Measurement of M_W with a Standard Candle Part I

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in collaboration with M. W. Krasny[b] & W. Płaczek[a] & F. Fayette[b]
the IN2P3-COPIN collaboration program 05-116

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OUTLINE

1. Introduction
2. Results for M_W
3. Conclusion

1. Introduction

Idea

General idea:

Optimise the use of the Z^0 boson in Drell–Yan-pair production processes as "*the standard reference candles*" for measuring the inclusive $W^\pm$ - boson production processes.

[F. Fayette, W. Krasny, W. Płaczek AS, Eur. Phys. J. C 51, 607 (2007)]

The strategy allows to factorise and directly measure QCD effects which affect differently the $W^\pm$ and Z^0 production processes.

- reduces significantly uncertainties in the partonic distribution functions while preserving their sensitivity to the SM parameters
- reduces by a factor of *10* the impact of systematic measurement errors, such as the energy scale and the measurement resolution.

Last MCnet meeting in Debrecen:

Florent Fayette's talk on W's mass asymmetry.

[F. Fayette, W. Krasny, W. Płaczek AS, arXiv:0812.2571]

Context & Strategy

- *Cuts and statistics*:
  - Cuts : $p_{T,l} > 20\,\mathrm{GeV}$ & $|\eta_l| < 2.5$, where $(l = \{e, \mu\})$
  - Stat : 1 ATLAS year at low luminosity $10 \cdot \mathrm{fb}^{-1}$
    - $\sigma^{cut}_{W^+ + W^-} \sim 18,8\,\mathrm{nb} \Rightarrow 188 \times 10^6$ W^+ and W^-
    - $\sigma^{cut}_{Z^0} \sim 2.1\,\mathrm{nb} \Rightarrow 21 \times 10^6$ Z^0
  - Charged lepton smearing : ATLAS Inner Detector
- *Systematics studies (the strongest effects in D0/CDF)*:
  - Experimental/Apparatus:
    - Energy Scale (ES): $p_{T,l} = (1 \pm \epsilon_s) \cdot p_{T,l_{truth}}$ and $\epsilon_s = \pm 0.5\%$ and $\pm 0.05\%$
    - Resolution Error (RE): 0.7 and 1.3 (wd. Gaussian smearing of track)
  - Theoretical/Modeling:
    - PDF effects (errors) - CTEQ6.1 [J. Pumplin et al JHEP07, 012 (2002)]
    - Primordial k_T - QCD effects (Non-perturbative and higher order effects)
    - QED radiative corrections - not included yet - ZINHAC++ in progress.
- *Tools* :
  - MC : WINHAC [W. Płaczek & S. Jadach, Eur. Phys. J. C **29** : 325-339, 2003]
  - QCD effects incorporated from PYTHIA

    [T. Sjostrand, S. Mrenna, and P. Skands, JHEP 05, 026 (2006)]

Analysis - χ^2 for M_W (Γ_W)

• The influence of effects both theoretical and experimental is extracted by performing binned χ^2 fits.

$$\chi^2_{\mathbf{eff}}\left(M_W^{PDG} \pm \Delta M_W\right) = \sum_i \frac{\left(N_i\left[M_W^{PDG} \pm \Delta M_W\right] - N_i^{\mathbf{eff}}\left[M_W^{PDG}\right]\right)^2}{\sigma^2_{N_i} + \sigma^2_{N_i^{eff}}}$$

where:

- N_i - the number of expected events in the template distribution in bin i
- $N_i^{\mathbf{eff}}$ - the number of expected events in the pseudo-data distribution in bin i
- **eff** = ES, RE, PDF min/max, kT

• After evaluation of all χ^2 for given *eff*, we fitted parabola, the position of its minimum estimates size of an *eff*, error (1σ) is calculated from the value $\chi^2 + 1$

• example in next slides.

