Semileptonic decays, rare decays and penguins at CDF

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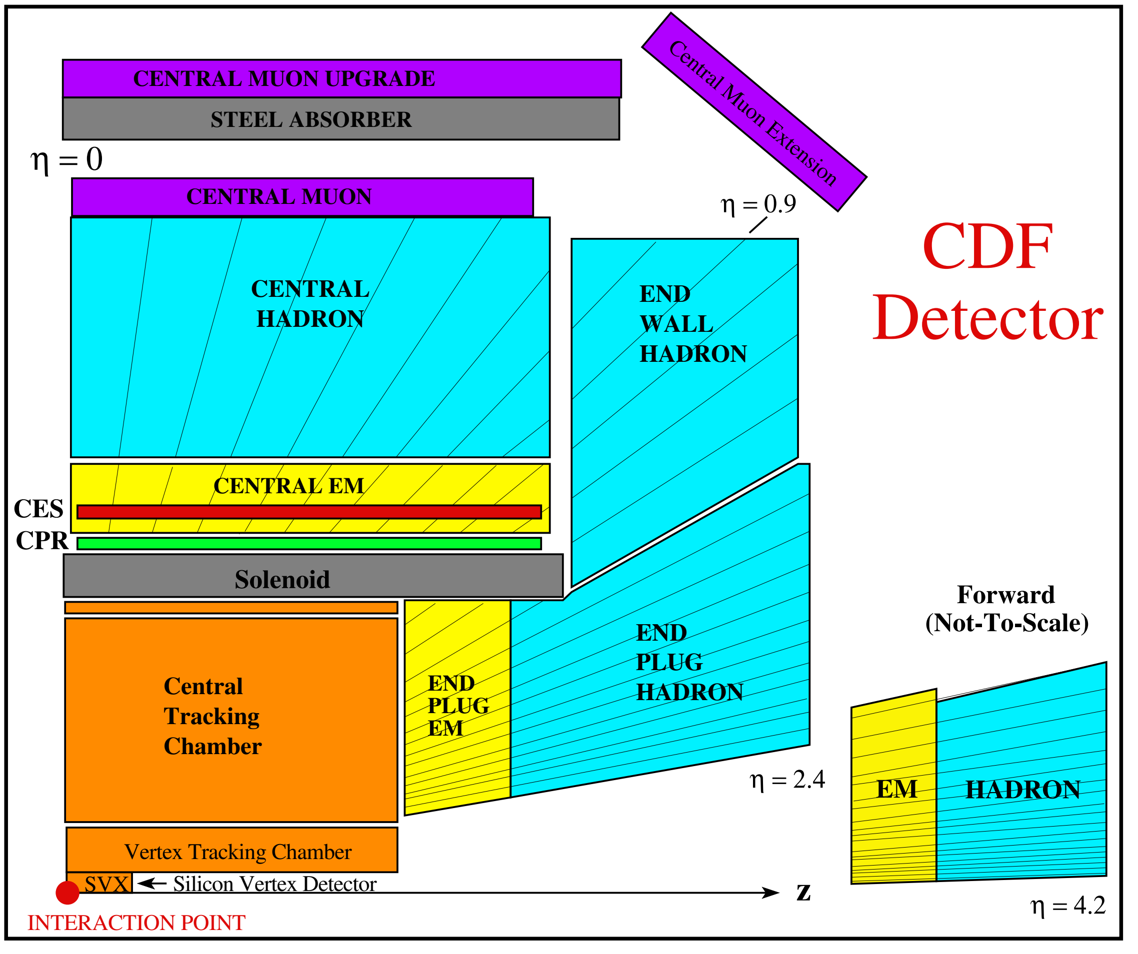
Talk outline

1. **Semileptonic decays**
   - CDF Detector and trigger in Run I
   - Run I Semileptonic data samples
   - Reconstructing the ν in Run I
   - CDF Detector and trigger in Run II
   - Run II possibilities
2. **Rare decays**
   - $B \to \mu\mu K^{(*)}$
3. **Radiative penguins:**
   - Using a special photon trigger
   - Using conversions ($\gamma \to e^+e^-$)

CDF detector in Run I



- **Silicon vertex detector (SVX)**
  typical error on proper time: $60\ \mu\mathrm{m}$ *(2D vertex fit)*

- **Central tracking chamber (CTC)**
  typical $J/\psi K_S^0$ mass resolution: $\sim 10\ \mathrm{MeV}/\mathrm{c}^2$

- **Muon systems, calorimeter**
  crucial for triggering and lepton identification

Run I trigger system

beam crossing

$\downarrow$ ~ 300 kHz — rate at $\mathcal{L} = 2 \times 10^{31}$

Level 1 — subsystems *(muon chambers, calorimeters...)*

$\downarrow$ *2000 Hz*

Level 2 — combine subsystems *(muon and electrons + tracking info)*

$\downarrow$ *30 Hz*

Level 3 — full event reconstruction

$\downarrow$ *10 Hz*

out to tape

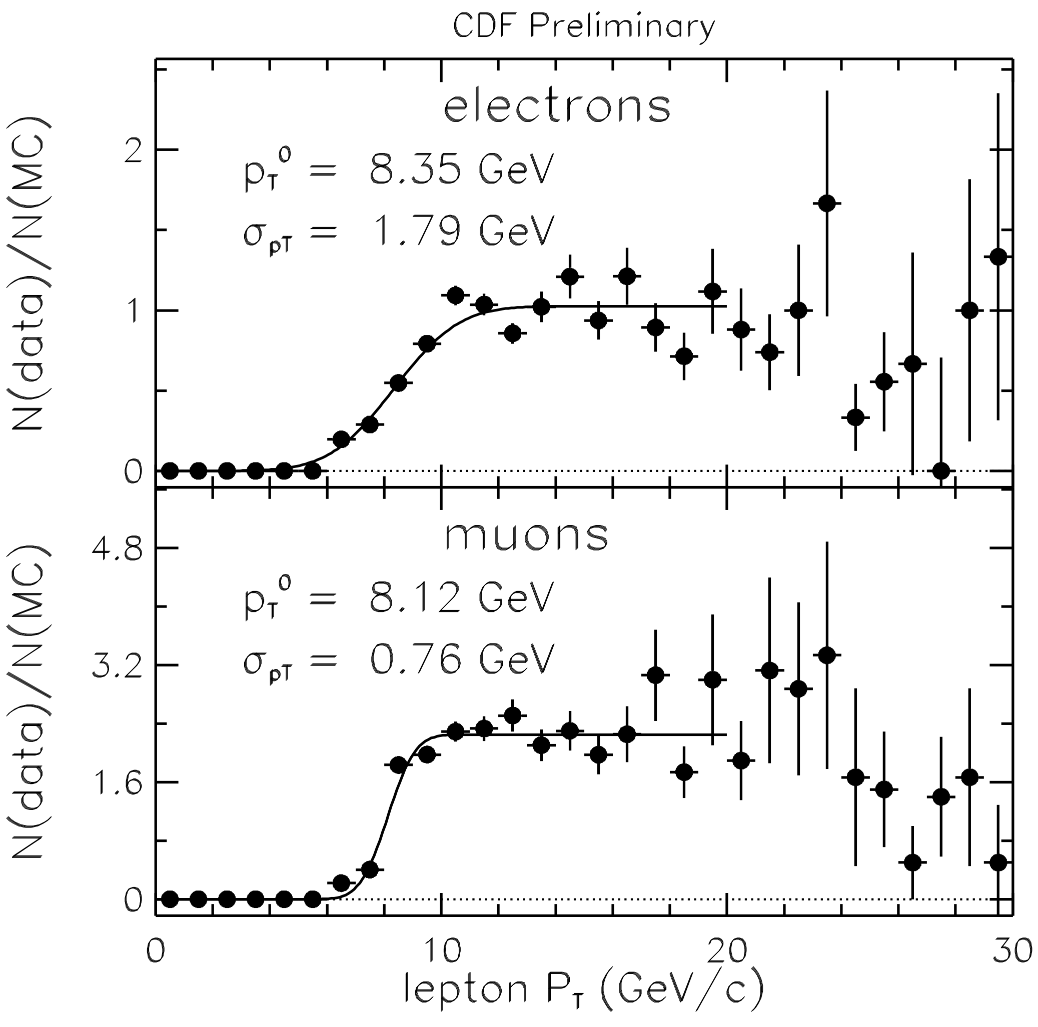
Central Fast Tracker: (unique to CDF)

