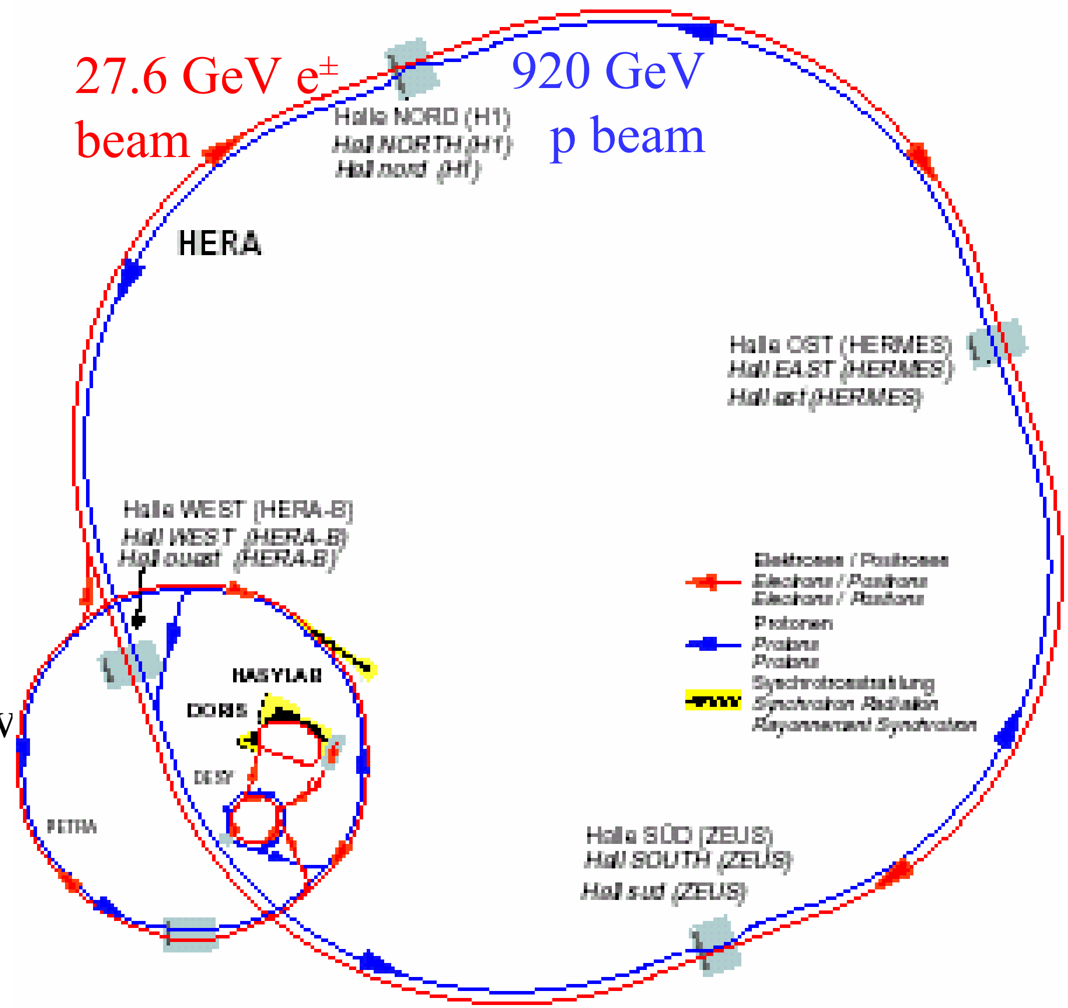
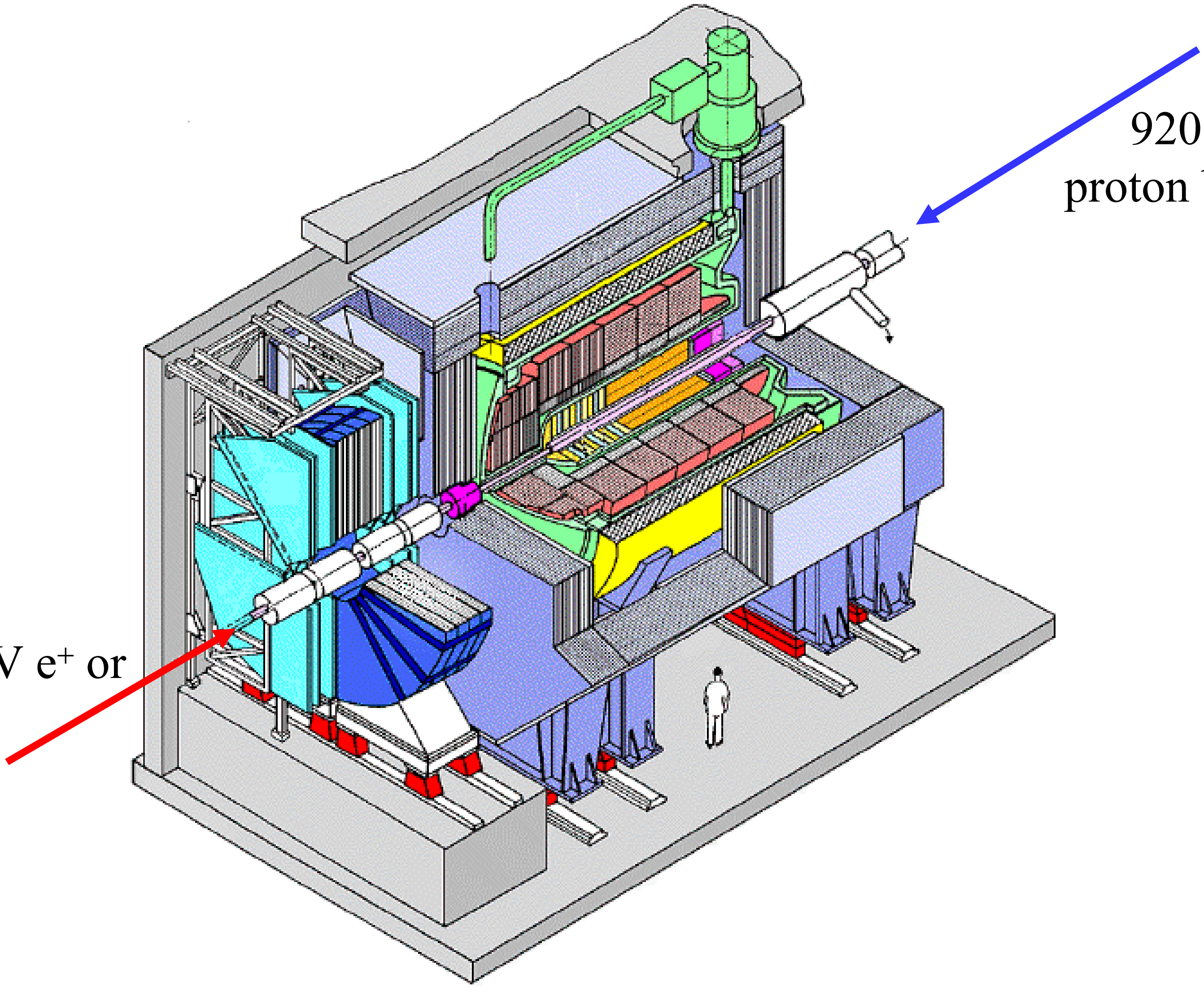
Čerenkov Radiation at H1 and Some Recent H1 Results

- Čerenkov radiation and the H1 luminosity system
- HERA and H1 upgrades
- Recent H1 results
  - Studies of QCD radiation
  - Beauty production in DIS
  - Evidence for an exotic anti-charmed baryon state
  - Diffraction
  - Comprehensive search for new physics at HERA
  - Isolated lepton events with missing p_T
- Summary

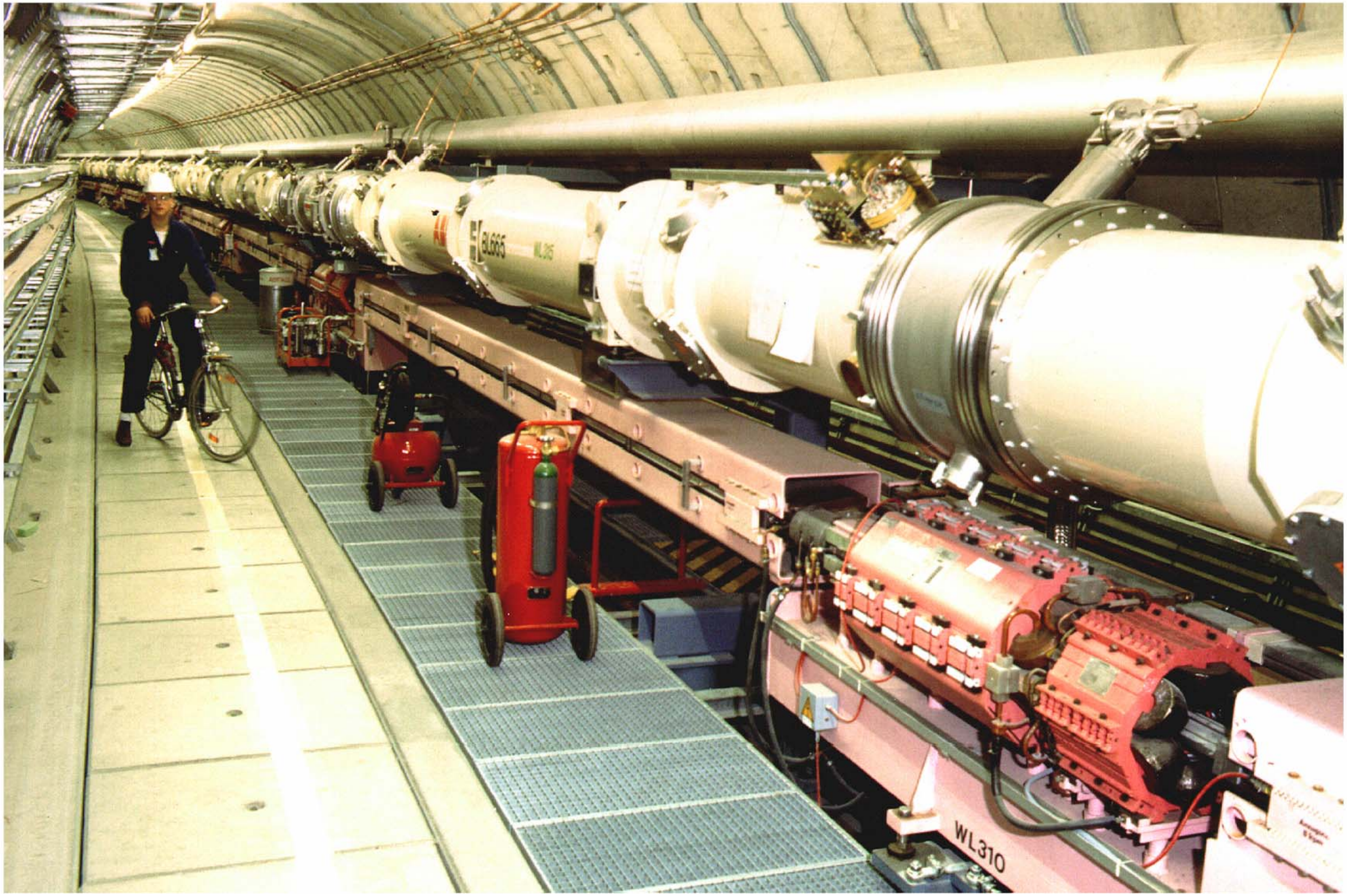


Tim Greenshaw, Liverpool University

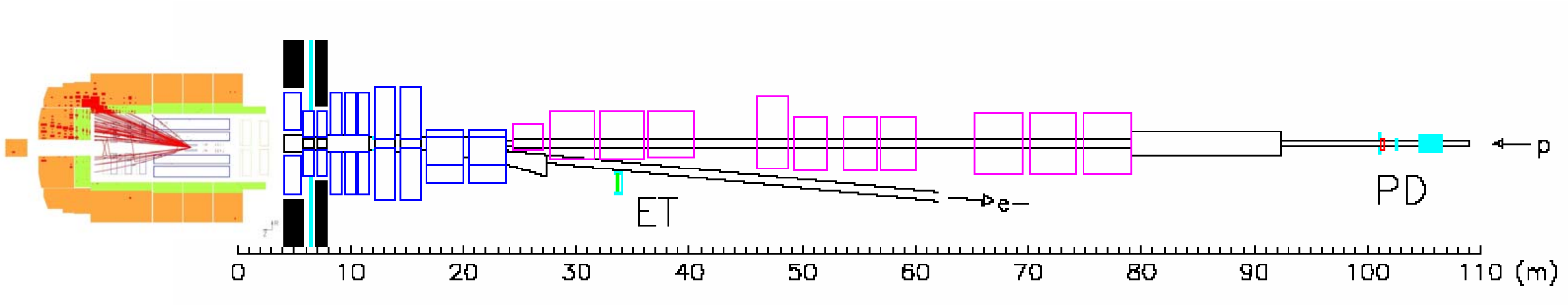
The H1 detector



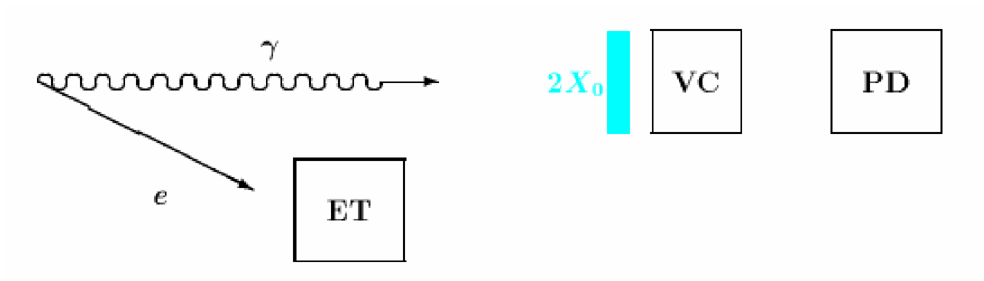
HERA tunnel



Luminosity measurement at H1 – HERA I



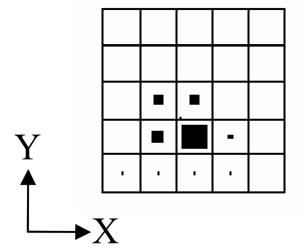
- Detect photon and scattered electron from ep → eγp events (Bethe-Heitler process) in Photon Detector and Electron Tagger, respectively.

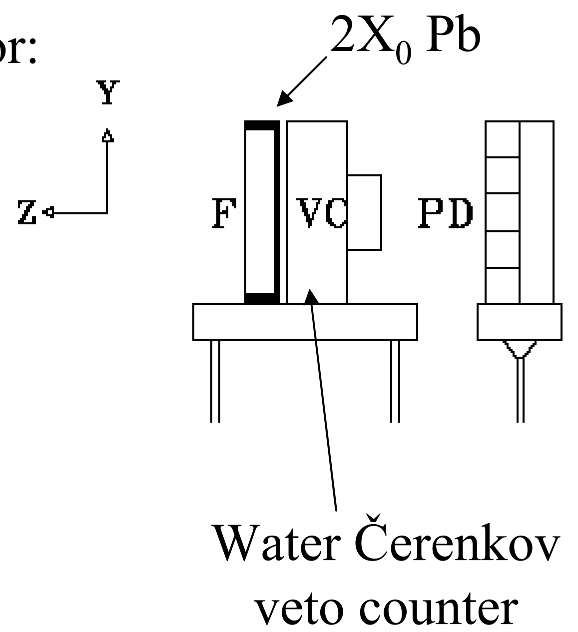


- Both PD and ET are KRS14 crystal Čerenkov counters: detect radiation emitted in electromagnetic cascade.
- B-H rate for E > 4 GeV:
  - ET 0.4 MHz.
  - PD 1.3 MHz.

