Lepton Flavor Violation at LHCb
The $\tau \rightarrow \mu\mu\mu$ decay

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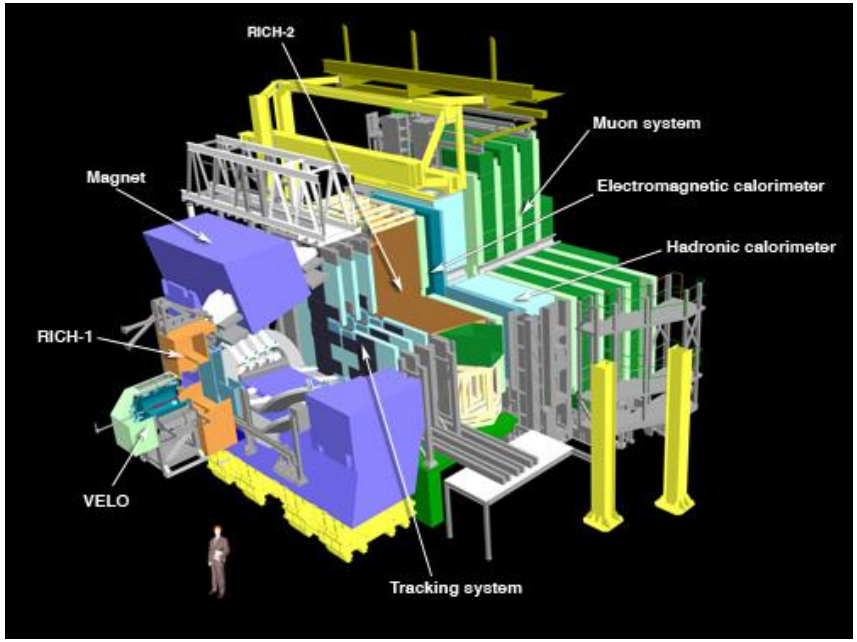
The LHCb Experiment



- Indirect search for new physics
  - CP Violation
  - Measurement of rare decays

- **Lepton Flavor Violating Decays**

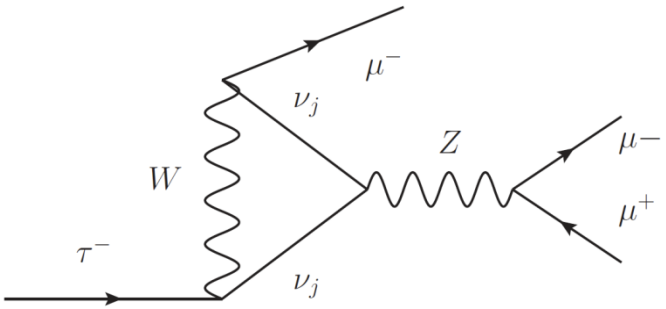
- 700 scientists from 52 institutions

Outline

- The $\tau \rightarrow \mu\mu\mu$ Decay
  - Why study it?
  - How to study it?
- Data Analysis
- **Results**

Motivation: Why τ → μμμ ?

- Study Lepton Flavor Violation
- Standard Model forbidden process
- Test and constrain New Physics models



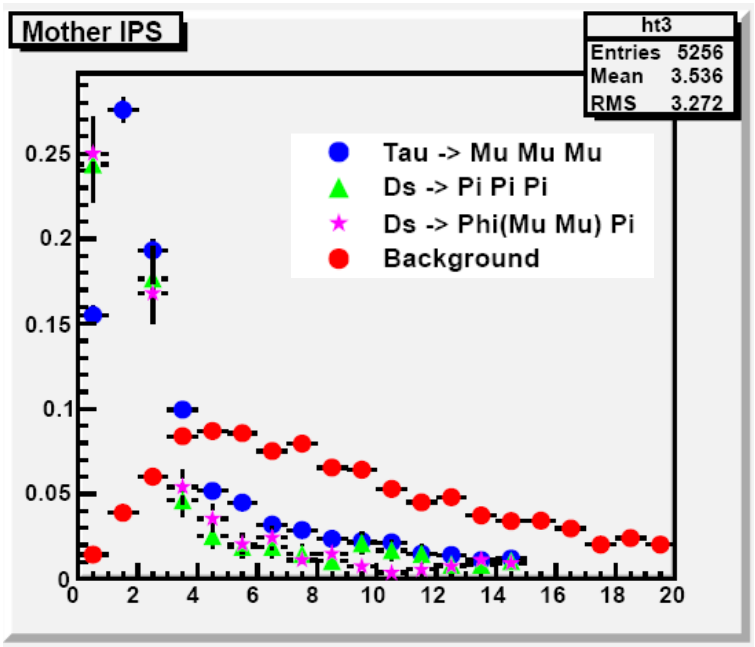
~~• SM + Heavy Majorana ν_r~~
~~• SUSY SO(10)~~
~~•mSUGRA + seesaw~~

(more likely)

OR

Methods: How τ → μμμ ?

