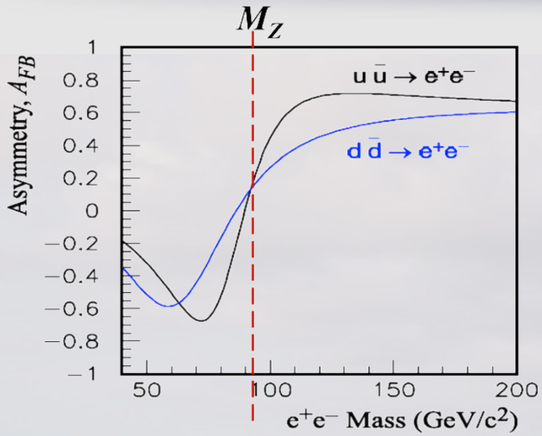
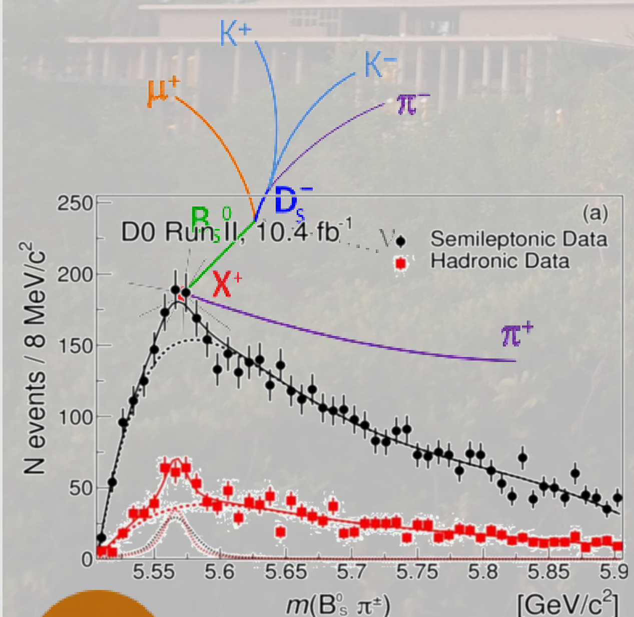
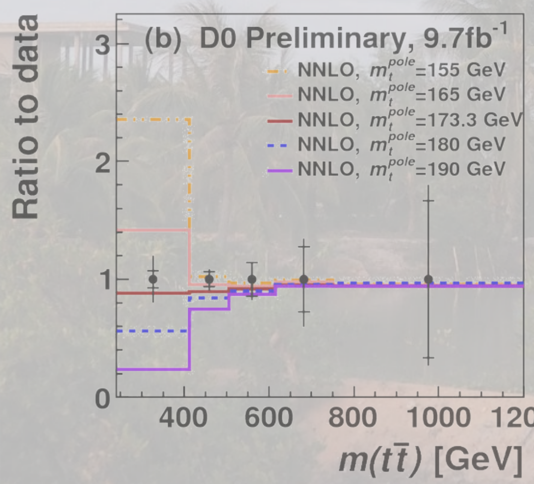
Recent results from the Tevatron

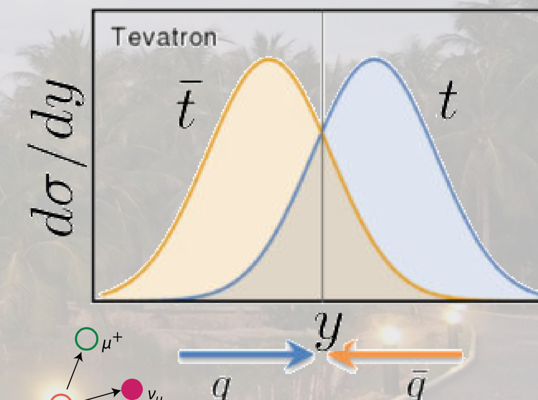
25th Anniversary of the Rencontres du Vietnam

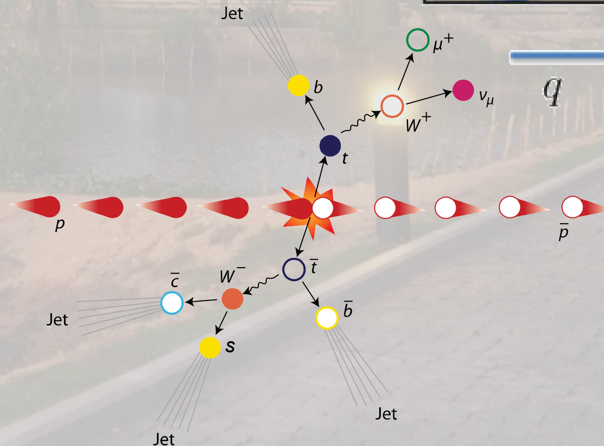


Bob Hirosky
UNIVERSITY *of* VIRGINIA
for
the CDF (40th anniversary) and DZero (35th anniversary) Collaborations





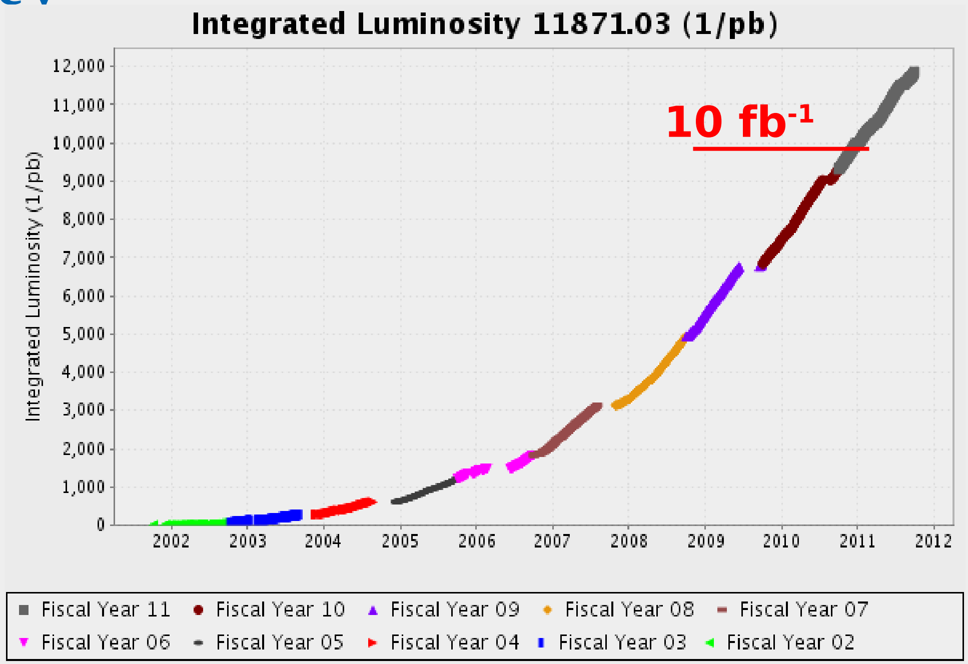




The Tevatron Collider

Run II data (2001-2011): $p\bar{p}$ at $\sqrt{s}$ = 1.96 TeV

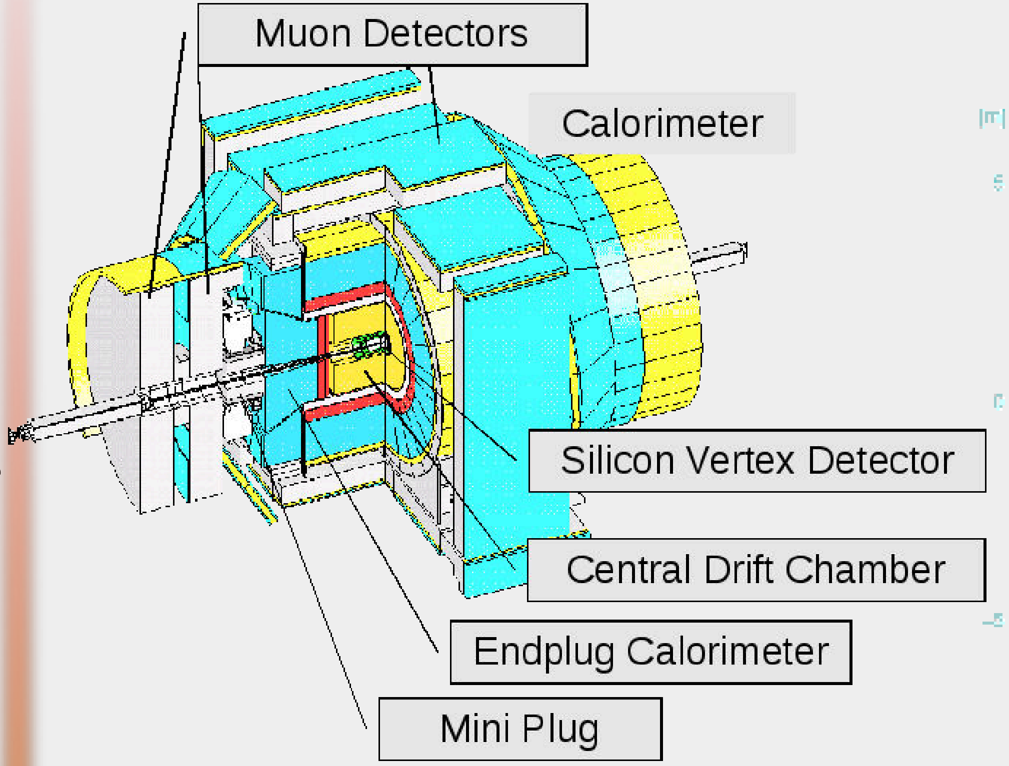
- ~12 fb^{-1} delivered per experiment
- ~10 fb^{-1} for analysis
- Max. Instantaneous Luminosity
L ≈ 4.3x10^{32} cm^{-2} s^{-1} (30M collisions/s)
- **Largest, highest energy $p\bar{p}$ data set**

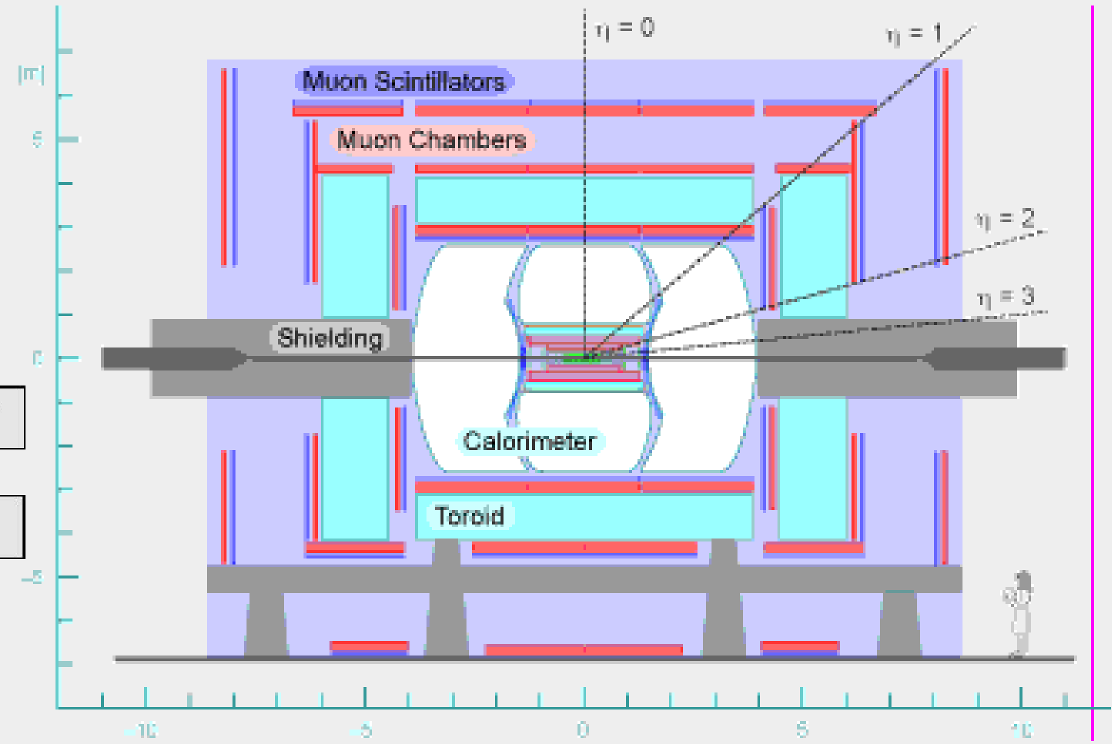


- Unique physics studies
- Complementary/competitive results in LHC era

The CDF and DØ Detectors

Multipurpose, large acceptance, well understood



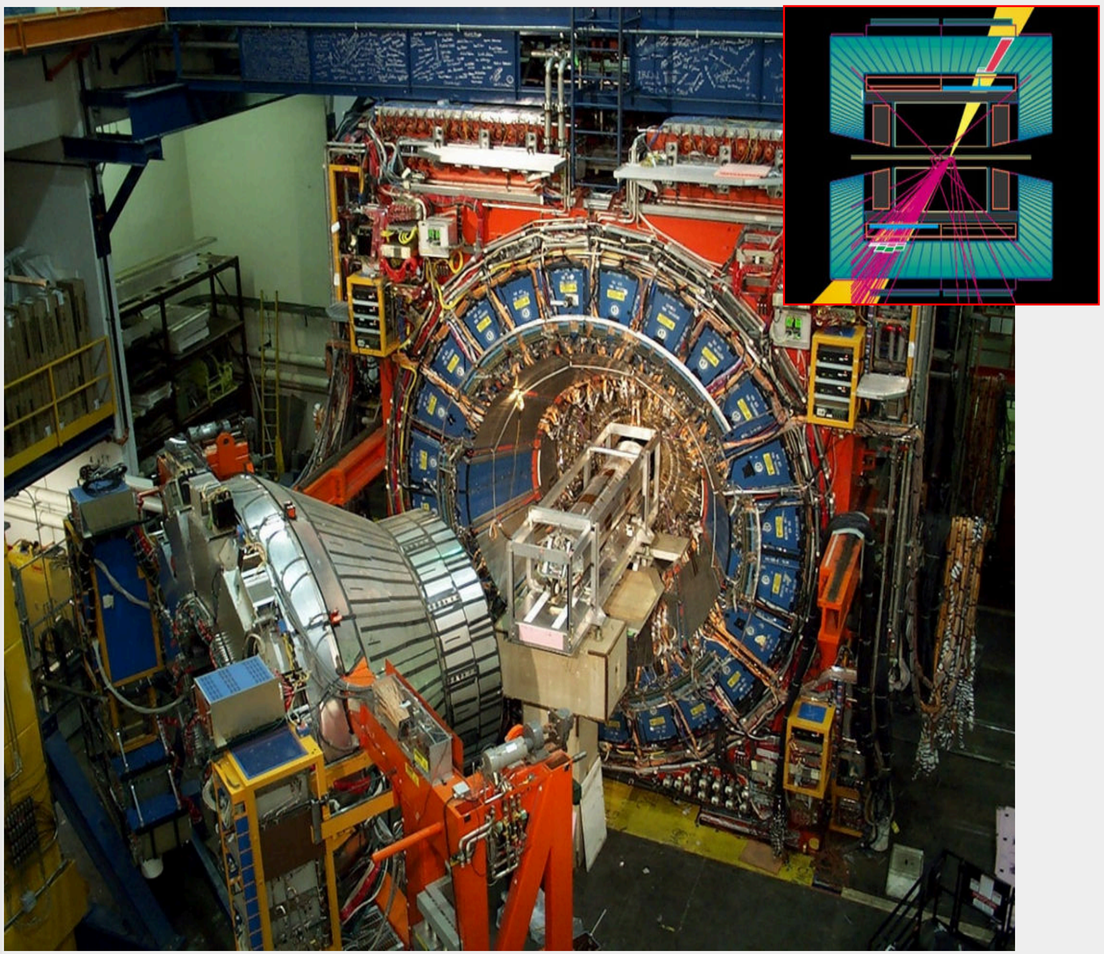


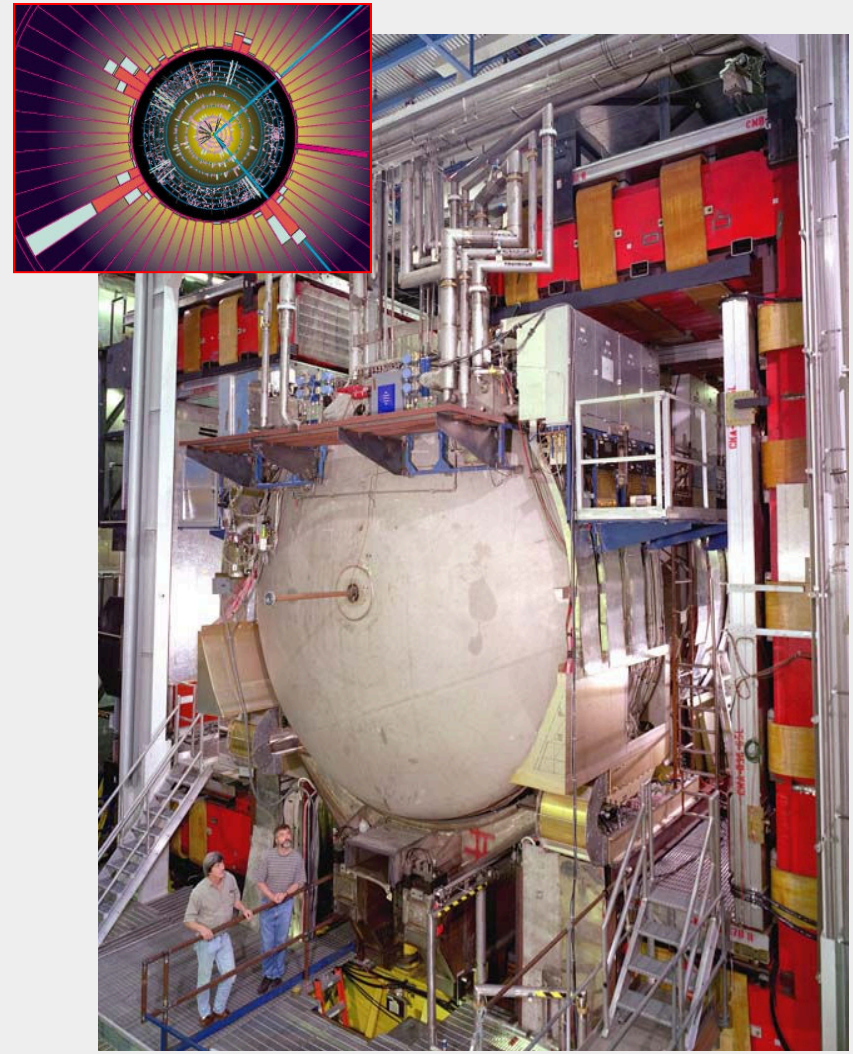
- **Emphasizes greater tracking volume/performance**
- Some trade offs in calorimeter depth and muon coverage

