Measurement of Hadronic Moments in Semileptonic *B* Decays

(Blessing Talk)

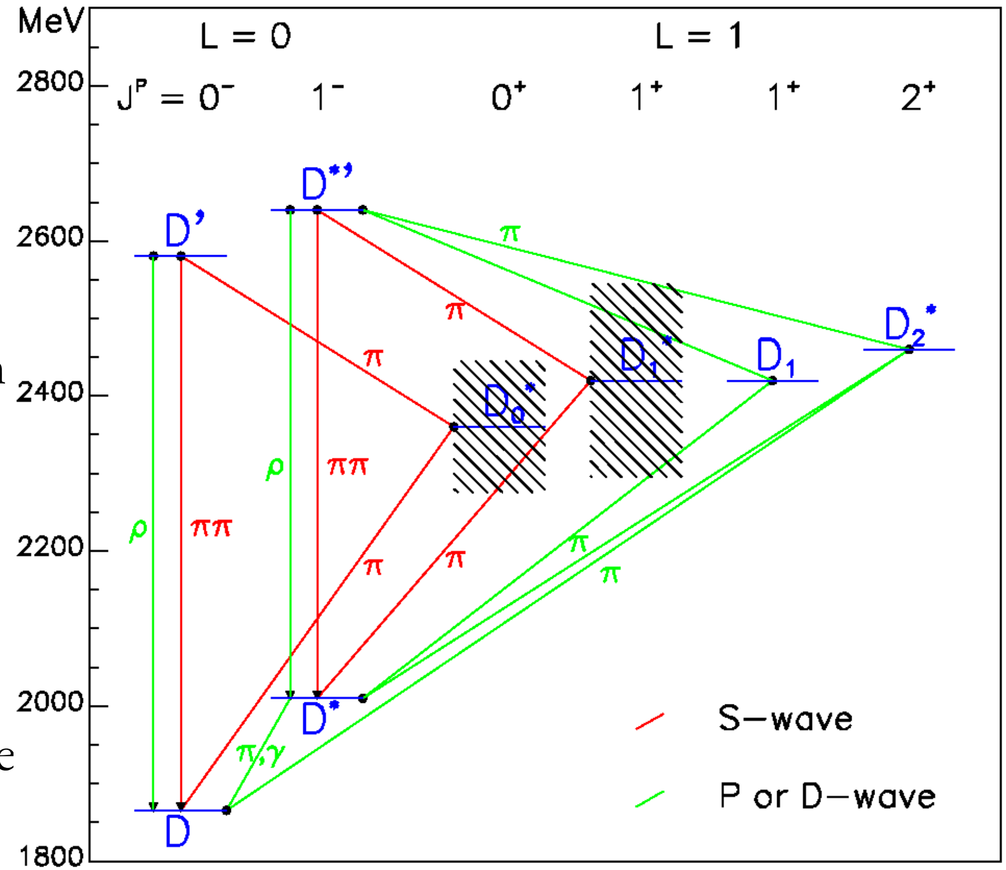
Alessandro Cerri, Hung-Chung Fang
Ramon Miquel, Marjorie Shapiro
Laurent Vacavant

Introduction

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

    B→X_c l ν

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



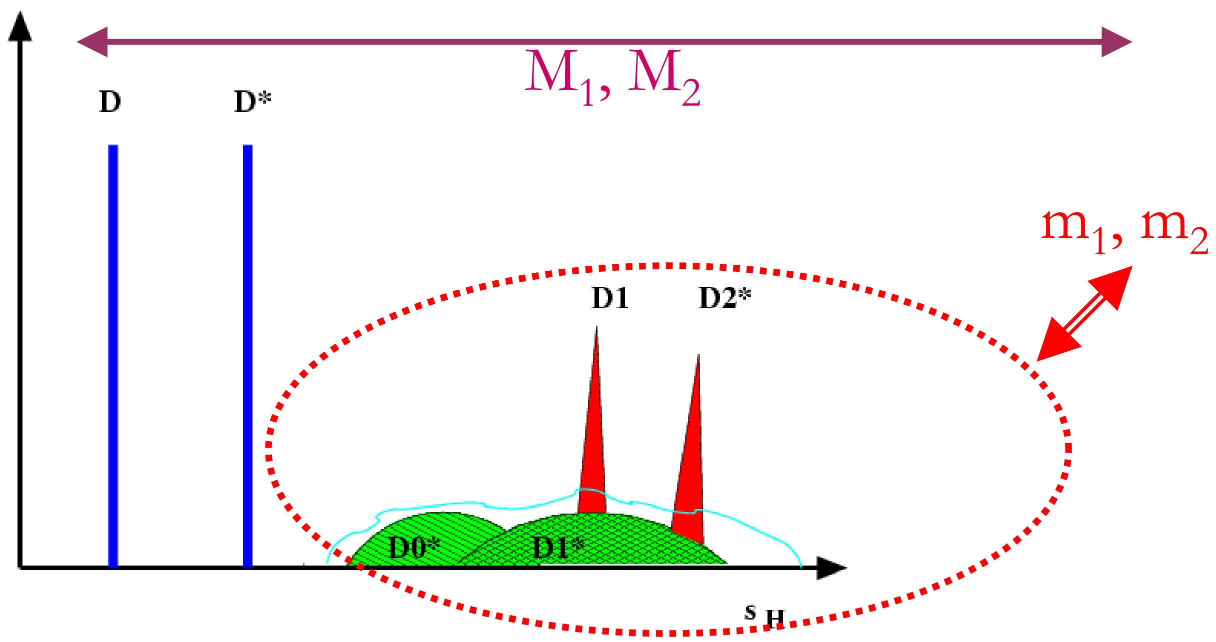
Inclusive V_{cb} Determination and hadronic moments

- 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

Hadronic Mass



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

- 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.

The strategy

CDF6754 | **CDF6972/6973** (covers steps 2–4)

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 $\pi^{**} \rightarrow D^{**}$ →

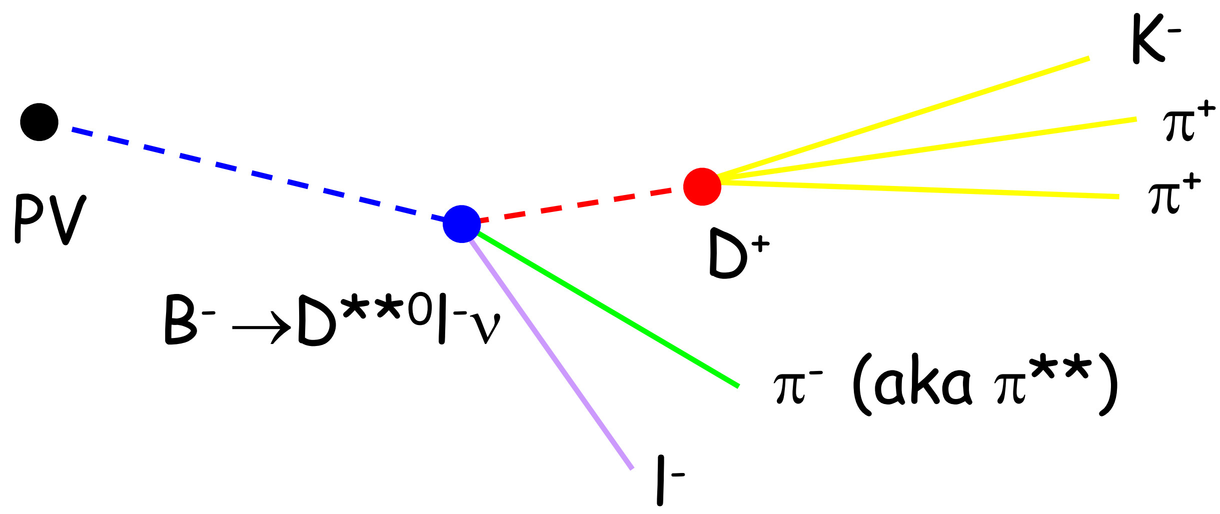
- Selection:
  - Optimize on MC+WS combinations
  - Cross check on π^*
- π^{**} Background
  - Combinatorial
  - D′
  - $B \rightarrow DD$
  - $c\bar{c}$
  - …

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



- 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

Changes to analysis since preblessing

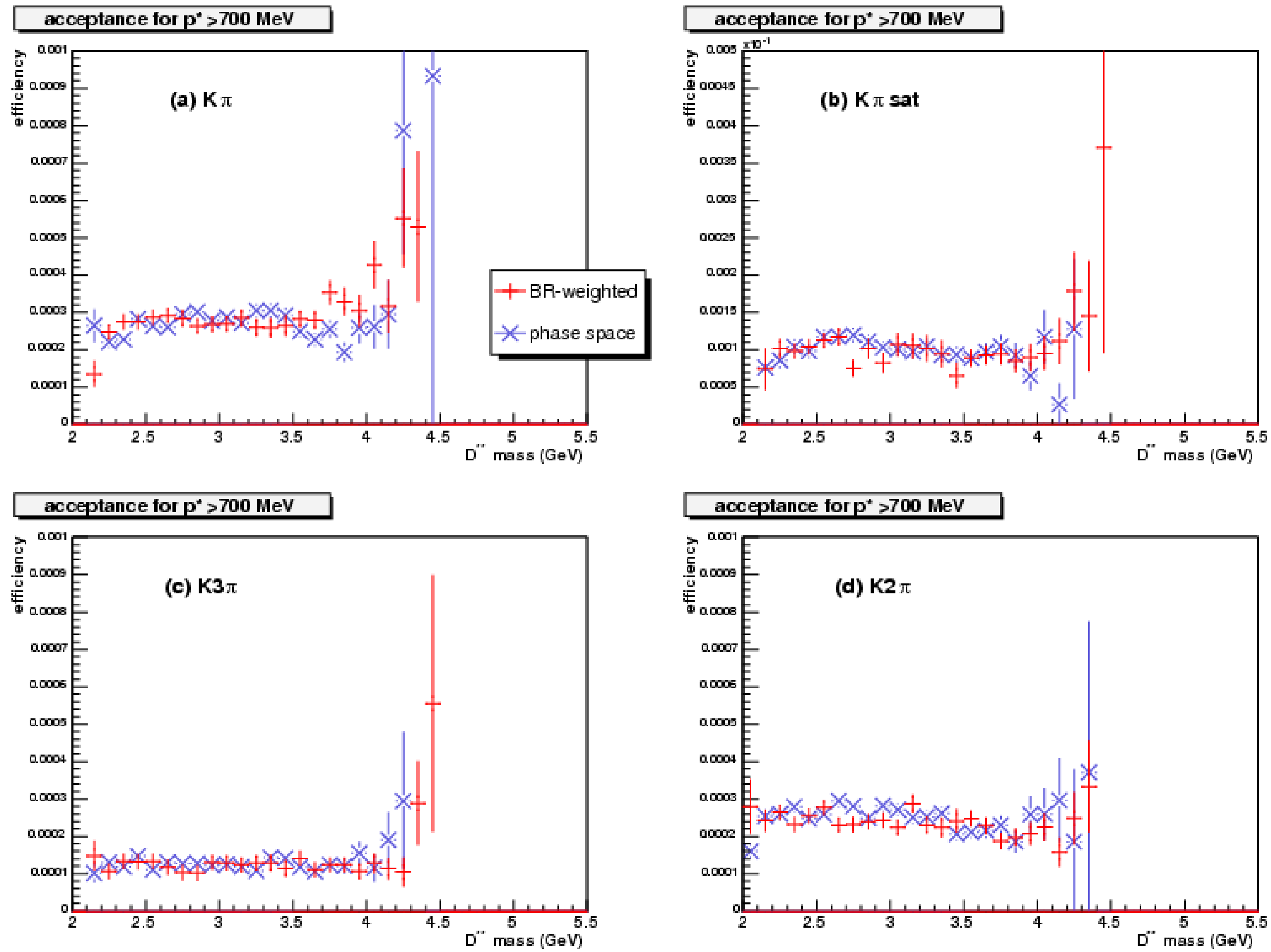
Systematic Errors

- During preblessing we were asked to see if we could improve our systematics
- Systematics dominated by modeling of efficiency:
  - MC statistics
  - MC/Data corrections
- m^{**} cut was set at 3.5 GeV for preblessing analysis
- We have increased our MC statistics and <u>removed</u> the 3.5 GeV cut.

Efficiency vs m^{**}

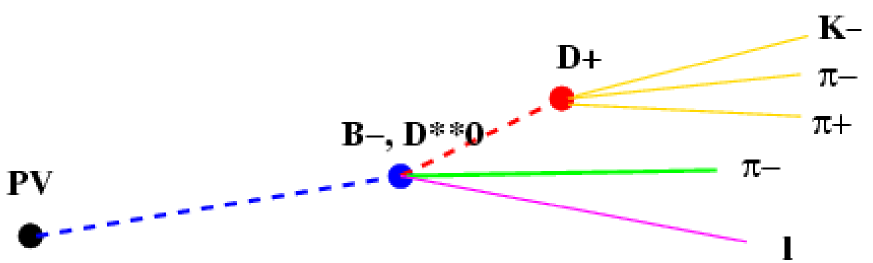
- Bulk measured from MC
- Low statistics at large m^{**} were significant source of uncertainty

