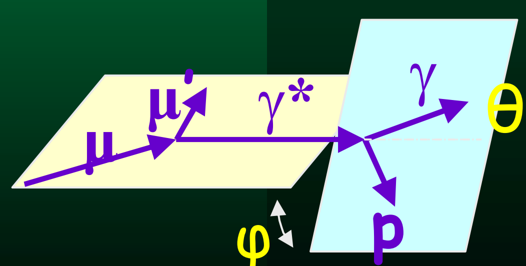


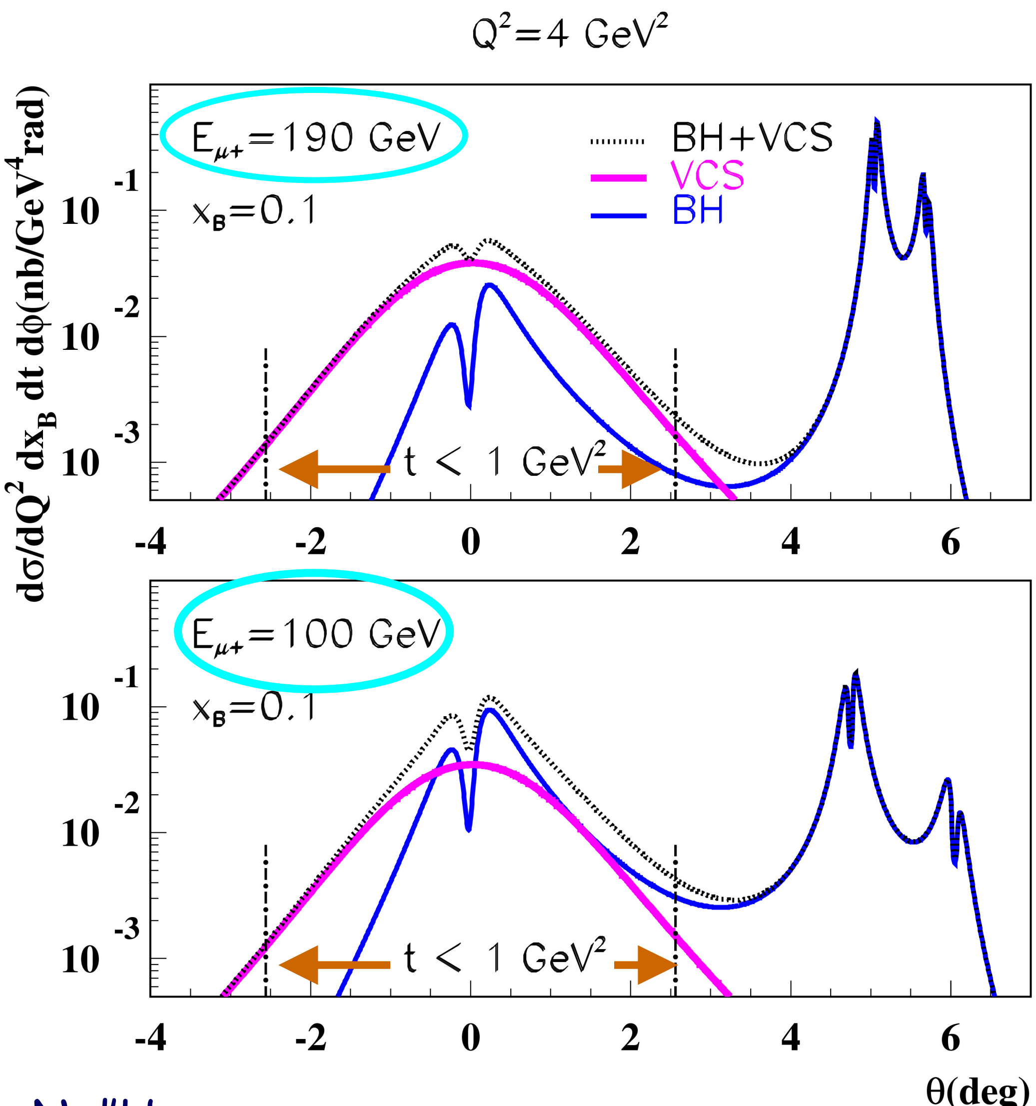
The high energy muon beam at COMPASS allows to play with the relative contributions DVCS-BH which depend on

