Results from the Tevatron

Outline:

- Top quark: single top
- Quark asymmetries
- Exotics: *W'*
- Electroweak: asymmetries
- Higgs spin-parity
- QCD: pion prod., double parton
- Future

Rick Van Kooten
Indiana University
on behalf of the
CDF & DØ Collaborations

48th FNAL Users Meeting
10 – 11 June 2015
Fermilab

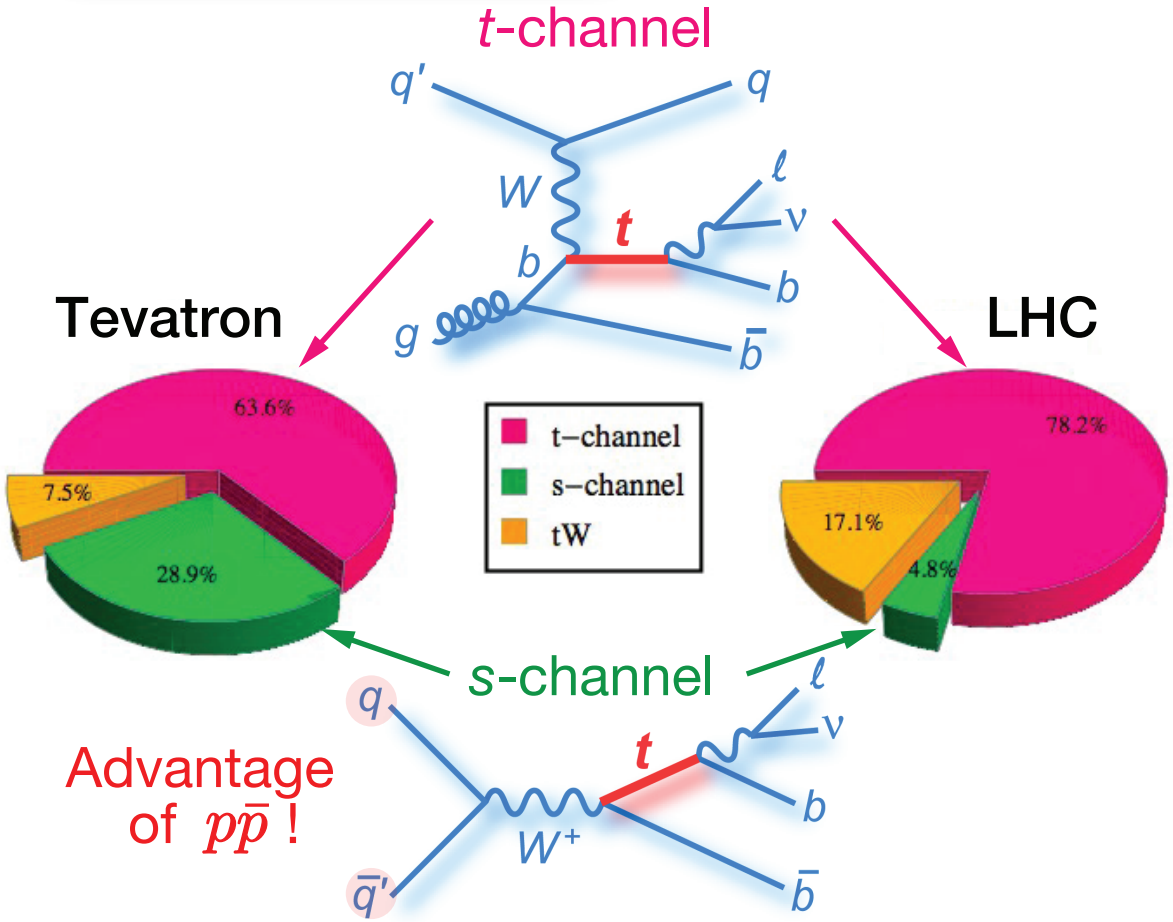
Introduction

- Tevatron: CDF & DØ collected ~10 fb^{-1} each from 2001–2011
- World's highest-energy $p\bar{p}$ collisions at 2 TeV

- Continue unique and legacy physics studies
- Complementary and in some cases remains competitive with LHC

Single Top

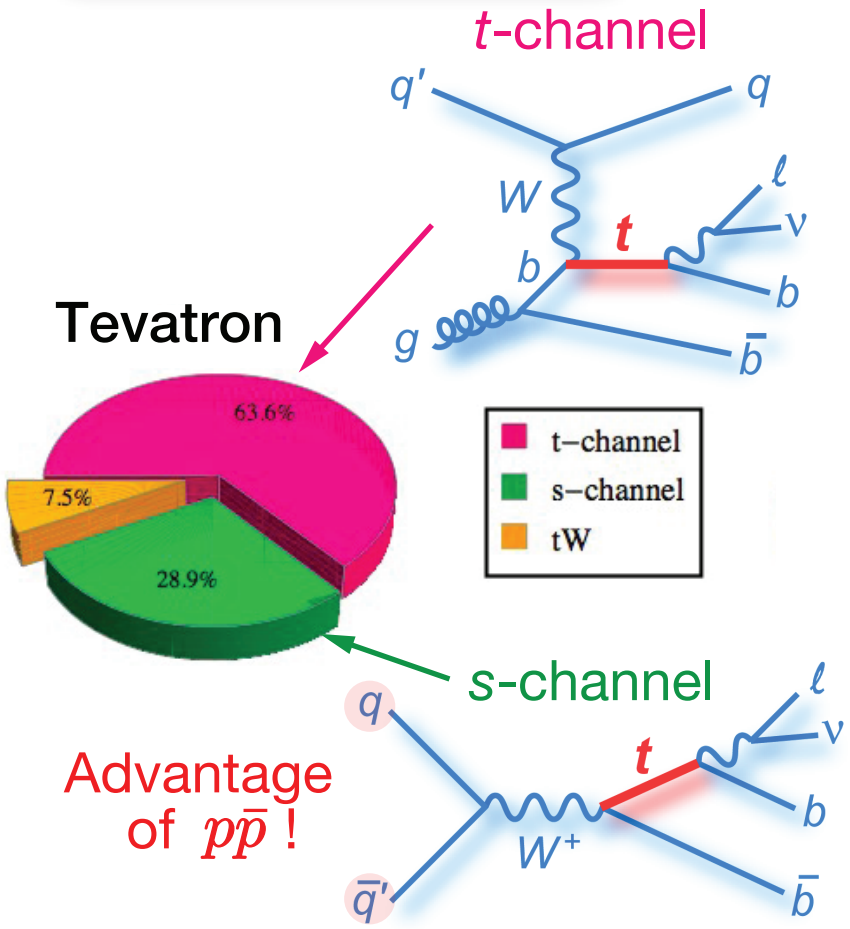
Wrapping up the story at the Tevatron



- s-channel observed at >5σ, Tevatron combination
  PRL **112**, 231803 (2014)

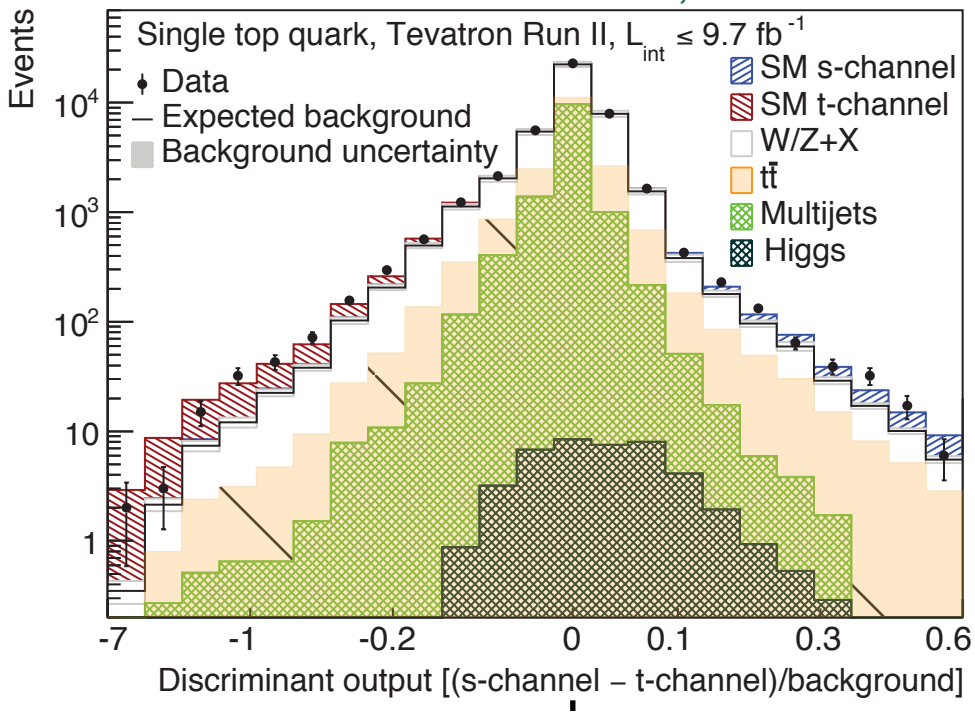
Single Top

Wrapping up the story at the Tevatron



- Now: Tevatron combination of both channels simultaneously; lepton + jets MET + jets
- Large backgrounds, small signal, many MVAs: NN, BNN, BDT, ME.
- Separate the channels:

arXiv:1503.05027, subm. to PRL



- s-channel observed at >5σ, Tevatron combination
  PRL **112**, 231803 (2014)

t-channel signal/backg. | *s*-channel signal/backg.

