From the Bottom to the Top at the Tevatron

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Pheno 2006, Madison, WI *-- Monday May 15, 2006*

Note to Slide Readers:

- You are encouraged to go to the CDF and D0 public results pages to see details of all of the many analyses that I didn't have time to cover here.

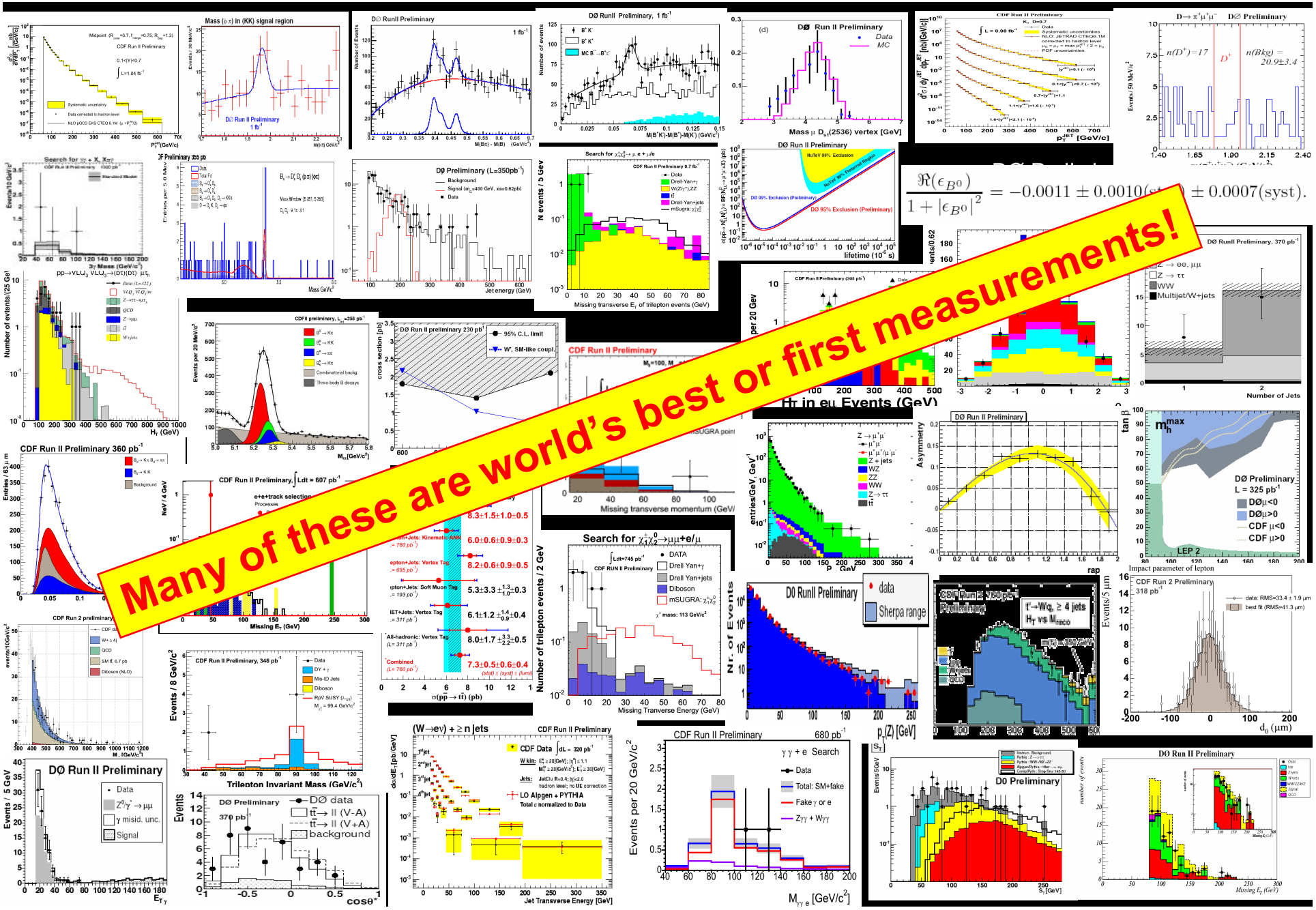
- This talk is best viewed in Powerpoint slideshow format, was created on a Mac.

- Fonts may not agree from machine-to-machine, depending on what you have loaded.

- Contains animations.

- Your mileage may vary.

A Few Tevatron Results Since Last Summer...



5 Years Ago…

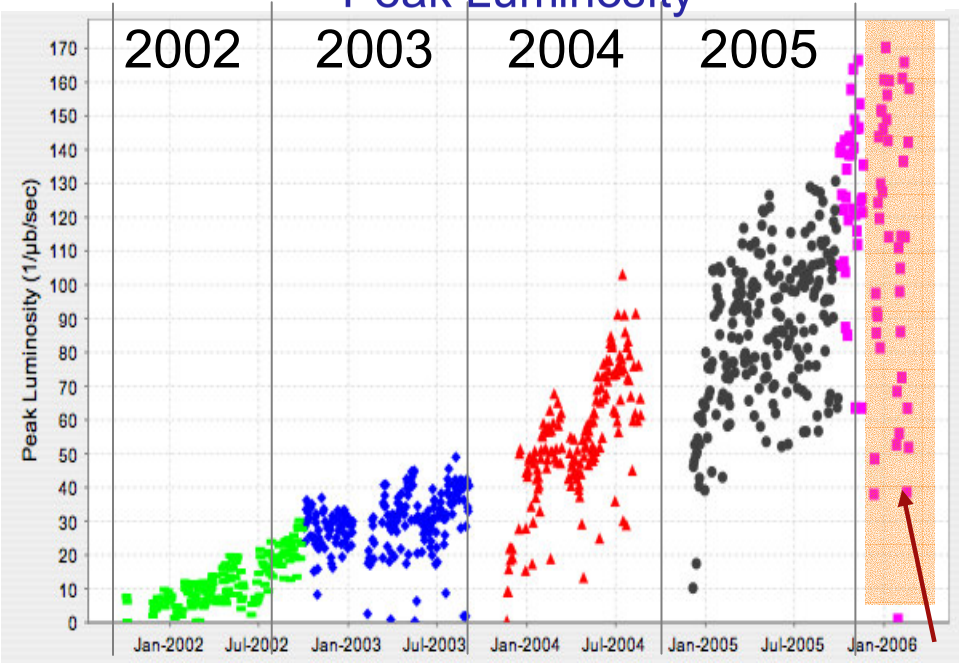
5 years ago (Apr 27, 2001) the lab had a party to celebrate the beginning of Run II.

- Same day: first 36x36 store in the Tevatron (#449)
- Luminosity of ~$1x10^{30}$
- From a stack in the Accumulator of $74x10^{10}$.

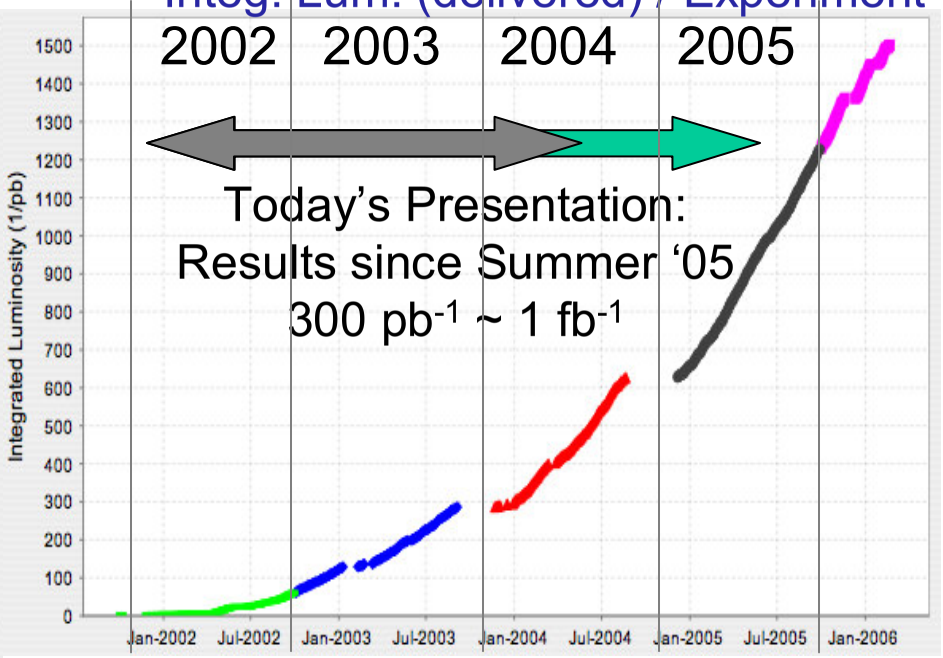
- Our most recent 36x36 store in the Tevatron (#4666)
- Luminosity of ~$1.6x10^{32}$
- From a stash in the Recycler of $243x10^{10}$.

Tevatron Luminosity

Peak Luminosity



Integ. Lum. (delivered) / Experiment



Includes machine studies and diffractive program (low L)

- **Peak luminosity record: 1.8 x10^{32} cm^{-2} s^{-1}**
- **Integrated luminosity**
  - **Weekly record: 27 pb^{-1} /week/expt**
  - **Total delivered: 1.5 fb^{-1} /expt. Total recorded: 1.3 fb^{-1} /expt**
- **Doubling time: ~1 year**
- **Future: ~2 fb^{-1} by 2006, ~4 fb^{-1} by 2007, ~8 fb^{-1} by 2009**

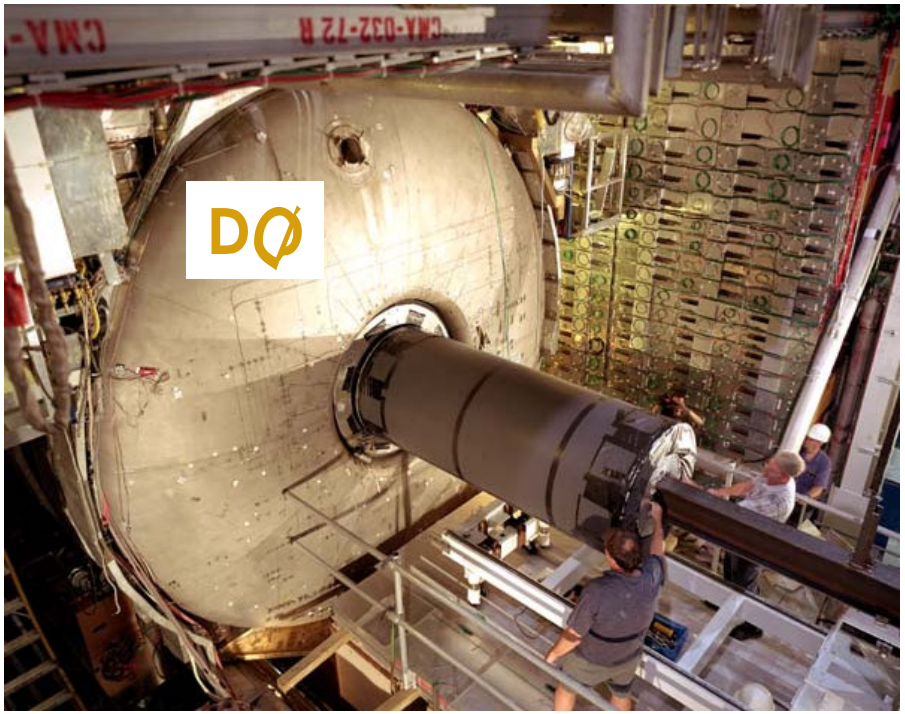
Celebrating 1 fb^{-1} Delivered to the Tevatron

gne toast for the beginning of the femtobar

Celebrating 1 fb^{-1} Delivered to CDF

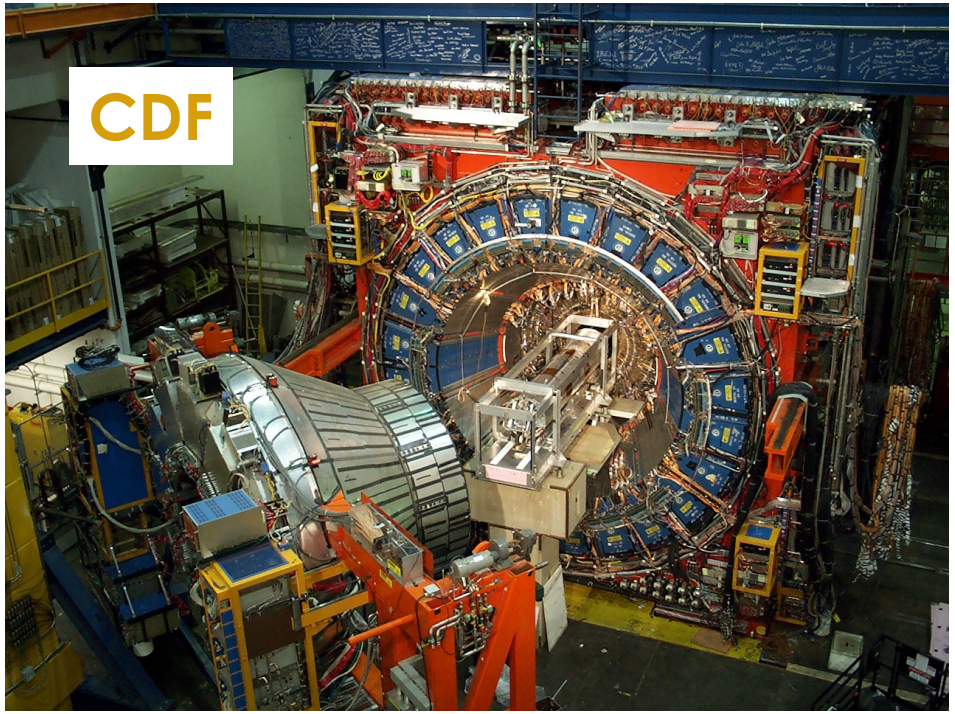
Big THANK YOU to the Accelerator Division !

Tevatron Run 2 Detectors



Both detectors

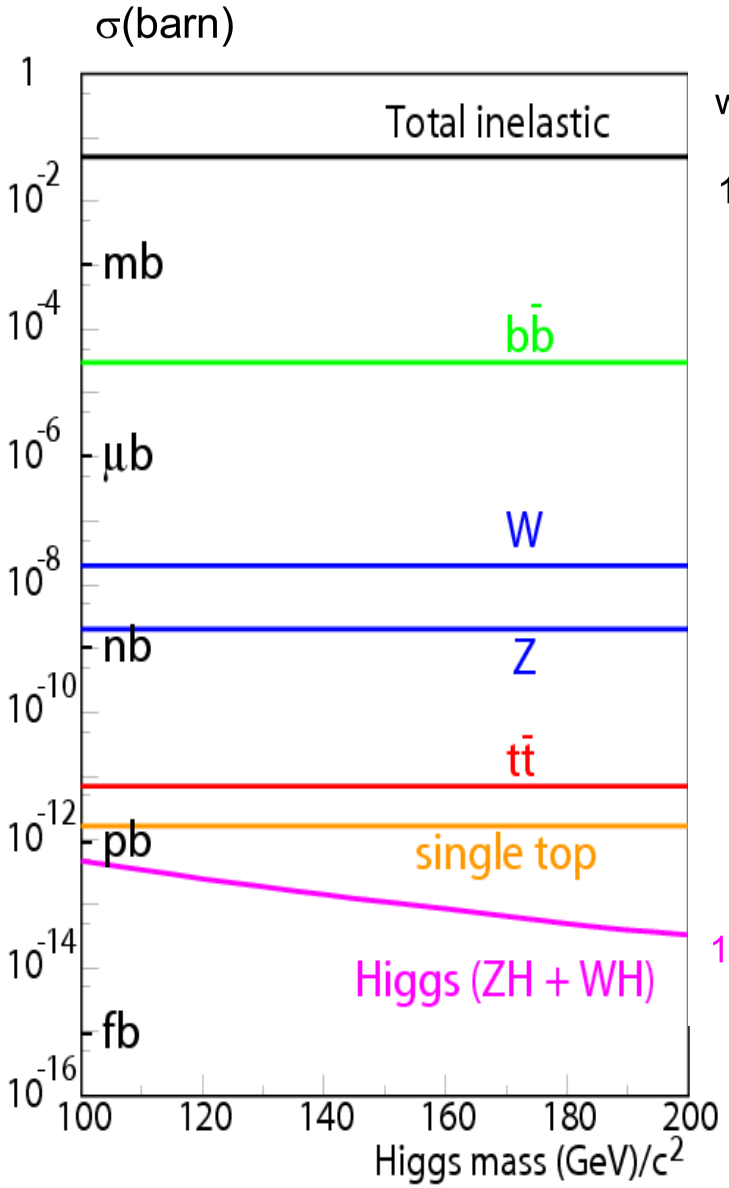
- Silicon microvertex tracker
- Solenoid
- High rate trigger/DAQ
- Calorimeters and muons



Excellent muon ID and acceptance
Excellent tracking acceptance $|\eta| < 2\text{-}3$

L2 trigger on displaced vertices
Excellent tracking resolution

Tevatron Physics



with 1 fb^{-1}

1.4 x 10^{14}

1 x 10^{11}

6 x 10^{6}

6 x 10^{5}

14,000

5,000

1000~100

100 ~10

$$\mathcal{L} = -\frac{1}{4}F^a_{\mu\nu}F^{a\mu\nu} + i\bar{\psi}D\psi$$ Gauge sector ✓

$$+ \psi_i\lambda_{ij}\psi_j h + \text{h.c.}$$ Flavor sector ✓

$$+ |D_\mu h|^2 - V(h)$$ EWSB sector ✓

$$+ \frac{1}{M}L_i\lambda^{\nu}_{ij}L_j h^2 \text{ or } L_i\lambda^{\nu}_{ij}$$ ν mass sector ?

… and beyond?

New Symmetry
New Force
LED X
…
Something new?

Tevatron Program

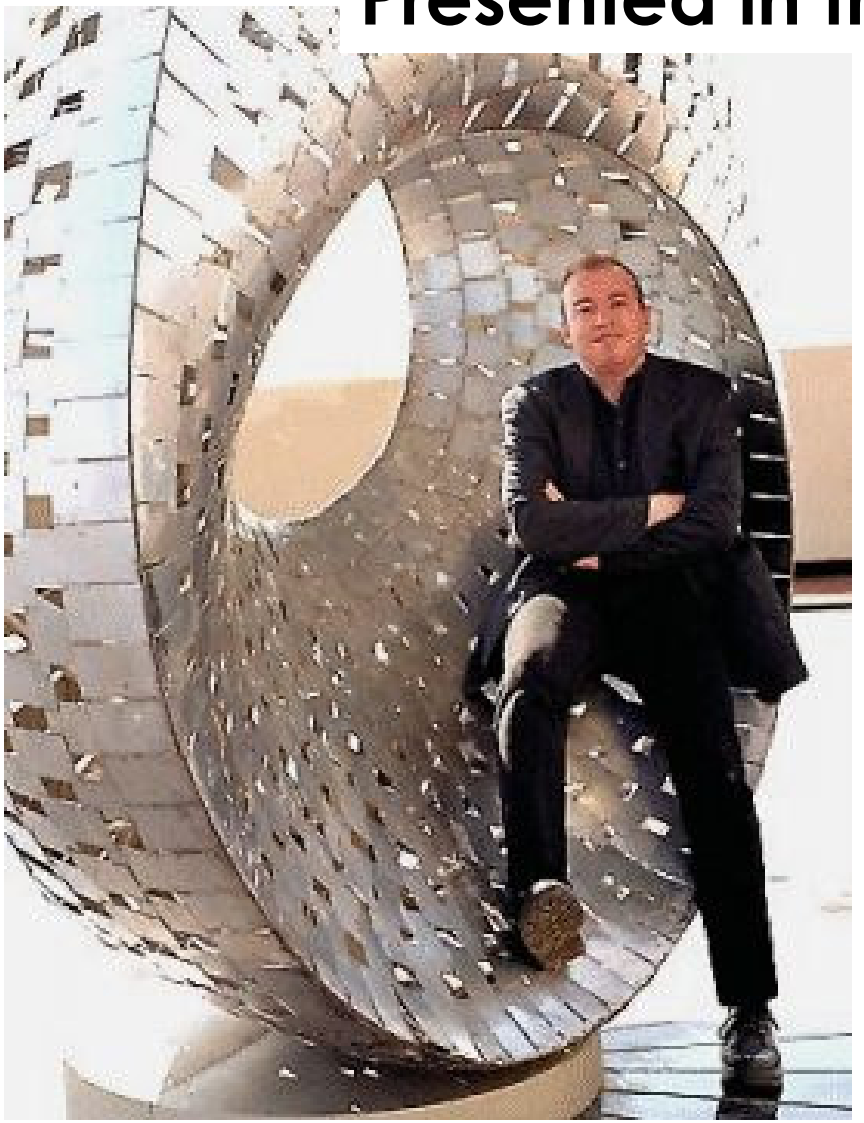
- **Standard Model Precision measurements**
  - Fundamental parameters: M_W, M_{top}, …
  - Spectroscopy: $X(3872) \rightarrow J/\psi\,\pi\pi$, B_1, B_2^*, B_{s2}^*, "pentaquarks", …
  - Heavy flavor production, decays: Λ_B, B_{c+}, τ_B, $B \rightarrow DD$, $\phi\phi$, ϕK, $\mu\mu$…
    B_s, B_d mixing, CP violation: $A_{cp}(B \rightarrow hh)$, $A_{cp}(D^0 \rightarrow K\pi)$, A_{SL}, …
  - Parton distribution functions: $u(x)/d(x)$, $g(x)$, …
  - Benchmark and new cross sections: σ_W, σ_Z, σ_{tt}, …

- **Beyond SM Searches (direct and indirect)**
  - Higgs
  - Supersymmetry
  - Large extra dimensions
  - New gauge bosons
  - New fermions
  - Signature-based searches
  - ….

Test every aspect of SM towards the Unknown!

Direct Searches for New Physics

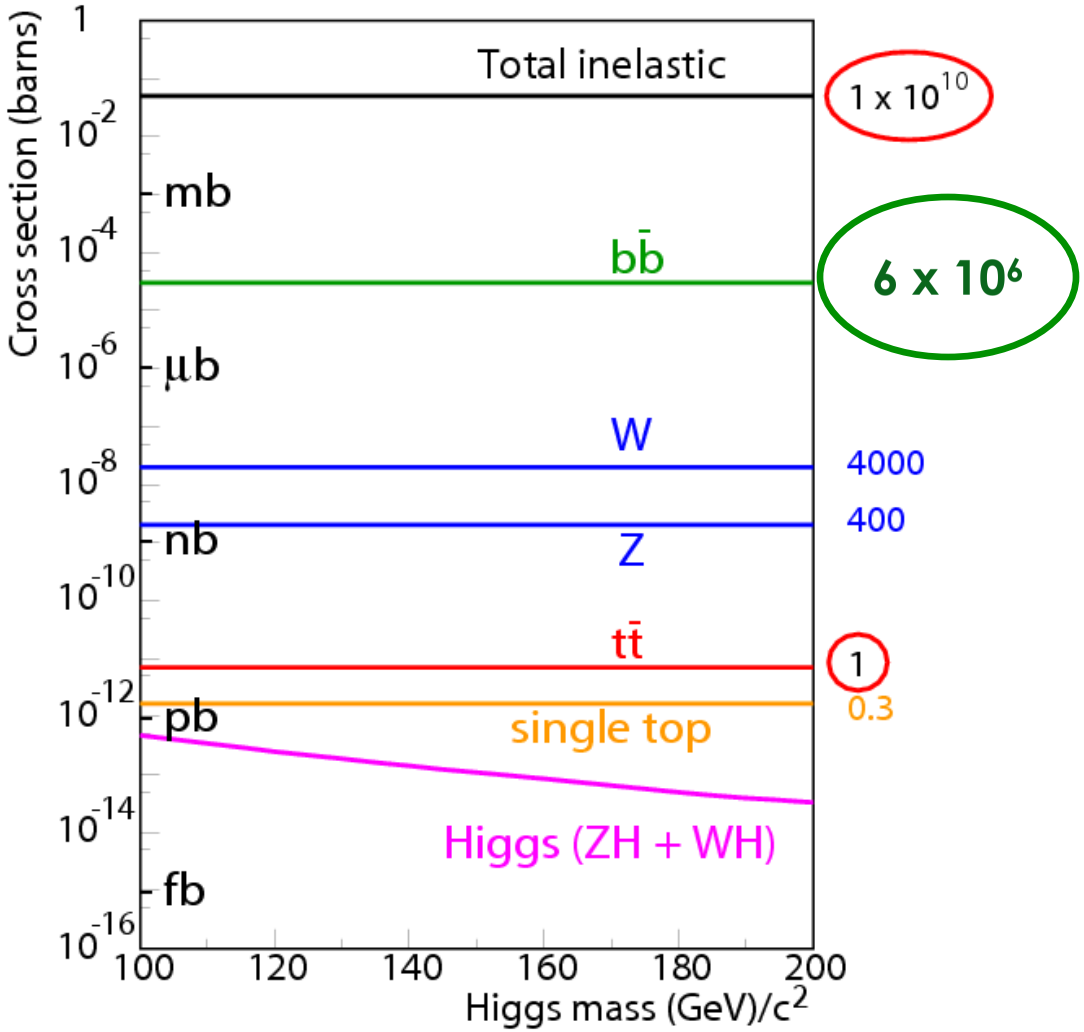
Presented in the Next Talk…



Special Guest

Starting at the Bottom…

Huge Heavy Flavor Production



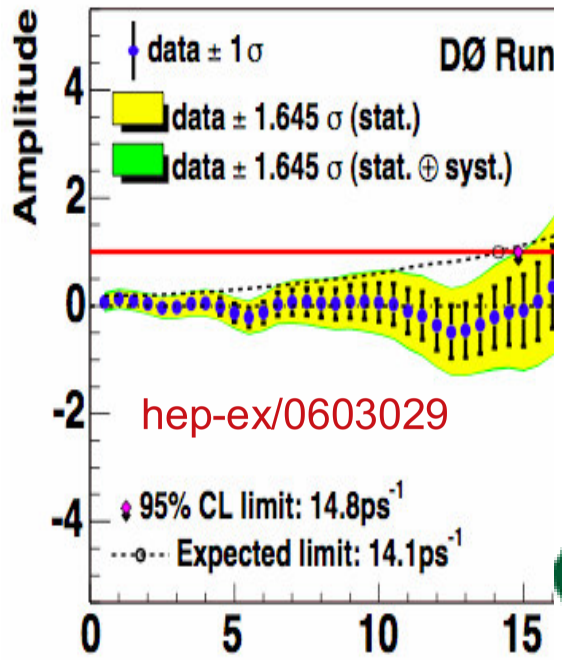
Tevatron cross sections for inelastic collisions at $\sqrt{s}$ = 1.96 TeV

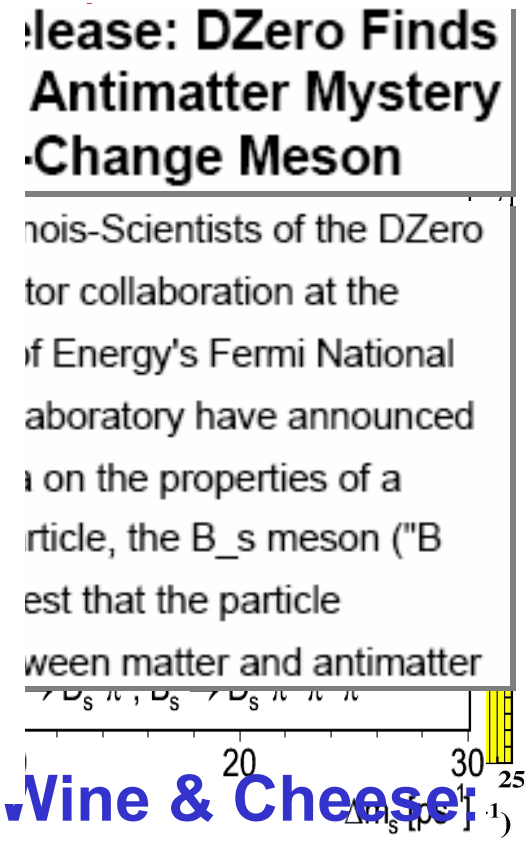
What can be more Beauty-ful?!

B_s Flavor Oscillations:

World averag[illegible] $\Delta m_s > 14.4$ ps^{-1} (S[illegible]mmer 2005)

DØ (1 fb^{-1}) Mar[illegible]





$17 < \Delta m_s < 21$ ps^{-1} at 90% CL

FNAL Wine & Cheese; S. Burdin, March 24

$\Delta m_s = 17.33^{+0.42}_{-0.21} \pm 0.07$ ps^{-1}!

A Lot of International Press

Die Welt - Germany

Freitag, 21. April 2006 — WISSENSCHAFT — DIE WELT Seite 31

WAS SAGT DER NAME?

Kräuter und Dostler

Der Familienname Krüdewagen belegt anschaulich, daß der frühe mittelalterliche Arzt auch notgedrungen sein eigener Apotheker war. Mit seinem Kräuterwagen zog er von Kirmes zu Kirmes und mixte den Leuten an Ort und Stelle Tinkturen und Salben.

In den Städten gab es eine Arbeitsteilung, die sich bis heute erhalten hat. Der vom Rat bestellte Arzt war zu teuer und zu beschäftigt, um sich mit dem Sammeln und Bevorraten von Kräutern und der Herstellung und Verwaltung von Medikamenten zu befassen. Der Arzt schrieb auf, was helfen sollte, und das besorgte man sich im „Kräuterhaus", für das sich schon im 13. Jahrhundert die Bezeichnung Apotheke einbürgerte. Das aus dem Griechischen entlehnte Wort bedeutet „Magazin", ein „Ort, wo man etwas aufbewahrt".

In der Überlieferung der Familiennamen geschieht aber Seltsames. Während in den alten Urkunden die Berufsbezeichnung Apothekarius, eingedeutscht zu Appentegger und Apteker, auch als Familienname oft vorkommt, gibt es ihn heute praktisch nicht mehr. Dafür ist an deutschen Apothekernamen kein Mangel: Apotheker waren die Vorfahren des Komponisten Peter Kreuder. Dazu gehört eine riesige Namenfamilie: Krämer, Kreuter, Kreutler, Kräutler, Kreutler, Kreutner, Kräutner, Krude, Krüder und Krüderer. Nicht zu vergessen die Wurzler, Würzler, Würzner, Wurzer, Wurz und Wurtz. Das bekannteste heimische heilkräftige Kraut, das Origanum vulgare, auf deutsch: Dost, schenkte die Namen Doster, Dostler und Dostmann. Der Salbenhersteller darf nicht fehlen: Schmierschneider. *Hans Markus Thomsen*

Das unvollständige Skelett der Ur-Schlange Najash rionegrina wurde in Argentinien entdeckt. Es bedeutet für Paläobiologen eine Sensation. Die Wissenschaftler fanden bei dem sehr ursprünglichen Tier Knochen von kräftigen Beinen, ein Kreuzbein und einen Beckengürtel — FOTO: AP

Materie kann sich in Antimaterie wandeln

Amerikanische Elementarteilchenphysiker melden Durchbruch – Software aus Deutschland ermöglichte die Messungen

VON CHRISTIAN MEIER

Chicago – Elementarteilchenphysiker melden eine Sensation: Sie haben erstmals die Umwandlungen zwischen Materie und Antimaterie direkt beobachtet. Das seit vielen Jahren existierende Standardmodell der Teilchenphysik – also das vorherrschende Modell für die kleinsten Teilchen und der Kräfte zwischen ihnen – sagt voraus, daß so genannten B-Mesonen die einzigartige Fähigkeit besitzen, sich spontan in ihr Antiteilchen umwandeln zu können – und umgekehrt. Jetzt ist es US-Physikern am Fermilab bei Chicago gelungen, die extrem schnelle Umwandlung zeitlich aufgelöst zu beobachten und damit die theoretische Vorhersage experimentell zu bestätigen.

