CDF Run II Prospects for Bs mixing

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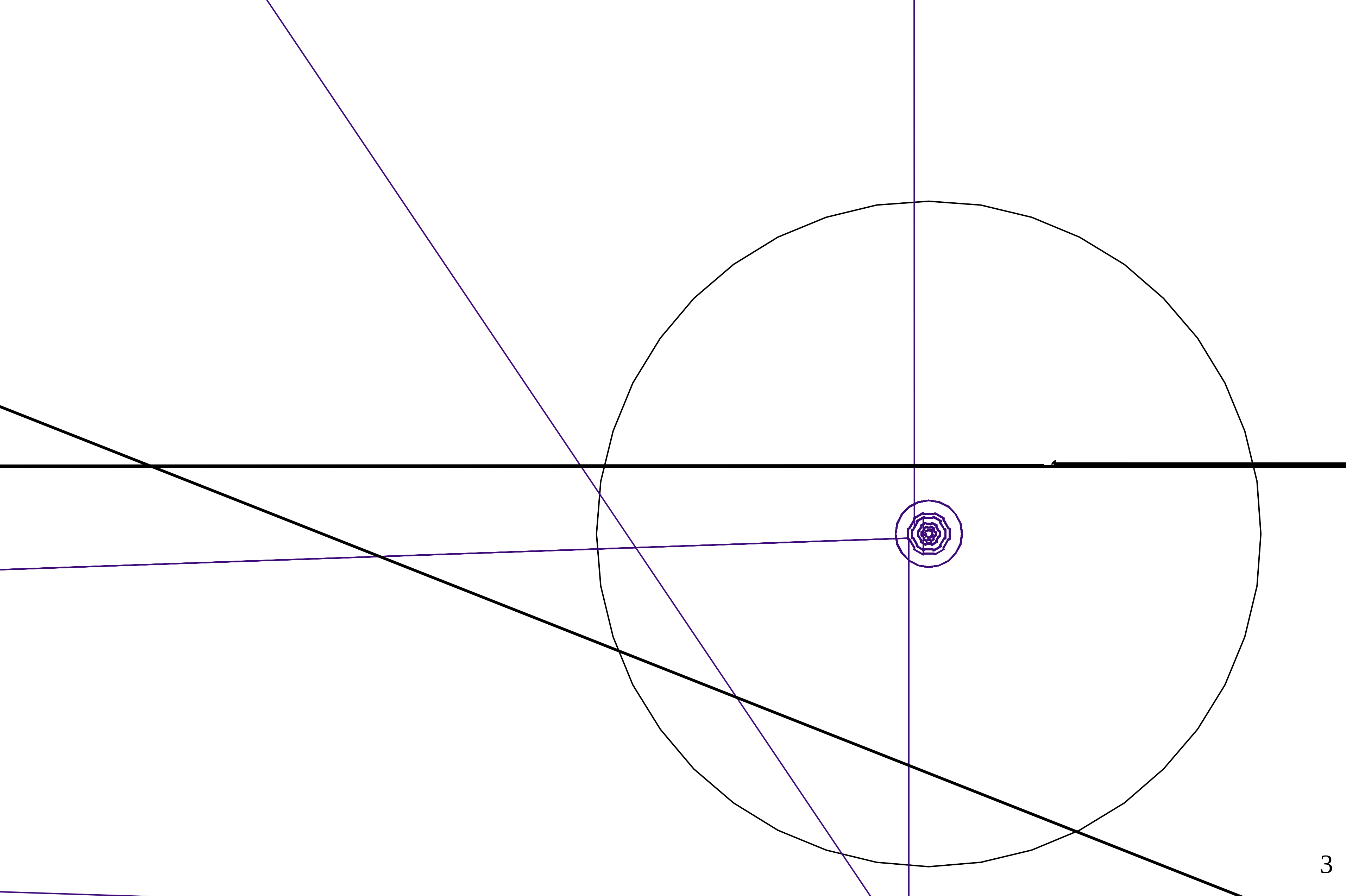
Relevant Detector Elements:

