Search for B_s^0 Oscillations: New Results from DØ

Rick Van Kooten
Indiana University
On behalf of the
DØ Collaboration

Outline:

- Motivation
- Analysis: overview & improvements
- Detector features
- Analysis: details
- Prospects

Joint Experimental
Theoretical Seminar
"Wine & Cheese"
2 Sept. 2005
FNAL

Acknowledgements

- First analysis involving a large team of colleagues within the DØ Heavy Flavor Working Group: *much appreciated!!*

- More details: publicly available DØ Conference Notes

  B_s mixing with $B_s \to D_s X$, $D_s \to \phi\pi$ and opposite-side flavor tagging

  B_s mixing with $B_s \to D_s X$, $D_s \to K^*K$ and opposite-side flavor tagging

  Combined opposite-side flavor tagging

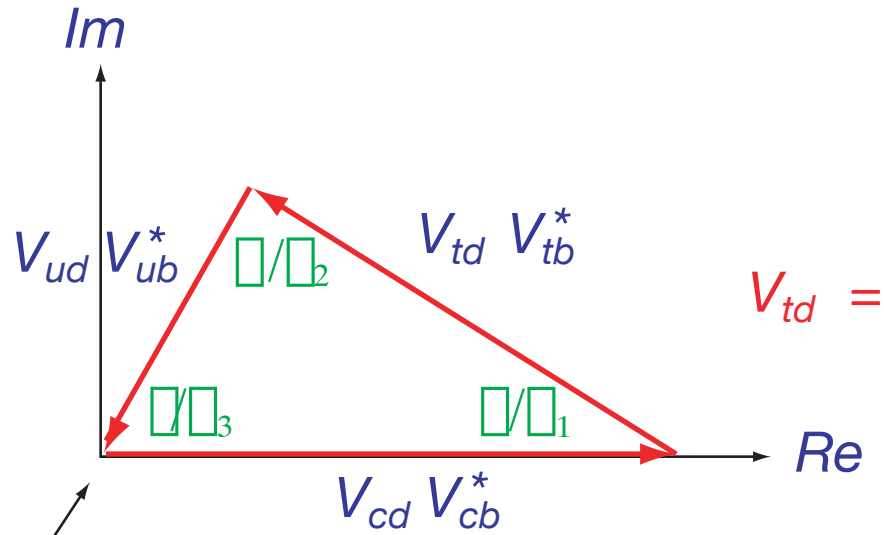
  B flavor tagging with opposite-side soft electrons

- 610 pb^{-1} of data processed up to June 2005

CKM Triangle

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

- Vector sum in complex plane:

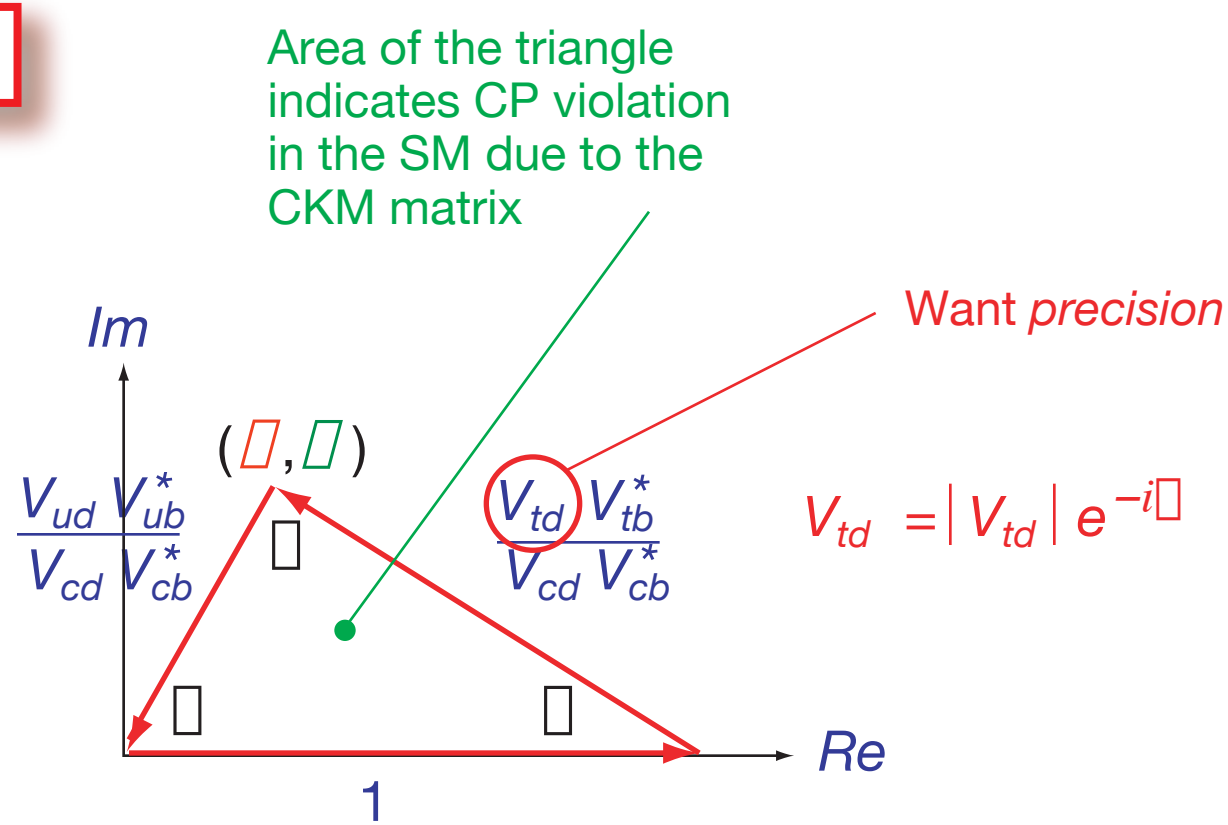


$$V_{td} = |V_{td}|\,e^{-i\gamma}$$

- Does it return to zero?
- Measure lengths of all sides
- Measure all three angles
- Consistent?

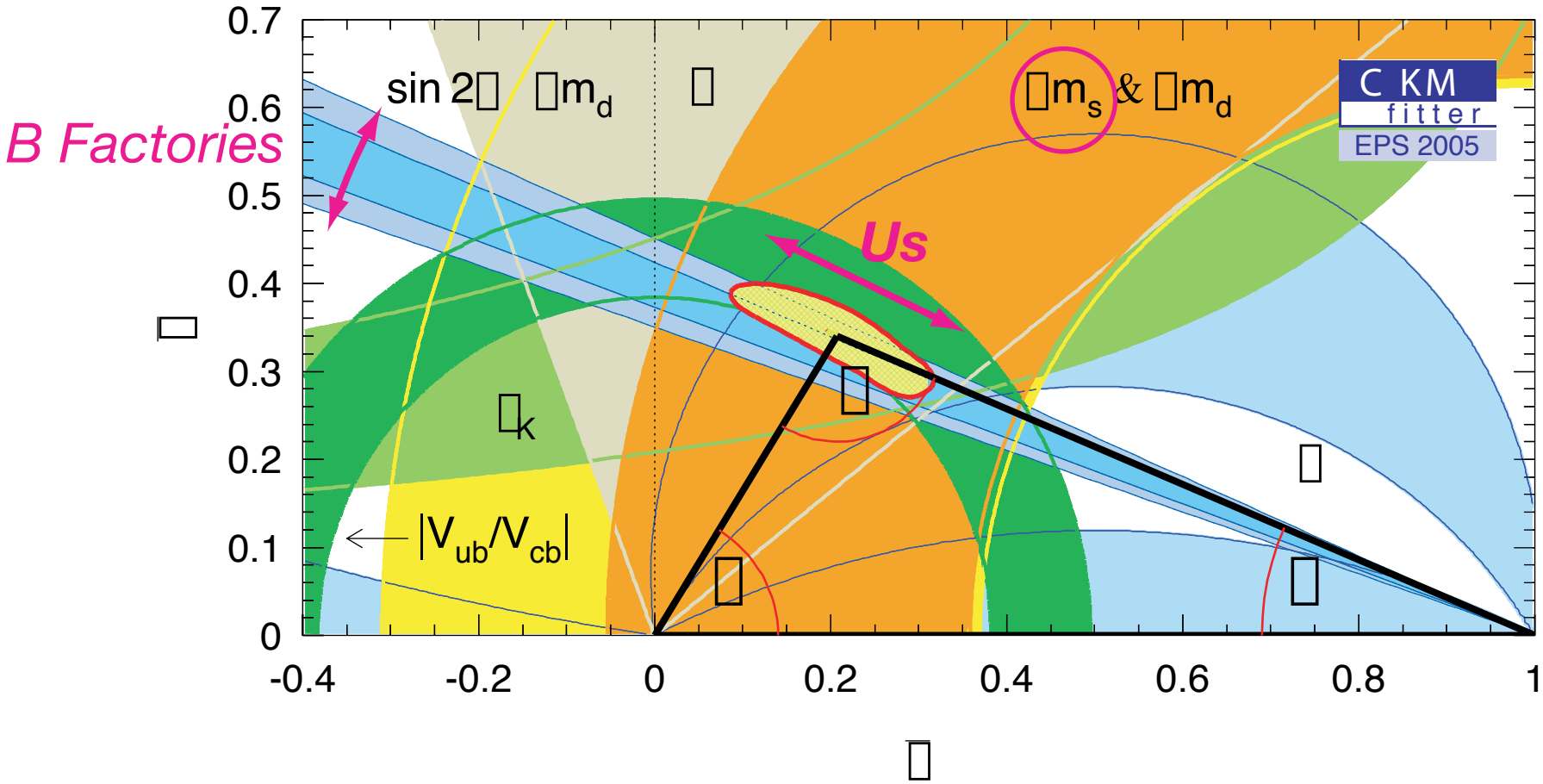
CKM Triangle

- Normalize one side:

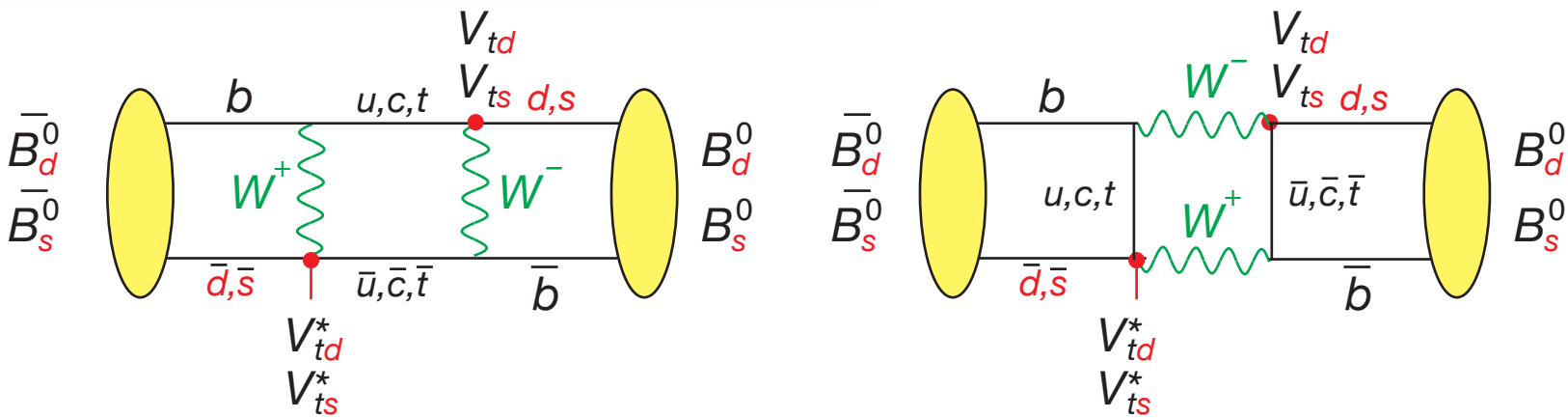


$$V = \begin{pmatrix} 1 - \lambda^2/2 & \lambda & A\lambda^3(\bar{\rho} - i\bar{\eta}) \\ -\lambda & 1 - \lambda^2/2 & A\lambda^2 \\ A\lambda^3(1 - \bar{\rho} - i\bar{\eta}) & -A\lambda^2 & 1 \end{pmatrix}$$

CKM Triangle



B^0-$\bar{B}^0$ Mixing and Oscillations



- B^0_d oscillation frequency: $\Delta m_d = \frac{G_F^2}{6\pi^2} m_b m_t^2 F\left[\frac{m_t^2}{m_W^2}\right] \eta_{QCD} B_{B_d} f_{B_d}^2 \left|V_{tb}^* V_{td}\right|^2$

Measured well

Large uncertainties! 15–20%

Want!

- If measure Δm_d *and* Δm_s : $\frac{\Delta m_s}{\Delta m_d} = \frac{m_{Bs}}{m_{Bd}} \frac{f_{Bs}^2}{f_{Bd}^2} \frac{B_{Bs}}{B_{Bd}} \left|\frac{V_{ts}}{V_{td}}\right|^2$

Smaller uncertainty

Unquenched LQCD
Stewart, LP'05

$(1.21 \pm 0.022^{+0.035}_{-0.014})^2$

Better Precision (only ~3% theory systematic)

B^0-$\bar{B}^0$ Mixing and Oscillations

$$|B_1\rangle = \frac{1}{\sqrt{2}}\left(|B^0\rangle + |\bar{B}^0\rangle\right) = |B_H\rangle$$

$$|B_2\rangle = \frac{1}{\sqrt{2}}\left(|B^0\rangle - |\bar{B}^0\rangle\right) = |B_L\rangle$$

Mass Eigenstates
(and CP eigenstates
if ignore CP violation)

Weak Eigenstates

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

- Then B_1 and B_2 are eigenstates with

masses: $m_{1,2} = M \pm \frac{\Delta m}{2}$ and lifetimes: $\tau_{1,2} = \tau \pm \frac{\Delta\Gamma}{2}$

... $\Delta\Gamma_s$ measurement at DØ, see
D. Zieminska's talk, Wine & Cheese,
18 March 2005

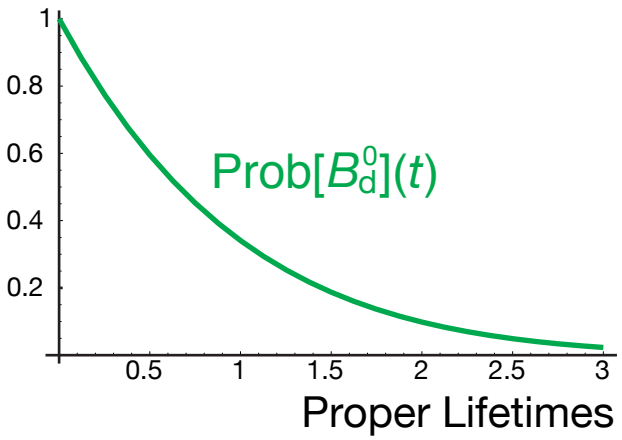
B^0-$\bar{B}^0$ Mixing and Oscillations

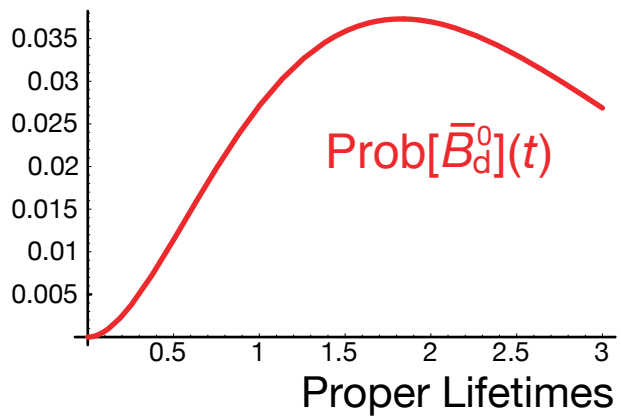
- If initially start with a B^0

$$\mathrm{Prob}[B^0](t) = \frac{1}{4}\left[\exp(-\Gamma_1 t) + \exp(-\Gamma_2 t) + 2\exp(-\Gamma t)\cos(\Delta m t)\right]$$

$$\mathrm{Prob}[\bar{B}^0](t) = \frac{1}{4}\left[\exp(-\Gamma_1 t) + \exp(-\Gamma_2 t) - 2\exp(-\Gamma t)\cos(\Delta m t)\right]$$

- For B_d^0





B^0-$\bar{B}^0$ Mixing and Oscillations

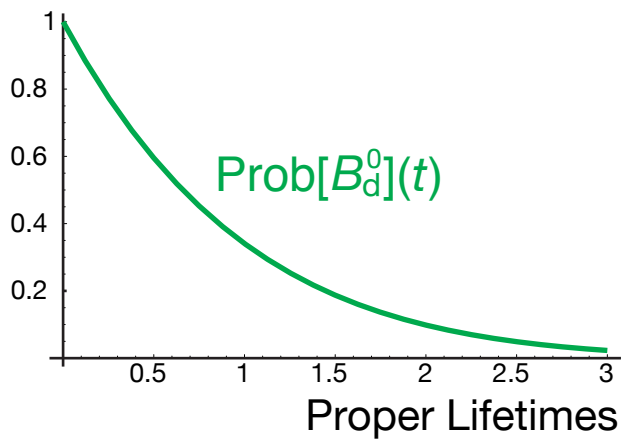
- If initially start with a B^0

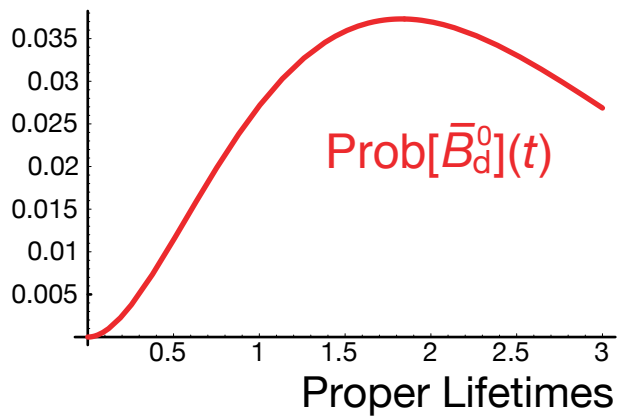
Extract

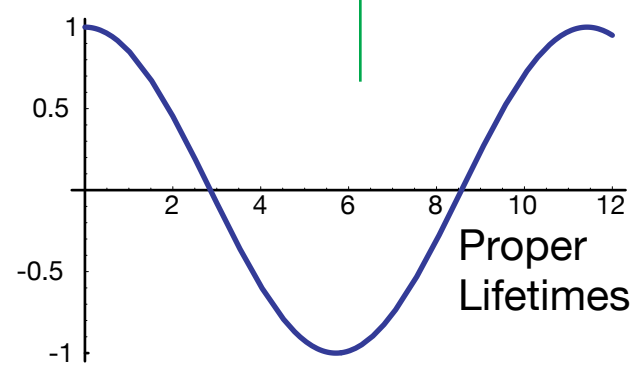
$$\mathrm{Prob}[B^0](t) = \frac{1}{4}\left[\exp(-\Gamma_1 t) + \exp(-\Gamma_2 t) + 2\exp(-\Gamma t)\cos(\Delta m_d t)\right]$$

$$\mathrm{Prob}[\bar{B}^0](t) = \frac{1}{4}\left[\exp(-\Gamma_1 t) + \exp(-\Gamma_2 t) - 2\exp(-\Gamma t)\cos(\Delta m_d t)\right]$$

- For B_d^0







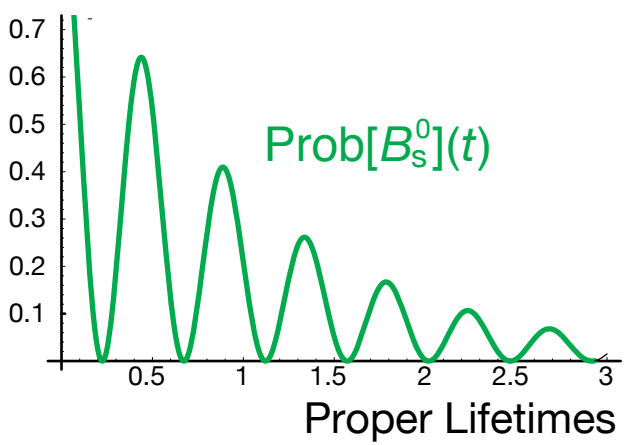
Take asymmetry of two: $A = \dfrac{N[B^0](t) - N[\bar{B}^0](t)}{N[B^0](t) + N[\bar{B}^0](t)}$

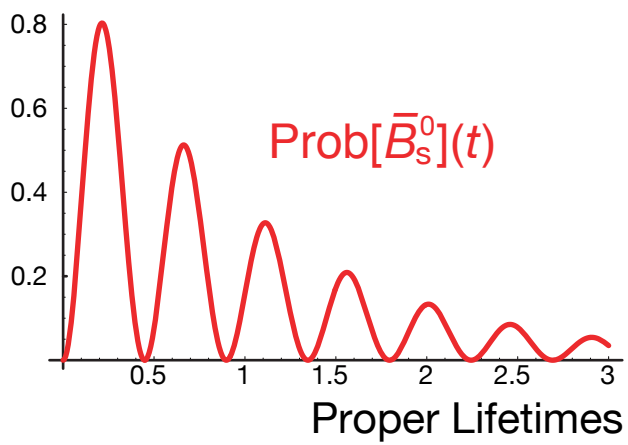
- What we get from it: $\Delta m_d \propto |V_{tb}^* V_{td}|^2$

B^0-$\bar{B}^0$ Mixing and Oscillations

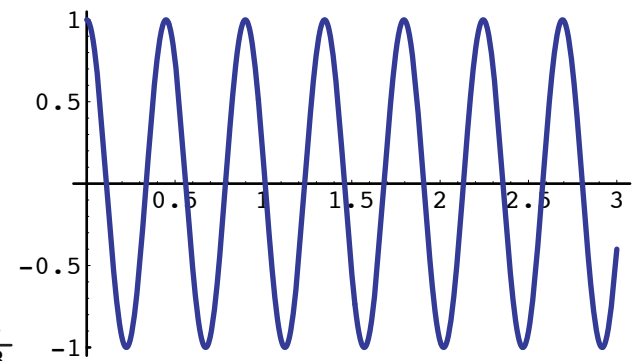
- $\Delta m_d \propto |V_{tb}^* V_{td}|^2$
  - V_{tb}^*: ~1
  - V_{td}: tiny
- $\Delta m_s \propto |V_{tb}^* V_{ts}|^2$
  - V_{tb}^*: ~1
  - V_{ts}: still small, but larger than V_{td}

- For B_s^0





Different proper time scale



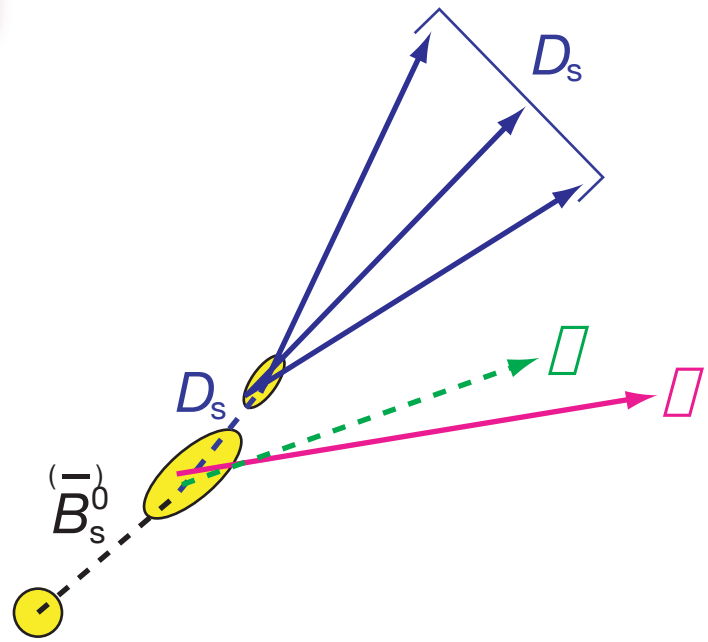
Take asymmetry of two: $A = \dfrac{N[B^0](t) - N[\bar{B}^0](t)}{N[B^0](t) + N[\bar{B}^0](t)}$

