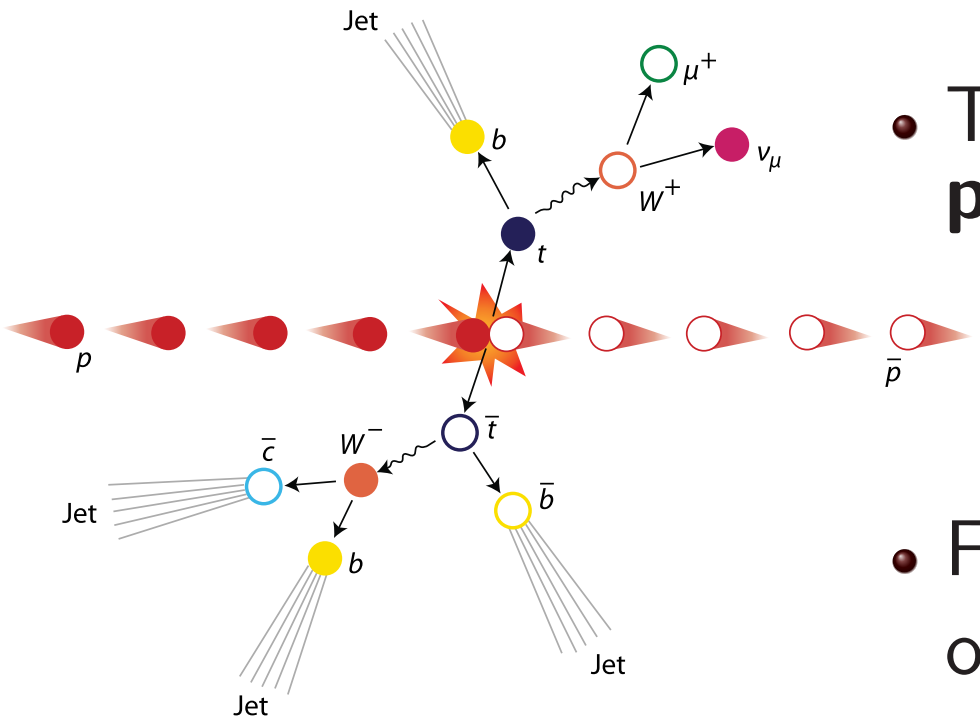
Forward–backward Asymmetry in Top Pair Production at CDF

Ziqing Hong
on behalf of the CDF Collaboration

New Perspectives 2015
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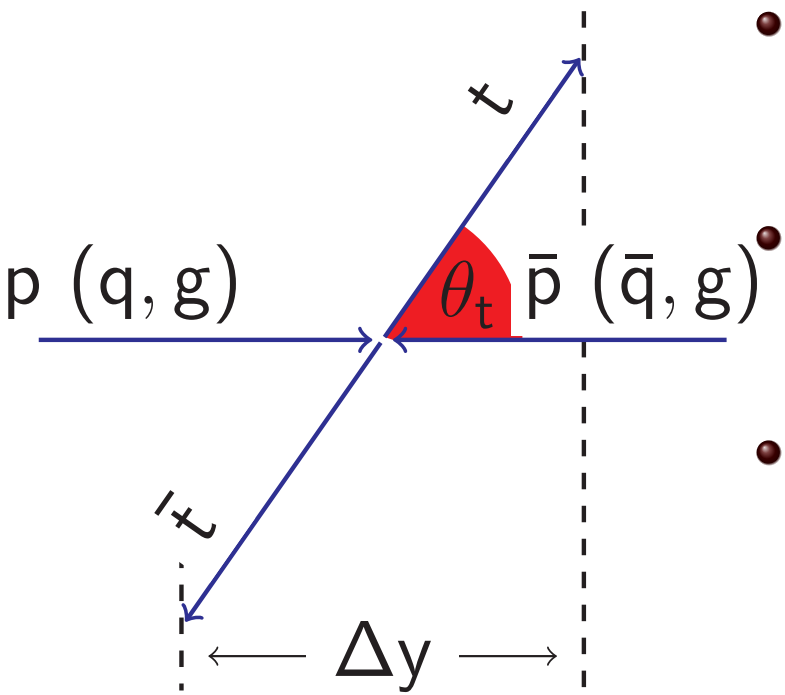


Top-Quark Pair at Tevatron



- $p\bar{p}$ collision at Tevatron
  - Asymmetric initial state
  - Proton direction as "forward"
- Top quark majorly produced **in pairs**
  - Very heavy particles
  - Very short lived, don't form hadrons
- Fascinating particle, unique opportunity to study a "bare" quark

