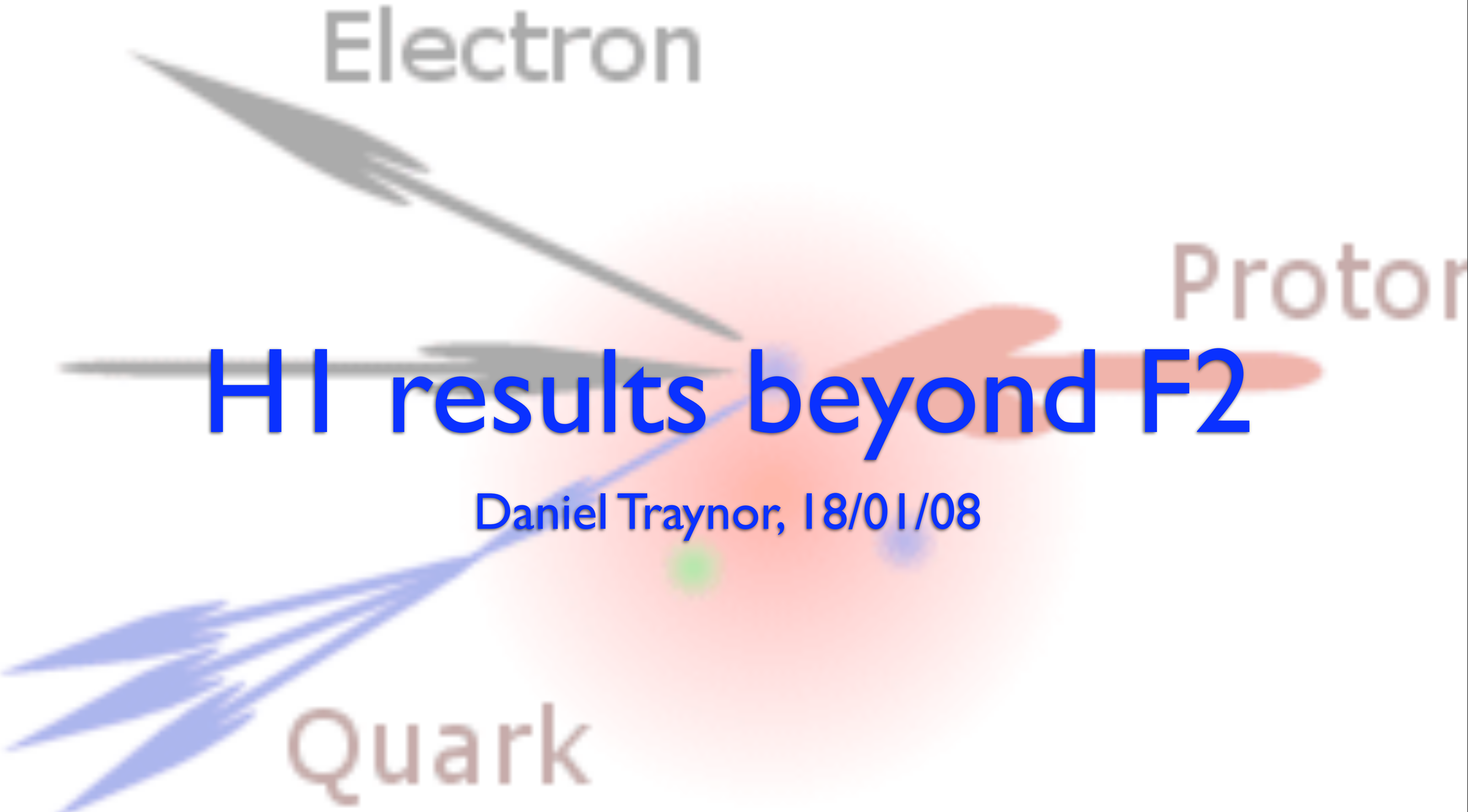
H1 results beyond F2

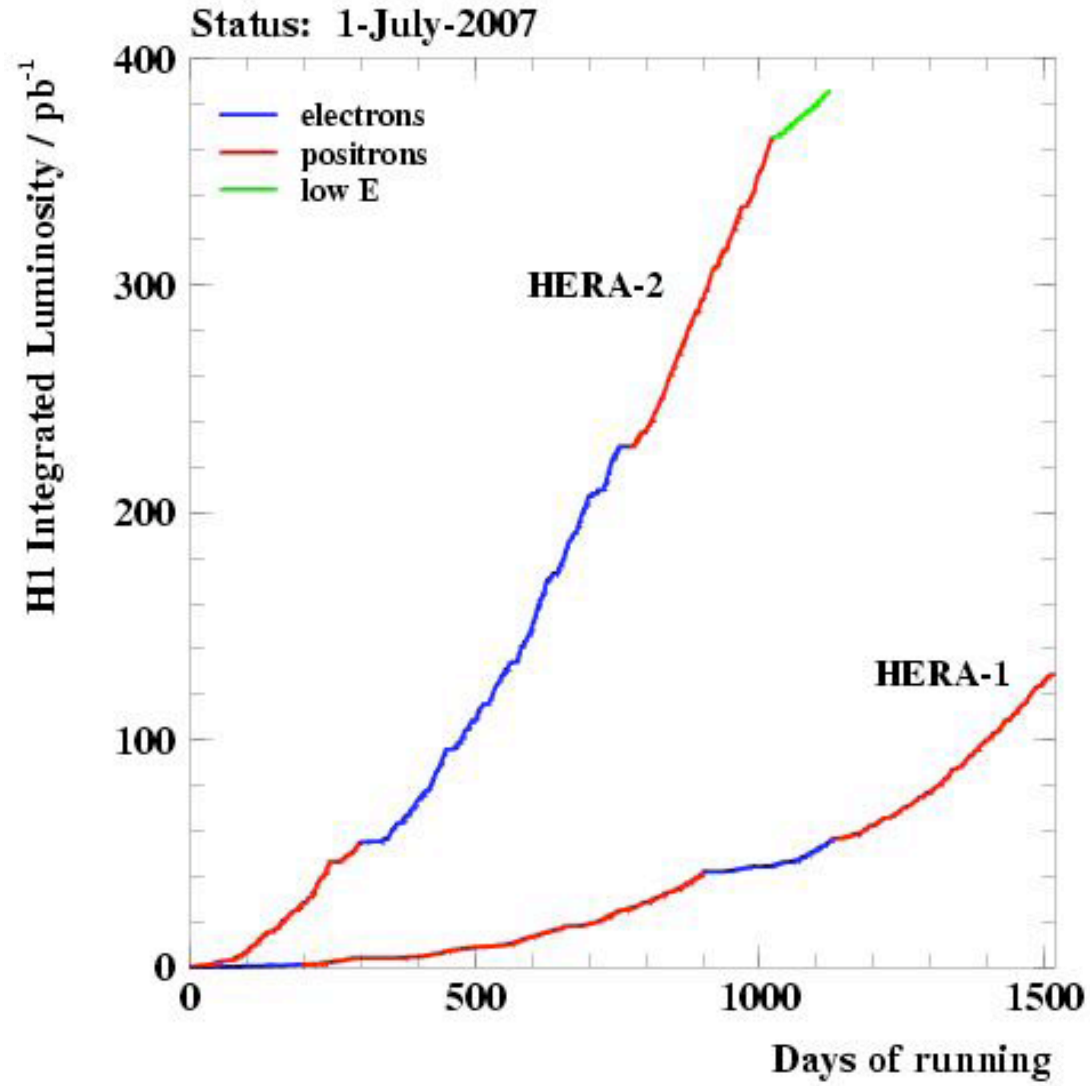
Daniel Traynor, 18/01/08



Overview

- Introduction to HERA physics and the H1 detector.
- The search for new physics.
- α_s from jets.

H1 and HERA



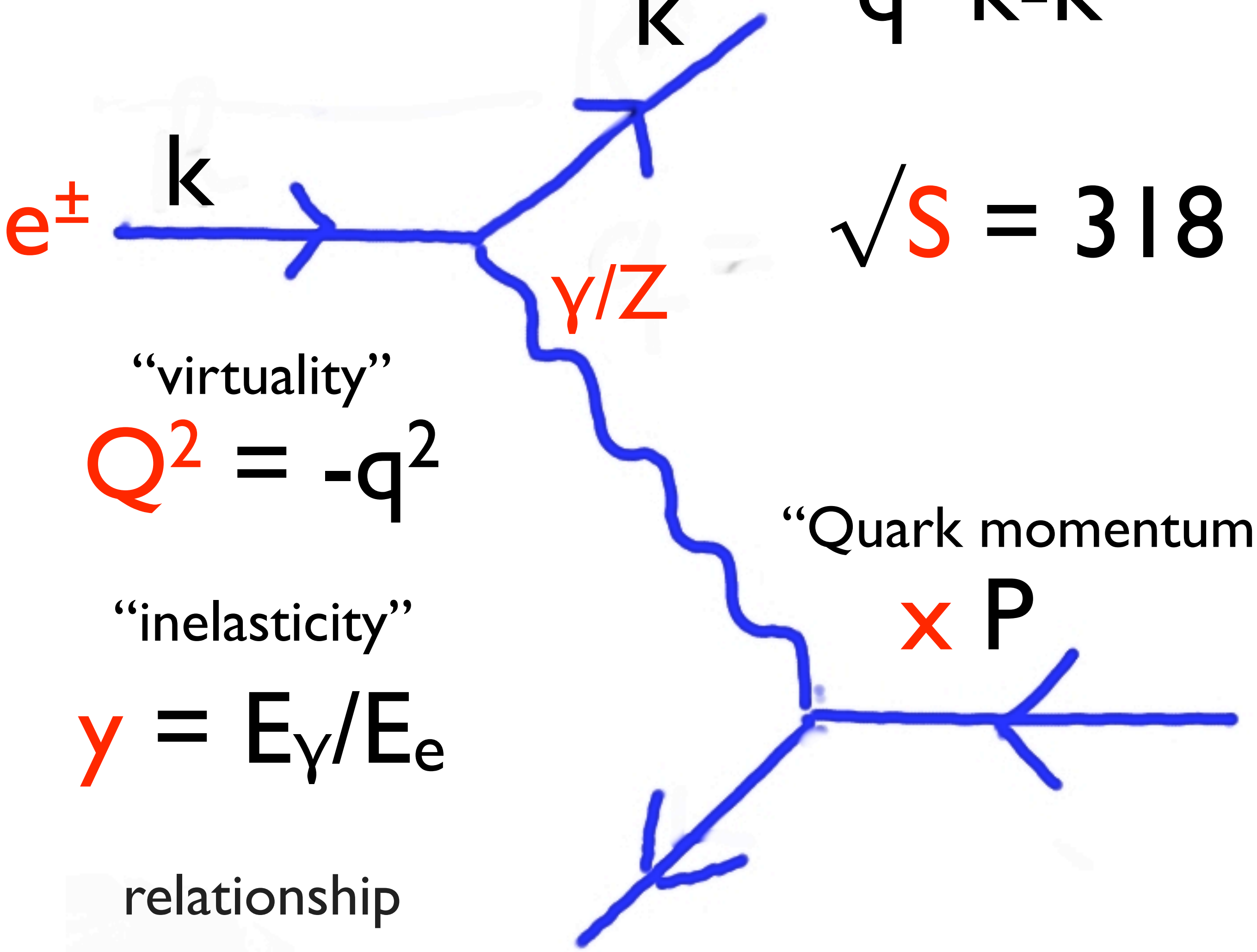
H1 Physics usable sample ~500 pb^{-1}

electrons or positrons

4 different proton energies

polarised lepton beams

Born level
"0th order QCD"!



$q=k-k'$

$\sqrt{S} = 318$ GeV

"virtuality"

$Q^2 = -q^2$

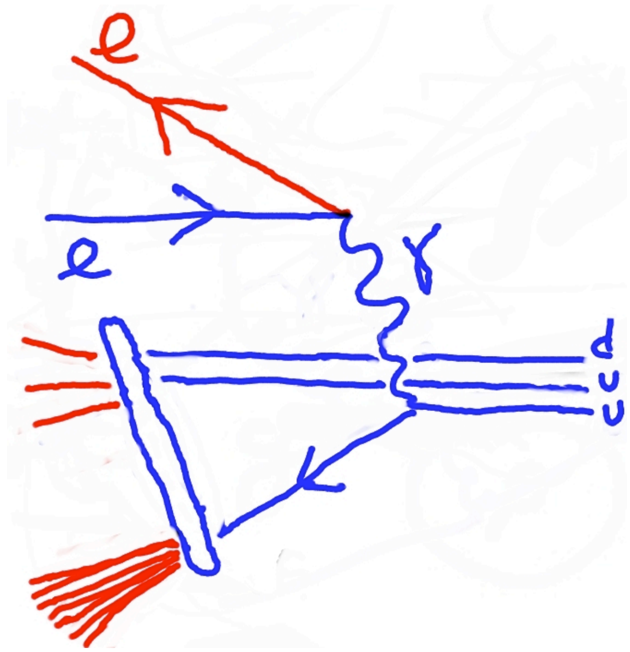
"inelasticity"

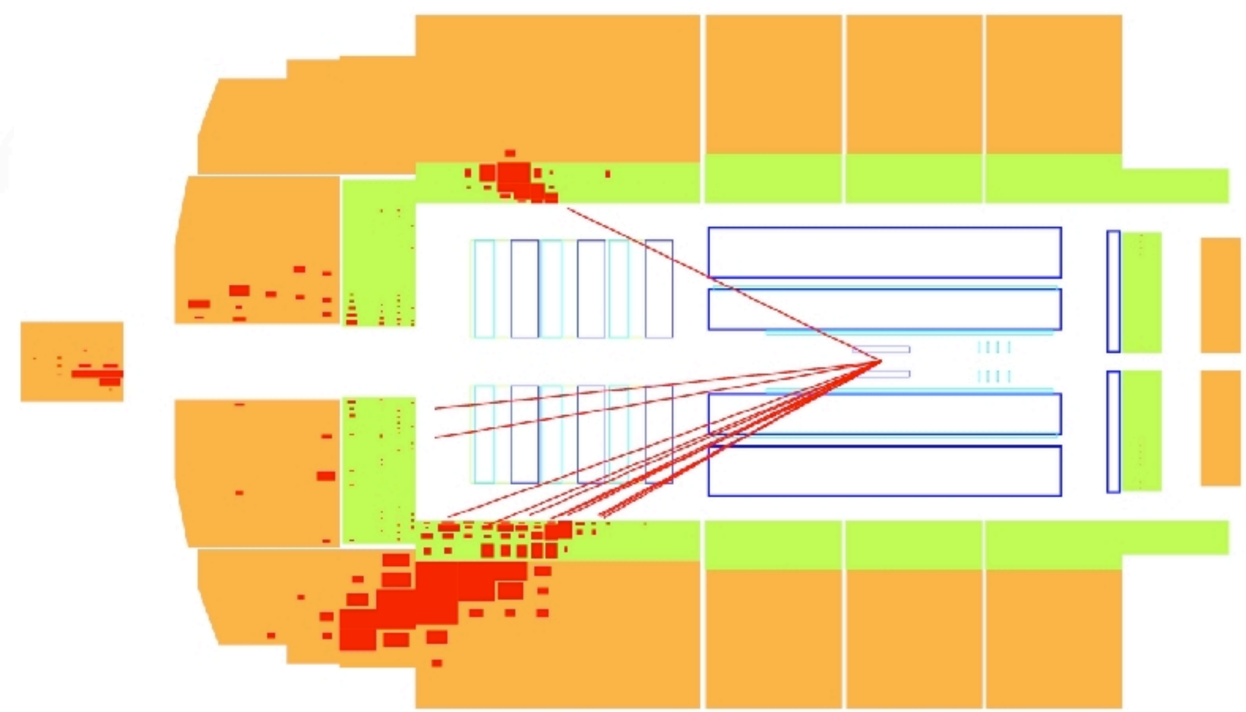
$y = E_{\gamma}/E_e$

relationship

$Q^2 = Sxy$

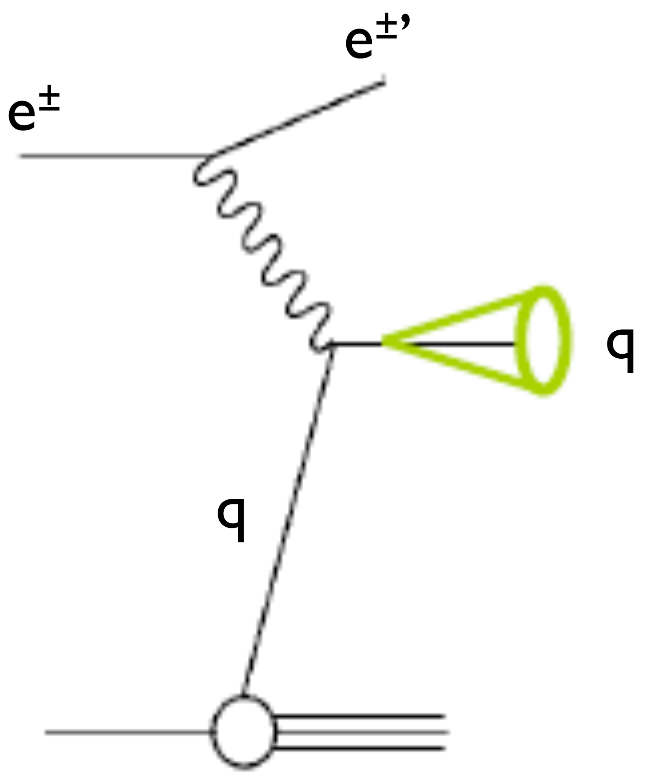
"Quark momentum"



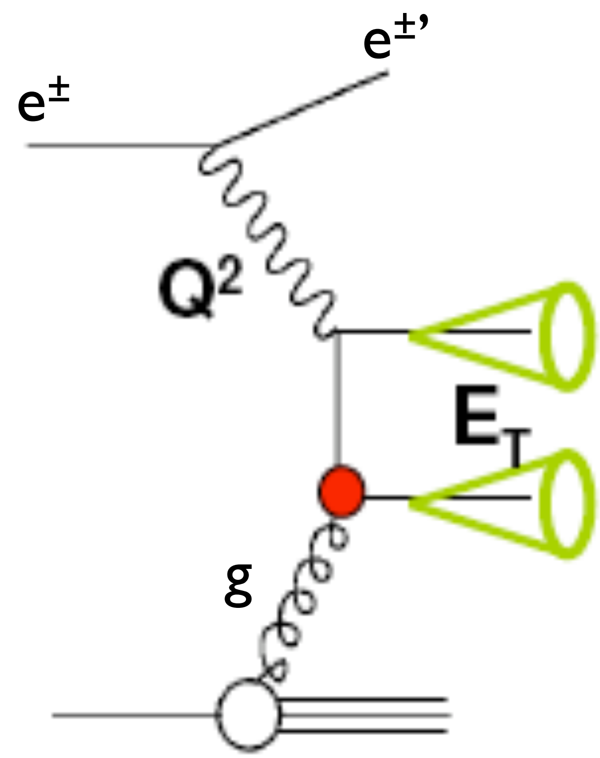


Deep Inelastic Scattering (DIS)

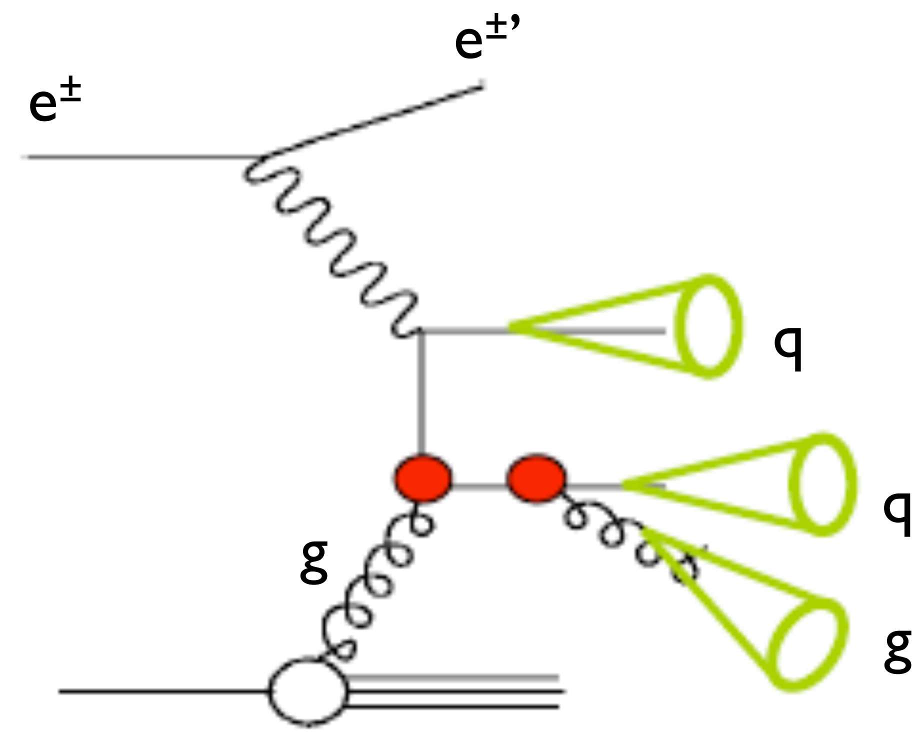
BORN



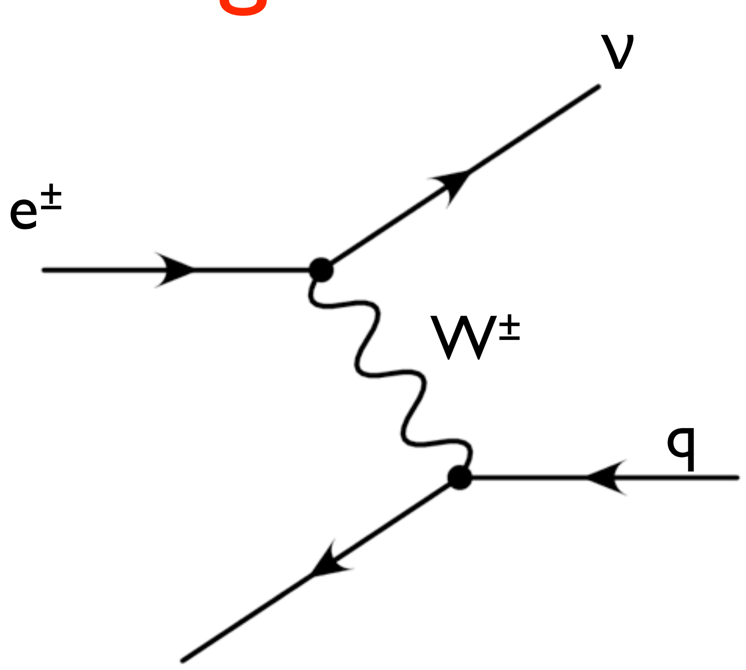
LO
BGF



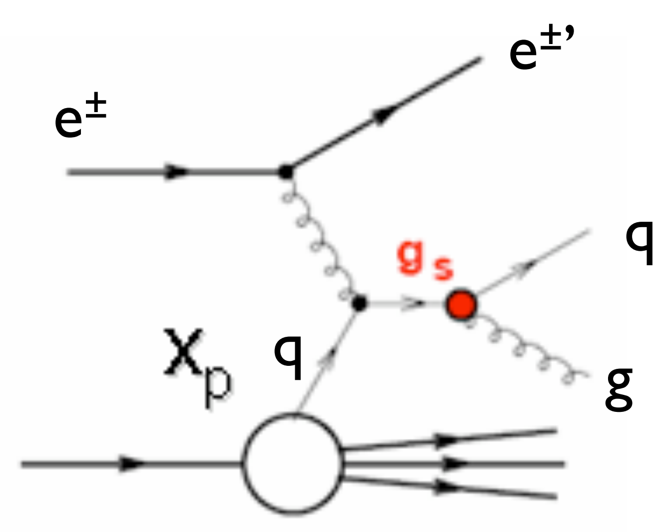
NLO



Charge Current

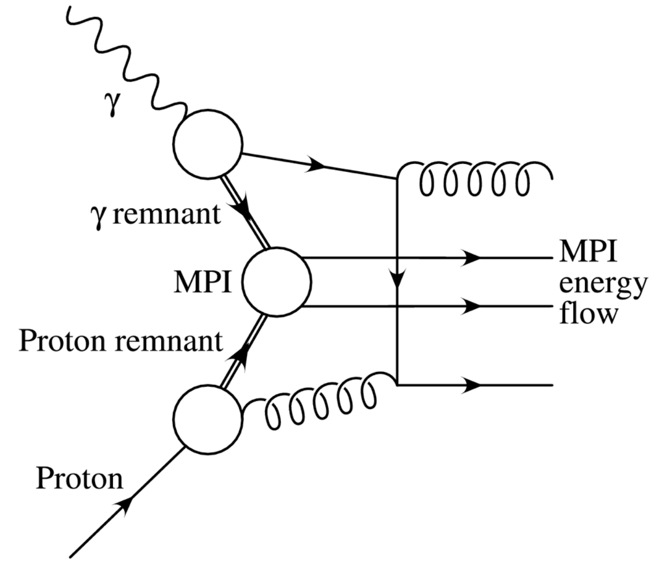


LO QCDCompton

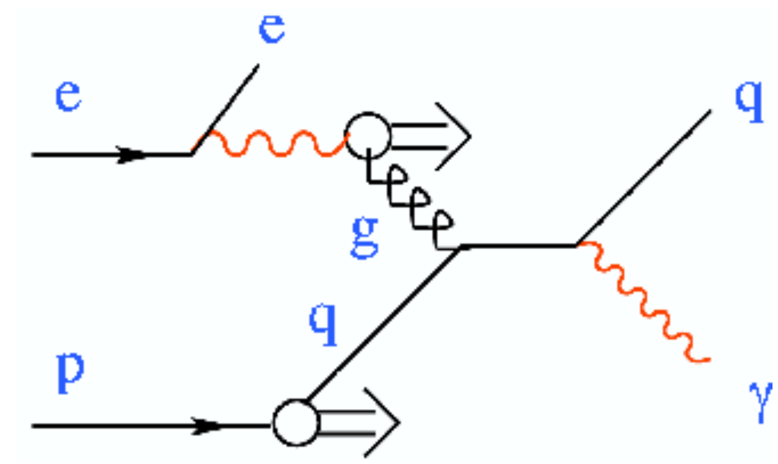


Not only but also

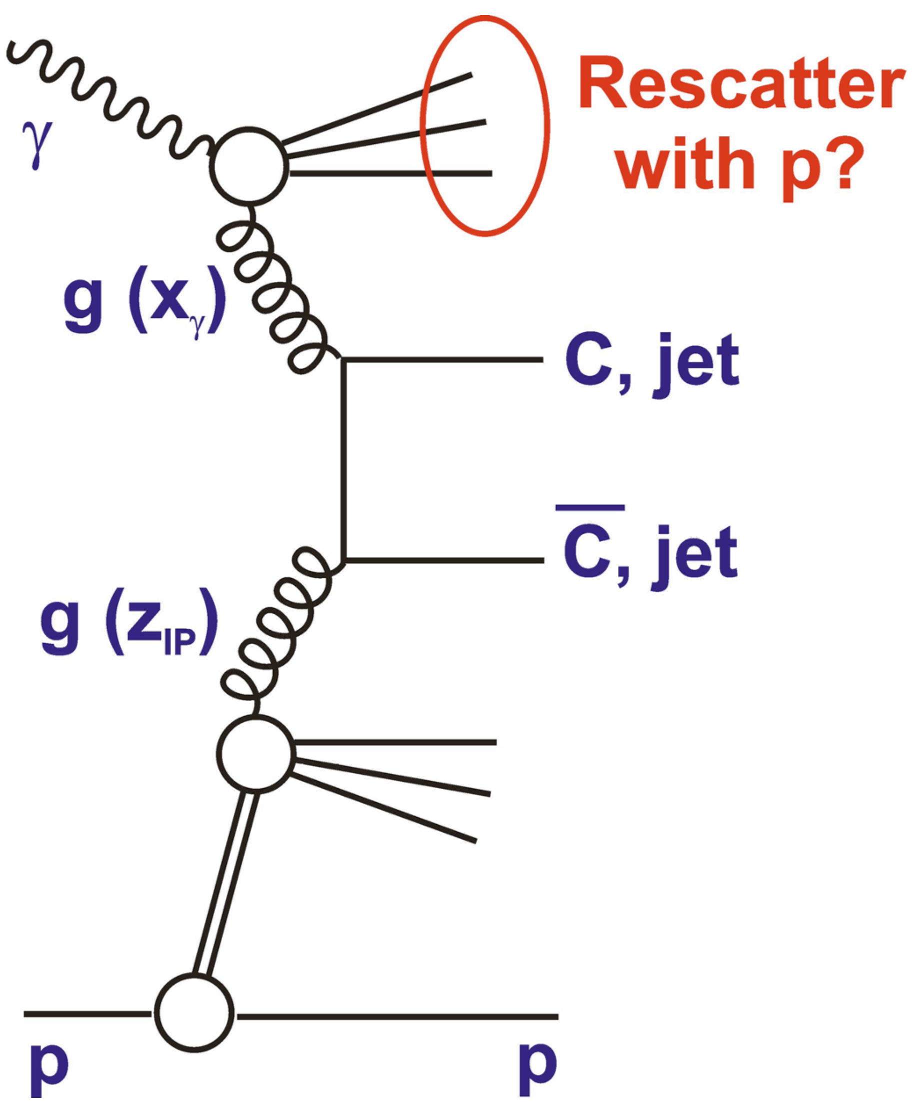
Underlying event



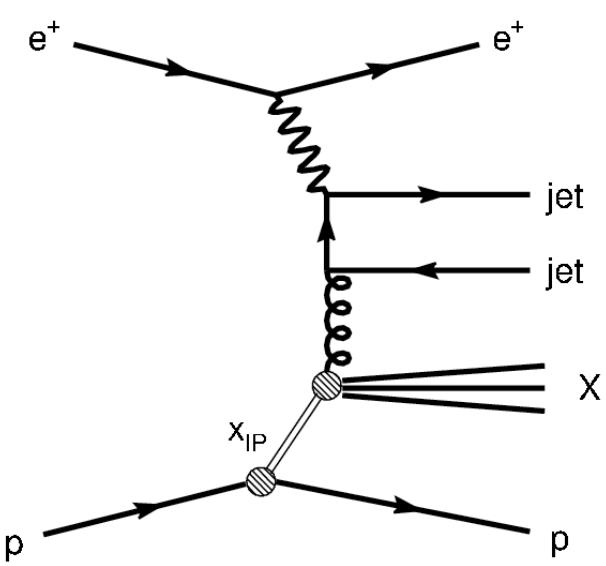
Prompt photons

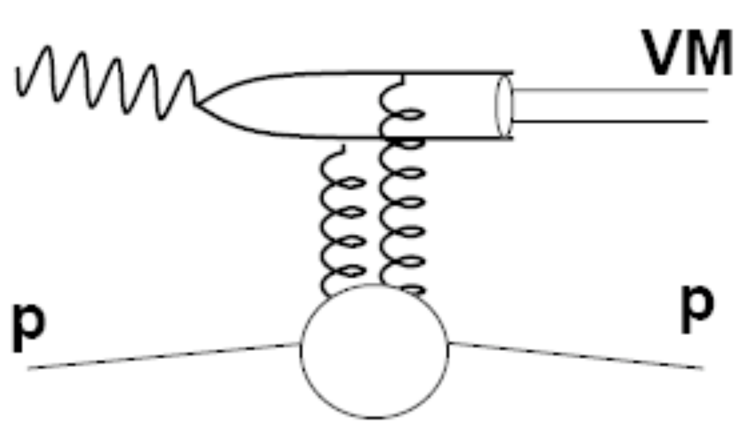


Photoproduction

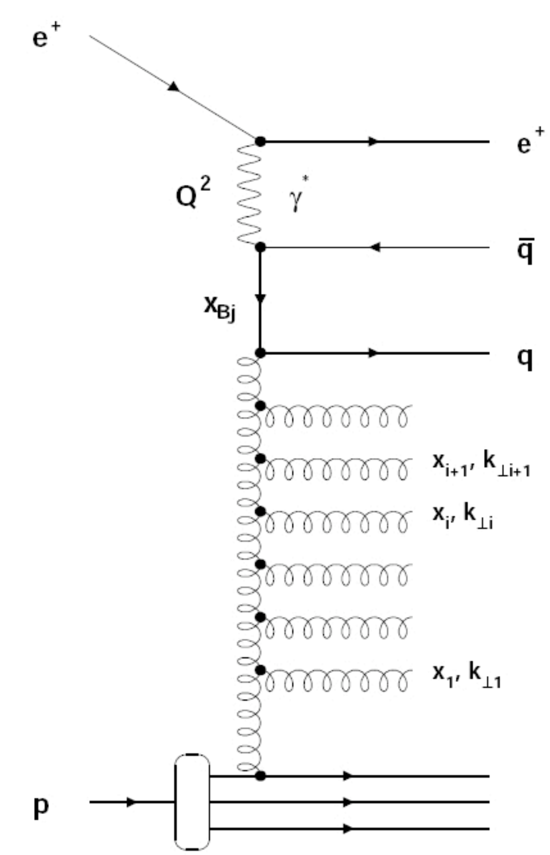


Diffraction





low x, BFKL



Physics goals from the '70's

- Measure structure functions:
  - F_2, xF_3, F_s, F_c, F_b, F_t.
- Test QCD.
- Study weak neutral and charged current with polarisation.
- Search for new physics:
  - *e* or *q* substructure, new gauge bosons, new interactions.
- Nothing on:
  - Diffraction, low-*x*.

