# Z+Jets results from CDF

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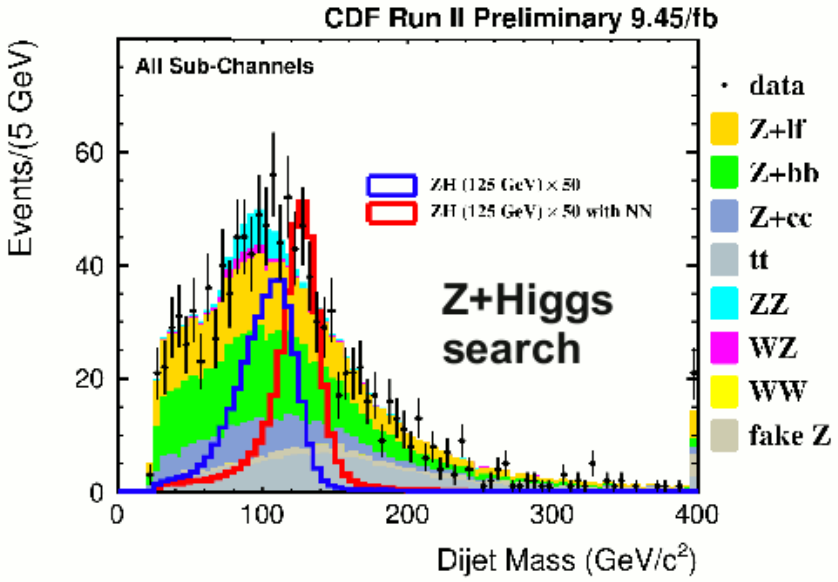
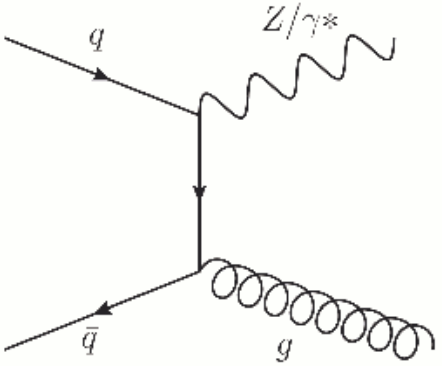
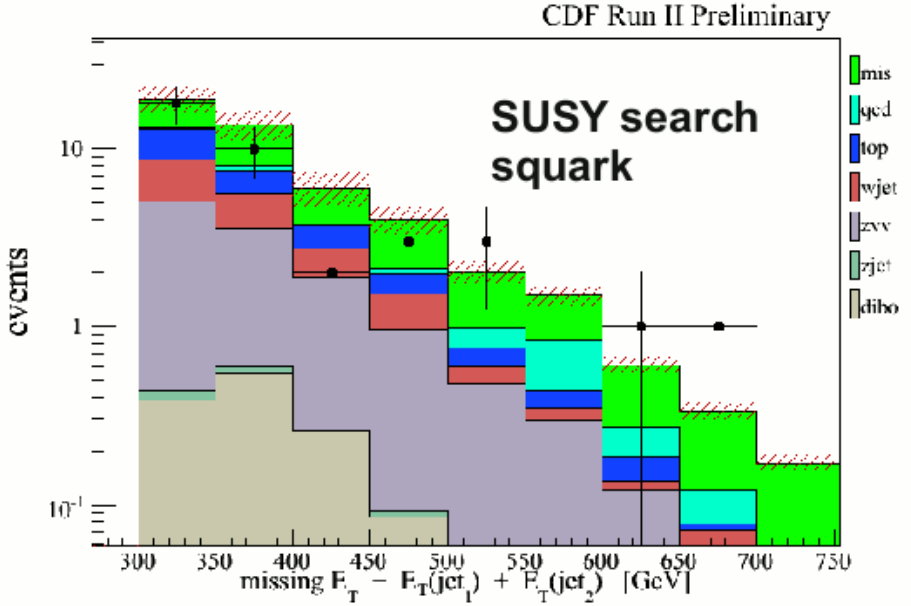
On Behalf of the
CDF Collaboration

# Motivation

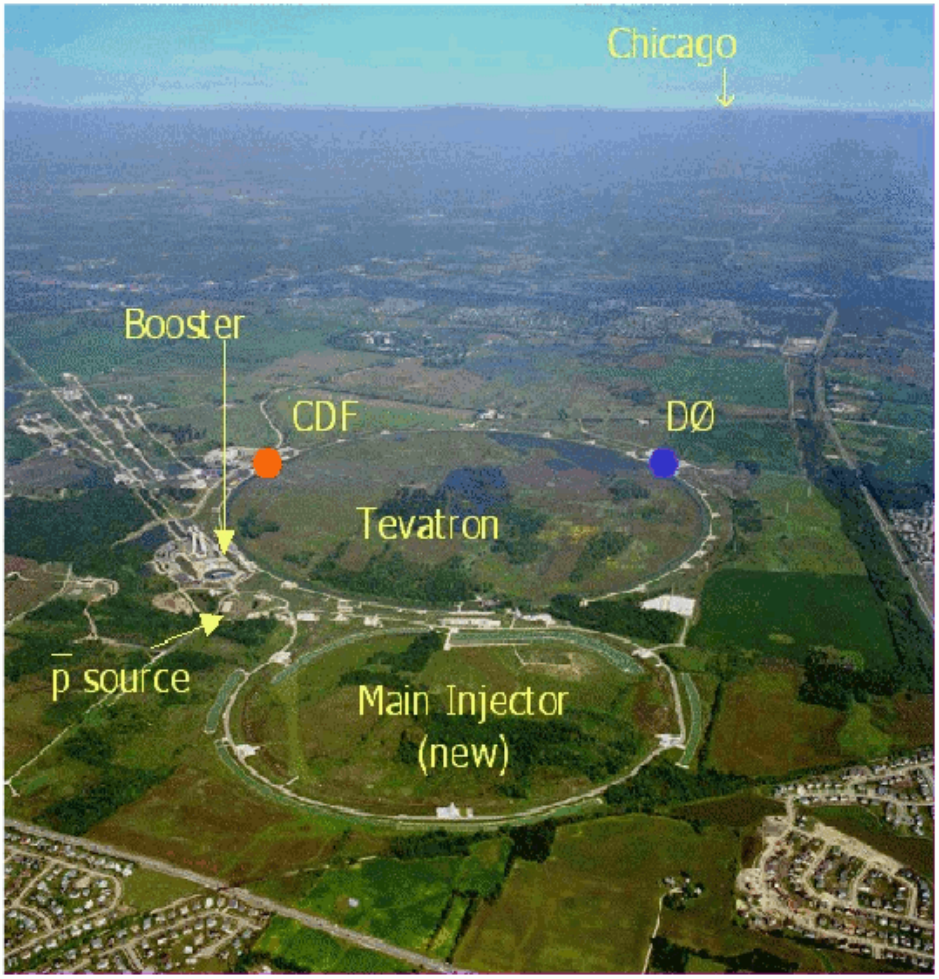



- Test perturbative QCD at high $Q^2$
- Background for rare SM processes (top, diboson) and new Physics searches
- High theoretical uncertainty in Z + HF
- Tevatron legacy measurements

