Looking for New Physics in the B_s-Meson System

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HEP seminar

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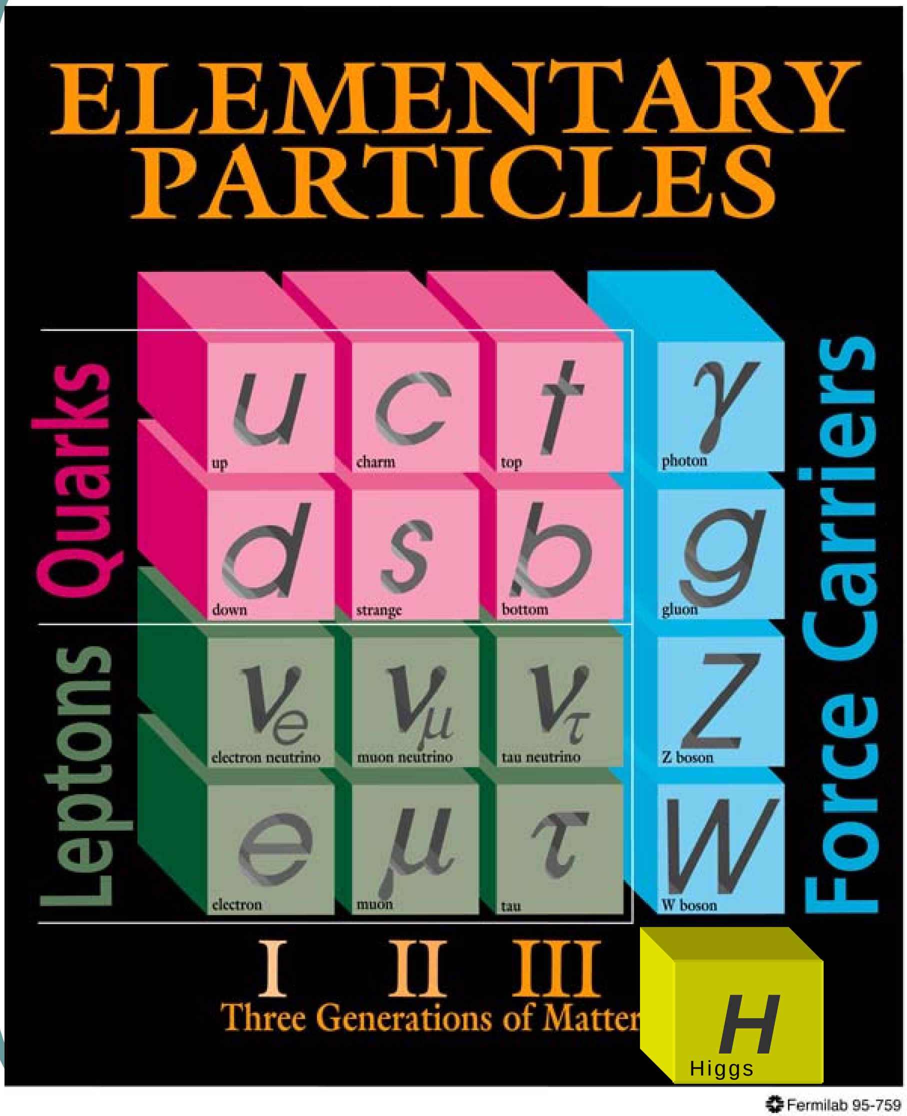
Outline

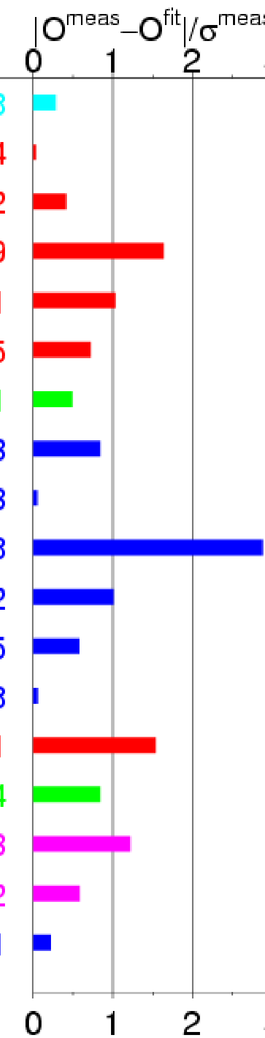
- Introduction
- B_s mixing
- Tevatron and DØ detector
- Δm_s
- $\Delta\Gamma$ and ϕ_s
- Summary

Standard Model



Preliminary

	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02758 ± 0.00035	0.02768
m_Z [GeV]	91.1875 ± 0.0021	91.1874
Γ_Z [GeV]	2.4952 ± 0.0023	2.4962
σ^0_{had} [nb]	41.540 ± 0.037	41.479
R_l	20.767 ± 0.025	20.741
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01645
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481
R_b	0.21629 ± 0.00066	0.21573
R_c	0.1721 ± 0.0030	0.1723
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1038
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0742
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1481
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.425 ± 0.034	80.383
Γ_W [GeV]	2.133 ± 0.069	2.092
m_t [GeV]	174.3 ± 3.4	175.1



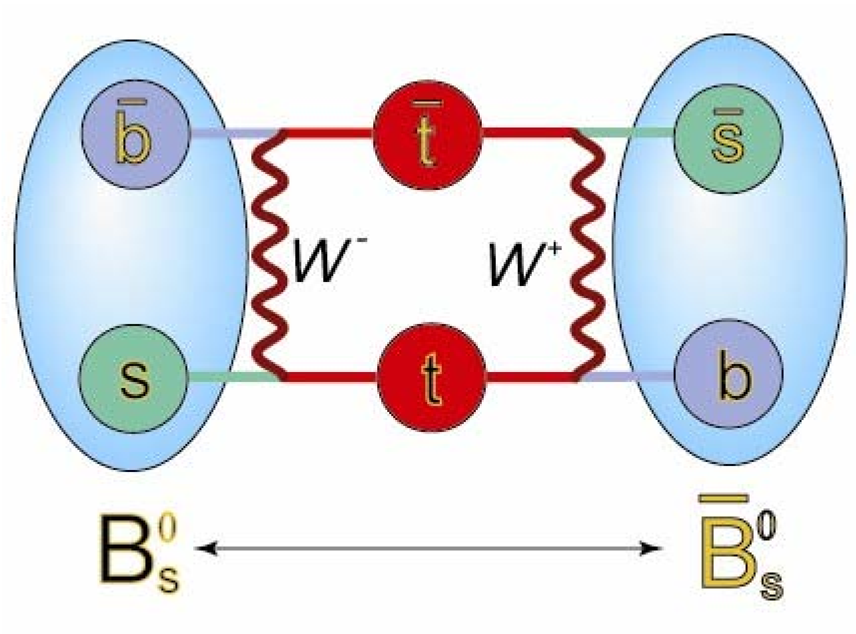
LEP EW-WG: Summer 2005

Prob(χ^2) ~ 16%

Physics Beyond the Standard Model

- Source of electroweak symmetry breaking
  - Higgs?
- Gravity not a part of the SM
- Grand unification
  - What is the origin of universe?
- Where is the Antimatter?
  - Why is the observed universe mostly matter?
- Dark Matter, Dark Energy?
  - Astronomical observations indicate that there is more “stuff” than we see
- Look for new physics that would explain these questions:
  - SUSY, Extra Dimensions ...

Neutral Mesons



- Meson consist of quark-antiquark pair held together by strong force
  - Charged, neutral
- Particle ↔ antiparticle oscillation
  - Spontaneously transform themselves into their own antiparticles
  - First pointed out by Gell-Mann and Pais in 1955 (Phys. Rev. **97**,1387 (1955))

History of Mixing

- Mixing in K^0 system → charm quark
  discovery of charge and parity violation (CPV)
  third generation
- Mixing in B_d system → early indication of a heavy top
- Mixing in neutrino system → neutrinos are massive
- Mixing in the B_s system → new physics ?

The Cabibbo-Kobayashi-Maskawa Matrix

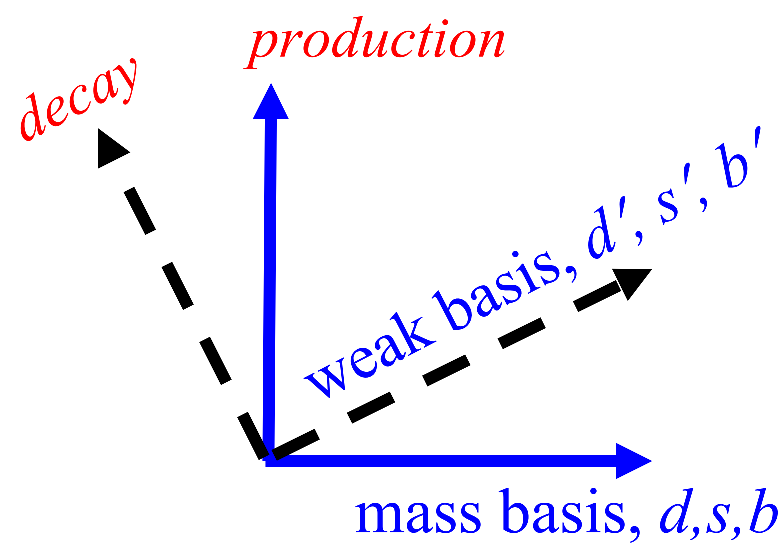
- Quark Weak ≠ Mass Eigenstates

$$L = \frac{g}{\sqrt{2}} \left(\overline{u}, \overline{c}, \overline{t} \right)_L V_{CKM} \, \gamma_\mu \begin{pmatrix} d \\ s \\ b \end{pmatrix}_L W^\mu + h.c.$$

$$\text{Weak} \quad \begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix} \quad \text{Mass}$$

quarks: $d'_i = V_{ij} d_j$

antiquarks: $\overline{d'_i} = V_{ij}^* \overline{d_j}$



The Cabibbo-Kobayashi-Maskawa Matrix

⇒ Unitary:

$$V_{ud}V_{ub}^{*} + V_{cd}V_{cb}^{*} + V_{td}V_{tb}^{*} = 0$$

Weak

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

Mass

⇒ CKM Mixing Matrix:

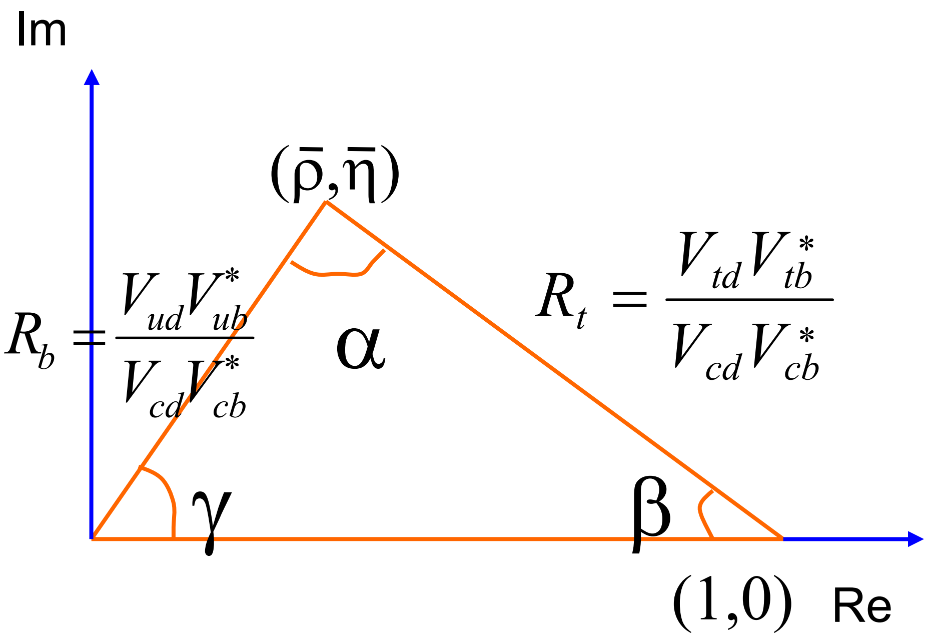
- 3 angles
- 1 complex phase ⇒ CP-violation

$$V_{ub} \neq V_{ub}^{*},\ V_{td} \neq V_{td}^{*} \ \Rightarrow \mathrm{CPV}$$

- CPV requires $m(q_i) \neq m(q_j)$

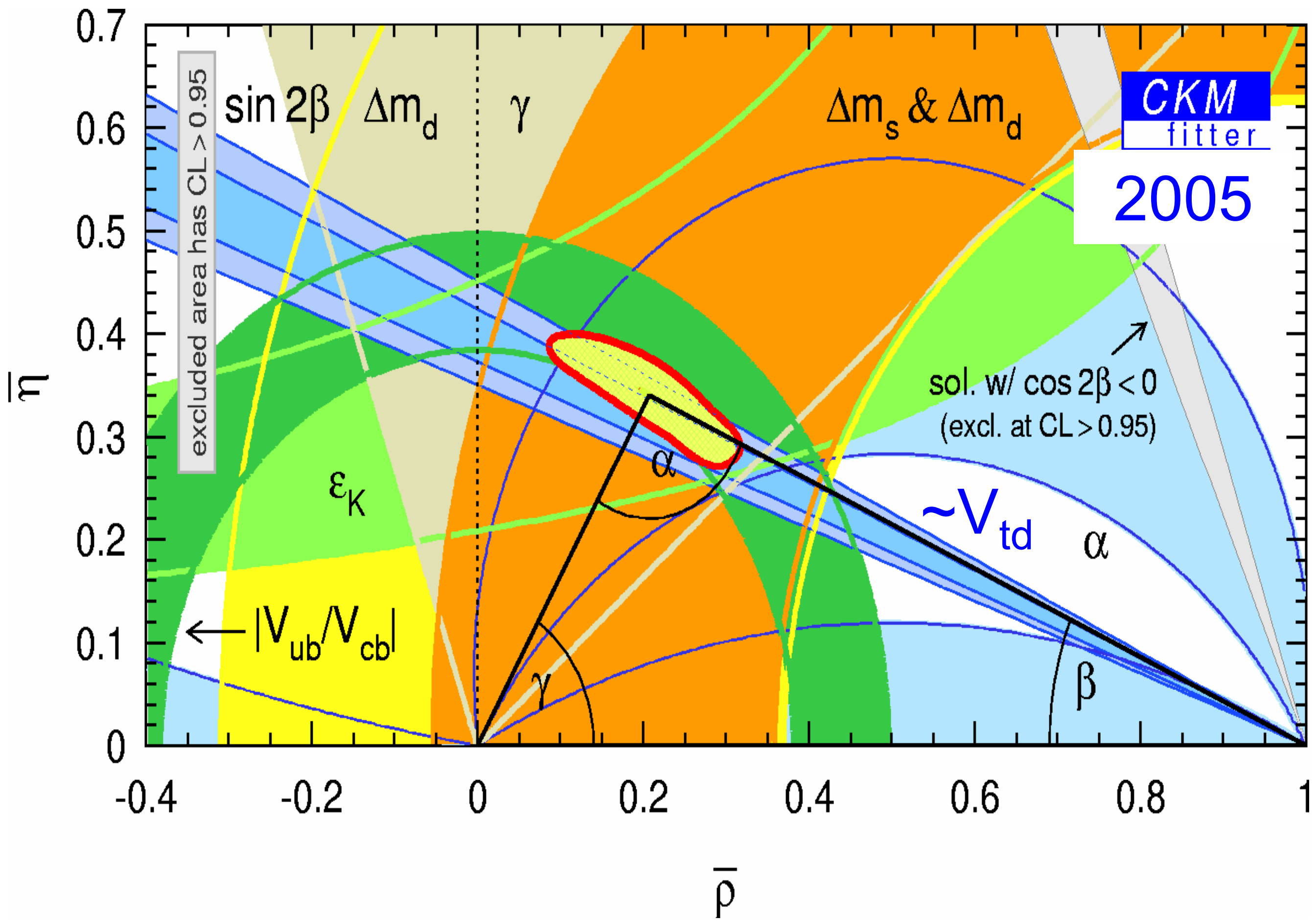
Unitarity Triangle

- Vector sum in complex plane

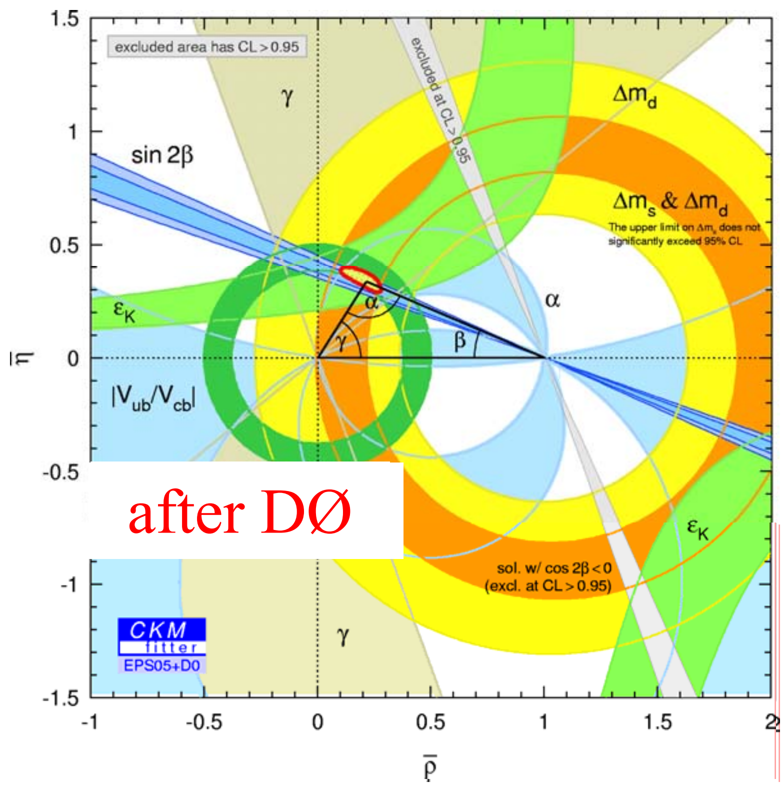


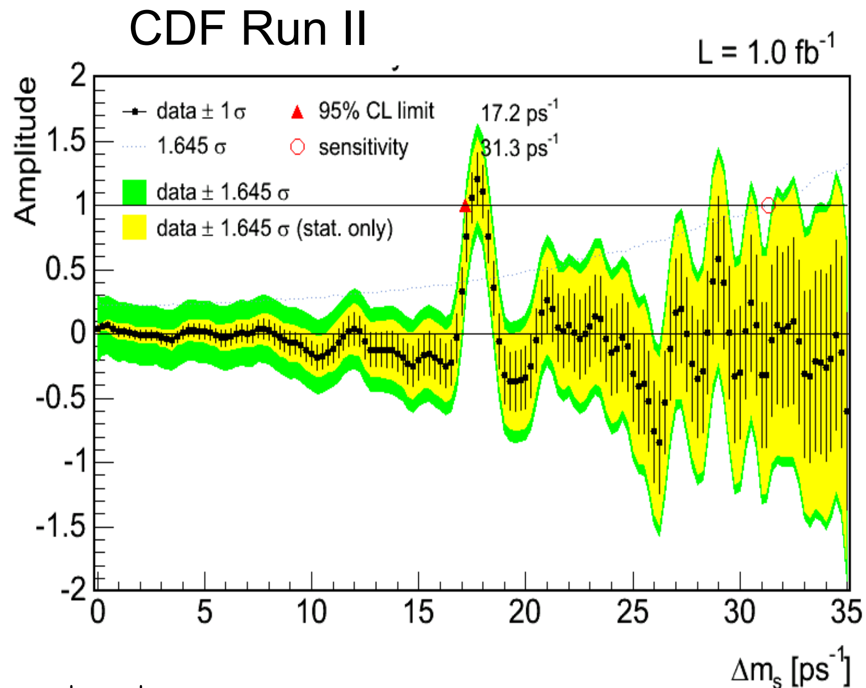
- In SM, has to be closed ($\alpha+\beta+\gamma=180^0$)
- Area of triangle indicates CP violation in SM due to CKM complex phase
- Measure all sides
- Measure all angles
- Are they consistent?