→ Increase MC statistics

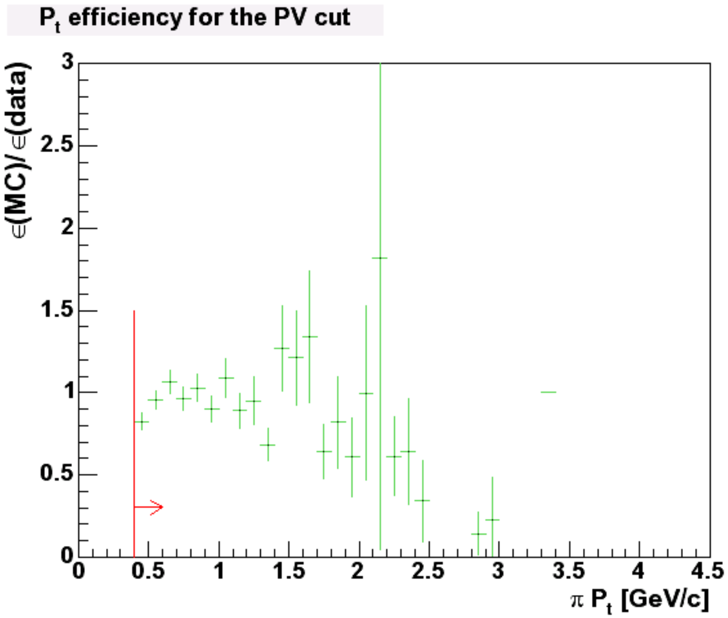


MC/Data corrections

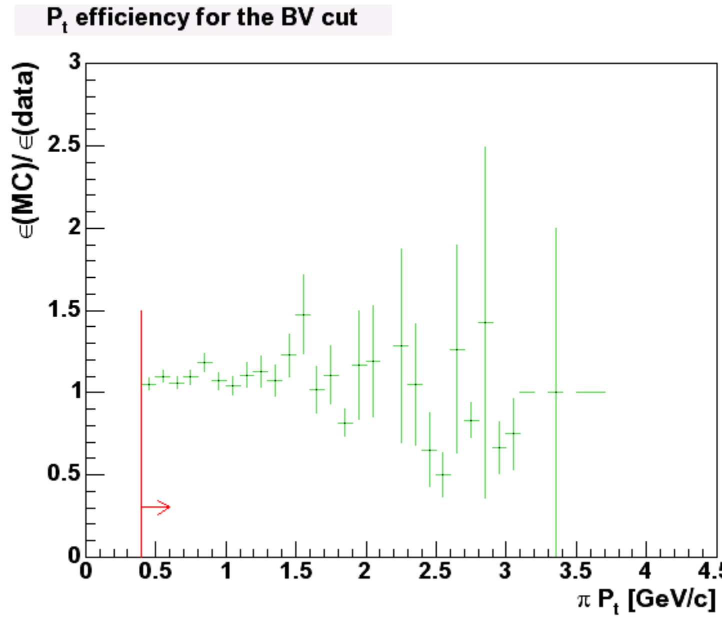
- Dominant source of systematics!
- π^* reproduces π^{**} topology but statistics too low:
  - Use more D^* candidates (two weeks ago we were using only $D^0 \rightarrow K\pi$)
  - Cross check on non-triggering D^0 daughters (helps for p_T)



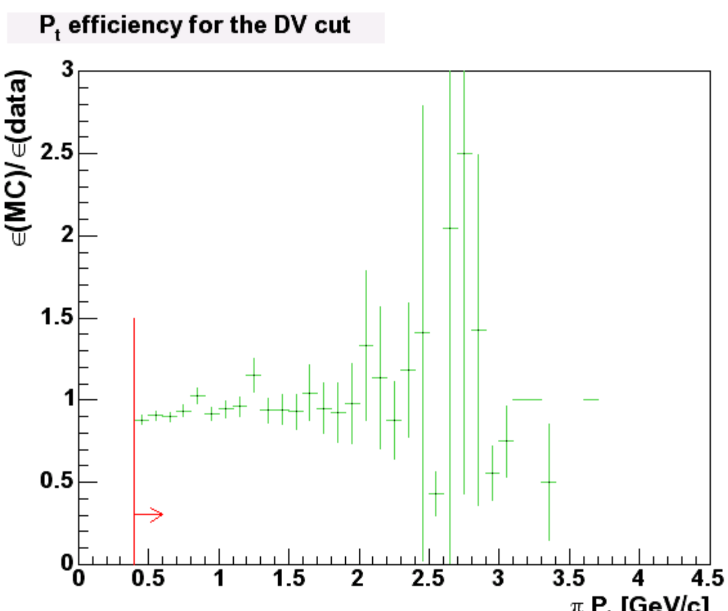
π^*



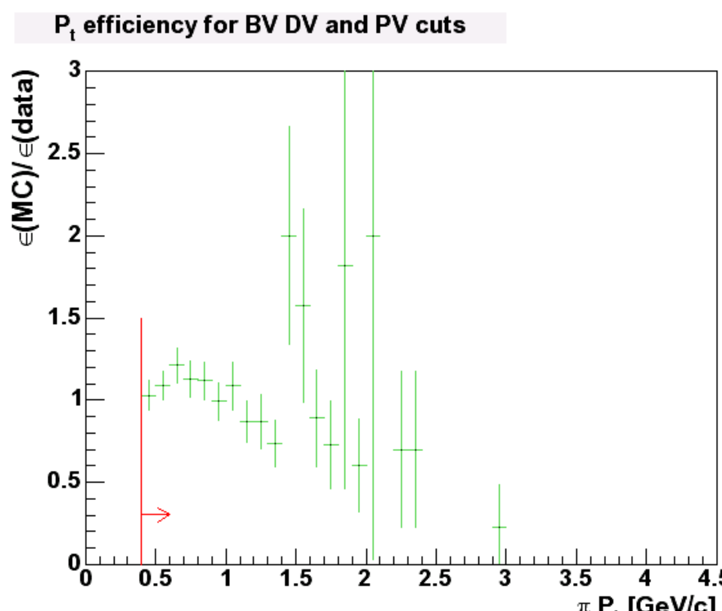
P_t efficiency for the PV cut
∈(MC)/∈(data)
0
0.5
1
1.5
2
2.5
3
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
π P_t [GeV/c]



P_t efficiency for the BV cut
∈(MC)/∈(data)
0
0.5
1
1.5
2
2.5
3
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
π P_t [GeV/c]

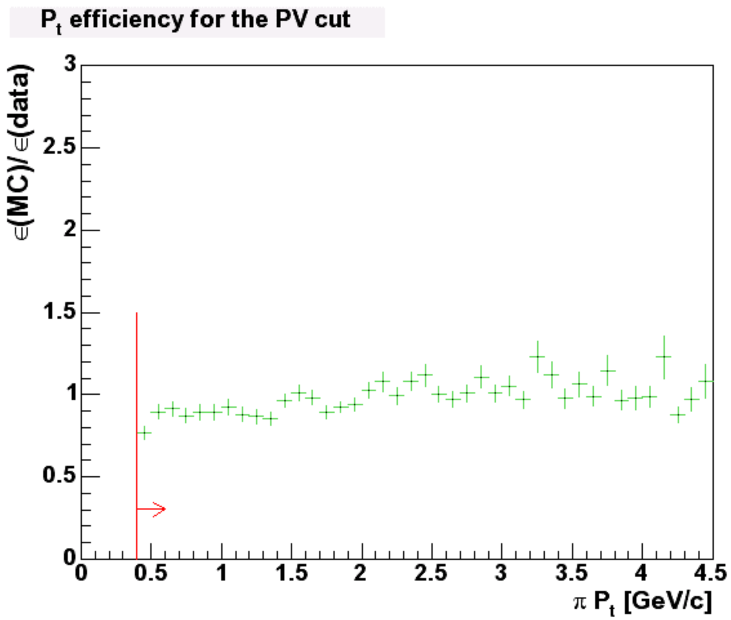


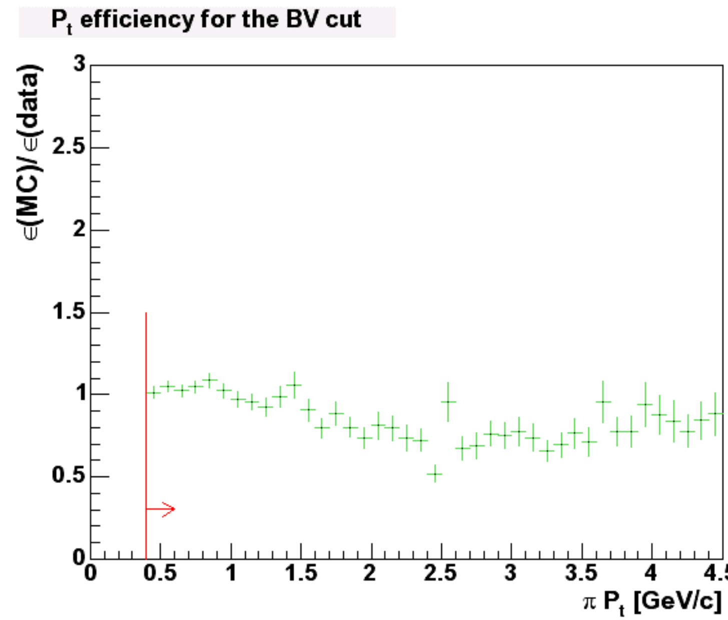
P_t efficiency for the DV cut
∈(MC)/∈(data)
0
0.5
1
1.5
2
2.5
3
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
π P_t [GeV/c]

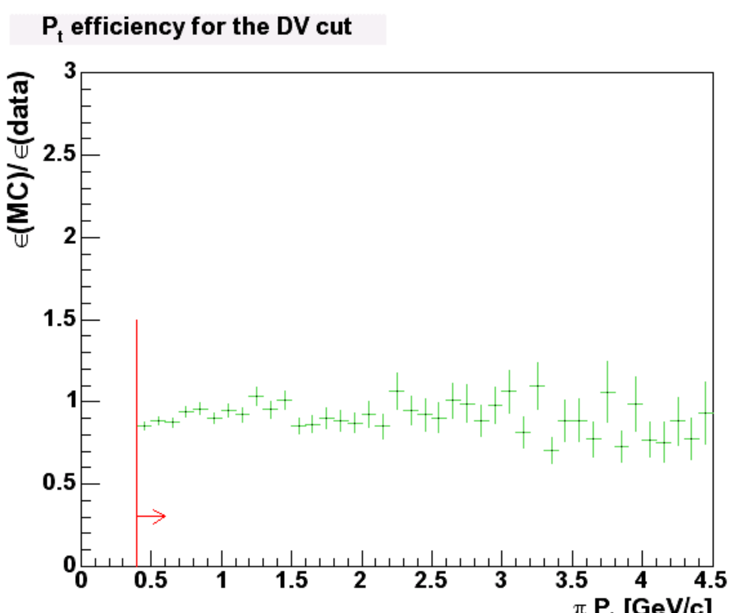


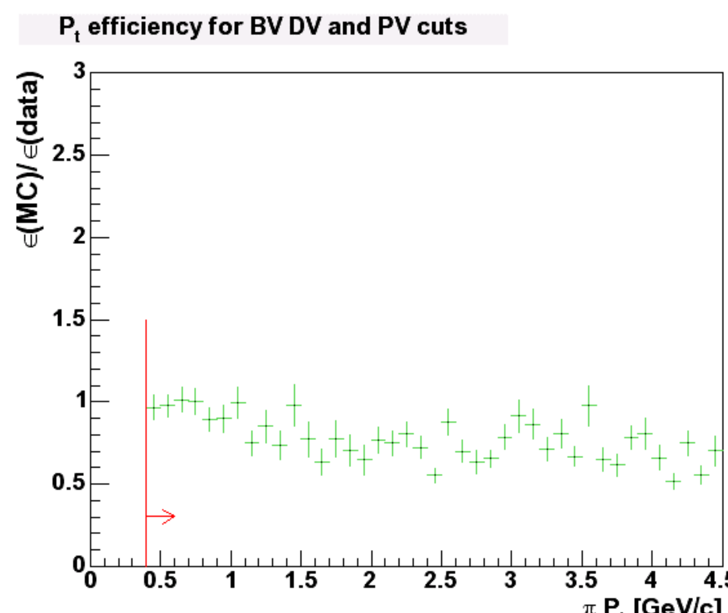
P_t efficiency for BV DV and PV cuts
∈(MC)/∈(data)
0
0.5
1
1.5
2
2.5
3
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
π P_t [GeV/c]

