Extracting Electroweak Parameters from the Lineshape

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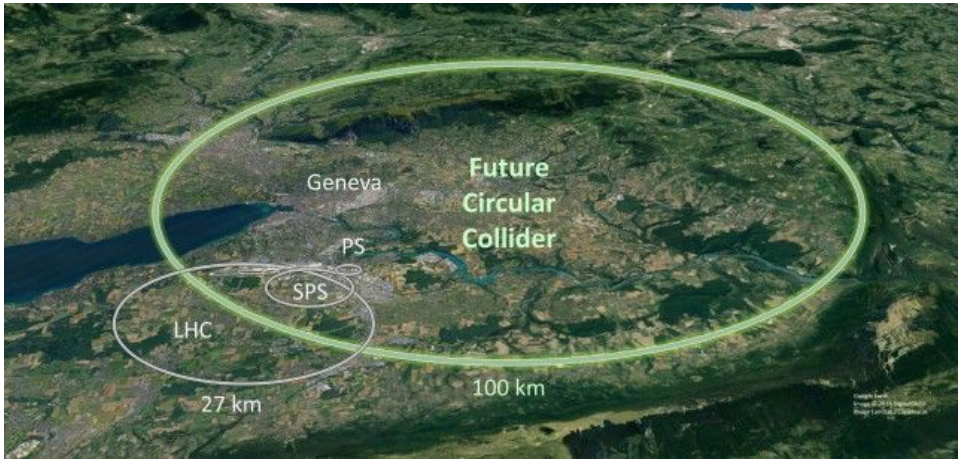
FCC-ee Feasibility Study

The goal of the Future Circular Collider (FCC) feasibility study is to design a new infrastructure for a particle collider. It is proposed to build a large, 100km circular tunnel that will collide electrons and positrons (FCC-ee). The goal is to reach higher energies and intensities than those of the previous Large Electron-Positron Collider (LEP).



Project Overview

Goal: Minimize the uncertainty on the Z-boson mass and width measurements by determining the optimal number of energy points and what luminosity to run the accelerator at.

Questions to consider:

- How spread out should the energy points be from the peak?
- How do we divide luminosity among the points?
- What are the present realistic uncertainties and their impact?
    - luminosity, center of mass, and the cross sections

Measuring the Z boson resonance

Cross section

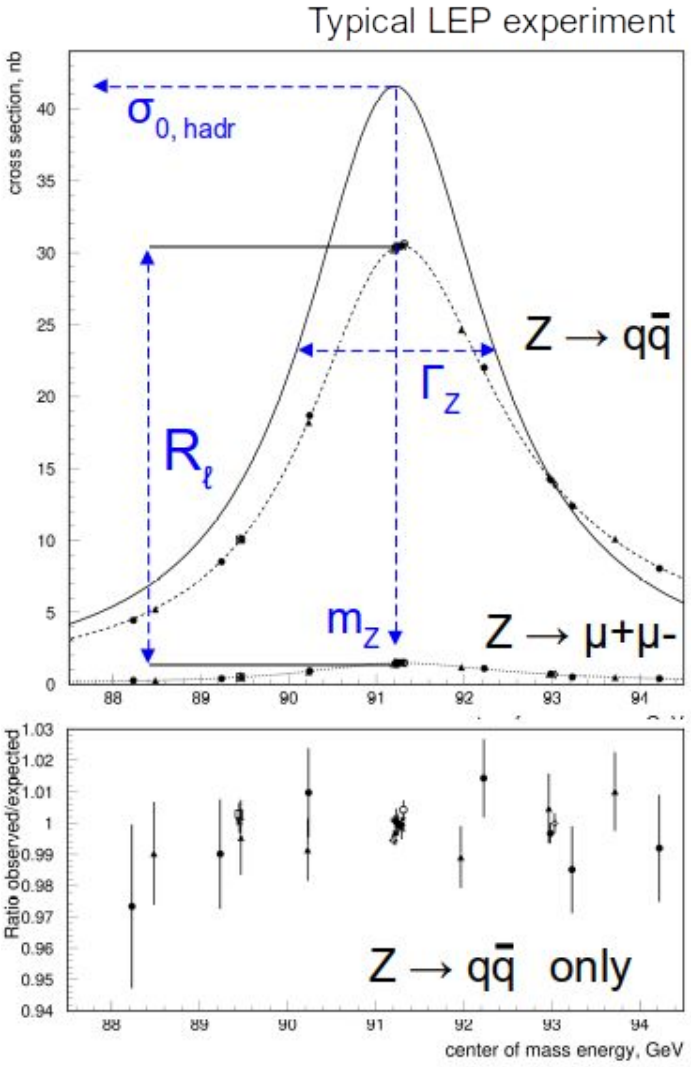
$$\sigma(\sqrt{s}) = \frac{N_{\text{signal}}}{\mathcal{L}} = \frac{N_{\text{selected}} - N_{\text{background}}}{\varepsilon A \mathcal{L}}$$