The CKM Triangle (2005)



Δm_s and V_{td}





$$\frac{|V_{td}|}{|V_{ts}|} = 0.2060 \pm 0.0007(ex.)^{+0.0081}_{-0.0060}(theo.)$$

Rule out large new physics effects: DØ Collab. PRL 97 021802 (2006)

Precision SM measurement: CDF Collab. PRL 97 242003 (2006)

B^0_s-$\overline{B}^0_s$ Mixing and V_{td}

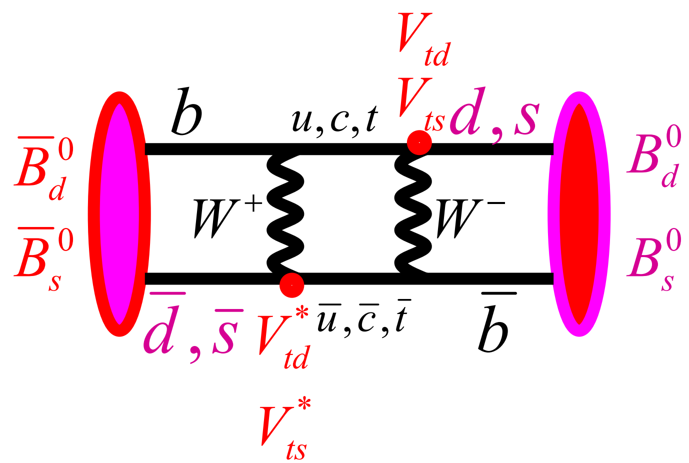
- B^0_d ($\bar{b}d$) oscillation frequency:

$$\Delta m_d = \frac{G_F^2}{6\pi^2} m_{B_d} m_t^2 \, F\!\left(\frac{m_t^2}{m_W^2}\right) B_{B_d} f_{B_d}^2 \eta_{QCD} \left| V_{tb}^* V_{td} \right|^2$$

Well measured
$\Delta m_d = 0.509 \pm 0.004$ ps^{-1}

Large uncertainty ~15-20%

Want



- Dominant theoretical uncertainties cancel in the ratio ⇒

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{B_s} f_{B_s}^2 B_{B_s}}{m_{B_d} f_{B_d}^2 B_{B_d}} \cdot \left| \frac{V_{ts}}{V_{td}} \right|^2$$

Smaller uncertainty

Measure Δm_s

B^0_s-$\overline{B}^0_s$ Mixing

- Light and heavy B meson mass eigenstates differ from flavor eigenstates:

$$|B_L\rangle = p|B^0\rangle + q|\overline{B}^0\rangle$$
$$|B_H\rangle = p|B^0\rangle - q|\overline{B}^0\rangle$$

$$\hat{H}\begin{pmatrix} B^0 \\ \bar{B}^0 \end{pmatrix} = \begin{pmatrix} M - \frac{i\Gamma}{2} & M_{12} - \frac{i\Gamma_{12}}{2} \\ M_{12}^* - \frac{i\Gamma_{12}^*}{2} & M - \frac{i\Gamma}{2} \end{pmatrix}\begin{pmatrix} B^0 \\ \bar{B}^0 \end{pmatrix}$$

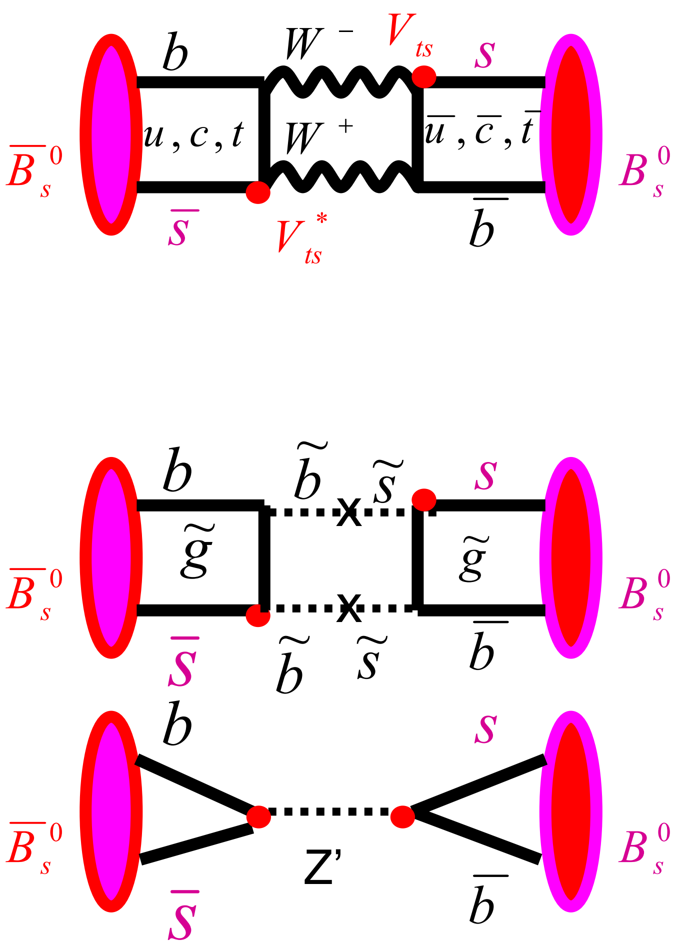
$$\Delta m_s = M_H - M_L \cong 2|M_{12}|$$

$$\Delta\Gamma_s = \Gamma_L - \Gamma_H \cong 2|\Gamma_{12}|\cos\varphi_s$$

$$\varphi_s = \arg\left(-\frac{M_{12}}{\Gamma_{12}}\right); \quad A_{SL} = \mathrm{Im}\frac{\Gamma_{12}}{M_{12}} = \left|\frac{\Gamma_{12}}{M_{12}}\right|\sin\varphi_s$$

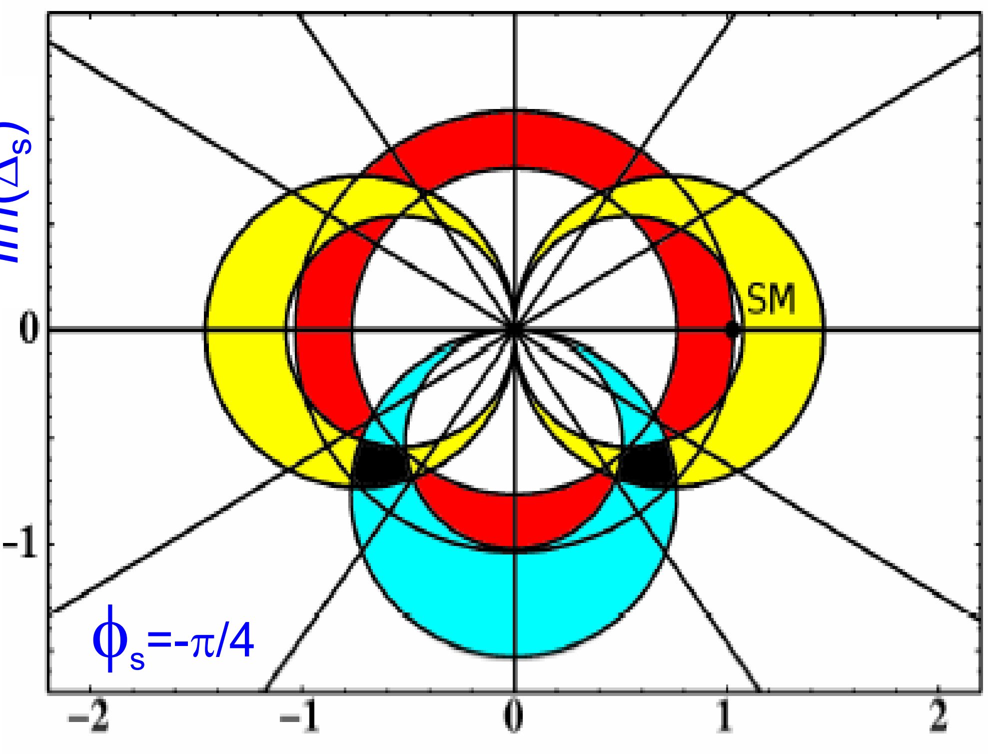
Measure all three at Tevatron

Standard Model and New Physics



- Γ^s_{12} governs decays (tree level)
  - No New Physics expected
- M^s_{12} governs oscillations (loop level)
  - Sensitive to New Physics
  - New CP-violating phase
    - $\phi_s = \phi_s^{SM} + \phi^{NP}$
    - $M^s_{12} = M^{SM}_{12} \bullet \Delta_s$, $\Delta_s = |\Delta_s| e^{i\phi NP}$
      - Reduced Δm_s
      - $\Delta_s = 1$ in SM
    - $\Delta\Gamma_s = \Delta\Gamma_s^{SM} \bullet |\cos \phi_s|$
      - Reduced width

Standard Model and New Physics



$Im(\Delta_s)$

$|\Delta_s| = \Delta m_s / \Delta m_s^{SM}$

- SM prediction:

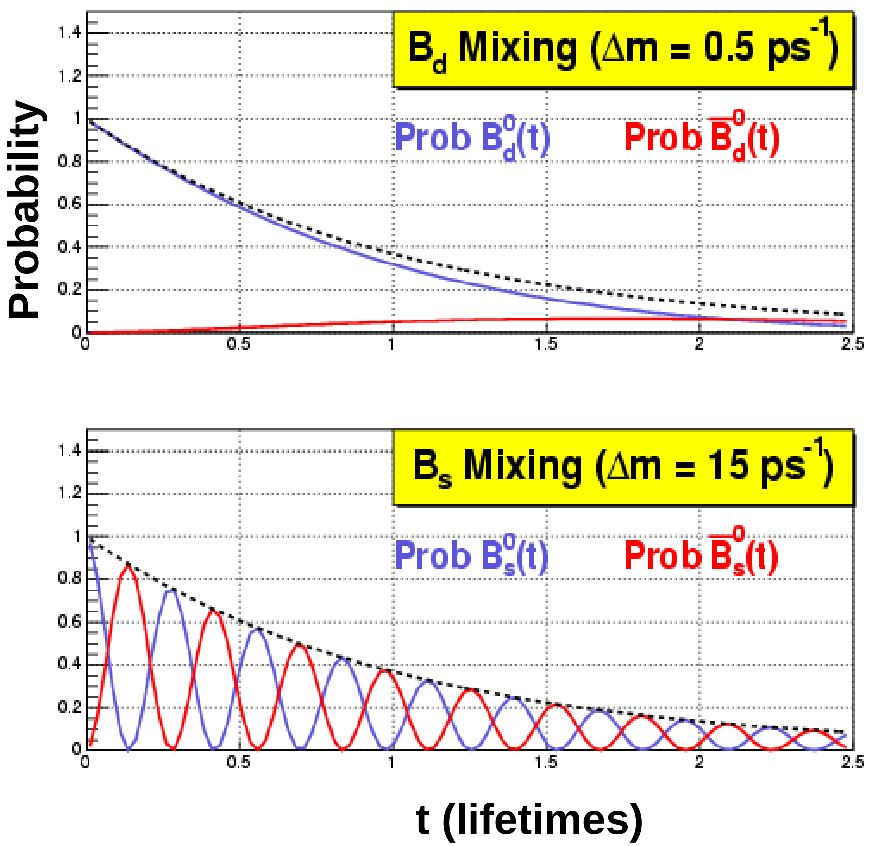
A.Lenz U. Nierste hep-ph/0612167

- $\Delta m_s = 19.3 \pm 6.7\ ps^{-1}$
- $\Delta\Gamma_s = 0.088 \pm 0.017\ ps^{-1}$
- $\phi_s = (4.2 \pm 1.4)x10^{-3}$

$\Delta M_s = 17.4\,\mathrm{ps}^{-1}$, $\Delta\Gamma_s = 0.068\,\mathrm{ps}^{-1}$, (Hypothetical measurements)

$\frac{\Delta\Gamma_s}{\Delta M_s} = 3.91 \cdot 10^{-3}$, $a_{\mathrm{fs}}^s = -3.89 \cdot 10^{-3}$.

B^0_s-$\overline{B}^0_s$ Mixing



$$P(B \to B) = \frac{e^{-\Gamma t}}{2}\left(\cosh\frac{\Delta\Gamma t}{2} + \cos\Delta m t\right)$$

$$P(B \to \overline{B}) = \frac{e^{-\Gamma t}}{2}\left(\cosh\frac{\Delta\Gamma t}{2} - \cos\Delta m t\right)$$

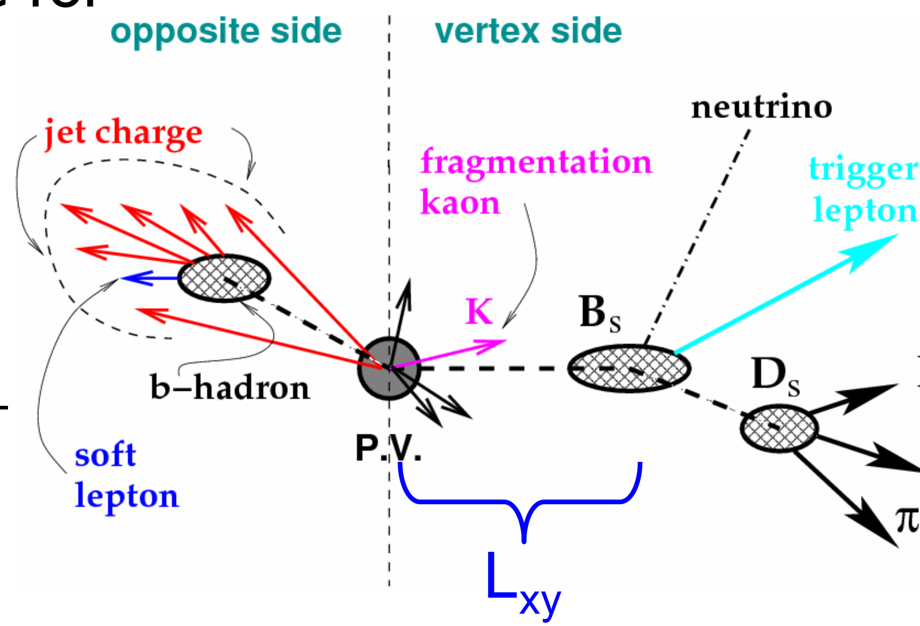
- Assume $\Delta\Gamma = 0$

$$P_{u,m}(t) = \frac{1}{2}\Gamma e^{-\Gamma t}\left(1 \pm \cos\Delta m t\right)$$

- Δm_s large → measurement experimentally very challenging

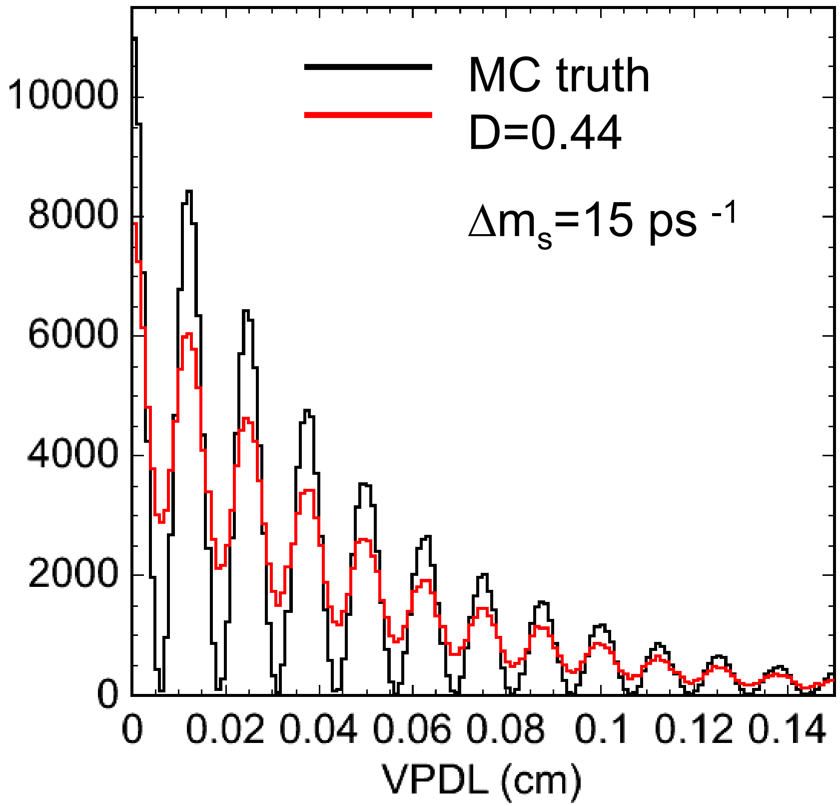
Analysis Overview

- Select final states suitable for the Δm_s measurement
  - Flavor specific decays
  - S – signal; B - background
- Determine proper decay time: $ct = m_{Bs}L_{xy}/p_T$
  - Resolution *(σ_t)*
- Tag mixed and unmixed
  - Tag B_s meson flavor at production time (initial state)
    - $Q_i=Q_f$ mixed
    - $Q_i=Q_f$ unmixed
    - *εD^2- tagging power*
- Fit for Δm_s



$$S(\Delta m, \sigma_t) = \frac{S}{\sqrt{S+B}} \sqrt{\frac{\varepsilon D^2}{2}} \times e^{-(\Delta m \sigma_t)^2/2}$$

Effect of Flavor Tagging



- Lifetime distribution for unmixed B^0_s mesons

$$P_{osc,nosc}(t) = \frac{1}{2}\Gamma e^{-\Gamma t}\left(1 \mp \cos \Delta m t\right)$$

$$\Downarrow$$

$$P_{osc,nosc}(t) = \frac{1}{2}\Gamma e^{-\Gamma t}\left(1 \mp D \cos \Delta m t\right)$$

D- Dilution

Effect of Resolution

- Proper decay time resolution has contribution from decay length (L_T) and boost

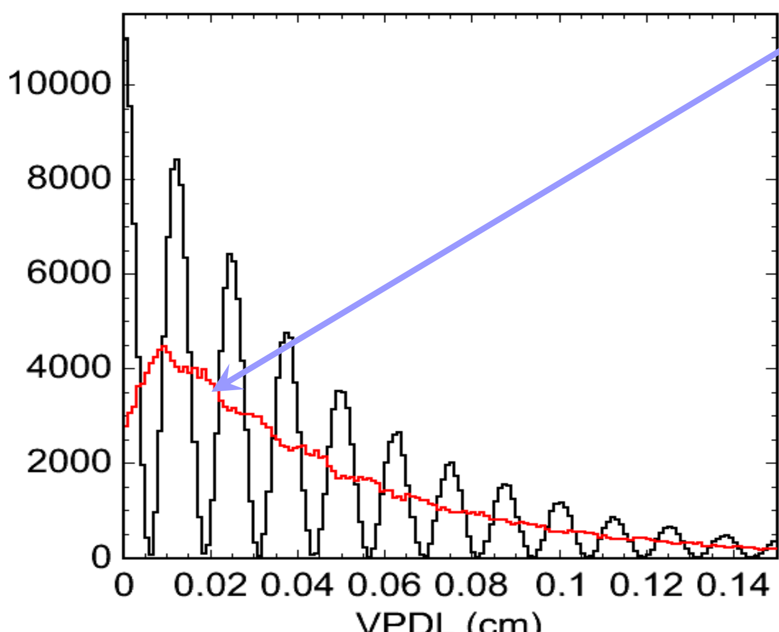
Proper decay time:

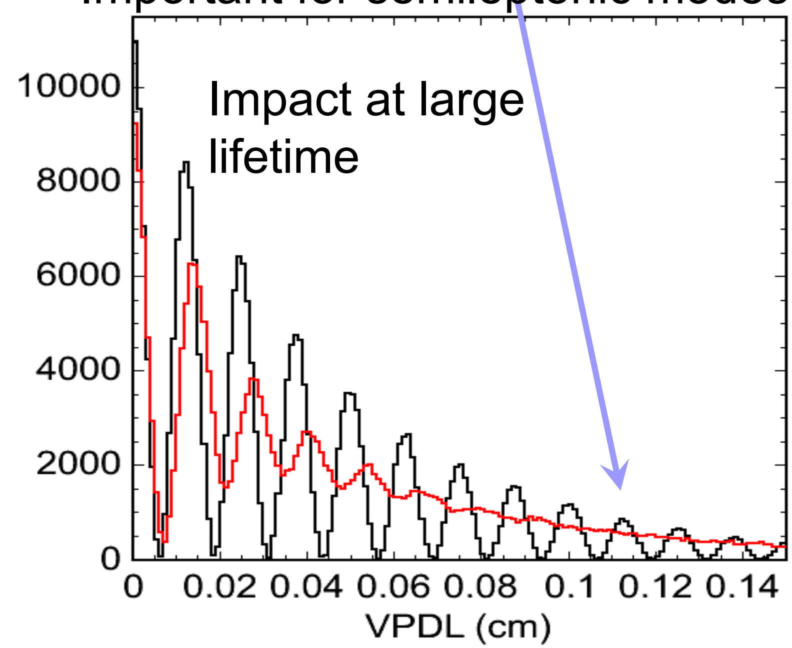
$$ct = m_{B_s} \cdot \left(\vec{L}_T \cdot \vec{p}_T^{B_s}\right) \Big/ \left(p_T^{B_s}\right)^2$$

Resolution:

$$\sigma_t^2 = \left(\frac{\sigma_L}{\gamma\beta c}\right)^2 + \left(\frac{\sigma_p}{p} t\right)^2$$

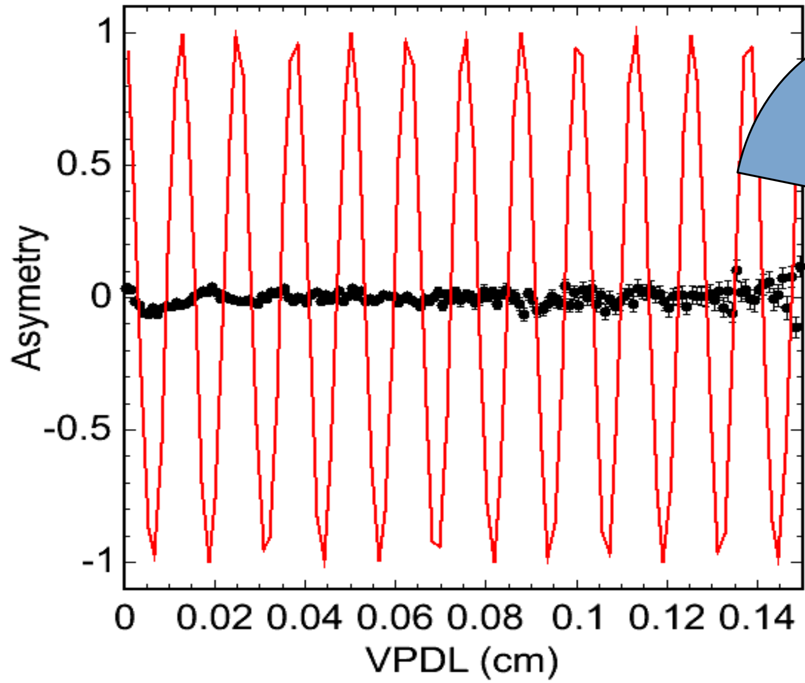
Important for semileptonic modes

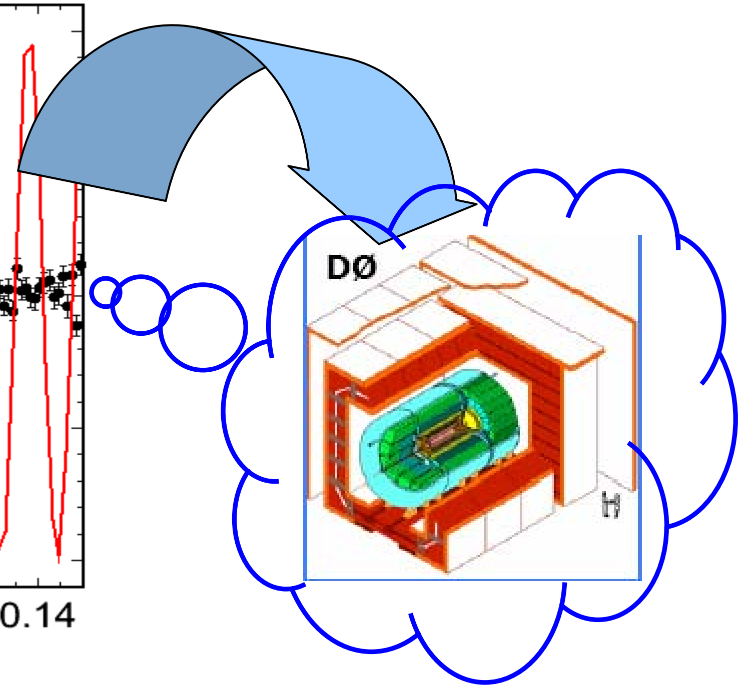




B^0_s-$\overline{B}^0_s$ Oscillations Measurement

$$A(t_{B_s}) = \frac{N^{non-osc}(t_{B_s}) - N^{osc}(t_{B_s})}{N^{non-osc}(t_{B_s}) + N^{osc}(t_{B_s})} \propto \cos(\Delta m_s \cdot t_{B_s})$$