Analysis Outline

Signal Selection

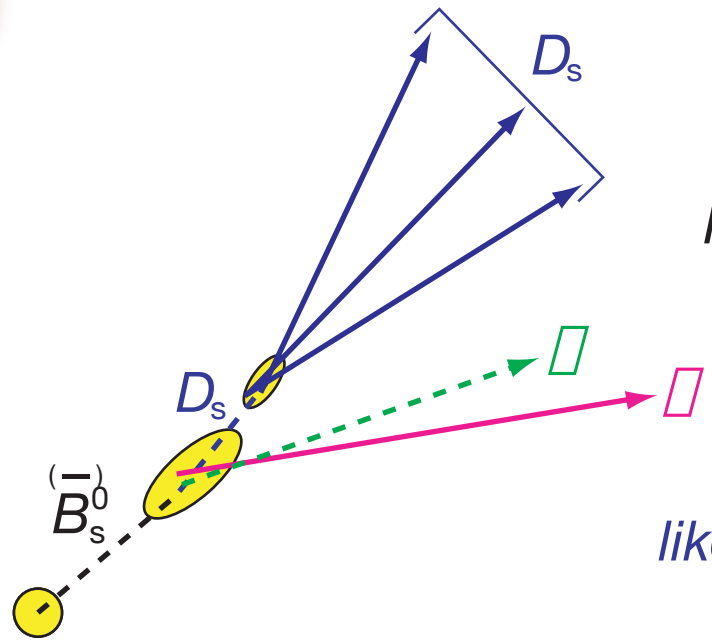
Moriond 2005

D_s □ □□
□ K^+K^-



Analysis Outline

Signal Selection



Moriond 2005

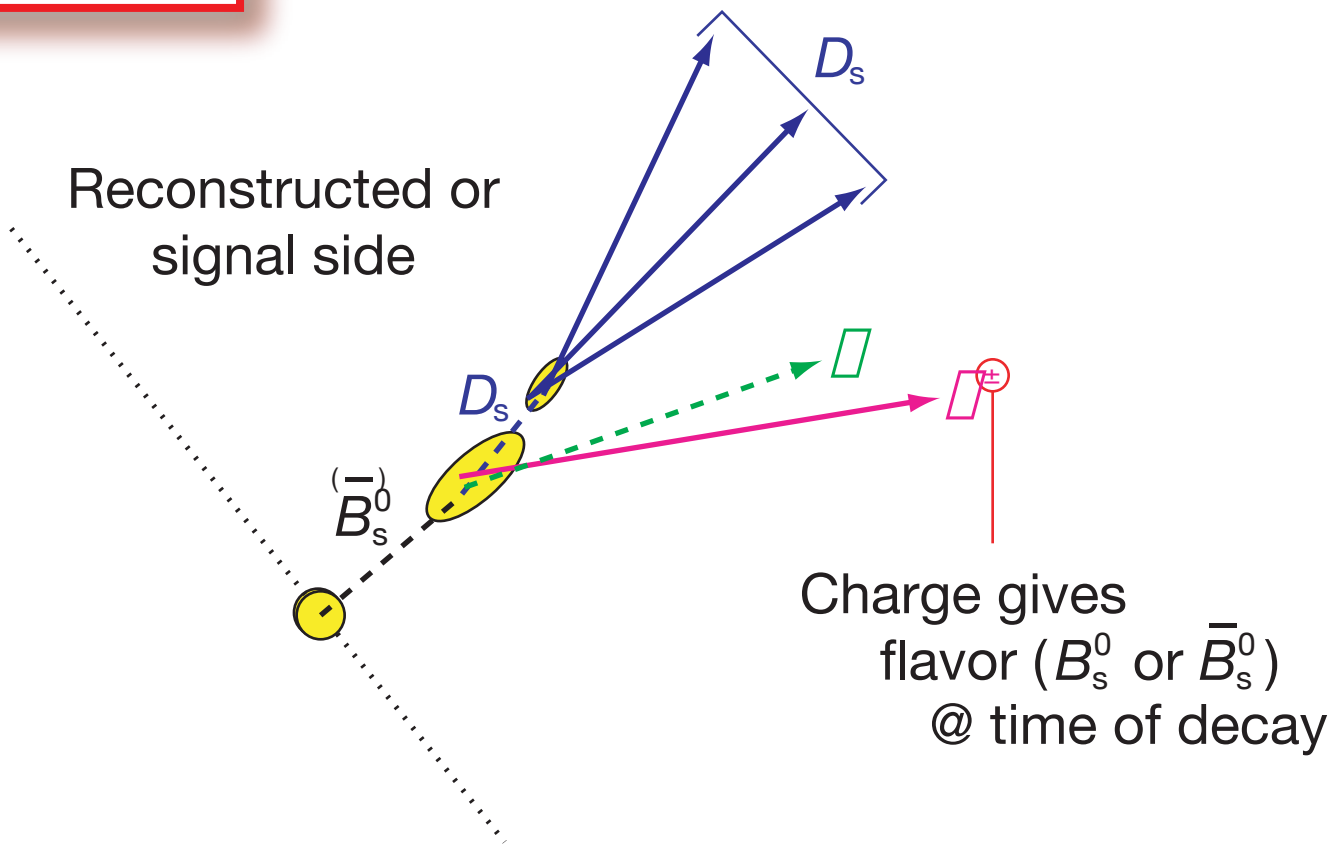
D_s [illegible] K^+K^-

Now: add

- D_s [illegible] K^*K [illegible] K [illegible]
- *Improved likelihood selection*

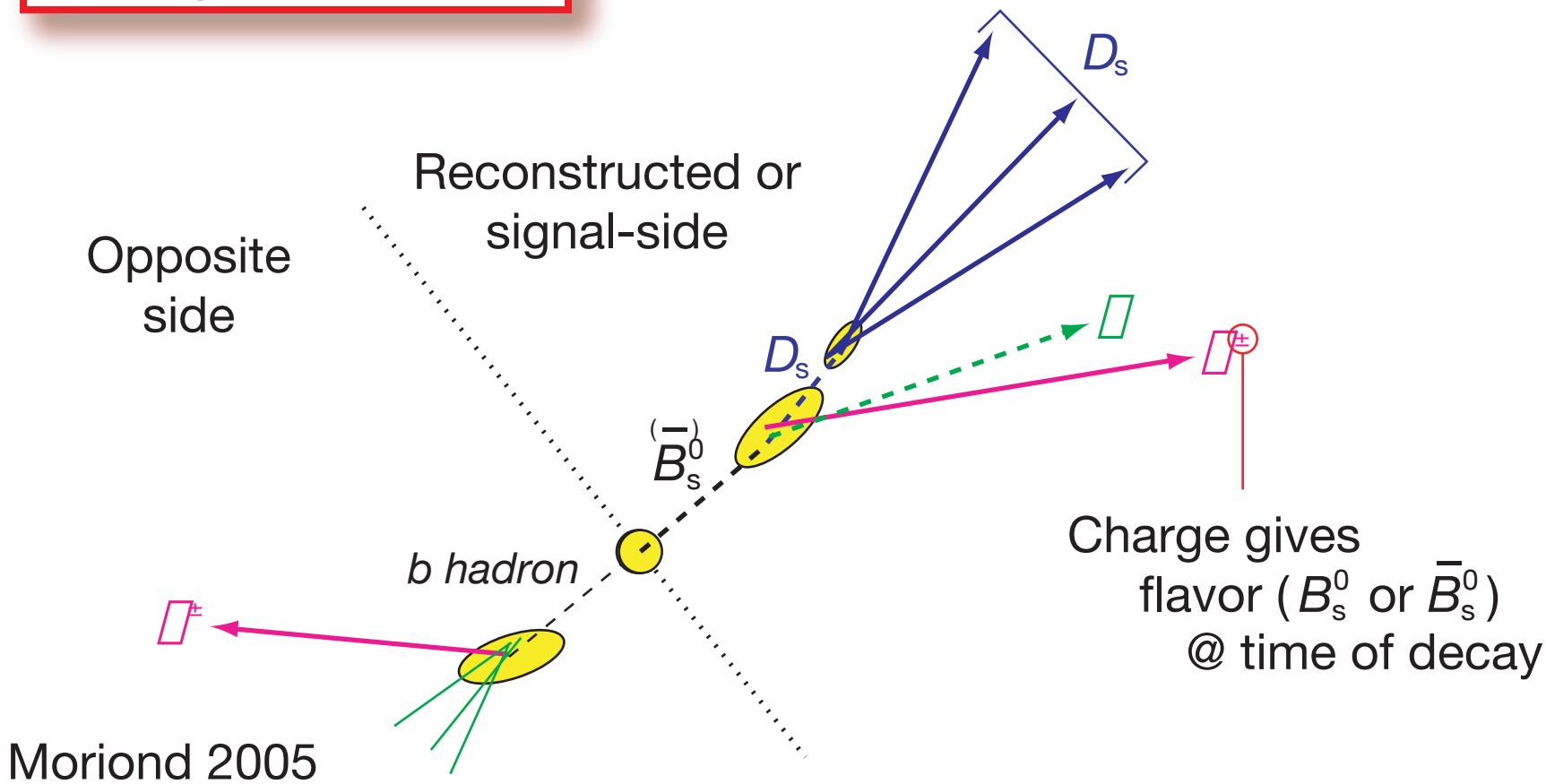
Analysis Outline

Flavor at decay time



Analysis Outline

Flavor at time of production



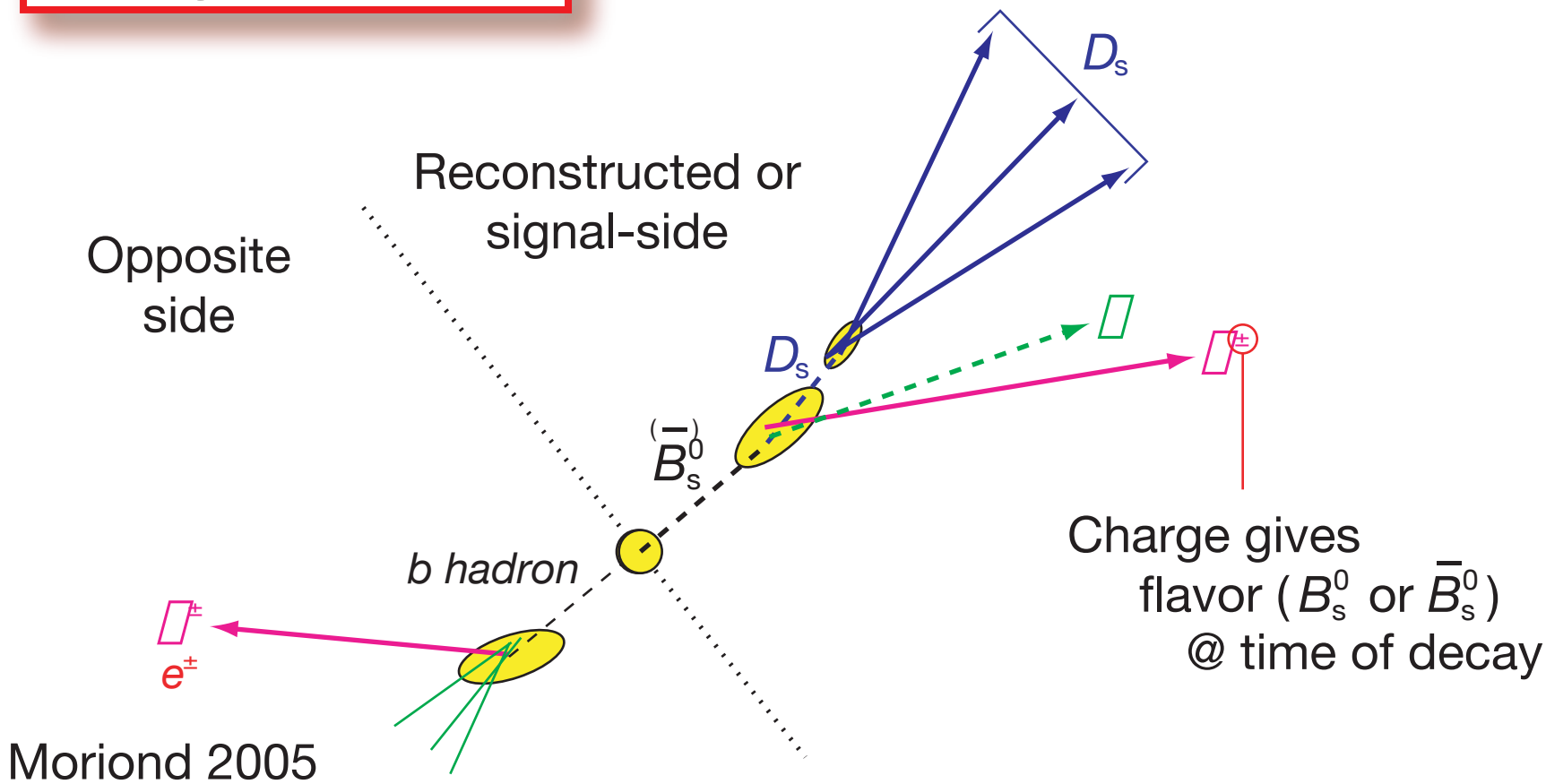
Moriond 2005

- jet charge including $\ell^\pm$, secondary vertex charge, etc.

  Flavor of signal-side at time of production (since b–$\bar{b}$ production)

Analysis Outline

Flavor at time of production



Moriond 2005

- jet charge including $\ell^{\pm}$, secondary vertex charge, etc.

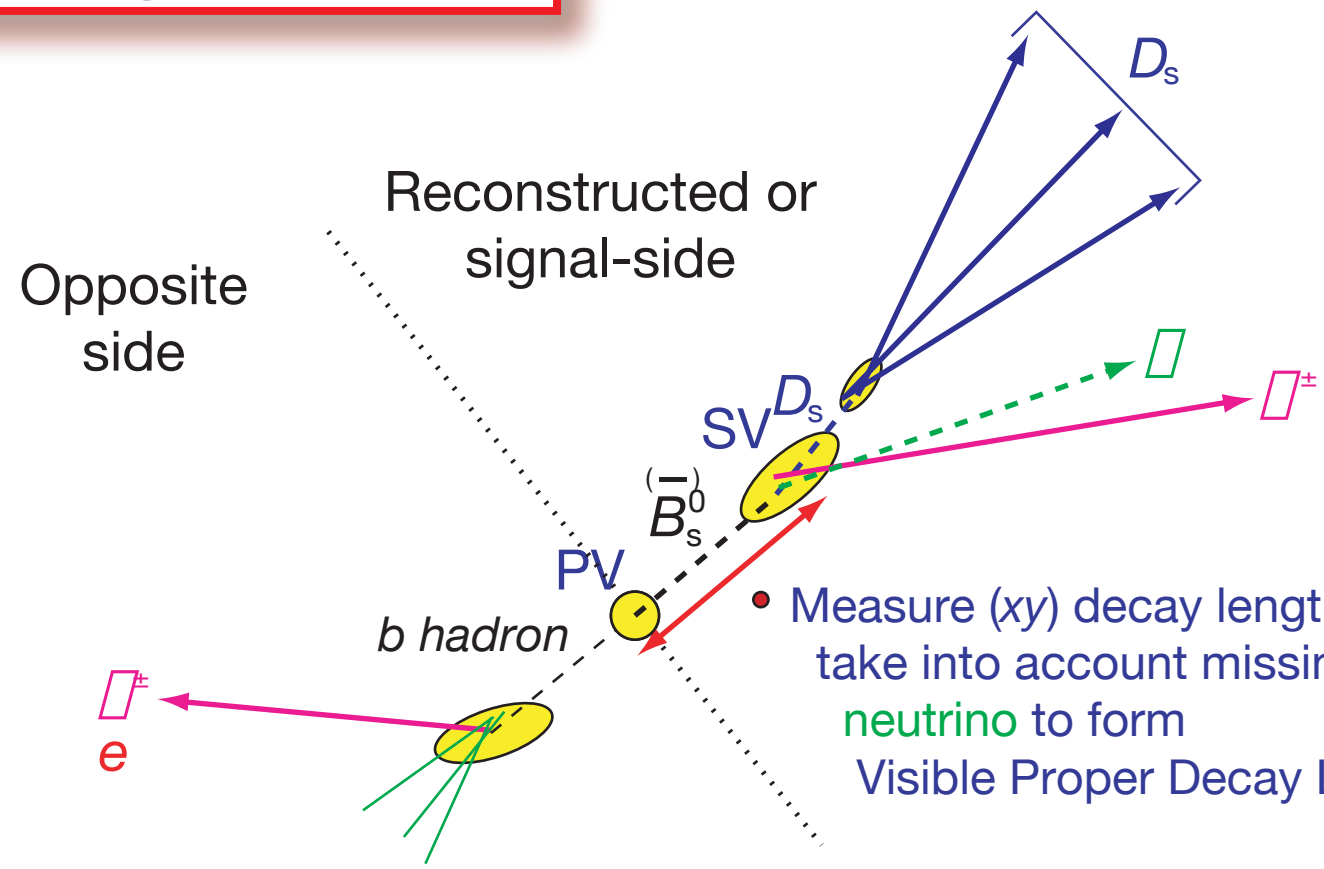
  Flavor of signal-side at time of production (since b–$\bar{b}$ production)

Now, add

- soft electrons, secondary vertex without muon, event charge

Analysis Outline

Proper decay time, asymmetry



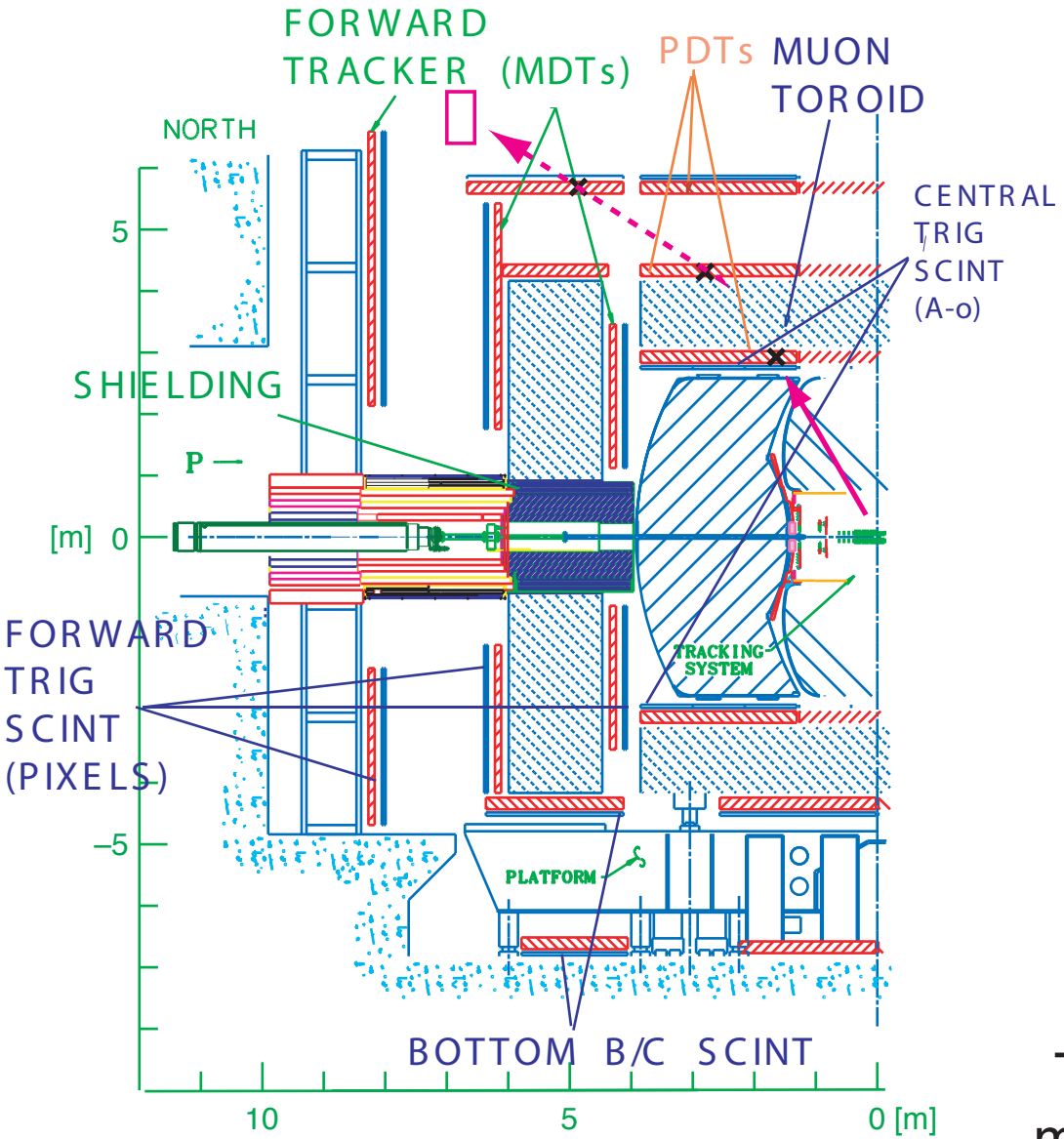
- Measure (*xy*) decay length, take into account missing neutrino to form Visible Proper Decay Length (VPDL)
- Plus important to know VPDL *uncertainty*

