Dijet Angular distributions at $\sqrt{s} = 14\text{TeV}$

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July 16, 2009

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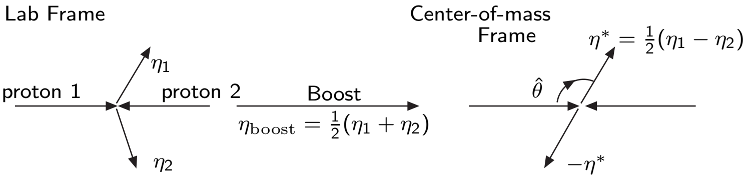
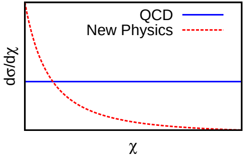
Introduction



- Dijet final state, in pp-collisions through qq, qg and gg interactions.
- Variable of interest: $\chi = \exp(|\eta_1 - \eta_2|) = \frac{1+|\cos(\hat{\theta})|}{1-|\cos(\hat{\theta})|}$
- Take bins in dijet invariant mass M_{jj}.
  At LO: $M_{jj} = x_1 x_2 s = p_T(\sqrt{\chi} + 1/\sqrt{\chi})$
- Calculate dijet angular distribution: $d\sigma/d\chi$ vs χ



- QCD curve is rather flat (Rutherford scattering)
- New physics usually more isotropic events $\Rightarrow$ peak at small χ
- New physics? Gravitational effects from large extra dimensions, quark compositness, ...

Selection cuts

- 4 Mass (M_{jj}) bins: $[0.5, 1]$, $[1, 2]$, $[2, 3]$ and > 3TeV
- Detector: can measure η up to $\eta_{\max}$, in this study $\eta_{\max}$ =3.1 or 4.0
- Physics: 2 orthogonal selections cuts (see backup slides for more info):

$$|\eta_1 + \eta_2| < c \quad (1)$$

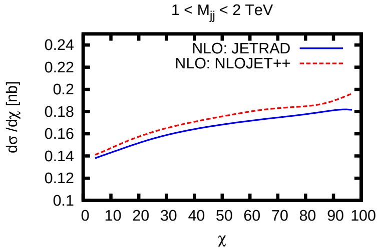
$$|\eta_1 - \eta_2| < 2\eta_{\max} - c \Longleftrightarrow \chi < \exp(2\eta_{\max} - c), \quad (2)$$

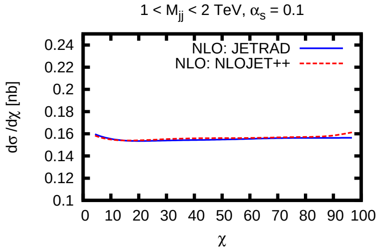
with $c = 1.5 \Rightarrow \chi_{\max} \approx 100$ or 600.

QCD up to NLO: JETRAD and NLOJET++

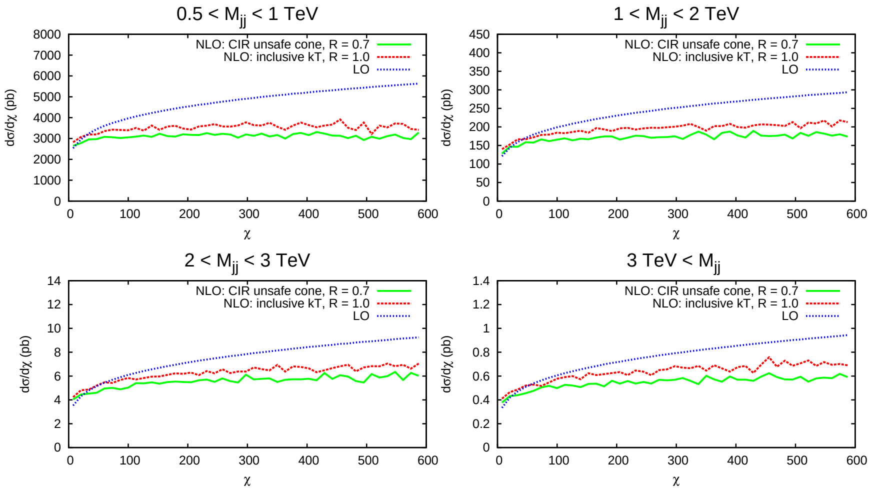
2 programs for NLO calculations: JETRAD and NLOJET++

- JETRAD: phase space slicing
- NLOJET++: applies the Catani-Seymour dipole subtraction scheme with some modifications introduced because of computational reasons
- NLOJET++ uses different parametrization of α_s than JETRAD (left plot), difference disappears when with fixed $\alpha_s = 0.1$ (right plot)



