QCD studies and Higgs searches at the LHC
part two

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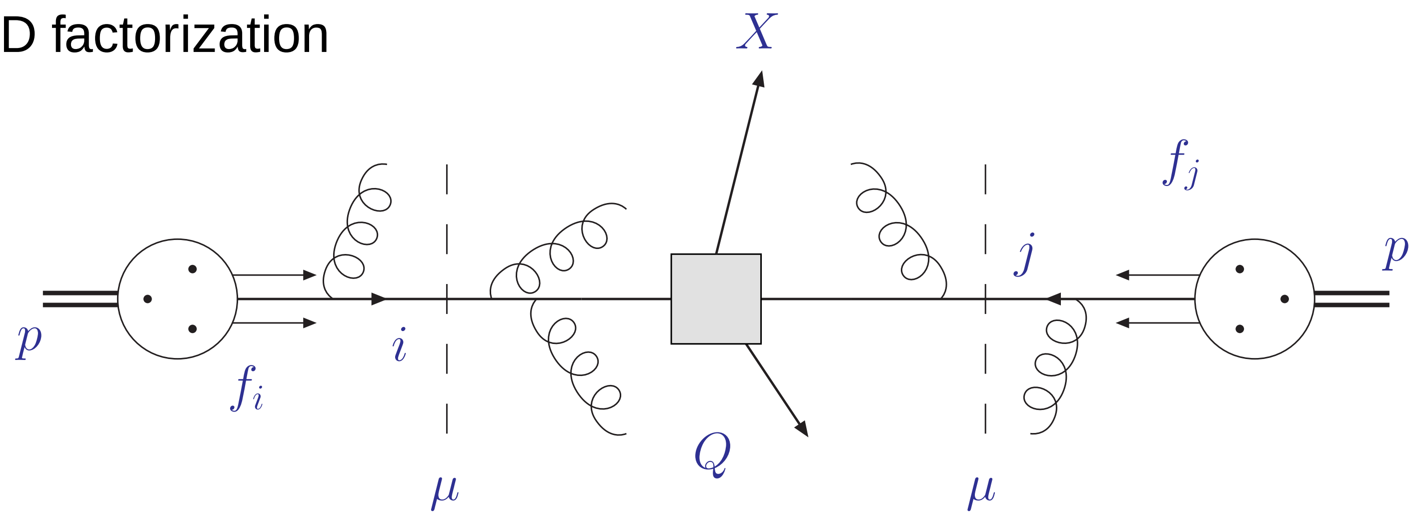
Introduction

- QCD factorization

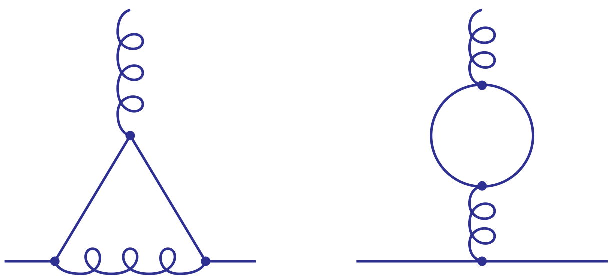


$$\sigma_{pp\to X} = \sum_{ij} f_i(\mu^2) \otimes f_j(\mu^2) \otimes \hat{\sigma}_{ij\to X}\left(\alpha_s(\mu^2), Q^2, \mu^2, m_X^2\right)$$

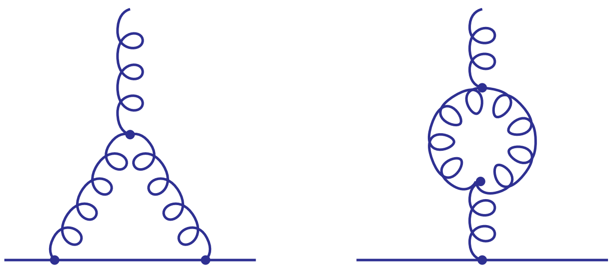
- Hard parton cross section $\hat{\sigma}_{ij\to X}$ calculable in perturbation theory
  - known to NLO, NNLO, . . . ($\mathcal{O}(\text{few}\%)$ theory uncertainty)
- Non-perturbative parameters: parton distribution functions f_i, strong coupling α_s, particle masses m_X
  - known from global fits to exp. data, lattice computations, . . .

Running coupling

- Effective couplung constant α_s
  - depends on resolution, momentum scale Q



– screening (like in QED)



– anti-screening (color charge of g)

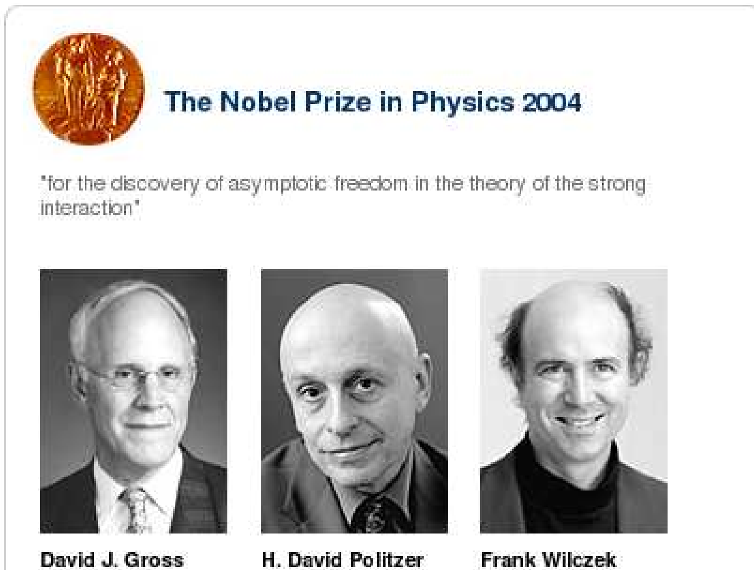
- Scale dependence governed by β-function of QCD

$$\frac{d\,\alpha_s}{d\,\ln Q^2} = \beta\,(\alpha_s) = -\beta_0 \alpha_s^2 - \beta_1 \alpha_s^3 - \dots$$

  - perturbative expansion with coefficients $\beta_0, \beta_1, \beta_2, \dots$

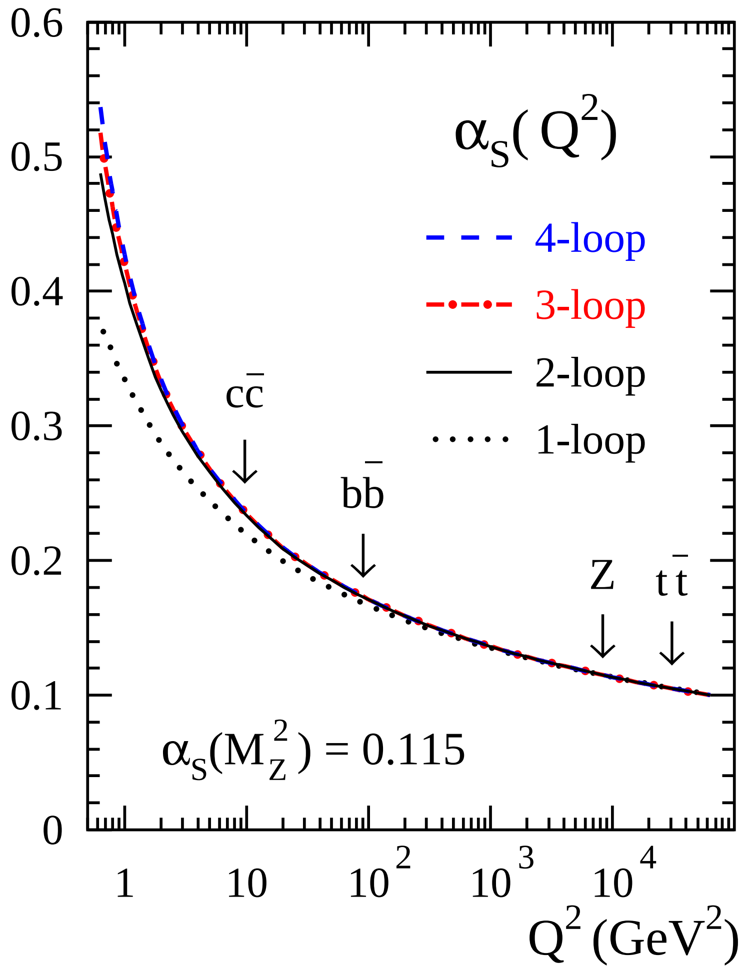
$$\beta_0 = \frac{1}{4\pi}\left(\frac{11}{3} C_A - \frac{2}{3} n_f\right)$$

Asymptotic freedom in QCD



Asymptotic freedom in QCD

- Solution of QCD β-function
  - perturbation theory applicable at large scales (but $\alpha_s \gg \alpha_{\text{QED}}$)

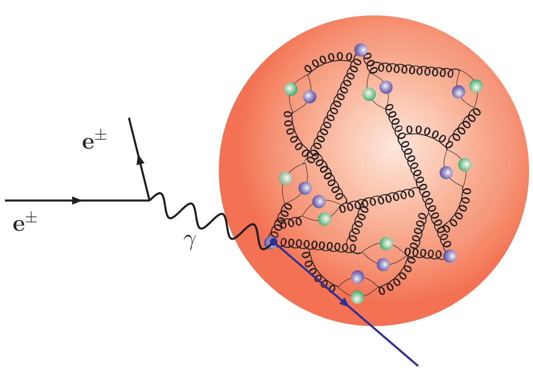


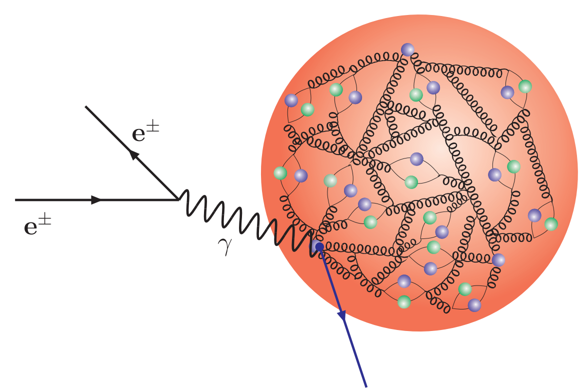
Perturbative QCD at colliders

- Deep-inelastic scattering
  - test parton dynamics at factorization scale μ

$$\sigma_{\gamma p \to X} = \sum_i f_i(\mu^2) \otimes \hat{\sigma}_{\gamma i \to X} \left(\alpha_s(\mu^2), Q^2, \mu^2 \right)$$

- QCD factorization
  - constituent partons from proton interact at short distance
  - photon momentum $Q^2 = -q^2$, Bjorken's $x = Q^2/(2p \cdot q)$
  - low resolution   high resolution

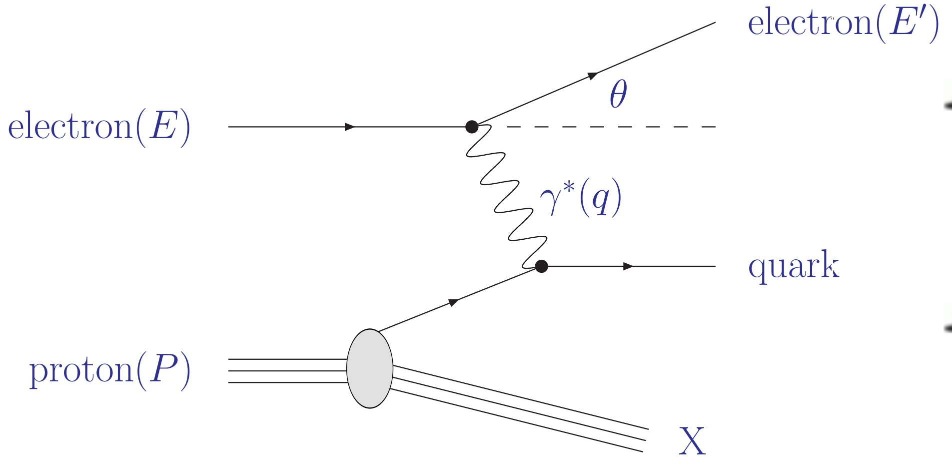




Once upon a time in the west . . .

