# Report on the Dileptons

Samir Ferrag
On behalf of the Dilepton group

**Greg L, Samir F, Edward B, Rohini G, Gregory M, Marcel V, Saurabh R, Claire S-T, Valerie H, Tim T, Kevin B, Meena M, Michel H. Doreen W, Fulvio P, Stefano P, Stefano M, Johann K, Maarten B, Marie L, Henri B,**

# Introduction

- ***2 sides: Understand the Standard Model before looking for BSM***

– **Standard Model side**: *Controlling the "Drell-Yan"*
  - **Uncertainties:**
    - PDF:
      - theory
      - experimentation
    - Factorisation and renormalisation scale
  - **Higher order corrections:**
    - QCD NLO (NNLO)
    - EW NLO
    - EW logs

  **. Doreen W, Fulvio P, Stefano P, Stefano M, Claire S-T, Samir F, Johann K, Nadia A, Valerie H.**

→ ***Draw the uncertainty band of SM prediction and any deviation of this band signs new physics***

– **Exotic side**
  - **Many models**
    - S-channel resonances: Z' $Z_{H,}Z_{KK}$ G
    - Virtual exchange of gravitons
    - Leptoquarks, Leptogluons, Heavy scalars...
  - **Disentangle the models:**
    - Invariant mass spectrum, angular distributions, parameter measurements...
    - **Greg L, Samir F, Edward B, Rohini G, Gregory M, Marcel V, Saurabh R, Claire S-T, Valerie H, Tim T, Kevin B, Meena M, Michel H.**
  - **Dileptons in KK: Edward B.**
  - **EW fits:**
    - **Maarten B, Marie L, Henri B,**

# Projects at les houches

- Controlling the Drell-Yan
  - Defining the strategy (ll+X, ll+vetoes...?): Samir +Claire
  - Combining QCD & EW MCs for the Drell Yan: code from Fulvio, Doreen (Samir, Claire...)
  - Including beyond EW NLO corrections in MC: Doreen, Fulvio, Stefano
- Exotic
  - Disentangling models: Greg et al
  - EW Fits: Saclay

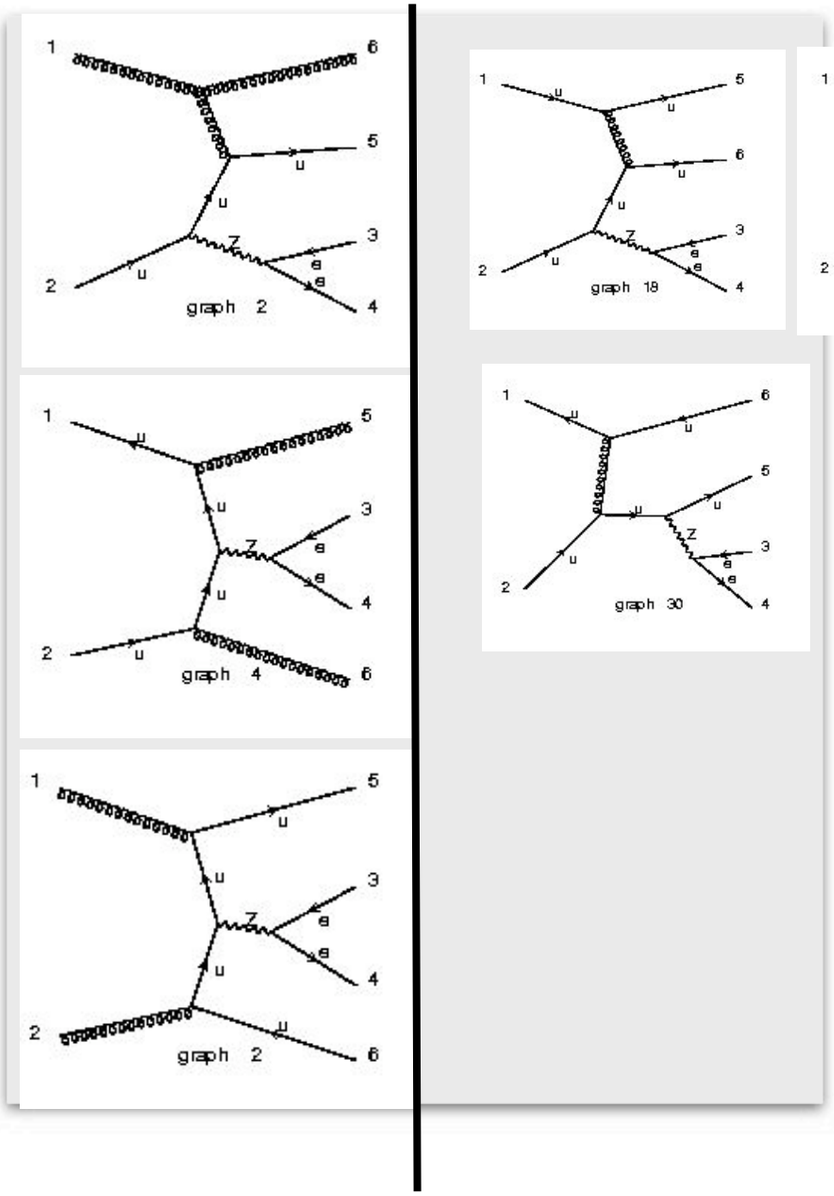
# ee or ee+X

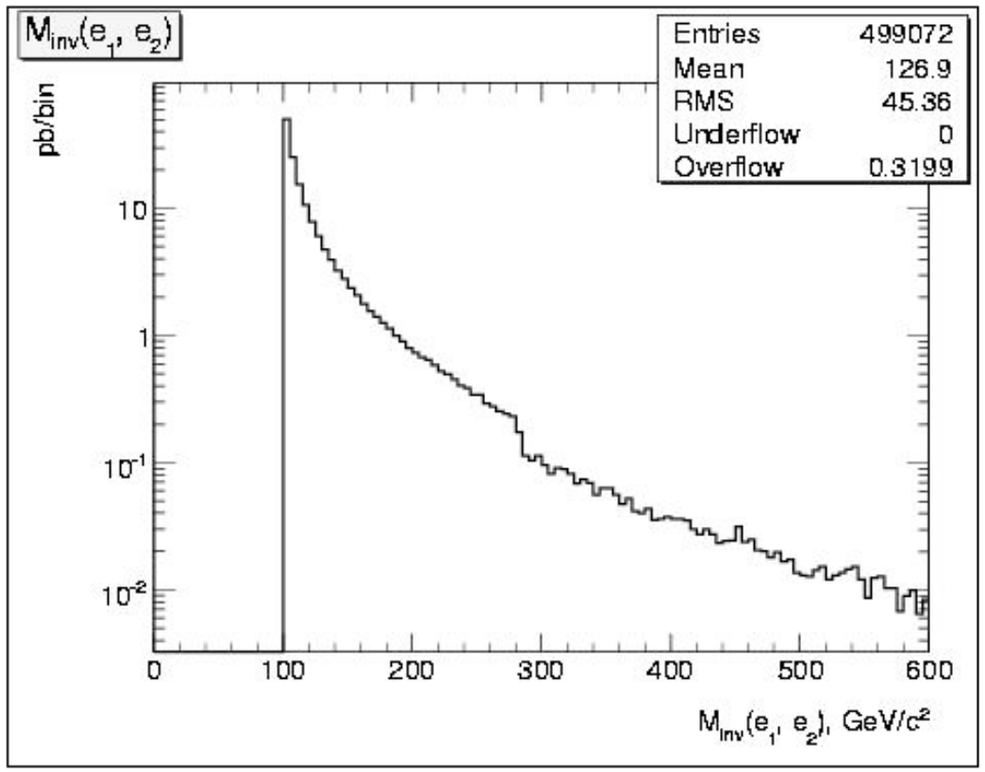
- eejj as a background/part of NNLO (QCD) for ee
  - effect of vector boson emission
  - ll + jet,Etmiss veto or ll+X ?
- Produced with MadGraph: 500k (eejj) + 50k (ee) event
  - $m_{ee}$ > 100 GeV, | $_{e,j}$ |< 3, Delta(R)$_{jj}$ > 0.3
  - cross sections and 1st surprise:
    - ee:30.1± 0.1(pb), eejj:15.52± 0.02(pb)

