Hadronic Moments in Semileptonic B decays

Preblessing

CDF 6754, 6972, 6973

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Contents

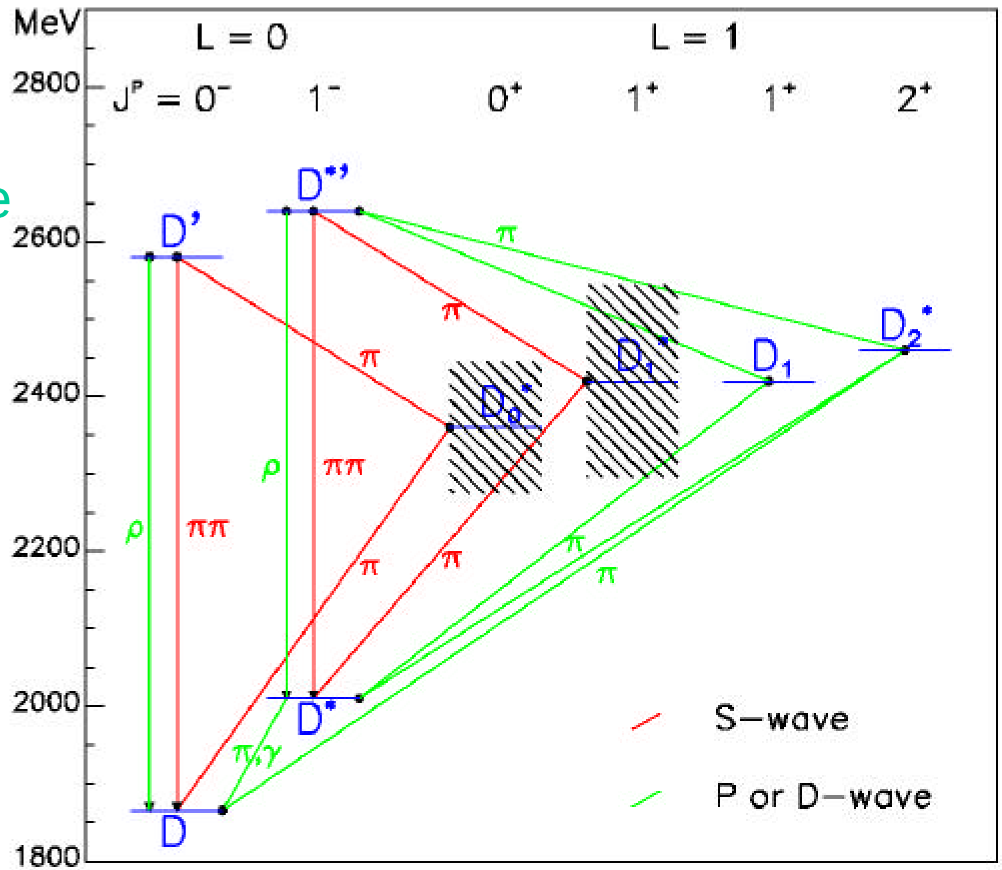
- What are these moments? Why are they interesting?
- Analysis strategy
  - Selection of $l\nu D^*/l\nu D^+$ samples
  - Montecarlo validation
  - π^{**} selection & optimization
  - Raw mass distributions
  - Background modeling
  - Background Subtraction
  - Acceptance corrections
  - Final fit to 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: $g(\Lambda, \lambda_1, \lambda_{2,\ldots})$
  - 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 $s_H = m_X^2 - m^2_{Dspin}$

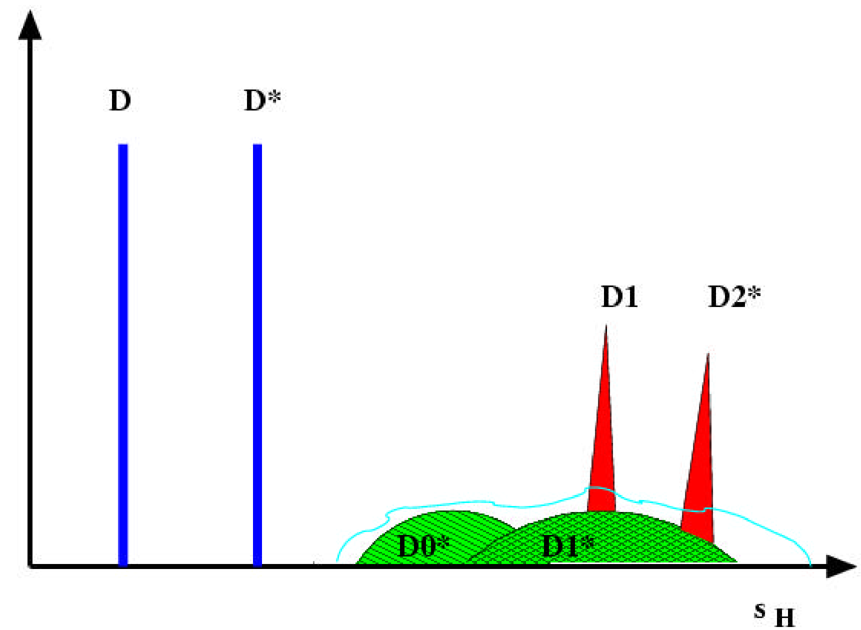
($m_{Dspin} = 0.25 m_D + 0.75 m_{D^*}$ spin averaged mass)

Hadronic Mass

- Hadronic mass spectrum:

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

  - 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 neutral B

- $\underline{B}^0 \rightarrow D^{**+}\ l^-\ \underline{\nu}$
  - $D^{**+} \rightarrow D^0\ \pi^+$ OK
  - $D^{**+} \rightarrow D^+\ \pi^0$ Not reconstructed. Half the rate of $D^+\ \pi^-$
  - $D^{**+} \rightarrow D^{*0}\ \pi^+$
    - $D^{*0} \rightarrow D^0\ \pi^0$ Not reconstructed. Background to $D^0\ \pi^+$
    - $D^{*0} \rightarrow D^0\ \gamma$ Not reconstructed. Background to $D^0\ \pi^+$
  - $D^{**+} \rightarrow D^{*+}\ \pi^0$ Not reconstructed. Half the rate of $D^{*+}\ \pi^-$

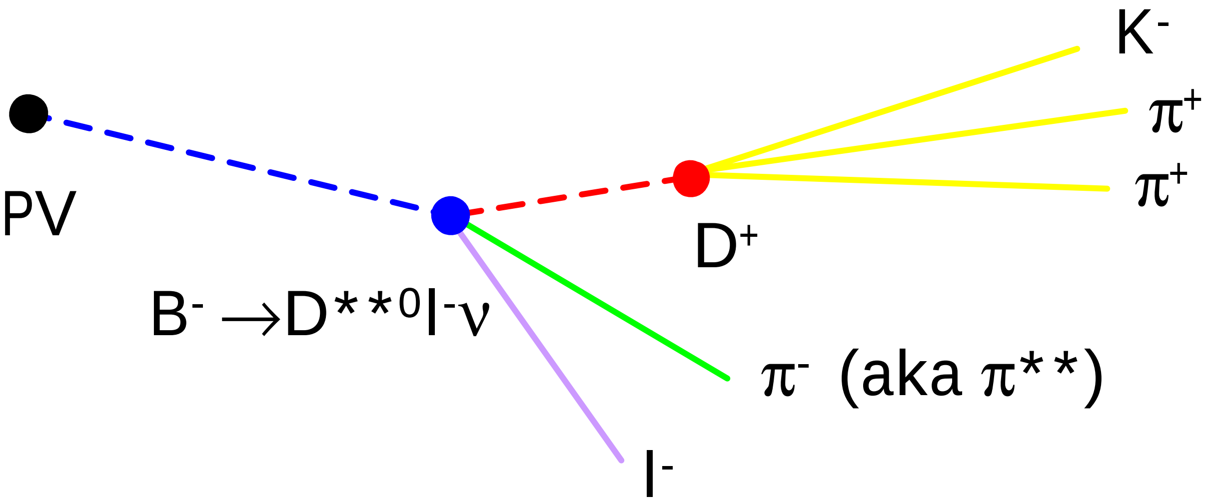
➡ For the time being let's forget about the neutral B.

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 do well the charged B.

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

Reconstruct D^*/D^+

- 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

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

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

Correct for $\varepsilon(m_{**})$, $\varepsilon(D^+)/\varepsilon(D^*)$

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

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

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

Reconstruct D*/D+

$D^{(*)+}$ Reconstruction

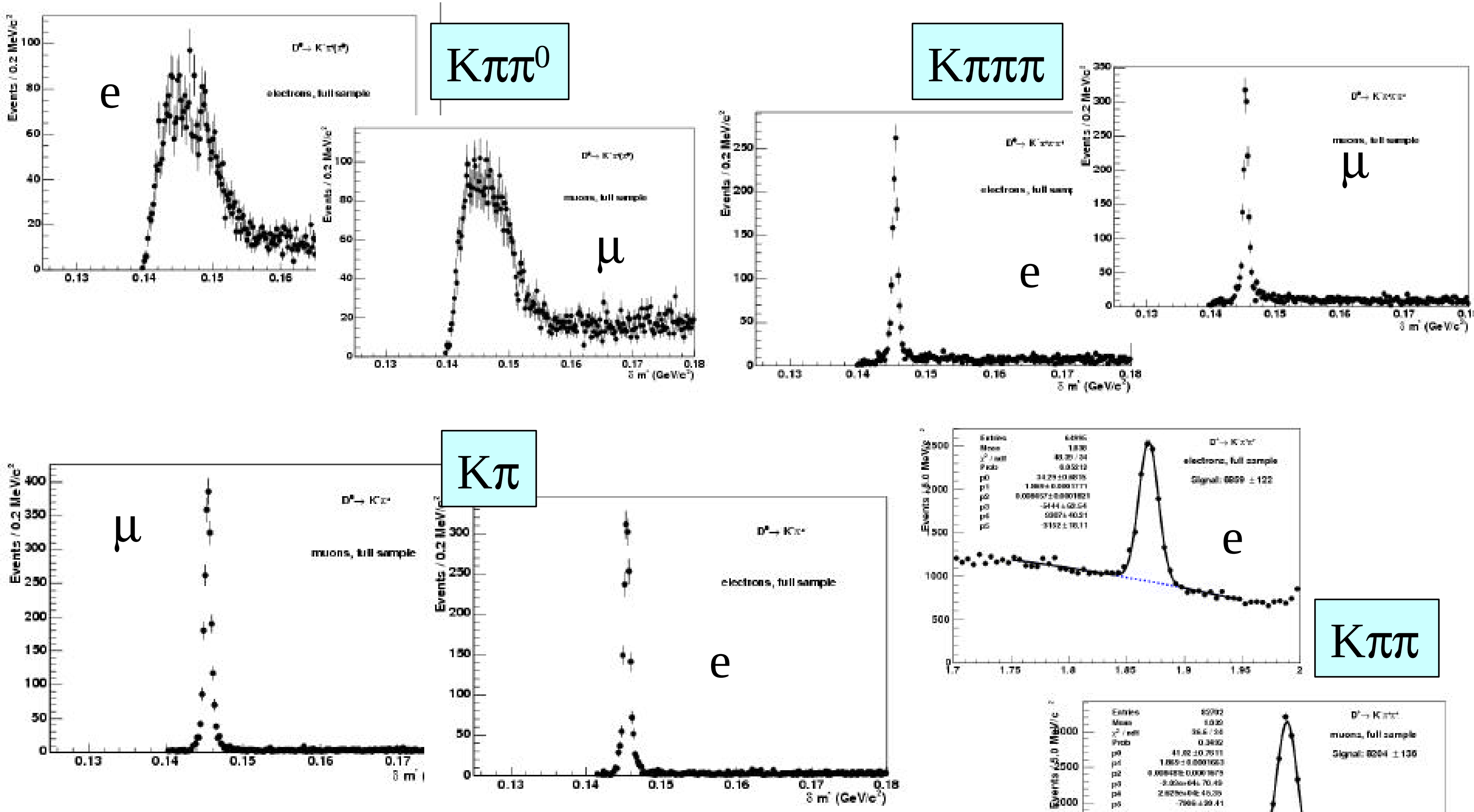
Dataset & Initial Selection

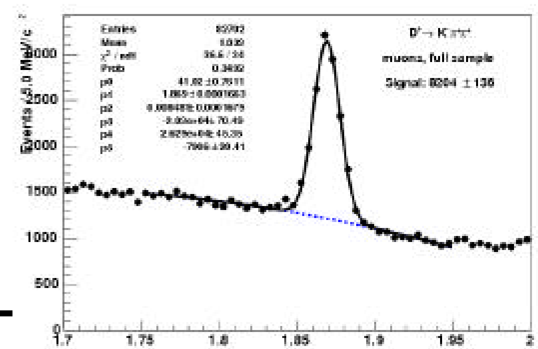
- Dataset:
  - Jbot2h/0i: muon + SVT
  - Jbot8h/4i: electron + SVT

  Thru run 165297
- Refit:
  - KAL (fixed), 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





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

MC samples and validation

Montecarlo Generation

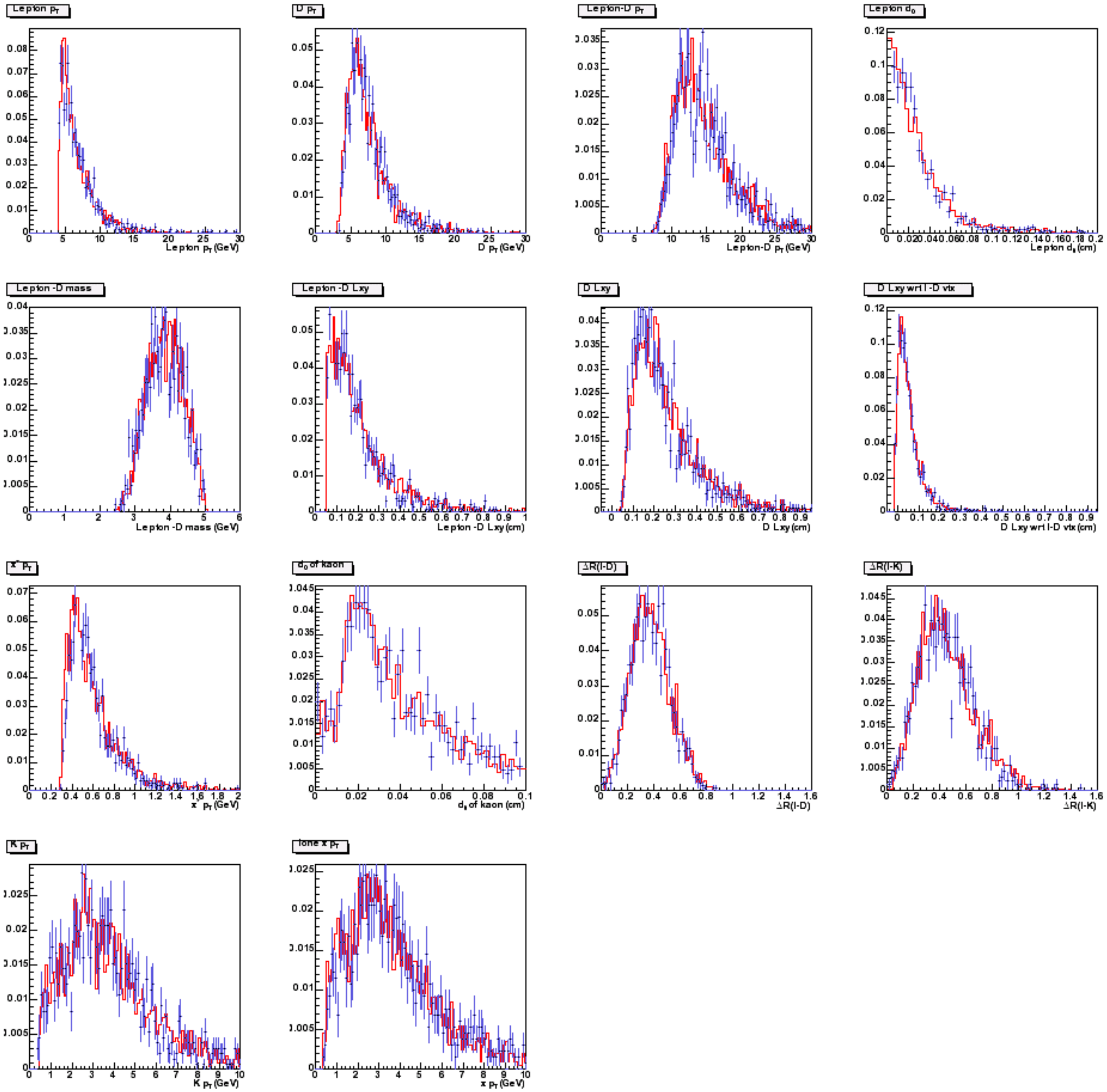
- Bgenerator/EvtGen/CdfSim/TRGSim++
- "realistic simulation"
- Different samples:
  - MC Validation
    - D samples $\rightarrow$ inclusive $B \rightarrow X_c l \nu$
    - π^* tracking (π^{**} proxy) $\rightarrow$ exclusive $B \rightarrow D^* l \nu$
  - Optimization $\rightarrow$ inclusive $B \rightarrow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

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

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: lD*, $D^0 \to K\pi$



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

Matching - c^2 **prob (%)**	Kπ		Kπ(π^0)		Kπππ		Kππ	
	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” yields?