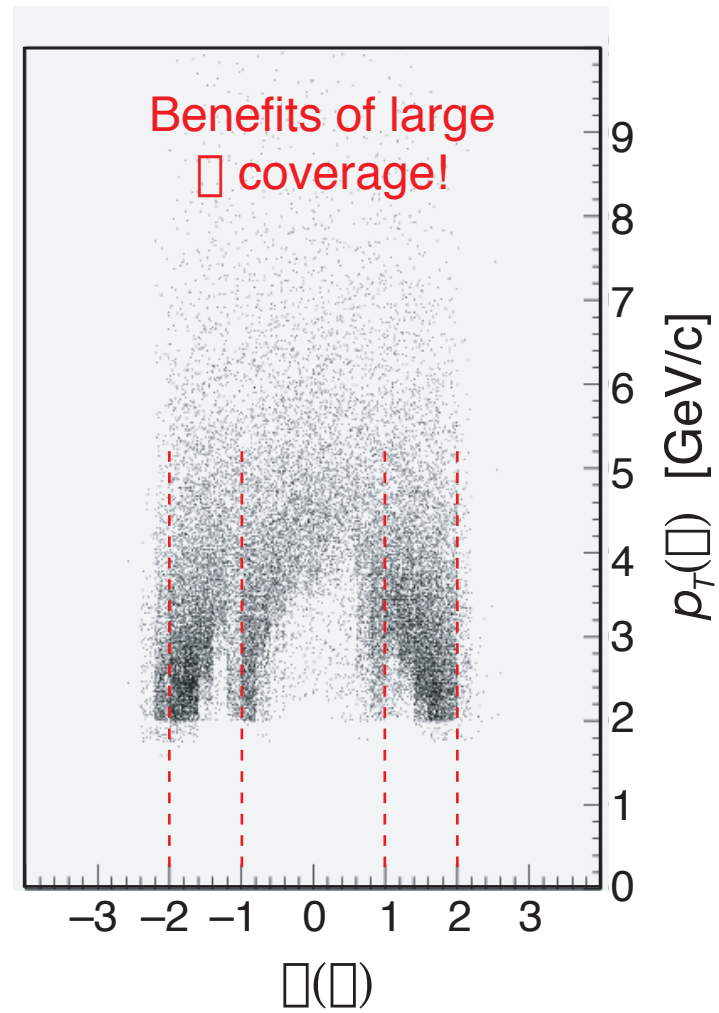
- Form asymmetry, $A = \dfrac{N_{\text{non-osc.}} - N_{\text{osc.}}}{N_{\text{non-osc.}} + N_{\text{osc.}}}$ in bins of VPDL,

  compare with expected asymmetry for a given Δm_s

Muon System

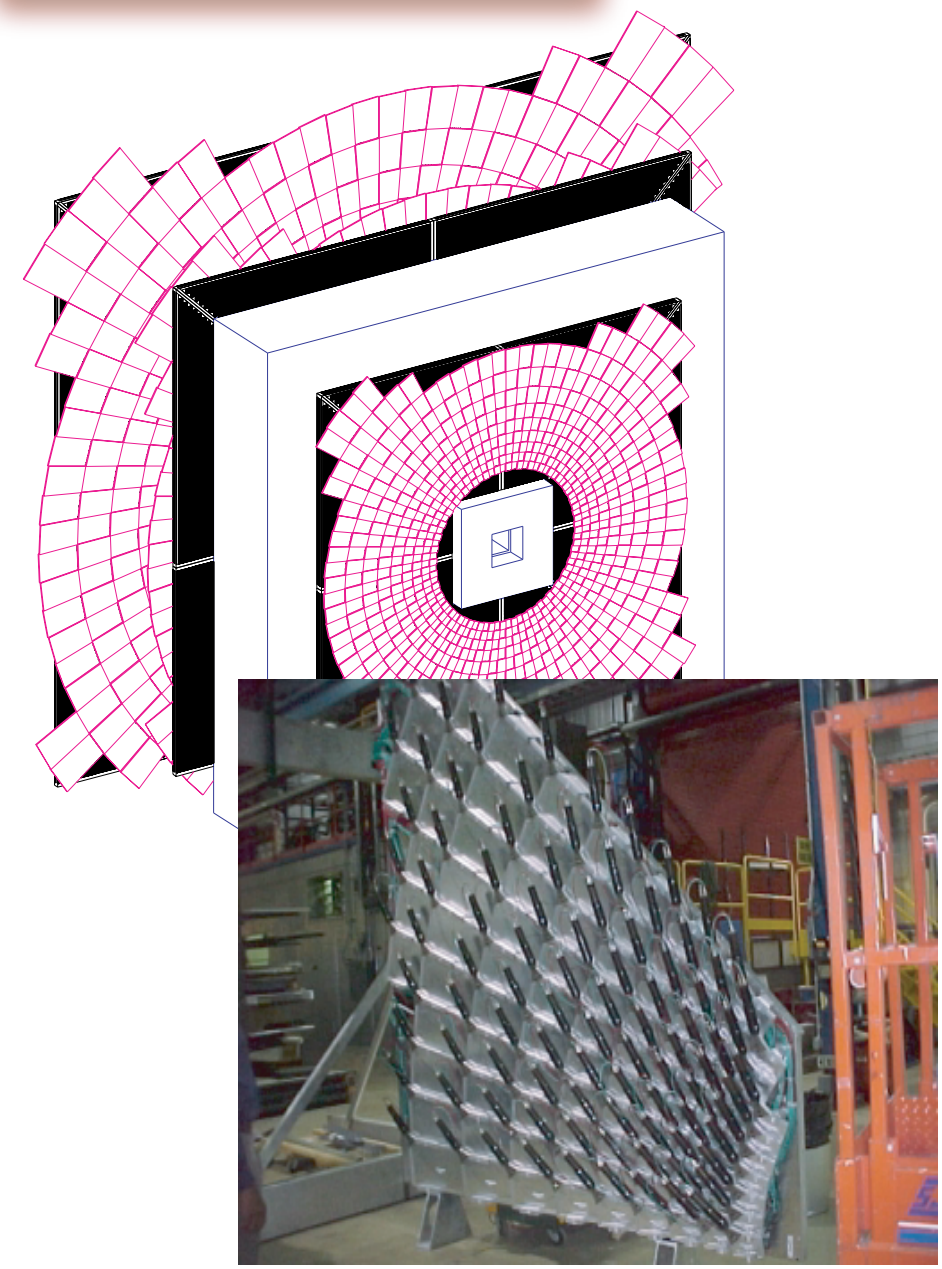
- "Local" momentum measurement in toroidal field





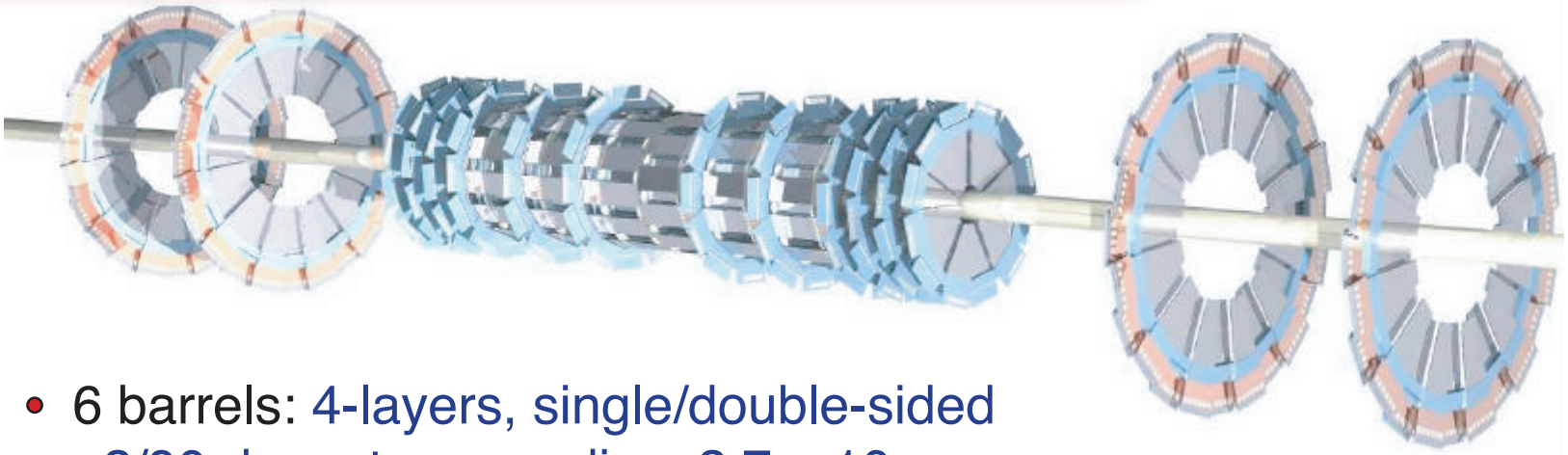
Triggered *and* reconstructed muons (semileptonic *b* decay)

Muon Triggers



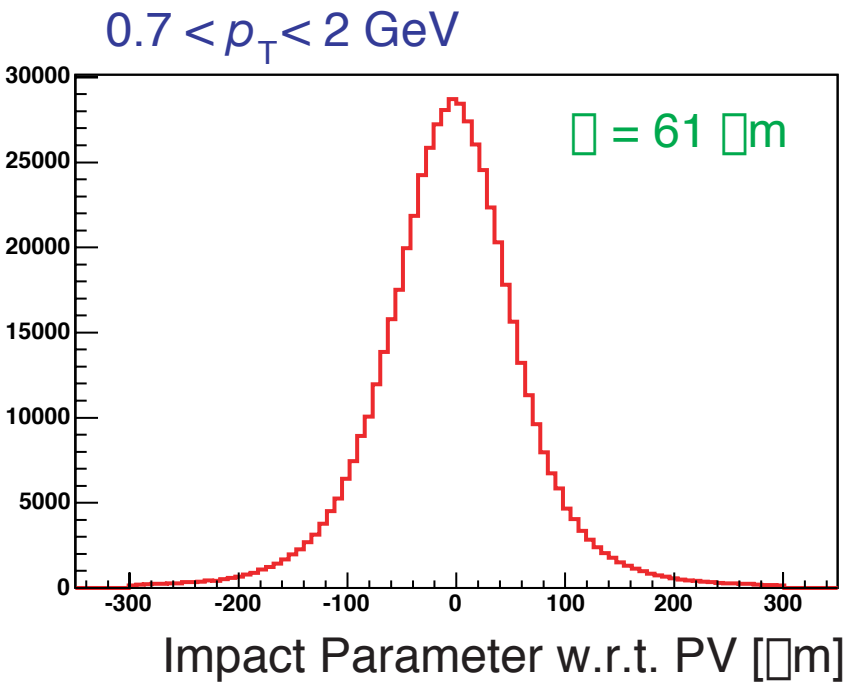
- Single inclusive muons,
  $|\eta| < 2.0$, $p_T > 3, 4, 5$ GeV
  - Muon + track match at Level 1 and a muon at Level 2
  - Unbiased; prescaled or turned off depending on inst. lumi.
    Used for this analysis
  - *B* physics triggers at all lumi's: extra tracks at medium lumi's, impact parameter requirements, associated invariant mass track selections at Level 3 when higher
- Dimuons: other muon for flavor tagging
- e.g., at low luminosity,
  15–20 x 10^{-30} $cm^{-2}s^{-1}$,
  ~25 Hz of 50–60 Hz at Level 3
  (...and no rate problems at L1/L2)

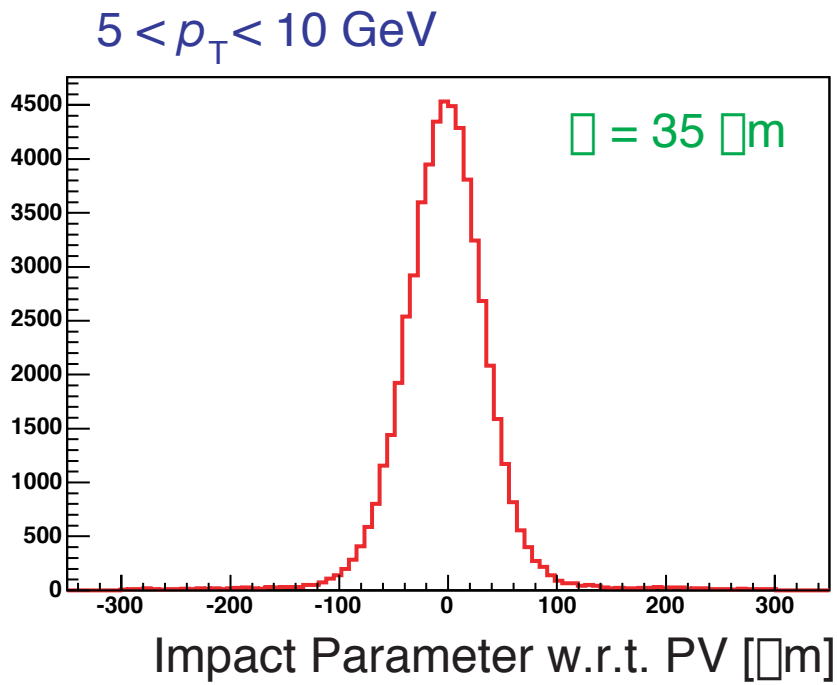
Silicon Microvertex Tracker (SMT)



- 6 barrels: 4-layers, single/double-sided
  2/90 deg. stereo, radius: 2.7 – 10 cm
- 12 central F disks: double-sided, ± 15 deg. stereo
- 4 forward H disks: single-sided, ±7.5 deg. stereo,
  |z| = 1.2 m, radius: 9.5 – 20 cm
- Single hit resolution of 10 μm, S/N > 10
- Tracking out to η ~ 3 (θ ~ 6 deg.)
- Rad. hard to 1 MRad ("Layer 0" at *r* ~ 1.7 cm to be installed)

Impact Parameter Resolution





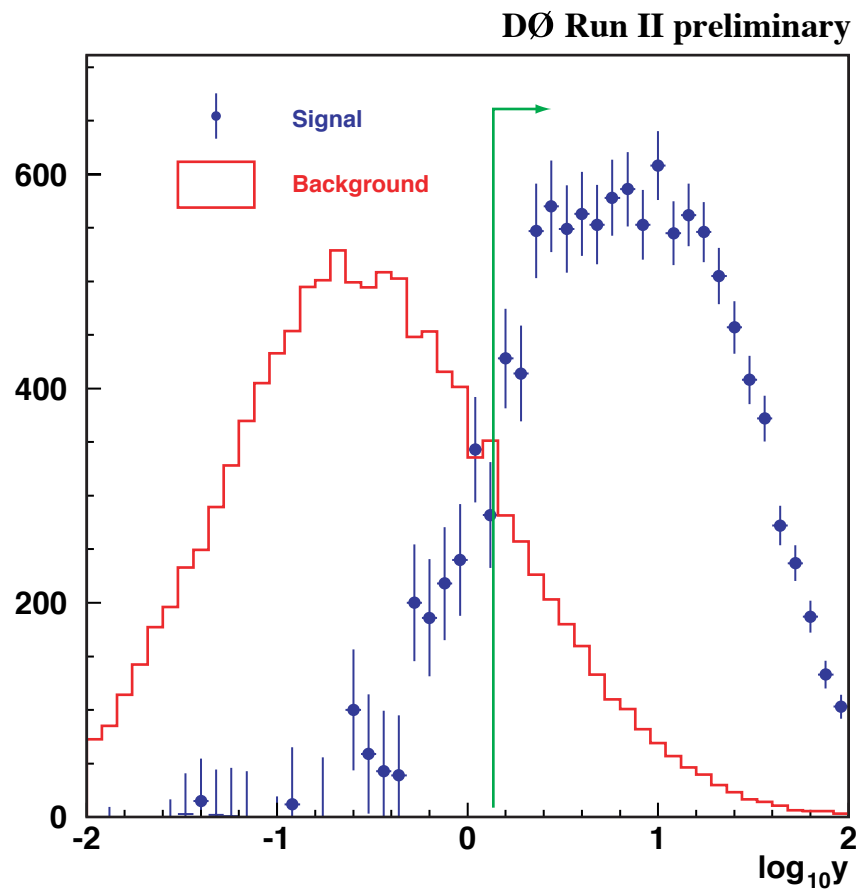
Both include σ_{PV}~ 26 m from primary vertex
(subtract out in quadrature)

Signal Selection

Further improvement in S/B following initial vertex, lifetime & mass window cuts:

- Set of discriminating variables x_i constructed for each event
- Cut on combined variable, product of likelihood ratios (PDF for background and PDF for signal):

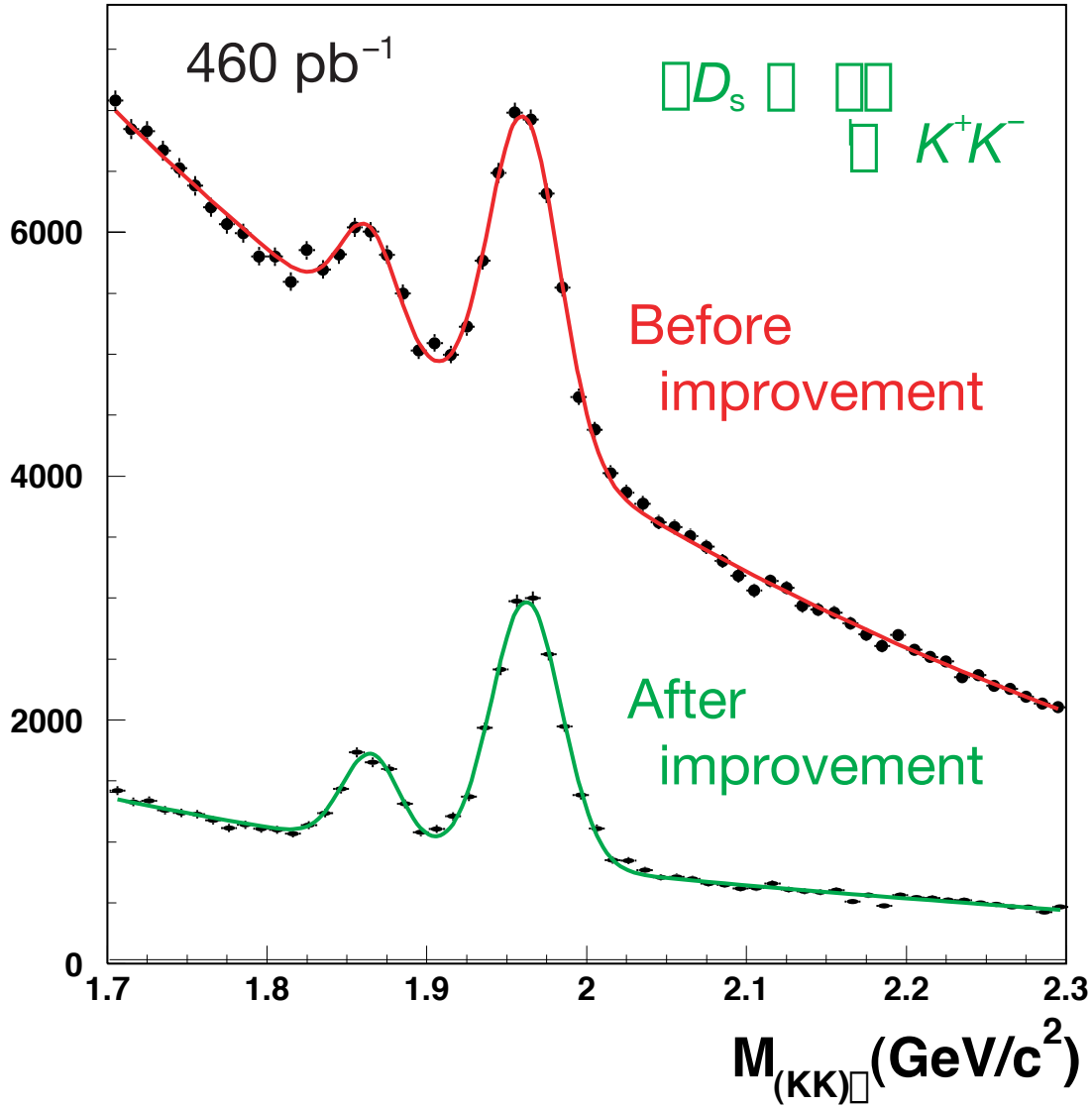
$$y = \prod_{i}^{n} y_i \; ; \qquad y_i = \frac{PDF_i^{s}(x_i)}{PDF_i^{b}(x_i)}$$



The following discriminating variables were used:

- Helicity angle, defined as the angle between the D_s and K_1 momenta in the (K_1, K_2) center of mass system;
- Isolation, computed as $Iso = p^{tot}(\mu D_s)/(p^{tot}(\mu D_s) + \sum p_i^{tot})$. The sum $\sum p_i^{tot}$ was taken over all charged particles in the cone $\sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} < 0.5$, where $\Delta\eta$ and $\Delta\phi$ are the pseudorapidity and the azimuthal angle with respect to the (μD_s) direction. The μ, K_1, K_2 and π were not included in the sum;
- $p_T(K_1 K_2)$;
- Invariant mass, $M(\mu D_s)$;
- χ^2 of the D_s vertex fit;
- $M(K_1 K_2)$.

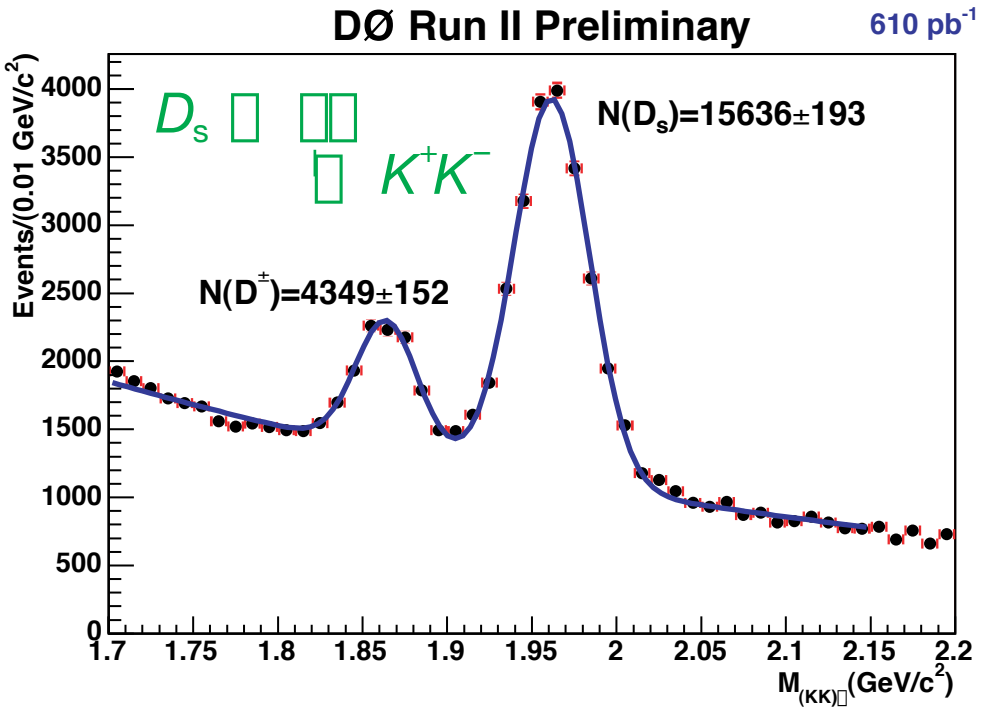
For D_s [illegible] K^+K^-

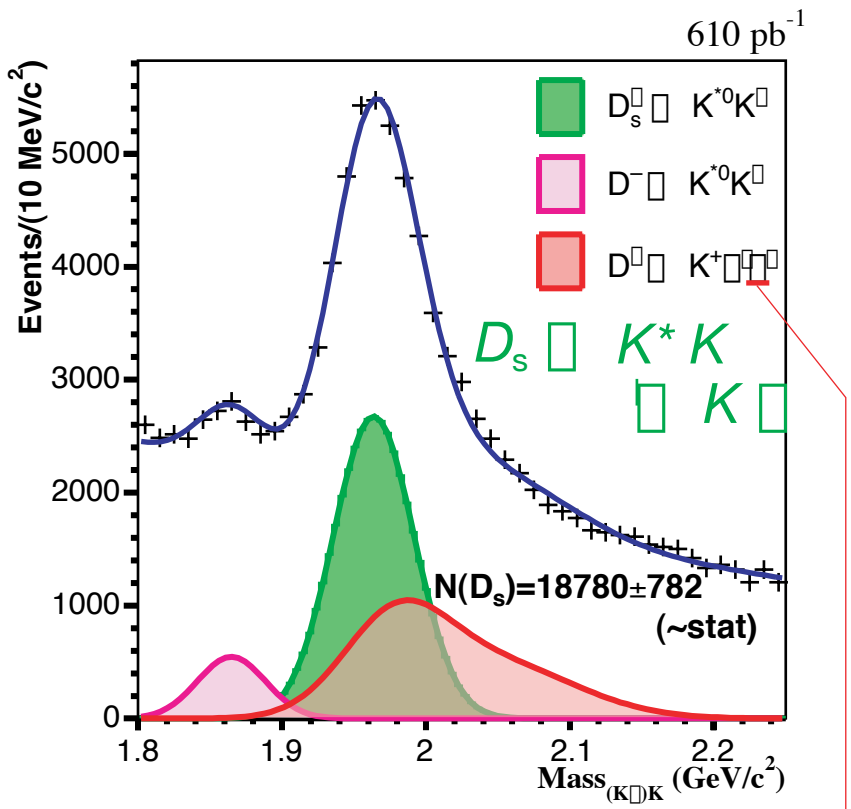

460 pb^{-1}
D_s
K^+K^-
Before improvement
After improvement
6000
4000
2000
0
1.7
1.8
1.9
2
2.1
2.2
2.3
$M_{(KK)}$ (GeV/c^2)

Signal

$B_s^0 \to D_s^- \mu^+ \nu$

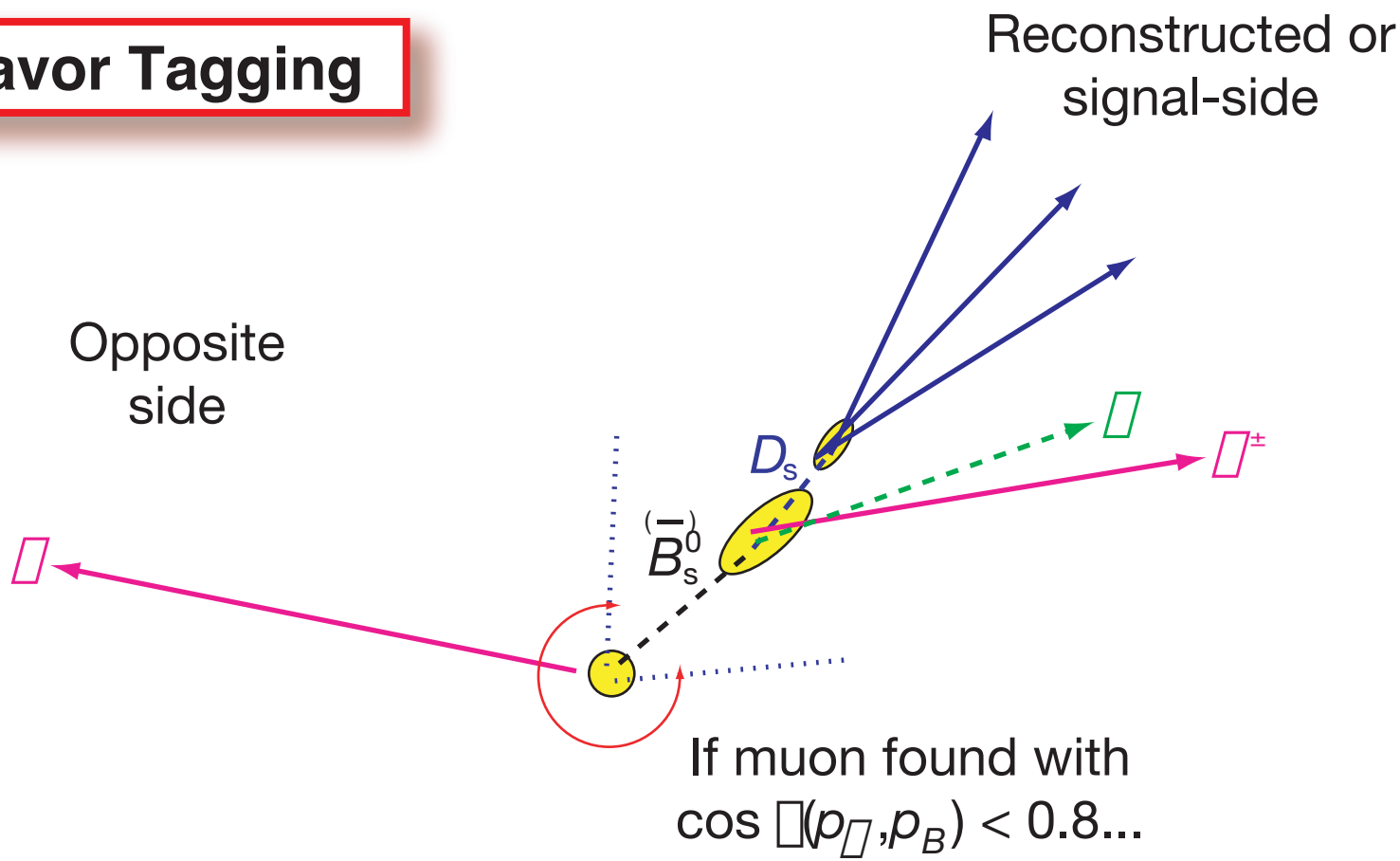
- Impressively large semileptonically decaying B_s^0 sample (~34k)!





