Hadronic Moments in Semileptonic B decays

Preblessing
CDF 6754, 6972, 6973

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Contents

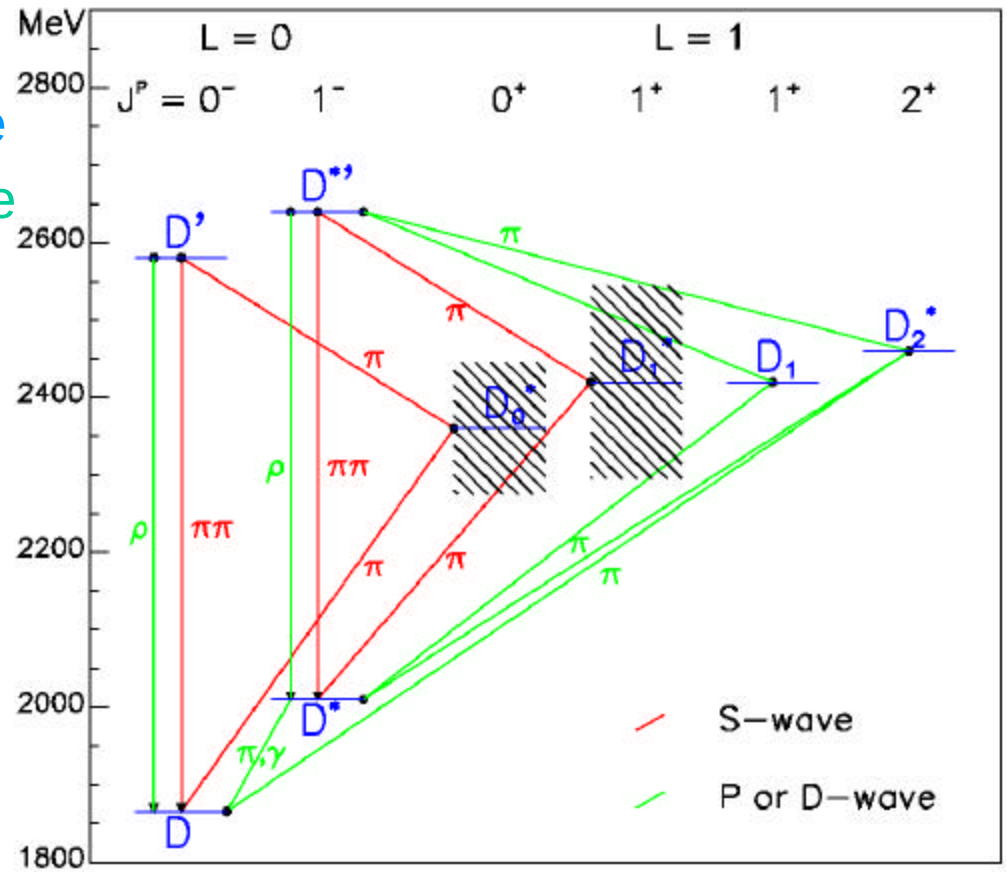
- What are these moments? Why are they interesting?
- Analysis strategy
  - Selection of $l\nu D^*/l\nu D^+$ samples
  - Montecarlo validation
  - π^{**} selection & optimization
  - Raw mass distributions
  - Background modeling
  - Background Subtraction
  - Acceptance corrections
  - Final fit to m^{**}
  - Extraction of QCD parameters

Introduction

- V_{cb} connected to $B \rightarrow X_c l \nu$
  - X_c=anything(c) ➡ Inclusive
  - Xc=$D^{0/*/+}$ ➡ Exclusive
- Hadronic mass moments:
  - Hadronic mass distribution from semi-leptonic decays:

$$B \rightarrow X_c \, l \, \nu$$

  - D, D*, D**
  - only D** component needs to be measured



Inclusive V_{cb} Determination and hadronic moments

- Inclusive semi-leptonic B decays:

$$\Gamma(B \rightarrow X_c l \nu) = |V_{cb}|^2 f(\Lambda, \lambda_1, \lambda_{2,\ldots})$$

- Moments: $g(\Lambda, \lambda_1, \lambda_2, \rho_1, \rho_2, T_i, \alpha_s)$
  - one can measure the moments to improve the knowledge on V_{cb}
  - currently the theory uncertainties dominate
  - general test of non-perturbative aspects of HQET
  - measuring Λ, λ_1 in several ways and finding consistency would be a powerful test of the OPE treatment of HQET
- Experimentally:
  - CLEO, BABAR: inclusive technique with fully reconstructed B on the away side
  - DELPHI: inspired our approach

Moments Definition

- Spectral Moments:
  - lepton energy: $\int E^n (d\Gamma/dE)dE \;/\; \int (d\Gamma/dE)dE$
  - photon energy in $b \rightarrow s\gamma$
  - hadronic mass:

$$\int ds_H \, s_H^n \, (d\Gamma/ds_H) \;/\; \int ds_H \, (d\Gamma/ds_H)$$

where $s_H = m_X^2$

  - usually $s_H = m_X^2 - m^2_{Dspin}$

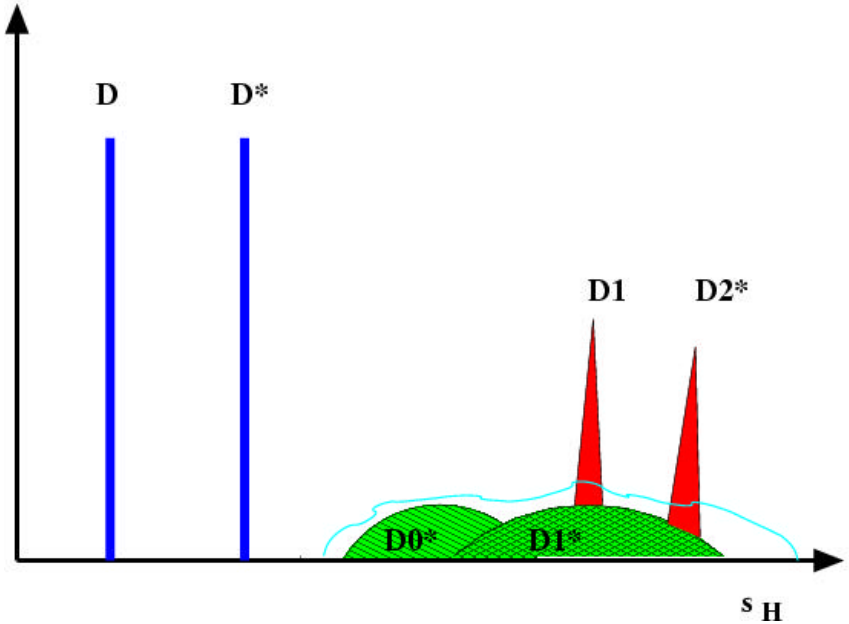
($m_{Dspin} = 0.25 m_D + 0.75 m_{D^*}$ spin averaged mass)

Hadronic Mass

- Hadronic mass spectrum:

$$\frac{1}{\Gamma_{SL}}\frac{d\Gamma_{SL}}{ds_H} = \frac{\Gamma_D}{\Gamma_{SL}} d\left(s_H - m_D^2\right) + \frac{\Gamma_{D^*}}{\Gamma_{SL}} d\left(s_H - m_{D^*}^2\right) + \left(1 - \frac{\Gamma_D}{\Gamma_{SL}} - \frac{\Gamma_{D^*}}{\Gamma_{SL}}\right) f^{**}(s_H)$$

  - Explicitly measure only the D^{**} component, $f^{**}(s_H)$, normalized to 1. Only the shape is needed.
  - PDG values for D and D* masses and b.r. will be inserted.



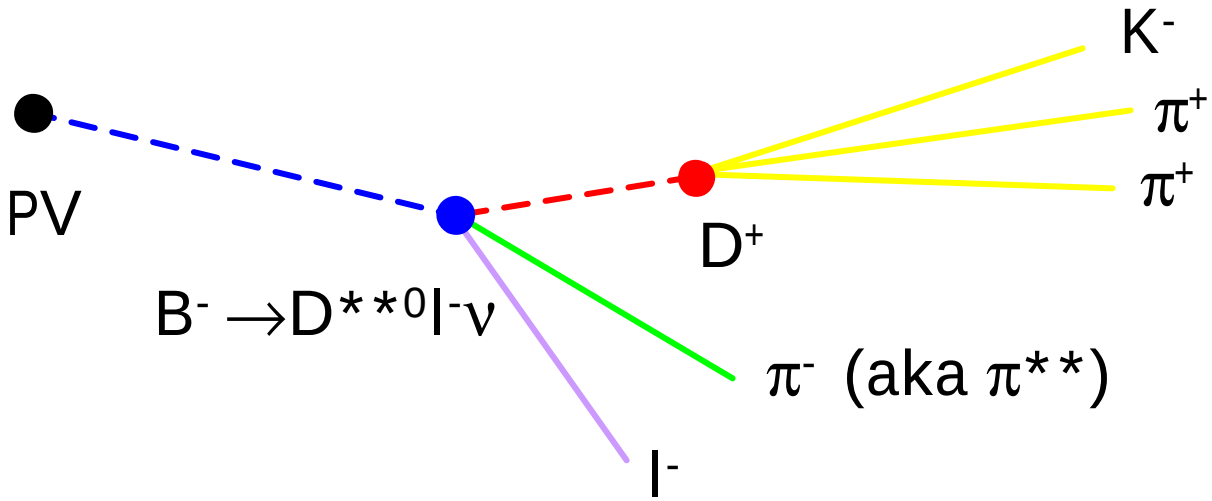
Channels with charged B

- $B^- \rightarrow D^{**0}\, l^-\, \underline{\nu}$
  - $D^{**0} \rightarrow D^+\, \pi^-$ OK
  - $D^{**0} \rightarrow D^0\, \pi^0$ Not reconstructed. Half the rate of $D^+\, \pi^-$
  - $D^{**0} \rightarrow D^{*+}\, \pi^-$
    - $D^{*+} \rightarrow D^0\, \pi^+$ OK
    - $D^{*+} \rightarrow D^+\, \pi^0$ Not reconstructed. Feed-down to $D^+\, \pi^-$
    - ➢ bckgd shape from channel above ($D^0\pi^-$), rate is half
  - $D^{**0} \rightarrow D^{*0}\, \pi^0$ Not reconstructed. Half the rate of $D^{*+}\, \pi^-$

⇒ We can reconstruct all the X_c spectrum

⇒ Neutral B would add statistics but involve neutrals

Event Topology



- D^0, D^+, D^{*+}: 3D vertex of $K\pi(\pi)$
- Lepton +D: 3D vertex
- Additional track (π^{**}) for D^{**}
  - use the track's d0 w.r.t. the B and Primary vertices to tell π^{**} from prompt tracks

The strategy

CDF6754

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Reconstruct D^*/D^+ → **Add another $\pi^{**} \to D^{**}$** → **Correct for $\varepsilon(m_{**})$, $\varepsilon(D^+)/\varepsilon(D^*)$** → **Measure $\langle m_{**}^2 \rangle$, $\langle m_{**}^4 \rangle$**

- Collect as many modes as possible:
  - $(K\pi)\pi^*$
  - $(K\pi\pi\pi)\pi^*$
  - $(K\pi\pi\pi^0)\pi^*$
  - $K\pi\pi$
- Check yields
- Validate MC

- Selection:
  - Optimize on MC+WS combinations
  - Cross check on π^*
- π^{**} Background
  - Combinatorial
  - D'
  - $B \to DD$
  - $c\bar{c}$
  - ...