- **Select signal, reject background**
  - Draft sets of cuts
  - Study cut effects on signal and background distributions



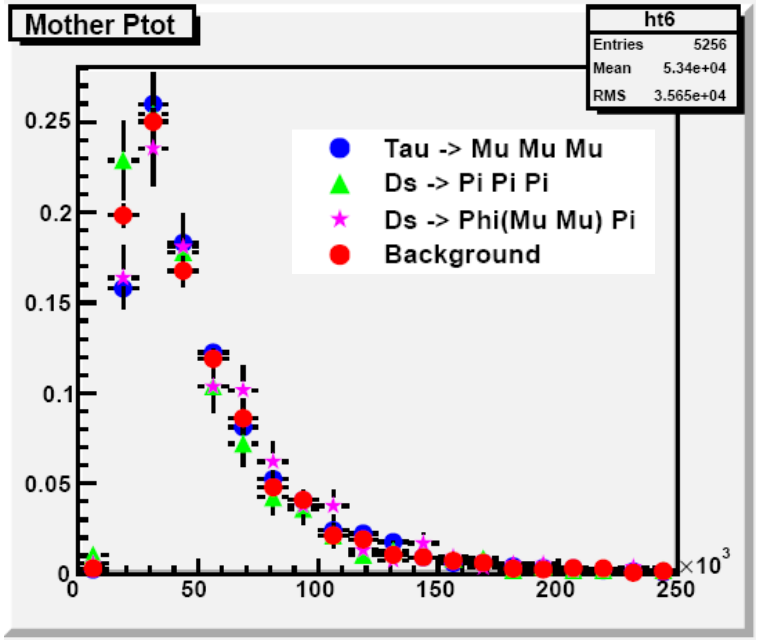
Example of a variable distribution which might be cut on.

Control Channels

- $D_s \rightarrow \pi\,\pi\,\pi$
- $D_s \rightarrow \phi(\mu\mu)\,\pi$

– Distributions as similar as possible to signal

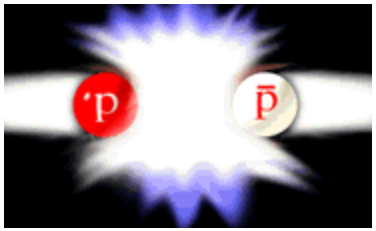
– Want cuts with similar effects across all three channels



Example of a variable distribution demonstrating good agreement between signal and control channels.

$$BR(\tau \rightarrow \mu\mu\mu) = \frac{N(\tau \rightarrow \mu\mu\mu)}{N(D_s \rightarrow \pi\pi\pi)} * \frac{BR(D_s \rightarrow \pi\pi\pi)}{BR(D_s \rightarrow \tau X)} * f_{prod}(\tau\ from\ D_s) * \frac{\varepsilon(D_s \rightarrow \pi\pi\pi)}{\varepsilon(\tau \rightarrow \mu\mu\mu)}$$