- Nasty reflections!
  (recall: no π/K identification, misid a π as a K) use MC

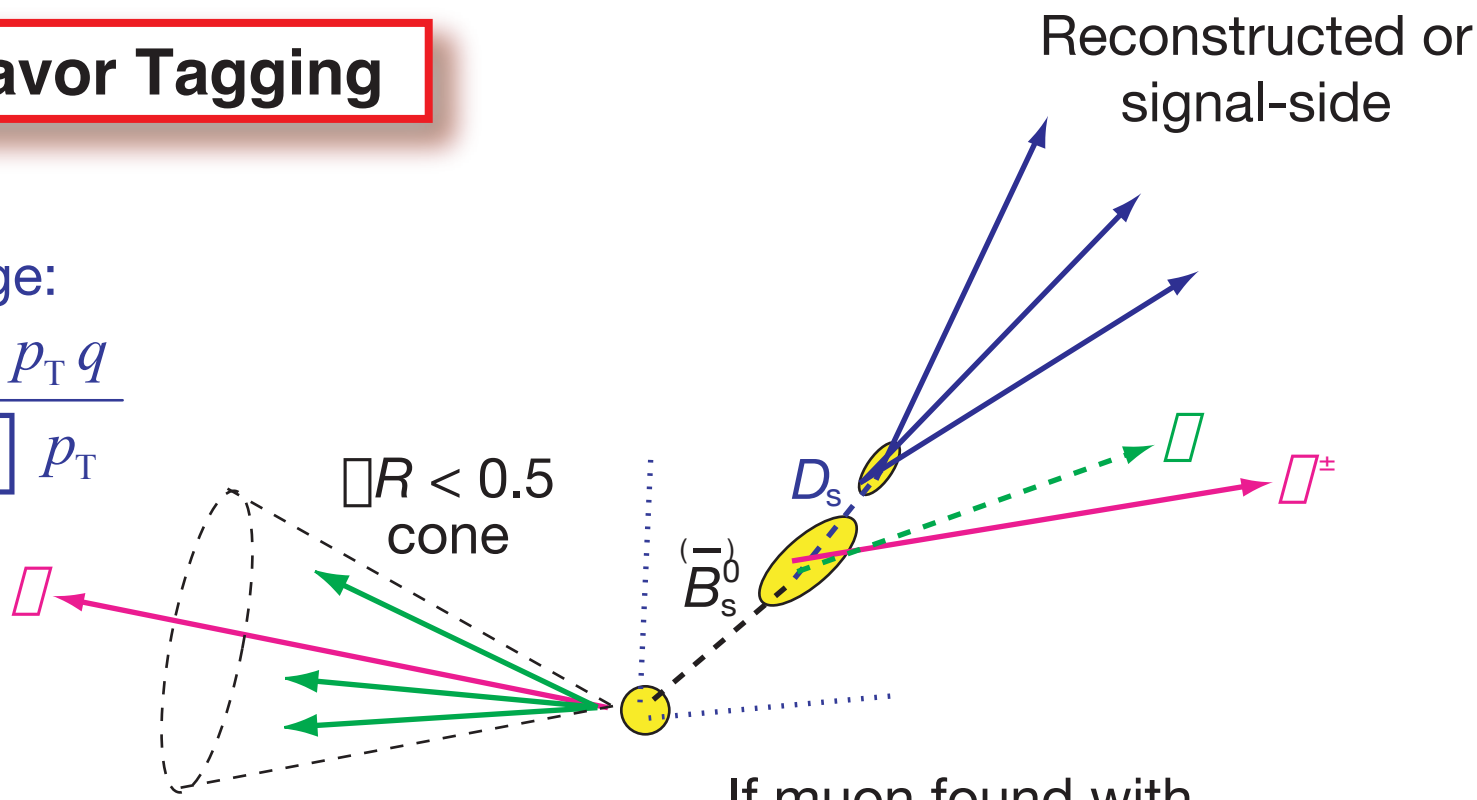
Initial Flavor Tagging



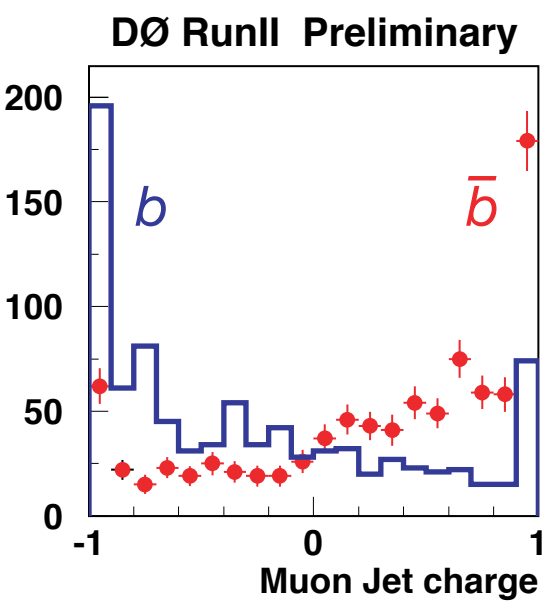
Initial Flavor Tagging

Muon jet charge:

$$Q_J^{\mu} = \frac{\sum p_T q}{\sum p_T}$$

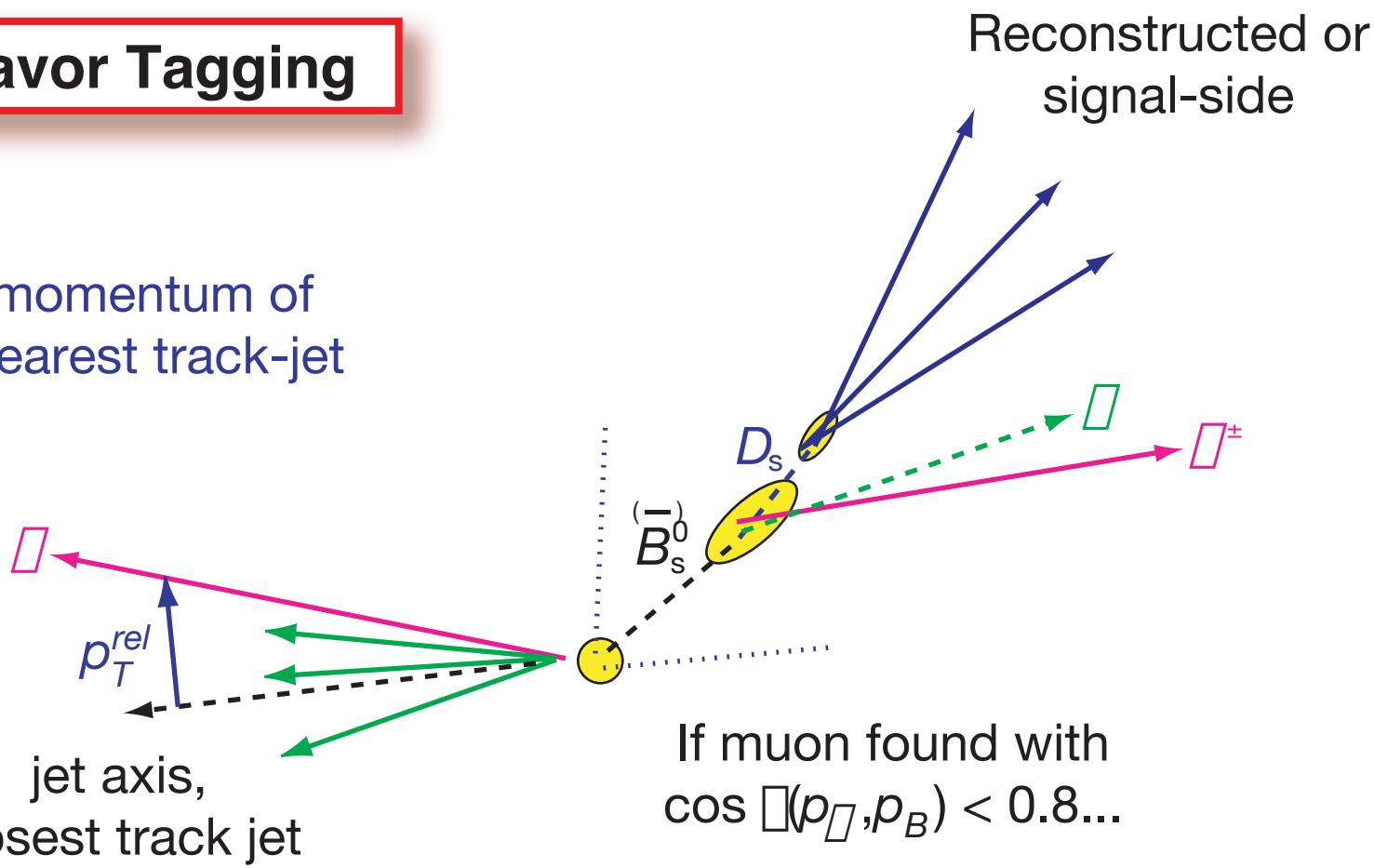


If muon found with $\cos\theta(p_\mu, p_B) < 0.8$...

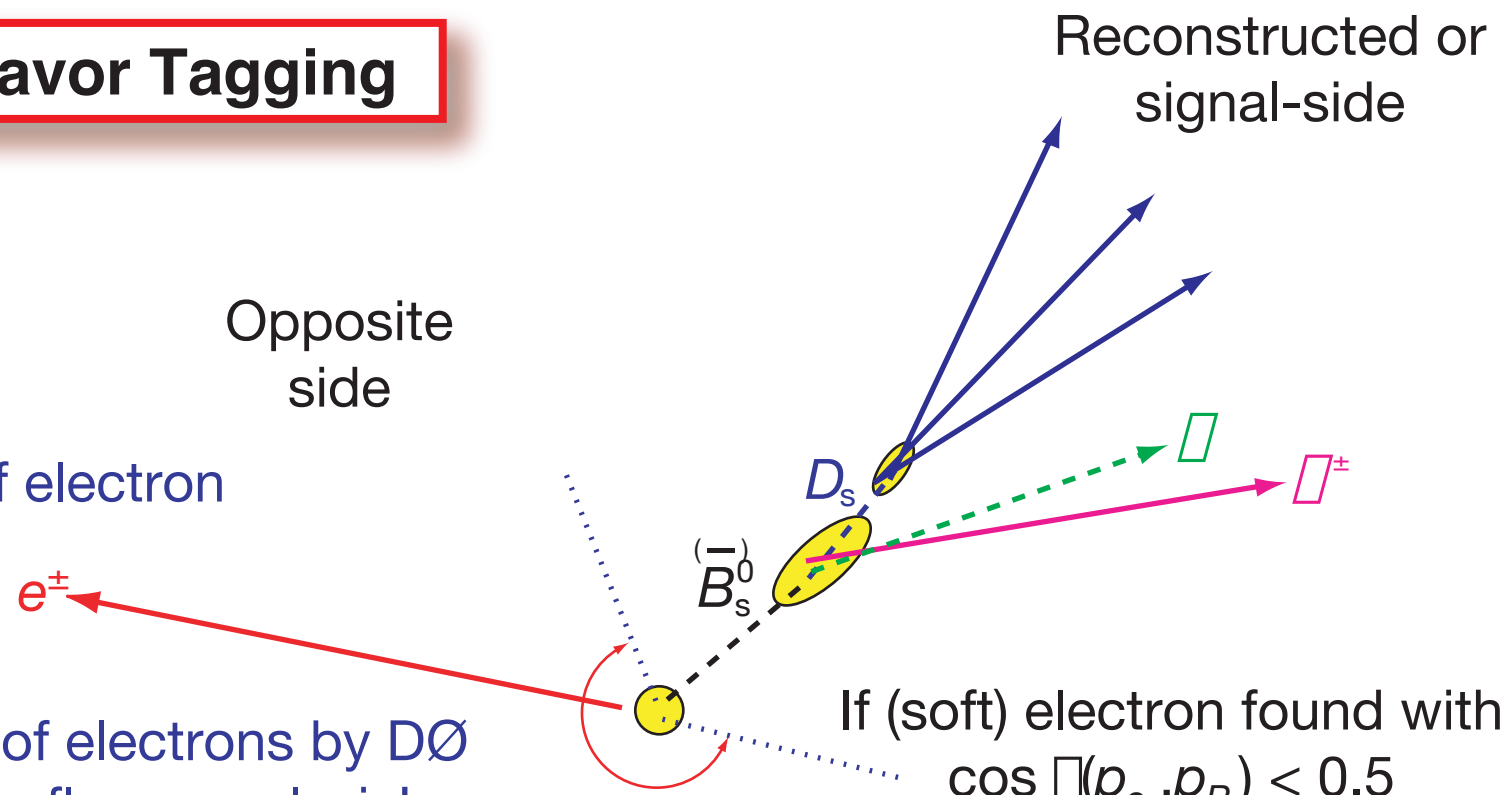


Initial Flavor Tagging

Transverse momentum of
muon w.r.t. nearest track-jet

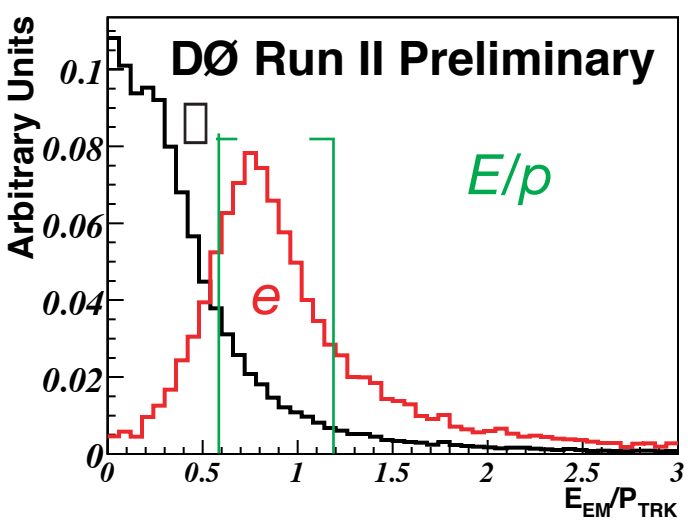


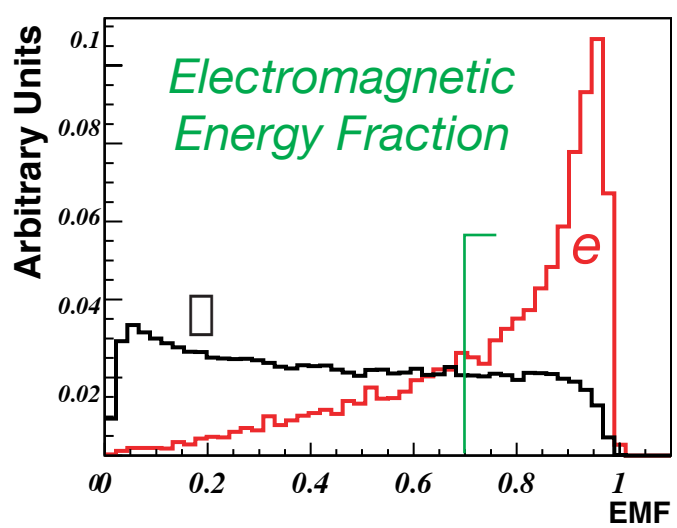
Initial Flavor Tagging



- Charge of electron
- First use of electrons by DØ in a heavy-flavor analysis!

If (soft) electron found with $\cos\theta(p_e, p_B) < 0.5$



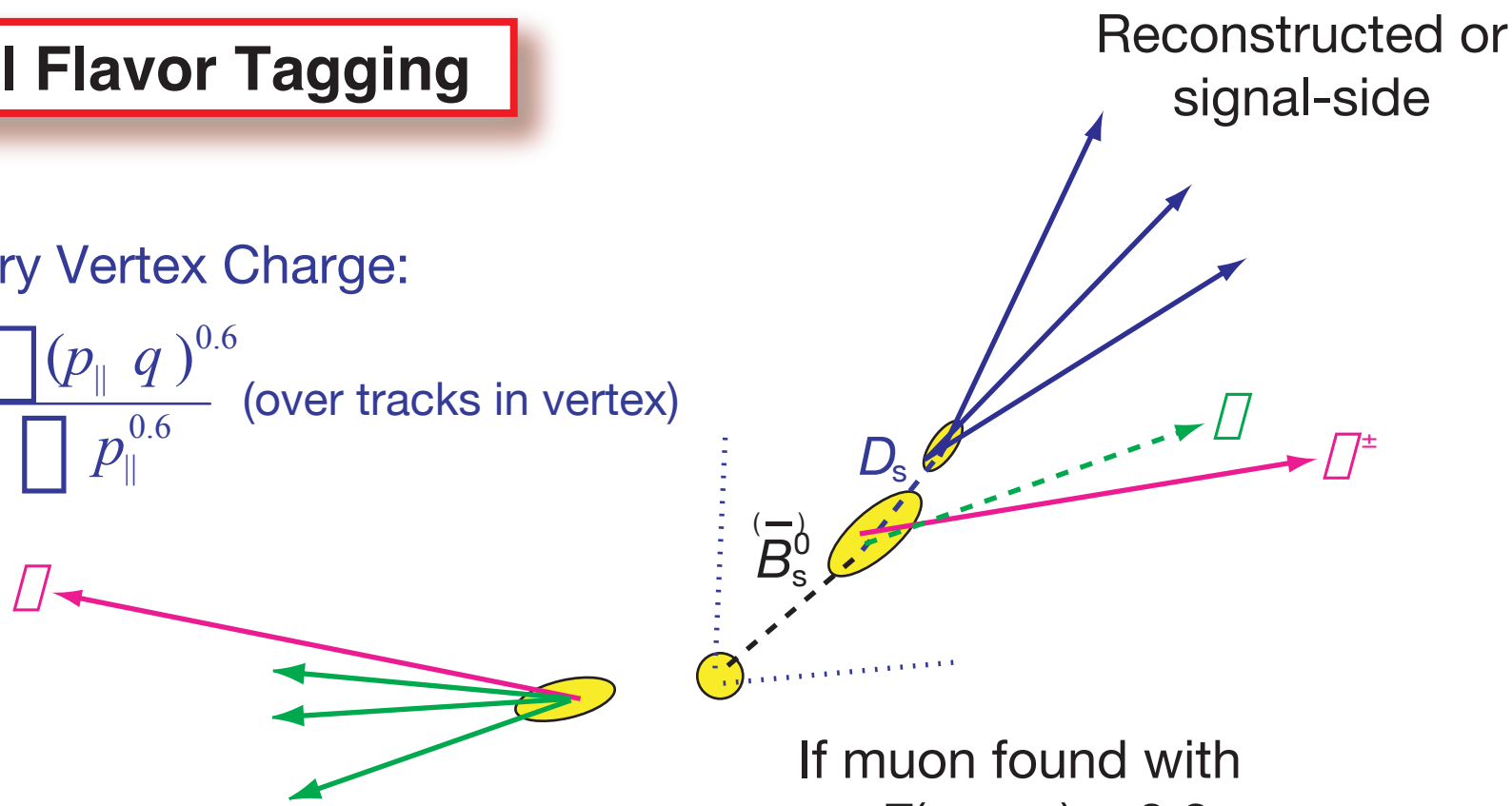


- $p_T > 2$ GeV
- Energies in calorimeter in road along electron track

Initial Flavor Tagging

- Secondary Vertex Charge:

$$Q_{SV} = \frac{\sum (p_{\parallel}\, q)^{0.6}}{\sum p_{\parallel}^{0.6}}$$ (over tracks in vertex)



If muon found with $\cos\angle(p_{\mu}, p_B) < 0.8$...

- Secondary Vertex p_T^{SV}

also even if no muon found, but $\cos\angle(p_{SV}, p_B) < 0.8$...