- **Emphasizes calorimeter depth/hermeticity, muon coverage**
- Some trade off in tracking volume

The CDF and DØ Detectors

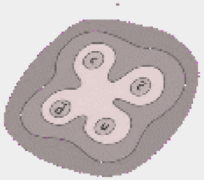
Multipurpose, large acceptance, well understood



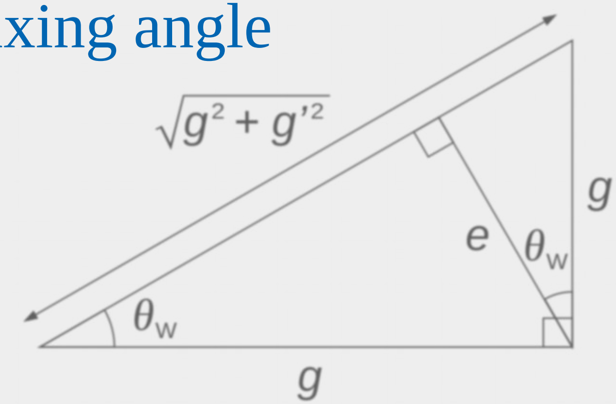


New results from Tevatron experiments continue to be released

Topics presented



- Studies of X(5568)
- Evidence for $Z_C^{\pm}(3900)$
- Precision measurement of electroweak mixing angle
- Top quark production asymmetry
- Indirect measure of top quark pole mass



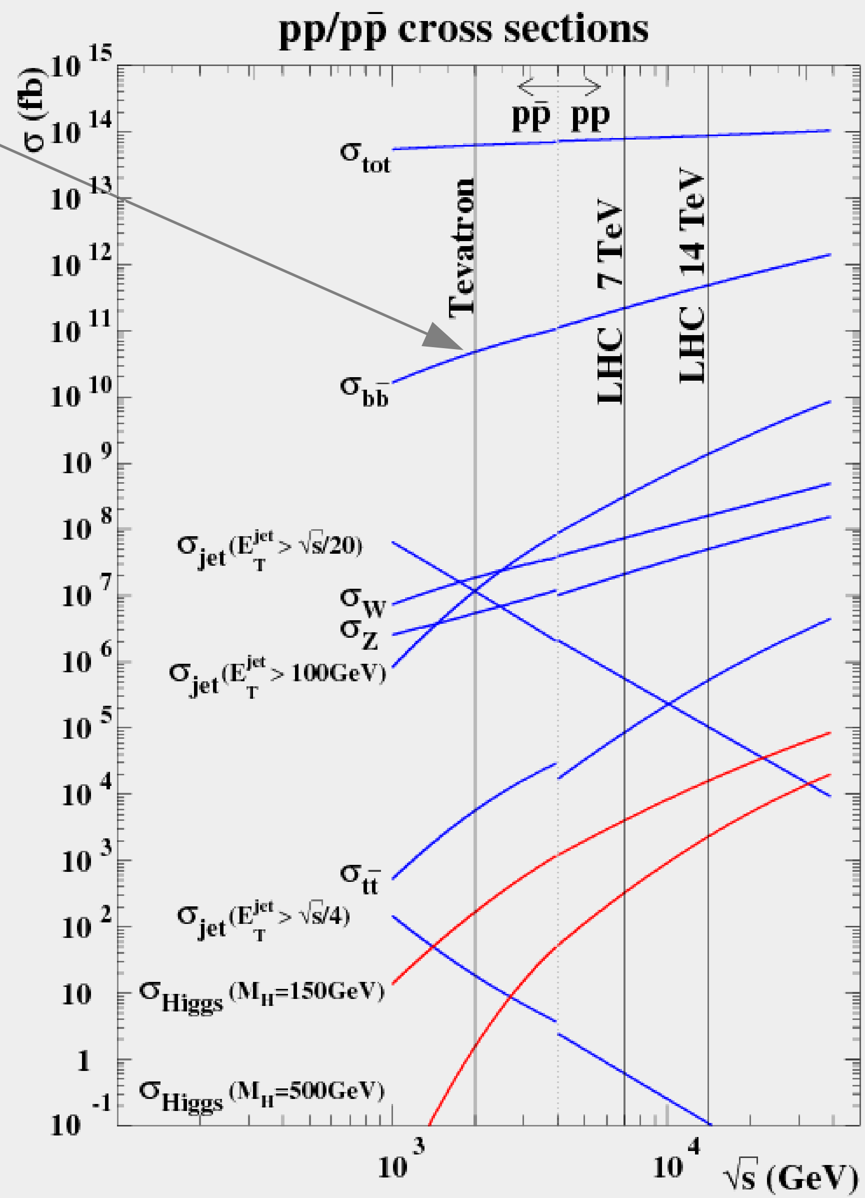
Exotic (heavy flavor) hadrons

Heavy flavor production @ hadron colliders

High b quark cross section: ~10^{-3} σ_{tot}

~10^4 b's per second produced!

All species containing b quark are produced $B^{\pm}$, B^0, B_s, B_c, Λ_b…

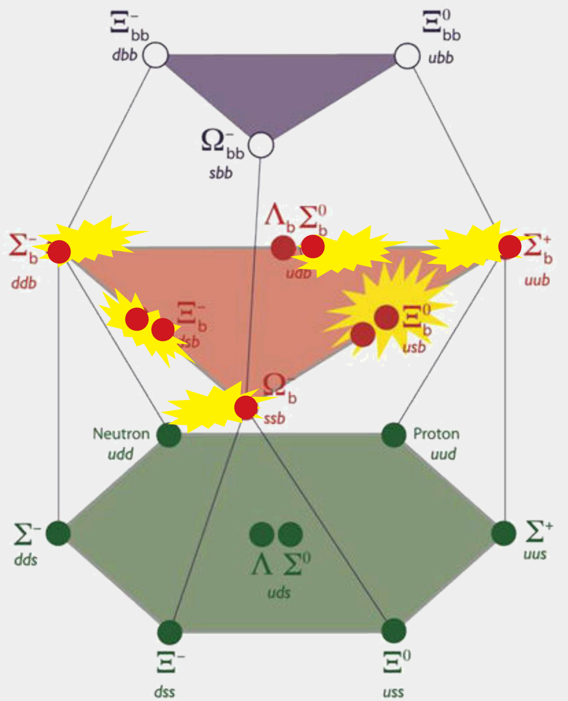


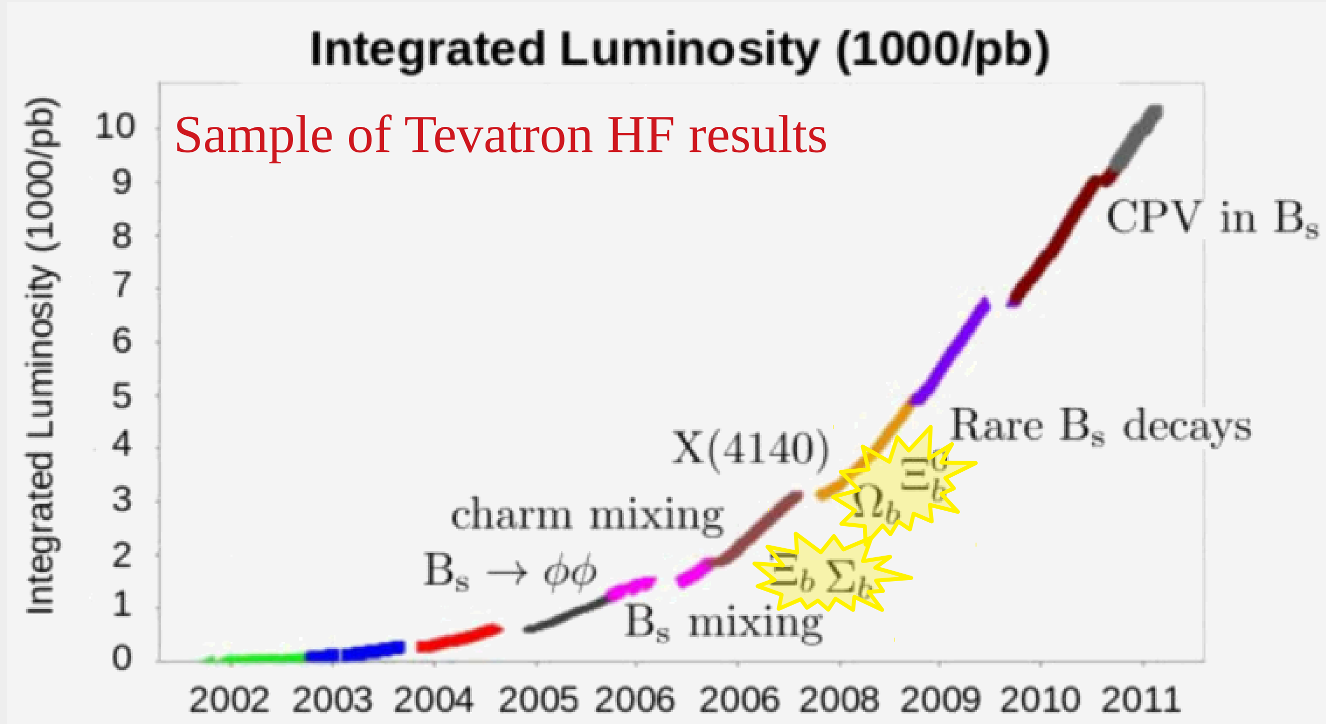
Large b quark data samples provide

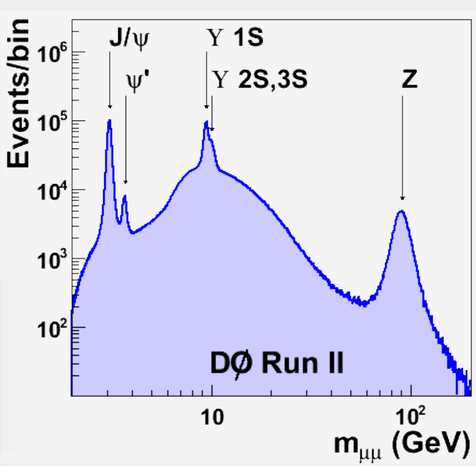
- B mesons lifetime studies
- Mass spectroscopy (B_c, etc.)
- Studies of B_s oscillations
- CP violation studies
- Search for new b hadrons
- Search for rare decays

HF in Tevatron Run II

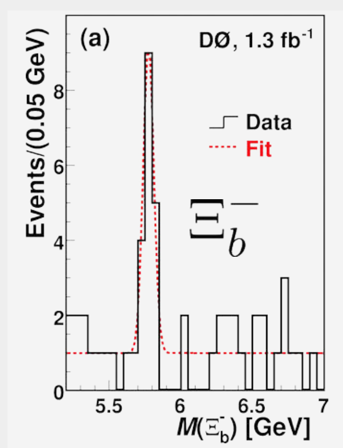
Long history of discovery + studies of (exotic) hadron states



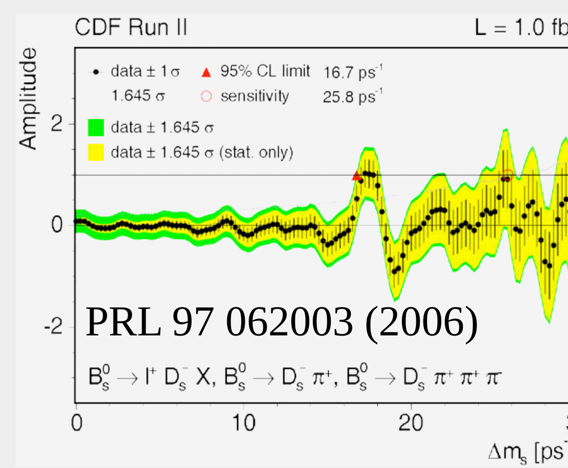




NIM A 737, 281 (2014)

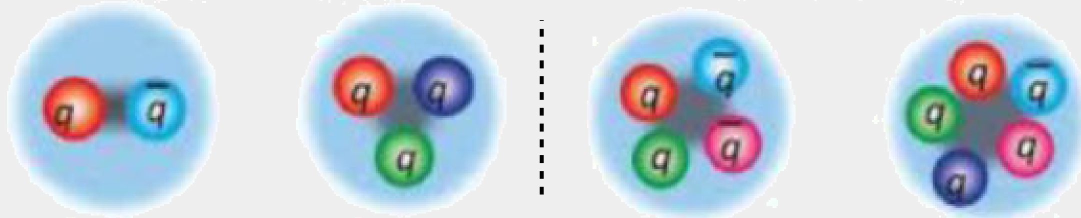


PRL 99 052001 (2007)



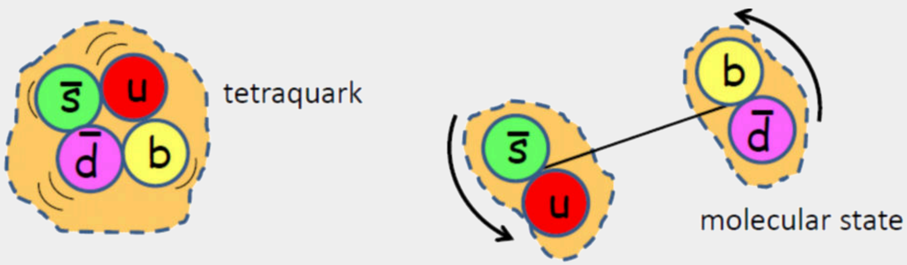
Multi-quark states

Standard Hadrons



Exotic Hadrons

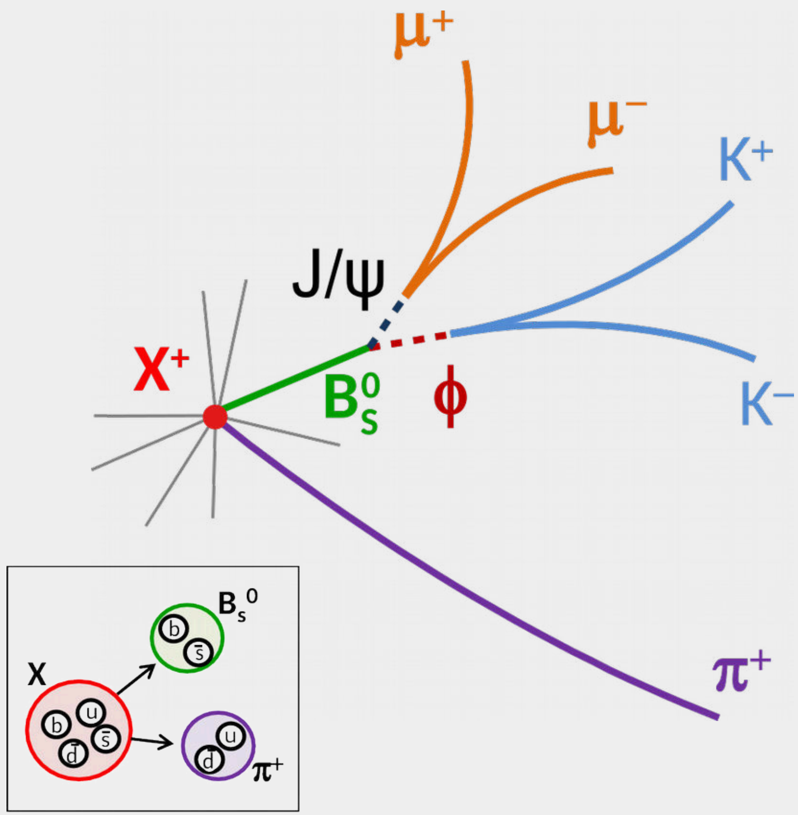
- ~20 exotic states observed since 2003 with high significance
  - BES, Belle, Babar, CDF, D0, LHCb, Atlas, CMS
- Some examples of multi-quark states
  - Tetraquark candidates **X(3782)**$\to J/\psi\pi^+\pi^-$, **Z^+(4430)**$\to \Psi'\pi^+$, **X(4140)**$\to J/\psi\phi$, **Z_b^+(10610)**$\to \Upsilon\pi^+$, **Z_b^+(10650)** $\to \Upsilon\pi^+$
  - Pentaquark candidates **P_c^+(4450)** $\to J/\psi p$, **P_c^+(4380)** $\to J/\psi p$
- Four-quark states interpretations:
  - tetraquarks (large binding energy),
  - molecular states (small BE),
  - mixture with conventional states (if possible)