All non-trigger *D** daughters



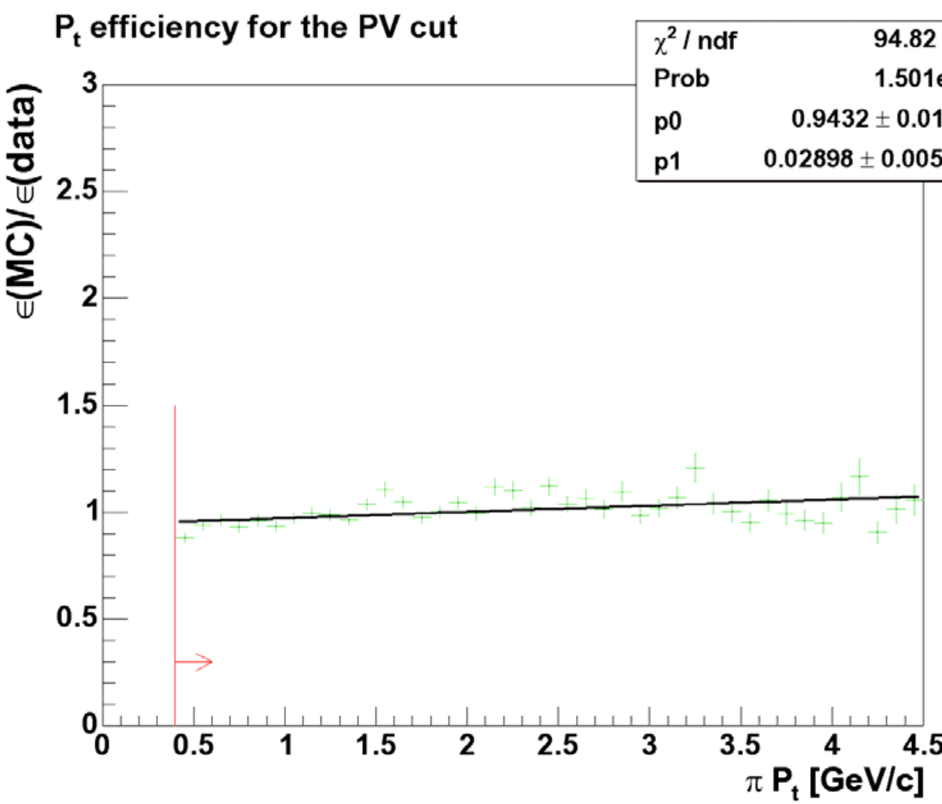


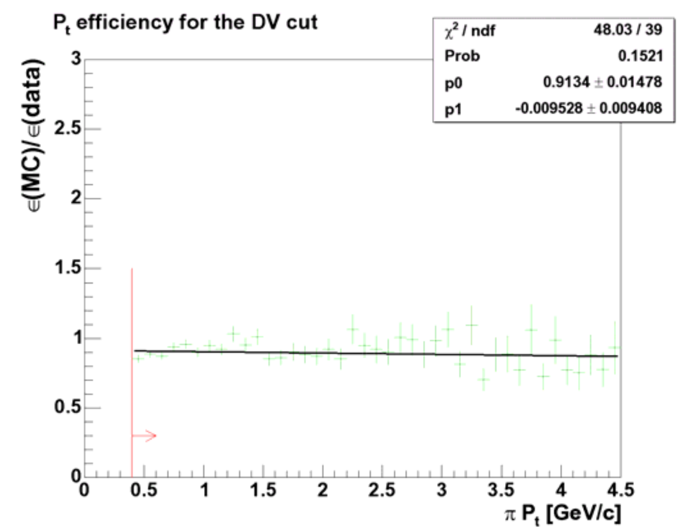


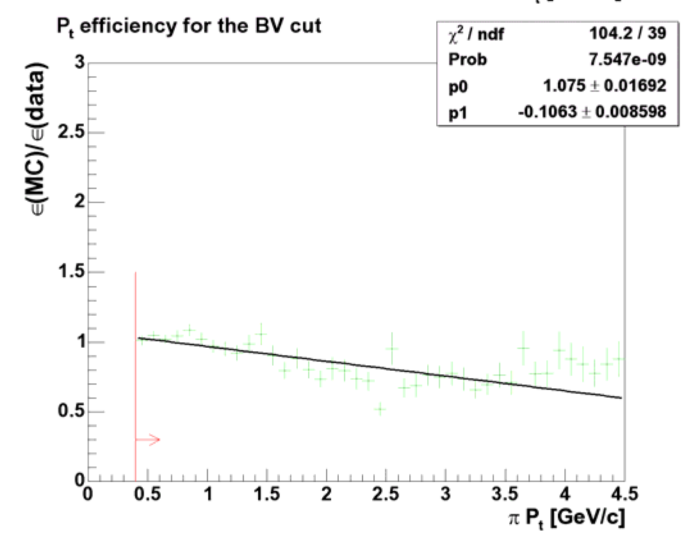


New corrections

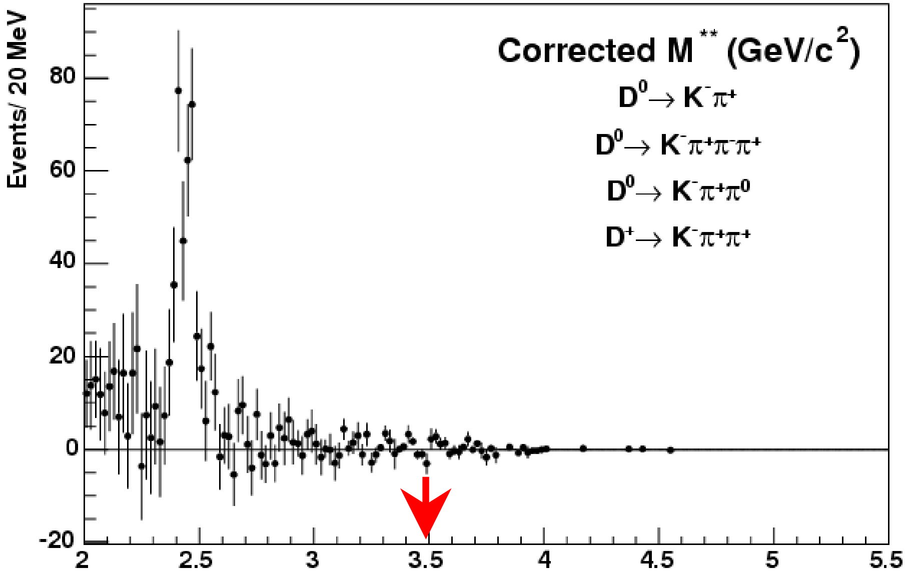
- Use all D^* daughters to estimate PV, BV and DV alone, based on a linear fit
- Replace with flat line fit to estimate systematics







m^{**} cutoff



- Cut-off is a tool to trade off statistics↔systematics
- None of this affects m_1 substantially: $\boldsymbol{m_2}$ ($\sim m^4$) is more sensitive
- Extrapolation attempted (both functional and with MC histograms):
  - Systematic error with cut-off ~ statistical error without cut-off
  - Introduces model-dependency

We have removed the cutoff

- Larger (~x1.5 for m_2) statistical uncertainty than what shown last week
- Improved efficiency corrections make it more reasonable than what initially estimated
- Completely model-independent
- ***0*** systematics from cut-off
- Expect a significant shift in $\boldsymbol{m_2}$

New Results

systematics

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	0.16	0.69	0.037	0.25	0.075	0.055
Total systematic	0.08	0.20	0.065	0.12	0.090	0.082
Mass resolution	0.02	0.13	0.005	0.04	0.012	0.009
Efficiency (data)	0.03	0.13	0.006	0.05	0.014	0.011
Efficiency (MC)	0.06	0.05	0.016	0.03	0.017	0.006
p_l^* cut	—	—	0.001	0.00	0.001	0.000
Background scale	0.01	0.03	0.002	0.01	0.003	0.002
Physics background	0.01	0.02	0.002	0.01	0.004	0.002
D^+/D^{*+} BR	0.01	0.02	0.002	0.01	0.004	0.002
D^+/D^{*+} Eff.	0.02	0.03	0.004	0.01	0.005	0.002
Semileptonic BR's	—	—	0.062	0.10	0.064	0.022
ρ_1	—	—	—	—	0.041	0.069
T_i	—	—	—	—	0.032	0.031
α_s	—	—	—	—	0.018	0.007
m_b, m_c	—	—	—	—	0.001	0.008
Choice of p_l^* cut	—	—	—	—	0.019	0.009

Old values

0.02	0.34
0.03	0.29

New Results

moments

OLD

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

NEW

$$m_1 = (5.83 \pm 0.16_{\rm stat} \pm 0.08_{\rm syst})\ {\rm GeV}^2$$
$$m_2 = (1.30 \pm 0.69_{\rm stat} \pm 0.20_{\rm syst})\ {\rm GeV}^4$$

- m_2 significantly affected, as expected
- Change is within statistical error:

$$(1.30-0.85)= \mathbf{0.45} \sim \mathbf{0.48} = (0.69^2-0.49^2)^{1/2}$$

OLD

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

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

NEW

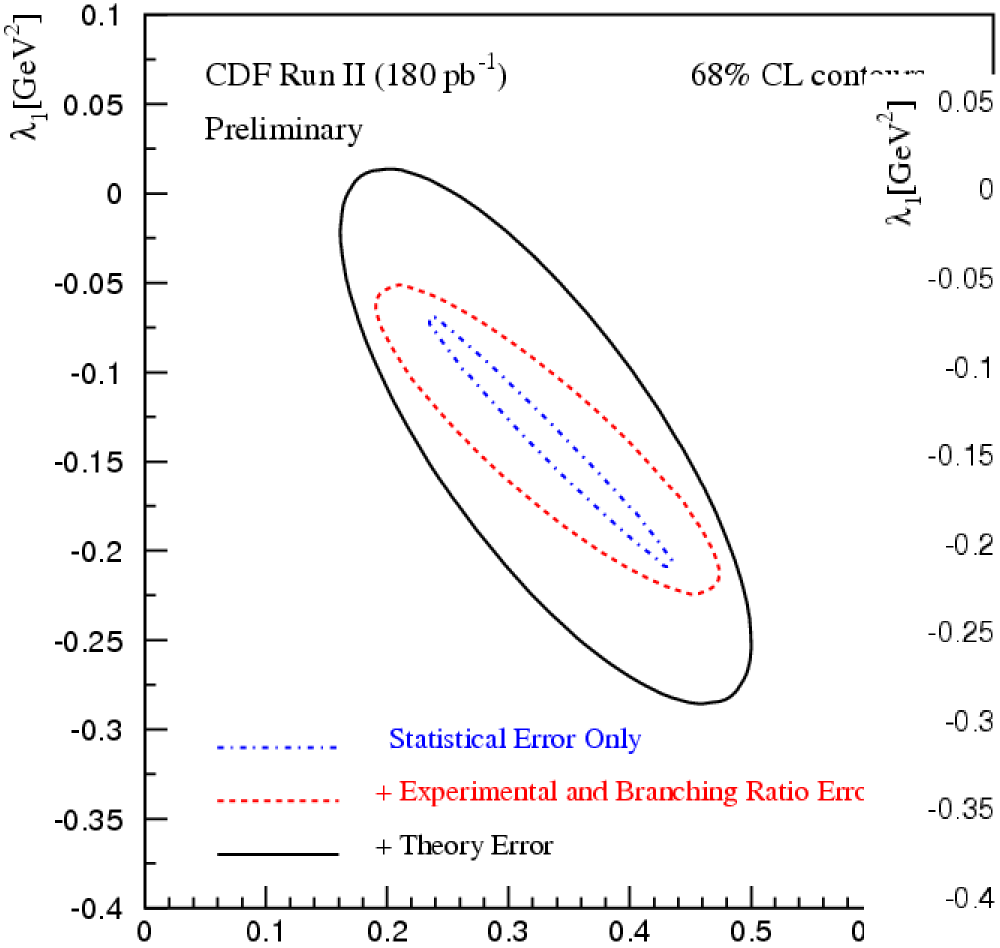
$$M_1 = (0.459 \pm 0.037_{\rm stat} \pm 0.019_{\rm exp} \pm 0.062_{\rm BR})\ {\rm GeV}^2$$
$$M_2 = (1.04 \pm 0.25_{\rm stat} \pm 0.07_{\rm exp} \pm 0.10_{\rm BR})\ {\rm GeV}^4 \quad ,$$

$$\Lambda = (0.390 \pm 0.075_{\rm stat} \pm 0.026_{\rm exp} \pm 0.064_{\rm BR} \pm 0.058_{\rm theo})\ {\rm GeV}$$
$$\lambda_1 = (-0.182 \pm 0.055_{\rm stat} \pm 0.016_{\rm exp} \pm 0.022_{\rm BR} \pm 0.077_{\rm theo})\ {\rm GeV}^2$$

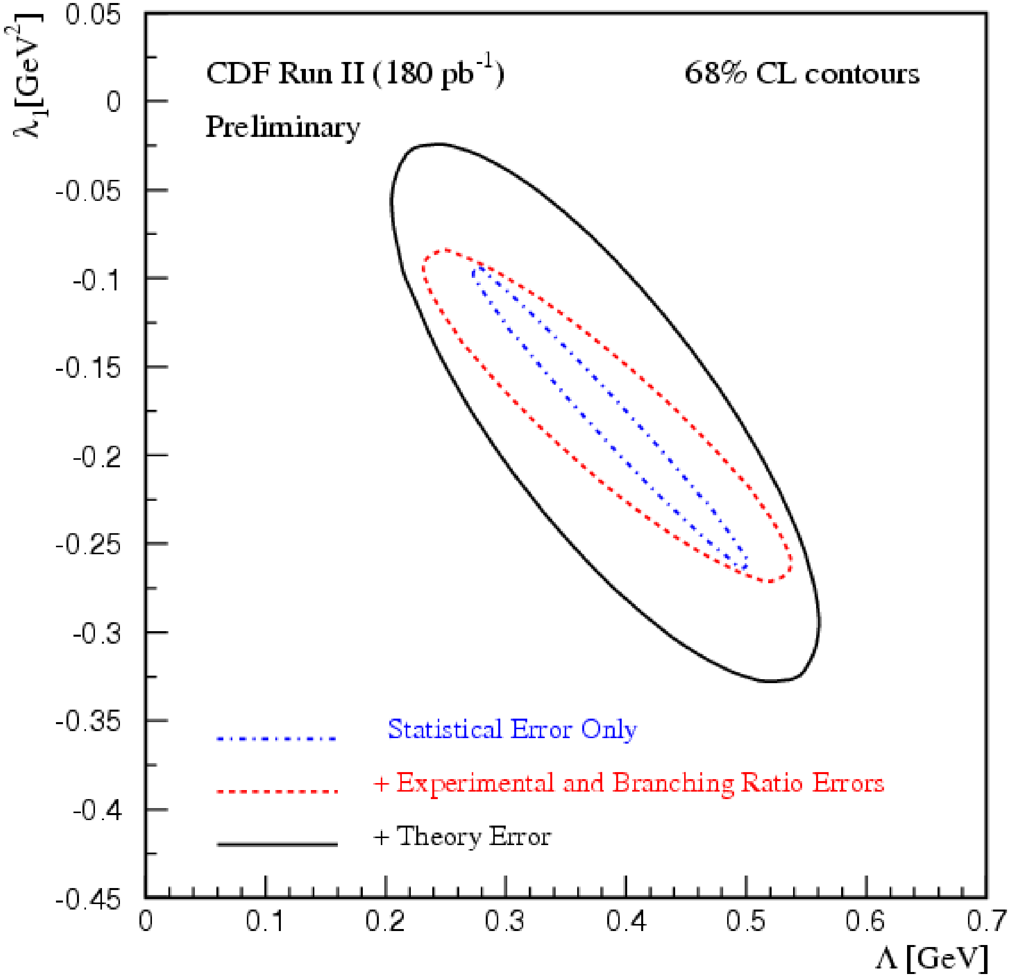
Λ , λ_1

Histogram *y* ranges are different!!!

OLD



NEW



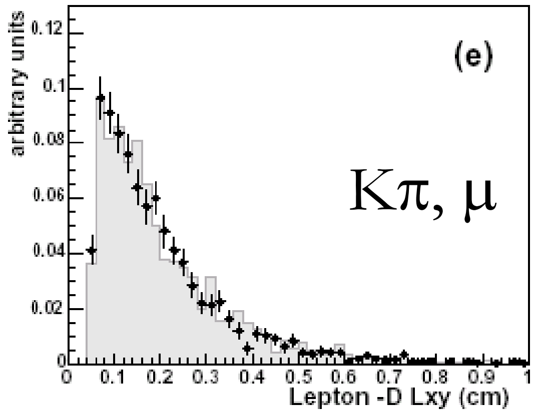
Questions from preblessing

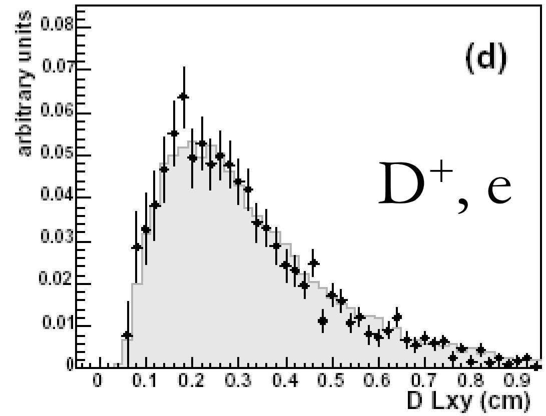
“Reconstruction efficiency of soft pion from D^* will have to be understood with respect to the D^-.”

- This efficiency only relevant for relative D^+/D^{*+} normalization.
- Analysis uses D^+/D^* efficiency ratio from MC
- Check:
  - Count D^+ and D^* in data and compare with MC prediction
  - ratio MC/data is 0.87±0.08
  - Assign the full difference as a systematic
- This difference amounts to 13%
- This is anyway a small source of systematics for m_1 and m_2

“Z-hits have not been dropped from this analysis. Double careful for providing that Lxy is reliably predicted.”