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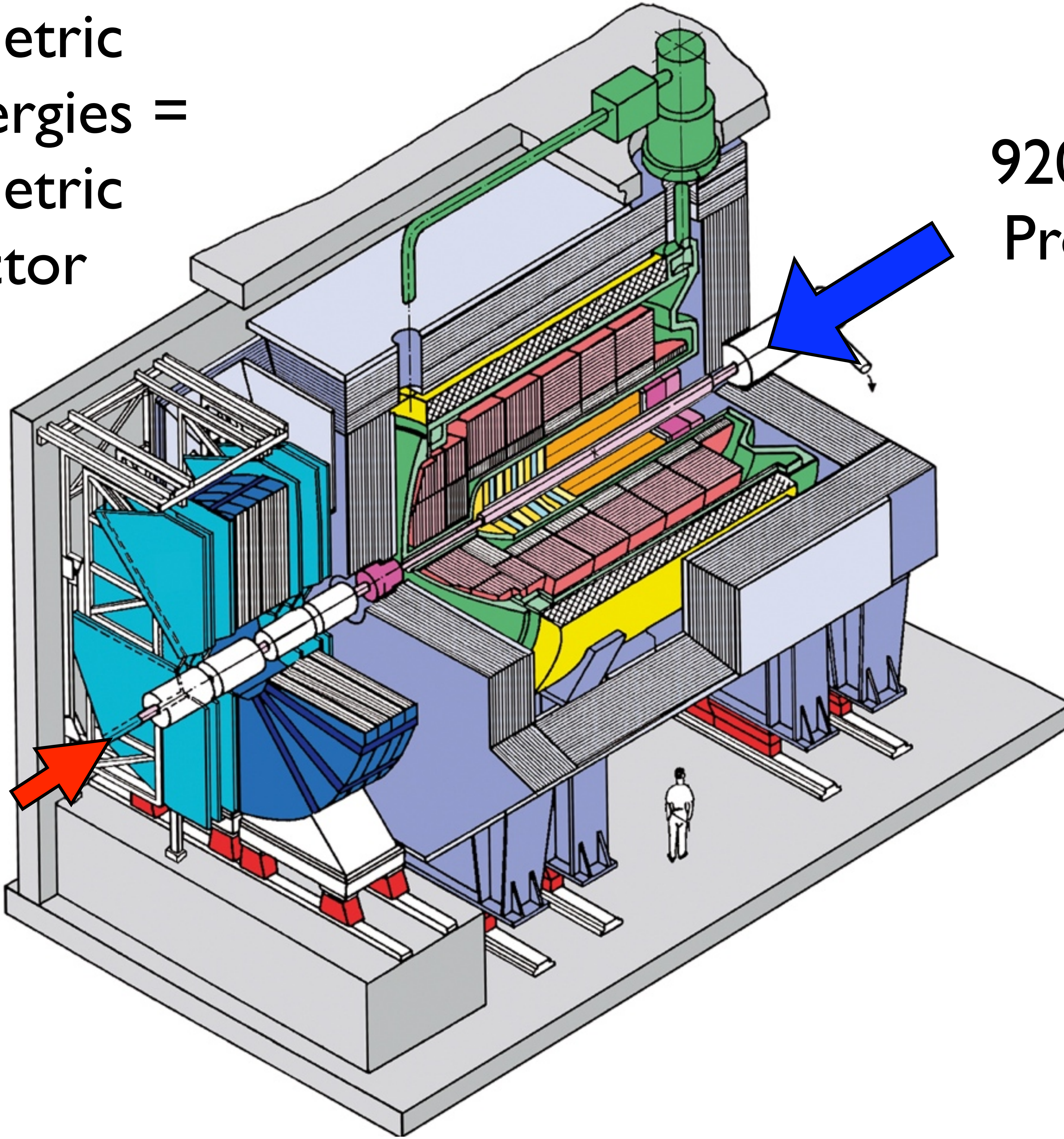
- Nothing on:
    - Diffraction, low-*x*. → Sends most people to sleep

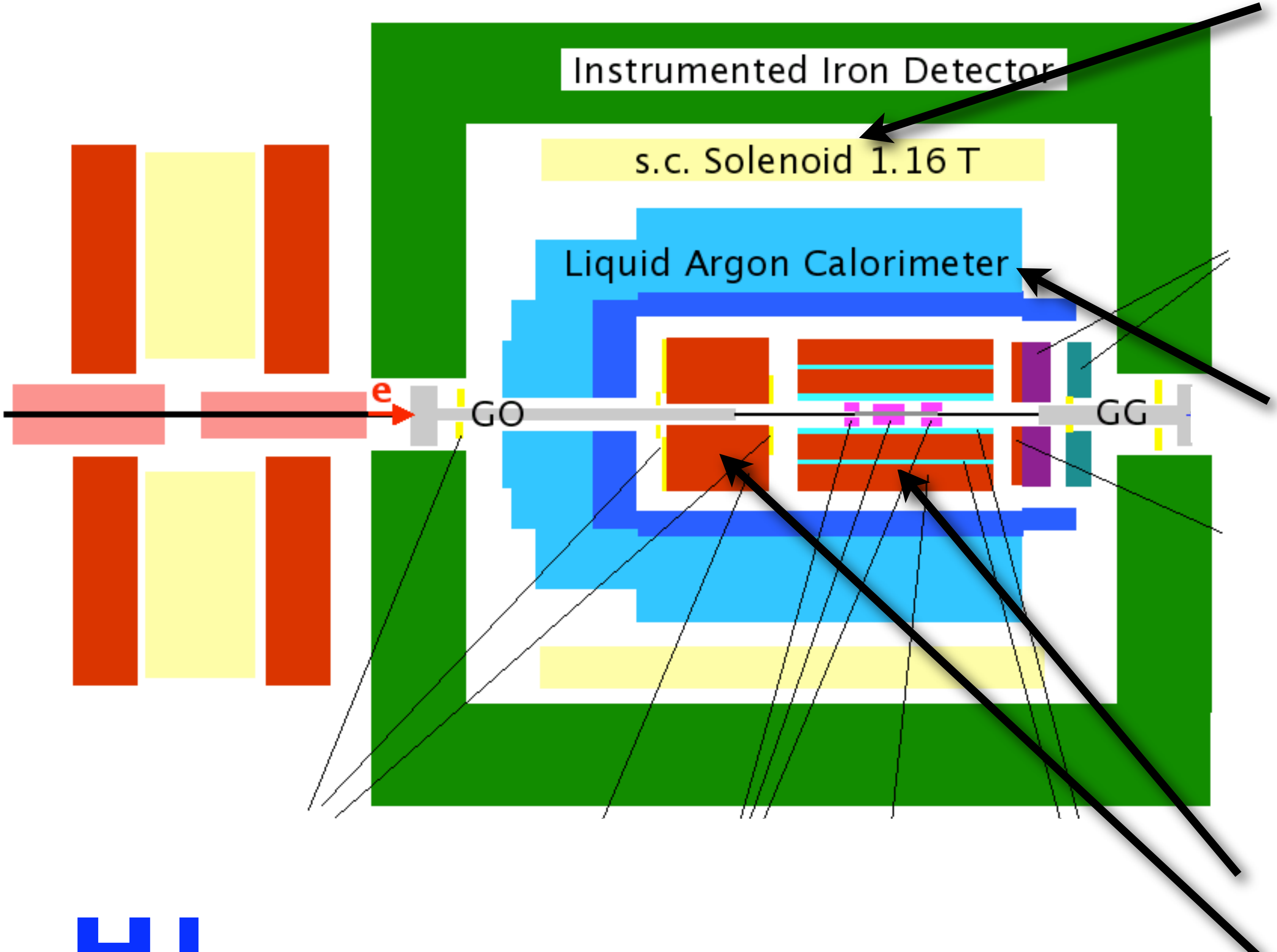
asymmetric
beam energies =
asymmetric
detector

920 GeV
Protons



27.5 GeV
electrons

H1



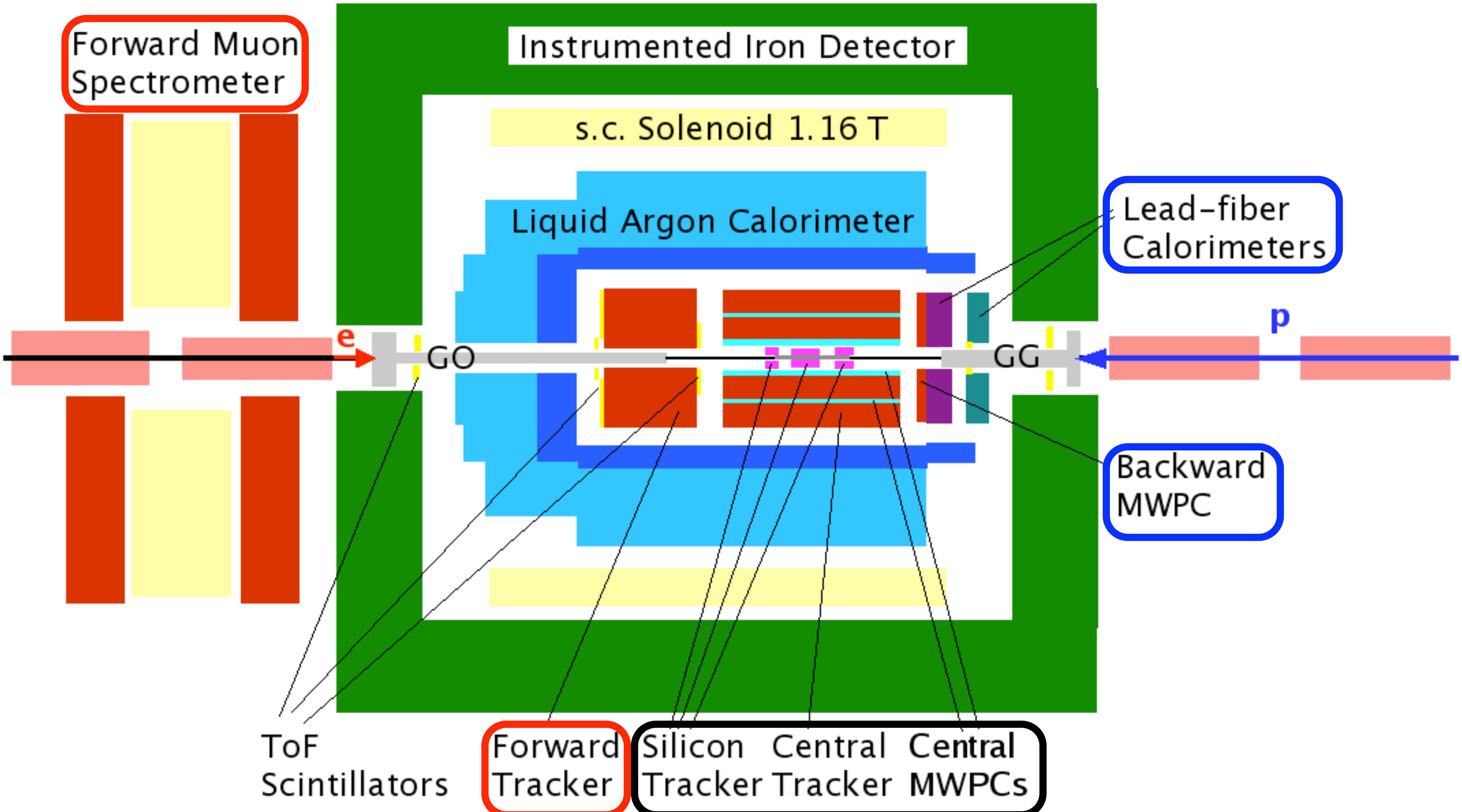
1.16 T solenoid, radius 2.7 m (ALEPH like)

coil outside calorimeter for best resolution!

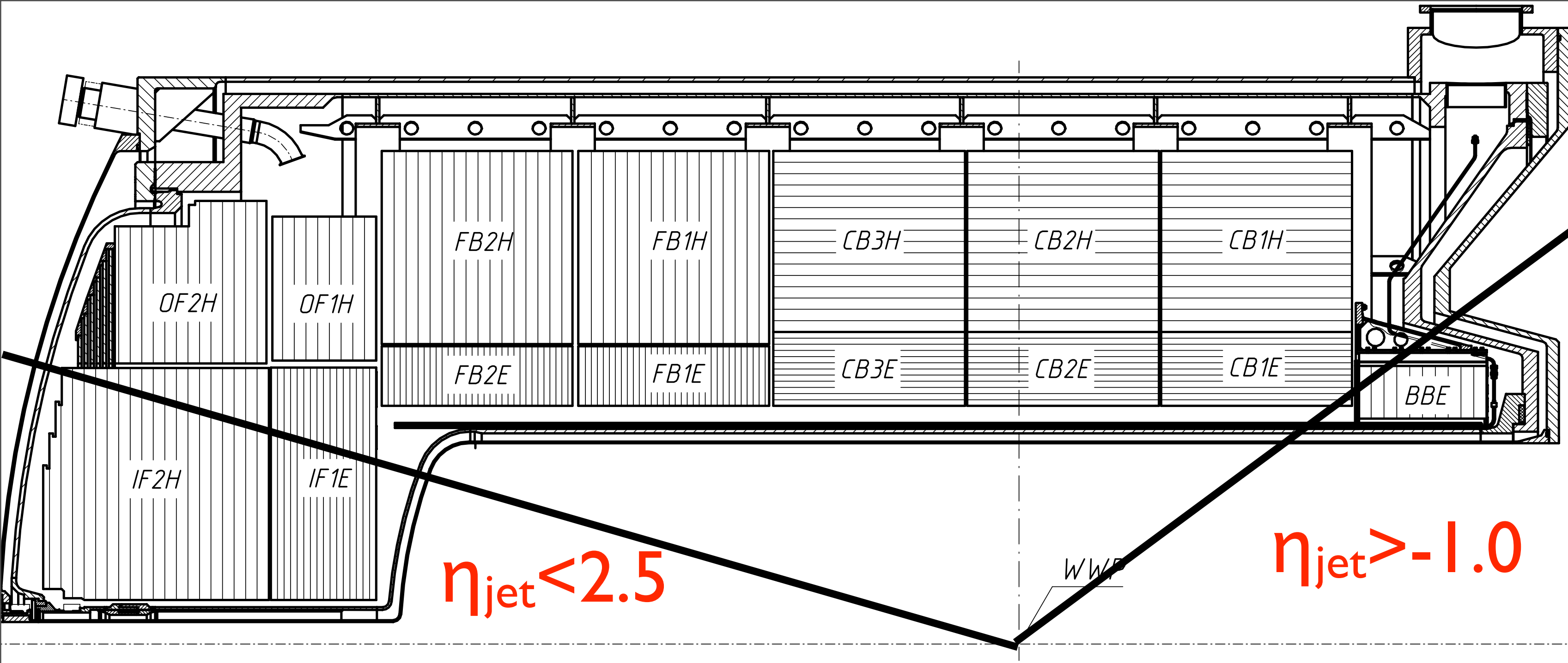
Uniform field for tracking (central and forward)!

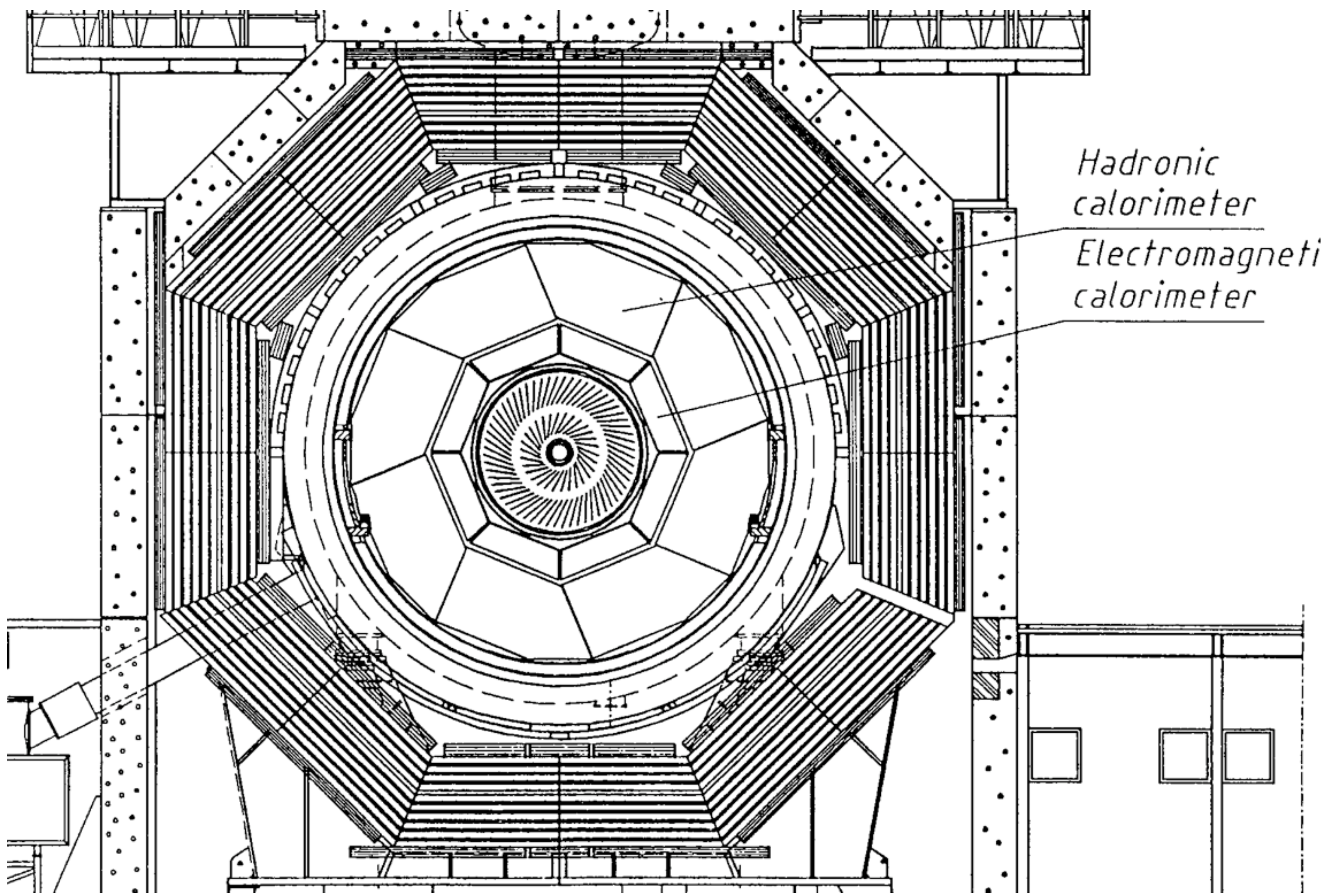
H1

central muon detector



H1





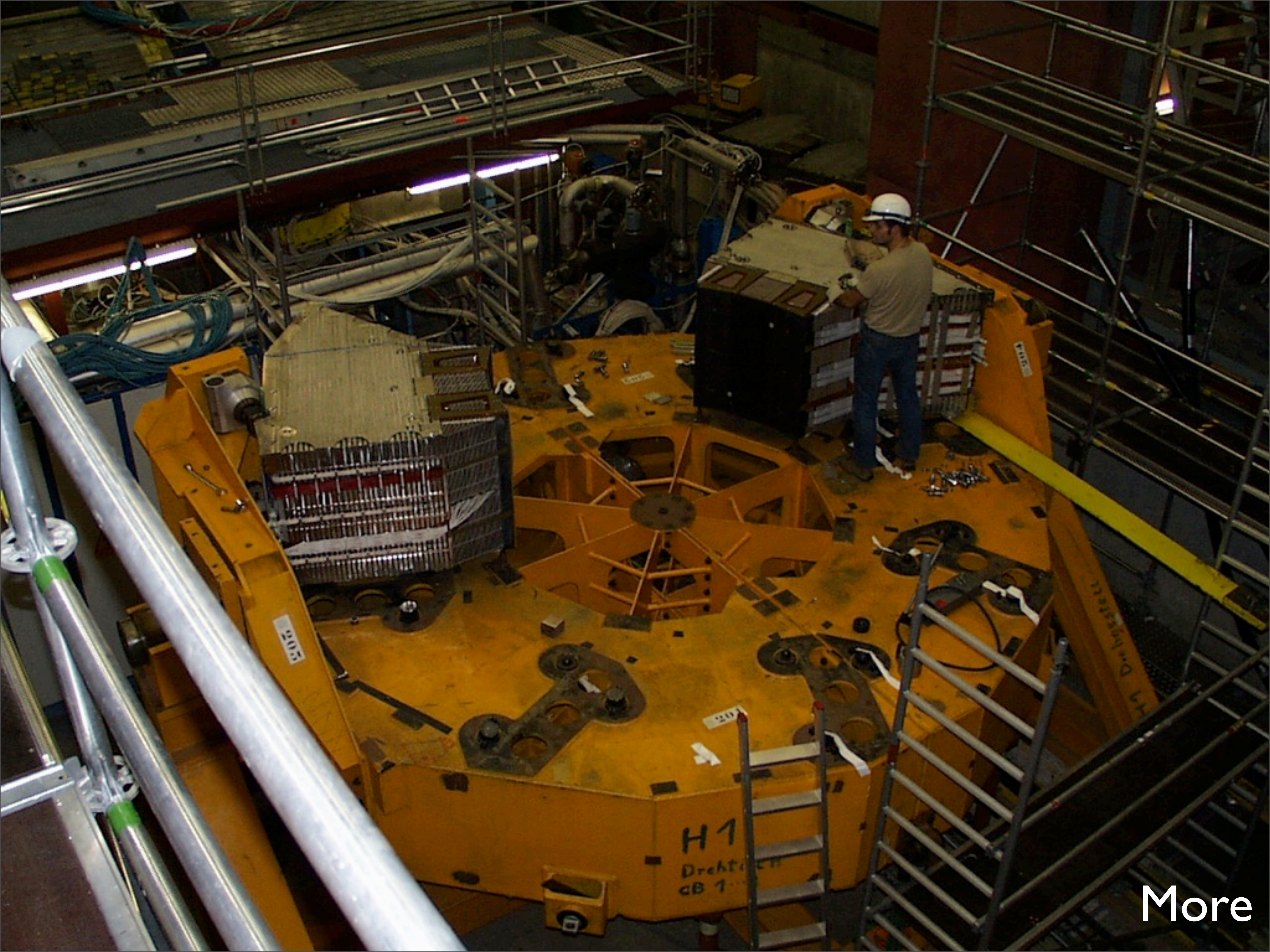
LAr colorimeter has 44,000 cells! with lead (EM) and steal (hadronic) absorbers

Uses software energy reweighting for EM and hadronic parts

EM resolution
$\sigma_E/E = 0.12/E(GeV)$

Hadronic resolution
$\sigma_E/E = 0.5/E(GeV)$

EM energy scale <1%
Hadronic energy scale <2%
1% for final publications


H1
More

Context

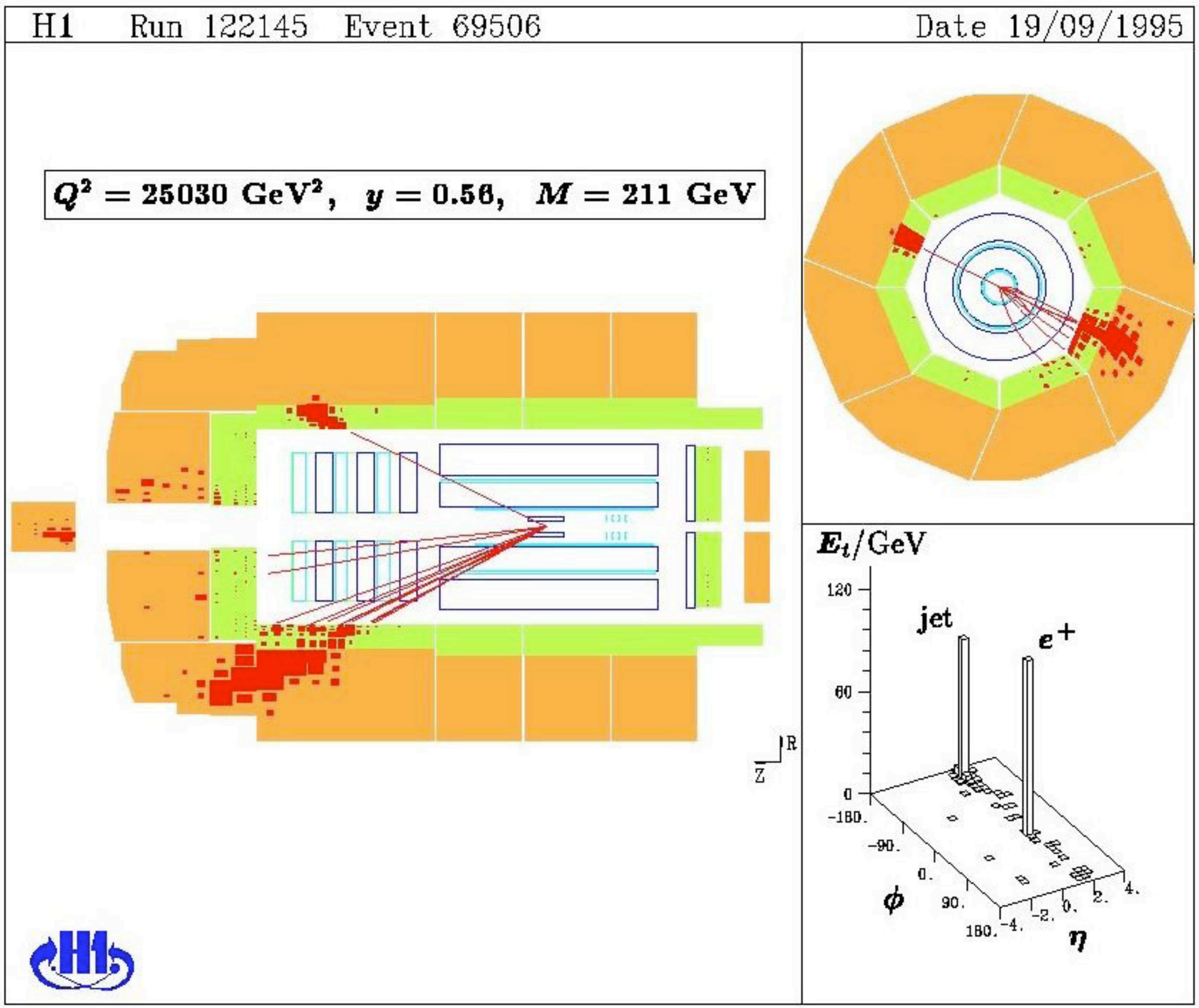
	H1 (1992)	ATLAS (2008)
Bunch crossing intervals	96 ns (10.4 MHz)	25 ns (40 MHz)
L1 trigger rate	1 kHz (2.5 µs)	75 kHz (2.5 µs)
# of channels	750,000	14,000,000
event size	100 kBytes	1.5 MByte
Physics out put	5 Hz 1996 (50 Hz 2007)	200 Hz
data production	10 GBytes /day	100 GBytes / day
overall size	10 x10 x12 m	25 x 25 x 46 m

Search for new Physics

"HERA as a frontier collider"

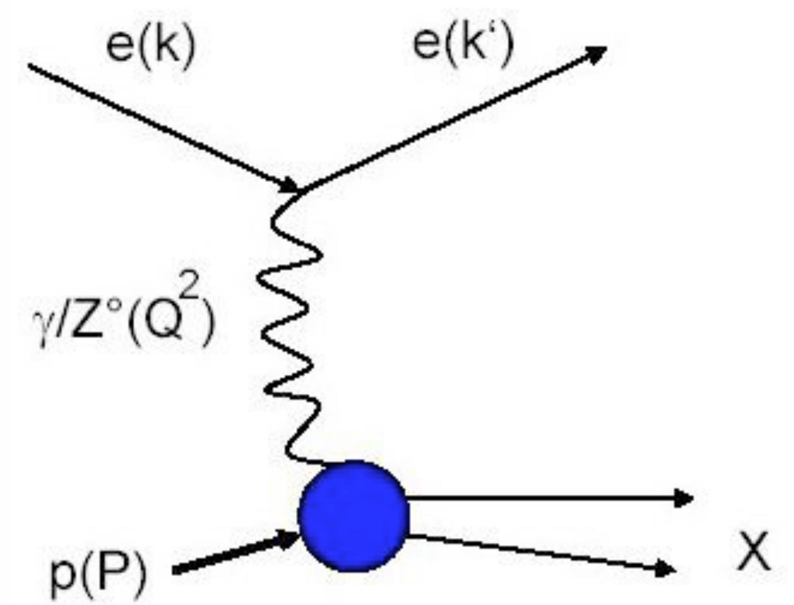
- NC cross section and the quark radius.
- Polarised CC cross section and wrong handed neutrinos.
- Isolated leptons with missing P_t.