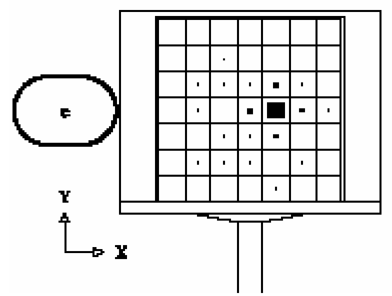
Luminosity measurement at H1 – HERA I

- Properties of KRS14 crystals:
  - Composition, TlCl:TlBr 78:22.
  - X_0 = 9.3 mm, R_M = 21 mm.
  - Length 200 mm.
- Readout via FEU-147 PMs.
- Lumi performance:
  - Energy resolution $1 \oplus 10\% / \sqrt{E\,(\mathrm{GeV})}$.
  - Position resolution 0.3...1.2 mm.
  - Time resolution better than 3 ns.
  - Luminosity determined to precision of 1.4%.
- Photon detector:



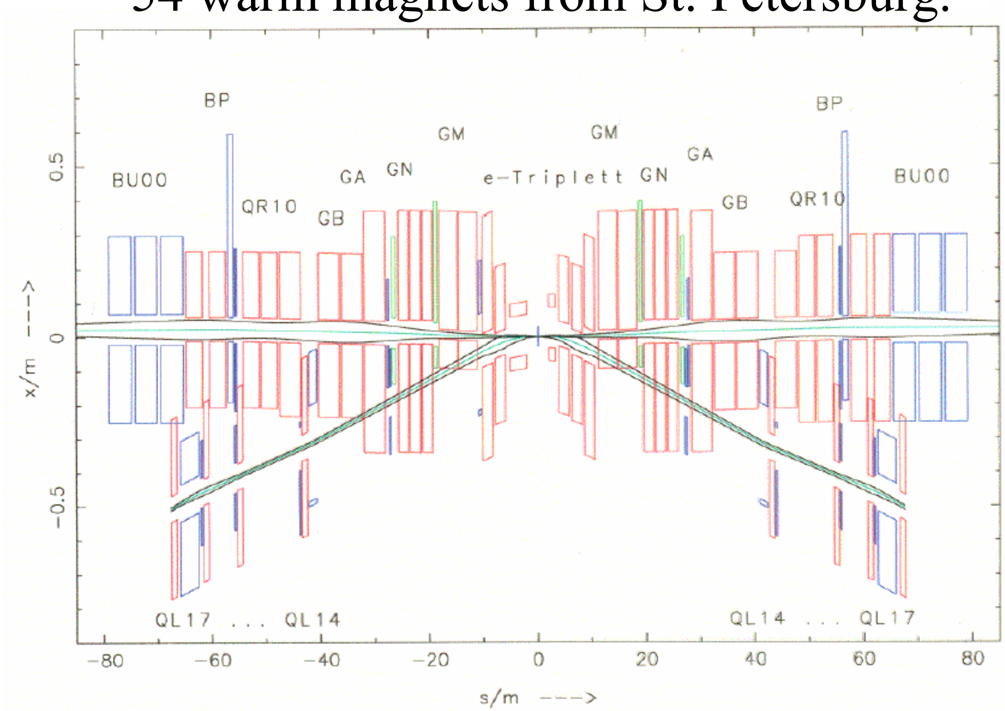


- Electron Tagger

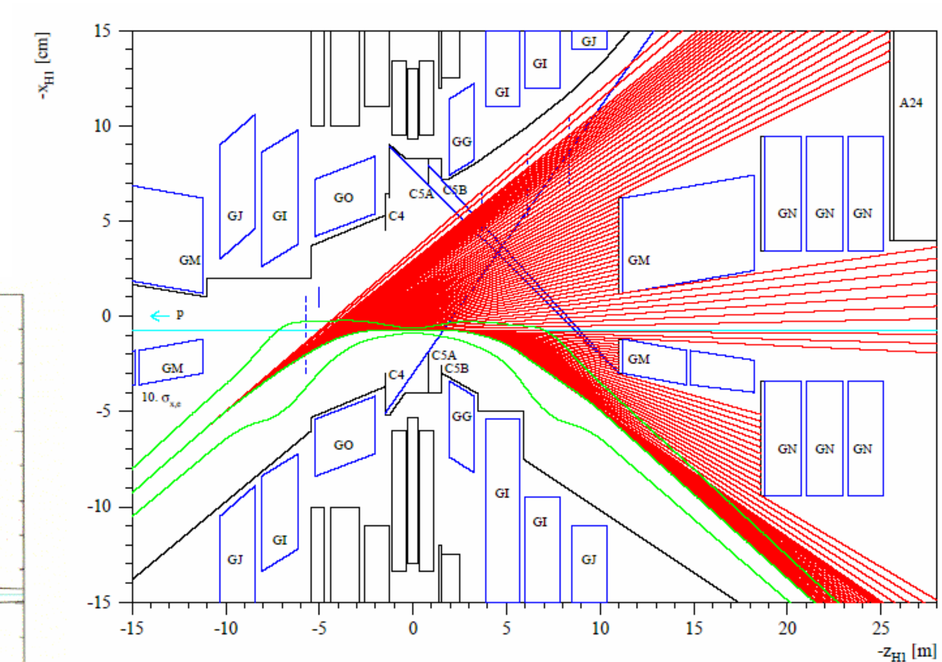


HERA upgrade and the H1 luminosity system

- HERA ep collider upgraded to provide 5-fold increase in luminosity and polarised e^+/e^- beam.
- Achieved by tighter beam focussing.
- Four SC magnets from Brookhaven, 54 warm magnets from St. Petersburg.



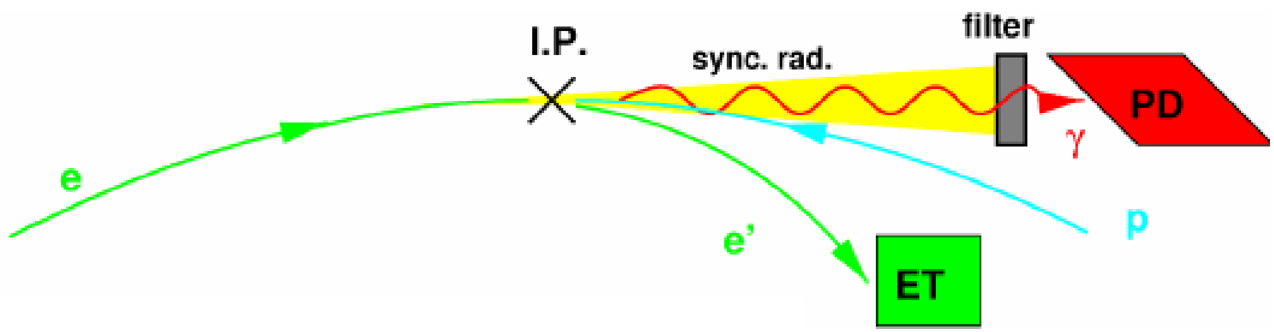
- Power of SR emitted close to IP increased:



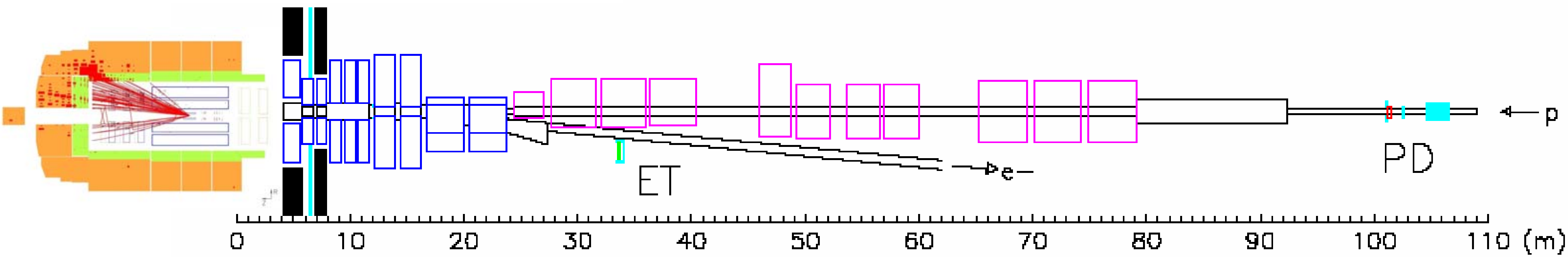
- H1 must measure luminosity and polarisation for each pair of colliding bunches in order to determine polarised cross sections.

Čerenkov radiation at H1

- Following HERA upgrade, γ rate on PD ~ 170 MHz for $E_\gamma > 0.5$ GeV, resulting dose ~ 25 Mrad/yr.

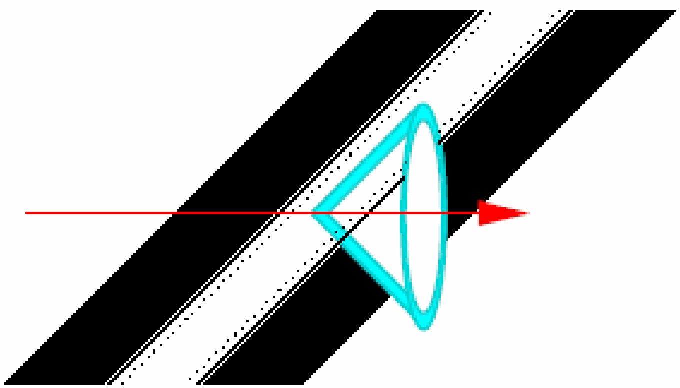


- Unshielded SR dose on PD ~ 1 Trad/yr.
- PD upgrade needed to cope with Bethe-Heitler rate and increased SR load.

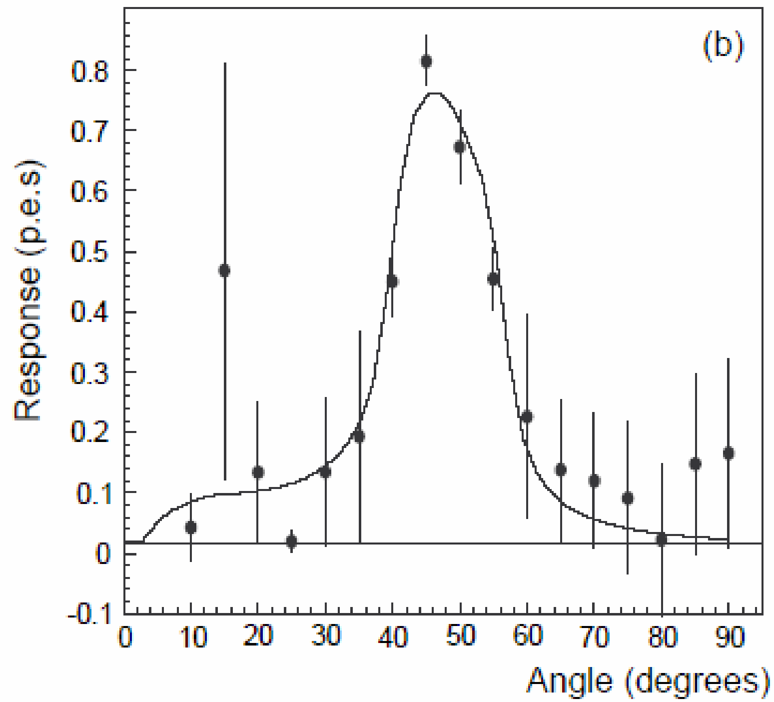


Čerenkov radiation at H1

- Measure photons using radiation hard tungsten/quartz-fibre calorimeter.
- As before, detect Čerenkov radiation emitted in electromagnetic shower.
- Problem: poor response in “traditional” calo; light not trapped in fibres..
- Solution: orientate fibres at Čerenkov angle w.r.t. incoming photons.

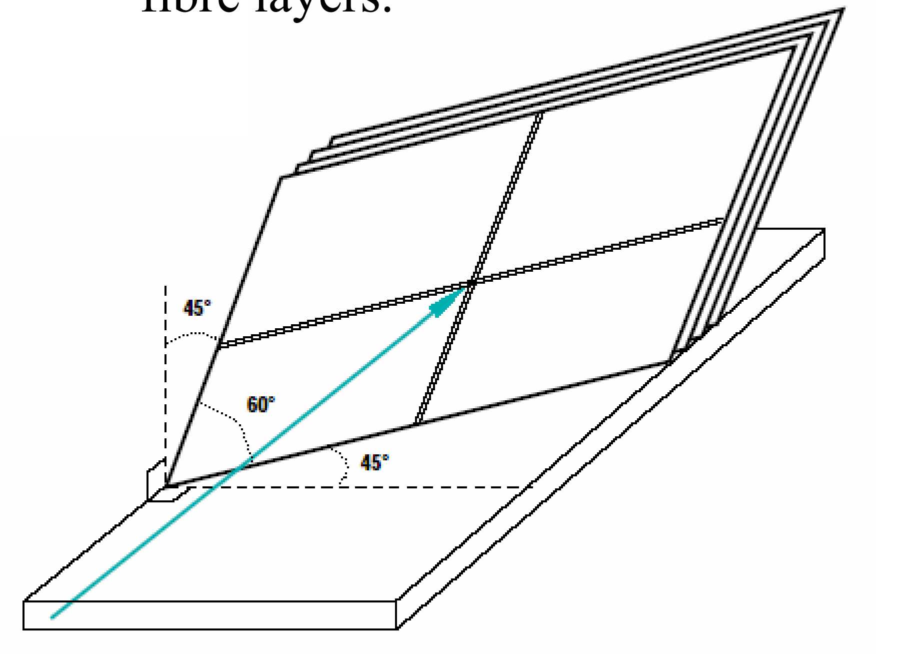


- Result is significant increase in response:



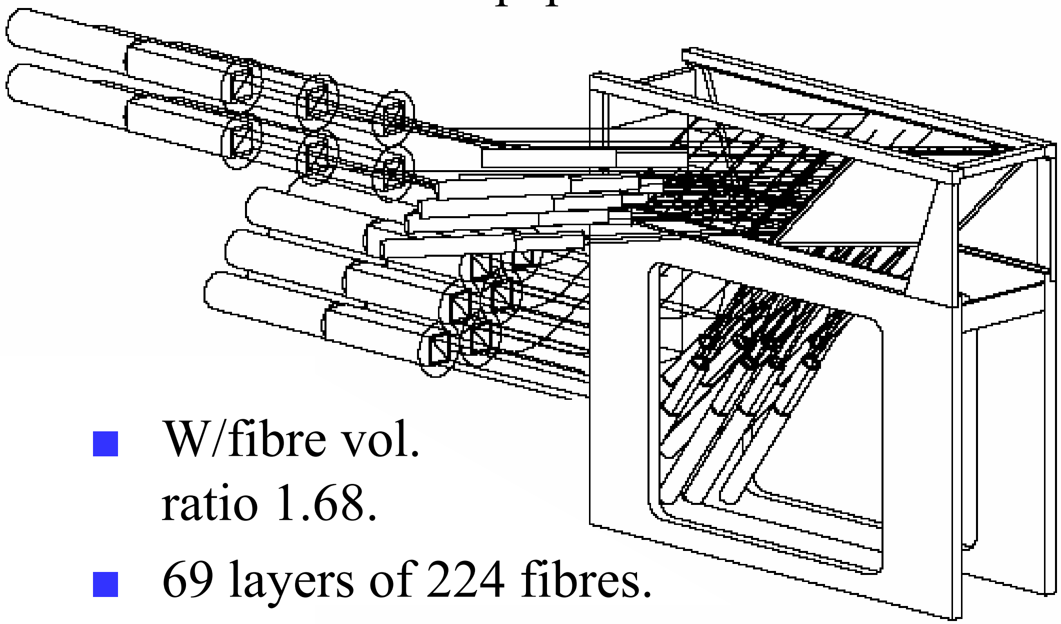
Čerenkov radiation at H1

- Spatial resolution in 2D achieved by orthogonal orientation of alternate fibre layers.



- Beam/fibre angle 45°.
- Beam incident angle 54.7 °.

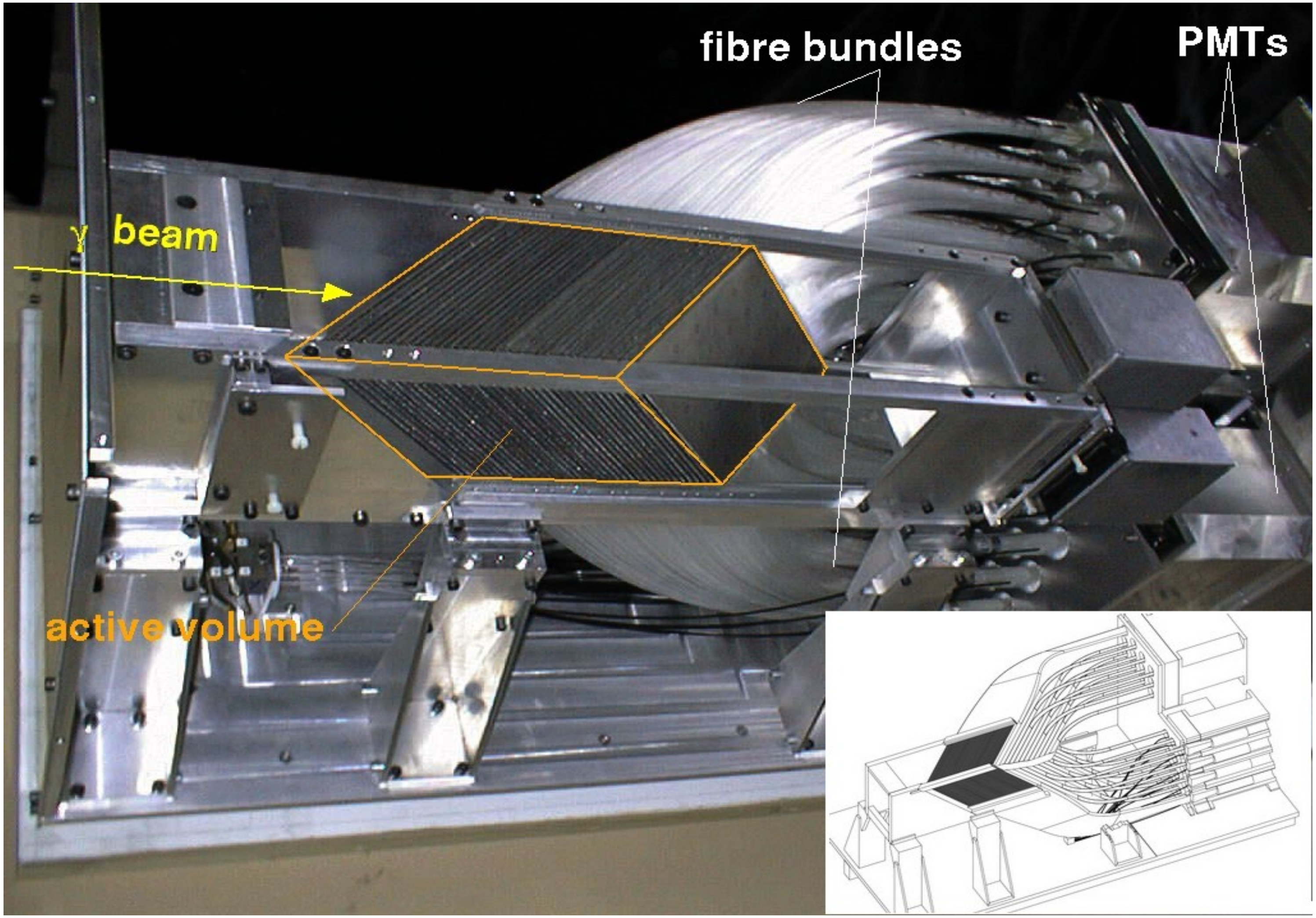
- Calorimeter on paper...



- W/fibre vol. ratio 1.68.
- 69 layers of 224 fibres.
- 70 W radiators, 0.7 mm thick.
- Photonis XP2978 phototubes.
- X_0 = 7.8 mm, R_M = 17.2 mm.
- Depth 25 X_0.
- Active vol. 12 x 12 x 17 cm^3.