- uses lookup table of hit patterns
- returns p_T of the best match

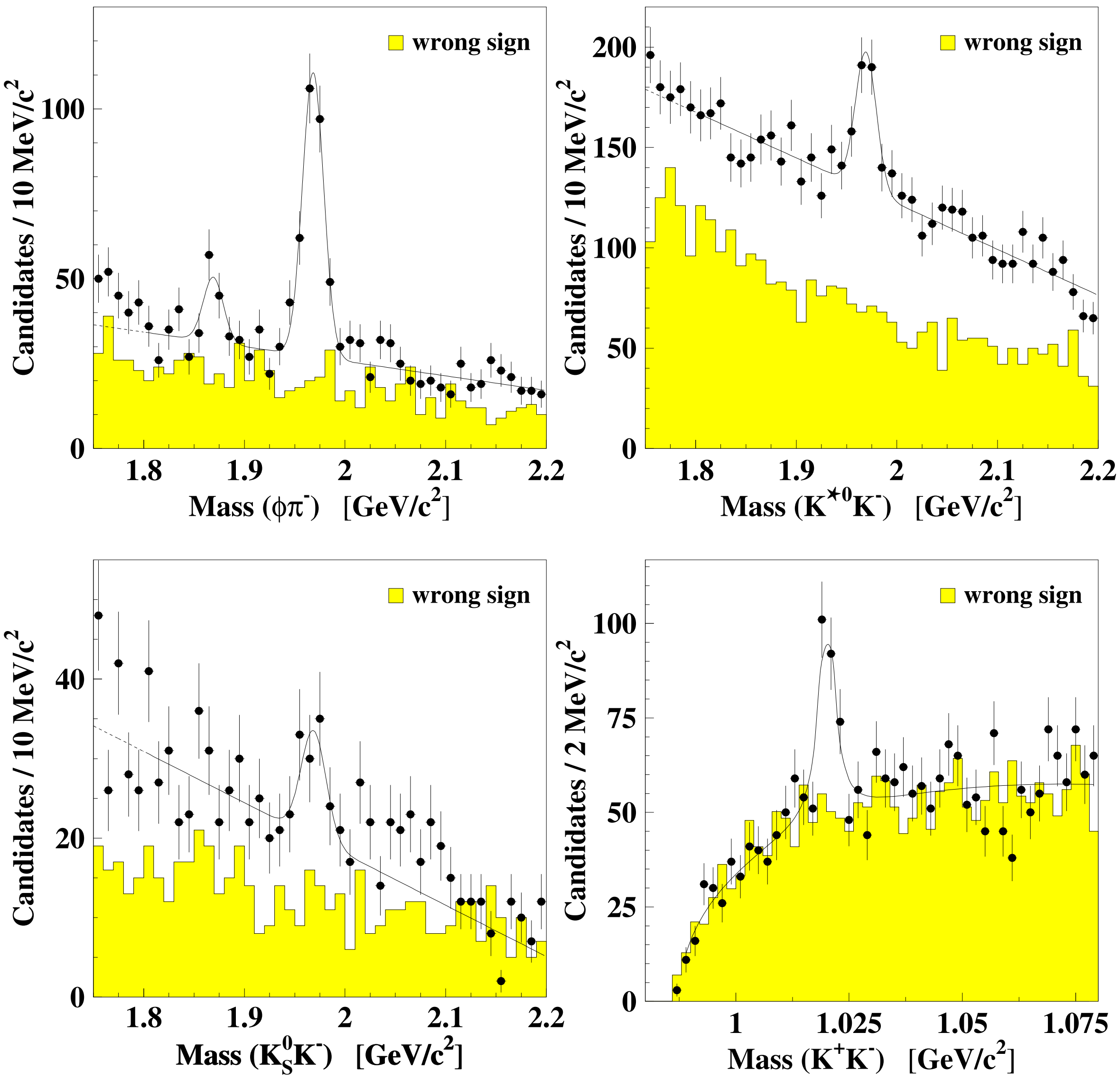
$\Longrightarrow$ cut on $p_T(\mu)$ and $p_T(e)$ at Level 2

Run I inclusive lepton trigger

- **Electrons:** **central EM tower at Level 1, central EM cluster at Level 2, matched to a CFT track**
- **Muons:** **a stub in muon chambers (CMU, CMP, CMX), matched to a CFT track at Level 2**
- **both verified at Level 3 – full event reconstruction** *(e.g. pattern recognition in CTC)*



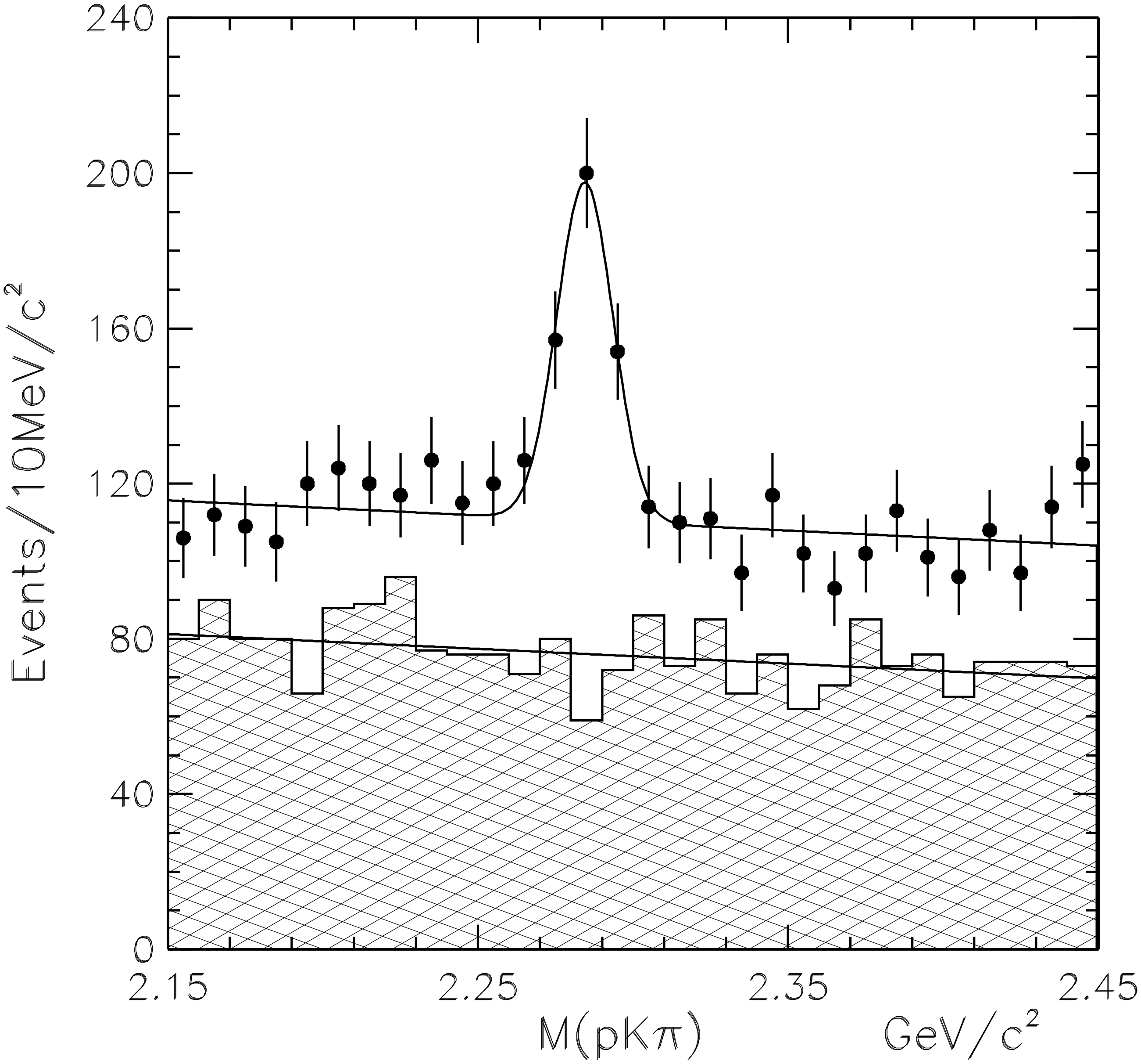
Run I semileptonic samples: $B_s \to \nu \ell D_s$