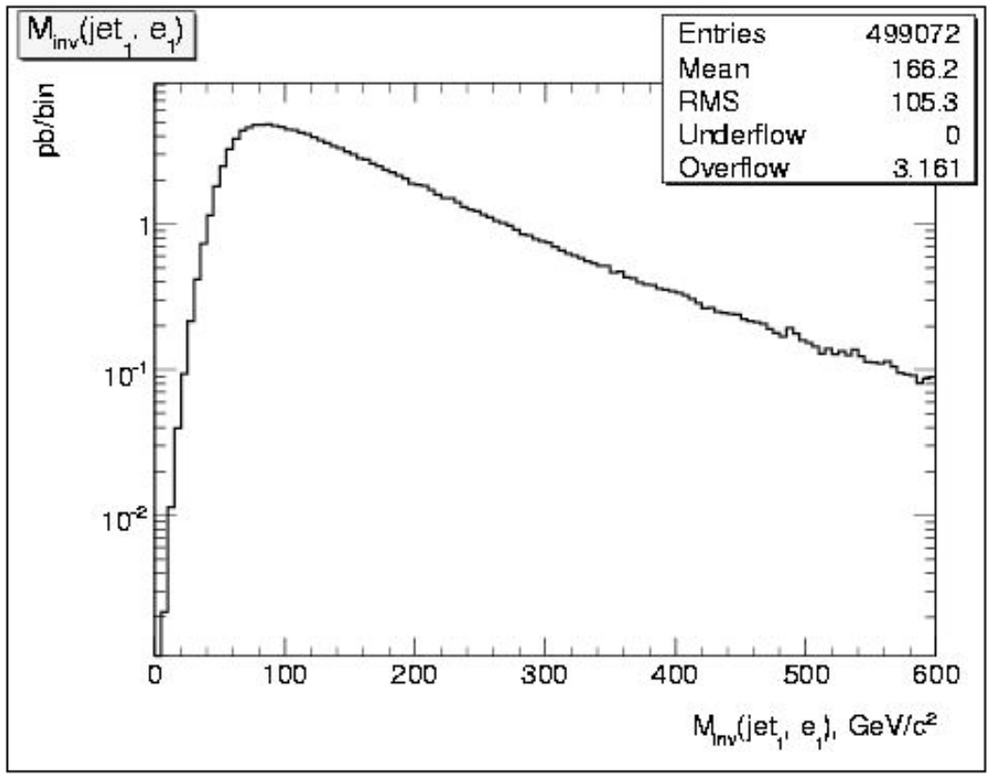
# Contributios to the cross section

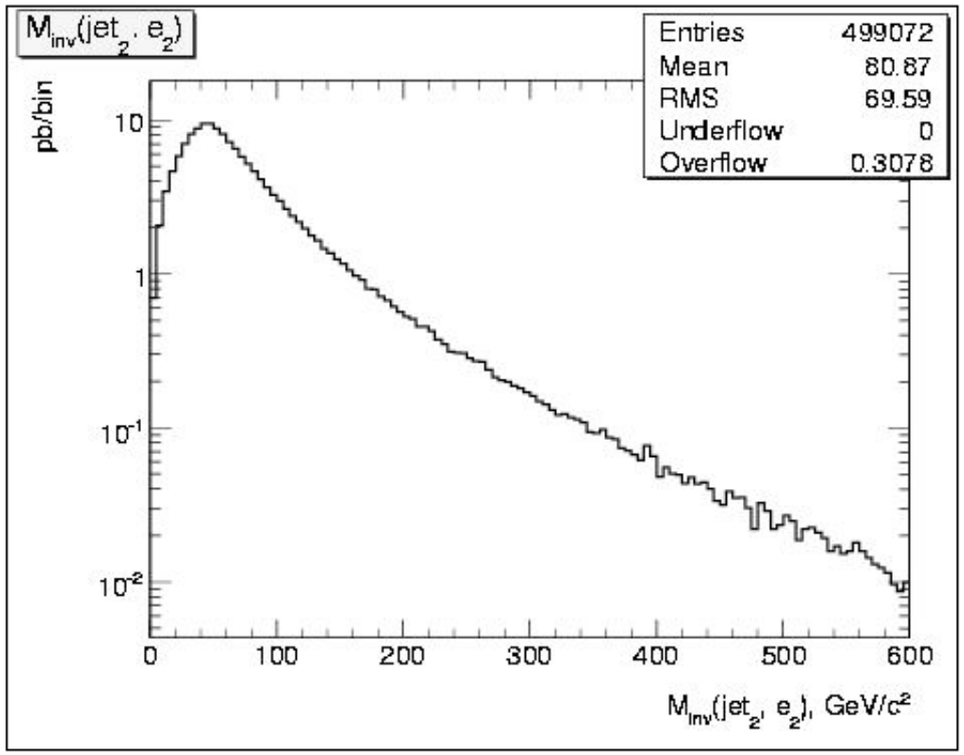
**Process results**
**s= 15.519± 0.025(pb)**