- Event charge:

$$Q_{EV} = \frac{\sum p_T\, q}{\sum p_T}$$ for charged tracks outside cone of $\Delta R > 1.5$ of B_s^0

Initial Flavor Tagging

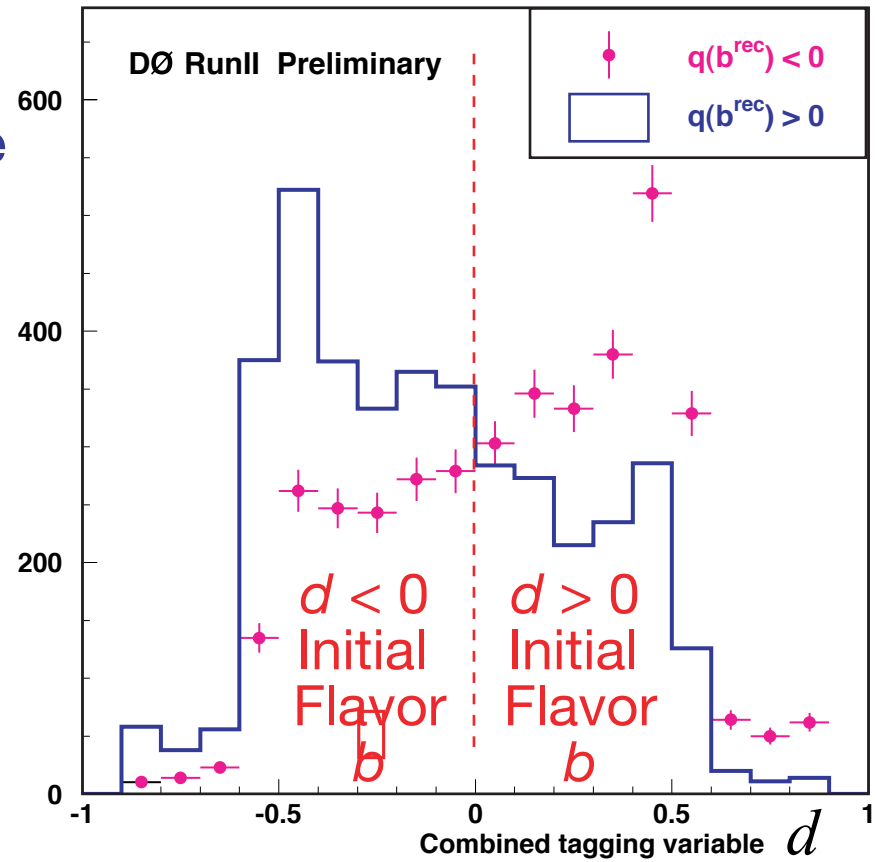
- Each flavor discriminating variable x_i as used described previously,

  likelihood ratio: $y = \prod_{i}^{n} y_i \; ; \quad y_i = \dfrac{PDF_i^{\bar{b}}(x_i)}{PDF_i^{b}(x_i)}$

  From *data*, $B_d^0 \to D^{*-} \mu^+ \nu$ wrong-sign subtracted, at short lifetimes *(non-oscillated)*

- Form single flavor-tag variable

$$d = \frac{1 - y}{1 + y}$$



more pure ← → more pure

Proper Decay Length

- Measure decay length in *x-y* plane (and error from track parameter errors), need boost, but due to escaping neutrino, can only reconstuct partially:

$$x^M = \left(\vec{L}_{xy} \cdot \vec{p}_{xy}^{\,D_s\phi}\right) / \left(p_T^{D_s\phi}\right)^2 m_{B_s} \qquad K = p_T^{D_s\phi} / p_T^{B_s} \qquad ct_{B_s} = x^M K$$

Measured visible proper decay length, VPDL

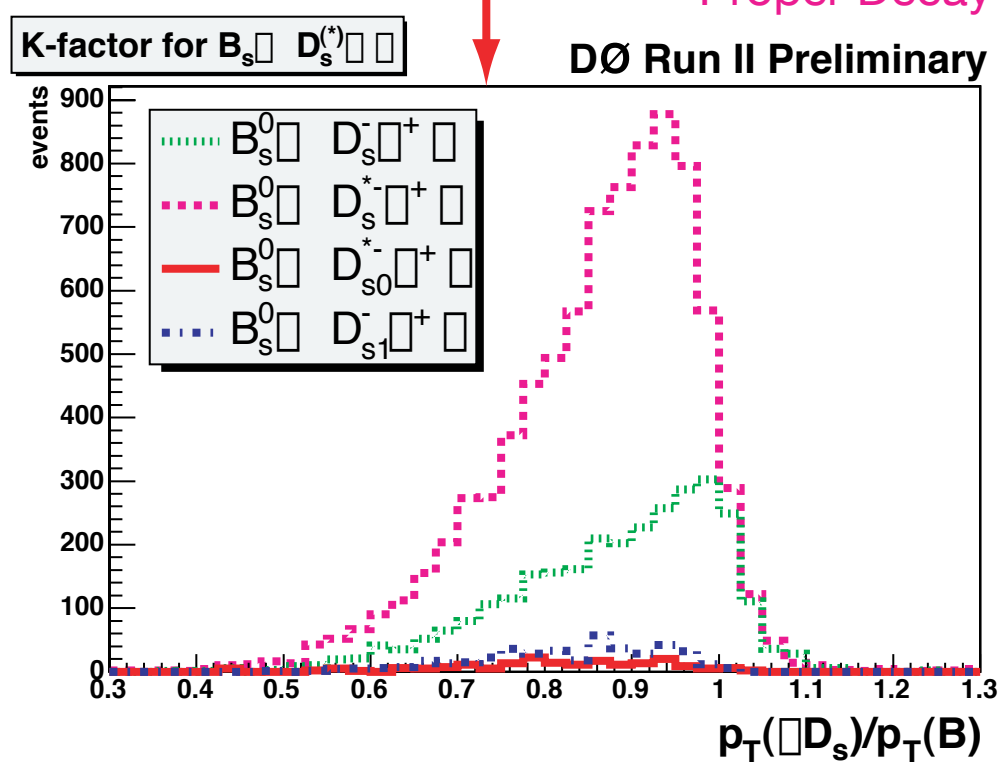
"K Factor"

Measured Proper Decay Length

- From MC, each decay mode
- Also takes into account other missing particles

$B_s^0 \to D_s^{*-} \mu^+ \nu$

$\hookrightarrow D_s^- \gamma$



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Measured visible proper decay length, VPDL

$$K = p_T^{D_s\square} / p_T^{B_s}$$

"K Factor"

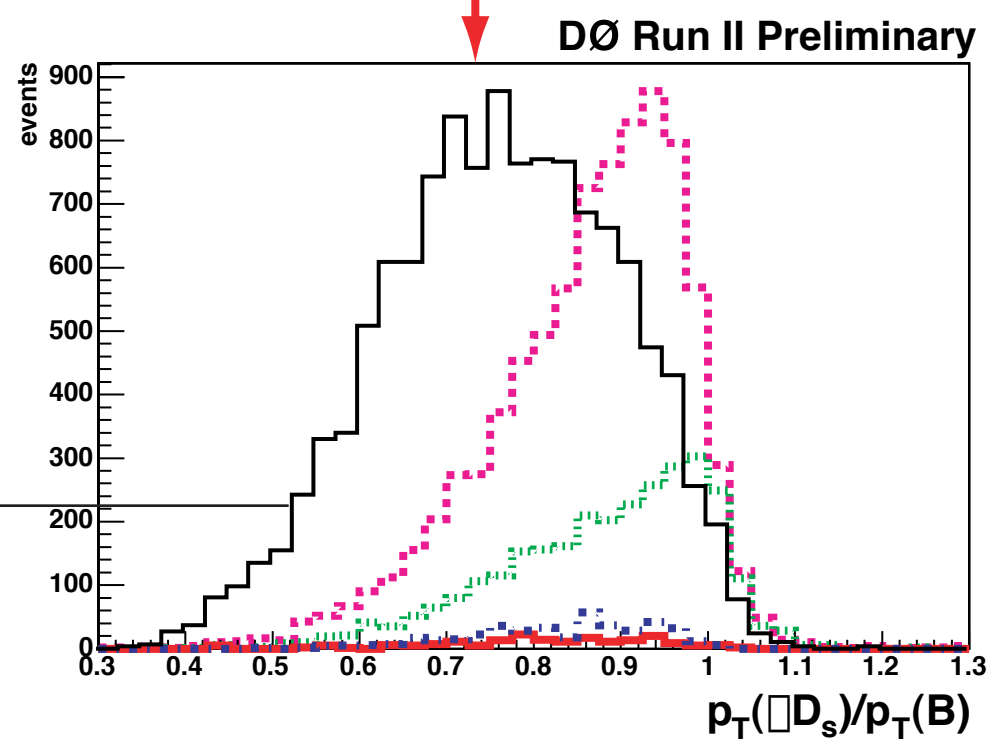
$$\boxed{ct_{B_s} = x^M K}$$

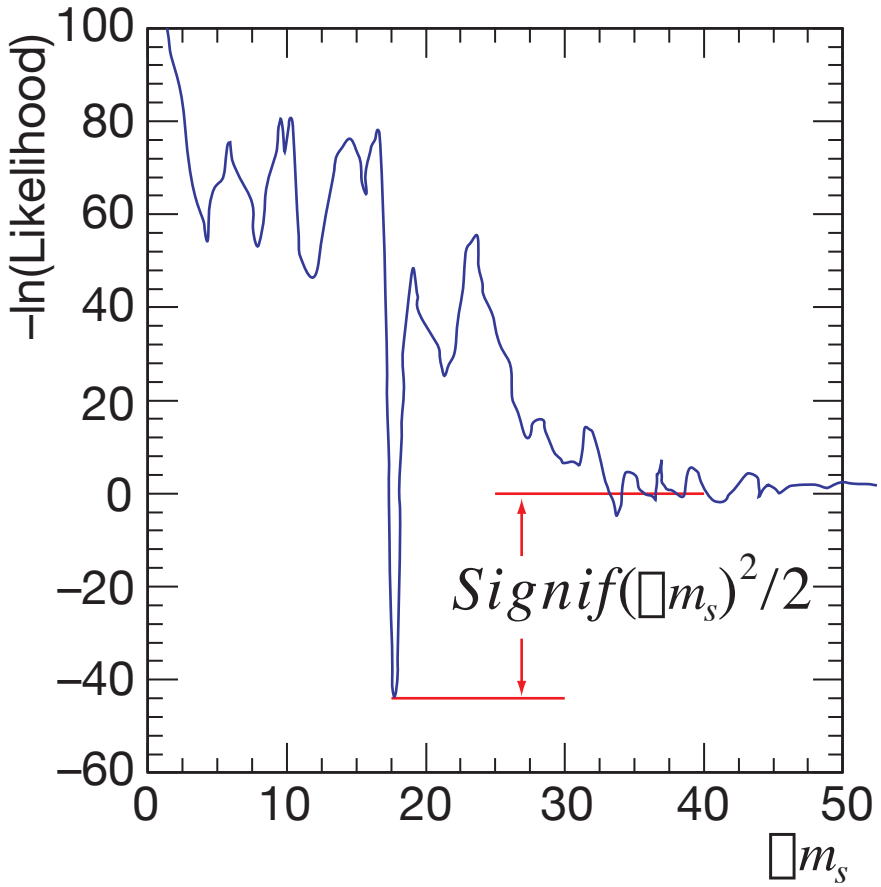
Measured Proper Decay Length

- From MC, each decay mode
- Also takes into account other missing particles

$B_s^0 \square \; D_s^- D_s^+ X$

$\square \; \square\square X$





Effective flavor tagging power

Proper time resolution

$$Signif = \sqrt{\frac{N\varepsilon\mathcal{D}^2}{2}}\, e^{-\frac{(\Delta m_s \sigma_t)^2}{2}} \sqrt{\frac{S}{S+B}}$$

- "Depth" of dip of likelihood in frequency space

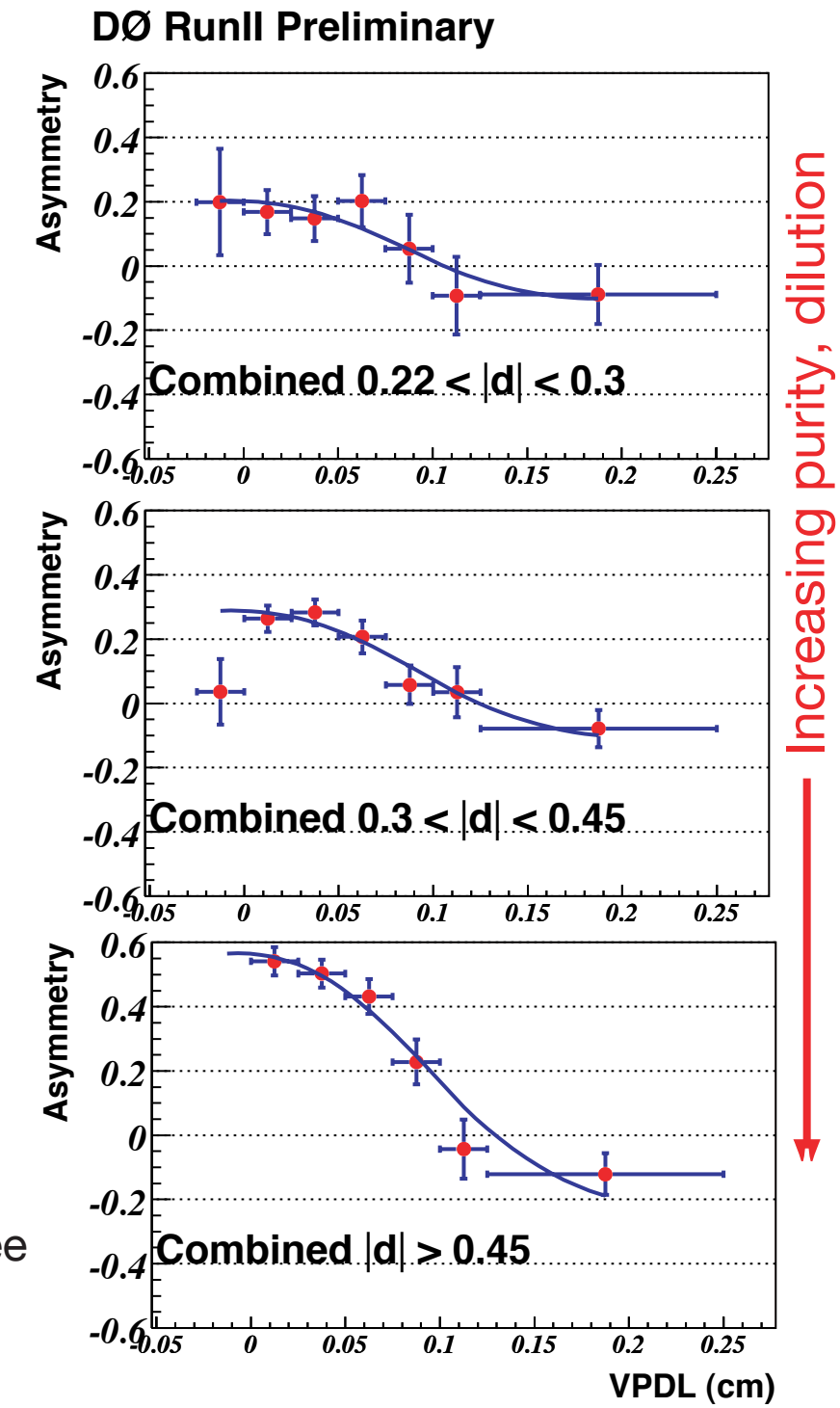
Efficiency	Purity	Dilution
$\varepsilon = \frac{N_{\text{total flav. tagged events}}}{N_{\text{total events}}}$	$\varepsilon = \frac{N_{\text{correct flav. tagged events}}}{N_{\text{total flav. tagged events}}}$	$\mathcal{D} = 2\varepsilon - 1$ (less than 1, ~ multiplier of "ideal" ±1 amplitude of asymmetry)

Initial Flavor Tagging

Measuring Dilution with Data

- Make B_d^0 oscillation measurement with same opposite-side tagger as for B_s^0, use as inputs
  (since signal and opposite-side B species uncorrelated. Same-side tagging does depend of specific species fragmentation, will need MC to get dilutions, more uncertainty.)
- Take |d| > 0.3, amplitude gives dilution, $\mathcal{D}$, frequency gives Δm_d
- $\Delta m_d = 0.501 \pm 0.030 \pm 0.016$ ps
  (WA 0.509 ± 0.004 ps^{-1})
- Dilutions
  - $\mathcal{D}(B_d^0) = 0.414 \pm 0.023 \pm 0.017$
  - $\mathcal{D}(B^+) = 0.368 \pm 0.016 \pm 0.008$
  - $\mathcal{D}_{comb.} = 0.384 \pm 0.013 \pm 0.006$
    $\Delta\mathcal{D}^2 = (1.94 \pm 0.14 \pm 0.09)\%$
  - MC shows that dilutions for B_s^0 and B_d^0 agree
  - Dilution for B_d^0 agrees in data and MC

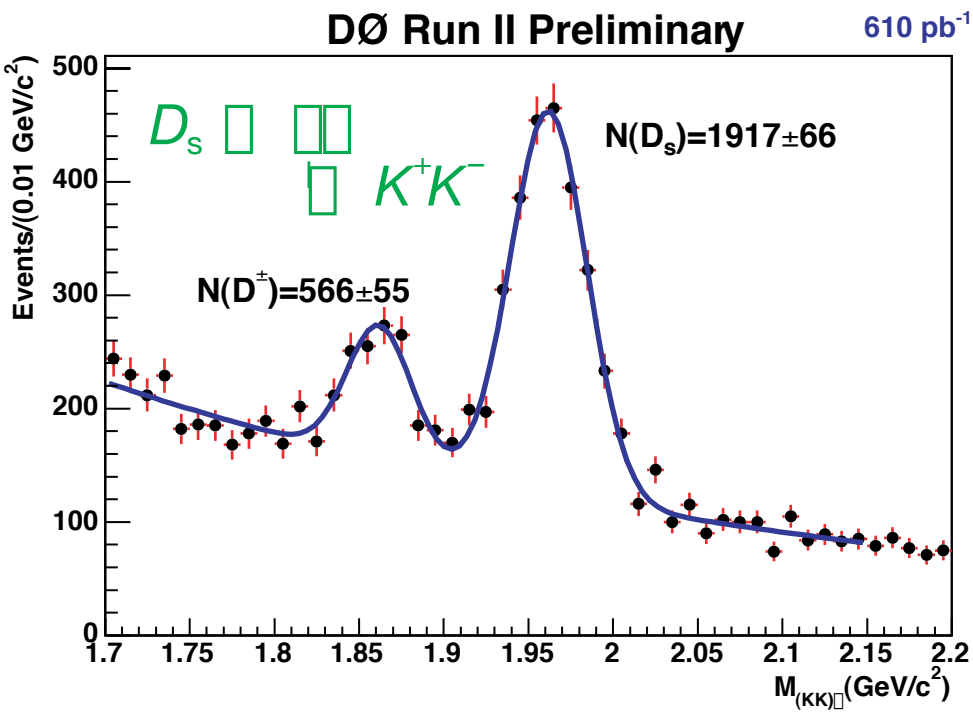
syst.

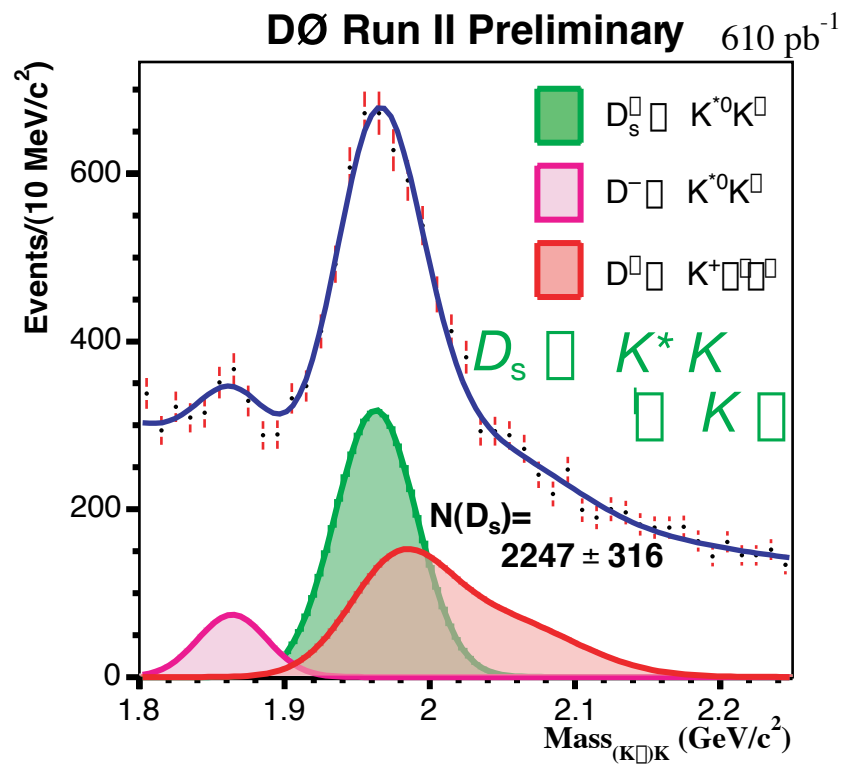


Flavor-tagged Signal

$B_s^0 \to D_s^- \mu^+ \nu$

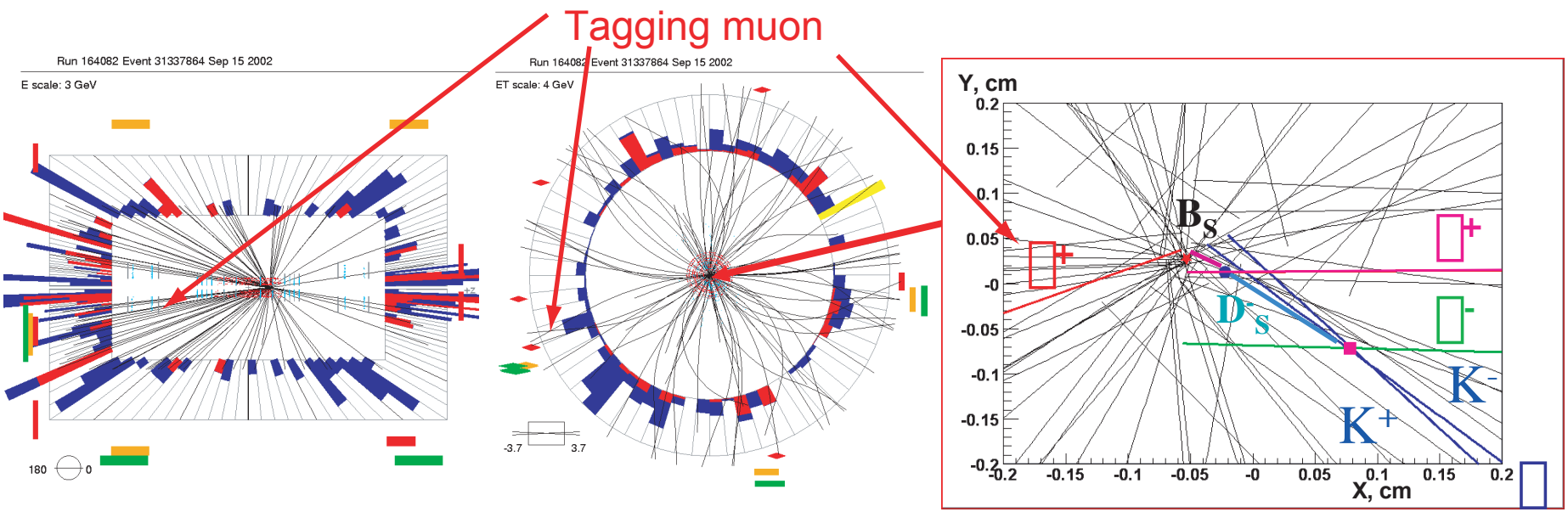
- Flavor-tagging efficiency for combined opposite-side tag, ε = 12.3%





