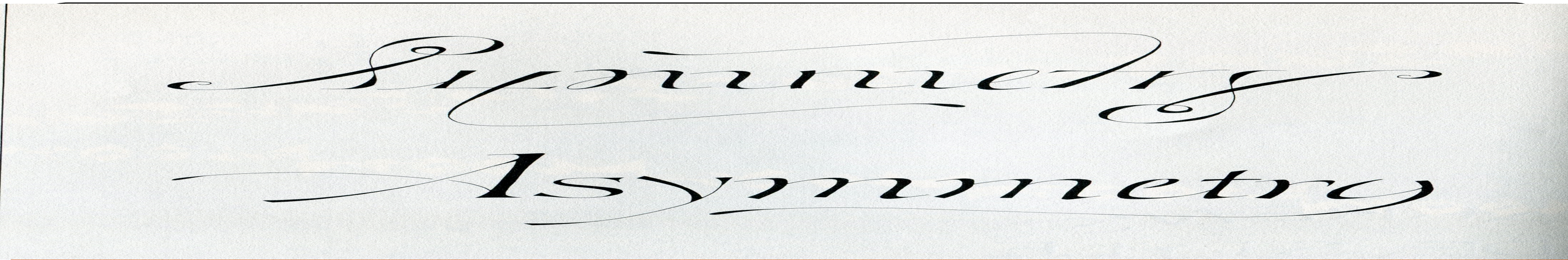


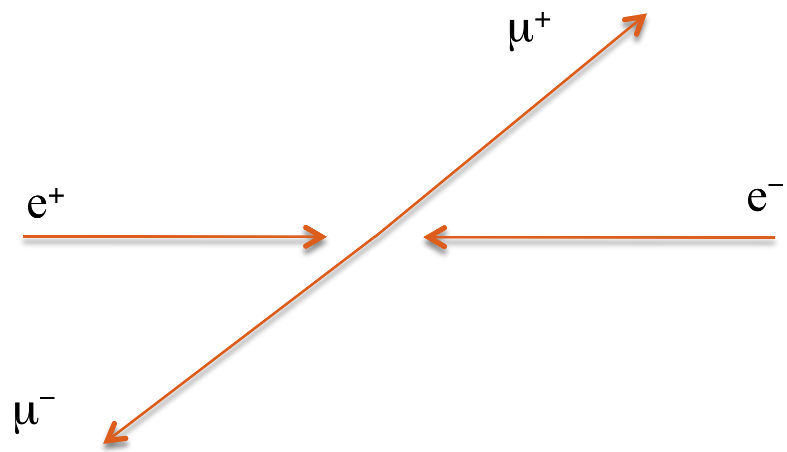
Asymmetries in top-antitop production

Regina Demina, University of Rochester

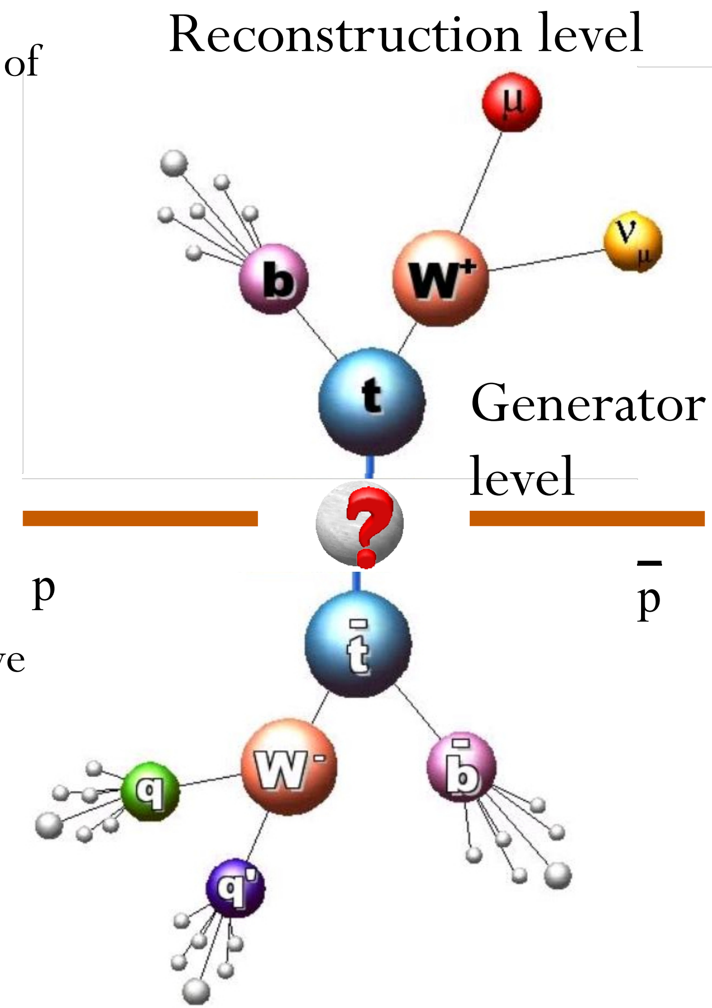
07/19/2013

Asymmetry in top-antitop production

- In early 80s asymmetry observed in $e^+e^- \rightarrow \mu^+\mu^-$ at sqrt(s)=34.6 GeV<< M_Z was used to verify the validity of EW theory (Phys. Rev. Lett. 48, 1701–1704 (1982))



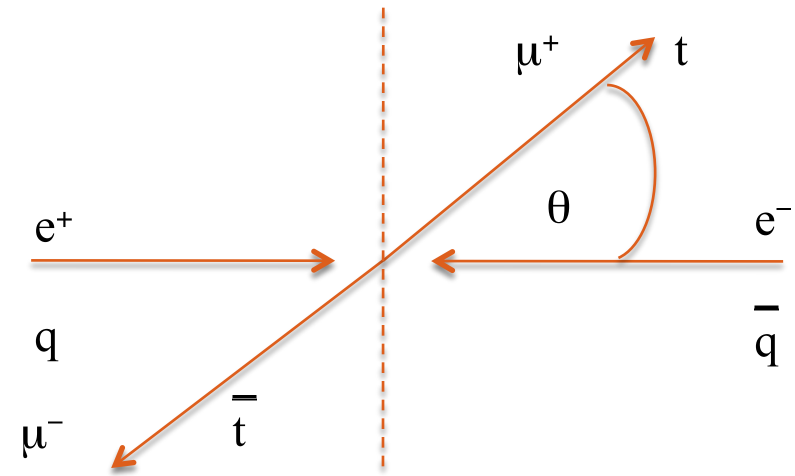
- Similarly, asymmetry in $p\bar{p} \rightarrow t\bar{t}$ production could give information about new physics
  - Mediator with axial coupling in s-channel
  - Abnormally enhanced t-channel production
- Complications:
  - Top is not observed directly, but reconstructed through its decay products
  - Proton and antiproton are not point-like objects, lab frame is different from rest frame



