DESY Particle Physics Programme

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DESY

Isfahan
23 April 2009

HELMHOLTZ
ASSOCIATION

DESY: Deutsches Elektronen-Synchrotron

> One of the largest German research centres
  - Founded in 1959

> Two sites:
  - Hamburg
  - Zeuthen (since 1992)

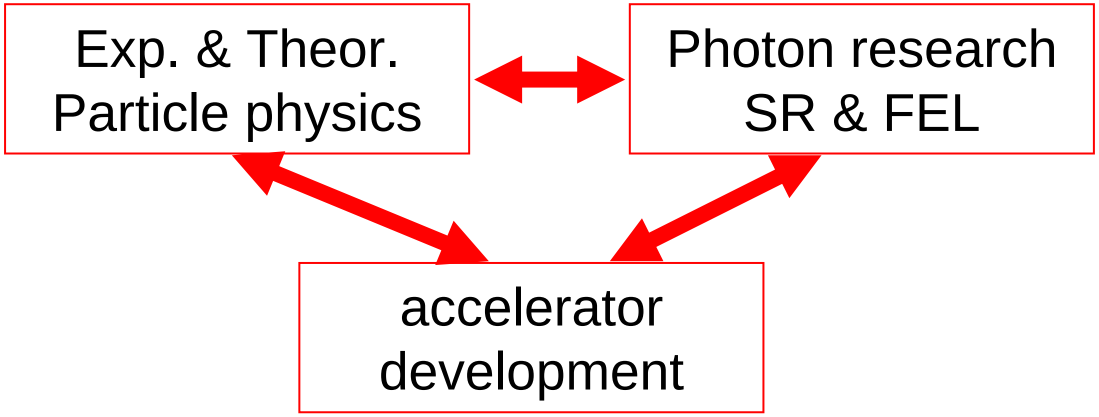
Elementary Particle Physics at DESY

> **DESY has a long successful history in three areas of basic science and high technology:**

- **Particle physics (one of 5 major laboratories world wide),**
- **Research with X-rays (synchrotron radiation, FEL) and**
- **Accelerator development.**

Particle Physics at DESY Highlights:

- **DORIS: discovery of B-mixing**
- **PETRA: discovery of the gluon**
- **HERA: precise studies of the proton and the strong force**



Accelerators at DESY

Circular:

> **DESY**
- completed in 1964
- electrons of 7.4 GeV
- still used as pre-accelerator and testbeam facility (DESY III)

> **DORIS**
- e^+e^- collider (2*3.5 GeV, upgraded to 2*5 GeV)
- Completed 1974, particle physics until 1992
- Since 1980: synchrotron light source

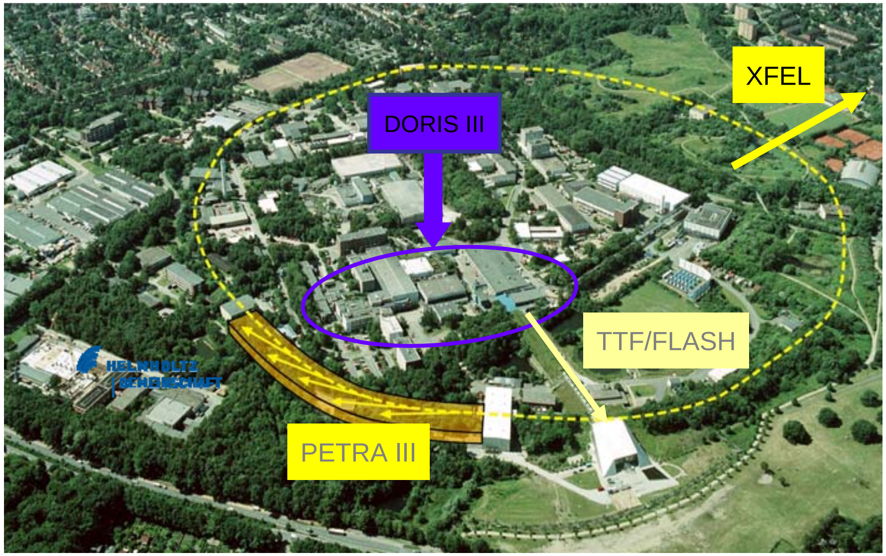
> **PETRA**
- e^+e^- collider, 2*23 GeV
- Particle physics: 1978 – 1986
  pre-accelerator for HERA until 2007
- As of 2009: synchrotron light source (PETRA III)

> **HERA**
- Electron-proton collider 27/920 GeV
- Particle physics 1991 - 2007

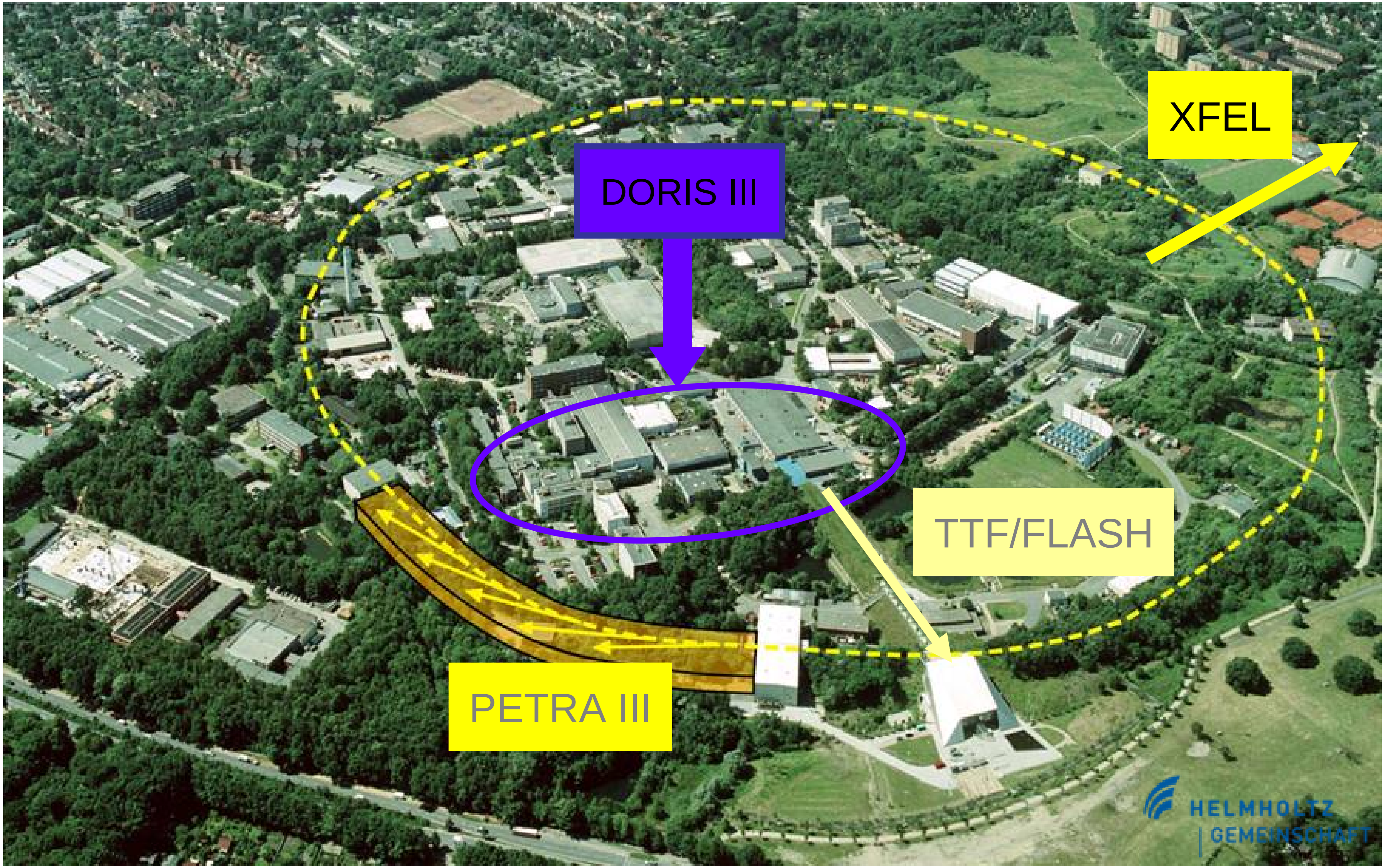
Linear:

> **TTF/FLASH**
- 1997 completed 1997 as TESLA Test Facility
- Supra-conducting linear accelerator
- Since 2005 Free –Electron Laser at Hamburg (FLASH)
- First soft X-ray FELworld-wide

> **European XFEL**
- Construction started in 2009



DESY Accelerators



DESY: Long-term Strategy in Particle Physics

Structure of the proton | **Explore the Terascale** | **Precision physics**

Contributions to

- Accelerators
- Detectors
- Physics

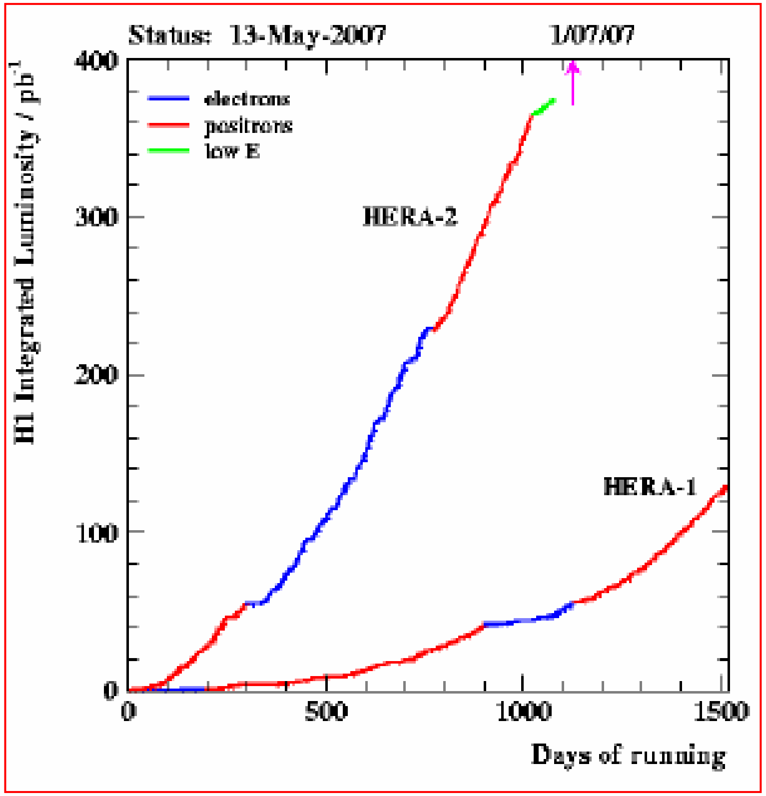
on an international scale

Supported by

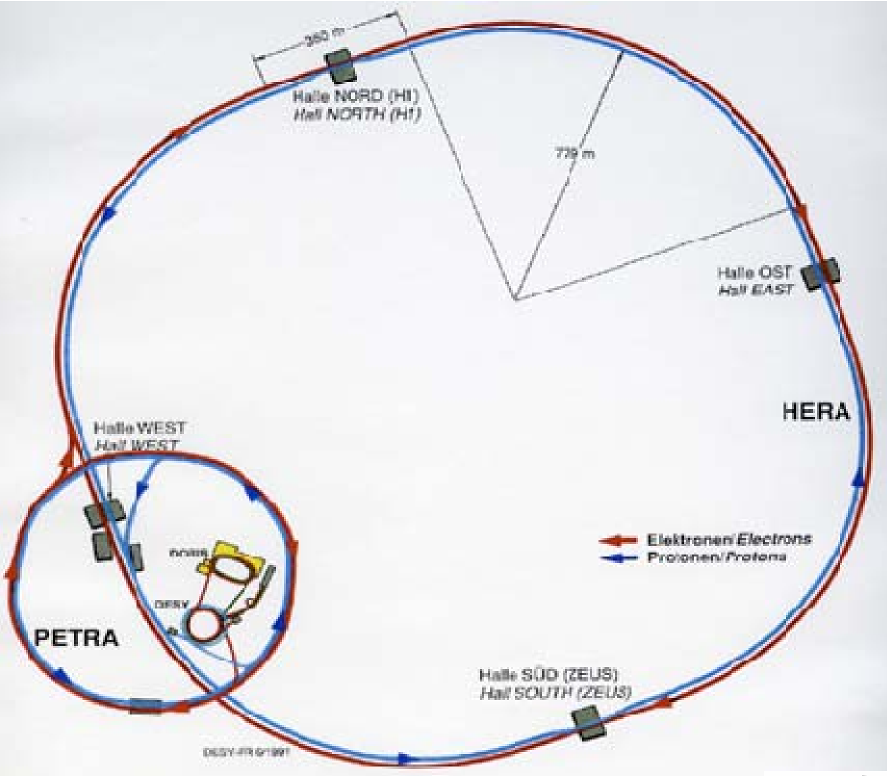
- Strong and broad theory group
- Computing infrastructure (KIT and DESY)
- Testbeam & other infrastructures

HERA: Electron-Proton Collider

> **HERA data taking ended on 30 June 2007**

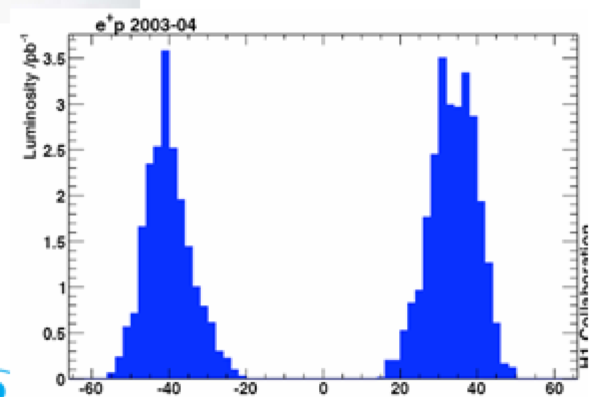


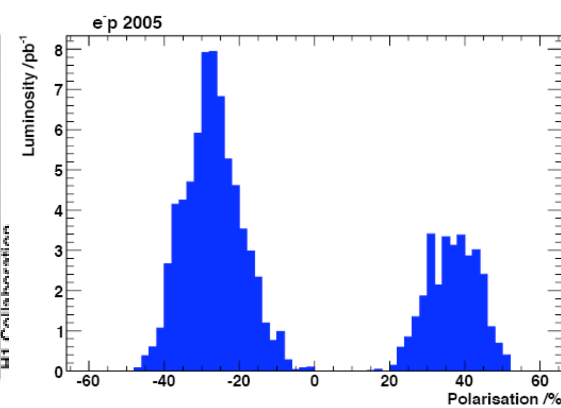
HERA: Electron-Proton Collider



	e^+/e^-	Protons
Energy nominal (GeV)	27.6	920
Energy range (GeV)	10 – 35	460-920
Luminosity	$5 \times 10^{31} cm^{-2}s^{-1}$	
Circumference	6.3 km	
Magn. Field (T)	0.165	4.7
Beam current (mA)	58	160
Bunches	200	
e^+/e^- polarized		
Petra Injection (GeV)	12	40

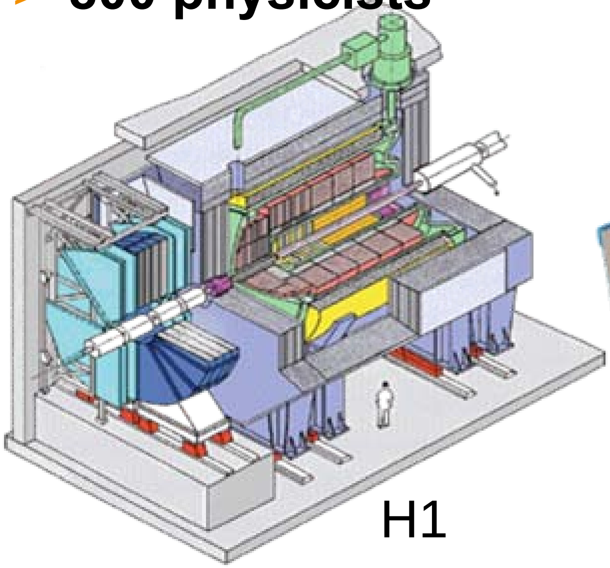
Polarisation:



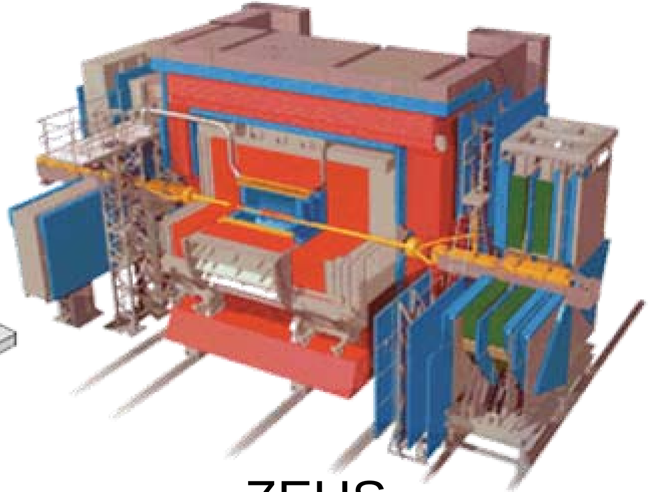


HERA Detectors

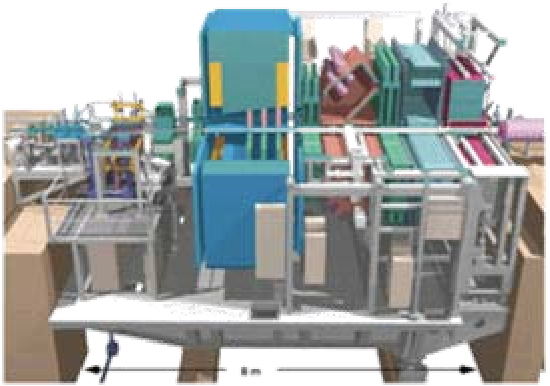
- 800 physicists



H1

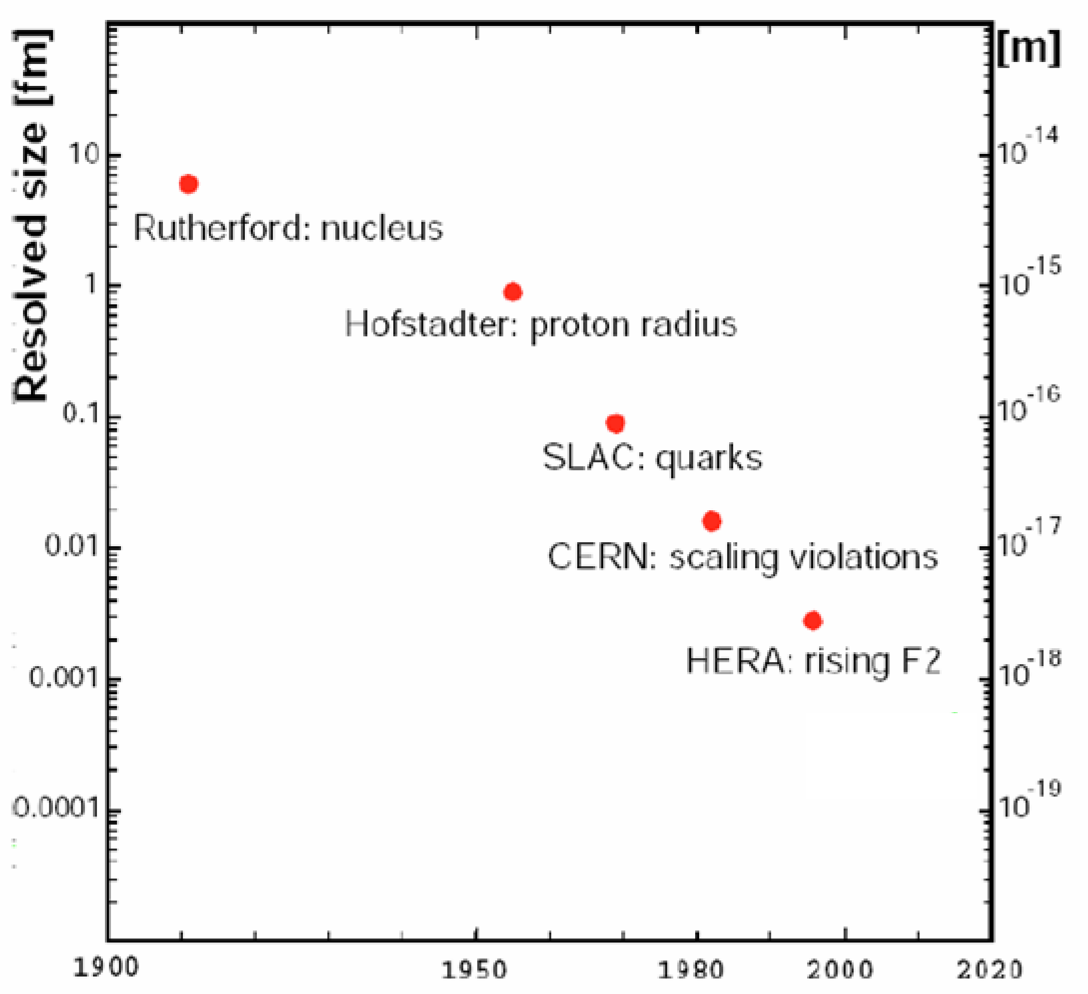


ZEUS



HERMES

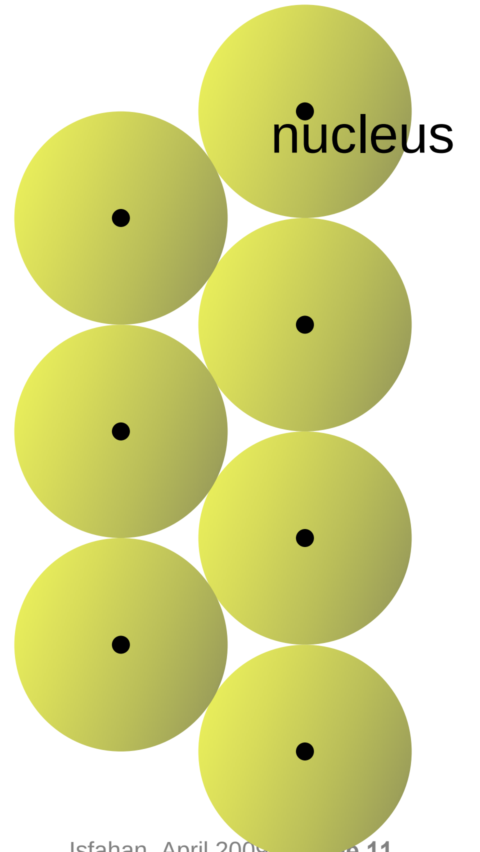
HERA Physics



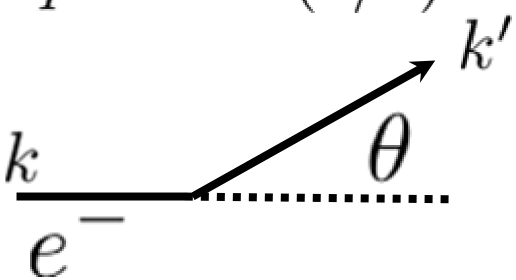
- Proton structure
- Quark structure

Rutherford Scattering (1905)

$$\frac{d\sigma}{dq^2} = 4\pi\alpha^2 \frac{Z^2}{q^4}$$



$$q^2 \propto \sin^2(\theta/2)$$



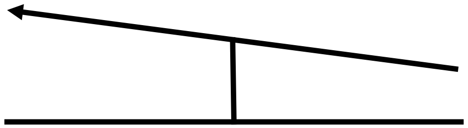
$$q = k - k'$$

Hofstadter: Radius of nucleus

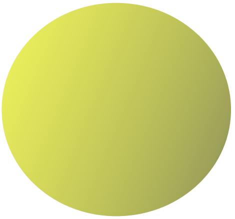
> **1960**

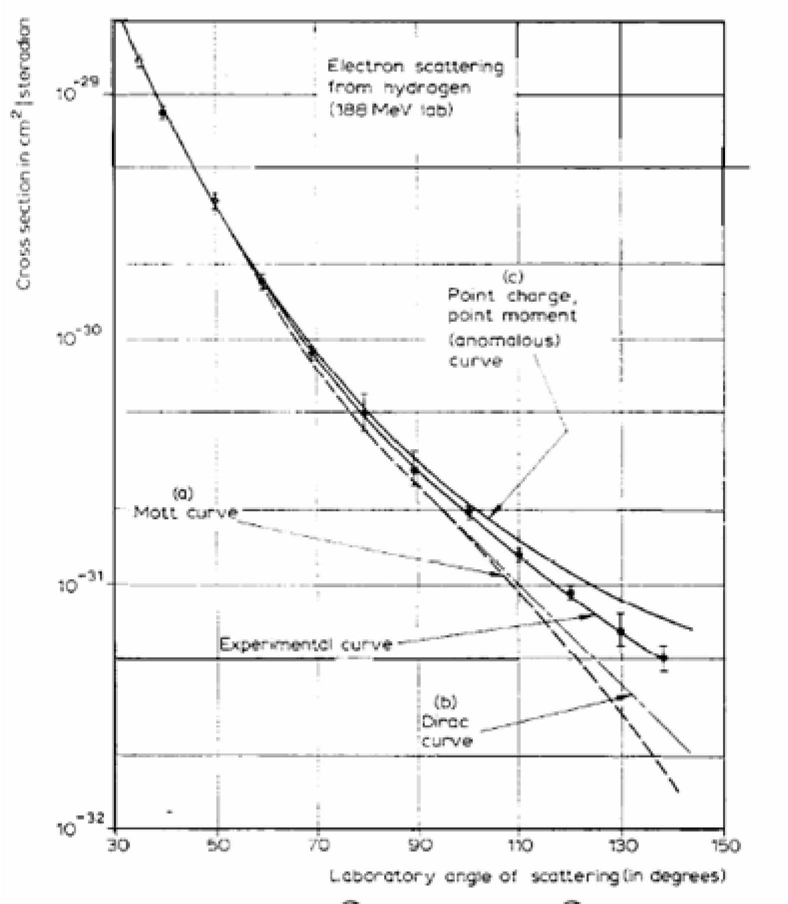
$$\frac{d\sigma}{dQ^2} = 4\pi\alpha^2 \frac{Z^2}{q^4} F(q^2)$$

electron



Nucleon





$$q^2 \propto \sin^2(\theta/2)$$

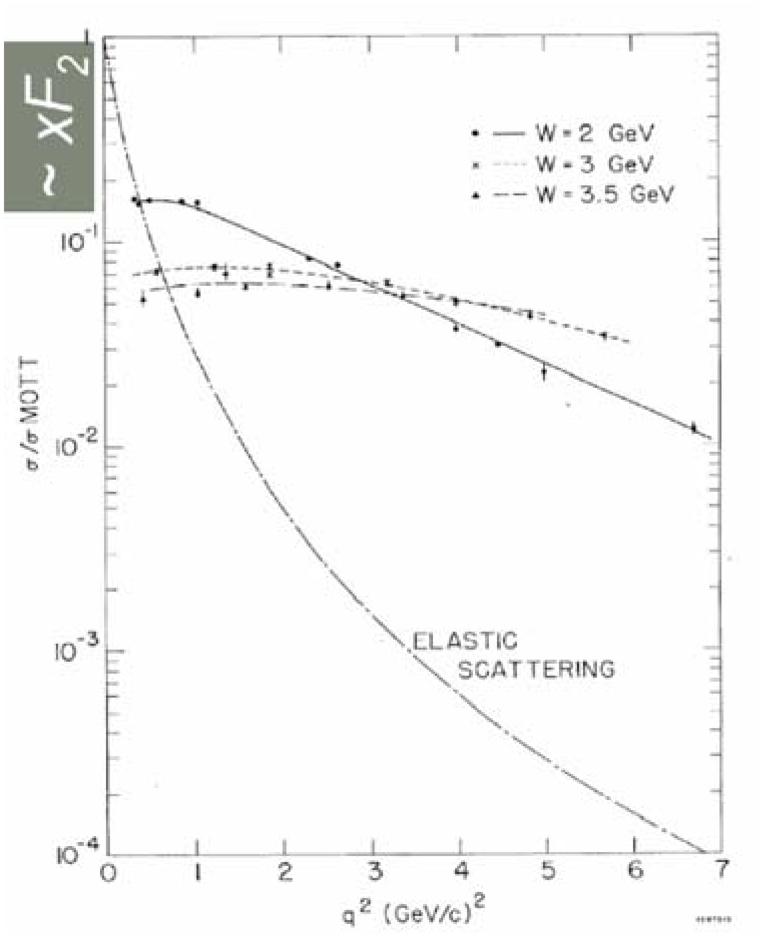
$$R \approx 1\,\text{fm} = 10^{-15}\text{m}$$

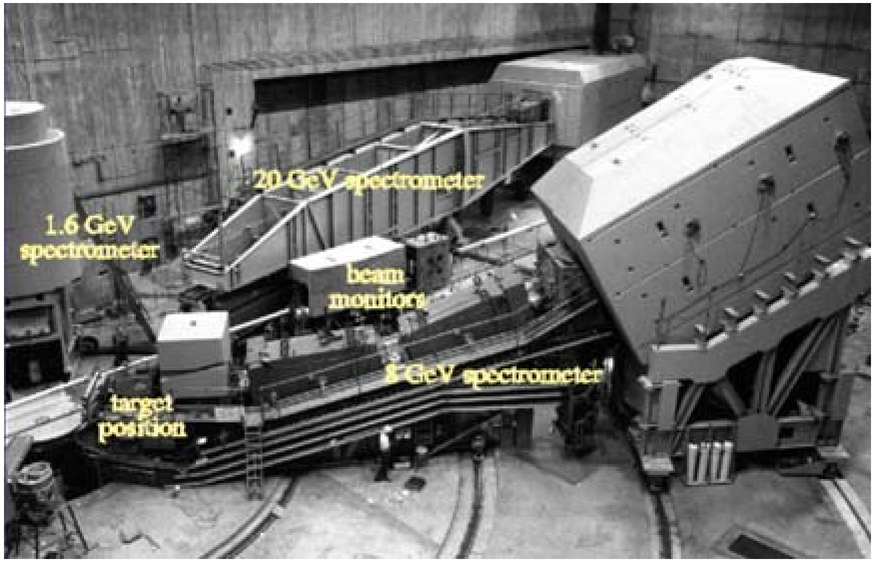
Deep-inelastic Scattering

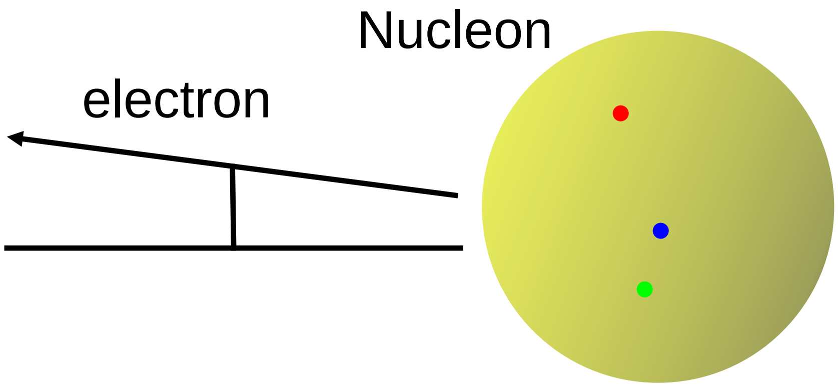
> **1969**

$$\frac{d^2\sigma}{dq^2dx} = \frac{4\pi\alpha^2}{q^4 x}[(1-y)F_2(x,Q^2) + xy^2F_1(x,Q^2)]$$

