Update on Charmless B decays at CDF

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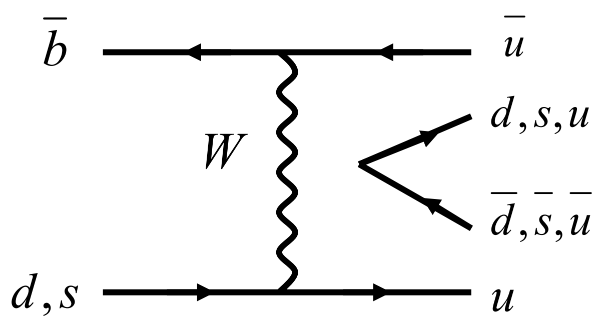
For the CDF Collaboration

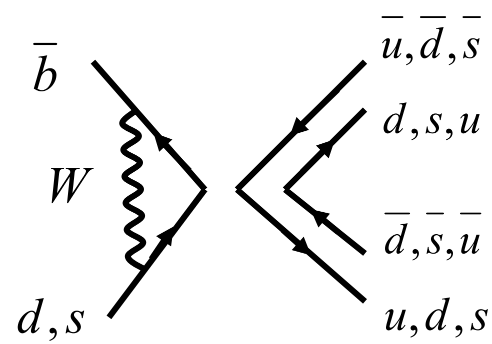
Why charmless B decays?

Are after two body decays of $B \rightarrow h^+h'^-$ and $\Lambda \rightarrow p^+h^-$
- Here h represents charmless mesons

Has thus far proved very rich for CDF
- Phys.Rev.Lett. 106, 181802 (2011), Phys.Rev.Lett. 103, 031801 (2009), Phys.Rev.Lett. 97, 211802 (2006), and Phys. Rev. D72, 051104 (2005))

Now searching specifically for decays of $B_S \rightarrow \pi^+\pi^-$ and $B^0 \rightarrow K^+K^-$
- All final state quarks different from initial state quarks
- Both proceed through penguin annihilation diagrams
- Provides crucial experimental information to reduce theory uncertainties due to soft QCD in many predictions





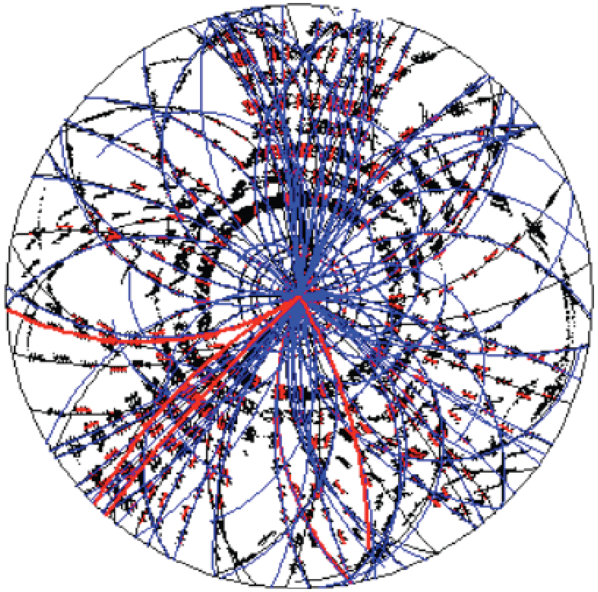
A difficult analysis however

Total inelastic cross-section is 10^3 times larger than σ(bb)

- Desired branching ratios are on the order of 10^{-6}

Modes appear very similar to each other, a simple mass fit wont cut it

- Need to get many different handles to separate signal (more on this later…)

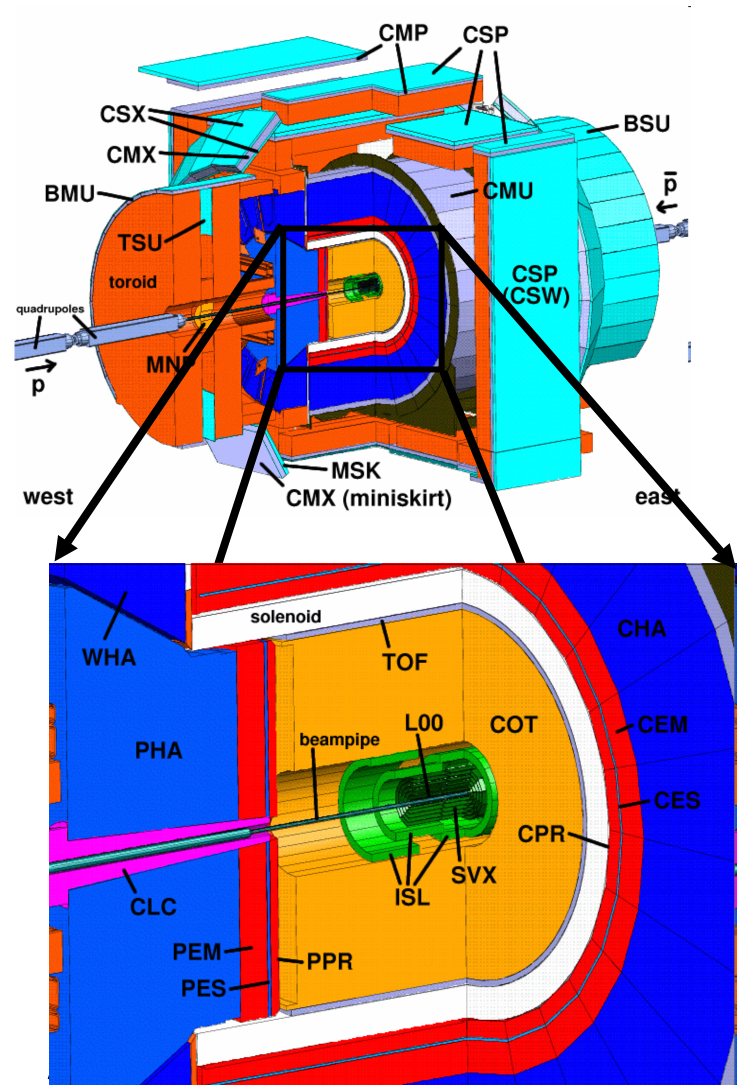


Short detector introduction

- Like a lot of B analyses, this is solely reliant on tracking

- COT drift chamber
  - Allows dE/dx measurement
  - $\sigma(p_T)/p_T^2 \sim 0.1\%\ \mathrm{GeV/c}^{-1}$

