Metody eksperymentalne w fizyce wysokich energii

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Wykład XIV

- Pomiary przekroju czynnego

⇒ przekrój całkowity

⇒ przekrój różniczkowy

Cross Section: Experimentally

Number of observed events: counted

Background: Measured from data / calculated from theory

$$\sigma = \frac{N_{obs} - N_{BG}}{\int L\,dt \cdot \varepsilon}$$

Cross section σ

Luminosity: Determined by accelerator, trigger prescale, …

Efficiency: optimized by experimentalist

Includes acceptance due to kinematics, geometry, cuts etc.

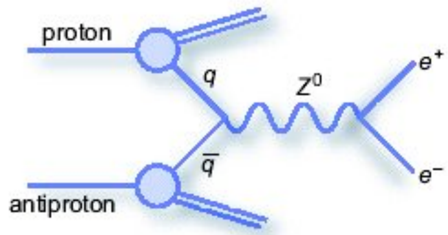
Acceptance / Efficiency

- Actually rather complex:
  - Many ingredients enter here
  - You need to know:

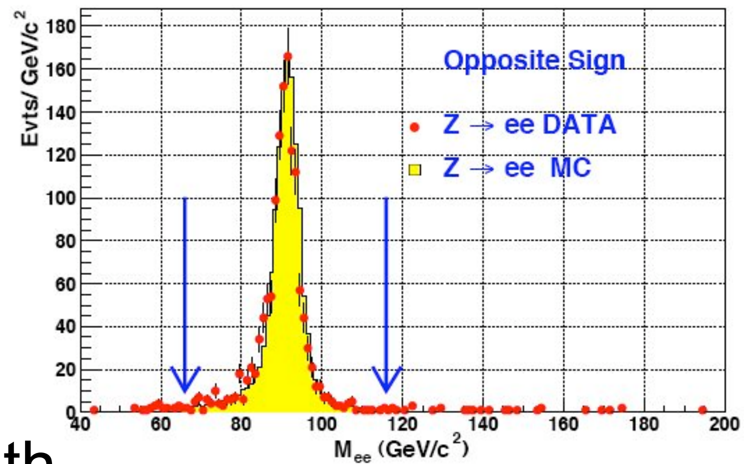
$$\varepsilon_{total} = \frac{\textbf{Number of Events used in Analysis}}{\textbf{Number of Events Produced}}$$

- Ingredients:
  - Trigger efficiency
  - Identification efficiency
  - Kinematic acceptance
  - Cut efficiencies
- Using three example measurements for illustration:
  - Z boson, top quak and jet cross sections

Z Boson Cross Section



- Trigger requires one electron with E_T>20 GeV
  - Criteria at L1, L2 and L3/EventFilter
- You select two electrons in the analysis
  - With certain quality criteria
  - With an isolation requirement
  - With E_T>25 GeV and |eta|<2.5
  - With oppositely charged tracks with p_T>10 GeV



- You require the di-electron mass to be near the Z:
  - 66<M(ll)<116 GeV

=> $\varepsilon_{total} = \varepsilon_{trig}\varepsilon_{rec}\varepsilon_{ID}\varepsilon_{kin}\varepsilon_{track}$

Uncertainty on Cross Section

- You will want to minimize the uncertainty:

$$\frac{\delta\sigma}{\sigma} = \sqrt{\frac{\delta N_{obs}^2 + \delta N_{BG}^2}{(N_{obs} - N_{BG})^2} + \left(\frac{\delta\mathcal{L}}{\mathcal{L}}\right)^2 + \left(\frac{\delta\epsilon}{\epsilon}\right)^2}$$

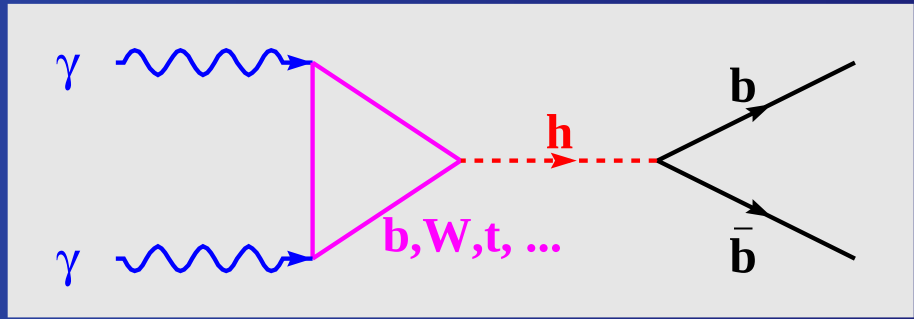
stat. sys. sys. sys.

- Thus you need:
  - N_{obs}-N_{BG} small (I.e. N_{signal} large)
    - Optimize selection for large acceptance and small background
  - Uncertainties on efficiency and background small
    - Hard work you have to do
  - Uncertainty on luminosity small
    - Usually not directly in your power

$m_h \approx 120$ GeV

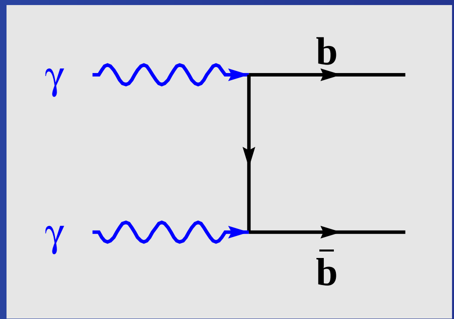
Process: $\gamma + \gamma \to h \to b + \bar{b}$

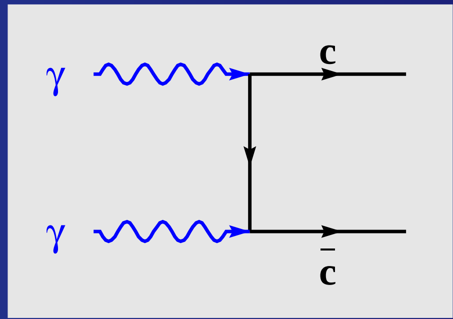
$$J_z = 0$$



"Hard" background:

- $\gamma + \gamma \to b + \bar{b}$
- $\gamma + \gamma \to c + \bar{c}$





$\sigma \propto Q_q^4$

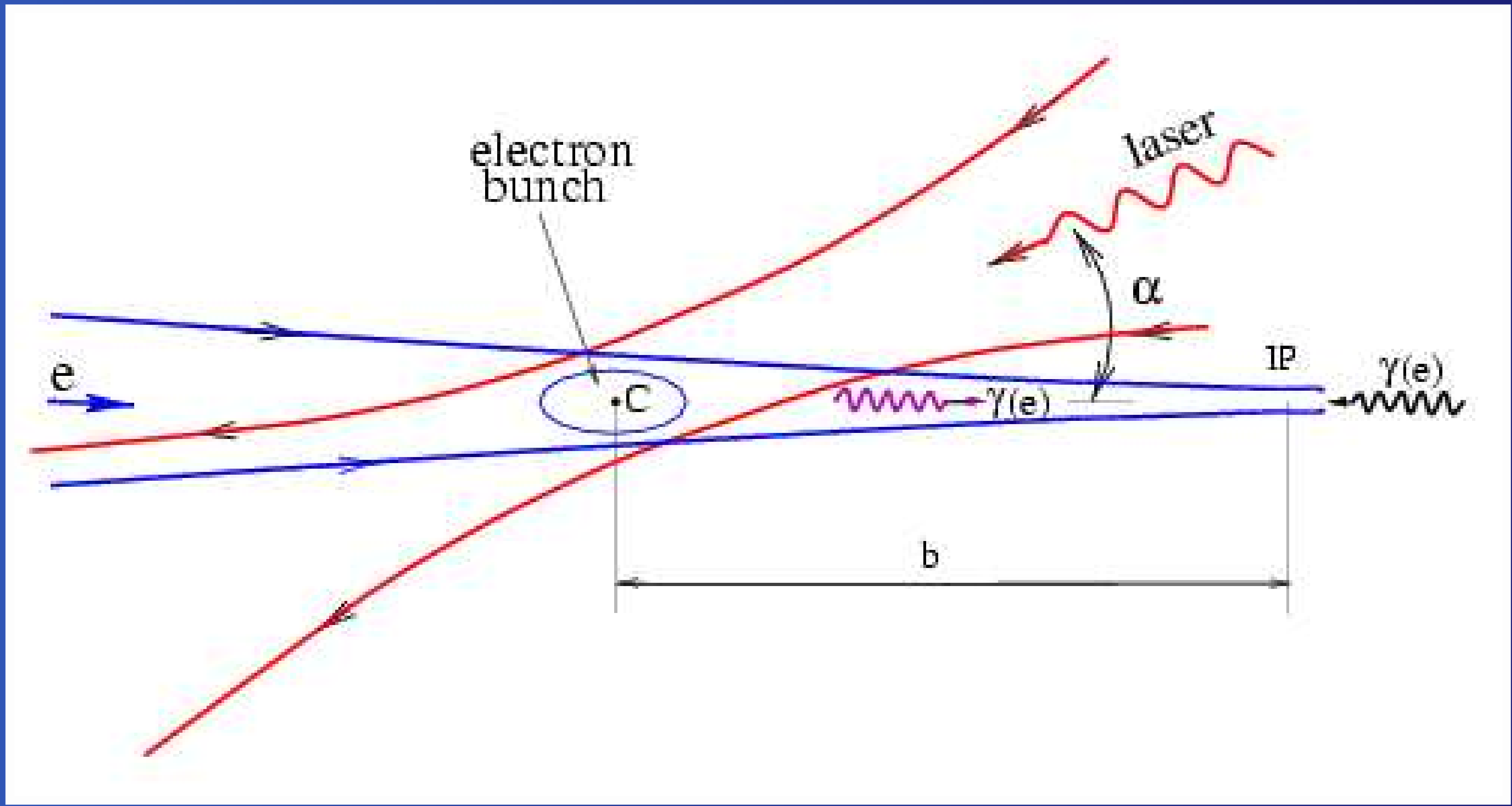
$\sigma^{LO}(|J_z| = 2) \gg \sigma^{LO}(J_z = 0)$

Other background:

- Resolved photon(s) interactions $\gamma + \gamma \to X + Q + \bar{Q}$
- Overlaying events
  (high intensity of photon-beams in the low-energy part of the spectrum)

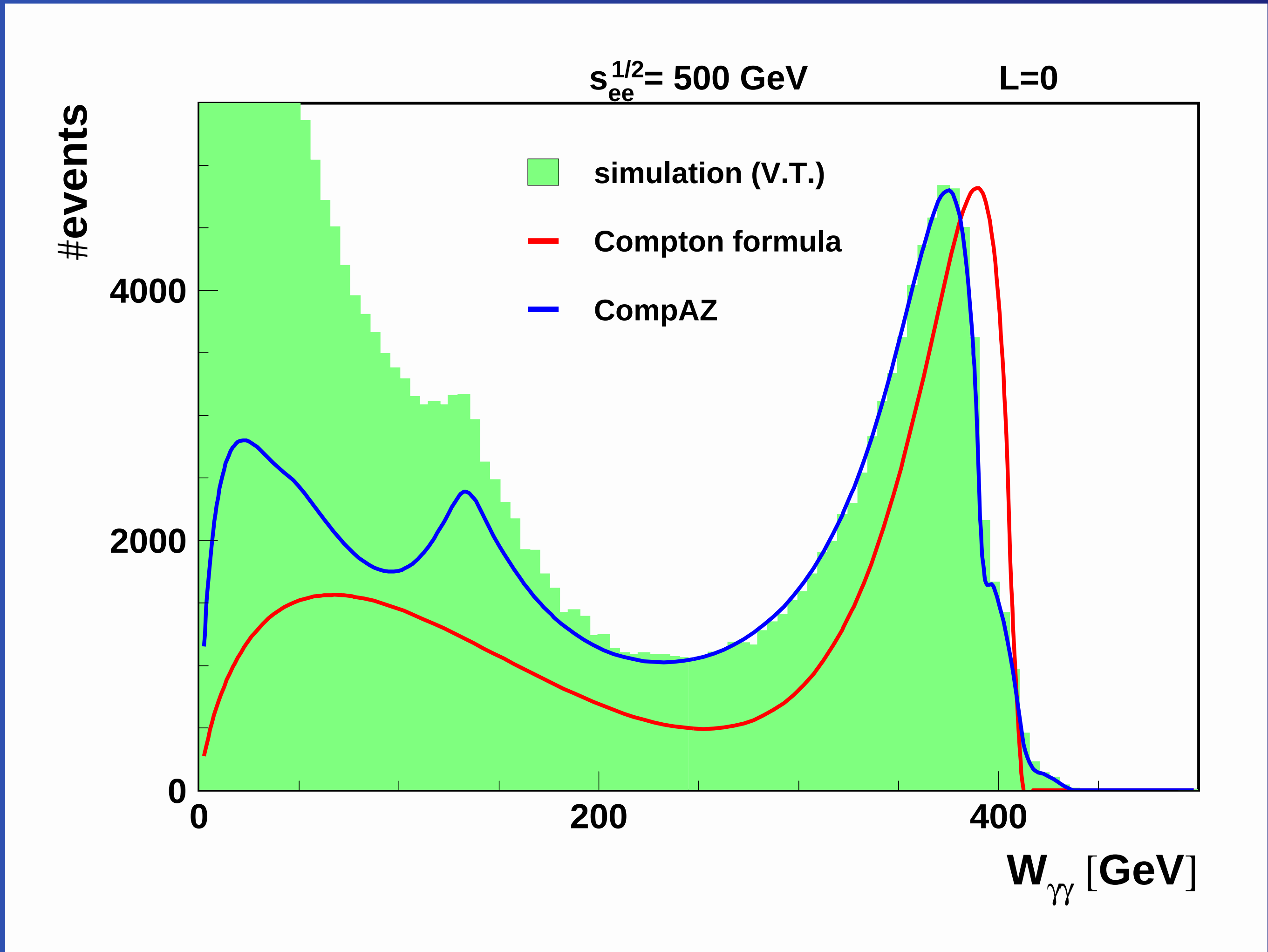
Photon Collider

High-energy photons obtained in the Compton back-scattering



Photon Collider

$\gamma\gamma$-luminosity spectrum



Generation & Simulation. Selection.

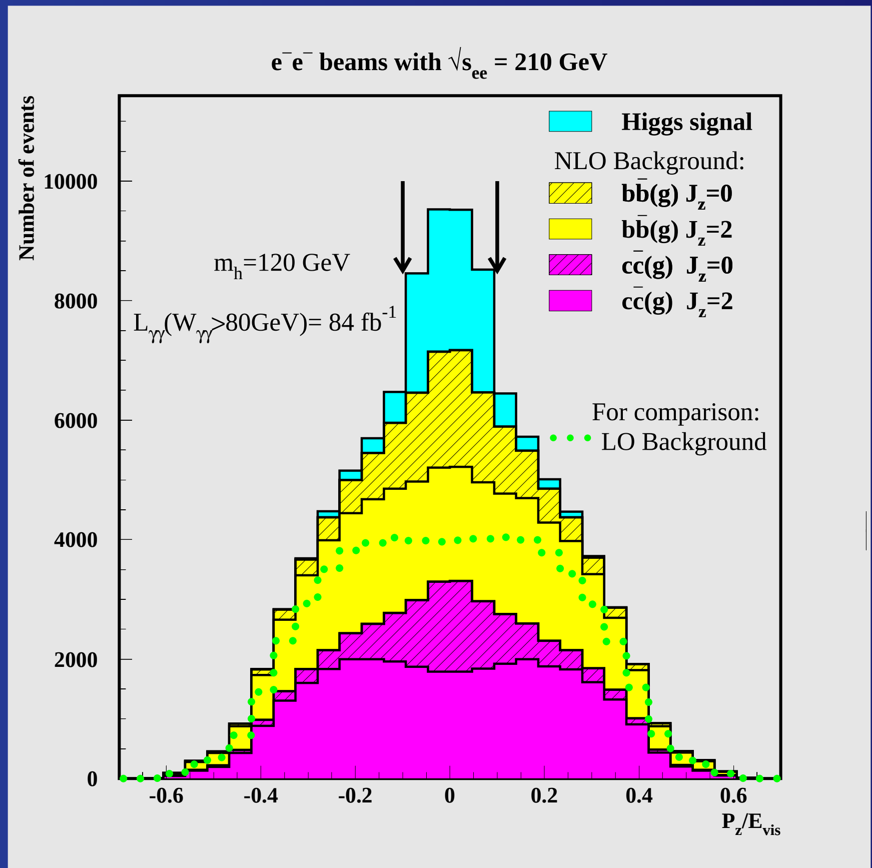
Photon-photon spectrum: CompAZ

Signal: HDECAY, PYTHIA
Background: program by G. Jikia
Fragmentation: Lund in PYTHIA

Detector performance: SIMDET (parametric simulation)
Jets: Durham algorithm with $y_{cut} = 0.02$

Selection of $b\bar{b}$ events:

- 1) Assumed bb-tagging and mistagging
  2) Using ZVTOP-B-Hadron-Tagger
- $E_{vis} > 90$ GeV
- $N_{jets} = 2, 3$
- $|P_z|/E_{vis} < 0.1$

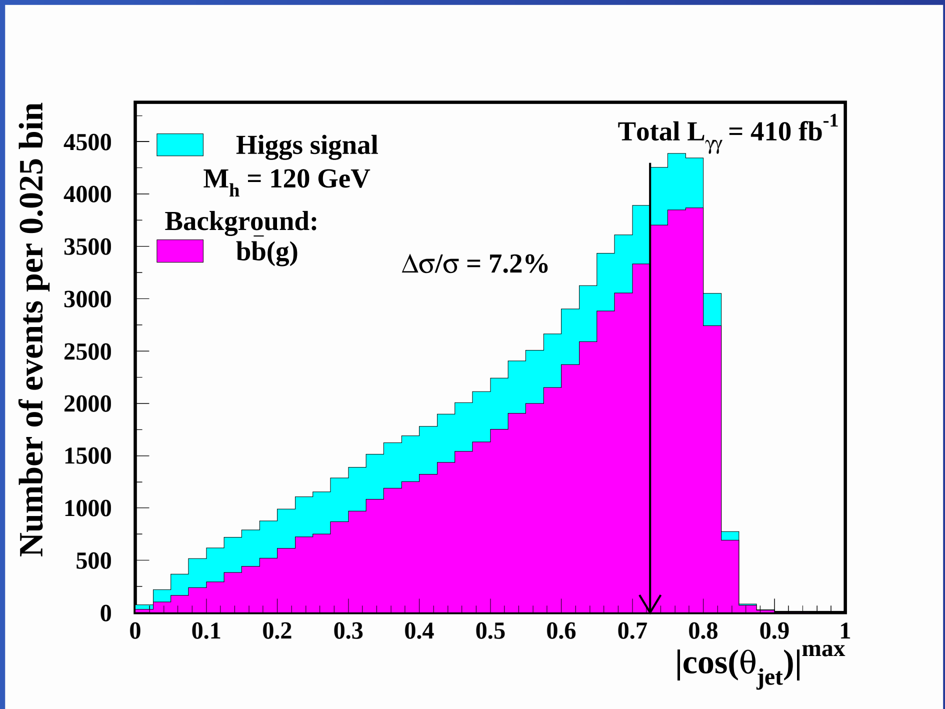


Cuts

Cuts optimized by minimizing:

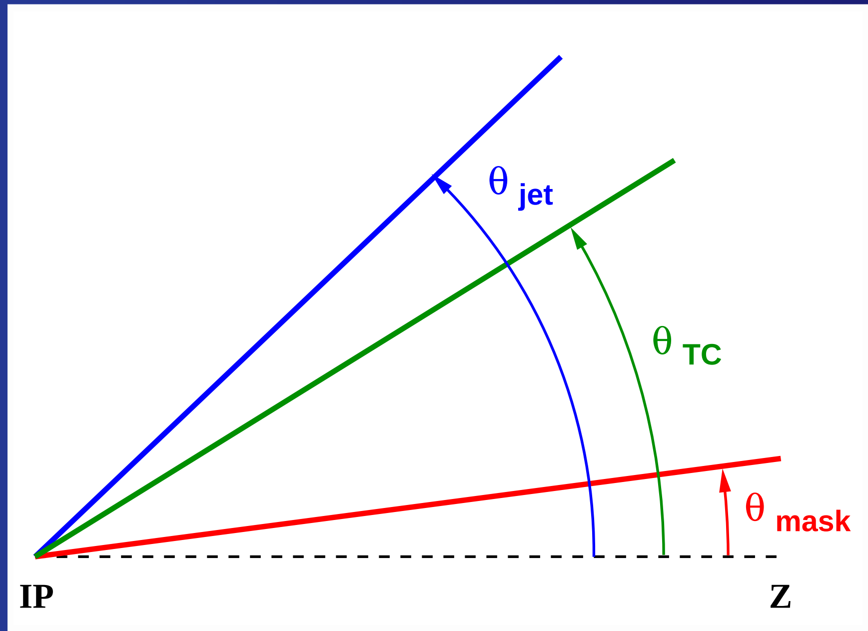
$$\frac{\Delta\sigma(\gamma\gamma \to h \to b\bar{b})}{\sigma(\gamma\gamma \to h \to b\bar{b})} = \frac{\sqrt{\mu_S + \mu_B}}{\mu_S},$$