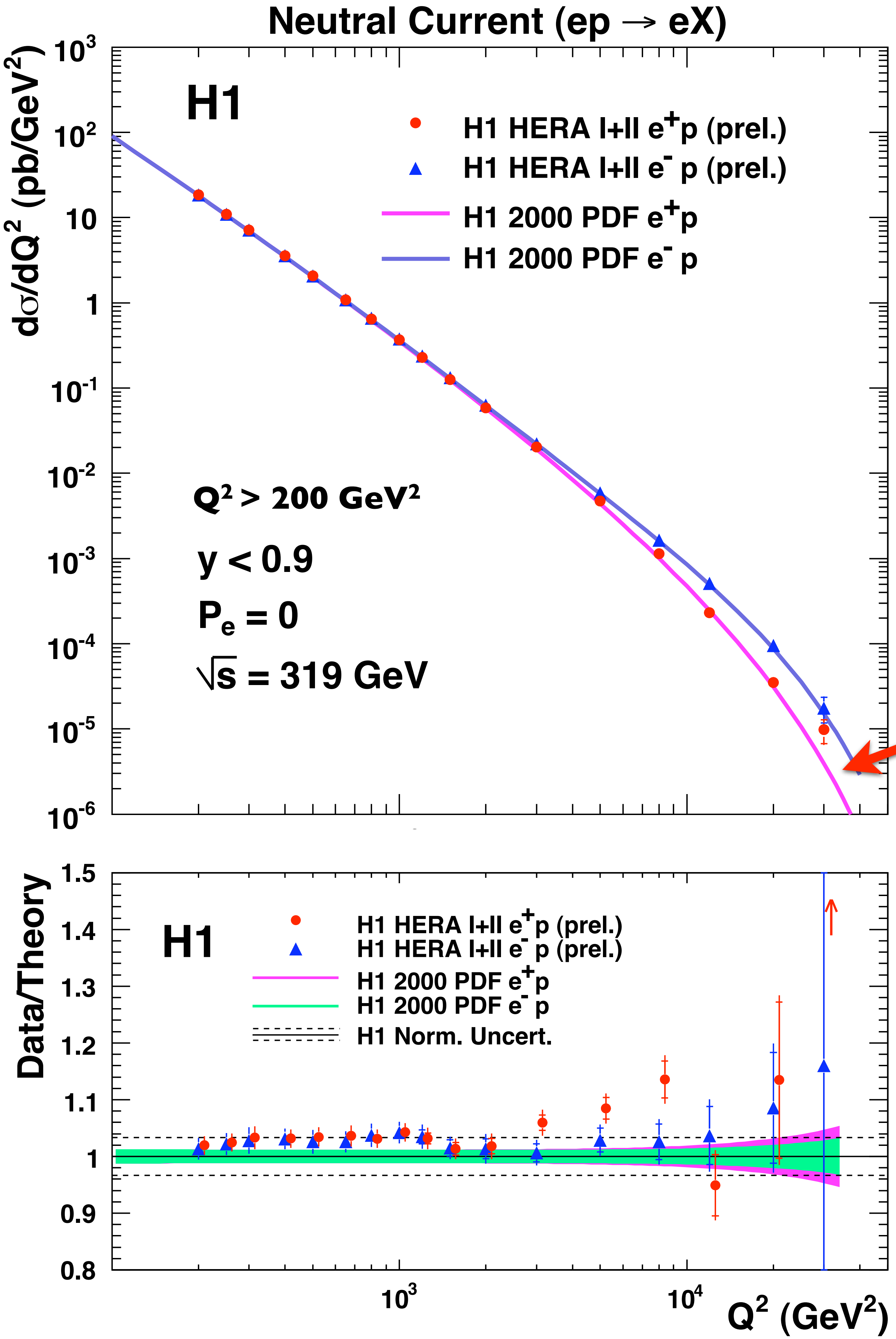
Neutral Current Measurements



$e^{\pm}p \rightarrow e^{\pm}X$

Signature: scattered electron and hadron jet(s), transverse momentum balance





Neutral current single differential cross section

$$e^{\pm}p \rightarrow e^{\pm}X$$

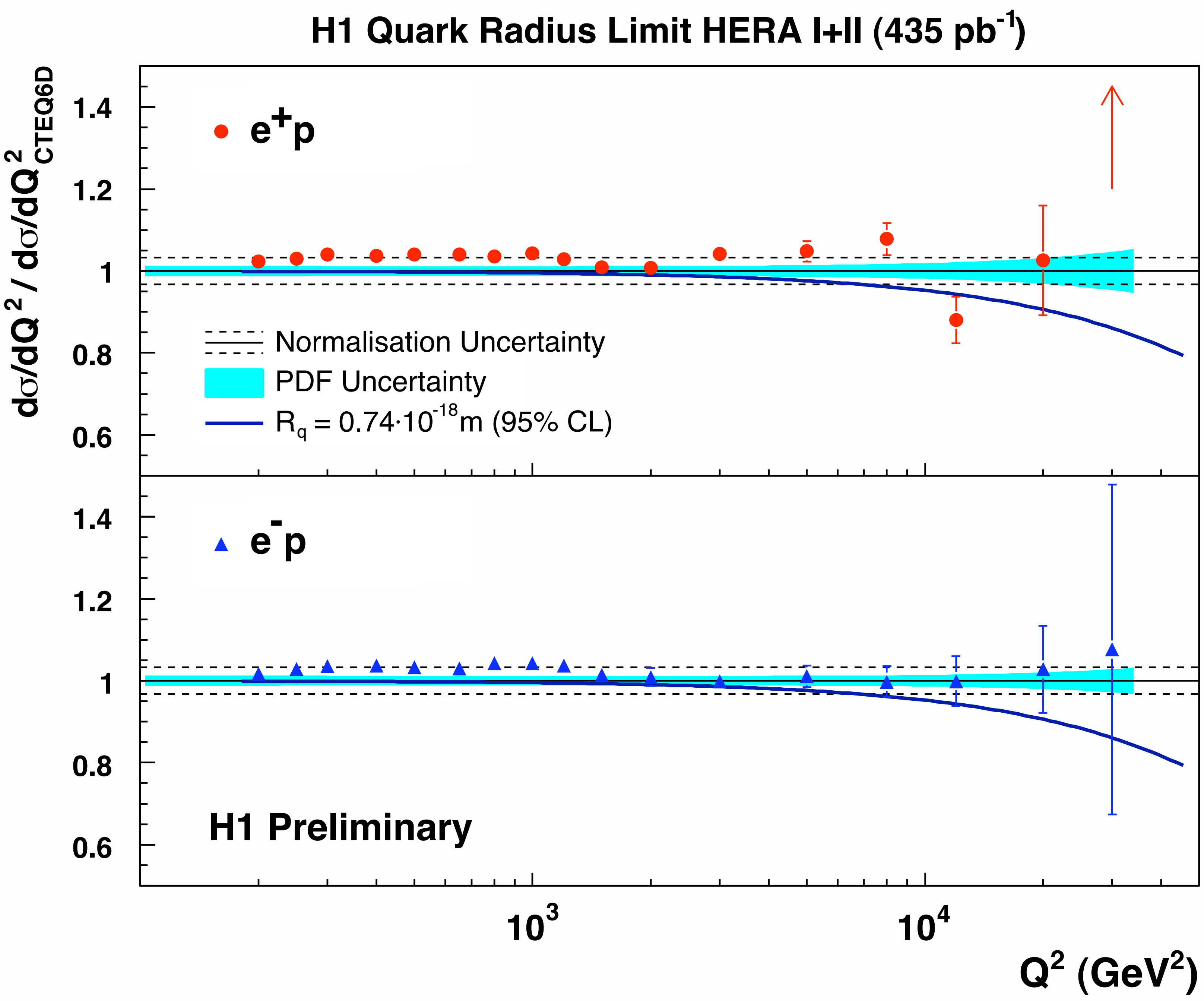
HERAI+II luminosity (435 pb^{-1})

electroweak interference effects

Beam charge (and polarisation) effects due to the interference of photon with Z boson

Data and standard model prediction agree within errors

Fermion substructure



Use form factors for electrons and quarks

$$f(Q^2) = 1 - \frac{< r^2 >}{6} Q^2$$

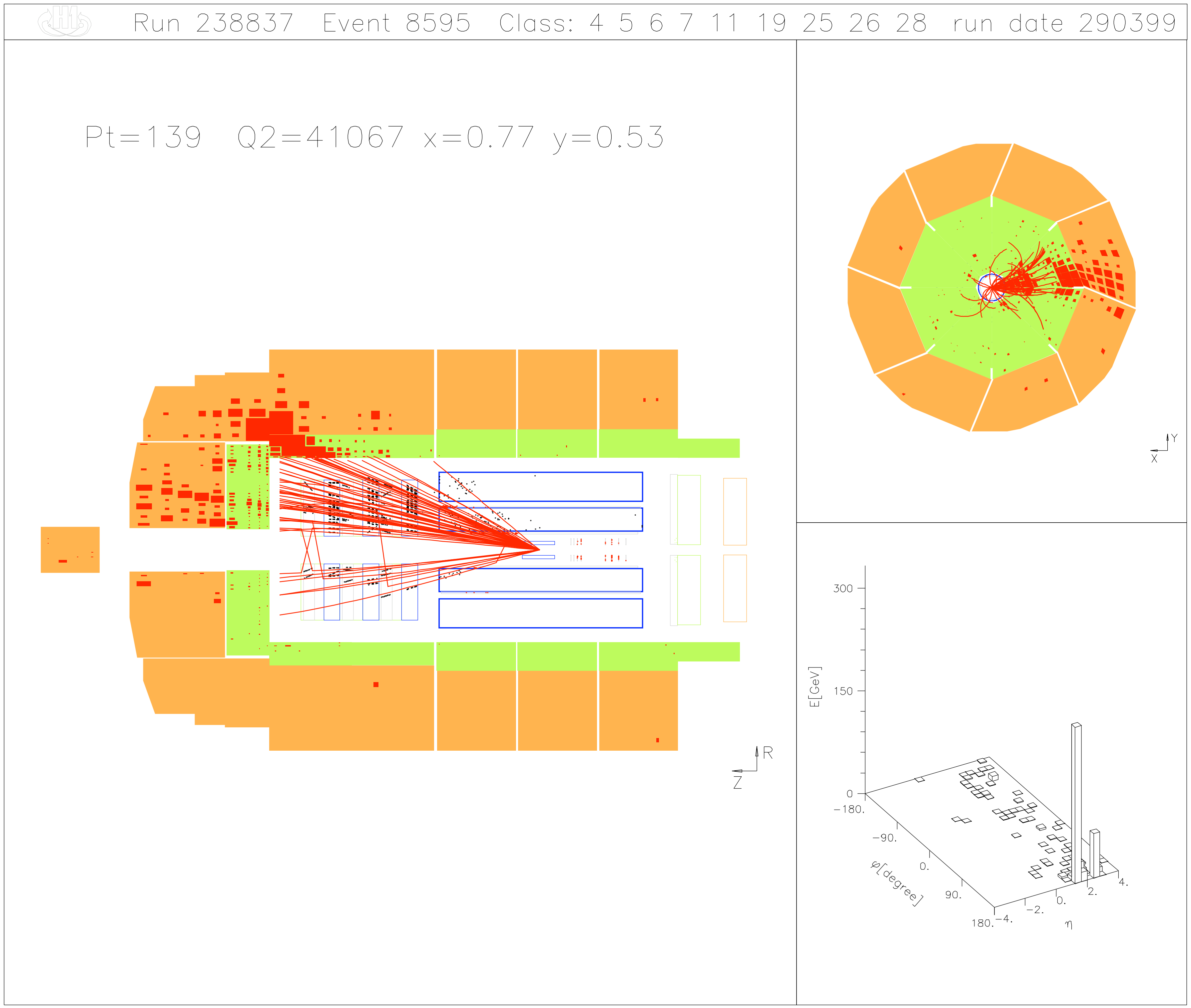
r ~ electroweak charge distribution

$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{SM}}{dQ^2} f_e^2(Q^2) f_q^2(Q^2)$$

$$R = \sqrt{(< r^2 >)}$$

$R_{e,q} < 0.74 \cdot 10^{-18}$m at 95% CL

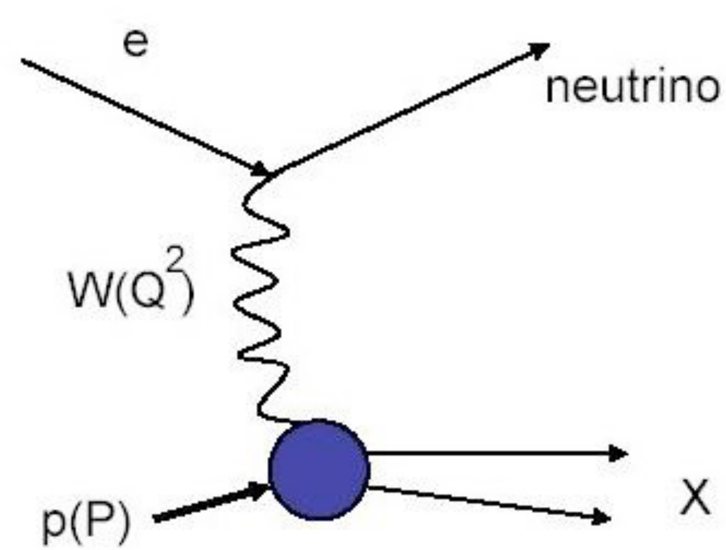
Charged Current Measurements



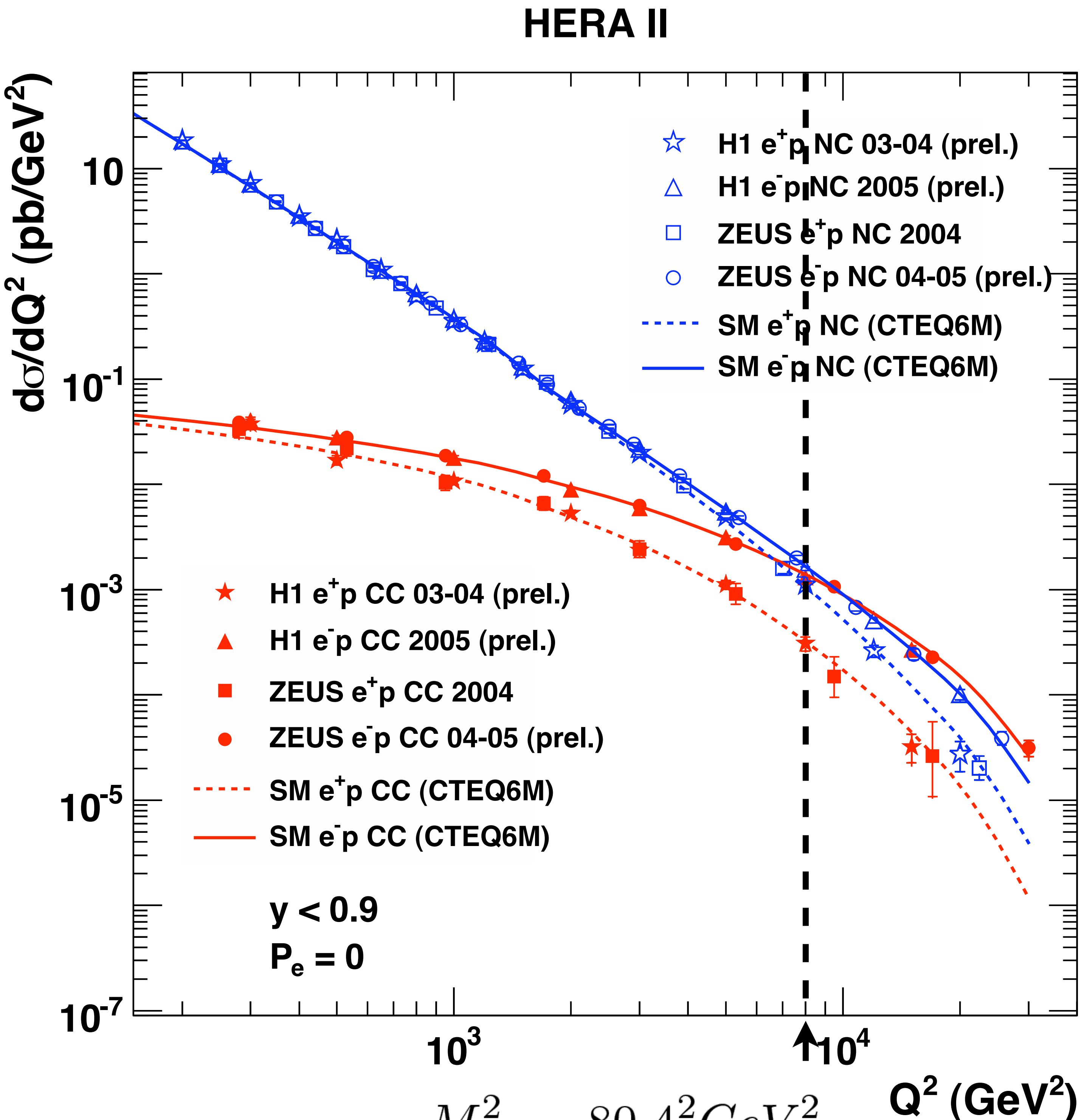
$$e^+p \rightarrow \bar{\nu}_e X$$

$$e^-p \rightarrow \nu_e X$$

Signature: no scattered electron, missing p_t



Charged Current single differential cross section



$$M_W^2 = 80.4^2 GeV^2$$

Suppressed cross section at low Q^2 due to propagator mass (M_W~80 GeV)

NC ~ $1/Q^4$

CC ~ $[M^2_W/Q^2 + M^2_W]^2$

At high Q2 NC and CC cross section approximately equal

Difference between e^+ and e^- CC

1) Two *u*'s and one *d* quark.

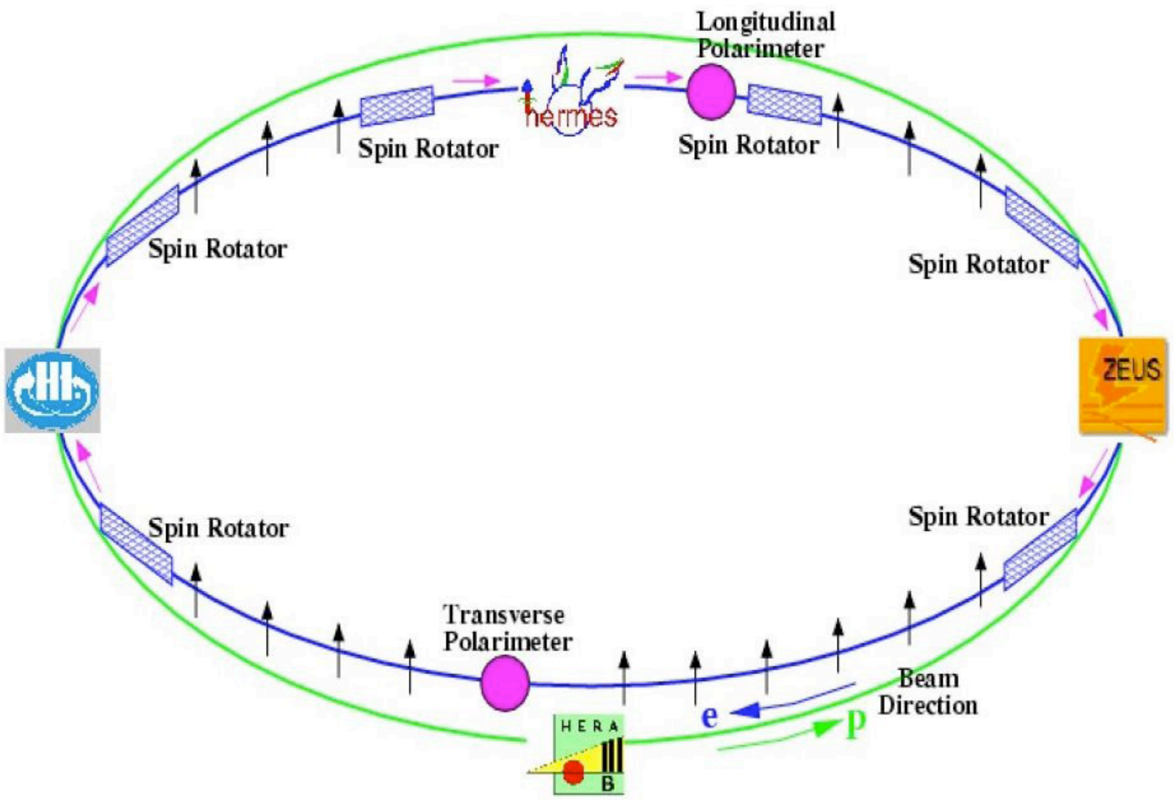
2) Angular momentum conservation

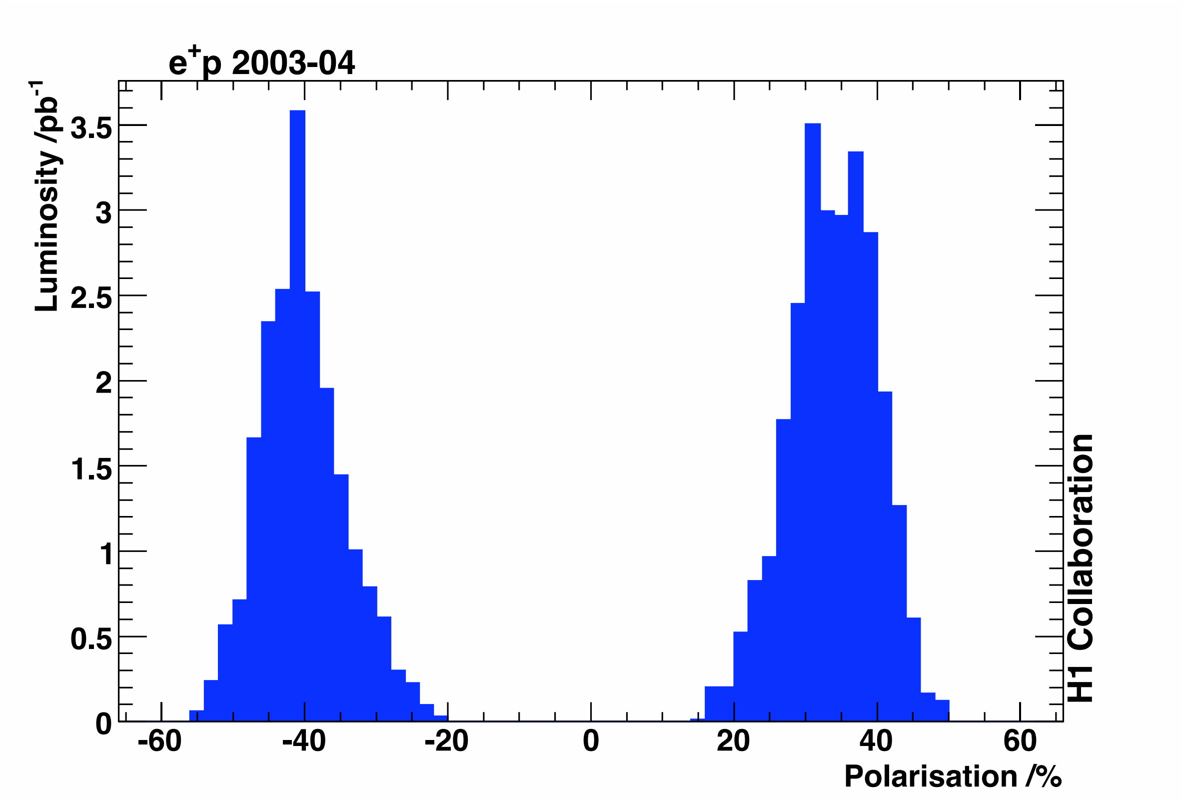
$e^+(\rightarrow) + d(\rightarrow) \Rightarrow J_z=1 \Rightarrow (1 - y2)$

$e^-(\leftarrow) + u(\rightarrow) \Rightarrow J_z=0 \Rightarrow$ isotropic

Data and standard model agree.

Charged Current Polarisation





Longitudinal polarisation of lepton beam: new at HERA II.

The transverse polarisation builds up naturally (SokolovTernov effect)

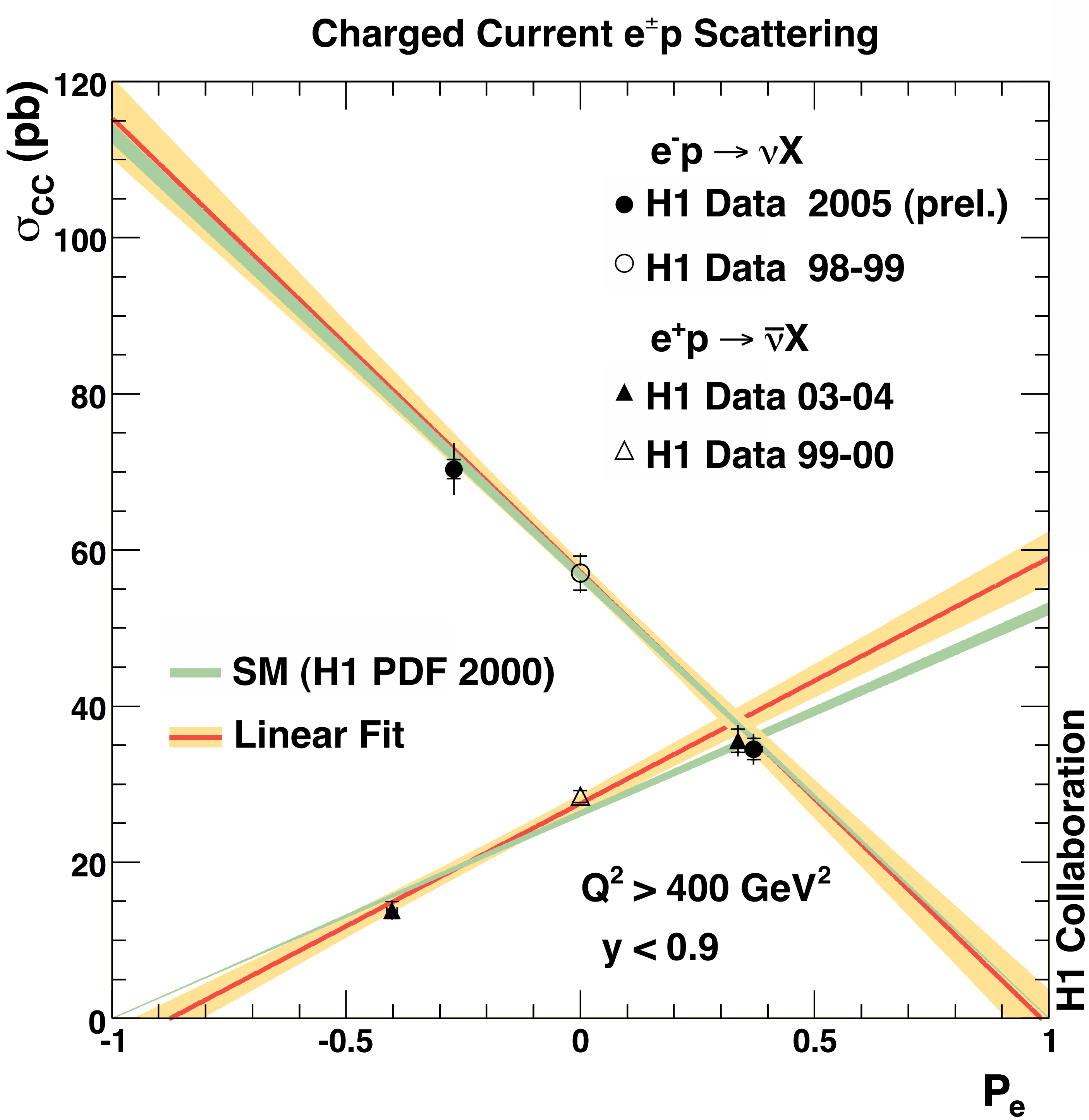
Spin rotators flip the polarisation to longitudinal just before the interaction regions.

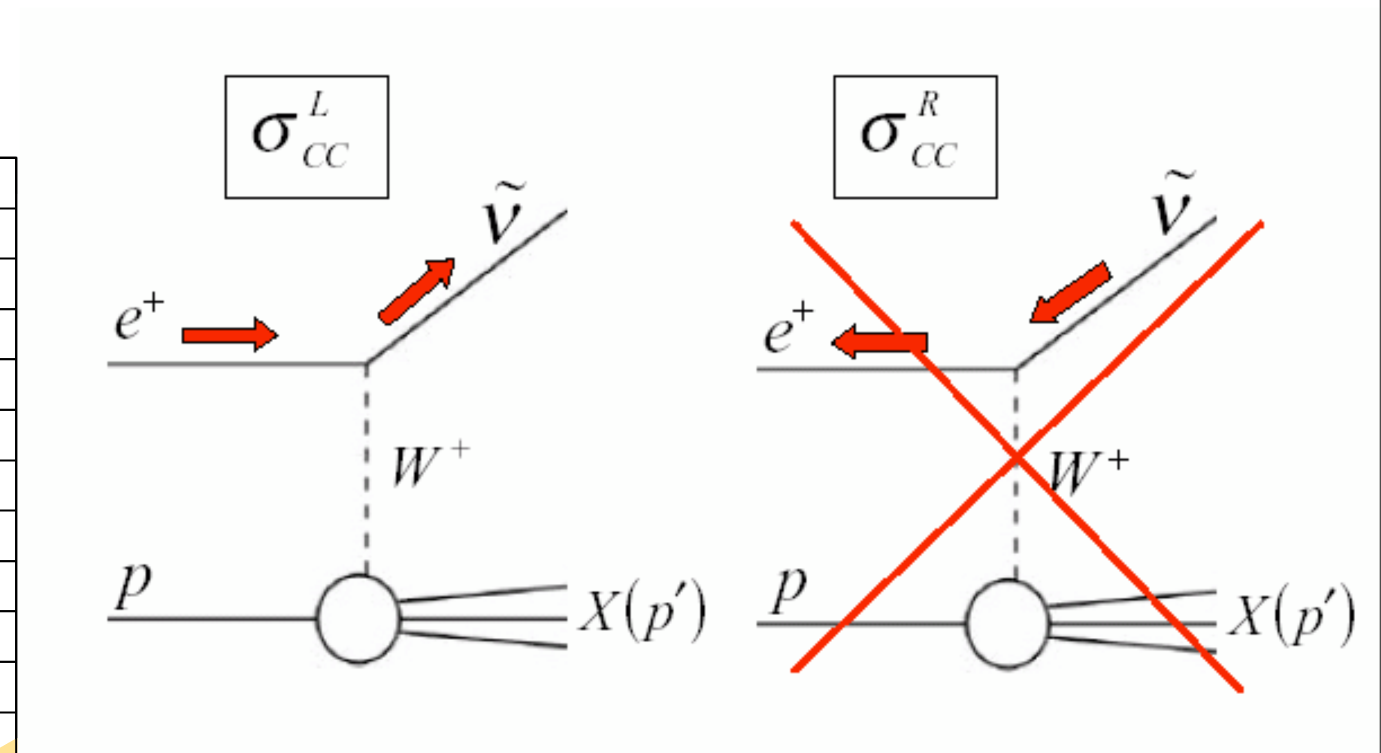
Typical level of polarisation 30 – 40 %

In SM only left handed particles (right handed antiparticles) interact via CC

Expect linear dependence of CC cross section on Polarisation!

