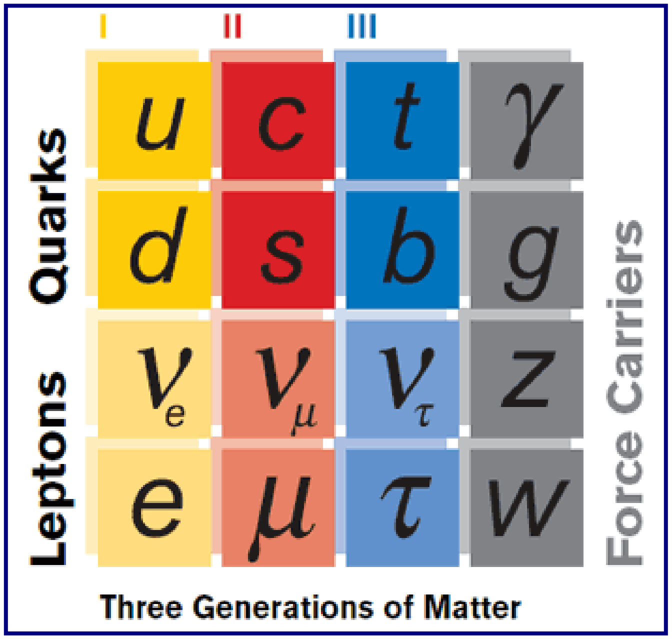
Standard Model

Eckhard von Törne
Universität Bonn, Kansas State University

14./15. Februar 2006

Overview

1. Theory Overview
2. Experimental Verification of QCD
3. Experimental Verification of Electroweak Sector
4. Higgs Search Strategies at the LHC
5. Experimental Evidence for Physics beyond the Standard Model
6. "Exam"



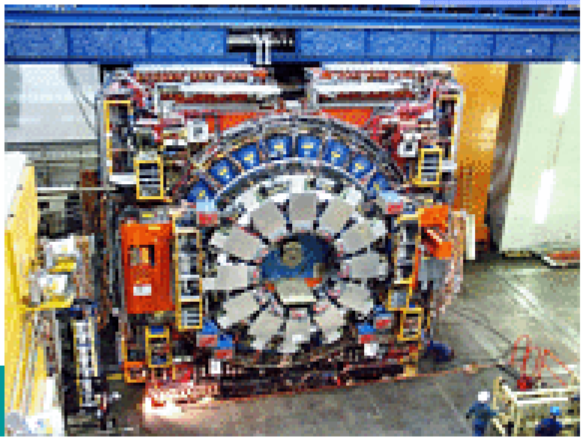
Section 1

Theory Overview

- 1.1 Introduction
- 1.2 Lagrange Density of the SM
- 1.3 Symmetry Breaking
- 1.4 Couplings + Weinberg Angle
- 1.5 QCD

1.1 Introduction

- Underlying principle of the SM is ‘Frugality’
  (if a term does not need to be in the Lagrange density, leave it out)
- Standard model is not a “shifting target”
- Example “neutrino masses are still not part of the SM” -> Why?
  (see also section 5 tomorrow)
- SM topics not covered here:
  - Top — •**P. Uwer + S. Menke**
  - Bottom — •**A. Buras**
  - Monte Carlo generators — •**T. Sjostrand**
- This is a talk with experimental flavor
  but no detectors (see lecture by Hausch.)

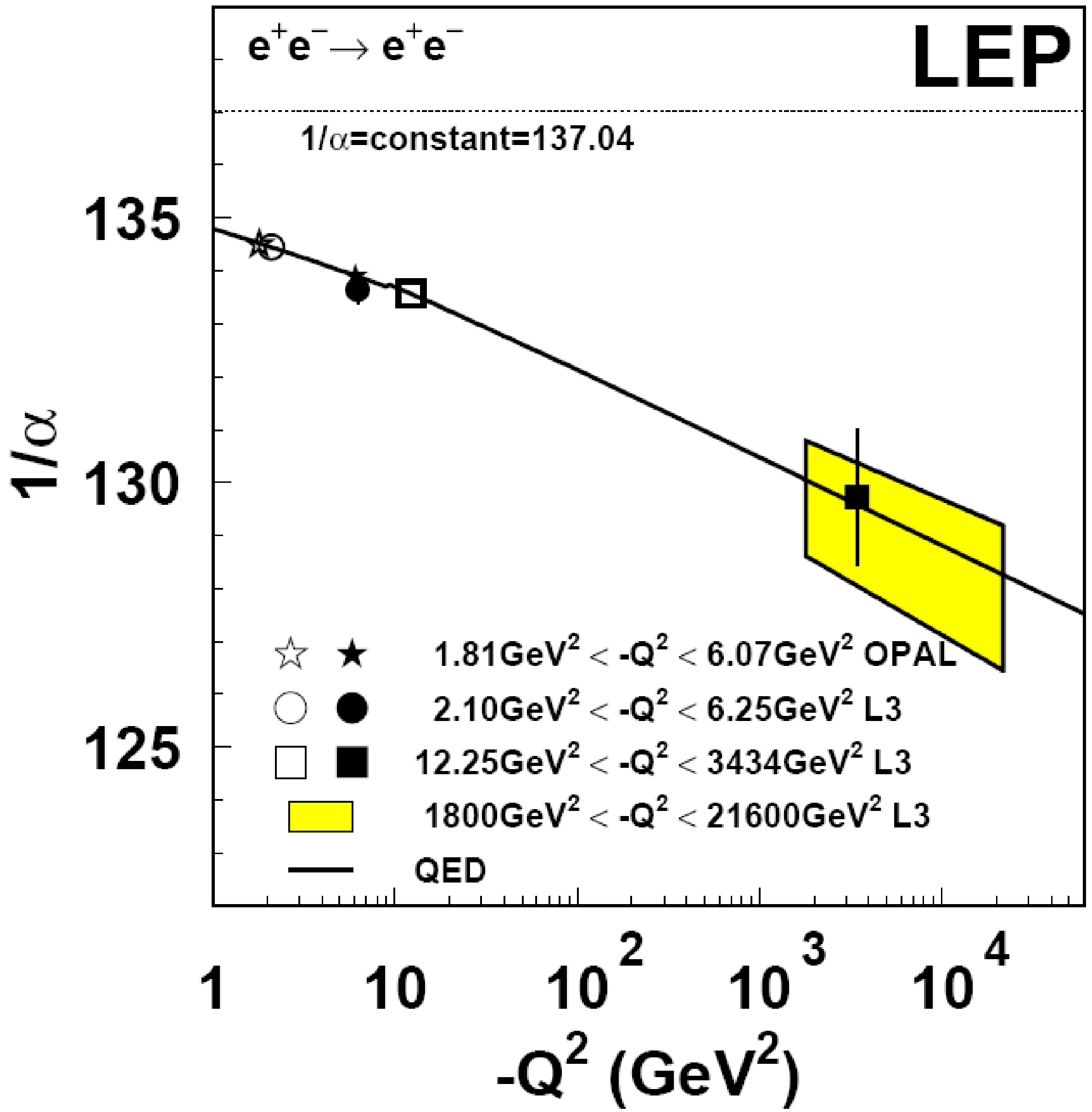


What you should remember from your Quantum Field Theory class

- Most problems students encounter with SM due to QFT in general - not specific to SM. Good review of QFT:

  Zee, *QFT in a Nutshell*, Princeton University Press 2003, 518 pages
- A specific QFT is defined by its Lagrange density and by transformation behavior of fields.
- The Lagrange density exhibits local gauge symmetry
- Most QFTs do NOT work right out of the box. They require regularization and renormalization. coupling strengths (and masses) become scale-dependent (no more coupling *constants*).

  Example: α_{QED} = 1/137 at low energy and 1/129 at $m(Z^0)$.
- The Standard model is a QFT with a specific lagrange density which is parameterized by 19 free parameters - measured with varying accuracy. Worst-known parameter is probably M_{Higgs}


$e^+e^- \to e^+e^-$
LEP
$1/\alpha$=constant=137.04
135
130
125
$1/\alpha$
1.81GeV^2 < -Q^2 < 6.07GeV^2 OPAL
2.10GeV^2 < -Q^2 < 6.25GeV^2 L3
12.25GeV^2 < -Q^2 < 3434GeV^2 L3
1800GeV^2 < -Q^2 < 21600GeV^2 L3
QED
1
10
10^2
10^3
10^4
-Q^2 (GeV^2)

Standard Model Gauge Symmetry

Local Gauge Symmetry:

$$SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$$

Color-degree of freedom (quarks)

Weak Isospin (quarks+lepton+Higgs)

Hypercharge (quarks+lepton+Higgs)

1.2 Standard Model Lagrange Density

$$G^a_{\mu\nu} = \partial_\mu G^a_\nu - \partial_\nu G^a_\mu - g_s f_{abc} G^b_\mu G^c_\nu$$

Gauge

$$-\tfrac{1}{4} W^a_{\mu\nu} W_a^{\mu\nu} - \tfrac{1}{4} B_{\mu\nu} B^{\mu\nu} - \tfrac{1}{4} G^a_{\mu\nu} G_a^{\mu\nu}$$

Leptons

$$+\bar{L}\gamma^\mu \left(i\partial_\mu - g\tfrac{1}{2}\tau_a W^a_\mu - g'\frac{Y}{2} B_\mu \right) L$$

$$+\bar{R}\gamma^\mu \left(i\partial_\mu - g'\frac{Y}{2} B_\mu \right) R$$

Quarks

$$+\overline{q_L}\gamma^\mu \left(i\partial_\mu - g\tfrac{1}{2}\tau_a W^a_\mu - g'\frac{Y}{2} B_\mu - g_s T_a G^a_\mu \right) q_L$$

$$+\overline{q_R}\gamma^\mu \left(i\partial_\mu - g'\frac{Y}{2} B_\mu - g_s T_a G^a_\mu \right) q_R$$

Higgs

$$+\left| \left(i\partial_\mu - g\tfrac{1}{2}\tau_a W^a_\mu - g'\frac{Y}{2} B_\mu \right) \phi \right|^2 - \left(-\mu^2\phi^2 + \lambda\phi^4 \right)$$

Yukawa

$$-\left(G\bar{L}\phi R + hermitian\ \ conjugate \right)$$

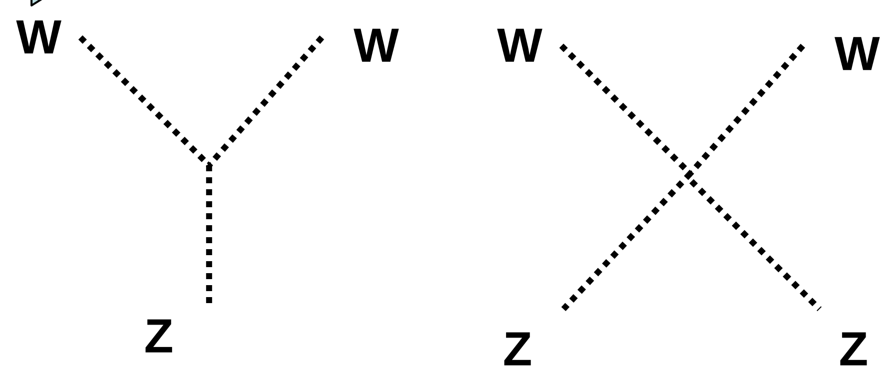
$$-\left(G_1 \overline{q_L} \phi q_R + G_2 \overline{q_L} \phi_c q_R + hermitian\ \ conjugate \right)$$

$$\phi_c = -i\tau_2\phi^*$$

Standard Model Lagrange Density

$$-\tfrac{1}{4}W^a_{\mu\nu}W_a^{\mu\nu} - \tfrac{1}{4}B_{\mu\nu}B^{\mu\nu} - \tfrac{1}{4}G^a_{\mu\nu}G_a^{\mu\nu}$$

Gauge boson self interaction



$$+\bar{L}\gamma^\mu\left(i\partial_\mu - g\tfrac{1}{2}\tau_a W^a_\mu - g'\frac{Y}{2}B_\mu\right)L$$

$$+\bar{R}\gamma^\mu\left(i\partial_\mu - g'\frac{Y}{2}B_\mu\right)R$$

$$+\overline{q_L}\gamma^\mu\left(i\partial_\mu - g\tfrac{1}{2}\tau_a W^a_\mu - g'\frac{Y}{2}B_\mu - g_s T_a G^a_\mu\right)q_L$$

+ ...

$$+\overline{q_R}\gamma^\mu\left(i\partial_\mu - g'\frac{Y}{2}B_\mu - g_s T_a G^a_\mu\right)q_R$$

$$+\left|\left(i\partial_\mu - g\tfrac{1}{2}\tau_a W^a_\mu - g'\frac{Y}{2}B_\mu\right)\phi\right|^2 - \left(-\tfrac{1}{2}\mu^2\phi^2 + \tfrac{1}{4}\lambda\phi^4\right)$$

$$-\left(G\bar{L}\phi R + hermitian\ \ conjugate\right)$$

$$-\left(G_1\overline{q_L}\phi q_R + G_2\overline{q_L}\phi_c q_R + hermitian\ \ conjugate\right)$$

Standard Model Lagrange Density

$$-\tfrac{1}{4}W^{a}_{\mu\nu}W^{\mu\nu}_{a}-\tfrac{1}{4}B_{\mu\nu}B^{\mu\nu}-\tfrac{1}{4}G^{a}_{\mu\nu}G^{\mu\nu}_{a}$$

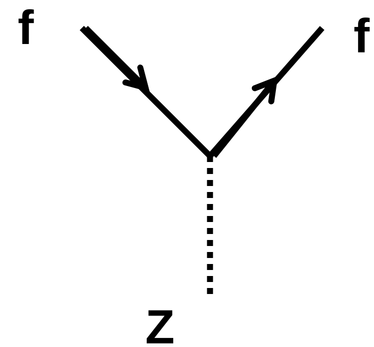
$$+\bar{L}\gamma^{\mu}\left(i\partial_{\mu}-g\tfrac{1}{2}\tau_{a}W^{a}_{\mu}-g'\frac{Y}{2}B_{\mu}\right)L$$

$$+\bar{R}\gamma^{\mu}\left(i\partial_{\mu}-g'\frac{Y}{2}B_{\mu}\right)R$$

$$+\overline{q_{L}}\gamma^{\mu}\left(i\partial_{\mu}-g\tfrac{1}{2}\tau_{a}W^{a}_{\mu}-g'\frac{Y}{2}B_{\mu}-g_{s}T_{a}G^{a}_{\mu}\right)q_{L}$$

$$+\overline{q_{R}}\gamma^{\mu}\left(i\partial_{\mu}-g'\frac{Y}{2}B_{\mu}-g_{s}T_{a}G^{a}_{\mu}\right)q_{R}$$

Fermion Gauge interaction



+ …

$$+\left|\left(i\partial_{\mu}-g\tfrac{1}{2}\tau_{a}W^{a}_{\mu}-g'\frac{Y}{2}B_{\mu}\right)\phi\right|^{2}-\left(-\tfrac{1}{2}\mu^{2}\phi^{2}+\tfrac{1}{4}\lambda\phi^{4}\right)$$

$$-\left(G\bar{L}\phi R+hermitian\ \ conjugate\right)$$

$$-\left(G_{1}\overline{q_{L}}\phi q_{R}+G_{2}\overline{q_{L}}\phi_{c}q_{R}+hermitian\ \ conjugate\right)$$

Standard Model Lagrange Density

$$-\tfrac{1}{4}W^a_{\mu\nu}W_a^{\mu\nu}-\tfrac{1}{4}B_{\mu\nu}B^{\mu\nu}-\tfrac{1}{4}G^a_{\mu\nu}G_a^{\mu\nu}$$

$$+\overline{L}\gamma^\mu\left(i\partial_\mu-g\tfrac{1}{2}\tau_a W^a_\mu-g'\frac{Y}{2}B_\mu\right)L$$

$$+\overline{R}\gamma^\mu\left(i\partial_\mu-g'\frac{Y}{2}B_\mu\right)R$$

$$+\overline{q_L}\gamma^\mu\left(i\partial_\mu-g\tfrac{1}{2}\tau_a W^a_\mu-g'\frac{Y}{2}B_\mu-g_sT_aG^a_\mu\right)q_L$$

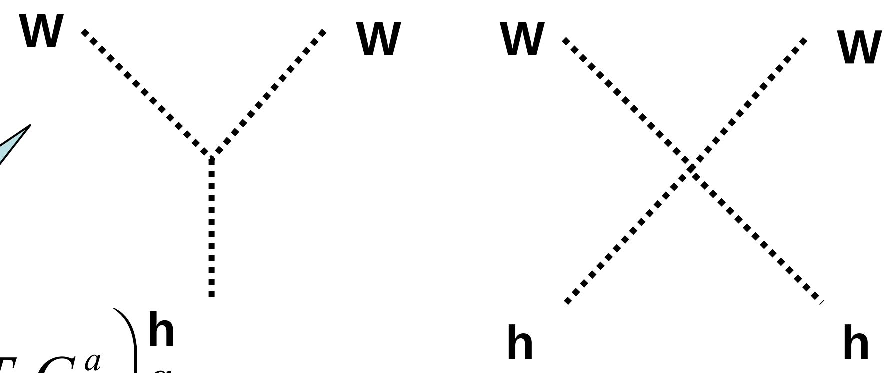
$$+\overline{q_R}\gamma^\mu\left(i\partial_\mu-g'\frac{Y}{2}B_\mu-g_sT_aG^a_\mu\right)q_R$$

$$+\left|\left(i\partial_\mu-g\tfrac{1}{2}\tau_a W^a_\mu-g'\frac{Y}{2}B_\mu\right)\phi\right|^2-\left(-\tfrac{1}{2}\mu^2\phi^2+\tfrac{1}{4}\lambda\phi^4\right)$$

$$-\left(G\overline{L}\phi R+hermitian\ \ conjugate\right)$$

$$-\left(G_1\overline{q_L}\phi q_R+G_2\overline{q_L}\phi_c q_R+hermitian\ \ conjugate\right)$$

Gauge Higgs interaction



+ …

Standard Model Lagrange Density

$$-\tfrac{1}{4}W^{a}_{\mu\nu}W_{a}^{\mu\nu}-\tfrac{1}{4}B_{\mu\nu}B^{\mu\nu}-\tfrac{1}{4}G^{a}_{\mu\nu}G_{a}^{\mu\nu}$$

$$+\overline{L}\gamma^{\mu}\left(i\partial_{\mu}-g\tfrac{1}{2}\tau_{a}W^{a}_{\mu}-g'\frac{Y}{2}B_{\mu}\right)L$$

$$+\overline{R}\gamma^{\mu}\left(i\partial_{\mu}-g'\frac{Y}{2}B_{\mu}\right)R$$

$$+\overline{q_{L}}\gamma^{\mu}\left(i\partial_{\mu}-g\tfrac{1}{2}\tau_{a}W^{a}_{\mu}-g'\frac{Y}{2}B_{\mu}-g_{s}T_{a}G^{a}_{\mu}\right)q_{L}$$

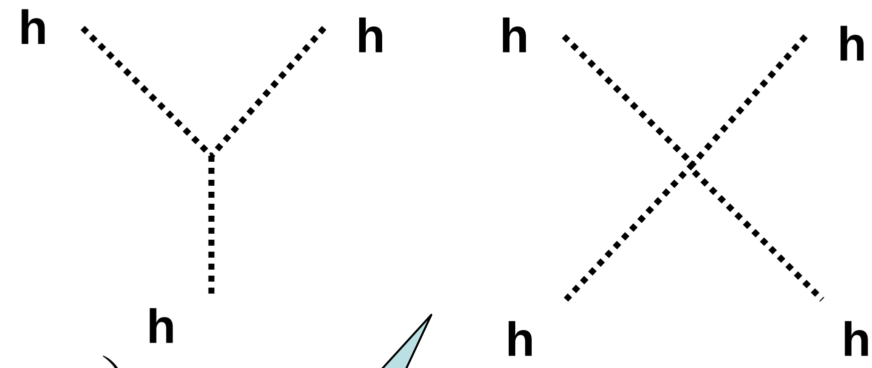
$$+\overline{q_{R}}\gamma^{\mu}\left(i\partial_{\mu}-g'\frac{Y}{2}B_{\mu}-g_{s}T_{a}G^{a}_{\mu}\right)q_{R}$$

$$+\left|\left(i\partial_{\mu}-g\tfrac{1}{2}\tau_{a}W^{a}_{\mu}-g'\frac{Y}{2}B_{\mu}\right)\phi\right|^{2}-\left(-\tfrac{1}{2}\mu^{2}\phi^{2}+\tfrac{1}{4}\lambda\phi^{4}\right)$$

$$-\left(G\overline{L}\phi R+hermitian\ \ conjugate\right)$$

$$-\left(G_{1}\overline{q_{L}}\phi q_{R}+G_{2}\overline{q_{L}}\phi_{c}q_{R}+hermitian\ \ conjugate\right)$$