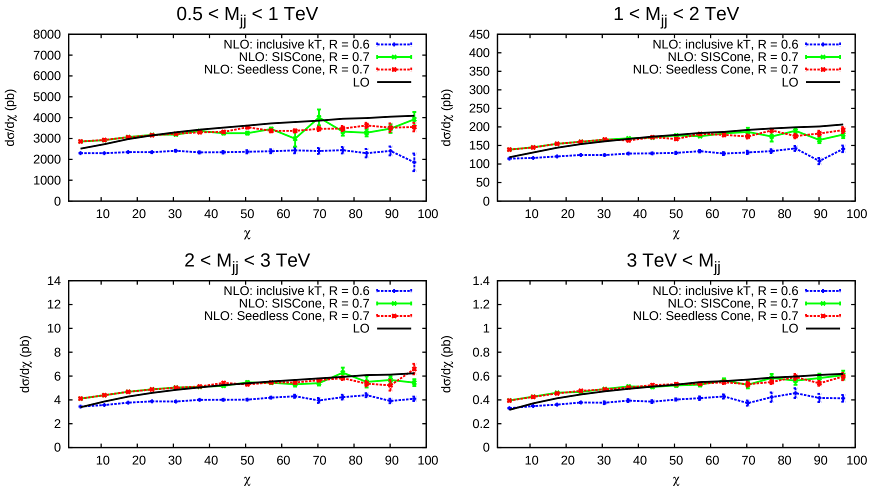


NLO calculations with JETRAD



- Calculations done with seeded cone 0.7 and inclusive k_T 1.0
- 4 different mass bins, $\chi < 600$
- At NLO, the different jet algorithm tends to give the same shape of the distributions, but a different normalization

NLO calculations with NLOJET++



- jet algorithms: seedless cone 0.7 with overlap 0.5 and SISCone 0.7 with overlap 0.75
- 4 different mass bins, $\chi < 100$

Systematic uncertainties

Uncertainties from theoretical calculations:

- renormalization (μ_R) and factorization scale (μ_F)
- PDFs

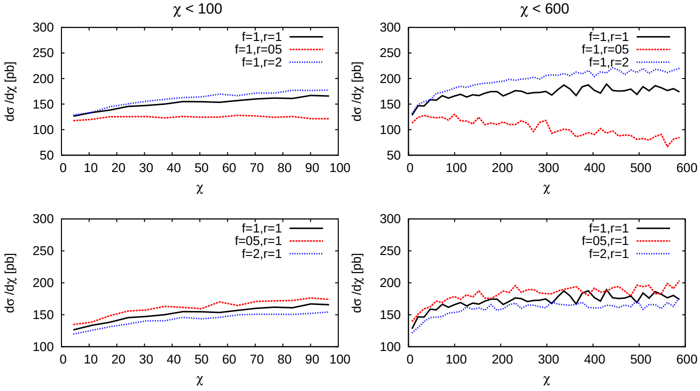
Experimental uncertainties:

- Dominating uncertainty from jet energy calibration $\Rightarrow$ normalize distributions to unit area to reduce the impact ($(1/\sigma)d\sigma/d\chi$ vs χ)

Systematic uncertainty coming from μ_R and μ_F

How to investigate?

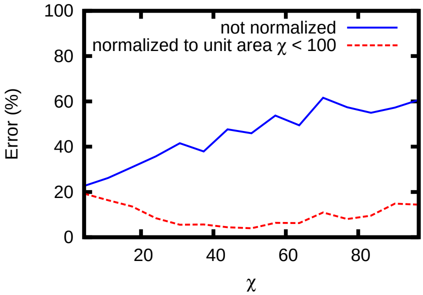
- Take $\mu_{R,F} = 0.5, 1, 2 \times p_T$ highest jet $\rightarrow$ 9 possible combinations
- *Figure*: mass bin $1 < M_{jj} < 2$ TeV, r and f are the fraction of the transverse momentum of the highest jet at which respectively μ_R and μ_F are evaluated. Left: $\chi < 100$, right: $\chi < 600$.



Systematic uncertainty coming from μ_R and μ_F

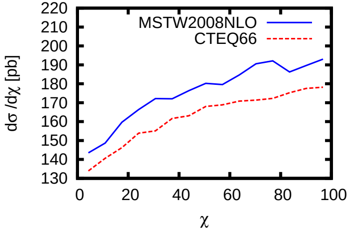
- Different μ_F mainly influences the absolute normalization, while μ_R influences both shape and normalization.

