Properties of the strong coupling constant α_S in the proton-proton collisions

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Prague, 8th October, 2018

Obsah

Elementary properties of α_S

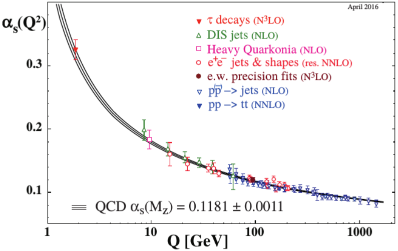
- Basic parameter of SM $\rightarrow$ **coupling constant of the strong interaction**
- Strong interaction $\rightarrow$ **renormalizable** QCD
- Dependence on the choice of the **renormalization scale** $\mu_R \leftrightarrow$ **running coupling**
- $\alpha_S(Q^2 \simeq \mu_R^2) \Rightarrow$ proportional to an effective strength of the interaction
- **Renormalization group equation**:

$$\mu_R^2 \frac{d\alpha(\mu_R)}{d\mu_R^2} = \beta(\alpha_S(\mu_R)) = -(b_0\alpha^2 + b_1\alpha^3 + \ldots), \quad (1)$$

- First loop coefficient: $b_0 = \frac{33 - 2n_f}{12\pi}$
- Its value can not be obtained from the theory $\rightarrow$ it must be inserted.

In LO:

$$\alpha_S(Q^2) = \frac{\alpha_S(Q_0^2)}{1 + \frac{7}{4\pi}\alpha_S(Q_0^2)\ln(\frac{Q^2}{Q_0^2})} = \frac{1}{C\ln(\frac{Q^2}{\Lambda^2})}, \quad (2)$$



Motivation for measurement of α_S

Where is the value of α_S needed?

- In enters to all calculations of the matrix elements (QCD) ⇒ cross sections σ at the LHC
- Indirectly to parton distribution functions (DGLAP)
- Question concerning about the unification of interactions/coupling constants at high energetic scales

$$\sigma_{AB} = \sum_{a,b} \int_0^1 dx_1 \int_0^1 dx_2 f_{a/A}(x_1, \mu_F^2) f_{b/B}(x_2, \mu_F^2) \underbrace{[\sigma_0 + \alpha_S(\mu_r^2)\sigma_1 + \cdots]_{ab}}_{\sigma_{ab}}, \quad (3)$$

Example - $\sigma_{Higgs-boson}$

- Prediction of Lattice QCD: $\alpha_S(M_Z^2)$ =0.11840±0.00060
- Prediction based on fit of thrust distribution from e^+e^- collisions: $\alpha_S(M_Z^2)$ =0.1135±0.00105
- Difference in value 0.118 and 0.113 ⇒ **reduction of 8–9%**
- Higher variation than is caused by any theoretical or experimental uncertainty

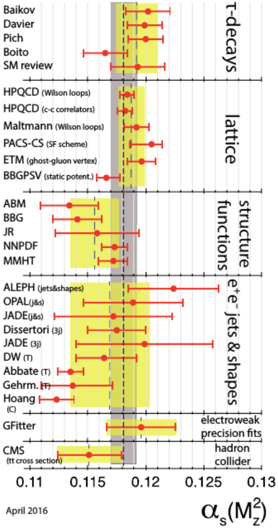
- The value of α_S is needed to know with a high precision (under 1%)

Recent results of α_S:

- Prediction based on cross sections (collisions of hadron-hadron, hadron-lepton) production of $t\bar{t}$ (ATLAS, CMS a Tevatron): $\alpha_S(M_Z^2)$ =**0.1157±0.0034**
- Lattice QCD (FLAG): $\alpha_S(M_Z^2)$ =**0.1184±0.0012**
- Jet production and observables (OPAL): $\alpha_S(M_Z^2)$ =**0.1189±0.0041**
- τ decay (Devier et al.): $\alpha_S(M_Z^2)$ =**0.1199±0.0015**
- Structure fuction - PDF and evolution equation (CT14): $\alpha_S(M_Z^2)$ =$\mathbf{0.1150^{+0.0036}_{-0.0024}\pm 0.0010}$