- HERA: deep structure of proton at highest Q^2 and smallest x

Inelastic electron-proton scattering



- Virtuality of photon: resolution

$$Q^2 \equiv -q^2 = 4EE' \sin^2(\theta/2)$$

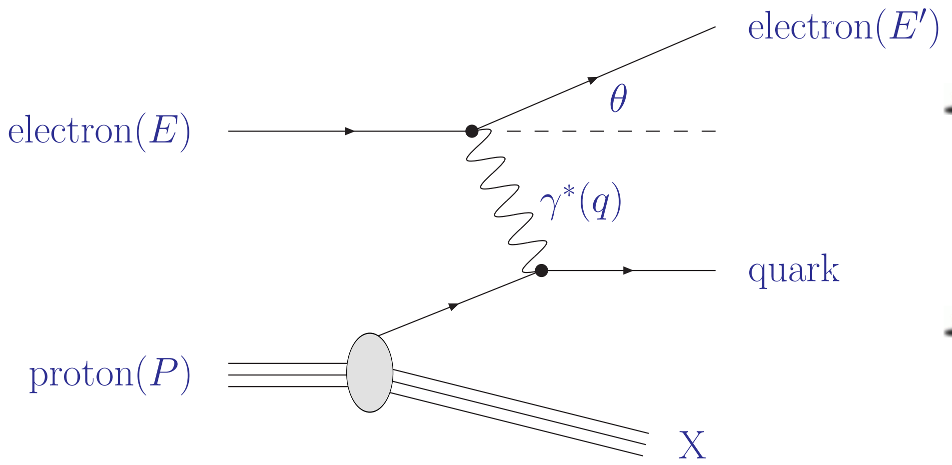
- Bjorken variable: inelasticity

$$x = \frac{Q^2}{2P\cdot q} < 1$$

- Cross section (X inclusive): proton structure function F_i^p

$$(E - E')\frac{d\sigma}{d\Omega\, dE'} \stackrel{\text{lab}}{=} \underbrace{\frac{\alpha^2 \cos^2\frac{\theta}{2}}{4E^2 \sin^4\frac{\theta}{2}}}_{\text{Mott-scattering (point-like)}} \left\{ F_2^p(x,Q^2) + \tan^2\frac{\theta}{2}\, F_1^p(x,Q^2) \right\}$$

Inelastic electron-proton scattering



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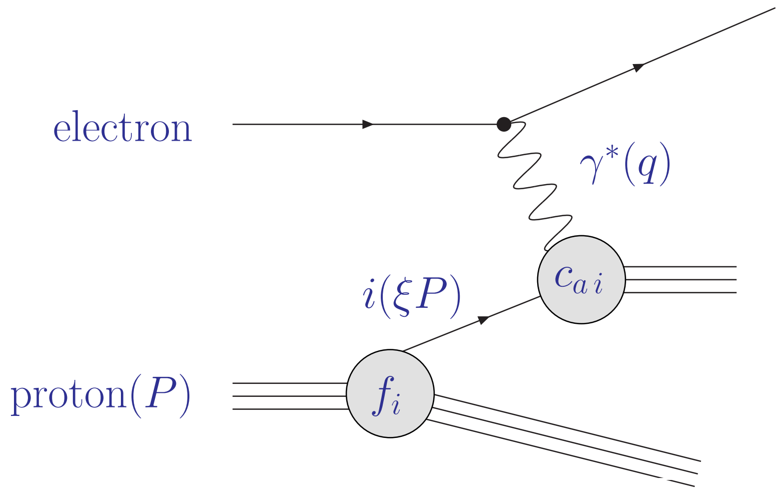
- Deep-inelastic scattering (Bjorken limit: $Q^2 \to \infty$ and x fixed)
Parton modell (quasi-free point-like constituents, incoherence)
$$F_2(x,Q^2) \simeq F_2(x) = \sum_i e_i^2\, x f_i(x)$$
  - $x f_i(x)$ distribution for momentum fraction x of parton i

QCD corrections in deep-inelastic scattering



- Structure function F_2 (up to terms $\mathcal{O}(1/Q^2)$)
  - Renormalization/factorization scale $\mu = \mathcal{O}(Q)$

$$x^{-1} F_2^p(x,Q^2) \;=\; \sum_i \int_x^1 \frac{d\xi}{\xi}\, c_{2,i}\left(\frac{x}{\xi}, \alpha_s(\mu^2), \frac{\mu^2}{Q^2}\right) f_i^p(\xi,\mu^2)$$

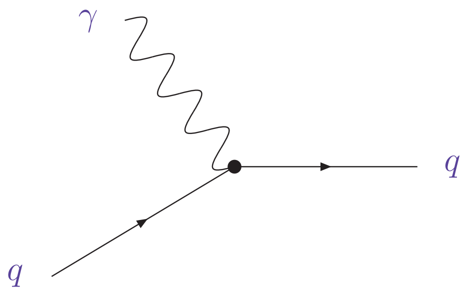
- Coefficient functions c_a

$$c_a \;=\; \underbrace{\alpha_s^{n_a}\Big[c_a^{(0)} + \alpha_s\, c_a^{(1)}}\; + \; \alpha_s^2\, c_a^{(2)} \; + \; \dots \Big]$$

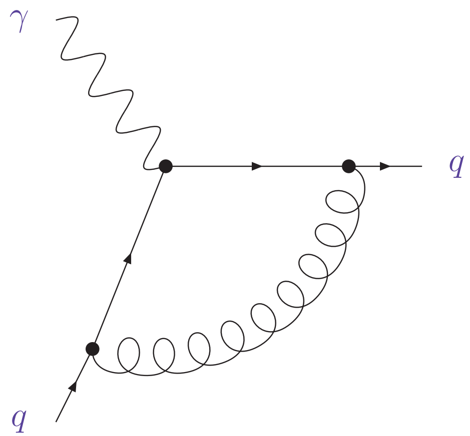
NLO: standard approximation (large uncertainties)

Radiative corrections in a nutshell

- Leading order
  - partonic structure function
    $\hat{F}_{2,q}^{(0)} = e_q^2 \delta(1-x)$

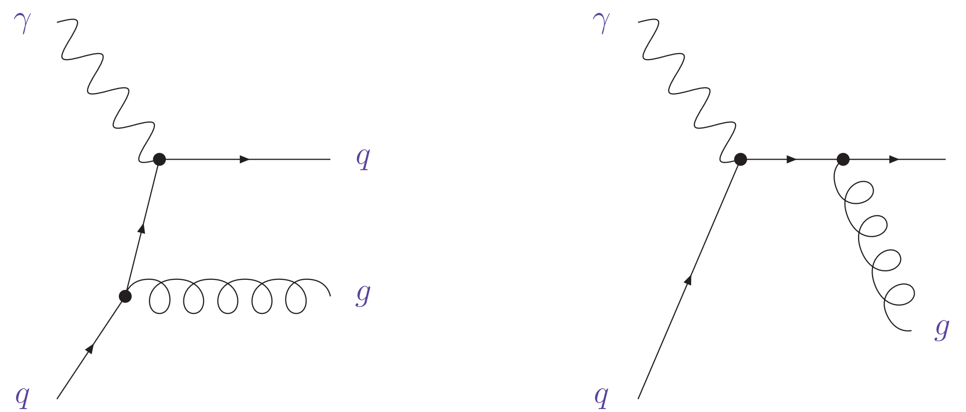


- Next-to-leading order
  - virtual correction
    (infrared divergent; proportional to Born)
  - dimensional regularization $D = 4 - 2\epsilon$



$$\hat{F}_{2,q}^{(1),v} = e_q^2 \, C_F \, \frac{\alpha_s}{4\pi} \, \delta(1-x) \left(\frac{\mu^2}{Q^2}\right)^\epsilon \left(-\frac{2}{\epsilon^2} - \frac{3}{\epsilon} - 8 + \zeta_2 + \mathcal{O}(\epsilon)\right)$$

- Next-to-leading order



  - add real and virtual corrections $\hat{F}_{2,q}^{(1)} = \hat{F}_{2,q}^{(1),r} + \hat{F}_{2,q}^{(1),v}$
  - collinear divergence remains splitting functions $P_{qq}^{(0)}$

$$
\begin{aligned}
\hat{F}_{2,q}^{(1)} \quad = \quad & e_q^2\, C_F\, \frac{\alpha_s}{4\pi} \left(\frac{\mu^2}{Q^2}\right)^{\epsilon} \left\{ \frac{1}{\epsilon} \left(\frac{4}{1-x} - 2 - 2x + 3\delta(1-x) \right) \right. \\
& +4\frac{\ln(1-x)}{1-x} - 3\frac{1}{1-x} - (9 + 4\zeta_2)\delta(1-x) \\
& -2(1+x)(\ln(1-x) - \ln(x)) - 4\frac{1}{1-x}\ln(x) + 6 + 4x \\
& \left. +\mathcal{O}(\epsilon) \right\}
\end{aligned}
$$

- Structure of NLO correction
  - absorb collinear divergence $P_{qq}^{(0)}$ in renormalized parton distributions

$$\hat{F}_{2,q}^{(1),\mathrm{bare}} = e_q^2 \frac{\alpha_s}{4\pi} \left(\frac{\mu^2}{Q^2}\right)^{\epsilon} \left\{ \frac{1}{\epsilon} P_{qq}^{(0)}(x) + c_{2,q}^{(1)}(x) + \mathcal{O}(\epsilon) \right\}$$

$$q^{\mathrm{ren}}(\mu_F^2) = q^{\mathrm{bare}} - \frac{\alpha_s}{4\pi} \frac{1}{\epsilon} P_{qq}^{(0)}(x) \left(\frac{\mu^2}{\mu_F^2}\right)^{\epsilon}$$

  - partonic (physical) structure function at factorization scale μ_F

$$\hat{F}_{2,q} = e_q^2 \left(\delta(1-x) + \frac{\alpha_s}{4\pi} \left\{ c_{2,q}^{(1)}(x) - \ln\left(\frac{Q^2}{\mu_F^2}\right) P_{qq}^{(0)}(x) \right\} \right)$$

Evolution

- Evolution formulates dependence of cross sections for observable on momentum transfer
- Classic example: scaling violations of structure functions
  Gross, Wilczek '73; Politzer '73
- Physical cross section in factorization ansatz cannot depend on μ
  $Q^2\, \sigma_{\rm phys}\,(Q) = \hat{\sigma}_{\rm pt}\,(Q/\mu, \alpha_s(\mu))\, \otimes\, f\,(\mu)$
  - factorization scale μ arbitrary $\mu \frac{d\,\sigma_{\rm phys}}{d\mu} = 0$
- Immediate consequence **DGLAP**: Altarelli, Parisi '77

$$\mu \frac{d\, f(\mu, m)}{d\mu} = P\,(\alpha_s(\mu))\, \otimes\, f(\mu, m) + \mathcal{O}\left(\frac{1}{Q^2}\right)$$

$$\mu \frac{d\, \hat{\sigma}_{\rm pt}\,(Q/\mu, \alpha_s(\mu))}{d\mu} = -P\,(\alpha_s(\mu))\, \otimes\, \hat{\sigma}_{\rm pt}\,(Q/\mu, \alpha_s(\mu)) + \mathcal{O}\left(\frac{1}{Q^2}\right)$$

- PDF evolution from renormalization group equation

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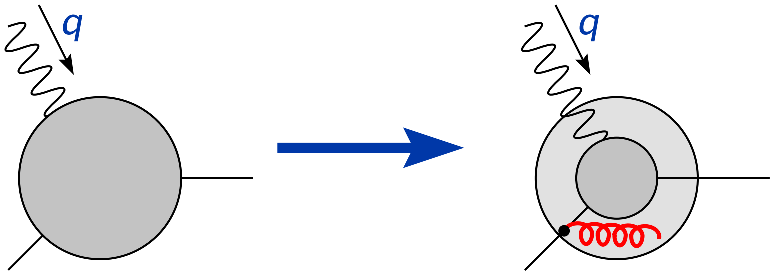
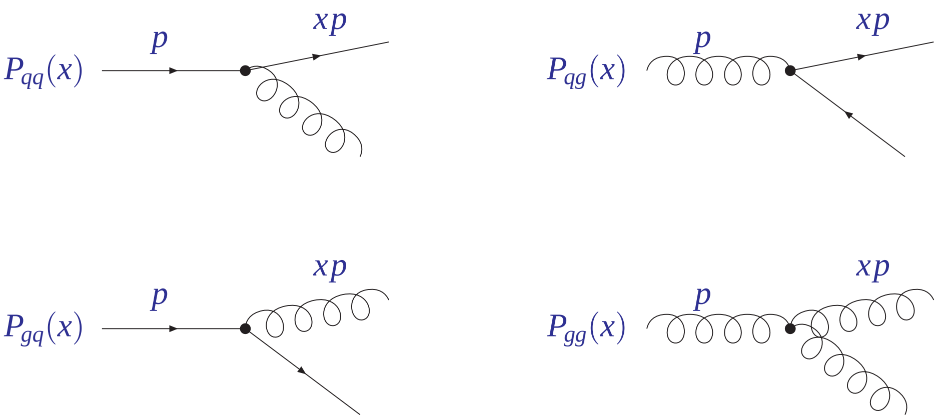
- PDF evolution from renormalization group equation
  - splitting functions calculable in QCD

Parton evolution



- Proton in resolution $1/Q \longrightarrow$ sensitive to lower momentum partons

- Feynman diagrams in leading order



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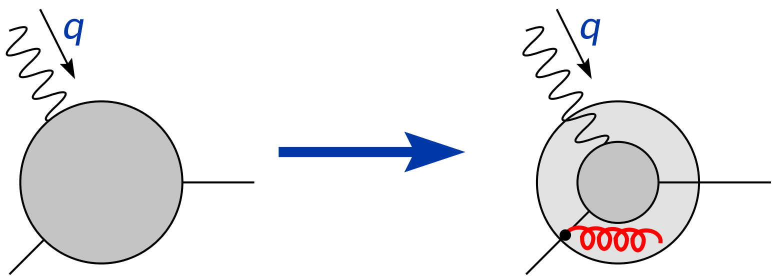

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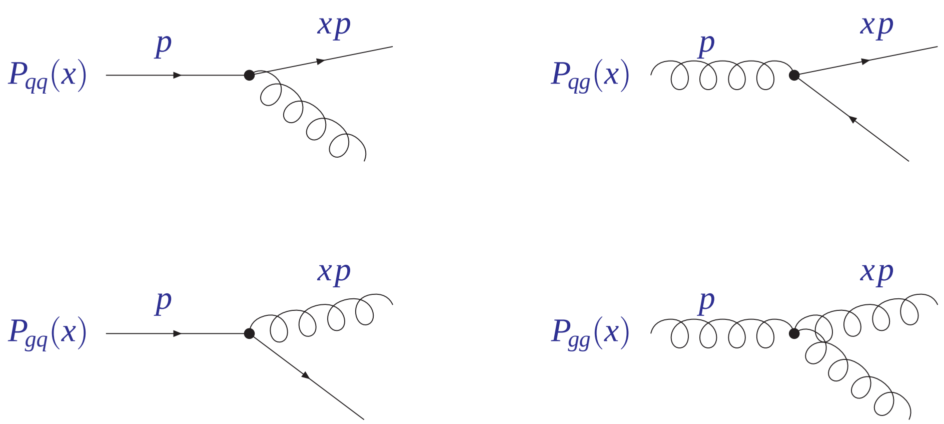

