

# ***NEPPSR Analysis Project***

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# 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

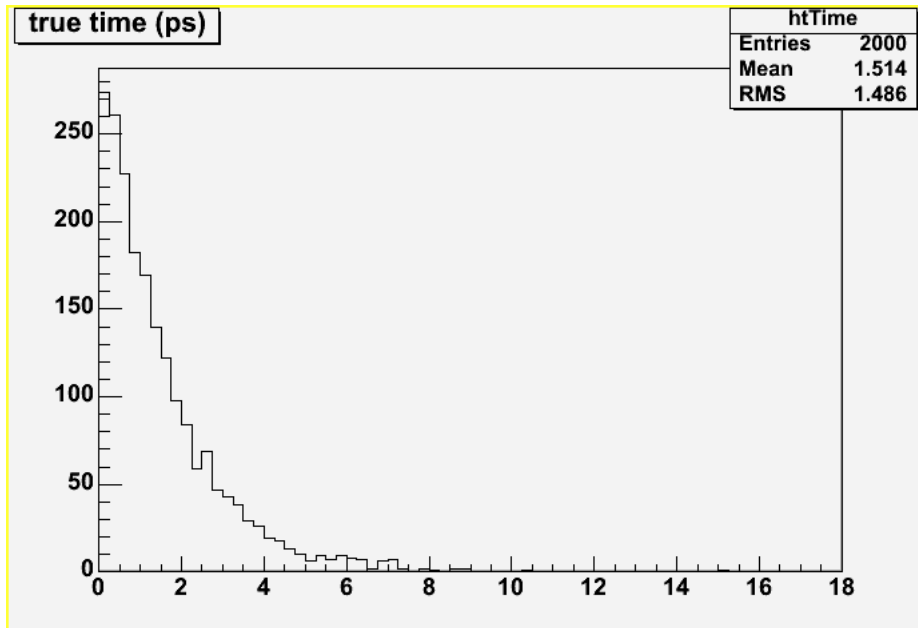
# Project I: B Lifetime Analysis

- 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

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

2) 'Unbinned' Maximum Likelihood with true proper time

→ Compute and display  $-\log(\text{likelihood})$  as a function of lifetime

3) 'Unbinned' Maximum Likelihood with reconstructed proper time

→ Need to determine time resolution

→ Compute and display  $-\log(\text{likelihood})$  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)

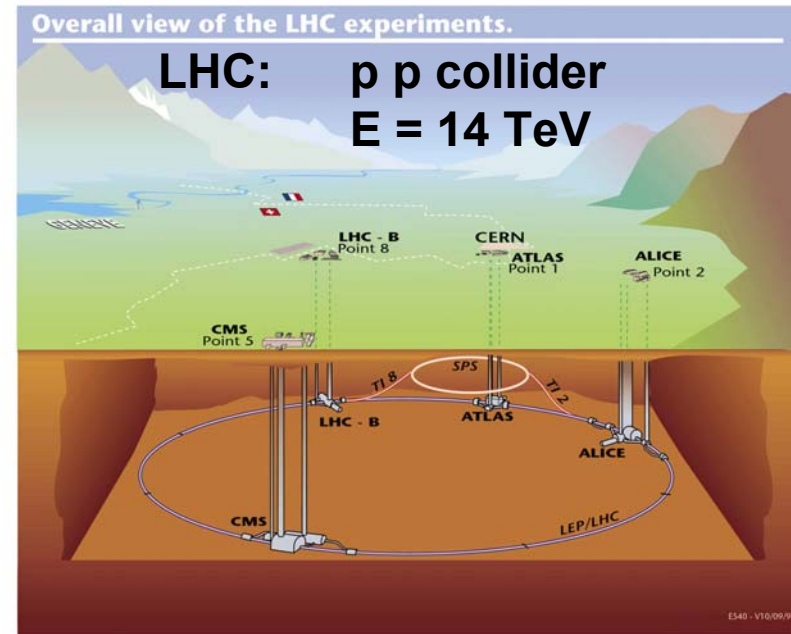
- ATLAS Experimental effects taken into account: detector acceptance, efficiency, resolution, etc.