Charged current Measurements



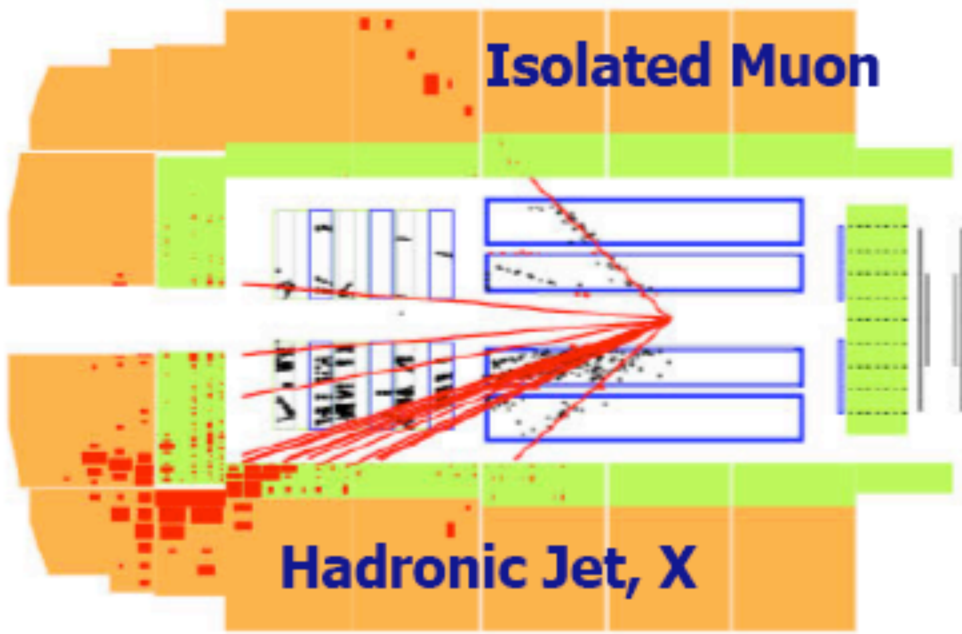


$P_{e^-} = 1, \sigma_{cc} = 0$

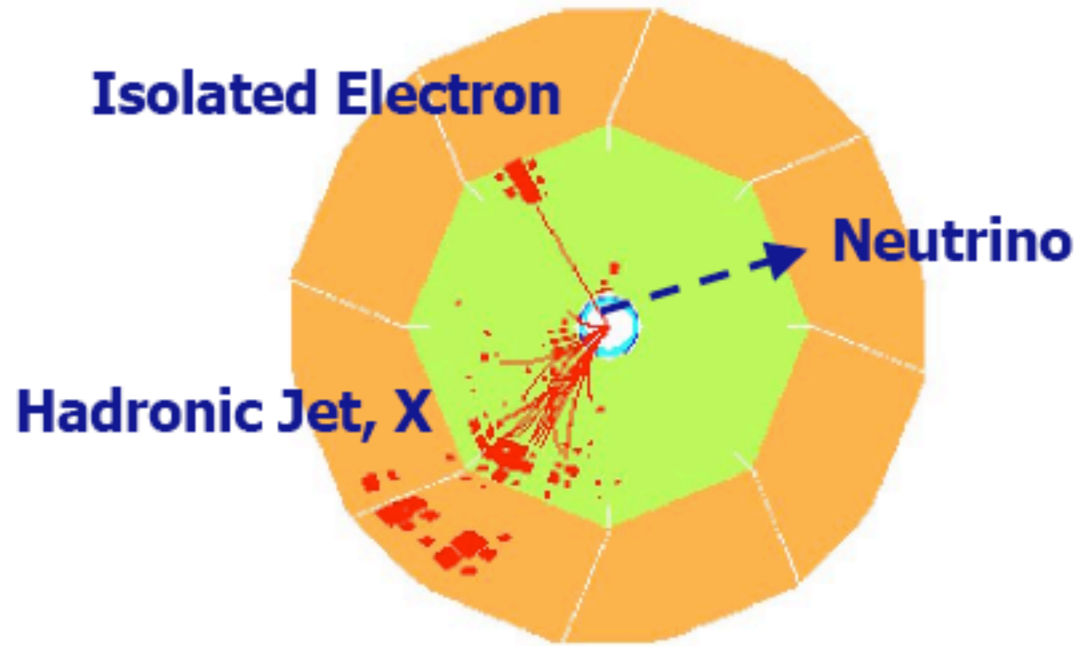
In SM only left handed particles (right handed antiparticles) interact via CC

Right handed fermions mediated by a boson of mass below 186GeV excluded at 95% CL assuming SM and a massless right handed ν_e

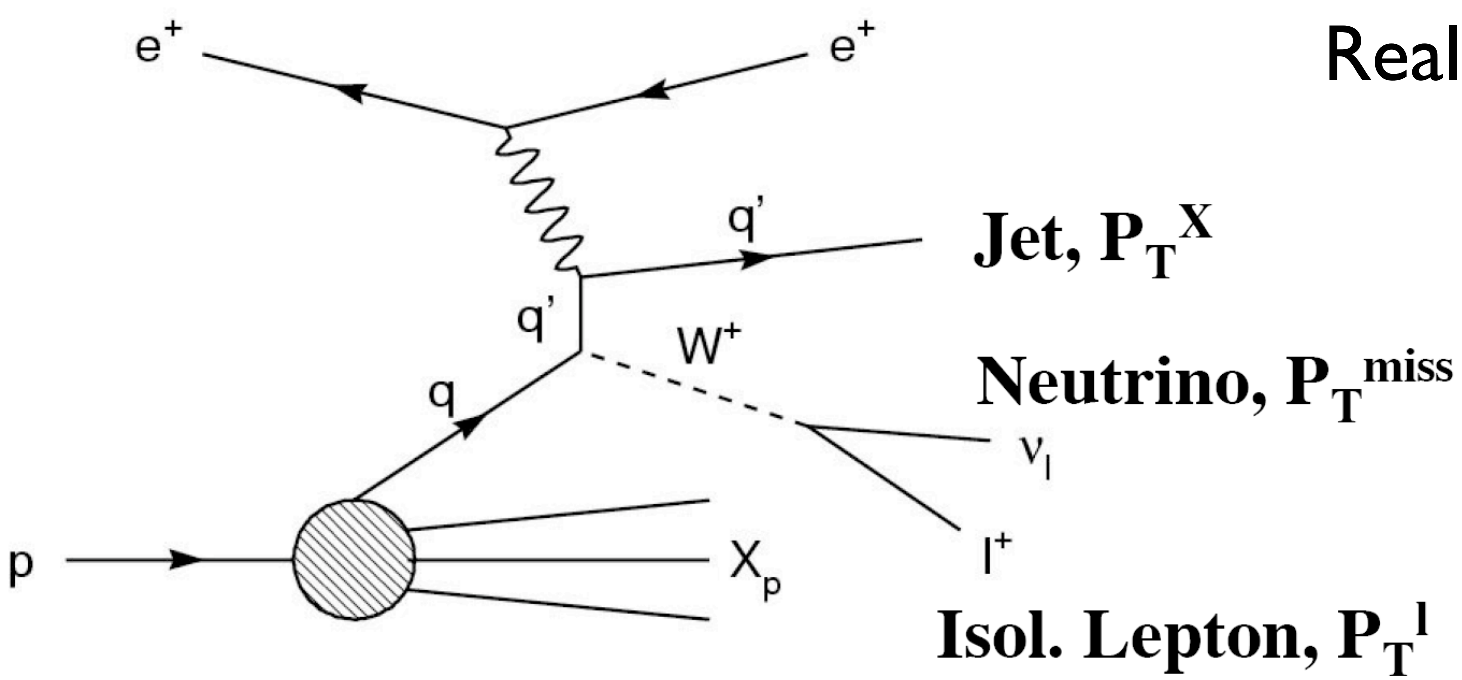
Isolated leptons with missing Pt



H1 HERA I $\mu + P_T^{miss}$ event

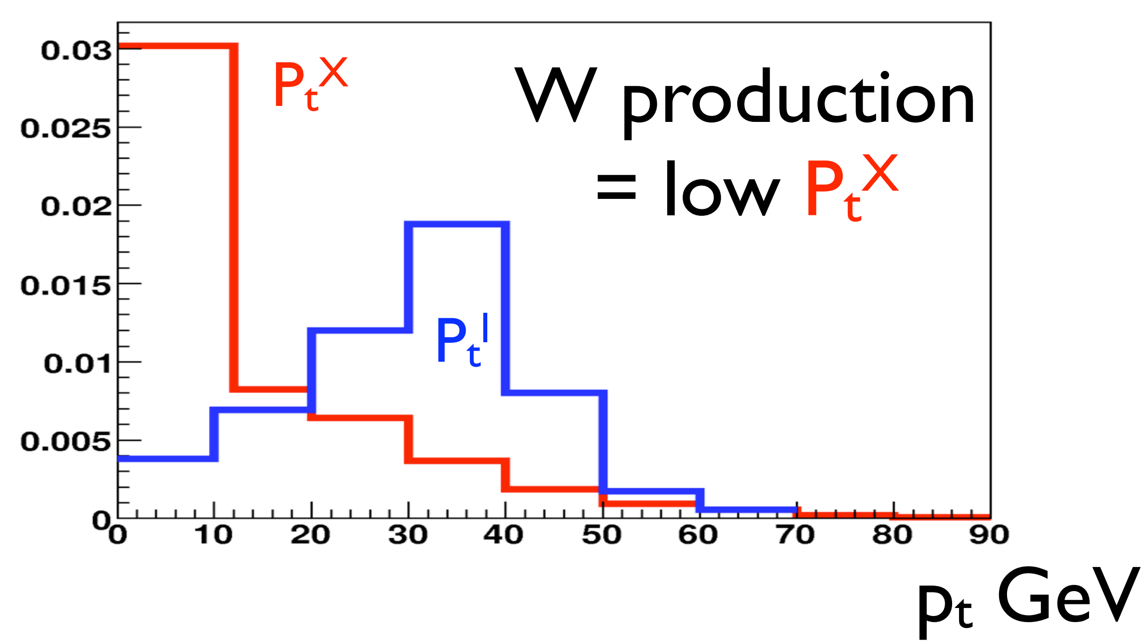


H1 HERA I $e + P_T^{miss}$ event



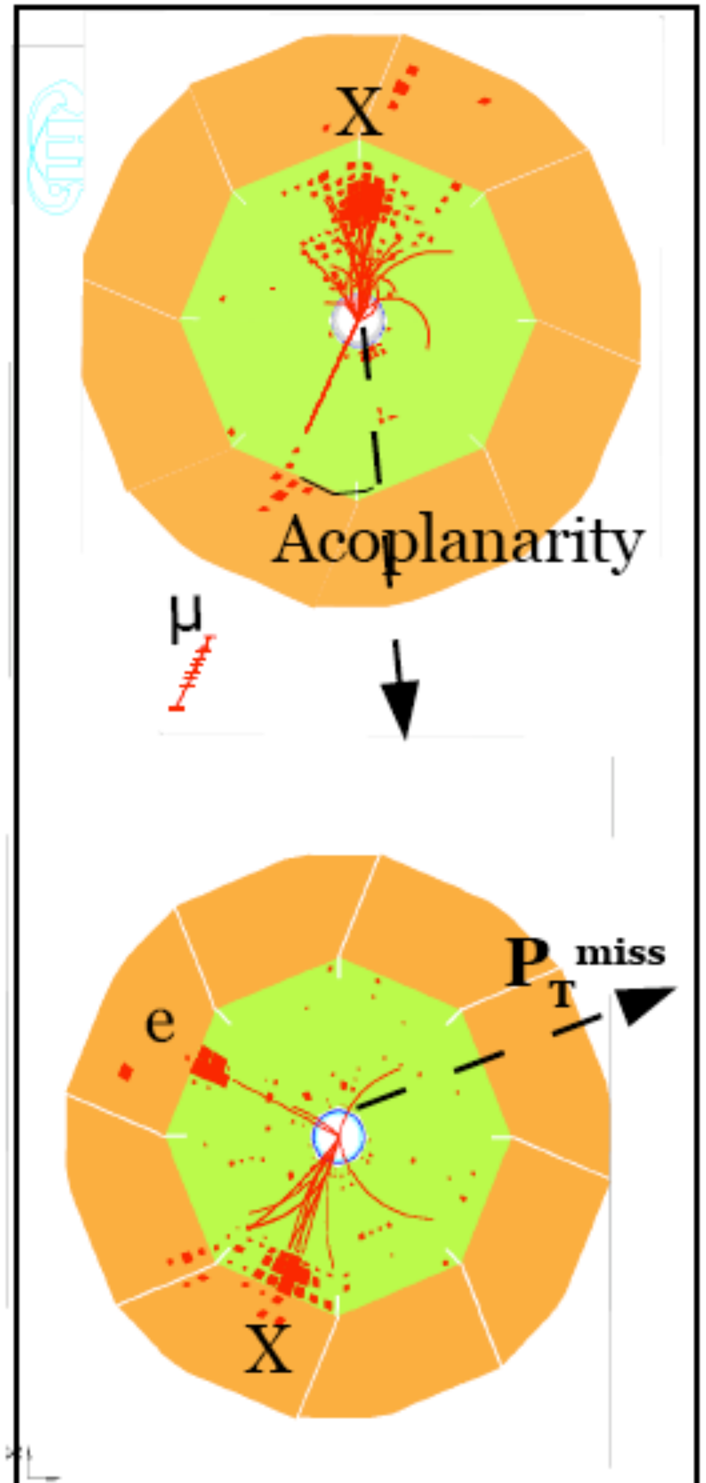
Main SM signal contribution:

Real W production cross section ~1 pb

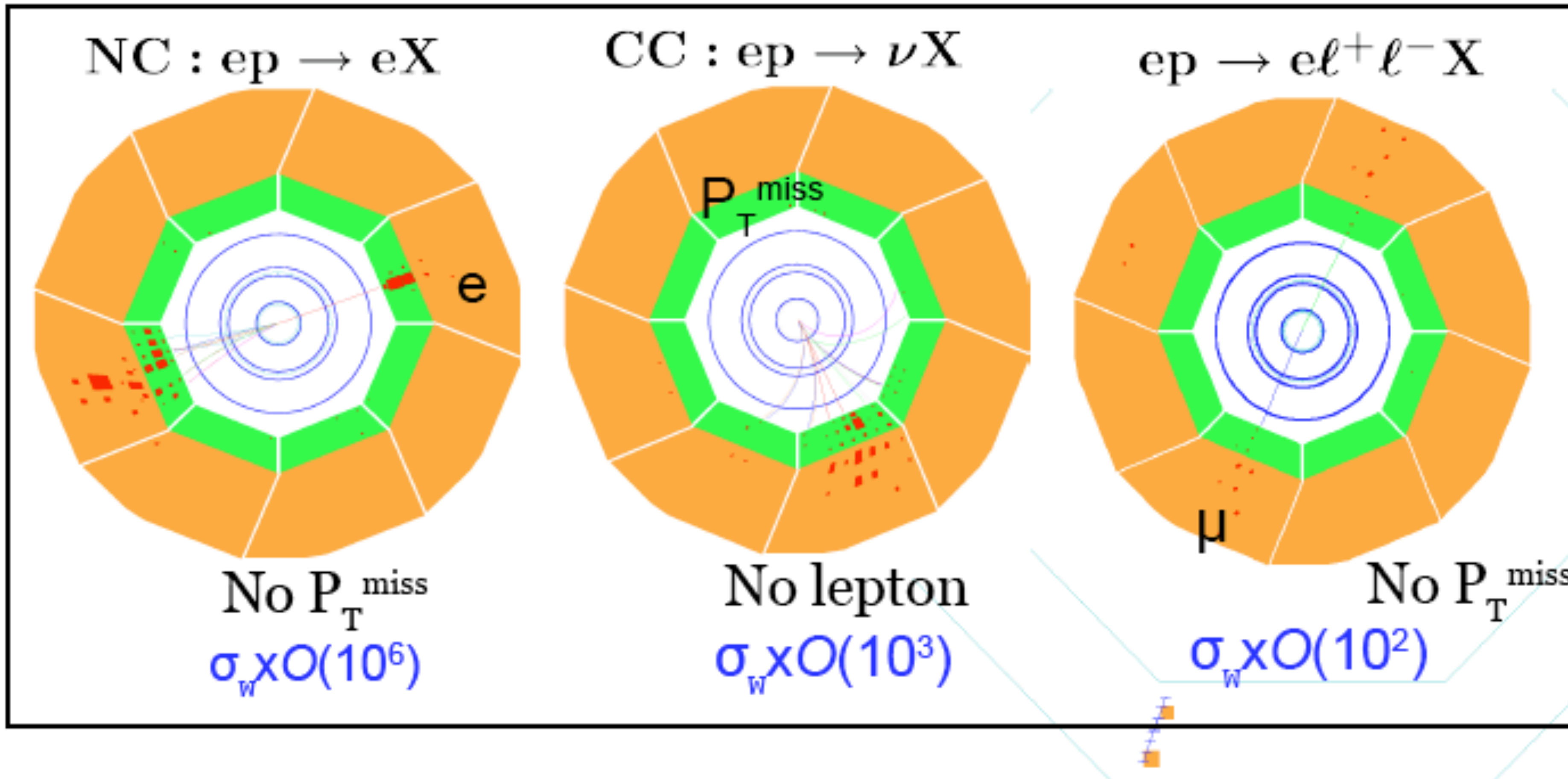


Isolated leptons with missing Pt

Signal



Backgrounds



Based on topologies, define detection phase space:

P_t^l>10 GeV, P_{Tmiss}>12 GeV, θ in [5, 140]°

this reduces most of the background.

Further background suppression using:

-lepton isolation

-event balance (Acoplanarity)

-other kinematical and topological variables

<u>event views</u>

Isolated leptons with missing Pt: HERA1 result

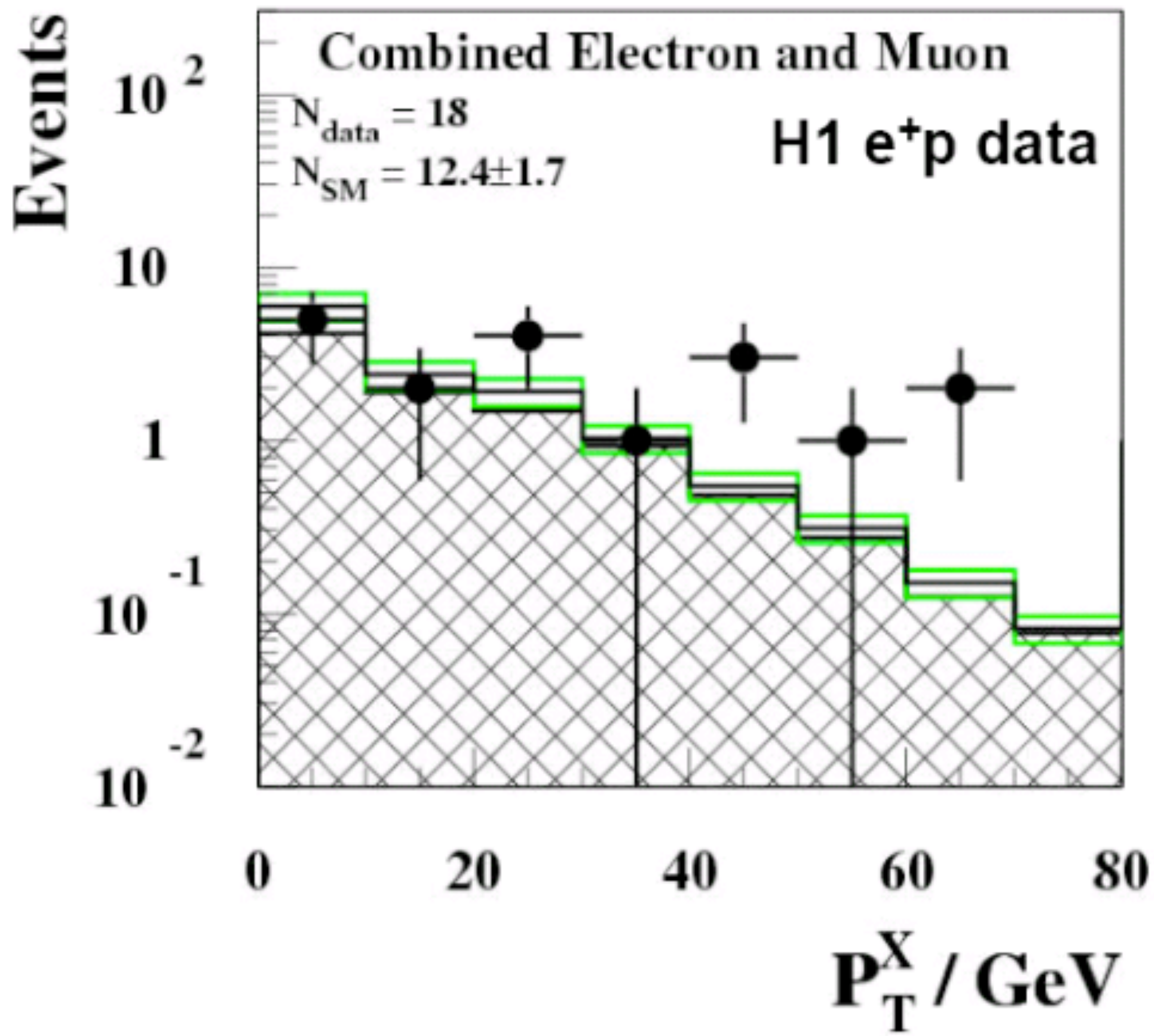
Phys. Lett. B561 (2003) 241

In the e^+p data for P_T^X >25 GeV (atypical of W)

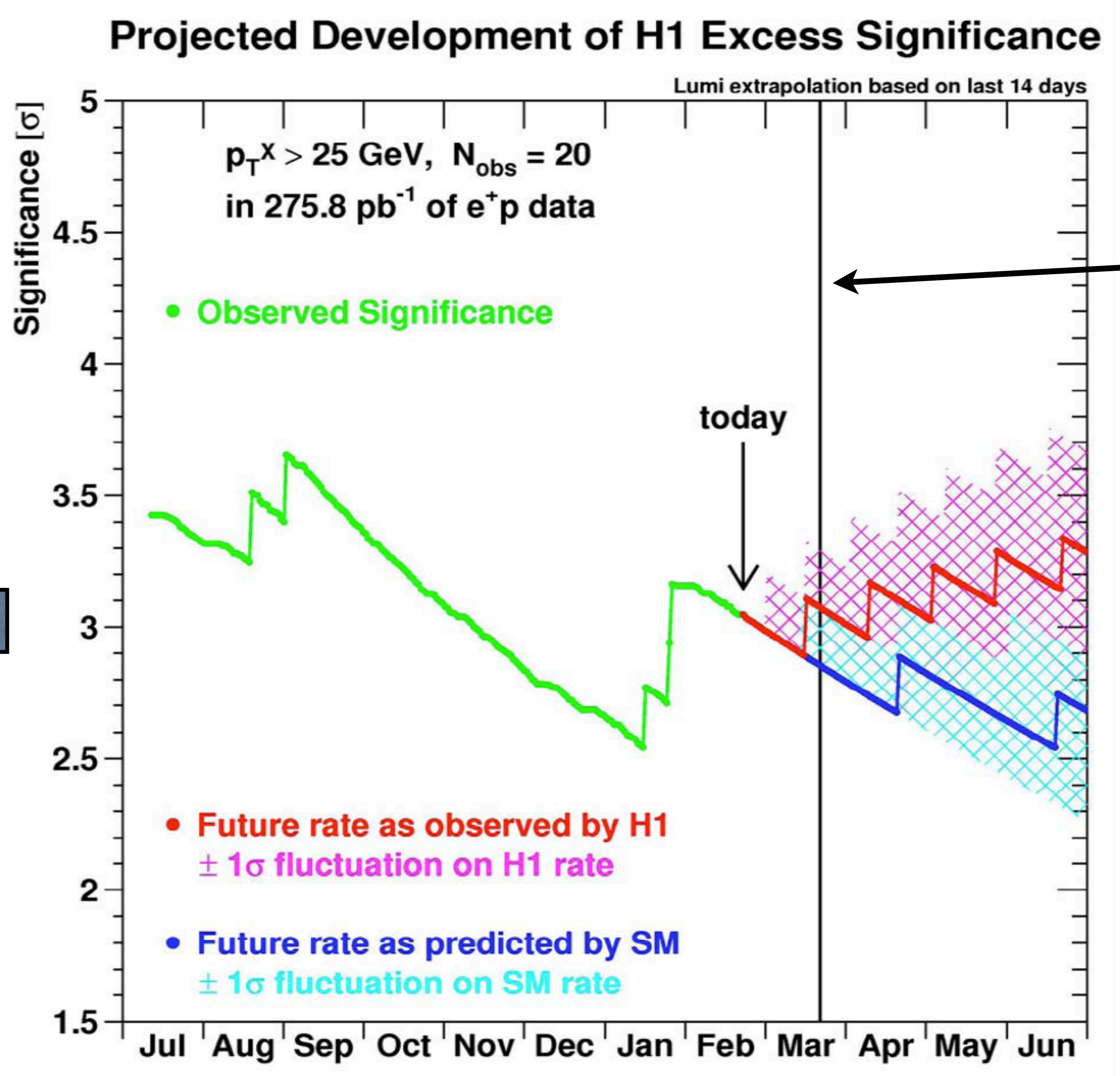
10 events observed

2.91 expected

which corresponds to a 3 sigma excess!



Isolated leptons with missing Pt: data taking

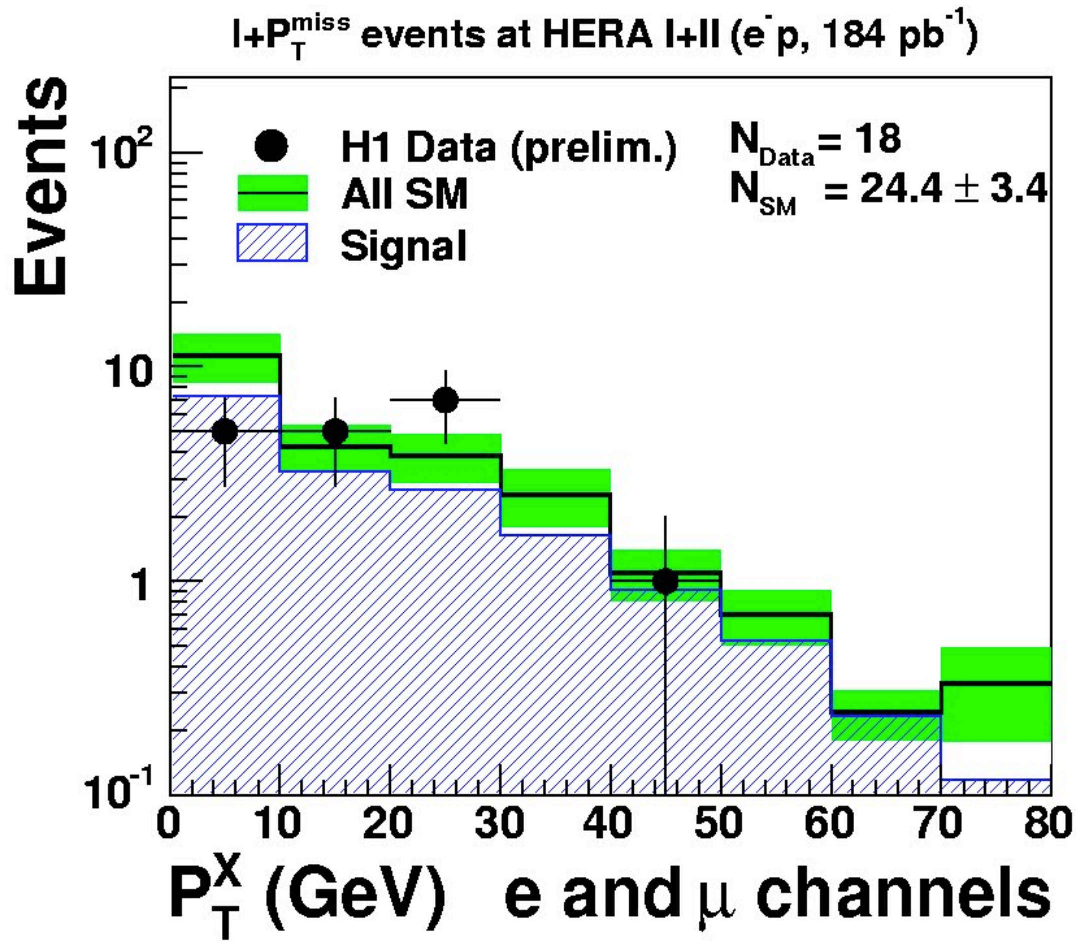


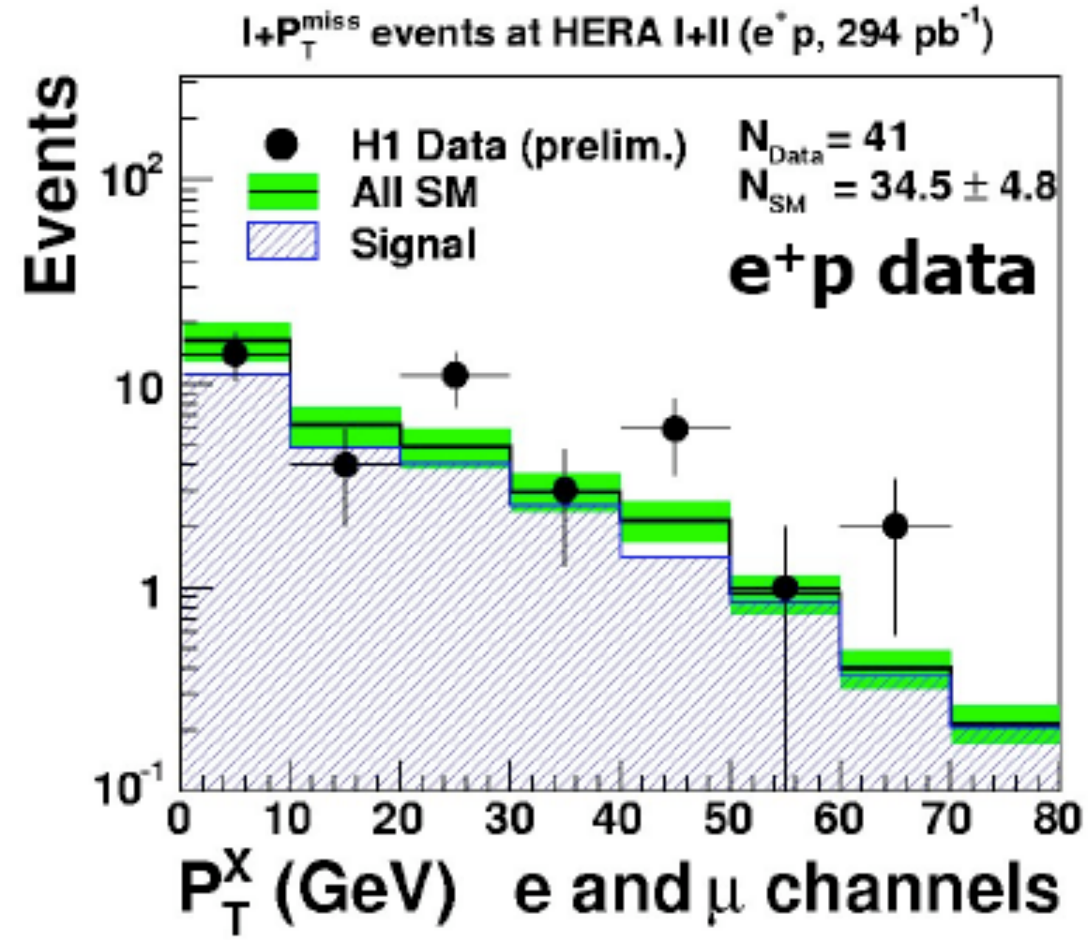
end of high energy running

2004

2006 2007

Isolated leptons with missing Pt: HERAII





H1 HERA I+II $P_T^X > 25$ GeV	e channel obs. / exp. (signal)	μ channel obs. / exp. (signal)	e and μ channels obs. / exp. (signal)
e^+p data (294 pb^{-1})	11 / 4.7 ± 0.9 (75%)	10 / 4.2 ± 0.7 (85%)	21 / 8.9 ± 1.5 (80%)
e^-p data (184 pb^{-1})	3 / 3.8 ± 0.6 (61%)	0 / 3.1 ± 0.5 (74%)	3 / 6.9 ± 1.0 (67%)

- ***Excess at 3.0σ level in e^+p data only*** - difference between data sets

Isolated leptons with missing Pt: HERAII

BUT

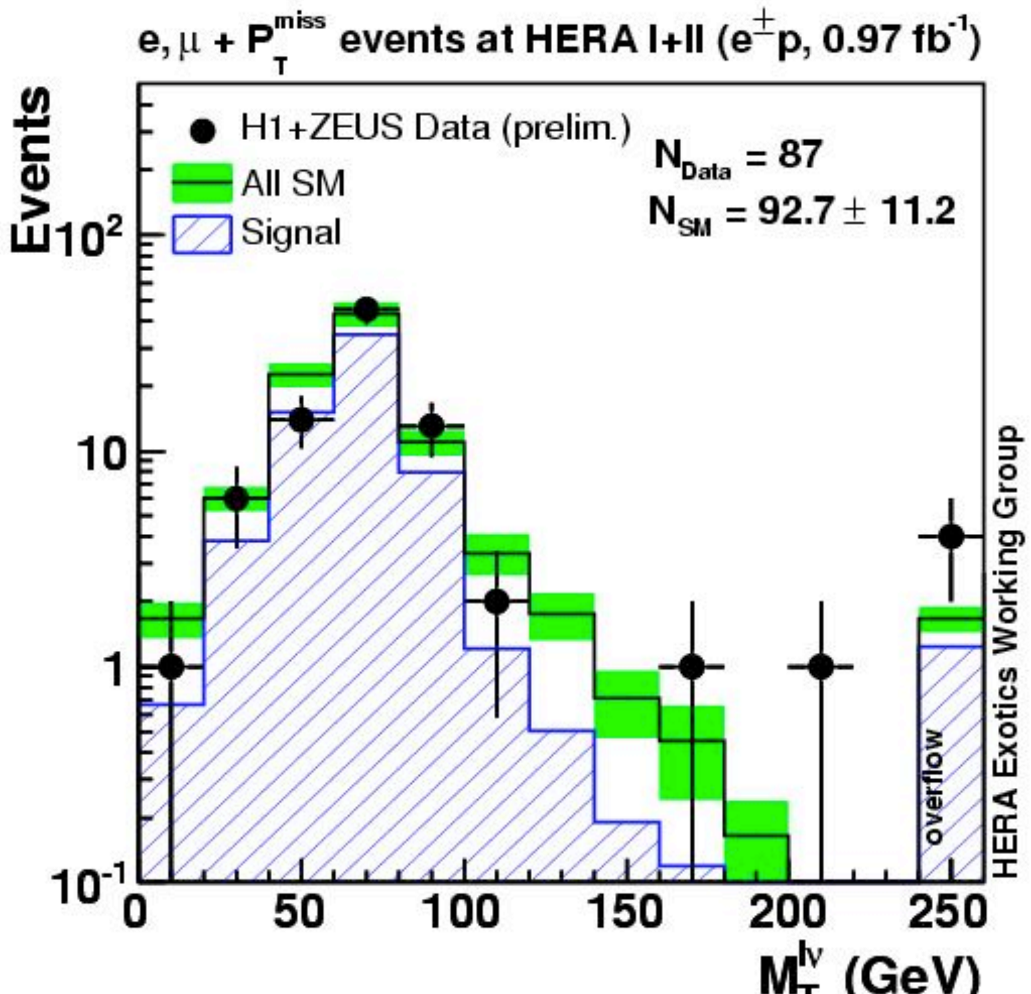
ZEUS: good agreement with the Standard Model

