CKM physics at CDF

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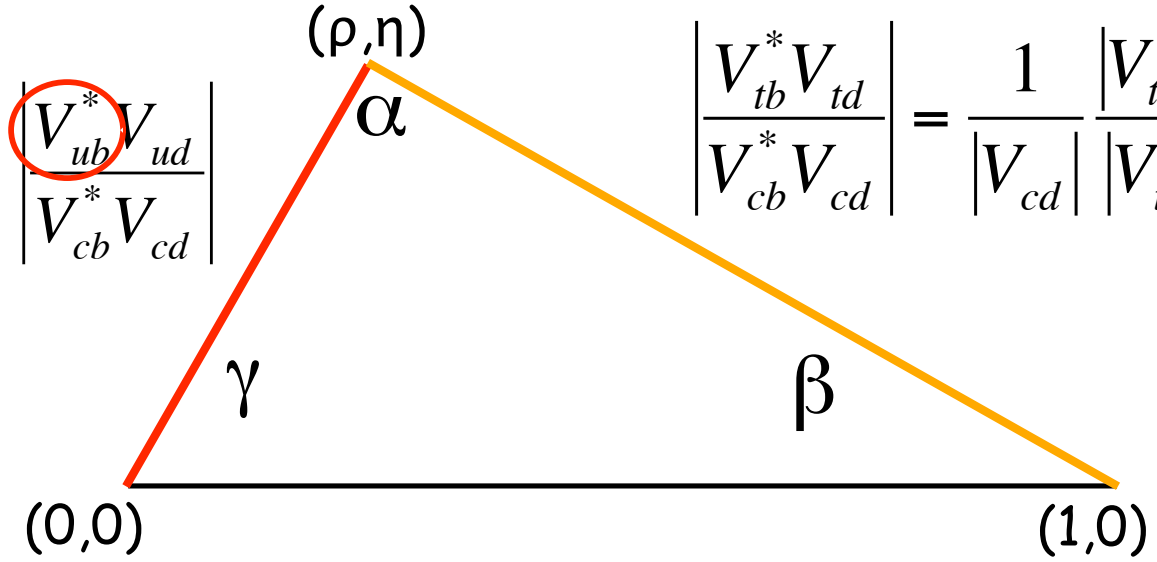
CKM Matrix

Wolfenstein parameterization

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

b → u transition
B meson system

CP violation → $\eta \neq 0$

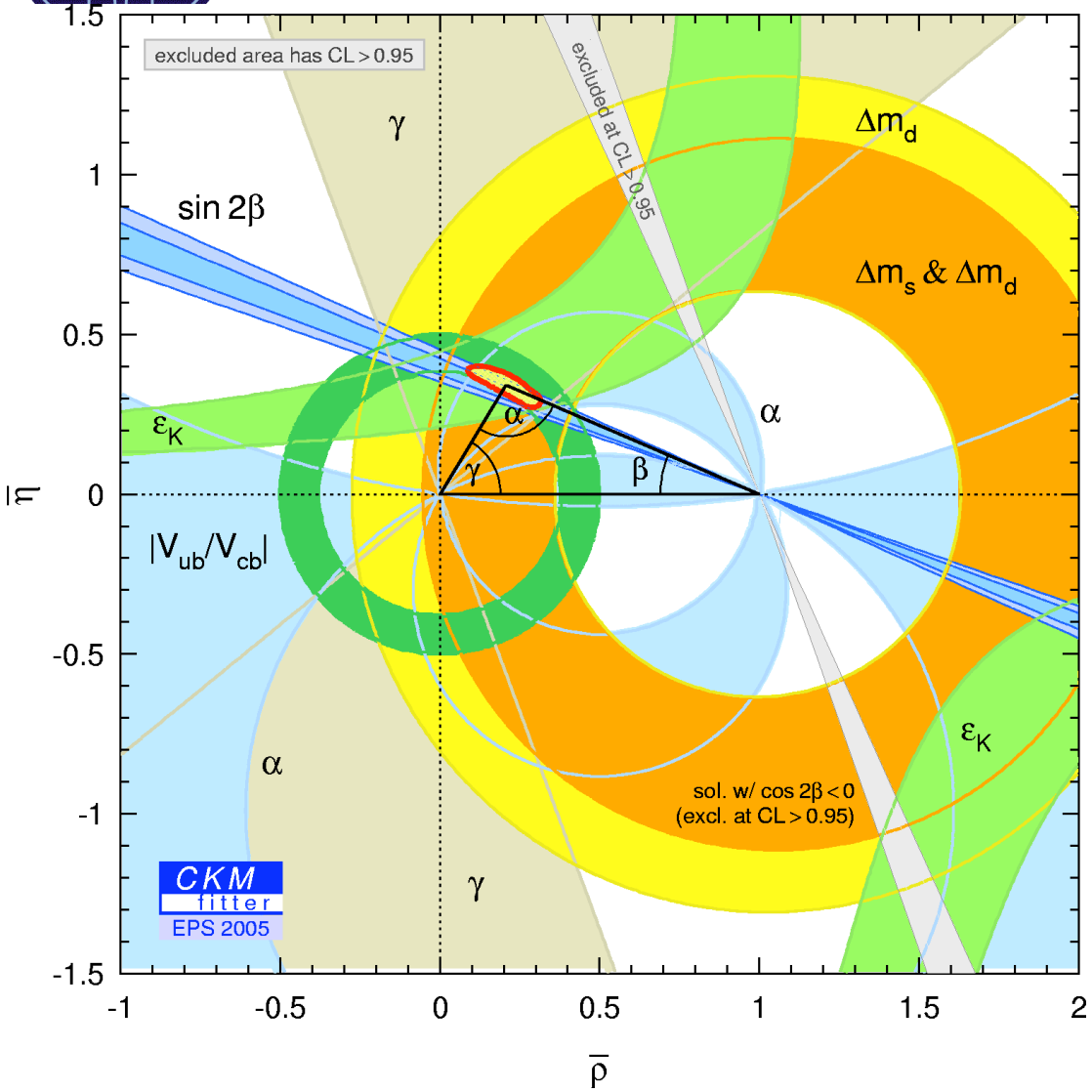


$$\left|\frac{V_{ub}^* V_{ud}}{V_{cb}^* V_{cd}}\right|$$

$$\left|\frac{V_{tb}^* V_{td}}{V_{cb}^* V_{cd}}\right| = \frac{1}{|V_{cd}|}\frac{|V_{td}|}{|V_{ts}|}$$