- 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

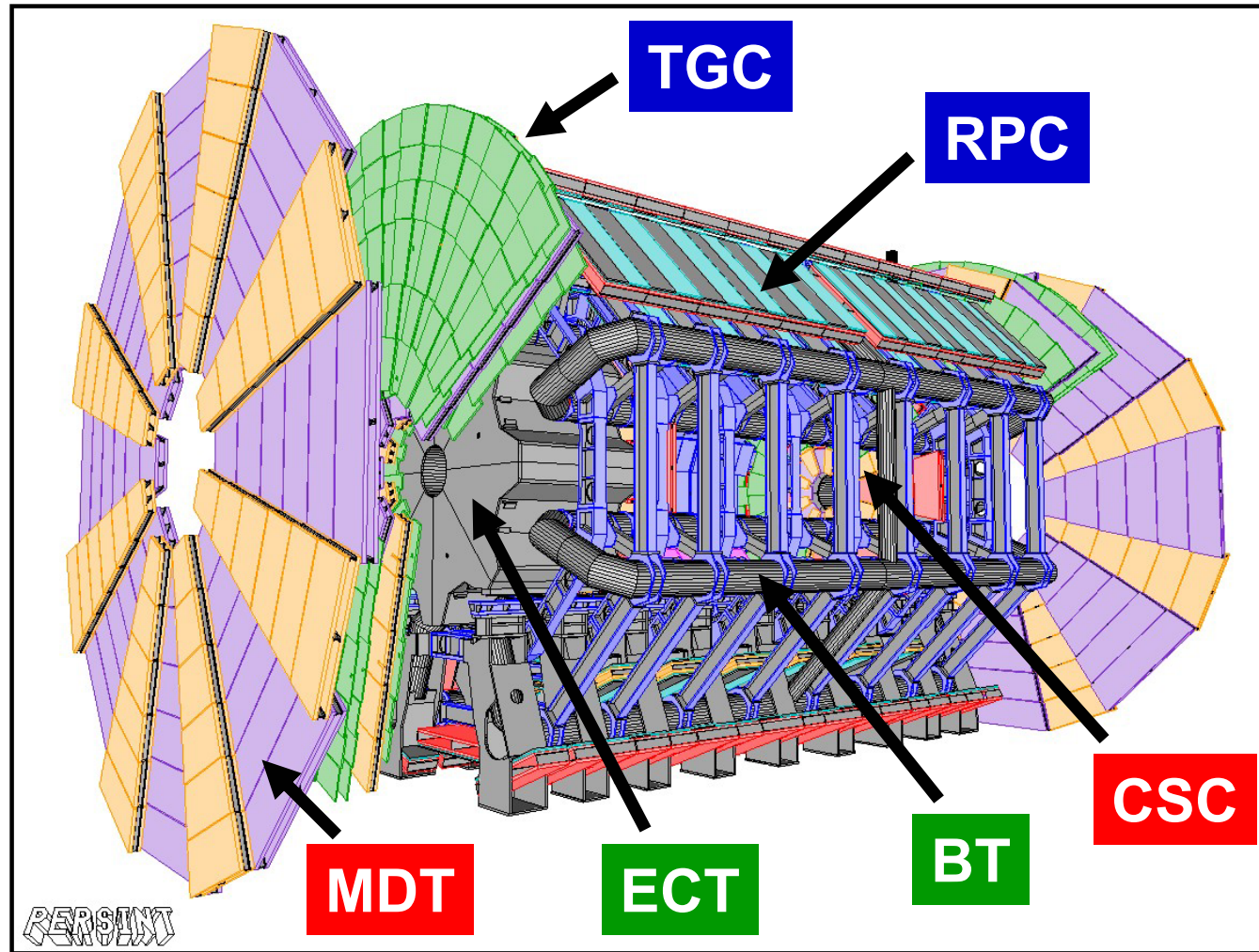
- Resistive Plate Chambers (**RPC**)
- Thin Gap Chambers (**TGC**)

- Precision System

- Monitored Drift Tubes (**MDT**)
- Cathode Strip Chambers (**CSC**)