Definitions

- Asymmetry defined for ee→μμ

$$A = \frac{N(\cos\theta > 0) - N(\cos\theta < 0)}{N(\cos\theta > 0) + N(\cos\theta < 0)}$$



- In proton-antiproton collisions cosθ→y
- Δy is invariant to boosts along z-axis

$$\Delta y = y_t - y_{\bar{t}} = q_l(y_{leptonic} - y_{hadronic})$$

- **Asymmetry based on Δy** is the same in lab and tt rest frame

$$A = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

- **Asymmetry based on rapidity of lepton** from top decay
  - Lepton angles are measured with a good precision

$$A_l = \frac{N(q_l y_l > 0) - N(q_l y_l < 0)}{N(q_l y_l > 0) + N(q_l y_l < 0)}$$

A bit of history

- SM prediction: <4% (2006) → >8% (now)

D0*: 12±8(stat)±1(sys)% 0.9 fb^{-1} PRL100(2008)142002, 206 cit's

CDF:24±13(stat)±4(sys)% 1.9 fb^{-1} PRL101(2008)202001, 202 cit's

CDF:15.8±7.2(stat)±1.7(sys)% 5.3 fb^{-1} PRD83(2011)112003,351cit's

D0: 19.5±6.0(stat)$\pm^{1.8}_{2.6}$(sys)% 5.4 fb^{-1} PRD84(2011)112005, 224 cit's

Tevatron stopped taking data in Sep 2011

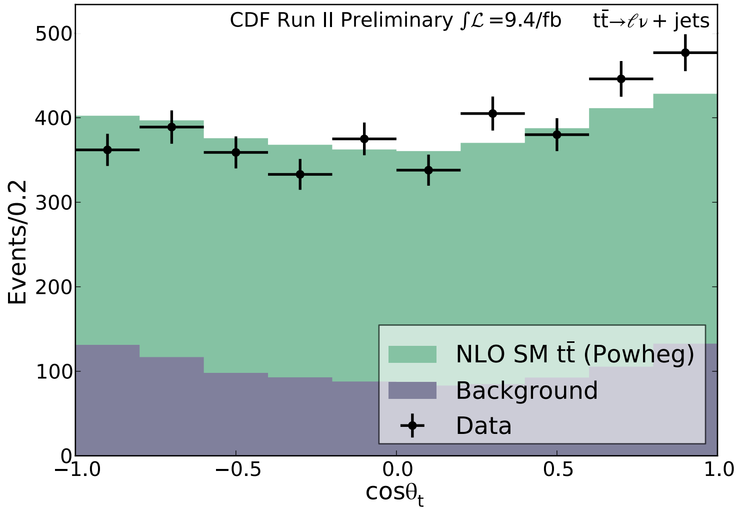
CDF:16.4±3.9(stat)±2.6(sys)% 9.4 fb^{-1} PRD87(2013)092002, 26 cit's

Latest trend – to increase the statistical strength by bringing additional information

- Use full angular distribution – Legendre polynomial expansion (CDF)
- Use leptonic asymmetries and their momentum dependencies (D0)

*reconstruction- level asymmetry only

CDF: Legendre Polynomials

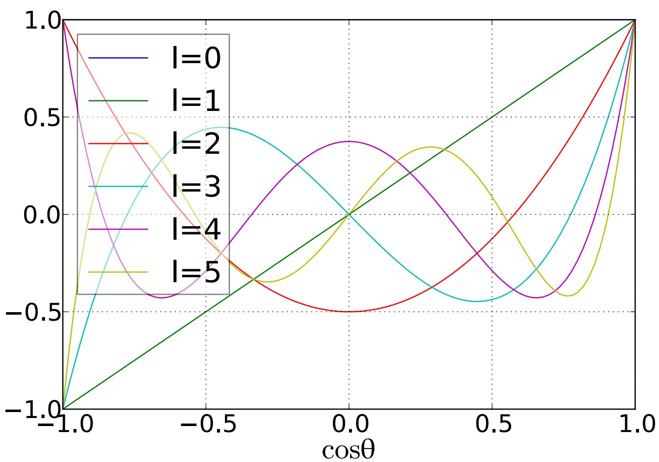


$\cos\theta$ of top quark wrt the beam axis in $t\bar{t}$ rest frame

Asymmetry summarizes the angular distribution in one number.

Use expansion in Legendre polynomials:

$$\frac{d\sigma(t\bar{t})}{d\cos\theta} = \sum a_l P_l(\cos\theta)$$



Measure moments

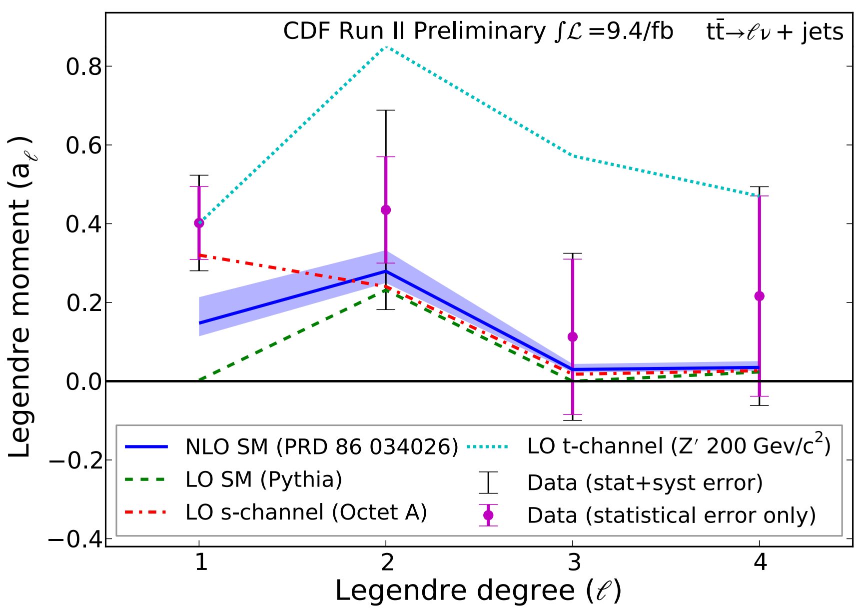
a_0-a_8

ℓ	$P_\ell(x)$
0	1
1	x
2	$\frac{1}{2}(3x^2-1)$
3	$\frac{1}{2}(5x^3-3x)$
4	$\frac{1}{8}(35x^4-30x^2+3)$
5	$\frac{1}{8}(63x^5-70x^3+15x)$

CDF: Legendre Polynomials

A diagram that proceeds with total angular momentum J, interfering with a diagram that proceeds with total angular momentum J', contributes to the Legendre moments with $| |J-J'| \leq \ell \leq J+J'$.

