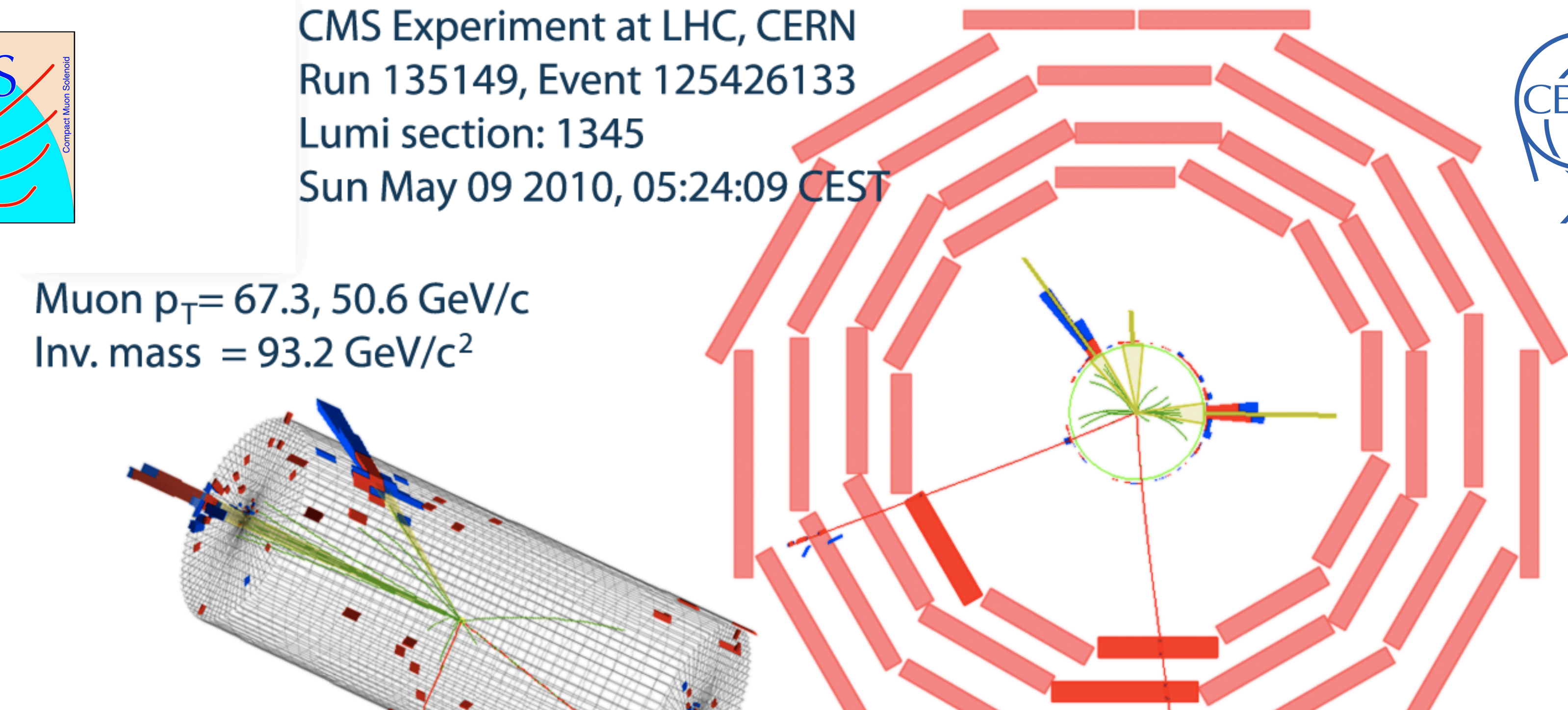
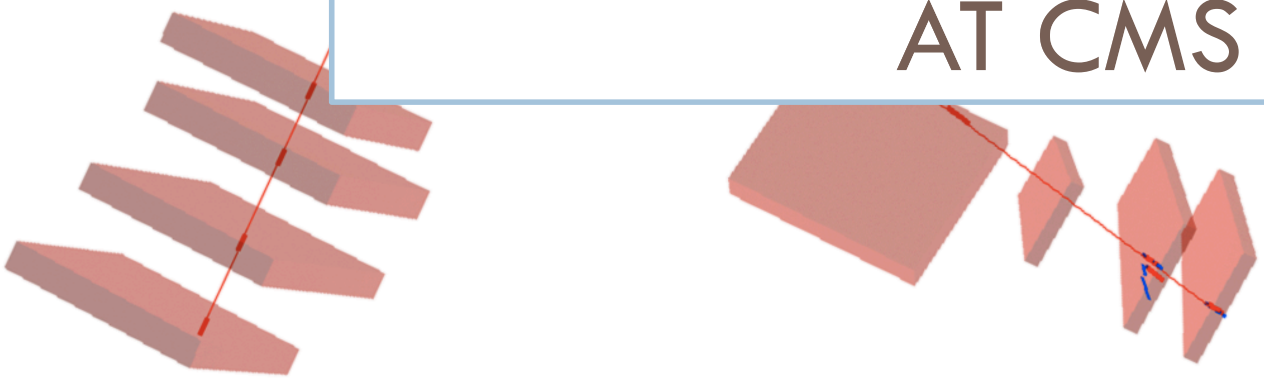


W,Z+JETS PRODUCTION AT CMS



Will Reece (CERN)

Introduction

- W & Z produced in abundance at LHC
  - Important SM candles for detector commissioning
  - Test properties at 7 TeV: W polarization
- V+Jets major background to many NP searches
  - High jet-multiplicity final states of particular interest
  - Adding extra jet reduces rate by ~5
  - Measured N_{jet} scaling: Use as handle
- Heavy flavour production
  - Interplay with top physics + 3rd generation NP models
- Test and tune Matrix Element+PS MC & NLO codes