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

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

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

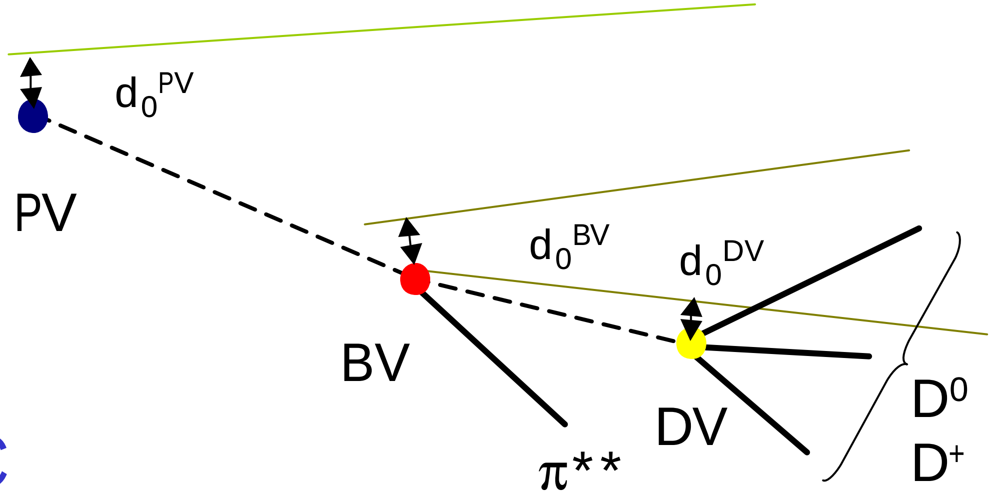
Add another

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

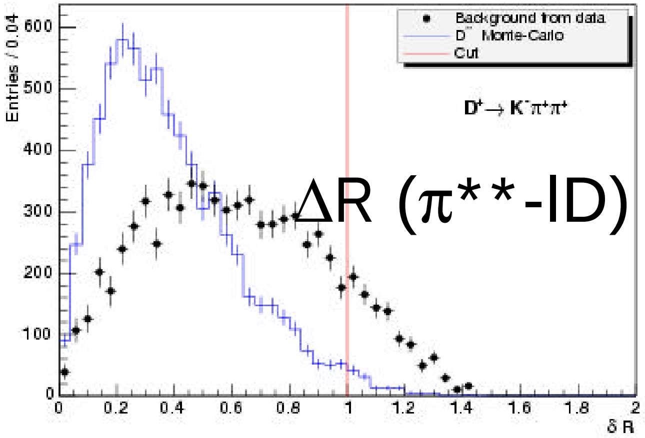
D^{**}

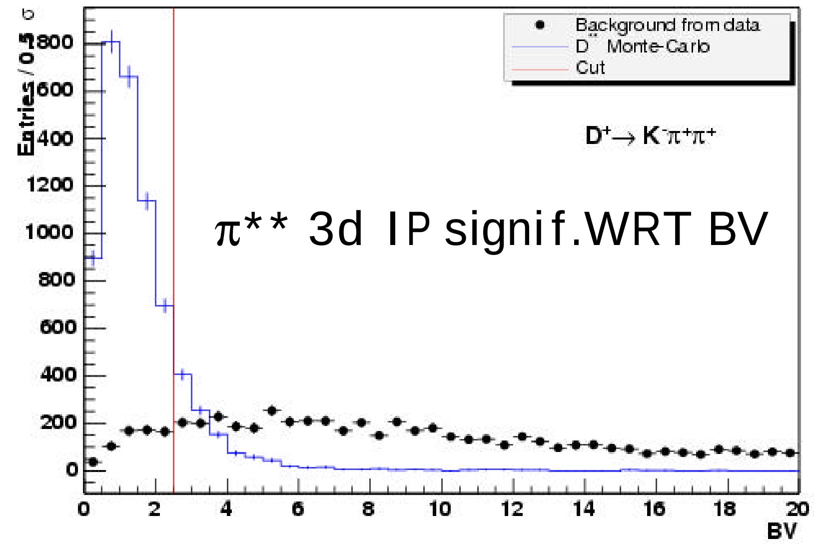
Optimization

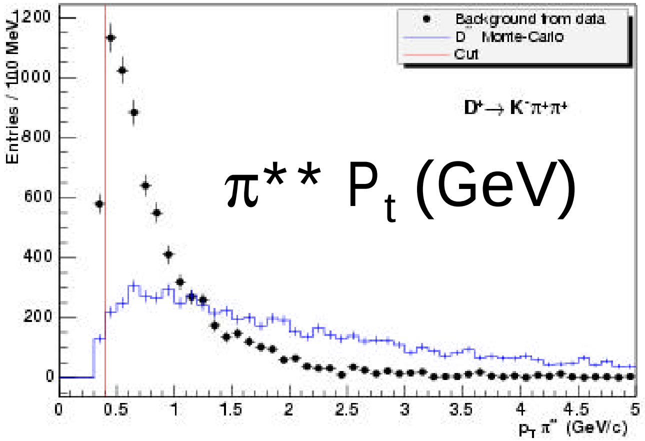
- The relevant discriminants are:
  - P_t
  - ΔR
  - d_0^{PV}
  - d_0^{BV}
  - d_0^{DV}
  - $L_{xy}^{B\to D}$
- Signal model: MC
- Background model:
  - WS π^{**}-l charge
- Optimize significance

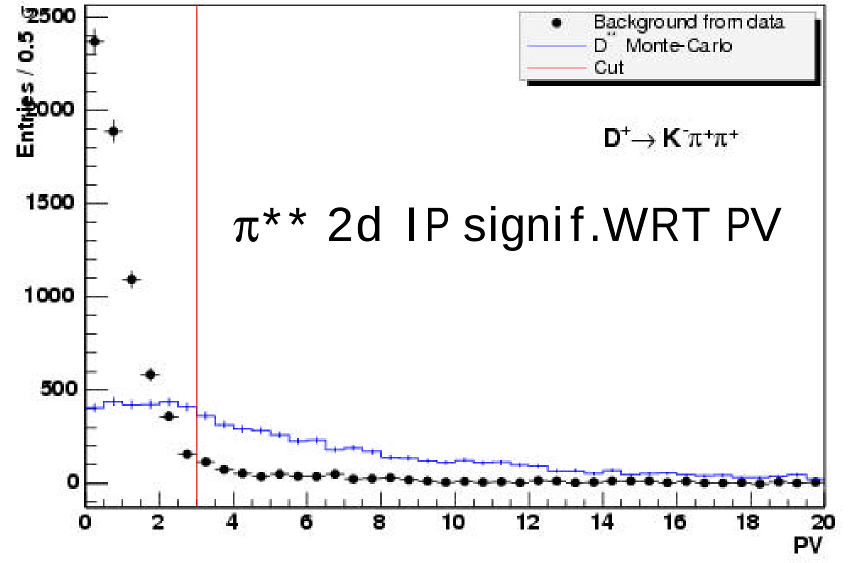


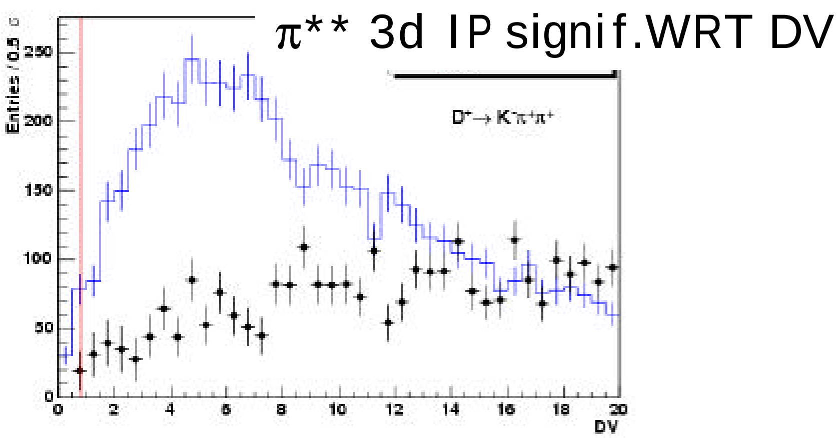
Discriminating Variables











Signal model for optimization

- Generate D** montecarlo (the shape)
- Use D from data to set the scale:
  - Measure the number of reconstructed D* (or D^+) on data and MC
  - Rescale for the fraction of $D^{**} \rightarrow D^{(*)+}$

    (PDG + EvtGen)
- This gives an absolute yield! ⇨ Optimize!

Optimization!

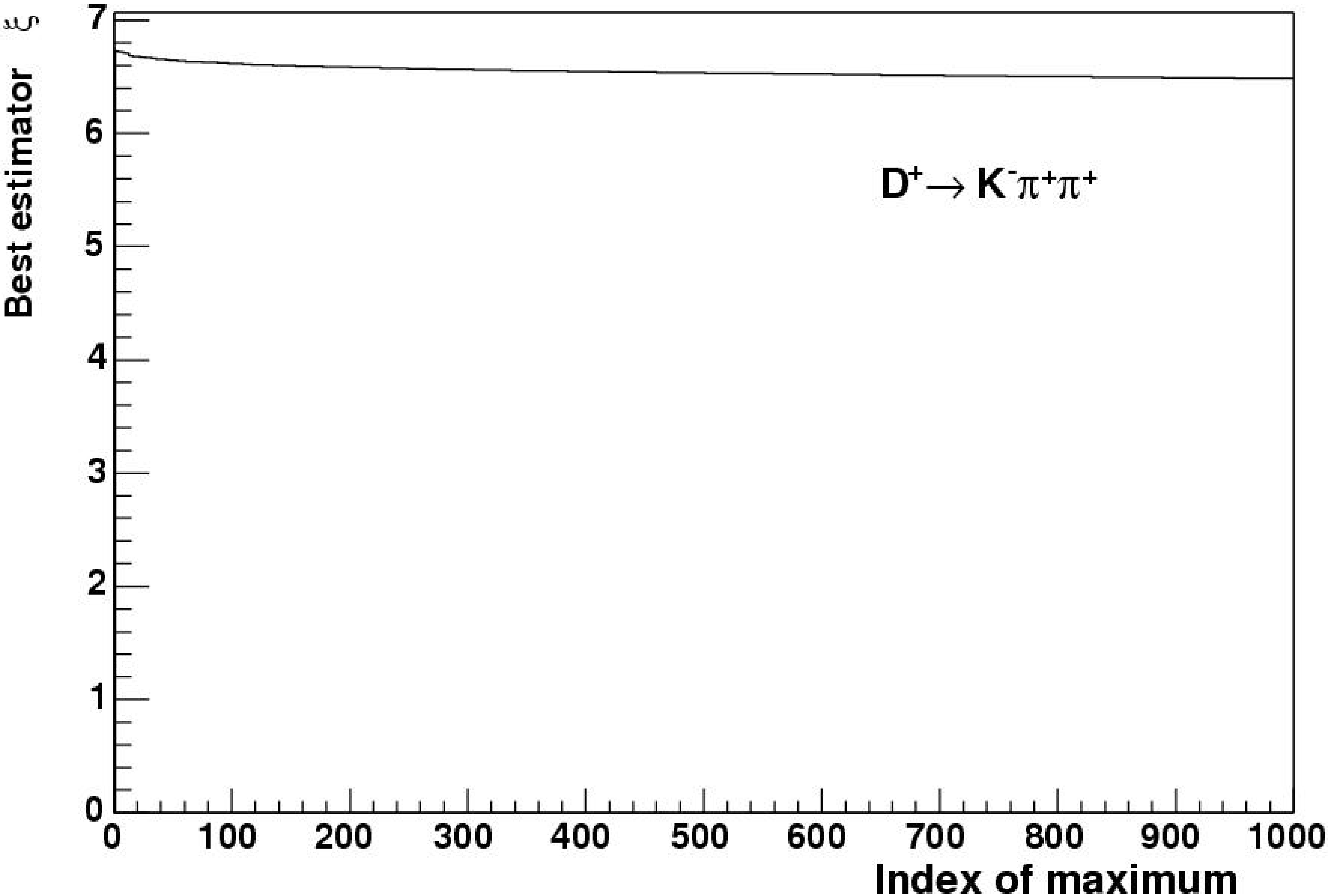
Now we can turn the crank and optimize…

But what?

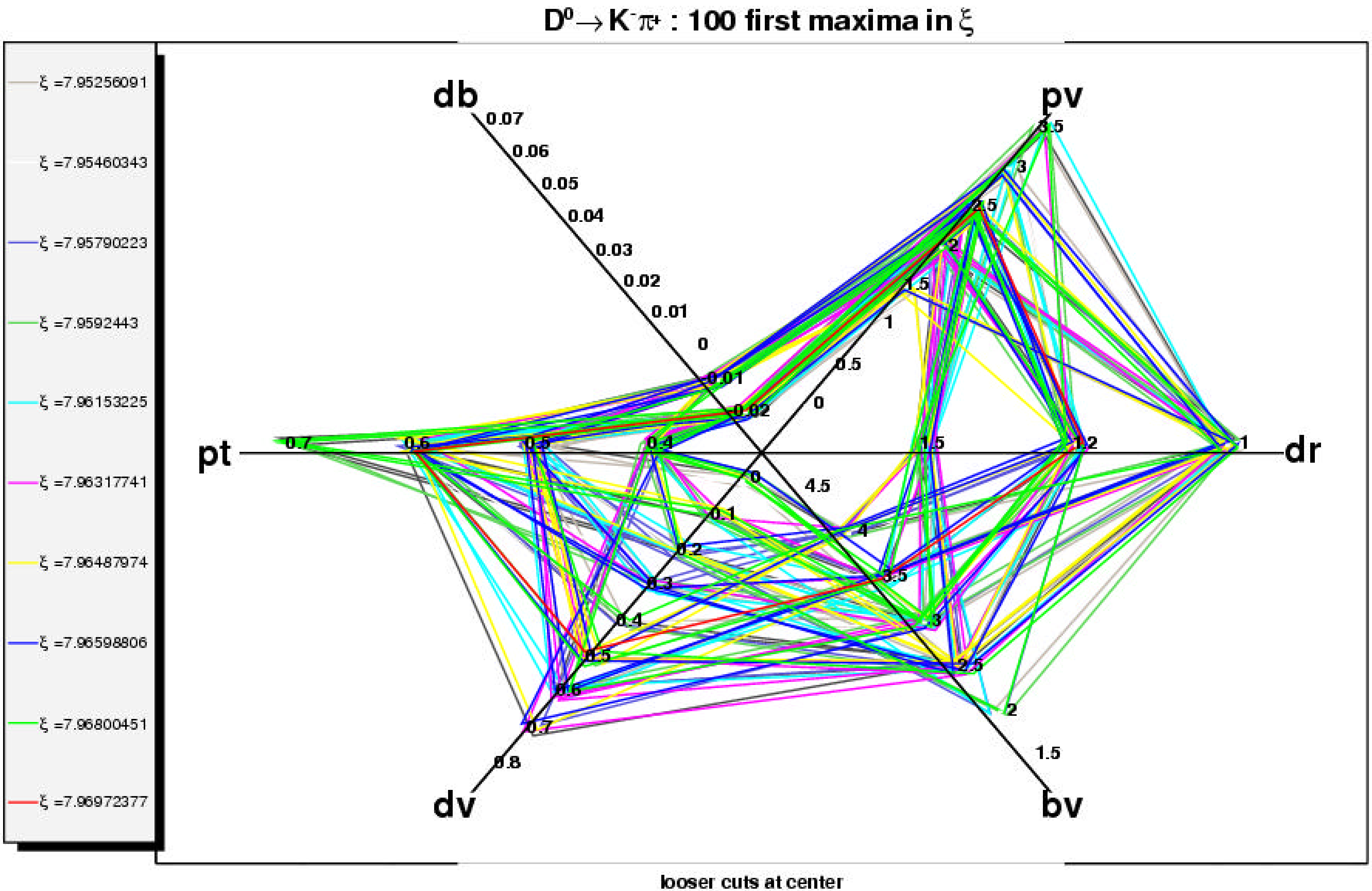
$$\frac{S}{s_{bin}} \approx \frac{S}{\sqrt{S + 2*S_{WS} + a^2*(SB_{RS} + SB_{WS}) + a*(SB_{RS} - SB_{WS})}}$$

- 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

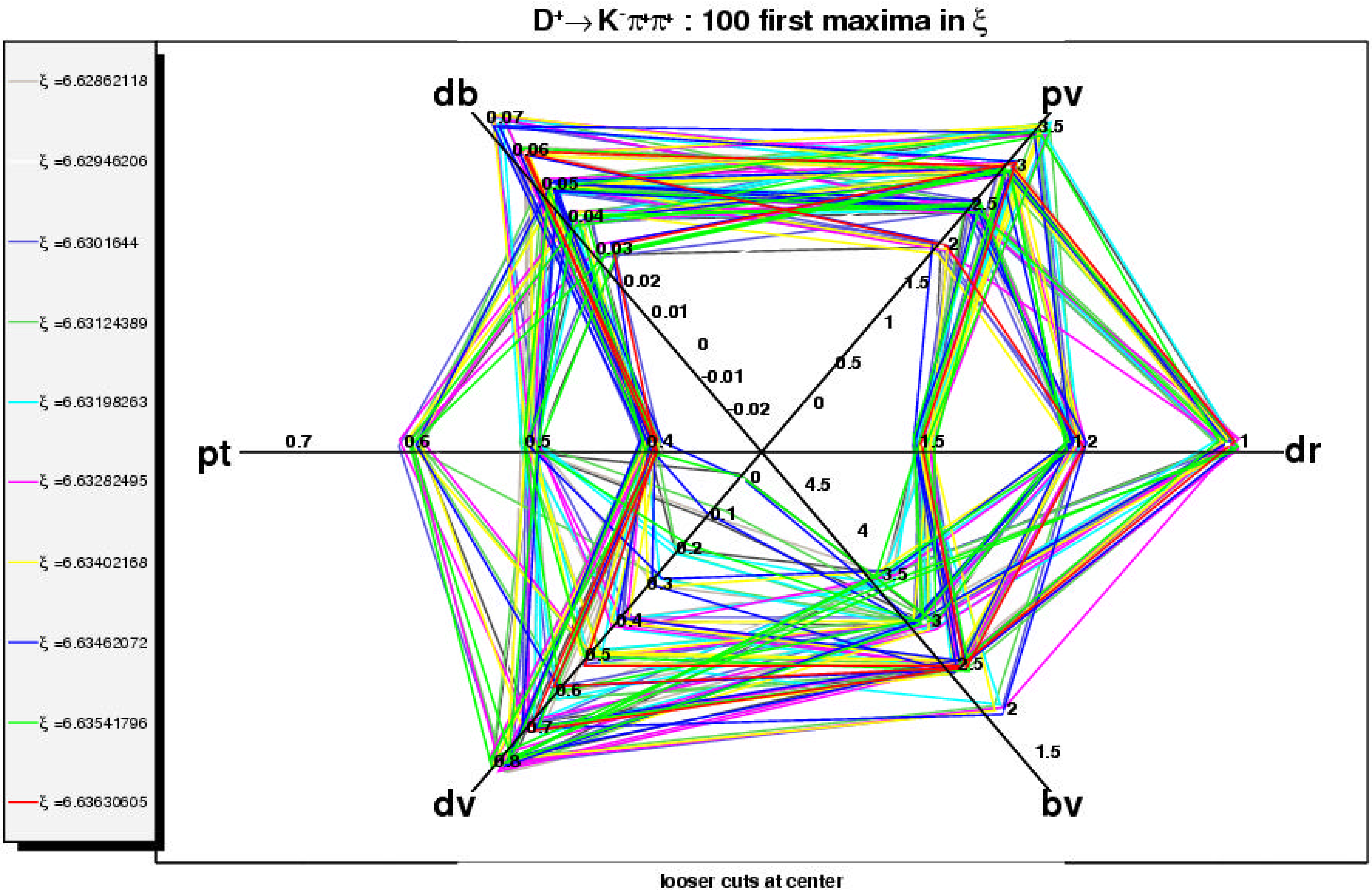
Estimator Behaviour



Kπ Optimization



D^+ Optimization



Optimal point:

D^+

- D^*
  - •$P_t(\pi^{**}) > 0.4$ GeV
  - •$\Delta R < 1.0$
    - $|d_0^{PV}/\sigma| > 2.5$
    - $|d_0^{BV}/\sigma| < 3.0$
  - •$S/\mathrm{sqrt}(\ldots) \approx 8$
- • $|d_0^{DV}/\sigma| > 0.8$
  - $L_{xy}(B \rightarrow D) > 0.05$ cm
- •$S/\mathrm{sqrt}(\ldots) \approx 6.6$

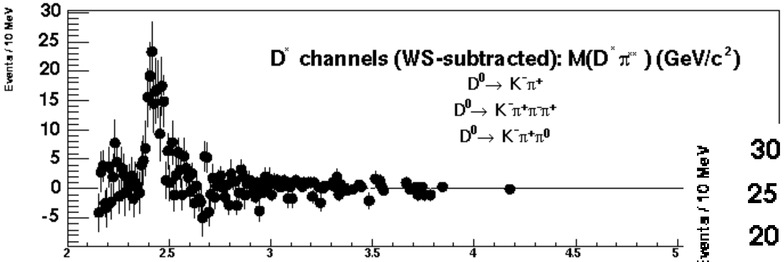
•We have to live with different selections for $D^{**} \rightarrow D^+$ and $D^{**} \rightarrow D^*(\rightarrow K\pi)$

Measure

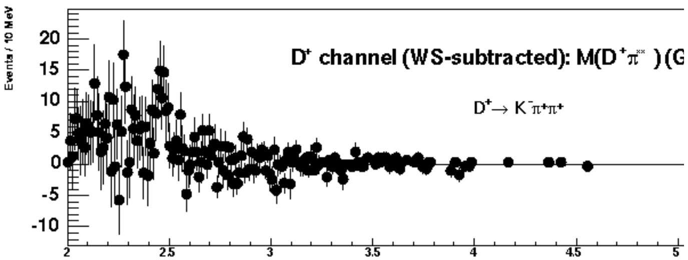
$\langle m_{**}^2 \rangle$, $\langle m_{**}^4 \rangle$

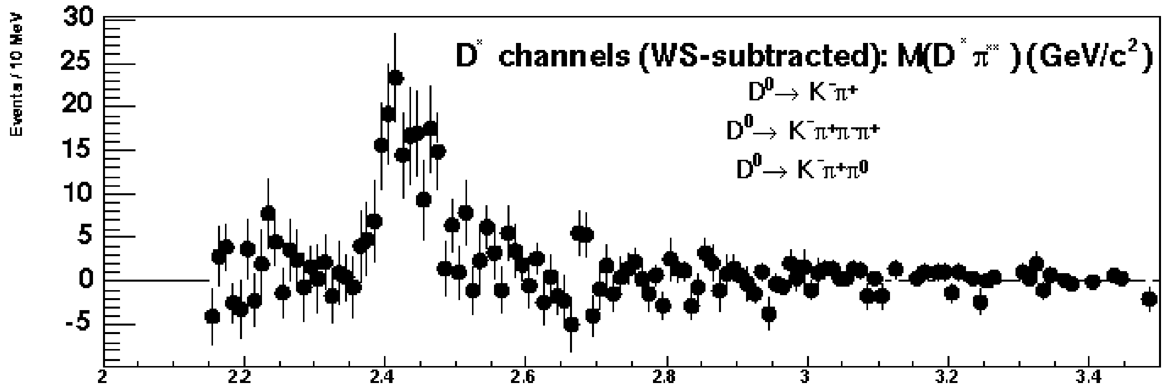
m^{**}

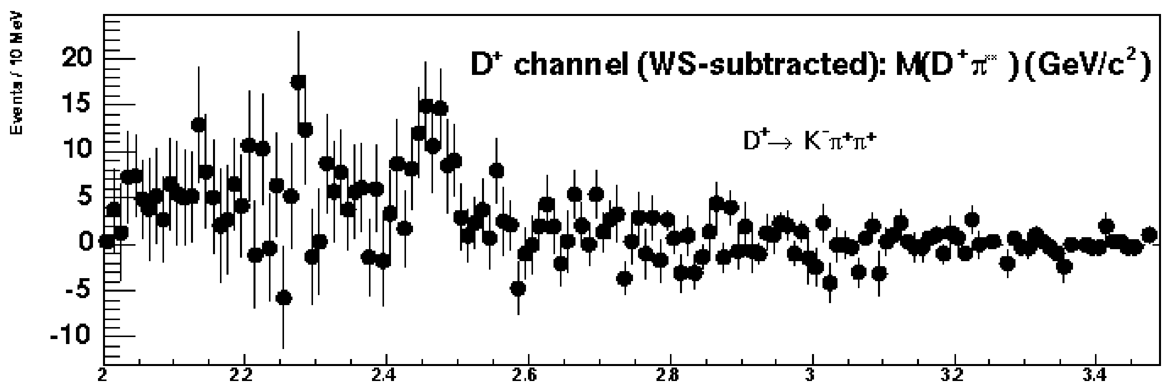
Current Mass Distributions



Full statistics







	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 ($K\pi$)

~80 (D^+)

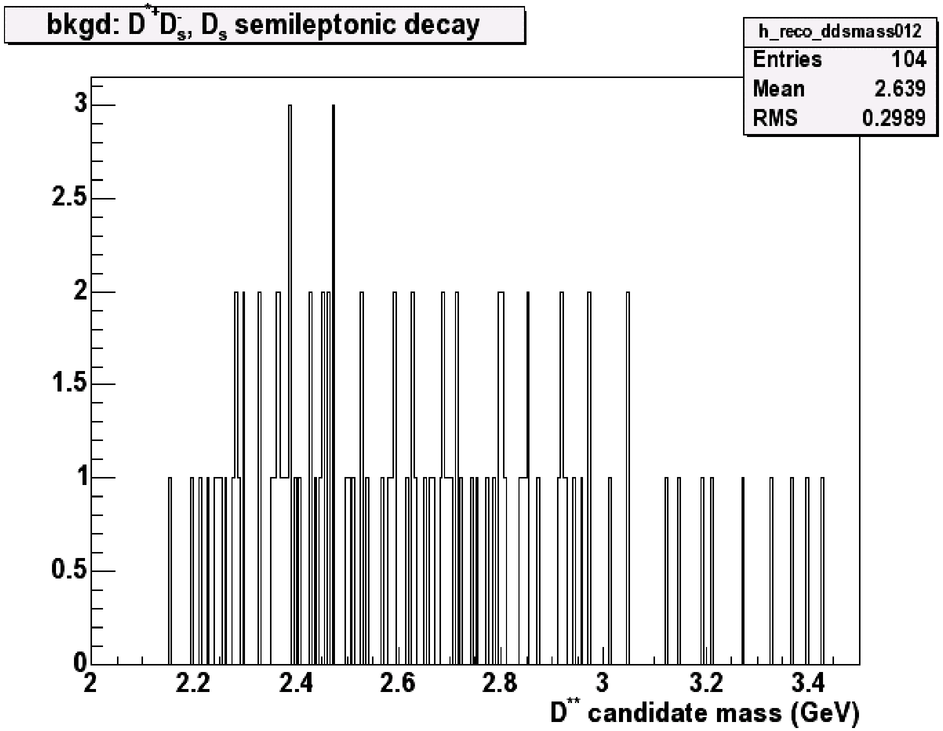
Background

Backgrounds

- Background from B decays:
  - Know how to model
  - Study using Bgenerator/EvtGen/TRGSim++/CdfSim
- 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 mostly from $B \rightarrow D^{(*)+} D_s^-$

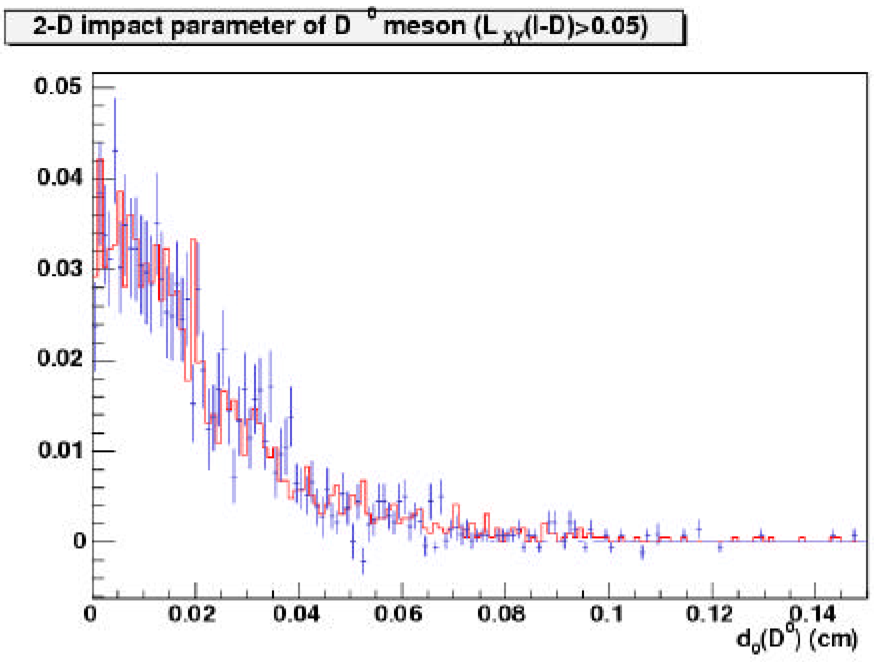


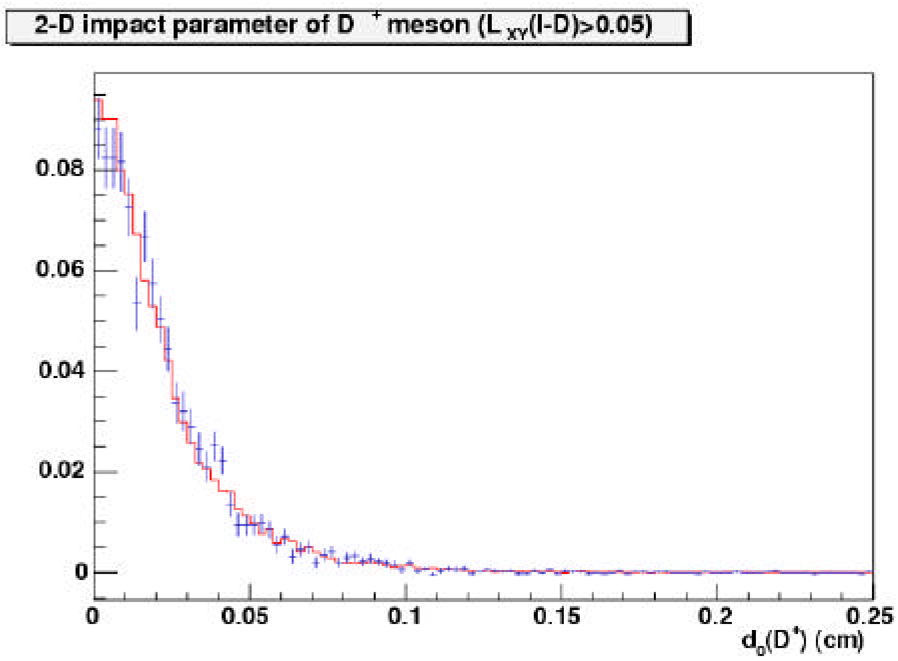
Background: Feed Down

- Irreducible $D^{**0} \to D^{*+}(\to D^{+}\pi^{0})\pi^{-}$ background to $D^{**0} \to D^{+}\pi^{-}$ subtracted statistically:
  - M shape of $D^{+}\pi^{-}$ combination above is like $D^{0}\pi^{-}$ from $D^{**0} \to D^{*+}(\to D^{0}\pi^{+})\pi^{-}$
  - 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

Pollution from ccbar?

- Rem: we are cutting hard on $L_{xy}(B)$ (500μm), this is known to “solve” the lifetime problem (see Satoru’s talk)
- Look at D^+/D^0 impact parameter for evidence of prompt objects:





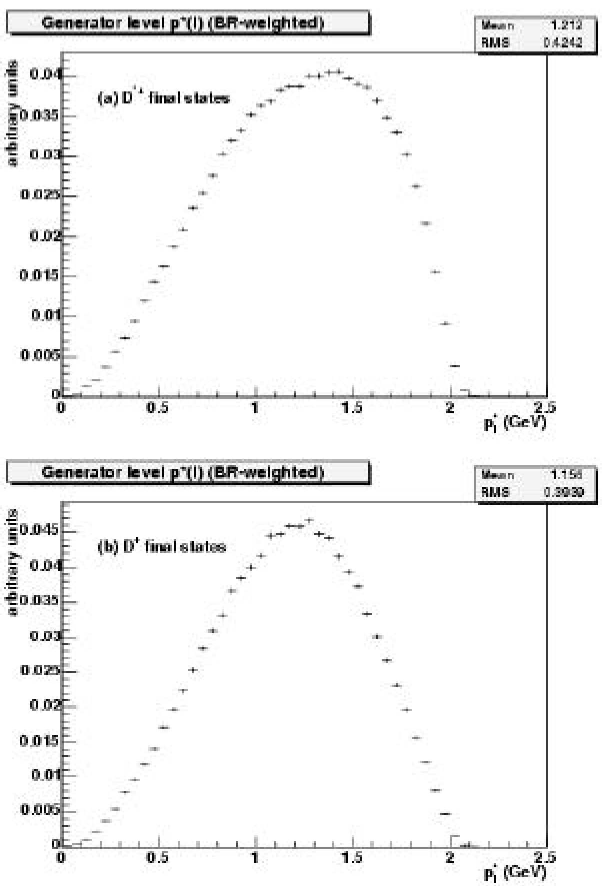
Measure

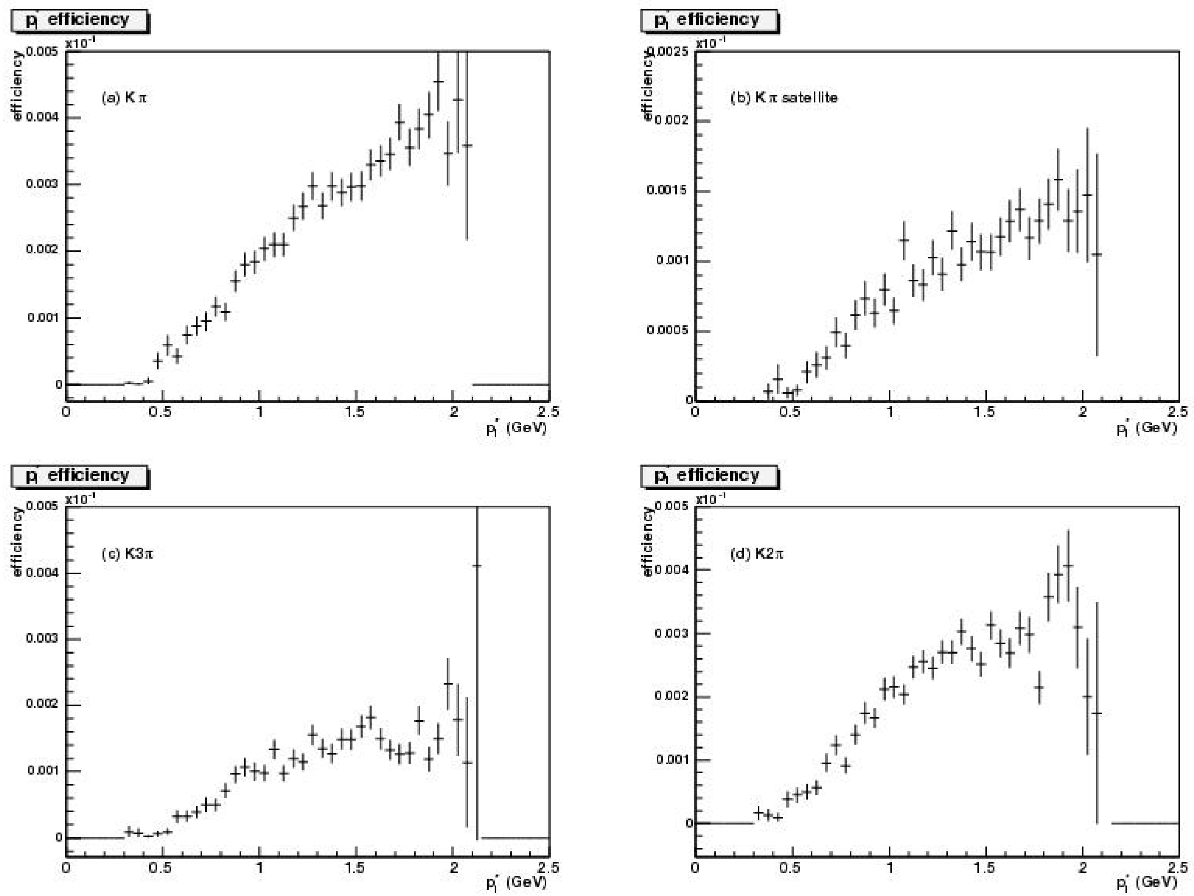
$\langle m_{**}^2 \rangle$, $\langle m_{**}^4 \rangle$

Efficiency Corrections

P_l*

- Theory prediction depends on P_l* biases. We cannot do much but:
  - see how our analysis bias looks like
  - Use a threshold-like correction
  - Evaluate systematics for different threshold values