For example:



Maximal value of $|\cos\theta_{jet}|$
over all jets in the event

All angular cuts



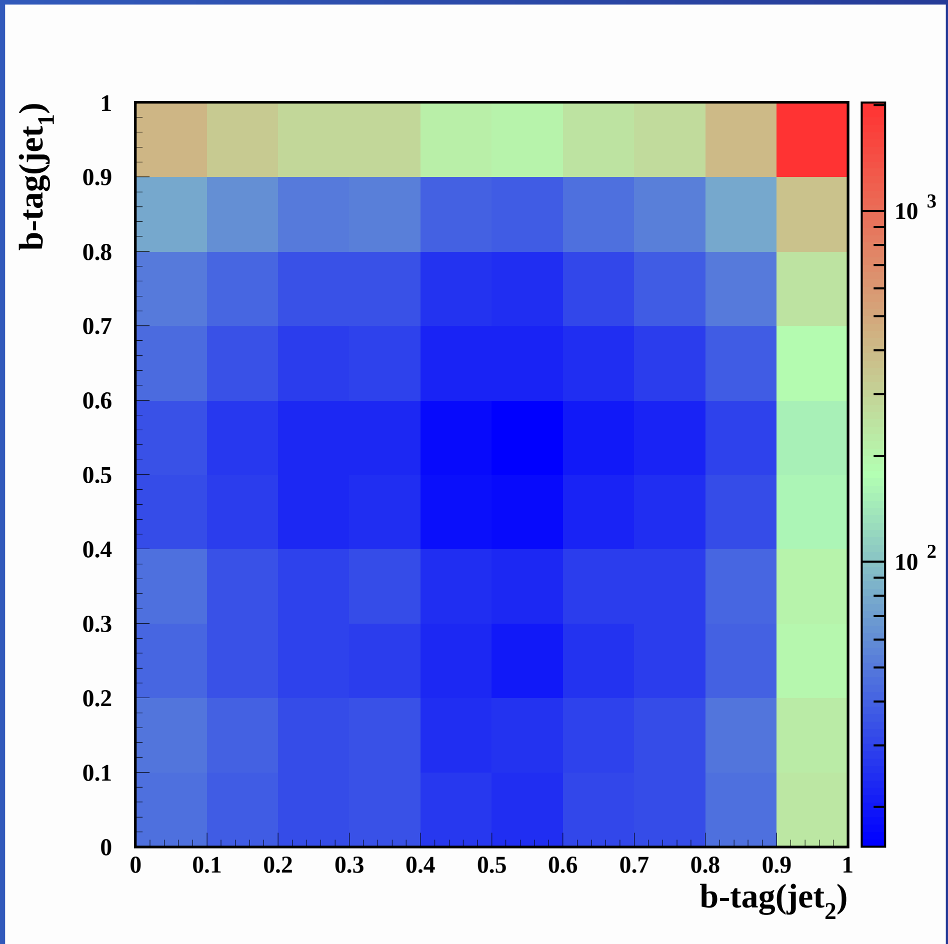
Detector mask
Particles on Pythia level: $\cos\theta_{mask} \approx 0.99$

OE suppression
Tracks & clusters: $\cos\theta_{TC} = 0.85$

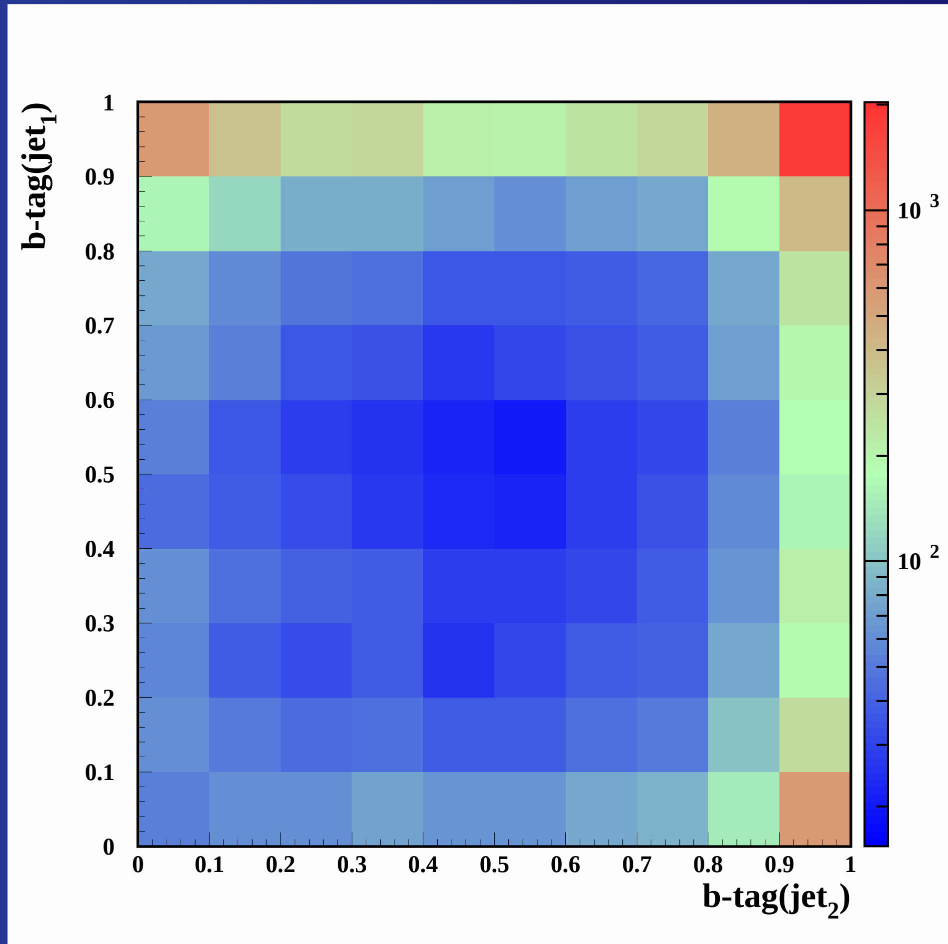
$\gamma\gamma \to Q\bar{Q}(g)$ suppression
Jets: $|\cos\theta_{jet}|^{\max} = 0.725$

$b\bar{b}$-tagging

$\gamma\gamma \to h \to b\bar{b}$



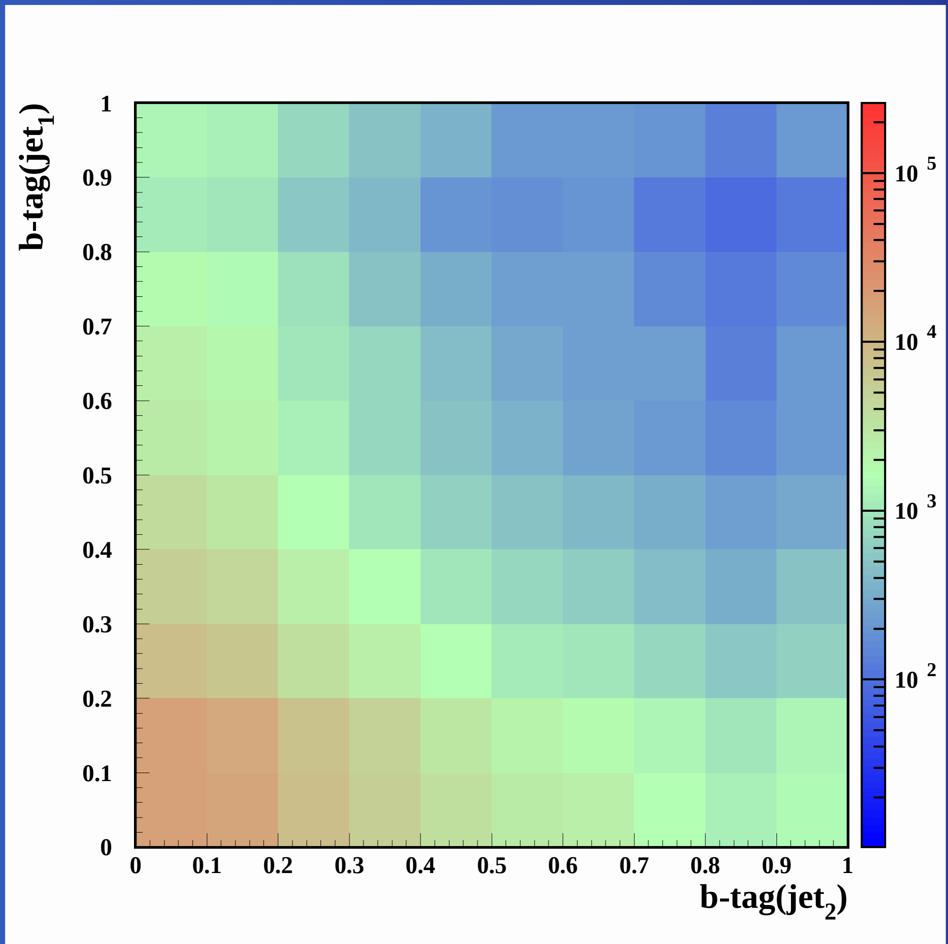
$\gamma\gamma \to b\bar{b}(g)$



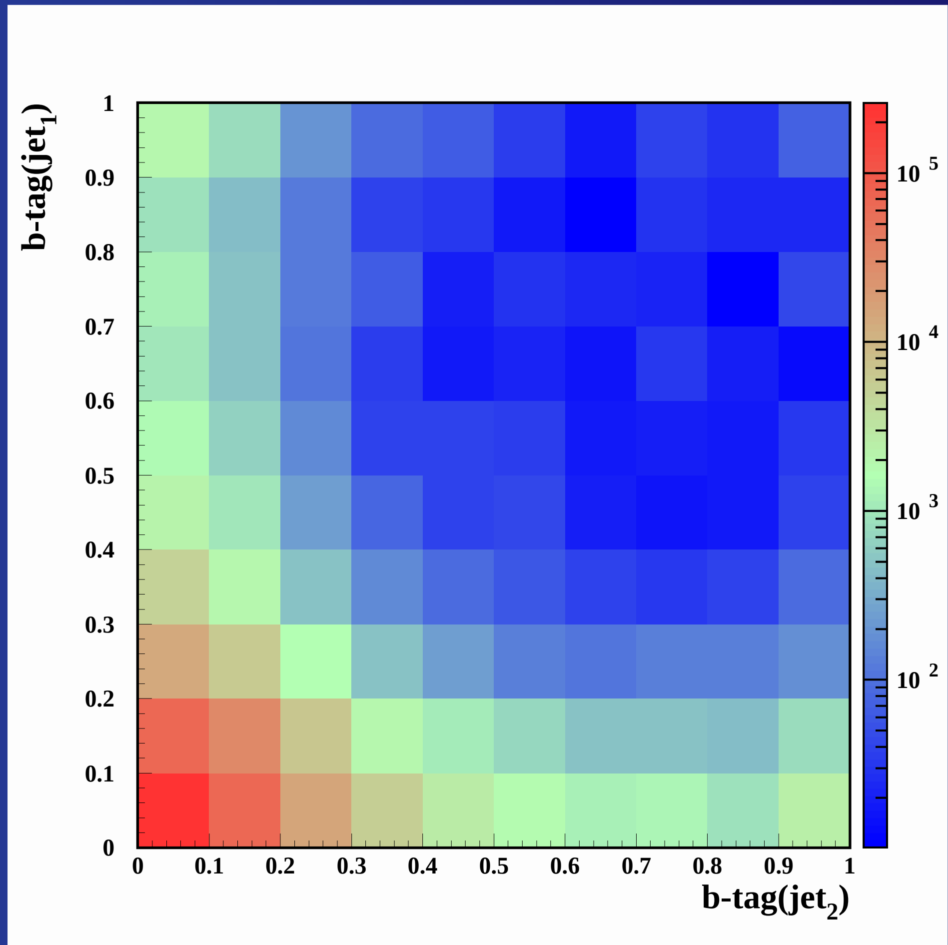
$J_z = 0$ suppressed for $b\bar{b}$
$\Rightarrow$ hard g-jet with low b-tag

$b\bar{b}$-tagging

$\gamma\gamma \rightarrow c\bar{c}(g)$



$\gamma\gamma \rightarrow q\bar{q}\ (q = u, d, s)$

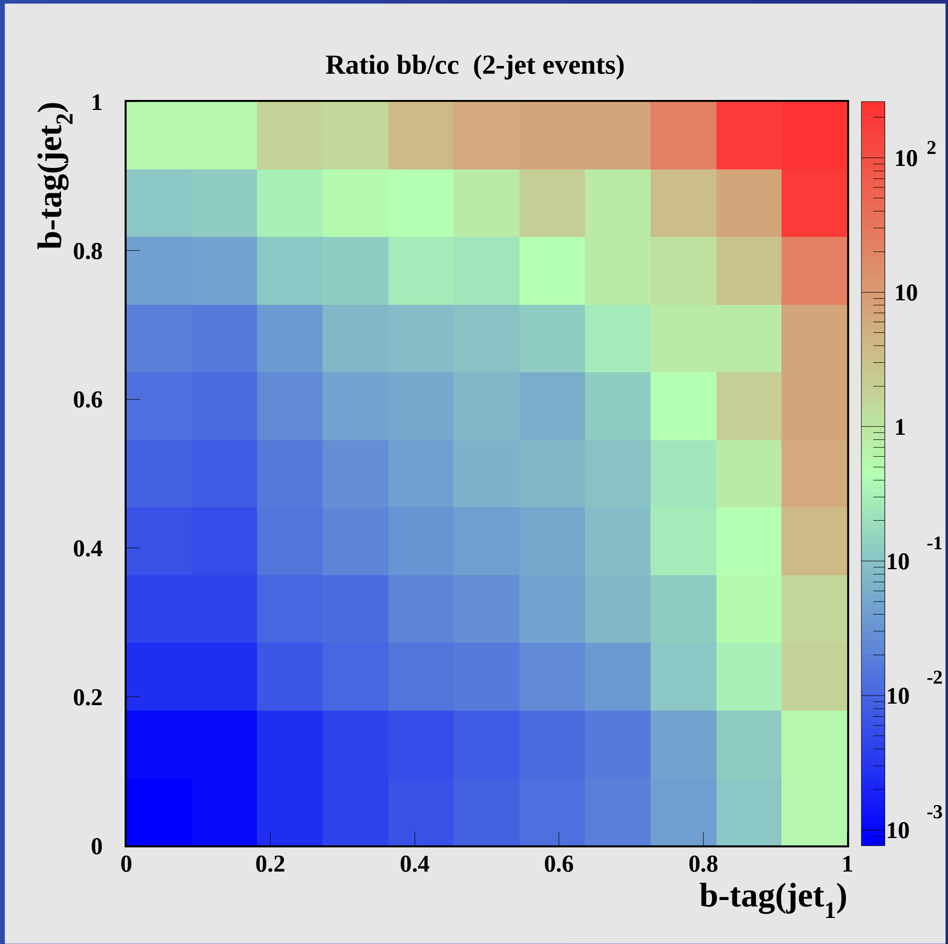


Significant fraction mistagged

$\Rightarrow$ double b-tag

B-tagging

ZVTOP-B-Hadron-Tagger



$$\frac{S}{B} = \frac{\#(\gamma\gamma \to b\bar{b})}{\#(\gamma\gamma \to c\bar{c})}$$

higgs-tagging at $M_h = 120$ GeV

higgs-tagging: a cut on the ratio of $\gamma\gamma \to h \to b\bar{b}$ to $\gamma\gamma \to b\bar{b}(g),\ c\bar{c}(g)$ events

$\Rightarrow \varepsilon_{higgs} = 70$ %

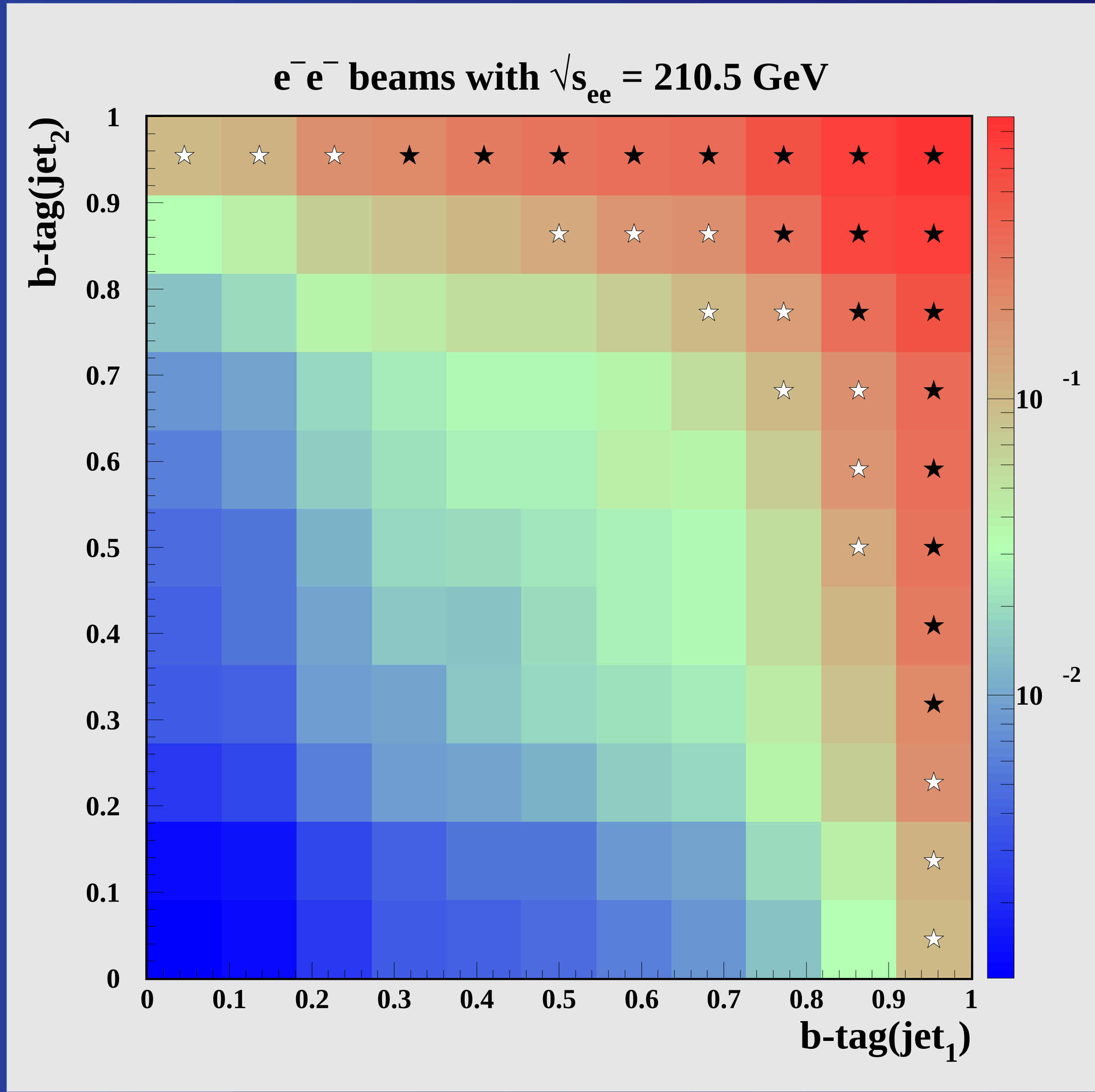
$\varepsilon_{bb} = 66\%$, $\varepsilon_{cc} = 4\%$

Earlier we used b-tagging: a cut on the ratio of $\gamma\gamma \to b\bar{b}(g)$ to $\gamma\gamma \to c\bar{c}(g)$ events