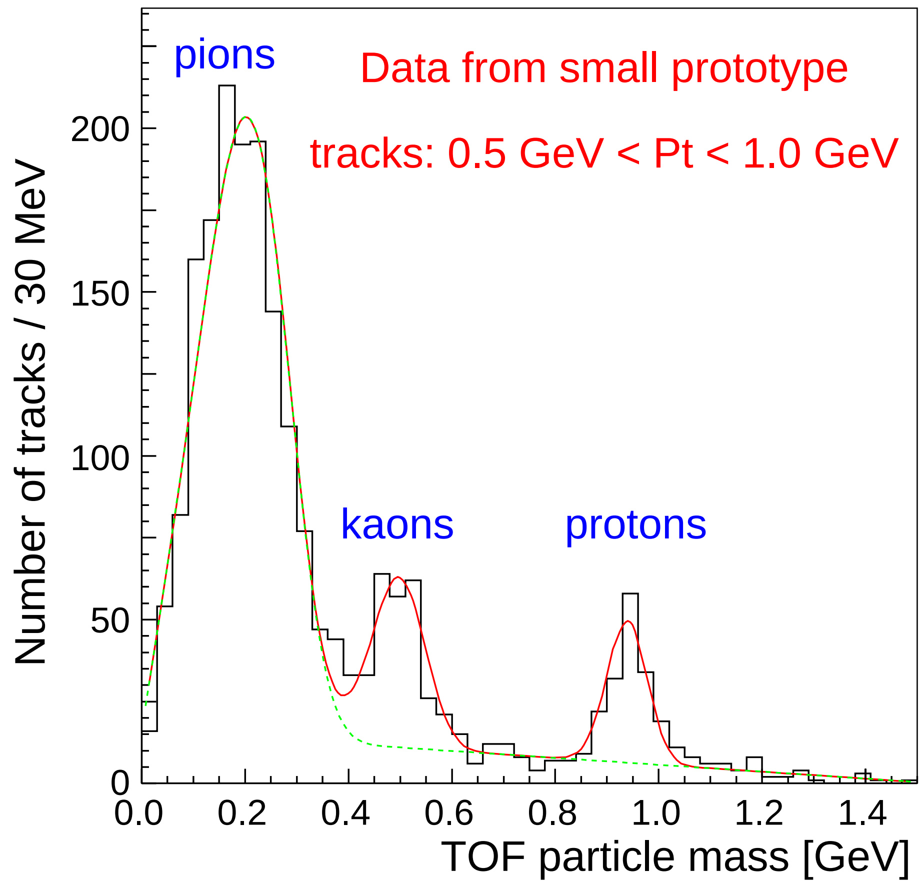


Time of Flight (TOF):

Particle Identification (For B_s mixing: especially Kaons)

TOF:

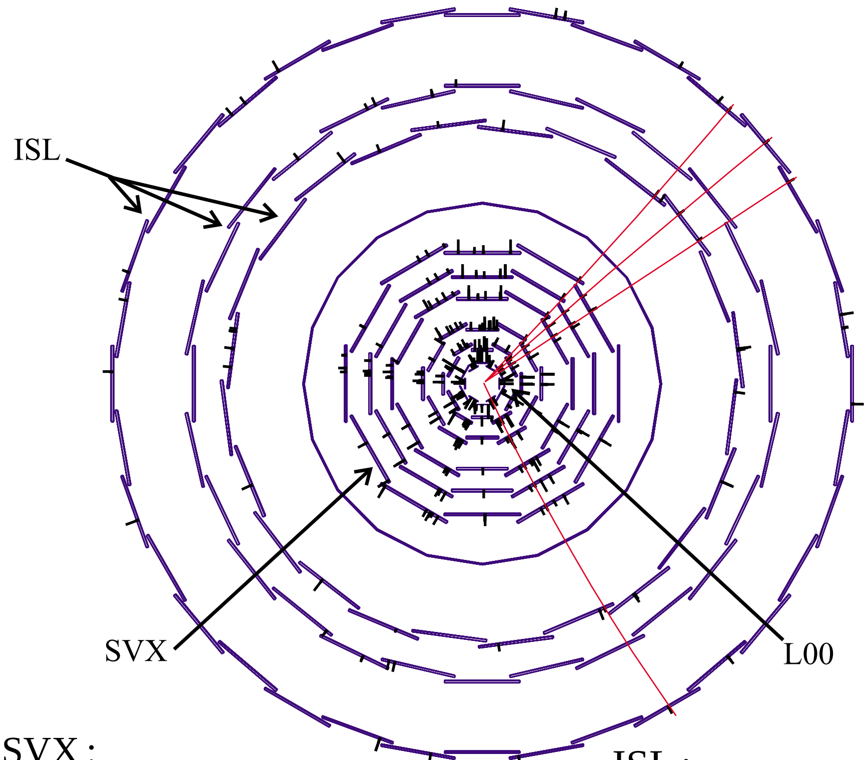
- 216 bars of Scintillator
- Radius: 138 cm
- Each read out both ends by PMT's
- Expected ave resolution: 100 psec



Zooming in...