$$\frac{|V_{td}|^2}{|V_{ts}|^2} \approx \frac{\Delta m_d}{\Delta m_s}$$

The unitary triangle

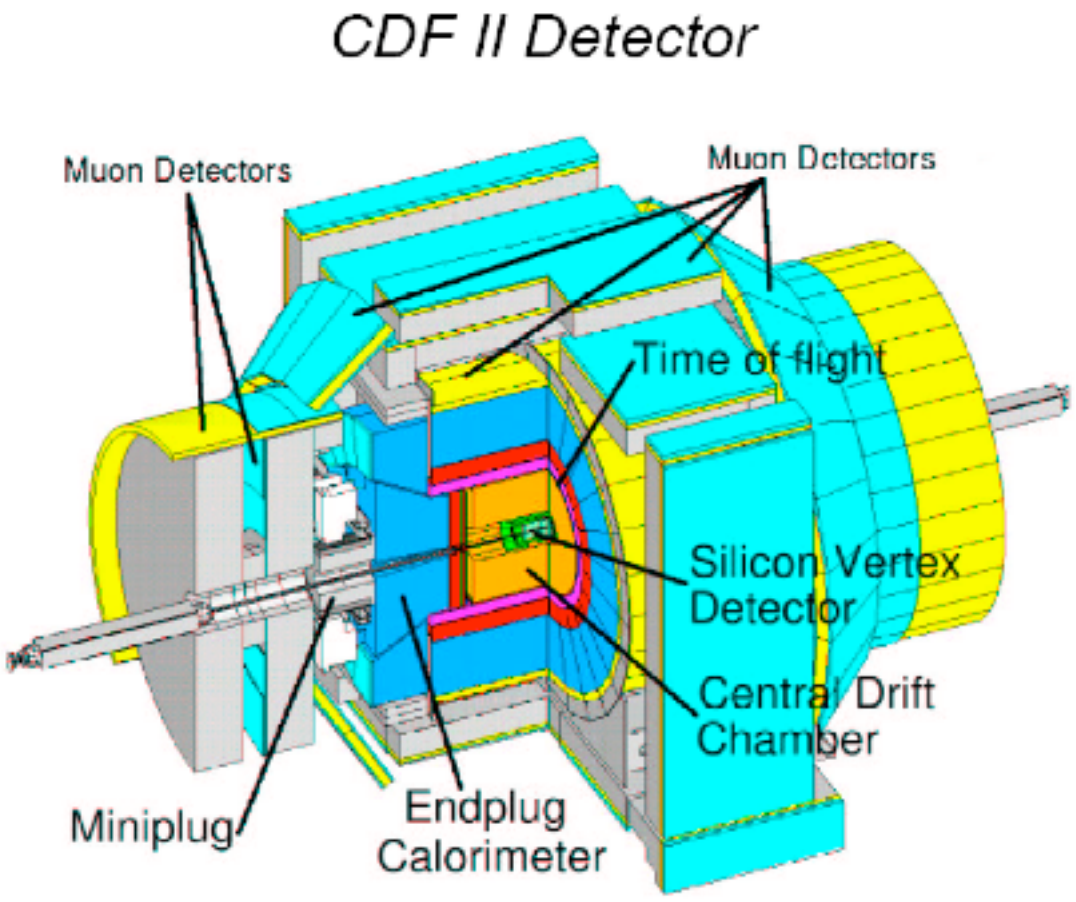


$$\frac{|V_{td}|^2}{|V_{ts}|^2} \approx \frac{\Delta m_d}{\Delta m_s}$$

γ angle measurement

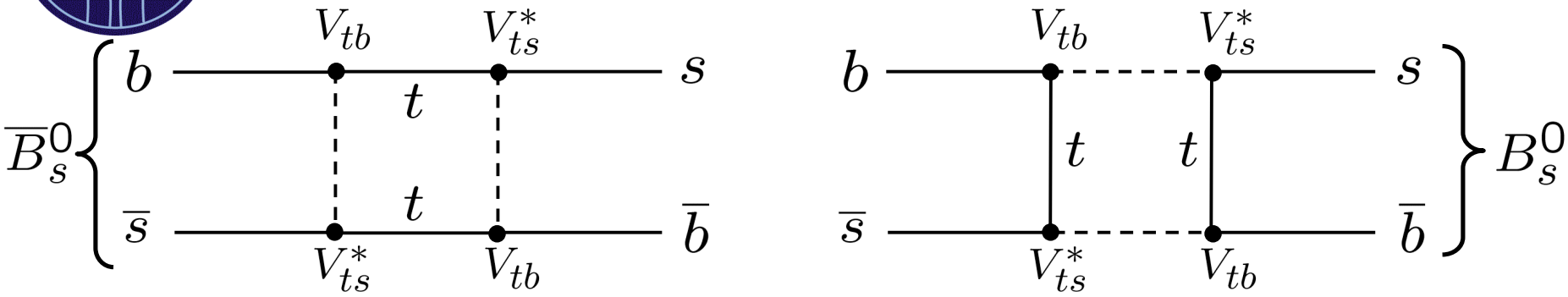
The CDFII detector

- Yield:
  - SVT based triggers
- Tagging Power:
  - TOF, dE/dx in COT
- Proper time resolution:
  - SVXII, L00



B_s mixing: measurement of $|V_{td}|/|V_{ts}|$

Bs mixing



$$\Delta m_s \sim m_{B_s} f_{B_s}^2 B_{B_s} \left| V_{tb} V_{ts}^* \right|^2$$

$$\Delta m_d \sim m_{B_d} f_{B_d}^2 B_{B_d} \left| V_{tb} V_{td}^* \right|^2$$

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

Δm_d and masses are well measured → m_{Bs}/m_{Bd} = 0.9830 PDG 2006
Δm_d = 0.507 ± 0.005 PDG 2006

$$\xi = \frac{f_{B_s}}{f_{B_d}} \sqrt{\frac{B_{B_s}}{B_{B_d}}} = 1.210^{+0.047}_{-0.035}$$

From lattice QCD
(hep-lat/0510113)

Search for B_s Oscillations

- Reconstruct B_s decays
- Measure proper decay time precisely
- Identify initial flavor state (B_s or $\overline{B}_s$)

$$\frac{1}{\sigma} = \sqrt{\frac{S}{S+B}}\sqrt{\frac{S\varepsilon D^2}{2}}e^{-\sigma_{ct}^2 \Delta m_s^2 / 2}$$

Effective tagging power:

ε = efficiency of taggers

D = 1 – 2w w = mistag prob.

εD^2 figure of merit

εD^2 ~ 1.5 % OST

εD^2 ~ 4 % SST

$$ct = \frac{L_{xy}}{\beta_T \gamma} = \frac{L_{xy} m(B)}{p_T(B)}$$

vertexing and momentum resolution

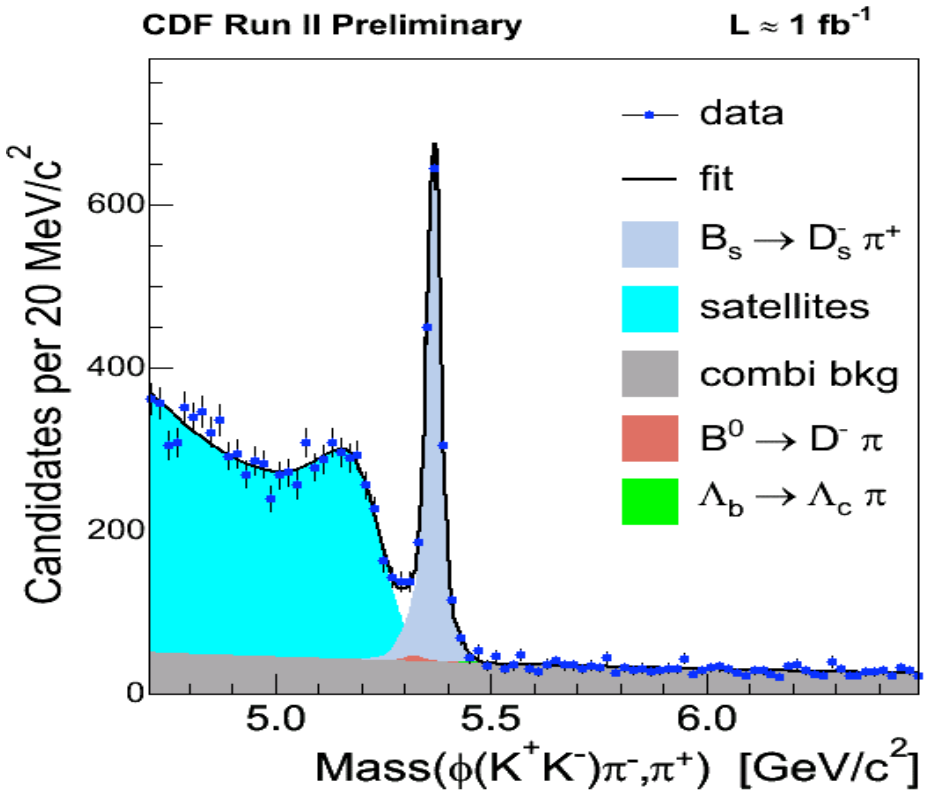
$$\sigma_{ct} = \left(\frac{\sigma_{L_{xy}} \cdot m(B)}{p_T(B)}\right) \oplus \left(\frac{\sigma_{p_T}}{p_T(B)}\right) \cdot ct$$