Introduction

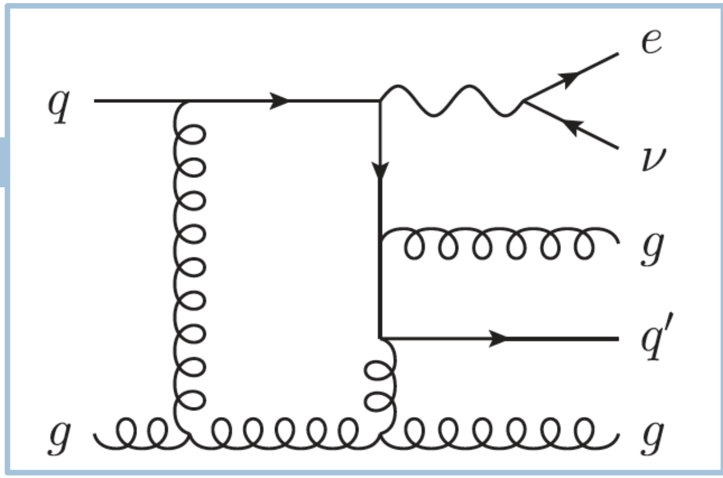
- W & Z produced in abundance at LHC

This Talk: Present three 36pb^{-1} analyses from CMS

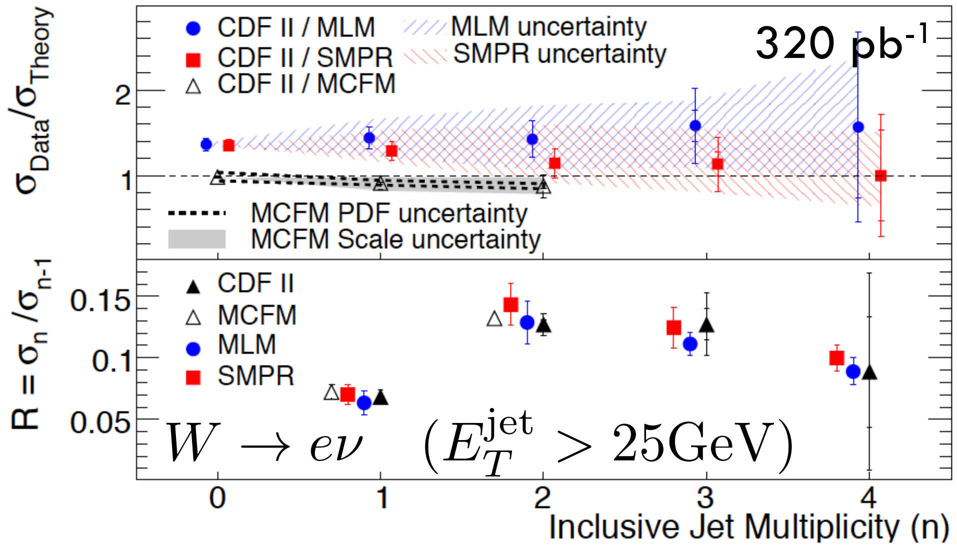
- W & Z + jet cross-section and scaling properties
  - CMS-PAS-EWK-10-012
- Measurement of polarization in boosted W decays
  - CMS-EWK-10-014
- Z production with heavy-flavour jets
  - CMS-PAS-EWK-015

- Test and tune Matrix Element MC + NLO codes

V+Jets at the LHC



- EWK+QCD process
  - Extra jets: NLO predictions challenging
  - W(Z)+4(3)J, calculations available
    - Phys.Rev.Lett.**106**:092001,2011 Phys.Rev.**D82**:074002,2010
- Leptons, MET, Jets in final state
  - Commission physics objects
  - Validate ME+PS MC
- Complementary to Tevatron
  - Confirm scaling behavior at 7TeV



CDF, Phys.Rev.**D77**:011108, 2008

W+Jet Selection

All results quoted inside acceptance

Muons

- **Leading:** P_T > 20 GeV; | η | < 2.1; Tight isolation, matched to HLT object; Tight muon ID
- **Transverse Mass:** M_T > 20 GeV using Particle-flow MET
- **Z Veto:** Full Z selection applied

Electrons

- **Leading:** P_T > 20 GeV; Tight isolation, matched to HLT object; 1.44< | η |<1.57 excluded; Electron ID, conversion rejection
- **Transverse Mass:** M_T > 20 GeV using Particle-flow MET
- **Z Veto:** Remove events with 2nd electron failing Z selection if P_T > 10

Jets

- Anti-KT Particle-flow jets with cone radius of 0.5
- E_T > 30 GeV; | η | < 2.4; Pile-up subtracted (Phys.Lett.**B659**:119-126,2008)
- **Muons:** Removed before jet clustering; **Electrons:** Use ΔR veto of 0.3

Z+Jet Selection

All results quoted inside acceptance

Muons

- **Leading:** $P_T > 20$ GeV; $|\eta| < 2.1$; Tight isolation, matched to HLT object; Tight muon ID
- **Second:** $P_T > 10$ GeV; $|\eta| < 2.4$; Loose muon ID, no isolation
- **Mass:** 60 GeV $< M_{\mu\mu} <$ 120 GeV

Jets

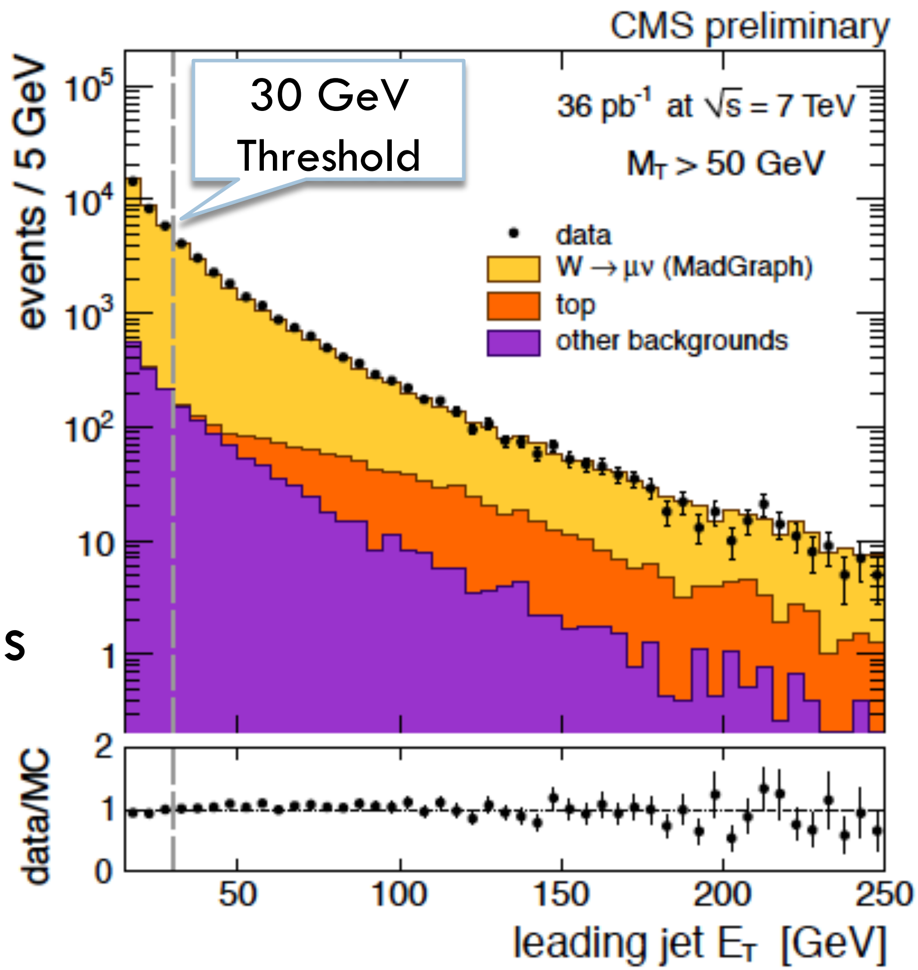
Electrons

- **Leading:** $P_T > 20$ GeV; Tight isolation, matched to HLT object
- **Second:** $P_T > 10$ GeV; $|\eta| < 2.5$; Loose isolation
- **Both:** $1.44 < |\eta| < 1.57$ excluded; Electron ID, conversion rejection
- **Mass:** 60 GeV $< M_{ee} <$ 120 GeV

- Anti-KT Particle-flow jets with cone radius of 0.5
- $E_T > 30$ GeV; $|\eta| < 2.4$; Pile-up subtracted (Phys.Lett.**B659**:119-126,2008)
- **Muons:** Removed before jet clustering; **Electrons:** Use ΔR veto of 0.3

