Cross Section Measurement of Open Charm Final States

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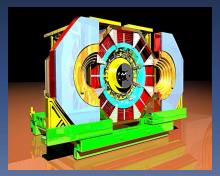
Charmonium Meeting 5.4.17



Overview

1. Basic Event Reconstruction
2. Fitting Procedure
3. Consistency Checks of Fitting Method
4. Cross Section Measurement

Basic Event Reconstruction

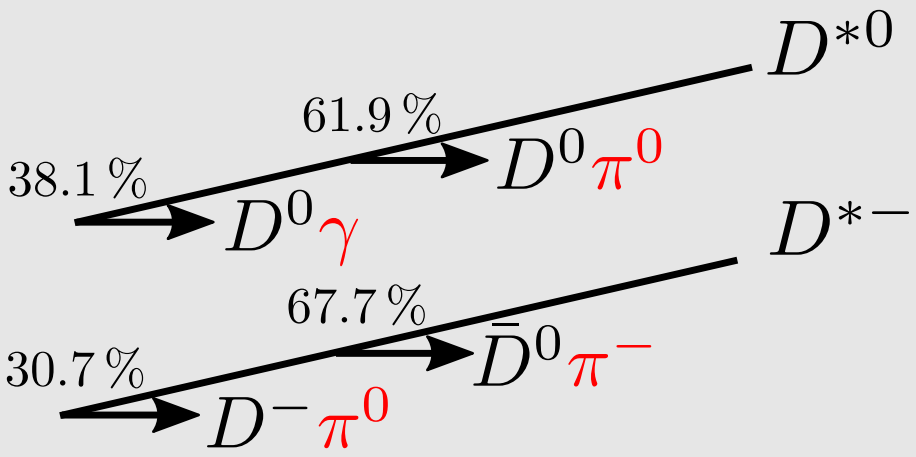
Event Topology

Simulation and Analysis with

BOSS 6.6.5.p01 and 7.0.2.p02

Use double D-Tags

$$e^+e^- \longrightarrow (\pi) D^{(*)} \bar{D}^{(*)}$$



red:
Measurement via missing fourmomentum or exclusively.

D^0 Decay Channels

$D^0 \to$	$K^-\pi^+$	$(Br = 3.88\,\%)$
$D^0 \to$	$K^-\pi^+\pi^0$	$(Br = 13.9\,\%)$
$D^0 \to$	$K^-2\pi^+\pi^-$	$(Br = 8.08\,\%)$
$D^0 \to$	$K^-2\pi^+\pi^-\pi^0$	$(Br = 4.2\,\%)$

$$\sum Br_i = 30.06\,\%$$

D^+ Decay Channels

$D^+ \to$	$K^-2\pi^+$	$(Br = 9.13\,\%)$
$D^+ \to$	$K^-2\pi^+\pi^0$	$(Br = 5.99\,\%)$
$D^+ \to$	$K_S\pi^+$	$(Br = 1.47\,\%)$
$D^+ \to$	$K_S\pi^+\pi^0$	$(Br = 6.99\,\%)$
$D^+ \to$	$K_S2\pi^+\pi^-$	$(Br = 3.12\,\%)$
$D^+ \to$	$K^-K^+\pi^+$	$(Br = 0.954\,\%)$

$$\sum Br_i = 27.65\,\%$$

Basic Event Selection

Good Tracks

- Cut on interaction region: $R_{xy} < 1\,\mathrm{cm}$, $R_z < 10\,\mathrm{cm}$.
- Cut on direction: $|\cos\vartheta| < 0.93$.

$\pi^{\pm}$ from K_S Decays

- Cut on interaction region: $R_{xy} < 20\,\mathrm{cm}$, $R_z < 20\,\mathrm{cm}$.
- Cut on direction: $|\cos\vartheta| < 0.93$.

Good Photons

- $0 < t < 700\,\mathrm{ns}$.
- Barrel ($|\cos\theta| < 0.8$): $E_\gamma > 25\,\mathrm{MeV}$.
- Endcap ($0.84 < |\cos\theta| < 0.92$): $E_\gamma > 50\,\mathrm{MeV}$.