Same MC event (one $p\bar{p}$ interaction):

Silicon System:



SVX :

$2.54 < \mathrm{r} < 10.64\ \mathrm{cm}$

$|z| = 43.5cm$

$|\eta| < 2.0$

$\sigma_\phi < 30\mu m\, , \sigma_z < 60\mu m$

(for central high mom tracks)

ISL :

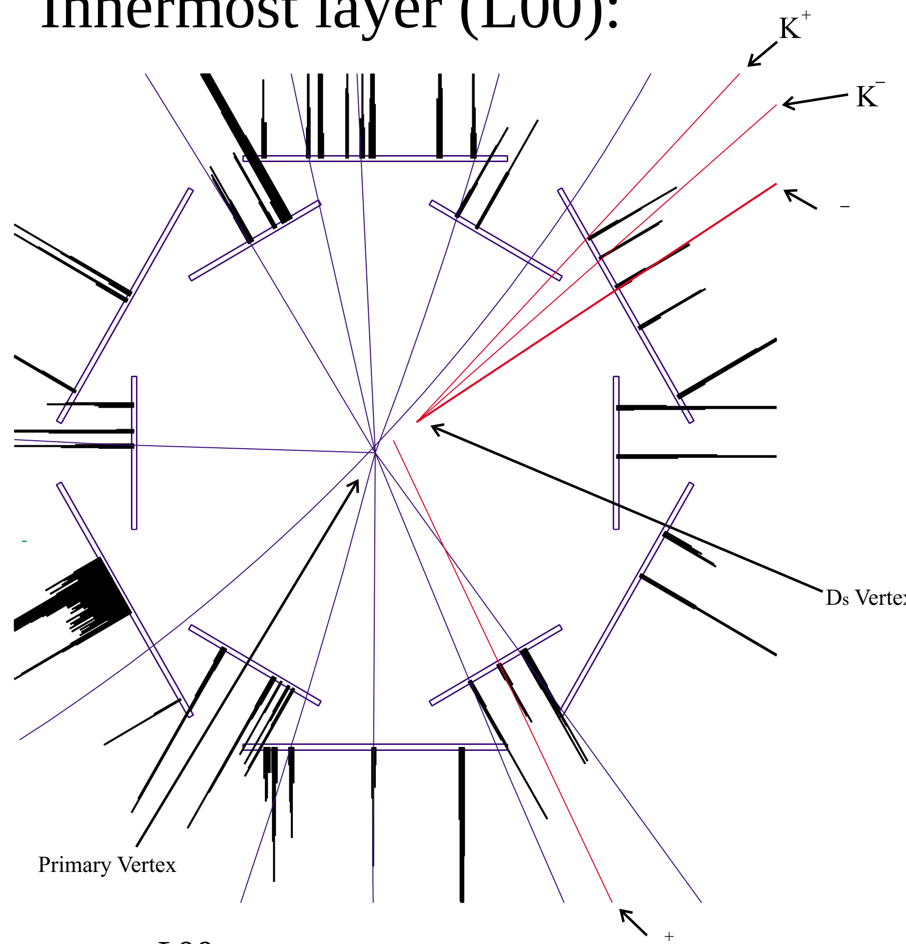
$20 < r < 30cm$

$|z| = 65cm$ (inner layer)

$|z| = 87.5cm$ (outer layer)

$|\eta| < 1.9$

Innermost layer (L00):



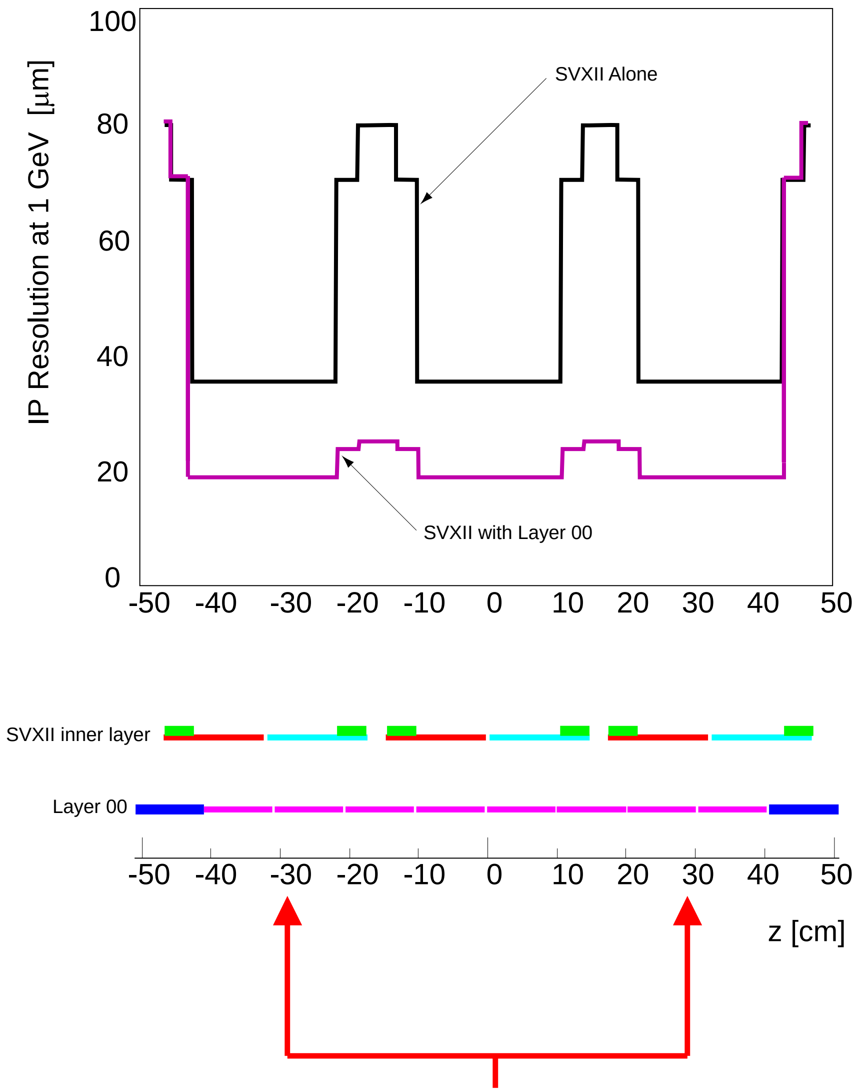
$L00$:

$r_{narrow} = 1.35cm, r_{wide} = 1.62cm$

$|z| \approx 6 \times 7.84 = 47.04cm$

$|\eta| < 4$

Importance of L00:



1σ of luminous region (30cm)

Run II at CDF:

- CM Energy from 1.8 Tev to 2.0 Tev
- Significant Luminosity upgrade ($2\,fb^{-1}$ expected in first 2 years.)

Scenario	$T_{bunch}\ (ns)$	L $(\times 10^{32}\ cm^{-2} s^{-1})$	$\langle N_{p\bar{p}} \rangle$
A	396	0.7	2
B	132	2.0	2
C	396	1.7	5

- Significant detector upgrades (as described).
- Status of Tracking and TOF:
    - Central Outer Tracker:
        - Physical detector installed. Calibration soon.
    - SVX (main silicon detector) and ISL (Intermediate Silicon Layers):
        - Ladder assembly complete for SVXII, at 80% for ISL
        - 2 of 3 barrels are complete for SVXII. Ladder mounting on the frames is underway for ISL
    - L00 (inner layer of silicon):
        - On target for Oct 3rd completion.
    - TOF:
        - Mechanical Installation complete.

Bs Mixing: A brief reminder

$$\left.\begin{array}{l} |B_s,L\rangle = p|B_s\rangle + q|\overline{B_s}\rangle \\ |B_s,H\rangle = p|B_s\rangle - q|\overline{B_s}\rangle \end{array}\right\} |B_s\rangle, |\overline{B_s}\rangle$$ strong interaction eigenstates

$|B_s, L\rangle, |B_s, H\rangle$ are what decay (L=light, H=heavy).

$$|B_s,L\rangle(t) = e^{-\Gamma_L t - iM_L t}|B_s,L\rangle$$
$$|B_s,H\rangle(t) = e^{-\Gamma_H t - iM_H t}|B_s,H\rangle$$

$$\left(\begin{array}{l} \Delta M = M_H - M_L \\ \mathbf{x_s} = \frac{\mathbf{M}}{\ }, \; \Gamma = \frac{\Gamma_H + \Gamma_L}{2} \end{array}\right)$$

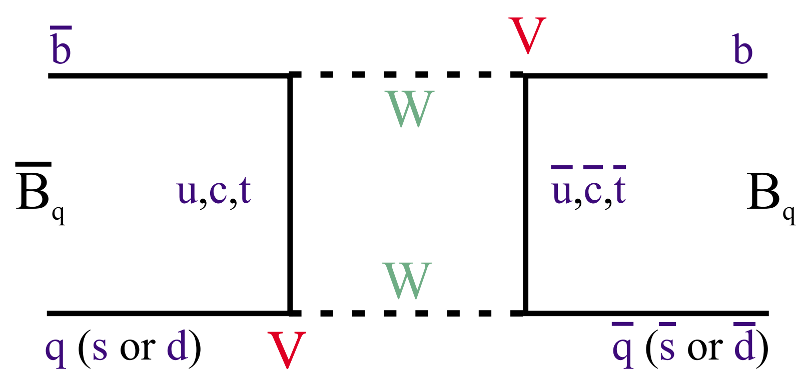
So a particle which is initially a Bs has a time evolution:

$$|\Psi\rangle(t) = \left(\frac{1}{2p}\right)\left[e^{-\Gamma_L t - iM_L t}|B,L\rangle + e^{-\Gamma_H t - iM_H t}|B,H\rangle\right]$$

and since $\begin{cases} M_H \neq M_L \\ \Gamma_H \neq \Gamma_L \end{cases}$

$$|\Psi\rangle(t) = f(t)|B_s\rangle + g(t)|\overline{B_s}\rangle$$ where $\begin{cases} g(t) \neq 0 \text{ for } t > 0 \\ f(t) = 1 \text{ for } t = 0 \end{cases}$

A Box Diagram for Neutral B Mixing



V are CKM Matrix elements, eg V_{ts} or V_{td} for B_s and B_d respectively.

→ x_s is what we want to measure.

