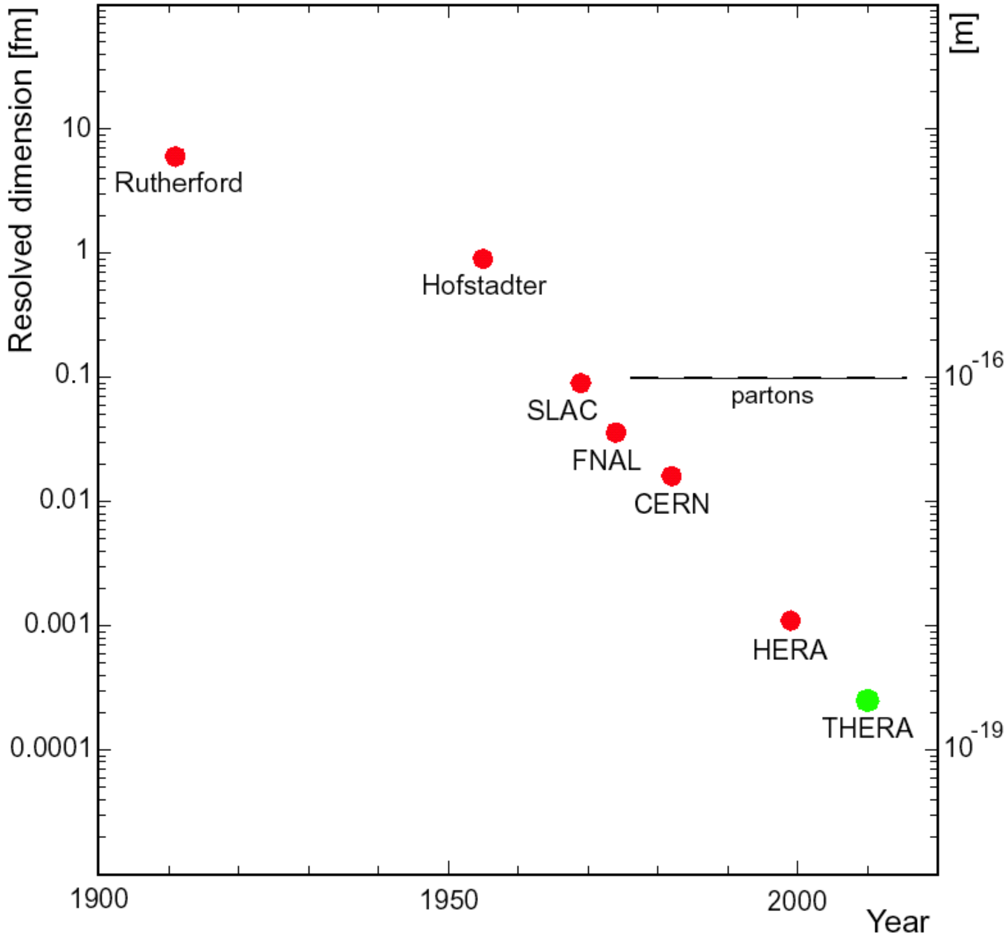
Options and implications of ep experiments at HERA and beyond

- HERA luminosity upgrade
- upgrades of the ZEUS and H1 detectors
- future options for ep (eA)

Lepton-Hadron Scattering

Resolving the Structure of Matter
with Deep Inelastic Scattering (DIS)



Fixed target experiments

- polarized, unpolarized and semi-polarized:

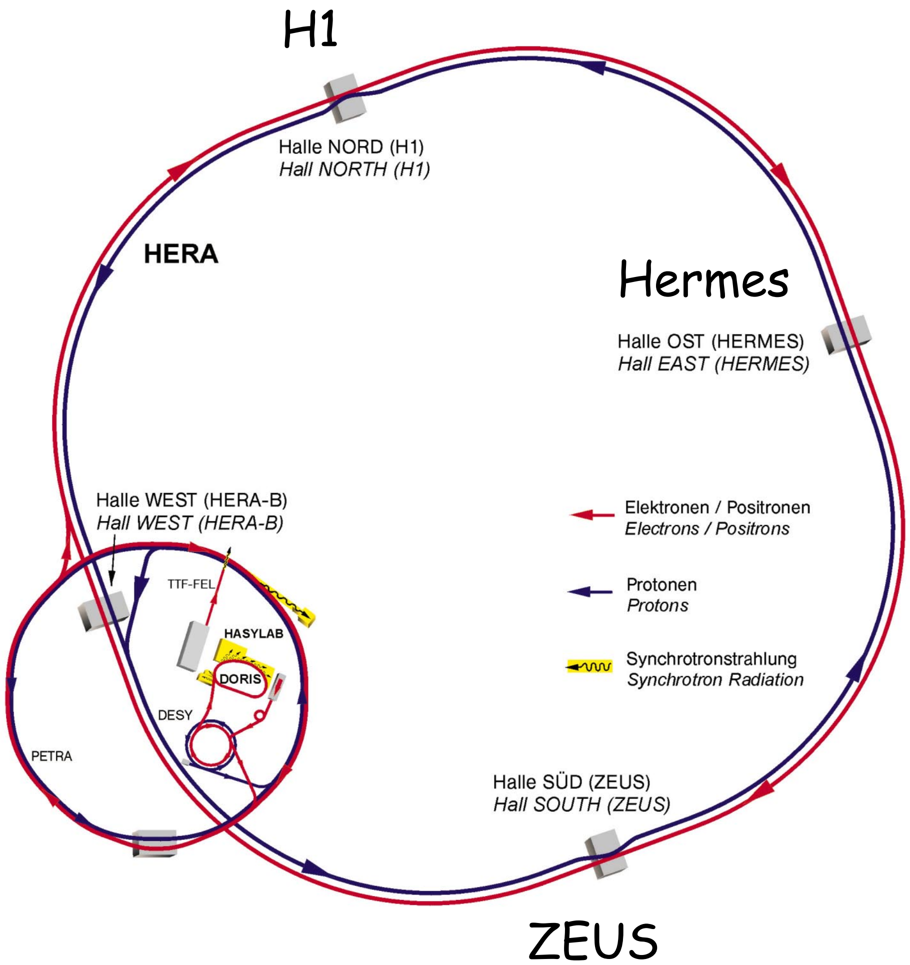
- e-p, e-A (SLAC/DESY)
- μ-p, μ-A (CERN/FNAL)
- ν-p, ν-A (FNAL)

Collider experiments

- so far only unpolarized

- e-p (H1&ZEUS @ DESY) ⇐

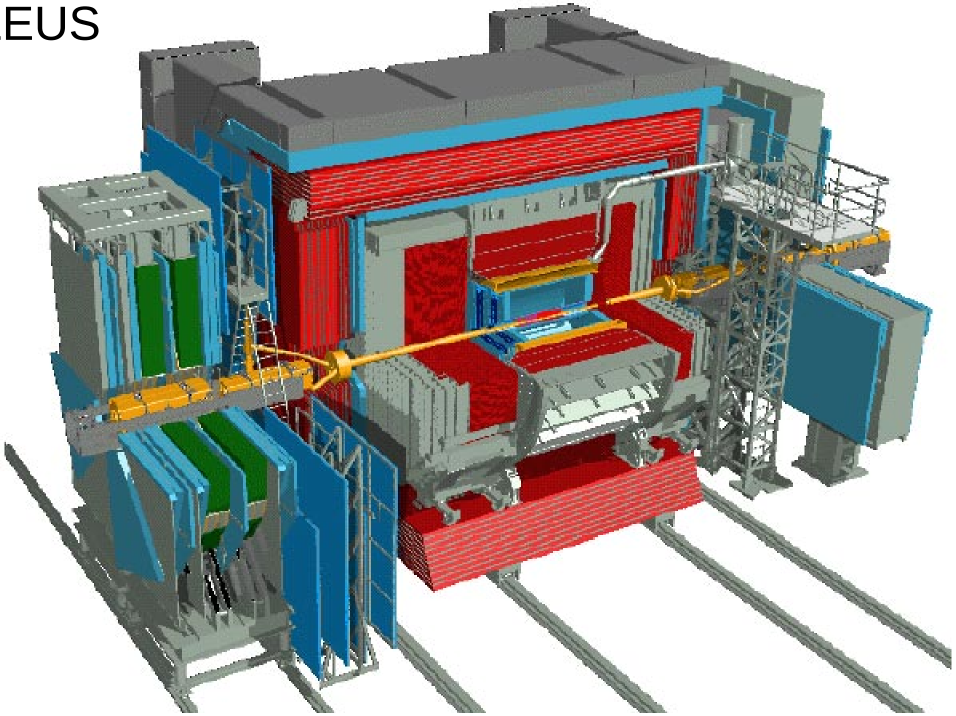
HERA at DESY

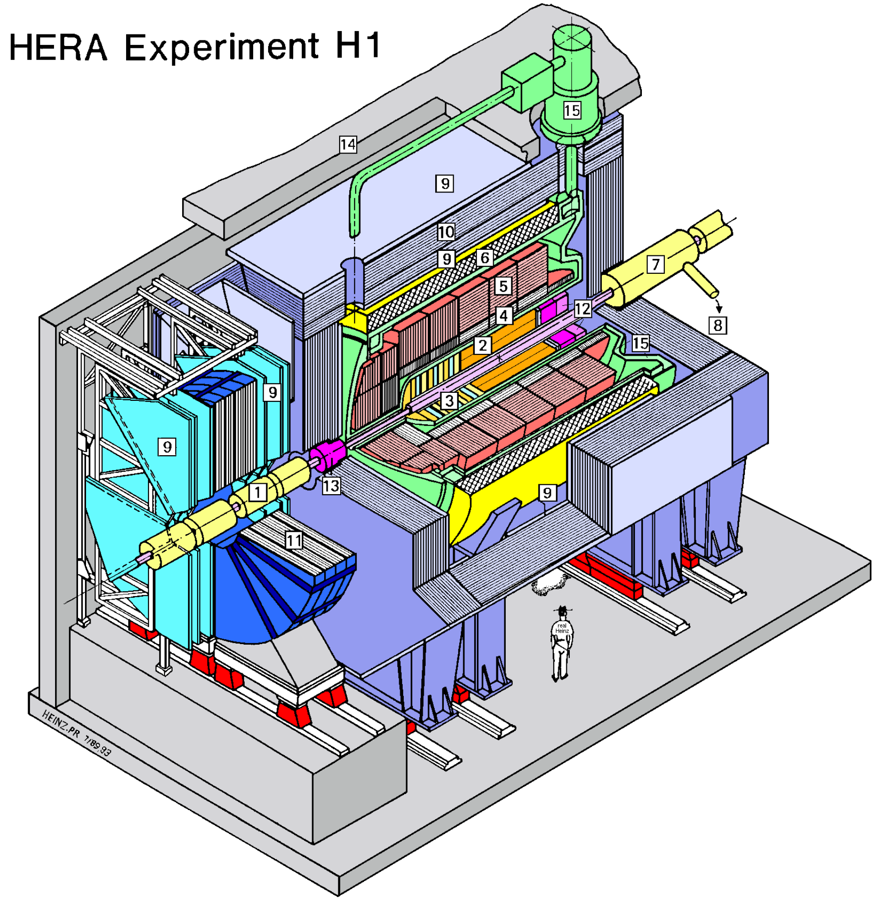


Protons		Electrons/Positrons	
Source	20 keV	Source	150 keV
RFQ	750 keV	Linac II	450 MeV
Linac III	50 MeV	Pia	450 MeV
DESY III	8 GeV	DESY II	7 GeV
PETRA	40 GeV	PETRA	12 GeV
HERA-p	**920 GeV**	**HERA-e**	**27.5 GeV**

