Quark Compositeness in ATLAS

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Quark compositeness in ATLAS

- To describe quark compositeness a simple isoscalar left-left four-fermion contact interaction was added to QCD (as an analogy to Fermi approximation):

$$L_{qqqq} = \frac{\eta g^2}{2\Lambda_q^2} \overline{\Psi_q^L} \gamma^\mu \Psi_q^L \overline{\Psi_q^L} \gamma^\mu \Psi_q^L,$$

$$L = L_{QCD} + L_{qqqq}$$

- Λ (TeV) – scale, η – interference sign (+1 used here, destructive), $g^2 = 4\pi$.
- Are quark composite? Tevatron Run I: not up to $\Lambda \sim 2$ TeV.
- ATLAS detector with E_{CMS} = 14 TeV, calorimeter $\eta_{max} = 4.9$ and ability to measure high-p_T jets is especially suitable to extend our knowledge further.

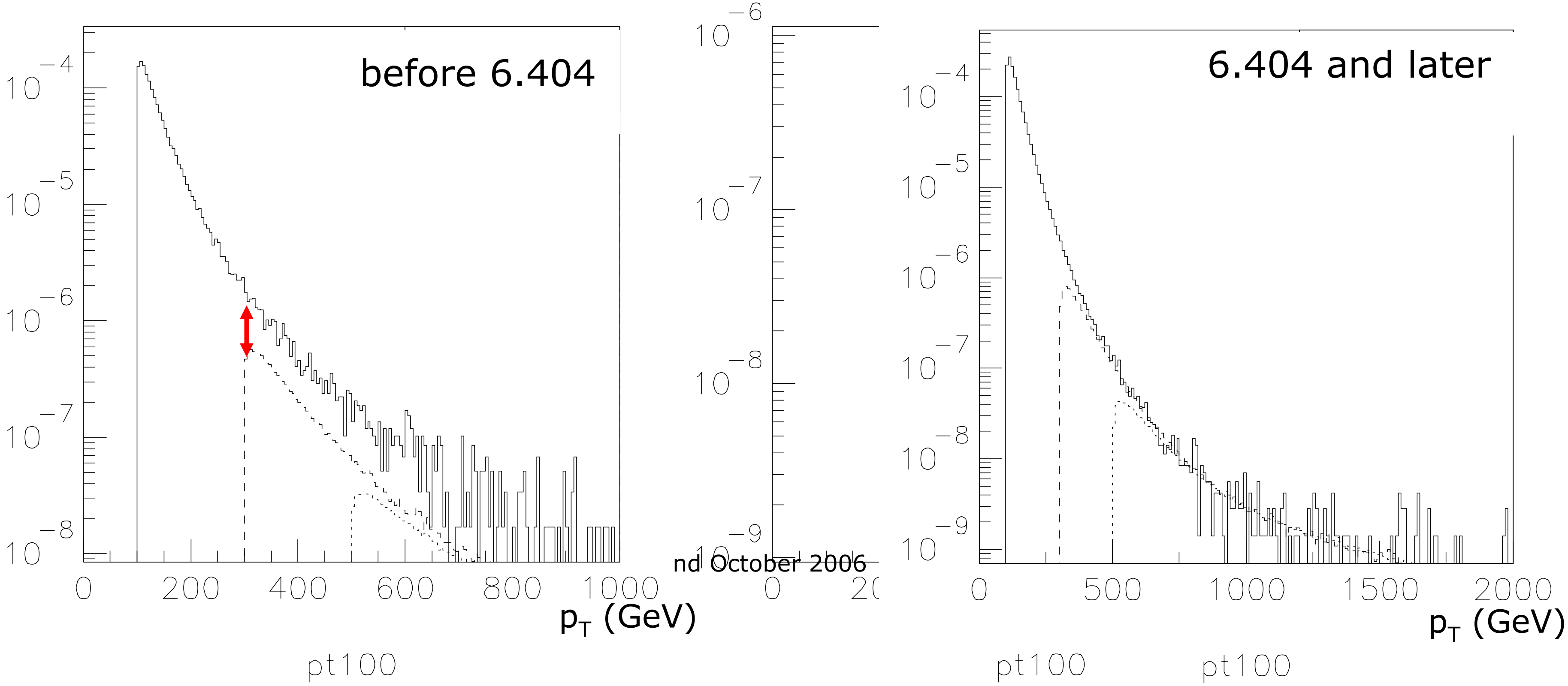
Quark compositeness

- Simulated samples:
  - Λ = 3, 5, 10, 20 and 40 TeV, QCD.
  - All quarks composite
  - Events generated in Pythia (Rome settings), fast simulation done in Athena 11.0.41 framework, using Atlfast. Analysis done on Analysis Object Data (AOD).

- What is investigated:
  - Inclusive jet production cross-section $d\sigma/dp_T$. For high p_T the contact term above (CT) causes excess of events above standard QCD p_T spectrum. p_T spectrum is sensitive to PDF uncertainties and systematics (e.g. calorimeter nonlinearity). This effect can mask or fake compositeness scenario.
  - Dijet angular distribution. Contact term causes excess of events with small pseudorapidity. Smaller dependance on systematics.

