Recent Tevatron Results from the Winter Conferences 2017

Peter H. Garbincius - Fermilab – member of *DØ*

April 28, 2017

D0 Forward-Backward Asymmetry in $Z^0 \rightarrow \mu^+ \mu^-$, $\sin^2 \theta_W$, and indirect M_W

CDF inclusive-isolated prompt photons

D0 X5568 $\rightarrow B_s \pi$ via semileptonic decay $B_s \rightarrow \mu \nu D_s X$ and combination with $B_s \rightarrow J/\psi \phi$

D0 Search for an exotic $J/\psi \Lambda$ resonance

first public presentation : CDF $\sigma_{Z^0} * B(Z^0 \rightarrow b\ bbar)$ and b-jet Energy Scale

In Memory of Marj Corcoran

Our D0 Colleague, Friend, and co-Leader of the D0 HF/QCD Group

Tevatron $p\bar{p}$ at $\sqrt{s}$ = 1.96 TeV

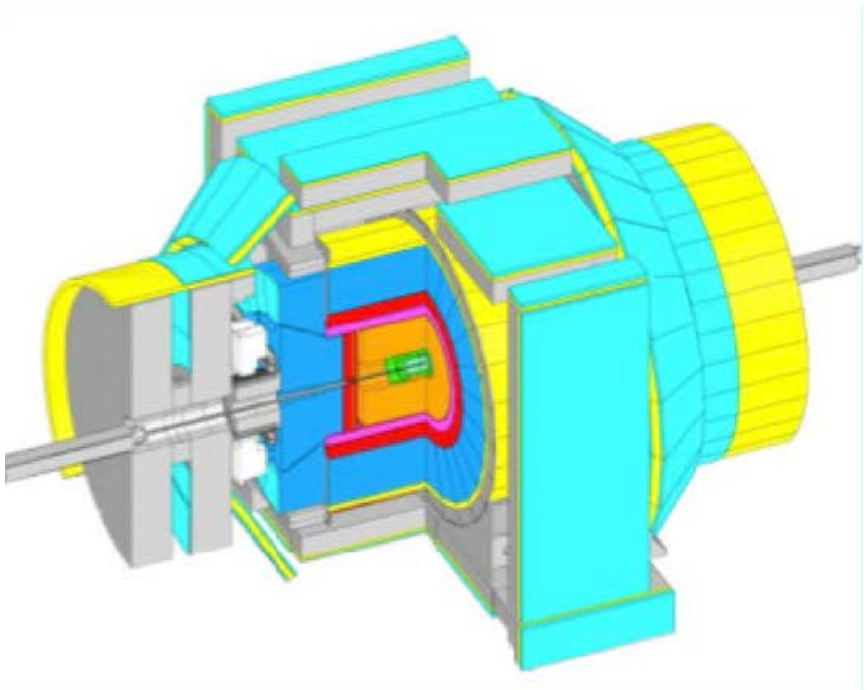
shutdown at end of September 2011 $\int \mathcal{L}\, dt = 10\ \text{fb}^{-1}$

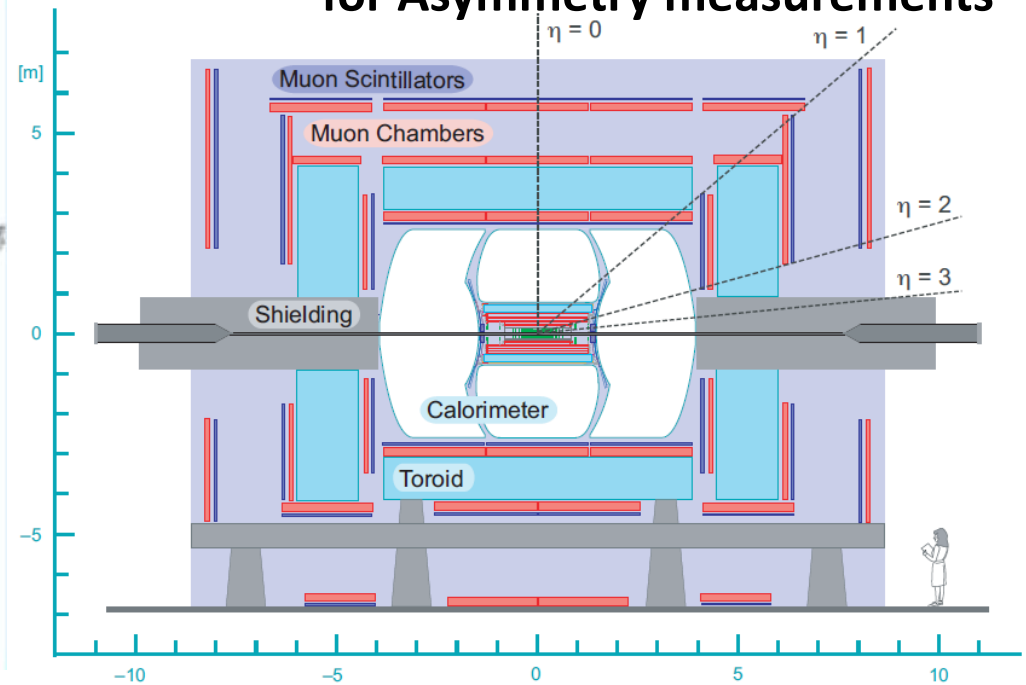
***FINAL* analyses based on Run II data sets 2001-2011**

uniquely $p\bar{p}$!

CDF II: **displaced vertex triggers**
PID by *dE/dx* and TOF

DØ: **excellent μ-id and coverage**
flip solenoid & toroid polarities
for Asymmetry measurements





We are grateful to the Fermilab Scientific Computing Division for its continuing support of computing infrastructure for these analyses

Lots to cover, so

Unless they are vital to a specific analysis,

I'll try to separate and brush over

the mundane features, such as

triggers, event selection, p_T cuts,

mass windows & sidebands, etc.

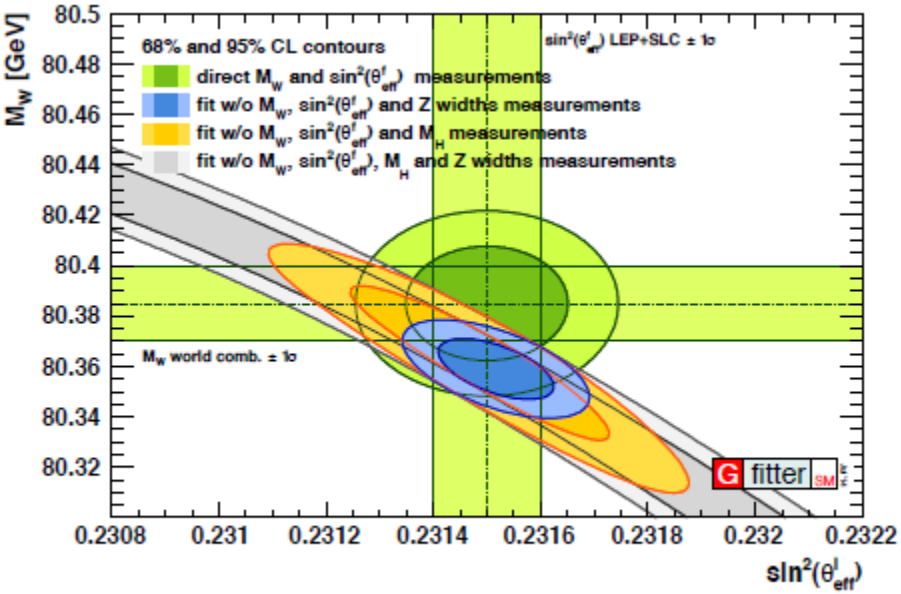
Of course, this information will be available

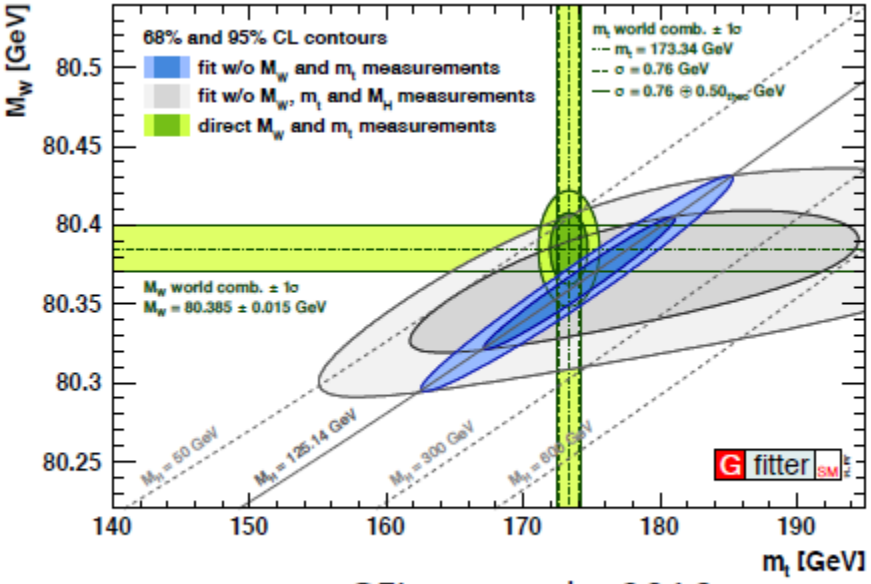
in the back-up slides

I'll skip this info unless asked.

Importance of EW studies

attack the Standard Model from many directions, using e^+e^-, p-pbar, p-p, and ν beams to study $W^\pm$, Z^0, $\sin^2\theta_W$, t-tbar, Higgs verifying consistency or searching for deviations



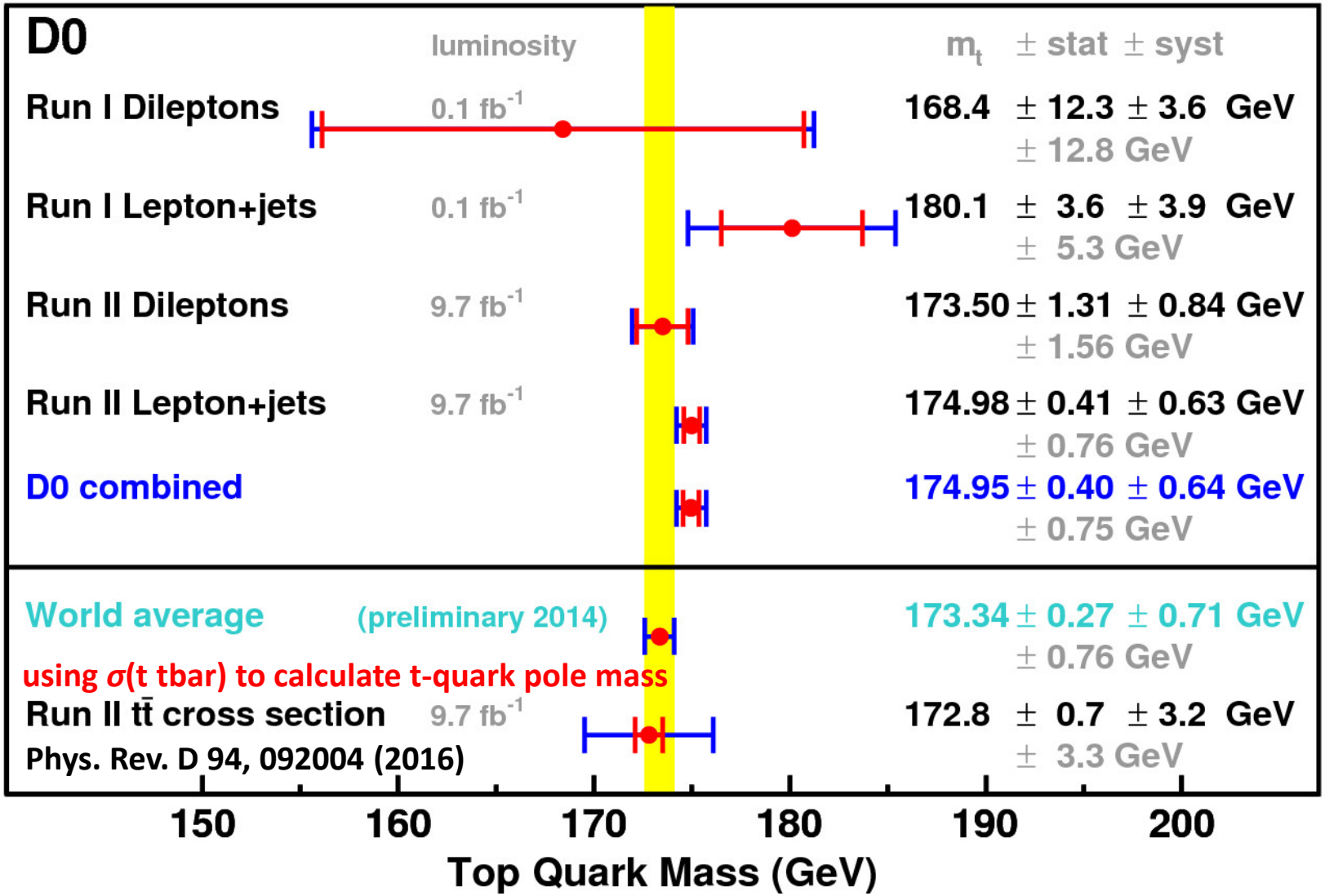


GFitter results 2016

D0 Top Mass Combination

FERMILAB-PUB-17-079-E arXiv:1703.06994 *now submitted to Phys. Rev. D*

refine measurement with increasing integrated luminosity

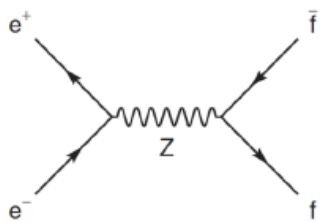


new D0 $\sin^2\theta_{eff}^{lept}$ for $Z/\gamma^* \rightarrow \mu\,\mu$

preliminary - D0 Note 6497-CONF March 17, 2017

https://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/EW/E42/E42.pdf

- The forward-backward asymmetry A_{fb} arises from the interference of the vector and axial vector couplings.



$$-i\frac{g}{2\cos\theta_W}\bar{f}\gamma^\mu(g_V^f - g_A^f\gamma_5)fZ_\mu \qquad \begin{cases} g_V^f = I_3^f - 2Q_f\sin^2\theta_W \\ g_A^f = I_3^f \end{cases}$$

$$\sin^2\theta^f_{eff} = \frac{1}{4|Q_f|}\left(1 - \frac{g^f_V}{g^f_A}\right)$$

EM: $Q_f\,\bar{f}\,\gamma^\mu\,f\,A_\mu$

- Convert $\sin^2\theta_{eff}^{ll}$ to $\sin^2\theta_W$ using conversion factor calculated using ZFitter (depends on well known M_Z): Re(κ) ~ 1.037

$$\boxed{\sin^2\theta_{eff}^{Lept} = \mathrm{Re}[\kappa_l(M_Z)]\cdot\sin^2\theta_W}$$

("effective", Zfitter)

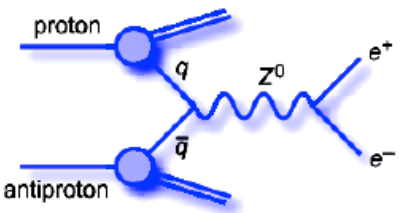
$$\boxed{\sin^2\theta_W = 1 - \frac{M_W^2}{M_Z^2}}$$

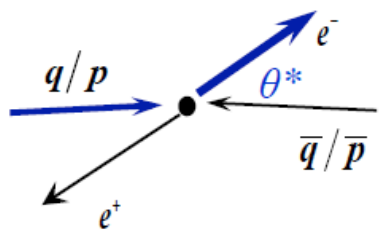
("on-shell")

Can be directly measured via Parity-violating observables at Z-pole

new D0 $\sin^2\theta_{eff}^{lept}$ for $Z/\gamma^* \rightarrow \mu\,\mu$

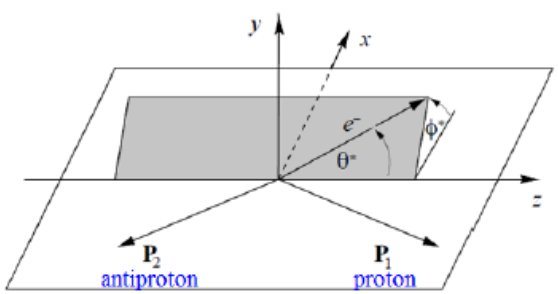
Measure background-subtracted A_{FB} in the Collins-Soper reference frame (minimizes effect of p_T of the *di-lepton*)



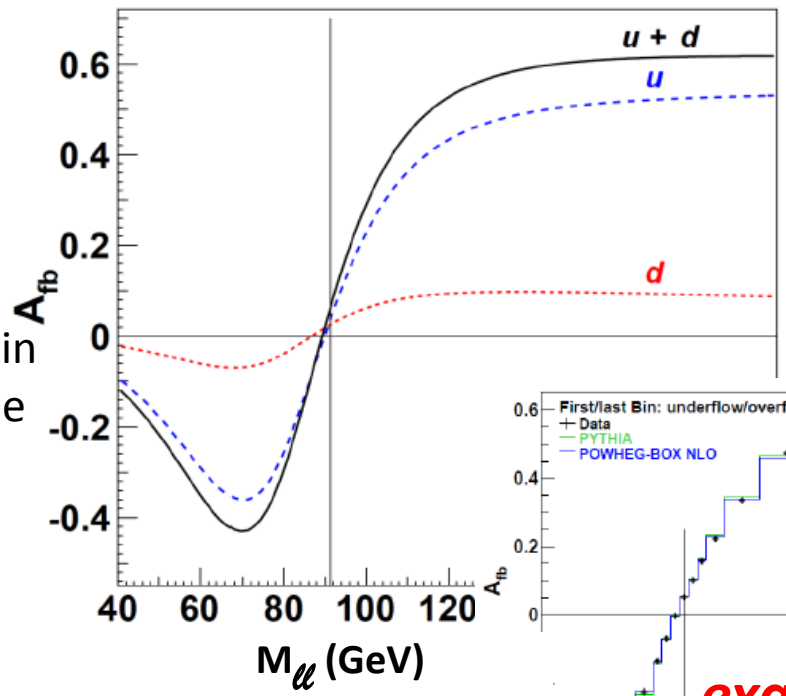


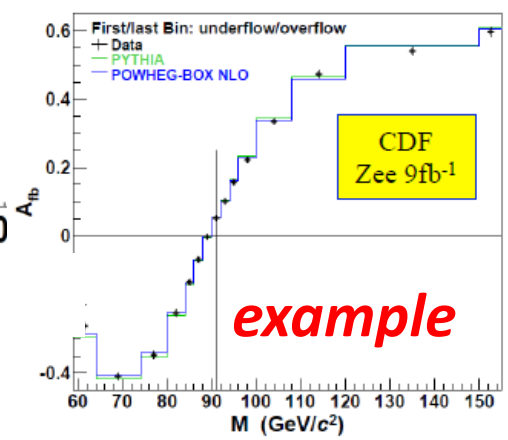
$$\cos\theta^* = \frac{2(p_l^+ p_{\bar{l}}^- - p_l^- p_{\bar{l}}^+)}{m(l\bar{l})\sqrt{m^2(l\bar{l}) + p_T^2(l\bar{l})}}$$

$$p_l^{\pm} = p_0 \pm p_3$$ calculated in LAB frame



$$A_{fb} = \frac{N(\cos\theta^* > 0) - N(\cos\theta^* < 0)}{N(\cos\theta^* > 0) + N(\cos\theta^* < 0)}$$





