HERA – a deep look into the proton

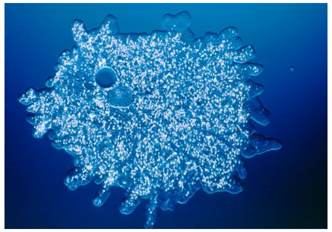
25. 10. 2012, DESY CMS HERA event

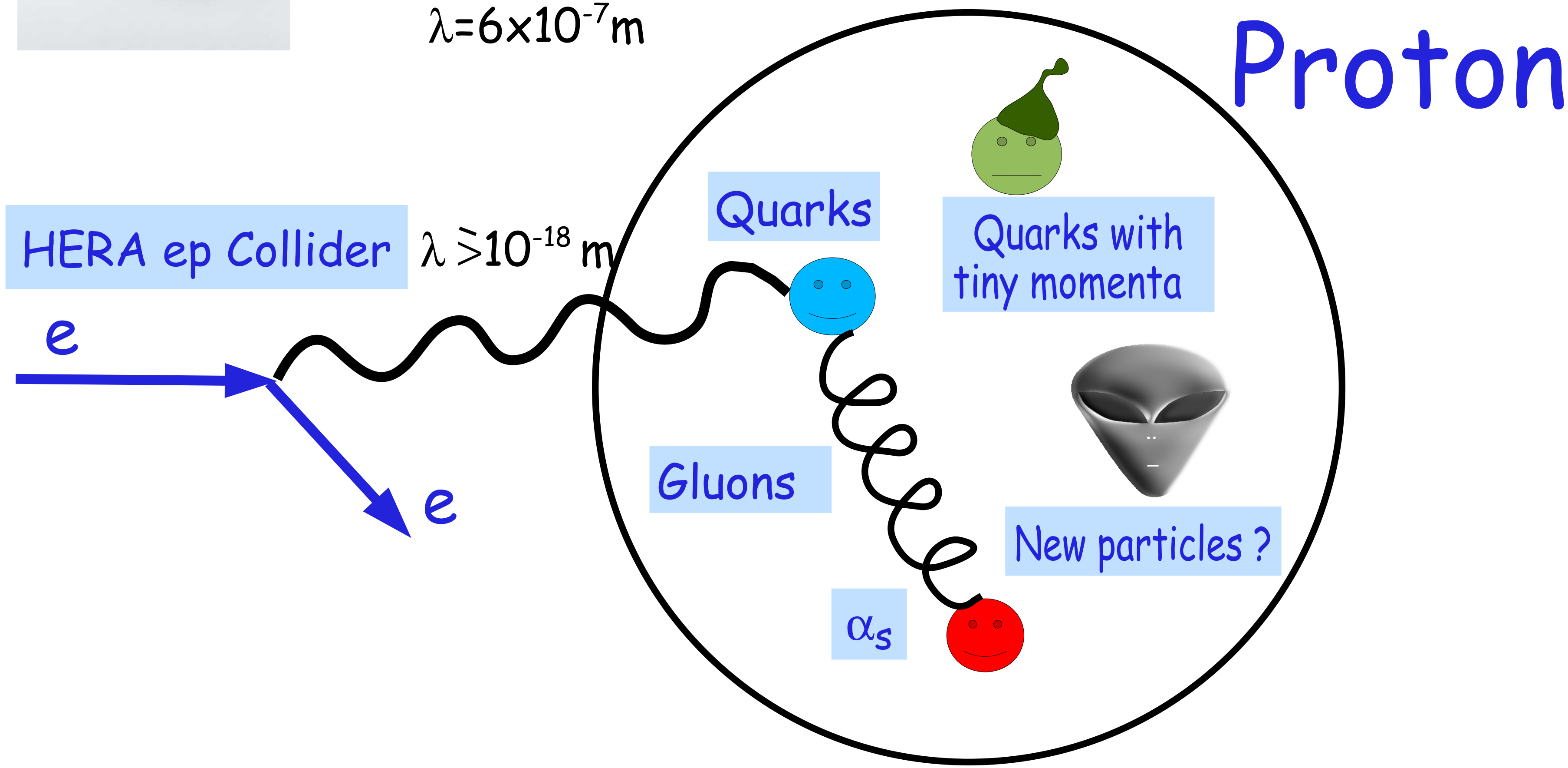
Olaf Behnke, DESY

HERA - the "Super microscope"

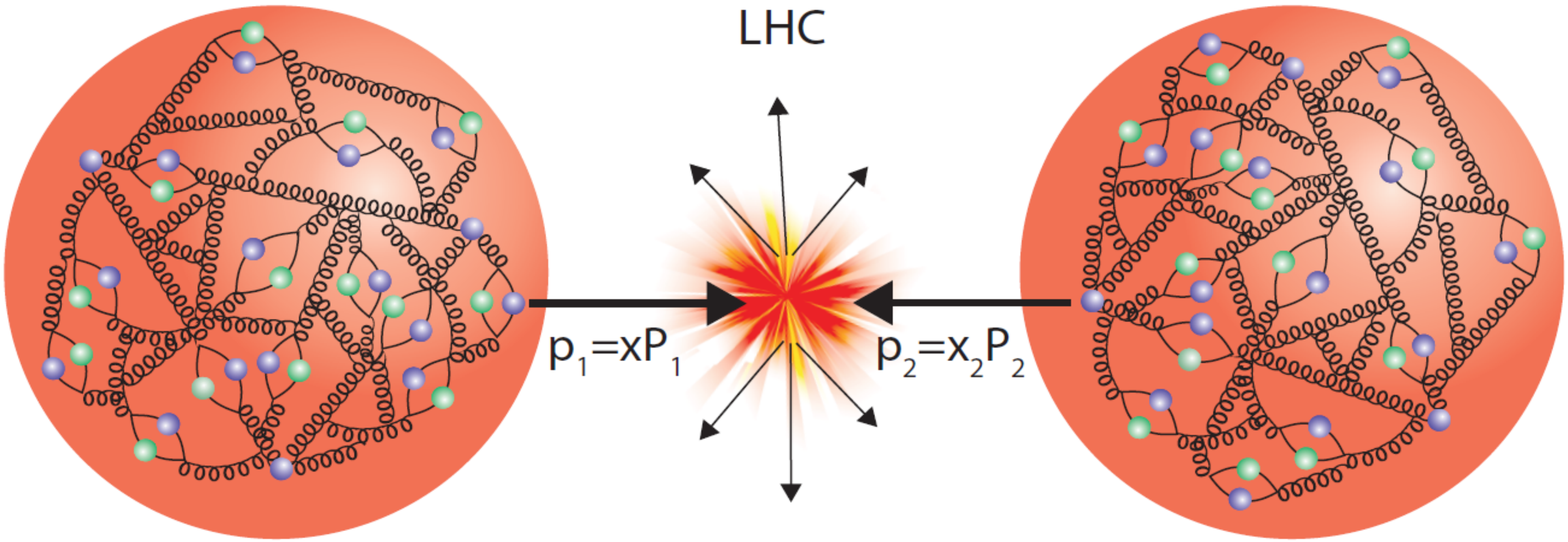
λ=6x10^{-7}m

Amoeba





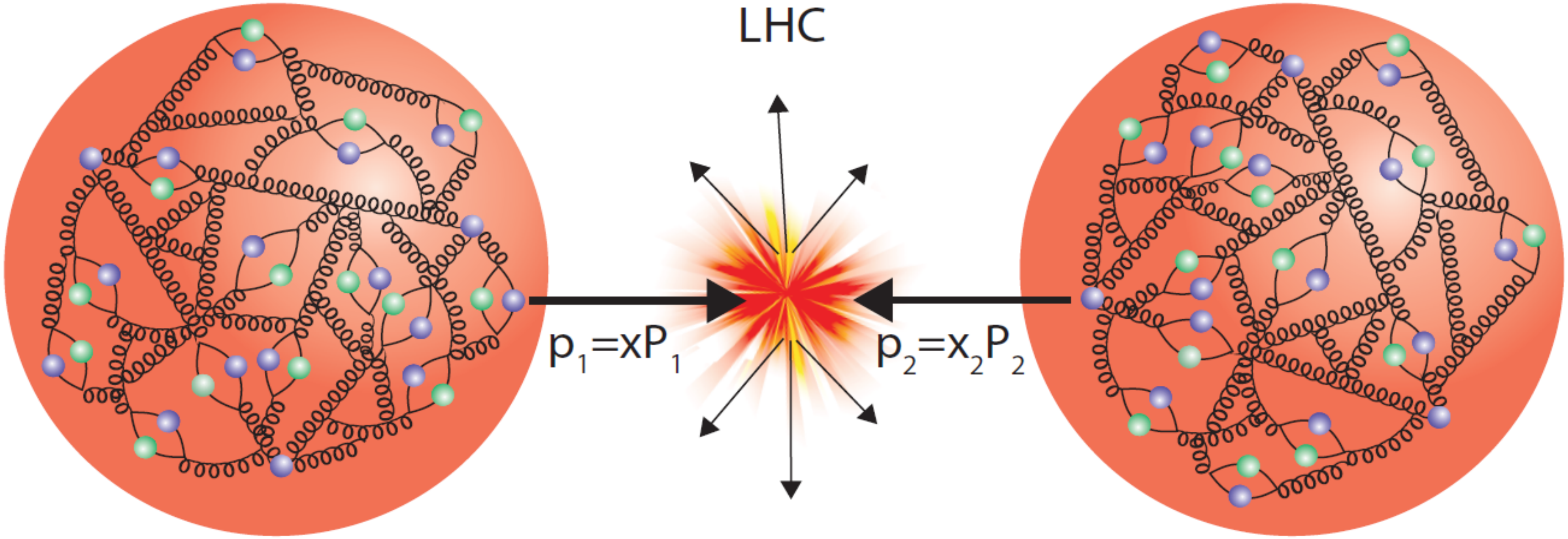
HERA is needed to understand LHC reactions

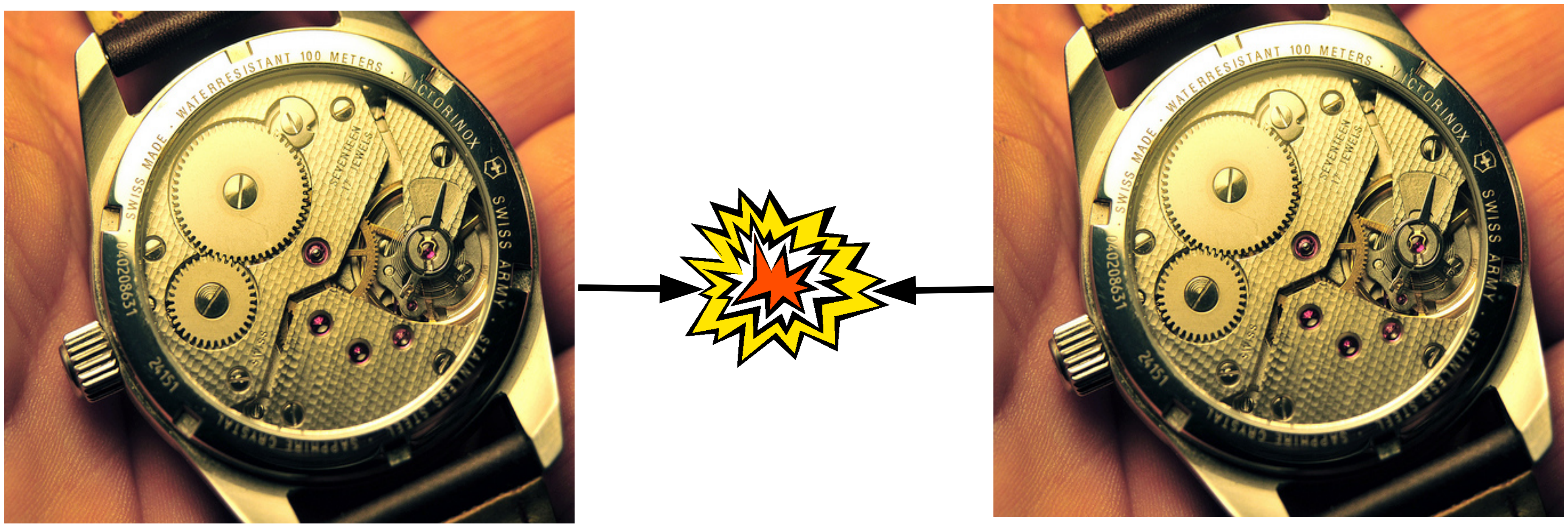


Looking for exciting (new) reactions but need to know proton content for any prediction

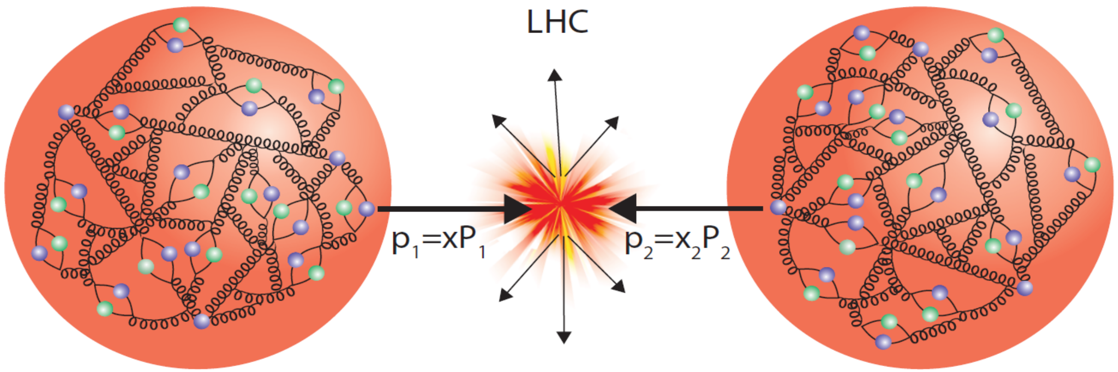
Understanding proton from pp collisions: "is like smashing two Swiss watches together to figure out how they work!" (R.P. Feynman)

HERA is needed to understand LHC reactions

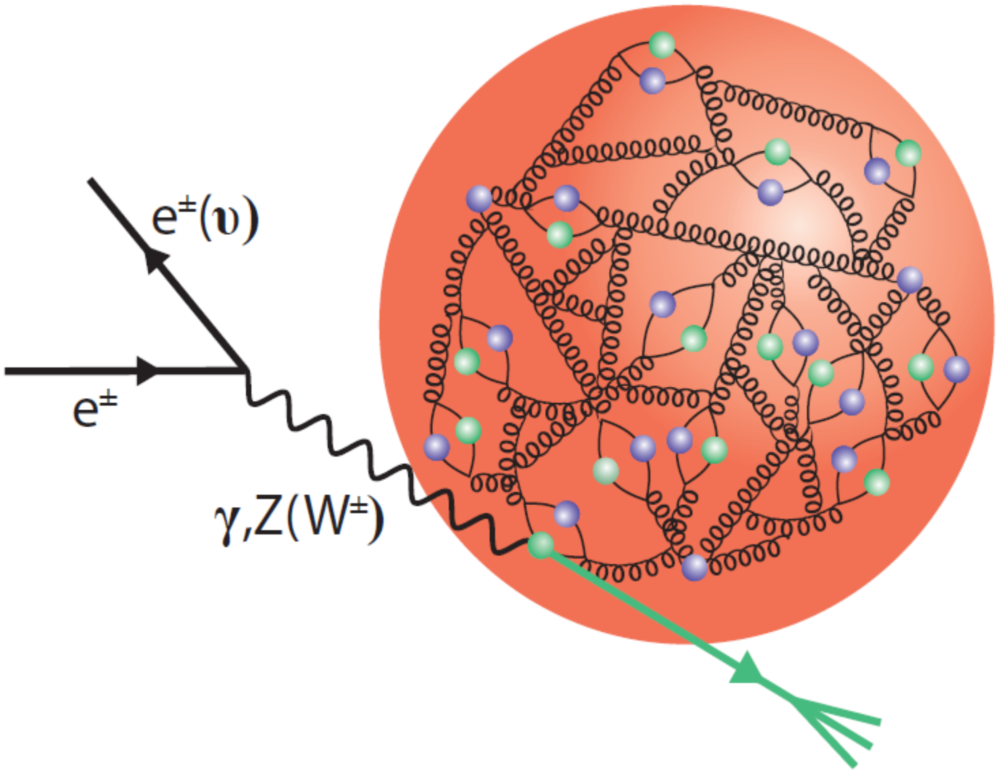




HERA is needed to understand LHC reactions

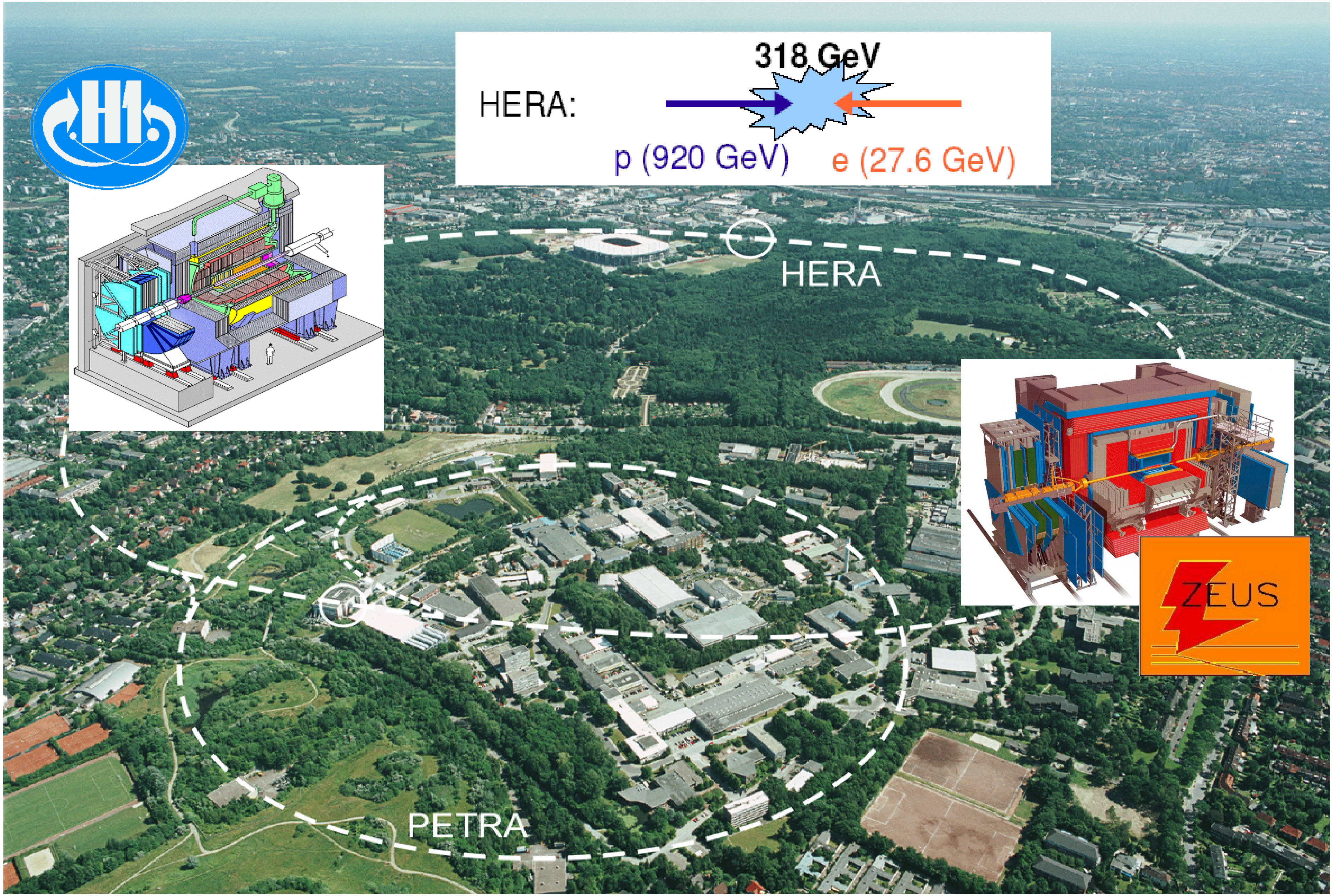


HERA



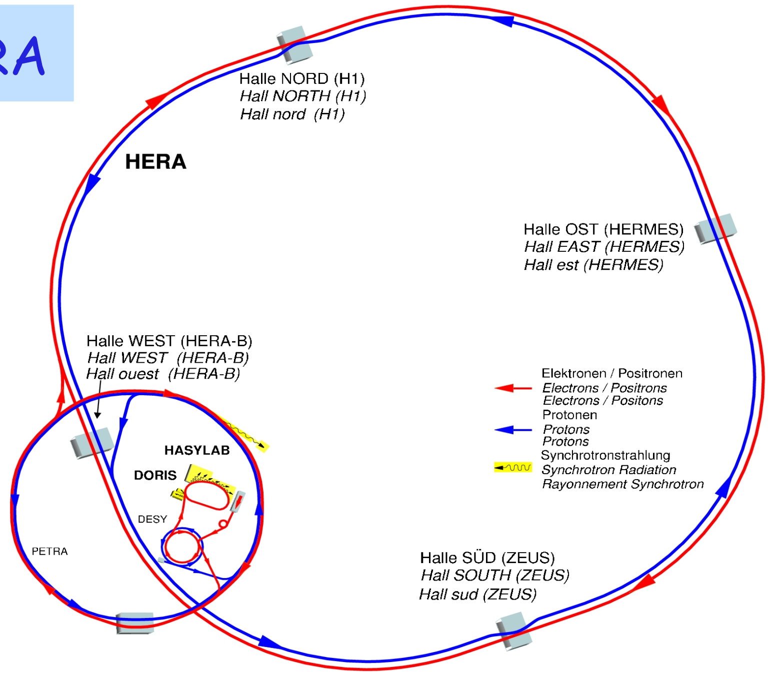
Using clean electroweak probes to reveal the content of the proton