Kinematic fit

- Selection of topology by best $\mathcal{P}$-Value.
- $\chi^2 < 80$.

PID Pions ($\mathrm{d}E/\mathrm{d}x$, ToF1 and ToF2)

$$L(\pi) > L(K).$$

Cut on π^0 mass

$115\,\mathrm{MeV} < m_{\gamma\gamma}c^2 < 150\,\mathrm{MeV}$.

Cut on K_S mass

$487\,\mathrm{MeV} < m_{\pi^+\pi^-}c^2 < 511\,\mathrm{MeV}$.

Cut on K_S decay length

$L/\sigma_L > 2$.

PID Kaons ($\mathrm{d}E/\mathrm{d}x$, ToF1 and ToF2)

$$L(K) > L(\pi).$$

Open Charm Channels

Type	Channel			
DD	D^+D^-	$D^0\bar{D}^0$		
DD^*	$D^0\bar{D}^{*0}$	$D^+\bar{D}^{*-}$		
D^*D^*	$D^{*0}\bar{D}^{*0}$	$D^{*+}\bar{D}^{*-}$		
πDD	$\pi^+D^0D^-$	$\pi^0D^+D^-$	$\pi^0D^0\bar{D}^0$	
πDD^*	$\pi^+D^0D^{*-}$	$\pi^+D^{*0}D^-$	$\pi^0D^0\bar{D}^{*0}$	$\pi^0D^+D^{*-}$
πD^*D^*	$\pi^+D^{*0}D^{*-}$	$\pi^0D^{*+}D^{*-}$	$\pi^0D^{*0}\bar{D}^{*0}$	

- There are 16 channels of type $e^+e^- \to (\pi)D^{(*)}\bar{D}^{(*)}$.
- 11 channels include one or more D^* mesons (DD^*, D^*D^*, πDD^* , πD^*D^*).
- 5 channels are without D^* mesons (DD, πDD).