σ_{ct} ~ 87 fs for hadronic decays

σ_{ct} for semileptonic decays is worse

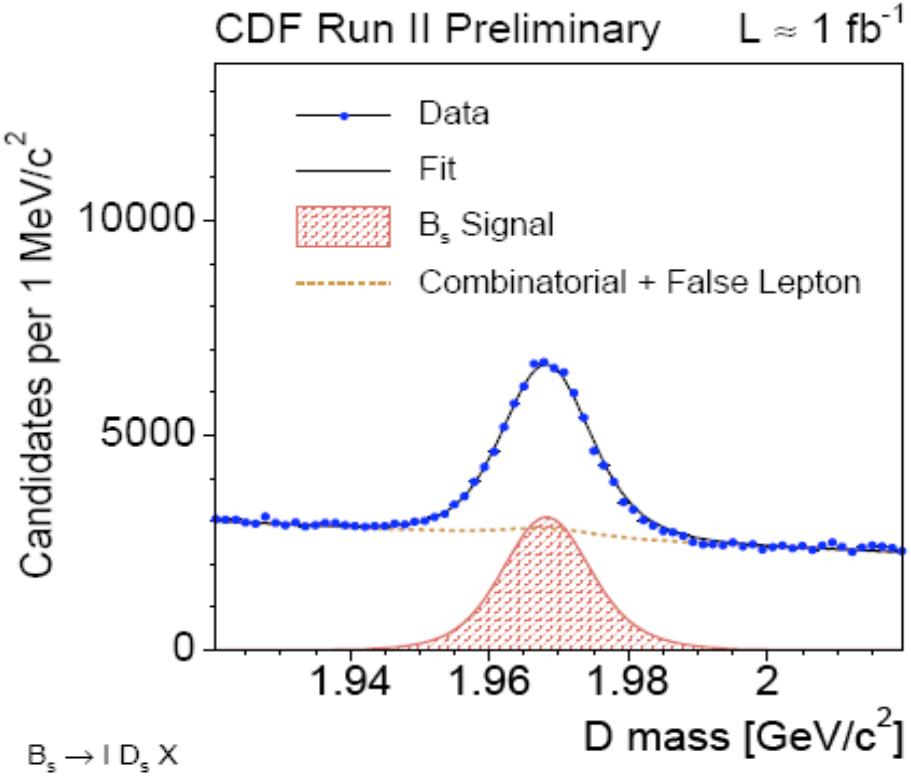
Signal Reconstruction

$B_s^0 \to D_s^- \pi^+$, $D_s\ 3\pi$



3,700 fully reconstructed

$B_s^0 \to D_s^- l^+ \nu_l X$

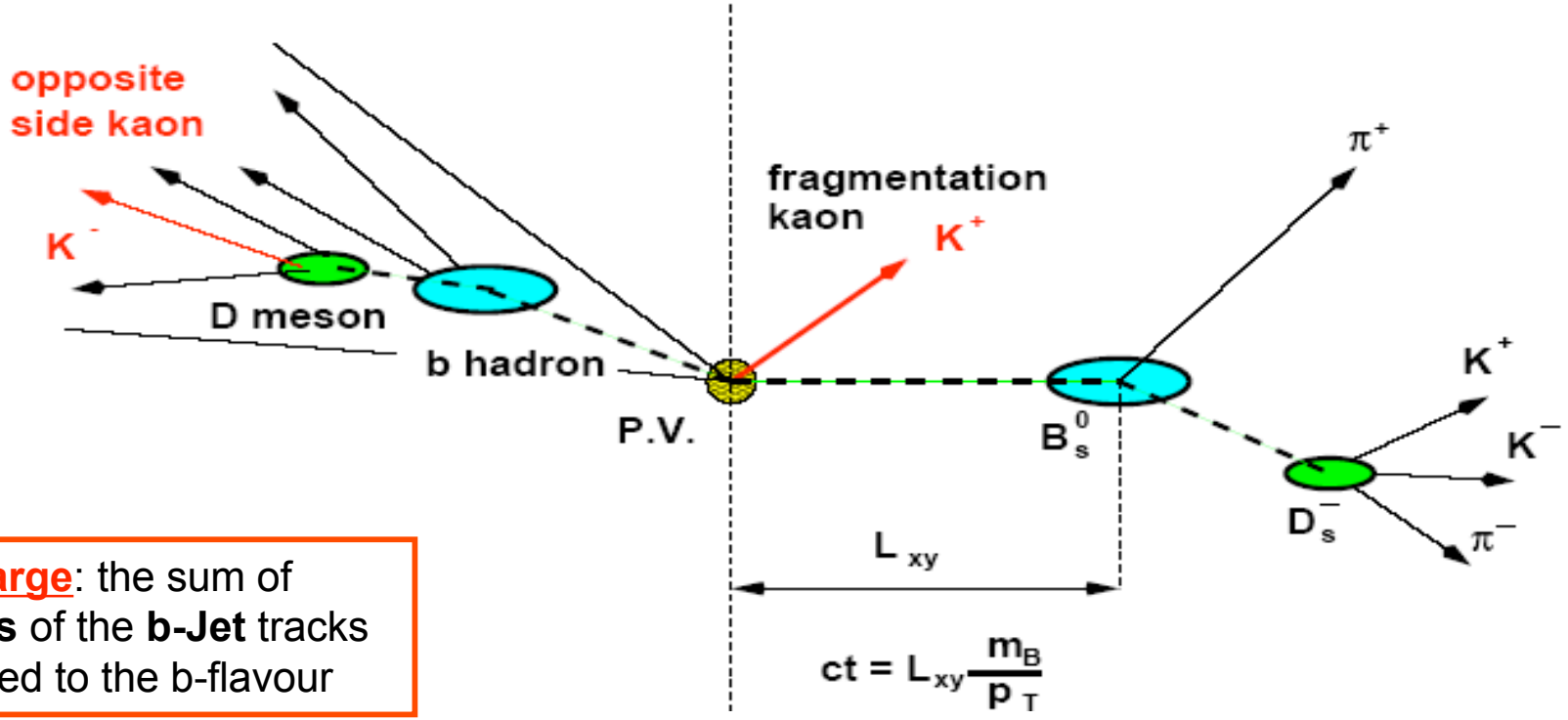


53,000 partially reconstructed

Flavor Tagging

The dominant b quark production mechanism produce $b\bar{b}$ pairs.
We can define two zones:

Opposite Side **Same Side**



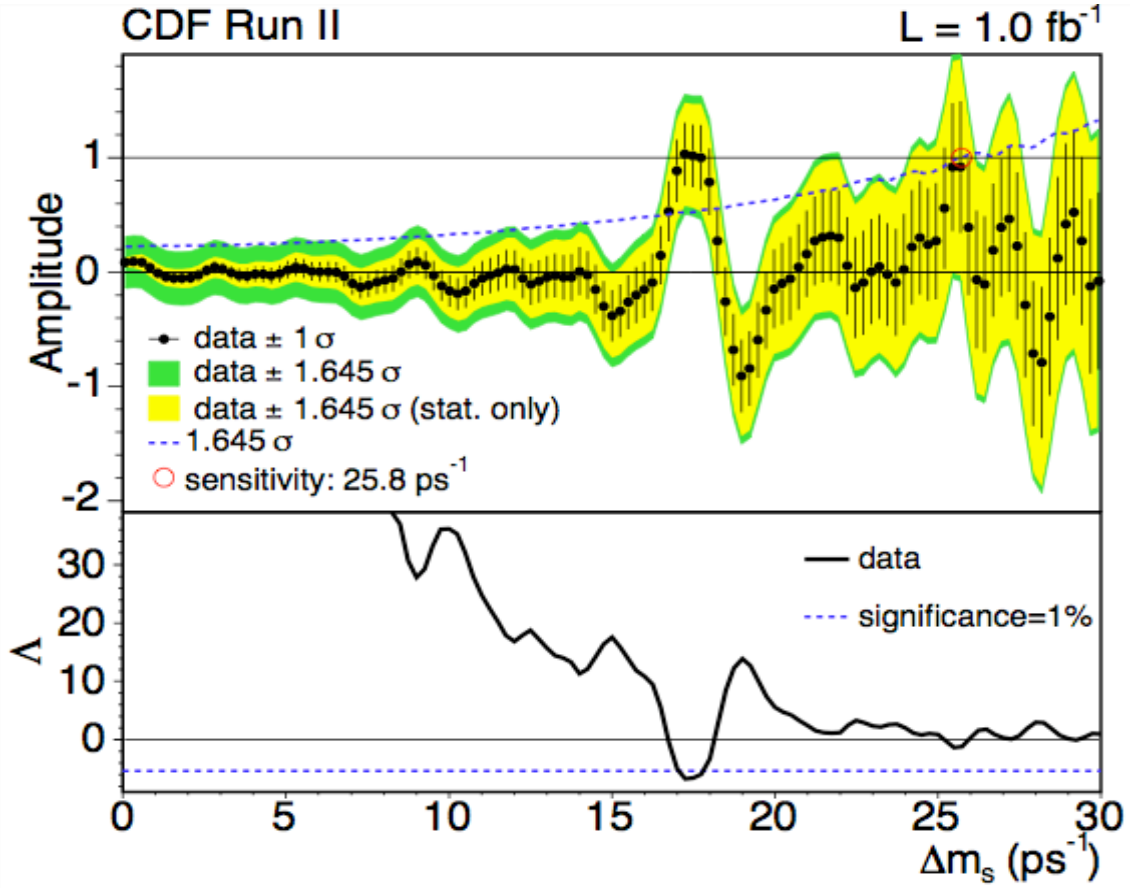
Jet Charge: the sum of **charges** of the **b-Jet** tracks correlated to the b-flavour

Soft Lepton (e,μ) due to **b→ℓνX**
ℓ charge correlated to b-flavour

Same Side Kaon: for B^0_s is likely to have close in ΔR a **K+** from fragmentation

Result

$$P_{mix/unmix}(t) \sim (1 \pm A\, D_{tag} \cos(\Delta m_s t))$$



Amplitude scan

Expect $A=1$ at true Δm_s

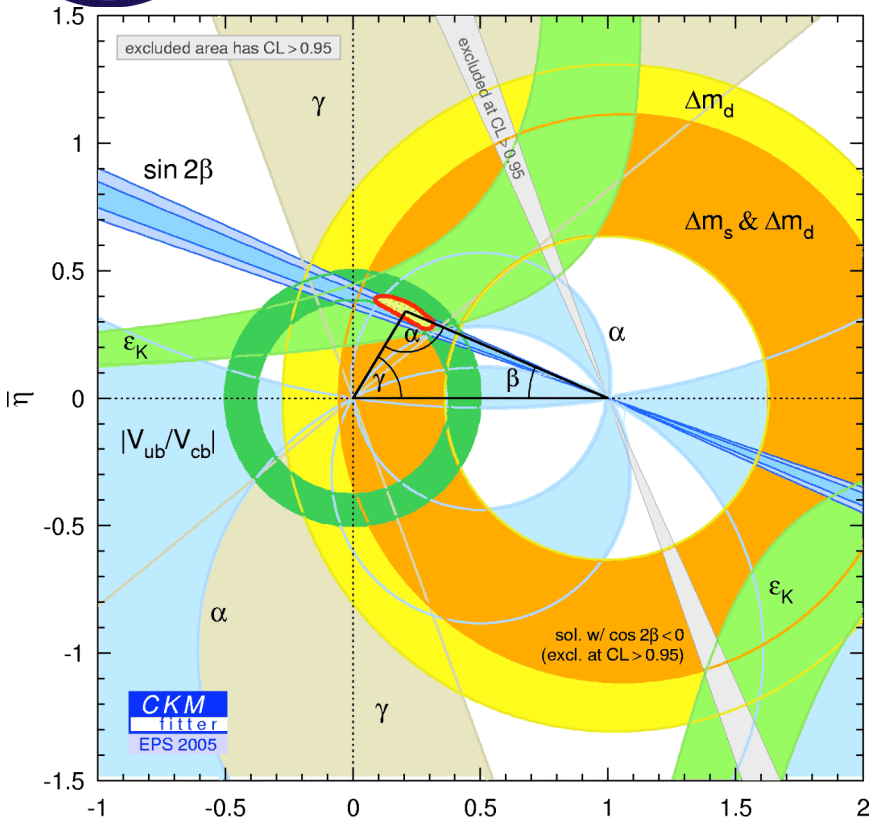
$\Lambda = \log[L^{A=0}/L^{A=1}(\Delta m_s)]$