PRD 93(2016)112016

new D0 $\sin^2\theta_{eff}^{lept}$ for $Z/\gamma^* \rightarrow \mu\,\mu$

angular distribution in Collins-Soper frame

$$d\sigma/d\cos\theta^* \sim 1 + \cos^2\theta^* + A_4 \cos\theta^*$$

where around the Z^0 pole, $A_{FB}(m) = \frac{3}{8} A_4(m) \sim f(\sin^2\theta_W)$

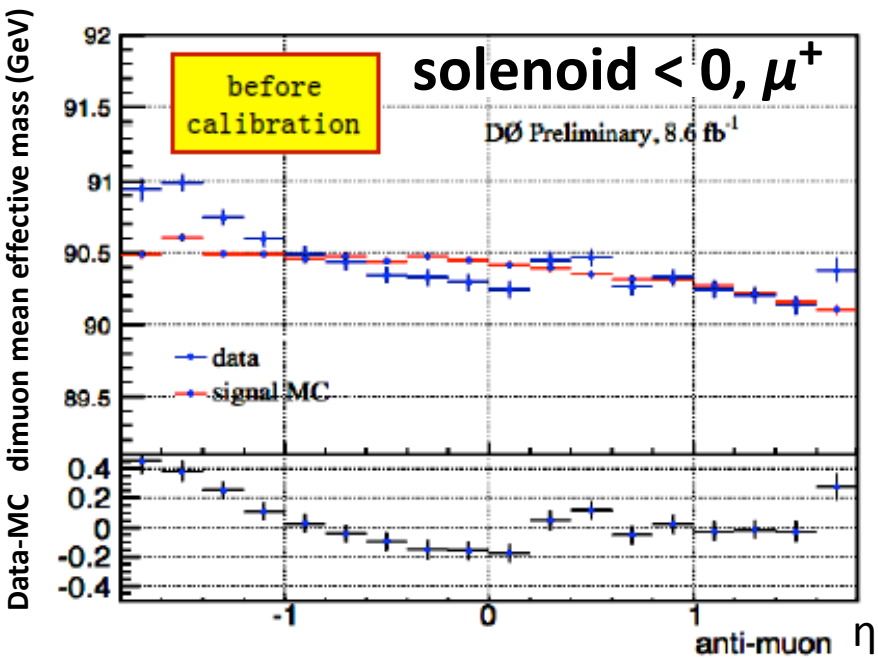
The directly measured $A_{fb}^{\ell\ell}$ corresponds to
PYTHIA Born-level (parton-level) $\sin^2\theta_W^B$
and needs higher order QCD, QED, & EW corrections

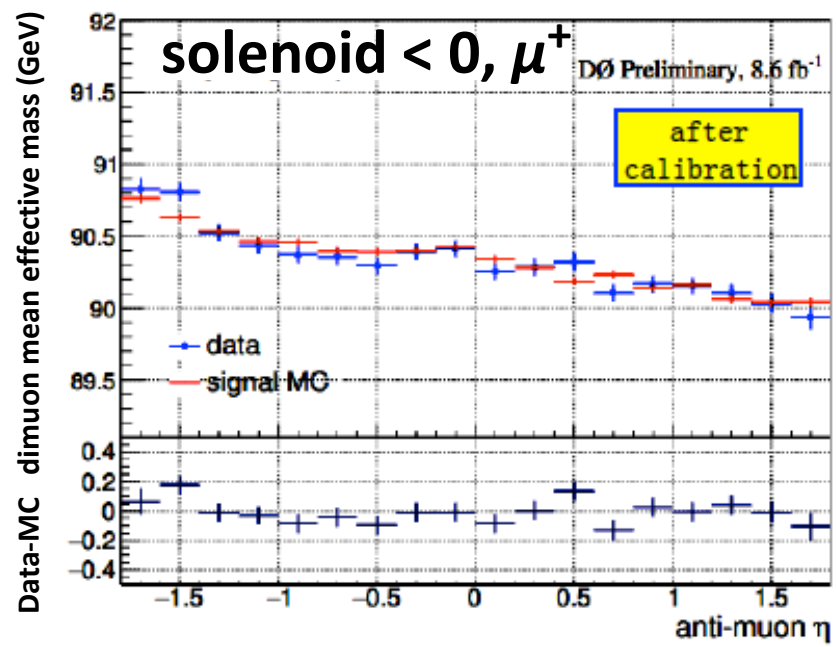
$A_{fb}^{\ell\ell}$ also measured at LHC,
but without valence anti-quarks in beam,
needs to assume longitudinal boost of Z caused by valence quark annihilating with sea anti-quark
sometimes incorrect → *dilution*

new D0 $\sin^2\theta_{eff}^{lept}$ for $Z/\gamma^* \rightarrow \mu\,\mu$

Scale momenta **of both reconstructed Monte Carlo and reconstructed data to agree with the generated MC model as function of η for each μ^- and μ^+ charge (q) and for each solenoid polarity (S)**

$$P(\eta, q, S) = \alpha(\eta, q, S) \times P_{\text{obs}}(\eta, q, S)$$

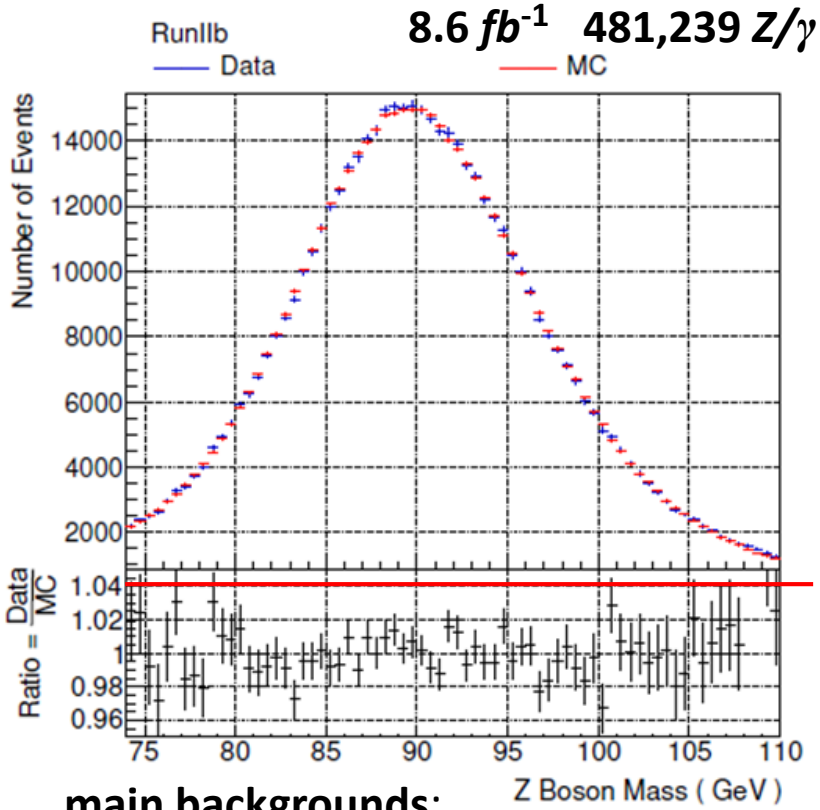


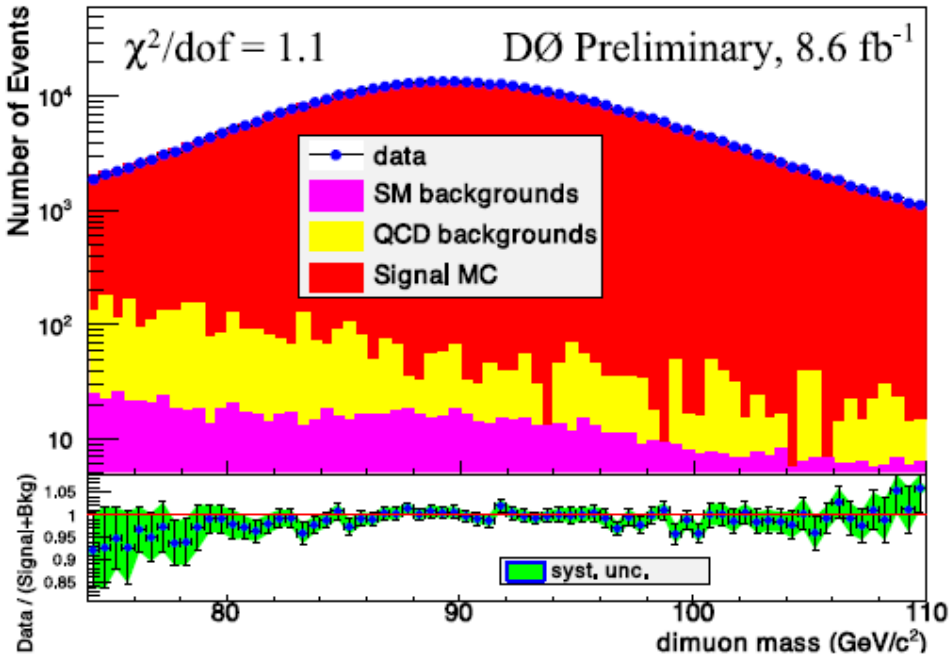


note: $\langle M_{\mu\mu}\rangle$ is for sum of events over acceptance varying with η

new D0 $\sin^2\theta_{eff}^{lept}$ for $Z/\gamma^* \rightarrow \mu\,\mu$

8.6 fb^{-1} 481,239 $Z/\gamma^* \rightarrow \mu\,\mu$ candidate events





main backgrounds:

analysis range: $74 < M_{\mu\mu} < 110$ GeV

0.68% multi-jets faking muons

– model with same sign muons & "reversing" the muon cuts

0.20% *W+jets*, $Z/\gamma^* \rightarrow \tau\,\tau$, diboson (*WW* + *ZZ*), *t-tbar*

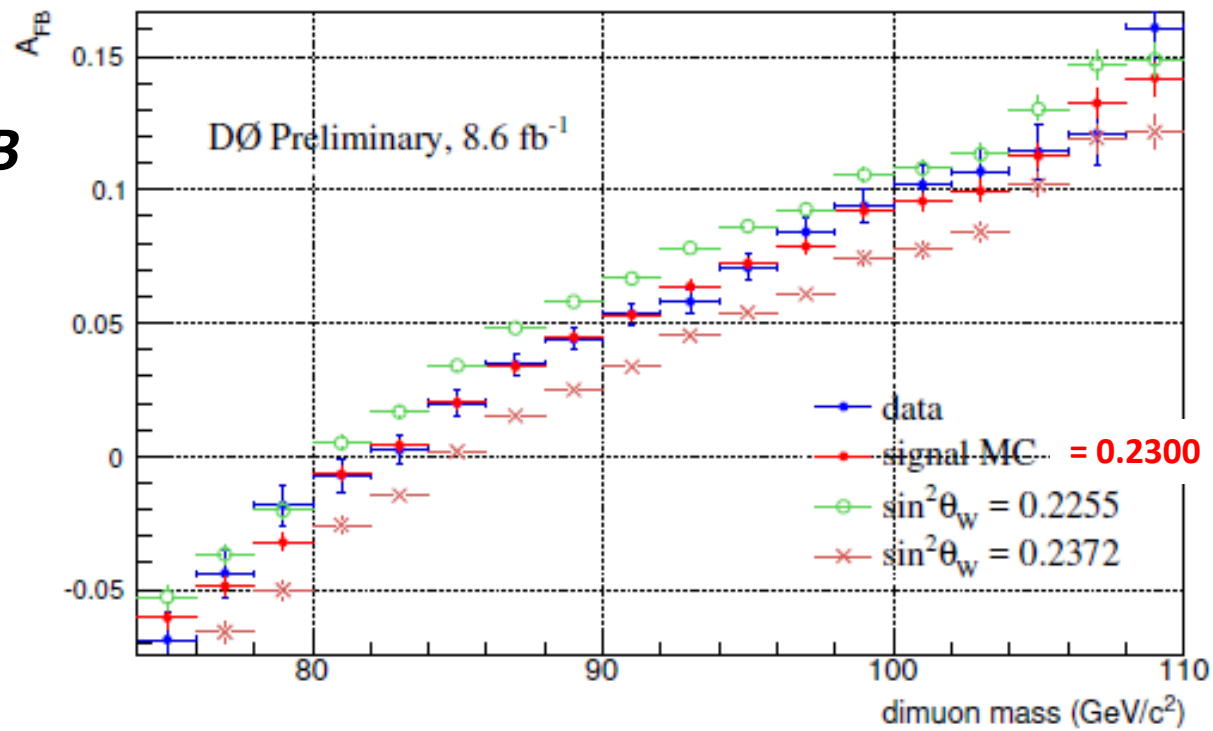
- *W+jets* est using ALPGEN for matrix elements & PYTHIA for showering & hadronization

- $Z/\gamma^* \rightarrow \tau\,\tau$, diboson (*WW* + *ZZ*), *t-tbar* are estimated using PYTHIA for matrix elements, showering, and hadronization

new D0 $\sin^2\theta_{eff}^{lept}$ - analysis flow

form templates for $A_{FB}(M_{\mu\mu})$ for diff values of $\sin^2\theta_W^{born}$ using LO PYTHIA and NNPDF 3.0 corrected to NNLO

A_{FB}



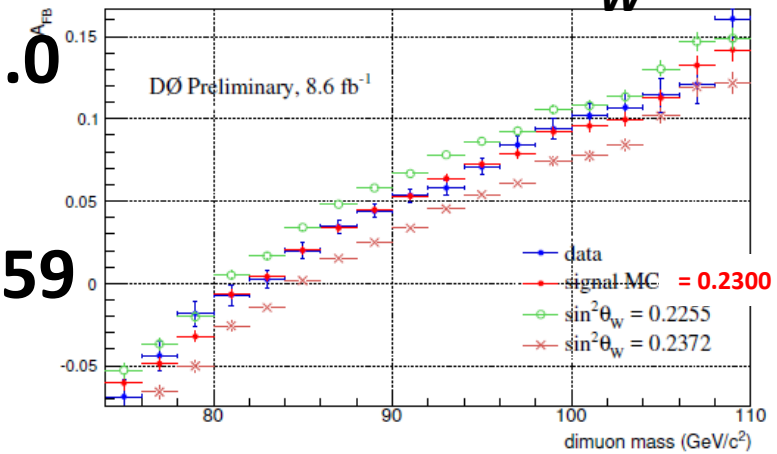
$M_{\mu\mu}$

fit for best match to background subtracted A_{FB} data

→ $\sin^2\theta_W^{born}$ = 0.22994 ± 0.00059 (stat.)

new D0 $\sin^2\theta_{eff}^{lept}$ - analysis flow

form templates for $A_{FB}(M_{\mu\mu})$ for diff values of $\sin^2\theta_W^{born}$
using LO PYTHIA NNPDF 3.0



fit for best match to A_{FB} data

→ $\sin^2\theta_W^{born} = 0.22994 \pm 0.00059$

correct LO PYTHIA → NLO RESBOS

including effects of specific *u*-, *d*-quark couplings

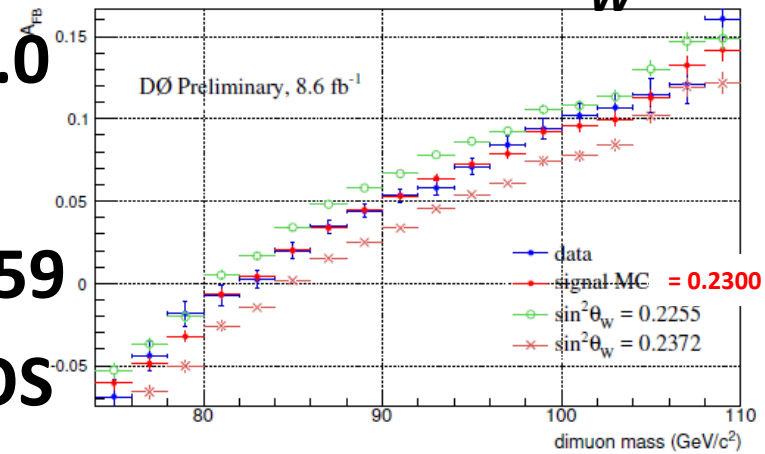
relative to charged *lepton* couplings

$\sin^2\theta_{eff}^{lept} = 0.22994 + 0.00008 = 0.23002 \pm 0.00066$

includes systematic uncertainty
see next page for details

new D0 $\sin^2\theta_{eff}^{lept}$ - analysis flow

form templates for $A_{FB}(M_{\mu\mu})$ for diff values of $\sin^2\theta_W^{born}$
using LO PYTHIA NNPD F3.0



fit for best match to A_{FB} data

→ $\sin^2\theta_W^{born} = 0.22994 \pm 0.00059$

correct LO PYTHIA → NLO RESBOS

$\sin^2\theta_{eff}^{lept} = 0.22994 + 0.00008 = 0.23002 \pm 0.00066$ includes systematic uncertainty

