Measuring the Drell-Yan Forward-Backward Asymmetry with CMS

Oz Amram

Advisor: Morris Swartz

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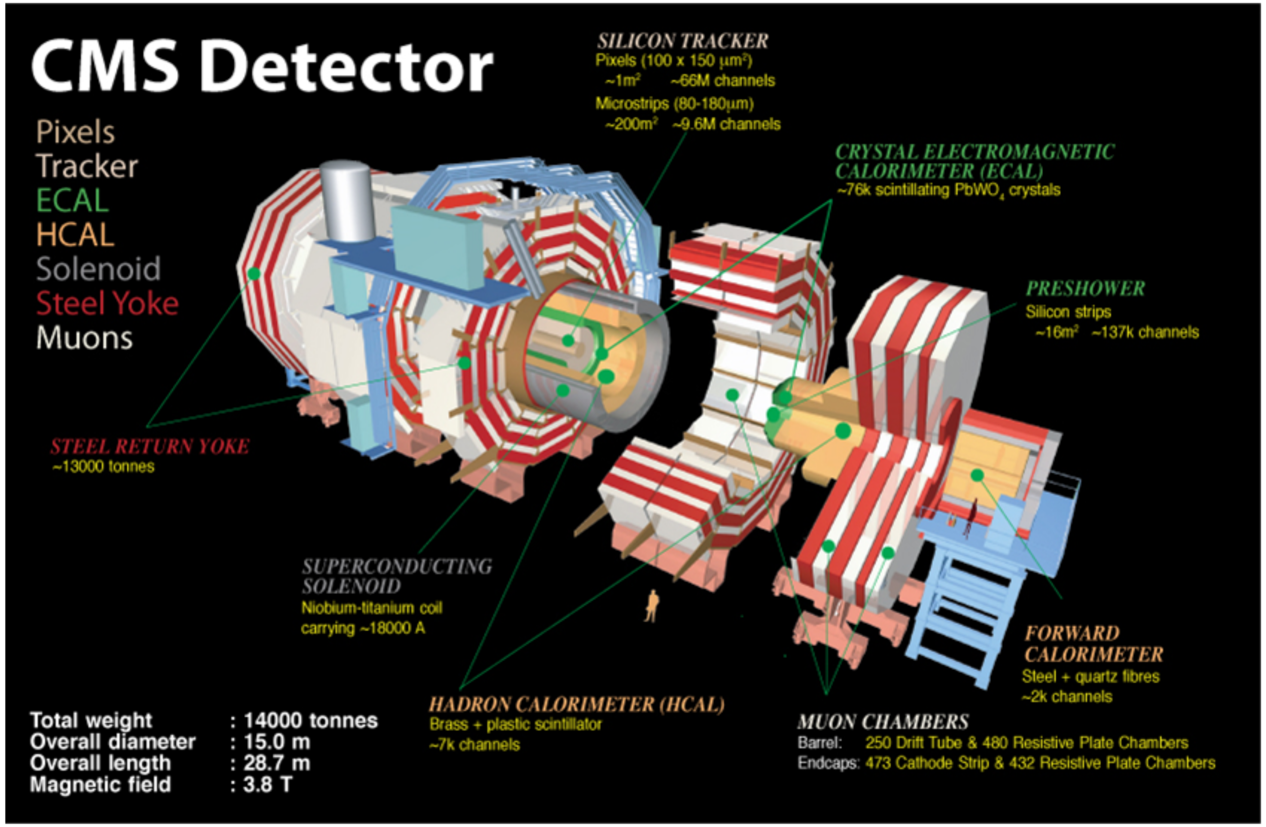
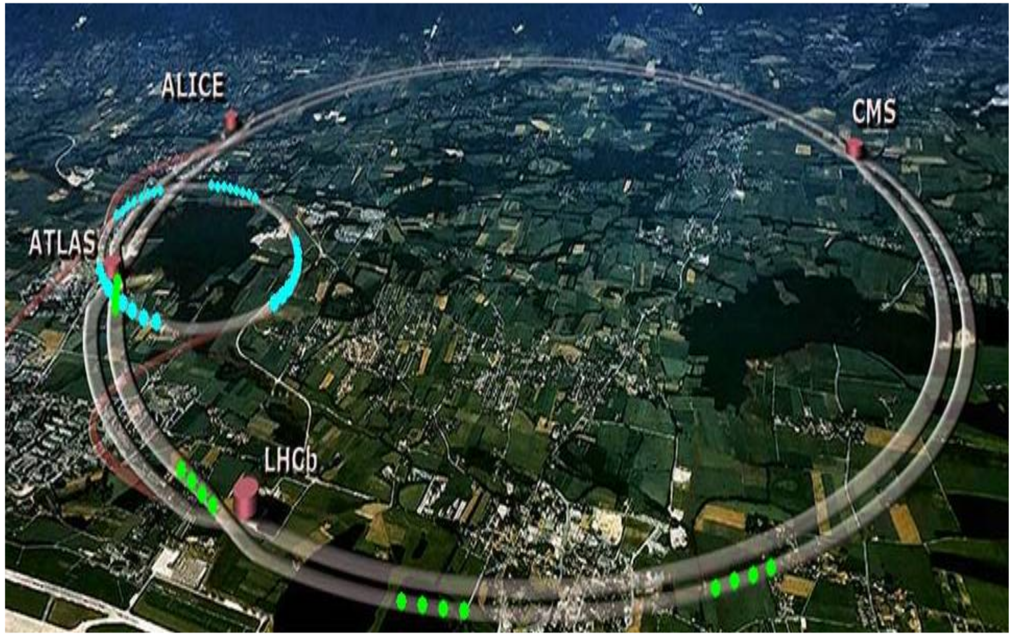
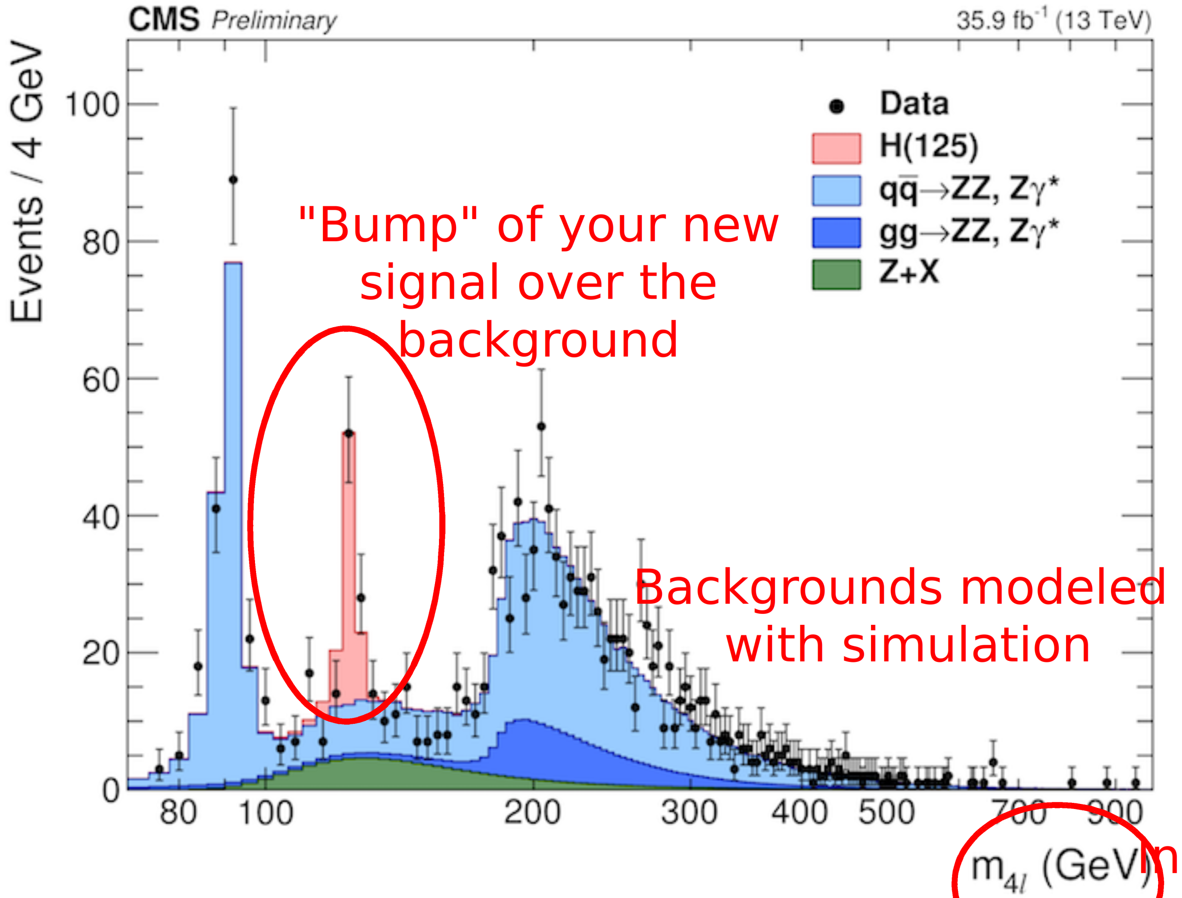
- CMS at the LHC
- Background: Parity & Parton Distribution Functions (pdf’s)
- Analysis Technique
- Current Results and Future Work