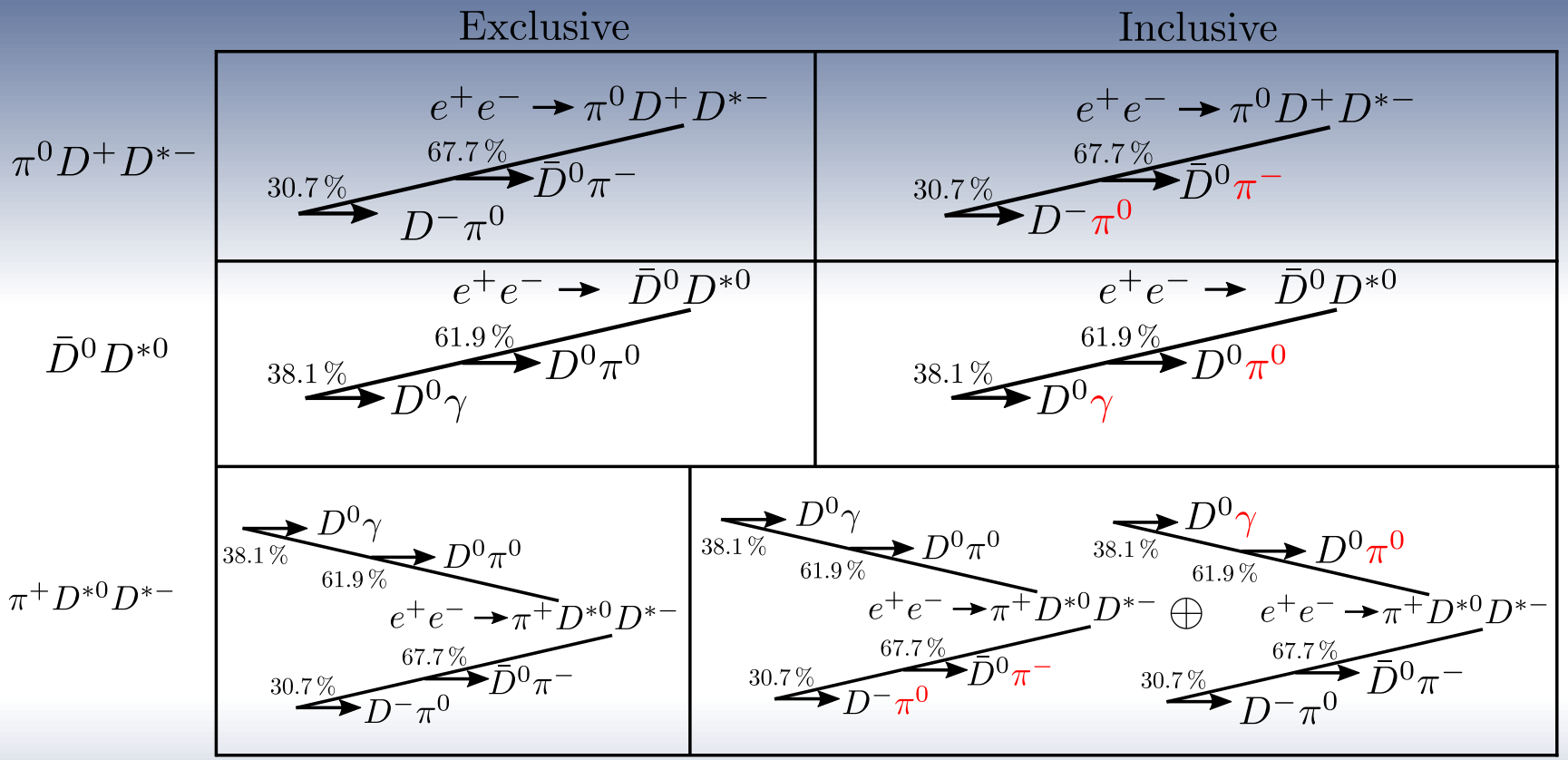
5 channels without D^* mesons

- Use exclusive reconstruction.

11 channels with one or more D^* mesons

- Use inclusive reconstruction.
- Exclusive reconstruction as cross check.
- Why? Low efficiency for exclusive reconstruction.

Kinematic Fit



red: Measurement via missing mass

- Perform a kinematic for all event topologies allowed by final state particles.
- Save all fit results for converging fits.
- For multiple converging fits of the same topology (e.g. $e^+e^- \to \pi^+ D^0 D^{*-}$ with $D^{*-} \to \bar{D}^0\pi^-$, $\bar{D}^0 \to K^+\pi^-$, $D^0 \to K^-\pi^+\pi^0$) save the fit with best $\mathcal{P}$-value.

Decision Process: Simple Example

final state particles
$K^+K^-\pi^+\pi^-\pi^0$

exclusive

$D^0\bar{D}^0\pi^0$
↳ $K^+\pi^-$
↳ $K^-\pi^+$

$D^0\bar{D}^0$
↳ $K^+\pi^-\pi^0$
↳ $K^-\pi^+$

$D^0\bar{D}^0$
↳ $K^+\pi^-$
↳ $K^-\pi^+\pi^0$

by $\mathcal{P}$-value

select best exclusive fit

inclusive

$D^{*0}\bar{D}^{*0}$
↳ $\bar{D}^0\pi^0_{\text{miss}}$
↳ $D^0\pi^0$ ↳ $K^+\pi^-$
↳ $K^-\pi^+$

$D^{*0}\bar{D}^{*0}$
↳ $\bar{D}^0\pi^0$
↳ $D^0\pi^0_{\text{miss}}$ ↳ $K^+\pi^-$
↳ $K^-\pi^+$

$D^{*0}\bar{D}^{*0}$
↳ $\bar{D}^0\pi^0$
↳ $D^0\gamma_{\text{miss}}$ ↳ $K^+\pi$
↳ $K^-\pi^+$