ZFITTER for weak corrections & fermion loop corrections to photon propagator (complex and mass dependent)

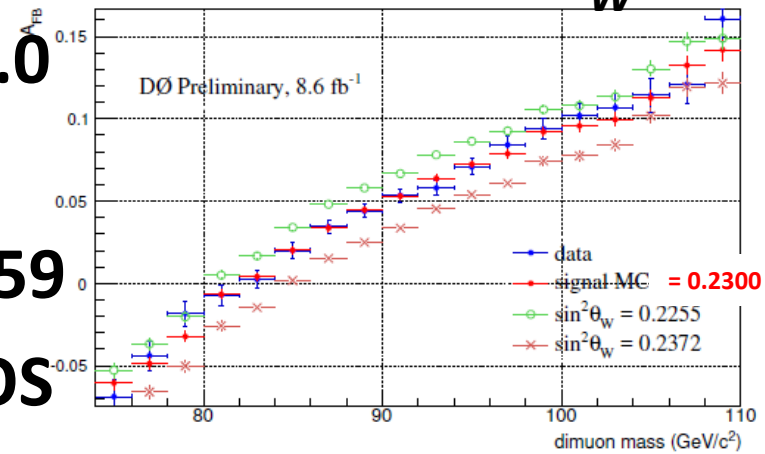
ZFITTER uses on-shell renormalization scheme

$$\sin^2\theta_W = \sin^2\theta_{eff}^{lept}/\mathrm{Re}[\kappa_\ell(M_z)] = \sin^2\theta_{eff}^{lept}/1.037$$

$$\sin^2\theta_W = 0.22181 \pm 0.0064$$

new D0 $\sin^2\theta_{eff}^{lept}$ - analysis flow

form templates for $A_{FB}(M_{\mu\mu})$ for diff values of $\sin^2\theta_W^{born}$
using LO PYTHIA NNPDF 3.0



fit for best match to A_{FB} data

→ $\sin^2\theta_W^{born} = 0.22994 \pm 0.00059$

correct LO PYTHIA → NLO RESBOS

$\sin^2\theta_{eff}^{lept} = 0.22994 + 0.00008 = 0.23002 \pm 0.00066$ includes systematic uncertainty

convert to on-shell renormalization scheme w Zfitter

$$\sin^2\theta_W = \sin^2\theta_{eff}^{lept}/\mathrm{Re}[\kappa_\ell(M_z)] = \sin^2\theta_{eff}^{lept}/1.037$$

$$\sin^2\theta_W = 0.22181 \pm 0.00064$$

using PDG value of M_Z

$$M_W = M_Z * \sqrt{1 - \sin^2\theta_W} = 80{,}441 \pm 33\ \mathrm{MeV}/c^2$$

new D0 $\sin^2\theta_{eff}^{lept}$ for $Z/\gamma^* \rightarrow \mu\,\mu$

$$\sin^2\theta_W^B = 0.22994 \pm 0.00059$$

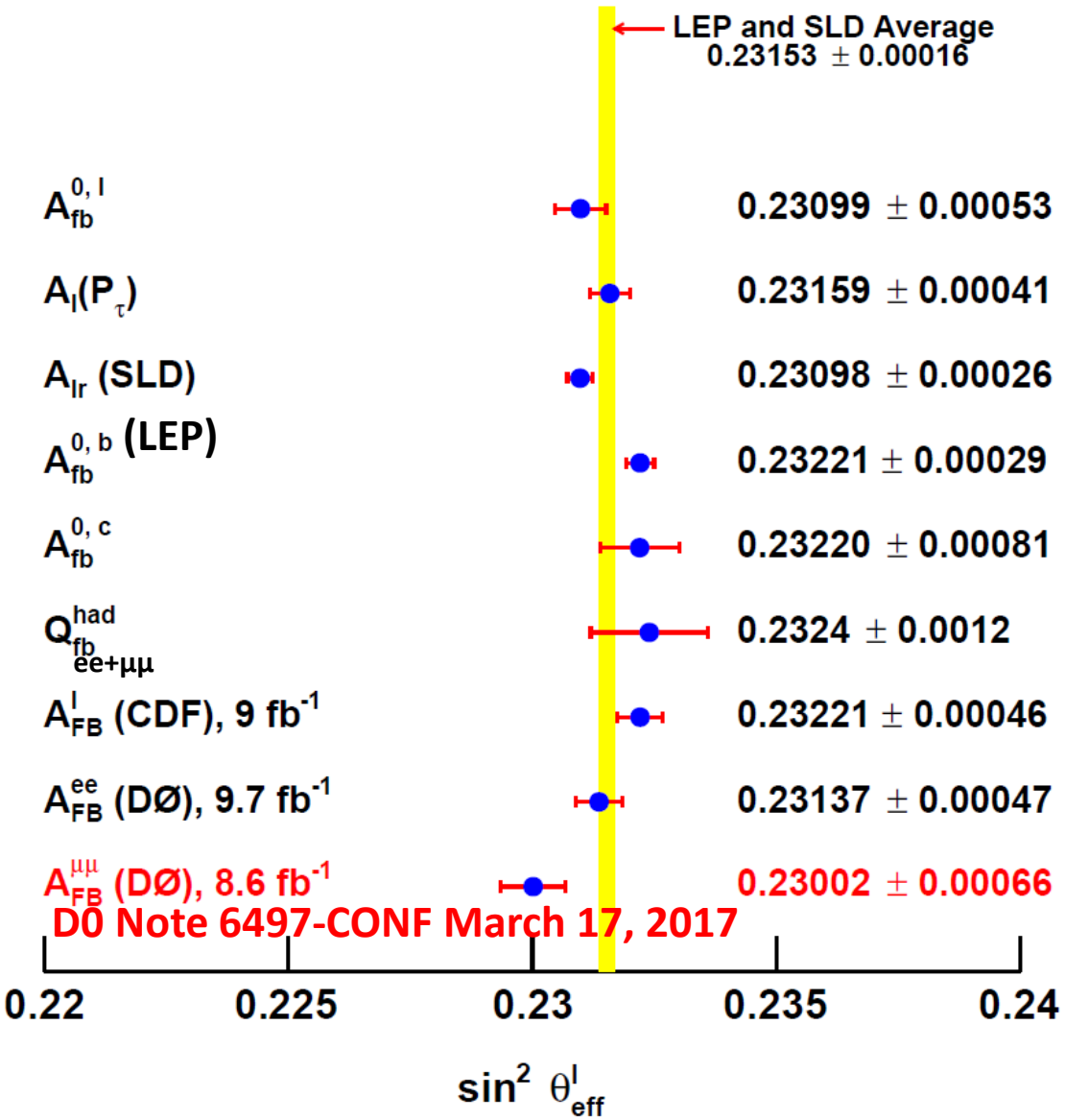
$\sin^2\theta_W^B$	0.22994
Statistical uncertainty	0.00059
Systematic uncertainties	
Momentum calibration	0.00002
Momentum resolution	0.00004
Background	0.00010
Efficiencies	0.00001
Total systematic	0.00011
PDF	0.00027
Total	0.00066

Question at Wine &Cheese:
What is uncertainty on form factor
$\mathrm{Re}[\kappa_\ell(M_Z)]$? Answer: see
http://tevewwg.fnal.gov/wz/sw2eff/
$\Delta\sin^2\theta_W = \pm\,0.00008$ due to ΔM_{top}

preliminary:

need to finalize EW corrections and QED radiative corrections

new D0 $\sin^2\theta_{eff}^{lept}$ for $Z/\gamma^* \rightarrow \mu\,\mu$



A_{LR} (SLD)

3.2 σ tension between two most precisely measured

$A_{FB}^{0,b}$ (LEP)

FERMILAB-CONF-16-295-E using NNPDF 3.0

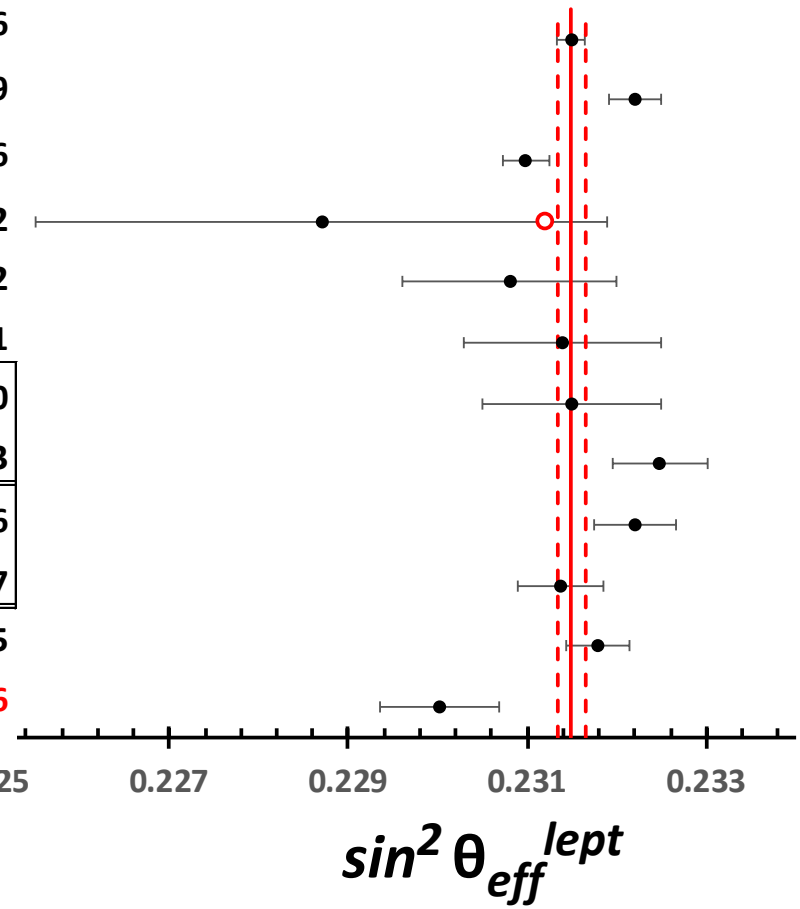
→ M_W = 80441 ± 33 MeV

new D0 $\sin^2\theta_{eff}^{lept}$ for $Z/\gamma^* \rightarrow \mu\,\mu$

compare $\sin^2\theta_{eff}^{lept}$ with other hadron collider experiments

LEP-1 and SLD: Z-pole	0.23149	±	0.00016
LEP-1 and SLD: $A_{FB}^{0,b}$	0.23221	±	0.00029
SLD: A_ℓ	0.23098	±	0.00026
CMS $\mu\mu$ 1 fb^{-1} @ 7 TeV	0.2287	±	0.0032
ATLAS $ee+\mu\mu$ 5 fb^{-1} @ 7 TeV	0.2308	±	0.0012
LHCb $\mu\mu$ 3 fb^{-1} @ 7-8 TeV	0.2314	±	0.0011
CDF $\mu\mu$ 9 fb^{-1}	0.2315	±	0.0010
CDF ee 9 fb^{-1}	0.23248	±	0.00053
CDF $ee+\mu\mu$ 9 fb^{-1}	0.23221	±	0.00046
D0 ee 10 fb^{-1} Aug 2016 prelim.	0.23137	±	0.00047
TeV combo CDF+D0 Aug 2016	0.23179	±	0.00035
D0 $\mu\mu$ 10 fb^{-1} March 2017 prelim.	0.23002	±	0.00066

(not yet included in Tevatron Combination)



(not yet included in Tevatron combination)

These are the most recent LHC results:

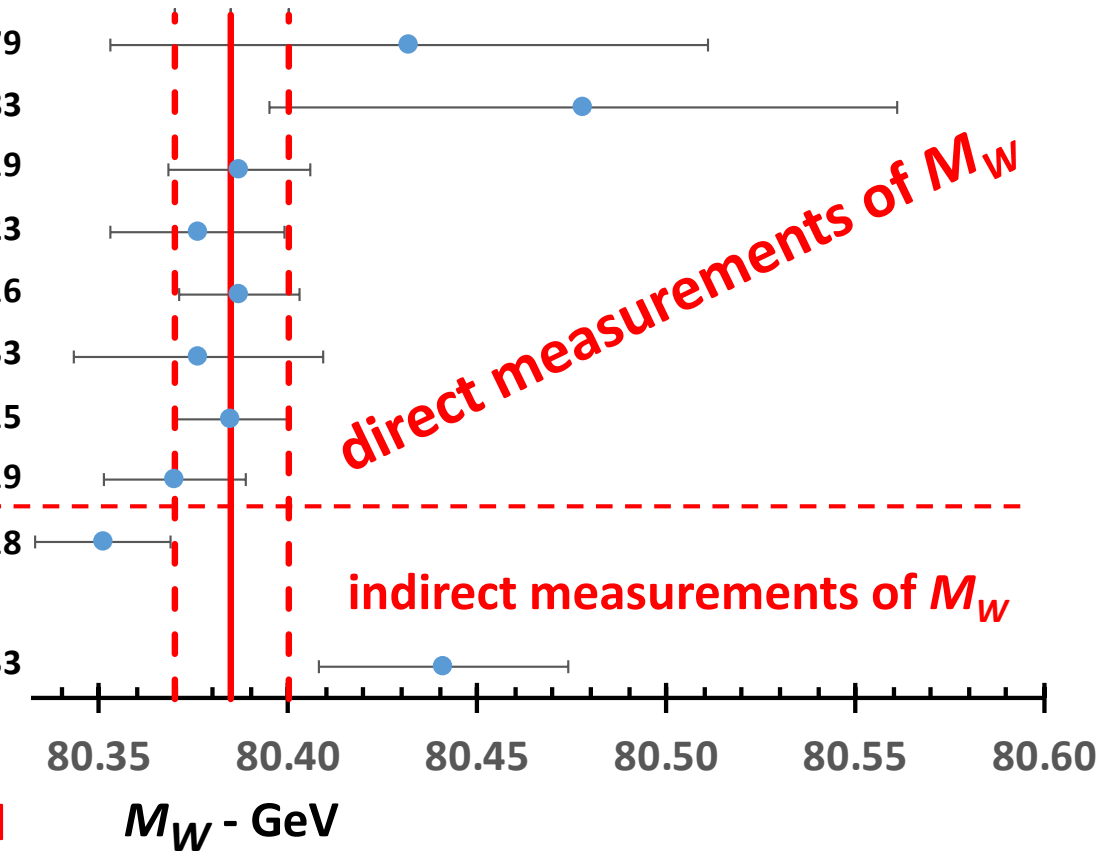
ATLAS: JHEP 09(2015)049 @ 7 TeV

LHCb: JHEP 11(2015)190 = 1 fb^{-1} @ 7 TeV & 2 fb^{-1} @ 8 TeV

CMS: Phys. Rev. D 84, 112002 (2011) @ 7 TeV & ee+μμ: EPJC 76 (2016) 325: 19.7 fb^{-1} @ 8 TeV consistent w 0.2312

new D0 $\sin^2\theta_{eff}^{lept}$ for $Z/\gamma^* \rightarrow \mu\,\mu$
compare indirect M_W to directly measured

CDF 1988-1995	80.432 ±	0.079
D0 1992-1995	80.478 ±	0.083
CDF 2002-2007	80.387 ±	0.019
D0 2002-2009	80.376 ±	0.023
Tevatron 2012	80.387 ±	0.016
LEP	80.376 ±	0.033
World Avg - PDG	80.385 ±	0.015
ATLAS arXiv:1701.07240	80.370 ±	0.019
$CDF^{ee} + CDF^{\mu\mu} + D0^{ee}$ $\sin^2\theta_{eff}^{lep}$	80.351 ±	0.018
FERMILAB-CONF-16-295-E		
D0 $\sin^2\theta_{eff}^{\mu\mu}$	80.441 ±	0.033
D0 Note 6494-CONF March 17, 2017		



new D0 $\sin^2\theta_{eff}^{\mu\mu}$ not included in Tevatron average

new D0 $\sin^2\theta_{eff}^{lept}$ *for* $Z/\gamma^* \rightarrow \mu\,\mu$

D0 **is still working on consistency of *EW* corrections and *QED* radiative corrections between *CDF* ^{ee}, *CDF* $^{\mu\mu}$, *D0* ^{ee}, and *D0* $^{\mu\mu}$ before performing the Tevatron combination**

expect combined Tevatron measurement to have a precision of ~0.0003 which will be comparable with those of SLD and LEP

CDF – inclusive-isolated prompt photons

arXiv:1703.00599 – March 2, 2017 - submitted to PRD-RC

prompt photons in proton-antiproton collisions:

important test for perturbative quantum chromodynamics (pQCD);

probe the parton distribution functions (PDFs)

and the parton-to-photon fragmentation function (FFs);

constitute a major background for many Standard Model processes

such as $H \rightarrow \gamma\gamma$ and for non-SM searches including photons

***"prompt"* = produced directly in hard interactions, not from decays**

E_T^γ < 100 GeV: mostly quark-gluon Compton scattering $q\ g \rightarrow q\ \gamma$

higher E_T^γ : mostly quark-antiquark annihilation $q\ q\text{-}bar \rightarrow g\ \gamma$

fragmentation of final-state partons, e.g. $gluon \rightarrow X_{anything}\ incl.\ \gamma$

CDF – inclusive-isolated prompt photons

Full Run II (2001-2011) CDF data set of 9.5 fb^{-1}

Extend E_T^{γ} range to 30 – 500 GeV by 100 GeV over previous pub

Event selection: isolation cone radius R = $\sqrt{\Delta\eta^2 + \Delta\varphi^2}$ = 0.4

EM calorimeter isolation = Σ E_T^{cal} (within isolation cone) - E_T^{γ} < 2 GeV

track isolation = scalar sum of p_T of all tracks from primary vertex within R = 0.4 isolation cone of the prompt γ < 5 GeV

ratio of energy deposit in EHad cal/Energy in EM cluster < 0.125

CDF – inclusive-isolated prompt photons

→ 2.1 x 10^6 prompt γ + X candidates

remaining background comes from decay of hadrons, e.g. $\pi^0 \rightarrow \gamma\,\gamma$