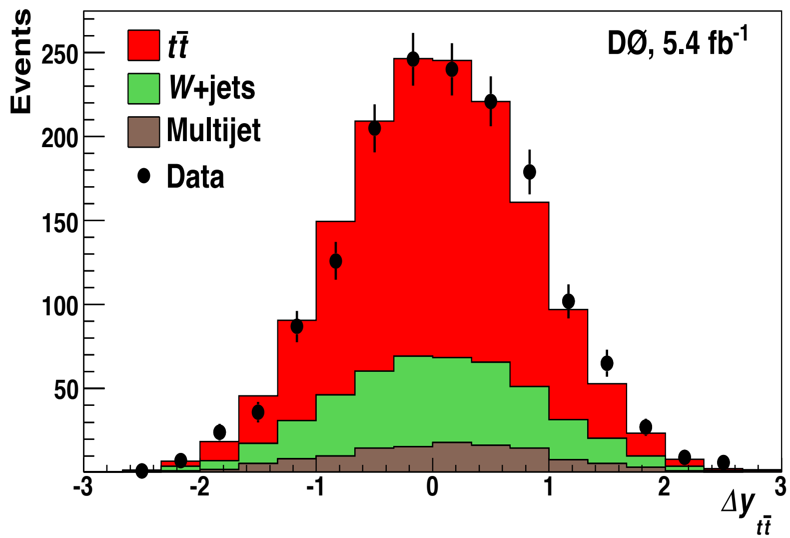
In SM J=1, so $l=0,1,2$, but 1 is not a P eigenstate.

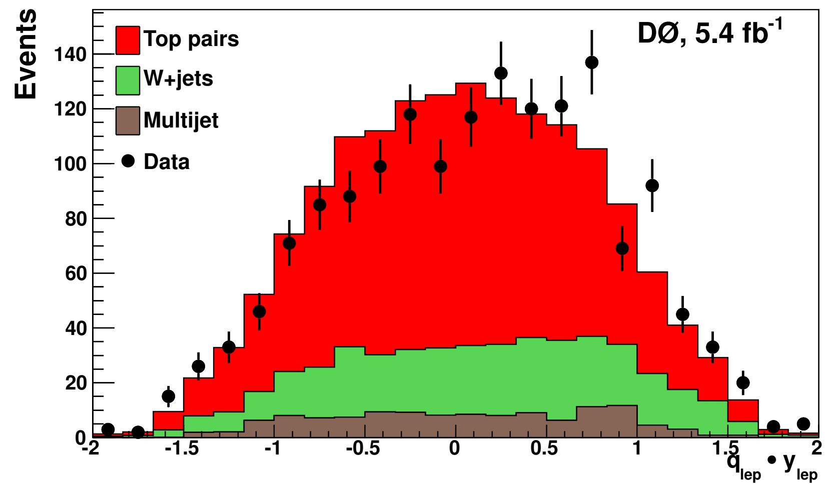


After correcting to parton level all moments are consistent with the SM expectation except 1st, which has 2.1σ deviation from the NLO SM

Such behavior is consistent with an exchange in s-channel of s=1 particle, which is not a parity eigenstate (Z', or axigluon).

Measured Asymmetry – D0 – 5.4fb^{-1}





Fully reconstructed $t\bar{t}$ asymmetry

$$A_{gen} = (19.6 \pm 6.0^{+1.8}_{-2.6})\%$$

$$A(MC@NLO) = 4.4\%$$

Asymmetry of leptons from top decay

$$A_l = 15.2 \pm 3.8^{+1.0}_{-1.3}\%$$

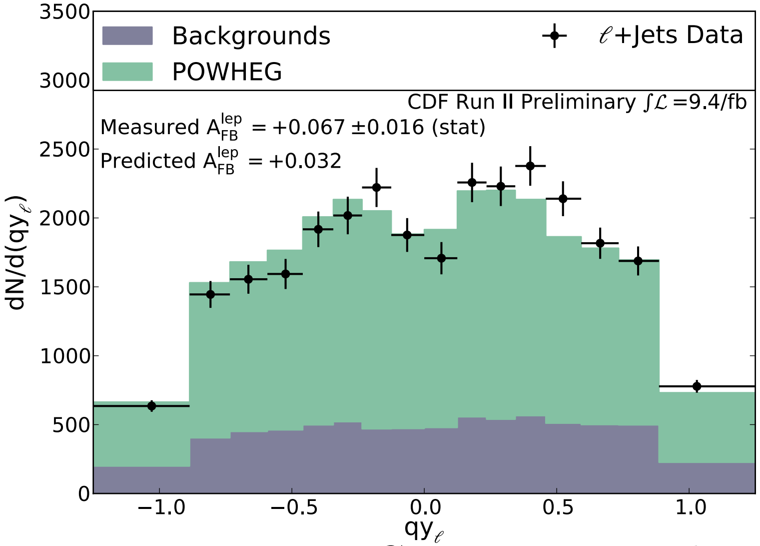
$$A_l(MC@NLO) = 2.1 \pm 0.1\%$$

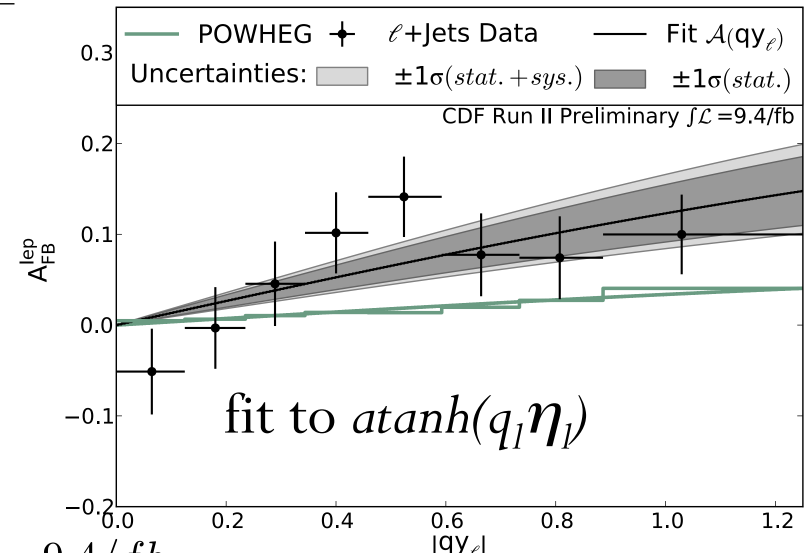
Asymmetry based on leptons from top decay originally was intended to be a simple cross check of the fully reconstructed asymmetry.