$D^{*0}\bar{D}^{*0}$
↳ $\bar{D}^0\gamma_{\text{miss}}$
↳ $D^0\pi^0$ ↳ $K^+\pi^-$
↳ $K^-\pi^+$

by $\mathcal{P}$-value

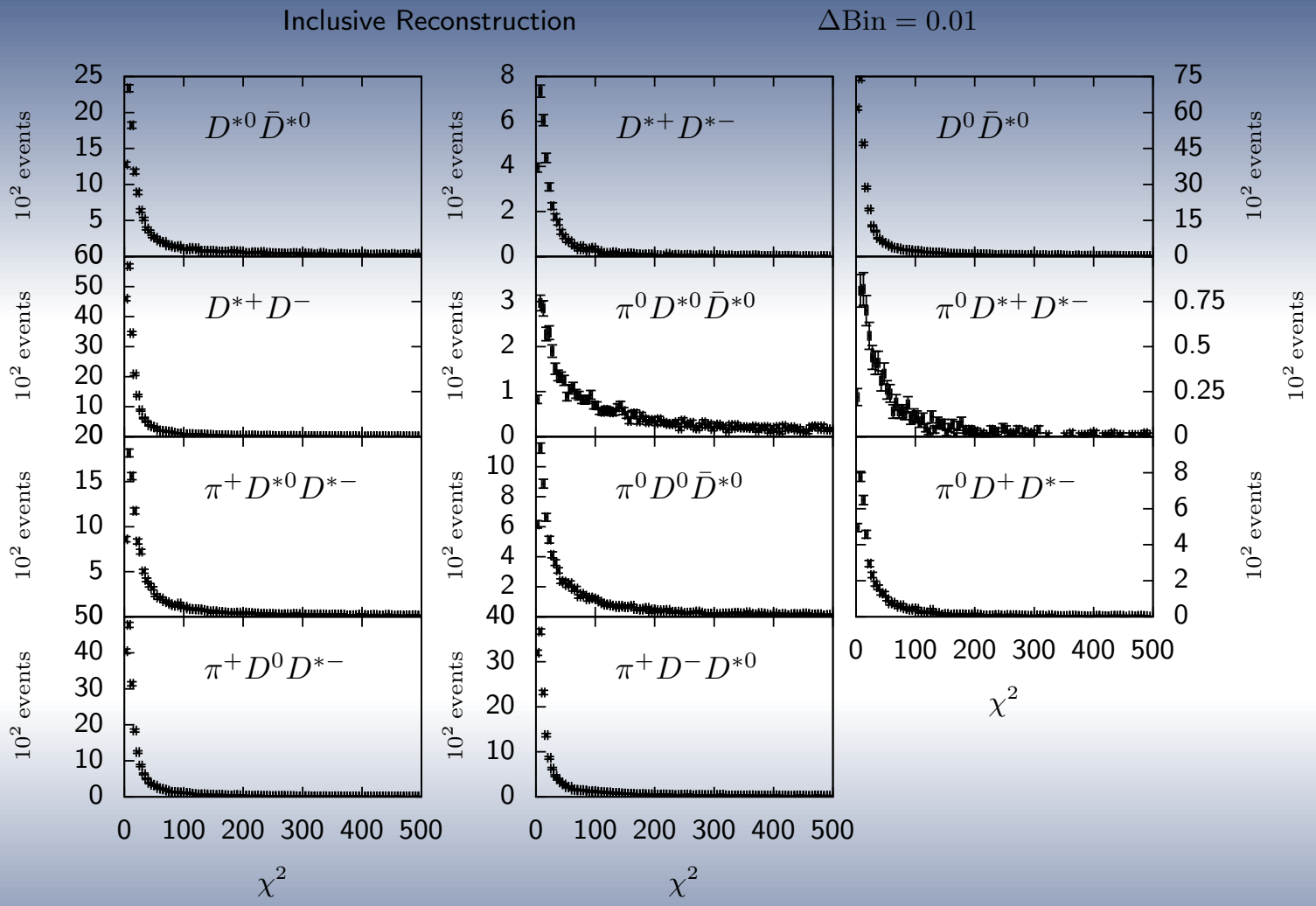
select best inclusive fit

Selection

- Select best event topology by highest $\mathcal{P}$-value.
- Use either inclusive or exclusive reconstruction, never mix.