2. Results for M_W studies

Starting information

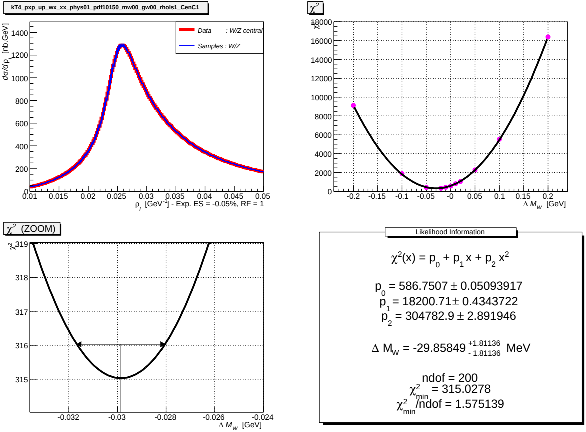
- *Assumption*: the masses of the W^+ and W^- bosons are the same [1].
- Present:
  - $M_W = 80.413 \pm 0.048\,\mathrm{GeV}$ [recent CDF]

- M_W & Γ_W measured in hadronic collisions via $W^\pm \to l^\pm \overset{(-)}{\nu}_l$ ($l^\pm = \{e^\pm, \mu^\pm\}$)
  - $p_{T,l} \quad \to l^\pm$
  - $m_{T,l\,\nu_l} \to l^\pm$ & $\overset{(-)}{\nu}_l$ ($\not{E}_T$)
  - $\not{E}_T \quad \to \overset{(-)}{\nu}_l$

- "Standard method" during this talk $\equiv$, the method currently used in hadron colliders. (the plots: $\rho_l = 1/p_{T,l}$)

[1](see F. Fayette talk or [arXiv:0812.2571])

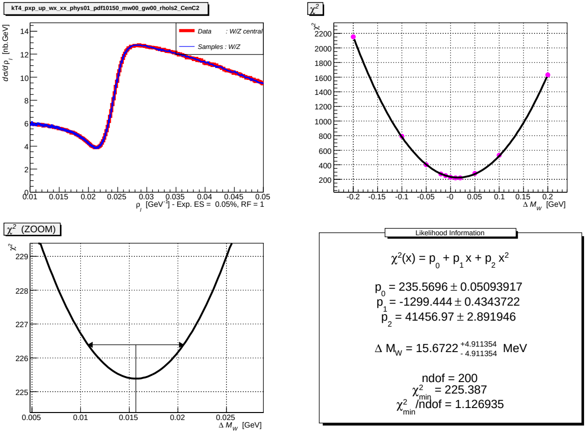
Standard Method - systematical effect - ES $=$ 0.05 %



- The others systematical effects (RE, k_T, PDFs) are even bigger.

Simple Z - Candle

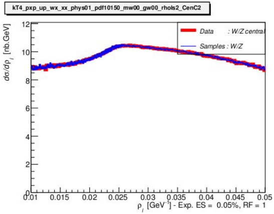
Simple Z - Candle - $R_{\text{simple}} = \frac{\rho_l^W}{\rho_l^Z}$ - systematical effect - ES $= 0.05$ %

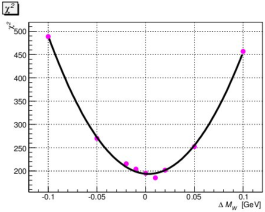


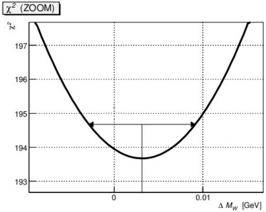
- One of the lepton from the Z^0 boson is (randomly) removed from the charged

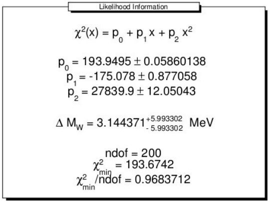
Z Candle

Z Candle - $R_{candle} = \frac{\rho_l^W(s_1, i_1)}{\rho_l^Z(s_2, i_2)}$ - systematical effect - ES = 0.05 %









- Description: $R_{candle} = \frac{\rho_l^W(s_1, i_1)}{\rho_l^Z(s_2, i_2)}$
  - s_1 and s_2 are CM-energy of the beam $\sqrt{s_1} = \frac{M_W}{M_Z}\sqrt{s_2}$.
    $\Longrightarrow$ the momentum fractions of the partons producing Z^0 and Ws are equal
  - at the energy $\sqrt{s_1}$ the coil current has been rescaled down by the factor $\frac{M_W}{M_Z}$.
    $\Longrightarrow$ the distribution of the curvature radius (ρ_l) for charged leptons originating from the decays of the Z^0 and W are the same.