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- Evolution equations for parton distributions f_i
  - predictions from fits to reference processes (universality)

$$\frac{d}{d \ln \mu^2} f_i(x, \mu^2) = \sum_k \left[P_{ik}(\alpha_s(\mu^2)) \otimes f_k(\mu^2) \right] (x)$$

- Splitting functions P

$$P = \underbrace{\alpha_s P^{(0)} + \alpha_s^2 P^{(1)}} + \alpha_s^3 P^{(2)} + \ldots$$

NLO: standard approximation (large uncertainties)

Complete set of splitting functions and PDFs

- Evolution equations
  - non-singlet ($2n_f - 1$ scalar) and singlet (2×2 matrix) equations

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- Non-singlet and singlet distributions $q^{\pm}$, q^{v} and q_{s}, g

$$q^{\pm}_{\mathrm{ns},ik} = q_i \pm \bar{q}_i - (q_k \pm \bar{q}_k)$$ flavour asymmetries

$$q^{\mathrm{v}}_{\mathrm{ns}} = \sum_{r=1}^{n_f} (q_r - \bar{q}_r)$$ total valence distribution

$$q_{\mathrm{s}} = \sum_{r=1}^{n_f} (q_r + \bar{q}_r)$$ flavour singlet distribution, $f_i = \begin{pmatrix} q_{\mathrm{s}} \\ g \end{pmatrix}$

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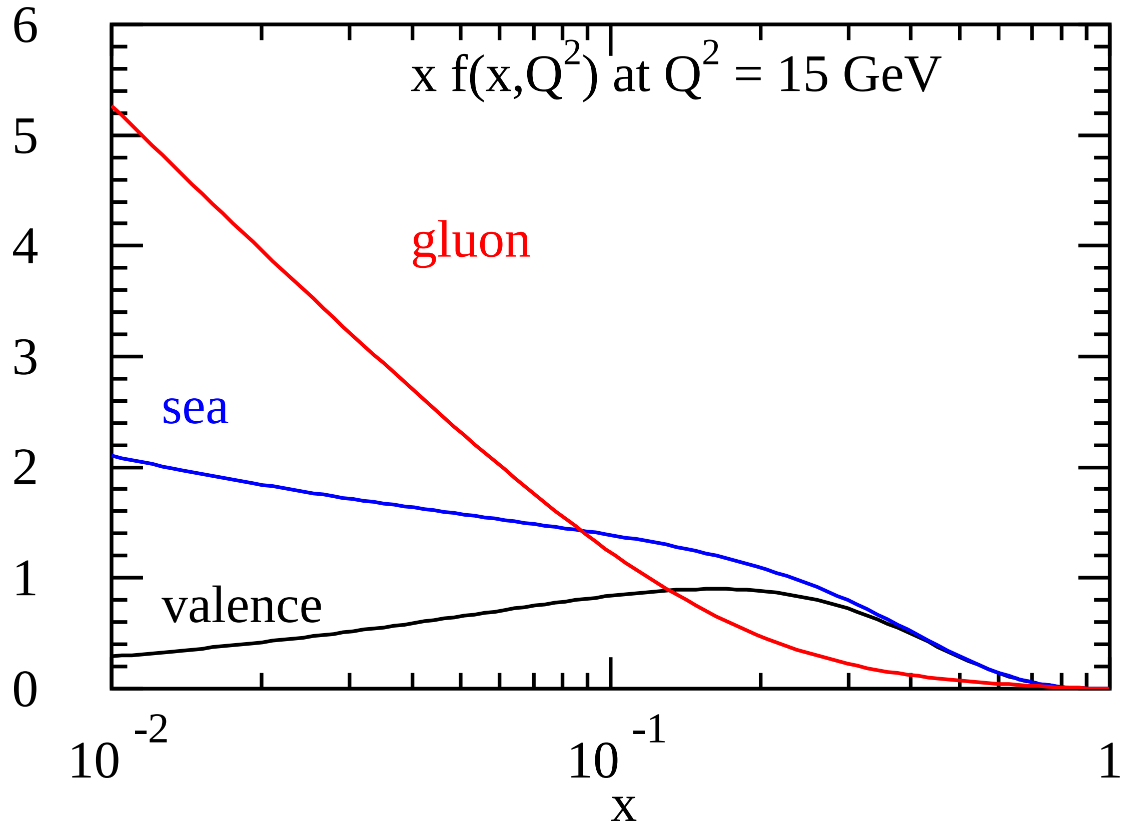
- Splitting function combinations

$$P^{\pm}_{\rm ns}\,, \qquad P^{\rm v}_{\rm ns} = P^{-}_{\rm ns} + P^{\rm s}_{\rm ns}$$ non-singlet

$$P_{\rm s} = \begin{pmatrix} P_{\rm qq} & P_{\rm qg} \\ P_{\rm gq} & P_{\rm gg} \end{pmatrix}\,, \qquad P_{\rm qq} = P^{+}_{\rm ns} + P_{\rm ps}$$ singlet

Parton distributions in proton

- Valence $q - \bar{q}$ (additive quantum numbers) sea (part with $q + \bar{q}$)



- Parameterization (bulk of data from deep-inelastic scattering)
  - structure function $F_2 \longrightarrow$ quark distribution
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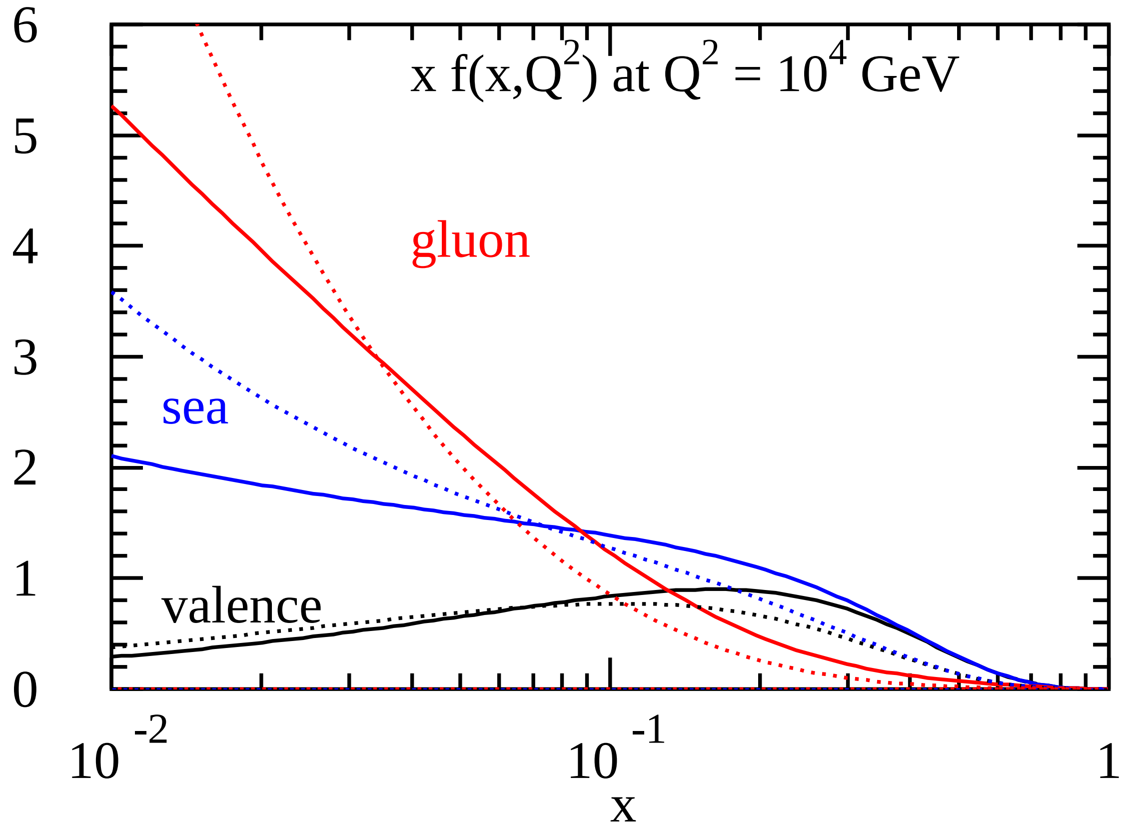

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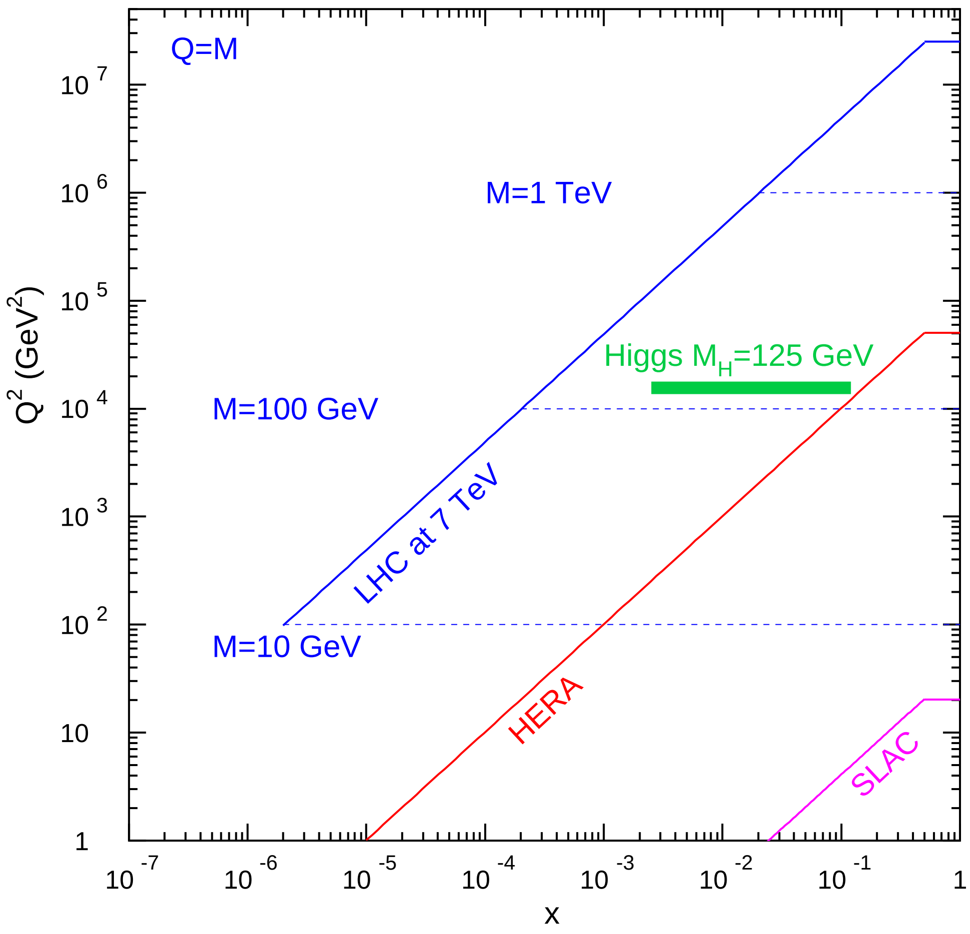
Parton luminosity at LHC



- LHC run at $\sqrt{s}$ = 7/8 TeV
  - parton kinematics well covered by HERA and fixed target experiments
- Parton kinematics at effective $\langle x \rangle = M/\sqrt{S}$
  - 100 GeV physics: small-x, sea partons
  - TeV scales: large-x

Global fits of parton distributions

PDF fits in a nut shell

- Determination of PDFs and strong coupling constant α_s to NNLO QCD
- Consistent scheme for treatment of heavy quarks
  - fixed-flavor number scheme for $n_f = 3, 4, 5$
- Full account of error correlations

Data considered in the fit

- Analysis of world data for deep-inelastic scattering and fixed-target data for Drell-Yan process
  - inclusive DIS data HERA, BCDMS, NMC, SLAC
  - Drell-Yan data (fixed target) E-605, E-866
  - neutrino-nucleon DIS data (di-muon production) CCFR/NuTeV
  - other data . . .