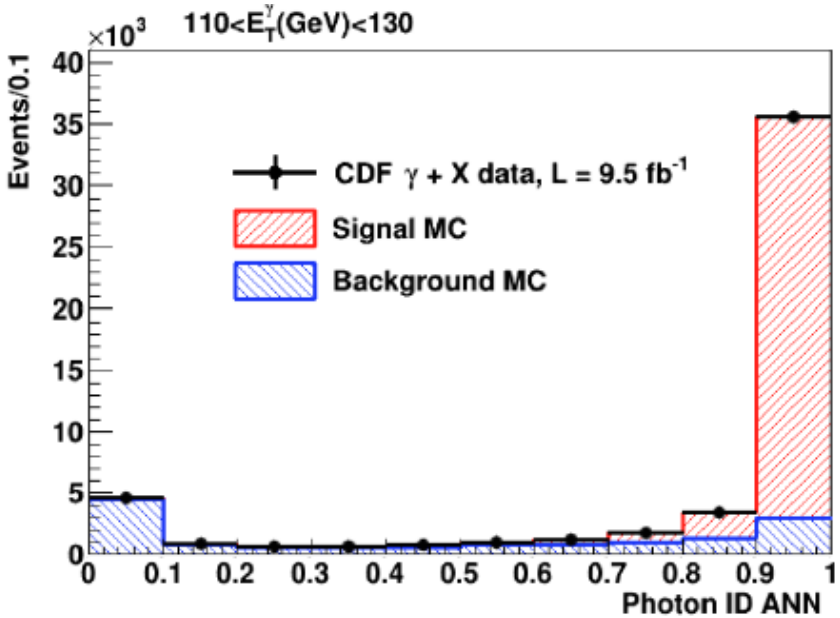
cannot reject on an event-by-event basis, so use a
statistical background-subtraction technique

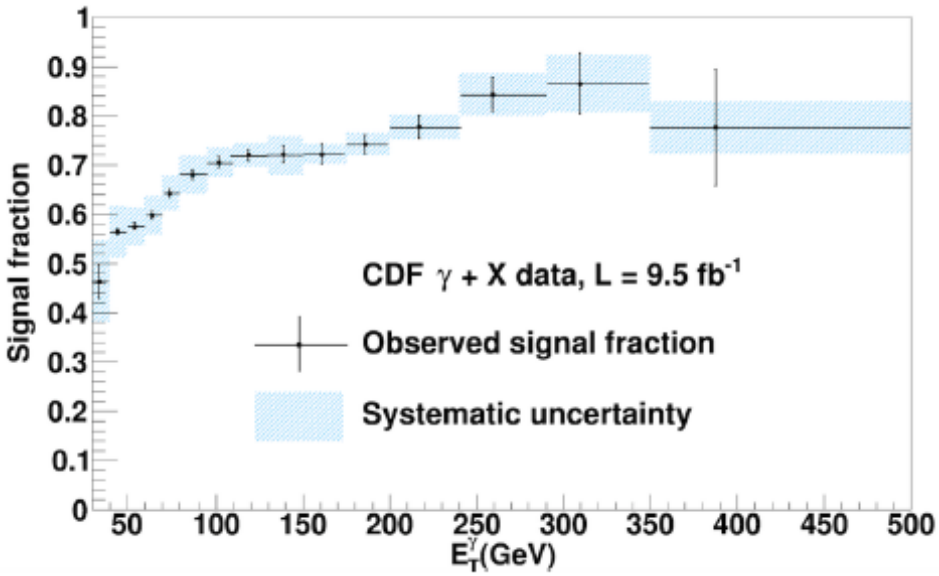
Define a Artificial Neural Net (ANN) metric using inputs:
shower shape, transverse profile, and isolation variables
for both data and simulations, for each E_T^{γ} data point (bin)
MC events are reweighted to observed luminosity profile.

Expected distributions in ANN output metric are generated for
signal = PYTHIA inclusive-photon prediction (verified w Z^0 data)
background = PYTHIA dijet MC prediction (verified w dijet data)

CDF – inclusive-isolated prompt photons

for each E_T^γ data bin, *fit* as linear comb. of signal & background ANN template distributions, determining *signal fraction (purity)*

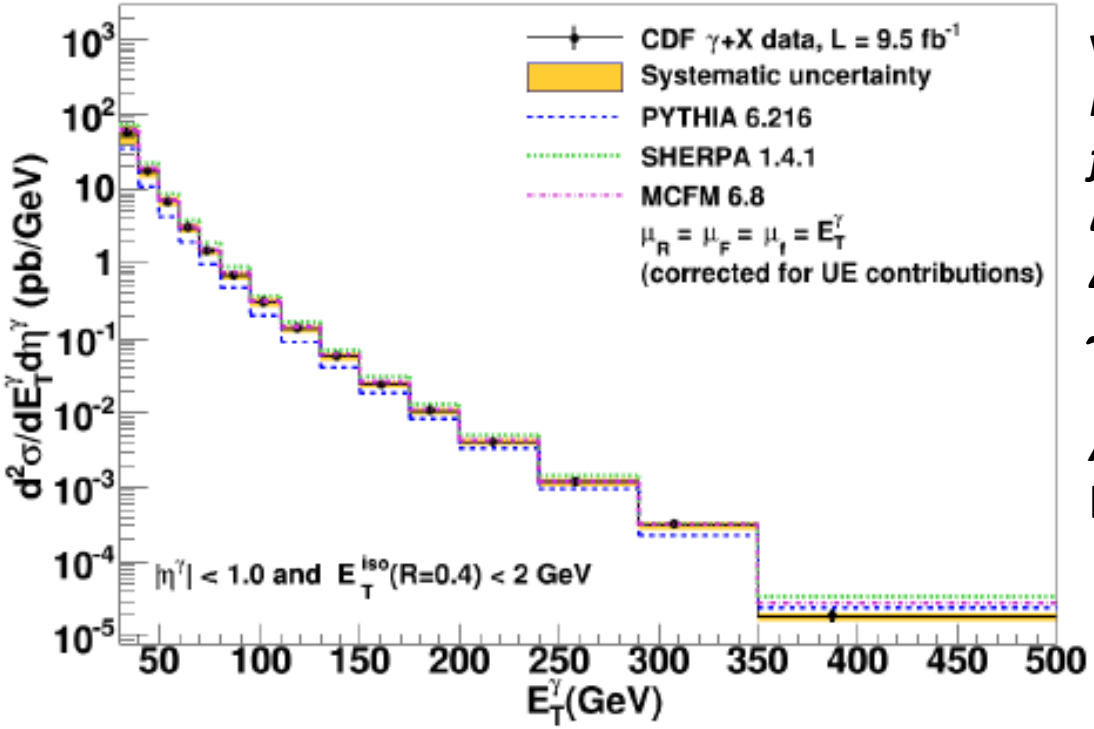




Est systematic uncertainty on signal fraction (purity) by varying fit configurations and ANN input variables within their uncertainties. Dominant uncertainty is modeling calorimeter isolation energy. systematic uncertainty 8%, ~ 3%, 6% for E_T^γ < 40, 40-300, > 300 GeV

CDF – inclusive-isolated prompt photons

$$d^2\sigma/(dE_T^\gamma d\eta^\gamma) = (N f^\gamma)/(\Delta E_T^\gamma \Delta\eta^\gamma \mathcal{L} A \times \epsilon)$$



where for each ΔE_T^γ $\Delta\eta^\gamma$ bin:

N = # γ observed per bin

f^γ = signal fraction (purity)

ΔE_T^γ = bin width

$\Delta\eta^\gamma$ = 2 since $|\eta^\gamma| < 1$

$\mathcal{L}$ = integrated luminosity = 9.5 fb^{-1}

(common ± 6% - not included)

$A \times \epsilon$ = acceptance, resolution, eff

largest uncertainties:

6% from γ energy scale at high E_T^γ

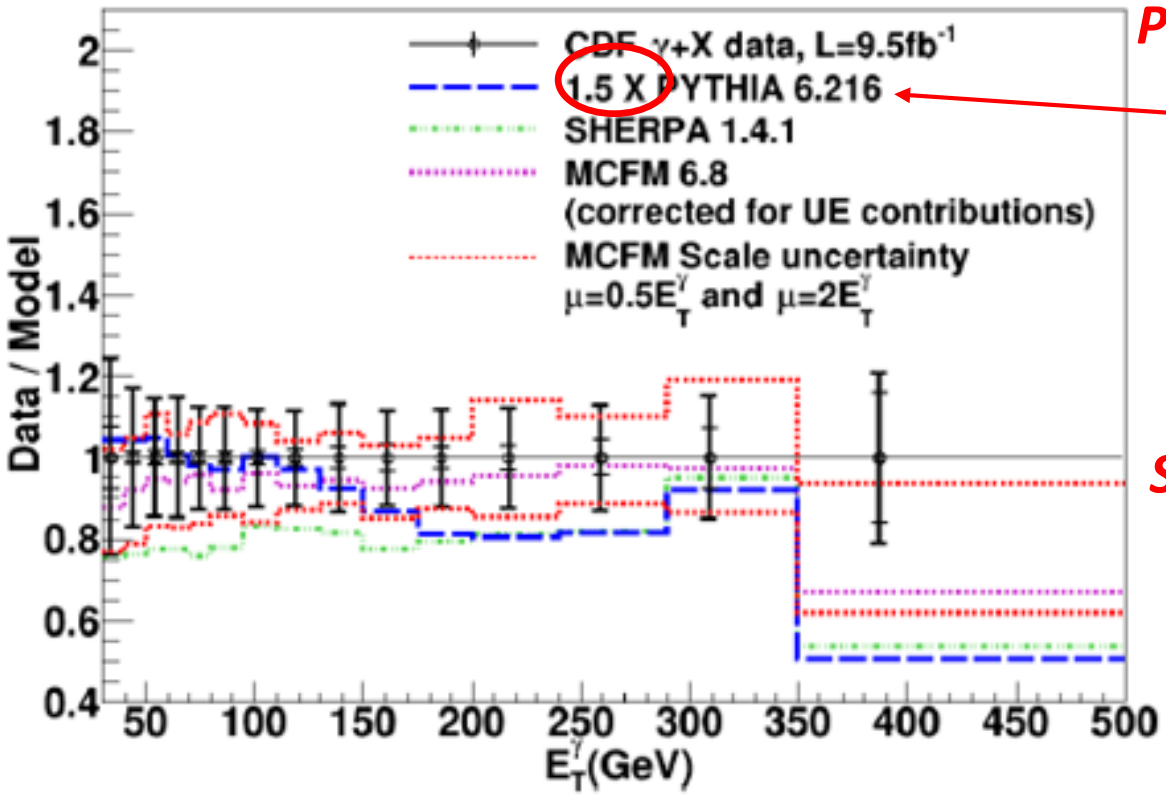
8% from $A \times \epsilon$

(compare PYTHIA-SHERPA)

generally good agreement with theoretical models,
but difficult to quantitatively compare on a semi-log scale
see next page for comparison using ratio of theory/data

CDF – inclusive-isolated prompt photons

compare theory & simulations: ***overall $d^2\sigma/dE_T^\gamma\, d\eta^\gamma$ shape well represented***



PYTHIA **underestimates by factor of ~ 1.5 @ low E_T^γ possibly due to lack of higher-order terms in γ + jet matrix elements**

SHERPA **~ 1.1 – 1.2 larger missing virtual corrections *non-pQCD* effects, e.g. mis-tuned fragmentation**

NLO **=** ***MCFM*** **& scaling band good agreement for all E_T^γ**

PYTHIA T. Sjöstrand, S. Mrenna, and P. Skands, J. High Energy Phys. 05 (2006) 026
SHERPA T. Gleisberg et al., J. High Energy Phys. 02 (2009) 007
MCFM J. Campbell and R. Ellis, Phys. Rev. D 65, 113007 (2002)

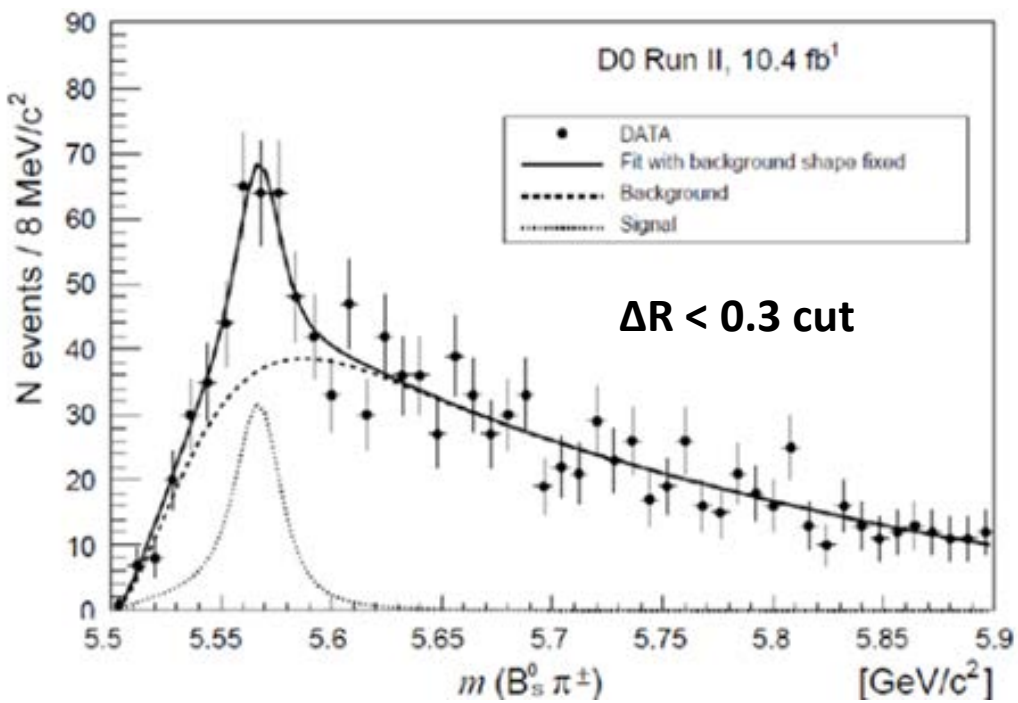
D0: Confirmation of the X(5568) with the semileptonic decay of B_s^0

D0 Note 6489-CONF – March 24, 2017

https://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/B/B68/B68.pdf

Last year D0 → ***Evidence for a new X → π B_s state with B_s → J/ψ ϕ***

Phys. Rev. Lett. 117, 02203 (2016)



$\Delta R = \sqrt{\Delta\eta^2 + \Delta\varphi^2} < 0.3$ betw π & Bs

fitted M_x doesn't vary with ΔR cut

$M_x = 5567.8 \pm 2.9$ (stat) $^{+0.9}_{-1.6}$ (syst) MeV

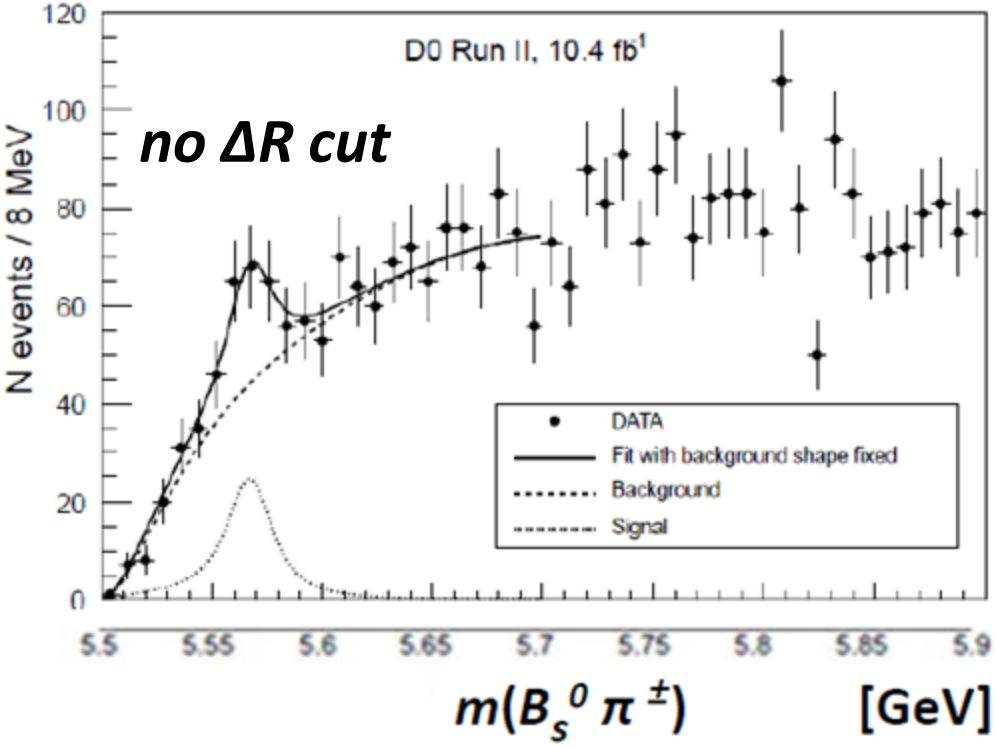
$\Gamma_x = 21.9 \pm 6.4\ ^{+5.0}_{-2.5}$ MeV

global Significance including LEE & systematic uncertainty = 5.1 σ

$\rho = \sigma(X5568 \rightarrow Bs\ \pi)/\sigma(Bs) =$
$= [8.6 \pm 1.9 \pm 1.4]\%$

D0: SL X5568 – prior result via Bs => J/ψ φ

Also, in last year's PRL without the ΔR cut:



$X \rightarrow \pi B_s (\rightarrow J/\psi\ \phi)$ with M_x and Γ_x fixed to same values as for analysis with ΔR cut, Significance including LEE & syst. uncert. = 3.9 σ

***LHCb* and *CMS* have not observed this state in 7 & 8 TeV pp collisions**

CMS-PAS-BPH-16-002, LHCb: PRL 117, 152003 (2016)