$\Rightarrow \varepsilon_{higgs} = 85$ %

$\varepsilon_{bb} = 82\%$, $\varepsilon_{cc} = 2\%$

Tighter cuts are needed due to OE contribution

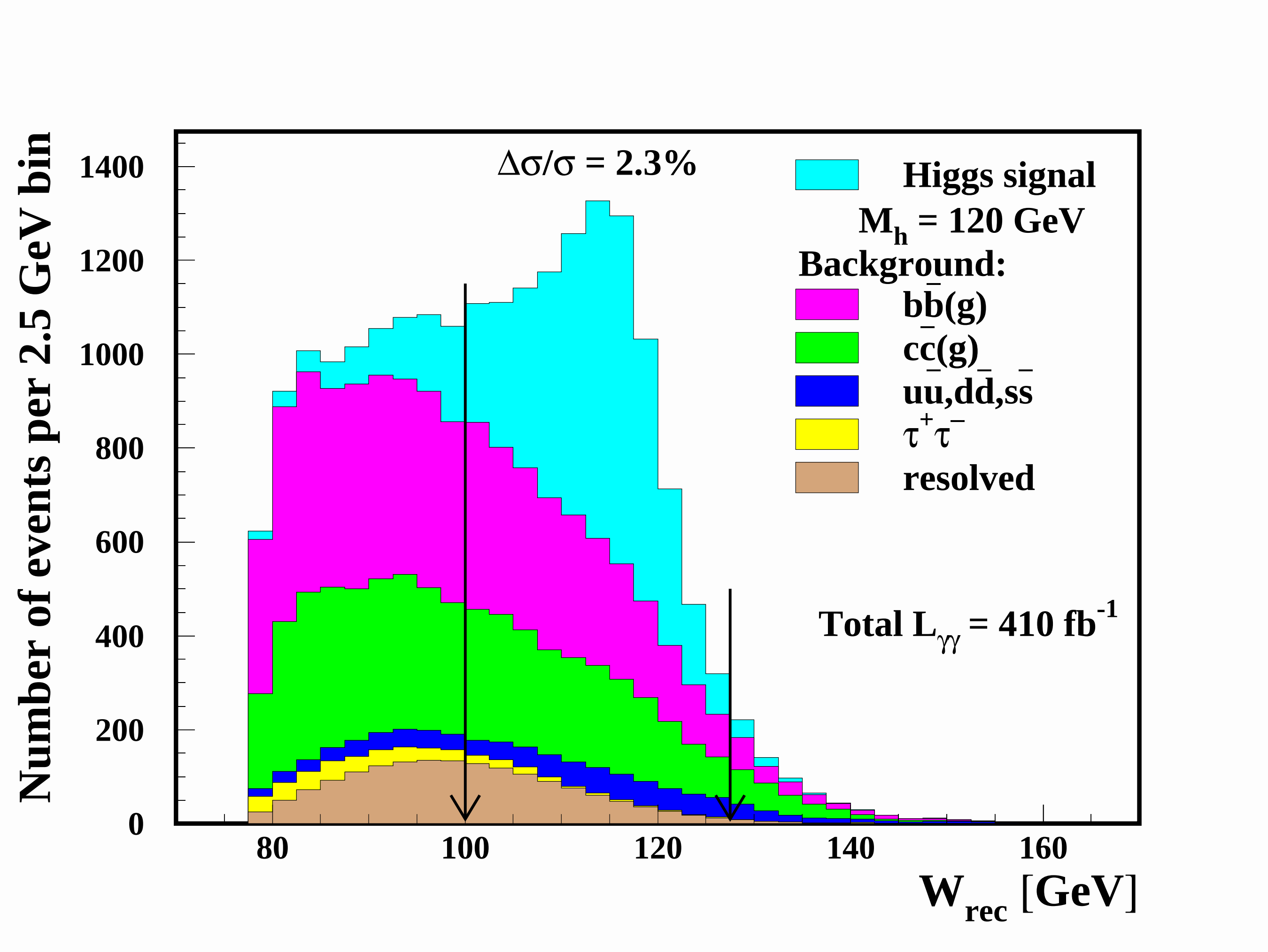


Black stars – optimized selection

Black+white stars – analysis without OE

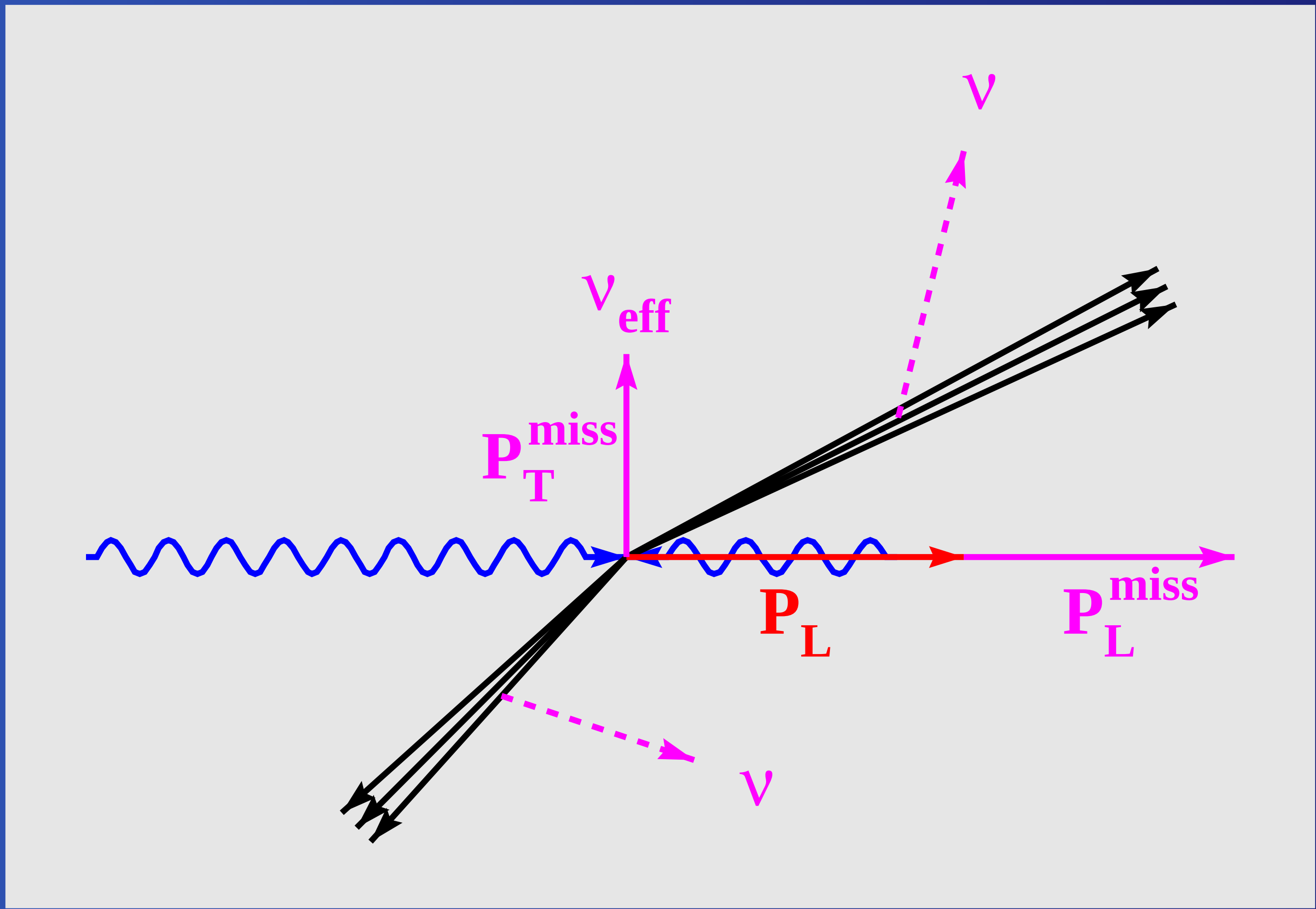
SM, $M_h = 120$ GeV

Final results



Missing P_T

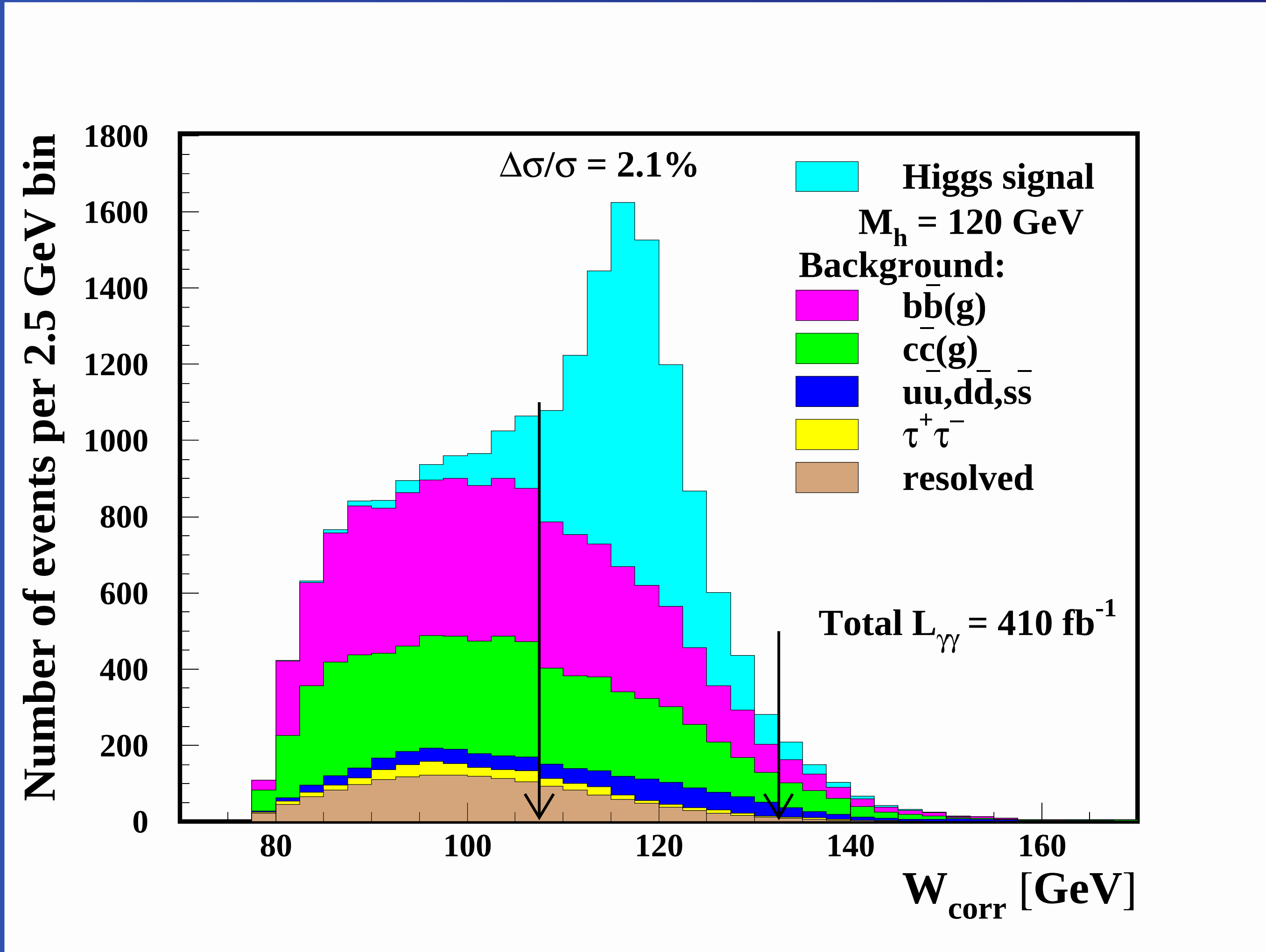
Neutrinos from semileptonic decays of D- and B-mesons.



$$W_{corr} \equiv \sqrt{W_{rec}^2 + 2P_T(E_{vis} + P_T)}$$

SM, $M_h = 120$ GeV

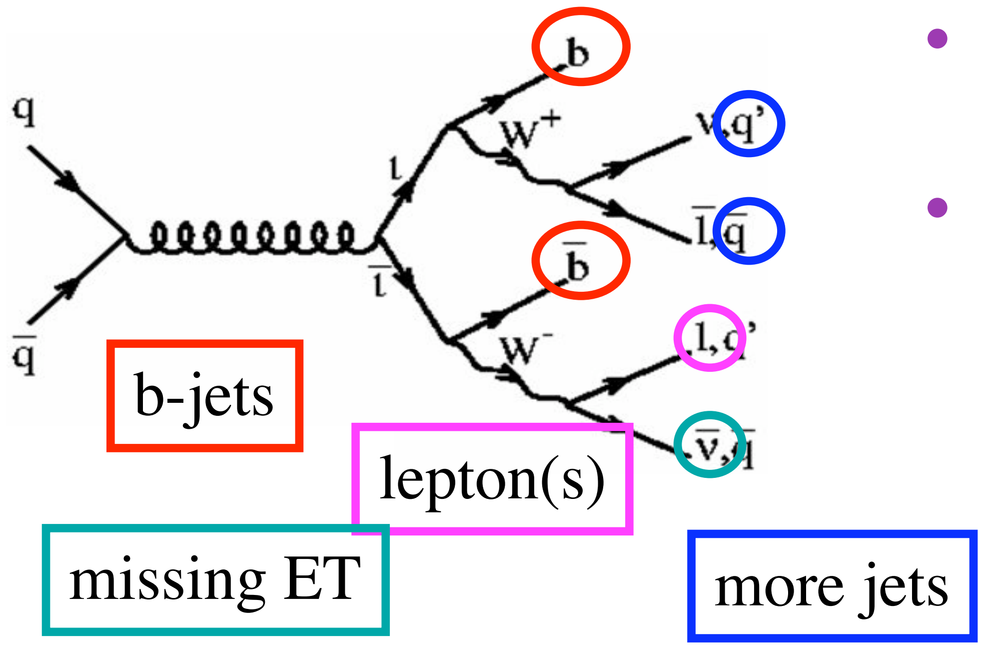
Final results



Top Quark Cross Section

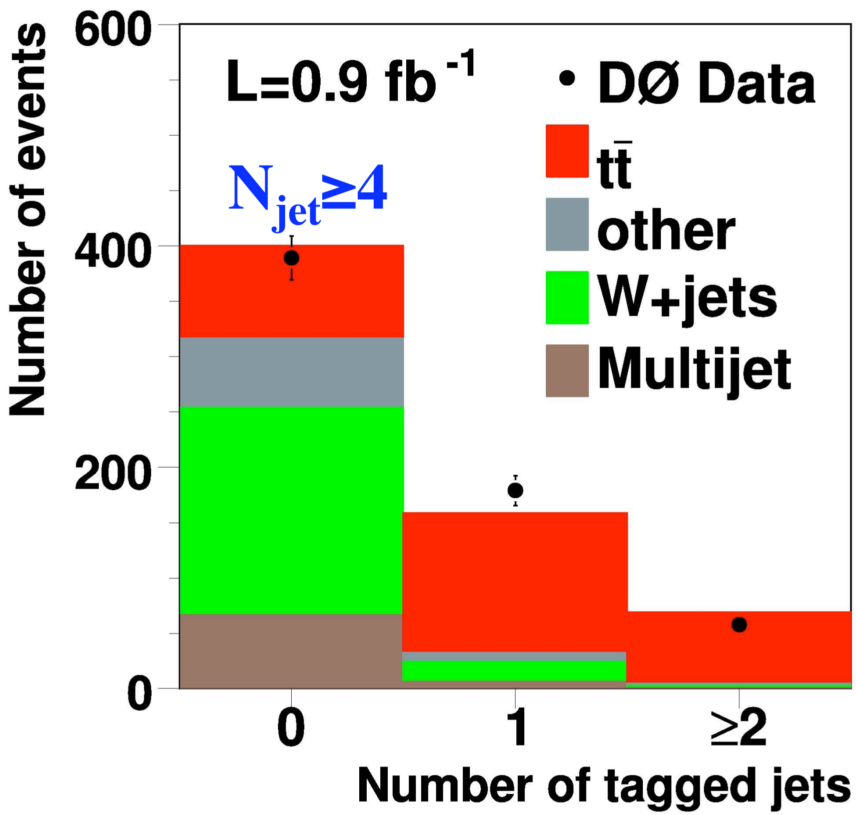
SM: $t\bar{t}$ pair production, Br($t \rightarrow bW$)=100% , Br(W->lv)=1/9=11%

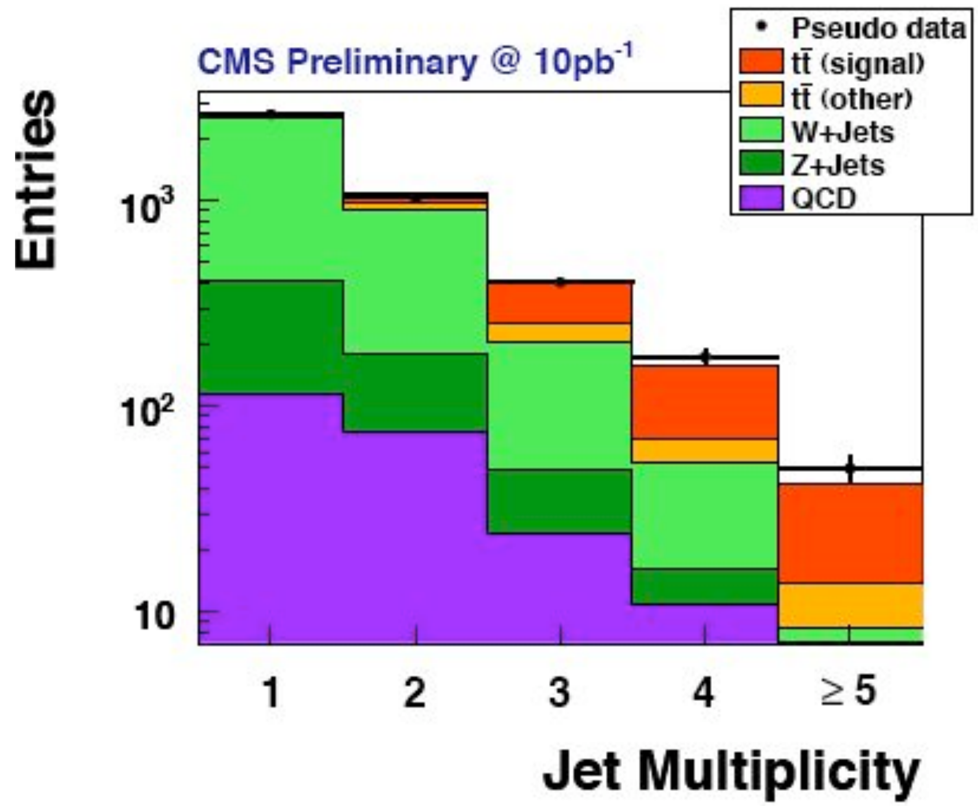
dilepton	*(4/81)*	2 leptons + 2 jets + missing E_T
lepton+jets	*(24/81)*	1 lepton + 4 jets + missing E_T
fully hadronic	*(36/81)*	6 jets



- Trigger on electron/muon
  - Like for Z's
- Analysis cuts:
  - Electron/muon p_T>25 GeV
  - Missing E_T>25 GeV
  - 3 or 4 jets with E_T>20-40 GeV

Finding the Top Quark





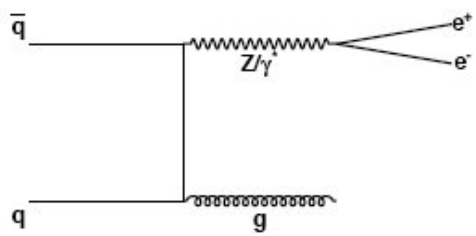
- **Tevatron**
  - Top is overwhelmed by backgrounds:
  - Top fraction is only 10% (≥3 jets) or 40% (≥4 jets)
  - Use b-jets to purify sample => purity 50% (≥3 jets) or 80% (≥4 jets)
- **LHC**
  - Purity ~70% w/o b-tagging (90% w b-tagging)

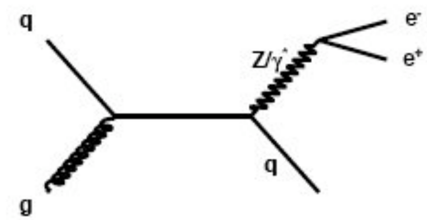
Systematic uncertainties

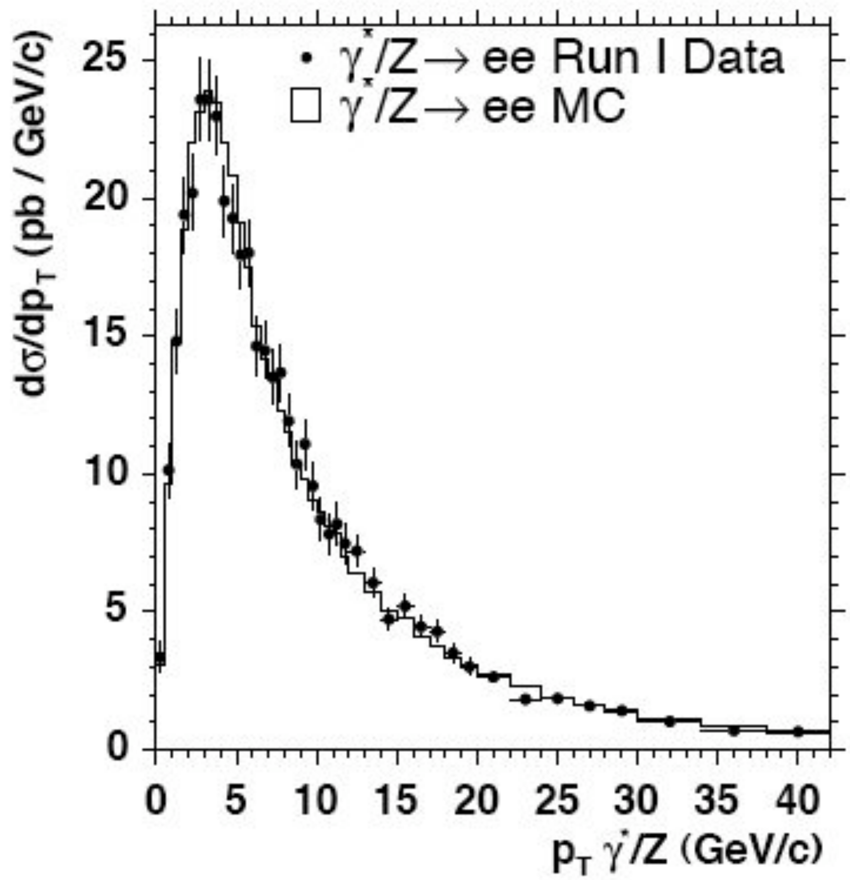
- This will likely be >90% of the work
- **Systematic errors cover our lack of knowledge**
  - need to be determined on every aspect of measurement by varying assumptions *within sensible reasoning*
  - Thus there is no "correct way":
    - But there are good ways and bad ways
    - You will need to develop a feeling and discuss with colleagues / conveners / theorists
    - There is a lot of room for creativity here!
- What's better? Overestimate or underestimate
  - Find New Physics:
    - it's fine to be generous with the systematics
    - You want to be really sure you found new physics and not that "Pythia doesn't work"
  - Precision measurement
    - Need to make best effort to neither overestimate nor underestimate!