CDF – l+jets, 9.4 fb^{-1}

CDF Run II Preliminary $\int \mathcal{L} = 9.4/fb$

Model	$A_{FB}^{\Delta y}$	A_{FB}^{lep}	Polarization	
ALPGEN	−0.000 (1)	+0.003 (1)	+0.009 (2)	LO Standard Model
POWHEG	+0.052 (0)	+0.024 (0)	+0.001 (1)	NLO Standard Model
Octet A	+0.156 (1)	+0.070 (2)	−0.005 (3)	LO unpolarized axigluon
Octet L	+0.121 (1)	−0.062 (1)	−0.290 (3)	LO left-handed axigluon
Octet R	+0.114 (2)	+0.149 (2)	+0.280 (3)	LO right-handed axigluon



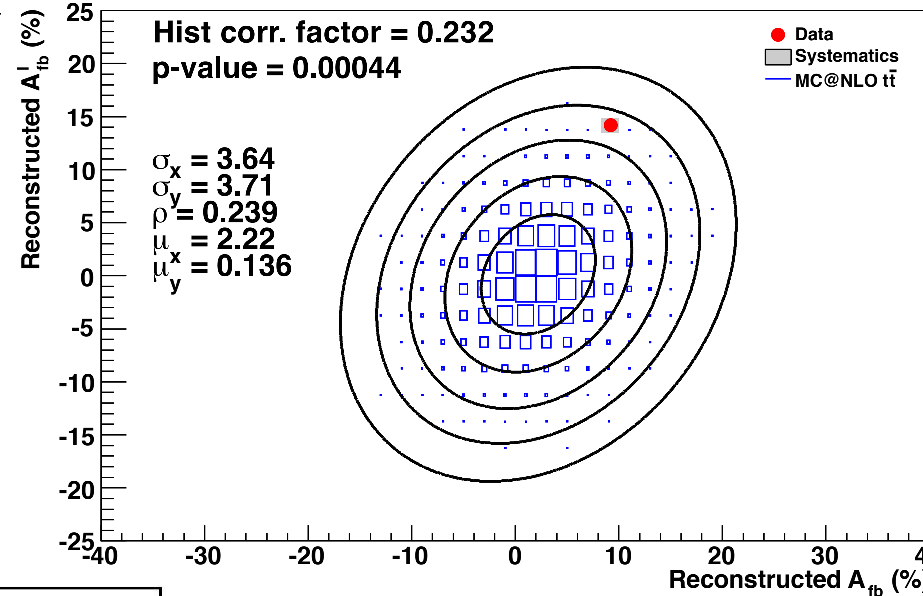


CDF Run II Preliminary $\int \mathcal{L} = 9.4/fb$

Correction Level	CDF Data	POWHEG
Data Only	0.067±0.016	0.032
Backgrounds Subtracted	0.070±0.019 ± 0.011	0.023
Fully Extrapolated	$0.094\pm0.024^{+0.022}_{-0.017}$	0.027

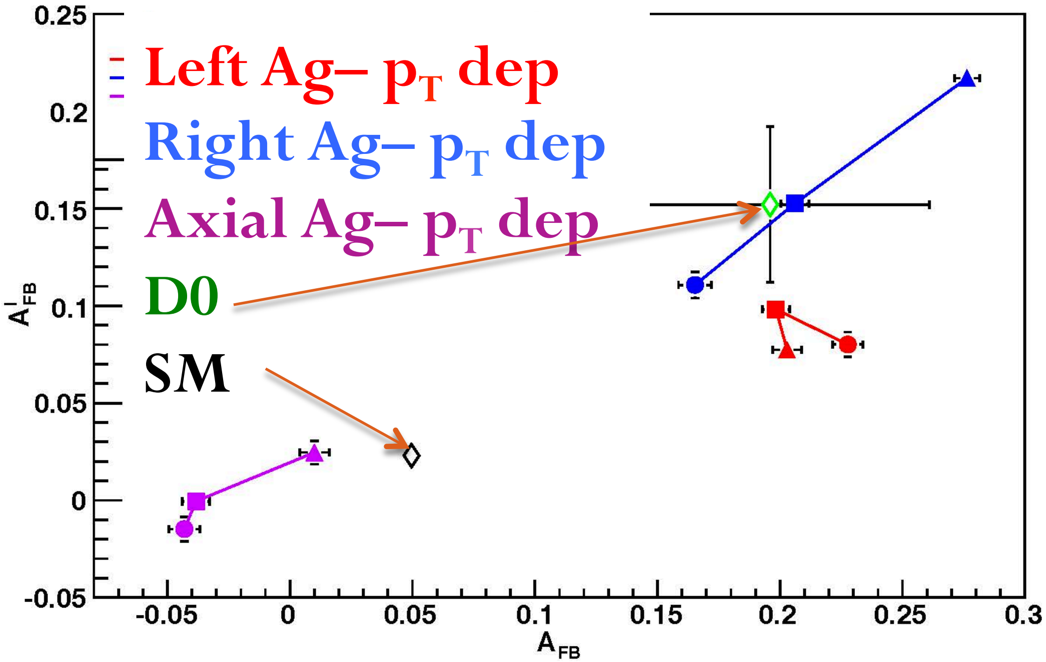
Extrapolate to full rapidity range assuming SM distribution

A_{FB}^{lep} vs A_{FB}



Lepton polarization is predicted in some BSM models.

Axigluons M=500 GeV, G=100 GeV



A_{FB} and A_{FB}^{lep} each provide additional information and help to distinguish between models. Dependence on lepton momentum is yet another handle.