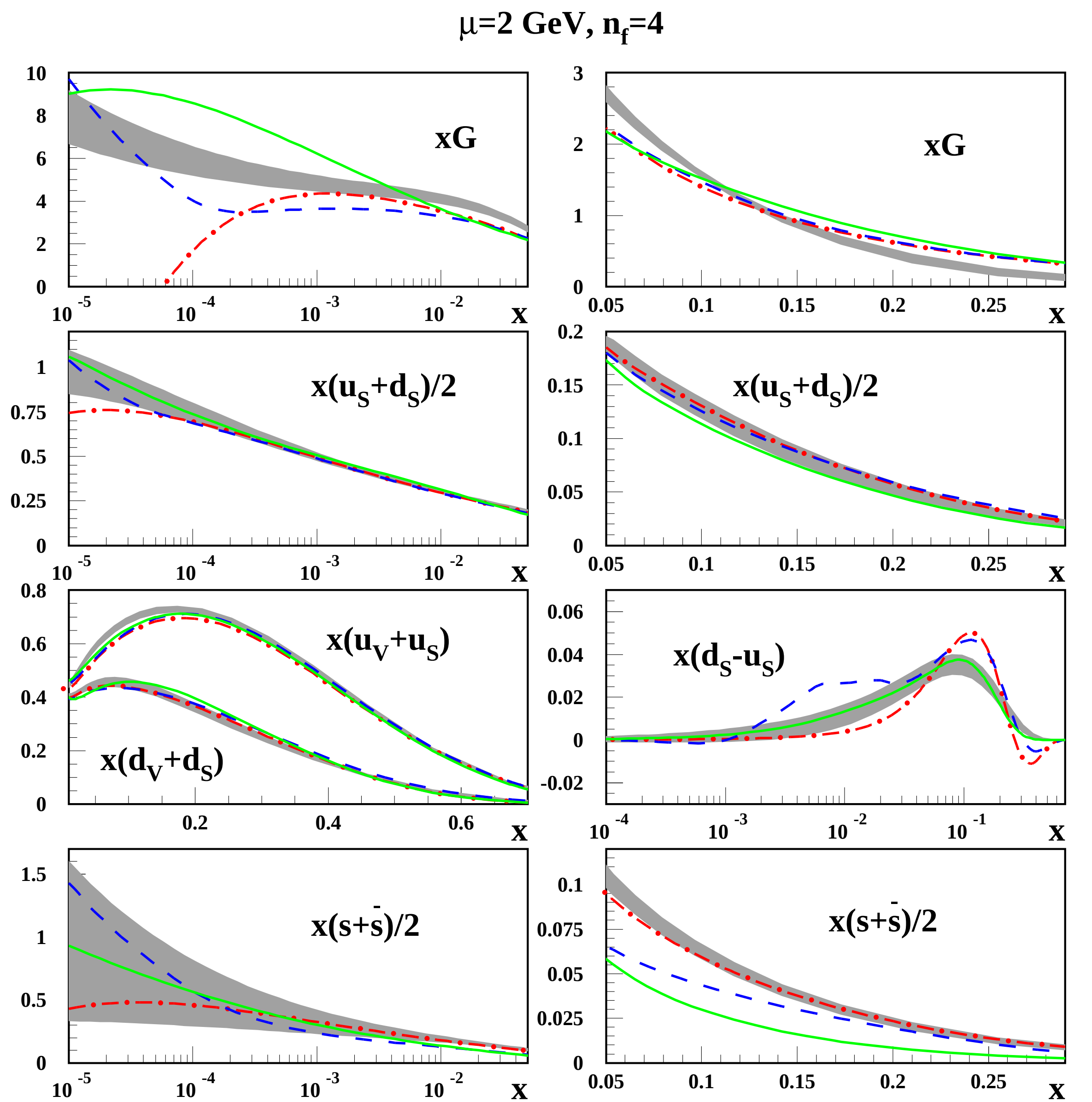
PDF ansatz

- PDFs parameterized at scale $Q_0 = 3\mathrm{GeV}$ in scheme with $n_f = 3$; e.g., Alekhin, Blümlein, S.M. '12
  - ansatz for valence-/sea-quarks, gluon with polynomial $P(x)$
  - strange quark is taken in charge-symmetric form
  - 24 parameters in polynomials $P(x)$
  - 4 additional fit parameters: $\alpha_s^{(n_f=3)}(\mu = 3$ GeV), m_c, m_b and deuteron correction

$$
\begin{aligned}
xq_v(x, Q_0^2) &= \frac{2\delta_{qu} + \delta_{qd}}{N_q^v} x^{a_q} (1-x)^{b_q} x^{P_{qv}(x)} \\
xu_s(x, Q_0^2) = x\bar{u}_s(x, Q_0^2) &= A_{us} x^{a_{us}} (1-x)^{b_{us}} x^{a_{us} P_{us}(x)} \\
x\Delta(x, Q_0^2) = xd_s(x, Q_0^2) - xu_s(x, Q_0^2) &= A_\Delta x^{a_\Delta} (1-x)^{b_\Delta} x^{P_\Delta(x)} \\
xs(x, Q_0^2) = x\bar{s}(x, Q_0^2) &= A_s x^{a_s} (1-x)^{b_s} \,, \\
xg(x, Q_0^2) &= A_g x^{a_g} (1-x)^{b_g} x^{a_g P_g(x)}
\end{aligned}
$$

- Ansatz provides sufficient flexibility; no additional terms required to improve the quality of fit

PDFs for the LHC



- 1σ band for ABM11 PDFs (NNLO, 4-flavors) at $\mu = 2$ GeV
  Alekhin, Blümlein, S.M.'12
- comparison with:
  JR09 (solid lines),
  MSTW (dashed dots) and
  NN21 (dashes)
- Some interesting observations to be made ...

Strong coupling constant

Essential facts

- $\alpha_s(M_Z)$ from e^+e^- data high
- $\alpha_s(M_Z)$ from DIS data low
- World average 1992
  $\alpha_s(M_Z) = 0.117 \pm 0.004$

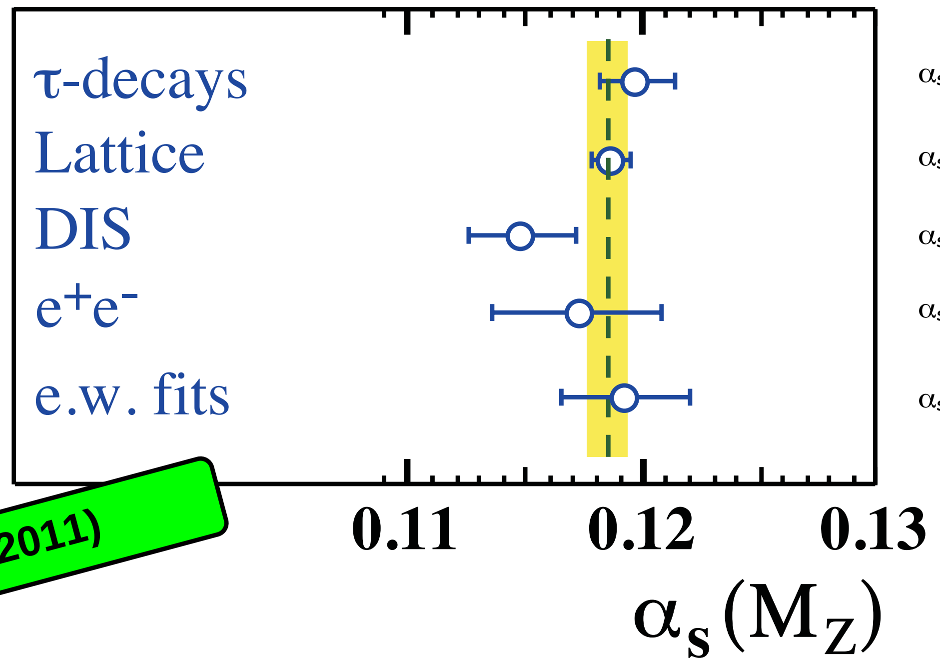
Bethke, Catani CERN TH-6484/92

	Process	Ref.	Q [GeV]	$\alpha_s(Q)$	$\alpha_s(M_{Z^0})$	$\Delta\alpha_s(M_{Z^0})$ exp.	$\Delta\alpha_s(M_{Z^0})$ theor.	order of perturb.
1	R_τ [LEP]	[7-10]	1.78	$0.318\ ^{+0.048}_{-0.039}$	$0.117\ ^{+0.006}_{-0.005}$	$^{+0.003}_{-0.004}$	$^{+0.005}_{-0.004}$	NNLO
2	R_τ [world]	[2]	1.78	0.32 ± 0.04	$0.118\ ^{+0.004}_{-0.006}$	–	–	NNLO
3	DIS [ν]	[3]	5.0	$0.193\ ^{+0.019}_{-0.018}$	$0.111\ ^{+0.006}_{-0.007}$	$^{+0.004}_{-0.006}$	0.004	NLO
4	DIS [μ]	[12]	7.1	0.180 ± 0.014	0.113 ± 0.005	0.003	0.004	NLO
5	$J/\Psi, \Upsilon$ decay	[4]	10.0	$0.167\ ^{+0.015}_{-0.011}$	$0.113\ ^{+0.007}_{-0.005}$	–	–	NLO
6	e^+e^- [σ_{had}]	[14]	34.0	0.163 ± 0.022	0.135 ± 0.015	–	–	NNLO
7	e^+e^- [shapes]	[15]	35.0	0.14 ± 0.02	0.119 ± 0.014	–	–	NLO
8	$p\bar{p} \to b\bar{b}X$	[11]	20.0	$0.136\ ^{+0.025}_{-0.024}$	$0.108\ ^{+0.015}_{-0.014}$	0.006	$^{+0.014}_{-0.013}$	NLO
9	$p\bar{p} \to W\ jets$	[13]	80.6	0.123 ± 0.027	0.121 ± 0.026	0.018	0.020	NLO
10	$\Gamma(Z^0 \to \text{had.})$	[5]	91.2	0.133 ± 0.012	0.133 ± 0.012	0.012	$^{+0.003}_{-0.001}$	NNLO
11	Z^0 ev. shapes							
	ALEPH	[7]	91.2	$0.119\ ^{+0.008}_{-0.010}$		–	–	NLO
	DELPHI	[8]	91.2	0.113 ± 0.007		0.002	0.007	NLO
	L3	[9]	91.2	0.118 ± 0.010		–	–	NLO
	OPAL	[10]	91.2	$0.122\ ^{+0.006}_{-0.005}$		0.001	$^{+0.006}_{-0.005}$	NLO
	SLD	[6]	91.2	$0.120\ ^{+0.015}_{-0.013}$		0.009	$^{+0.012}_{-0.009}$	NLO
	Average	[6-10]	91.2		0.119 ± 0.006	0.001	0.006	NLO
12	Z^0 ev. shapes							
	ALEPH	[7]	91.2	0.125 ± 0.005		0.002	0.004	resum.
	DELPHI	[8]	91.2	0.122 ± 0.006		0.002	0.006	resum.
	L3	[9]	91.2	0.126 ± 0.009		0.003	0.008	resum.
	OPAL	[10]	91.2	$0.122\ ^{+0.003}_{-0.006}$		0.001	$^{+0.003}_{-0.006}$	resum.
	Average	[7-10]	91.2		0.123 ± 0.005	0.001	0.005	resum.

Table 1: Summary of measurements of α_s. For details see text.

α_s 2012

World Summary of α_s 2011:



$\alpha_s(M_Z) = 0.1197 \pm 0.0016$

$\alpha_s(M_Z) = 0.1186 \pm 0.0008$

$\alpha_s(M_Z) = 0.1148 \pm 0.0024$

$\alpha_s(M_Z) = 0.1172 \pm 0.0037$

$\alpha_s(M_Z) = 0.1193 \pm 0.0028$

S. Bethke (Ringberg 2011)

–> $\alpha_s(M_Z) = 0.1185 \pm 0.0008$

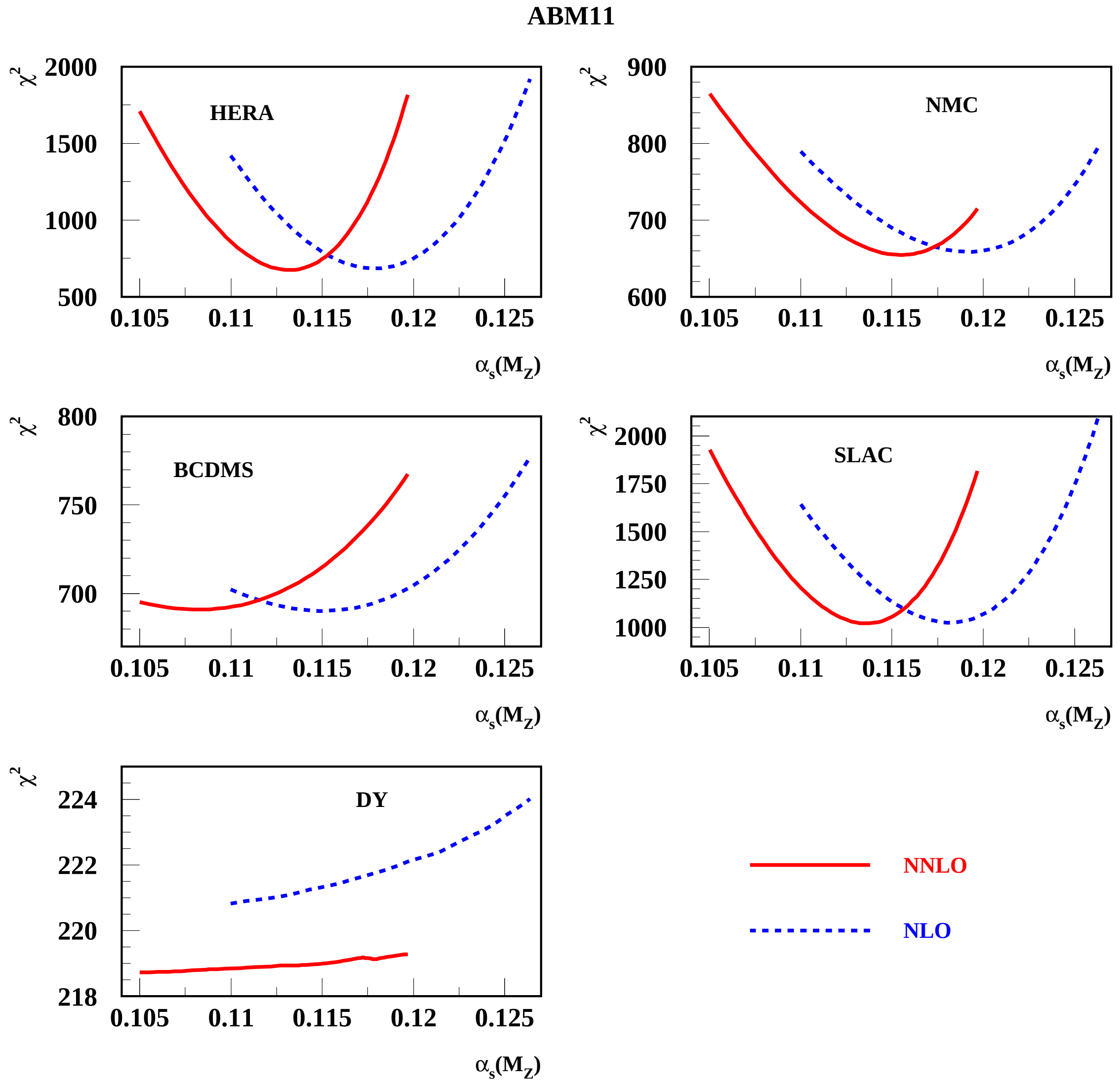
(–> RPP 2012)