CMS and the LHC





The most direct/common search for a new particle is a 'bump hunt'



"Bump" of your new signal over the background

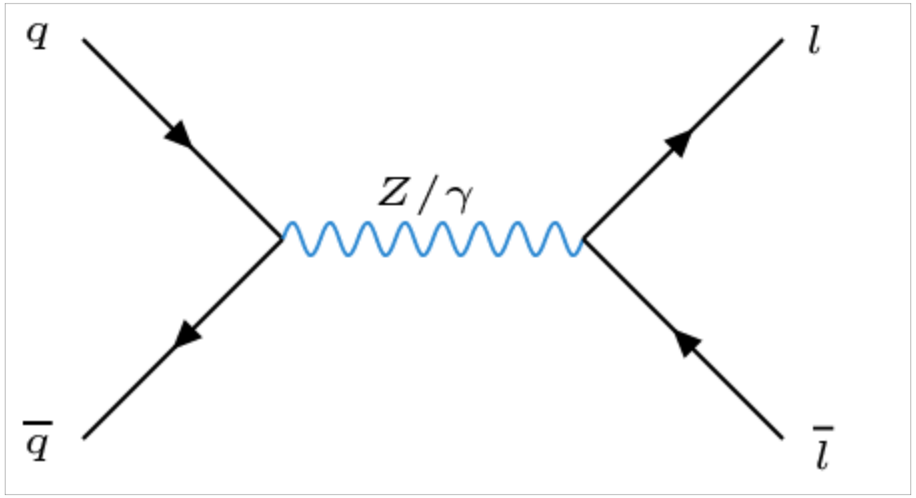
Backgrounds modeled with simulation

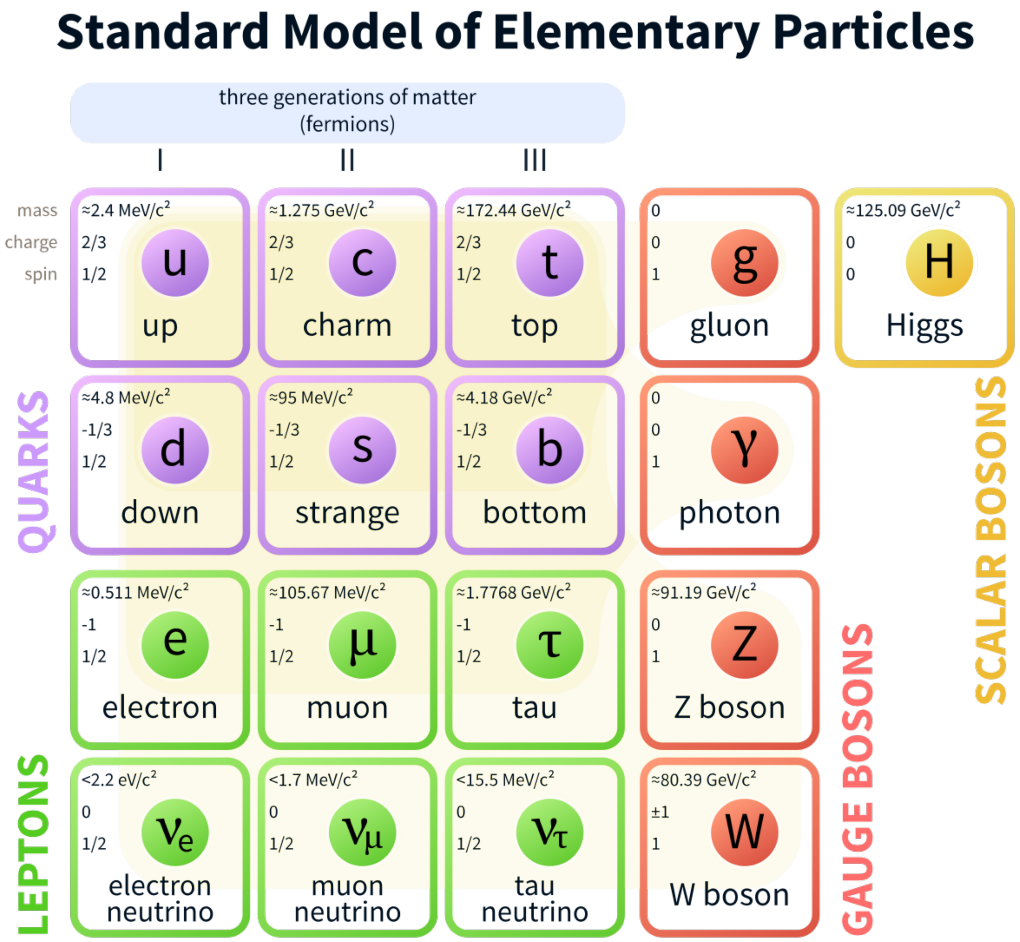
Invariant mass of final State Particles

Indirect Searches are Anything Else

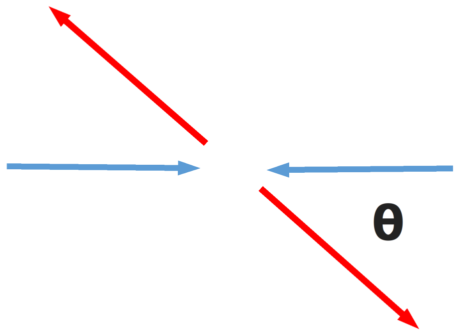
- Deviations from any Standard Model predictions would be evidence of new physics
- Precision measurements of the Standard Model:
  - Muon magnetic moment
    - Currently ~3 σ deviation
  - Decay rate of a particle
    - Currently a ~4 σ deviation across multiple experiments of B-meson decays
    -
  - <u>Asymmetries in the angular distribution of particles (my analysis)</u>

My Process (Drell-Yan): A Feynman Diagram





Angular Distributions



Looking at the angle between the incident **quark** and final state **lepton**

σ_F= cross section of events with θ > 0

σ_B = cross section of events with θ < 0