What can we extract?

- m_Z, Γ_Z, Hadronic peak cross section ($\sigma_{0,\,hadr}$)
- (Ratio of leptons (R_ℓ), Number of light neutrinos)

Hadronic final state has smallest uncertainties

- quarks have color charge
- will focus only on hadron cross sections



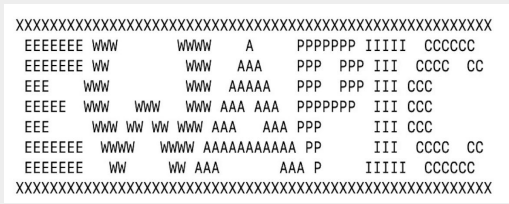
How did we do the fitting?

Revived the old L3 program to fit two-fermion data

- Various LEP theory programs are interfaced (TOPAZ0, ZFITTER, ALIBHABHA, MIBA, ….): ZFITTER is the only program used for the following studies
- Some weird old program names … PAW, KUIP, SIGMA and COMIS?
- For verification the full L3 cross section and forward-backward asymmetry dataset was fit, including all details and the numbers in the last L3 paper were reproduced
- Thanks to Martin Grünewald who recovered the program from backups

We need to figure out how to do this for real with FCC data: Is Fortran making a come back?

Number of energy points
Cross Sections
Luminosity Ratio



Z-boson
mass/width error

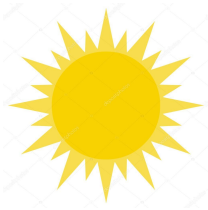
How good can the determination be?

Extract Pseudo Observables: m_Z, Γ_Z and $\sigma_{0,hadr}$; Inputs: hadronic cross sections, 5 points, 30/ab each

1. Statistical uncertainty on hadrons only, nothing else
2. Add fully correlated systematic uncertainty as large as peak stat. uncertainty
3. Add stat. uncertainty on luminosity corresponding to 14 nb cross section
4. Add 10^{-4} syst. fully correlated, and another 10^{-5} uncorrelated
5. Add 10 keV correlated uncertainty on ECMS
6. Or alternatively 100 keV correlated uncertainty on ECMS