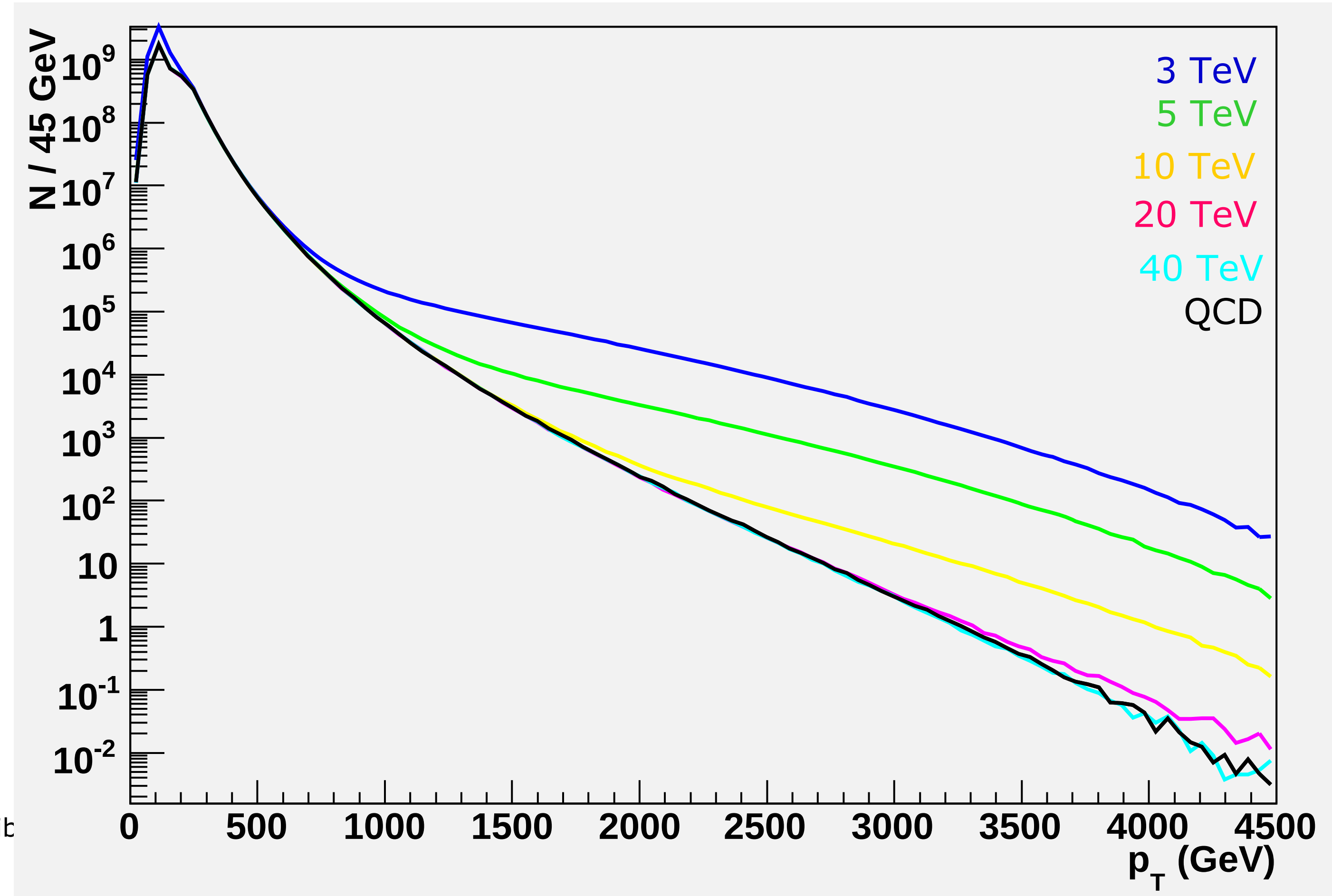
About Pythia

- Switch MSEL=51 used
  - problem with ISR encountered
  - thanks to T. Davidek for help
  - solved in 6.404 (thanks to T.Sjostrand)
  - solution compiled to Athena 11.0.41