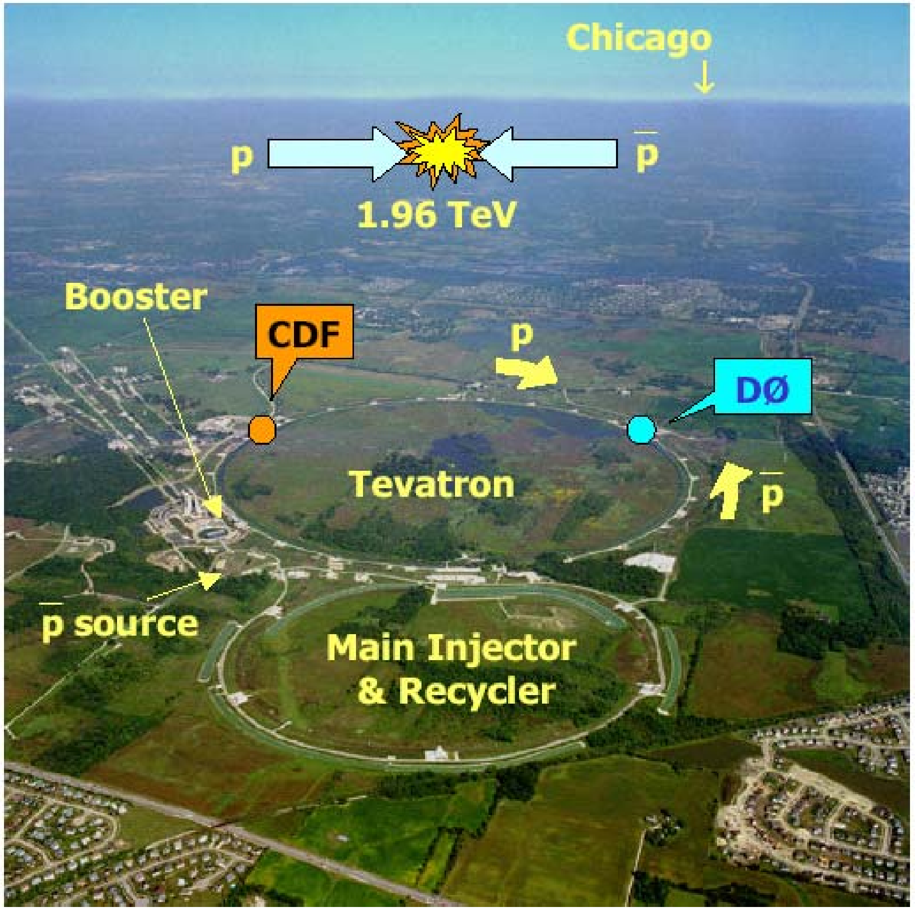




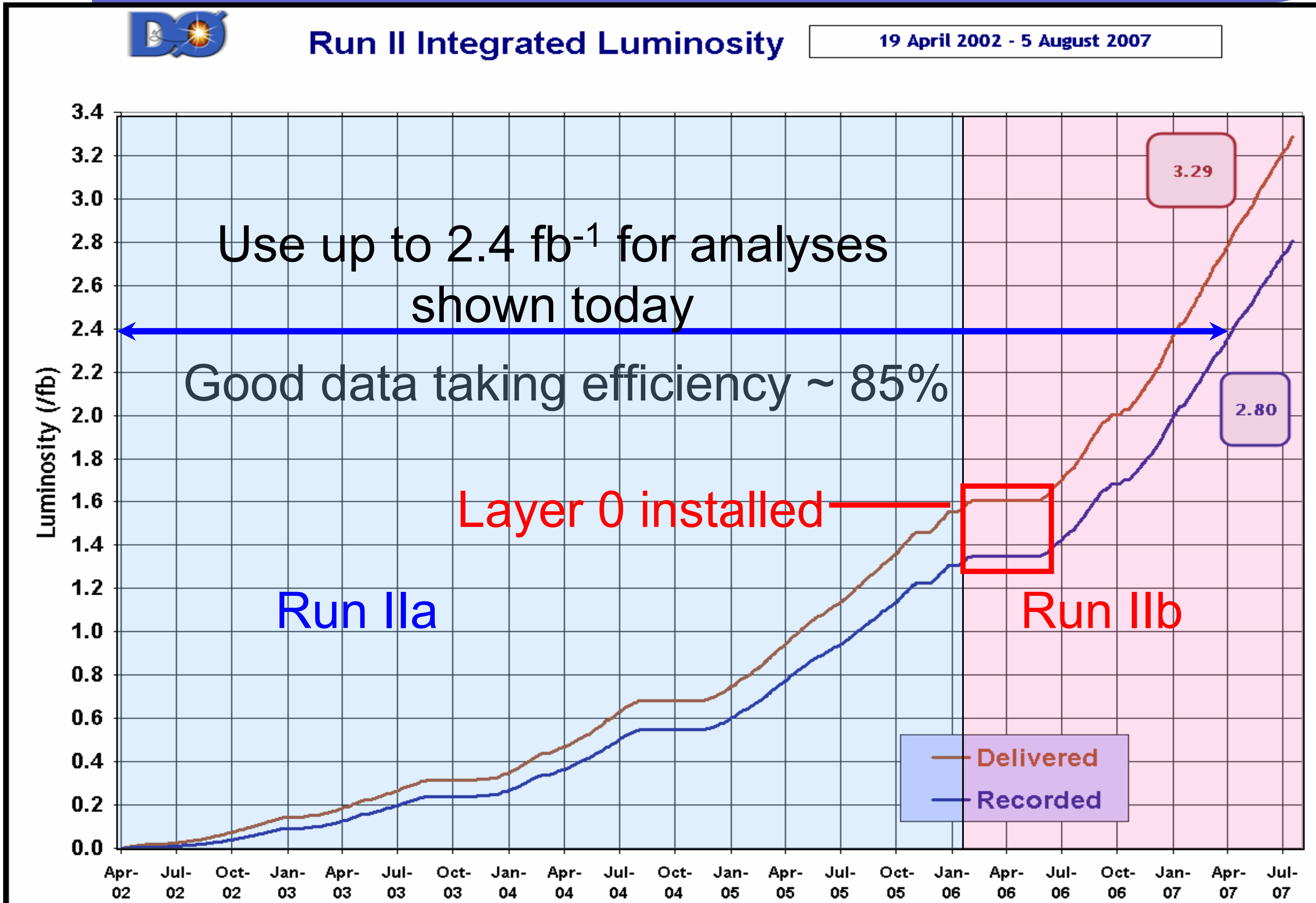
Tevatron and DØ Detector

The Tevatron Accelerator

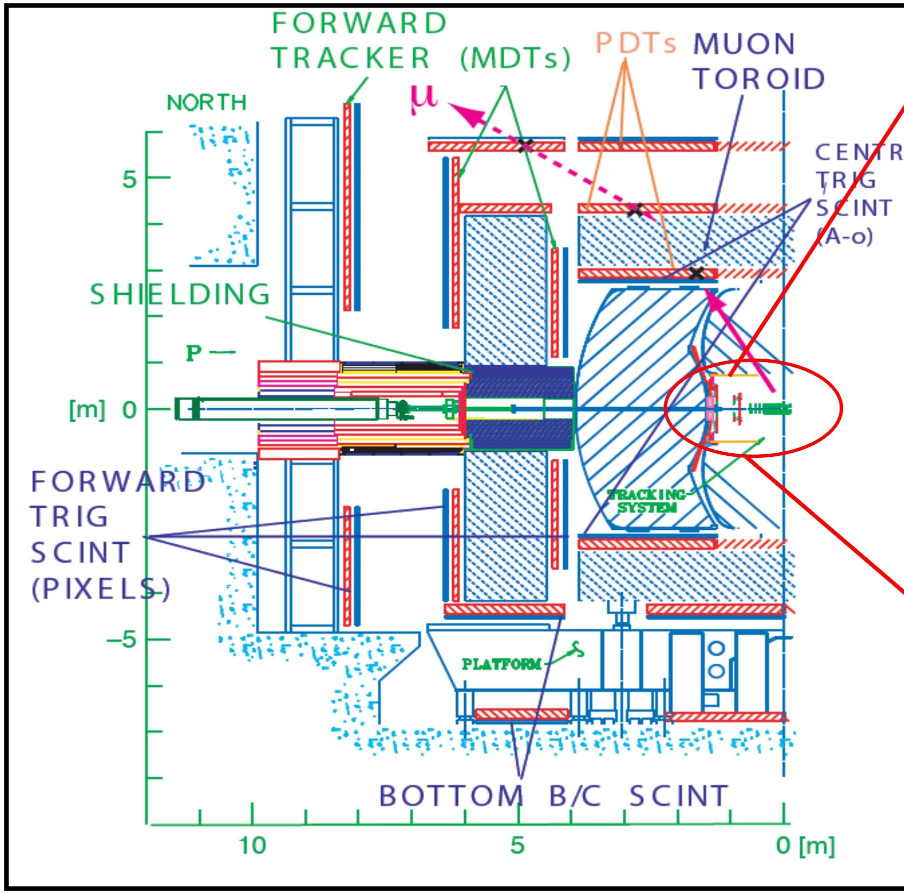
- World's highest energy collider
  - 2008?
  - Proton-antiproton synchrotron
  - Experiments CDF and DØ
- Run II (2001-200?)
  - $\sqrt{s}$ = 1.96 TeV
  - Current peak luminosity $\mathcal{L} \sim 30.0 \times 10^{31}\ cm^{-2}s^{-1}$
  - Expect up to $L = \int \mathcal{L} dt = 8\ fb^{-1}$ integrated luminosity in Run II
  - Number of events = $L\ \sigma$
- Large $p\bar{p}$ cross-section
  - Trigger is important

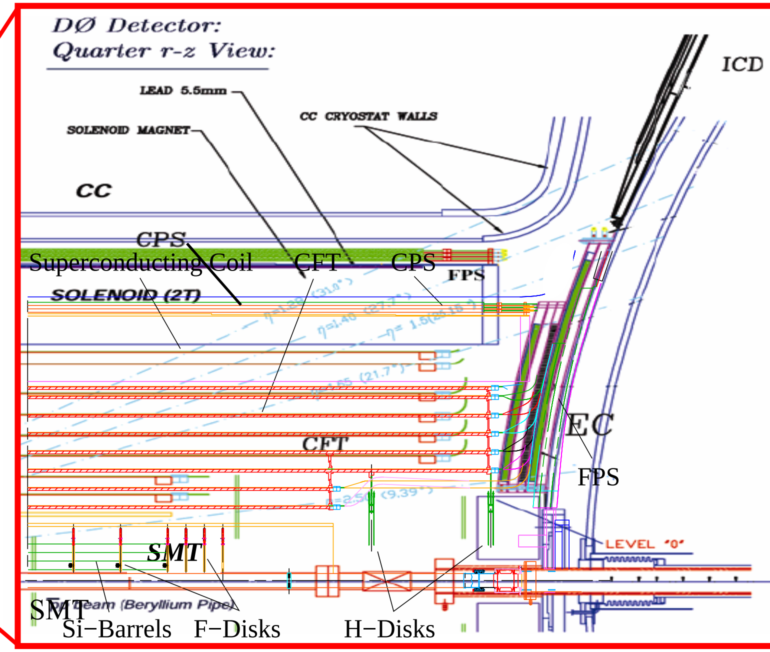


Excellent Tevatron Performance



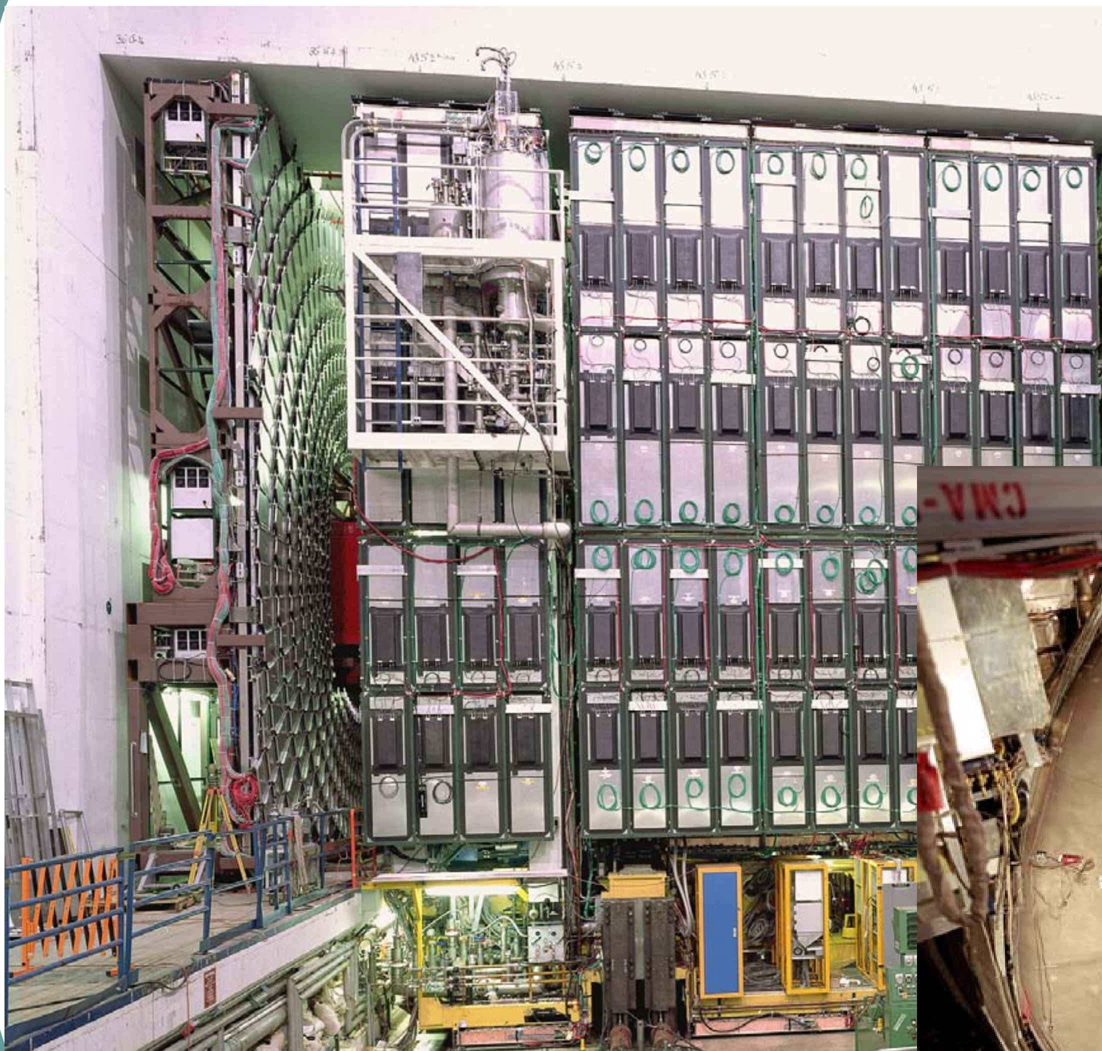
DØ Detector

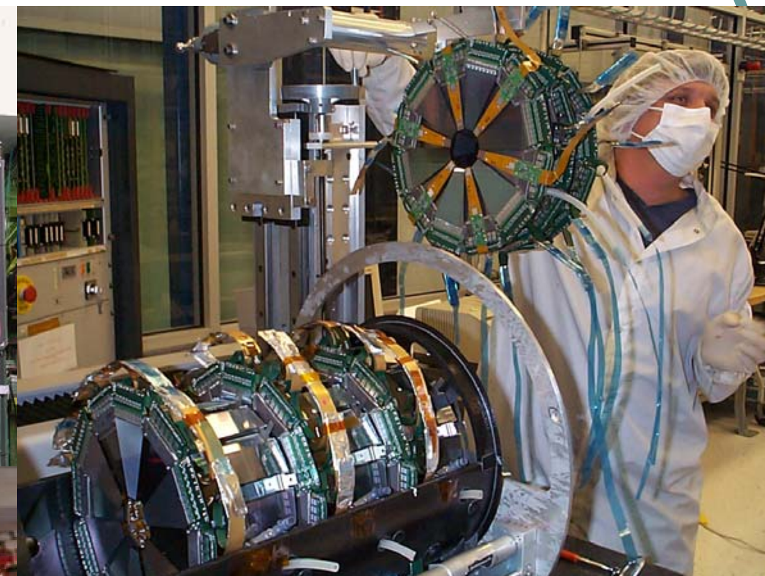


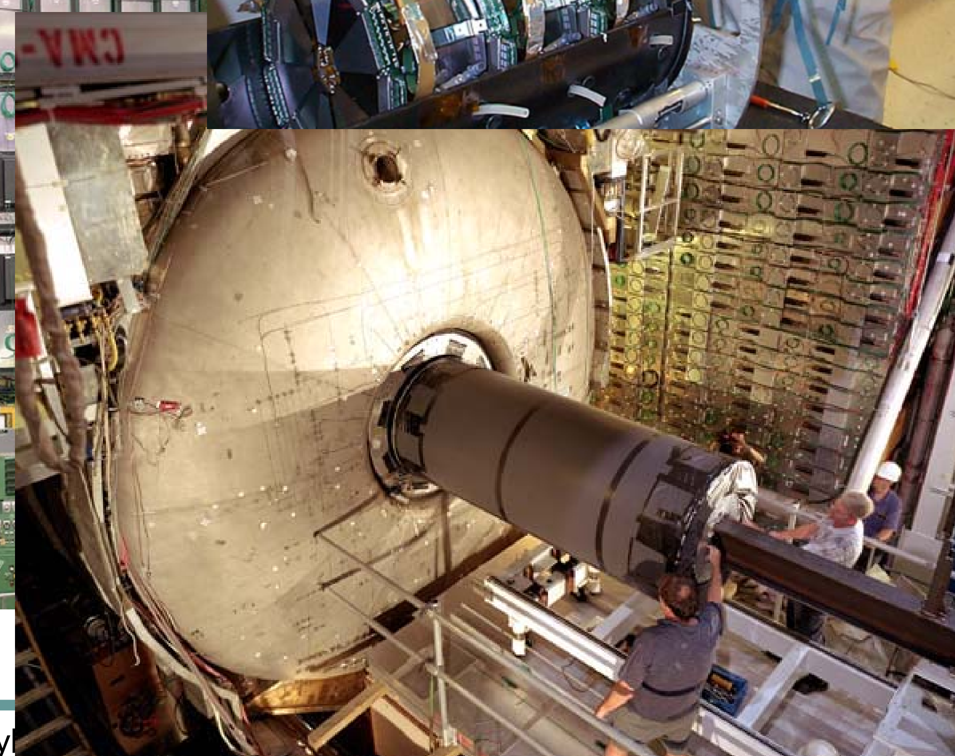


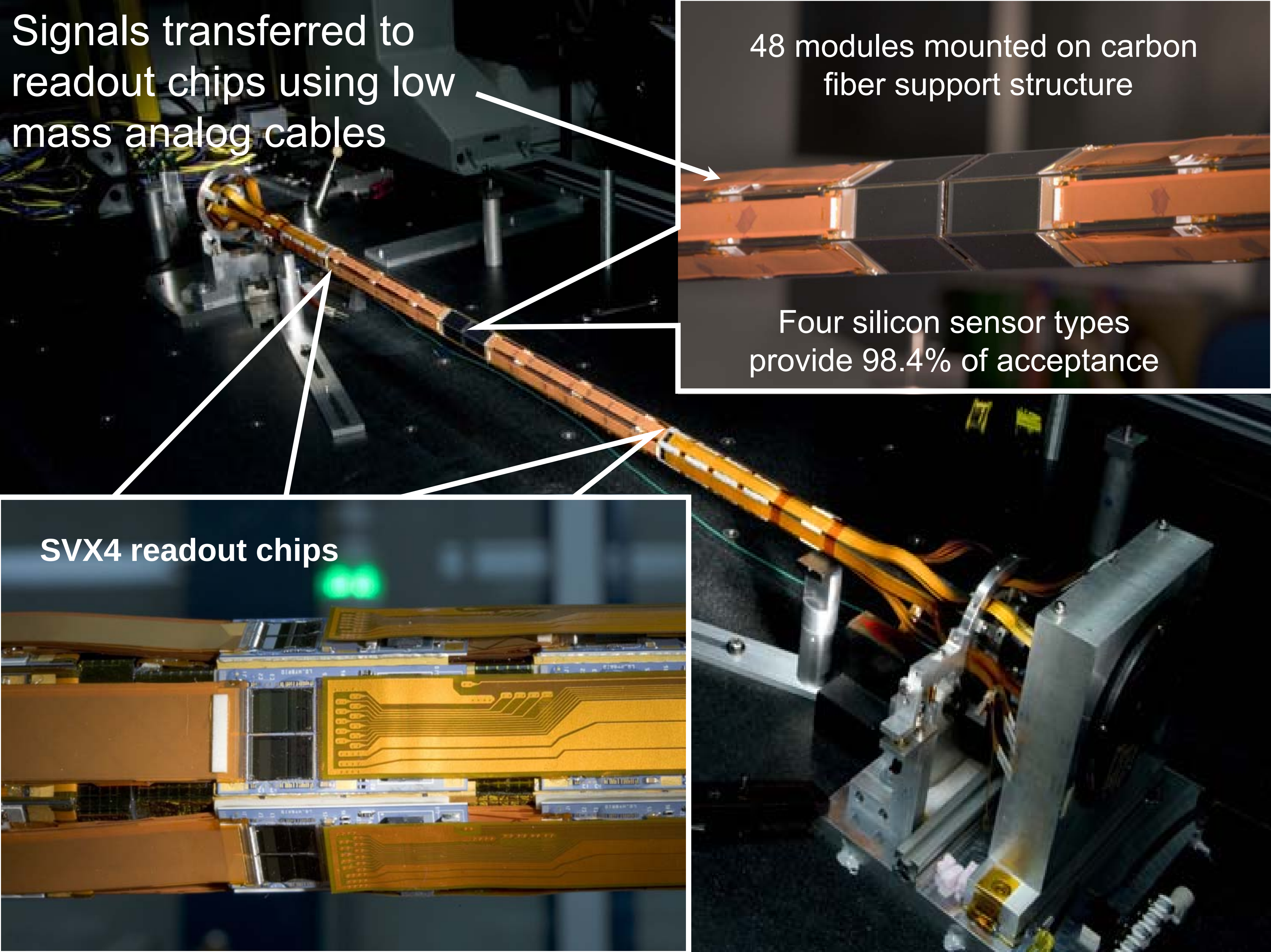
- General purpose detector
- Excellent coverage of Tracking and Muon Systems ($|\eta|<2$)
- Excellent vertex resolution
- 2T Solenoid