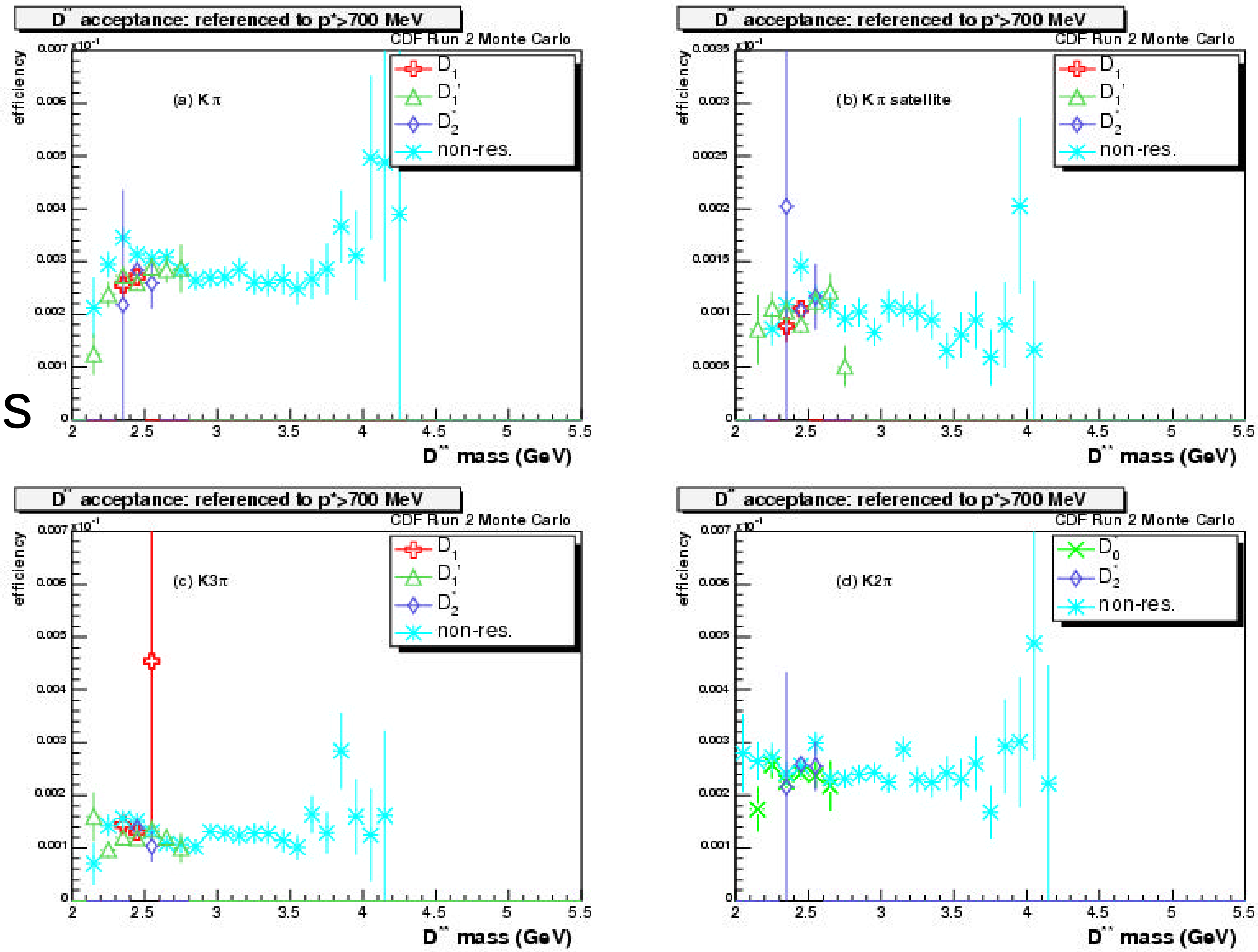




MC efficiencies

	resonant D^{**}				non-resonant D^{**}	
	D_0^*	D_1	D_1'	D_2^*	Goity-Roberts	phase-space
$K\pi$	-	4.50	4.50	4.50	13.50	26.85
$K\pi$ satellite	-	4.50	4.50	4.50	8.85	27.00
$K3\pi$	-	4.50	4.35	4.50	9.00	27.00
$K2\pi$	4.50	-	-	4.50	9.00	28.00

- $\varepsilon(M)$ is dependent on:
  - Model
  - P_l* cut
- Use different models/cuts to evaluate systematics



MC Validation

- π^* is an unique probe:
  - Large statistics
  - Low background
  - "Similar" spectrum to π^{**}
  - Can reconstruct with minimal cuts (e.g. COT only)
- Technique:
  - Search for π^* with very loose cuts
  - Do not include in B vertex
  - Study biases to kinematics from tracking
  - Study IP resolution(data/MC): Primary, B & D vertices
  - Study ε(data/MC) vs selection criteria

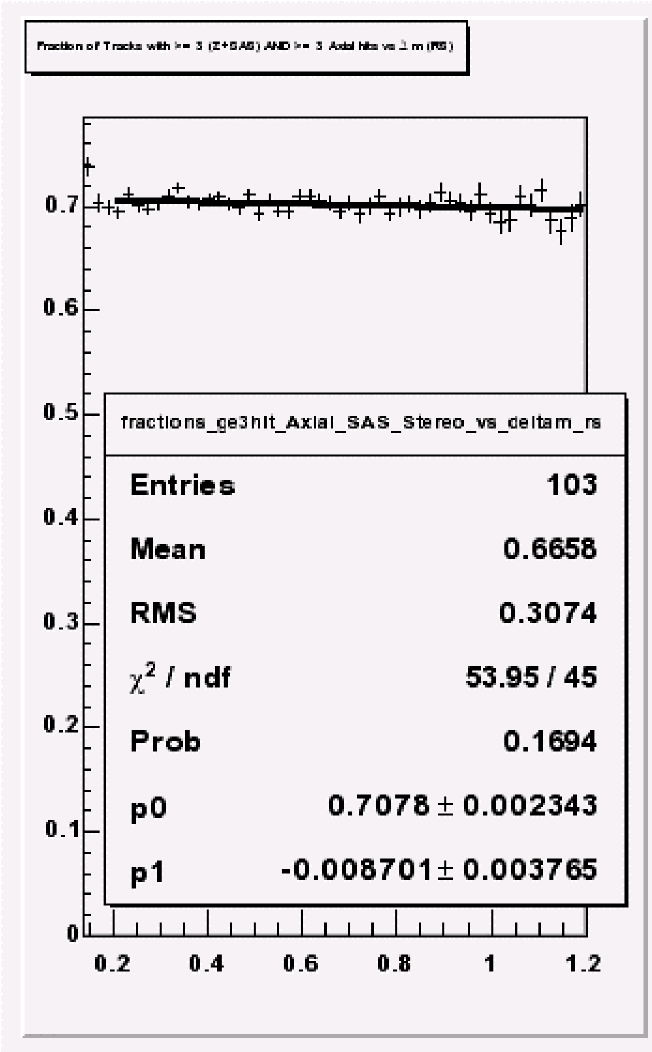
MC validation

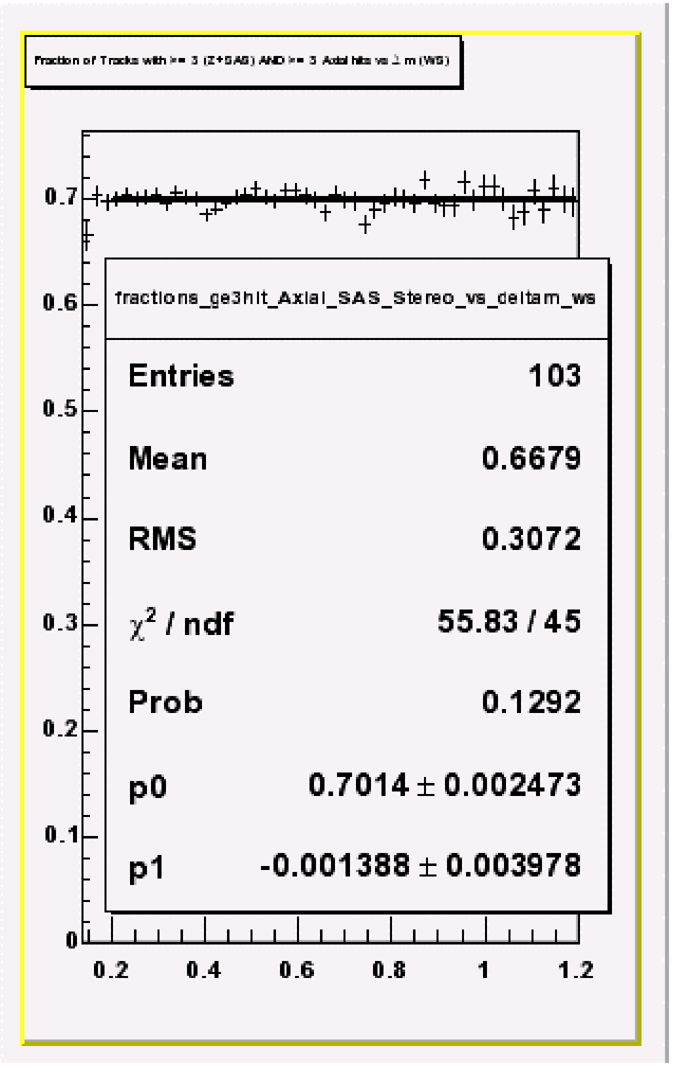
- Cross-check kinematic variables
  - B spectrum modeling
  - Trigger emulation
- Validate CdfSim model of tracking resolution
  - Relative efficiencies
  - π^{**} selection/bias

- Compare many data/MC distributions using binned χ^2
  - Every possible decay mode
  - Sideband subtracted before comparison
  - Duplicate removal ($D^0 \rightarrow K\pi\pi\pi$)

π^* probes tracking bias

- $D^{0/+}$ reco is based on trigger tracks
- Si requirements can bias $\Delta\phi(D^0\pi^{**})$
- $\Delta\phi(D^0\pi) \leftrightarrow \Delta m^{**}$

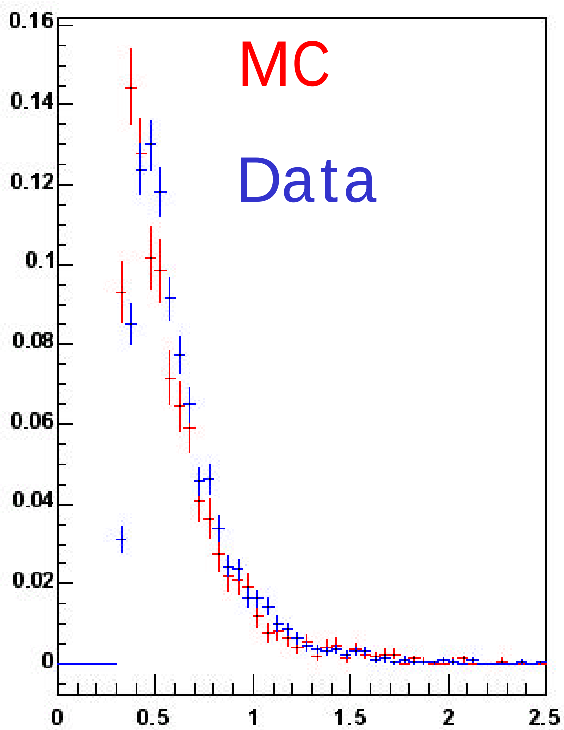




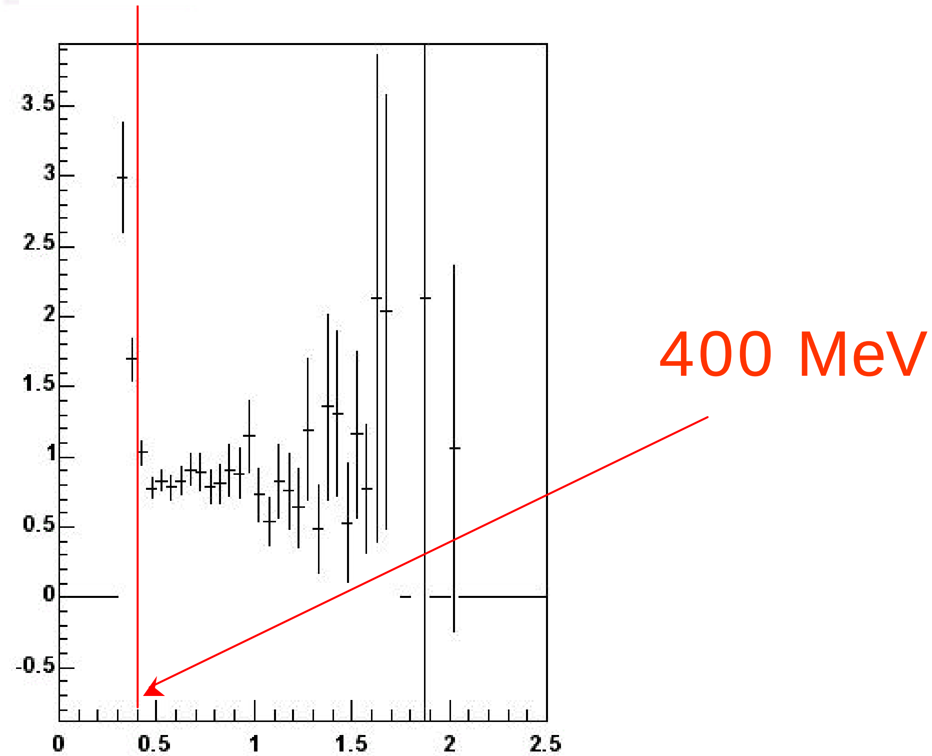
Kinematics

- Can we rely on kinematical biases estimated from MC?
- Rem: we don’t care about absolute scales
- Pt dependent MC/data ratio:

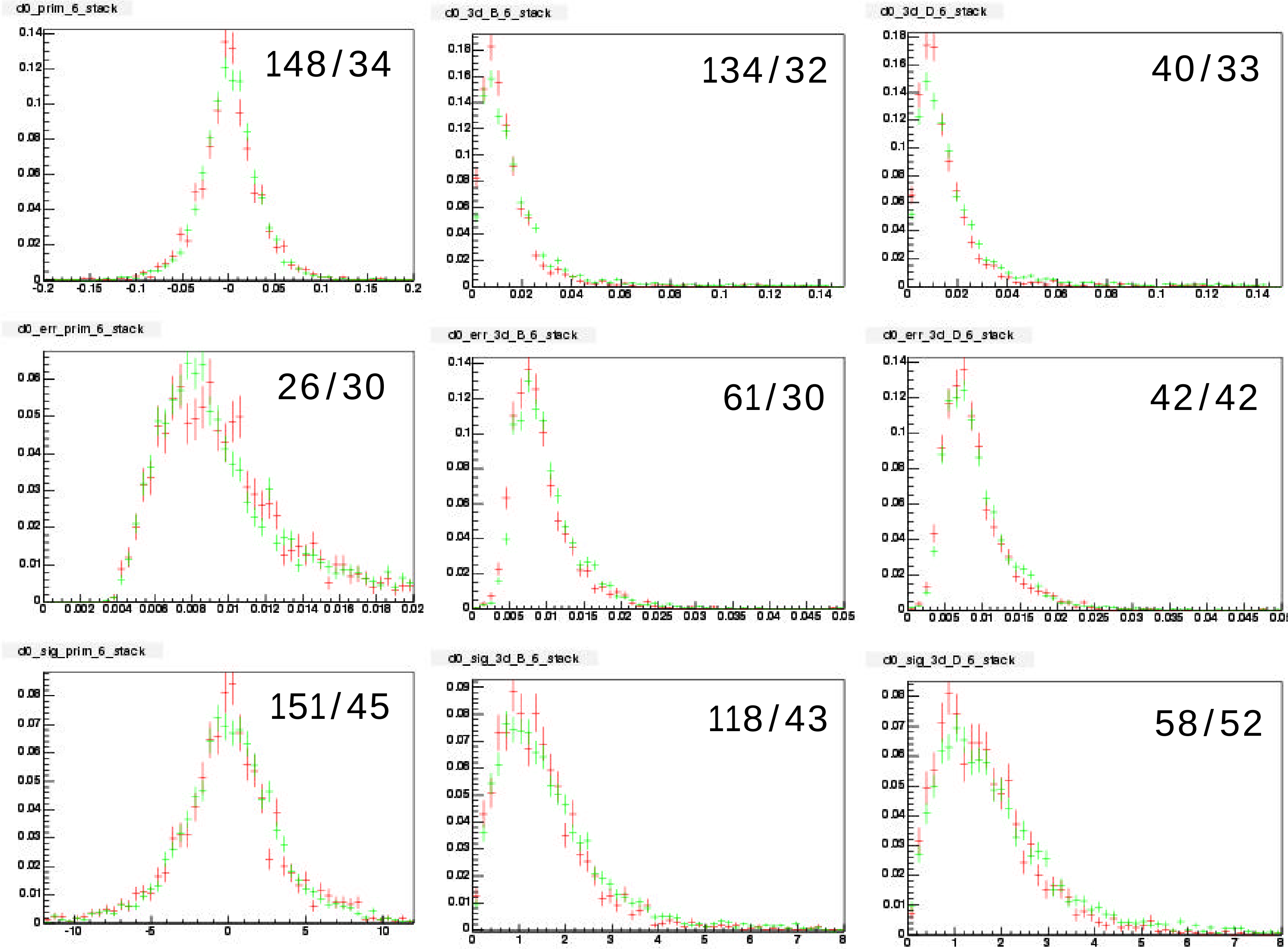
π* Pt



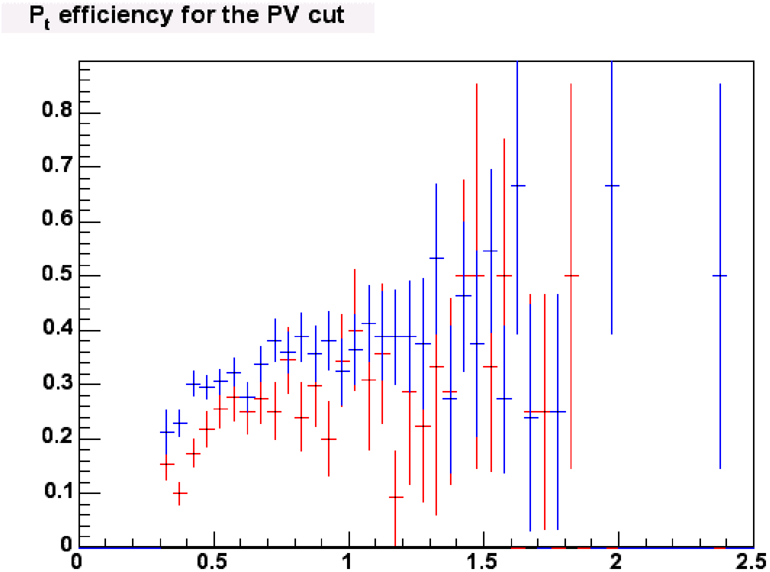
MC/Data vs Pt

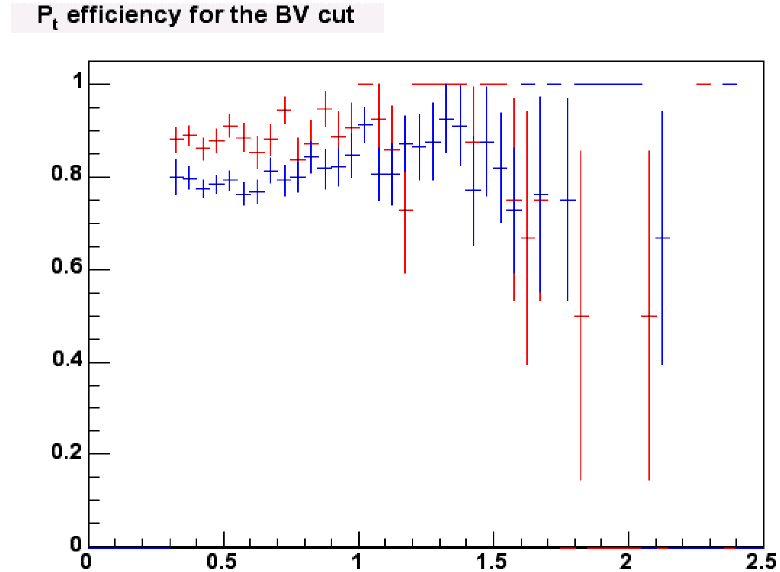


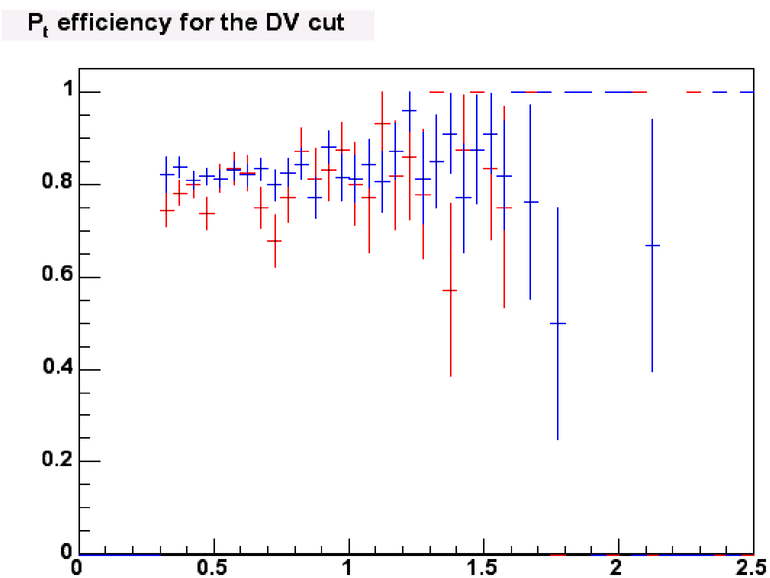
Impact Parameters

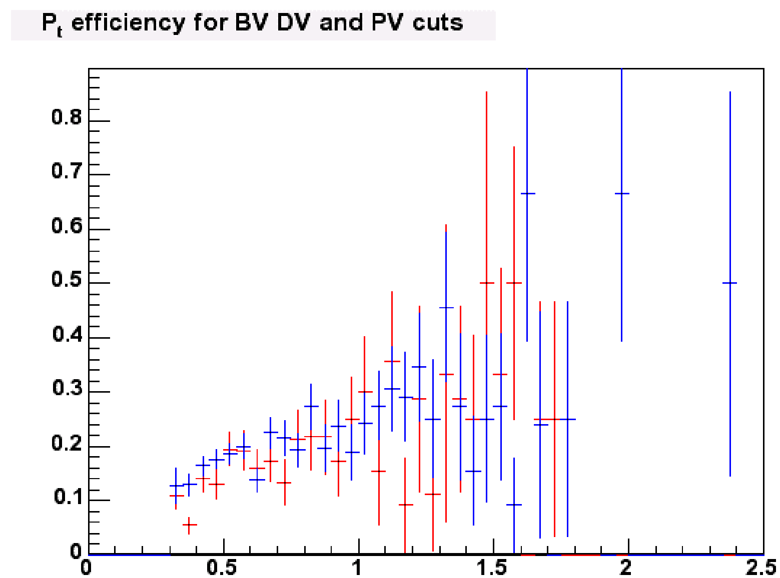


ε(MC), ε(data) vs selection criteria



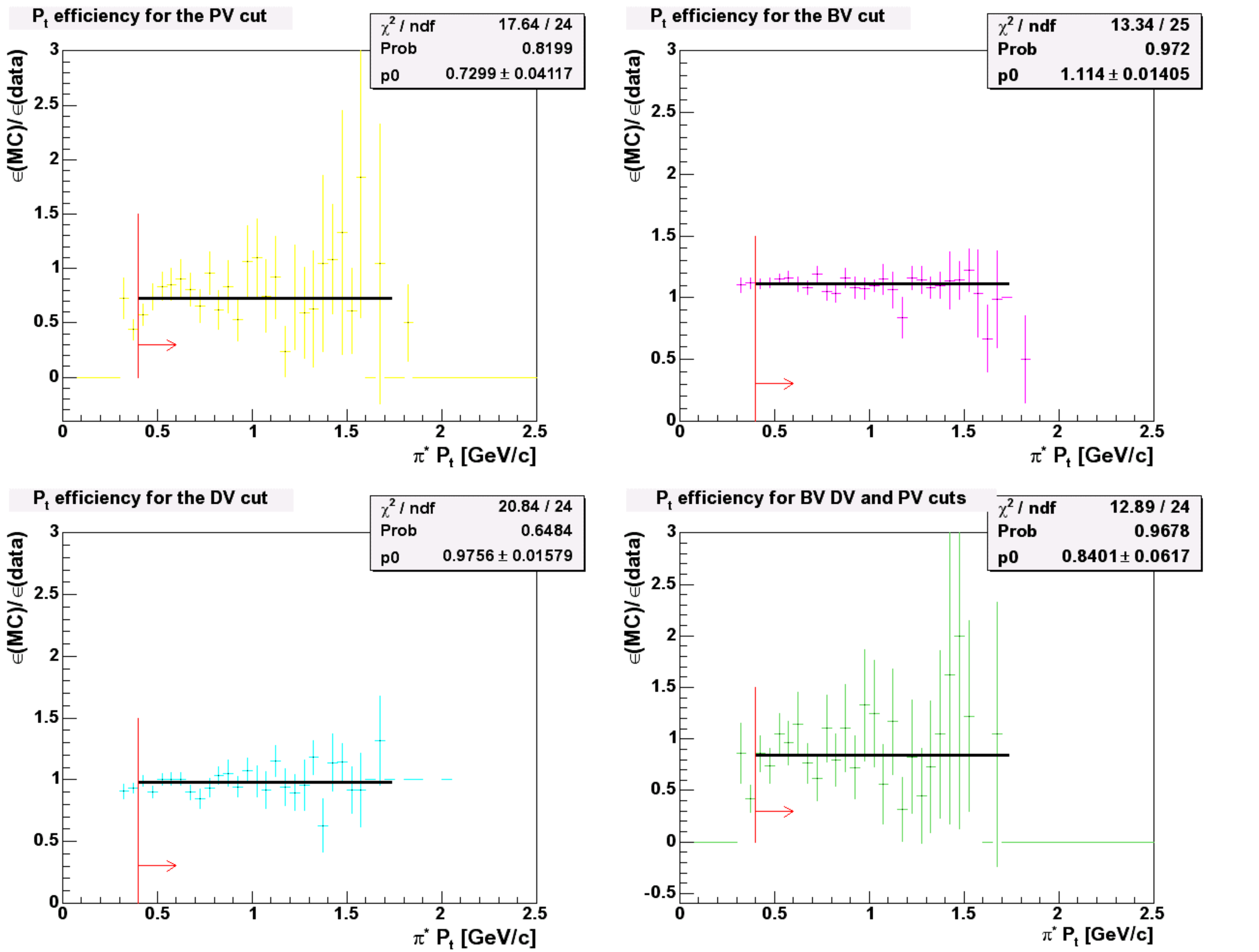




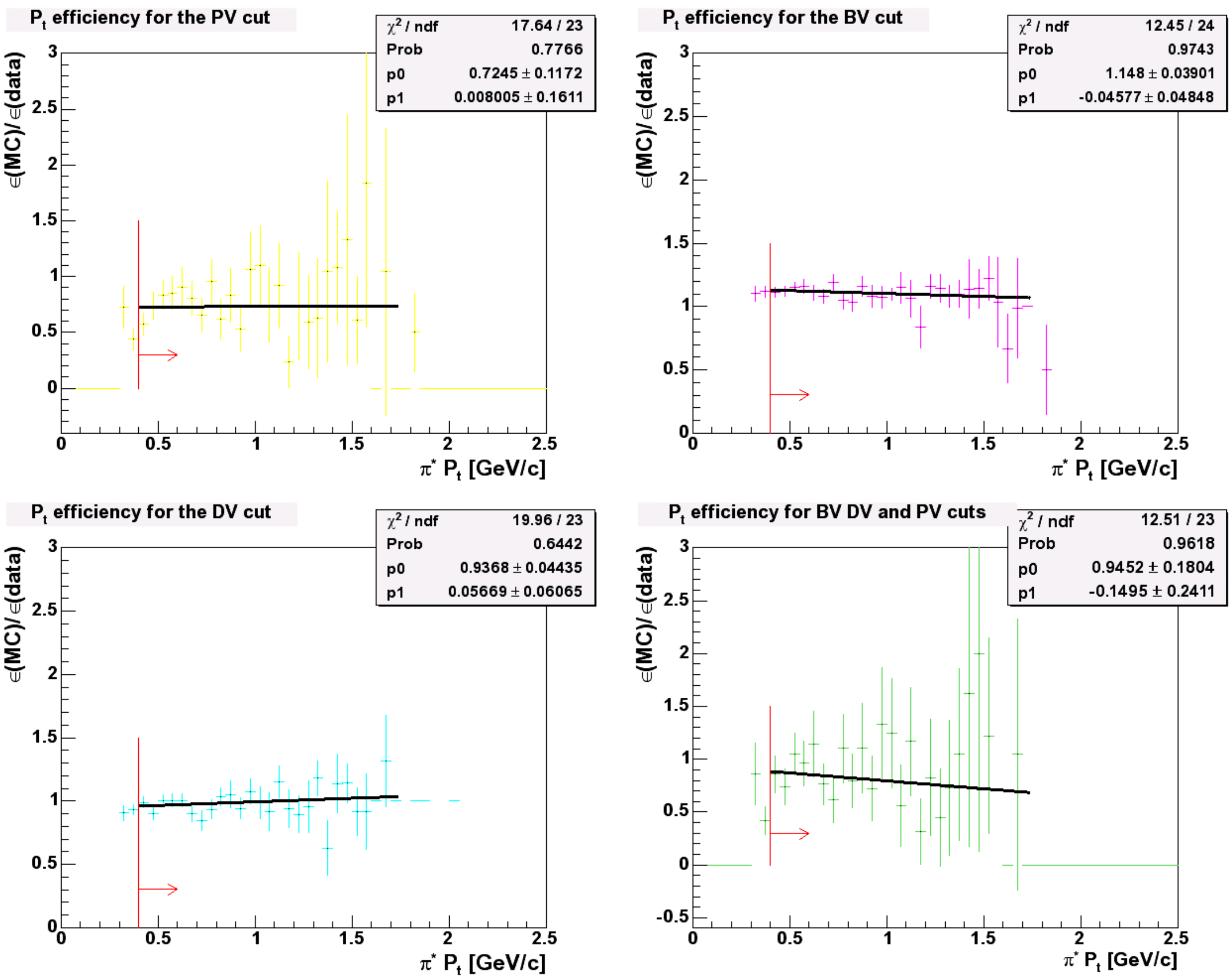


Another perspective:

MC(after/before) / data(after/before)



MC(after/before) / data(after/before)
Plan for the evaluation of systematics



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
  - Negative weights for background events
  - Efficiencies are propagated on weights:
    - $W=w/[\varepsilon_{MC}(m^{**})\ (a\times P_t^{**}+b)\ (a\times m^{**}+b)]$
- A toy Monte Carlo program has been written in order to test the procedure
- Details: unless you ask, see Ramon's talk from March 2^{nd} at the semileptonic meeting

Signal and Combinatorial Background

- Signal right sign (SRS) events for all channels are assigned w = +1. Then weight is corrected for relative efficiency factors from MC and π^* data.
- Signal wrong sign (SWS) events are assigned w = -1, and then corrected as above.
- Sideband right sign (SBRS) events are assigned w = $-a_i$, where a_i is the ratio of background events in S and SB regions. Then the weight is corrected as above.
- Sideband wrong sign (SBWS) are assigned w = $+a_i$ and corrected.

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.

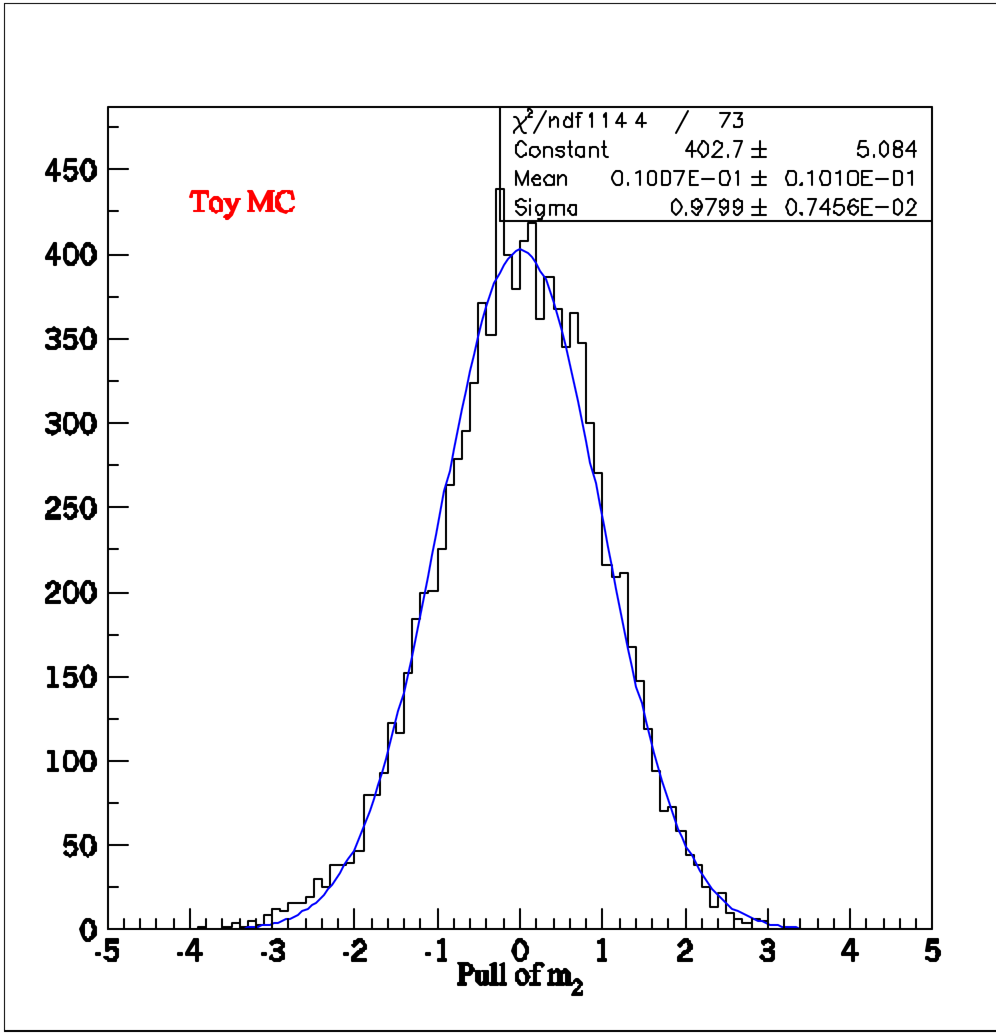
D^+, D^{*+} Relative Normalization

- 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, including SRS,SWS,SBRS,SBWS,feed-down and physics background have their weights modified as:

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

D** Moments

- Combine all events of all types in all channels (D^*,D^+,SRS,SBRS,feed-down, etc.)
- Compute mean (m_1) and variance (m_2) of M^2 distribution with weighted events.
- Errors and correlation computed with MC (for toy MC) or bootstrap (for data).
- For some realizations, one finds a negative value for $m_2 = Var(M^2) = \langle M^4 \rangle - \langle M^2 \rangle^2$.



Computing the Overall Moments

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

$$M_1 = \mu - m_D^2 \,,$$

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

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.

Inputs for the D^0 and D^{*0} Contributions

- For the BR's, results from charged and neutral B decays are combined using isospin: partial widths are assumed equal.
- BR's, ratio of lifetimes and ratio of production fractions are taken from PDG.
- Toy Monte Carlo is used to propagate the uncertainties from m_1, m_2, the BR's, etc., to uncertainties on M_1 and M_2 and their correlation.