Error coming from choice of μ_R and μ_R:

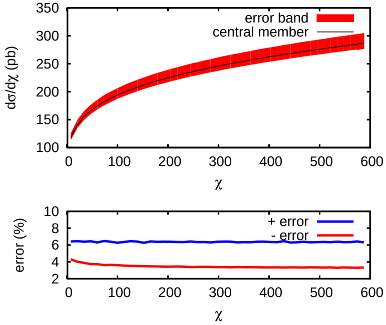


Systematic uncertainty coming from PDFs

- Study 2 different PDF-sets: CTEQ66 and MSTW2008NLO in $[1, 2]$TeV mass bin:

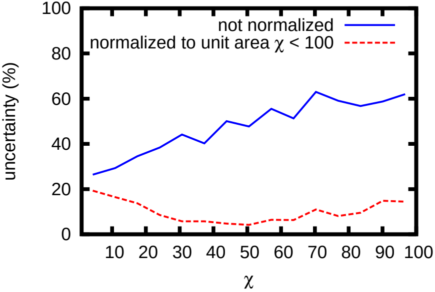


- For CTEQ66: study all $2N = 44$ error members, use Master Equation (hep-ph/0611148v1) to calculate uncertainty:



QCD Uncertainty

- Combining uncertainties from μ_R and μ_F, and intrinsic uncertainty from the CTEQ66 PDF in quadrature
- Uncertainty both on distributions normalized to unit area $\chi < 100$ and not normalized
- Dominating uncertainy from μ_R



Conclusions and outlook

Dijet angular distributions

- $d\sigma/d\chi$ vs χ in bins of dijet invariant mass
- allows to distinguish more isotropic scattering (new physics) from Rutherford scattering (QCD)

QCD calculations up to NLO, using JETRAD and NLOJET++

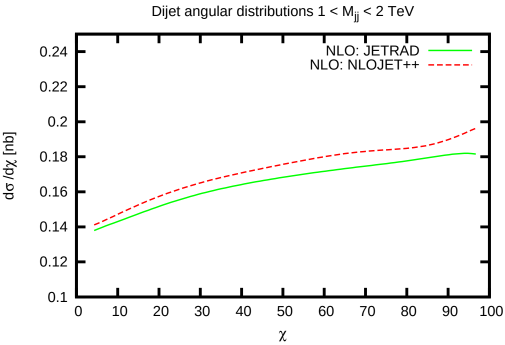
- NLOJET++ and JETRAD agree reasonably well (difference in parametrization of α_s)
- LO and NLO agree quite well at low χ, but differ at large χ
- Different jet algorithms give different normalization
- Biggest uncertainty coming from the choice of μ_R
- Choice of μ_F and the PDF-sets has mainly impact on absolute normalization, minimalize the uncertainty by normalizing the distributions
- Biggest uncertainty at large χ.

Outlook

- ATLAS: early (2010) measurement ($\chi < 30$)

NLOJET++ vs JETRAD

- NLOJET++ uses different parametrization of α_s than JETRAD
- NLOJET++: $\alpha_s(Q) = \frac{4\pi}{\beta_0 \ln(Q^2/\Lambda^2)} \left(\frac{1}{1 + \frac{2\beta_1}{\beta_0^2} \frac{\ln\ln(Q^2/\Lambda^2)}{\ln(Q^2/\Lambda^2)}} \right)$
- JETRAD: $\alpha_s(Q) = \frac{4\pi}{\beta_0 \ln(Q^2/\Lambda^2)} \left(1 - \frac{2\beta_1}{\beta_0^2} \frac{\ln\ln(Q^2/\Lambda^2)}{\ln(Q^2/\Lambda^2)} \right)$



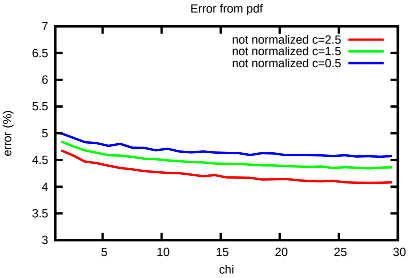
Selection cuts

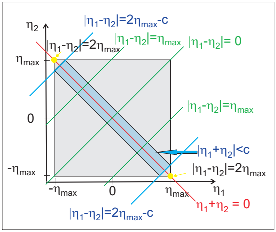
- Two orthogonal selection cuts:

$$|\eta_1 + \eta_2| < c \quad (3)$$

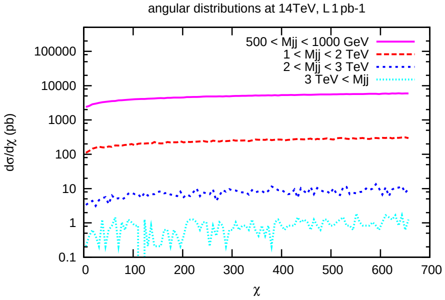
$$|\eta_1 - \eta_2| < 2\eta_{\max} - c \Longleftrightarrow \chi < \exp(2\eta_{\max} - c) \quad (4)$$