The Colliding Beam Experiments

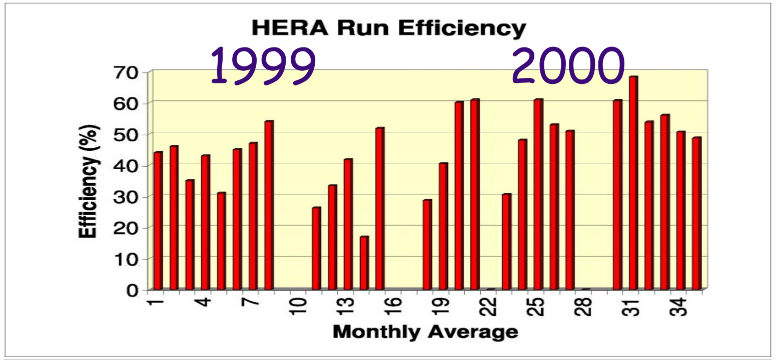
ZEUS

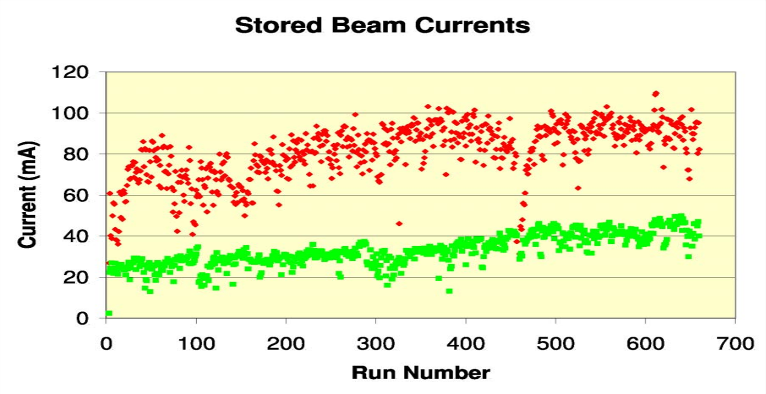


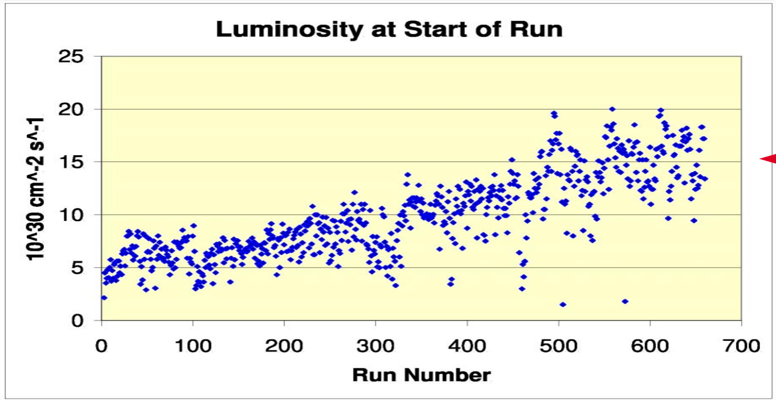


- multi-purpose detectors
- almost 4π acceptance

HERA Performance until 2000

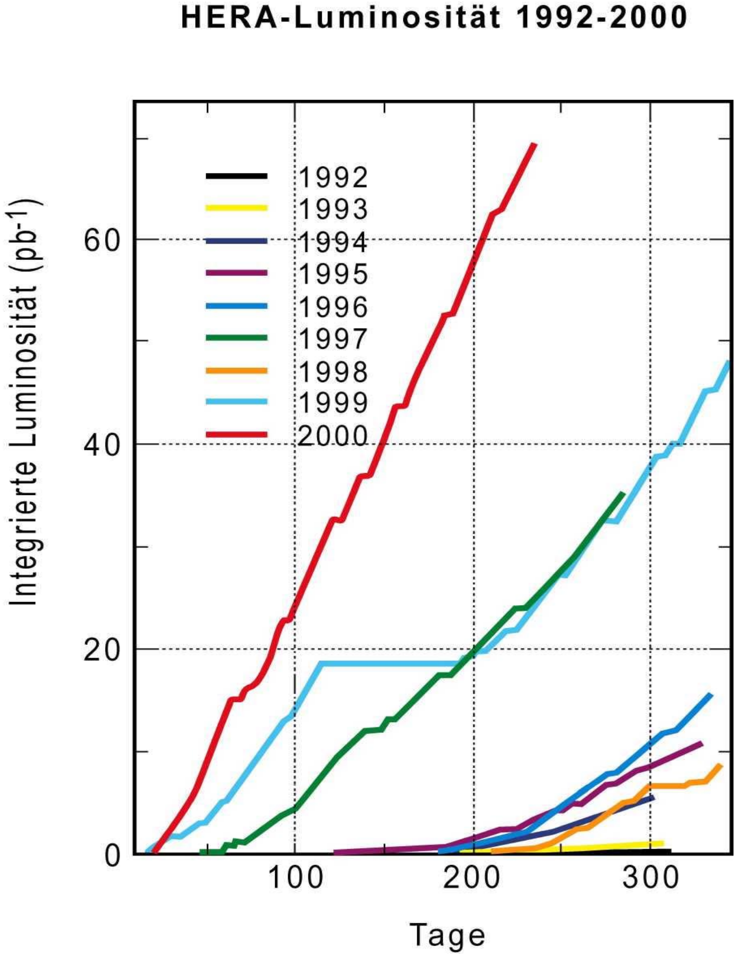






- *ever increasing performance since 1992*
- *some saturation reached 2000*

Design value

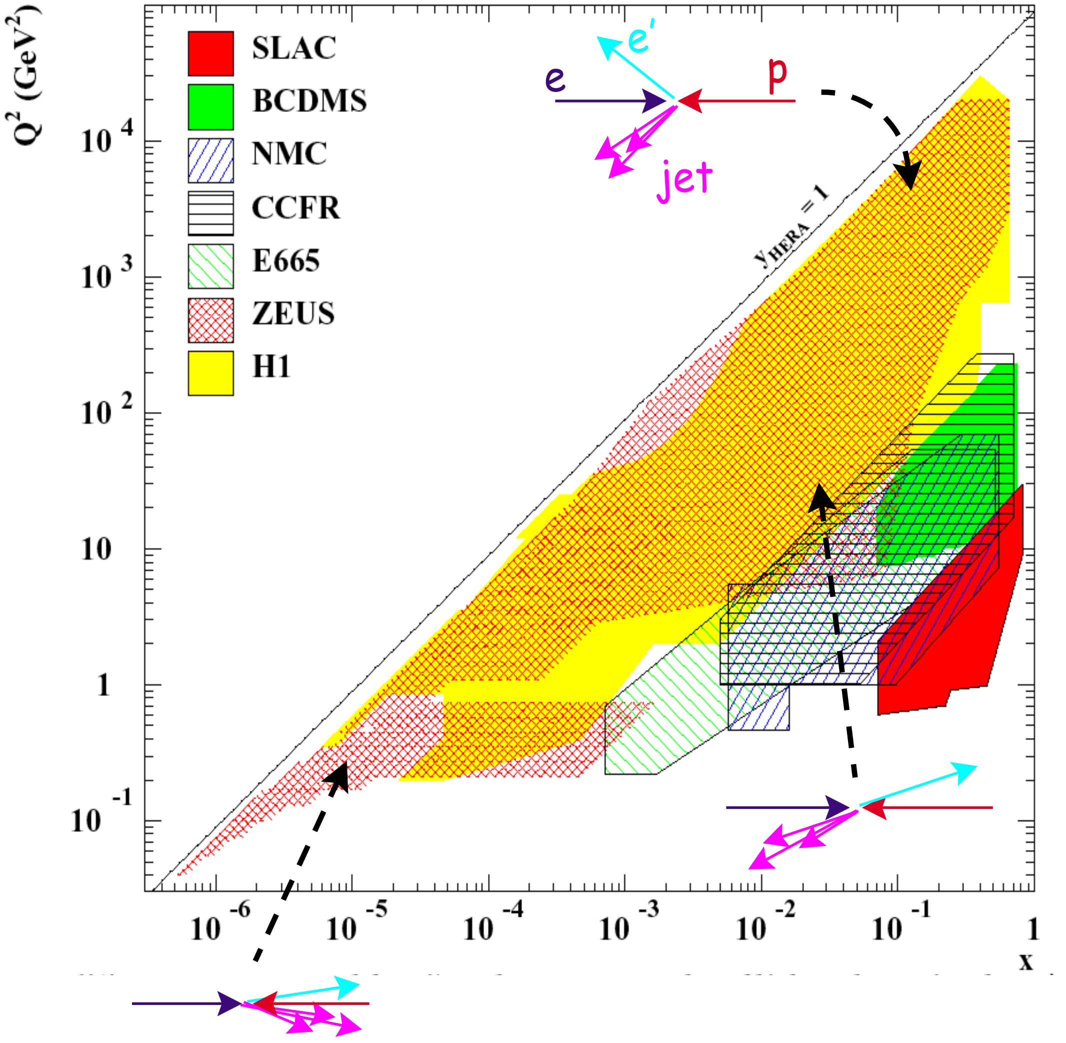


Kinematic Range and Highlights from HERA I

Significant increase in kinematic range beyond the fixed target experiments

Highlights from HERA I (1992-2000)

- proton structure & QCD
  rise of F2, role of gluons, jet physics, α_s determination, electroweak physics
- low x physics
  high parton densities, diffractive physics
- photon structure
- physics beyond the Standard Model
  lepto-quarks, contact interactions, exited leptons, isolated leptons



HERA II

- Luminosity upgrade
- Spin rotators for ZEUS and H1 ⇒ longitudinally polarized electrons/ positrons (→see talk by Ken Long 5.3.)
- H1 and ZEUS detector upgrades

Options for Luminosity Upgrade

Constraints for the Luminosity at HERA

$$L = \frac{\gamma_p}{4\pi e} \cdot \frac{N_p}{\varepsilon_N} \cdot I_e \cdot \frac{1}{\sqrt{\beta^*_{p,y} \cdot \beta^*_{p,x}}}$$

1. Proton beam brightness $N_p/\varepsilon_N \Uparrow$: (space charge effects in injector chain)

   increasing $N_p/\varepsilon_N \rightarrow$ larger $\beta^* \Rightarrow$ no large increase factor possible at HERA except with electron cooling

2. Electron Current $I_e \Uparrow$:

   no fundamental limitations, but costs. Points to consider:
   - RF power (12 MW now)
   - vacuum system
   - feedback system designed for ≤60 mA
   - beam-beam force on protons ?

3. Reduce beam size at interaction point by stronger focusing $\beta^* \Downarrow$: ← chosen because safest method

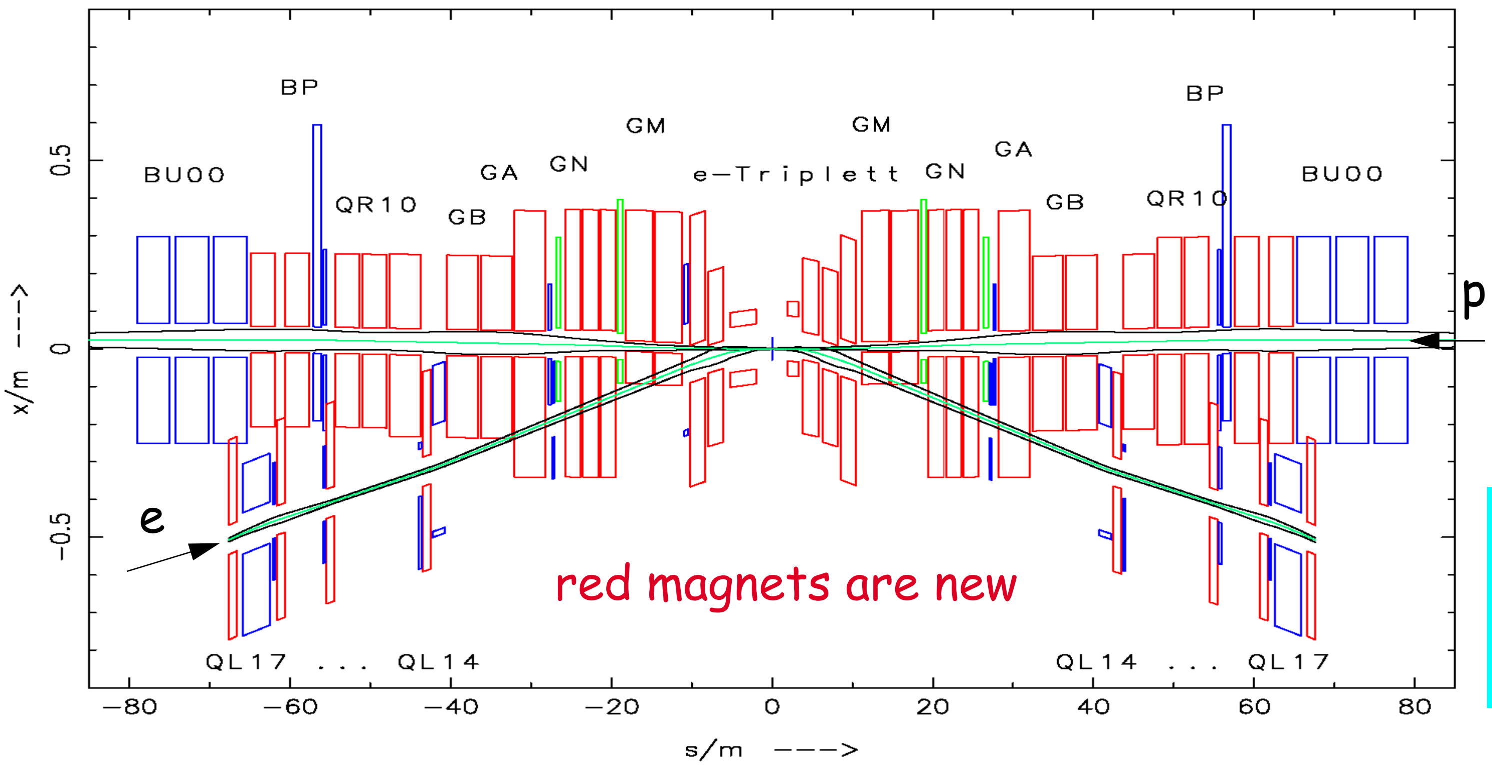
   move proton final focus quadrupoles closer to IP: 26m $\rightarrow$ 11m
   - need early seperation of protons and lepton beam

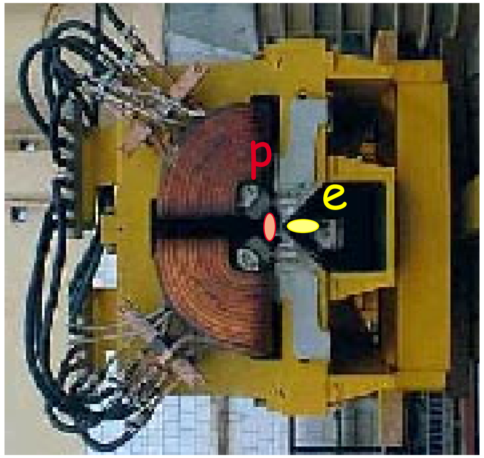
New Interaction Region

Parameters	before Upgrade		after Upgrade	
	e-ring	p-ring	e-ring	p-ring
E [GeV]	27.5	920	27.5	920
I [mA]	50	100	58	140
N_{ppb} [10^{10}]	3.5	7.3	4.0	10.3
n_{bunch}	174	174	174	174
β_x^* [m]	0.90	7.0	0.63	2.45
β_y^* [m]	0.60	0.5	0.26	0.18
ε_x [nm]	41	5000/γ	22	5000/γ
$\varepsilon_y / \varepsilon_x$	10%	1	18%	1
σ_x ; σ_y [μm]	190 ; 50	190 ; 50	120 ; 30	120; 30
σ_z [mm]	12	130	12	130
$\Delta\nu_x$	0.012	0.0013	0.027	0.002
$\Delta\nu_y$	0.03	0.00035	0.041	0.0005
L [$cm^{-2}s^{-1}$]	**1.5×10^{31}**		**7×10^{31}**	

- 448 m new vacuum beam pipe
- 4 superconducting magnets
- 54 new normal conducting magnets (Efremov Institute St. Petersburg)
- 2 spin rotators

Concept of new Interaction Regions



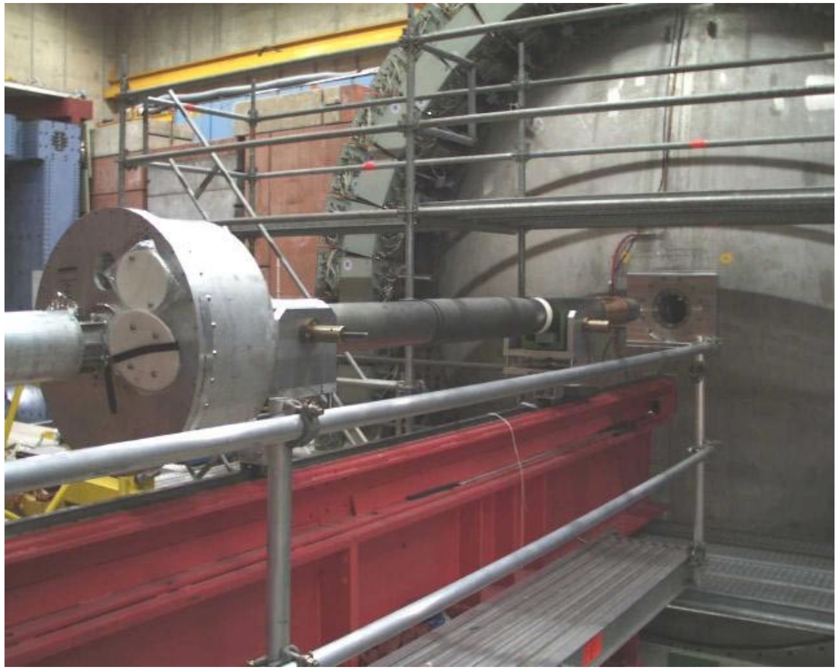


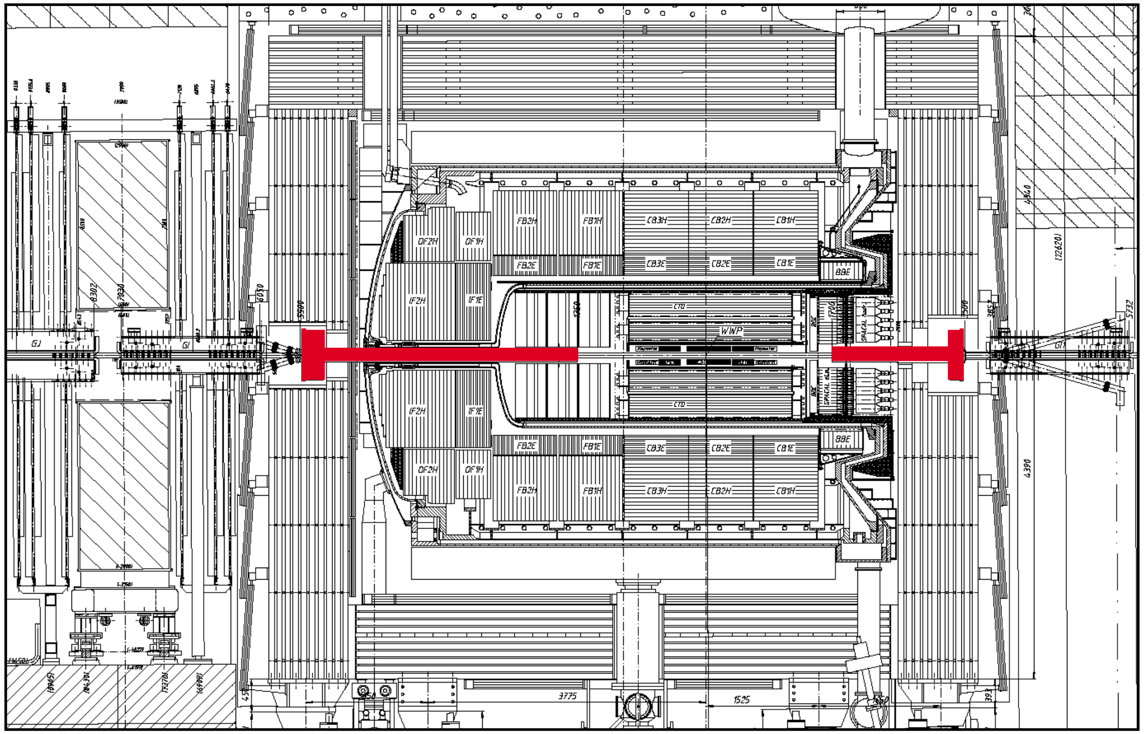
GM: new septum quadrupole for protons with **thin** mirror plate (Brett Parker)

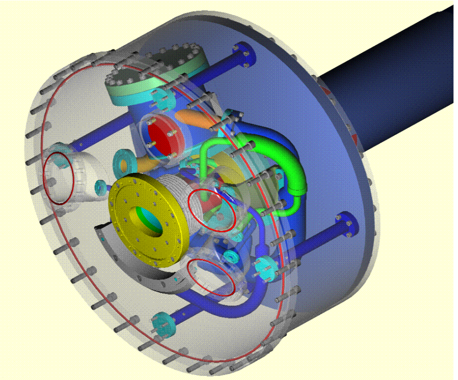
Stronger focusing of protons by moving proton quadrupoles closer to IR : 26m $\rightarrow$11m $\Rightarrow$

- early beam separation by superconducting magnets in the detectors
- reduced e-bending radius: 1200 m $\rightarrow$ 400 m
- increased synchrotron radiation power: P_{tot} = 28 kW @ 58mA , $E_{crit} \leq$ 150keV
- radiation has to pass the detector and will be absorbed at 11, 19 and 25 m behind the experiments

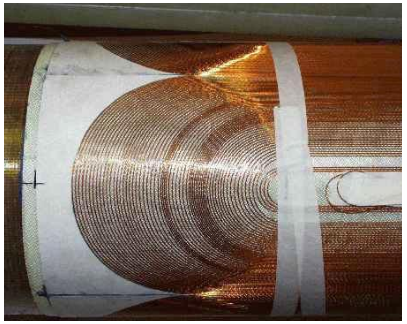
New Superconducting Magnets in the Experiments