Forward-Backward Asymmetry $A_{FB} = \dfrac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$

Changes as a function of mass but asymptotes to a large value at high energy (~0.6) in the standard model

Parity

- Parity (P) is the 'mirror operation', P(x) = -x. It takes right-handed things to left-handed things

- Vectors are eigenstates of parity with eigenvalue -1:
  - Eg $P(\mathbf{p}) = -\mathbf{p}$
  -

- Axial-vectors (pseudo-vectors) are eigenstates of parity with eigenvalue 1:
  - Eg $P(\mathbf{L}) = P(\mathbf{r} \times \mathbf{p}) = P(\mathbf{r}) \times P(\mathbf{p}) = (-\mathbf{r}) \times (-\mathbf{p}) = \mathbf{L}$

- Your intuition might tell you that Parity is a symmetry of nature , but …

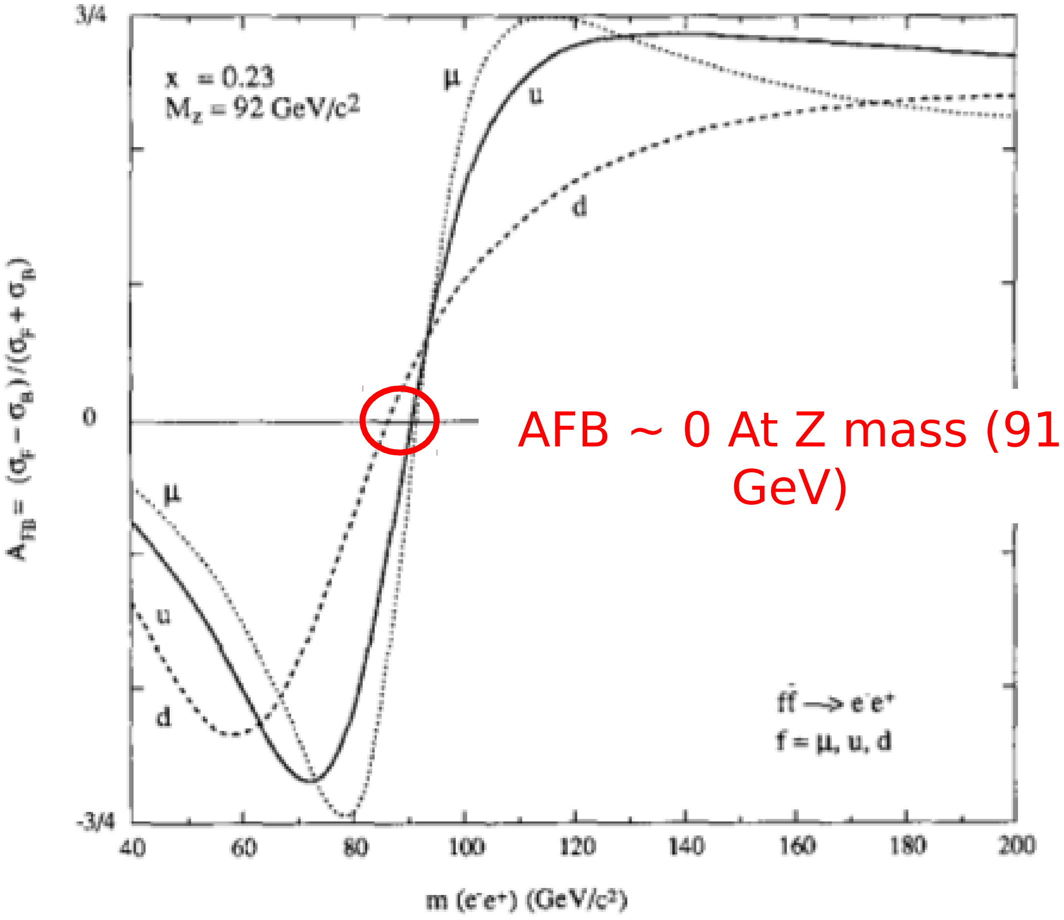
EM processes conserve parity, weak processes **don't**

DY is mediated by both photons and Z's (electroweak)

Photons have a vector coupling, Z's have an (almost) axial-vector coupling to leptons