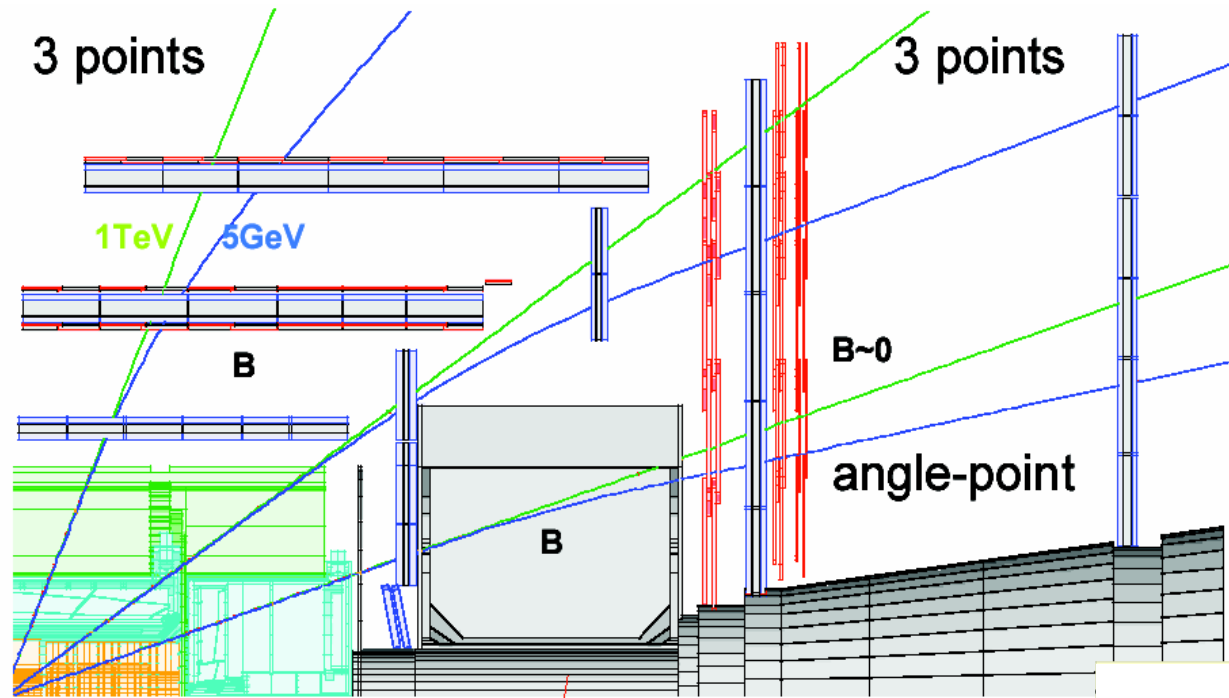
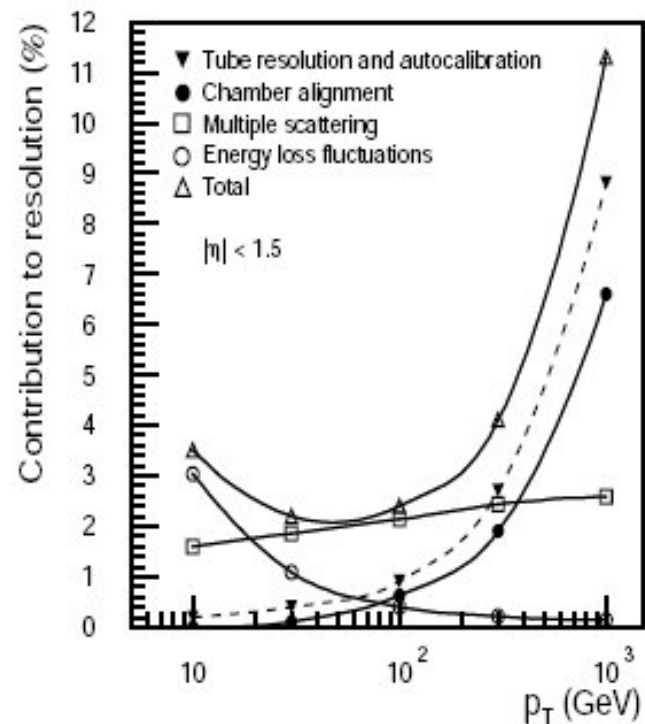
- Magnet System

- Barrel Toroid (**BT**)
- Endcap Toroids (**ECT**)