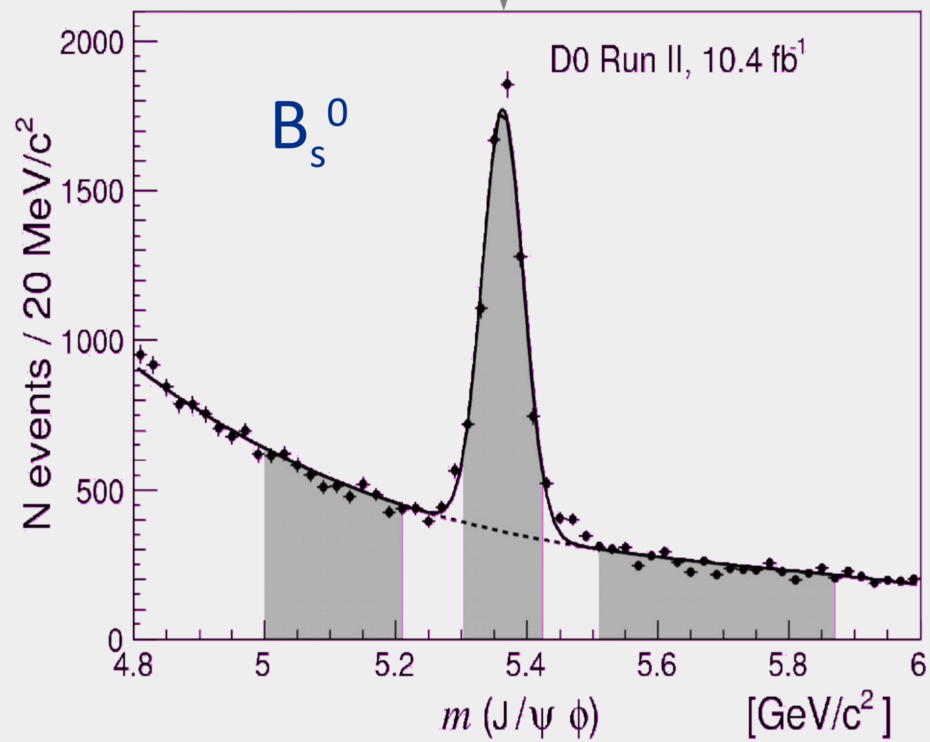


- Many observed multi-quark states lie close to two-hadron mass thresholds and, therefore, they can be interpreted as molecular states

Recent review by Olsen, Skwarnicki, Zieminska Rev. Mod. Physics 90 (2018)

Search for four quark state
$X(5568) \rightarrow B_s^0\pi^{\pm}$, $B_s^0 \rightarrow J/\psi\varphi$

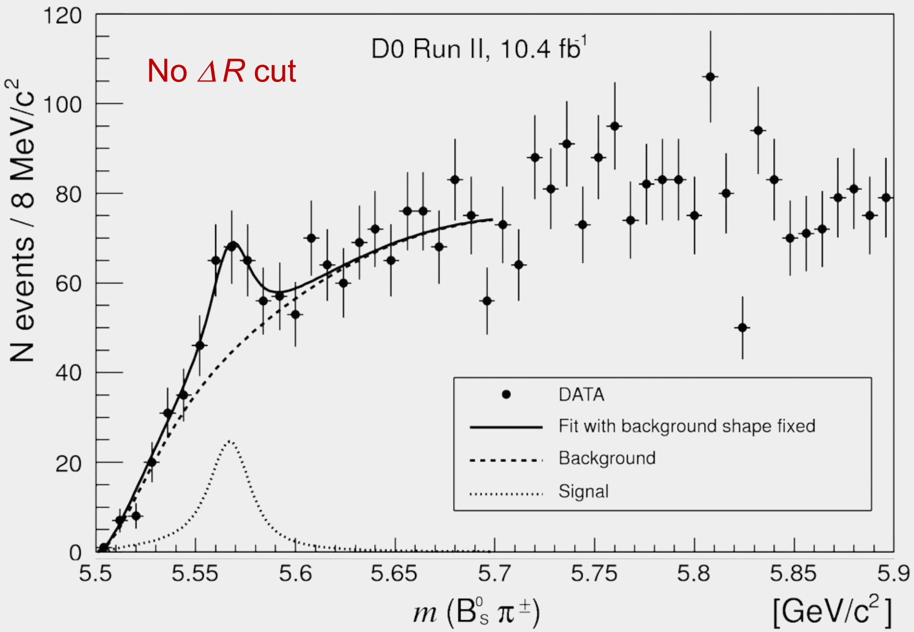




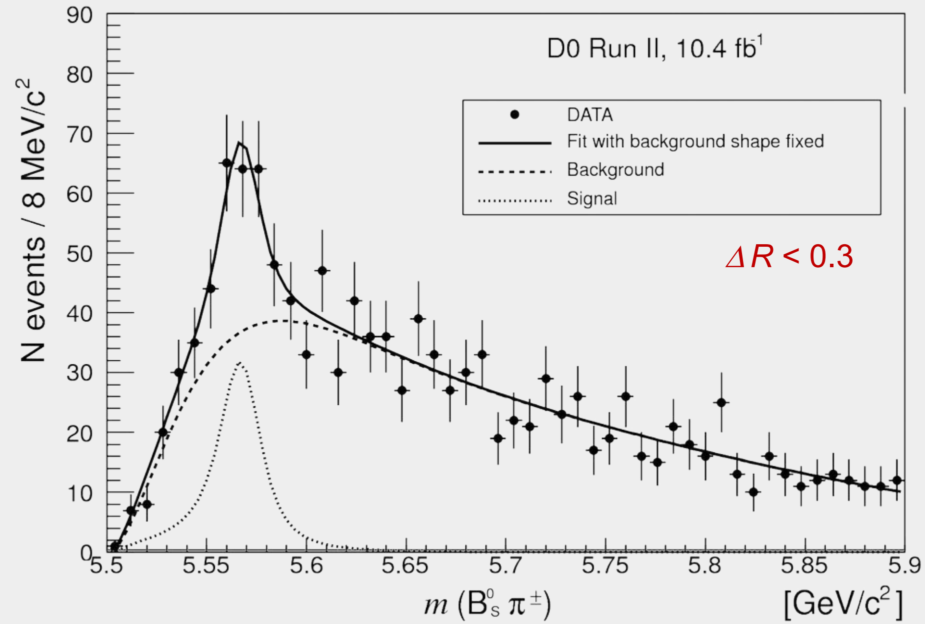
- Look for possible strong decays of four-quark object containing four different quarks: u, d, s and b
- Require the pion to come from the proton-antiproton interaction vertex

PRL 117 022003 (2016)

X(5568) → $B_s^0\pi^\pm$, B_s^0 → J/ψφ



$\Delta R = \sqrt{\Delta\eta^2 + \Delta\varphi^2}$ ($B_s \angle \pi^+$)



- **Evidence for new X(5568) → $B_s^0\pi^\pm$, state with B_s^0 → J/ψ ϕ**
  - Final state with four flavors (*b,s,u,d*)
  - Signal with a mass of $5567.8 \pm 2.9^{+0.9}_{-1.9}$ MeV/c²
  - $\Gamma = 21.9 \pm 6.4^{+5.0}_{-2.5}$ MeV/c²
- Large $M(B_d)+M(K^+) - M(X)$ disfavors molecular interpretation

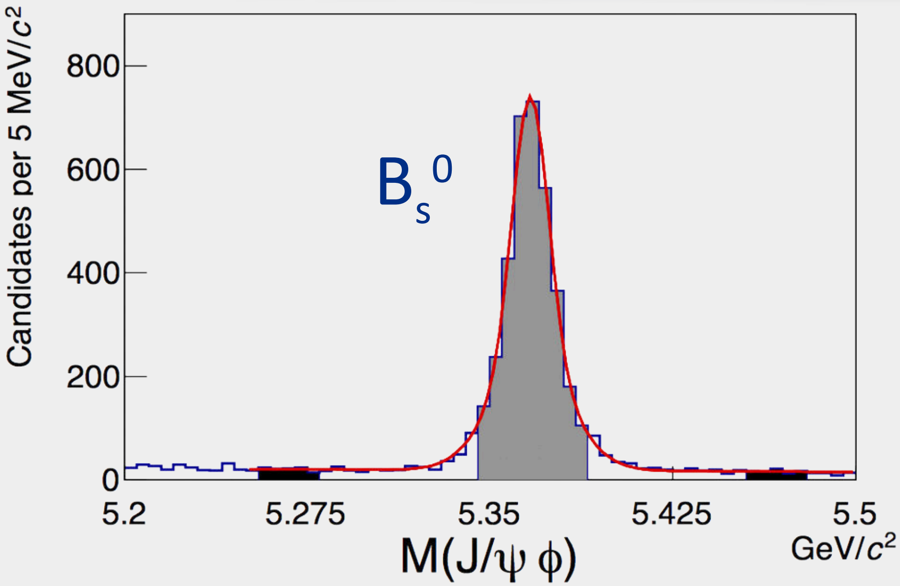
Primary analysis imposed ΔR<0.3 cut on (Bs,π) trajectories to reduce high mass background

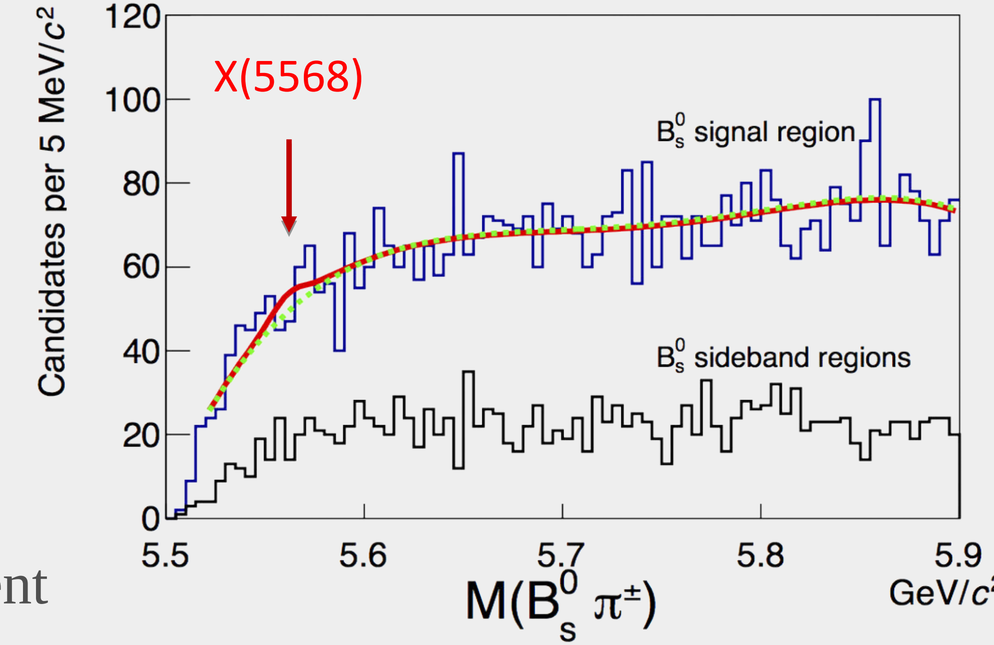
Global Significance including LEE & syst. uncertainty = 5.1 σ (3.1 σ w/o ΔR cut)

PRL 120, 202006 (2018)

NEW

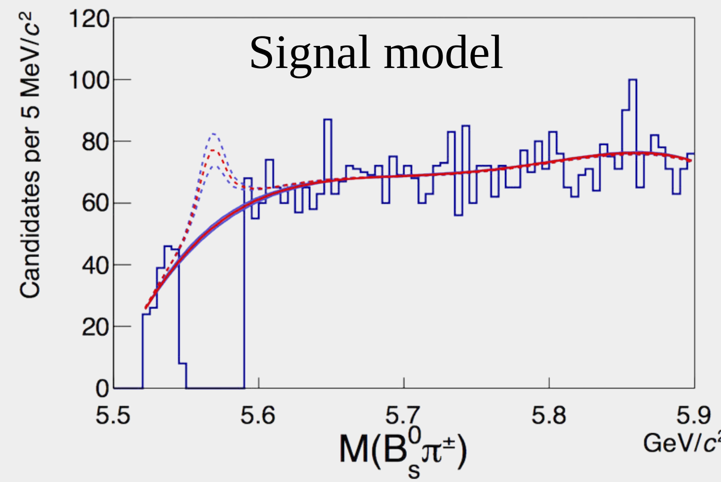
CDF Search for X(5568) → $B_s^0\pi^\pm$, B_s^0 → J/ψφ





CDF measurement with somewhat different selections wrt D0 (eg substantially smaller muon eta coverage |η|<1 vs |η|<2, some kinematic selections)

- No significant signal observed and upper limit set at 6.7% at 95% CL
- If DØ restricts muon eta coverage to CDF value, most of the X(5568) signal is gone
- Need better understanding of physics of the production and decay of multi-quark objects



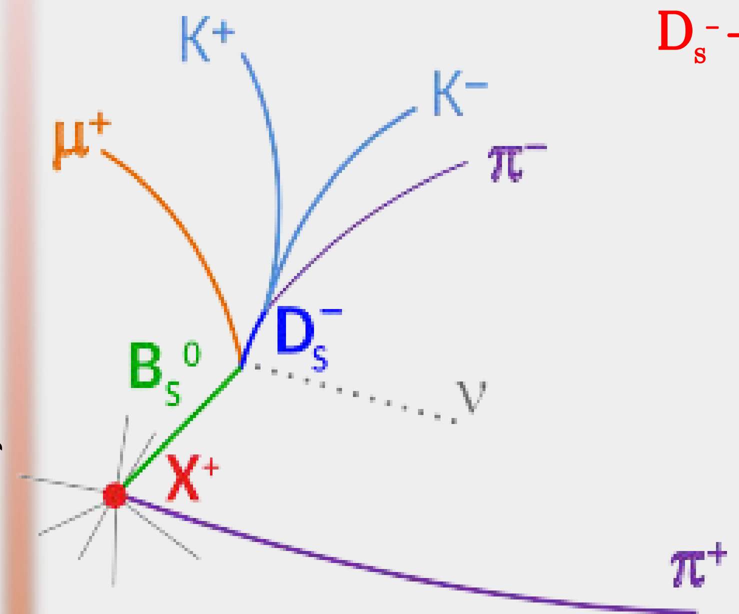
PRD 97, 092004 (2018)