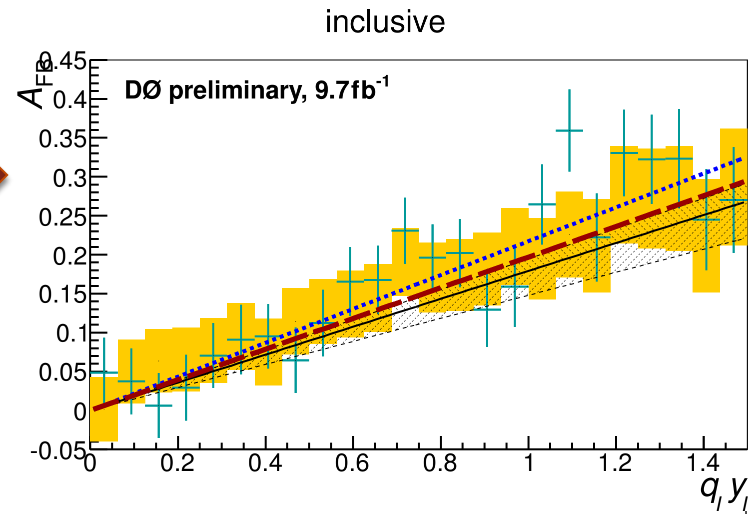
Based on ideas from

A. Falkowski, M. L. Mangano, A. Martin, G. Perez, and J. Winter, arXiv:1212.4003 [hep-ph]

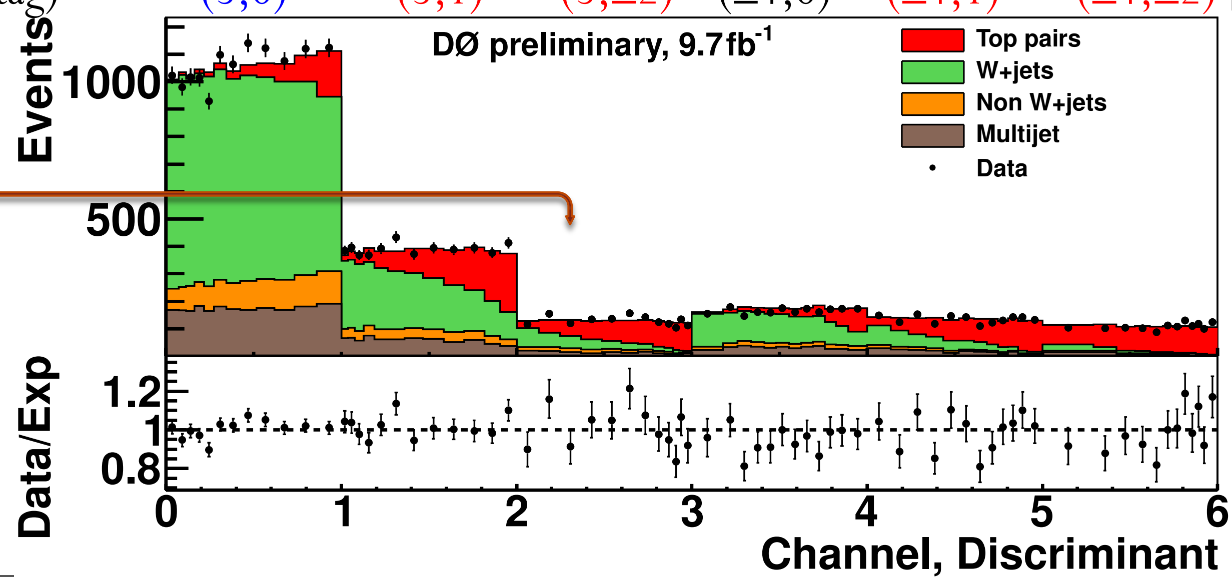
D0: lepton+jets system, 9.7 fb^{-1}

Issues in lepton asymmetry measurement

- Asymmetric background: W+jets
  - Calibrate on data using 3jet, 0tag
  - Red line - nominal set of PDFs CTEQ6L1
  - Yellow – PDF uncertainties
  - Blue points and line – D0 data and result of the fit
  - Black dashed – alternative set of PDFs CTEQ6.1M
  - Carefully propagate PDF systematics (all eigenvectors) to the final result



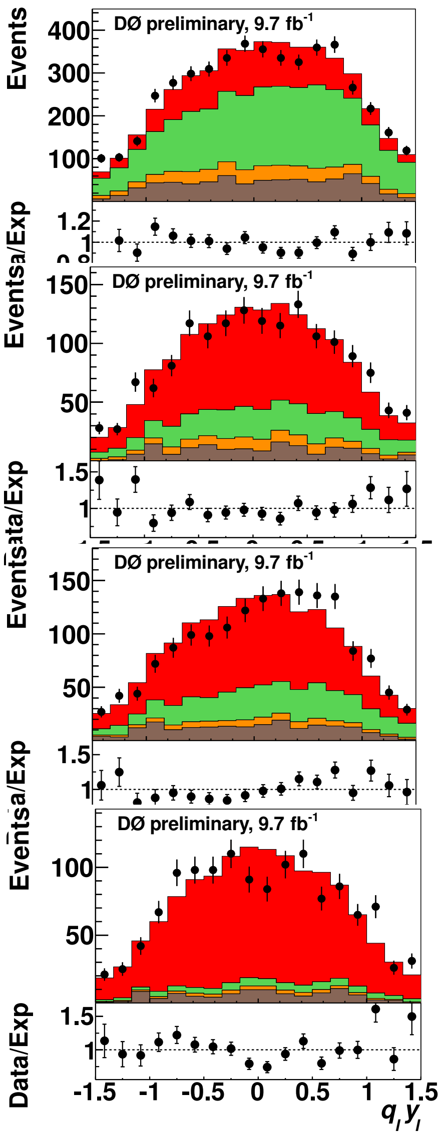
(Njet, Nbtag)= (3,0) (3,1) (3,≥2) (≥4,0) (≥4,1) (≥4,≥2)



- Use l+3 jets ≥1 tag

Subsample in addition to l+≥4jets

D0: A_{FB}^{l} in lepton+jets, 9.7 fb^{-1}

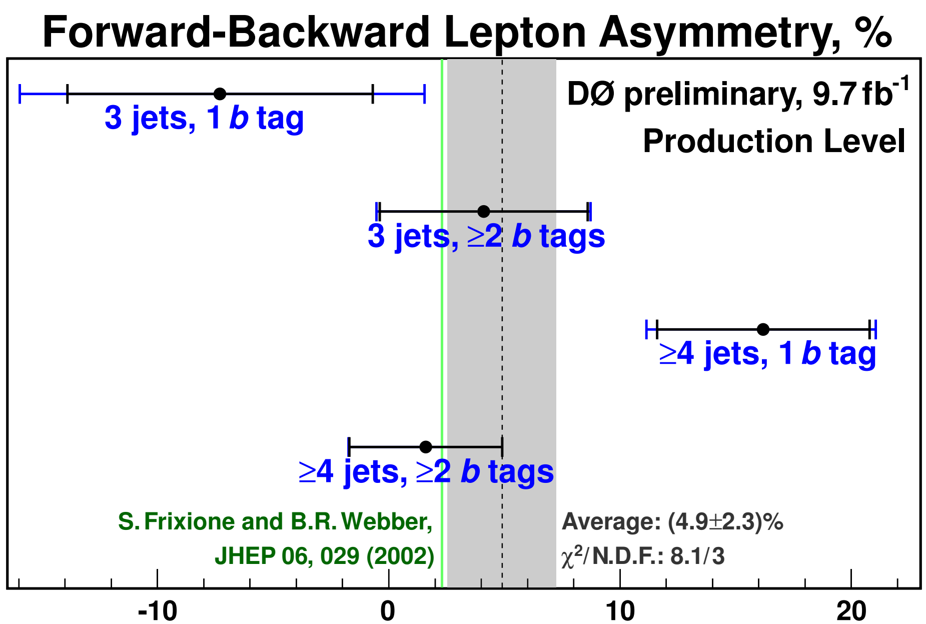


Consistency with the old result (based on 5.4fb^{-1})