- SVX silicon detector
  - Impact parameter resolution around $35\ \mu\mathrm{m}$ for $p = 2\ \mathrm{GeV/c}$

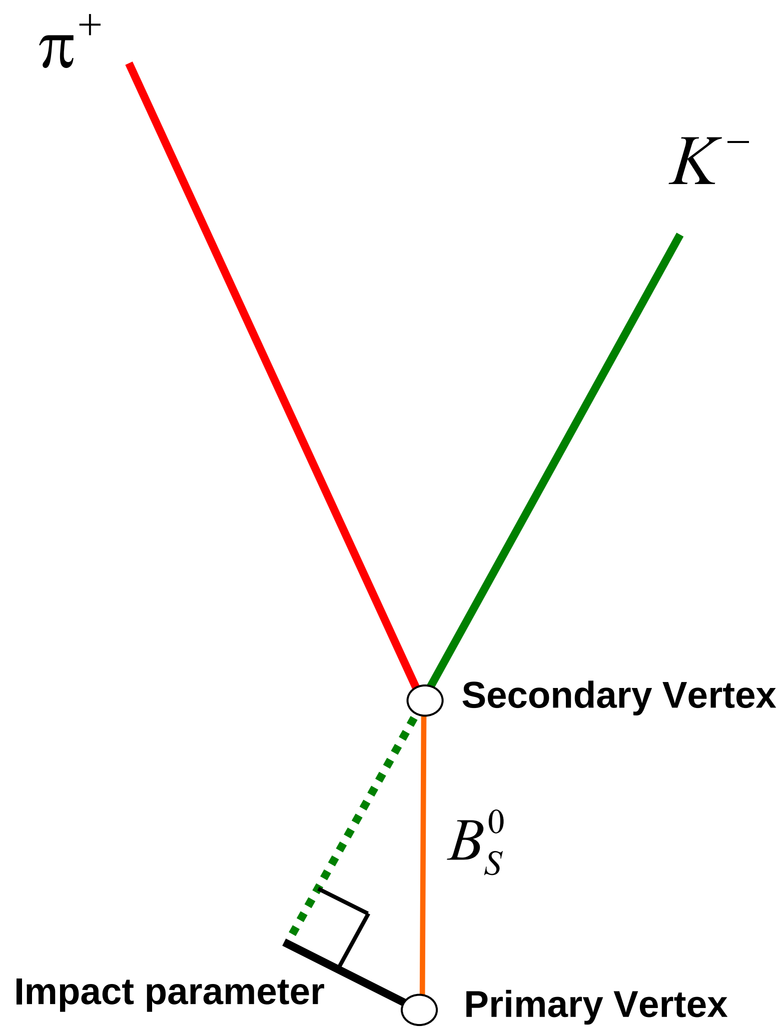


Trigger strategy

CDF's Silicon Vertex Trigger makes an analysis like this possible

- The b has a conveniently long lifetime, ~450 μm, results in large impact parameters for daughters

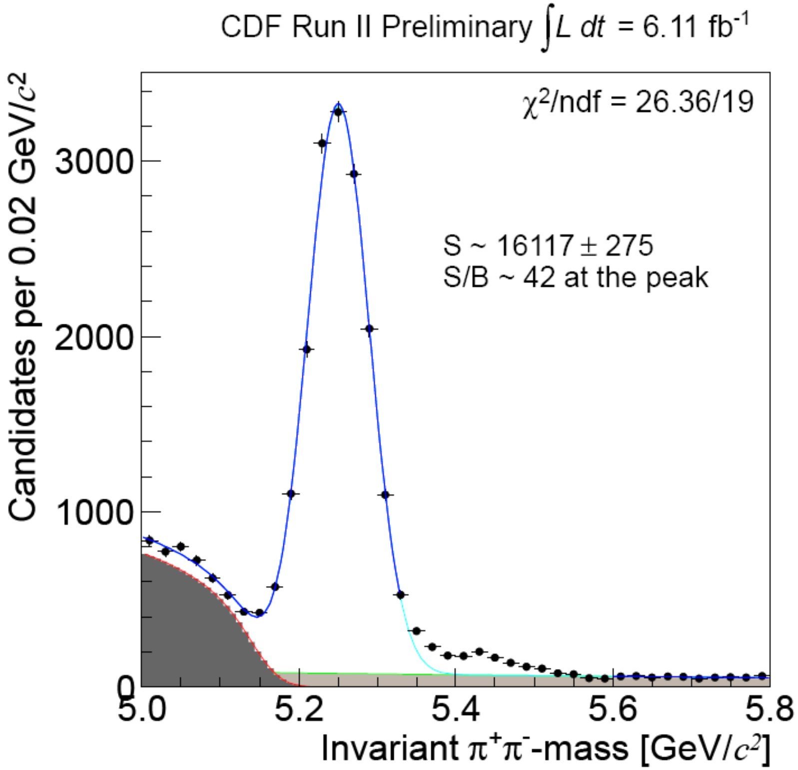
- CDF's trigger system allows us to take advantage of this and at trigger level makes cuts such as:
  - Track and B impact parameter
  - B transverse decay length
  - Transverse opening angle
  - p_{T1}, p_{T2}, and $p_{T1} + p_{T2}$