QCD Modeling of Process

- Kinematics affected by p_T of Z boson
  - Determined by soft and hard QCD radiation
    - tune MC to describe data
- Limitations of Leading Order Monte Carlo
  - Compare to NNLO calculation





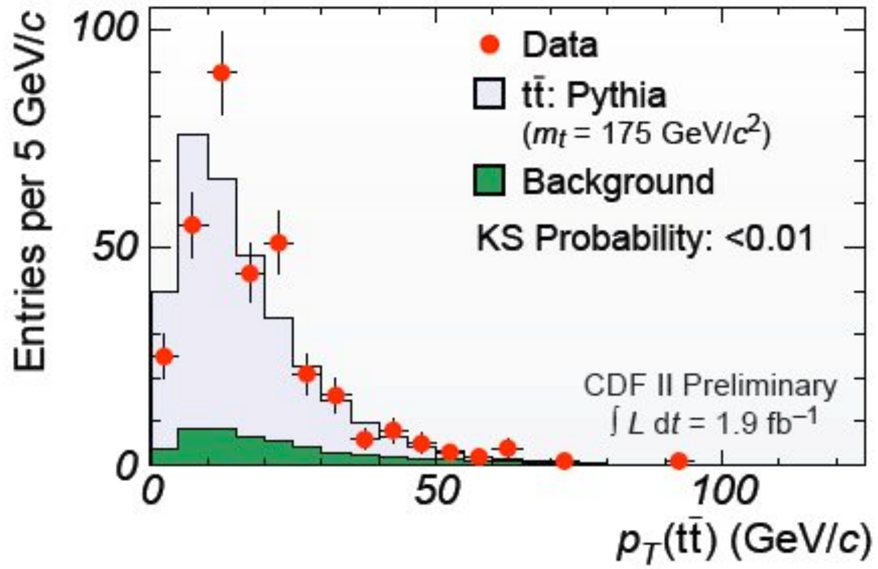


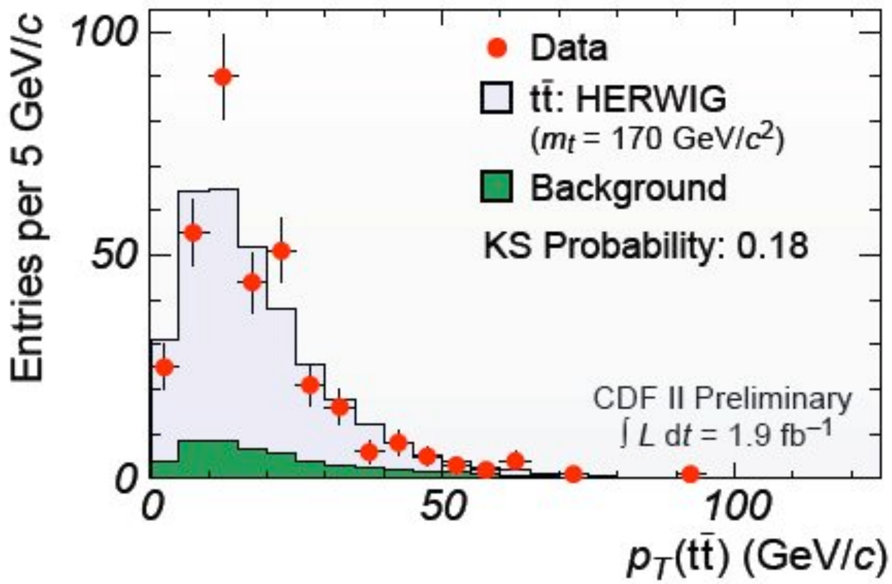
CDF TABLE XII: Central acceptance values for our candidate samples based on $d\sigma/dy$ distributions obtained from both NNLO and PYTHIA simulation.

Acceptance	NNLO Calc.	PYTHIA	Difference (%)
$A_{W\to\mu\nu}$	0.1970	0.1967	+0.15
$A_{W\to e\nu}$	0.2397	0.2395	+0.08
$A_{Z\to\mu\mu}$	0.1392	0.1387	+0.36
$A_{Z\to ee}$	0.3182	0.3185	-0.09
$A_{Z\to\mu\mu}/A_{W\to\mu\nu}$	0.7066	0.7054	+0.17
$A_{Z\to ee}/A_{W\to e\nu}$	1.3272	1.3299	-0.20

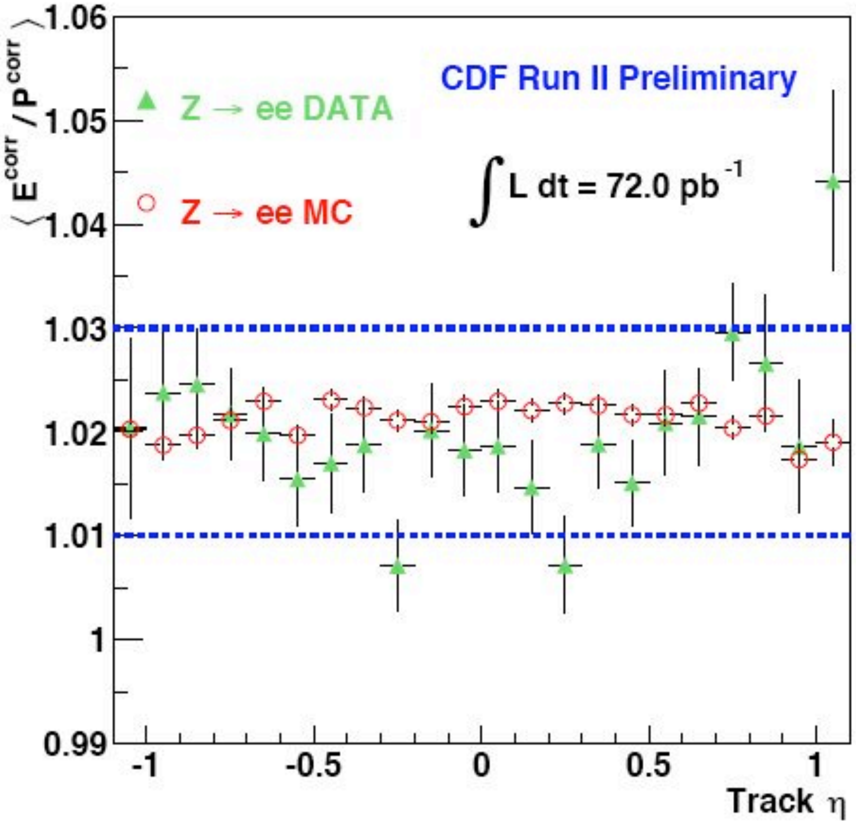
MC Modeling of top

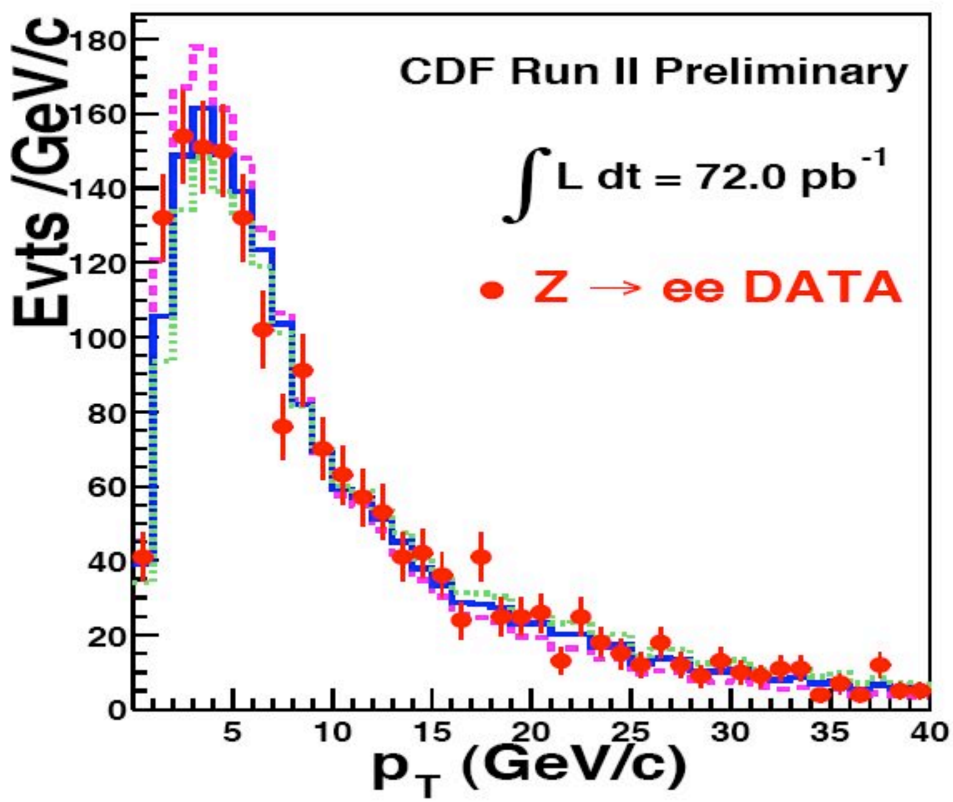
- Use different MC generators
  - Pythia
  - Herwig
  - Alpgen
  - MC @ NLO
  - …
- Different tunes
  - Underlying event
  - Initial/final state QCD radiation
  - …
- Make many plots
  - Check if data are modelled well





Examples for Systematic Errors





- Mostly driven by comparison of data and MC
  - Systematic uncertainty determined by (dis)agreement and statistical uncertainties on data

Systematic Uncertainties: Z and top

Z cross section (not all systematics)

source	variation	ΔA_Z	$\Delta A_Z / A_Z$
E_T^e scale	1% variation	0.03%	0.3%
E_T^e resolution	2% extra smearing	0.02%	0.2%
p_T^e scale	1% variation	0.01%	0.1%
p_T modelling		0.01%	0.1%
Material	5.5 % X_0	0.54%	4.7%
PDFs	reweighting of y	0.34%	2.9%
overall		0.64%	5.5%

top cross section

Systematic	Inclusive (Tight)	Double (Loose)
Lepton ID	1.8	
ISR	0.5	0.2
FSR	0.6	0.6
PDFs	0.9	
Pythia vs. Herwig	2.2	1.1
Luminosity	6.2	
JES	6.1	4.1
b-Tagging	5.8	12.1
c-Tagging	1.1	2.1
l-Tagging	0.3	0.7
Non-W	1.7	1.3
W+HF Fractions	3.3	2.0
Mistag Matrix	1.0	0.3
Total	11.5	14.8

- Relative importance and evaluation methods of systematic uncertainties are very, very analysis dependent

Final Result: Z cross section

- Now we have everything to calculate the final cross section

TABLE XXXVII: Summary of the input parameters to the $\gamma^*/Z \to \ell\ell$ cross section calculations for the electron and muon candidate samples.

	$\gamma^*/Z \to ee$	$\gamma^*/Z \to \mu\mu$
N_Z^{obs}	4242	1785
N_Z^{bck}	62 ± 18	13 ± 13
A_Z	$0.3182\ ^{+0.0039}_{-0.0041}$	$0.1392\ ^{+0.0027}_{-0.0033}$
ϵ_Z	0.713 ± 0.012	0.713 ± 0.015
$\int \mathcal{L}dt$ (pb^{-1})	72.0 ± 4.3	72.0 ± 4.3

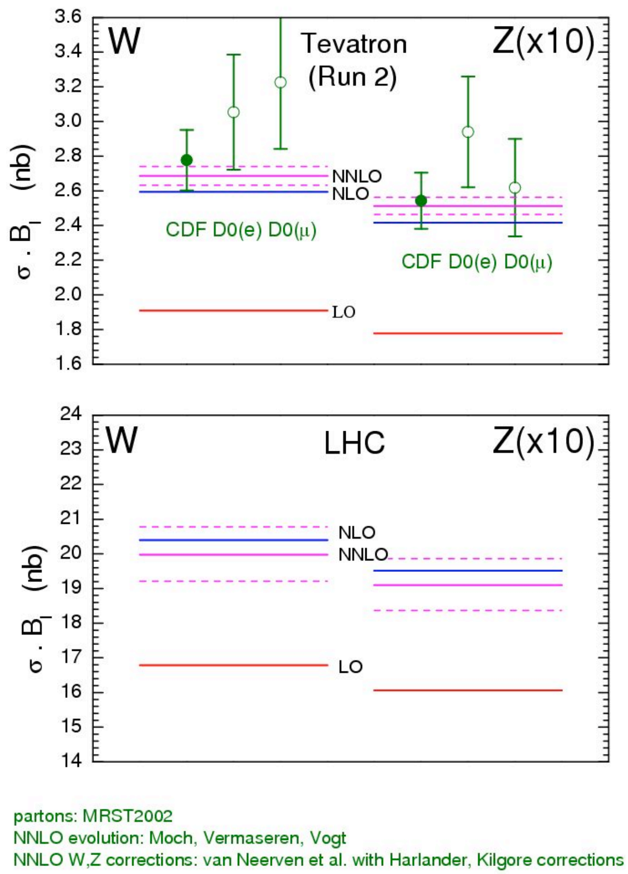
$$\sigma_{\gamma^*/Z} \cdot Br(\gamma^*/Z \to ee) = 255.8 \pm 3.9(stat.) \pm {}^{5.5}_{5.4}(syst.) \pm 15.3(lum.)\ \text{pb}$$

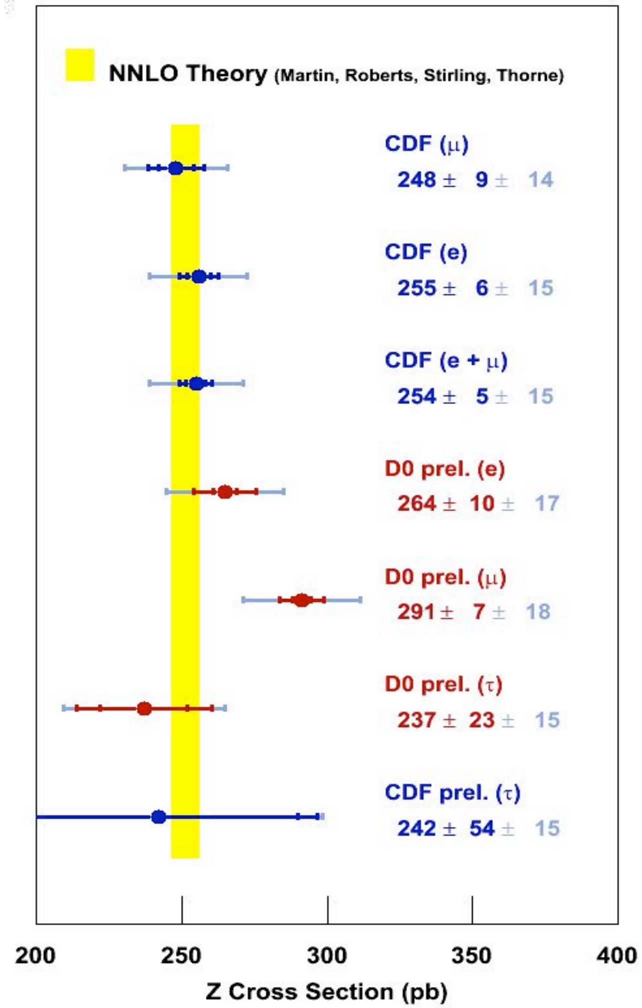
Measurement gets quickly systematically limited

Comparison to Theory

- Experimental uncertainty: ~2%
- Luminosity uncertainty: ~6%
- Theoretical uncertainty: ~2%

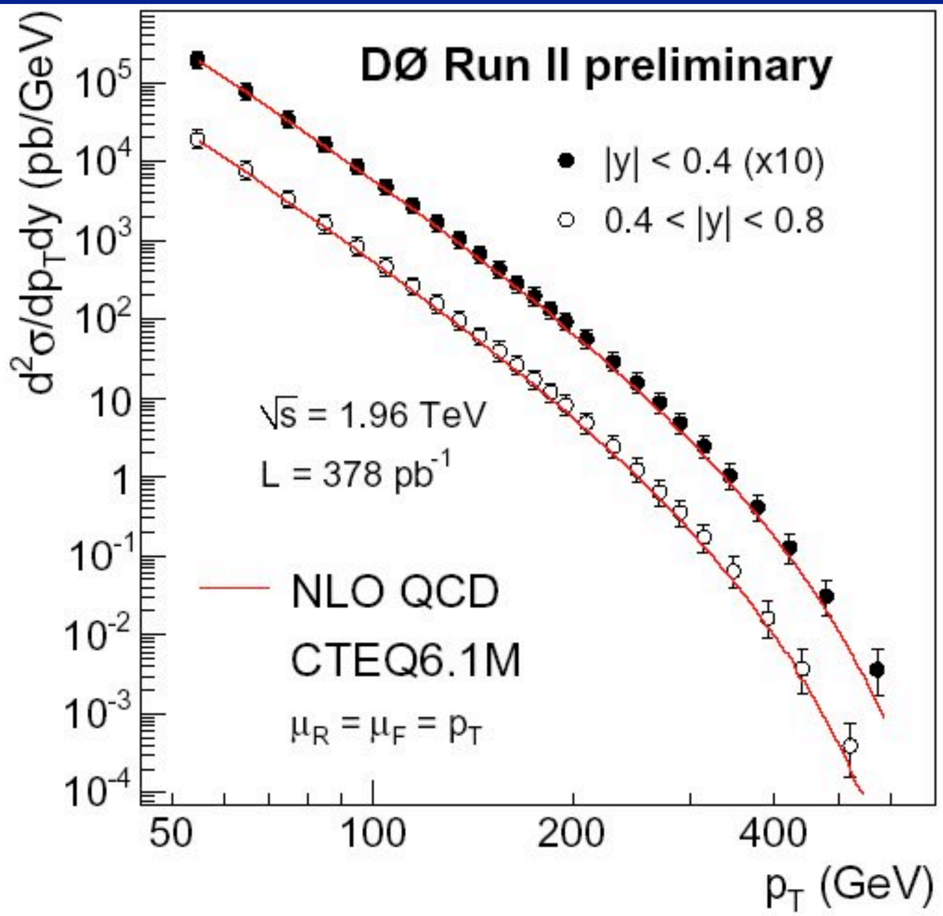
$\sigma_{Th,NNLO}$=251.3±5.0pb
(Martin, Roberts, Stirling, Thorne)