- Measure selection bias on m_{**} from:
  - MC
  - D^* candidates
- Rely on MC (& PDG) for:
  - $\varepsilon(D^+)/\varepsilon(D^*)$
  - Unseen modes (Isospin)
  - Lepton spectrum acceptance

- Subtract backgrounds
- Use PDG to go $\Delta m_{**} \to m_{**}$
- Compute $\langle m_{**}^2 \rangle$ & $\langle m_{**}^4 \rangle$
- Include $D^{(*)0}$
- Extract Λ, λ_1
- Systematics

Reconstruct
D*/D+

$D^{(*)+}$ Reconstruction

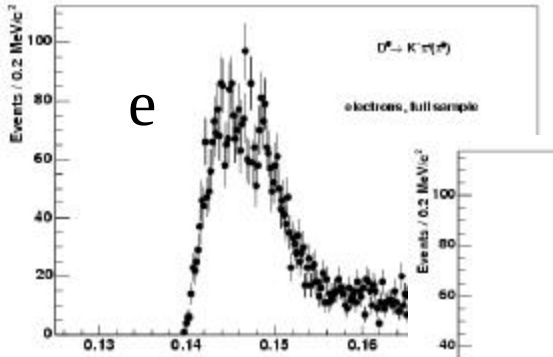
Dataset & Initial Selection

- Dataset:
  - Jbot2h/0i: muon + SVT
  - Jbot8h/4i: electron + SVT

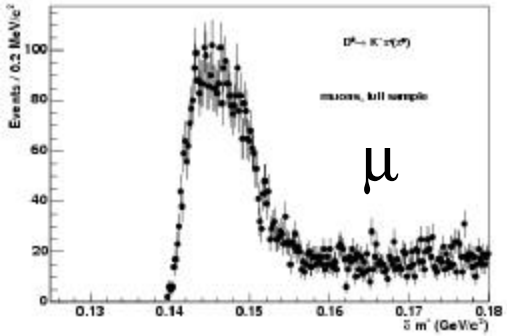
  } Thru run 165297
- Refit:
  - G3X (standard B, phantom layer), beamline 19
  - ISL, L00 hits dropped
  - COT scaling:
    $(curv, d_0, \phi_0, \lambda, z_0) = (5.33, 3.01, 3.7, 0.58, 0.653)$
- LeptonSvtSel: default cuts

Track & Vertex Cuts

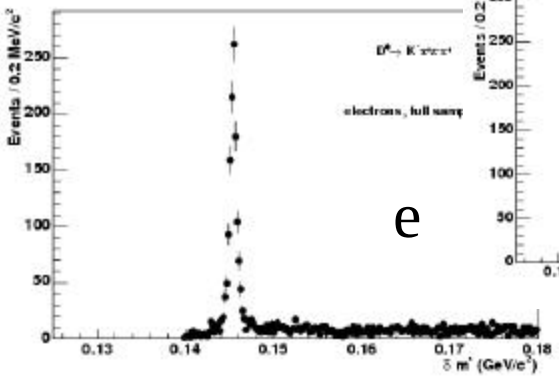
- TrackSelector:
  - COT hits: >20 Ax, >20 St
  - Si hits: ≥3 Ax
  - K, π: $p_T > 0.4$ GeV/c
  - leptons: $p_T > 4$ GeV/c (from LeptonSvtSel)
- D vertex:
  - 3D fit
  - one track has to be matched to the SVT track
- Lepton+D vertex:
  - 3D fit
- π**:
  - 20+20 COT hits
  - Si hits: ≥3 Ax, ≥3 SAS+Z (-30% stat, x2 S/B)
  - Pt>0.4 GeV/c

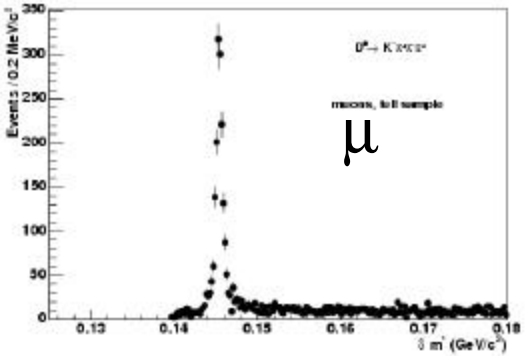


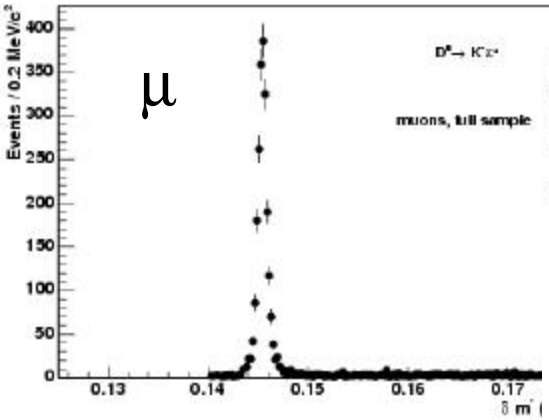
$K\pi\pi^0$



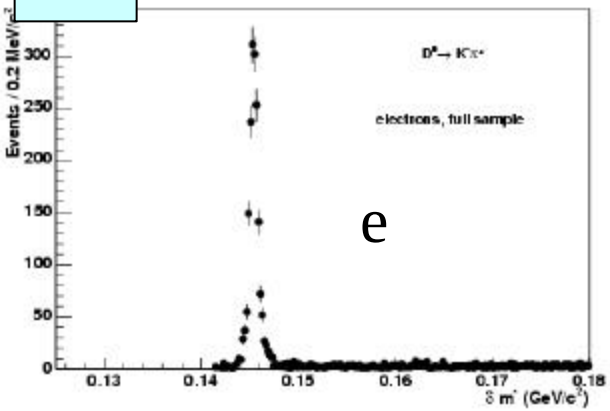
$K\pi\pi\pi$

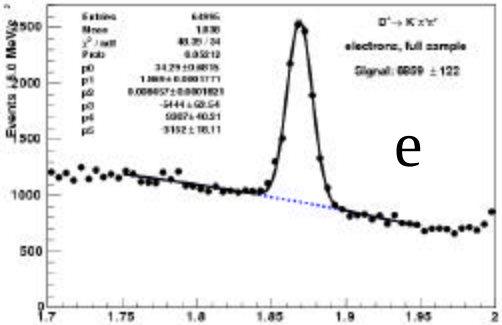




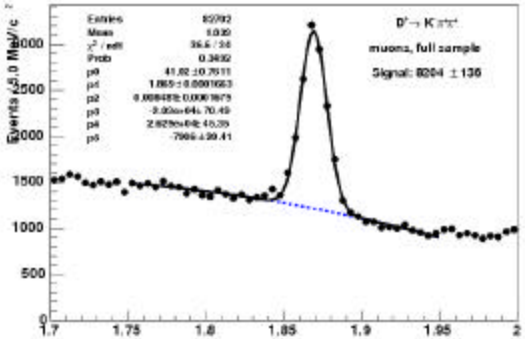


$K\pi$





$K\pi\pi$



	$K\pi$	$K\pi\pi^0$	$K\pi\pi\pi$	$K\pi\pi$
Yield	3890 ± 63	6638 ± 98	2994 ± 57	15067 ± 182

MC samples and validation

Montecarlo Generation

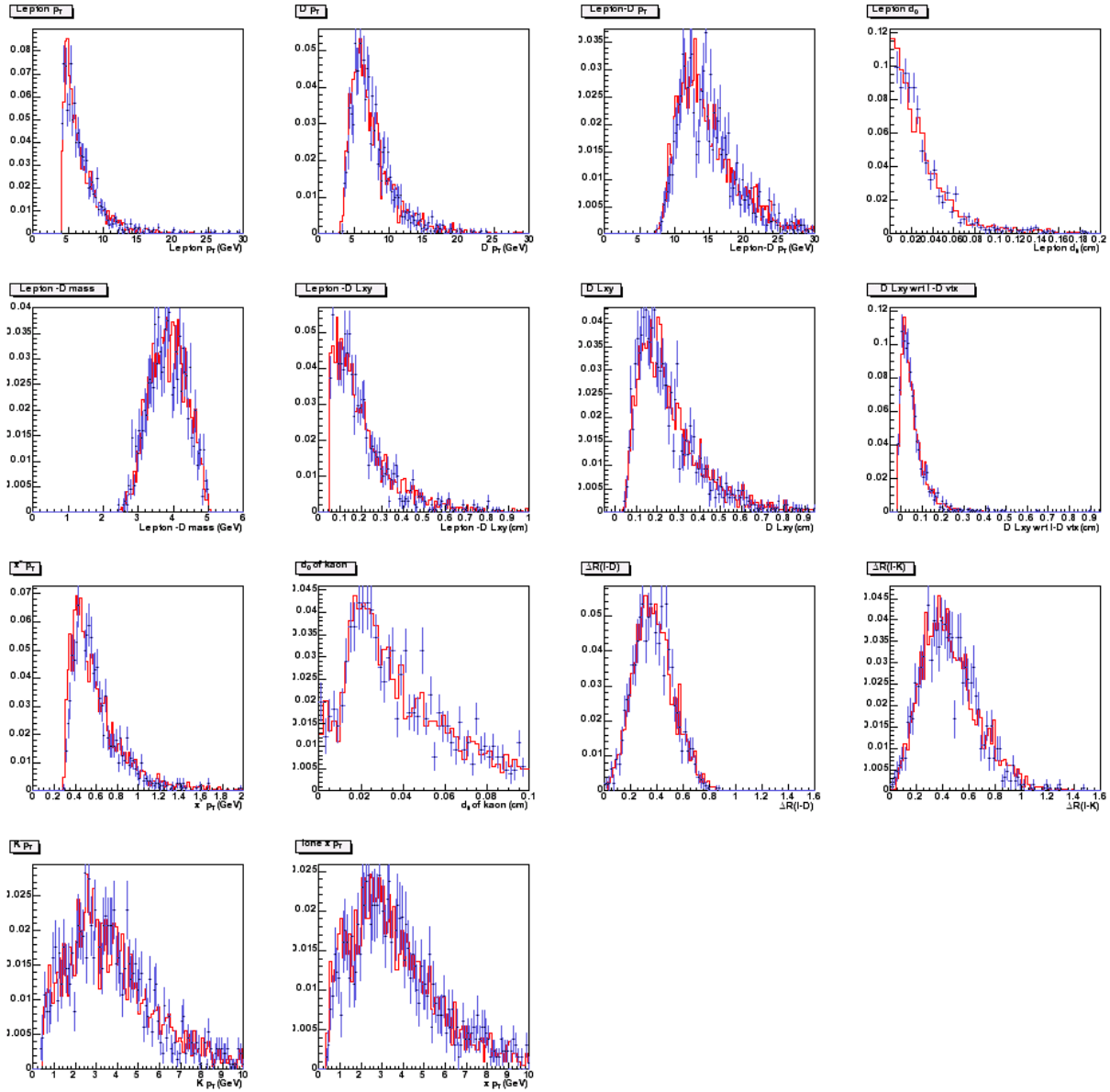
- Bgenerator/EvtGen/CdfSim/TRGSim++
- "realistic simulation" with representative run number
- Different samples:
  - MC Validation
    - D samples $\rightarrow$ inclusive $B \rightarrow X_c l \nu$
    - π^* tracking (π^{**} proxy) $\rightarrow$ exclusive $B \rightarrow D^* l \nu$
  - Optimization $\rightarrow$ inclusive $B \rightarrow l \nu D^{**}$
  - Efficiency, M^{**} bias $\rightarrow$ individual D^{**} mesons

    (e.g. $B \rightarrow D_1 l \nu$, $D_1 \rightarrow D^* \pi$, $D^* \rightarrow D^0 \pi$, $D^0 \rightarrow K \pi$)

Approach to MC validation

- Cross-check kinematic variables
  - B spectrum modeling
  - Trigger emulation
- Compare many data/MC distributions using binned χ^2
  - Every possible decay mode
  - Sideband subtracted before comparison
  - Duplicate removal ($D^0 \rightarrow K\pi\pi\pi$)

Kinematic Comparisons: μD^*, $D^0 \rightarrow K\pi$



P_t^{l}	P_t^{D}	P_t^{lD}	d_0^{l}
m_{lD}	L_{xy}^{lD}	L_{xy}^{D}	$L_{xy}^{lD\rightarrow D}$
$P_t^{\pi^*}$	d_0^{K}	ΔR^{lD}	ΔR^{lK}
P_t^{K}	P_t^{π}		