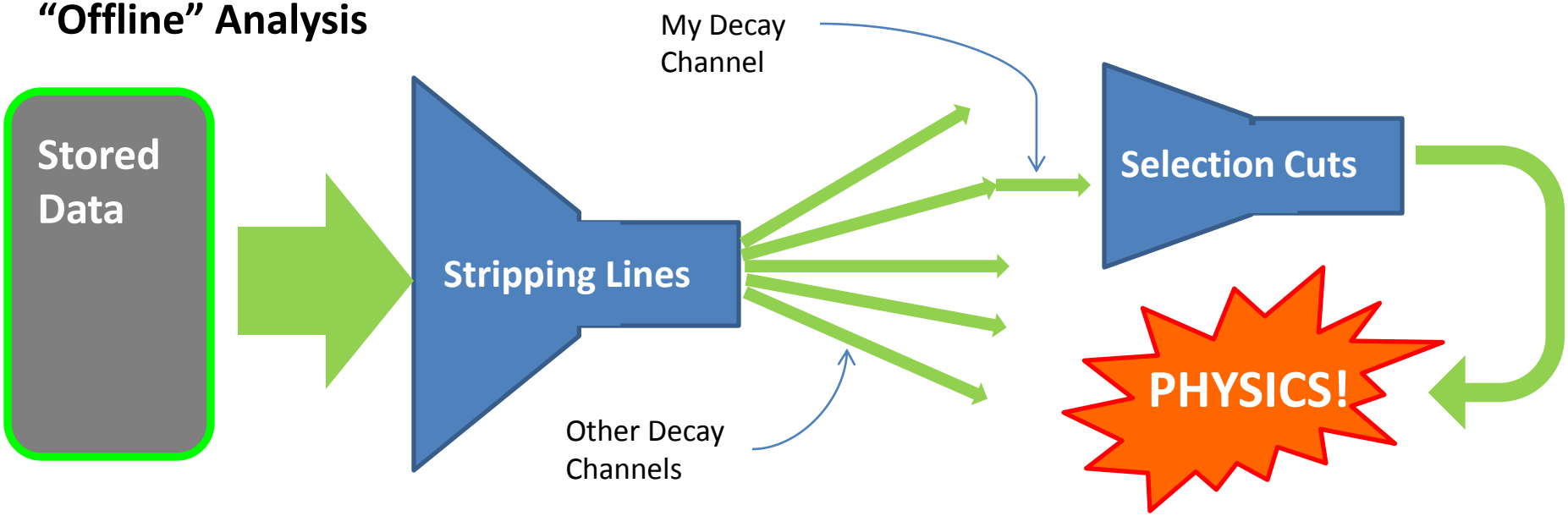
Data Analysis



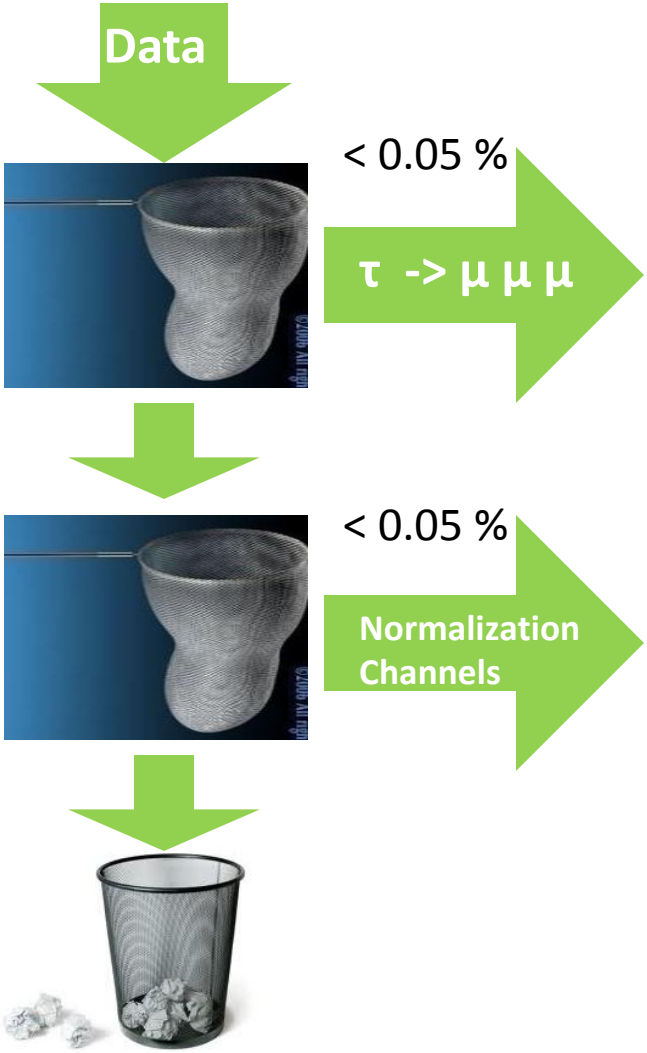
40 MHz → L0 Trigger → 1 MHz → High Level Trigger → 3 kHz

"Online" Analysis

"Offline" Analysis



Step 1: Stripping



Signal Monte Carlo Efficiency

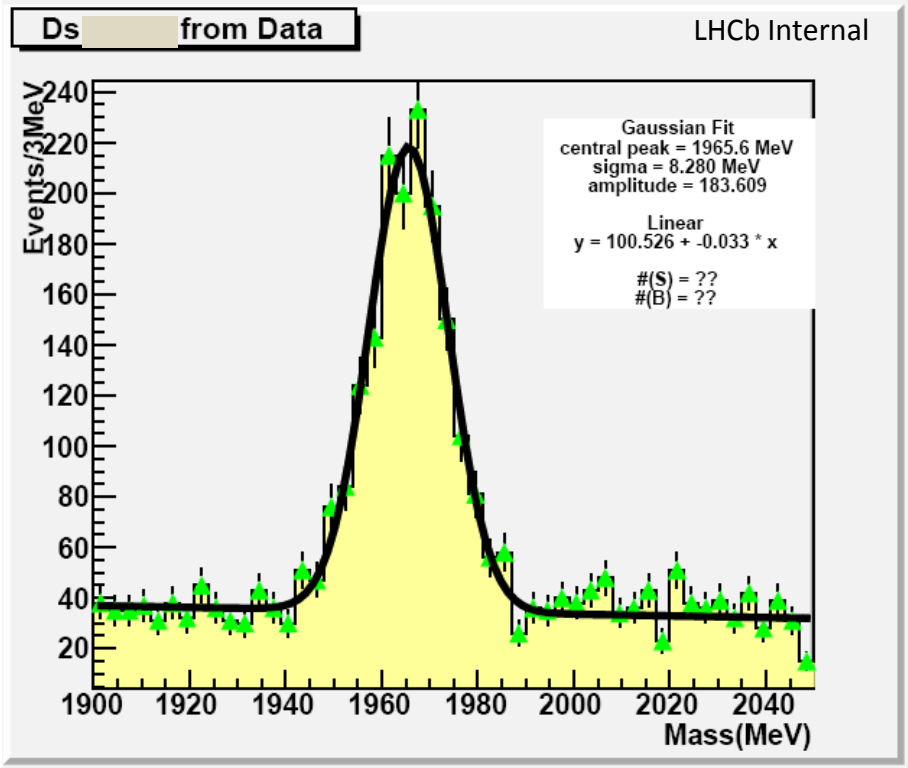
Selection	ε_r (τ -> μμμ)	ε_r (Ds -> ππ π)	ε_r (Ds ->φπ)
Proposed	**0.683**	**0.501**	**0.563**
Previous	0.623	0.116	0.234

Background Elimination – Remaining Events

Selection	ε_r (τ -> μμμ)	ε_r (Ds -> ππ π)	ε_r (Ds ->φπ)
Proposed	**0.04%**	**0.21%** ***(Prescale)***	**0.044%**