- Comparisons of $L_{XY}(l\text{-}D)$ and $L_{XY}(D)$ (figs. 15 and 16 of CDF 6754)





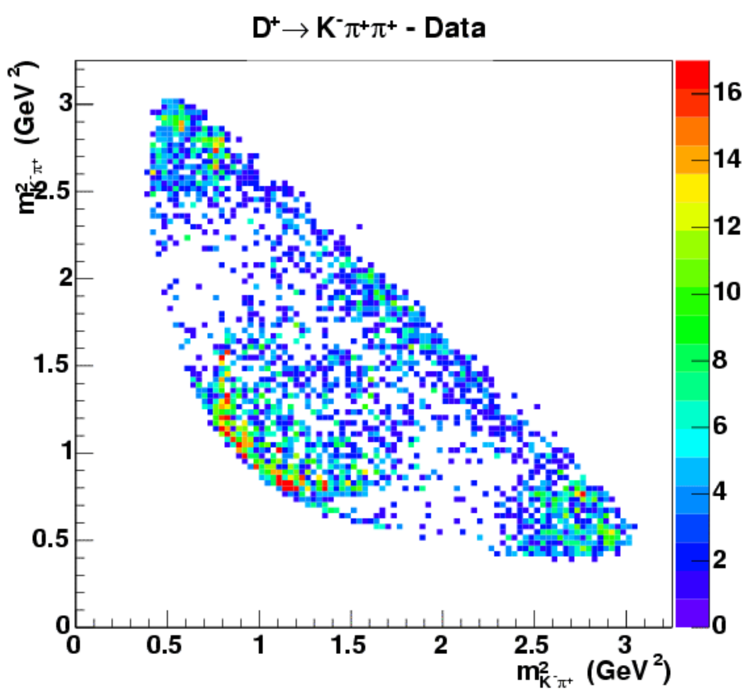
- Data-MC chi-sq probability (in %) comparisons:

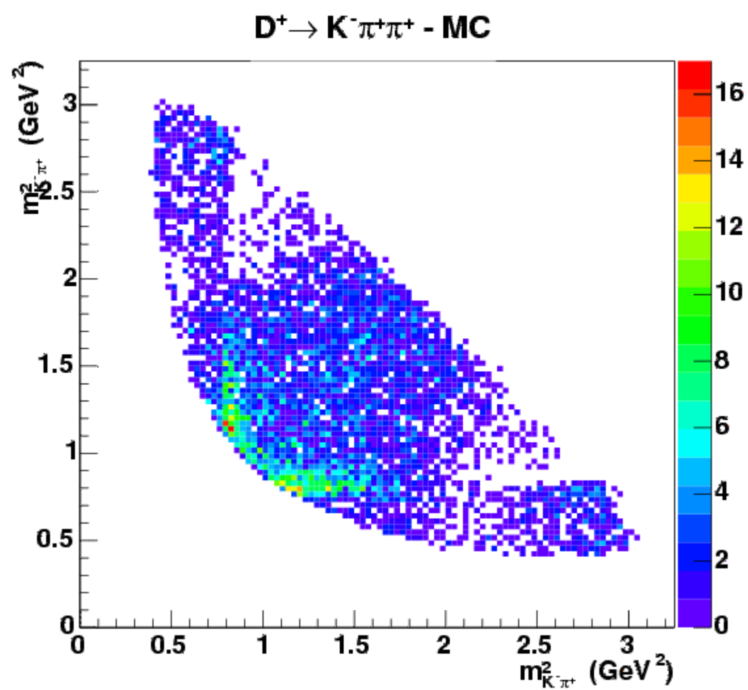
	Kpi		Sat		K3pi		D^+	
	e	μ	e	μ	e	μ	e	μ
Lxy(*l-D*)	48	23	41	12	32	69	29	0.07
Lxy(*D*)	23	88	69	99	95	47	67	2
Lxy(*D→lD*)	61	29	6	13	17	89	24	2

"Check Dalitz structure of D^+ decay to make sure we understand the efficiencies and the possible background beneath the peak, same for D^0."

- Evtgen *includes* Dalitz structure in decay table.
- Comparison of data and MC show disagreement in amount of destructive interference.
- Measurement of D^+/D^{*+} (MC/data) yields = 0.87±0.08

  $\rightarrow$ use 13% systematic uncertainty on relative. normalization





“What is the effect of incompletely reconstructed *D* mesons in the sidebands when you do sideband subtraction? Can you quantify the contributions?”

- For D^*, sideband subtraction is done using Δm. (Shape determined using WS π^*. Normalization from RS sideband region.)
- For D^+, sidebands in $K2\pi$ are used.
- In all cases, fit uses

$$(RS\ signal - WS\ signal) - (RS\ bkgd - WS\ bkgd)\ .$$

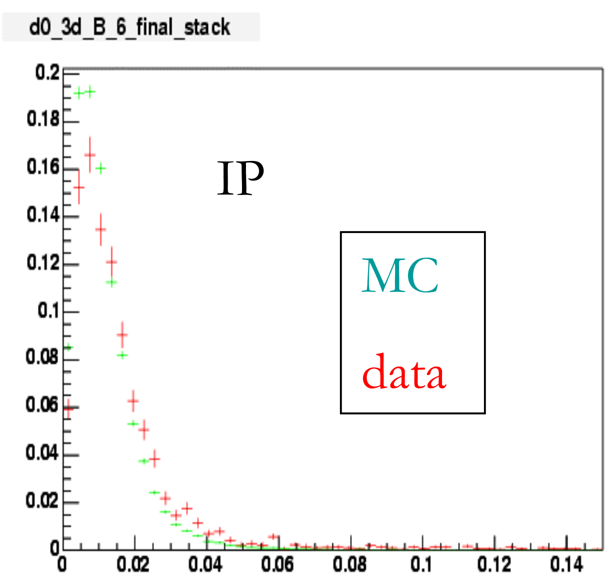
This should statistically remove such partially reconstructed events, at cost of increased statistical uncertainty.

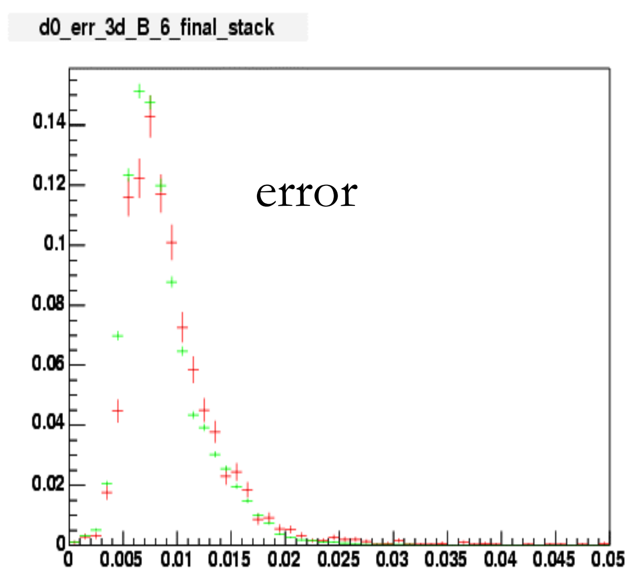
“What is the effect of the auto-reflections in $D^0 \rightarrow K\pi$ and $D^0 \rightarrow K\pi\pi\pi$ in calculating relative rates? $K\pi$ should be negligible but $K3\pi$ there will be some duplicates.”

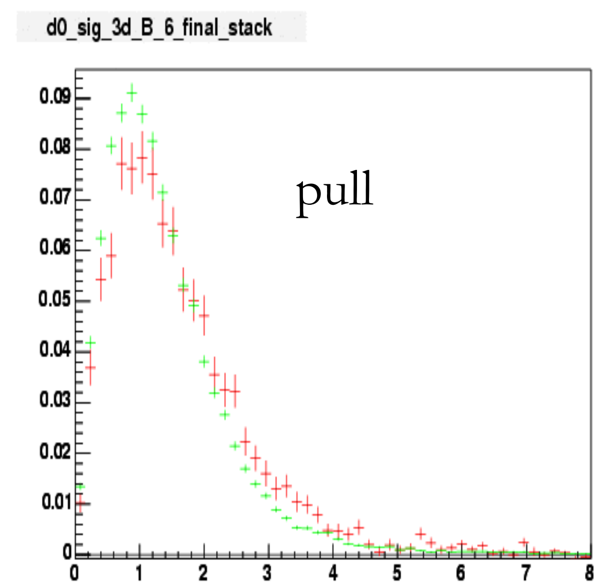
- (10.2 ±0.5)% of $K3\pi$ have duplicates due to K-π swapping.
- We explicitly remove duplicate candidates. (These will give nearly identical Δm.)
- Note: only $D^0 \rightarrow K\pi$ used to calculate normalization w.r.t. D^+.
- $K3\pi / K\pi$ (MC/data) yields = 1.04 ±0.06.

“Comparison of impact parameter significances: it would be nice to understand how the discrepancy between MC and data is split between numerator and denominator”

- BV comparisons significantly worse than PV. Chi-sq indicate neither errors nor values are statistically compatible, pulls better in general
- Both error and value shifted slightly to left for MC relative to data.

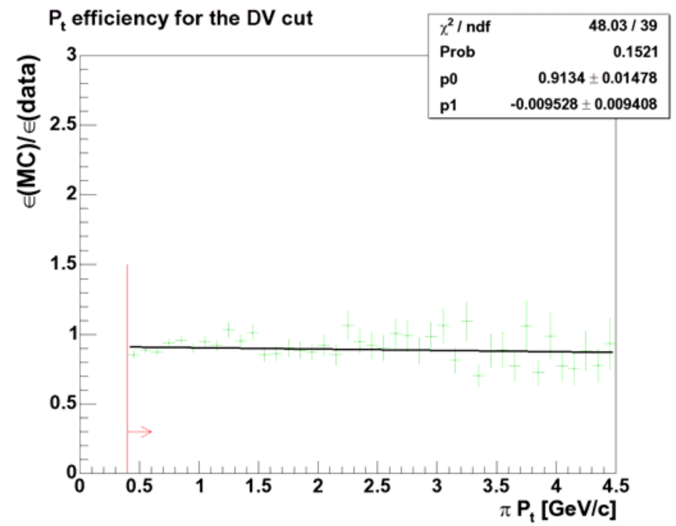


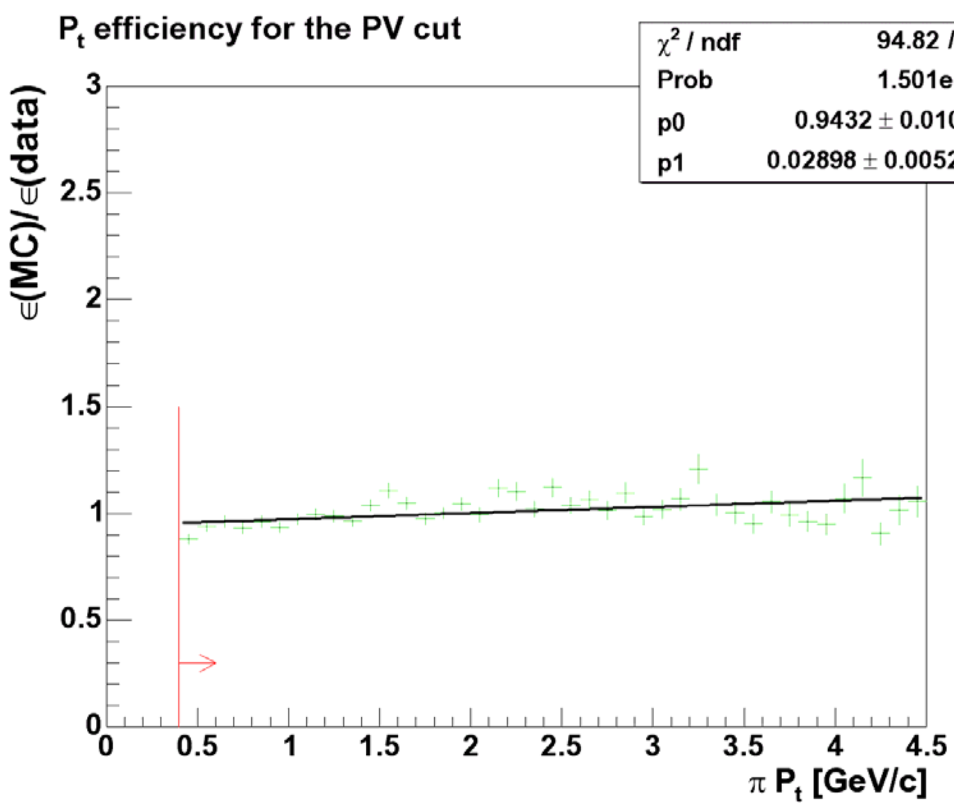


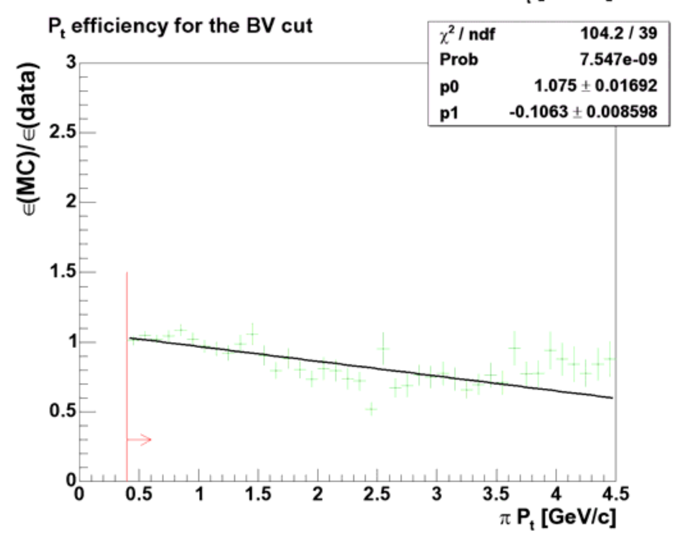


“Systematics for the π^* efficiency should be repeated with more statistics since it dominates the systematics.”

- Done!







“Background from fake leptons and a D^*? How large is it?”

- Masa presented study of fake rates using WS l-D^0 and l-D^* (10 Feb and 17 Feb, Semileptonic mtg.)
- μ and e rates similar: 5-6 %
- Study of RS e fakes using dE/dx shows #(RS fakes)~# (WS fakes)

  $$(212 \pm 34)\mathrm{RS} : (360 \pm 40)\mathrm{WS}.$$

  Although ~2σ difference, allow for ~25% charge asymmetry.
- This would imply a ≤ 6%×25% = 1.5% correction after WS π^{**} subtraction.
- This is small compared to the 4% charge asymmetry systematic uncertainty used in this analysis.

“Background shape from the embedding technique has to be finished and presented.”

- After **300** embedding passes on complete fully-reconstructed sample, only ~30 events pass final selection cuts.

  More passes through embedding would result in same events being used multiple times.
- With current fully-reconstructed statistics, we cannot reliably measure shape.