Als einzige deutsche Institution war die Universität Karlsruhe maßgeblich an dem Experiment beteiligt. Zwanzig Physiker um Thomas Müller und Michael Feindt haben die komplexe Software für eine gezielte Auswertung der Rohdaten geliefert. Das Team gehört zu der Kollaboration „Collider Detector at Fermilab" (CDF), an der etwa 700 Physiker von 66 Institutionen beteiligt sind.

Im Fermilab, dem leistungsfähigsten Teilchenbeschleuniger der Welt, werden Protonen und Antiprotonen auf nahezu Lichtgeschwindigkeit beschleunigt und dann aufeinander geschossen. Die dabei neben vielen anderen Teilchen entstehenden B-Mesonen, im Bereich, den das Standardmodell vorhersagt", erläutert Müller. „Wenn man sich Materie vorstellt, die mit Antimaterie tanzt, dann haben wir das unglaubliche Tempo dieses Tanzes gemessen, aber im jungen Universum kurz nach dem Urknall vorhanden. Physiker können sie nur in großen Teilchenbeschleunigern untersuchen. Sie wollen so sicht nur Erkenntnisse über die Eigenschaften der Elementarteilchen, sondern auch über die Entwicklung des frühen Universums gewinnen.

Seit 1990 arbeiteten die Karlsruher an Software, die aus dem Gewirr elektronischer Teilchenspuren im CDF-Detektor rekonstruieren kann, ob ein B-Meson bei seiner Entstehung Teilchen oder Antiteilchen war. Dies gelang mit komplexen statistischen Verfahren. Zusammen mit der Messung der Lebensdauer des B-Mesons (rund eine Millionstel Millionstel Sekunde) und der relativ einfach zu gewinnenden Information, ob es beim seinem Zerfall Teilchen oder Antiteilchen war, kann auf die Anzahl der Umwandlungen pro Sekunde geschlossen werden.

„Wenn man sich Materie vorstellt, die mit Antimaterie tanzt, dann haben wir das unglaubliche Tempo dieses Tanzes gemessen"

Jacobo Konigsberg, Sprecher der Teilchenphysiker-Gruppe

Tempo dieses Tanzes gemessen", sagt Jacobo Konigsberg, Sprecher der CDF-Kollaboration.

B-Mesonen existieren im heutigen Kosmos nicht mehr, waren wandeln sich pro Sekunde 2,8 Billionen Mal in Anti-B-Mesonen um und zurück, also jede Sekunde etwa 500-mal öfter als Menschen auf der Erde leben. „Dieser Wert liegt

Ur-Schlange hatte Hüfte und Beine

São Paulo – Forscher haben erstmals versteinerte Reste einer Schlange gefunden, die außer Beinen auch eine richtige Hüfte hatte. Es handle sich zudem um die älteste bekannte Festland-Schlangenart.

Das in der argentinischen Provinz Rio Negro im Norden Patagoniens entdeckte Fossil stamme aus der Oberkreidezeit vor rund 66 bis 100 Millionen Jahren, berichten Hussam Zaher von der Universität São Paulo und Sebastian Apesteguia aus Buenos Aires in „Nature". Ihre Entdeckung stützt die Hypothese, daß Schlangen auf dem Festland und nicht im Wasser entstanden sind. Die entdeckte Schlange hat ein Kreuzbein, das einen Beckengürtel trage, sowie kräftige und funktionstüchtige Beine. Bislang bekannt waren nur Schlangenfossile mit gut entwickelten Hinterbeinen (wie Haasiophis, Pachyrhachis und Eupodophis) ohne richtige Hüften.

Der Skelettaufbau noch heute lebender Schlangen beschränkt sich auf Schädel, Wirbel und Rippen. Nur bei primitiven Arten wie den Riesenschlangen gibt es Reste von Becken und Oberschenkel. *DW*

WISSENSCHAFT KOMPAKT

RAUMFAHRT

Start von „Cloud-Sat"

Die Nasa will heute den Wolkenforschungssatelliten „Cloud-Sat" in eine Erdumlaufbahn schießen. Mit Hilfe von Radarsensoren soll er tief in das Innere von Wolken blicken und so den Wetter- und Klimaforschern neue Erkenntnisse liefern. *N.L.*

KERNENERGIE

Rückholbare Nuklearabfälle

Das französische Parlament hat sich dafür ausgesprochen, radioaktive Abfälle so zu lagern, daß sie jederzeit rückholbar sind. Damit wird die Option offengehalten, diese Abfälle in den sogenannten Reaktoren der vierten Generation zu entsorgen. *nio*

MEDIZIN

Krebs-Protein entdeckt

Wissenschaftler der Universität Zürich haben ein Protein entdeckt, das bei der Entstehung von Krebs offenbar eine zentrale Rolle spielt. Das Protein Paraftromin ist zwar schon seit vielen Jahren bekannt, doch erst jetzt entdeckten die Forscher, daß es bei der Aktivierung von genetischen Programmen im Zellkern eine zentrale Rolle spielt und folglich auch an der Entstehung von Fehlfunktionen und Krebs beteiligt sein kann. *AP*

Glückshormon gut für die Leber

Das Glückshormon Serotonin fördert die Regeneration von verletztem Lebergewebe. Dies beobachteten Forscher des Max-Planck-Instituts für molekulare Genetik und des Max-Delbrück-Centrums in Berlin. *N.L.*

Musik lindert Schmerzen

Patienten, die während einer Operation in ärztlicher Betäubung Musik hören, benötigen weniger Schmerzmittel, berichtet die Ärztezeitschrift „Praxis-Depesche". *fk.*

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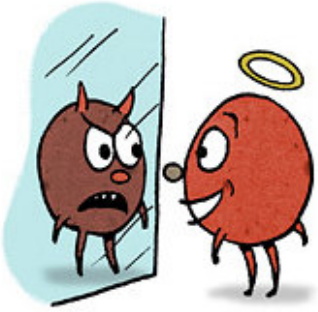
NY Times



David Goldin

Russia

Ученые сделали сенсационное открытие

Tokyo

総合・核心 11版 2006年(平成18年)4月13日(木曜日)

高速変身粒子を初観測

1秒に2兆8000万回

筑波大と高エネルギー加速器研究機構（KEK）は十二日、米国で進める国際共同実験で、一秒間に約二兆八千万回もまぐるしく「変身」する粒子を初めて観測したと発表した。ノーベル賞の期待がかかる小林・益川理論の検証にもなるという。

筑波大などが観測されたのはB中間子と呼ばれる粒子。Bs中間子は一瞬のうちに、正反対の性質を持つ反Bs中間子に変わり、ふたたび元のBs中間子に戻る性質を持つ。

米国のフェルミ国立加速器研究所にある世界最高エネルギーの加速器でBs中間子を作り、日米など十二カ国の研究チームが四年がかりで観測した。その結果、変身が二兆八千万回分の一秒の速さで起きていることが分かった。

Bs中間子が猛烈なスピードで変身することは、小林誠・前KEK素粒子原子核研究所長と益川敏英・京都産業大教授が一九七三年に発表した小林・益川理論で予想されていた。

The Economist (UK)

Cosmology and particle physics

What can the matter B?

Apr 20th 2006

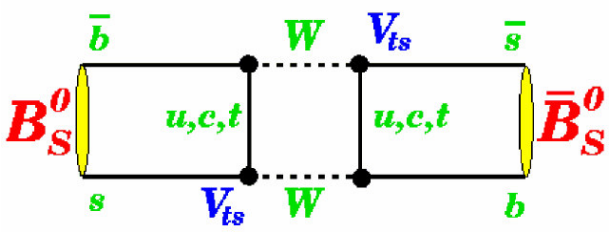
From The Economist print edition

A new result bearing on the question of why the universe is made of matter

The Idea Behind B_s Mixing

Neutral B Meson system

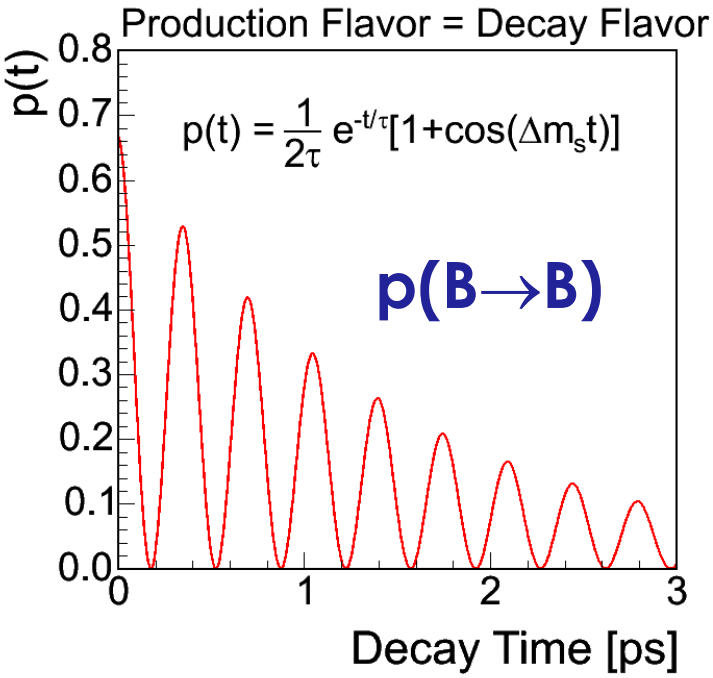
$$|B\rangle = (b\bar{s}); \quad |\bar{B}\rangle = (\bar{b}s)$$



mixture of two mass eigenstates (No CP violation case):

$$|B_H\rangle = \frac{1}{\sqrt{2}}\left(|B\rangle + |\bar{B}\rangle\right)$$

$$|B_L\rangle = \frac{1}{\sqrt{2}}\left(|B\rangle - |\bar{B}\rangle\right)$$



B_H and B_L may have different mass and decay widths:

- $\Delta m_s = M_H - M_L$ (>0 by definition)
- $\Delta\Gamma = \Gamma_H - \Gamma_L \sim 0$

FNAL Wine & Cheese: I. Furic, April 10 (stream)

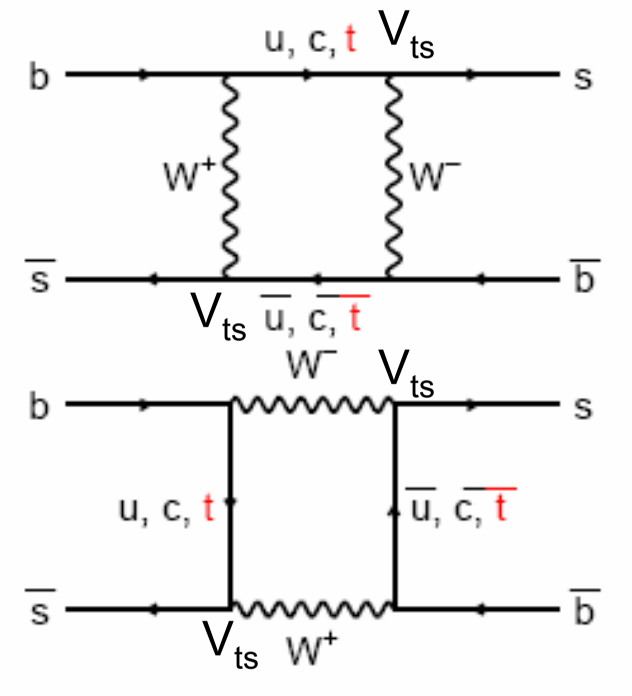
Mixing in the Standard Model

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

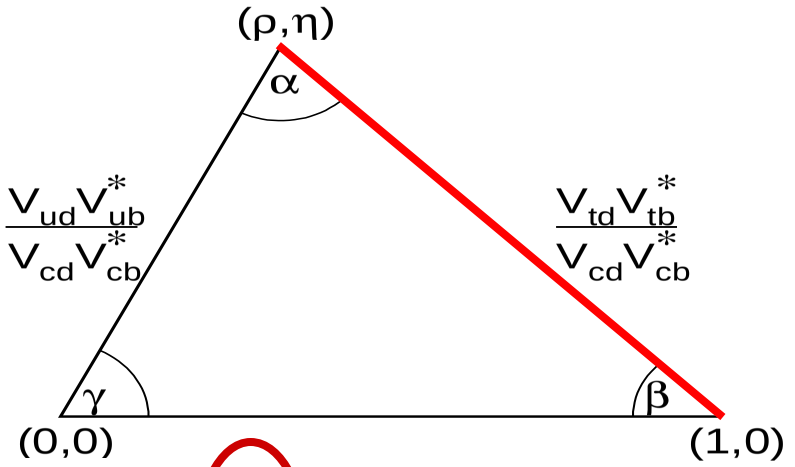
CKM Matrix

Ratio of frequencies for B^0 and B_s:

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{Bs}}{m_{Bd}} \xi^2 \frac{|V_{ts}|^2}{|V_{td}|^2}$$



Unitarity Triangle



$$\left|\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*}\right| = \frac{|V_{td}|}{|V_{ts}|} \times \frac{1}{|V_{cd}|} \sim \sqrt{\frac{\Delta m_d}{\Delta m_s}}$$

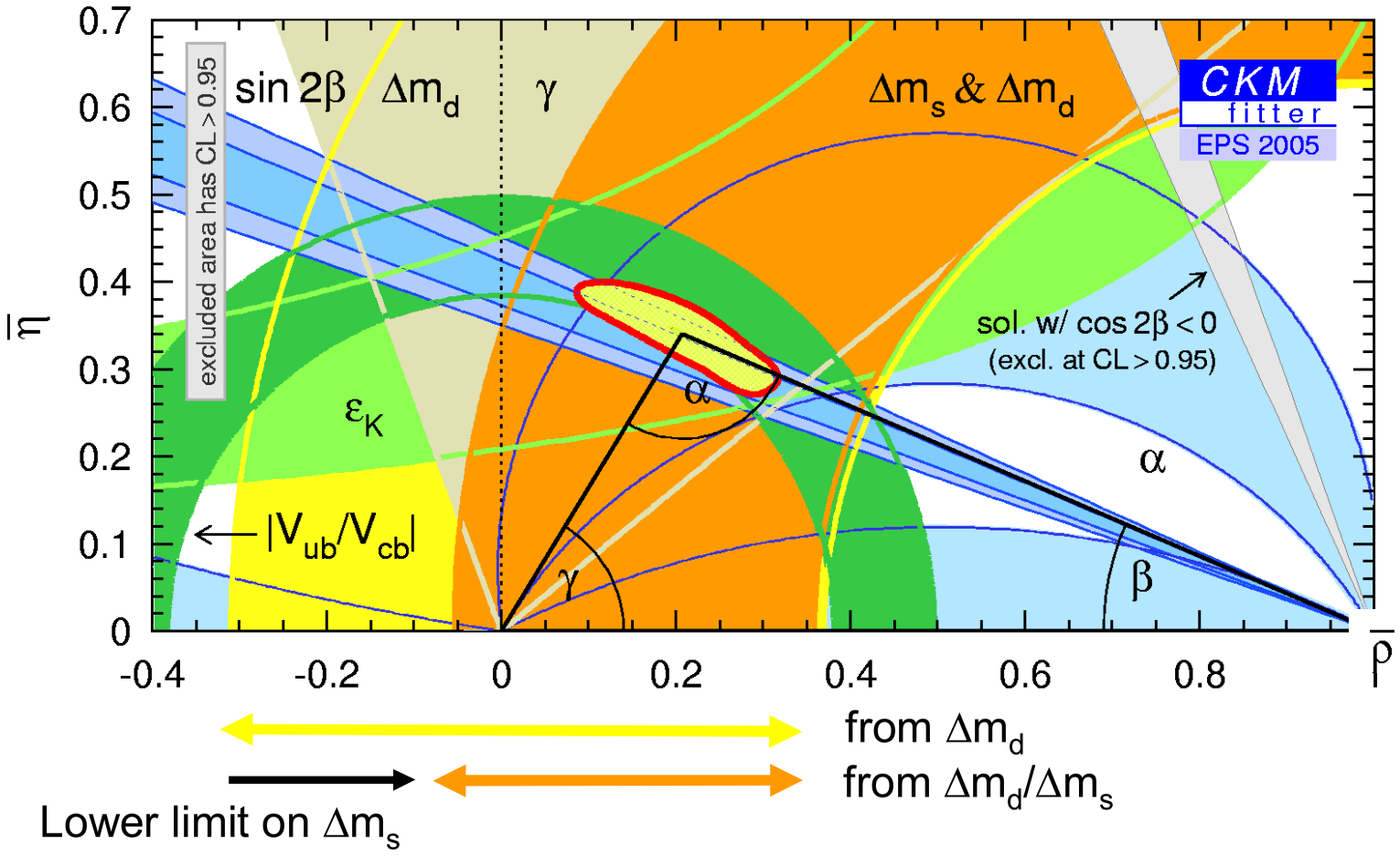
Mixing in the Standard Model

CKM Fit Result:

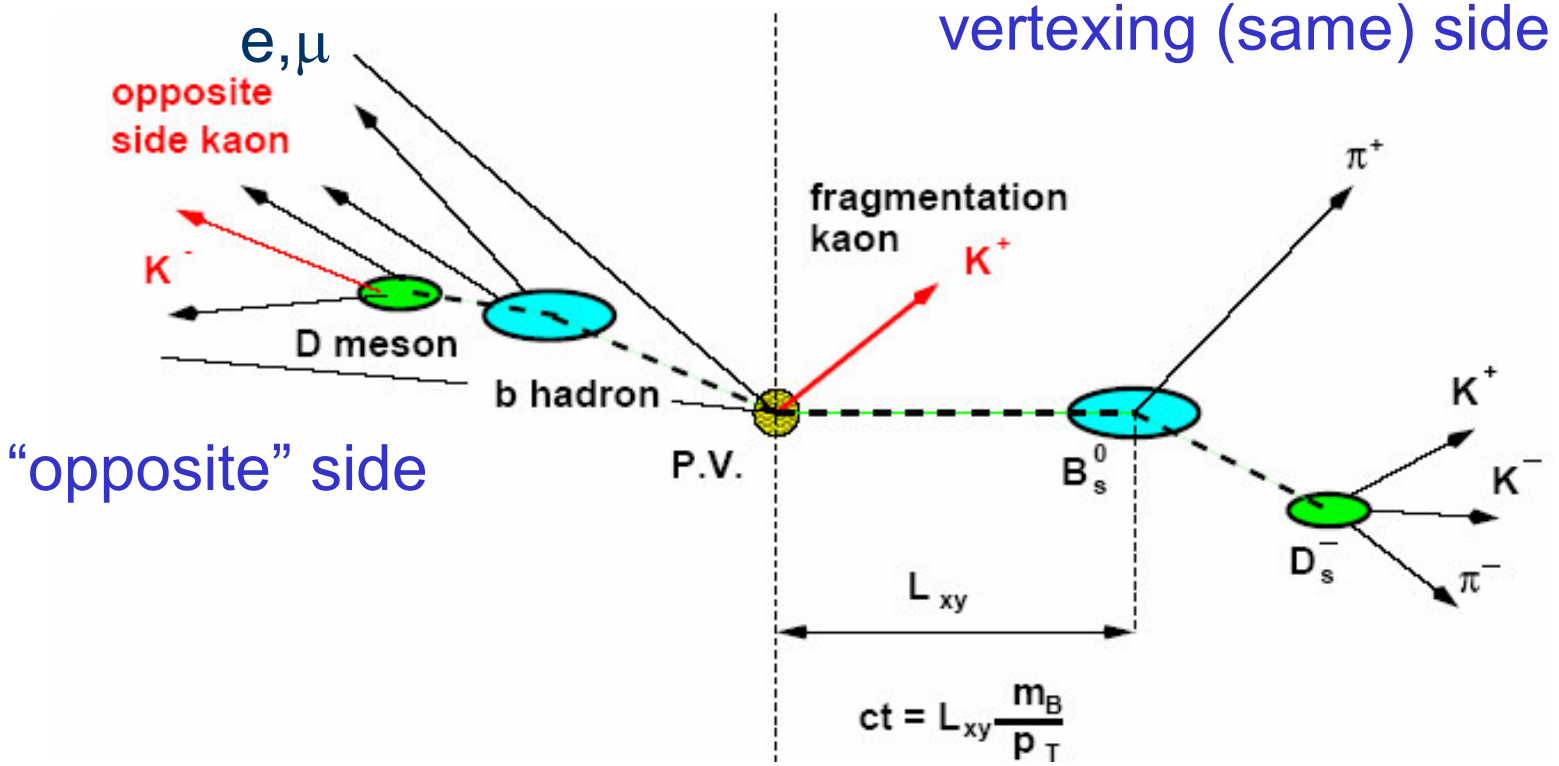
$\Delta m_s = 18.3\ ^{+6.5}_{-1.5}\ ps^{-1}$

1σ : [16.8, 24.8] ps^{-1}

2σ : [15.5, 31.3] ps^{-1}



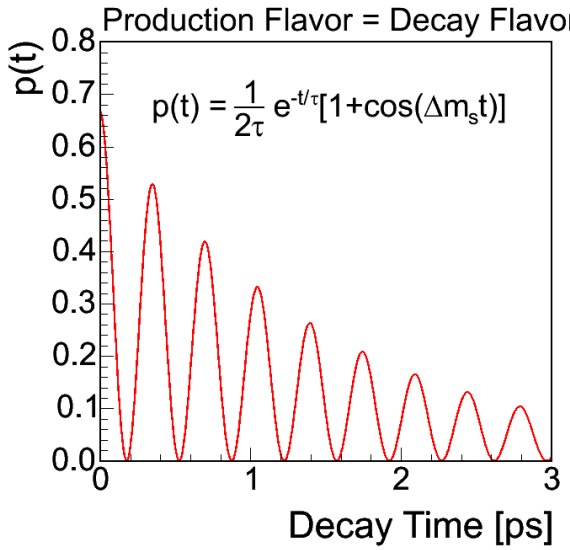
Looking for B_s Mixing



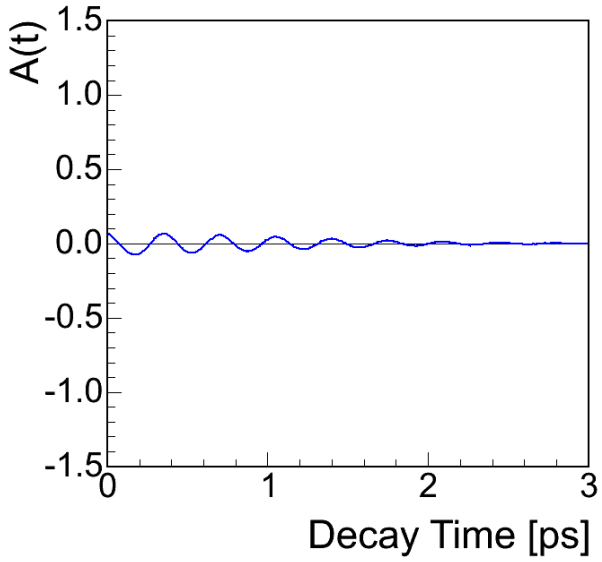
- **Reconstruct B_s decays:decay flavor from decay products**
- **Measure proper time of the decay (very precisely)**
- **Infer B_s production flavor (production flavor tagging)**

Right Sign, Wrong Sign

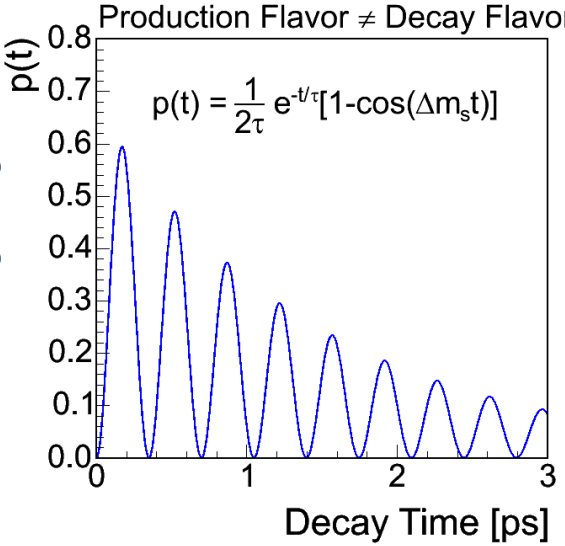
"Right Sign"



$$A(t) = \frac{N_{RS} - N_{WS}}{N_{RS} + N_{WS}}$$

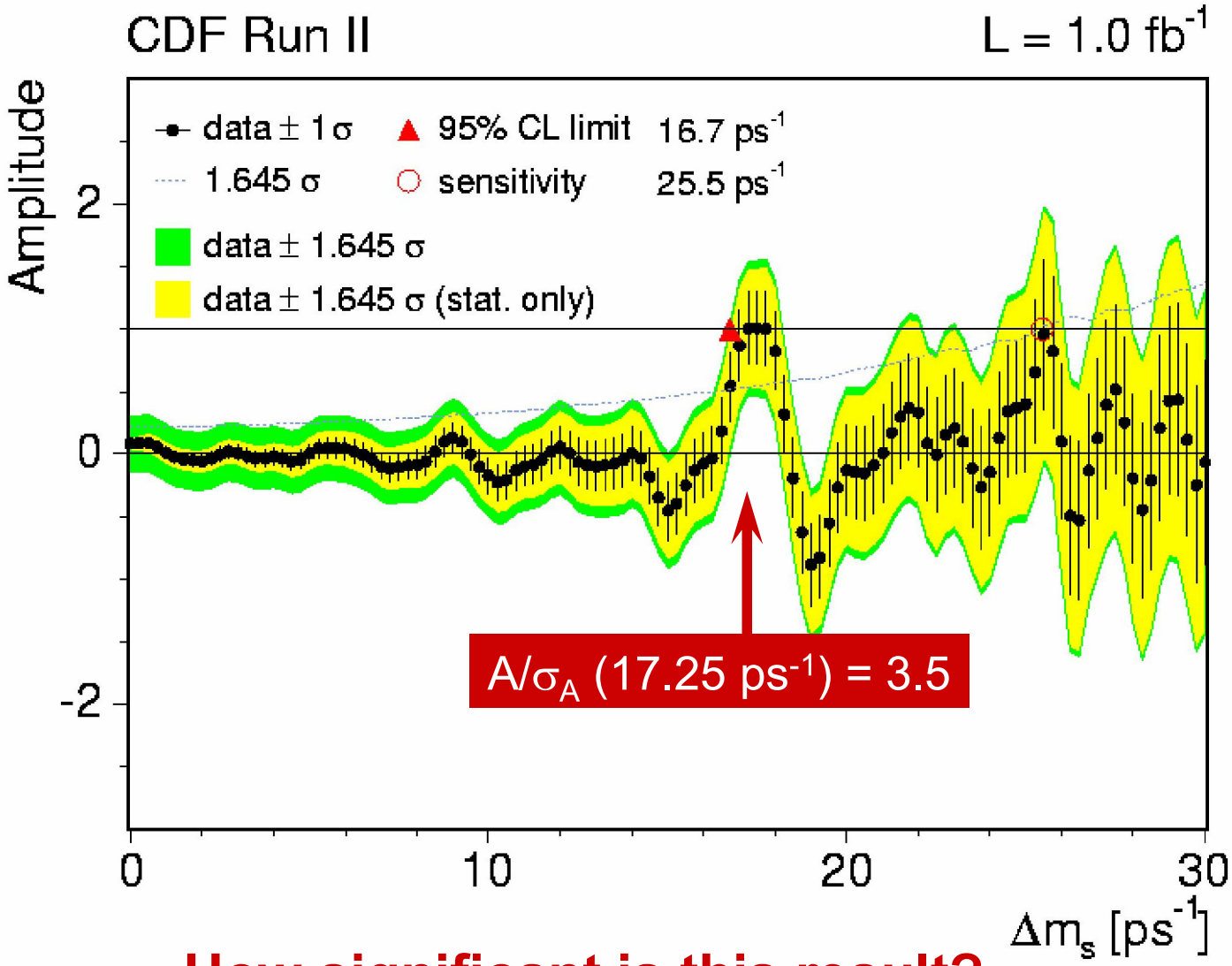


"Wrong Sign"



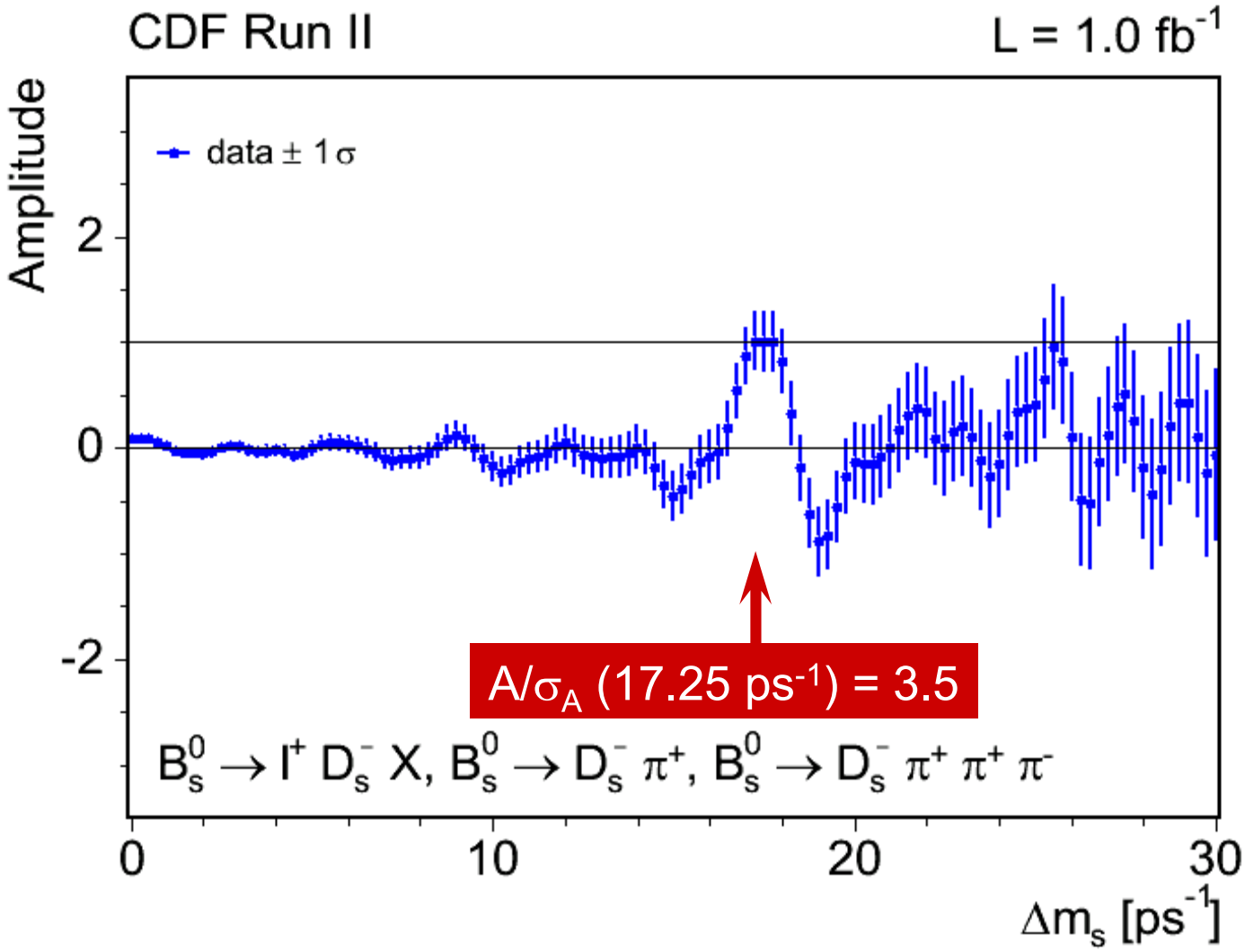
So easy??
What about detector effects?