Measure

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

Moments Extraction

Results and Systematics

Systematics

- Signal & Reconstruction:
  - Δm_{**} scale and resolution
  - Δm_{**} bias from reconstruction cuts
  - Relative yields correction

  Sensitive to B P_t model

  - Reliance on PDG masses/BR for D^*/D^+
- Backgrounds
  - Sideband subtractions (fake leptons, D)
  - π^{**} Background subtraction (fake D^{**})
- Radial excitations
  - Upper limit

Systematics

shopping list

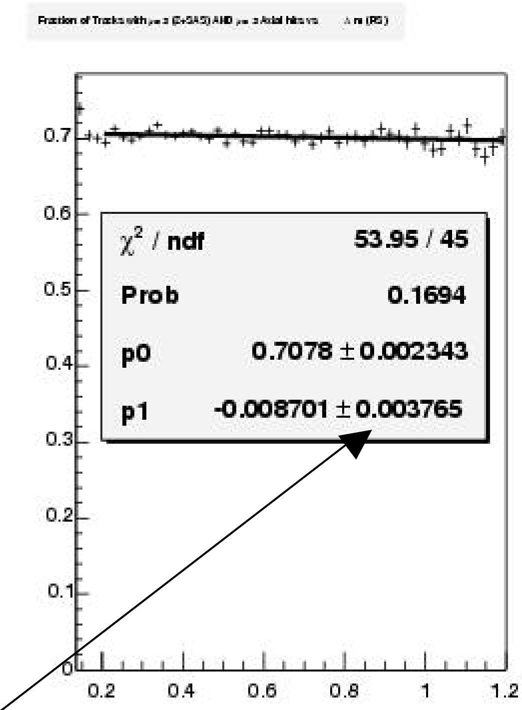
- Mass scale and resolution
- Efficiency corrections
  - from data (stat. Uncertainty)
  - From MC (modeling)
- Lepton momentum cut
- Background model
- Physics background (BR)
- Relative D^+/D^* normalization
- Semileptonic B branching ratios
- D** mass cut

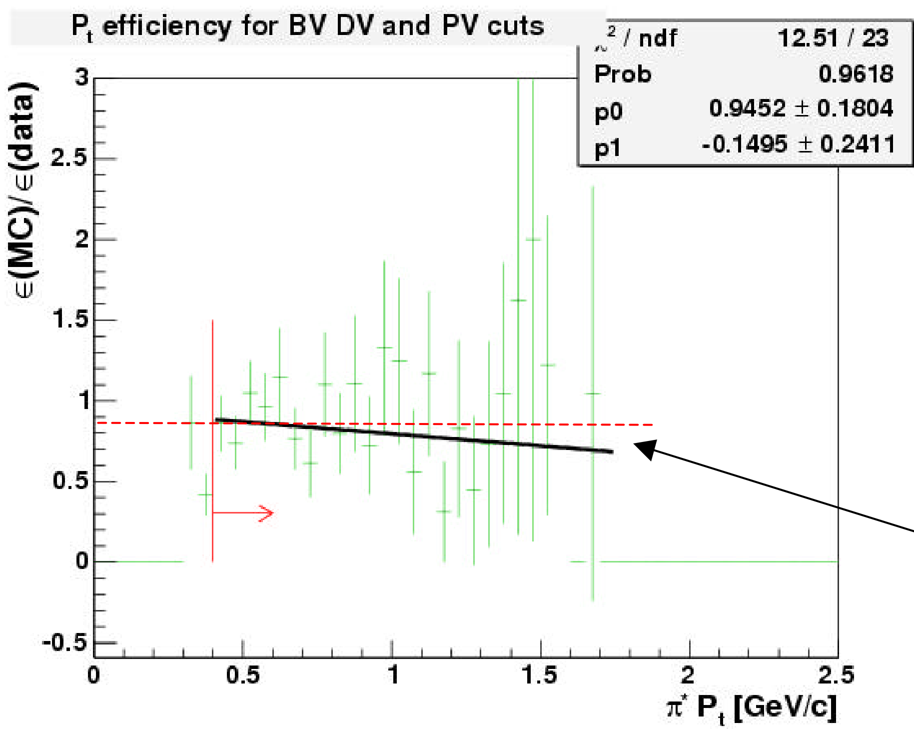
Mass scale/resolution

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

Efficiency Corrections from data

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



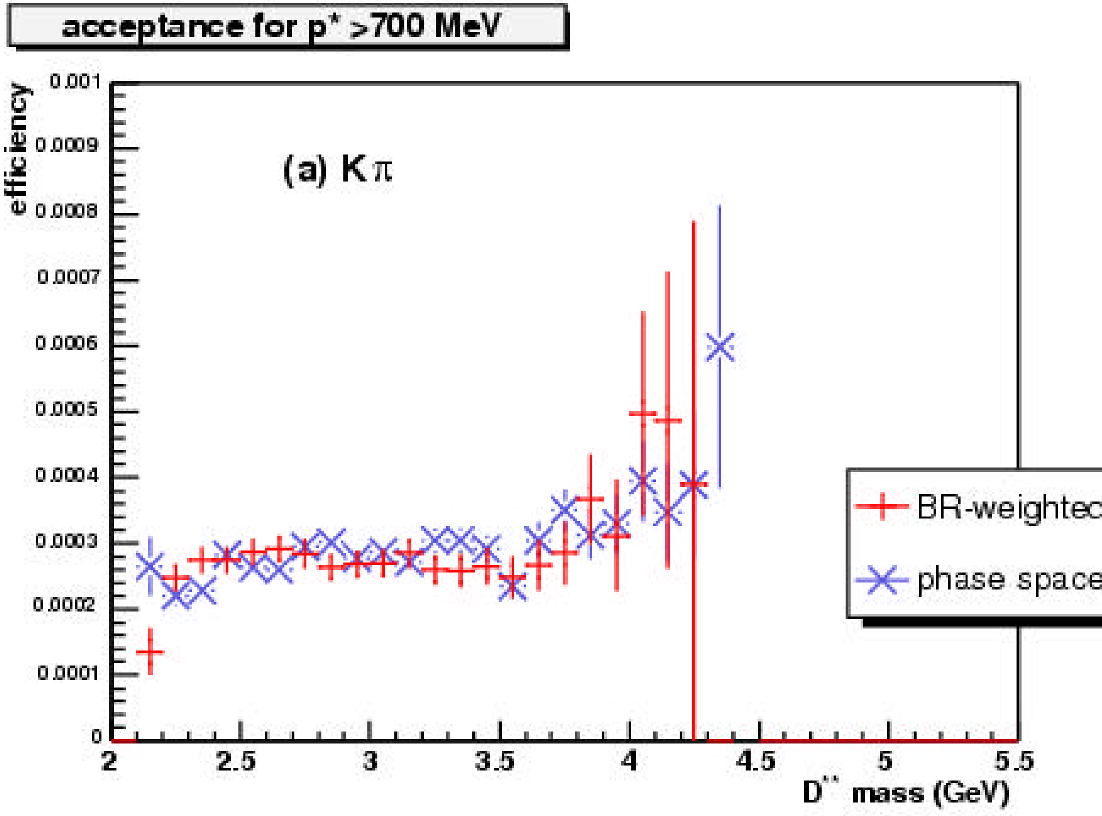


- Mass-dependent: use stat error on slope

- Pt-dependent: use $0^{th}/1^{st}$ order polynomial difference

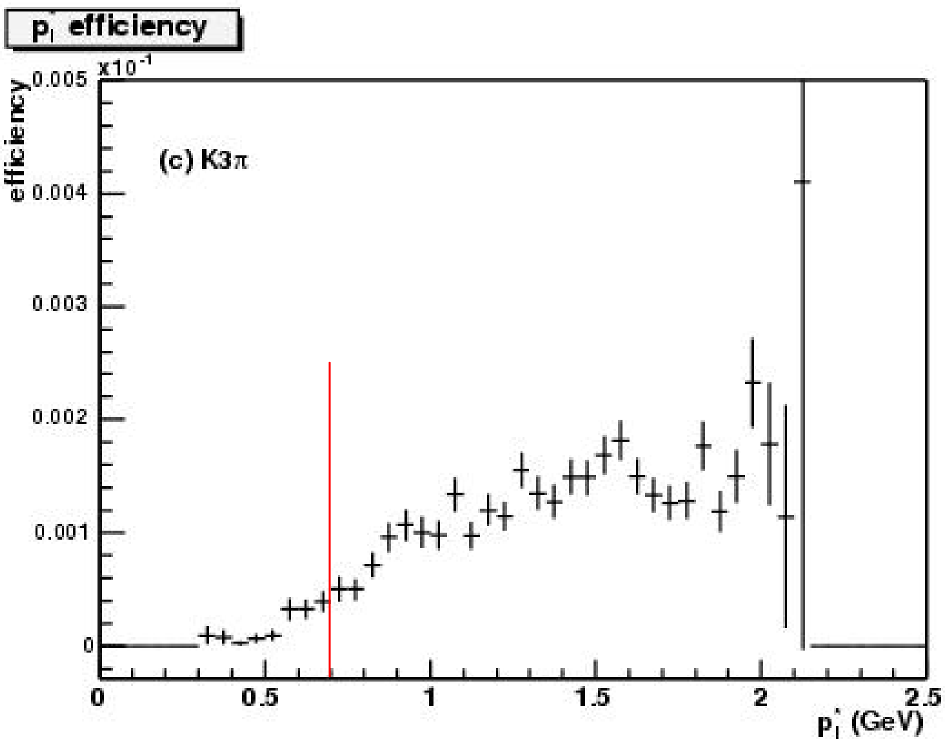
Efficiency corrections from MC

- 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...



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 marginal

Residual Numerology...

- D^+/D^{*+} relative scale:
  - PDG BR are varied by $\pm 1\sigma$
  - MC based efficiencies $\pm$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 $\pm 1\sigma$

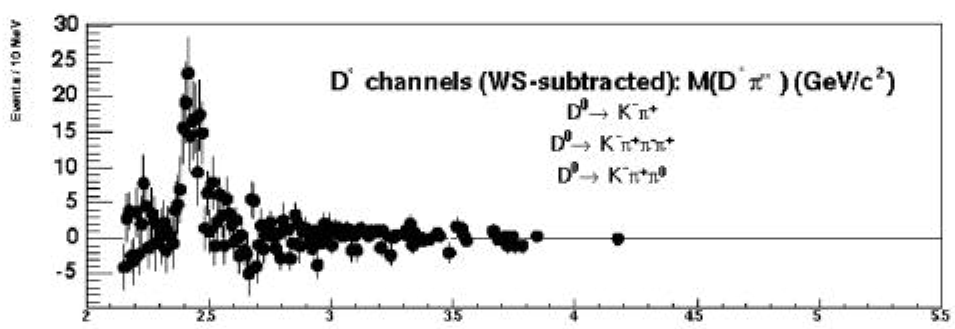
- Theory parameters (ρ_1, α_S, T_i, m_b, m_c) varied according to expectations (100%, 5%, 0.5GeV^3, 200MeV, 200 MeV)

Distribution Cut-off

- The sample has basically no statistical power above 3.5 GeV
- We need to apply a cutoff in order not to compromise the statistical uncertainty
- Trade off:
  - Drop the statistical error, but increase the sizew 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 models
  - WS
  - Embedding
- Shape: use embedding instead of WS
- Scale:Based on the charge multiplicites from embedding we have ~4% discrepancy between RS and WS

	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.

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 model						
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

Conclusions

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

or

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

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

or

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

- We can measure them!
- All systematics in place except the one based on embedding MC
- Would like to prebless on Thursday and address remaining issues

Backup Slides

V_{cb}: exclusive determination

- Measure absolute scale of $B \rightarrow D^* l\nu$
- D^{**} states also important for $|V_{cb}|$ exclusive determination
  - end-point in q^2 for $B \rightarrow D^* l\nu$ decays
  - systematic uncertainty from $B \rightarrow D^{**} l\nu$ background

Data Stability

A: (152595-154012) Before winter 2003 shutdown

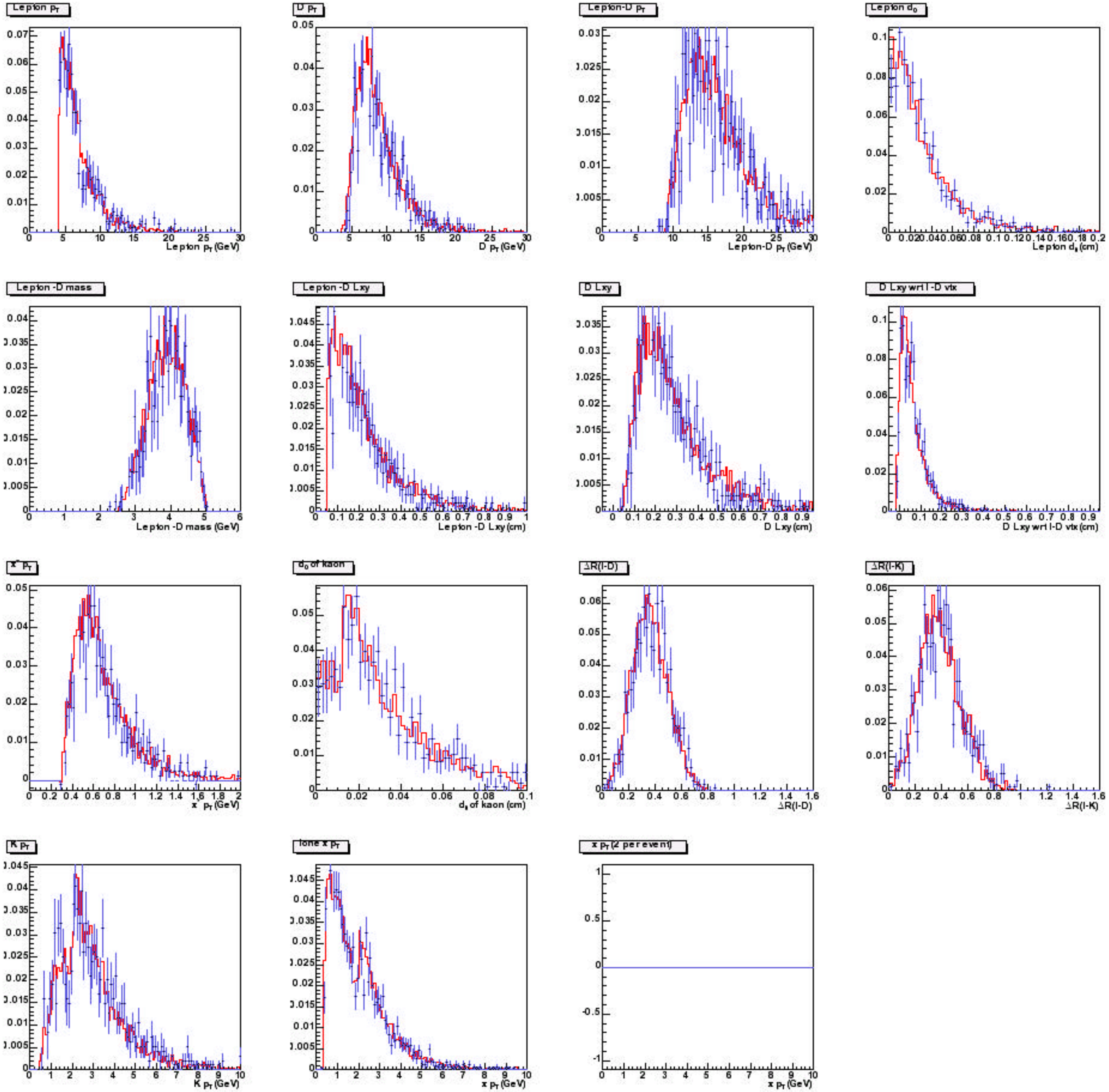
B: (158826-165297) After winter 2003 shutdown

C: (164303-165297) SVT 4/5

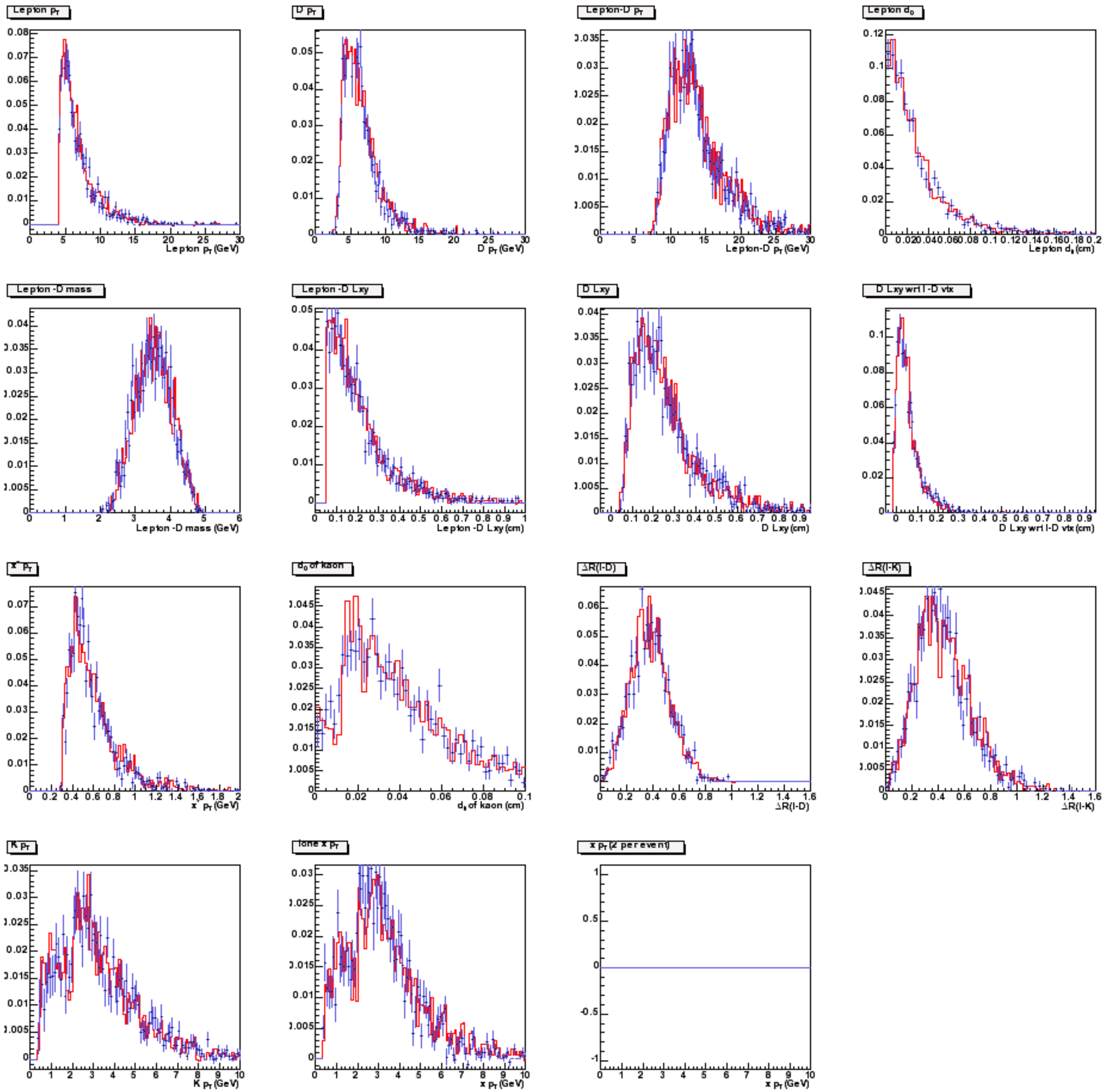
Kinematic variable	$D^0 \to K^-\pi^+$		$D^0 \to K^-\pi^+\pi^0$		$D^0 \to K^-\pi^+\pi^-\pi$		$D^+ \to K^-\pi^+\pi^+$	
	e	μ	e	μ	e	μ	e	μ
$p_T(\ell)$	11	95	34	94	0.9	57	2	78
$p_T(D)$	21	24	5	68	98	88	35	92
$p_T(\ell D)$	4	8	23	40	89	8	39	13
$d_0(\ell)$	6	58	77	88	94	3	18	98
$m(\ell D)$	33	20	4	51	5	57	46	6
$L_{xy}(\ell D)$	76	78	28	97	78	26	24	58
$L_{xy}(D)$	58	96	23	9	69	51	96	62
$L_{xy}(D \text{ to } \ell D)$	48	3	30	15	3	53	78	45
$p_T(\pi^*) > 0.4$ GeV	0.2	33	41	21	71	92		
$d_0(K)$	28	82	20	92	32	68	29	46
$\Delta R(\ell D)$	38	0.9	30	95	7	13	21	92
$\Delta R(\ell K)$	54	46	44	18	83	14	24	30
$p_T(K)$	51	33	76	26	15	30	28	33
lone π p_T	77	58	64	33	54	19		
π p_T (2 per event)							90	25

Table 3: Matching χ^2 probability (in %) between the periods A+B and period C in data for several kinematic variables and for the different channels.