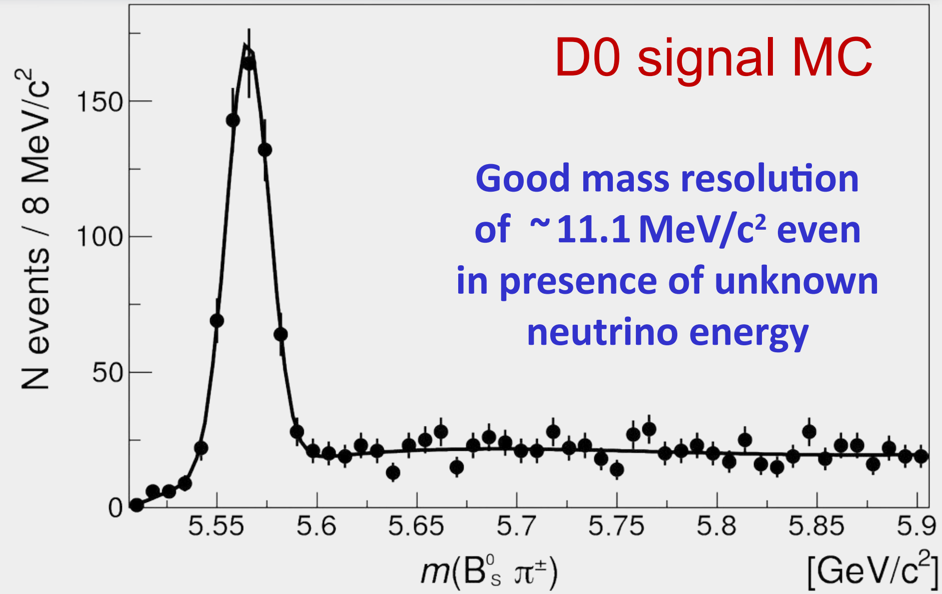
$X(5568) \rightarrow B_s^0\pi^\pm$ with Semileptonic decay $B_s^0 \rightarrow D_s^-\mu^+X$

$X^+(5568) \rightarrow B_s\pi^+$, $B_s \rightarrow D_s^-\mu^+ X_{any}$

$D_s^- \rightarrow \phi(1020)\,\pi^-$

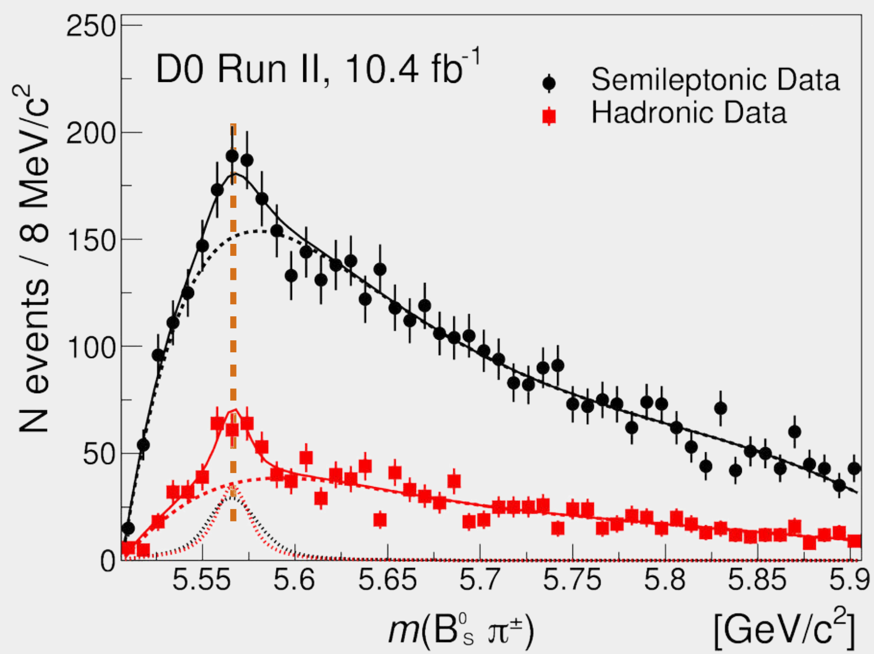
$\phi \rightarrow K^+K^-$





1. Calculate visible mass $M(D_s^-\mu^+)$
2. Use visible mass as B_s mass
3. Combine B_s and π^+ to form **X**
4. Estimate $\mathbf{M(X) = M(B_s^0\pi^\pm)} =$

   $\mathbf{M(D_s\mu\pi) - M(D_s\mu) + M_{PDG}(B_s^0)}$



Summary of SL analysis

$B_s^0\pi^\pm$, $B_s^0 \rightarrow \mu + \nu D_s^- X_{anything}$	Nominal Fit	
	w/ ΔR cut	w/o ΔR cut
Fitted mass, MeV/c^2	$5566.4^{+3.4}_{-2.8}$	$5566.7^{+3.6}_{-3.4}$
Fitted width,* MeV/c^2	$2.0^{+9.5}_{-2.0}$	$6.0^{+9.5}_{-6.0}$
Fitted number of signal events	121^{+51}_{-34}	139^{+51}_{-63}
χ^2/ndf	34.9/(50 – 4)	30.4/(50 – 4)
Local significance	4.3σ	4.5σ

Observed yields consistent w/ coming from a common particle – given number of B_s^0 events in the sample and B_s^0 branching ratios

* reconstruction in SL channel shows little sensitivity to decay width

Combination of channels	Cone Cut	No Cone Cut
Fitted mass, MeV/c^2	$5566.9^{+3.2}_{-3.1}$ (stat) $^{+0.6}_{-1.2}$ (syst)	$5565.8^{+4.2}_{-4.0}$ (stat) $^{+1.3}_{-2.0}$ (syst)
Fitted width, MeV/c^2	$18.6^{+7.9}_{-6.1}$ (stat) $^{+3.5}_{-3.8}$ (syst)	$16.3^{+9.8}_{-7.6}$ (stat) $^{+4.2}_{-6.5}$ (syst)
Fitted number of hadronic signal events	131^{+37}_{-33} (stat) $^{+15}_{-14}$ (syst)	99^{+40}_{-34} (stat) $^{+18}_{-33}$ (syst)
Fitted number of semileptonic signal events	147^{+42}_{-37} (stat) $^{+17}_{-16}$ (syst)	111.7^{+46}_{-39} (stat) $^{+20}_{-38}$ (syst)
χ^2/ndf	94.7/(100 – 6)	54.2/(50 – 6)
p-value	2.2×10^{-14}	1.9×10^{-8}
Local significance	$7.6\,\sigma$	$5.6\,\sigma$
Significance with LEE	$6.9\,\sigma$	$5.0\,\sigma$
Significance with LEE+systematics	$6.7\,\sigma$	$4.7\,\sigma$

Substantial increase in significance combining two independent data samples

Results from five collider experiments on X(5568)

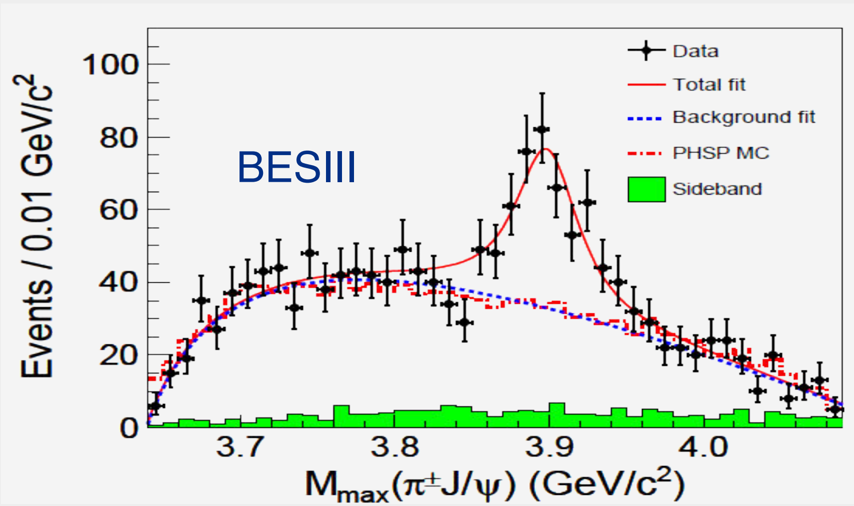
Analysis	Production ratio (B_s / X(5568))	Reference
D0 ($J/\psi\ \phi$)	8.6 ± 1.9 ± 1.4%	PRL 117,022003(2016)
D0 ($\mu\ D_s$)	$7.3^{+2.8}_{-2.4}{}^{+0.6}_{-1.7}$%	PRD 97, 092004 (2018)
LHCb	< 2.4% ($p_T(B_s^0)$ > 10 GeV)	PRL 117,152003 (2016)
CMS	< 1.1% ($p_T(B_s^0)$ > 10 GeV)	PRL 120, 202005 (2018)
ATLAS	< 1.5% ($p_T(B_s^0)$ > 10 GeV)	PRL 120, 202007 (2018)
CDF	< 6.7% (2.3 ± 1.9 ± 0.9%)	PRL 120, 202006 (2018)

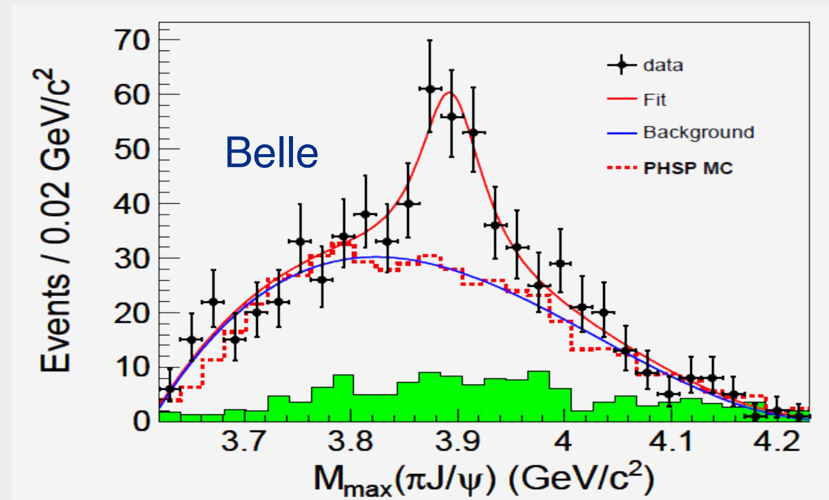
- LHC experiments do not observe X(5568) at higher collisions energy
- CDF result is in ~2s tension with DØ studies in hadronic decay channel
  - Fiducial/kinematic selections vary substantially
- Without theoretical model of X(5568) production and decays it is hard to compare various experiments quantitively
  - Ratio to B_s^0 production might not be the best metric

Search for $Z_c^+(3900)$ in hadron collisions

- $Z^+(3900)$ was discovered in 2013 by Belle and BESIII in the strong interaction decay:

  $e^+e^- \rightarrow Y(4260) \rightarrow Z_c^+(3900)\pi^-,\ Z_c^+ \rightarrow J/\psi\pi^+$ (+ c.c.)

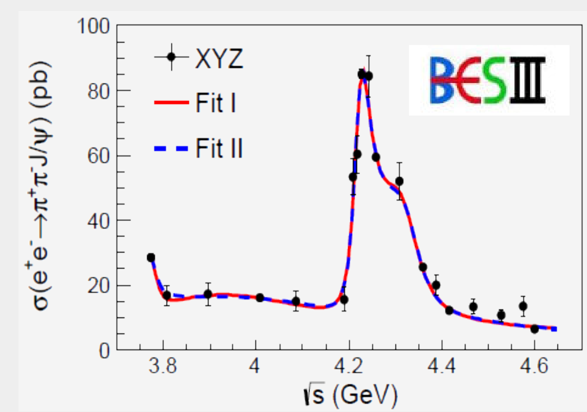




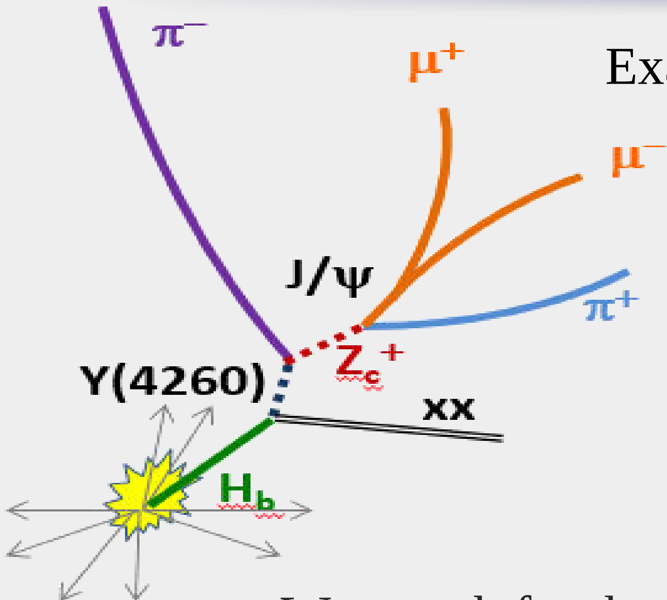
- Minimum $Z_c^+(3900)$ quark content cc(bar)ud(bar)

  M = 3886.6 ± 2.4 MeV   Γ = 28.1 ± 2.6 MeV

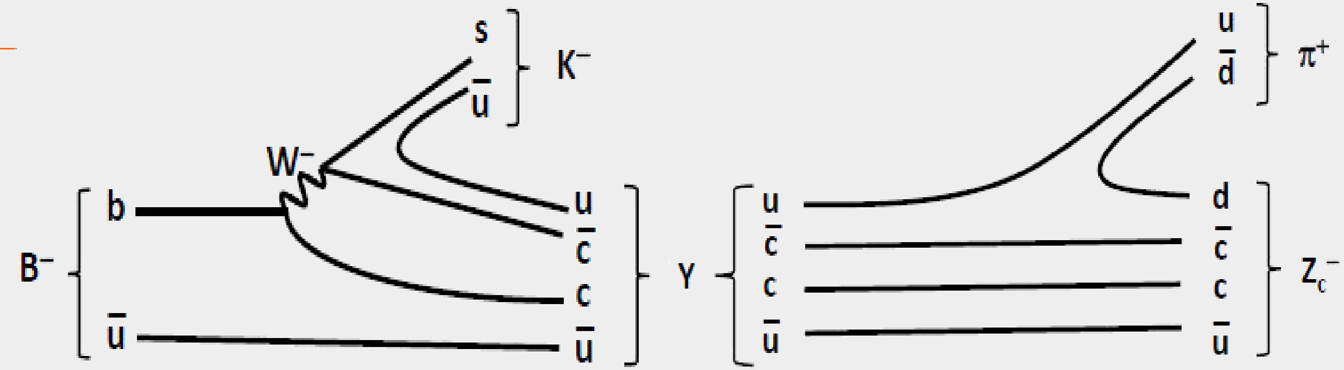
- Latest from BESIII
  - "Y (4260)" consists of two interfering resonances
  - PDG 2018 names them ψ(4260) and ψ(4360)
- Questions
  - Which component of the Y decays to the $Z_c(3900)$?
  - Are there decays $H_b \rightarrow Y\ (\rightarrow Z_c^+(3900)\pi^-)$ + anything?
  - Are there additional, higher mass $Y \rightarrow J/\psi\pi$ states?