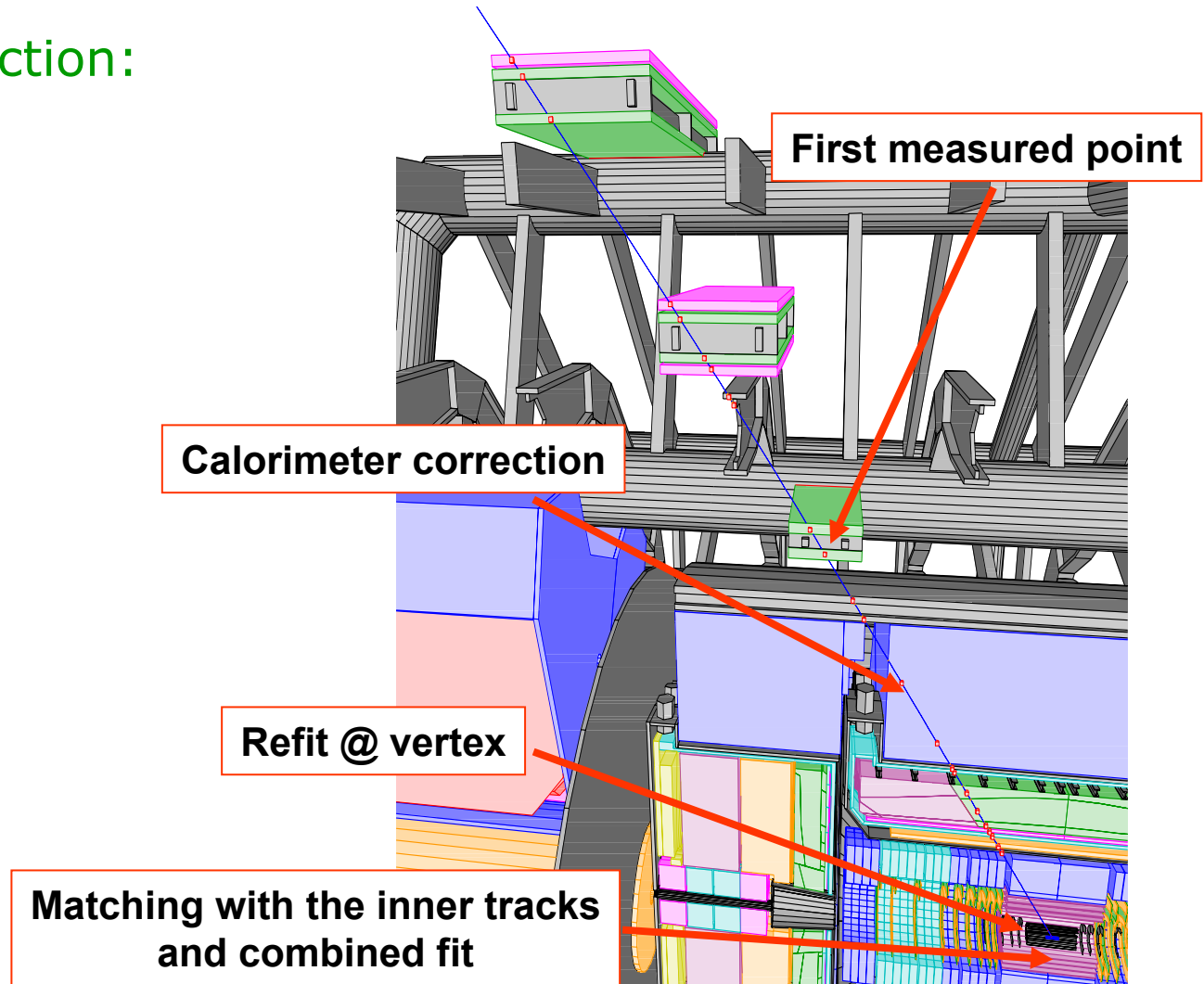
# ATLAS Muon Spectrometer

- Aim:
- Muon Trigger & Identification with high-efficiency
  - Precise measurement of muon 3-momentum  
 $\sigma(p_T)/p_T = 10\%$  at  $p_T = 1 \text{ TeV}/c$  for most  $\eta$  range  
→ requires  $\sim 50 \mu\text{m}$  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*