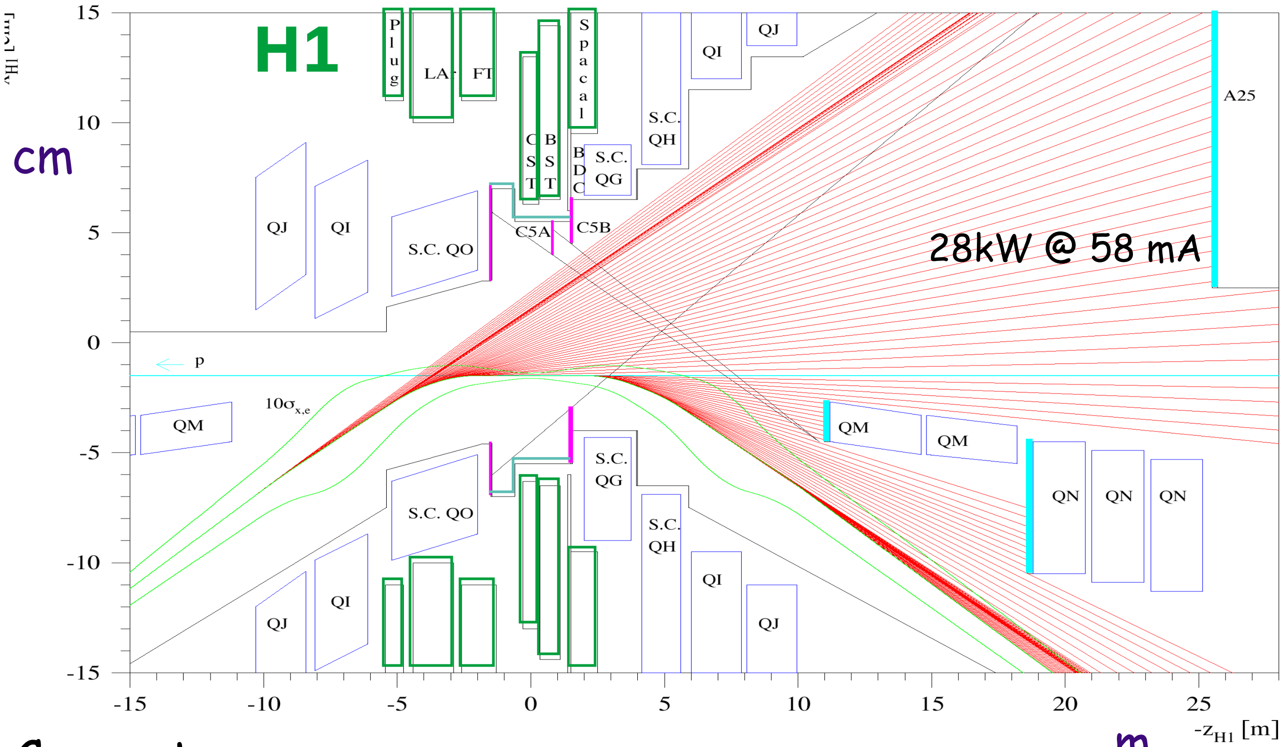
end can with
He supply lines

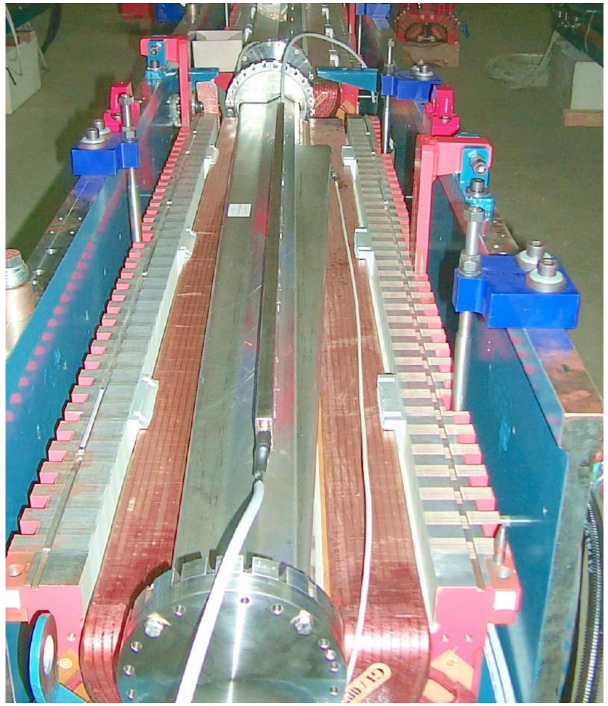


superconductor
positioning precision
0.01mm

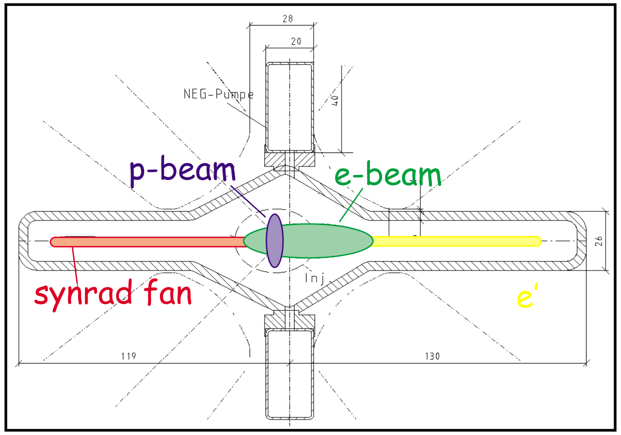
- combined function magnets including dipole, quadrupole, skew dipole, skew quads, sextupole
- very tight space requirements (ø <180 mm)
- ⇒ super conducting magnets
- designed and constructed at BNL
- complicated movable supports needed inside detectors (forces on LAr cryostat)

Challenge: Synchrotron Radiation





Need rather complicated beampipe (steel) to accomodate 3 different beams



Concept:

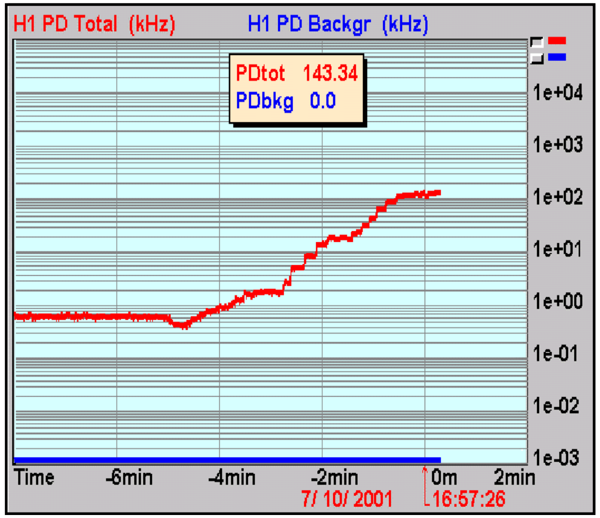
- synchrotron radiation may hit detector or beampipe only after at least two scatters
- central beampipe made from Al/Be-alloy (.38/.62) elliptical shape (64mm x 129mm, d=2mm ≈ 0.8 X_0)
- combination of downstream absorbers and tight collimators integrated in beampipe to shield against backscattered radiation

Where do we stand with the Upgrade ?

Protons: 28.7. first injection
10.8. ramp up to 920 GeV

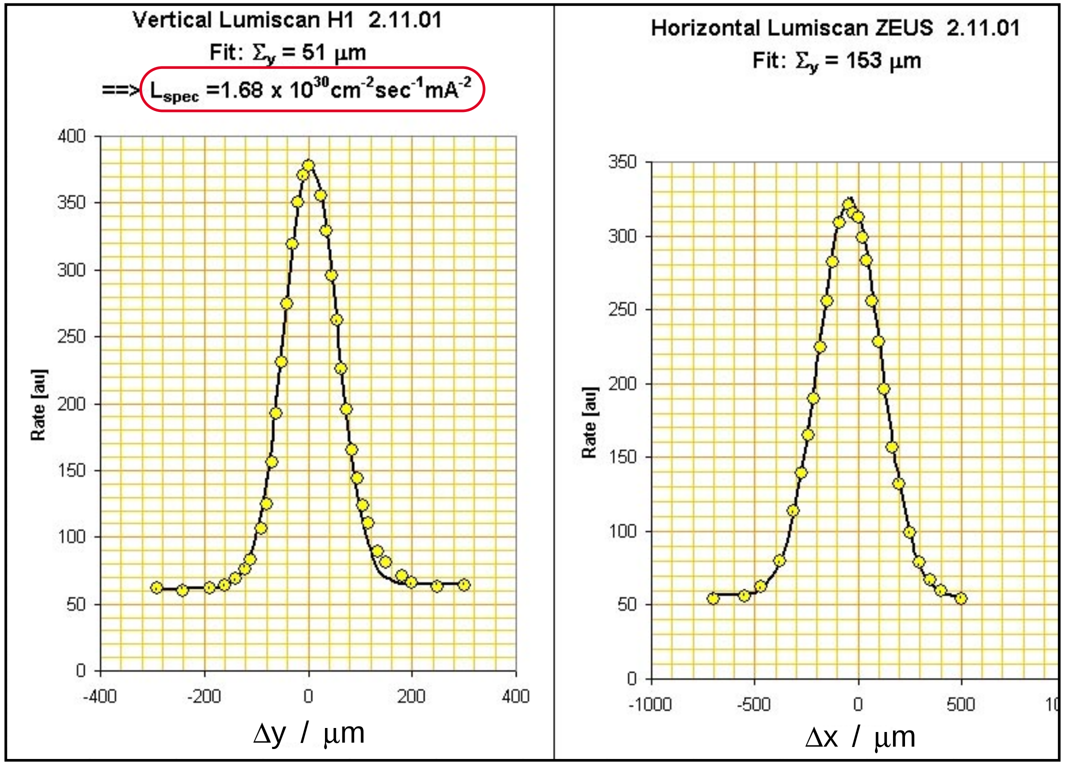
Positrons: 16.8. first injection
5.9. ramp up to 27.5 GeV
18.9. switch on solenoids

7.10. first ep collisions in HERA II



Increased rate in the H1 photon detector of the new luminosity system when horizontal bump was driven for the e+ beam

Lumiscan in November



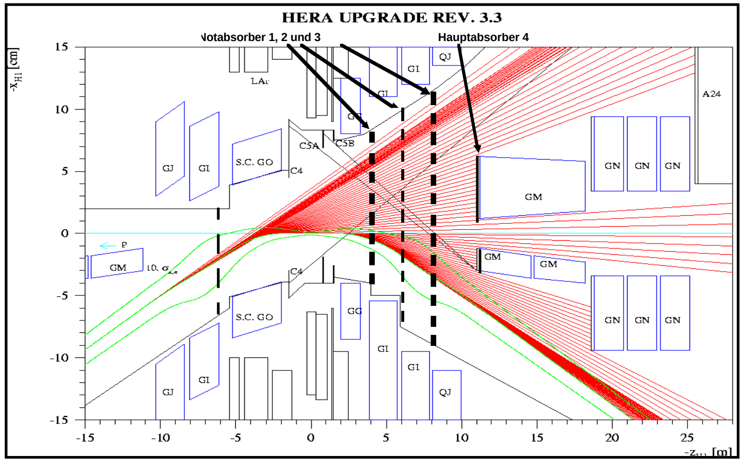
2.Nov.: $L_{spec} = 1.68 \times 10^{30}/cm^2\ s^1\ mA^2$

$\Rightarrow$ agrees within 10 % with design value of
$L_{spec} = 1.88 \times 10^{30}/cm^2\ s^1\ mA^2$

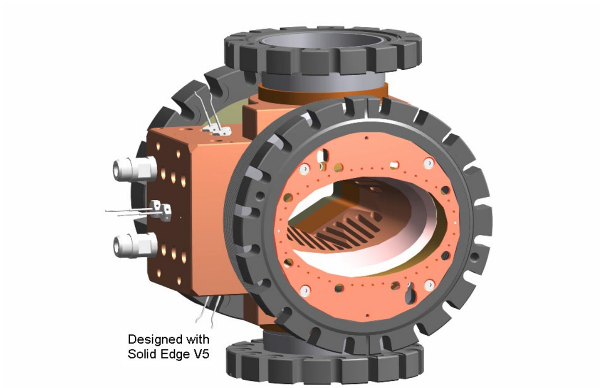
Remaining Problems

- Jan/Feb repair work in cold drift section of HERA-p
- Sofar it was only possible to store ≤2mA of positrons in the machine without risking damage of the silicon detectors
- A lot of effort was spent in determining the positions of beam elements and detectors using survey techniques and beam based alignment
- The present understanding is that the tight requirements in positioning precision of better than 0.3mm have not yet been met everywhere in the new machine (± 60m around IPs !)

Vertical collimators/absorbers



- As a consequence of this mis-alignment the synchrotron radiation fan produced in front of the experiments is too wide for the present configuration in the vertical direction and backscatters into experiments ⇒

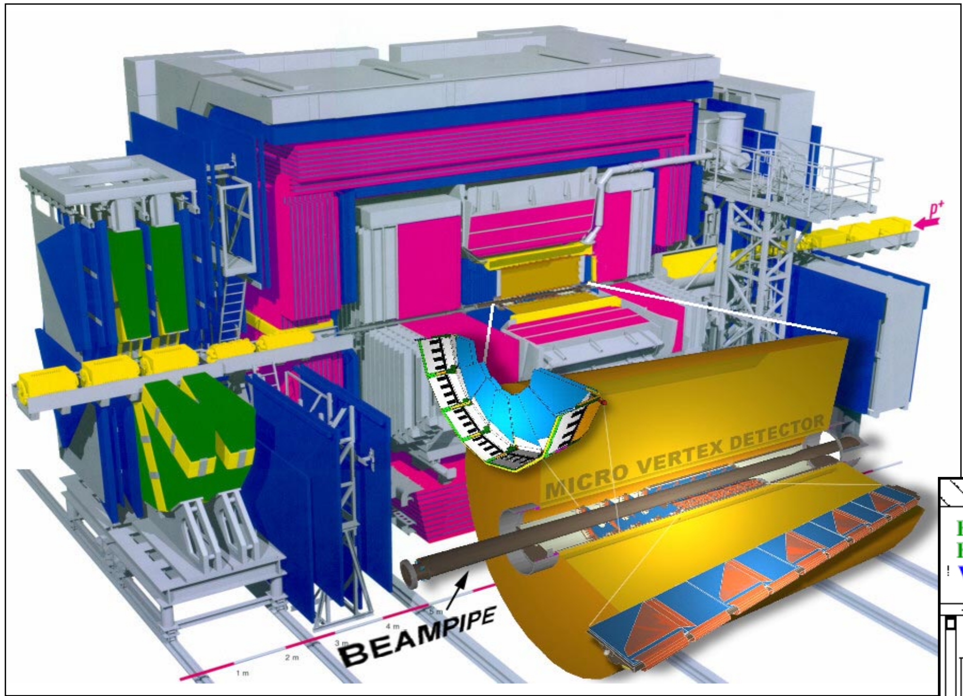


Absorber 1 @ z=3.5m

Measures taken right now:

- installation of additional collimators at -66m (hor.) and -6m (ver.) in front of the experiments
- increase vertical aperture of 2 emergency collimators (+3.5m, +5.9m) which protect the steel beam pipe behind the detectors
- installation of active protection for beam pipe
- try modified optics with reduced divergence

Detector Upgrades

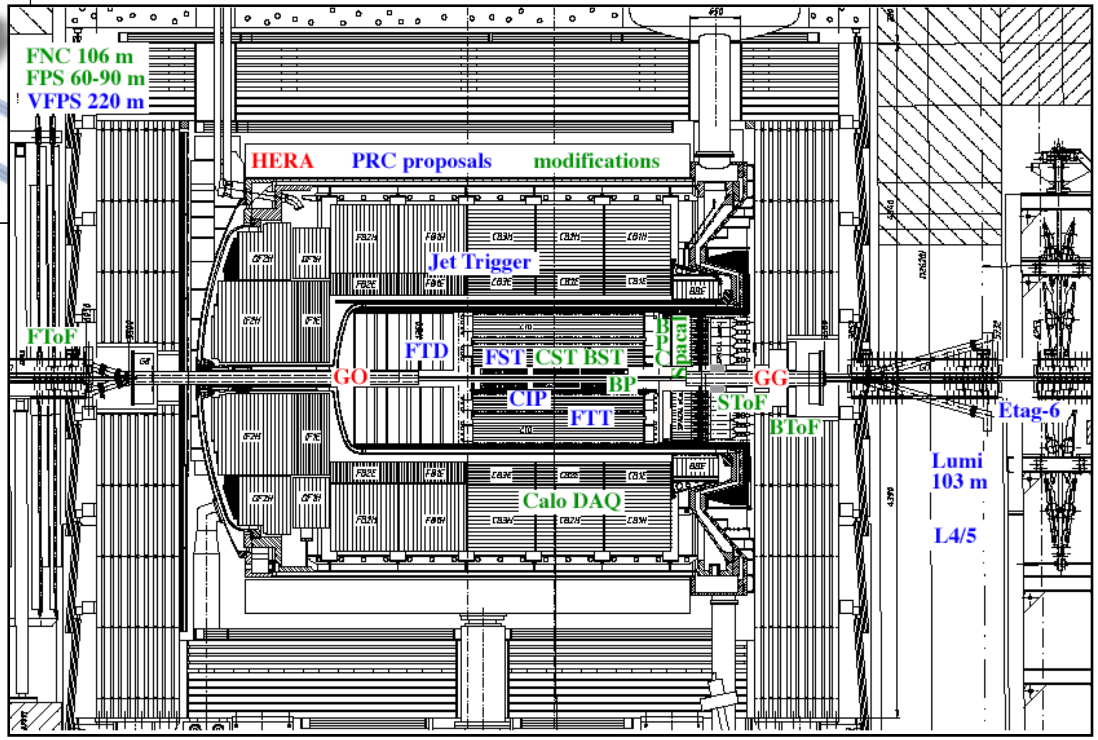


Many upgrade projects

with emphasis on enhanced capabilities for
- tracking (in forward direction)
- triggering (data taking rate ≈ constant)

Mandatory: luminosity detector upgrade
- need radiation hard γ detector
- cope with bunch to bunch pile up

... details not covered here
→ see talks this afternoon by:
- Ulrich Koetz for ZEUS
- Arndt Specka for H1



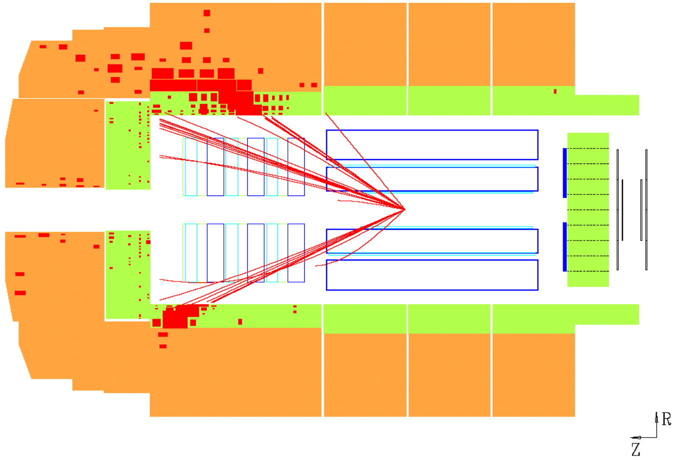
Forward Tracking

Problems for track finding in forward direction

- large background close to beam pipe
- high track densities from showers or jets