HERA - the Super microscope

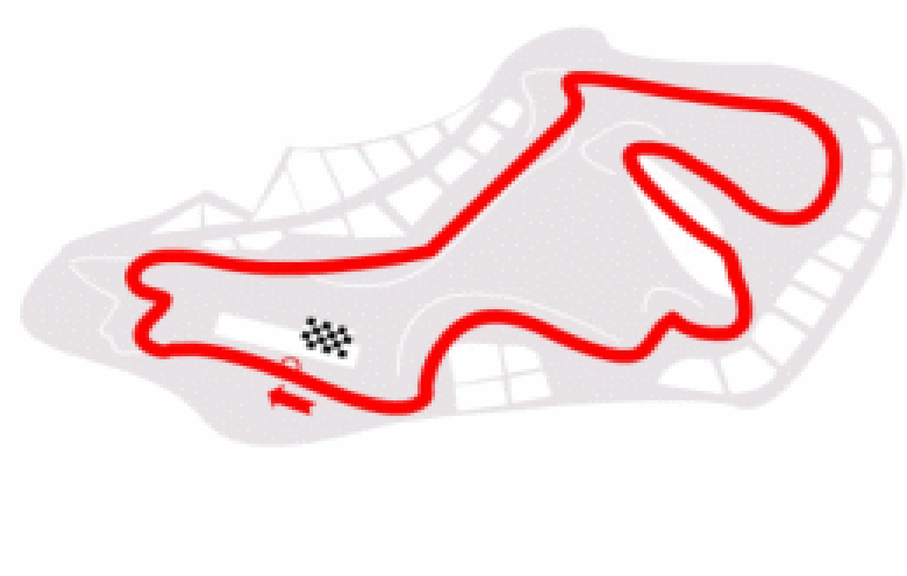


HERA - some facts

HERA



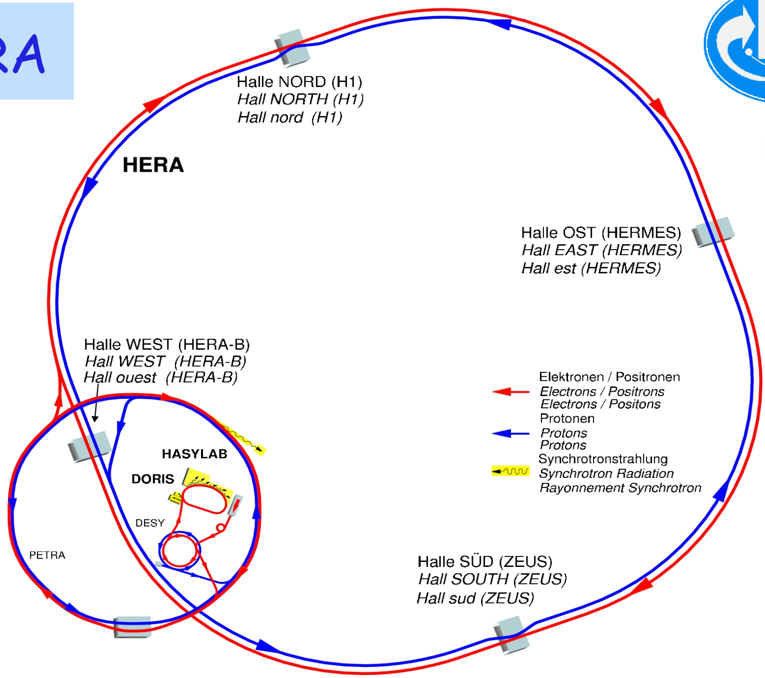
Formula 1 race track Istanbul



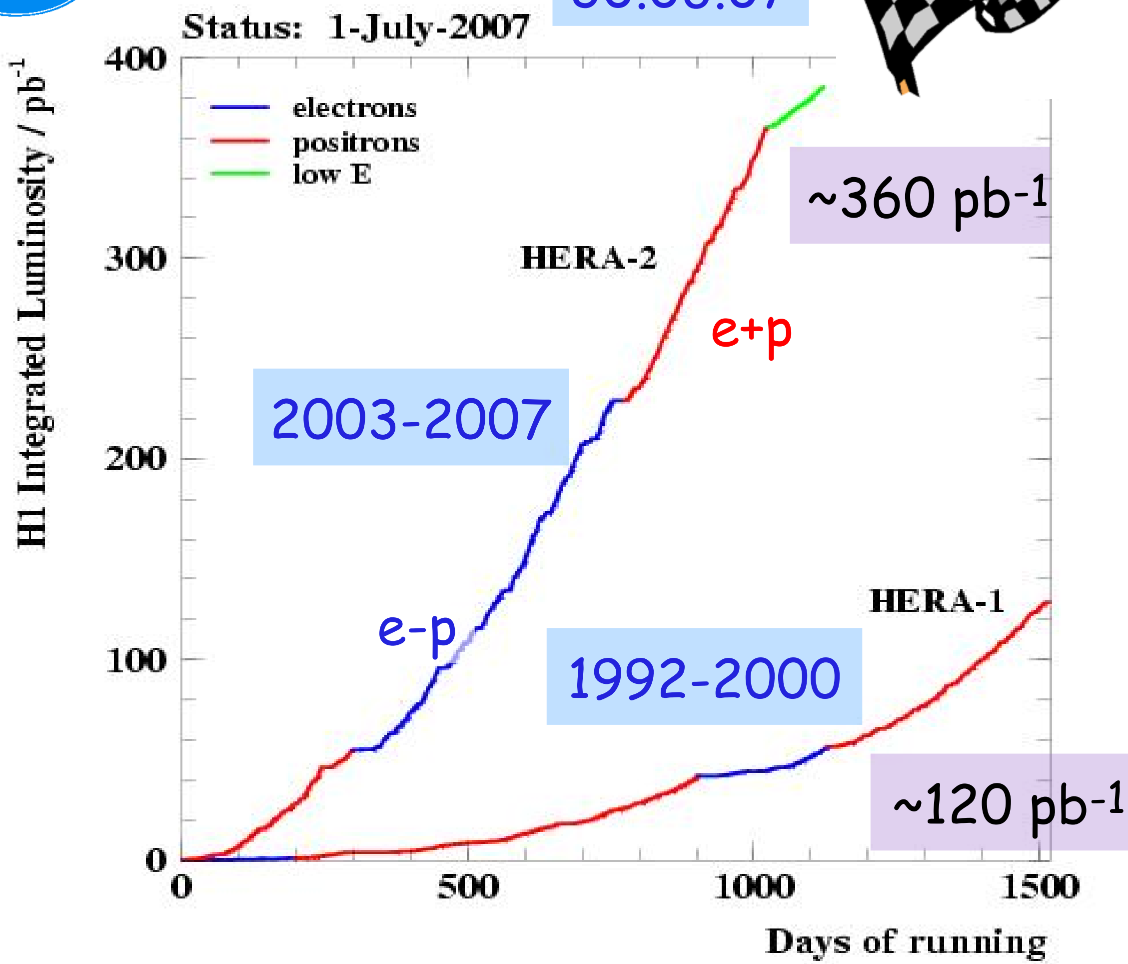
Ring	Circum ference	Road width	Vehicles	Vmax	#Collisions	Total kin. Energy	Construction costs
F1 Istanbul	5.8 km	~15 m	21	330 km/h	-	2 MJ/car	80 MEuro
HERA	6.3 km	1 mm	10^{13}p $0.5*10^{13}$e	c	~50/s recorded	1.6 MJ	500 MEuro

