NEPPSR Analysis Project

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New England Particle Physics Student Retreat
Craigville, 15-19 August 2005

Analysis Project

- Goals of the Project

  - Learn basic use of ROOT data analysis tool
    → Standard tool in particle physics

  - Apply statistical analysis to extract physical information (particle lifetime, mass, etc…)

  For more info on ROOT, physics, and project instructions, see

  http://www.hepl.harvard.edu/~kblack/neppsr.html

Three Analysis Projects

1. B lifetime measurement with likelihood method
2. 'Particle hunting' and mass measurement via muon final states
3. $Z \rightarrow \mu^+ \mu^-$ forward-backward asymmetry study

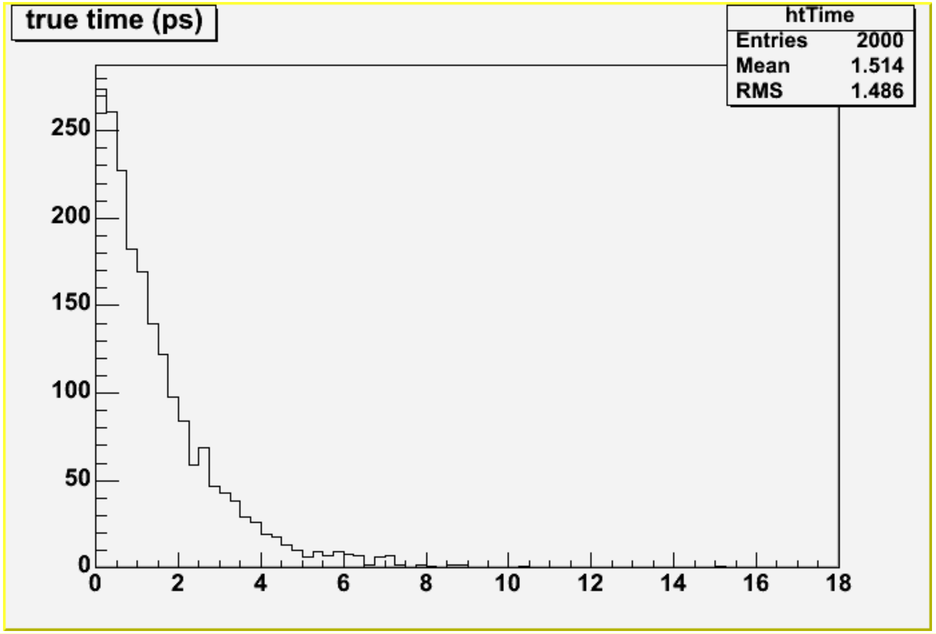
Project I: B Lifetime Analysis

- Sample

  - Simulation of the *exponential* proper time distribution of B mesons

    → Effect of limited resolution in the measured proper time simulated by smearing the true proper time with a constant Gaussian resolution

    → ROOT tuple contains: True time and measured time (in units of ps) for 2000 events



Lifetime used in the generation of the events was 1.532 ps

Project I: B Lifetime Analysis

- Project

- *Determine the B meson lifetime and its statistical uncertainty* using each of the following methods:

1) Least-squares fit to the true proper time histogram

→ Need to provide function to fit the distribution with

f(t) = N exp(-t / tau)

→ Use ROOT built-in interface to do the chi-squared minimization

$$\chi^2 = \sum_{i=1}^{nbins} \left(\frac{\left(f(t_i) - N_i \right)^2}{\sigma_i^2} \right)$$