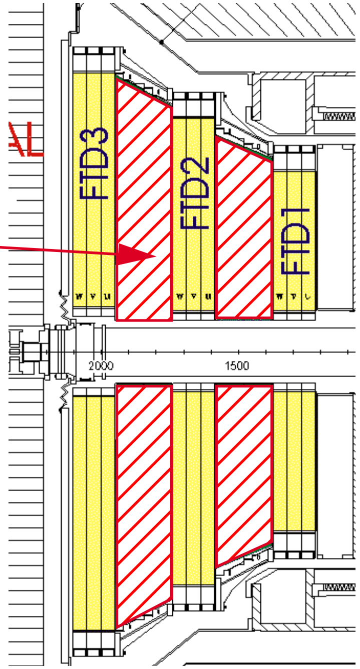
originally TRDs in H1 and ZEUS

⇒ increase redundancy by replacing TRDs with robust and well understood tracking devices



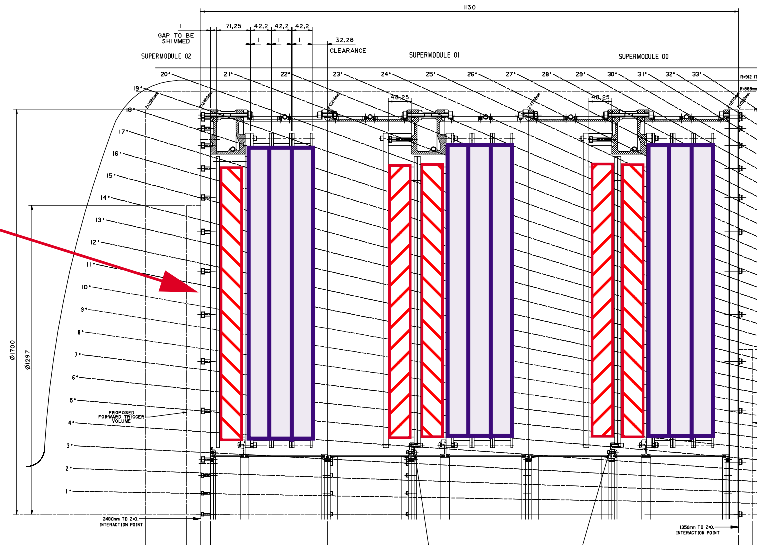
ZEUS

replace TRD with new straw tube tracker

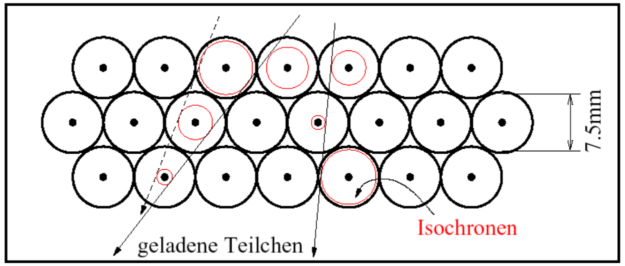


H1

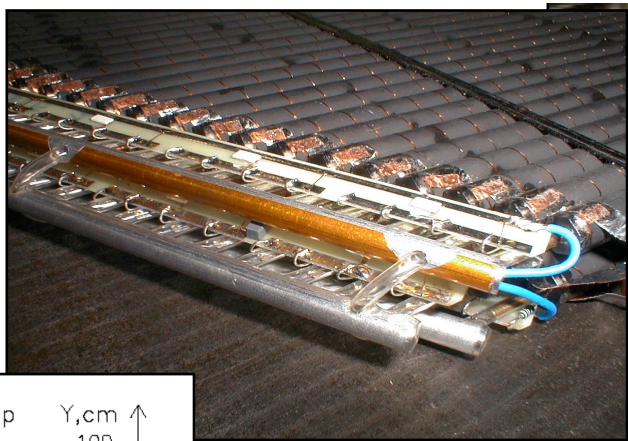
replace TRD and Radial drift chambers with 5 planar drift chambers (8 wires each)

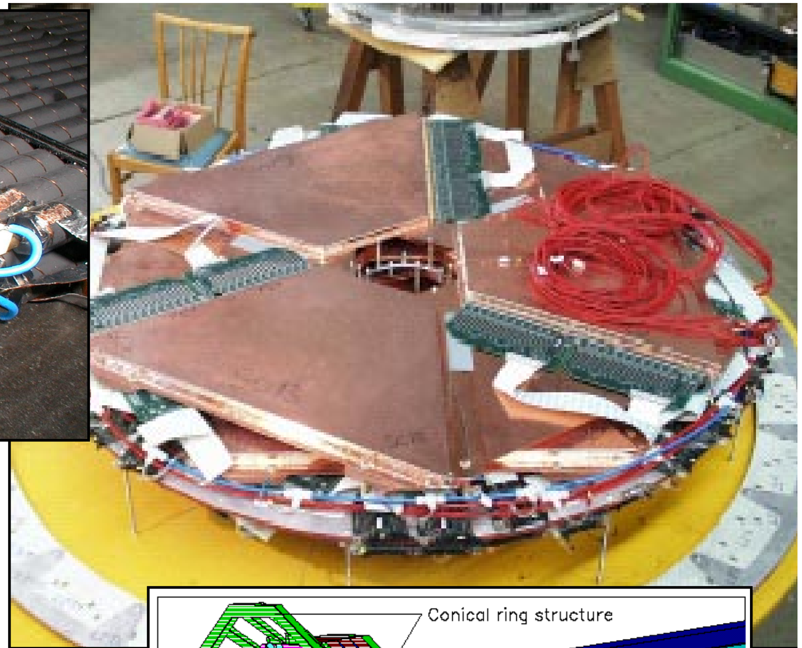


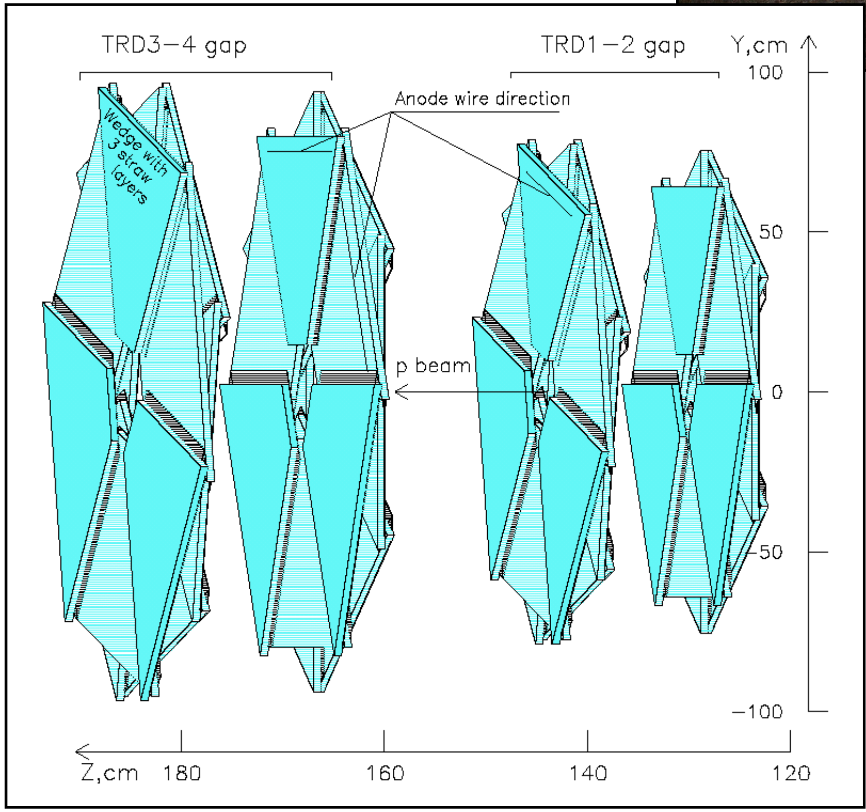
Straw Tube Tracker for ZEUS



straws: 2 layers 50μm Kapton foil

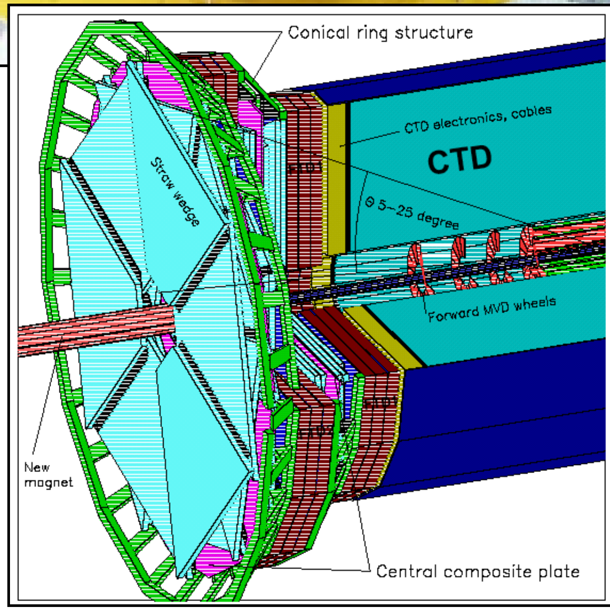






Concept:

- 2 gaps left free from original TRD each 208mm in z
- cover polar angle 6° to 24° and full azimuth
- 4 super layers per gap



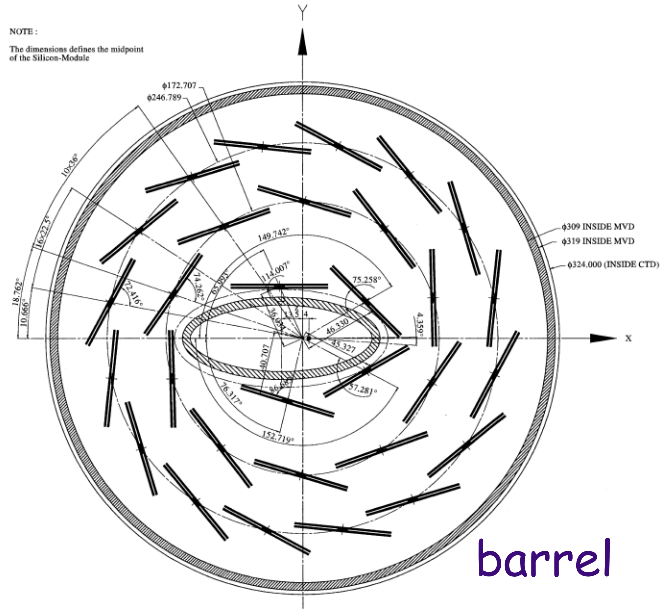
ZEUS Micro Vertex Detector

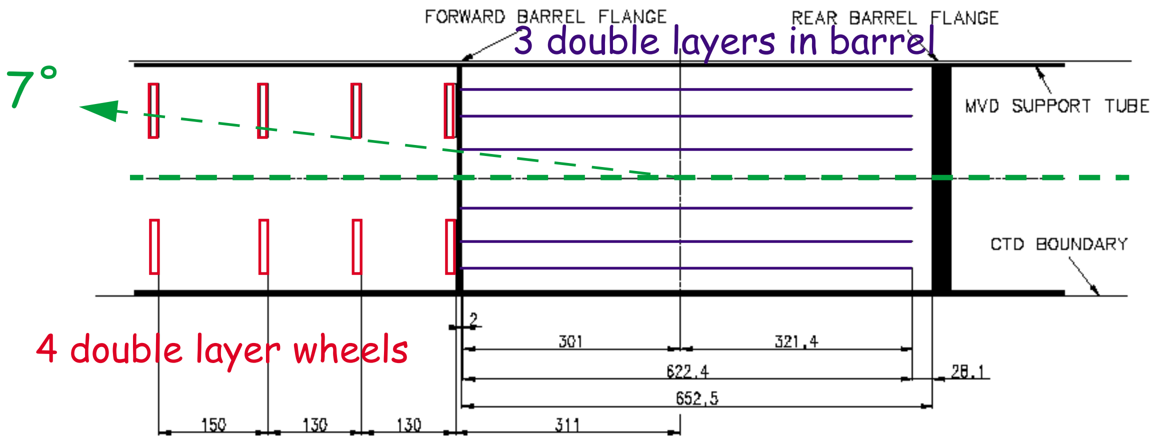
Design goals

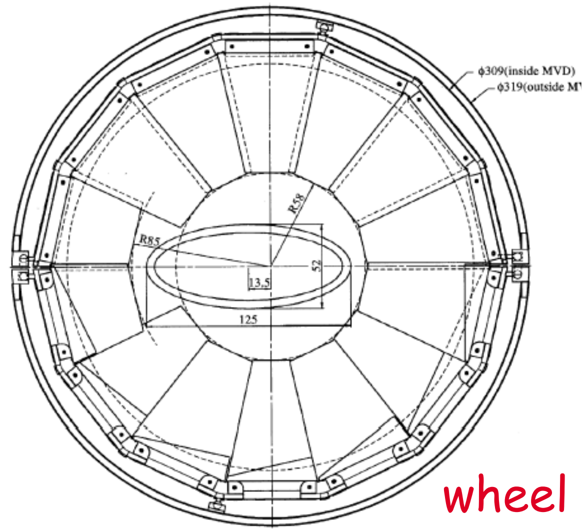
- three spatial measurements per track in two projections
- polar angle coverage 10°-170°
- <20μm intrinsic hit resolution for normal incidence
- impact parameter resolution ≈100 μm for p>2GeV
- high efficiency (>97%)