HERA - delivered ep Collisions

HERA

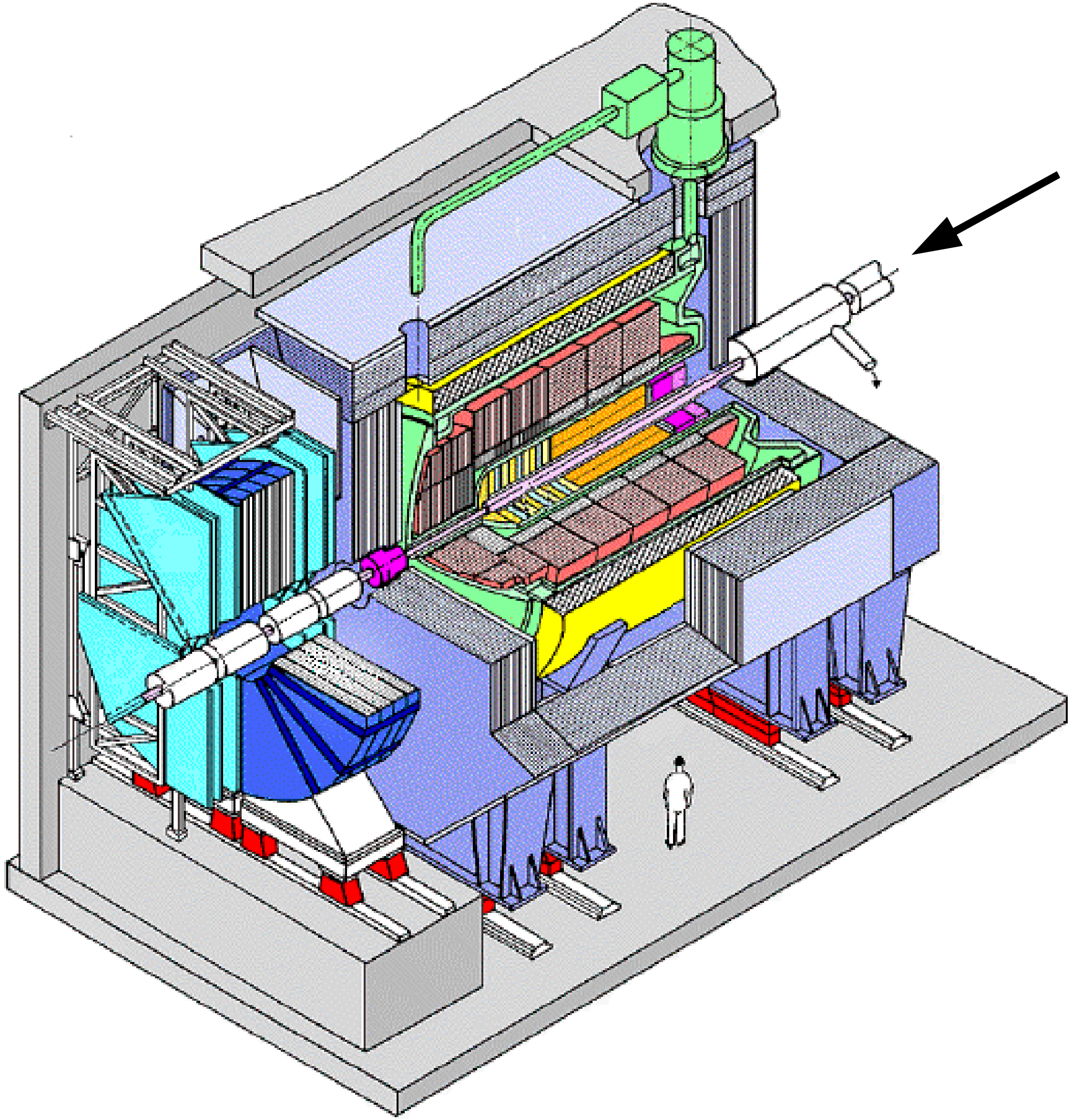


30.06.07



➔ About one billion nice ep events on tape

The H1 Detector

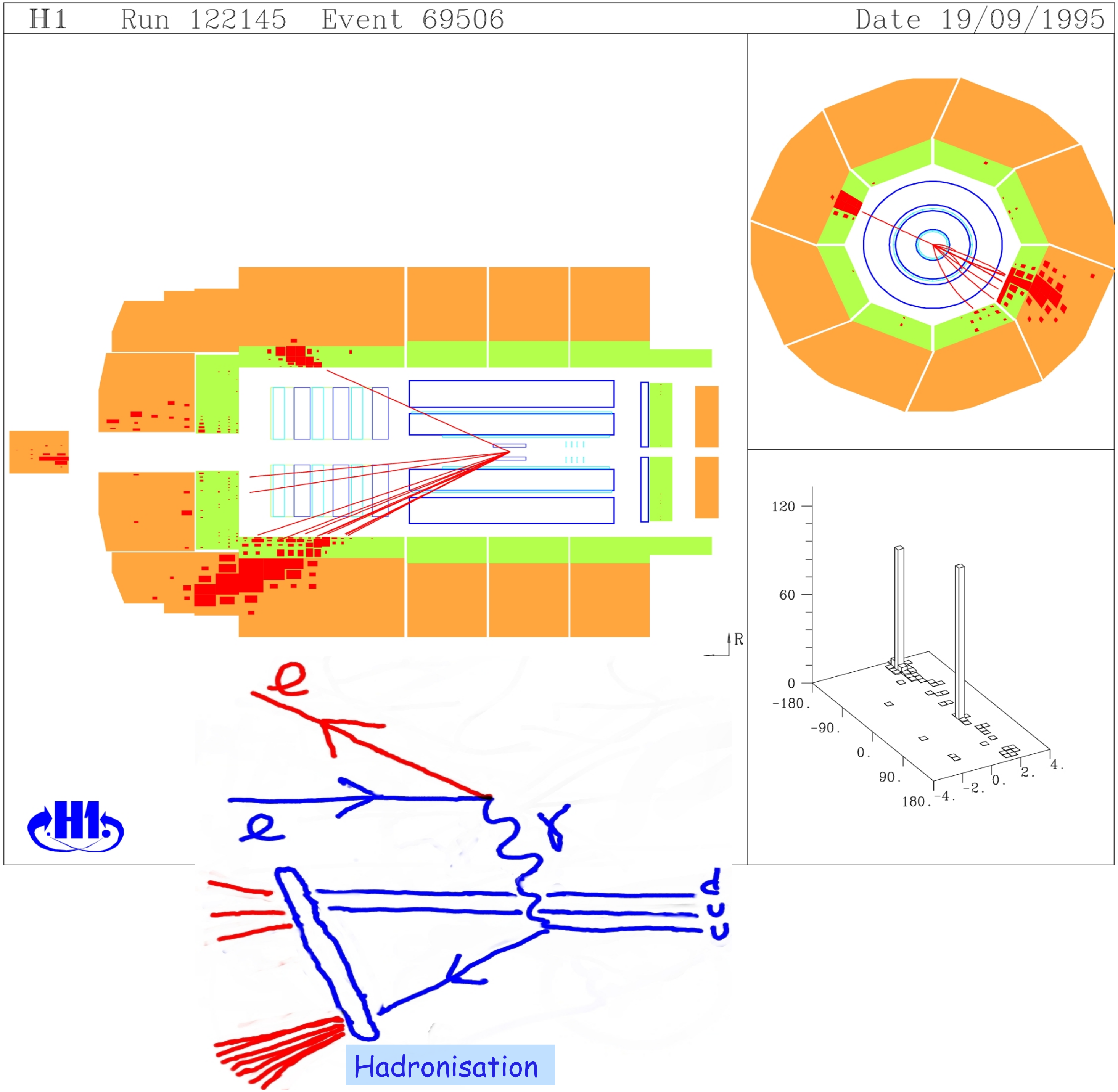


p

e±

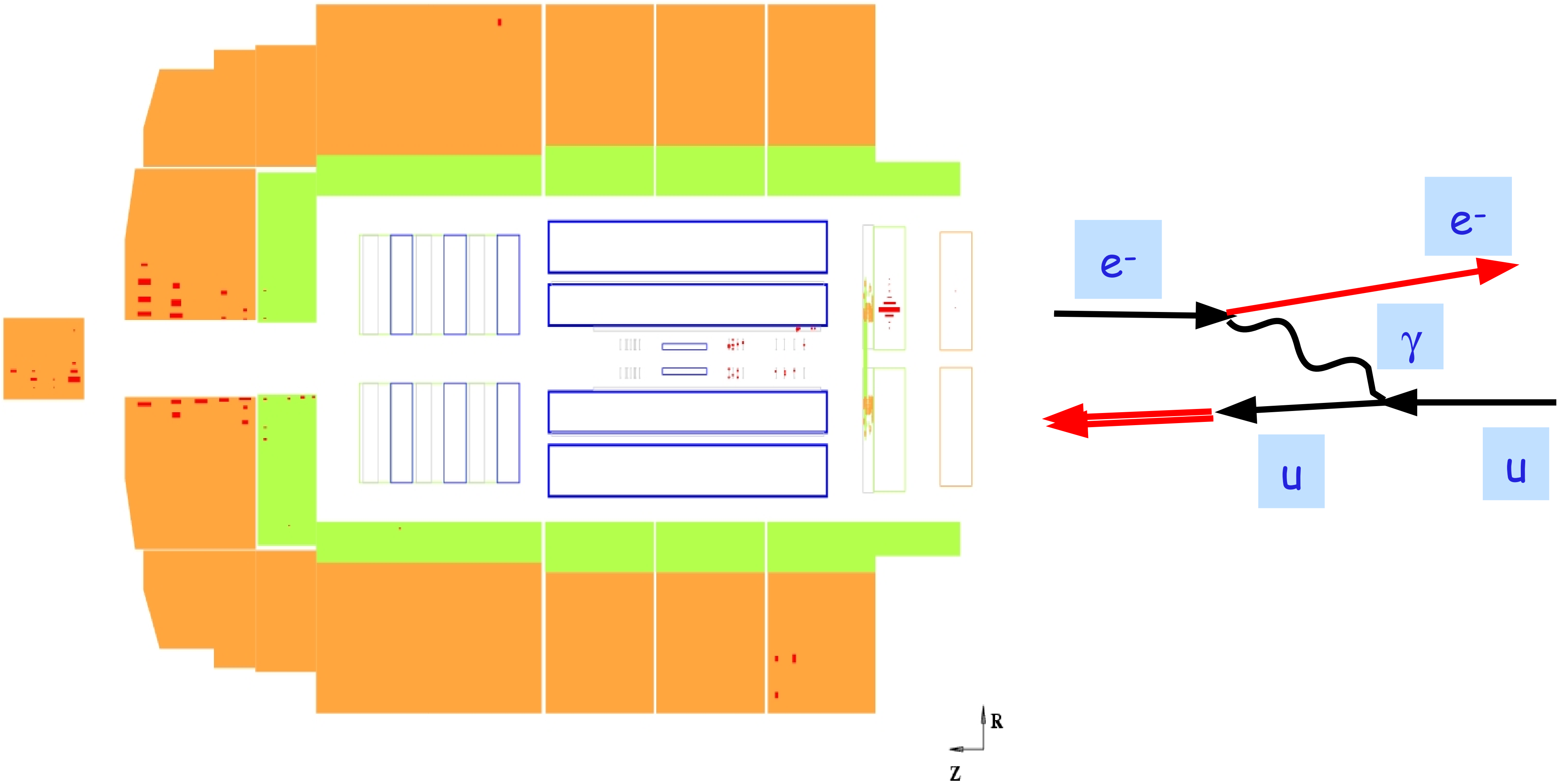
≈ 4π Detector

Weight: 2800 Tons

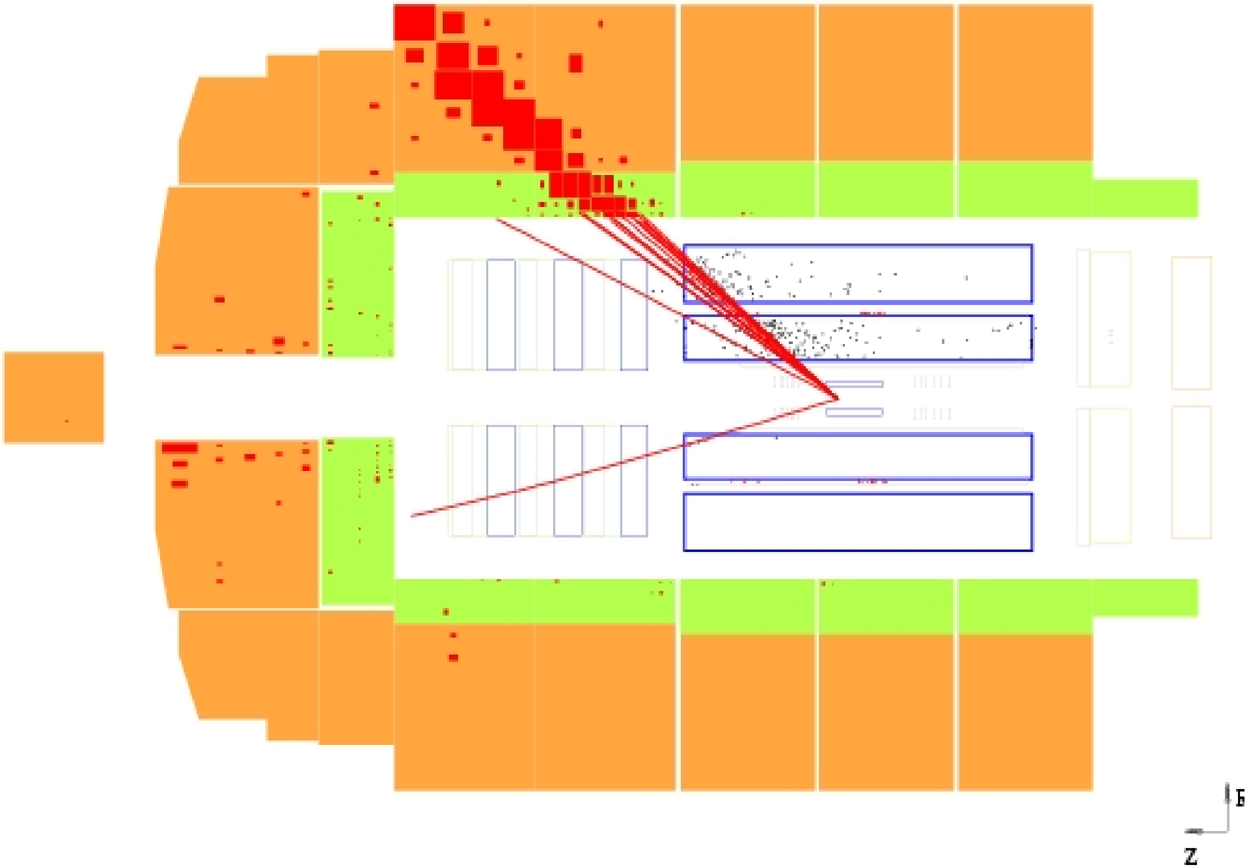


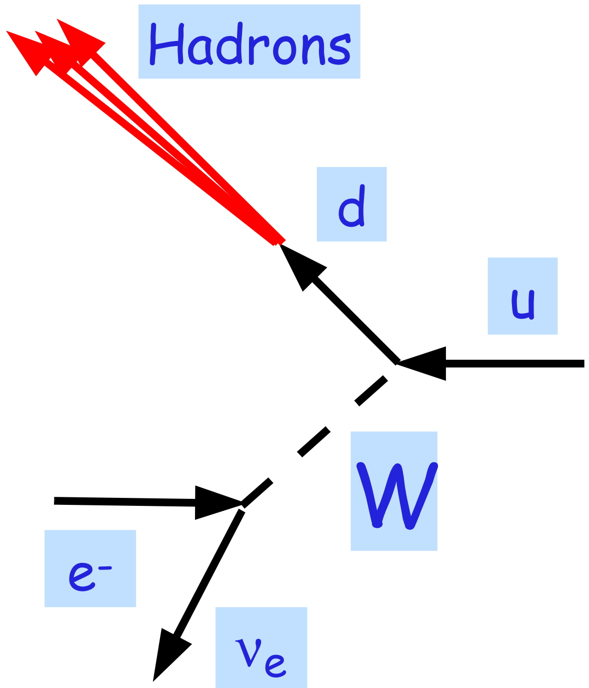
ep-scattering in H1 Detector

Quark-Electron Scattering with low Momentum transfer



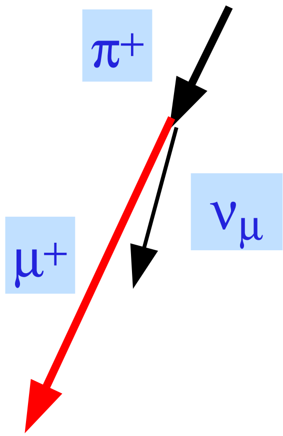
W-Exchange



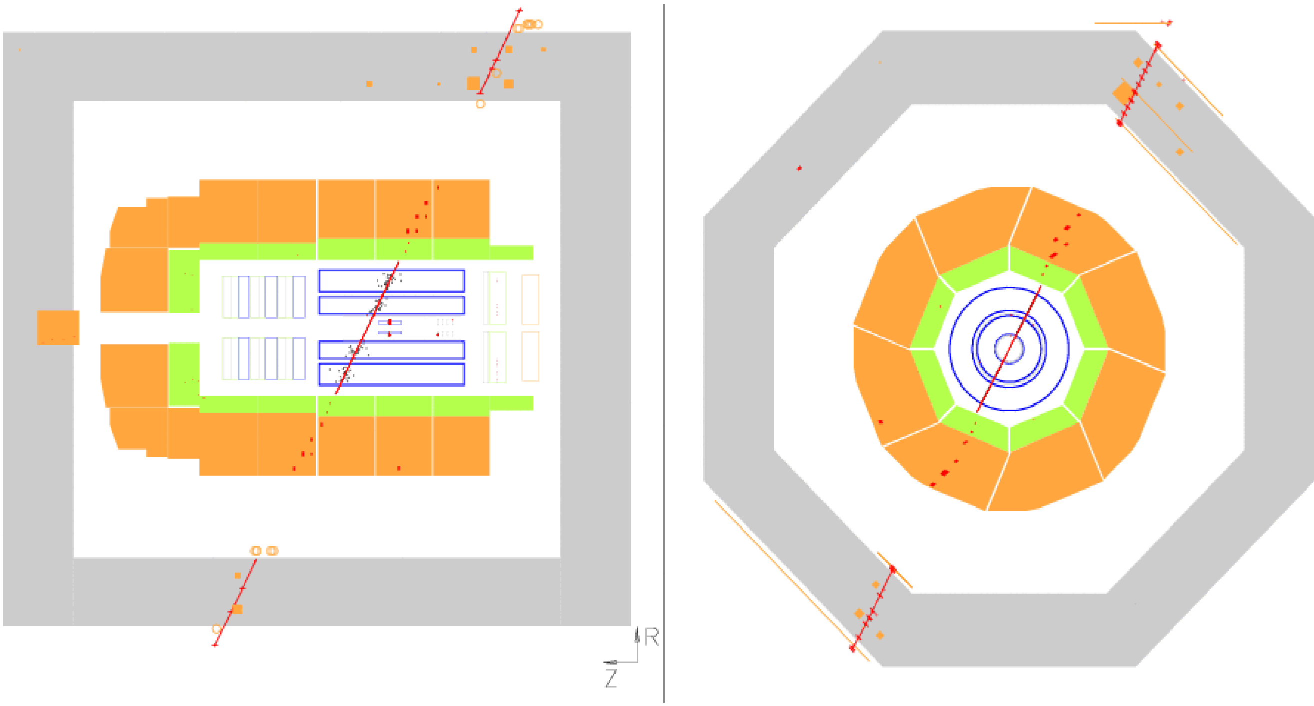


There was also background...

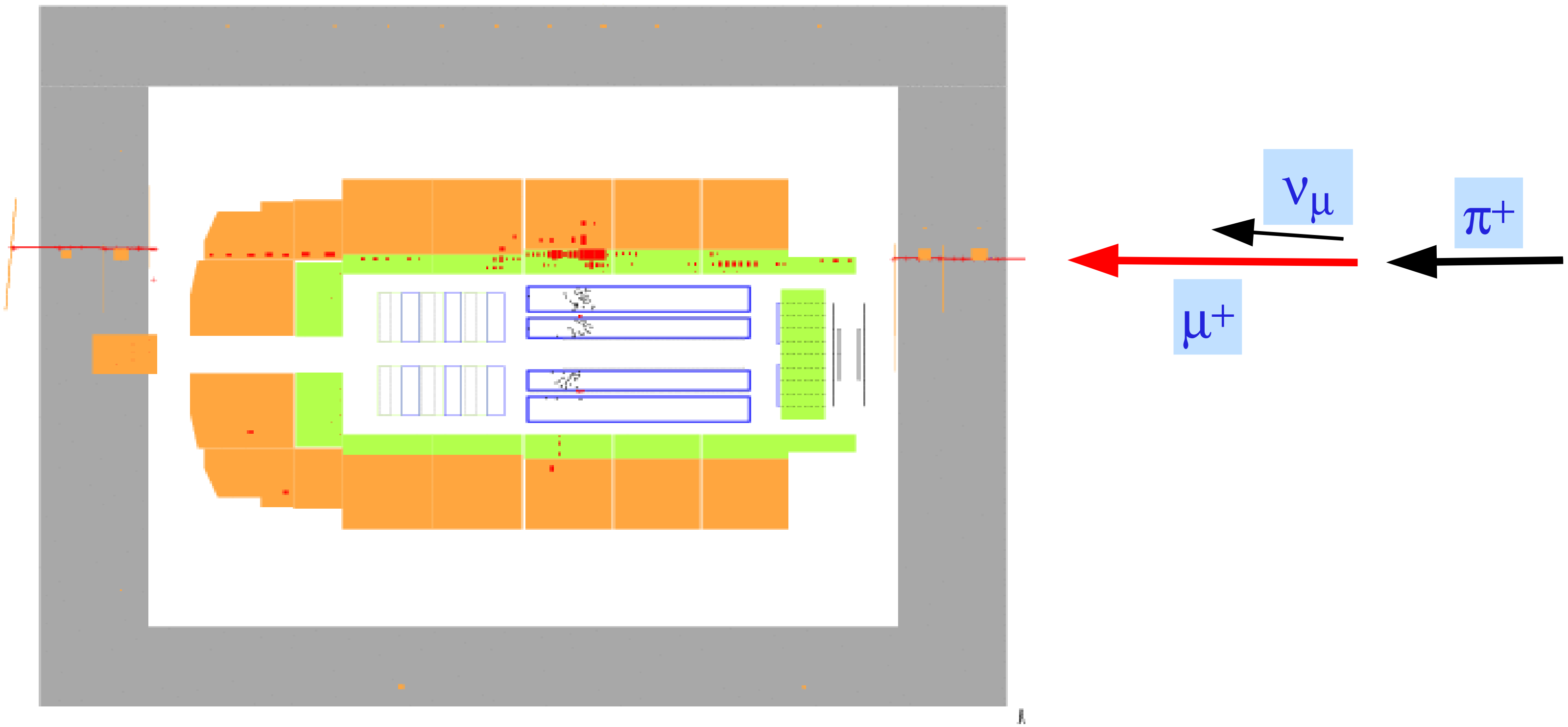
Cosmic Muon



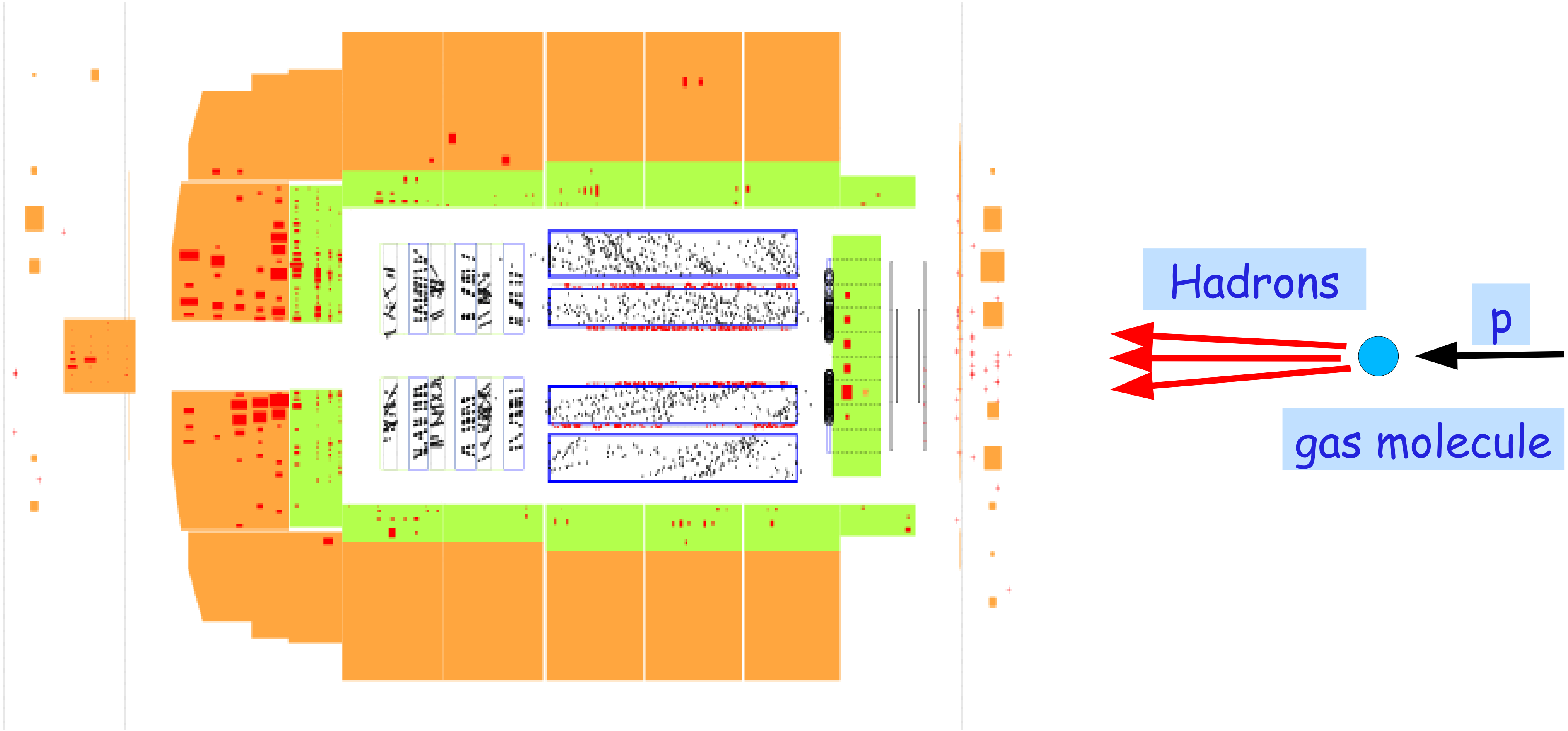
30 km
Altitude



Beam Halo muons



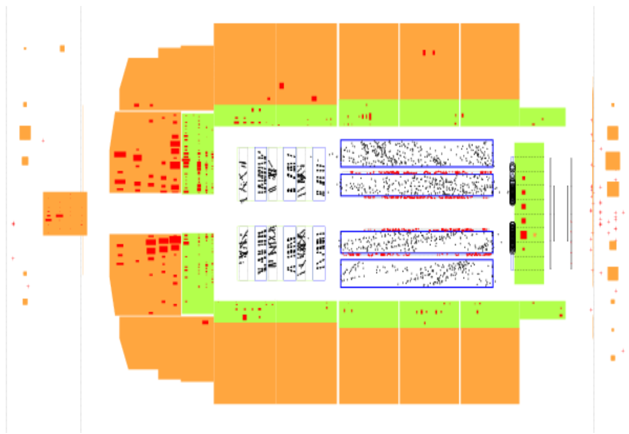
Beam Gas Interaction



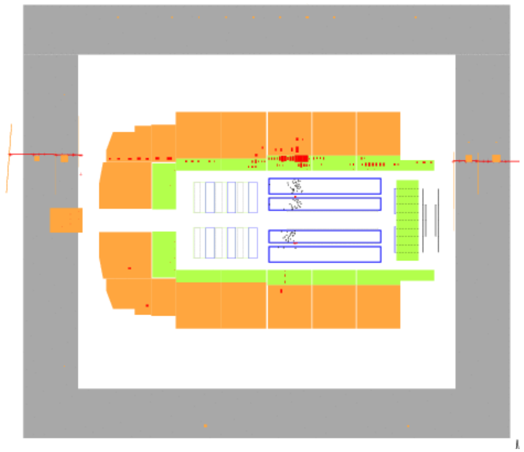
Typical Rates

1/month 10 Hz 3 KHz 100kHz 100 Hz 1/month

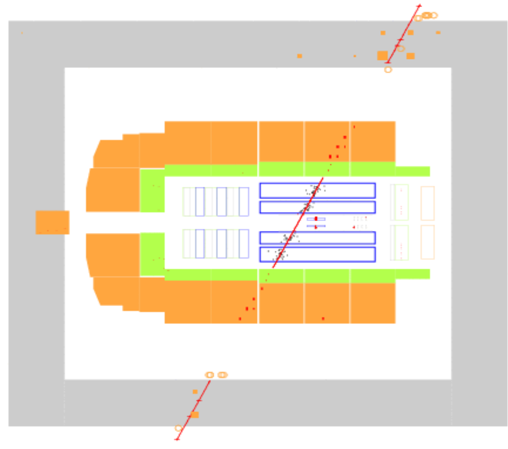
Beam-gas:



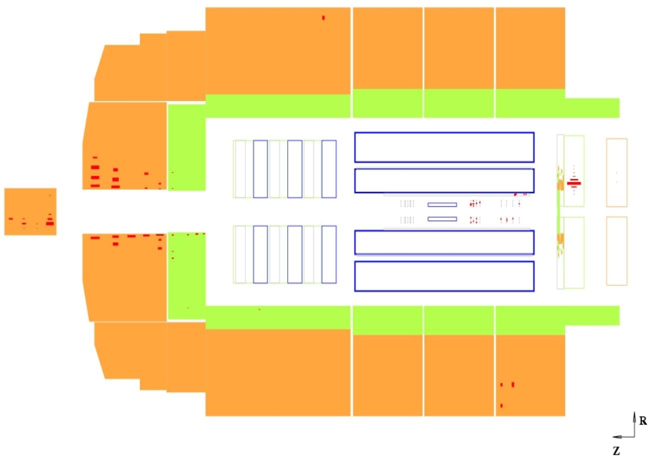
Beam-Halo μ:



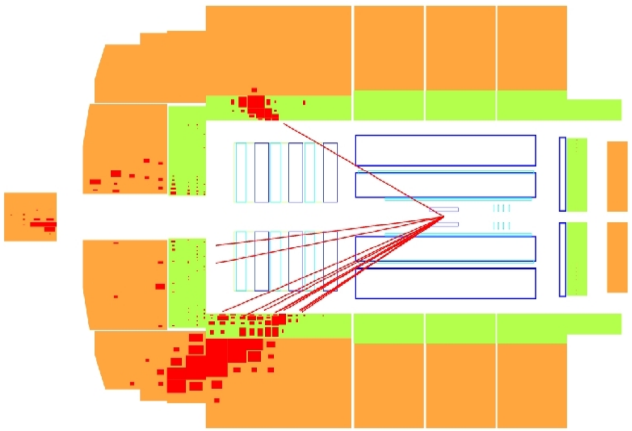
Cosmic μ:



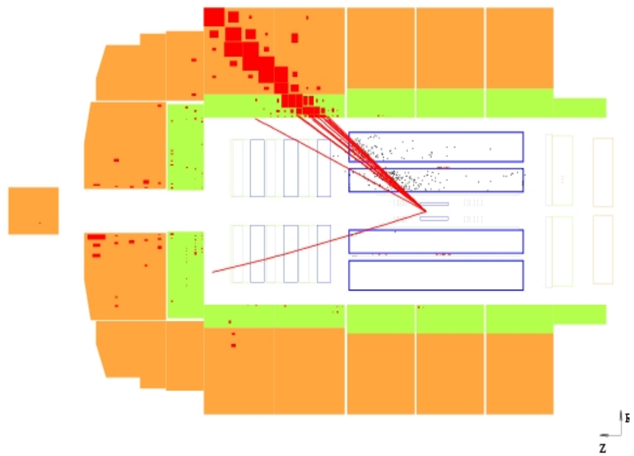
ep Scattering;



Super-hard ep Scattering;

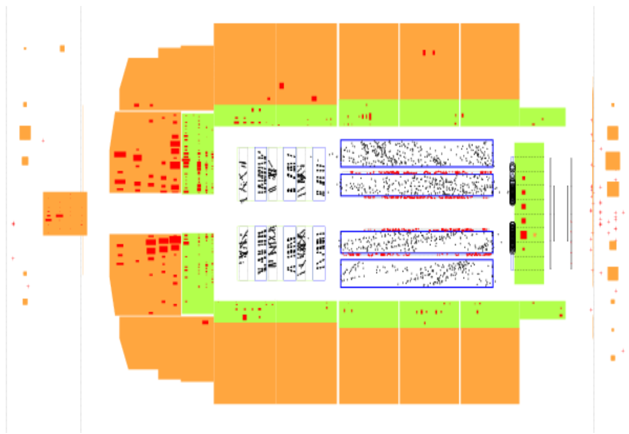


Super-hard W-Exchange;