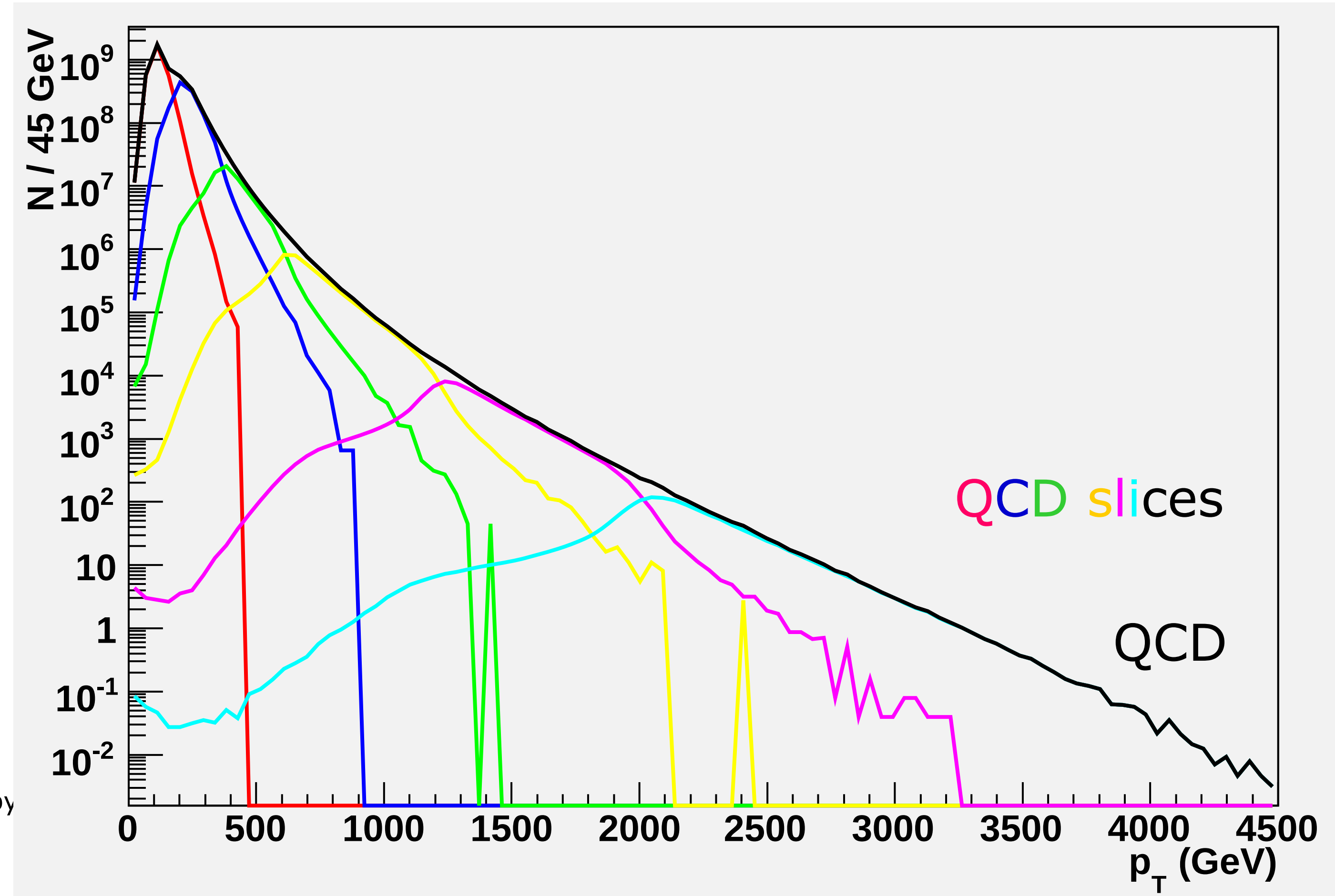
Inclusive jet production cross-section

- Inclusive leading dijet p_T spectrum for various Λ.
- Integral luminosity 20 fb^{-1}.



Inclusive jet production cross-section

- In order to cover such a large p_T range (from trigger 2j350 to TeV scale), the data had to be sewn from several p_T slices.



Inclusive jet production cross-section

- To characterize the excess of high-pT events one can use:

$$R = \left(\frac{N(E_T > E_T^0)}{N(E_T < E_T^0)} \right)_{CT+QCD} / \left(\frac{N(E_T > E_T^0)}{N(E_T < E_T^0)} \right)_{QCD}$$

- E_T^0:=1100 GeV to optimize R_{dist}. For 10 fb^{-1}:

Λ (TeV)	R	σR	R_{dist}
3	3.39	0.02	145
5	1.81	0.01	78
10	1.05	<0.01	8.0
20	1.01	<0.01	2.2
40	1.004	0.006	0.62

To quantify the distance from QCD spectrum:

$$R_{dist} = \frac{R(\Lambda) - R\,(SM)}{\sigma_{R(\Lambda)}}$$

Inclusive jets – discovery limits

- Int. luminosities to achieve R_{dist} = 3

Λ (TeV)	3	5	10	20	40
L (fb^{-1})	4.3 pb^{-1}	15 pb^{-1}	1.4 fb^{-1}	19 fb^{-1}	234 fb^{-1}

- R_{dist} values for L = 300 fb^{-1}.