$\Lambda_{\overline{MS}}^{(5)} = (214 \pm 10)$ MeV

$\Lambda_{\overline{MS}}^{(4)} = (298 \pm 12)$ MeV

S. Bethke: α_s (2011) summary *Ringberg workshop on HERA physics* *Sep. 26, 2011* 10

α_s from DIS and PDFs



- Profile of χ^2 for different data sets

α_s from DIS and PDFs

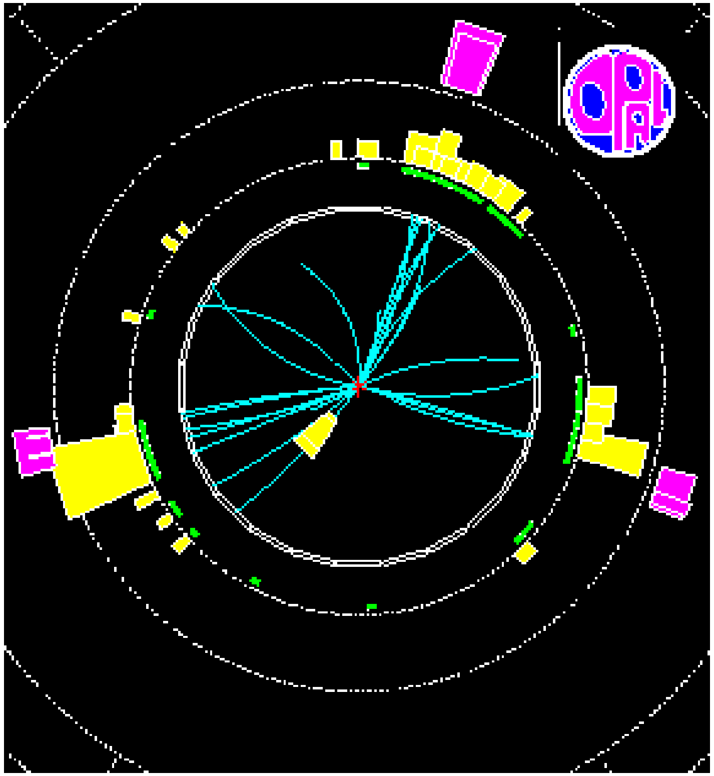
- Comparison of α_s values
  - effects for differences between ABM and MSTW understood

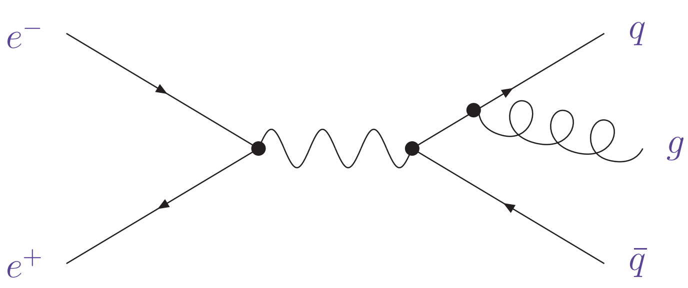
	α_s at NNLO	target mass corr.	higher twist	error correl.
ABM11	0.1134 ± 0.0011	yes	yes	yes
NNPDF2.1	0.1166 ± 0.0008	yes	no	yes
MSTW	0.1171 ± 0.0014	no	no	no

Jets in QCD

Notion of a jet

- High energy event with collimated bunch of hadrons flying roughly in same direction is called a jet
(hundreds of hadrons; contains a lot of information)





- Jets related to underlying QCD dynamics (quarks and gluons)

Jet algorithms

- Reduce complexity of final state
  (combine many hadrons to simpler objects)
- Connects parton picture to experimental signature
  (precise and quantitative)
- Mapping of particle 4-momenta $\{p_i\}$ to set of jets $\{j_k\}$

$$\left\{ p_i \right\} \quad \longrightarrow \quad \left\{ j_k \right\}$$

Properties of jet definitions

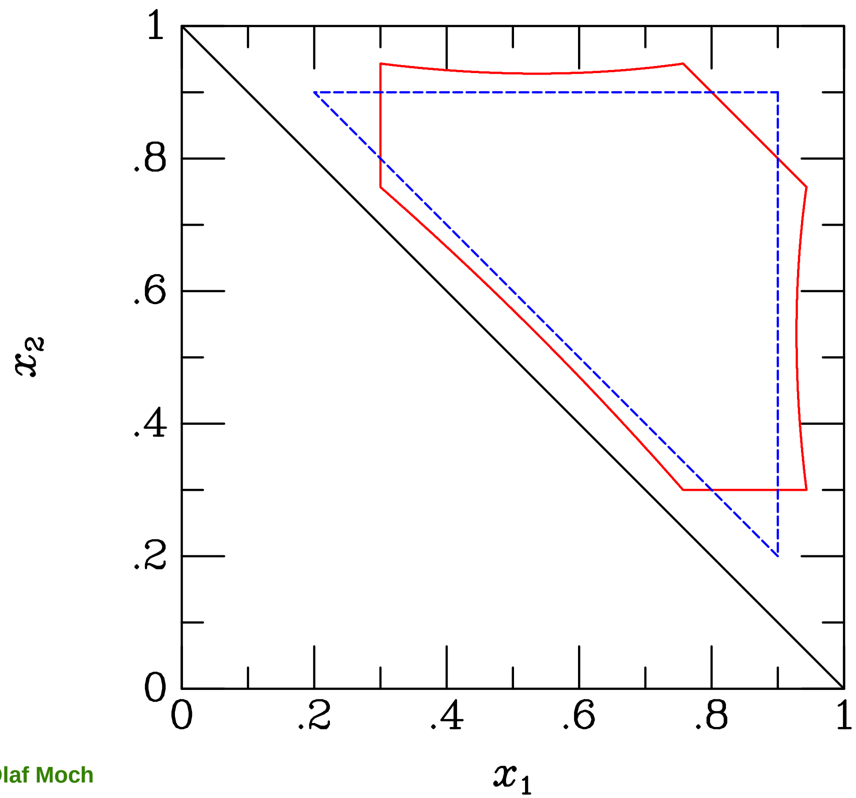
" Toward a standardization of jet definitions" FERMILAB-CONF-90-249-E

1. Simple to implement in an experimental analysis;
2. Simple to implement in a theoretical calculation;
3. Defined at any order of perturbation theory;
4. Yields finite cross section at any order in perturbation theory;
5. Yields a cross section that is relatively insensitive to hadronization.

Historical definitions

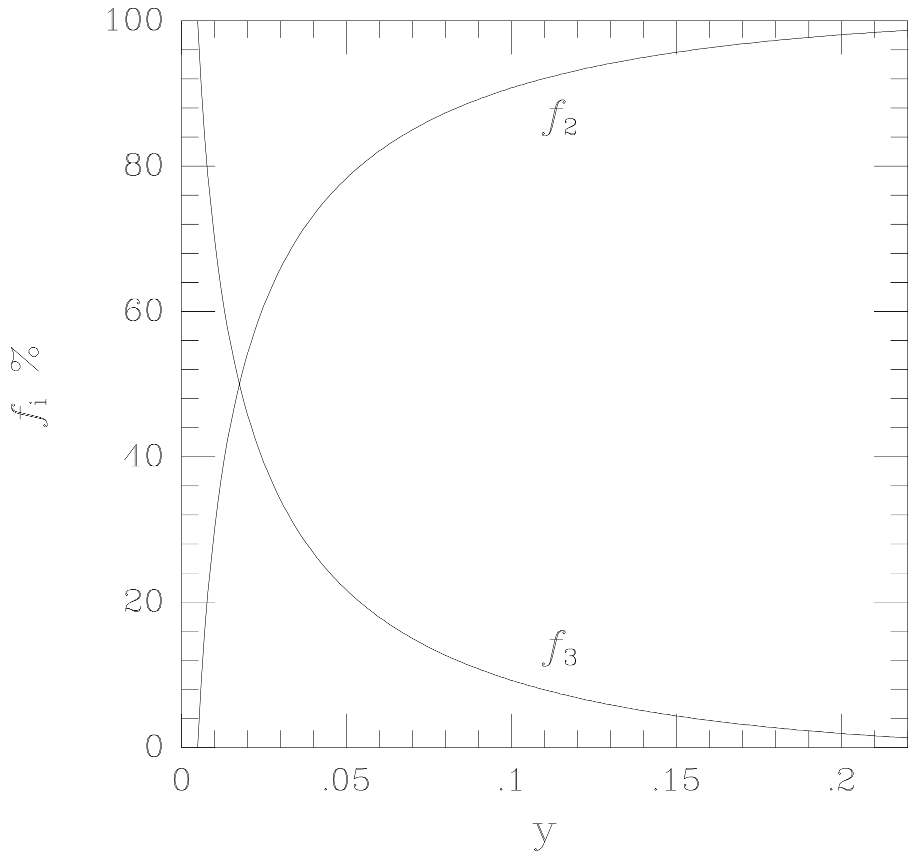
- Historically: Sterman-Weinberg criterium for two-jet event
  - energy fraction $1 - \epsilon$ in cone of half angle δ
  - not practical for multi-particle events
- JADE algorithm: $\min\,(p_i + p_j)^2 = \min 2E_iE_j\,(1 - \cos\theta_{ij}) > y_{\rm cut}\,s$
  - disadvantage: combines also soft gluons at large relative k_t e.g. potential three-jet event

Di-jet phase space in e^+e^- annihilation



- phase space boundaries for region with two and three jets
  - Sterman-Weinberg with $(\epsilon, \delta) = (0.3, 30)$ (solid lines)
  - JADE algorithm with $y_{\rm cut} = 0.1$ (dashed lines)

Jet rates in e^+e^- annihilation



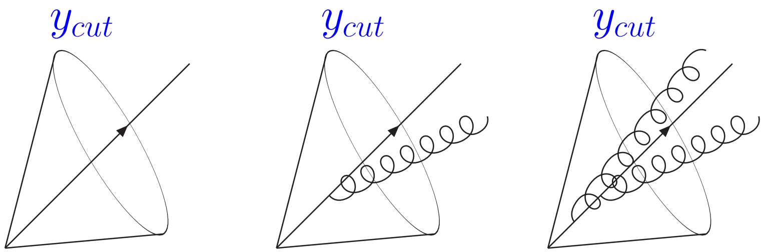
- Ratio of rates $f_i = \frac{\sigma_{i-\mathrm{jet}}}{\sigma}$ for two and three jets
  - JADE algorithm with $y_{\mathrm{cut}} \leq 0.3$

- Recall: three-jet cross section $\sigma^{q\bar{q}g}$

$$\sigma^{q\bar{q}g} \quad = \quad \sigma^{(0)}\, 3 \sum_q e_q^2\, C_F\, \frac{\alpha_s}{2\pi} \int dx_1 dx_2\, \frac{x_1^2 + x_2^2}{(1 - x_1)\,(1 - x_2)}$$

Modern jet definitions

- Two main classes of jet algorithms
- Sequential recombination algorithms (bottom-up approach)
  - combine particles starting from closest ones
  - choose distance measure
  - iterate recombination until few objects left, call them jets
  - e.g. k_t-clustering algorithm: $2 \min(E_i^2, E_j^2)(1 - \cos\theta_{ij}) > y_{\rm cut}\, s$



Jets in hadronic collisions

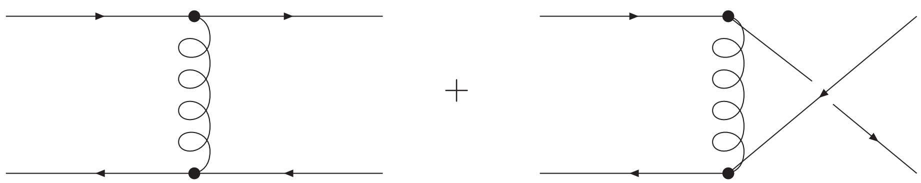
- Metric of η, ϕ
  - define cone of radius R in η, ϕ for $R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$

Hadronic di-jets

- Di-jet differential cross section for scattering
  $\mathrm{parton}_i(k_1) + \mathrm{parton}_j(k_2) \rightarrow \mathrm{parton}_k(k_3) + \mathrm{parton}_l(k_4)$

$$\frac{d^3\sigma}{dy_3 dy_4 dp_t^2} = \frac{1}{16\pi s^2} \sum_{i,j,k,l=q,\bar{q},g} \frac{f_i(x_1)}{x_1} \frac{f_j(x_2)}{x_2} \overline{\sum} \frac{1}{1+\delta_{kl}} |\mathcal{A}(ij \rightarrow kl)|^2$$