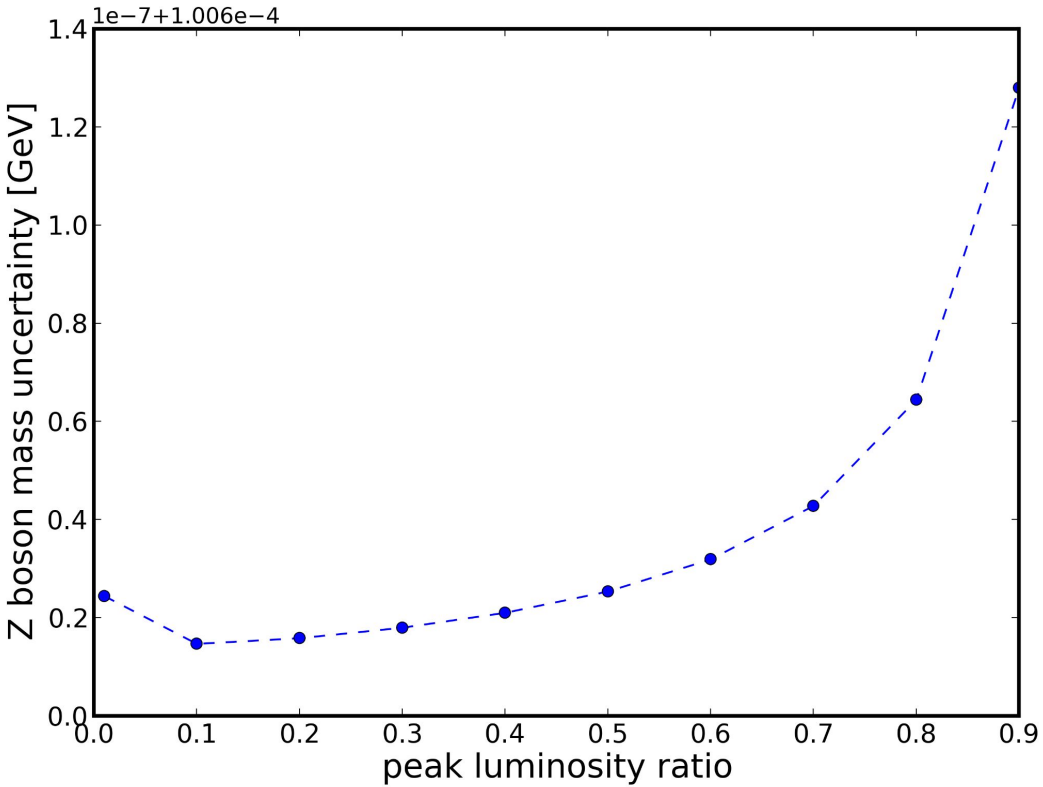
Setup	delta(m_Z)	delta(Γ_Z)	delta($\sigma_{0,\,hadr}$)
units	[keV]	[keV]	[pb]
1	1.2	3.4	0.044
2	1.2	3.4	0.044
3	1.7	5.2	0.076
4	8.4	26	4.2
5	13	26	4.2
6	101	26	4.2

Luminosity



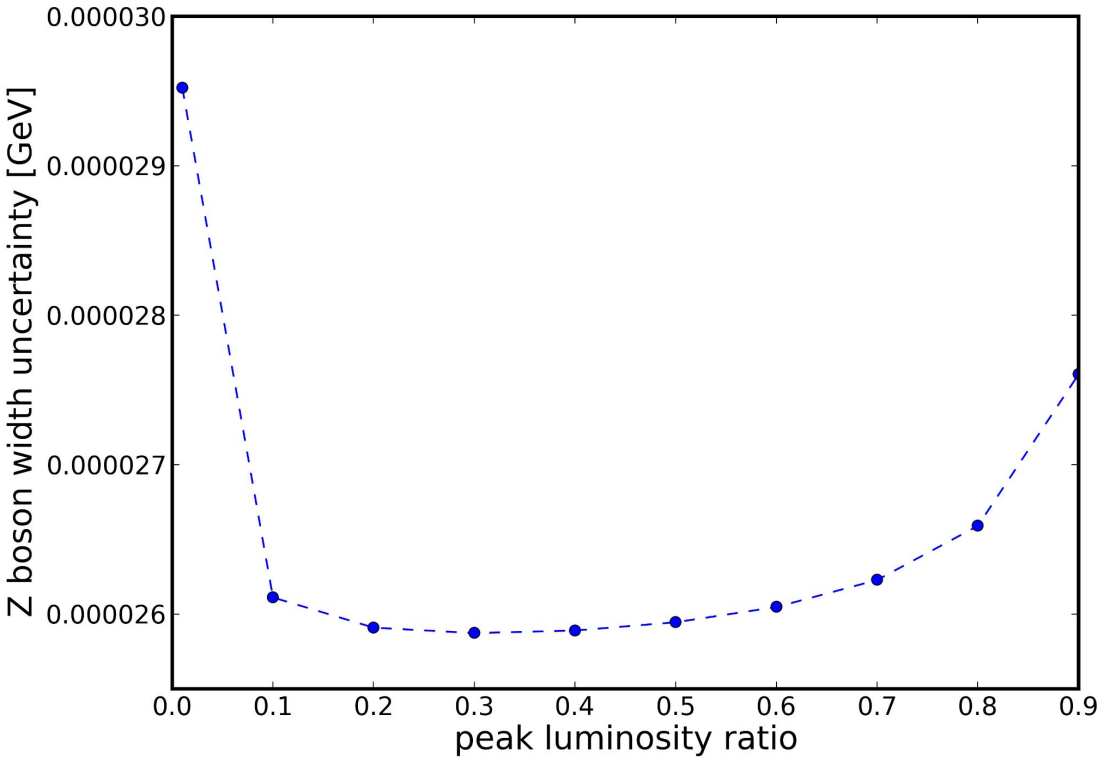
- In the program, we iterate over the luminosity ratios with increments of .10, from .10 to .90
  - The ratio is the amount of luminosity used on peak divided by the total luminosity (150 ab^-1)
- The purpose of this iteration was to find the optimal luminosity used on the peak that minimizes the uncertainties on the Z boson mass, width and the peak hadronic cross section measurements.