Production of $Z_c^{\pm}(3900)$ in b-hadron decays



Example production chain

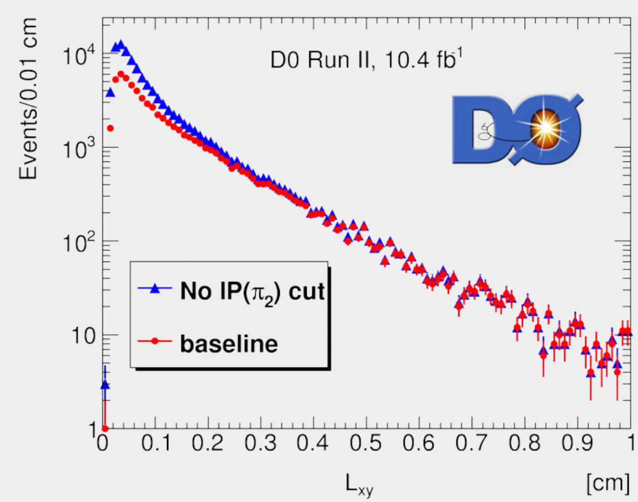


We search for the $Z_c^{+}(3900)$ production in H_b decays via the following decays:

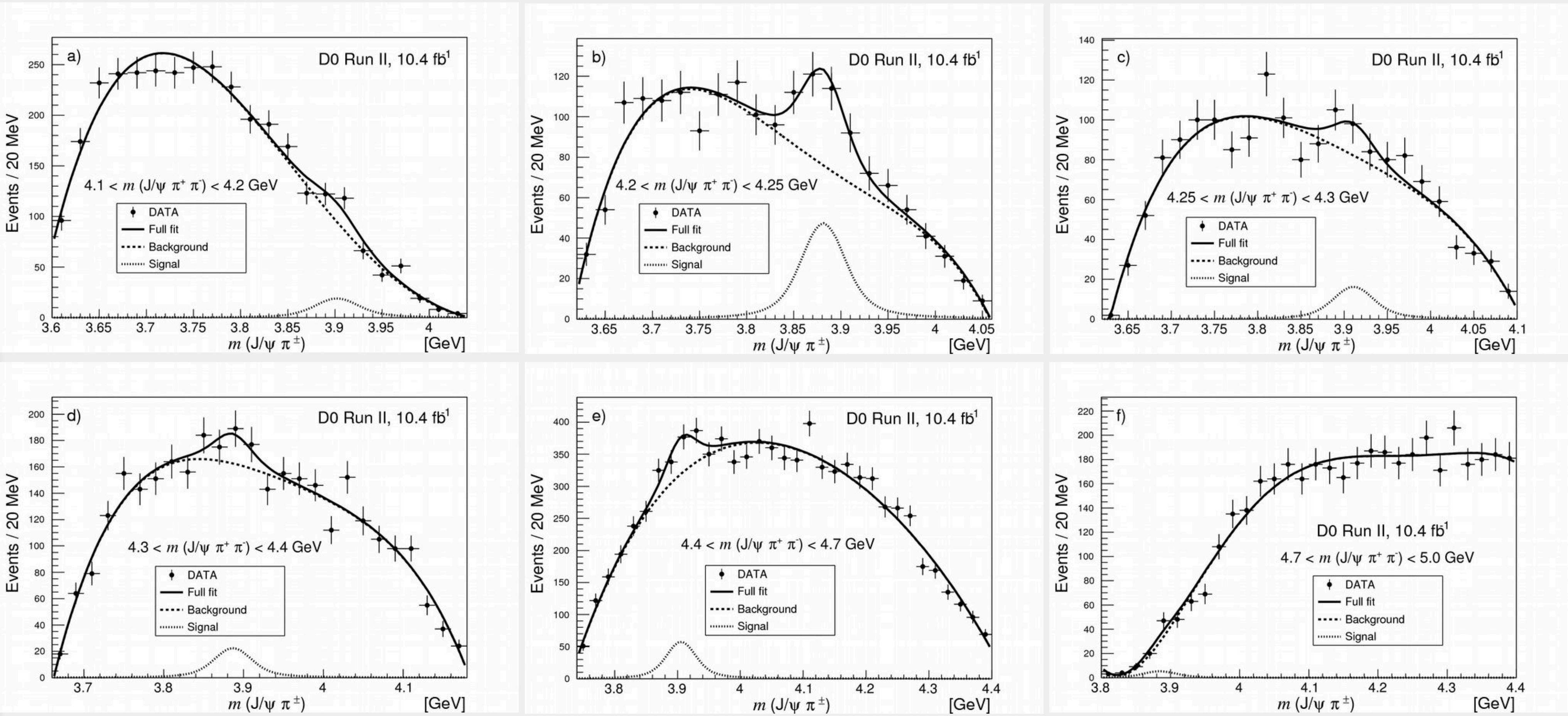
$H_b \rightarrow Y(4260)$ + anything , $Y(4260) \rightarrow Z_c^{\pm}(3900)\pi^{\mp}$, $Z_c^{\pm}(3900) \rightarrow J/\psi\pi^{\pm}$

where H_b is any b-flavored hadron

- $10.4\ fb^{-1}$ of $p\bar{p}$ collisions at 1.96 TeV, collected with single and di-muon triggers
- Select events with $J/\psi \rightarrow \mu^+\mu^-$ in the final state plus two tracks
- Treat both tracks as pions: charge($track_1$) $*$ charge($track_2$) < 0
- **Select events with displaced $J/\psi\pi^+\pi^-$ vertices (new!)**
  - **L_{xy} distribution has slope consistent with B hadron decays lifetime**

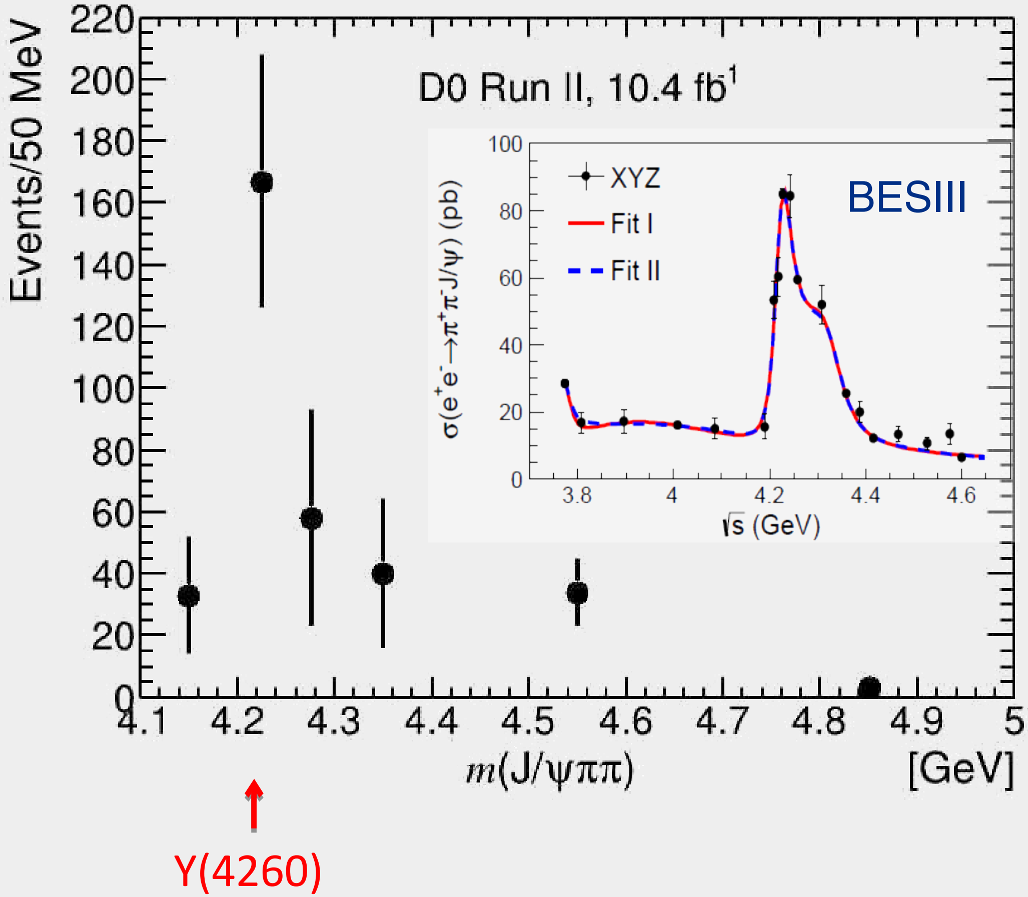


$m(J/\psi\pi^+)$ in slices of $m(J/\psi\pi^+\pi^-)$



- Fit $m(J/\psi\pi^+)$ in slices of $m(J/\psi\pi^+\pi^-)$ using S-wave relativistic B-W function
- Γ fixed to PDG value for the $Z_c^+(3900)$
- Signal and bkg parametrized with Chebyshev polynomials

$Z_c^{\pm}(3900)$ events vs $m(J/\psi\pi^+\pi^-)$

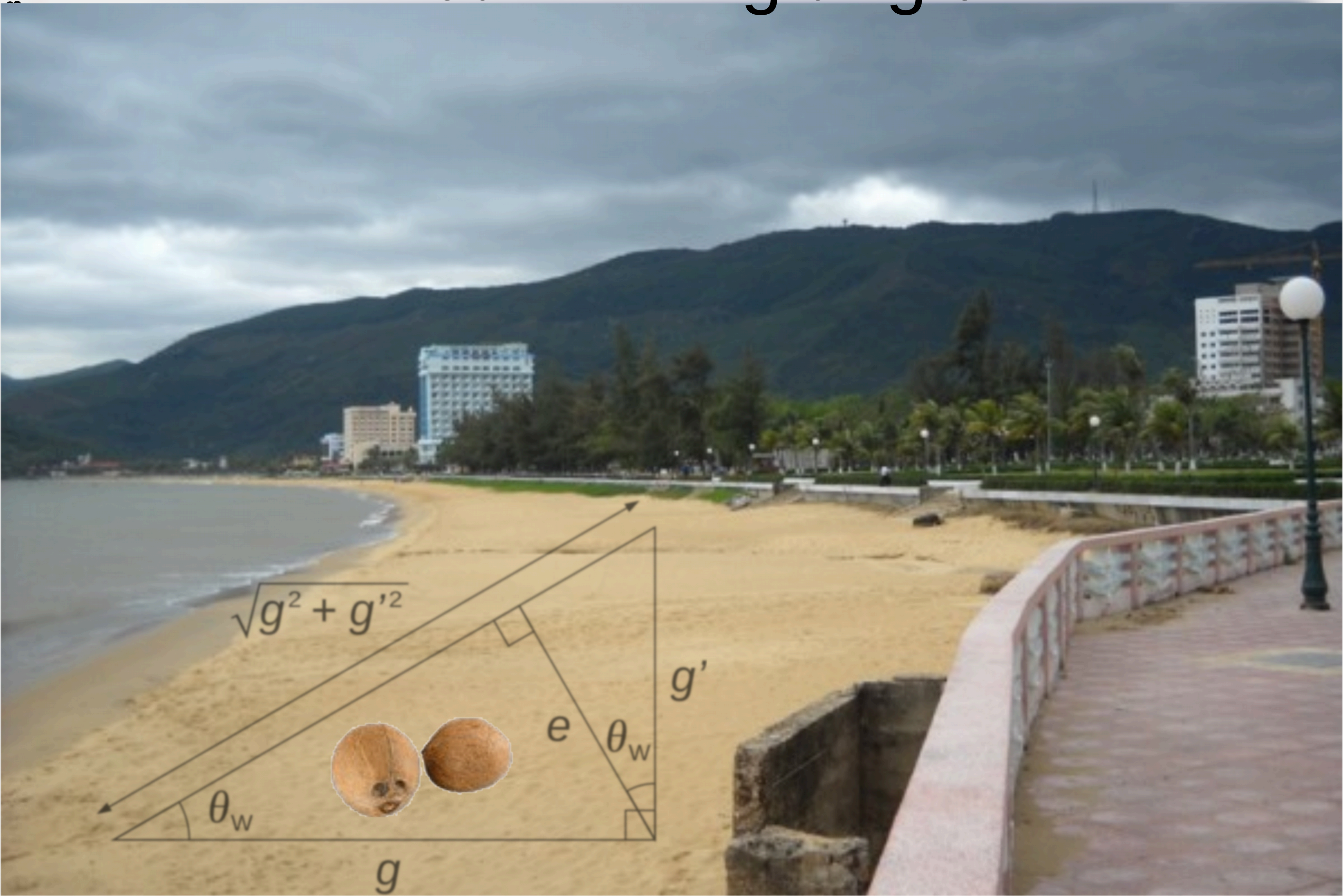


Majority of $Z_c^+(3900)$ events, as expected, are coming from $J/\psi\pi^+\pi^-$ states with masses in the 4.2 to 4.3 GeV region.

But there is an indication that some Z_c events come from $J/\psi\pi^+\pi^-$ masses above the Y(4260) and Y(4360)

- Measured $Z_c^+(3900)$ mass is M = 3895.0±5.2 (stat)$^{+4.0}_{-2.7}$(syst) MeV
  - In good agreement with BESIII and Belle
- Systematic uncertainties reduce significance of $Z_c^+(3900)$ peak to 4.6σ
- First observation of $Z_c^+(3900)$ as product of b-hadron decays

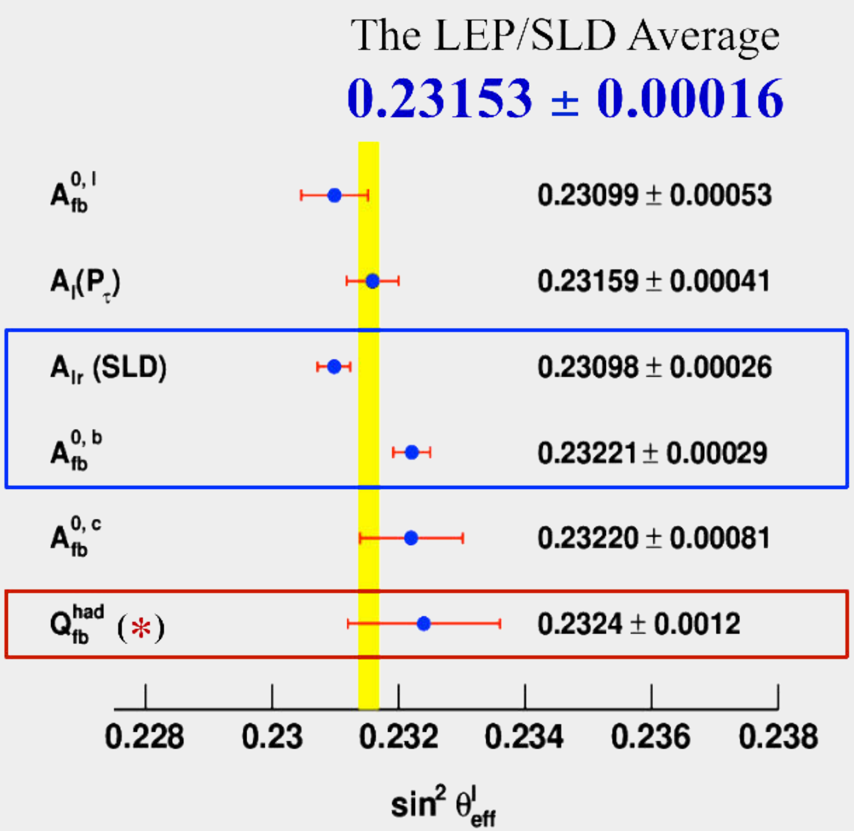
Weak mixing angle



The weak mixing angle ($\sin^2\theta_W$)

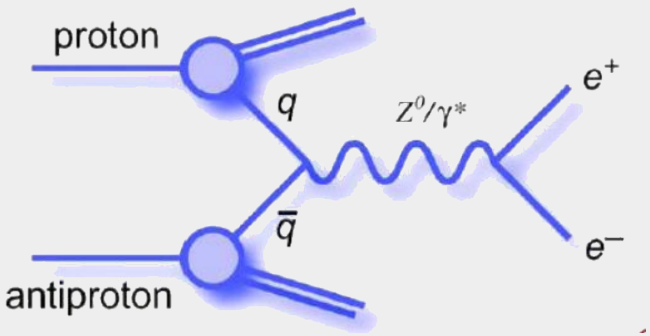
- Fundamental parameter of Standard Model
- The least precisely known among all electroweak fundamental parameters
- Most precise results from LEP/SLD have long standing discrepancy
- Large uncertainty in LEP $\sin^2\theta_W$ from light quark $q\bar{q}$ asymmetry Q_{fb}^{had} (*)
- Before Run II, prediction for the Tevatron experiment single channel: ~0.00050 (arXiv:hep-ex/0011009)

	relative uncertainty from experiments
fine structure constant α	$\sim 10^{-8}$
fermi-constant G_F	$\sim 10^{-5}$
Z boson mass M_Z	$\sim 10^{-5}$
weak mixing angle $\sin^2\theta_W$	best single measurement: 10^{-3}
	LEP/SLD combine: 6×10^{-4}



Weak-mixing angle @ Tevatron

- Drell-Yan lepton pairs are produced at the Tevatron through $p\bar{p} \to \gamma^*/Z \to \ell^+\ell^-$



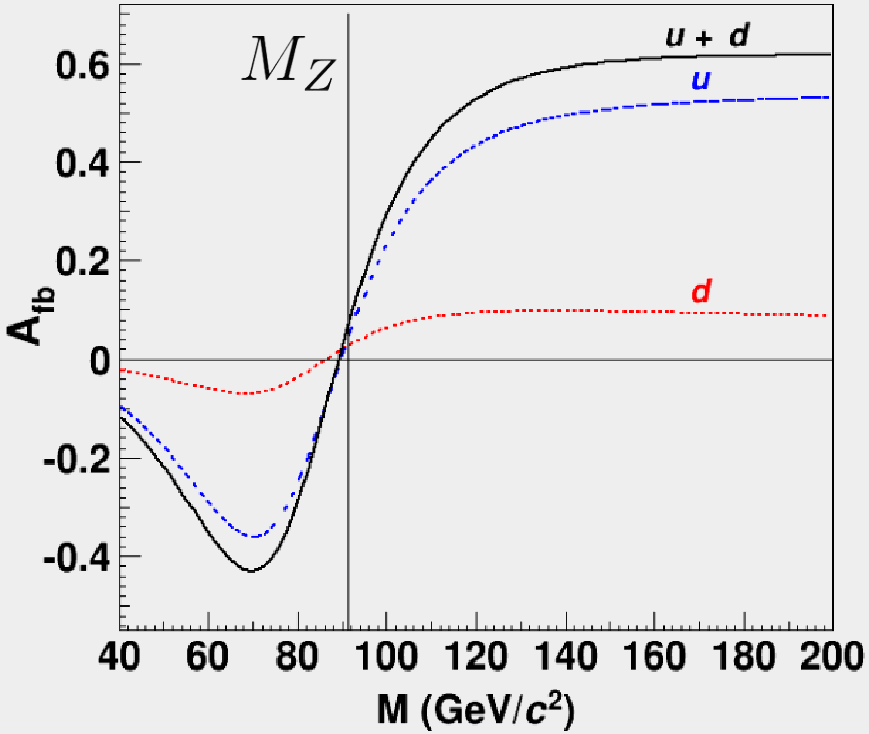
- The weak mixing angle can be measured from the forward-backward asymmetry A_{FB} of the polar angle distribution of these Drell-Yan pairs