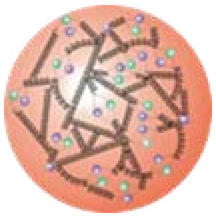
SLAC

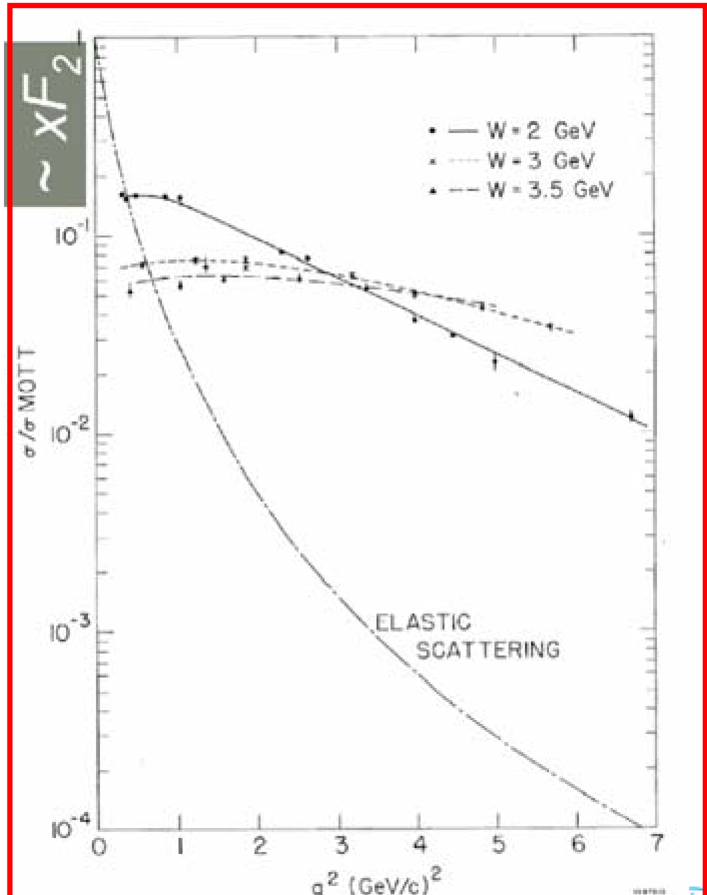




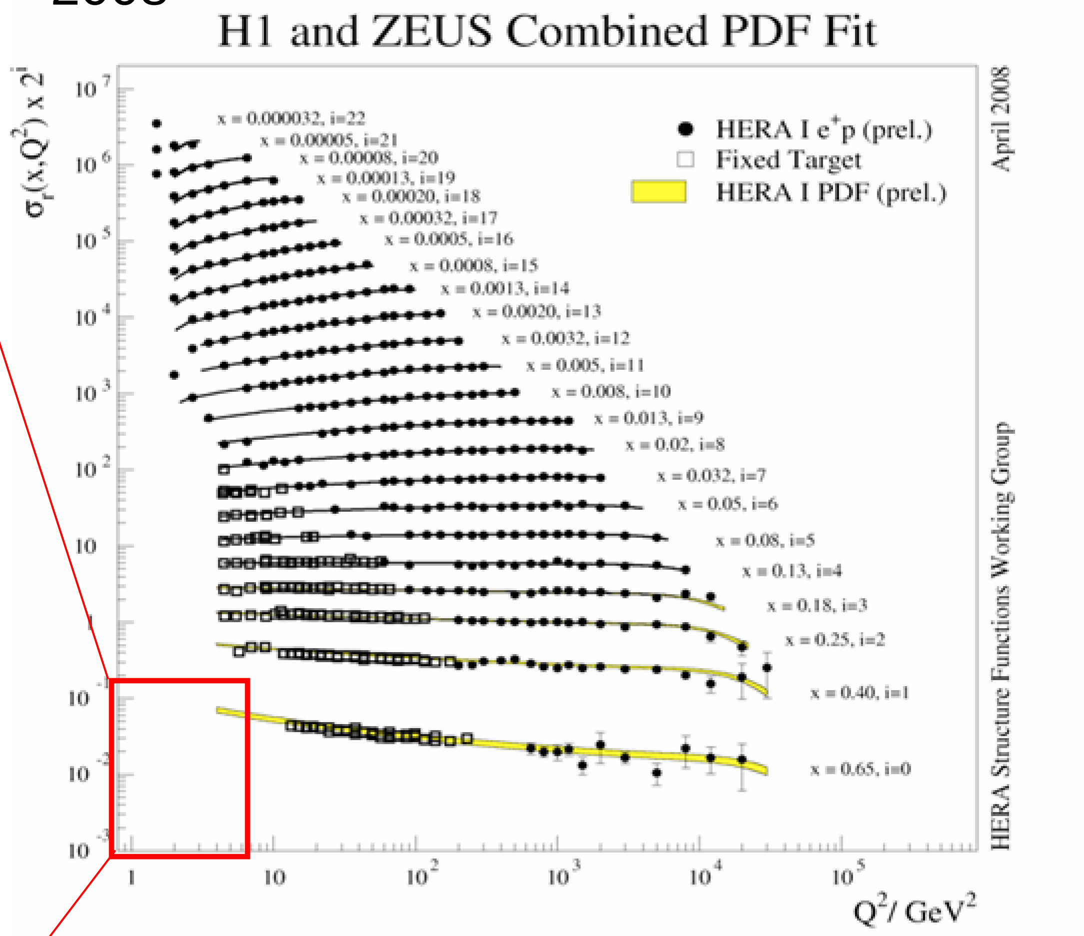


DIS at HERA





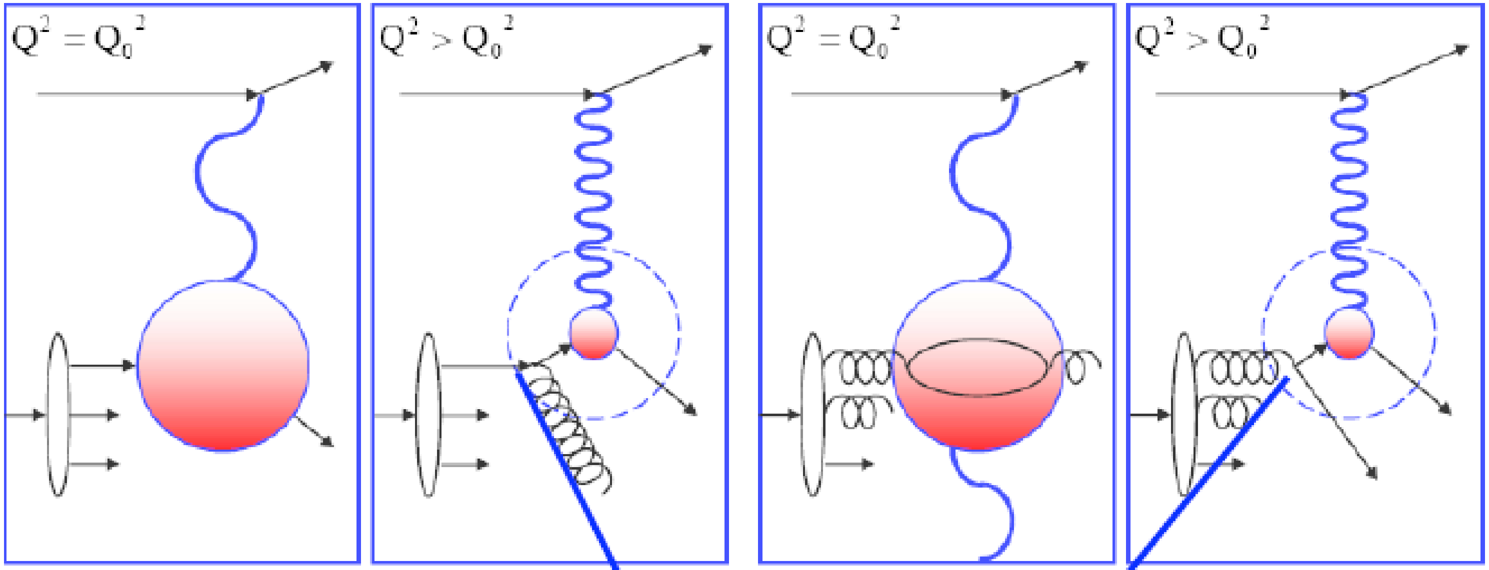
2008



Scaling Violation

Large x:
quarks radiate gluons,
photon probes smaller x,
$\Rightarrow F_2$ falls with Q^2.

Small x:
gluons split into sea quarks,
photon resolves qq pair,
$\Rightarrow F_2$ rises with Q^2.

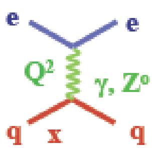


$$\frac{d\Sigma(x,Q^2)}{d\ln Q^2} = \frac{\alpha_s(Q^2)}{2\pi}\int_x^1 \frac{dz}{z}\left[P_{qq}\left(\frac{x}{z}\right)\Sigma(z,Q^2) + P_{qg}\left(\frac{x}{z}\right)g(z,Q^2)\right]$$

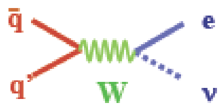
DGLAP equation of QCD. Now calculated in NNLO (α_S^3).

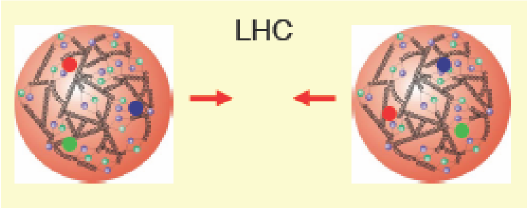
Parton Distribution Functions (pdf)