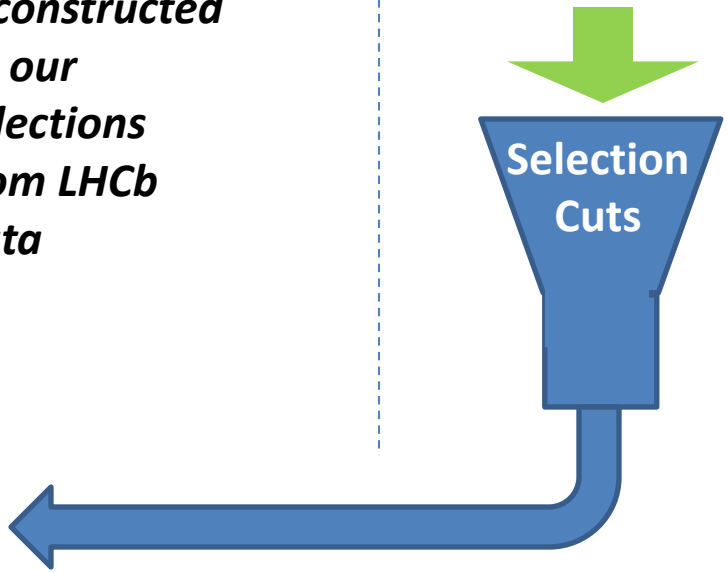
APPROVED

Step 2: Selection



D_s mass peak reconstructed by our selections from LHCb data

3 596 228 events



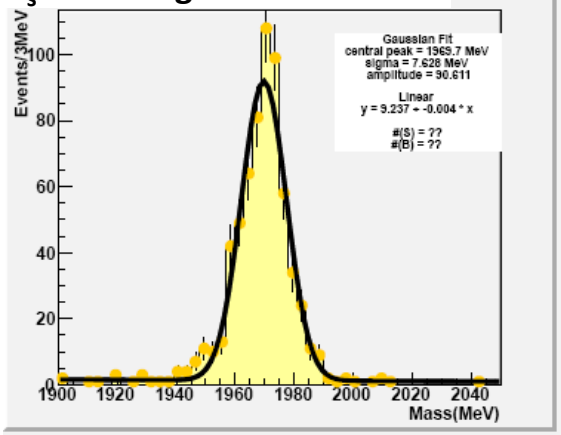
***(Not yet signal specific selection)**

Selection Cuts Efficiencies	ε_r (τ -> μμμ) * (Monte Carlo)	ε_r (Ds -> πππ)* (Monte Carlo)	ε_r (Ds ->φπ)* (Monte Carlo)	LHCb Real Data (Background)
Currently:	8.6 %	17.7%	19.0 %	0.00046 %

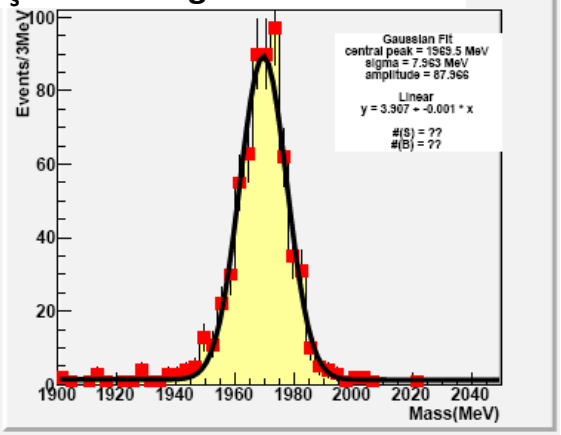
Efficiency = (# candidates after stripping + selection) / (# candidates after stripping)

Control Channel Mass Peaks

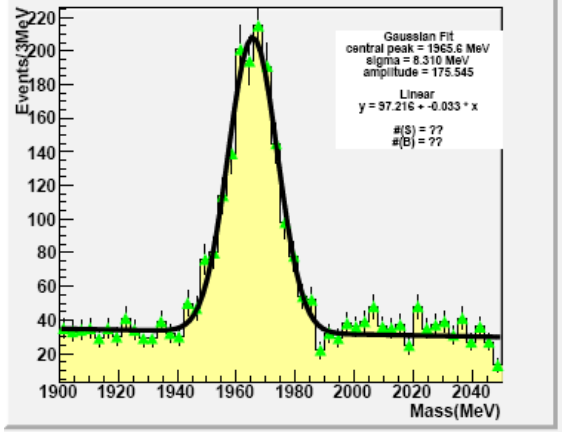
D_s -> 3 Pi Signal Monte Carlo



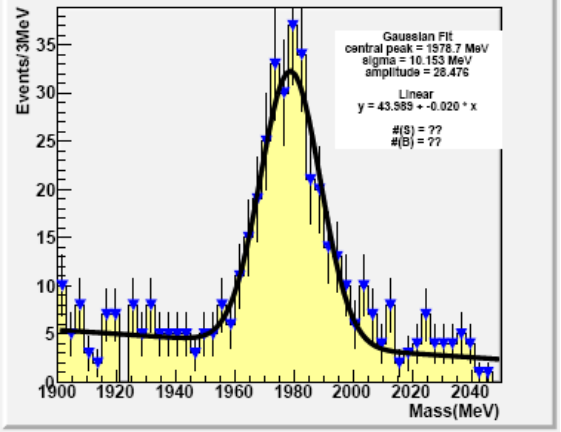
D_s -> Phi Pi Signal Monte Carlo



D_s -> 3 Pi from data LHCb Internal



D_s -> Phi Pi from data LHCb Internal



- D_s peak split into the 2 channels
- Signal MCs on top
- Extracted peaks below

Future Work

- Re-optimize $D_s \rightarrow \pi\ \pi\ \pi$ stripping to eliminate need for pre-scaling
- **Further study of daughter PID cuts to split the three channels**
- **Analyze selection of $\tau \rightarrow \mu\ \mu\ \mu$. We imagine starting with an earlier, looser version of the D_s cuts, then optimizing to the channel.**
- Perform rigorous statistical analysis of cut effects at all stages
- Look at a lot of data!

Thank You!

I cannot thank the following people enough:

- CERN Summer Student Program
  - **Dr. Johannes Albrecht – Supervisor**
  - Dr. Marco Gersabeck – Substitute Supervisor

- The University of Michigan REU program
  - Dr. Homer Neal
  - Dr. Jean Krisch
  - Dr. Junjie Zhu
  - Dr. Steve Goldfarb
  - Lauren Rigani

Thank you!

What a summer!