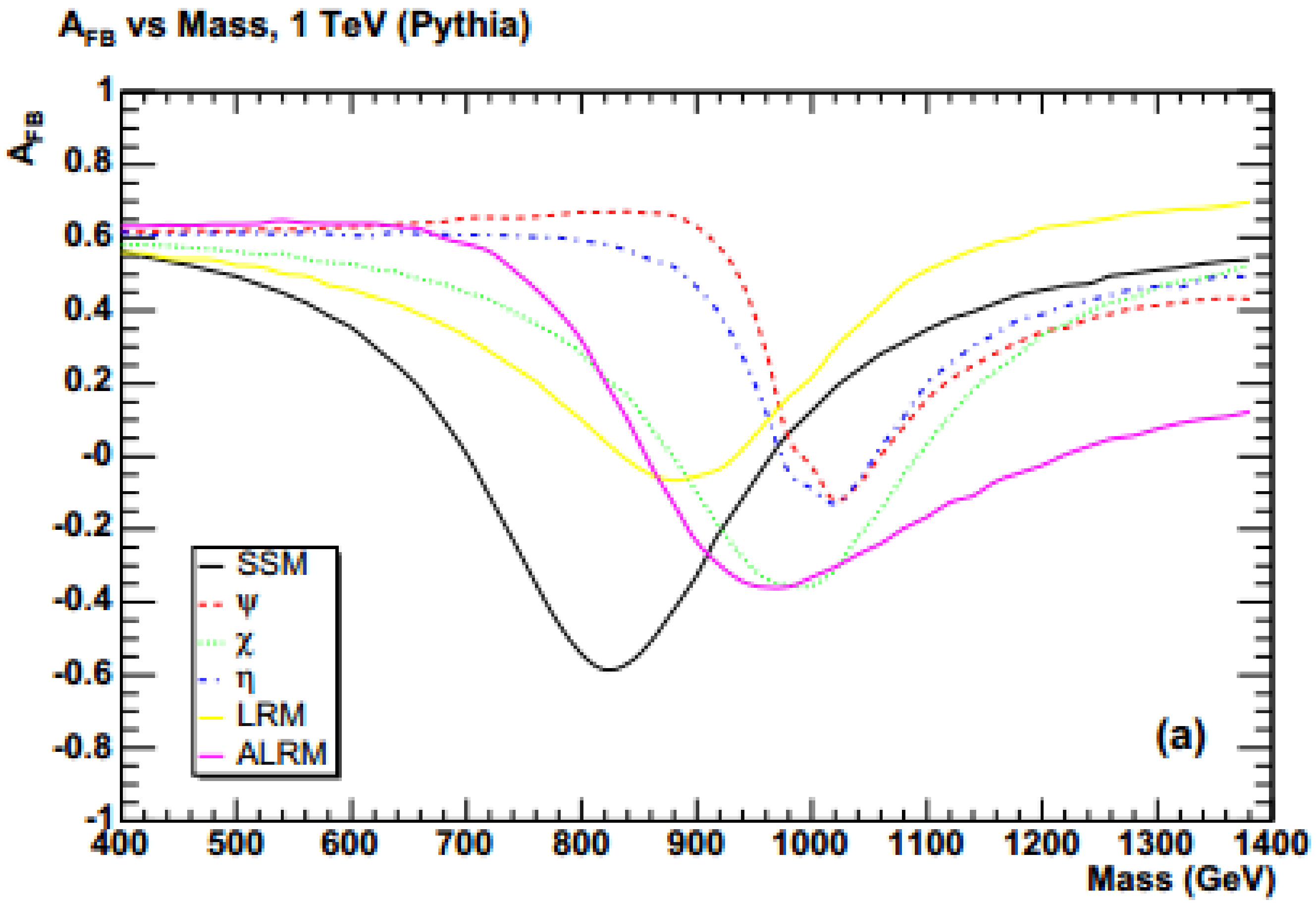
The interference between the two leads to the violation of parity

The amount of interference changes with energy



AFB ~ 0 At Z mass (91 GeV)

New bosons would effect the A_{FB} at energies lower than their mass



One challenge of measuring this at the LHC:

What is the incident quark direction?

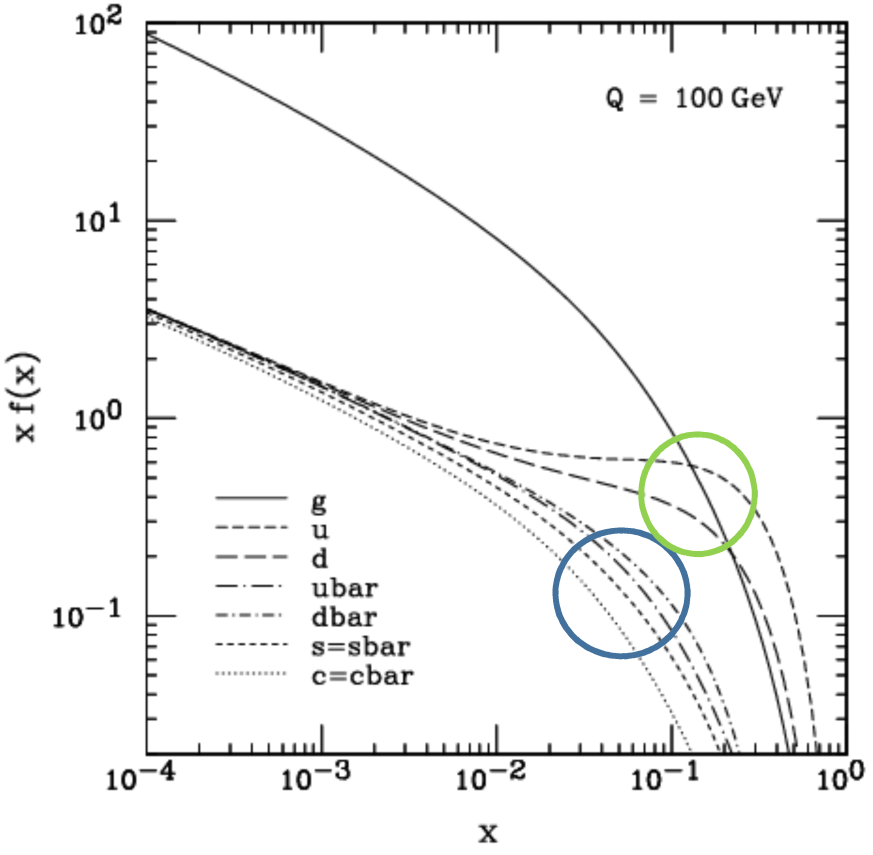
We can use our knowledge of proton structure to make an educated guess.

Protons have complicated structure

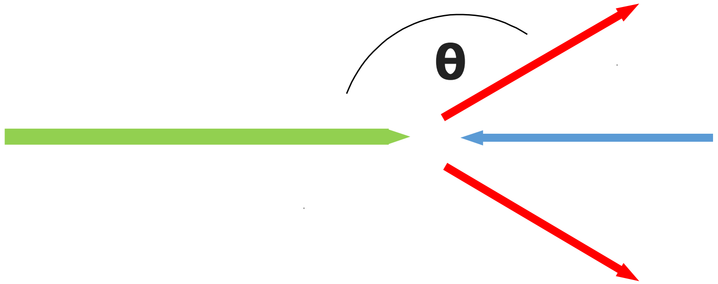
- Up Up Down (valence) quarks are there, but so are gluons, anti-up, anti-down, strange, … (sea)

- We can't really compute exactly what's going on so we have to measure it.