Higgs self interaction



Standard Model Lagrange Density

$$-\tfrac{1}{4}W^{a}_{\mu\nu}W^{\mu\nu}_{a}-\tfrac{1}{4}B_{\mu\nu}B^{\mu\nu}-\tfrac{1}{4}G^{a}_{\mu\nu}G^{\mu\nu}_{a}$$

$$+\overline{L}\gamma^{\mu}\left(i\partial_{\mu}-g\tfrac{1}{2}\tau_{a}W^{a}_{\mu}-g'\frac{Y}{2}B_{\mu}\right)L$$

$$+\overline{R}\gamma^{\mu}\left(i\partial_{\mu}-g'\frac{Y}{2}B_{\mu}\right)R$$

$$+\overline{q_{L}}\gamma^{\mu}\left(i\partial_{\mu}-g\tfrac{1}{2}\tau_{a}W^{a}_{\mu}-g'\frac{Y}{2}B_{\mu}-g_{s}T_{a}G^{a}_{\mu}\right)q_{L}$$

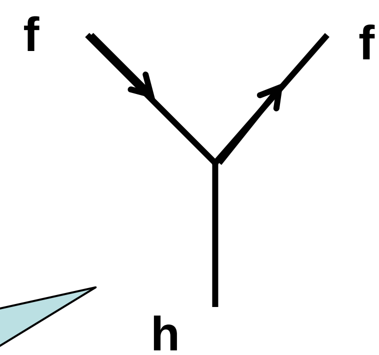
$$+\overline{q_{R}}\gamma^{\mu}\left(i\partial_{\mu}-g'\frac{Y}{2}B_{\mu}-g_{s}T_{a}G^{a}_{\mu}\right)q_{R}$$

$$+\left|\left(i\partial_{\mu}-g\tfrac{1}{2}\tau_{a}W^{a}_{\mu}-g'\frac{Y}{2}B_{\mu}\right)\phi\right|^{2}-\left(-\tfrac{1}{2}\mu^{2}\phi^{2}+\tfrac{1}{4}\lambda\phi^{4}\right)$$

$$-\left(G\overline{L}\phi R+hermitian\ \ conjugate\right)$$

$$-\left(G_{1}\overline{q_{L}}\phi q_{R}+G_{2}\overline{q_{L}}\phi_{c}q_{R}+hermitian\ \ conjugate\right)$$

Higgs fermion couplings



1.3 Symmetry breaking in the SM

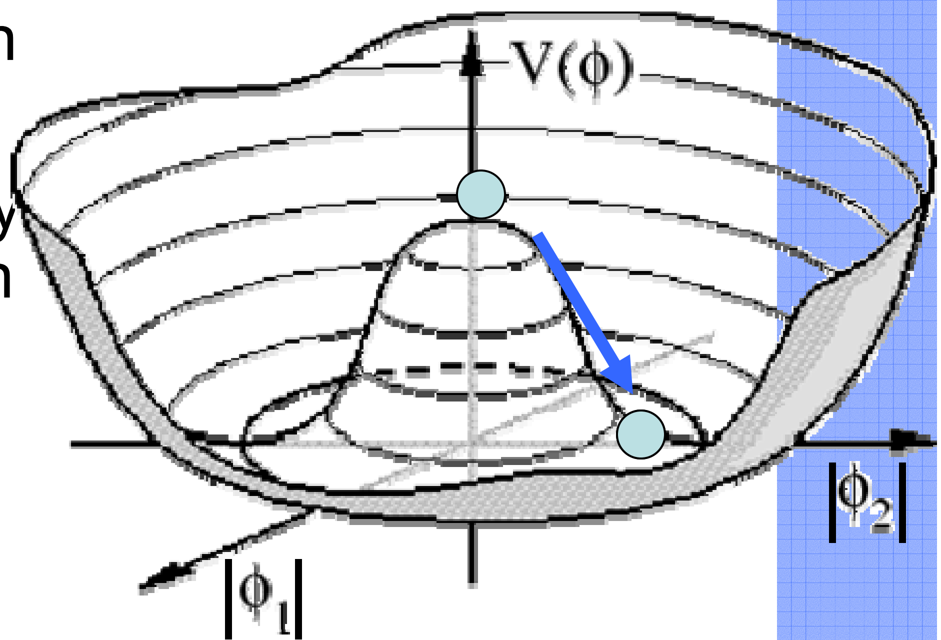
- $SU(2)_L$ is spontaneously broken
- Flavor and CP are explicitly broken by Yukawa couplings
- Chiral symmetry in QCD is dynamically broken
- No anomalous symmetry breaking (SM is anomaly free)

(notation according to Zee, QFT i.a.N., Princeton University Press (2003))

Higgs Mechanism

- More details see talk by W.Kilian
- Potential V(ϕ) minimal for $\phi \neq 0$.
- Symmetry breaks spontaneously → non-zero vacuum expectation value (vev) for ϕ:

  We consider fluctuation around this minimum
- Breaking of rotational symmetry leads to goldstone bosons that are absorbed by W^+, W^-, Z^0 (3rd polarization degree) → gauge bosons become massive
- Excitations of the Higgs field around minimum lead to Higgs particle d.o.f.



- Counting of degrees of freedom: ϕ has two complex = 4 real d.o.f. , W+,W-,Z0 absorb three, one real remains → Higgs boson

$$\phi = \begin{pmatrix} \phi_1 \\ \phi_2 \end{pmatrix} \rightarrow \begin{pmatrix} 0 \\ v + h \end{pmatrix}$$

1.4 Charges + Weinberg Angle

- Electric Charge = linear combination of I_3 and Y which couples not to vev **$Q = I_3 + Y/2$**

  $U(1)_{em}$ remains unbroken
- Photon is linear combination of W_3 and B

$$A_\mu = \cos\vartheta_W B_\mu + \sin\vartheta_W W_\mu^3 \qquad \tan\vartheta_W = \frac{g'}{g}$$

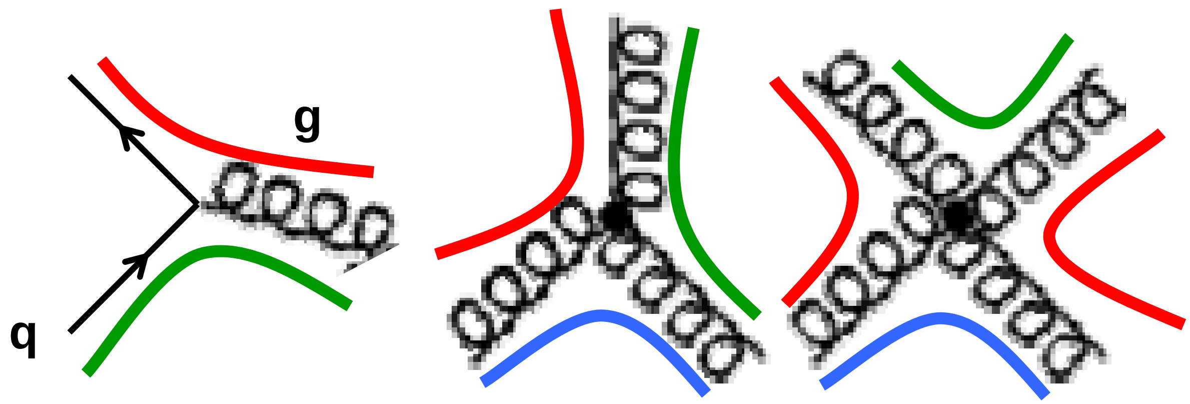
Table of Charges

Left-handed	Y	I_3	Q
ν_e	-1	½	0
e^-	-1	-½	-1
u	1/3	½	2/3
d	1/3	- ½	-1/3

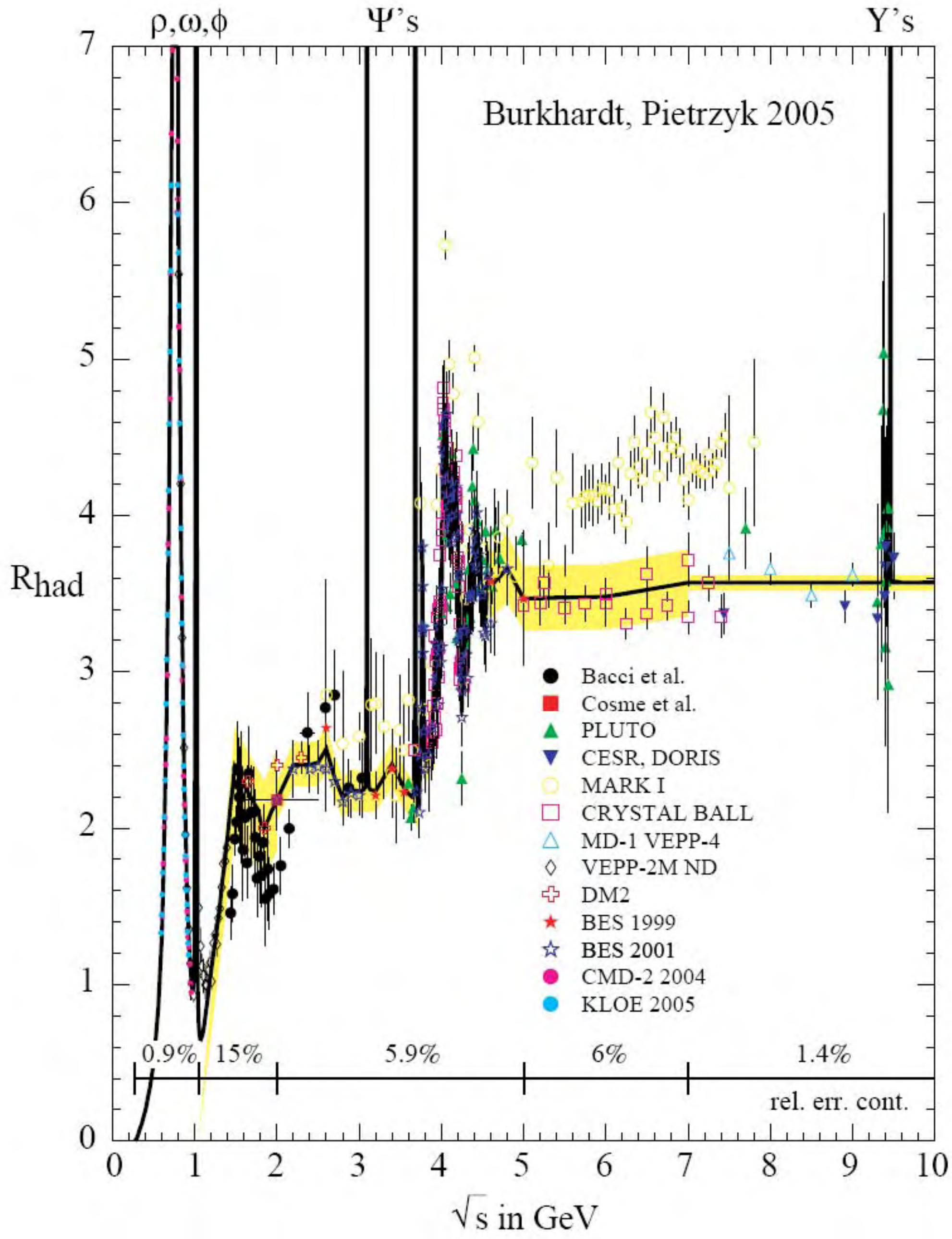
Right-handed	Y	I_3	Q
ν_e	-	-	-
e^-	-2	0	-1
u	4/3	0	2/3
d	-2/3	0	-1/3

Quantum Chromodynamics

- Gluons carry color-charge $3 \otimes \bar{3} = 8 \oplus 1$
- Color flux (must match at vertex)

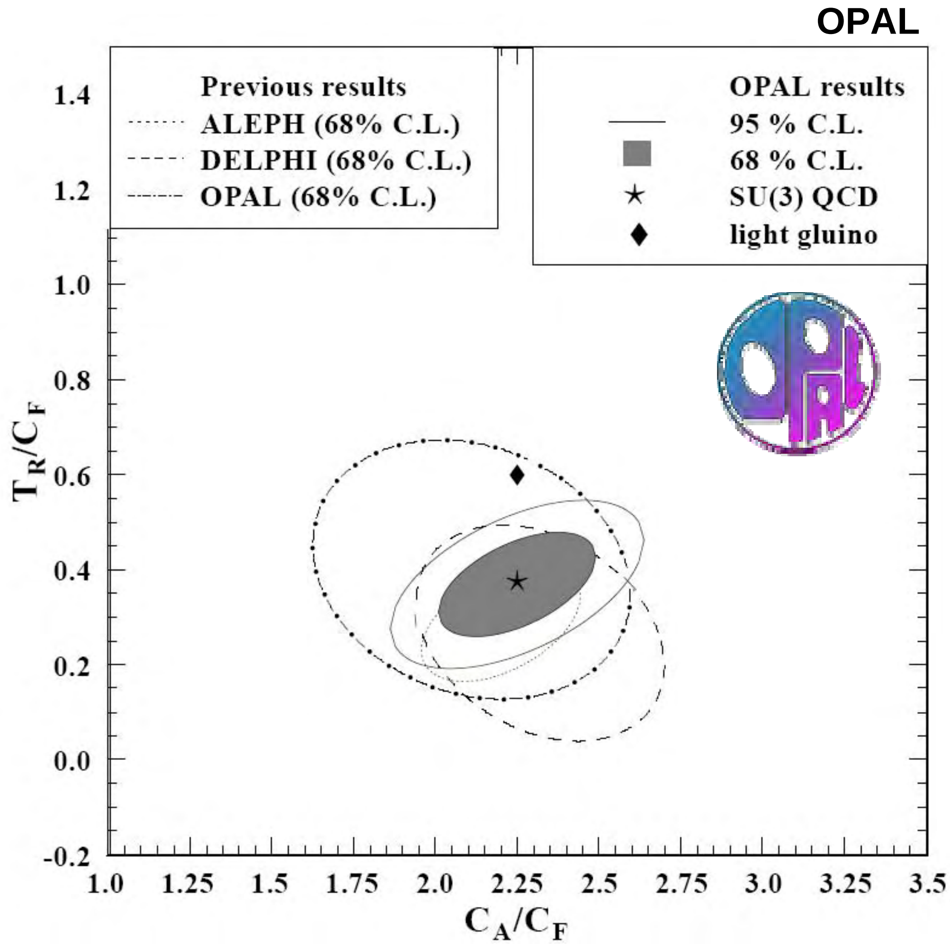


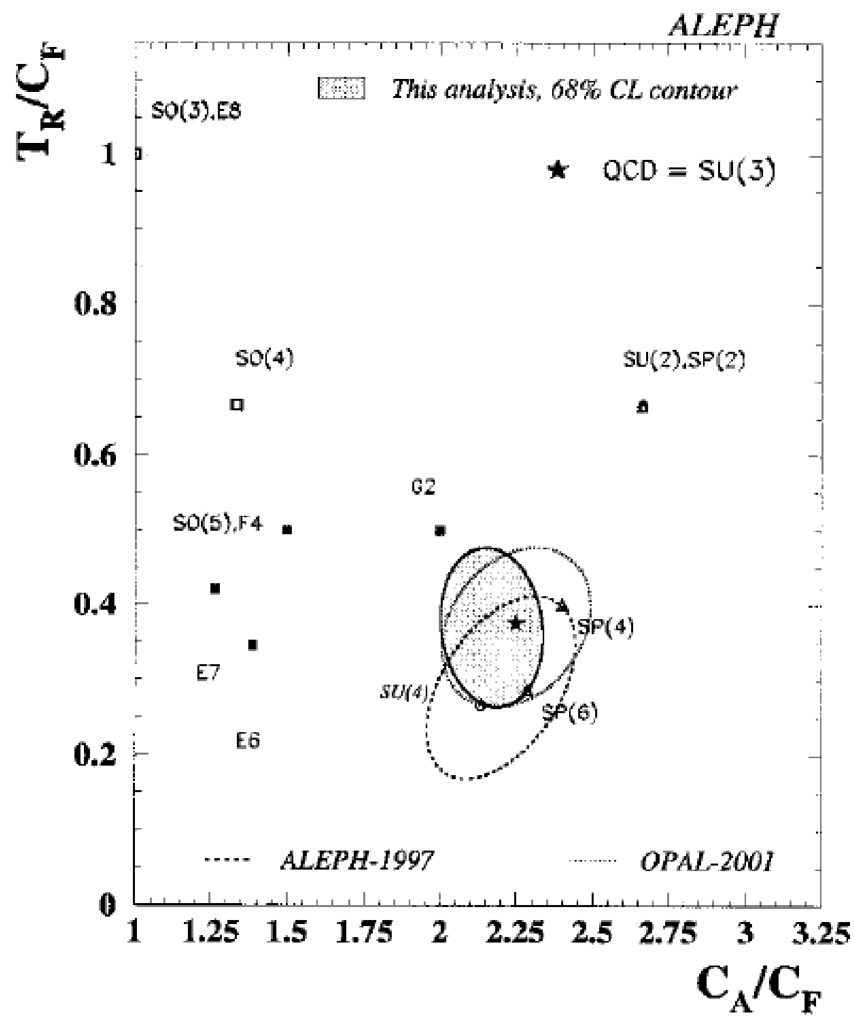
- Gauge structure can be expressed by color factors, Eigenvalues of Casimir operators invariant under $SU(3)_C$ transf. → observables
- N-colors "known" from Quark model of Hadrons and from $\sigma(e^+e^- \rightarrow \text{hadrons})$



$R_{had} = \sigma(had)/\sigma(QED)$

Color factors from four-jet events





G.Abiendi et al, Eur.Phys.J.C20:601-615,2001

A.Heister et al, Eur.Phys.J.C27:1-17,2003

Section 2

Experimental Verification of QCD

- 2.1 Factorization at Hadron Colliders
- 2.2 Parton Distribution Functions
- 2.3 QCD @ Tevatron
- 2.4 QCD @ LEP
- 2.5 QCD @ Hera
- 2.6 α_S (Q^2)
- 2.7 QCD @ LHC

2.1 Factorization at Hadron Colliders

Cross section for hadron-hadron scattering h1 + h2 → H + X

$$\sigma(p_1, p_2; Q, \{\ldots\}) =$$
$$\sum_{a.b} \int_{x_{\min}}^{1} dx_1\, dx_2\, f_{a/h_1}(x_1, \mu_F^2)\, f_{b/h_2}(x_2, \mu_F^2)\, \hat{\sigma}_{ab}(x_1 p_1, x_2 p_2; Q, \{\ldots\}; \mu_F^2)$$

+soft corrections $O(\Lambda_{QCD}/Q)$

- Factorization formula, see also (J.C.Collins, D.E.Soper, G.Sterman "*Perturbative Quantum Chromodynamics*" World Scientific 1989)
  convolution of process-independent bound state effects (proton structure) and partonic cross sections (perturbative series expansion)
- parton distributions $f_{a/h1}(x_1,\mu_F)$ process-independent
  Momentum sum rule: $\sum_a \int_0^1 dx\, x\, f_a(x, \mu^2) = 1$
- Factorization scale μ_F and renormalization scale μ_R usually chosen to be the same and equal to the scale of the process Q

Partonic cross sections

❑Fixed order expansion

Usual choice $\mu_R = \mu_F$

$$\hat{\sigma}(p_1, p_2; Q, \{Q_1, \ldots\}; \mu_F^2) = \alpha_S^k(\mu_R^2) \left\{ \hat{\sigma}^{(LO)}(p_1, p_2; Q, \{Q_1, \ldots\}) + \alpha_S(\mu_R^2)\, \hat{\sigma}^{(NLO)}(p_1, p_2; Q, \{Q_1, \ldots\}; \mu_R^2; \mu_F^2) + \alpha_S^2(\mu_R^2)\, \hat{\sigma}^{(NNLO)}(p_1, p_2; Q, \{Q_1, \ldots\}; \mu_R^2; \mu_F^2) + \ldots \right\}$$