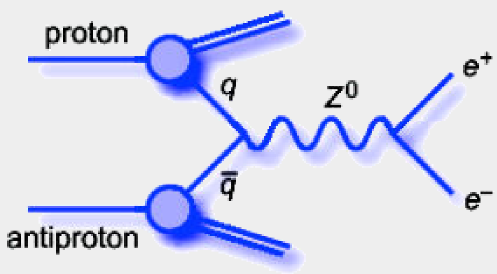
$q\bar{q} \to \gamma^* \to l^+l^-$	**Born level couplings**	$q\bar{q} \to Z \to l^+l^-$
$g_V^f = Q_f$	$\langle \bar{f} \vert (g_V + g_A\gamma^5)\gamma^\mu \vert f \rangle$	$g_V^f = I_3 - 2Q_f \sin^2\theta_W$
$g_A^f = 0$		$g_A^f = I_3$

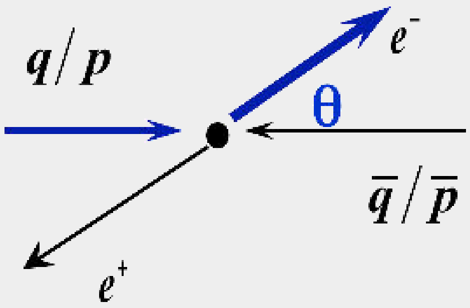
- Weak couplings altered by radiative corrections
- Multiplicative factor of a few % gives effective $\sin^2\theta_W$ coupling $\to \sin^2\theta^l_{eff}$
- **Can be measured via Parity-violating observables at Z-pole**

$$\sin^2\theta^l_{eff} = \mathrm{Re}[\kappa_l(M_Z)] \cdot \sin^2\theta_W$$

Weak-mixing angle @ Tevatron







Measure $l^- l^+$ angular distribution A_{FB} in the Collins-Soper rest frame of the boson. Polar angle, θ*, of the l^- is defined relative to direction of incoming quark

- **ZZ interference**
  - Sensitive to $\sin^2\theta_W$
  - near Z-pole: Best statistics/precision,
  - minimal γZ interference
- **γZ interference**
  - Independent of $\sin^2\theta_W$
  - Zero at Z-pole
  - Dominates away from Z-pole and sensitive to PDFs

Forward: $\cos\theta^* > 0$

Backward: $\cos\theta^* < 0$

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

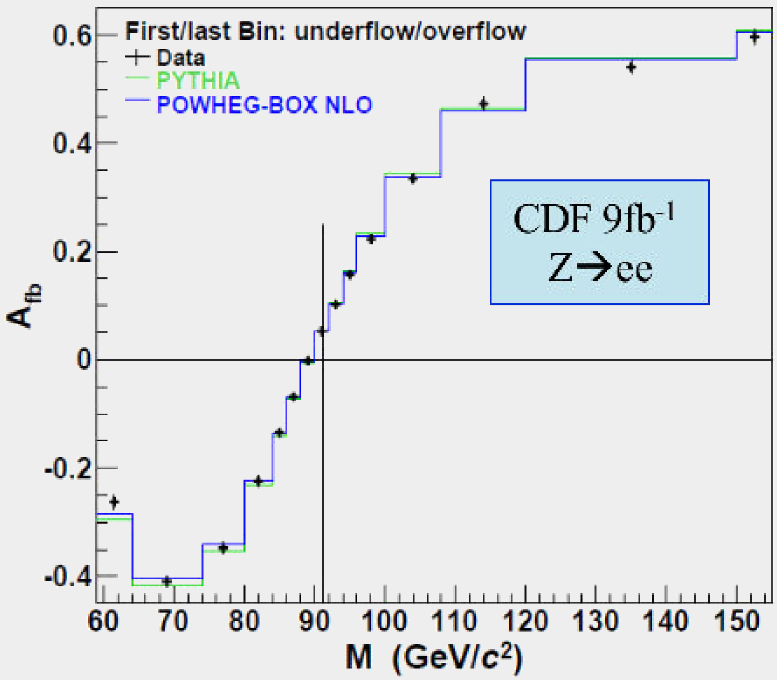
Measure at the Z pole!

Weak-mixing angle @CDF&DØ

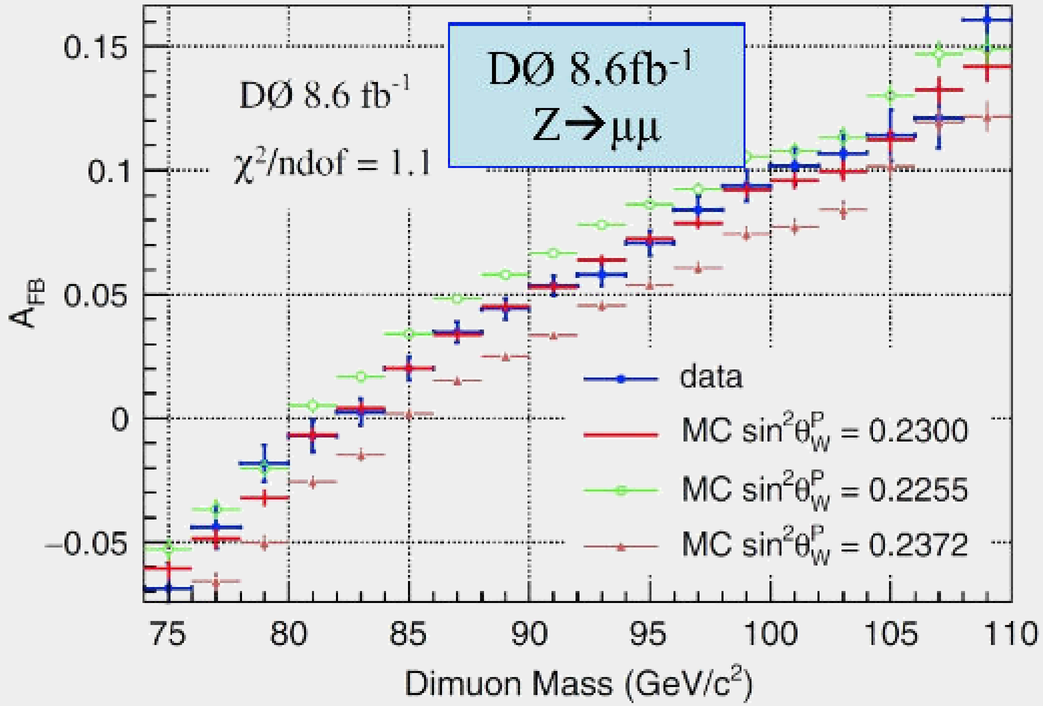
Common strategy

- Selection: strict di-lepton events in Z-pole mass region
- Extraction: observed $A_{FB}(M_{ll})$ vs MC templates with different $\sin^2\theta_W$ inputs
- Uncertainty: statistical + PDF + systematic (dominated by lepton calibrations)

PRD 93(2016)112016



New! **PRL120(2018)241802**



Weak-mixing angle @CDF&DØ

Common strategy

- Selection: strict di-lepton events in Z-pole mass region
- Extraction: observed $A_{FB}(M_{ll})$ vs MC templates with different $\sin^2\theta_W$ inputs
- Uncertainty: statistical + PDF + systematic (dominated by lepton calibrations)

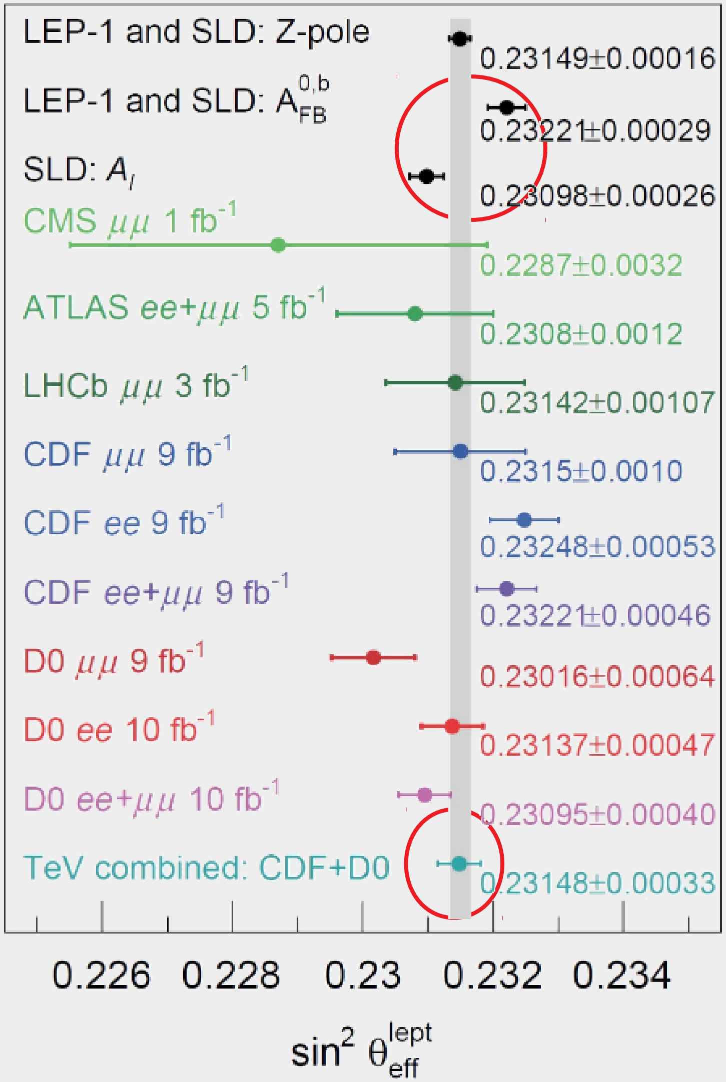
Summary of individual measurements:

	$\sin^2\theta_W \pm$ stat. $\pm$ syst. $\pm$ PDF	Total uncertainty
CDF $Z\to ee$ $9fb^{-1}$	$0.23248 \pm 0.00049 \pm 0.00004 \pm 0.00019$	± 0.00053
DØ $Z\to ee$ $9.7fb^{-1}$	$0.23147 \pm 0.00043 \pm 0.00008 \pm 0.00017$	± 0.00047
CDF $Z\to \mu\mu$ $9fb^{-1}$	$0.2315 \pm 0.0009 \pm 0.0002 \pm 0.0004$	± 0.0010
DØ $Z\to \mu\mu$ $8.6fb^{-1}$	$0.\ 23016 \pm 0.00059 \pm 0.00005 \pm 0.00024$	± 0.00064

Phys. Rev. D 97, 112007 (2018)

Weak-mixing angle @ Tevatron

Combination : High order corrections as ZFITTER + NNPDF3.0



CDF: 0.23221±0.00043±0.00007±0.00016
= 0.23221± 0.00046

DØ: 0.23095±0.00035±0.00007±0.00019
= 0.23095 ± 0.00040

- PDF uncertainty 100% correlated

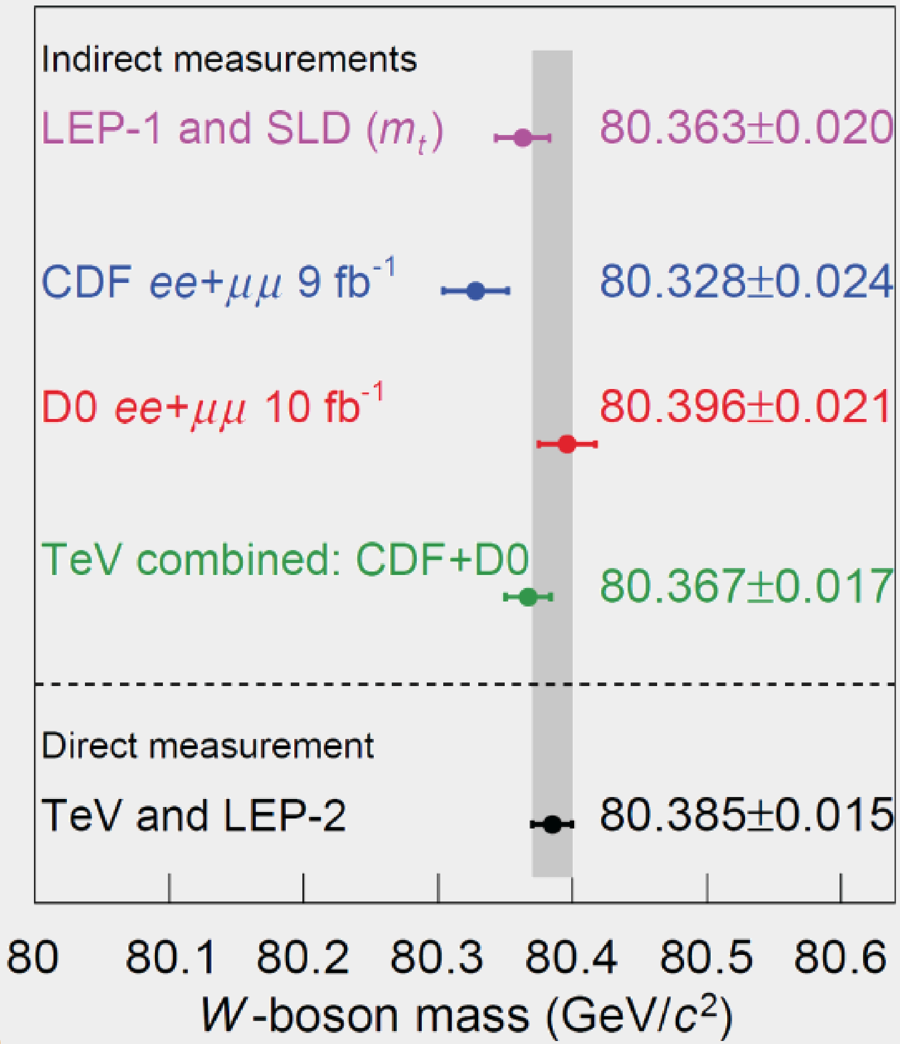
$$\sin^2\theta^l_{eff}[\text{Tev}] = 0.23148 \pm 0.00027(\text{stat}) \pm 0.00005(\text{syst}) \pm 0.00018(\text{PDF}) = \mathbf{0.23148 \pm 0.00033}$$

- Weight CDF/DØ: 0.4/0.6

- Tevatron legacy measurement
- Most precise measurement involving light quarks

Indirect W mass @ Tevatron

Using ZFITTER SM conversion of the effective and on-shell definitions as



$$\begin{cases} \sin^2\theta^l_{\text{eff}} = \text{Re}[\kappa_l(M_Z)] \cdot \sin^2\theta_W \\ \sin^2\theta_W = 1 - \dfrac{M_W^2}{M_Z^2}; \end{cases}$$

- M_W determination in the SM context:

80.367 ± 0.017 (Tevatron Indirect)

80.385 ± 0.015 (Tevatron+LEP Direct)