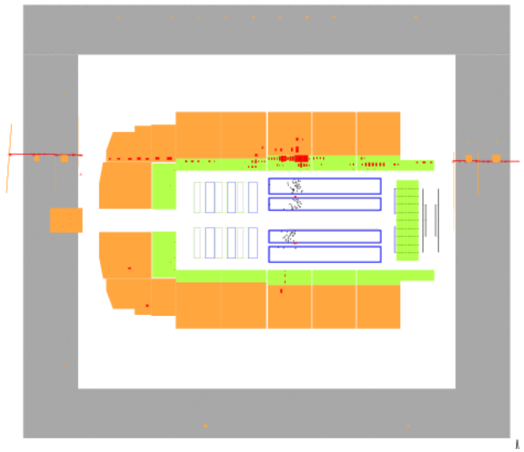


Typical Event Rates

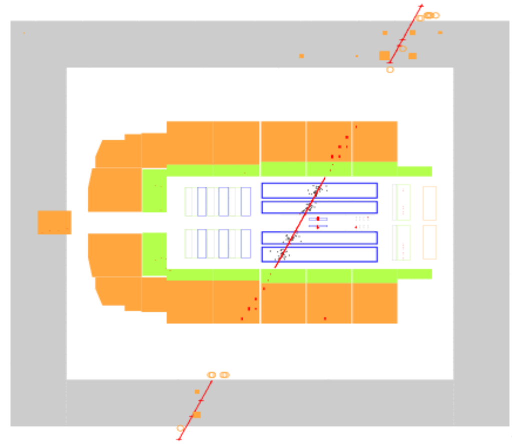
Beam-gas: 100kHz



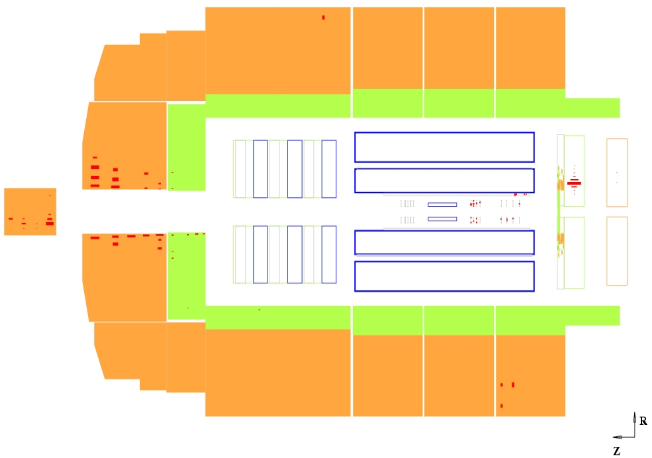
Beam-Halo μ: 100 Hz



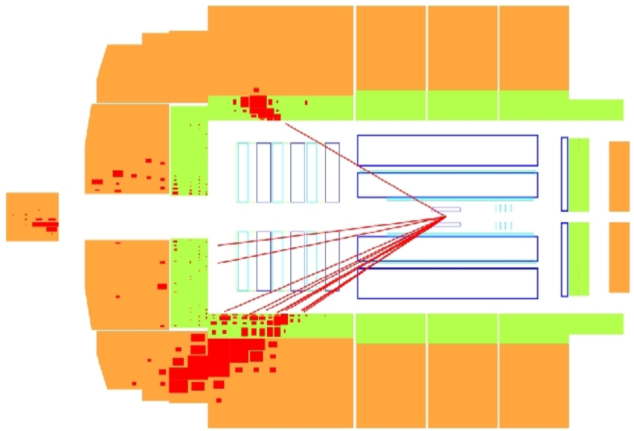
Cosmic μ: 3 KHz



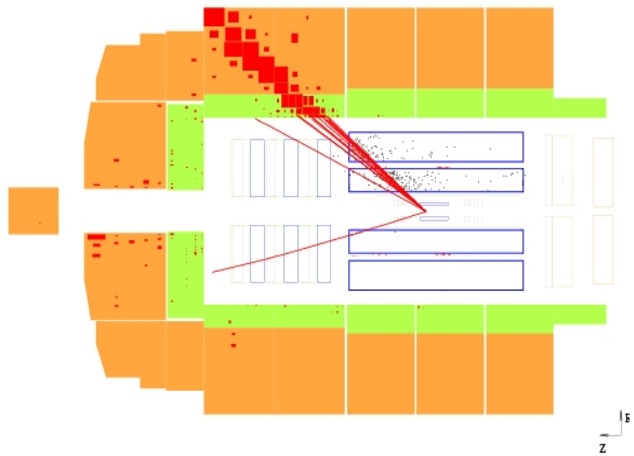
ep Scattering; 10 Hz



Super-hard ep Scattering; 1/Monat

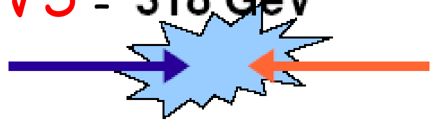


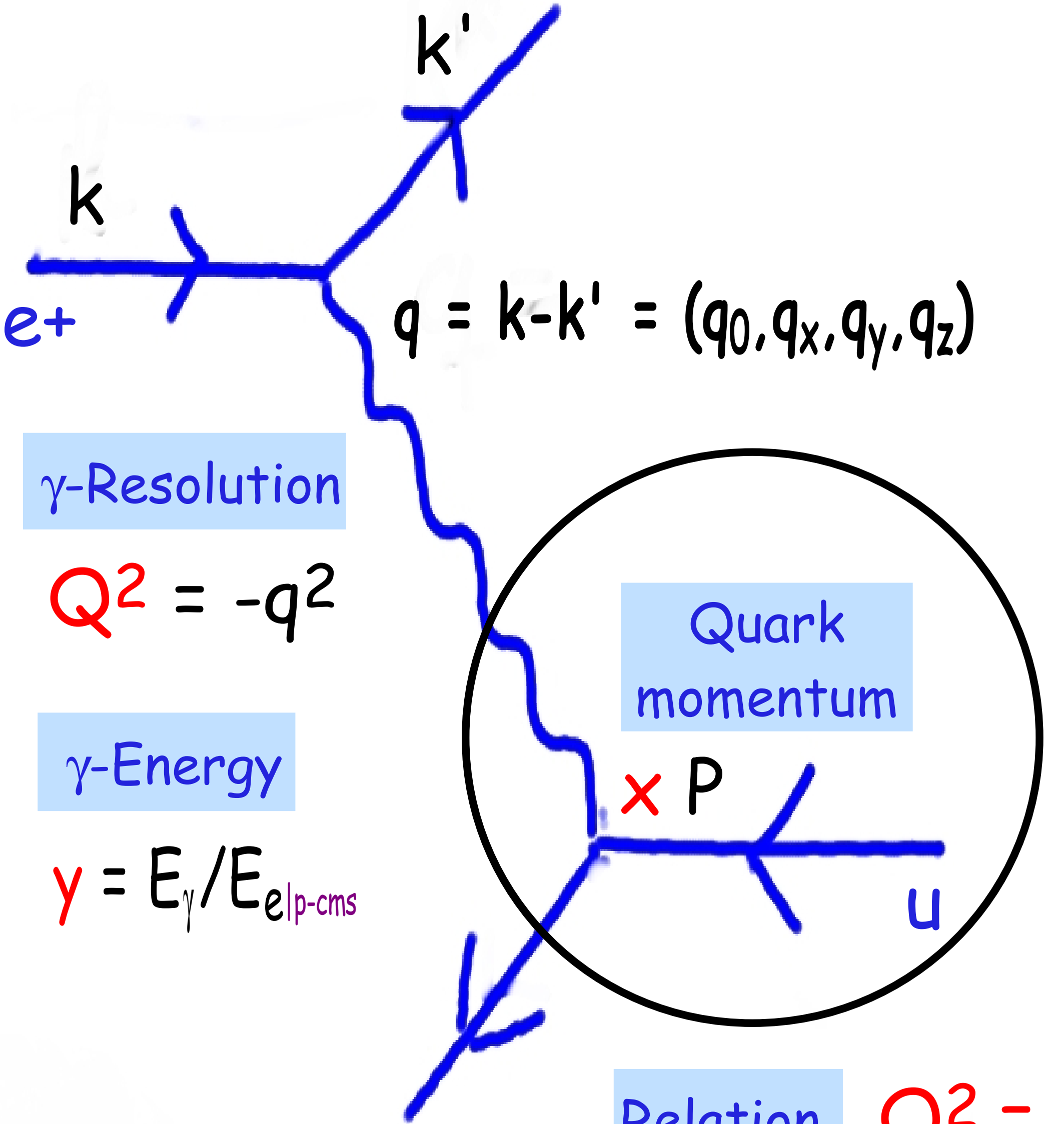
Super-hard W-exchange; 1/Monat



Kinematics of ep scattering

HERA: $\sqrt{S}$ = 318 GeV





$q = k - k' = (q_0, q_x, q_y, q_z)$

γ-Resolution

$Q^2 = -q^2$

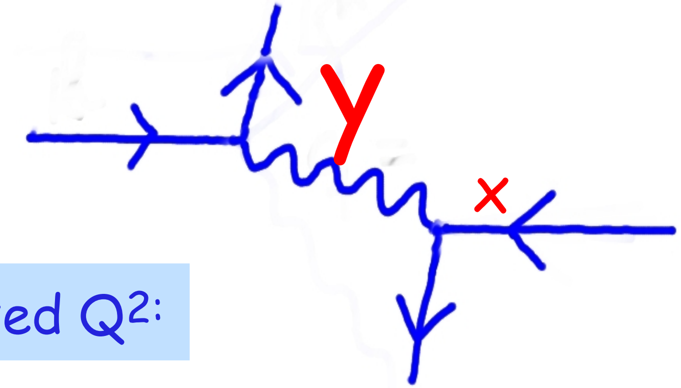
γ-Energy

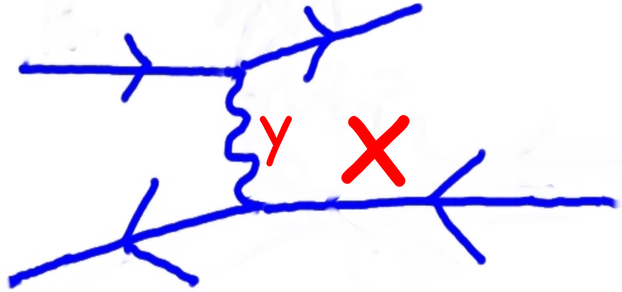
$y = E_\gamma / E_{e|p\text{-cms}}$

Quark momentum

Relation $Q^2 = Sxy$

For fixed Q^2:

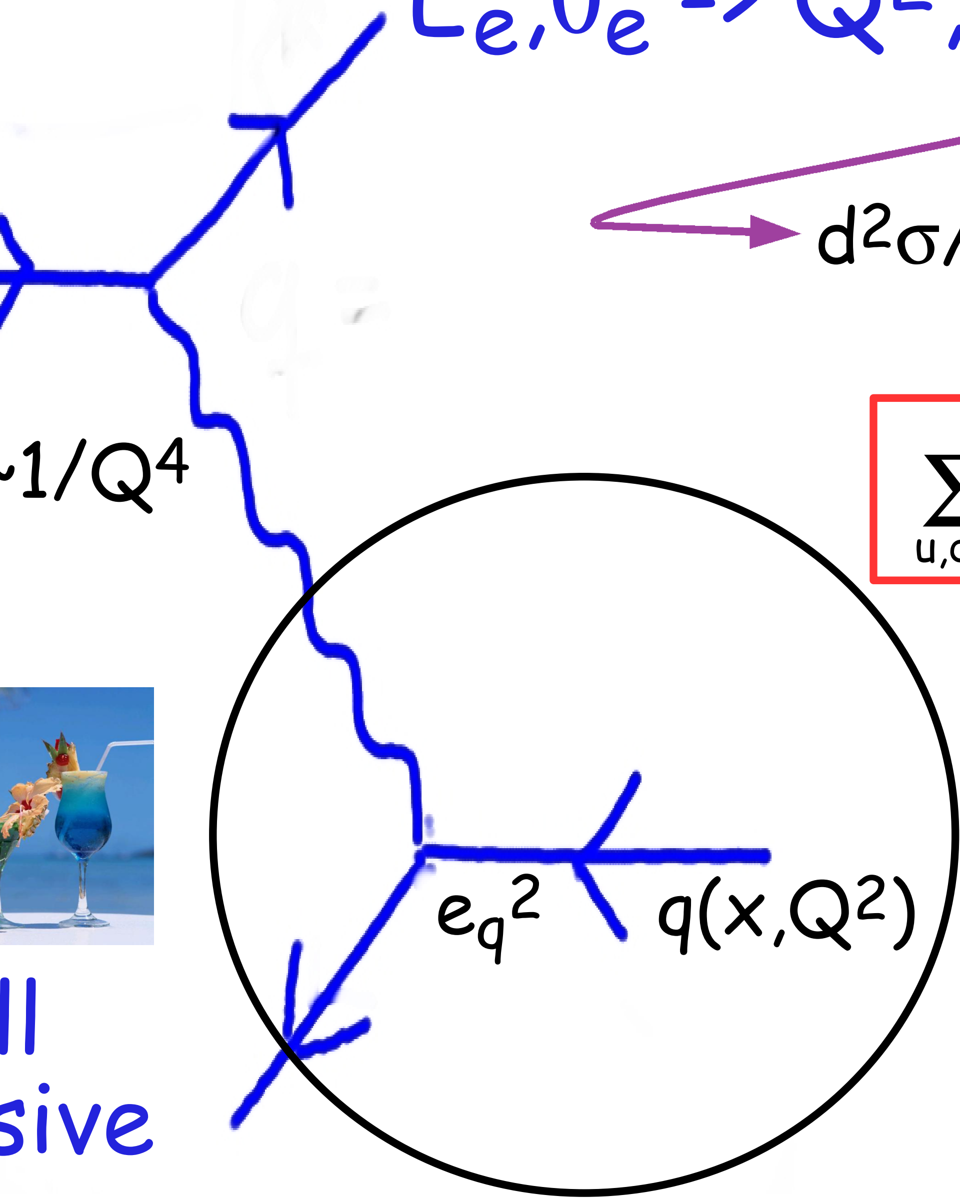




Inclusive ep scattering

$E_e, \theta_e \rightarrow Q^2, x$

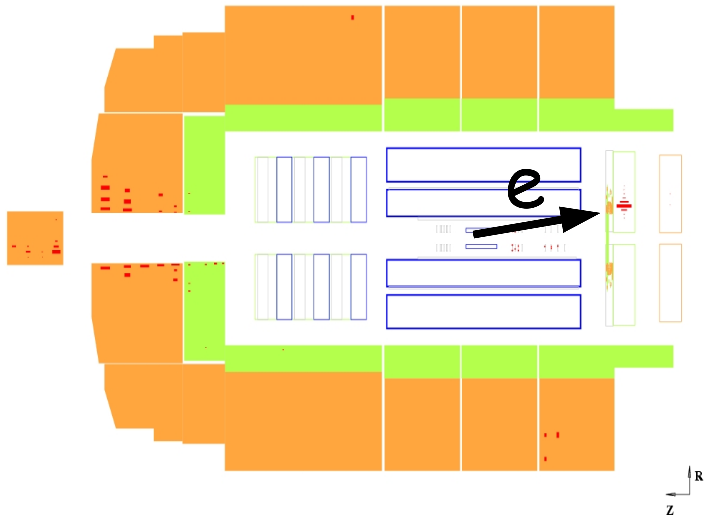
Measure # scattered Elektrons in bins of Q^2,x



$$d^2\sigma/dQ^2dx \sim \alpha/Q^4 \cdot F_2(x,Q^2)$$

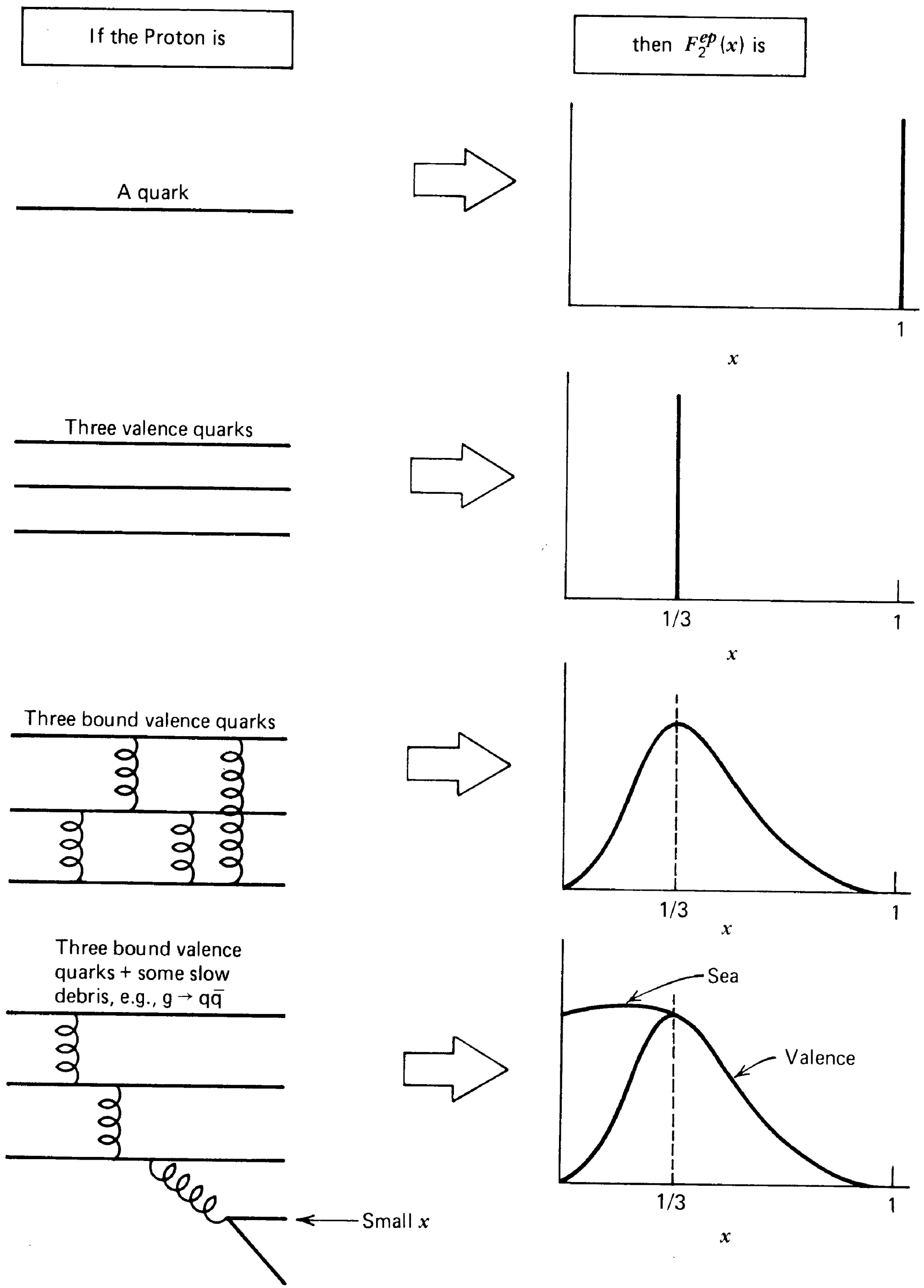
$$\boxed{\sum_{u,d,s} x e_q^2 [\, q(x,Q^2) + \bar{q}(x,Q^2) \,]}$$

All inclusive

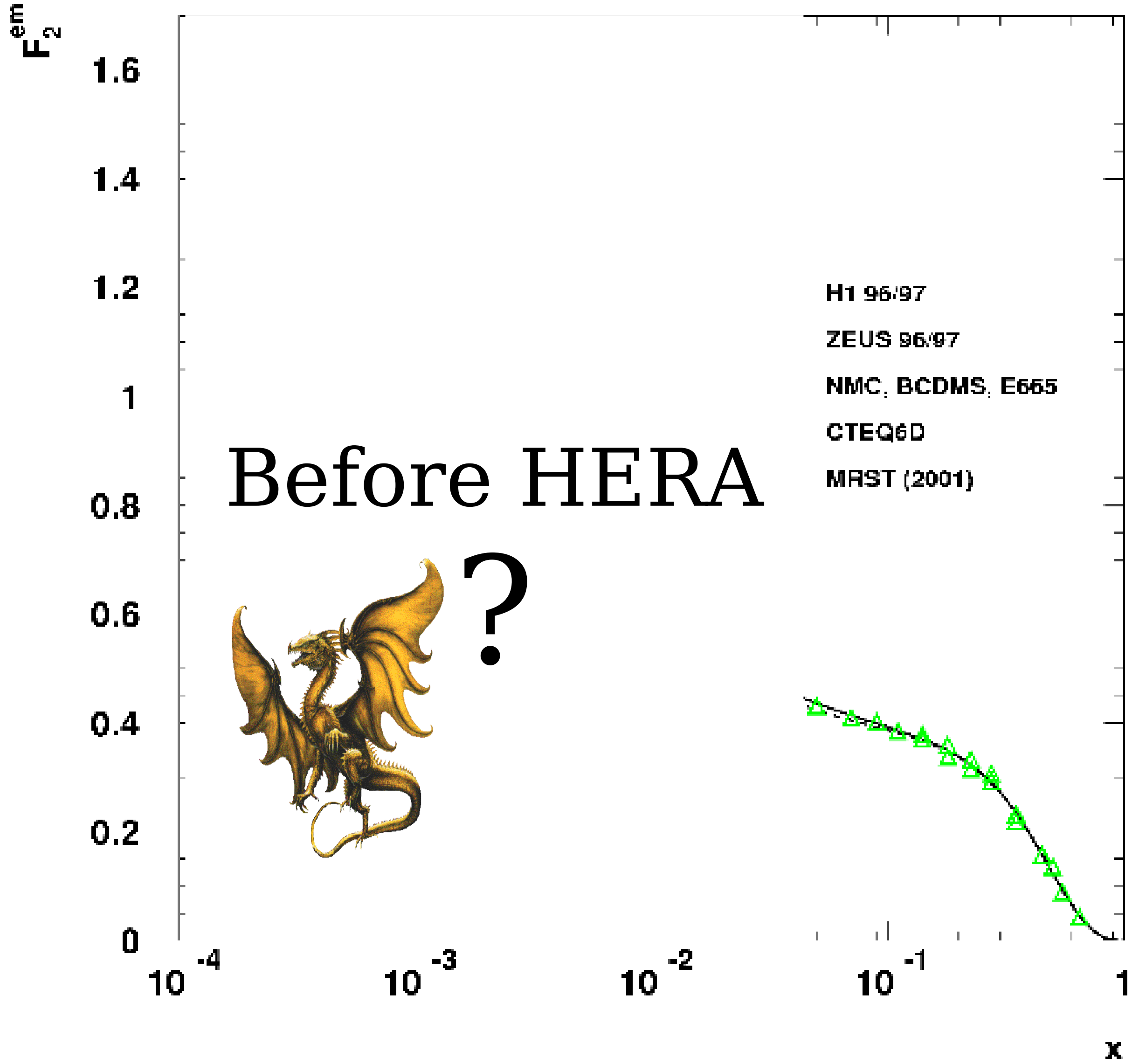


The Proton and F_2

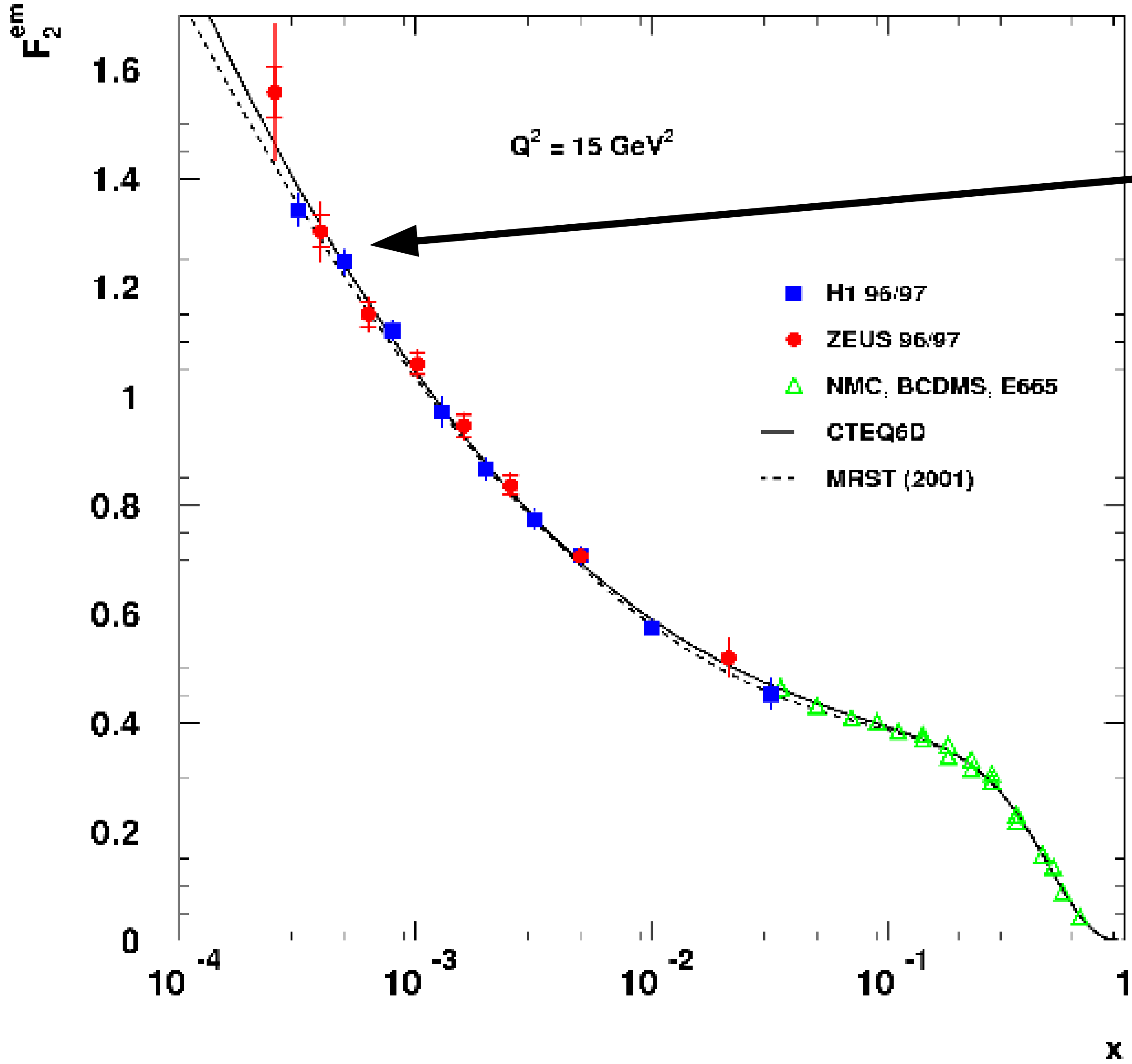
$$F_2 = \sum_{u,d,s} x e_q^2 [\, q(x,Q^2) + \bar{q}(x,Q^2)]$$