Constraints

- elliptical beam pipe
- CTD inner diameter 320mm
- 96 ns bunch crossing time

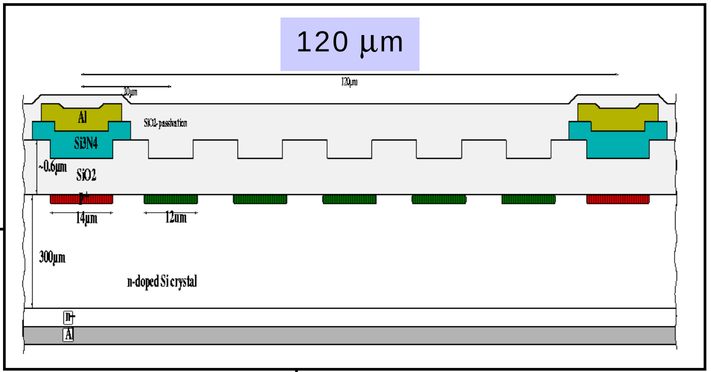


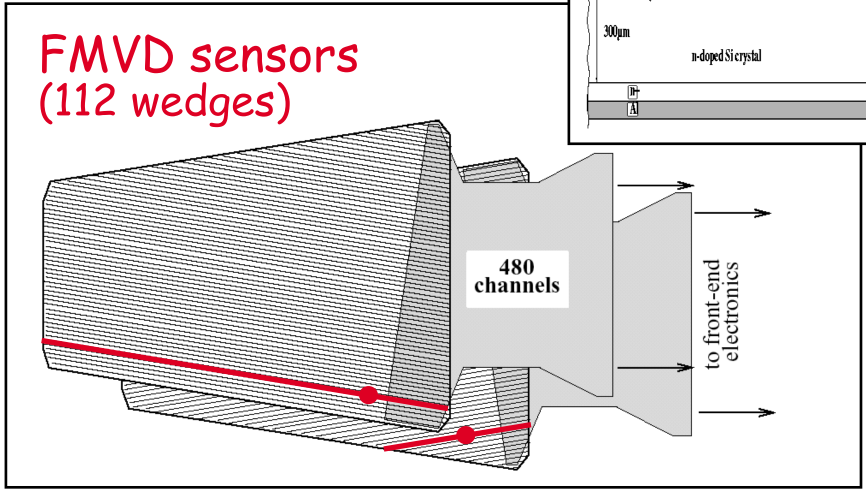


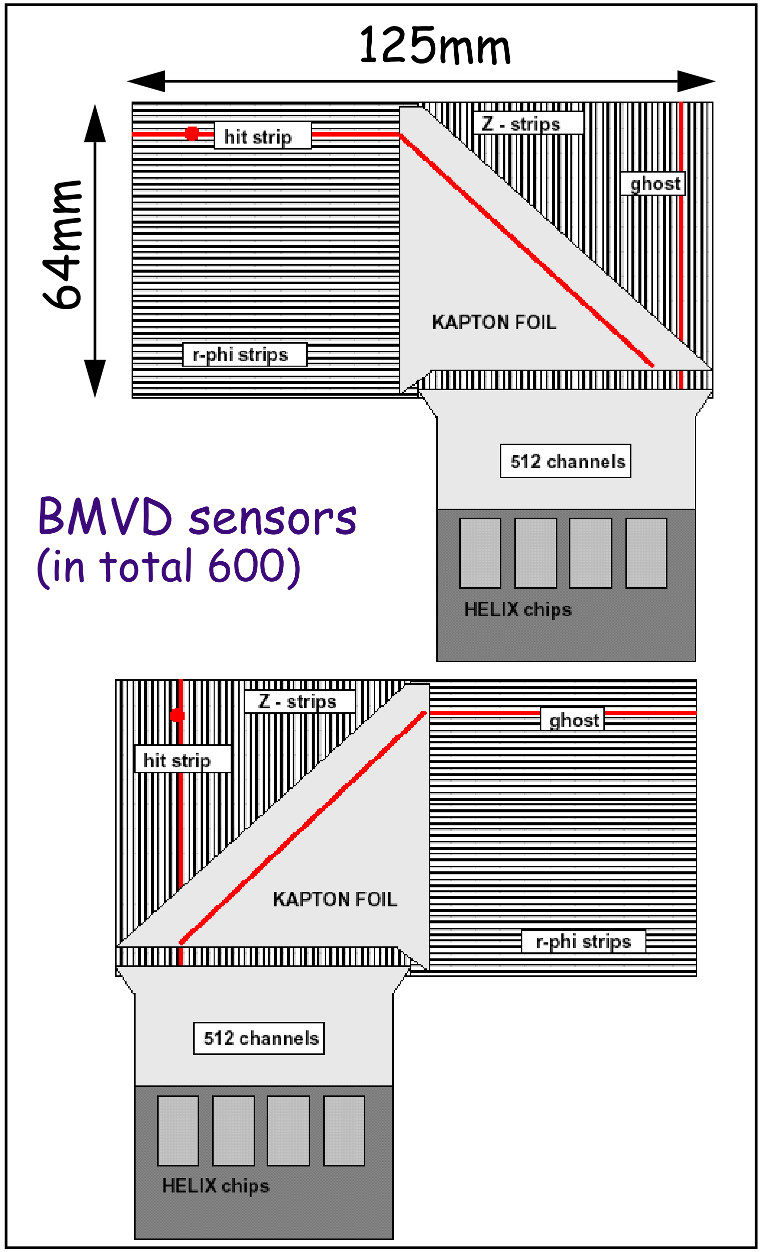


MVD Sensors

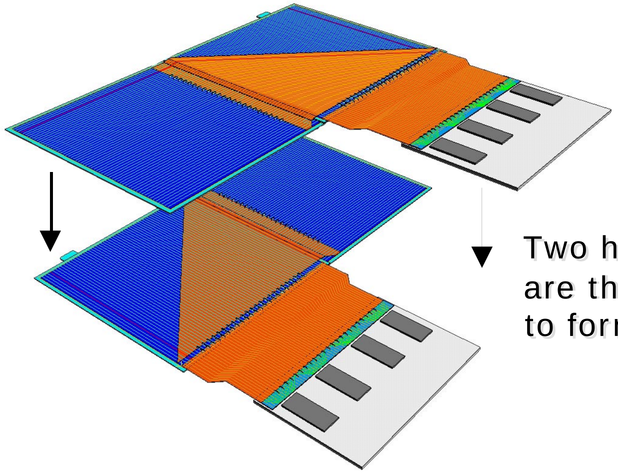
- n-doped silicon wafers (300µm, 3-6kΩcm) with p+ implantations (12 or 14 µm wide) (Hamamatsu Photon.)
- analog readout of every 6th strip HELIX 3.0 , 0.8µm CMOS AMS
- by using capacitive charge sharing good resolution despite 120µm r/o pitch
- 512 (barrel) 480 (wheel) readout channels per sensor
  $\Rightarrow$ 207000 readout channels in total



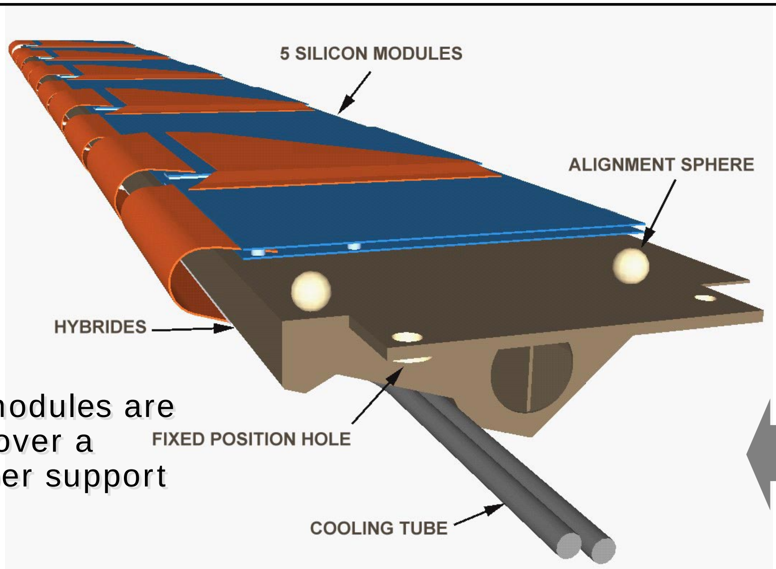




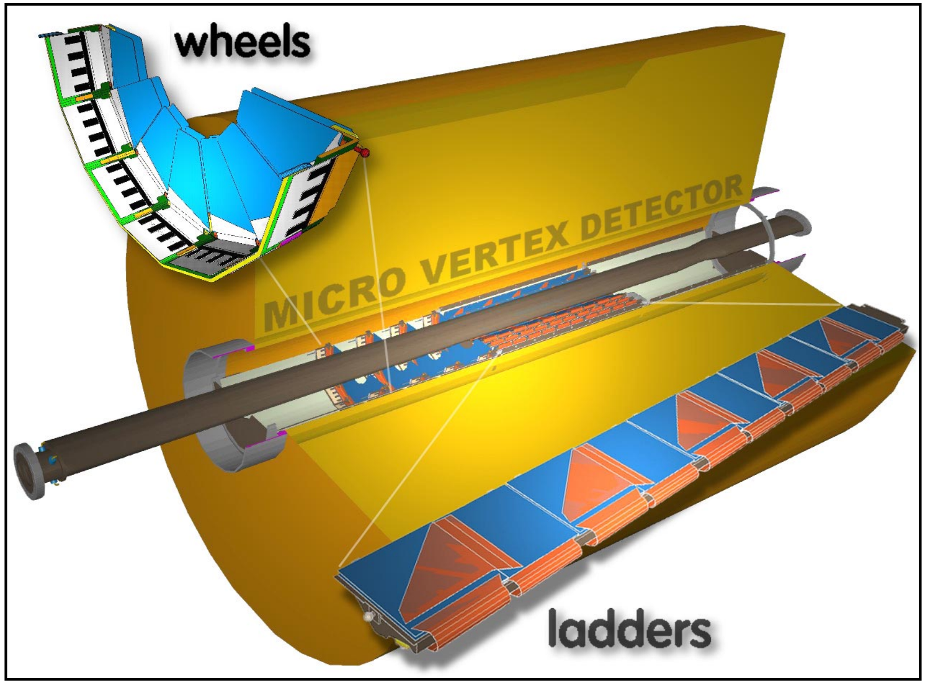
MVD Details



Two half modules are then glued together to form a full module

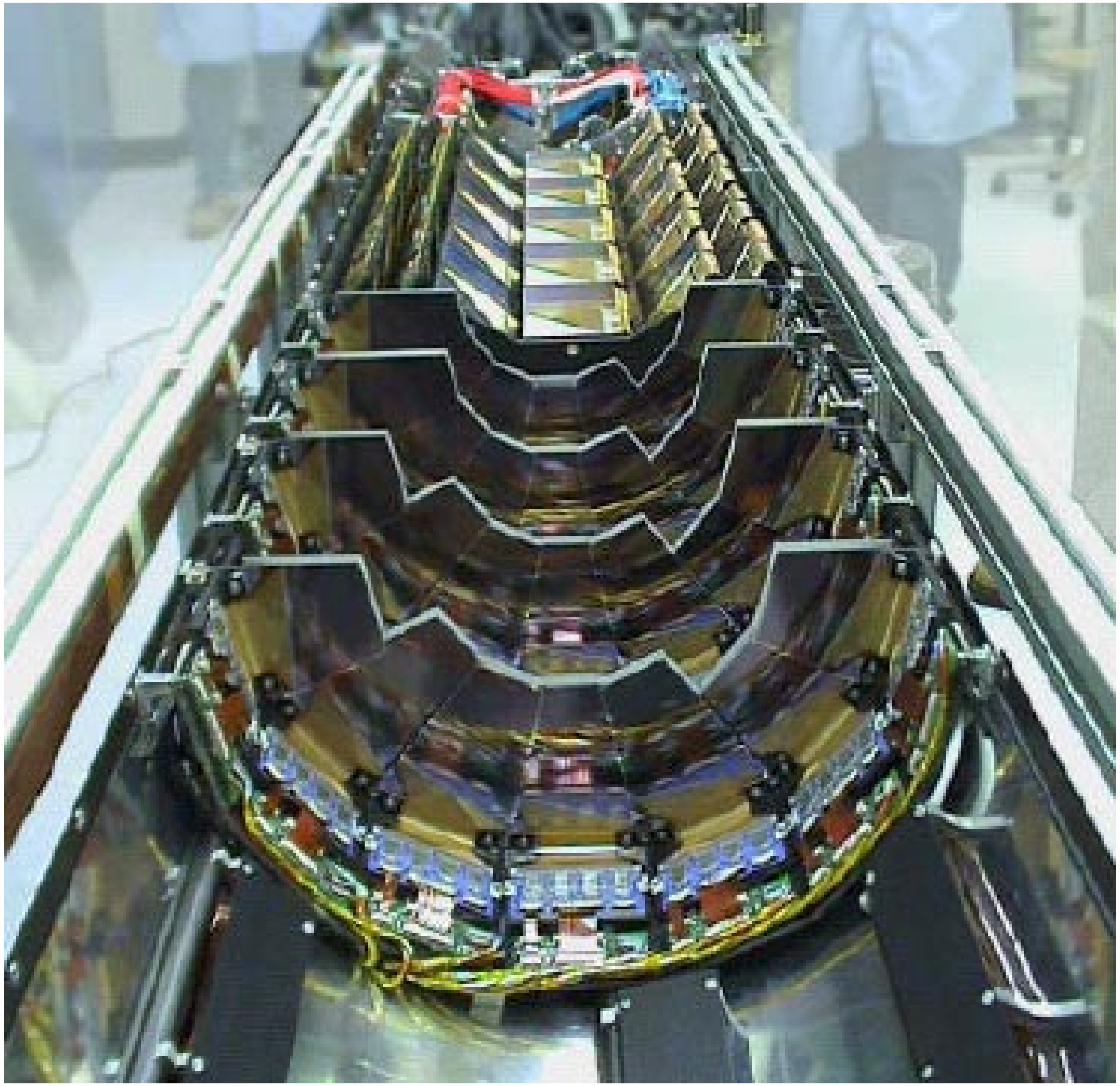


Five full modules are disposed over a carbon fiber support



material budget: 3% X_0 per ladder

One MVD half assembled

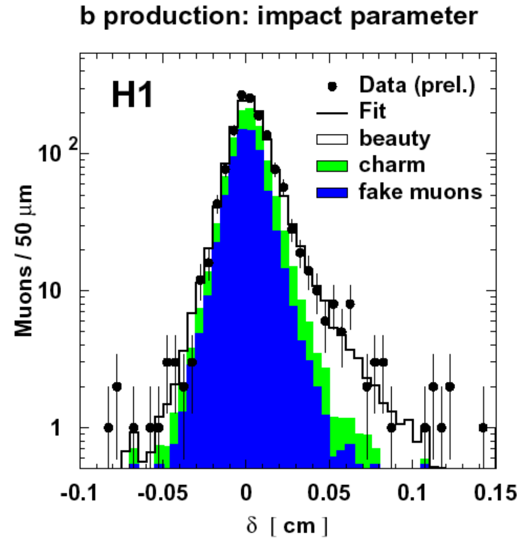


H1 Silicon Detector Upgrade

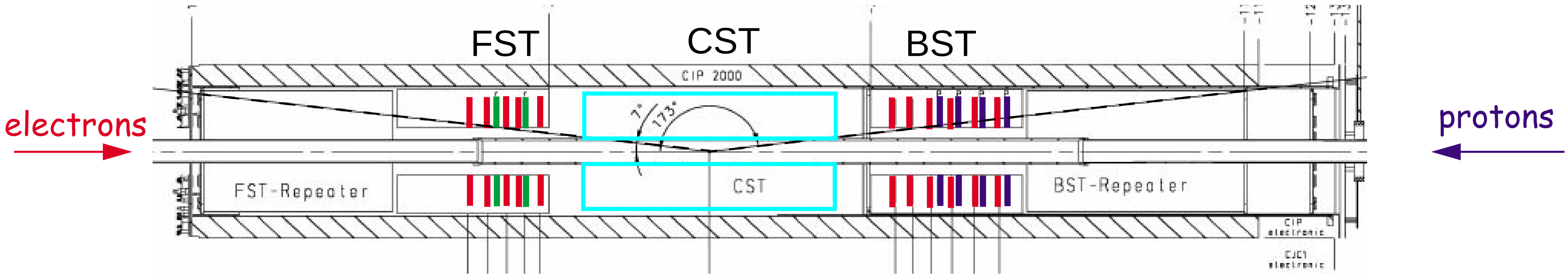
H1 successfully operates CST and BST since 1997

Upgrade

- adapt to new beampipe geometry
- backward region BST
  - rearrange existing BST: 6 u/v planes
  - add 4 planes with pad detectors for triggering
- central region CST
  - radiation damage observed
  - radiation hard readout electronics for CST
- forward region FST
  - add 5 u/v planes
  - add 2 r planes



H1 Collaboration: Abstract 979, submitted to the 30th InternationalConference on High Energy Physics, ICHEP 2000, Osaka, Japan, July 2000.

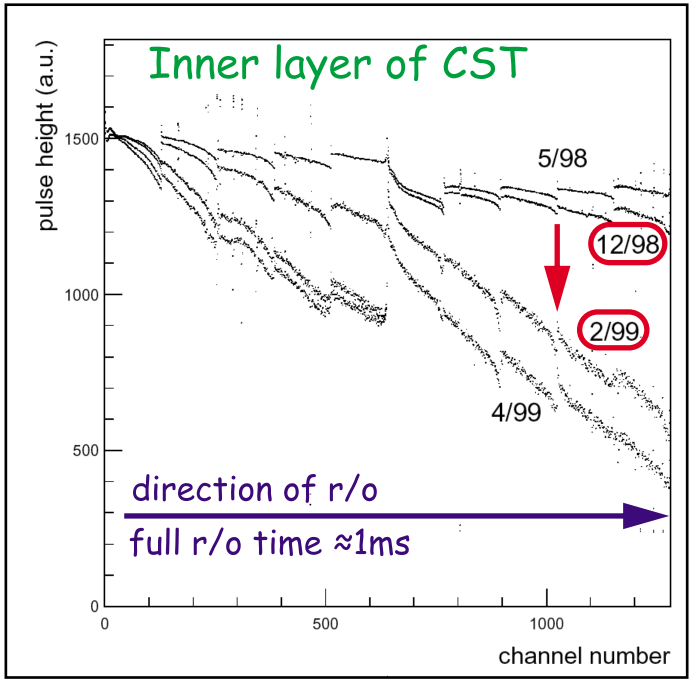


CST Upgrade

CST sensors

- 5.9cmx3.4cmx300µm
- double sided, DC coupled
- 3 sensors bonded together to form one ladder

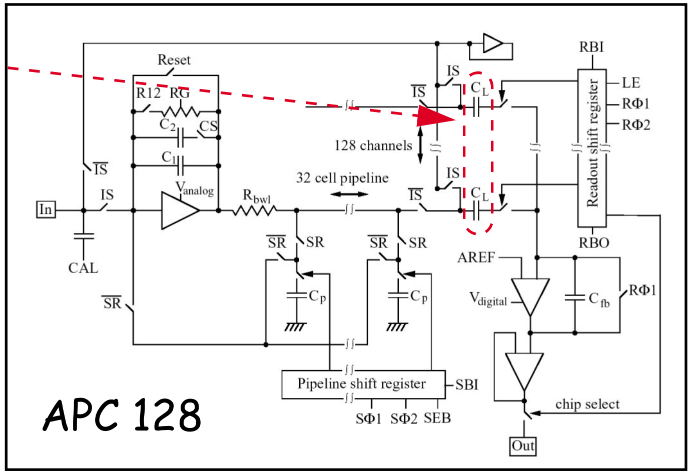
- p side: 25µm pitch, 50µm r/o pitch, 3x9 pF/strip
- n side: 88µm pitch, 3x19pF, double metal



Readout

- readout at the end of the ladder:
  ⇒ only 2 x 0.75% X_0 dead material
- Analog Pipeline Chip APC128 (SACMOS-1µ)
  - 32 stage analog pipeline
  - radiation damage seen in inner layer after ≈250Gy
  - problem: internal leakage current in chip (latch-capacitors C_L)

  ⇒ transfer ASIC design from SACMOS to radiation hard DMILL technology
  (Durci Mixte sur Isolant Logico-Lineaire [CEA])



- DMILL
  - bipolar CMOS, 0.8µm, silicon on insulator
  - radiation hard up to 10Mrad