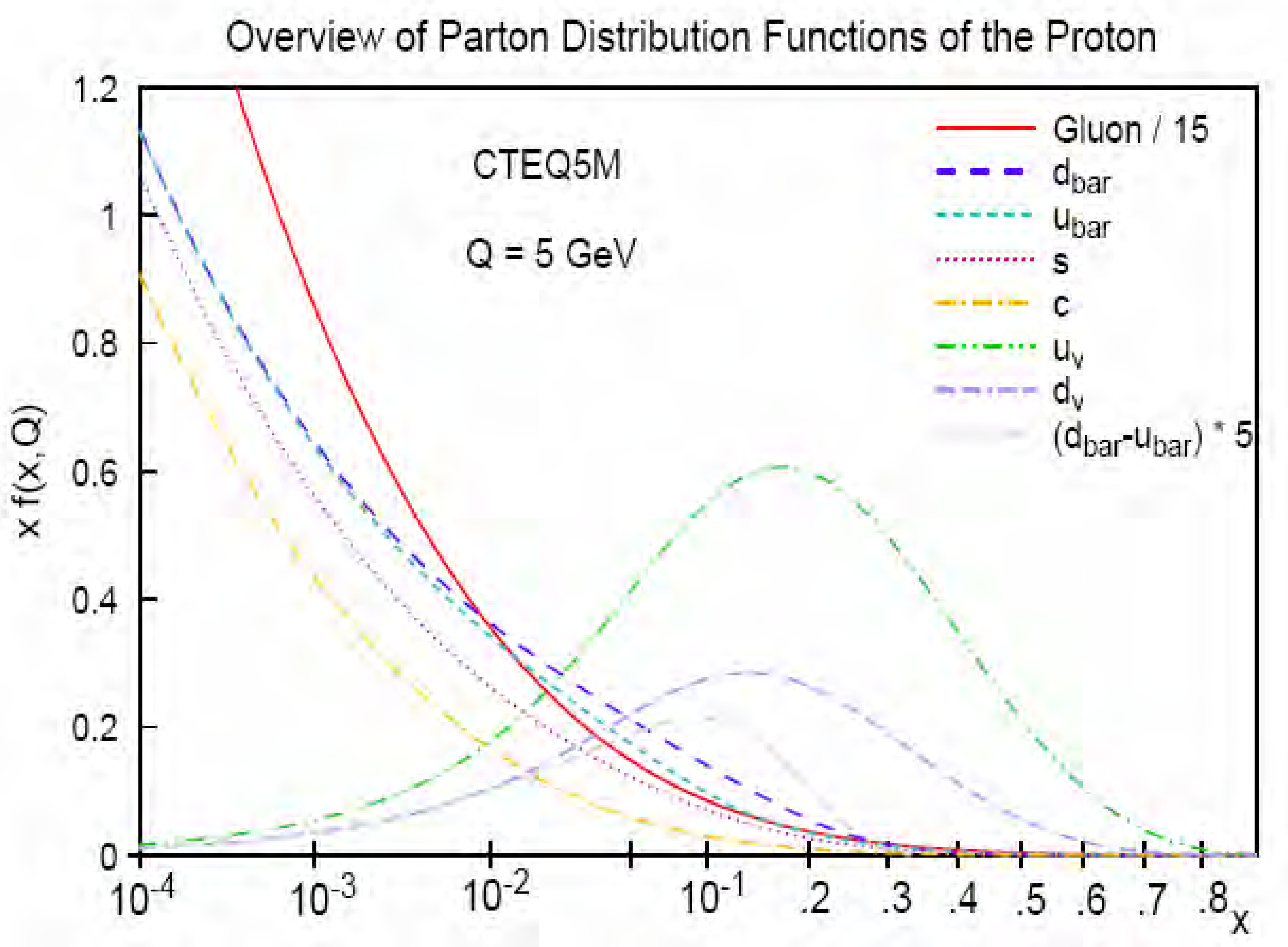
- **Leading order (LO)**
- **Next-to-leading order (NLO)**
- **K-factor correction K=σ(NLO)/σ(LO) ~ 1-1.5**

❑In presence of largely differing scales:

- **Leading Log (LL) resummations $(\ln(Q^2/\mu^2)\,\alpha_s(Q^2))^n$**
- **Next-to-Leading-Log (NLL) $\alpha_s(Q^2)\,(\ln(Q^2/\mu^2)\,\alpha_s(Q^2))^n$**

❑Parton shower calculations (see also Talk by T.Sjostrand)

2.2 Parton Distribution Functions



S. Catani, hep-ph/0005233

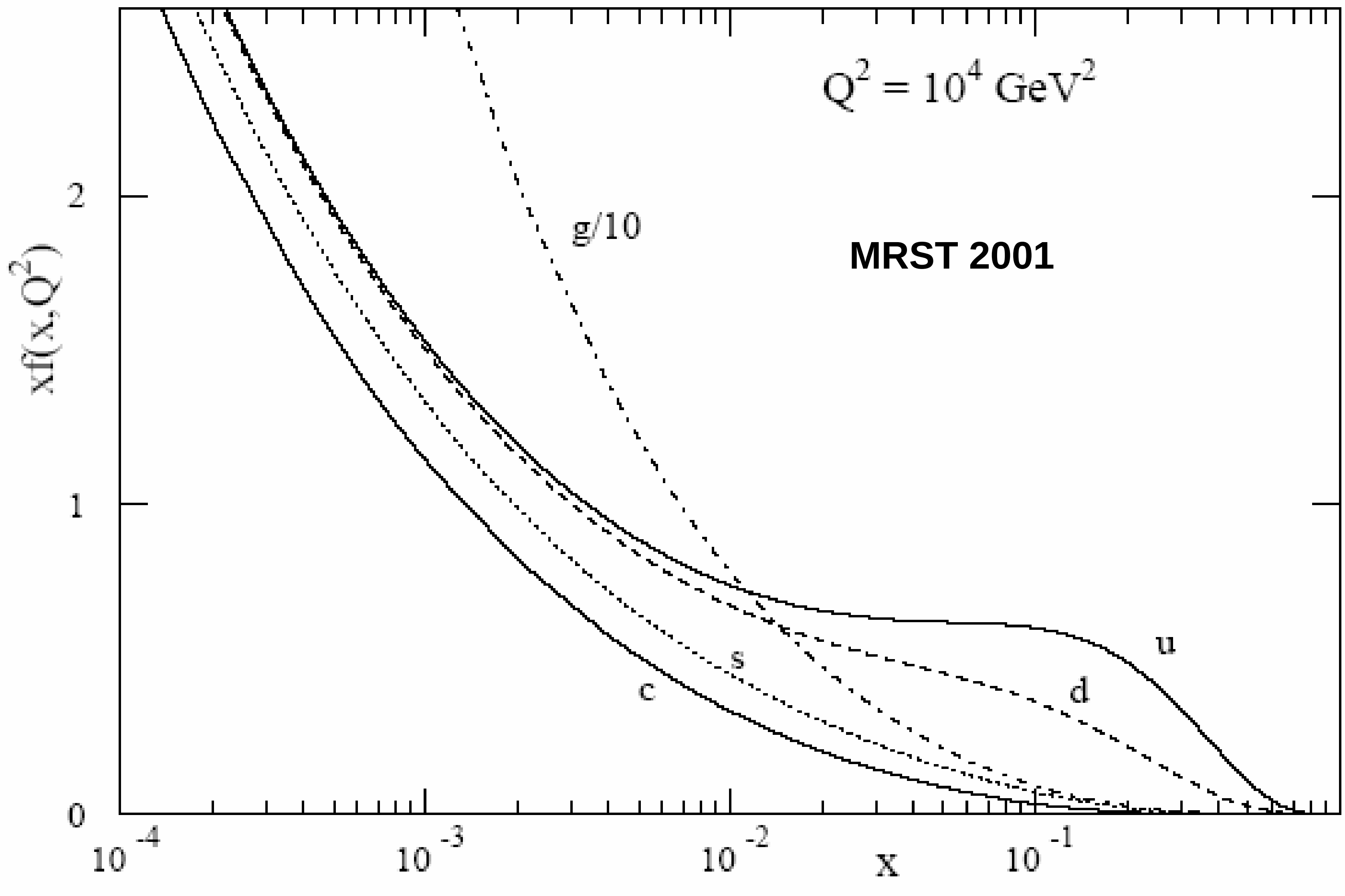
PDF Fits

- Main contenders: MRST and CTEQ (both use NLO)
  - MRST: hep-ph/0110015 (MRST 2001) → low Scale Q_0=1.0 GeV
  - CTEQ: hep-ph/0201195 (CTEQ6M) → low Scale Q_0=1.3 GeV
  - Disagreement on sensitivity to $\alpha_S(M_Z)$ [see hep-ph/0512167]

    MRST: $\alpha_S(M^2_Z) = 0.119 \pm 0.002$ (expt.) ± 0.003 (theory).
- Input D.I.S. + Tevatron jets + Fixed target + …
- Constraints
  - $f \geq 0$ (problematic as distributions evolve to lower Q^2)
  - Momentum sum rule
- Parton distributions parameterized at one scale Q_0 and evolved with DGLAP

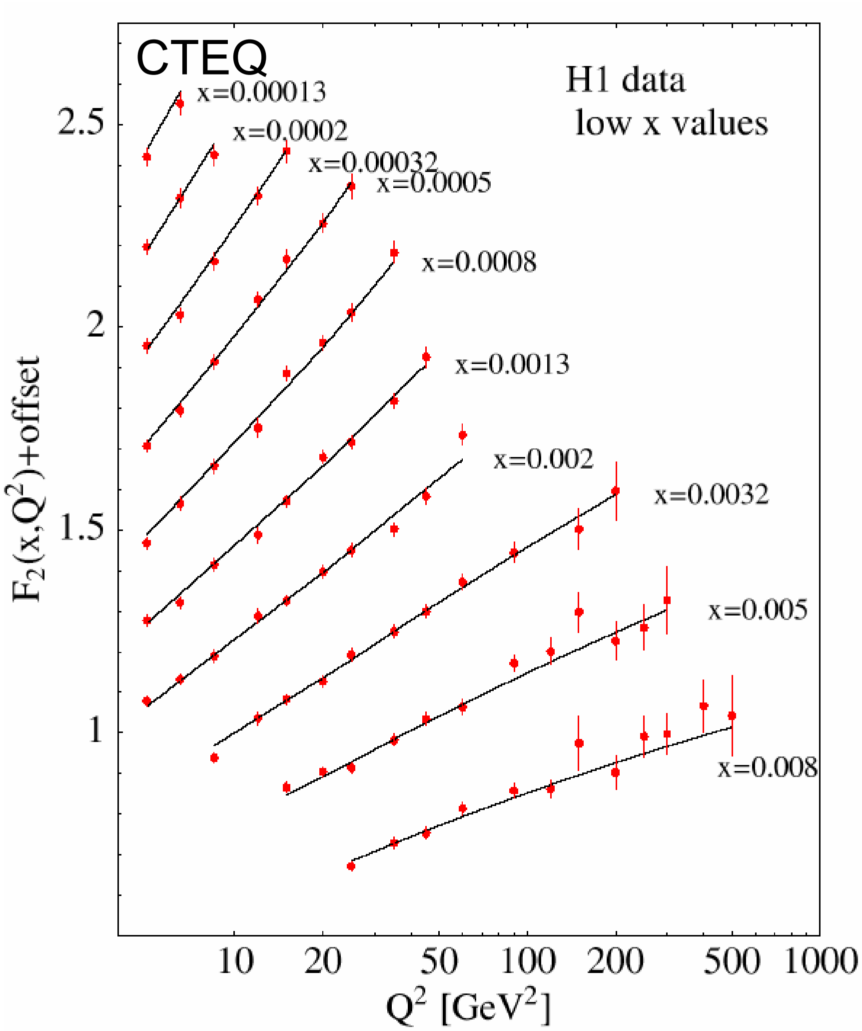
$$\frac{d\, f_a(x,\mu^2)}{d\ln\mu^2} = \sum_b \int_x^1 \frac{dz}{z} P_{ab}(\alpha_S(\mu^2), z)\, f_a(x/z, \mu^2)$$

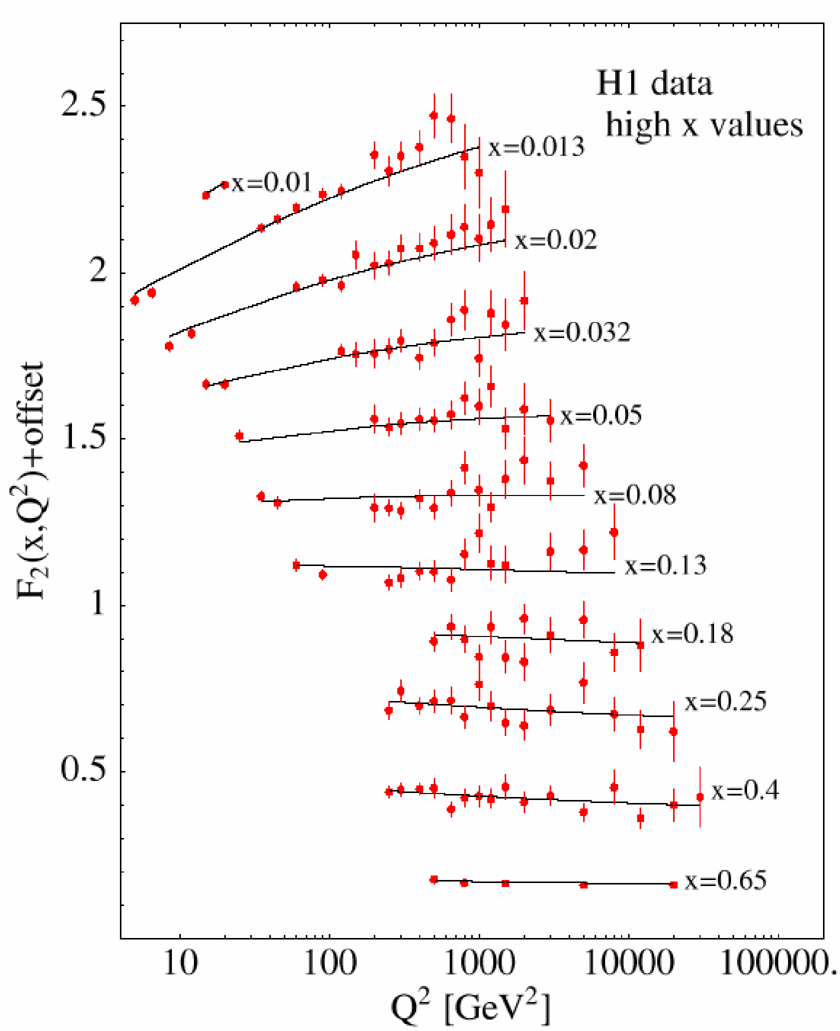
P_{ab}: Altarelli-Paresi splitting functions computable in pQCD



$Q^2 = 10^4$ GeV^2
MRST 2001
g/10
u
d
s
c
$xf(x,Q^2)$
x
0
1
2
10^{-4}
10^{-3}
10^{-2}
10^{-1}