$A_{FB}^{t\bar{t}}$ at Tevatron

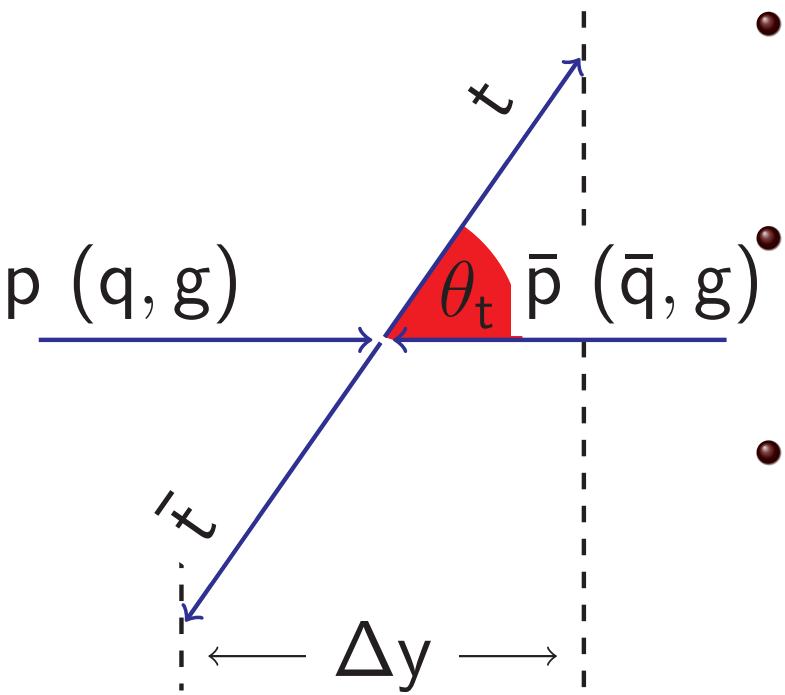


$$y = \frac{1}{2} \ln \frac{E + p_z}{E - p_z}$$

- Forward-backward asymmetry (A_{FB})
- **Does top quark prefer proton direction or the opposite?**
- Characterized by rapidity difference between top and anti-top, $\Delta y = y_t - y_{\bar{t}}$
- Define A_{FB} of $t\bar{t}$ production:

$$A_{FB}^{t\bar{t}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

$A_{FB}^{t\bar{t}}$ at Tevatron



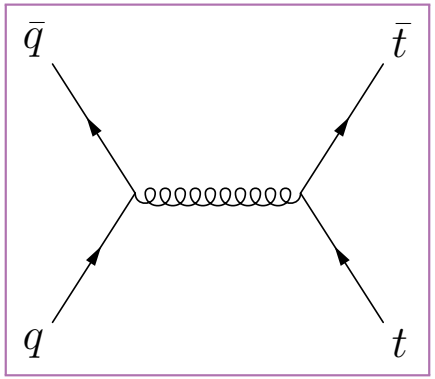
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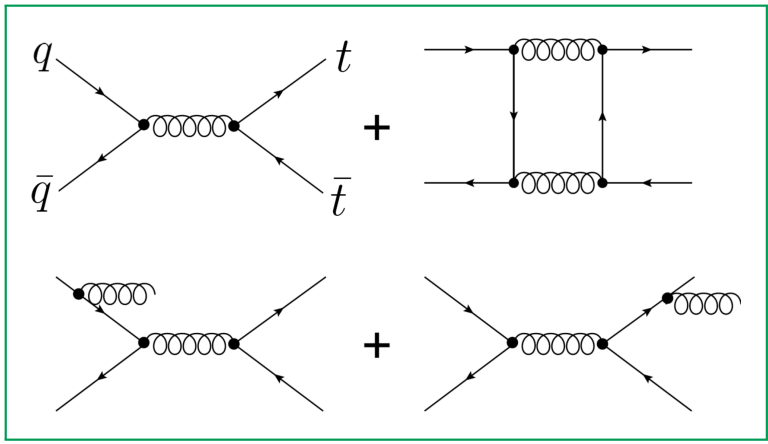
$$A_{FB}^{t\bar{t}} = \textbf{P(top}\rightarrow\textbf{) - P(}\leftarrow\textbf{top)}$$

A_{FB} at Tevatron: Why important?

Why this is important?