Matching - c^2 prob (%)	$K\pi$		$K\pi(\pi^0)$		$K\pi\pi\pi$		$K\pi\pi$	
	e	μ	e	μ	e	μ	e	μ
$p_T(l)$	4	12	43	40	38	11	16	1
$p_T(D)$	3	7	8	2	6	79	12	4
$p_T(l\text{-}D)$	41	17	30	2	49	22	9	4
$d_0(l)$	10	92	75	27	30	4	95	2
$m(l\text{-}D)$	2	3	50	61	48	69	16	42
$L_{XY}(l\text{-}D)$	48	23	41	12	32	69	29	0.07
$L_{XY}(D)$	23	88	69	99	95	47	87	2
L_{XY}(B to D)	61	29	6	13	17	89	24	2
$p_T(\pi^*)$ >0.4 GeV	28	42	21	70	38	1	–	–
$d_o(K)$	68	72	83	54	74	15	17	72
$\Delta R(l\text{-}D)$	34	29	26	51	86	33	57	30
$\Delta R(l\text{-}K)$	17	12	33	66	38	2	29	2
$p_T(K)$	22	20	49	52	83	10	25	15
$p_T(\pi)$	90	20	14	59	2	8	–	–
$p_T(2\pi)$	–	–	–	–	–	–	67	64

Can we "predict" relative yields?

$$R_{D^+/K\pi} \equiv \frac{N(B \to D^+ l\bar{\nu} X, D^+ \to K^-\pi^+\pi^+)}{N(B \to D^{*+} l\bar{\nu} X, D^{*+} \to D^0\pi^+, D^0 \to K^-\pi^+)}, \qquad R_{K3\pi/K\pi} \equiv \frac{N(D^{*+} l\bar{\nu} X, D^{*+} \to D^0\pi^+, D^0 \to K^-\pi^+\pi^-\pi^+)}{N(D^{*+} l\bar{\nu} X, D^{*+} \to D^0\pi^+, D^0 \to K^-\pi^+)}.$$

Two methods (a,b) to derive this BR

a) Based on inclusive $b \to D^{(*)+} l\nu$

b) Based on exclusive $B \to D^{(*)+} l\nu$, $D^{**} l\nu$

+PDG BR + MC efficiency ratios

	$R_{pred.}$	R_{data}	$R_{pred.}/R_{data}$
$R_{D^+/K\pi}$			
data (sans D_s)		3.71 ± 0.08	
Method (a)	3.31 ± 0.58		0.89 ± 0.16
Method (b)	$3.23 \pm 0.29 \pm ?$		$0.87 \pm 0.08 \pm ?$
$R_{K3\pi/K\pi}$			
data		0.77 ± 0.02	
	0.80 ± 0.04		1.04 ± 0.06

Assume MC predictions and use 13% systematics

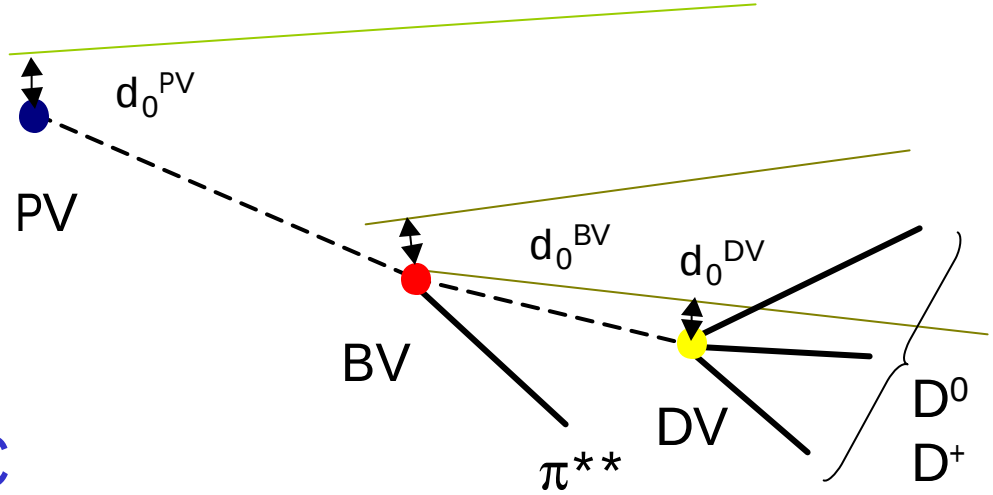
Add another

$\pi^{**} \rightarrow D^{**}$

D^{**}

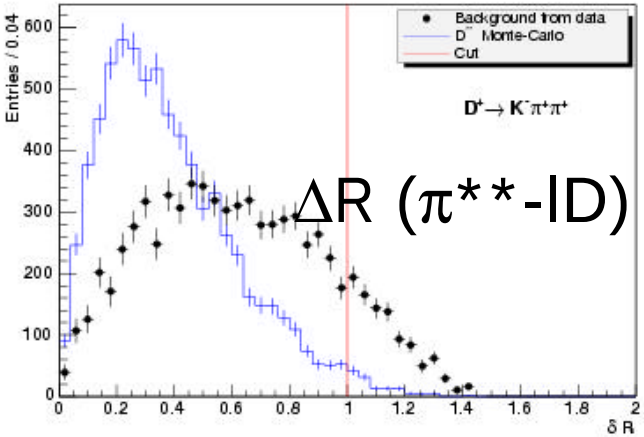
Optimization

- The relevant discriminants are:
  - P_t
  - ΔR
  - d_0^{PV}
  - d_0^{BV}
  - d_0^{DV}
  - $L_{xy}^{B\to D}$

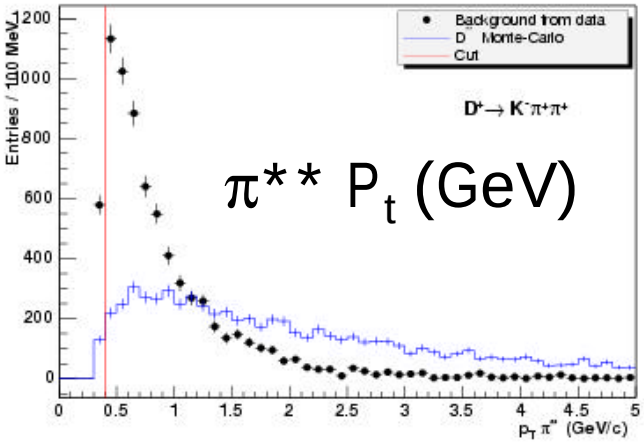


- Signal model: MC
- Background model:
  - WS $\pi^{**} \leftrightarrow$ l charge
- Optimize significance

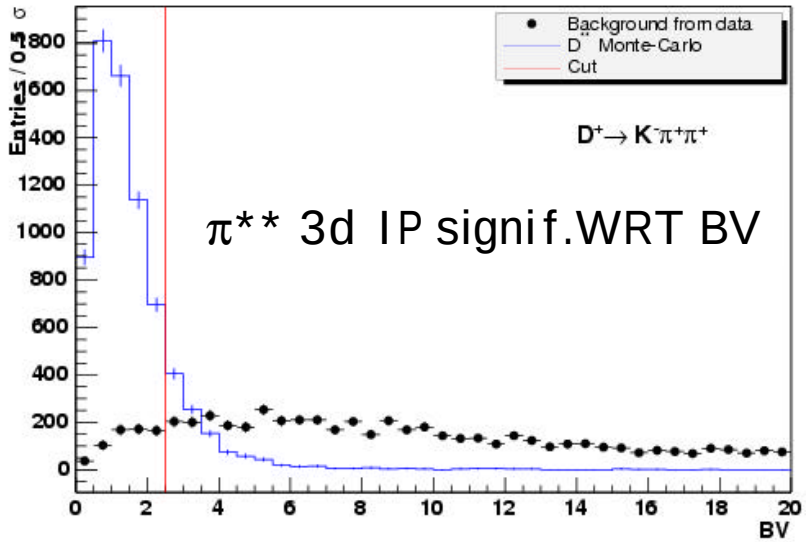
Discriminating Variables



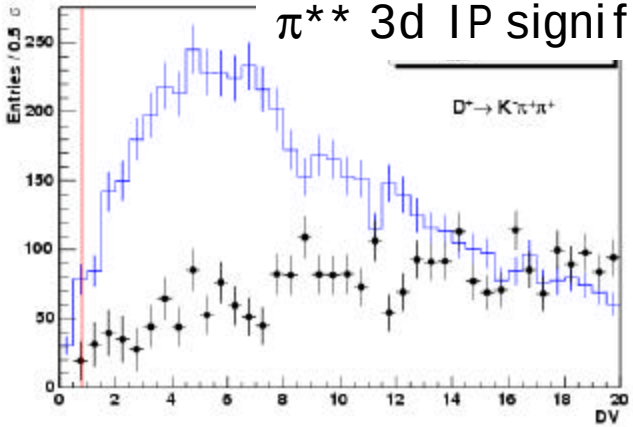
ΔR (π**-ID)



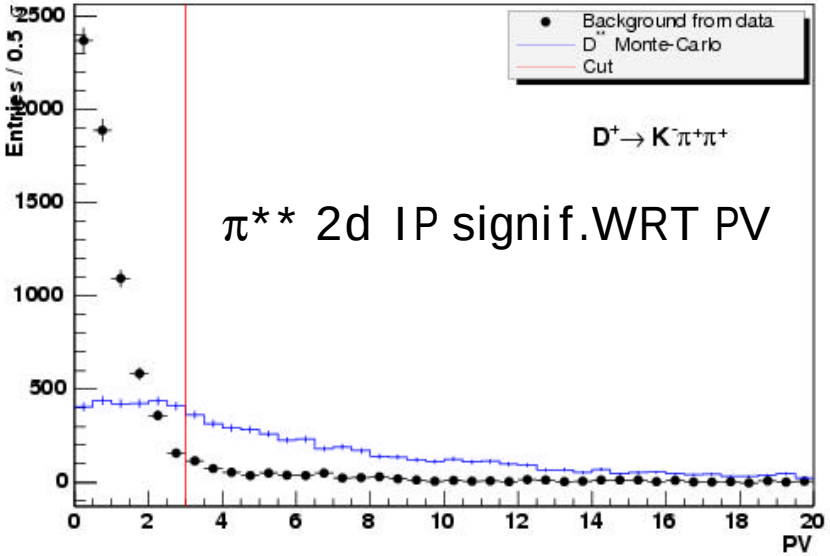
π** P_t (GeV)



π** 3d IP signif.WRT BV



π** 3d IP signif.WRT DV



π** 2d IP signif.WRT PV

Optimization!