Jet E_T Distributions: W

- Compare to leading jet E_T to MC
- MC Simulation:
  - W, Z, top: Madgraph+Pythia
  - QCD: Pythia
  - GEANT based Full-Sim
  - Scale to (N)NLO cross-sections
- Agreement very good
  - Some tune dependence
  - Show Z2 tune here



Jet E_T Distributions: Z

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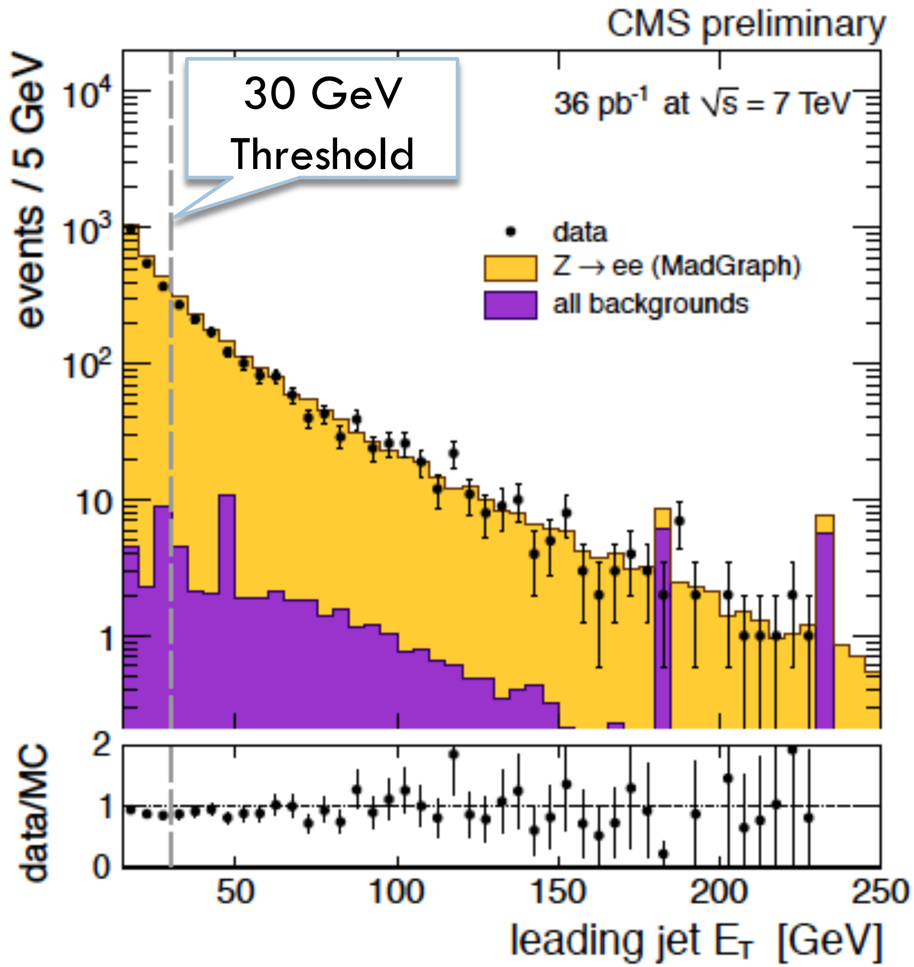
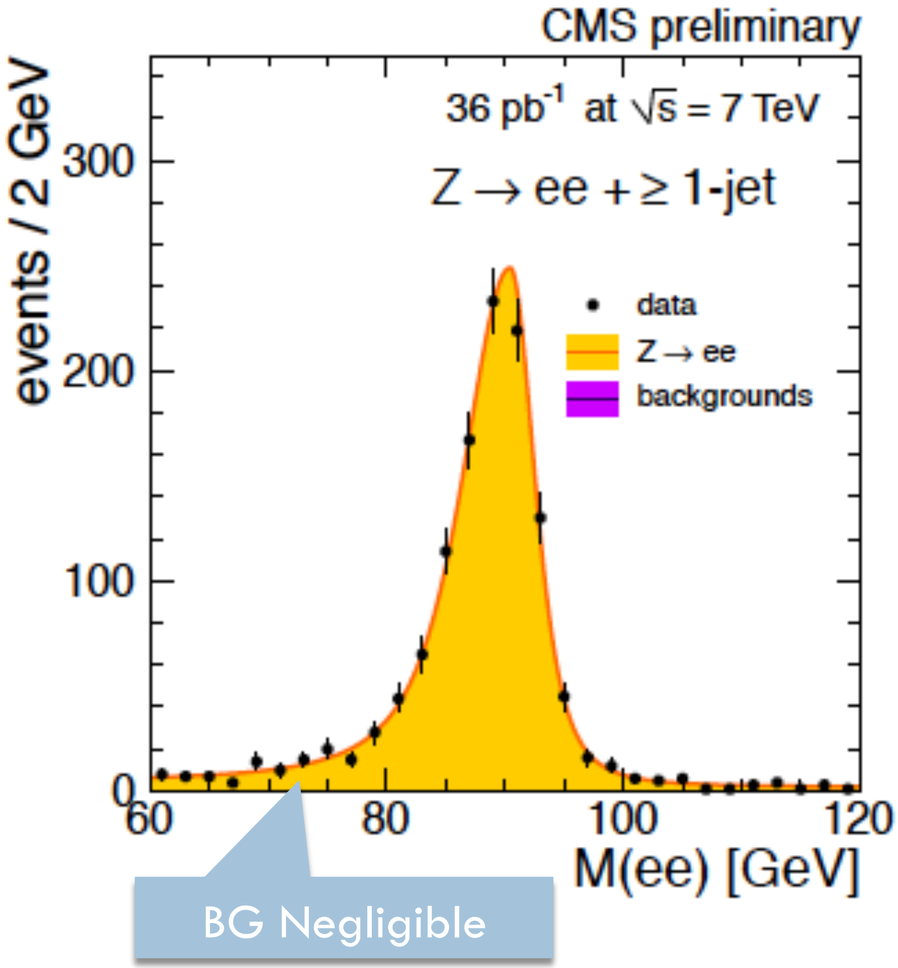


Signal Extraction

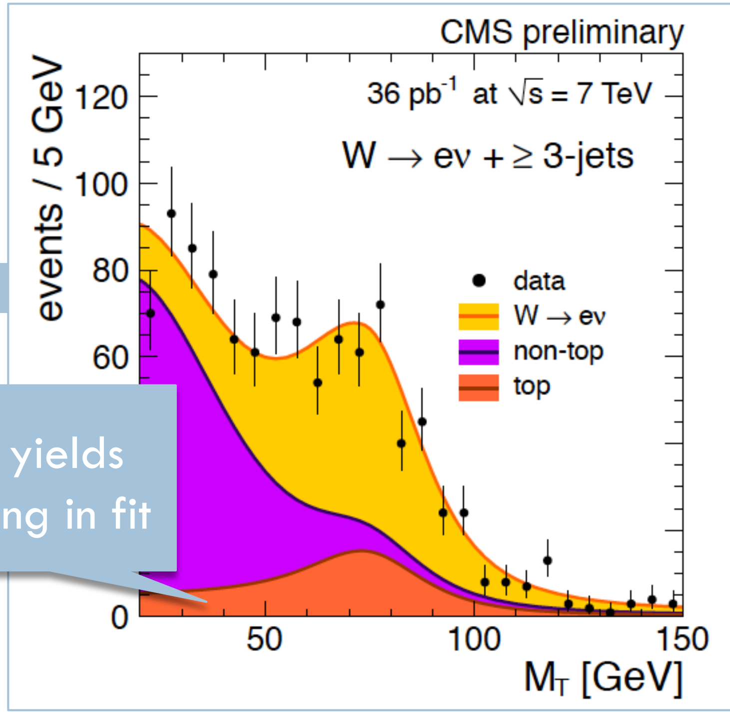
- Use unbinned ML fit
- Z: Two components (S+B)
  - Fit to di-lepton mass; shape parameters floated
  - Signal yields in exclusive jet bins ($N_{jet} \leq 4$)
- W: Signal, BG, top
  - Fit transverse mass & b-tag distribution
  - Most shape parameters taken from data