Combined Data Scan



How significant is this result?

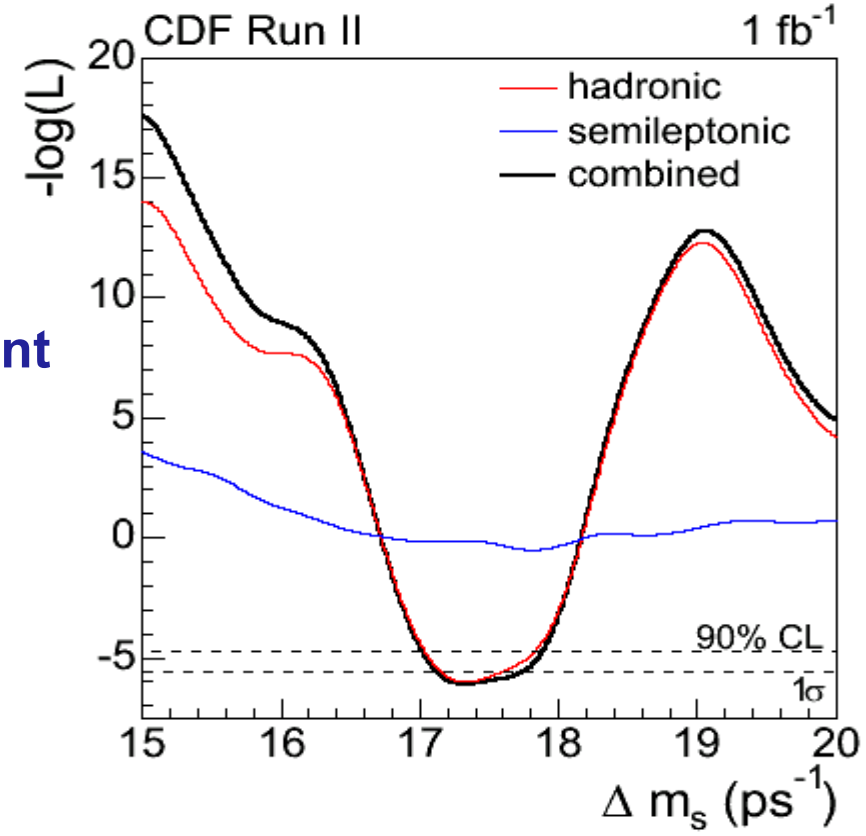
Combined Data Scan



probability of fake from random tags = 0.5%

CDF Measurement of Δm_s

The measurement is already very precise! (at 2.5% level)



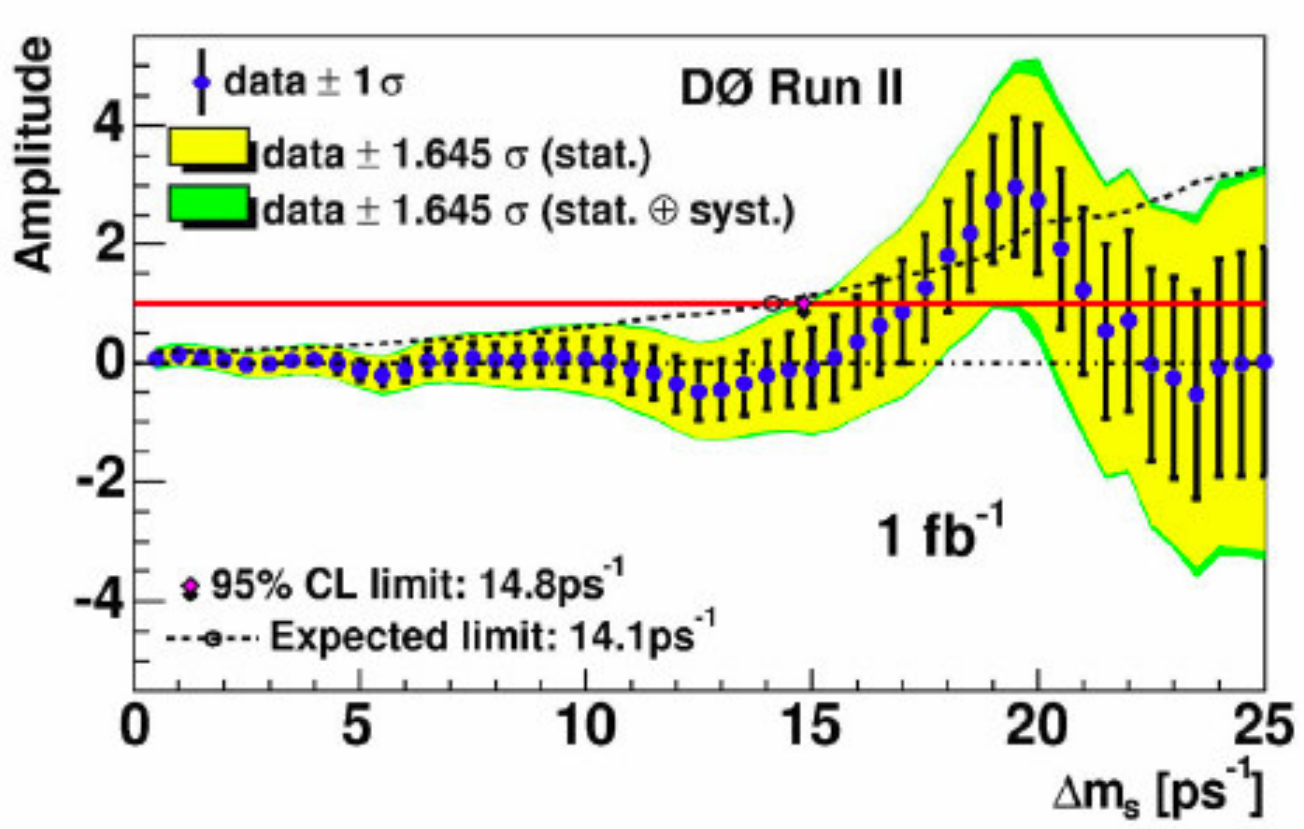
$$\Delta m_s = 17.33\ ^{+0.42}_{-0.21}\ (\text{stat}) \pm 0.07\ (\text{syst})\ \text{ps}^{-1}$$

Consistent with DØ measurement and limit:

$$|V_{td} / V_{ts}| = 0.208\ ^{+0.008}_{-0.007}\ (\text{stat + syst})$$

$17 < \Delta m_s < 21$ ps^{-1} at 90% CL

DØ Measurement of Δm_s

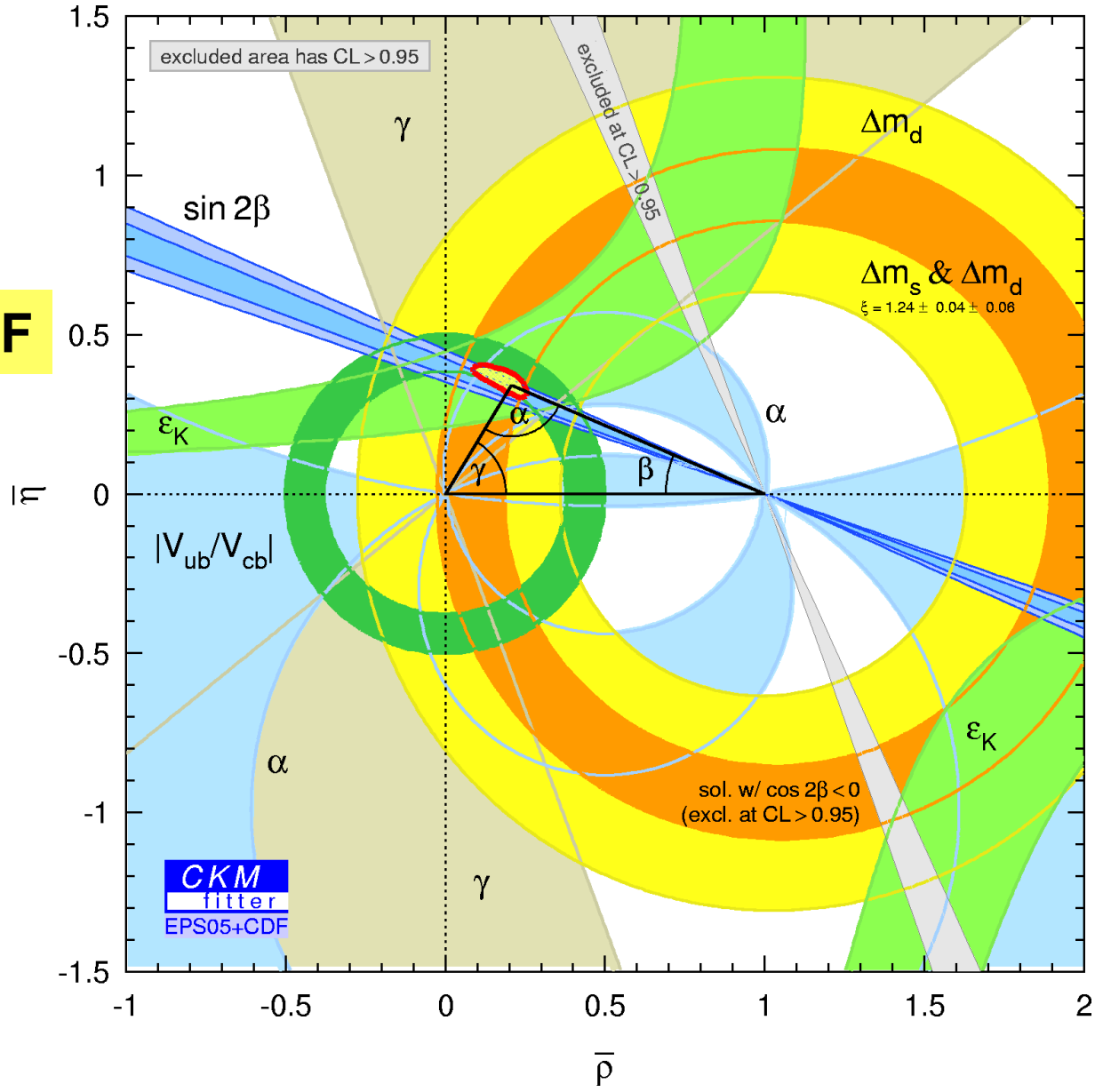


Deviation of the amplitude at 19 ps^{-1}

2.5 σ from zero
1.6 σ from one!

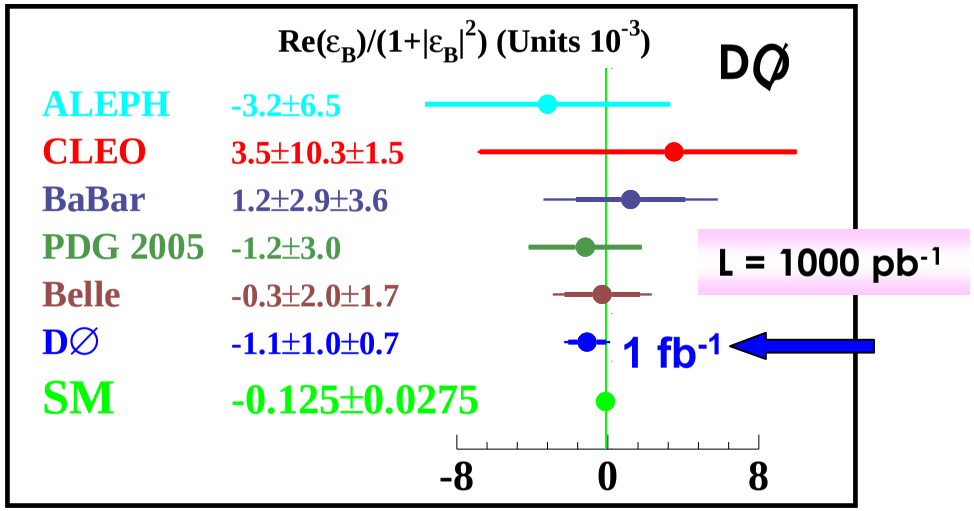
World Knowledge of CKM

EPS05 + CDF

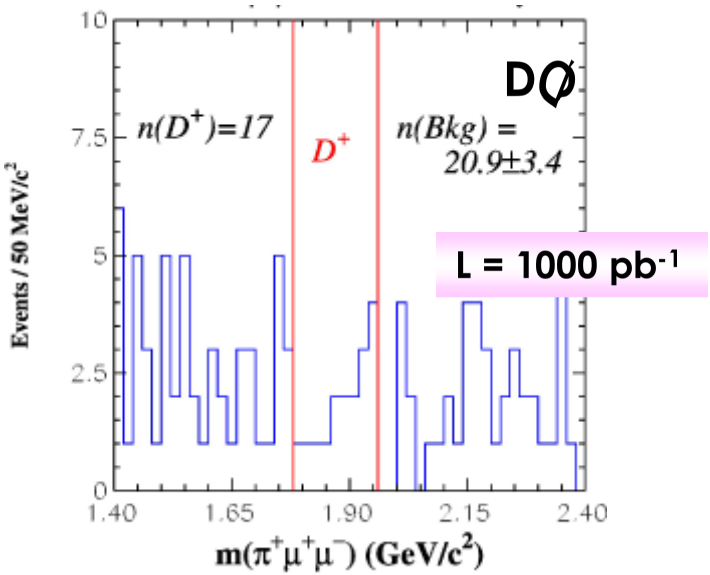


Other Recent Beauty…

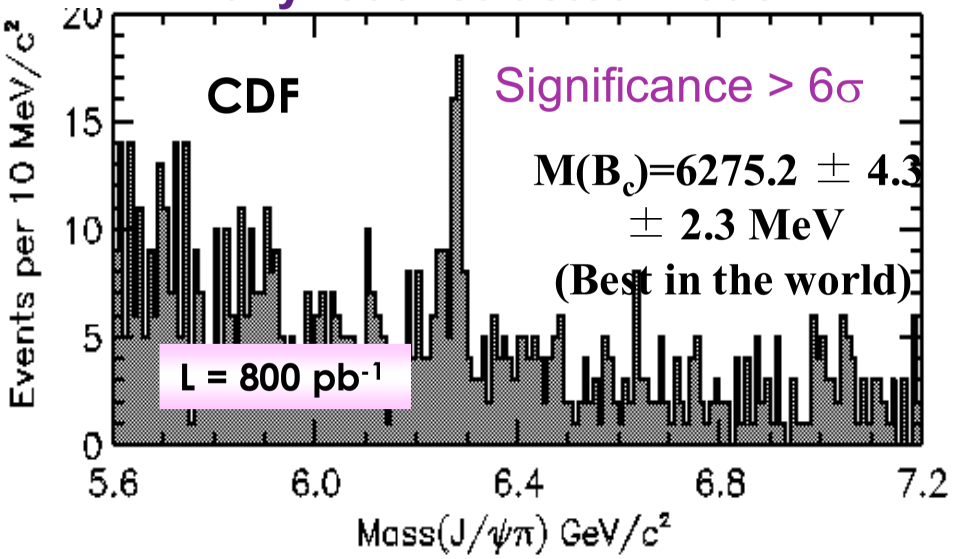
CP Violation in Mixing

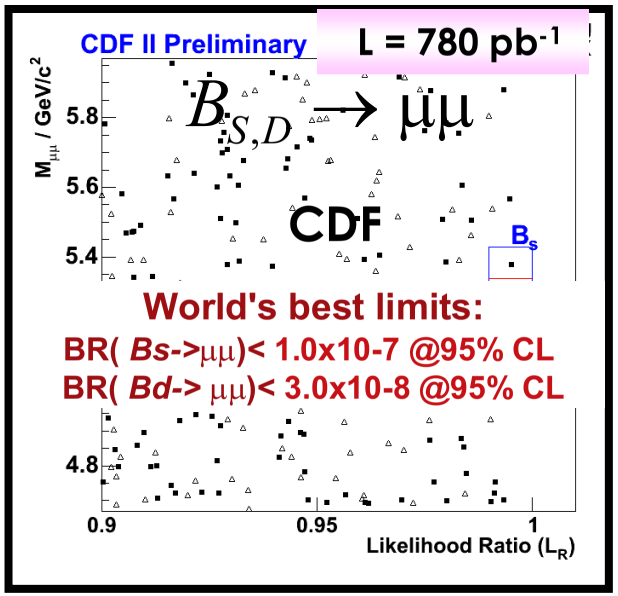


Search for FCNC in $D \to \pi^+\mu^+\mu^-$



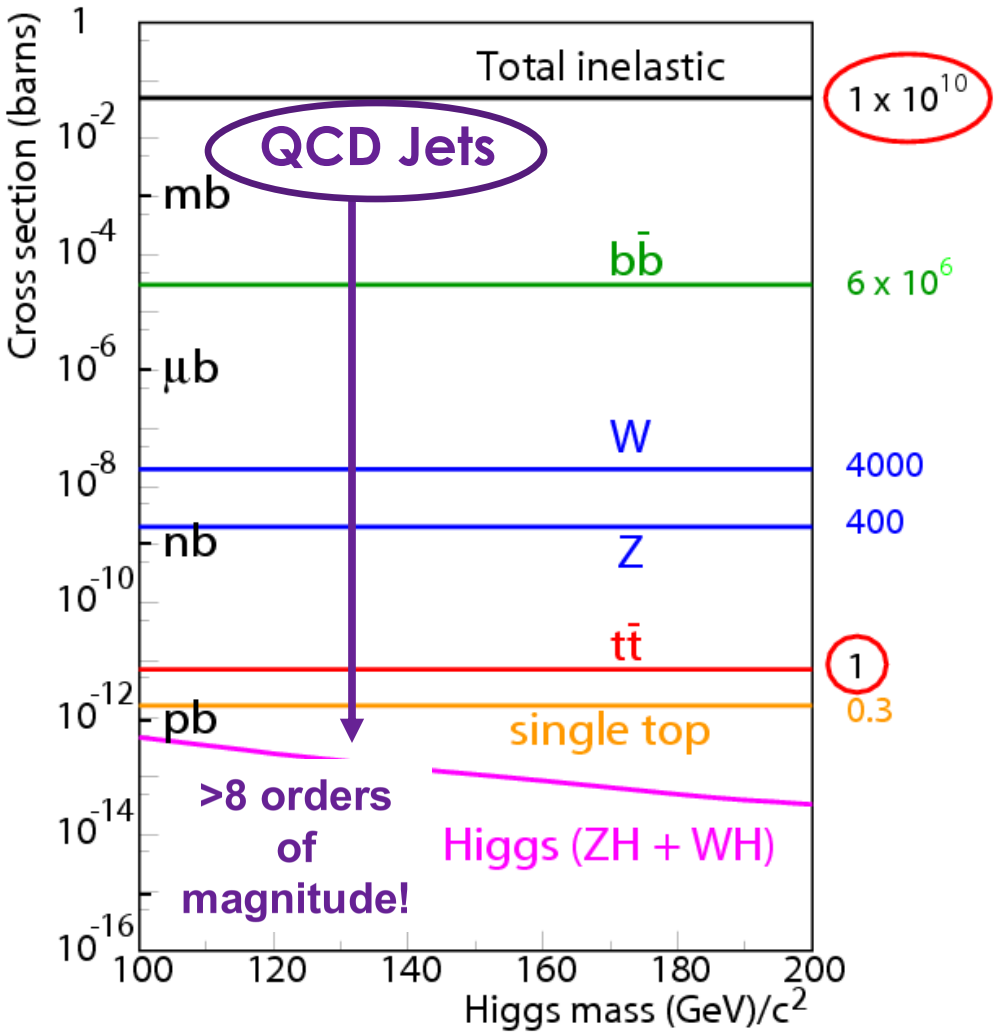
Observation of B_c exclusive decay, fully reconstructed mode





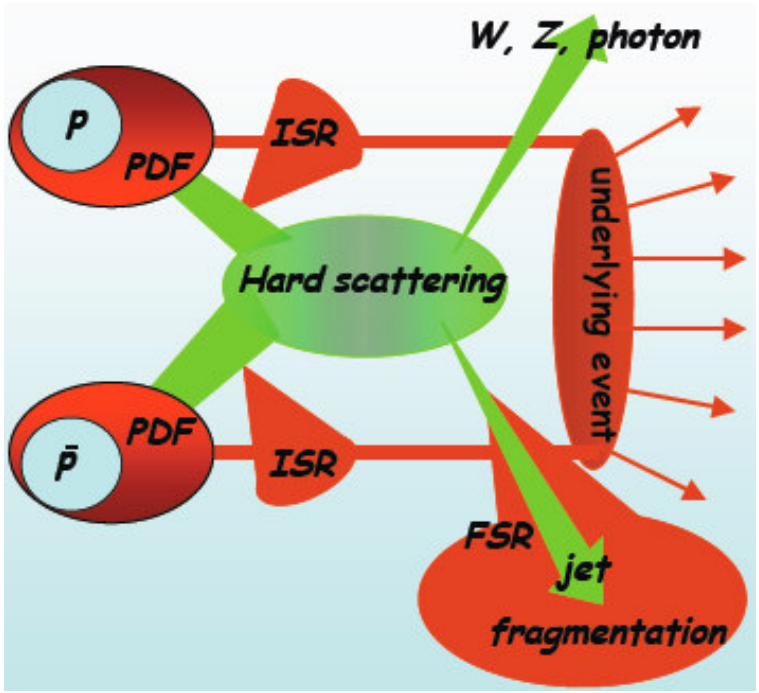
On to the Strong Force…

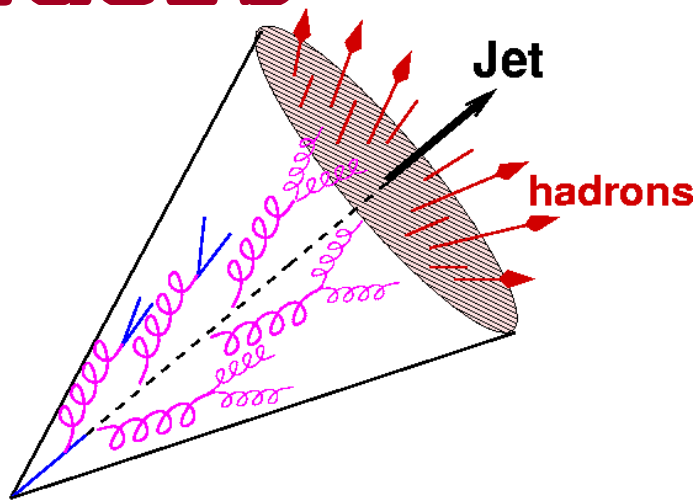
Might Makes Right!



Tevatron cross sections for inelastic collisions at $\sqrt{s}$ = 1.96 TeV

Jets at Hadron Colliders



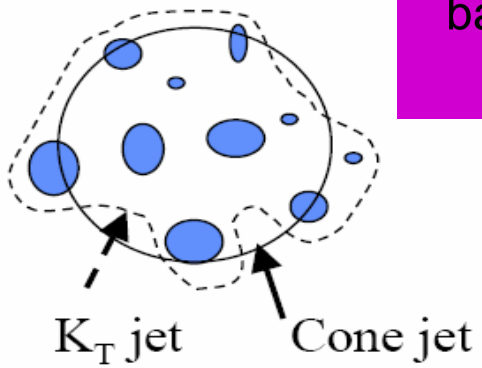


MidPoint (cone)

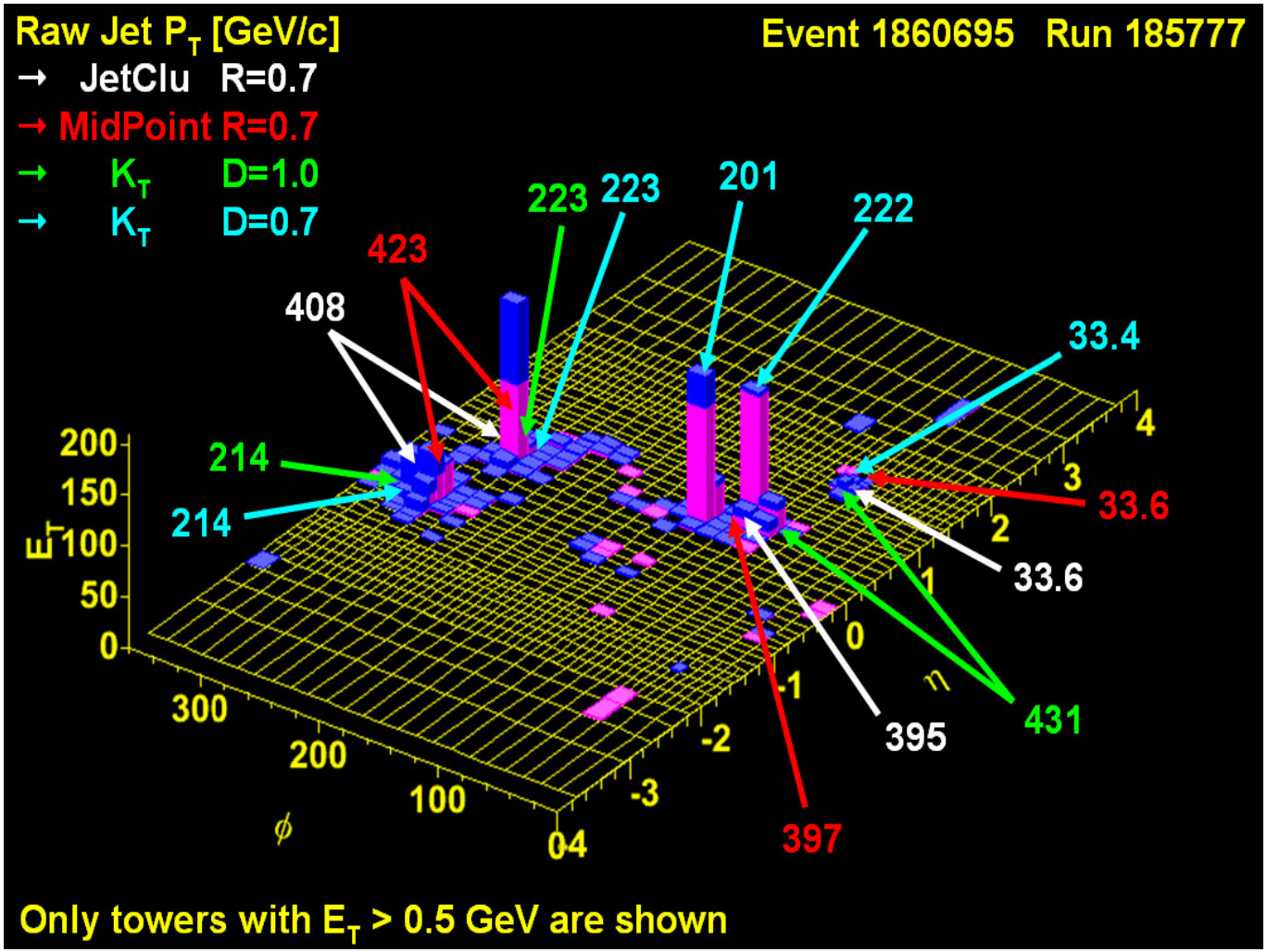
Cluster particle/towers based on their proximity in the y-ϕ plane

K_T

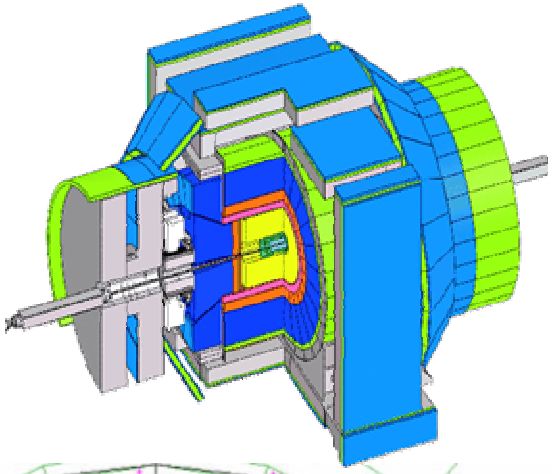
Cluster particle/towers based on their relative p_T. Infrared and coll. safe. No merging/spitting