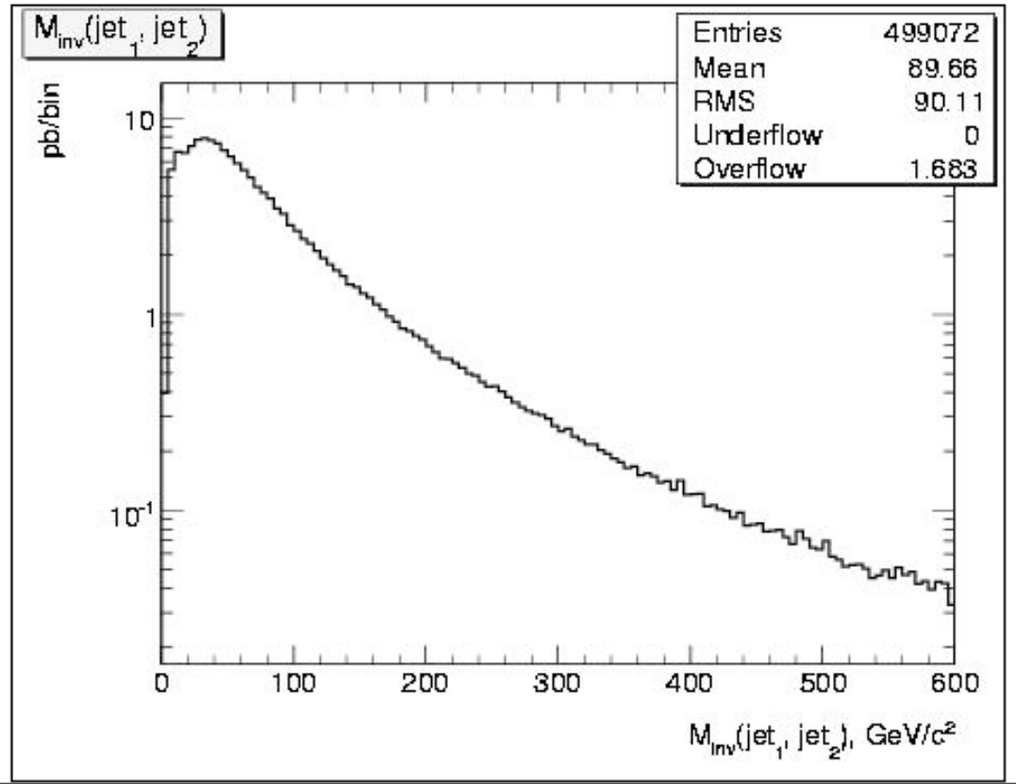
| Graph | Cross Sect(pb) | Error(pb) | Events (K) | Eff | Unwgt | Luminosity |
|---|---|---|---|---|---|---|
| **Sum** | **15.519** | **0.025** | **14845** | **6.2** | | |
| P_gu_e+e-ug | 2.105 | 0.009 | 439 | 2.7 | | 3240.00 |
| P_ug_e+e-ug | 2.099 | 0.008 | 373 | 2.4 | | 3240.00 |
| P_dg_e+e-dg | 1.572 | 0.009 | 703 | 4.9 | | 3440.00 |
| P_gd_e+e-dg | 1.567 | 0.006 | 803 | 3.7 | | 4080.00 |
| P_gdx_e+e-dxg | 0.994 | 0.005 | 350 | 3.1 | | 3250.00 |
| P_dxg_e+e-dxg | 0.991 | 0.006 | 602 | 5.0 | | 3480.00 |
| P_uxg_e+e-uxg | 0.824 | 0.005 | 347 | 3.9 | | 3340.00 |
| P_gux_e+e-uxg | 0.816 | 0.006 | 333 | 4.1 | | 3720.00 |
| P_uxu_e+e-gg | 0.675 | 0.003 | 84 | 1.5 | | 3250.00 |
| P_uux_e+e-gg | 0.667 | 0.004 | 170 | 2.3 | | 3240.00 |
| P_dxd_e+e-gg | 0.544 | 0.005 | 319 | 5.3 | | 3480.00 |
| P_ddx_e+e-gg | 0.541 | 0.003 | 524 | 4.5 | | 3510.00 |
| P_gg_e+e-uux | 0.457 | 0.003 | 292 | 3.8 | | 3790.00 |
| P_gg_e+e-ddx | 0.451 | 0.003 | 230 | 3.5 | | 4370.00 |
| P_uu_e+e-uu | 0.077 | 0.000 | 186 | 2.3 | | 4560.00 |
| P_ud_e+e-ud | 0.068 | 0.001 | 165 | 3.7 | | 9610.00 |
| P_du_e+e-ud | 0.067 | 0.001 | 135 | 3.4 | | 11200.00 |
| P_uxu_e+e-uux | 0.053 | 0.000 | 180 | 2.1 | | 12300.00 |
| P_uux_e+e-uux | 0.053 | 0.000 | 185 | 2.4 | | 5000.00 |
| P_dxd_e+e-ddx | 0.045 | 0.000 | 155 | 4.0 | | 5710.00 |
| P_ddx_e+e-ddx | 0.045 | 0.000 | 165 | 3.3 | | 14400.00 |
| P_dd_e+e-dd | 0.040 | 0.000 | 147 | 2.6 | | 16000.00 |
| P_dxu_e+e-udx | 0.034 | 0.000 | 140 | 3.9 | | 8750.00 |
| P_udx_e+e-udx | 0.034 | 0.000 | 124 | 2.8 | | 27300.00 |
| P_su_e+e-us | 0.024 | 0.000 | 110 | 2.1 | | 32300.00 |