DØ Detector





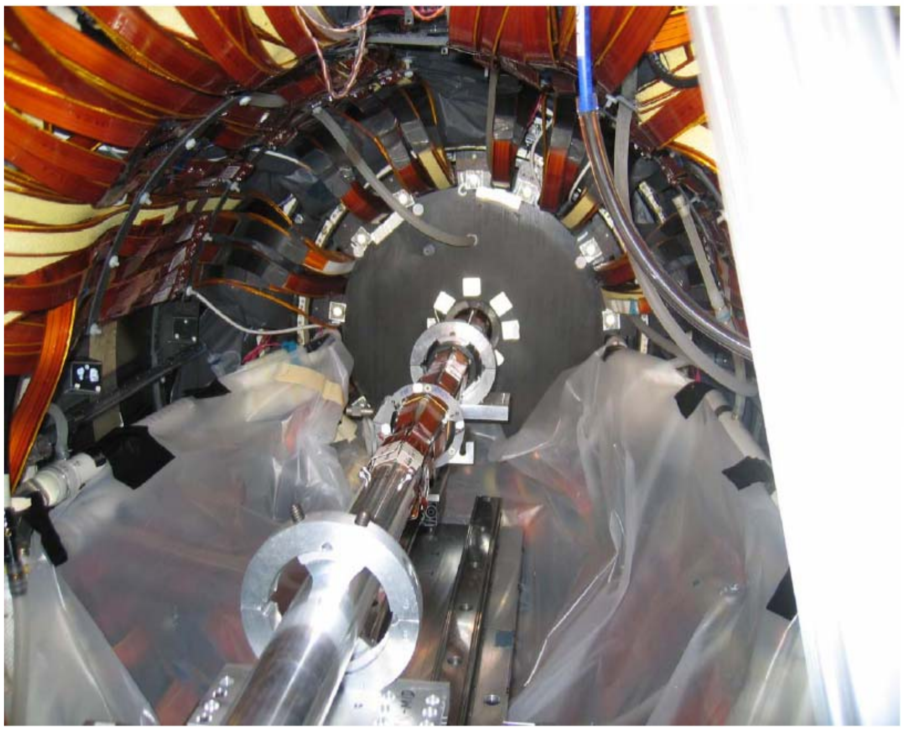


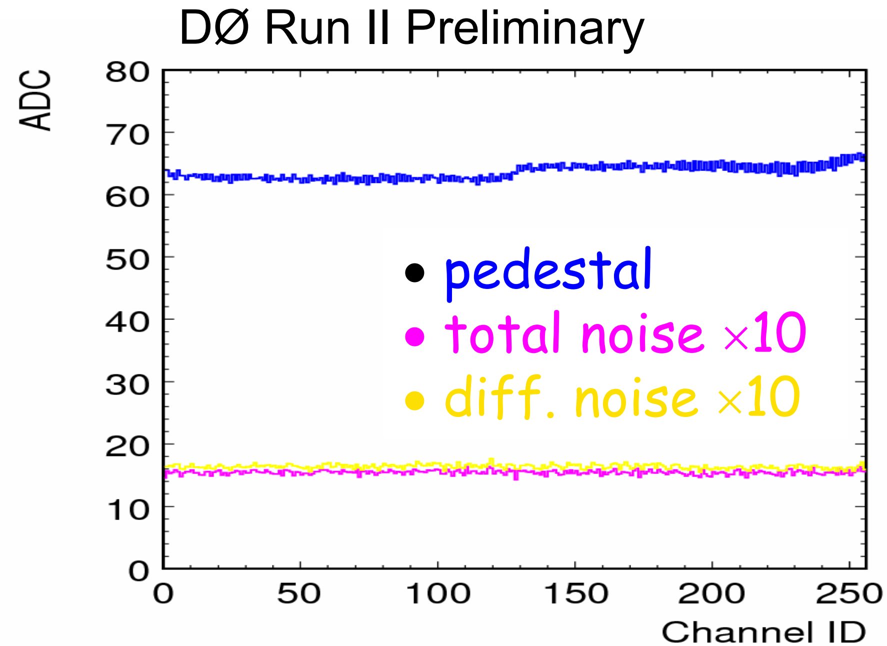


Signals transferred to readout chips using low mass analog cables
48 modules mounted on carbon fiber support structure
Four silicon sensor types provide 98.4% of acceptance
SVX4 readout chips

Layer 0

Installed inside existing DØ silicon detector





- First sensor at r=16 mm
- Outstanding noise performance for this type of device
  - ~1.7 ADC
  - Signal/Noise ~ 18

Δm_s Measurement

B_s Candidate Selection

- Select B_s candidate
  - Example $B_s \rightarrow \mu D_s X$
- Combine two oppositely-charged tracks into $\phi \rightarrow KK$
  - Add third track (π) to form D_s
- Form B_s candidate:
  - Semileptonic decay - add lepton

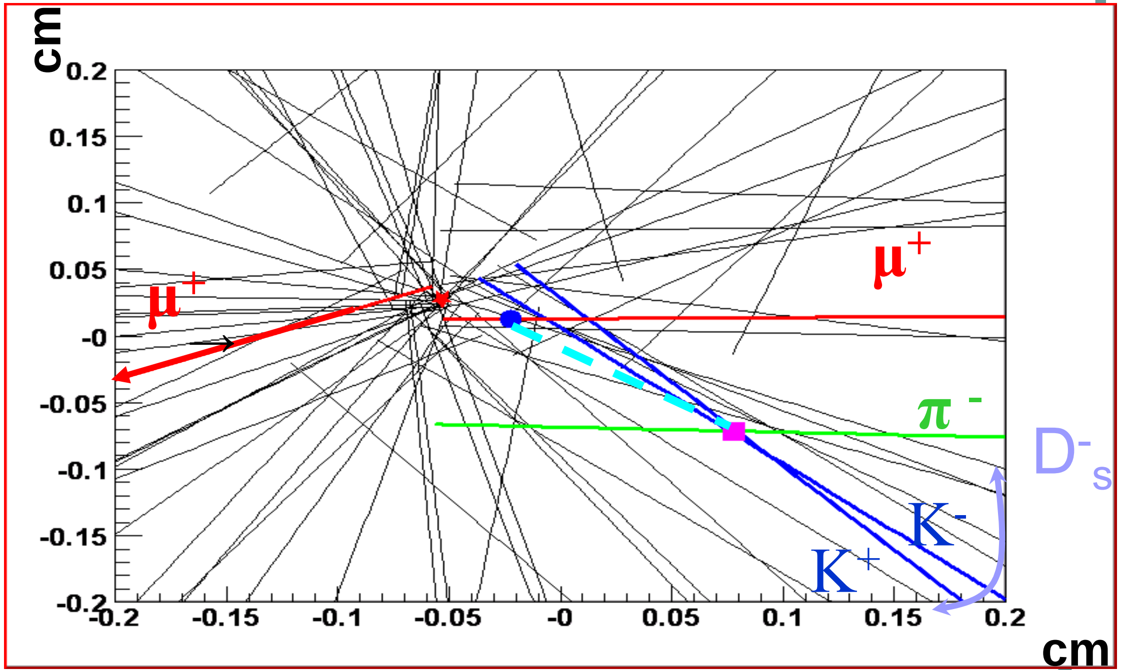
  - $B_s \rightarrow D_s \mu \nu X$, $D_s \rightarrow \phi\pi$ - Golden mode at DØ
  - $B_s \rightarrow D_s \mu \nu X$, $D_s \rightarrow K^*K$
  - $B_s \rightarrow D_s \mu \nu X$, $D_s \rightarrow K_s K$
  - $B_s \rightarrow D_s e \nu X$, $D_s \rightarrow \phi\pi$
  - $B_s \rightarrow D_s \pi X$, $D_s \rightarrow \phi\pi$

$$B_s^0 \rightarrow D_s^- \mu^+ \nu X$$

$$D_s^- \rightarrow \varphi \pi^-$$

$$\varphi \rightarrow K^+ K^-$$

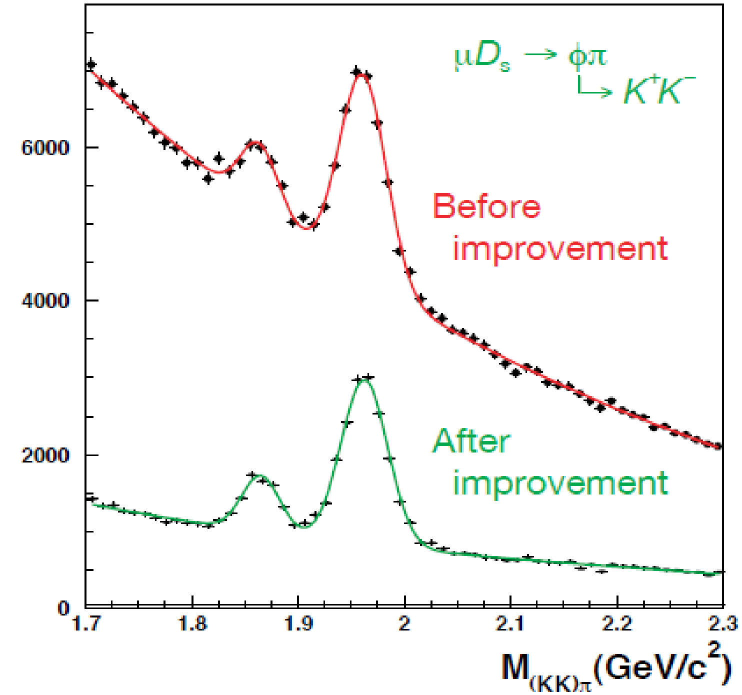
High track multiplicity per event



Final Signal Selection

- Use likelihood ratio method
  - Set of discriminating variables x_i constructed for each event
    - Helicity Angle (D_s,K_1)
    - $\mu(\pi)D_s$ Isolation
    - $p_T(K_1K_2)$
    - $m(\mu D_s)$
    - χ^2 of D_s Vertex Fit
    - $m(K_1K_2$ or $K_1\pi)$
  - Construct likelihood ratio for each variable
    - bgrd from $m(D_s)$ sidebands
    - signal from bgrd-sub peak

$$y_i = \frac{f_i^S(x_i)}{f_i^B(x_i)}$$



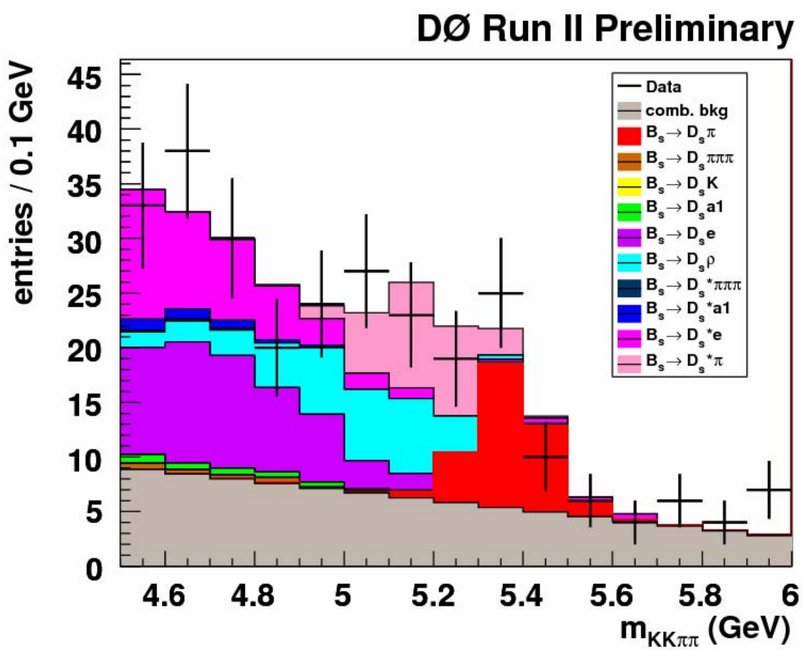
- Combine into single variable
  - Use for final selection

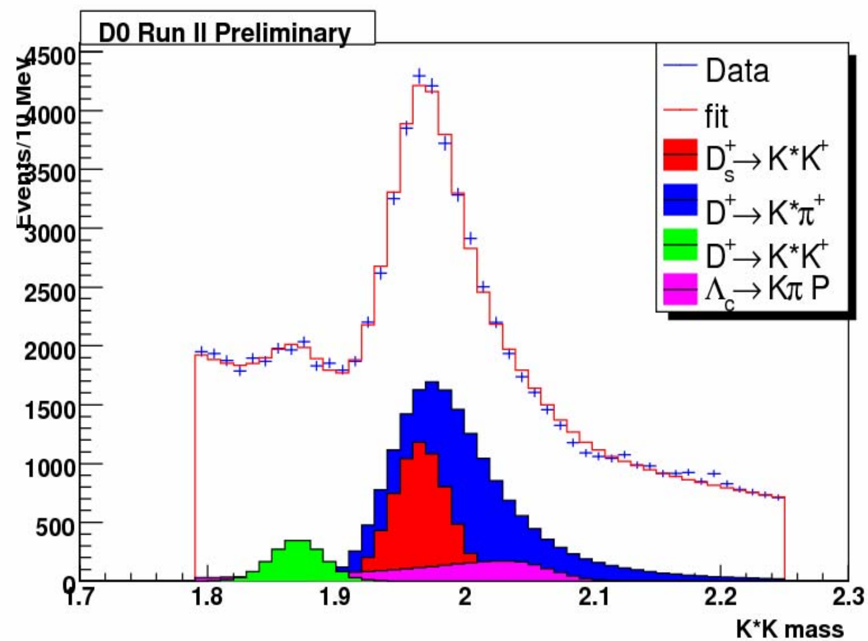
$$Y = \prod_i^n y_i$$

Samples

- Hadronic samples
  - Small BR, Low yield
  - No dedicated trigger
  - Good cτ resolution
- Semileptonic samples
  - Large BR, high event yield
  - Clean trigger
  - Poorer cτ resolution, due to missing neutrino

Sample composition





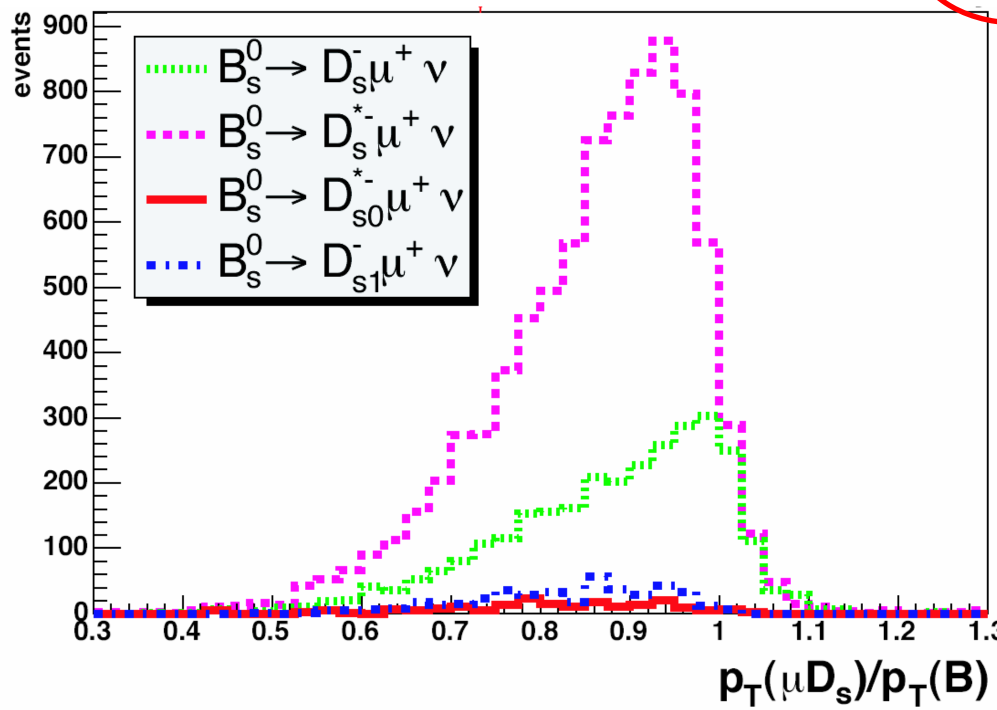
Proper Decay Length
(Partially Reconstructed Decays)

$$x^M = m_{B_s} \cdot \left(\vec{L}_T \cdot \vec{p}_T^{\,D_s\mu}\right) \Big/ \left(p_T^{D_s\mu}\right)^2$$

- Proper Decay Length is determined from the Visible Proper Decay Length

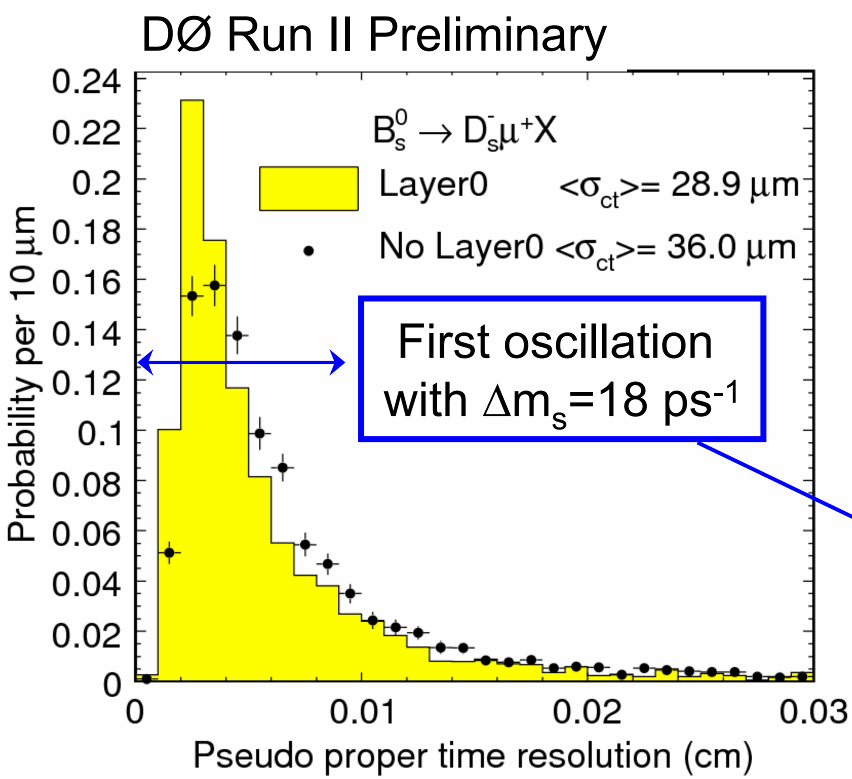
$$ct = x^M K \Leftarrow K = p_T^{D_s\mu} \Big/ p_T^{B_s}$$

- K-factor takes into account the escaping neutrino and other missing particles
  - From MC for each decay mode

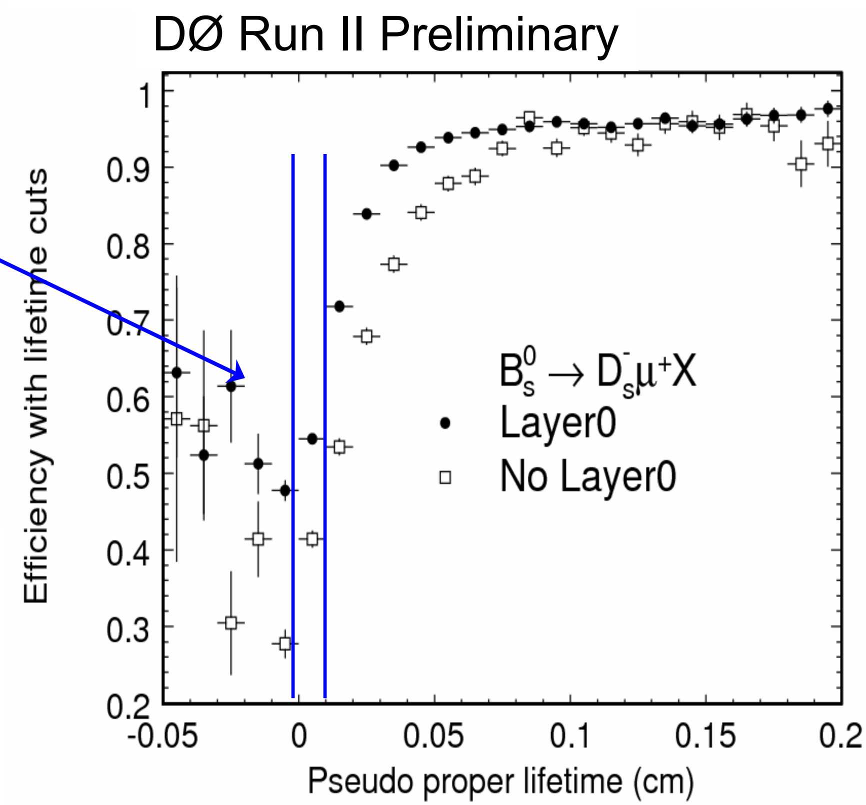


Proper Time Resolution

- Vertex position determined on event by event basis
  - Uncertainty per candidate included in the Δm_s fit



Example $B_s \rightarrow D_s \mu X$



Initial State Flavor Tagging

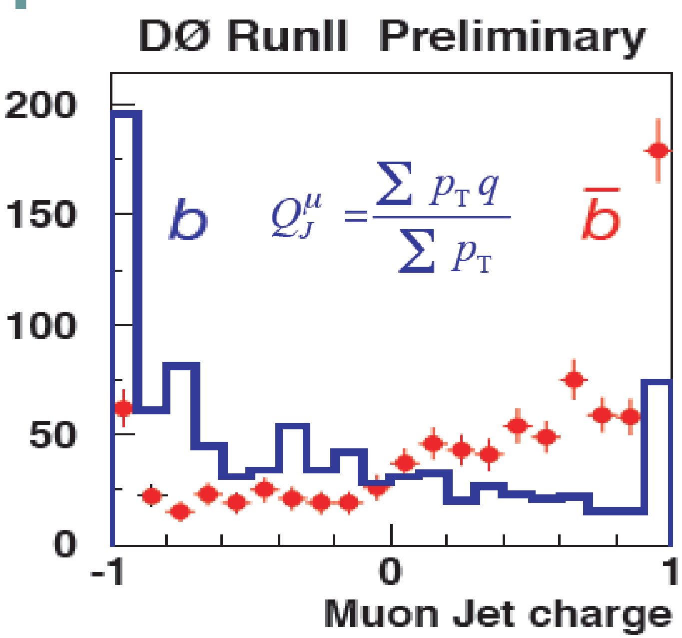
- Get best estimate for reconstructed B meson to contain $b(\overline{b})$ at origin
  - Find set of discriminating variables $x_1,\ldots,x_n$
  - Combine different taggers