2) 'Unbinned' Maximum Likelihood with true proper time

→ Compute and display -log(likelihood) as a function of lifetime

3) 'Unbinned' Maximum Likelihood with reconstructed proper time

→ Need to determine time resolution

→ Compute and display -log(likelihood) as a function of lifetime

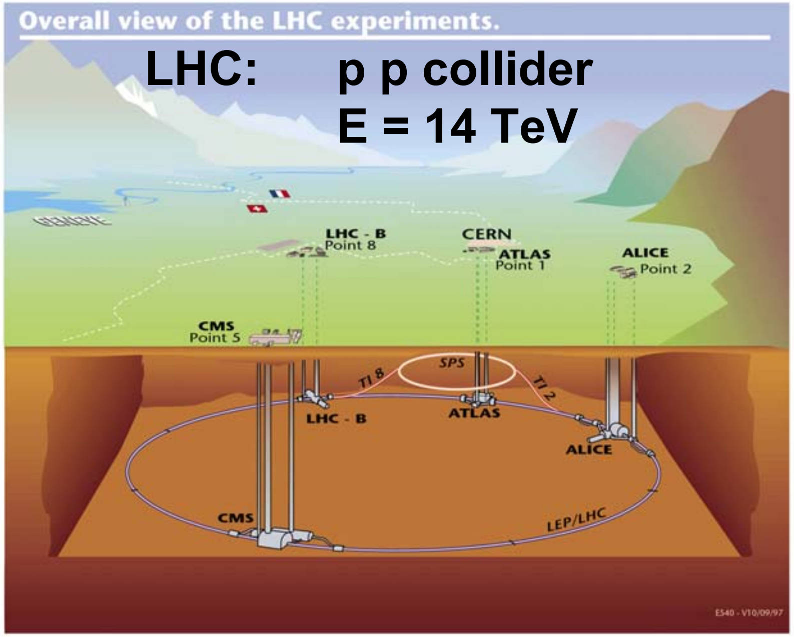
(use ROOT's TMath::Erfc(x))