$F_2(x)$ at Q^2=15 GeV^2

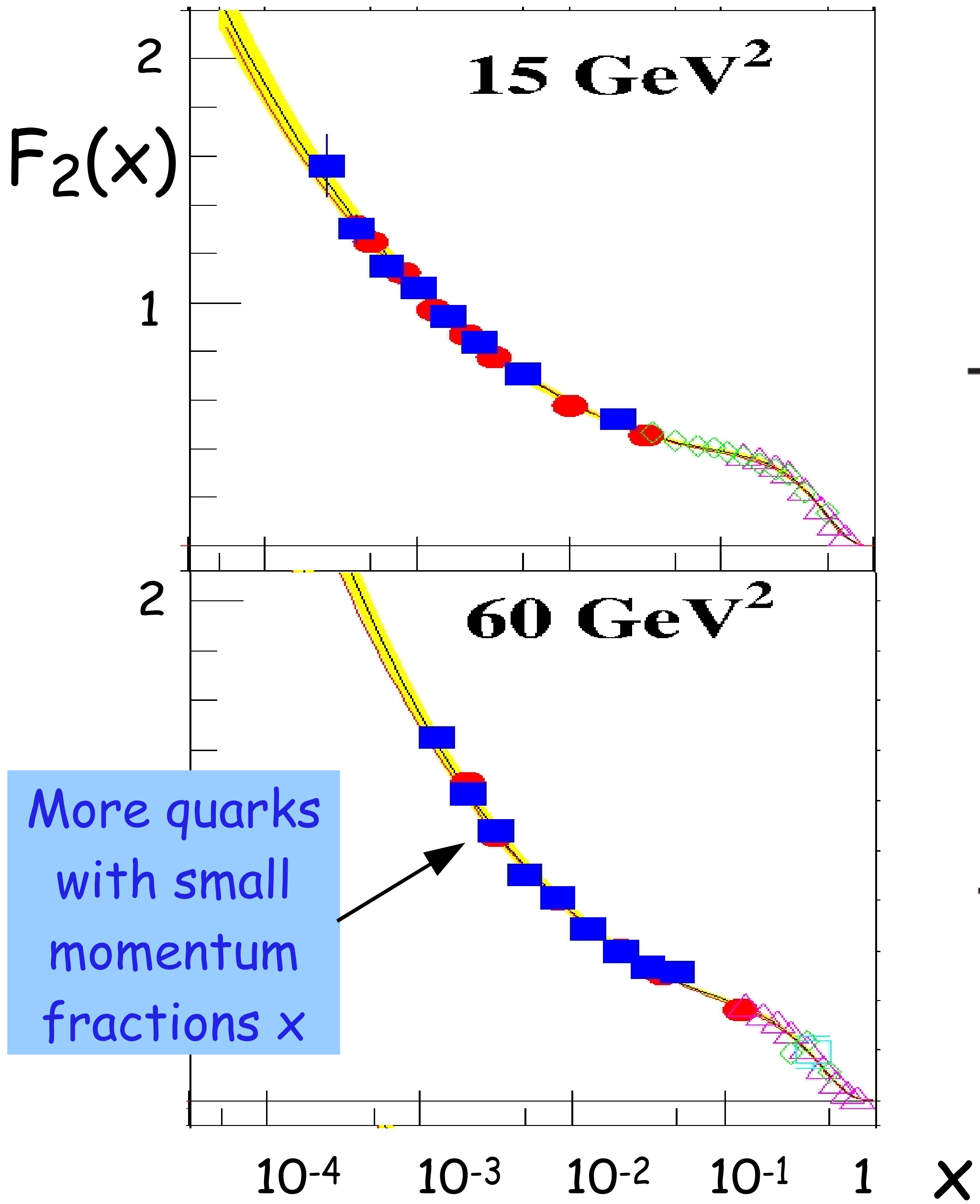


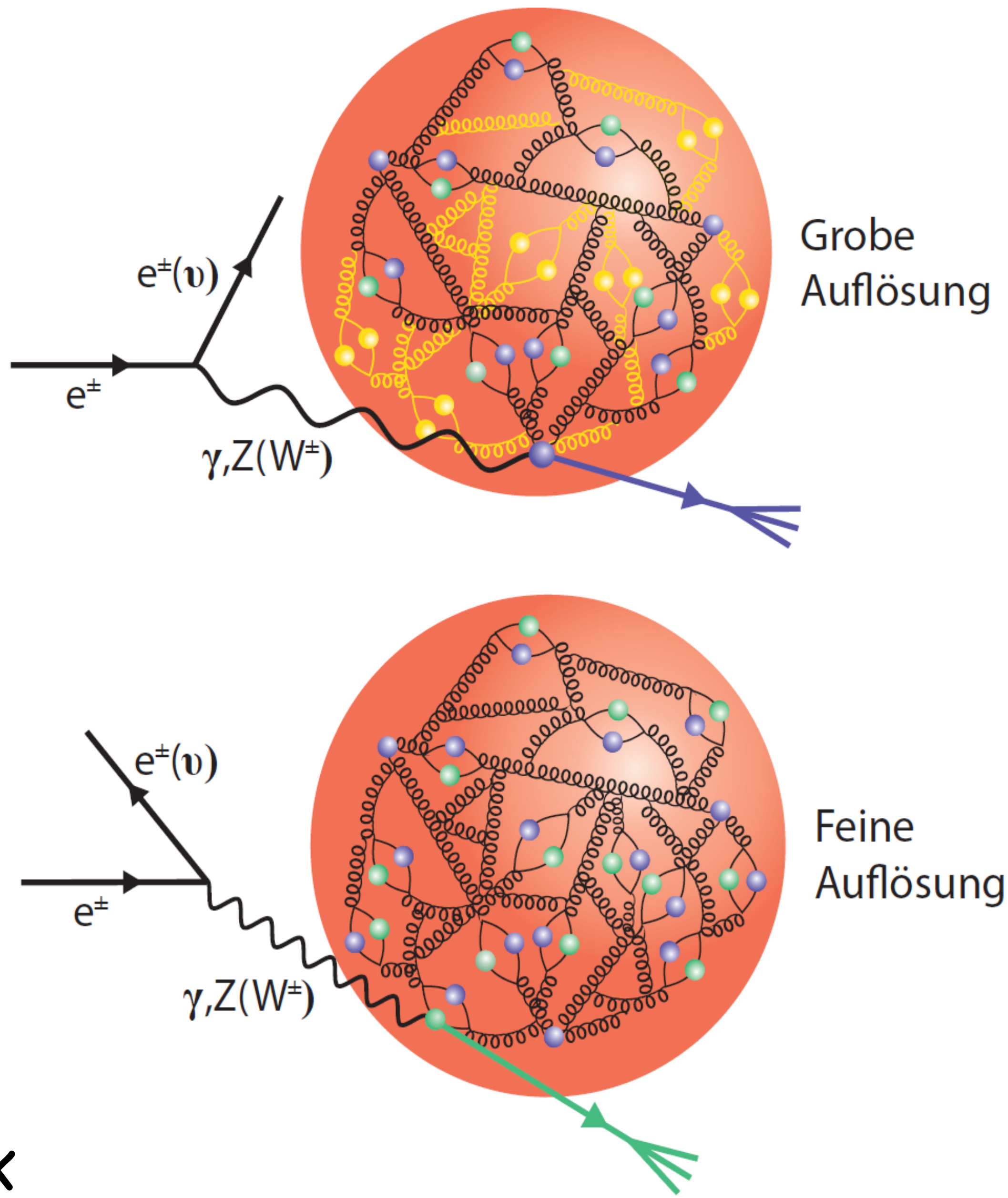
$F_2(x)$ at $Q^2=15\ GeV^2$



Many sea quarks with small momentum fractions x

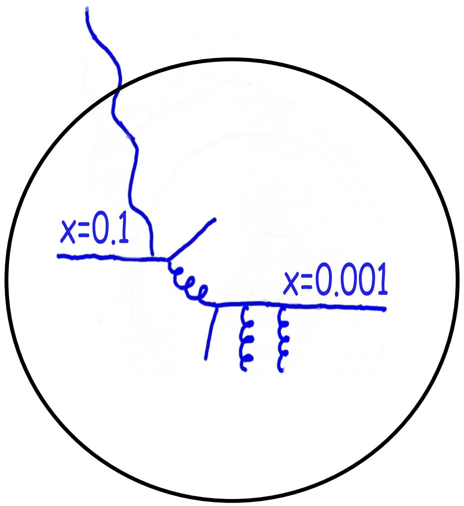
Increase resolution power Q^2





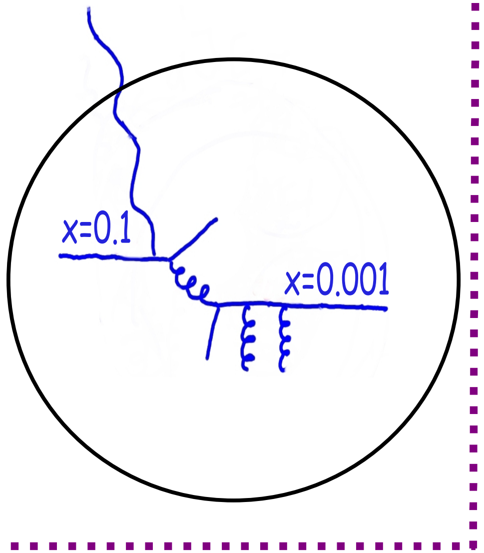
Proton 'Toolkit'

Fixed Target



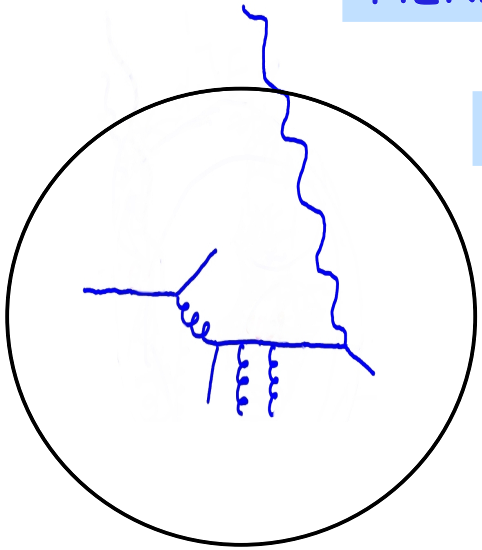
Proton 'Toolkit'

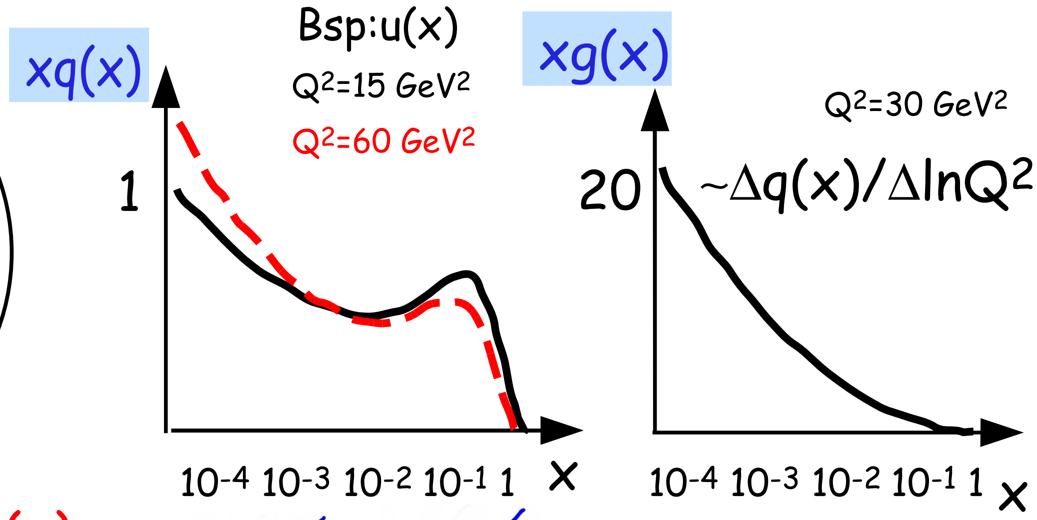
Fixed Target



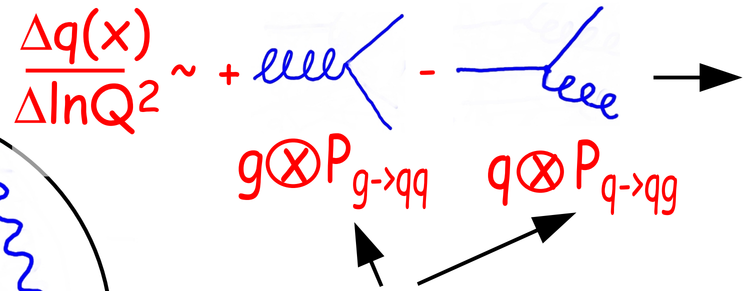
Q²=15 GeV²

HERA





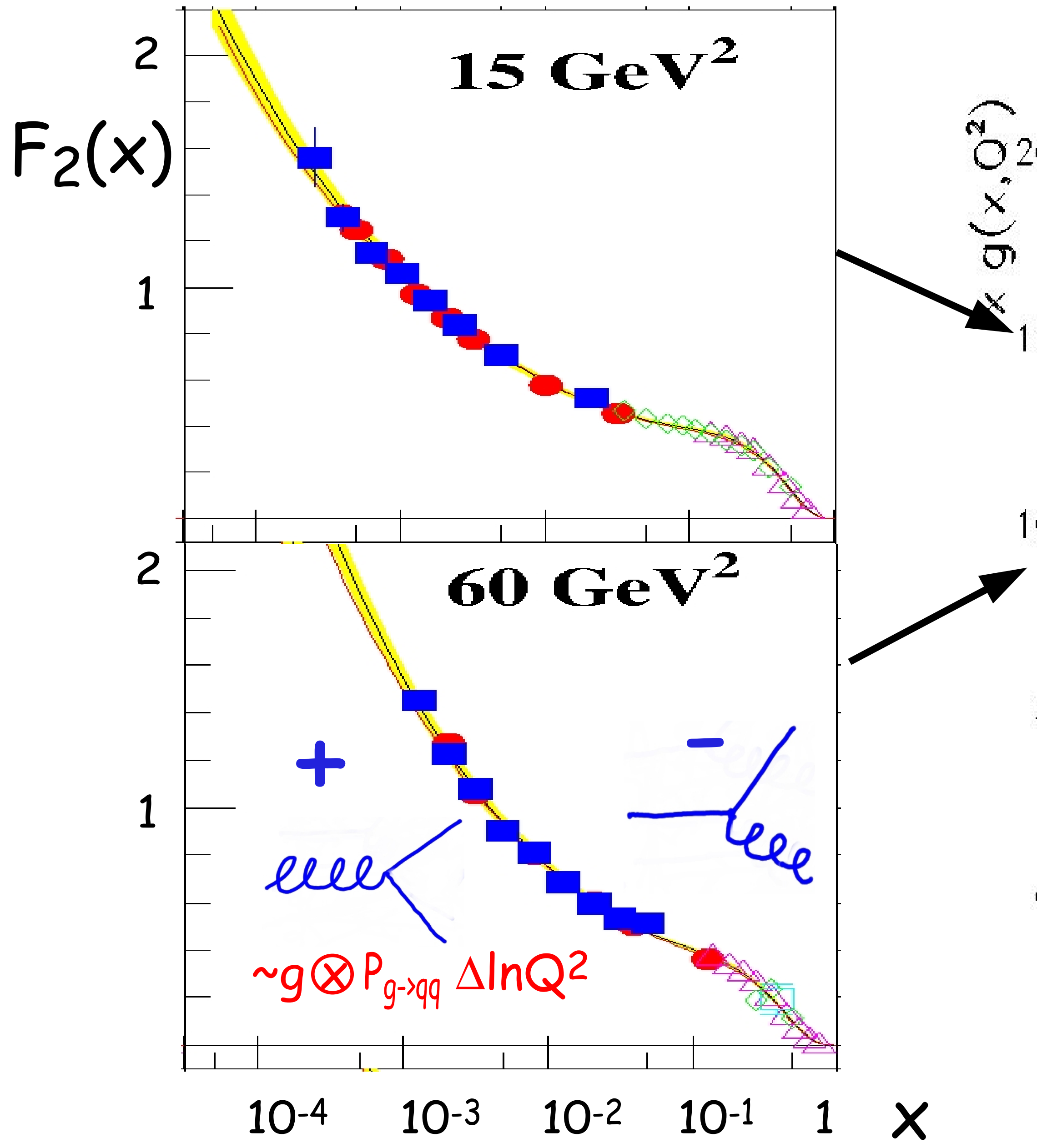
Q²=60 GeV²

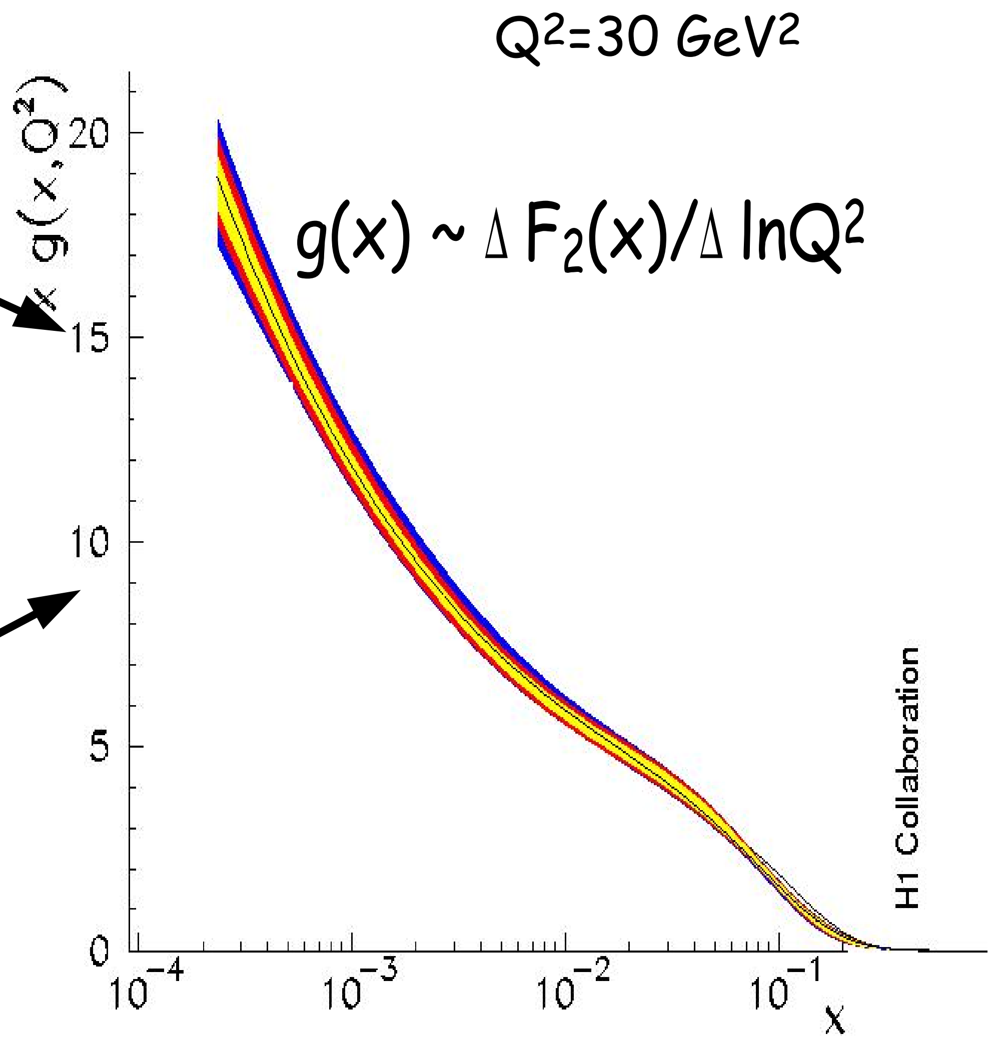


Calculable-> DGLAP evolution equations

Quark and gluon densities not yet predictable as function of x, but once known at a given Q^2 they can be predicted (by evolving) at any Q^2 scale.

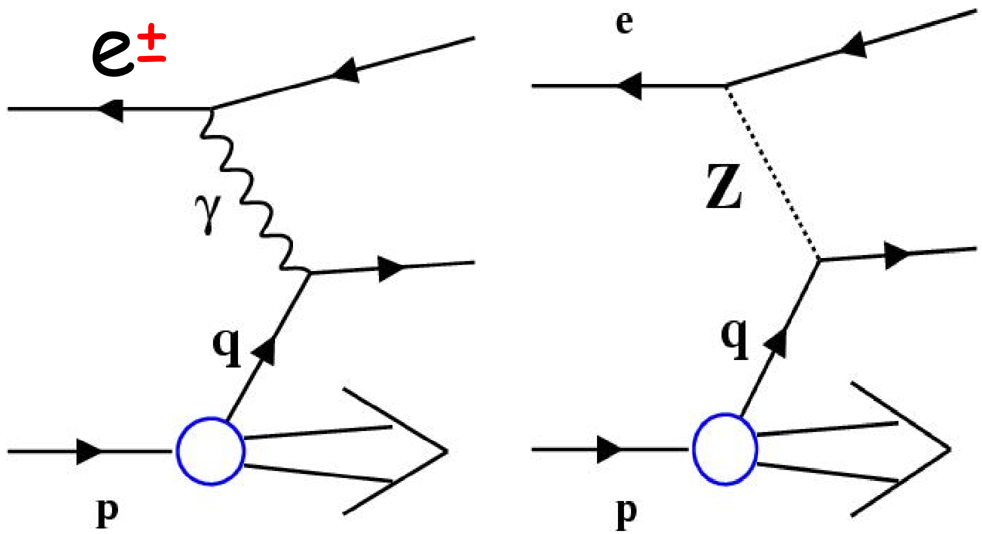
Determine gluon density from scaling violations





➔ Huge crowd of gluons in Proton!