Single Top

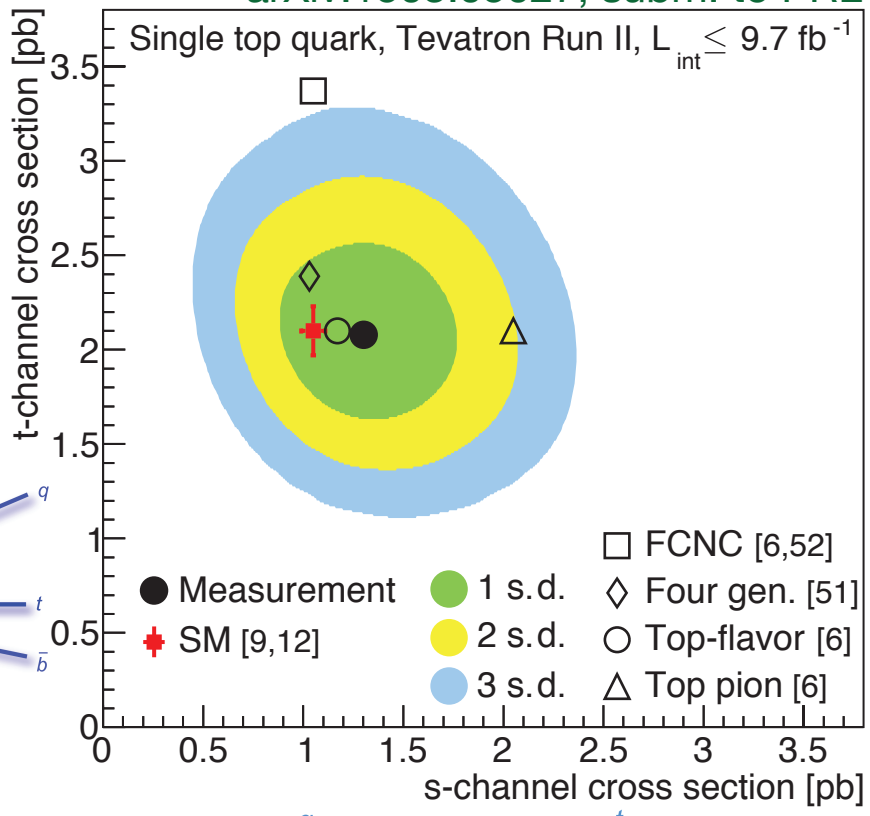
Wrapping up the story at the Tevatron

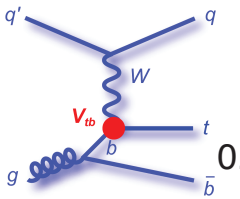
$$\sigma_{s+t} \propto |V_{tb}|^2$$

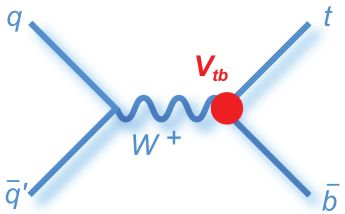
No assumptions of

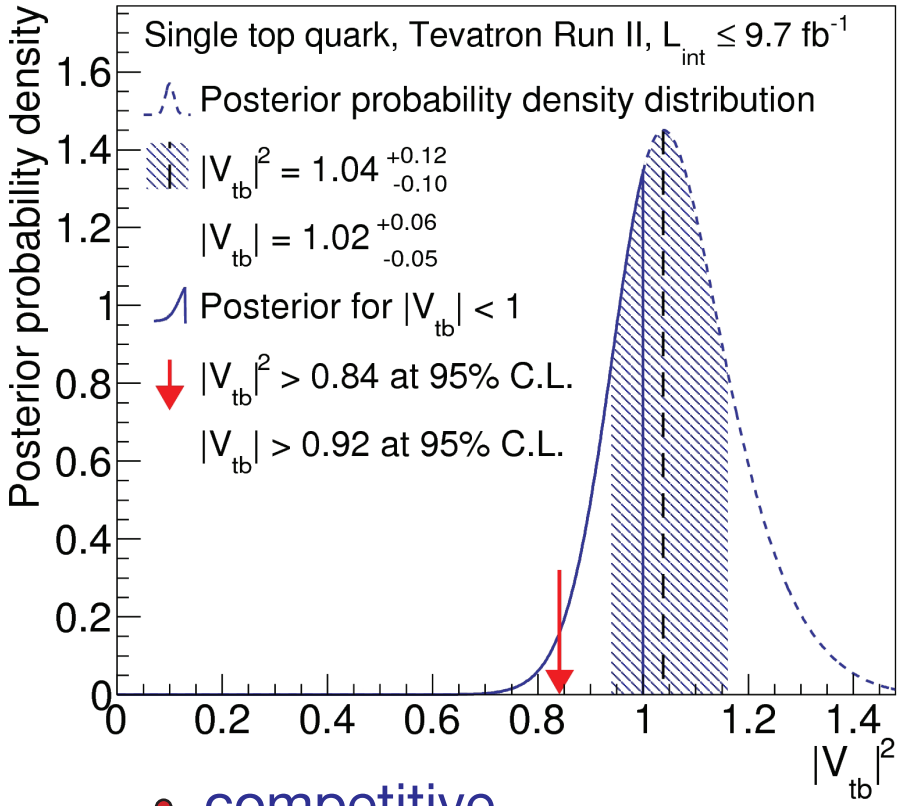
- unitarity of CKM matrix
- number quark families

arXiv:1503.05027, subm. to PRL



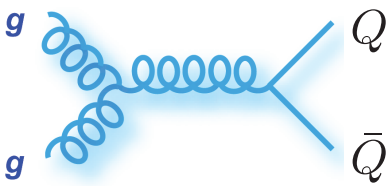




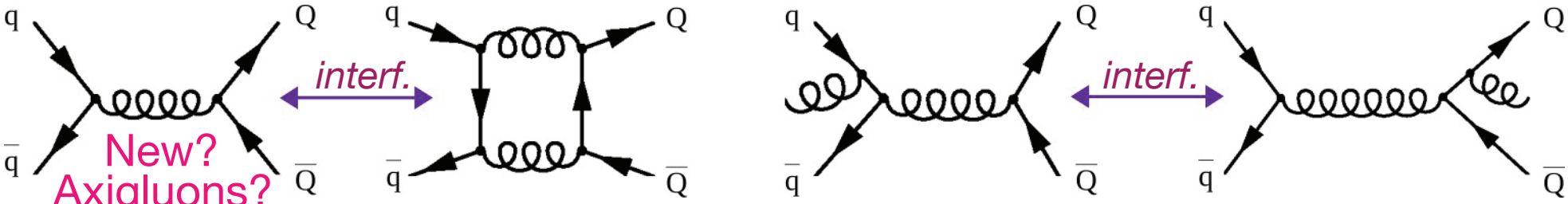


- competitive

Forward-Backward $Q\bar{Q}$ Asymmetries



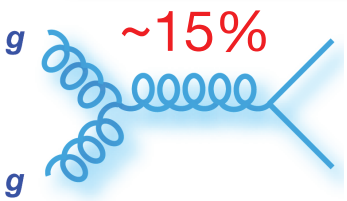
- No forward-backward asymmetry in gg fusion
- Contributions to asymmetry via *interference* between $q\bar{q}$ and qg at NLO



New? Axigluons? Changes A_{FB}

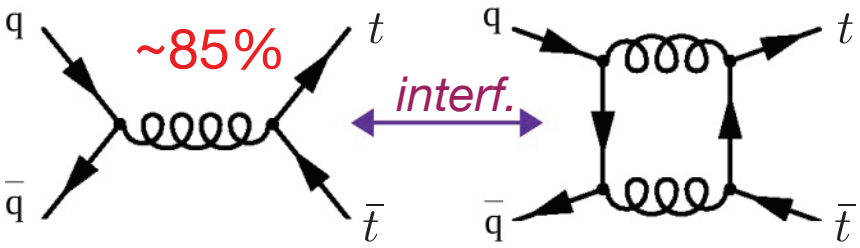
Forward-Backward $t\bar{t}$ Asymmetries

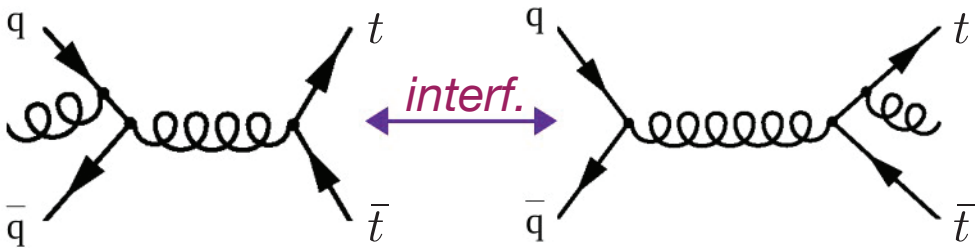
$Q = t$



No A_{FB}

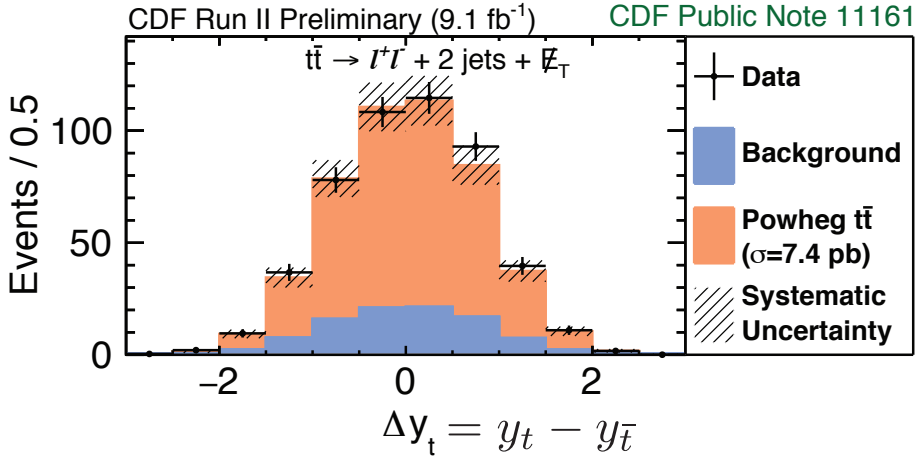
- Forward-backward top quark asymmetry expected to be significant