- Can use these processes to normalize luminosity absolutely
  - However, theory uncertainty larger at LHC and theorists don't agree (yet)

Differential Cross Section



- Measure jet spectra differentially in E_T and η
- Cross section in bin i: $$\sigma(i) = \frac{N_{obs}(i) - N_{BG}(i)}{\int L dt \, \varepsilon(i)}$$

Differential Cross Section: Unfolding

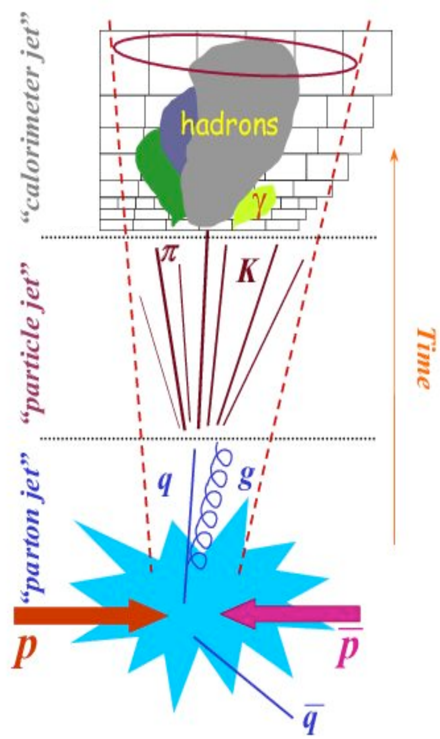
- “Unfolding” critical for jet cross sections
- Measure:
  - Cross section for calorimeter jets
- Want:
  - Cross section for hadron-jets
- Unfolding factor (bin by bin):

$$C_i = \frac{N^{HAD}_{JET\ i}}{N^{CAL}_{JET\ i}}$$

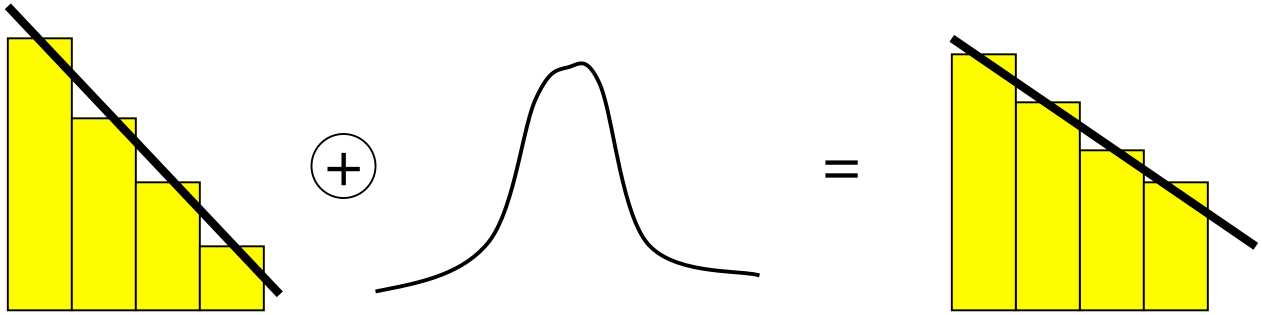
- Then:

$$N^{DATA\ UNFOLDED}_{JET\ i} = C_i \cdot N^{DATA\ NOT\ UNFOLDED}_{JET\ i}$$

- But, unfolding factors depend on MC E_T spectrum



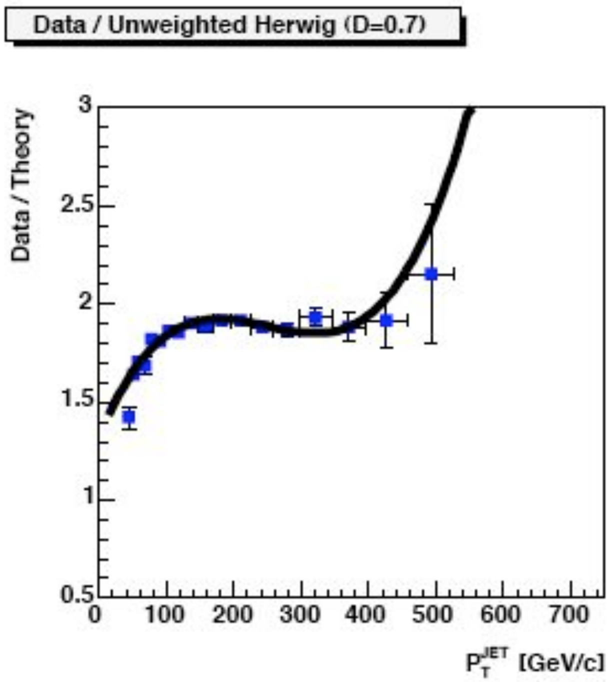
Differential Cross Section: Unfolding

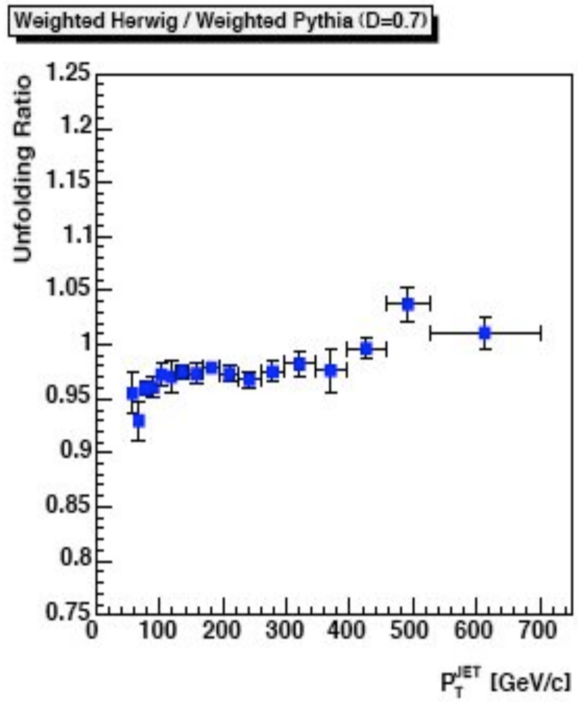


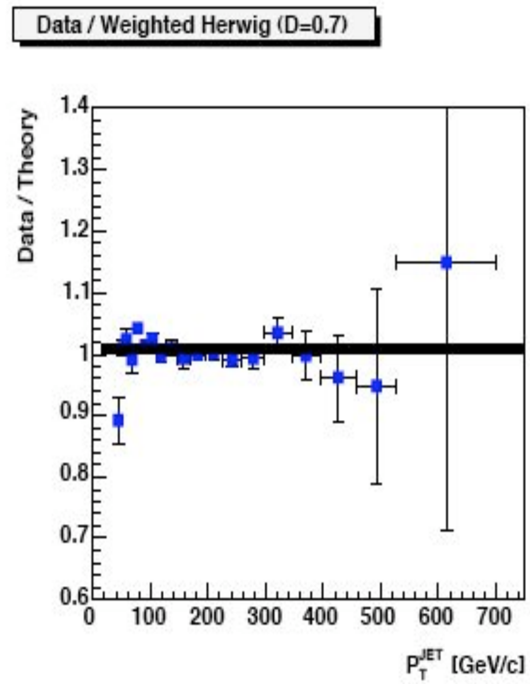
- **Problem:**
  - Steeply falling spectrum causes migrations to go from low to high p_T
    - Measured spectrum “flatter” than true spectrum
  - Size of migration depends on input spectrum

- **Requires iterative procedure** (bin-by-bin unfolding):
  1. Measure using spectrum from MC
  2. Fit measurement
  3. Reweight MC to reflect data measurement => go back to 1.

Example for Bin-by-Bin Unfolding

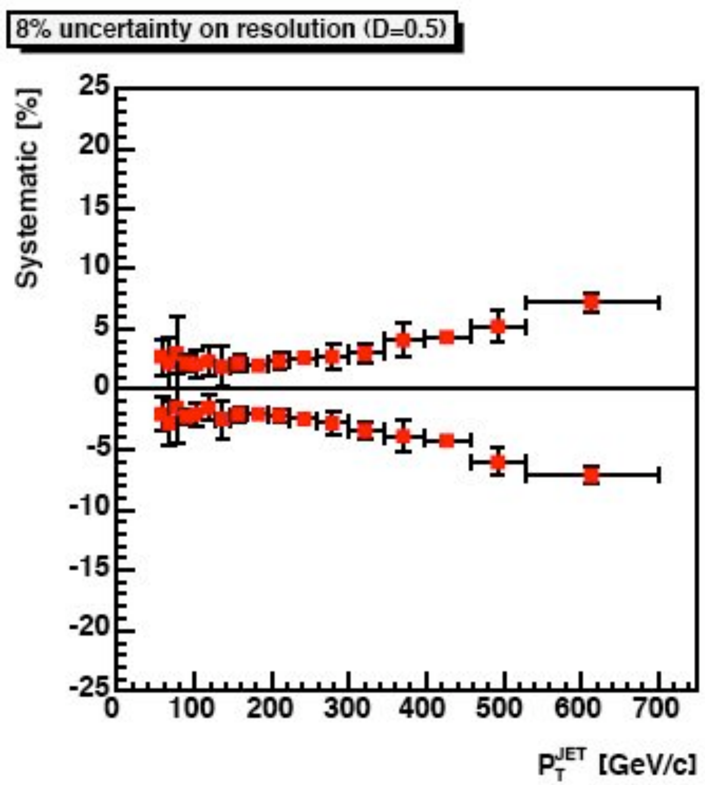


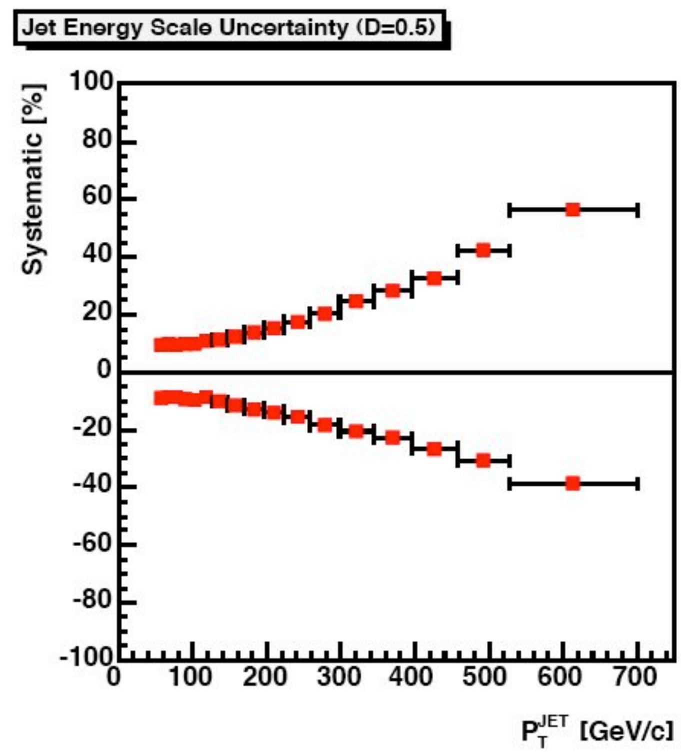




- Correction to unfolding factors <10%
  - One iteration sufficient in this example
  - Starting spectrum was already quite close to data

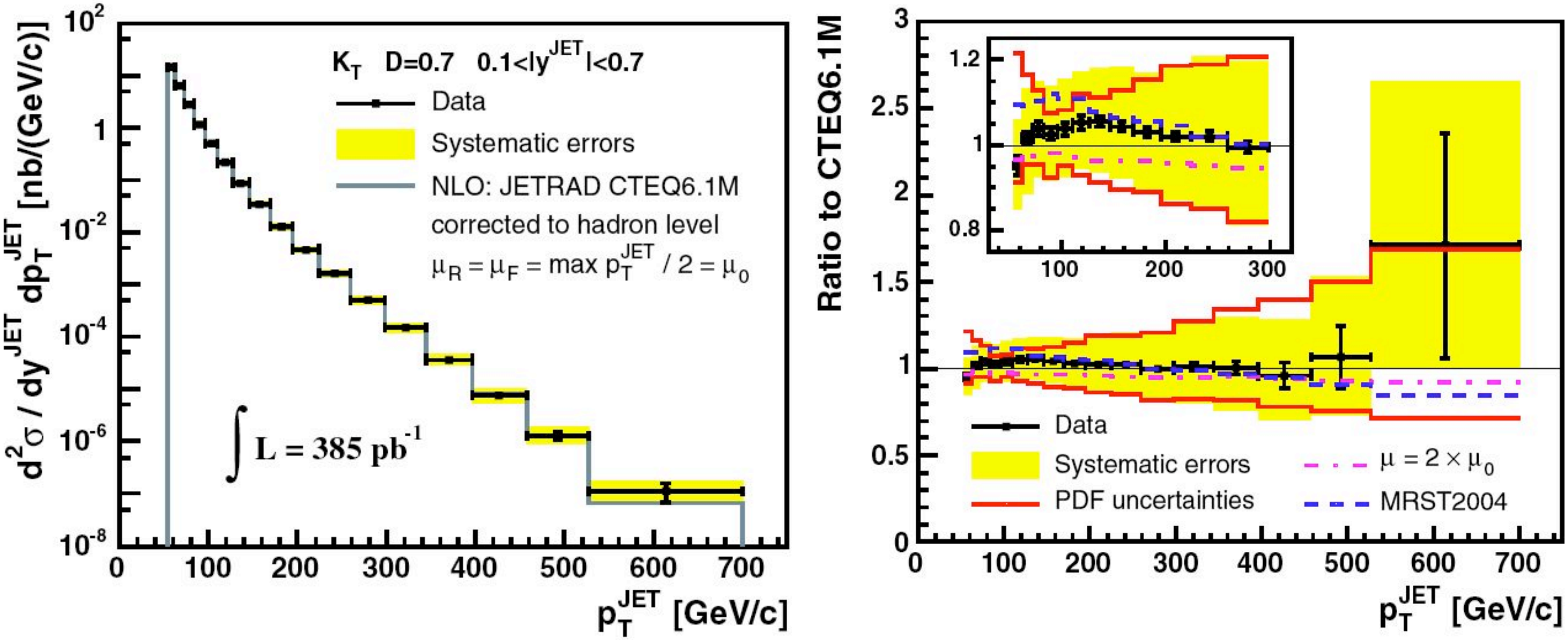
Systematic Uncertainties: Jet Cross Section





- For Jet Cross Section the Jet Energy Scale (JES) uncertainty is dominant systematic error
  - 3% uncertainty on JES results in up to 60% uncertainty on cross section
  - 8% uncertainty on JE resolution causes <10% uncertainty on cross section

Jet Cross Section Result

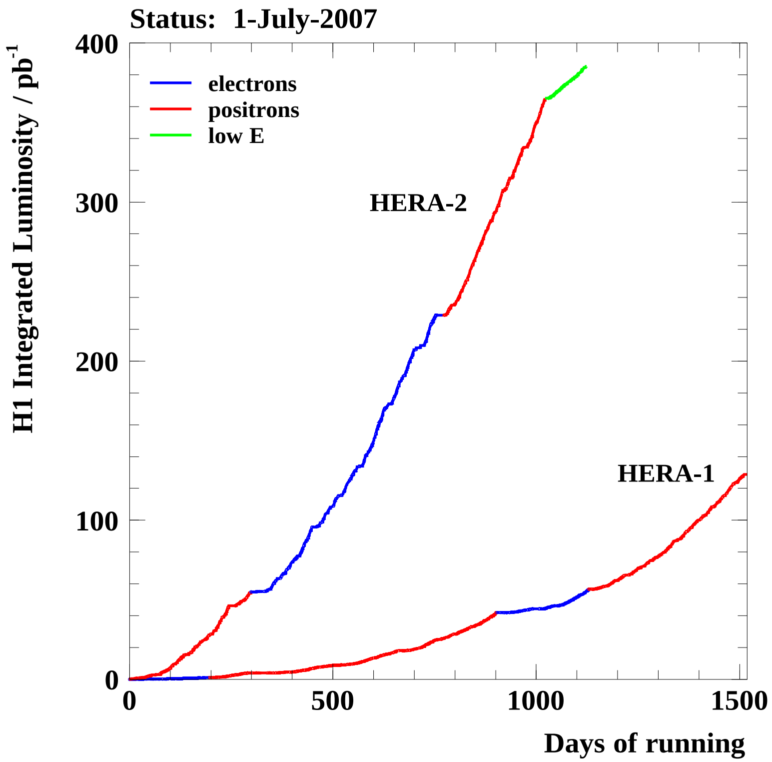


- Cross section falls by 8 orders of magnitude in measured E_T range
- Data in good agreement with QCD prediction
  - Experimental and theoretical errors comparable

Introduction

HERA

electron(positron)-proton collider at DESY



HERA I 1994-2000

over 100pb^{-1} collected per experiment

mainly e^+p data

HERA II 2002-2007

about 400pb^{-1} per experiment

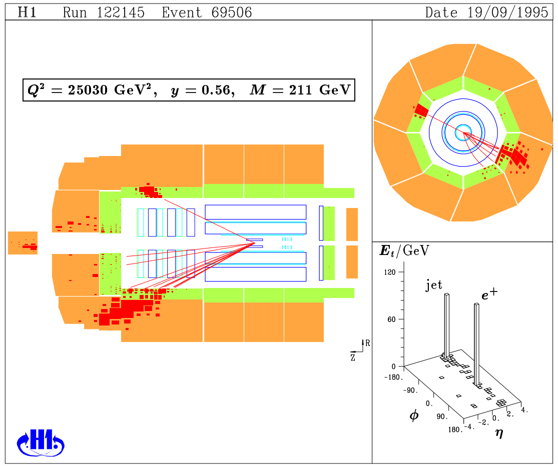
similar amount of e^-p and e^+p data

$\sim 20pb^{-1}$ of data from low and medium energy running: not considered here

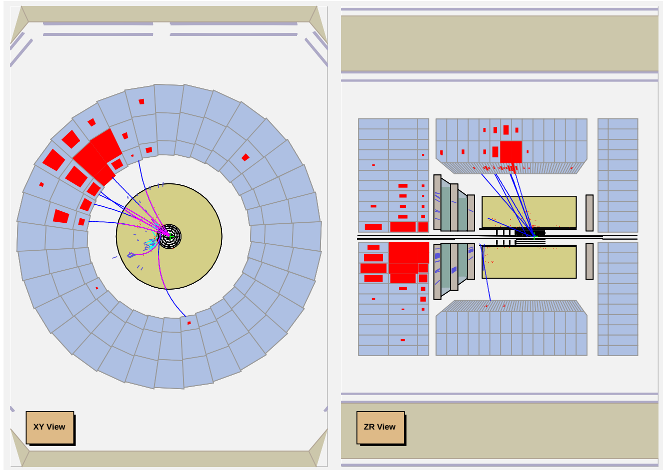
Deep Inelastic $e^{\pm}p$ Scattering

Main process studied at H1 and ZEUS

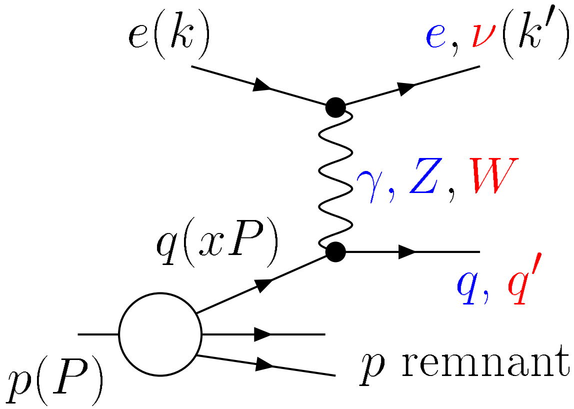
NC DIS



CC DIS



Kinematic variables:



$$Q^2 = -(k - k')^2$$

$$x = \frac{Q^2}{2P \cdot (k - k')}$$

$$y = \frac{P \cdot (k - k')}{P \cdot k}$$

|virtuality| of the exchanged boson

$\Rightarrow$ spatial resolution $\lambda \sim 1/Q$

$\Rightarrow$ sensitivity to mass scales $\Lambda \sim Q$

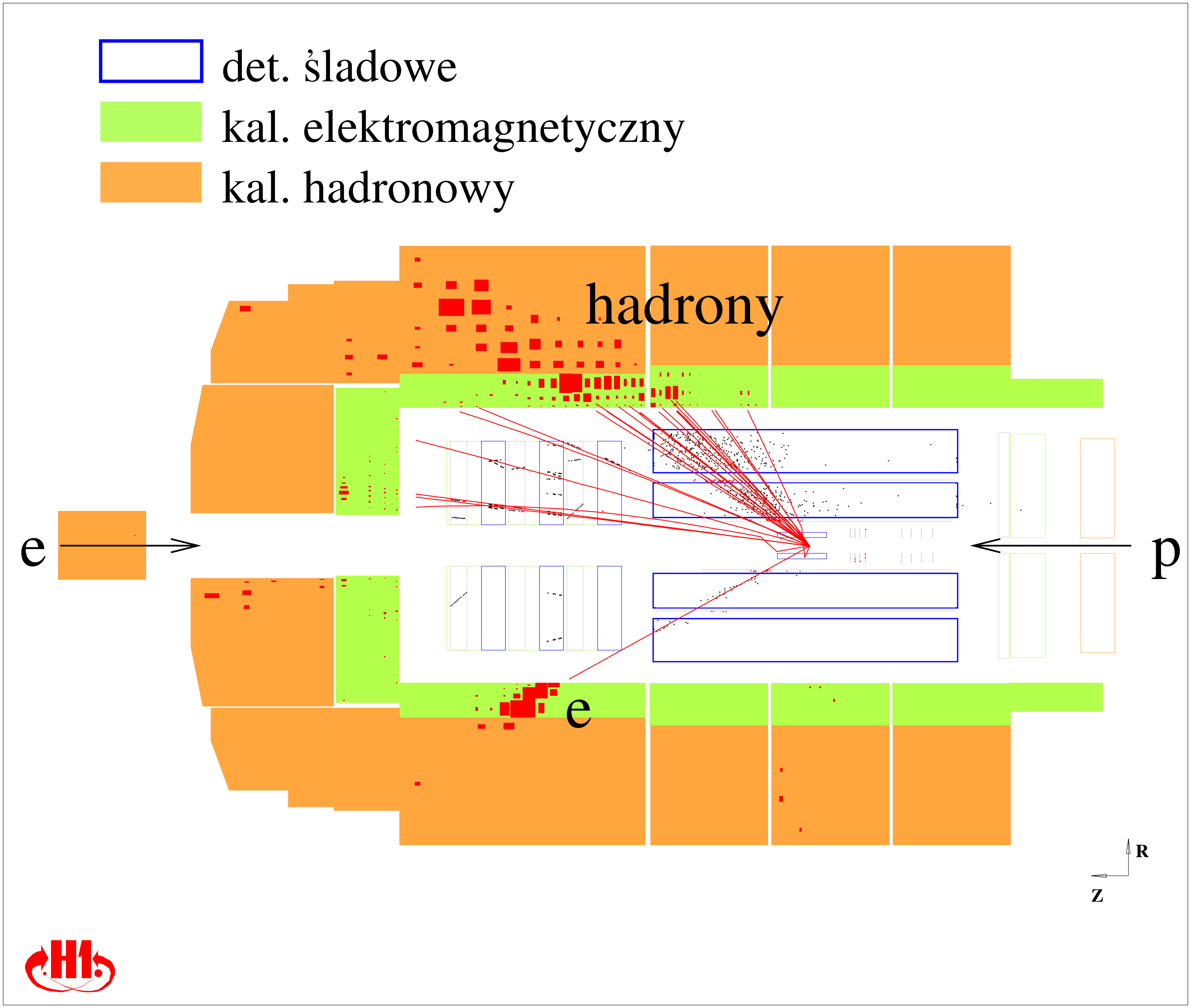
Przypadek
NC DIS

Ekspertment H1

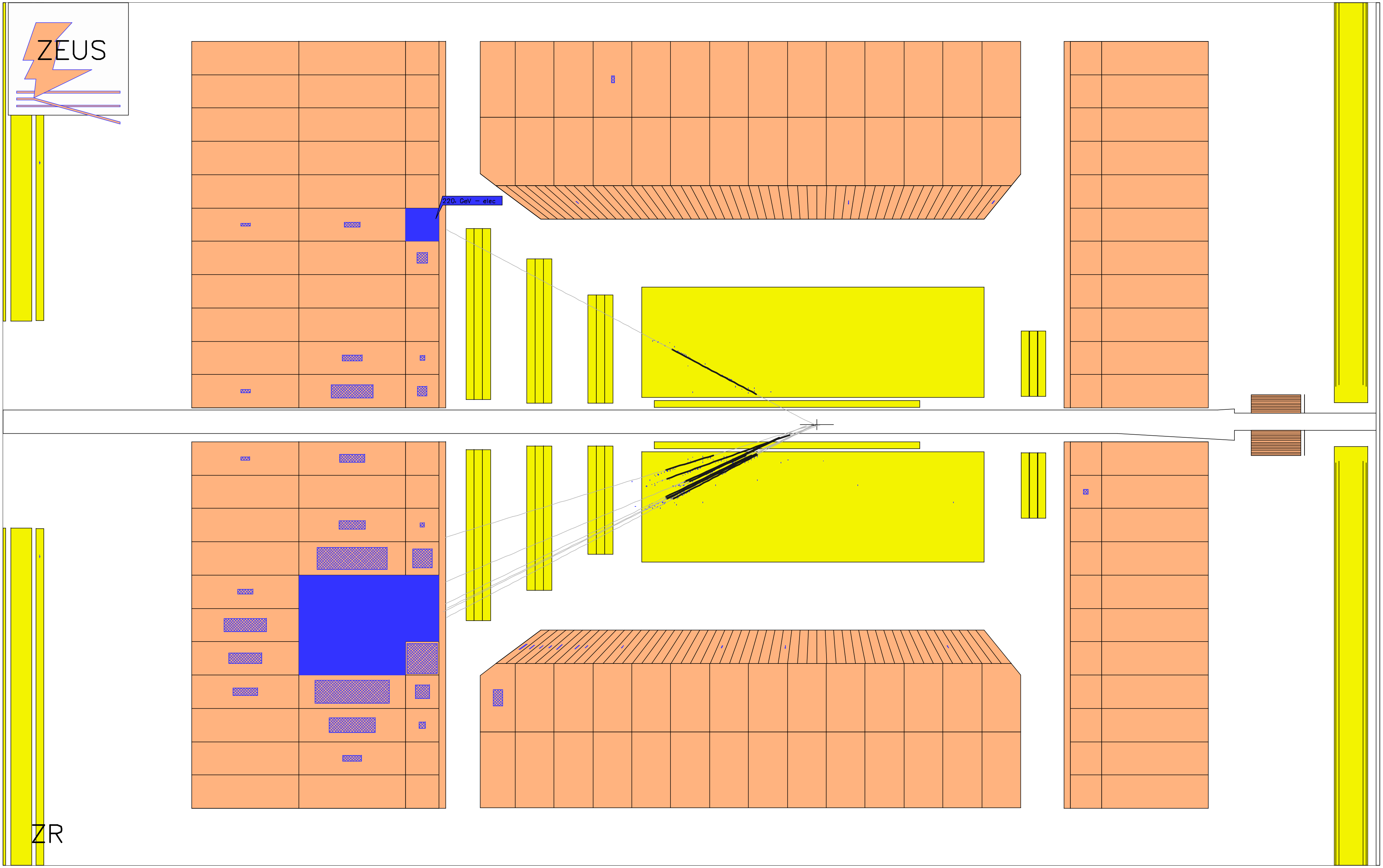
mierzymy energię
i kąt rozproszenia
elektronu

$\Rightarrow$ x, Q^2

można też mierzyć
stan hadronowy...



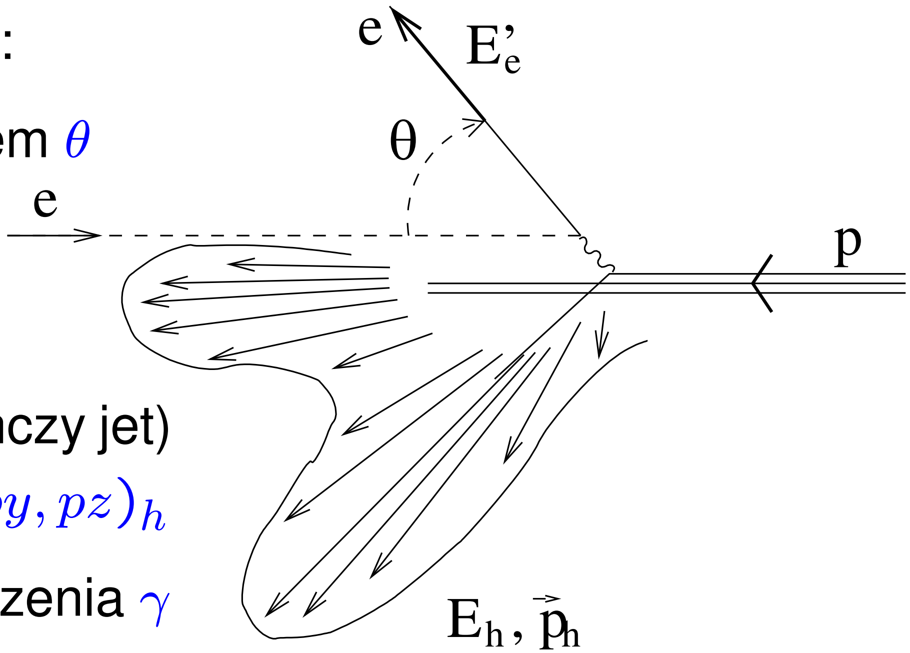
Przypadek NC DIS **Ekspertment ZEUS**



Rekonstrukcja przypadków

Pomiar w detektorze

W przypadkach NC DIS w detektorze mierzymy:



- elektron o energii E'_e rozproszony pod kątem θ
- stan hadronowy (na ogół nie jest to pojedyńczy jet) o całkowitej energii E_h i pędzie $\vec{p}_h = (p_x, py, pz)_h$

$\Rightarrow$ możemy wyznaczyć efektywny kąt rozproszenia γ i energię E_q jetu $\Rightarrow$ partonu

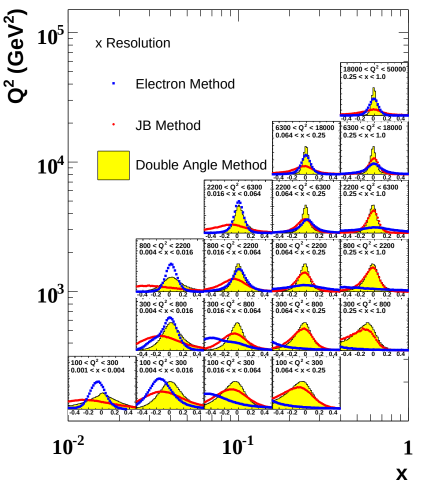
Chcemy wyznaczyć **dwie** zmienne, np. x i Q^2 (trzecią zmienną mamy z relacji: $Q^2 = xys$)

Mamy **cztery** wielkości mierzone: E'_e, θ, E_q i γ $\Rightarrow$ mamy dużą swobodę wyboru metody

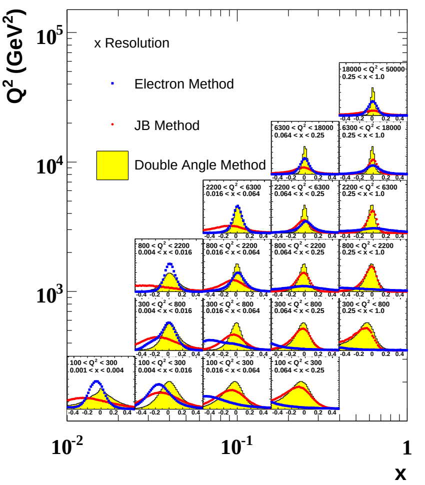
Teoretycznie (nieskończenie dokładny pomiar) wszystkie metody są równoważne.

Efekty doświadczalne (błędy pomiarowe) powodują jednak znaczne różnice w dokładności wyznaczenia x, y i Q^2 różnymi metodami $\Rightarrow$ wybór zależy od eksperymentu...

Nominal



Using MEPS



Wyznaczanie funkcji struktury

Przekrój czynny

Funkcję struktury $F_2(x,Q^2)$ wyznaczamy bezpośrednio z pomiaru różniczkowego przekroju czynnego na NC DIS:

$$\frac{d^2\sigma}{dx\, dQ^2} = \frac{4\pi\alpha^2}{xQ^4}(1-y+\frac{y^2}{2})\, F_2(x,Q^2)\, (1+\delta_L+\delta_Z+\delta_{rad})$$

Wyznaczane teoretycznie poprawki pochodzą od:

- δ_L – tzw. podłużnej funkcji struktury F_L
  (wkład gluonów powoduje, że $F_L \equiv F_2 - 2xF_1 \neq 0$)
- δ_Z – wymiany bozonu Z°
  (istotne tylko dla bardzo dużych Q^2)
- δ_{rad} – procesów radiacyjnych
  (poprawki radiacyjne; emisja γ przez elektron przed lub po zderzeniu)

Wyznaczanie funkcji struktury

Przekrój czynny

Różniczkowy przekrój czynny wyznaczamy mierząc liczbę przypadków zrekonstruowanych w przedziałach x i Q^2:

$$\Delta N^{(x\pm\frac{\Delta x}{2},Q^2\pm\frac{\Delta Q^2}{2})} = \frac{d^2\sigma}{dx\,dQ^2}\cdot\Delta x\cdot\Delta Q^2\cdot\mathcal{L}_{int}\cdot\mathcal{E}\cdot\mathcal{A}$$

gdzie:

- $\mathcal{L}_{int}$ – scałkowana świetlność
- $\mathcal{E}$ – efektywność selekcji przypadków
- $\mathcal{A}$ – poprawka związana z niedokładnością pomiaru („przesypywanie” przypadków pomiędzy przedziałami)

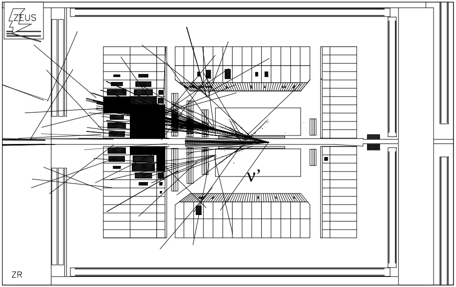
NC Selection Part 1

- EVtake, POLtake, MVDtake, REG trk
- FLT: 28, 30, 39, 40, 41, 43, 44, 46
- SLT: DIS07, EXO1, EXO2, EXO3
- TLT: DIS03
- $Q^2_{DA} > 185$ GeV^2
- 38 GeV $< \delta <$ 65 GeV
- $|Z_{vtx}| < 50$ cm
- $y_e < 0.95$
- $y_{JB}(1 - x_{DA})^2 > 0.004$
- Elastic QEDC rejection

- P_T balance
  - $P_T / \sqrt{E_T} < 4$ GeV$^{1/2}$
  - $P_T / E_T < 0.7$
- Chimney, supercrack, box cuts
- $R_e^{RCAL} < 175$ cm
- $R_{had}^{FCAL} > 18$ cm
- Electron identification
  - First EM candidate
  - $EM_{prob} > 0.001$
  - $E'_e > 10$ GeV
  - E^{cone}(not e-) < 5 GeV
- Yongdok's new alignment and electron energy corrections
- Umer's new backsplash cut for CorAndCut

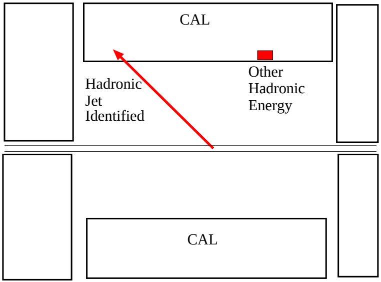
Backsplash

MC CC Event (MC tracks overlayed)



- Proper reconstruction of hadronic final state important
- Can use to determine kinematic variables
- Measured hadronic quantities can be altered by
  - Backsplash from the CAL
  - Scattering from dead material
- Cause energy deposits far from true particle direction
- Noticably increases measured $(E - P_z)_h$ and γ_h at low y

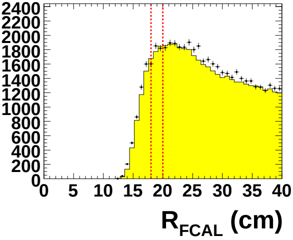
Using Data to Derive Backsplash Cut Parameters



- We began a new jet based approach
- Use most backward jet found and associate its jet axis with the "true entry" position
- Look for cone islands backward from the jet
- Use distance from jet axis to cone islands to flag backsplash deposits
- Method can be applied to data and MC

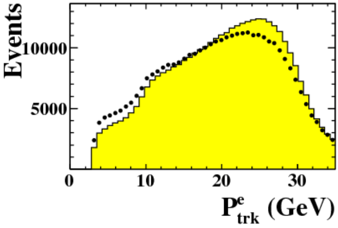
NC Selection Part 2

- Inside CTD acceptance:
  - CTD exit Radius > 45 cm
  - $P_{ele}^{trk} > 3$ GeV
  - DCA < 10 cm
  - DME > 1.5 cm
- Forward of CTD acceptance:
  - $P_{T,ele} > 30$ GeV



Changes to standard selection:

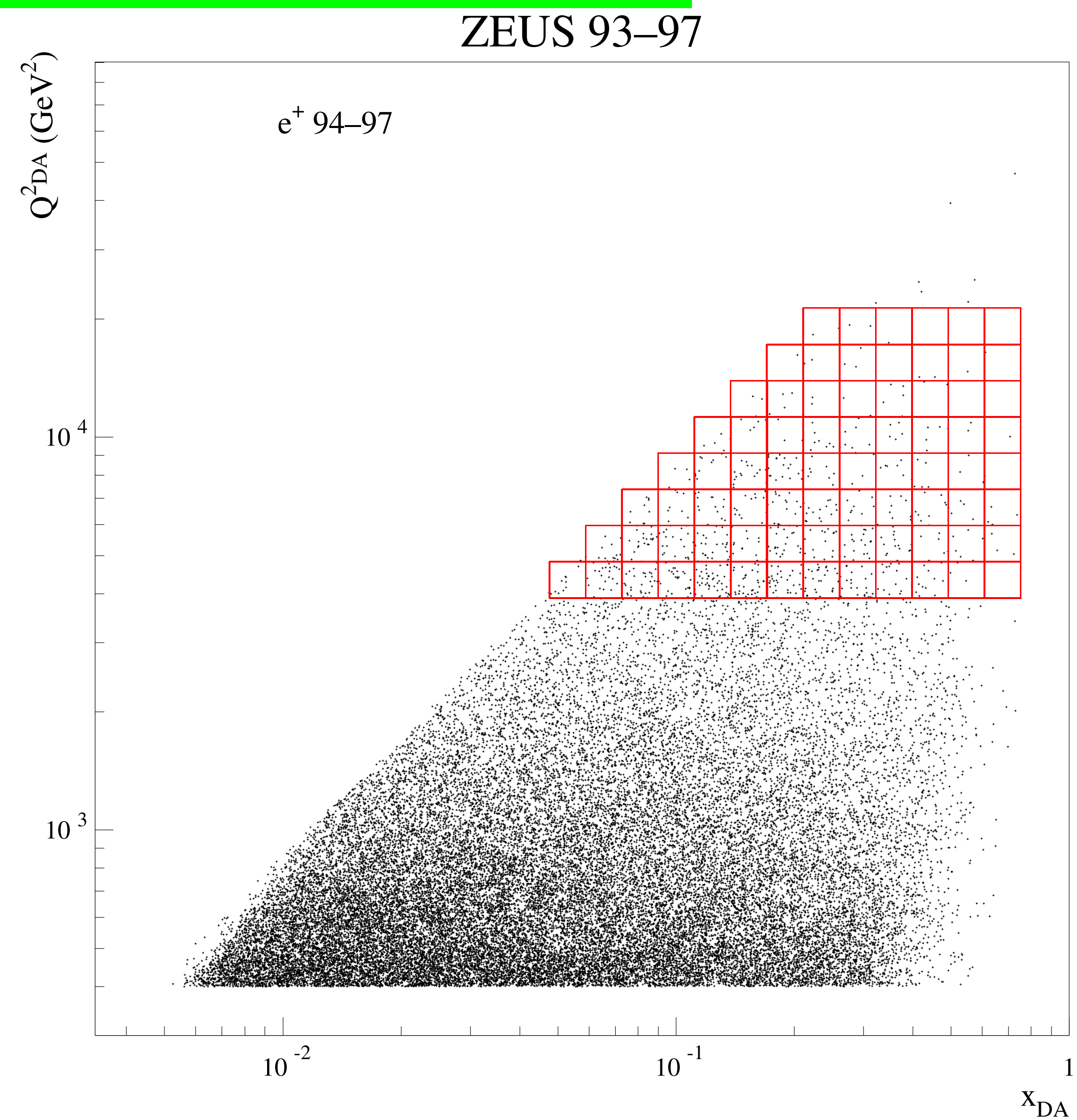
- $Q_{DA}^2 > 200 \rightarrow 185$ GeV^2
  - Lower bin edge of reduced cross section
- $R_{had}^{FCAL} > 20 \rightarrow 18$ cm
- $P_{ele}^{trk} > 5 \rightarrow 3$ GeV
  - Contrain systematics



Wyznaczanie funkcji struktury

Rozkład mierzonych przypadków NC DIS w zmiennych x, Q^2.