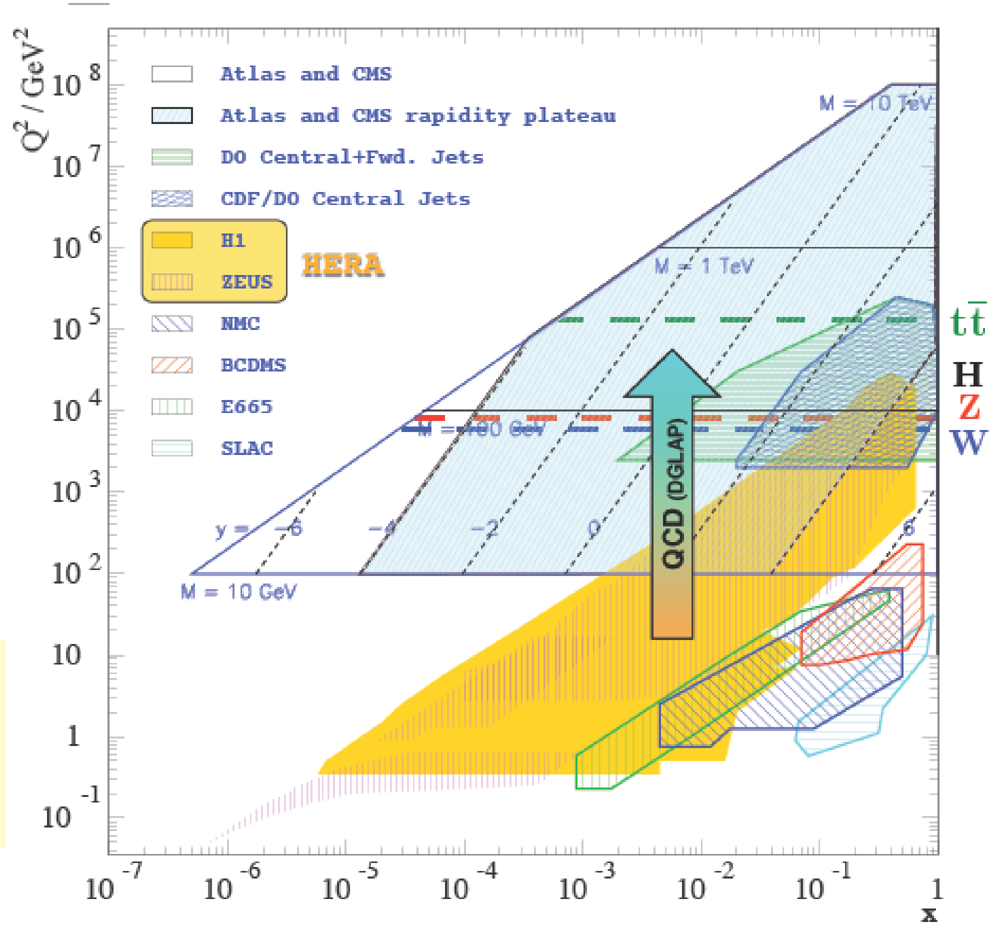
HERA



LHC

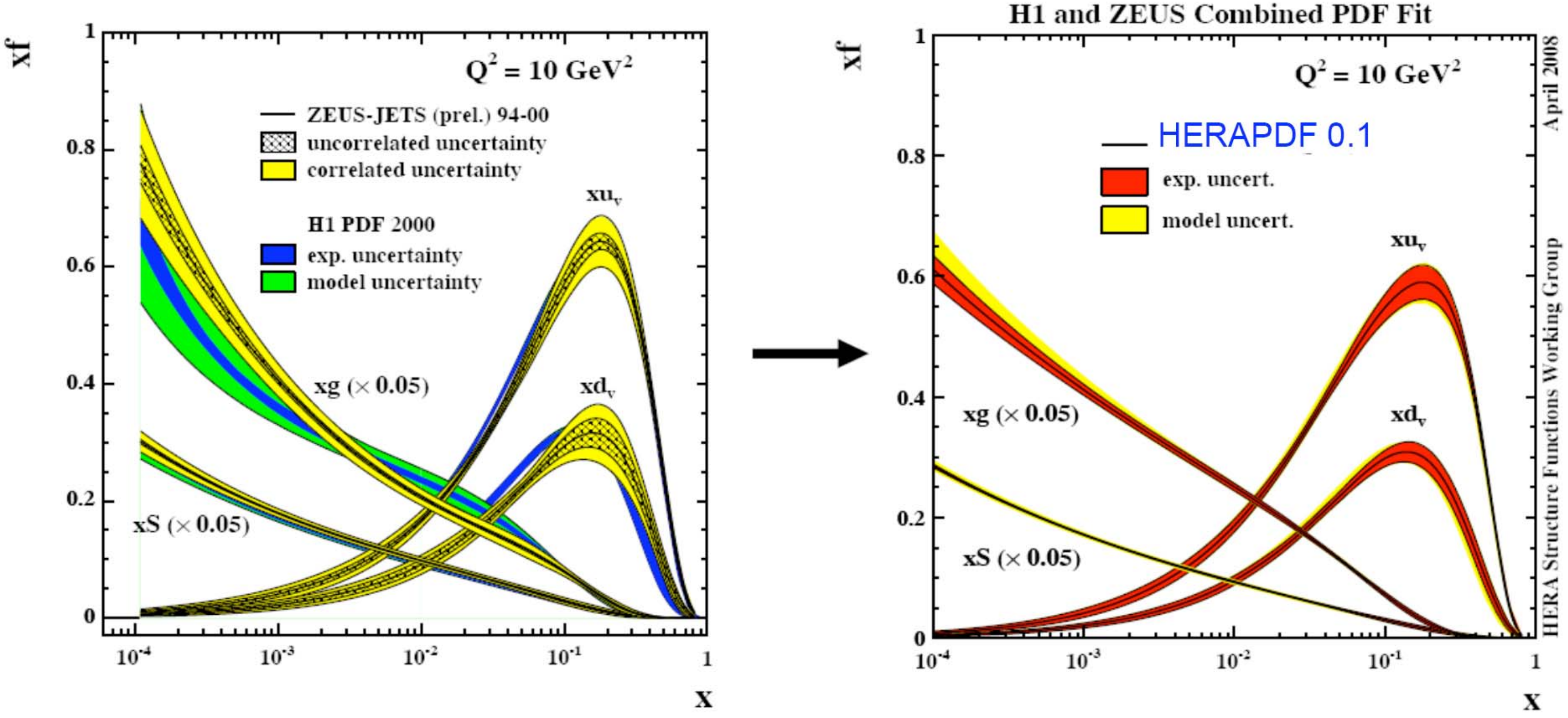






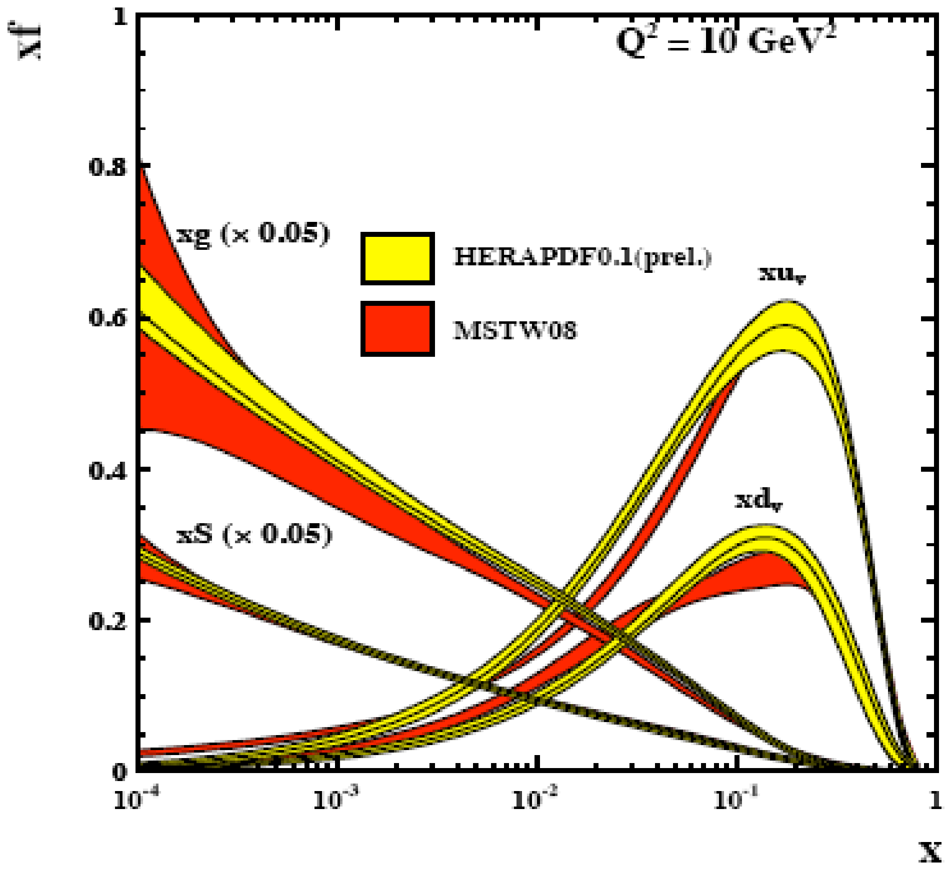
New Results on PDF

- Single experiment
- Combination H1 and ZEUS



- Significant improvement
- Cross-calibration of systematic errors

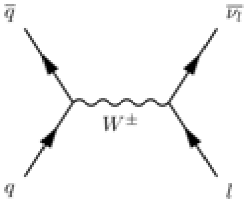
New Results on PDF

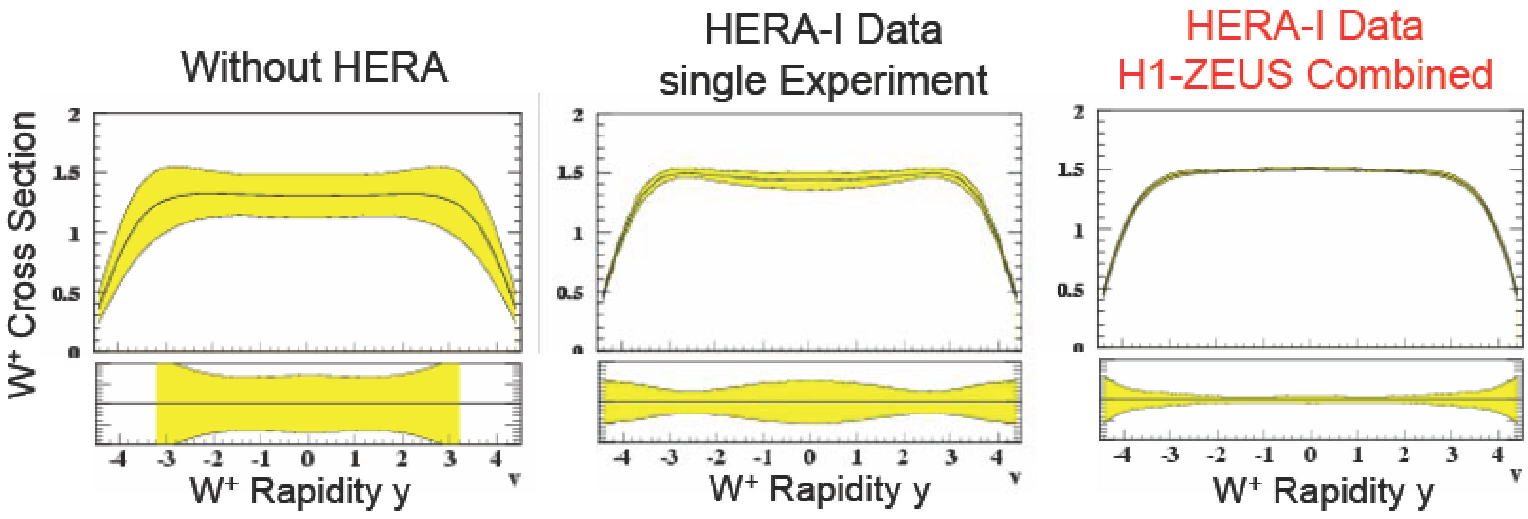


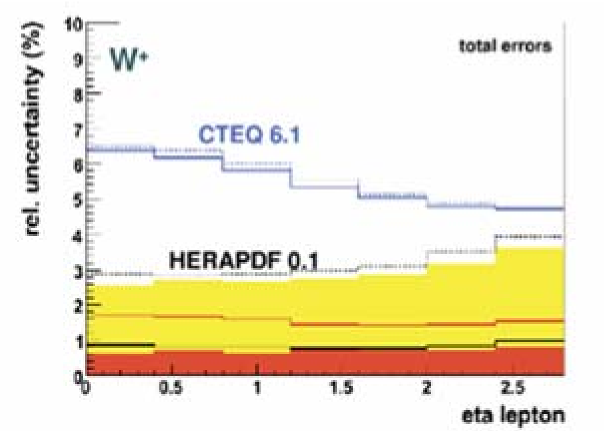
- Large improvement wrt previous results
- In particular low-x gluons
- Note:
  HERA II data still to be included

Application for LHC

> **Example: prediction for W cross section at LHC**





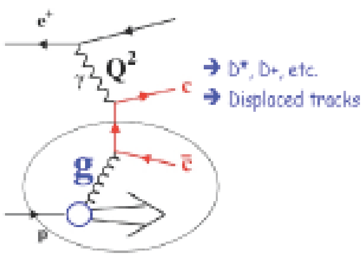


> **Uncertainty reduced to approx. 3%**

Charm and Bottom Content of the Proton

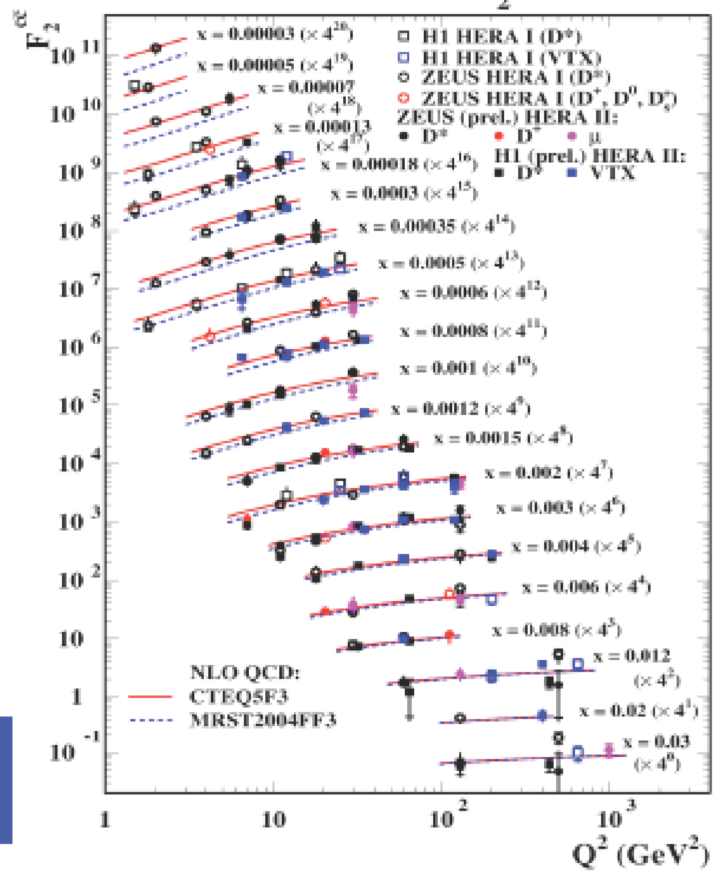
Expected: Charm: 20 - 30%, Bottom: few percent

Proton's charm and beauty

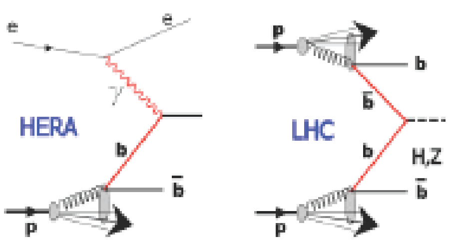


$$\sigma_r^{cc/bb} = F_2^{cc/bb} - y^2/Y_+ F_L^{cc/bb}$$

HERA $F_2^{c\bar{c}}$

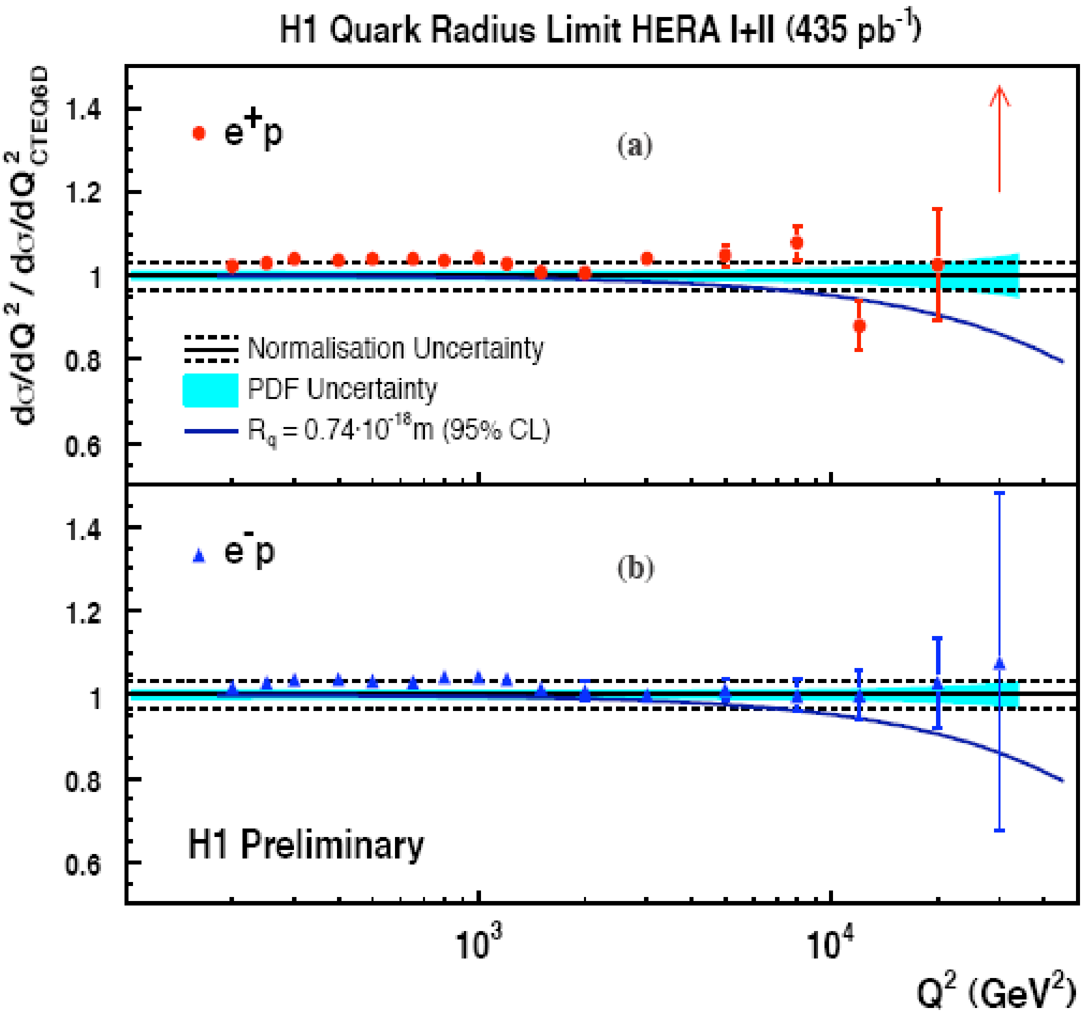


Present precision: charm 10%, beauty 20%



Goal:
More data, combinations: charm 5% , beauty 15%
Include in the final PDF's

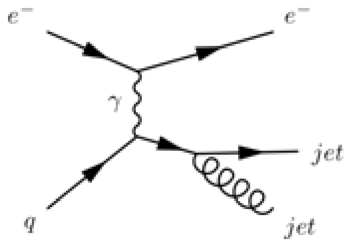
Structure of Quarks?



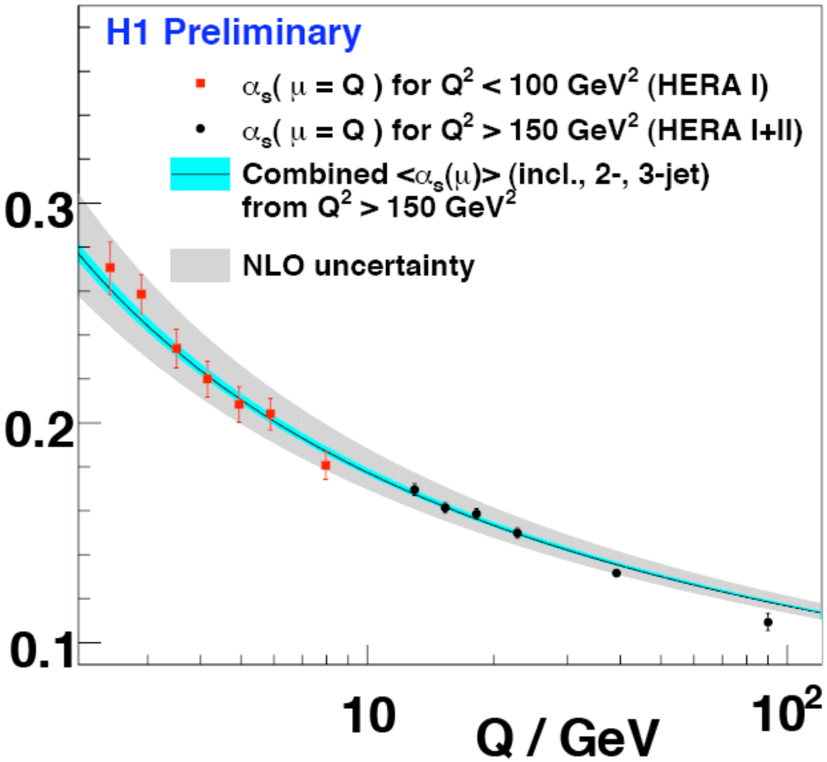
> $R_q < 0.74 \cdot 10^{-18}$ m (95% CL)