LHCb

BACKUP SLIDES

Backup Slides - τ -> μ μ μ Stripping Line

Previous Cuts

Mother Cuts

- Mass Window = ± 400 MeV
- Vchi2 < **25**
- c * τ > **70** μm
- **Child with P_t > 1 GeV**

Daughter Cuts (for *all* 3)

- P_t > 300 MeV
- mu track χ^2 / DoF < 5
- (Mu IPS)^2 > **6**

Proposed Cuts

Mother Cuts

- Mass Window = ± 400 MeV
- Vchi2 < **20**
- c * τ > **100** μm
- τ IPS < **15**

Daughter Cuts (for *all* 3)

- P_t > 300 MeV
- mu track χ^2 / DoF < 5
- (Mu IPS)^2 > **9**

Previous Cuts

Mother Cuts

- Mass Window = ± 250 MeV
- Vchi2 < **25**
- c * τ > 200 μm
- D_s IPS < **3**
- **P_t > 2 GeV**

Daughter Cuts (for *all* 3)

- P_t > 300 MeV
- mu track χ^2 / DoF < 5
- (Mu IPS)^2 > **12**

Proposed Cuts

Mother Cuts

- Mass Window = ± 80 MeV
- Vchi2 < **20**
- c * τ > 200 μm
- D_s IPS < **15**
- **Ds->3π required to be TIS**

Daughter Cuts (for *all* 3)

- P_t > 300 MeV
- mu track χ^2 / DoF < 5
- (Mu IPS)^2 > **9**

Current Working Version of Selection Cuts

1) Mother Impact Parameter Significance (= $\sqrt{(\chi^2)}$) < 1.8
2) Mother Vertex χ^2 < 6
3) max (Delta Log Likelihood(Pion - Kaon)) < 0
4) max (Daughter Track χ^2) < 1.4
5) Cos (angle) > 0.999875
6) max (Daughter P_{tot}) < 40 GeV
7) max (Delta Log Likelihood(Pion - Proton)) < 5

Stripping Cuts Tuning: Step 2

Selection #	ε_r (Tau -> 3 Mu)	ε_r (Ds -> 3 Pi)	ε_r (Ds -> Phi Pi)
2_6	**0.683**	**0.6825**	**0.762**
2_7	0.517	0.554	0.532
2_8	0.257	0.306	0.347

ε_r := (# candidates after new stripping lines) / (# candidates after truth matching)

Selection Cuts - efficiencies

Selection #	Ds -> 3 Pi	Ds -> Phi Pi	Signal Blinded Data
(a)	0.299	0.347	0.00301
(b)	0.301	0.282	0.00197
(c)	0.1790	0.1595	0.000385
(d)	0.127	0.114	0.000185
(e)	**0.177**	**0.190**	**0.000462**

Efficiency = (# candidates after stripping + selection) / (# candidates after stripping)

More Detailed Efficiency

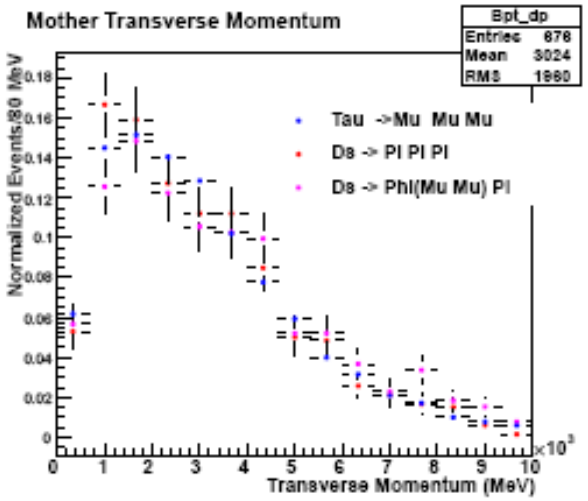
	ε for this cut only			(N-1) ε for this cut		
Cut	Ds -> 3 Pi	Ds -> Phi Pi	Background	Ds -> 3 Pi	Ds -> Phi Pi	Background
(e) 1	0.565	0.564	0.0936	0.732	0.735	0.106
2	0.750	0.757	0.351	0.857	0.900	0.454
3	0.730	0.664	0.118	0.952	0.935	0.541
4	0.952	0.970	0.895	0.923	0.973	0.893
5	0.639	0.660	0.190	0.659	0.758	0.250
6	0.841	0.874	0.648	0.984	1.000	.995
7	0.714	0.664	0.485	0.800	0.800	0.465
8	--	--	--	--	--	--