ΔM_w [MeV]	$ES = 0.05\%$	$ES = -0.05\%$	$RF = 0.7$	$RF = 1.3$	$\Delta kT = -1$[GeV]	$\Delta kT = +1$[GeV]
Standard	-29 ± 1.8	25 ± 1.8	14.1 ± 1.8	-22.8 ± 1.8	> 31	> 40
Simple Z Candle	-19 ± 4.91	15 ± 4.9	> 50	> 77	> 66	> 76
Z candle	0.4 ± 5.9	3.1 ± 5.9	6.6 ± 5.9	-3.7 ± 5.9	17.7 ± 6.11	-9.77 ± 6.0
$\chi^2/200$	1.01	0.96	0.99	1.06	1.20	1.19

- PDF effect are not presented but the mass shifts calculated using CTEQ6.1 [J. Pumplin et al JHEP07, 012 (2002)] method are also below statistical errors.
- The effect of $\mathrm{ES} = 0.5\%$ for "Standard Method" is huge > 270 MeV, the Standard Candle method can reduce it to $\sim 15 \pm 6.0$ MeV with $\chi^2 = 0.95$, nbof$= 200$.

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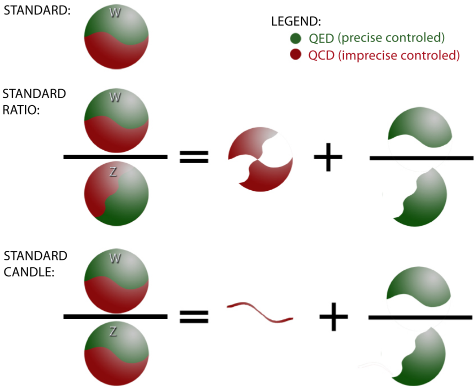
State of the art



$$\rho_l^W = 1/p_{T,l}$$

$$R_{\rm simple} = \frac{\rho_l^W}{\rho_l^Z}$$

$$R_{candle} = \frac{\rho_l^W(s_1,i_1)}{\rho_l^Z(s_2,i_2)}$$

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$\chi^2/200$	1.01	0.96	0.99	1.06	1.20	1.19

ES $= 0.5\%$ for "Standard Method": > 270 MeV, the Z Candle method: $\sim 15 \pm 6.0$ MeV!! ($\chi^2 = 0.95$)

- The remaining QCD asymmetries: 

which are reflected by the height values of the k_T in the Table we correct by C_{QCD} factor which can be measured rather then modeled using MC simulation.

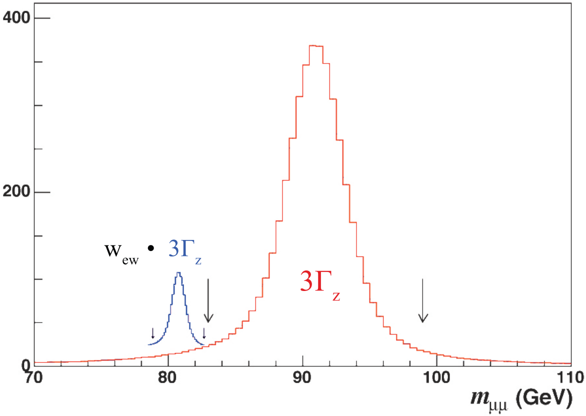
$$C_{QCD} = \frac{\int_{M_Z-3\Gamma_Z}^{M_Z+3\Gamma_Z} N^{l+l-}(s_2, i(s_2), M^{l+l-})\, dM^{l+l-}}{\int_{M_W-3\Gamma_W}^{M_W+3\Gamma_W} f_{BW}(s^{l+l-}; M_W, \Gamma_W)\, w_{EW}\, N^{l+l-}(s_1, i(s_1), M^{l+l-})\, dM^{l+l-}}$$