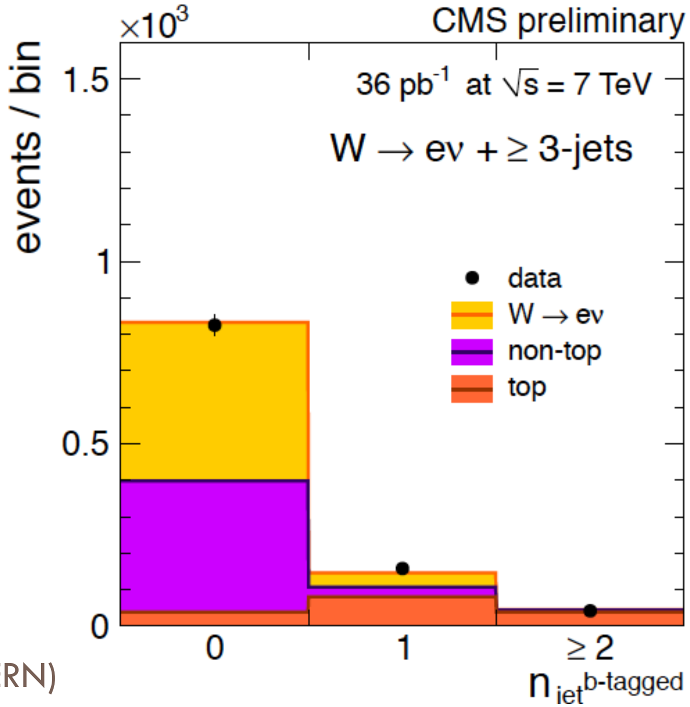


Signal Extraction

- Use unbinned ML fit
- Z: Two components (S+B)
  - Fit to di-lepton mass; shape parameters floated
  - Signal yields in exclusive jet bins ($N_{jet} \leq 4$)
- W: Signal, BG, top
  - Fit transverse mass & b-tag distribution
  - Most shape parameters taken from data