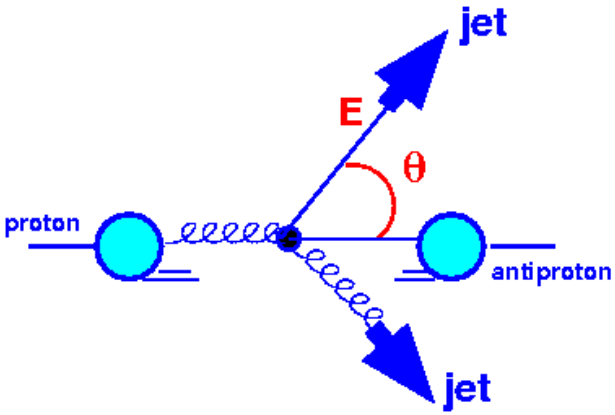


Jets at Hadron Colliders

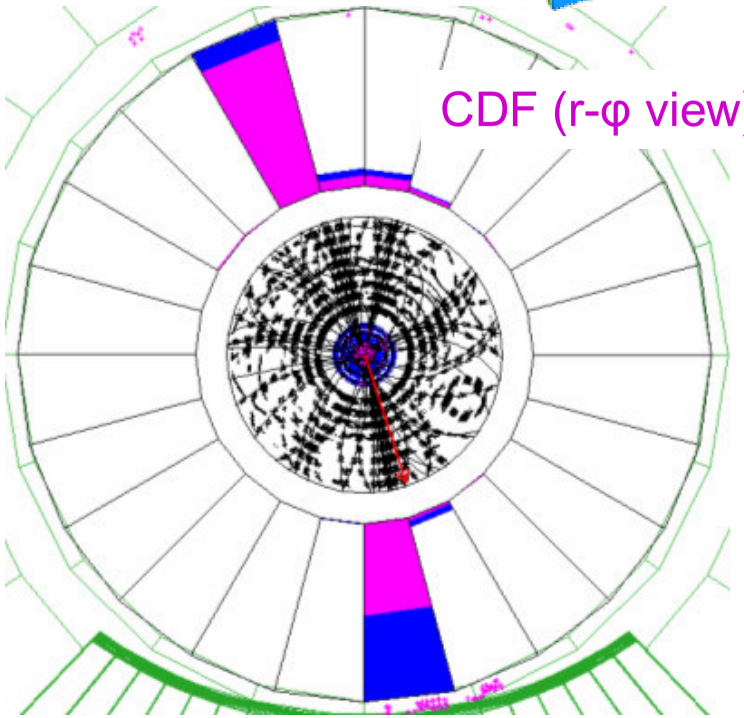


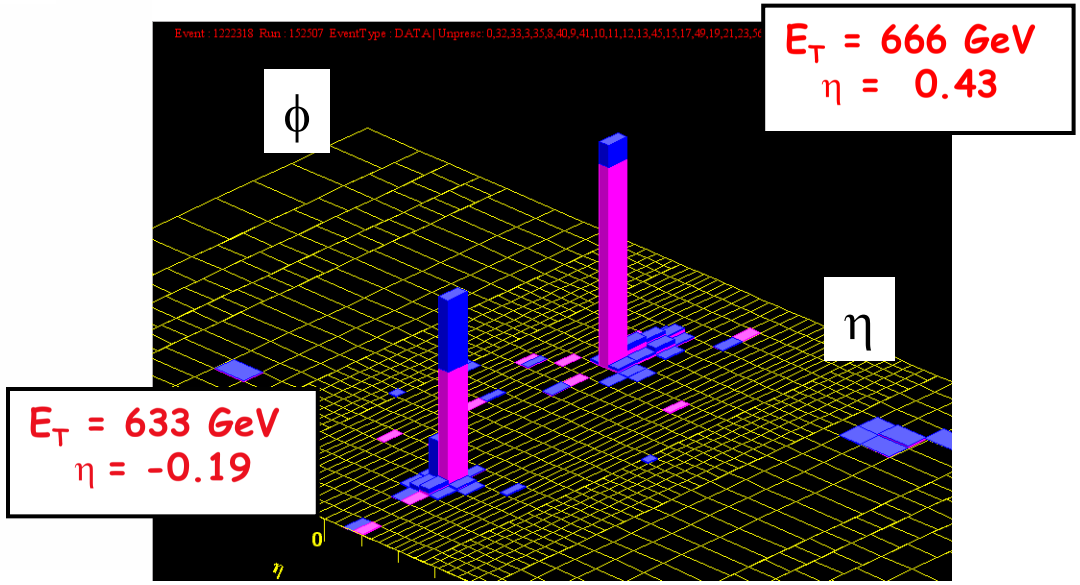
Highest Di-Jet Mass Event



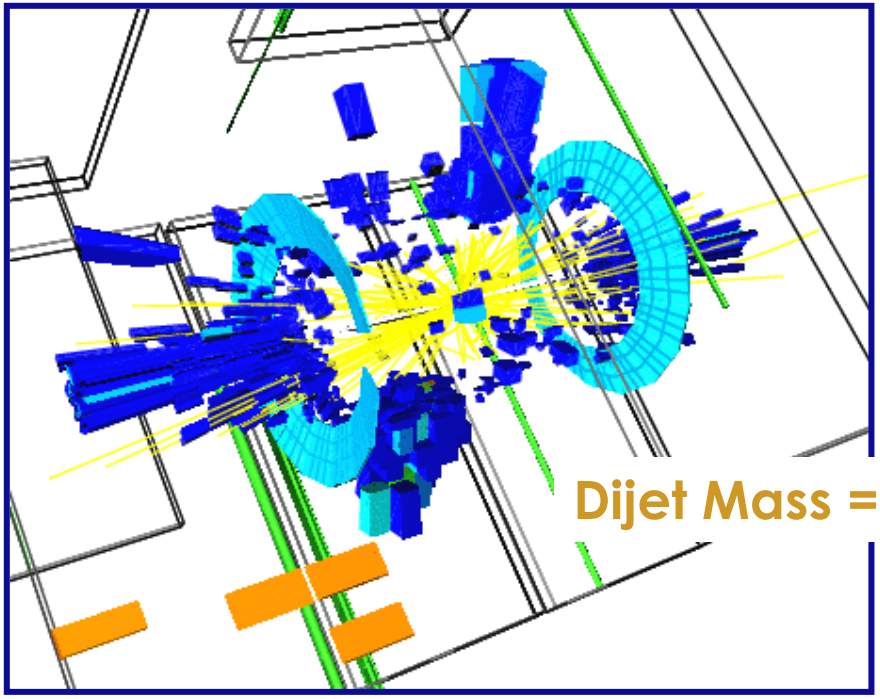


Dijet Mass = 1.36 TeV
(probing distance ~10^{-19} m)

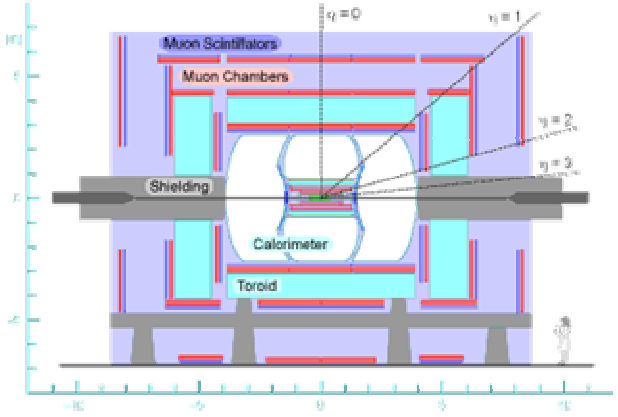




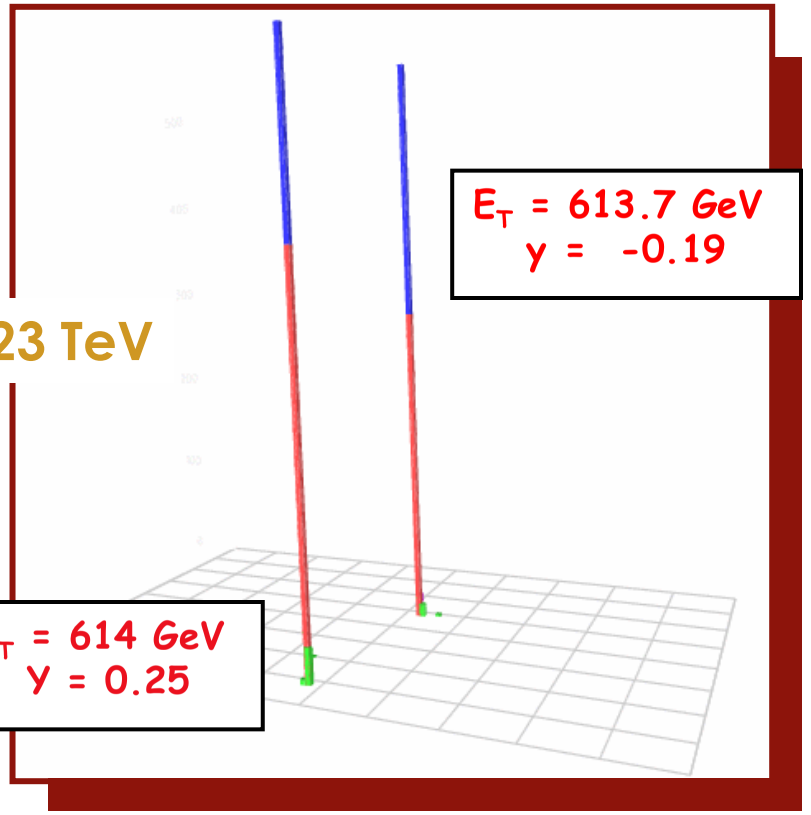
Highest Di-Jet Mass Event



Dijet Mass = 1.23 TeV

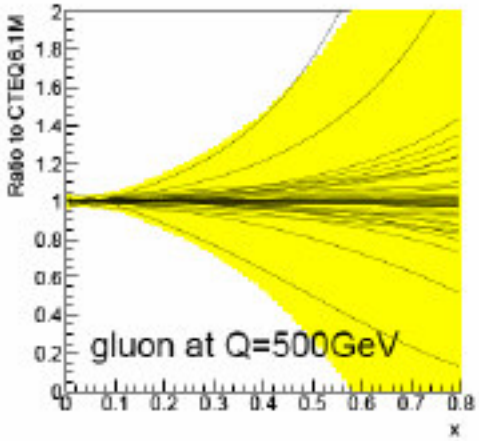


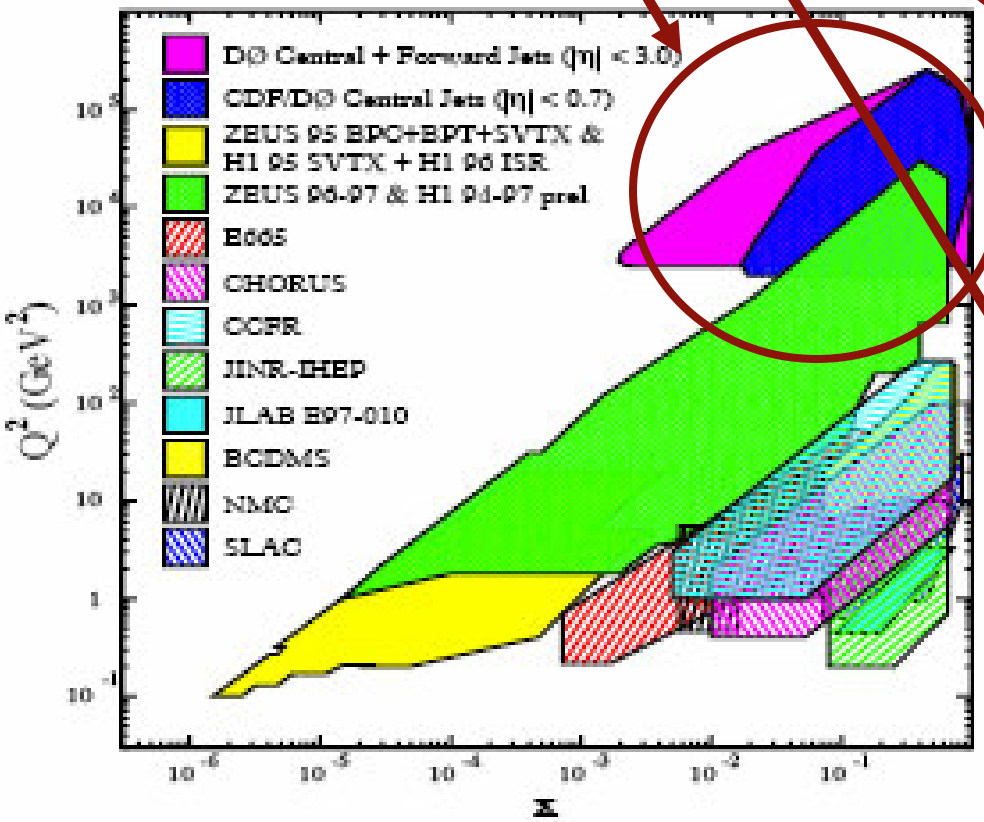
Similar event from DØ

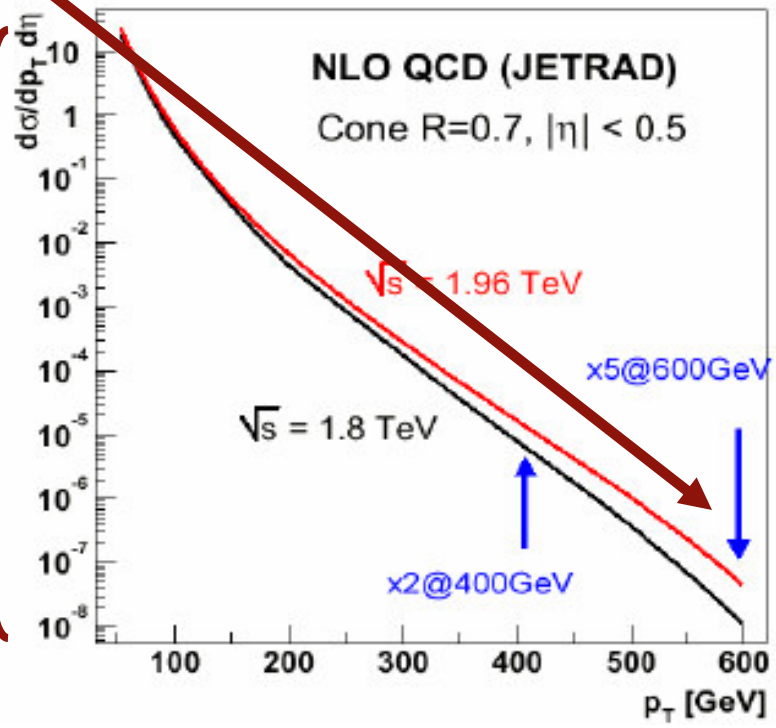


Inclusive Jets at Hadron Colliders

- Probes physics at small distances $\approx 10^{-19}$m
- Higher reach in pT due to increased $\sqrt{s}$
- Test pQCD over more than 9 decades in σ
- Sensitive to PDF (gluon @ high-x, forward)

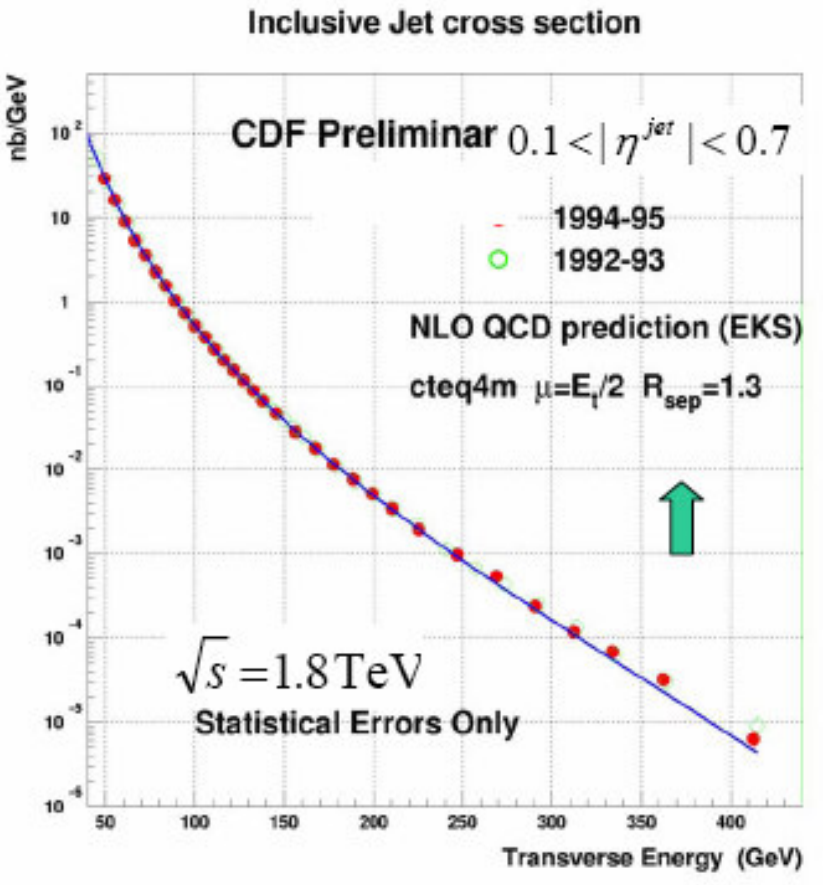




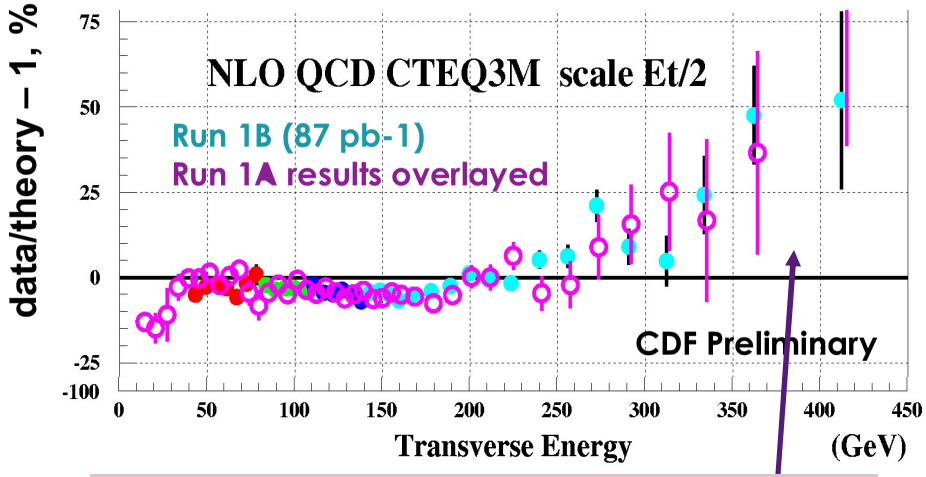


Interesting History…

Run 1 data versus pQCD NLO



Run 1 JetClu Cone Algorithm



Observed deviation in the tails:
Sign of new physics? PDF effect?

- More g-g content at high E_T
- Gluon PDF not well known
- Improved tools for Run 2:
  - Midpoint Cone Algorithm
  - K_T algorithm
  - More data!

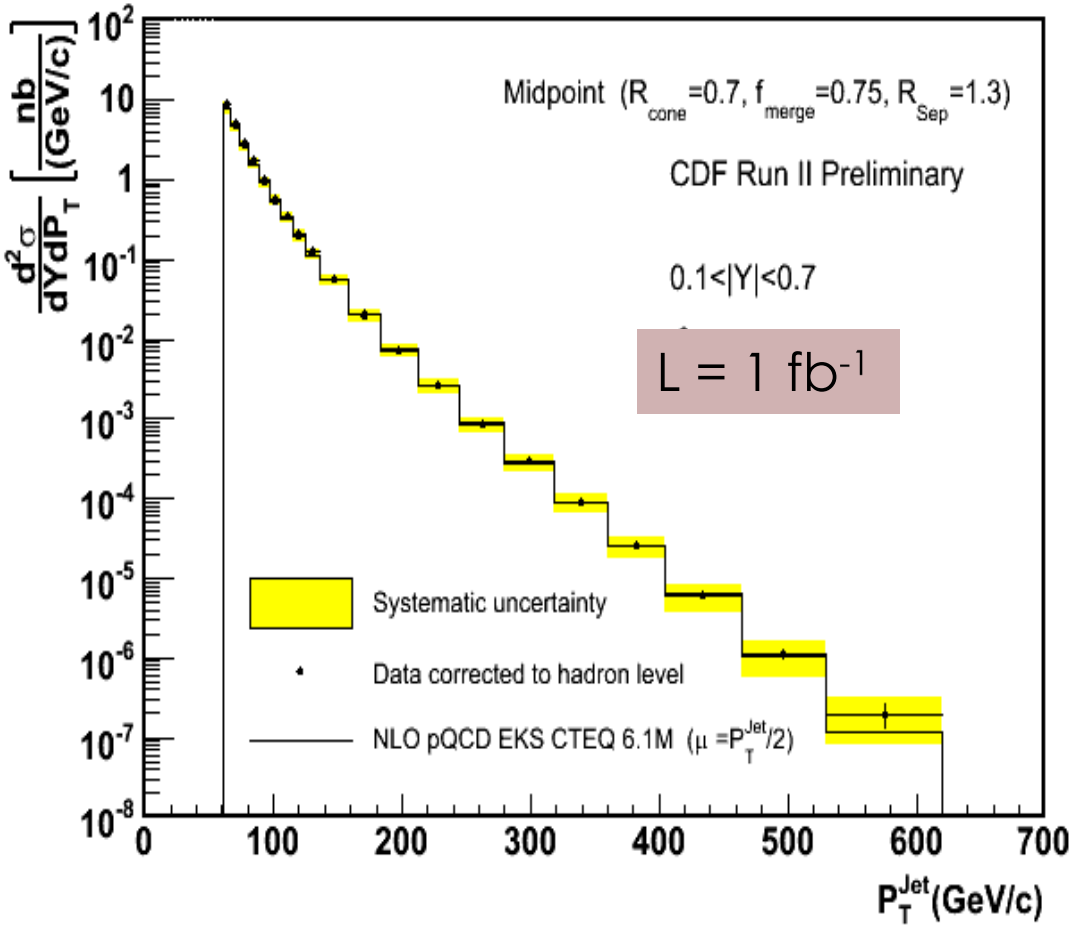
Run 2 CDF Inclusive Jet (Midpoint)

Midpoint cone algorithm with R=0.7

Central jets: $0.1<|y^{jet}|< 0.7$

More than 8 orders of magnitude covered

1 fb^{-1} of data!



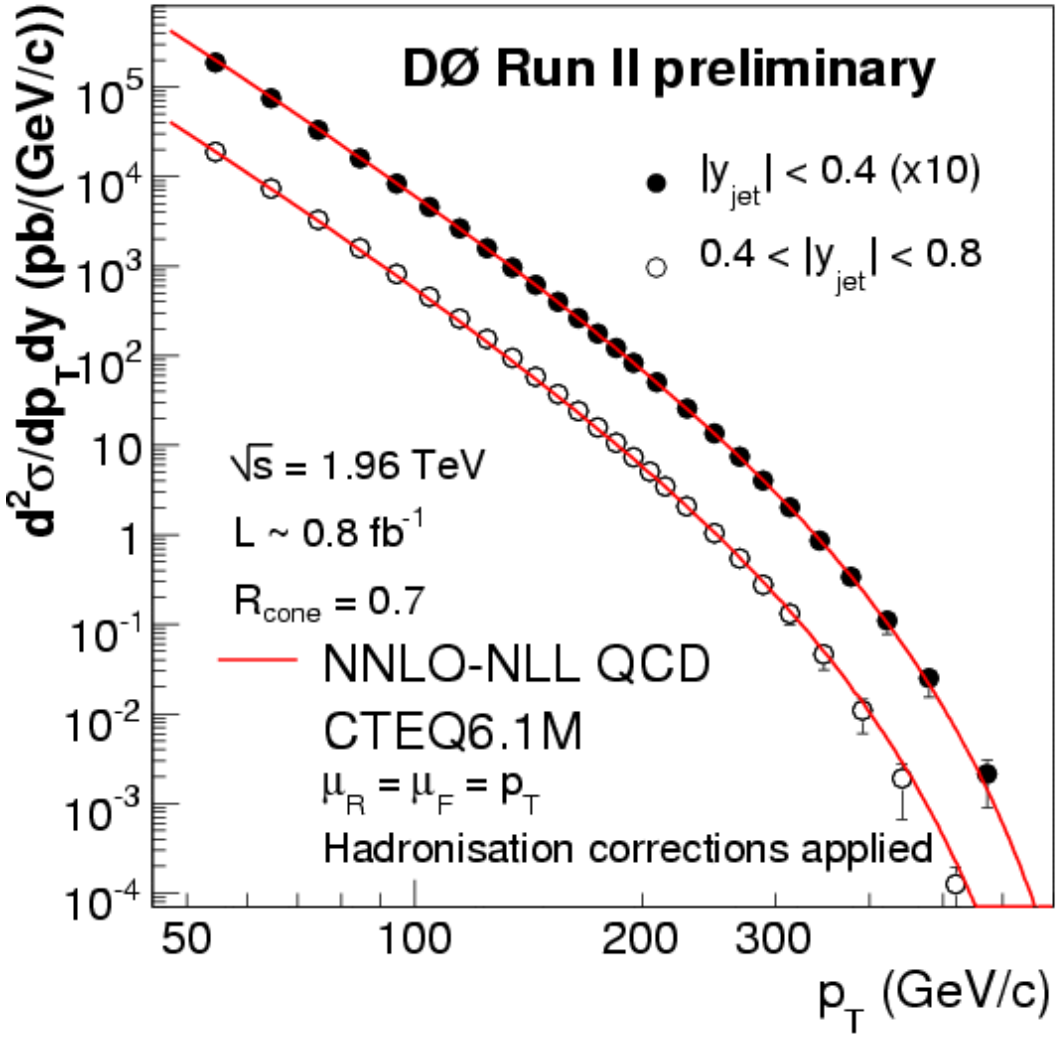
Run 2: Good agreement with NLO predictions

New Run 2 D0 Inclusive Jet

Hot off The press!!

Midpoint jets at different rapidities, 0.8 fb^{-1}

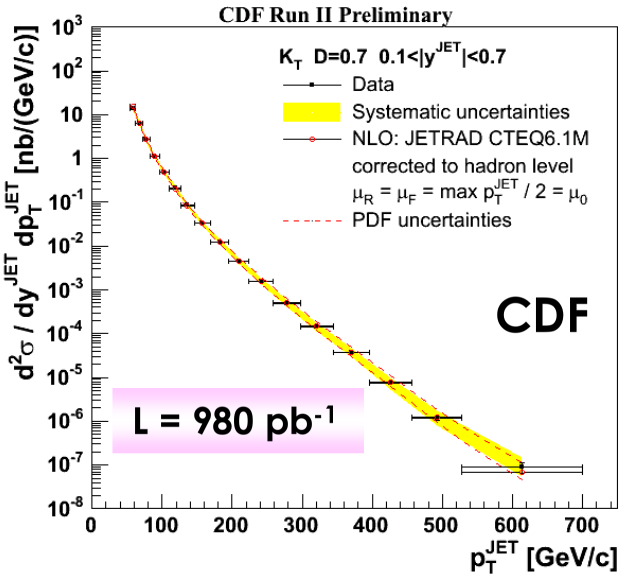
See Craig Group's incl. jet talk, parallel session 2.



Direct comparison of hadron to parton level (i.e. neglect fragmentation and UE)

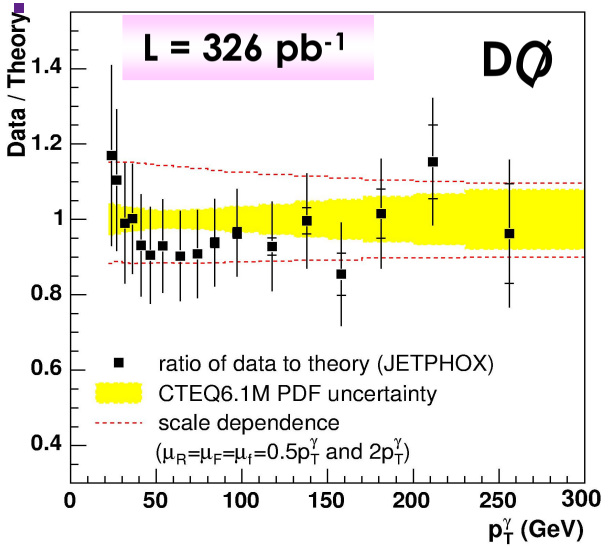
Other Recent QCD Results

KT Algorithm Good for Hadron Colliders

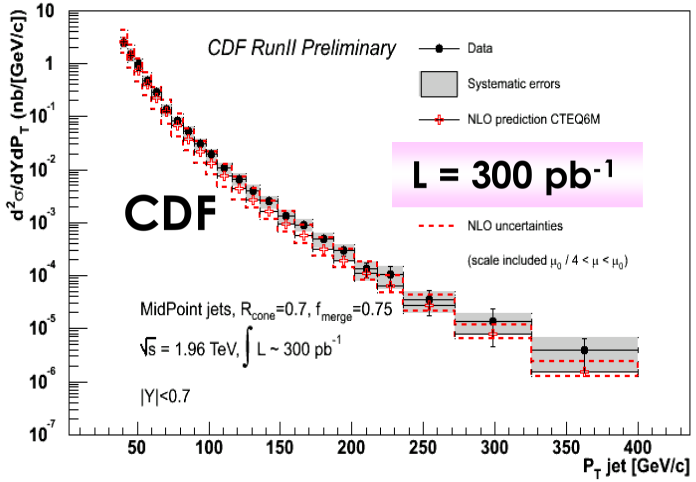


Inclusive γ Cross Section, Errors ~20%, At ~fb^{-1} could constrain high x gluon PDFs

Highest $p_T(\gamma)$ is 442 GeV/c

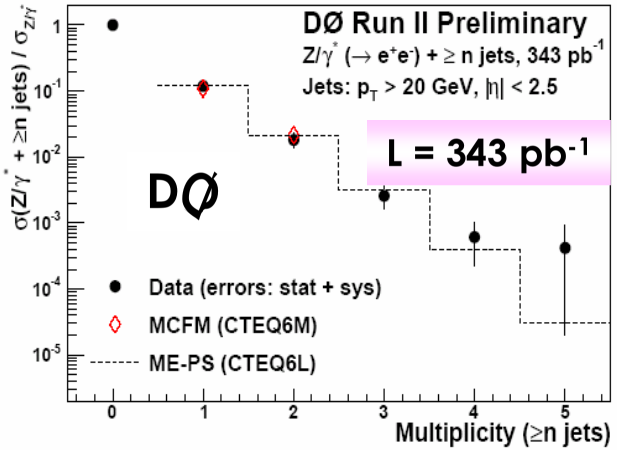


B Jet cross section agrees with NLO



Z+jets Prod. agrees w/ MCFM, Madgraph

W+Jets, see B. Cooper, parallel session 2

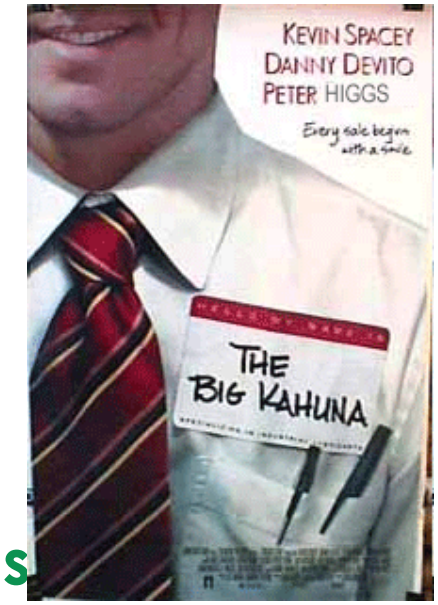


From the Strong to the (Electro)Weak…

What Can We Learn from EWK?

The Big Kahuna: Electroweak Symmetry Breaking!!

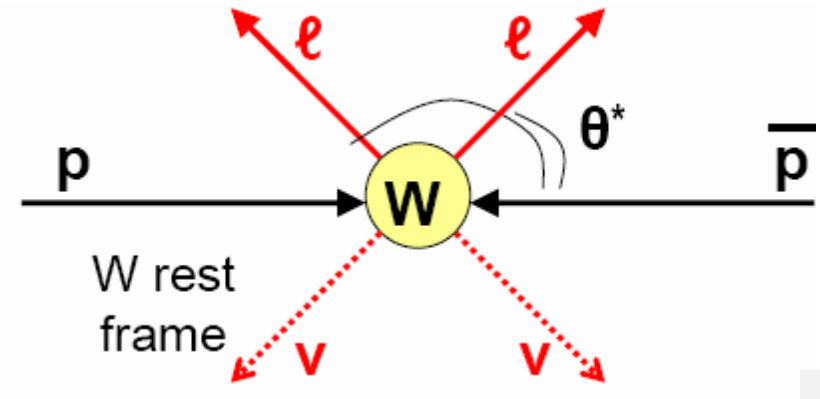
Why is the photon massless, while W/Z~100 GeV?