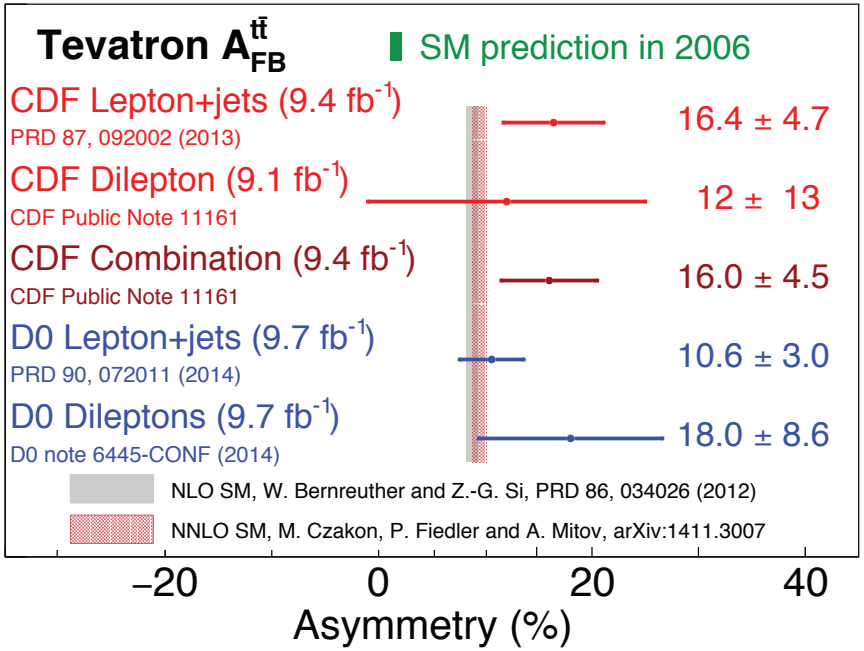
- CDF: both t and $\bar{t}$ decaying leptonically

$$A_{FB}^{t\bar{t}} = \frac{N_{\Delta y_t>0} - N_{\Delta y_t<0}}{N_{\Delta y_t>0} + N_{\Delta y_t<0}}$$



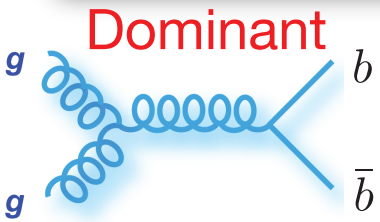
New

- Once both CDF and DØ publish final dilepton results, then final Tevatron comb.



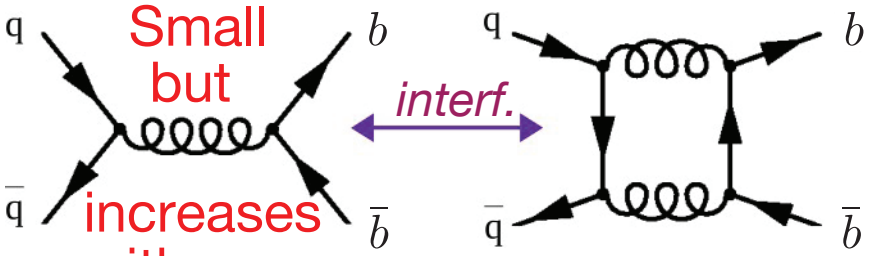
Forward-Backward $b\bar{b}$ Asymmetries

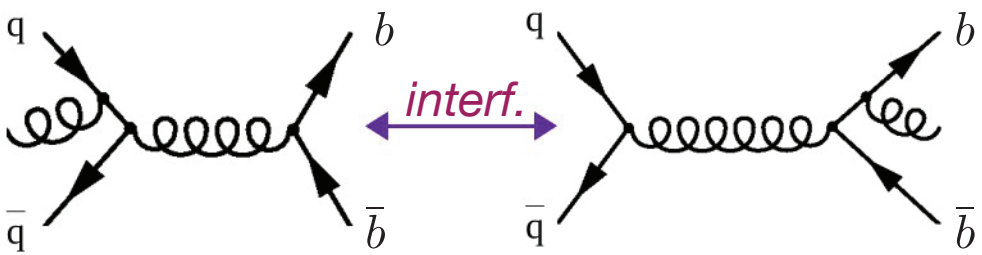
$Q = b$



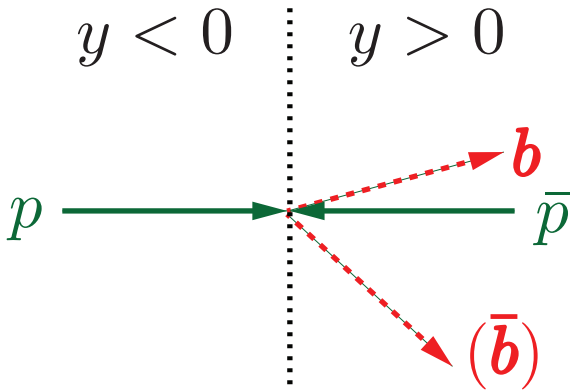
No A_{FB}

- Forward-backward *b* quark asymmetry expected to be small





- Depends upon flavor excitations
- Depends on invariant mass $m_{b\bar{b}}$
- Small contribution from electroweak Drell-Yan $q\bar{q} \to Z/\gamma \to b\bar{b}$



$$A_{FB} = \frac{N_F - N_B}{N_F + N_B}$$

$y = y_b - y_{\bar{b}}$

CDF: tagged $b\bar{b}$ jets at low and high $m_{b\bar{b}}$

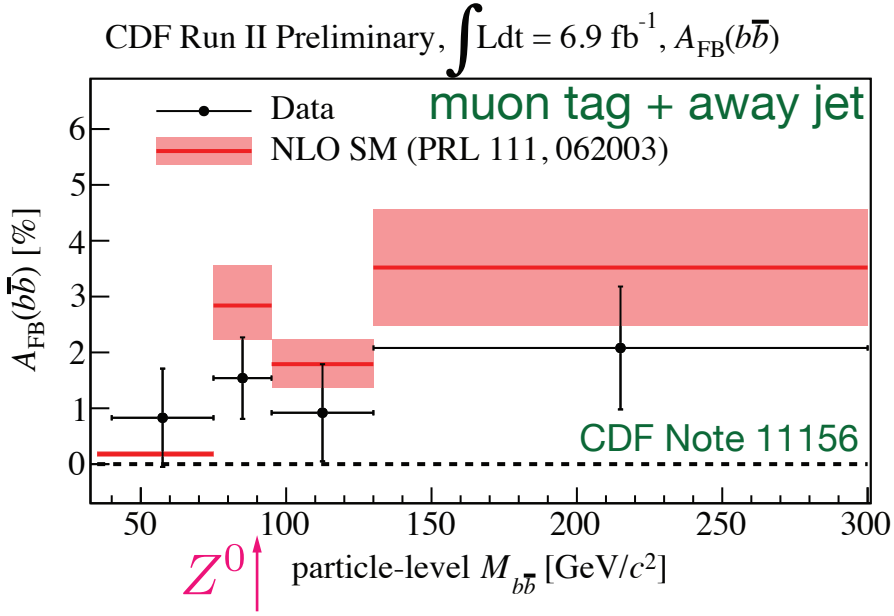
DØ: fully reconstructed B^- $(b\bar{u})$

Λ_b^0 (bud)