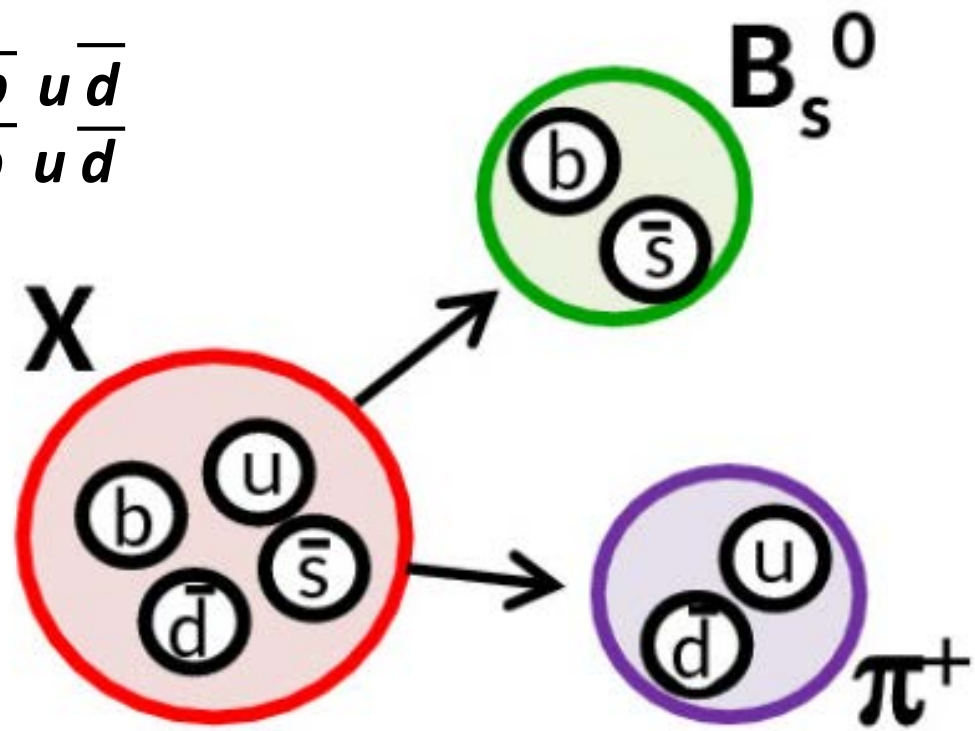
D0: Evidence for an exotic $B_s^0 \pi^{\pm}$ b, s, u, d state

First observation of a state with *4 different quarks*
for example, previous observed exotics are:

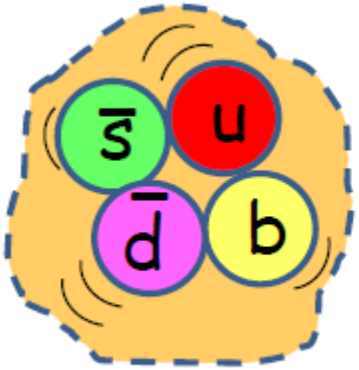
$X(3872) \rightarrow J/\psi\, \pi^+ \pi^- = c\,\bar{c}\,u\,\bar{u} + c\,\bar{c}\,d\,\bar{d}$
$Z^+(4430) \rightarrow \psi'\, \pi^+ = s\,\bar{s}\,u\,\bar{d}$
$Z_b^+(10610) \rightarrow \Upsilon(nS)\, \pi^+ = b\,\bar{b}\,u\,\bar{d}$
$Z_b^+(10650) \rightarrow \Upsilon(nS)\, \pi^+ = b\,\bar{b}\,u\,\bar{d}$

$P_c^+ \rightarrow J/\psi\, p = c\,\bar{c}\,u\,u\,d$
and many, many more

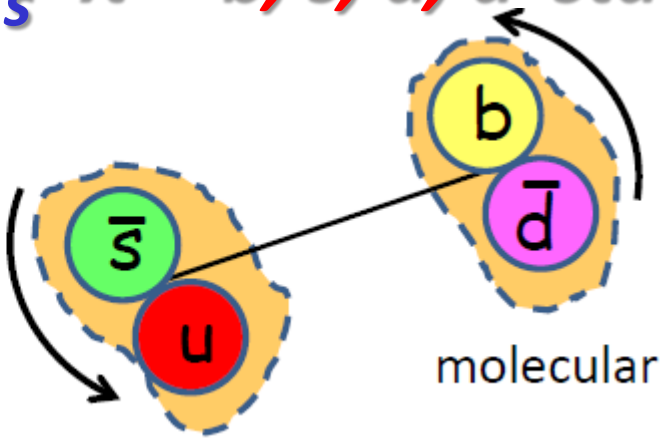
see backup slides
for a
more extensive list
of meson-like exotics



D0: Evidence for an exotic $B_s^0 \pi^{\pm}$ b, s, u, d state



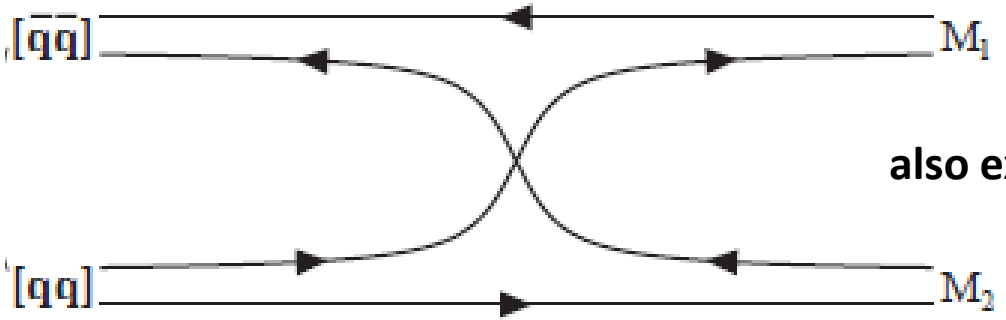
tetraquark



molecular state

BK **molecule is bound by colorless hadron and is expected to have mass near** ***BK*** **threshold**
BK **molecule is disfavored for** ***X*****(5568) since it would have ~ 206 MeV Binding Energy**

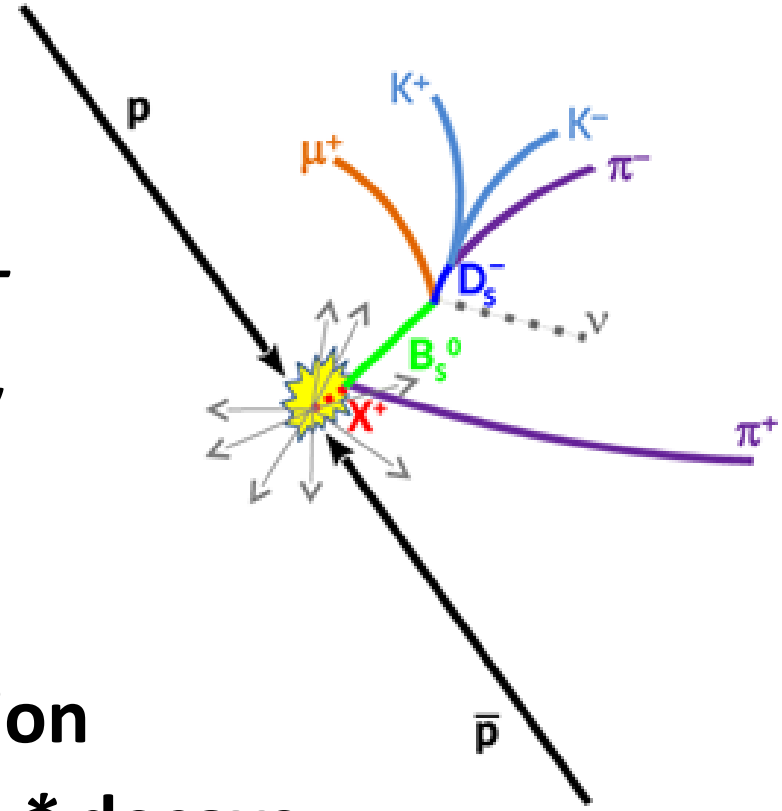
or the diquark + anti-diquark model by Maiani *et al*.



also expects higher $M(B_s\,\pi)$

L. Maiani *et al*., "New Look at Scalar Mesons", Phys. Rev. Lett. 93, 212002 (2004)

use new decay mode!



use $B^0_s \rightarrow \mu^+ \nu D_s^- X_{anything}$

with $D_s^- \rightarrow \phi \pi^-$ then $\phi \rightarrow K^+ K^-$

complications due to missing ν

- requiring $M(\mu D_s) > 4.5$ GeV
- limits missing ν energy and
- thus improves mass resolution

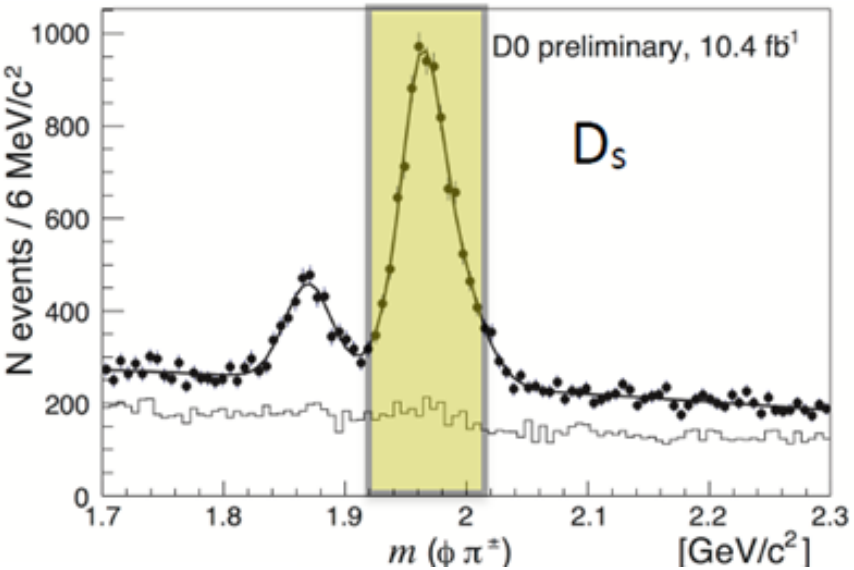
$X_{anything}$ mostly γ *(or* π^0*)* from D_s^* decays

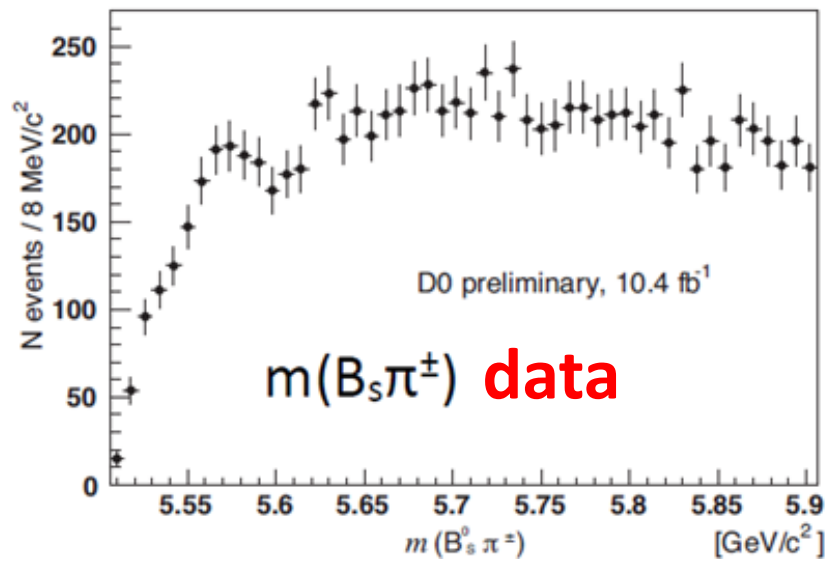
add $\pi^\pm$ from primary vertex to form $X \rightarrow B_s^0 \pi^\pm$

estimate for invariant mass:

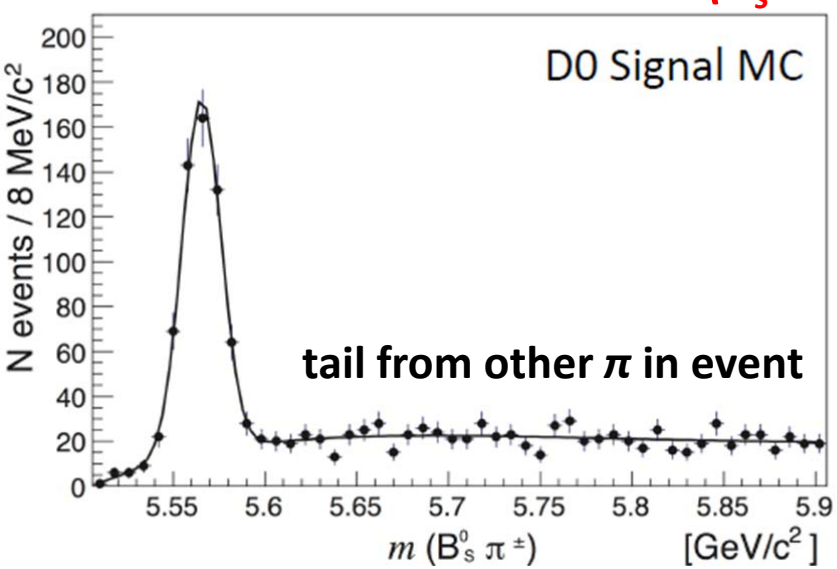
$$M(B_s^0 \pi^\pm) = M(\mu D_s \pi) - M(\mu D_s) + M_{PDG}(B_s^0)$$

D0: SL X5568





How well does the estimate: $M(B_s^0\,\pi^{\pm}) = M(\mu\,D_s\,\pi) - M(\mu\,D_s) + M_{PDG}(B_s^0)$ work?



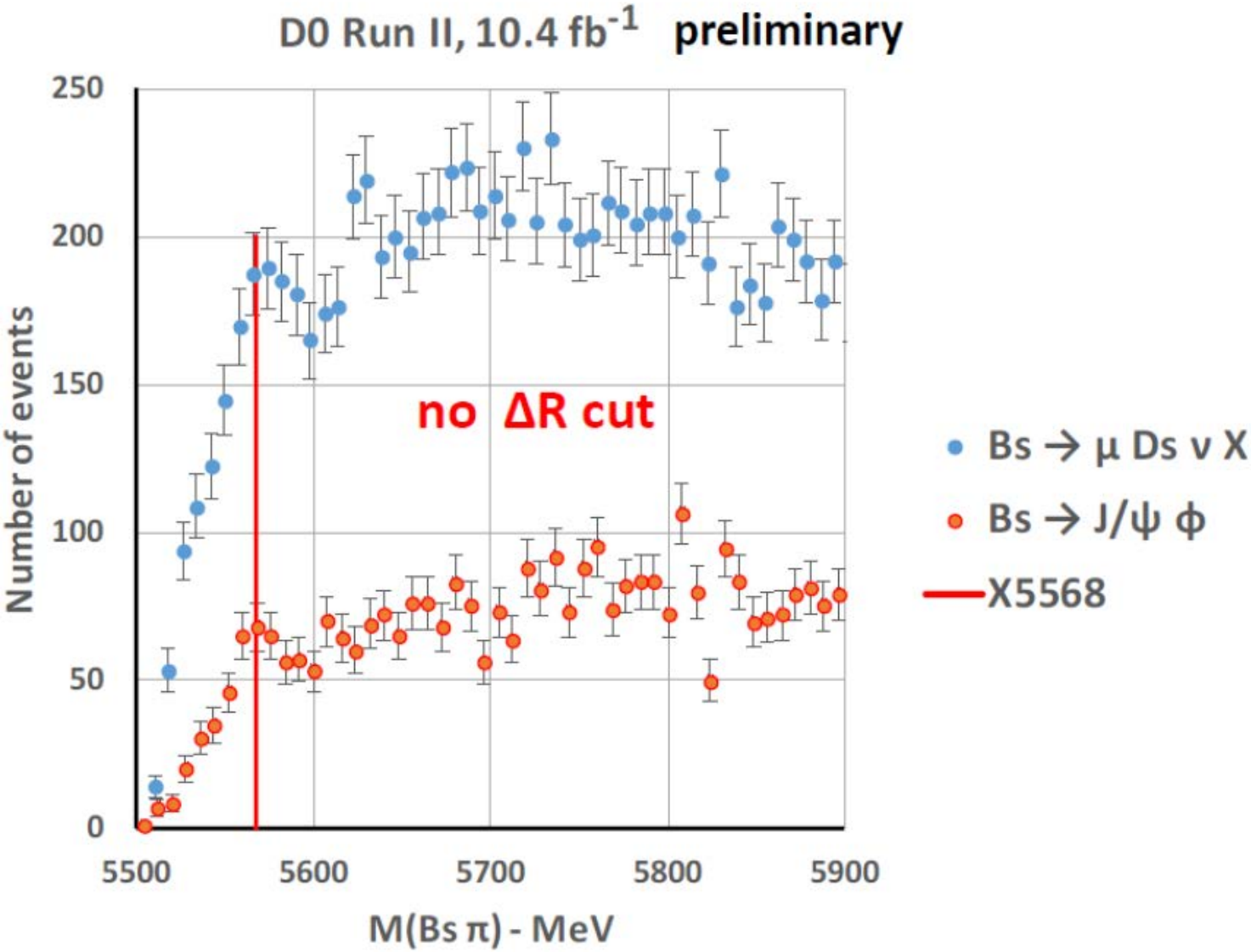
full MC simulation for "heavy B-meson" decaying into Bs π with input M = 5568 MeV and Γ = 0

MC gives reconstructed:

<M> = 5565 ± 1 MeV

and Gaussian σ = 11.1 ± 0.5 MeV

D0: SL X5568

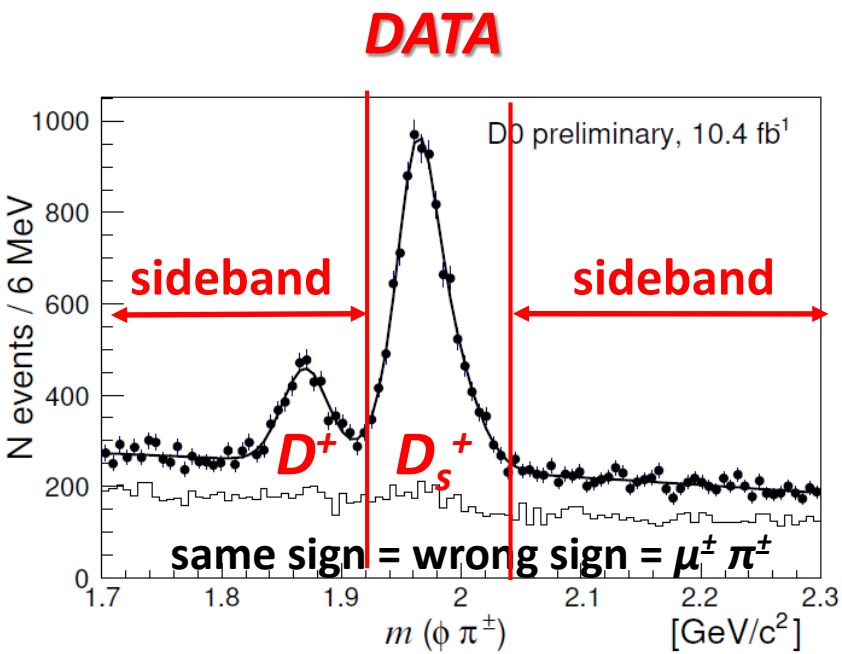

D0 Run II, 10.4 fb^{-1} preliminary
Number of events
250
200
150
100
50
0
5500
5600
5700
5800
5900
M(Bs π) - MeV
no ΔR cut
Bs → μ Ds ν X
Bs → J/ψ φ
X5568