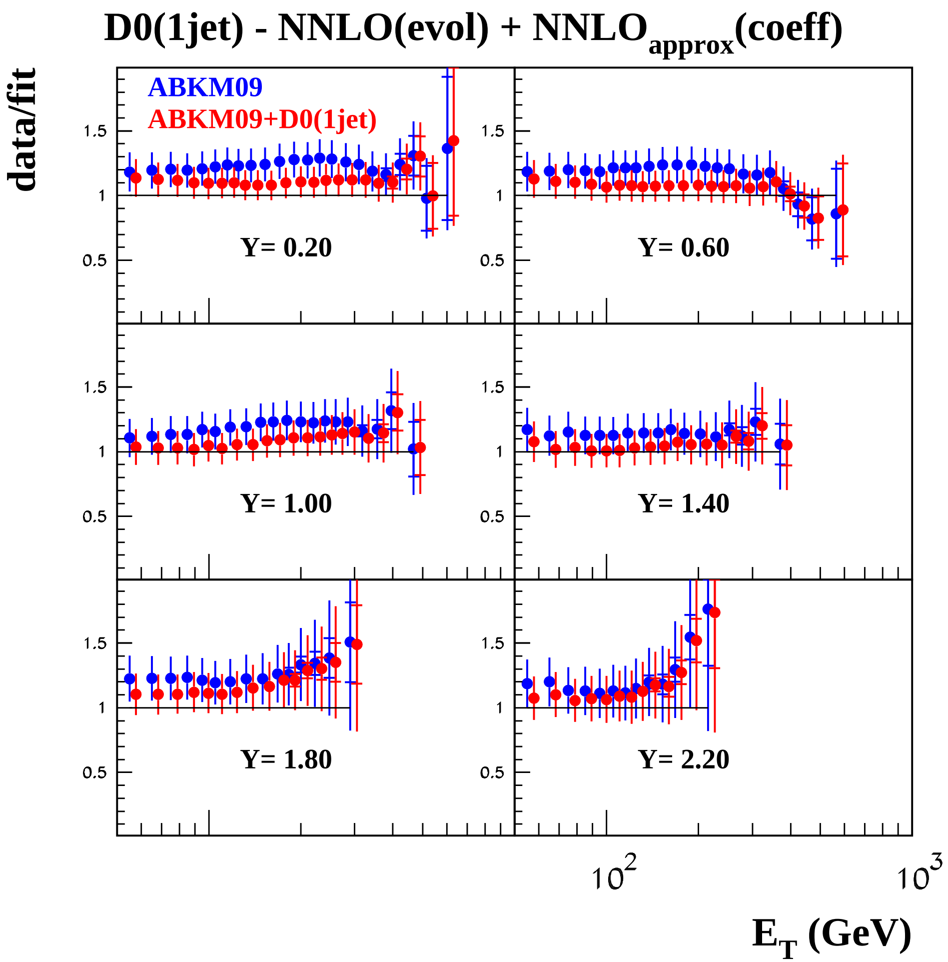
- Example: $\hat{\sigma}^{ud}$ with
  $\overline{\sum} |\mathcal{A}|^2 = (4\pi\alpha_s)^2 \frac{4}{9} \frac{s^2+u^2}{t^2}$

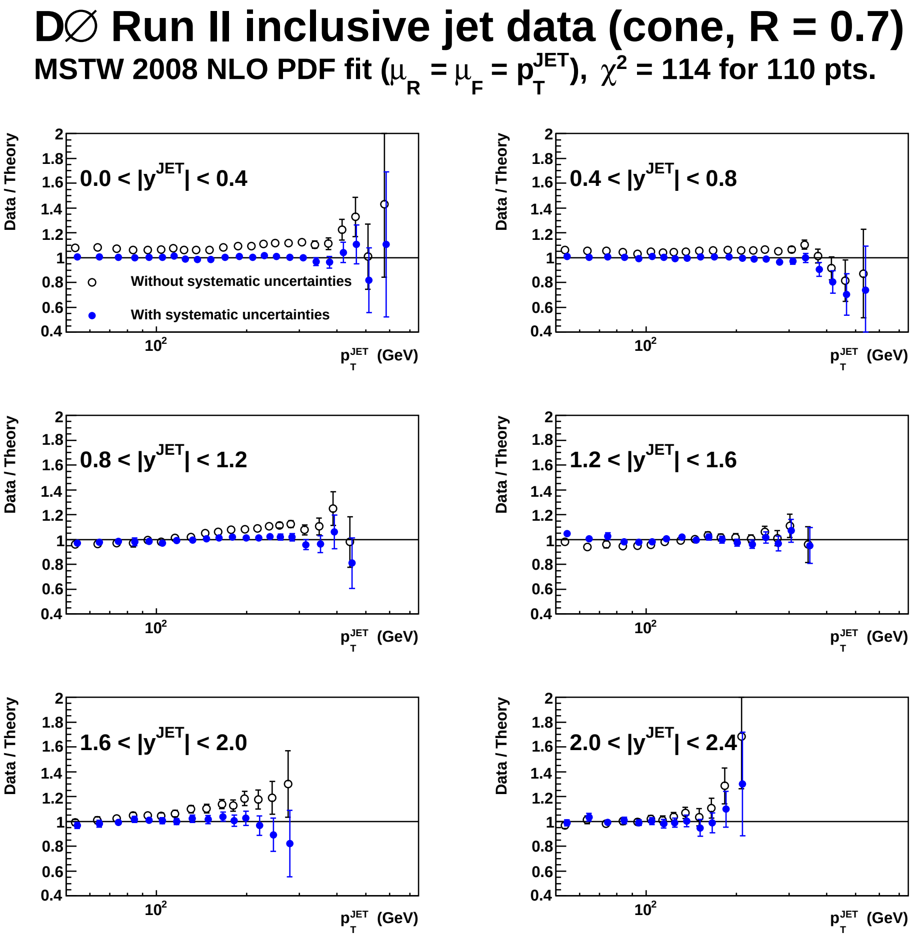


(Some) uses of hadronic di-jets

- Hadronic di-jets: large statistics even with high-p_t cuts
  - experimental calibration (HCAL uniformity, establish missing E_t)
  - searches for quark sub-structure (di-jet angular correlations)
  - gluon jets constrain gluon PDF at medium/large x

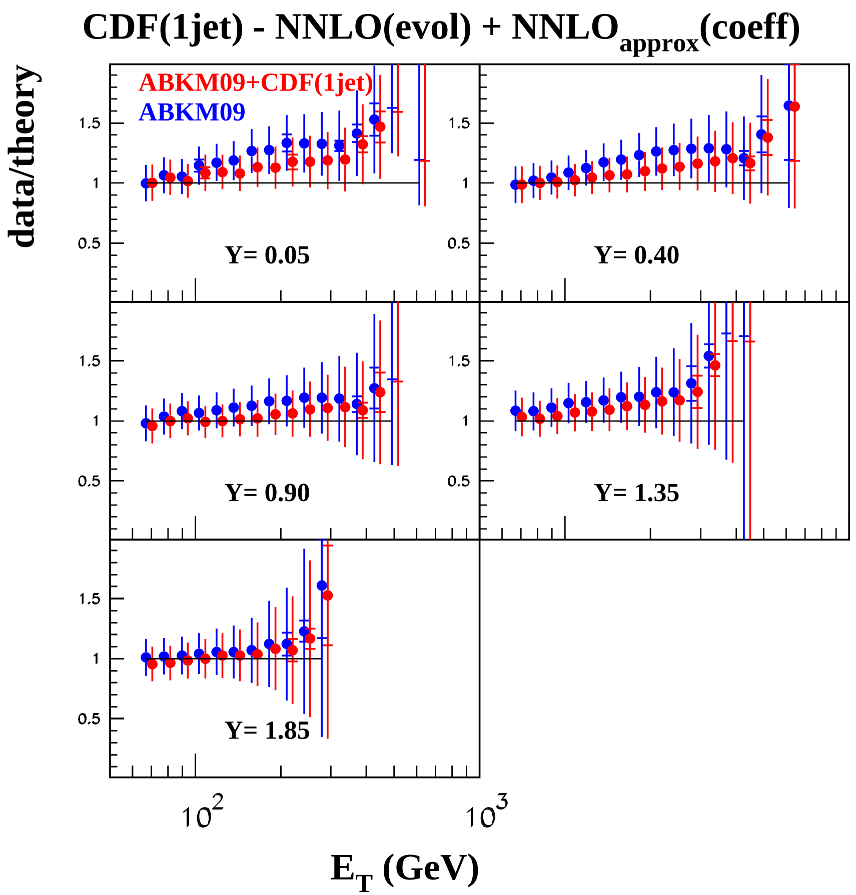
Tevatron jet data (D0) – 1-jet inclusive

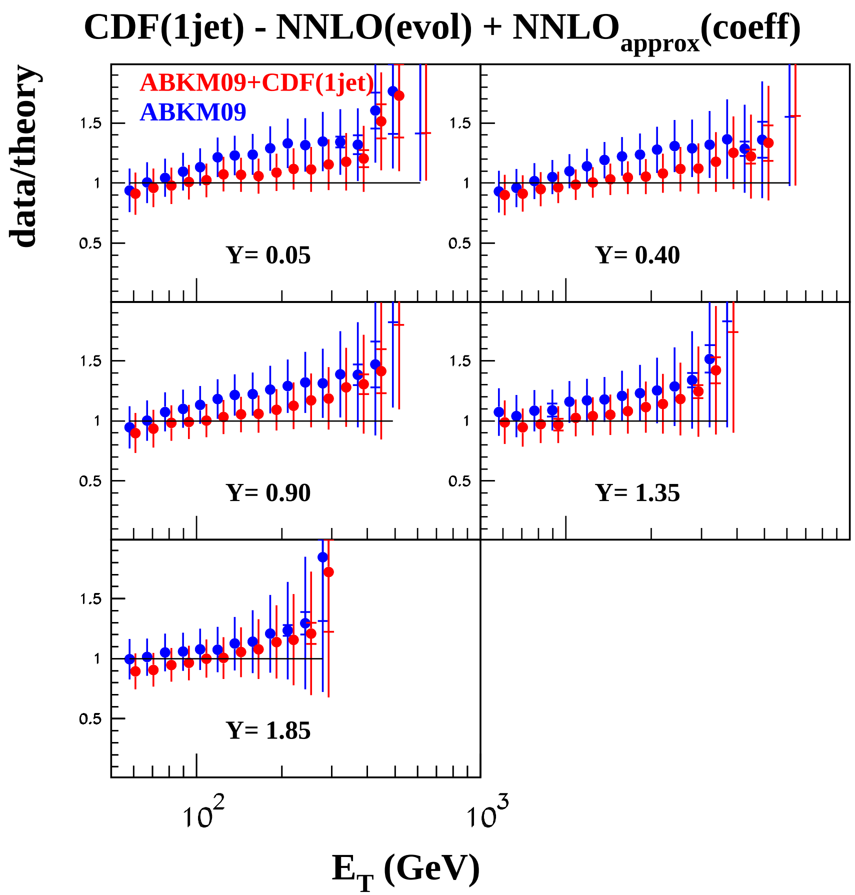




- PDF fits to Tevatron jet data (with NNLO$_{\rm approx}$ corr. Kidonakis, Owens '01) Alekhin, Blümlein, S.M. '11 (left); MSTW `arXiv:0901.0002` (right)
- 3-flavor PDFs for DIS, 5-flavor PDFs for jets, scale $\mu_r = \mu_f = E_T$

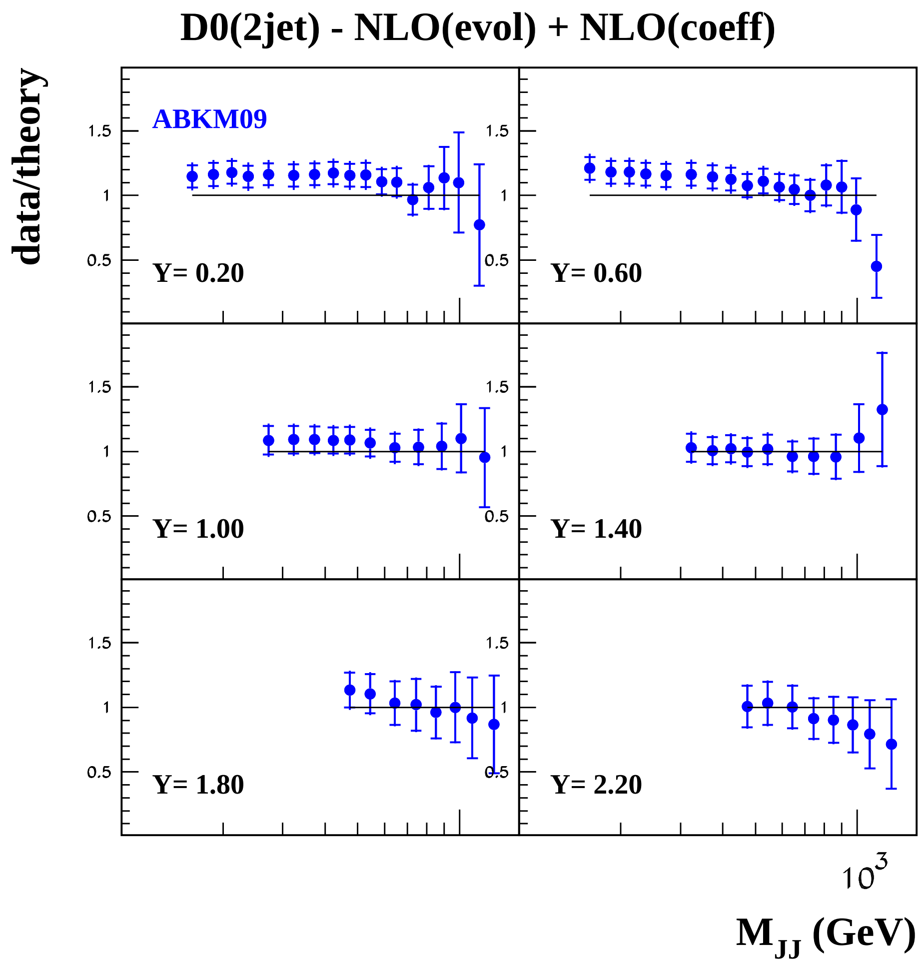
Tevatron jet data (CDF) – 1-jet inclusive