CST for HERA II

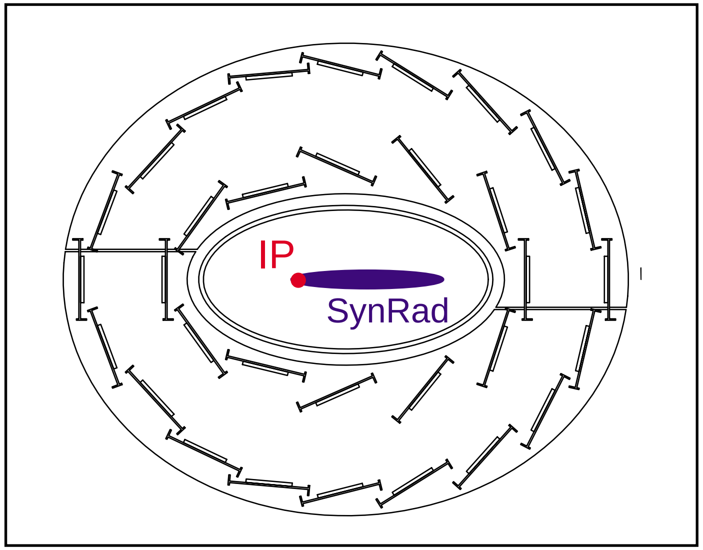
Re-use old silicon

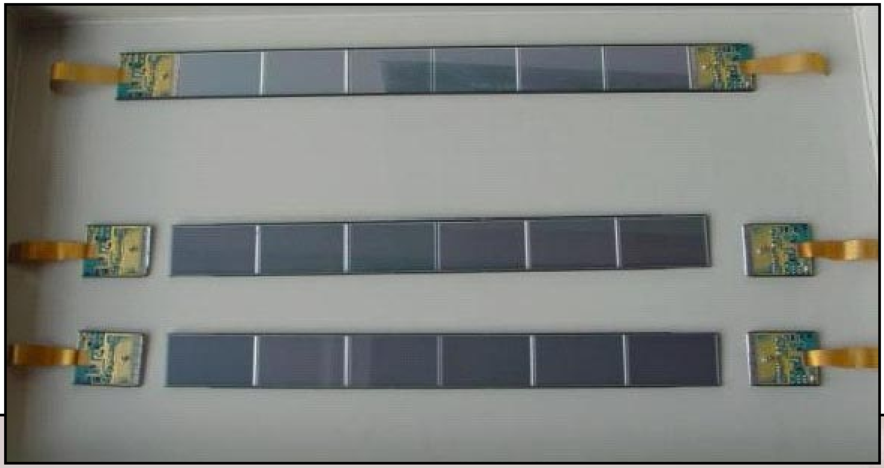
⇒ remove 1280 bonds for each hybrid

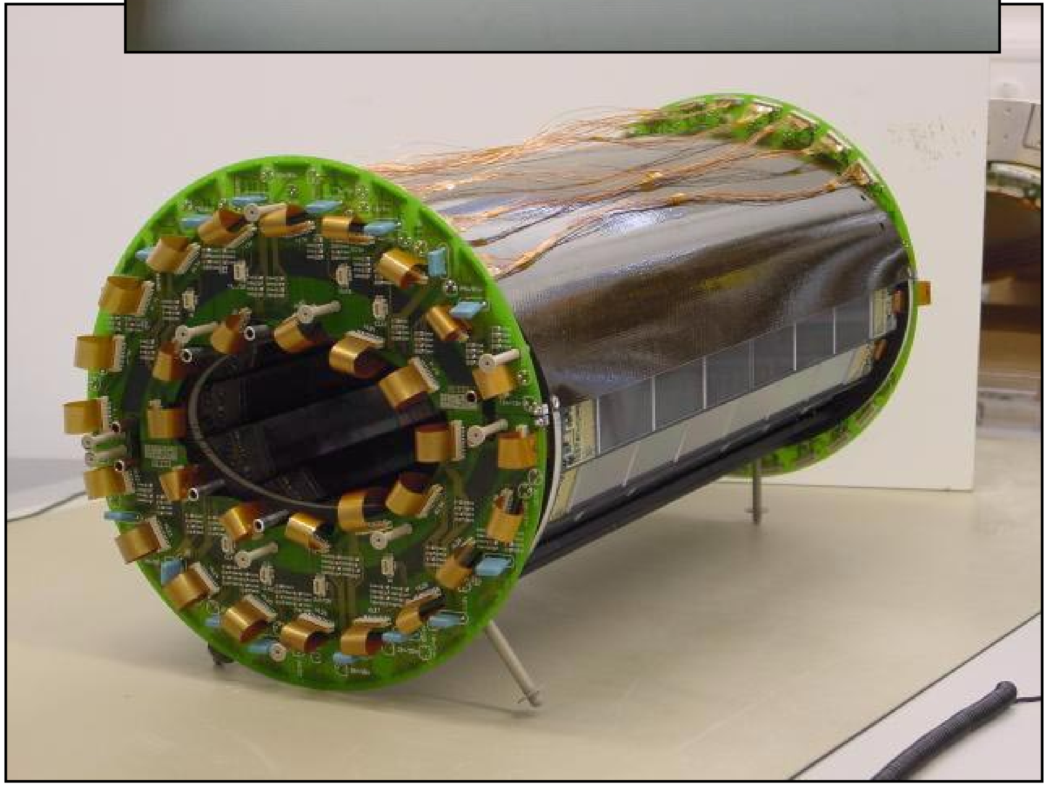
1. break hybrid from silicon
2. glue bonds to chip on hybrid
3. tear off hybrid: 95% of bond wires go off

New ladder arrangement

- two layers
- sensors perpendicular to rays from the IP
- overlaps in rϕ for internal alignment



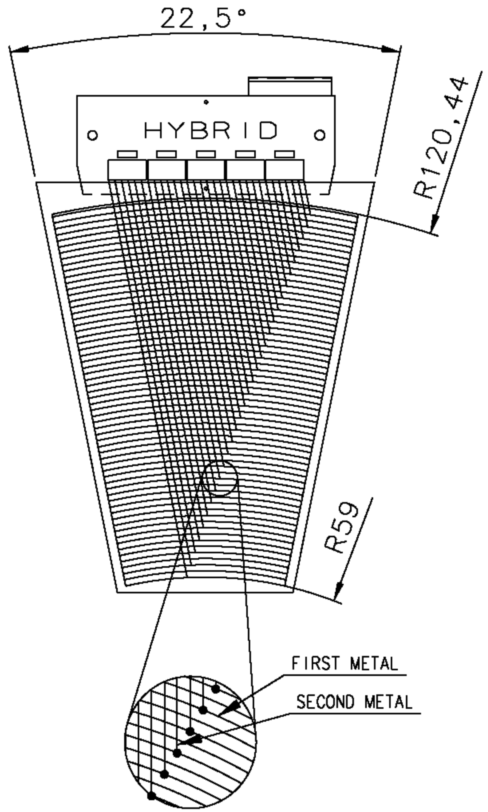




BST and FST Sensors

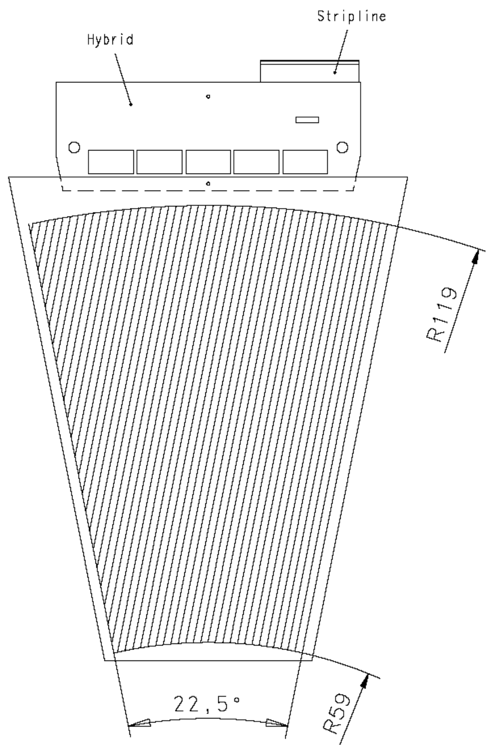
- AC coupled
- 280 μm thick
- p+ doped strips
- 640 active strips

r strips



- double metal
- 1 intermediate strip
- r/o pitch 96 μm

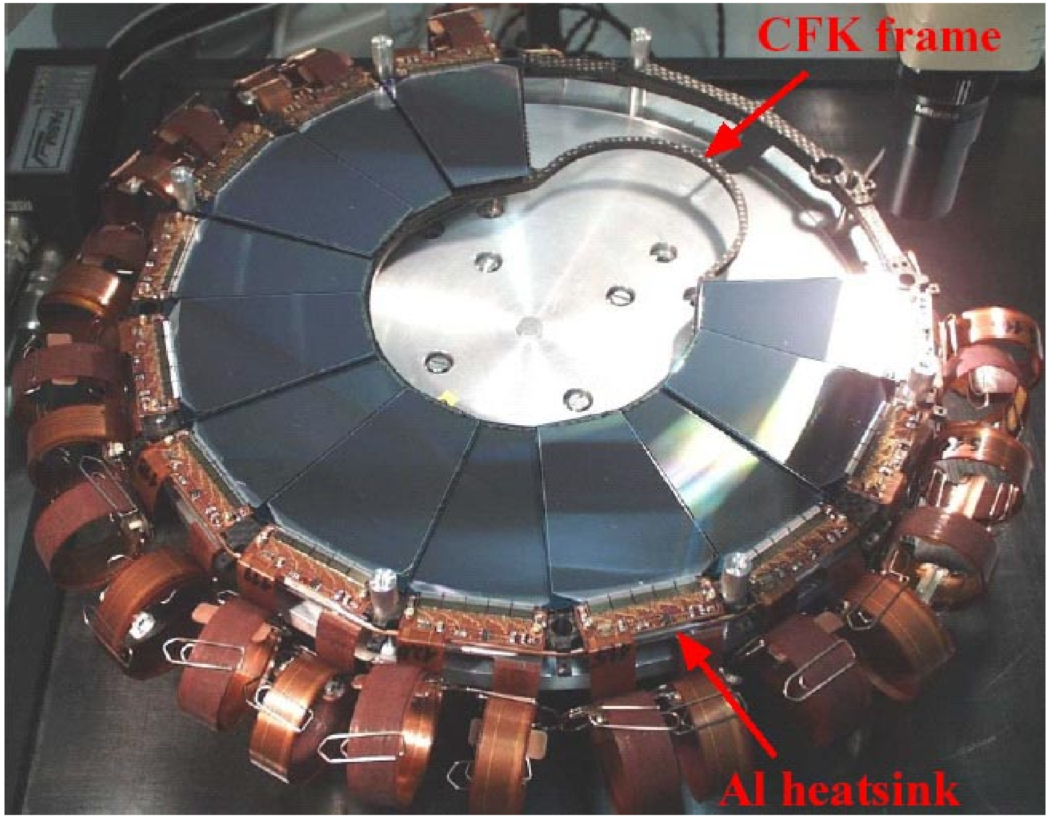
φ strips (u/v)



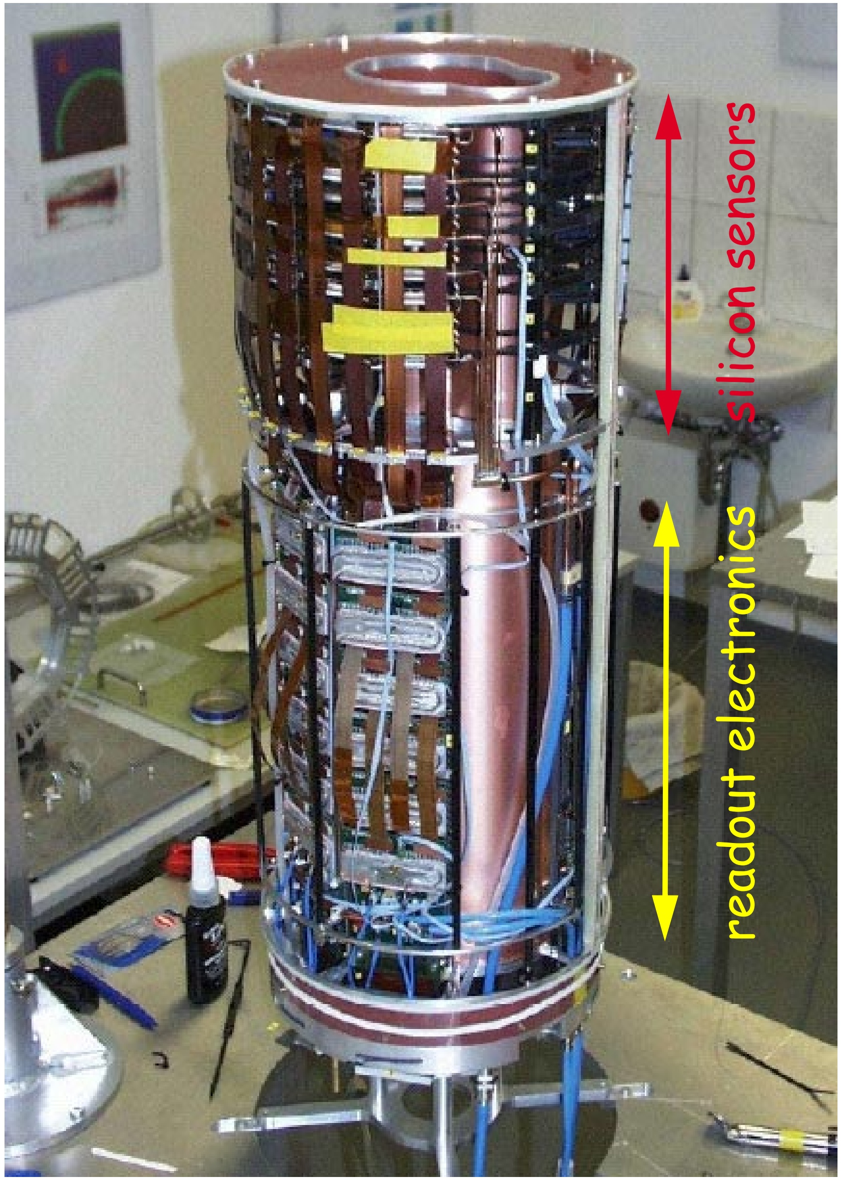
- single metal
- 2 intermediate strip
- r/o pitch 75 μm

FST

single wheel

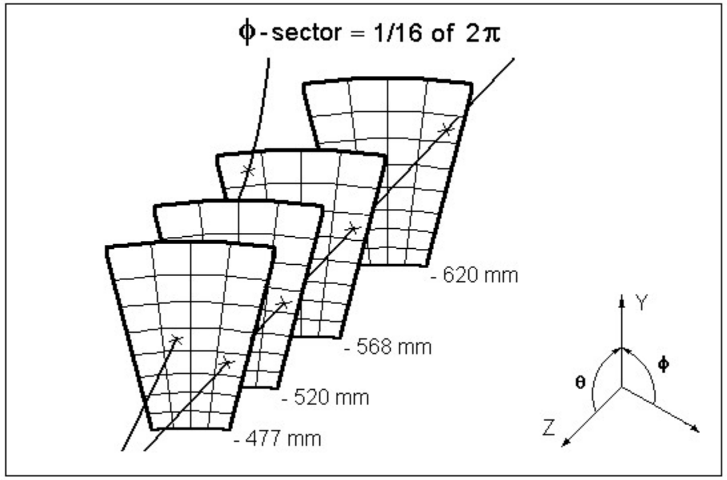


full detector

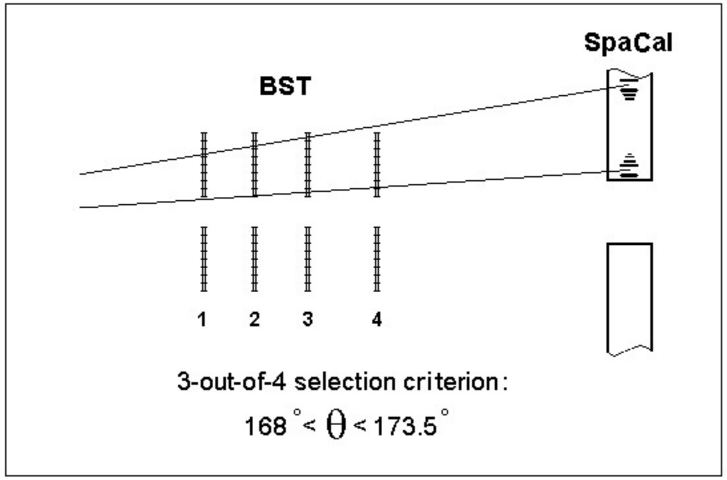


BST-Pad Detector

Trigger concept



4 pads x 8 rings x 12 sectors x 4 wheels = 1536 cells



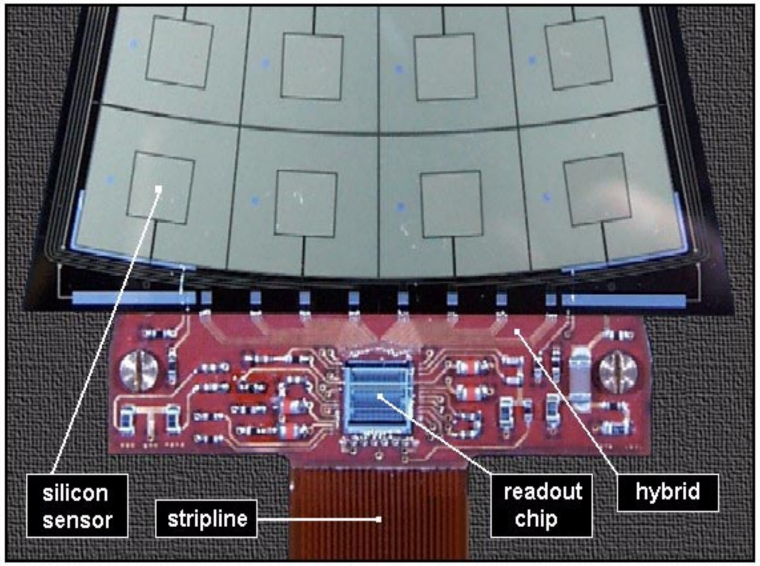
Purpose

- trigger on backwards going particles (scattered electron)
- reject upstream proton background

Detector module

- 380 μm single sided
- FOXFET biasing
- AC-coupled pads

Micron Technologies Ltd. (Lancing)