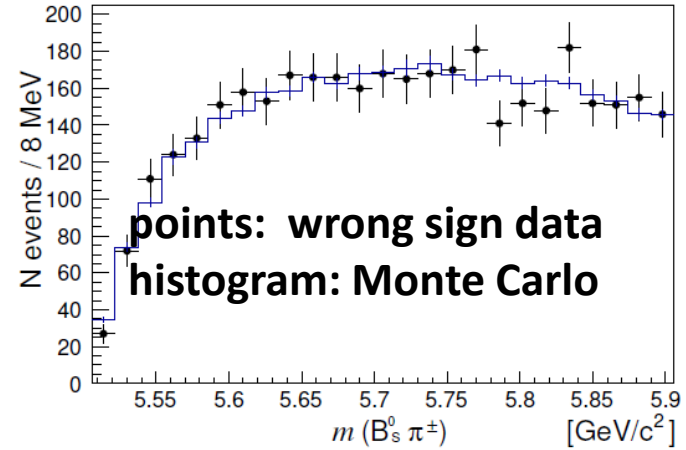
D0: SL X5568 - background

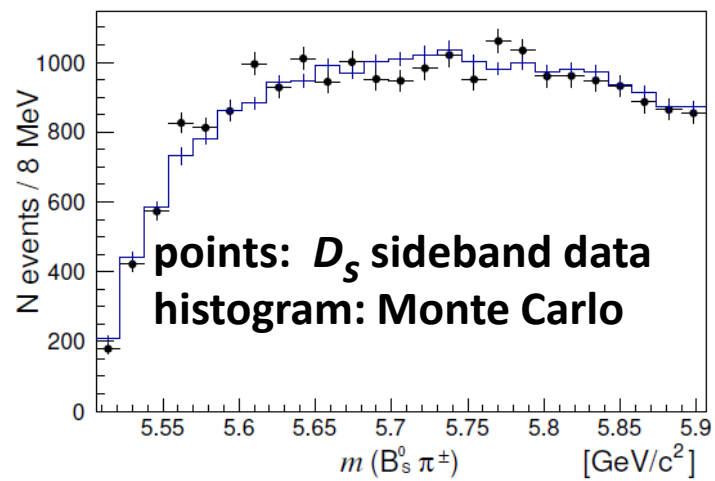
BKGD Model – re-weighted PYTHIA – EVTGEN MC

for data – MC agreement using $p_T(\mu)$ and $p_T(\mu\ D_s)$ **see SL specifics 3,4**

compare with D_s wrong sign & sideband bkgds







MC shape reproduces both the sideband and same (wrong) sign backgrounds very well

D^+ peak is ~ 10% of total sidebands

D0: SL X5568 – data fit

$$F = f_{\rm sig} F_{\rm sig}(m, M_X, \Gamma_X) + f_{\rm bgr} F_{\rm bgr}(m)$$

$$BW(m) \propto \frac{M_X^2 \Gamma(m)}{(M_X^2 - m^2)^2 + M_X^2 \Gamma^2(m)}$$

S-wave relativistic Breit-Wigner

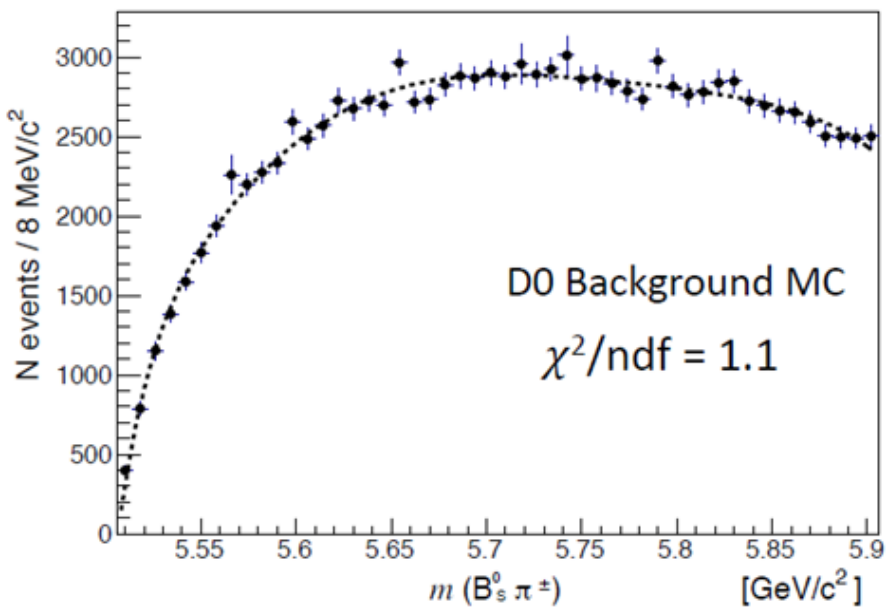
$$\Gamma(m) = \Gamma_X \cdot (q_1/q_0)$$

convoluted with Gaussian resolution

$$\sigma_{\rm SL} = \left[3.85 + 60.93(m - m_{\rm th})^{0.85}\right] \ {\rm MeV}/c^2$$

4-track + missing *ν* components

$$F_{\rm bgr}(m) = \left(C_1 m_0 + C_2 m_0^2 + C_3 m_0^3 + C_4 m_0^4\right) \exp\left(C_5 m_0 + C_7 m_0^2\right)$$

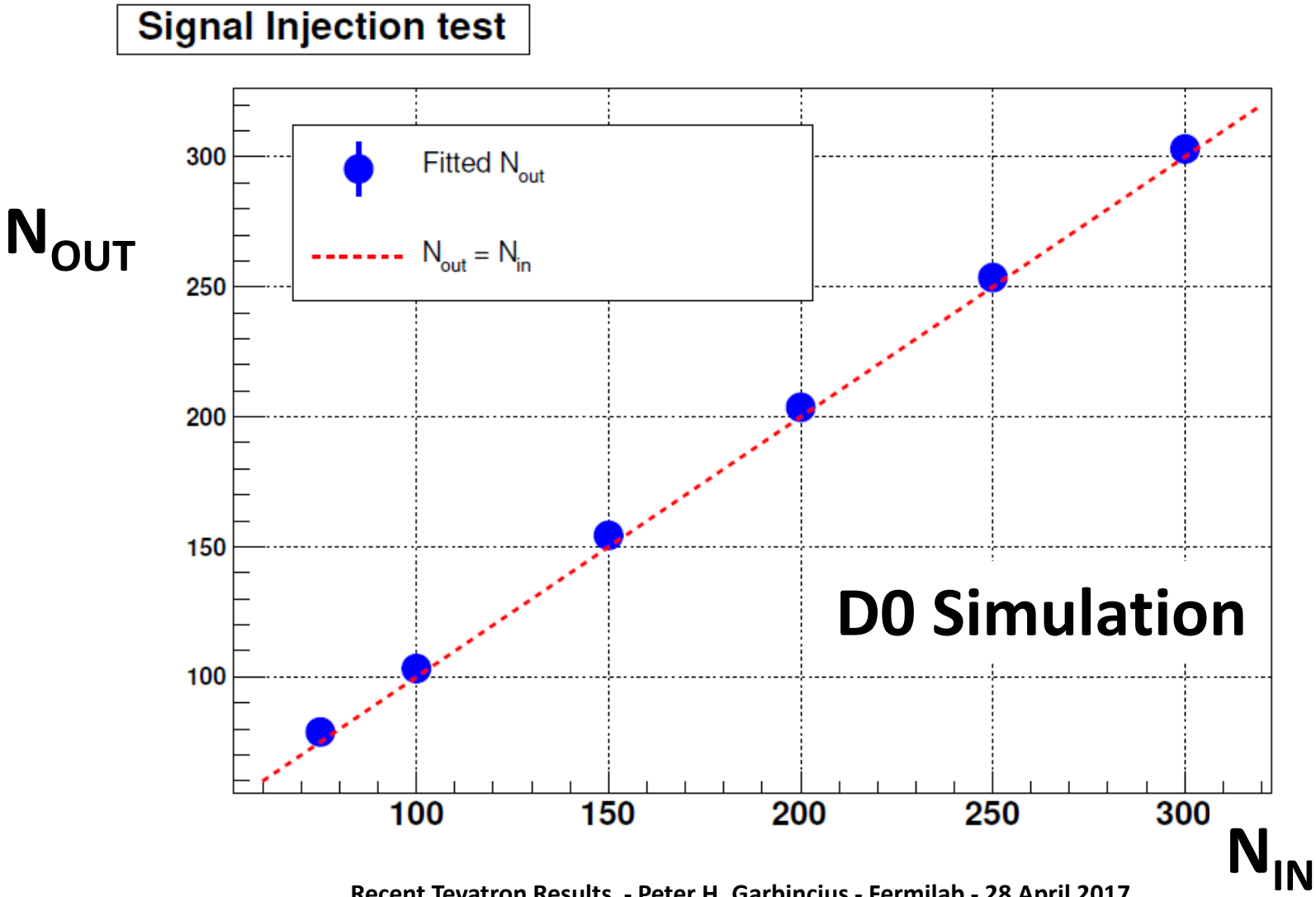


nominal $F_{bgr}(m)$ function A (defined just above) fitted to re-weighted BKGD Monte Carlo

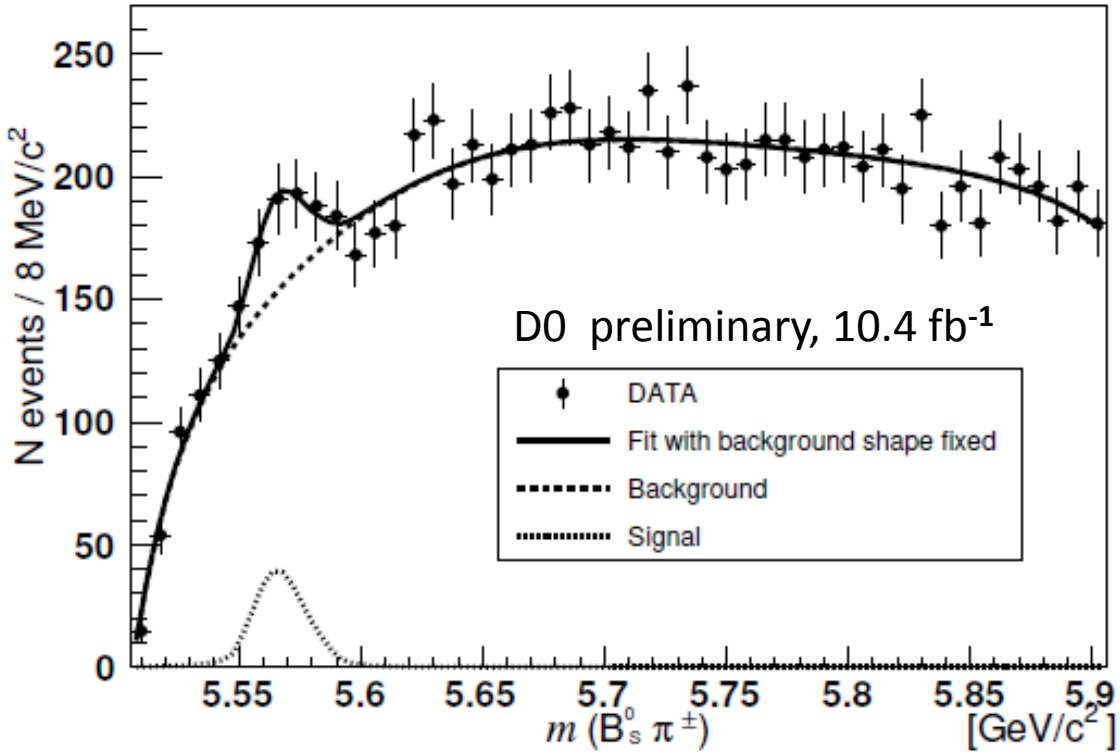
See D0: SL X5568 details in backup slides: for Alternative BKGD fits B & C

D0: SL X5568 – signal injection closure test

Add MC signal of Nin events to MC background (scaled to bkgd level in data) and find that fitted $N_{OUT} = N_{IN}$ as expected



D0: SL X5568 – data fit



Background shape fixed

$M_x = 5566.7\ ^{+3.6}_{-3.4}$ MeV

$\Gamma_x = 6.0\ ^{+9.5}_{-6.0}$ MeV

$N_x = 139\ ^{+51}_{-63}$ events

$\chi^2 = 32$ for 46 DF

Local Significance = $\sqrt{-2\ ln(\frac{\mathcal{L}_o}{\mathcal{L}_{max}})}$ **= 4.5 σ**

where $\mathcal{L}_0$ is for fit to null hypothesis = BKGD only

and $\mathcal{L}_{max}$ is for fit with Signal + BKGD

Including systematic uncertainties, Significance → 3.2 σ

D0: SL X5568 – systematic uncertainties

Source	mass, MeV/c^2	width, MeV/c^2	event yield, events
Background shape description	+0.0 ; −0.7	+0.7 ; −2.5	+4.8 ; −28.0
Background reweighting	+0.1 ; −0.1	+0.7 ; −0.7	+5.0 ; −5.0
B_s^0 mass scale, MC and data	+0.3 ; −0.5	+1.0 ; −1.4	+7.5 ; −9.6
Detector resolution	+0.0 ; −0.5	+1.3 ; −2.6	+3.7 ; −6.4
P-wave Breit-Wigner	+0.0 ; −0.2	+0.0 ; −2.4	+0.0 ; −7.0
Missing neutrino effect	+1.0 ; −0.0	-	-
Total	+1.0 ; −1.0	+1.9 ; −4.6	+10.9 ; −31.5

see *D0: SL X5568 specifics* in backup slides
for studies of alternative background shapes

D0: SL X5568 – combine with *Bs* → *J/ψ* ϕ

	Semileptonic	Hadronic, cone cut	Hadronic, no cone cut
Fitted mass, MeV/c^2	$5566.7^{+3.6}_{-3.4}{}^{+1.0}_{-1.0}$	$5567.8 \pm 2.9^{+0.9}_{-1.9}$	5567.8
Fitted natural width, MeV/c^2	$6.0^{+9.5}_{-6.0}{}^{+1.9}_{-4.6}$	$21.9 \pm 6.4^{+5.0}_{-2.5}$	21.9
Fitted number of signal events	$139^{+51}_{-63}{}^{+10.9}_{-31.5}$	$133 \pm 31 \pm 15$	106 ± 23
Local significance	4.5σ	6.6σ	4.8σ
Significance with systematics	3.2σ	5.6σ	- (not quoted in PRL)
Significance with LEE+systematics	-	5.1σ	3.9σ
* Combine SL & Hadronic modes		5.7σ	4.7σ

no LEE applied for semileptonic channel because we already know where X5568 is

* **This combination uses**

$$p = p_{HAD} * p_{SL} \, [1 - \ln (p_{HAD} * p_{SL})]$$

which applies since *HAD* and *SL* measurement are independent:

different trigger conditions: *HAD* = 2 *μ*, *SL* = 1 *μ*

different B_s channel: *HAD* = *J/ψ* ϕ, *SL* = *μ ν* D_s *X*

D0: SL X5568 – fraction of B_s from $X5568$

Determine inclusive # B_s by fitting the $M(\phi\ \pi)$ distribution and correct by removing the prompt and the same sign $\mu^{\pm}\ D_s^{\pm}$

for $p_T(\mu^+\ D_s^-) > 10$ GeV and 4.5 GeV $< M(\mu^+\ D_s^-)$

$$X \rightarrow B_s\ \pi / B_s = \rho(\mathrm{SL}) = [7.3\ ^{+2.8}_{-2.4}\ (\mathrm{stat})\ ^{+0.6}_{-1.7}\ (\mathrm{syst})]\%$$

consistent with prior $p_T(J/\psi\ \phi) > 10$ GeV

$$X \rightarrow B_s\ \pi / B_s = \rho(\mathrm{HAD}) = [8.6 \pm 1.9\ (\mathrm{stat}) \pm 1.4\ (\mathrm{syst})]\%$$

D0: SL X5568 – conclusions

We have presented the results of a search for the $X(5568) \rightarrow B_s^0 \pi^{\pm}$ with semileptonic decays of the B_s^0 meson.

There is an excess of events in the data consistent with the decay $X(5568) \rightarrow B_s^0 \pi^{\pm}$ with $B_s^0 \rightarrow J/\psi\ \phi$.

The mass, natural width, and production rates in the semileptonic and hadronic channels are consistent.

The signal p-value for the semileptonic channel is 6.4×10^{-4} and the significance is 3.2 σ when including systematic uncertainties, but not including Look Elsewhere Effect.