≈ 600 events total in four D_s channels
($p_T(\ell) > 8$GeV$/c$)

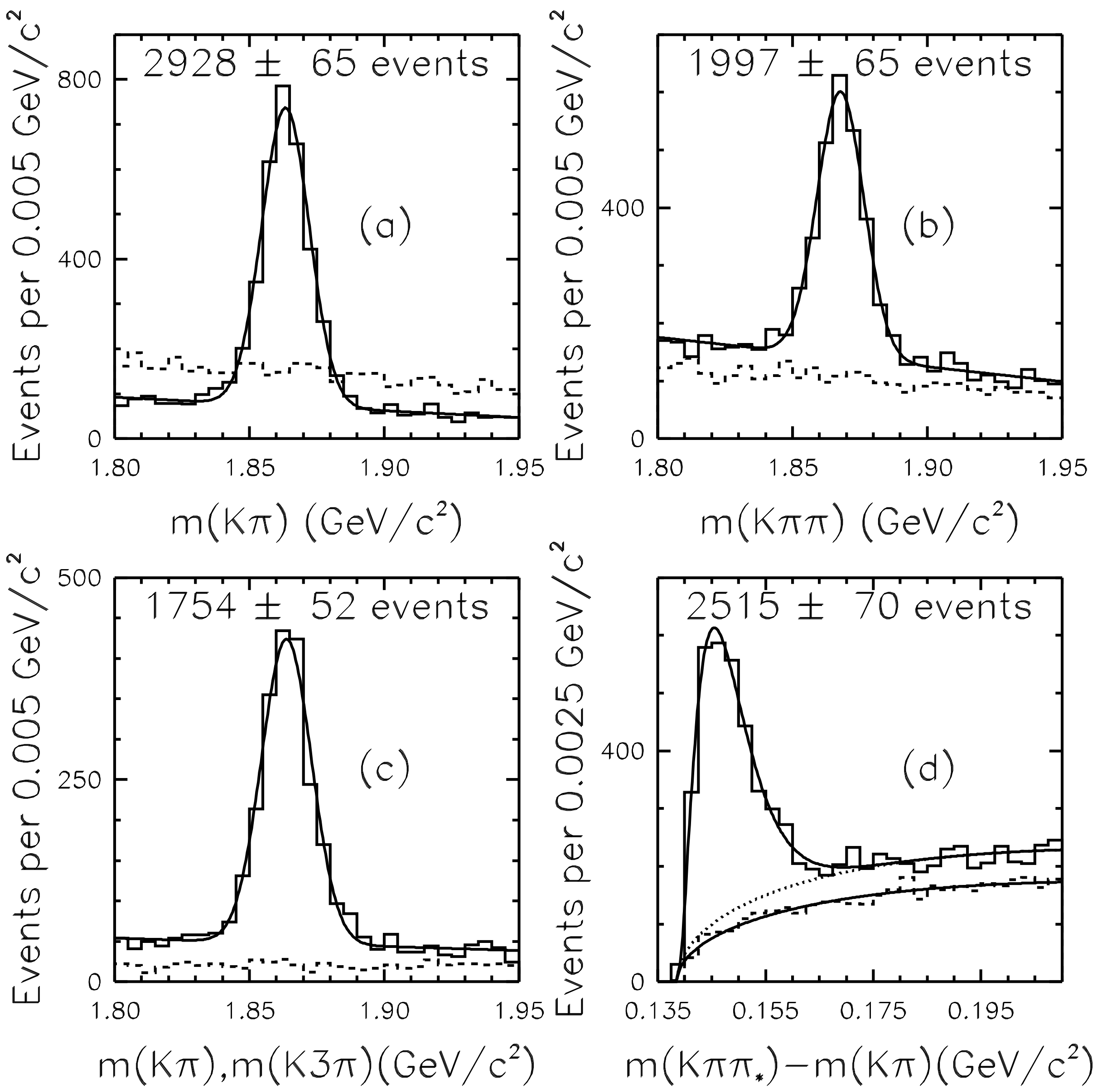
- $D_s^- \to \phi\pi^-$, $\phi \to K^+K^-$
- $D_s^- \to K^{*0}K^-$, $K^{*0} \to K^+\pi^-$
- $D_s^- \to K^0_S K^-$, $K^0_S \to \pi\pi$
- $D_s^- \to \mu^- \phi X$

Run I semileptonic samples: $\Lambda_b \to \nu \ell \Lambda_c$



- $\Lambda_c \to pK\pi$
- **because of proton, dE/dx really helps**
- **yield = 197 ± 25 signal events**

Run I semileptonic samples: $B^{+,0} \to \nu \ell D^{(*)}$



$$B^+ \to \nu \ell^+ \overline{D^0}, \qquad \overline{D^0} \to K^+ \pi^-$$

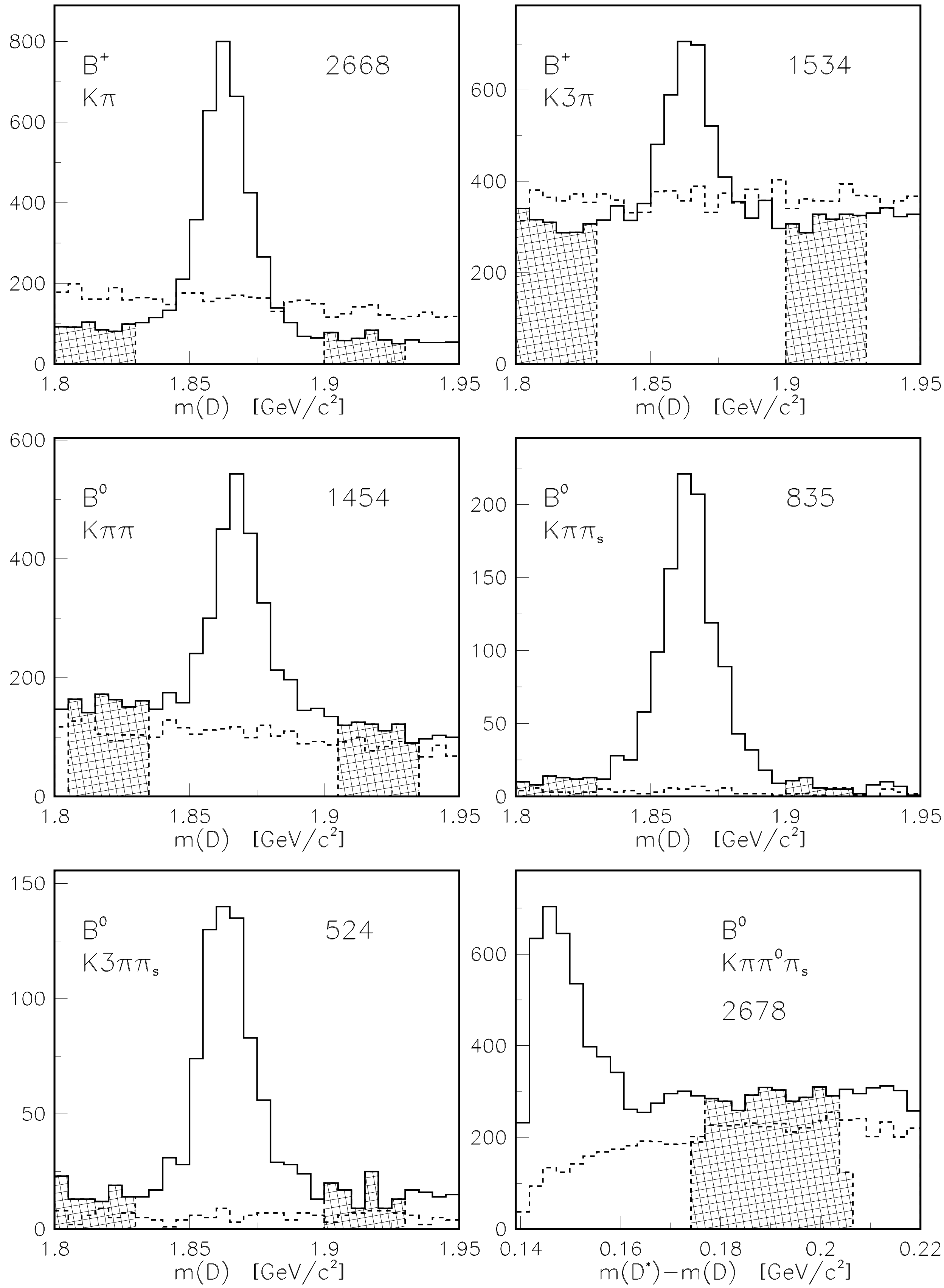
$$B^0 \to \nu \ell^+ D^-, \quad D^- \to K^+ \pi^- \pi_2^-$$