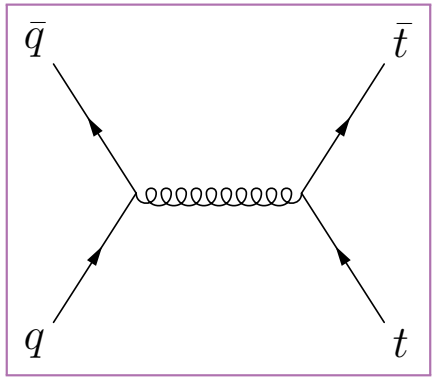


- No net asymmetry in leading order diagram
- Slight asymmetry starting from next-to-leading order (NLO) effects
- Large EW correction (25%@LO) and higher order QCD corrections (27%@NNLO) complicate the calculation
- **Precision probe of SM predictions with large mass particles**



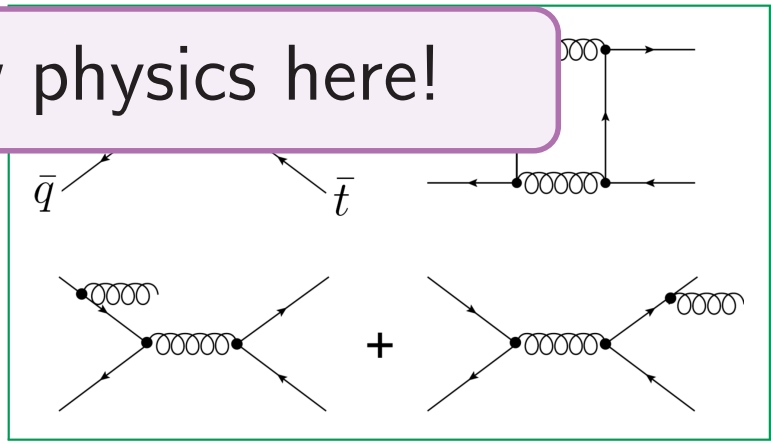
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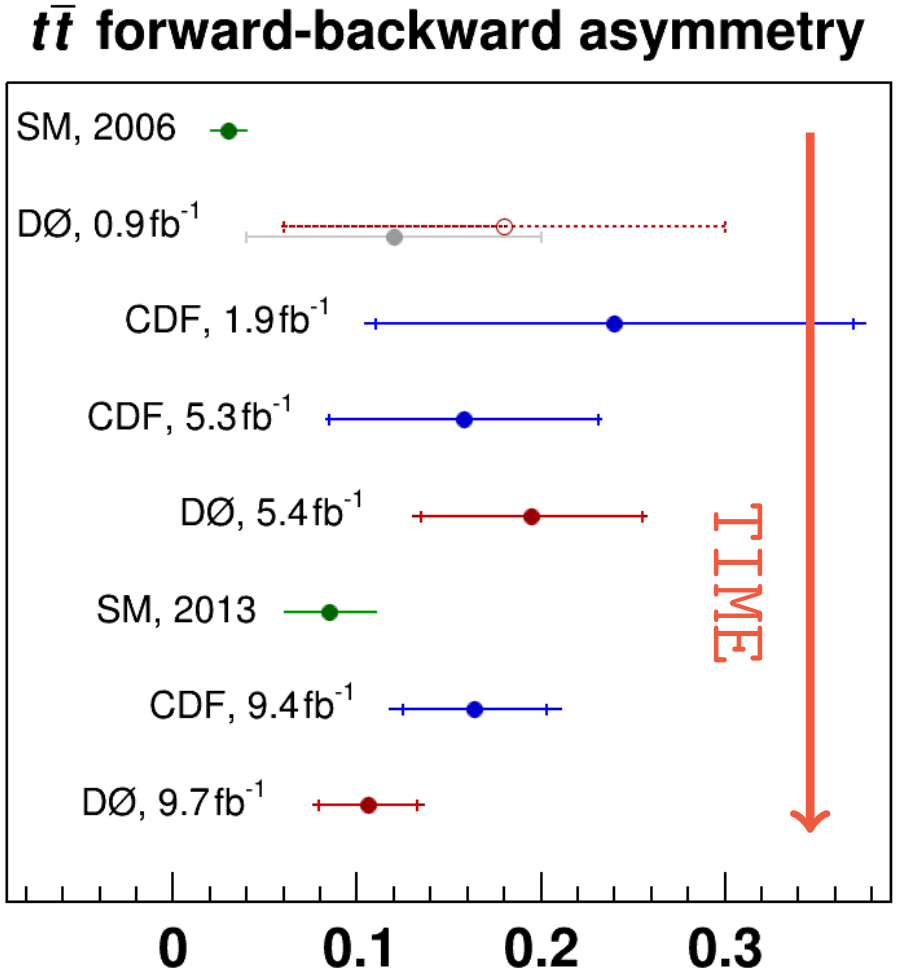
Might even find signs for new physics here!