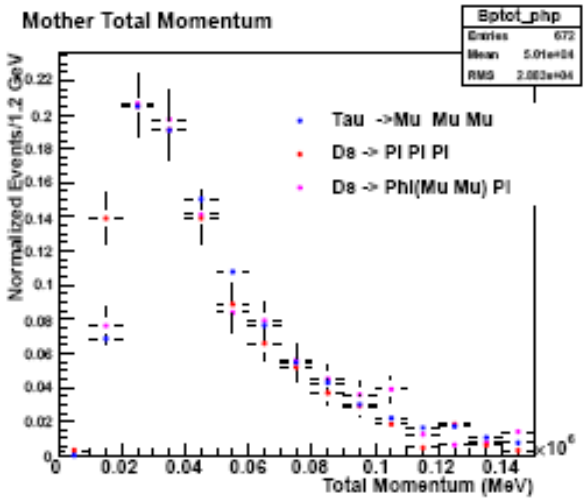
Mass Peak Fit Parameters

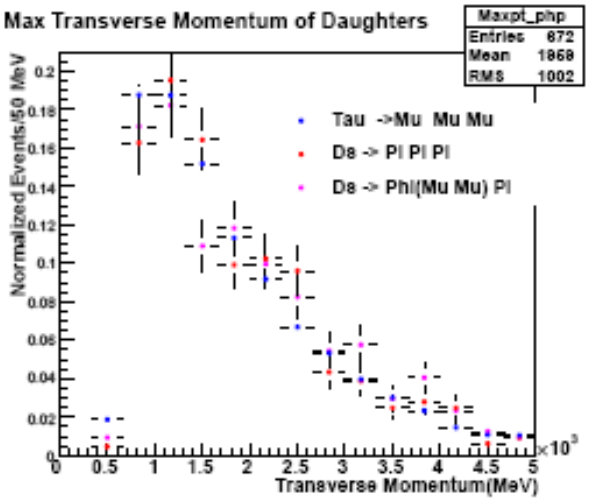
	(a)	(b)	(c)	(d)	(e)		S / B - fits integrated on (1900,2050)
Ds -> 3 Pi							
(1)	-166.39	201.1	129.2	91.0	100.53	(a):	0.380
(2)	0.244	-0.021	-0.042	-0.04	-0.033	(b):	0.374
(3)	809.1	440.03	223.0	70.2	183.6	(c):	0.680
(4)	1965.6	1965.7	1965.5	1965.5	1965.6	(d):	0.734
(5)	8.860	8.12	8.443	7.51	8.28	(e):	0.719
Ds -> Phi Pi							
(1)	127.7	188.2	110.5	30.84	106.9	(a):	0.340
(2)	-0.03	-0.076	-0.05	-0.014	-0.05	(b):	0.375
(3)	110.5	73.82	38.7	16.58	34.5	(c):	0.591
(4)	1977.7	1976.9	1976.4	1975.4	1976.4	(d):	0.664
(5)	12.62	11.57	10.734	7.65	10.07	(e):	0.791

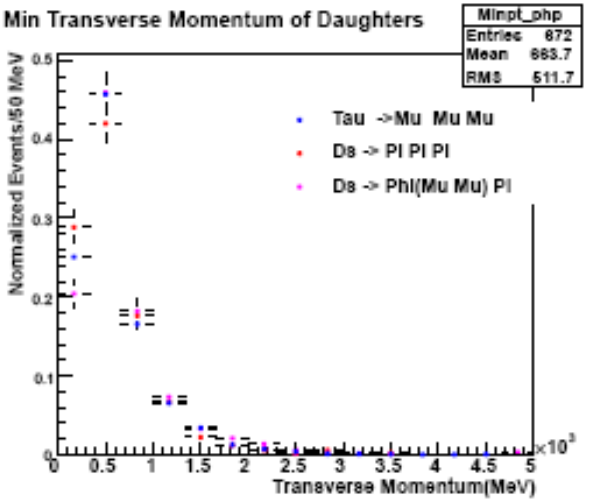
#	Parameter
(1)	Linear fit constant
(2)	Linear fit slope
(3)	Gaussian amplitude
(4)	Gaussian Center
(5)	Gaussian Sigma