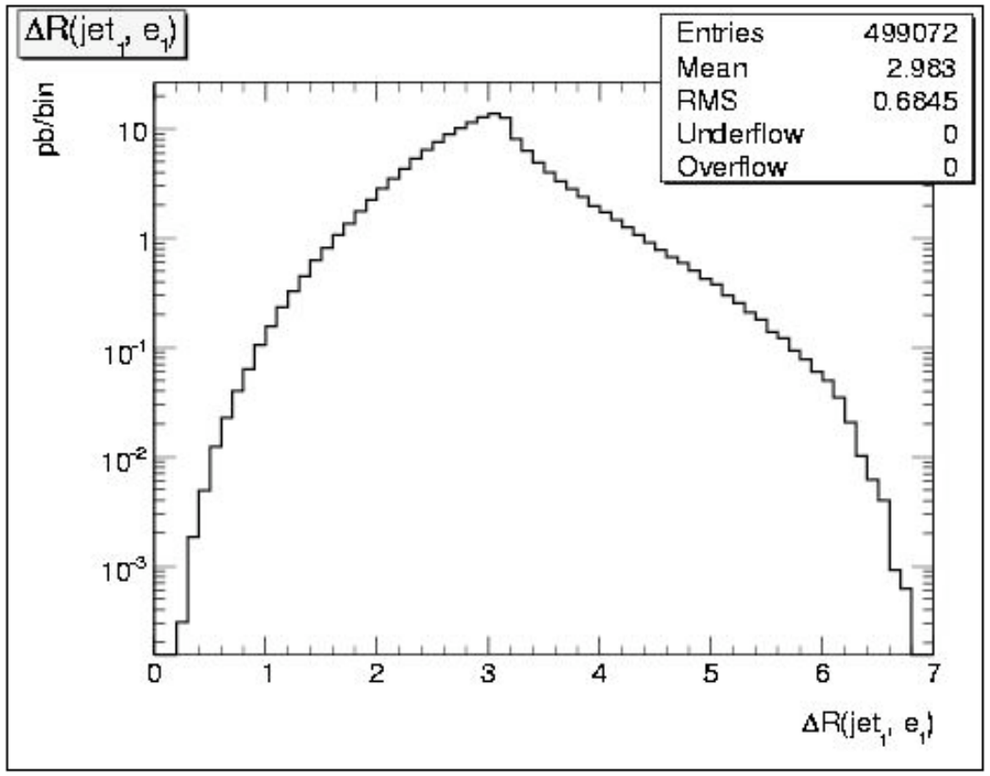


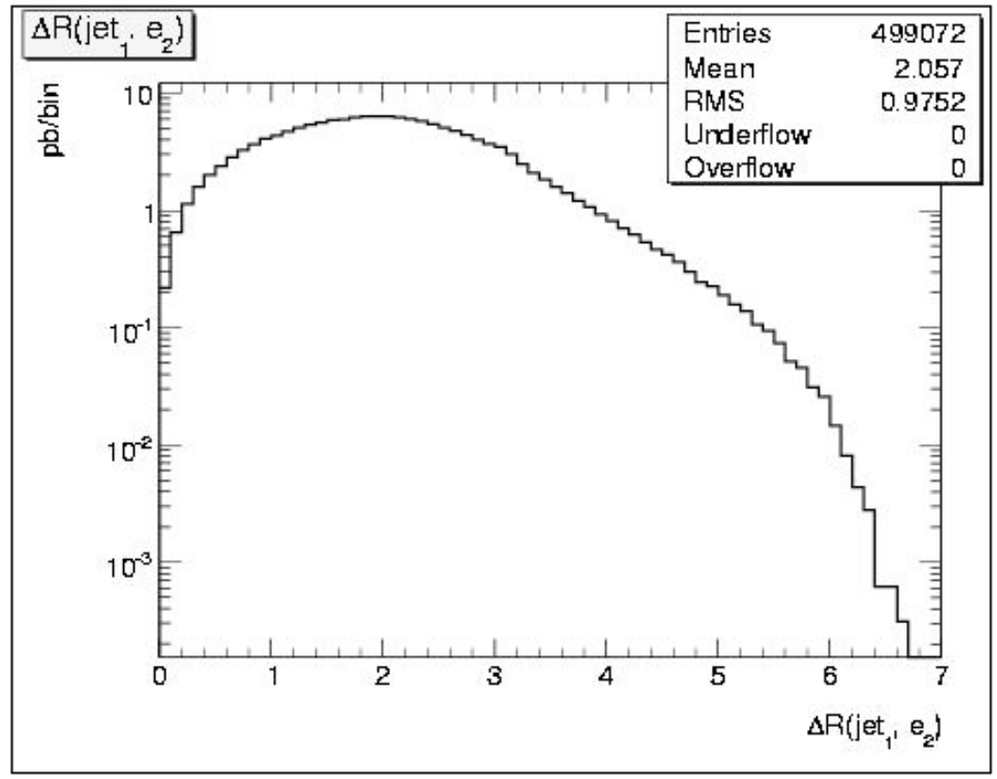

$M_{inv}(e_1, e_2)$
Entries 499072
Mean 126.9
RMS 45.36
Underflow 0
Overflow 0.3199
pb/bin
$M_{inv}(e_1, e_2)$, GeV/c²

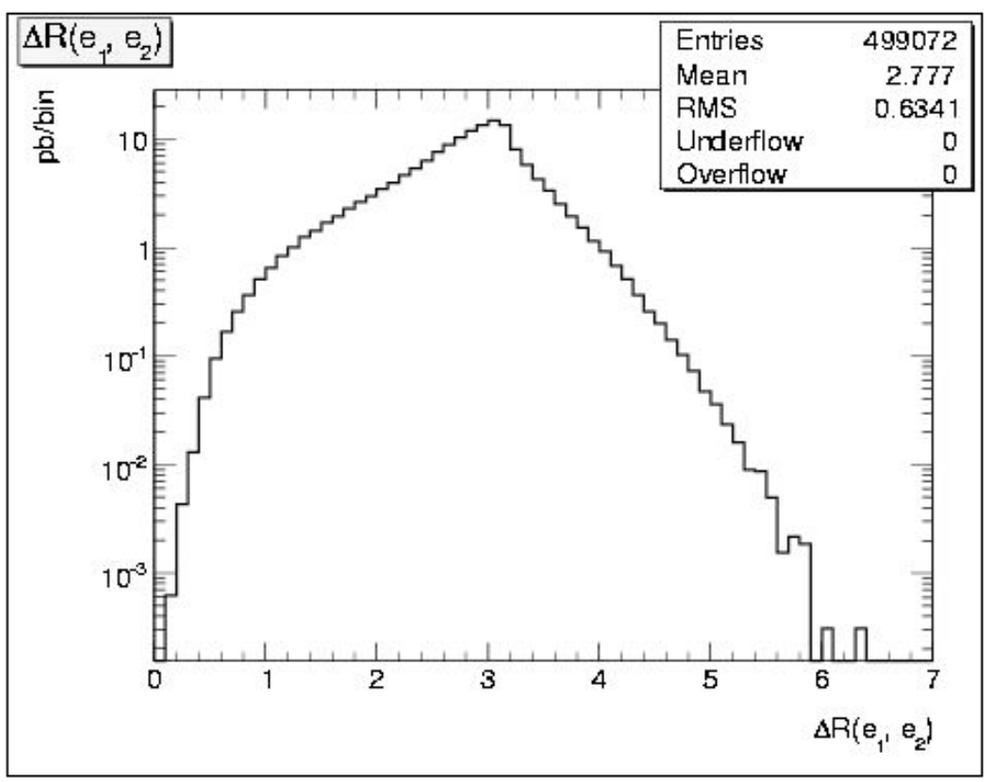

$M_{inv}(jet_1, e_1)$
Entries 499072
Mean 166.2
RMS 105.3
Underflow 0
Overflow 3.161
pb/bin
$M_{inv}(jet_1, e_1)$, GeV/c²