Dane współpracy ZEUS $\Rightarrow$

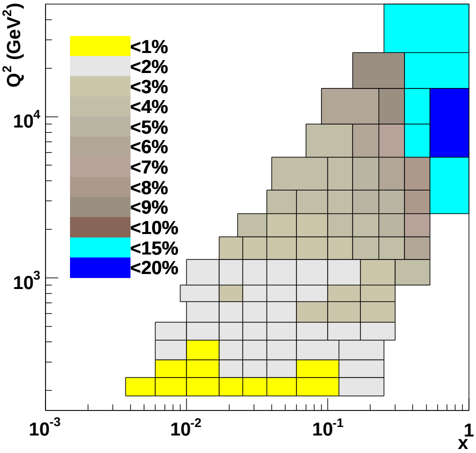


Liczba przypadków w binach maleje szybko z Q^2

$$\Delta N \sim \frac{1}{Q^4}$$

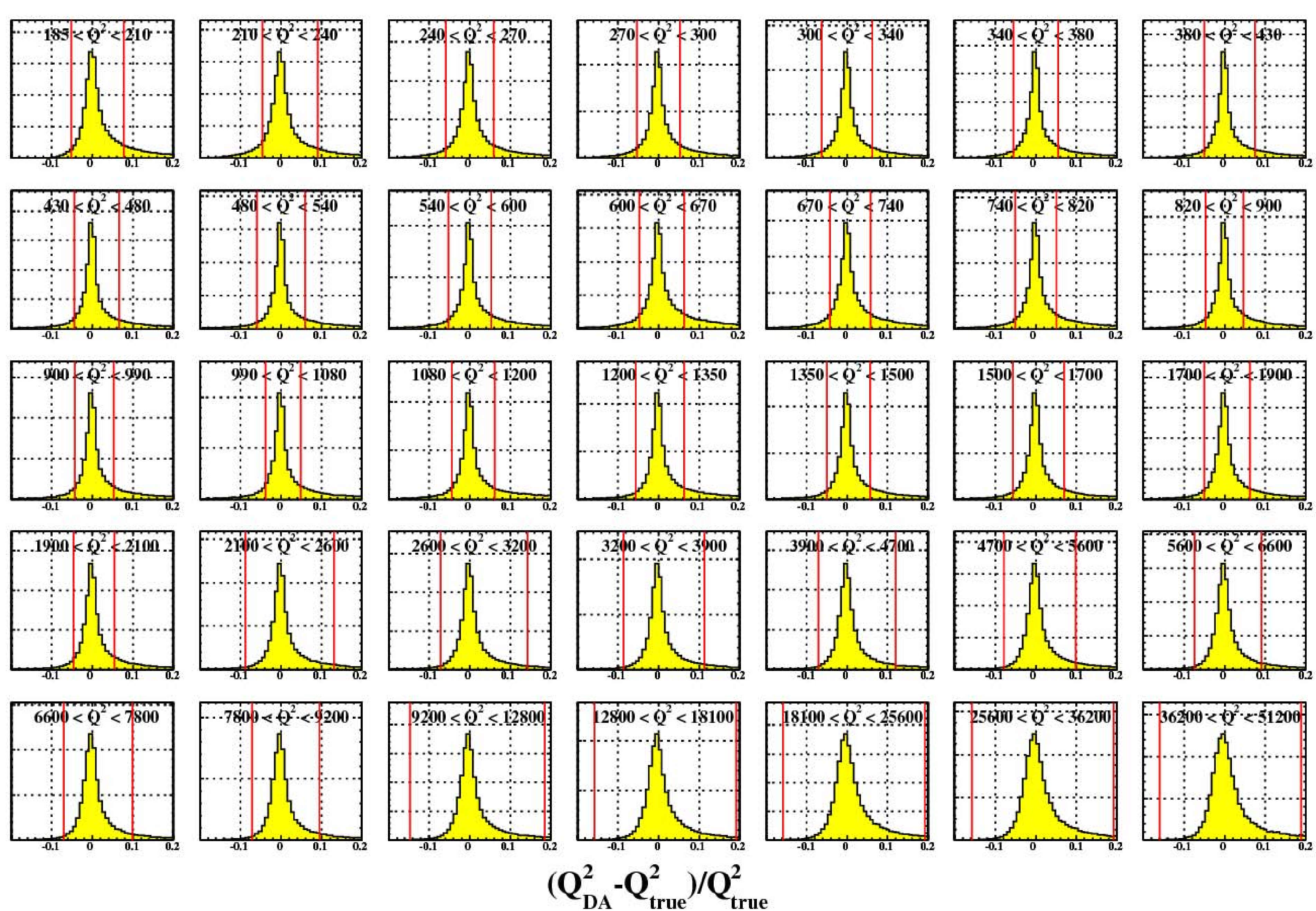
$\Rightarrow$ pomiar ograniczony do $Q^2 \leq 2 \cdot 10^4 \; GeV^2$

Statistical Error in Bins used for $d^2\sigma/dxdQ^2$

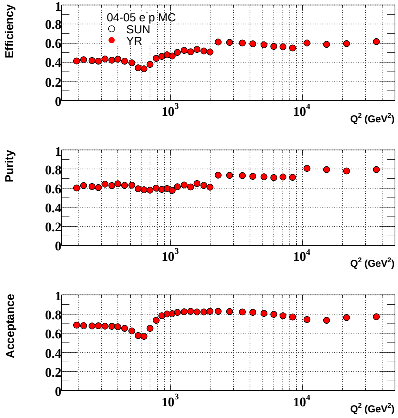


Data

$d\sigma/dQ^2$: Bias and Resolution



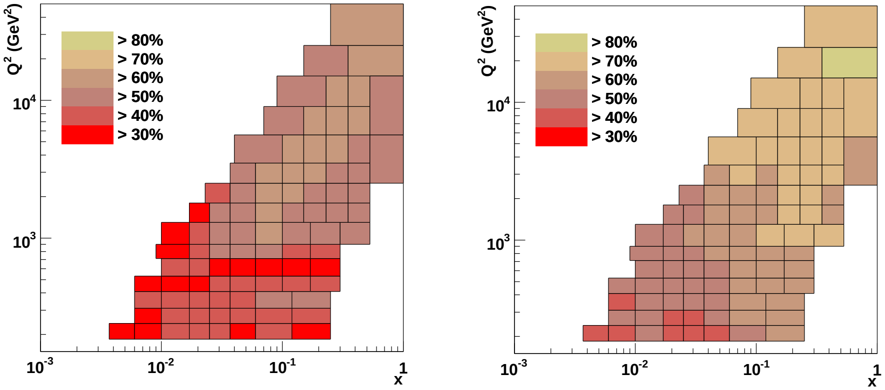
Efficiency and Purity for $d\sigma/dQ^2$



- $\text{Efficiency} = \dfrac{\text{Generated \& Accepted}}{\text{Generated}}$
- $\text{Purity} = \dfrac{\text{Generated \& Accepted}}{\text{Accepted}}$
- $\text{Acceptance} = \dfrac{\text{Efficiency}}{\text{Purity}}$

Efficiency and Purity in $d^2\sigma/dxdQ^2$

$$\text{Efficiency} = \frac{\text{Generated \& Accepted}}{\text{Generated}} \qquad \text{Purity} = \frac{\text{Generated \& Accepted}}{\text{Accepted}}$$

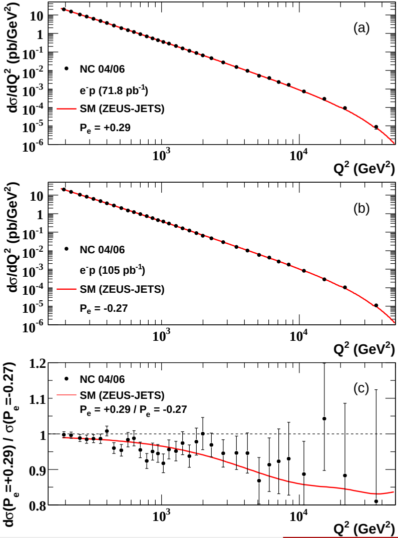


Unfolding Cross Sections

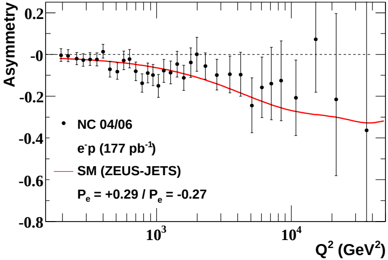
Cross sections extracted using:

- $\frac{d\sigma}{dQ^2}\Big|_{Q_0^2} = \frac{(N_{DATA} - N_{BG})}{N_{MC}} \frac{d\sigma}{dQ^2}\Big|_{Q_0^2}^{theory}$
- With Born-level unpolarised MC and theory values
- See backup for bin selection (based on HERA I binning)
    - Finer in $d\sigma/dQ^2$
    - Higher/lower bins in $d\sigma/dx$, $d\sigma/dy$
    - Keep same for reduced cross sections

$d\sigma/dQ^2$



- χ^2 test for all ratio points:
- +ve P_e / -ve P_e = 1 case
  - χ^2 / ndf = 83 / 34
- +ve P_e / -ve P_e = SM case
  - χ^2 / ndf = 28 / 34



Wyznaczanie funkcji struktury

Liczba mierzonych przypadków decyduje o błędzie statystycznym wyznaczonych wartości $F_2(x,Q^2)$:

$$\frac{\sigma_{F_2}^{stat}}{F_2} = \frac{1}{\sqrt{\Delta N}}$$

Błędy statystyczne dominują przy dużych Q^2, przy małych Q^2 są zaniedbywalne.

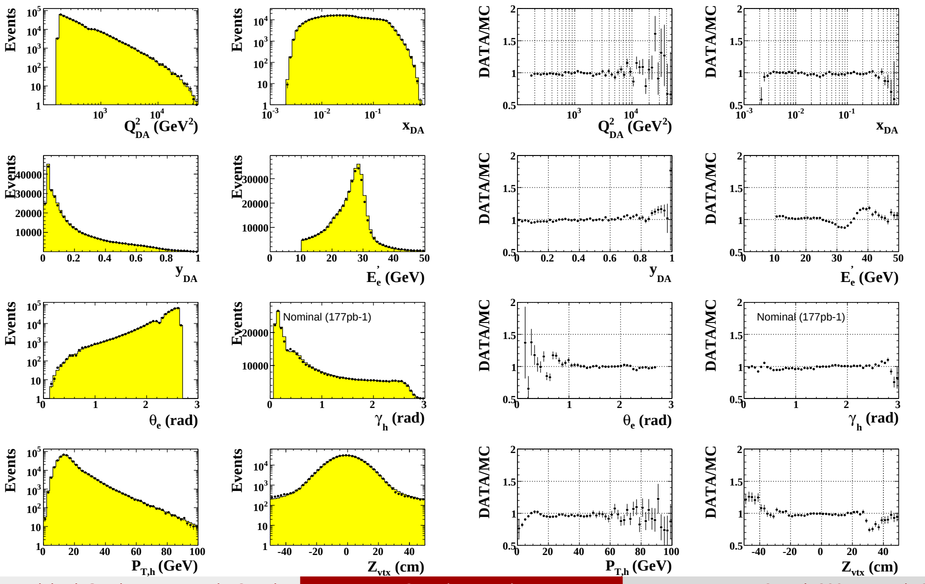
Błąd systematyczny pomiaru wynika z **niepewności**:

- poprawek teoretycznych δ_L, δ_Z i δ_{rad}
- pomiaru świetności $\mathcal{L}_{int}$
- wyznaczenia poprawek $\mathcal{E}$ i $\mathcal{A}$
  (niepewności związane z symulacją Monte Carlo badanego procesu i działania detektora)

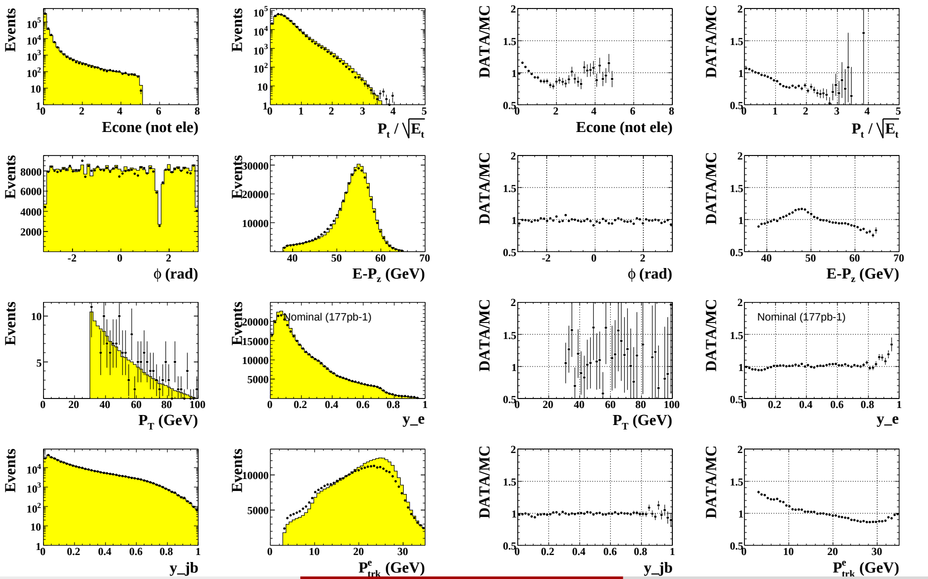
Błędy systematyczne dominują przy małych Q^2.

Na ogół są na poziomie kilku % (obecne pomiary w HERA)

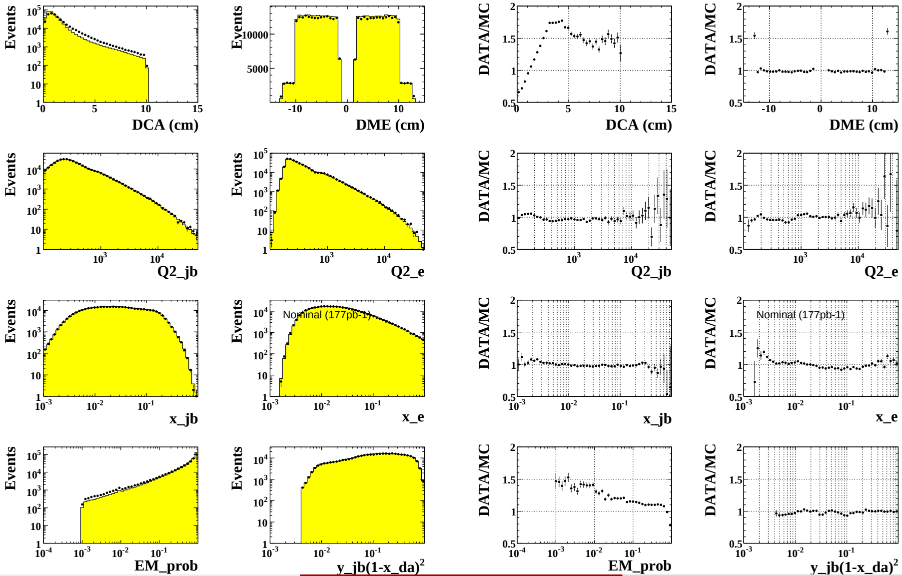
Control Plots



Control Plots



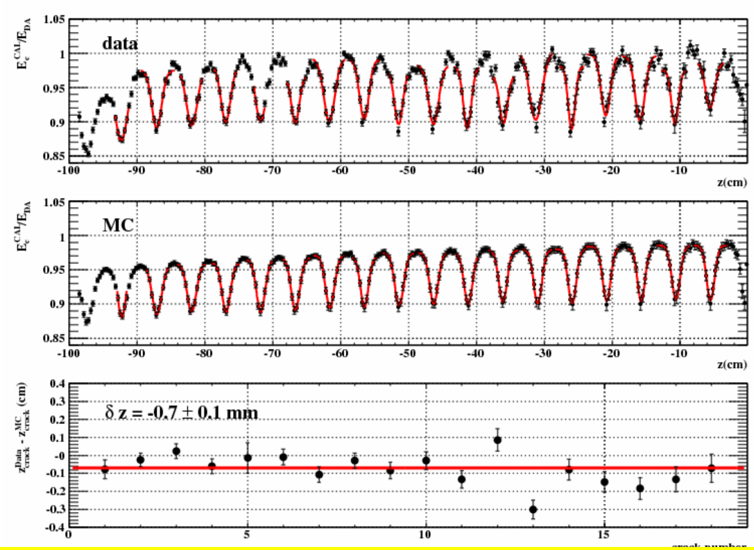
Control Plots



CAL alignment with respect to CTD

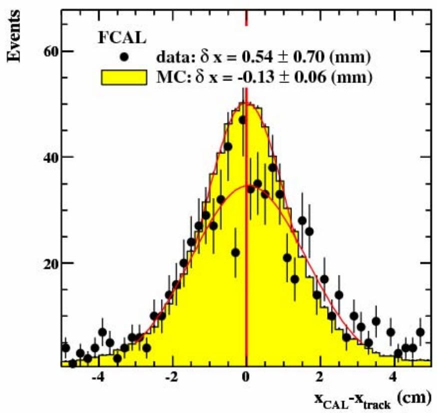
Stat error only.

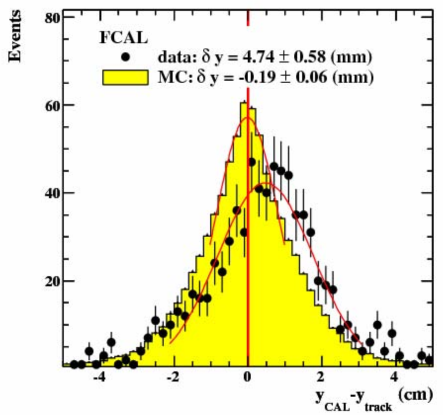
	RHES left	RHES right
$\delta\phi$	+1.6±0.1mrad	+0.9±0.1mrad
δz	+2.0±0.2mm	-0.9±0.2mm
δx	+1.9±0.1mm	-1.7±0.1mm
δy	+1.4±0.1mm	-1.0±0.1mm



RCAL is aligned within 2.0mm in x and y direction.

BCAL is aligned within 1.0mm. (Only z shift is checked.)