- Generate D** montecarlo (the shape)
- Normalize D** MC to data with reasonable cuts
- Now we can turn the crank and optimize…

But what?

$$\frac{S}{s_{bin}} \approx \frac{S}{\sqrt{S + 2*S_{WS} + a^2*(SB_{RS} + SB_{WS}) + a*(SB_{RS} - SB_{WS})}}$$

- a is the ratio of background events between signal and sideband region (a<1, usually)
- S is the MC signal (right sign combinations, signal region)
- S_{WS} is the WS data in the signal region
- SB_{RS} is the RS data in the sideband region
- SB_{WS} is the WS data in the sideband region

Optimal point:

D^+

- D^*
  - $Pt(\pi^{**})>0.4$ GeV
  - $\Delta R<1.0$
  - $-|d_0^{PV}/\sigma|>2.5$
  - $-|d_0^{BV}/\sigma|<3.0$
- $|d_0^{DV}/\sigma|>0.8$
- $L_{xy}(B\rightarrow D)>0.05$ cm

- $S/sqrt(...)\approx 8$
- $S/sqrt(...)\approx 6.6$

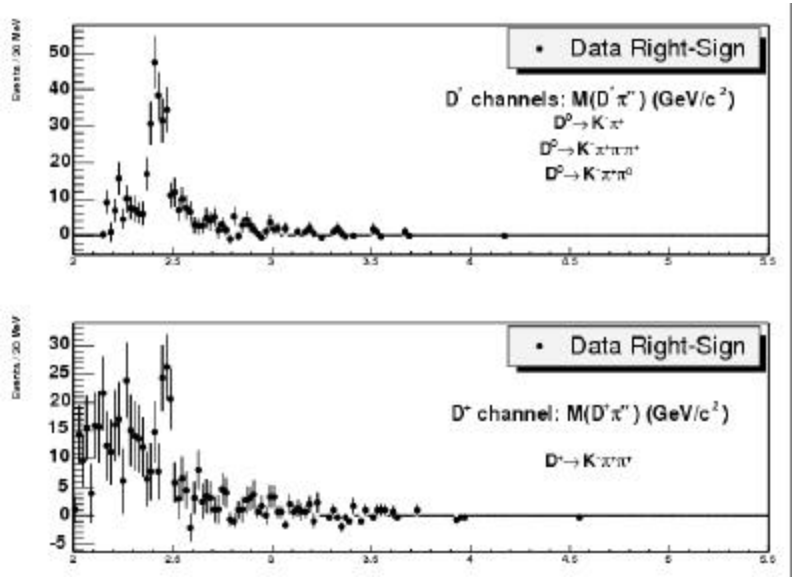
- We have to live with different selections for $D^{**}\rightarrow D^+$ and $D^{**}\rightarrow D^*$

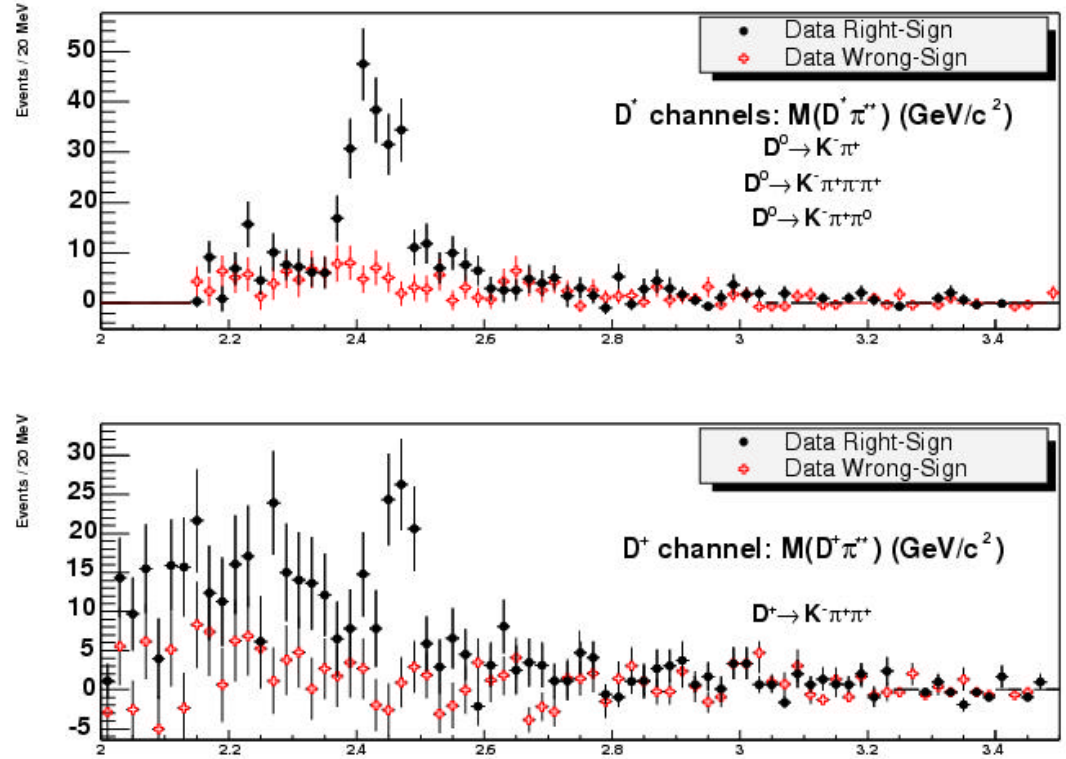
Measure

$\langle m_{**}^2 \rangle$, $\langle m_{**}^4 \rangle$

m**

Current Mass Distributions





	SRS	SWS	SBRS	SBWS	Signal Yield	MC
$D^{*+}(K\pi)$	112	36	31	39	77 ± 12	89 ± 3
$D^{*+}(K3\pi)$	95	49	131	155	48 ± 12	69 ± 3
$D^{*+}(K\pi\pi^{\circ})$	271	180	217	289	114 ± 22	147 ± 6
D^{+}	860	514	1352	1349	345 ± 41	257 ± 6

DELPHI:

~80 (Kπ)

~80 (D^+)

Background

Backgrounds

- Background from B decays:
  - Know how to model
  - Study using Bgenerator/EvtGen/TRGSim++/CdfSim
- "Feeddown"
- Combinatorial background under D peaks:
  - side-band subtraction
- Prompt pions in $D^{(*)+}\pi^{-}l^{-}$:
  - Mostly from fragmentation
  - wrong-sign combination $D^{+}\pi^{+}l^{-}$
- $c\bar{c}$
  - D^0 impact parameter distribution

Physics Background

- Physics background studied with $B \rightarrow D^{(*)+} D_s^-$
- Size wrt signal:

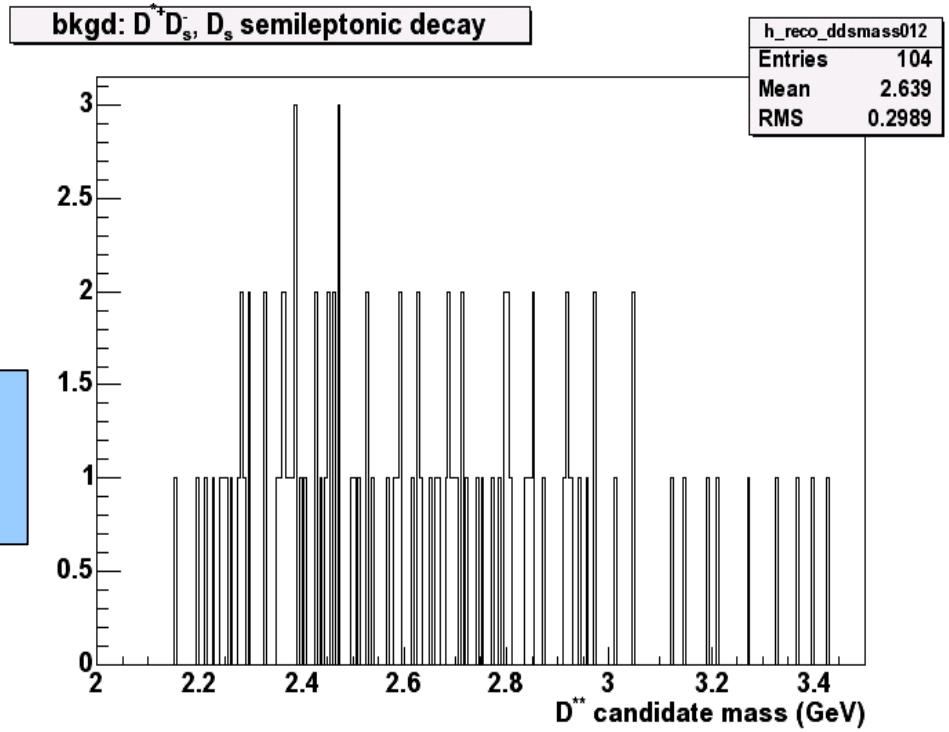
$$e \times BR(D_s \rightarrow lX) \times \frac{BR(B \rightarrow D_s D^{(*)+})}{BR(B \rightarrow signal)} \times 1.5$$

~7%

~7%

~1

Other modes



- 100% uncertainty

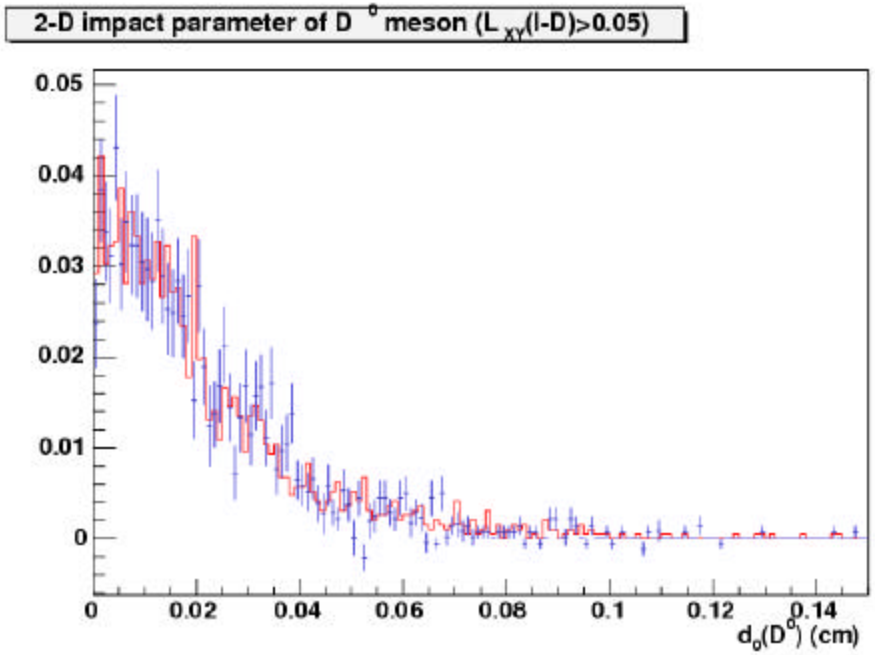
Background: Feed Down

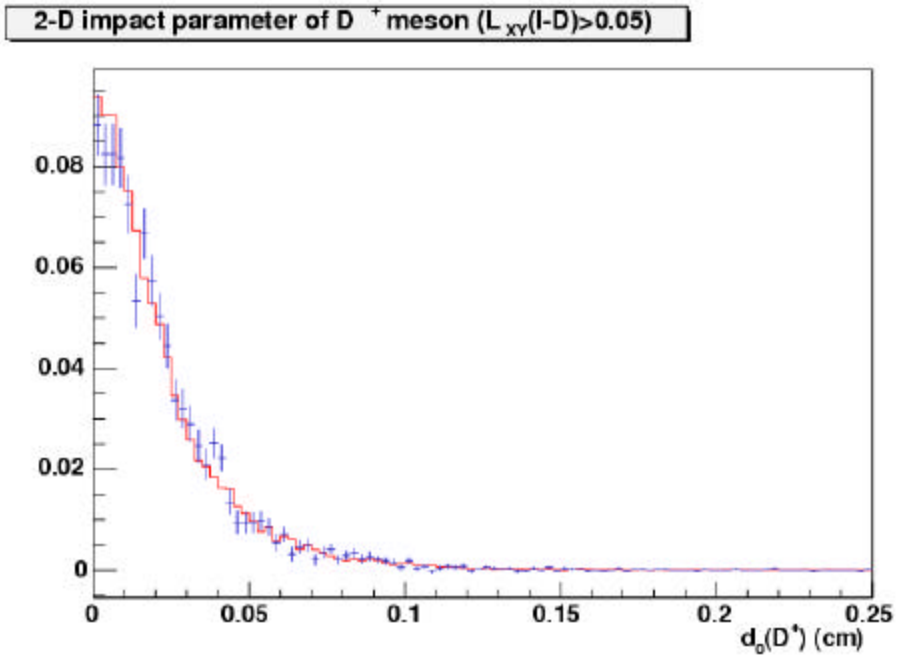
- Irreducible $D^{**0} \rightarrow D^{*+}(\rightarrow D^{+}\pi^{0})\pi^{-}$ background to $D^{**0} \rightarrow D^{+}\pi^{-}$ subtracted statistically:
  - M shape of $D^{+}\pi^{-}$ combination above is like $D^{0}\pi^{-}$ from $D^{**0} \rightarrow D^{*+}(\rightarrow D^{0}\pi^{+})\pi^{-}$
  - Rate is one half (isospin) times the relative efficiency in both channels time the ratio of the D^{0} and D^{+} B.R.'s used in the analysis

$$\frac{e(Kpp)}{e(Kp)} \times \frac{BR(D^{+} \rightarrow Kpp)}{BR(D^{0} \rightarrow Kp)} \times \frac{1}{2}$$

Pollution from ccbar?