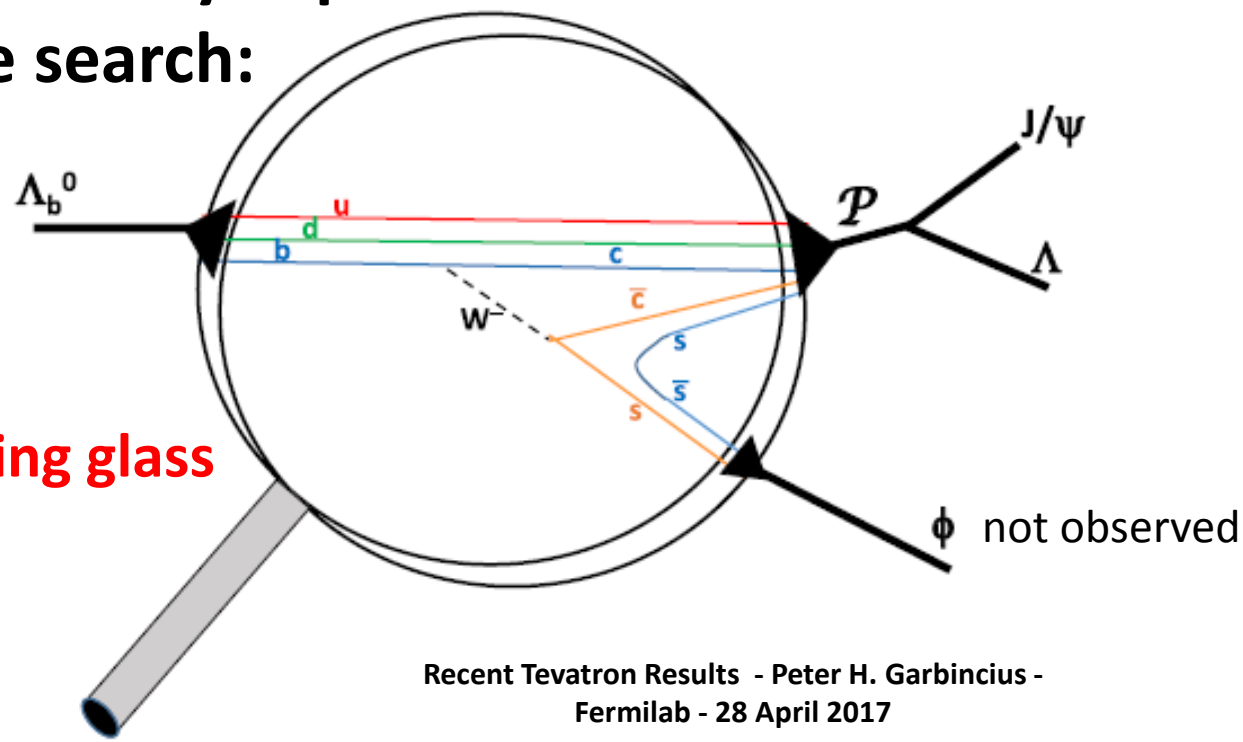
The combined p-value for the hadronic and semileptonic channels is 5.6×10^{-9} with a corresponding significance of 5.7 σ.

D0: Search for exotic baryons decaying into J/ψ Λ

D0 Note 6494-CONF – March 22, 2017

https://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/B/B69/B69.pdf

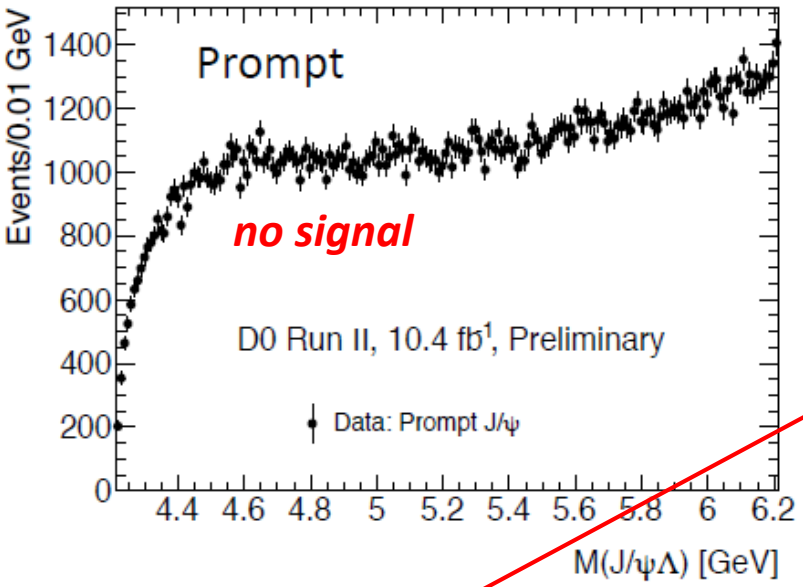
analog of LHCb $P_c^+ \rightarrow J/\psi\, p$ discovered by LHCb in Λ_b decays; theoretically expect states within 500 MeV of threshold, we search:

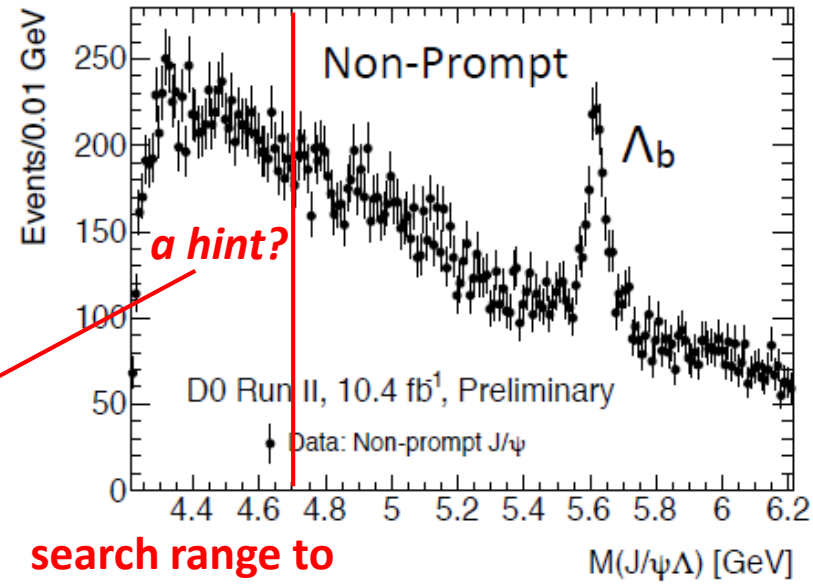


under a magnifying glass

D0: J/ψ Λ search

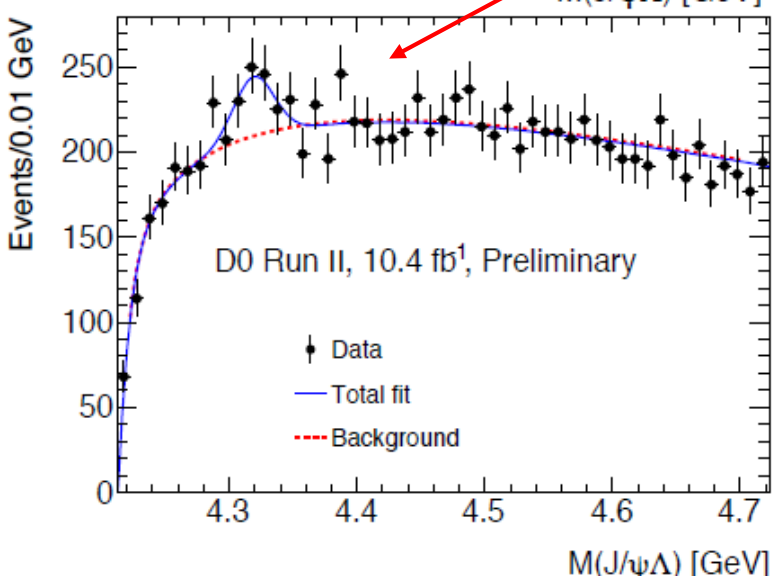
non-prompt events have significance of *J/ψ* decay length > 3





fit 805 ± 61 Λ_b decays

search range to $M_{theshold}$ + 500 MeV



$$F_{\rm fit}(M, M_X, \Gamma_X) = f_{\rm bg} F_{\rm bg} + f_{\rm sig} F_{\rm sig}$$

$$F_{\rm bg} \propto M \left(\frac{M^2}{M_{\rm th}^2}\right)^{c_1} \exp(c_2 M) \left[1 - \exp\left(\frac{M - M{\rm th}}{c_3}\right)\right]$$

signal shape = Gaussian w free width

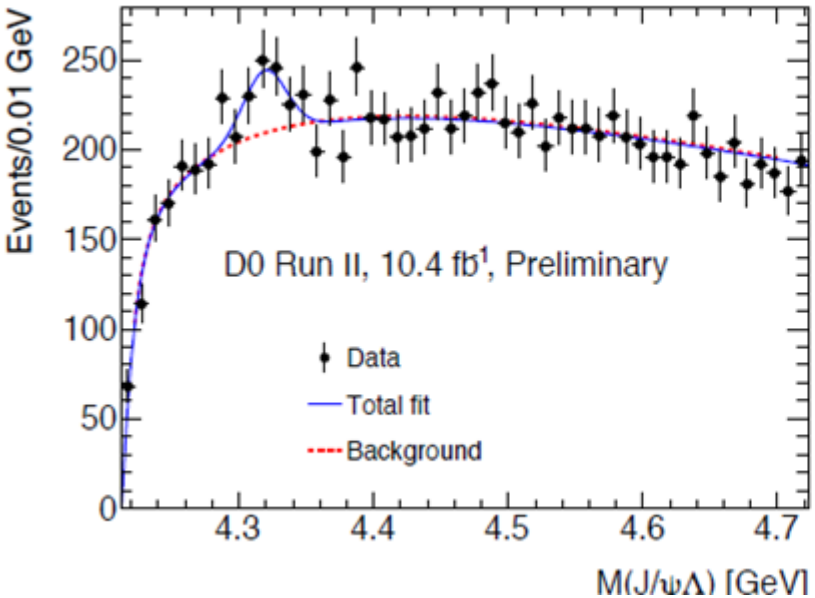
<M> = 4319.3 ± 6.6 MeV

σ = 15.6 ± 7.7 MeV resolution ~ 5 MeV

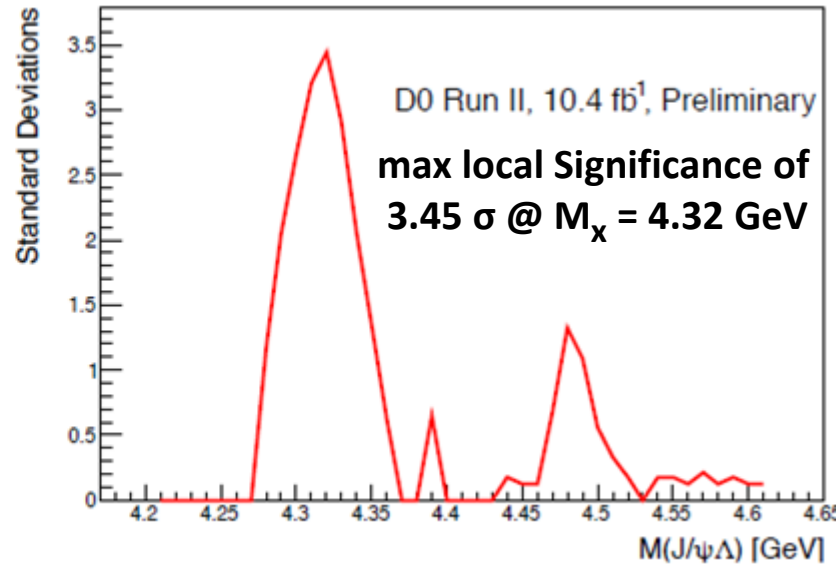
Nx = 142 ± 66 events χ2/#df = 26/41

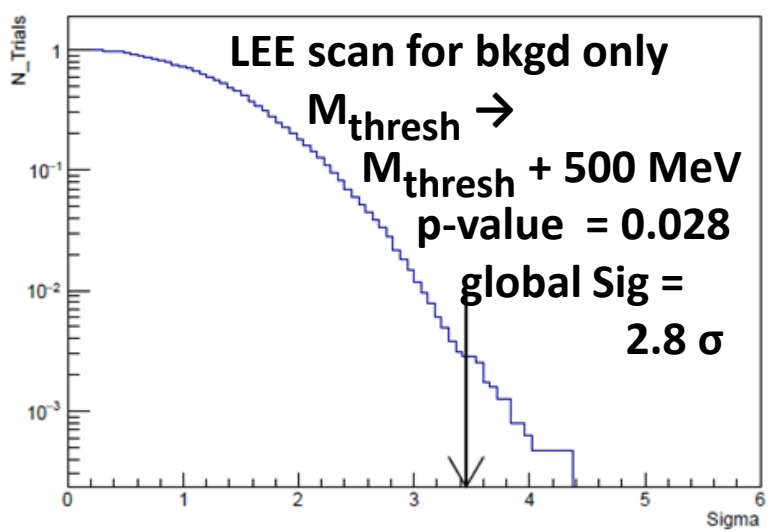
D0: J/ψ Λ search

Same as prior slide (for reference)



Scan <M_X>, fit signal width, & bkgd shape





local Significance = $\sqrt{-2\,ln(\frac{\mathcal{L}_o}{\mathcal{L}_{max}})}$

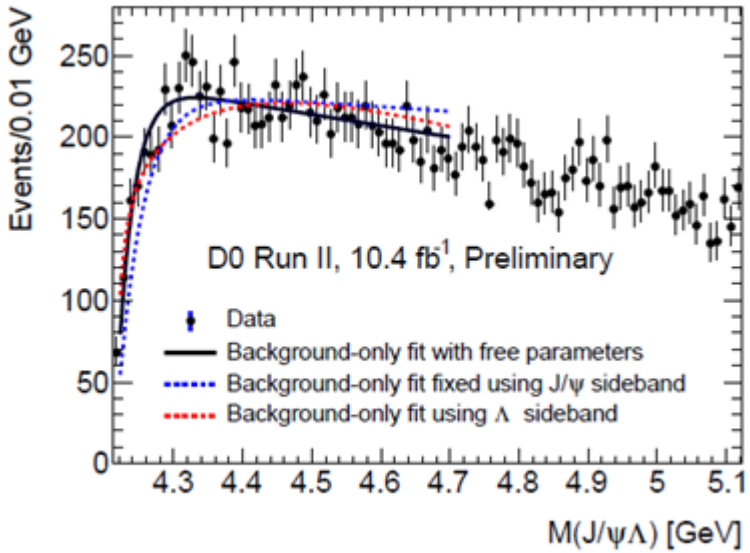
where $\mathcal{L}_{max}$ is for signal + bkgd fit

$\mathcal{L}_0$ is null hypothesis for bkgd only

global Signifigance =2.8 σ

D0: J/ψ Λ search

alternative background shapes using J/ψ & Λ mass sidebands



Sideband shapes give larger Significance so using free background shape gives the minimum Significance in terms of systematic variations. Also investigated non-rel. BW signal and ARGUS bkgd shapes.

global Significance is 2.8 σ, so cannot claim any evidence for a non-prompt signal in J/ψ Λ

a starting point for other searches by other experiments

new: CDF σ_{Z^0} x B(Z^0 → b bbar) and determination of b-jet Energy Scale

CDF/PHYS/ELECTROWEAK/PUB/11219 April 14, 2017

study Z^0 production

demonstrate validity of using data to evaluate *b-bbar* QCD background

enables further searches for new resonances → *b-bbar*

benchmarks *b-jet* Energy Scale wrt MC simulations

new: CDF σ_{Z^0} x B($Z^0 \rightarrow$ b bbar) and determination of b-jet Energy Scale

5.4 fb^{-1} – 2008 (new hardware & software) → 2011

trigger jet requires at least two tracks w Impact Parameter compatible with a *b*-hadron decay and associated with that jet

Monte Carlo simulation of efficiencies and shape of background di-jet mass is tuned on data

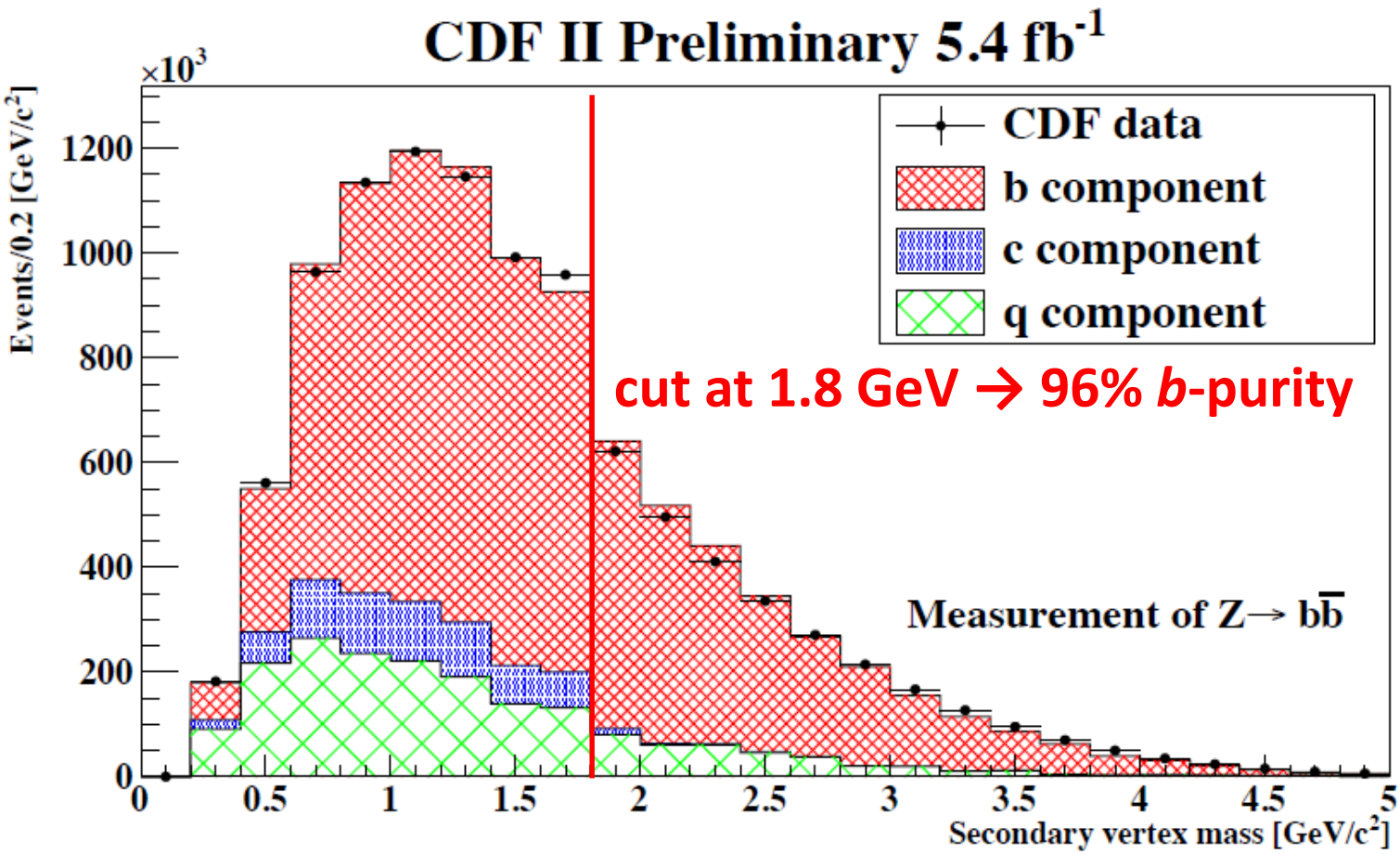
evaluation of *b-bbar* QCD background contribution is performed using the data itself

requires each p_T^{jet} > 22 GeV, but no explicit $p_T^{di\text{-}jet}$ cut

allowing reconstruction of low invariant mass di-jets to better constrain BKGD

compared to ATLAS $p_T^{di\text{-}jet}$ > 200 GeV

new: CDF σ_{Z^0} x B($Z^0 \rightarrow$ b bbar) and determination of b-jet Energy Scale