PDG world average:

$$\alpha_S(M_Z^2) = 0.1181 \pm 0.0011$$

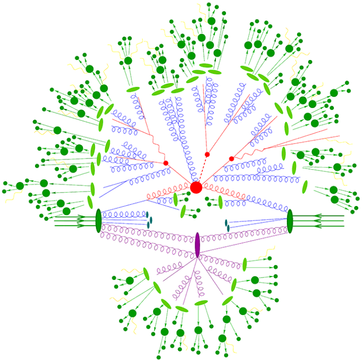


Parameters of the simulation

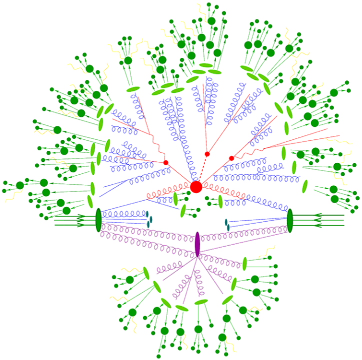
- Collisions of pp with energy $\sqrt{s} = 13$ TeV
- MC generator: Pythia 8.235
- Tune: A14 (ATLAS 2014)
- LO PDF set: MSTW2008, HERAPDF15, CTEQ6l1, NNPDF23
- Range of α_S = 0.105 - 0.133
- Generated in 17 $\hat{p}_T$ bins from 50 to 4941 GeV with 10^5 events

50	200	300	400	500	642
786	894	952	1076	1162	1310
1530	1992	2500	3137	3937	4941

- Use of default processes (hard QCD, ISR, FSR, MPI, etc.)
- Cuts: $p_T > 50$ GeV a $|y| < 3$ ($|y^*| < 3$ for dijet)
- Jet algorithm: Anti-k$_t$ s R =0.4



Parameters of the simulation



- LO QCD2to2 Herwig 7.1.2, MMHT2014,
  $15 \cdot 10^6$ events in 6 samples (in GeV):

  40 | 100 | 200 | 400 | 800 | 1600 | 8000

- LO Matchbox Herwig 7.1.2,
  MadGraph OpenLoops, MMHT2014,
  $17.5 \cdot 10^6$ events 5 samples (in GeV):

  50 | 650 | 1000 | 1500 | 2000 | 8000

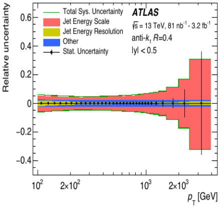
- NLO Matchbox Herwig 7.1.2,
  MadGraph OpenLoops, MMHT2014,
  $6 \cdot 10^6$ events 2 samples (in GeV):

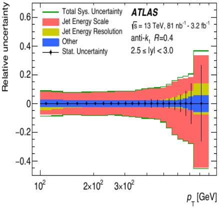
  50 | 650 | 8000

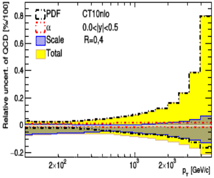
- Cuts: $p_T > 100$ GeV a $|y| < 4.8$

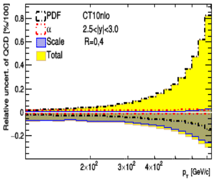
Set of variables

- Inclusive cross section:
  $\frac{d\sigma}{dp_T}$, $\frac{d\sigma}{dm_{jj}}$, $\frac{d^2\sigma}{dp_T dy}$
- Normalized cross section:
  $\frac{1}{\sigma}\frac{d\sigma}{d\Phi}$, $\frac{1}{\sigma}\frac{d\sigma}{dy}$, $\frac{1}{\sigma_{dijet}}\frac{d\sigma_{dijet}}{d\Delta\Phi_{dijet}}$
- Ratio of cross sections:
  $R_{\Delta\Phi}$, $R_{3/2}$, $R_{\Delta R}$
- **Main experimental uncertainty**: Jet σ is depended on jet p_T $\Rightarrow$ highly affected by calibration of jet energy (**JES**)
- **Main theoretical uncertainty:** originates from **PDF**
- A variable, which reduces these uncertainties, is needed $\rightarrow$ normalization/ratios
- Sensitivity to α_S value