$$1/y = 2\, m_p\, E_\ell\, x_{Bj}\, /Q^2$$

Higher energy: DVCS>>BH
⇒ DVCS Cross section

Smaller energy: DVCS~BH
Interference term will provide the DVCS amplitude





N.d'Hose

Advantage of μ^+ and μ^-

for Deeply virtual Compton scattering (+Bethe-Heitler

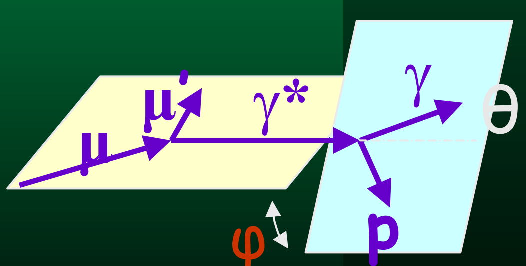
$$A^{DVCS}_{(\mu p\to\mu p\gamma)} = \int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi+i\varepsilon} = \mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi} - i\pi H(x=\xi,\xi,t)$$

$t, \xi \sim x_{Bj/2}$ fixed

$$d\sigma_{(\mu p\to\mu p\gamma)} = d\sigma^{BH} + d\sigma^{DVCS}_{unpol} + P_\mu\, d\sigma^{DVCS}_{pol}$$

$$+ e_\mu\, a^{BH}\, \mathcal{Re}\, \mathbf{A}^{DVCS} + e_\mu P_\mu\, a^{BH}\, \mathcal{Im}\, \mathbf{A}^{DVCS}$$

$\times \cos n\varphi$ $\quad$ $\times \sin n\varphi$



$P_{\mu+}=-0.8$ $P_{\mu-}=+0.8$

$$\sigma^{\mu+}_{s} + \sigma^{\mu-}_{r} \sim H(x=\xi,\xi,t)$$

$$\sigma^{\mu+}_{s} - \sigma^{\mu-}_{r} \sim \mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi}$$

Diehl

Parametrization of GPDs

Model 1: $H(x,\xi,t) \sim q(x)\, F(t)$

Model 2: is more realistic

it considers that fast partons in the small valence core and slow partons at larger distance (wider meson cloud)

it includes correlation between x and t

$\langle b^2_\perp \rangle = \alpha' \ln 1/x$ transverse extension of partons in hadronic collisions

$$H(x,0,t) = q(x)\, e^{t \langle b_\perp^2 \rangle} = q(x) / x^{\alpha' t}$$ (α' slope of Regge traject.)

This ansatz reproduces the

Chiral quark-soliton model: *Goeke et al., NP47 (2001)*

DVCS Beam Charge Asymmetry (BCA) measured with the 100 GeV muon beam at COMPASS

$$\sigma^{\mu+} - \sigma^{\mu-} \sim \mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi}$$