Λ (TeV)	3	5	10	20	40
R_{dist}	794	427	44	12	3.4

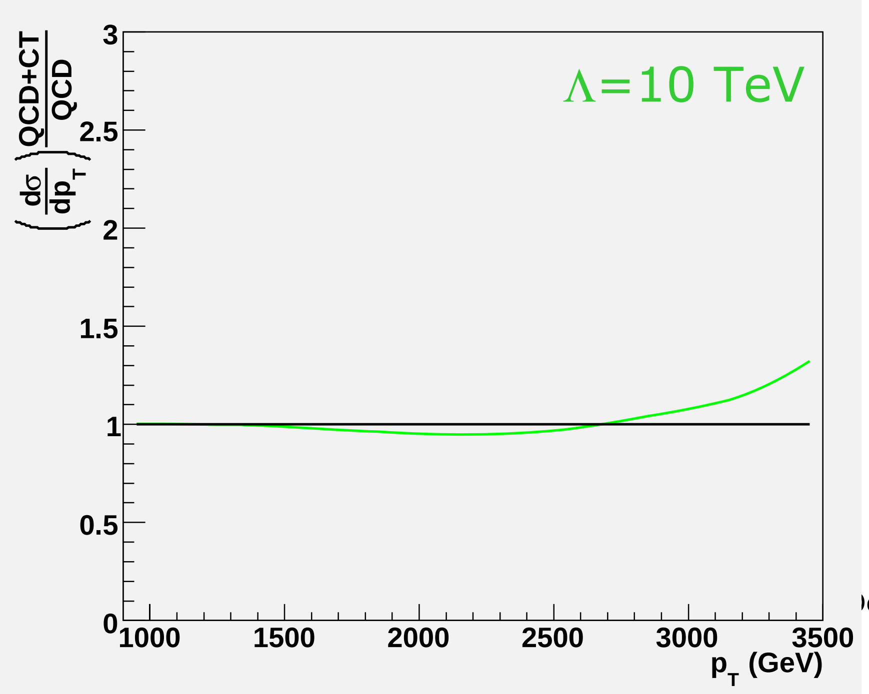
- Λ = 3, 5, 10 TeV might be rulled out or verified with first tens of pb^{-1} of good data.
- But *no systematics* is included (PDF, nonlinearity,...)
- Therefore the required L will be larger, in case of Λ = 40 TeV the discovery is still unclear.

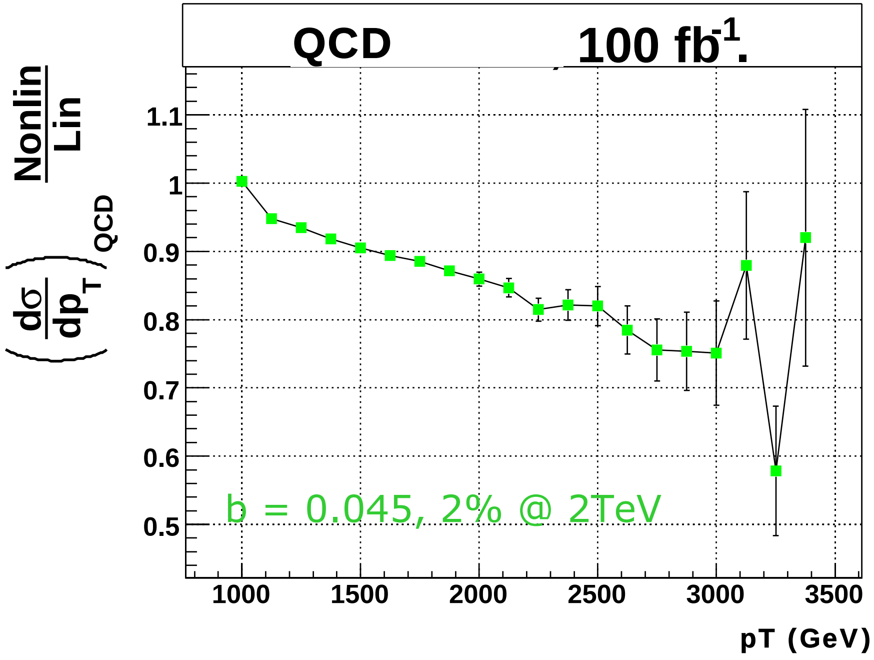
Inclusive jets – calorimeter nonlinearity

- What effect a calorimeter nonlinearity will make?
- To parametrize nonlinearity of ATLAS hadronic calorimeter (simple method):