$$B^0 \to \nu \ell^+ D^{*-}, \qquad D^{*-} \to \overline{D^0} \pi_s^-, \qquad \overline{D^0} \to K^+ \pi^-$$

$$B^0 \to \nu \ell^+ D^{*-}, \qquad D^{*-} \to \overline{D^0} \pi_s^-, \qquad \overline{D^0} \to K^+ \pi^- \pi_2^- \pi_3^+$$

$$B^0 \to \nu \ell^+ D^{*-}, \qquad D^{*-} \to \overline{D^0} \pi_s^-, \qquad \overline{D^0} \to K^+ \pi^- \pi^0$$

Run I semileptonic samples: $B^{+,0} \to \nu \ell D^{(*)}$



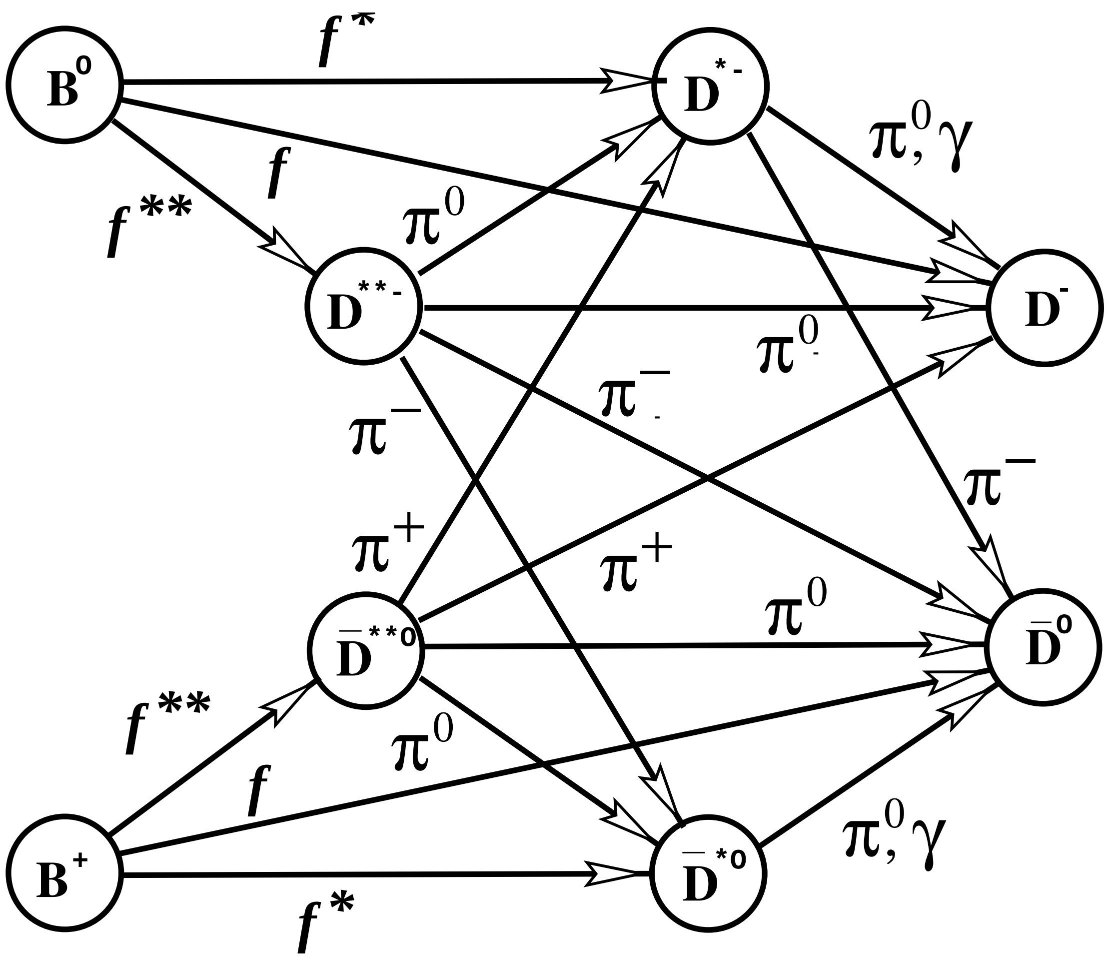
Sample composition of the $B^{+,0} \to \nu\ell D^{(*)}$ sample

What looks like $B^+ \to \nu\ell^+\overline{D^0}$:

1. $B^0 \to \nu\ell^+ D^{*-}$, $D^{*-} \to \overline{D^0}\pi_s^-$ **if the soft pion π_s^- is not reconstructed.**

2. $B^0 \to \nu\ell^+ D^{**-}$, $D^{**-} \to \overline{D^0}\pi_{**}^-$ **since in most cases we cannot fully reconstruct the D^{**} meson.**

The full complexity of the sample composition:



Excited charm states

The expected D^{**} states (with the widths expected from Heavy Quark Effective Theory):

name	J^P	width	decay modes
D_0^*	0^+	wide	$D\pi$
D_1^*	1^+	wide	$D^*\pi$
$D_1(2420)$	1^+	narrow	$D^*\pi$
$D_2^*(2460)$	2^+	narrow	$D\pi$, $D^*\pi$

Seen possible evidence in $B^{+,0} \to \nu\ell D^{(*)}$ data, but needs further study.

$\Rightarrow$ **Important, as the largest systematics in analysis that need to distinguish B^0 from B^0 in $B^{+,0} \to \nu\ell D^{(*)}$ samples.**

Correcting for the missing momentum

For most analyses, we need the three-momentum of the b-hadron.

Example: measurement of the proper time. We need:

- **decay distance in transverse plane L_{xy}^B**
- **Lorentz boost, $1/(\beta\gamma) \equiv m_B/p_T^B$**

  (m_B is the mass of the B meson, while p_T^B is its momentum in the transverse plane)
- **true proper time**