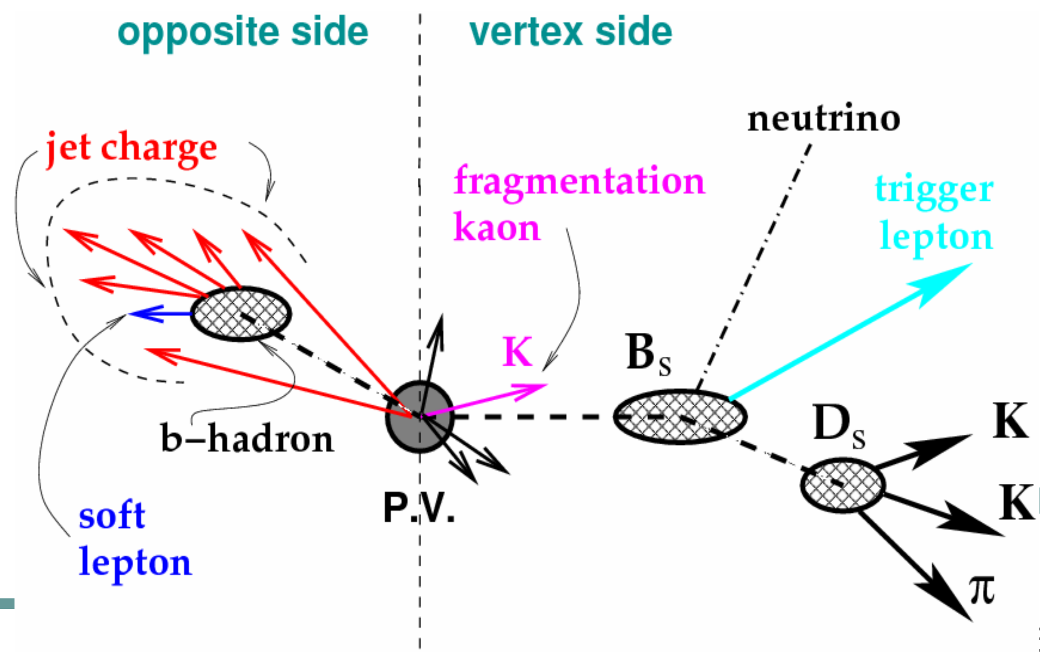
    using likelihood ratio method:

    $$y = \prod_i^n y_i \;; \qquad y_i = \frac{PDF_i^{\overline{b}}(x_i)}{PDF_i^{b}(x_i)}$$

    d - combined discriminating variable

    redefine d = (1-y)/(1+y) [-1,1]





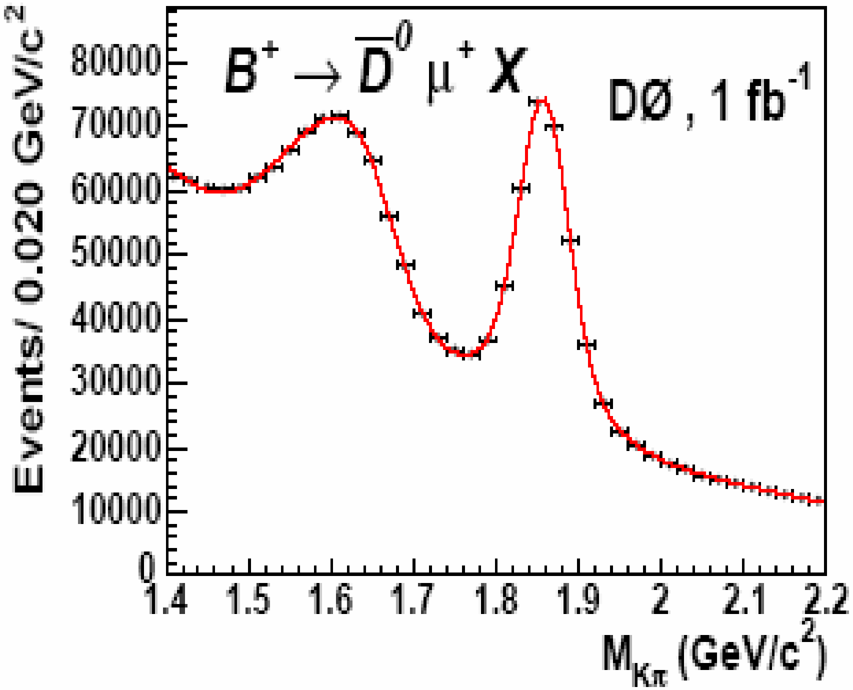
Initial State Flavor Tagging

- Definitions:
  - Efficiency: $\varepsilon = \dfrac{N_{tagged}}{N_{total}}$
  - Dilution: $D = \dfrac{N_{nosc} - N_{osc}}{N_{nosc} + N_{osc}}$
  - Tagging power: $\varepsilon \cdot D^2$
    - use to compare the performance of taggers

Opposite Side Tagging (OST)

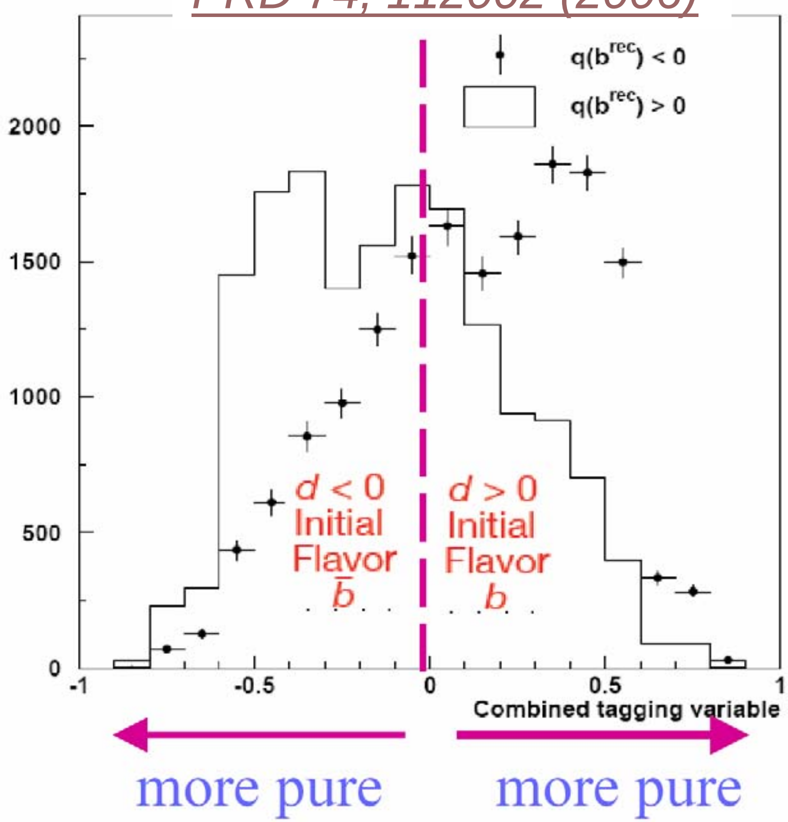
PRD 74, 112002 (2006)

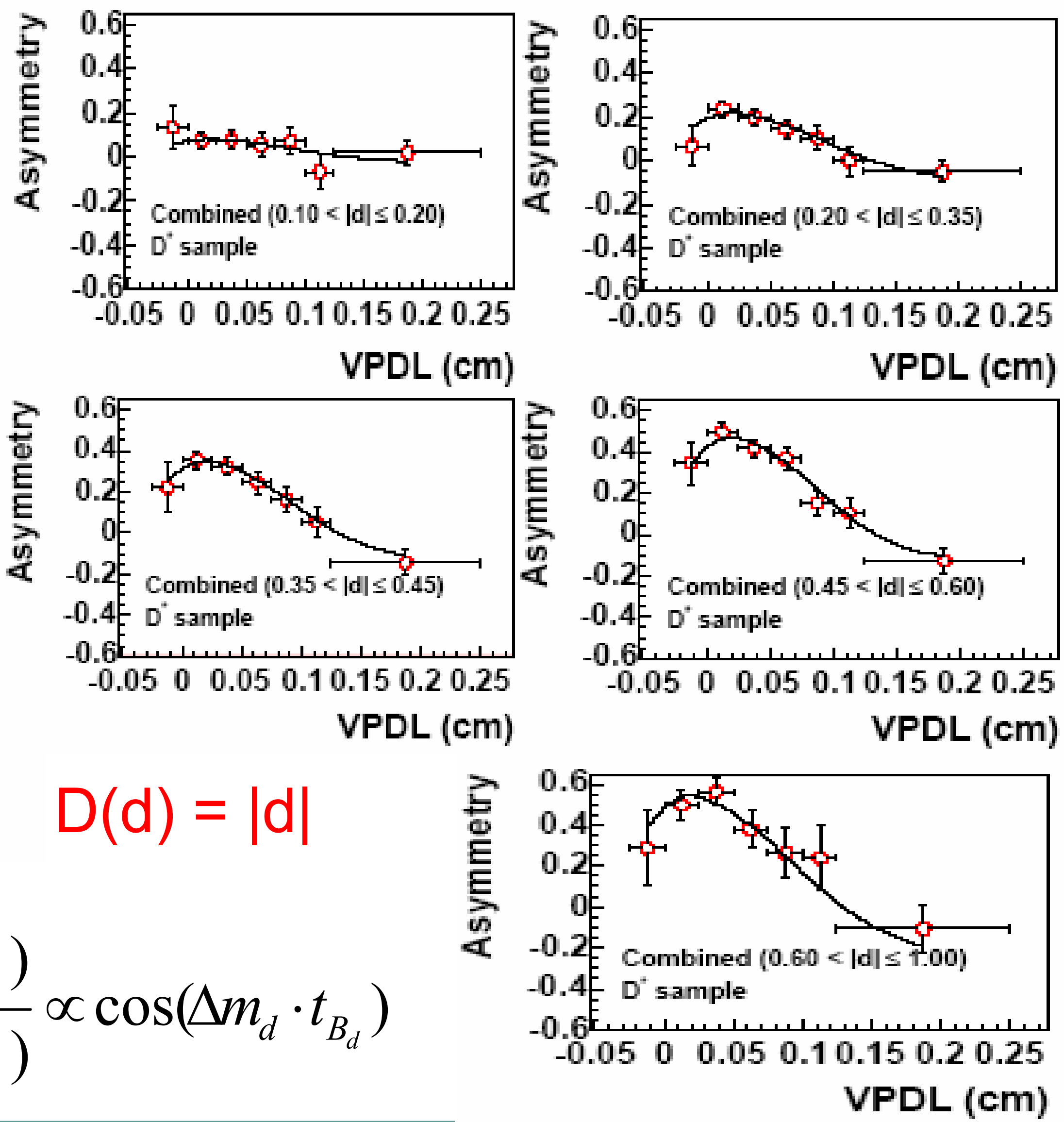
- Independent from the reconstructed B side (B_u,B_d,B_s)
  - Rely on fact that b produced as b-anti b pair
- Construct P.D.Fs using $B^\pm \to \mu^\pm \nu D^0 X$ sample with VPDL = [0—0.050] μm
  - ~98% pure
  - Subtract background using wrong sign combination
- Measure dilutions in large $B^0_d \to \mu\nu D^* X$ and $B^\pm \to \mu\nu D^0 X$ samples



OST Tagger

PRD 74, 112002 (2006)





D(d) = |d|

$$A(t_{B_d}) = \frac{N^{non-osc}(t_{B_d}) - N^{osc}(t_{B_d})}{N^{non-osc}(t_{B_d}) + N^{osc}(t_{B_d})} \propto \cos(\Delta m_d \cdot t_{B_d})$$

Combined Tagger

- Combine OST and SST if both present
  - Assume both independent
- Combine SST and "Event charge" if both present
  - Σq_i of all tracks on opposite side

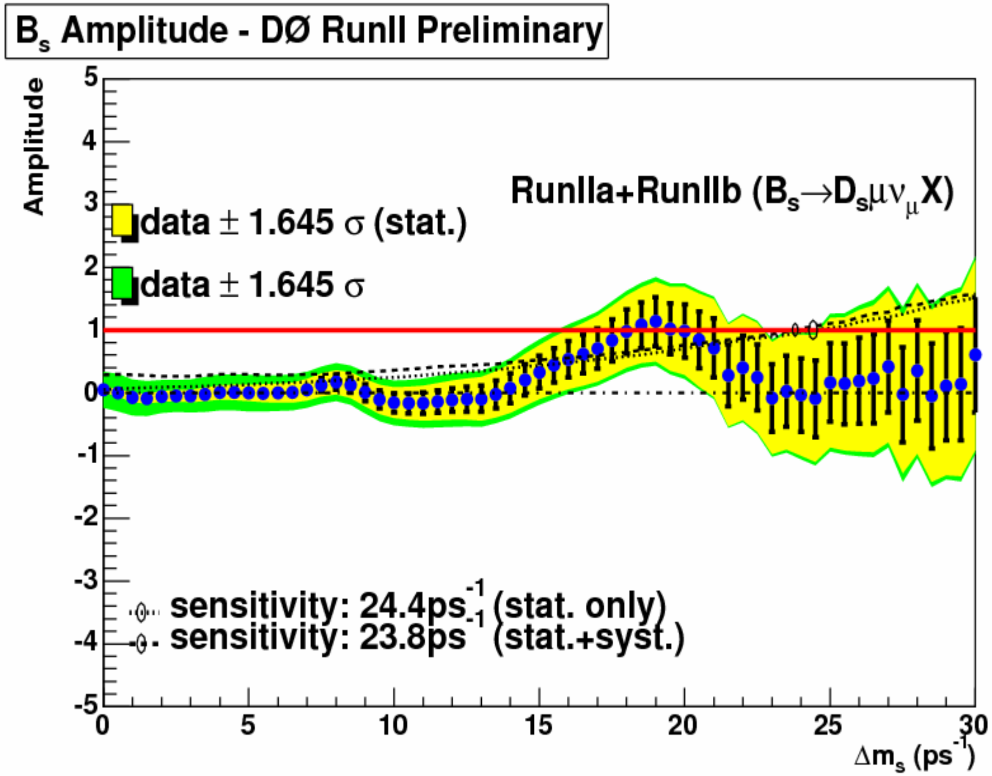
DØ Run II Preliminary

Tagger	ϵD^2
Comb. SST	$1.7 \pm 0.6\%$
Comb. OST without Evt. Charge	$2.5 \pm 0.2\%$
Evt. Charge	$1.5 \pm 0.5\%$
All	$4.5 \pm 0.9\%$

Amplitude Method

$$p_s^{nos/osc} \sim \left(1 \pm \mathcal{D}\cos\left(\Delta m_s \cdot Kx/c\right)\right) \rightarrow p_s^{nos/osc} \sim \left(1 \pm \mathcal{D}\cos\left(\Delta m_s \cdot Kx/c\right)\cdot \mathcal{A}\right)$$

- If mixing signal with Δm_s, amplitude $\mathcal{A} = 1$ (statistically significant) otherwise $\mathcal{A} = 0$
- Scan Δm_s, for each value find $\mathcal{A} \pm \sigma_{\mathcal{A}}$
  - Fit of proper decay length distribution for mixed and unmixed B_s using unbinned likelihood

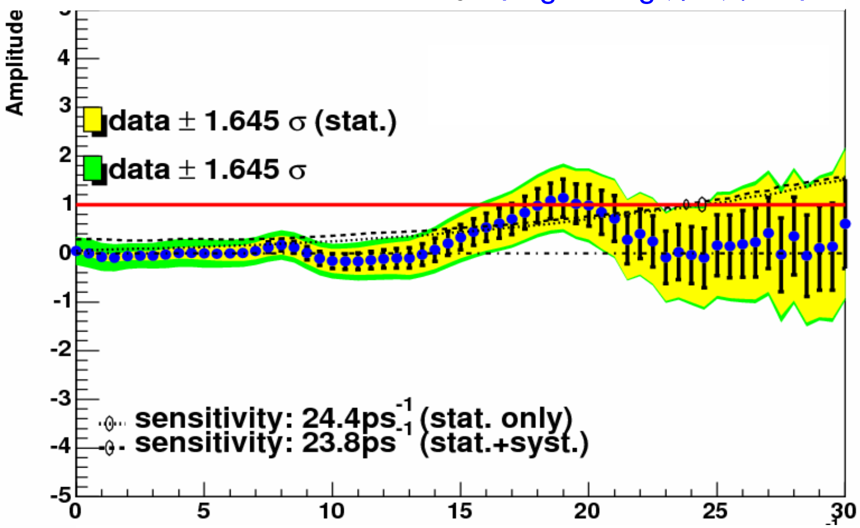


Δm_s excluded at 95%CL for $A+1.645\sigma_A < 1$

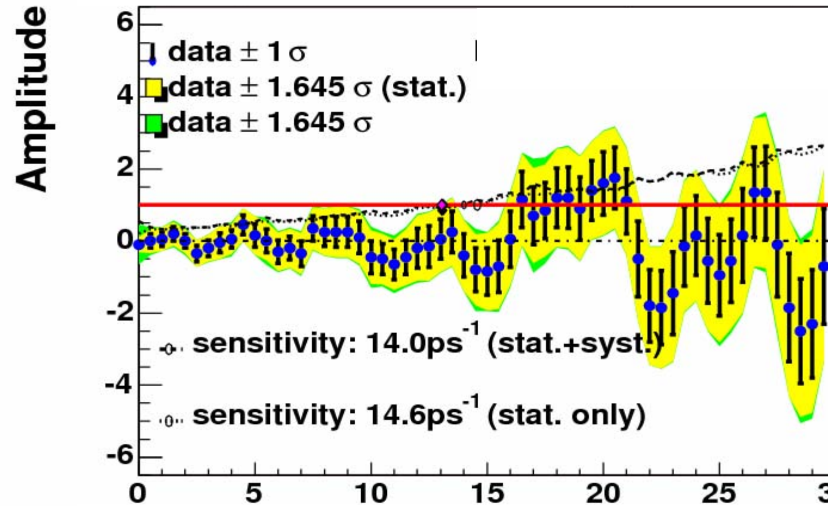
Sensitivity at Δm_s for $1.645\sigma_A$ A=0

Amplitude Scans (Ldt=2.4 fb^{-1})

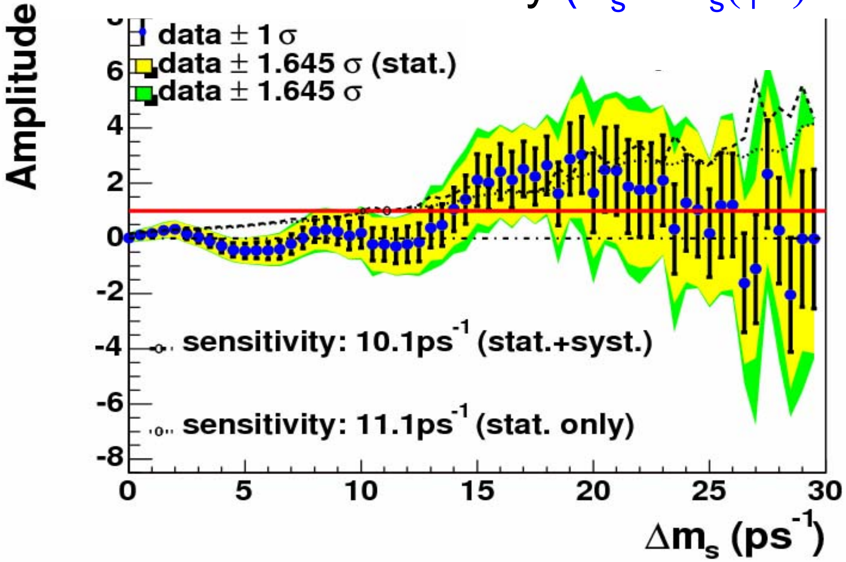
DØ Run II Preliminary ($B_s \to D_s(\phi\pi)\mu X$)



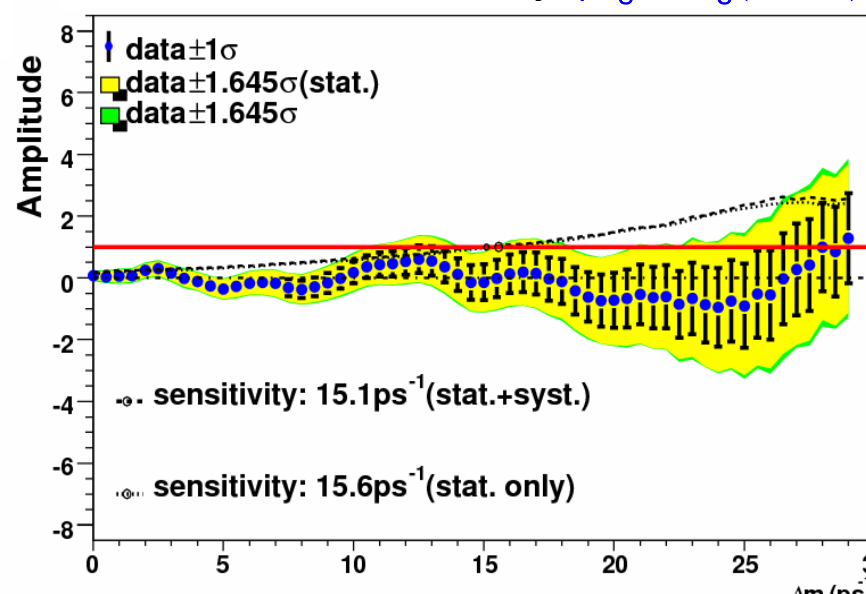
DØ Run II Preliminary ($B_s \to D_s(\phi\pi)\pi X$)



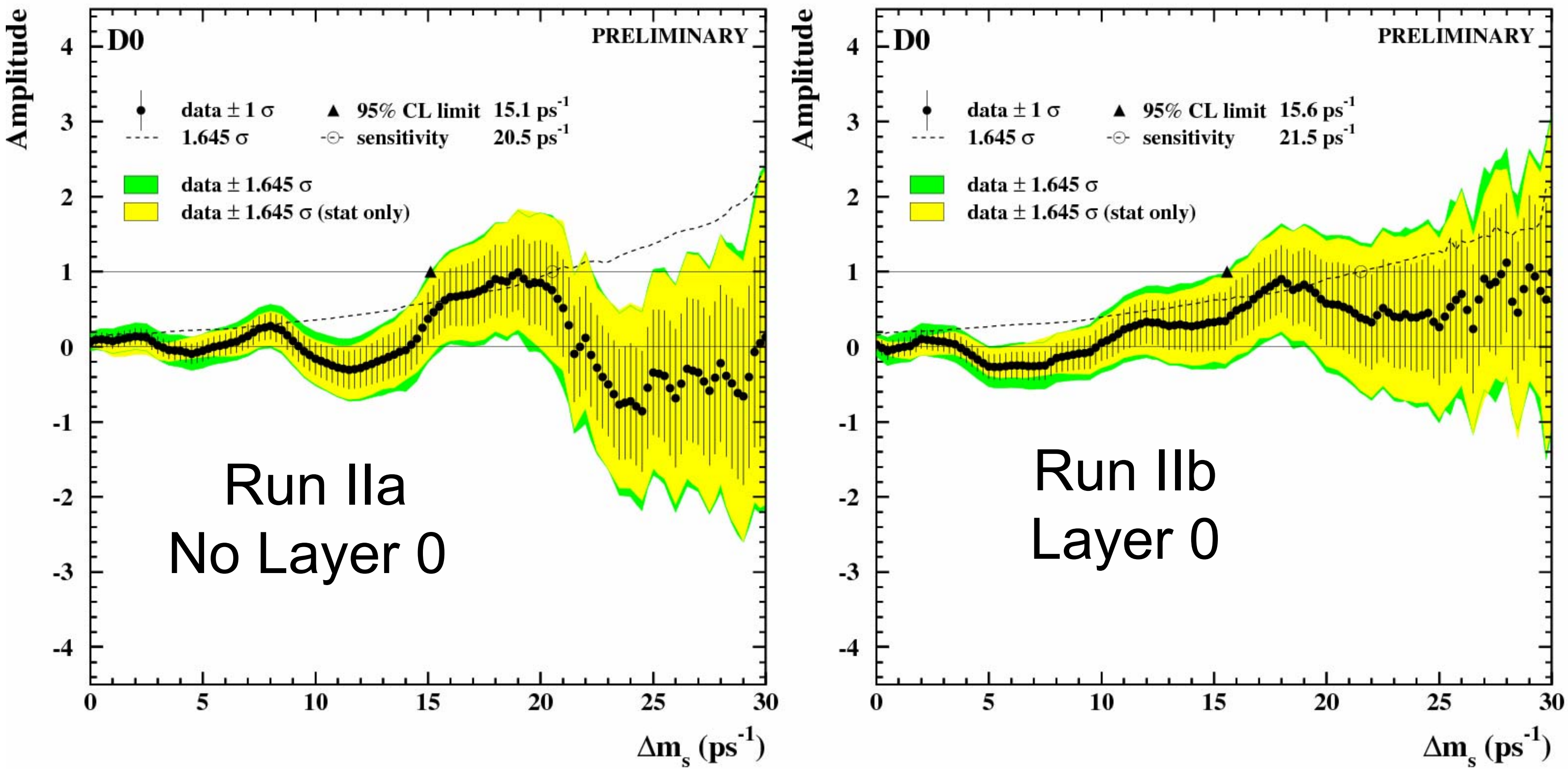
DØ Run II Preliminary ($B_s \to D_s(\phi\pi)eX$)