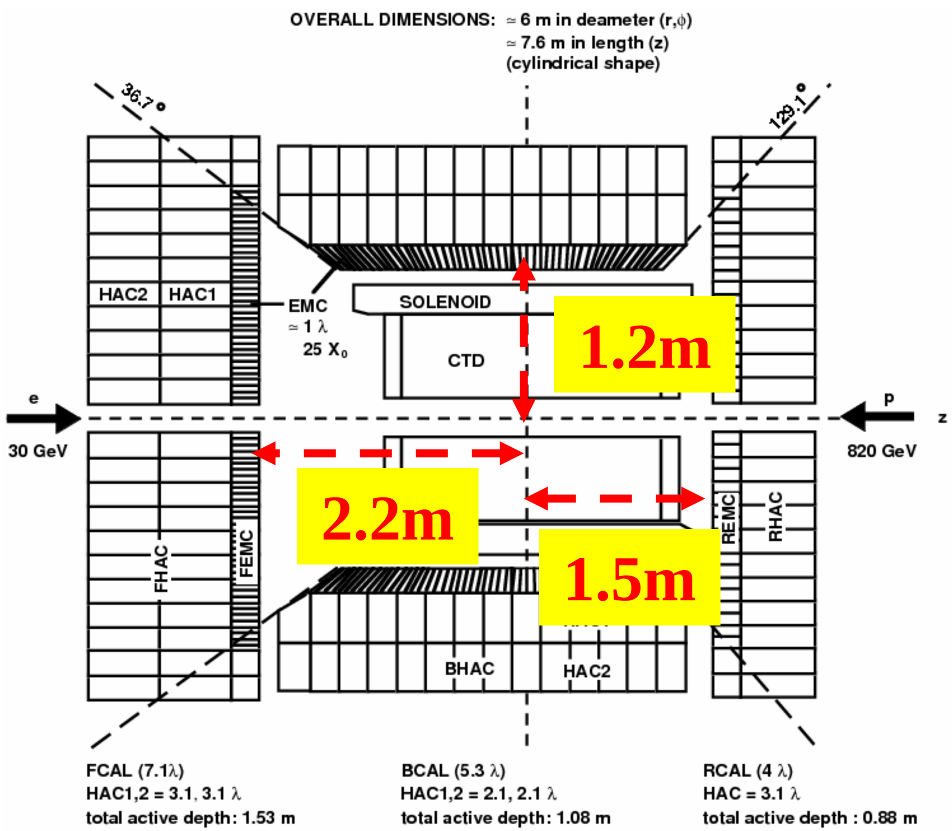
FCAL position correction : Shift the e position with -4mm in y for data.(Hadronic system is neglected.)

FCAL is aligned within 2.0mm.

For more details, see talk at F_L review meeting on 09/Feb/2007.

Uncertainty of CAL position

Estimate the effect on cross section by varying the θ_e.



$$\delta\theta = \delta l / r$$

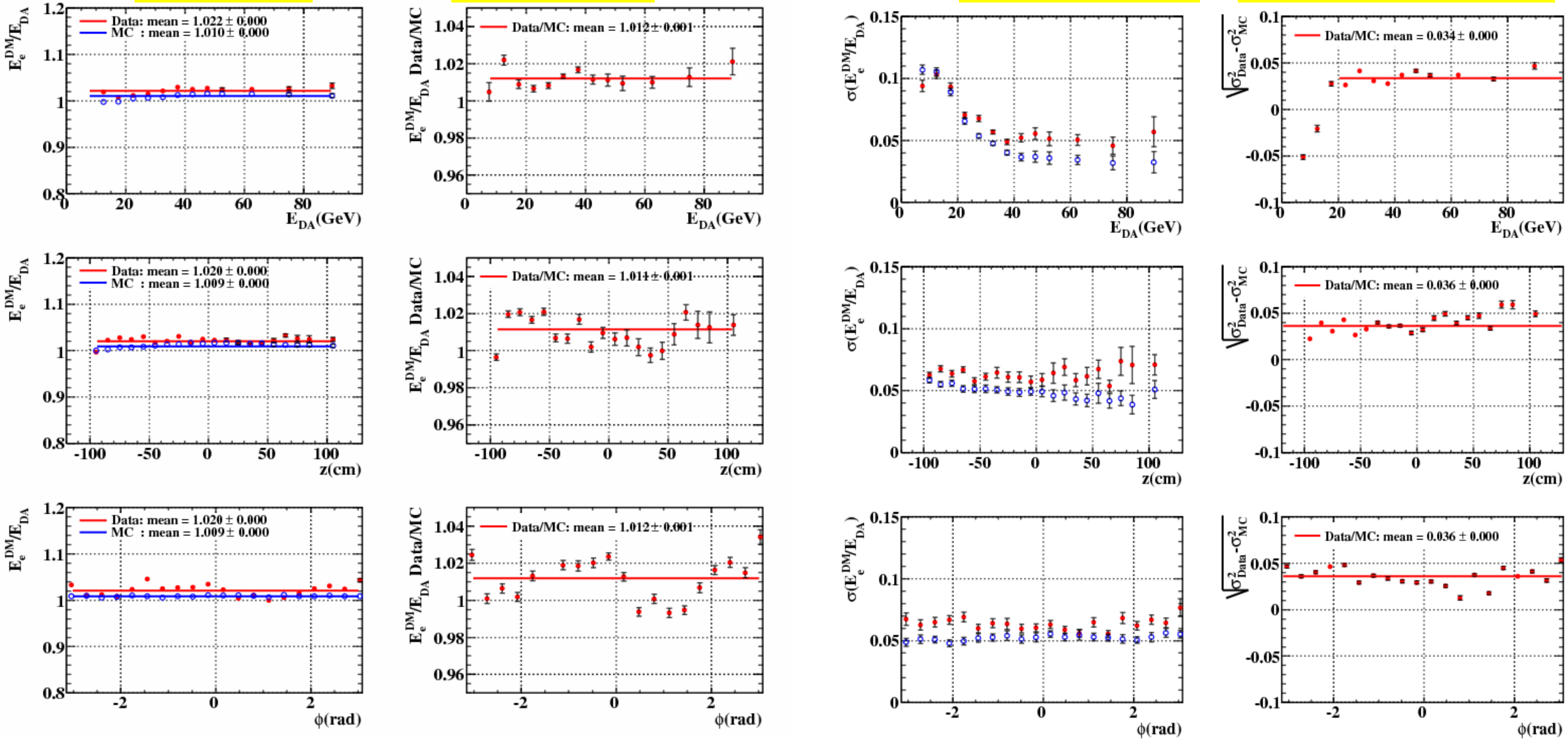
- RCAL : δl=2mm, r=1.5m
  → $\delta\theta$=1.3mrad
- BCAL : δl=1mm, r=1.2m
  → $\delta\theta$=0.8mrad
- FCAL : δl=2mm, r=2.2m
  → $\delta\theta$=0.9mrad

$\theta_e \pm$ 1mrad is adequate as systematic check.

BCAL electron energy

E_e is corrected by dead-material map and non-uniformity.

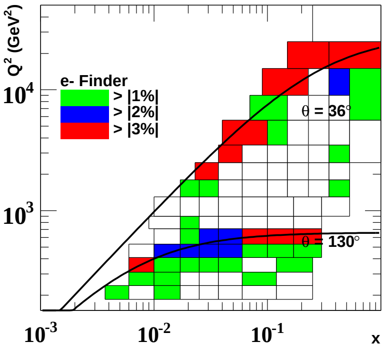
E_e/E_{DA} | Data/MC | $\sigma(E_e/E_{DA})$ | $\sqrt{\sigma_{Data}^2 - \sigma_{MC}^2}$

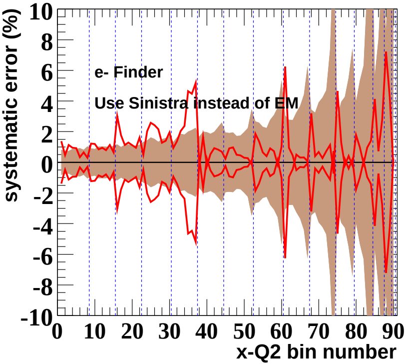


Scale uncertainty is 2%.

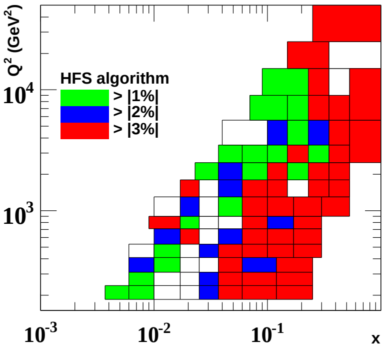
Smearing factor is 3.4%.

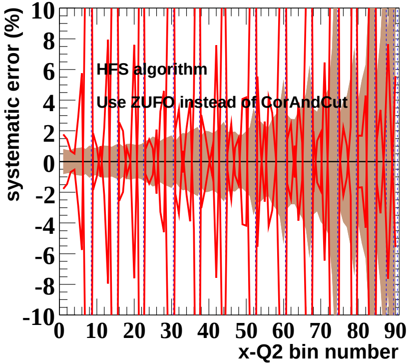
Systematics in $d^2\sigma/dxdQ^2$ for EM→SINISTRA





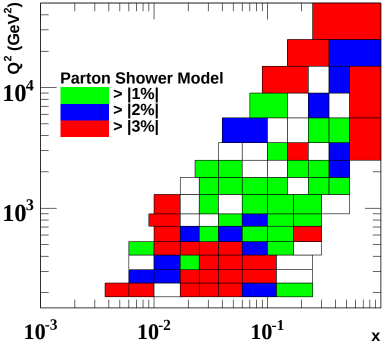
Systematics in $d^2\sigma/dxdQ^2$ for CorAndCut→ZUFO

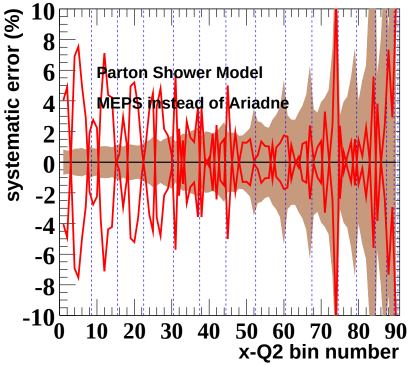




- Using ZUFOs from EM_HAD block

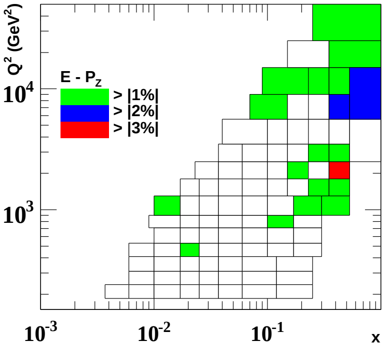
Largest Systematics in Dbl Diff bins - MEPS

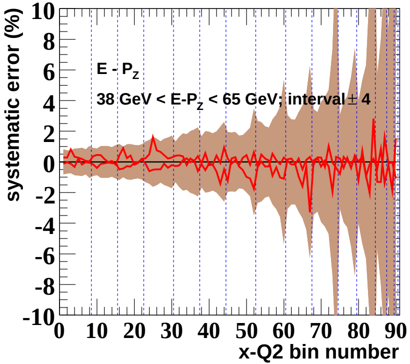




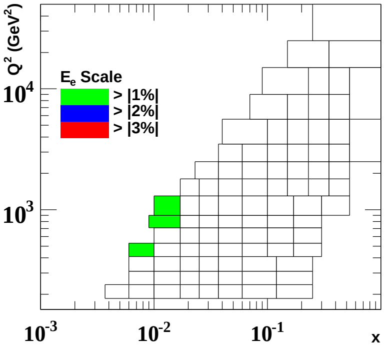
- Dominates low Q^2 region

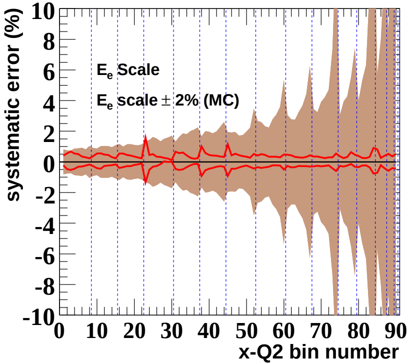
Largest Systematics in Dbl Diff bins - $E - P_Z$



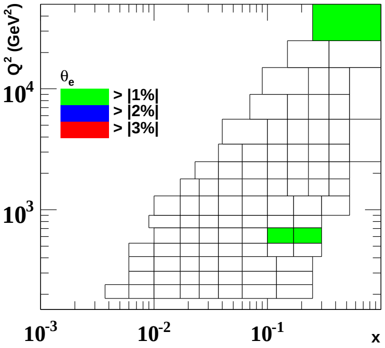


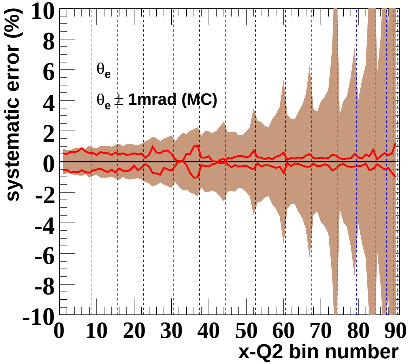
Largest Systematics in Dbl Diff bins - E_e scale



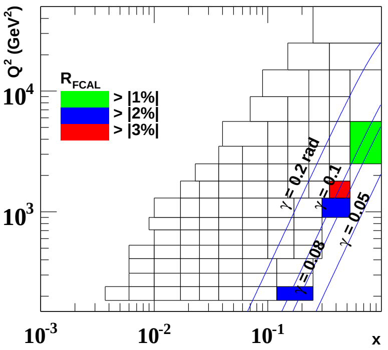


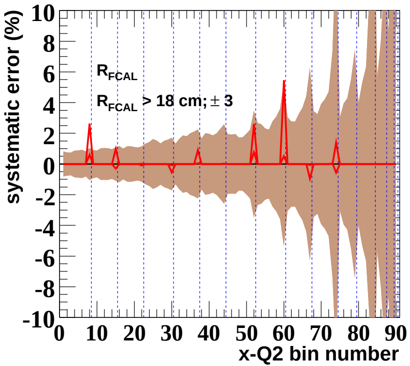
Largest Systematics in Dbl Diff bins - θe





Largest Systematics in Dbl Diff bins - R_{FCAL}



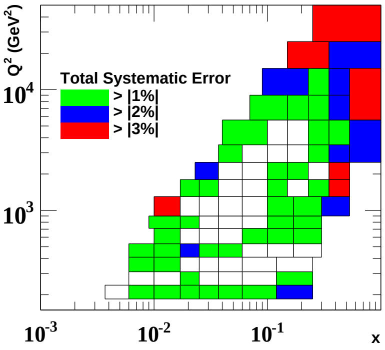


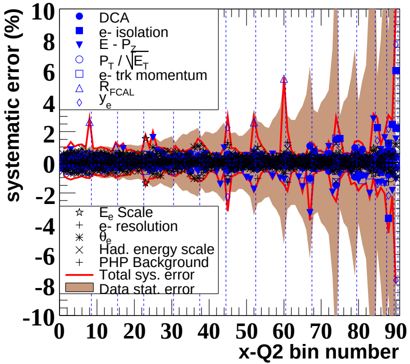
- Projection of γ_h onto face of FCAL
- Dominates in lowest γ_h regions

Systematic Checks

- DCA $>$ 10 cm; 8cm
- $E^{cone}_{note-} < 5$ GeV; $\pm$ 2 GeV
- 38 GeV $< E - P_Z <$ 65 GeV; interval $\pm$ 4 GeV
- $P_T/\sqrt{E_T} < 4\sqrt{GeV}; \pm 1\sqrt{GeV}$
- $P^e_{trk} >$ 3 GeV; $\pm$ 1 GeV
- $R_{FCAL} >$ 18 cm; $\pm$ 3 cm
- $y_e <$ 0.95; 0.9
- E_e scale $\pm$ 2% (MC)
- E_e smeared $\pm$ 1% (MC)
- $\theta_e \pm$ 1mrad (MC)
- E_h scale $\pm$ 3% (MC)
- PHP MC normalization $\pm$ 100%
- Checks not used in error calculations:
  - ARIADNE $\rightarrow$ MEPS
  - EM $\rightarrow$ Sinistra
  - CorAndCut $\rightarrow$ ZUFOs

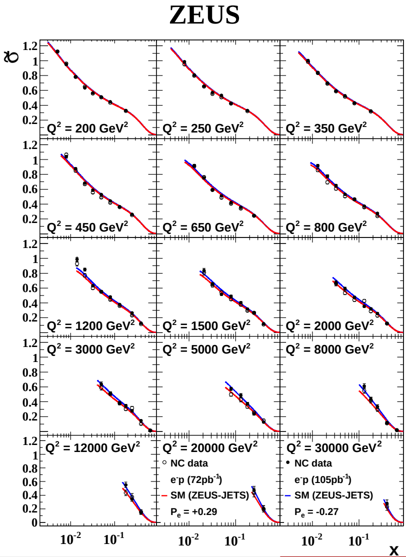
Systematics in $d^2\sigma/dxdQ^2$



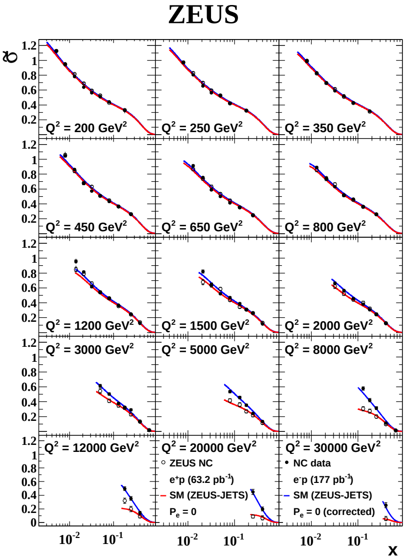


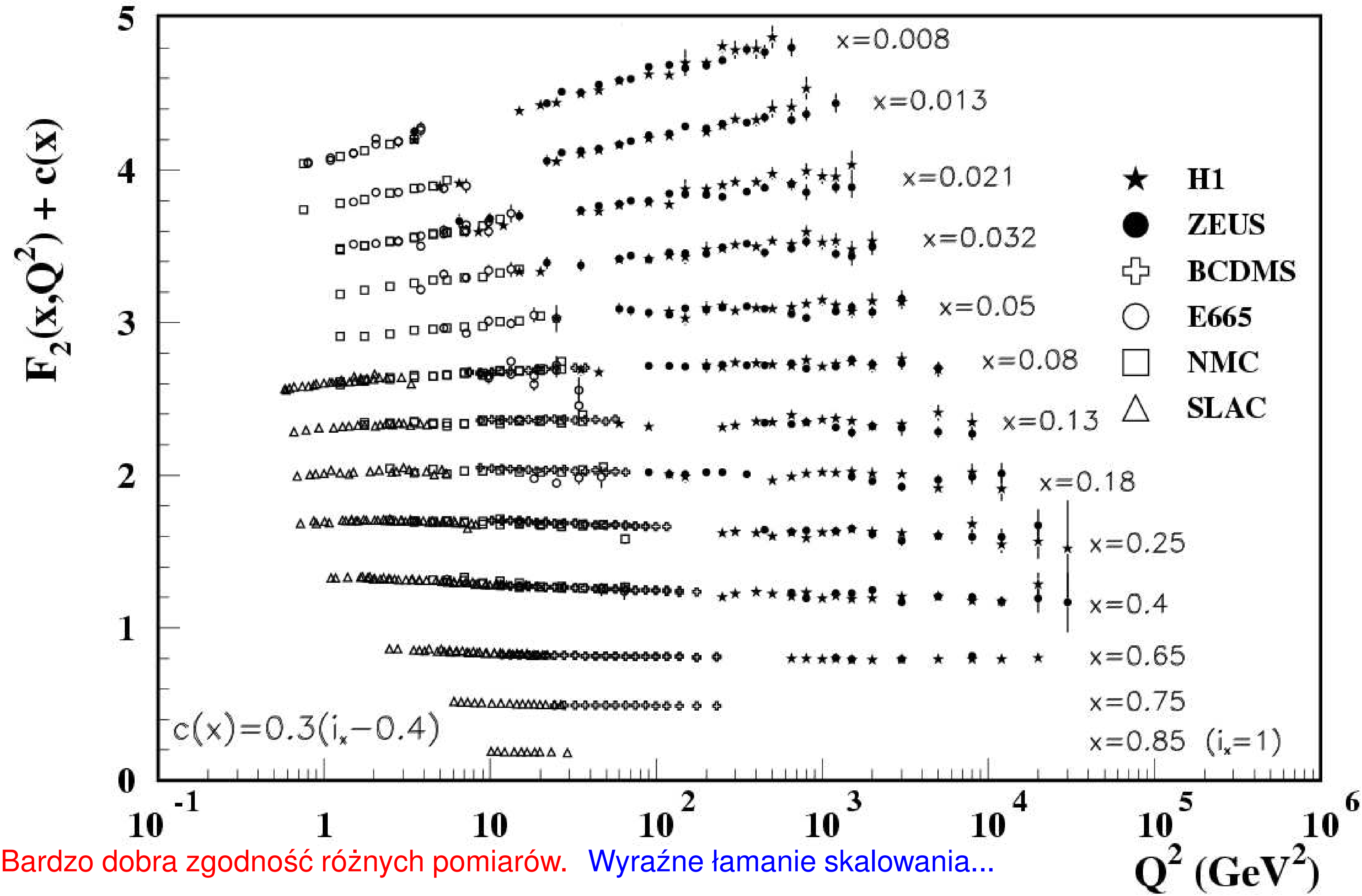
Reduced Cross Sections

LH and RH separate



Entire data set





Bardzo dobra zgodność różnych pomiarów. Wyraźne łamanie skalowania...