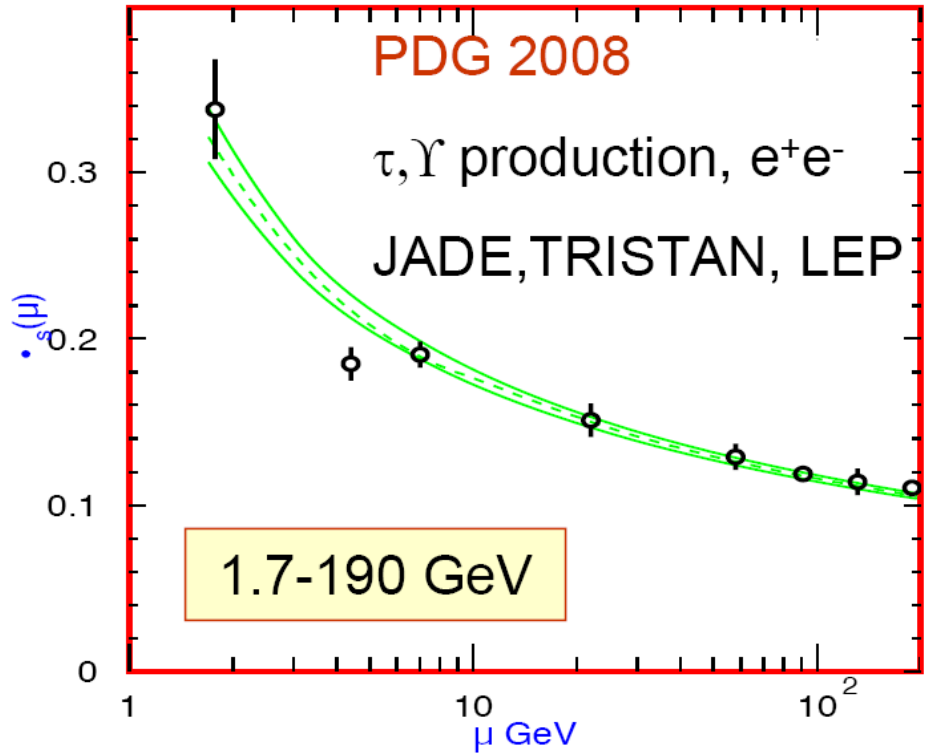
Tests of QCD

> **Running of α_s**



α_s from Jet Cross Sections

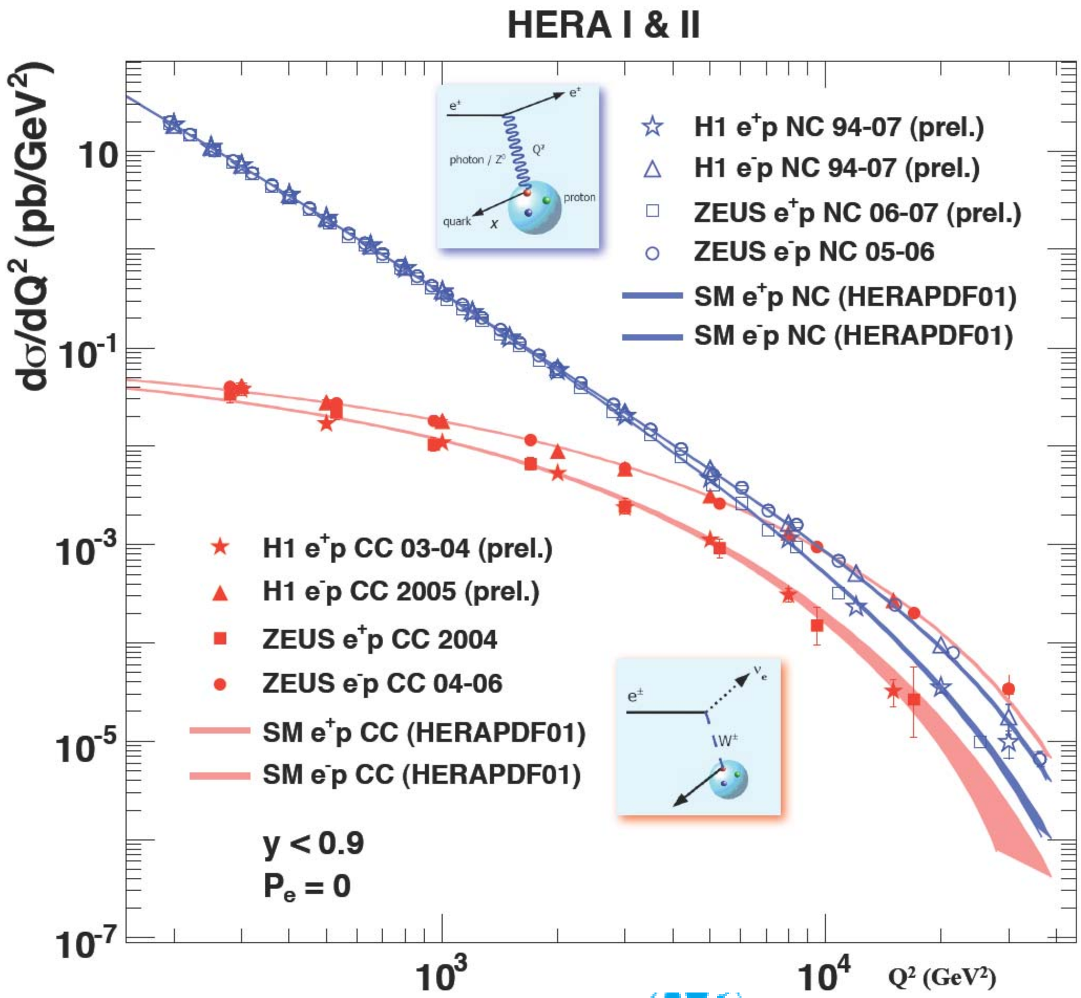


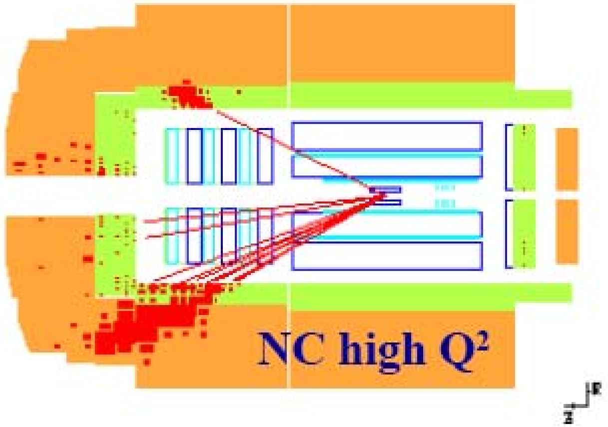


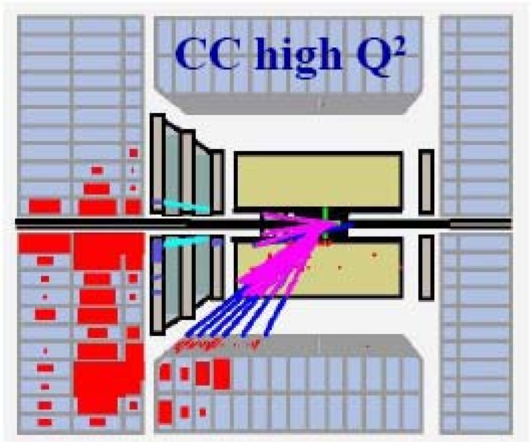
$$\alpha_s(M_Z) = 0.1168 \ \pm 0.0007\,(\text{exp.})\ {}^{+0.0046}_{-0.0030}\,(\text{th.})\ \pm 0.0016\,(\text{PDF})$$

Tests of Electroweak Interactions

- Textbook example: electromagnetic and weak interaction interactions become equally strong at high energies

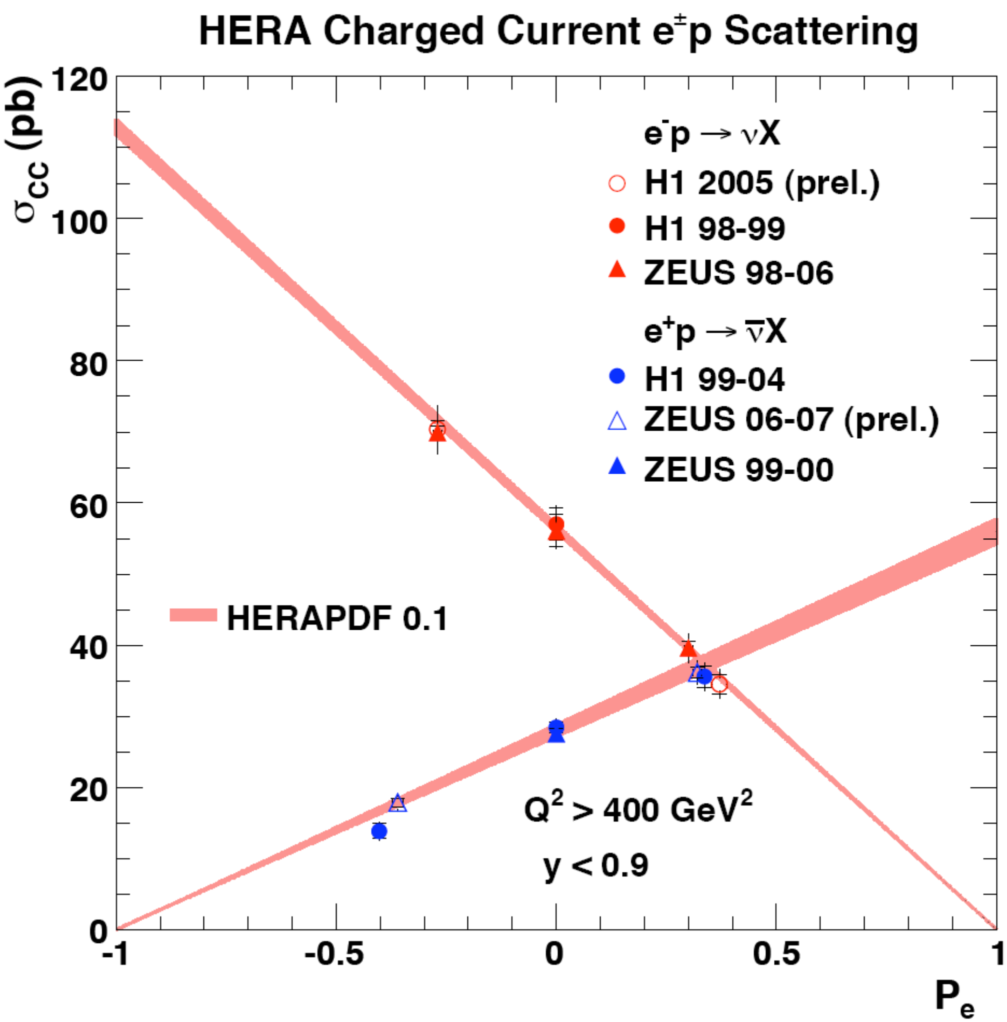


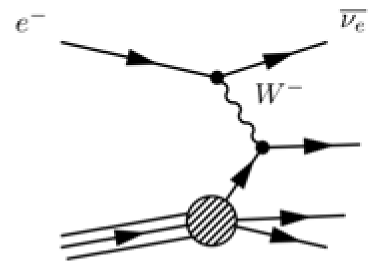


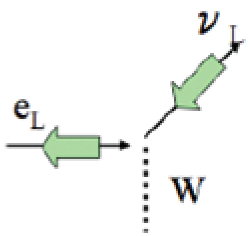


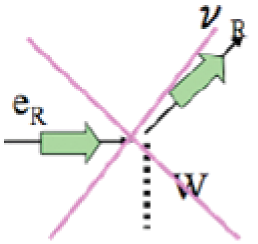
Tests of Electroweak Interactions

> **Polarised CC cross section**









> **No right-handed charged currents**

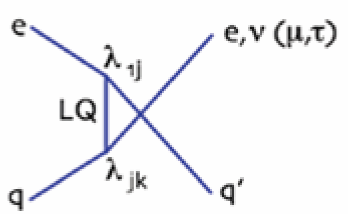
New Physics?

> **Search for Lepto-Quarks**

Heavy leptoquarks

For high mass leptoquarks

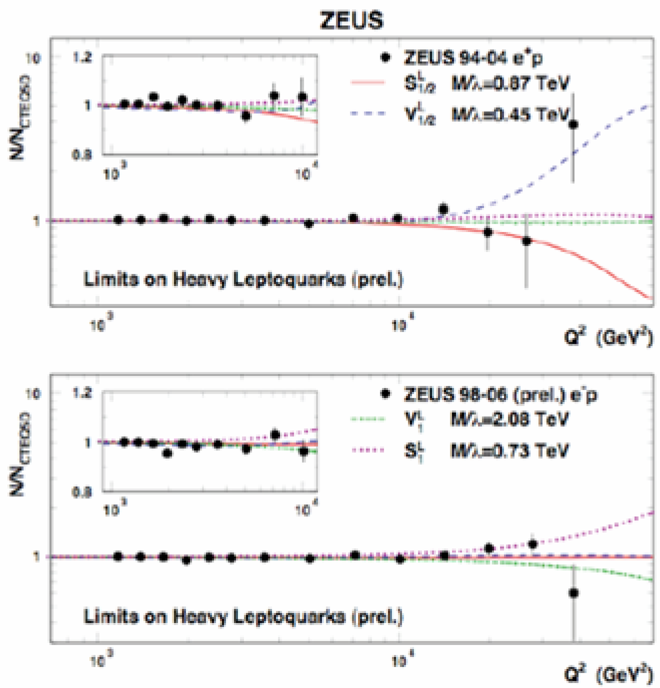
$M_{LQ} >> \sqrt{s}$



virtual LQ production/exchange results in an effective contact interaction type coupling:

$$\eta_{CI} \sim \left(\frac{\lambda}{M}\right)^2$$

where λ is the leptoquark Yukawa coupling



ZEUS 94-06 data

M_{LQ}/λ_{LQ} > 0.29 - 2.08 TeV at 95% CL

ICHEP, Philadelphia, Aug. 1st, 2008 Amita Raval 16

LHC

- DESY joined ATLAS and CMS in 2006
- Contributions to
  - Physics Analysis
  - Technical coordination
  - Trigger & DAQ
  - Software & computing
  - Tier-2 for ATLAS, CMS & LHC-b
  - Smaller detector components
    ATLAS: ALFA, CMS: CASTOR
- will not go into detail here…

CMS centre @ DESY

Electron-Positron Linear Collider

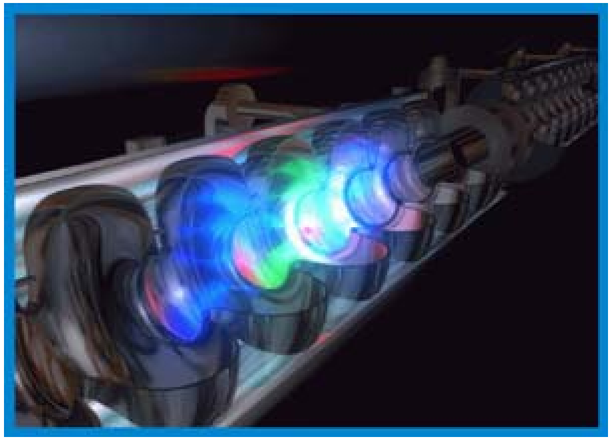
> **DESY pursues for > 15 years development of electron-positron linear collider**

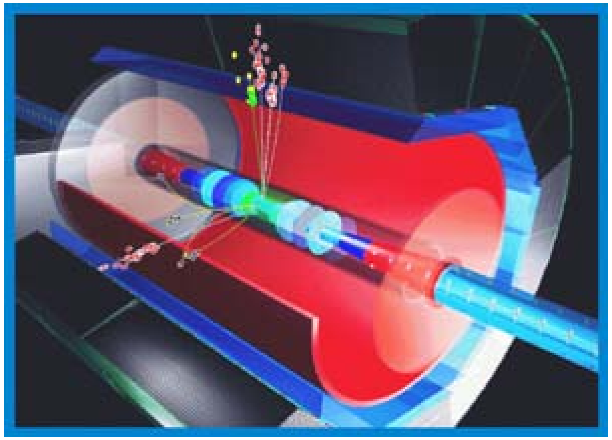
→ TESLA TDR in 2001

> **Supra-conducting RF technology**

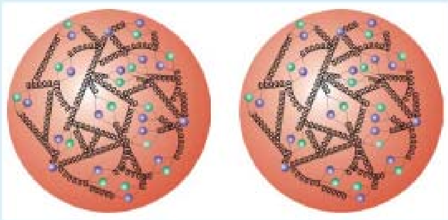
- **2004: Selected technology for the International Linear Collider (ILC)**

> **Global effort involving all major laboratories from all regions**





Comparison Proton to Electron Colliders

p  p

e • • e

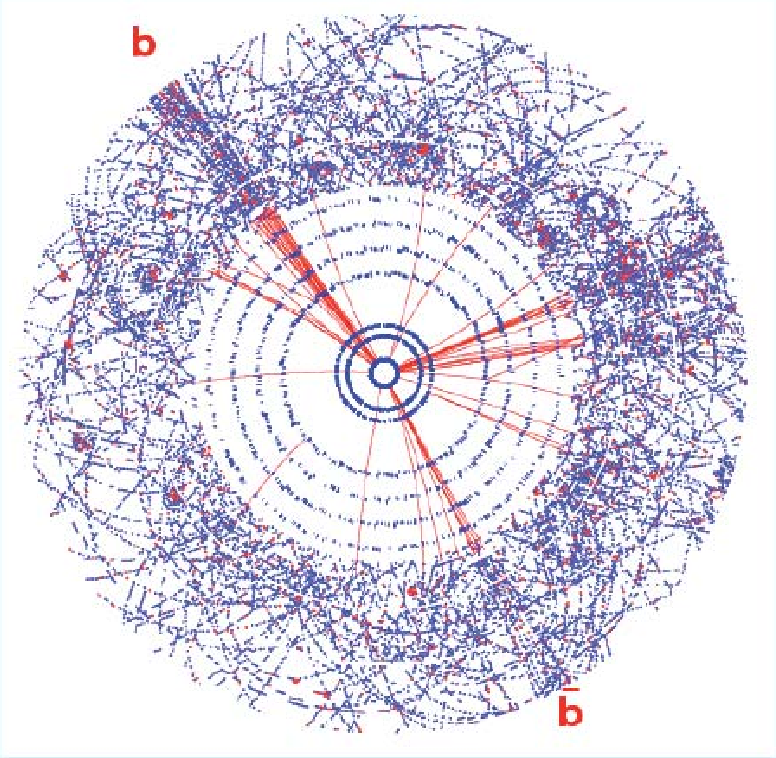
- Proton (anti-) proton colliders:
  - Energy range higher (limited by magnet bending power)
  - Composite particles, different initial state constituents and energies in each collision
  - Hadronic final states difficult
- Discovery machines
- Excellent for some precision measurements

- Electron positron colliders:
  - Energy range limited (by RF power)
  - Point-like particles, exactly defined initial state quantum numbers and energies
  - Hadronic final states easy
- Precision machines
- Discovery potential

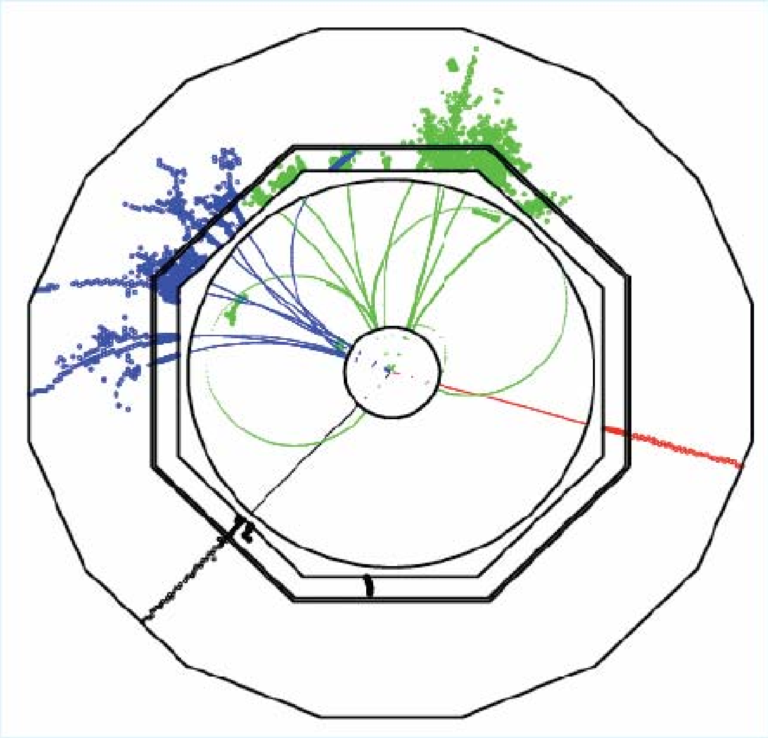
> **Precision is main motivation for a new electron positron collider**