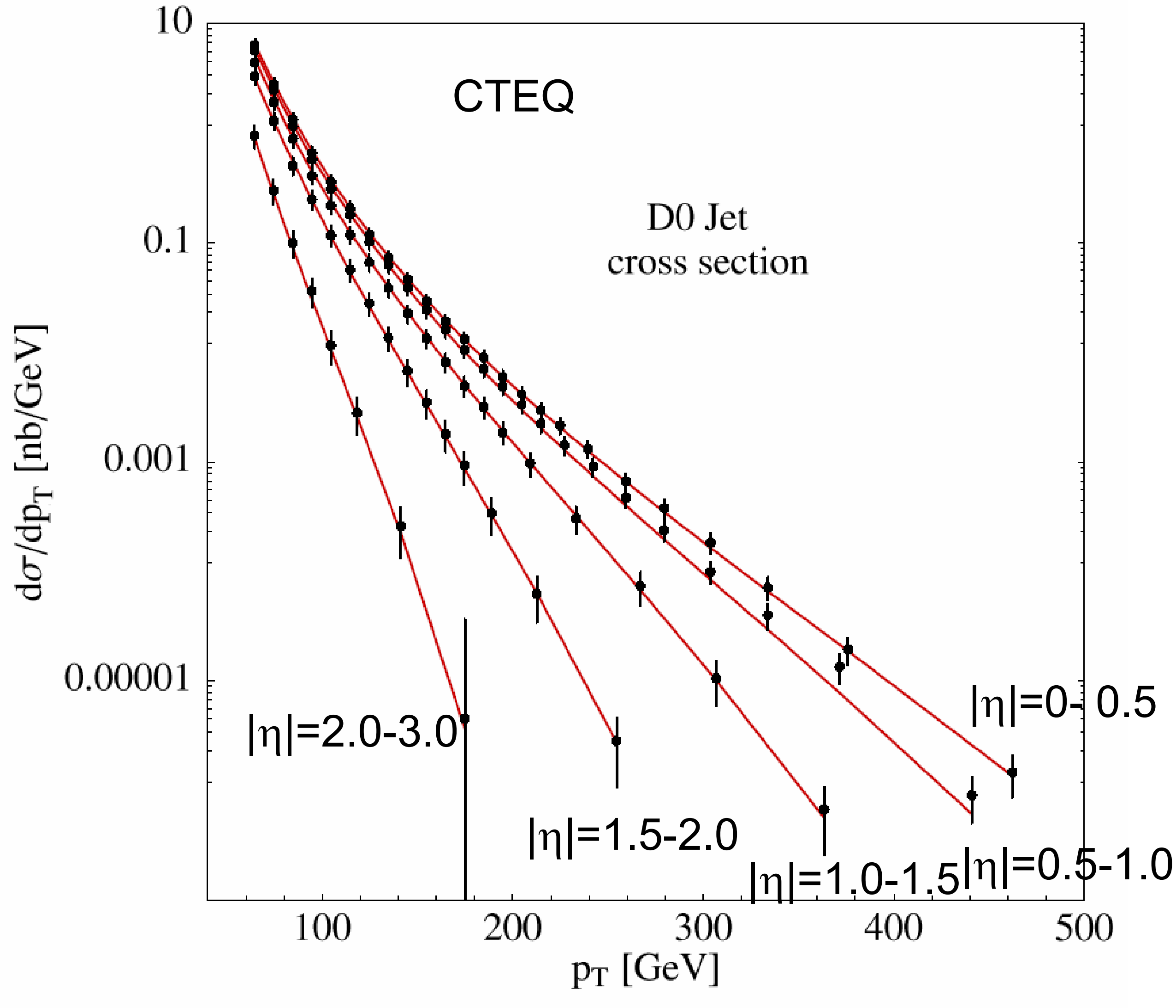
CTEQ Fit to H1 Data



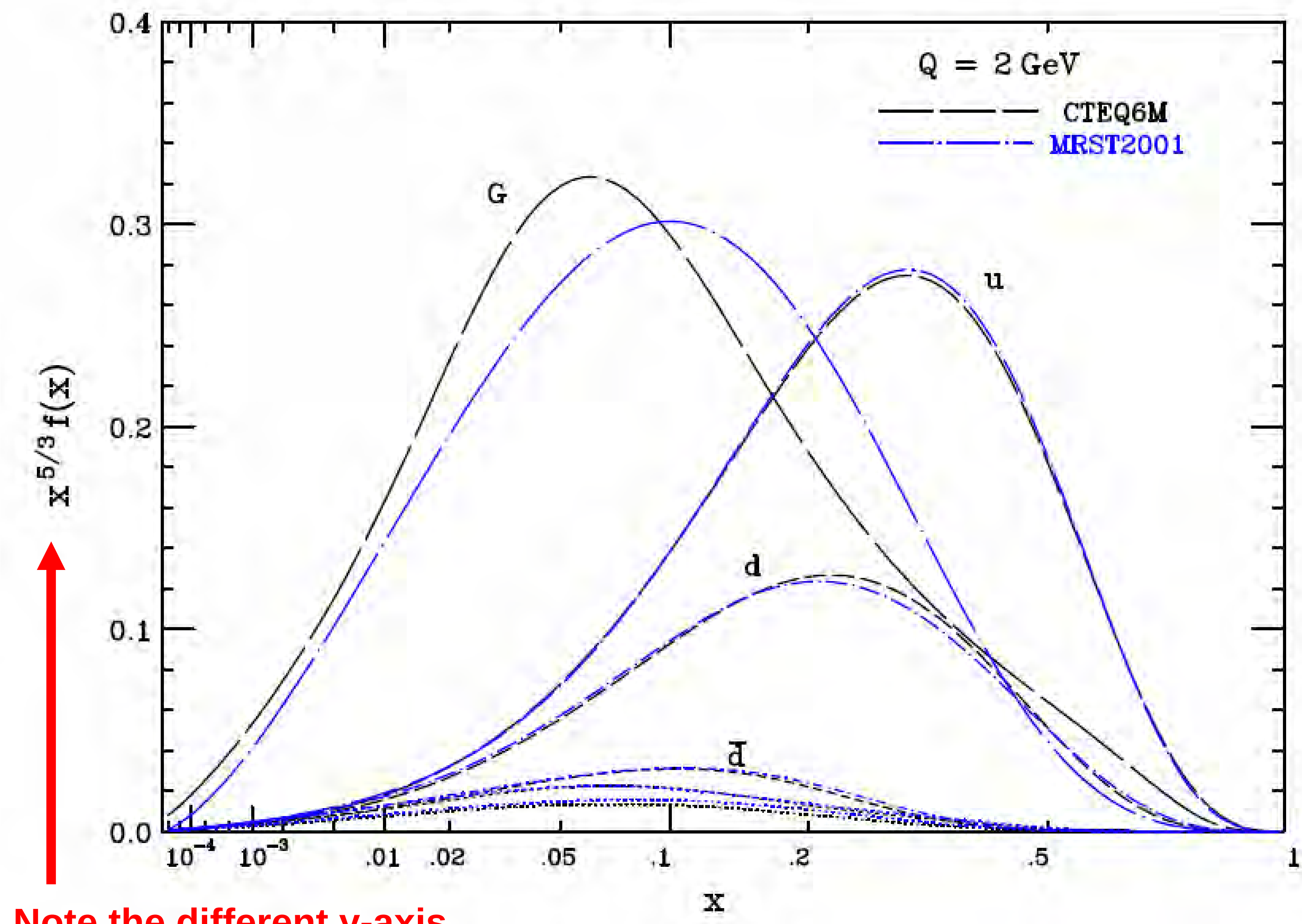


Fitted at Q^2 = 100 GeV^2 and extrapolated with DGLAP

Fit to D0 jet cross section

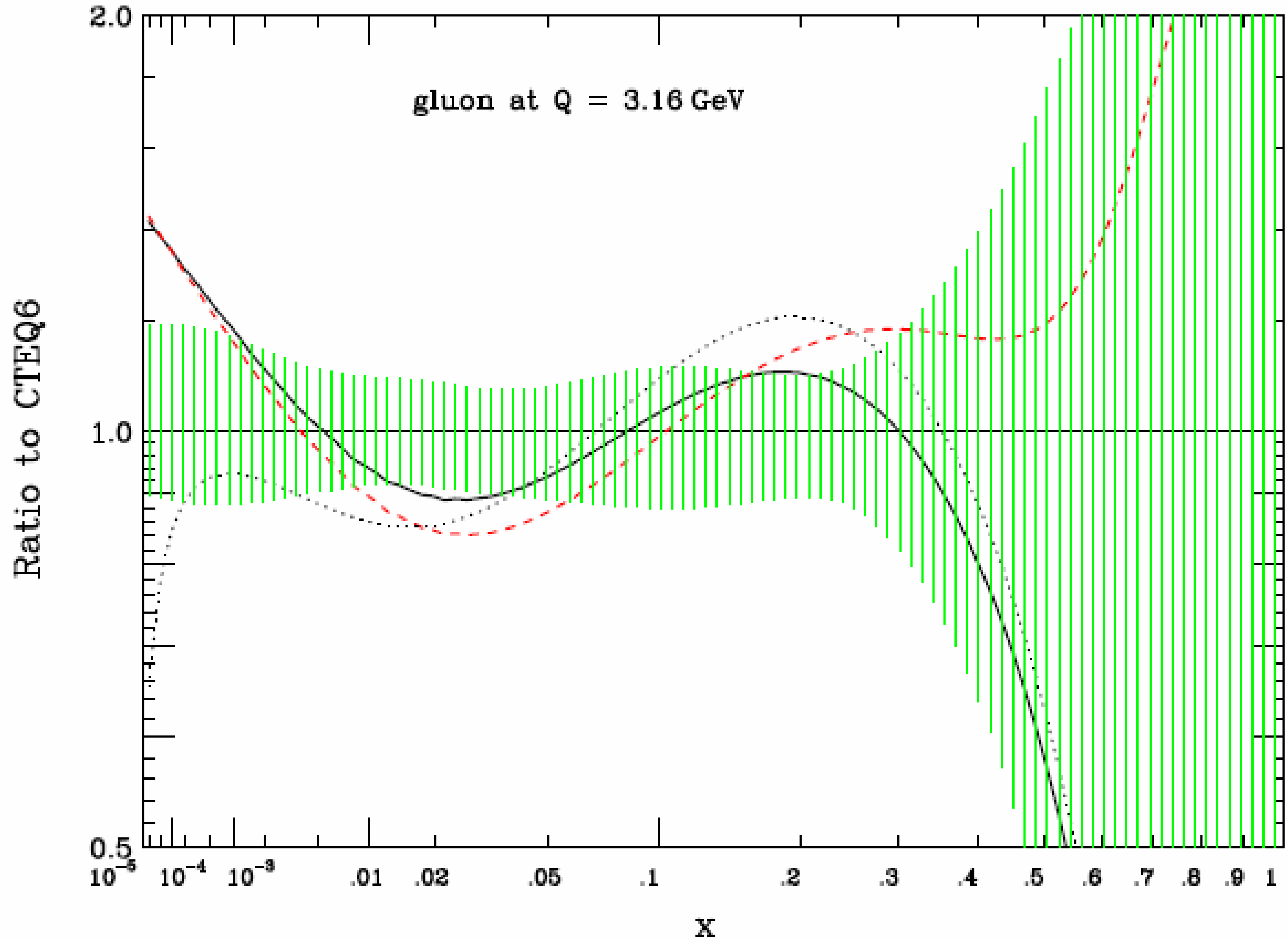


Comparison CTEQ / MRST

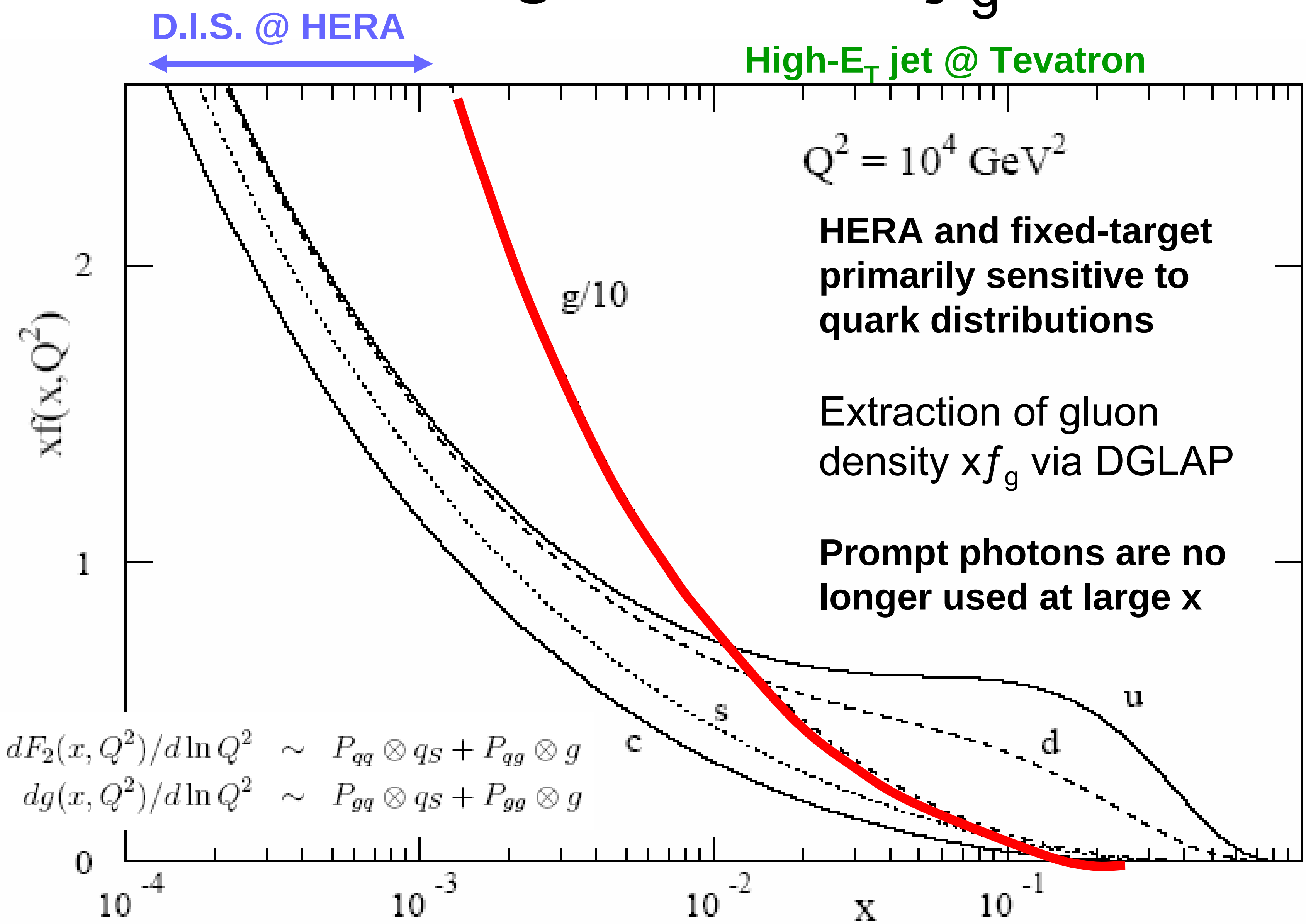


Note the different y-axis

PDF Uncertainties



The gluon PDF f_g



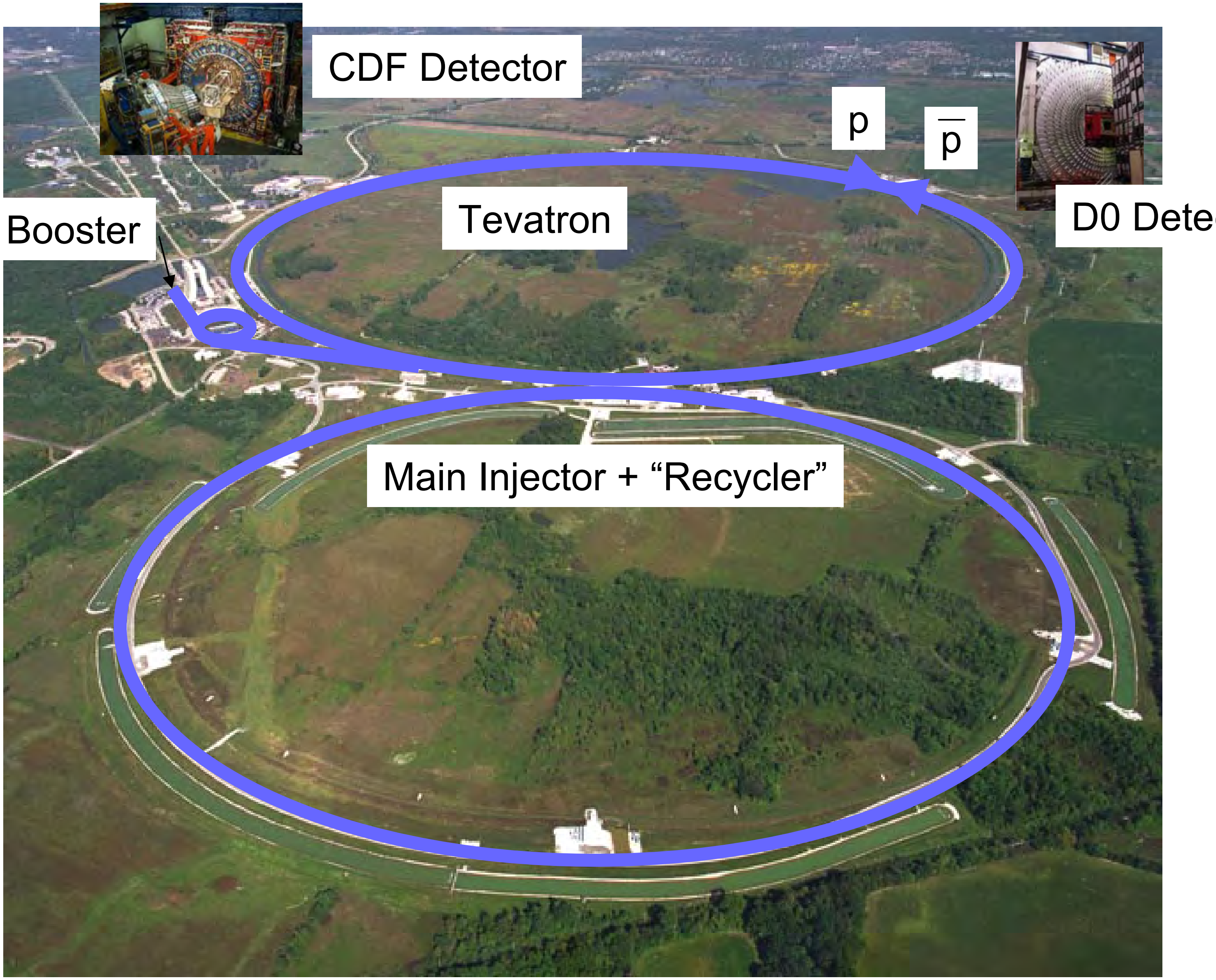
HERA and fixed-target primarily sensitive to quark distributions

Extraction of gluon density xf_g via DGLAP

Prompt photons are no longer used at large x

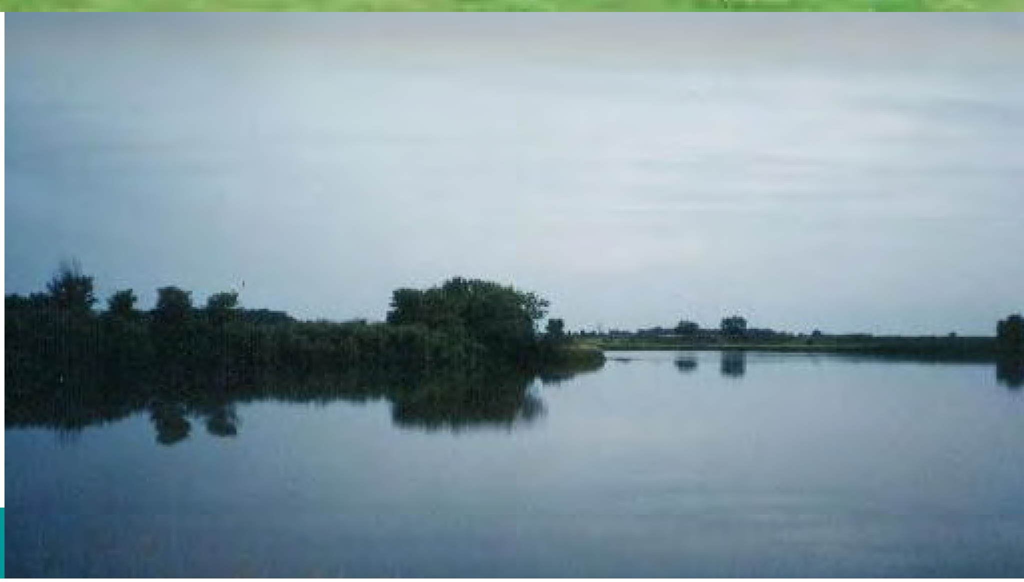
$$dF_2(x,Q^2)/d\ln Q^2 \sim P_{qq} \otimes q_S + P_{qg} \otimes g$$
$$dg(x,Q^2)/d\ln Q^2 \sim P_{gq} \otimes q_S + P_{gg} \otimes g$$