(75 ± 2) %
(7 ± 1) %
(18 ± 2) %

secondary vertex mass for at least one b-tag trigger jet

new: CDF σ_{Z^0} x B($Z^0 \rightarrow$ b bbar) and determination of b-jet Energy Scale

Apply MC template *shapes* to di-jet mass distributions for

Bb, bB, Bc, cB, Bq, and qB

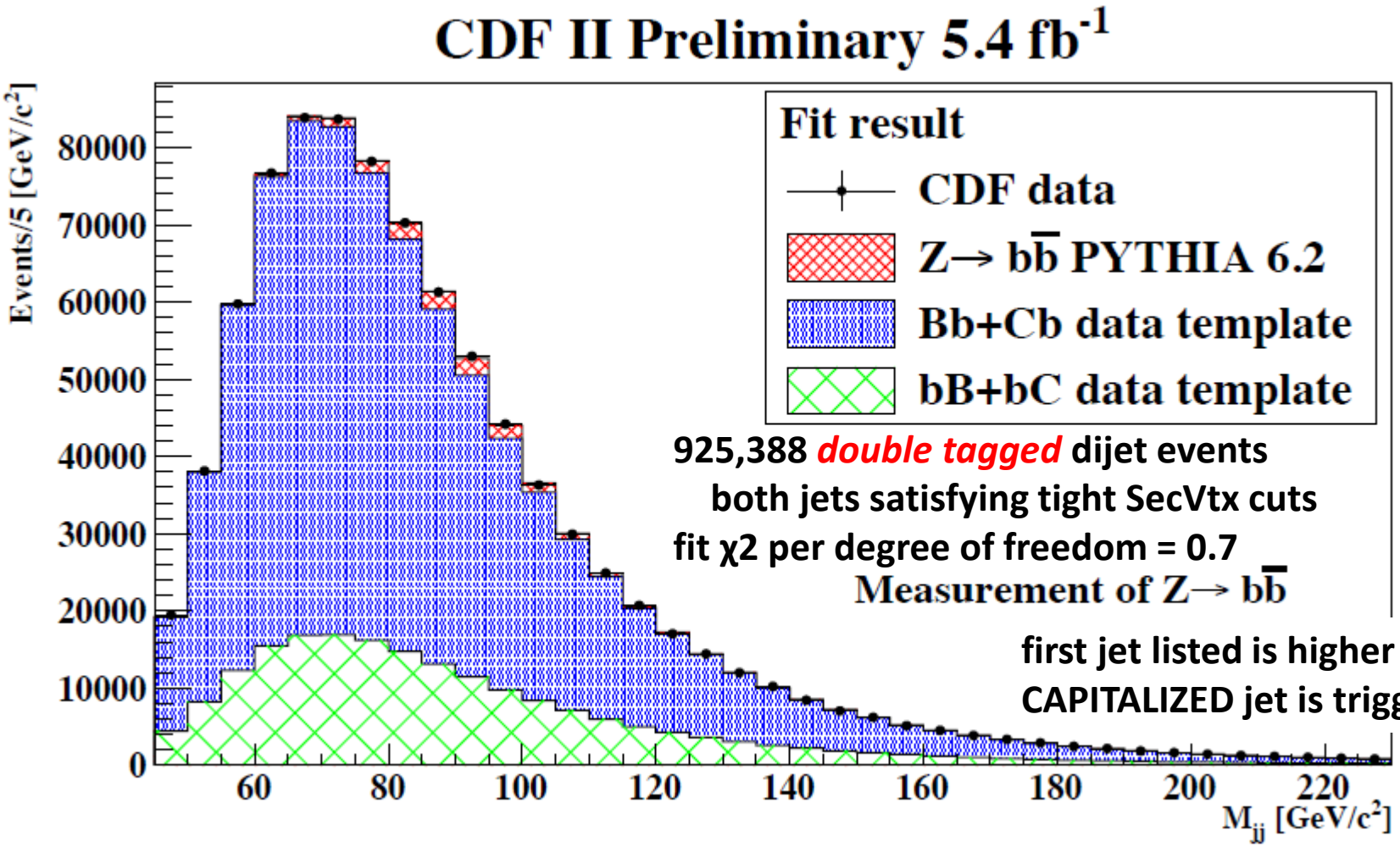
where first jet listed has higher ET
and upper case denotes the trigger jet

Since mass templates for b-tag and c-tag are similar,
they are merged, so for background
only use Bb, bB, Bq, & qB components

signal $Z^0 \rightarrow$ *b bbar* fully simulated by Monte Carlo

binned $$\mathcal{L} = \prod_{i=1}^{N} \frac{n_{\rm s}^i P_{\rm s}(m_{\rm jj}^i) + \sum_{\rm b} n_{\rm b}^i P_{\rm b}(m_{\rm jj}^i)}{n_{\rm s}^i + \sum_{\rm b} n_{\rm b}^i}$$

new: CDF σ_{Z^0} x B($Z^0 \rightarrow$ b bbar) and determination of b-jet Energy Scale

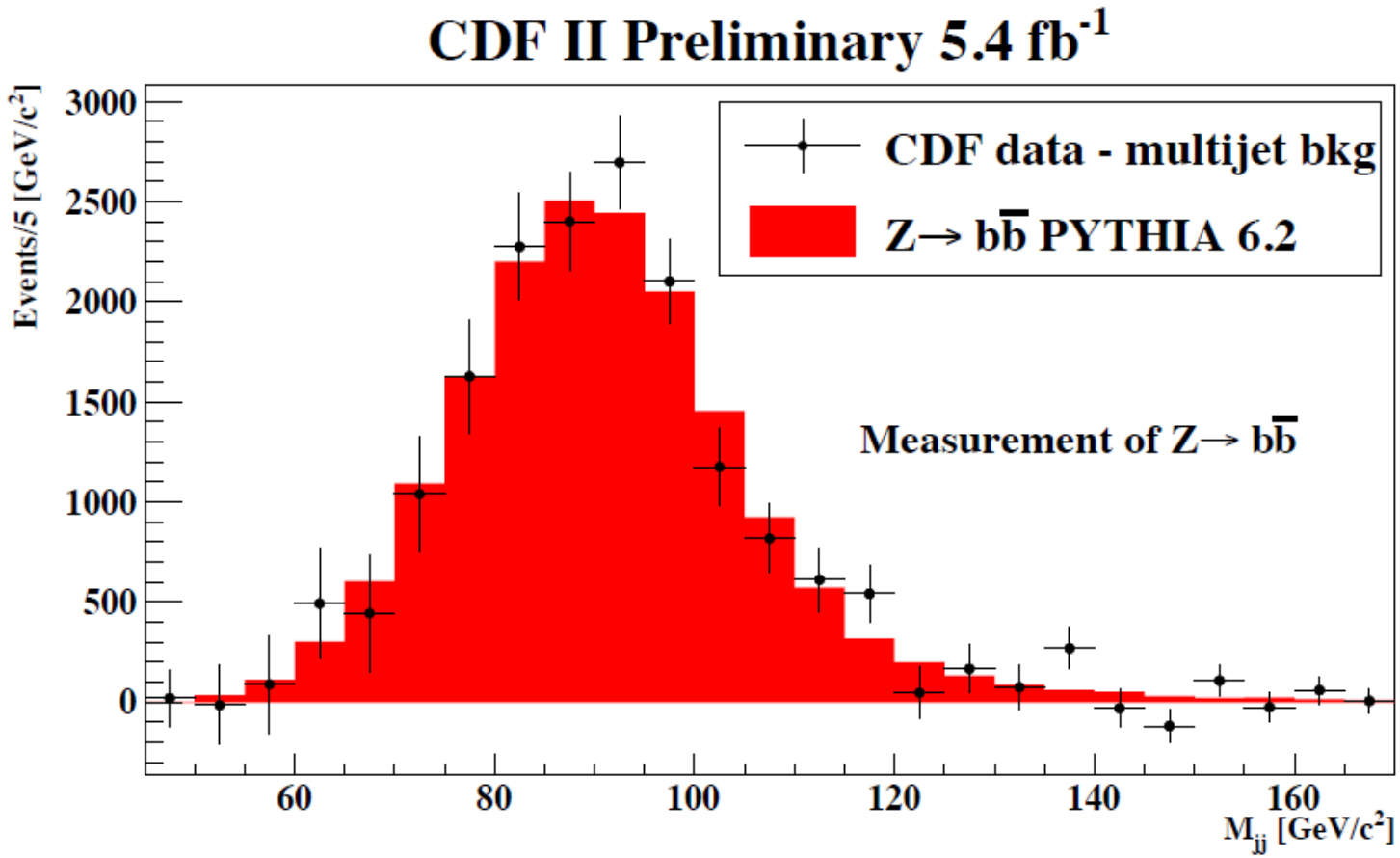


1.9%
76.4%
21.8%
negligible # *light-q* jets

first jet listed is higher p_T jet
CAPITALIZED jet is trigger jet

new: CDF σ_{Z^0} x B($Z^0 \rightarrow$ b bbar) and determination of b-jet Energy Scale

after subtracting background



new: CDF σ_{Z^0} x B($Z^0 \rightarrow$ b bbar) and determination of b-jet Energy Scale

To check MC b-jet Energy Scale,

Repeat above fits varying the MC energy scale for each of the two b-jets for the $Z^0 \rightarrow b\ bbar$ by multiplicative factor $0.90 < k < 1.10$ in 0.01 steps, finding k for minimum $\chi 2$, and spread $\pm \Delta k$ corresponding to $\chi 2 = \chi 2(k_{min}) + 1$

the measured *b*-JES mult. factor $k = 0.993 \pm 0.022$

(stat. uncert. only)

new: CDF σ_{Z^0} x B(Z^0 → b bbar) and determination of b-jet Energy Scale

$$\sigma_Z \times B(Z \to b\bar{b}) = \frac{N_{\text{sig}}}{\epsilon_{\text{kin}} \cdot \epsilon_{\text{trig}} \cdot \epsilon_{\text{tag}} \cdot SF_{\text{trig}} \cdot SF_{\text{tag}} \cdot \mathcal{L}}$$

σ_Z x *B(Z → b bbar)* = 1.11 ± 0.08 (stat only) nb

CDF II Preliminary 5.4 fb^{-1}

Source	Affecting JES	Affecting the cross section
Luminosity		5.9%
Background template statistics	0.004	2.3%
c-quark component in $b\bar{b}$ templates	0.005	2%
Signal Monte Carlo statistics	0.002	3%
b-tag energy dependence	0.004	5%
b-tag scale factor		5%
Trigger and b-tag combined scale factor		4%
JEC Jet Energy Correction		1.4%
FSR Final State Radiation		2.6%
PDF Parton Distribution Function		1.1%
Total	0.008	11.4%

→ ± 0.13 (syst) nb

TABLE II. Summary of the systematic uncertainties.

new: CDF σ_{Z^0} x B($Z^0 \rightarrow$ b bbar) and determination of b-jet Energy Scale

measured *b*-JES multiplicative factor:

k = 0.993 ± 0.022 (stat) ± 0.008 (syst)

builds confidence in CDF *b-jet* model and *b*-JES

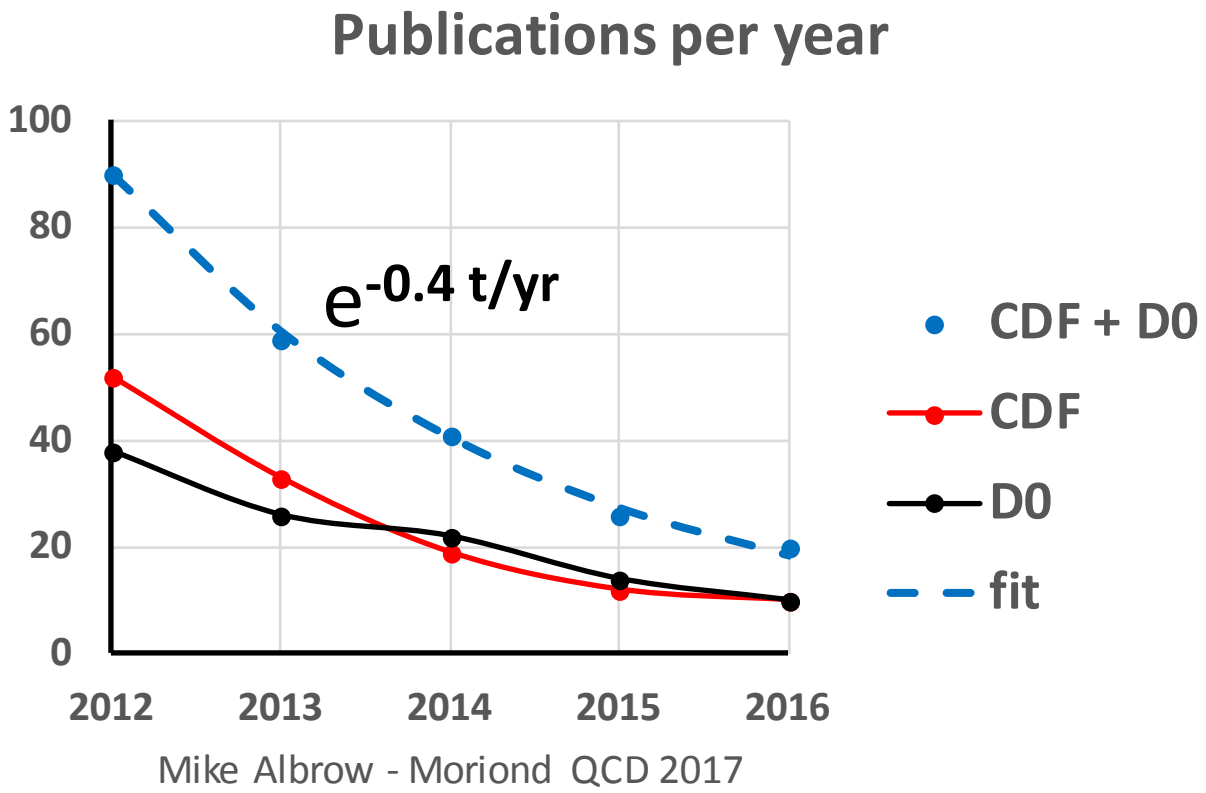
σ_Z x *B(Z → b bbar)* = 1.11 + 0.08 (stat) ± 0.13 (syst) nb

compare to NLO σ_Z x B_{PDF}(*Z → b bbar*) = 1.13 ± 0.02 nb

but not competitive with σ_Z x *B*($Z \rightarrow e^+e^-$ or $\mu^+\mu^-$)

demonstrates BTAG-trigger sample is well-understood and proofs technique to search for *b-bbar* resonances

what have CDF & D0 done lately?



Past performance is no guarantee of future returns,
but might expect another 25 publications in the future!

Anticipated Publications

from CDF & D0 Spokespersons
a sample, other pubs might be added

***CDF*:**

***top* mass lepton+jets matrix element**

***top* mass combination**

***t tbar* cross section**

top polarization

W asymmetry

inclusive photon cross sect.

***Z* → *b bbar* cross section**

***multi-b* resonances**

***X(5568)* study**

D0:

***top* quark pole mass**

***W* mass full Run II**

$A_{fb}(\mu\mu)$ **and** $sin^2\theta_W$

$d\sigma/dp_T(W)$

***ttH* search and limits on *t'* quarks inaccessible at LHC**

X*(5568) confirmation in *Bs* →*Ds μ X

Search for *J/ψ Λ* pentaquark

$A_{fb}(\Lambda_c)$

Ratio of exclusive to inclusive jet production

Anticipated Publications

CDF and D0 and World Combinations:

Tevatron *top* mass

World *top* mass

Tevatron *t tbar F-B* asymmetry

Tevatron *t tbar* cross sections

Tevatron *W* mass

World *W* mass

Tevatron $sin^2\theta_W$

Summary and Conclusions

D0 A_{FB} ($Z^0 \rightarrow \mu^+ \mu^-$) $\rightarrow$ $\sin^2 \theta^{\mu\mu}_{eff}$ = 0.23002 ± 0.00066
and indirect M_W = 80.441 ± 0.033 GeV
working on Tevatron Average w CDF $\ell^+\ell^-$ & D0 e^+e^-

CDF extended inclusive-isolated prompt photons to
E_T^γ = 500 GeV for comparison with QCD models

D0 provided supporting evidence for *X5568* $\rightarrow B_s\, \pi^\pm$
via semileptonic decay $B_s \rightarrow \mu\, \nu\, D_s\, X$

D0 did not find statistically significant evidence for an
exotic $J/\psi\, \Lambda$ resonance (P_c^+ counterpart)

CDF verified methodology σ_{Z^0} x $B(Z^0 \rightarrow b\ bbar)$ and
b-jet Energy Scale factor k = 0.993 ± 0.022

More to come from CDF & D0 in the near future!

Thank you!

Questions?

I'd like to thank all my colleagues from whom I learned much and from whom I stole ideas, graphics, etc.

Peter