Significance = 0.2 %

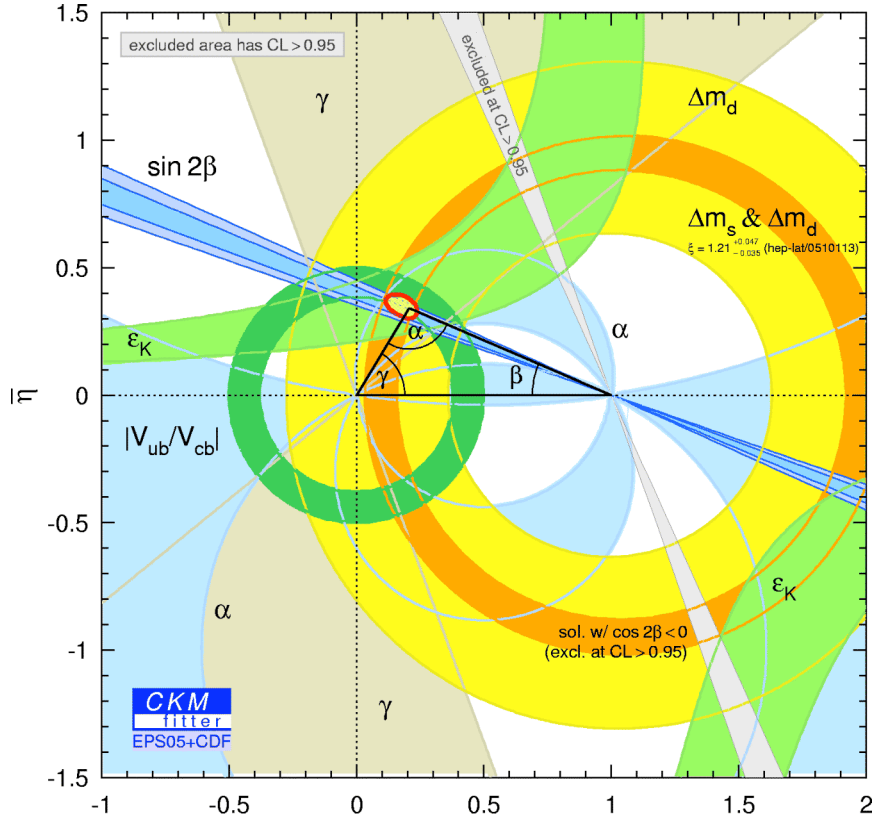
$$\Delta m_s = 17.31^{+0.33}_{-0.18}(stat.) \pm 0.07(syst.)\, ps^{-1}$$

Constraints on CKM matrix

Before



After



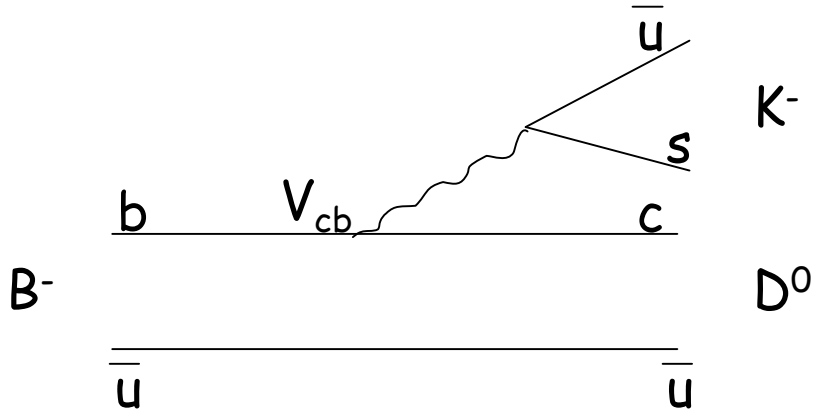
$$\left|V_{td}\right|/\left|V_{ts}\right| = 0.208^{+0.001}_{-0.002}(\text{exp.})^{+0.008}_{-0.006}(\textit{theo.})$$

Uncertainty already dominated by lattice calculations rather than Δm_s

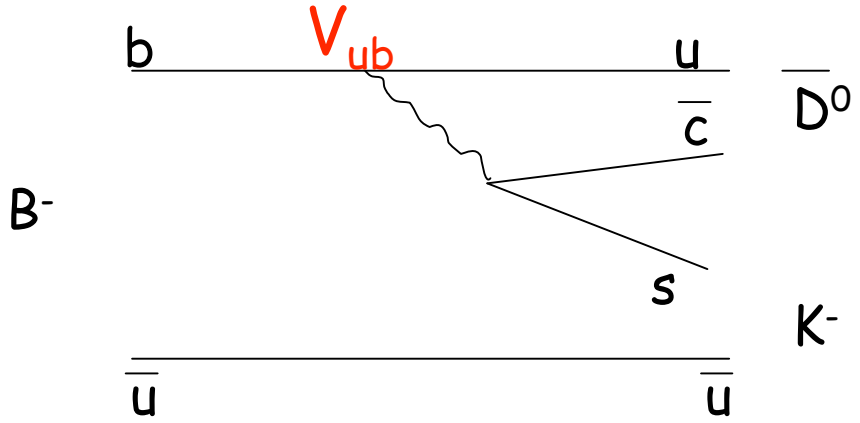
A step towards CKM γ angle using $B \rightarrow D K$

γ angle using DK modes

Cabibbo favored



Cabibbo and color suppressed



Strategy : Several methods to extract γ, depending on D^0 modes used

- GLW method *[PLB253,483 PLB265,172]* using
  $D^0_{flav}(K^-\pi^+) + D^0_{CP}(K^+K^-, \pi^+\pi^-)$
- ADS method *[PRL78,3257;PRD63,036005]* using
  $D^0_{flav}(K^-\pi^+) + D^0_{DCS}(K^+\pi^-)$
- Dalitz *[PRL78,3257;PRD68,054018]* using
  $D^0 \rightarrow K^0_s \pi^+\pi^-$

GLW method

$$R_{CP\pm} = \frac{\Gamma(B^- \to D^0_{CP\pm} K^-) + \Gamma(B^+ \to D^0_{CP\pm} K^+)}{[\Gamma(B^- \to D^0 K^-) + \Gamma(B^+ \to D^0 K^+)]/2}$$

$$A_{CP\pm} = \frac{\Gamma(B^- \to D^0_{CP\pm} K^-) - \Gamma(B^+ \to D^0_{CP\pm} K^+)}{\Gamma(B^- \to D^0_{CP\pm} K^-) + \Gamma(B^+ \to D^0_{CP\pm} K^+)}$$

From theory:

$R_{CP\pm} = 1 + r^2 \pm 2r \cos\delta \cos\gamma$

$A_{CP\pm} = 2r \sin\delta \sin\gamma / R_{CP\pm}$

$$r \equiv \frac{A(B^- \to \overline{D}^0 K^-)}{A(B^- \to D^0 K^-)} \sim 0.1 - 0.2$$