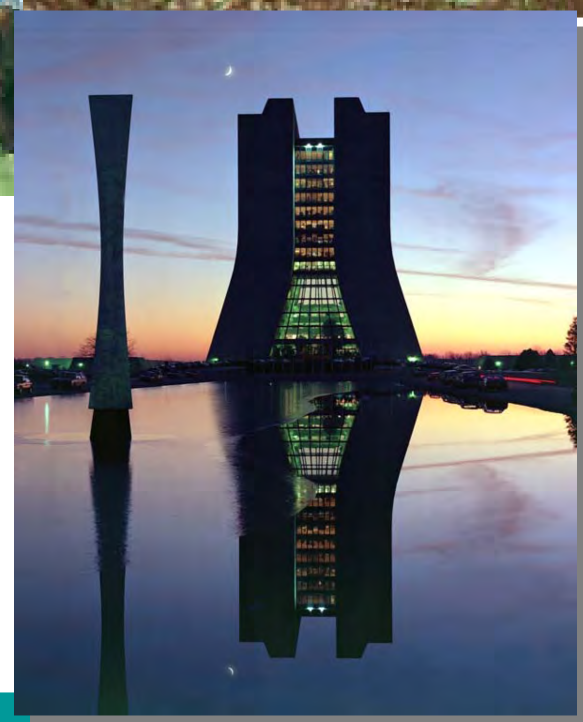
QCD@Tevatron



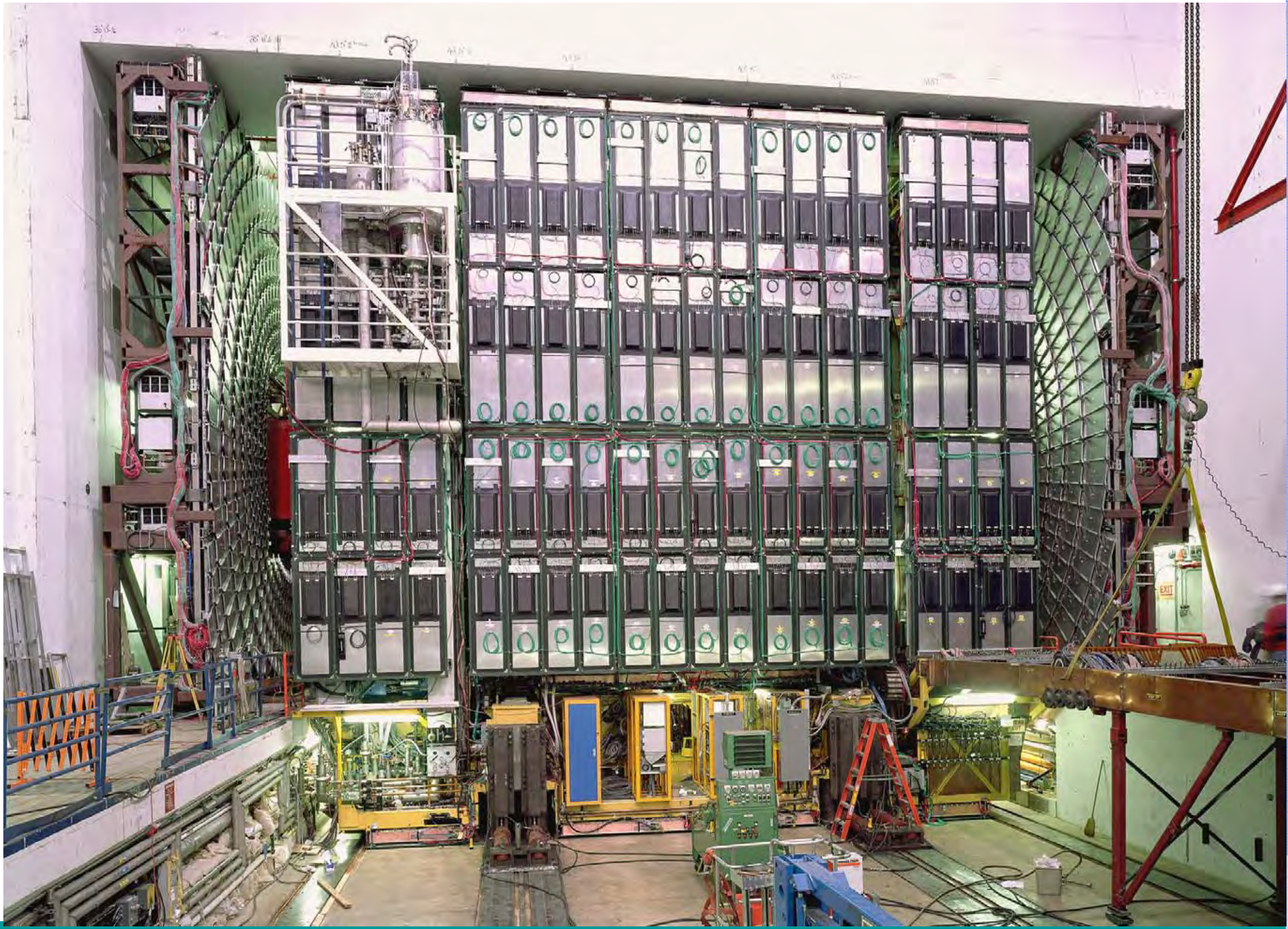
München
Feb. 2006

Fermilab

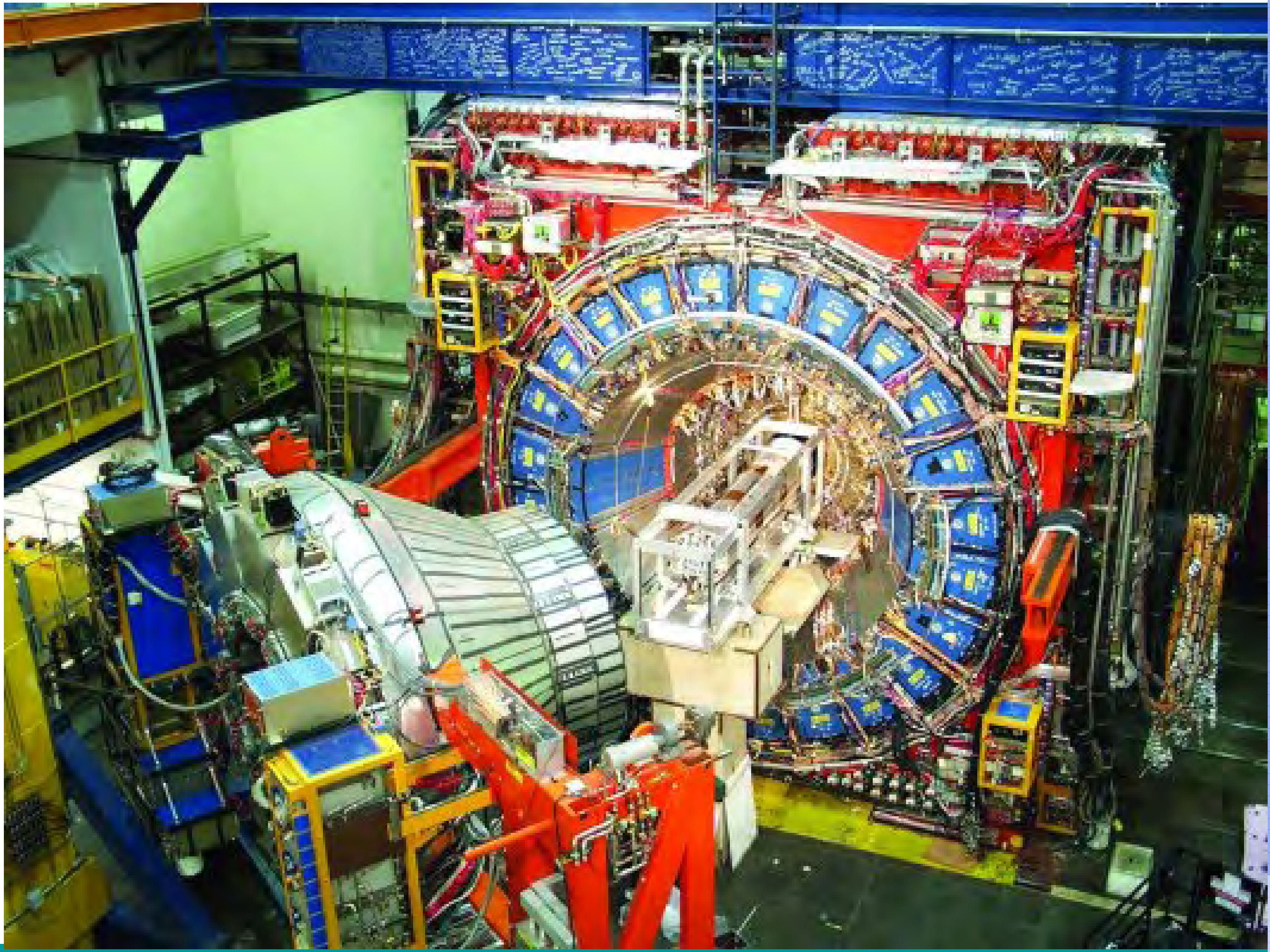




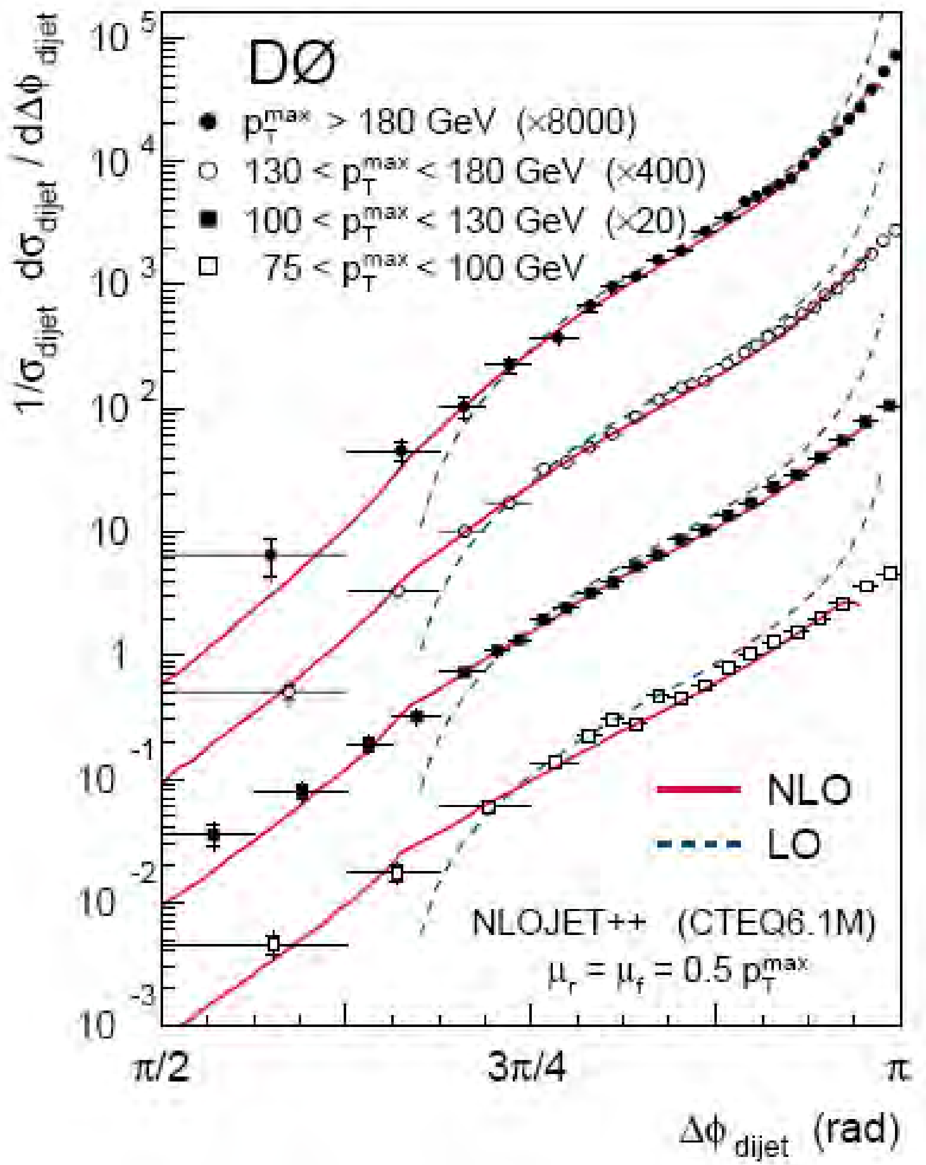
DØ Detector



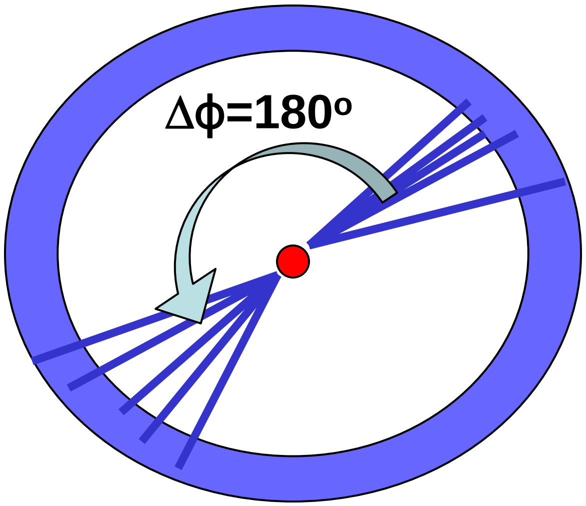
CDF Detector



Azimuthal Angle Correlations



Transverse Plane



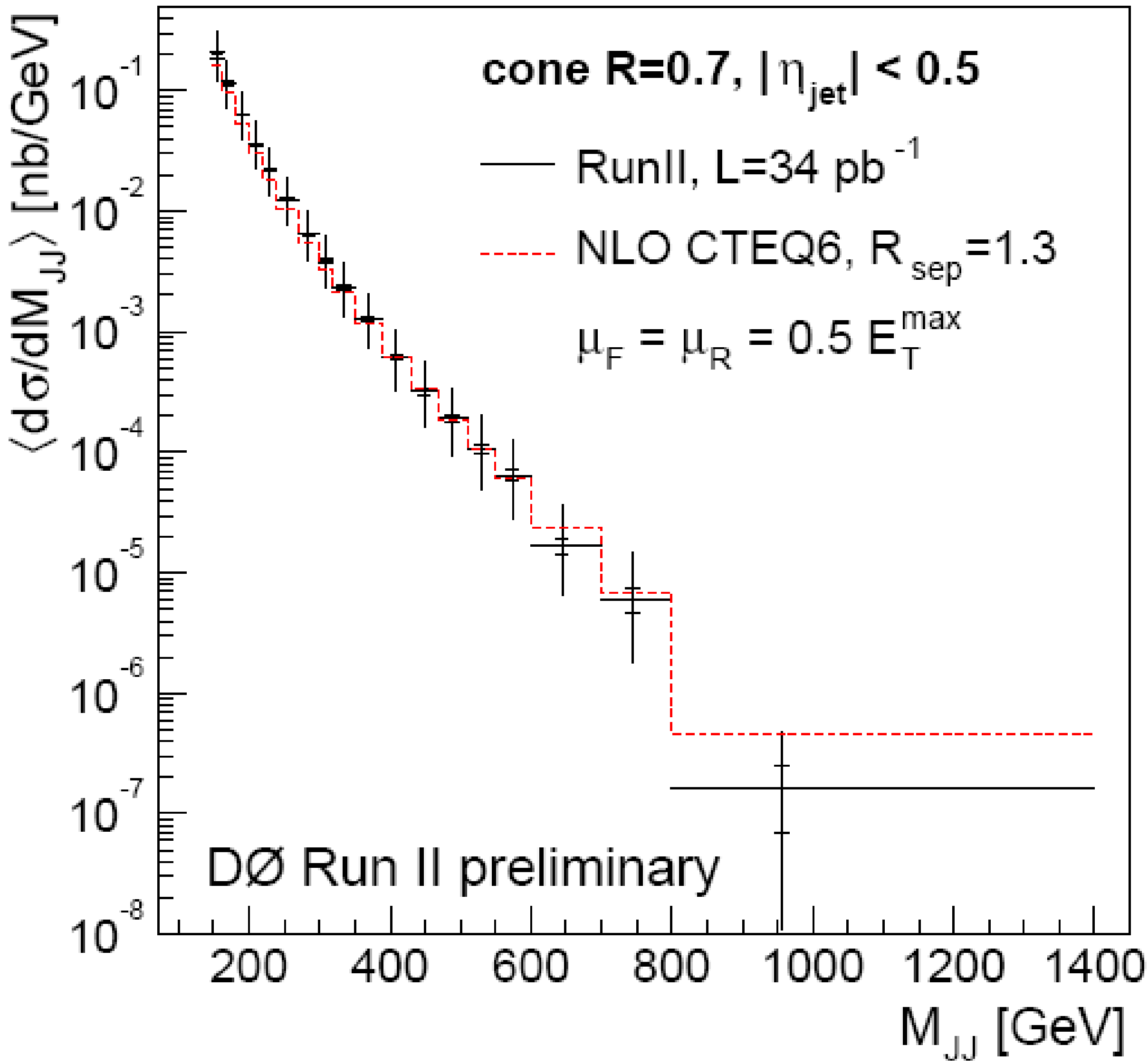
Ideal 2-jet event

$$\hat{s} = M_{jj}^2 = s x_1 x_2$$

$$P_{z(2-jet)} = P_{beam}(x_1 - x_2)$$

More jets (ISR, FSR):
Δϕ between highest p_T-jets deviates from 180°

Dijet Mass



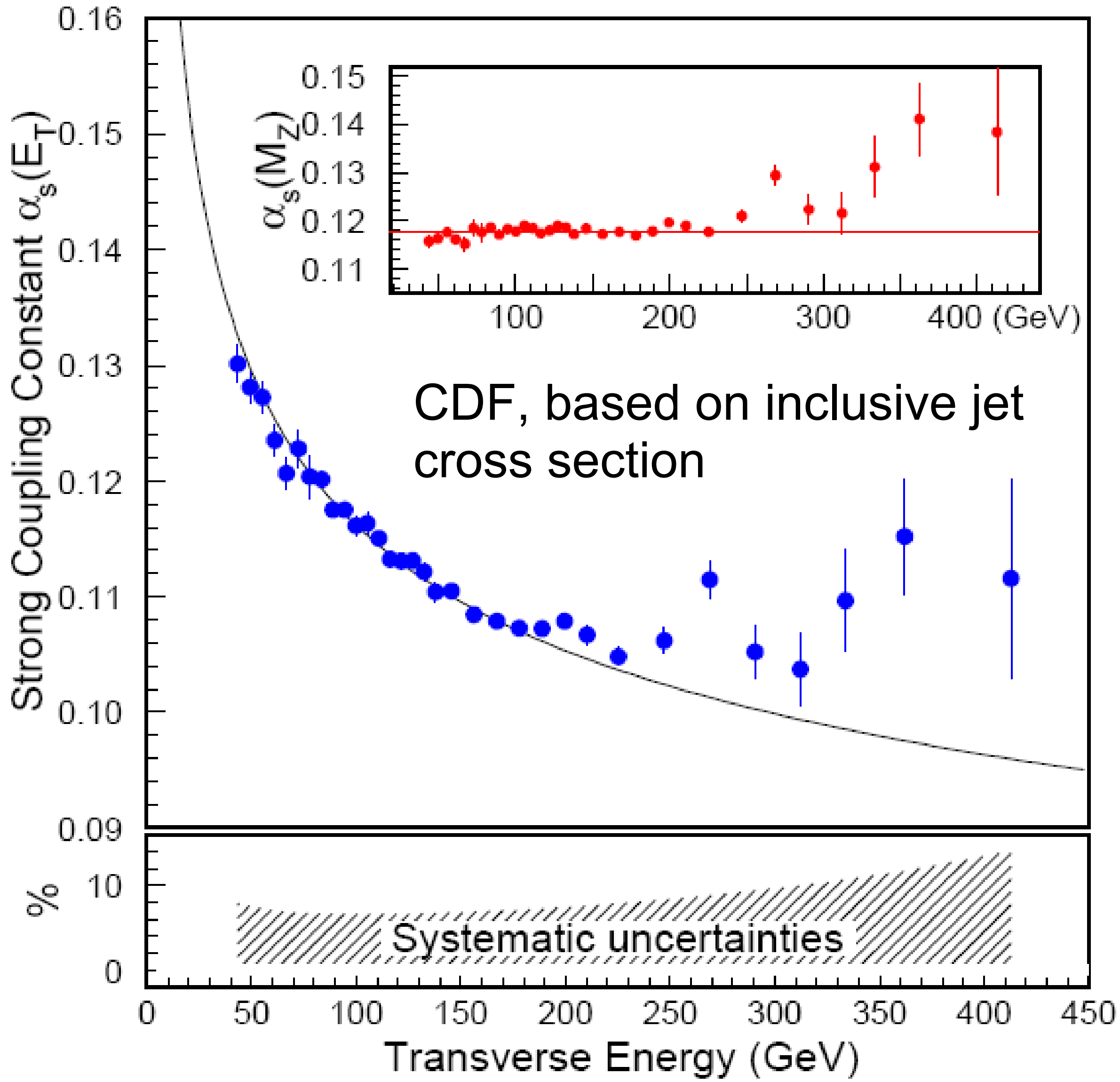
M_{jj} of two highest-pT jets (true mass)

Seeded cone algorithm with midpoint

$E_{T\text{-}mis}/P_{t\text{-}jet}<0.7$

E_{cm} = 1.96 TeV

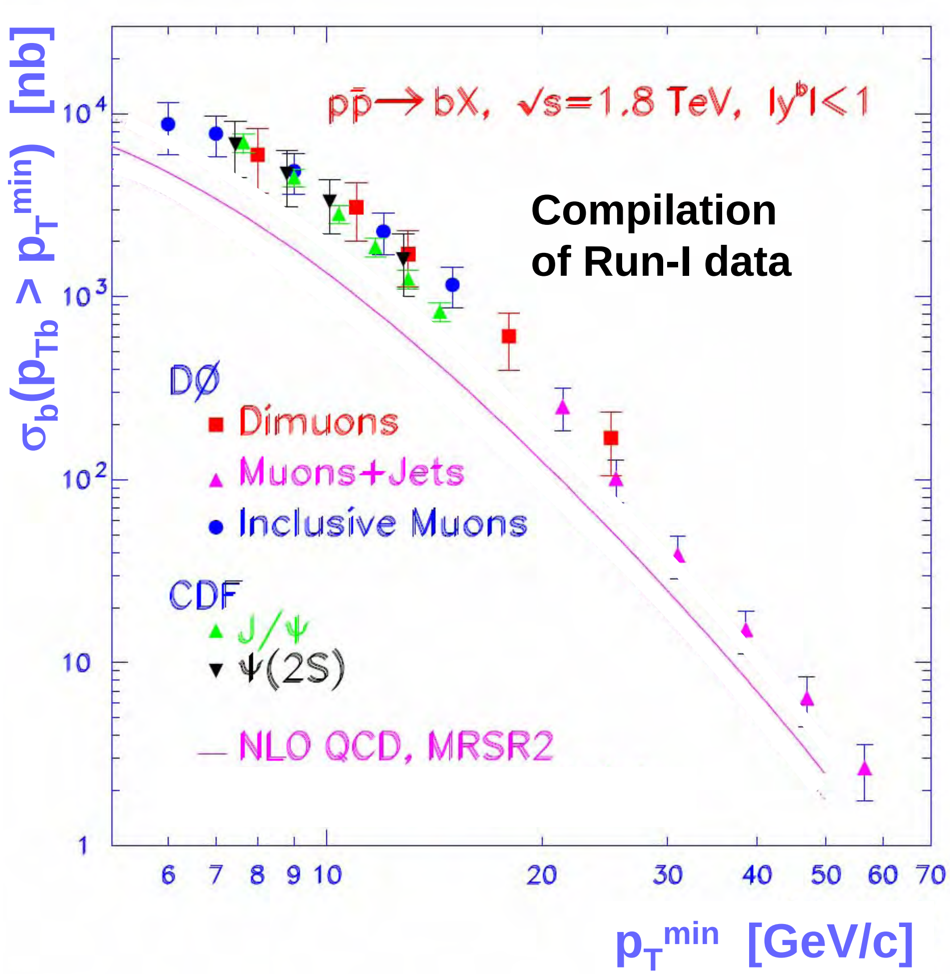
Evolution of $\alpha_s(Q^2)$ at high Energy



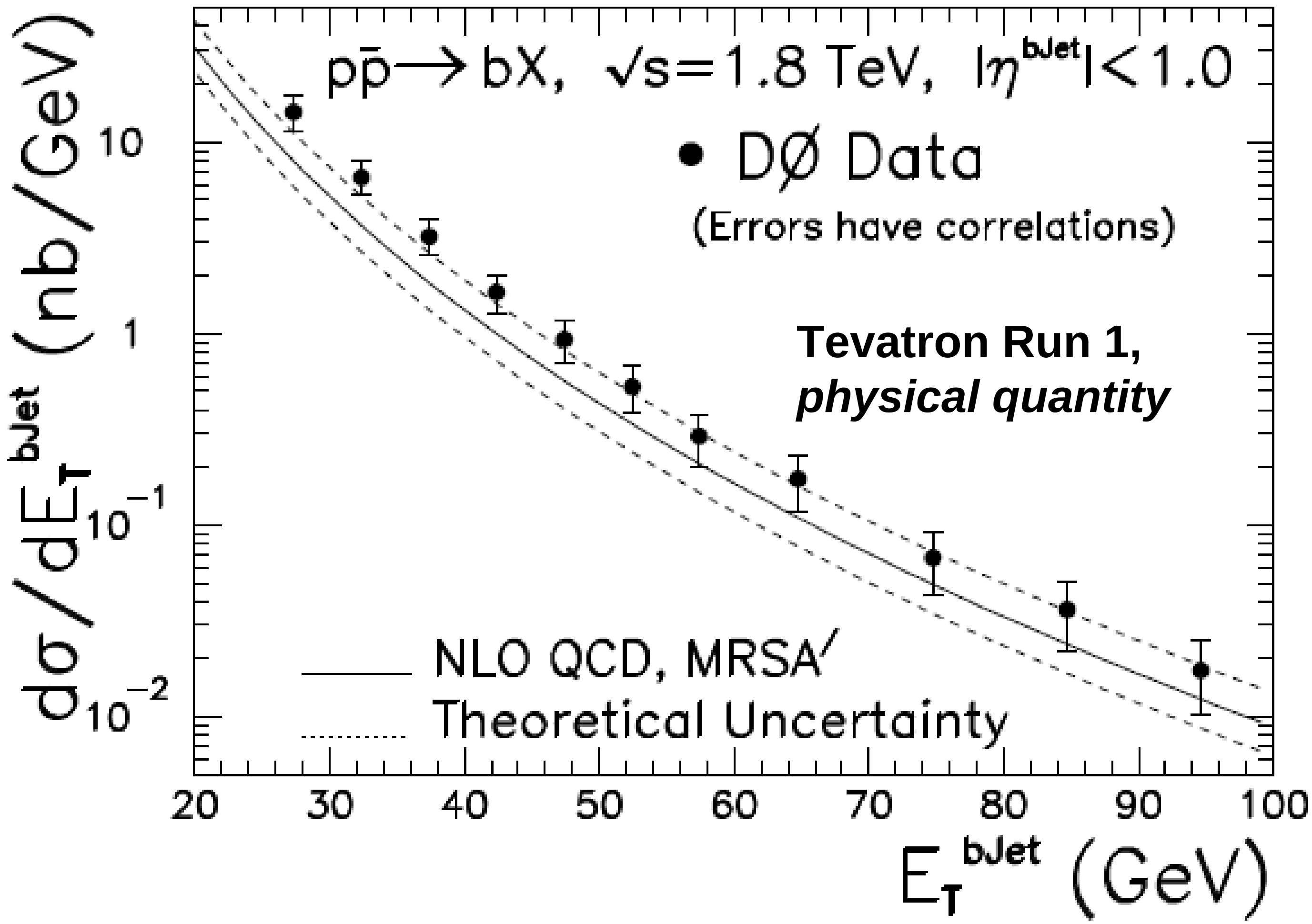
σ_{bb} @ Tevatron

- What happened to the Tevatron bb-excess?
  (for a nice review see M.Cacciari, hep-ph/0407187)
- Even light b-**s**quarks were postulated to explain excess
- Excess was also “seen” in two-photon evts and at HERA