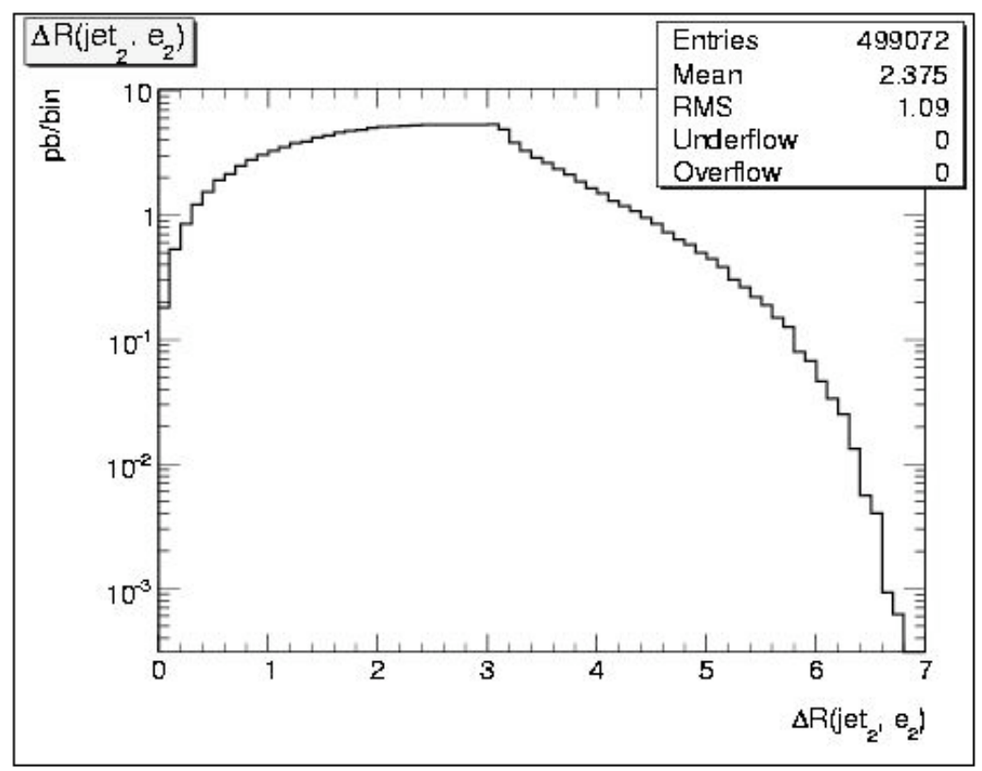

$M_{inv}(jet_2, e_2)$
Entries 499072
Mean 80.87
RMS 69.59
Underflow 0
Overflow 0.3078
pb/bin
$M_{inv}(jet_2, e_2)$, GeV/c²

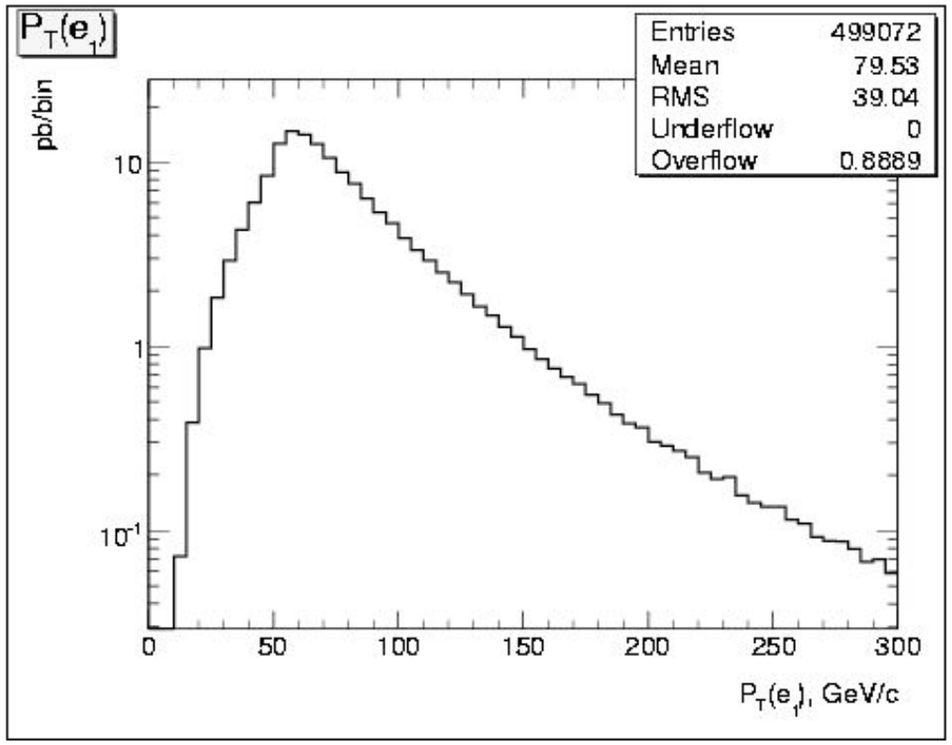

$M_{inv}(jet_1, jet_2)$
Entries 499072
Mean 89.66
RMS 90.11
Underflow 0
Overflow 1.683
pb/bin
$M_{inv}(jet_1, jet_2)$, GeV/c²

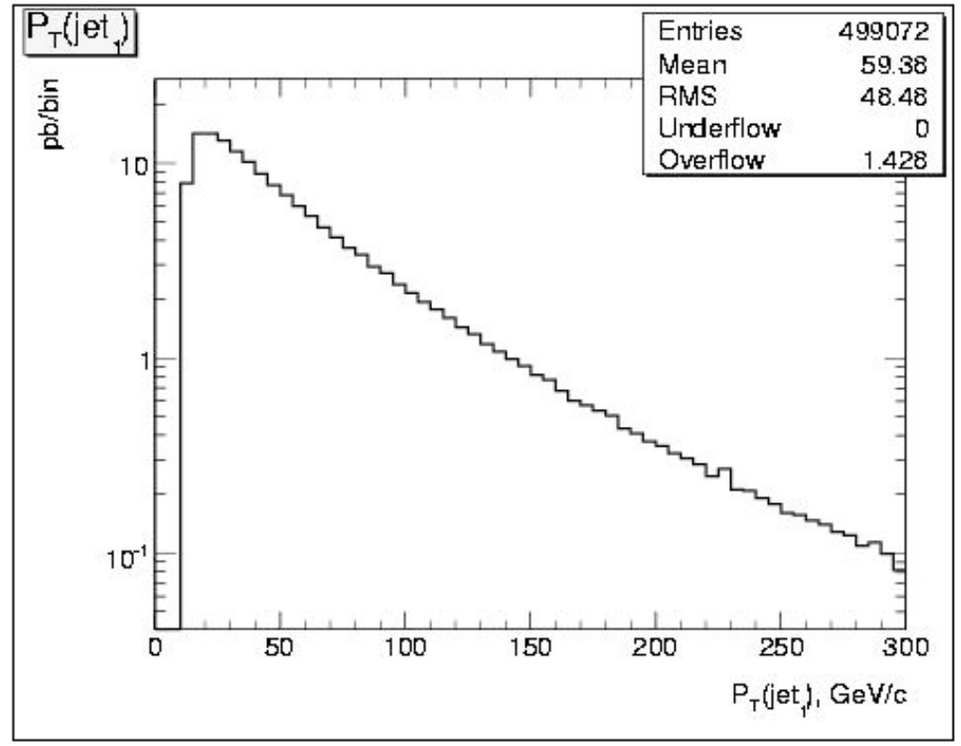

ΔR(jet1, e1)
Entries 499072
Mean 2.983
RMS 0.6845
Underflow 0
Overflow 0
pb/bin
ΔR(jet1, e1)