The importance of x_s

• Important goal: Measure CPV in the interference between decays, with and without mixing.

(Clean theoretical interpretation for some modes)

• But the time dependent asymmetry modulated by mixing:

Given 2 time evolving neutral B states which start out as B and $\overline{B}$ respectively, compare their rates to a given CP eigenstate:

$$\frac{\Gamma\left(\overline{B}^0{}_{phys}(t) \to f_{CP}\right) - \Gamma\left(B^0{}_{phys}(t) \to f_{CP}\right)}{\Gamma\left(\overline{B}^0{}_{phys}(t) \to f_{CP}\right) + \Gamma\left(B^0{}_{phys}(t) \to f_{CP}\right)} = \mathrm{Im}\left(\lambda_{f_{CP}}\right)\sin\left(\Delta m_B t\right)$$

• Without being able to resolve Mixing, a measurement of this asymmetry in the B_s sector will be nearly impossible.

• also…..

x_s in the Standard model and beyond:

- The Standard Model does not easily allow $x_s \gtrsim 30$

  So could see new physics here (eg $x_s >> 30$)

- However, in the ratio $\frac{\Delta\Gamma_s}{x_s}$ some theoretically uncertain quantities cancel. So in conjunction with a measurement of $\Delta\Gamma_s$ could provide cleaner evidence of new physics.

- A measurement of x_s would help to constrain the elements of the CKM matrix.

Reminder of what we measure:

- Note: Ignoring CPV, but expected to be negligibly small.

•What is measured: $$A_{(mixed)}(t) = \frac{N_{unmixed}(t) - N_{mixed}(t)}{N_{unmixed}(t) + N_{mixed}(t)}$$

- So must tag the initial flavour of the B:
  - Same side tagging: Fragmentation Kaon.
  - Opposite side tagging: Semileptonic Decay, Jet Charge, Kaon Charge Asymmetry

- Don't get it right all the time. Parameterise this by Dilution: $D = \frac{N_R - N_W}{N_R + N_W}$

  Where N_R (N_W) is number of correct (incorrect) tags.

- Related to mistag rate: $D = 1 - 2w$

  (eg if out of 100 events we tag 60 right and 40 wrong, $D = 0.2, w = 0.4$)

- Tagging efficiency ε is defined as the fraction of signal for which we could calculate a tagging quantity.

The significance of a measurement:

- In order to find x_s fit the measured asymmetry to:

$$a(t) = A\cos\left(\frac{x_s t}{\tau}\right)$$ (by minimizing a log-likelihood quantity).

- The significance, in *equivalent standard deviations* can be expressed:

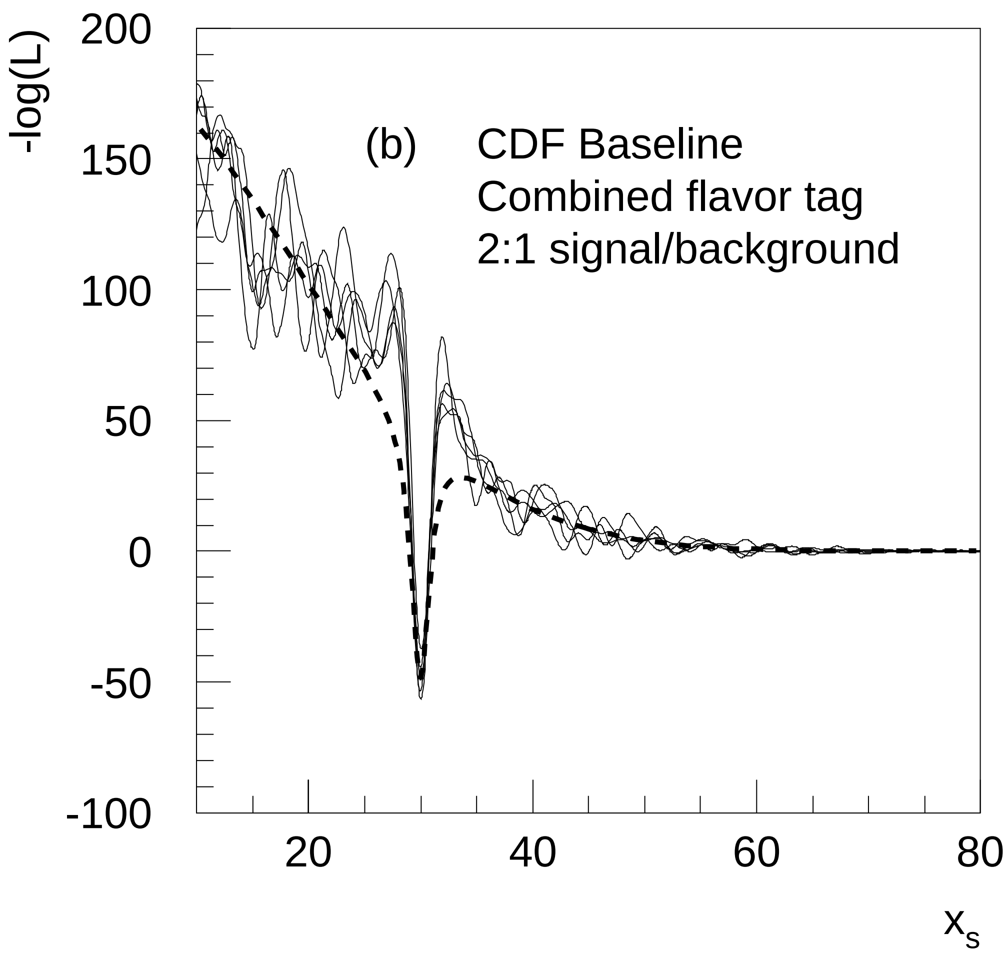
$$Sig = \sqrt{\left(2\times\Delta\log[L]\right)}$$