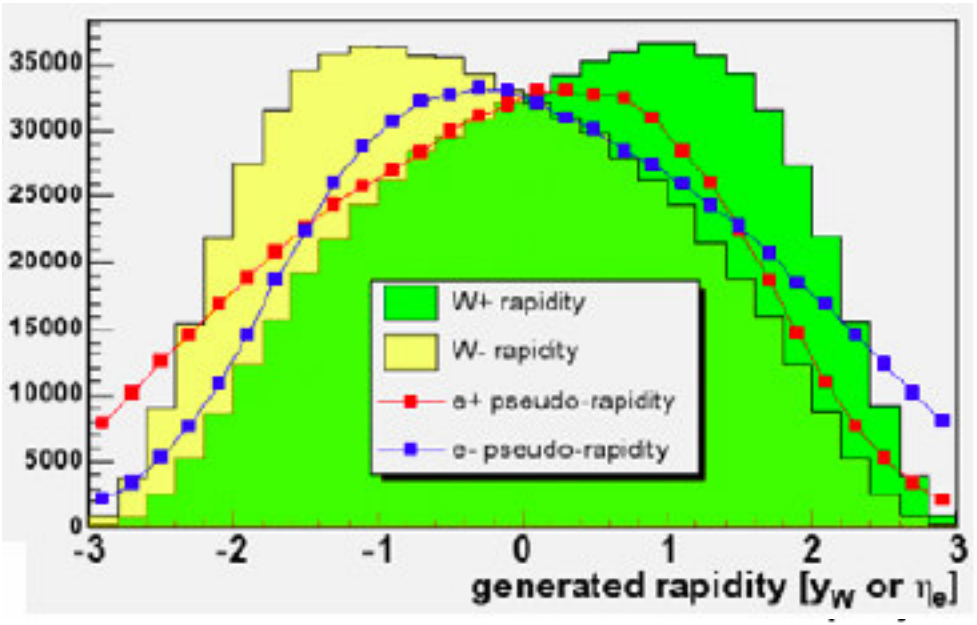
Look at the Higgs:

- Direct search (Landsberg)
- Test properties of the Higgs
  - –Direct couplings
  - –Loop effects
- Verify EW Couplings among bosons
  - –Search for new interactions to cancel s dynamics
- Search for new gauge bosons
  - –Generic prediction of dynamical symmetry breaking

W Charge Asymmetry



- u quarks carry more momentum than d: W charge asymmetry
- DØ use $W \rightarrow \mu\nu$, muon Q asymmetry



- Sensitive to PDF of u, d quarks
- Convolute V-A asymmetry
- Will feed in to PDF fits, $Q^2 \sim M^2_W$

$$A(y_\mu) = \frac{N_{\mu+}(y) - kN_{\mu-}(y)}{N_{\mu+}(y) + kN_{\mu-}(y)}$$

CDF Result with ~400 pb^{-1} just missed Pheno 06

Search for New Z' Boson

Most extensions to the Standard Model predict new g e boson

CDF Searches for Z'→ee using M_{ee} and cosθ* with s models

Method: generate 1000s of parameterize and look a allowed coupling strength in data

Carena, Daleo, Dobrescu,Tait PRD70:0930

$g_z = 0.01$

$g_z = 0.10$

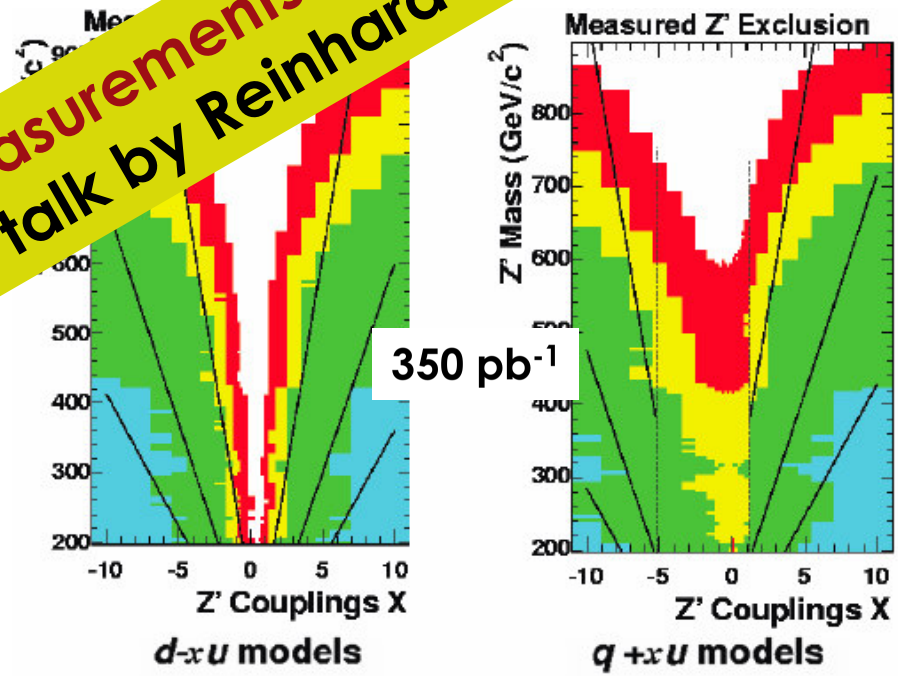
Use FCNC constraints, n (a la [illegible]) ncellations: 4 classes of solution

Within each ling parame

- On z
- One ing, x
- One overall co

Limits show classes

Framework ws tests of new models in the future.



Z' Exclusion at 1 fb^{-1} by CDF-- See Parallel Session 1 talk by Catalin Ciobanu!

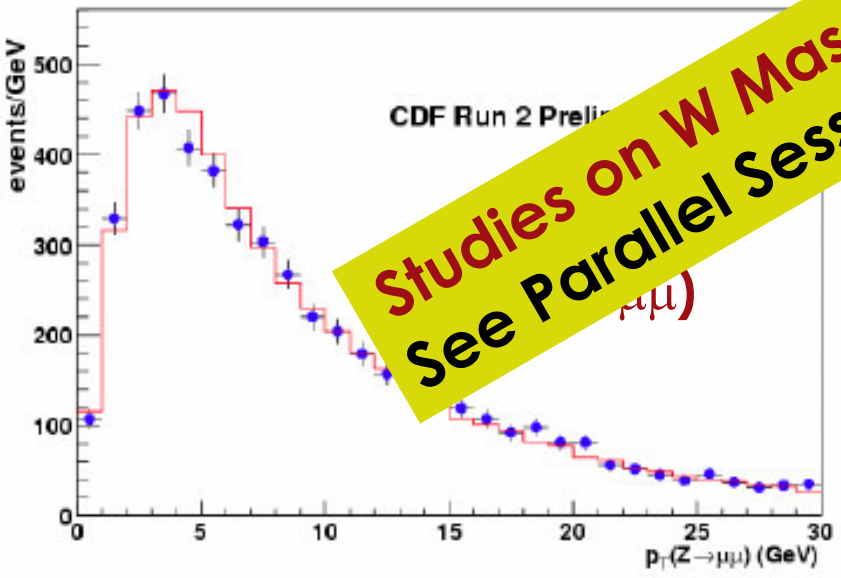
Latest on W' Measurements from DØ -- See Parallel Session 1 talk by Reinhard Schwienhorst!

W Mass Measurements

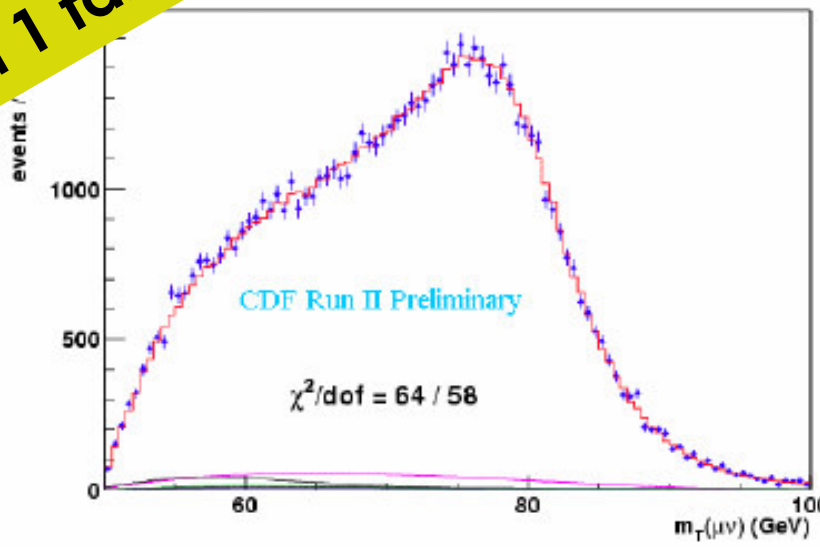
"Much progress has been made, but it involves a lot of problem-solving…

It took 5 years after the end of Run 1 for CDF to publish W mass. We've had these data for 2.5 years. We're not behind, we're ahead!"

Studies on W Mass Uncertainties from DØ: See Parallel Session 1 talk by Tim Andeen!

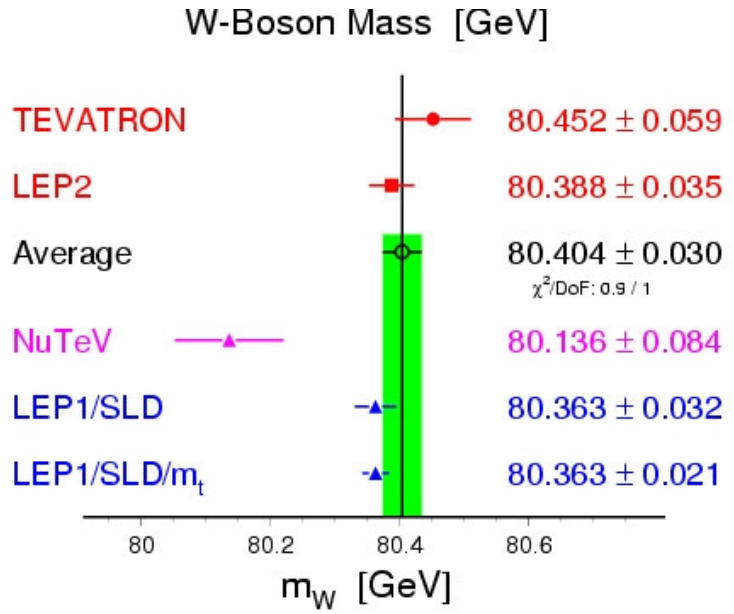


$p_T(Z)$: Test hadronic recoil



Statistics Enough to best Lep 2

W Mass Measurements



Tevatron Projections for M_W:

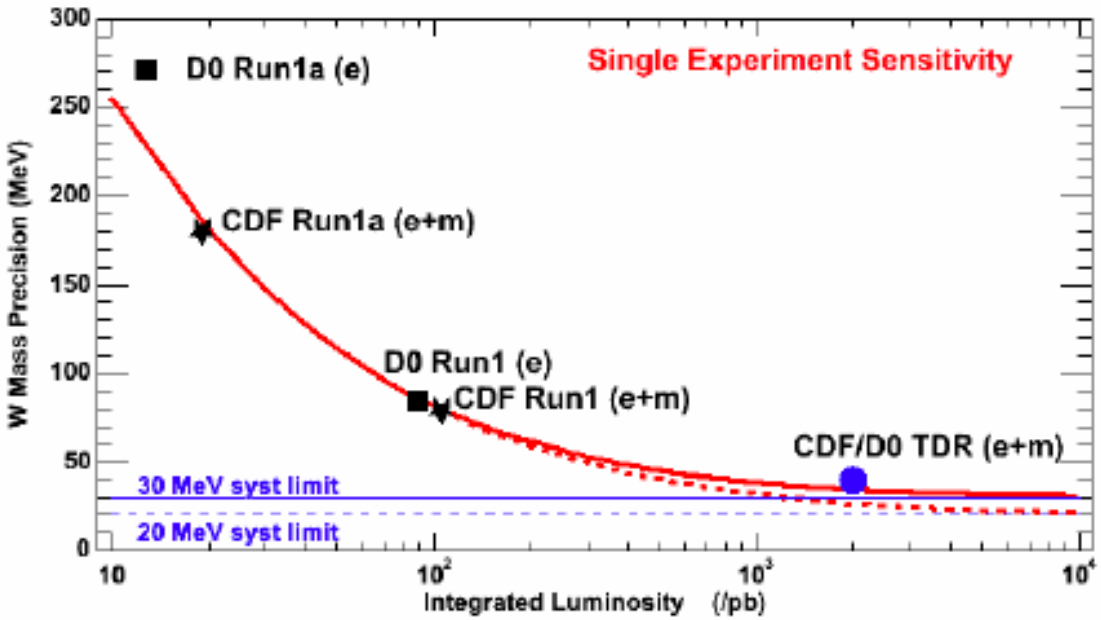
- Uncertainties extrapolated from Run 1b

Uncertainties scaling with luminosity:

- Statistical uncertainties
- Energy/momentum scales, hadron recoil against W

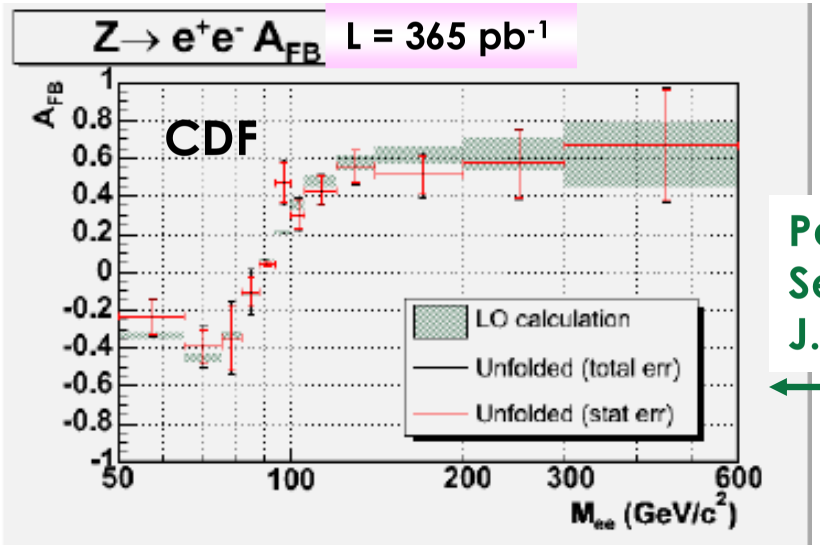
Uncertainties not scaling with luminosity:

- PDFs, $d\sigma(W)/dp_T$, higher order QED/QCD
- Expect these between 20 and 30 MeV



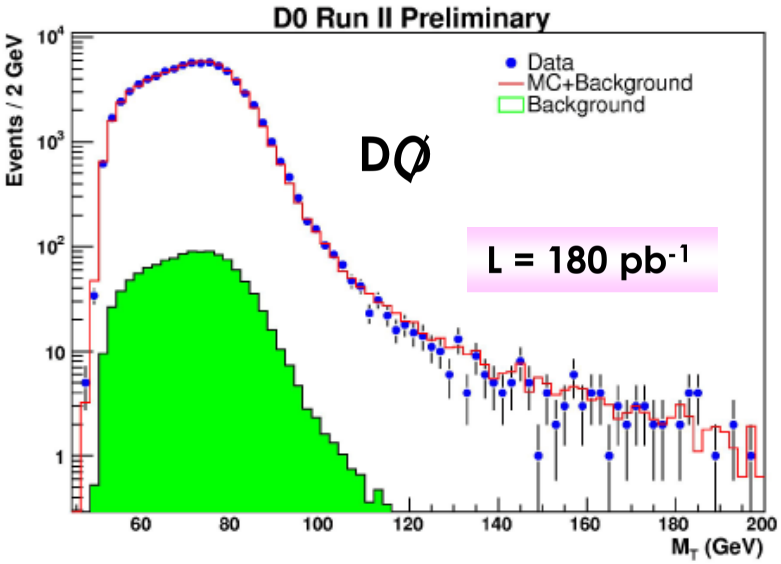
Other Recent EWK Results

Drell Yann Forward Backward Asymmetry

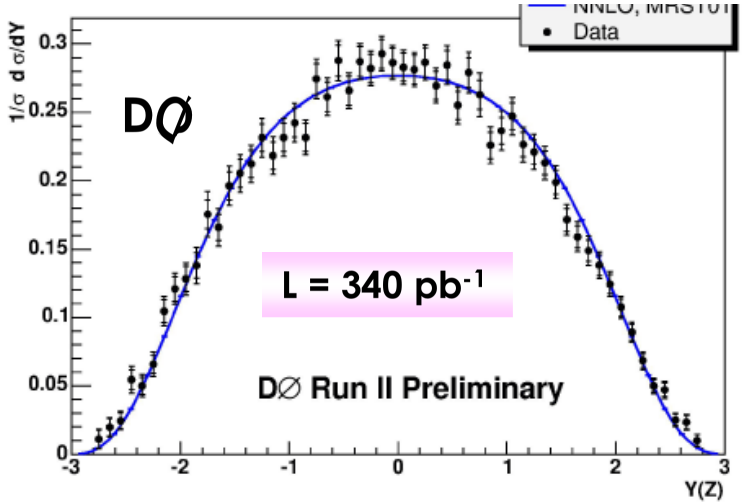


Parallel Session 1: J. Lee

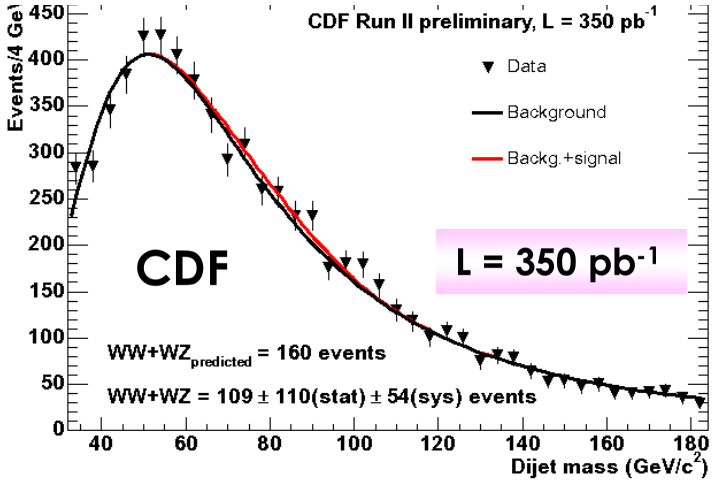
Direct Measurement W boson Width



Z rapidity agrees with NNLO, MRST01



WW/WZ→lνjj Cross Section and search for Anomalous Couplings



All the Way to the Top!

Top Turned Ten in 2005!

Big international celebration of 10th anniversary of discovery.

Final Run 1 analyses ~110pb^{-1}

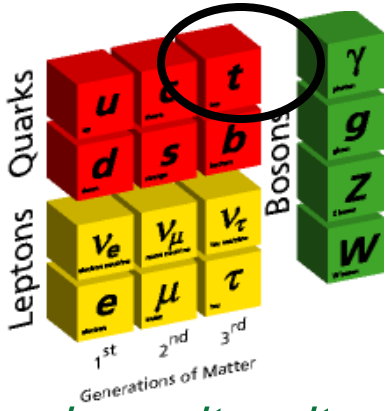
~ 30 events per experiment

Precision Era in Run 2!

Collected > 1 fb^{-1}

Factor ~ 10 more data so far

Tevatron the only place to study top until into the LHC era.



http://www-cdf.fnal.gov/physics/new/top/top.html

Why is Top So Special?

Top is massive!

M_{top} = 172.5 ± 2.3 GeV (TEWG hep-ex/0603039)

Decays before hadronizing:

$\tau_{top} \sim 10^{-24}$ s, $\Gamma \sim 1.5$ GeV >> Λ_{QCD} ~200 MeV

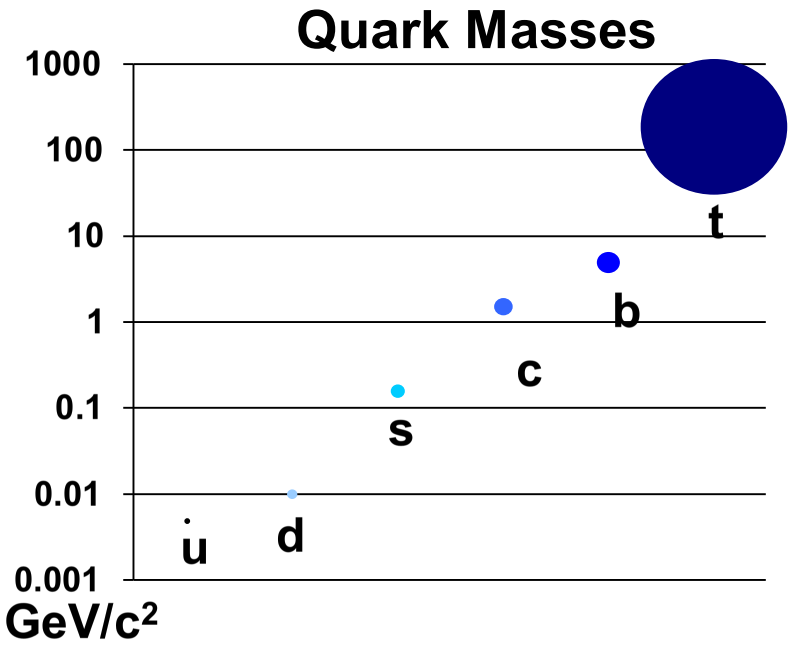
→No spectroscopy

→Spin transferred to decay products

Special Role in EWSB?

Top Yukawa coupling is "natural" (~1)

Together with M_W constrains M_{higgs}



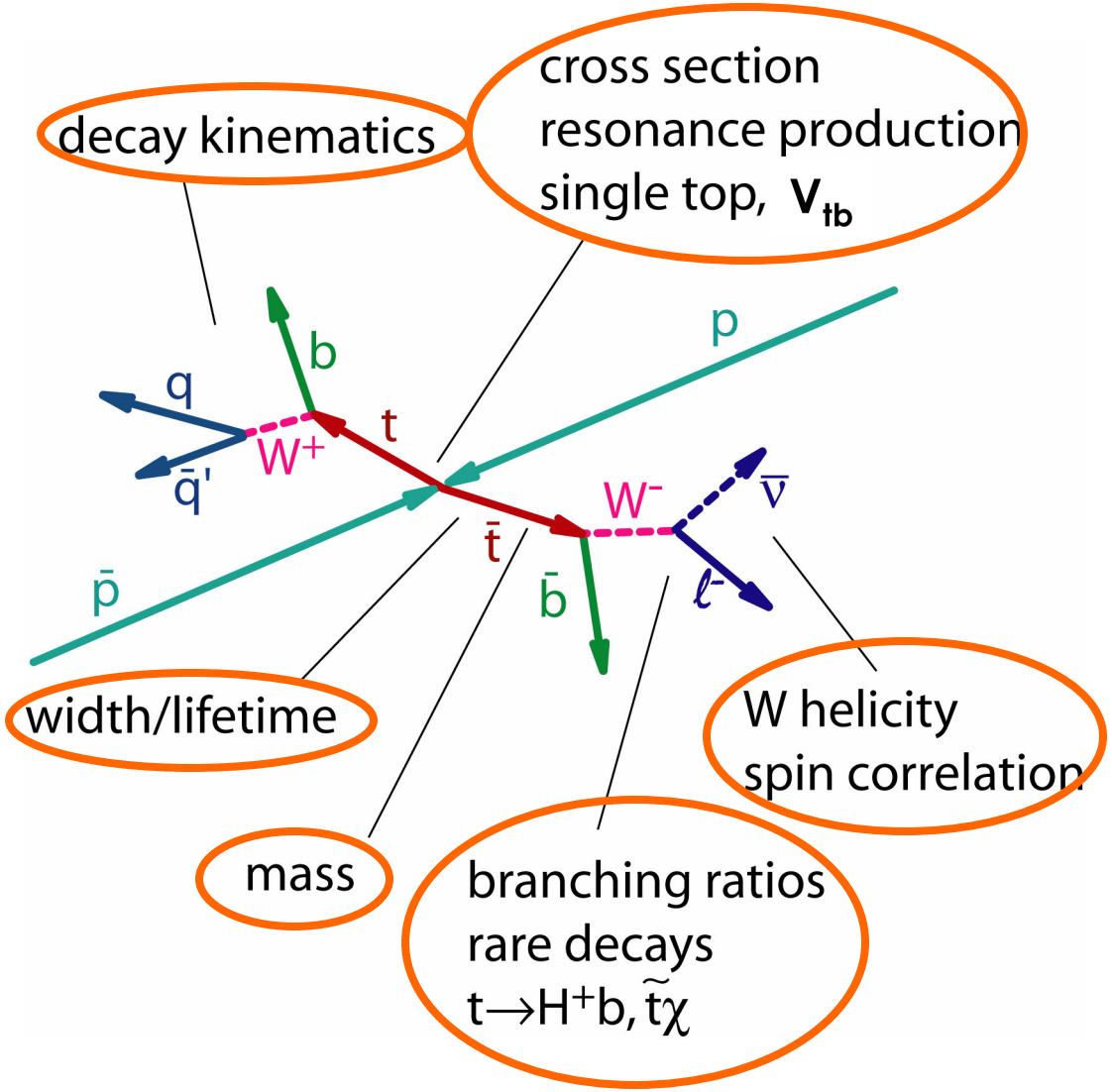
5 orders of magnitude between quark masses!

Probes physics at higher scales than other known fermions:

Top or heavy top hip in many EWSB models:

Higgs, Top Color, Little Higgs, SUSY mirror…

Elucidating the Top Quark in Run 2



Top pairs: $\sigma(tt)$ ~7 pb

- Top production rate
- Mass of top
- W helicity in top events
- QCD tests
- New physics! $X\to tt$
- Anomalous couplings, heavy top, …

Single top: $\sigma(tb)$ ~3 pb

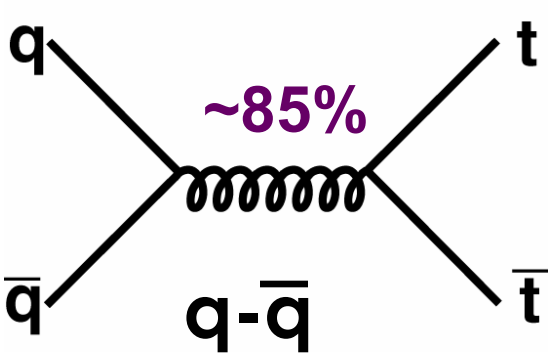
- $|V_{tb}|$
- QCD tests
- New physics!

Physics of the Top Quark

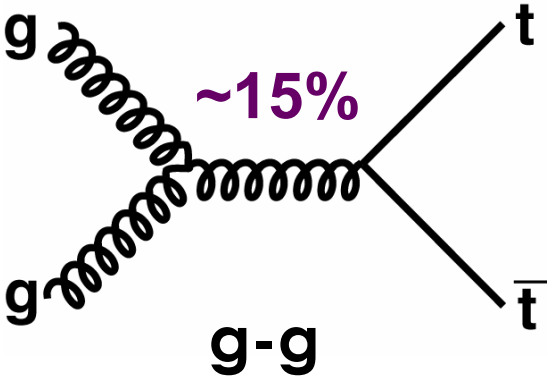
When Trish discovers Ned works exclusively with top quarks, she will be putty in his hands.

Top physics is still one of the more sexy things to study at the Tevatron…

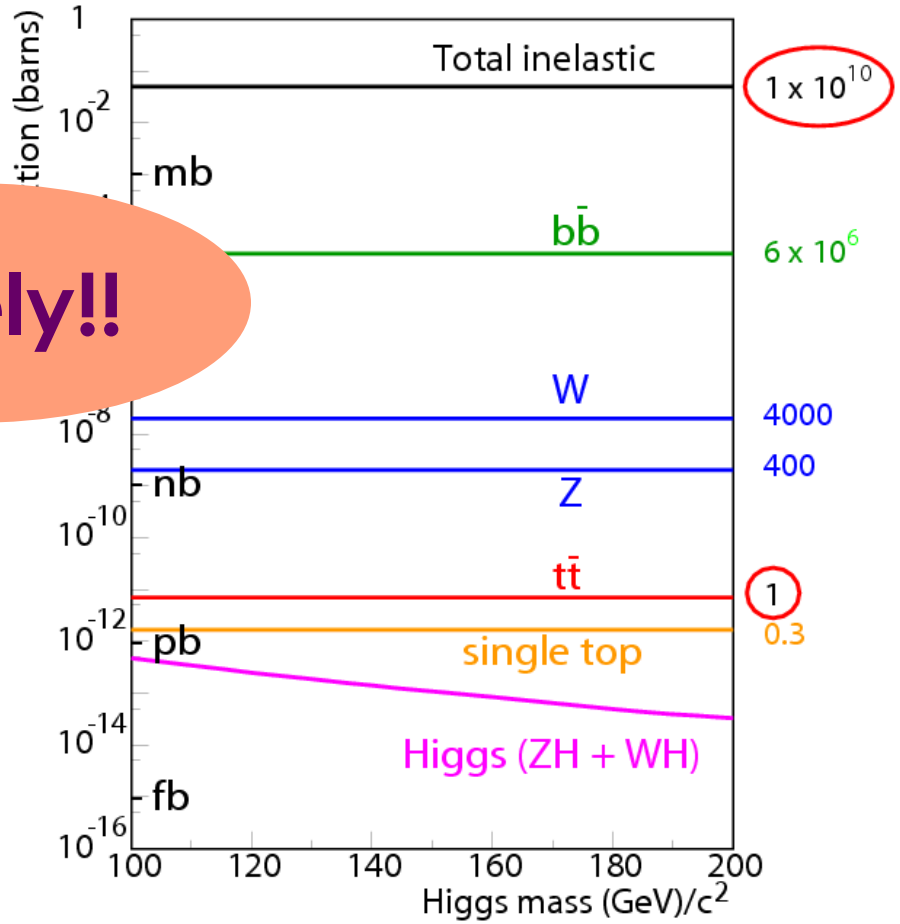
How is Top Produced?



Standard Model
Tevatron Pair Production
Through Strong Interaction



Rarely!!



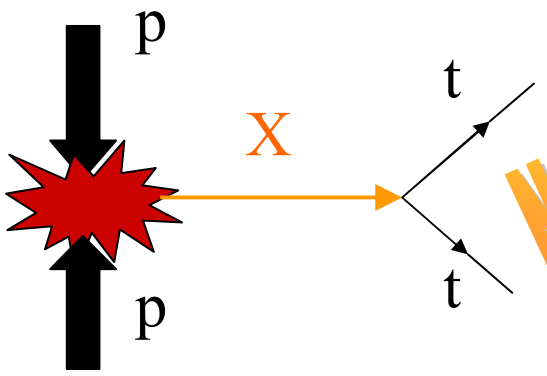
$$\sigma(\bar{p}p \to t\bar{t} \,@\, M_{top} = 175 GeV) \approx 6.7 \text{ pb}$$

One top pair each 10^{10} inelastic collisions at $\sqrt{s}$ = 1.96 TeV

How *Else* is Top Produced?