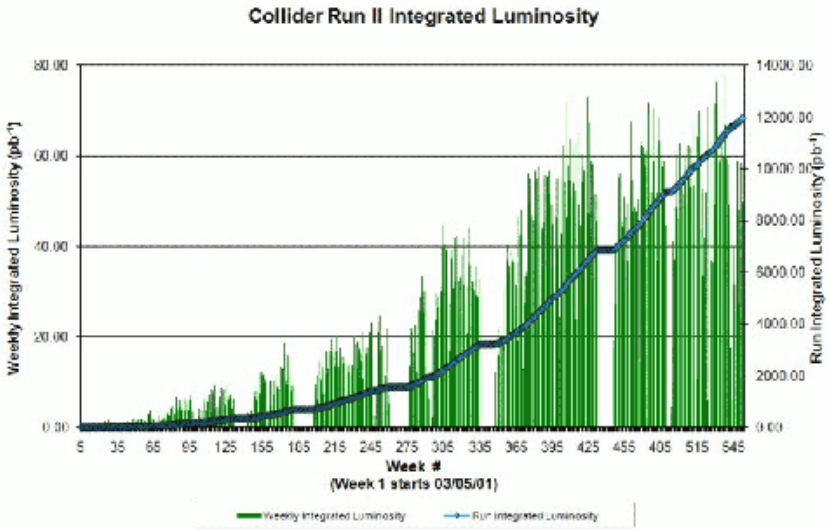


# Tevatron

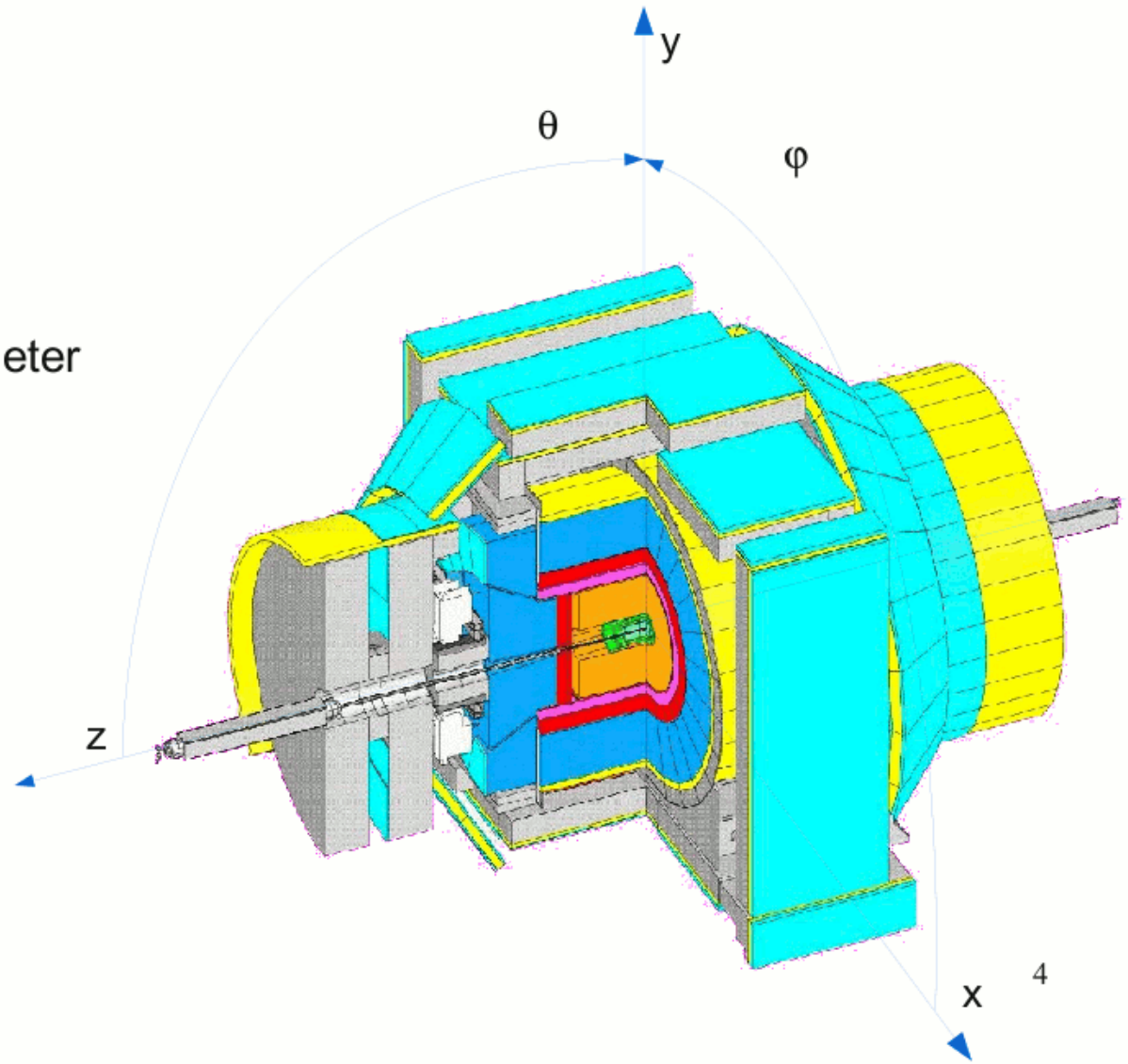



- $p\bar{p}$ collisions at $\sqrt{s}$ = 1.96 TeV
- Peak instantaneous luminosity ~ 4 x $10^{32}$ $cm^{-2}$ $s^{-1}$
- ~ 10 $fb^{-1}$ of integrated luminosity available for data analysis



# CDF Detector

- Tracking system
  - Silicon detectors
  - Drift chambers COT
- 1.4 T Magnetic field
- Calorimeter
  - Electromagnetic calorimeter
  - Hadronic calorimeter
- Muon detectors
  - Wire chambers
  - Scintillators
- 3 Level Trigger System
  - Level 3 → ~ 100 Hz



**Z Kinematic region**

$66 < M_Z < 116$ GeV/c²

$E_T^l > 25$ GeV/c, $|\eta^l| < 1$

**Jets**

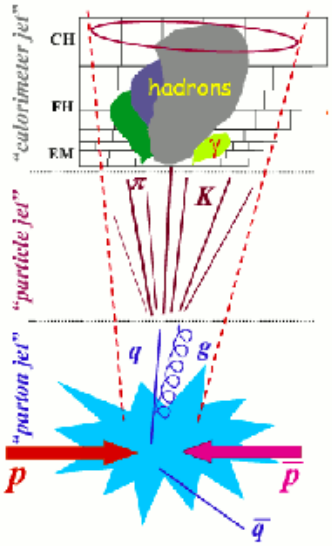
MIDPOINT R=0.7

$p_T > 30$ GeV/c, $|Y| < 2.1$

# $Z/\gamma^* \rightarrow l^+l^-$ + jets

Full Tevatron dataset results

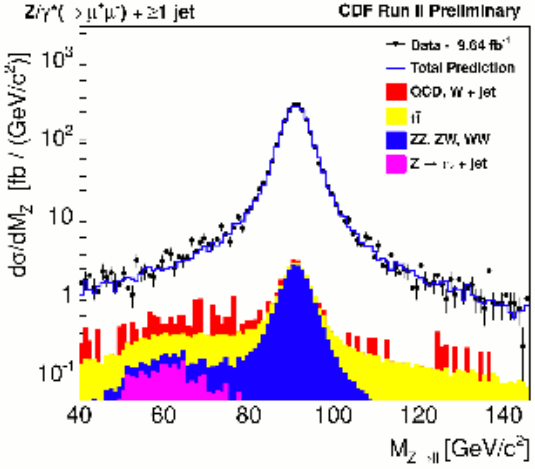
$\mathcal{L} = 10$ fb$^{-1}$



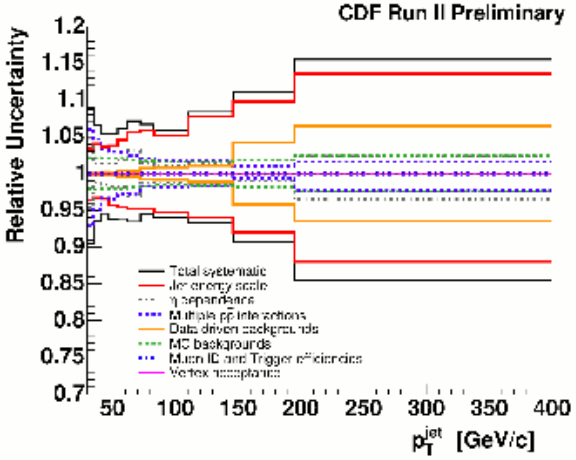

$Z \rightarrow \mu^+\mu^-$ and $Z \rightarrow e^+e^-$ channels combined accounting for correlation between uncertainties