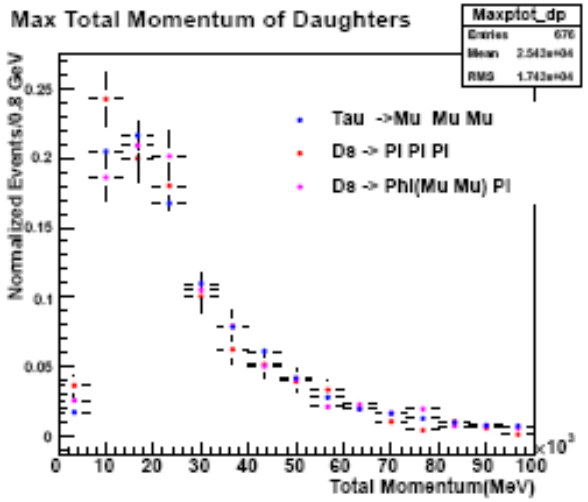
Backup Slides - Kinematics Plots

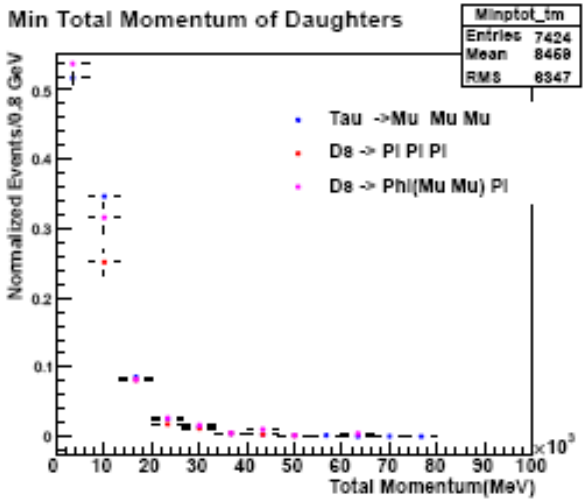




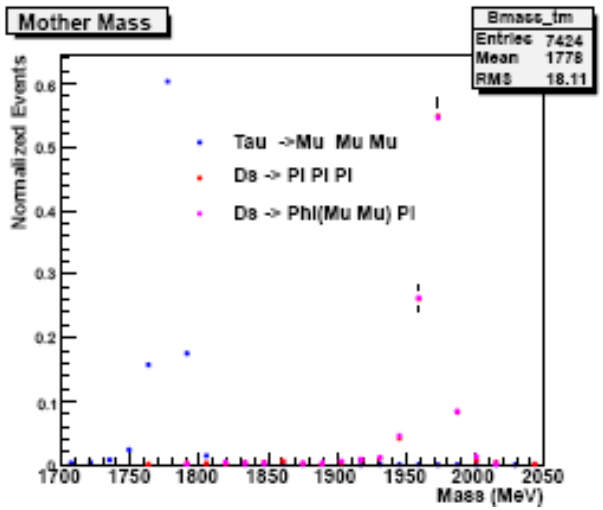


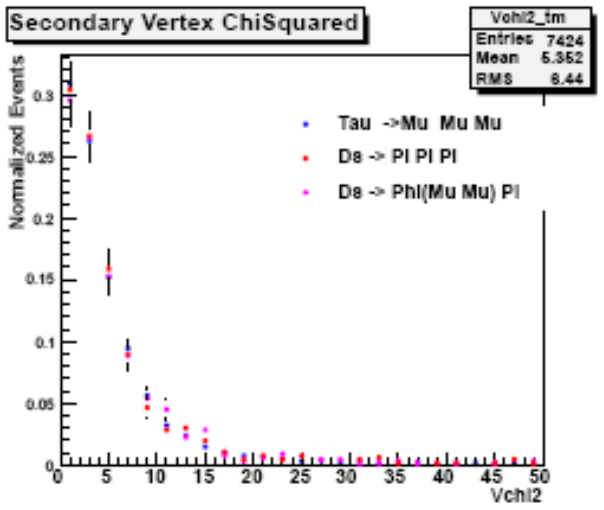


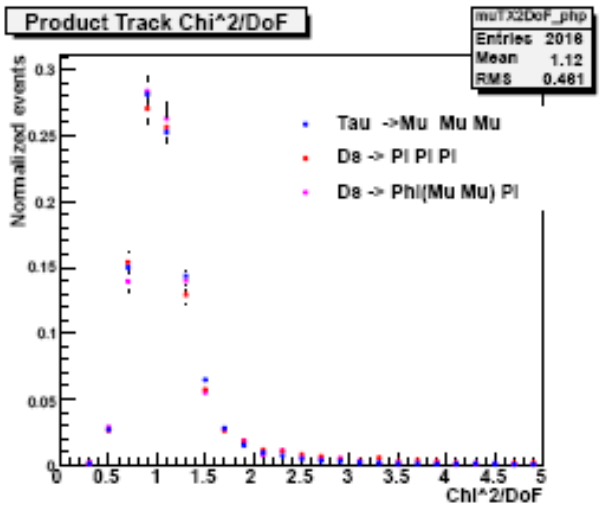


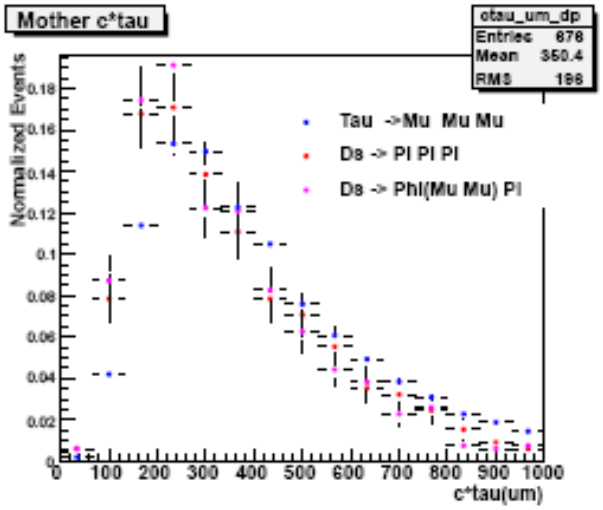


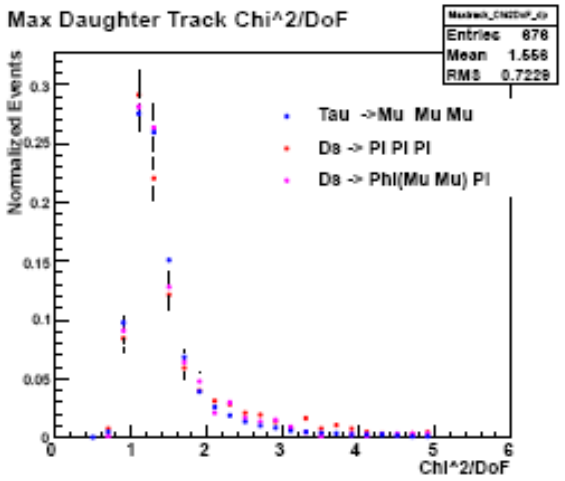
Backup Slides - More Plots