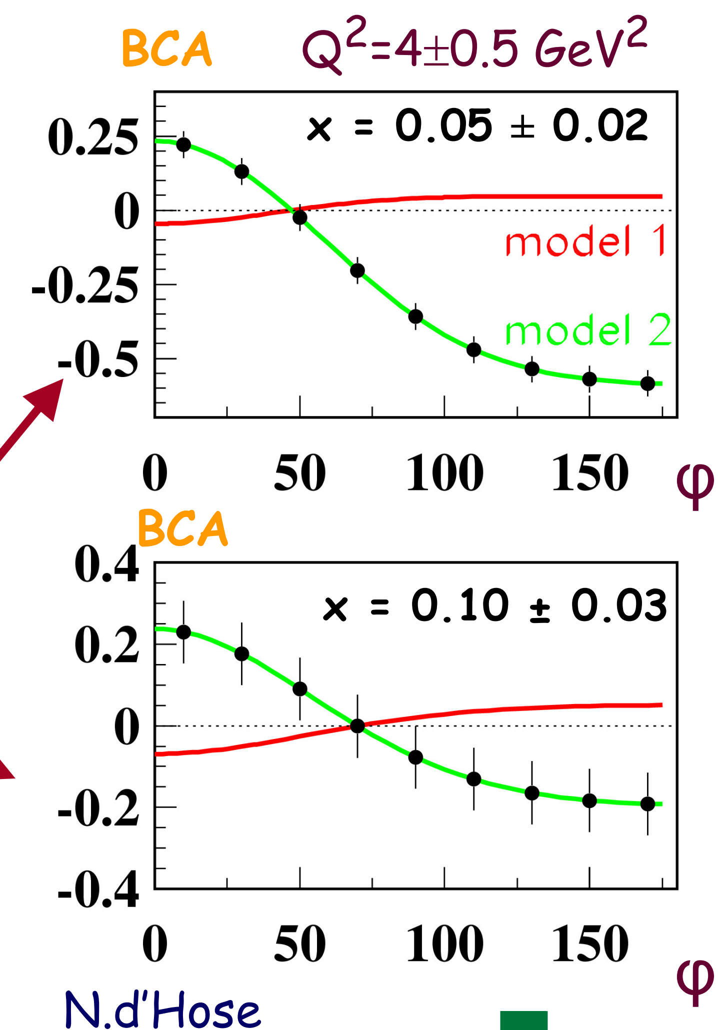
Model 1: $H(x,\xi,t) \sim q(x)\, F(t)$

Model 2: $H(x,0,t) = q(x)\, e^{t \langle b_\perp^2 \rangle} = q(x) / x^{\alpha' t}$

$\mathcal{L}$ = 1.3 10^{32} cm^{-2} s^{-1}
efficiency=25%
150 days data taking

3 bins in x_{Bj} = 0.05, 0.1, 0.2
6 bins in Q^2 from 2 to 7 GeV^2

2/18 sets



sensitivity to the different spatial distribution of partons ↗ when xBj ↘

N.d'Hose

" Longitudinal " Meson production : filter of GPDs

Cross section:

Vector meson production $(\rho,\omega,\phi\ldots)$ $\Rightarrow$ H & E

Pseudo-scalar production $(\pi,\eta\ldots)$ $\Rightarrow$ $\tilde{H}$ & $\tilde{E}$