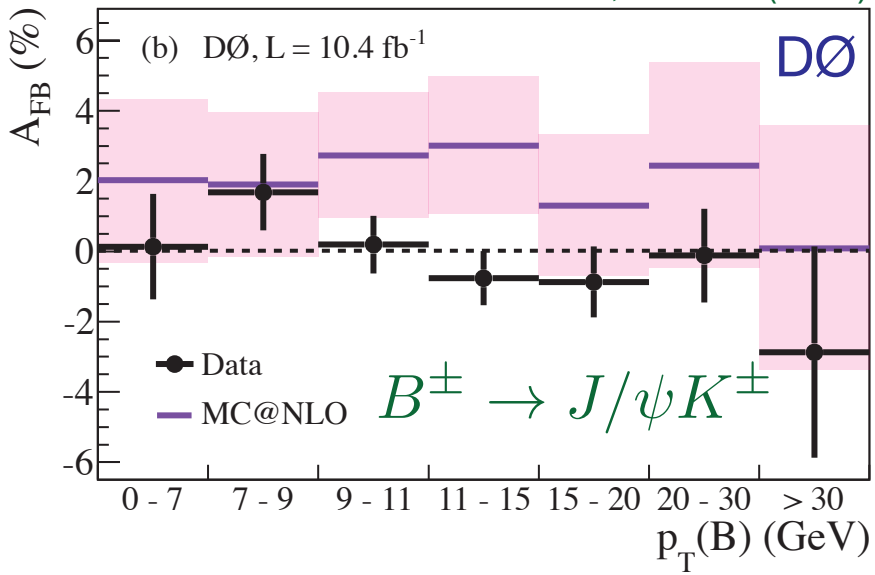
Forward-Backward $b\bar{b}$ Asymmetries

$Q = b$

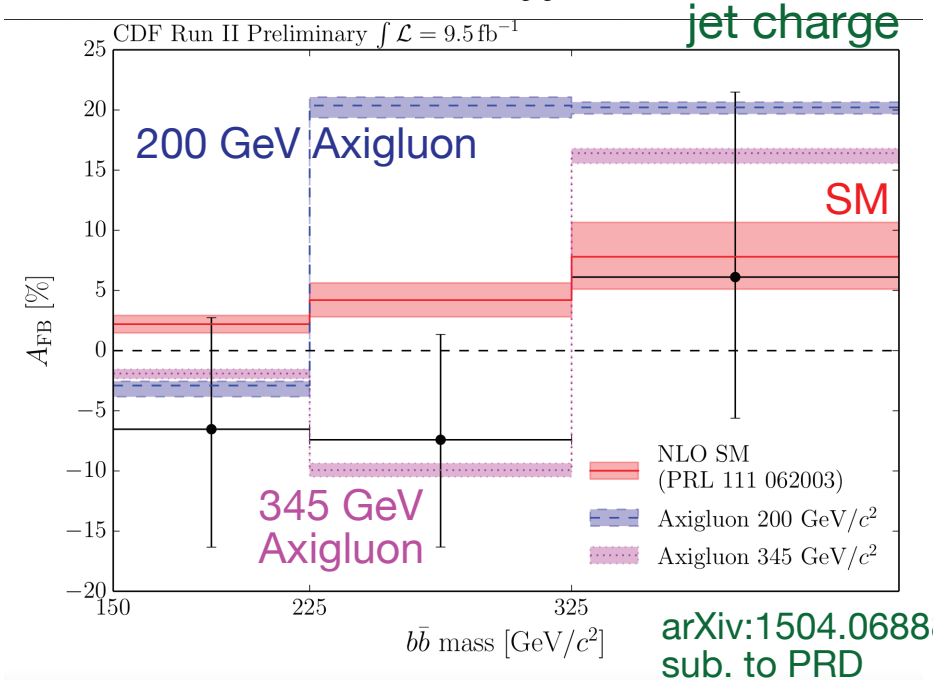
- CDF, low mass $m_{b\bar{b}} > 40$ GeV



PRL **114**, 051803 (2015)



- CDF, high mass $m_{b\bar{b}} > 150$ GeV



arXiv:1504.06888, sub. to PRD

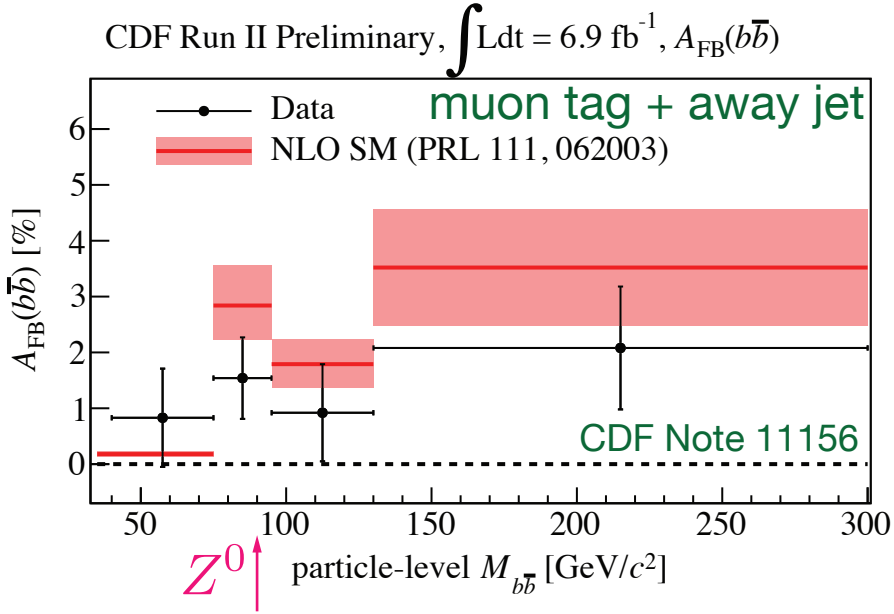
- Consistent with zero & SM
- Exclude wide axigluon *m*~200 GeV

- Data systematically lower than MC@NLO, More rigorous prediction needed to interpret results

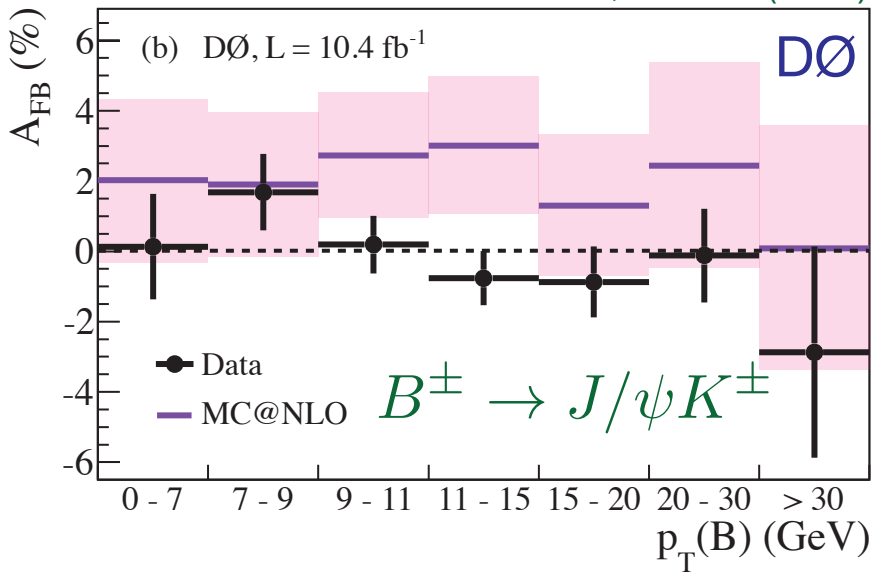
Forward-Backward $b\bar{b}$ Asymmetries

$Q = b$

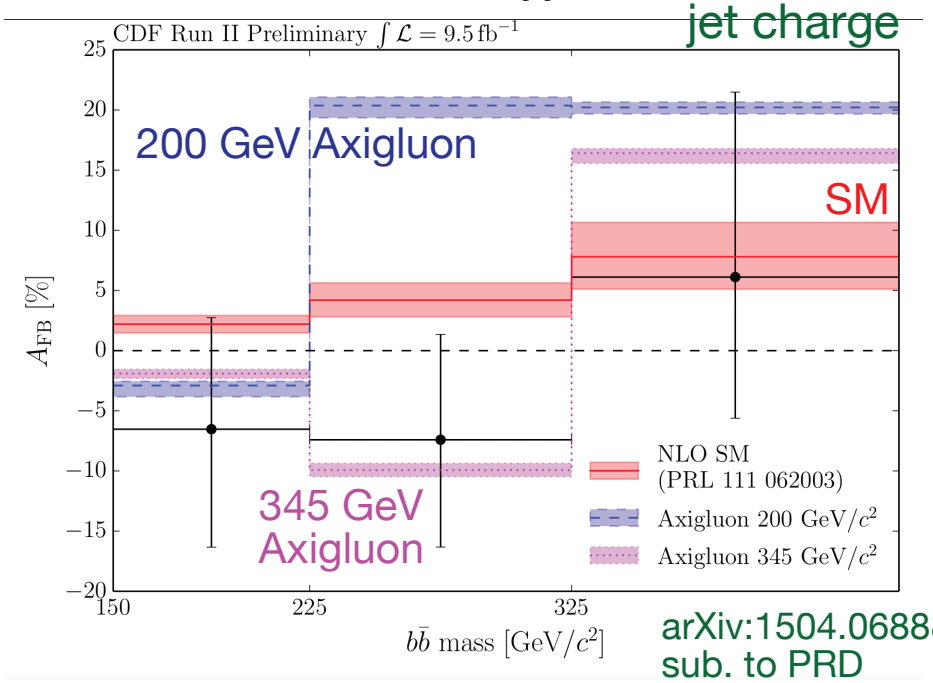
- CDF, low mass $m_{b\bar{b}} > 40$ GeV



PRL **114**, 051803 (2015)



- CDF, high mass $m_{b\bar{b}} > 150$ GeV

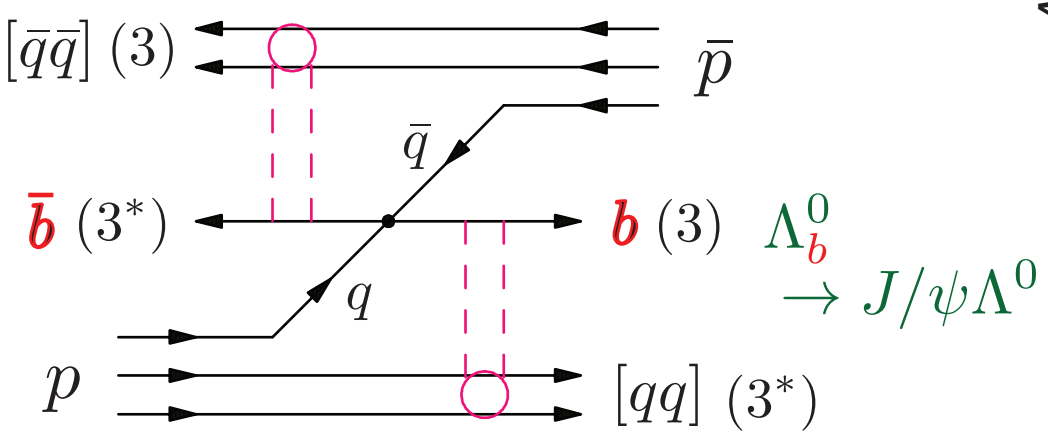


arXiv:1504.06888, sub. to PRD

Less room for new physics causing anomalous A_{FB} (both in *t* and *b*)