	$P_T^X > 25$ GeV		electrons Data/SM	muons Data/SM
e^+p	H1	294 pb^{-1}	11/4.7±0.9	10/4.2±0.7
	ZEUS	228 pb^{-1}	1/3.2±0.4	3/3.1±0.5
e^-p	H1	184 pb^{-1}	3/3.8±0.6	0/3.1±0.5
	ZEUS	204 pb^{-1}	5/3.8±0.6	2/2.2±0.3

H1+ ZEUS combined analysis

High P_T^X excess in e^+p data remains, even after inclusion of the ZEUS data, with a lower significance of 1.8σ

No obvious physics process



α_s from Jets

H1 Collab., A. Aktas et al., Phys.Lett.B653: 134-144, 2007

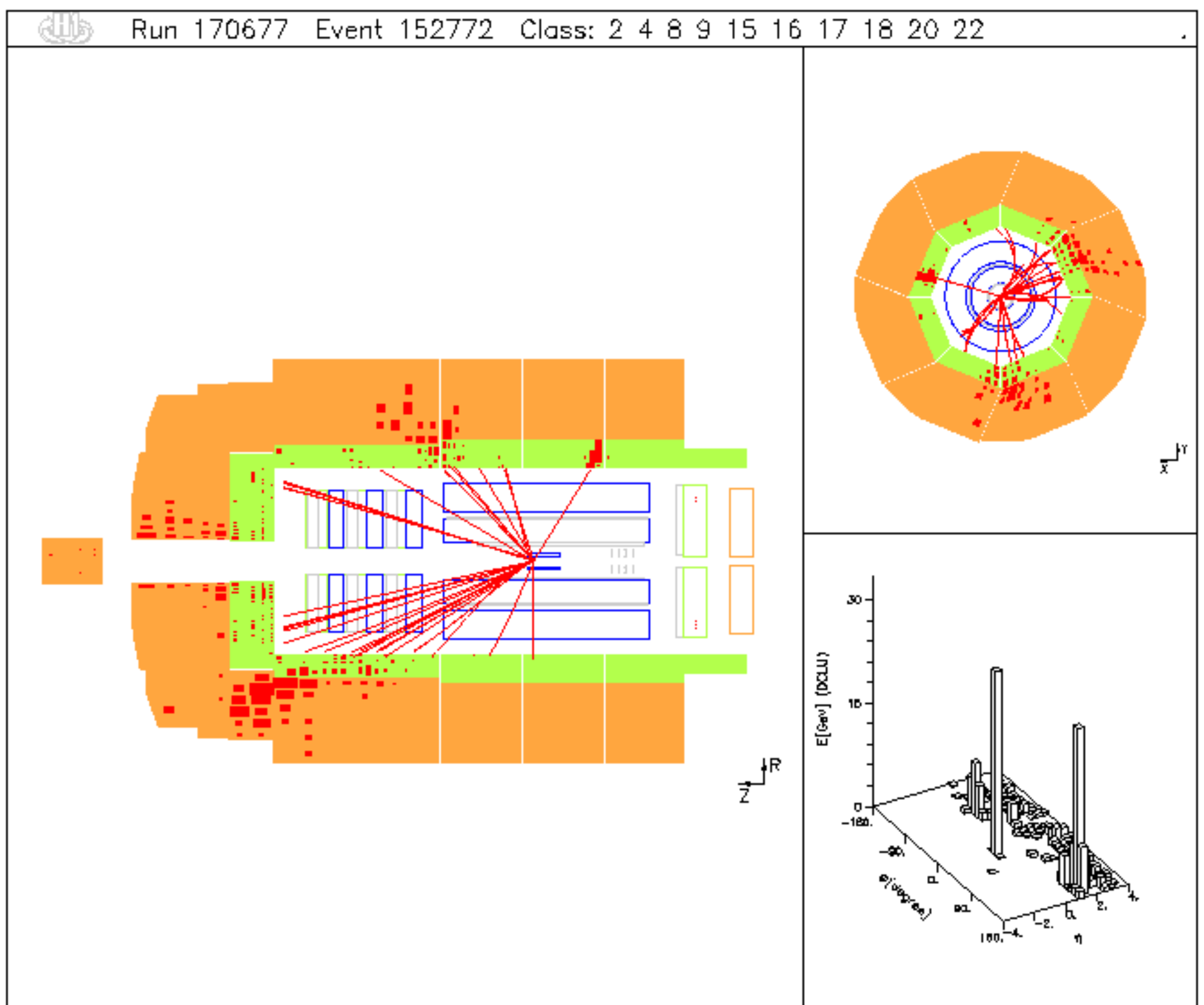
Jet production in DIS at high Q^2 as a handle on pQCD

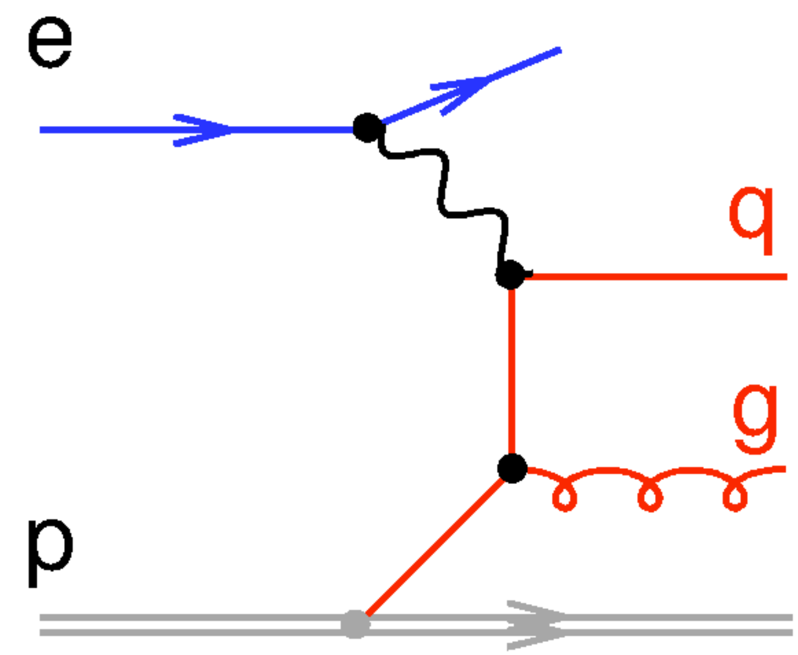
<u>Count all jets in phase space as function of Q^2</u>

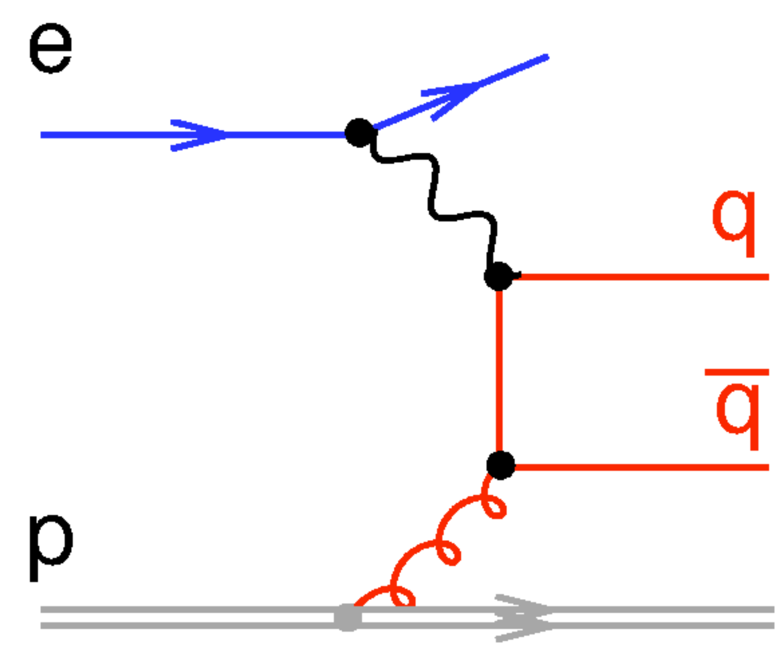
Cross section depends on:

1. QCD matrix elements.
2. *Strong coupling α_S.*
3. Parton density functions of the proton.

Determine a α_S by fitting the theory to data







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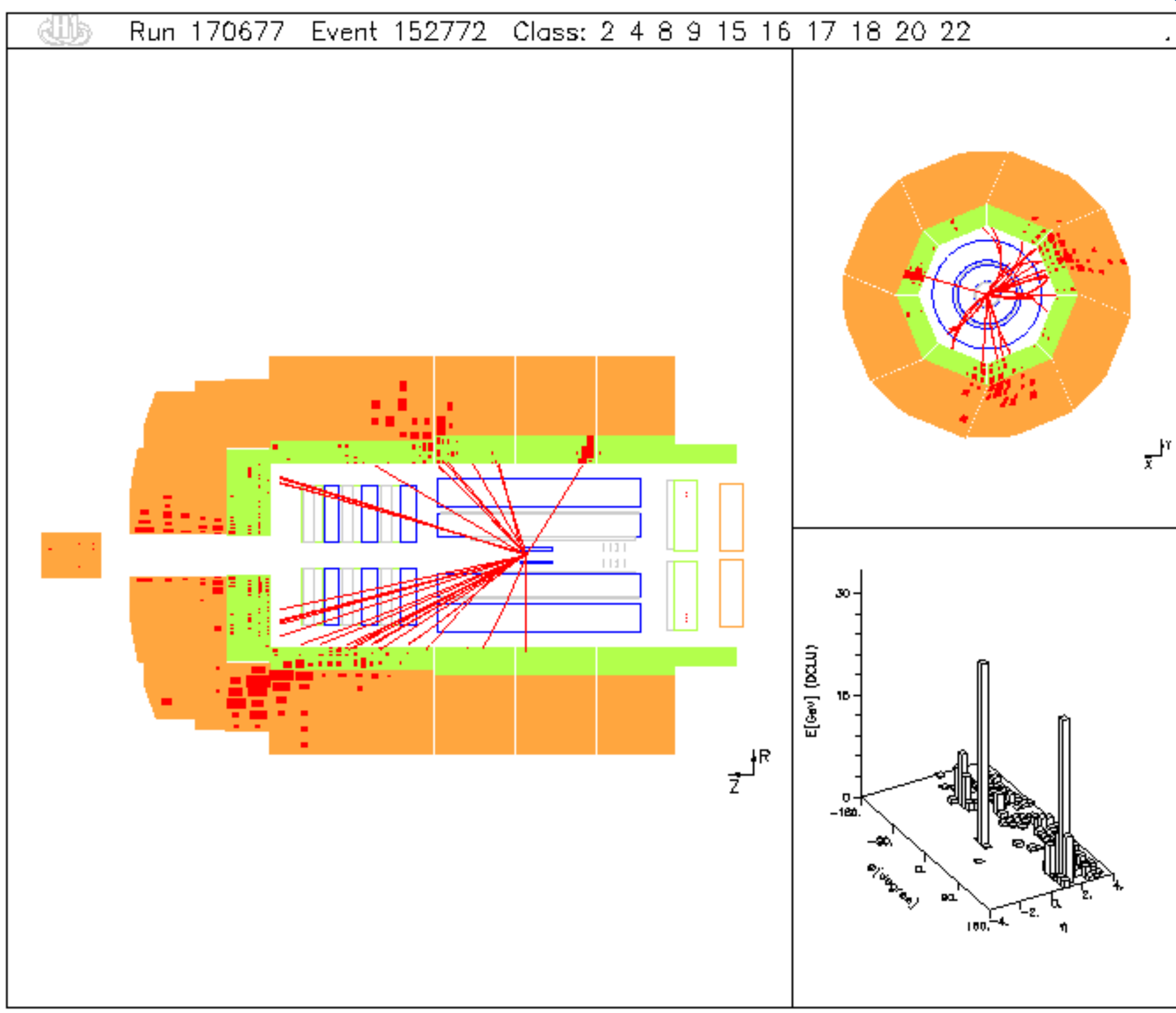

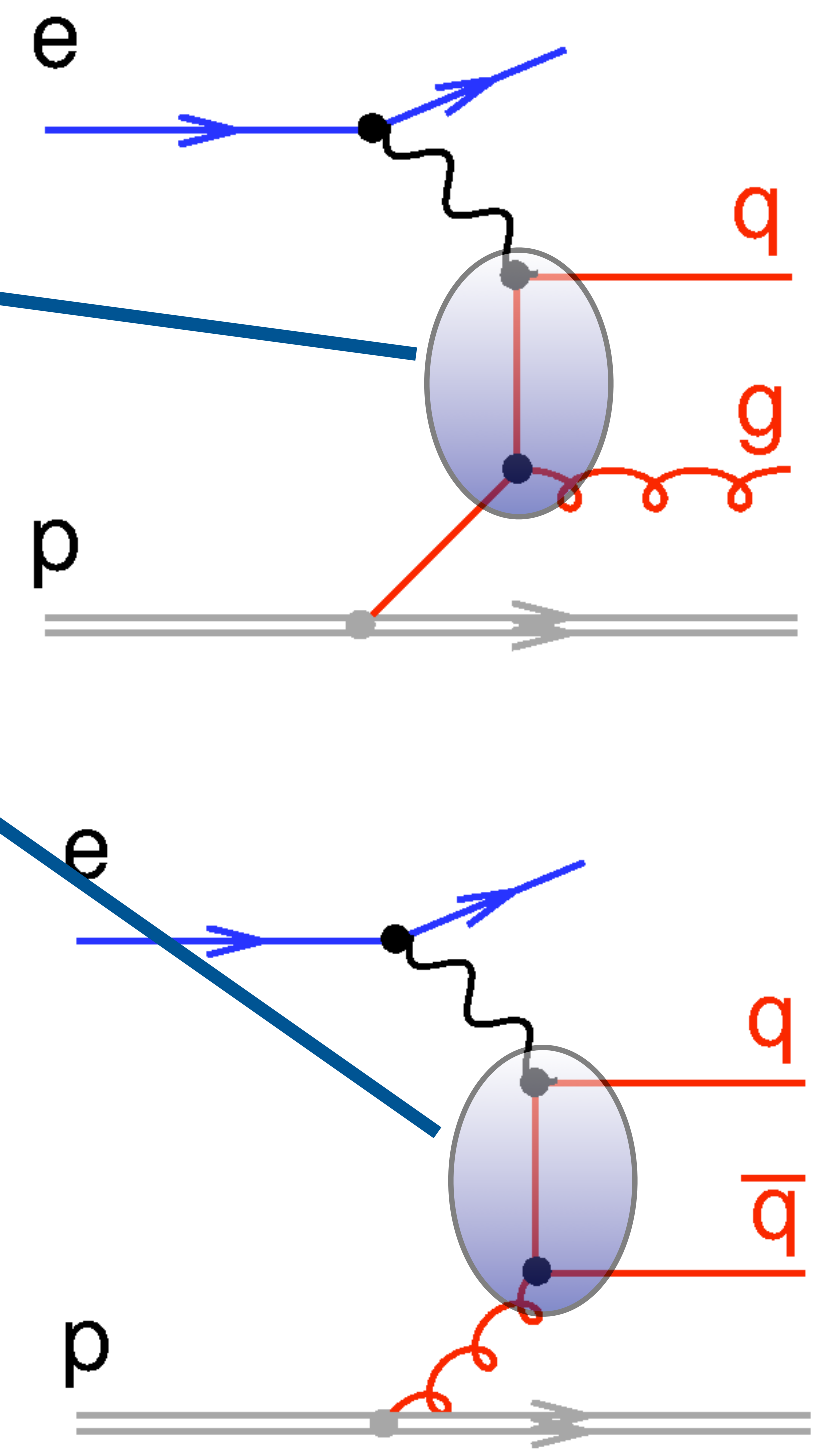

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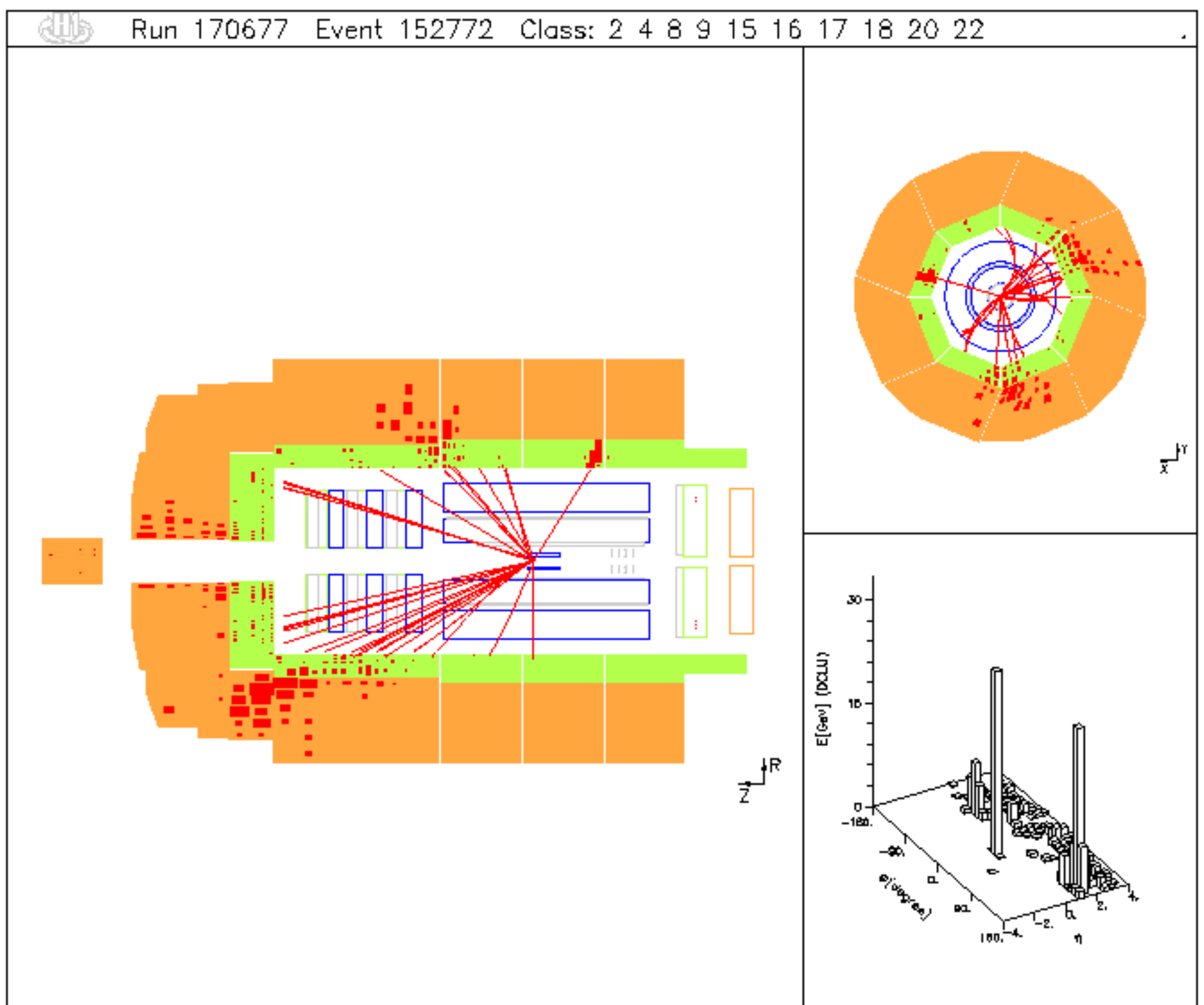
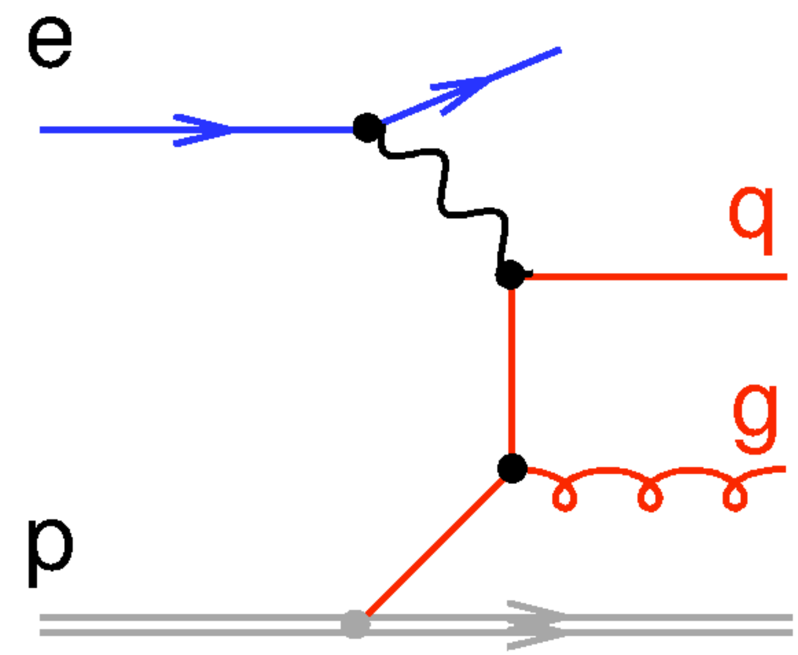
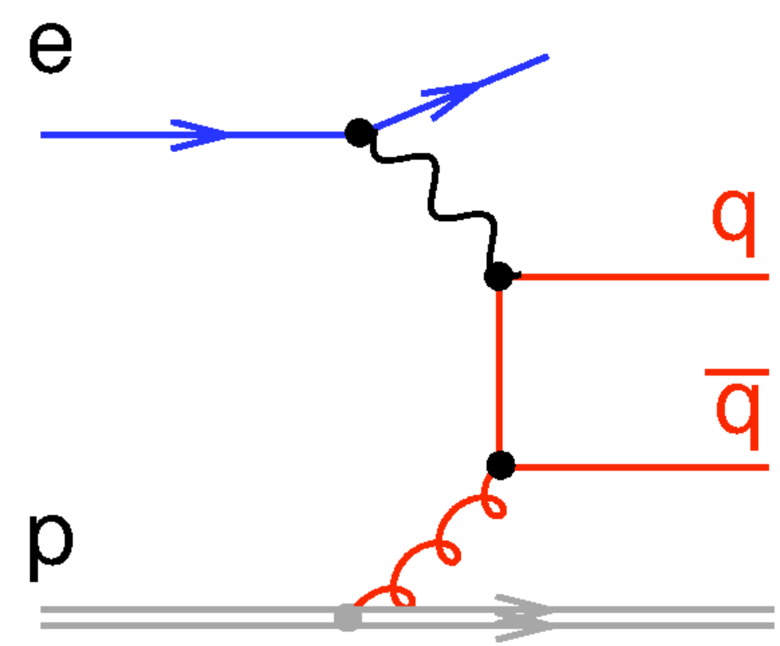






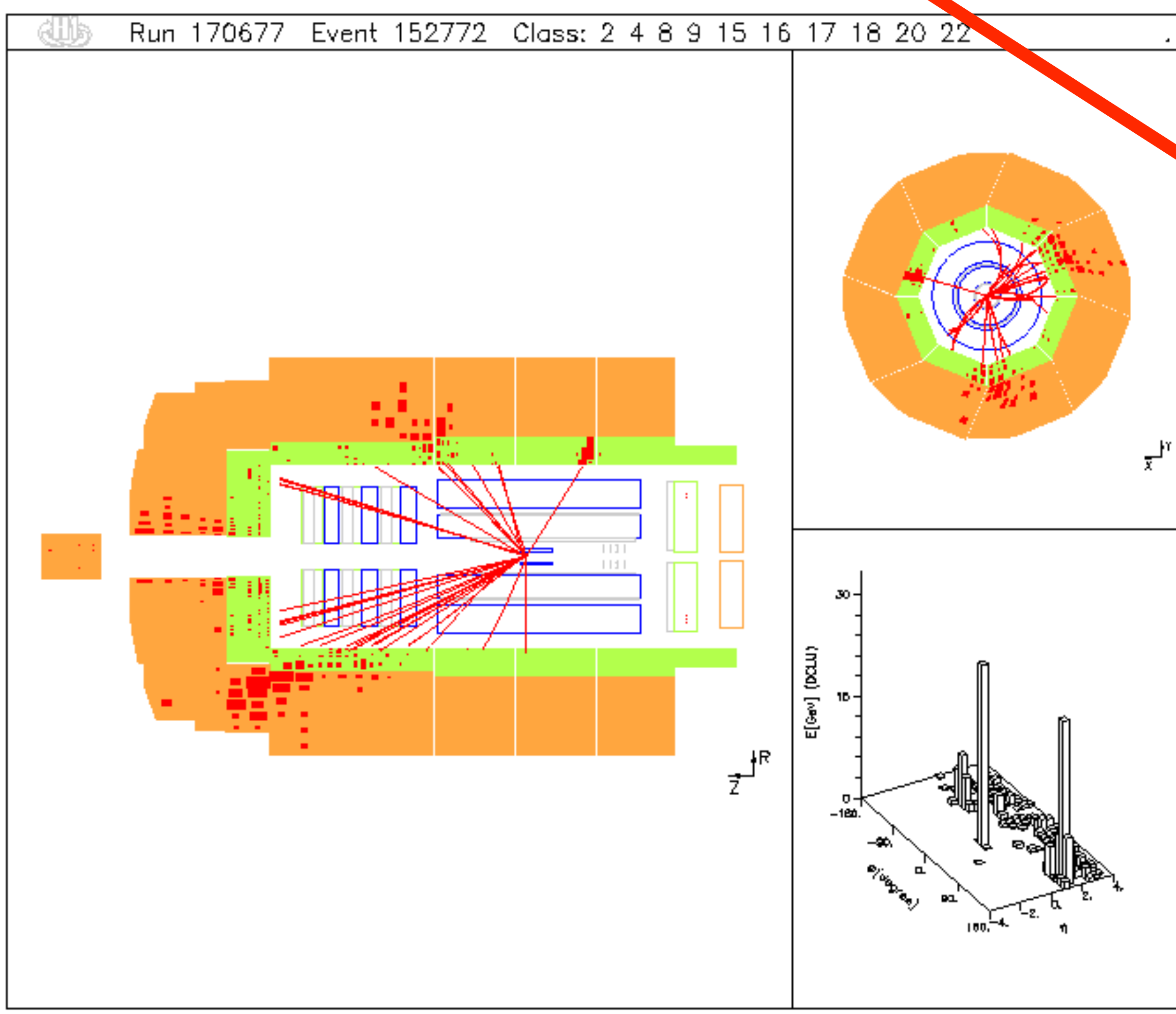
Jet production in DIS at high Q^2 as a handle on pQCD

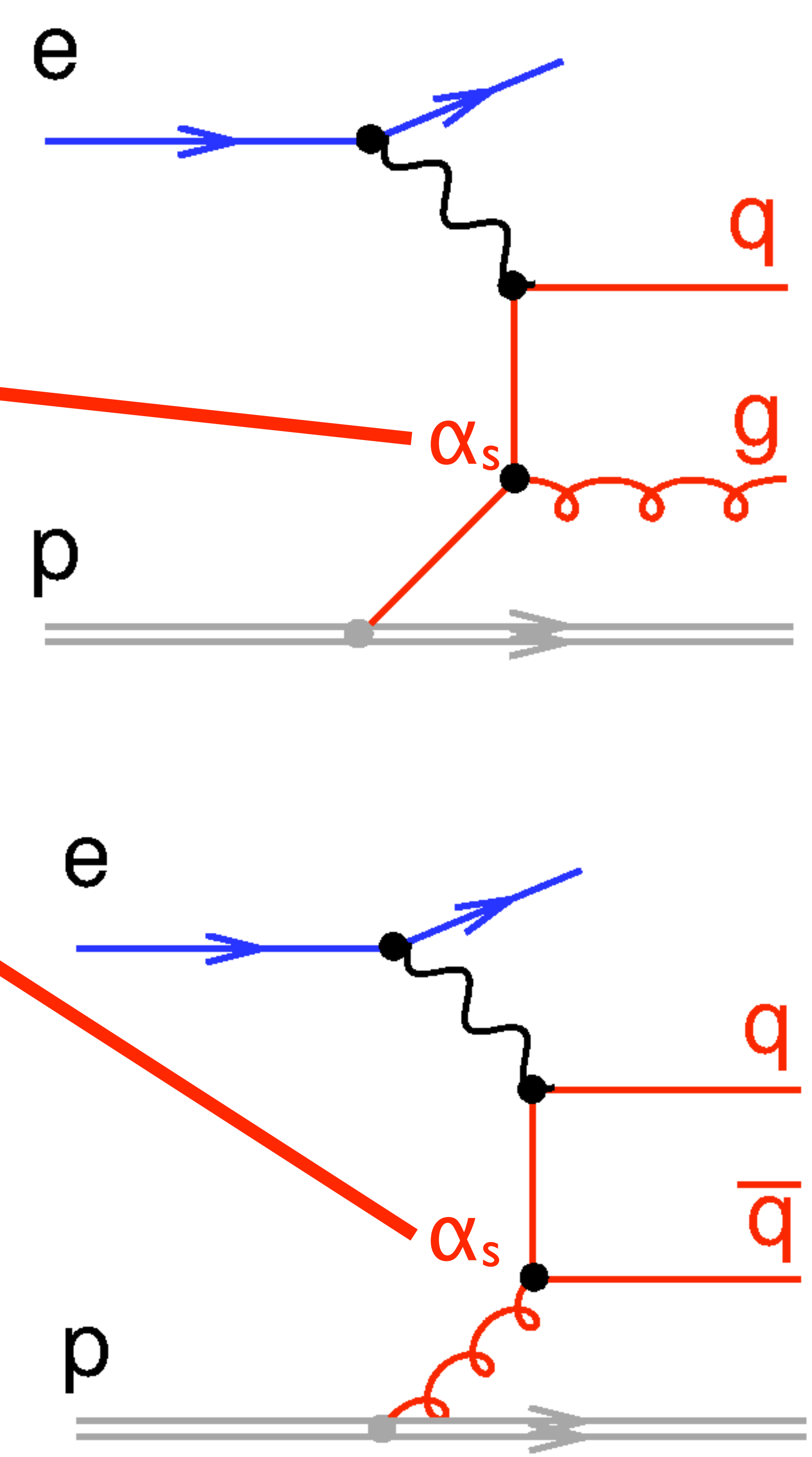
<u>Count all jets in phase space as function of Q^2</u>

Cross section depends on:

1. QCD matrix elements.
2. *Strong coupling α_S.*
3. Parton density functions of the proton.

Determine a α_S by fitting the theory to data





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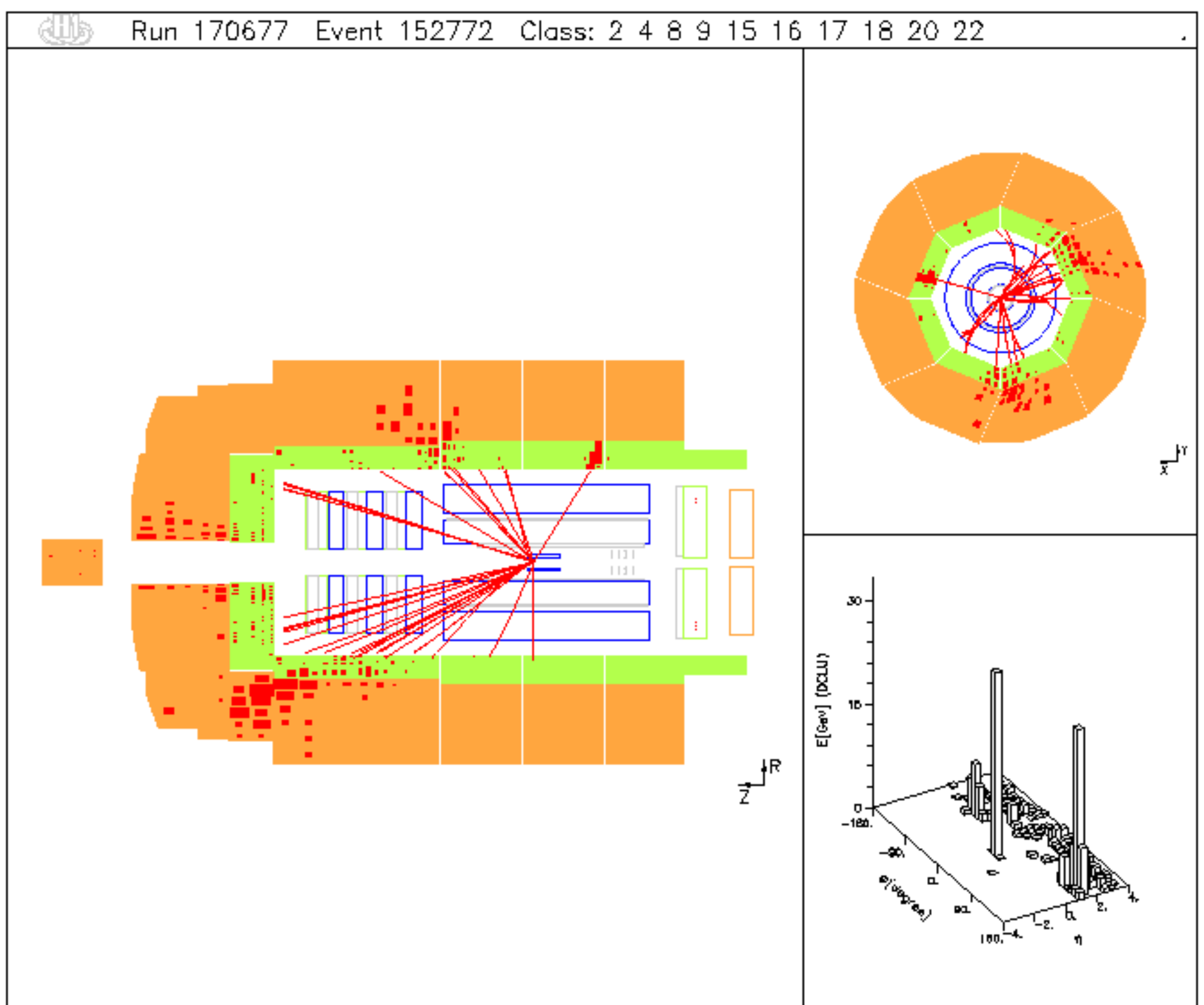

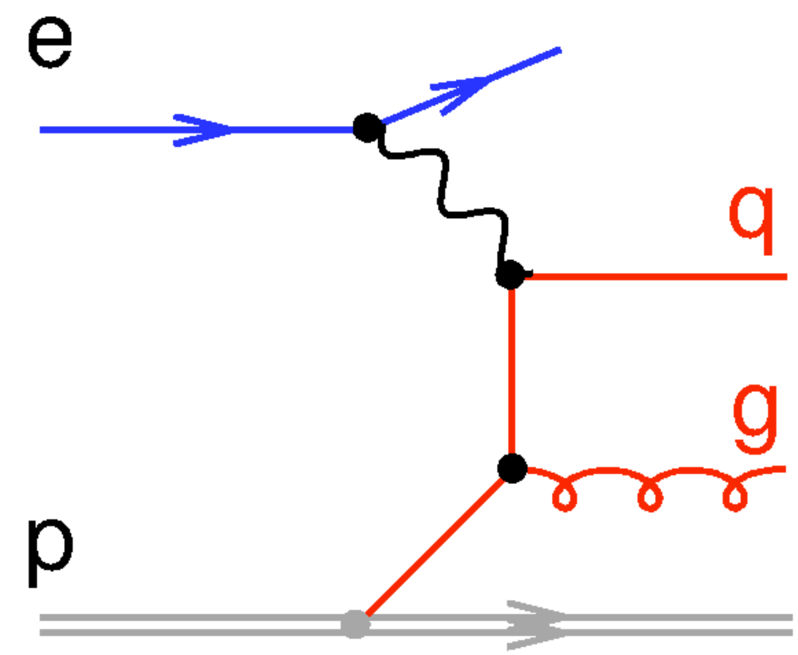

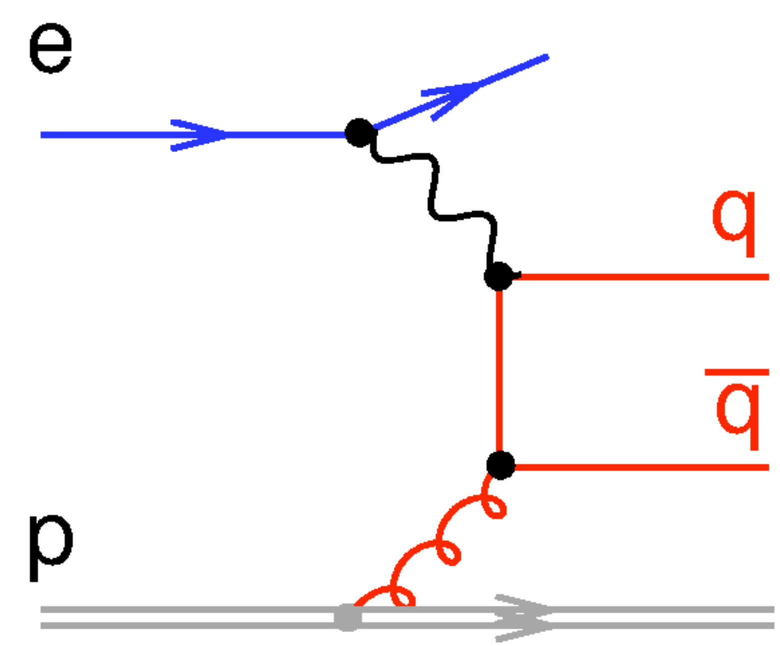

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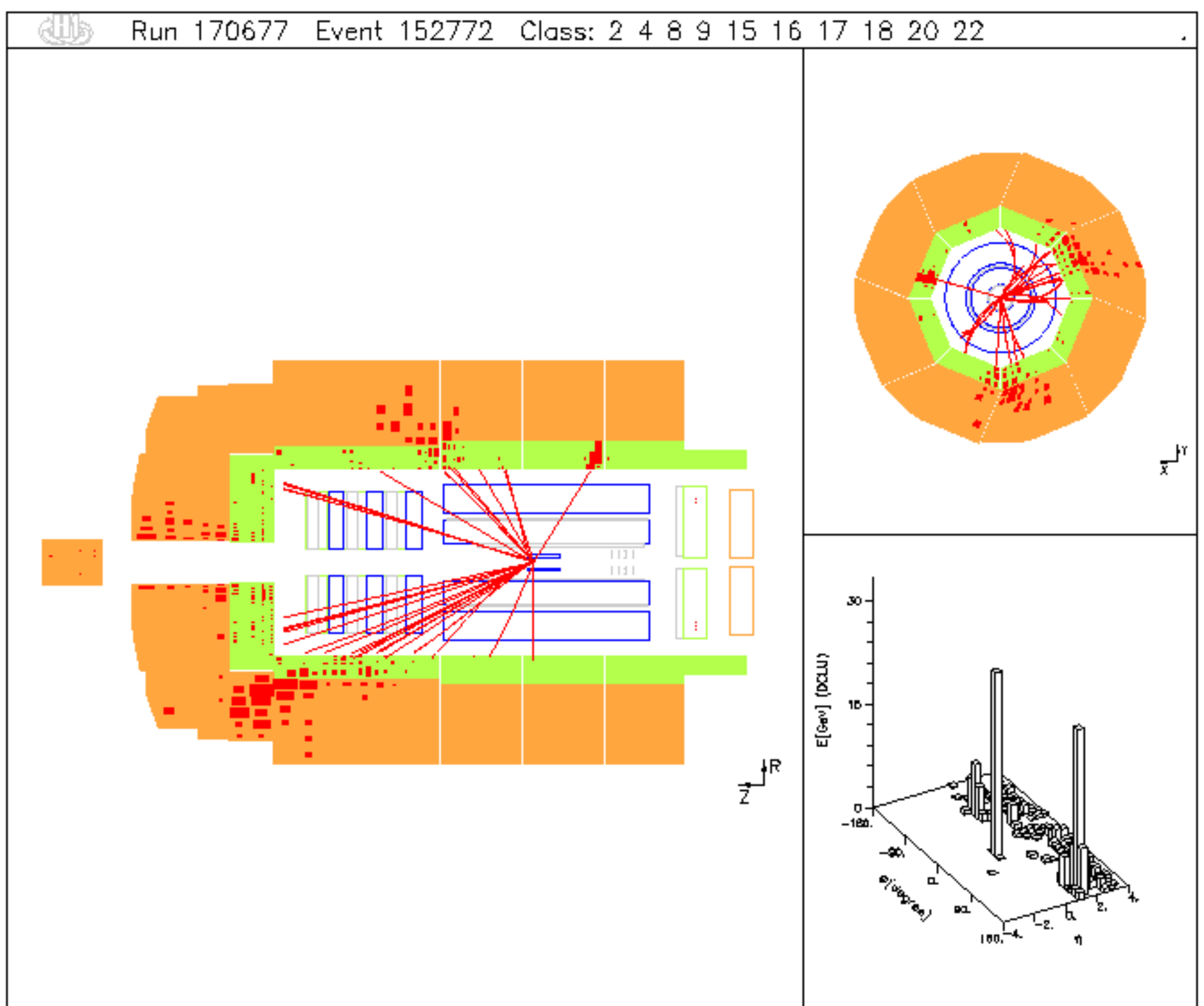
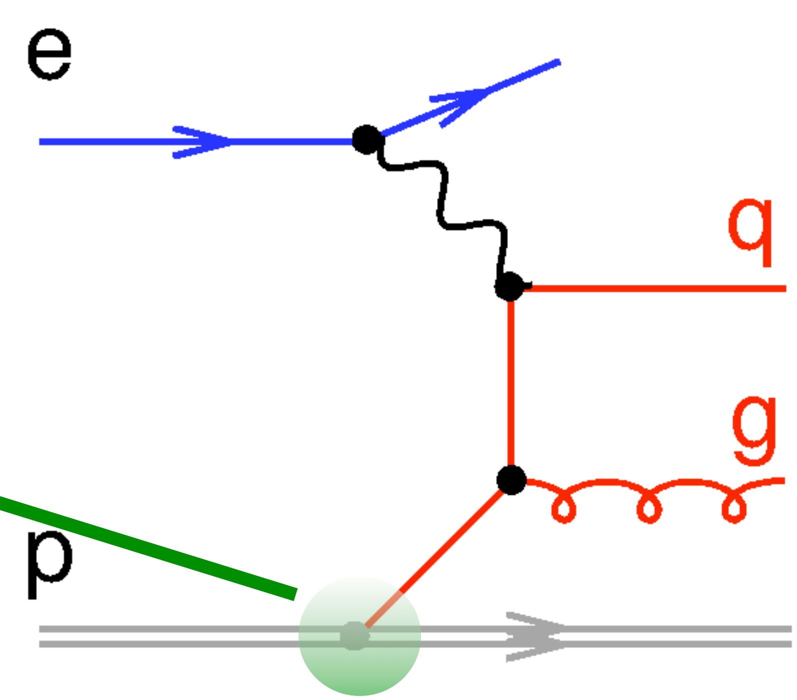
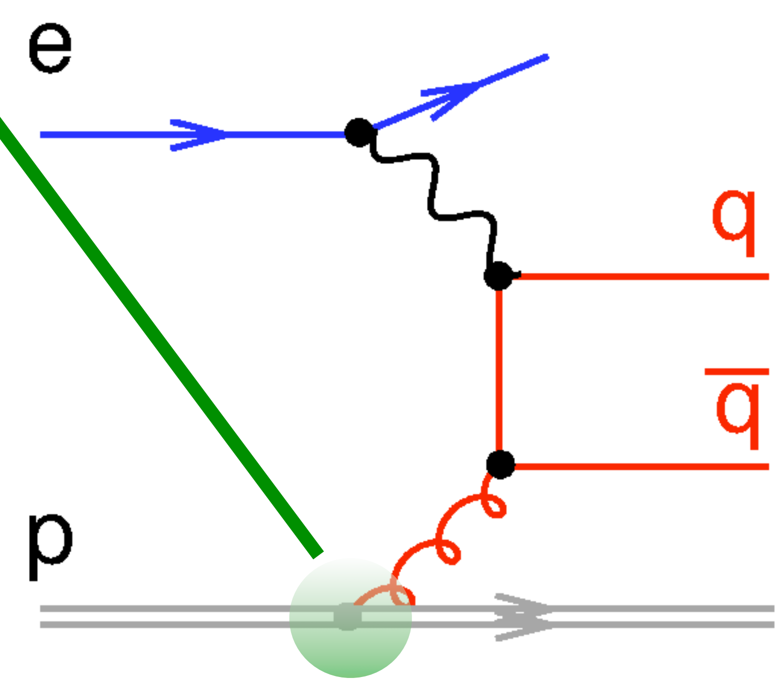


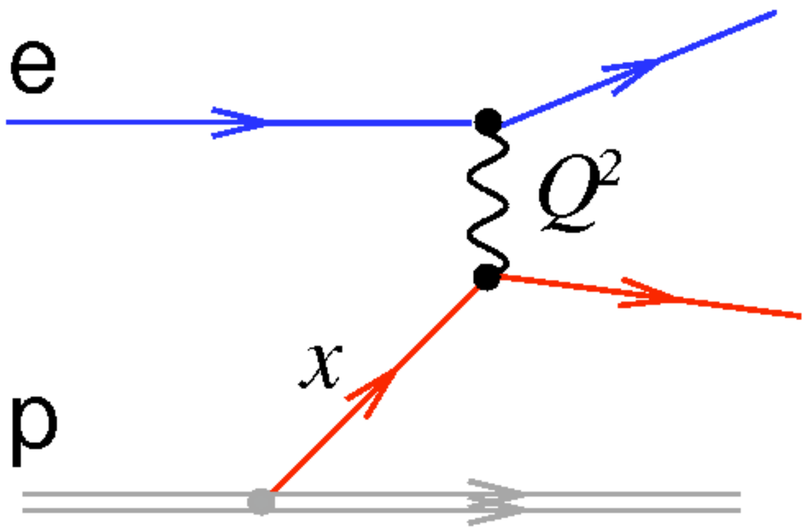




Frame of reference

LAB

Born level

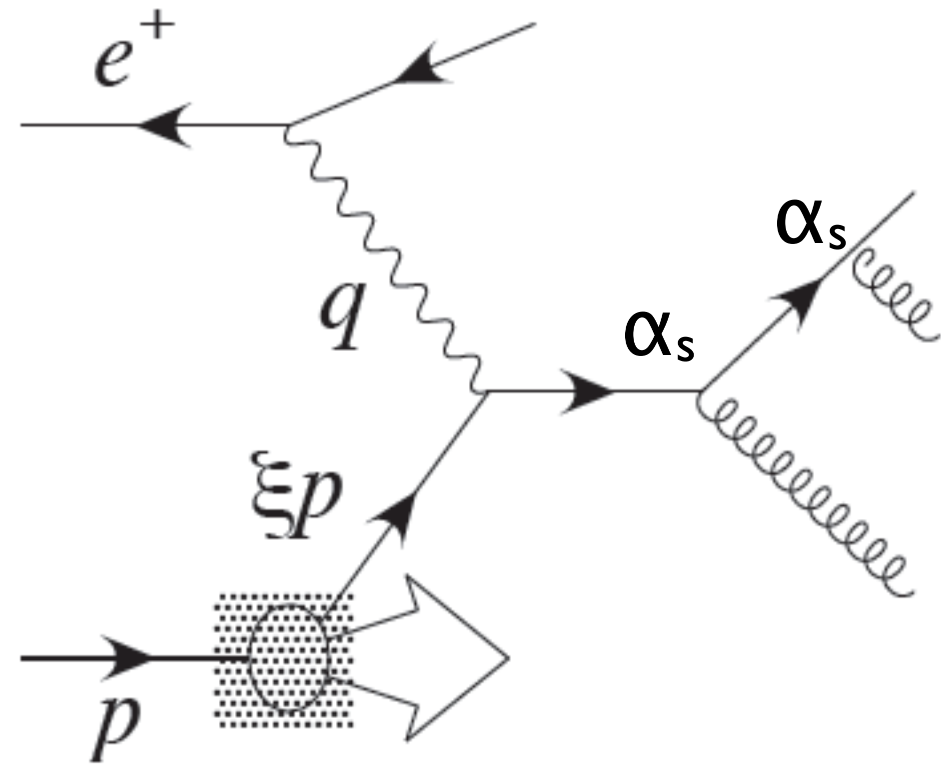


0'th order α_s

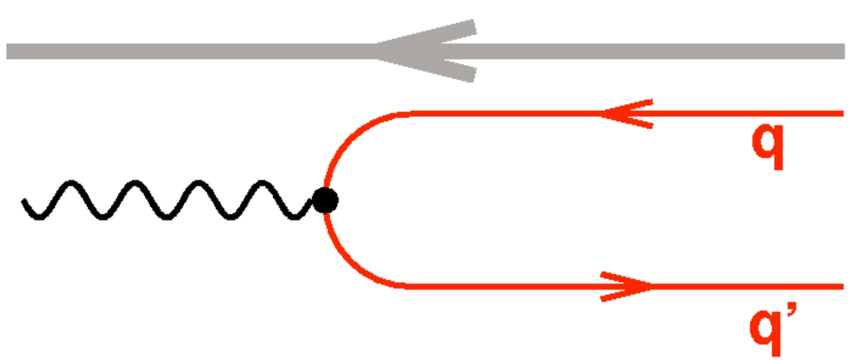
no hard QCD radiation

One jet in Lab frame

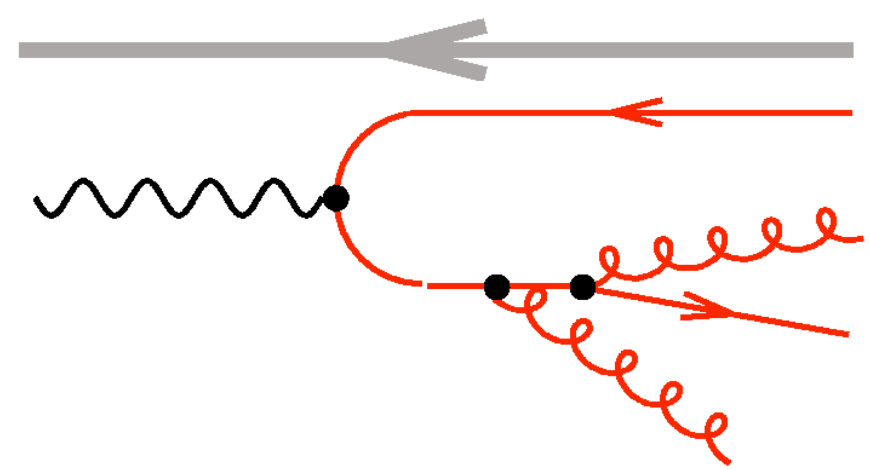
order α_s^2, NLO pQCD



BREIT



No E_T ,
No jets in Breit frame!



In the Breit frame, QCD radiation generates E_T

Event selection NC DIS

$150 < Q < 15000$ GeV^2,
$0.2 < y < 0.7$,
99/2000 data set, 64.5 pb^{-1}
Jet selection:
Inclusive k_T, p_T recombination scheme, R=1.0
$-1.0 < \theta_{LAB} < 2.5$, $7 < E_{T,BREIT} < 50$ GeV,
"inclusive jet cross section": each jet of an event contributes to the cross section

Jet Reconstruction

No unique definition of a jet, but
Inclusive k_t cluster algorithm:

1. Similar to e+e- algorithms
2. Favoured by theory over (most) cone algorithms
3. Infrared and collinear safe at all orders
4. Factorisable
5. Smaller Hadronisation corrections

JHEP 05(2007)086

Data Correction & Systematics

Correction for acceptance and resolution using Monte Carlo RAPGAP (ME+PS) and DJANGO (CDM) <20%.

Correction for QED radiation with HERACLES < 15%.

Systematic uncertainties:

1. 2% hadronic energy scale → 4% on cross section.
2. Model dependence (ME+PS, CDM) → 3% on cross section.
3. Lepton energy scale, lepton angle → small.
4. ... → small

Experimental error ~5%, mainly due to hadronic energy scale and model dependence.

NLO pQCD Theory

NLOJet++ (Zoltan Nagy)

Proton PDF

Hadronisation correction

Matrix Element

$$\sigma_{jet} = \sum_{i=q,\bar{q},g} \int dx\, f_i(x, \mu_F, \alpha_S)\, \hat{\sigma}_{QCD}(x, \mu_F, \mu_R, \alpha_S(\mu_R)) \cdot (1 + \delta_{had})$$

More

NLO pQCD Theory

NLOJet++ (Zoltan Nagy)

Proton PDF

Matrix Element

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$$\sigma_{\mathrm{jet}} = \sum_{i=q,\bar{q},g} \int dx\, f_i(x, \mu_F, \alpha_S)\, \hat{\sigma}_{QCD}(x, \mu_F, \mu_R, \alpha_S(\mu_R)) \cdot (1 + \delta_{\mathrm{had}})$$

CTEQ6.5
error: ± 20 eigenvectors

More

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CTEQ6.5
error: ± 20 eigenvectors

Assess theoretical uncertainty due to missing higher orders through μ_R (and μ_F) dependence of σ_{jet}
convention : $\mu_{R,F}$ ↑ x2 and $\mu_{R,F}$ ↓ x0.5

More

NLO pQCD Theory

NLOJet++ (Zoltan Nagy)

Proton PDF

Matrix Element

Hadronisation correction

$$\sigma_{\text{jet}} = \sum_{i=q,\bar{q},g} \int dx\, f_i(x, \mu_F, \alpha_S)\, \hat{\sigma}_{\text{QCD}}(x, \mu_F, \mu_R, \alpha_S(\mu_R)) \cdot (1 + \delta_{\text{had}})$$

CTEQ6.5
error: ± 20 eigenvectors

Apply hadronisation correction (δhad) to parton level predictions to be able to compare with data uncertainty taken from difference of Monte Carlo models (PS /CDM)

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More

NLO pQCD Theory

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Proton PDF

Matrix Element

Hadronisation correction

$$\sigma_{\mathrm{jet}} = \sum_{\mathrm{i=q,\bar{q},g}} \int \mathrm{dx}\, \mathrm{f_i}(\mathrm{x}, \mu_\mathrm{F}, \alpha_\mathrm{S})\, \hat{\sigma}_{\mathrm{QCD}}(\mathrm{x}, \mu_\mathrm{F}, \mu_\mathrm{R}, \alpha_\mathrm{S}(\mu_\mathrm{R})) \cdot (1 + \delta_{\mathrm{had}})$$

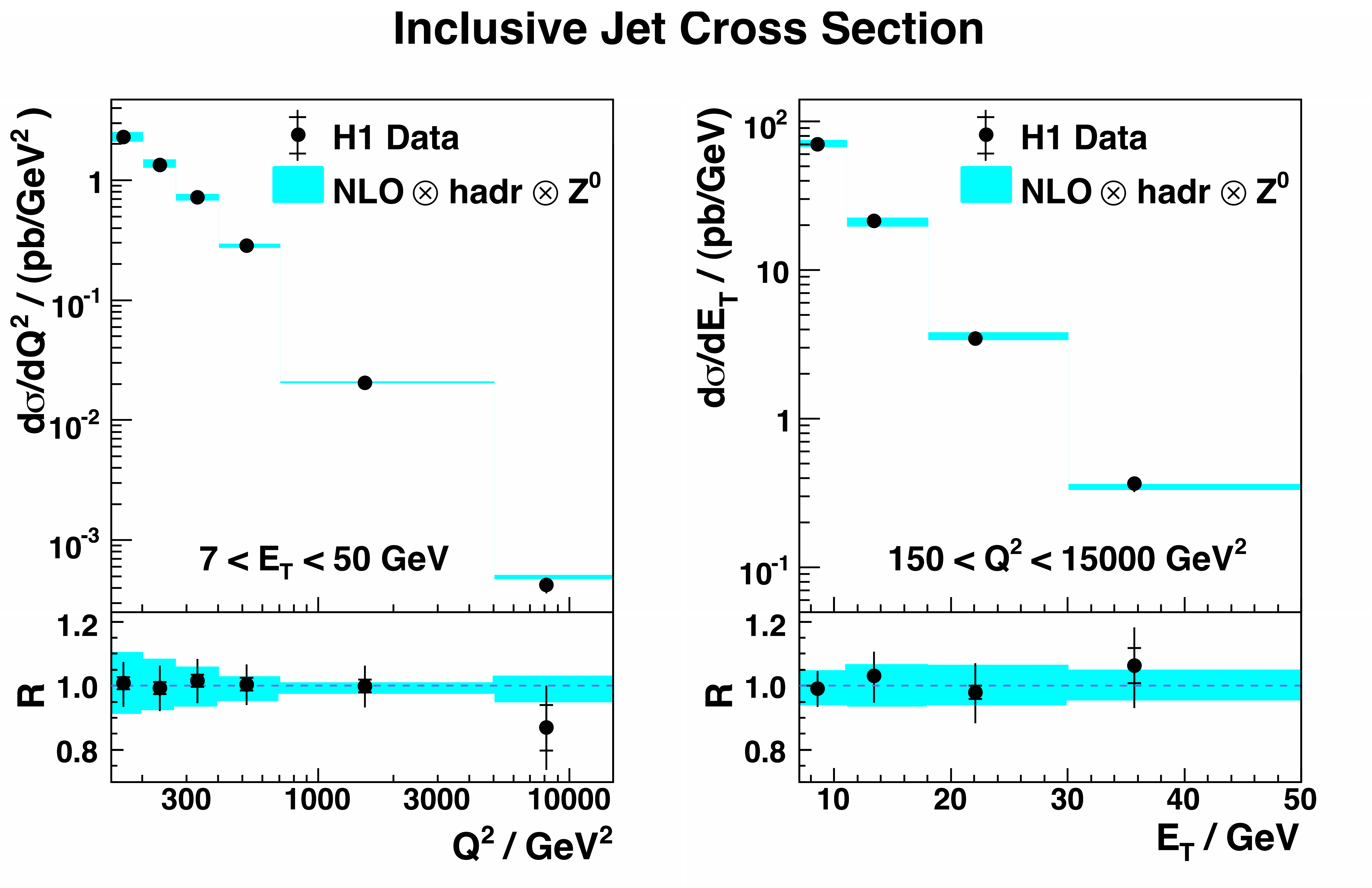
CTEQ6.5
error: ± 20 eigenvectors
±5%

Assess theoretical uncertainty due to missing higher orders through μ_R (and μ_F) dependence of σ_{jet}
convention : $\mu_{R,F}$ ↑ x2 and $\mu_{R,F}$ ↓ x0.5
±5%

Apply hadronisation correction (δhad) to parton level predictions to be able to compare with data
uncertainty taken from difference of Monte Carlo models (PS /CDM)
±2%

More

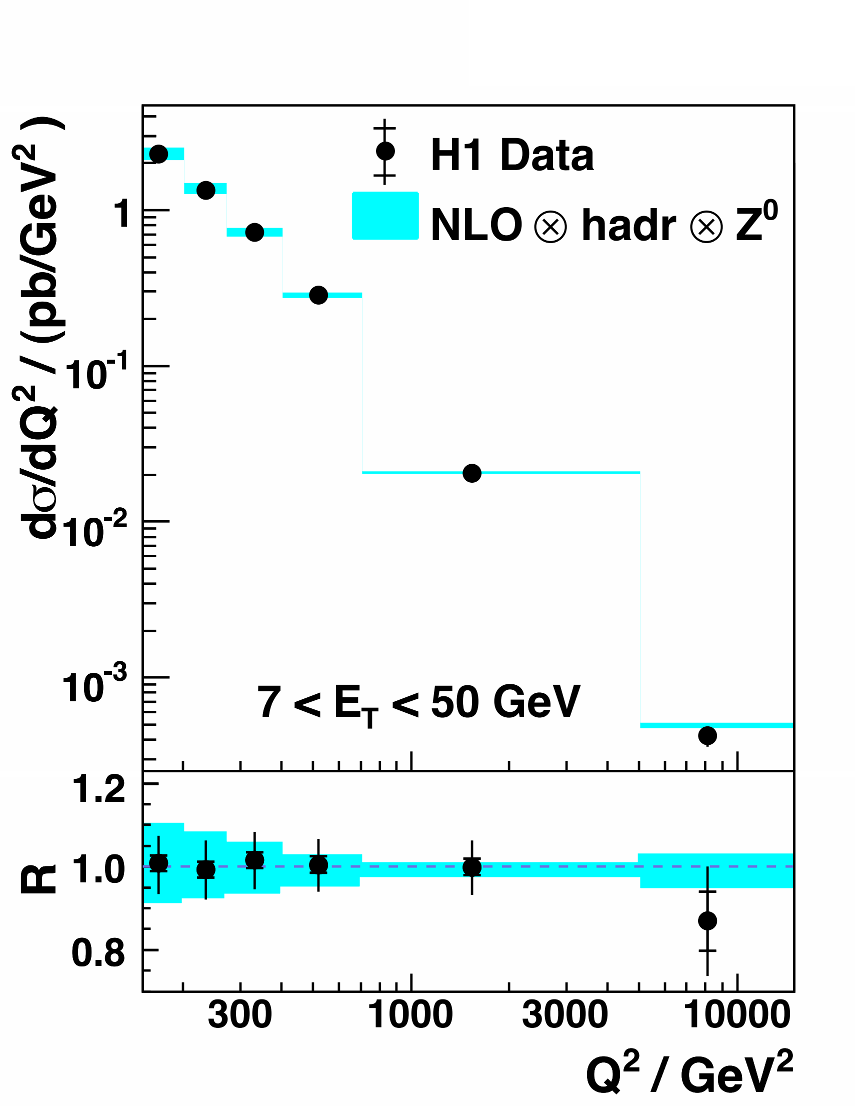
Results

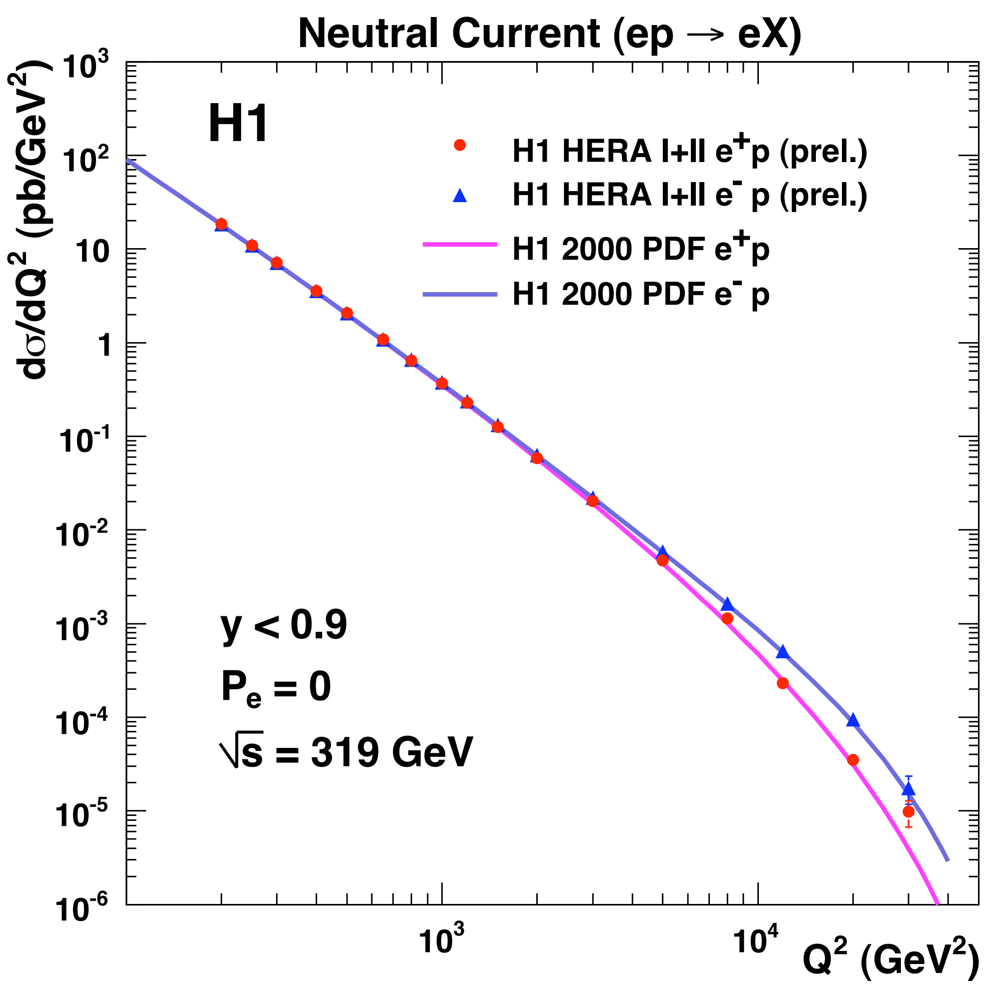


Good description of the data by theory (too good?)