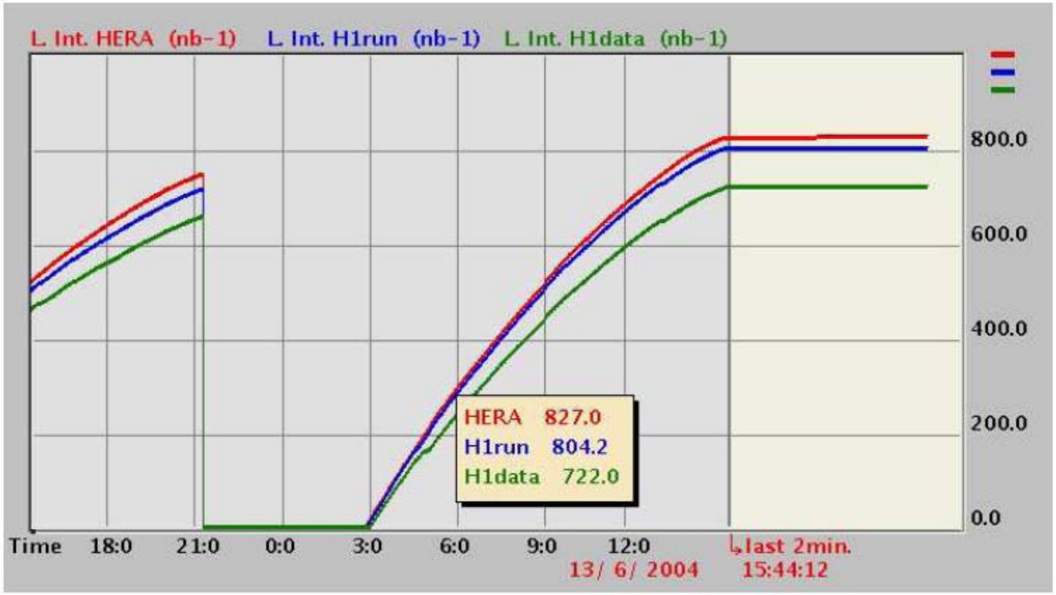
Čerenkov radiation at H1

- ...and in real life:
- Energy res. ~ 20%/√E GeV.
- Spatial res. ~ 5 mm/√E GeV.

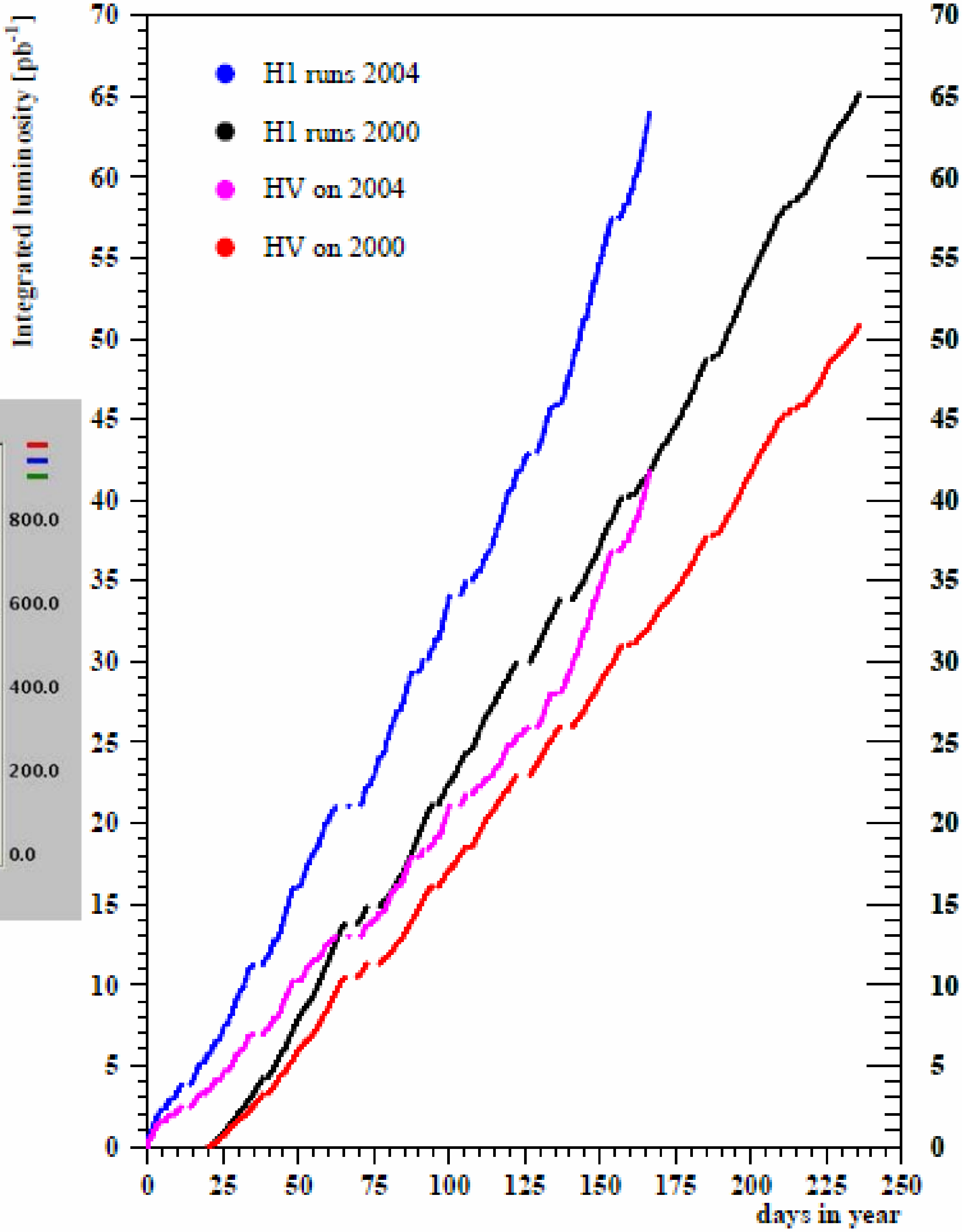


HERA luminosity

- Highest ever HERA luminosities measured recently.

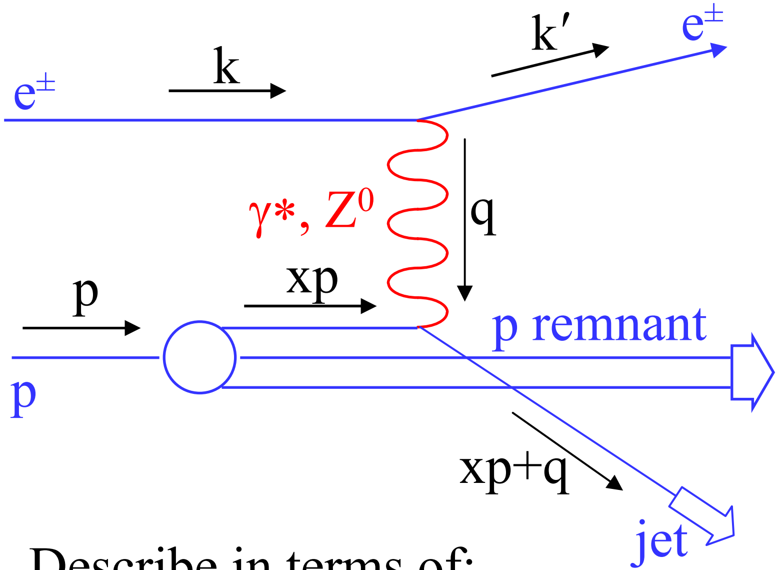


- Ultimate precision $\delta\mathfrak{L} \sim 1\%$, at which point improved B-H calculation necessary.



H1 physics – introduction

- Deep inelastic ep scattering:

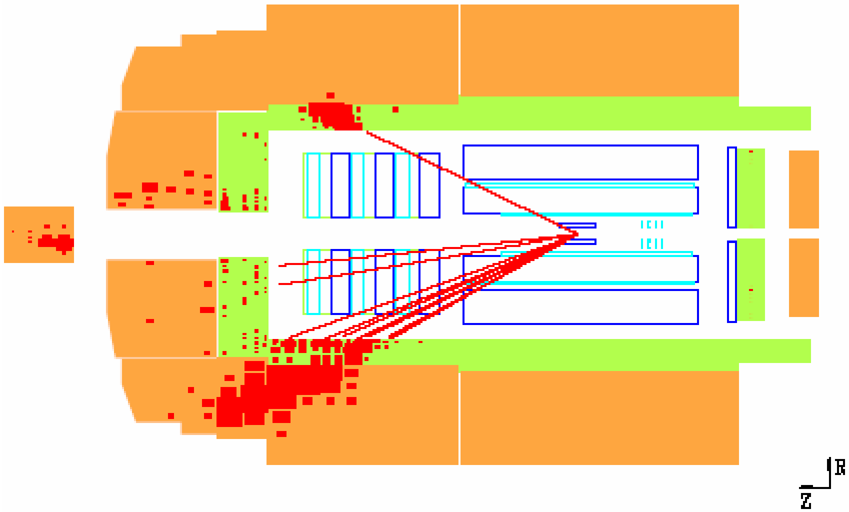


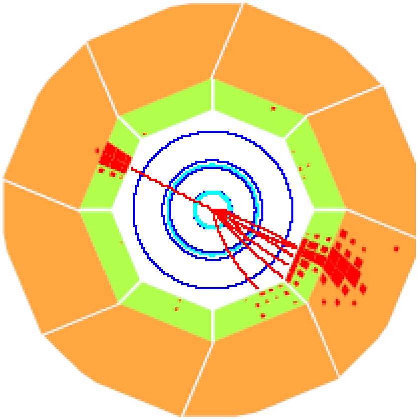
- Describe in terms of:

$$Q^2 = -q^2,\ \ x = \frac{Q^2}{2p\cdot q}\ \text{and}\ \ y = \frac{p\cdot q}{p\cdot k}$$

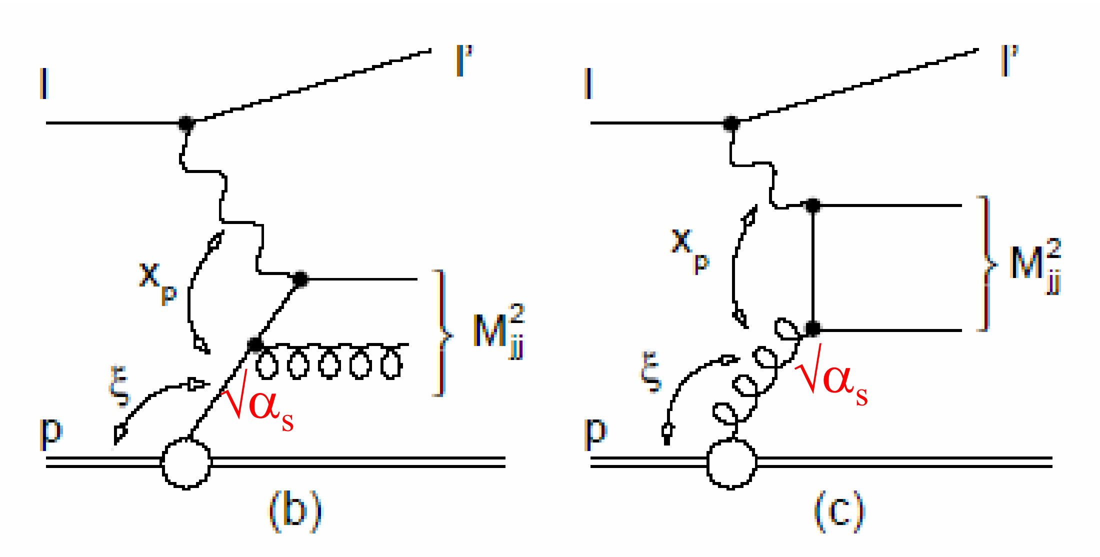
- Study also photoproduction, $Q^2 \sim 0$.

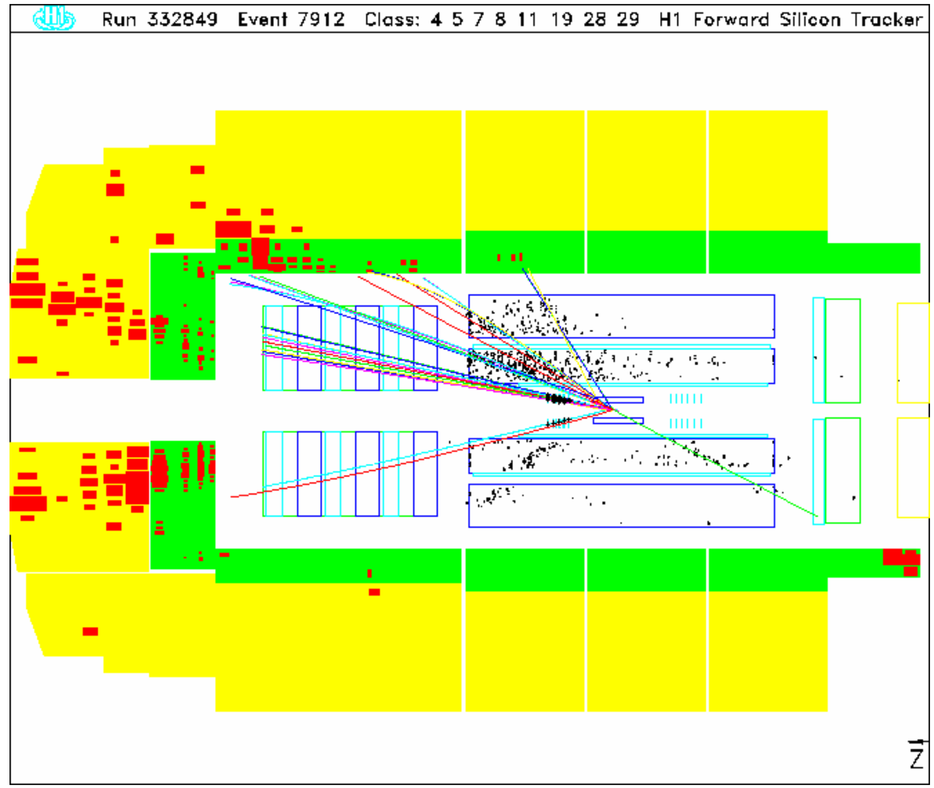
- DIS event in H1 detector:





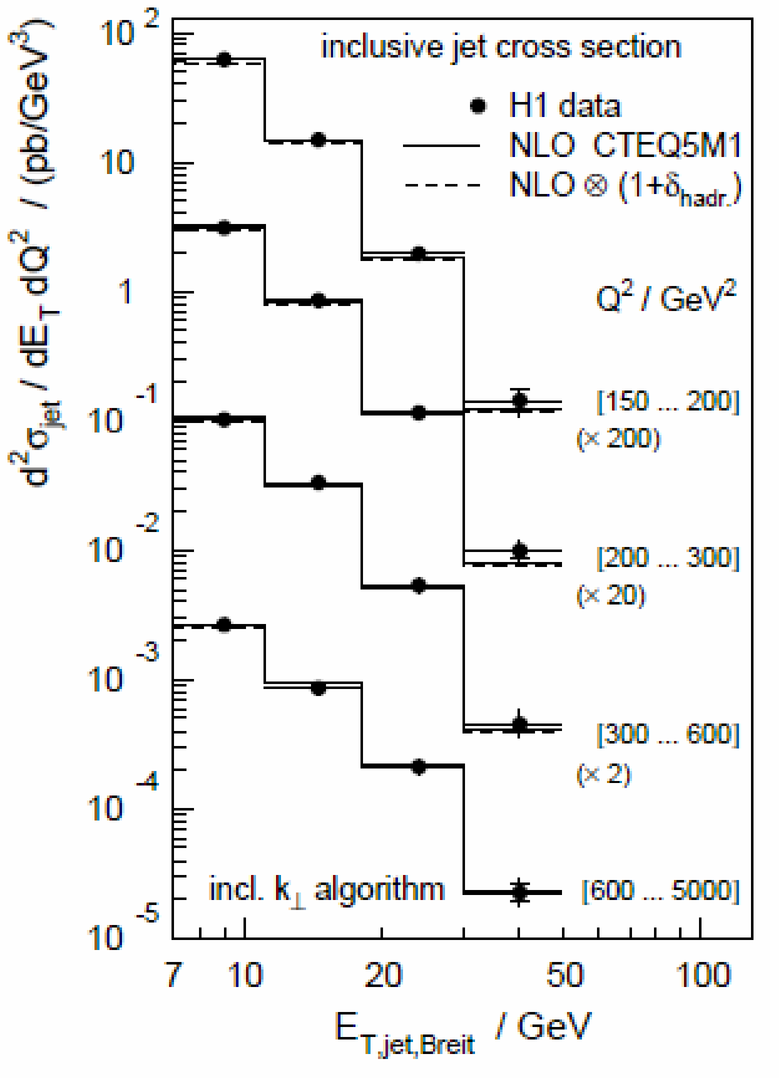
Studying QCD radiation at HERA, jet measurements



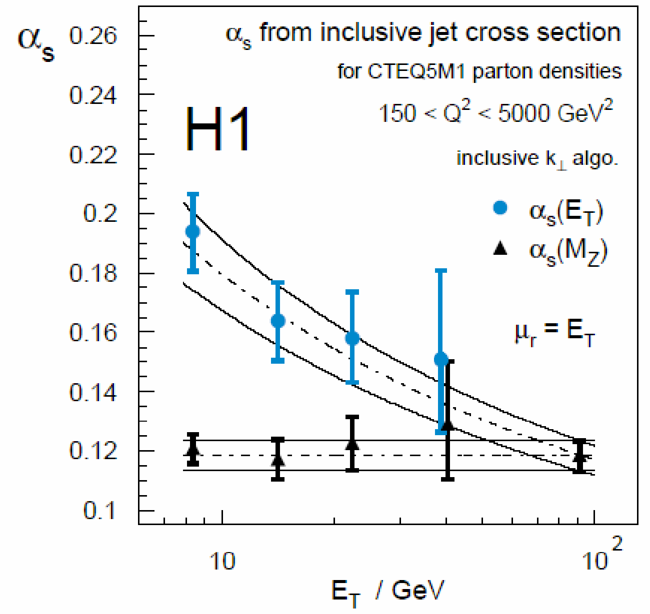


- Look at central dijet production.
- Jets defined using inclusive k_T algorithm in Breit frame with:
  - $E_T^{(1,2)} > 5$ GeV
  - $E_T^{(1)} + E_T^{(2)} > 17$ GeV.