Differential distributions in Z + ≥1, 2, 3 jets final state

Measurements are unfolded back to Particle Level




**5% to 15% systematic uncertainties**
**Jet Energy Scale is the dominant**

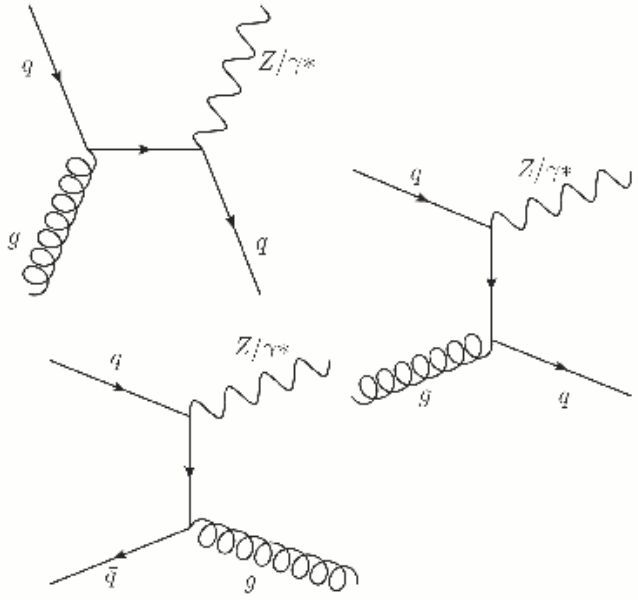



Data driven backgrounds
- QCD multi-jet
- W + jet

MC backgrounds
- Top
- Diboson
- $Z \rightarrow \tau\tau$ + jets

Total backgrounds between 2%-10%

# Z/γ* + jets Theory Predictions




Comparison with many available theoretical predictions

- Largest theory uncertainty: $\mu_0$ scale variation
- PDF uncertainties: 2%-4%

**MCFM and BLACKHAT+SHERPA**
NLO fixed order perturbative QCD
→ reduced scale uncertainty

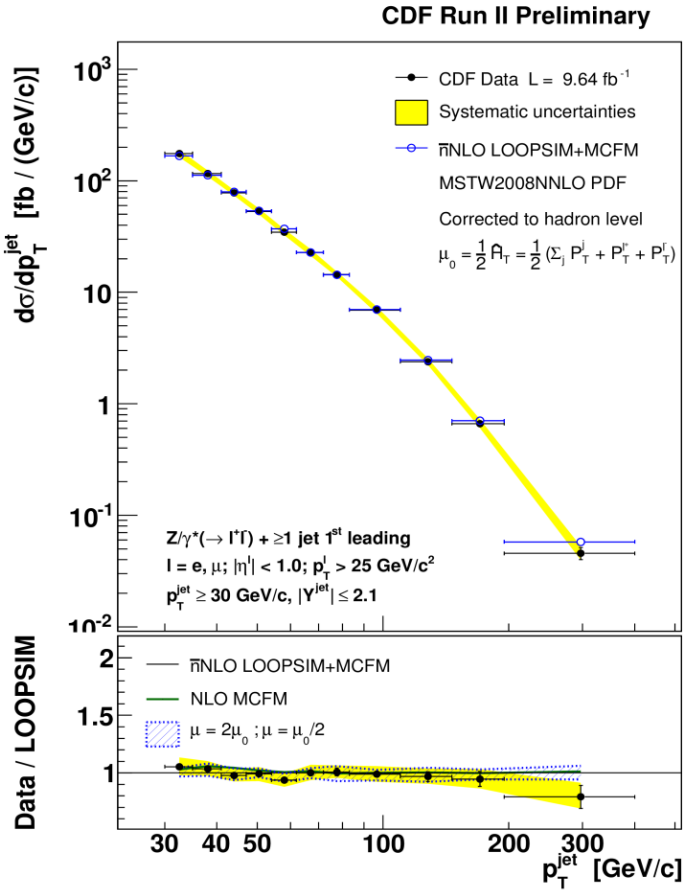
**ALPGEN+PYTHIA**
Matched LO-ME+PS
→ fundamental tool for Z+jets simulation

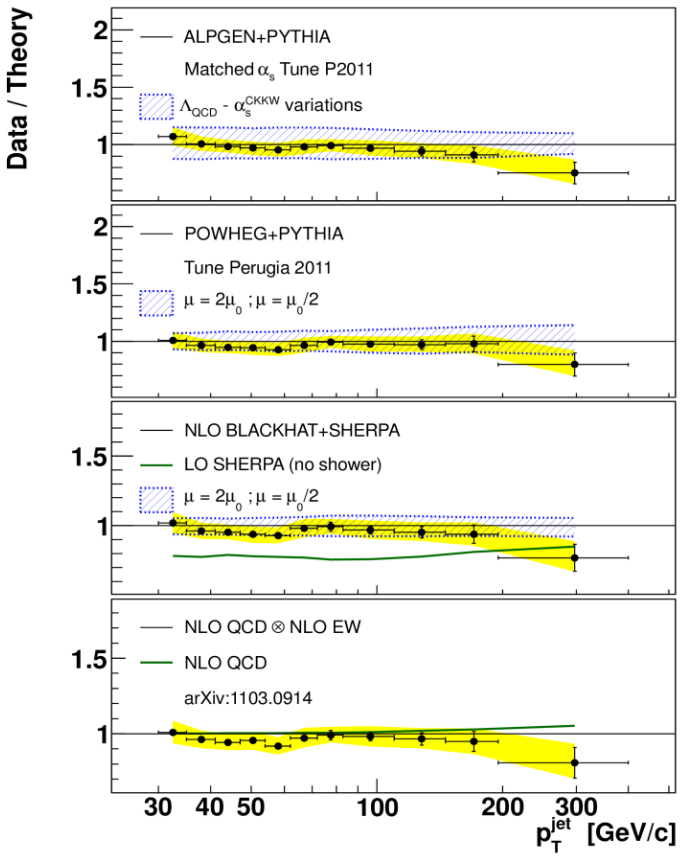
**POWHEG+PYTHIA**
Merged NLO+PS
→ good modeling of pQCD and non-pQCD physics