- Parton Distribution Function
  - Probability of a finding a given parton with a certain fraction of the protons total momentum



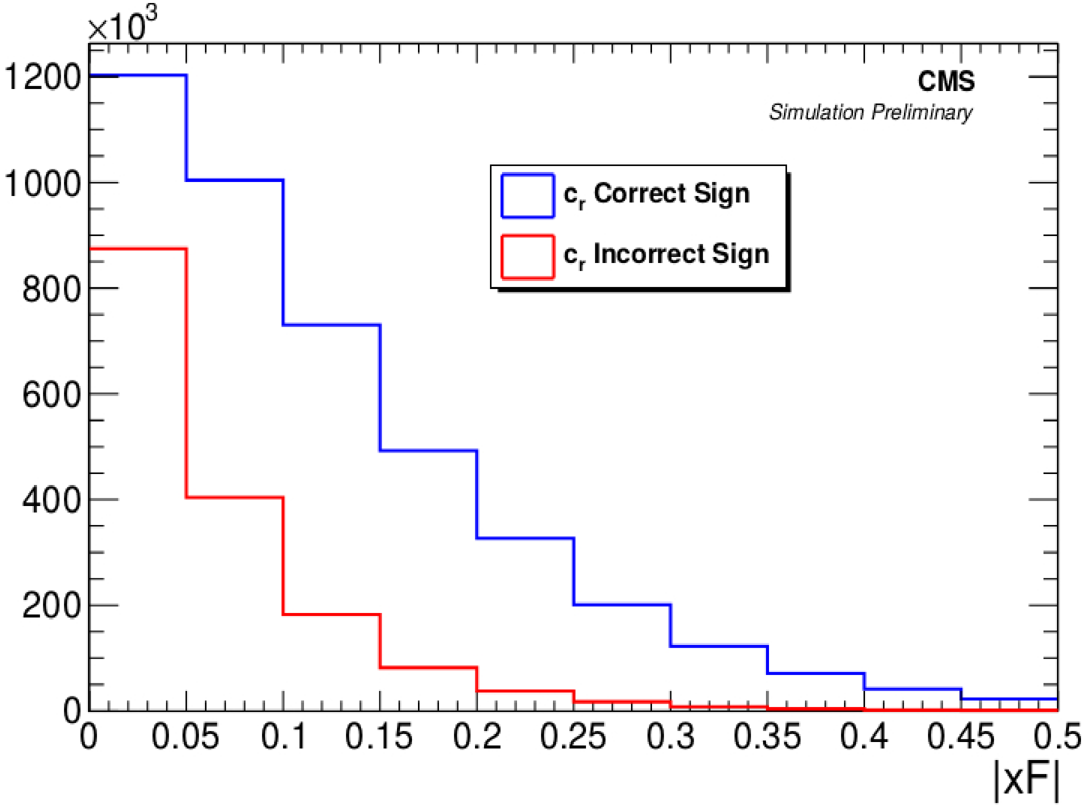
Using PDF's



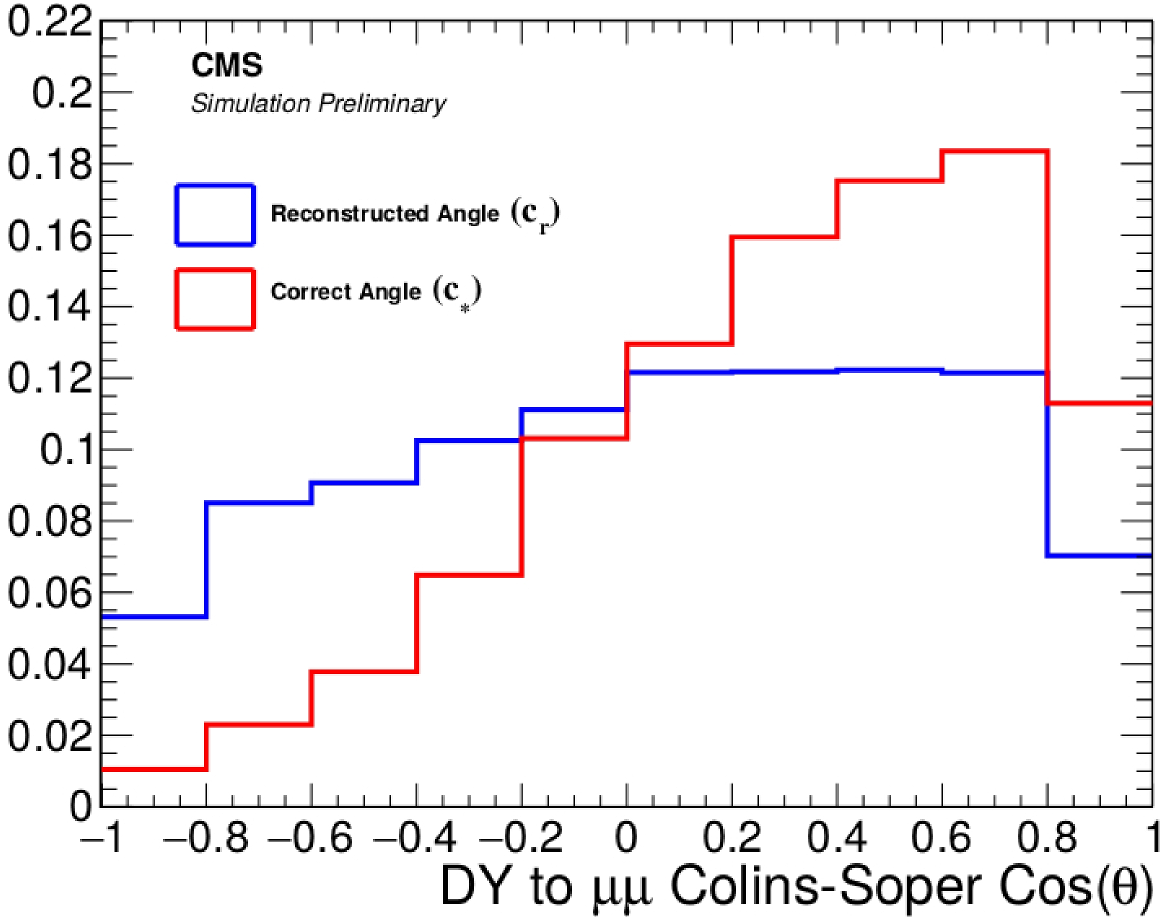
- We need to know the initial direction of the quark
- On average valence quarks (our quarks) have more momentum than sea quarks (our anti-quarks)
- We guess that the direction of the final lepton pair is the direction of the initial quark