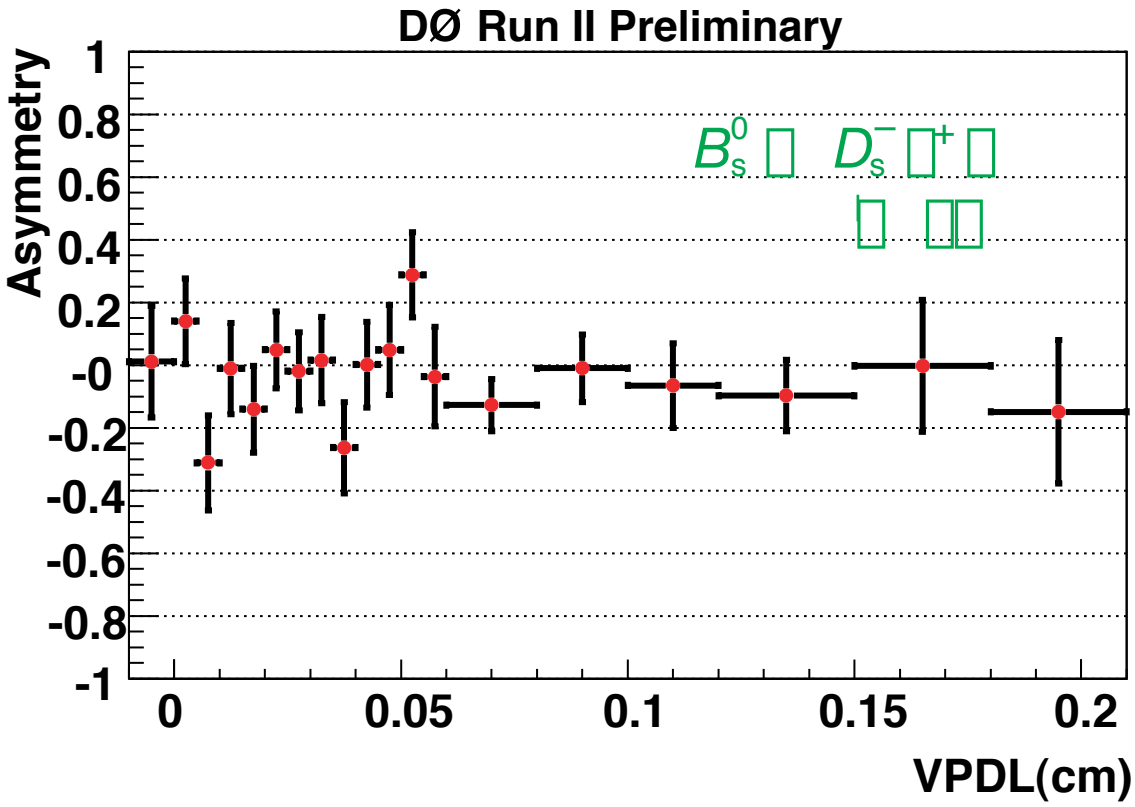
- ~4.2k total flavor-tagged candidates

- An example of a OST muon tagged B_s □ D_s □□ event

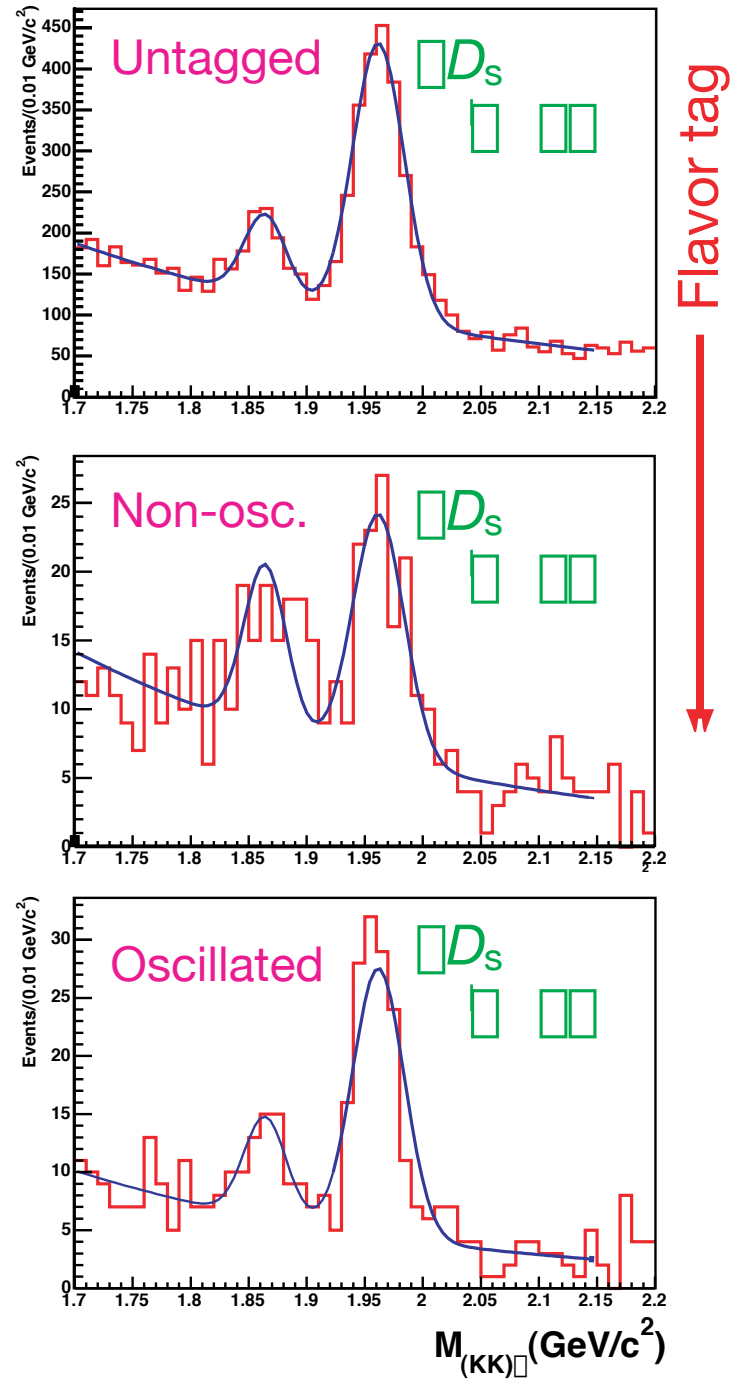


Measured Asymmetry

- Fit for D_s (+□) yield in bins of VPDL
- Form asymmetry, $A = \dfrac{N_{\text{non-osc.}} - N_{\text{osc.}}}{N_{\text{non-osc.}} + N_{\text{osc.}}}$ in each bin



e.g., 0.06 < *VPDL* < 0.08 cm



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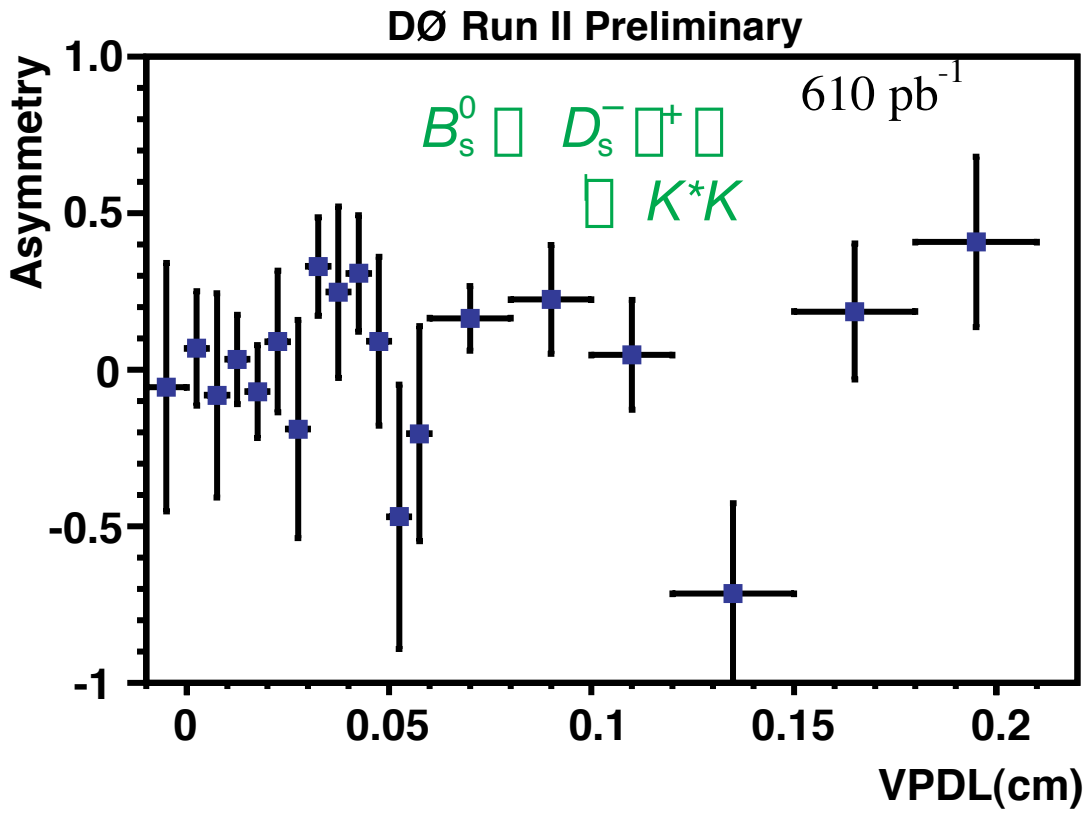

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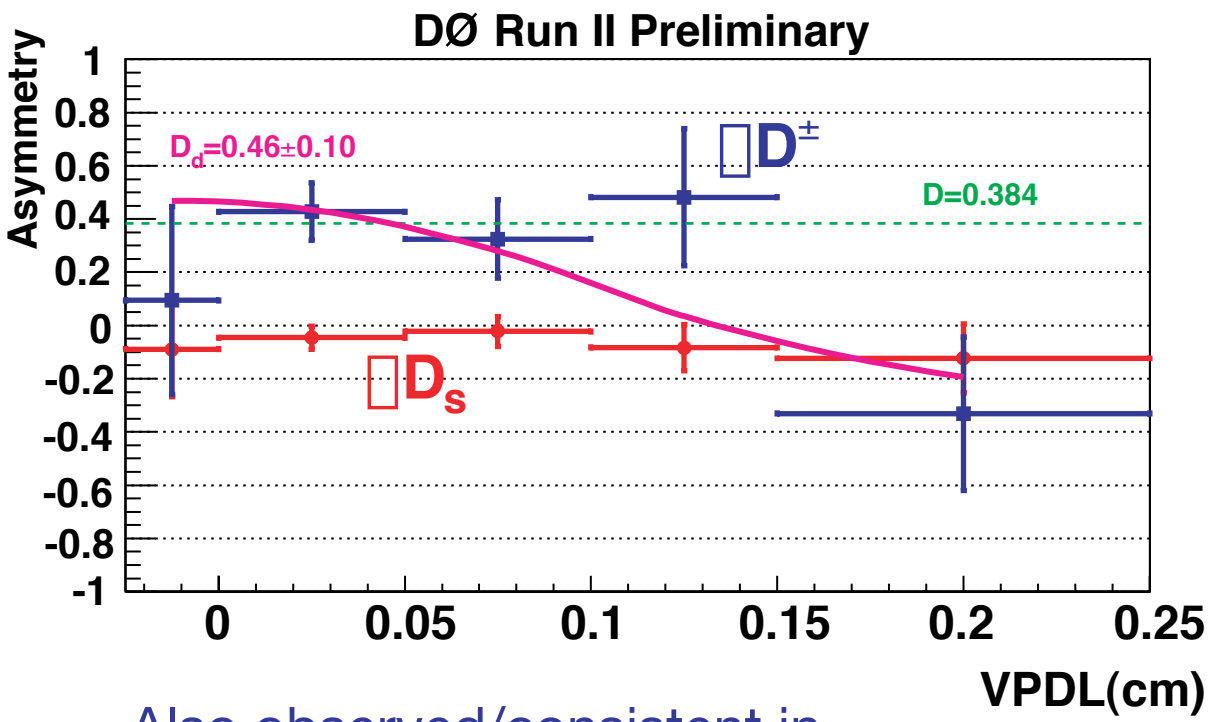

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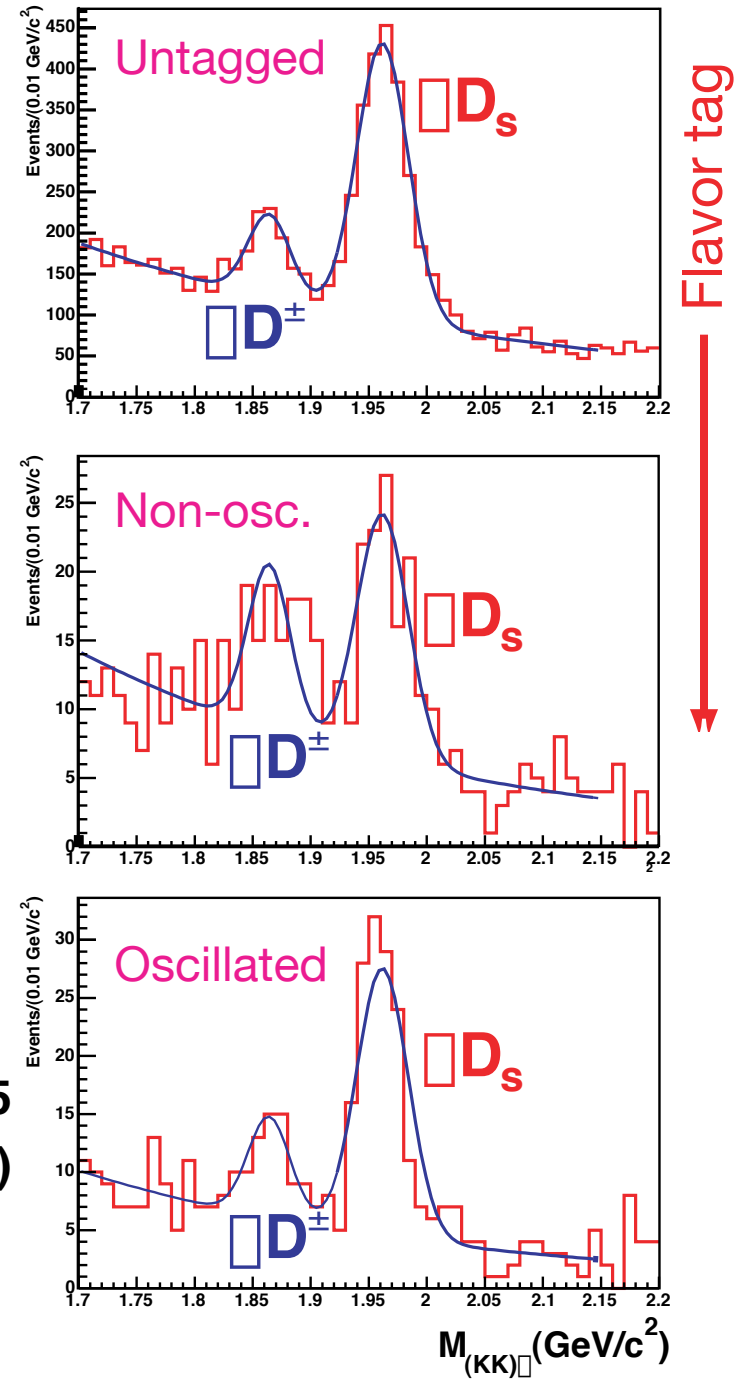


Also observed/consistent in

B_s^0 □ D_s^- □$^+$ □

□ K^*K

Expected Asymmetry

- Ideal no. expected (for signal), as function of *true* visible proper decay length, x

$$n_s^{osc,non\text{-}osc}(x) = \frac{K}{c\tau} \cdot 0.5 \cdot (1 \mp \underbrace{(2\omega - 1)}_{\text{Dilution, } \mathcal{D}} \cdot \cos(\Delta m_s \cdot Kx/c))$$

- Number expected as function of *measured* visible decay length, for *each* decay mode j

$$N_{d,u,s}^{osc,non\text{-}osc}(x^M) = \int dx \underbrace{Res_j(x - x^M, x)}_{\text{VPDL Resolution}} \underbrace{Eff_j(x)}_{\text{Due to lifetime cuts}} \int dK \underbrace{D_j(K)}_{K\text{-factor Distributions}} \tau(x) \; \underbrace{n_{(u,d,s)}^{osc,non\text{-}osc}(x,K)}$$

- Integrate over VPDL bins, sum over sample composition *Br*'s

Sample Composition

- So what's in that signal peak? ($\square + D_s$)
  Estimate using MC simulation, PDG *Br*'s, Evtgen exclusive *Br*'s:

For $B_s^0 \square\ D_s^- \square^+ \square$, $B_s^0 \square\ D_s^- \square^+ \square$ is similar

$\square\ \square\square$ $\square\ K^*K$

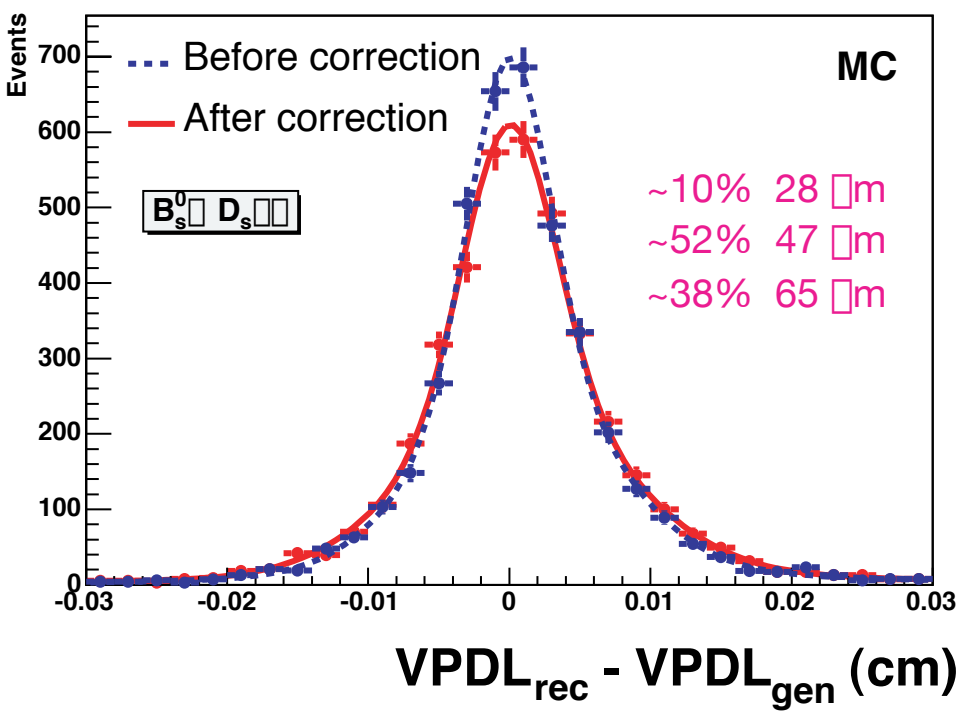
Decay Mode	Sample Fraction
$B_s^0 \square\ D_s^- \square^+ \square$	21.7%
$\square\ D_s^{*-} \square^+ \square$	60.7%
$\square\ D_{0s}^{*-} \square^+ \square$	1.4%
$\square\ D_{1s}^{*-} \square^+ \square$	3.1%
$\square\ D_s^- \square^+ \square$	1.3%
$\square\ D_s D_s X$	2.9%
$\square\ D_s D\ X$	0.9%
$B_d^0 \square\ D_s D\ X$	4.0%
$B^{\square} \square\ D_s D\ X$	4.1%

Useful signal fraction 88.3%

VPDL Resolution

Essential to understand to be able to determine expected asymmetry for given Δm_s

- Use charged tracks in data to find impact parameter (IP) resolution depending on:
  - Track momenta and angles
  - Silicon detector hit configuration and cluster width
- Tune MC and data to ensure:
  - Data track IP errors match data IP resolution
  - MC IP resolution matches data IP resolution



- Describe VPDL resolution using 3 Gaussians
- One resolution scale factor of 1.142 ± 0.020 ($D_s \to \pi\pi$)
  1.168 ± 0.024 ($D_s \to K^* K$)
  for all three

VPDL Resolution

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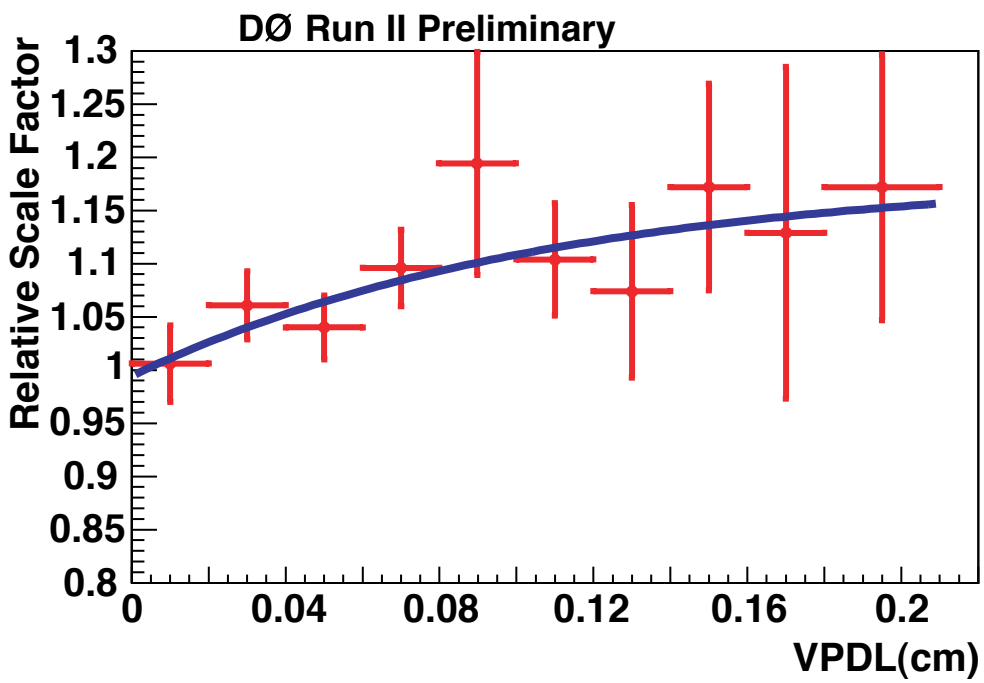
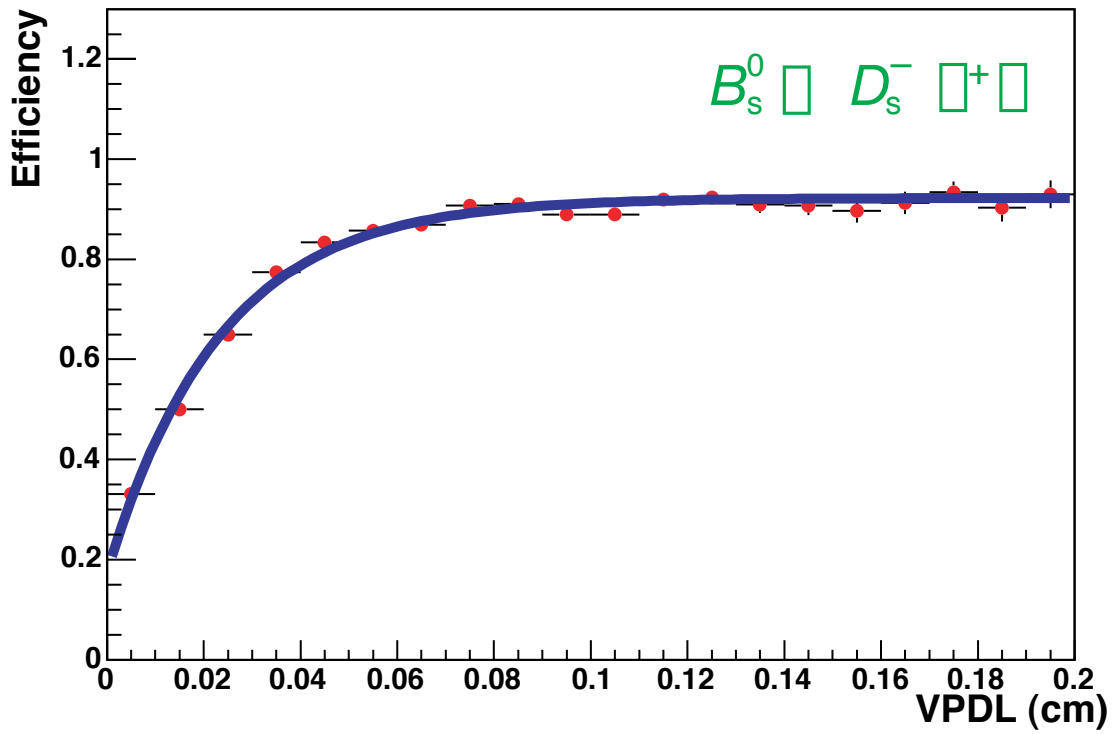


- Resolution depends on VPDL (large VPDL correlated with large boost, i.e. with more collimated decay products; also lifetime signficance cuts)
- Use a VPDL-dependent resolution scale factor

Signal Efficiency vs. VPDL

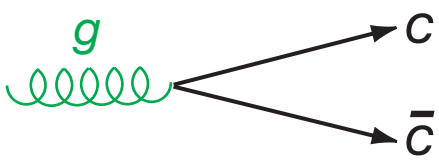
- ...due to lifetime and impact parameter significance cuts in selection:



- Done for each decay mode, similar turn-on curves
  for different decay modes in signal region