DØ Run II Preliminary ($B_s \to D_s(K^{*0}K)\mu X$)

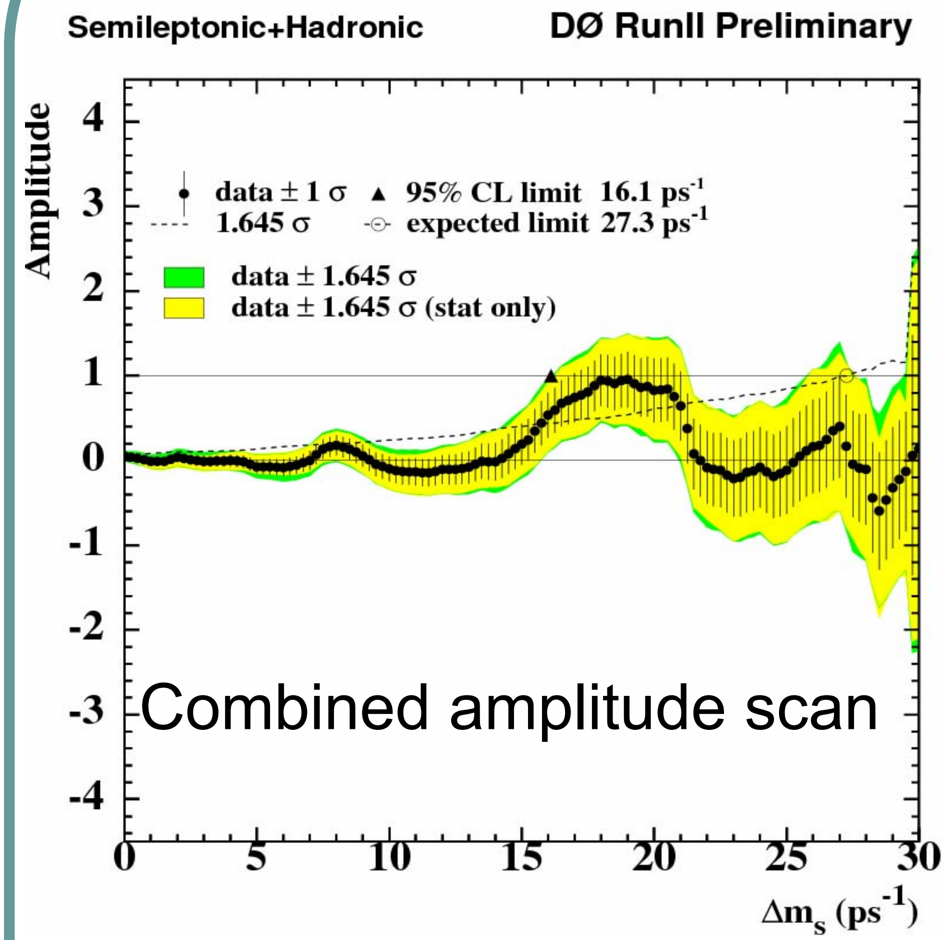


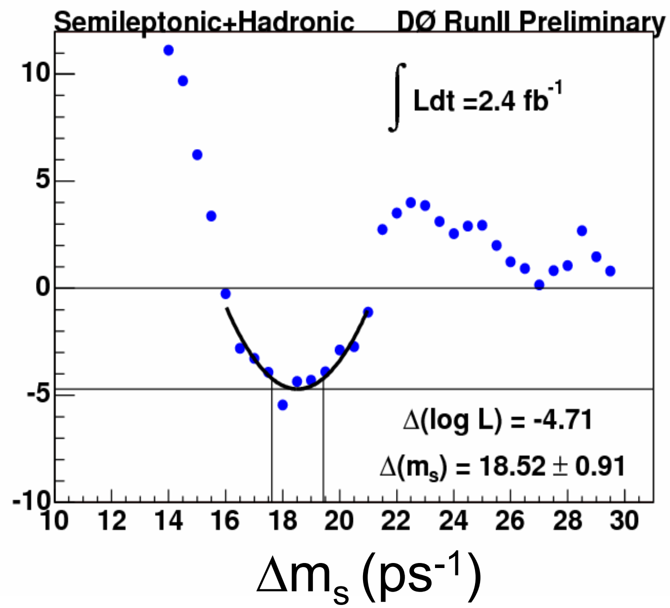
Layer 0 Impact



- Better sensitivity with only 60% statistics

Results





- A parabolic fit to likelihood scan for Δm_s returns:
  - $\Delta m_s = 18.5 \pm 0.9\ ps^{-1}$
- 3.1σ statistical significance
- In agreement with CDF

$\Delta m_s = 17.77 \pm 0.1$ (stat.) ± 0.07 (syst.) ps^{-1}

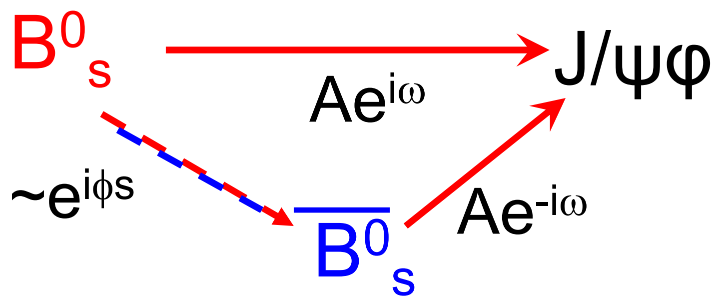
PRL 97 242003

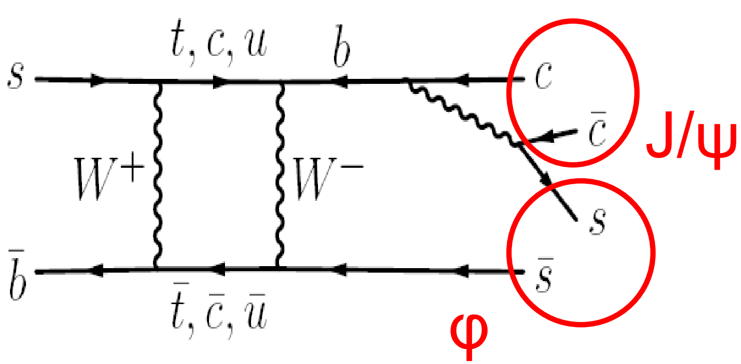
Other Parameters: $\Delta\Gamma_s$ and ϕ_s

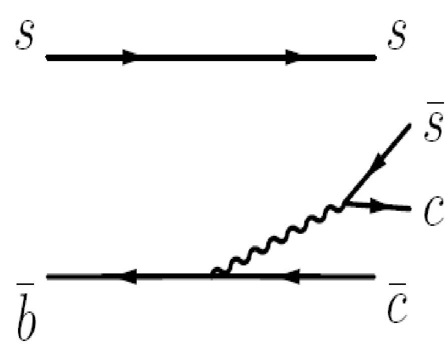
CP Violation in $B_s \rightarrow J/\psi\varphi$ Decays

- CP violation phase in SM is predicted to be very small: $2\beta_s = -\arg\left[\left(V_{tb}V_{ts}^*\right)^2 / \left(V_{cb}V_{cs}^*\right)^2\right] = 0.04 \pm 0.01$
- New Physics affects the CP violation phase:

$$\varphi_s = 2\beta_s - \varphi_s^{NP} \Rightarrow \Delta\Gamma_s = \Delta\Gamma_s^{SM} \cdot |\cos\phi_s|$$

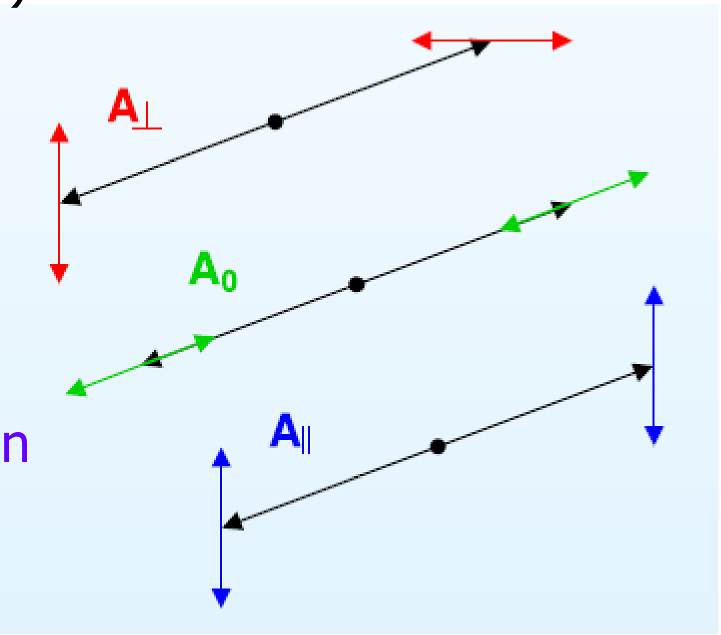






B_s Lifetime Difference and ϕ_s

- Measure lifetime in $B_s \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$
  - Pseudoscalar → Vector Vector
  - 3 angular momentum final states (L=0,1,2)
- The mass eigenstates are expected to be almost pure CP-eigenstates
  - **S, D** (CP even ~ B^L_s): linear combination of $\mathbf{A_0}$, $\mathbf{A_{||}}$
  - **P** (CP odd - B^H_s): $\mathbf{A_\perp}$
- Decay parameterized by three angles
  - Use "transversity basis"



B_s Lifetime Difference and ϕ_s

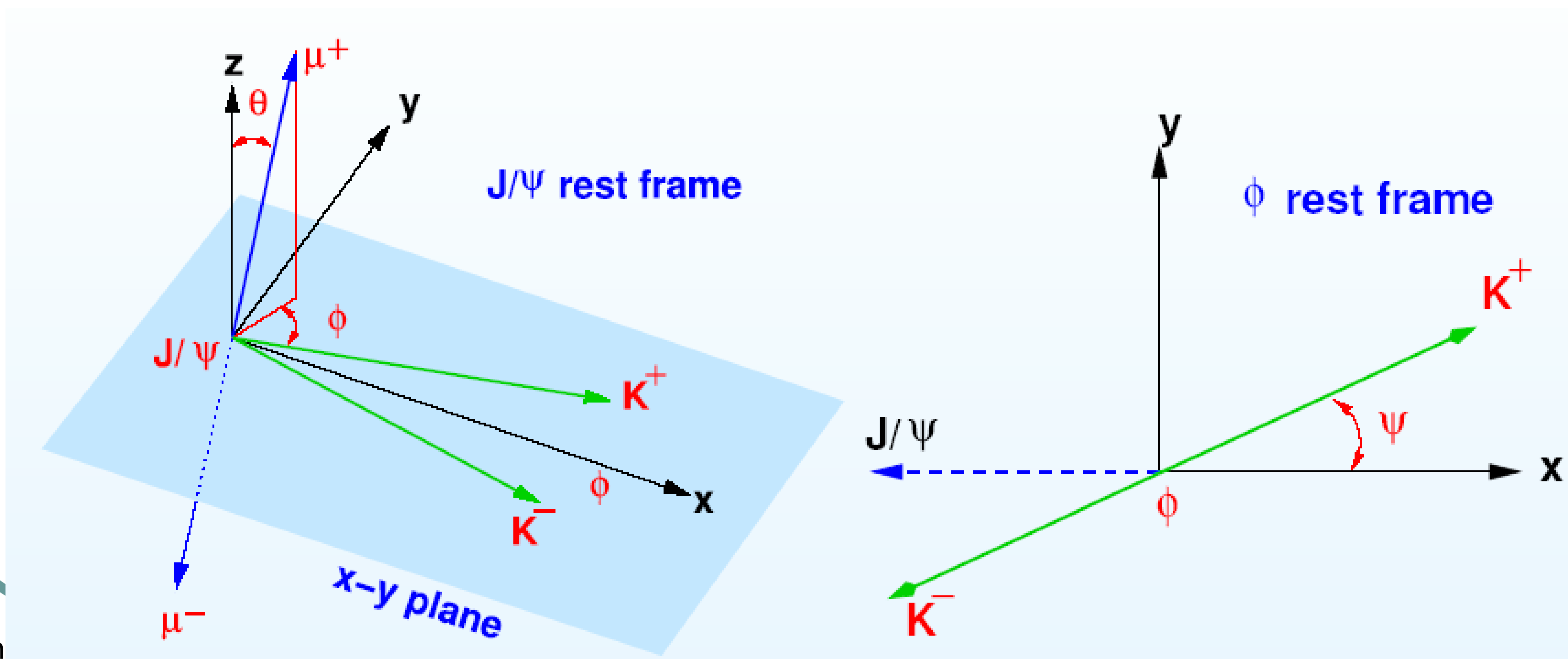
$$\Gamma(t) \approx \left|A_{even}(\theta,\psi,\varphi,t)\right|^2 + \left|A_{odd}(\theta,\psi,\varphi,t)\right|^2$$

$$+A^* A(CPC)$$ CP-conserving interference

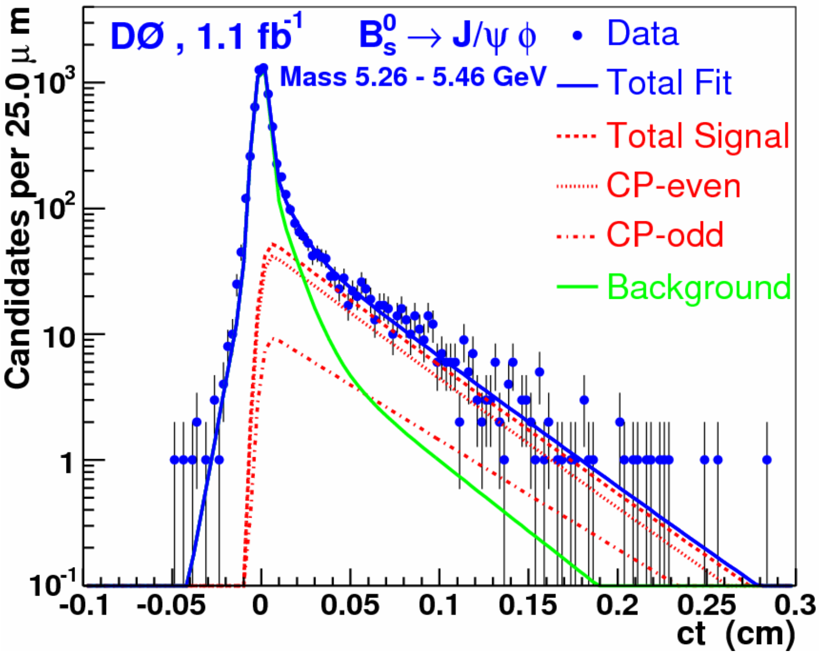
$$+A^* A(CPV)\left(e^{-\Gamma_L t} - e^{-\Gamma_H t}\right)\sin\varphi_s$$

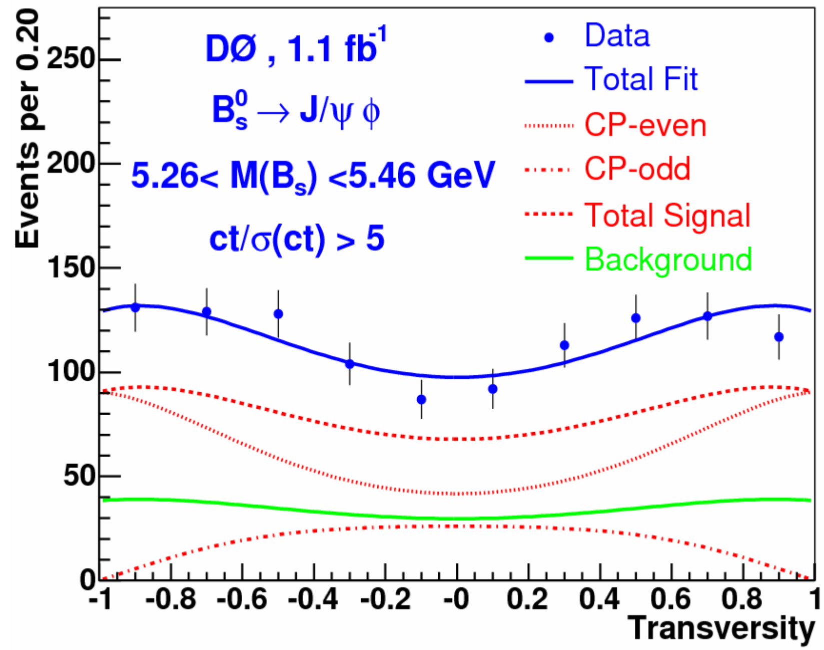
CP-violating interference

- CP eigenstates - well separated in transversity ($\cos\theta$)



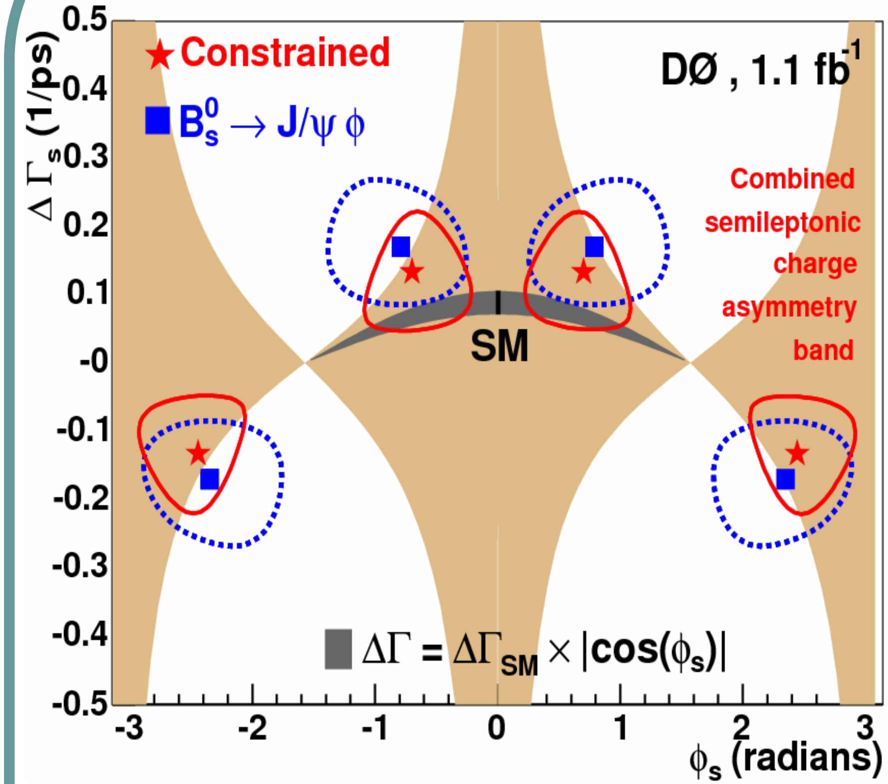
$\Delta\Gamma_s$ and ϕ_s in $B_s \rightarrow J/\psi\varphi$





- Simultaneous fit of mass, lifetimes, time-dependant angular distributions to extract $\Delta\Gamma_s$ and ϕ_s

Δm_s, $\Delta\Gamma_s$ and ϕ_s



- Fit for $\Delta\Gamma_s$ and ϕ_s using A_{sl} measurement and world average τ_{fs}

PRD 76, 057101 (2007)