$$E_T(meas.) = E_T \frac{1}{c(1+(e/h-1)b\ln E_T)}$$

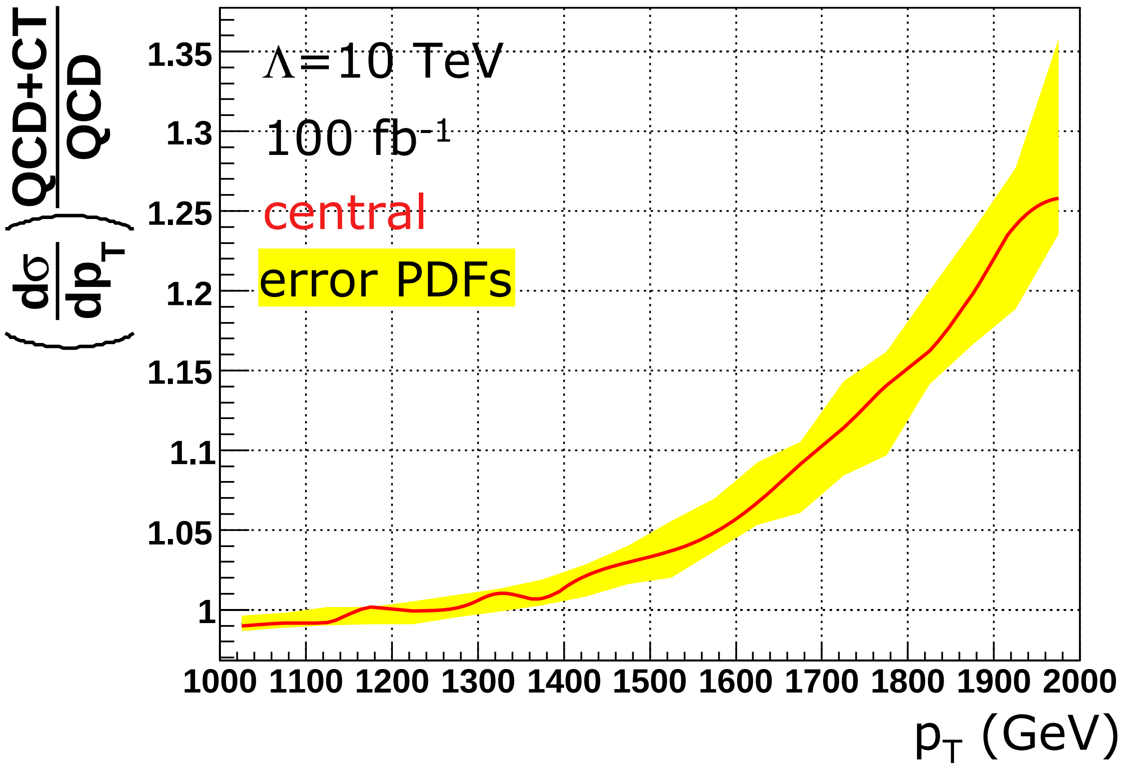
- e/h - noncompensation, b – nonlinearity (smaller values achievable by e.g. weighting method)
- c makes nonlin. and lin. spectra equal at 500 GeV.





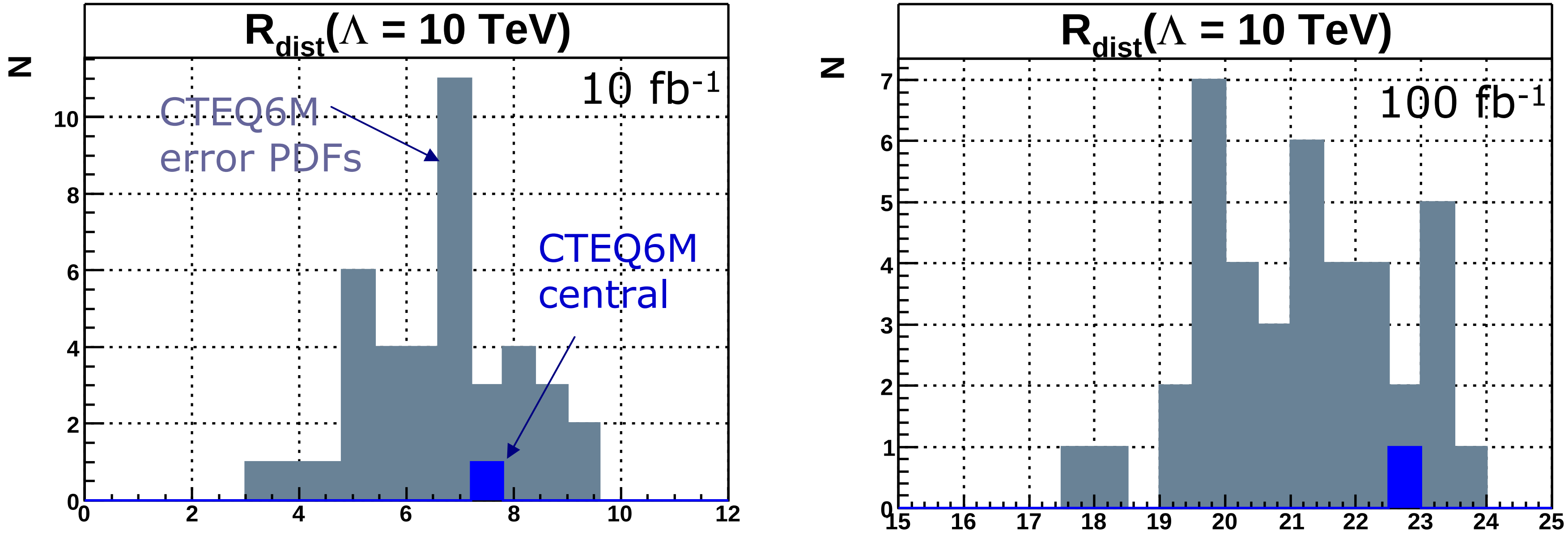
PDF uncertainty studies

- For the purpose of uncertainty calculations CTEQ6M PDFs were used. These are based on NLO calculations fitted to DIS data.
- The global fit of data is 20 parametric, thanks to that we have 40 error PDFs (+ one central value) that were used to generate the data below.
- PDF uncertainty studies done with Pythia 6.326, but repaired for ISR, p_T > 1 TeV.