However…
- Theory uncertainties were not always taken into account
- Older Tevatron analyses compared σ vs pT(b-quark)
  - deconvolution is problematic if σ steeply falls off
- Newer analyses use physical quantities: E(b-jet), pT(B-Hadron), pT(J/Ψ)
- True error assignments to extrapolation in unmeasured regions (low p_T, far forward region)



σ_{bb} @ Tevatron



München
Feb. 2006

σ_{bb} @ Tevatron

Run-II Data,physical quantity pT(J/ψ),

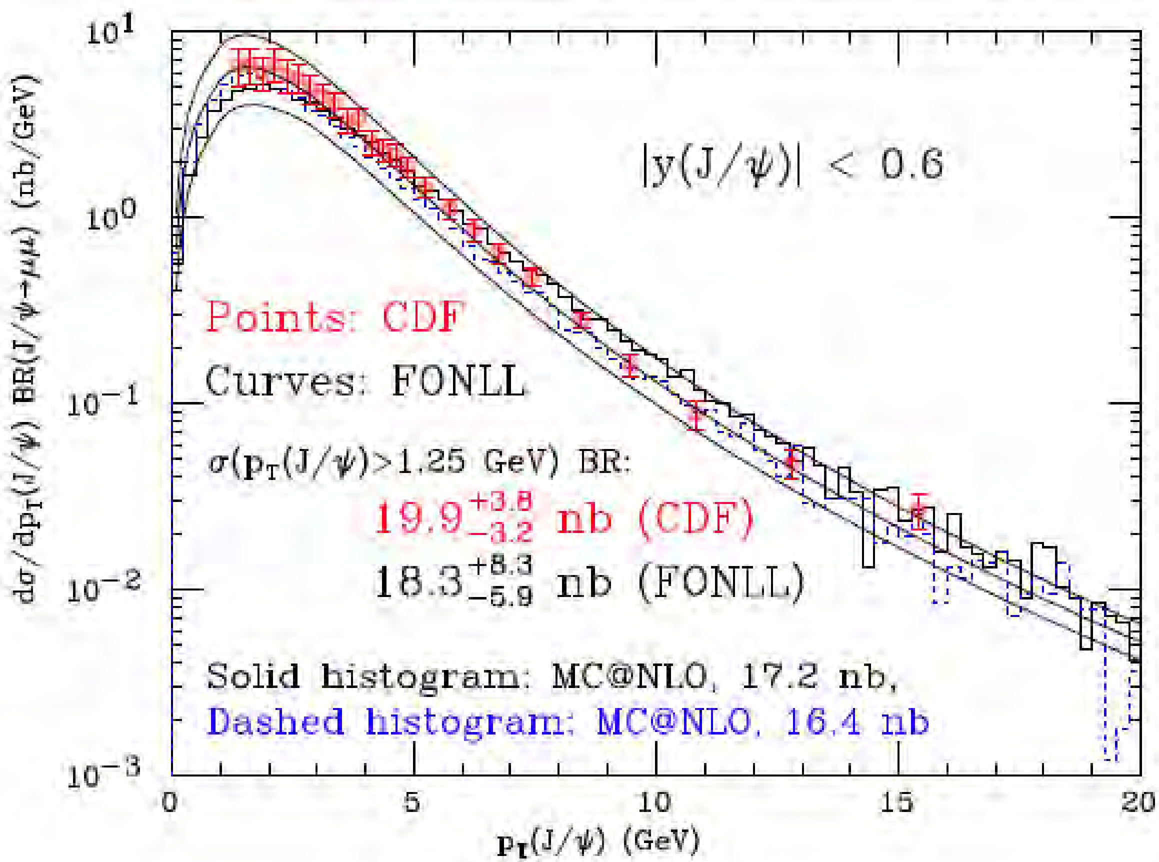
low need for extrapolation into unmeasured region (cross section truncated in pT and y)

Improved calculations with reduced theory errors

Updated b-fragmentation functions from LEP

Good agreement between Data and Theory

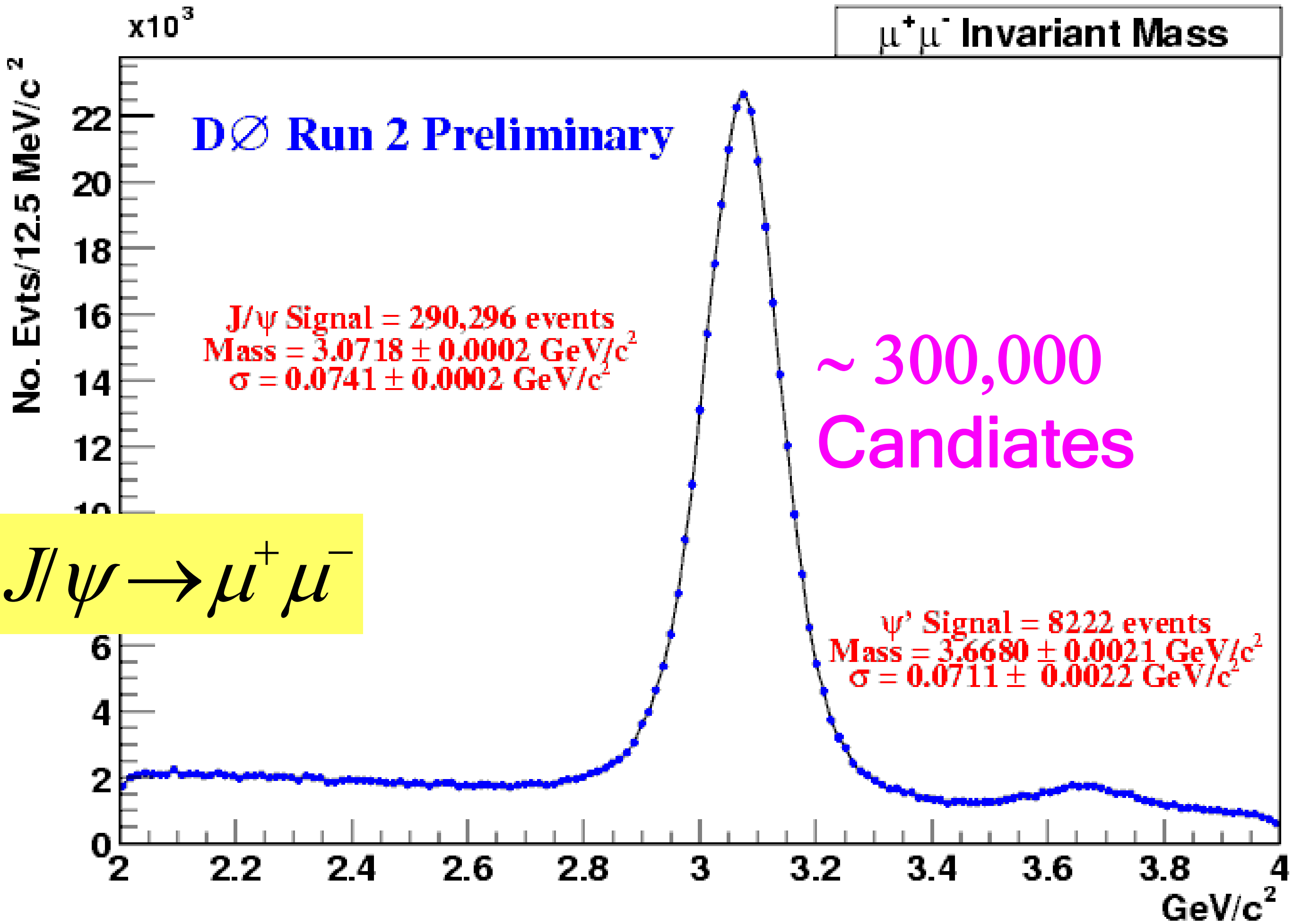
Exp. Data went up a little, but are in agreement with older data



FONLL= Fixed Order NLO calc. with massive quarks plus matching to NLL resummation

M. Cacciari, M.Greco, P.Nason hep-ph/9803400

$$J/\psi \rightarrow \mu^+\mu^-$$



~ 300,000 Candiates

$$J/\psi \rightarrow \mu^+\mu^-$$

2.4 QCD @ LEP

- LEP-I ~4 Million hadronic evts per experiment (200 pb^{-1}) on and around Z-resonance
- LEP-II ~800 pb^{-1} between 130 – 209 GeV E_{cm}
- Well-defined initial state
  - precision measurements of α_S
  - tuning of Fragmentation models

Jet Rates

Durham jetfinding scheme

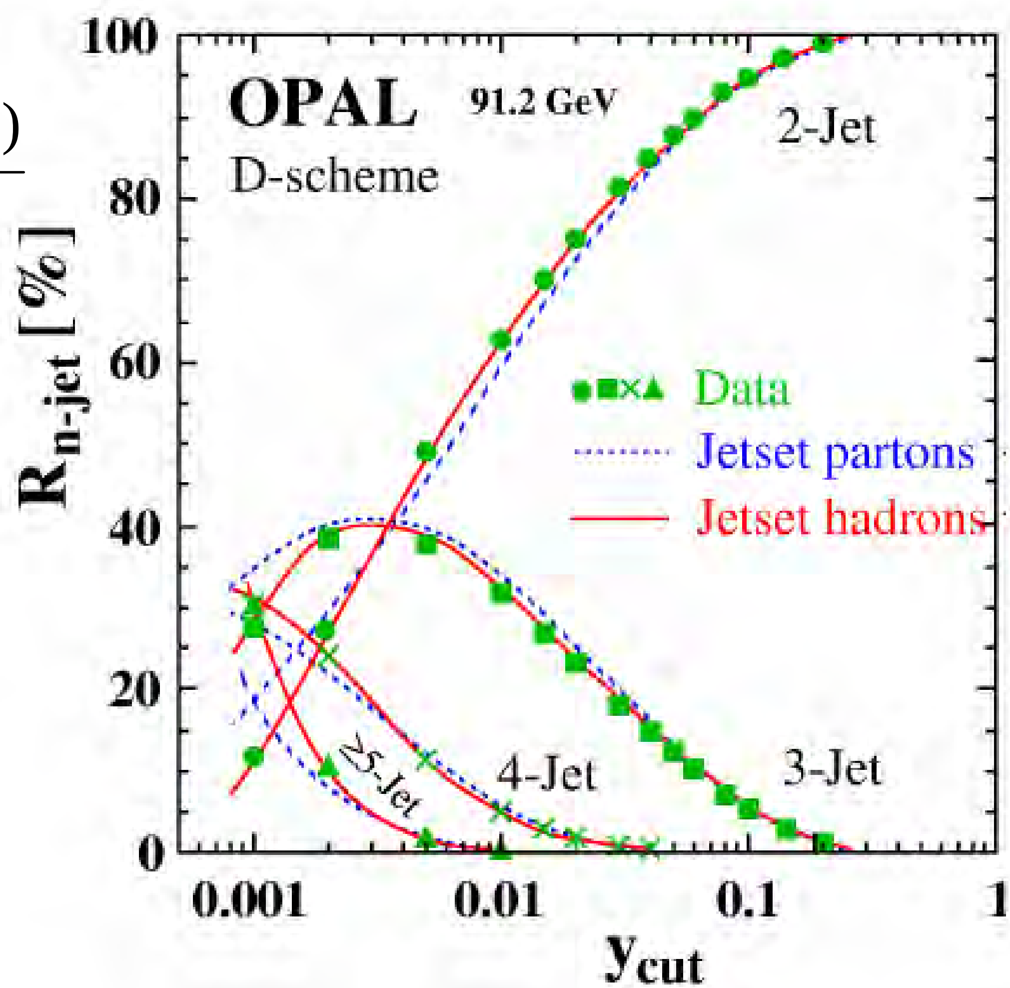
Jet-jet separation measure

$$y_{ij} = \frac{2\min(E_i^2, E_j^2)(1-\cos\theta_{ij})}{E_{vis.}^2}$$

Jet resolution parameter y_{cut}

Jet algorithm:
Iterative procedure until all jet-jet distances are above ycut

Only small dependence on hadronisation

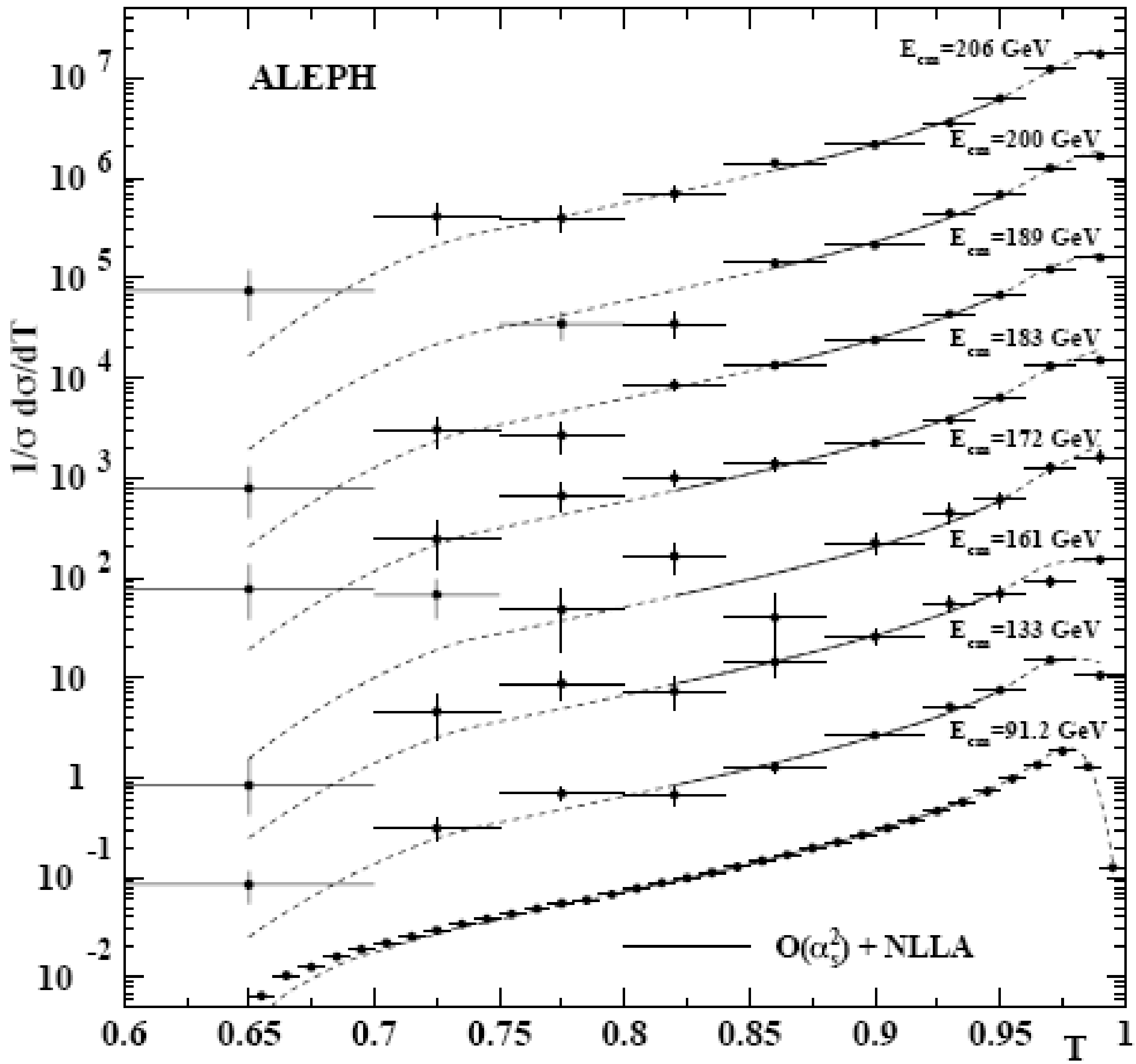


Event Shape Variable Thrust

Thrust T

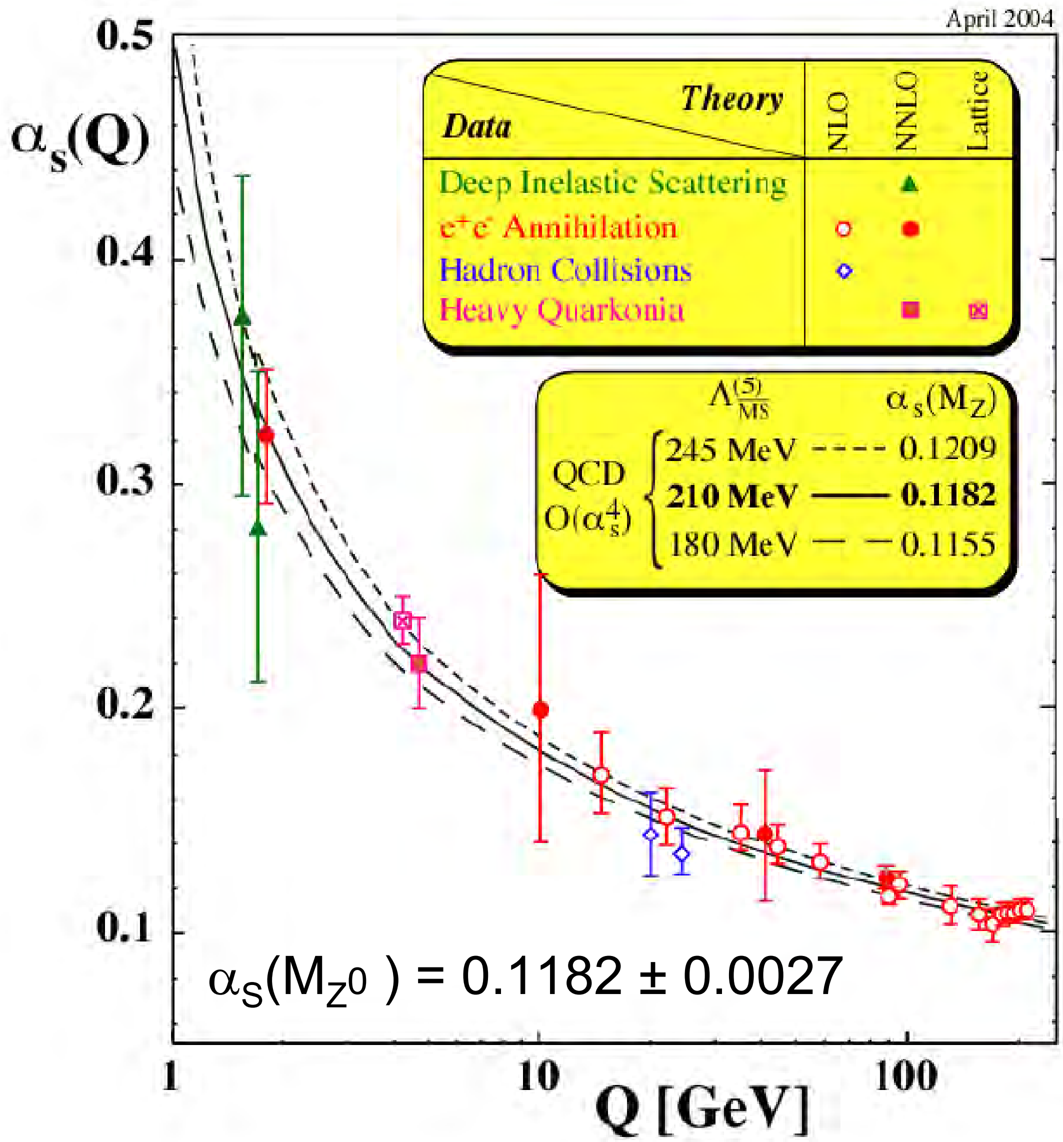
$$T = \max_{\vec{n}} \left(\frac{\sum_i |\vec{p}_i \bullet \vec{n}|}{\sum_i |\vec{p}_i|} \right)$$