Code provided on web site

See Colin Gay's lecture

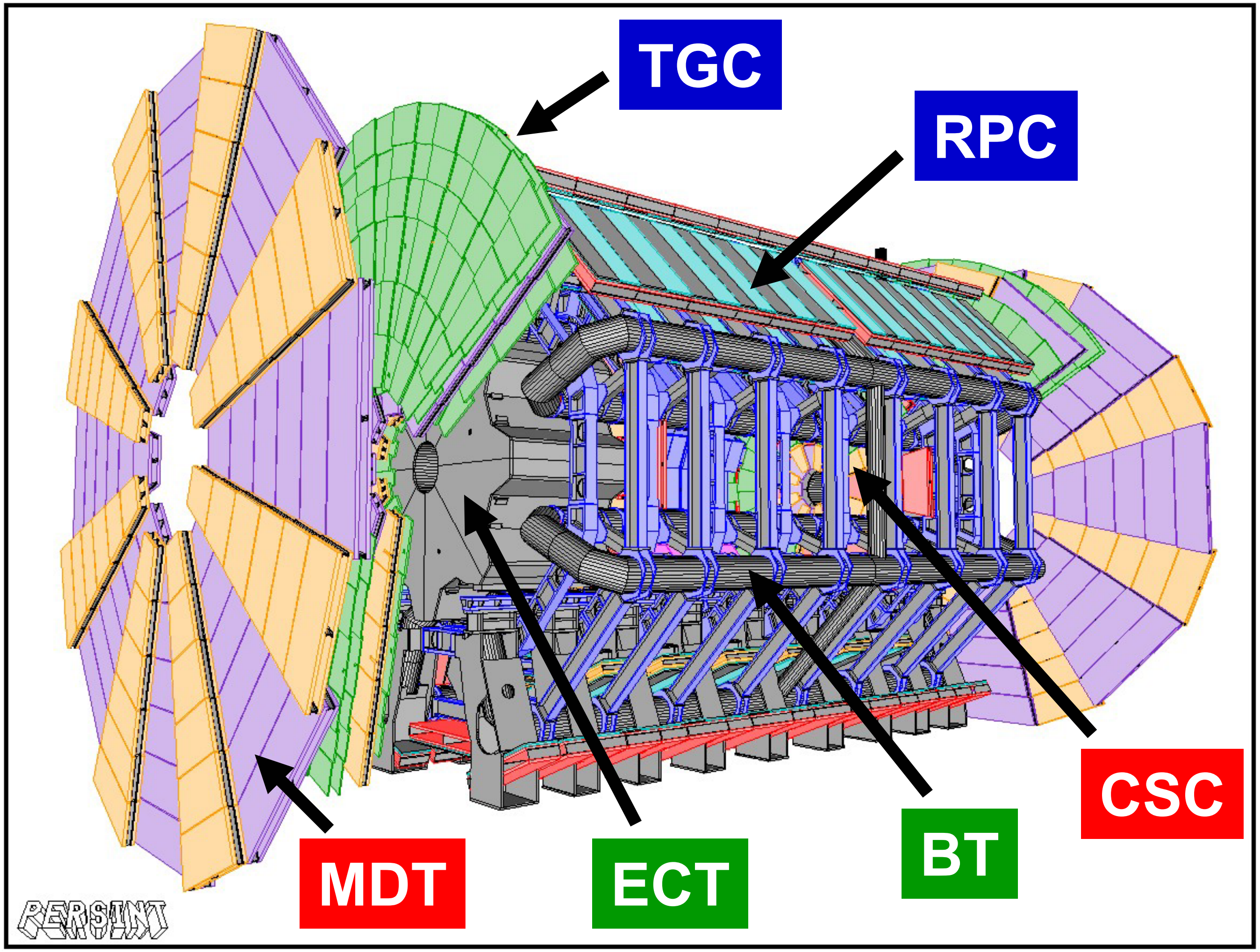
Project II: Muons as Discovery Tools

- Sample
  - Simulation of p p collisions at the LHC (using Pythia)
    → ATLAS Experimental effects taken into account: detector acceptance, efficiency, resolution, etc.
  - ROOT tuple:
    → 34700 events
    → measured 4-momenta of electrons, muons and jets
    + transverse missing energy
    → sample contains *mostly* muons originating from the decay of known and yet-to-be discovered particles



ATLAS Muon Spectrometer

- Trigger System
  - Resistive Plate Chambers (**RPC**)
  - Thin Gap Chambers (**TGC**)
- Precision System
  - Monitored Drift Tubes (**MDT**)
  - Cathode Strip Chambers (**CSC**)
- Magnet System
  - Barrel Toroid (**BT**)
  - Endcap Toroids (**ECT**)