Jets and the strong coupling constant



- Beautiful description possible.
- Allows extraction of strong coupling constant:
- $\alpha_s(M_Z^2) = 0.1186 \pm 0.0030\,(\mathrm{Exp})\;{}^{+0.0039}_{-0.0045}\,(\mathrm{Th})\;{}^{+0.0033}_{-0.0023}\,(\mathrm{PDF})$
- HERA II goal, 1% measurement of $\alpha_s(M_Z^2)$.



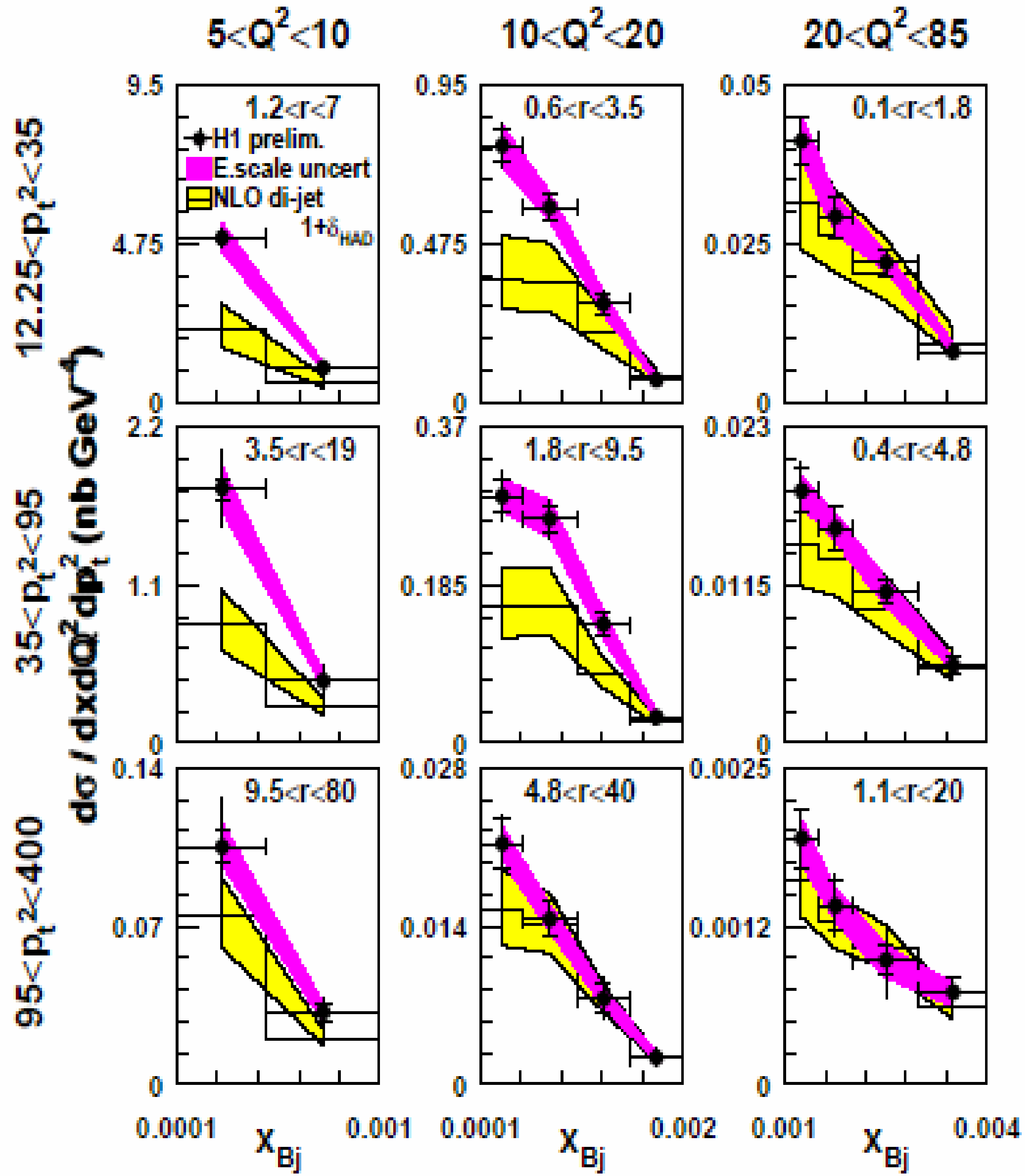
Forward jets and NLO QCD

- Measure triple differential cross section for jets satisfying:

  $1.74 < \eta_{jet} < 2.79$

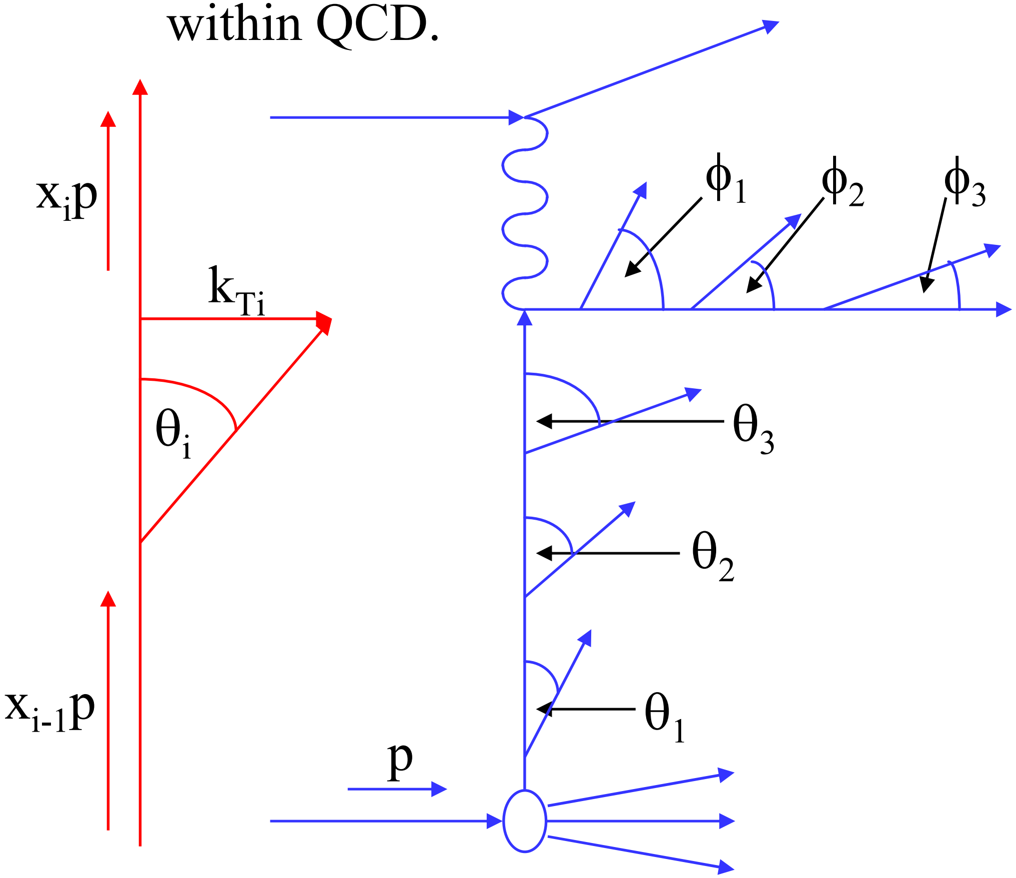
  $x_{jet} = \frac{E_{jet}}{E_p} > 0.035$

- Good agreement previously observed has vanished!
- What is going wrong?

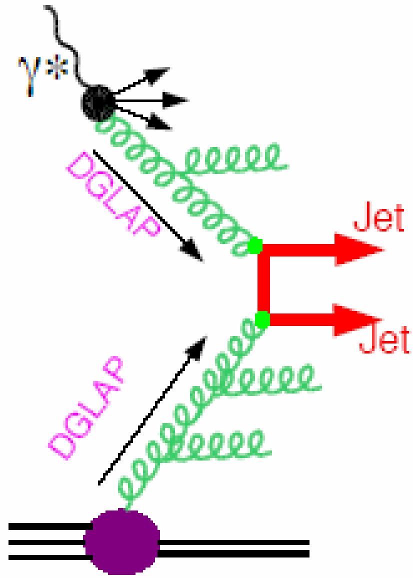


QCD radiation at small x

- Several alternative approaches for description of parton dynamics within QCD.

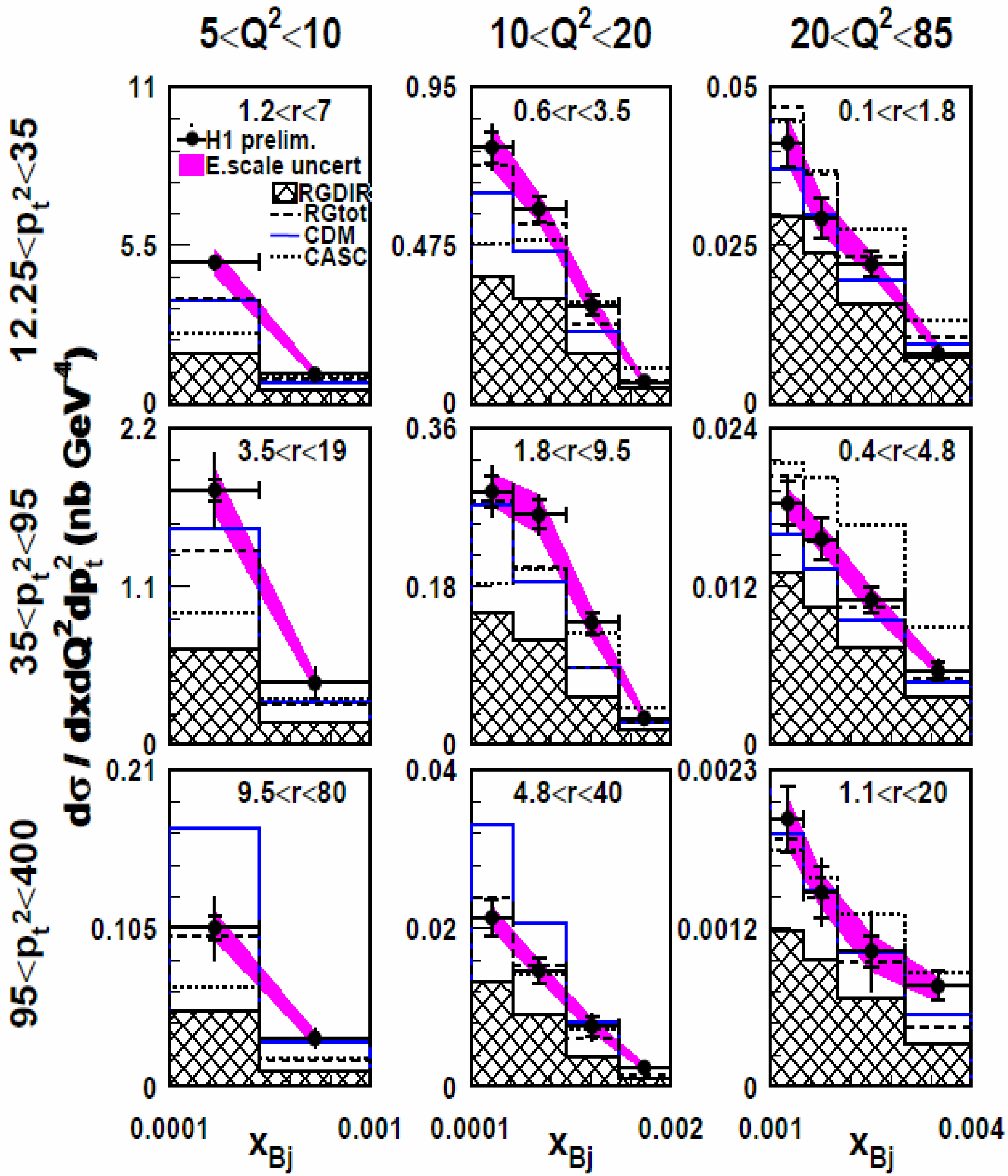


- DGLAP, angular ordering given by $k_{T1} << k_{T2} << \ldots << k_{Tn} = Q^2$.
- BFKL, angular ordering given by $x_1 >> x_2 >> \ldots >> x_n = x_{Bjorken}$.
- CCFM implements angular ordering, $\theta_1 < \theta_2 < \ldots < \theta_n$.
- Further possibility: γ^* structure:



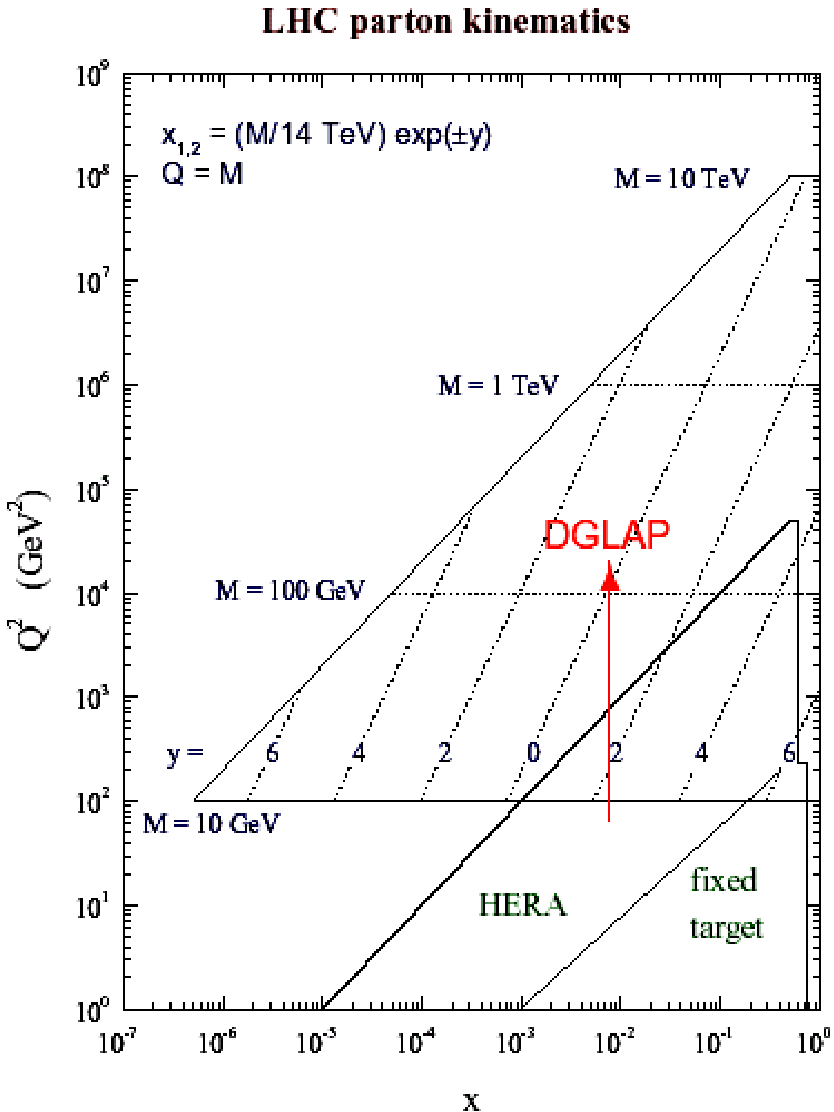
Forward jets and QCD models

- DGLAP (RGDIR) poor except for region $Q^2 > p_T^2$, $r < 1$, (i.e. where reasonable "lever arm" in k_T).
- "BFKL" (CDM) problems in resolved γ region $p_T^2 > Q^2$, $r > 1$ (i.e. where parton from proton probes photon).
- CCFM (CASC) results are improvement on RGDIR.
- DGLAP model including resolved γ^* (RGtot) gives best results overall.



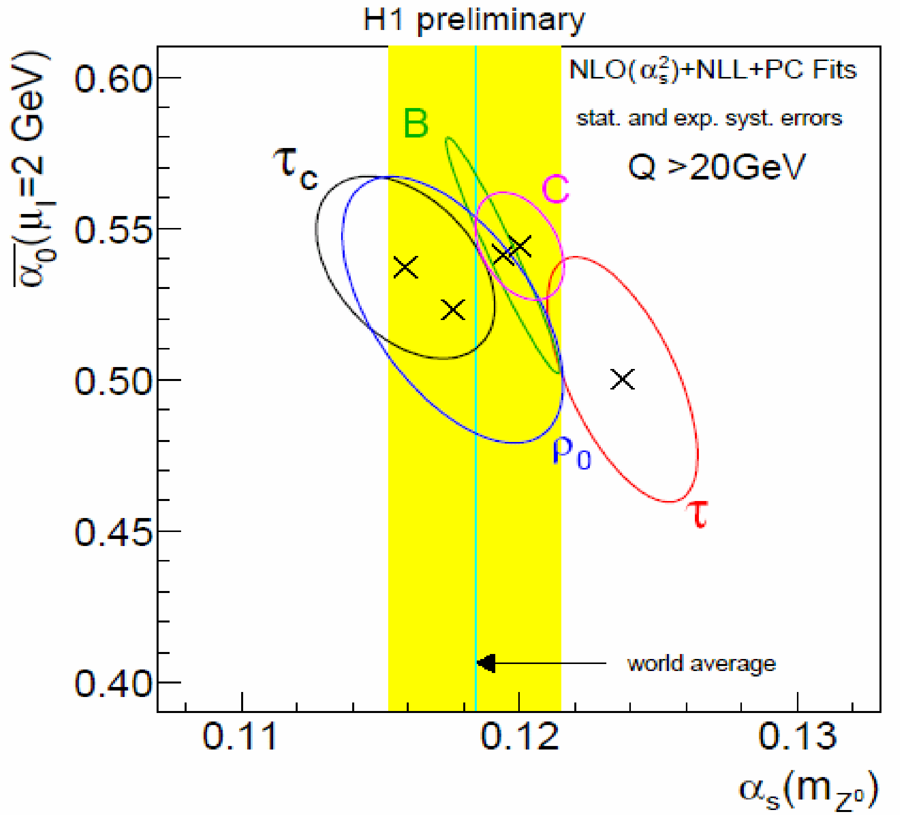
Parton dynamics and the LHC

- Problem of parton dynamics not only of interest to those who wish to understand QCD.
- Searches for Higgs boson(s), super-symmetric particles... at LHC will rely on HERA measurements and extrapolations to the LHC kinematic domain using QCD evolution equations for background calculations, determination of partonic cross-sections...