where $\Delta\log[L]$ is the depth of the minimum compared to the next-to-deepest minimum.

- This can be expressed analytically:

$$Sig(x_s) = \sqrt{\frac{N\varepsilon D^2}{2}}\exp\left(\frac{\left[-x_s\sigma_{ct}\right]^2}{2}\right)\sqrt{\frac{S}{1+S}}$$

CDF baseline Likelihood function:



Semileptonic modes:

- Look in: $B_s \to l\nu\, D_s$

  $B_s \to l\nu\, D_s^{\,*}$

- Proper time resolution worse than $B_s \to D_s^{-}\pi^{+}$

- Expect $N \approx 40{,}000$ semileptonic sample size

- Extrapolating from Run I data, expect to be able to measure $x_s \approx 30$ from semileptonics alone.

Fully Hadronic Modes:

- Look for fully reconstructed Bs decays: minimise σ_{ct}
- Requires triggering on hadrons: a challenge at a hadron machine.
  Use an extremely fast hardware impact parameter trigger
  (has to able to cope with an input rate $\approx 20\,kHz$)

$$B_s \to D_s^{\,-}\pi^+ \text{ where} \begin{cases} D_s^{\,-} \to \phi\pi^- \\ \phi \to K^+K^- \end{cases}$$

$$B_s \to D_s^{\,-}\pi^+\pi^-\pi^+ \text{ where} \begin{cases} D_s^{\,-} \to \phi\pi^- \\ \phi \to K^+K^- \end{cases}$$

$$B_s \to D_s^{\,*-}\pi^+ \text{ where} \begin{cases} D_s^{\,*-} \to D_s^{\,-}\gamma \\ D_s^{\,-} \to \phi\pi^- \\ \phi \to K^+K^- \end{cases}$$

- Seek to reconstruct other modes of the Ds

Assumptions behind prediction:

- Only consider fully reconstructable modes
- Predictions take into account:
  - Expected Luminosity
  - Expected occupancy
- Tagging power: $\varepsilon D^2 = \begin{cases} 5.7\% & \text{without TOF} \\ 11.3\% & \text{with TOF} \end{cases}$
- Proper time resolution: $\sigma_{ct} = \begin{cases} 60\,\text{fs} & \text{without Layer 00} \\ 45\,\text{fs} & \text{with Layer 00} \end{cases}$
- Number of fully reconstructed Bs events ≈ 20000

Senario	$T_{bunch}\ (ns)$	L $(\times 10^{32}\ cm^{-2} s^{-1})$	$\langle N_{p\bar{p}} \rangle$
A	396	0.7	2
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Mode	A	B	C
$B_s \to D_s^- \pi^+$	10600	8400	7200
$B_s \to D_s^- \pi^+ \pi^- \pi^+$	12800	10400	8100
$B_s \to D_s^{*-} \pi^+$	9400	7400	5800

- $2\,fb^{-1}$ in the first 2 years of running.

The Prediction.

Maximum values of x_s for which a 5 σ observation is possible:

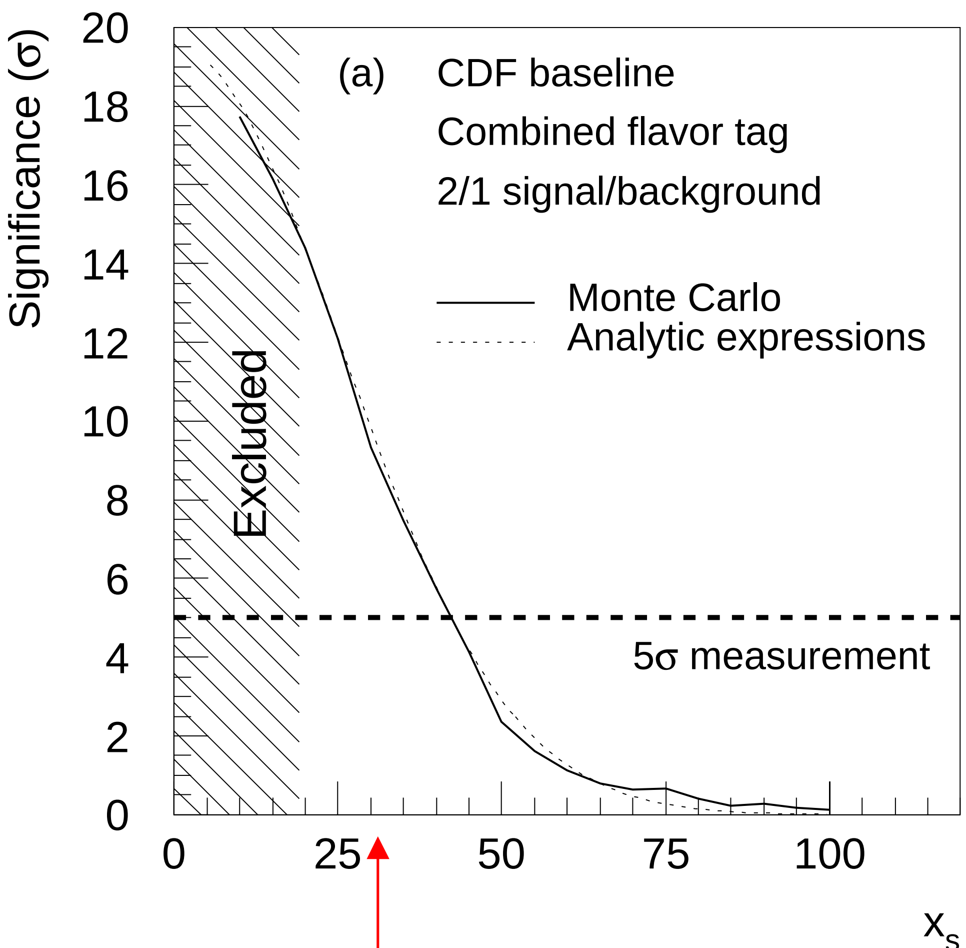
N(Bs)	S/B=2:1		S/B=1:2	
	Baseline	TOF+L00	Baseline	TOF+L00
5000	30	49	21	39
10000	37	56	30	49
20000	42	63	37	56
30000	45	67	40	60

Minimum values of signal-to-background ratio for which a 5 σ observation is possible:

N(Bs)	xs=30		xs=40	
	Baseline	TOF+L00	Baseline	TOF+L00
5000	2.20	0.24	-	0.53
10000	0.52	0.11	-	0.21
20000	0.21	0.05	0.99	0.10
30000	0.13	0.03	0.50	0.06

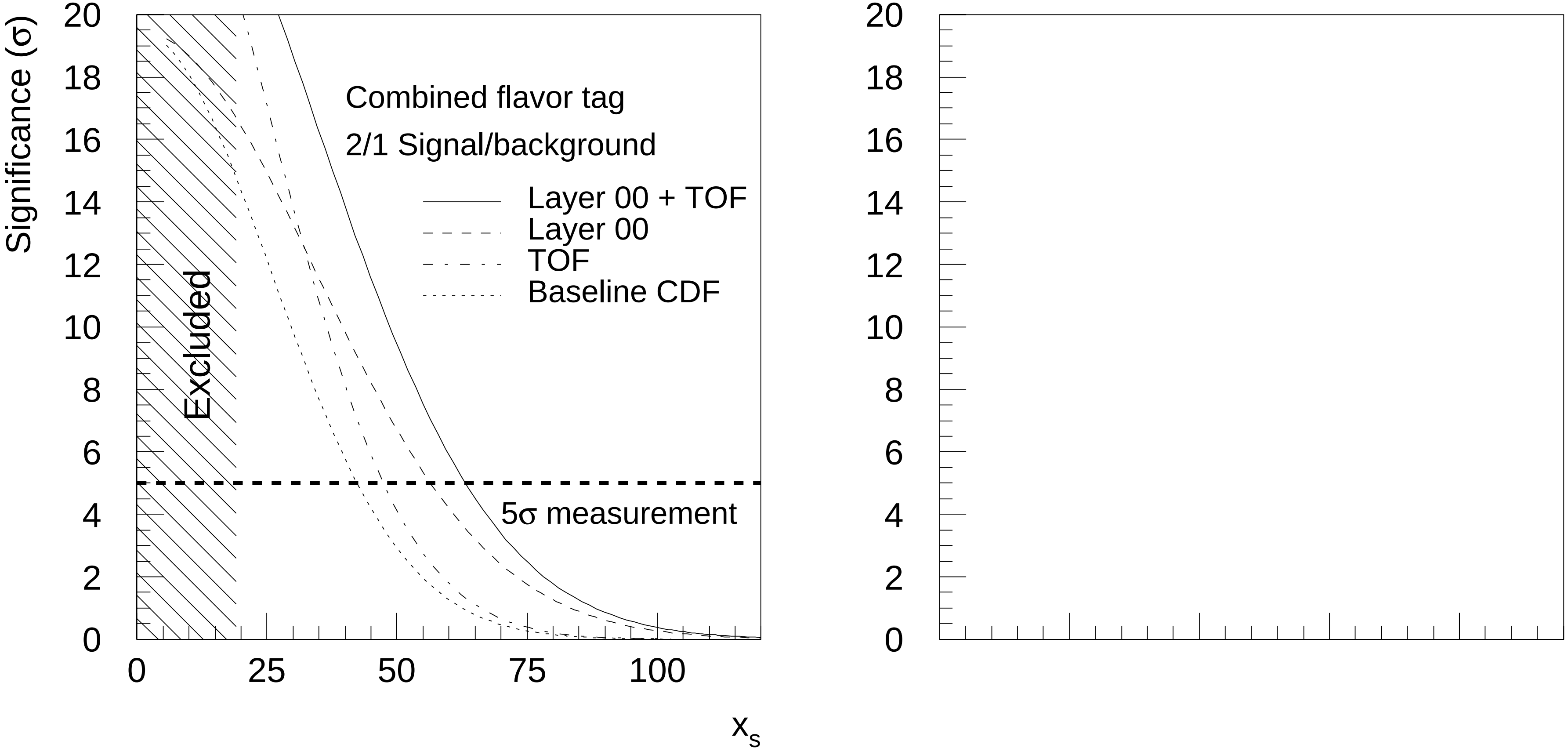
$$Sig(x_s) = \sqrt{\frac{N\varepsilon D^2}{2}} \exp\left(\frac{\left[-x_s\sigma_{ct}\right]^2}{2}\right)\sqrt{\frac{S}{1+S}}$$