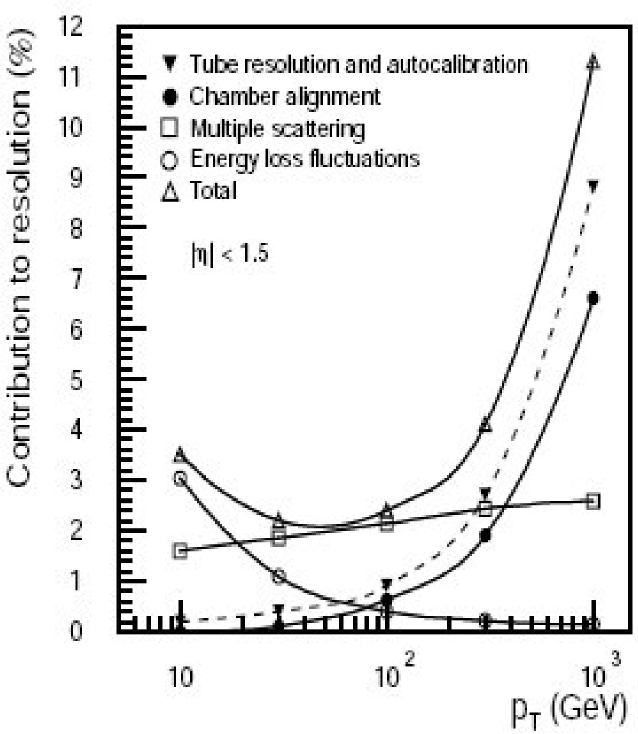


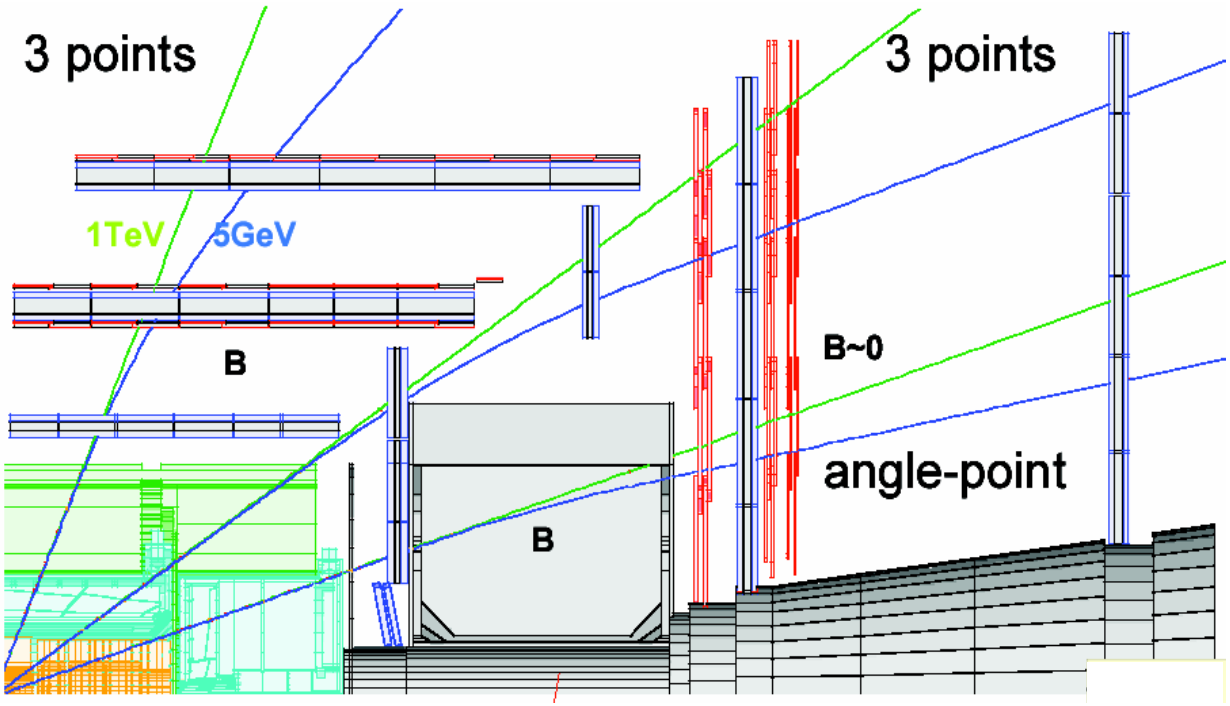
ATLAS Muon Spectrometer

Aim:
- Muon Trigger & Identification with high-efficiency
- Precise measurement of muon 3-momentum