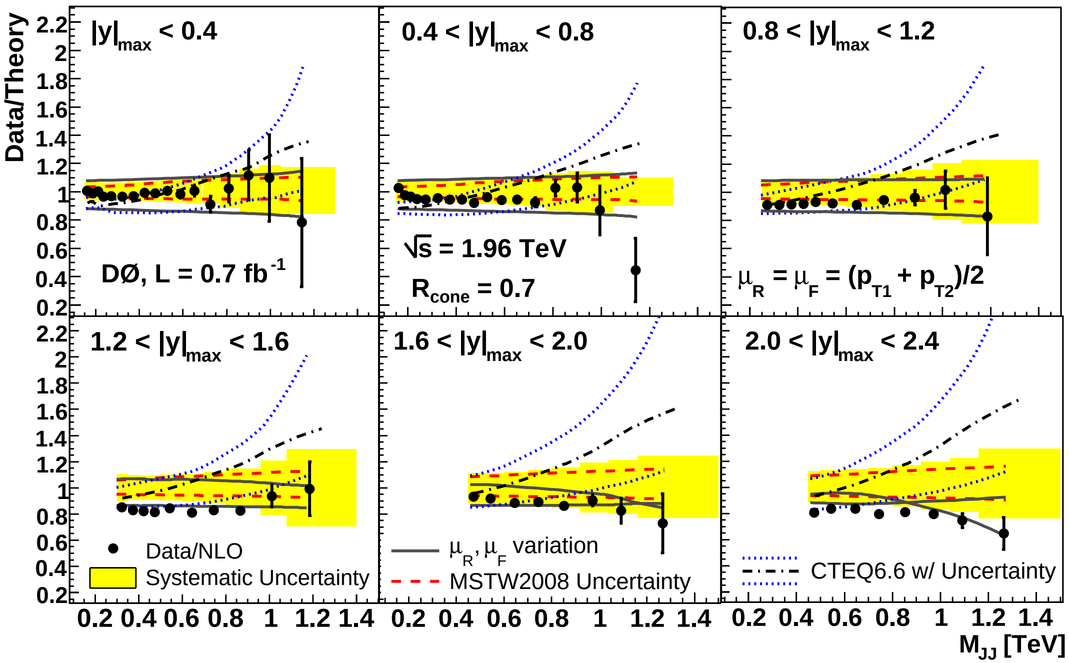




- Cone algorithm (left); k_T algorithm (right); scale $\mu_r = \mu_f = p_T$
- Disagreement in slope at large E_T can hardly be improved
  - large E_T is dominated by quark-quark scattering; PDFs well constrained

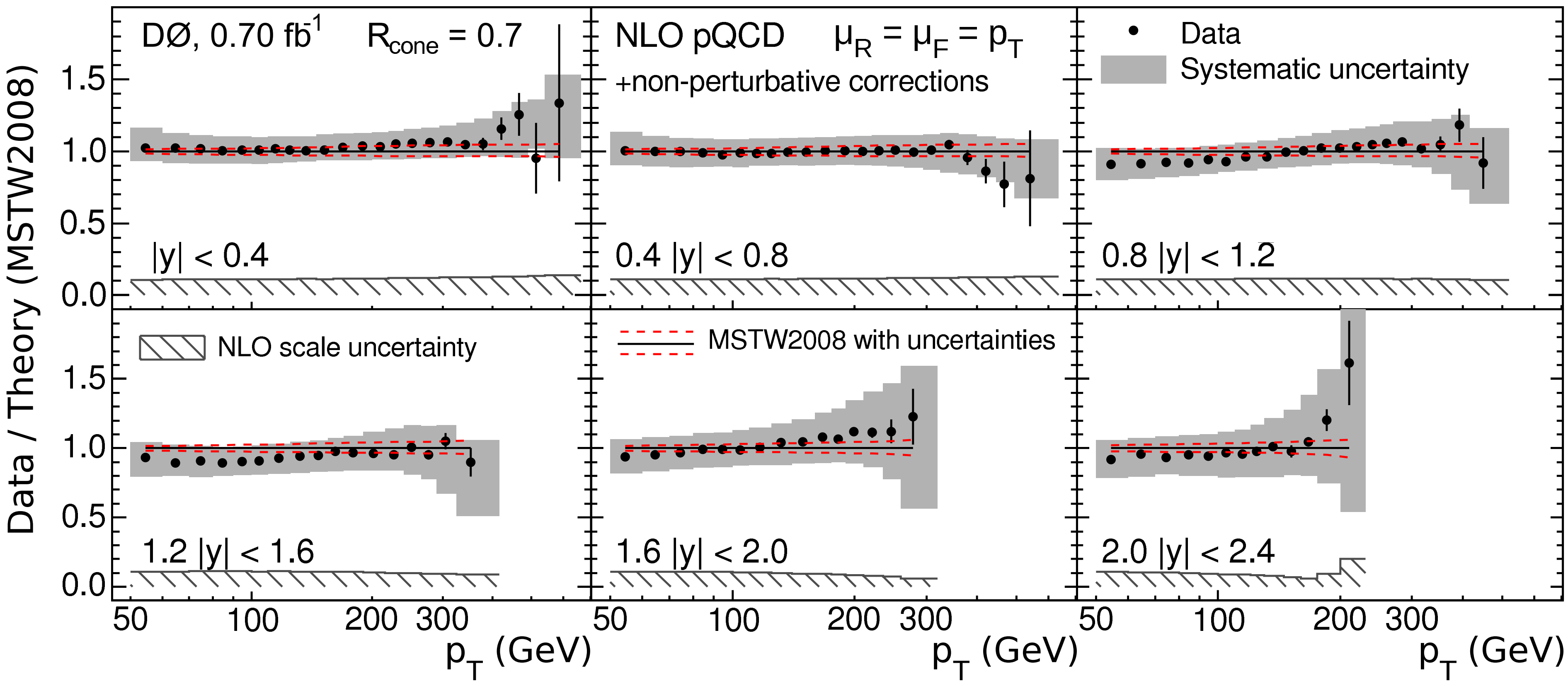
Tevatron jet data (D0) – di-jet invariant mass





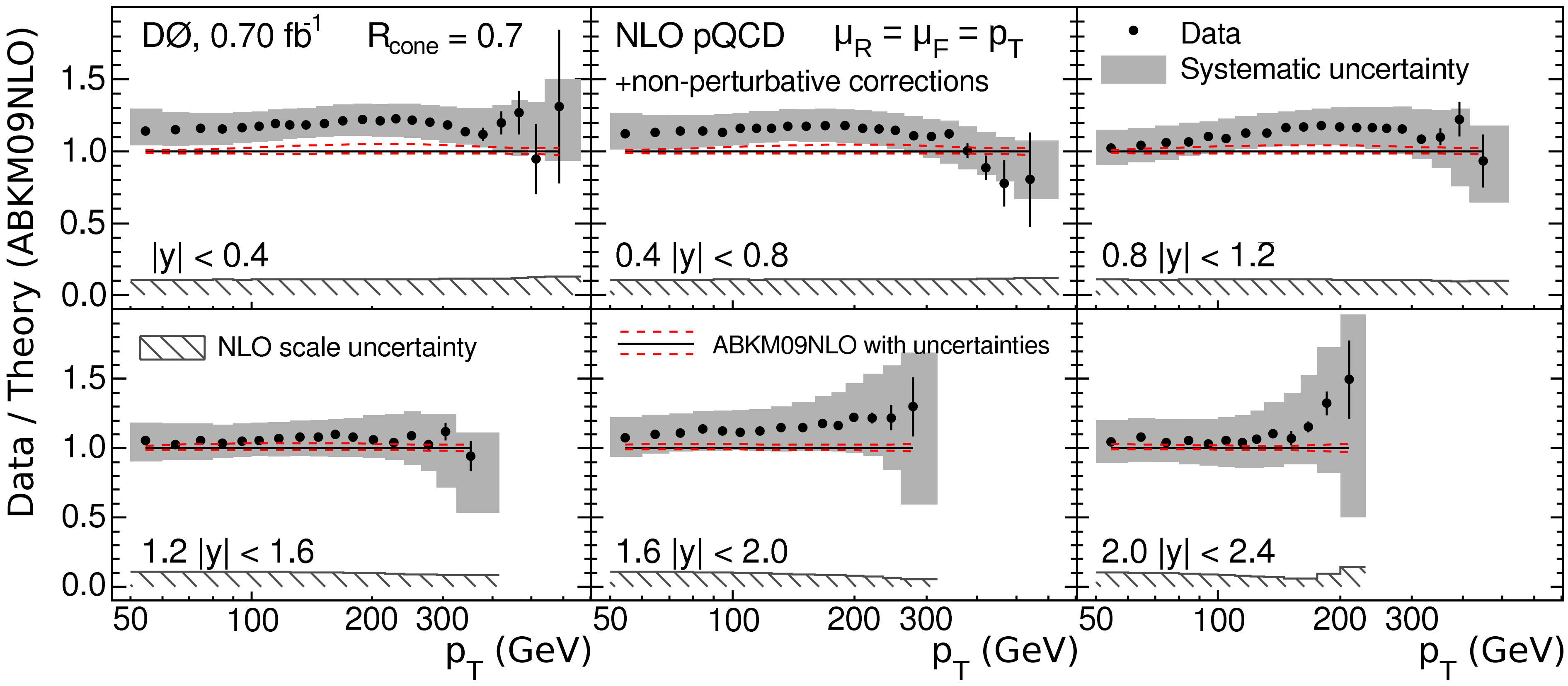
- Predictions for Tevatron di-jet data (no NNLO corrections known)
  Alekhin, Blümlein, S.M. '11 (left); D0 coll. `arXiv:1002.4594` (right)
- Uncertainty due to missing NNLO corrections; scale $\mu_r = \mu_f = M_{JJ}$

New analysis (D0) – 1-jet inclusive



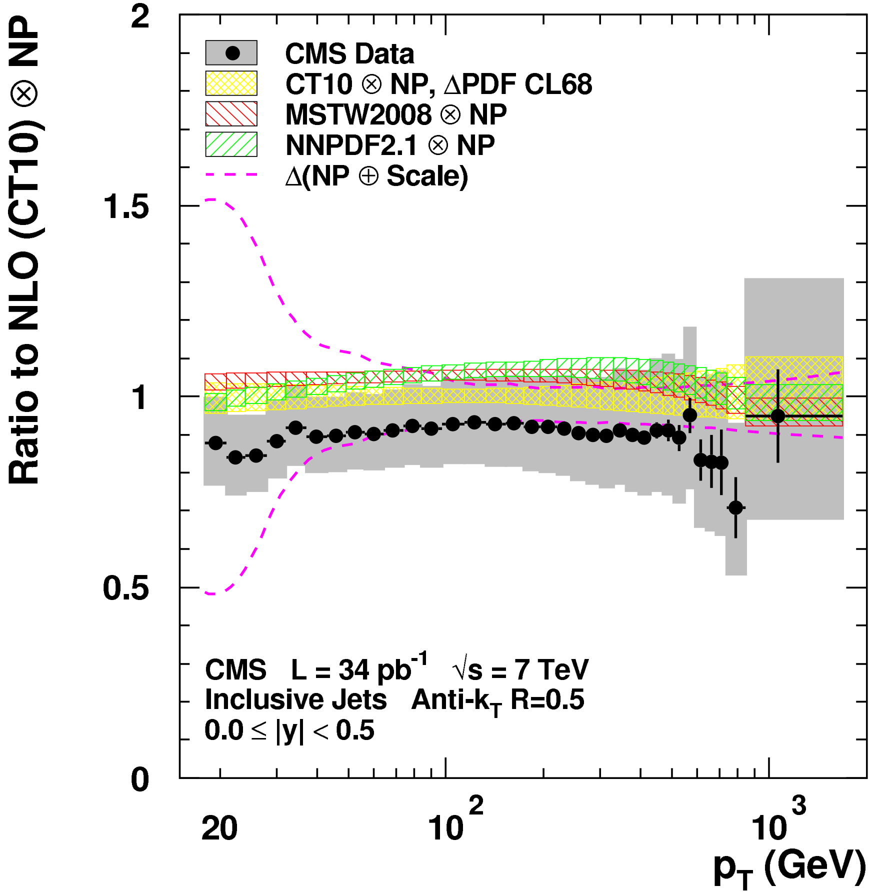
- New analysis of 1-jet inclusive data D0 coll. arXiv:1110.3771
  - MSTW PDF set with PDF (red) and theory (shaded) uncertainty

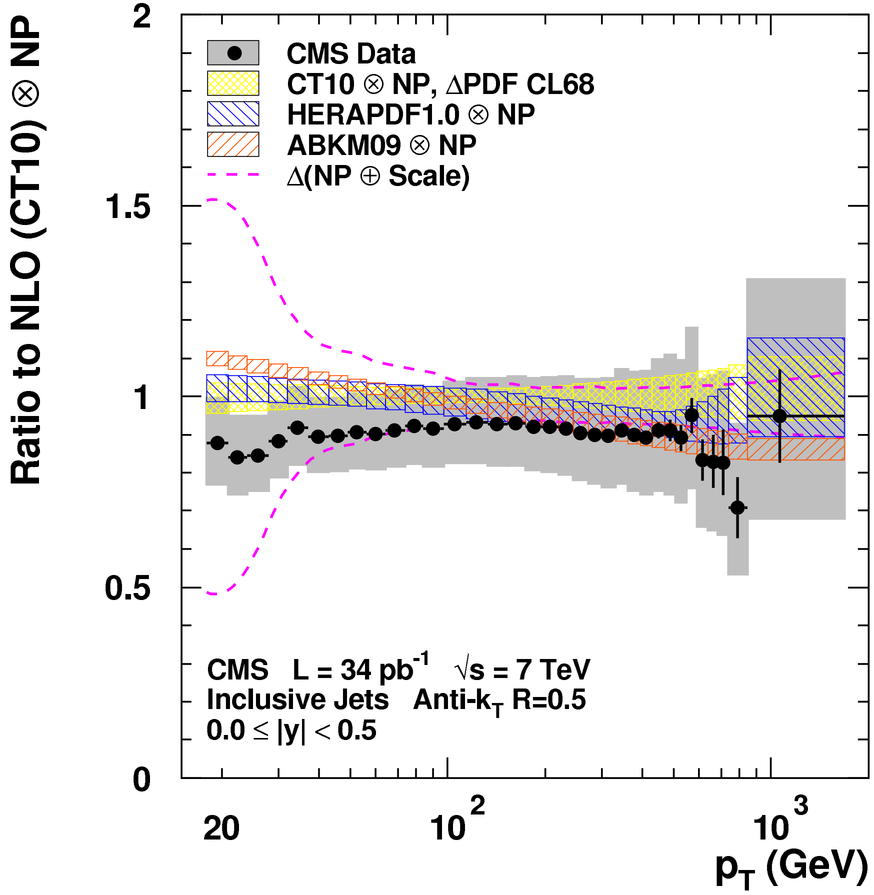
New analysis (D0) – 1-jet inclusive



- New analysis of 1-jet inclusive data D0 coll. arXiv:1110.3771
  - ABKM PDF set with PDF (red) and theory (shaded) uncertainty