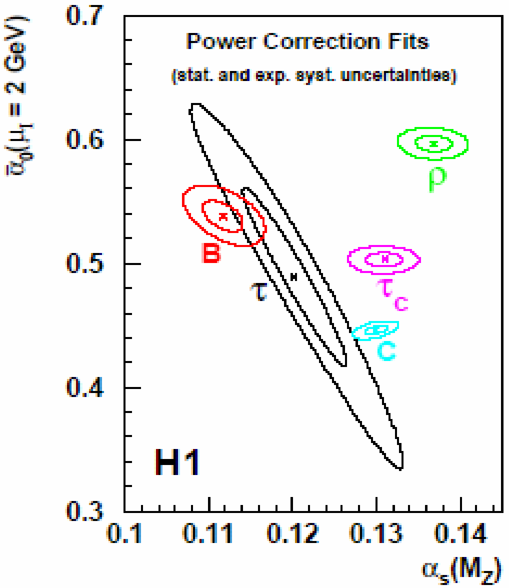


Event shapes

- Repeat for further "two jet" variables.
- Resulting $\alpha_s(M_Z)$ and $\overline{\alpha}_0$ values:



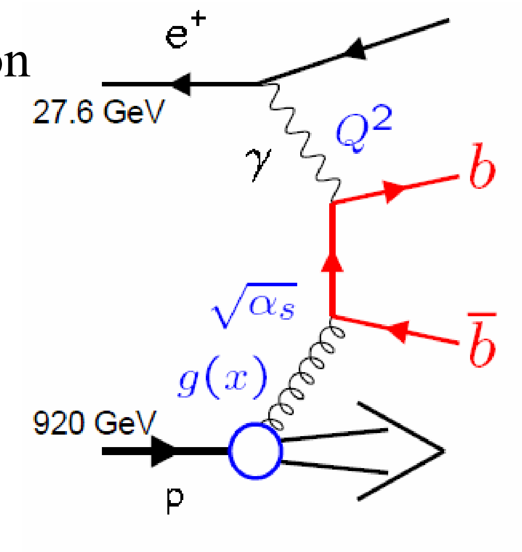
- Fitting spectra with NLO + NLL + power corrections results in improved consistency.

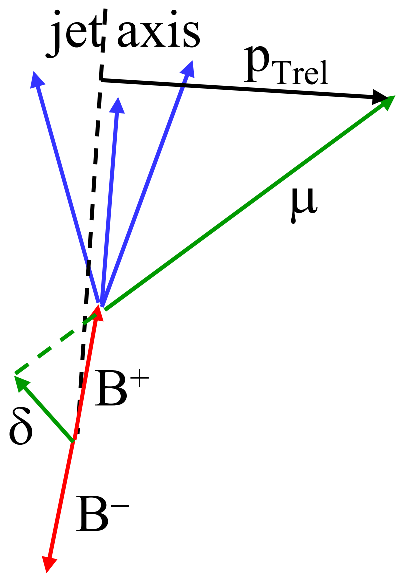


- Agreement with world average $\alpha_s(M_Z^2)$ and with $\overline{\alpha}_0$ as determined in e^+e^- analysis of mean event shapes.
- Measurements of 2, 3 and 4-jet event rates and of "three jet" event shape variables also made.

Beauty production in DIS

- Main production mechanism in DIS

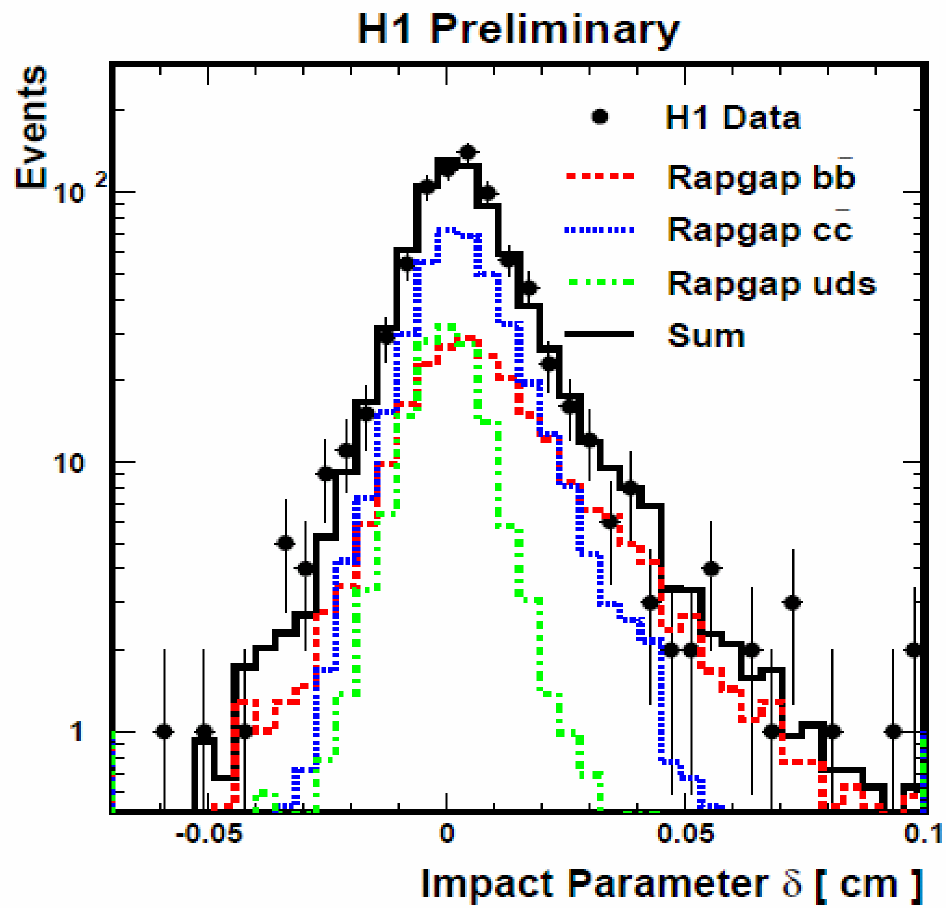




- Identify semi-muonic beauty decays via p_{Trel} and impact parameter δ of muon.

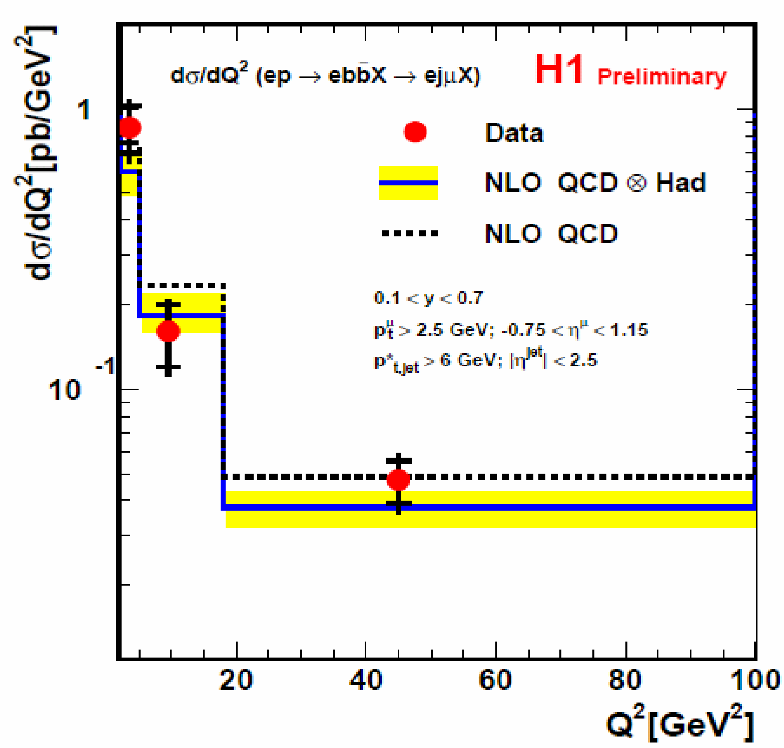
- Measure $e\,p \rightarrow e\,b\,\bar{b}\,X \rightarrow e\,\mathrm{jet}\,\mu\,Y$

- Data well understood, e.g. δ distribution in DIS:

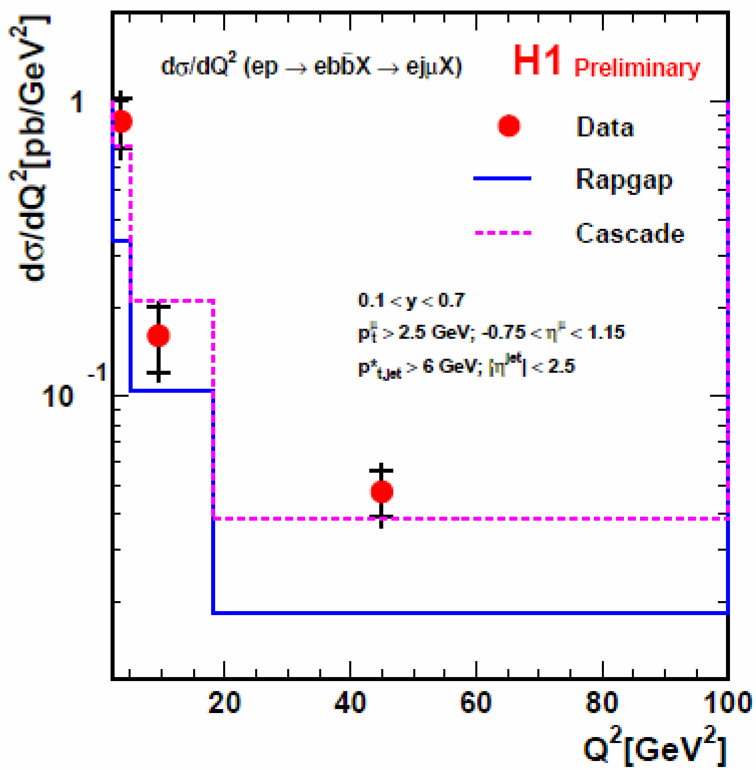


Beauty in DIS – comparison with NLO QCD and QCD based models

- Fit 2D distribution in (δ, p_{Trel}) to obtain beauty contribution.
- DIS cross section well described by NLO QCD calc. (HVQDIS):



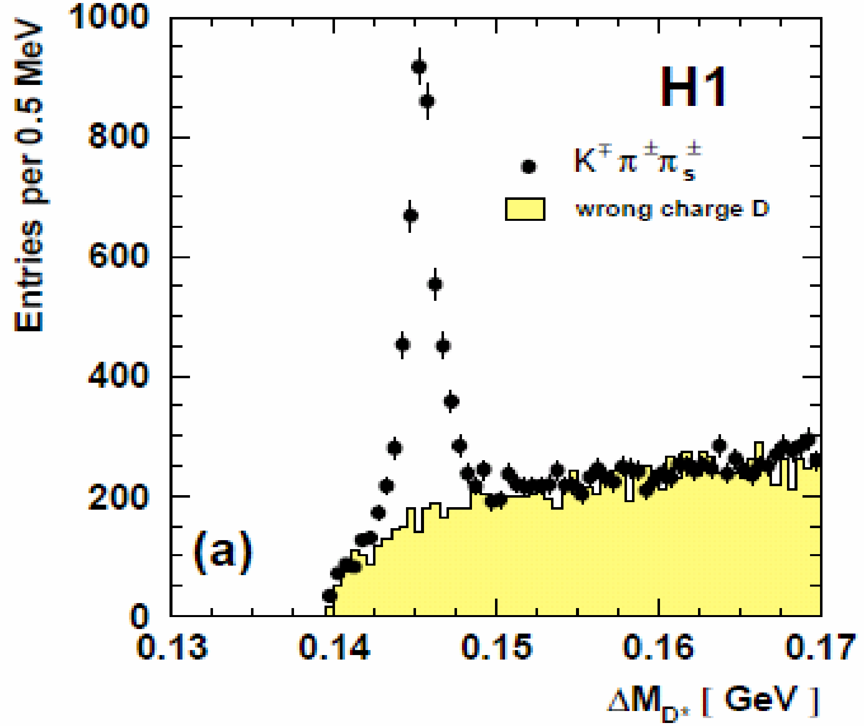
- CCFM-based Cascade provides better description of data than the DGLAP model Rapgap.



Evidence for a narrow anti-charmed baryon state

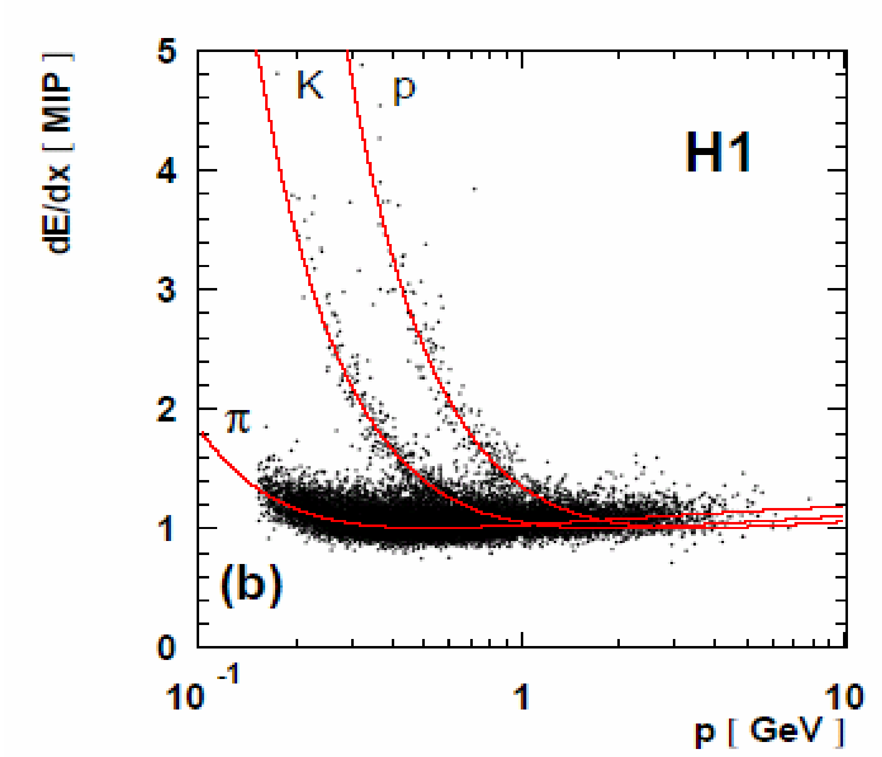
- Strange pentaquark ($uudd\bar{s}$) seen by many expts in channels $\Theta_s \rightarrow K^+ n$ and $\Theta_s \rightarrow K_S{}^0 p$.
- Search for equivalent charmed state, Θ_c ($uudd\bar{c}$).
- Look for narrow resonance in D^*p mass spectrum.
- Use DIS D^* sample with selection that ensures good S/B ratio.
- $\Delta m_{D*} = m(K^-\pi^+\pi_s{}^+) - m(K^-\pi^+)$.
- BG $m(K^+\pi^+\pi_s{}^+) - m(K^+\pi^+)$.

- Δm_{D*} spectrum:

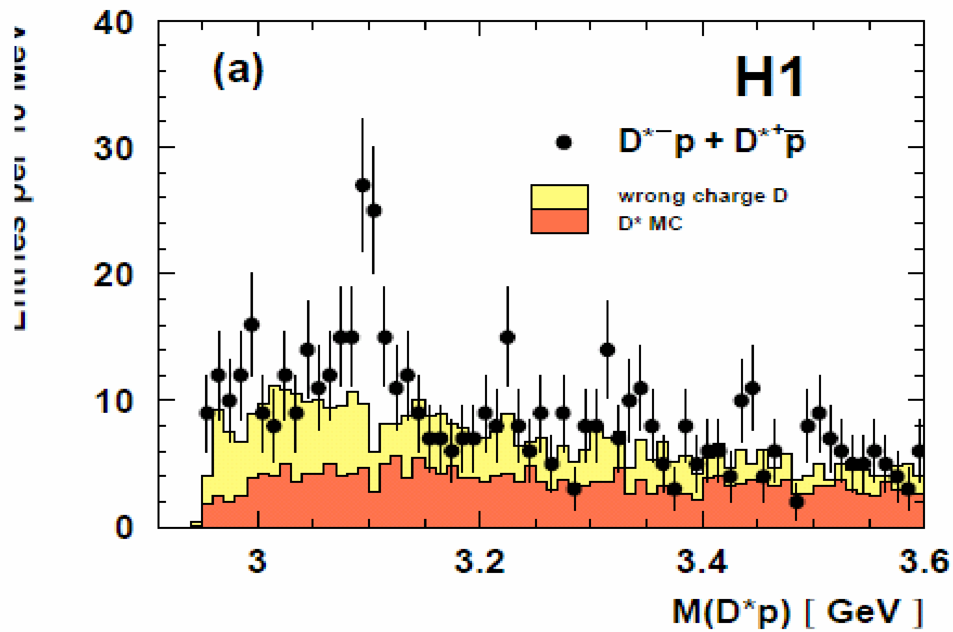


Evidence for a narrow anti-charmed baryon state

- Suppress non-proton BG using dE/dx measurements in H1 central jet chambers.