  $\sigma(p_T)/p_T = 10\%$ at $p_T = 1$ TeV/c for most η range

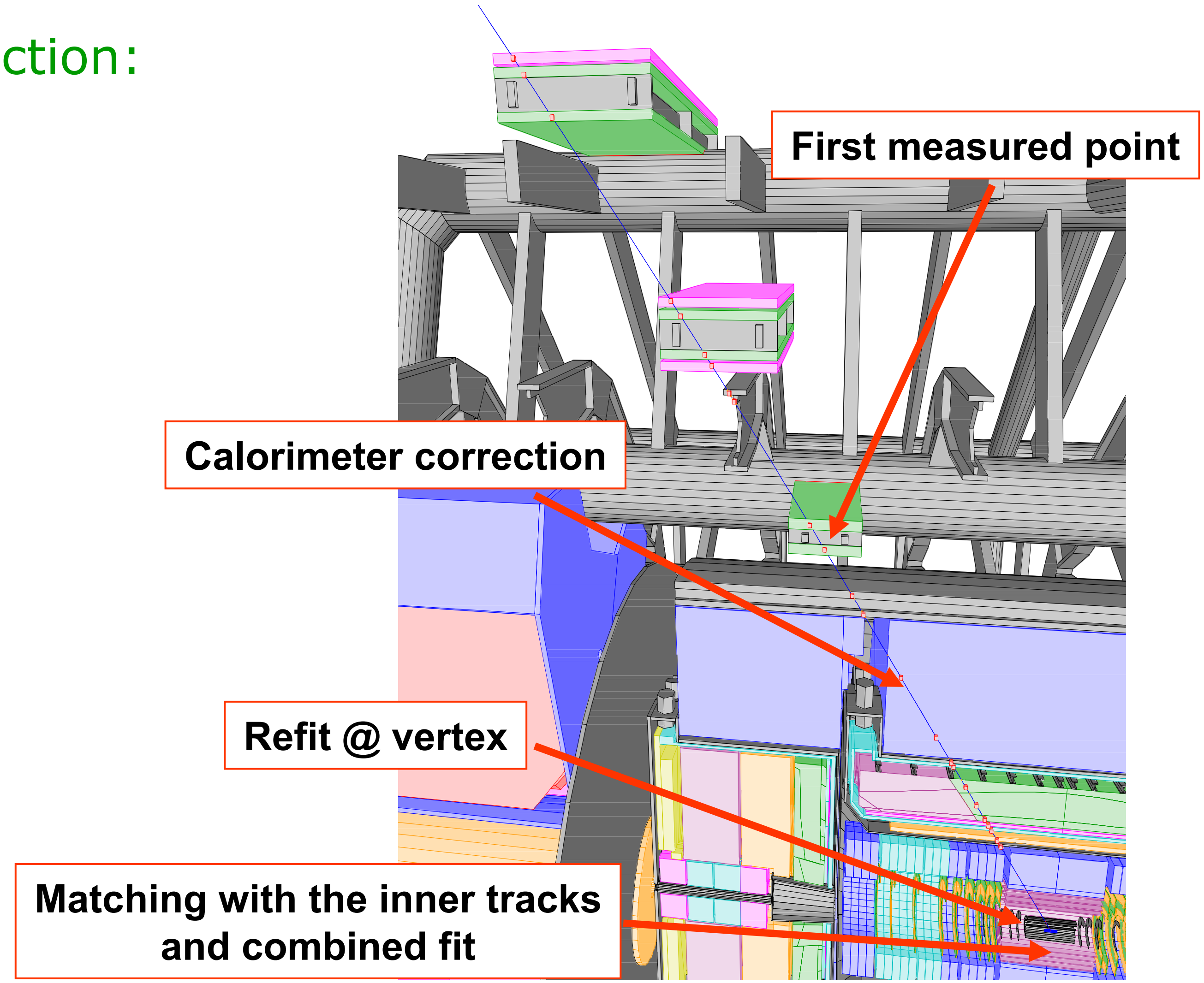
  → requires ~50 μm position precision





ATLAS Muon Spectrometer

Muon Reconstruction:



Project II: Muons as Discovery Tools

- Project

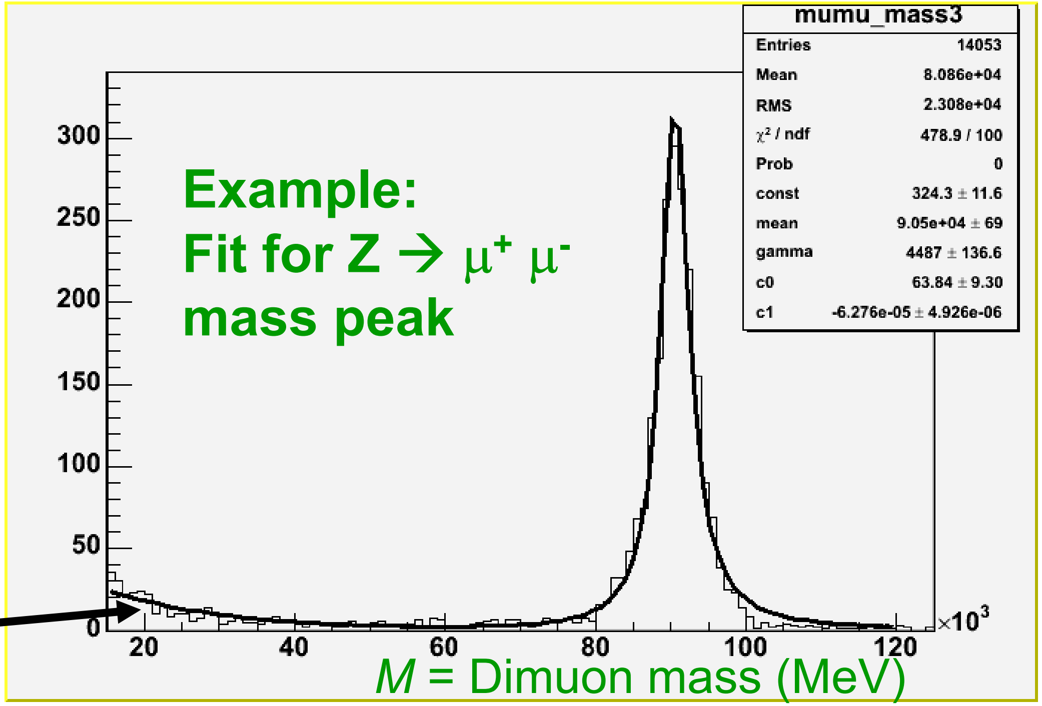
  - 'Discover' all resonances/particles produced in the sample provided
    Note: All but one decay into muon-only final states