Normalised Jet Cross Section

Instead of counting number of jets use (#jets/#events)
Equals σ_{jet} / $\sigma_{NC\ DIS}$ (normalised incl. jet cross section)
Experimental and theory errors reduced, e.g.
Luminosity uncertainty cancels,
PDF uncertainty reduced.
Improve precision for results and of final α_s extraction.





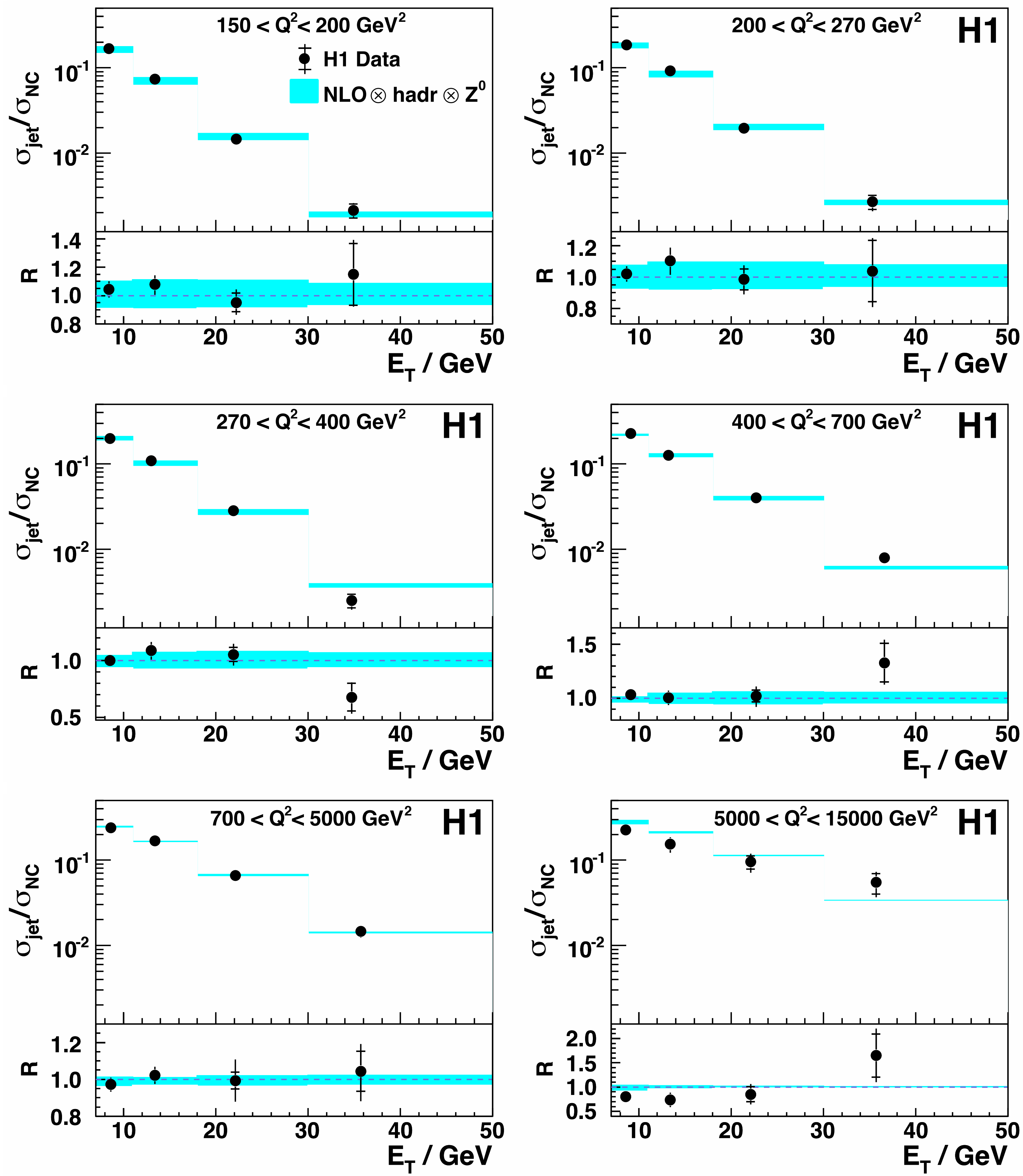
Normalised Inclusive Jet Cross Section

Appearance very similar to inclusive jet cross section

E_T spectrum gets harder with increasing Q^2

More jets per event with increasing Q^2

Reproduced at NLO



α_s Extraction

QCD predictions of the jet cross sections are calculated as a function of $\alpha_s(\mu_r = E_T)$ with the fastNLO package

Measurements and theory predictions are used to calculate a $X^2(\alpha_s)$ with the Hessian method

Fully takes into account correlations of experimental uncertainties

The experimental uncertainty of α_s is defined by that change in α_s which gives an increase in X^2 of one unit with respect to the minimal value.

The theory error is estimated by adding in quadrature the deviation of α_s from the central value when the fit is repeated with independent variations of the renormalisation scale, the factorisation scale and the hadronisation correction factor.

more

α_s Extraction

Each data point yields one α_s

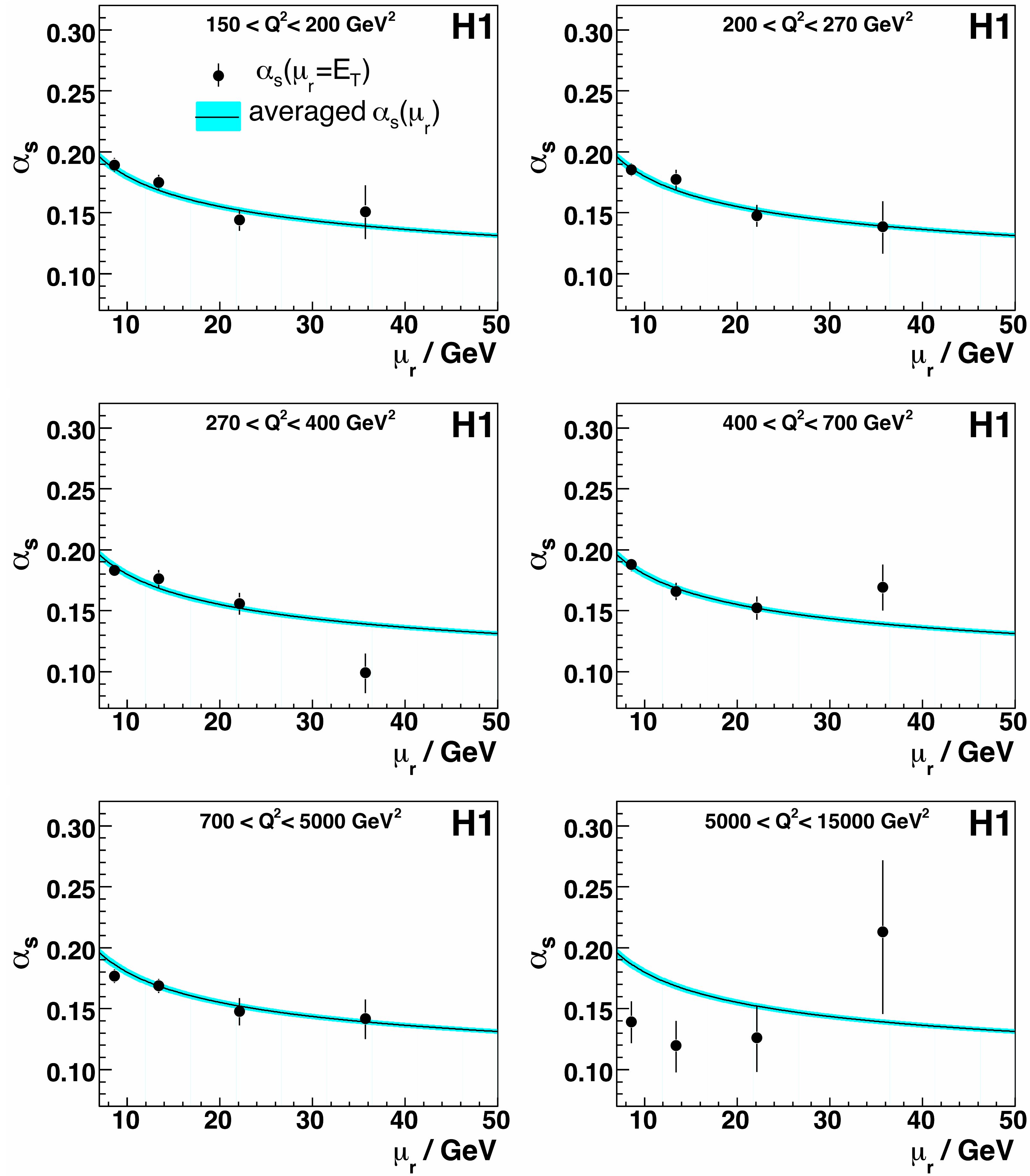
Renormalisation scale chosen as E_T of the jet

Highest Q^2 interval statistically limited

Running of α_S is demonstrated in one experiment

Results are compatible → calculate the average

α_s from Norm. Inclusive Jet Cross Section



more

α_s Extraction

Inclusive jet cross section, using all 24 data points

$$\alpha_s(M_Z) = 0.1179 \pm 0.0024\,(\text{exp})\,^{+0.0052}_{-0.0032}\,(\text{th}) \pm 0.0028\,(\text{pdf})$$

Normalised inclusive jet cross section, using all 24 data points

$$\alpha_s(M_Z) = 0.1193 \pm 0.0014\,(\text{exp})\,^{+0.0047}_{-0.0030}\,(\text{th}) \pm 0.0016\,(\text{pdf})$$

Compatible within error, significant reduction of experimental uncertainty
Theory error main contribution (need NNLO / resumation?)

Restricting phase space to where theory error is smallest,
ZEUS approach, (700-5000GeV2)

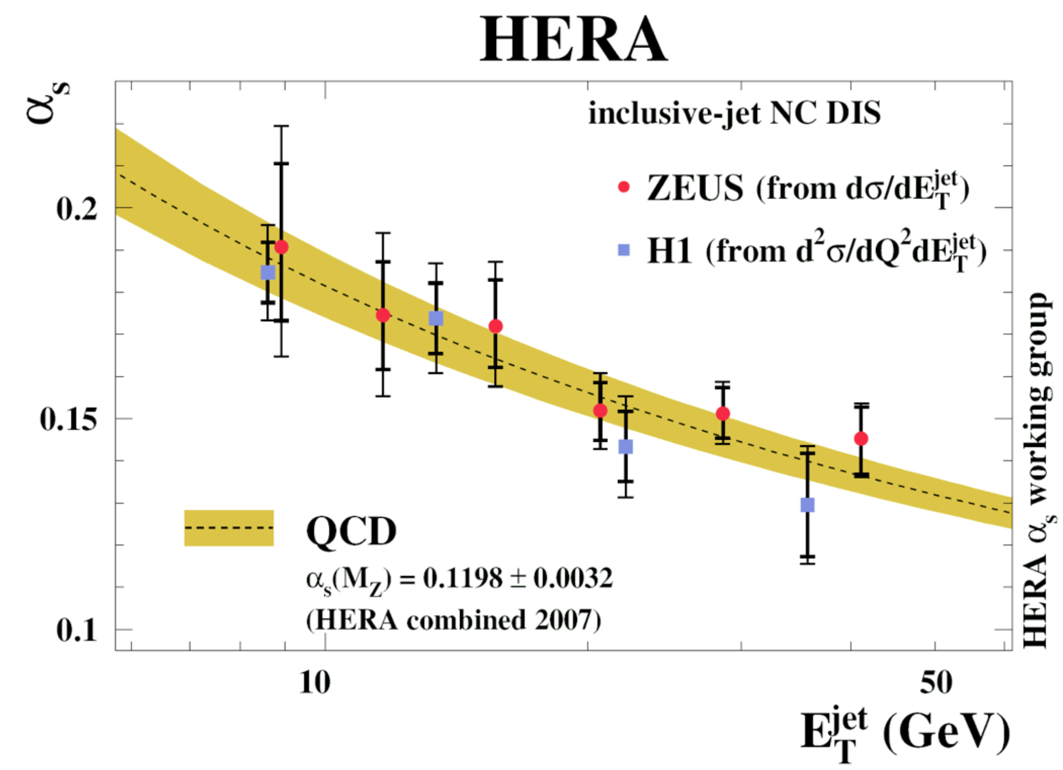
$$\alpha_s(M_Z) = 0.1171 \pm 0.0023\,(\text{exp})\,^{+0.0032}_{-0.0010}\,(\text{th}) \pm 0.0010\,(\text{pdf})$$

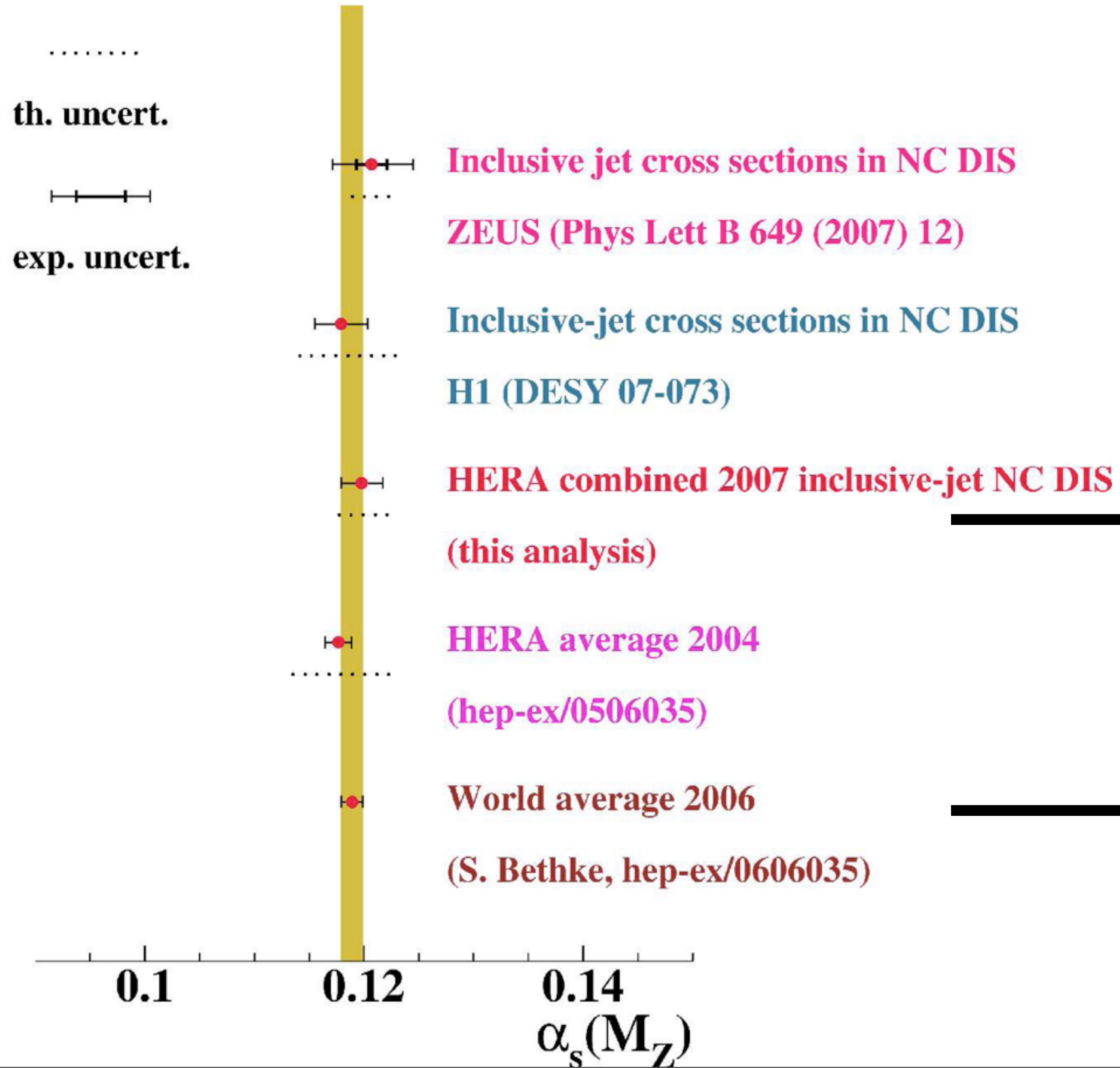
<u>H1 view</u>

Do not take scale error value too seriously, only order of magnitude!

HERA α_s Working Group

$\alpha_s(M_Z)=0.1198 \pm 0.0019(\text{exp.}) \pm 0.0026(\text{th.})$





HERA combined 2007 (2.7%)

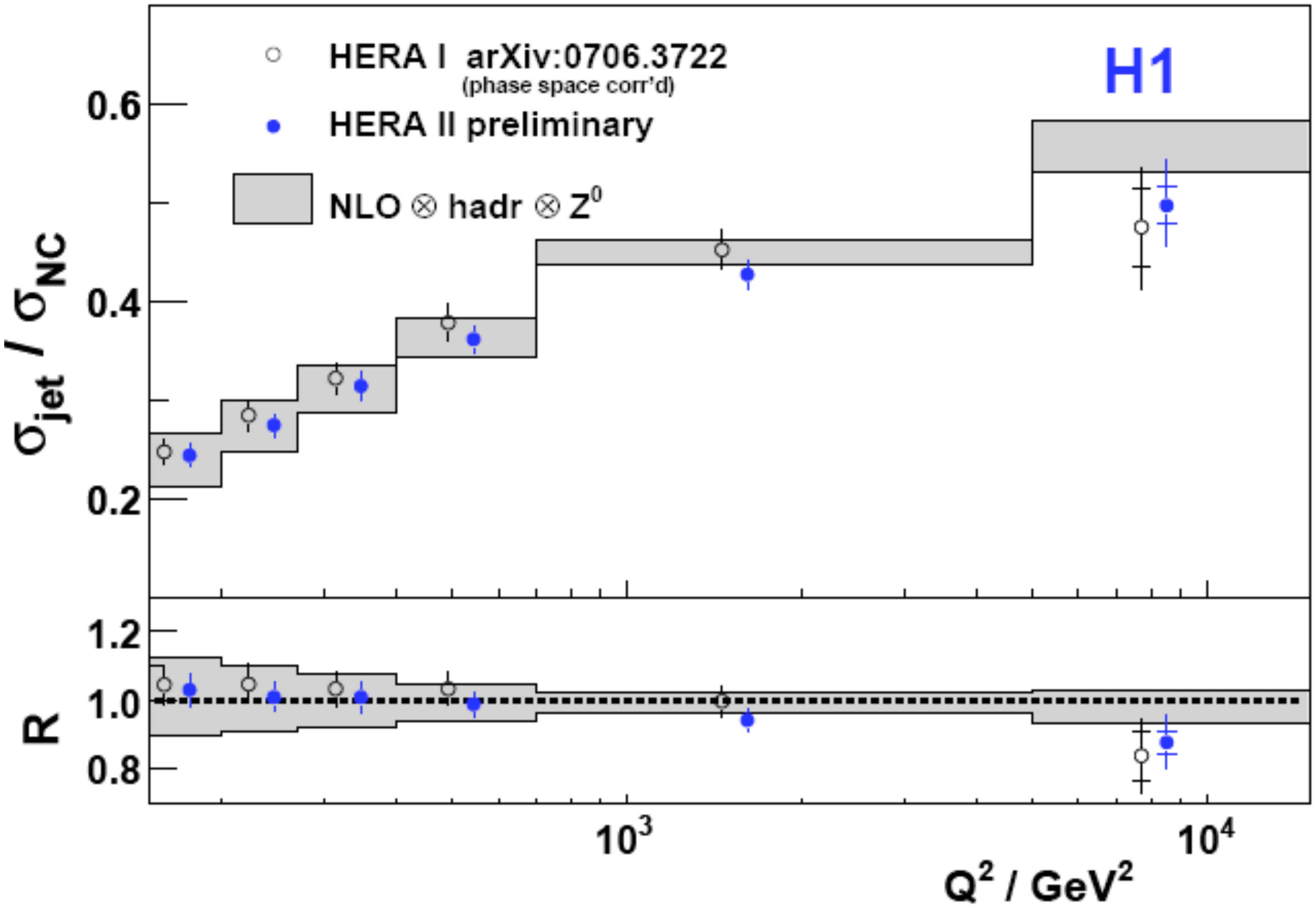
World average (0.8%)

The Future 1 : HERAII

HERA I - 65.4 pb-1

↓

HERA II - 320 pb-1



reduced errors

Hadronic energy scale
2% here →
1.5 % for publication

also possible

Optimised NLO scale choice, $\mu_{r,f}$,
Q^2, Q/2, 2Q, E_T+Q etc...

Improve description of data
by LO Monte Carlos.

Conclusions

High statistics results from HERA II show (mostly) that the Standard model still works

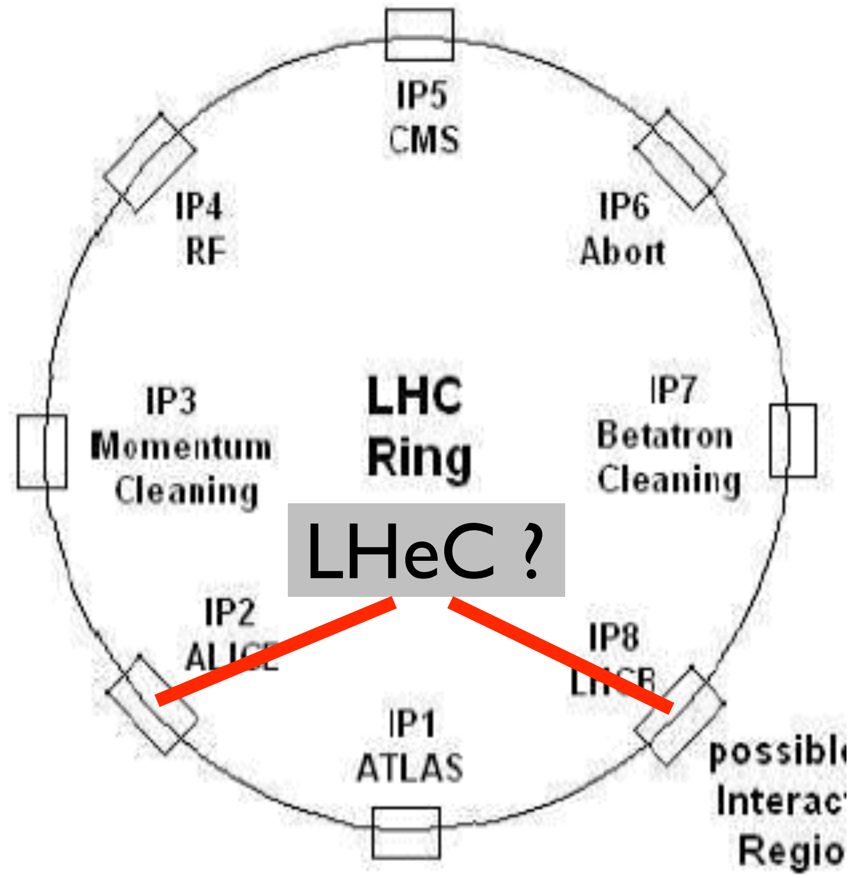
High precision measurements allow the extraction of a competitive value of α_s.

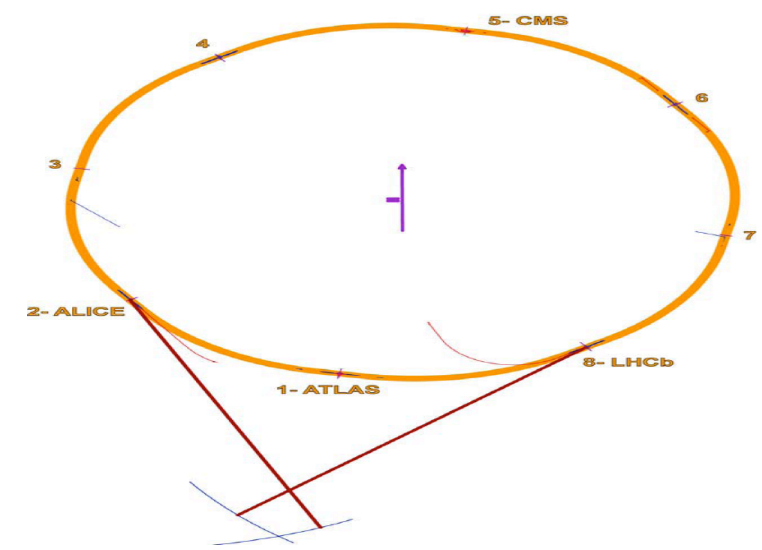
$\alpha_s(M_Z)=0.1198 \pm 0.0019(\text{exp.}) \pm 0.0026(\text{th.})$

Future HERA data will improve on the accuracy

Measurements at H1 (HERA) will still be the state-of-the-art until the next ep collider is built. which will be in ...

The Future: LHeC



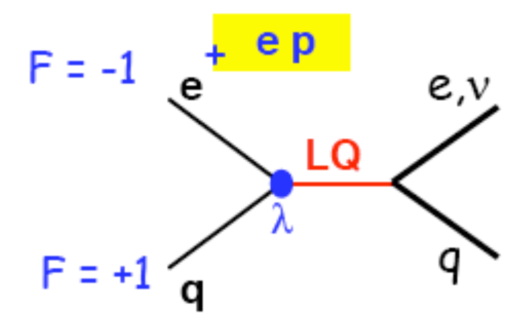


What?

40-140 GeV e ⊗ 1-7 TeV p

ring-ring or linac

ECFA/CERN endorsed workshops



Why?

Leptoquarks, σ x1000 LHC quark substructure

Very low x, Very high Q, precision QCD, Nuclear PDFs

When?

2008 - 2009: Workshops + CDR

~2011 :TDR < 2020 beams

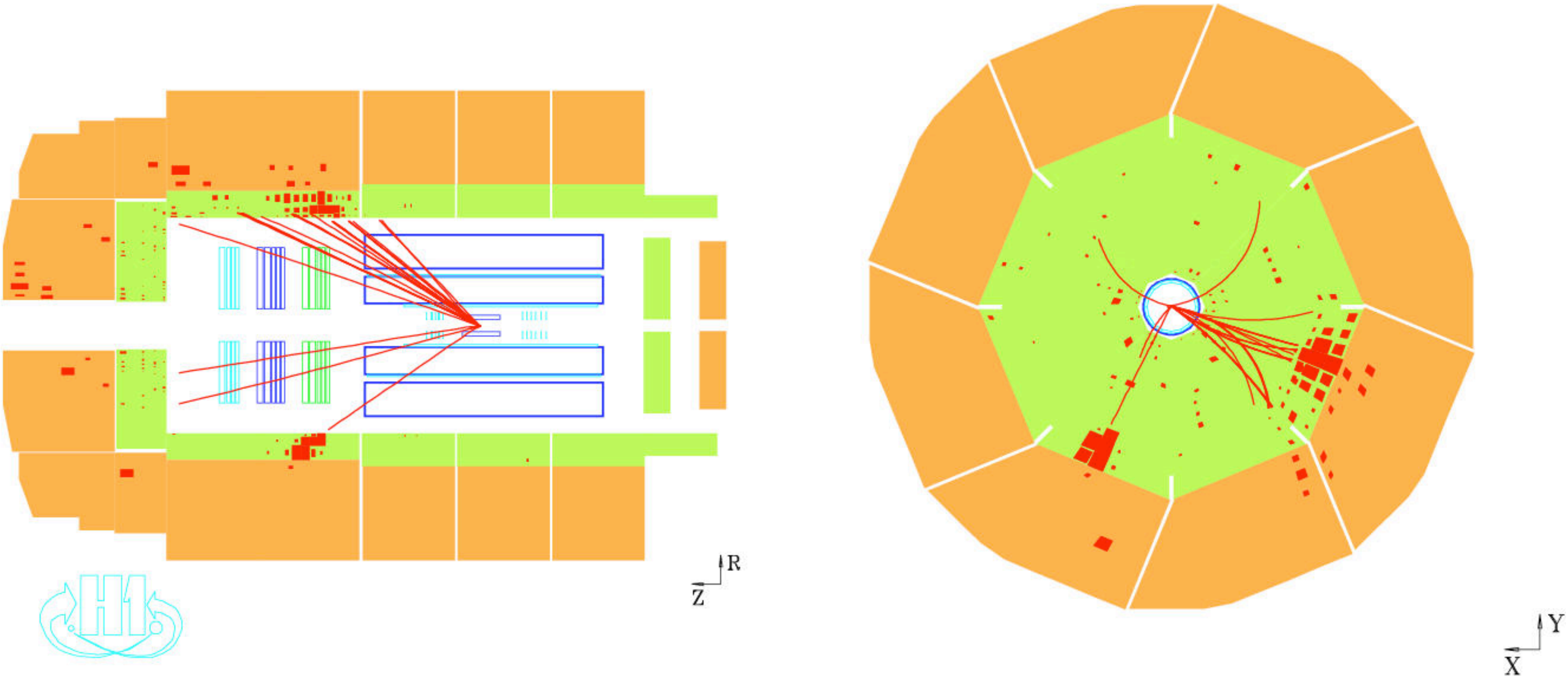
STFC funding oscillations?