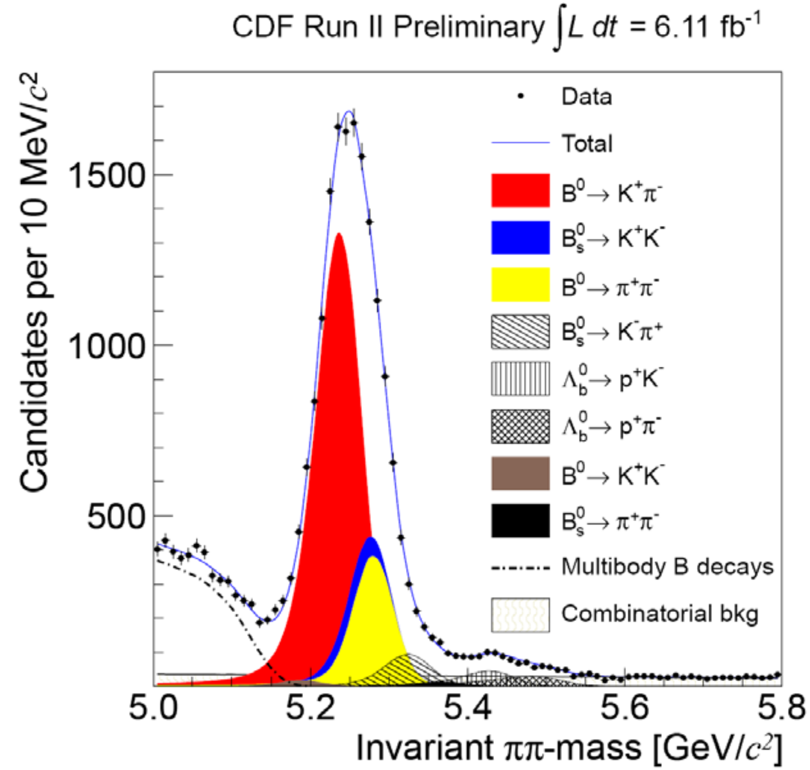


The analysis strategy

- Analysis begun by taking two tracks, assigning them the π mass, and reconstructing a B
- As already mentioned, signals look very similar to each other, effectively becoming background for each other
  - Take advantage of kinematic differences between decay modes
  - Make use of dE/dx
- Further need to determine relative efficiencies to evaluate branching fraction ratios

Consequences of π mass assignment





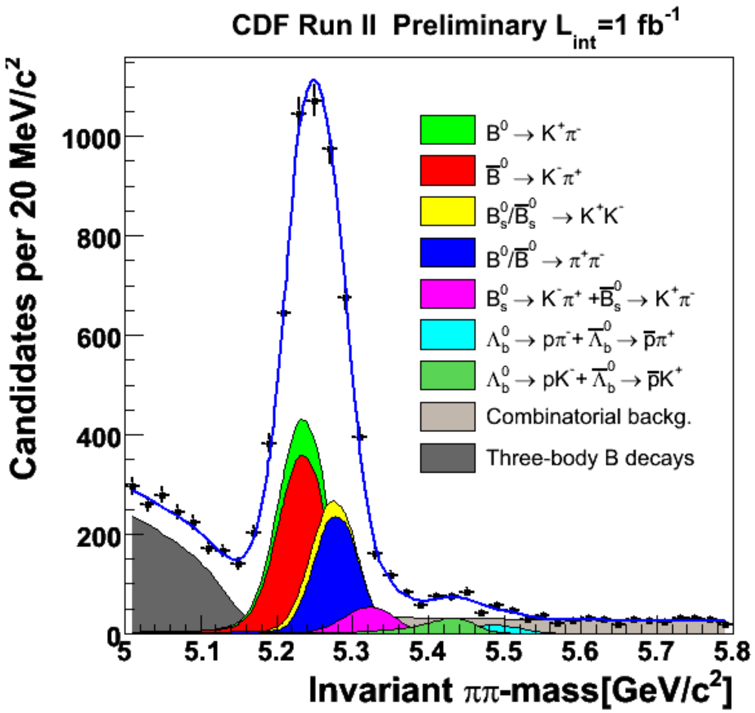
Despite good mass resolution (~22 MeV/c²), modes overlap in large peak (~35 MeV/c²)

Previous CDF result over $1fb^{-1}$

Several first observations (blue)

$\mathcal{B}(10^{-6})$	
Mode	
$B_s^0 \to K^-\pi^+$	$5.0 \pm 0.7 \pm 0.8$
$B_s^0 \to \pi^+\pi^-$	$0.49 \pm 0.28 \pm 0.36$ (< 1.2 @ 90% CL)
$B_s^0 \to K^+K^-$	$23.9 \pm 1.5 \pm 3.6$

$\mathcal{B}(10^{-6})$	
Mode	
$\Lambda_b^0 \to pK^-$	$5.6 \pm 0.8 \pm 1.5$
$\Lambda_b^0 \to p\pi^-$	$3.5 \pm 0.6 \pm 0.9$



First measurement of direct CP asymmetry in a B_S^0 decay

$$\frac{\mathcal{B}(\overline{B}_s^0\to K^+\pi^-)-\mathcal{B}(B_s^0\to K^-\pi^+)}{\mathcal{B}(\overline{B}_s^0\to K^+\pi^-)+\mathcal{B}(B_s^0\to K^-\pi^+)} \qquad 0.39 \pm 0.15 \pm 0.08$$

Selection criteria optimized for decays of $B_S \to K^-\pi^+$

b isolation $= \dfrac{p_T(B)}{p_T(B)+\sum_i p_{Ti}} > 0.525$

χ^2 from 3-d vertex fit < 5

b impact parameter $d_b < 60\ \mu m$

track impact parameter $d > 120\ \mu m$

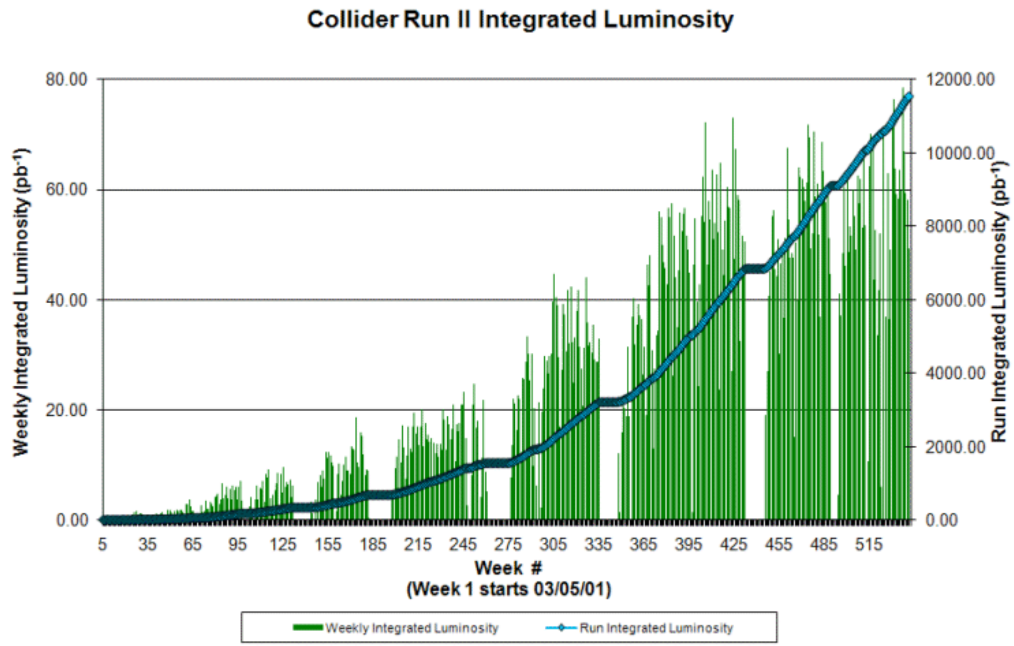
b transverse decay length $L_T > 350\ \mu m$