  - Measure their mass via a least-squares fit to a histogram
    with Breit-Wigner function (*follow B lifetime ROOT fit example*)
    or Gaussian function

$$f_{BW}(M) = N \frac{M^2 \Gamma_{res}^2}{\left(M^2 - M_{res}^2\right)^2 + M_{res}^2 \Gamma_{res}^2}$$

M_{res} = mass of resonance

Γ_{res} = width of resonance



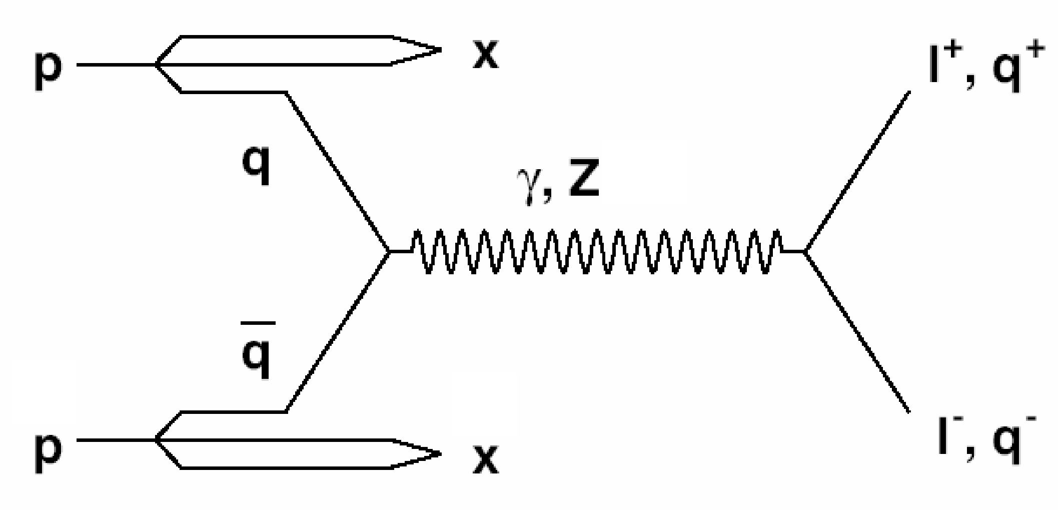
May need to add polynomial or exponential function to describe background

Project III: Forward-Backward Asymmetry

- Sample

  - Simulation of p p collisions at the LHC

    + ATLAS Experimental effects



  - ROOT tuple:

    → 10000 events

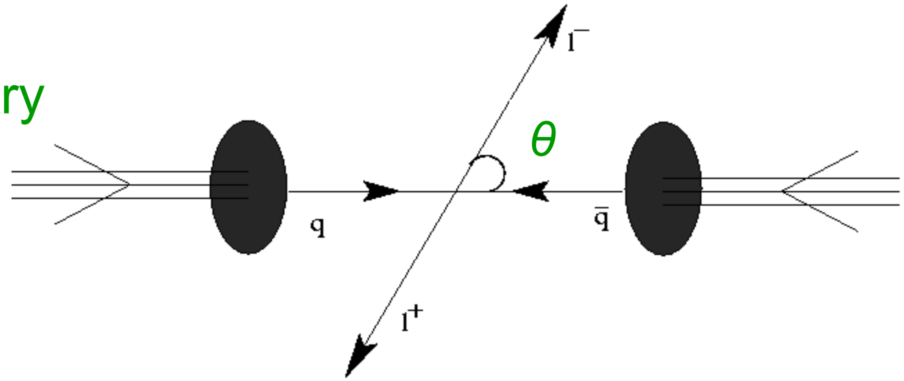
    → true 4-momenta of annihilating quark and antiquark

      + Z-decay muons (*provided in the sample analysis code*)

Project III: Forward-Backward Asymmetry

- Project (motivation)

  - Study the forward-backward asymmetry as a sensitive probe of couplings btw Z boson and fermions



$$\frac{d\sigma(q\bar{q}\to\ell^+\ell^-)}{d\cos\theta} = C\frac{\pi\alpha^2}{2s}[Q_\ell^2 Q_q^2(1+\cos^2\theta) + Q_\ell Q_q Re(\chi(s))(2g_V^q g_V^\ell(1+\cos^2\theta) + 4g_A^q g_A^\ell\cos\theta) + |\chi(s)|^2\left(({g_V^q}^2 + {g_A^q}^2)({g_V^\ell}^2 + {g_A^\ell}^2)(1+\cos^2\theta) + 8g_V^q g_A^q g_V^\ell g_A^\ell\cos\theta\right)]$$

$$d\sigma/d\cos(\theta) = N\,[\,3/8(1+\cos^2\theta) + A_{FB}\cos\theta\,] \qquad \textbf{Eq.(1)}$$