- We are cutting hard on $L_{xy}(B)$ (500μm), this is known to "solve" the lifetime problem
- Look at D^+/D^0 impact parameter for evidence of prompt objects: we do not see any





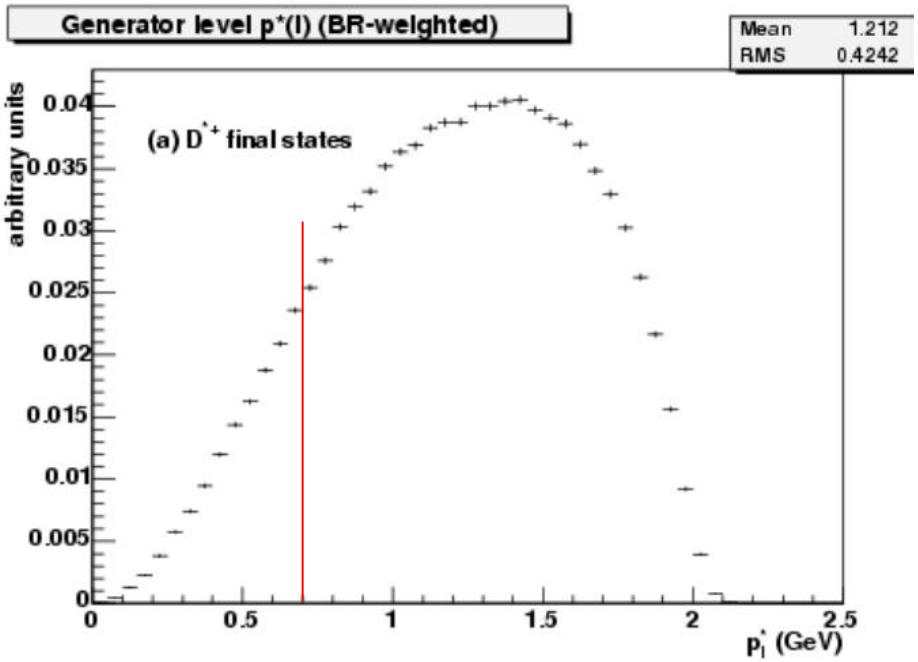
Measure

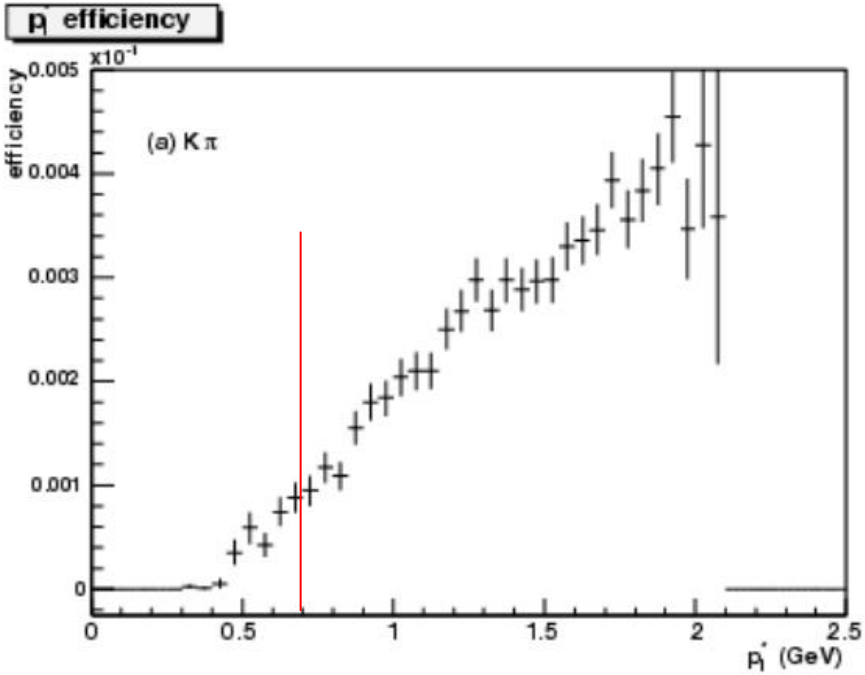
$\langle m_{**}^2 \rangle$, $\langle m_{**}^4 \rangle$

Efficiency Corrections

P_l*

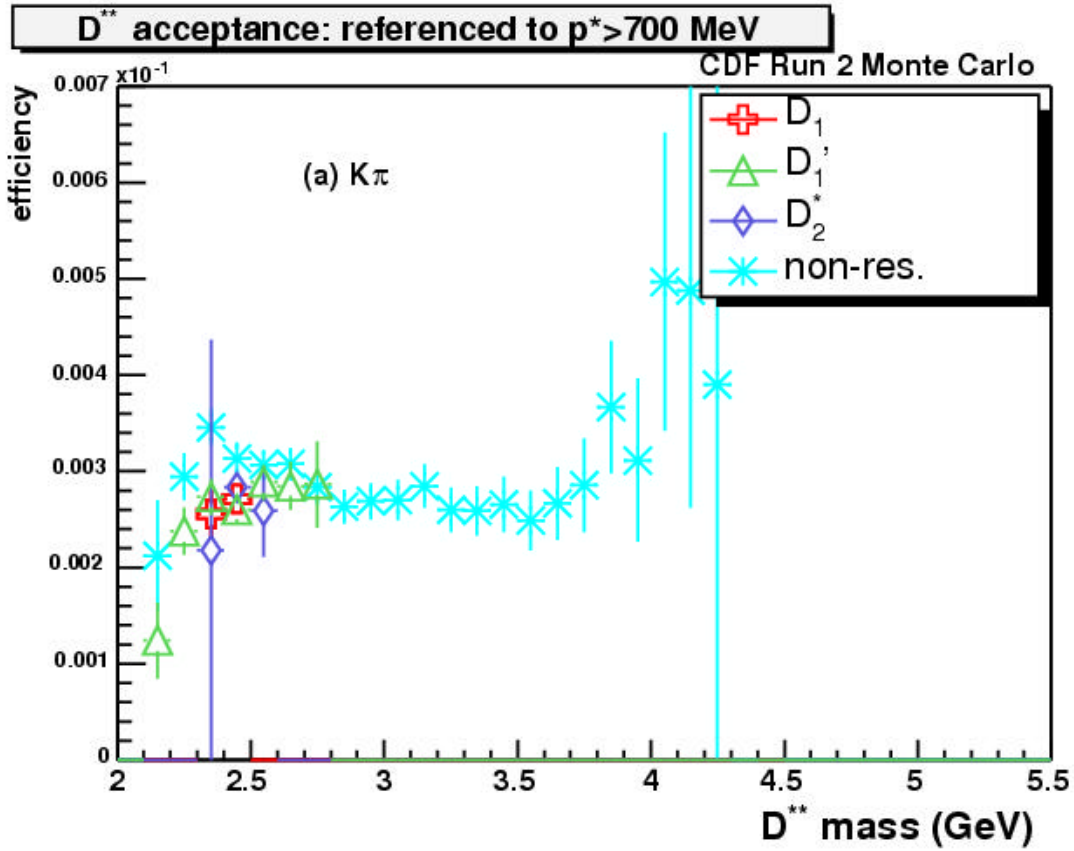
- Theory prediction depends on P_l* cuts. We cannot do much but:
  - see how our efficiency as a function of P_l^* looks like
  - Use a threshold-like correction
  - Evaluate systematics for different threshold values





MC efficiencies

- $\varepsilon(M)$ is dependent on:
  - D** decay Model
  - P_l* cut
- Use different models/cuts to evaluate systematics:
  - Individual resonances
  - Goity-Roberts
  - Phase space (not shown)
- Baseline: BR weighted (EvtGen) average of modes

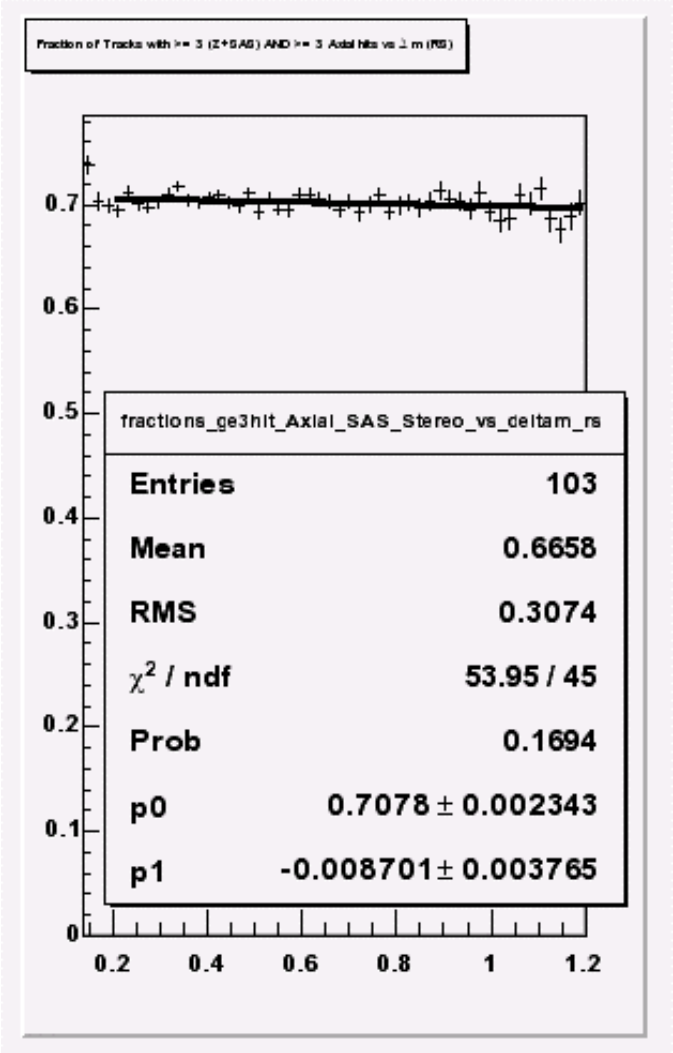


Corrections to MC efficiencies

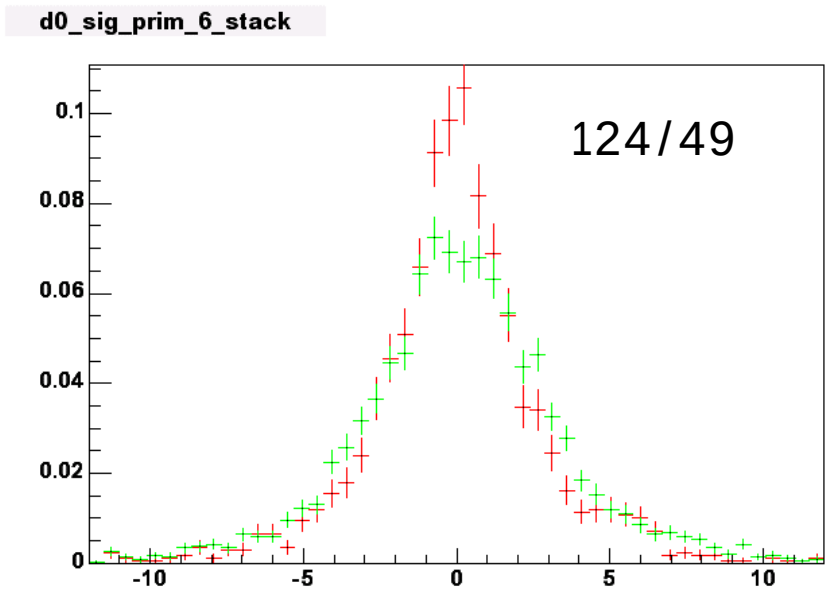
- Worried about possible shortcomings of the MC simulation:
  - Efficiency for requiring Si hits
  - π^{**} separation variables not perfectly reproduced by MC
- Use π^* candidates from data to derive corrections