$A_{FB}^{t\bar{t}}$ at Tevatron: History

Previous experimental results?

- CDF: $A_{FB}^{t\bar{t}} = 0.164 \pm 0.047$
  (Lep+jets, PRD **87**, 092002 (2013))
- D0: $A_{FB}^{t\bar{t}} = 0.106 \pm 0.030$
  (Lep+jets, PRD **90**, 072011 (2014))
- $A_{FB}^{t\bar{t}} = 0.180 \pm 0.086$
  (Dilepon, D0 note 6445-CONF (2014))
- Final result from CDF in tension with NNLO SM calculation (0.095), with both results from D0 consistent with calculation

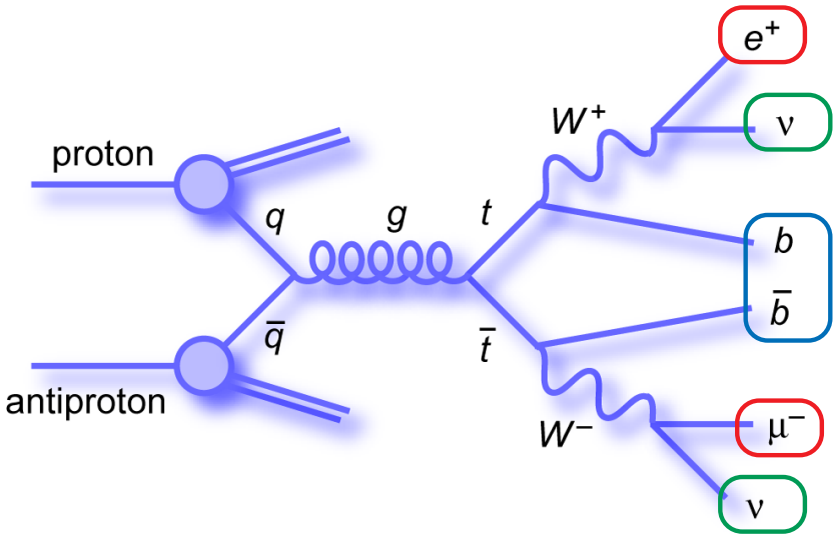


Outline

- First time presentation of:
- $A_{\mathrm{FB}}^{t\bar{t}}$ measurement in **dilepton final state** at CDF
- $A_{\mathrm{FB}}^{t\bar{t}}$ CDF combination

$t\bar{t} \rightarrow$ dilepton
Event selection

- Need a sample enriched by $t\bar{t}$ events with dilepton signature:
  - Two opposite charged leptons
  - At least two jets, from b-quark hadronization
  - Large imbalanced p_T, due to neutrinos
- Details of $t\bar{t} \rightarrow$dilepton data selection criteria, and signal and background modeling in the backups



$t\bar{t}$ Kinematic Reconstruction

- Need to reconstruct the $t\bar{t}$ momenta to find Δy_t
  - Usually just identify the final-state particles and add up the momenta – Not in dilepton channel
- Dilepton channel: **under-constrained system**
  - Mainly due to two neutrinos leaving the detector
  - Also, don't measure jet energies and imbalanced p_T well
  - Plus, cannot tell which jet is from b and which is from $\bar{b}$
- Quantify the probability of a certain configuration (thus a certain Δy_t) coming from a measured $t\bar{t}$ dilepton event with a likelihood term
- Employ Markov-chain Monte Carlo (MCMC) to map out the probability distribution of Δy_t for each event