- Measured all three parameters that characterize B_s system at DØ

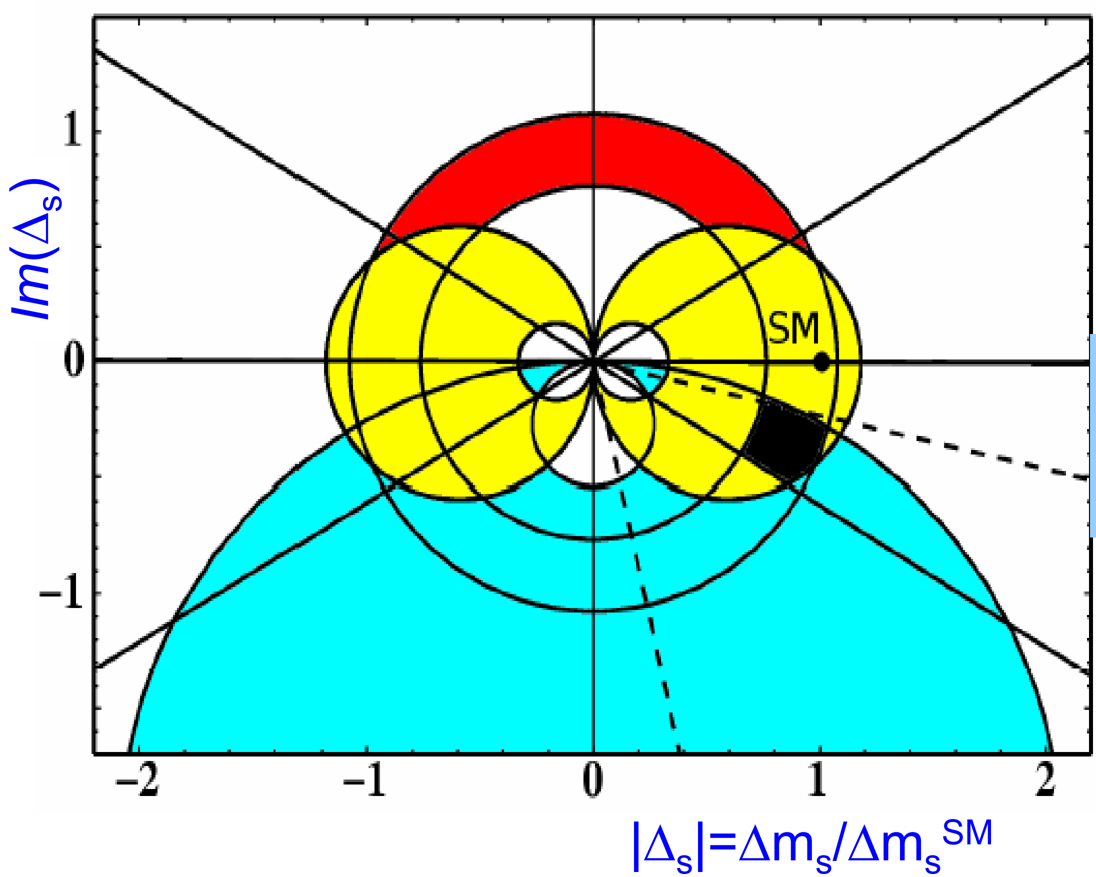
$$\Delta m_s = 18.5 \pm 0.9\ \mathrm{ps}^{-1}$$

$$\Delta\Gamma_s = 0.13 \pm 0.09\ \mathrm{ps}^{-1}$$

$$\phi_s = -0.70^{+0.47}_{-0.39}$$

$$a_{SL}^{s} = 0.0001 \pm 0.0090$$

Δm_s, $\Delta\Gamma_s$ and ϕ_s



$$\Delta m_s = 17.77 \pm 0.11\,\text{ps}^{-1}$$

$$\Delta\Gamma_s = 0.13 \pm 0.09\,\text{ps}^{-1}$$

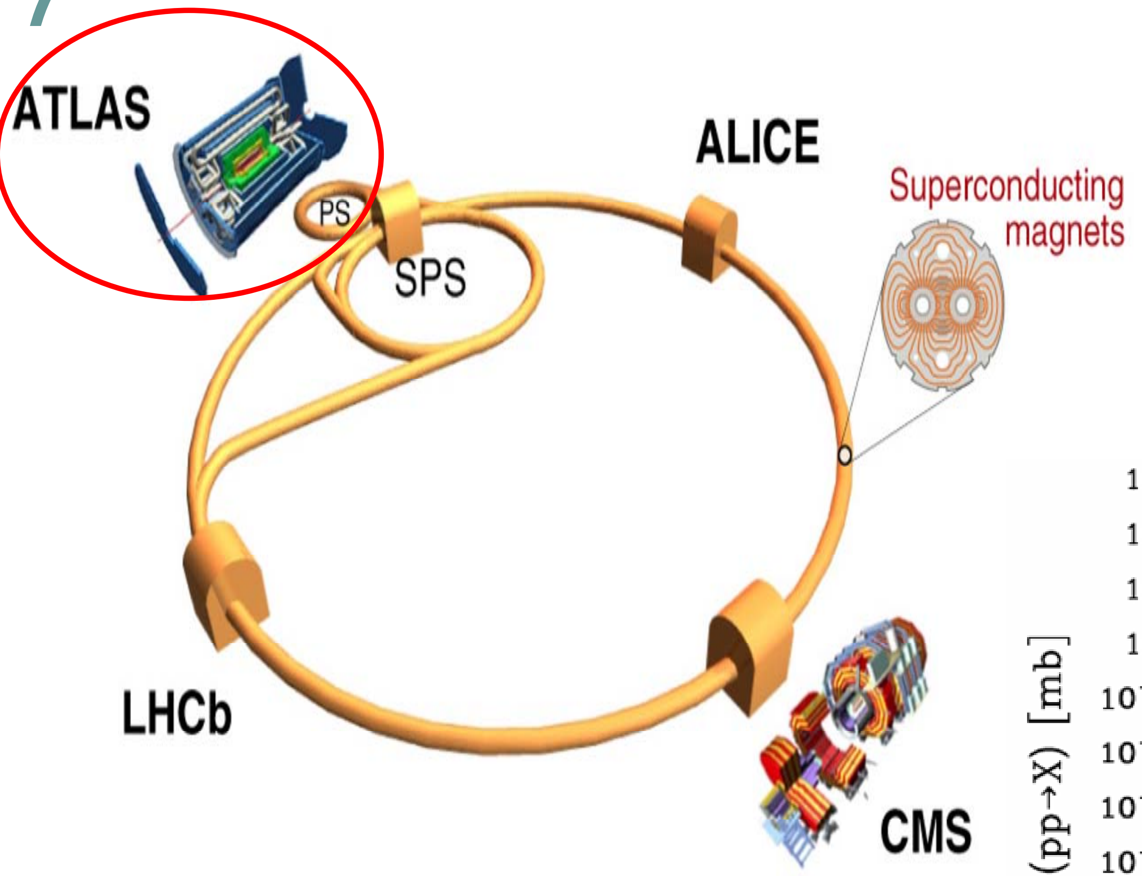
$$\phi_s = -0.70^{+0.47}_{-0.39}$$

$$a^s_{SL} = 0.0001 \pm 0.0090$$

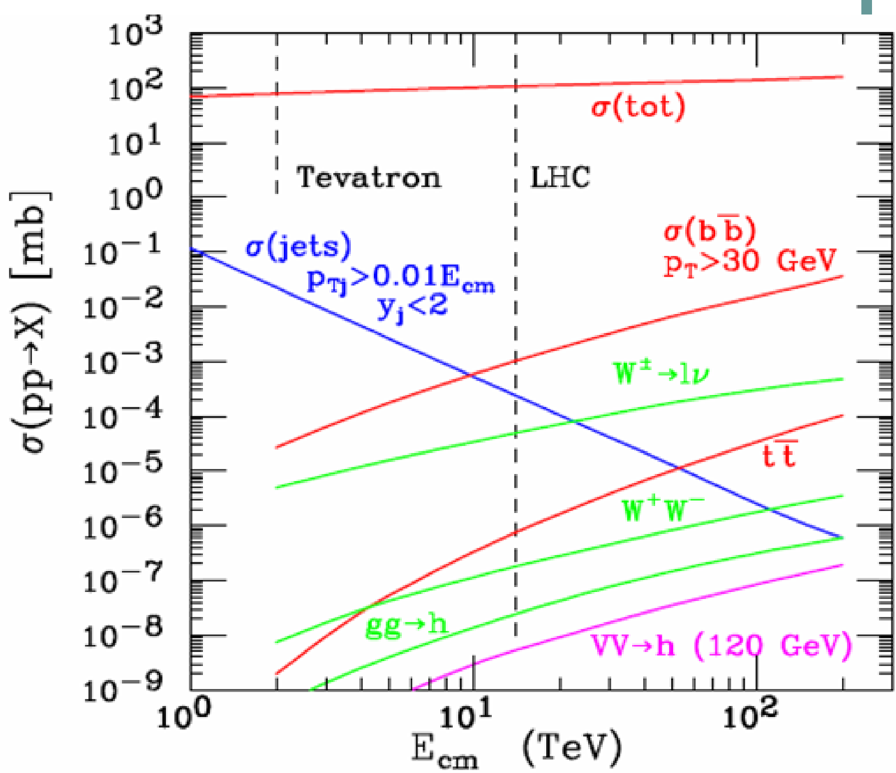
$$\Delta\Gamma_s \tan\phi_s = 0.02 \pm 0.16\,\text{ps}^{-1}$$

Need more data!

Road to Discovery ?



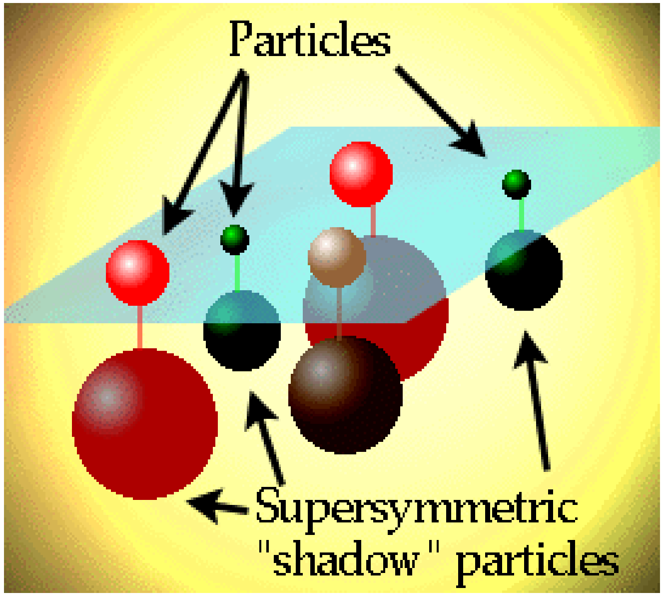
- The Large Hadron Collider
  - Proton-Proton
  - $\sqrt{s}$ =14 TeV
  - $\mathcal{L}$~10^{34} $cm^{-2}s^{-1}$



SUperSYmmetry

- A symmetry between fermions and bosons
  - R-parity = $(-1)^{3B+L+2S}$
  - Solves fine-tuning of SM, lead to GUTs, possible dark matter candidate (LSP), may incorporate gravity

SM Particles	SUSY Particles			
quarks: q	q	squarks: $\tilde{q}$		
leptons: l	l	sleptons: $\tilde{l}$		
gluons: g	g	gluino: $\tilde{g}$		
charged weak boson: $W^{\pm}$	$W^{\pm}$	Wino: $\widetilde{W}^{\pm}$	$\tilde{\chi}^{\pm}_{1,2}$	chargino
Higgs: H^0	$H^{\pm}$	charged higgsino: $\widetilde{H}^{\pm}$		
	h^0, A^0, H^0	neutral higgsino: $\tilde{h}^0, \tilde{A}^0$,	$\widetilde{H}^0$	higgsino
neutral weak boson: Z^0	Z^0	Zino: $\tilde{Z}^0$	$\tilde{\chi}^0_{1,2,3,4}$	neutralino
photon: γ	γ	photino: $\tilde{\gamma}$		



- SUSY breaking mechanism is unknown ⇒ many params. ☹
  - mSUGRA: m_0, $m_{1/2}$, A_0, tan β, Sign(μ)

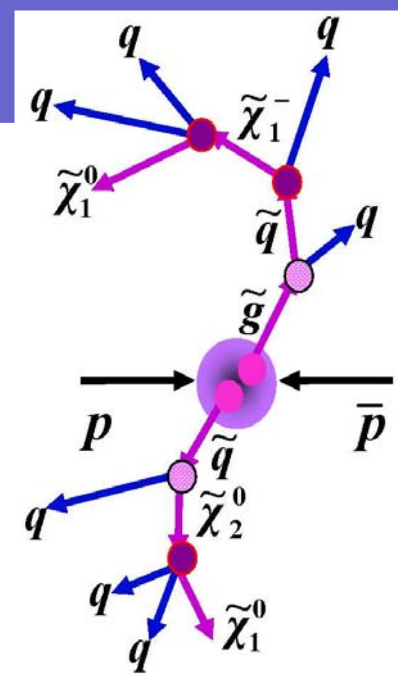
Search Strategies

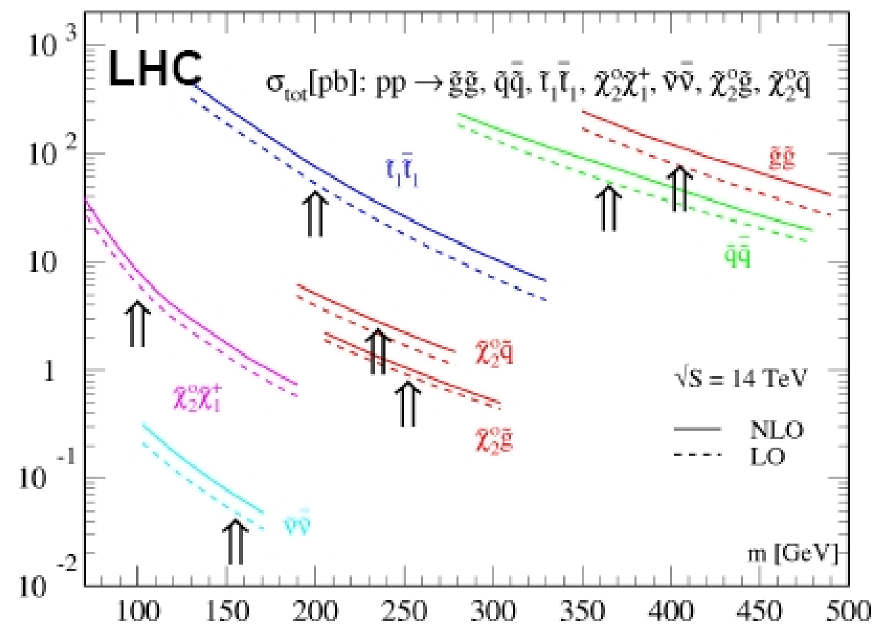
- Concentrate on inclusive signatures for SUSY
  - Masses not known $\Rightarrow$ different decay scenarios possible
    - Squark, gluino pairs
    - Stop : $\tilde{t} \rightarrow \tilde{\chi}^{+} b \rightarrow \tilde{\chi}^{0}_{1} W^{*} b$;

      $\tilde{t} \rightarrow c\tilde{\chi}^{0}_{1}$
    - Sbottom
  - Canonical SUSY signatures :
    - Jets (b,c) + Missing transverse energy
    - Lepton + jets (b,c) + Missing transverse energy

Inclusive MET + Jets

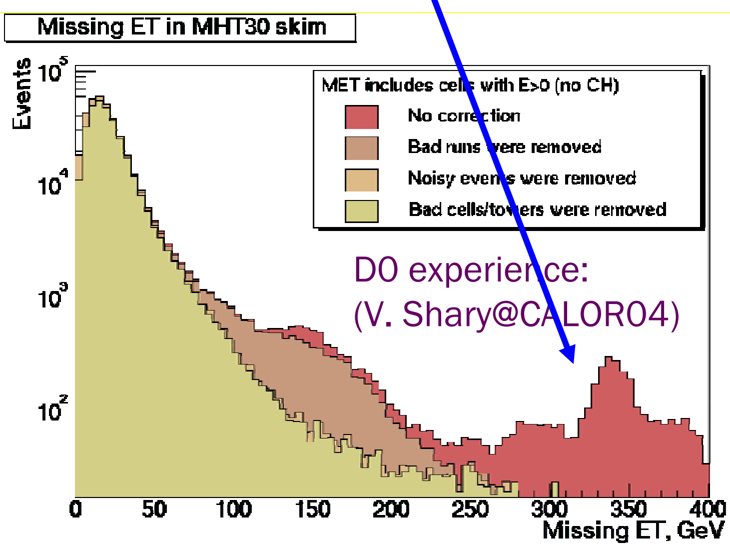
- One of the most sensitive channels
  - Squarks, gluinos interact strongly
- Low mass Supersymmetry
  - Large cross section at the LHC
- Difficult part is to convince yourself that there is a real excess!
  - MET dataset cleanup
    - Beam and instrumental backgrounds
  - Use control regions that enhance background over signal to calibrate from data W/Z+jets, top pairs, QCD dijets
- Understanding of systematic uncertainties
  - Jet energy scale uncertainty and MET resolution





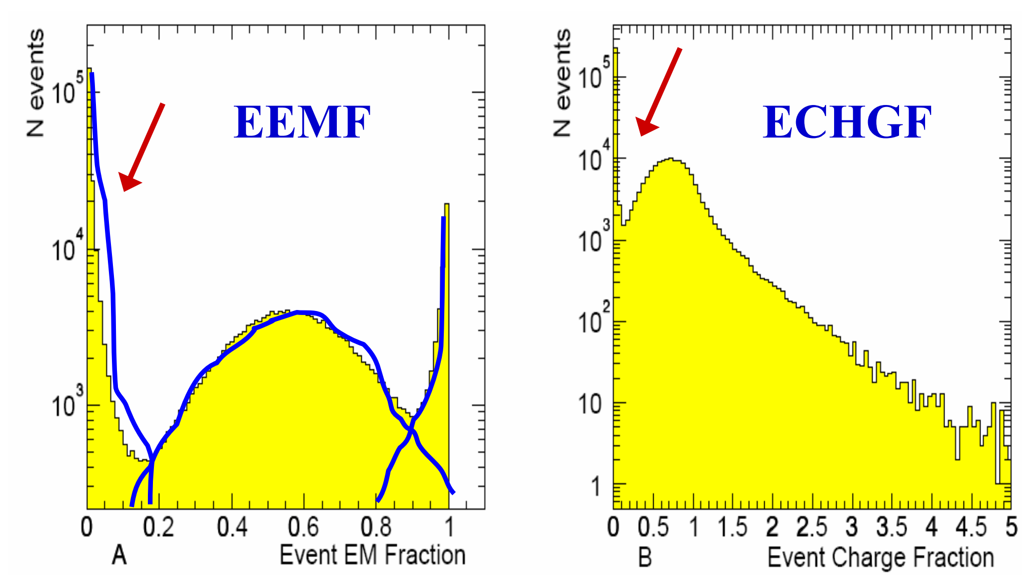
Transverse Missing Energy

- E_T^{miss} is a discriminating variable for SUSY discovery
  - Our searches rely on the excess in the $E_T^{miss}(M_{eff})$ distribution.
- Large tail in E_T^{miss} due to the fakes serious for SUSY searches.
  - QCD-jet background (no real E_T^{miss}, but large x-section)



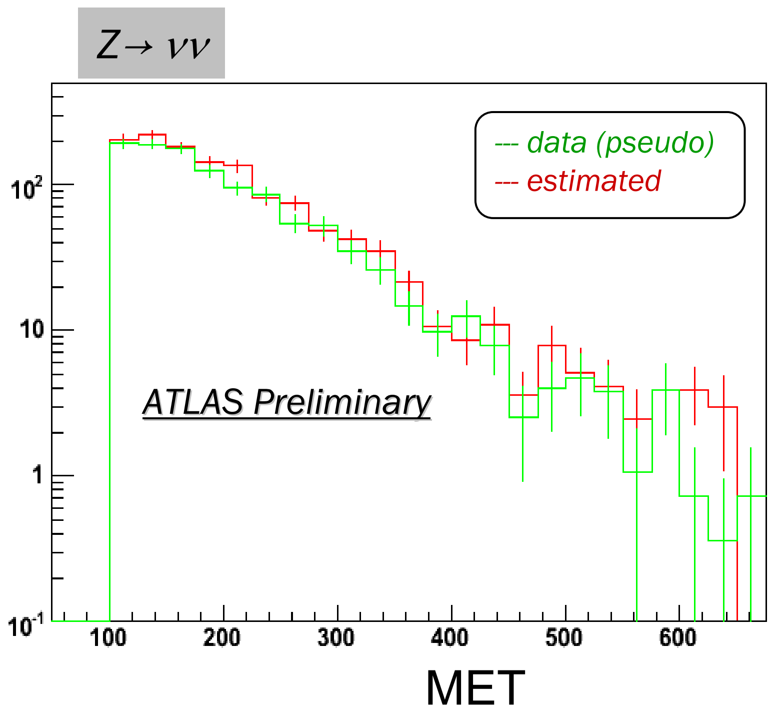
Fermilab-thesis-2004-58

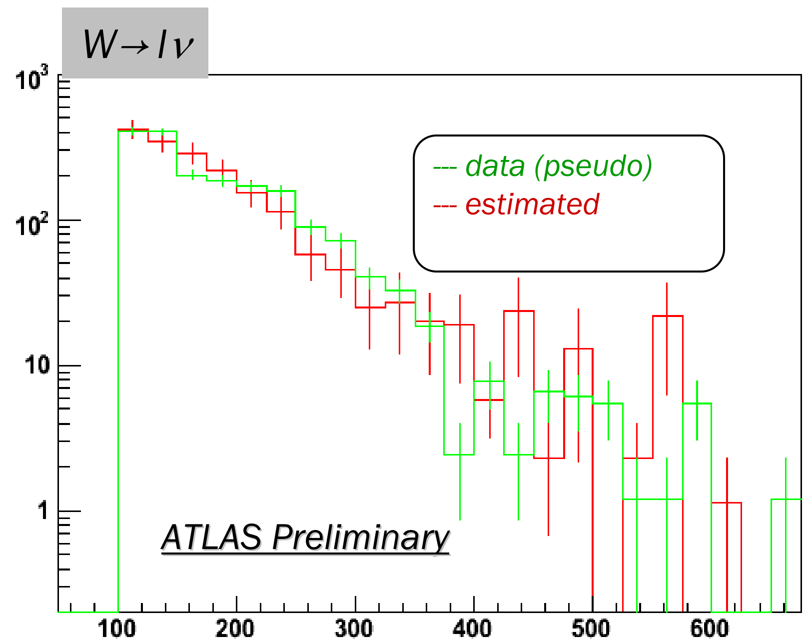
CDF



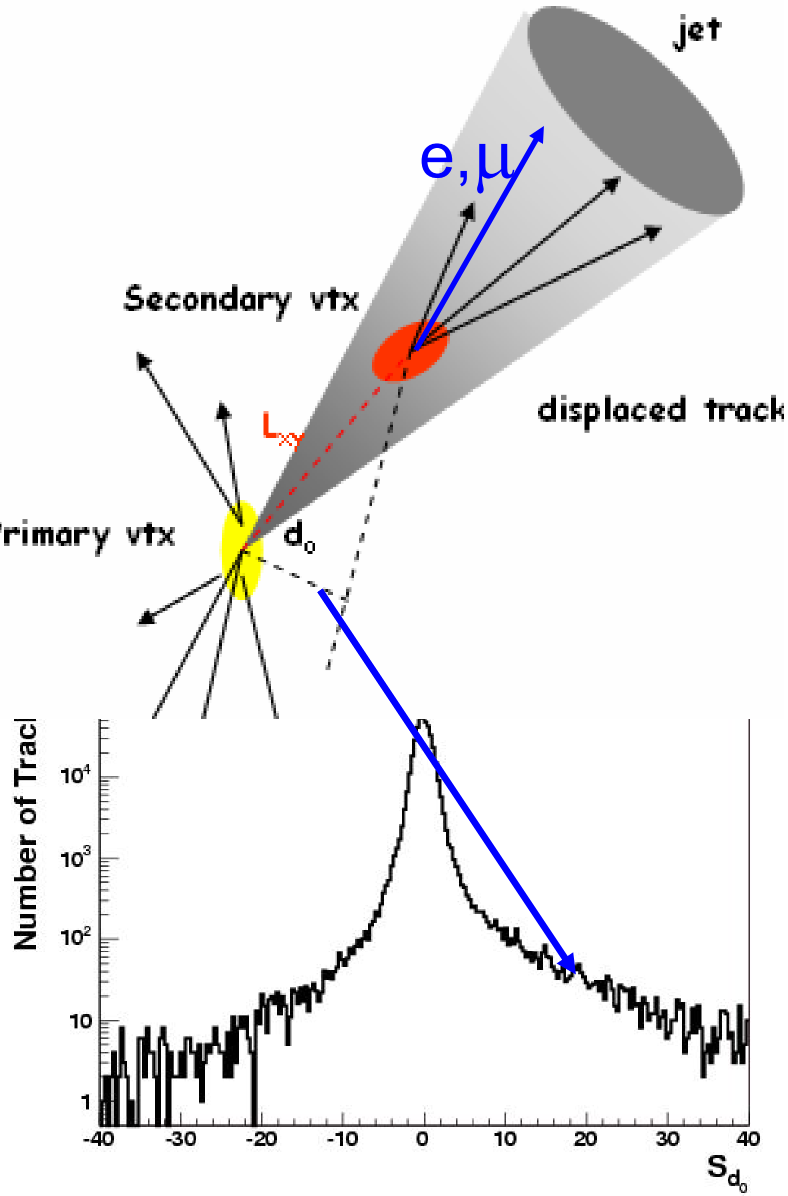
MET Calibration from Z+jets

- Measure Z+jets with $Z \to \mu\mu, ee$ in data to normalize the $Z \to \nu\nu$ + jets (invisible) contribution and calibrate MET spectrum
- With ~1fb^{-1} should have enough Z+jets events
- May use W+jets through the W/Z ratio and lepton universality