$$A_l(5.4\,fb^{-1}) = 15.2 \pm 3.8^{+1.0}_{-1.3}\%$$

$$A_l(9.7\,fb^{-1}) = 4.7 \pm 2.3 \pm^{1.1}_{1.4}\ \%$$

$$A_l(MC@NLO) = 2.3 \pm 0.2\%$$



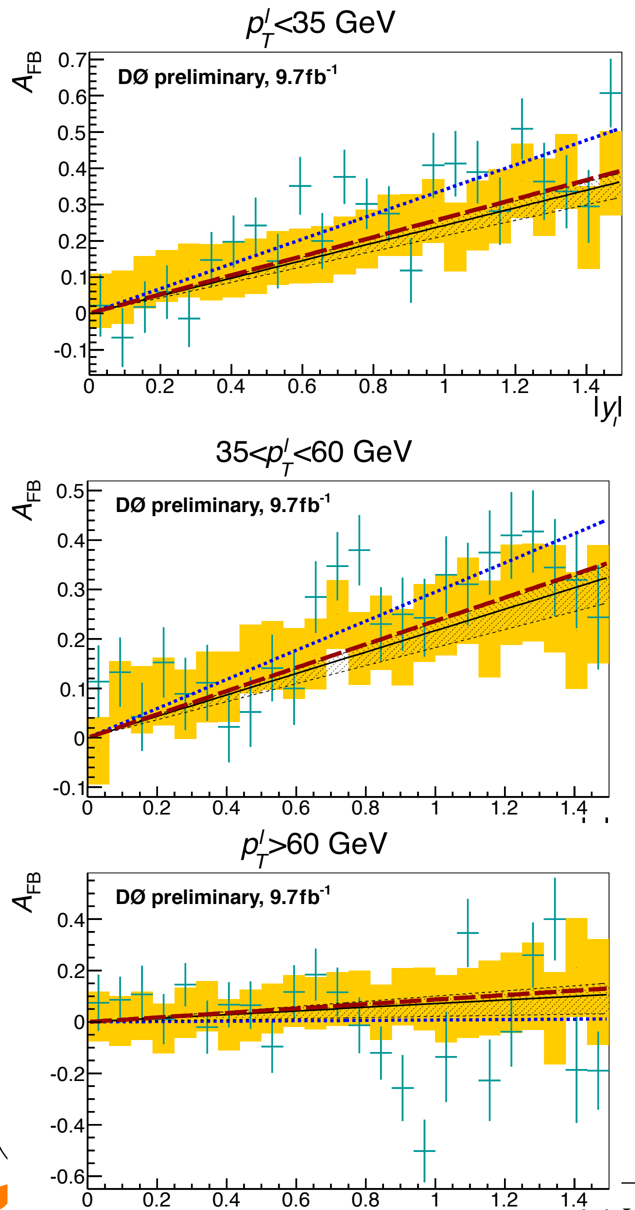
l+3 jets - New channels

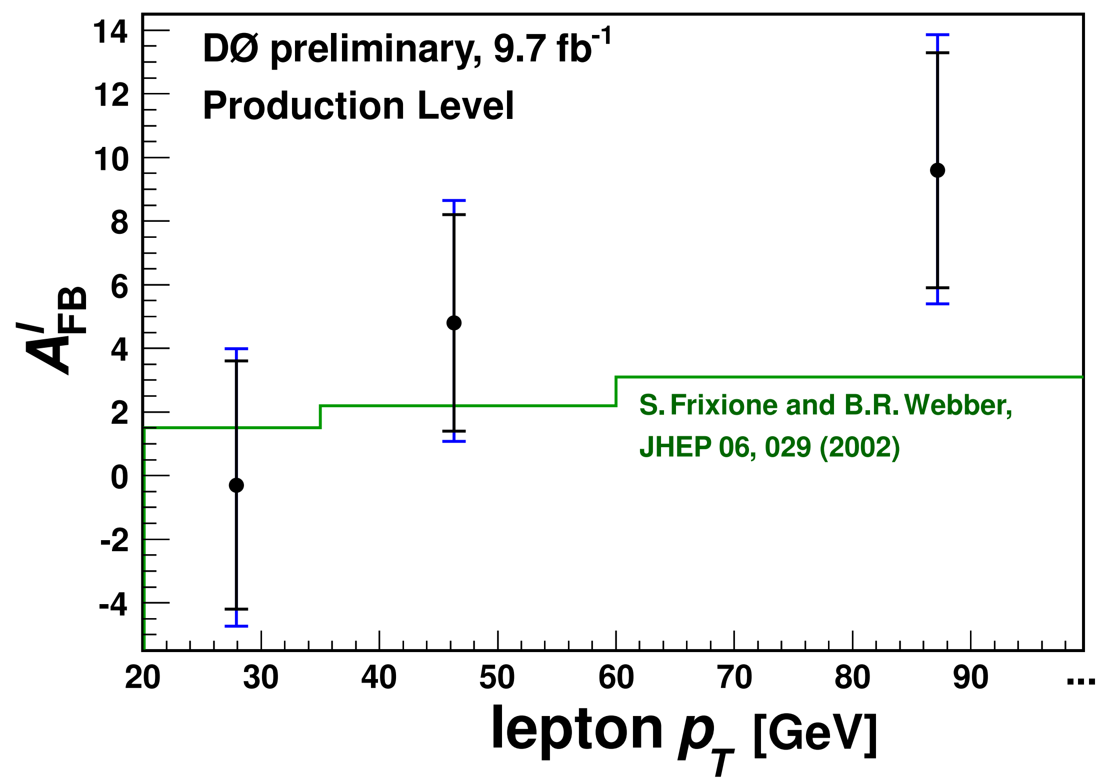
1 tag - Was high in 5.4fb^{-1}

2 tags - Now has higher weight because of higher purity

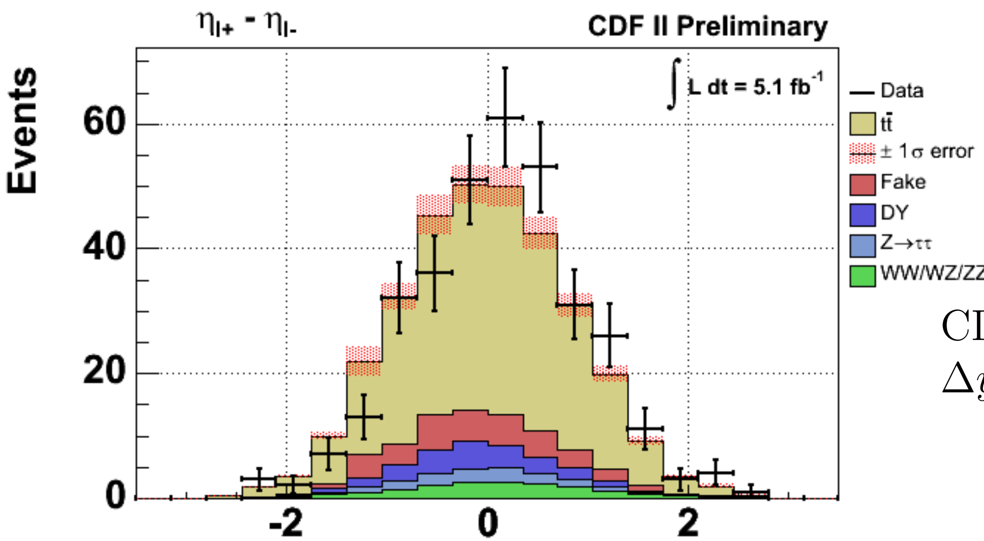
D0: Asymmetry dependence on lepton p_T

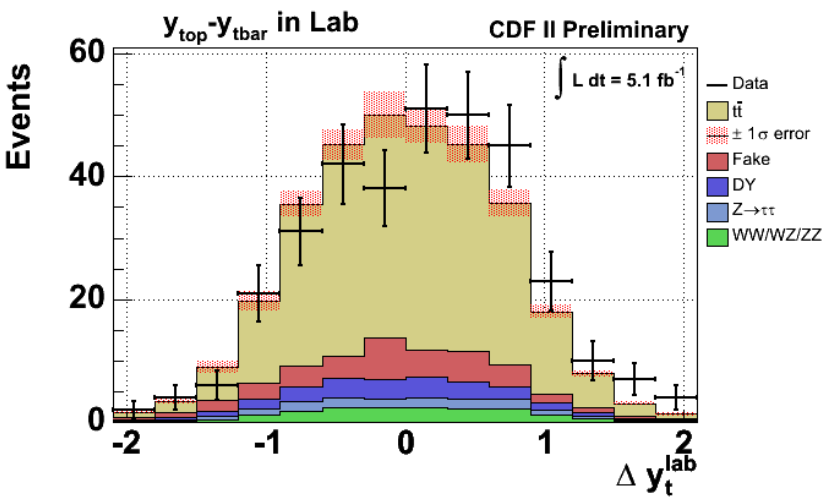
Asymmetry in W+jets background was calibrated on data in 3 lepton p_T bins