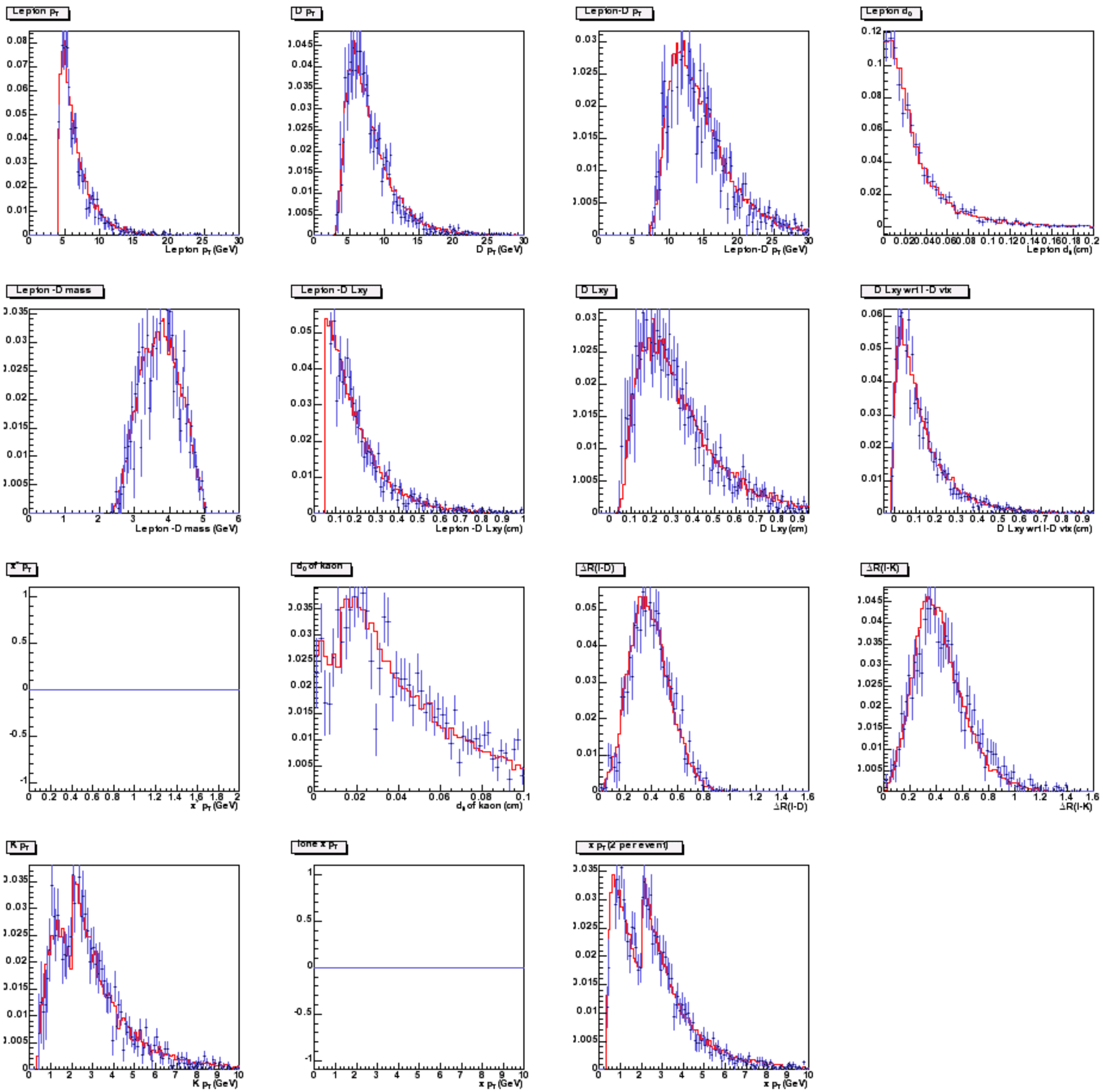
Kinematic Comparisons lD*, $D^0 \to K\pi\pi\pi$



Kinematic Comparisons ID*, $D^0 \to K\pi\pi^0$



Kinematic Comparisons: D^+



Can we "predict" yields?

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

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

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

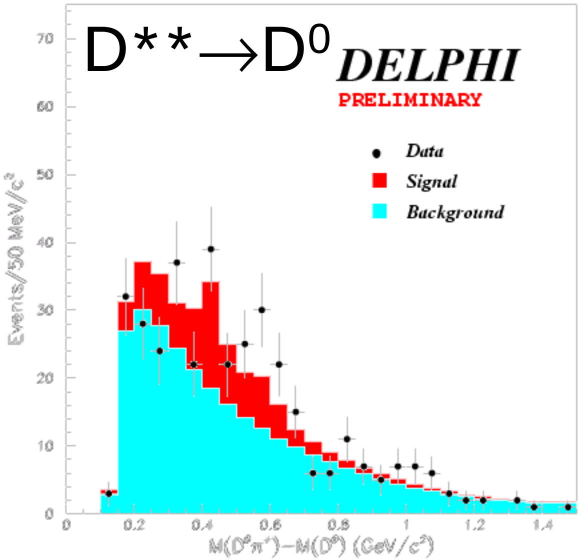
	$R_{pred.}$	R_{data}	$R_{pred.}/R_{data}$
$R_{D+/K\pi}$			
data (sans D_s)		3.71 ± 0.08	
Method (a)	3.31 ± 0.58		0.89 ± 0.16
Method (b)	$3.23 \pm 0.29 \pm ?$		$0.87 \pm 0.08 \pm ?$
$R_{K3\pi/K\pi}$			
data		0.77 ± 0.02	
	0.80 ± 0.04		1.04 ± 0.06

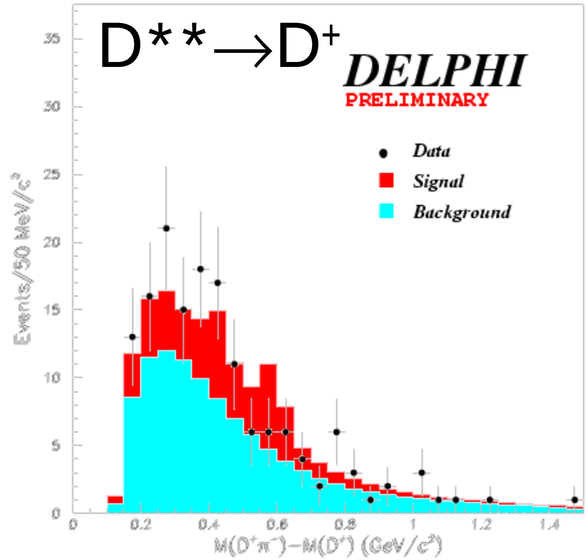
Directory name	Summary			Decay Table	Gen	Sim(s)	Prod	PHOTOS
PDSF://auto/cdf2/hcfang								
Direct decay of B into D and D*								
DplusK2Pi_MC_4.9.1pms/	B–>eD$^+$v		D$^+$–> K2pi	bdtoedpl_dplink2pi_hcfang	4.9.1pms	4.9.1pms	4.9.1pms	y
DplusK2Pi_MC_4.9.1pms_4.10.0/	B–>eD$^+$v		D$^+$–> K2pi	same as above	4.10.0	4.10.0	4.9.1pms	y
DstarK3Pi_MC_4.9.1pms/	B–>eD*v		D^0–> K3pi	bdtoedst_dzink3pi_hcfang	4.9.1pms	4.9.1pms	4.9.1pms	y
muDstarK1Pi_MC_4.9.1pms_4.10.0/	B–>muD*v		D^0–> Kpi	bdtomudst_dzinkpi_hcfang	4.10.0	4.10.0	4.9.1pms	y
bdtoedst_dstind0pi_d0ink3pi_4.10.0_prod4.9.1hpt1/	B–>eD*v		D^0–> K3pi	bdtoedst_dstind0pi_d0ink3pi_hcfang	4.10.0	4.10.0	4.9.1hpt1	y
bdtoedst_dstind0pi_d0inkpipi0_4.10.0_prod4.9.1hpt/	B–>eD*v		D^0–> Kpipi0	bdtoedst_dstind0pi_d0inkpipi0_hcfang	4.10.0	4.10.0	4.9.1hpt1	y
D** MC files								
Dstarstar_GenLvlMC_4.10.0/	B–>eD**v	D**–>D*		bptodss	4.10.0	––	––	y
Dstarstar_MC_files_4.9.1pms/	B–>eD**v	D**–>D*		same as above	4.9.1pms	4.9.1pms	4.9.1pms	y
Dstarstar_MC_files_4.9.1pms_part2/	(continuation of above)			same as above				
bptoedss_noPHOTOS_GenLvl_4.10.0/	B–>eD**v	D**–>D*		bptoedss_noPHOTOS	4.10.0	––	––	n
bptomudss_noPHOTOS_GenLvl_4.10.0/	B–>muD**v	D**–>D*		bptomudss_noPHOTOS	4.10.0	––	––	n
dsstodpl_dplink2pi_GenLvl_4.10.0/	B–>eD**v	D**–>D$^+$	D$^+$–> K2pi	bptodss_dsstodplpi_dpltok2pi	4.10.0	––	––	y
dsstodpl_dplink2pi_4.10.0_4.9.1pmsProd/	B–>eD**v	D**–>D$^+$	D$^+$–> K2pi	same as above	4.10.0	4.10.0	4.9.1pms	y
PDSF://auto/pdsfdv47/cdf/hcfang/								
Direct decay of B into D and D*								
Dstar_MC_files_4.9.1pms_try2/	B–>eD*v		D^0–> Kpi	bdtoedst_dzinkpi_hcfang	4.9.1pms	4.9.1pms	4.9.1pms	y
bdtoedst_dstindplpi0/	B–>eD*v	D*–>D+pi0	D+–> K2pi	bdtoedst_dstindplpi0	4.10.0	4.10.0	4.9.1pms	y
D** MC files								
bptoedssCont_noPHOTOS_GenLvl/	B–>eD**(non–res)v	D**–>D*pi		bptoedssCont_noPHOTOS	4.10.0	––	––	n
bptoedssCont_noPHOTOS/	B–>eD**(non–res)v	D**–>D*pi		same as above	4.10.0	4.10.0	4.9.1pms	n
bptoedssContDpl_noPHOTOS_GenLvl	B–>eD**(non–res)v	D**–>D+pi		bptoedssContDpl_noPHOTOS	4.10.0	––	––	n
bptoedssContDpl_noPHOTOS	B–>eD**(non–res)v	D**–>D+pi		same as above	4.10.0	4.10.0	4.9.1pms	n
PDSF://auto/pdsfdv50/cdf/hcfang/								
D** MC files								
B0SemiLeptonic/	B–>muD**v	all final states with		bdto_decayB0SemiLeptonic	4.10.0	4.10.0	4.9.1pms	y
BPlusSemiLeptonic/	B–>muD**v	Kpi, K2pi, K3pi		bpto_decayBPlusSemiLeptonic	4.10.0	4.10.0	4.9.1pms	y
Hadronic B decays								
bdtodstarpi_d0tokpi/	B–>D*pi+	D*–>D^{0}pi	D^0–> Kpi	bdtodstarpi_d0tokpi	4.10.0	4.10.0	4.9.1pms	n

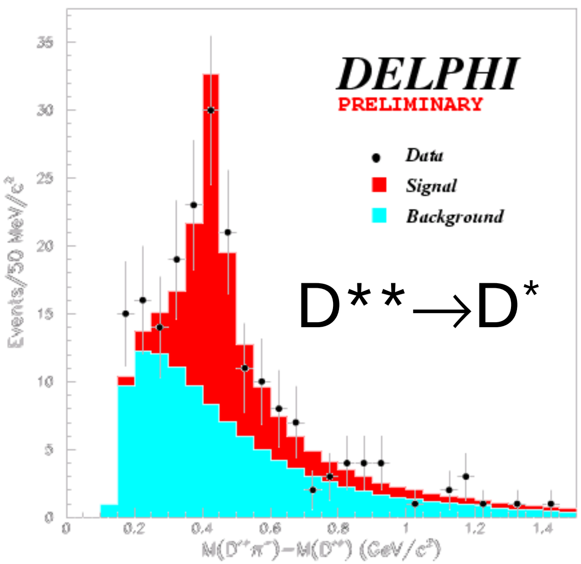
What background model for what?

- WS is often used in this kind of analyses as a model for the background
- We can also use our fully reco'd B from other triggers
- We choose to use WS for the optimization
- Embedding is being used as a cross-check for systematics

What's available on the market…





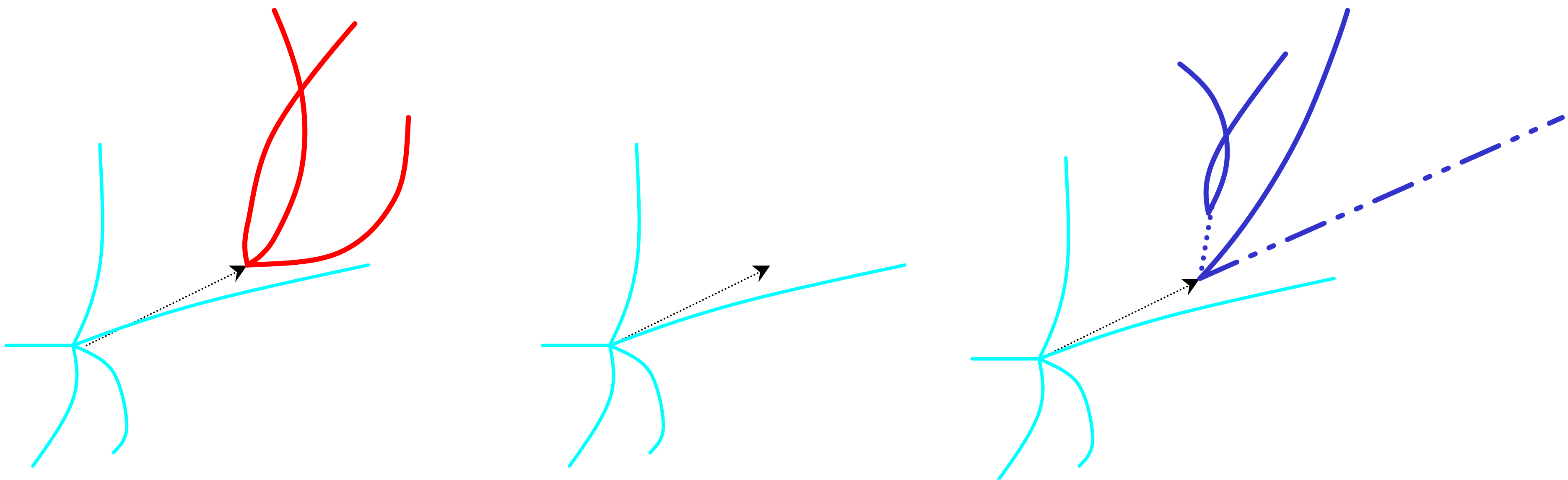


- No background subtraction
- ~80 events in D^{*+}
- ~80 events in D^{+}
- ~215 events on D^{0}

uncertainty > sqrt(n)

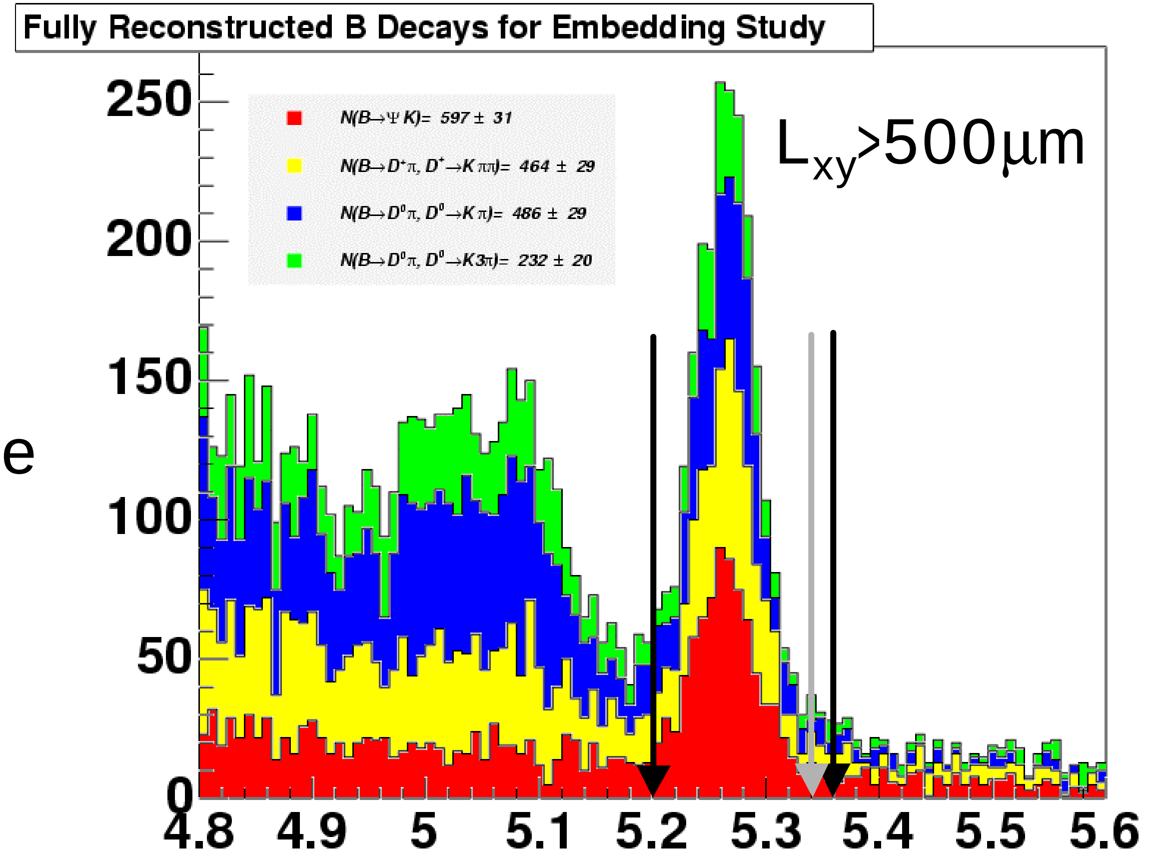
Combinatorial Background

- WS π**
  - Already used for the optimization
  - Physics can be different
- Fully reco. B
  - independent emulation of the background
  - Limited statistics
  - Needs some machinery for emulating a semileptonic decay!
    - Eliminate the B daughters
    - Replace the B with a semileptonic B with the same 4-momentum: a template montecarlo where the B decay comes from EvtGen and the rest of the event comes from the data!