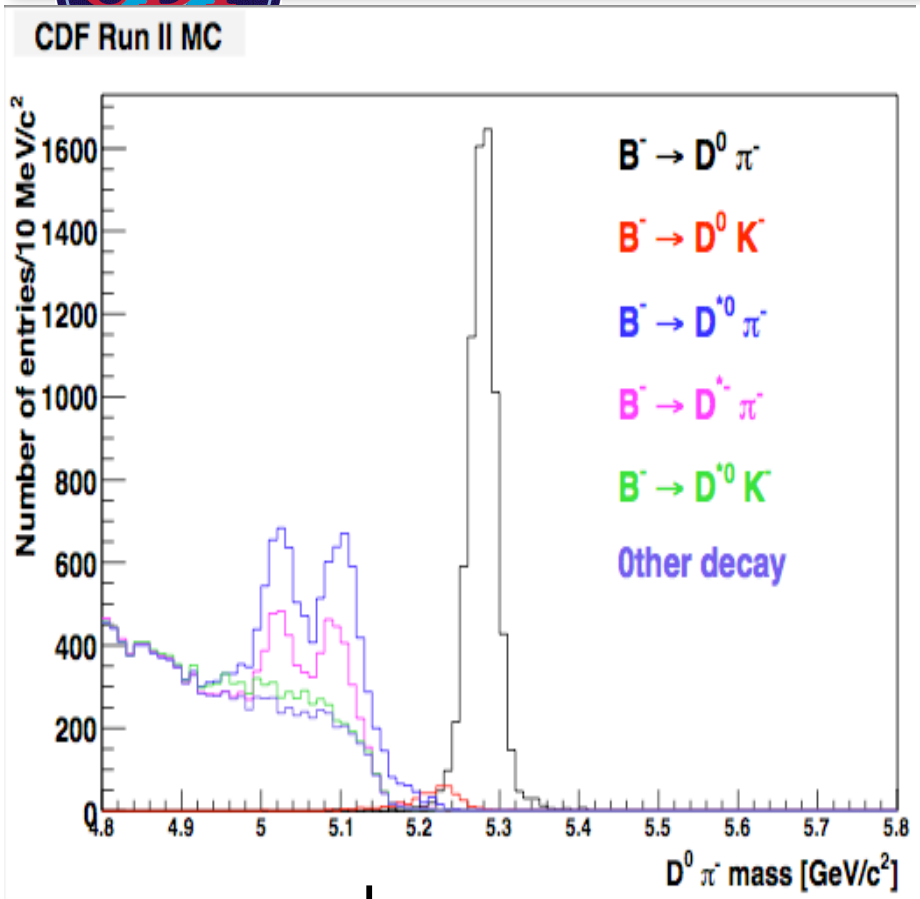
Measure:

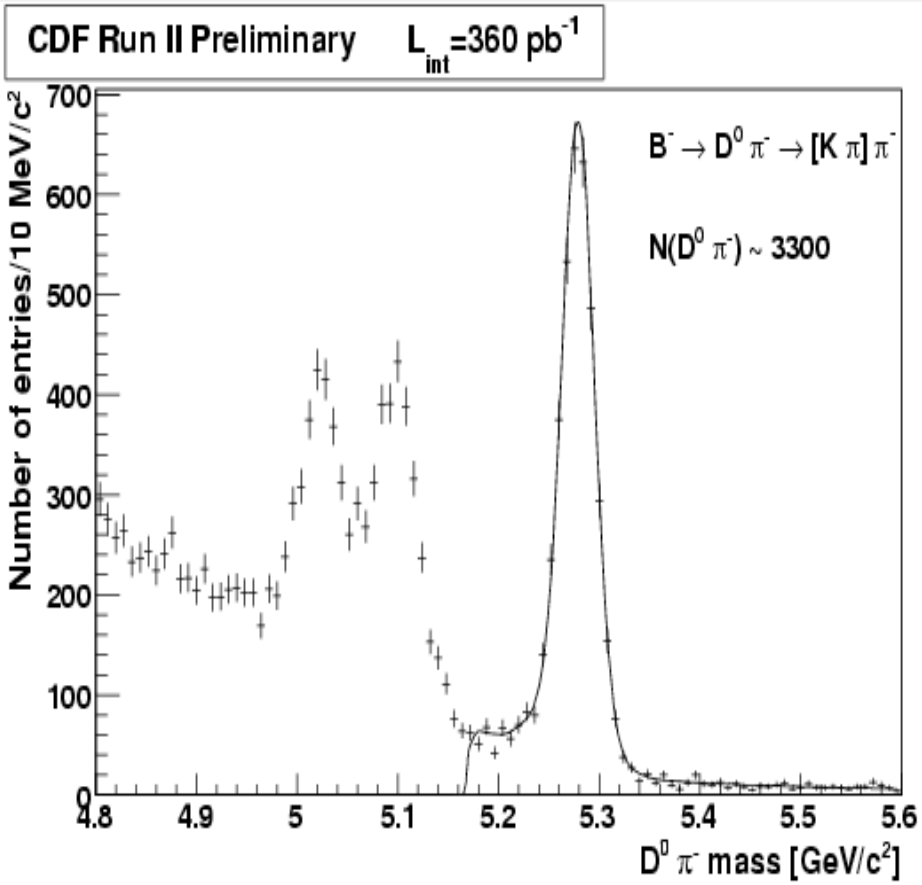
$$R = \frac{B(B^- \to D^0 K^-) + B(B^+ \to \overline{D^0} K^+)}{B(B^- \to D^0 \pi^-) + B(B^+ \to \overline{D^0} \pi^+)}$$

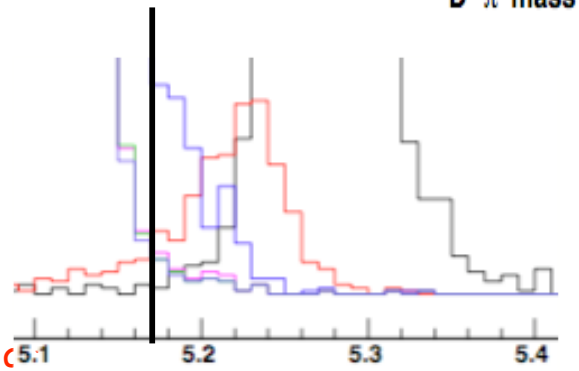
$$R_\pm = \frac{B(B^- \to D^0_{CP\pm} K^-) + B(B^+ \to D^0_{CP\pm} K^+)}{B(B^- \to D^0_{CP\pm} \pi^-) + B(B^+ \to D^0_{CP\pm} \pi^+)}$$

$R_{CP\pm} = R_\pm / R$

DATA sample 360 pb^{-1}



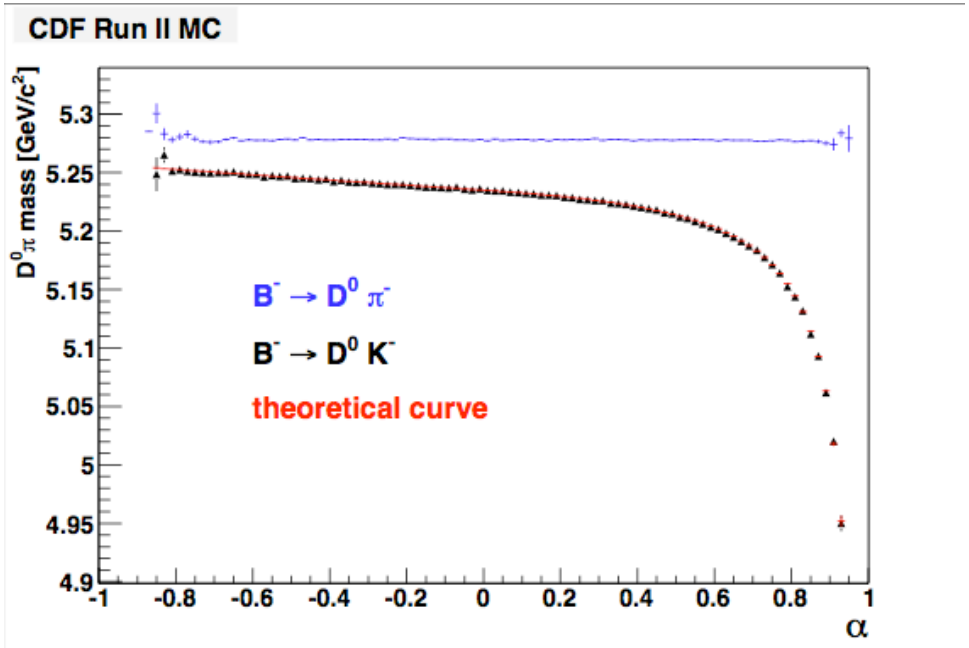


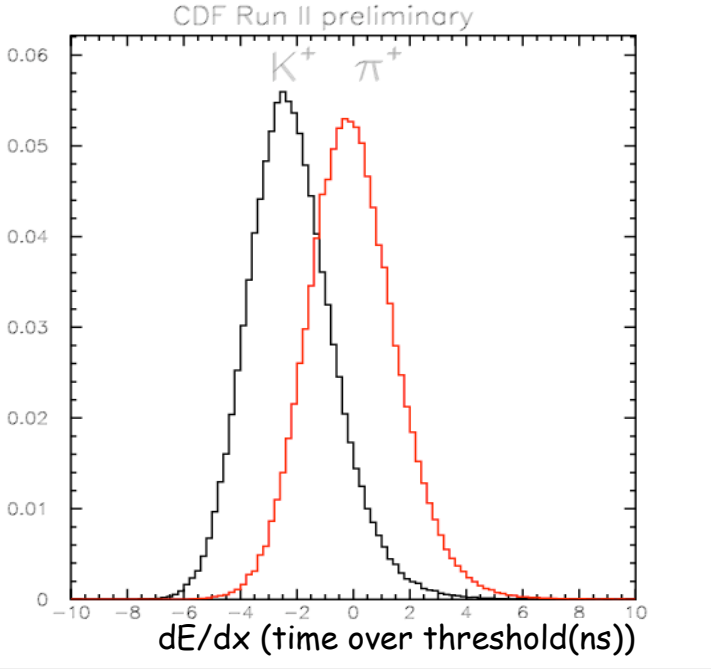


To reject most of the physical backgrounds, narrow fit windows [5.17,5.6]