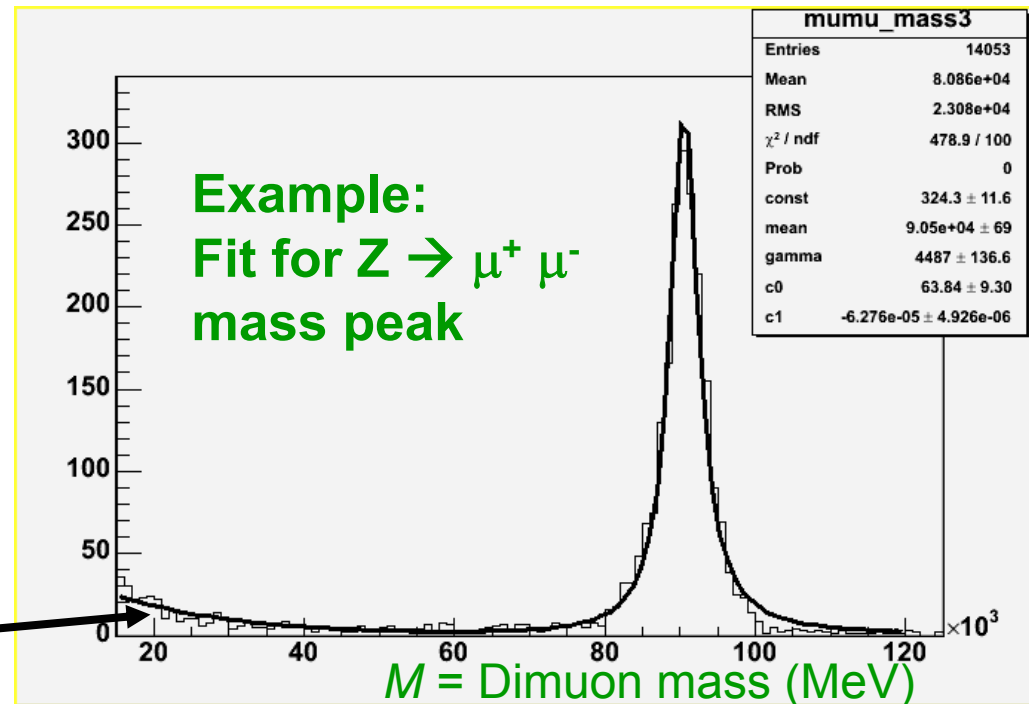
- Measure their mass via a least-squares fit to a histogram with Breit-Wigner function (follow *B lifetime ROOT fit example*) or Gaussian function

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

$M_{res}$  = mass of resonance

$\Gamma_{res}$  = width of resonance

May need to add polynomial or exponential function to describe background

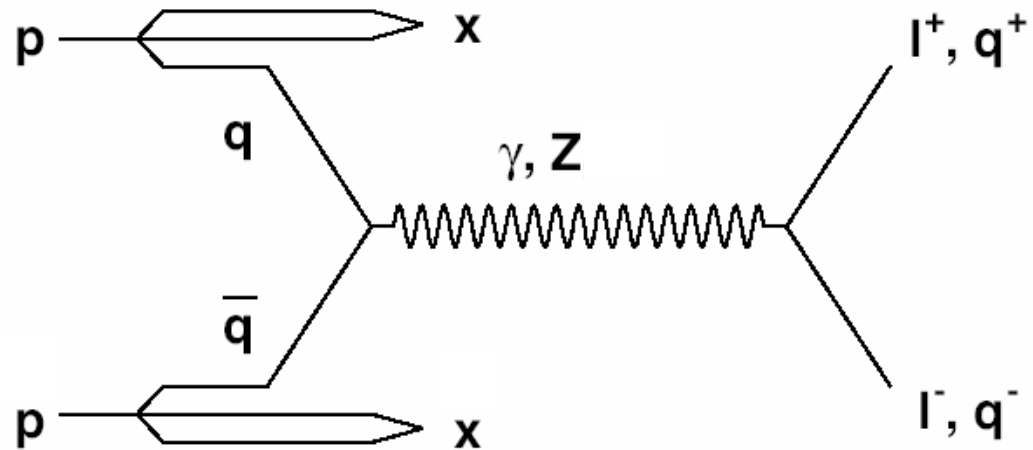


# Project III: Forward-Backward Asymmetry

- Sample

- Simulation of p p collisions at the LHC

- + ATLAS Experimental effects



- ROOT tuple:

- 10000 events

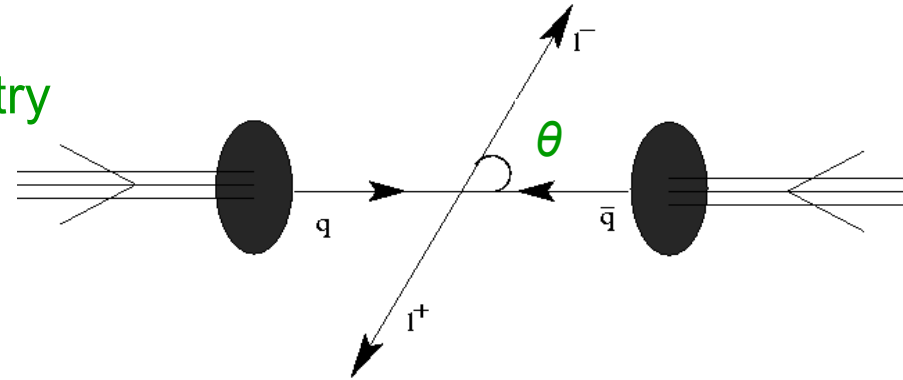
- true 4-momenta of annihilating quark and antiquark

- + 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



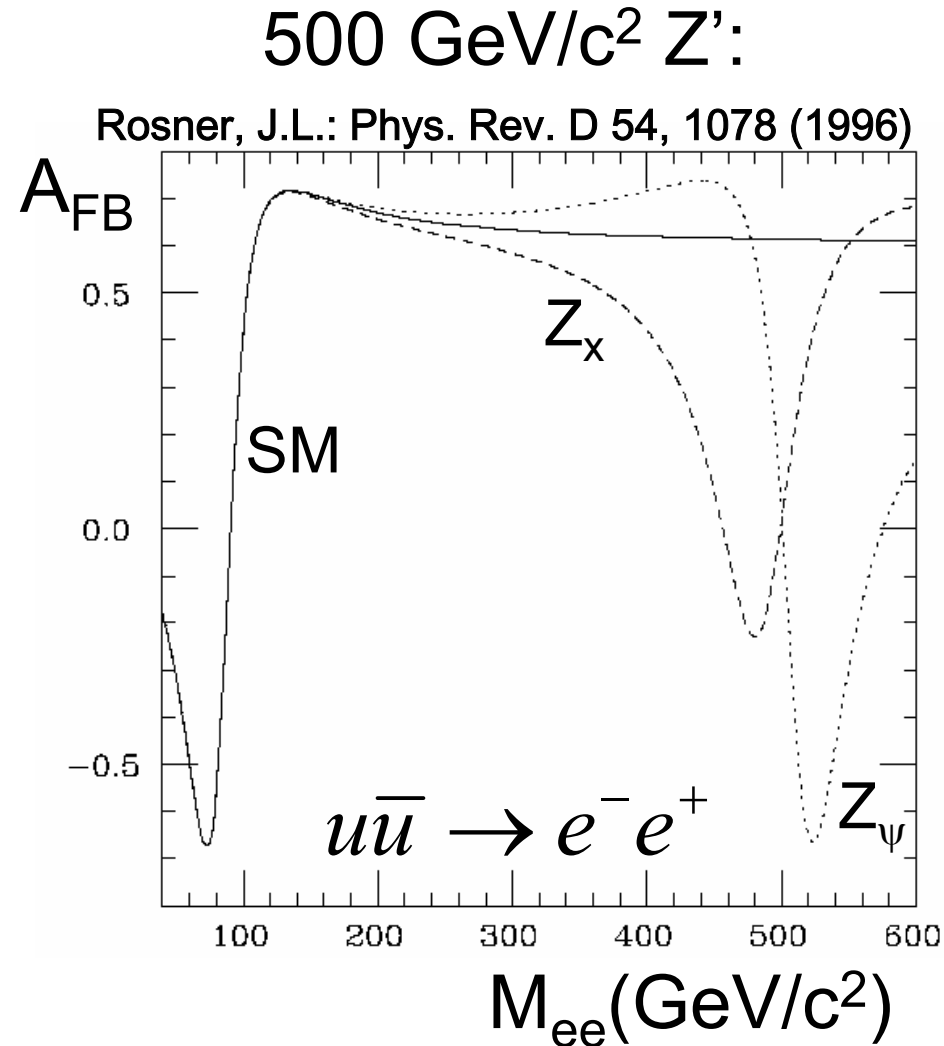
$$\frac{d\sigma(q\bar{q} \rightarrow \ell^+\ell^-)}{d\cos\theta} = C \frac{\pi\alpha^2}{2s} [Q_\ell^2 Q_q^2 (1 + \cos^2\theta) + Q_\ell Q_q \text{Re}(\chi(s)) (2g_V^q g_V^\ell (1 + \cos^2\theta) + 4g_A^q g_A^\ell \cos\theta) + |\chi(s)|^2 ((g_V^q)^2 + (g_A^q)^2)(g_V^\ell)^2 + (g_A^\ell)^2 (1 + \cos^2\theta)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