This iteration

Firstly, added data up to $6fb^{-1}$, signal yields increased by roughly a factor of 3

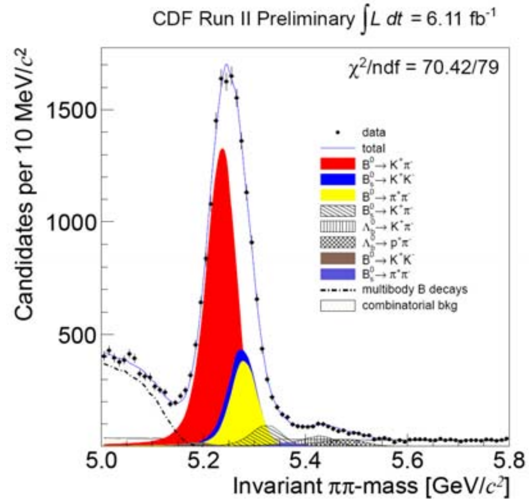
Improved data modeling in the fit

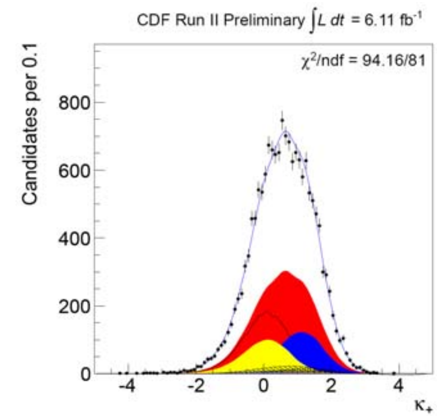
Selection criteria identical to $1fb^{-1}$ result, criteria for $B_S \rightarrow K^- \pi^+$ also useful for $B_S \rightarrow \pi^+ \pi^-$

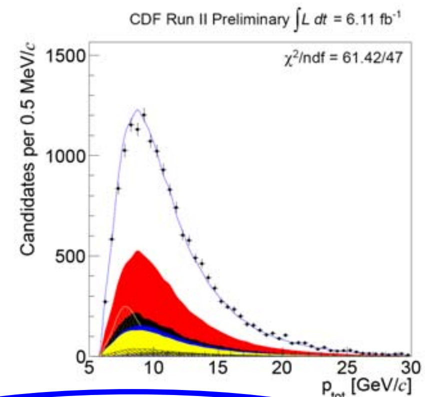


The fit applied

1. $m^2_{\pi\pi}$ – inv. mass squared, π mass assignment
2. β – charged momentum asymm., $\beta = (p^+ - p^-)/(p^+ + p^-)$
3. p_{tot} – scalar sum of particle momentum
4. $\kappa_\pm$ – kaonness, dE/dx dependent variable







$$\mathcal{L}(\vec{\theta}) = \prod_{i=1}^{N} \mathcal{L}_i(\vec{\theta})$$

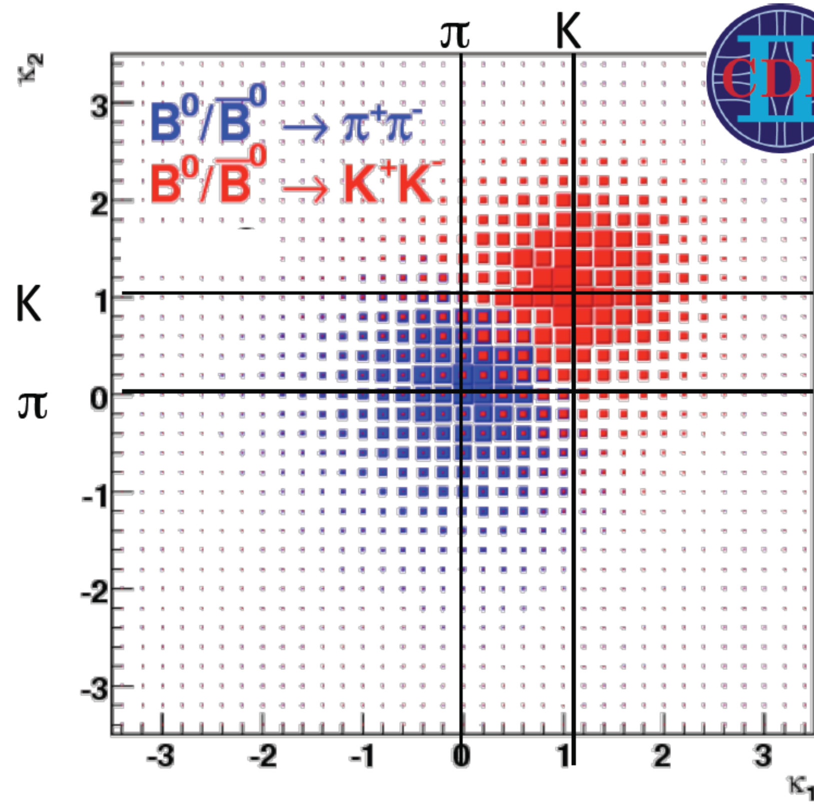
$$\mathcal{L}_i(\vec{\theta}) = (1-b)\sum f_j \mathcal{L}_j^{sig} + b\mathcal{L}^{bkg}$$

$$pdf_j^m(m^2_{\pi\pi} \,|\, \beta, p_{tot}; \vec{\theta}) \times pdf_j^p(\beta, p_{tot}; \vec{\theta}) \times pdf_j^{PID}(\kappa_+, \kappa_- \,|\, p_{tot}, \beta; \vec{\theta})$$