Standard Model Tevatron Single Top Production

$$\sigma(\bar{p}p \to t + X @ M_{top} = 175 GeV) \approx 3 \text{ pb}$$



Not Yet Observed

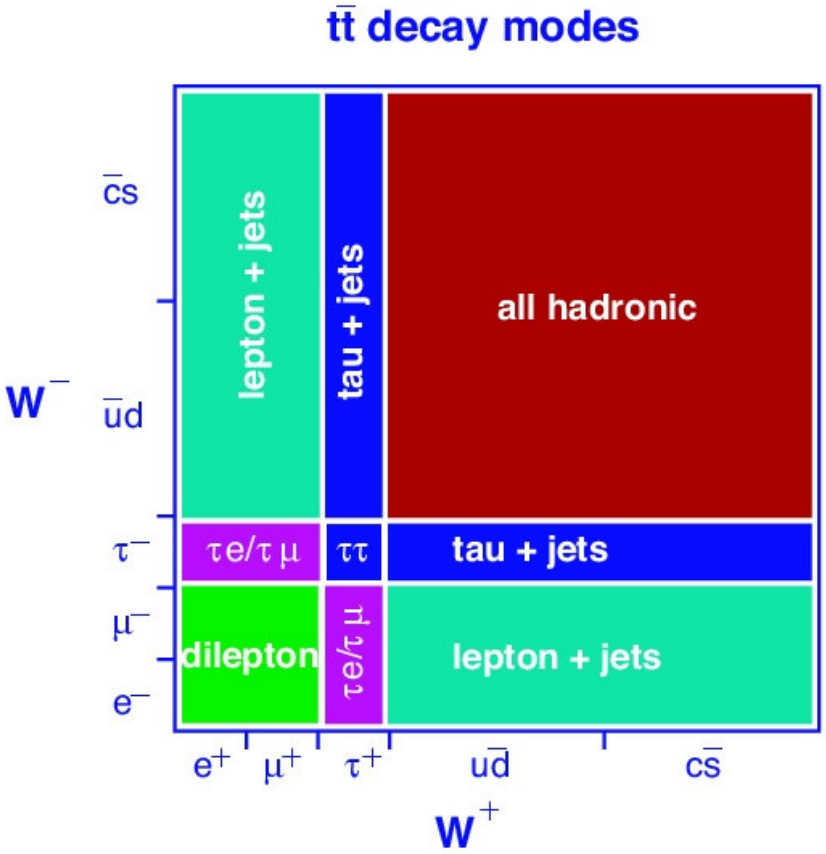
R... Production?

... Color-Assisted Technicolor

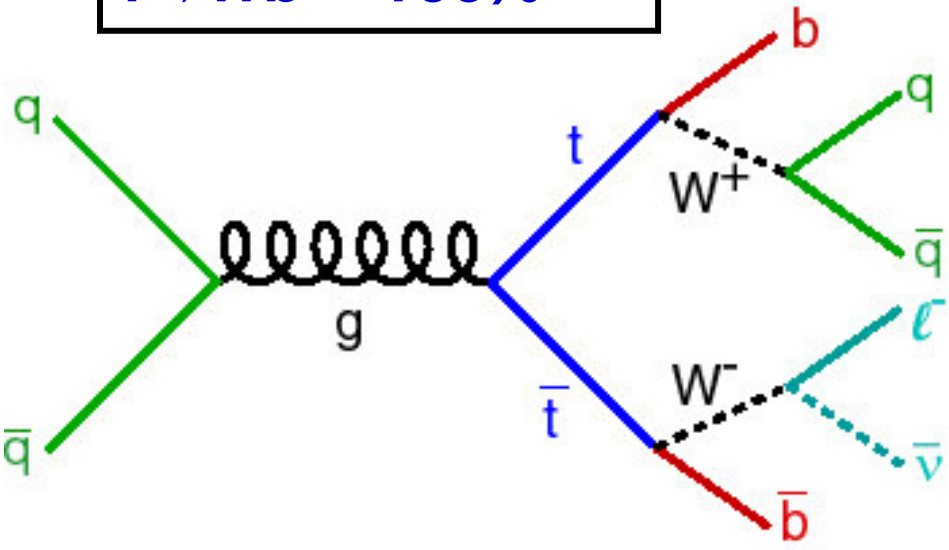
OR

?????

How Does Top Decay?



Standard Model:
$t \to Wb \sim 100\%$



Main "usable" top event topologies:

- $t\bar{t} \to l\nu l\nu bb$ **di-lepton** **5% e+μ**
- $t\bar{t} \to l\nu qqbb$ **lepton+jets** **30% e+μ**
- $t\bar{t} \to qqqqbb$ **all hadronic** **45%**

Measuring Top Pair Production

$$\sigma(tt) = \frac{N_{events} - N_{background}}{\text{Luminosity} * \varepsilon}$$

Production Cross Section

Why is measuring the rate of top production important?

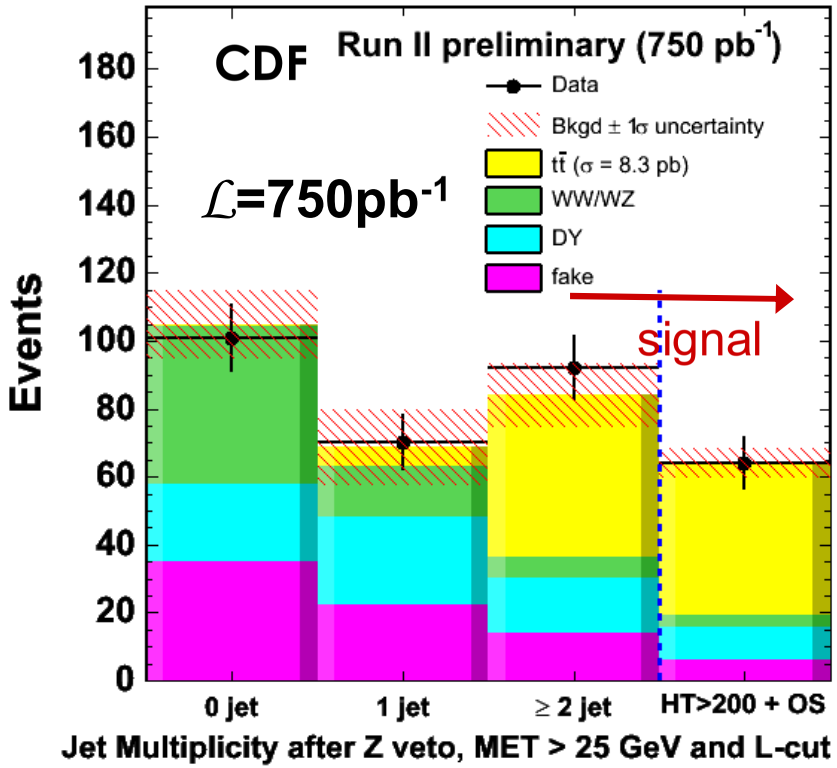
- Higher cross section than predicted could be a sign of non-standard model production mechanisms

  Resonant state X→ tt **OR** Anomalous couplings in QCD?

- It could also mean new physics in the top sample!

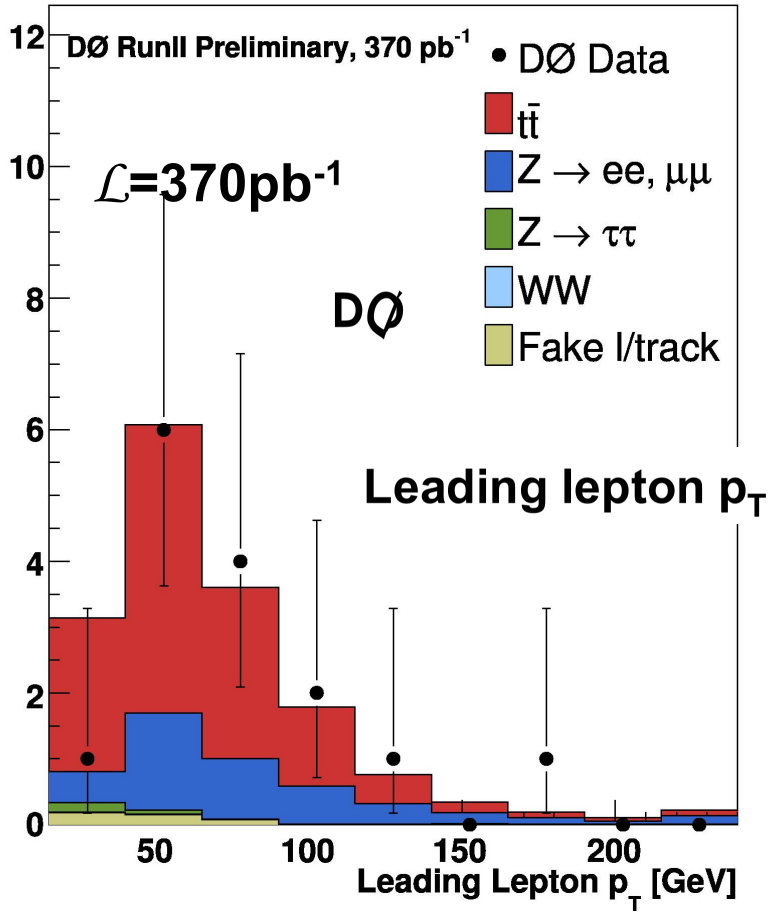
Dilepton Channel Cross Sections

Signal: lepton+track, MET, ee/μμ/eμ



$\sigma(tt)=8.3\pm 1.5(stat) \pm 1.1(sys)$ pb

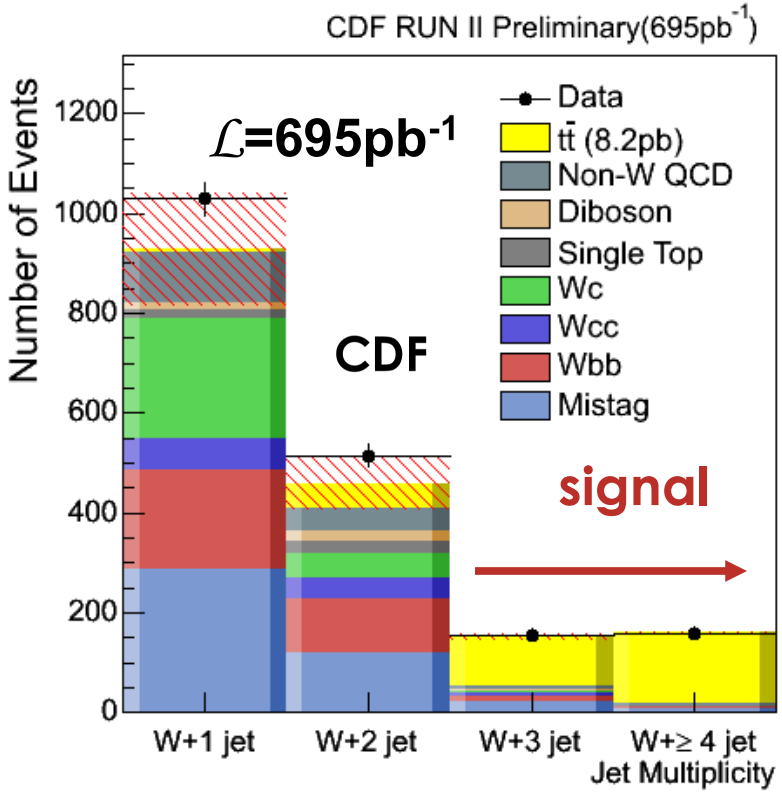
Signal: lepton+track, MET, b-tag+eμ



$\sigma(tt)=8.6\pm 1.8(stat) \pm 1.3(sys)$ pb

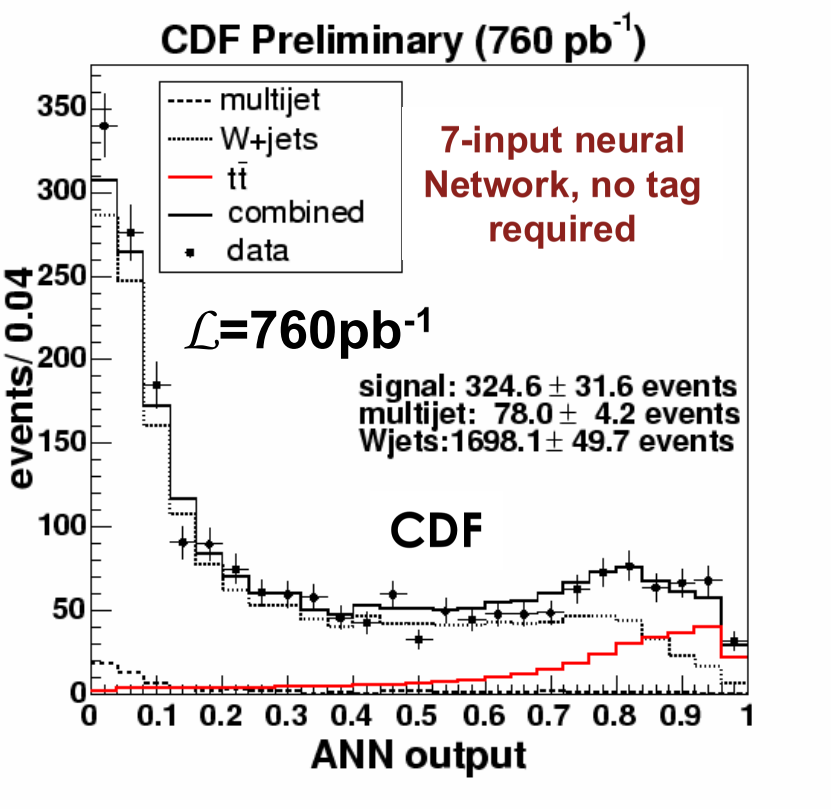
Lepton+Jets Channel Cross Sections

Signal: lepton+ ≥3 jets, MET, ≥1 b-tag



$\sigma(t\bar{t})=8.2\pm0.6(\text{stat})\pm1.0(\text{sys})$ pb

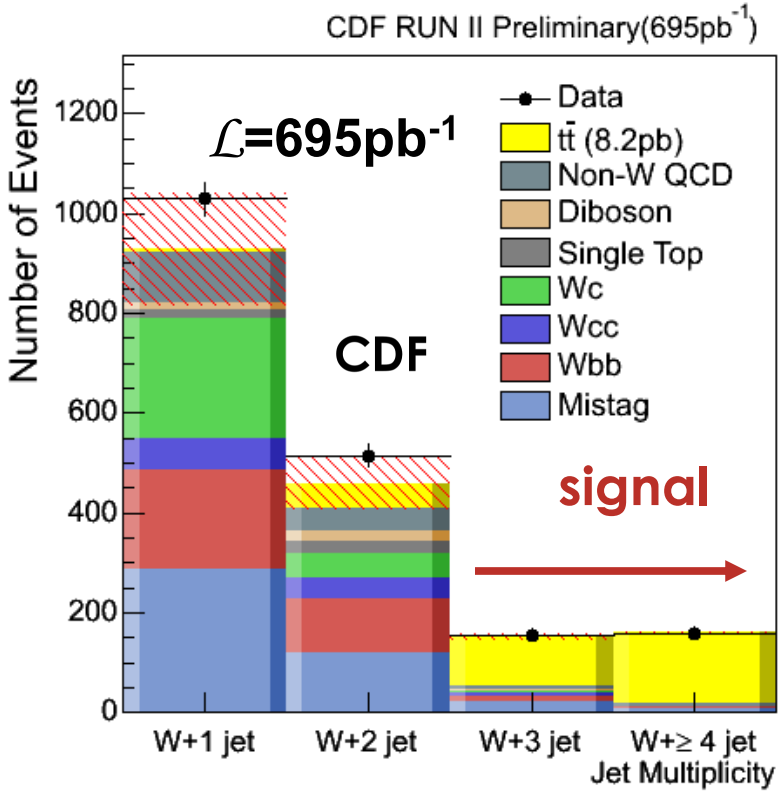
Signal: lepton+ ≥3 jets, MET



$\sigma(t\bar{t})=6.0\pm0.6(\text{stat})\pm1.1(\text{sys})$ pb

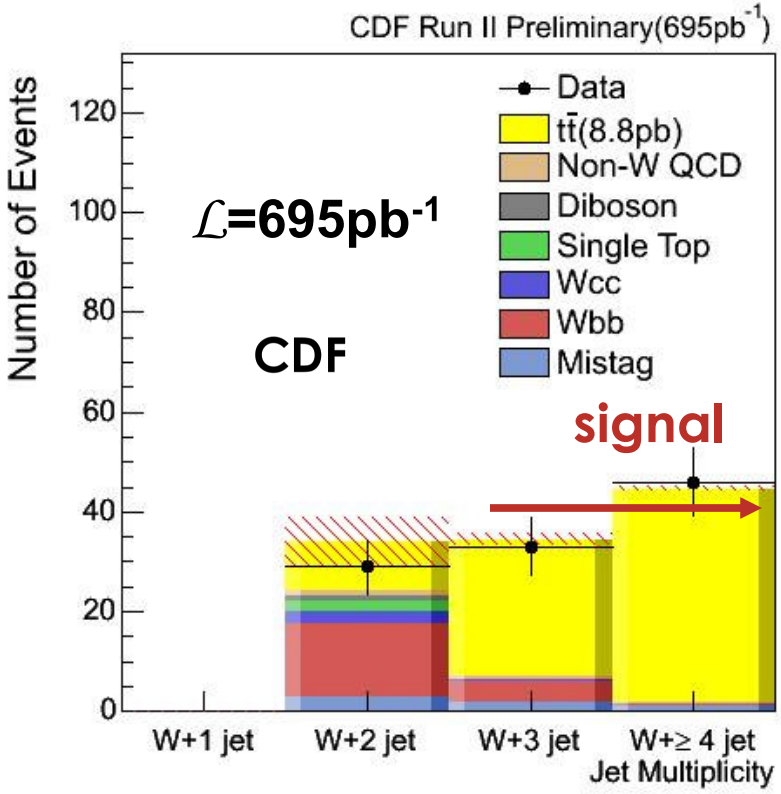
Lepton+Jets: How're the double tags?

Signal: lepton+ ≥3 jets, MET, ≥1 b-tag



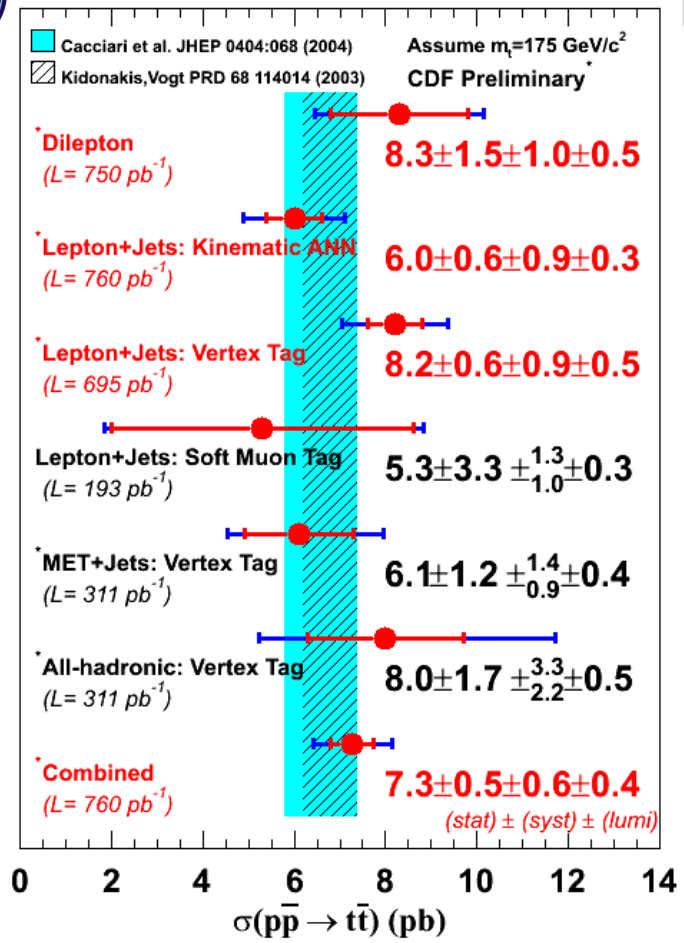
$\sigma(tt)=8.2\pm0.6(stat)\pm1.0(sys)$ pb

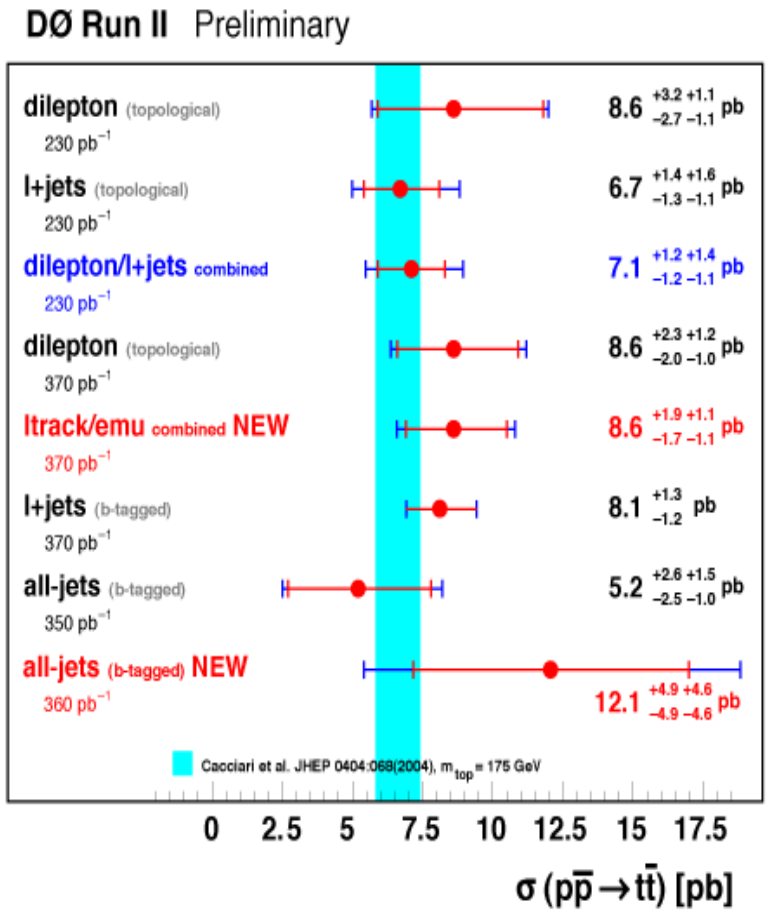
Signal: lepton+ ≥3 jets, MET, ≥2 b-tags!



$\sigma(tt)=8.8\pm1.2(stat)\pm1.7(sys)$ pb

Top Pair Production Cross Sections

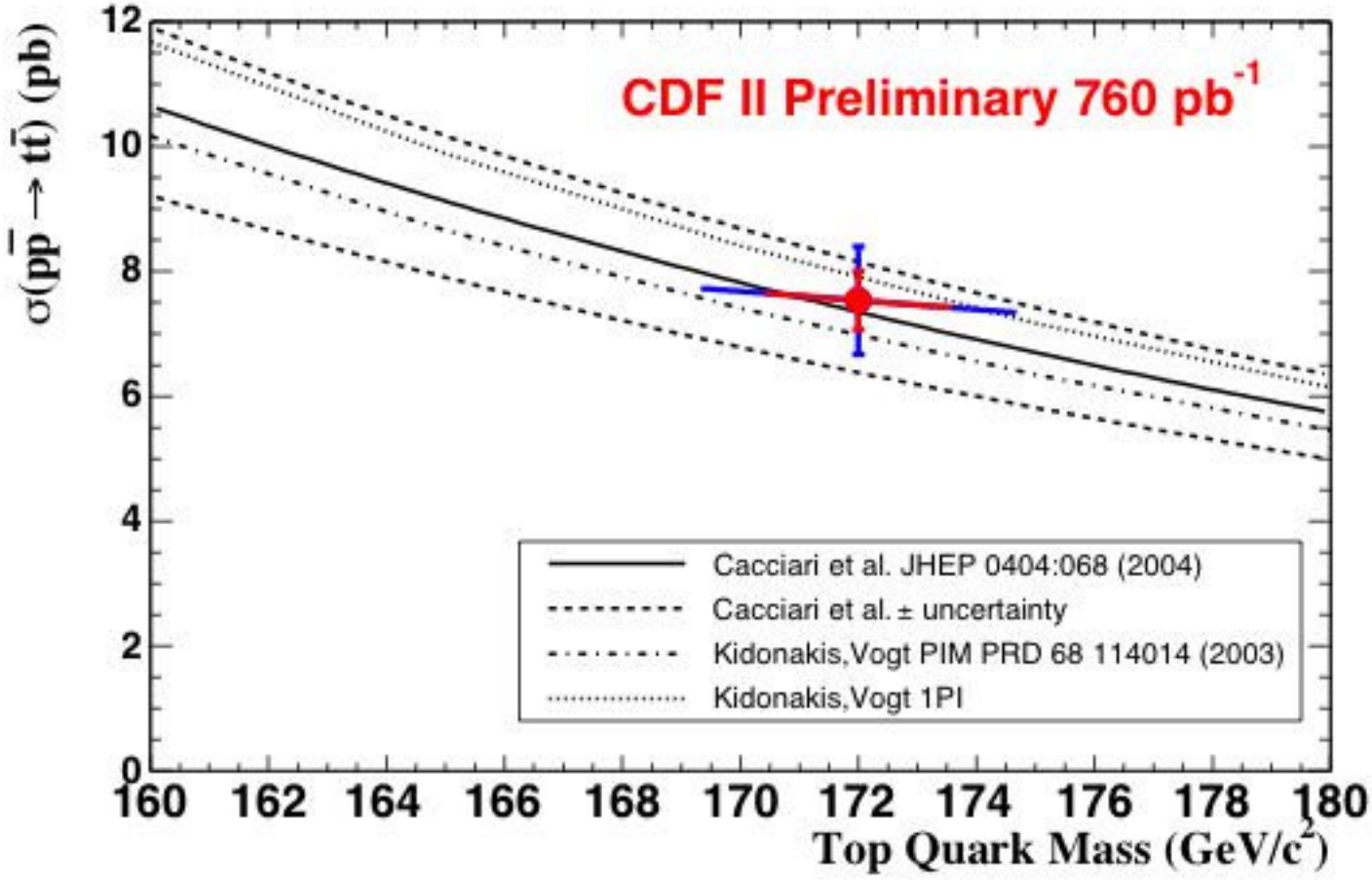




Goals:

Tevatron: 10% uncertainty/experiment with 2 fb^{-1}.
LHC: <10% with 10 fb^{-1} and ultimately <5%.

Winter CDF-only Combination

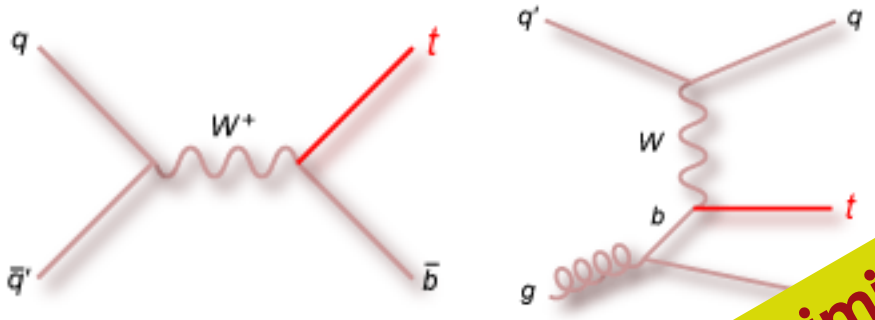


Combined CDF measurements ~14%.

Ongoing effort to have a Tevatron combined average.

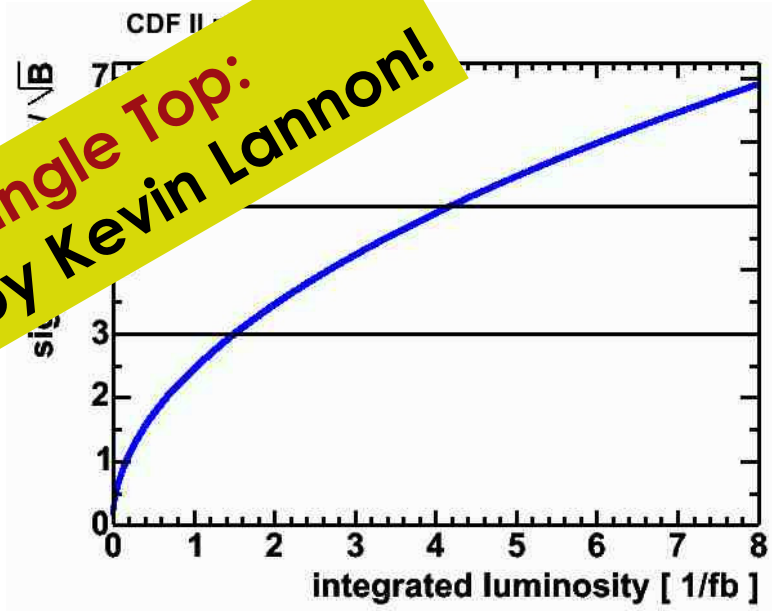
Searching for Single Top

0.88 pb 1.98 pb



NN & multivari
Techni

Current Best Limits on Single Top:
See Parallel Session 2 talk by Kevin Lannon!



Result with 696 pb^{-1}

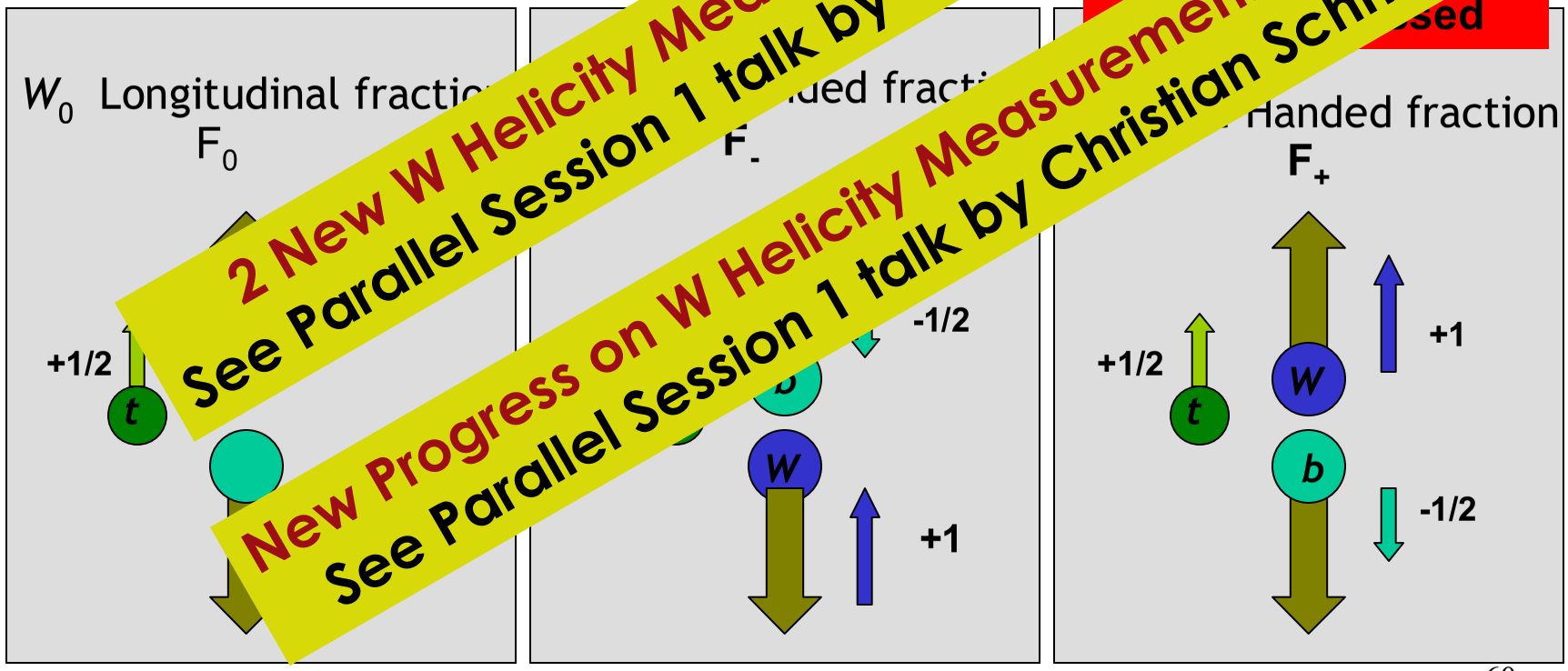
PROJECTIONS

s+t channel <3.4 pb @ 95% C.L.
t-channel <3.1 pb @ 95% C.L.
s-channel <3.2 pb @ 95% C.L.