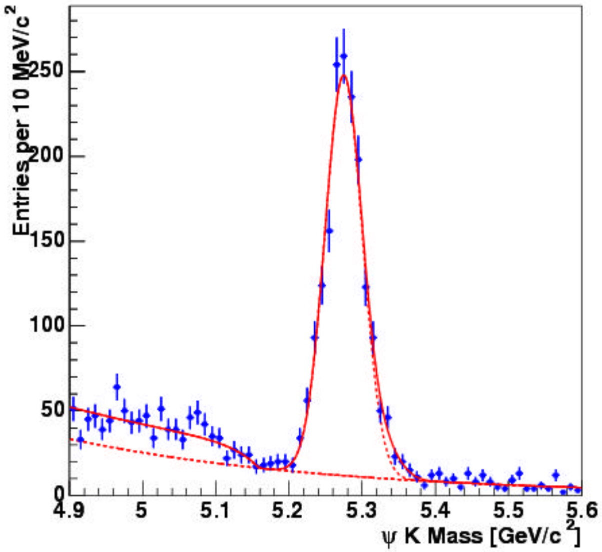


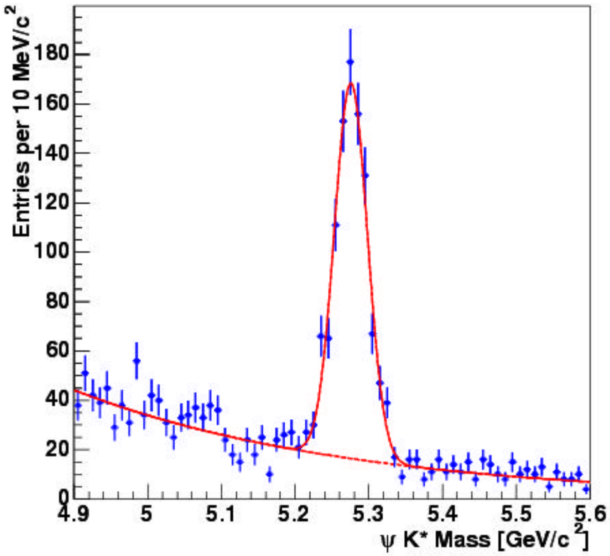
Background Modeling II

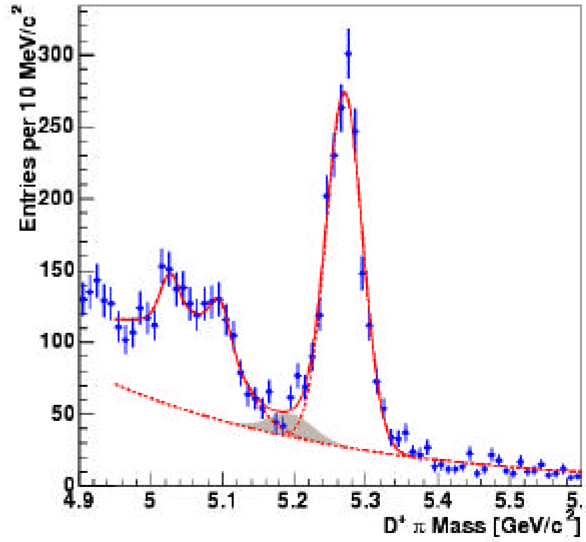
- Tight cuts (avoid subtractions)
- Exclude B tracks
- Replace with MC B
- QuickCdfObjects/GenTrig
- Re-decay N times
- Same analysis path from there on

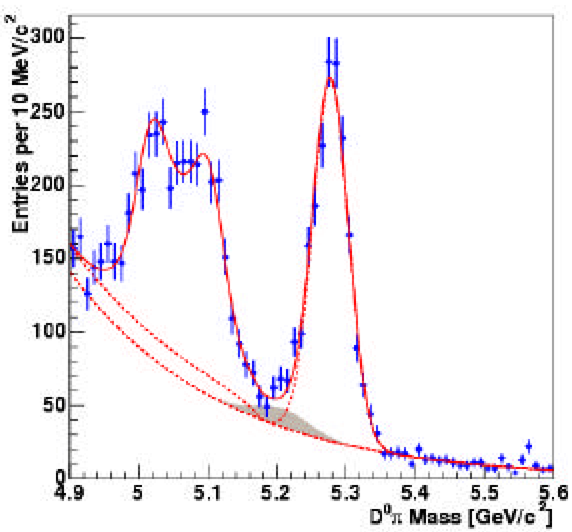


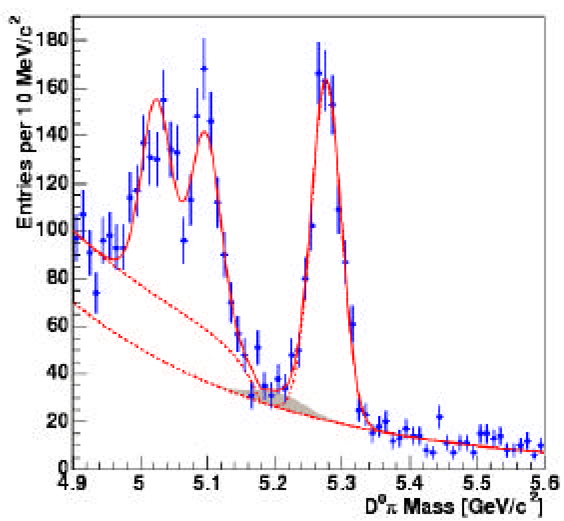
Signal Fits


Entries per 10 MeV/c^2
ψ K Mass [GeV/c^2]


Entries per 10 MeV/c^2
ψ K* Mass [GeV/c^2]


Entries per 10 MeV/c^2
D* π Mass [GeV/c^2]


Entries per 10 MeV/c^2
D^{0}π Mass [GeV/c^2]


Entries per 10 MeV/c^2
D^{0}π Mass [GeV/c^2]

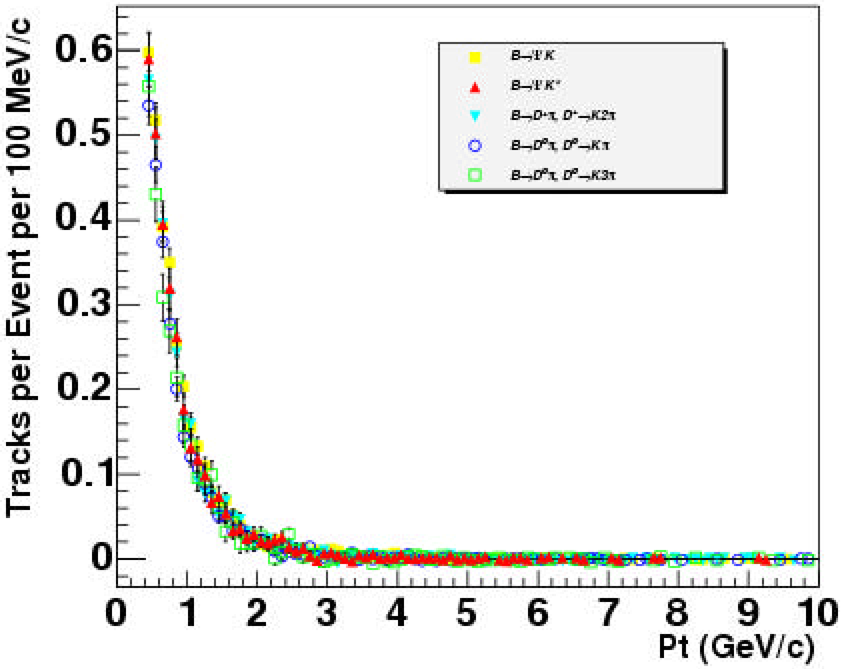
Sample Consistency

	$B^+ \to \psi K^+$	$B^+ \to D^0\pi^+$ $D^0 \to K\pi$	$B^+ \to D^0\pi^+$ $D^0 \to K3\pi$	$B^0 \to \psi K^*$	$B^0 \to D^+\pi^-$ $D^+ \to K\pi\pi$
N_{ch}	3.24 ± 0.06	2.78 ± 0.05	2.76 ± 0.05	3.09 ± 0.06	2.90 ± 0.05
N_{ch}^{OS}	1.77 ± 0.04	1.53 ± 0.03	1.56 ± 0.04	1.53 ± 0.04	1.49 ± 0.03
N_{ch}^{SS}	1.47 ± 0.04	1.25 ± 0.03	1.20 ± 0.04	1.56 ± 0.04	1.41 ± 0.03
p_t	0.93 ± 0.01	0.87 ± 0.007	0.85 ± 0.005	0.92 ± 0.01	0.90 ± 0.007
Iso	0.81 ± 0.003	0.81 ± 0.002	0.85 ± 0.002	0.81 ± 0.003	0.82 ± 0.003
ΔR	0.62 ± 0.004	0.62 ± 0.003	0.60 ± 0.004	0.62 ± 0.004	0.60 ± 0.003

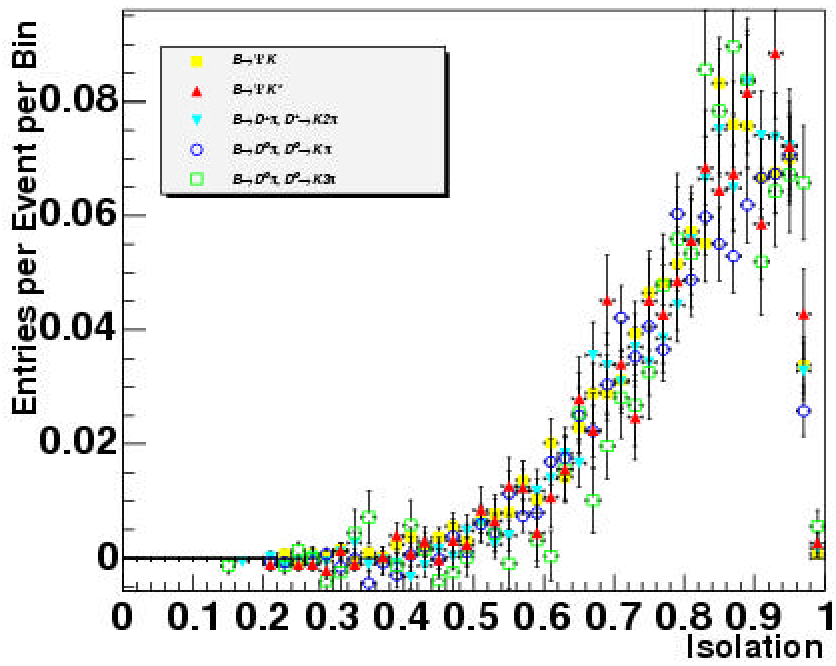
Table 1: The average value of various tracking quantities for the 5 samples described in the text. In all cases, tracks are required to have at more than 2 axial silicon hits. Only tracks with $\Delta R < 1.0$ with respect to the B meson are included. Uncertainties quoted here are statistical only.

	$B^+ \to \psi K^+$	$B^+ \to D^0\pi^+$ $D^0 \to K\pi$	$B^+ \to D^0\pi^+$ $D^0 \to K3\pi$	$B^0 \to \psi K^*$	$B^0 \to D^+\pi^-$ $D^+ \to K\pi\pi$
N_{ch}	3.35 ± 0.07	3.12 ± 0.05	3.07 ± 0.08	3.17 ± 0.07	3.21 ± 0.05
N_{ch}^{OS}	1.82 ± 0.04	1.72 ± 0.04	1.73 ± 0.05	1.56 ± 0.04	1.67 ± 0.04
N_{ch}^{SS}	1.53 ± 0.04	1.39 ± 0.04	1.34 ± 0.05	1.60 ± 0.04	1.53 ± 0.04
pt	0.95 ± 0.01	0.87 ± 0.008	0.84 ± 0.003	0.90 ± 0.004	0.86 ± 0.007
Iso	0.80 ± 0.004	0.81 ± 0.003	0.84 ± 0.003	0.81 ± 0.004	0.82 ± 0.003
ΔR	0.62 ± 0.004	0.63 ± 0.004	0.60 ± 0.005	0.62 ± 0.005	0.62 ± 0.004

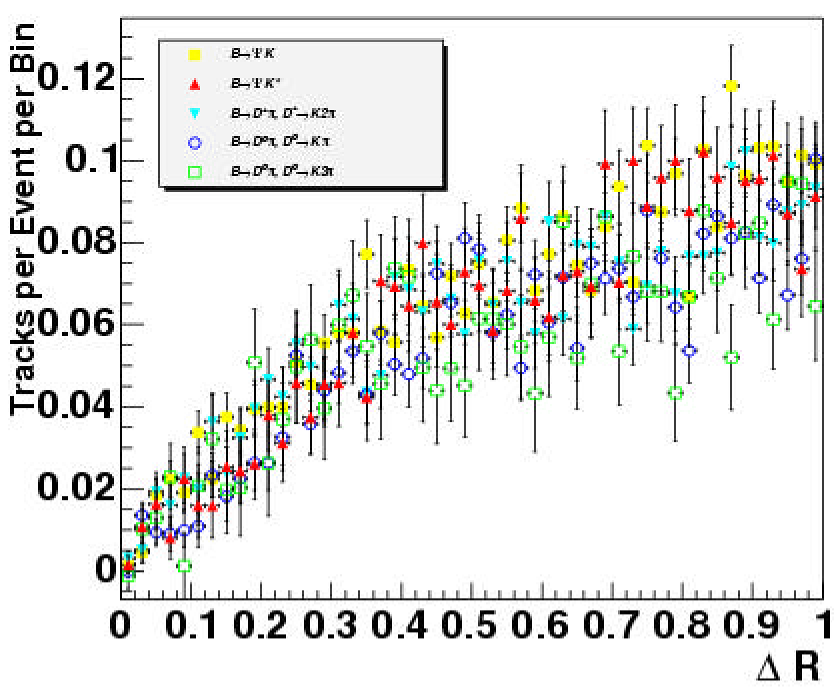
Table 2: The average value of various tracking quantities for the 5 samples described in the text. These results differ from Table 1 in that the pseudorapidity range of the B candidate is now limited to $|\eta_B^{detector}| < 0.6$



Tracks per Event per 100 MeV/c
Pt (GeV/c)
B→ΥK
B→ΥK*
B→D+π, D+→K2π
B→D0π, D0→Kπ
B→D0π, D0→K3π

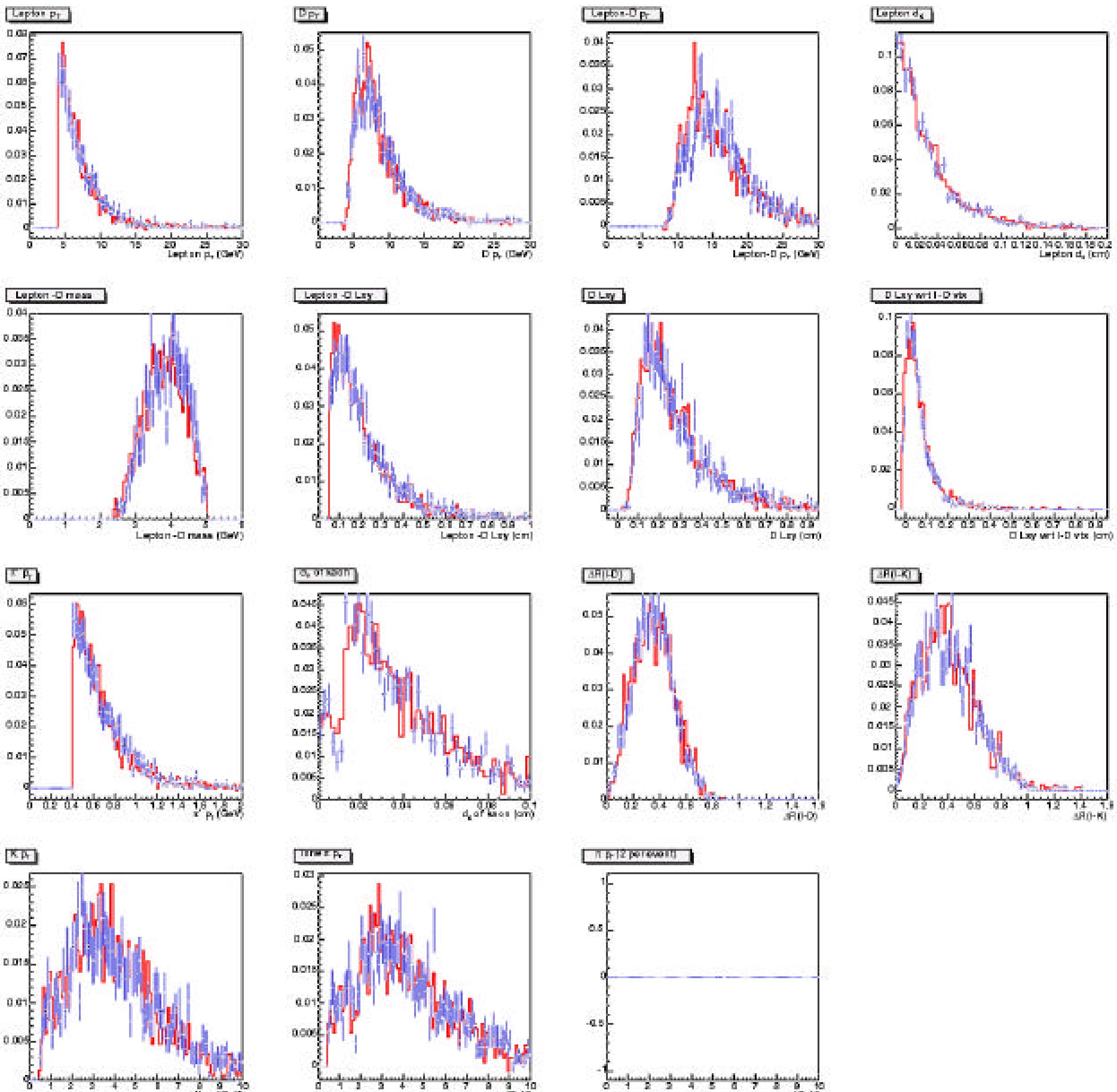


Entries per Event per Bin
Isolation
B→ΥK
B→ΥK*
B→D+π, D+→K2π
B→D0π, D0→Kπ
B→D0π, D0→K3π



Tracks per Event per Bin
Δ R
B→ΥK
B→ΥK*
B→D+π, D+→K2π
B→D0π, D0→Kπ
B→D0π, D0→K3π

Embedded MC vs Semileptonics



MC yield scaled to number of data events

Kinematic Variable	Probability	χ^2/Dof
$p_T(\ell)$	0.0862432	(37.4921/ 27)
$p_T(D)$	0.00854948	(65.6659/ 41)
$p_T(\ell D)$	0.00287925	(84.576/ 52)
$d_0(\ell)$	0.977983	(9.38652/ 20)
$m(\ell D)$	0.0109354	(79.3892/ 53)
$L_{xy}(\ell D)$	0.961646	(16.2703/ 28)
$L_{xy})(D)$	0.646029	(40.9047/ 45)
$L_{xy}(D\ to\ \ell D)$ vtx	0.109883	(33.9083/ 25)
$p_T(\pi^*)$	0.294054	(39.0136/ 35)
$d_0(K)$	0.562681	(40.9019/ 43)
$\Delta R(\ell D)$	0.151552	(42.4505/ 34)
$\Delta R(\ell K)$	0.0608588	(55.8548/ 41)
$p_T(K)$	0.558166	(53.8112/ 56)
lone π p_T	0.155844	(71.0372/ 60)