CDF baseline 5 σ Mixing Reach:

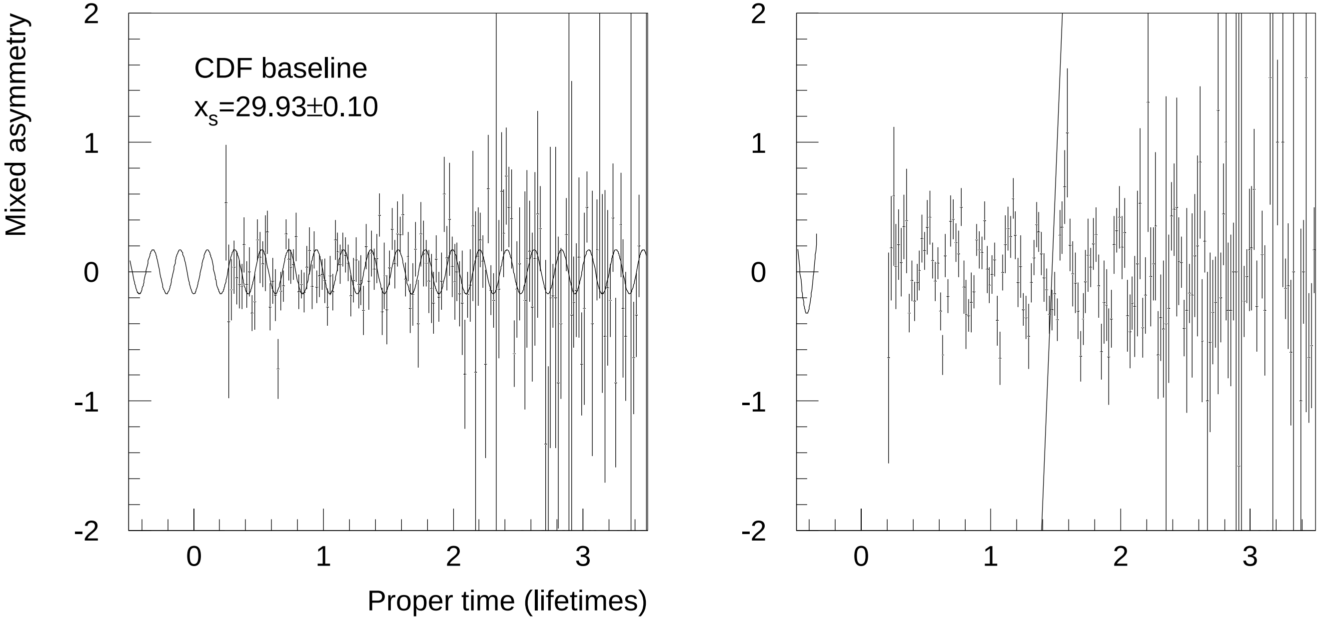


Approx SM limit (30)

Beyond the baseline reach:



More intuitive picture:



Conclusions

- SM prediction: $x_s \lesssim 30$
- With TOF and Layer 00:
  - Even for pessimistic sample size, SM prediction well within reach.
  - Even for pessimistic signal to background ratio, SM prediction well within reach.