Extract truth-level $A_{FB}^{t\bar{t}}$

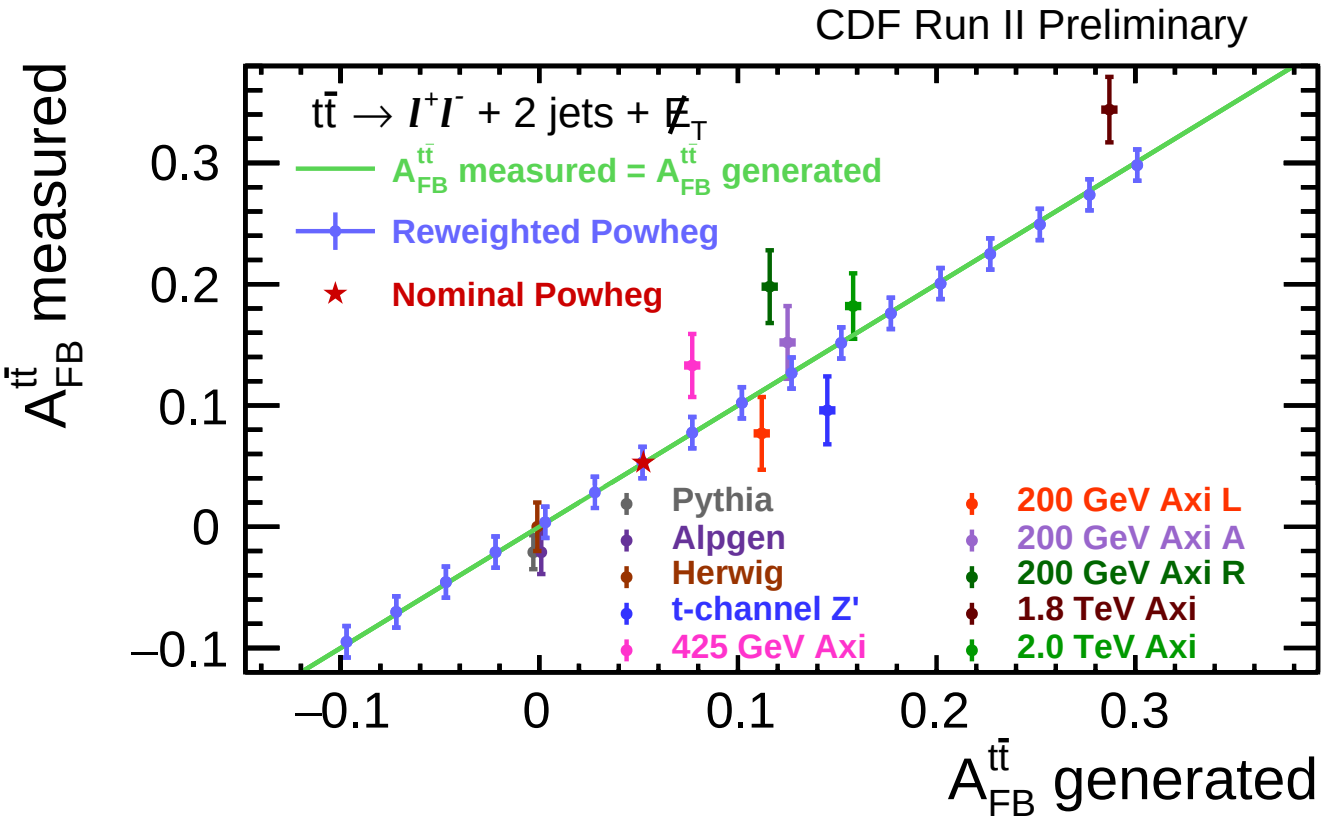
- Have the measurement after top reconstruction
- Need to correct it to truth-level
  - What you would get imagining you could see top quarks directly
- Correct for two effects in a Bayesian model
  - **Smearing** caused by detector response and $t\bar{t}$ reco
  - **Acceptance** imposed by detector coverage and **efficiency** caused by object ID and event selection

$$\exp[r] = \sum_{t=1}^{4} \mathrm{truth}[t] * \mathrm{Eff}[t](A_{FB}^{t\bar{t}}) * \mathrm{Det}[t][r] + \mathrm{bkg}[r]$$