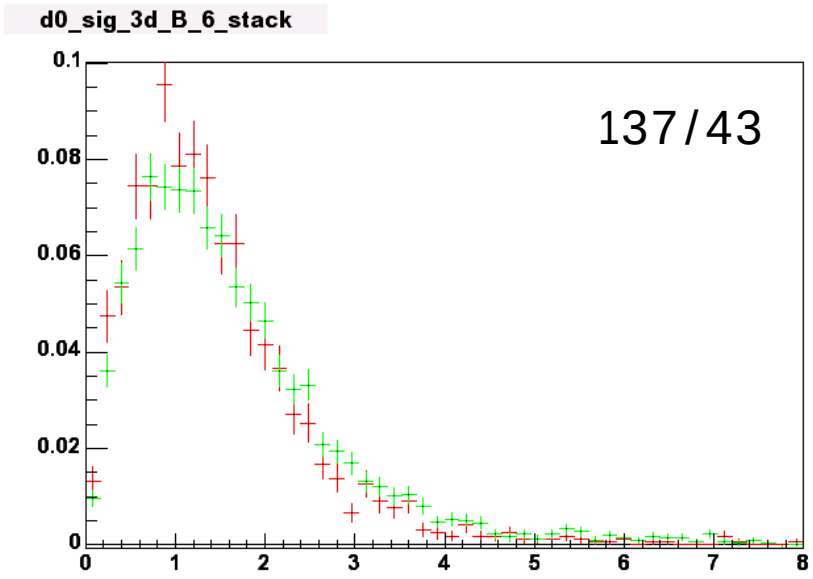
π^* probes Si hit efficiency

- $D^{0/+}$ reco is based on trigger tracks
- Si requirements can bias $\Delta\phi(D^0\pi^{**})$
- $\Delta\phi(D^0\pi)\leftrightarrow\Delta m^{**}$
- Take COT-only π^*
- Apply 3Ax+3 (Stereo+SAS)
- Measure fraction as a function Δm^{**}
- Use slope ($\pm$error) as correction

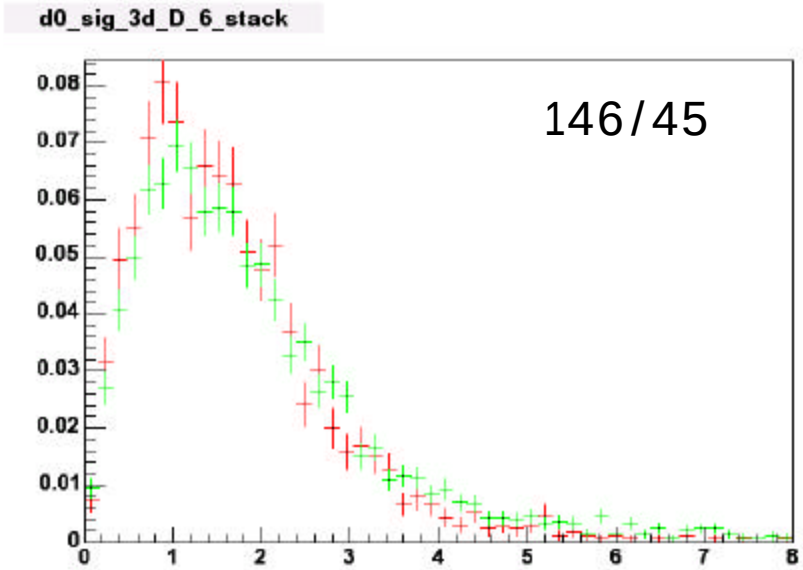


π** Separation Variables



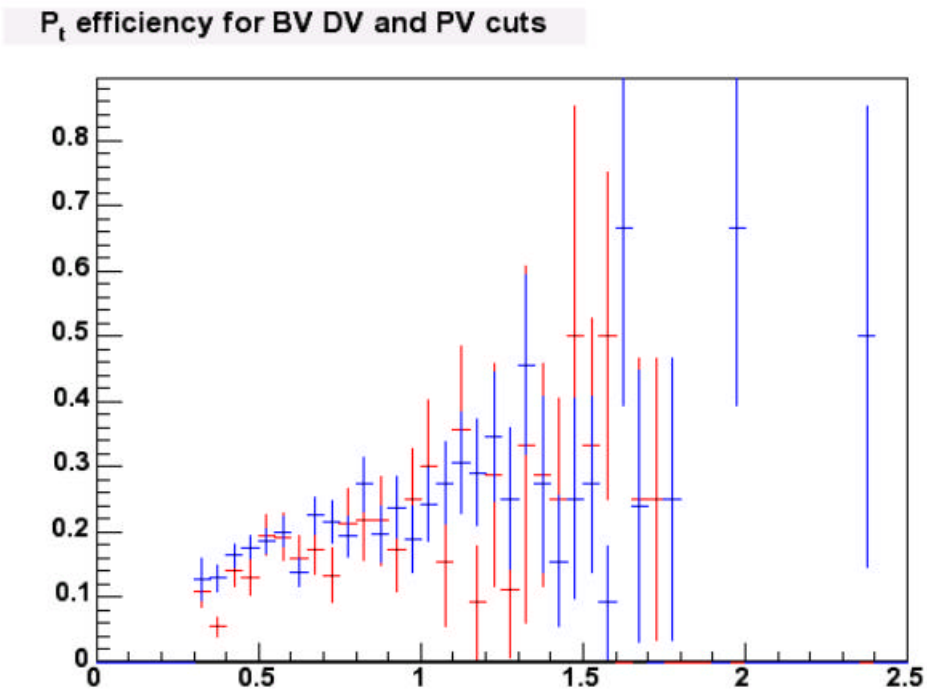


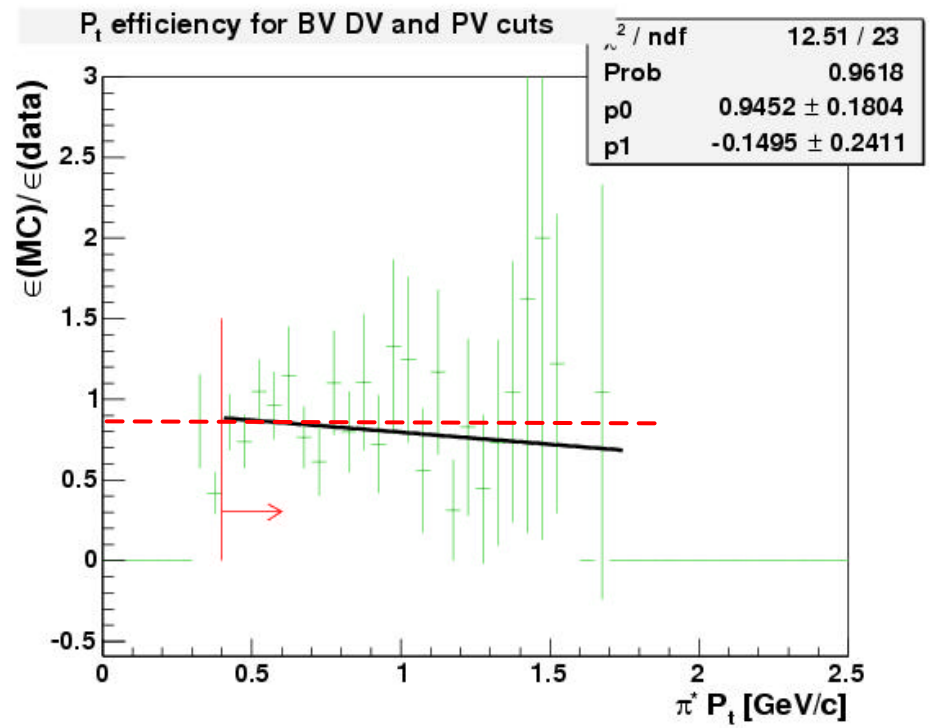
- Data MC comparison
- Behavior is similar, but there are discrepancies
- Derive corrections from this comparison



Data vs MC efficiencies

- Apply to π^* the same tracking requirements we usually apply to π^{**} (including Si hits)
- Measure efficiencies for π^{**} selection cuts applied to π^*
- Take the ratio of MC and Data efficiencies as a function of Pt





Measure

$\langle m_{**}^2 \rangle$, $\langle m_{**}^4 \rangle$

Moments Extraction

Procedure

Computing the D** Moments

- All the pieces are put together in an unbinned procedure using weighted events
- Signal right sign (SRS) $w = +1$
- Signal wrong sign (SWS) $w = -1$
- Sideband right sign (SBRS) $w = -a_i$
- Sideband wrong sign (SBWS) $w = +a_i$
- Apply efficiency corrections: efficiencies are propagated on weights

$$W = w\,(a \times P_t^{**} + b) / [\varepsilon_{MC}(m^{**})(c \times m^{**} + d)]$$

More Backgrounds

- Feed-down pseudo-events are formed from the $D^0\pi^{-**}$ mass in $K\pi$ events (in SRS,SWS,SBRS,SBWS). The weight is

$$w = -w \times \frac{e(Kpp)}{e(Kp)} \times \frac{BR(D^+ \to Kpp)}{BR(D^+ \to Kp)} \times \frac{1}{2}$$

- Physics background events are generated and assigned a weight

$$w = -\frac{e}{1+e} \times BR(D_s \to lX) \times \frac{BR(B \to D_s D^{(*)+})}{BR(B \to signal)} \times \frac{N_{D^{**}}}{N_{back}}$$

where ε =0.07 is the efficiency of the background relative to the signal. The weight is then corrected with the efficiency factor from MC.

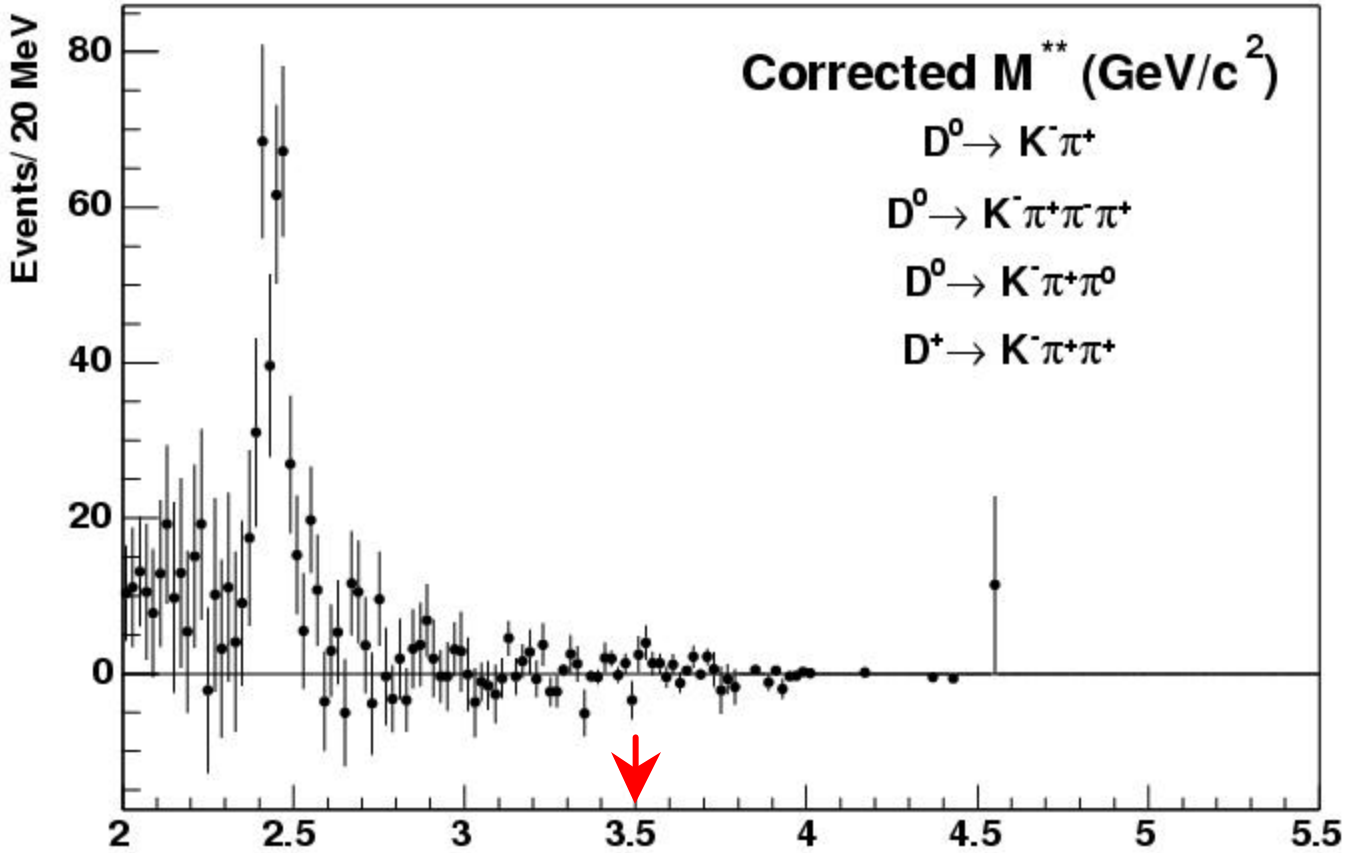
D^+, D^{*+} Relative Normalization

- Relative normalization of D* channels is irrelevant since they all have the same underlying M distribution.
- D^+ channel has a different M distribution. All D^+ events have their weights modified as:

$$W = w \times \frac{e(Kp)}{e(Kpp)} \times \frac{BR(D^{*+} \to D^0 p^+) BR(D^0 \to K^- p^+)}{BR(D^+ \to K^- p^+ p^+)} \times \frac{N_{D^*}}{N_{Kp}}$$

- Systematics:
  - BR uncertainties from PDG (±7%)
  - ε ratio from studies on data (±13%)

Resulting m** distribution



$$m_1 = \left\langle m_{D**}^2 \right\rangle = (5.73 \pm 0.15) GeV^2$$

$$m_2 = \left\langle \left(m_{D**}^2 - m_1 \right)^2 \right\rangle = (0.85 \pm 0.49) GeV^4$$

Computing the X_c Moments

- The D^0 and D^{*0} pieces have to be added to the D^{**0} moments, according to

$$
\begin{aligned}
M_1 &= \mu - m_D^2 \,, \\
M_2 &= \frac{\frac{\Gamma_0}{\Gamma_{sl}} \cdot \left(m_{D^0}^2 - \mu\right)^2 f_0 + \frac{\Gamma_*}{\Gamma_{sl}} \cdot \left(m_{D^{*0}}^2 - \mu\right)^2 f_* + \left(1 - \frac{\Gamma_0}{\Gamma_{sl}} - \frac{\Gamma_*}{\Gamma_{sl}}\right) \cdot \left(m_2 + (m_1 - \mu)^2\right) f_{**}}{\frac{\Gamma_0}{\Gamma_{sl}} f_0 + \frac{\Gamma_*}{\Gamma_{sl}} f_* + \left(1 - \frac{\Gamma_0}{\Gamma_{sl}} - \frac{\Gamma_*}{\Gamma_{sl}}\right) f_{**}}
\end{aligned}
$$

f

with μ defined as

$$
\mu = \frac{\frac{\Gamma_0}{\Gamma_{sl}} \cdot m_{D^0}^2 f_0 + \frac{\Gamma_*}{\Gamma_{sl}} \cdot m_{D^{*0}}^2 f_* + \left(1 - \frac{\Gamma_0}{\Gamma_{sl}} - \frac{\Gamma_*}{\Gamma_{sl}}\right) \cdot m_1 f_{**}}{\frac{\Gamma_0}{\Gamma_{sl}} f_0 + \frac{\Gamma_*}{\Gamma_{sl}} f_* + \left(1 - \frac{\Gamma_0}{\Gamma_{sl}} - \frac{\Gamma_*}{\Gamma_{sl}}\right) f_{**}} \,.
$$

where the f_i are the fractions of $D^i l$ events above the p_l^*cut. Only ratios of f_i's enter the final result.

$$
\begin{aligned}
M_1 &= (0.437 \pm 0.035_{\text{stat}} \pm \quad {}_{\text{exp}} \pm 0.060_{\text{BR}}) \ \text{GeV}^2 \\
M_2 &= (0.86 \pm 0.20_{\text{stat}} \pm \quad {}_{\text{exp}} \pm 0.07_{\text{BR}}) \ \text{GeV}^4 \,,
\end{aligned}
$$

Measure

$\langle m_{**}^2 \rangle$, $\langle m_{**}^4 \rangle$

Moments Extraction

Systematics

Systematics

shopping list

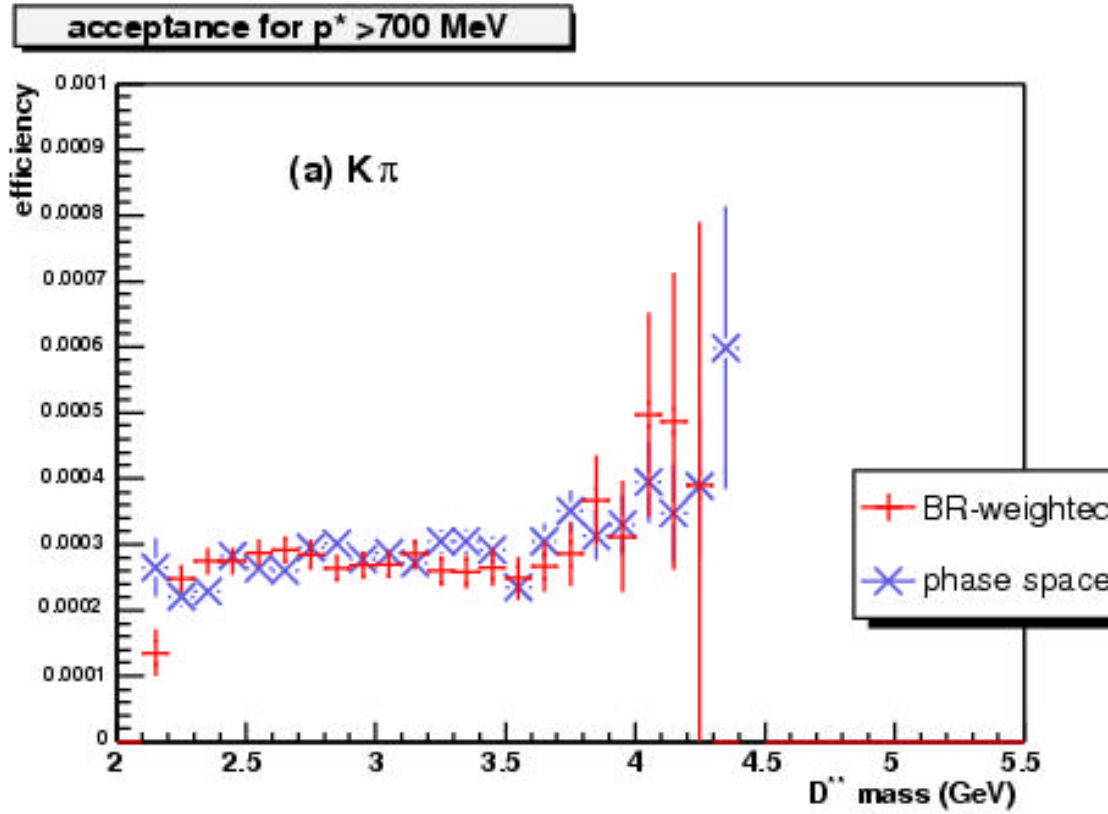
- Mass scale and resolution
- Efficiency corrections
  - From MC
  - from data
- Lepton momentum cut
- Background model
- Radial excitations
- Physics background
- Relative D^+/D^* normalization
- Semileptonic B branching ratios
- D** mass cut

Mass scale/resolution

- We are measuring Δm^{**} and then adding the PDG masses for D+/D*
- Basically insensitive to absolute scale issues
- Mass resolution matters
- The sample with the worst resolution is $K\pi\pi^0$
- Re-smear $K\pi\pi^0$ with 60MeV gaussian and use this as systematic

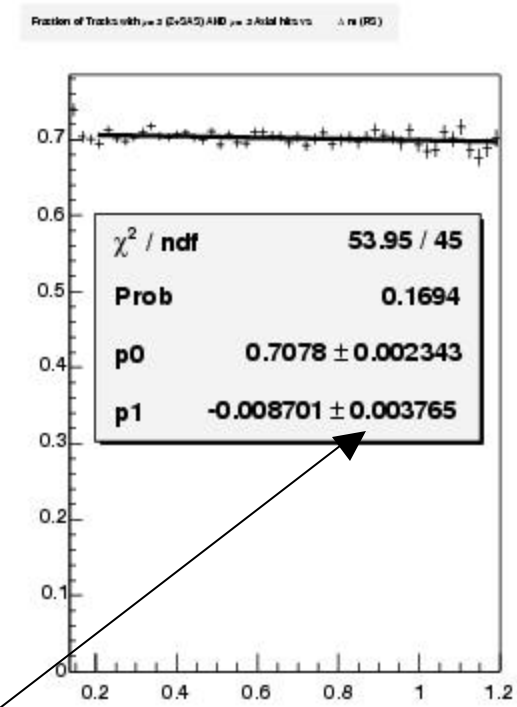
Efficiency corrections from MC

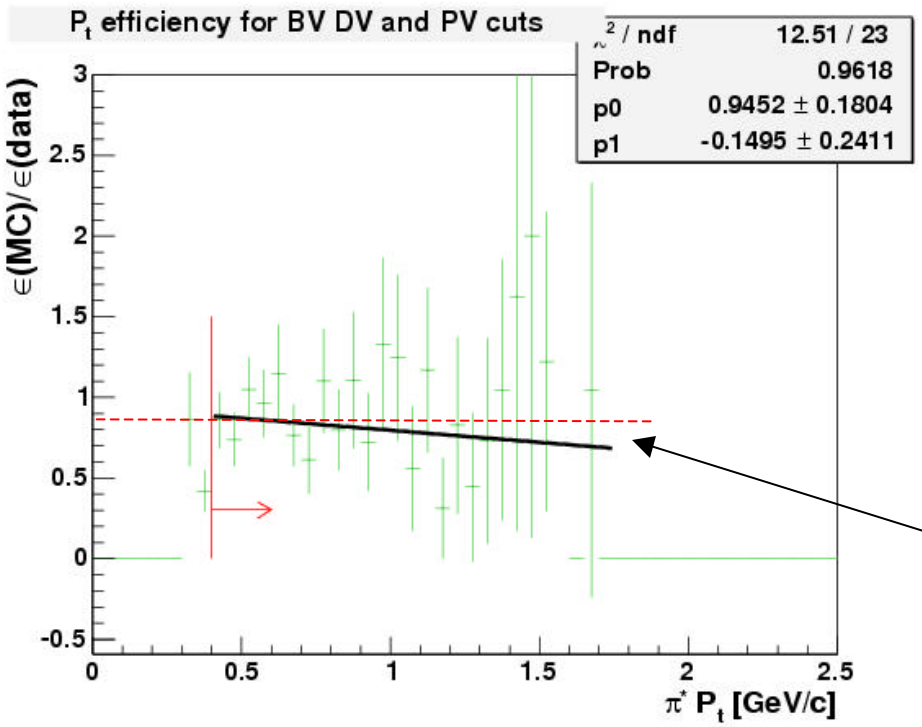
- Uncertainty comes from lack of knowledge on the D** BR and phase space structures…
- Two possible MC models:
  - BR weighted EvtGen admixture, to the best of today's knowledge
  - Plain phase space
  - Switch to evaluate systematics…