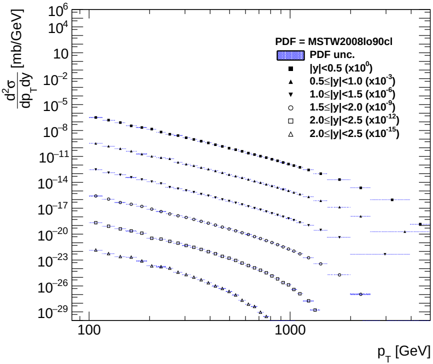




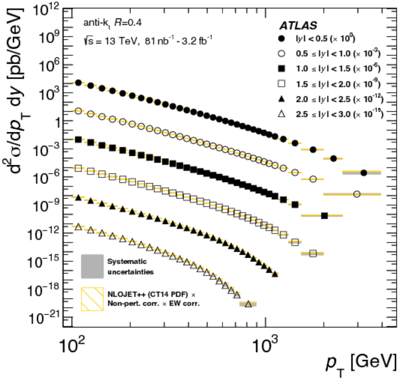


Double differential inclusive cross sections

Inclusive p_T y spectrum (our result, Pythia LO):

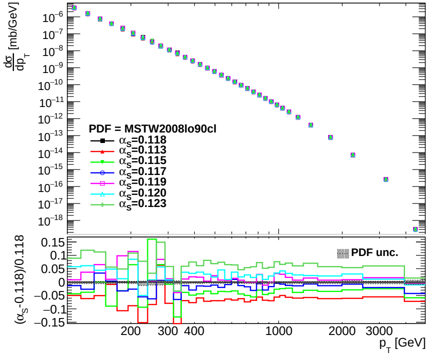


ATLAS paper $\sqrt{s} = 13$ TeV[ref]:

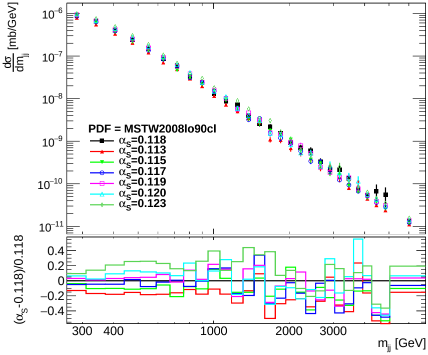


Differential inclusive cross sections

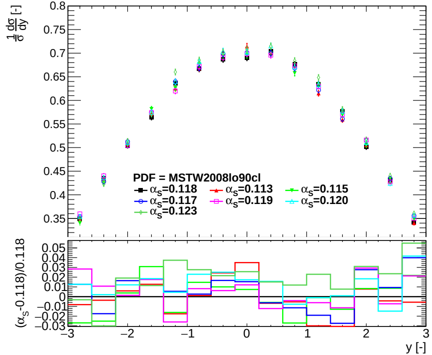
Inclusive p_T spectrum (Pythia LO):

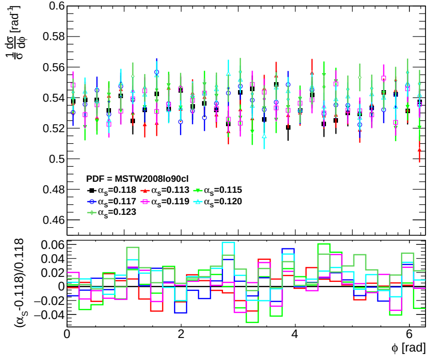


Dijet mass spectrum (Pythia LO):