Asymmetries for b and s Baryons

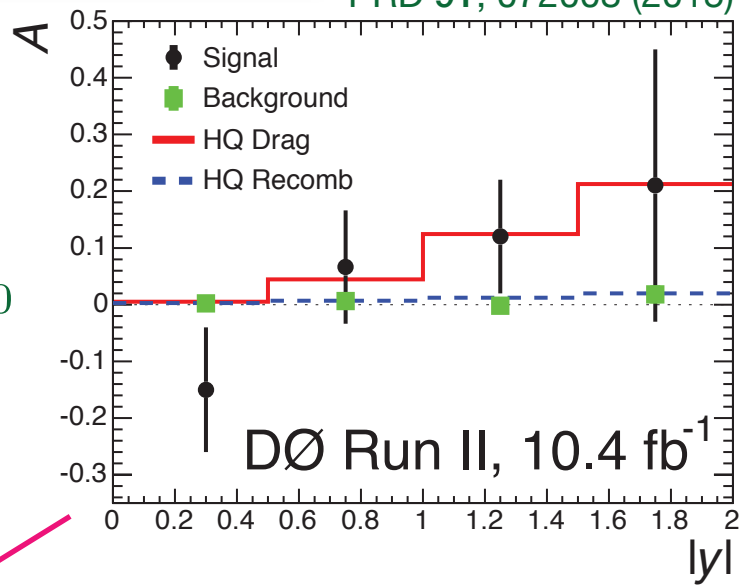
"String Drag"

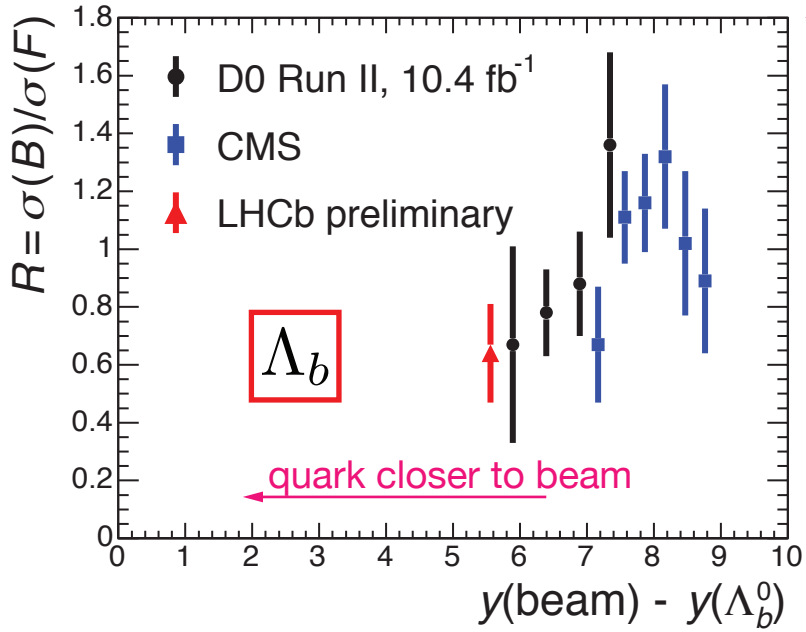


Rosner, PRD **90**, 014023 (2014)

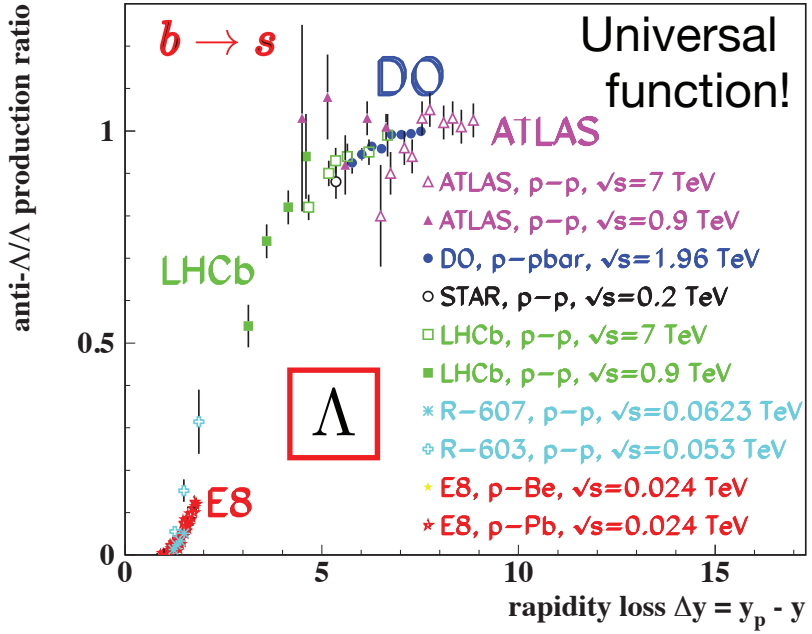
- Color strings "tug" quarks to higher rapidity

PRD **91**, 072008 (2015)



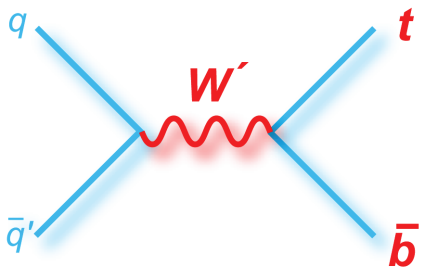


DØ, 10.4 fb^{-1}, preliminary DØ Note 6464-CONF



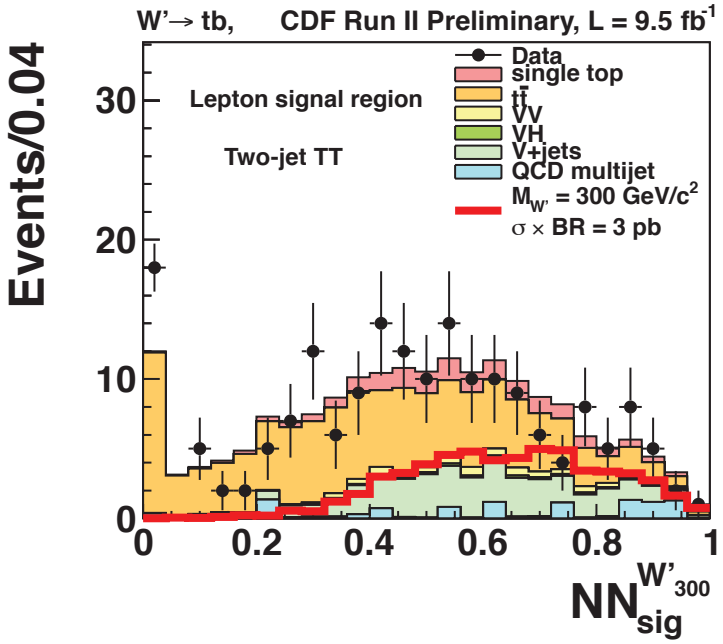
Exotics

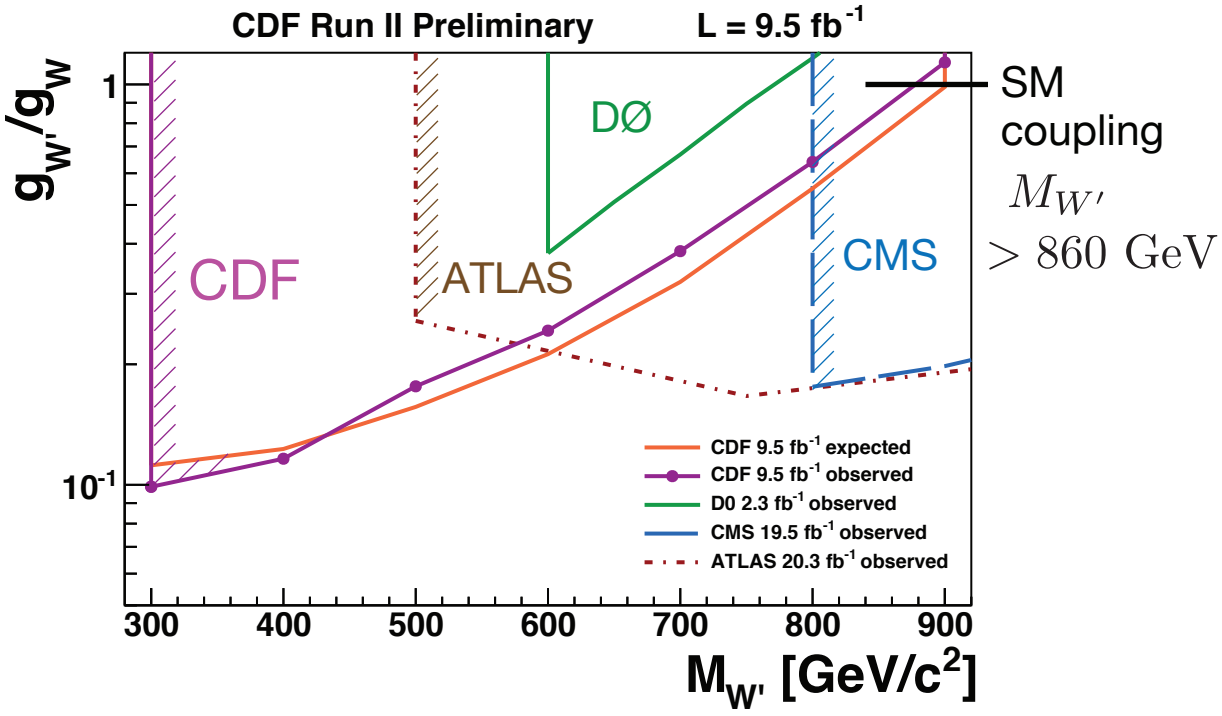
Search for $W' \to t\bar{b}$ Resonances



- Excellent example where Tevatron "fills in low mass gap" where searches difficult at LHC
- Benchmark of left-right symmetric NLO model, allowed or forbidden leptonic decay modes