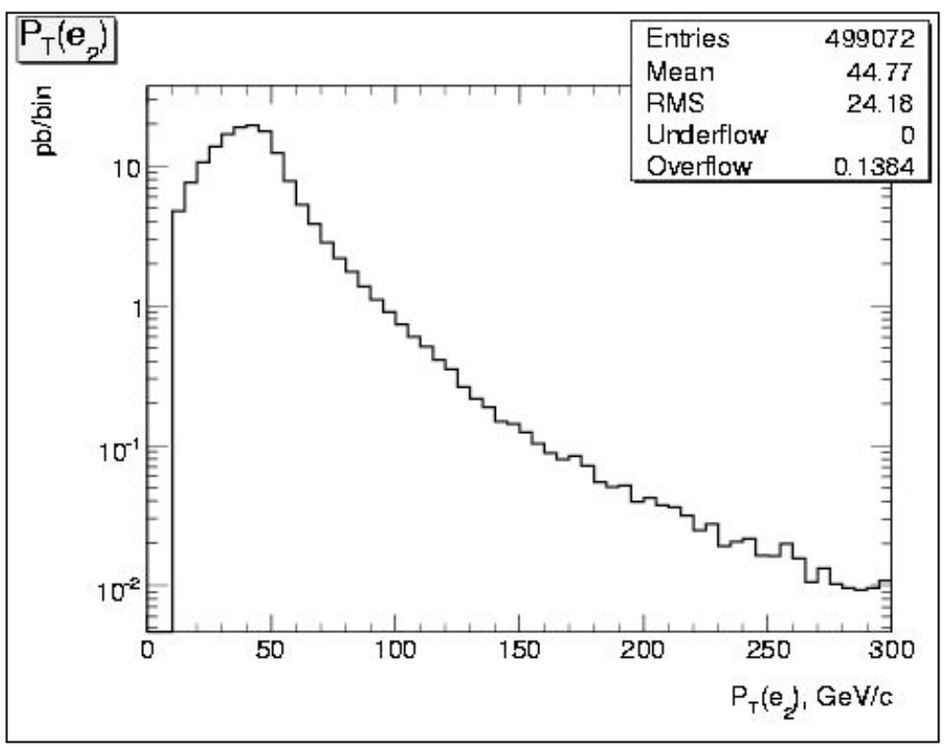

ΔR(jet1, e2)
Entries 499072
Mean 2.057
RMS 0.9752
Underflow 0
Overflow 0
pb/bin
ΔR(jet1, e2)


ΔR(e1, e2)
Entries 499072
Mean 2.777
RMS 0.6341
Underflow 0
Overflow 0
pb/bin
ΔR(e1, e2)

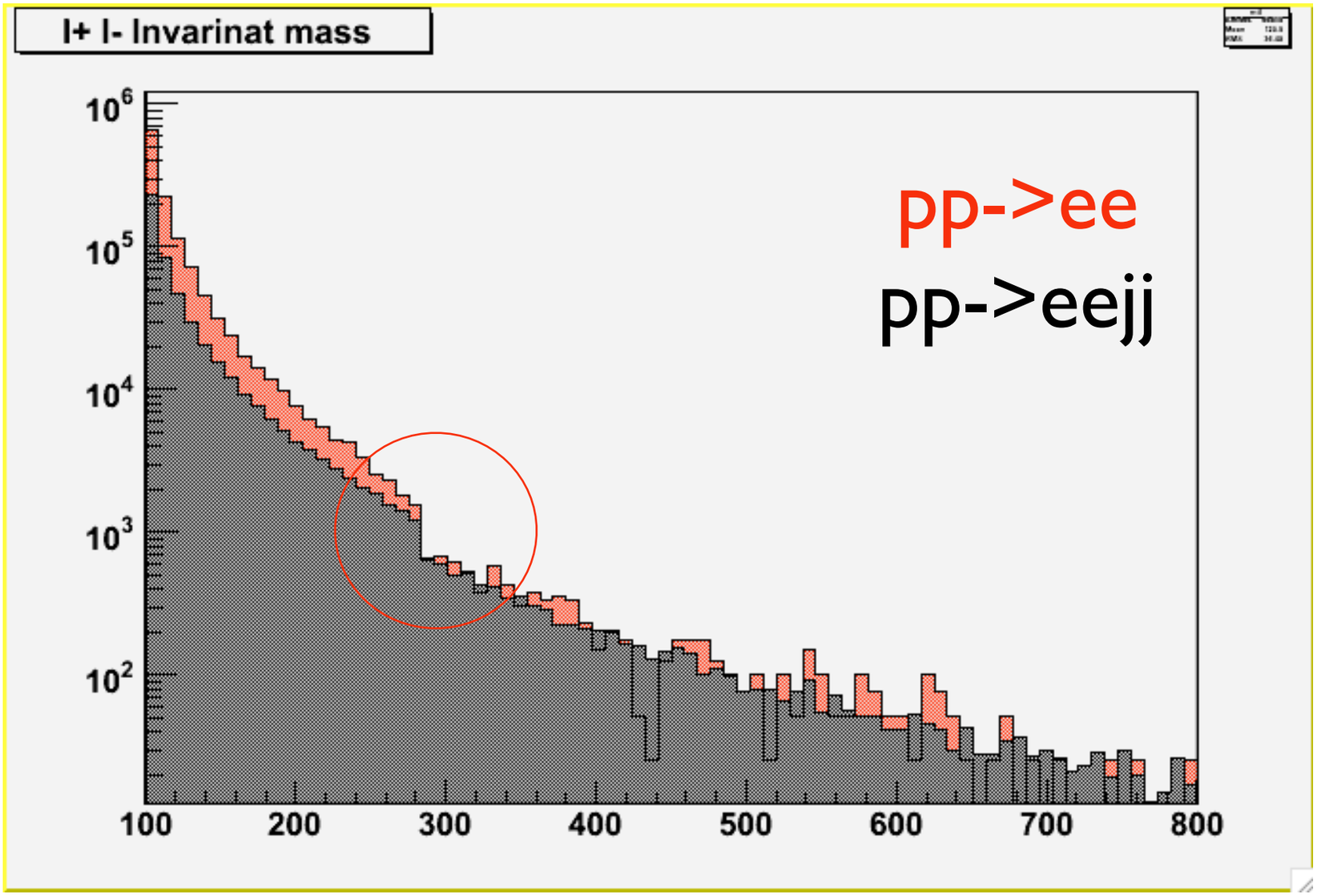

ΔR(jet2, e2)
Entries 499072
Mean 2.375
RMS 1.09
Underflow 0
Overflow 0
pb/bin
ΔR(jet2, e2)


$P_T(e_1)$
Entries 499072
Mean 79.53
RMS 39.04
Underflow 0
Overflow 0.8889
pb/bin
$P_T(e_1)$, GeV/c


$P_T(jet_1)$
Entries 499072
Mean 59.38
RMS 48.48
Underflow 0
Overflow 1.428
pb/bin
$P_T(jet_1)$, GeV/c


$P_T(e_2)$
Entries 499072
Mean 44.77
RMS 24.18
Underflow 0
Overflow 0.1384
pb/bin
$P_T(e_2)$, GeV/c