Minimum Z Mass Uncertainty



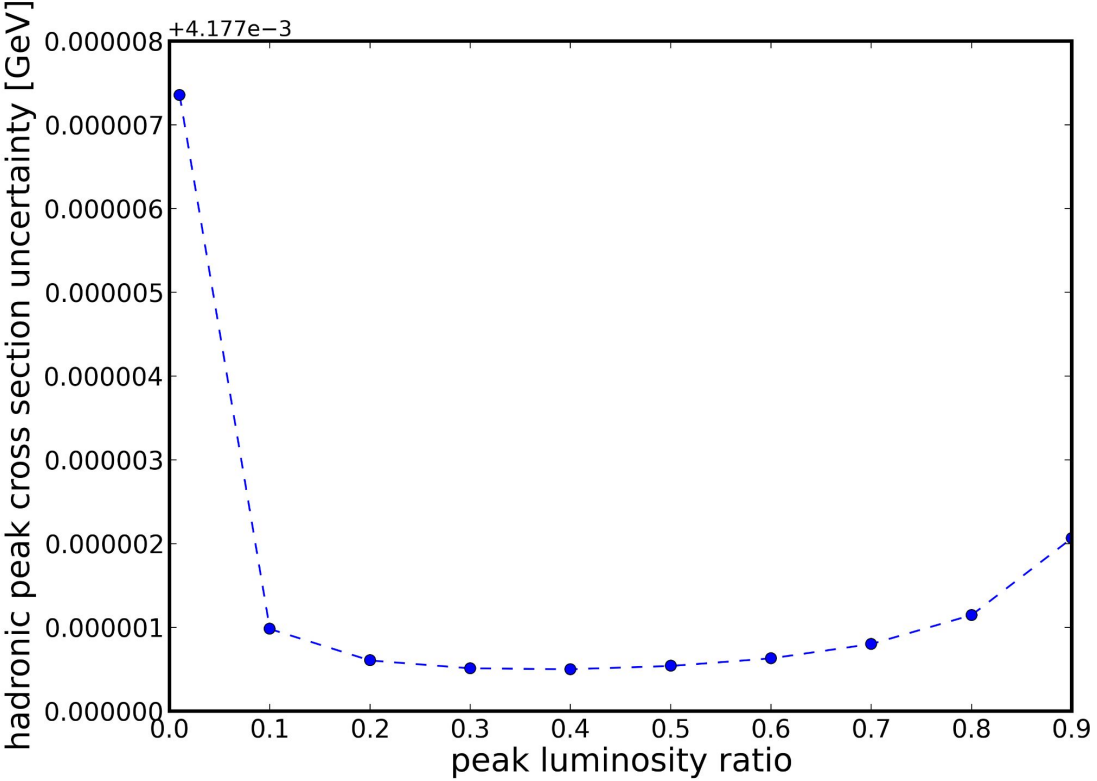
Z-boson mass uncertainty is minimized at peak luminosity ratio of about 0.1

Minimum Z Width Uncertainty



Z-boson width uncertainty is minimized at ~0.3 peak luminosity ratio.