> **Complementarity to proton machines, e.g. SppS/Tevatron and LEP**

Comparison Proton to Electron Colliders



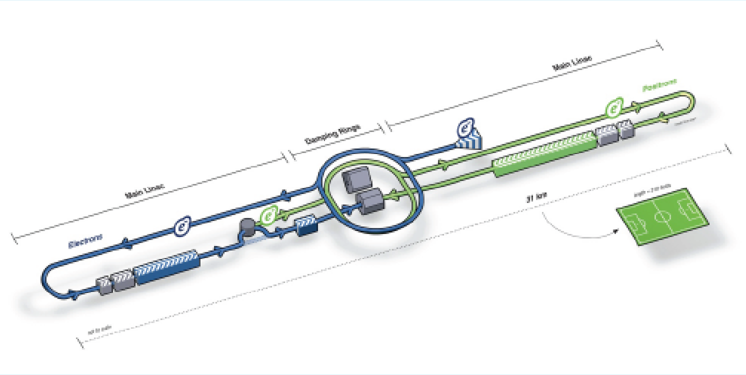
pp ➔ H + X



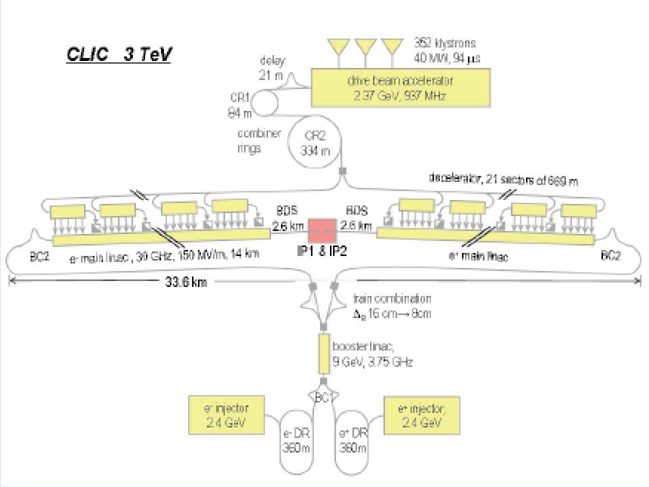
e+e- ➔ HZ

Linear Collider Concepts

- International Linear Collider ILC
  - superconducting acceleration
  - 31.5 MeV/m, 1.3 GHz
  - advanced design (c.f. XFEL)
  - 500 GeV (→ 1TeV)
  - Luminsosity: 2 x 10^{34} cm^{-2} s^{-1}



- Compact Linear Collider CLIC
  - normalconducting acceleration
  - 100 MeV/m, 12 GHz
  - two-beam acceleration principle
  - up to several TeV
  - still in fundamental R&D phase

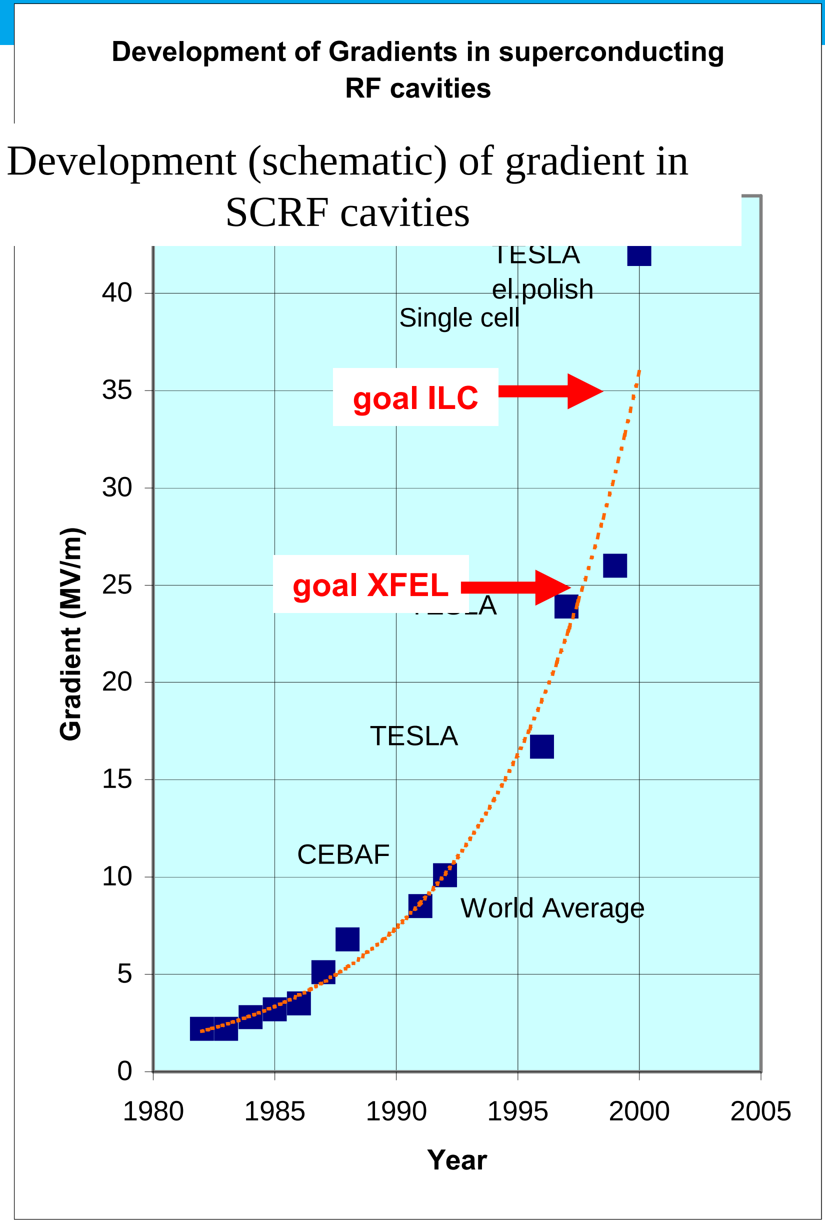


> **ILC ready to go ahead, but limited in energy reach (≤ 1 TeV)**

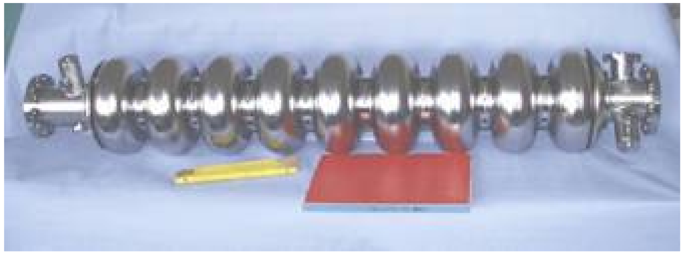
> **CLIC in very early state, but may pave the way for higher energy**

Challenges

- Quest for the highest possible accelerator gradient
- ILC goal: 35 MV/m
- Huge progress over the last 15 years
  - 25-fold improvement in perfomance/cost
- Major impact on next generation light sources:
  - XFEL designed for ≥ 25 MV/m
  - 10% prototype for ILC
- Recall: LEP II used 7 MV/m

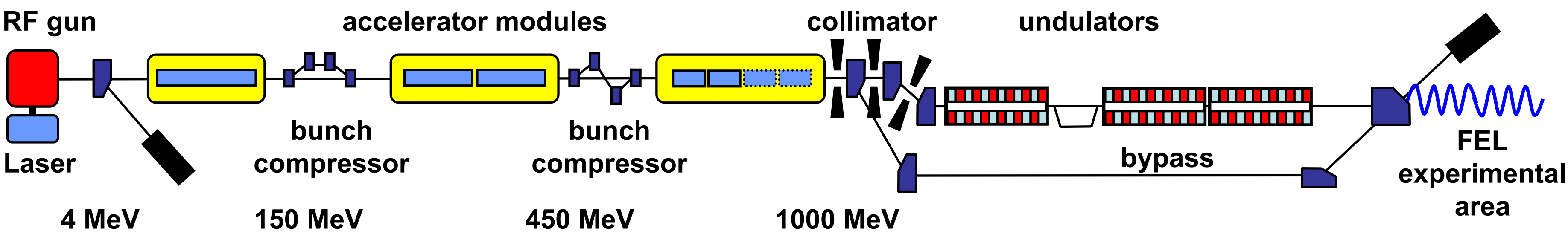


TESLA 9-cell cavity:

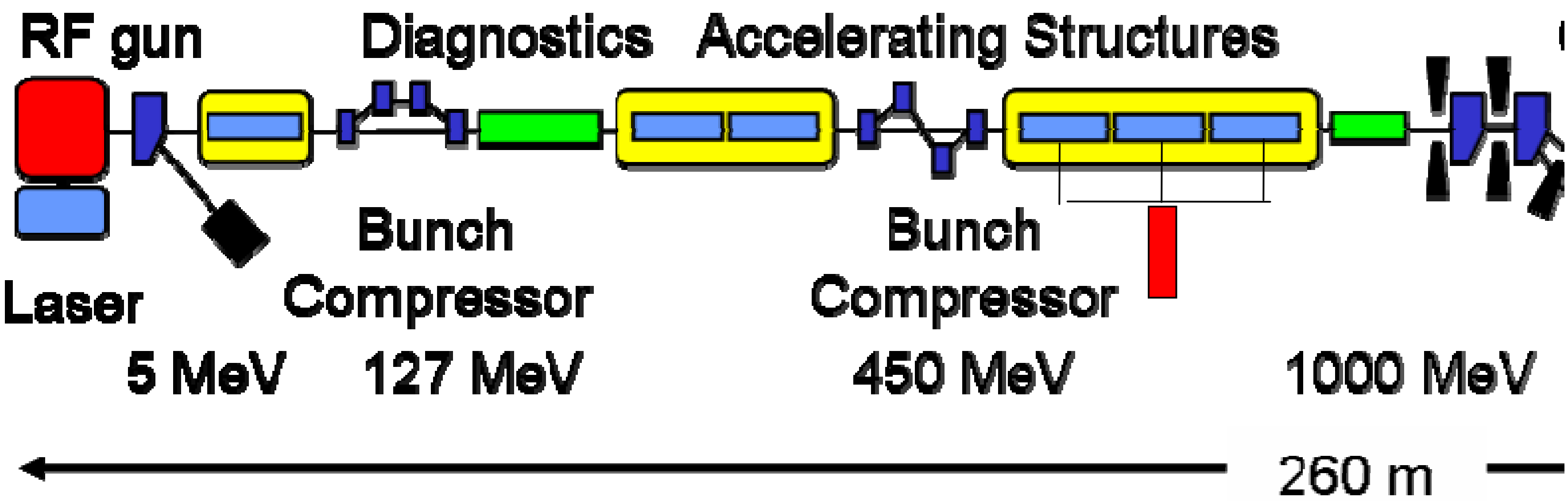


FLASH/TTF: Prototype for XFEL and ILC

- 1 GeV electron LINAC based on SCRF
- used for ILC studies and as light source (free electron laser)



Beam Tests at FLASH

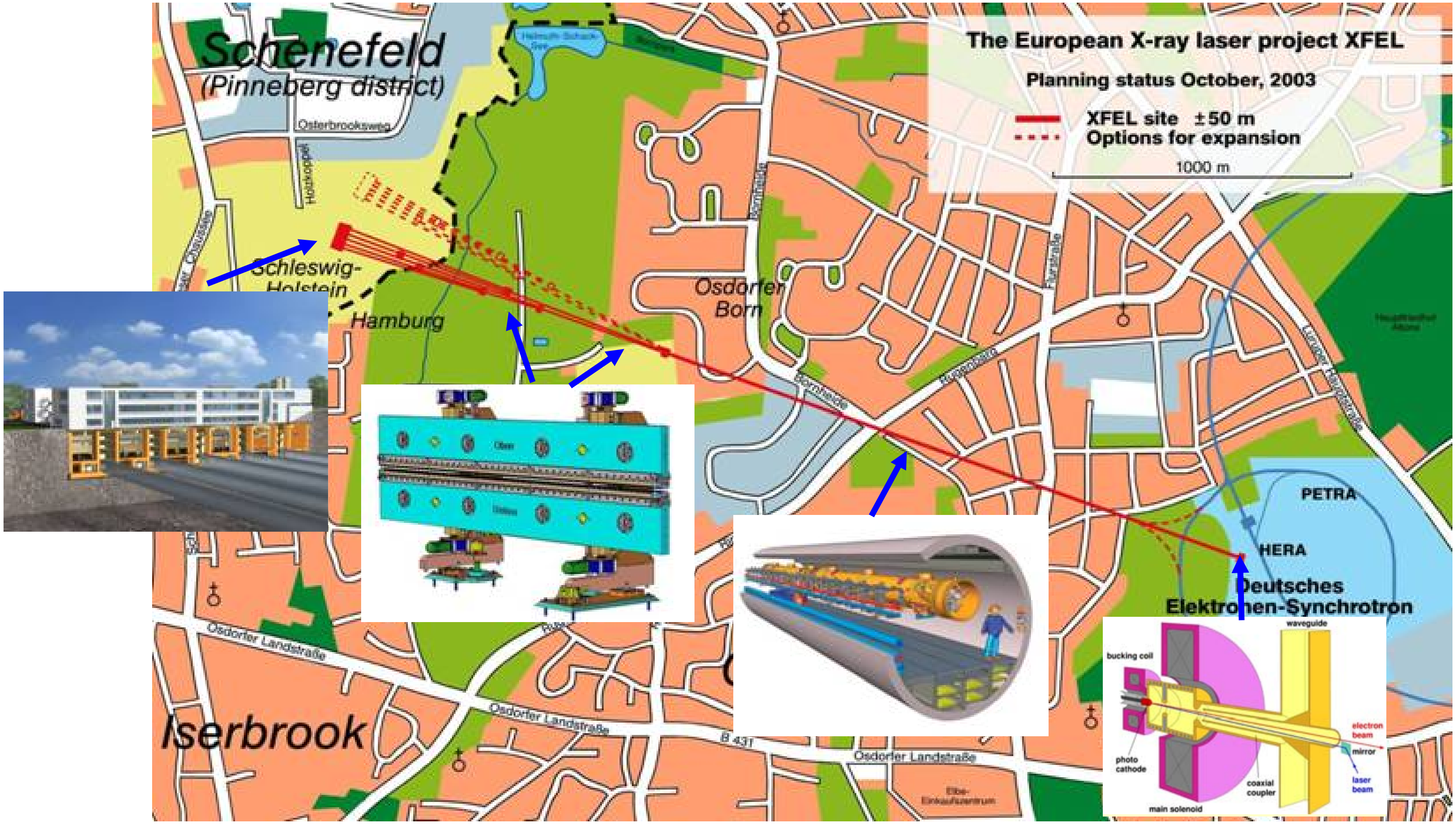


		XFEL X-Ray Free-Electron Laser	ilc	FLASH design	FLASH experiment
Bunch charge	nC	1	3.2	1	3
# bunches		3250*	2625	7200*	2400
Pulse length	µs	650	970	800	800
Current	mA	5	9	9	9