- Four particle mass resolution about 35 MeV: use "Δm" technique to improve resolution near threshold, i.e. $m(K\pi\pi_s p) - m(K\pi\pi_s) + m(D^*)_{PDG}$.



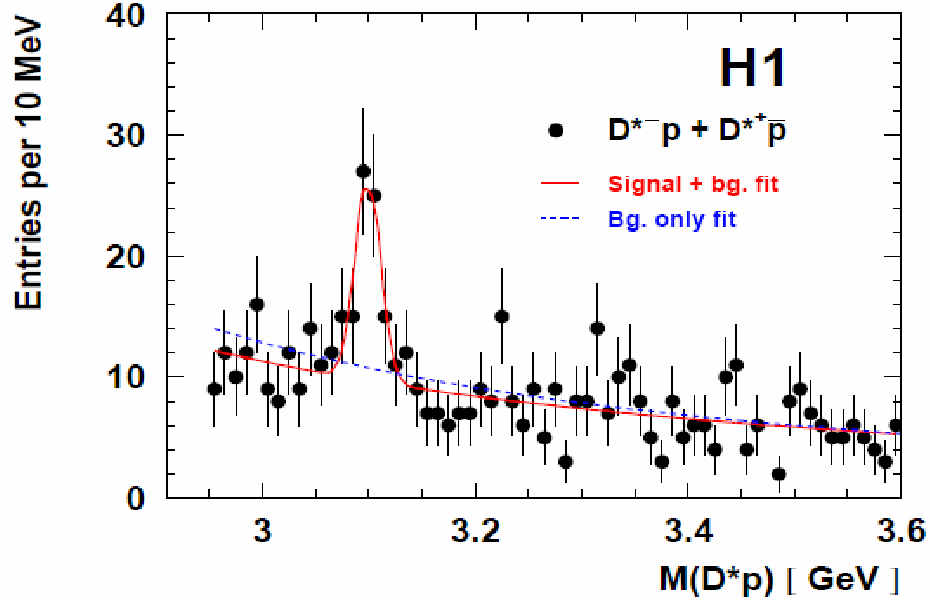
- BG described by "wrong charge D^0" sample + D^* MC (Rapgap).

Evidence for a narrow anti-charmed baryon state

- Peak seen in $D^{*-}p$ and $D^{*+}\overline{p}$ channels and in γp data.
- Masses and widths (consistent with resolution) compatible in all data samples.

Sample	Mass (MeV)	σ (MeV)	N_S
$D^{*-}p + D^{*+}\overline{p}$ (DIS)	3099 ± 3	12 ± 3	50.6 ± 11.2
$D^{*-}p$ (DIS)	3102 ± 3	9 ± 3	25.8 ± 7.1
$D^{*+}\overline{p}$ (DIS)	3096 ± 6	13 ± 6	23.4 ± 8.6
$D^{*-}p + D^{*+}\overline{p}$ (γp)	3103 ± 4	7 ± 3	43 ± 14

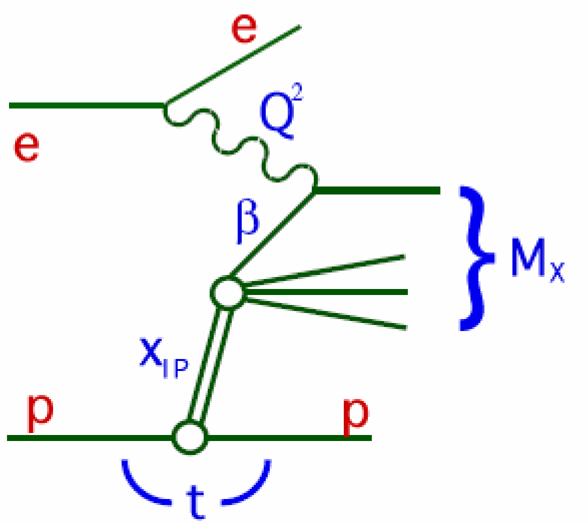
- Significance estimate.



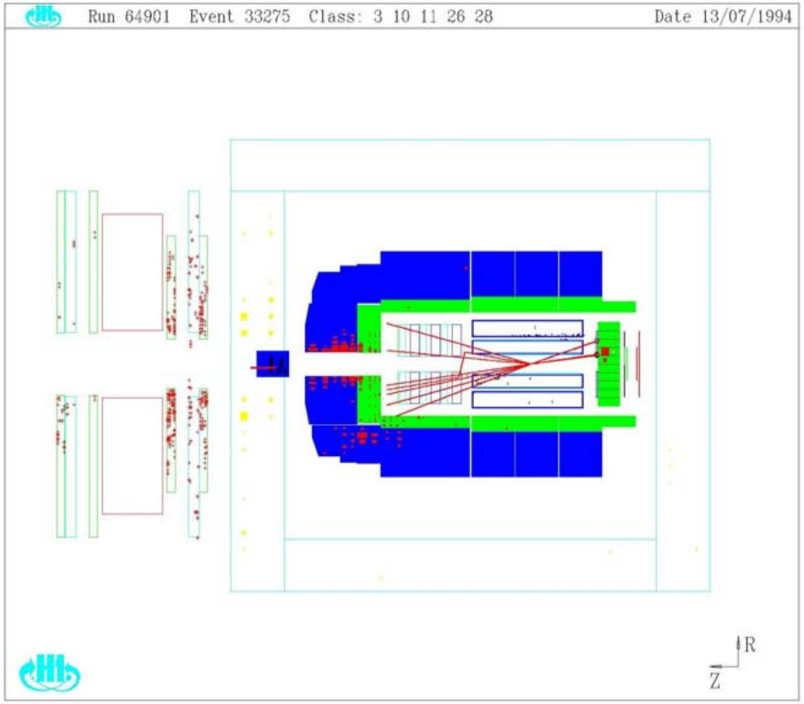
- BG only fit gives $N_b = 51.7 \pm 2.7$ in signal region (within 2σ of peak).
- Prob. that this fluctuates to produce signal is 4 x 10^{-8} (Poisson) or 5.4 σ.

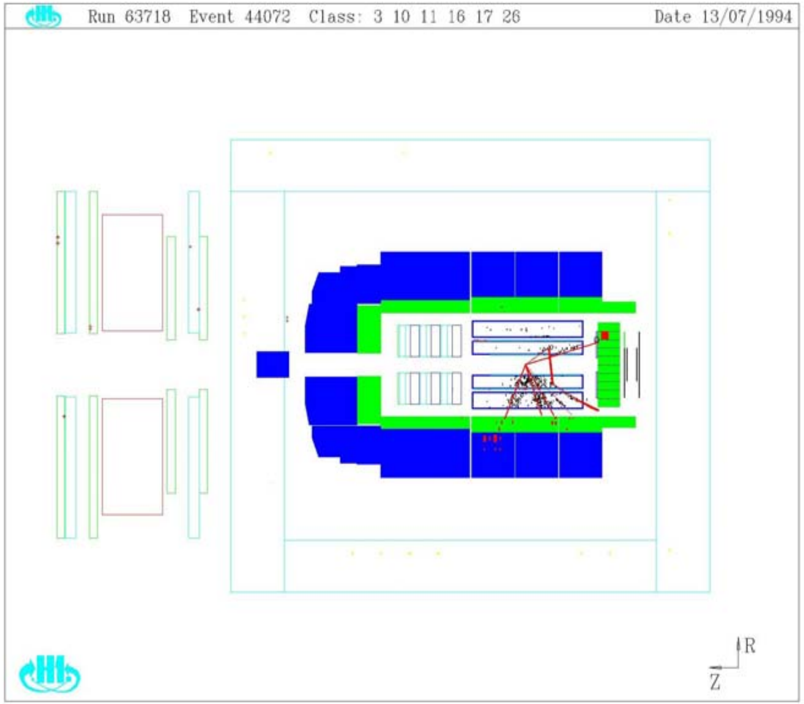
Studying diffraction at H1

- Colourless exchange leads to suppression of QCD radiation close to proton remnant:



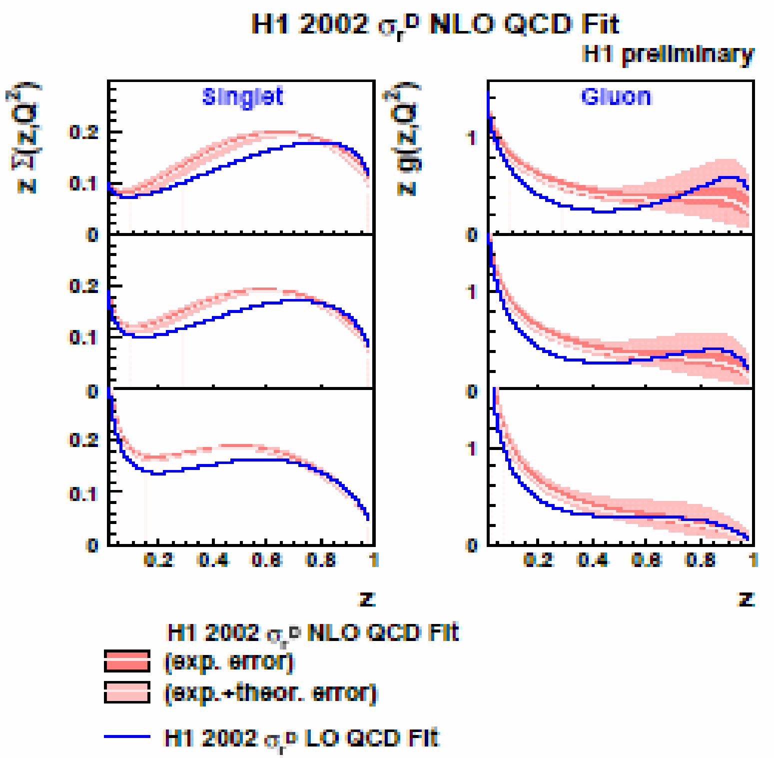
- Measure cross section and hence determine partonic structure of this component of proton.
- Factorisation proved by Collins.

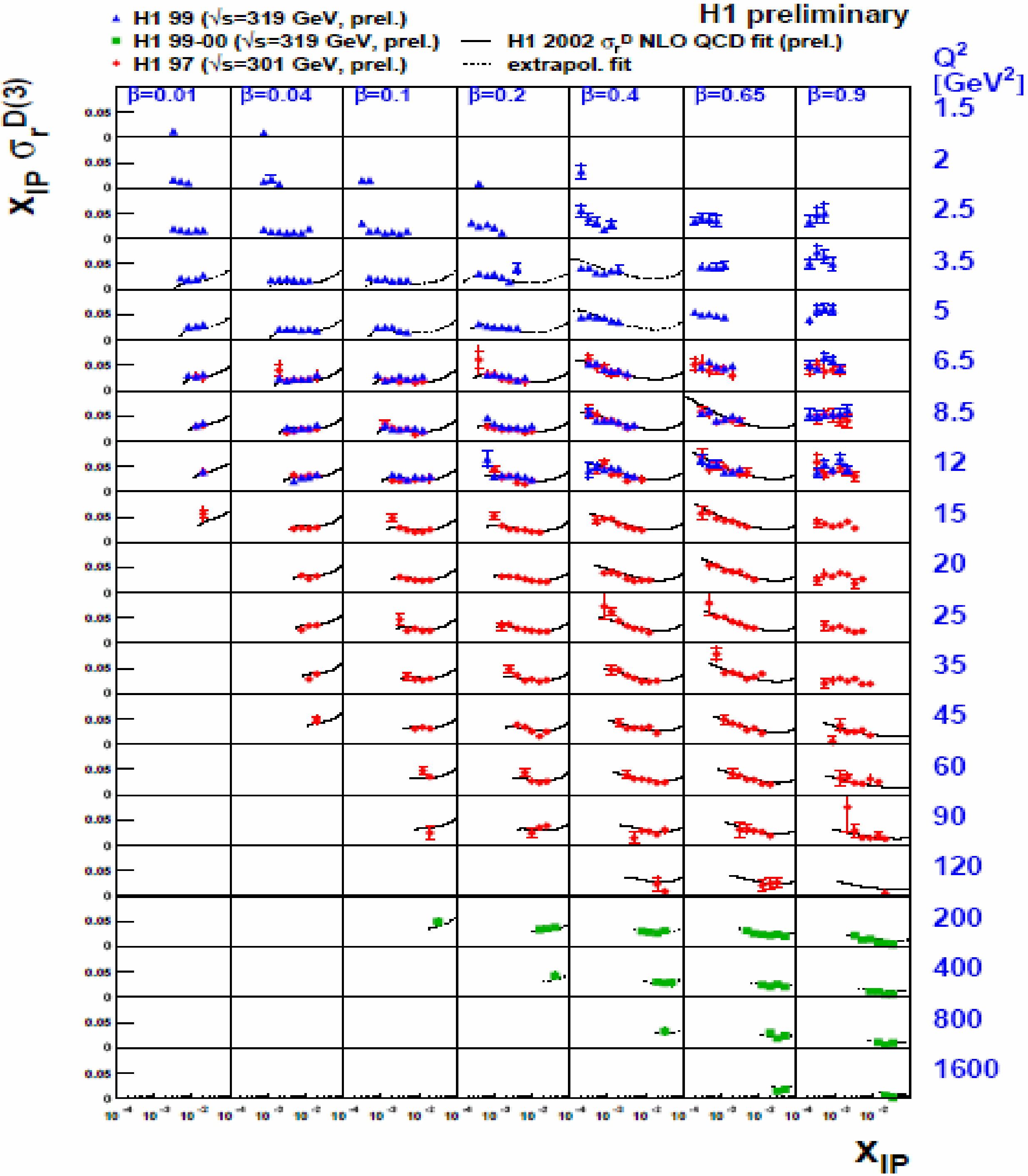




The structure of diffraction

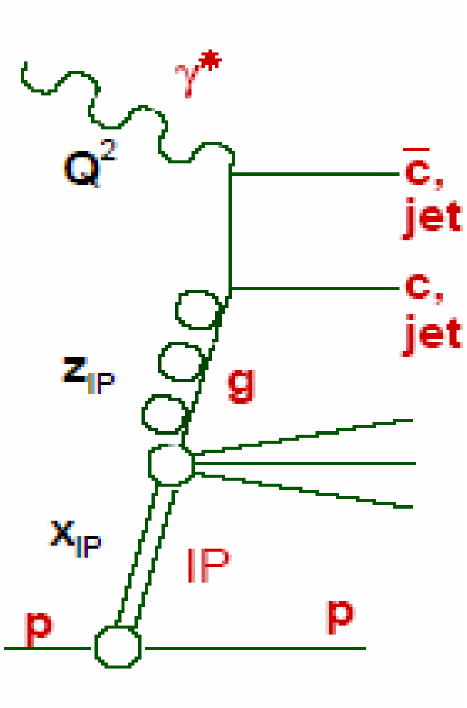
- H1 measurements cover complete kinematic range accessible at HERA I.
- NLO diffractive PDFs extracted from DGLAP fit.

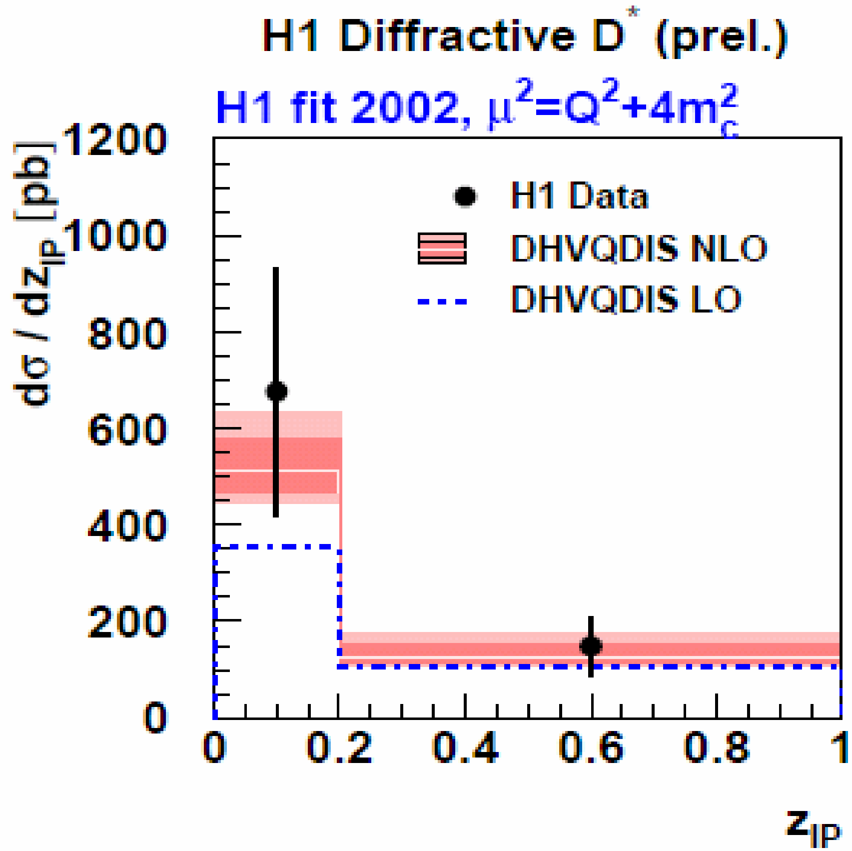




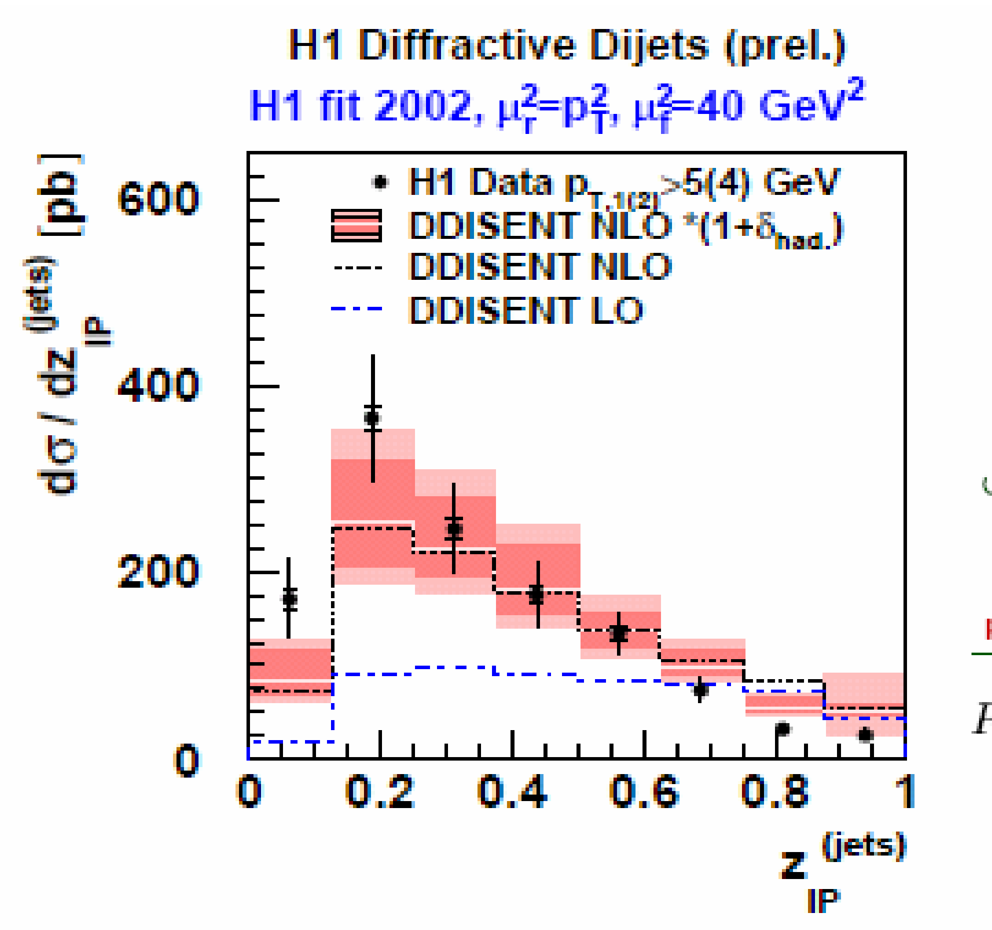
Compare diffractive final state measurements with NLO QCD predictions

- Study dijets in diffraction and the production of charm (tagged via D^*).