$c\bar{c}$ Contamination

- When from gluon splitting, charm hadrons close to each other



e.g.,

$$D^0 X \to K \to X$$

$$D^* X \to D^0 \to_s X \to K \to \to \to_s X$$

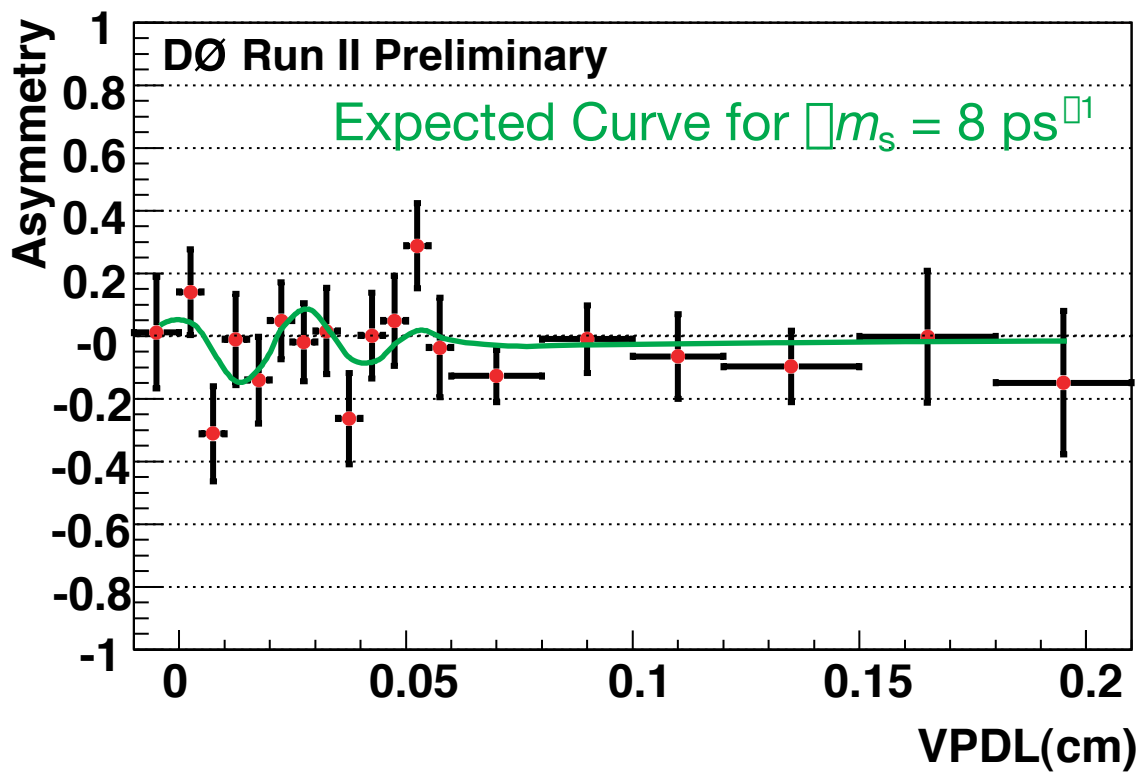
- Flavor-tagging surpressed contribution by factor ~3
- Estimated fraction of (3.5 ± 2.5)%, VPDL from MC, added in

Amplitude Method

Insert

$$n_s^{osc,non\text{-}osc}(x) = \frac{K}{c\tau} \cdot 0.5 \cdot (1 \mp (2\tau/\tau - 1) \cdot \mathcal{A} \cos(\Delta m_s \cdot Kx/c))$$

- If mixing signal with Δm_s , amplitude $\mathcal{A} = 1$ otherwise $\mathcal{A} = 0$
- Scan Δm_s, for each value, minimize χ^2 between expected and measured asymmetry vs. VPDL and find $\mathcal{A} \pm \Delta\mathcal{A}$



$B_s^0 \to D_s^- \mu^+ \nu$

Amplitude Method

Insert

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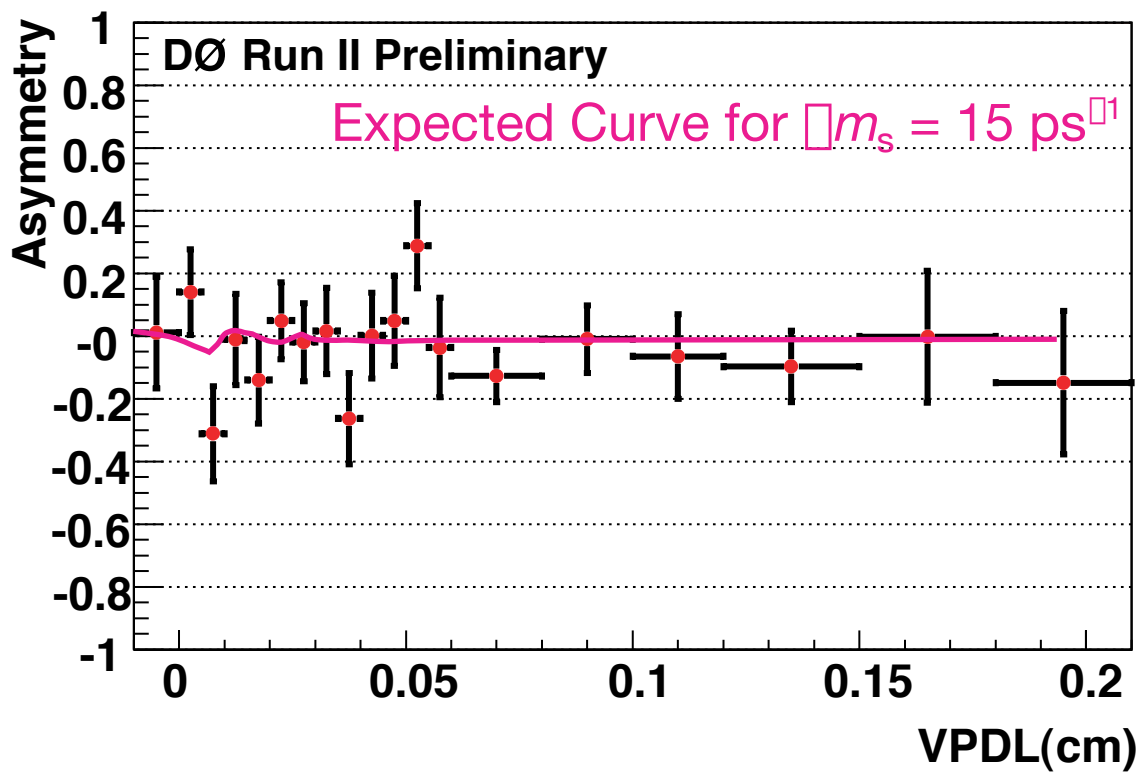
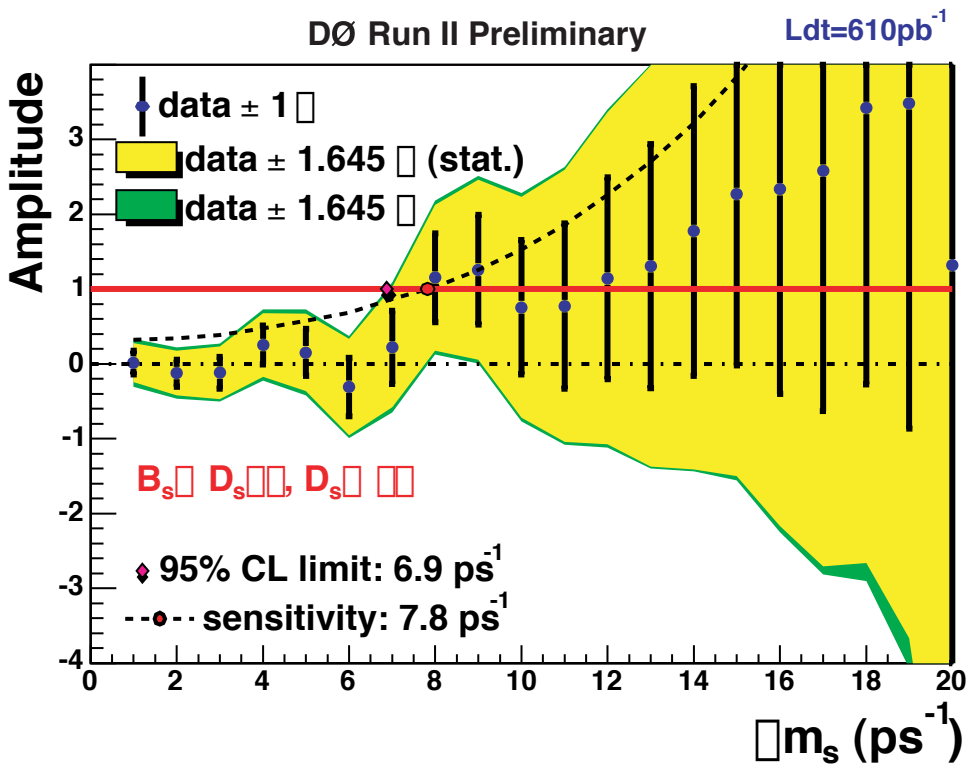
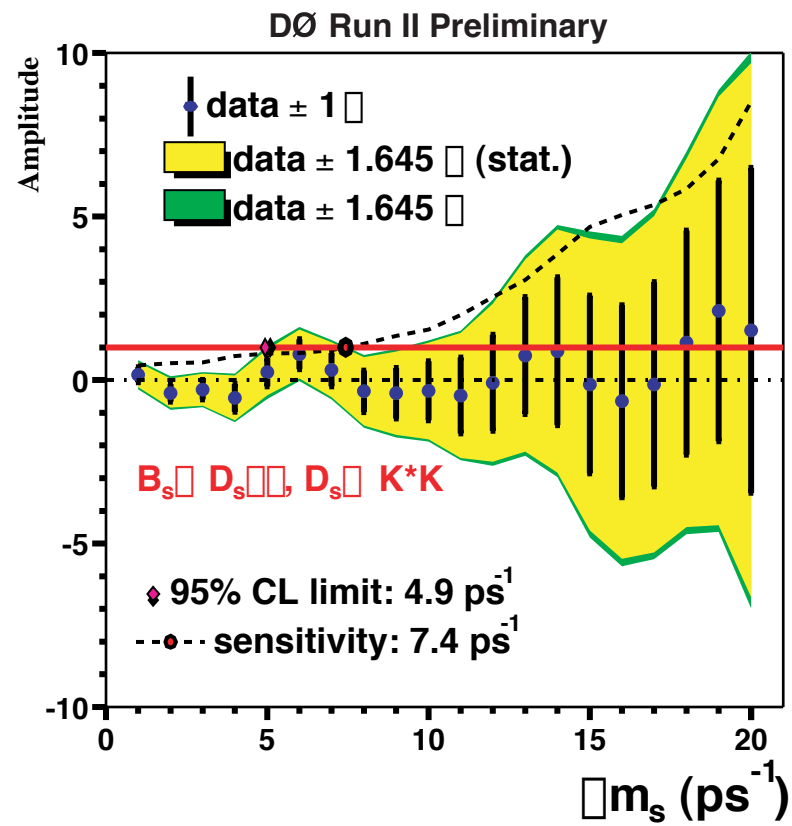


Limits and Sensitivities

- Verified with Toy Monte Carlos

- Sensitivity: value where $\mathcal{A} = 0$
  with experimental error could fluctuate up to $\mathcal{A} = 1$
- Limit: value where actual fitted value of $\mathcal{A}$
  with experimental error could fluctuate up to $\mathcal{A} = 1$





- Factor 1.7 better than Winter 05 result
- New result since Winter 05

Systematic Errors

- Done for each value of Δm_s

- Example point, 8 ps^{-1} ,

  $\mathcal{A}$ = 1.150 $\quad \Delta_{stat}$ = 0.593

  Δ_{syst} = 0.197

  Δ_{tot} = 0.625

- Dominant ones:

  Purity/dilution uncertainty

  Level of $c\bar{c}$ contamination

  Inclusive $Br(B_s^0 \to D_s^- \ell^+ X)$ = (7.9 ± 2.4)%

  Resolution scale factor uncertainty

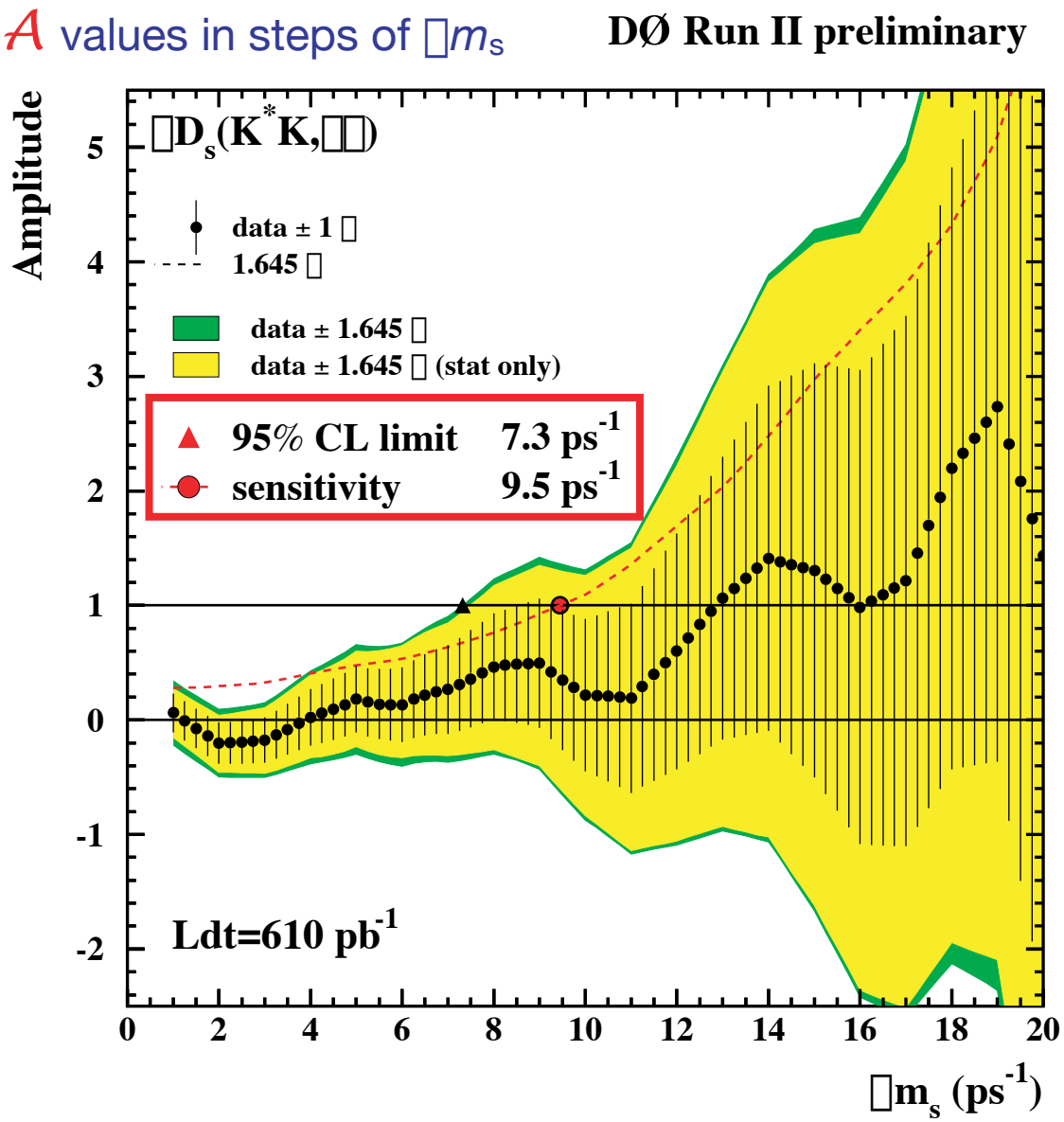
  K-factor uncertainties

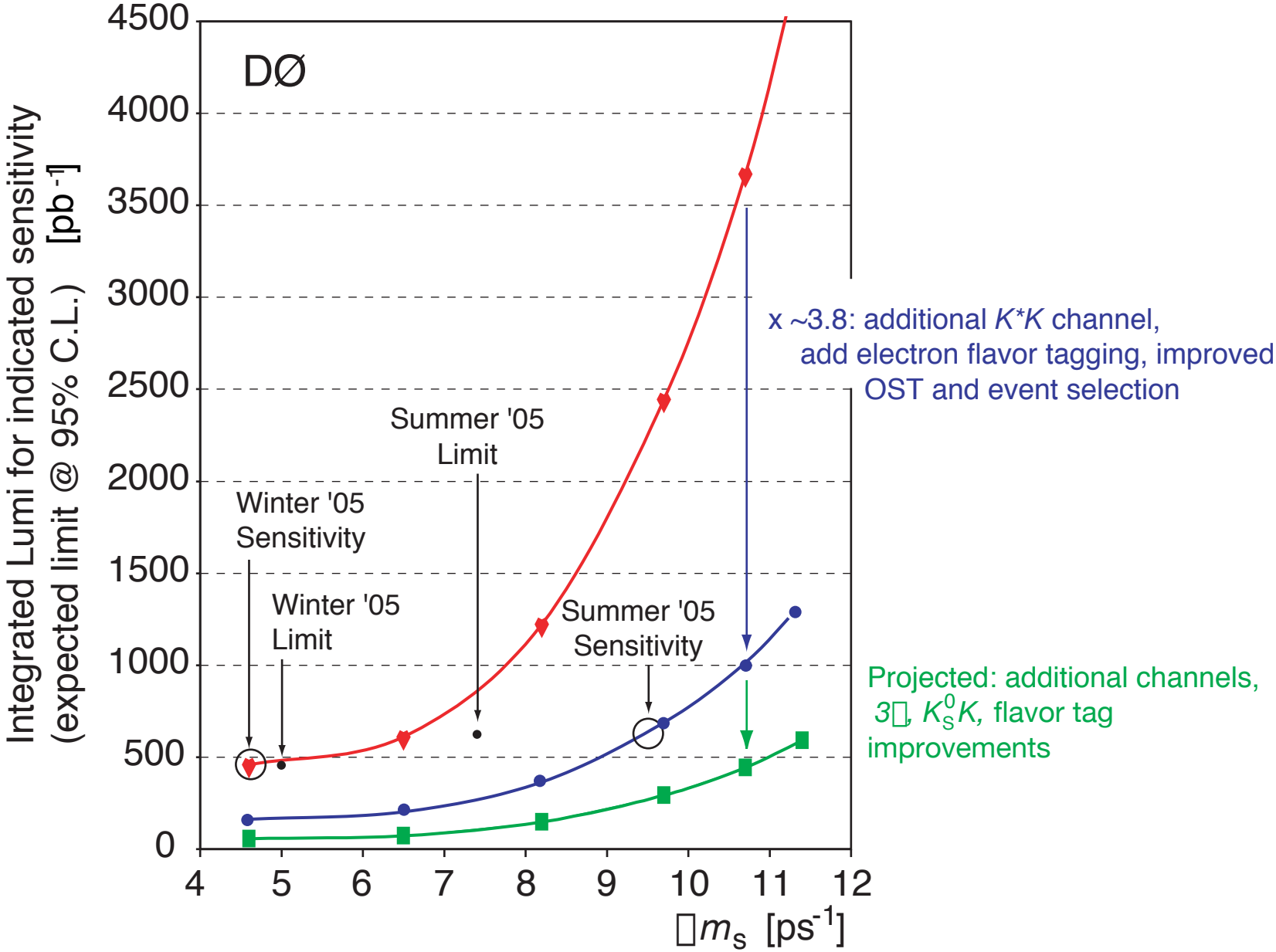
  $D_s \to K^* K$, add:

  Uncertainty in fit to reflection modes

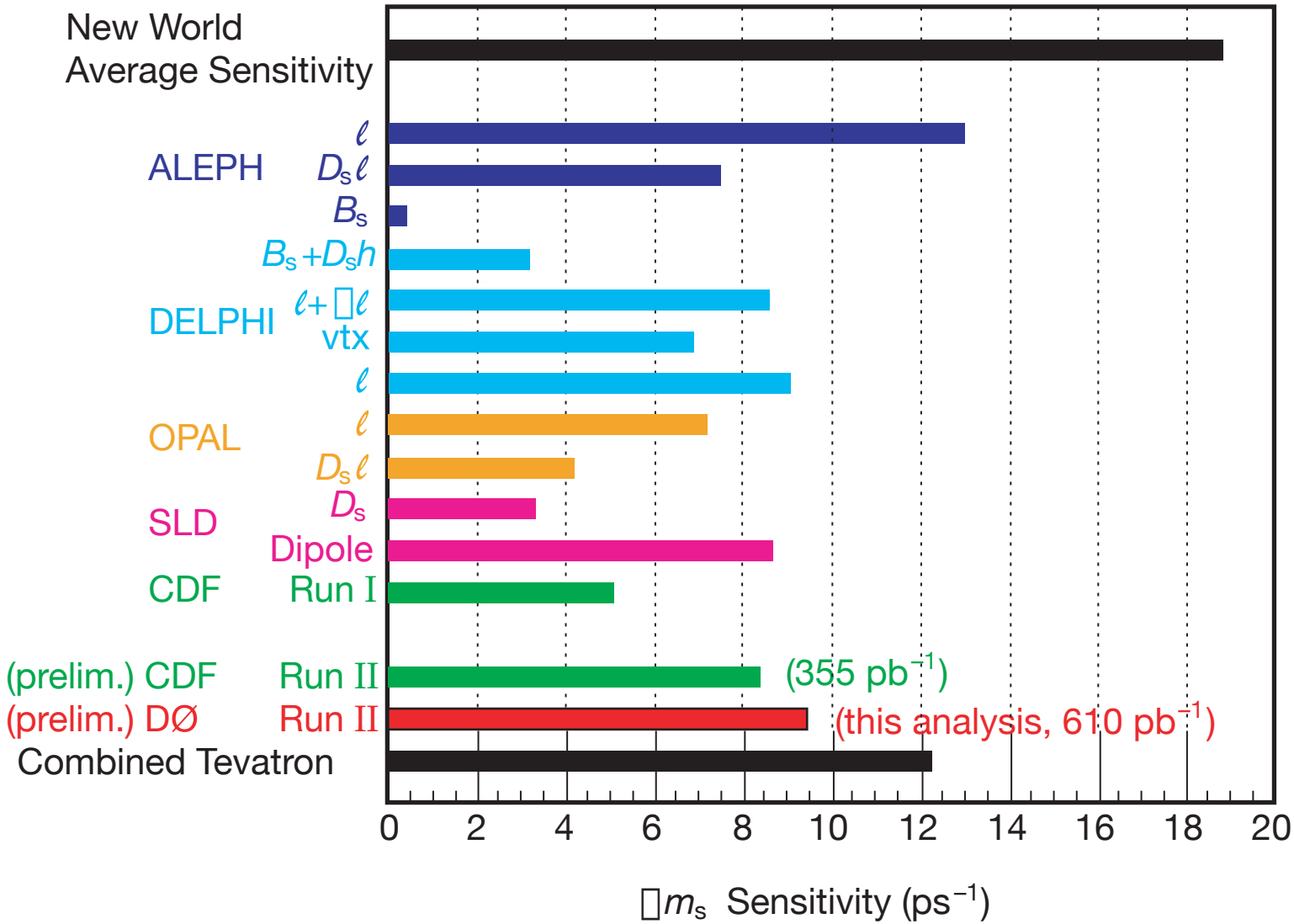
Limits and Sensitivities

- Combine: $\mathcal{A}$ values in steps of Δm_s



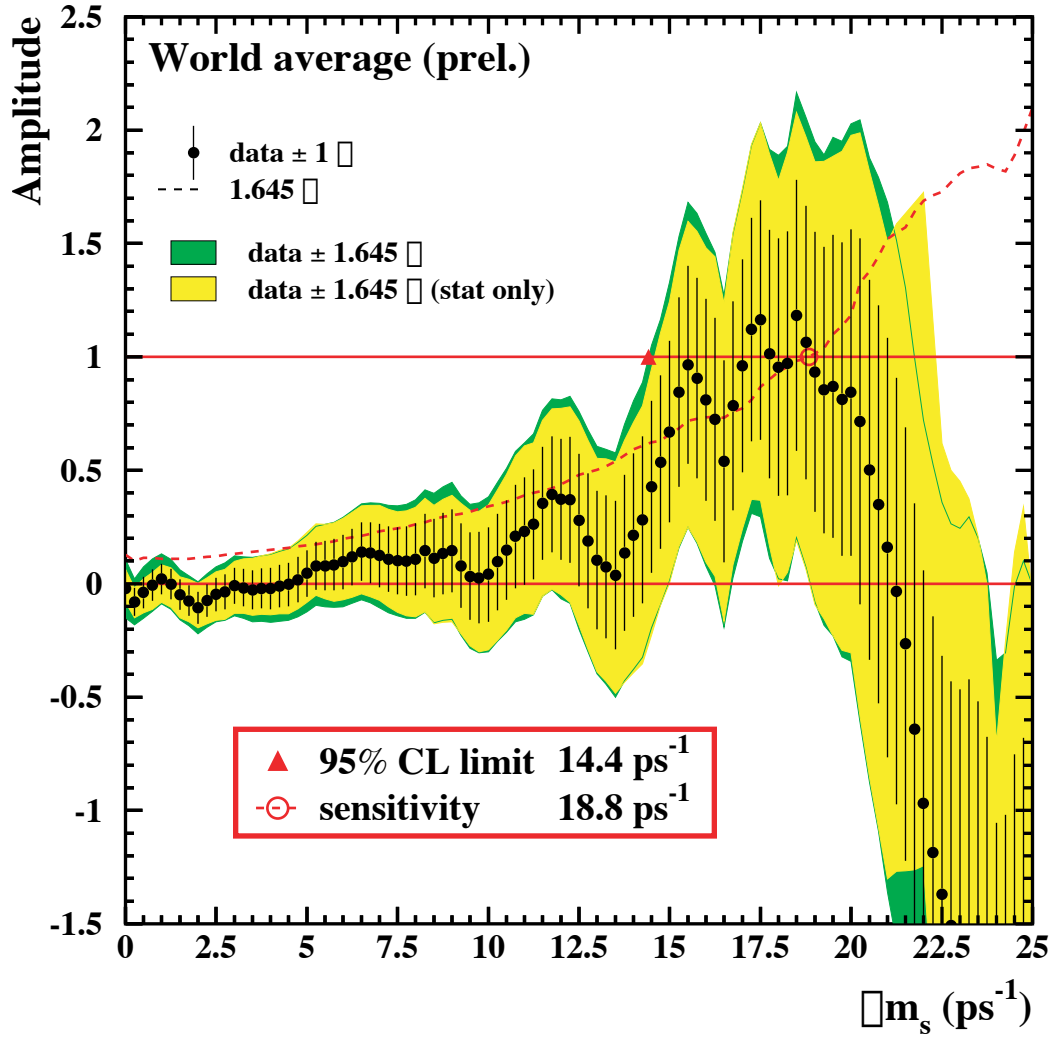

DØ
Integrated Lumi for indicated sensitivity
(expected limit @ 95% C.L.) [pb-1]
4500
4000
3500
3000
2500
2000
1500
1000
500
0
4
5
6
7
8
9
10
11
12
Δm_s [ps-1]
Summer '05
Limit
Winter '05
Sensitivity
Winter '05
Limit
Summer '05
Sensitivity
x ~3.8: additional K*K channel,
add electron flavor tagging, improved
OST and event selection
Projected: additional channels,
3π, K_S^0 K, flavor tag
improvements

Comparing Sensitivities



New World Average

Includes preliminary Run II
DØ and CDF results



Future Improvements

- Analysis techniques

  Add more decay channels: $D_s \to K_S^0 K, K^* K^*, 3\pi$

  Improve opposite-side tag and boost estimate, add same-side tagging

  Unbinned likelihood fit: event-by-event resolution and tagging purity

- Bandwidth increase

  Current limit for *B* physics triggers is rate to tape

  L3 bandwidth increase from 50 to 100 Hz (tests successful)

  Proposal to process extra 50 Hz of *B* physics data at remote institutes

  (matching funds commitment from Indiana U., Oklahoma U.)