PRO / A readout chip

- 1.2 μm N-well CMOS process (AMS)
- Designed in collaboration with IDE AS (Oslo)

$$\frac{\text{MIP signal}}{\text{inherent noise}} \gtrsim 10$$

Triggering at HERA II

HERA Upgrade:

- higher background from synchrotron radiation
- larger event rates, but output rate ≈ constant

⇒ Need also improvements for trigger:

- higher redundancy → better background rejection

  H1: replace central inner proportional chamber CIP by new one with 5 instead of 2 layers

  optical readout of of 8500 pads for L1 (2.3μs) decision

- higher selectivity

  ZEUS General Track Trigger (GTT): new second level trigger including based on PC farm

  input from:

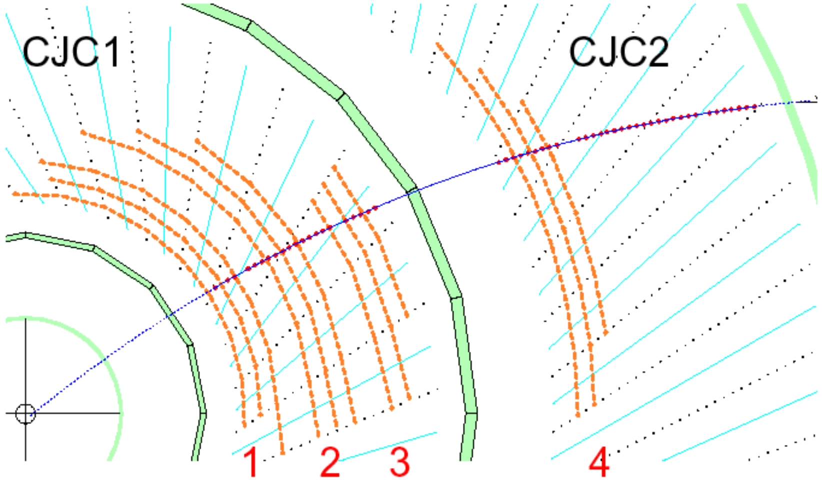
  - micro vertex detector MVD
  - central track detector CTD
  - straw tube tracker STT

  H1 Fast Track Trigger

  - input from Central Jet Chamber

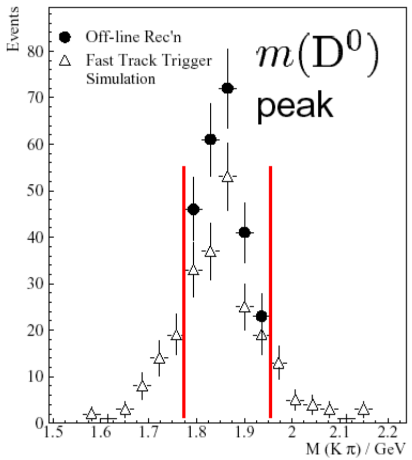
Fast Track Trigger FTT

- Level 1: 2.3 μs
  - signal digitization
  - finding track segments from hits
  - coarse track linking for L1 trigger signal
- Level 2: 22 μs
  - track segment linking
  - fitting track parameters (3D)
  - trigger decision based on basic event properties
- Level 3: ≈100 μs (processor board farm)
  - identification of particle decays



$r - \Phi$ view of the central drift chamber

- makes extensive use of content addressable memories (CAM)
- only possible with new generation of programmable electronics
  - high density FPGAs
  - DSPs
- performance approaches offline reconstruction in precision



Future of HERA

- Anticipated luminosity profile of HERA II:

2002:	120 pb^{-1} (?)	2005:	240 pb^{-1}
2003:	180 pb^{-1}	2006:	240 pb^{-1}
2004:	240 pb^{-1}	Total	>1000pb^{-1}

- 2007: Due to increasing demands there is a strong need for a dedicated source for hard synchrotron radiation. Two options are presently evaluated

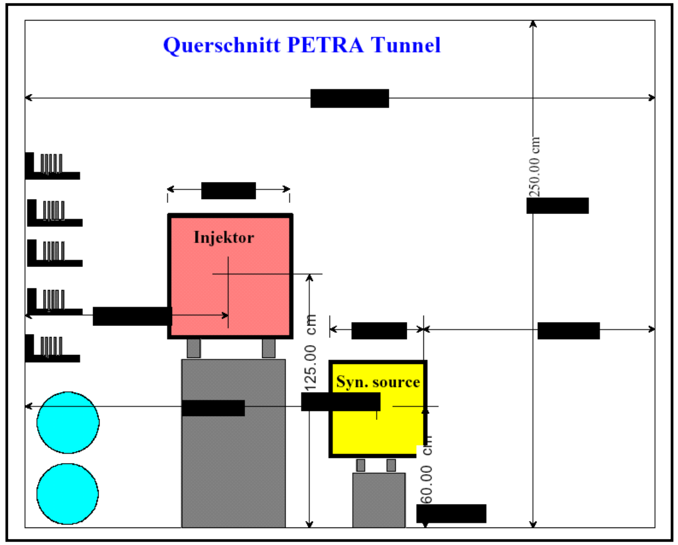
  1) build new additional PETRA ring for synchrotron radiation in the same tunnel

  would allow for a HERA III program beyond 2006

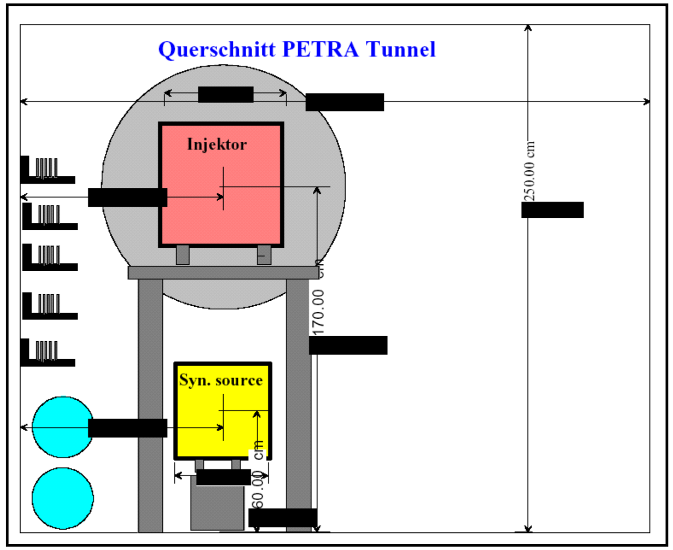
  - ed (polarized), eA $\rightarrow$ Durham Workshop Dec.01

  2) conversion of the existing PETRA into a dedicated synchrotron radiation source incompatible with using PETRA as injector for HERA

- Highest priority of DESY is TESLA $\Rightarrow$ any extention of HERA running beyond 2006 needs very convincing physics case which has to be laid down until end of 2003



two possibilities for an additional machine in PETRA tunnel

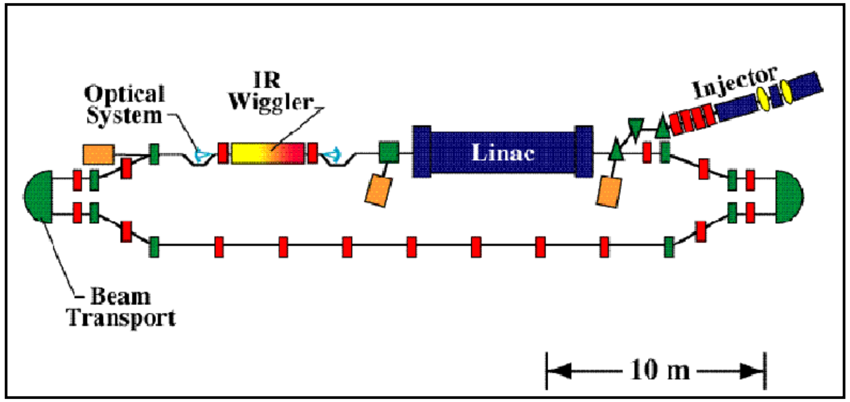


Future Lepton-Hadron Colliders: Technologies

- Basically two options:

1. Ring-Ring
   - proven technology eg HERA
   - electron polarization by Sokolov-Ternov effect
   - luminosity in the range of >$10^{33} cm^{-2} s^{-1}$ seems feasible
2. Linac-Ring
   - easier spin manipulations (spin flip), high polarization
   - far less synchrotron radiation in experiment
   - for competative luminosity need energy recovery

- Energy Recovery Linac (ERL)
  - required rf power nearly independent of energy
  - overall system efficiency increased
  - less energy to be dissipated in e-beam dump
  - promising results at JLAB IR FEL (low energy)



- Proton/Ion Ring
  - limiting factor for intensity: intra beam scattering IBS
    - ⇒ can be improved by electron cooling
  - mandatory for ions if want to reach $L_A \approx L_p/A$, helps also for protons ($L_p \rightarrow 2xL_p$)

Sources of information:

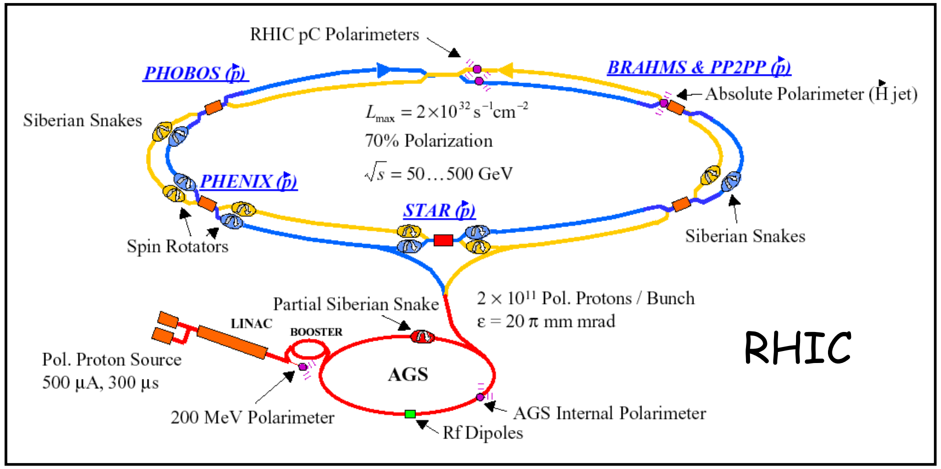
- Series of workshops at DESY
- EIC white report
- Snowmass WG M5
- Recent Durham Workshop

Polarization at Lepton-Hadron Colliders

Polarization for Electrons, Protons, Deuterons

a) Acceleration and Storage of Polarized Protons

- promising: recent success @ RHIC, 25.Jan.02: store, accelerate to 100 GeV and collide polarized protons (& measure their polarization)

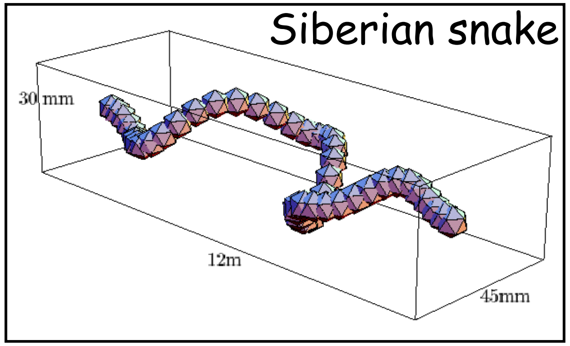


b) Acceleration and Storage of Polarized Deuterons

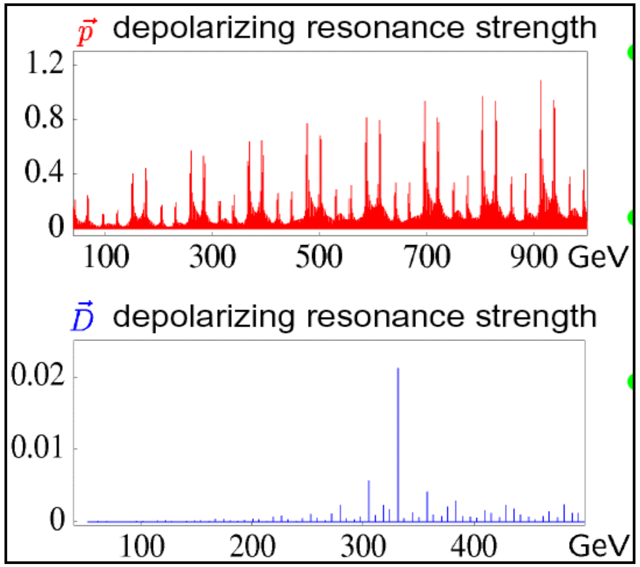
recently attracted very much attention:

deuteron has small gyromagnetic moment

$G_d = -0.14$ $(G_p = 1.79) \Rightarrow$ siberian snakes don't work



new approach (Ya.S. Derbenev, V.A. Anferov physics/0003104):



achieve spin flip by horiz. rf field

additonal advantage: for deuterons depolarising resonances are

- 25 times weaker and fewer
- 12.5 times farther apart

$\Rightarrow$ acceleration should be much easier

needs to be proven experimentally

c) Polarimetry for Protons and Deuterons

d) Polarized proton or deuteron sources

e) Electron Polarization Buildup

Future Lepton-Hadron Colliders under Consideration

- THERA, the TESLA on HERA collider
  - 250 GeV electrons on 920 GeV protons: E_{CM} = 960 GeV
  - $L \approx 0.5\text{-}2 \times 10^{31}\ cm^{-2}s^{-1}$
- eRHIC, Electron-Hadron Collisions with RHIC

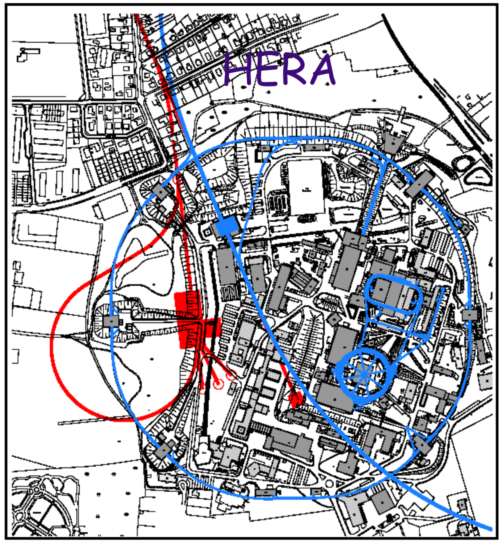
  a) Linac-Ring Version
  - 10 GeV electrons on 250 GeV protons (Au): E_{CM} = 100 GeV
  - $L \approx 1.1 \times 10^{33}\ cm^{-2}s^{-1}$

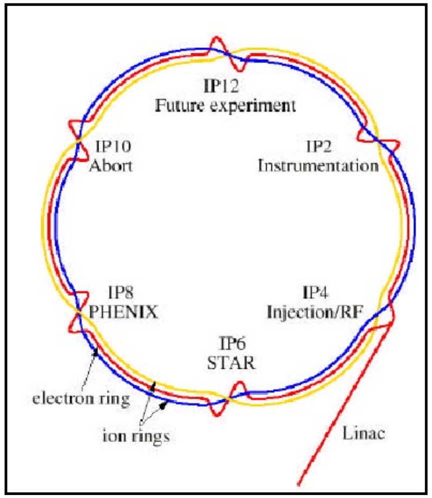
  b) Ring-Ring Version
  - 10 GeV electrons on 250 (100) GeV protons (Au): E_{CM} = 100 GeV
  - $L \approx 0.6\text{-}2 \times 10^{33}\ cm^{-2}s^{-1}$
- EPIC, the High Luminosity Electron (Polarized) Ion Collider

  a) Linac-Ring Version
  - 5 GeV electrons on 50 GeV protons: E_{CM} = 32 GeV
  - $L \approx 0.6\text{-}2 \times 10^{33}\ cm^{-2}s^{-1}$

  b) Ring-Ring version
  - 7 GeV electrons on 32 GeV protons: E_{CM} = 30 GeV
  - $L \approx 1.1 \times 10^{33}\ cm^{-2}s^{-1}$

TESLA





eRHIC Ring-Ring

Electron Ion Collider

Electron Ion Collider (EIC) Project

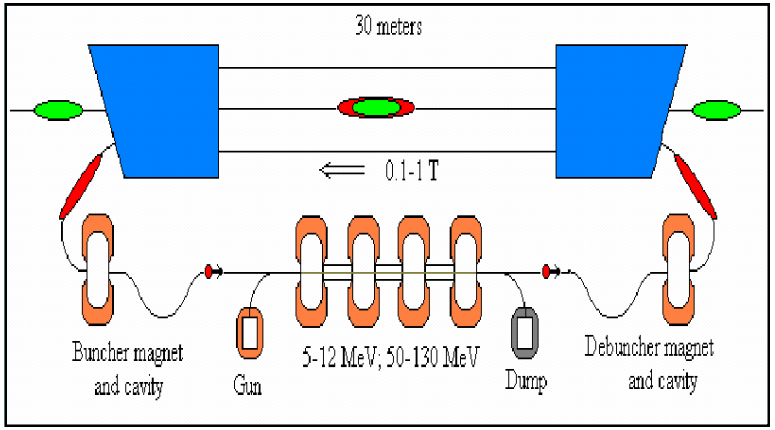
recent idea (white paper in March 2001): merge eRHIC and EPIC initiatives

- ep or eA collider
- variable CMS energy 15 GeV to 100 GeV for protons (63 GeV/A for ions)
- high luminosity (>10^{33} cm^{-2} s^{-1})
- polarization of electrons and protons
- options
  - ring-ring
  - linac-ring
  - recirculator-ring: mixture of the two

    store a few hundred revolutions

    advantages of linac: high polarization
high Luminosity at all energies
- need electron cooling
  - operation in a collider not yet done

possible layout for Energy Recovery Linac (ERL) in the EIC cooler

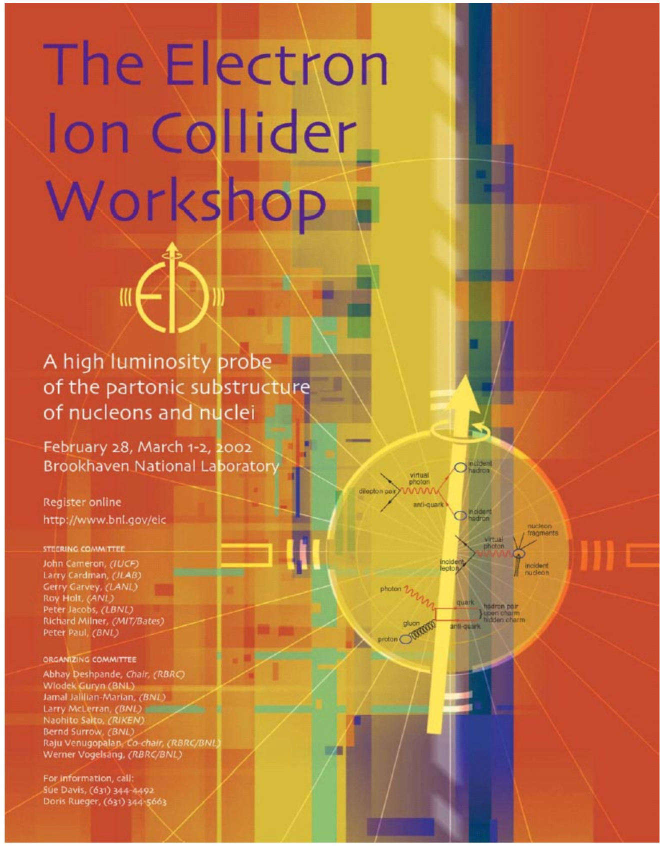


Electron Ion Collider Workshop

26.-27.2

1. The ring-ring collider scheme working group (RR Group)
2. The linac-ring collider scheme working group (LR Group)
3. Interaction region working group (IR Group)

28.2.-2.3.