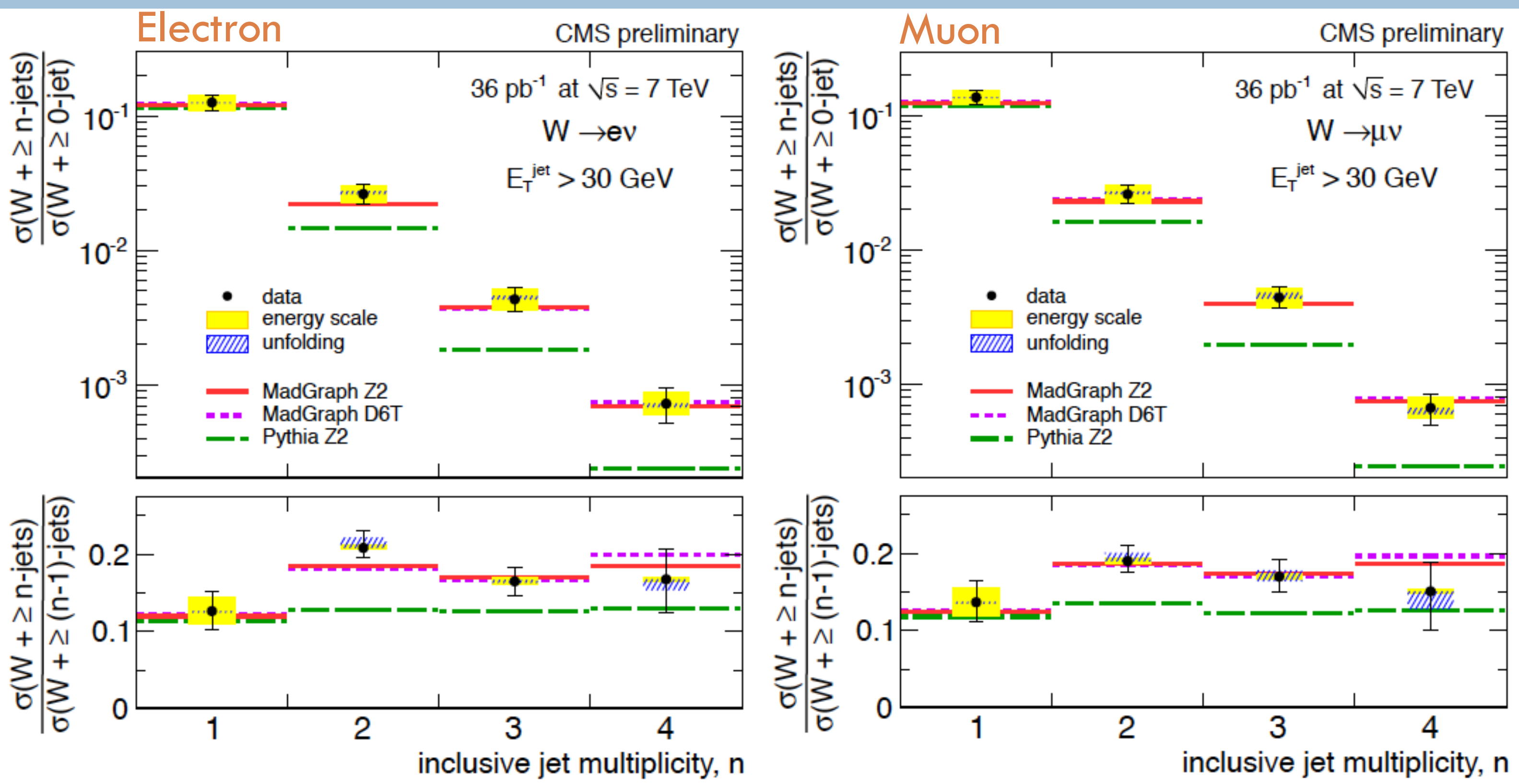
Top yields floating in fit





Results: W

Lepton reconstruction, trigger, selection efficiencies corrected with T&P

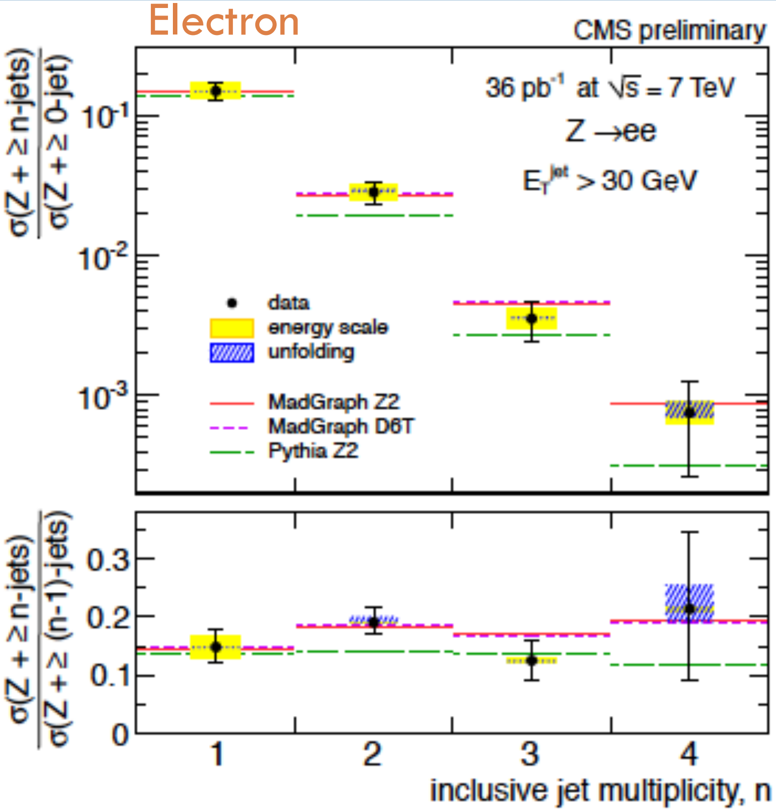


- Use SVD unfolding to remove jet-resolution effects
- Compare with MC: Matrix-Element looks good

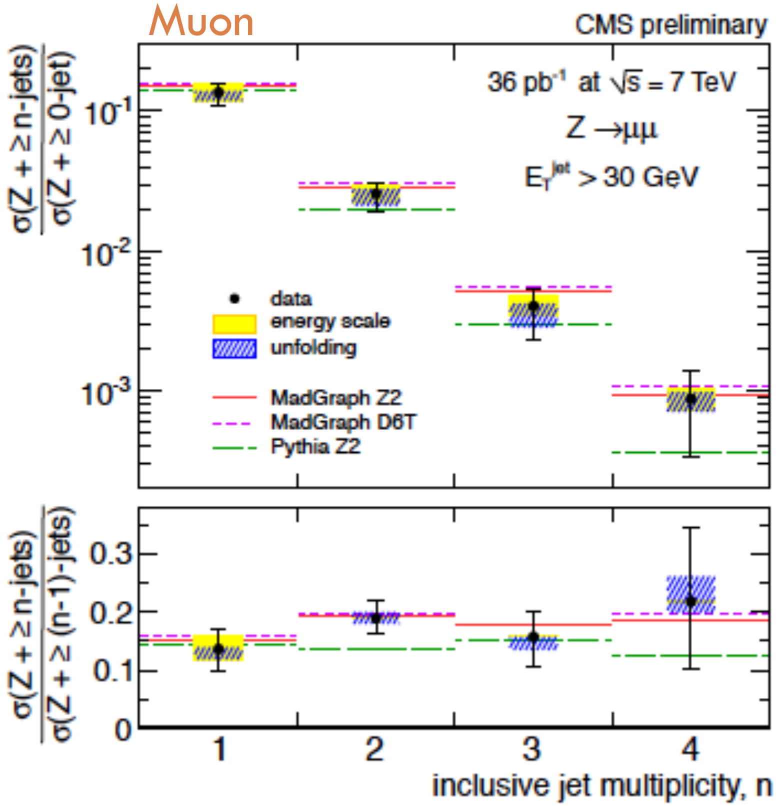
Results: Z

Lepton reconstruction, trigger, selection efficiencies corrected with T&P

Electron



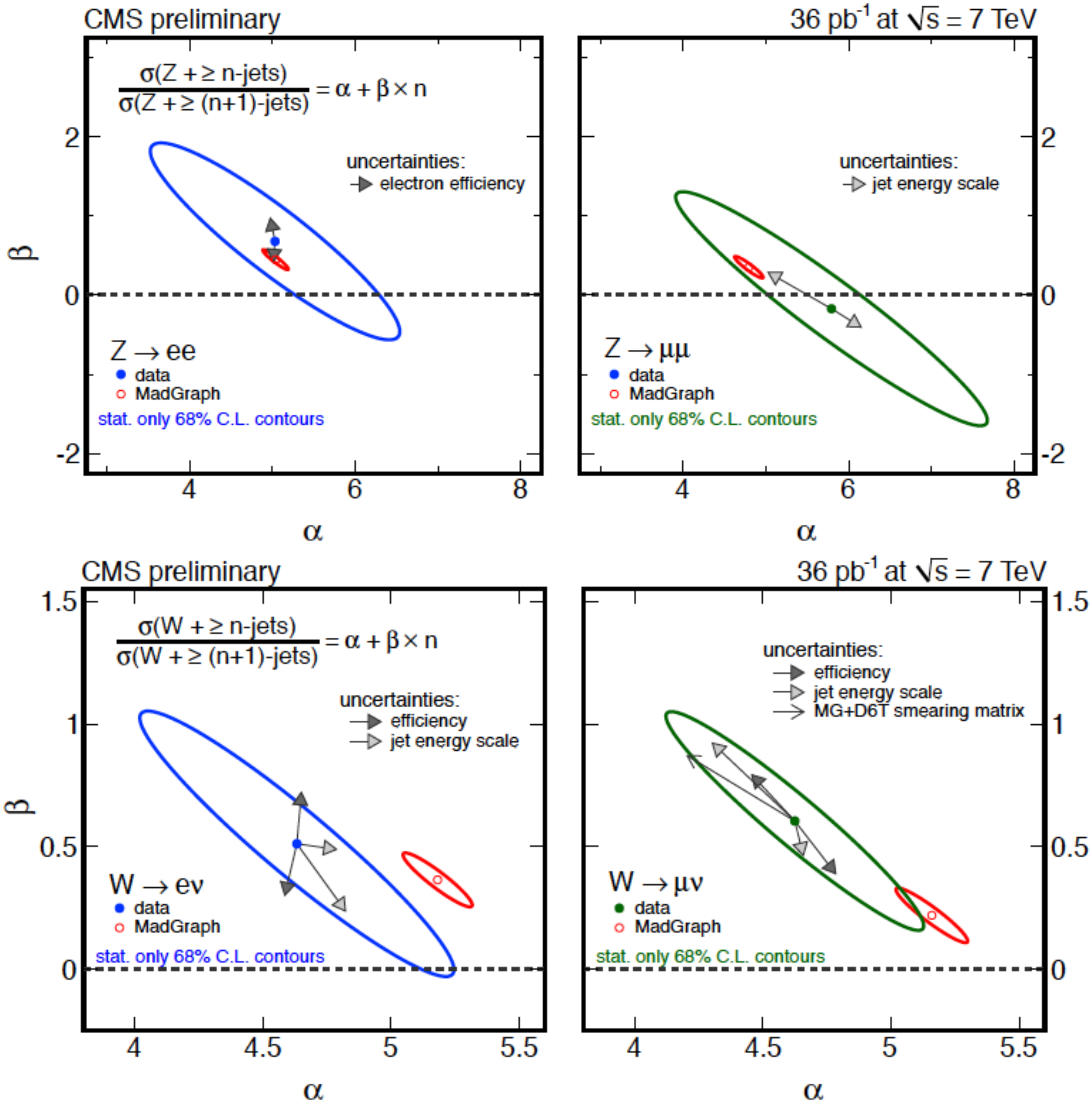
Muon



- Use SVD unfolding to remove jet-resolution effects
- Compare with MC: Matrix-Element looks good