PDF uncertainty studies

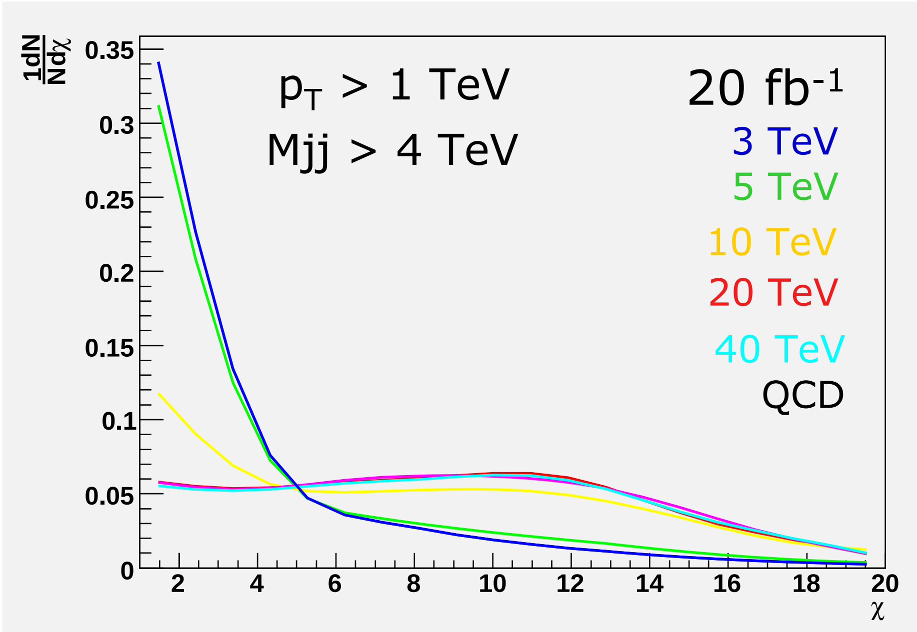
- R_{dist} can be calculated for each PDF:



- Systematic error due to PDF uncertainties in this case $\sigma_{PDF}(R_{dist})$= 1.40. Compare it to $R_{dist}(\Lambda$=40TeV, 300 fb^{-1}) = 3.40.

Dijet angular distibution - Rχ

- We need a variable less sensitive to calo nonlinearity and more unique to compositeness (inclusive jet c.s is similar to graviton)- dijet angular distribution.



- Two leading jets with η_1, η_2.

$$\chi = e^{|\eta_1 - \eta_2|}$$

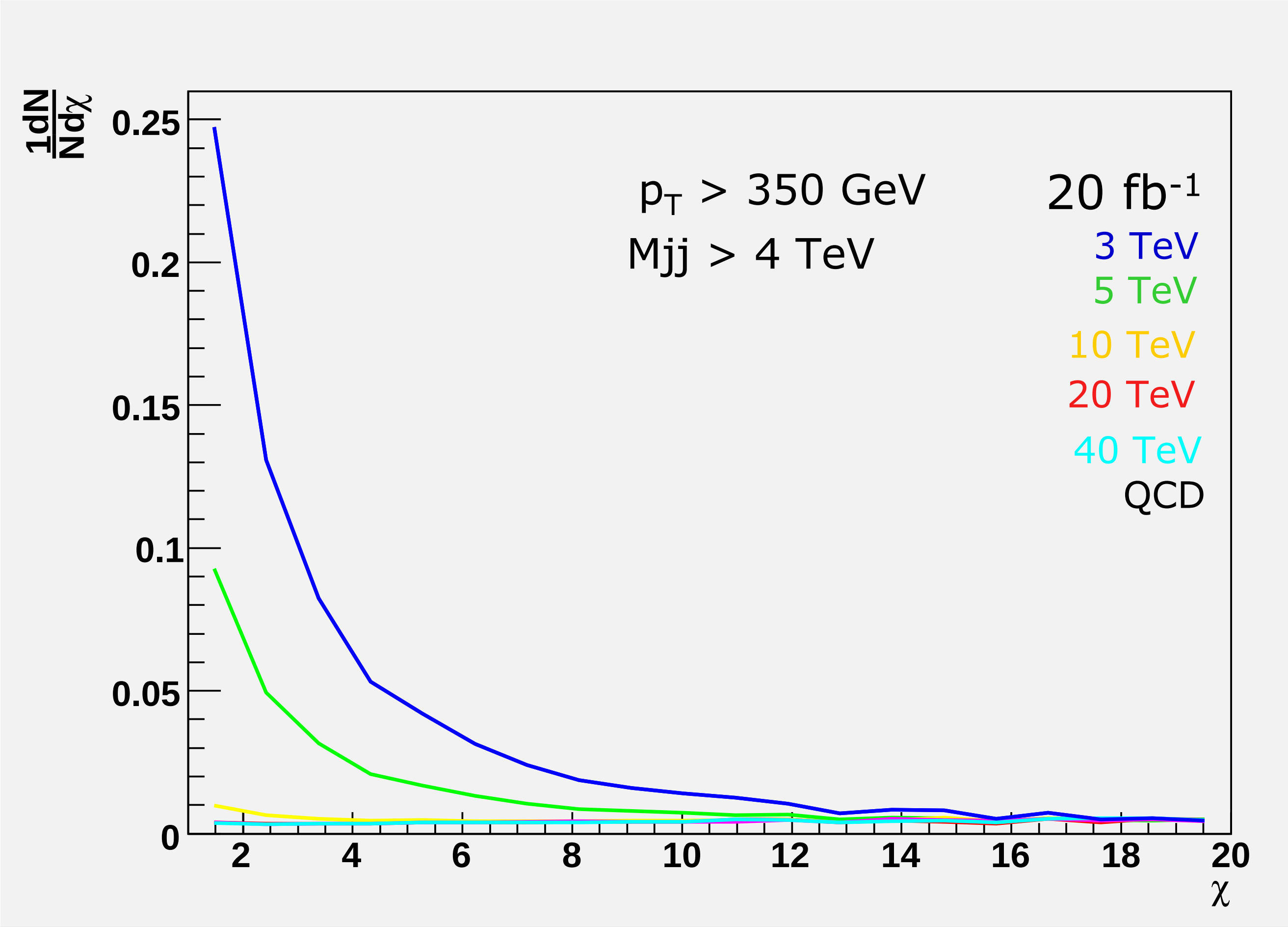
- To characterize this distribution:

$$R_\chi = N(\chi < \chi_{cut}) / N(\chi > \chi_{cut})$$

- χ_{cut}= 2.8 (to get the largest difference between Λ and SM)

Dijet angular distibution

- It is worth using again pT > 350 GeV (see later).



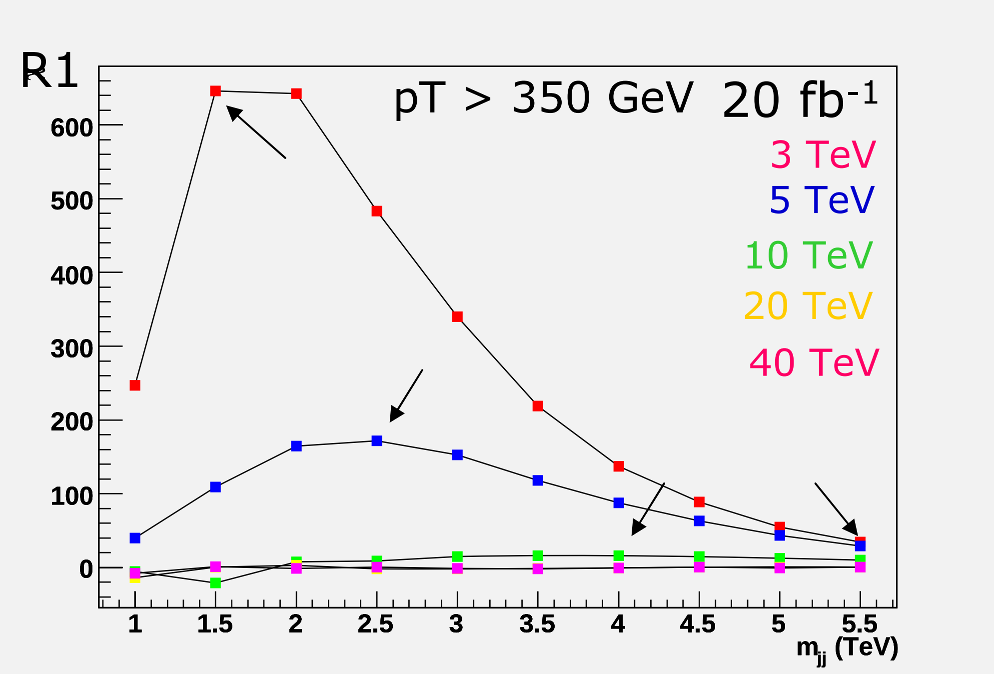
R1

- Way to quantify difference between SM QCD and QCD+CT:

$$R_1 = \frac{R_\chi(\Lambda) - R_\chi(SM)}{\sqrt{\sigma_\Lambda^2 + \sigma_{SM}^2}}$$

- For 20 fb^{-1}:

Λ(TeV)	$R1_{350}$	$R1_{1000}$
3	646	100
5	172	71
10	16	10
20	2.3	0.7
40	0.65	<0.1



- Dijet invariant mass (m_{jj}) lower cut tuned also to optimum for each Λ.

R1 – discovery limits

- Int. luminosities to achieve R1 = 3

Λ (TeV)	3	5	10	20	40
L (fb^{-1})	< 1 pb^{-1}	6 pb^{-1}	0.7 fb^{-1}	34 fb^{-1}	426 fb^{-1}

- R1 values for L = 300 fb^{-1}.