# Problem


l+ l- Invarinat mass
pp->ee
pp->eejj
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
100
200
300
400
500
600
700
800

# Using the EW and QCD Tools

## QCD

- NLO/NNLO corrections to $W/Z$ total production rate

  G. Altarelli, R.K. Ellis, M. Greco and G. Martinelli, Nucl. Phys. B246 (1984) 12

  R. Hamberg, W.L. van Neerven, T. Matsuura, Nucl. Phys. B359 (1991) 343

  W.L. van Neerven and E.B. Zijlstra, Nucl. Phys. B382 (1992) 11

- Fully differential NNLO corrections to $l\bar{l}'$ (FEWZ)

  C. Anastasiou et al., Phys. Rev. D69 (2004) 094008

  K. Melnikov and F. Petriello, hep-ph/0603182

- resummation of LL/NLL $p_T^W/M_W$ logs (RESBOS)

  C. Balazs and C.P. Yuan, Phys. Rev. D56 (1997) 5558

- NLO ME merged with HERWIG PS (MC@NLO)

  S. Frixione and B.R. Webber, JHEP 0206 (2002) 029

- Matrix elements Monte Carlos (ALPGEN, SHERPA,...) matched with PS

  M.L. Mangano et al., JHEP 0307, 001 (2003)

  F. Krauss et al., JHEP 0507, 018 (2005)

## EW

- $\mathcal{O}(\alpha_S^2) \approx \mathcal{O}(\alpha_{\rm em})$ → need to worry about electroweak corrections!
- Electroweak corrections to $W$ production
  - ⋆ Pole approximation ($\sqrt{\hat{s}} = M_W$)
    - → D. Wackeroth and W. Hollik, PRD 55 (1997) 6788
    - → U. Baur et al., PRD 59 (1999) 013002
  - ⋆ Complete $\mathcal{O}(\alpha)$ corrections
    - → V.A. Zykunov et al., EPJC 3 9 (2001)
    - → S. Dittmaier and M. Krämer, PRD 65 (2002) 073007 DK
    - → U. Baur and D. Wackeroth, PRD 70 (2004) 073015 WGRAD2
    - → A. Arbuzov, et al., EPJC 46,407 (2006) SANC
    - → C.M. Carloni Calame. et al., JHEP12 016 (2006) HORACE
- Multi-photon radiation
  - → C.M. Carloni Calame et al., PRD 69, 037301 (2004), JHEP 0505:019 (2005), JHEP12 016 (2006) HORACE
  - → S. Jadach, W. Płaczek, EPJC 29 325 (2003) WINHAC

- Lot of MC tools including QCD and EW corrections exist
- Resembled in the W production study (Piccinini et al)
- Get the tuned software and redo the exercise for neutral D-Y

# Combining EW and QCD corrections

- our attempt (preliminary results) is based on the following formula

$$\left[\frac{d\sigma}{d\mathcal{O}}\right]_{\text{QCD}\oplus\text{EW}} = \left\{\frac{d\sigma}{d\mathcal{O}}\right\}_{\text{best QCD}} + \left\{\left[\frac{d\sigma}{d\mathcal{O}}\right]_{\text{best EW}} - \left[\frac{d\sigma}{d\mathcal{O}}\right]_{\text{Born}}\right\}_{\texttt{HERWIG}\ \text{PS}}$$

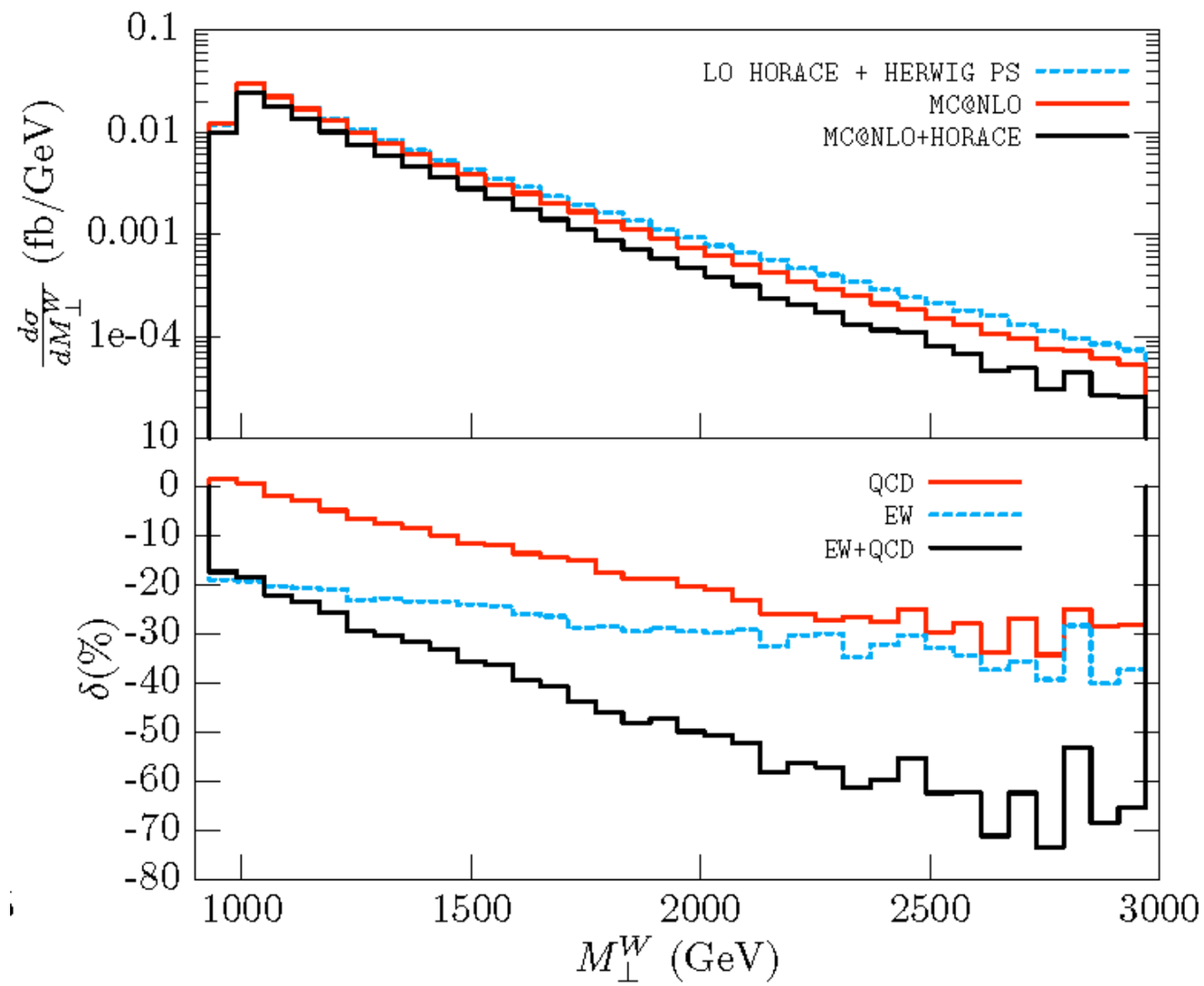
- best QCD $\Rightarrow$ `MC@NLO`, `ALPGEN` (with CKKW PS matching according to MLM prescription, `0+1 jet`, `0+1+2 jets`)
- EW part (`HORACE`) is interfaced to `HERWIG` PS (EW $\otimes$ QCD LL)
  - ⋆ NLO EW is convoluted with QCD LL parton shower $\Rightarrow \mathcal{O}(\alpha\alpha_s)$ corrections not reliable where hard non log QCD corrections are important (e.g. high $p_\perp$ lepton distribution without cut on the $W$ invariant mass). In this case a two-loop calculation needed for a sound estimate of $\mathcal{O}(\alpha\alpha_s)$ effects

⋆ not suited for true event generation...