Berends-Giele Scaling in V+Jets

- Test scaling behaviour: $C_n = \frac{\sigma_n}{\sigma_{n+1}}$ where $\sigma_n = \sigma(V + n \text{ jets})$
- Naïve LO expectation: $C_n = \alpha$ for n > 0
  - Constant proportional to α_S^{-1}
- Allow deviation from naïve scaling: $C_n = \alpha + \beta n$
- Extract α and β directly in simultaneous fit
  - Include unfolding matrix coefficients in likelihood
- Compare with Madgraph predictions at Gen-level
  - Direct and quantitative test of MC performance



CMS preliminary
36 pb^{-1} at $\sqrt{s}$ = 7 TeV
$\frac{\sigma(Z + \geq \text{n-jets})}{\sigma(Z + \geq \text{(n+1)-jets})} = \alpha + \beta \times n$
uncertainties:
electron efficiency
$Z \rightarrow ee$
data
MadGraph
stat. only 68% C.L. contours
uncertainties:
jet energy scale
$Z \rightarrow \mu\mu$
data
MadGraph
stat. only 68% C.L. contours
β
α
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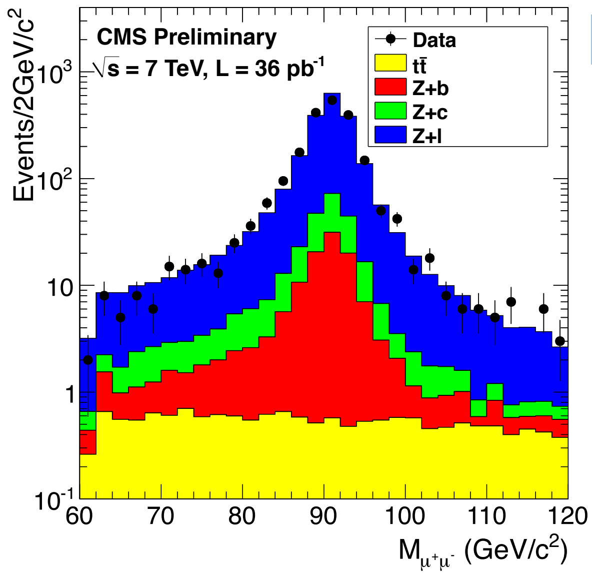
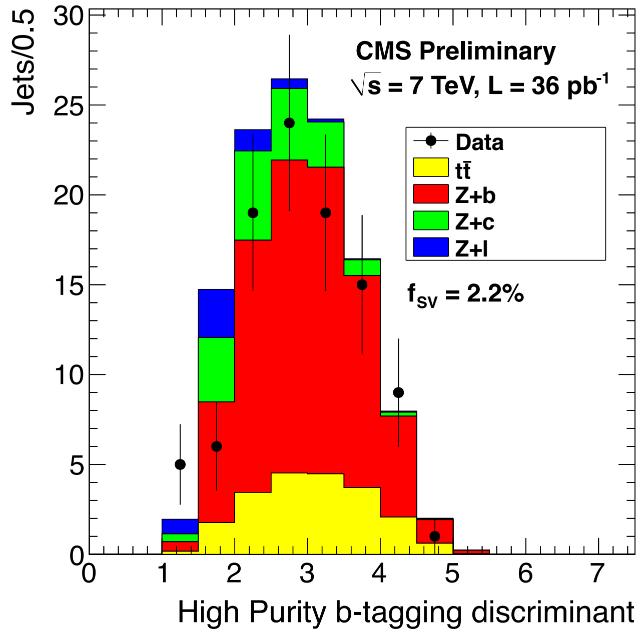
36 pb^{-1} at $\sqrt{s}$ = 7 TeV
$\frac{\sigma(W + \geq \text{n-jets})}{\sigma(W + \geq \text{(n+1)-jets})} = \alpha + \beta \times n$
uncertainties:
efficiency
jet energy scale
$W \rightarrow e\nu$
data
MadGraph
stat. only 68% C.L. contours
uncertainties:
efficiency
jet energy scale
MG+D6T smearing matrix
$W \rightarrow \mu\nu$
data
MadGraph
stat. only 68% C.L. contours

Heavy Flavour in Z Decays

- Z+b benchmark for high tan β MSSM Higgs searches
- H+b NLO: uncertainties large
  - 30% scheme dependence
  - Z+b data should help to clarify
- Select Z+≥1 jet events
  - Require secondary vertex
  - M_T < 40 GeV to reject top
  - Jet E_T > 25 GeV; ΔR veto: 0.5

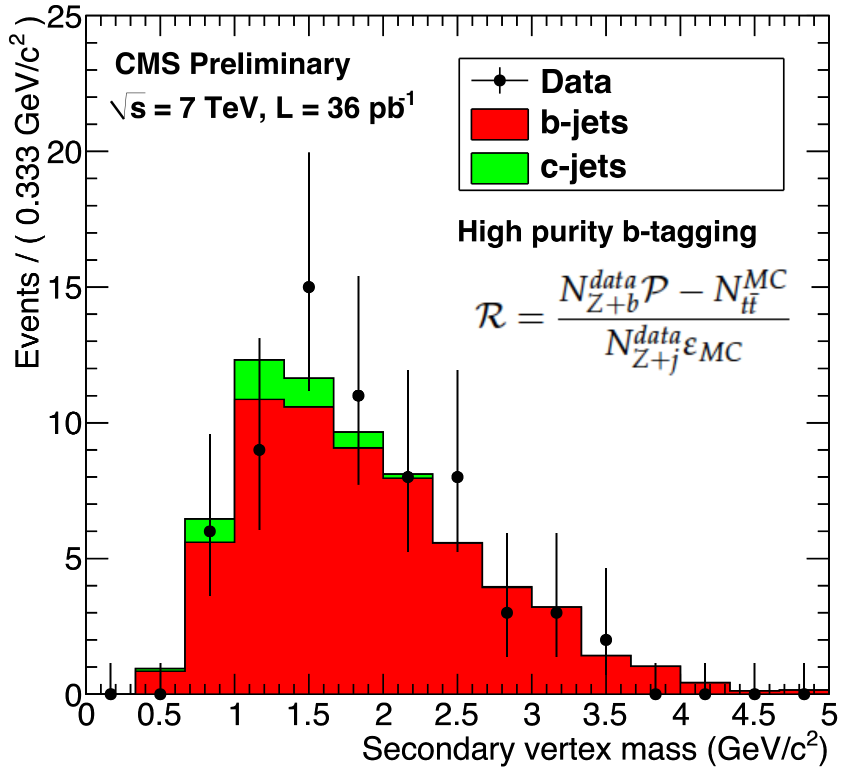




Z+b/Z+jet Ratio

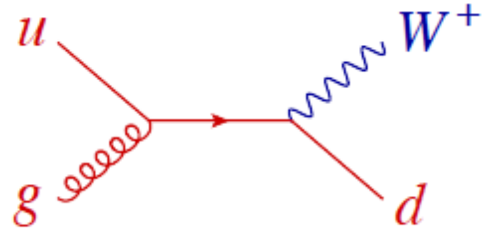
Purity (%)	SSVHE	SSVHP
data	55±9	88±11
MC	57±3	82±4