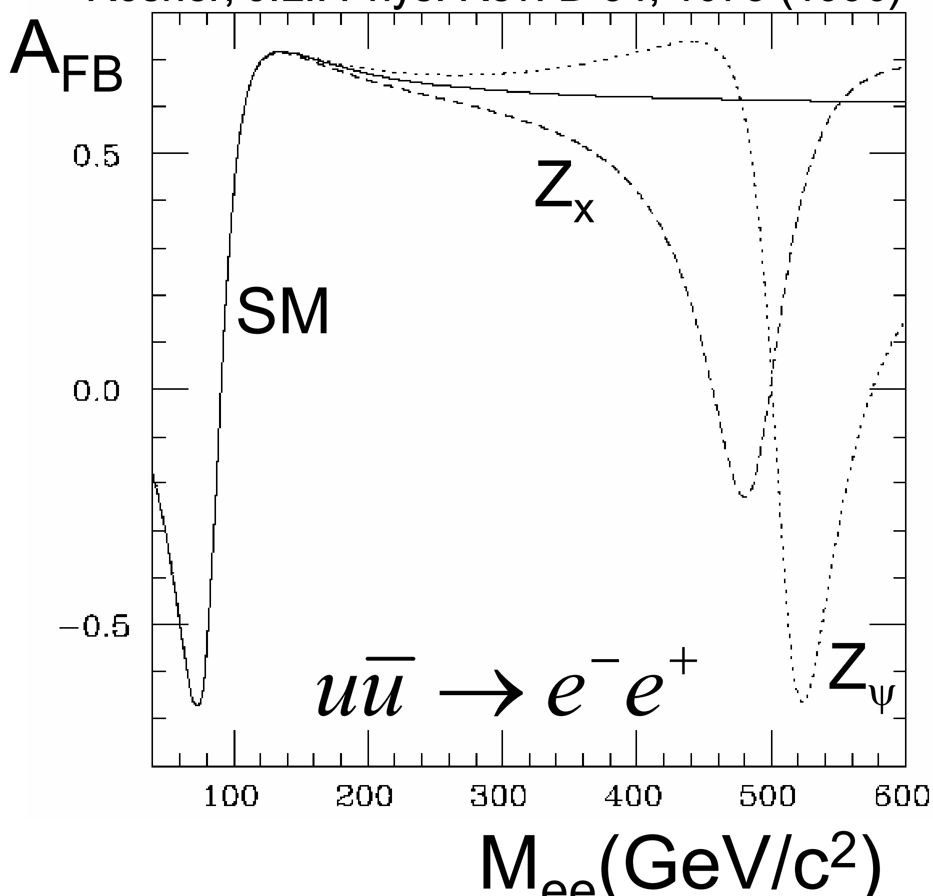
→ Interference between vector and axial-vector Zff amplitudes and between virtual photon and Z amplitudes gives rise to a preferential emission of fermions in the direction of the incoming quark (i.e. a forward-backward asymmetry in the Z frame)

Project III: Forward-Backward Asymmetry

- Project (motivation)
  - A_{FB} sensitive to new heavy gauge bosons predicted in many extensions of the Standard Model

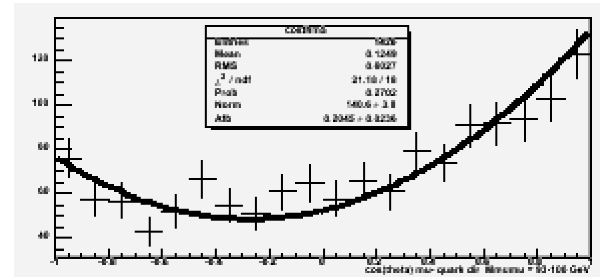
500 GeV/c^2 Z':

Rosner, J.L.: Phys. Rev. D 54, 1078 (1996)