- Hadronic B_s^0 decays

  Trigger on flavor-tagging muon, working on verifying yields

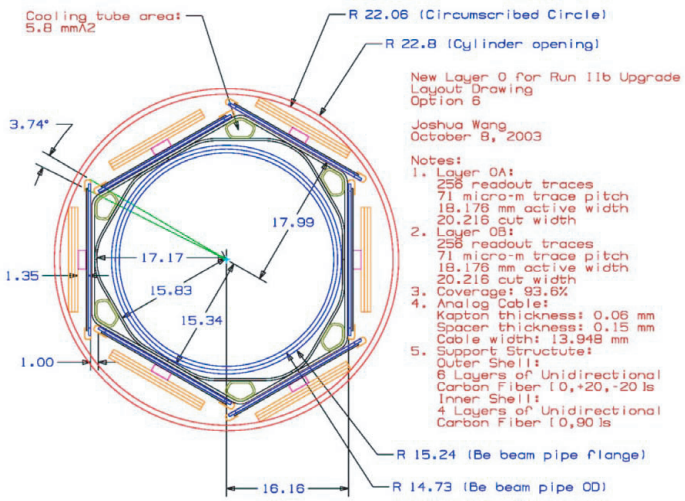
  Excellent decay length resolution (full reconstruction)

Future Improvements

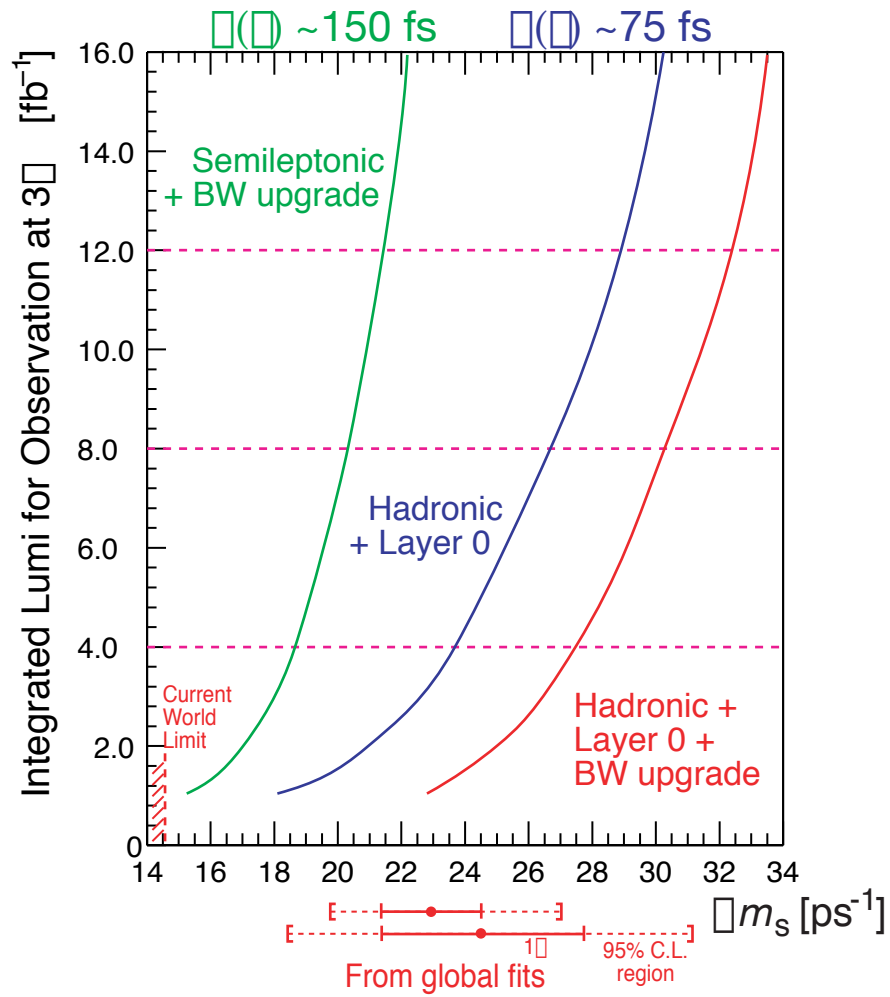
- New Layer 0 silicon detector

  Radius of 1.7 cm inside current detector

  Improve decay length resolution by ~30% even if lose Layer 1



- More data!



Conclusions

- Impressive work by a large team of people
- New preliminary result from DØ based on 610 pb^{-1}

Limit:	$\Delta m_s > 7.3\ ps^{-1}$ @ 95% C.L.
Sensitivity:	$\Delta m_s > 9.5\ ps^{-1}$ @ 95% C.L.

- Already competitive (second best sensitivity after ALEPH inclusive lepton)
- Excellent prospects in future with analysis & hardware improvements plus more data
- Can potentially cover the entire SM-predicted range; if oscillations *not* observed, new physics at some C.L.!

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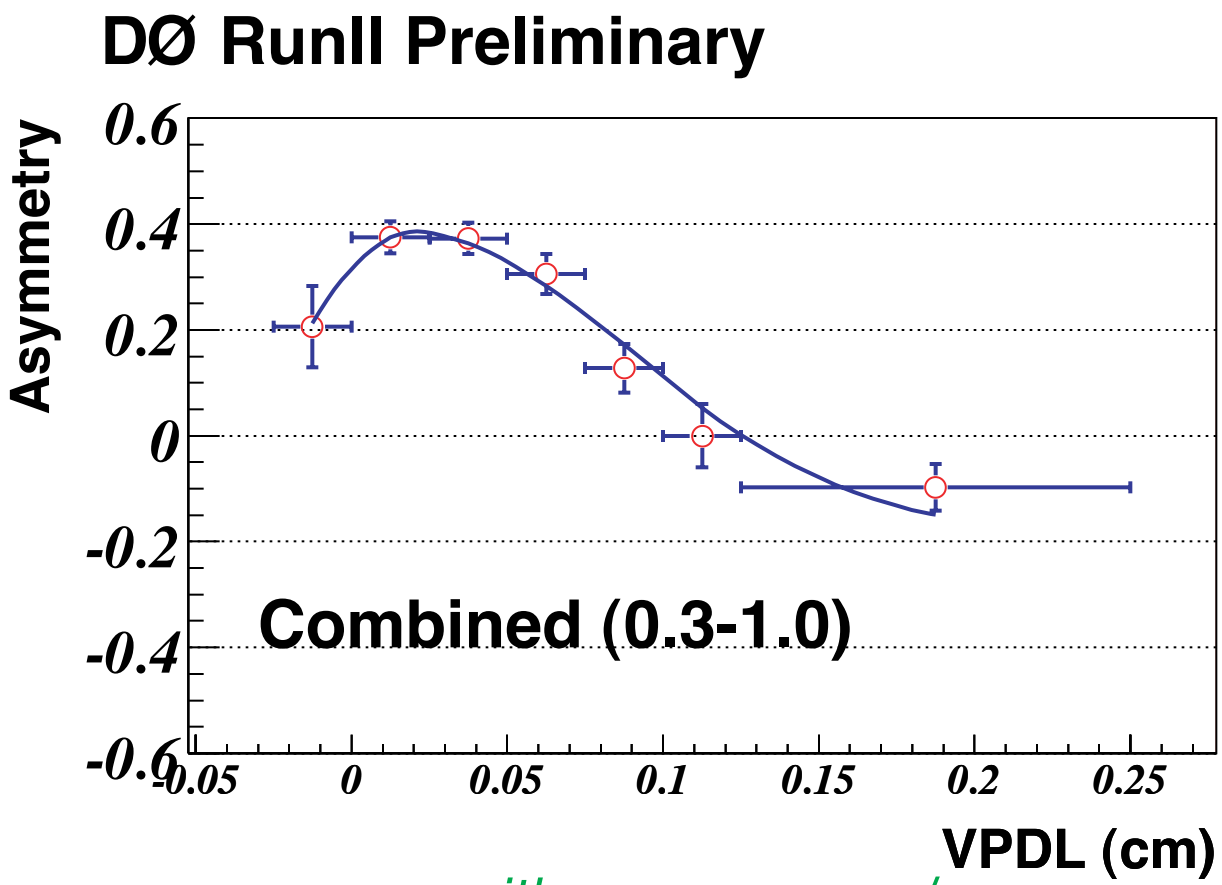
Tevatron → ***High-p_T Physics***
&
B_s^0 Factory!

Backup Slides

B_d oscillation fit *including* cc(bar) contamination, including VPDL<0



	with	*w/o*
□m	*= 0.504 +/- 0.029*	*(0.501+-0.030) ps-1*
Dilution0	*= 0.434 +/- 0.024*	*(0.414+-0.024)*
Dilution+	*=0.368 +/- 0.016*	*(0.367+-0.016)*

Initial Flavor Tagging

Individual Tagger Performance

Tagger	$\varepsilon(\%)$	$\mathcal{D}$	$\varepsilon\mathcal{D}^2(\%)$
Muon	5.65 ± 0.18	0.474 ± 0.018	1.27 ± 0.13
Electron	2.09 ± 0.12	0.370 ± 0.029	0.29 ± 0.06
SVCharge	5.42 ± 0.17	0.317 ± 0.019	0.54 ± 0.08
Combined ($\mid d \mid > 0.3$)	13.18 ± 0.27	0.384 ± 0.013	1.94 ± 0.17
Combined($0.22 < \mid d \mid < 0.3$)	2.67 ± 0.11	0.183 ± 0.027	0.089 ± 0.033
Combined($0.3 < \mid d \mid < 0.45$)	7.68 ± 0.21	0.309 ± 0.016	0.733 ± 0.100
Combined($\mid d \mid > 0.45$)	5.48 ± 0.17	0.496 ± 0.018	1.348 ± 0.129

cut used to study
$B_s/\overline{B}_s$ mixing

Systematic Errors

Osc. frequency (ps^{-1})		1	2	3	4	5	6	7	8	9	10
$\mathcal{A}$		0.014	-0.125	-0.120	0.251	0.152	-0.310	0.222	1.150	1.257	0.755
Stat. uncertainty		0.158	0.182	0.214	0.258	0.313	0.391	0.489	0.593	0.731	0.898
$\eta_s = 0.684$	$\Delta\mathcal{A}$	+0.000	-0.004	-0.004	+0.012	+0.007	-0.013	+0.010	+0.050	+0.054	+0.033
	$\Delta\sigma$	+0.007	+0.008	+0.009	+0.011	+0.014	+0.017	+0.021	+0.026	+0.032	+0.039
$c\bar{c}$: 6%	$\Delta\mathcal{A}$	+0.003	-0.009	-0.010	+0.021	+0.004	-0.076	-0.032	+0.093	+0.098	-0.021
	$\Delta\sigma$	+0.009	+0.007	+0.008	+0.013	+0.018	+0.026	+0.037	+0.049	+0.067	+0.091
D_sD_s : 4.7%	$\Delta\mathcal{A}$	+0.000	+0.003	+0.002	-0.005	-0.003	+0.006	-0.005	-0.024	-0.027	-0.018
	$\Delta\sigma$	-0.004	-0.004	-0.005	-0.006	-0.007	-0.008	-0.011	-0.013	-0.016	-0.019
$D_s\mu X$: 5.5%	$\Delta\mathcal{A}$	+0.003	-0.020	-0.015	+0.001	-0.001	-0.016	+0.007	+0.049	+0.056	+0.033
	$\Delta\sigma$	+0.007	+0.008	+0.010	+0.012	+0.014	+0.018	+0.022	+0.027	+0.033	+0.040
$c\tau_{B_s} = 455\mu m$	$\Delta\mathcal{A}$	+0.002	-0.001	-0.001	+0.003	-0.002	-0.007	+0.004	+0.010	+0.002	-0.009
	$\Delta\sigma$	+0.000	+0.000	+0.000	+0.001	+0.001	+0.002	+0.002	+0.003	+0.004	+0.006
same eff. curve	$\Delta\mathcal{A}$	+0.009	-0.001	-0.004	-0.001	-0.001	-0.008	-0.001	+0.012	+0.012	+0.003
for signal and bkg	$\Delta\sigma$	+0.001	+0.001	+0.002	+0.003	+0.003	+0.004	+0.005	+0.006	+0.008	+0.010
Resolution	$\Delta\mathcal{A}$	-0.006	+0.004	+0.007	+0.006	+0.000	+0.002	+0.002	-0.005	-0.007	-0.006
$S.F. = 2$ for bkg.	$\Delta\sigma$	-0.000	+0.000	-0.000	-0.001	-0.001	-0.002	-0.003	-0.004	-0.005	-0.006
D_s mass changed	$\Delta\mathcal{A}$	+0.002	-0.001	+0.000	-0.000	-0.002	-0.005	-0.003	+0.002	+0.001	+0.001
to $M_s + 1\sigma$	$\Delta\sigma$	-0.000	-0.000	+0.000	-0.000	-0.000	+0.000	+0.000	+0.000	+0.000	-0.000
D_s width changed	$\Delta\mathcal{A}$	+0.001	+0.002	-0.001	-0.001	+0.002	-0.000	-0.006	-0.010	-0.005	+0.008
to $\sigma_s - 1\sigma$	$\Delta\sigma$	+0.000	+0.000	+0.000	+0.001	+0.001	+0.001	+0.001	+0.001	+0.001	+0.002
D^+ mass changed	$\Delta\mathcal{A}$	+0.001	+0.000	-0.000	+0.001	+0.001	-0.000	-0.001	-0.002	-0.003	-0.005
to $M_+ - 1\sigma$	$\Delta\sigma$	-0.000	-0.000	+0.000	-0.000	-0.000	+0.000	-0.000	-0.000	-0.000	-0.000
Slope for bkg.	$\Delta\mathcal{A}$	-0.000	-0.001	+0.001	-0.002	-0.004	-0.002	-0.003	-0.002	-0.003	-0.006
changed by 1σ	$\Delta\sigma$	-0.001	-0.002	-0.002	-0.002	-0.002	-0.003	-0.003	-0.004	-0.005	-0.006
Bkg. parametrized	$\Delta\mathcal{A}$	+0.004	+0.009	-0.005	+0.011	+0.017	-0.001	-0.014	-0.025	-0.007	+0.044
by straight line	$\Delta\sigma$	+0.008	+0.009	+0.010	+0.011	+0.012	+0.015	+0.018	+0.021	+0.026	+0.030
mass bin	$\Delta\mathcal{A}$	+0.010	-0.007	-0.000	+0.013	+0.047	+0.053	+0.024	+0.005	+0.011	-0.025
smaller by 50%	$\Delta\sigma$	-0.001	-0.001	-0.000	-0.002	-0.003	-0.002	-0.005	-0.007	-0.003	-0.002
$\Delta\Gamma/\Gamma = 0.2$	$\Delta\mathcal{A}$	-0.000	-0.001	+0.000	-0.000	-0.000	+0.001	+0.001	+0.001	+0.001	+0.002
	$\Delta\sigma$	+0.001	+0.001	+0.001	+0.001	+0.001	+0.001	+0.001	+0.001	+0.001	+0.001
Resolution	$\Delta\mathcal{A}$	+0.001	-0.001	-0.004	+0.015	+0.024	-0.023	+0.009	+0.140	+0.188	+0.115
$S.F. = 1.162$	$\Delta\sigma$	+0.001	+0.003	+0.006	+0.012	+0.020	+0.035	+0.055	+0.079	+0.112	+0.152
K-factor	$\Delta\mathcal{A}$	+0.003	+0.004	-0.009	-0.026	+0.043	+0.016	-0.134	-0.110	+0.064	+0.087
variation 2%	$\Delta\sigma$	-0.001	-0.001	-0.001	-0.003	-0.008	-0.008	-0.011	-0.017	-0.022	-0.031
Total	σ_{tot}	0.191	0.206	0.233	0.282	0.340	0.414	0.526	0.624	0.757	0.919

Following slide from Ian Stewart's talk from Lepton-Photon 2005

Δm_s & Δm_d Constraints with Unquenched LQCD

$$\Delta m_d = C_{\rm short} m_{B_d} f_B^2 \hat{B}_d \, |V_{td} V_{tb}^*|^2$$

$$\frac{\Delta m_d}{\Delta m_s} = \frac{m_{B_d}}{m_{B_s}} \underbrace{\frac{f_B^2}{f_{B_s}^2} \frac{\hat{B}_d}{\hat{B}_s}}_{\xi^2} \frac{|V_{td}|^2}{|V_{ts}|^2}$$

$$\propto [(1-\bar{\rho})^2 + \bar{\eta}^2]$$

use $\frac{f_{B_s}}{f_B}$ & f_B with

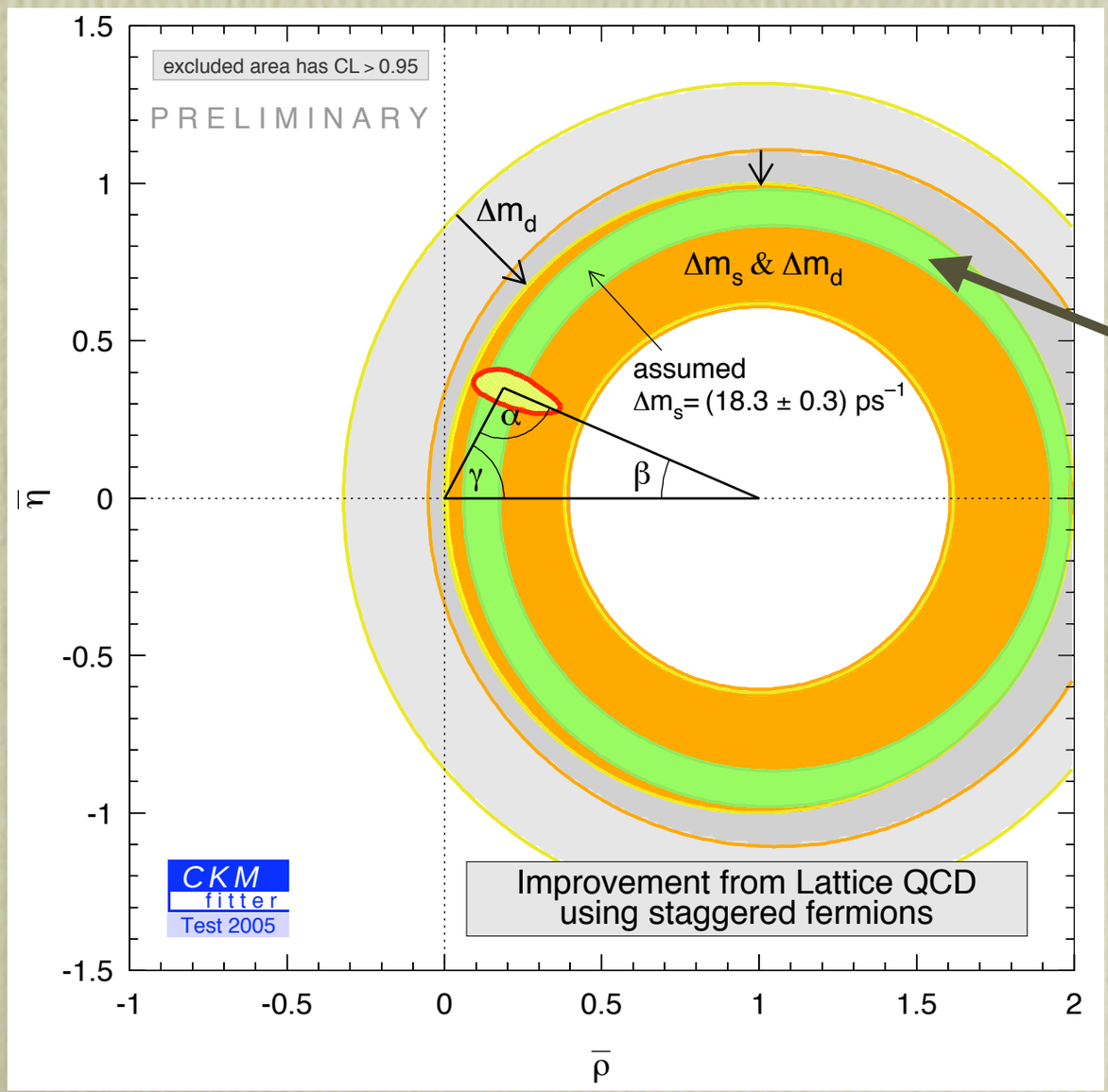
JLQCD ('03) $\hat{B}_d = 1.271(41)(^{+85}_{-94})$

$n_f = 2$ $\frac{\hat{B}_d}{\hat{B}_s} = 1.017(16)(^{+56}_{-17})$

$$\xi = 1.21 \pm 0.022^{+0.035}_{-0.014}$$

$$f_B \sqrt{\hat{B}_d} = (246 \pm 11 \pm 25)\,\text{MeV}$$

$$f_{B_s} \sqrt{\hat{B}_s} = (296 \pm 9 \pm 33)\,\text{MeV}$$



Assume Δm_s was measured.

New lattice errors on ξ reduced the width of the green band by $\sim 50\%$