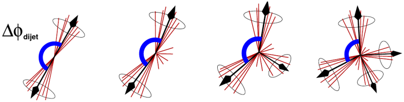


Normalized differential cross sections





Azimuthal correlation

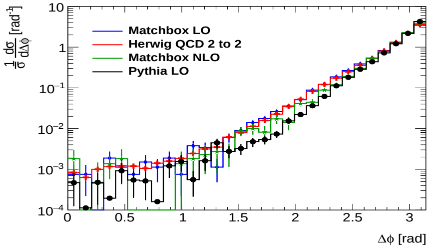


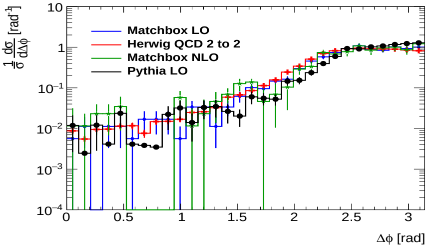
- Definition of observable [ref]:

$$\frac{1}{\sigma_{dijet}} \frac{d\sigma_{dijet}}{d\Delta\phi} \tag{4}$$

- Azimuthal angle: $\Delta\phi = |\phi_{jet1} - \phi_{jet2}|$
- Decrease of the angle is caused by **radiation of another energetic parton**
  $\Rightarrow$ sensitive to change of α_S
- **The normalization of the azimuthal correlation (division by** σ_{dijet}**)**
  $\Rightarrow$ reduction of the uncertainties (JES, PDF)

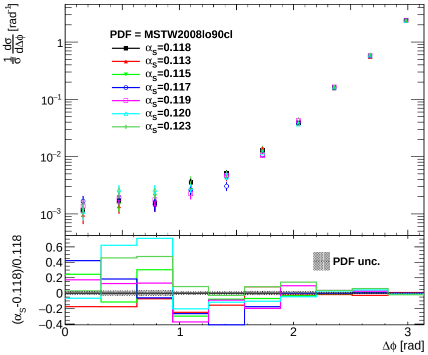
Events with at least 2 (upper) and 3 (lower) jets:



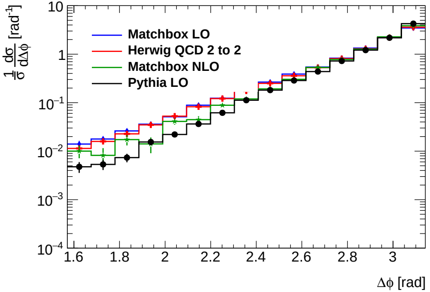


Normalised azimuthal angular correlation

Variation of α_S (Pythia LO):



Different MC generators:



Quantity $R_{\Delta\Phi}$

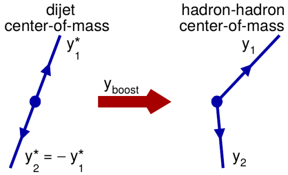
- Definition of the variable[ref]:

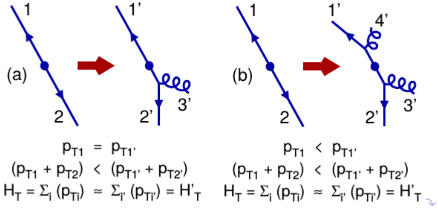
$$R_{\Delta\Phi}(H_T, y*, \Delta\Phi_{max}) = \frac{\frac{d^2\sigma\left(\Delta\Phi_{dijet}<\Delta\Phi_{max}\right)}{dH_T dy^*}}{\frac{d^2\sigma(inclusive)}{dH_T dy^*}} \qquad (5)$$

- Quantity H_T:

$$H_T = \sum_{j \in C} p_{Ti}, \quad C = \left[\, j \,|(p_{Tj} > p_{Tmin}) \,\vee\, (|y_j - y_{boost}| < y^*)\right] \qquad (6)$$

- A dependence of pQCD on rapidity can be probed in different intervals of y^*
- $\Delta\Phi_{max}$ $\rightarrow$ reflects the topology $\rightarrow$ "hardness"additional jet from dijet event