We Are Close!

W Helicity from t→Wb Decays

- Examines the nature of the tWb vertex, probing the structure of weak interactions at energy scales near EWSB
- Stringent test of SM and its V-A type of interaction



2 New W Helicity Measurements at CDF--
See Parallel Session 1 talk by Jeannine Wagner!

New Progress on W Helicity Measurements at DØ--
See Parallel Session 1 talk by Christian Schmitt!

Importance of the Top Mass

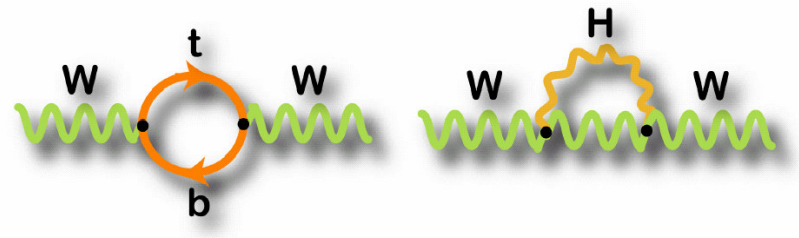
Direct measurement of M_{top}:

tests SM predictions

constrains SM Higgs mass

key to EWSB

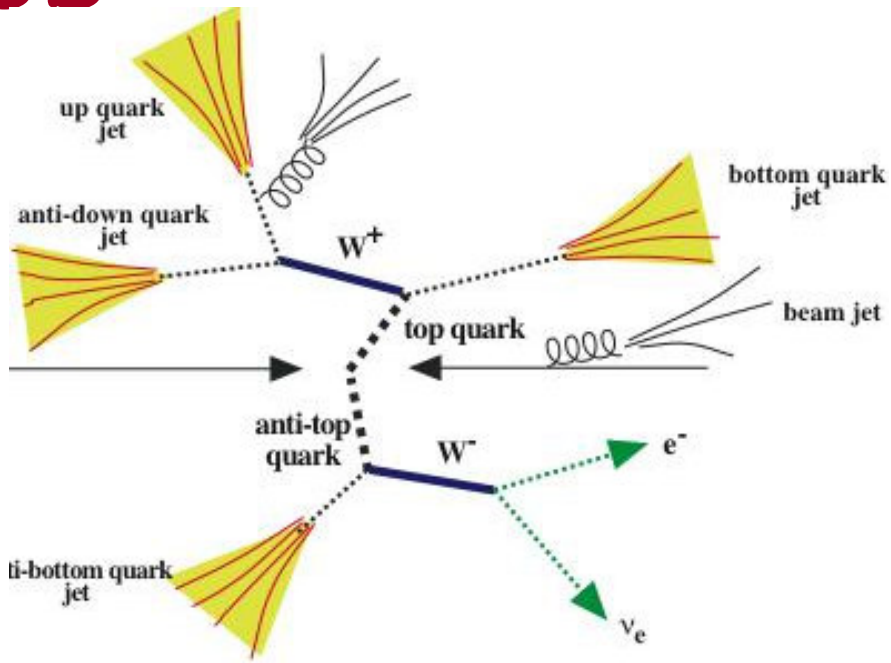
$\Delta M_W \propto M_{top}^2$ $\Delta M_W \propto \ln M_H$



Run II goal: < 3 GeV with 2 fb^{-1}
→Exceeded!

LHC goal: < 1 GeV with 10 fb^{-1}

→Will Tevatron get there first?



Challenging Measurement!

Combinatorics:

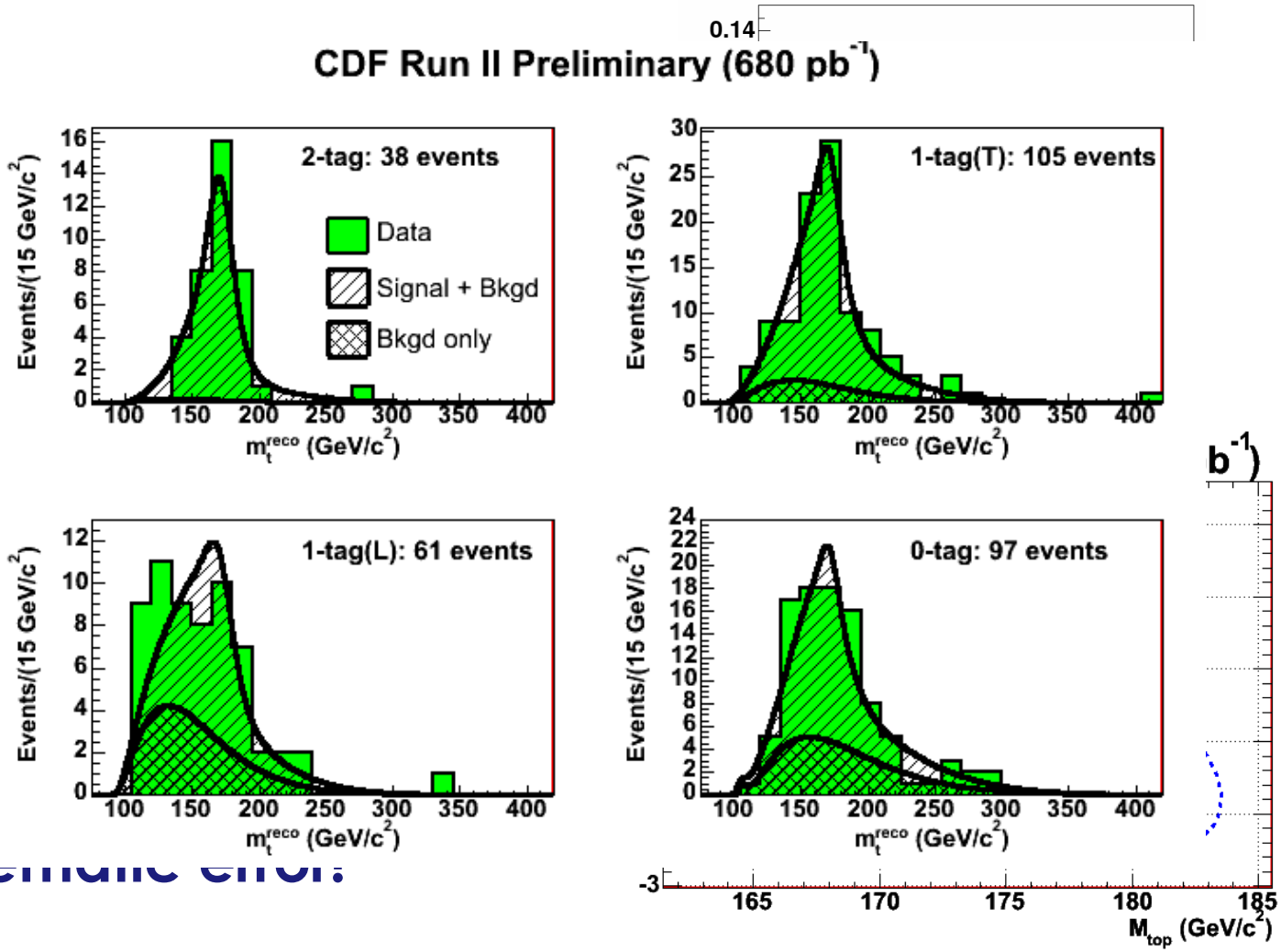
Experimental observations are not as *pretty* as Feynman diagrams!

Which jets go with which quarks?

Current World's Best Top Mass:
CDF Run 2-- Template Method

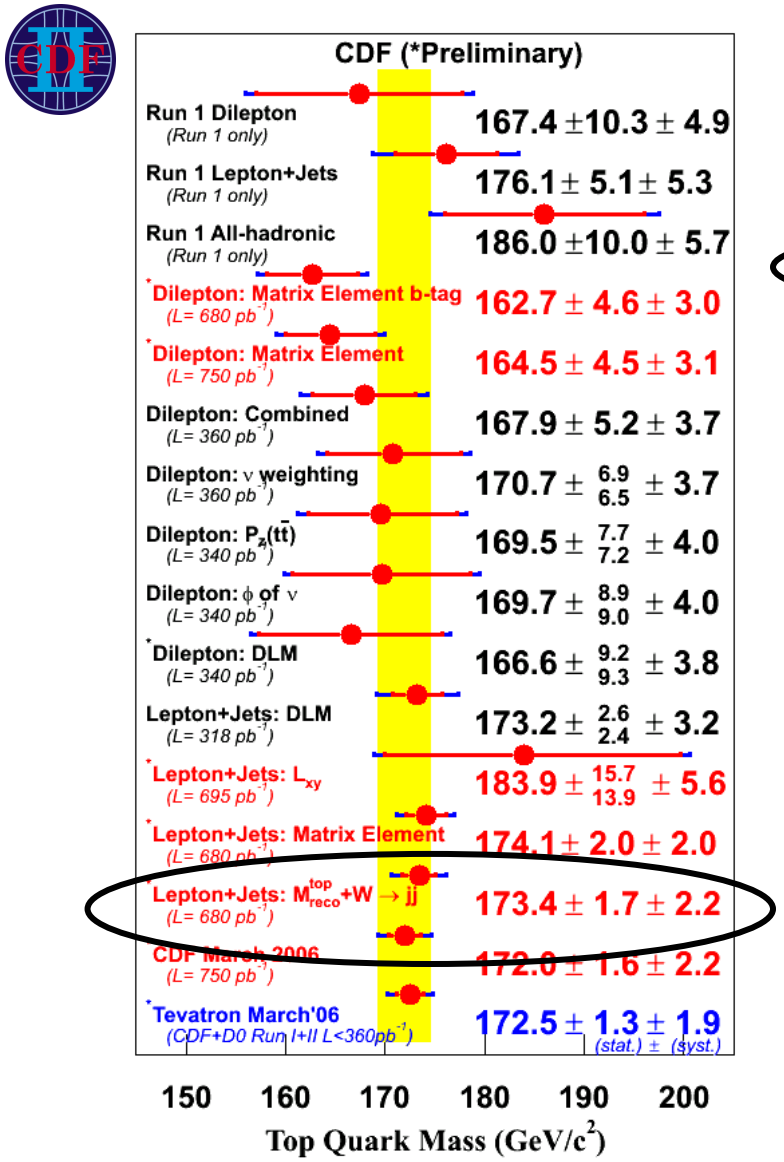
Key Ingre

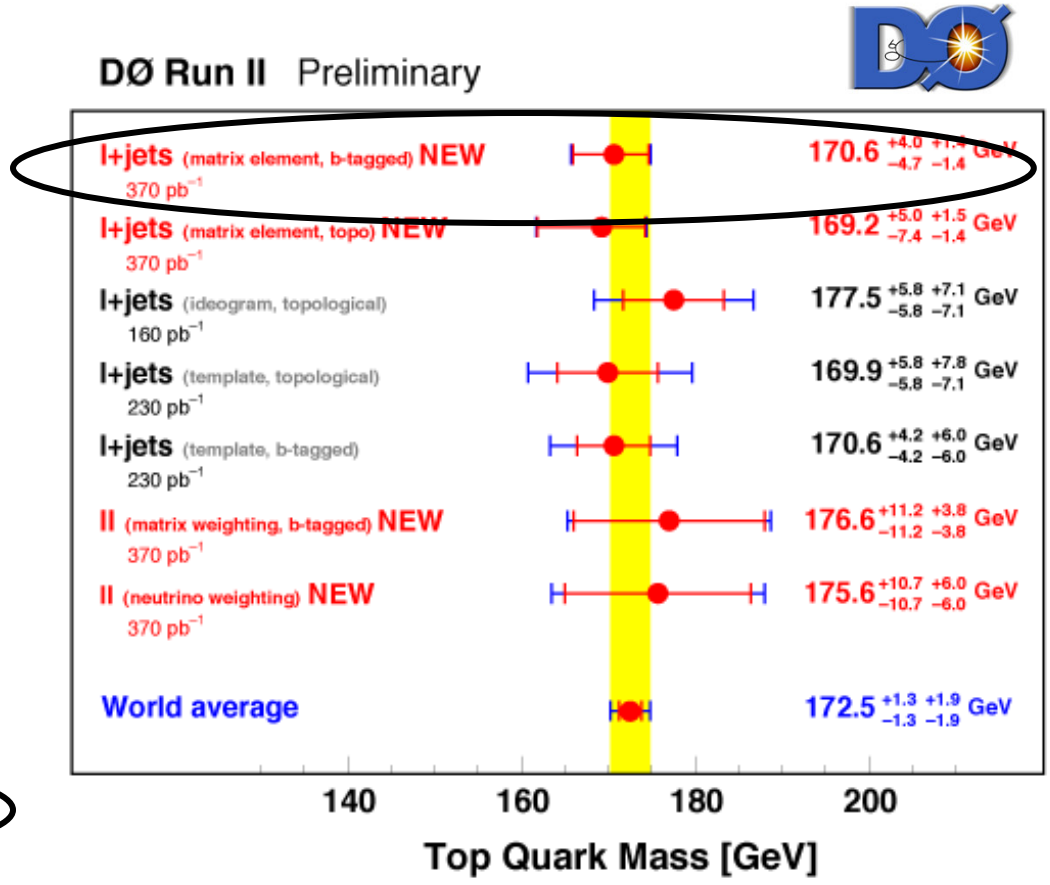
- **Statistics:**
  single and
  events fit si
- **Systemati**
  energy scc
  to top mas
  scale using
- **In-Situ ca**
  on JES syste



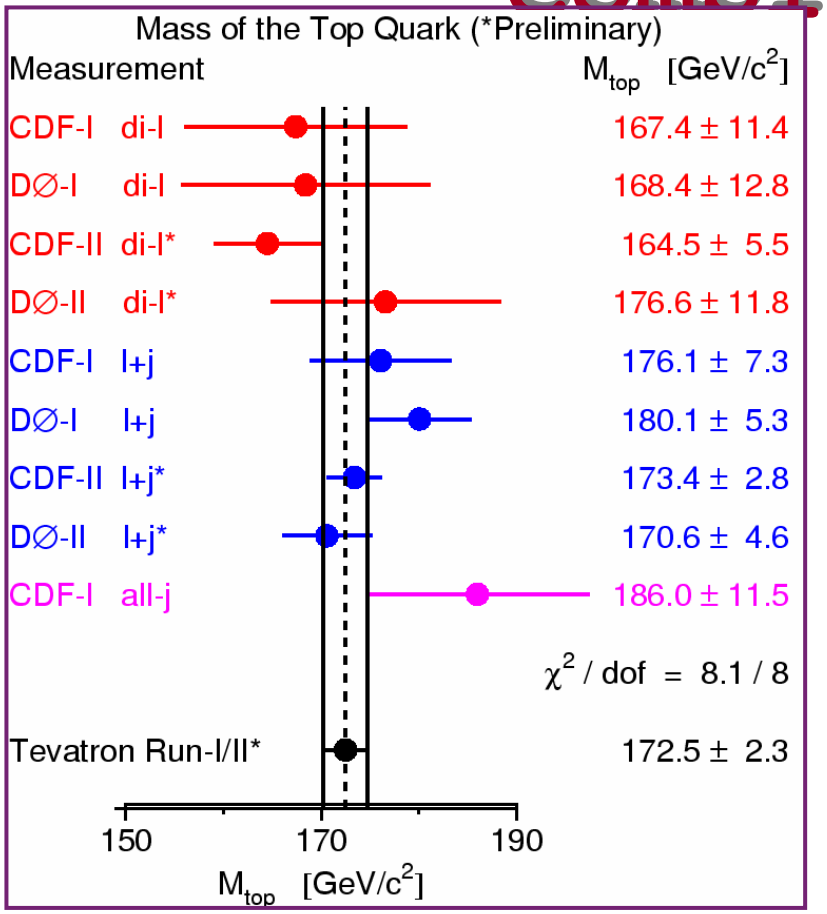
M_{top} = 173.4± 1.7 (stat) ± 1.8 (JES) ± 1.3 (sys) GeV/c^2

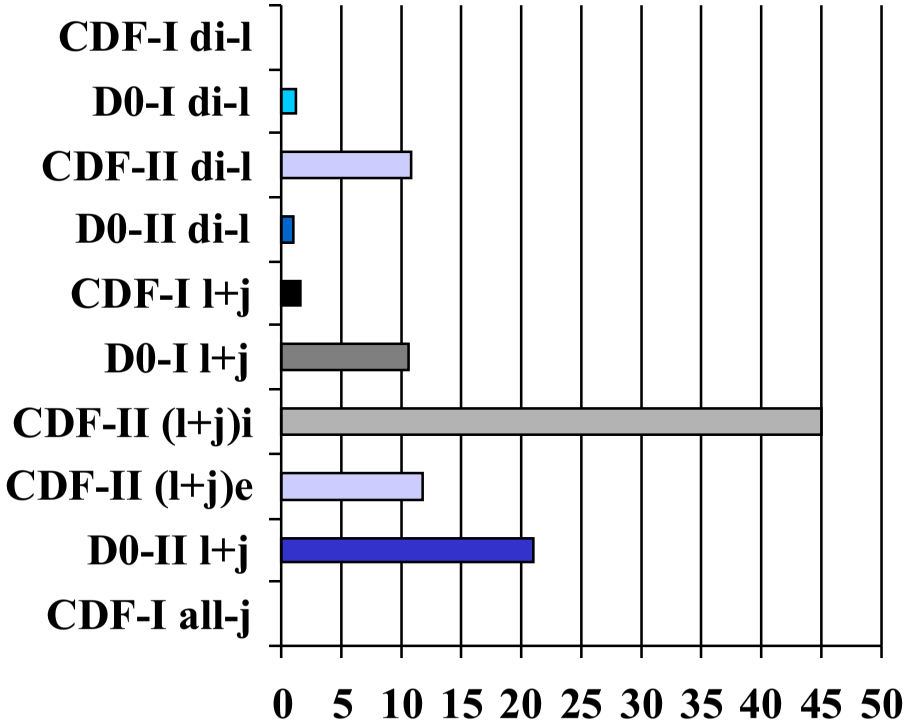
Tevatron Top Mass Measurements





Winter Tevatron M_{top} Combination

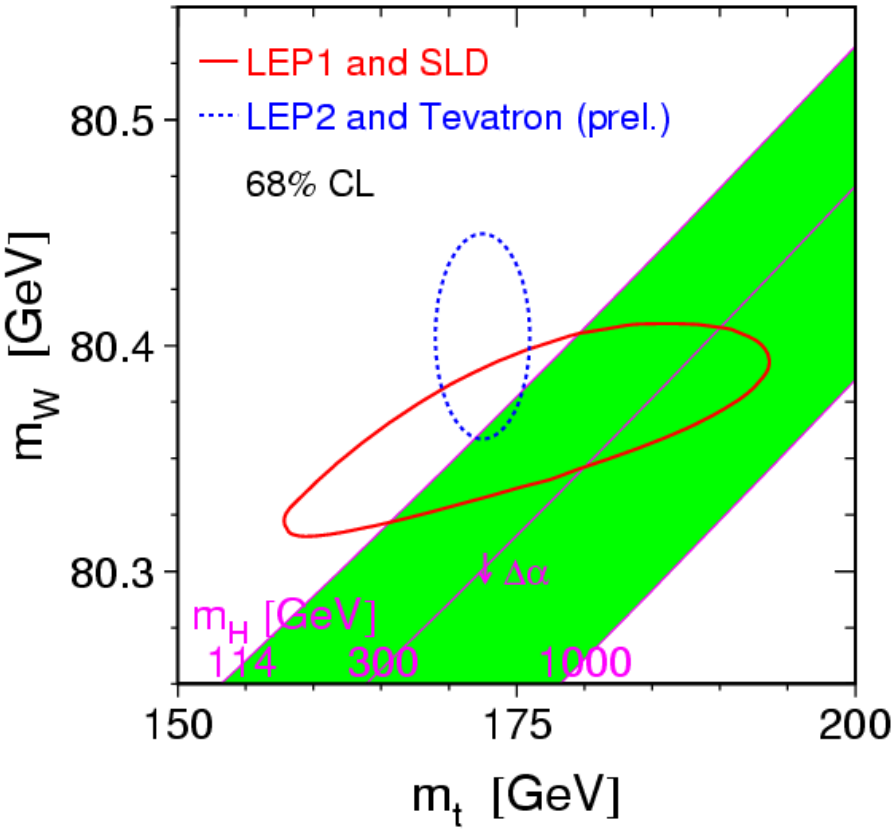


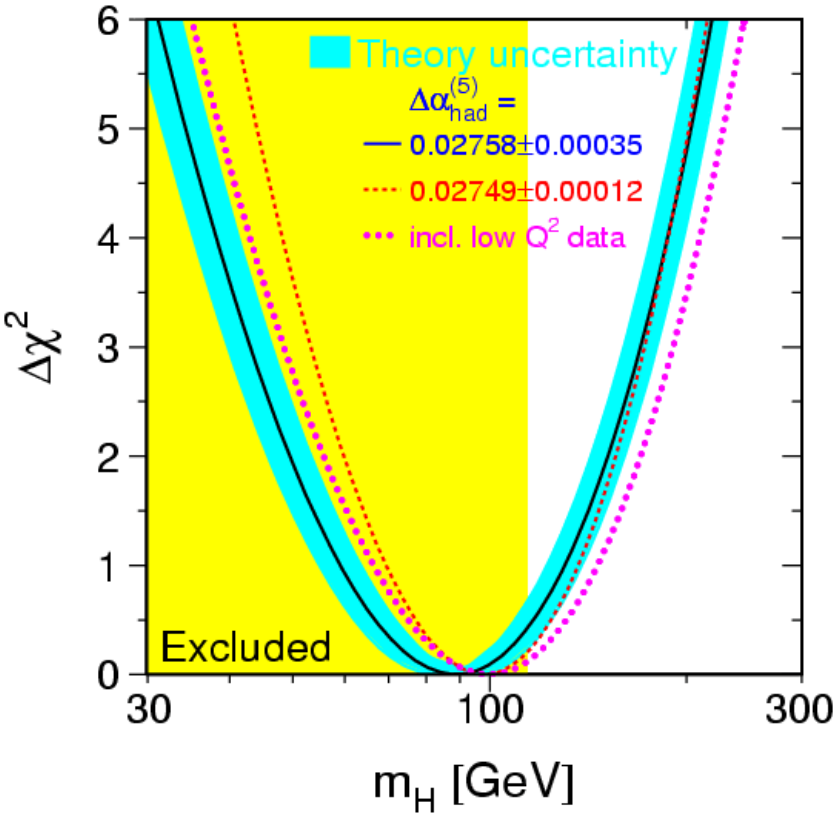


We combine published Run-I (1992- 1996) measurements with the most recent preliminary Run-II (2001- present) measurements using up to 750pb^{-1} of data.

Mtop = 172.5 ± 2.3 GeV

New World Electroweak Fits!





Best EWK fit value

$$M_H = 89^{+42}_{-30}\ \mathrm{GeV/c^2}$$

Fit limit (with theory uncertainty)

$M_H < 175\ \mathrm{GeV/c^2}$ @ 95% CL

Including LEP direct search limit

$M_H < 207\ \mathrm{GeV/c^2}$ @ 95% CL

Success of the Standard Model

- Making precision measurements of very important Standard Model parameters

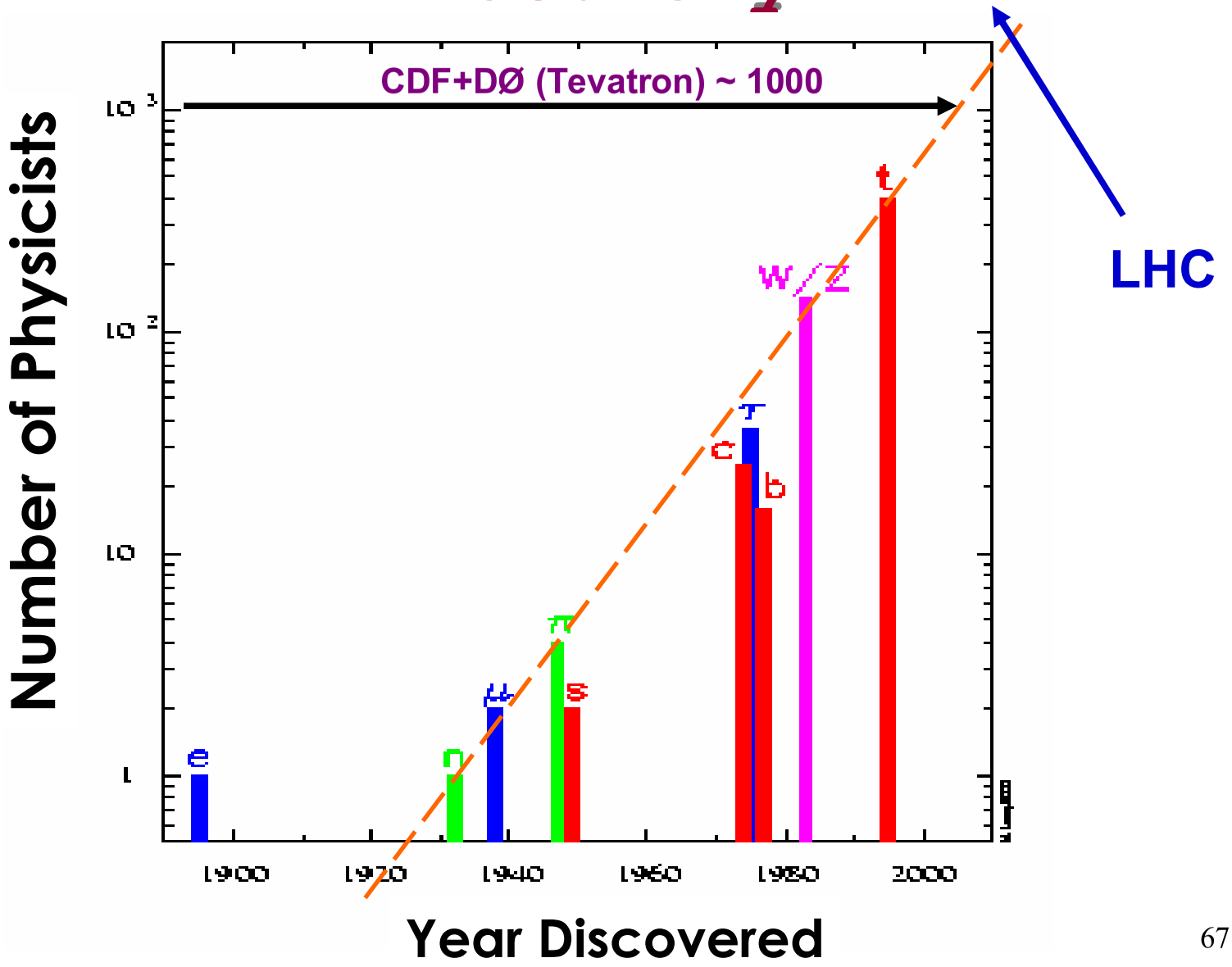
- Reaching sensitivity to BSM processes approaching the TeV scale

Standard Model has been (painfully) successful so far!

- Still, we are seeing many potentially interesting events (see next talk for a few).

- We will have to wait and see what happens. Next two years are crucial for the Tevatron…

of Physicists for Particle Discovery



Forward to the Femptobarn Era!

From top to bottom, the Standard Model physics program is vibrant and healthy. Beginning to have sensitivity to the unexpected in particle properties and the data samples!

- More data makes us smarter !
- It is not just the luminosity factor
- We become more daring and more creative
- New channels open up
  - For calibrations
  - For cross-checks
  - For understanding
- Many opportunities to do great physics

THE BEST IS DEFINITELY YET TO COME !

"Beauty is Truth,
and Truth Beauty"
-- that is all
Ye Know on Earth,
and All Ye Need to Know!"