European XFEL

> **Construction started January 2009**

3.4km



XFEL: X-Ray Free Electron Laser

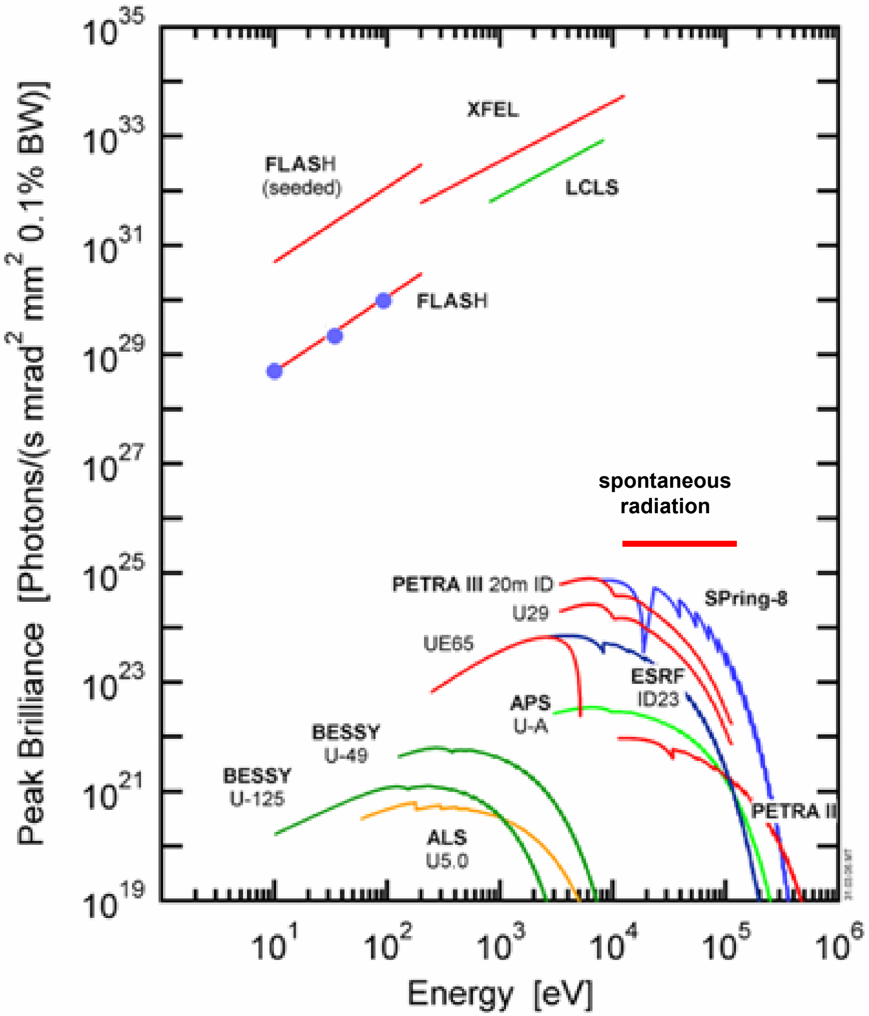
> **X-ray FEL radiation (0.2 - 12.4 keV)**
  - **ultrashort pulse duration** **<100 fs (rms)**
  - **extreme pulse intensities** **10^{12}-10^{14} ph**
  - **coherent radiation** **x10^9**
  - **average brilliance** **x10^4**

> **Spontaneous radiation (20-100 keV)**
  - **ultrashort pulse duration** **<100 fs (rms)**
  - **high brilliance**

> **For particle physics:**

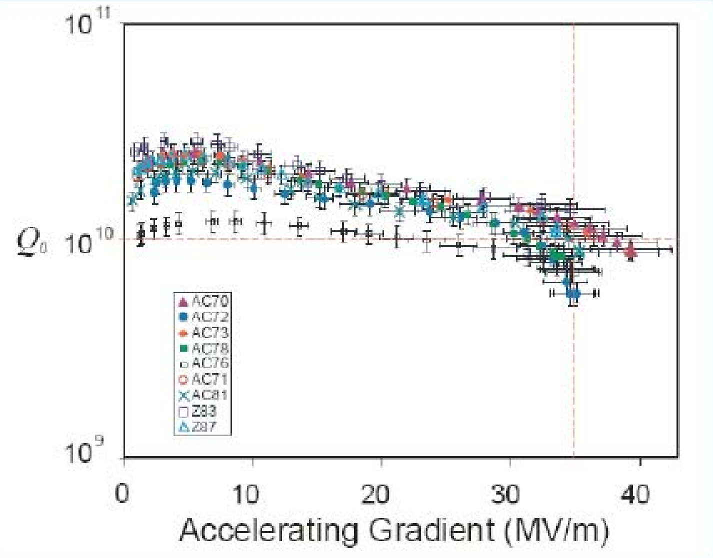
10% prototype for the ILC

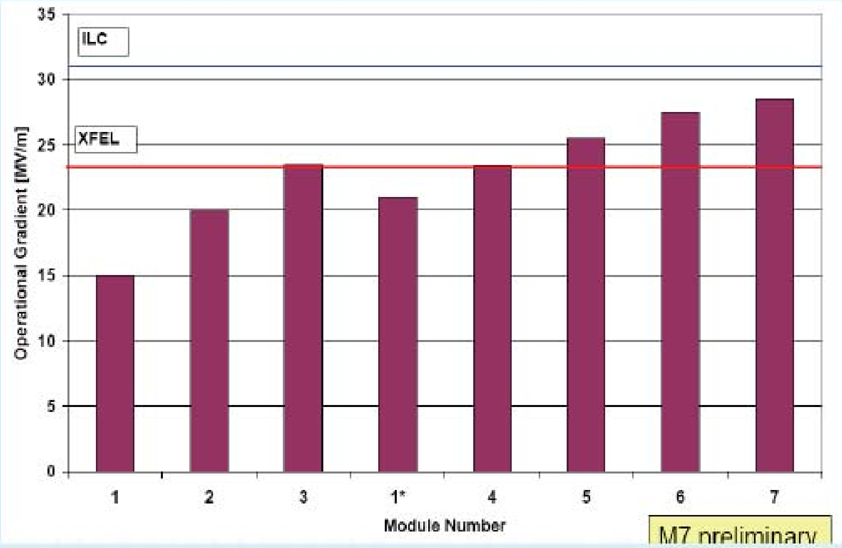
  - **Gradient**
  - **Beam dynamics,…**
  - **Industrialisation**
  - **Reliability (one tunnel)**
  - **….**



Getting to 35 MeV/m

- Acceleration gradient goal:
  - 35 MV/m in 9-cell cavities with production yield >80%
  - 50 MV/m have been reached with single cavities
  - Mass production reliability is the key problem

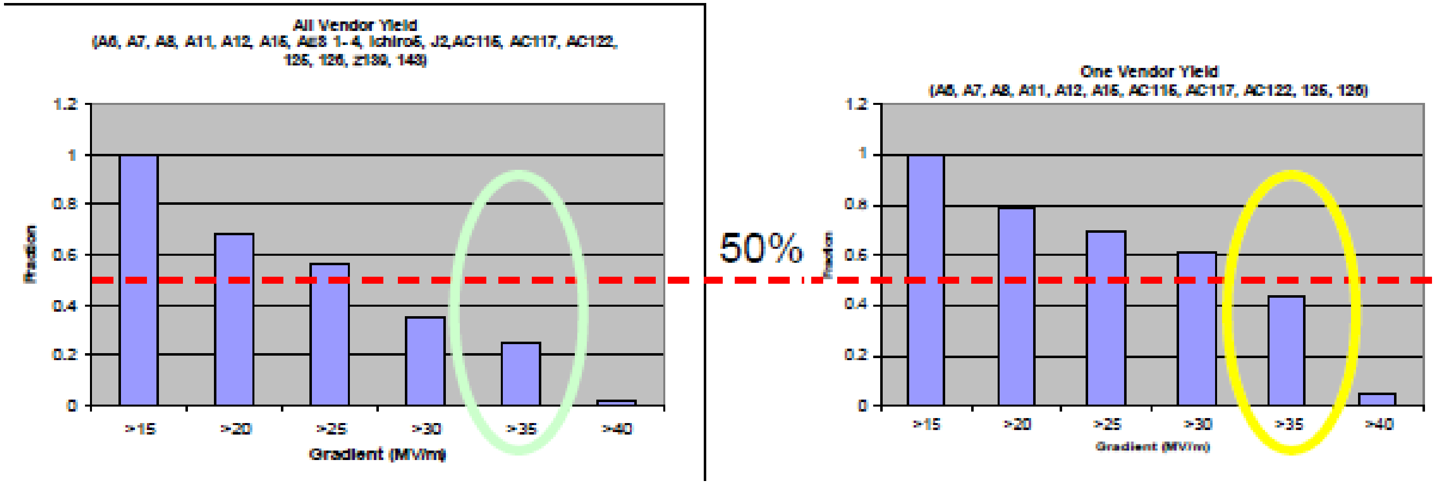




Status of 9-cell Cavity R&D

Combined Yield of Jlab and DESY Tests

48 Tests, 19 cavities	23 tests, 11 cavities
ACCEL, AES, Zanon, Ichiro, Jlab	One Vendor

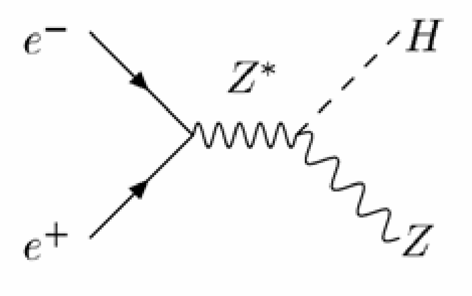


Yield 45 % at 35 MV/m being achieved
by cavities with a qualified vendor !!

ILC Physics Motivation

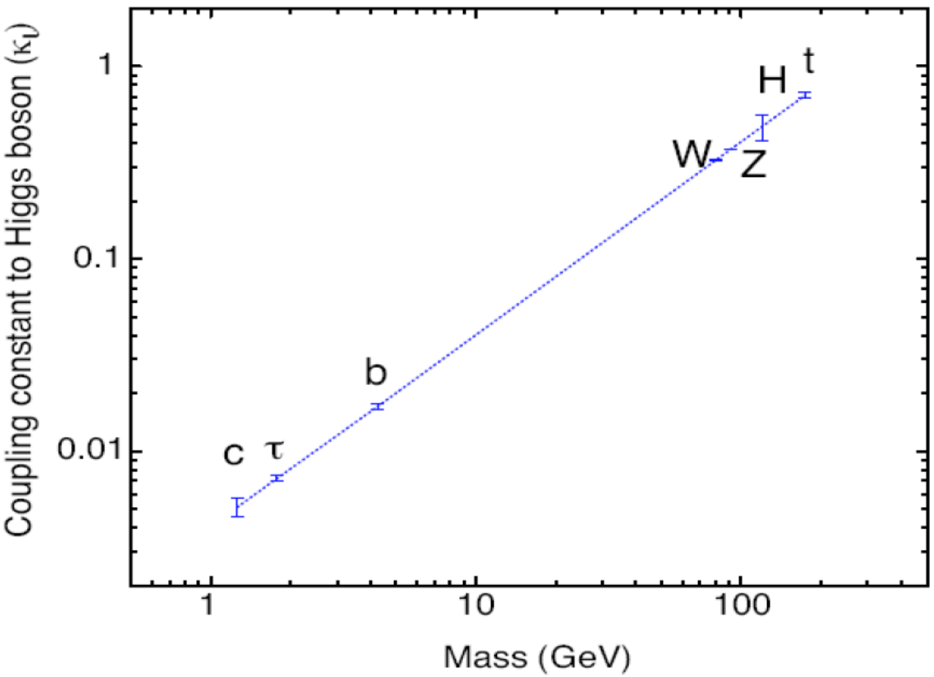
> ILC will complement LHC discoveries by precision measurements

> Here just two examples:

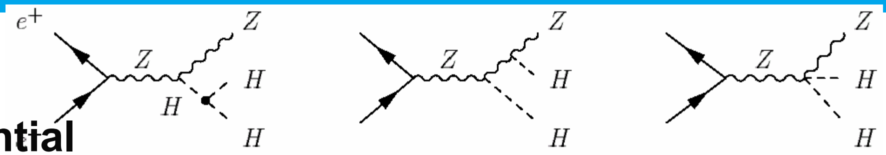


> 1) There is a Higgs, observed at the LHC

- e+e− experiments can detect Higgs bosons without assumption on decay properties Higgs-Strahlungs process (à la LEP)
- identify Higgs events in e+e− → ZH from Z → μμ decay
- count Higgs decay products to measure Higgs BRs and hence (Yukawa)-couplings

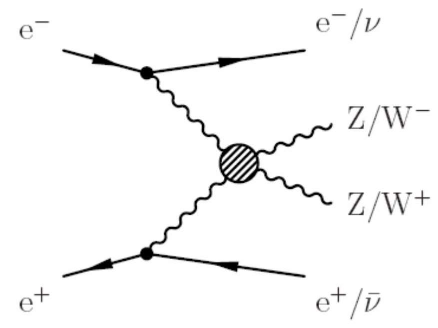


ILC Physics Motivation



- > Measure Higgs self-couplings
  - $e^+e^- \rightarrow ZHH$ to establish Higgs potential
- > Note: small signal above large QCD background

- > 2) There is NO Higgs (definite answer from LHC!)
  - something else must prevent e.g. WW
  - scattering from violating unitarity
  - at O(1 TeV)
  - strong electroweak symmetry breaking?
  - $\rightarrow$ study $e^+ e^- \rightarrow$ WWvv, Wzev and ZZee events



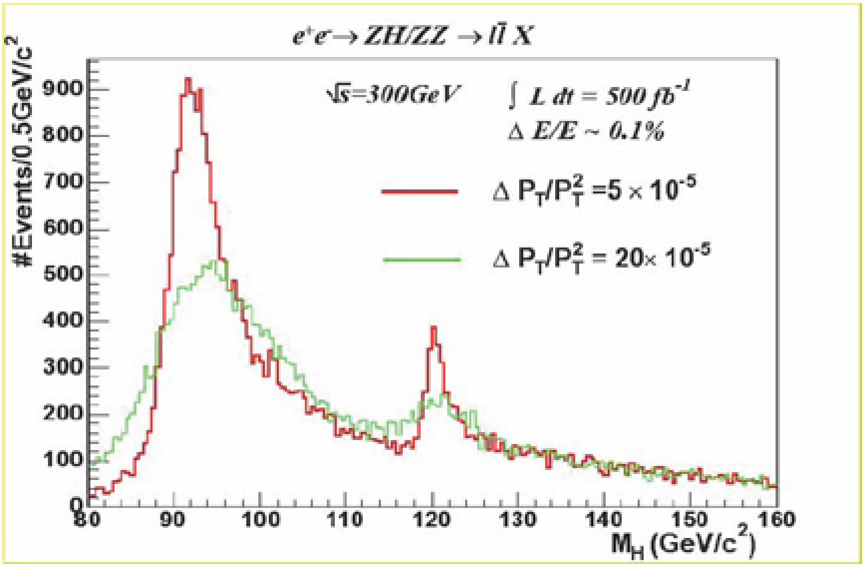
  - need to select and distinguish W and Z bosons in their hadronic decays!
  - BR (W/Z $\rightarrow$ hadrons) = 68% / 70%
- > Many other physics cases: SM, SUSY, new phenomena, …
- > Need ultimate detector performance to meet the ILC physics case

Impact on Detector Design

> **Vertex detector: e.g. distinguish c- from b-quarks**

- goal impact parameter resolution

  $\sigma_{r\varphi} \approx \sigma_z \approx 5 \oplus 10/(p \sin \Theta^{3/2})$ µm **3 times better than SLD**
- small, low mass pixel detectors, various technologies under study
- size $O(20 \times 20\ \mu m^2)$



> **Tracking:**

- superb momentum resolution to select clean Higgs samples
- ideally limited only by Γ_Z

→ $\Delta(1/p_T) = 5 \cdot 10^{-5}$ /GeV (whole tracking system)
3 times better than CMS

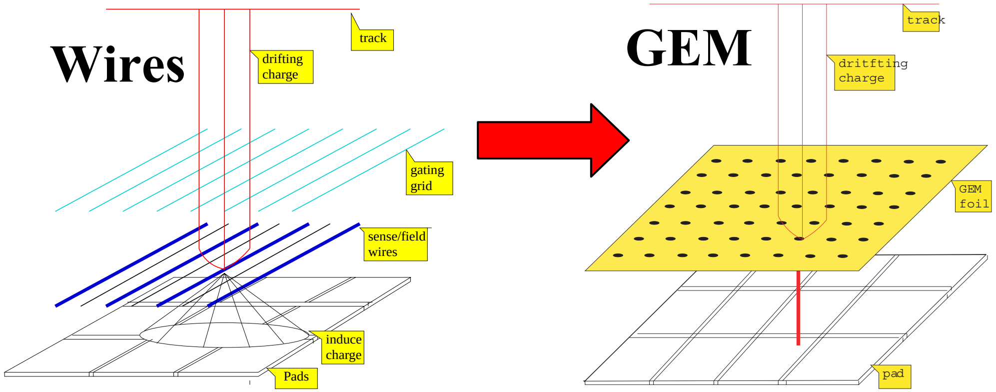
> **Options considered:**

- large silicon trackers (à la ATLAS/CMS)
- Time Projection Chamber with ≈ 100 µm point resolution (complemented by Si–strip devices)