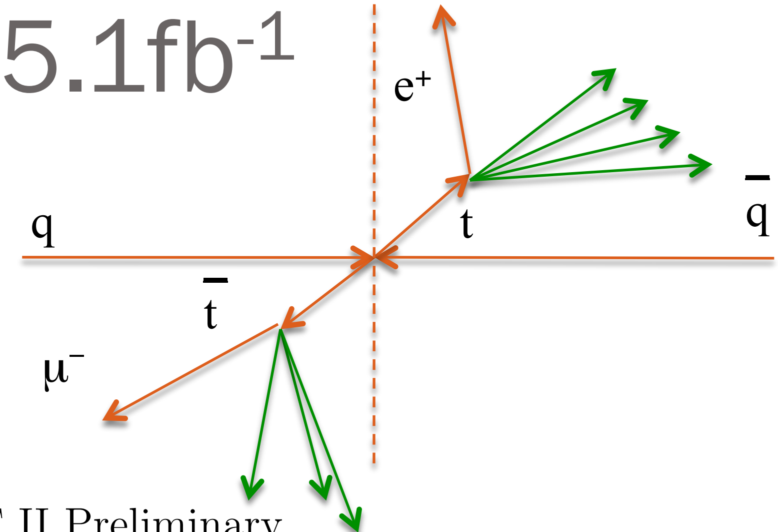




CDF: dilepton system, 5.1fb^{-1}







CDF II Preliminary

Δy_t:

$$A_{\rm obs} = 0.14 \pm 0.05({\rm stat.})$$

$$A_{\rm sub} = 0.21 \pm 0.07({\rm stat.}) \pm 0.02({\rm bkg.\ shape})$$

$$A_{\rm true} = 0.42 \pm 0.15({\rm stat.}) \pm 0.05({\rm syst.})$$

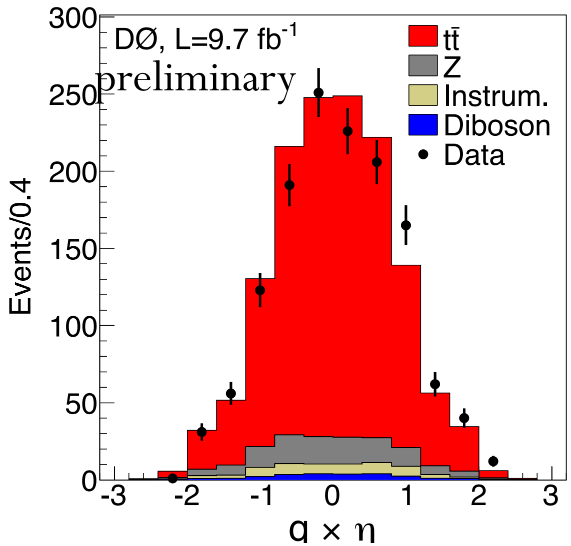
$$= 0.42 \pm 0.16$$

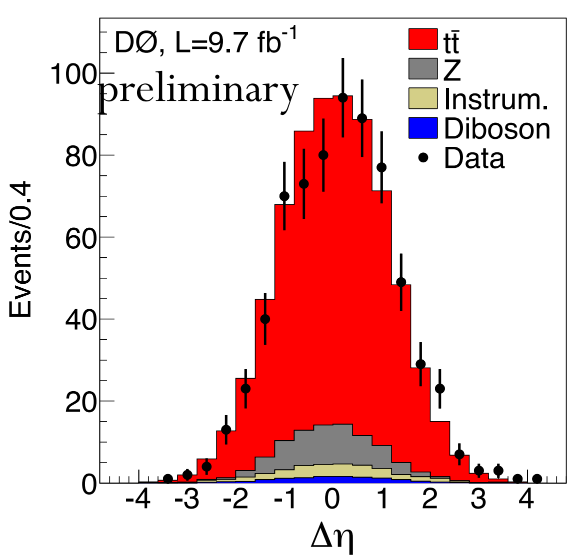
$\Delta \eta_\ell$:

$$A_{\rm obs}^{\Delta\eta_\ell} = 0.14 \pm 0.05({\rm stat.})$$

$$A_{\rm sub}^{\Delta\eta_\ell} = 0.21 \pm 0.07({\rm stat.}) \pm 0.02({\rm bkg.\ shape})$$