Direkt measurement of Valence quarks

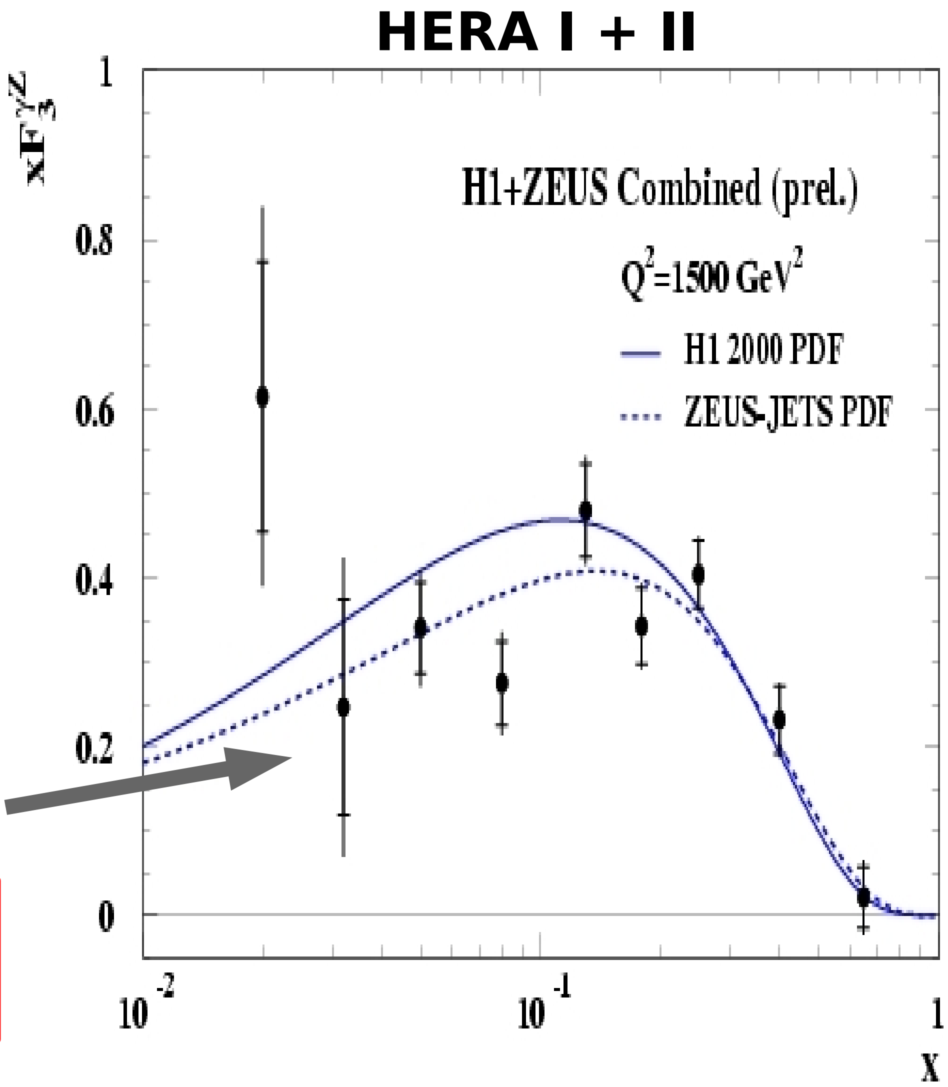


γZ Interference changes sign for e+p -> e-p

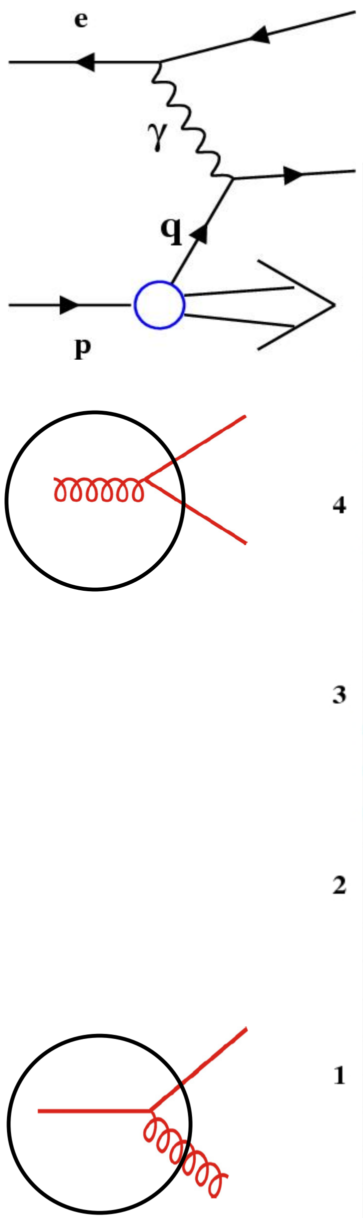
$$xF_3 \sim \sigma(e^+p) - \sigma(e^-p) \sim 2u_v + d_v$$

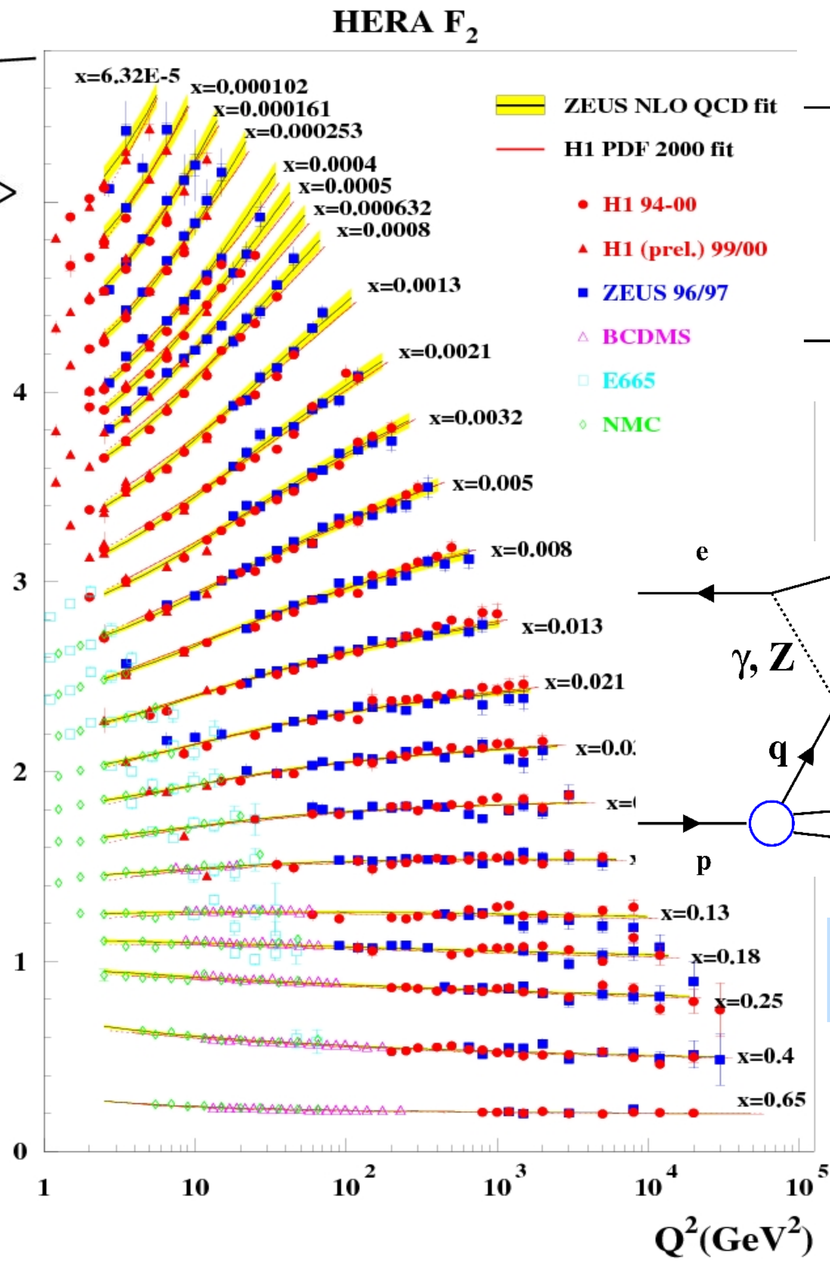
H1 & ZEUS combined Data

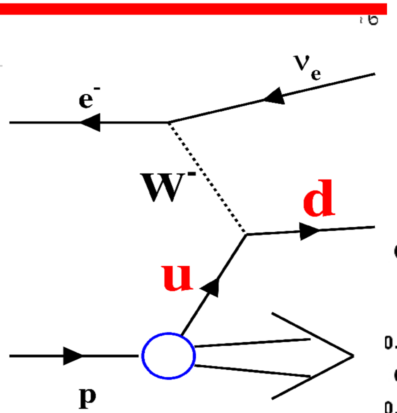
→ Info on valence quarks at small x

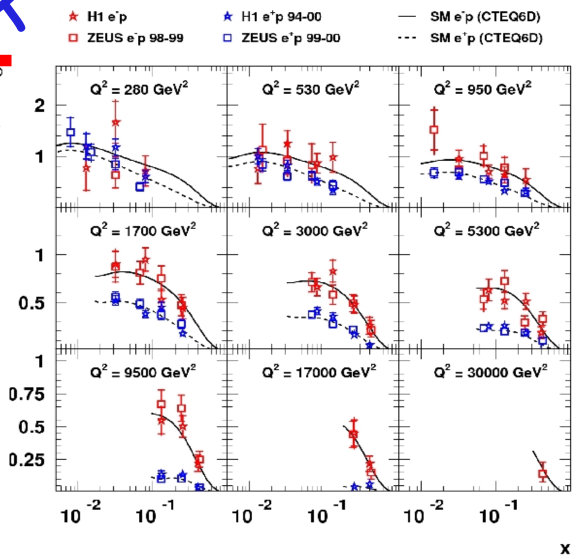


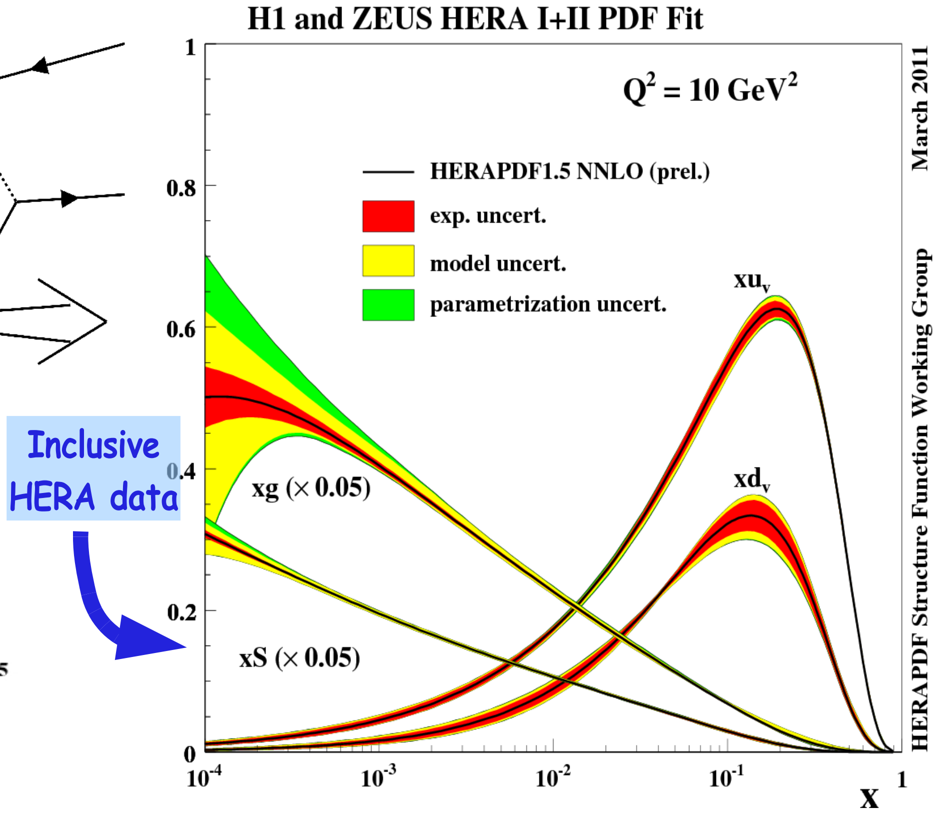
The HERA proton handbook



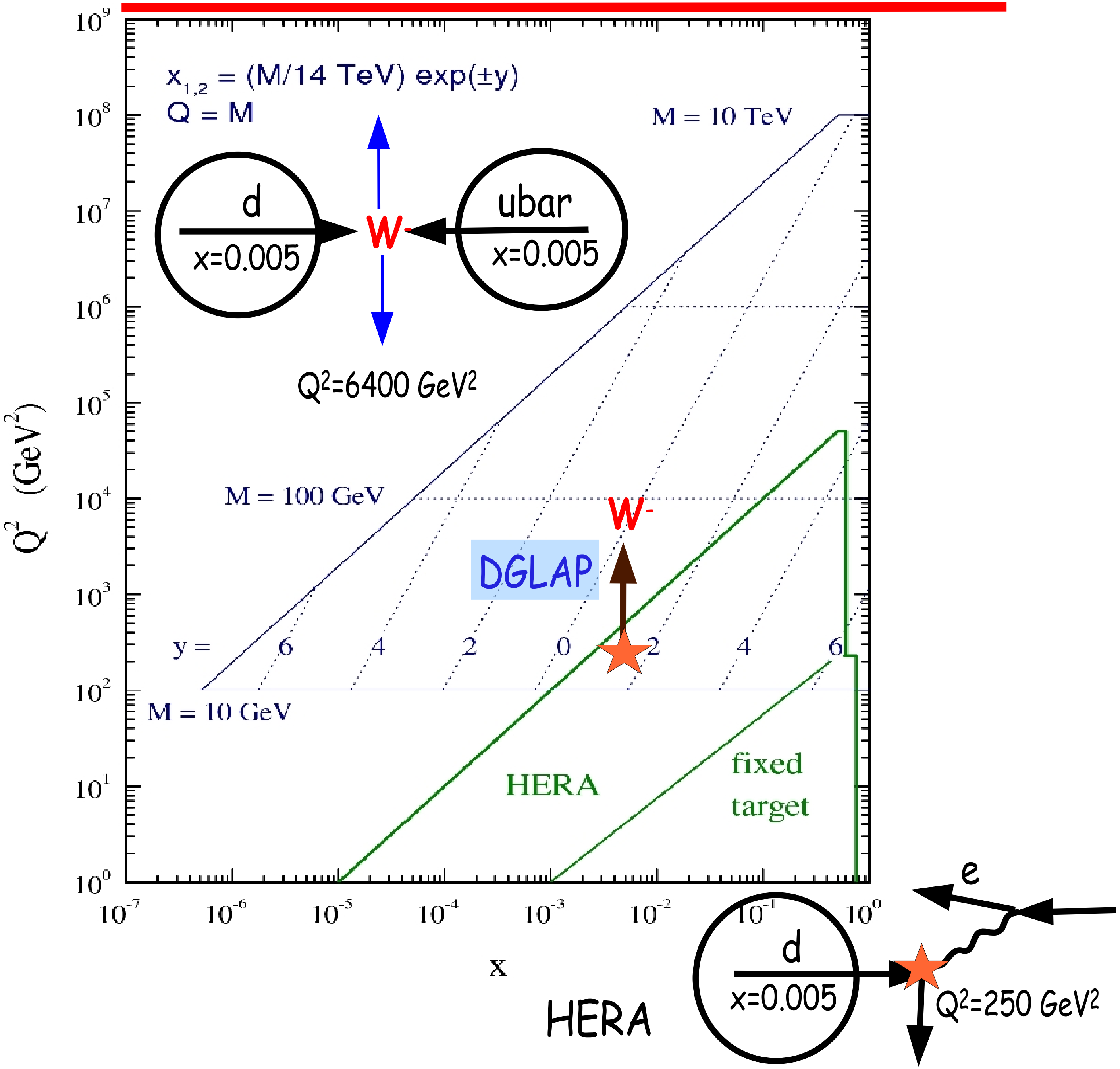






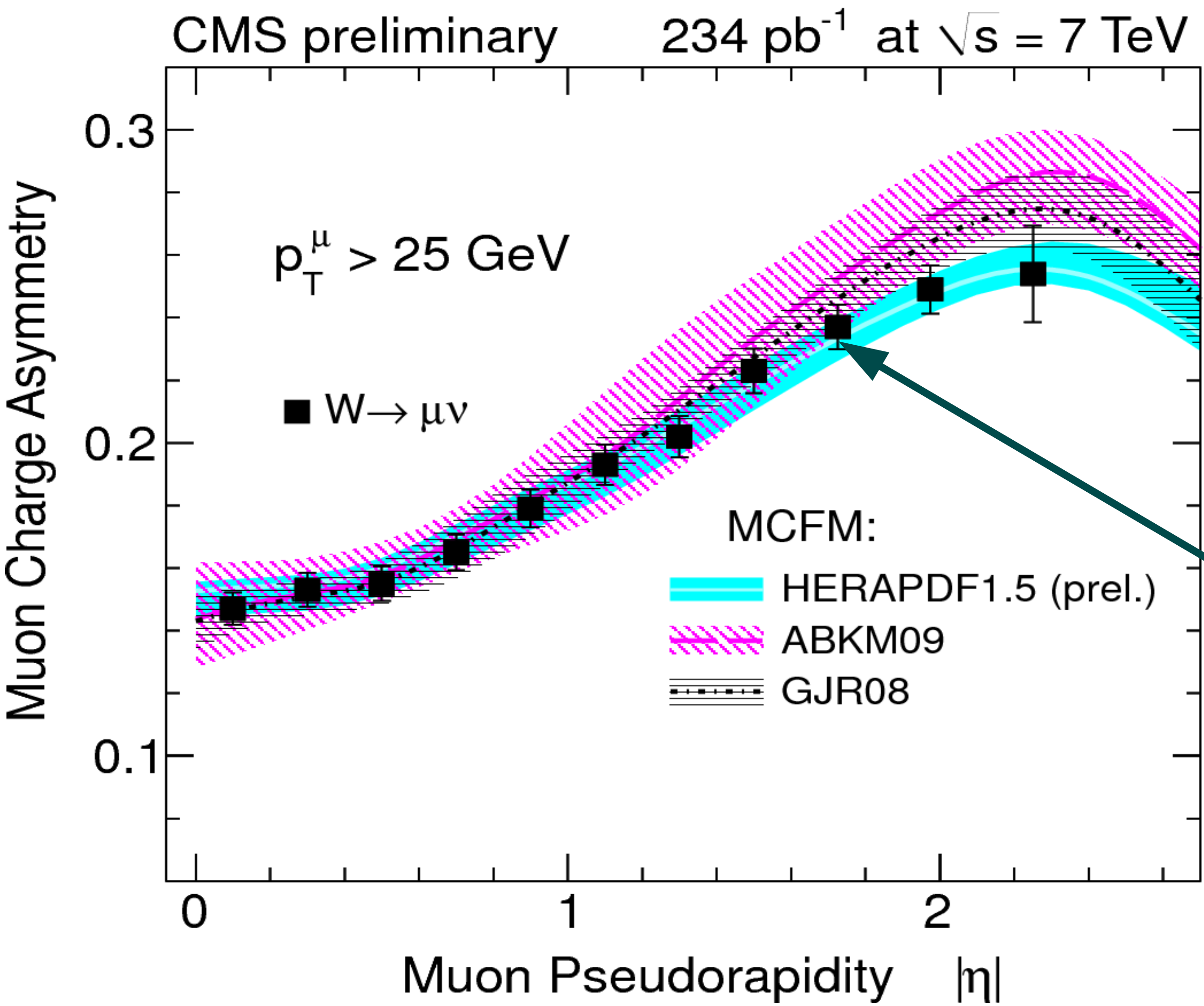


From HERA to LHC in a nutshell



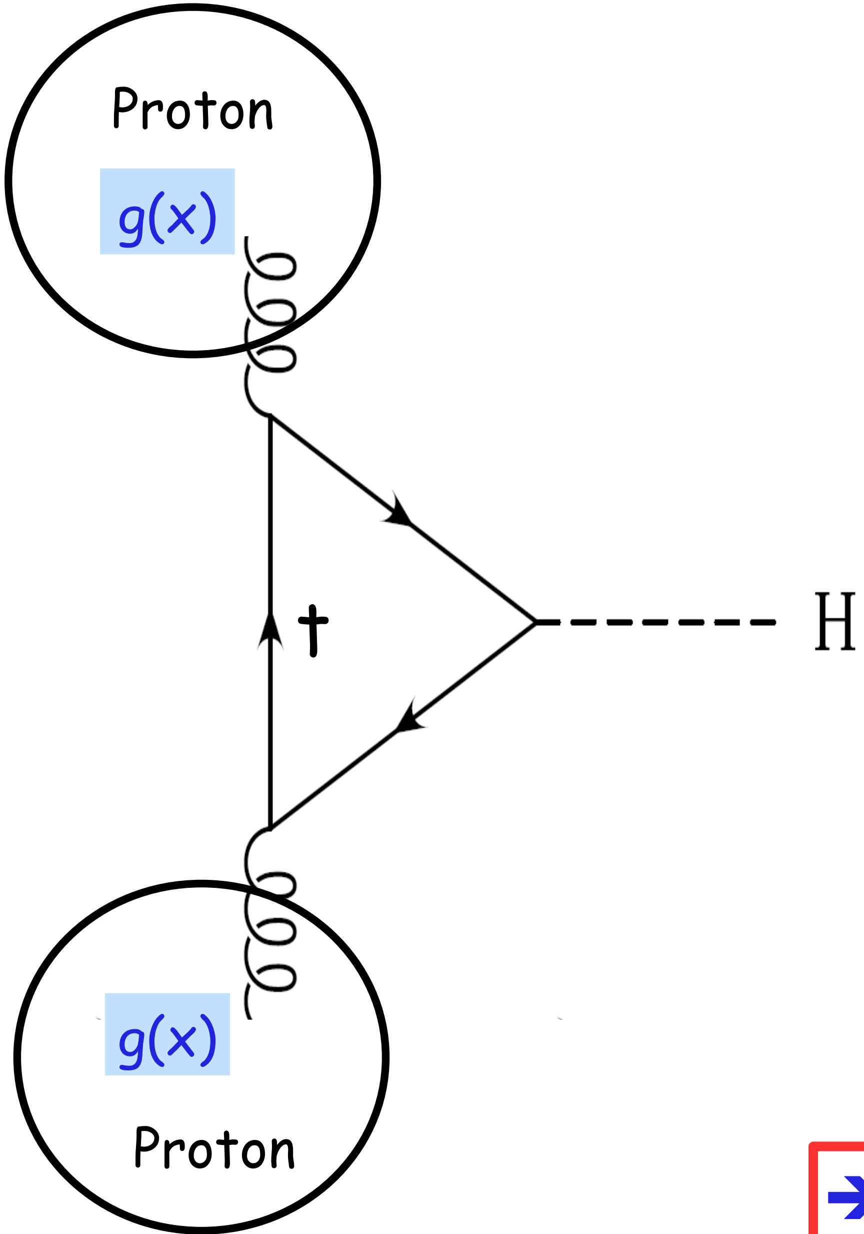
Compare HERAPDF based predictions to CMS data

$$\mathcal{A}(\eta) = \frac{d\sigma/d\eta(W^+ \to \ell^+\nu) - d\sigma/d\eta(W^- \to \ell^-\bar{\nu})}{d\sigma/d\eta(W^+ \to \ell^+\nu) + d\sigma/d\eta(W^- \to \ell^-\bar{\nu})}$$