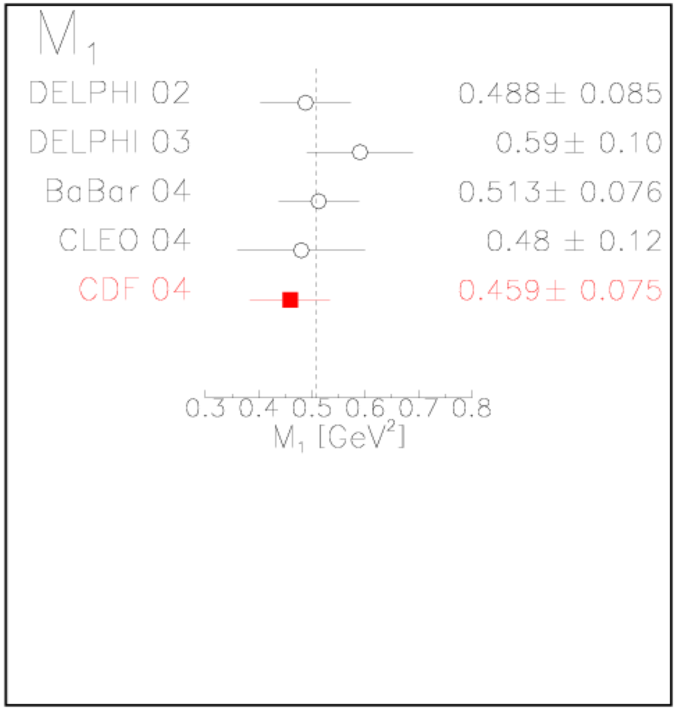
  We are forced to use WS events for background model.

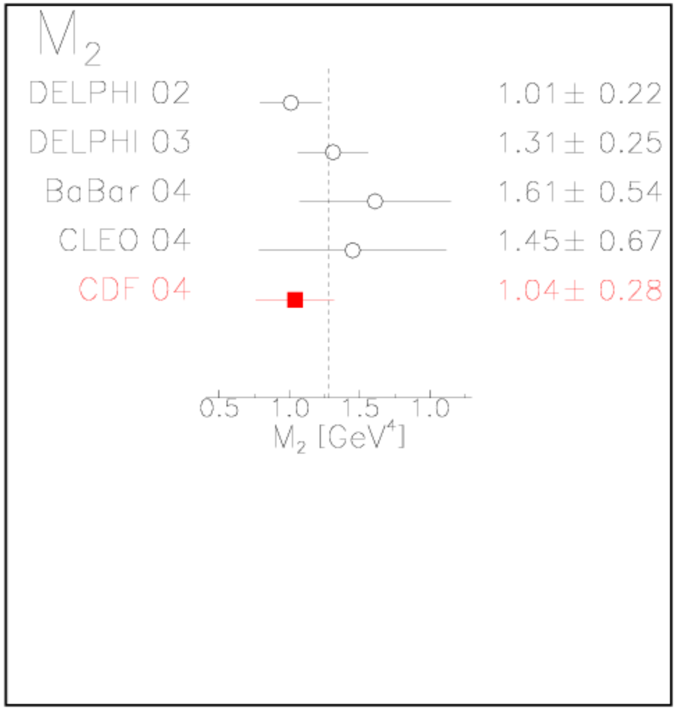
"What happens when you do not cut on the m^{**} distribution?"

- We have removed this cut from the default analysis. See previous discussion.

"How do the results compare to other experiments?"

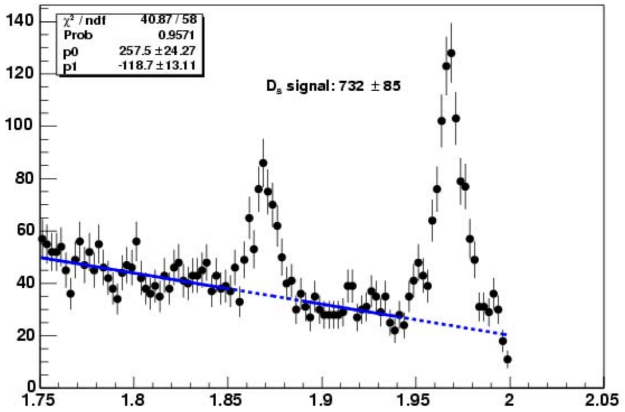
- Warning: results from other experiments translated to *p(l*)* >700 MeV by us for comparison only (assumes HQET ok)





"There may be '*D***' states that do not decay through $D^{(*)+}\pi$." (Elliot Lipeles)

- DELPHI has put limits on radial excitations (*D'*).
- We have looked for possible $D_S K$ states and see no evidence.
  - reconstructed $D_s \rightarrow \phi\pi$, "K**" not in the fit, std D^+ selection



after all out cuts:
RS K**-l: -4.4±9.9 evts
WS K**-l: 2.3±8.9 evts

- This analysis based on assumption that *D*** spectrum saturated by $D^{(*)}\pi$.

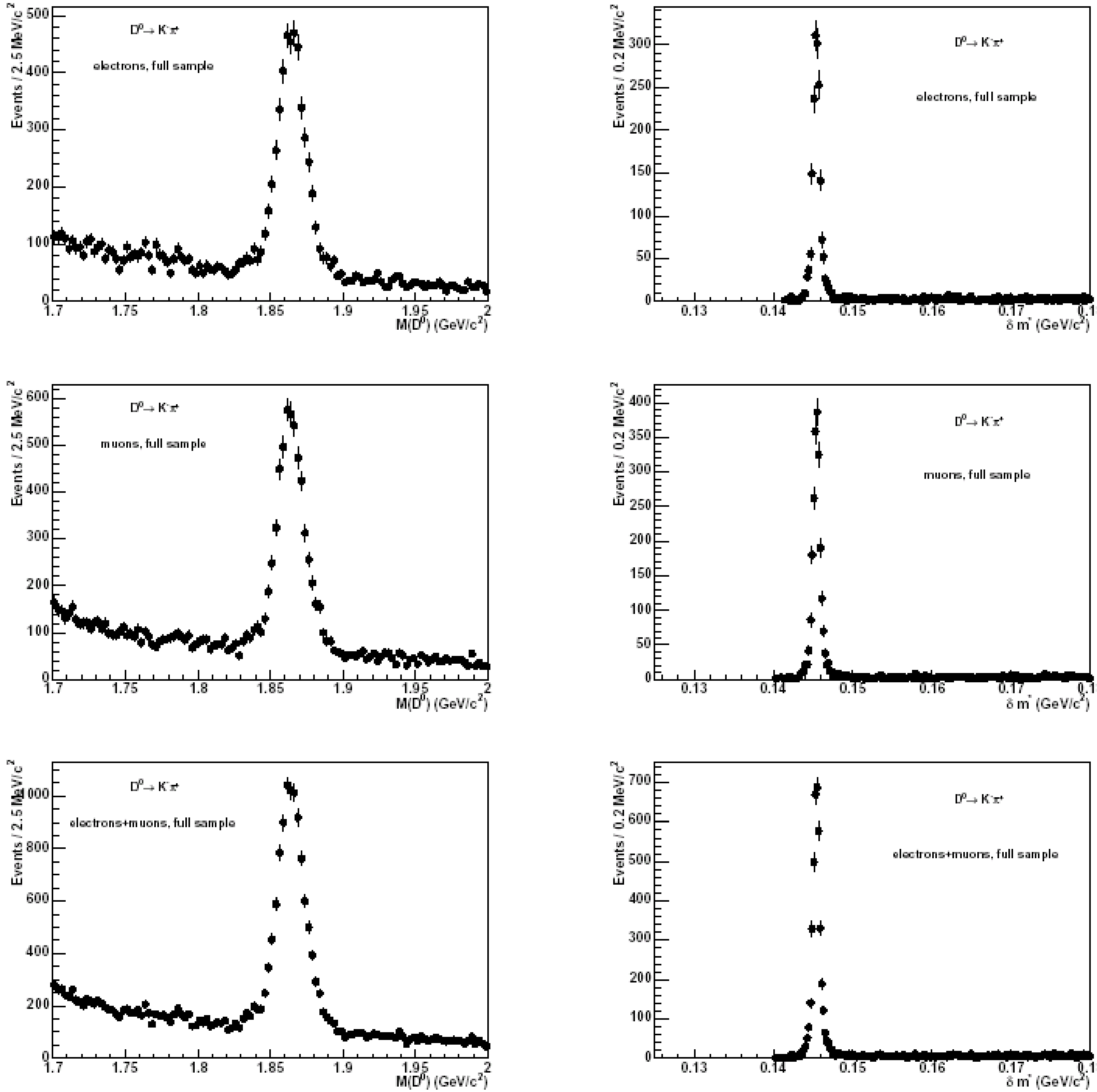
"Denser events may have higher failure rates in fully reconstructed *B* modes than in semileptonic modes. Could this affect 4% estimate of charge asymmetry uncertainty?"

(Matt Herndon)

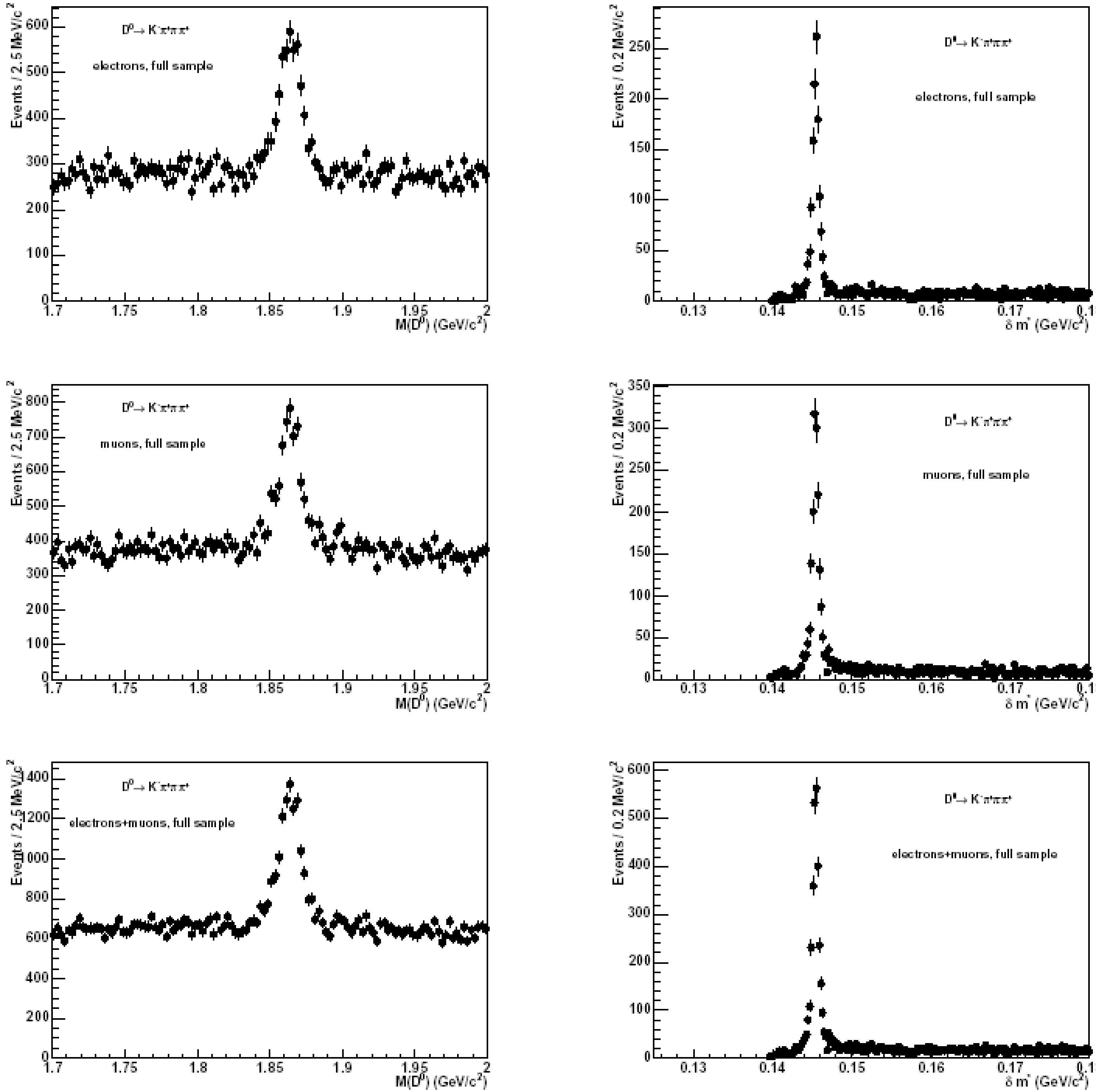
- **4%** is product of two factors:
  - **~20%** charge asymmetry in **underlying tracks** around $B^{\pm}$
  - **~20%** from $\boldsymbol{B^{\pm}}$ **content** in l-$D^{(*)+}$ sample
- Charge asymmetry similar in size to that observed in SST analyses.
- 4% uncertainty translates into one of our <u>smaller</u> systematics in our analysis.