Mass term — Momentum term — PID term

An introduction to kaonness

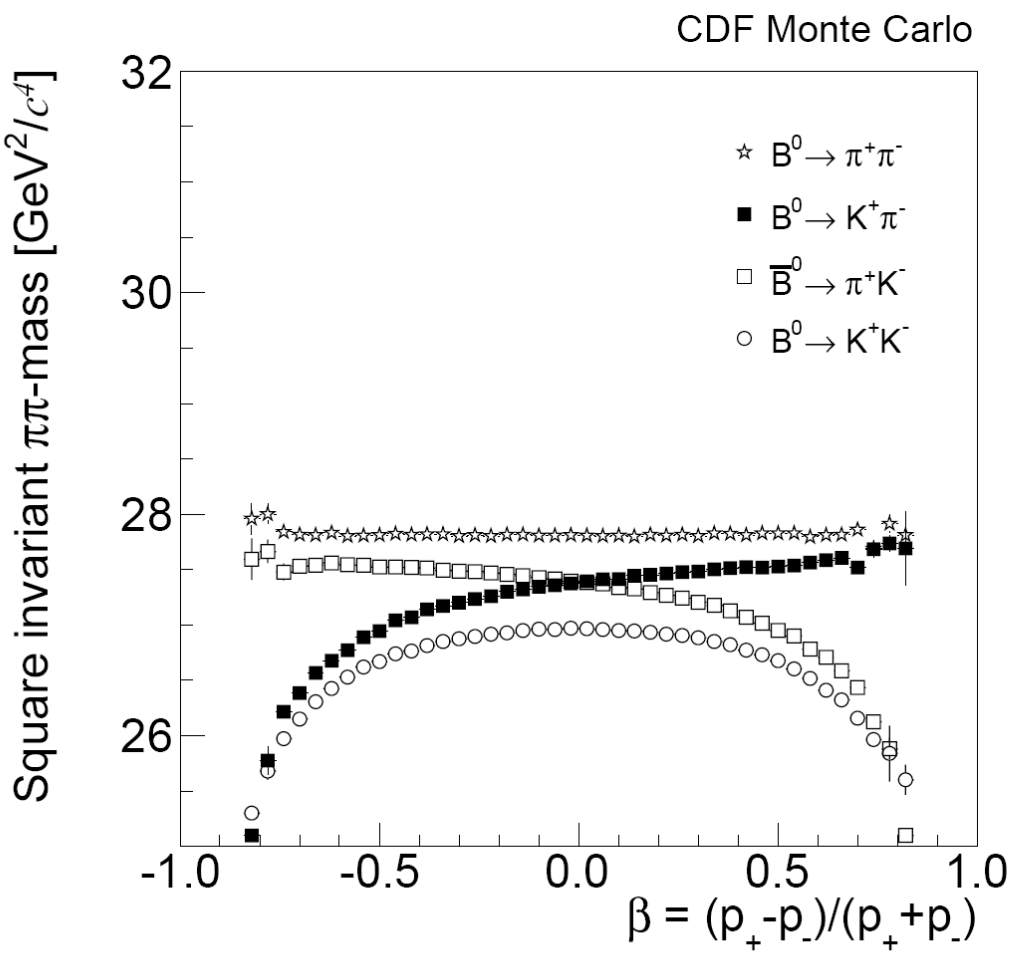
- Kaons and pions loose different energy amounts as they pass through detector, expressed as dE/dx
- CDF can take advantage of it, requires careful calibration and parameterization though
- When used, provides roughly 1.4σ separation between K - π and 2.0σ separation between pairs



The kaonness variable used in the fit is defined as:

$$\kappa = \frac{dE/dx_{observed} - dE/dx_{predicted\ for\ pion}}{dE/dx_{predicted\ for\ kaon} - dE/dx_{predicted\ for\ pion}}$$

Kinematics help a lot



- Take the charged momentum asymm. as an example

$$\beta = (p^+ - p^-)/(p^+ + p^-)$$

- Plot shows profile between β and $m^2_{\pi\pi}$

- Provides much needed separation between the B^0 modes

The branching ratios

- CDF measures the relative branching ratios with respect to $B^0 \to K^+\pi^-$

$$\frac{BR(B^0 \to K^+K^-)}{BR(B^0 \to K^+\pi^-)} = \frac{\hat{f}_{B^0 \to K^+K^-}}{\hat{f}_{B^0 \to K^+\pi^-}} \cdot \frac{\varepsilon(B^0 \to K^+\pi^-)}{\varepsilon(B^0 \to K^+K^-)}$$