Variable $R_{\Delta\Phi}$

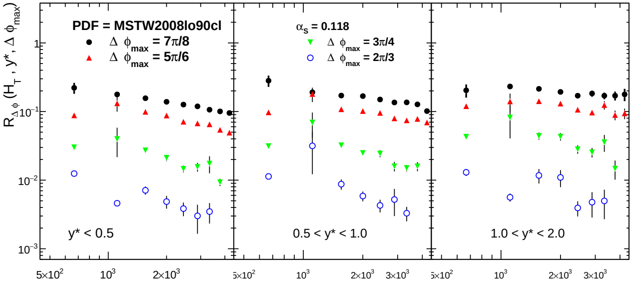
- Definition of the variable:

$$R_{\Delta\Phi}(H_T, y*, \Delta\Phi_{max}) = \frac{\frac{d^2\sigma\left(\Delta\Phi_{dijet} < \Delta\Phi_{max}\right)}{dH_T dy^*}}{\frac{d^2\sigma(inclusive)}{dH_T dy^*}} \quad (7)$$

- Quantity H_T:

$$H_T = \sum_{j \in C} p_{Ti}, \quad C = \left[\, j \,|(p_{Tj} > p_{Tmin}) \vee (|y_j - y_{boost}| < y^*)\right] \quad (8)$$

- **Dependence of pQCD on rapidity** can be probed in different intervals of y^*
- $\Delta\Phi_{max}$ $\rightarrow$ reflects the topology of the final state $\rightarrow$ **"hardness"of additional jet** to dijet event

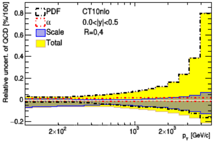


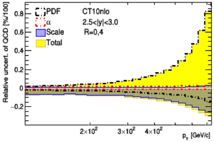
Parametrization of PDF:

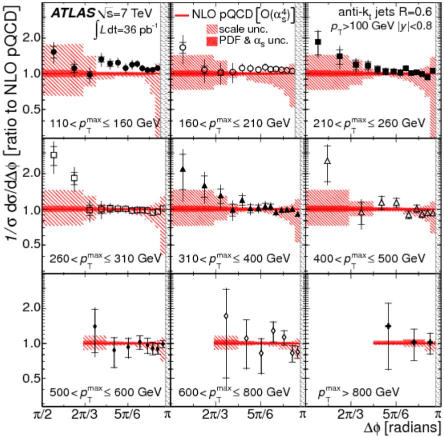
- Computation method differs for some PDF sets
- Most of them use *Hessian method*
- NNPDF sets proceed according to "envelope" (scales)

Scales μ_F and μ_R:

- Multiplied $(C_{\mu_F}; C_{\mu_R})$: (1/2;1), (1;1/2), (1/2;1/2), (2;1), (1;2), (2;2)
- Uncertainty = maximal contribution from all variations with respect to default one



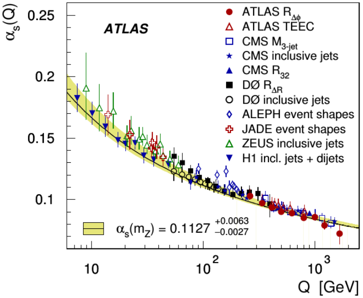




Conclusion

Future development:

- Finish the analysis and make a comparison with ATLAS data → prediction of α_S value
- Use another MC generator: Sherpa
- Different way of a theoretical prediction: NLOJET++



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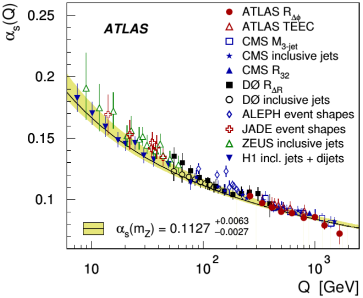

Thank you for your attention!