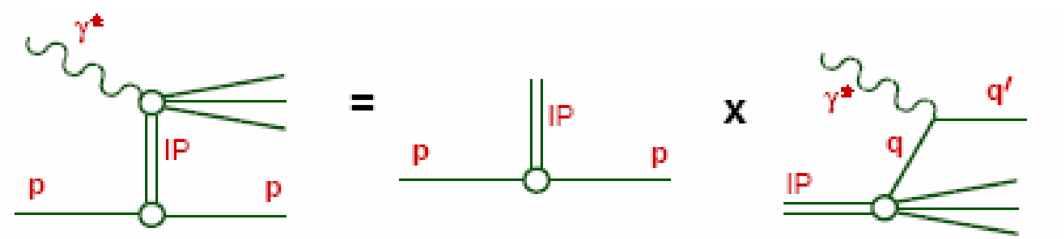




Compare diffractive final state measurements with NLO QCD predictions



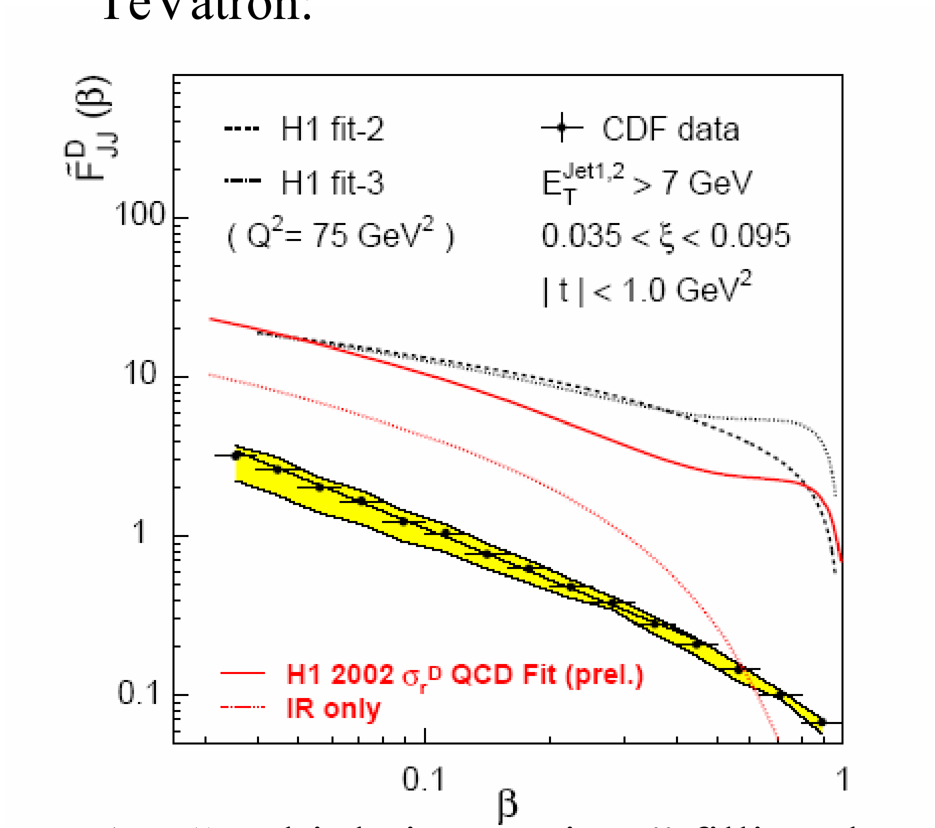
- Hadronisation and scale uncertainties large as scales small.
- Data well described within these uncertainties.
- Consistent description of diffraction: factorisation works at HERA.



$$F_2^D(x_{I\!P}, t, \beta, Q^2) = f_{I\!P/p}(x_{I\!P}, t)\, F_2^{I\!P}(\beta, Q^2)$$

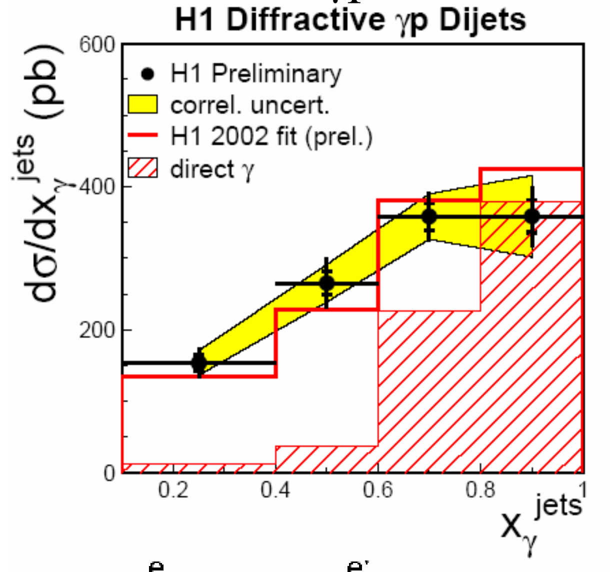
Diffraction at the TeVatron and LHC

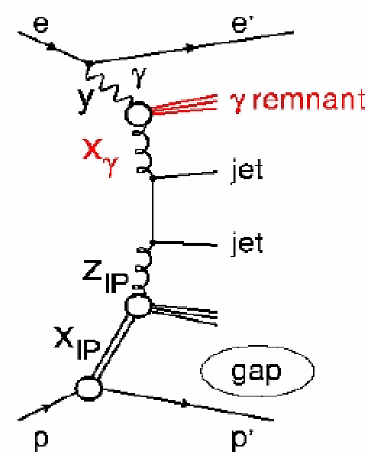
- Factorisation does not work at the TeVatron:



- Are "multiple interactions" filling the rapidity gap?

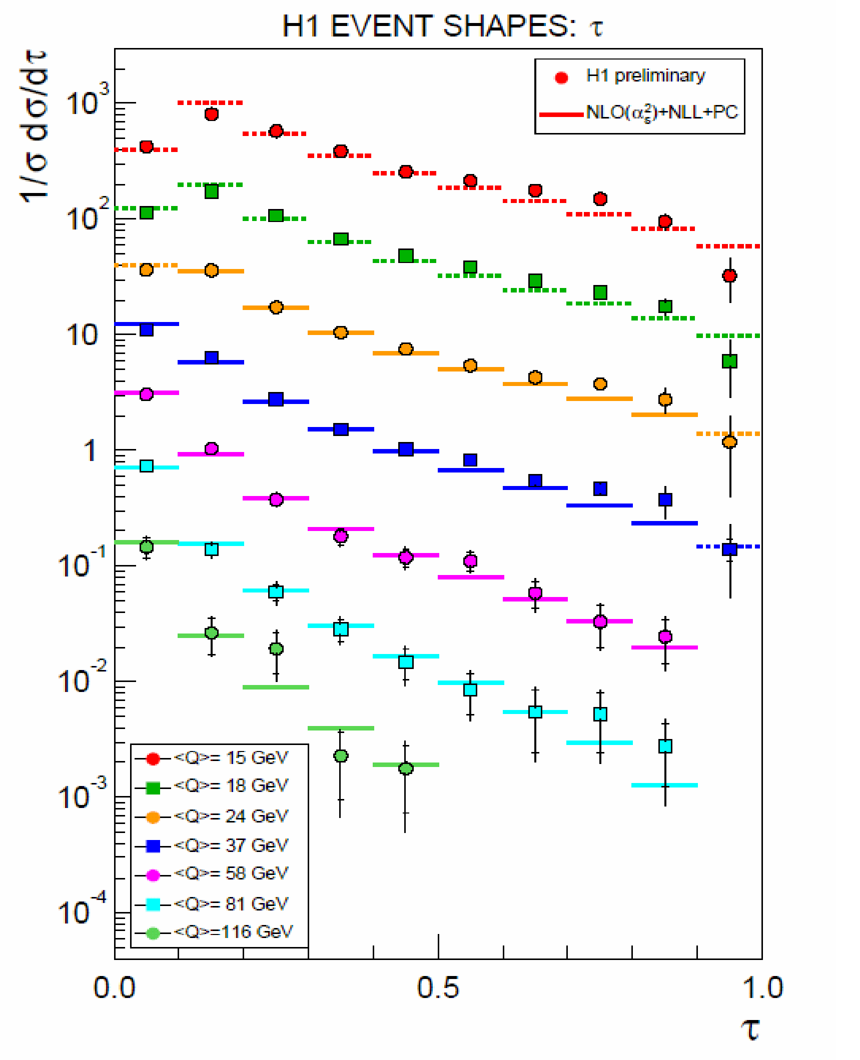
- Not in diffractive γp collisions at H1!





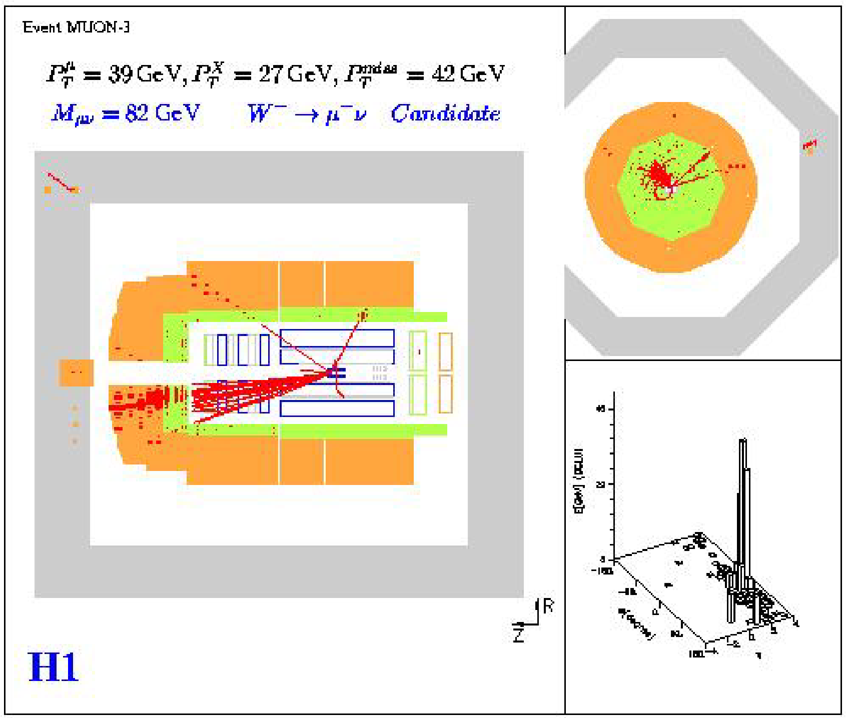
Event shapes

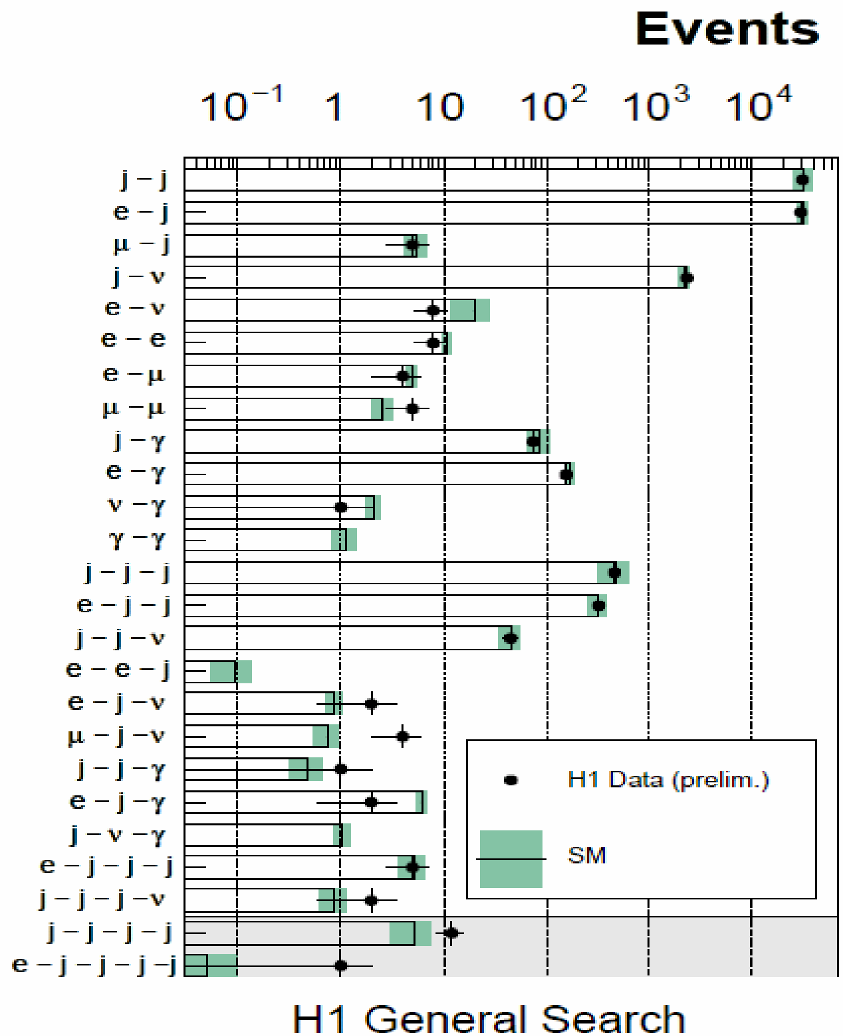
- Measurements of hadronic final state allow further tests of perturbative QCD and ideas beyond perturbation theory.
- Example, description of $\tau = 1 - T$ spectra using pQCD plus "power corrections".
- Introduces parameter $\overline{\alpha}_0$.
- Fit using re-summed NLL calculations matched to NLO as convergence of pert. series poor at small τ.
- Obtain values of $\overline{\alpha}_0$ and $\alpha_s(M_Z)$.



Comprehensive search for new physics in ep collisions

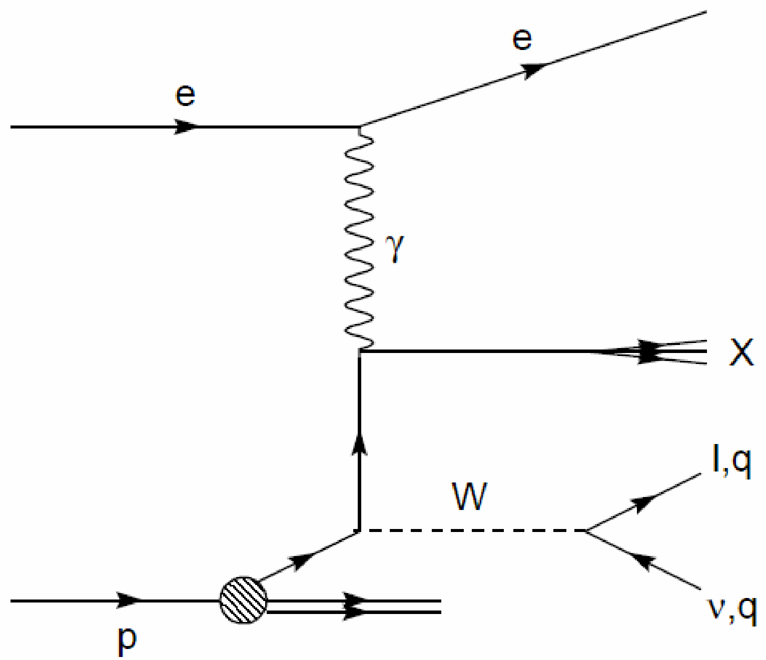
- Investigate final states containing 2 or more isolated high p_T j, e, μ, γ, ν.
- Agreement with SM (MC cocktail based on LO QCD + PS) impressive.
- Largest deviation, isolated lepton events.