Our guess gets better the more the lepton pair is boosted along the beam axis

Guessing the Initial Quark



X-axis, 'Feyman-x', tells you how much momentum the lepton pair has over the maximum possible



Method of Extracting AFB

- Our approach is to fit the asymmetry in the angular distribution

$$\frac{d\sigma}{dc_*}(q\bar{q}; M^2) = \frac{\pi\alpha(M^2)^2}{2M^2} K(M^2) \left\{ 1 + c_*^2 + \alpha(M^2) \left(1 - c_*^2\right) + \frac{4}{3} \left[2 + \alpha\right] A_{\mathrm{FB}}(M^2) c_* \right\}$$

- $c_* = \mathrm{Cos}(\theta)$, α the average longitudinal gluon polarization, K a normalization parameter and A_{FB} are functions of mass
- Observed distribution is convolution of cross section and detector resolution + efficiency
- Linearity of c_* odd term undisturbed
- Fitting function can be constructed from parameter independent histograms, or templates

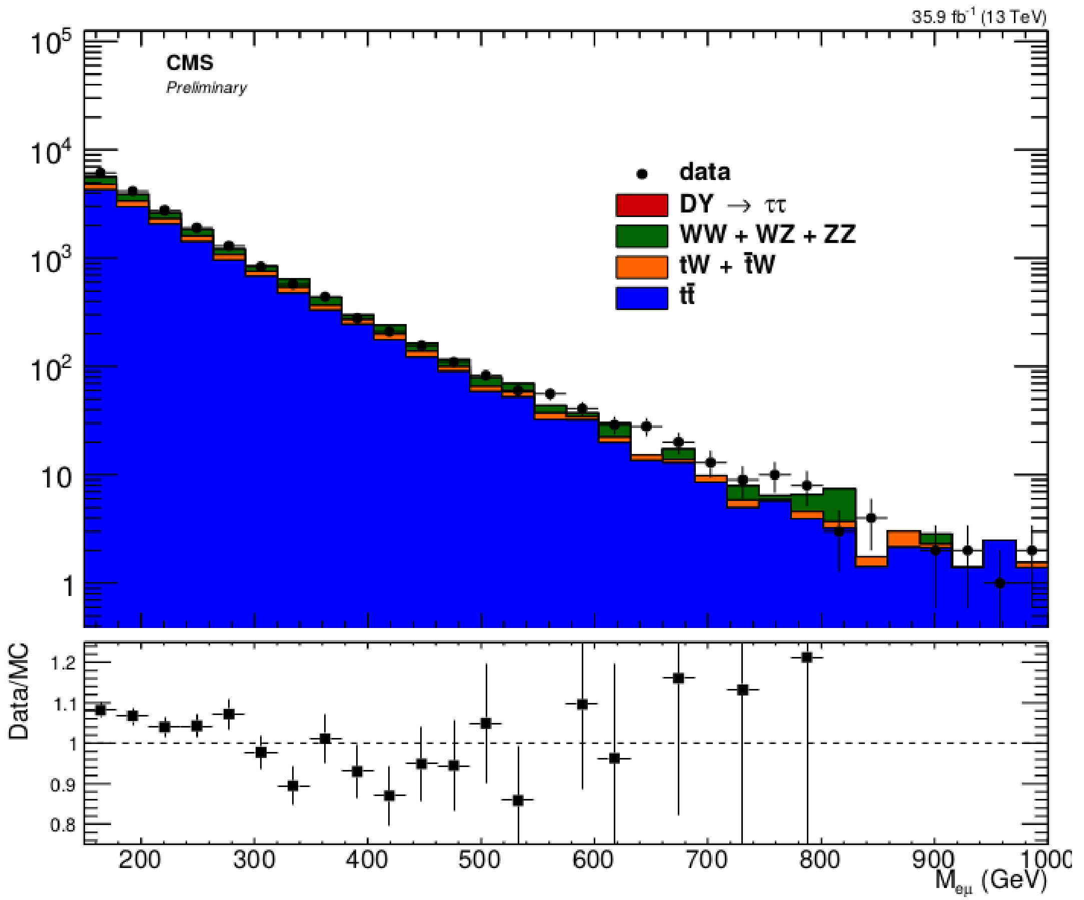
Template Fitting Method

- Straight forward to reconstruct muons and the 3 key variables x_F, M, and c_r
- Construct fully symmetric (f_s) and anti-symmetric (f_a) in c_r templates from DY MC
- Construct a background template (f_{bk}), and introduce background fraction parameter R_{bk}
- Perform a maximum likelihood fit on A_{FB} and R_{bk} with:
-

$$f(x_{\mathrm{r}}, M_{\mathrm{r}}, c_{\mathrm{r}}) = R_{\mathrm{bk}} f_{\mathrm{bk}}(x_{\mathrm{r}}, M_{\mathrm{r}}, c_{\mathrm{r}}) + \left(1 - R_{\mathrm{bk}}\right) \left[f_{\mathrm{s}}(x_{\mathrm{r}}, M_{\mathrm{r}}, c_{\mathrm{r}}) + A_{\mathrm{FB}} f_{\mathrm{a}}(x_{\mathrm{r}}, M_{\mathrm{r}}, c_{\mathrm{r}})\right]$$