arXiv:1504.01536, sub. to PRL



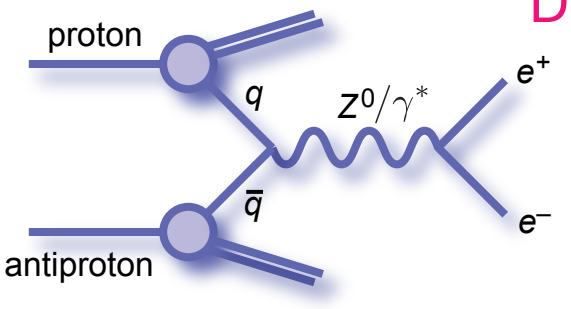


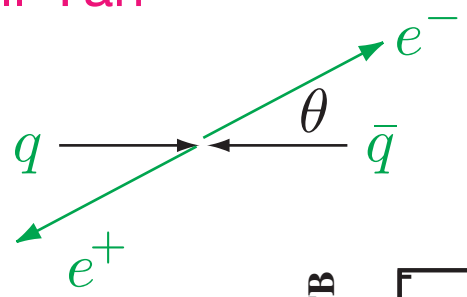
- Best exclusion limit below 550 GeV

Electroweak

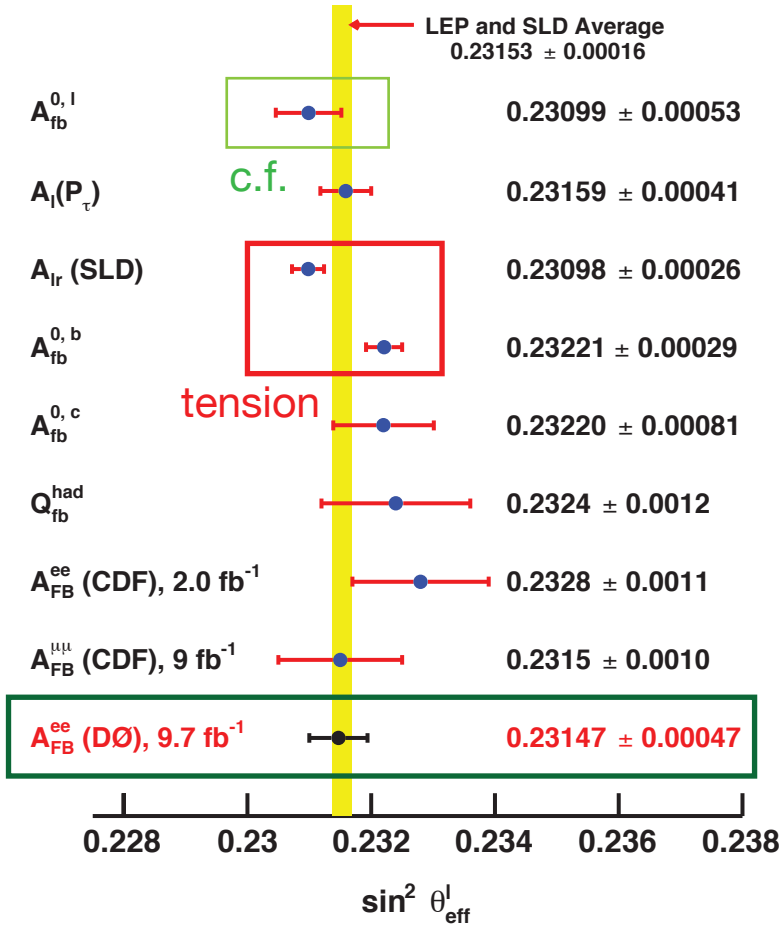
Effective weak mixing angle in $p\bar{p} \to Z/\gamma^* \to e^+e^-$

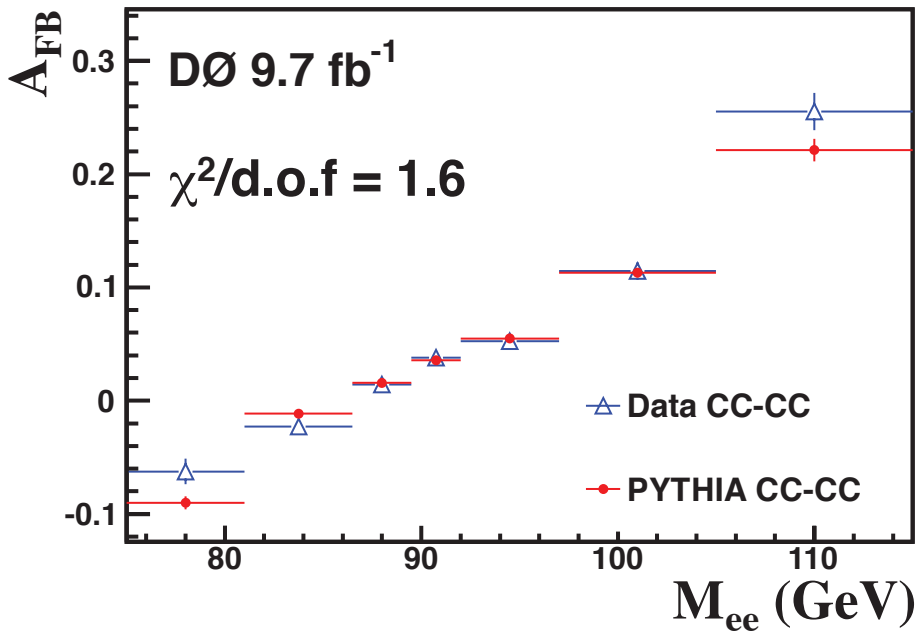
Drell-Yan





$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$



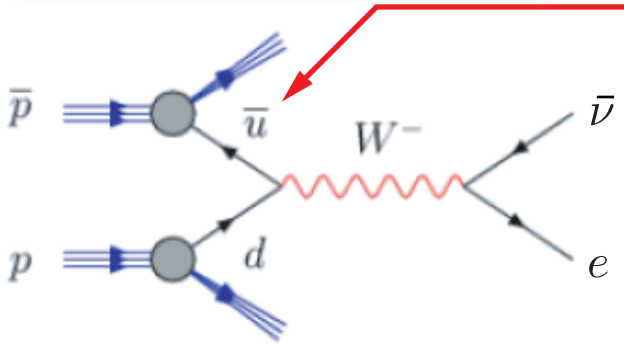


$$\sin^2 \theta^{\ell}_{\text{eff}} = 0.23147 \pm 0.00047$$

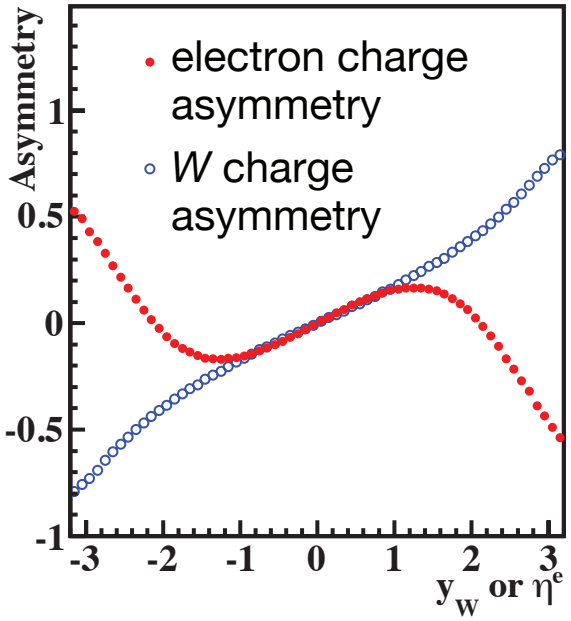
- World's best from hadron collider

Electroweak

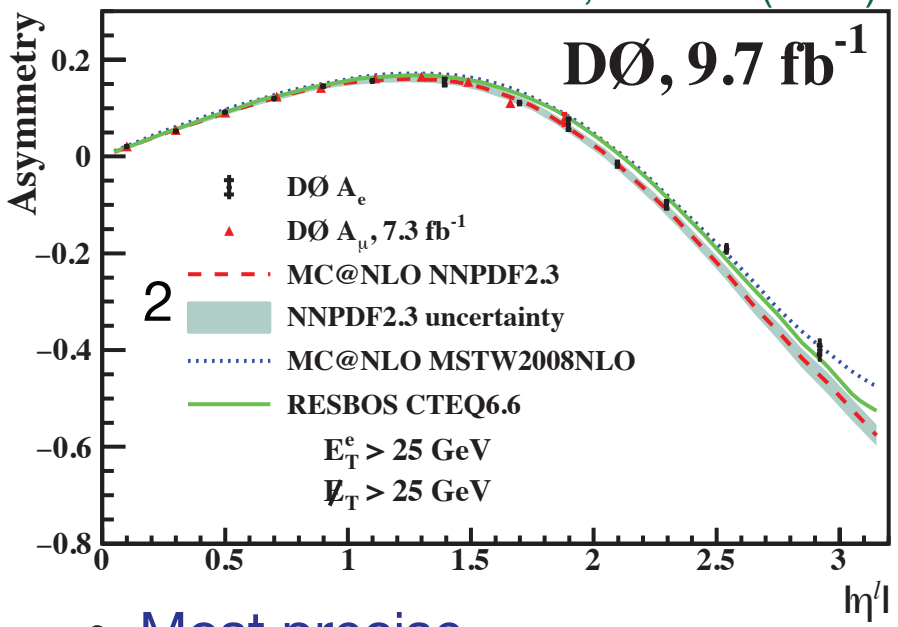
Electron charge asymmetry in $p\bar{p} \to W \to e\nu$



- Probe valence quark parton distribution function (PDF)
- Convolves *W* production asymmetry and *V* – *A* decay



PRD **91**, 032007 (2015)