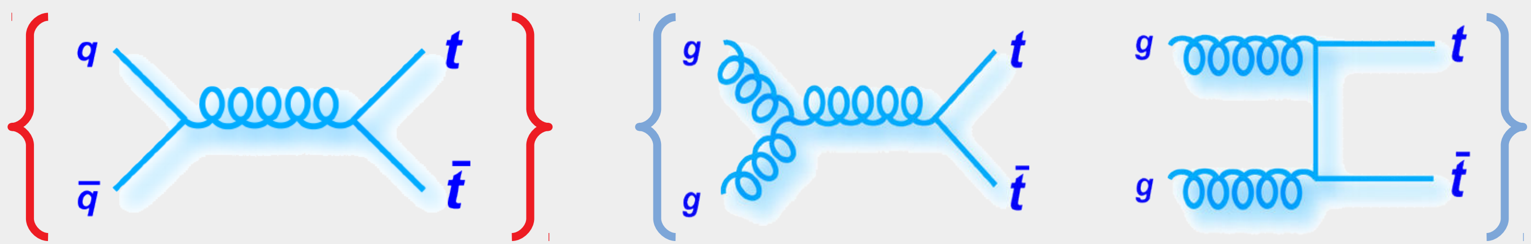
Top production and mass

Producing tops @ Tevatron

- At the Tevatron top mostly produced in pairs via $q\bar{q}$ annihilation

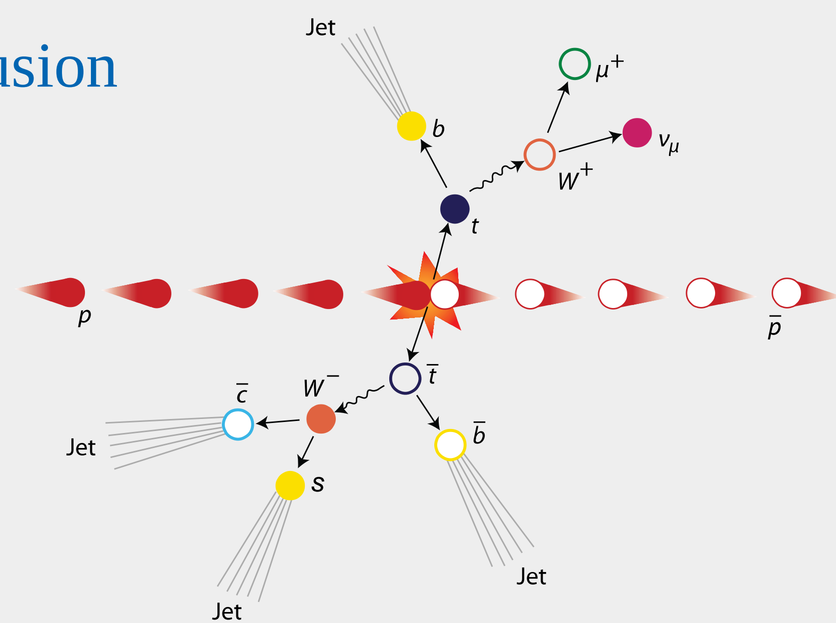
→ a unique data set for the top quark studies

~85%



~15%

- LHC: 80-90% gluon fusion



Cross-section $\sigma_{t\bar{t}} = 7.35^{+0.23}_{-0.27}$ pb

(NNLO +NNLL QCD for m_t=172.5 GeV):

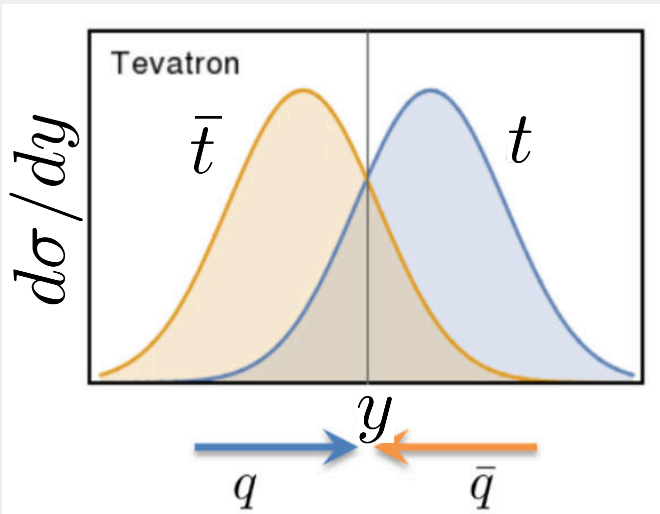
Czakon,Fiedler and Mitov, PRL **110** (2013) 252004
Czakon and Mitov, Comput. Phys. Commun. **185** (2014) 2930

$t\bar{t}$ production asymmetry

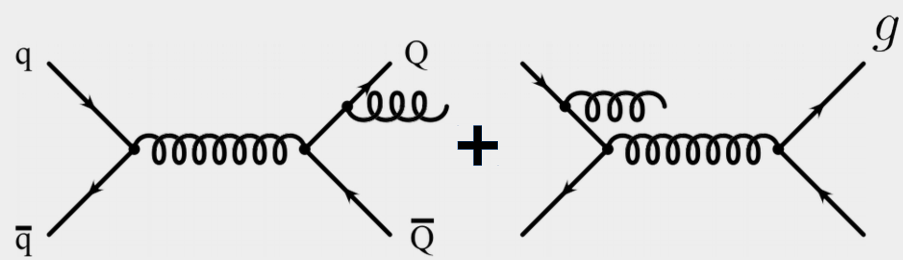
forward-backward asymmetry in $p\bar{p}$ collisions

$$\Delta y = y_t - y_{\bar{t}}$$

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

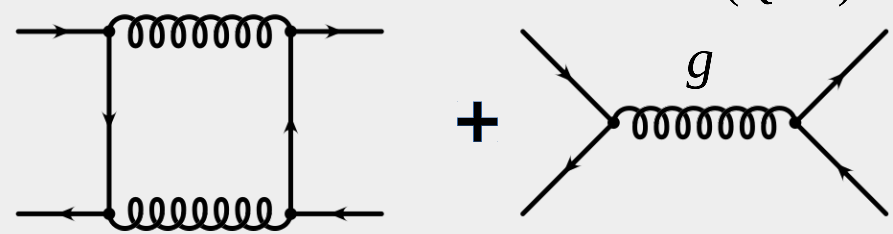


Negative asymmetry



Positive asymmetry

(QCD)



or Z/γ* (EW) non-neglegible

Differential distributions of heavy flavor produced in lowest order processes are symmetric for quark and antiquark final states

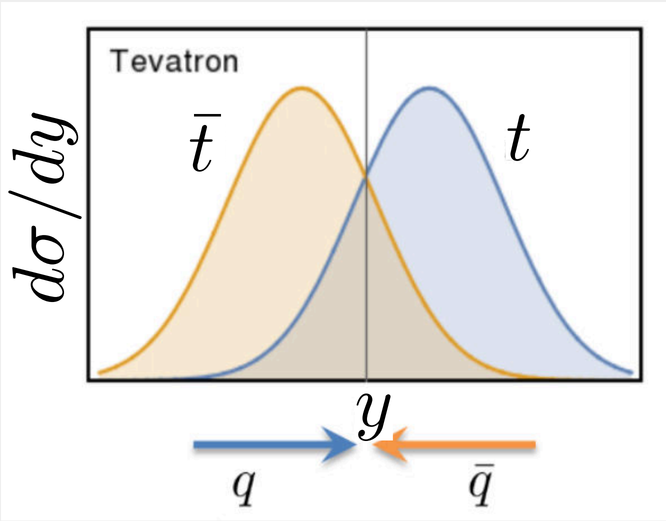
Interference with diagrams having real or virtual gluon emission have sizeable effect on Q, $\bar{Q}$ production

=> production charge asymmetry in SM, also sensitive to BSM effects

$t\bar{t}$ production asymmetry

forward-backward asymmetry in $p\bar{p}$ collisions

$$\Delta y = y_t - y_{\bar{t}}$$



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

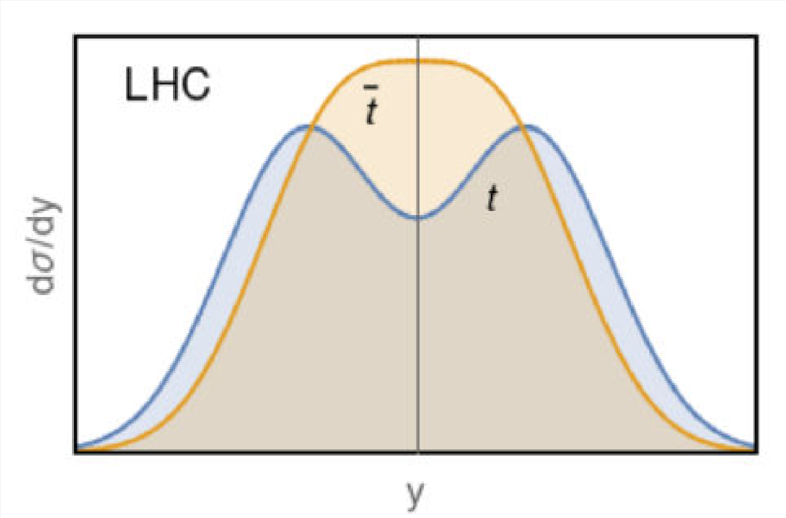
Comparison with pp collisions

Symmetric initial state

$$\Delta|y| = |y_t| - |y_{\bar{t}}|$$

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

(charge asym. ~ 1%)



- Asymmetric PDF for antiquarks (sea) and quarks (mostly valence)
- Observable effect => broadening distribution of top quarks

Tevatron and LHC measurements complementary for testing new physics models

Tevatron A_{FB} history

Measurements:

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

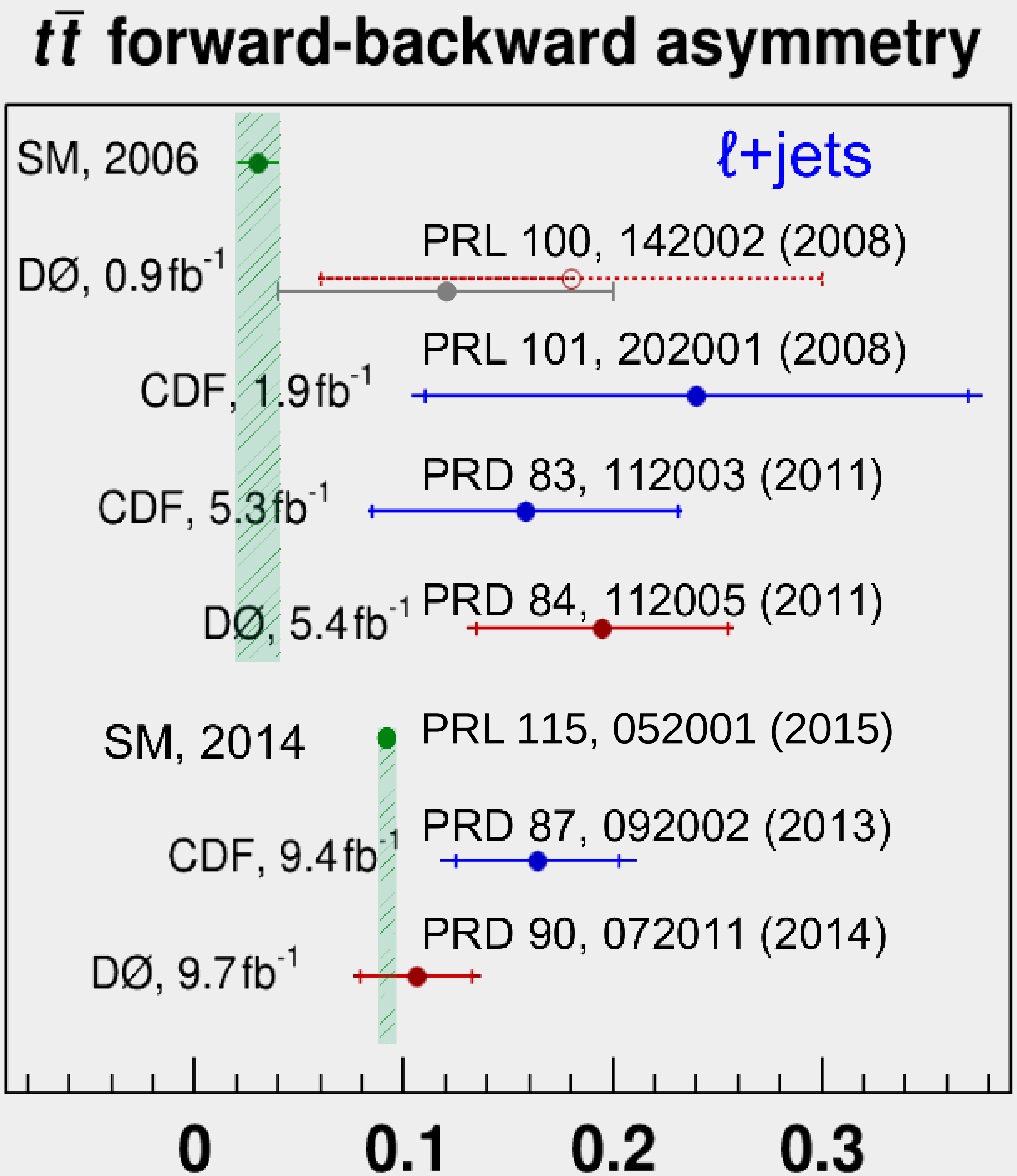
$$\Delta y = y_t - y_{\bar{t}}$$

Much interest in past years:

- ℓ+jets analyses showed departure from NLO SM expectations

More recent results:

- NNLO QCD+ NLO EW calculation gives larger effect: ~9.5±0.5%
- More data, analyses improved:
  - Dilepton channels added 2015 – 2016
  - Latest experimental results are lower
  - More compatible with SM



Tevatron A_{FB} history

Measurements:

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

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  - Dilepton channels added 2015 – 2016
  - Latest experimental results are lower
  - More compatible with SM

Understanding of asymmetry has evolved on multiple fronts:

- Improvements to theory calculations
- Data collection

latest

- **Combined Tevatron measurements and differential distributions**
  - All combinations calculated using BLUE method
  - Account for correlations in analysis methods and inputs

Phys. Rev. Lett. 120, 042001 (2018)

Tevatron Run II inclusive asymmetries

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

$$\Delta y = y_t - y_{\bar{t}}$$

$t\bar{t}$ asymmetry vs NNLO prediction: **1.3 SD**

$$A_{FB}^{\ell} = \frac{N_\ell(q \times \eta > 0) - N_\ell(q \times \eta < 0)}{N_\ell(q \times \eta > 0) + N_\ell(q \times \eta < 0)}$$

Lepton qη asymmetry vs NLO prediction: **1.6 SD**

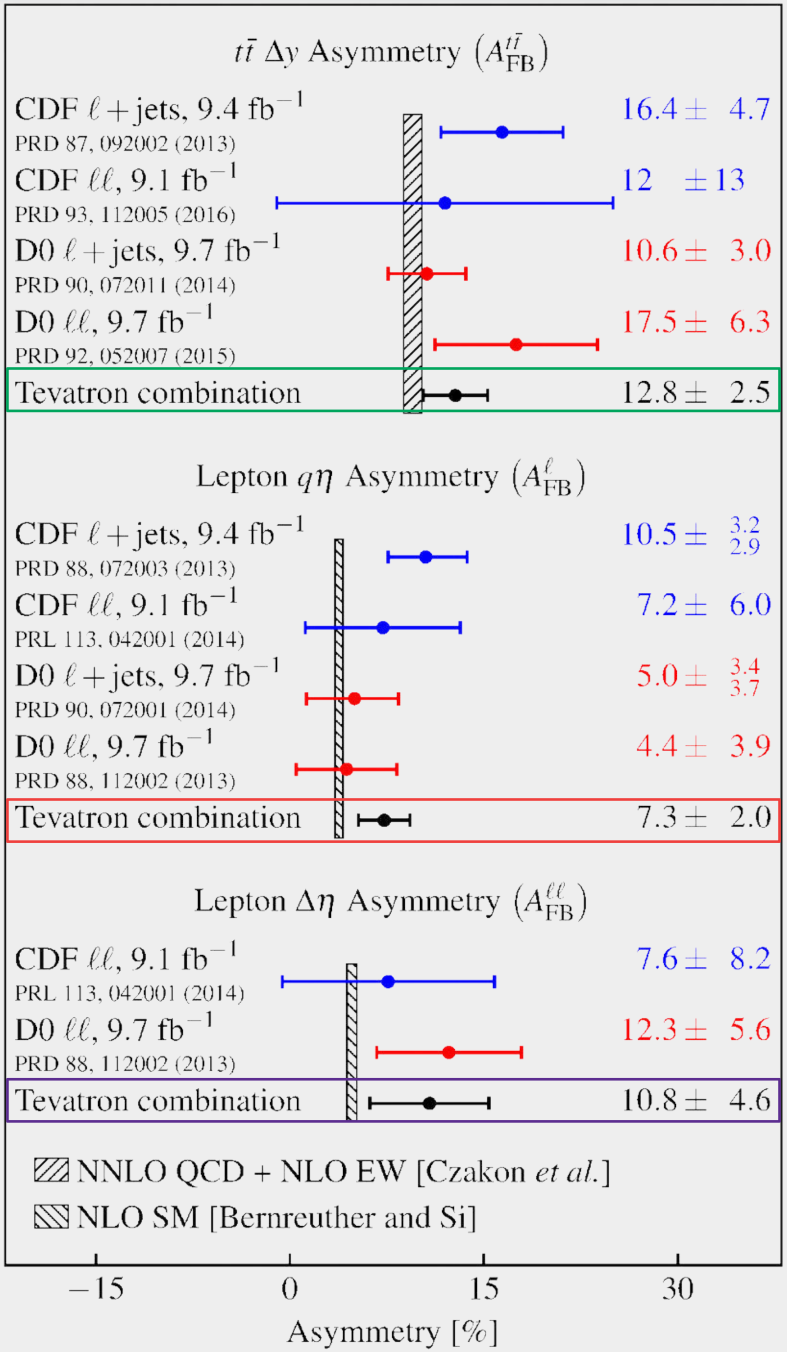
$$\Delta \eta = \eta_{\ell+} - \eta_{\ell-}$$

$$A_{FB}^{\ell\ell} = \frac{N(\Delta \eta > 0) - N(\Delta \eta < 0)}{N(\Delta \eta > 0) + N(\Delta \eta < 0)}$$