$$H\rho^0 = 1/\sqrt{2}\,(2/3\,H^u + 1/3\,H^d + 3/8\,H^g)$$

$$H\omega = 1/\sqrt{2}\,(2/3\,H^u - 1/3\,H^d + 1/8\,H^g)$$

$$H\phi = -1/3\,H^s - 1/8\,H^g$$

Single spin asymmetry $\sim E/H$

Meson Production

liquid Hydrogen target and the same muon flux as now

Measurement of hard exclusive meson production

ρ comfortable statistics until $Q^2 = 20\ GeV^2$

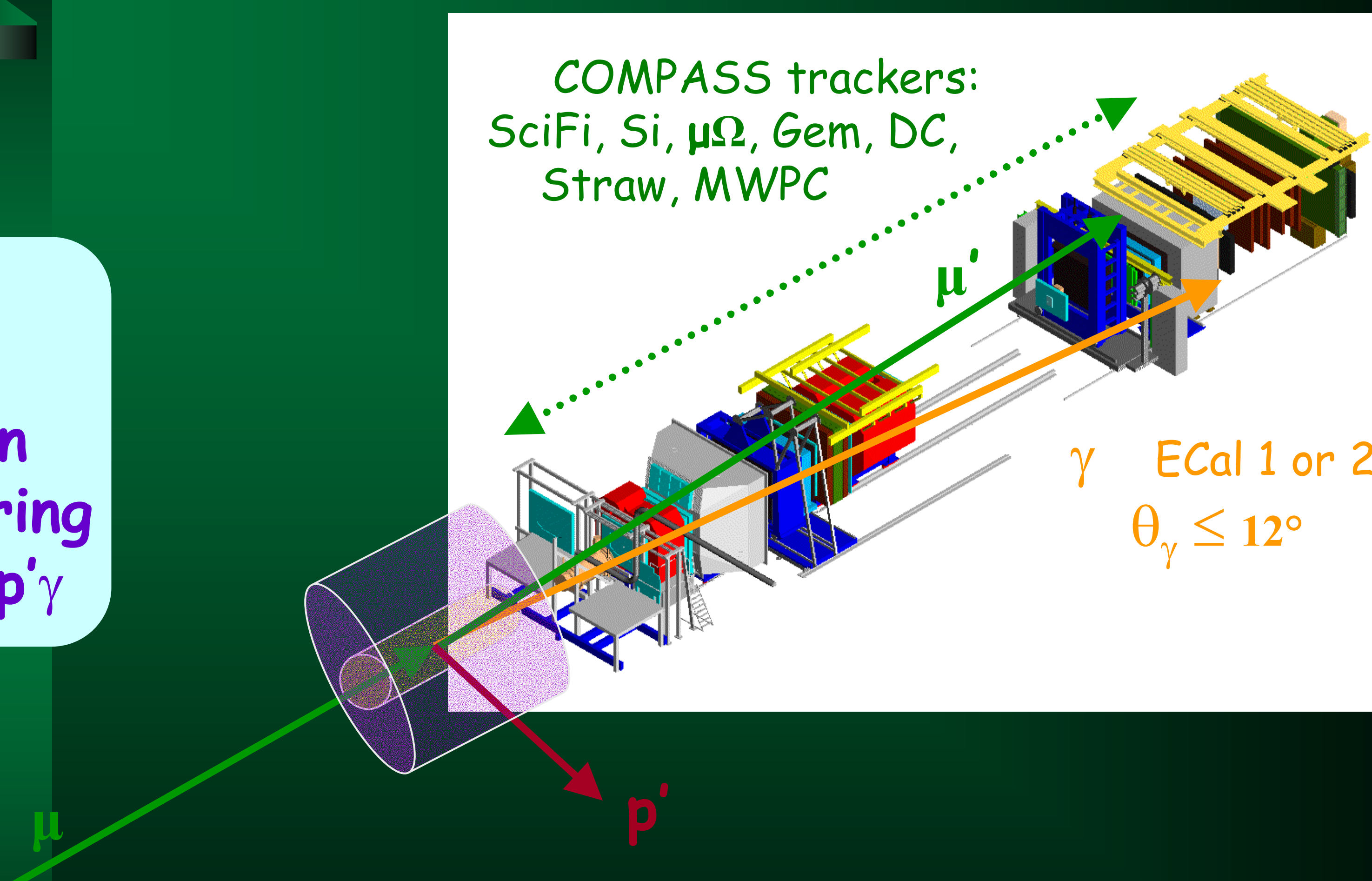
$\omega\ \pi\ \eta\ \phi$ ⟶ $Q^2 = 7\ GeV^2$

Benefit of an increase in intensity for an extension of the range in Q^2

NB: for ω results from JLab the SCHC was not observed at $Q^2 < 4 GeV^2$ and large $x_{Bj} \sim 0.4$