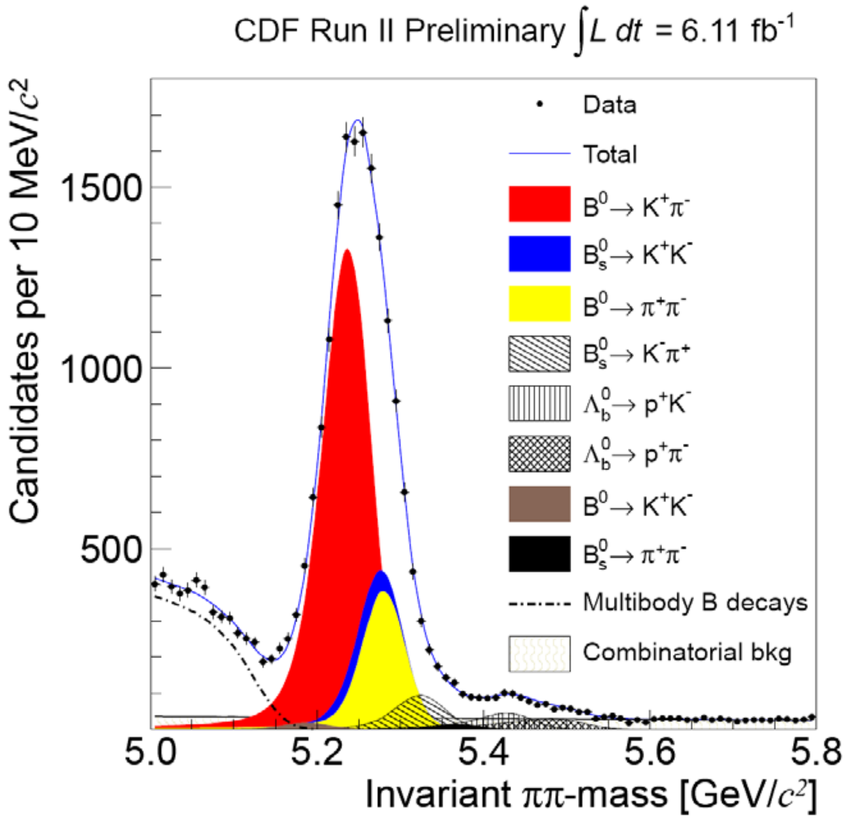
World average

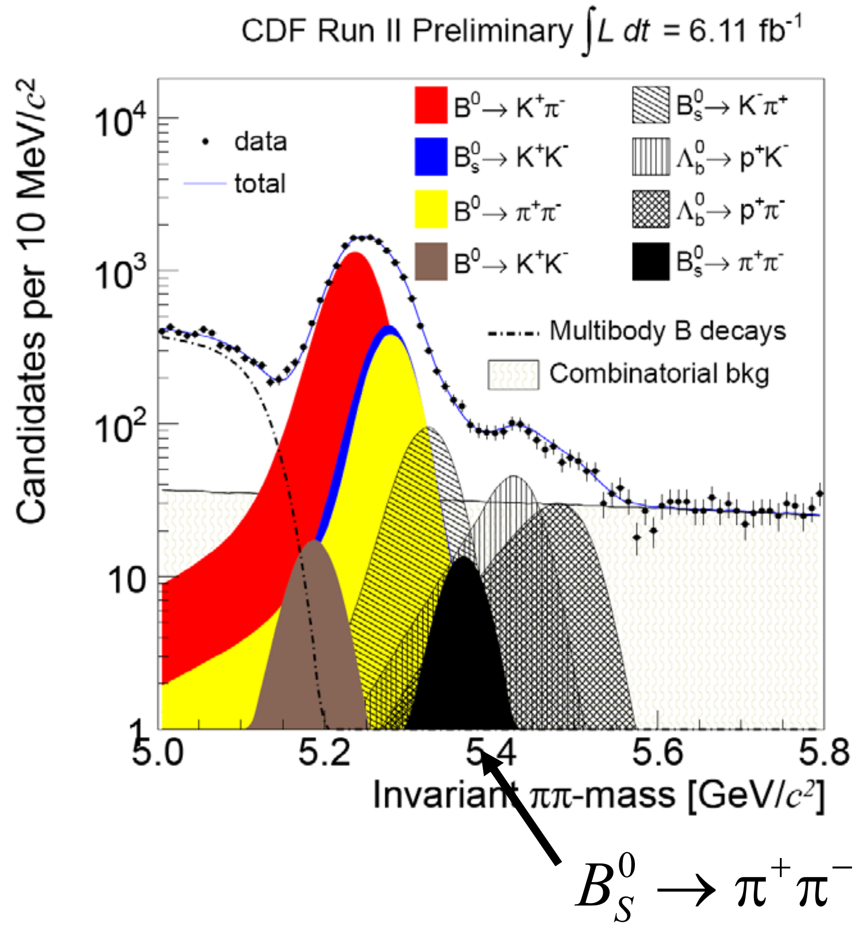
From fit

Measure separately

- This leaves the efficiencies ε left to be determined, which come in three components :
  1. Cuts from trigger and offline (modeled in Geant based MC)
  2. Trigger efficiency not modeled in MC
  3. Efficiency from the isolation cut