Fulvio

# Results on the charged Drell-Yan

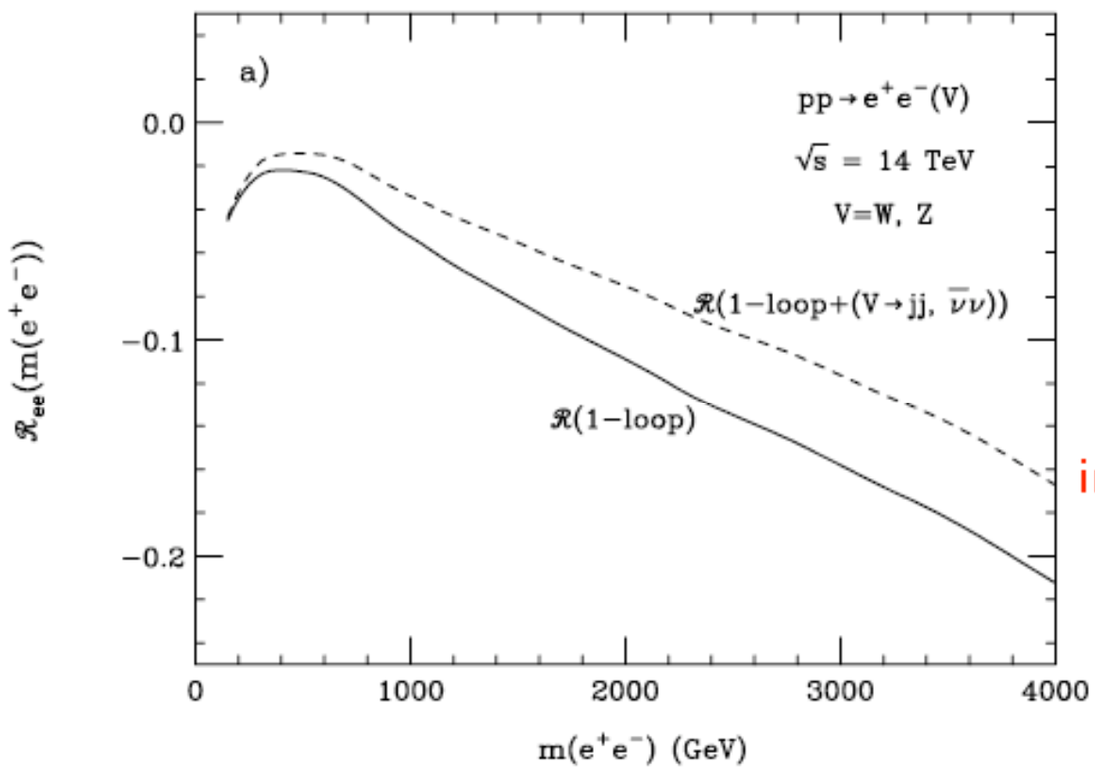
- Study done for both Tevatron and LHC
- PDF and energy scale uncertainties estimated
- QCD, EW, QCD+EW effects copared and estimated
- Fulvio and Doreen will provide us tuned software and we will be redo the exercise



# EW corrections beyond NLO

## Do we need to include them ?

Effect on $M(ee)$ distribution including complete $\mathcal{O}(\alpha)$ corrections (solid) and real $V = W, Z$ radiation (dashed):




impact of EW Sudakov-like logarithms

$\alpha^L log^N(s/M_V^2), 1 \leq N \leq 2L$

here: $L = 1$ (1-loop)

from U.Baur, PRD75 (2007)

NLO EW corrections decrease the LO $M(ee)$ distribution by -7%(-3%)at $M(ee) = 1\,TeV$ and by -20%(-16%)at $M(ee) = 4\,TeV$.

# EW corrections beyond NLO (II)

Status:

- EW logarithmic corrections to 4-fermion processes are known up to 2-loop $N^3LL$ order and are available in form of compact analytical formula.

  see publications by J. Kühn et al.

- But there have not been implemented in the available parton level MC programs.

Les Houches project:

- Are these analytical results suitable for implementation in MC codes ?
- If yes, we will include them in HORACE and ZGRAD2 and will study their impact on distributions, in particular on the $M(ll)$ distribution.

F. Piccinini, D. Wackeroth, S. Pozzorini

# EW corrections beyond NLO (III)

This study is part of a comprehensive Les Houches study of theoretical uncertainties of DY predictions which consists of

1. Tuned comparison of available higher order DY predictions including EW and/or QCD corrections.
2. Impact of higher order electroweak logarithms (this study).
3. Assessment of residual theoretical uncertainty when combining QCD and EW corrections to the best of our knowledge (with HORACE).

F. Piccinini, D. Wackeroth, S. Pozzorini

# disentangling the Exotic models

- Table of signatures

| Model | Effect | Next step |
|---|---|---|
| $G_{RS}$ | $\Lambda = 0$, $N \neq 0$ | Look in diphotons; look for BH, second resonance |
| $Z_{KK}$ | $\Lambda \neq 0$, $N \neq 0$ | Correlate the interference dip with the peak cross section |
| $Z'$ | $\Lambda = ?$, $N \neq 0$ | $C_u/C_d$ fit – get Tim Tait to work! |
| ADD | $\Lambda \neq 0$, $N = 0$ | Look in diphotons; look for BH |
| $\rho_T/\omega_T$ | $\Lambda = 0$, $N \neq 0$ | Look in W+jj channel; send Ken flowers; send Gordy a card |
| LQ's, RPV | $\Lambda \neq 0$, $N = 0$ | Look for pair LQ production in lljj; generic search for RPV SUSY |
| Compositeness | $\Lambda \neq 0$, $N = 0$ | Look in diphotons; correlate dielectrons and dimuons; look in dijets |

# Comments

- Amplitude vs. cross section fit:
  - Fitting amplitudes is theoretically cleaner
  - Extracting amplitudes may be experimentally challenging, especially due to NLO effects; need to study
- $C_u/C_d$ approach:
  - Promising
  - Need to understand limitations
  - How important is V-A and IS/FS helicity?
  - Attempt to put TC on the $C_u/C_d$ plane