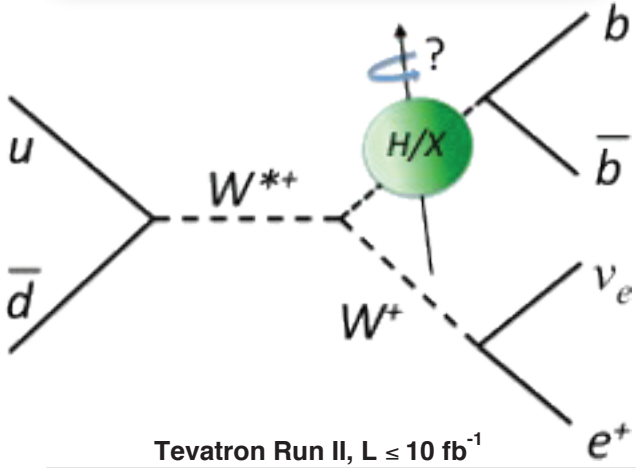


- Most precise

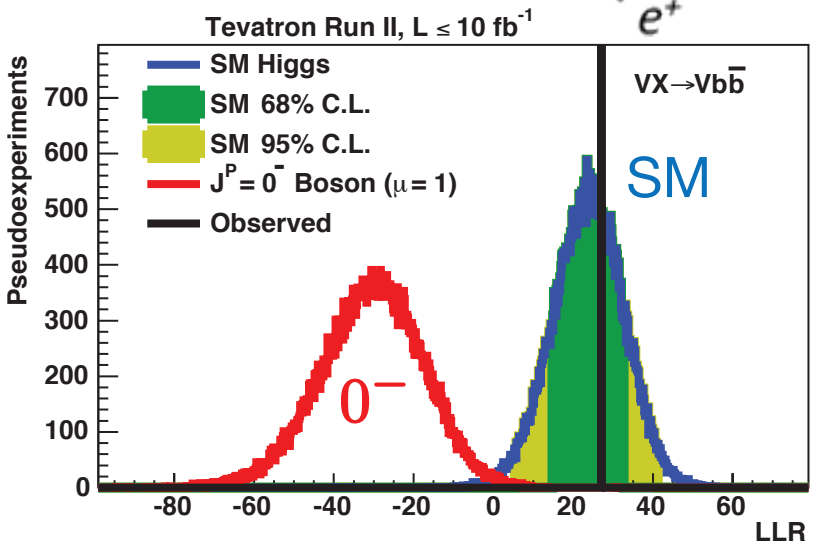
- Improves PDF models, benefits all hadronic measurements
- e.g., expect ~30% improvement (~2 – 3 MeV) on precision of *W* mass

Higgs

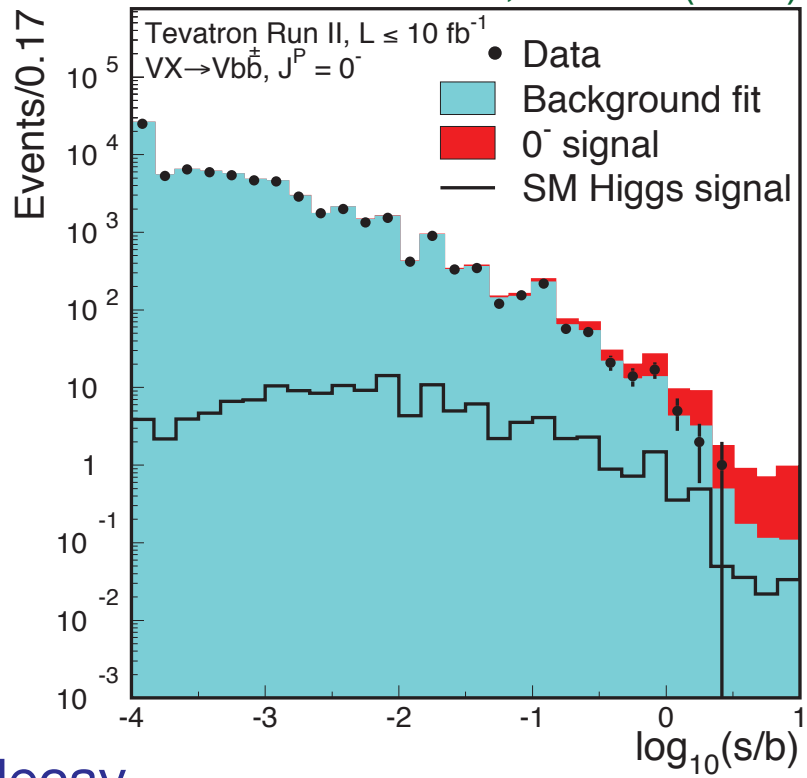
Constraints on Models of the Higgs Boson with Exotic J^P decaying to $b\bar{b}$ Pairs



- Tevatron combination, ~last Higgs "hurrah"
- Discriminate spin-parity via *production* differences (rather than decay), including invariant mass of $Vb\bar{b}$, $V = W, Z$



PRL **114**, 151802 (2015)



- If 0^+ absent, assuming SM prod. & decay
  $J^P = 0^-$ excluded at 4.9σ
  $= 2^+$ excluded at 5.0σ
- Complements LHC studies of $H \to VV$ decay

QCD

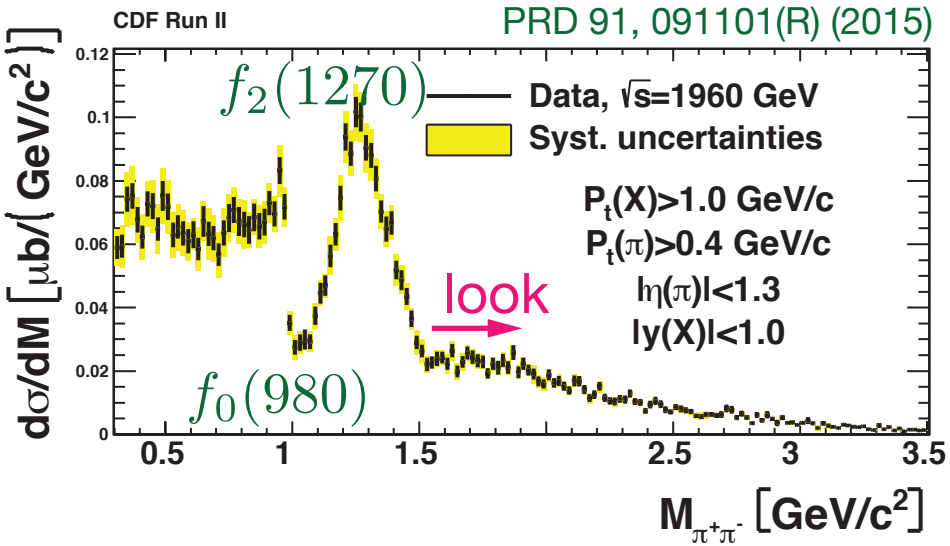
At Low-*x*: Central Exclusive Hadron Production in CDF

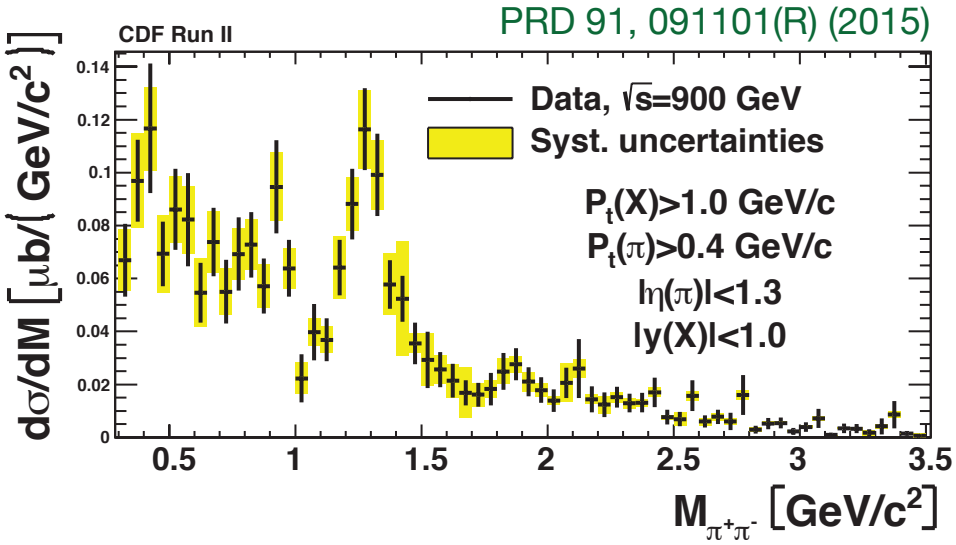
$$p\bar{p} \to p\,(\text{Rapidity Gap})\,X\,(\text{Rapidity Gap})\,\bar{p}$$