**LOOPSIM+MCFM**
Approximate nNLO
→ best pertubative QCD accuracy

**ArXiv:1103.0914**
NLO QCD x NLO EW perturbative prediction
→ Important corrections at high $p_t$

# $Z/\gamma^* + \geq 1$ jet leading $p_T^{jet}$

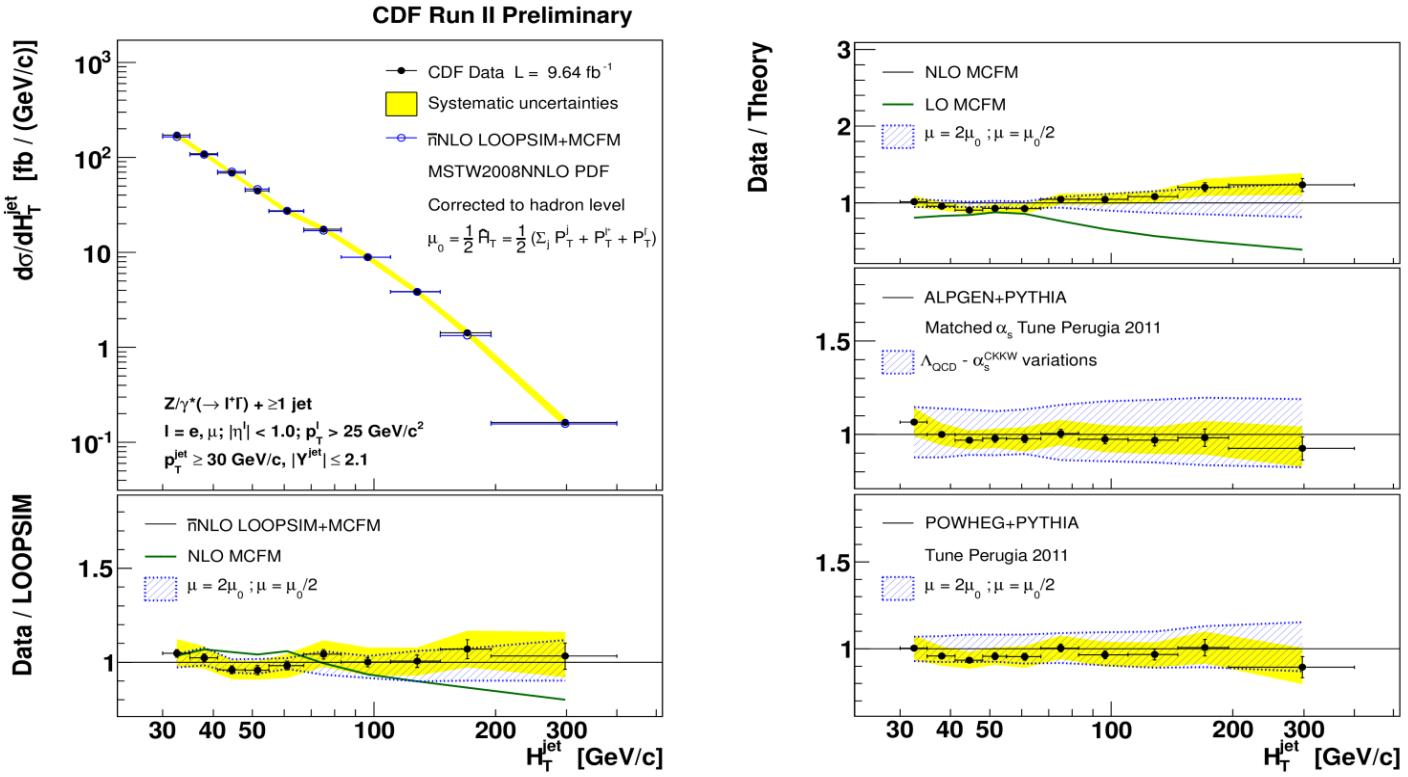



Good Agreement between data and predictions

- LOOPSIM+MCFM only 4%-6% scale uncertainty
- NLO EW correction ~5% at high pt → large virtual Sudakov logarithms

# $Z/\gamma^* + \geq 1$ jet $H_T^{jet}$

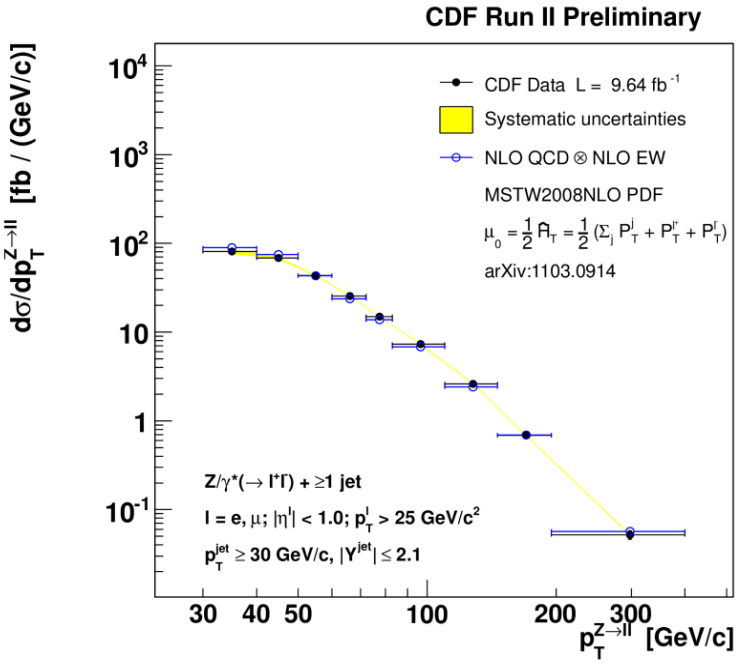


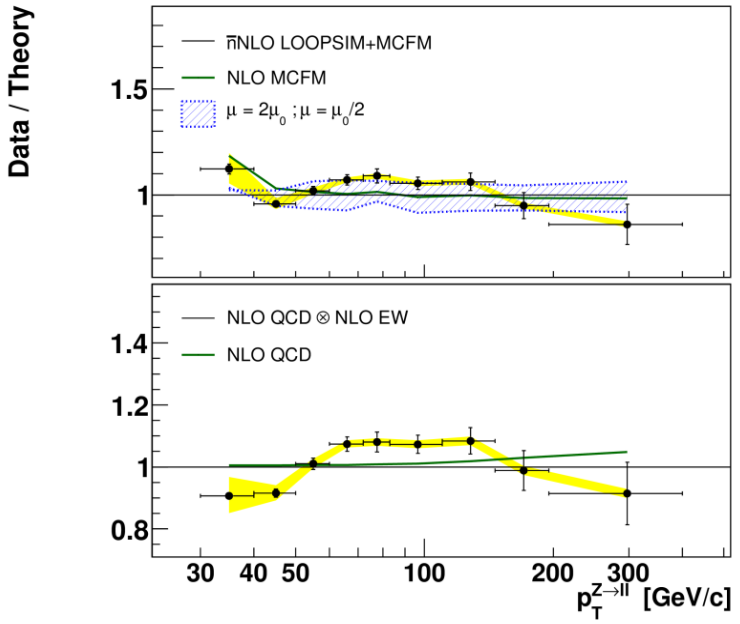

- Giant NLO/LO K factor ≥2 at high $H_t^{jet}=\Sigma\, p_T^{jet}$

→ Significant beyond NLO corrections

- LO-ME+PS (ALPGEN) and NLO+PS (POWHEG) properly model data with large scale uncertainty
- Good modeling of approximate nNLO LOOPSIM with reduced scale uncertainty