Necessity to complete at large angle the high resolution COMPASS spectrometer

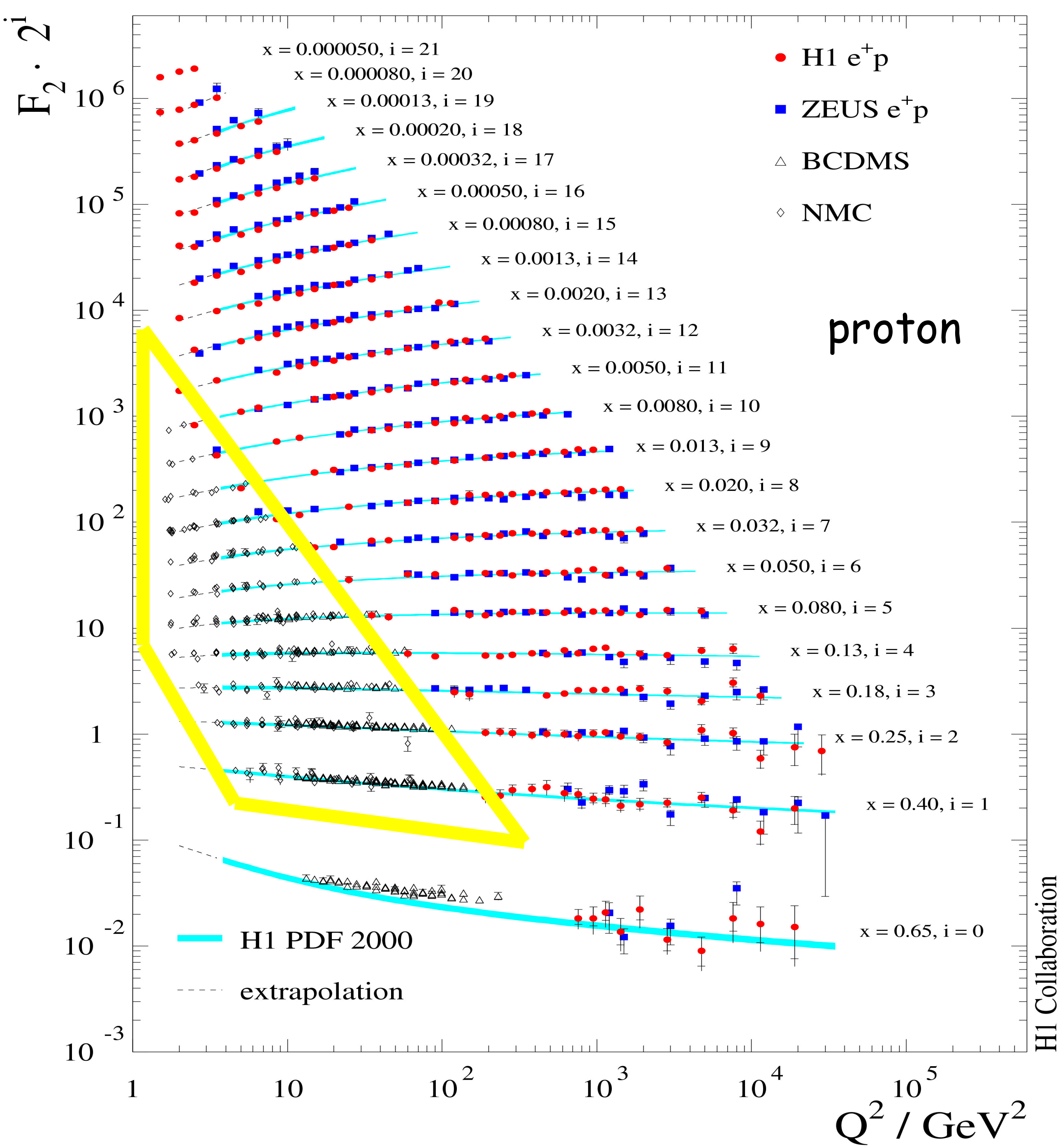
Deeply Virtual Compton Scattering
$\mu p \rightarrow \mu' p' \gamma$



by a recoil detector to insure the exclusivity of the reaction in parallel with DVCS running