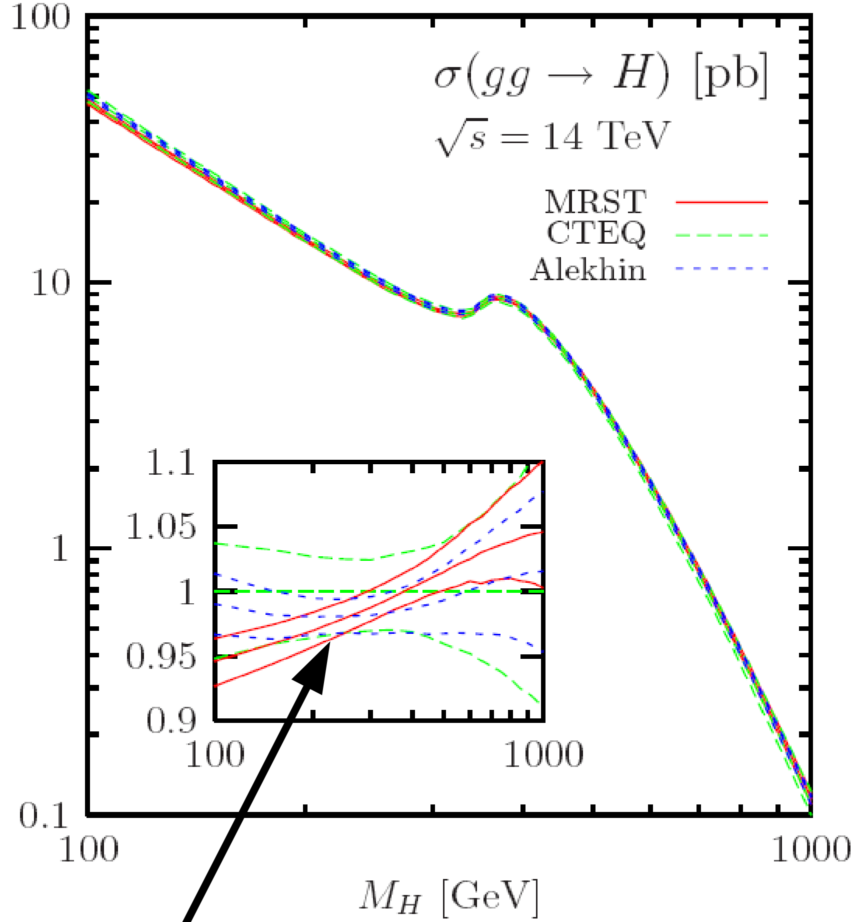


Very nice description by HERAPDF1.5

HERA Gluondichte --> LHC

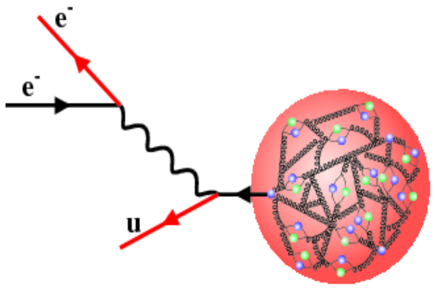


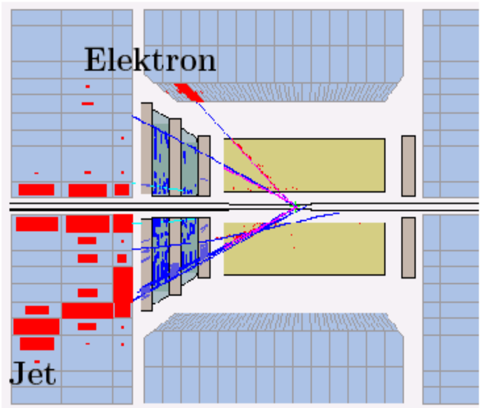
gg-> H
Vorhersage-Fehler

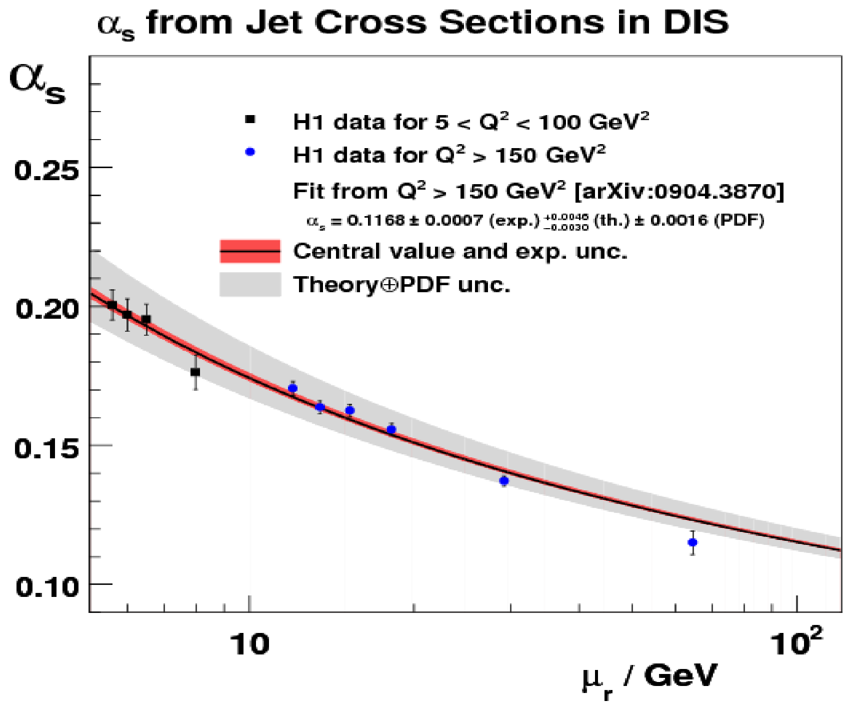


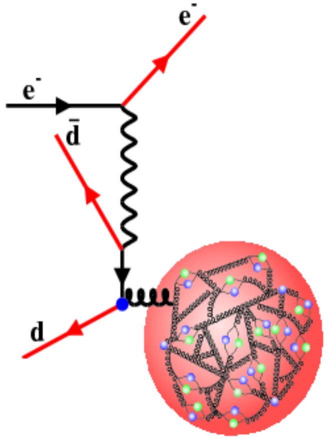
➔ HERA Gluondichte bestimmt Präzision!

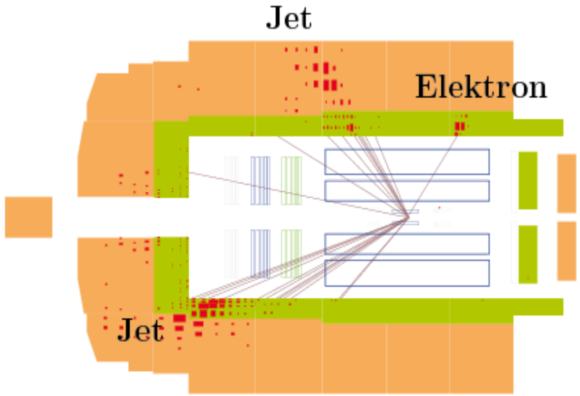
HERA: Studying the QCD perturbation series in the detector



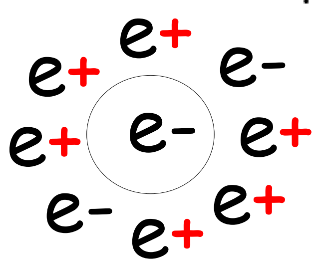






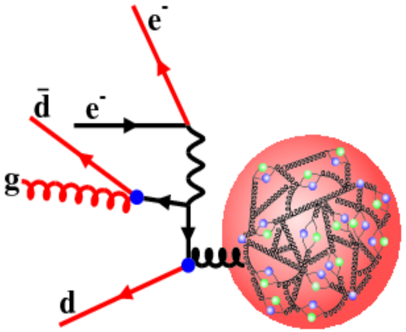


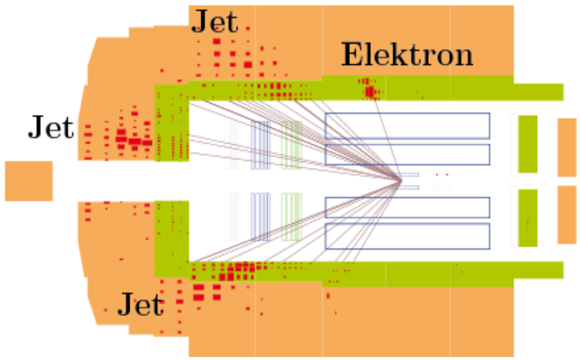
Elektrodynamics



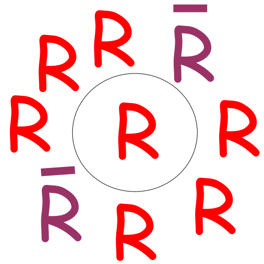
Screening

$\alpha(Q^2)$ Q^2





Strong force



Amplification

$\alpha_s(Q^2)$ Q^2

Search for new particles

HERA ep Collider

e

Proton

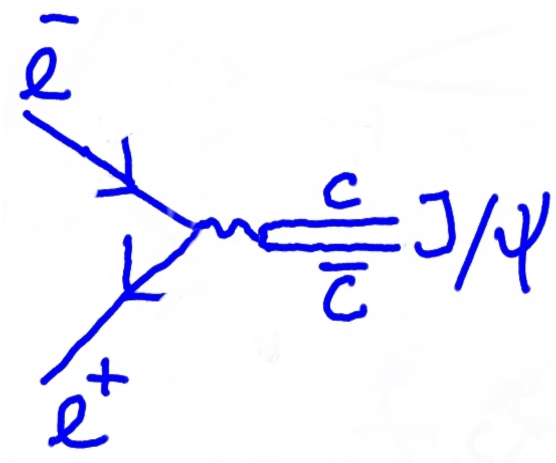
+ X

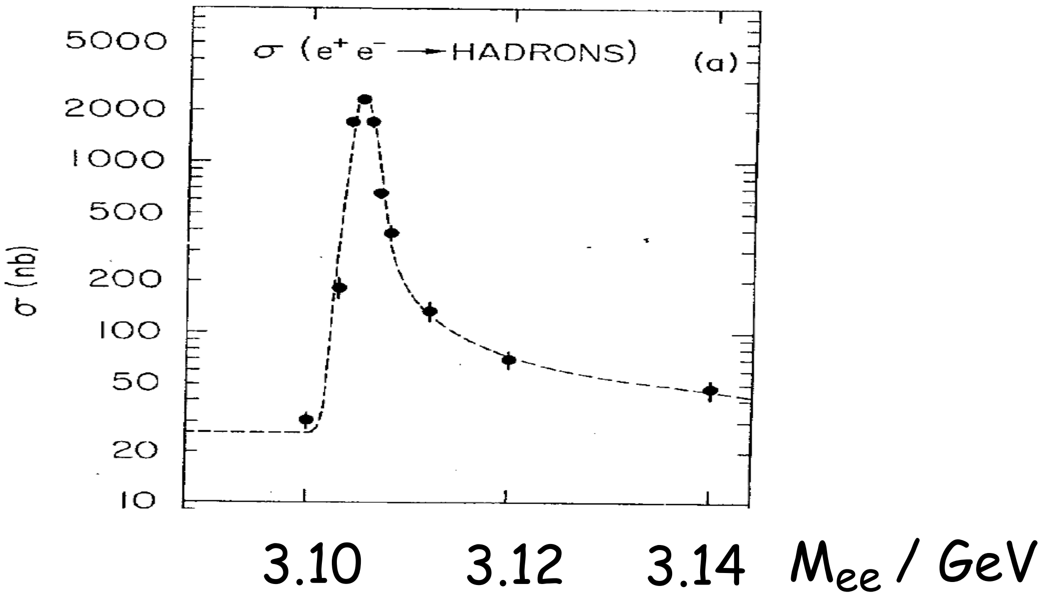
Leptoquarks ?
Susy-Particles?
Excited e,ν
....

$\sqrt{S}$ = 318 GeV

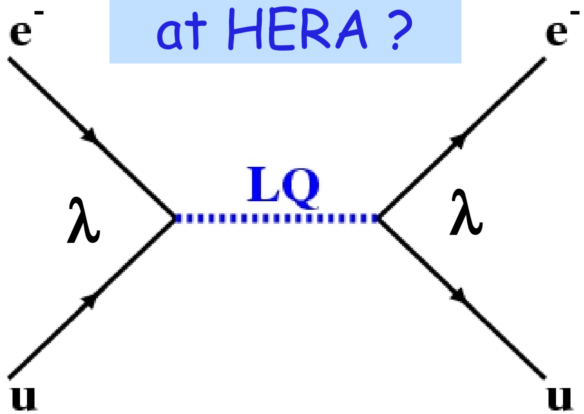
Search for Leptoquarks

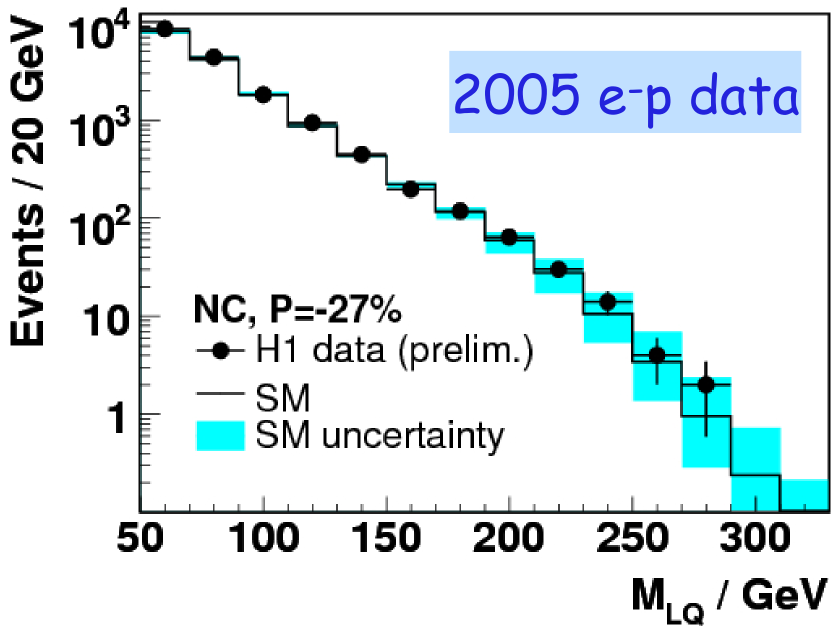
Discovery of charm quarks 1974





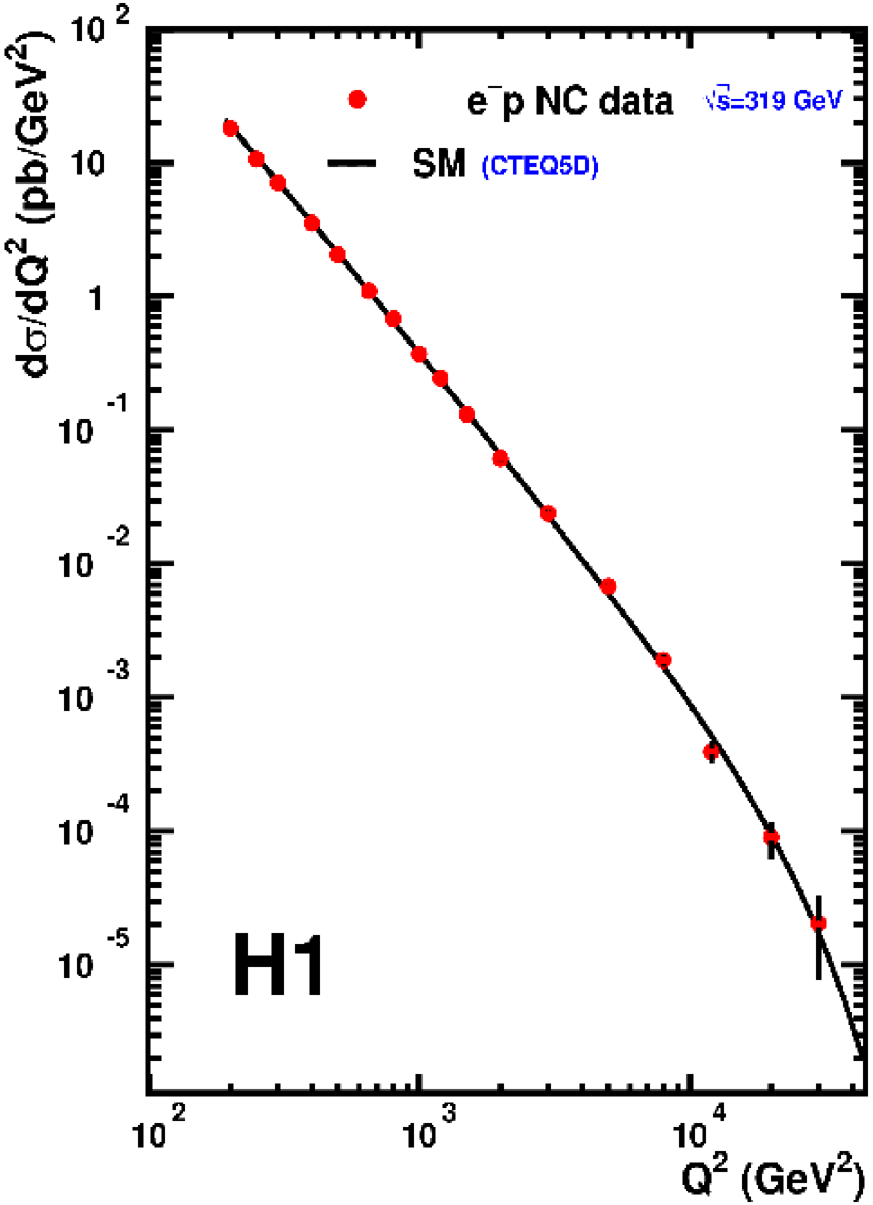
Leptoquarks at HERA ?





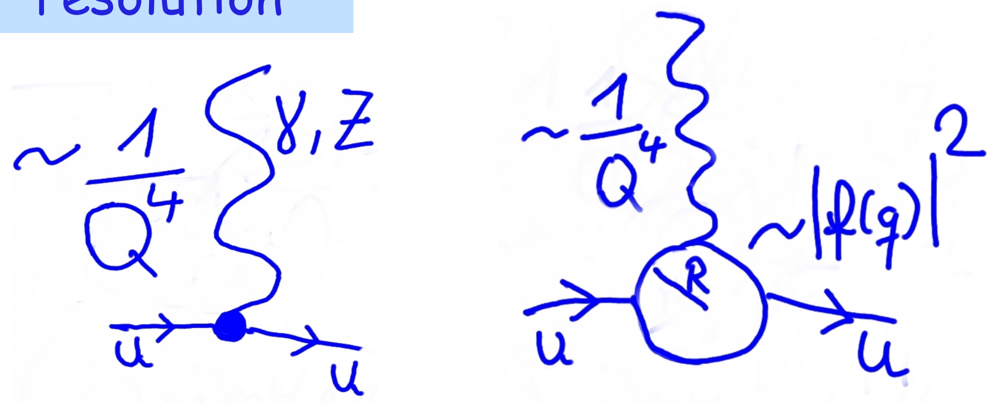
➔ NO hints for leptoquarks

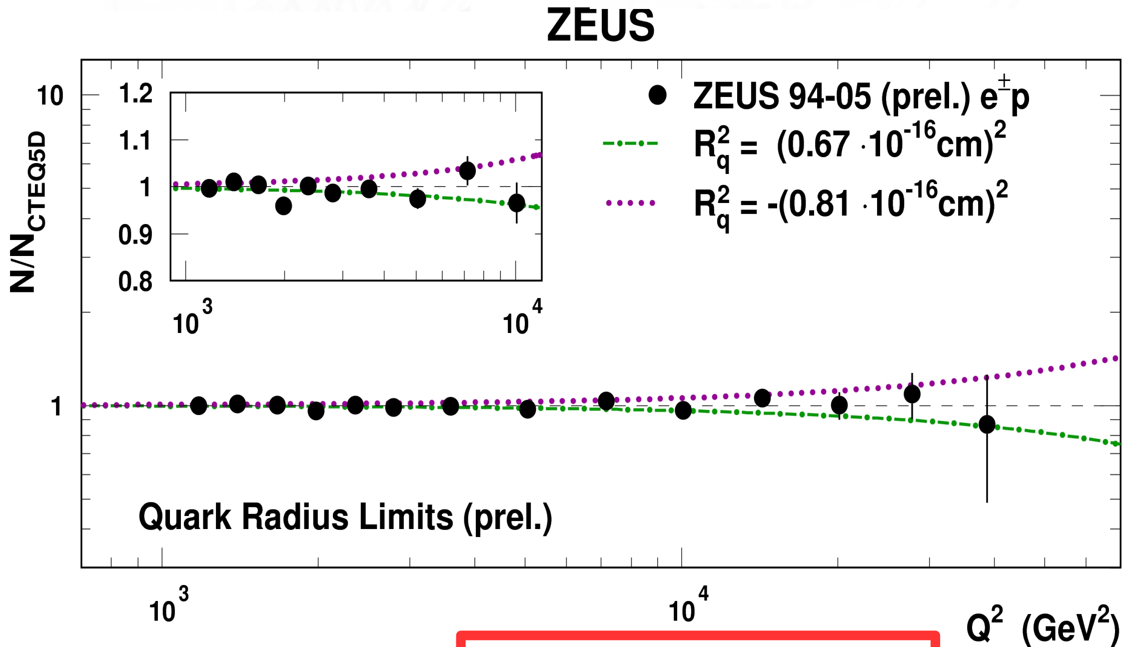
Do Quarks have an extension?