# $Z/\gamma^* + \geq 1$ jet $p_T^Z$



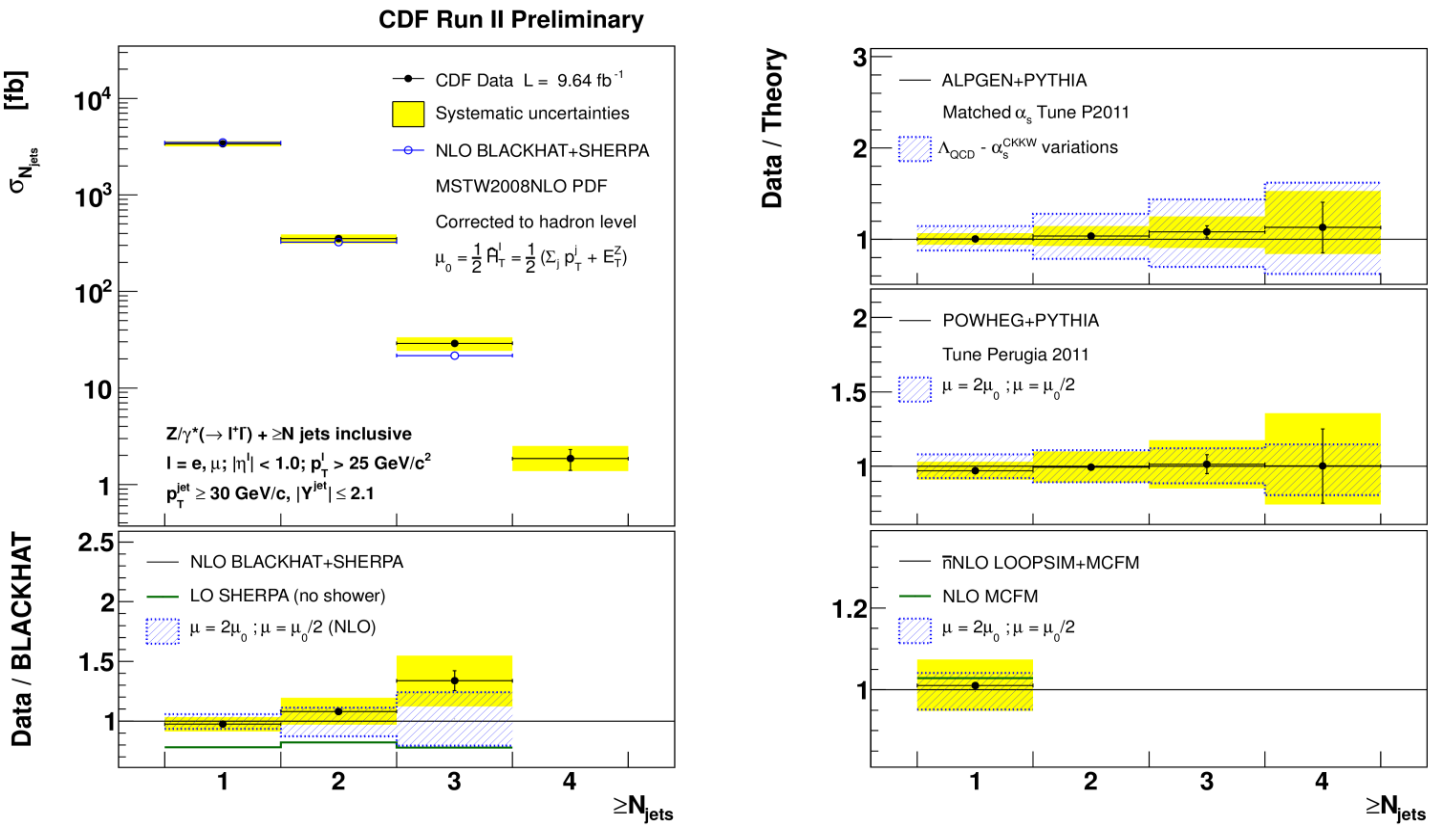

NLO EW and NLO QCD corrections applied with a *factorized* ansatz

- NLO EW correction ~5% at high $p_T$

→ large virtual Sudakov logarithms

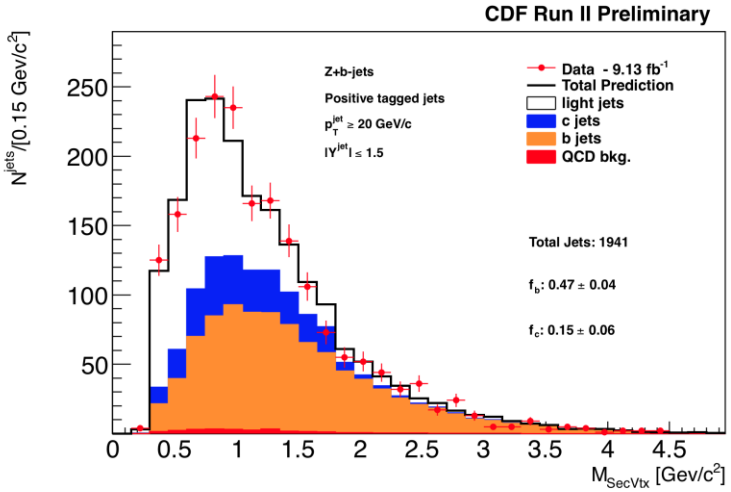
- NLO EW corrections of the same order of approximate nNLO scale uncertainty

# Z/γ* + ≥ N jets




- BLACKHAT+SHERPA NLO pQCD for Z + 3 jets
- LOOPSIM+MCFM scale variation lower than experimental uncertainty

# Measurement of b production Cross Section in association with a Z boson




$$\frac{\sigma_{Z_bjet}}{\sigma_Z} = 0.261 \pm 0.023^{stat} \pm 0.029^{syst}\%$$

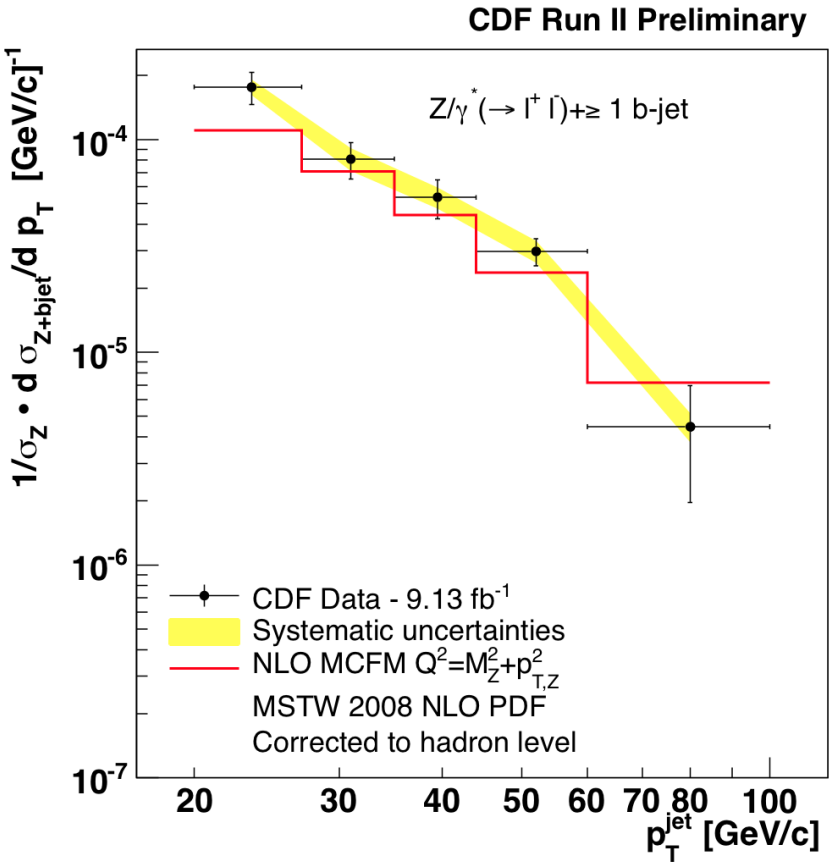
$$\frac{\sigma_{Z_bjet}}{\sigma_{Zjet}} = 2.08 \pm 0.18^{stat} \pm 0.27^{syst}\%$$

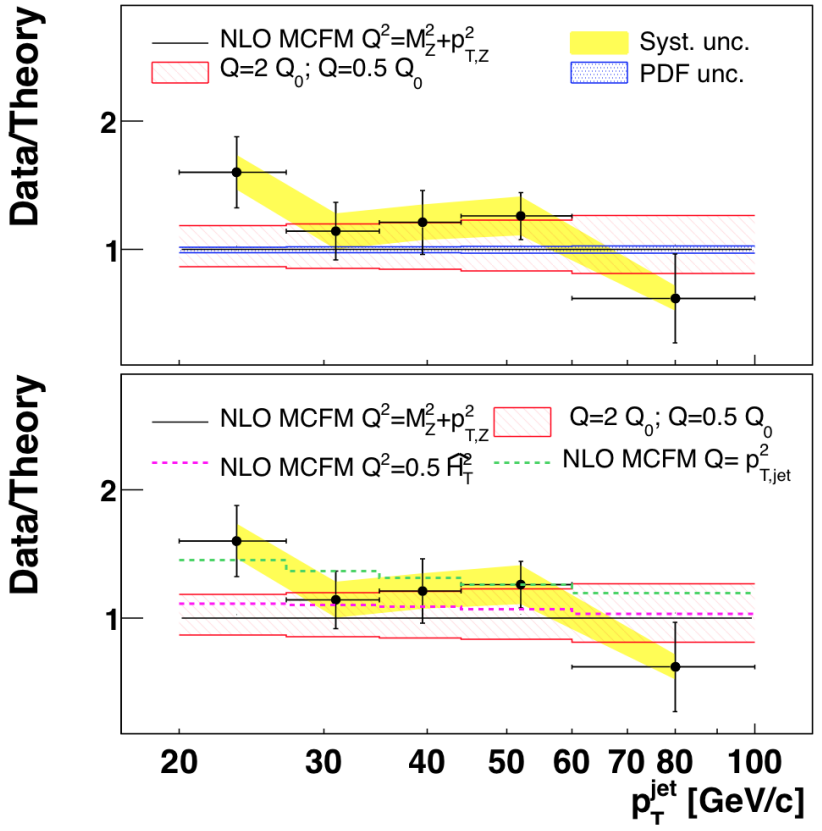
Main systematic uncertainties due to SecVtx template modeling