Efficiency Corrections from data

- Efficiencies measured on data have modeling uncertainties/stat. Errors
- Float parameters within ranges and compute the effect on the moments

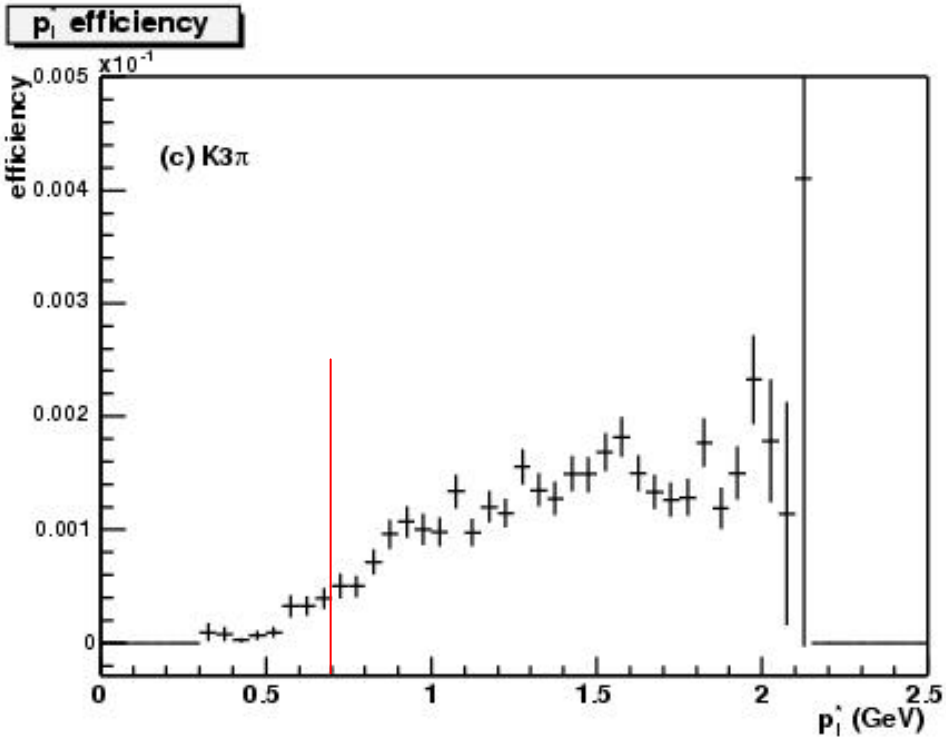




- Mass-dependent: use stat error on slope
- Pt-dependent: use $0^{th}/1^{st}$ order polynomial difference

Lepton momentum cut-off

- We are not “literally” cutting on Pl* (it is not accessible, experimentally)
- Detector implicitly cuts on it
- Assume a baseline cut-off
- Vary in a reasonable range to evaluate systematics



- We use f to derive f**, given f^0, f*
- $f=f(\Lambda,\lambda_1)$
- We use experimental prior knowledge on Λ,λ_1 to evaluate systematics
- Effect is negligible

Other Systematics

- D^+/D^{*+} relative scale:
  - PDG BR are varied by $\pm 1\sigma$
  - MC based efficiencies ±13%, according to studies in CDF6754 (D yields note)

- Physics background:

$$w = -\frac{e}{1+e} \times BR(D_s \to lX) \times \frac{BR(B \to D_s D^{(*)+})}{BR(B \to signal)} \times \frac{N_{D^{**}}}{N_{back}}$$

  – Branching ratios are poorly known (100% !!!)

- Relative $B \to D/D^*/D^{**}$ branching ratios
  - Take PDG values $\pm 1\sigma$

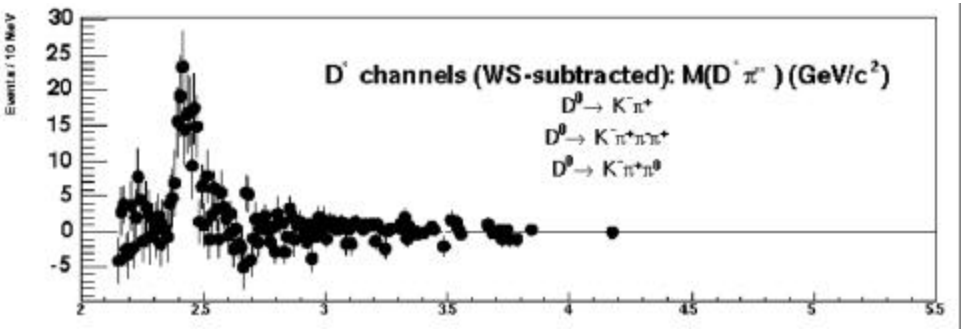
- Theory parameters (ρ_1, T_i, α_S, m_b, m_c) varied according to expectations (100%, 0.5GeV^3, 5%, 200MeV, 200 MeV)

Distribution Cut-off

- The sample has basically no statistical power above 3.5 GeV (EvtGen predicts ~1% signal above cut)
- We need to apply a cutoff in order not to compromise the statistical uncertainty
- Trade off:
  - Drop the statistical error, but increase the size of systematics
  - Becoming model dependent (we need a model for the extrapolation of the high tail in order to evaluate systematics)

Temporarily:

Evaluate moments with different cut-off (3.5-4.0)



Background Model

- We have 2 possible problems
  - Shape
    - Alternative model based on fully reconstructed B ("embedding" work in progress)
  - Scale
    - Based on the charge multiplicites from embedded B^+:
      - <20% discrepancy between RS and WS
      - ~20% of background comes from B^+

      ~4% uncertainty on WS/RS scale

	Data	$B^+ \to \psi K^+$	$B^+ \to D^0\pi^+$ $D^0 \to K\pi$	$B^+ \to D^0\pi^+$ $D^0 \to K3\pi$	$B^0 \to \psi K^*$	$B^0 \to D^+\pi^-$ $D^+ \to K\pi\pi$
N_{ch}^{RS}	–	0.98 ± 0.03	1.06 ± 0.03	0.83 ± 0.03	0.88 ± 0.04	0.71 ± 0.03
N_{ch}^{WS}	0.83 ± 0.02	0.77 ± 0.03	0.91 ± 0.03	0.85 ± 0.03	0.79 ± 0.04	0.74 ± 0.03

Table 4: Comparison of the right sign and wrong sign charged multiplicities for $B \to D^{*+}\ell\nu$ data and embedded Monte Carlo using the 5 fully reconstructed samples. For this table, tracks are required to have at least 3 axial and 3 stereo silicon hits and be in a cone $\Delta R = 1$ about the D meson. For the semileptonic data, only wrong sign combinations are shown since the right sign combinations are the D^{**} signal sample.

Radial Excitations

- $D' \rightarrow D^{(*)+}\pi\pi$ should be accounted for in m**
- Not yet observed
- DELPHI limits: $\begin{cases} BR(b \rightarrow D^{+}p^{+}p^{-}\ell^{-}n) < 0.18\% \text{ @ } 90\% \ CL \\ BR(b \rightarrow D^{*+}p^{+}p^{-}\ell^{-}n) < 0.17\% \text{ @ } 90\% \ CL \end{cases}$
- Embedding-WS comparison could give another limit
- For the time being we assume no D'

Systematics size

Error	Δm_1 (GeV^2)	Δm_2 (GeV^4)	ΔM_1 (GeV^2)	ΔM_2 (GeV^4)	$\Delta\Lambda$ (GeV)	$\Delta\lambda_1$ (GeV^2)
Statistical	0.15	0.49	0.035	0.20	0.066	0.046
Total systematic	0.08	0.46	0.063	0.15	0.092	0.088
Mass resolution	0.02	0.10	0.006	0.04	0.012	0.010
efficiency (data)	0.02	0.34	0.004	0.10	0.024	0.023
efficiency (MC)	0.03	0.29	0.007	0.05	0.005	0.011
p_l^* cut	—	—	0.001	0.00	0.001	0.000
Background scale	0.03	0.03	0.003	0.01	0.004	0.002
Physics background	0.01	0.03	0.003	0.02	0.008	0.006
D^+/D^{*+} BR	0.01	0.01	0.003	0.01	0.004	0.002
D^+/D^{*+} Eff.	0.02	0.01	0.005	0.02	0.008	0.004
$M(D^{**})$ cut	0.06	0.07	0.014	0.06	0.022	0.013
Semileptonic BR's	—	—	0.060	0.07	0.059	0.017
ρ_1	—	—	—	—	0.041	0.070
T_i	—	—	—	—	0.032	0.032
α_s	—	—	—	—	0.018	0.007
m_b, m_c	—	—	—	—	0.002	0.008
Choice of p_l^* cut	—	—	—	—	0.025	0.019

Results

$$m_1 = (5.73 \pm 0.15_{\text{stat}} \pm 0.08_{\text{syst}})\ \text{GeV}^2$$
$$m_2 = (0.85 \pm 0.49_{\text{stat}} \pm 0.46_{\text{syst}})\ \text{GeV}^4$$

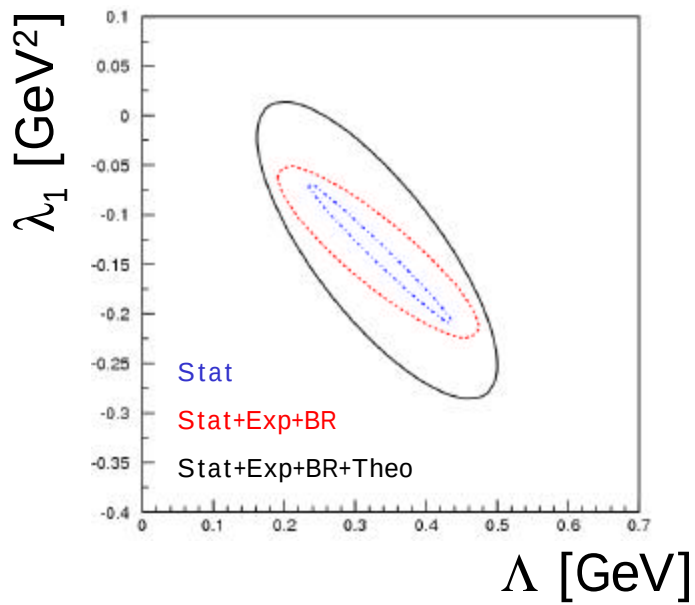
$$\Lambda = (0.337 \pm 0.066_{\text{stat}} \pm 0.037_{\text{exp}} \pm 0.059_{\text{BR}} \pm 0.060_{\text{theo}})\ \text{GeV}$$
$$\lambda_1 = (-0.141 \pm 0.046_{\text{stat}} \pm 0.035_{\text{exp}} \pm 0.017_{\text{BR}} \pm 0.080_{\text{theo}})\ \text{GeV}^2$$

or

or

$$M_1 = (0.437 \pm 0.035_{\text{stat}} \pm 0.018_{\text{exp}} \pm 0.060_{\text{BR}})\ \text{GeV}^2$$
$$M_2 = (0.86 \pm 0.20_{\text{stat}} \pm 0.15_{\text{exp}} \pm 0.07_{\text{BR}})\ \text{GeV}^4\ ,$$

$$m_b(1S) = (4.715 \pm 0.066_{\text{stat}} \pm 0.037_{\text{exp}} \pm 0.059_{\text{BR}} \pm 0.084_{\text{theo}})\ \text{GeV}$$
$$\lambda_1 = (-0.241 \pm 0.039_{\text{stat}} \pm 0.035_{\text{exp}} \pm 0.017_{\text{BR}} \pm 0.092_{\text{theo}})\ \text{GeV}^2$$



$\rho_{m1,m2}$=48%

$\rho_{M1,M2}$=62%

$\rho_{\Lambda,\lambda1}$=-77%

- All systematics in place except the background shape model (embedding)

Plan

- Embedding (background shape, D')
- Re-evaluate systematics on m** cutoff at 3.5 GeV
- Improve systematics on MC/data corrections (more π*)
- Bless in 2 weeks