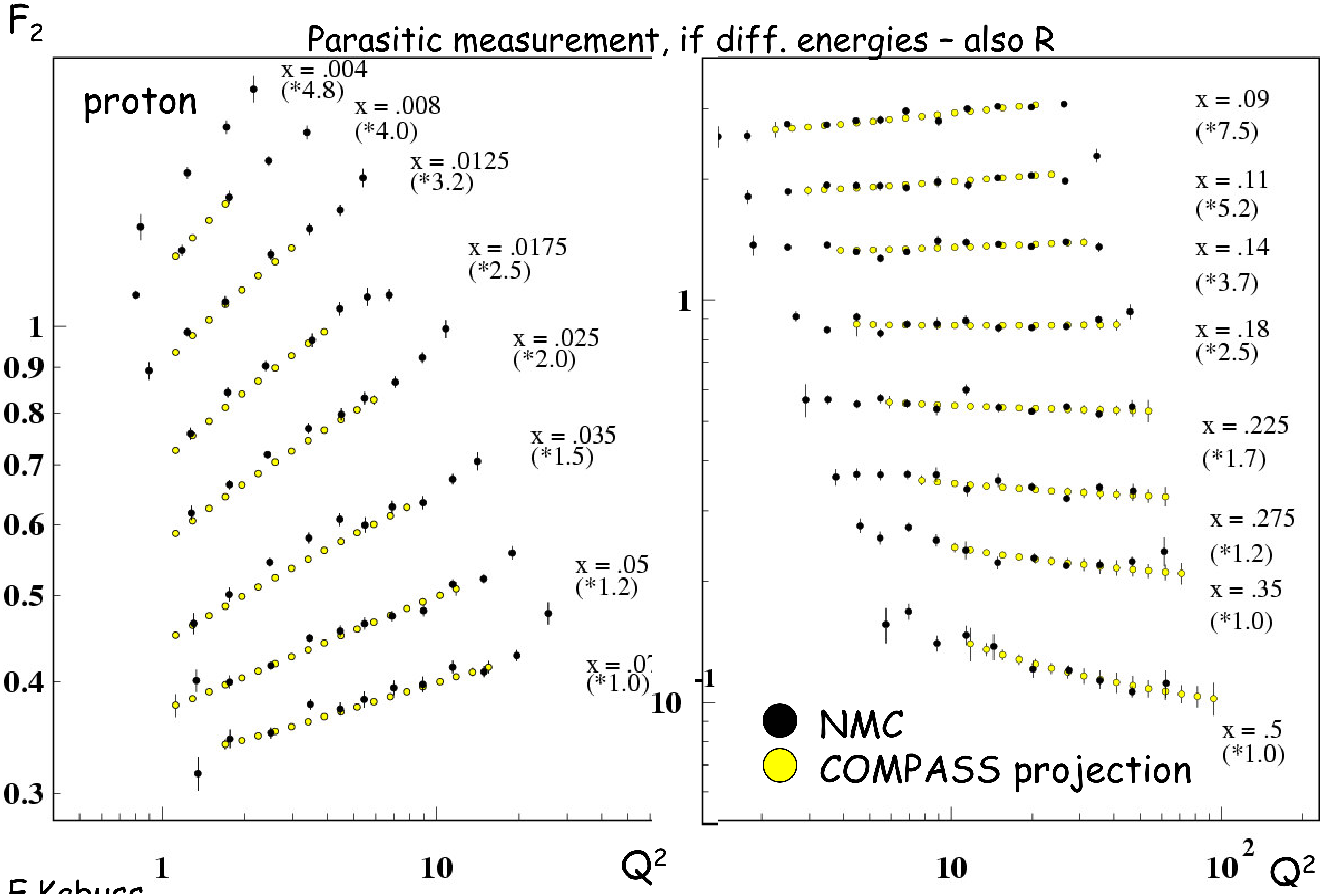
Possible new accurate measurement - COMPASS

F_L (R) determination (higher at lower Q^2)



