W Mass Theory Workshop
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Introduction and Overview

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Workshop Goals

- Theoretical inputs are an important aspect of the $W$ boson mass measurement at the Tevatron.
- CDF and D0 have published $W$ mass measurements from Run 1 data, $\sim 100 \text{ pb}^{-1}$ each, with a combined uncertainty of 59 MeV.
- Generator-level inputs contributed $\sim 25 \text{ MeV}$ uncertainty
  - Boson $p_T$: 15-20 MeV
  - QED radiative corrections: 12 MeV
  - PDFs: 8-15 MeV
- Experience shows that experimental uncertainties can be constrained with collider data and have reduced as $1/\sqrt{N}$
- Generator-level inputs would limit improvements in precision beyond $400 \text{ pb}^{-1}$ (have $\sim 200 \text{ pb}^{-1}$ already)
- LEP $W$ mass uncertainty $\sim 40 \text{ MeV}$
Workshop Goals

- Start thinking about improved generator-level tools for Run 2:
  - How should we compute PDF uncertainty?
  - How should we incorporate all the available information on boson $p_T$ (experimental, theoretical) into the W mass fit? What are the degrees of freedom in the $p_T$ spectrum?
  - How can we incorporate QED radiative corrections into our detector simulation and mass-fitting programs?
Review of Run 1 Techniques

- 3-momenta of charged lepton and radiative photon and hadronic recoil $p_T^- ( = -p_T^+(\text{boson}))$ represents generator-level event in simulation.

- Fast detector simulation processes $\sim 10M$ events/day

- High-statistics histograms (smooth templates) of detector-level kinematics such as $W$ transverse mass ($m_T$), $p_T(l)$, $p_T(\nu)$, $m_{\ell\ell}$ are generated for a range of finely-spaced values of true $M_W$ or $M_Z$

- “Measured” $M_W$, $M_Z$ correspond to the template chosen by maximum likelihood fit to data distribution.
Run 1 Generators

- No complete \((l, \nu, \gamma)\) final state generator available!
- QCD and QED/EWK physics of \(W\) and \(Z\) boson production patched together into homebrew generators by CDF and D0.
  - Triple differential boson cross section factorized into mass lineshape function and double-differential \((y, p_T)\) distributions
  - D0 used Ladinsky-Balazs-Yuan code for making \((y, p_T)\) grid, CDF used homebrew \(p_T(W,Z)\) parametrization
  - \(p_T\)-dependent \(W\) polarization due to QCD ISR taken from Mirkes' calculation, tacked on.
  - Photon FSR tacked on according to Berends-Kleiss (D0) or PHOTOS (CDF), checked by fitting against Baur et al. calculation.
Run 2 Technique (CDF)

- Separate generation and detector simulation programs
- Use generator level programs to write files containing 3-momenta of $l, \nu, \gamma$.
- Read events from vector files into detector simulation program to generate templates.
Generators @ CDF for Run 2

- Using **RESBOS** for full boson triple-differential cross section $\sigma(Q, y, p_T)$
  - Contains tunable parameters for $p_T$ spectrum
  - Can set $W$ mass and width independently (new from Csaba)
  - Contains $p_T$-dependent $W$ polarization effects from QCD (affects decay angular distribution a la Mirkes: 40 MeV effect on $W$ mass)
  - **Would like photon propagator contribution added for $Z \rightarrow ll$**

- **RESBOS does not generate QED-radiative photons**
Generators @ CDF for Run 2

- **WGRAD/ZGRAD** is current choice for generating radiated photons, **ISR** and **FSR**

- Photon needed in generated final state to simulate biases in lepton selection and kinematics

- But all QCD effects missing

- Need some way to incorporate both QED and QCD physics (with good accuracy) into a usable event-generation scheme
  - Hopefully better than Run 1 solutions
Proposals to combine QCD+QED

- Ideally: merge RESBOS and WGRAD into a single generator
  - Very worthwhile long-term investment: perhaps the only reliable solution for 20 MeV measurement of $W$ mass (with 2 fb$^{-1}$)

- Experimentalists' approaches:
  - Run WGRAD through parton showering MC's like PYTHIA, HERWIG, but
    - not easily tunable
    - missing depolarization a la Mirkes
  - Add Run 1 – style parametrization of QCD effects on WGRAD output, but
    - no theory control on the QCD physics
CDF Method of Merging RESBOS, WGRAD
(see Ian's talk)

• Create RESBOS and WGRAD event vector files
• For each RESBOS event
  – use WGRAD file as lookup table
  – find best-matching WGRAD event in production and decay kinematics
  – impart 3-momentum of \( W_{\text{RESBOS}} \) to \( W_{\text{WGRAD}} \)
  – Final event contains (?) the physics of both programs
• Can be adapted to new input programs, e.g. \( 2\gamma \) calculation.
PDFs and Boson $p_T$

- Run 1 (notorious) method for PDF error estimation: pick ~5 PDFs and compare $M_W$
  - CDF and D0 used different sets of 5 PDFs
  - CDF did further internal tuning based on W charge asymmetry measurement
  - Run 2: would like a more defensible, public method to estimate PDF uncertainty on $M_W$

- Boson $p_T$ error: $p_T(Z)$ parameters are fit to $Z \rightarrow ll$ data, parameter errors propagated to $p_T(W)$
  - does $p_T$(boson) model of RESBOS address all the degrees of freedom?
  - is there any additional uncertainty in predicting $p_T(W)$?
Workshop Agenda

- Discussion of WGRAD, RESBOS and unified generator (Doreen, Csaba, Pavel)
- WGRAD+RESBOS outputs merging scheme (Ian)
- New developments in Electroweak calculations (Ulrich)
- PDF errors: CTEQ scheme and resulting $\delta M_W$ (Joey, Oliver)
- Boson $p_T$ and other observables (Pavel)
- General discussion and summary