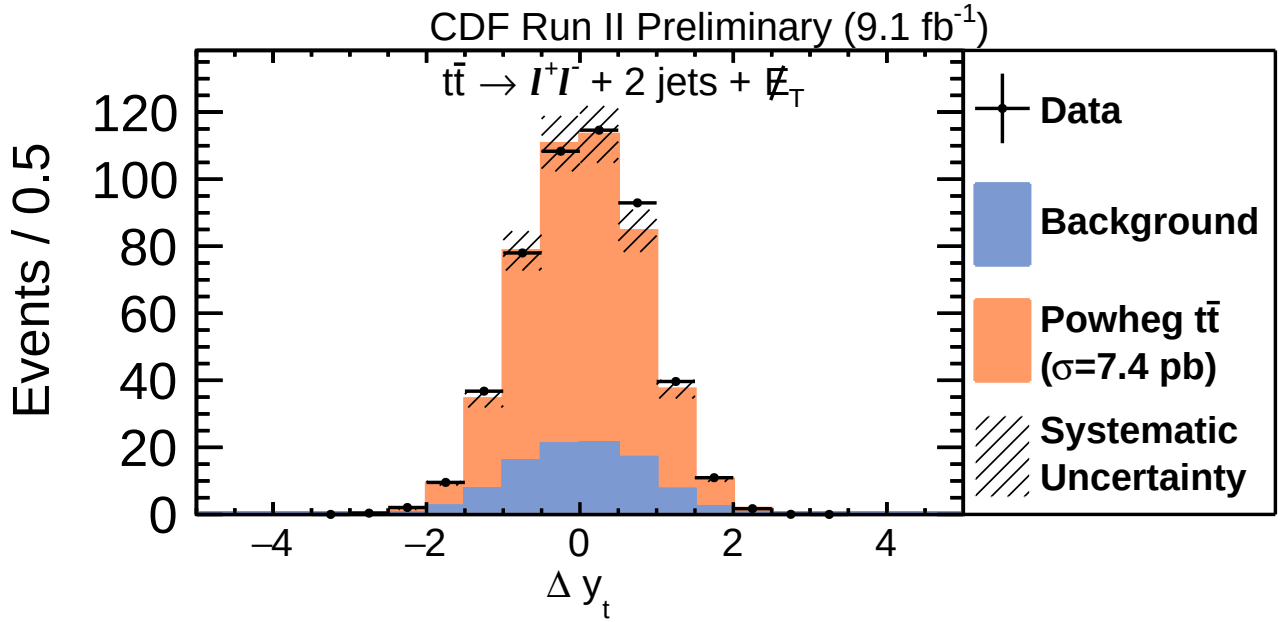
- Find truth-level $\mathrm{truth}[t]$ resulting in the expectation $\exp[r]$ that matches data best
- Truth-level $A_{FB}^{t\bar{t}}$ from best matched $\mathrm{truth}[t]$

Bias test

- Test the $A_{\mathrm{FB}}^{t\bar{t}}$ extraction algorithm with simulated samples
- No bias in SM-like scenarios
- Don't anticipate unfolding to work perfectly in BSM scenarios, though the deviation is modest



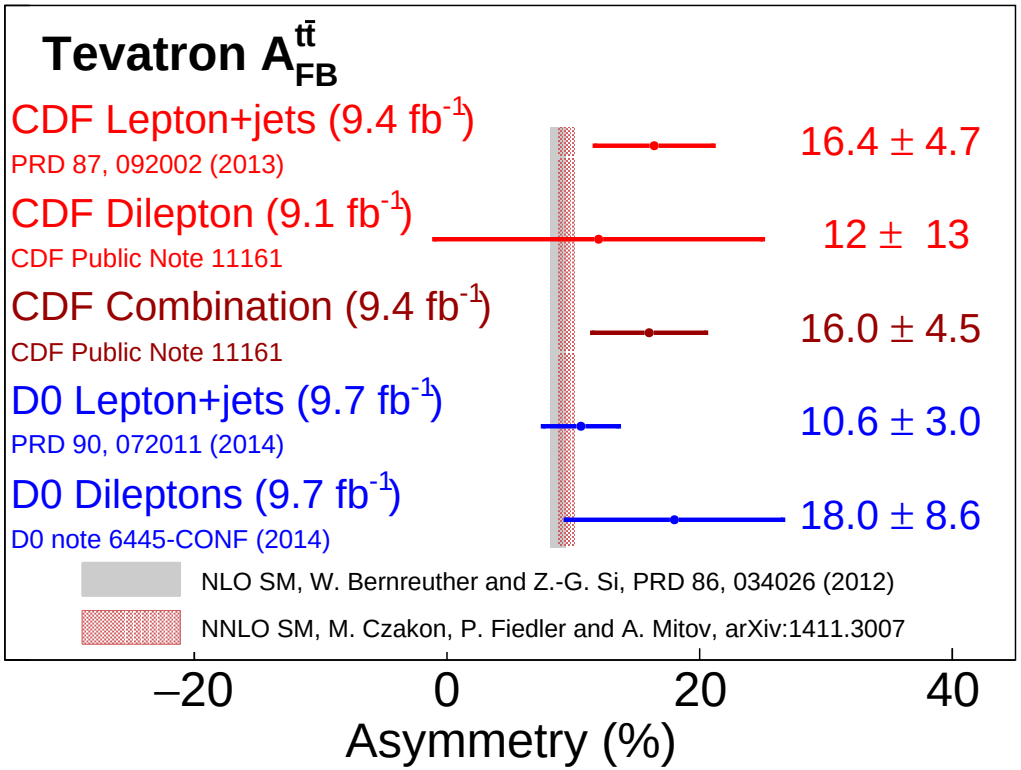
$A_{FB}^{t\bar{t}}$ in CDF Dilepton



- Apply reconstruction and unfolding algorithm to data
- $A_{FB}^{t\bar{t}} = 0.12 \pm 0.11(\text{stat}) \pm 0.07(\text{syst})$
- Table of uncertainties in backups
- Consistent with NNLO SM prediction 0.095 ± 0.007