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

- 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

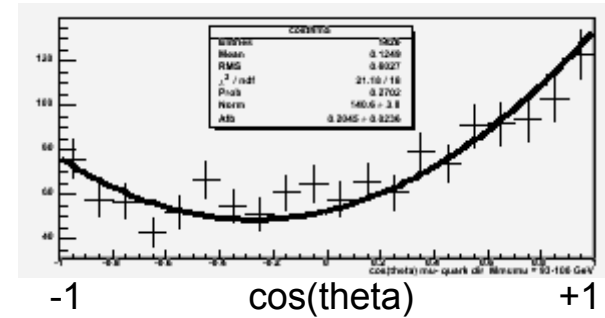
- Project (motivation)
  - $A_{FB}$  sensitive to new heavy gauge bosons predicted in many extensions of the Standard Model



# 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)

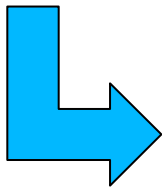


- *Issue at the LHC: How does one find the initial quark direction?*

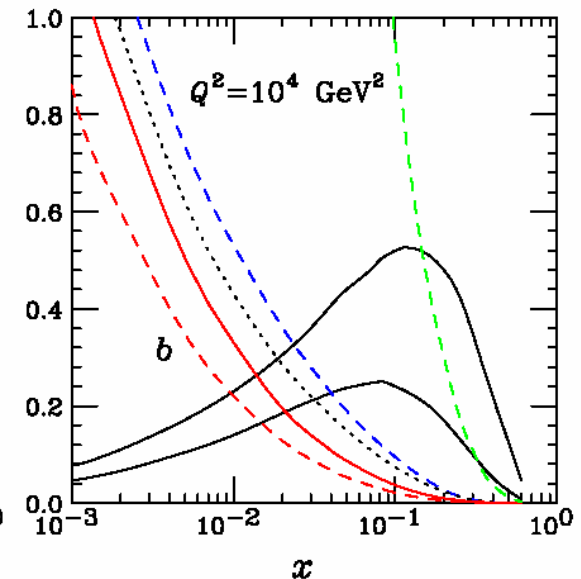
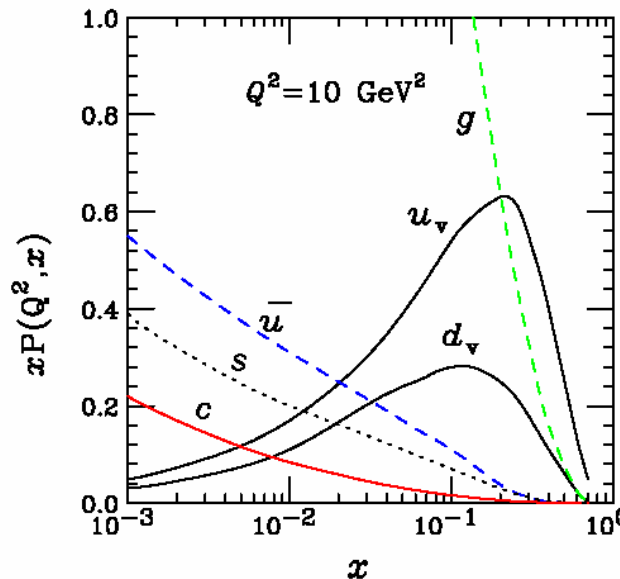
→ approximate the initial quark direction with that of the Z boson

→ 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...)

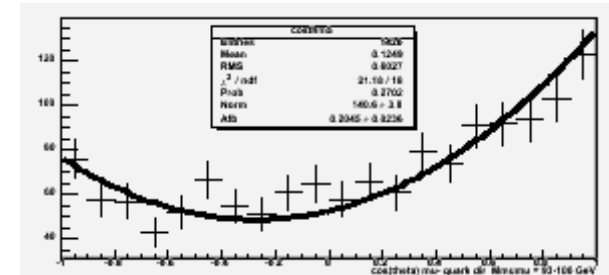
- Determine how often the Z direction approximation gives the correct “forward” tag

+ plot this fraction as a function of the Z rapidity ( $y$ )

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

- 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**