Results to bless

Mass plots:
Kπ channel
m and δm

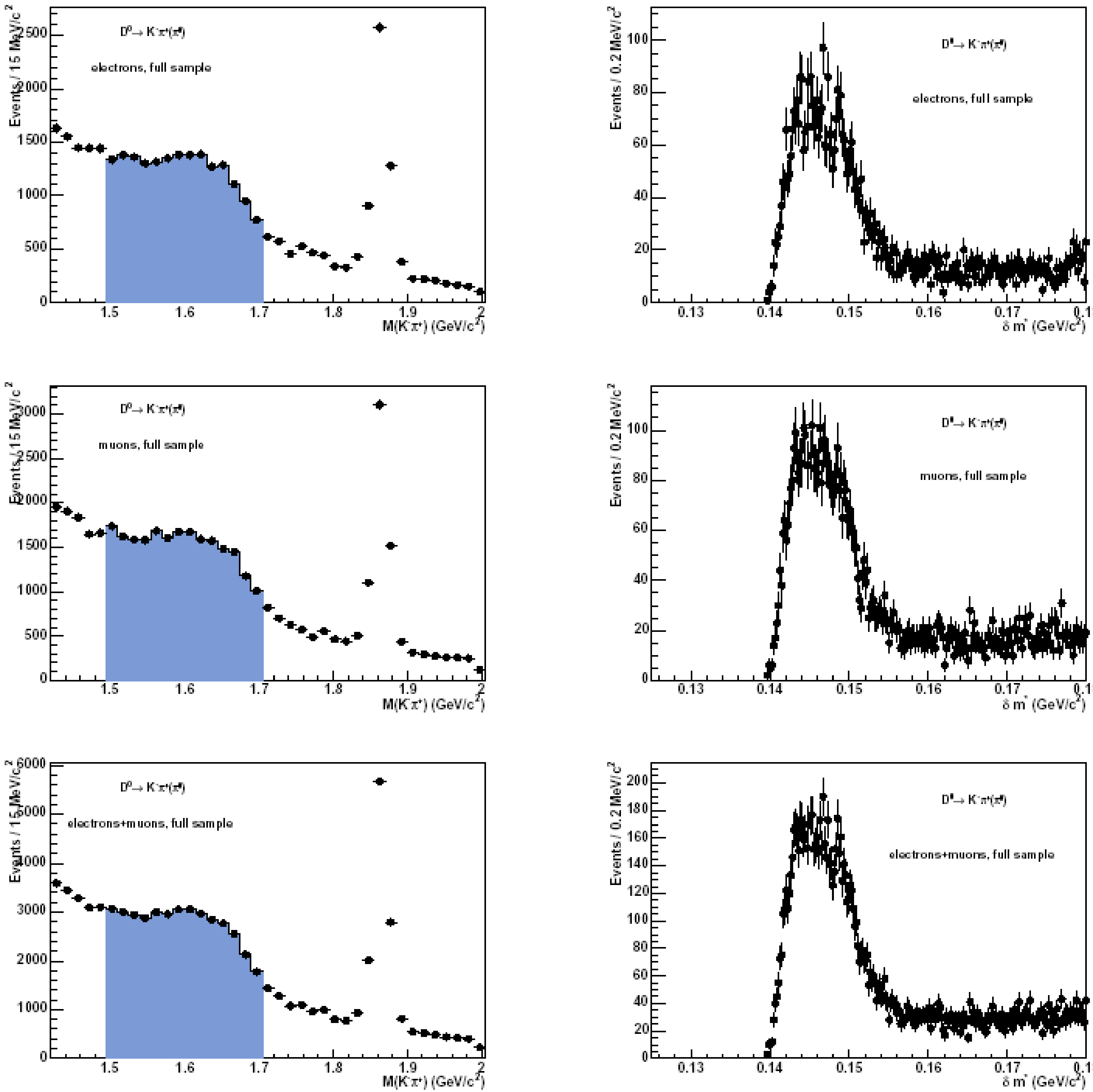


Mass plots: Kπππ channel m and δm

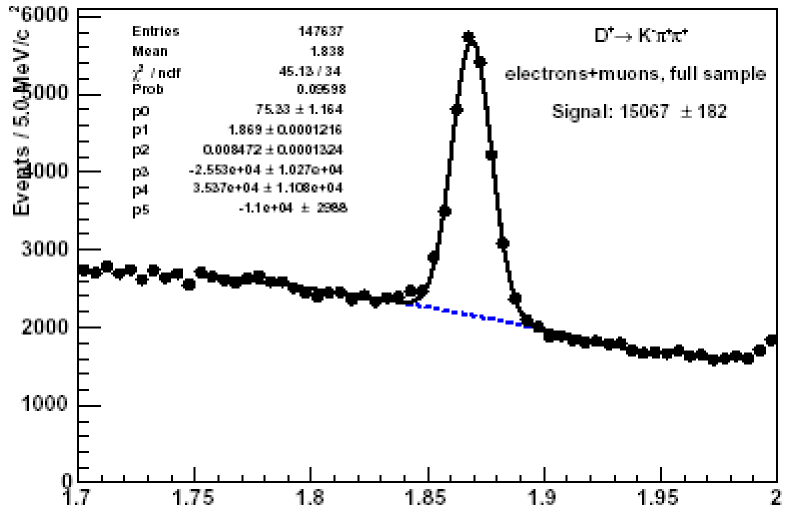


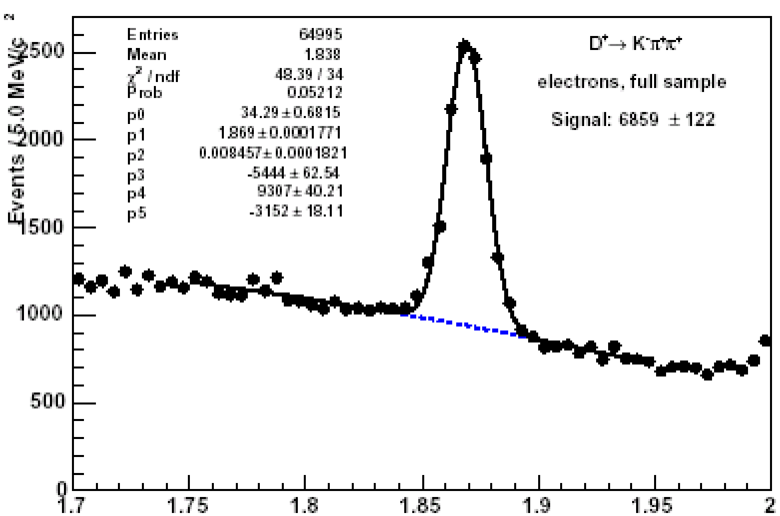
Mass plots: $K\pi\pi^0$ channel

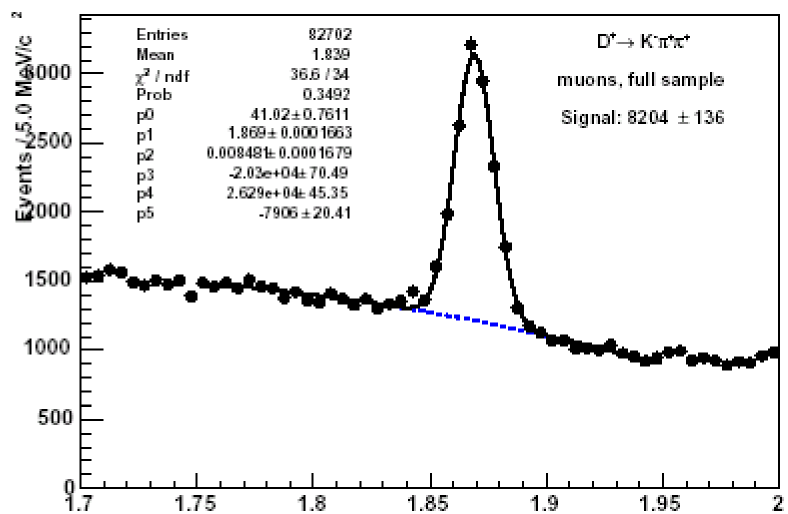
m and δm



Mass plots:
D^+ channel
m



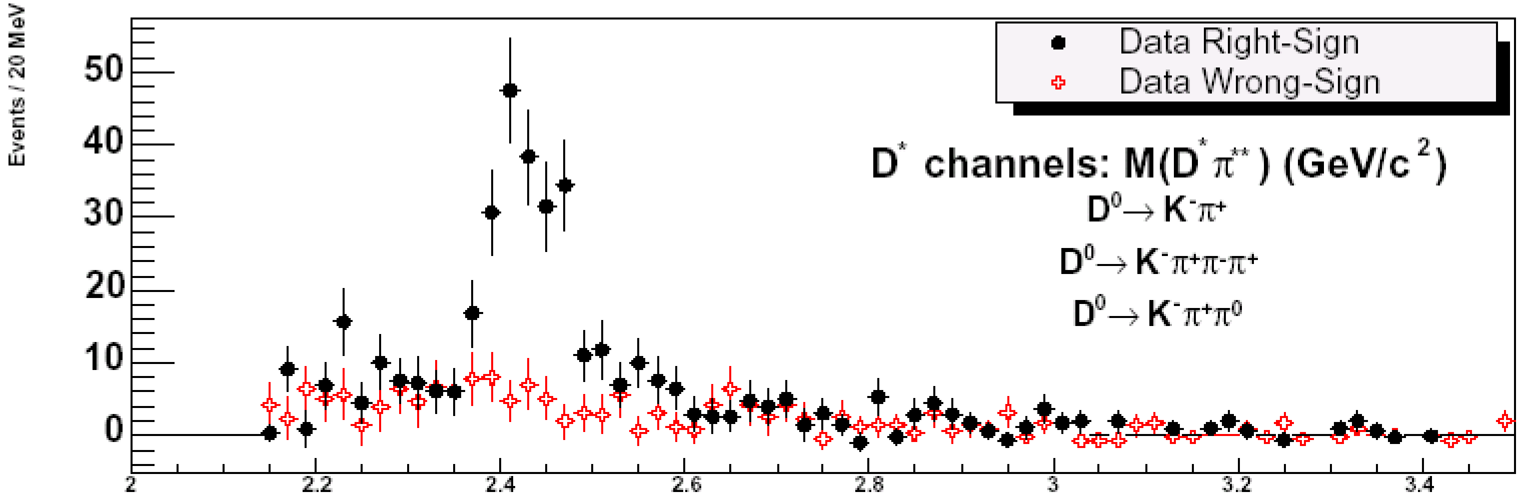


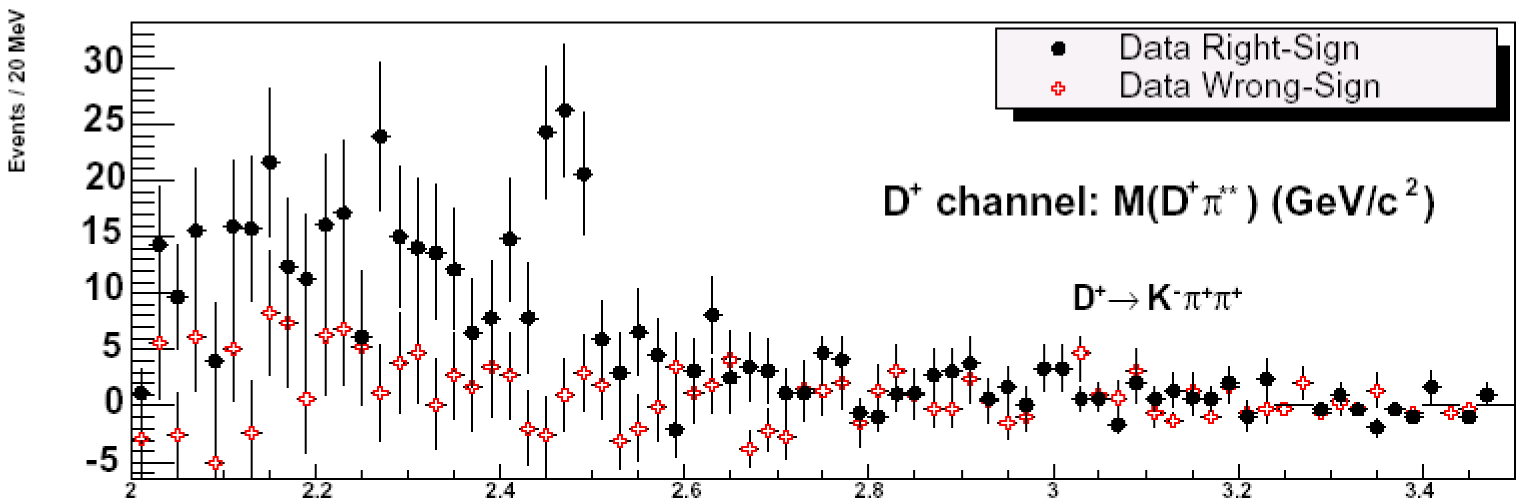


Yields:
for ~180 pb^{-1}

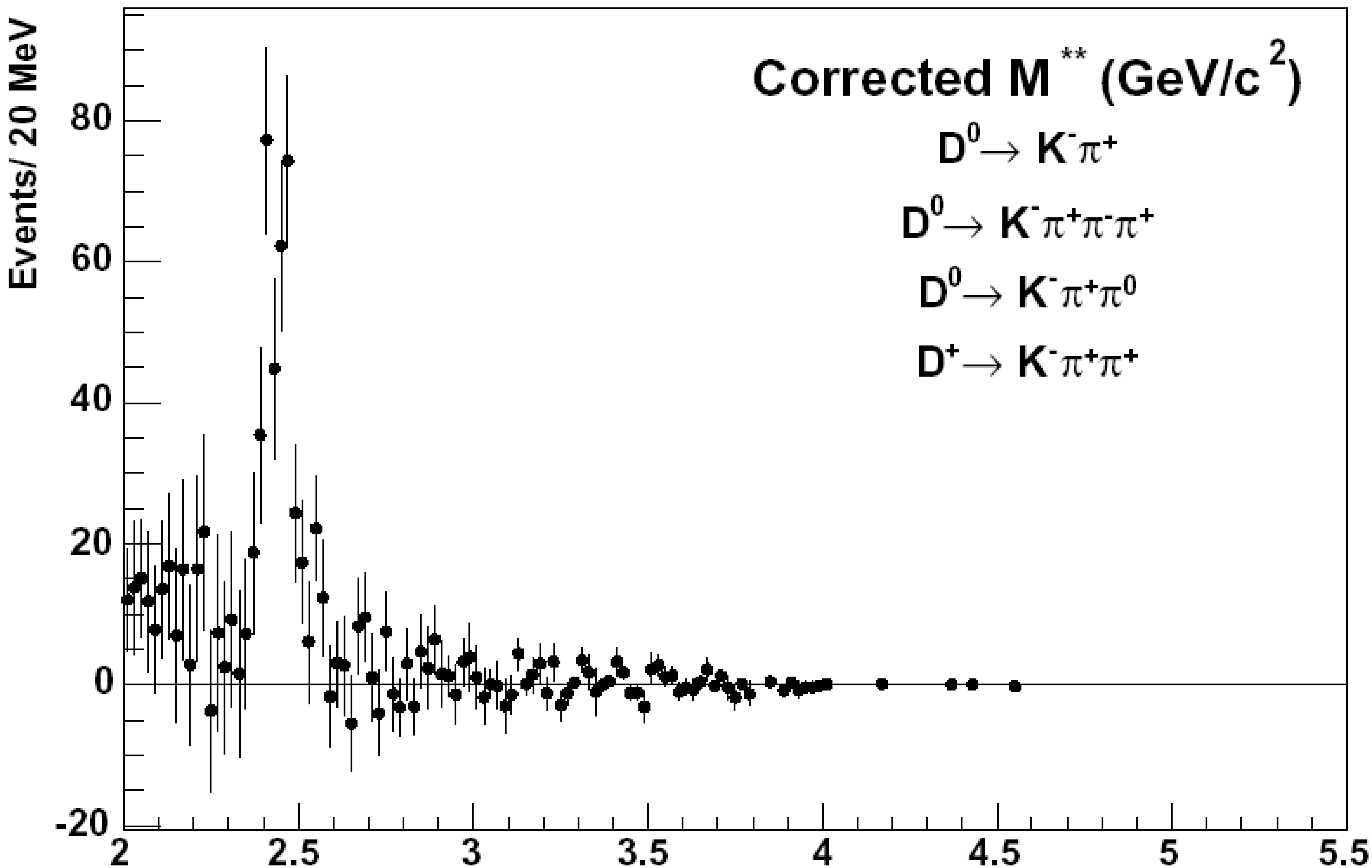
	D^{*+} channels			D^{+} channel
	$K^-\pi^+$	$K^-\pi^+\pi^-\pi^+$	$K^-\pi^+\pi^0$	$K^-\pi^+\pi^+$
$D^{(*)+}l^-$ yields				
Electrons	1723 ± 42	1299 ± 38	3037 ± 66	6859 ± 122
Muons	2168 ± 47	1695 ± 43	3611 ± 72	8204 ± 136
Combined	3890 ± 63	2994 ± 57	6638 ± 98	14416 ± 202