Each event having a reconstructed invariant mass in the latter region is weighted by the Breit–Wigner function

$$f_{BW}(s^{l+l-}; M_W, \Gamma_W) = \frac{1}{\pi} \frac{M_W \Gamma_W}{(s^{l+l-} - M_W^2)^2 + M_W^2 \Gamma_W^2},$$

where $s^{l+l-} = (M^{l+l-})^2$, and by the QCD-independent normalisation factor w_{EW}.

$$C_{QCD} = \frac{\int_{M_Z-3\Gamma_Z}^{M_Z+3\Gamma_Z} N^{l+l-}(s_2, i(s_2), M^{l+l-})\, dM^{l+l-}}{\int_{M_W-3\Gamma_W}^{M_W+3\Gamma_W} f_{BW}(s^{l+l-}; M_W, \Gamma_W)\, w_{EW}\, N^{l+l-}(s_1, i(s_1), M^{l+l-})\, dM^{l+l-}}$$



Results for "Z candle" with C_{QCD} factor:

ΔM_w [MeV]	$ES = 0.05\%$	$ES = -0.05\%$	$RF = 0.7$	$RF = 1.3$	$\Delta kT = +1$[GeV]	$\Delta kT = -1$[GeV]
Z candle	0.4 ± 5.9	3.1 ± 5.9	6.6 ± 5.9	-3.7 ± 5.9	17.7 ± 6.11	-9.77 ± 6.0
Z candle, C_{QCD}	-2.6 ± 6.2	1.0 ± 6.0	3.3 ± 5.9	-6.3 ± 6.3	-0.6 ± 6.0	-3.8 ± 6.1
χ^2/ndof	1.1	1.0	1.0	1.2	1.2	1.3

even larger shifts of K_T are also in the statistical errors:

ΔM_w [MeV]	$\Delta kT = -4$	$\Delta kT = -2$	$\Delta kT = -1$	$\Delta kT = 1$	$\Delta kT = 2$	$\Delta kT = 4$[GeV]
Z candle C_{QCD}	14.6 ± 6.1	5.6 ± 6.0	-0.6 ± 6.0	-3.8 ± 6.1	-6.8 ± 6.2	-26.7 ± 6.3
χ^2/ndof	1.3	1.4	1.2	1.3	1.1	1.5

Then using PYTHIA[2] we opened

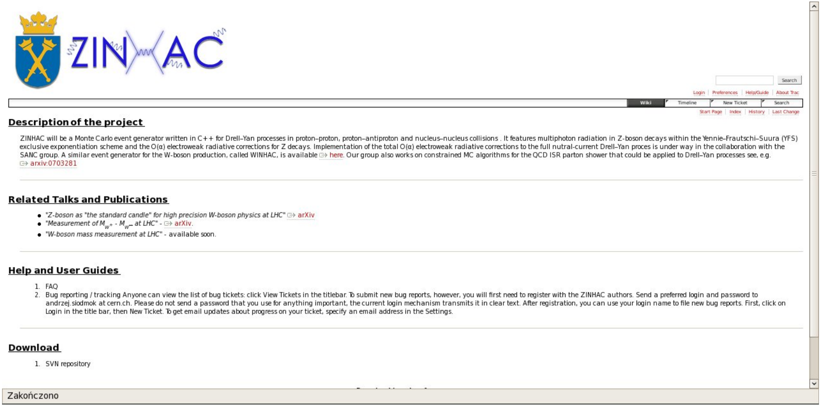
Pandora's box... 

but this is the next part of this story

soon on your arXiv mirror!:)

[2] and WINHAC + ZINHAC

ZINHAC



two students: Kamil Sobol and Piotr Stecko

3. Conclusion

Conclusion:

- We considered the main systematic errors which were the most important in previous measurements of W mass

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χ^2/ndof	1.1	1.0	1.0	1.2	1.2	1.3
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- the results are mainly constrained by statistical errors but studies were preform for one year of low luminosity $10\mathrm{fb}^{-}1$ run.
- the next part shows very interesting results (soon o arXiv).
- all this tricks are feasible at LHC (maybe in the mature stage ...)

Thank you for the attention!