Likelihood FIT

Implementation of a Likelihood FIT using kinematics and particle identification information





$D^0\pi$ mass *vs* momentum imbalance α

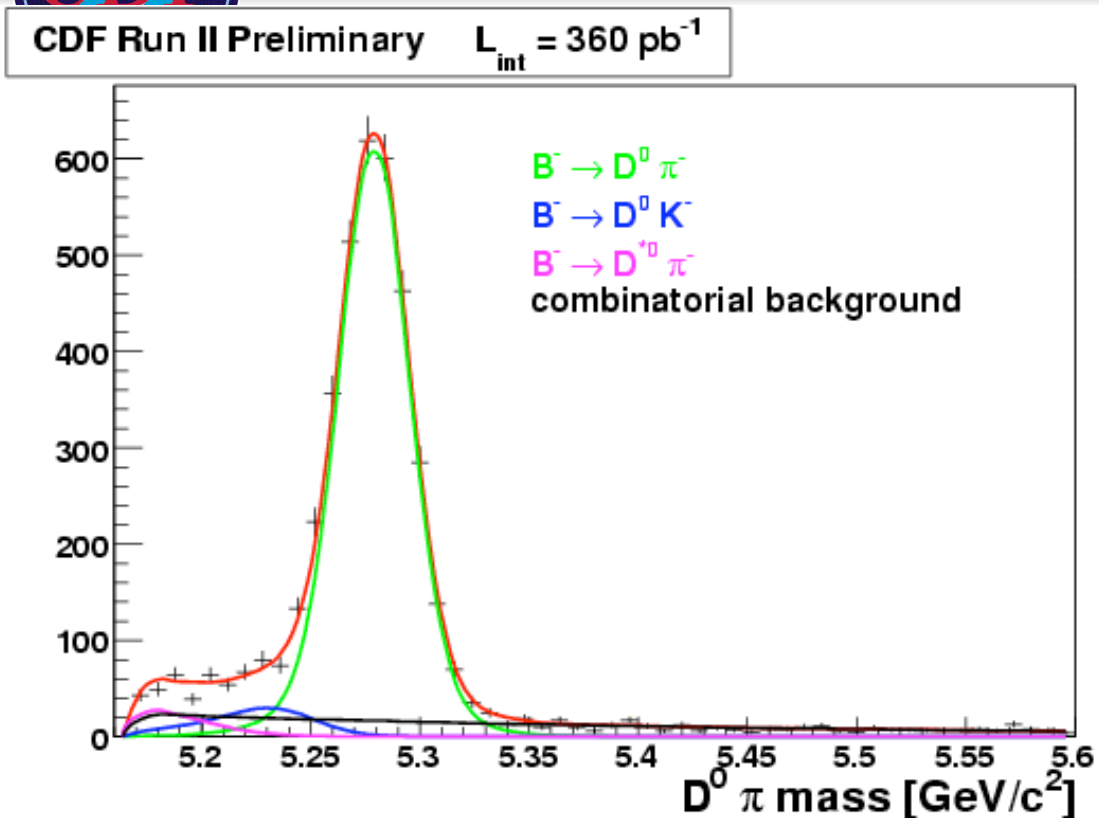
$P_t < P_{D0}$ $\quad \alpha = 1 - P_t/P_{D0} > 0$

$P_t >= P_{D0}$ $\quad \alpha = -(1 - P_{D0}/P_t) <= 0$

K - π separation: 1.5 σ for p > 2 GeV/c

Future: add the TOF info

Fit Results on 360 pb^{-1}



N ($D^0 \pi$) = 3265 ± 38

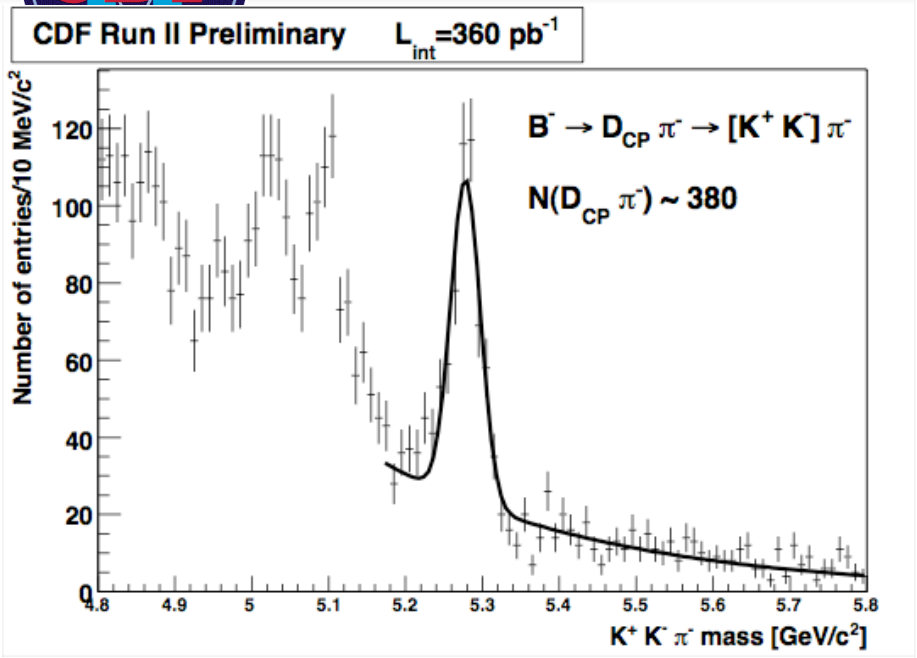
N (D^0 K) = 224 ± 22

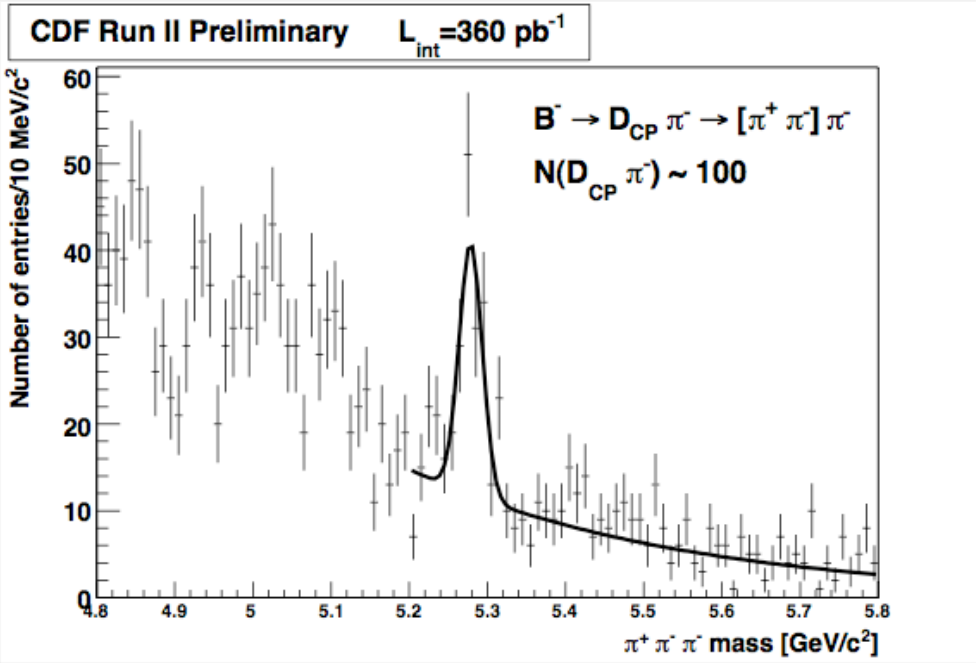
For same yields, resolution is the same as at B factories !

$$R = \frac{BR(B^+ \to D^0_{flav} K^+)}{BR(B^+ \to D^0_{flav} \pi^+)} = 0.065 \pm 0.007 \text{ (stat)} \pm 0.004 \text{ (sys)}$$

World average R = 0.083 ± 0.0035

DCP modes





Moving to the fb^{-1} for the complete analysis: 26000 $D^0\pi$

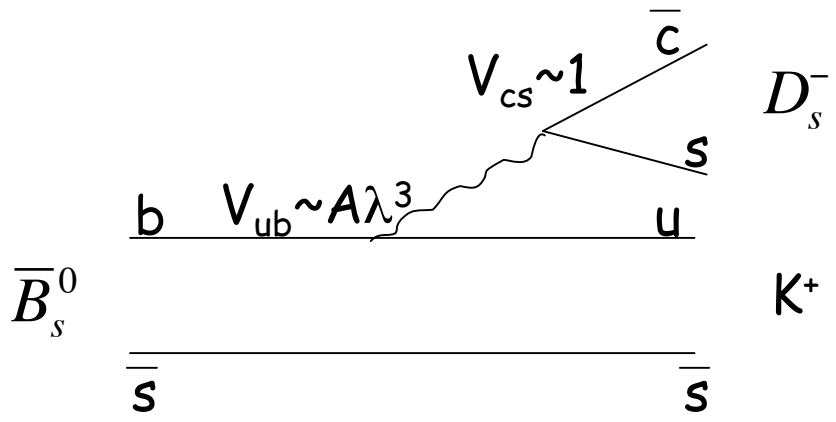
Resolution estimate for R_{CP} and A_{CP} ~ 0.1 comparable with the current resolution of B factories