$$ct_{true} \equiv L_{xy}^B \frac{m_B}{p_T^B}$$

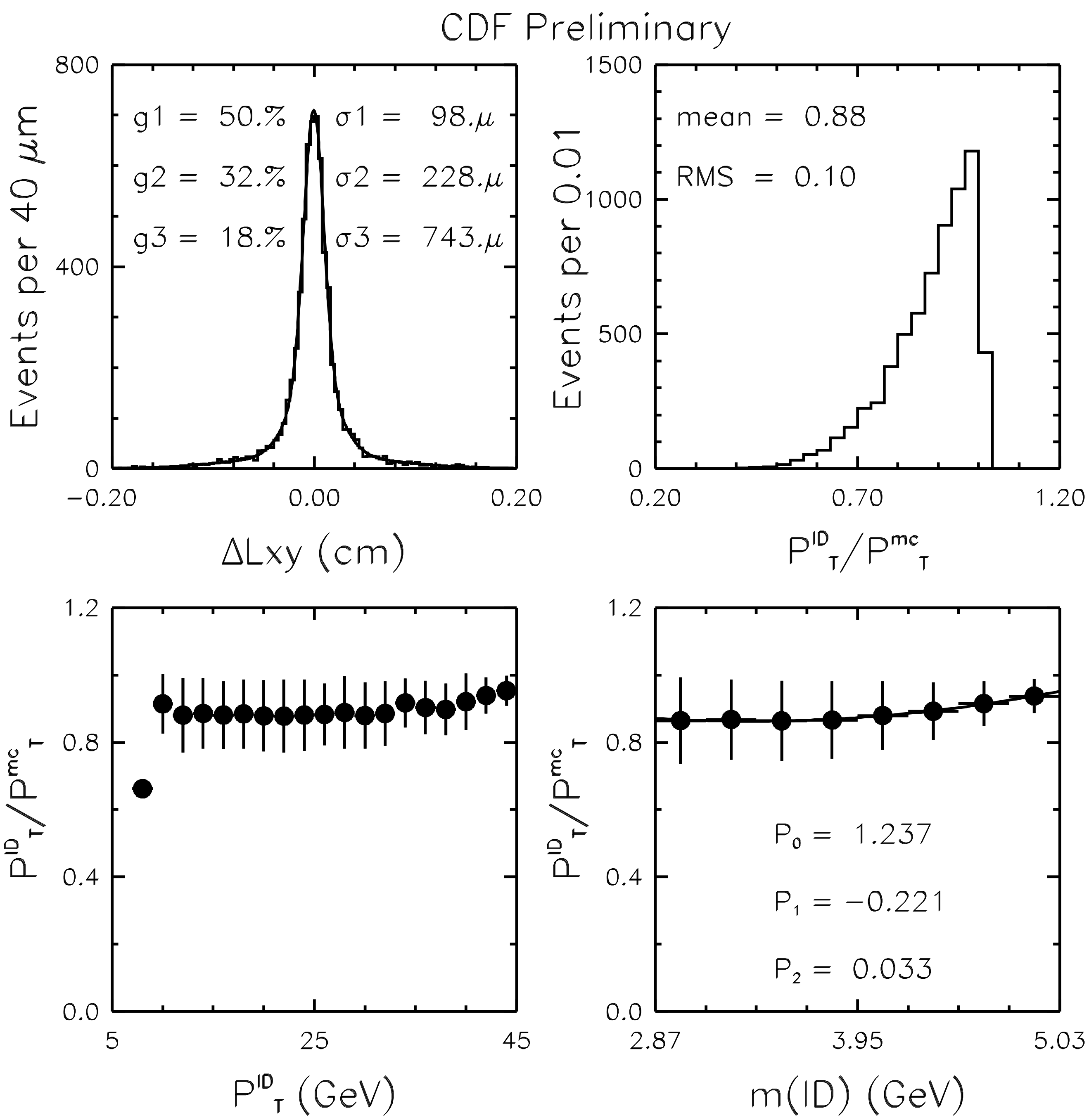
- **but ν escapes $\Rightarrow$ don't know p_T^B;** *approximate by using $p_T(\ell D)$ multiplied by a MC factor*

$$ct_{true} \approx ct \equiv L_{xy}^B \frac{m_B}{p_T^{\ell D}} \left\langle \frac{p_T^{\ell D}}{p_T^B} \right\rangle_{MC}$$