Raw m** distribution for signal and background:





Fully corrected m** distribution:



Systematics:

pole mass scheme:

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	0.16	0.69	0.037	0.25	0.075	0.055
Total systematic	0.08	0.20	0.065	0.12	0.090	0.082
Mass resolution	0.02	0.13	0.005	0.04	0.012	0.009
Efficiency (data)	0.03	0.13	0.006	0.05	0.014	0.011
Efficiency (MC)	0.06	0.05	0.016	0.03	0.017	0.006
p_l^* cut	—	—	0.001	0.00	0.001	0.000
Background scale	0.01	0.03	0.002	0.01	0.003	0.002
Physics background	0.01	0.02	0.002	0.01	0.004	0.002
D^+/D^{*+} BR	0.01	0.02	0.002	0.01	0.004	0.002
D^+/D^{*+} Eff.	0.02	0.03	0.004	0.01	0.005	0.002
Semileptonic BR's	—	—	0.062	0.10	0.064	0.022
ρ_1	—	—	—	—	0.041	0.069
T_i	—	—	—	—	0.032	0.031
α_s	—	—	—	—	0.018	0.007
m_b, m_c	—	—	—	—	0.001	0.008
Choice of p_l^* cut	—	—	—	—	0.019	0.009

Systematics (cont'd):

theo. systematic uncertainties for 1S scheme (exp. syst. similar to pole mass scheme):

Error	Δm_b^{1S} (GeV)	$\Delta\lambda_1$ (GeV^2)
ρ_1	0.060	0.077
T_i	0.049	0.048
α_s	0.006	0.004
m_b, m_c	0.002	0.006
Choice of p_l^* cut	0.043	0.023

Results:

Moments:

$$m_1 = (5.83 \pm 0.16_{\rm stat} \pm 0.08_{\rm syst})\ {\rm GeV}^2$$
$$m_2 = (1.30 \pm 0.69_{\rm stat} \pm 0.20_{\rm syst})\ {\rm GeV}^4$$

(61% correlation)

$$M_1 = (0.459 \pm 0.037_{\rm stat} \pm 0.019_{\rm exp} \pm 0.062_{\rm BR})\ {\rm GeV}^2$$
$$M_2 = (1.04 \pm 0.25_{\rm stat} \pm 0.07_{\rm exp} \pm 0.10_{\rm BR})\ {\rm GeV}^4$$

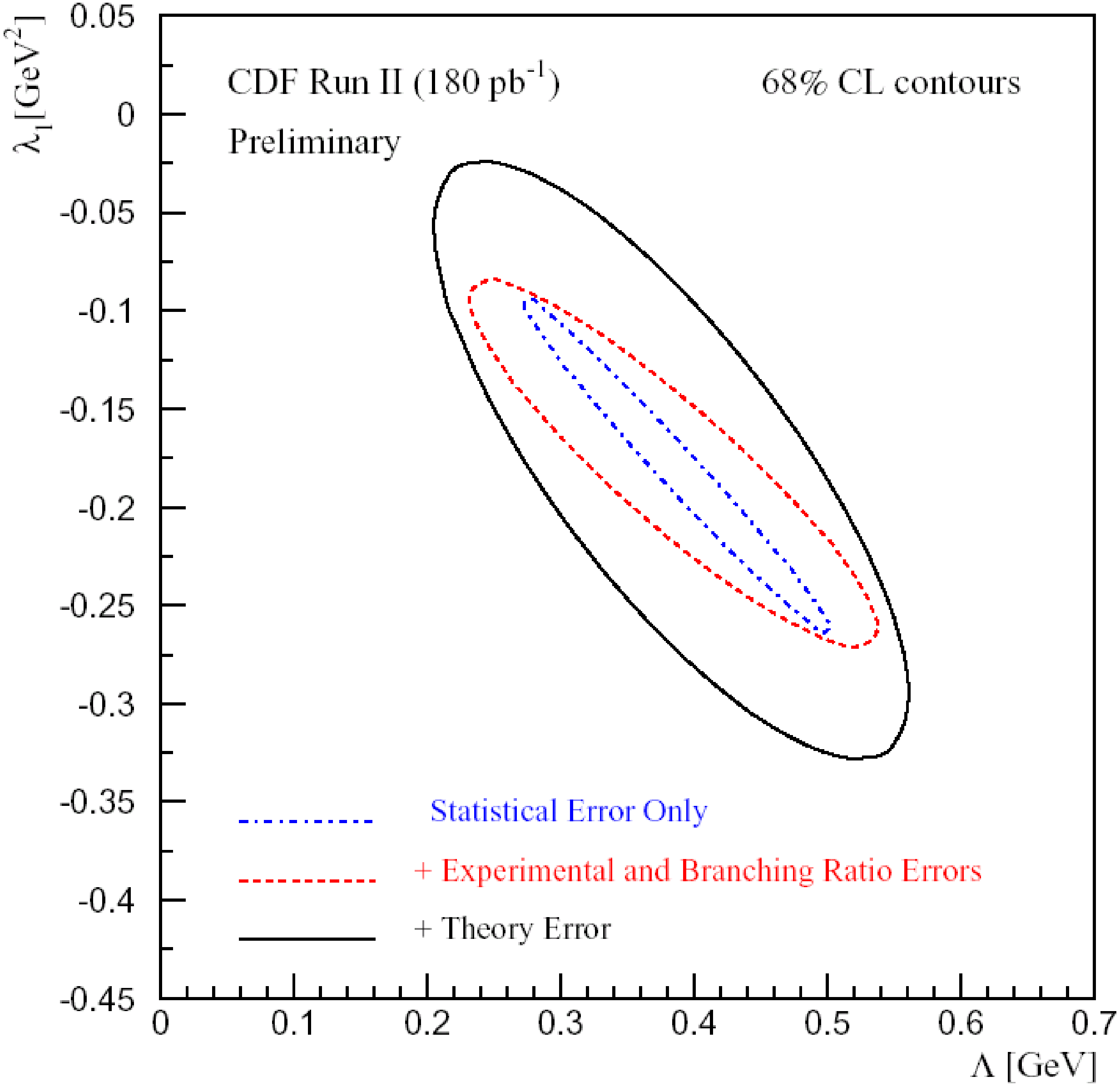
(69% correlation)

HQET parameters:

$$\Lambda = (0.390 \pm 0.075_{\rm stat} \pm 0.026_{\rm exp} \pm 0.064_{\rm BR} \pm 0.058_{\rm theo})\ {\rm GeV}$$
$$\lambda_1 = (-0.182 \pm 0.055_{\rm stat} \pm 0.016_{\rm exp} \pm 0.022_{\rm BR} \pm 0.077_{\rm theo})\ {\rm GeV}^2$$

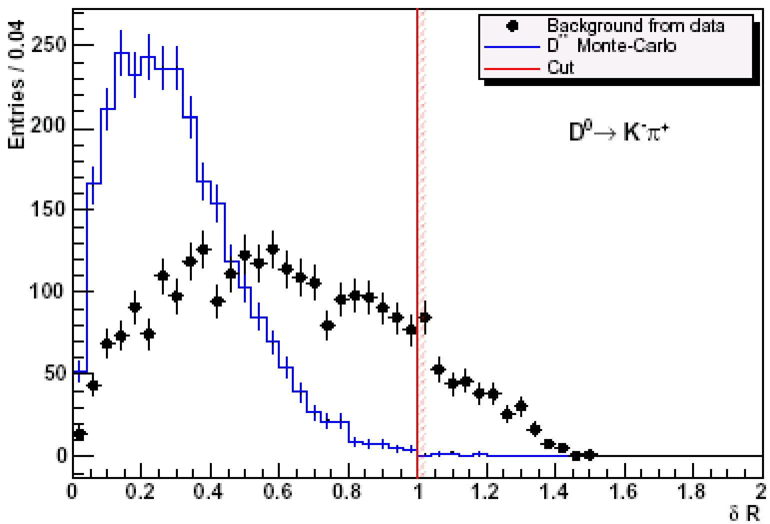
$$m_b^{1S} = (4.661 \pm 0.076_{\rm stat} \pm 0.026_{\rm exp} \pm 0.064_{\rm BR} \pm 0.089_{\rm theo})\ {\rm GeV}$$
$$\lambda_1 = (-0.276 \pm 0.047_{\rm stat} \pm 0.016_{\rm exp} \pm 0.022_{\rm BR} \pm 0.094_{\rm theo})\ {\rm GeV}^2$$

Results (cont'd):



Additional material we want to bless (mostly plots for seminar purposes)

Illustration of kinematical variables:



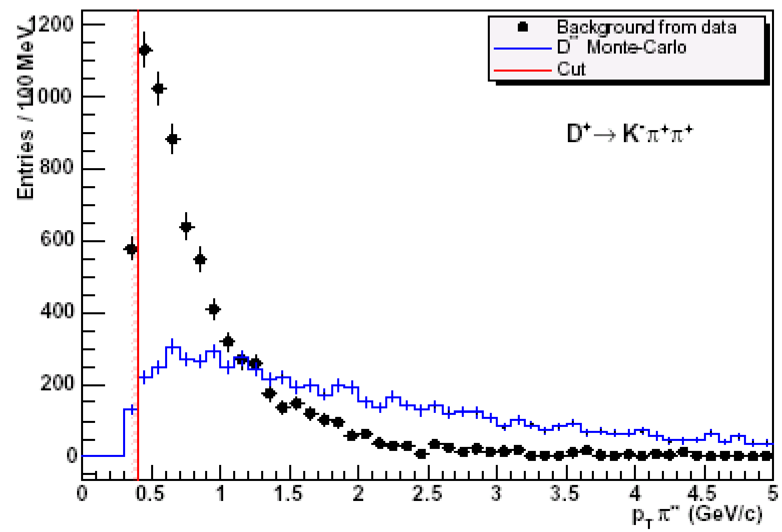
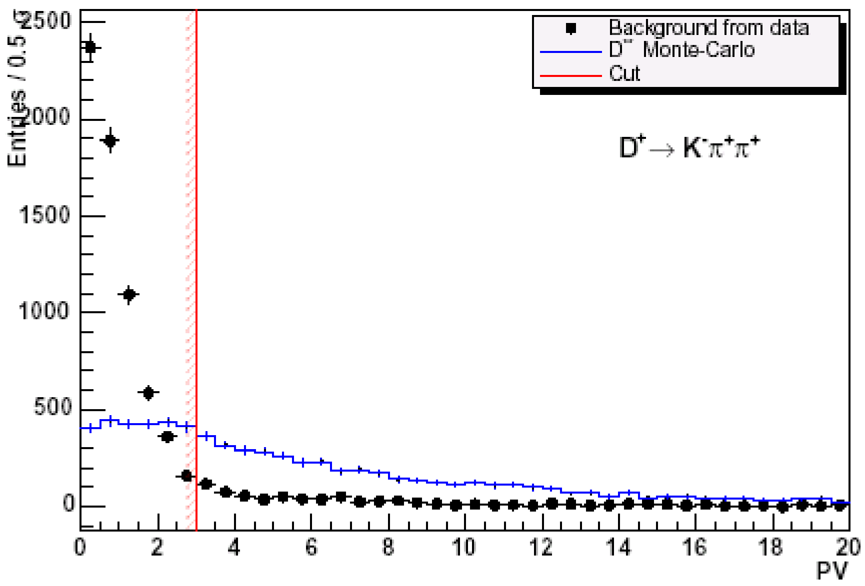
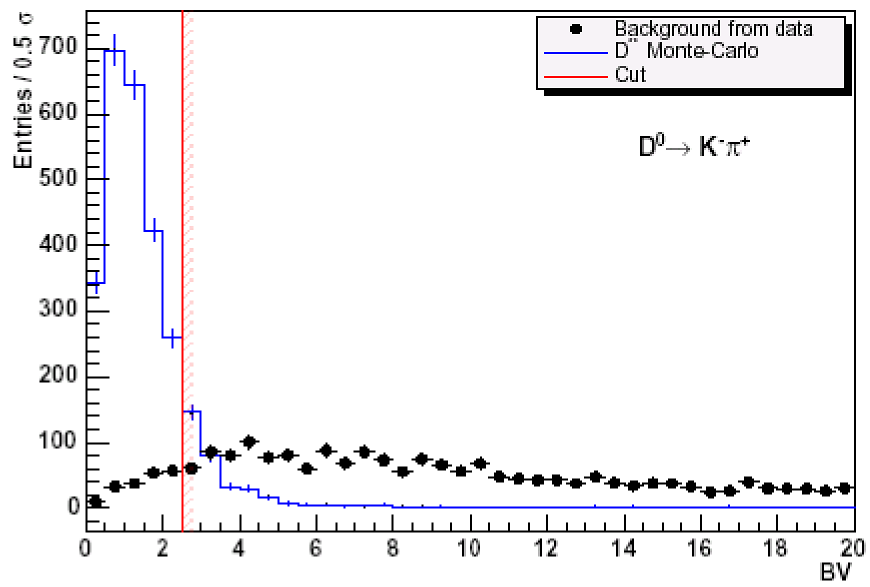
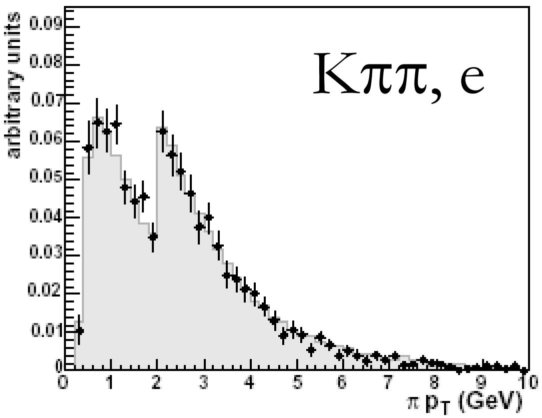