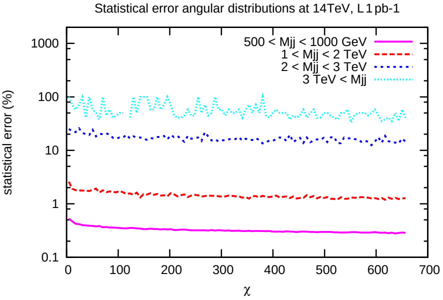
- Parameter c: trade-off between measurable χ-range and error coming from statistics and PDFs





Statistics at 1 pb^{-1}

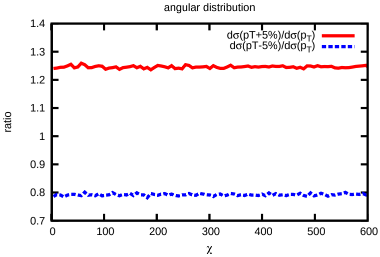




Impact Jet Energy Scale (JES)

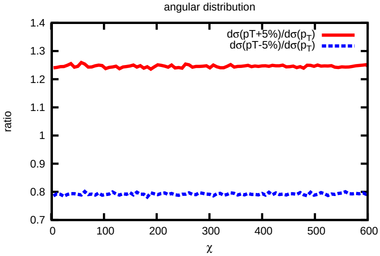
Simple test:

1. Generate events with pythia 6.4
2. Calculate $d\sigma/d\chi$ vs χ for $1 < M_{jj} < 2$ TeV
3. For each event: increase jet p_T with +5%: $p_T = p_T + 5\%$
4. Calculate $d\sigma_{\mathrm{increase}}/d\chi$ for $1 < M_{jj} < 2$ TeV
5. Take ratio of differential cross-sections: $(d\sigma_{\mathrm{increase}}/d\chi)/(d\sigma/d\chi)$ (red curve)
6. Repeat steps 3.-4.-5. with $p_T - 5\%$ (blue curve)



Impact Jet Energy Scale (JES)

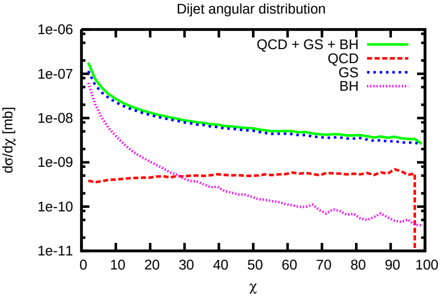
- Effect due to binning in $< M_{jj}$
- Shape of distributions not effected by a global (η independent) error on JES $\Rightarrow$ normalize distributions: $(1/\sigma)\mathrm{d}\sigma/\mathrm{d}\chi$ vs χ
- Remaining η dependence of JES



Gravitational scattering and black hole formation in large extra dimensions

- References: hep-ph/9811350, hep-ph/9811291, hep-ph/0608080, hep-ph/0608210
- ADD model including black hole formation (BH) and an effective field theory of gravity to describe gravitational scattering (GS)

Mass bin 3 TeV $< M_{jj}$, 6 extra dimensions and $M_{\mathrm{Planck}} \approx 1$ TeV:



Large extra dimensions: the ADD model

- Large hierarchy found in nature: EW-scale $\sim 10e2$ GeV, Planck Scale $\sim 10e^{19}$ GeV.
- Gravitational potential in world with n extra dimensions with compactification radius R:

$$V(r) \propto \begin{cases} \frac{1}{M_P^{n+2}} \frac{m}{r^{n+1}} & r \ll R \\ \frac{1}{M_P^{n+2} R^n} \frac{m}{r} & r \gg R \end{cases}$$

$M_P =$ fundamental Planck scale

- Compared with normal 4D-potential with 4D-Planck scale: $V(r) = \frac{\bar{h}c}{M_{P4}^2} \frac{m}{r}$

$$M_{P4}^2 \sim M_P^{2+n} R^n$$

- $\rightarrow$ Fundamental Planck scale can be small, while observed 4D-Planck scale is large
- Arkani-Hamed Dimopoulus Dvali (ADD) model = existence of large extra spatial dimensions in which gravity is allowed to propagate, while the SM fields are confined to a 4D-membrane

The ADD model

- Gravitational scattering through the exchange of virtual Kaluza-Klein (KK) modes
- Black Holes