D0: dilepton system, 9.7 fb^{-1}





$$A_l = 4.1 \pm 3.5 \pm 1.0\%$$

$$A_l(extrapolated) = 4.4 \pm 3.7 \pm 1.1\%$$

$$A_l(predicted) = 3.8 \pm 0.3\%$$

$$|\eta_{lep}| < 2.0$$

$$|\Delta\eta_{ll}| < 2.4$$

Results extrapolated to full pseudo rapidity range based on MC@NLO acceptance

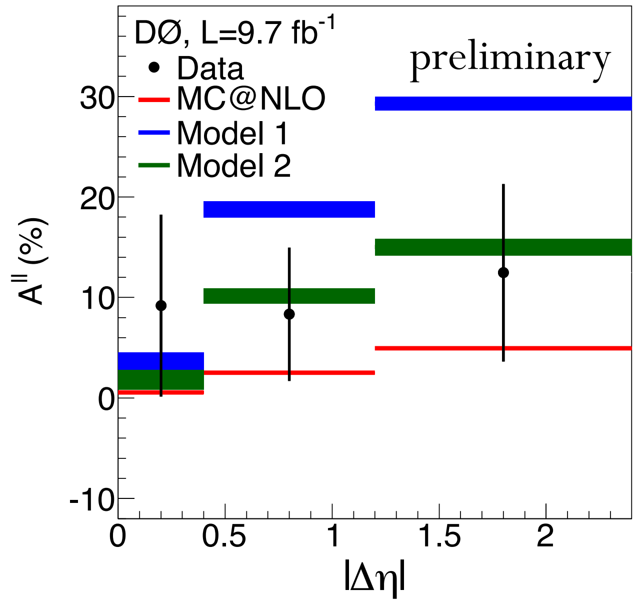
$$A_{ll} = 10.5 \pm 4.7 \pm 1.1\%$$

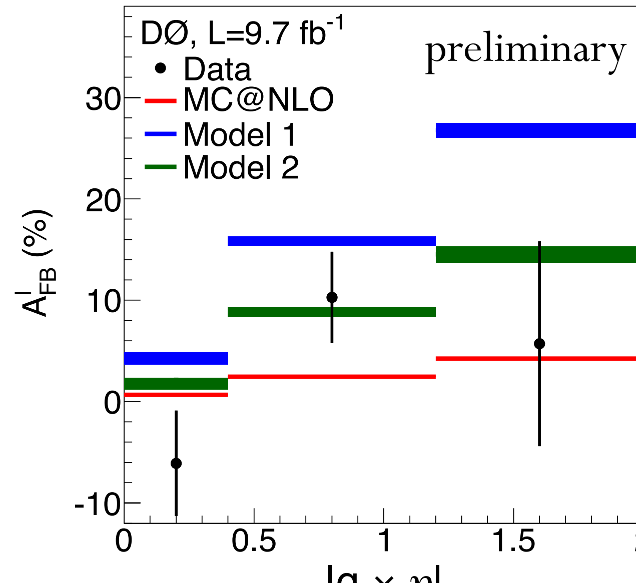
$$A_{ll}(extrapolated) = 12.3 \pm 5.4 \pm 1.5\%$$

$$A_{ll}(predicted) = 4.8 \pm 0.4\%$$

W. Bernreuther and Z.-G. Si, Phys. Rev. D 86, 034026 (2012)

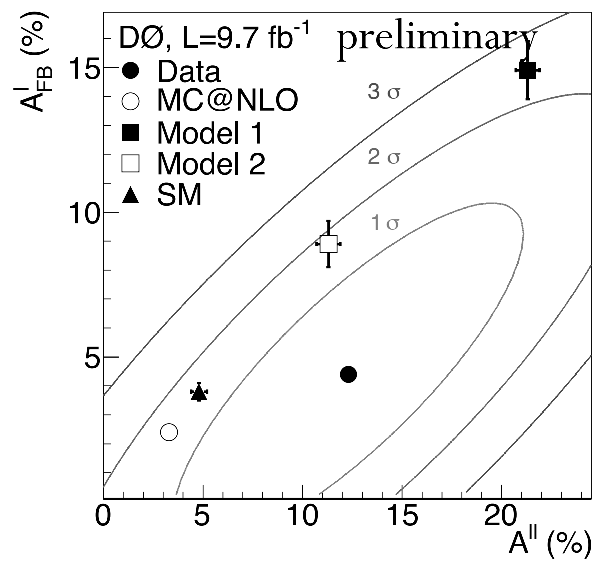
D0: Asymmetries in dilepton system



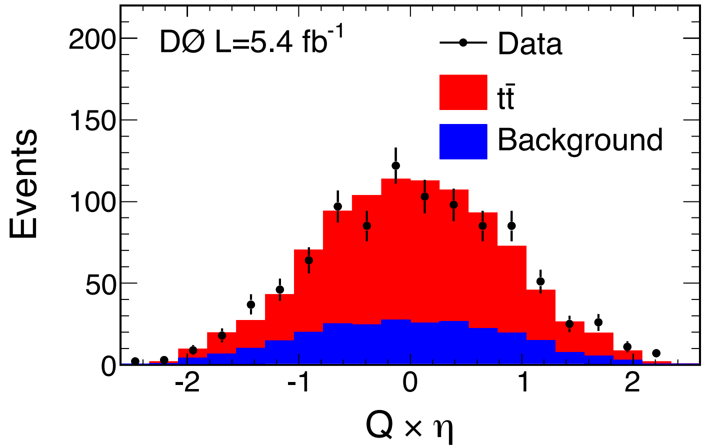


Model 1: Right handed axigluon M=200GeV, G=50 GeV

Model 2: Right handed axigluon M=2000GeV, G=670 GeV

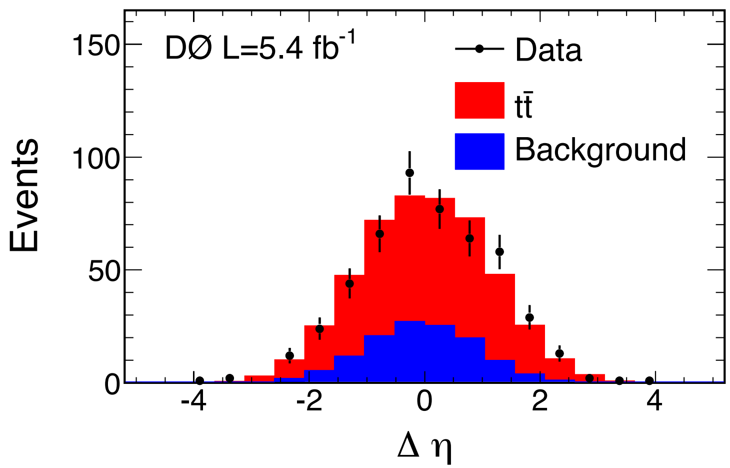


D0: Asymmetries in dilepton system



Asymmetry based on the direction of both leptons (two measurements per event)

$$A_l = 5.8 \pm 5.1 \pm 1.3\%$$



Asymmetry based on Δy between leptons

$$\Delta y = y_{l+} - y_{l-}$$

$$A_{ll} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

$$A_{ll} = 5.3 \pm 7.9 \pm 2.9\%$$

$$A_{ll}(theory) = 6.2 \pm 0.2\%$$

W. Bernreuther and Z.-G. Si, Phys. Rev. D 86, 034026 (2012)

Summary of lepton asymmetries

The results are smaller than originally observed value, consistent with calculations based on SM

$$A_l(CDF, l+jets, 9.4\,fb^{-1}) = 9.4 \pm 2.4 \pm^{2.2}_{1.7}\,\%$$

$$A_l(D0, l+jets, 9.7\,fb^{-1}) = 4.7 \pm 2.3 \pm^{1.1}_{1.4}\,\%$$

$$A_l(D0, dil, 9.7\,fb^{-1}) = 4.1 \pm 3.5 \pm 1.0\%$$

$$A_l(D0, dil, 5.4\,fb^{-1}) = 5.8 \pm 5.1 \pm 1.3\%$$

$$A_l(MC@NLO) = 2.3 \pm 0.2\%$$

$$A_l = 3.6 \pm 0.2\%$$

NLO SM
Bernreuther and Si (PRD 86 034026)