To compare with NLO prediction with MCFM:

| | $Q^2 = m_Z^2 + p_{T,Z}^2$ | $Q^2 = < p_{T,jet}^2 >$ |
|---|---|---|
| $\frac{\sigma_{Z_bjet}}{\sigma_Z}$ | 0.23 % | 0.29 % |
| $\frac{\sigma_{Z_bjet}}{\sigma_{Zjet}}$ | 1.8 % | 2.2% |

# Measurement of b production Cross Section in association with a Z boson



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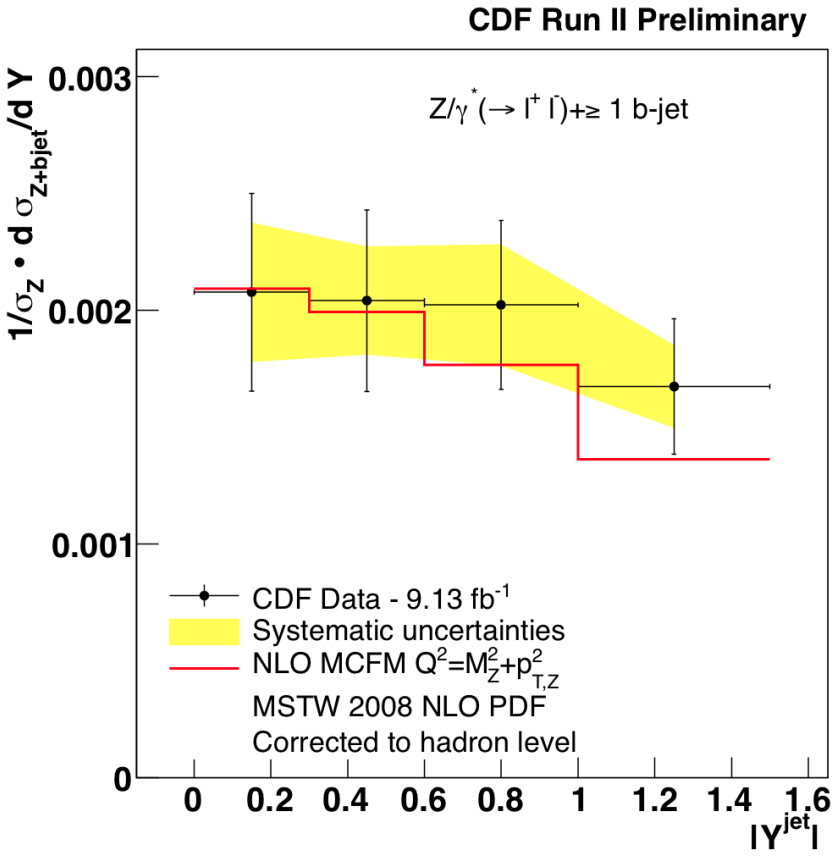
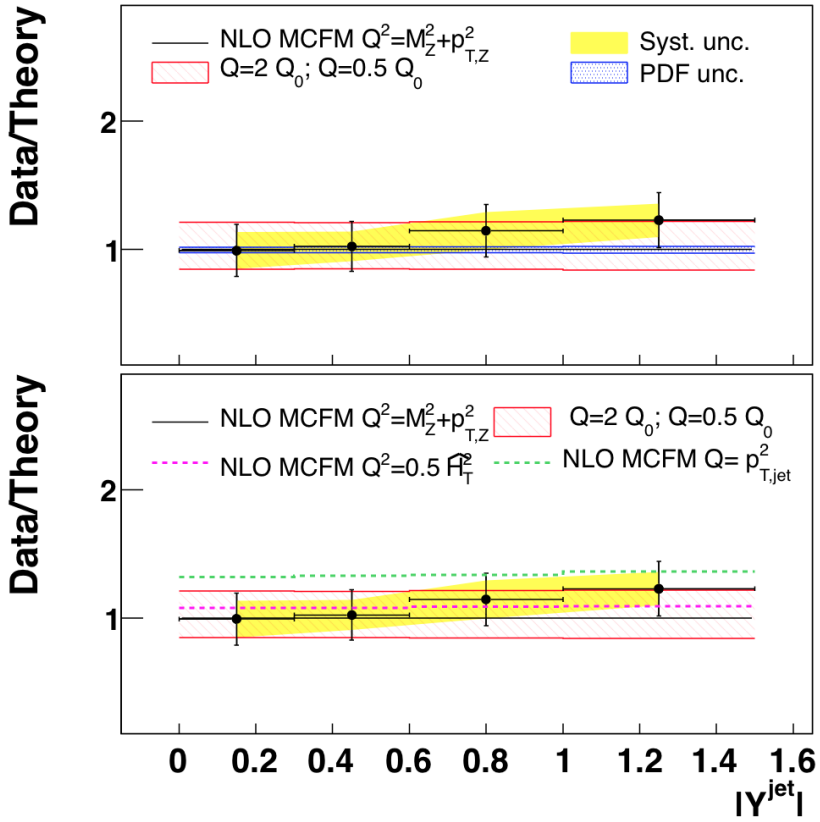


# Summary

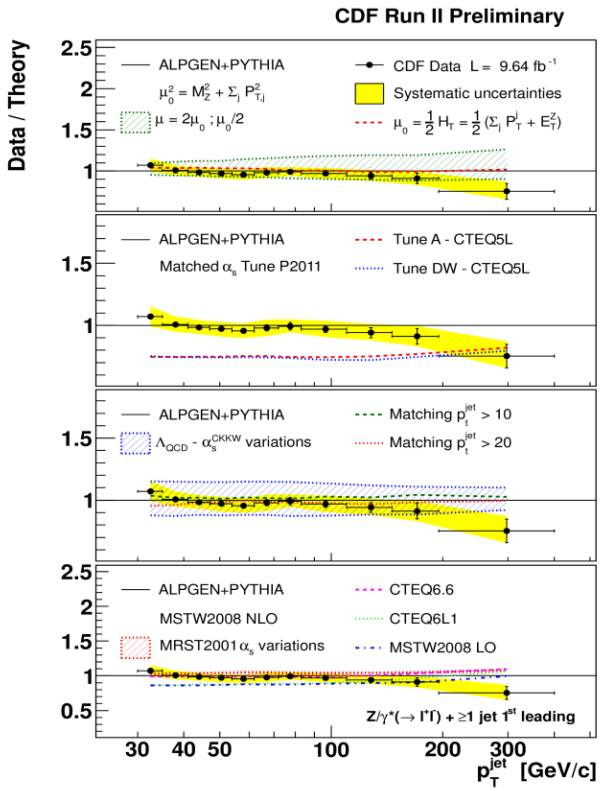
- Precise measurements of Z+jets, Z+b-jets with the full Run II dataset
- Tevatron legacy measurements
- General good agreement with state of the art theoretical predictions