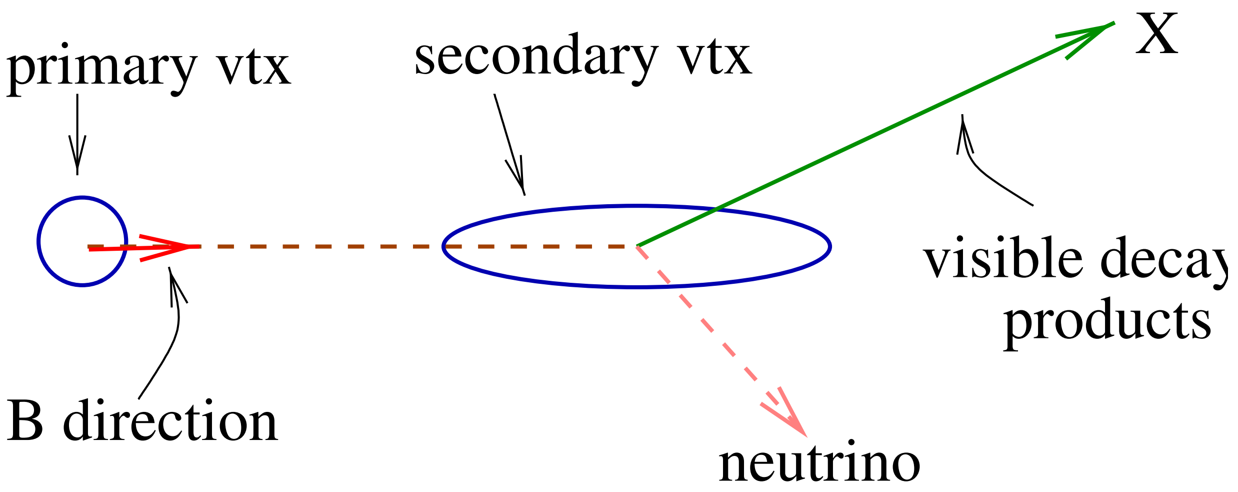
$\Rightarrow$ **the K*-factor*:**

$$K \equiv \left\langle \frac{p_T^{\ell D}}{p_T^B} \right\rangle_{MC}$$

Typical resolutions of semileptonic decays

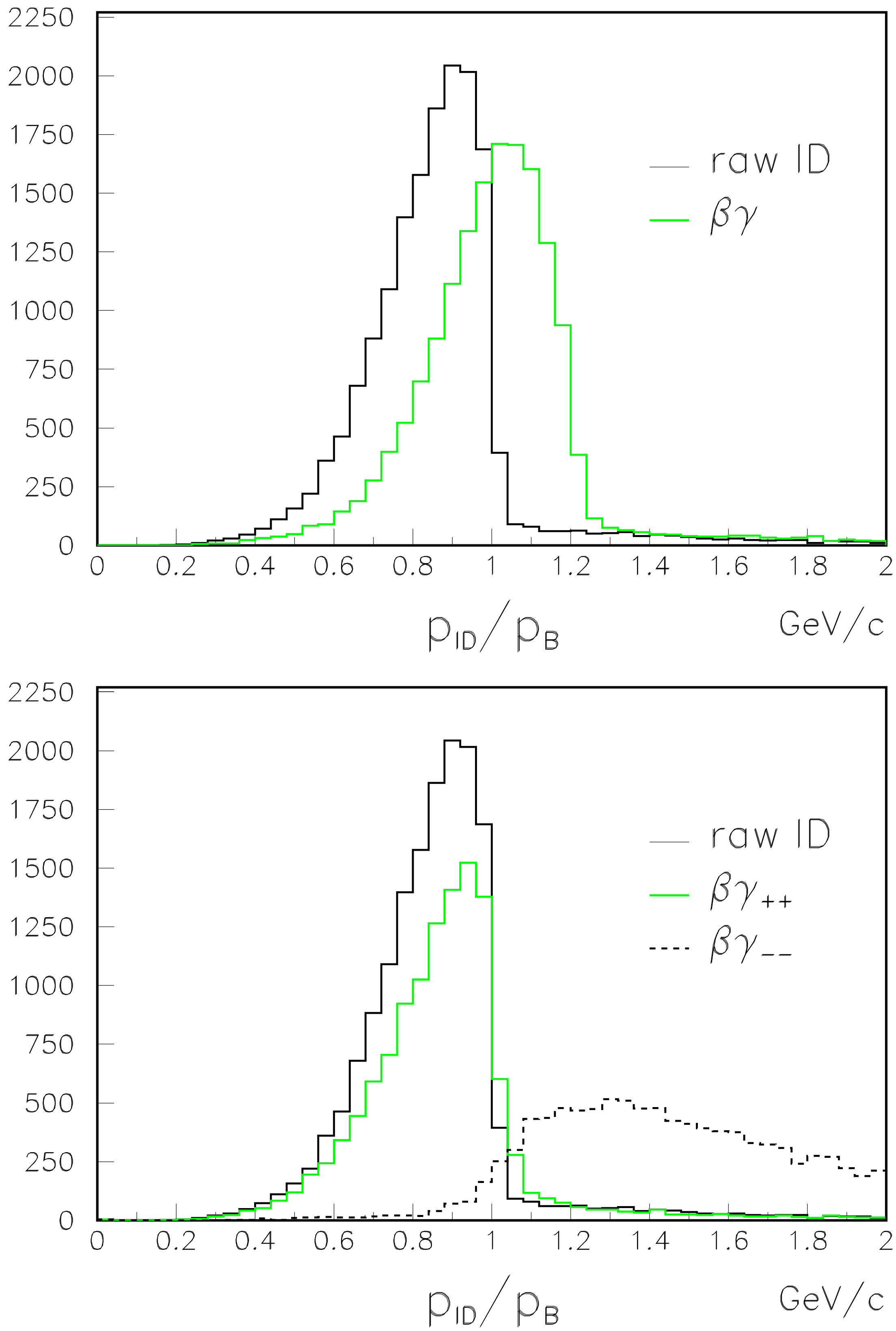


Calculating where the neutrino went – part I



- **Direction of motion of b-hadron contains additional info - encoded in position of secondary vertex**
- **In principle, if known in 3D, one can calculate exactly where the neutrino went!**
- **There are two solutions: but, the trigger ($p_T(\ell) > 8$ GeV$/c$) favors one solution**
- **Unfortunately, in Run I – *very* poor resol. of z of the sec.vertex $\Rightarrow$ insufficient**
- **Also, solutions are sometimes unphysical $\Rightarrow$ lose about 20% in efficiency.**

Calculating where the neutrino went – K-factor

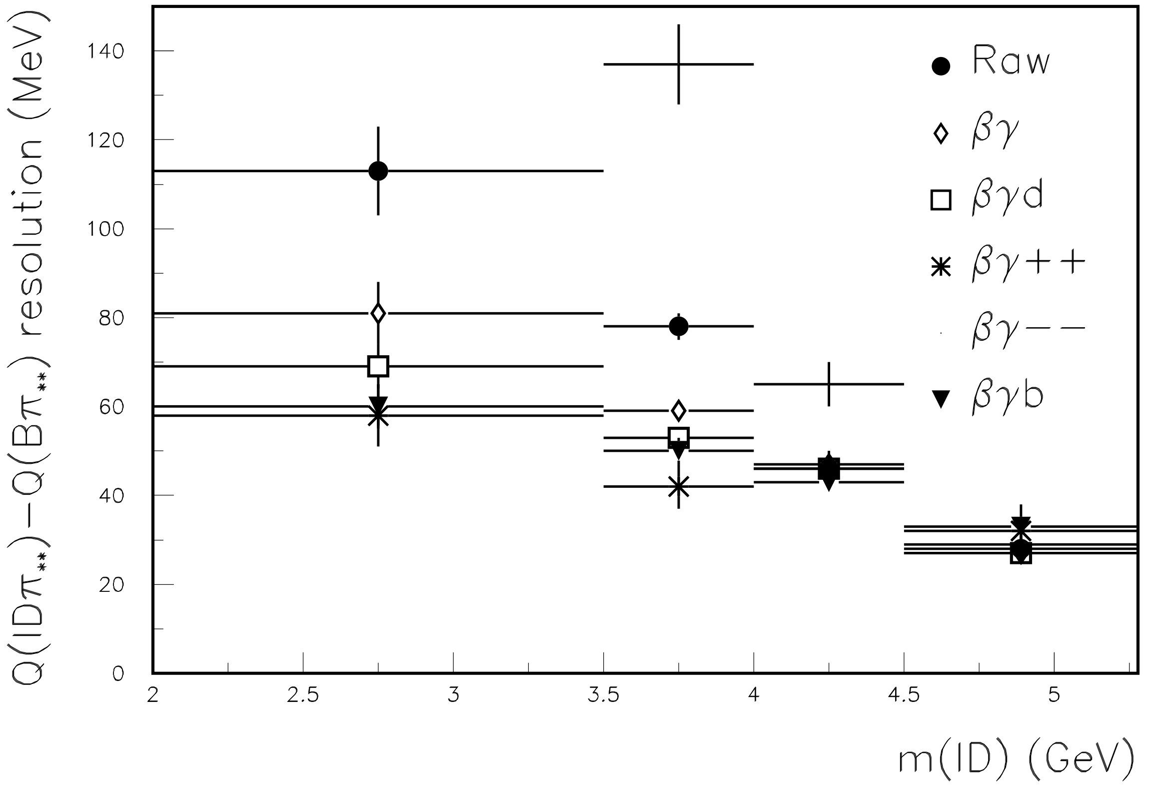


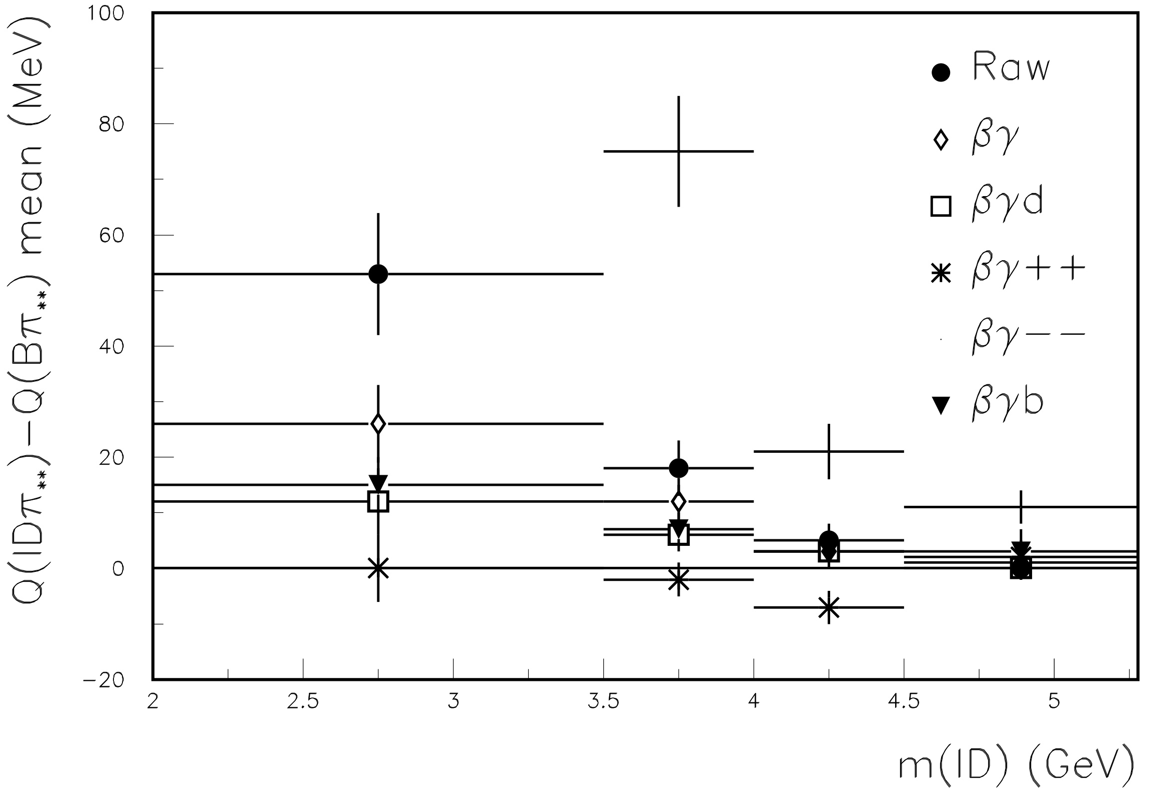
Hybrid correction for the missing momentum

- $|\vec{p}(B)|$ set to $|\vec{p}(\ell D)|$ corrected by average K-factor
- in transverse plane, B points from primary to secondary vertex: $\vec{p}_T(B) \propto \vec{V}_B$
- $\eta(B) = \eta(\ell D)$
- mass set to m_B

gain is modest, but **we don't lose any events**

Effects of various types of $\beta\gamma$ corrections





Calculating where the neutrino went – part II

Run II version:

- **we have a 3D silicon**

$\Rightarrow$ **the trick should work now!**

Work to do:

- **3D silicon tracking implemented recently $\Rightarrow$ needs testing**
- **but, looks promissing: in simulation, z-vertex resolution is comparable to expectations, ($\sim 100\mu$m?)**
- **the impact on the $\vec{p}_B$ still completely unknown!**

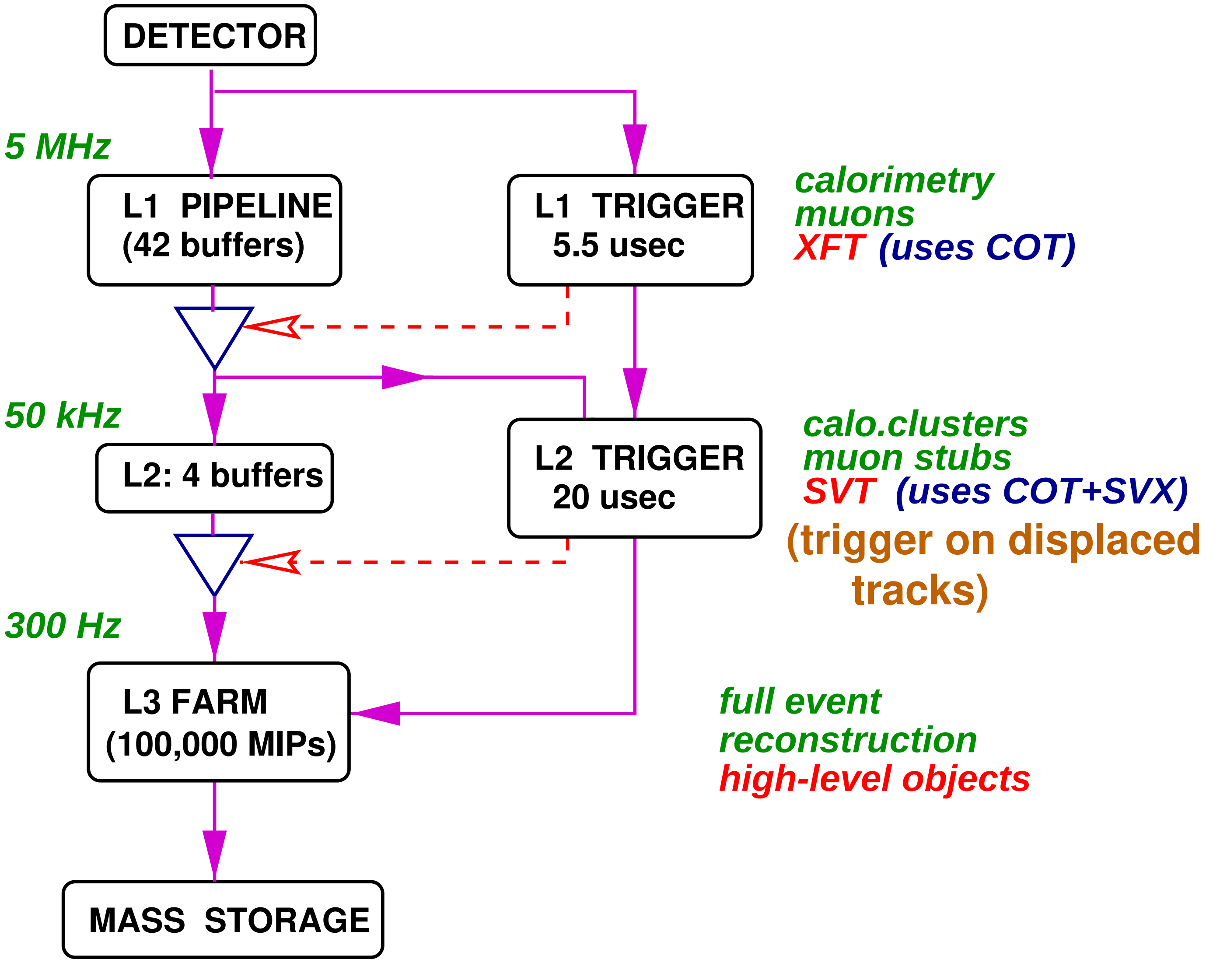
Applications:

1. **form factors in baryons**
1. **$|V_{cb}|$ (but BaBar/BELLE will likely do better)**
1. **B_s mixing in semileptonics (esp. if Δm_s is low)!**

Run II: Trigger & DAq overview

Goal: collect as many B's as possible

$\Rightarrow$ Trigger + SVX DAq run in deadtimeless mode



Run II b-physics triggers

- **Level 1: use lepton info + eXtremely Fast Tracker (XFT)**
- **Level 2: use Secondary Vertex Tracker (SVT) (find displaced tracks!)**
- **Level 3: develop smart algorithms to:**
  - **find secondary vertex seeded by SVT track(s)**
  - **(semi)exclusive B meson reconstruction**

New trigger paths

- **XFT, SVT, DAq: two displaced tracks**
  ***e.g.* for** $B^0 \to \pi^+\pi^-$**,** $B_s \to D_s\pi$

- **XFT, SVT: lepton** $+$ **displaced track(s)**

  - **lepton and track are on opposite side:**
    e.g. $B_s \to D_s\pi$ **with a *flavor tag***
  - **lepton and track are on same side:**
    $\Rightarrow$ **use this for semileptonic** $X_b \to \ell X_c$ **decays**

- **In all cases, try to reconstruct charm at Level 3**

Expected trigger for semileptonic decays

- **lepton:** $p_T(\ell) > 3$ **GeV**$/c$

- **track:**

  - $p_T($**track**$) > 2$ **GeV**$/c$
  - $|d_0| > 120\mu\mathrm{m}$

- **angle between lepton and track:** $\Delta\varphi < 60^o$

Search for radiative penguins

- **Search for**
  - $B_d \to K^{*0}\gamma$
  - $B_s \to \phi\gamma$
- **Standard Model predictions of the BR of the exclusive radiative-decays** $\sim 1 - 11 \times 10^{-5}$.
- **other experiments**
  1. **CLEO: inclusive,** $Br(b \to s\gamma) = (3.15 \pm 0.35_{stat} \pm 0.32_{syst} \pm 0.26_{model}) \times 10^{-4}$
  2. **ALEPH: inclusive,** $Br(b \to s\gamma) = (3.11 \pm 0.80_{stat} \pm 0.72_{syst}) \times 10^{-4}$
  3. **CLEO:** $Br(B^{0,\pm} \to K^{*,\pm}\gamma) = (4.2 \pm 0.8_{stat} \pm 0.6_{syst}) \times 10^{-5}$
  4. **DELPHI:** $Br(B_s \to \phi\gamma) < 7.0 \times 10^{-4}$ **at** 90% **C.L.**
- K^{*0} **and** ϕ **are not a problem: fully reconstructed**
  - $K^{*0} \to K^+\pi^-$
  - $\phi \to K^+K^-$
- **But how to find** γ**?**

Radiative penguins with special photon trigger

- **designed a special "penguin trigger"**
  - **cluster in the Central Electromagnetic (CEM) calorimeter with $E_T > 10$ GeV [2] (CEM covers $|\eta| < 1.1$)**
  - **no track with $p_T > 2$ GeV$/c$ points towards the same calorimenter wedge as the photon** *(isolation requirement)*
  - **two oppositely charged tracks with $p_T > 2$ GeV$/c$, within 18^o in φ, close to photon CEM wedge**
- **collected 23.3 pb^{-1} in a part of Run Ib**
- **one candidate for $B_d \to K^{*0}\gamma$:**

$$Br(B_d \to K^{*0}\gamma) < 2.2 \times 10^{-4}, 90\% C.L.$$

$$Br(B_d \to K^{*0}\gamma) < 2.9 \times 10^{-4}, 95\% C.L.$$

- **no candidates for $B_s \to \phi\gamma$:**

$$Br(B_d \to \phi\gamma) < 3.9 \times 10^{-4}, 90\% C.L.$$

$$Br(B_d \to \phi\gamma) < 5.7 \times 10^{-4}, 95\% C.L.$$

Radiative penguins with conversions

- γ **reconstruction**
  - $\gamma \to e^+e^-$ **conversions**
  - **one electron is a trigger lepton in inclusive electron sample ($p_T > 8$ GeV$/c$)** *(used 85 pb^{-1} of Run Ib)*
  - **loop over other tracks and try to find conversion partner** *(e^+ and e^- tracks are parallel at vertex $\Leftrightarrow$ zero mass)*
- **one candidate for $B_d \to K^{*0}\gamma$, with expected backgrounds of 0.6 events:**