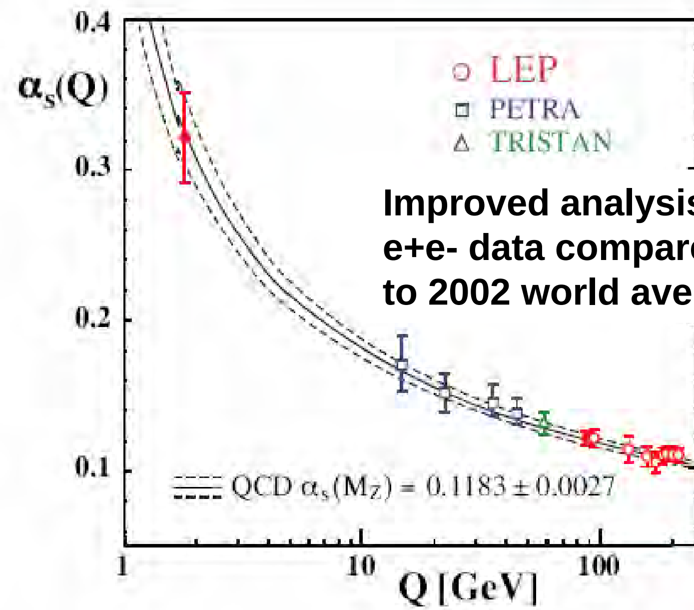
Collimated evt: T~1
Isotropic evt: T~1/2



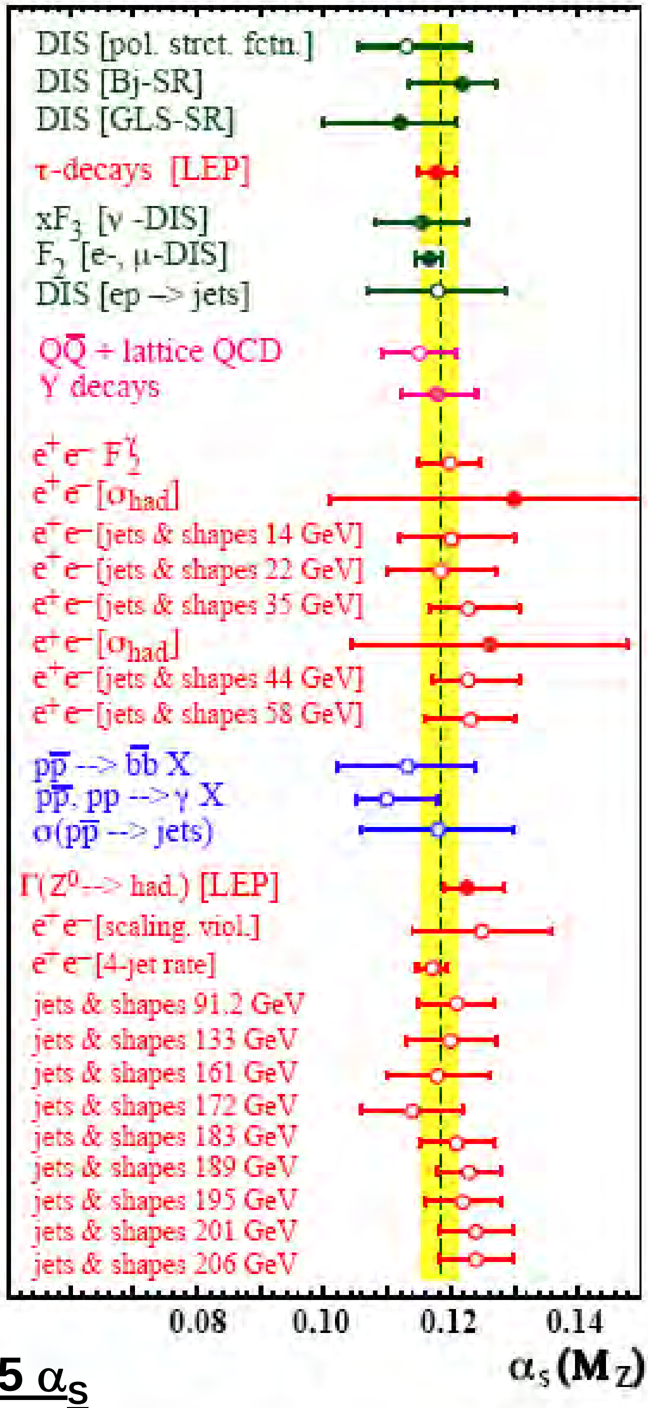
2.5 $\alpha_S (Q^2)$

S.Bethke,
hep-ex/0407021
+ hep-ex/0406058





Improved analysis old e+e- data compared to 2002 world average



- Rule of Thumb:

  accuracy inverse prop. to N_{had} in initial state

- α_s in τ-decays: from differential cross sections $\tau \rightarrow$ hadrons using identified final states

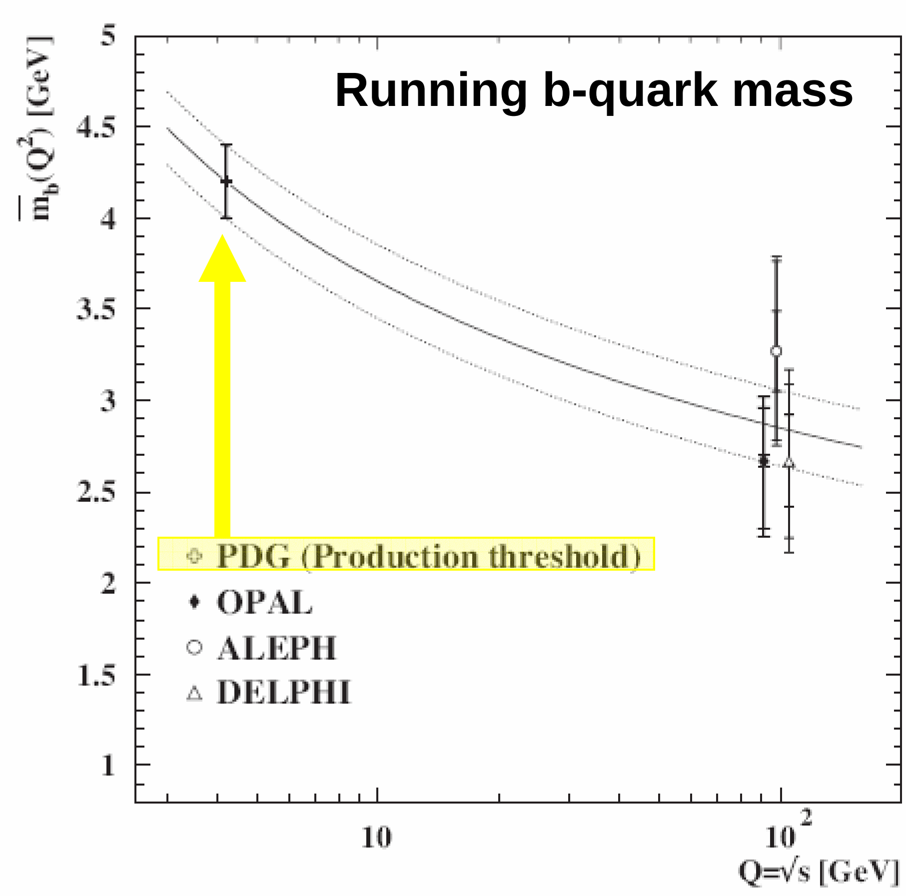
2.5 α_s

Flavor-independence of α_S

- α_S measurements for different flavors in agreement

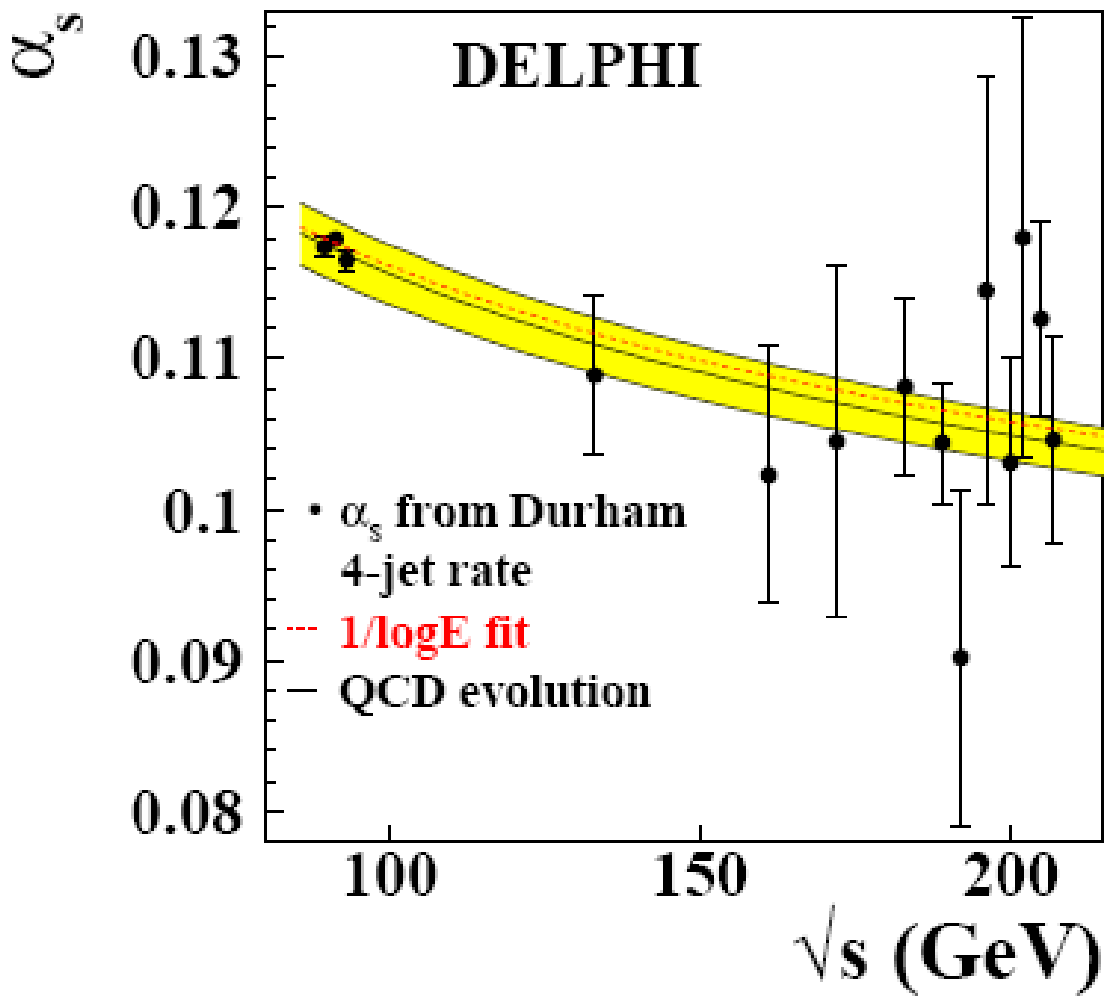
  (for b-quarks -- after taking heavy b-mass into account)
- Assuming flavor independence

  → b-mass meas.



$m_b(M_{Z^0}) = (2.82 \pm 0.02$ (stat.) ± 0.37 (sys.)$)$ GeV

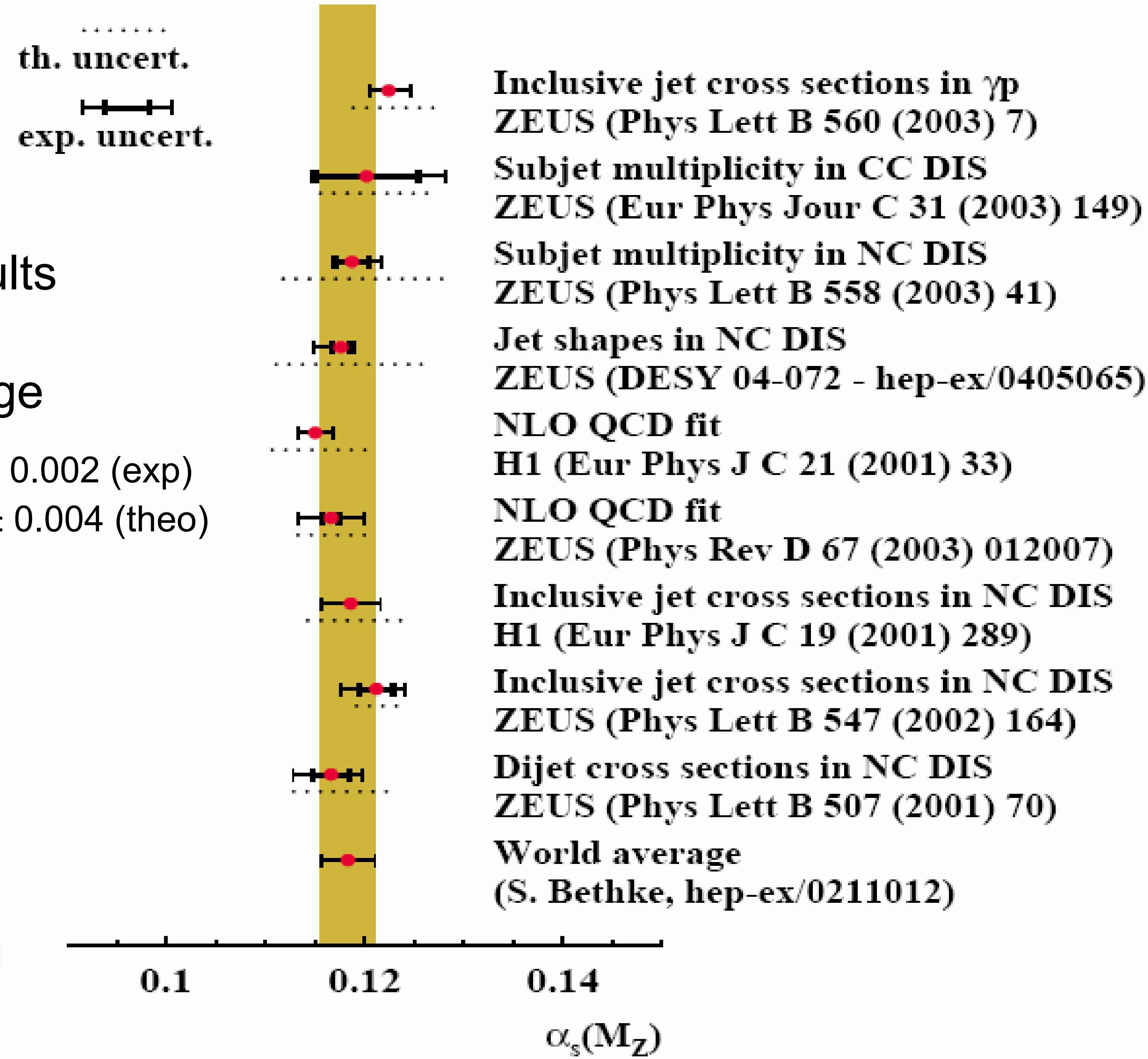
α_S at higher energies



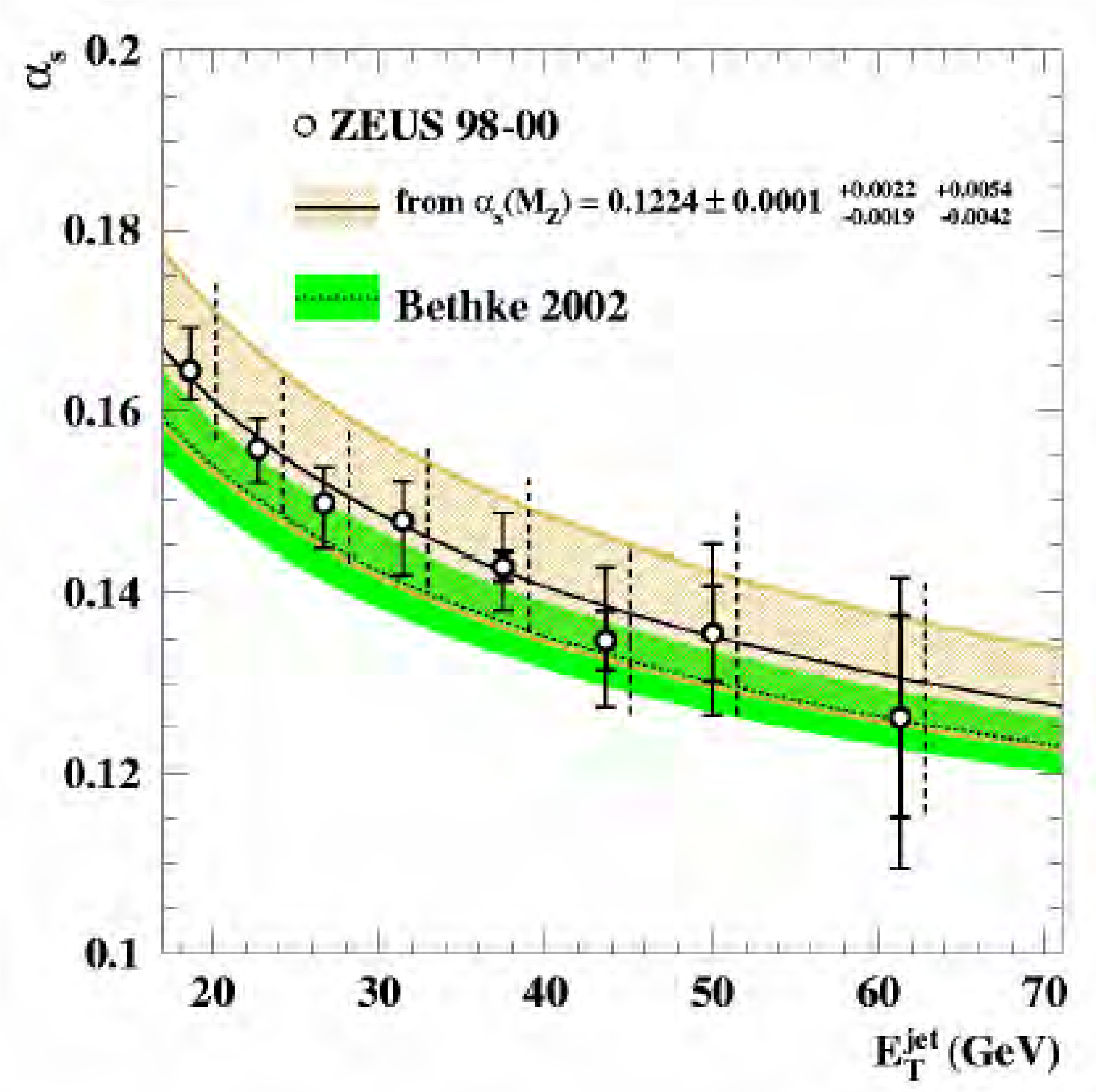
HERA α_S results

HERA average

$\alpha_S = 0.120 \pm 0.002$ (exp) ± 0.004 (theo)