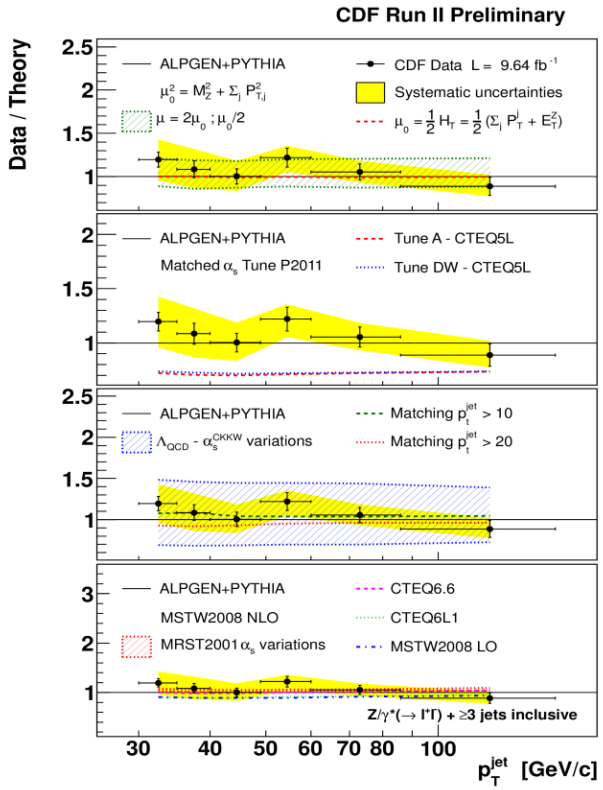
More details at:

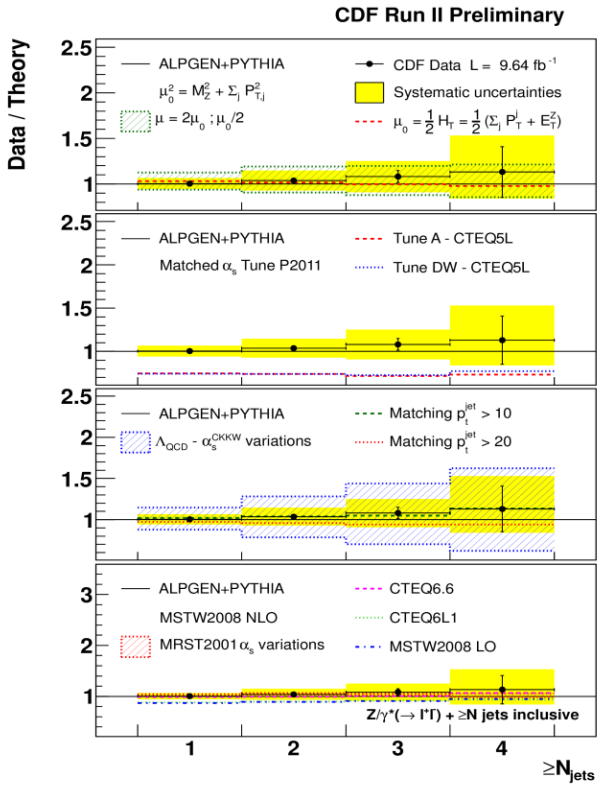
- http://www-cdf.fnal.gov/physics/new/qcd/QCD.html

# Backup slides

# Z/γ* + jets
# ALPGEN LO-ME+PS



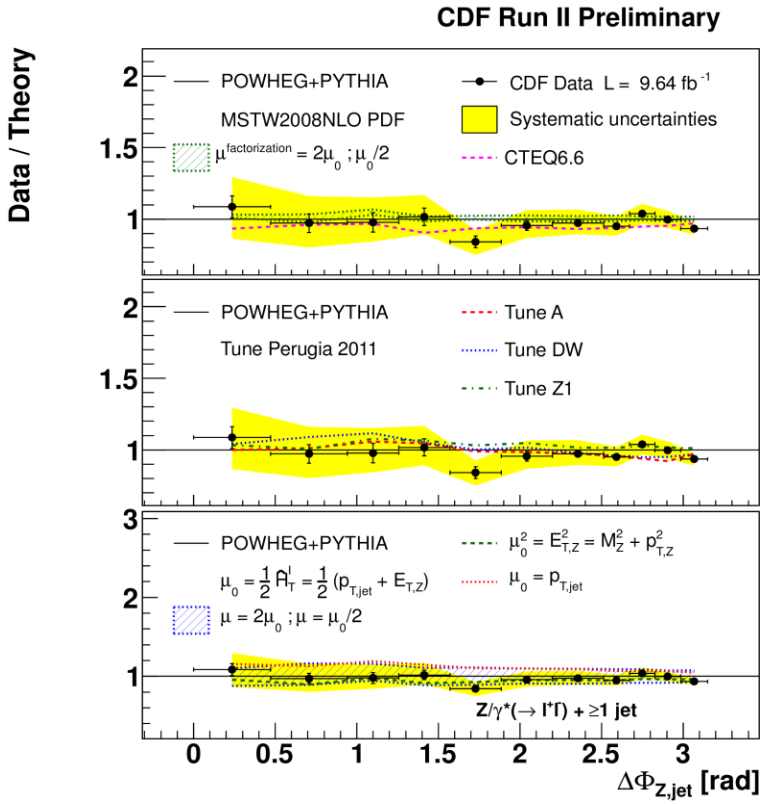

$\alpha_s$ "matched" ALPGEN+PYTHIA setting and Tune Perugia 2011

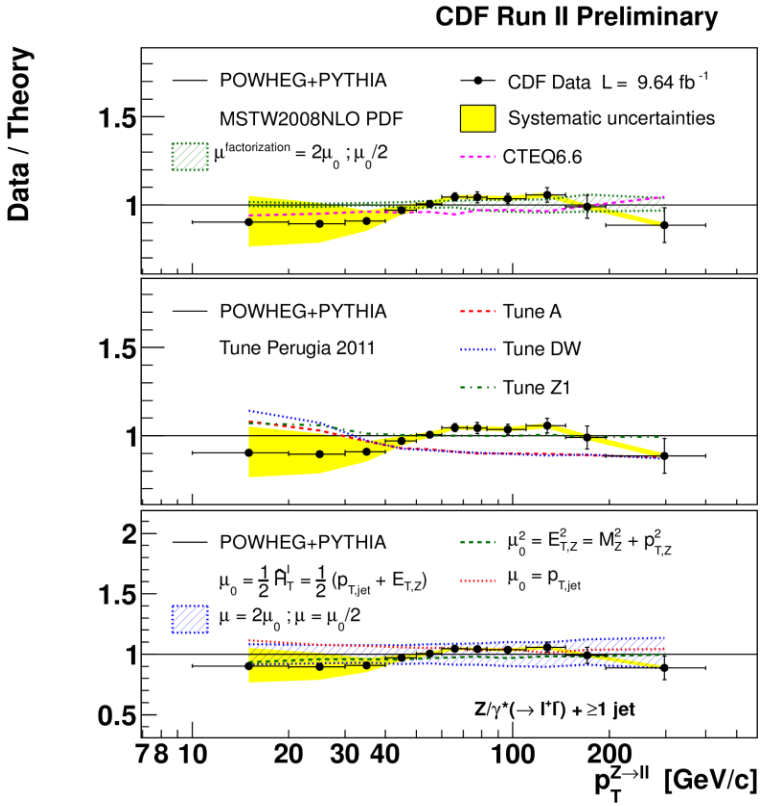
→ coherence between CKKW $\alpha_s$ in ALPGEN and $\lambda_{QCD}$ in PYTHIA

→ Can use NLO (2-loop) PDF

No normalization factor needed

# Z/γ* + ≥ 1 jet
# POWHEG NLO+PS



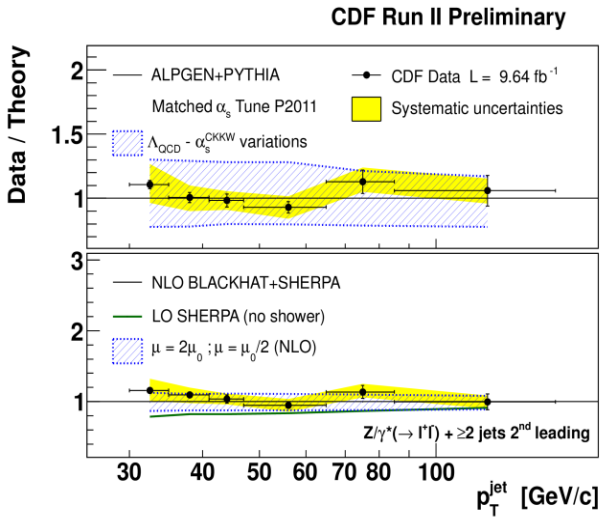

- Good modeling of perturbative high $p_T$ (NLO accuracy)