Minimum Hadron Peak Cross Section Uncertainty



Hadronic peak cross section uncertainty is minimized at a peak luminosity of ~0.4

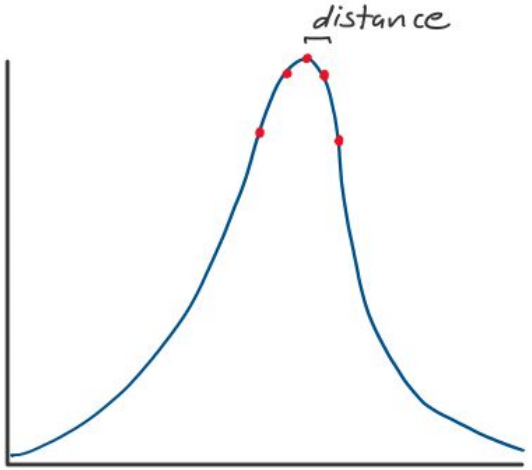
Point Distribution

In this study, we only fit the measurements using 5 points and varying their symmetric distances from the peak

- We have selected 4 different set ups at distances of:

  0.2, 0.5, 1.0, and 2.0 GeV

- The findings were particularly interesting since no distance gave us more than one minimal error.



What next?

- Analyze effects of varying the distribution of the luminosity among the off-peak points
- Testing with 3 or 4 energy points instead of 5
- Run more trials at varying distances to better determine a more precise optimal distance between points

Uncertainty configurations:

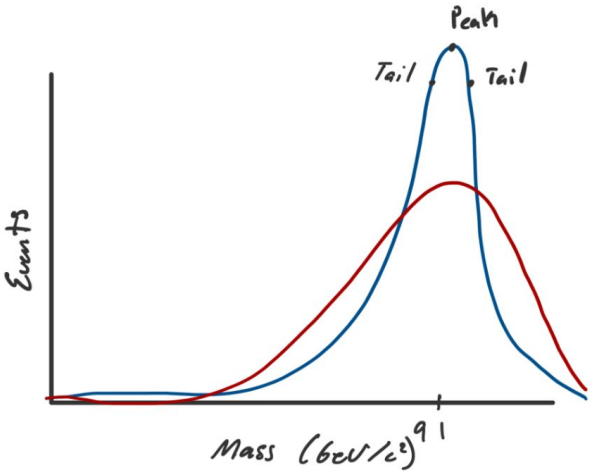
ECMS: default

Luminosity: statistical

Total cross section: negligible

B	C	D	E
ECMS Lumi QUAN	error mass	error width	error hadronic
default default default	1.17E-06	3.39E-06	4.45E-05
default default stat	1.17E-06	3.39E-06	4.45E-05
default default real	1.17E-06	3.39E-06	4.45E-05
default stat default	1.75E-06	5.25E-06	7.60E-05
default stat stat	1.75E-06	5.25E-06	7.60E-05
default stat real	1.75E-06	5.25E-06	7.60E-05
default real default	8.45E-06	2.57E-05	4.18E-03
default real stat	8.45E-06	2.57E-05	4.18E-03
default real real	8.45E-06	2.57E-05	4.18E-03
stat default default	1.17E-06	3.39E-06	4.45E-05
stat default stat	1.17E-06	3.39E-06	4.45E-05
stat default real	1.17E-06	3.39E-06	4.45E-05
stat stat default	1.75E-06	5.25E-06	7.60E-05
stat stat stat	1.75E-06	5.25E-06	7.60E-05
stat stat real	1.75E-06	5.25E-06	7.60E-05
stat real default	8.45E-06	2.57E-05	4.18E-03
stat real stat	8.45E-06	2.57E-05	4.18E-03
stat real real	8.45E-06	2.57E-05	4.18E-03
real default default	1.01E-05	3.40E-06	4.45E-05
real default stat	1.01E-05	3.40E-06	4.45E-05
real default real	1.01E-05	3.40E-06	4.45E-05
real stat default	1.02E-05	5.26E-06	7.60E-05
real stat stat	1.02E-05	5.26E-06	7.60E-05
real stat real	1.02E-05	5.26E-06	7.60E-05
real real default	1.31E-05	2.58E-05	4.18E-03
real real stat	1.31E-05	2.58E-05	4.18E-03
real real real	1.31E-05	2.58E-05	4.18E-03

Measuring the Z-boson Mass and Width



Breit-Wigner Dist.

Gaussian Dist.

- Fit samples with a Breit-Wigner distribution
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- Graph mass/width error again different luminosity ratios