Isolated lepton events with missing p_T

- Dominant SM production process.



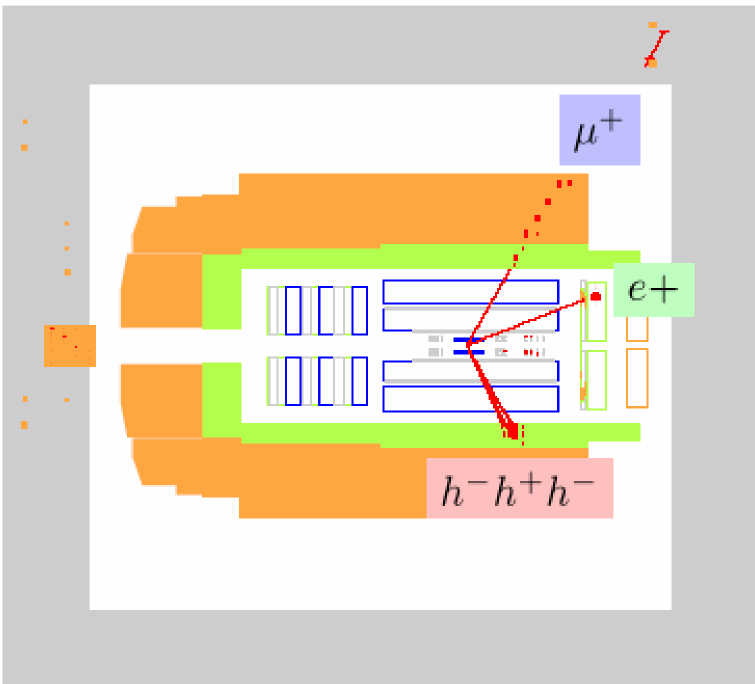
- Compare observed and predicted rates:

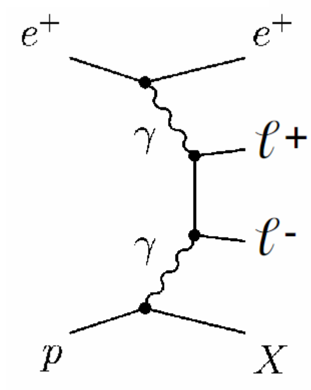
Data/ SM	HERA I e ($118\ pb^{-1}$)	HERA I μ ($118\ pb^{-1}$)
Full sample	11/11.54	8/2.94
$p_T^X > 25$ GeV	5/1.76	6/1.68

- Extend to τ production.
- More data needed: $500\ pb^{-1}$ sufficient to make 5 σ discovery of event rate maintained.

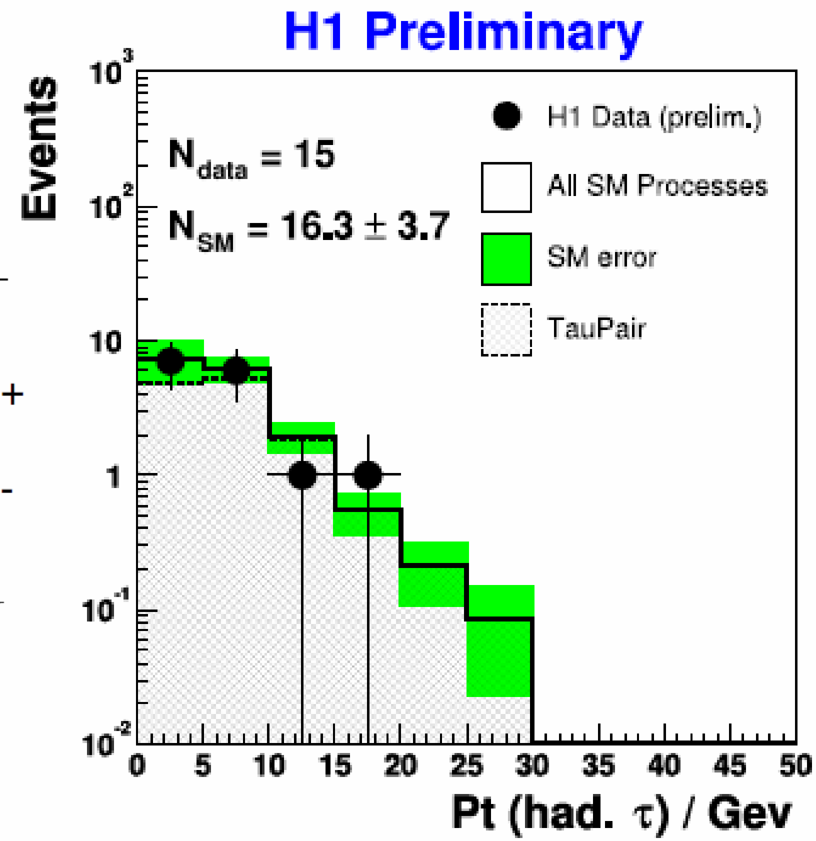
Identifying τ events

- Algorithms developed for τ ID.



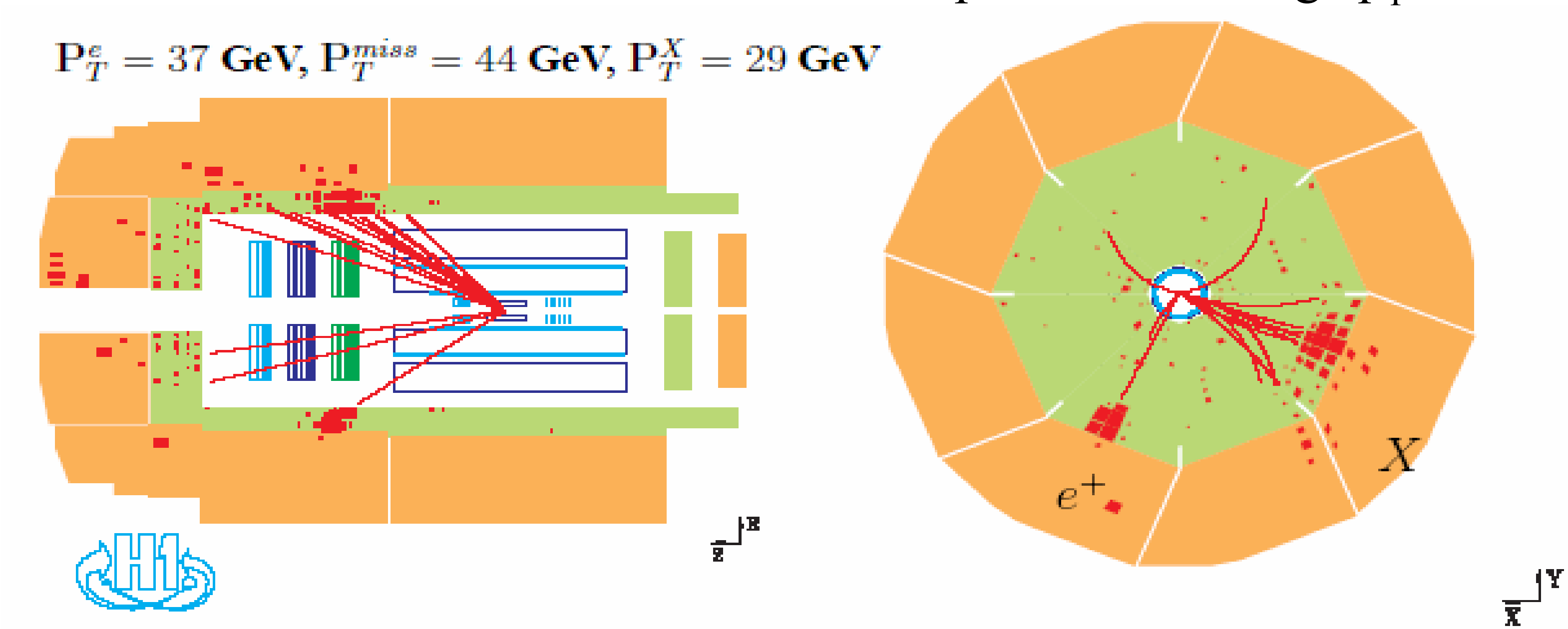


- Data on $ep \rightarrow e\tau\bar{\tau}p$ agree with SM:



Isolated lepton events at HERA II

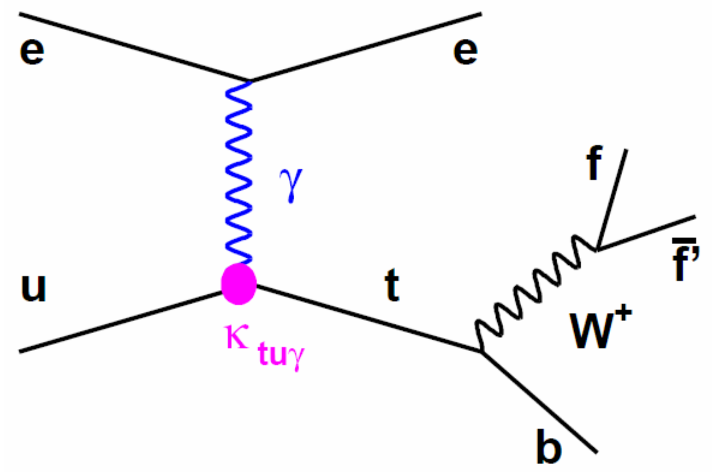
- New data contain isolated lepton events.
- Rate for isol. electrons above SM expectation for large p_T^X.



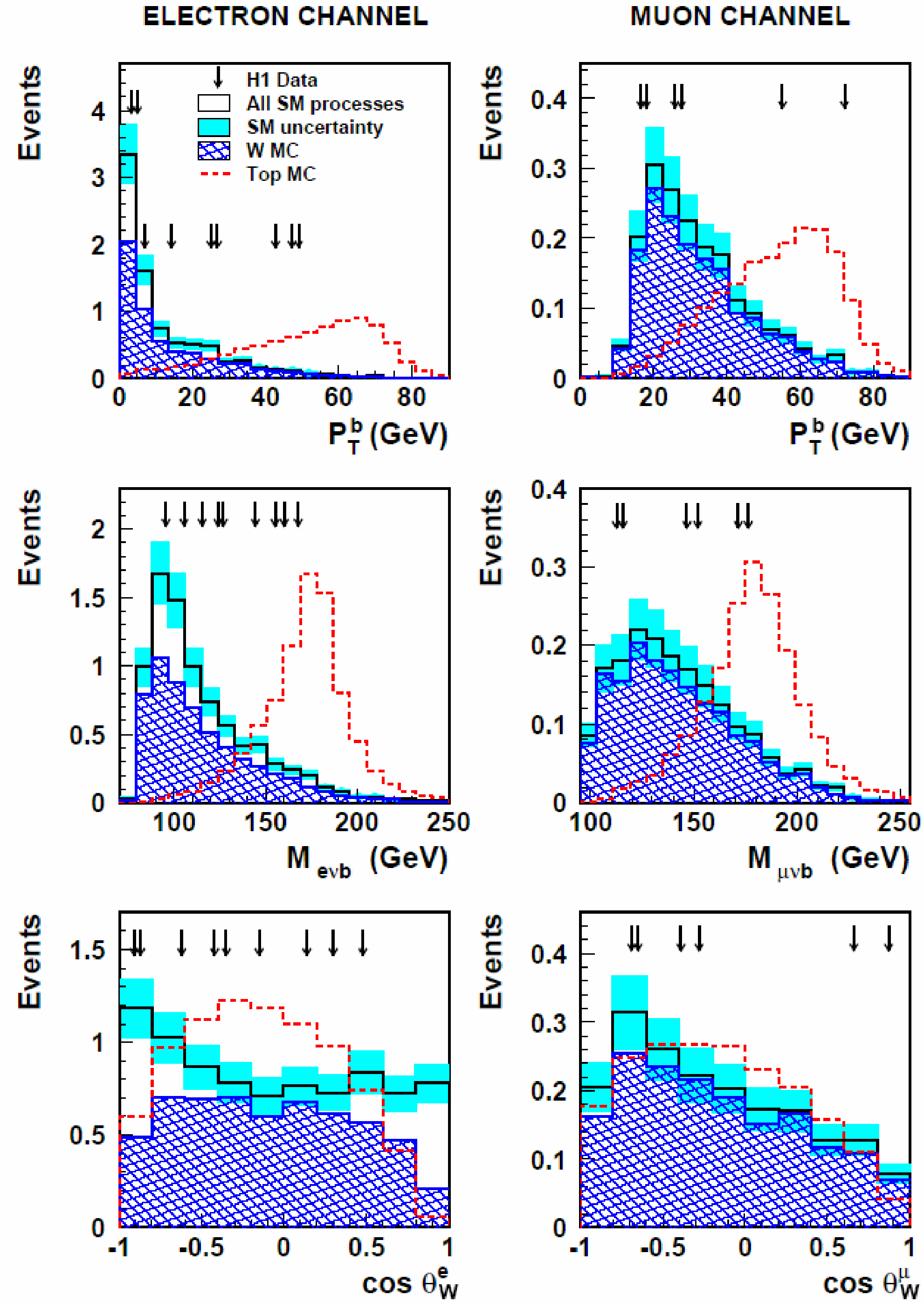
(Prel.) data/ SM	HERA I e (118 pb^{-1})	HERA I μ (118 pb^{-1})	HERA I τ (108 pb^{-1})	HERA II e (17 pb^{-1})	HERA II μ (17 pb^{-1})
Full sample	11/11.54	8/2.94	5/5.81	3/1.61	0/0.44
$p_T^X > 25$ GeV	5/1.76	6/1.68	0/0.53	2/0.34	0/0.29

Single top production at HERA

- Top quark production via a FCNC.



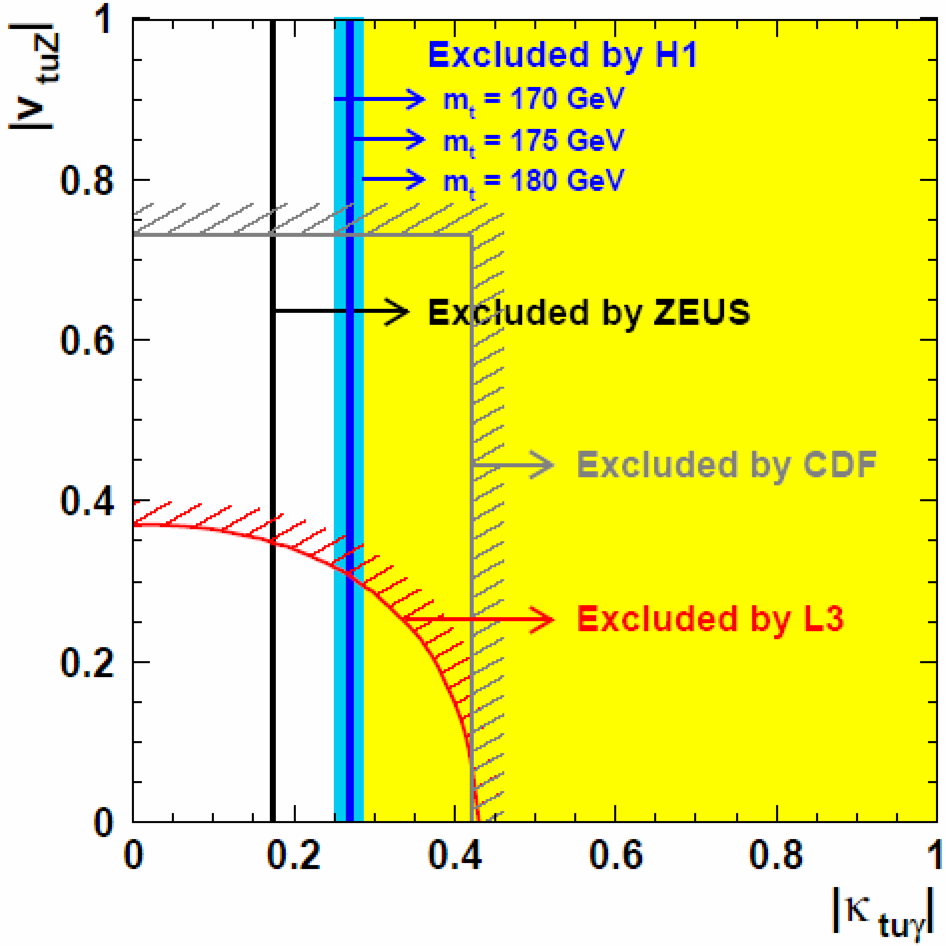
- Study $W \rightarrow \mu\nu_\mu$, $W \rightarrow \mu\nu_\mu$ and $W \rightarrow$ hadrons.
- Leptonic decays, look at p_{Tb}, $M_{l\nu b}$ and θ_{Wl} (angle between lepton in W rest frame and W in top rest frame).
- Cut and max likelihood analyses to identify top.



Single top production at HERA

- Cut based analysis:
  - Leptonic channels, 5 top candidates, SM 1.31 ± 0.22.
  - Hadronic channel, 18 top candidates, SM 20.2 ± 3.6.
- Likelihood analysis:
  - Leptonic channel $\sigma = 0.41^{+0.29}_{-0.19}$ pb.
  - Hadronic channel $\sigma = 0.04^{+0.27}_{-0.23}$ pb.
  - Combined $\sigma = 0.29^{+0.15}_{-0.14}$ pb. which implies that $\kappa_{tu\gamma} = 0.20^{+0.05}_{-0.06}$
- Upper limit on x-sect (95%CL): $\sigma(ep \to etX, \sqrt{s} = 319\,\text{GeV}) < 0.55\,\text{pb}.$

- Limits on anomalous tuγ coupling.



Summary

- Detectors based on the discovery made by Čerenkov 70 years ago have been crucial for the H1 physics programme so far and will remain so for as long as HERA and H1 are operated.
- These detectors have helped the upgraded HERA collider to achieve high luminosity operation and are now measuring that luminosity.
- HERA and H1 continue to provide an important testing ground for our ideas about perturbative and non-perturbative QCD.
- Comprehensive searches for new physics have been performed with existing H1 data: more data are needed to clarify and understand the observed anomalies.