Butterworth
hep-ph/0408061



jet transverse energy

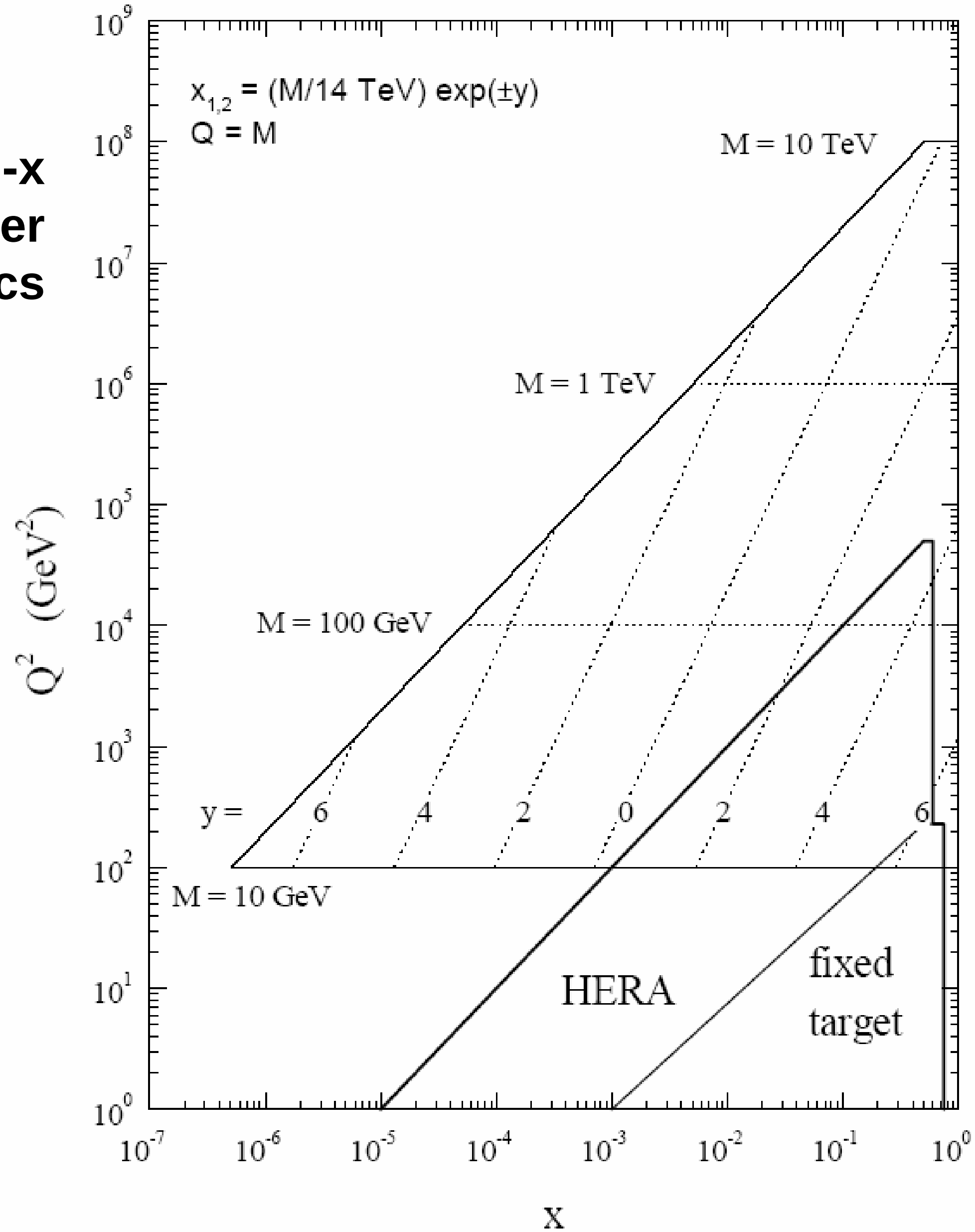
α_S values based on NLO QCD calculations

ZEUS Collaboration,
Phys. Lett. **B560** 7 (2003)
[hep-ex/0212064]

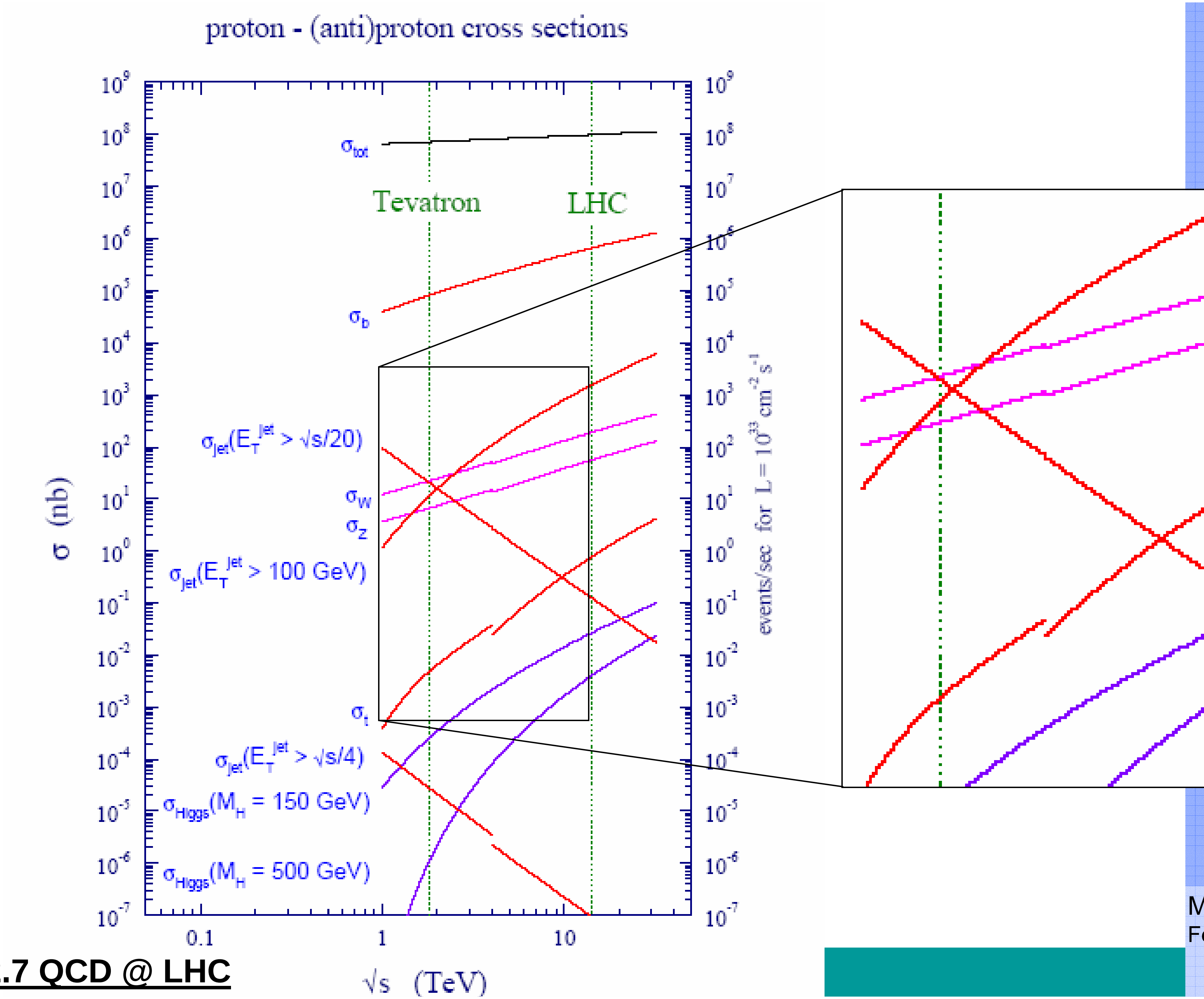
2.7 QCD@LHC

At the LHC:
Important to know high-x regions precisely in order to distinguish new physics from PDF mismatch

LHC parton kinematics



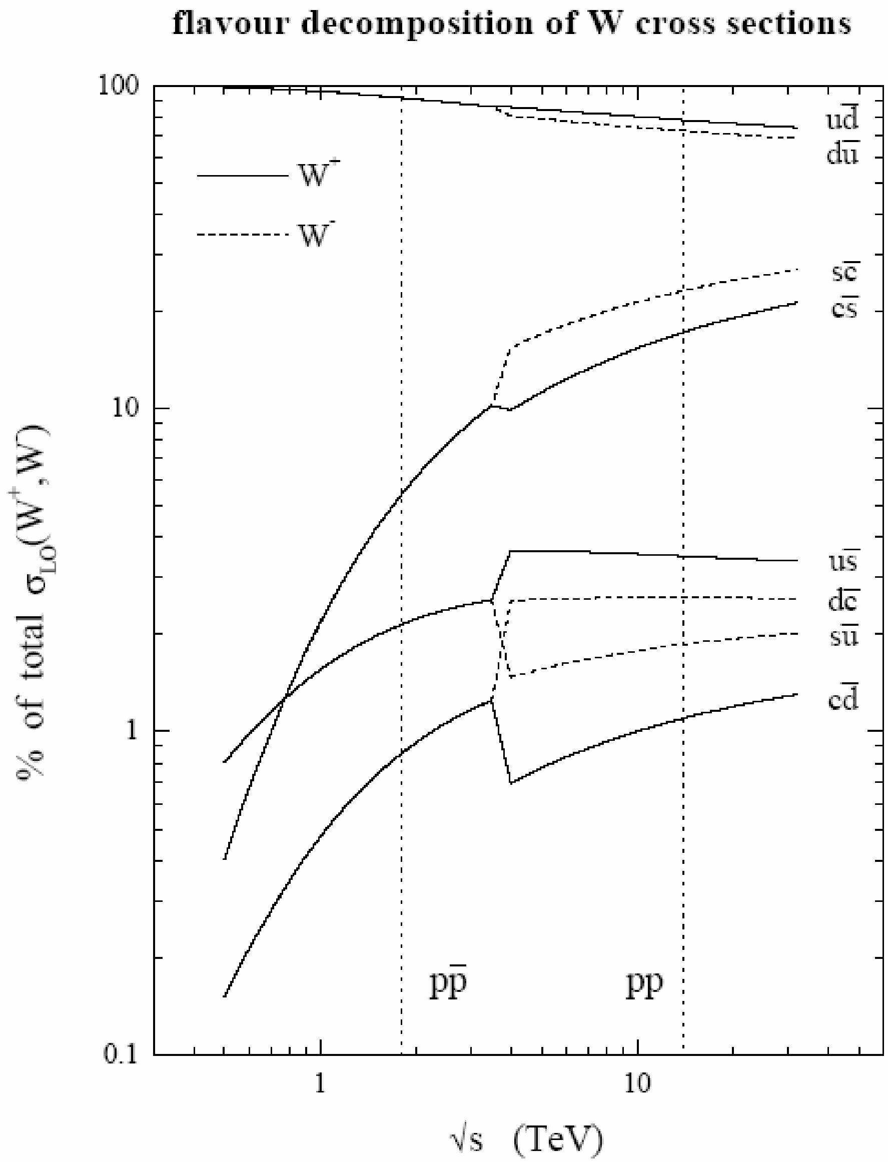
source
hep-ph/9907231


proton - (anti)proton cross sections
σ (nb)
events/sec for L = 10^33 cm^-2 s^-1
Tevatron
LHC
σ_tot
σ_b
σ_jet(E_T^jet > √s/20)
σ_W
σ_Z
σ_jet(E_T^jet > 100 GeV)
σ_t
σ_jet(E_T^jet > √s/4)
σ_Higgs(M_H = 150 GeV)
σ_Higgs(M_H = 500 GeV)
√s (TeV)
0.1
1
10
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7

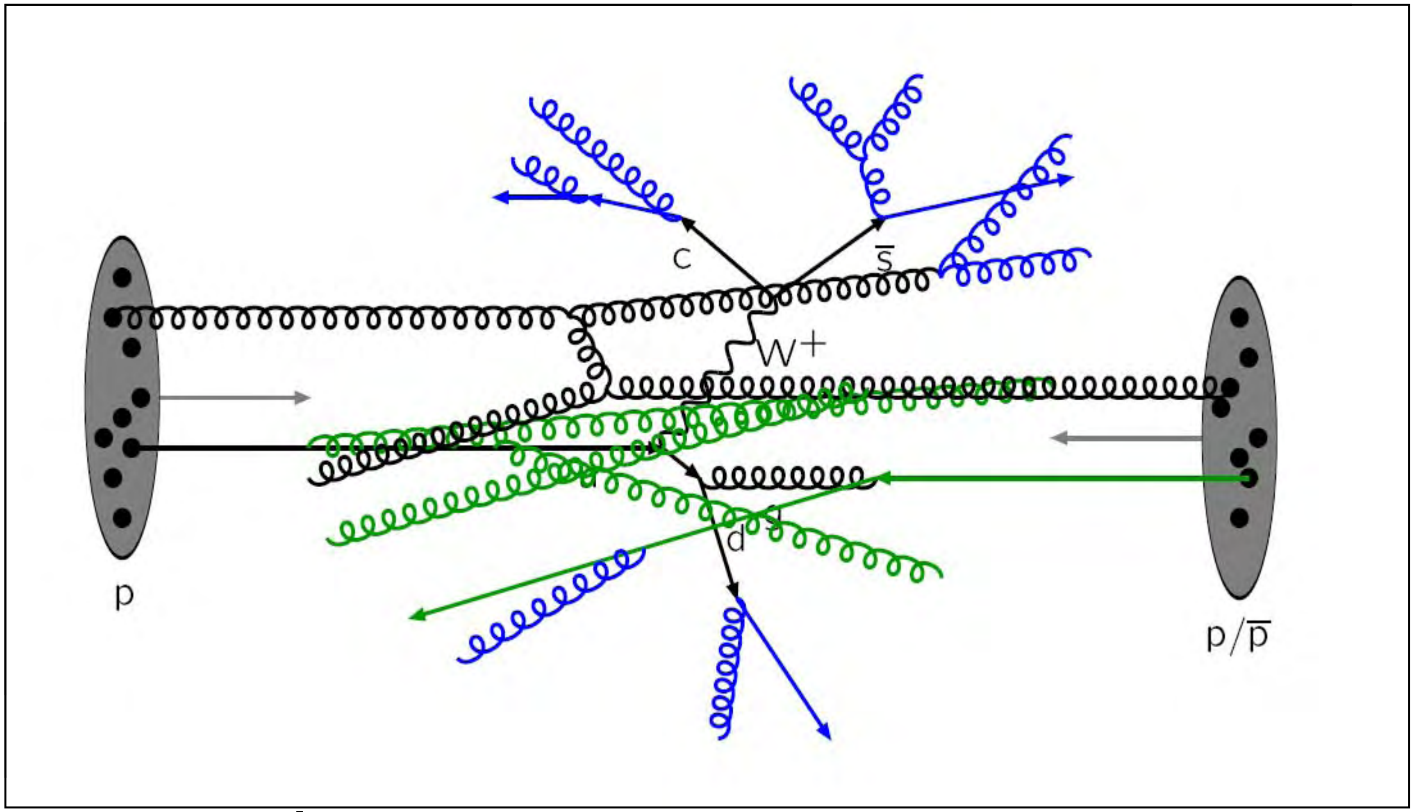
2.7 QCD @ LHC

W cross section @ LHC

- A.D.Martin, R.G. Roberts, W.J. Stirling, R.S.Thorne, hep-ph/9907231
- $\Delta\sigma(W)$=5% due to PDF uncertainties



Typical LHC event



LHC event = Hard Process
+ ISR/FSR
+ underlying evt
+ minimum bias evts
+ pile-up effect due to slow detector readout

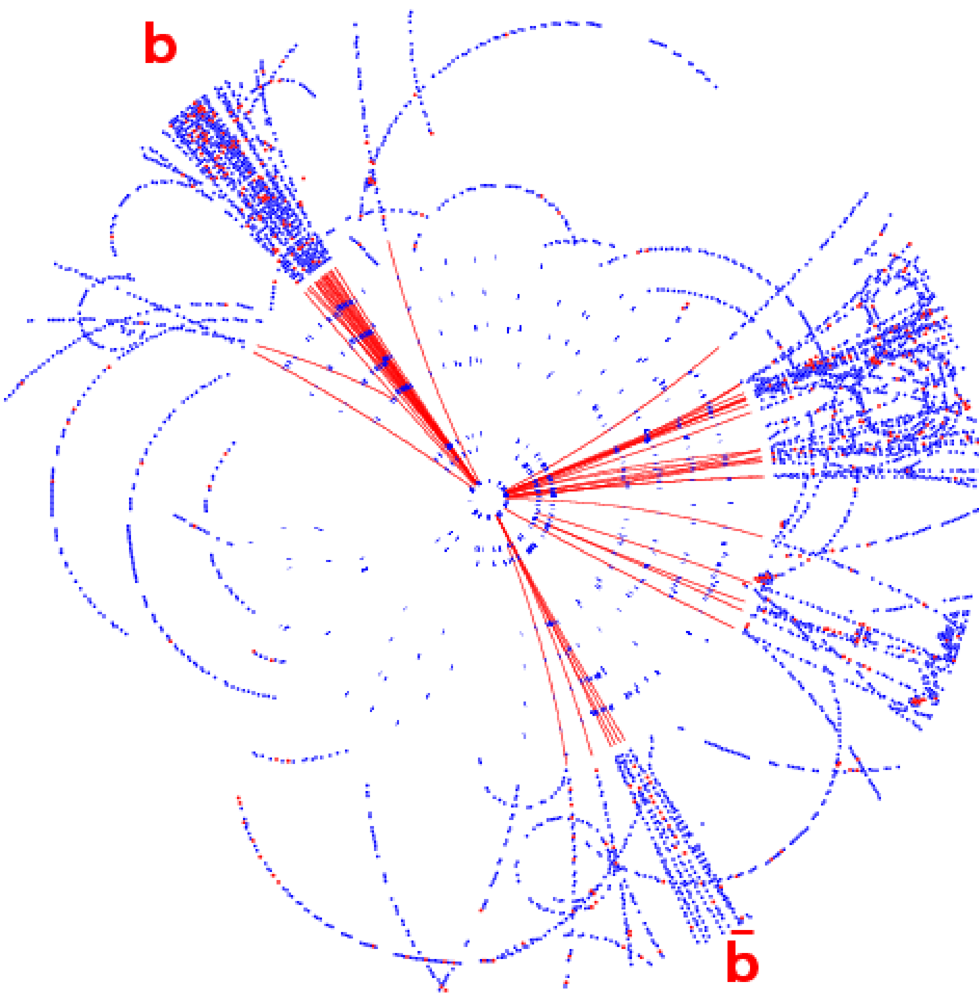
~23 additional pp-interactions per bunch crossing at high lumi (minimum bias events)

Monte Carlo (with Detector Simulation) will look quite different for low-lumi and high-lumi

ATLAS Barrel Inner Detector

$H \to b\bar{b}$

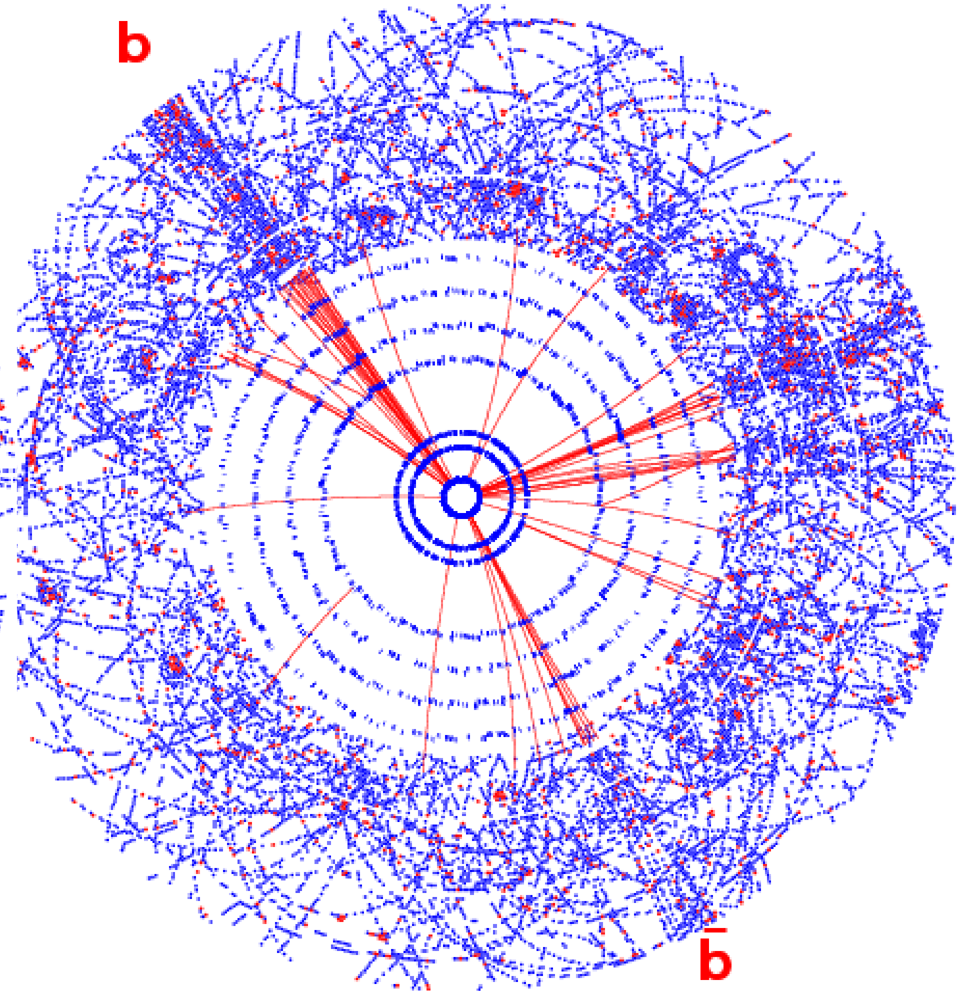
low lumi.



ATLAS Barrel Inner Detector

$H \to b\bar{b}$

high lumi.



Rule of Thumb: couple of Gev P_t per minBias evt per eta-phi bin

Minimum bias evts in Tevatron data

Beam profile in z
Tevatron ~33 cm
LHC ~ 7 cm

D0 Event display
Source Petr Vokac