more info http://www.lhec.org.uk http://xxx.soton.ac.uk/abs/hep-ex/0603016

Backup

H1 dismantling

Isolated leptons with missing Pt

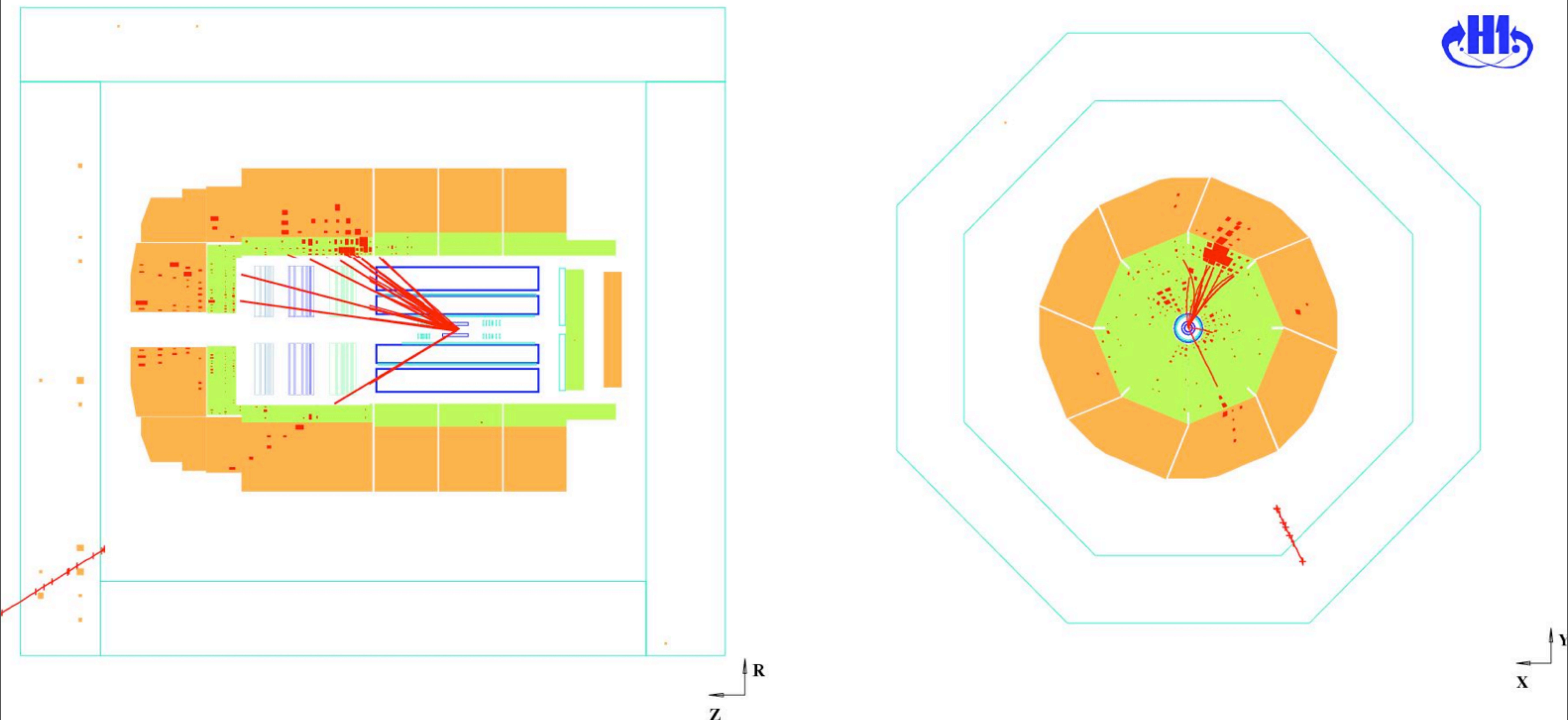


High P_T^X e + P_{TMiss} event in H1 HERA II e^+p data

P_T^e = 37 GeV, P_{TMiss} = 44 GeV, P_T^X = 29 GeV

Back

Isolated leptons with missing Pt

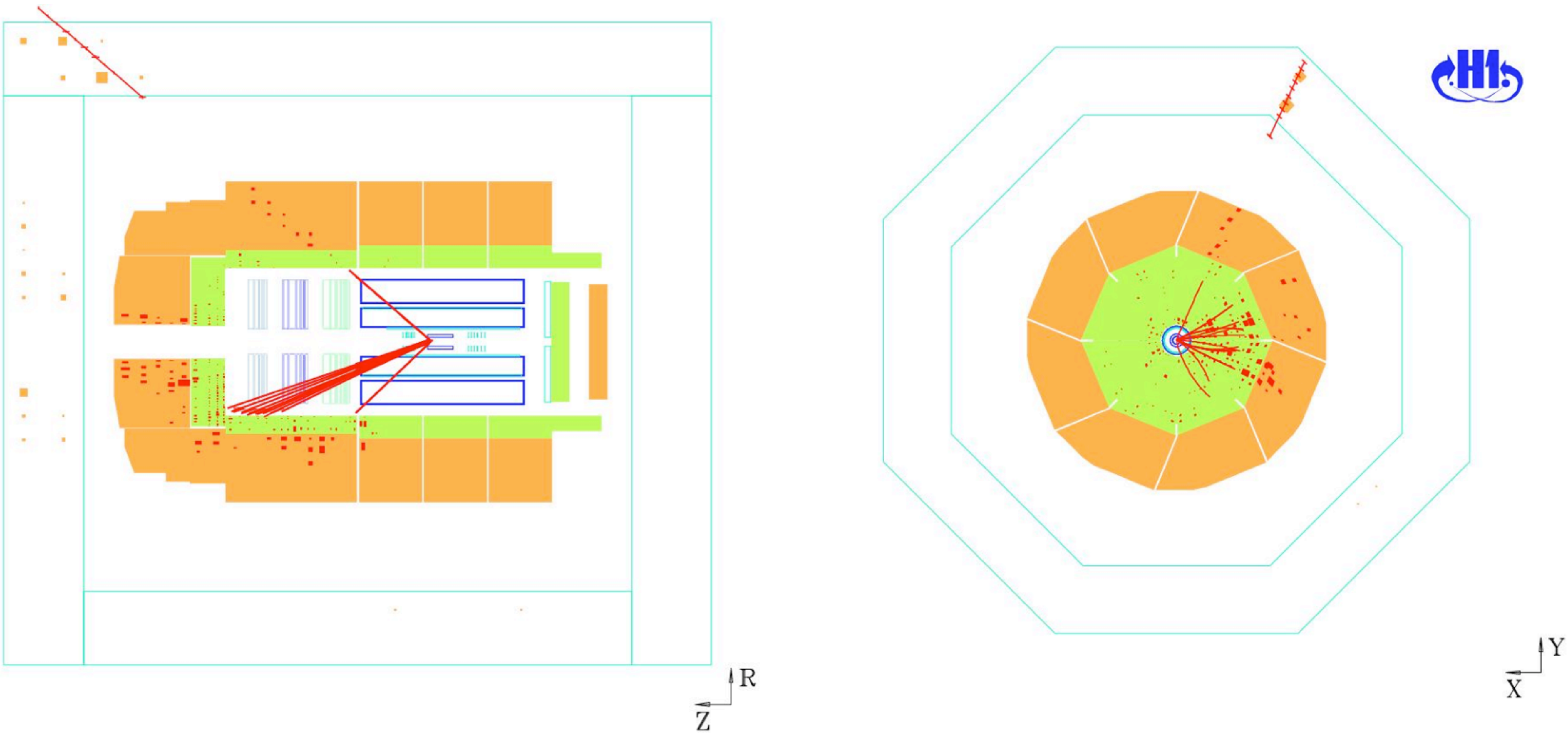


High P_T^X μ + P_{TMiss} event in H1 HERA II e^+p data

P_T^μ = 51 GeV, P_{TMiss} = 39 GeV, P_T^X = 48 GeV

Back

Isolated leptons with missing Pt



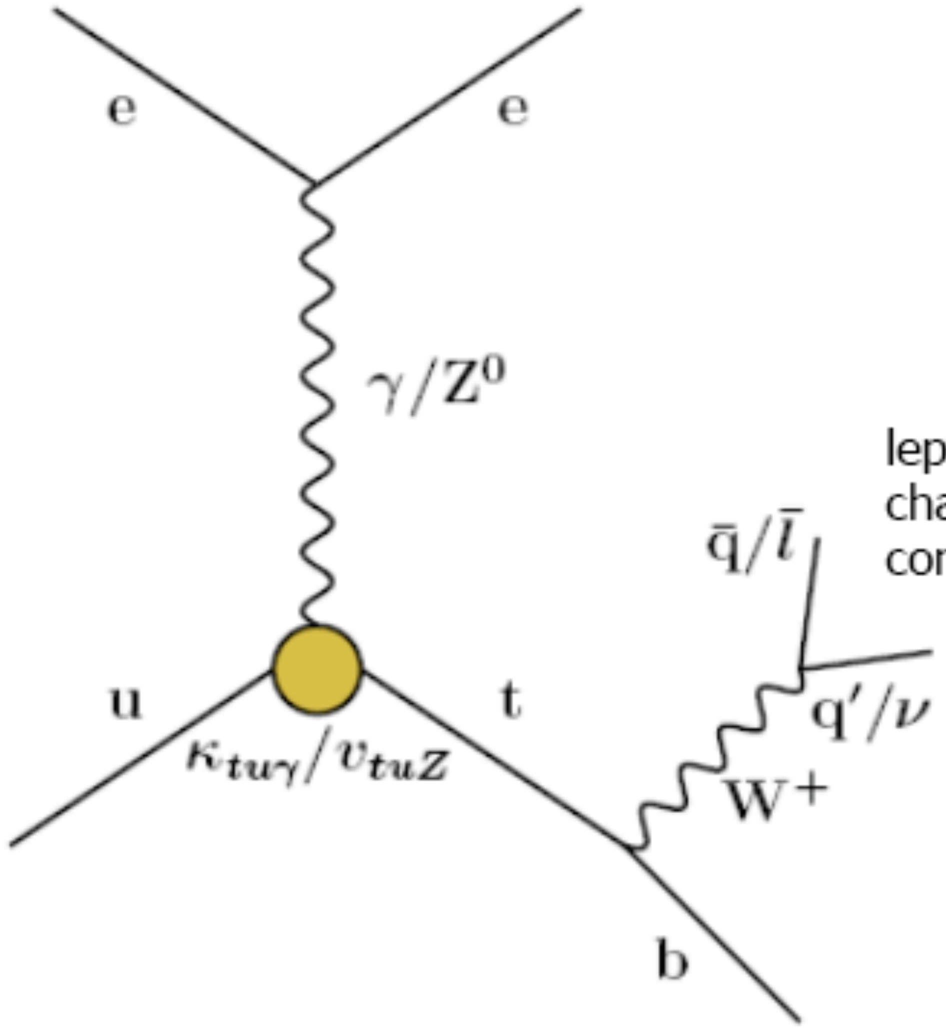
High P_T^X μ + P_{TMiss} event in H1 HERA II e^-p data

$P_T^\mu = 38$ GeV, $P_{TMiss} = 51$ GeV, $P_T^X = 24.7$ GeV

Back

Single Top Production at HERA

- Excess of observed events at high P_T^X unlikely to be due to W production (typically low P_T^X)
  - But! Observed topology is typical signature of top decay $t \rightarrow bW$
  - Tiny SM top production cross section < 1 fb
  - Anomalous top production via Flavour Changing Neutral Current ?
  - However: This process cannot explain asymmetry between datasets

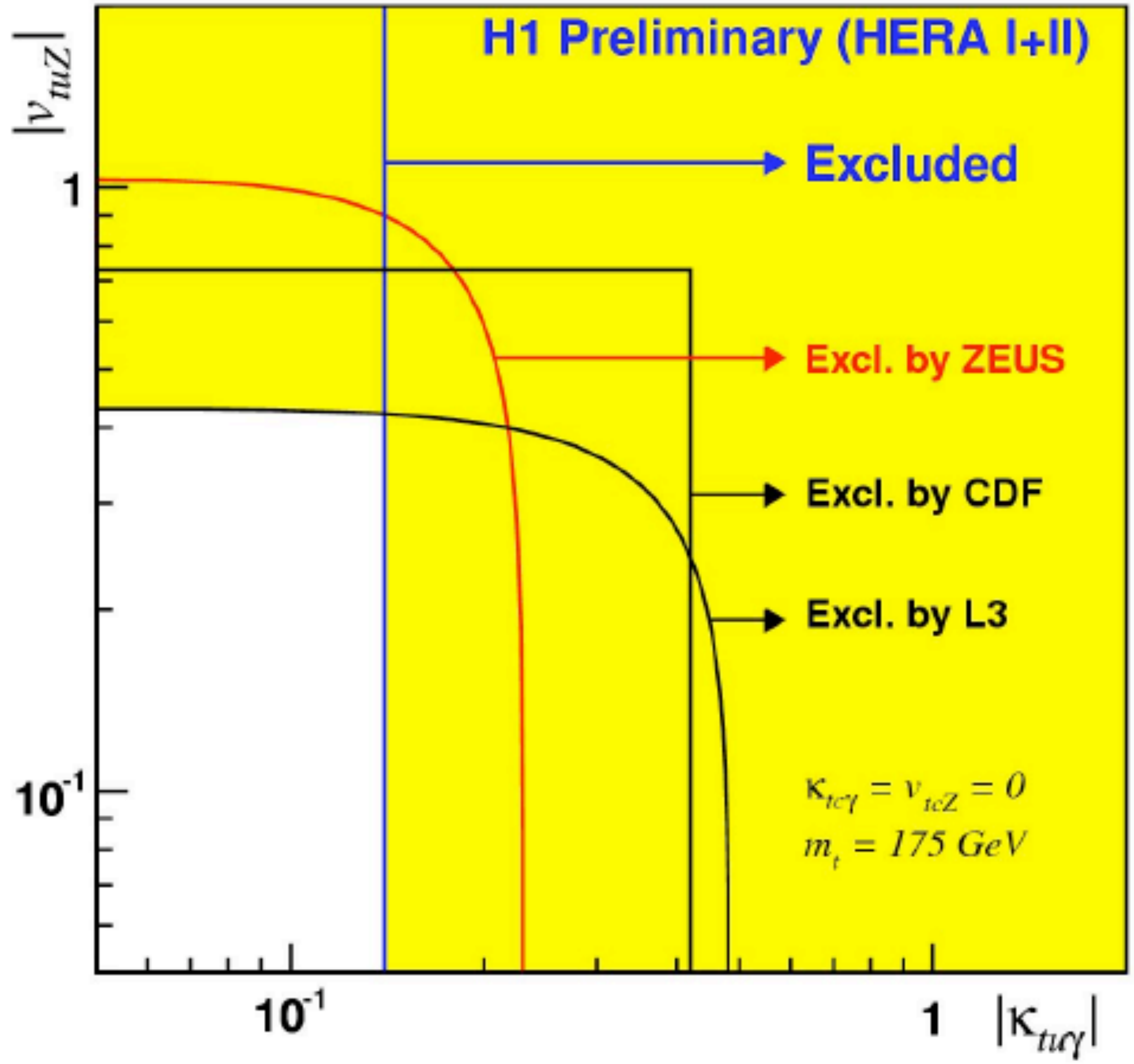


- HERA I analyses:
  - H1: $\sigma(ep \rightarrow etX) < 0.55$ pb
  - ZEUS: $\sigma(ep \rightarrow etX) < 0.23$ pb

$\kappa_{tu\gamma}$: Anomalous γ magnetic coupling
V_{tuZ} : Anomalous Z vector coupling

H1: HERA I+II Exclusion Limits

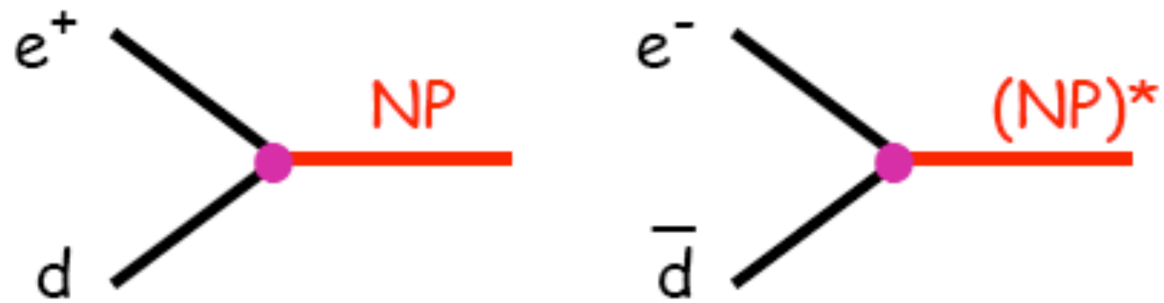
- Cross section limits on FCNC single top extracted from discriminator using a maximum likelihood method
- New H1 upper bound on the cross section at 95% CL:
  - $\sigma(ep \rightarrow etX) < 0.16$ pb
- Upper bound on the anomalous coupling
  - $\kappa_{tu\gamma} < 0.14$



- New limit extends into region of phase space uncovered by other colliders

A BSM Model favouring e^+p over e^-p

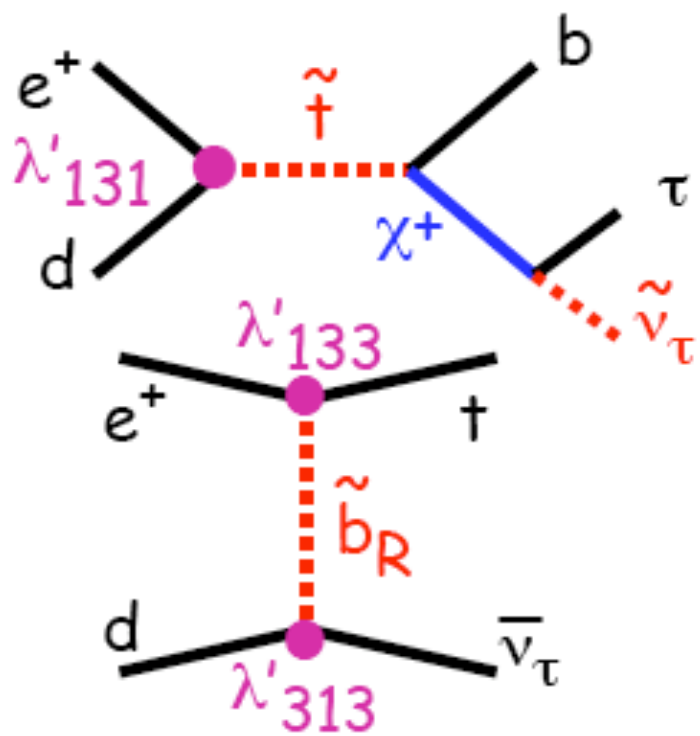
- Particle coupling to e-q with fermion number F=0 ?



Large mass i.e. large x_{Bj}

$d >> \bar{d}$, hence $\sigma(e+) >> \sigma(e-)$

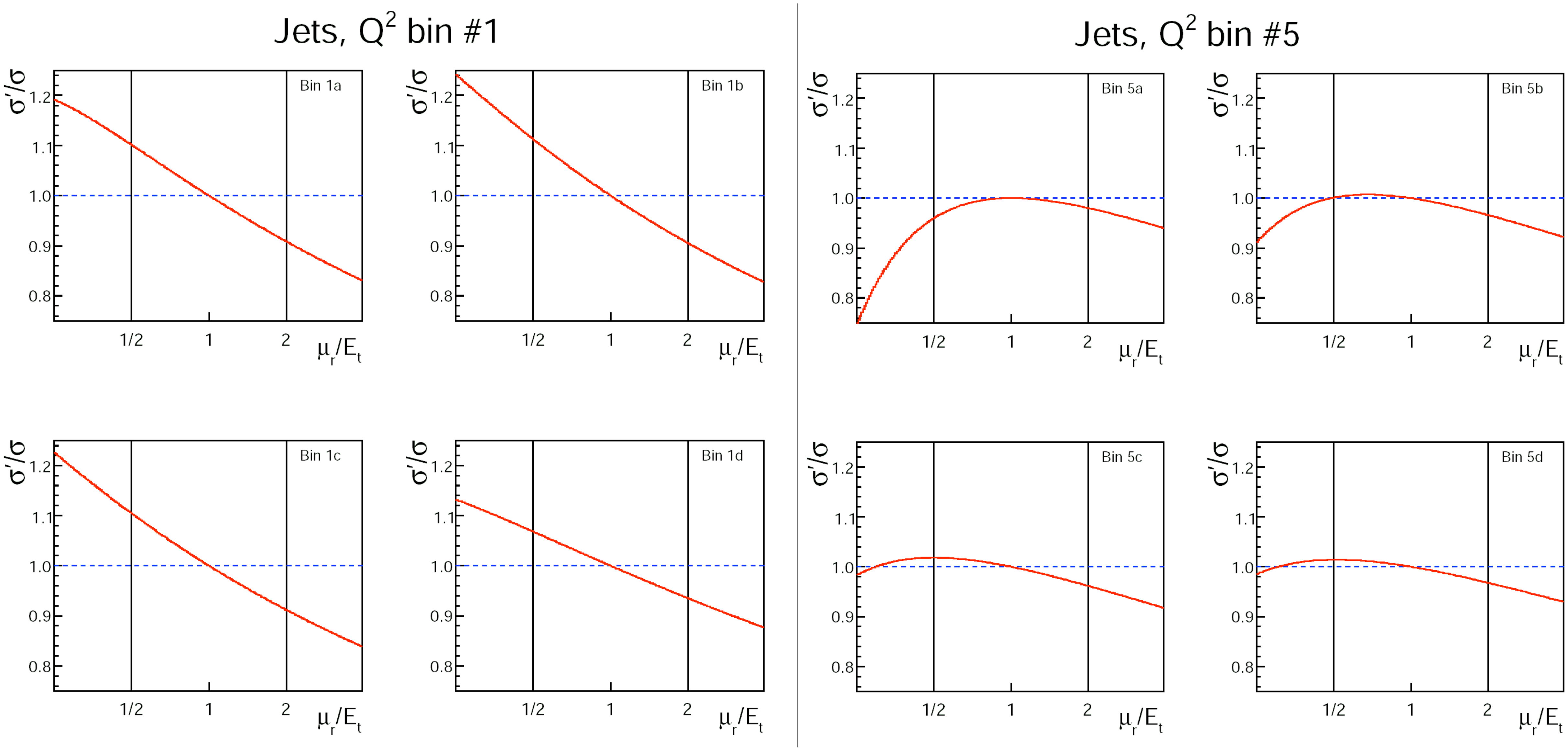
- Another example : Squarks in R-parity violating SUSY ?



If LSP is $\tilde{\nu}_\tau$ and no large RpV coupling involving the τ : $\tilde{\nu}_\tau$ could be long-lived

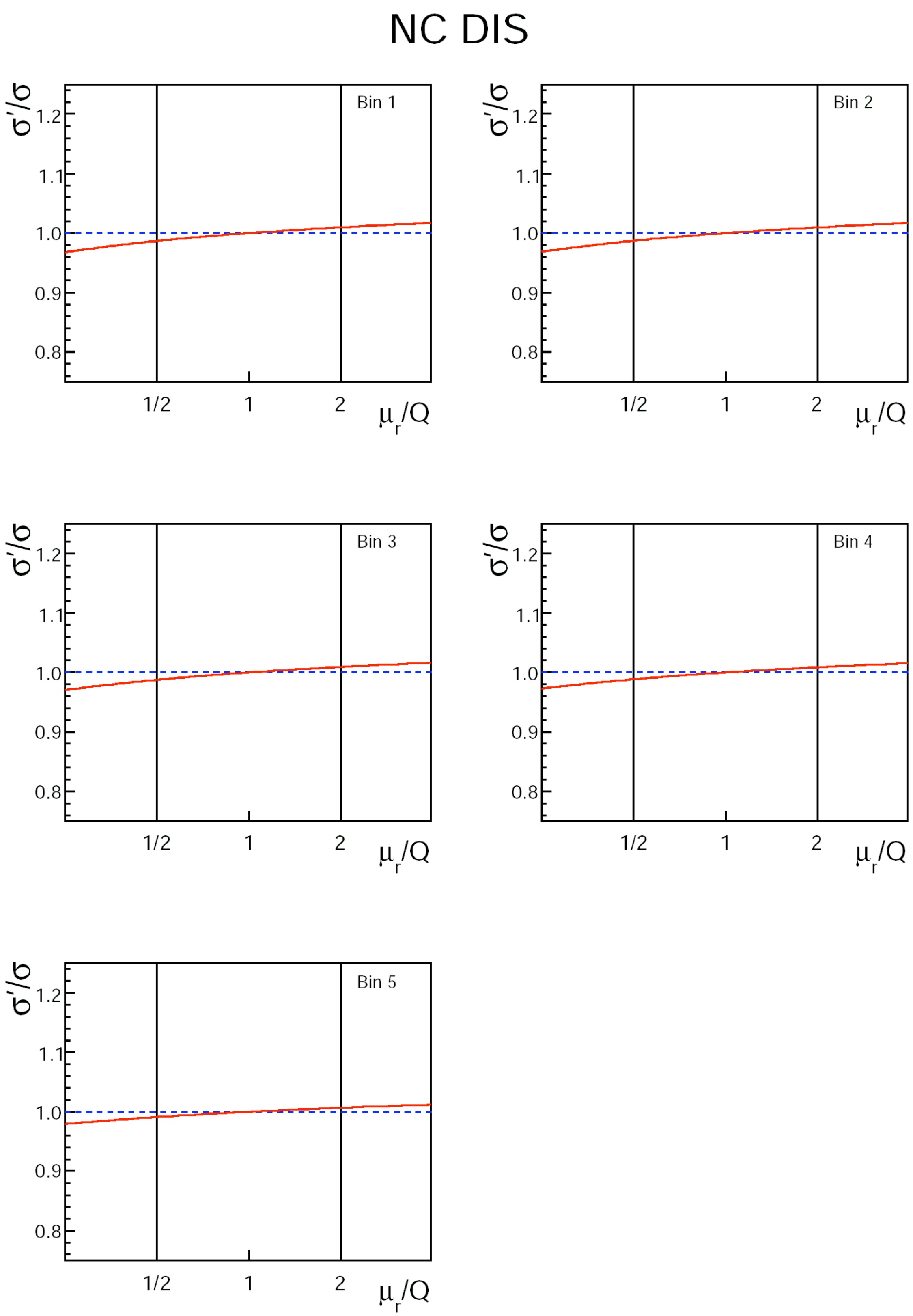
RpV via couplings involving two 3rd generation fields, light sbottom. Large $M_{top} \rightarrow$ large x_{Bj}

Scan of Renormalisation Scale



- Theory error: variation of μ_r by factor 2
- Do not use endpoints, but maxima within interval!
- Important at high Q^2, theory error gets a bit larger

Scan of Renormalisation Scale



- NC cross section shows opposite slope than jets
- No cancellations for the theory errors for the ratio jet/NC (just the opposite!)

back

QCD Fits

Fit of $\alpha_s(M_z)$ with fastNLO, NLOJET++ / DISENT

- **Cross section data points are correlated.**
- **Method used in 95-97 analysis & H1-01/98-536**
- χ^2 **definition**
  - $\chi^2 = \sum_i \frac{(\sigma_i^{exp} - \sigma_i^{FastNLO}(\alpha_s(M_Z))[1-\sum_k \delta_{i,k}(\epsilon_k)])^2}{\delta^2_{i,uncorr}} + \sum_k \epsilon_k^2$
  - i **runs over measured cross section**
  - $\sigma_i^{FastNLO}(\alpha_s(M_Z))$: **FastNLO calculation**
  - k **runs over all sources of correlated uncertainties**
  - $\delta_{i,k}(\epsilon_k)$: **contribution from kth correlated source to ith measurements**
  - $\alpha_s(M_Z)$ **and** ϵ_k: **fitted parameters**
- **Using TMinuit of ROOT package**

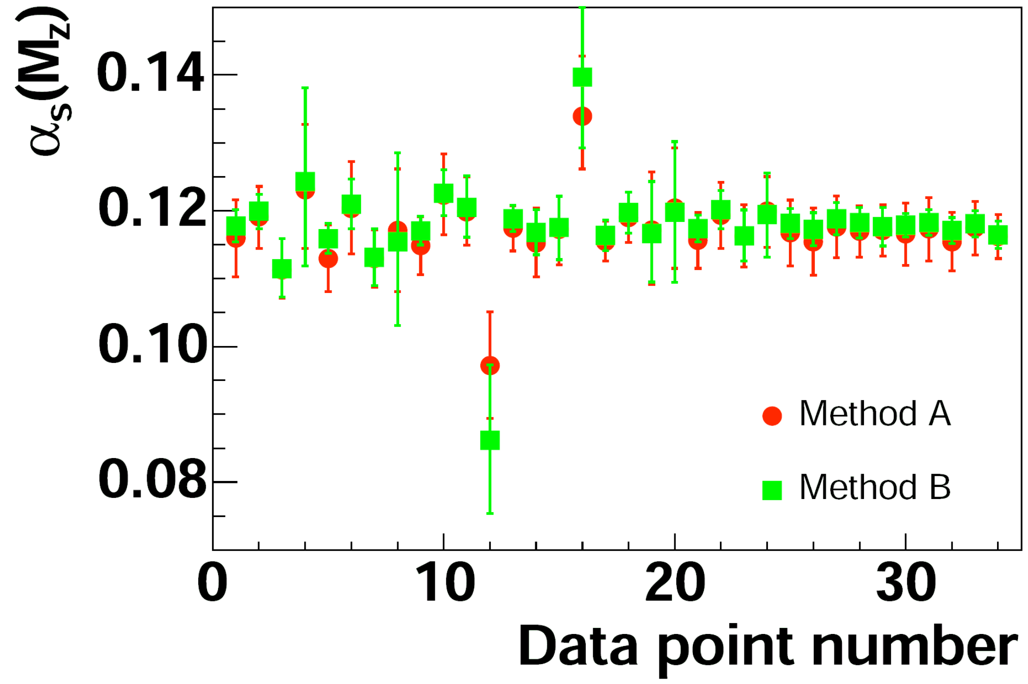
back

Check Fit Method

- In the fit we use CTEQ6.5 which was build assuming $\alpha_s(M_Z)=0.118$
- Do we bias our result, due to correlation between gluon and α_s ?
- Cross check with fit method „A“
  - interpolate between 10 values of $\alpha_s(M_Z)$ with CTEQ6AB
  - building averages of fits more involved

Standard Method B: $\alpha_s = 0.1158 \pm 0.0020$

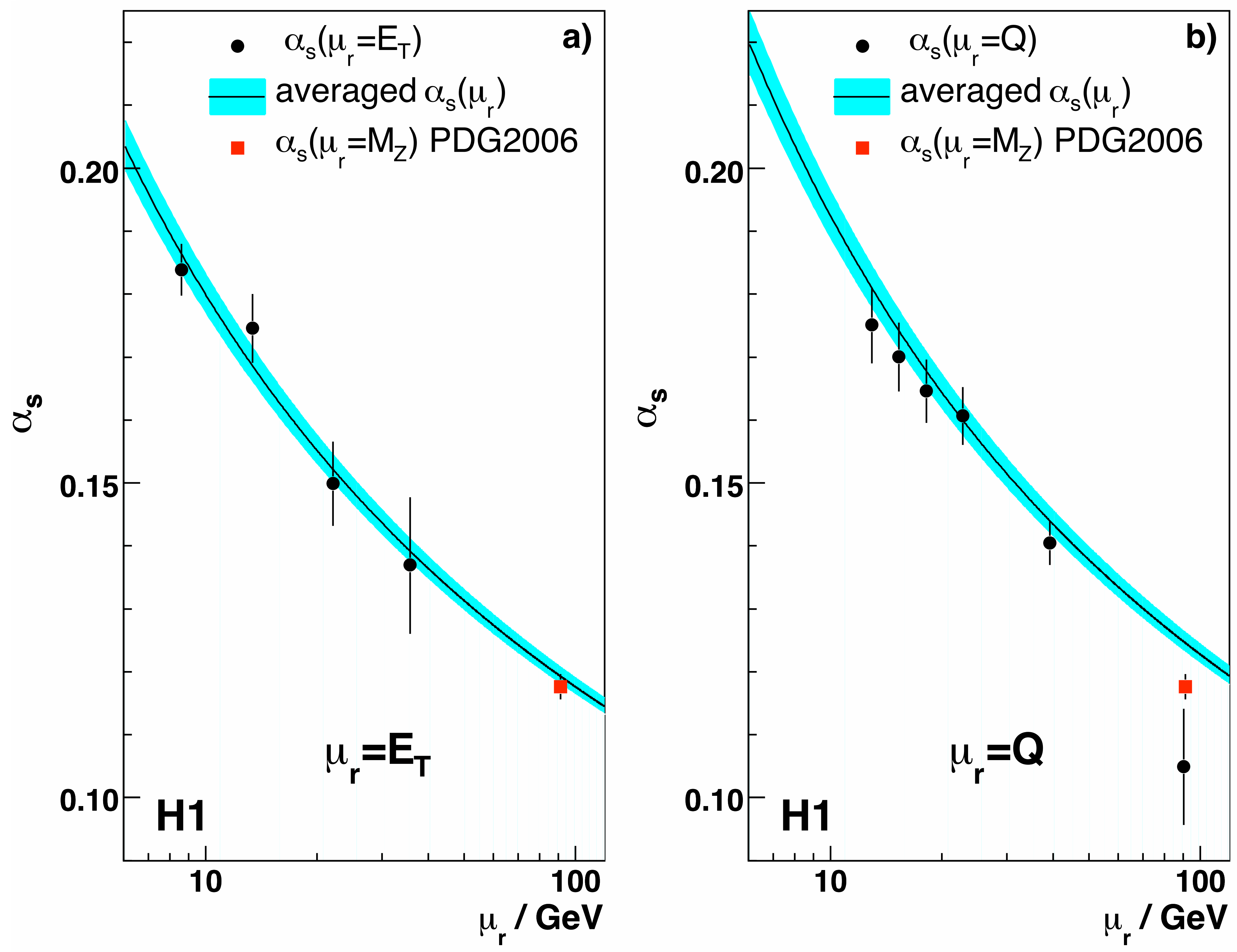
Method A: $\alpha_s = 0.1152 \pm 0.0025$



- Consistent results within error, no bias expected

back

α_s from Norm. Inclusive Jet Cross Section



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