Lepton Δη asymmetry vs NLO prediction: **1.3 SD**

Note: the three asymmetry measurements are correlated

Results compatible with SM

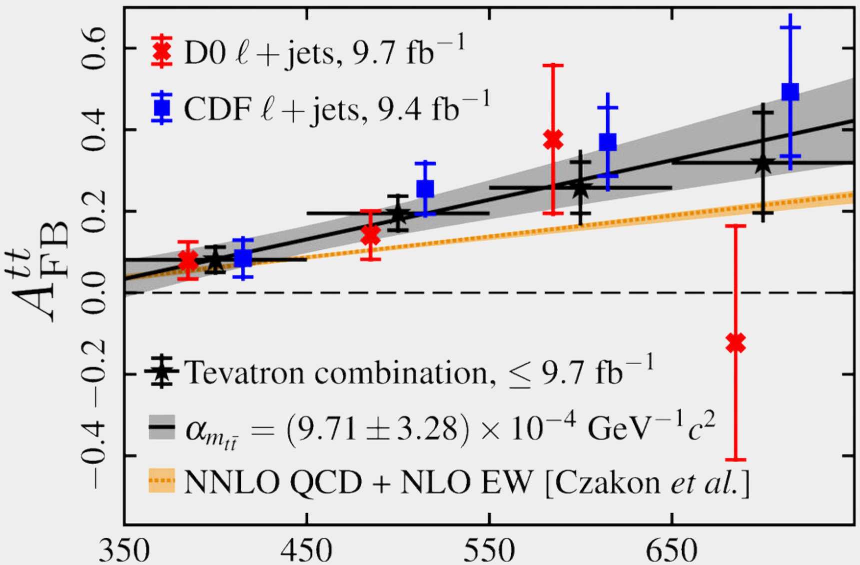


Phys. Rev. Lett. 120, 042001 (2018)

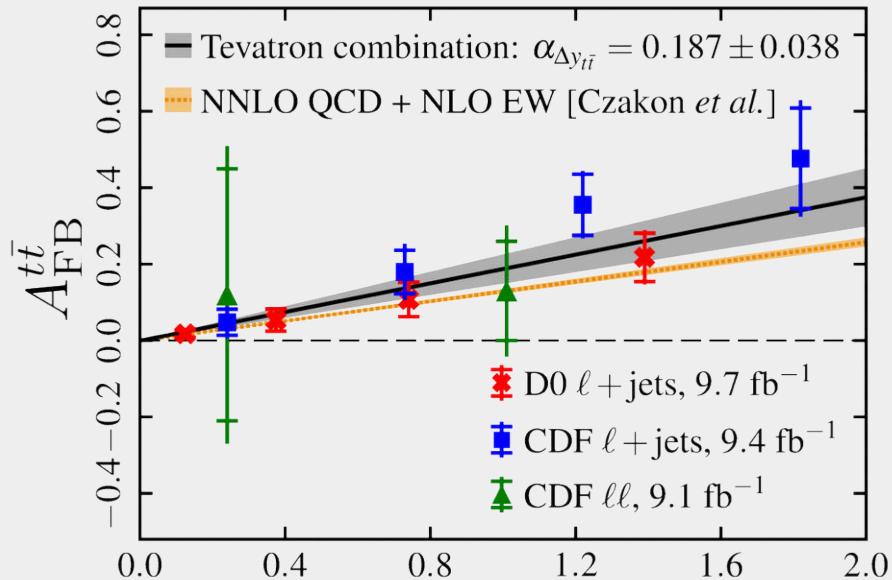
Differential measures of $A_{fb}^{t\bar{t}}$

Combined $A_{FB}^{t\bar{t}}$ as a function of $m_{t\bar{t}}$ and $\Delta y_{t\bar{t}}$

- Include bin-to-bin correlations due to unfolding
- Compare to NNLO QCD + NLO EW calculation



Mass ($m_{t\bar{t}}$ [GeV]) dependence combination



$\Delta y_{t\bar{t}}$ dependence

- Fit combination with $\beta+\alpha$ x ($m_{t\bar{t}}$-450 (GeV))
  - α=(9.71± 3.28)x10^{-4} /GeV,
  - β = 0.131 ± 0.034
- NNLO QCD + NLO EW prediction
  - α = $(5.11^{+0.42}_{-0.64})$x10^{-4} /GeV,
  - β = $0.087^{+0.005}_{-0.006}$
- Agreement within 1.3 s.d.

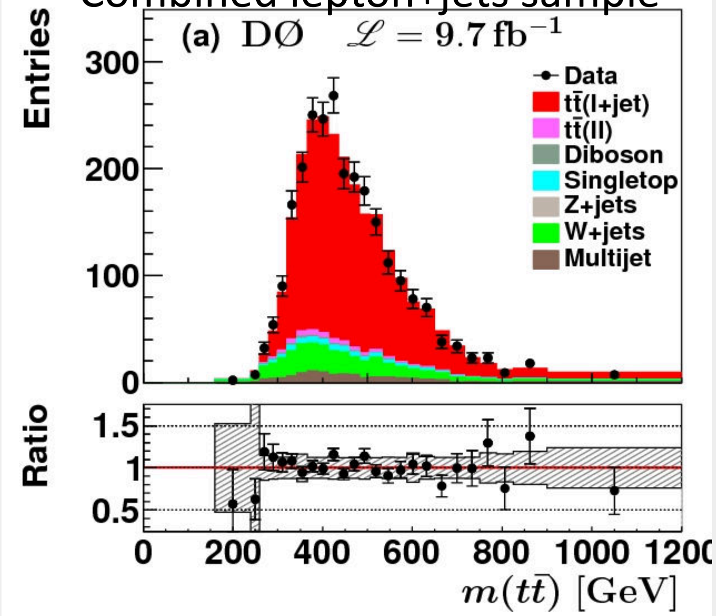
- Fit individual measurements with a single slope parameter α
  - α=(0.187± 0.038)
- NNLO QCD + NLO EW prediction
  - α=$(0.129^{+0.006}_{-0.012})$
- Agreement within 1.5 s.d.

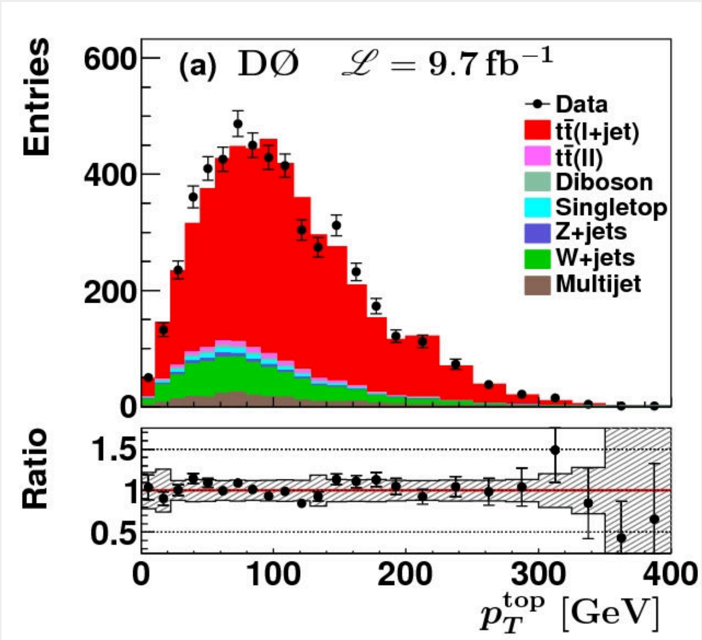
Top pole mass from differential XS

Total cross section depends on the pole mass. Can be determined in SM based on integrated or differential production cross sections

- Variables used
  - Mass of di-top system, m(tt)
  - Top transverse momenta, p_T(t)
- Data taken from published lepton+jets measurement [PRD 90 092006 (2014)]
- Need background subtracted and unfolded differential cross section to compare to theory calculations
- Use regularized matrix unfolding

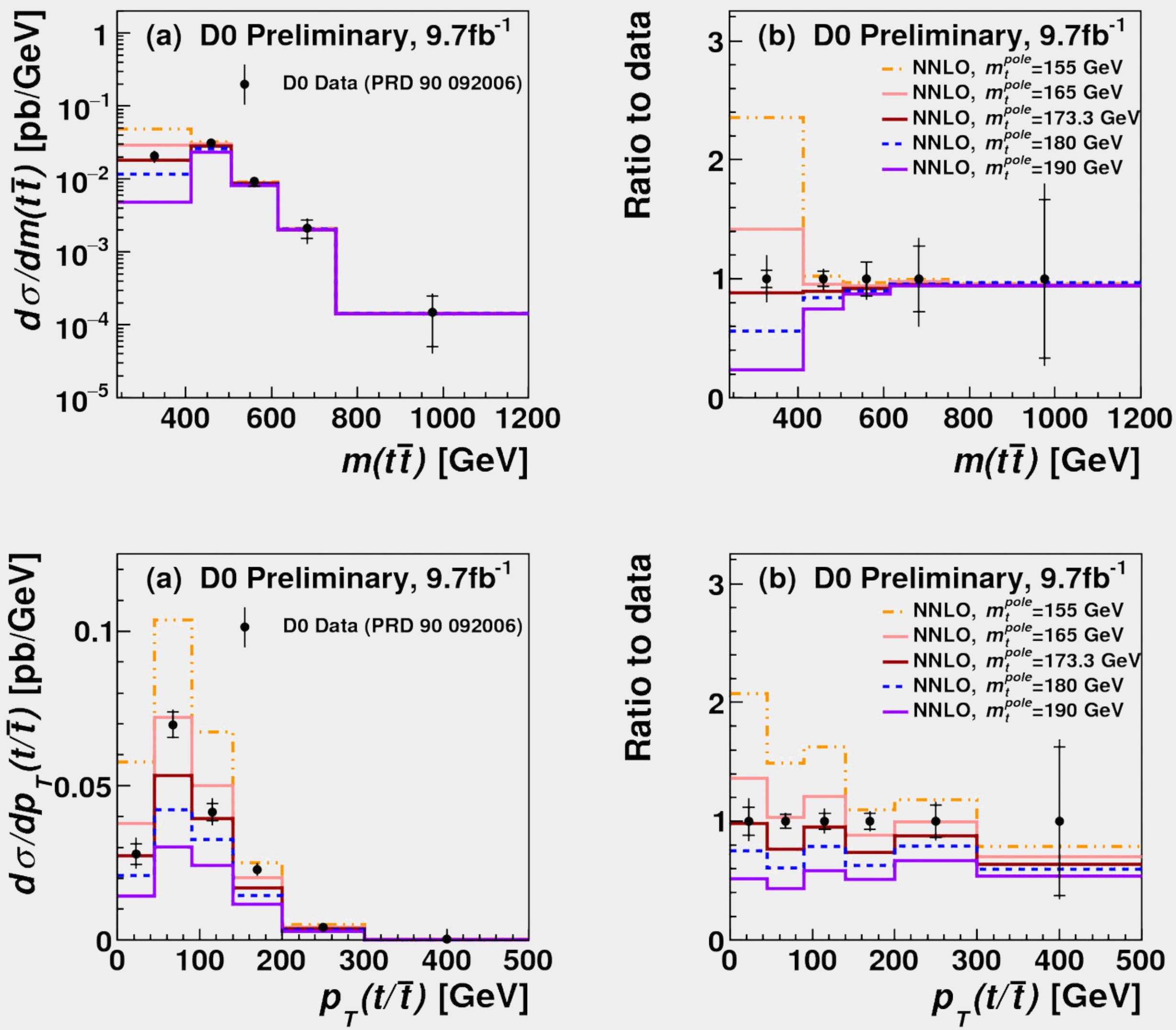
Combined lepton+jets sample





Top pole mass from differential XS

- Data taken from published lepton+jets measurement [PRD 90, 092006 (2014)]
- Pole mass is extracted for both NLO and NNLO PDF sets from MSTW2008, CT10, NNPDF2.3 and HERAPDF
- Here compared to NNLO pQCD calculations (Czakon, Fiedler, Heymes, Mitov, JHEP, 1605, 034 (2016)) with MSTW 2008.

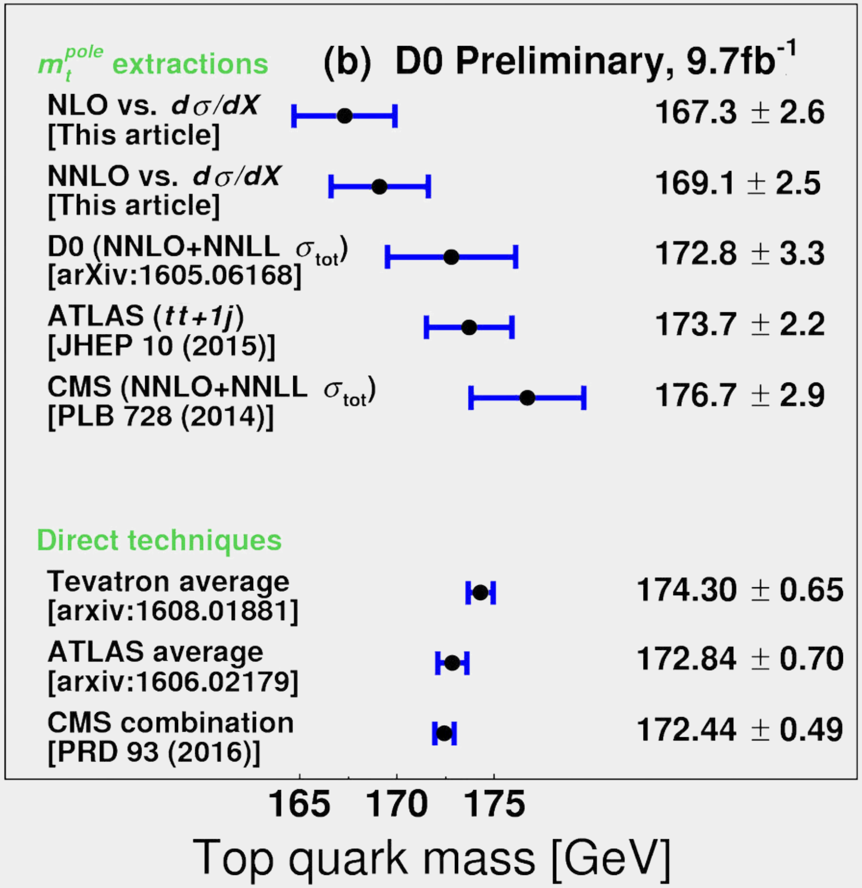


Sensitivity mainly at the threshold in m(tt) and for lower p_T(t)

Top pole mass from differential XS

Comparison of Results

- Good agreement between pole mass results within uncertainties.
- (Tevatron direct measure of top mass slightly higher than LHC average.)
- No significant difference between direct mass and pole mass.
- Final DØ pole mass result soon with smaller uncertainties and slightly shifted central value.



Extracted top mass using NNLO calculation: m_t = 169.1 ± 2.5 GeV

(NLO result m_t = 167.3 ± 2.6)

Compare to result using inclusive cross section: $m_t = 172.8^{+3.4}_{-3.2}\,(\text{tot.})\ \text{GeV}.$

Phys. Rev. D 94, 092004 (2016)

Summary

- DØ observes $Z_c^{\pm}(3900)$ exotic state decaying to $J/\psi\pi^{\pm}$ with 4.6σ significance
  - Production of $Z_c(3900)$ is consistent with coming from heavy flavor hadron decays

$$H_b \rightarrow Y(4260),\ Y(4260) \rightarrow Z_c^{\pm}(3900)\pi^{\mp},\ Z_c^{\pm}(3900) \rightarrow J/\psi\pi^{\pm}$$

- DØ confirms production of X(5568) state using semileptonic decay of B_s^0 meson
  - X(5568) properties are consistent in B_s^0 meson hadronic and semileptonic decays
  - 6.7σ combined significance of X(5568) state observation in the two channels

- CDF sets upper limit of $f[X(5568)/B_s^0]$ = 6.7% estimated @ (95% C.L.)
  - Nominal 2σ tension with DØ result
  - Different kinematic regions make “apples-to-apples” comparison difficult
- Studies of exotic mesons, including their properties, production and decay mechanisms should help to develop models of multi-quark configurations
  - Such models are important to guide experimental studies, understanding of strong interactions
- Tevatron combined weak mixing angle measure achieves the first precise light-quark related measurement at hadron colliders **$\sin^2\theta^l_{eff} = 0.23148 \pm 0.00033$**
- Twenty (plus) years after discovery, Tevatron data still providing new insights into top quark production and mass!

Looking forward to the next 25 years at RdV

Thank you!