$B_s \rightarrow D_s K$

In addition $B_s \rightarrow D_s K$ We expected ~ 200 events in 1 fb^{-1}

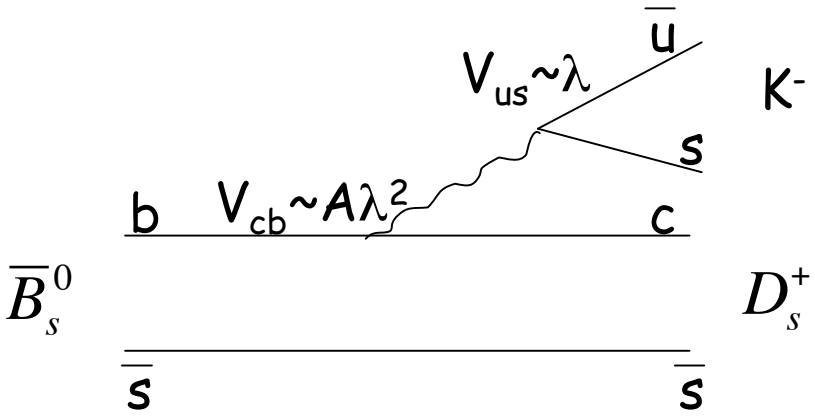
Final state of both sign are accessible by both B_s mesons with similar-sized amplitudes

$$B_s^0 \rightarrow D_s^{\pm} K^{\mp}$$
$$\overline{B}_s^0 \rightarrow D_s^{\mp} K^{\pm}$$



B_s oscillation then cause the amplitudes to interfere

This is the cleanest channel to measure γ (time dependent CP asymmetry measurement needed)



Conclusions

CKM physics at CDF:

- B_s mixing

$$\Delta m_s = 17.31^{+0.33}_{-0.18}(stat.) \pm 0.07(syst.)\, ps^{-1}$$

$$|V_{td}|/|V_{ts}| = 0.208^{+0.001}_{-0.002}(\exp.)^{+0.008}_{-0.006}(theo.)$$

Uncertainty already dominated by lattice calculations rather than Δm_s

- γ angle measurement (GLW and ADS method)

First step:

$$R = \frac{BR(B^+ \to D^0_{flav} K^+)}{BR(B^+ \to D^0_{flav} \pi^+)} = 0.065 \pm 0.007(stat.) \pm 0.004(sys.)$$

BACKUP

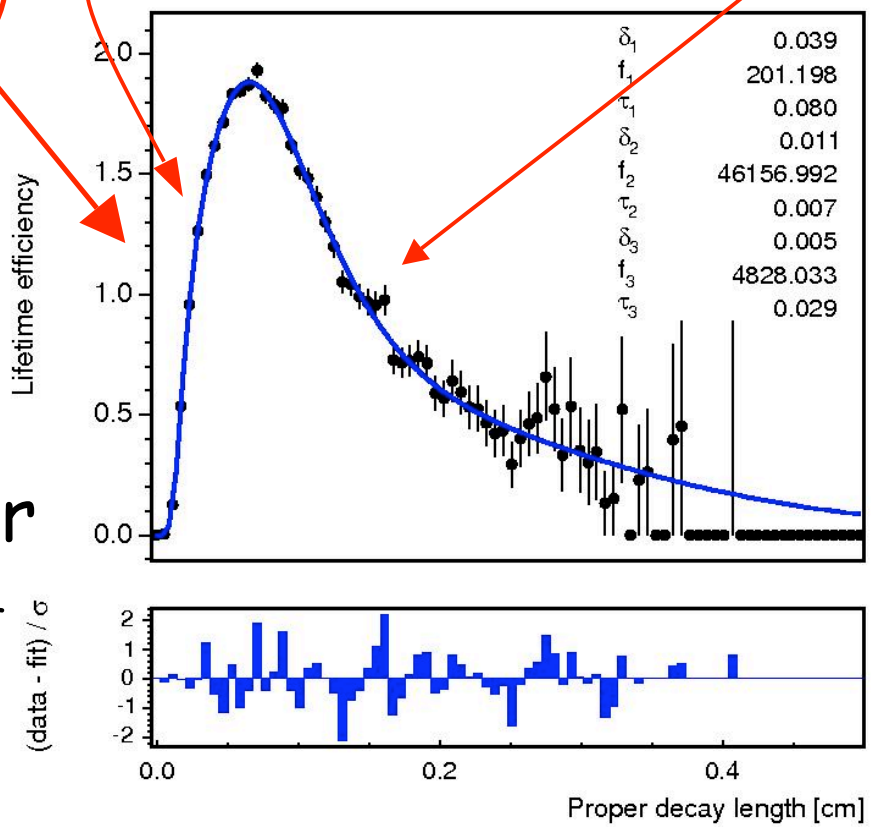
Proper Decay Time

- Proper decay time: $ct = L_{xy}\, M/p_T$
- Impact parameter trigger → lifetime bias

$$p(t;\tau) = \left(\underbrace{\frac{e^{-t/\tau}}{\tau}}_{\text{lifetime}} * \underbrace{R(t)}_{\text{resolution}} \right) \epsilon(t)$$

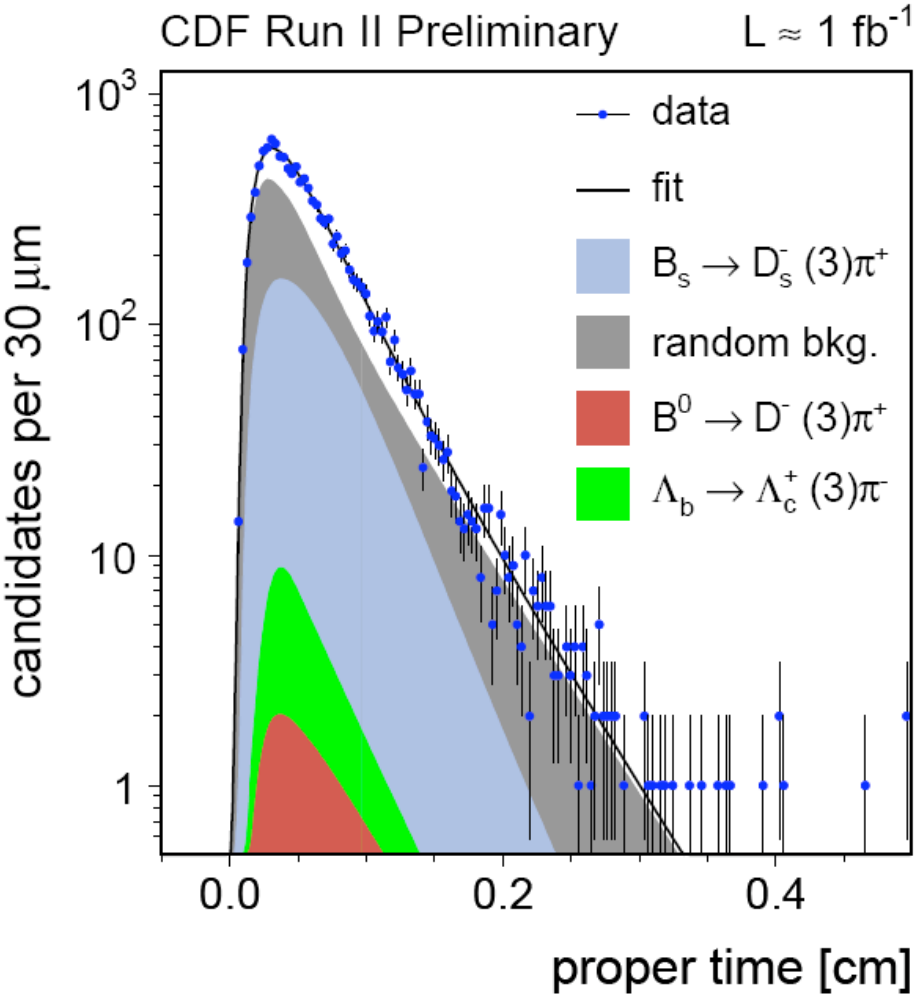
Limited number of patterns

Cut at $|d_0|>120$ μm



- Efficiency calculated using B Monte Carlo and an emulation of the trigger
- Checked using $B^+ \rightarrow J/\psi K^+$

Lifetime Measurements



Decay	Lifetime (ps)
$B^0 \to D^- \pi^+$	1.508 ± 0.017
$B^- \to D^0 \pi^-$	1.638 ± 0.017
$B_s^0 \to D_s(3)\pi$	1.538 ± 0.040