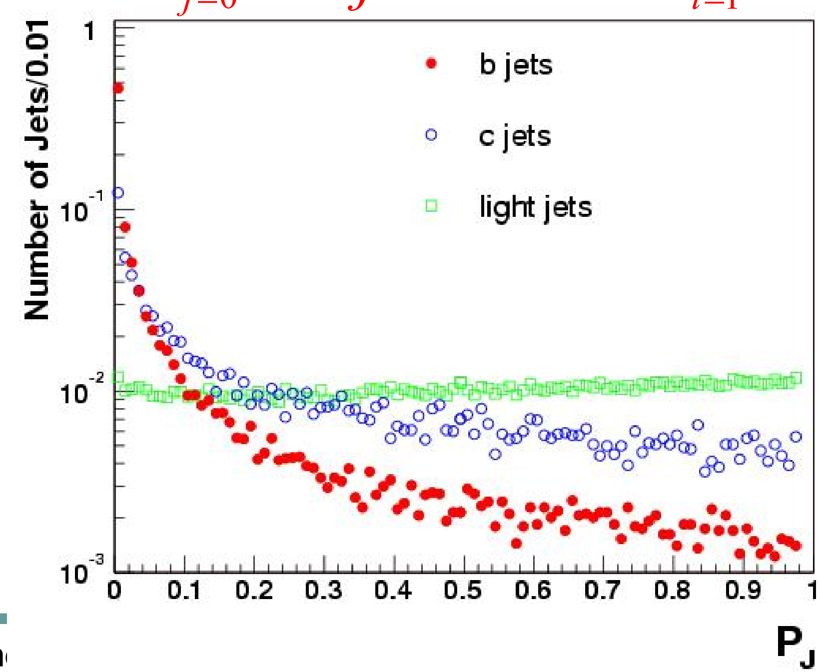


Heavy Flavor Tagging



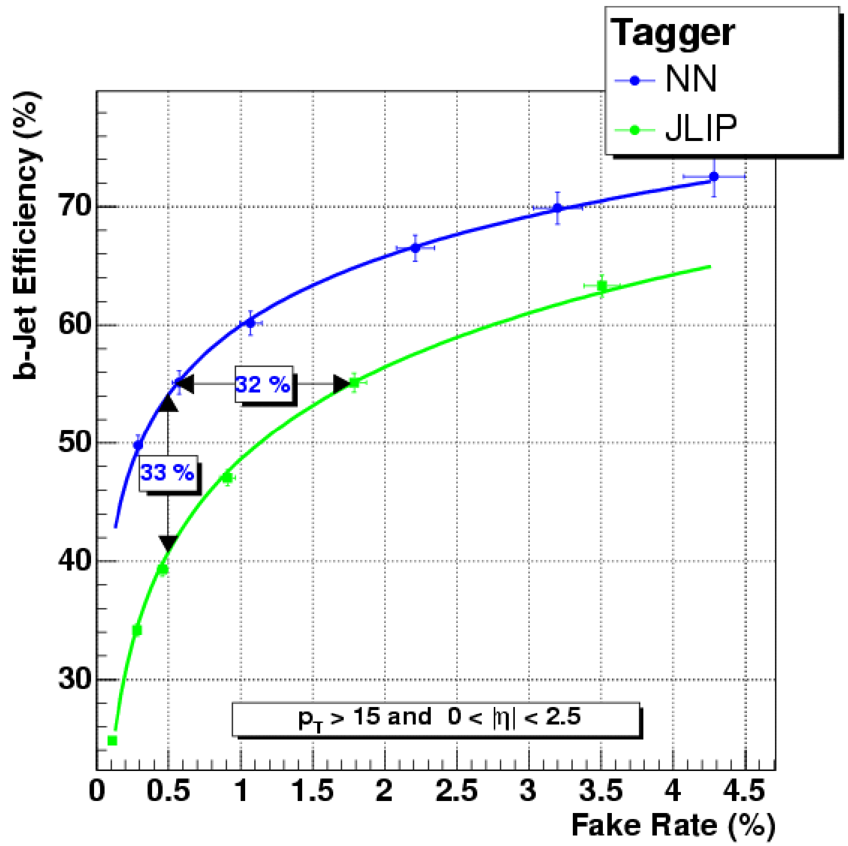
- b,c – long-lived, massive
  - Secondary vertex
  - Impact parameter significance
  - Soft lepton

$$P_{jet} = \Pi \cdot \sum_{j=0}^{N_{tr-1}} \frac{(-\ln \Pi)^j}{j!}, \quad \Pi = \prod_{i=1}^{N_{tr}} P_{tr\,i}$$



Tagger Combination

- Combine all the information in the event
  - Add flavor identification?
- Continuous variable vs single operating point
- Include all jets
  - Event probability
  - Include in the signal selection discriminant



Summary

- Measured all three parameters that characterize B_s system at D0
  - No significant deviations from the SM are observed
  - All results are still statistics limited
- Looking forward to collecting more data
  - Expecting quick turn around as we collect data
    - Mature analyses
- Very exciting time for high energy physics
  - LHC will help shed light on physics beyond SM
- Proposed plan relies on group expertise and builds on its strength

Backup Slides

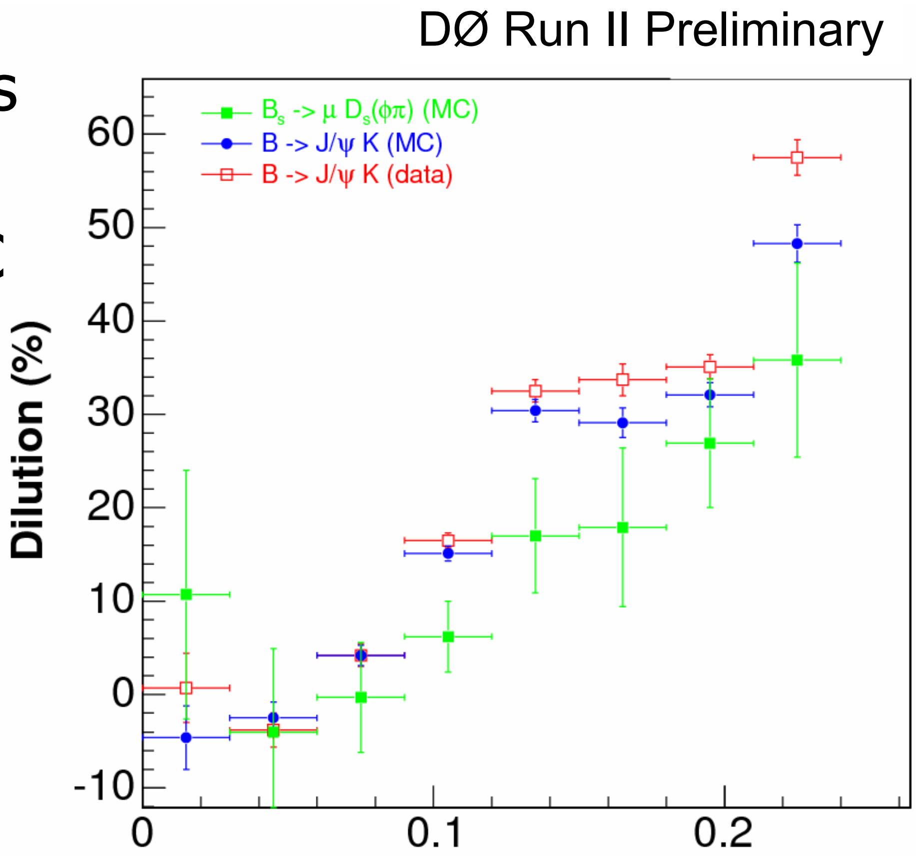
channel	yield
$B_s \to \mu^+ D_s^- X,\ D_s^- \to \phi\pi^-,\ \phi \to K^+K^-$	44777
$B_s \to e^+ D_s^- X,\ D_s^- \to \phi\pi^-,\ \phi \to K^+K^-$	1663
$B_s \to \pi^+ D_s^- X,\ D_s^- \to \phi\pi^-,\ \phi \to K^+K^-$	249
$B_s \to \mu^+ D_s^- X,\ D_s^- \to K^{*0}K^-,\ K^{*0} \to K^+\pi^-$	18098
TOTAL	64787

Systematics

- Vary each source separately within uncertainty
- Incorporate systematics as $\sigma^{sys}=\Delta A+(1-A)\Delta\sigma_A/\sigma_A$
- Consider following sources:
  - Dilution
  - K-factors
  - VPDL model
  - Mass fit model
  - Sample composition
  - Background description
- Systematic uncertainties are small compared to statistical

Same Side Tagging (SST)

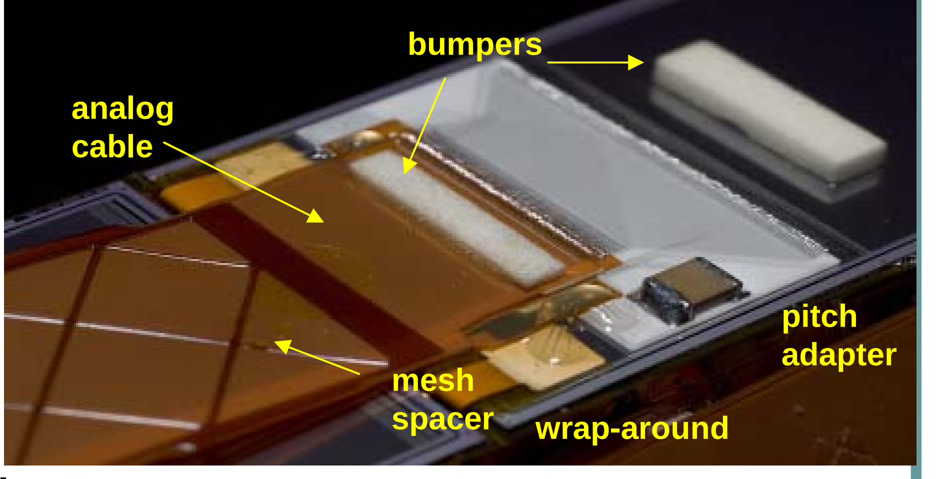
- Depends on B-hadron species
  - No direct transfer $B^+, B^0 \rightarrow B_s$
- Predict SST dilution using MC
  - No PID ☹
- Use kinematic variables ΔR, p_T^{rel},
- To verify compare data and MC with known flavor for individual taggers and combination
  - i.e. $B^+ \rightarrow J/\psi K^+$

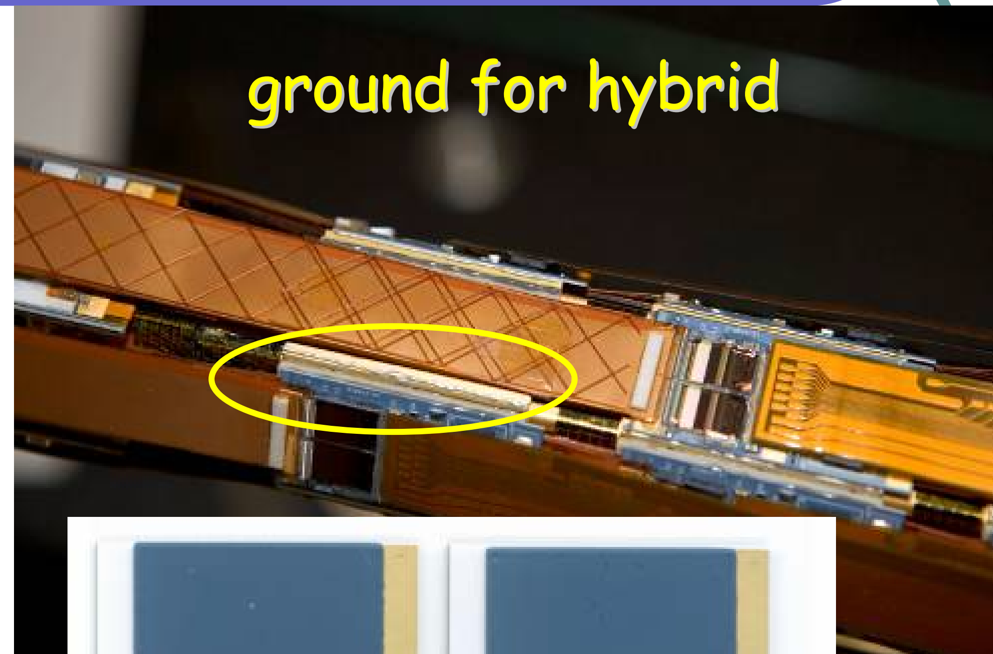


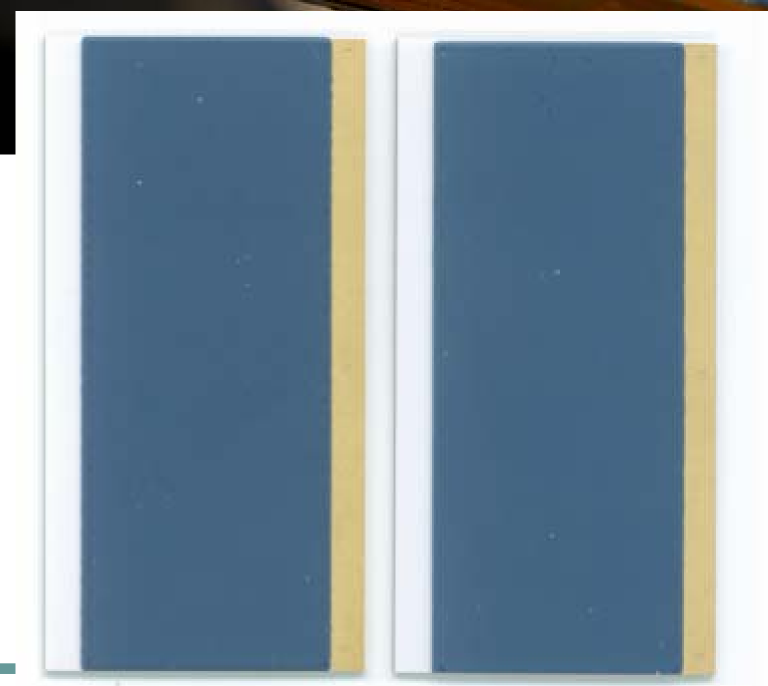
Combined discriminating variable

Noise Elimination – Layer 0 implementation

- Electronically create an isolated ground on the detector
  - Dedicated adapter card
    - Use ground isolated power regulators near the detector
    - All signals sent differentially across the barrier
  - CLC filter before regulators, for SVX4 power
- Isolated high voltage ground with 10K resistor
- Isolated ground needs reference to the outside world
  - This is provided by the high voltage ground resistor
- Mesh spacer to minimize capacitance between analog cables



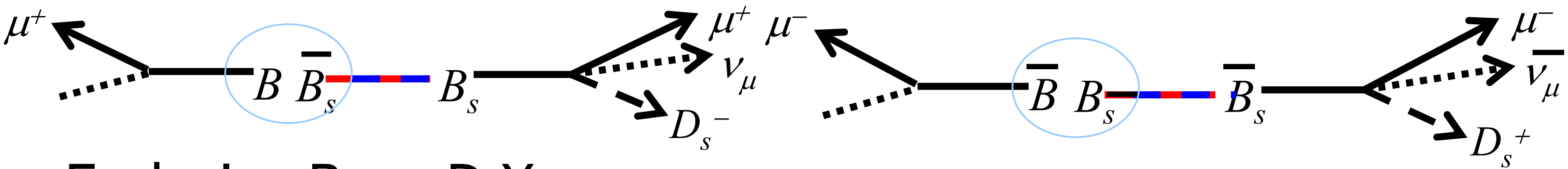




- Carbon fiber cocured with flex circuit with copper trace to achieve better contact
- Ground pads at backplane of hybrid
- Wrap-around to connect sensor GND to support (as well as bias voltage to backplane)

Charge Asymmetry and ϕ_s

- Measurement of the charge asymmetry induced by B_s mixing



- Exclusive $B_s \rightarrow \mu D_s X$

$$A_{SL}(untagged) = \frac{N(D_s\mu^+) - N(D_s\mu^-)}{N(D_s\mu^+) + N(D_s\mu^-)} = \mathrm{Im}\,\frac{\Gamma_{12}^s}{M_{12}^s} \cong \frac{\Delta\Gamma}{\Delta m}\tan\phi_s$$

$$A_{SL}(B_s) = 0.0245 \pm 0.0193 \pm 0.0035$$

PRL 98, 151801 (2007)

- Inclusive same-sign $\mu\mu$ sample PRD 74, 092001 (2006)

$$A_{SL}^{\mu\mu}(tag) = \frac{N(\mu^+\mu^+) - N(\mu^-\mu^-)}{N(\mu^+\mu^+) + N(\mu^-\mu^-)} = \frac{1}{4f}\left[A_{SL}^d + \frac{f_s\chi_{s0}}{f_d\chi_{d0}}A_{SL}^s\right] = 2A_{SL}(untagged)$$

$$A_{SL}(B_s) = 0.006 \pm 0.010$$

- Charge asymmetry in semileptonic B_s

$$a_{SL}^s = 0.0001 \pm 0.0090$$

$$\Delta\Gamma_s \tan\phi_s = 0.02 \pm 0.16\ \mathrm{ps}^{-1}$$

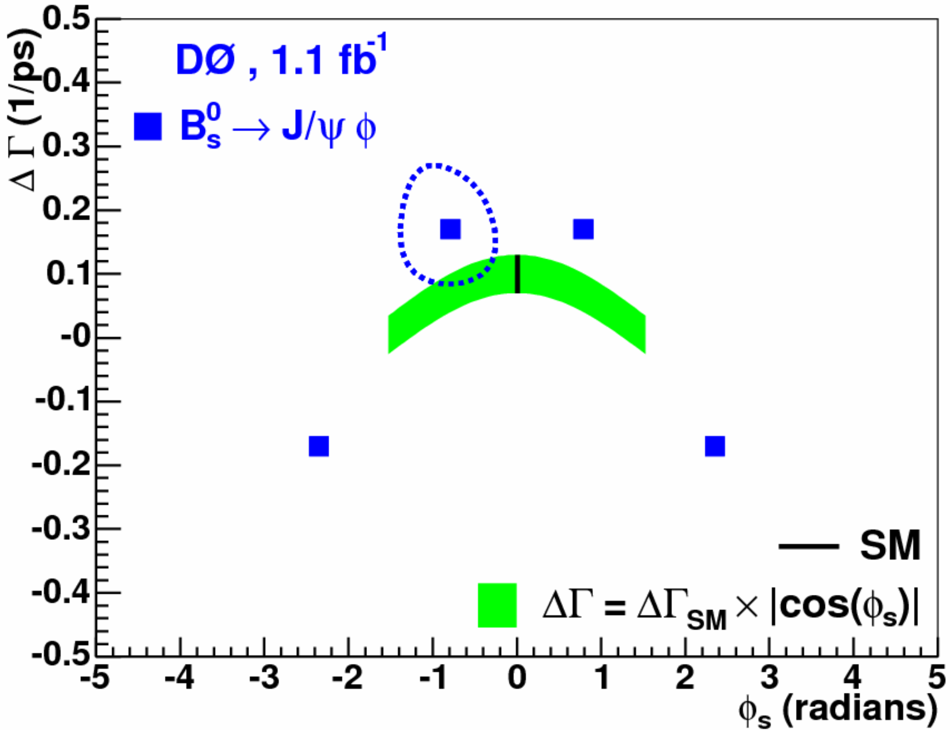
$\Delta\Gamma_s$ and ϕ_s, General Case

- Perform fit with ϕ_s as free parameter

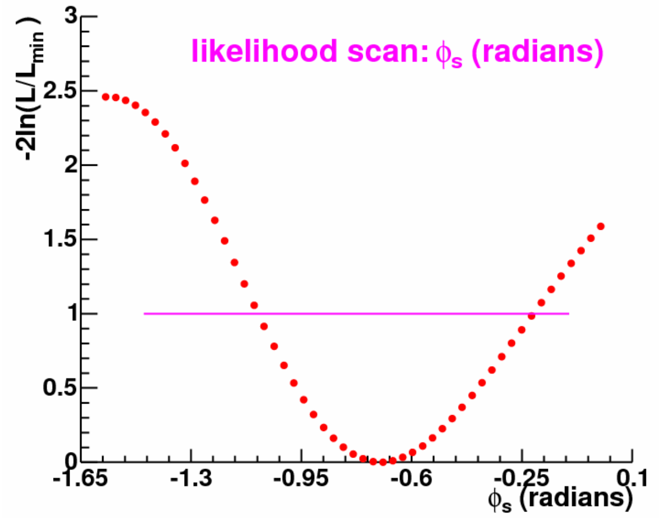
$$|\phi_s| = 0.79 \pm 0.56\,(\text{stat.})^{+0.14}_{-0.01}\,(\text{syst.})$$

$$\Delta\Gamma_s = 0.17 \pm 0.09\,(\text{stat.}) \pm 0.02\,(\text{syst.})\ \text{ps}^{-1}$$

PRL 98, 121801 (2007)



- 4-fold ambiguity



Muon Trigger

- Single inclusive muons
  - $|\eta|<2.0$, $p_T > 3, 4, 5$ GeV
  - Muon + track match at Level 1
  - No direct lifetime bias
  - Prescaled or turned off depending on inst. lumi.
  - Dimuons: other muon for flavor tagging
- e.g. at $50 \cdot 10^{30}$ $cm^{-2}s^{-1}$
  - 20 Hz of unbiased single μ
  - 2 Hz of di-μ
- No rate problem at L1/L2