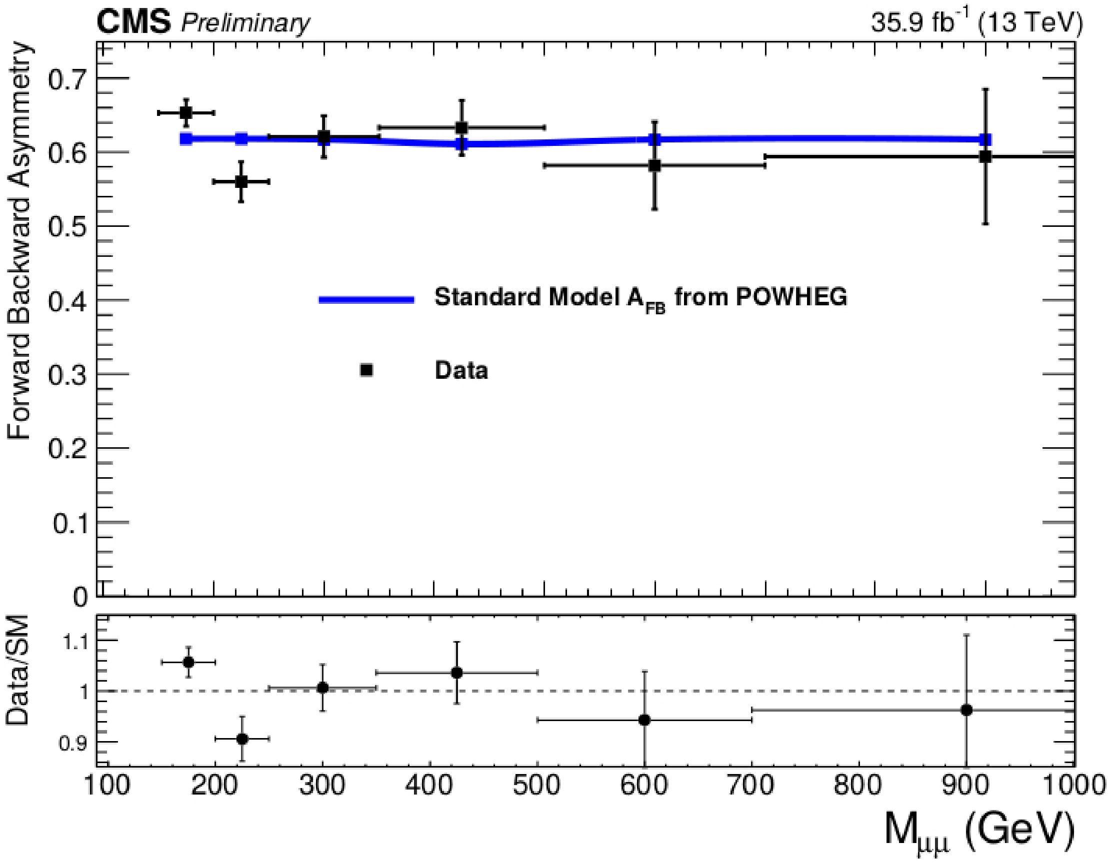
Background Estimation with eμ

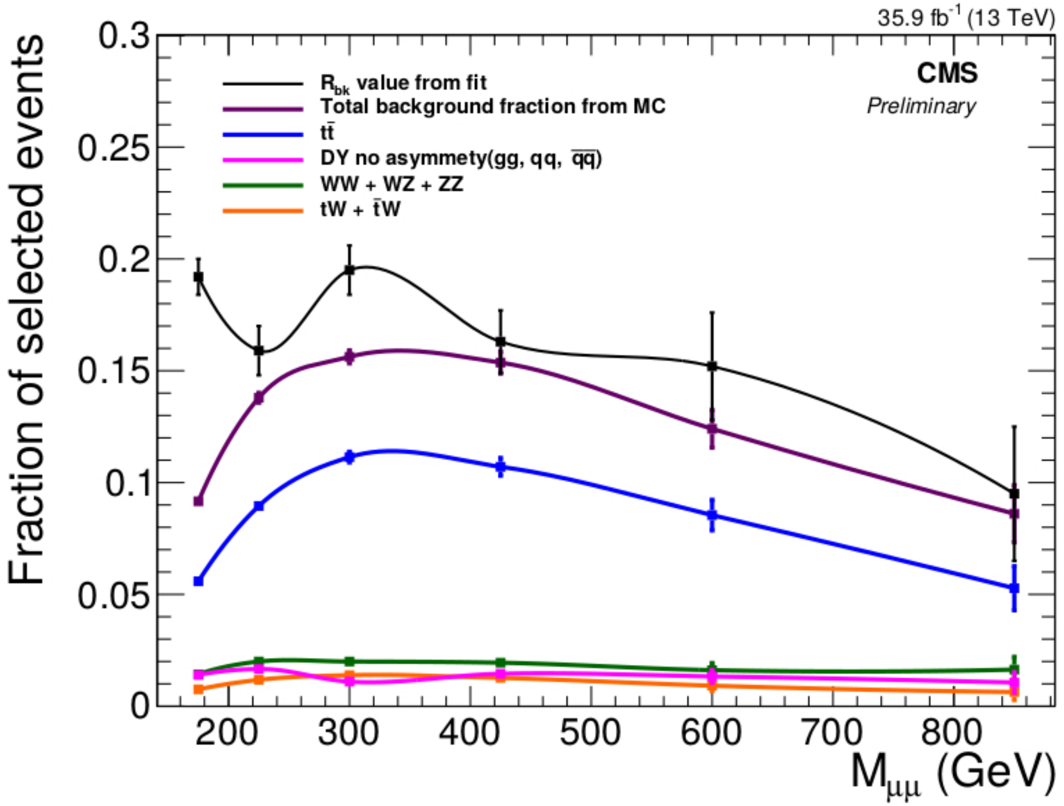
- All of our backgrounds also have decay channels to eμ
- Rescale the normalization of our backgrounds with the ratio of observed eμ events to MC eμ events
- Overall ratio is 1.05 ± 0.01



Results

- Perform fit in 6 mass bins, compare A_{FB} to POWHEG generator level simulation





R_{bk} compared to MC estimation of background fraction

Further Work

- Main issue is low statistics in MC templates for lowest two mass bins
    - Moderate disagreement for first two A_{FB} values and first 3 background fractions

- QCD backgrounds, jets misidentified as isolated muons, need to be accounted for, expect to be a very small fraction of events