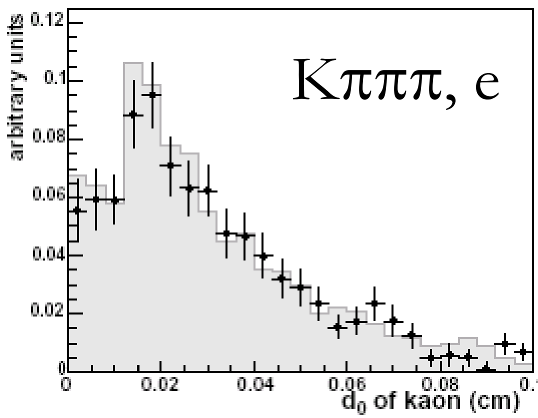
Illustration of topological variables:

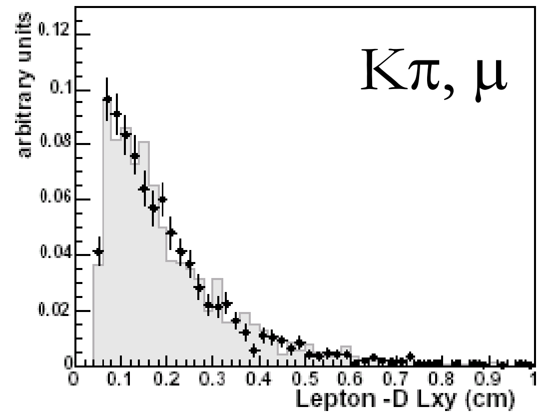


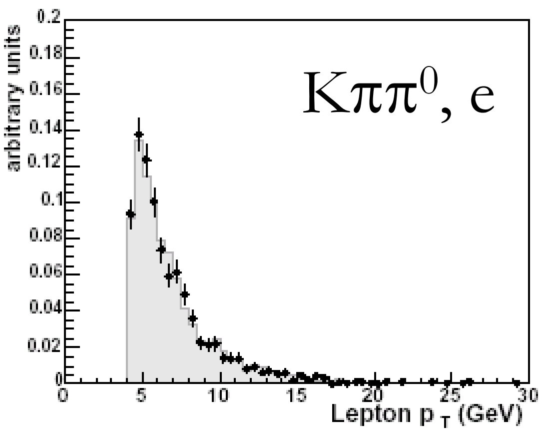


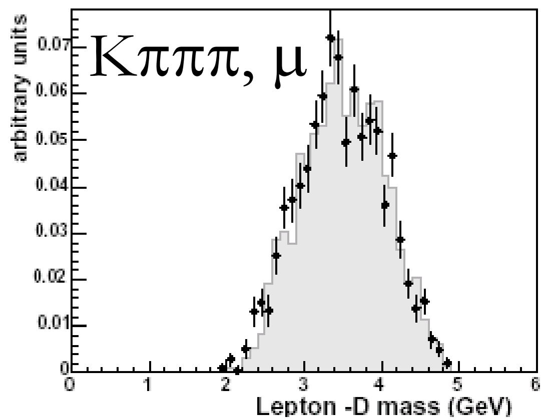
Realistic MC/data comparison: plots

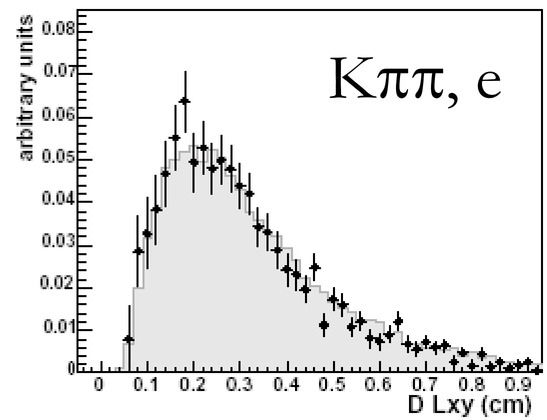












Realistic MC/data comparison: χ^2 prob. table

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

Matching χ^2 probability (in %) between data and Monte-Carlo for several kinematic variables and for the different channels.

MC predictions of 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

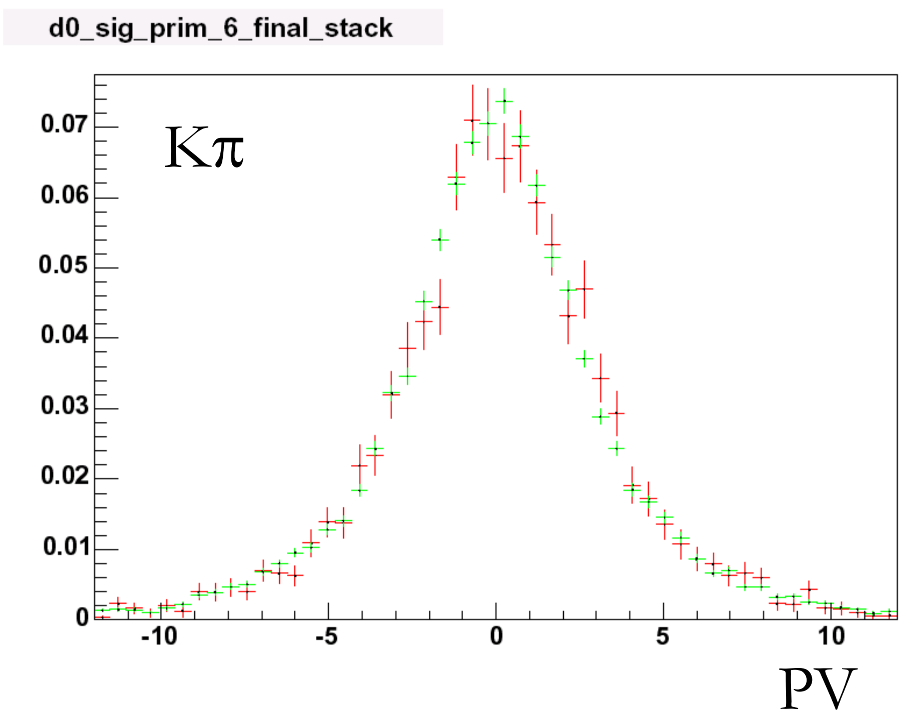
a) Based on inclusive $b \to D^{(*)+} l\nu$

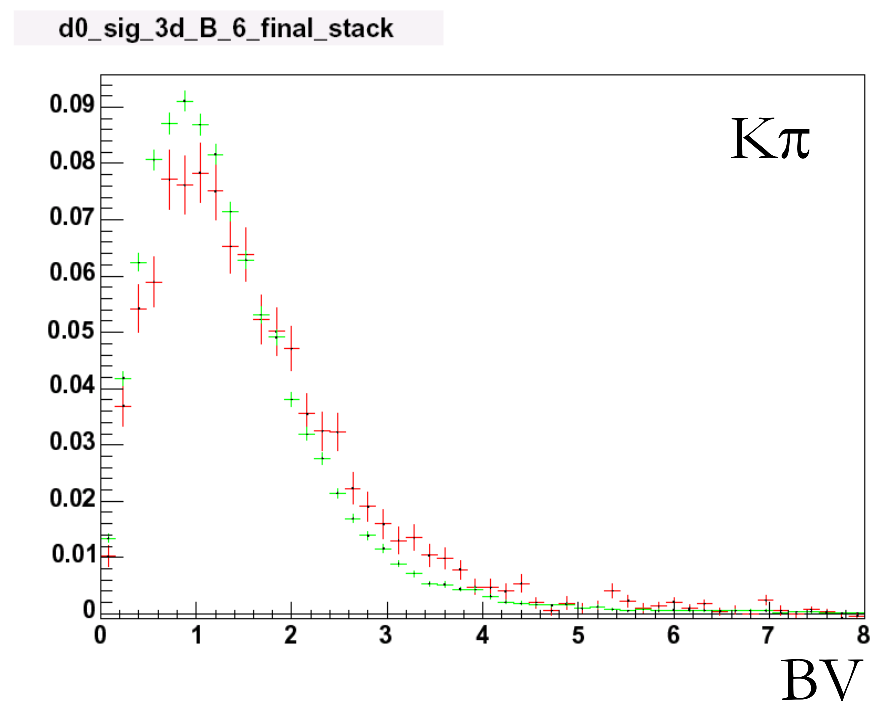
b) Based on exclusive $B \to D^{(*)+} l\nu$, $D^{**} l\nu$

To bless:

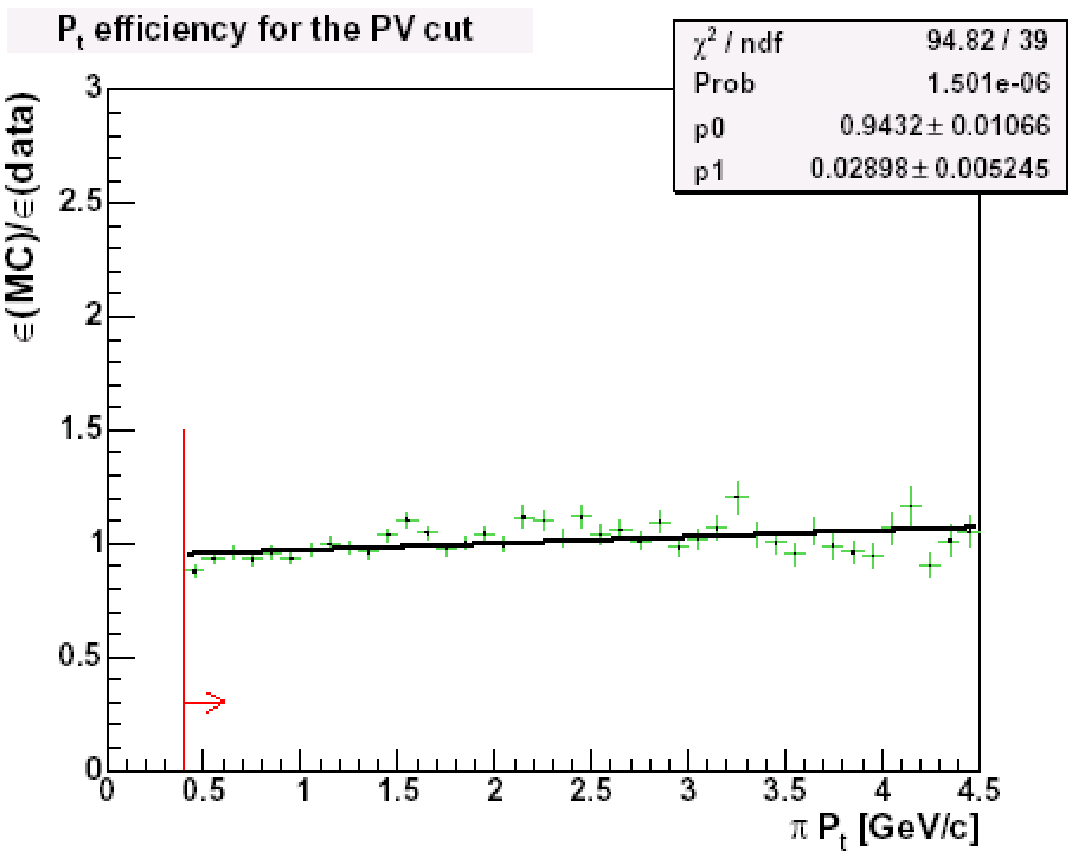
	$R_{pred.}$	R_{data}	$R_{pred.}/R_{data}$
$R_{D+/K\pi}$			
data (sans D_s)		3.71 ± 0.08	
Method (a)	3.31 ± 0.58		0.89 ± 0.16
Method (b)	$3.23 \pm 0.29 \pm ?$		$0.87 \pm 0.08 \pm ?$
$R_{K3\pi/K\pi}$			
data		0.77 ± 0.02	
	0.80 ± 0.04		1.04 ± 0.06

MC/data comparison with π^*: PV and BV

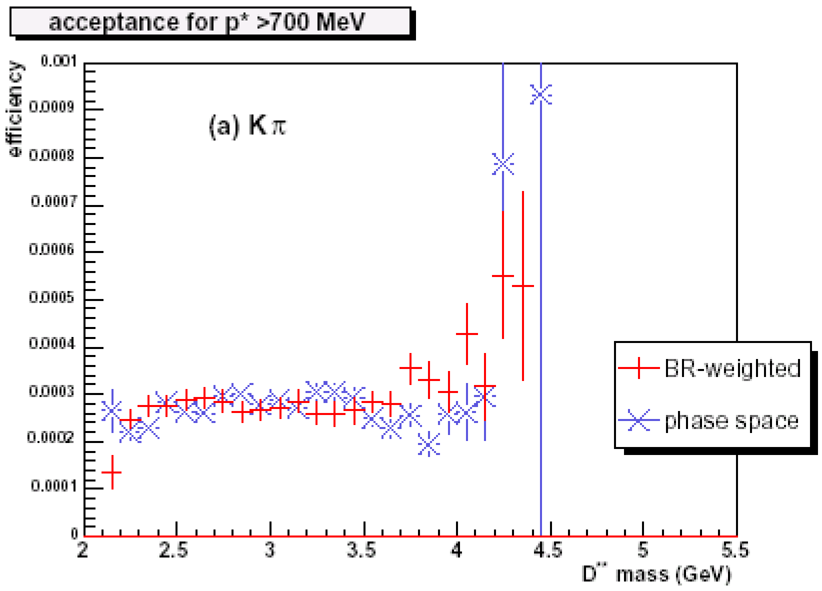


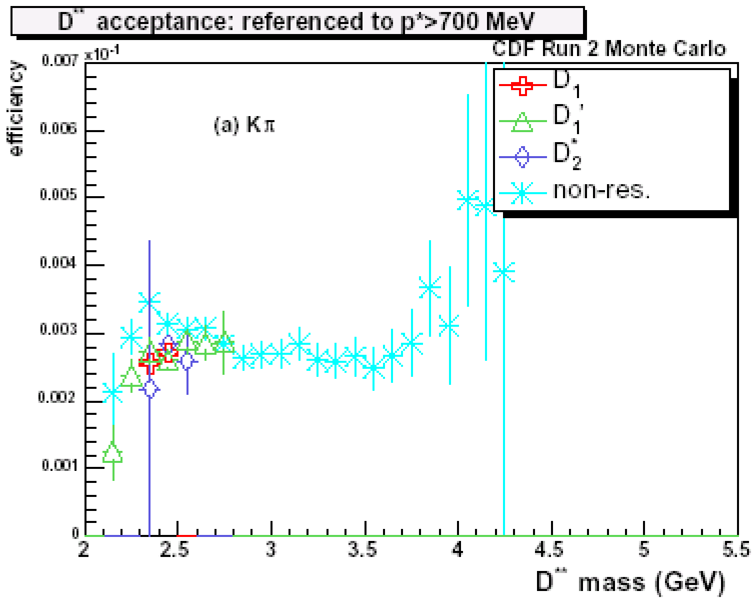


Relative efficiency correction:



Efficiency corrections:





Backup slides:

Backup slides:

Fraction of Tracks with >= 3 Axial hits vs P_t (RS)