-Keats

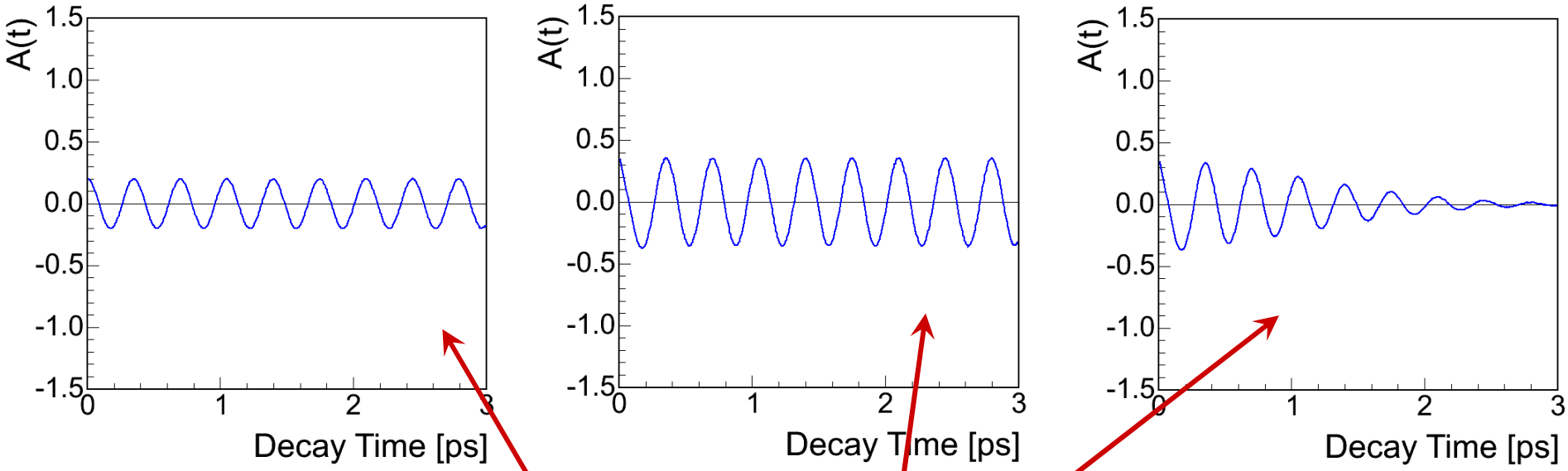
Backup Slides

Mixing: Detector Effects

flavor tagging power, background

displacement resolution

momentum resolution

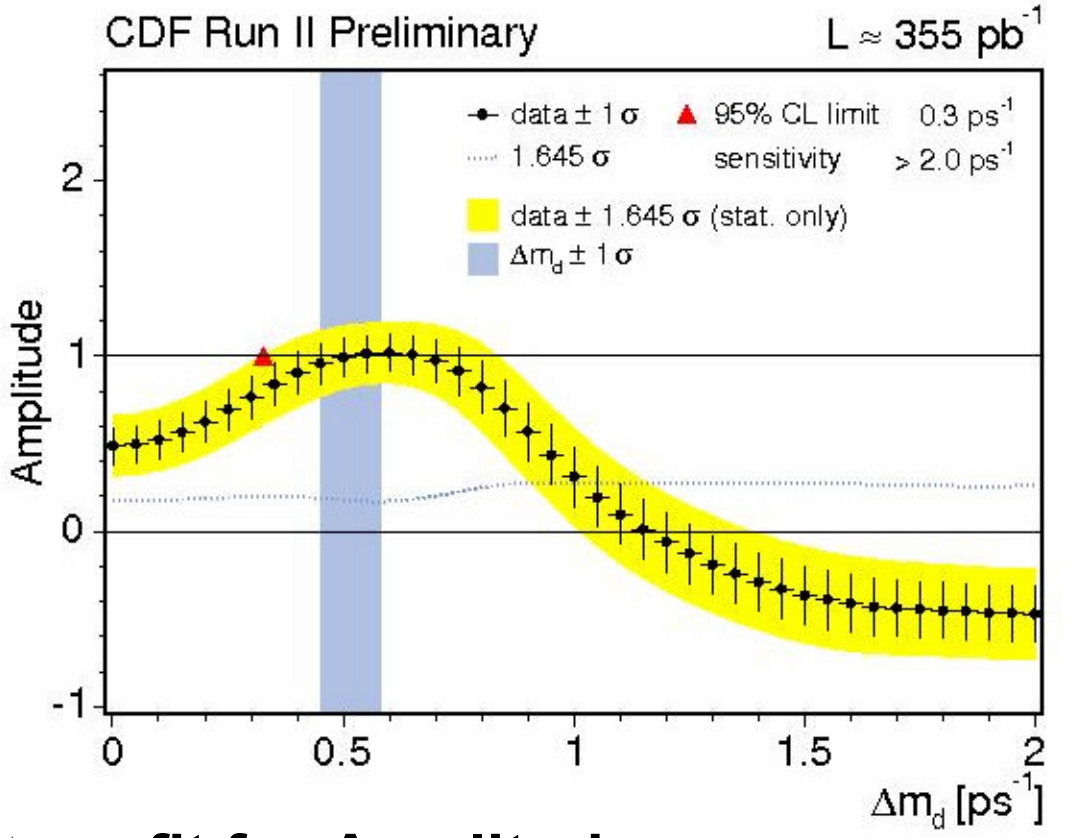


$$\frac{1}{\sigma} = \sqrt{\frac{S\epsilon D^2}{2}} e^{-\frac{(\Delta m_s \sigma_t)^2}{2}} \sqrt{\frac{S}{S+B}}$$

Amplitude Scans

Example:

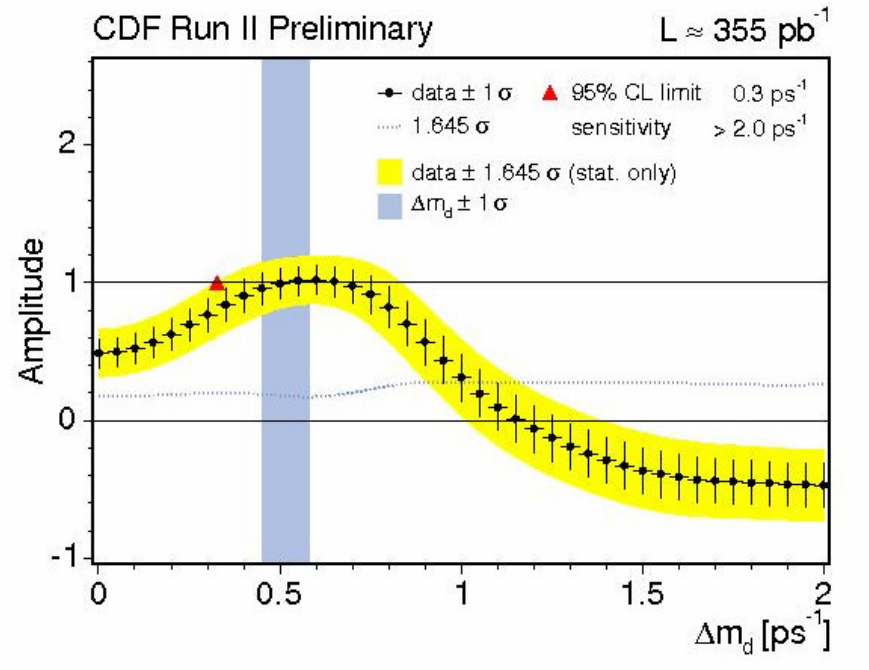
$B^0 \rightarrow D^- \pi^+$

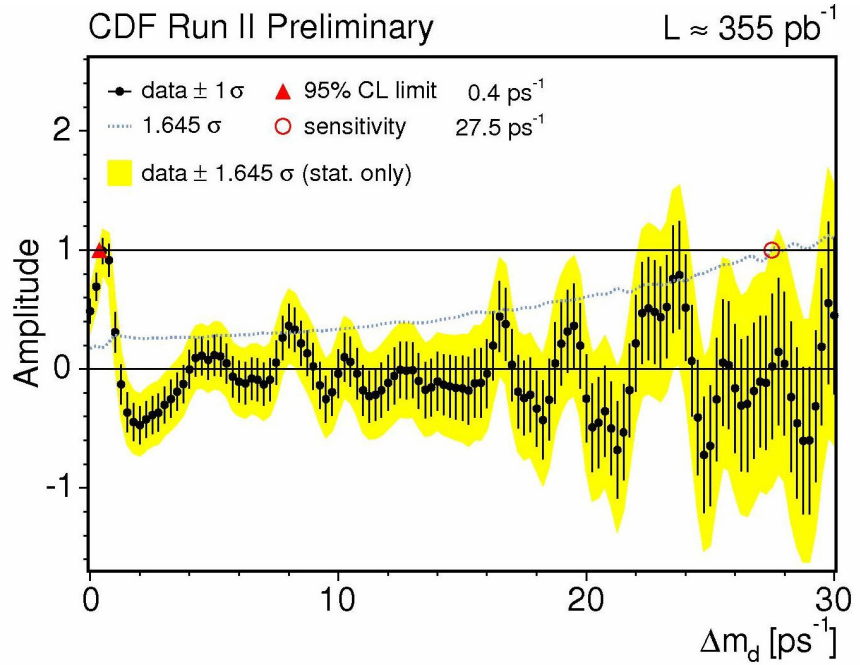


- **Fixed value of Δm_s, fit for Amplitude**
- **Repeat for different values of Δm_s**
- **Signal: A ~ 1, Background: A ~ 0**
- **If a signal is found, fit for mixing frequency!**

Amplitude Scans

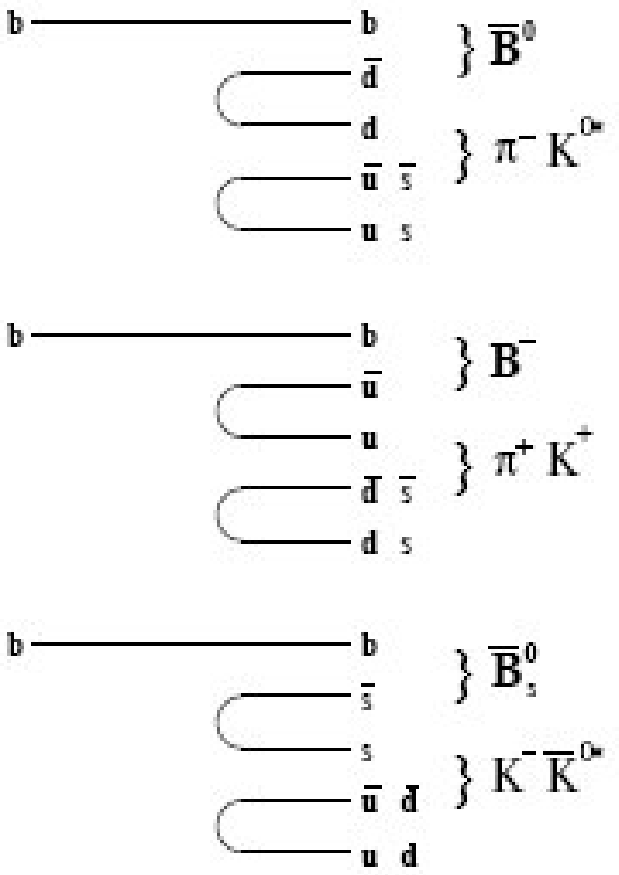
- example: B^0 Mixing signal in hadronic decays
- points: $A \pm \sigma(A)$ from likelihood fit for different Δm
- yellow band: $A \pm 1.645\ \sigma(A)$
- Δm values where $A+1.645\ \sigma(A) < 1$ are excluded at 95% C.L.
- dashed line: $1.645\ \sigma(A)$ as function of Δm
- measurement sensitivity: $1.645\ \sigma(A) = 1$



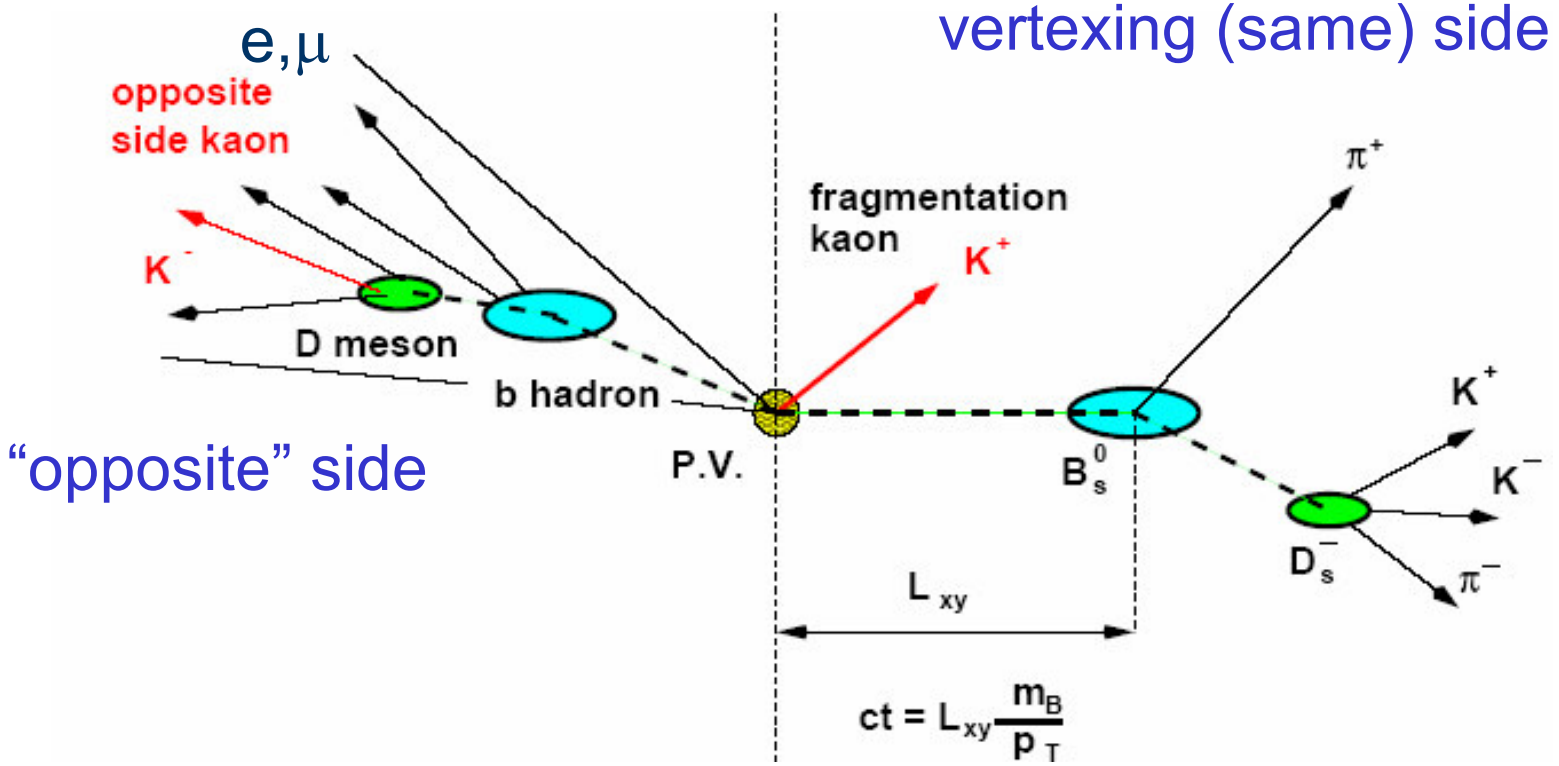


Same Side Kaon Tags

- exploit b quark fragmentation signatures in event
- B^0/B^+ likely to have a π^-/π nearby
- B_s^0 likely to have a K^+
- use TOF and COT dE/dX info. to separate pions from kaons
- problem: calibration using only B^0 mixing will not work
- tune Monte Carlo simulation to reproduce B^0, B^- distributions, then apply directly to B_s^0

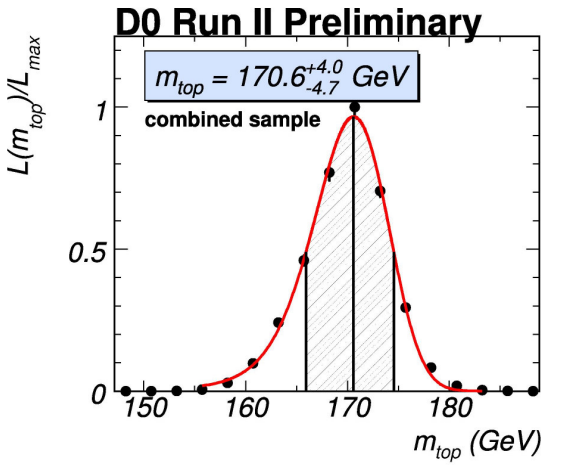


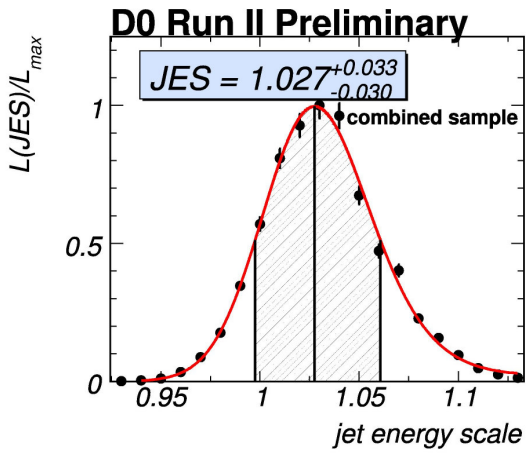
Mixing: Improved Sensitivity

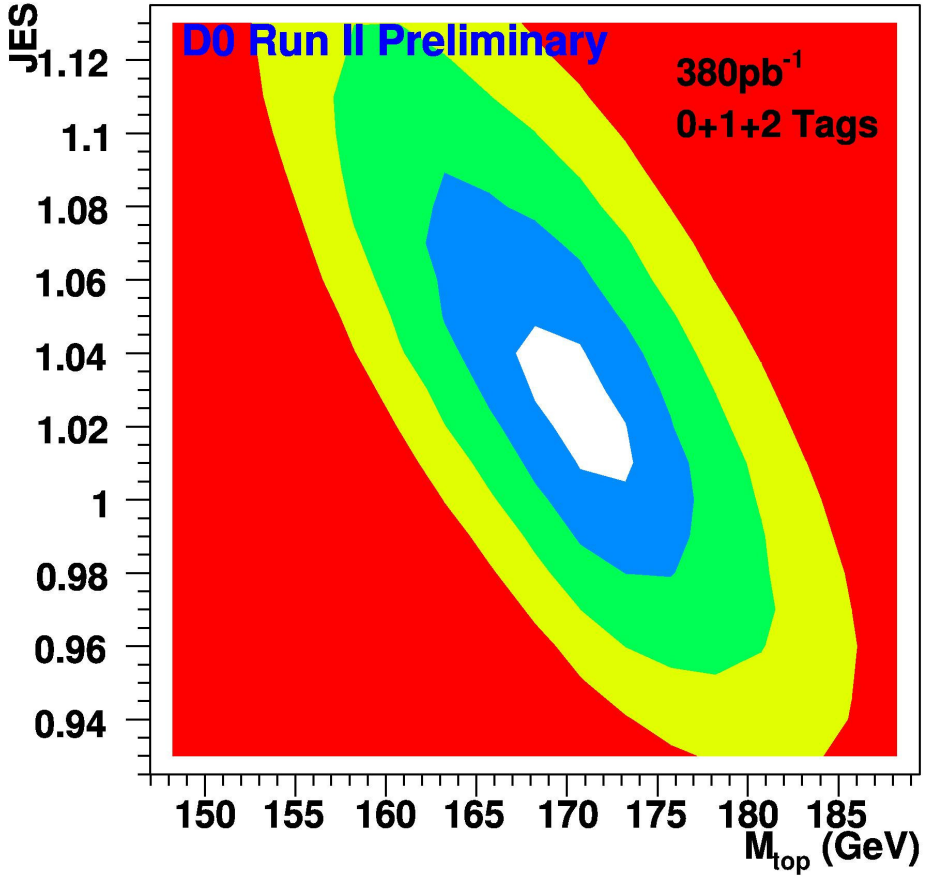


- **CDF able to use both hadronic and semileptonic decays.**
- **Same-side kaon tagging very difficult, but now it works!**
- **Impact parameter resolution (silicon Layer 00) helps proper time resolution; Mass resolution improved S/B.**

Top Mass in Lepton+Jets with ME







M_{top} = 170.6 ± 4.3 (stat+JES) ± 1.4 (sys) GeV/c^2

Top Mass Challenges

Jet Energy Scale:

- JES dominant systematic for M_{top} measurements!

- Current M_{top} Tevatron avg. systematic uncertainty is ±1.9GeV/c^2 :
  - 1.6 GeV/c^2 JES
  - 1.3 GeV/c^2 stat.

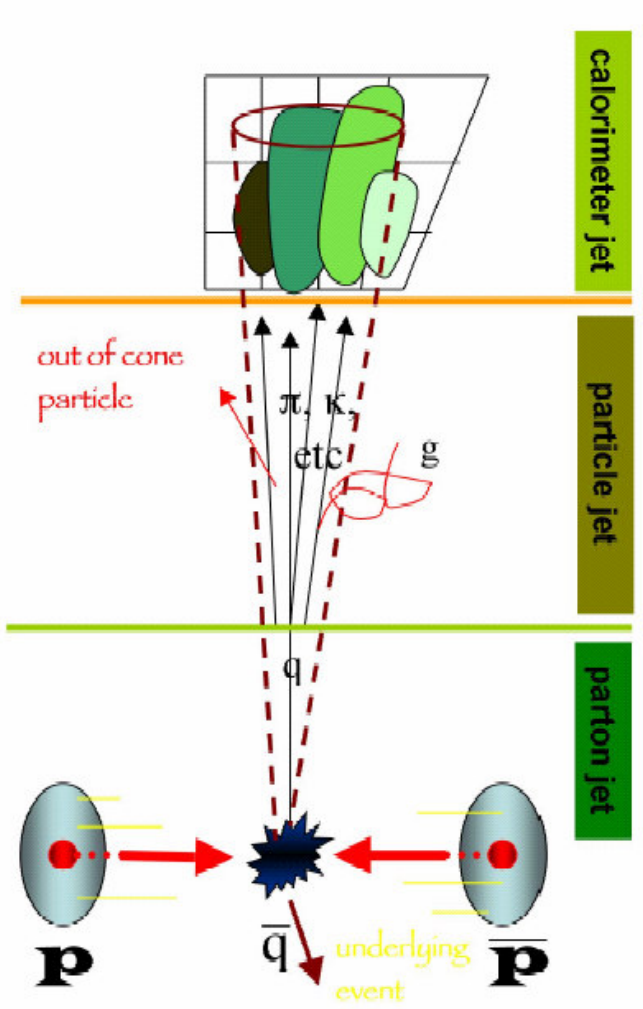
Handles on systematics:

- In-situ JES calibration: use W→jj mass to measure JES uncertainty. Scales directly with statistics!

- b-tagging: reduces combinatorial and physics bkgs.

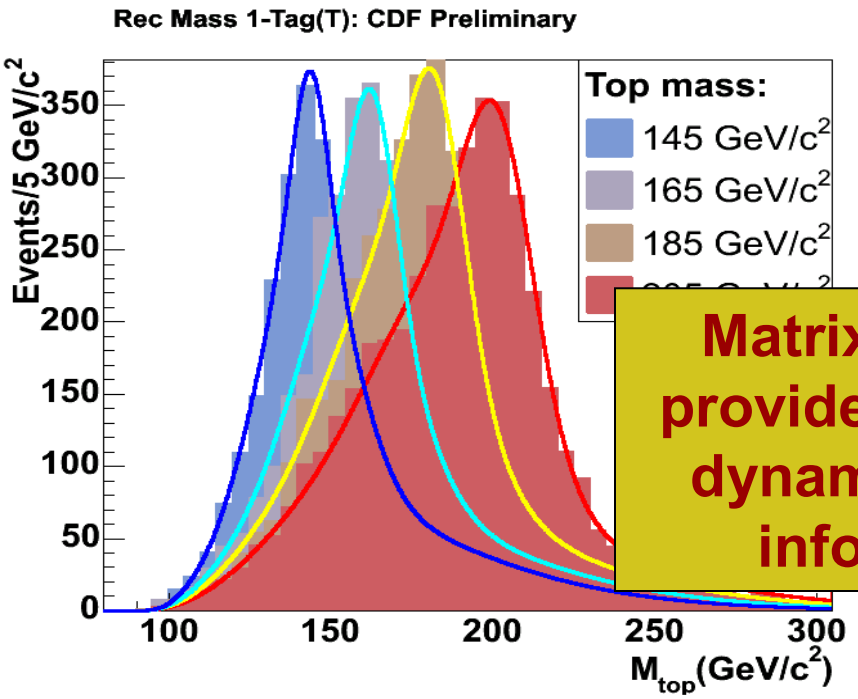
- High statistics: top in femptobarn era!

Determine true "parton" energy from measured jet energy in a cone



Top Mass Methodology

Template Analyses



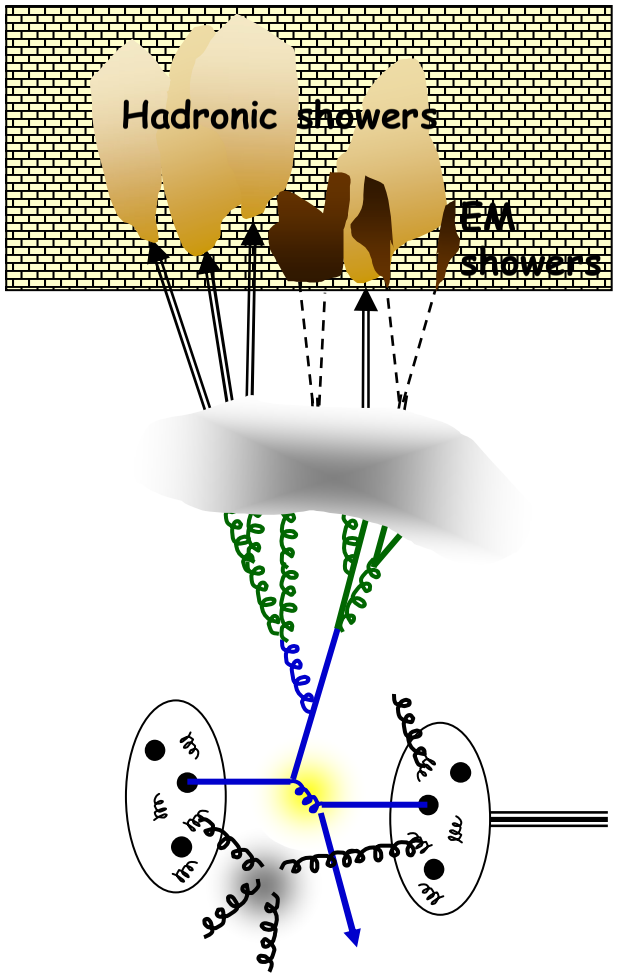
Matrix element provides complete dynamical event information

Matrix Element Analyses

- **Build a probability (ME+PDF+response functions) integrating over unmeasured quantities (signal and background)**
- **e the probability of vent as a function of the ss**
- **Calibrate (or not) using the simulation**

$$L^i(M_{top}) = \sum_{I_t}\sum_{I_s}\int \frac{2\pi^4}{Flux} F(z_a, z_b, p_T)\,|M|^2\,\delta(s_w - (\square+\nu)^2)\,w(I_t, \mathbf{x}\,|\,\mathbf{y}; M_{top})\,d\mathbf{x}\,ds_w$$

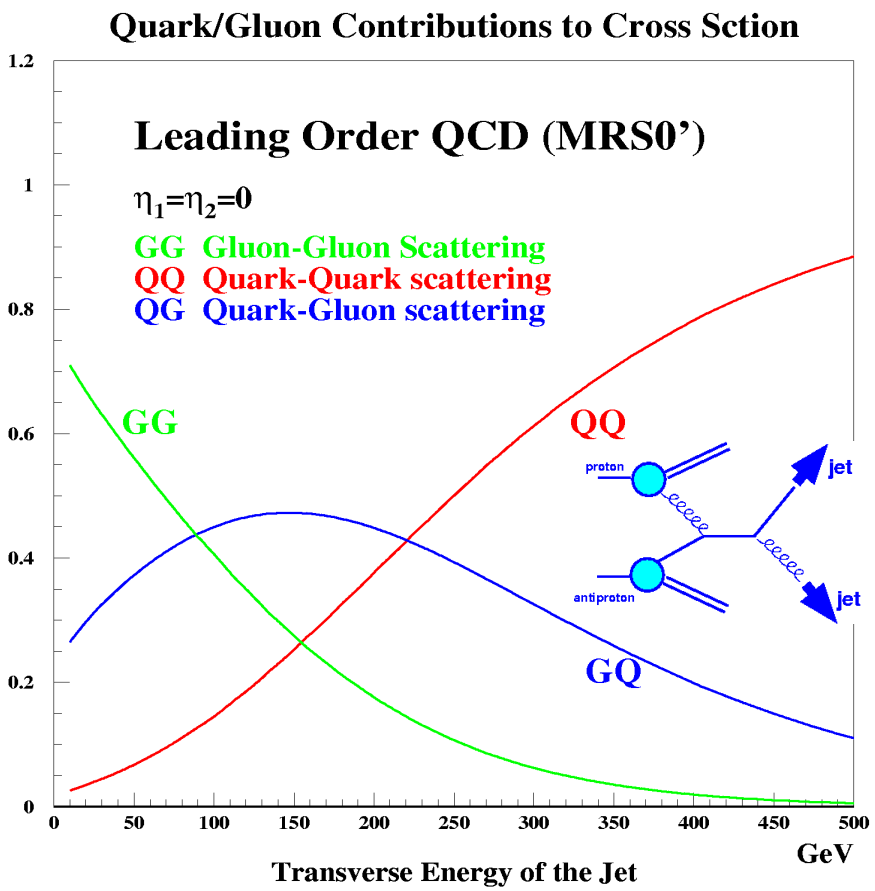
What Do We Measure?

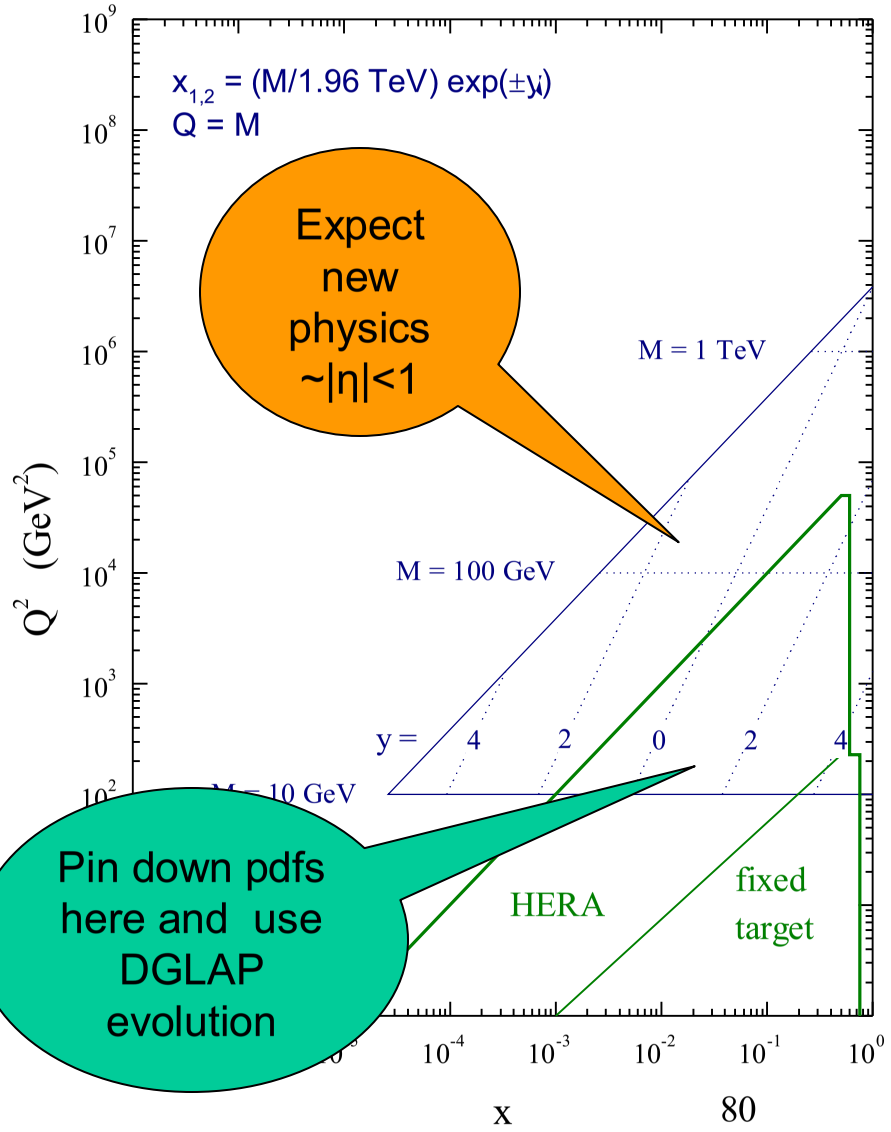


- **Calorimeter Jets:**
  - Cluster calorimeter towers to jets by a jet algorithm
  - Correct for detector resolution and efficiency
  - Correct for "pile-up" – extra minimum bias events
- **Hadron Jets:**
  - Cluster (stable) particles in a jet algorithm using MC – correct data for difference of MC particle jet to MC calorimeter jet
- **Parton Jets:**
  - Correct particle level jets for fragmentation effects
  - Correct for particles from the 'Underlying Event' (soft initial and final state gluon radiation and beam remnant interactions)

Measurement = PDF + pQCD ME + pQCD Approximation + UE + Had + Algo

Content of Jets at Tevatron





- Gluon contribution significant
- use forward jets to pin down pdfs versus new physics at higher Q^2 in central region

Z' Exclusion at 1 fb^{-1}

- First CDF Z' result with ~820 pb^{-1}
- Only limits on Z' for SM couplings ▪