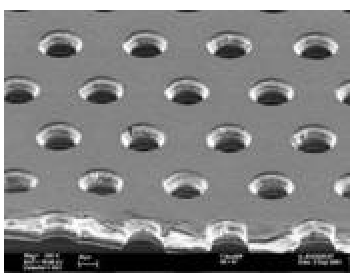
Development of a High Resolution TPC

- New concept for gas amplication at end flanges:
  - Replace proportional wires by
  - Micro Pattern Gas Detectors (MPGD)
- GEM or MicroMegas
  - finer dimensions
  - two-dimensional symmetry

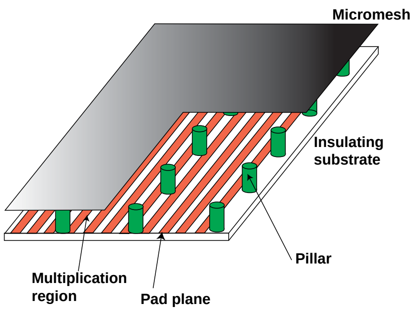
    → no E×B effects



GEM



µMegas



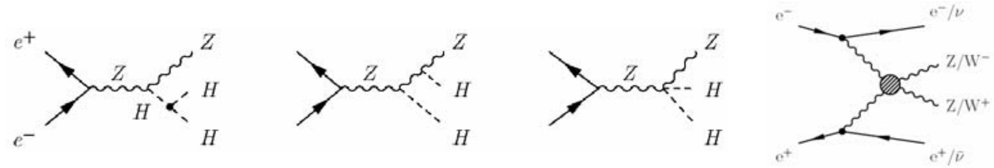
LCTPC collaboration in DESY testbeam:

Impact on Detector Design

> **Calorimeter:**

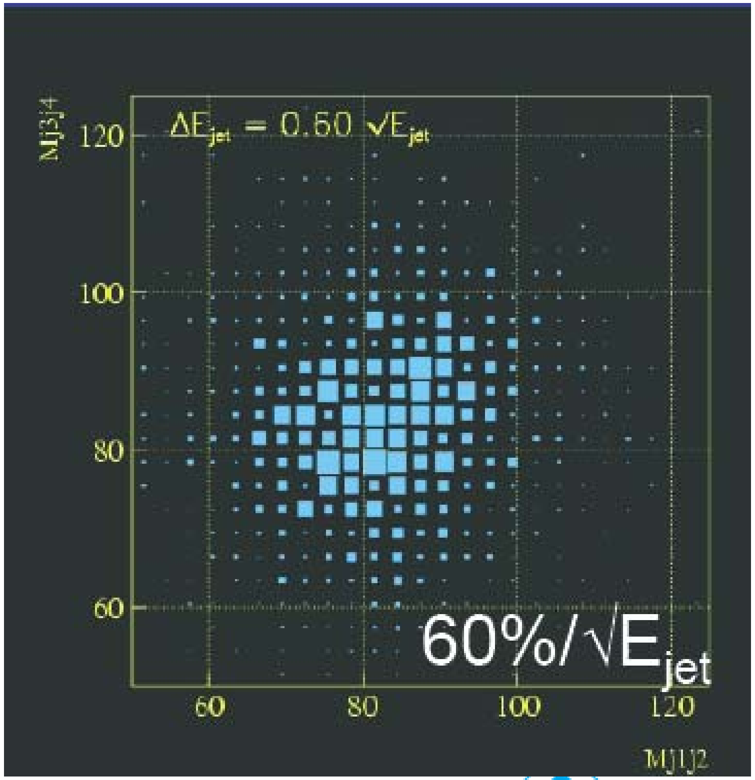
- **distinguish W- and Z-bosons in their hadronic decays**

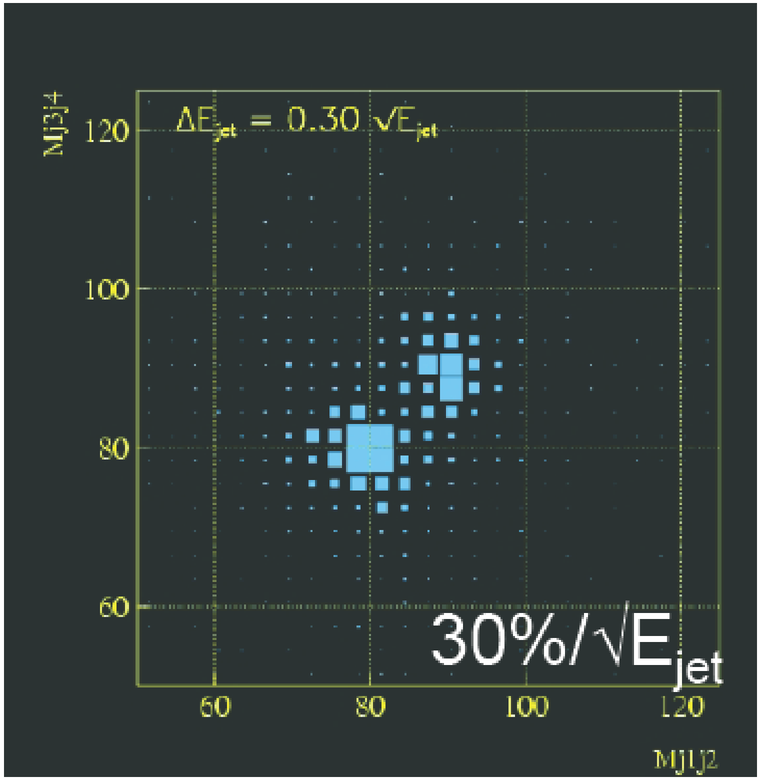
  → 30%/√E jet resolution!



2 times better than ZEUS

> **WW/ZZ → 4 jets:**





Particle Flow Algorithm

> **Try to reconstruct every particle**
- **measure charged particles in tracker**
- **measure photons in ECAL**
- **measure neutral hadrons in ECAL+HCAL**
- **use tracker + calorimeters to tell charged from neutral**

Average visible energy in a jet
≈ 60% charged particles
≈ 30% photons
≈ 10% neutral hadrons

particles in jet	fraction of energy in jet	detector	single particle resolution	jet energy resolution
charged particles	60 %	tracker	$\frac{\sigma_{p_t}}{p_t} \sim 0.01\% \cdot p_t$	negligible
photons	30 %	ECAL	$\frac{\sigma_E}{E} \sim 15\%/\sqrt{E}$	$\sim 5\%/\sqrt{E_{jet}}$
neutral hadrons	10 %	HCAL+ECAL	$\frac{\sigma_E}{E} \sim 45\%/\sqrt{E}$	$\sim 15\%/\sqrt{E_{jet}}$

> **Jet resolution**

$$\sigma = \sigma_{\text{charged}} \oplus \sigma_{\text{photons}} \oplus \sigma_{\text{neutral}} \oplus \sigma_{\text{confusion}}$$

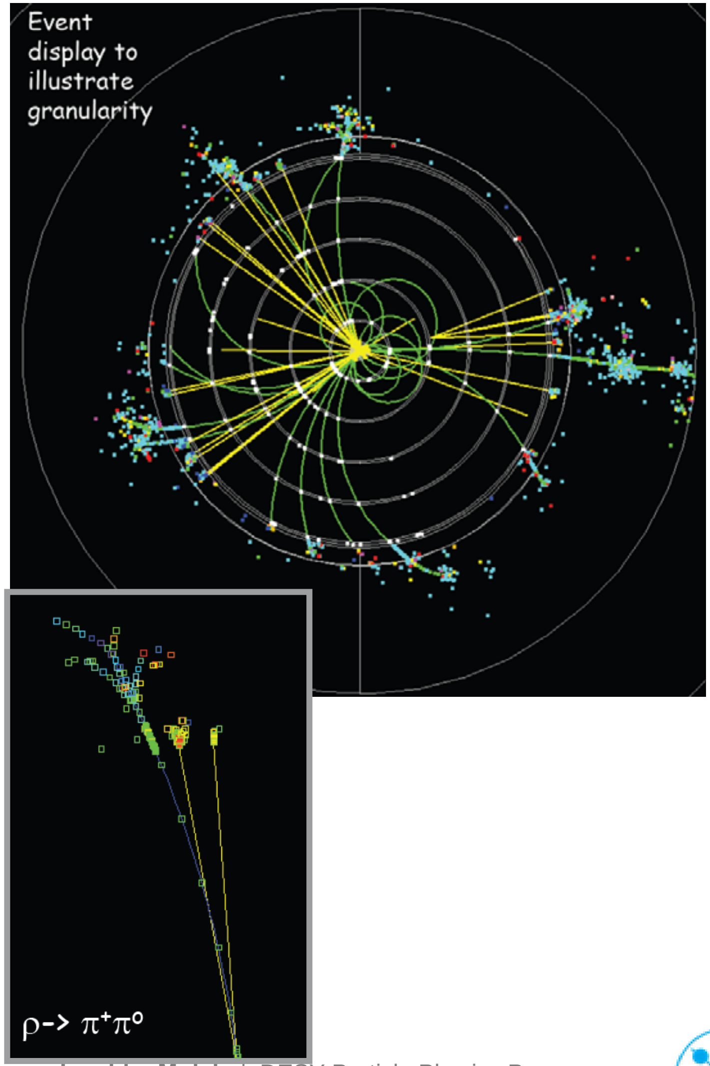
- **confusion term arises from**

  mis-assignment, double counting, overlapping clusters, …
- **minimizing confusion term requires highly granular calorimeter**

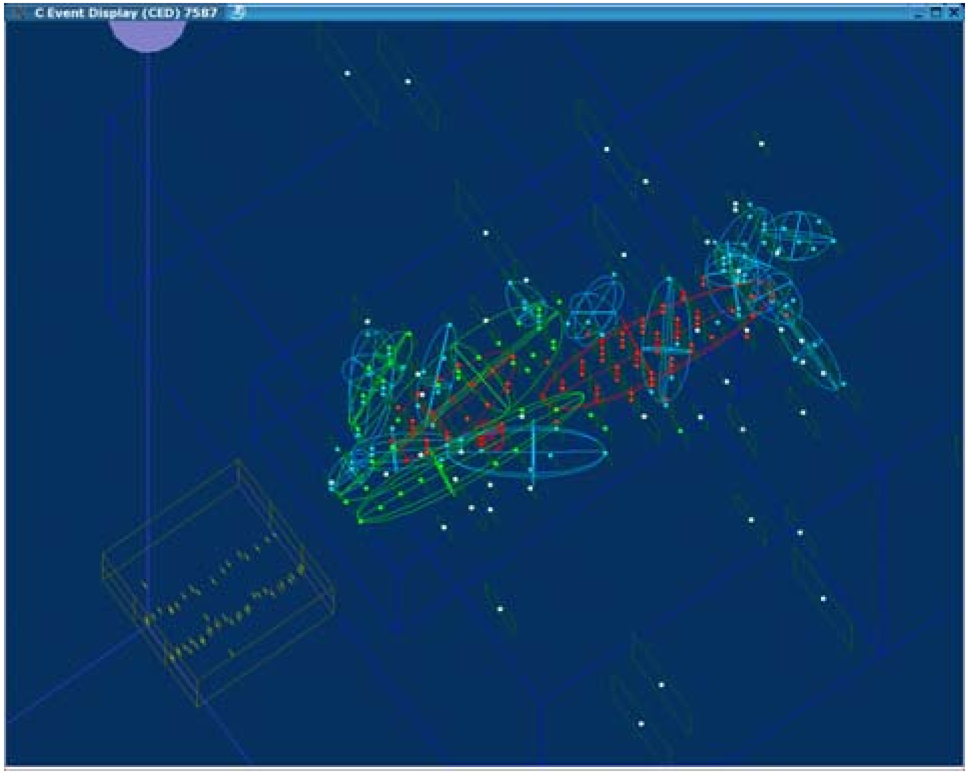
  both ECAL and HCAL

Development of PFA Calorimeter

> **Simulated ILC event**



> **Testbeam data**



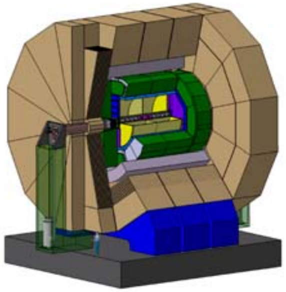
> **CALICE collaboration**

Detector Development

> **Detector Concepts:**

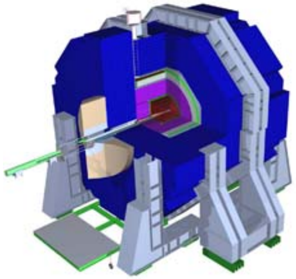
> **3 LOIs submitted in March 2009**

ILD



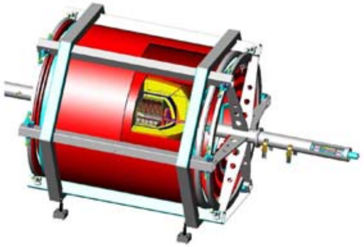
http://www.ilcild.org/documents/ild-letter-of-intent

SiD



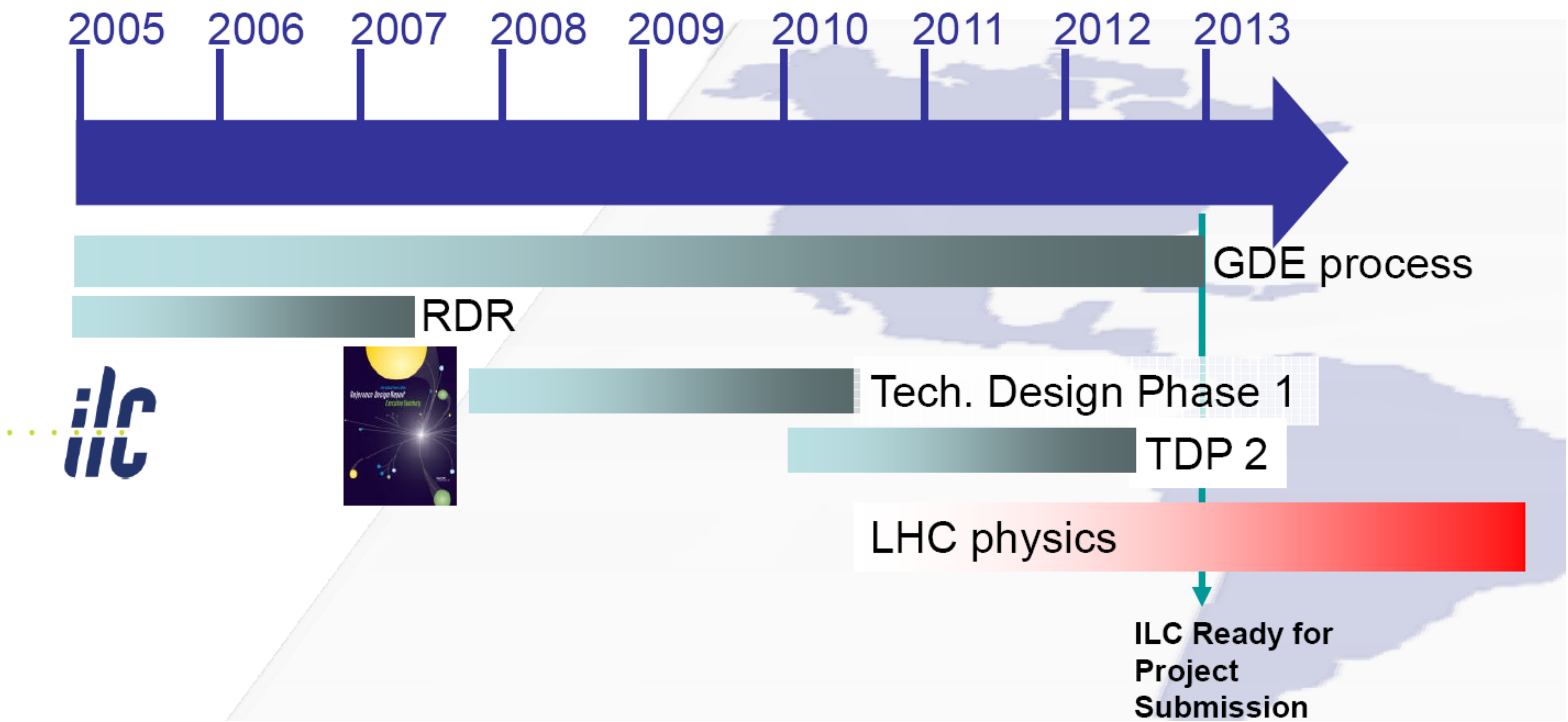
http://silicondetector.org/display/SiD/LOI

4th



http://www.4thconcept.org/4LoI.pdf

ILC Time Table



Summary

> **HERA experimental programme finished**

- **Structure of the proton, important input fir the LHC**
- **Tests of QCD and electrowek theory**
- **Searches for new physics**

> **Preparation for the ILC in full swing**

- **Prepare for proposal in 2012 (or earlier)**

> **DESY will remain strong laboratory for particle physics**

- **HERA analysis**
- **LHC**
- **Linear Collider (accelerator and detector)**

ILC: Technical Design Phase and Beyond