CDF $A_{FB}^{t\bar{t}}$ combination

- Combine with CDF result in lepton+jets
  - *Best Linear Unbiased Estimator* employed
  - Account for all uncertainties with correlations
- Result is $A_{FB}^{t\bar{t}} = 0.160 \pm 0.045$
- All results consistent with SM predictions



Conclusions: Top A_{FB}

- Final measurement of $A_{FB}^{t\bar{t}}$ in dilepton final state at CDF: $A_{FB}^{t\bar{t}} = 0.12 \pm 0.13$
- CDF combination yields $A_{FB}^{t\bar{t}} = 0.160 \pm 0.045$
- Consistent with NNLO SM calculation of 0.095 ± 0.007
- No clear sign of new physics, which is kind of disappointing
- Have been pushing top physics calculation to higher precision

Conclusions: Top A_{FB}

- Final measurement of $A_{FB}^{t\bar{t}}$ in dilepton final state at CDF: $A_{FB}^{t\bar{t}} = 0.12 \pm 0.13$
- CDF
- Cons

Thanks to the organizer for arranging this event

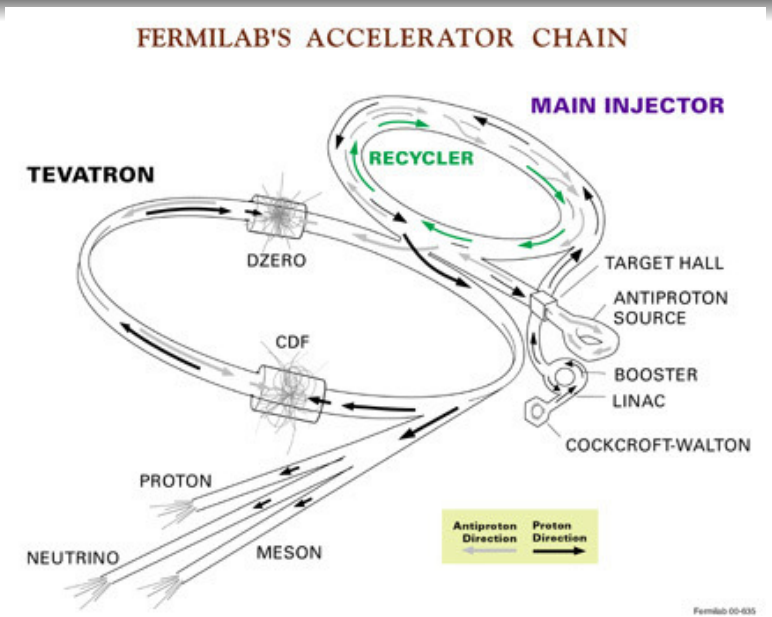
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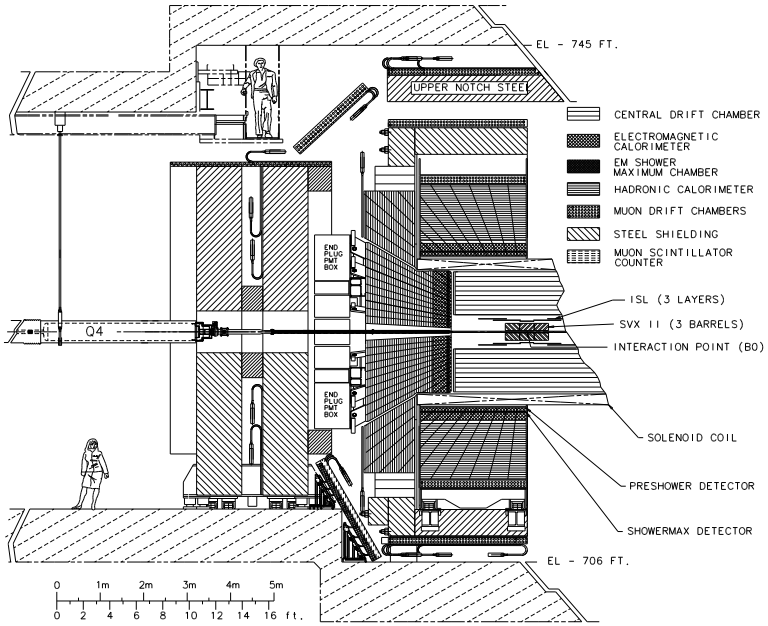
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Backup Slides