- Z+b purity from fit to:
  - Secondary vertex mass
  - B-tag discriminant shape
- Binned ML fit: MC templates
  - b, c, light-jet components
- Results compatible with Madgraph (scaled to NLO) & MCFM



Sample	$\frac{pp\to ee+b+X}{pp\to ee+j+X}$ (%) $p_T^e > 25$ GeV, $\lvert\eta^e\rvert < 2.5$	$\frac{pp\to \mu\mu+b+X}{pp\to \mu\mu+j+X}$ (%) $p_T^\mu > 20$ GeV, $\lvert\eta^\mu\rvert < 2.1$
Data SSVHE	$4.3 \pm 0.6(stat) \pm 1.1(syst)$	$5.1 \pm 0.6(stat) \pm 1.3(syst)$
Data SSVHP	$5.4 \pm 1.0(stat) \pm 1.2(syst)$	$4.6 \pm 0.8(stat) \pm 1.1(syst)$
MADGRAPH	$5.1 \pm 0.2(stat) \pm 0.2(syst) \pm 0.6(theory)$	$5.3 \pm 0.1(stat) \pm 0.2(syst) \pm 0.6(theory)$
MCFM	$4.3 \pm 0.5(theory)$	$4.7 \pm 0.5(theory)$

Boosted W Polarization

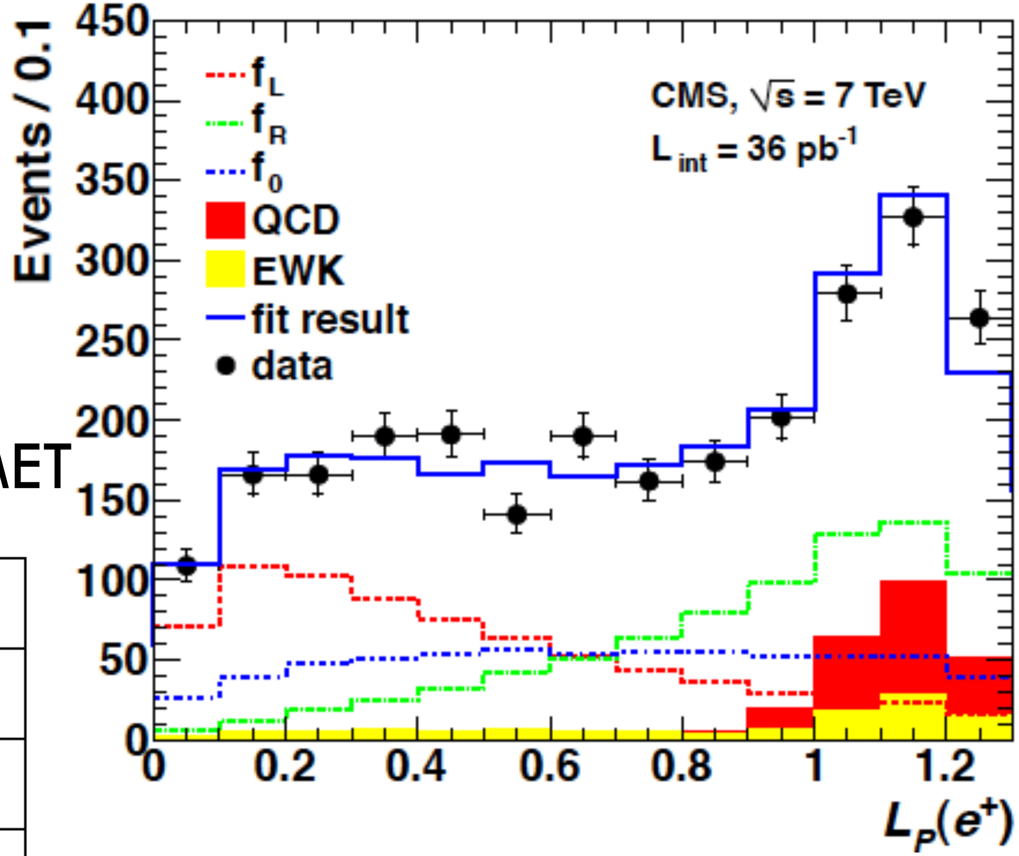


- High-P_T W at LHC: Produced from valence quarks (LO)
  - Due to PDFs: $\frac{d\sigma(ug \to W^+d)}{dp_T^W} > \frac{d\sigma(u\bar{d} \to W^+g)}{dp_T^W} > \frac{d\sigma(g\bar{d} \to W^+\bar{u})}{dp_T^W}$ 1103.5445
  - At Tevatron, anti-quark-gluon contribution equal
- SM Expectation: Left-handed W dominant
  - Heilicity arguments same for u→d initial state
- Select boosted W bosons (P_T > 50 GeV)
  - Cut on M_T to reduce BG: 50(30) GeV for electrons (muons)
  - $N_{jet} \leq 3$ for 30 GeV PF jets
- P_z(W) undetermined so define transverse variable
  - Lepton projection: $\mathrm{LP} = \frac{\vec{p}_T(\ell) \cdot \vec{p}_T(W)}{|\vec{p}_T(W)|^2}$ — MET + Lepton P_T

Boosted W Polarization

- Fit for polarization fractions: f_L, f_R, f_0
  - Signal shapes from MC; BG shapes from control
  - Systematics dominated by MET