Still dominated by statistical uncertainty

World Averages: hep-ex/0603003

Decay	Lifetime (ps)
$\tau(B^0)$	1.527 ± 0.008
$\tau(B^+)$	1.643 ± 0.010
$\tau(B_s^0)$	1.454 ± 0.040

DATA sample 360 pb^{-1}

$\chi^2_{3D} < 15$

Isol > 0.5

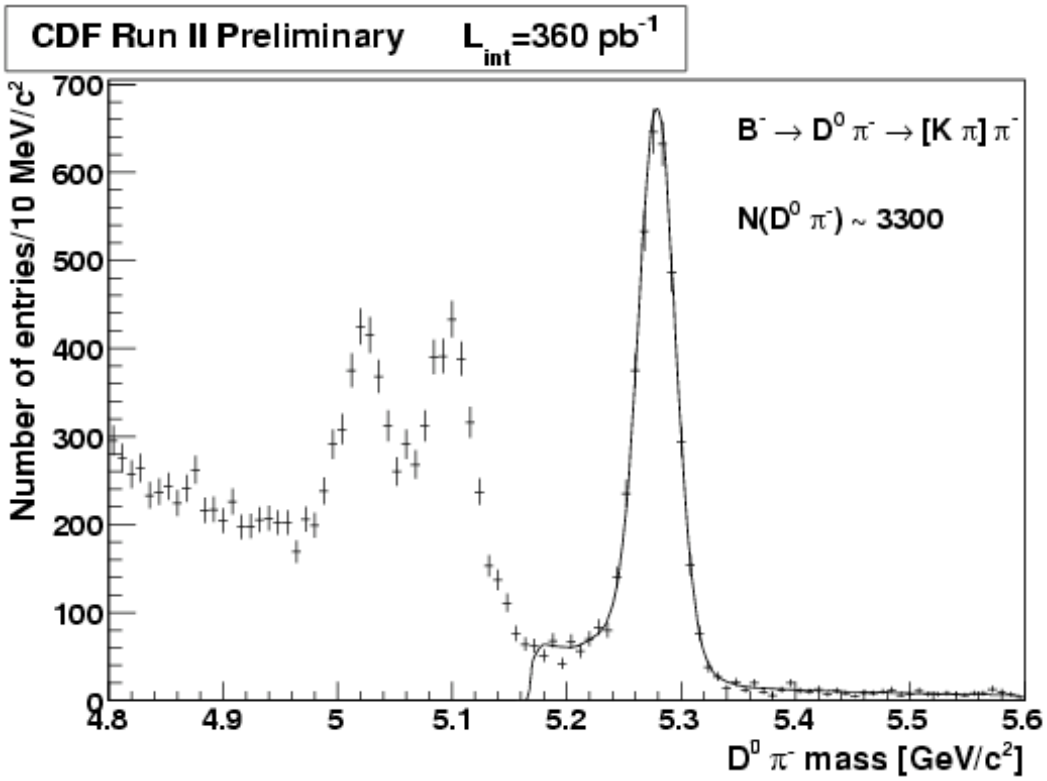
$L_{xy}(B)/\sigma_{Lxy(B)} > 8$

$L_{xy}(D)$ wrt B > -0.0015 cm

$|d_0(B)| < 0.008$ cm

P_t (track from B) > 2 GeV/c

$\Delta R_{\pi,D0} = (\Delta\phi^2 + \Delta\eta^2)^{1/2} < 2$



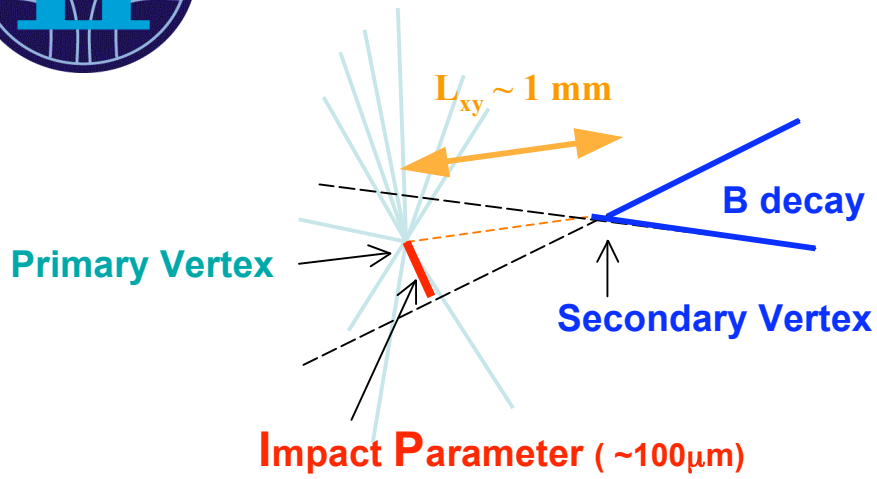
We select the sub-sample where the pion from B is a trigger track

The cuts on the isolation and on the tridimensional χ^2 permit to suppress the combinatorial background

Systematics

dE/dx	0.0015
Combinatorial background	0.001
Mass resolution tails	0.0006
Input mass	0.001
$D^{*0}\pi$ (1)	0.003
$D^{*0}\pi$ (2)	0.001
MC statistics	0.002
Total	0.004

SVT: the hadronic B trigger



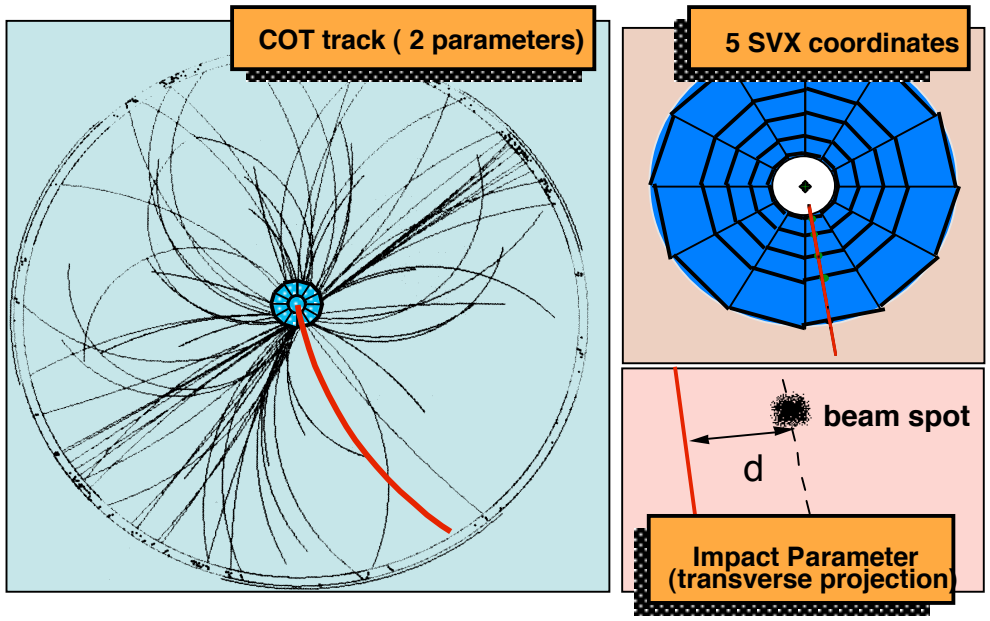
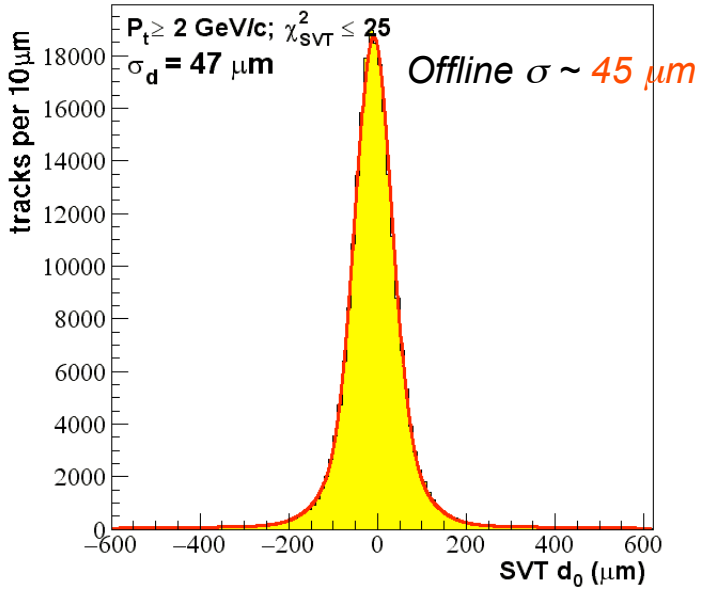
→Online Impact parameter
Available at Level 2 trigger (20μs latency)

→Convolution of transverse size of the beam spot with the impact parameter resolution of the SVT:

$$\sigma \approx 47\ \mu m \approx 35\ \mu m \oplus 30\ \mu m$$

SVT resolution

Beam spot size



Impact Parameter distribution