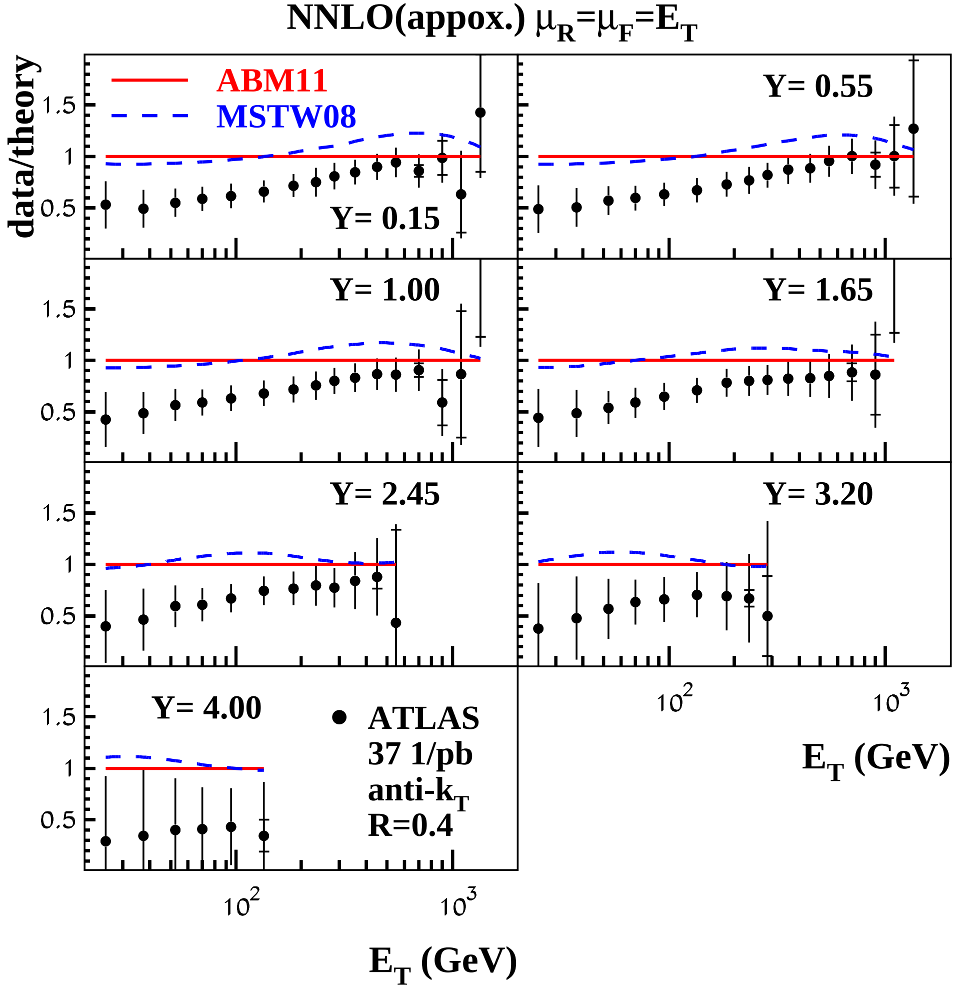
LHC jet data (CMS) – 1-jet inclusive

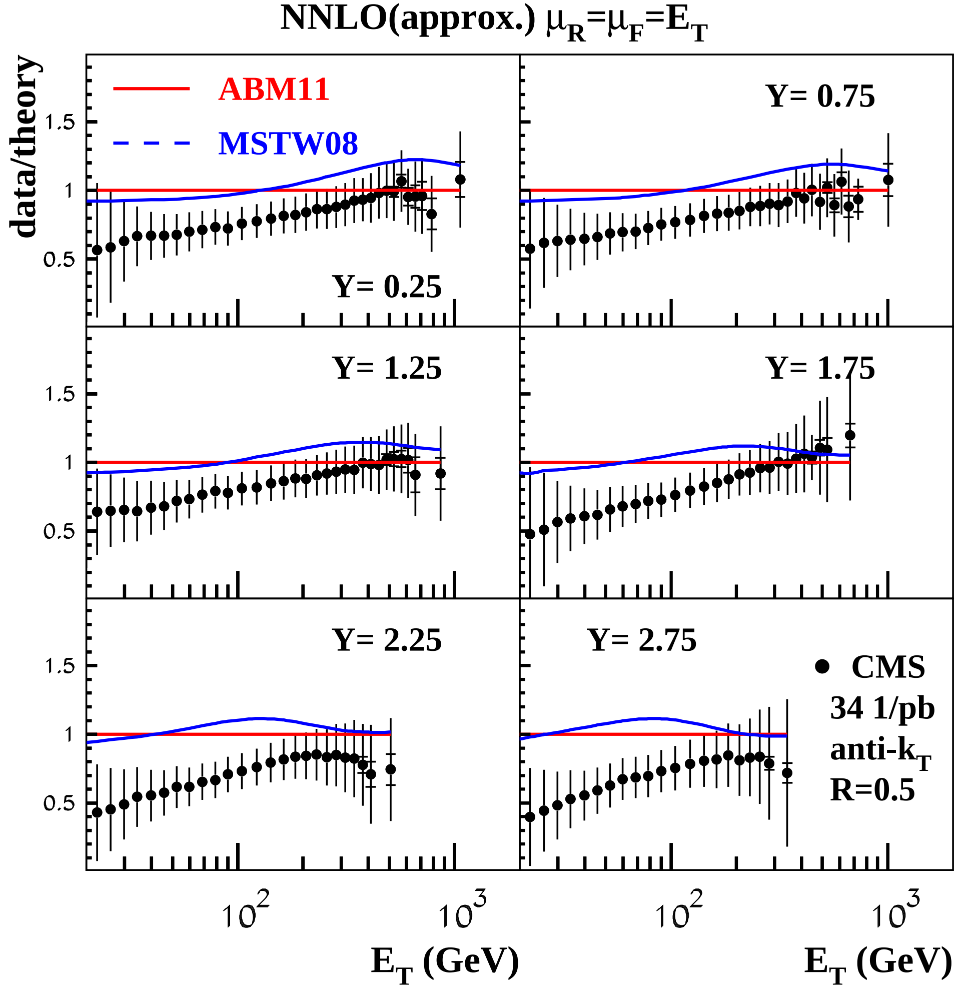




- Analysis of 1-jet inclusive data CMS coll. `CMS NOTE 2011/004`
  - Comparisions of various PDF sets courtesy K. Rabbertz

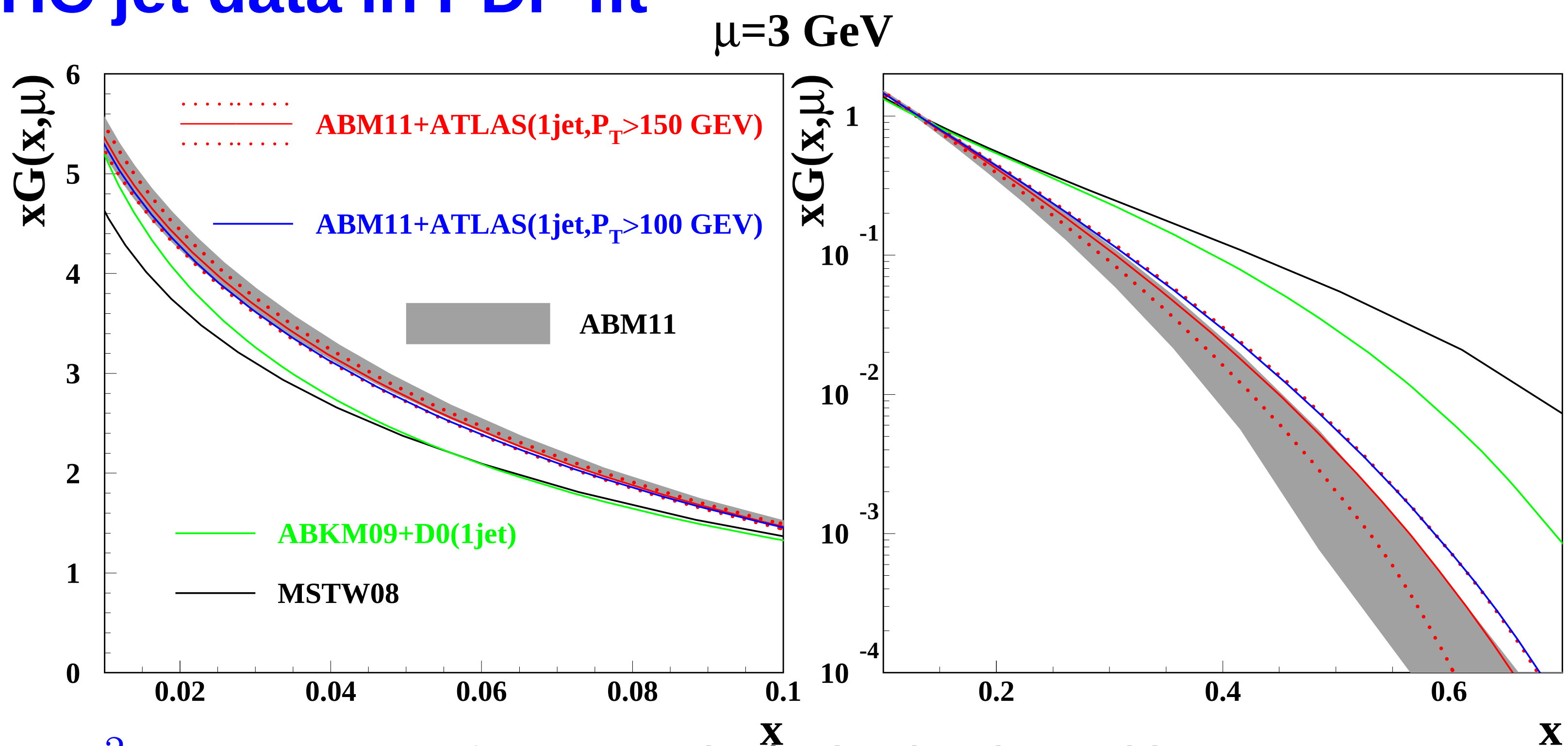
LHC jet data





- Comparision to LHC data: ATLAS coll. (left) and CMS coll. (right) in good agreement
- LHC jet data prefers small gluon PDF at large x

LHC jet data in PDF fit



- $\chi^2/\mathrm{NDP} = 55/55$ for ATLAS inclusive jet data with $p_T > 100/150$ GeV
  Alekhin, Blümlein, S.M. '12
- ATLAS jet data suggest softer gluons than Tevatron jets
- Comparison of α_s values
  - ABM11: $\alpha_s(M_Z) = 0.1134(11)$; Atlas jets: $\alpha_s(M_Z) = 0.1141(8)$
  - NLO analysis: $\alpha_s(M_Z) = 0.1151 \pm 0.0047(\mathrm{exp}) \pm 0.0023(\mathrm{PDFs})$
    Malaescu, Starovoitov '12

Impact on Higgs production rates (Atlas jets)

- Rates for Higgs production at LHC for m_H = 125 GeV
- Cross sections prediction fully consistent with ABM11

LHC at $\sqrt{s} = 7$ TeV	ABM11	Atlas jets $p_T \geq 100$ GeV	Atlas jets $p_T \geq 150$ GeV
$\sigma(H)$ [pb]	$\mathbf{13.23\ {}^{+1.35}_{-1.31}\ {}^{+0.30}_{-0.30}}$	$13.32\ {}^{+1.37}_{-1.33}\ {}^{+0.22}_{-0.22}$	$13.23\ {}^{+1.35}_{-1.31}\ {}^{+0.22}_{-0.22}$

LHC at $\sqrt{s} = 8$ TeV	ABM11	Atlas jets $p_T \geq 100$ GeV	Atlas jets $p_T \geq 150$ GeV
$\sigma(H)$ [pb]	$\mathbf{16.99\ {}^{+1.69}_{-1.63}\ {}^{+0.37}_{-0.37}}$	$17.10\ {}^{+1.71}_{-1.65}\ {}^{+0.27}_{-0.27}$	$16.98\ {}^{+1.69}_{-1.63}\ {}^{+0.27}_{-0.27}$

- MSTW for comparison
  - $\sigma(H) = 14.39\ {}^{+1.54}_{-1.47}\ {}^{+0.17}_{-0.22}$ for LHC7
  - $\sigma(H) = 18.36\ {}^{+1.92}_{-1.82}\ {}^{+0.21}_{-0.28}$ for LHC8

Summary (part II)

Parton distributions

- Legacy of HERA
- Source of largest differences for predictions of Higgs cross sections
  - impact of Tevatron jet data small

Confronting LHC data

- PDFs with LHC jet data change gluon PDF and $\alpha_s(M_Z)$ within quoted uncertainty
  - Atlas jets prefer softer gluon than Tevatron

Phenomenology

- Continuous benchmarking mandatory
  - source of interesting observations