Backup slides

Tevatron and CDF





Tevatron

- $p\bar{p}$ collider
- Center-of-mass energy 1.96 TeV
- Run II delivered $12\mathrm{fb}^{-1}$
- Acquired $\sim 10\mathrm{fb}^{-1}$ by CDF

CDF

- General purpose detector
  - 1.4 T magnetic field
  - Tracking, Calorimeter and Muon systems

$t\bar{t} \rightarrow$ dilepton event selection criteria

Baseline Cuts	Exactly two leptons with $E_T > 20$ GeV and passing standard identification requirements with following modifications -COT radius exit > 140 cm for CMIO -$\chi^2/ndf < 2.3$ for muon tracks At least one trigger lepton At least one tight and isolated lepton At most one lepton can be loose and/or non-isolated
	$\not\!\!E_T > 25$ GeV, but $\not\!\!E_T > 50$ GeV when there is any lepton or jet within 20° of the direction of $\not\!\!E_T$
	MetSig $(= \frac{\not\!\!E_T}{\sqrt{E_T^{sum}}}) > 4\ \sqrt{\text{GeV}}$ for ee and $\mu\mu$ events where 76 GeV/c^2 $< m_{ll} <$ 106 GeV/c^2
	$m_{ll} > 10$ GeV/c^2
Signal Cuts	Two or more jets with $E_T > 15$ GeV within $\lvert\eta\rvert < 2.5$
	$H_T > 200$ GeV
	Opposite sign of two leptons
Reco Quality	Jet-deviation in top reconstruction < 3.5
	$m^2_{lb} > 24000(\text{GeV}^2)$
	$\Delta R_{min}(\text{lepton}, \text{jet}) > 0.2$

$t\bar{t} \to$ dilepton
Signal and background modeling

- Signal modeling:
  - Prediction with POWHEG MC (NLO SM w/ only QCD correction)
- Background modeling:
  - Diboson production ($WW, WZ, ZZ, W\gamma$)
    MC prediction
  - Z/γ^*+jets
    MC prediction with correction from data
  - W+jets
    Data-based
  - $t\bar{t}$ non-dilepton
    Prediction with POWHEG MC
- Agreement is excellent

CDF Run II Preliminary ($9.1\ \mathrm{fb}^{-1}$)

Expected and observed events
($t\bar{t} \to l^+l^- + 2\mathrm{jets} + \not\!\!E_T$)

Source	Events
Diboson	26±5
Z/γ^*+jets	37±4
W+jets	28±9
$t\bar{t}$ non-dilepton	5.3±0.3
Total background	96±18
Signal $t\bar{t}$ ($\sigma = 7.4$ pb)	386±18
Total SM expectation	482±36
Observed	495

$t\bar{t}$ Likelihood

$$\mathcal{L}(\vec{p}_\nu, \vec{p}_{\bar{\nu}}, E_b, E_{\bar{b}}) = P(p_z^{t\bar{t}})P(p_T^{t\bar{t}})P(M^{t\bar{t}})\times$$
$$\frac{1}{\sigma_{\text{jet1}}}\exp\left(-\frac{1}{2}\left(\frac{E_{\text{jet1}}^{\text{measure}} - E_{\text{jet1}}^{\text{fit}}}{\sigma_{\text{jet1}}}\right)\right) \times \frac{1}{\sigma_{\text{jet2}}}\exp\left(-\frac{1}{2}\left(\frac{E_{\text{jet2}}^{\text{measure}} - E_{\text{jet2}}^{\text{fit}}}{\sigma_{\text{jet2}}}\right)\right)$$
$$\frac{1}{\sigma_x^{\not{E}_T}}\exp\left(-\frac{1}{2}\left(\frac{\not{E}_x^{\text{measure}} - \not{E}_x^{\text{fit}}}{\sigma_x^{\not{E}_T}}\right)\right) \times \frac{1}{\sigma_y^{\not{E}_T}}\exp\left(-\frac{1}{2}\left(\frac{\not{E}_y^{\text{measure}} - \not{E}_y^{\text{fit}}}{\sigma_y^{\not{E}_T}}\right)\right)$$

Table of uncertainties

CDF Run II Preliminary ($9.1\ \mathrm{fb}^{-1}$)

($t\bar{t} \to l^+l^- + 2\mathrm{jets} + \not\!\!E_T$)

Source of uncertainty	Value
$A_{\mathrm{FB}}^{t\bar{t}}$	
Statistical	0.11
Background	0.04
Parton Showering	0.03
Color reconnection	0.03
I/FSR	0.03
JES	0.02
Unfolding	0.02
PDF	0.01
Total systematic	0.07
Total uncertainty	0.13