Small-Medium resolution

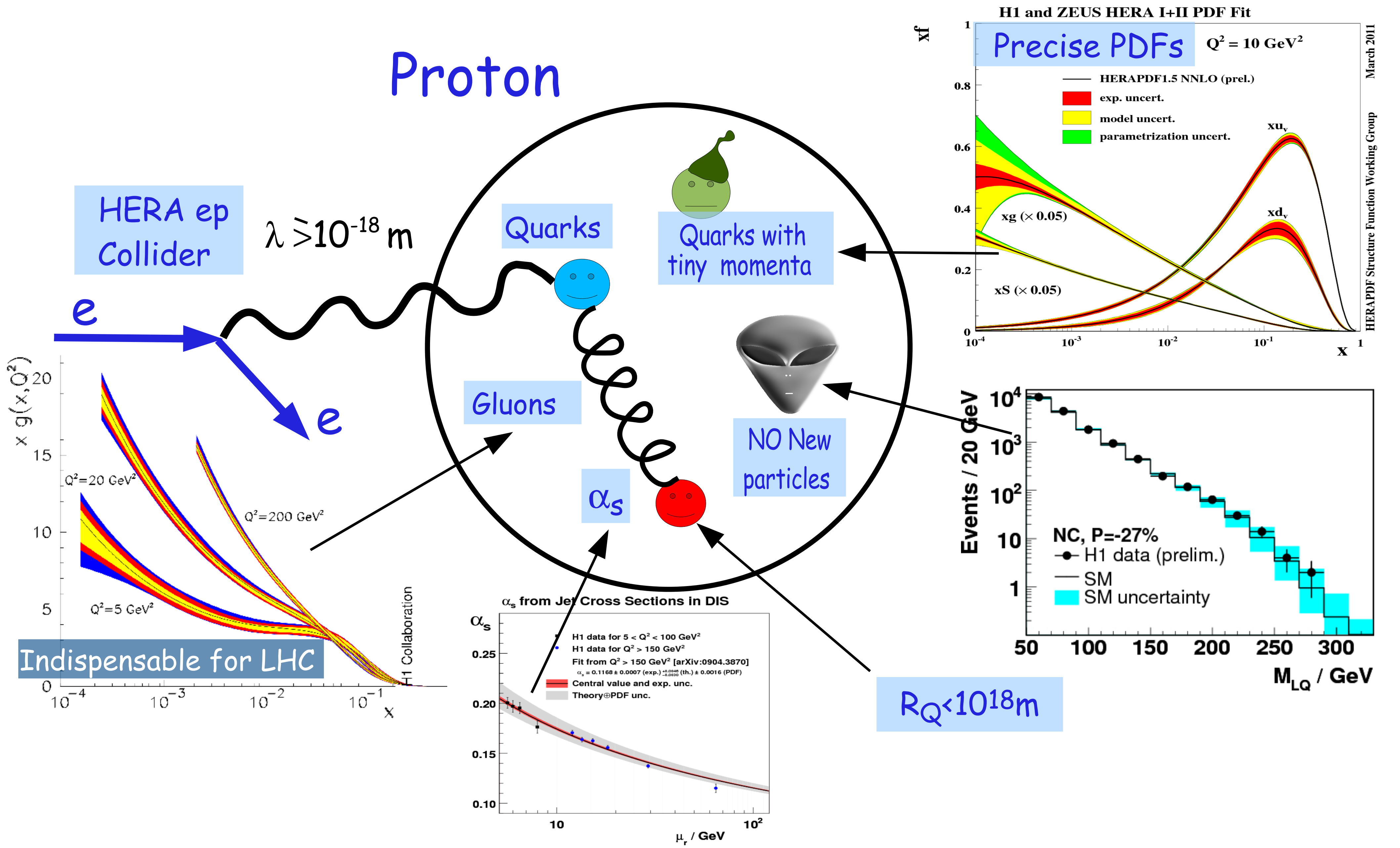
Highest resolution





$\boxed{\rightarrow R_q < 0.7 \cdot 10^{-18}\ \mathrm{m}}$

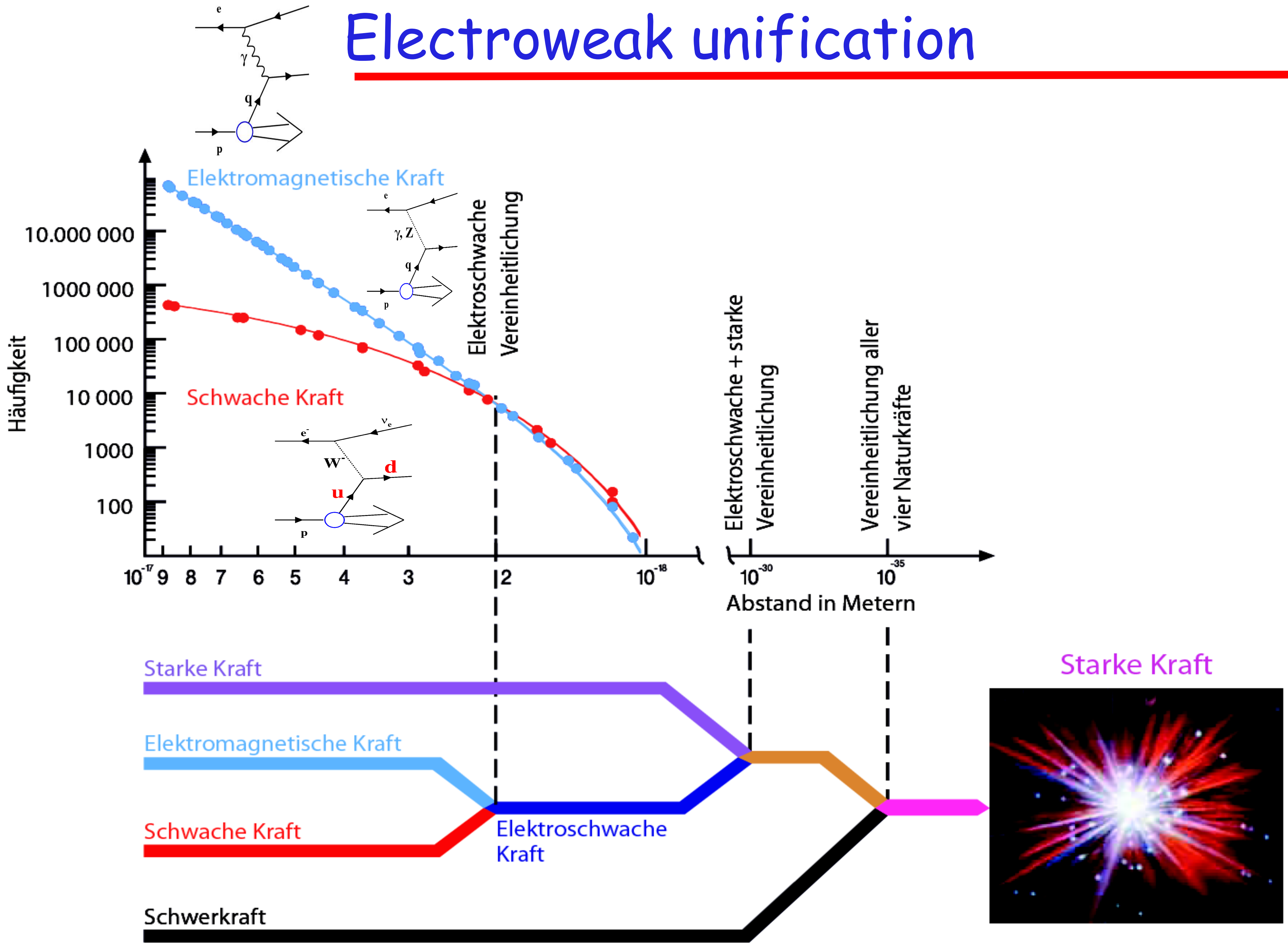
Summary



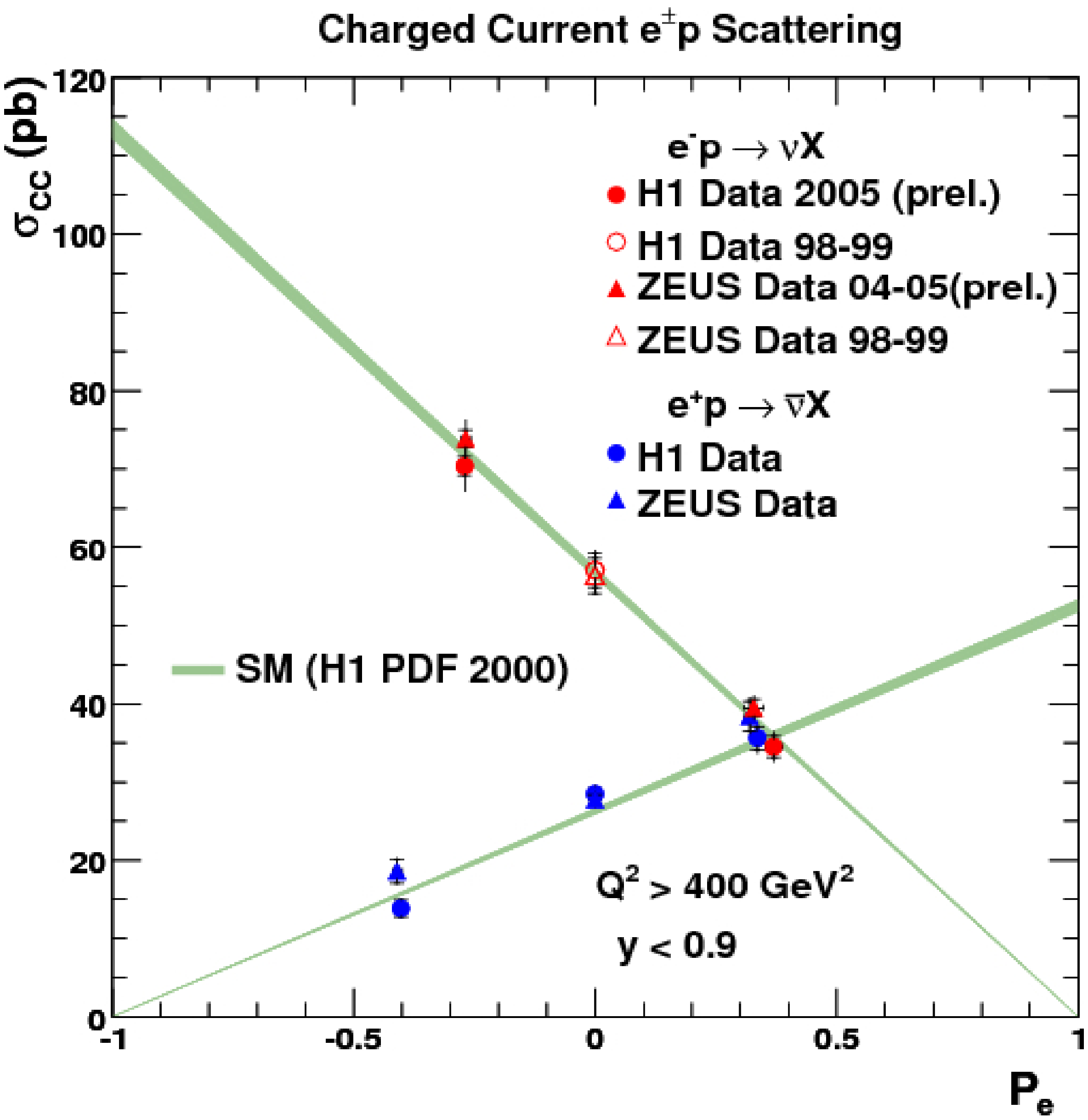
Proton
HERA ep Collider
λ ≳10^-18 m
e
e
Quarks
Quarks with tiny momenta
Gluons
αs
NO New particles
RQ<10^18m
Precise PDFs
H1 and ZEUS HERA I+II PDF Fit
Q² = 10 GeV²
HERAPDF1.5 NNLO (prel.)
exp. uncert.
model uncert.
parametrization uncert.
xuv
xdv
xg (× 0.05)
xS (× 0.05)
xf
x
March 2011
HERAPDF Structure Function Working Group
Indispensable for LHC
x g(x,Q²)
Q²=5 GeV²
Q²=20 GeV²
Q²=200 GeV²
H1 Collaboration
αs from Jet Cross Sections in DIS
H1 data for 5 < Q² < 100 GeV²
H1 data for Q² > 150 GeV²
Fit from Q² > 150 GeV² [arXiv:0904.3870]
Central value and exp. unc.
Theory⊕PDF unc.
μr / GeV
NC, P=-27%
H1 data (prelim.)
SM
SM uncertainty
Events / 20 GeV
MLQ / GeV

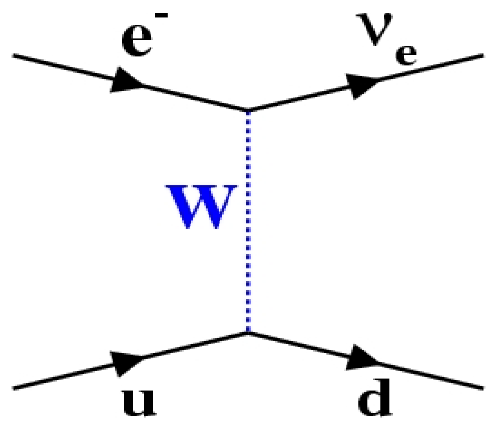
Backup slides

Electroweak unification



Electroweak tests: Charged current vs P_e



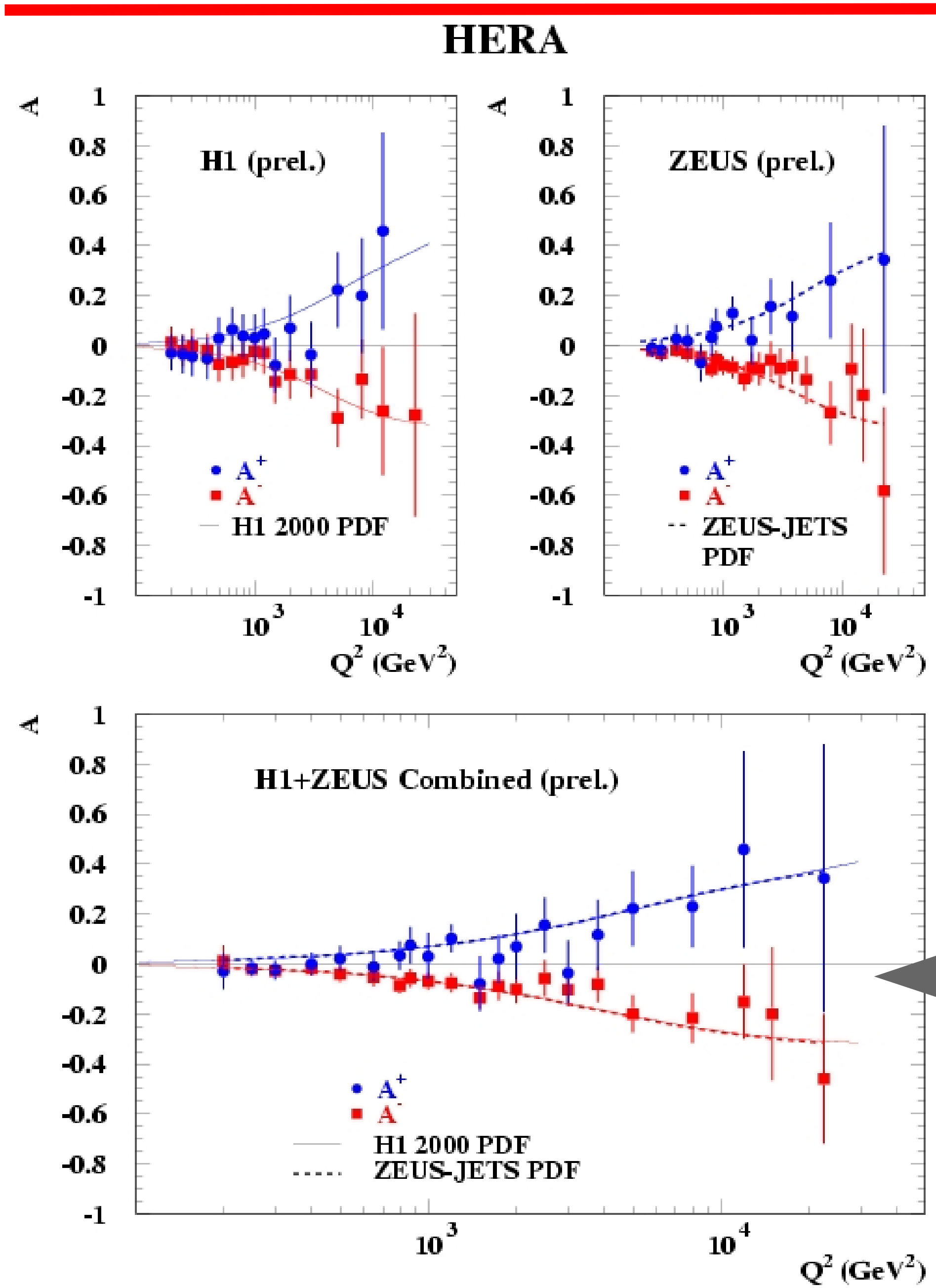


$$\sigma^{e^\pm p}_{\mathrm{polCC}}(Q^2,x) = \frac{1 \pm P_e}{2} \cdot \sigma^{e^\pm p}_{\mathrm{LHCC}}(Q^2,x)$$

→ Textbook plot!
Absence of RH charged currents

→ $M(W_R)$>~180-208 GeV with current precision

First H1+ZEUS results: Neutral Current P_e asymmetries



presented at ICHEP06:

$$A^{\pm} = \frac{2}{P_R - P_L} \cdot \frac{\sigma^{\pm}(P_R) - \sigma^{\pm}(P_L)}{\sigma^{\pm}(P_R) + \sigma^{\pm}(P_L)}$$

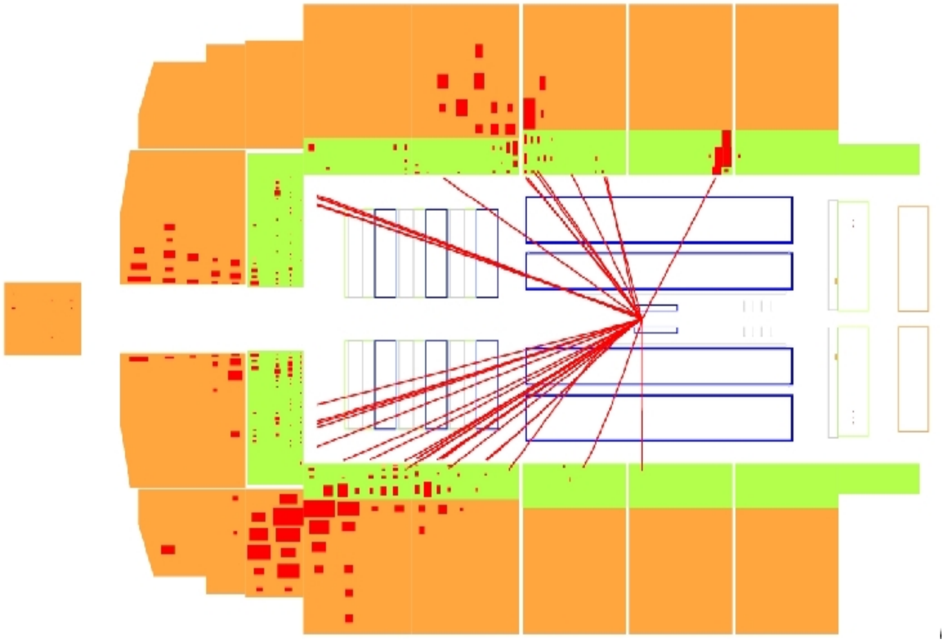
→ Probe parity violation in γ-Z interference

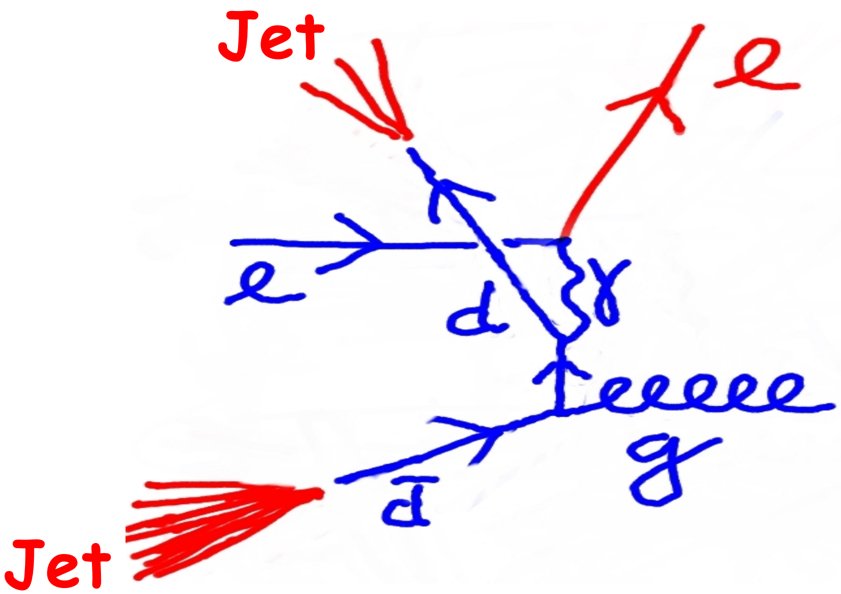
H1 & ZEUS combined data

→ First observation of parity viol. in NC e±p data at R down to 10-18 m

Jet Produktion und g(x)

Dijet-Ereignis

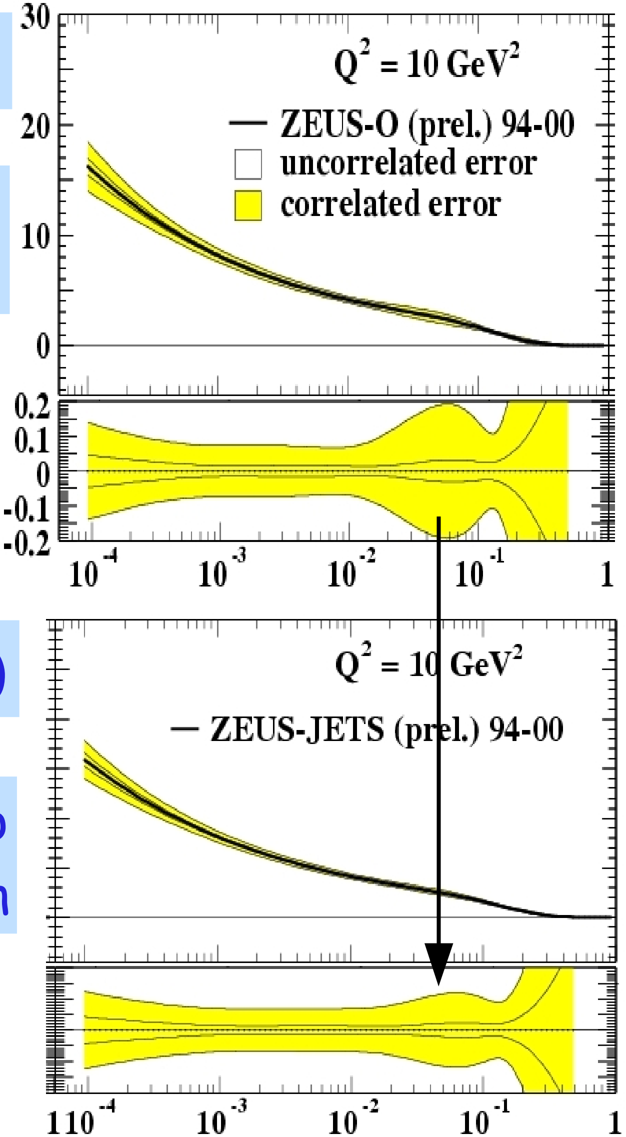




g(x)

Inklusive ep Daten

σ



g(x)

Inklusive ep + Jet-Daten

σ

➔ Veringere Fehler auf g(x) um bis zu 50%