Project III: Forward-Backward Asymmetry

- Project

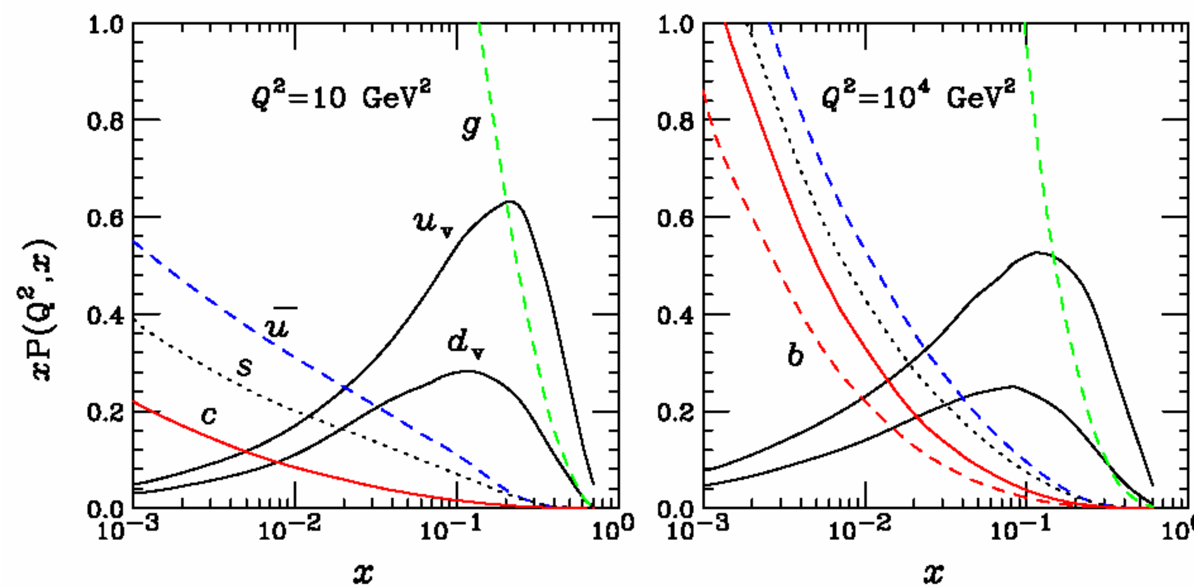


- Plot distribution of cosine of helicity angle of the negative muon in the dimuon rest frame, i.e. cos(theta), + fit for A_{FB} using Eq.(1)

- *Issue at the LHC: How does one find the initial quark direction?*

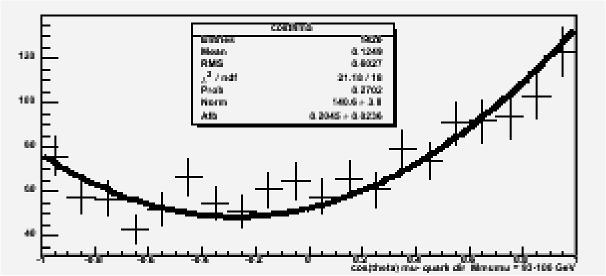
→ approximate the initial quark direction with that of the Z boson

→ this works because (valence) quarks carry a much larger fraction (x) of the proton beam momentum than antiquarks



See Darien Wood's lecture

Project III: Forward-Backward Asymmetry



- Project
  - Fit for A_{FB} using Eq.(1) for 2 cases:
    1) incoming quark direction approximated by the Z direction
    2) incoming quark direction used directly (can only do this with truth info…)

  - Determine how often the Z direction approximation gives the correct "forward" tag
    + plot this fraction as a function of the Z rapidity (y)

$$y = \tfrac{1}{2}\log\left(\frac{E+p_z}{E-p_z}\right) \qquad E = \text{ Z energy; } \quad p_z = \text{ Z momentum along beam}$$

  - Fit for A_{FB} in several bins of dimuon mass
    + plot A_{FB} as a function of mass

Analysis Project

CONTEST: Prize to be awarded to first who provides the name and mass of *all* resonances/particles in Project II

May want to check Particle Data Group's listings at http://pdg.lbl.gov/

Let us know if you have questions/problems/etc.

Instructions, ntuple files, ROOT sample code available on web site

http://www.hepl.harvard.edu/~kblack/neppsr.html

→ **Present and discuss results on Thursday evening**