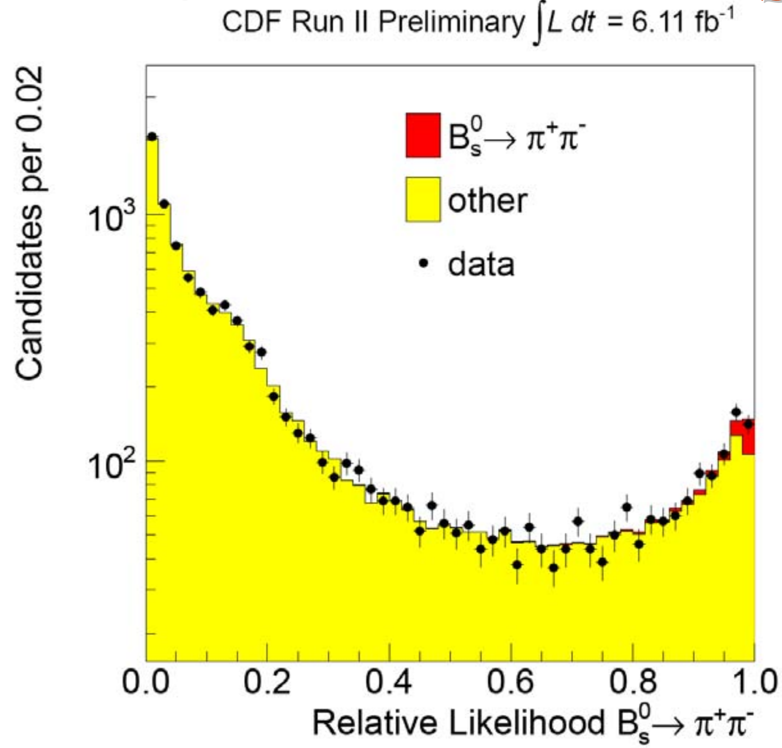
First evidence of $B_S \to \pi^+\pi^-$





CDF finds 94 ± 30 candidates with a significance of 3.7σ

Branching fraction for $B_S \rightarrow \pi^+\pi^-$

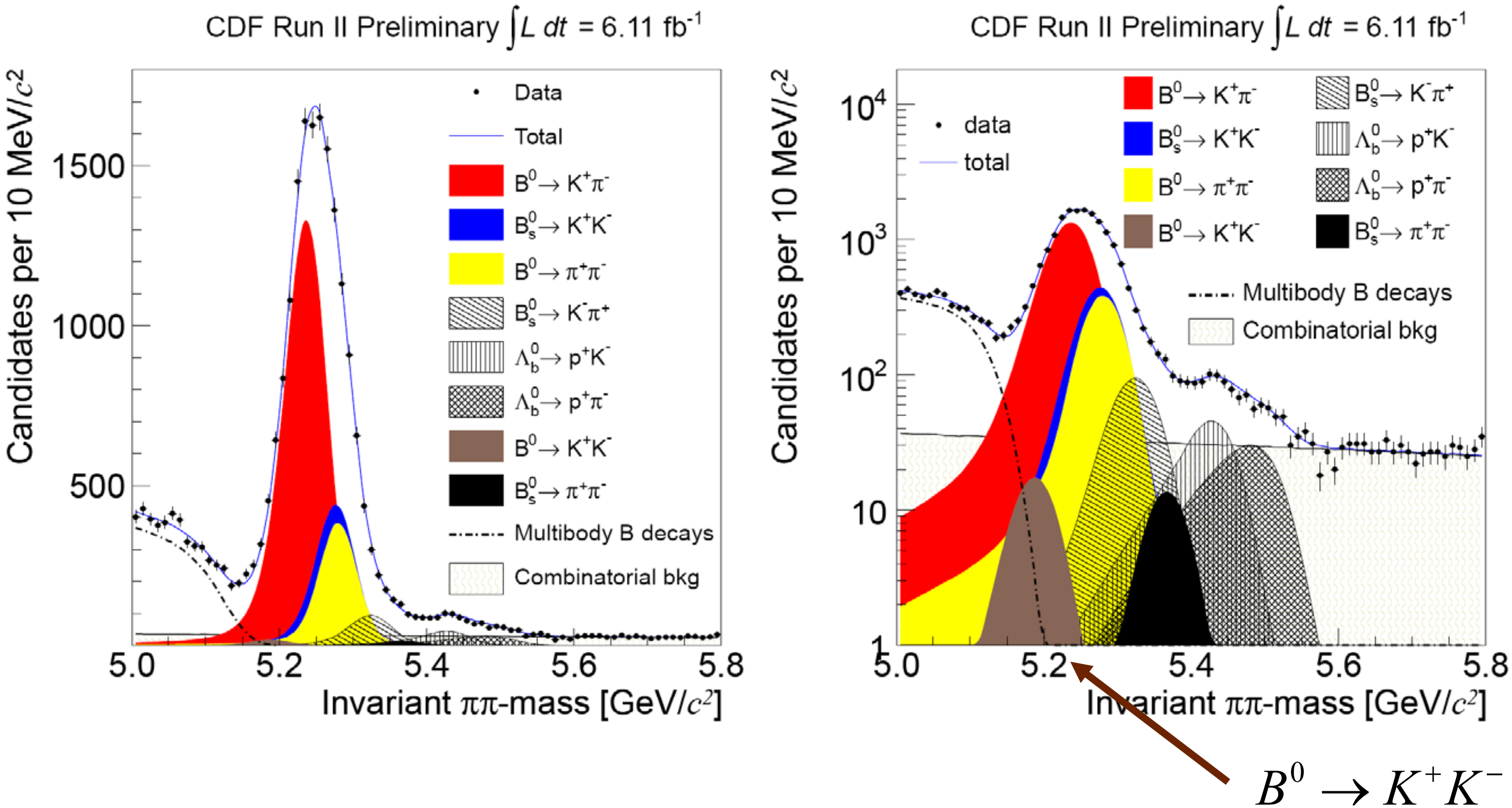


$$\frac{f_s}{f_d} \times \frac{BR(B_S^0 \rightarrow \pi^+\pi^-)}{BR(B^0 \rightarrow K^+\pi^-)} = 0.008 \pm 0.002(stat.) \pm 0.001(syst.)$$

$$BR(B_S^0 \rightarrow \pi^+\pi^-) = (0.57 \pm 0.15(stat.) \pm 0.10(syst.)) \times 10^{-6}$$

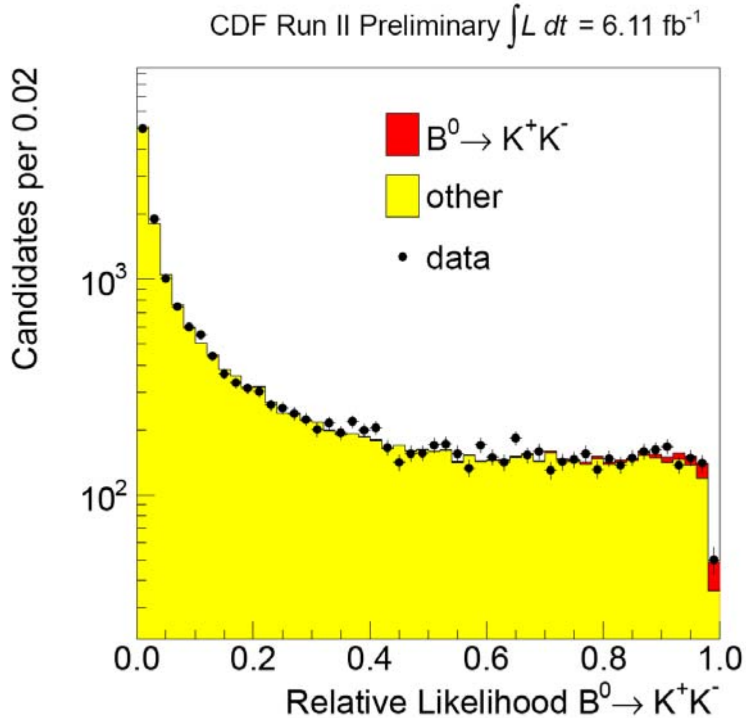
Agrees well with prediction from pQCD : $0.57^{+0.18}_{-0.16}$ PRD 76, 074018, and 0.42 ± 0.06 from Y Li et al., PRD 70 034009 (2004)

First hint of $B^0 \to K^+K^-$



CDF finds 120 ± 65 candidates with a significance of 2.0σ

Branching ratio for $B^0 \to K^+K^-$



$$\frac{BR(B^0 \to K^+K^-)}{BR(B^0 \to K^+\pi^-)} = 0.012 \pm 0.005(stat.) \pm 0.005(syst.)$$

$$BR(B^0 \to K^+K^-) = (0.23 \pm 0.10(stat.) \pm 0.10(syst.)) \times 10^{-6}$$

CDF sets the best two sided limit on $BR(B^0 \to K^+K^-)$ of $[0.05, 0.46] \times 10^{-6}$