$$Br(B_d \to K^{*0}\gamma) < 1.7 \times 10^{-4}, 90\% CL,$$

$$Br(B_s \to K^{*0}\gamma) < 2.2 \times 10^{-4}, 95\% CL,$$

- **no candidates for $B_s \to \phi\gamma$, with expected, backgrounds of 0.1 events:**

$$Br(B_d \to \phi\gamma) < 3.6 \times 10^{-4}, 90\% C.L.,$$

$$Br(B_s \to \phi\gamma) < 4.9 \times 10^{-4}, 95\% C.L.,$$

- **we used $f_s/f_u = 0.264 \pm 0.048$ from LEP;**

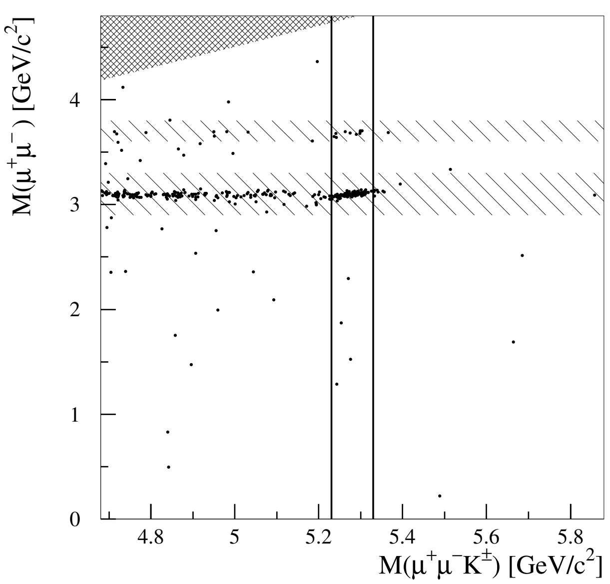
  (using CDF's $f_s/f_u = 0.420 \pm 0.105$ results in a slightly weaker limit)

FCNC: $\mu^+\mu^-K^+$ and $\mu^+\mu^-K^{*0}$

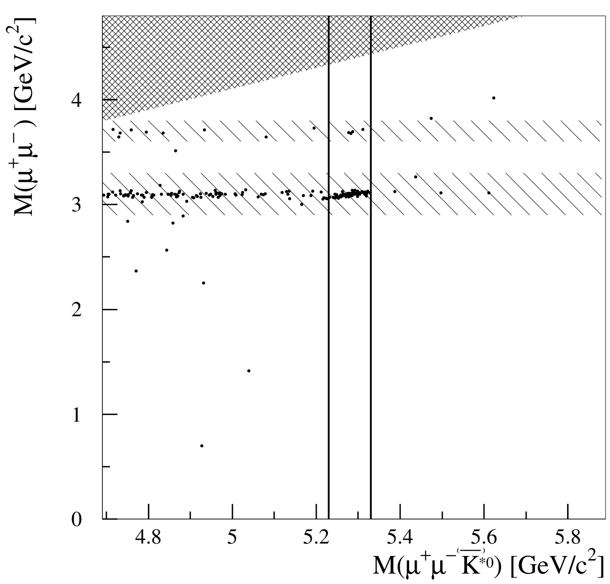
- 88 pb^{-1} of Run Ib data
- normalize to $B^+ \to J/\psi K^+$ and $B^+ \to J/\psi K^{*0}$
- $p_T(K^{(*)}) > 2$ GeV$/c$
- $\mu^+\mu^-K^{(*)}$ system must be *isolated*:

$$I \equiv \frac{p_T^B}{p_T^B + \sum_{cone} p_T^i} > 0.6$$

- $\mu^+\mu^-K^{(*)}$ vertex must be *displaced*:
  - $L_{xy}^B > 400\mu$m (*very* tight!)
  - $L_{xy}^B/\sigma(L_{xy}) > 2.0$



$B^+ \to \mu^+\mu^-K^+$



$B^0 \to \mu^+\mu^-K^{*0}$

$B \to \mu\mu K^{(*)}$ results

At 90% C.L.:

- $Br(B^+ \to \mu^+\mu^- K^+) < 5.2 \times 10^{-6}$
- $Br(B^0 \to \mu^+\mu^- K^{*0}) < 4.0 \times 10^{-6}$
- **CLEO has limits, at $\sim 9 \times 10^{-6}$**

Run II triggers

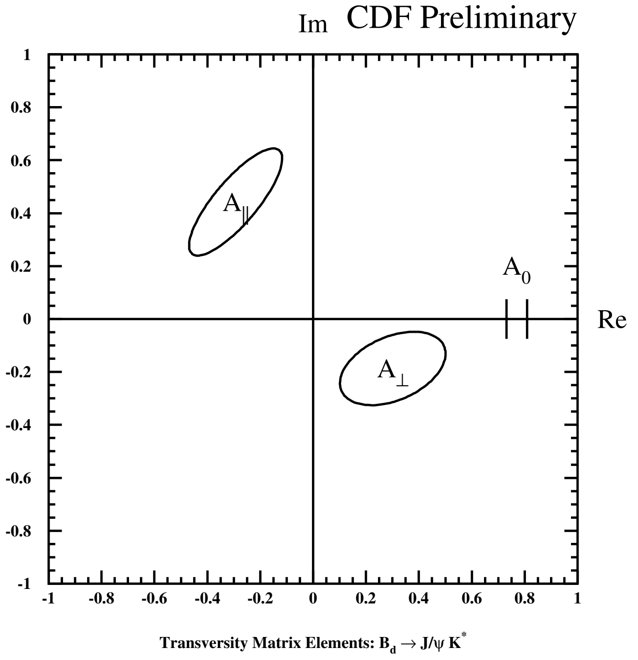
Studying possible triggers. Current plan:

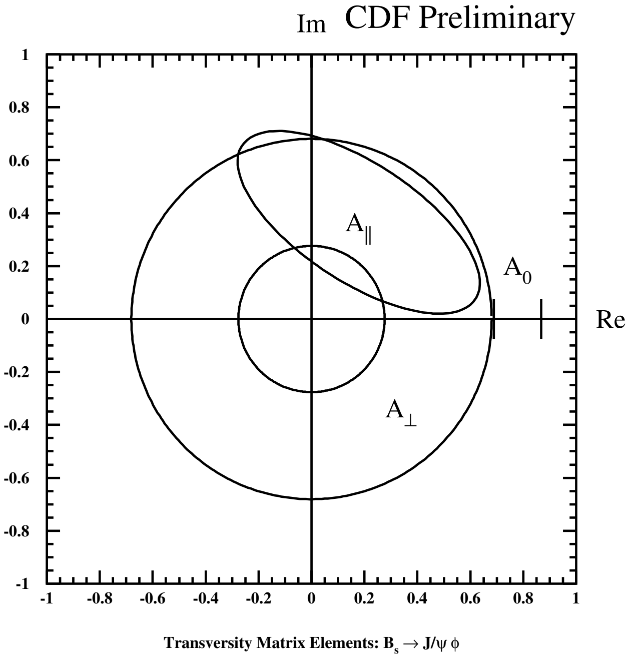
- **one CMP with $p_T > 3$ GeV$/c$**
  other anywhere with $p_T > 1.5$ GeV$/c$
- **or two anywhere with displaced (SVT) track**

Food for thought (*W. Wester*)

- **inclusive search $B \to \mu\mu X$, where X is:**
  - **one or more tracks**
  - **displaced vertex**

B^0, B_s polarization





$B_d \to J/\psi K^{*0}$ **about** 200 **events**

- **Competitive with CLEO.**

$B_s \to J/\psi\phi$ **about** 40 **events**

- **small statistics in Run I**
- **for** $B \to \mu\mu K^{(*)}$**, we expect similar statistics in Run II**
- **it would be** ***extremely interesting*** **to do a similar analysis with** $B \to \mu\mu K^{(*)}$ **candidate events!**