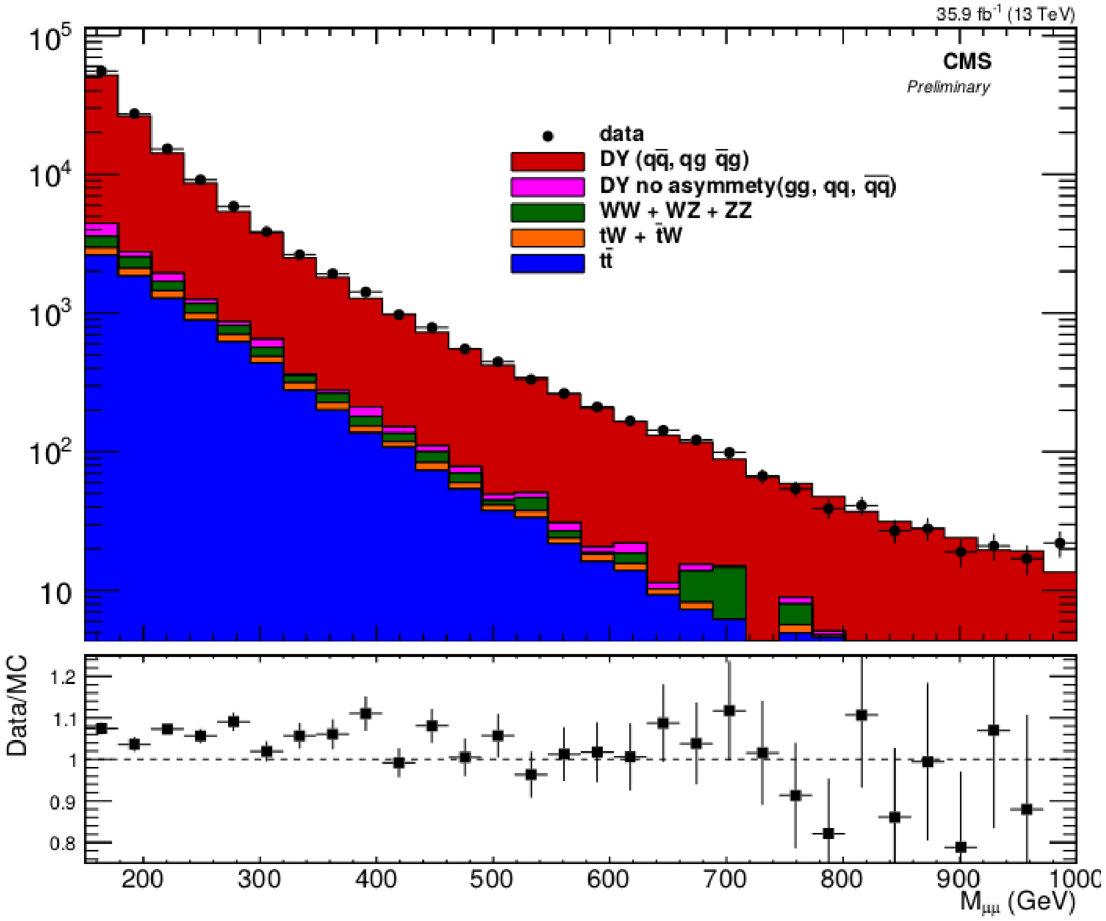
- Analysis is being extended to measure the AFB of electron pairs as well

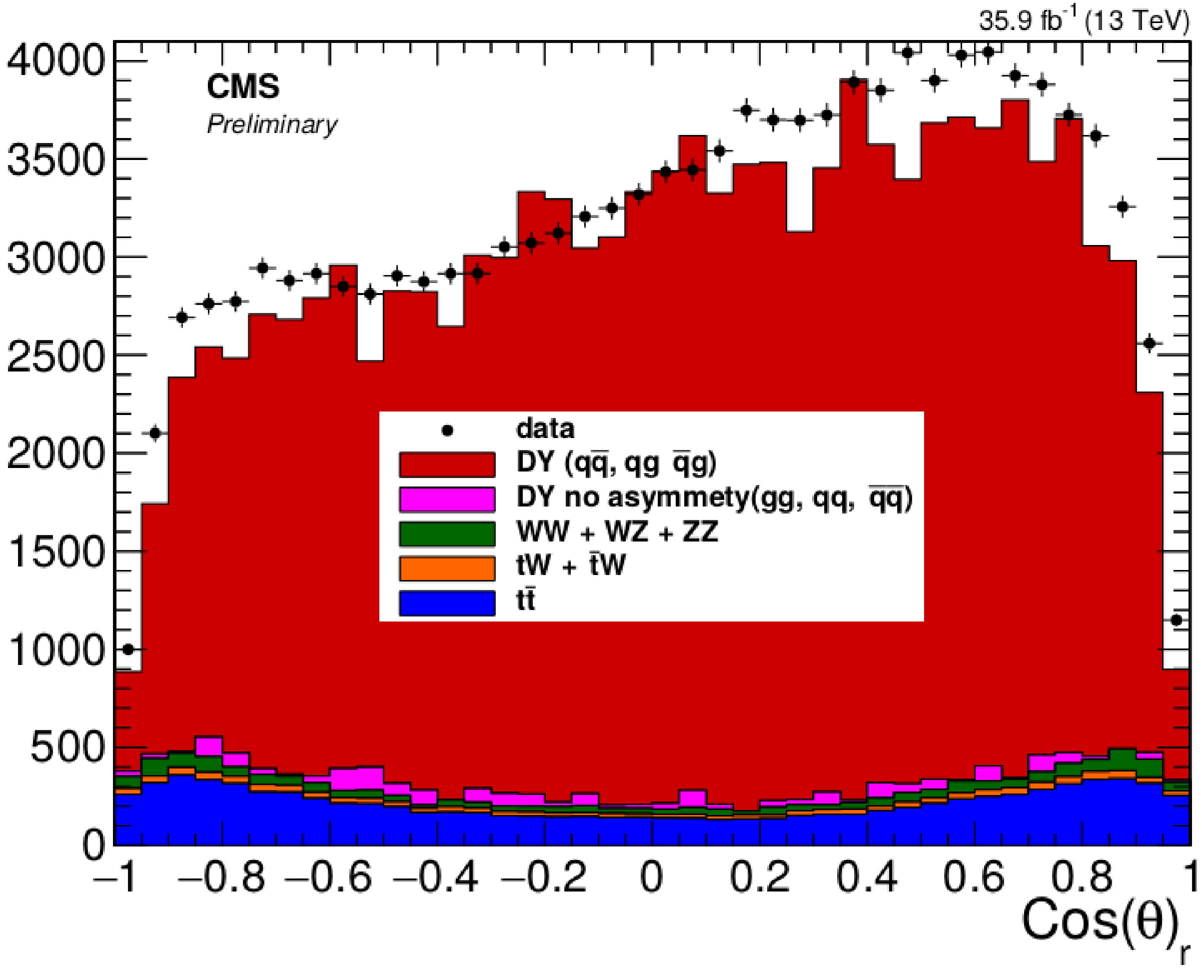
Backup Slides

Event Selection

- Trigger: HLT_IsoMu24 OR HLT_IsoTkMu24
- Kinematics: Leading muon P_t > 26 GeV, subleading muon P_t > 10 GeV, $|\eta|$ < 2.4, opposite charge
- Muon ID and Isolation: Tight
- tt background rejection: MET < 50 GeV and anti-b-tag on highest two P_t jets

Data vs. MC


35.9 fb-1 (13 TeV)
CMS
Preliminary
data
DY (qq̄, qg q̄g)
DY no asymmety(gg, qq, q̄q̄)
WW + WZ + ZZ
tW + t̄W
tt̄
Data/MC
M_μμ (GeV)


35.9 fb-1 (13 TeV)
CMS
Preliminary
data
DY (qq̄, qg q̄g)
DY no asymmety(gg, qq, q̄q̄)
WW + WZ + ZZ
tW + t̄W
tt̄
Cos(θ)_r

Defining the Angles

The 'Colins-Soper' Frame

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