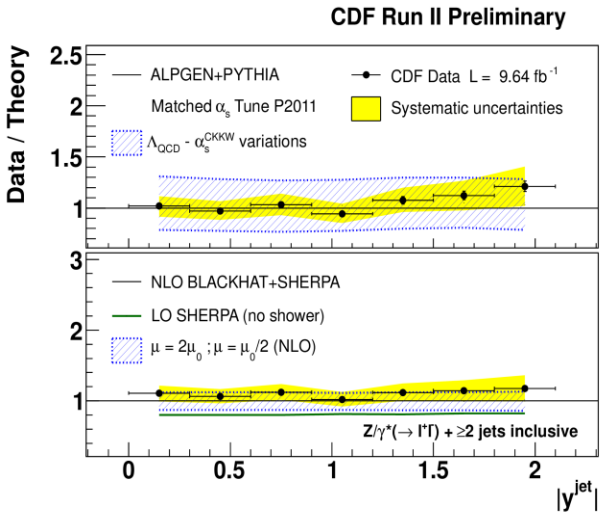
and non-perturbative low $p_T$ (PS+hadronization+UE) regions

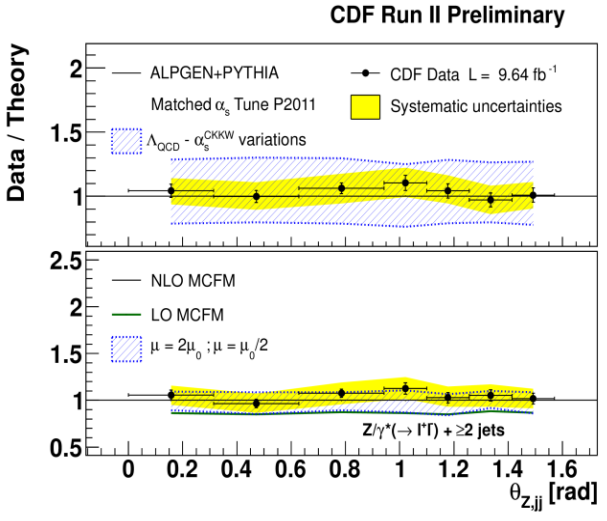
- POWHEG formula indipendent of parton shower modeling

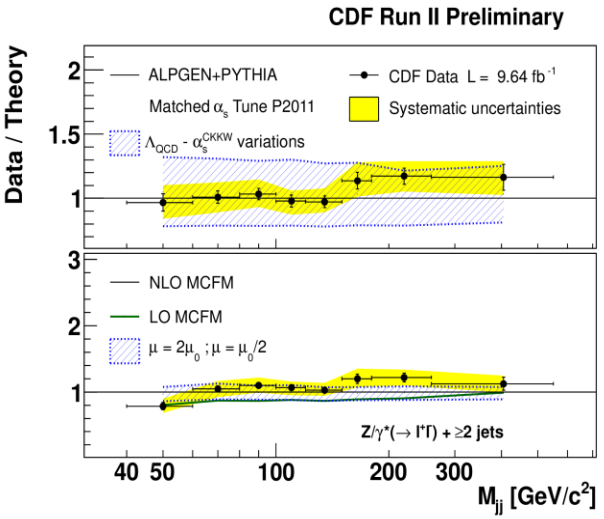
→ lower dependence from PYTHIA Tune

# Z/γ* + ≥ 2 jets




- Important final state for Higgs and beyond SM searches → sensitive to new resonances
- Measured cross sections compared to ALPGEN, MCFM and BLACKHAT
- Good modeling within experimental and theoretical uncertainties

# Measurement of b production Cross Section in association with a Z boson

Use same framework as Z+jets analysis

Add a NN for lepton ID
gain of 30-40% efficiency for Z reconstruction

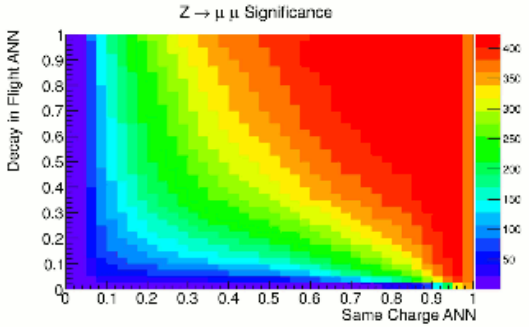
Leptons

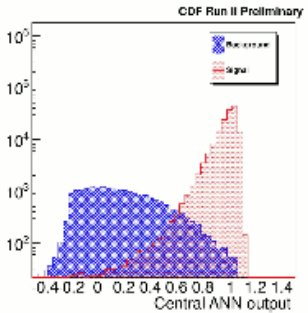
$|\eta| < 1.0$
$P_t > 20$ GeV/c

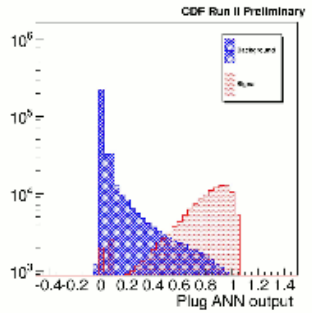
Jets

Midpoint algorithm cone 0.7
$|Y| < 1.5$
$P_t > 20$ GeV/c

B-tagging: 1 or more Tight SecVtx

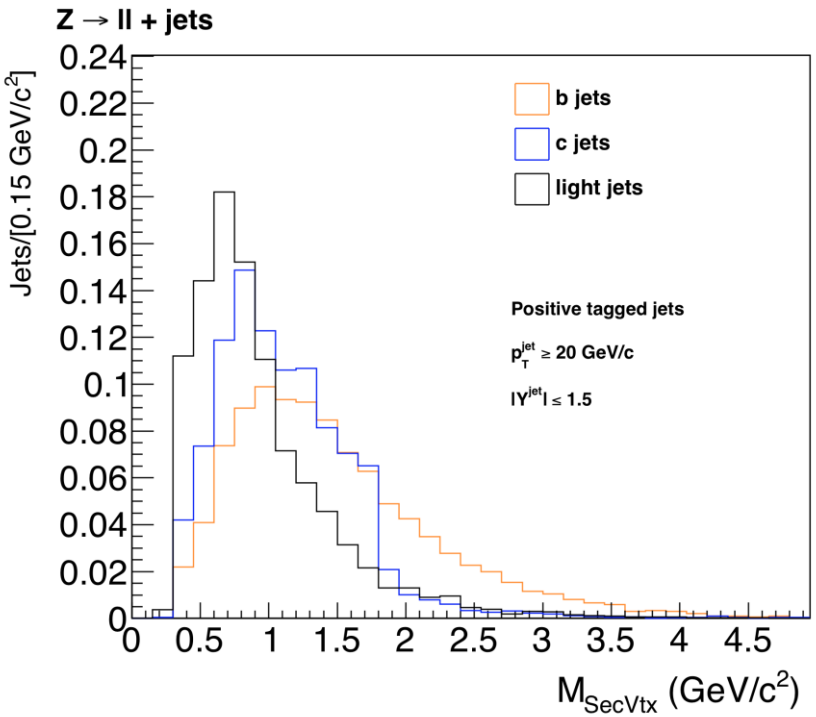


# Measurement of b production Cross Section in association with a Z boson

Measured the ratio of the b-jet XS with respect to the Z inclusive one and differential XS as a function of the b-jet transverse momentum and rapidity




fit SecVtx mass distribution to find b-fraction