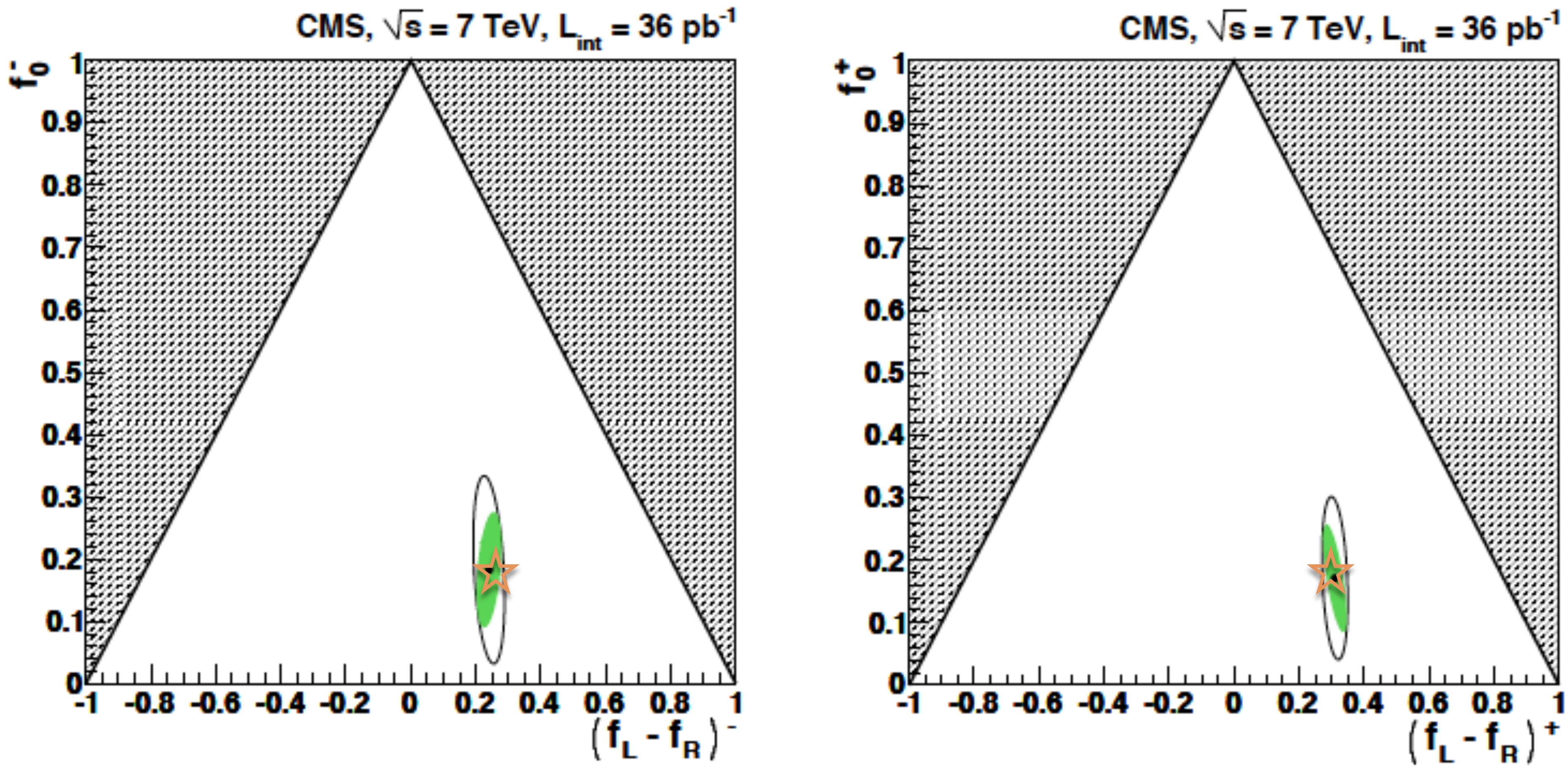
	Combined Results
$(f_L-f_R)^-$	0.226 ± 0.031 (stat) ± 0.050 (syst)
f_0^-	0.162 ± 0.078 (stat) ± 0.136 (syst)
$(f_L-f_R)^+$	0.300 ± 0.031 (stat) ± 0.034 (syst)
f_0^+	0.192 ± 0.075 (stat) ± 0.089 (syst)



$(f_L-f_R) > 0$ shows LH preference

W^+, W^-: Significance 6σ, 4.5σ

Boosted W Polarization



☆ Inclusive NLO for $P_T^W > 50$ GeV: (Bern et al,arXiv:1103.5445)

Summary

- Presented V+Jets results from CMS
  - 2010 data set; $36pb^{-1}$ integrated luminosity
- Measured Jet E_T distributions and rates
  - Good agreement with ME+PS MC simulation
- First direct measurement of Berends-Giele scaling
- Observation of Z+b events:
  - Z+b/Z+jet compared with NLO
- Measurement of boosted W polarization
  - NLO agreement startling
- Looking forward to 2011results!

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Backup Slides

V+Jets: MC Samples & Cross-sections

Generator	Process	Kinematic cuts (in GeV, $c = 1$)	σ (pb)
MadGraph	$W \to \ell\nu$	no cuts	3.1×10^4 (NNLO)
MadGraph	$Z \to \ell^+\ell^-$	$m_{\ell\ell} > 50$	3.0×10^1 (NNLO)
MadGraph	$t\bar{t}$	no cuts	1.6×10^2 (NLO)
MadGraph	single top tW channel	no cuts	1.1×10^1 (LO)
MadGraph	single top s and t channels	no cuts	3.5 (NLO)
Pythia	$W \to e\nu$	$\|\eta_e\| < 2.7$	8.2×10^3 (NNLO)
Pythia	$W \to \mu\nu$	$\|\eta_\mu\| < 2.5$	7.7×10^3 (NNLO)
Pythia	$W \to \tau\nu$	no cuts	1.0×10^4 (NNLO)
Pythia	$Z \to \ell^+\ell^-$	$m_{ll} > 20$	5.0×10^3 (NNLO)
Pythia	Inclusive μ QCD	$\hat{p}_T > 20$, $p_T^\mu > 10, \|\eta_\mu\| < 2.5$	3.4×10^5 (LO)
Pythia	EM-enriched QCD	$20 < \hat{p}_T < 170$	5.4×10^6 (LO)
Pythia	$b/c \to e$	$20 < \hat{p}_T < 170$	2.6×10^5 (LO)
Pythia	γ+jet	no cuts	8.5×10^7 (LO)

Berends-Giele Scaling Parameters

Table 9: Results for the Berends-Giele parameters in the electron channel compared with expectations from MadGraph Z2 at particle level.

		data	stat	JES	$\epsilon(\ell)$	Theory
Z	α	5.0	± 1.0	$^{+0.1}_{-0.0}$	$^{+0.00}_{-0.06}$	5.04 ± 0.10
	β	0.7	± 0.8	$^{+0.08}_{-0.04}$	$^{+0.3}_{-0.6}$	0.45 ± 0.08
W	α	4.6	± 0.4	$^{+0.2}_{-0.0}$	$^{-0.05}_{+0.02}$	5.18 ± 0.09
	β	0.5	± 0.4	$^{+0.0}_{-0.3}$	± 0.2	0.36 ± 0.07

Table 10: Results for the Berends-Giele parameters in the muon channel compared with expectations from MadGraph Z2 at particle level.

		data	stat	JES MC	$\epsilon(\ell)$	D6T tune	Theory
Z	α	5.8	$\pm$ 1.2	± 0.6	± 0.1	+0.3	4.8 ± 0.1
	β	-0.2	$\pm$ 1.0	± 0.3	± 0.1	-0.0	0.35 ± 0.09
W	α	4.3	± 0.3	± 0.2	± 0.2	-0.4	5.16 ± 0.09
	β	0.7	± 0.3	± 0.2	± 0.3	+0.3	0.22 ± 0.06

Boosted W at NLO

	W^+ NLO	W^+ ME+PS	W^+ LO	W^- NLO	W^- ME+PS	W^- LO
f_L	0.554	0.548	0.556	0.528	0.521	0.523
f_R	0.246	0.265	0.246	0.279	0.300	0.287
f_0	0.200	0.187	0.198	0.193	0.179	0.190

Inclusive NLO for P_T^W>50 GeV: (Bern et al,arXiv:1103.5445)

CMS Experiment at LHC, CERN
Run 135149, Event 125426133
Lumi section: 1345
Sun May 09 2010, 05:24:09 CEST

Muon p_T= 67.3, 50.6 GeV/c
Inv. mass = 93.2 GeV/c^2