Projection for COMPASS
75 days with Nμ=2.10⁸/spill and 2.5m Hydrogen target

Parasitic measurement, if diff. energies – also R



E Kabuss

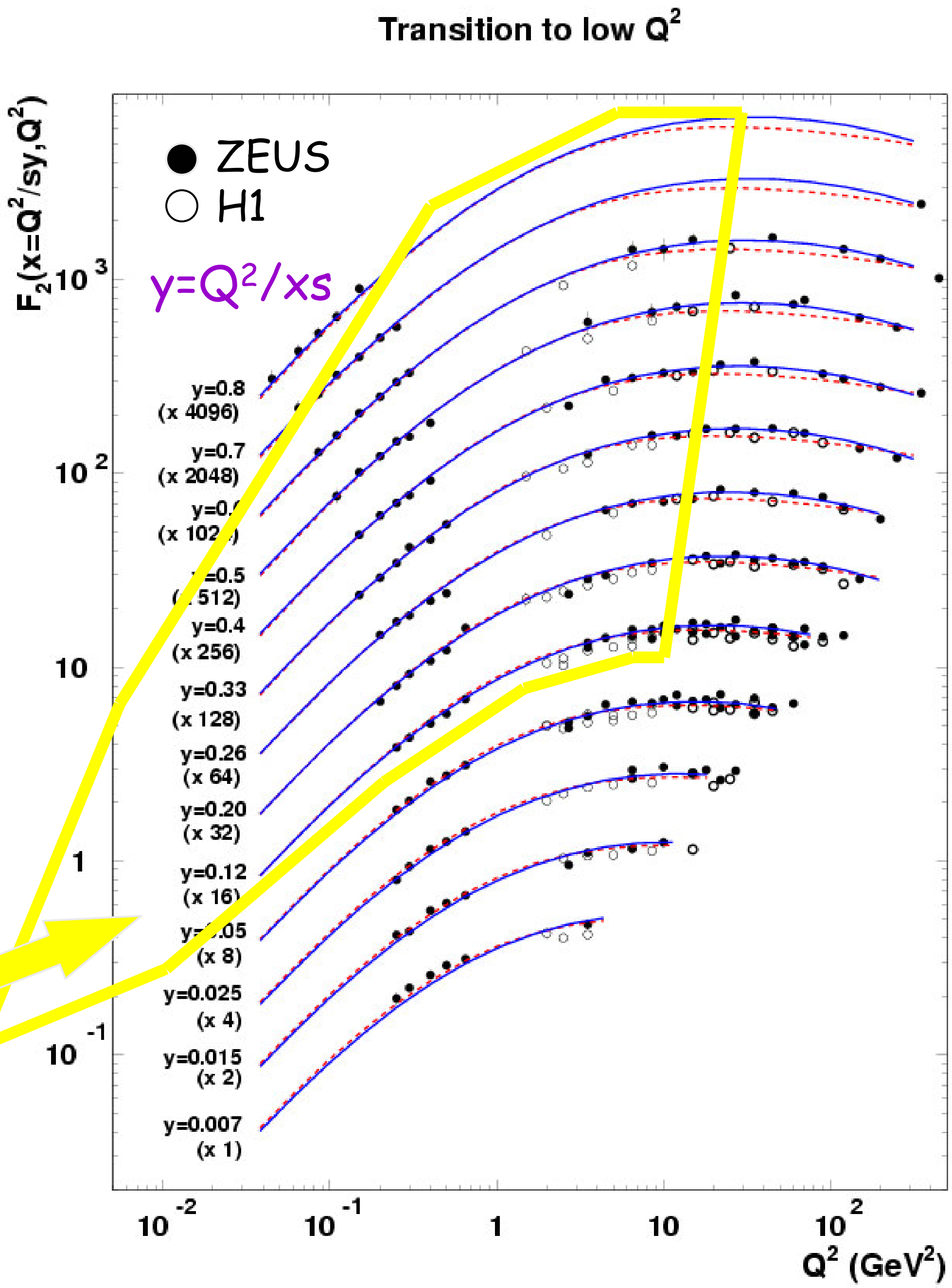
For understanding of perturbative – – nonperturbative transition

New phenomena at low x
coherent interaction of partons
Log1/x in the QCD evolution

Saturation model

Bartels, Golec-Biernat, Kowalski PRD66 (2002)

New data at low x low Q^2 with COMPASS



In the same region with nuclear targets colour transparency can be studied

Summary:

There is place for FT contribution

(after presently running and approved experiments)

- **Parity violating asymmetries** can help answering some open questions in parton distributions (mesurements planned at JLab, SLAC ???)

- **Complete 3-dimensional radiography** of the nucleon possible with **DVCS** data

  To do it we need data from broad kinematic region

- Proton luminosity upgrade at CERN allows signifficunt contribution in the field from Compass