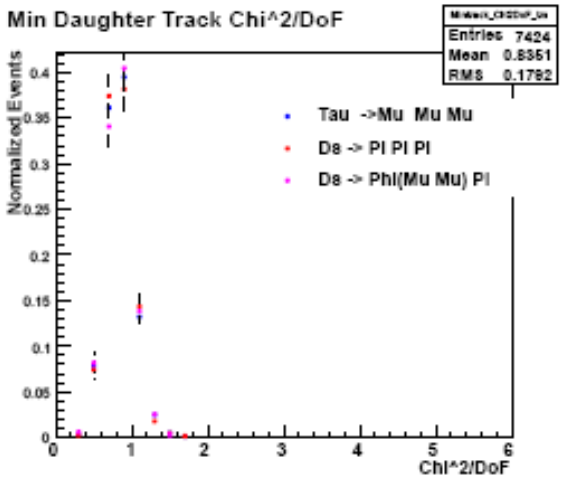




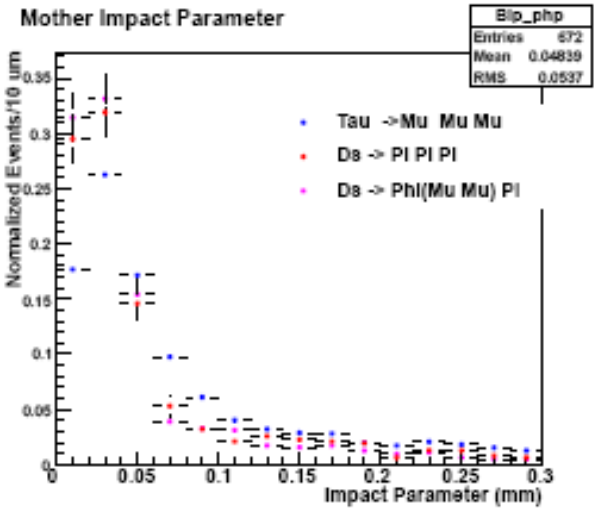


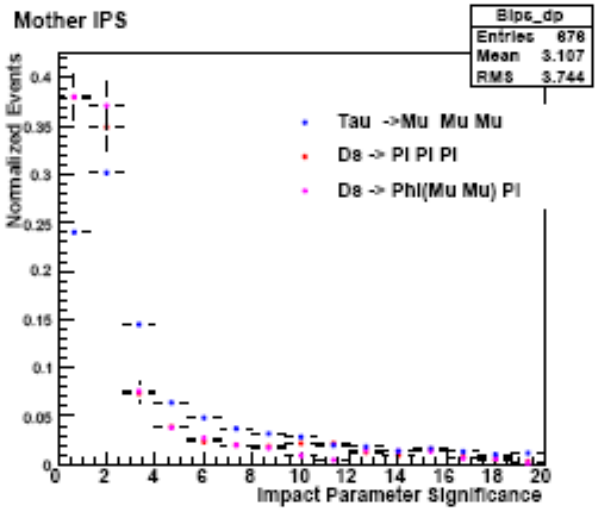


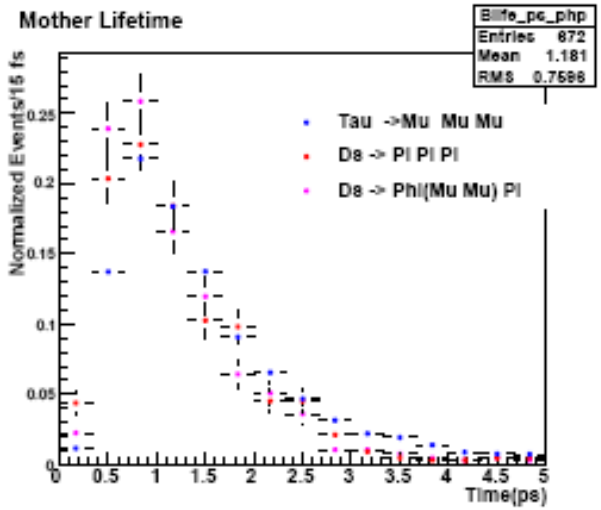


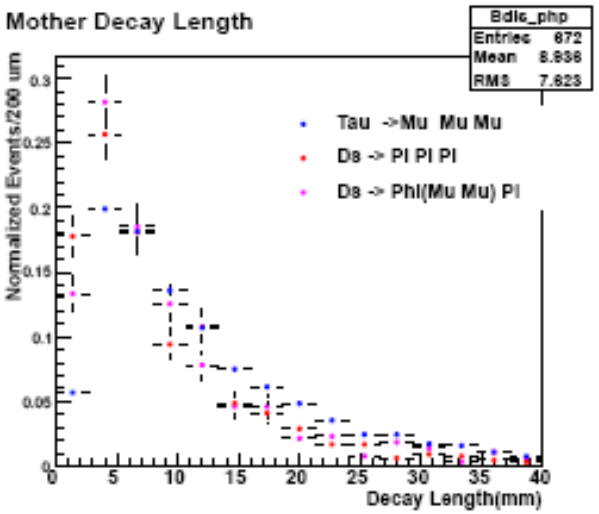


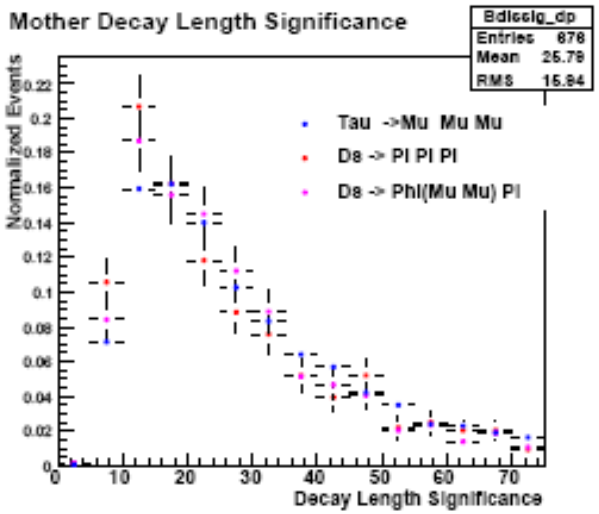
Backup Slides - Flight/IPS Plots

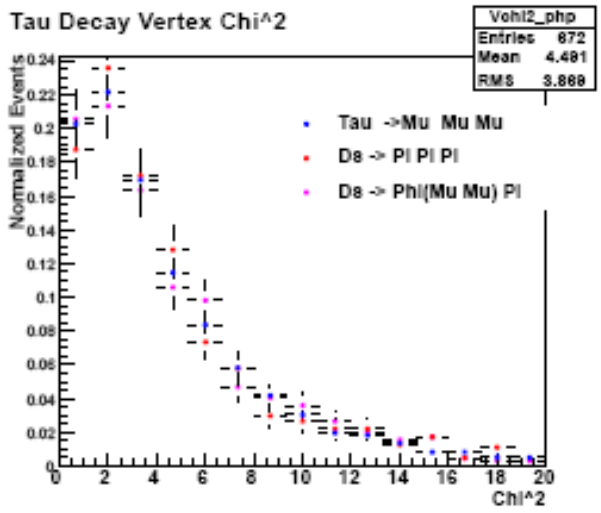












Backup Slides - More Plots