Systematic uncertainties

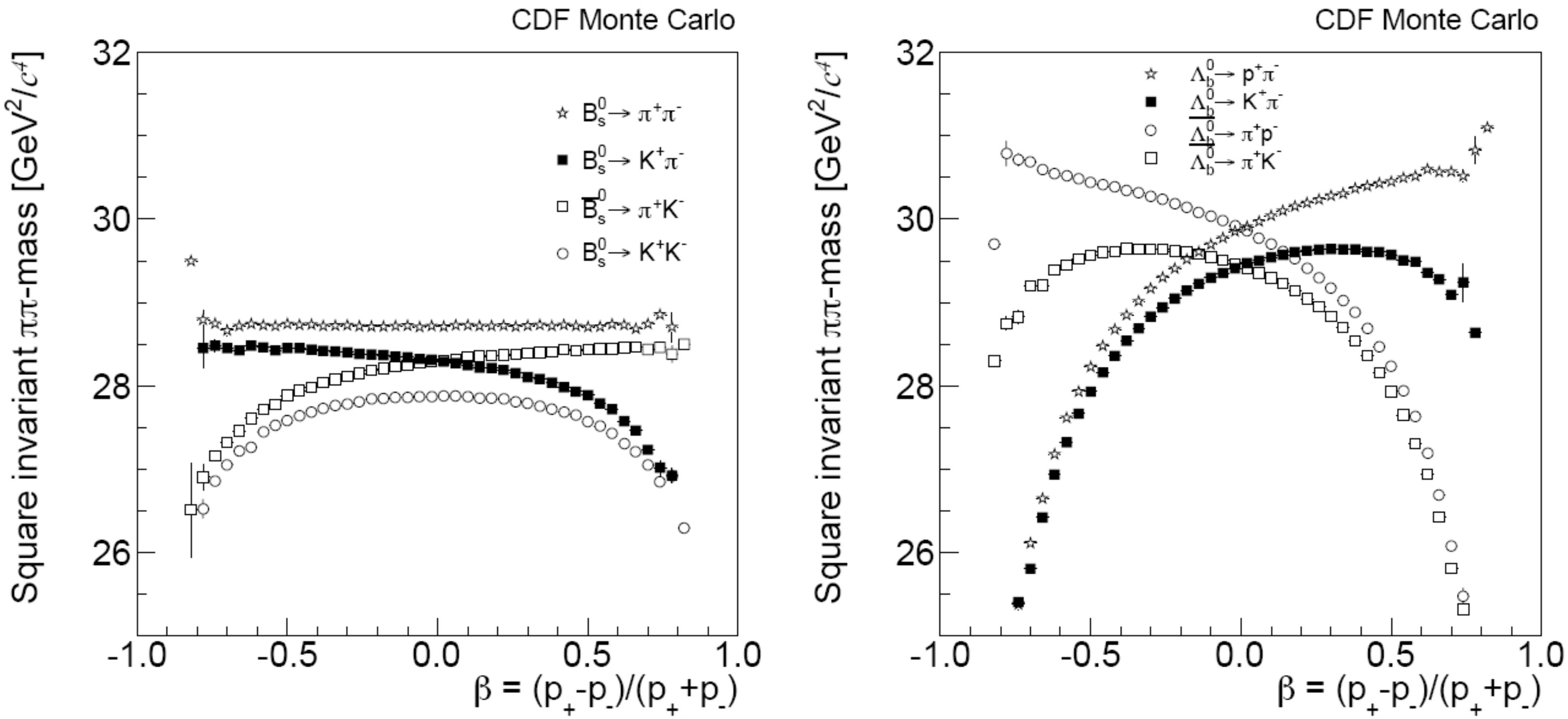
source	$\frac{\mathcal{B}(B^0\to K^+K^-)}{\mathcal{B}(B^0\to K^+\pi^-)}$	$\frac{f_s}{f_d} \times \frac{\mathcal{B}(B_s^0\to \pi^+\pi^-)}{\mathcal{B}(B^0\to K^+\pi^-)}$
Charge asymm. of momentum p.d.f	0.0001	0.0001
Combinatorial back. momentum p.d.f	0.0013	0.0002
Physics back. mometum p.d.f	0.0006	0.
Combinatorial back. mass p.d.f.	0.0001	0.0001
Physics back. mass p.d.f	0.0022	0.0003
Particle Identification model	0.0039	0.0008
$p_{\mathrm{T}}(\Lambda_b^0)$ spectrum	0.0006	0.0001
Efficiency corrections	0.0005	0.0004
Triggers relative efficiency	0.0005	0.0001
B-isol.	–	0.0002
$\Delta\Gamma_s/\Gamma_s$	–	0.
Nominal b-hadrons lifetimes	–	0.0001
Nominal b-hadrons masses	0.0005	0.0002
fit bias	0.0014	–
TOTAL	**0.005**	**0.001**

Conclusions and outlook

- CDF has already made a lot of headway in observing charmless b decays, many modes observed in previous update
- CDF have found evidence of $B_S^0 \to \pi^+\pi^-$
- CDF found a hint of the B^0 equivalent decay of $B^0 \to K^+K^-$
- Still working on updating A_{CP} measuremen ts ($B^0 \to K^+\pi^-$, $B_S^0 \to K^-\pi^+$, $\Lambda_b^0 \to p^+\pi^-$, and $\Lambda_b^0 \to p^+K^-$) in addition to several branching ratios

Back up

Kinematics help a lot

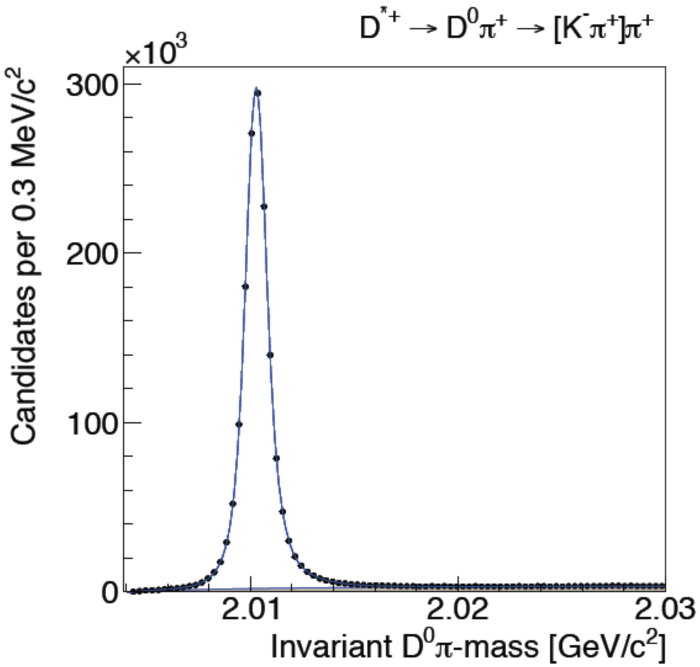


The same plot for the B_S and Λ_b modes

Trigger and isolation efficiencies

2. Trigger efficiency not modeled in MC

- Kaons have a lower specific ionization than pions, results in lower efficiency
- To measure this, decays of $D^* \rightarrow D\,\pi \rightarrow [K\,\pi]\,\pi$ are used from data, trigger on two tracks, look for third



3. Also need to evaluate efficiency with isolation requirement

- Isolation efficiency different between the B^0 and the B_S

- This was again measured using data, fully reconstructed decays of $B^0 \rightarrow J/\psi X$ and $B_S \rightarrow J/\psi X$