$-5.9 < \eta < -1.3$ $\quad$ $1.3 < \eta < 5.9$

Dominated by Double-Pomeron exchange

two charged tracks, mostly $\pi^+\,\pi^-$



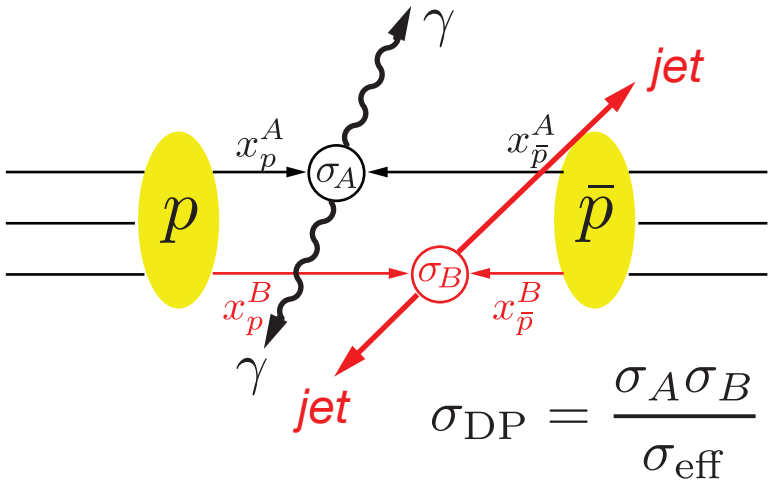


- First publication of 900 GeV data by CDF

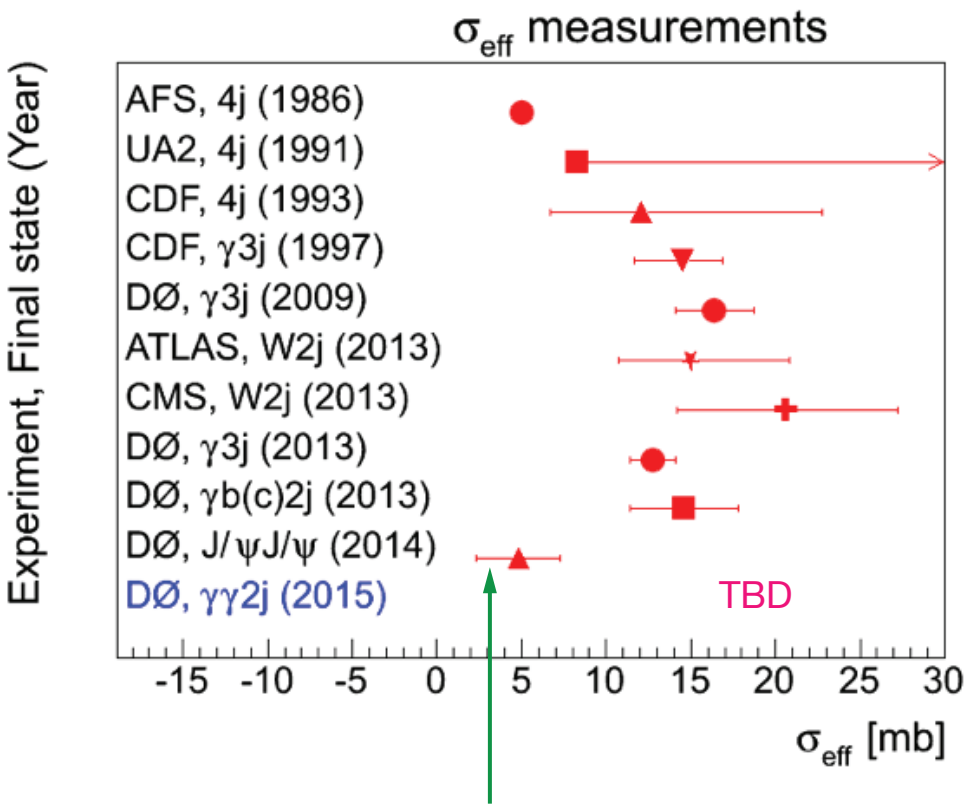
Info for:

- isoscalar meson spectroscopy
- pomeron in transition to pQCD

Double Parton Processes



- $\sigma_{\rm eff}$: a factor characterizing the size of the effective interacting region, contains info on spatial distribution of partons inside proton
  (large if uniform; small if "clumpy")
- In general, DP interactions can also be important backgrounds to some processes at LHC



- Suggests a smaller volume for gluons than quarks?

Summary & Future

- $p\bar{p}$ Tevatron program complementary, competitive; completing legacy results

Future, *not* inclusive:

- Top quark mass: publish last channels, agreement to combine with ATLAS & CMS later this year

  Finish other legacy top physics, all channels

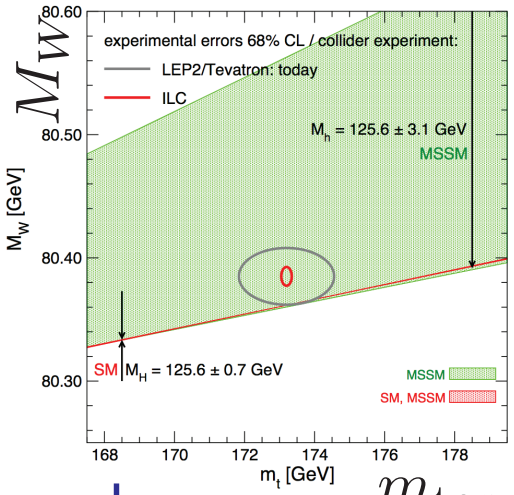
  asymmetries, polarization, spin correlations

- *W* boson mass: with full data set, extend η

  $\Delta M_W = 19-23\ \mathrm{MeV/exp.} \longrightarrow \simeq 15\,\mathrm{MeV/exp.},$

  $10\,\mathrm{MeV}$ Challenging to match at LHC

  Possible comb. target



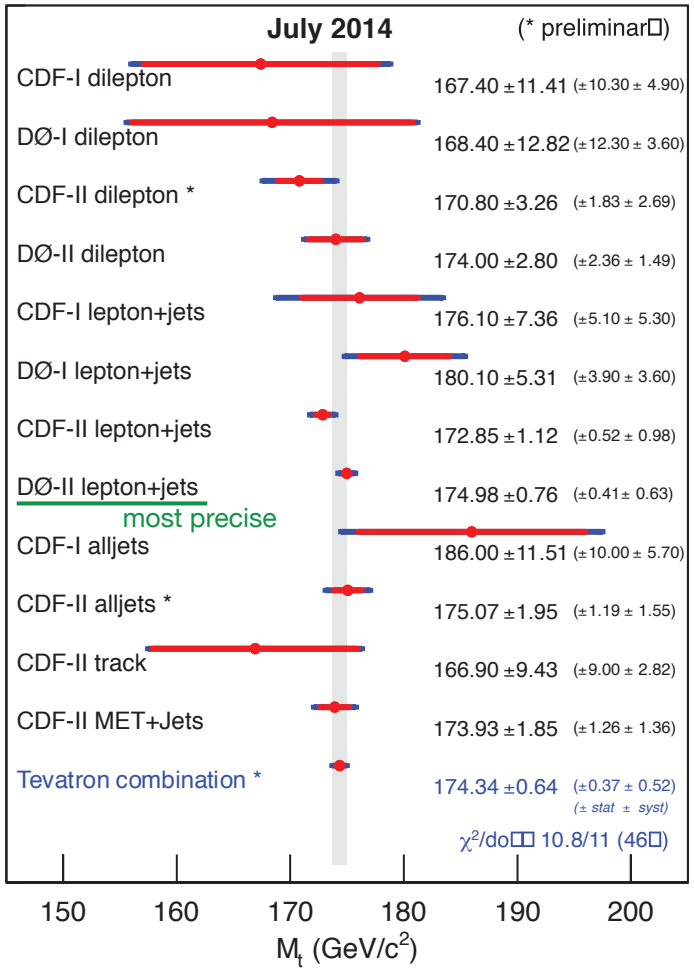
m_{top}

- Data preservation: Tevatron data are preserved on the most recent tapes to be available for many years

  Detailed documentation: CDF and DØ Notes in InSpire

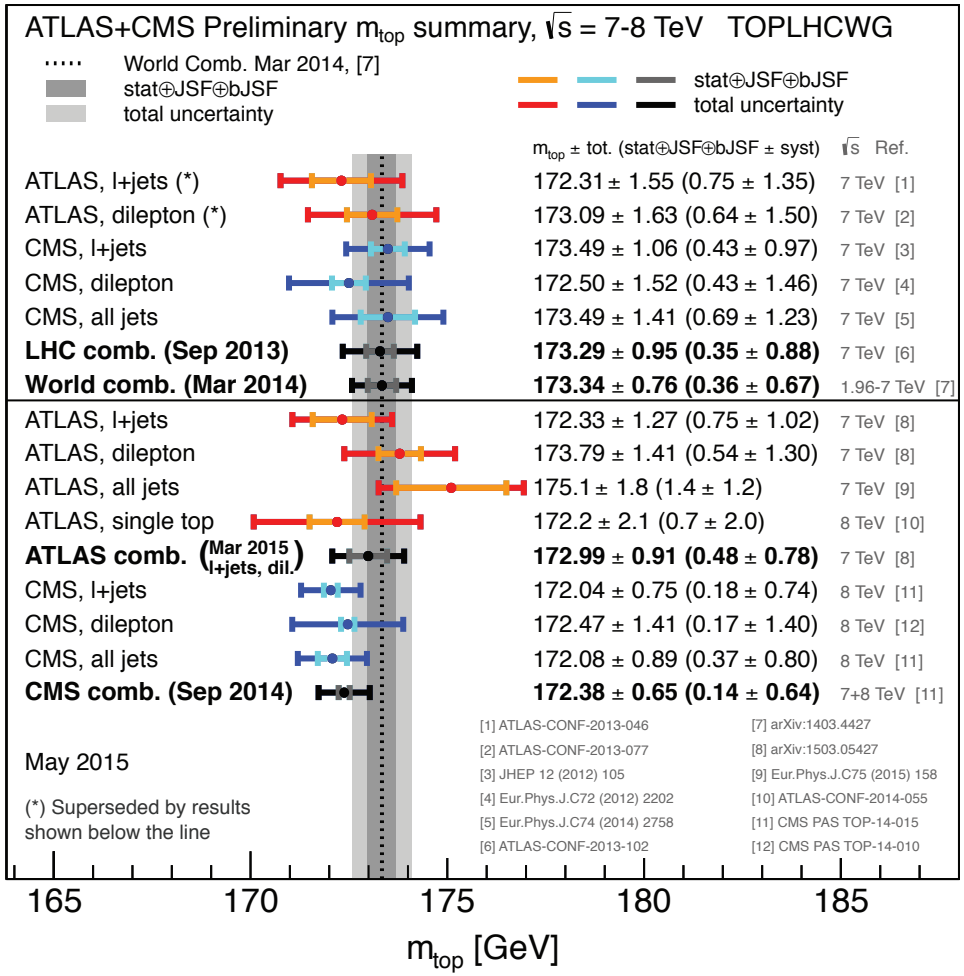
Top Quark Mass

Tevatron Electroweak Working Grp.



LHC

TOPLHCWG, May 2015



- Tevatron most precise (just) single measurement
- Tevatron combo. more precise than last year's world average