Λ (TeV)	3	5	10	20	40
R_{dist}	2500	665	62	8.9	2.5

- Λ = 3, 5, 10 TeV might be rulled out or verified with first tens of pb^{-1} of good data.
- But *no systematics* is included (PDF, nonlinearity,...)
- Therefore the required L will be larger, in case of Λ = 40 TeV the discovery is unclear.

R1 – attempt without gluons

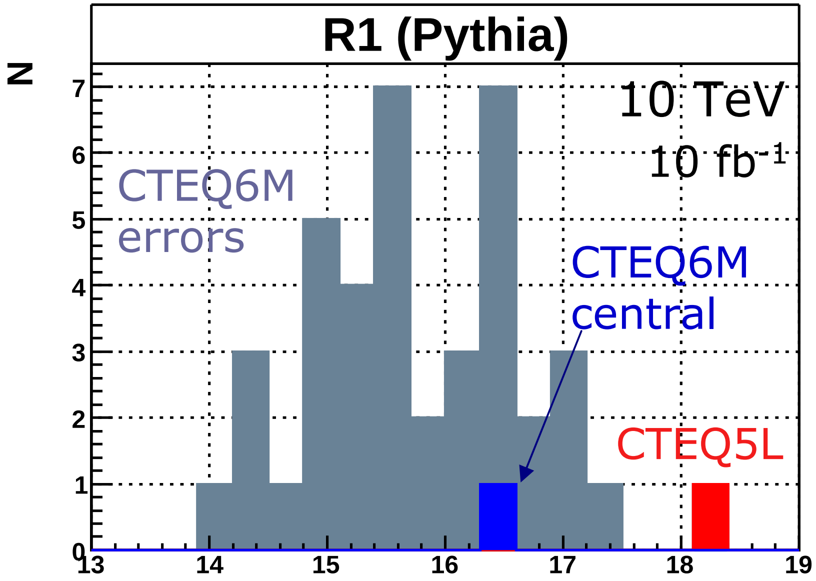
- Gluons do not enter the CT. When omitting the gluon jets, the discovery potential increases (20 fb^{-1}):

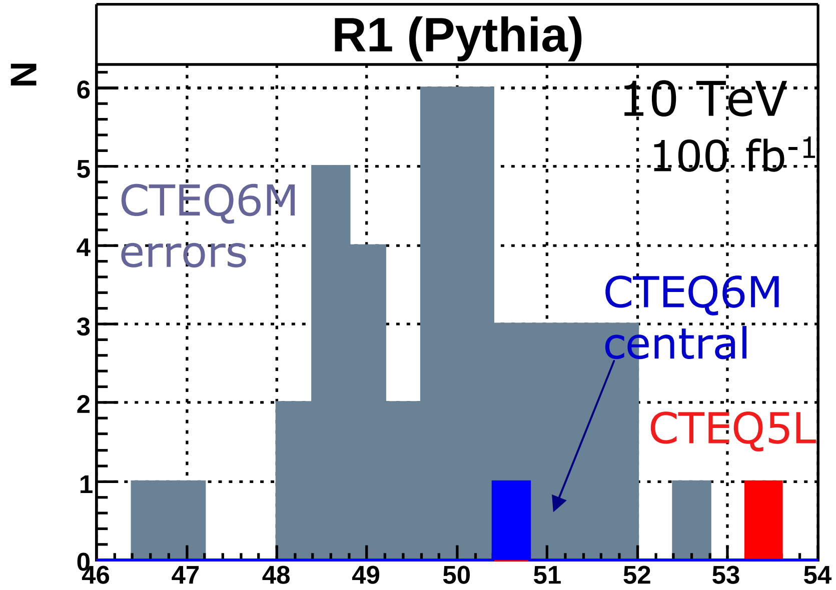
Λ(TeV)	R1 no gluons	R1 w/ gluons
3	700	*646*
5	210	*172*
10	18	*16*
20	2.5	*2.3*
40	0.70	*0.65*

- Gluon jets have different jet shapes. The efficiency of spotting such a jet still has to be studied.

No systematic errors included.

PDF uncertainties (R1)





- R1 from Pythia (2 partons with highest p_T), Λ = 10 TeV, m_{jj} = 4 TeV, p_T > 1 TeV.
- Systematic error due to PDF uncertainties in this case σ_{PDF}(R1)= 0.88. That is comparable to R1(Λ=40TeV, 30 fb^{-1}) = 0.80.
- Preliminary to say it is less sensitive than R_{dist}.

Conclusions

- Early limits: $\Lambda \sim 10$ TeV might be discovered or rulled out with first tens of pb^{-1} of good data.
- $\Lambda \sim 20$ TeV still should be visible with larger int. luminosity.
- Discovering $\Lambda \sim 40$ TeV requires better energy linearity than 2% @ 2TeV.
- Systematic errors still need to be understood in this study.
- To be continued ...