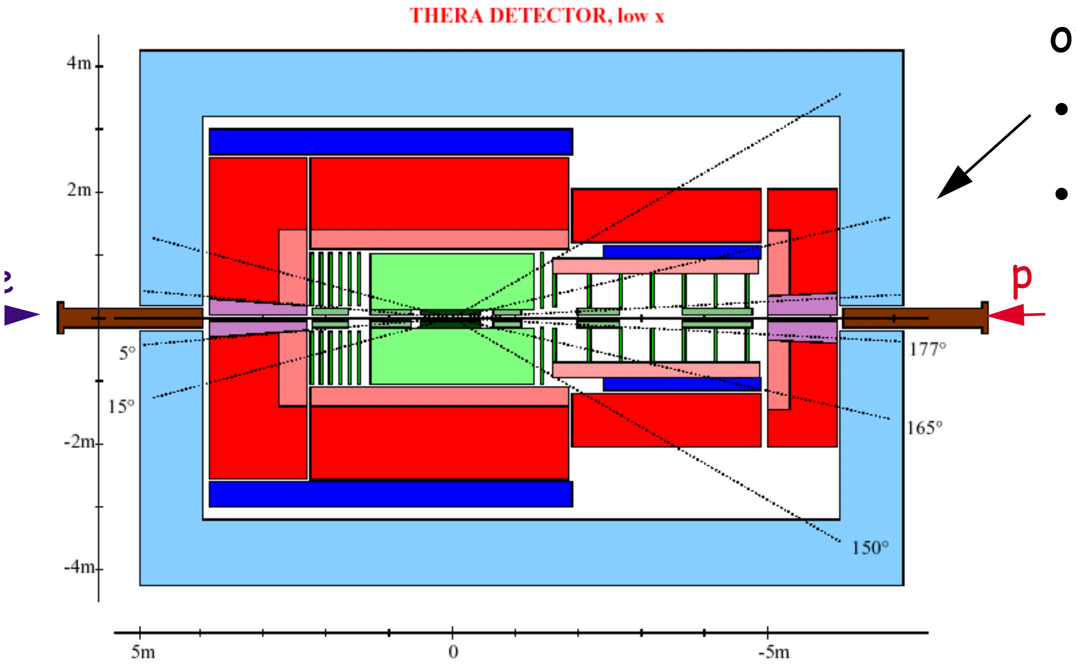
Goals:

- form collaboration this spring and formulate detailed construction proposal by 2005
- start R&D program ⇒
- start construction ≈2010-12 ?

Even further in the Future

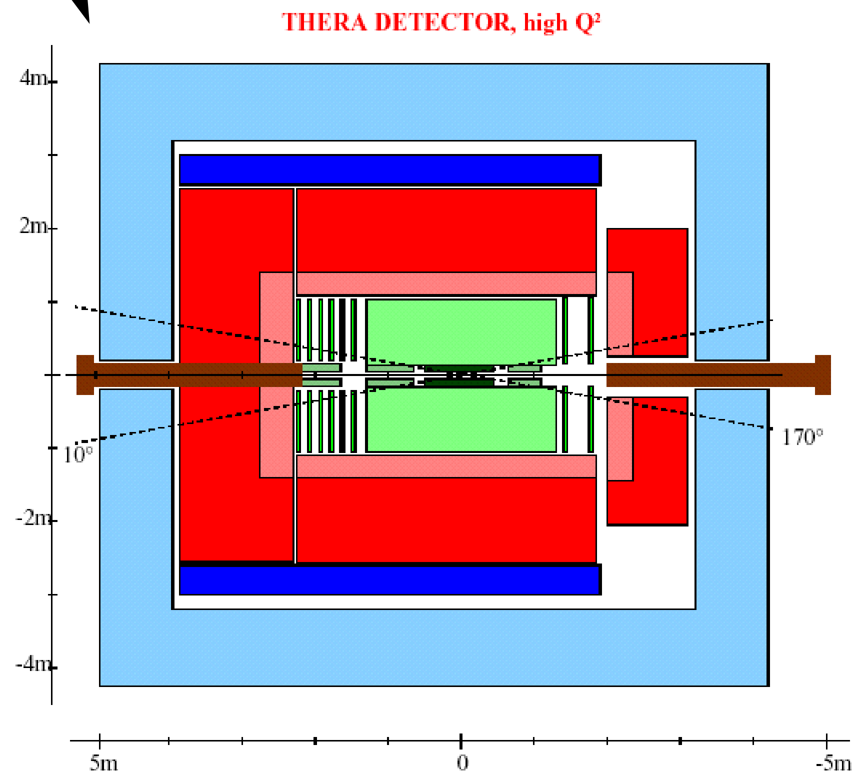
- eLHC, Electron-Proton Collisions with LHC
  - 60 GeV leptons on 7 TeV protons: E_{CM} = 1296 GeV
  - $L \approx 2.5 \times 10^{32}$ $cm^{-2}s^{-1}$
- epVLHC, Electron-Proton Collisions with VLHC
  - electron ring in the VLHC booster tunnel parallel to construction of VLHC
  - 80 GeV electron on 3 TeV proton: E_{CM} = 980 GeV
  - $L \approx 2.6 \times 10^{32}$ $cm^{-2}s^{-1}$
- R&D Issues for Future Lepton-Hadron Colliders
  - High-current energy-recovery linacs
  - High-energy electron cooling
  - Polarized electron sources
  - High-energy deuteron and proton polarization
  - Proton polarimetry
  - Integration of the detectors and colliders

Toy Model for Detector Configurations at THERA



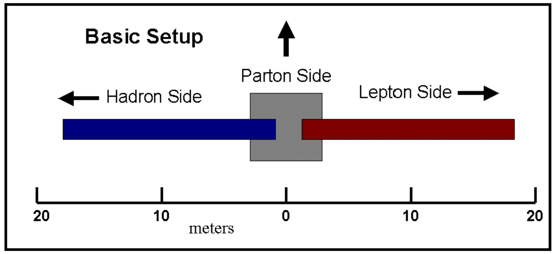
two different setups for different phases of the experiment

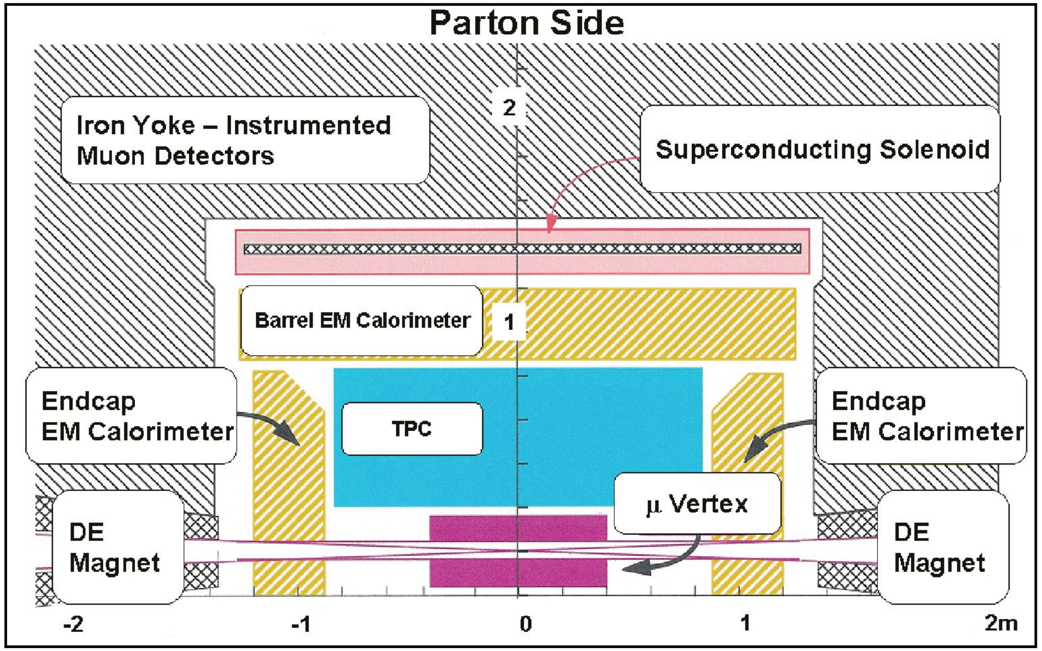
- low Luminosity & low x
- high Luminosity & high Q^2

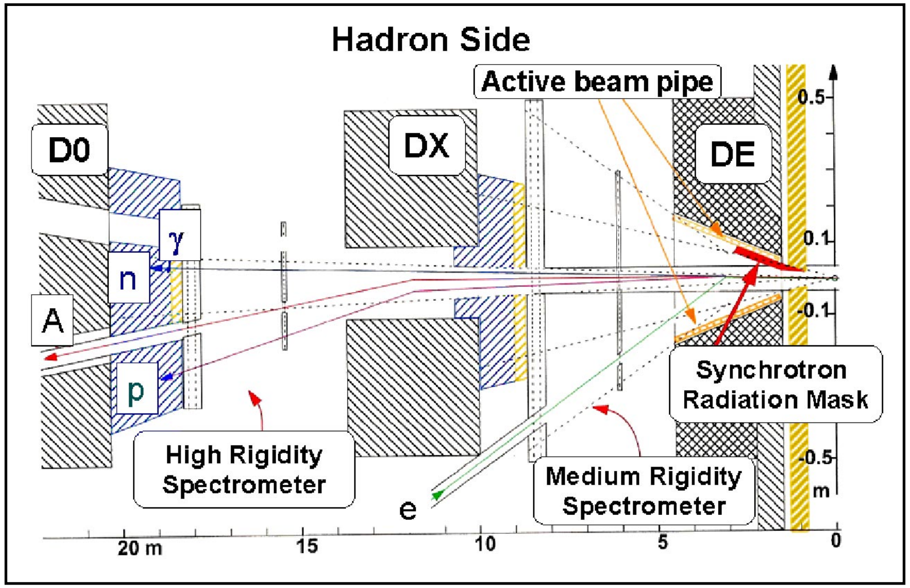


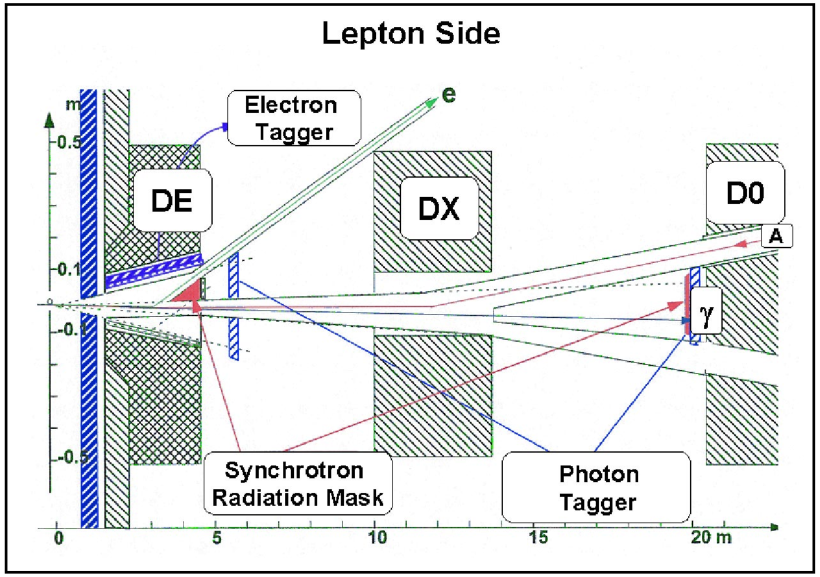
Ep=920 GeV: proton energy unchanged
→ detector resembles H1 + ZEUS

Prototype Detector for EIC



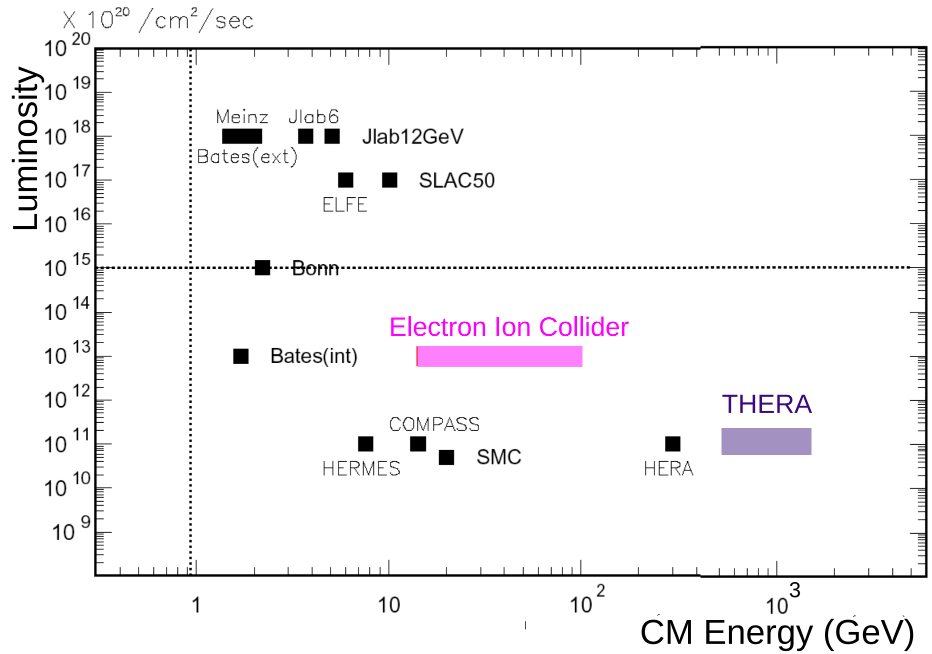


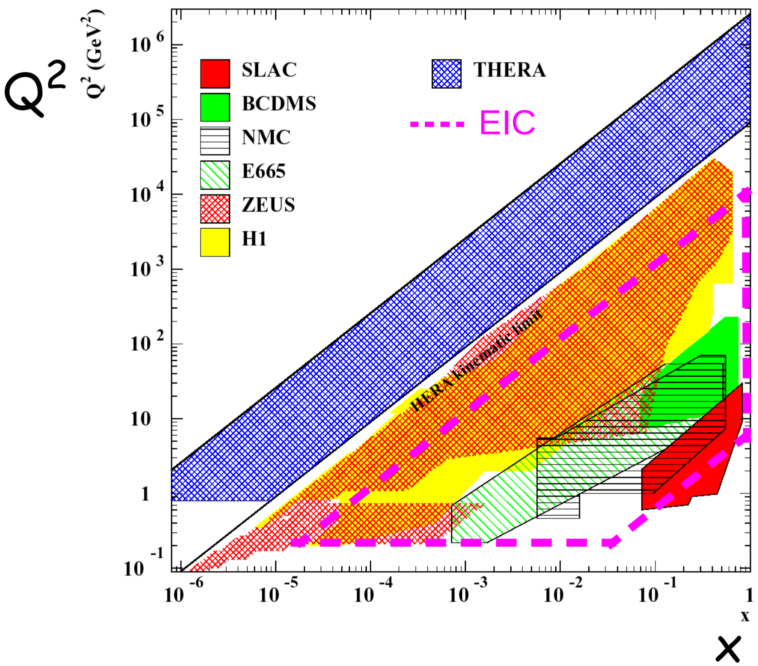




Summary and Conclusion

- HERA luminosity upgrade completed
  source of synchrotron background identified and being worked on
- ep and eA physics is very active field also beyond HERA II
- options exist for:
  - higher luminosity
  - higher E_{CM}
  - polarization (deuterons)
- R&D needed mainly for accelerator issues





kinematic plane