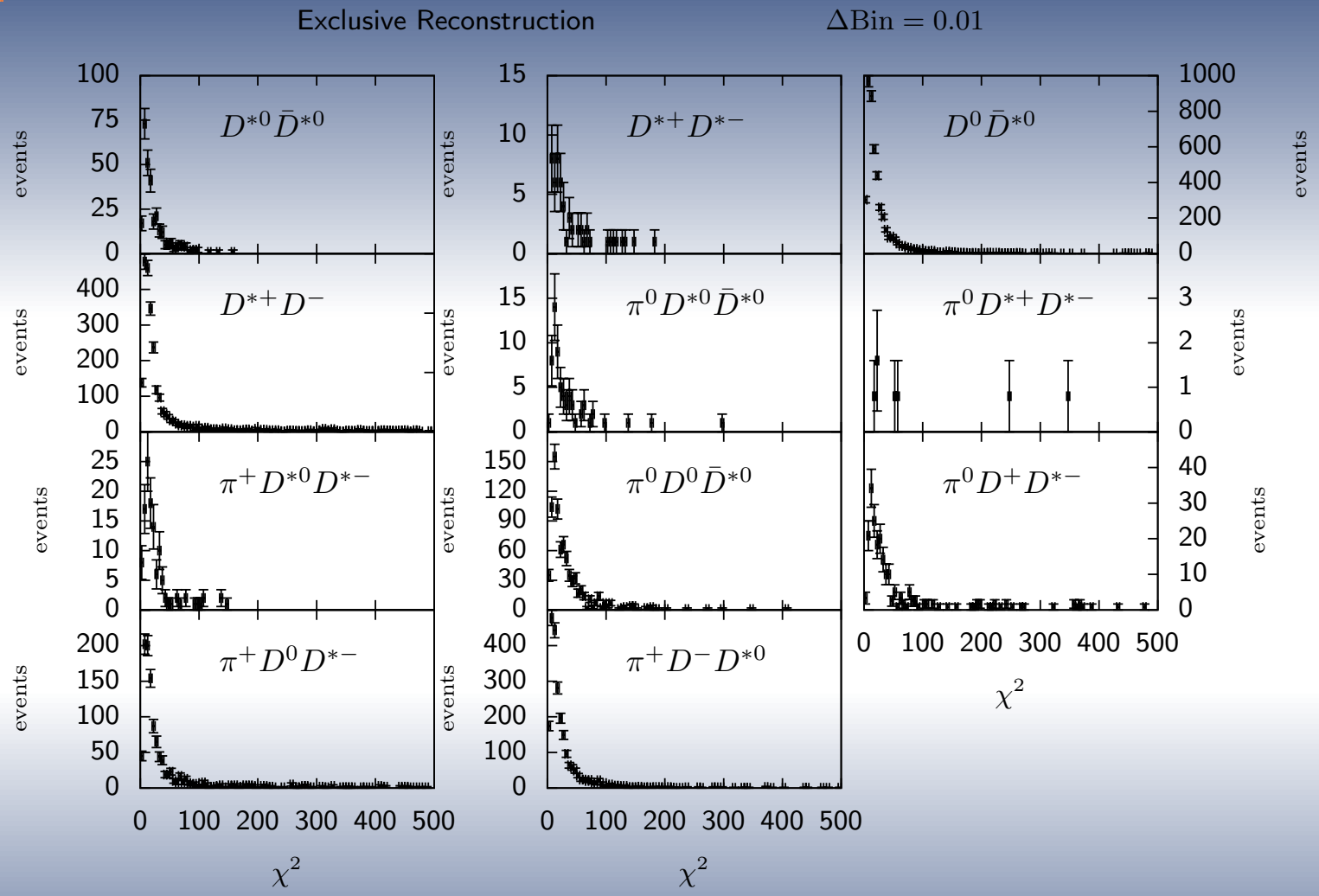
Consistency Check

Consistency Check: Inclusive Reconstruction



- Check χ^2 distribution for different channels.
- Technically: use inclusive sample and sort by Monte Carlo Truth.
- Here: $\sqrt{s} = 4.42\,\mathrm{GeV}$.

Consistency Check: Exclusive Reconstruction



- Check χ^2 distribution for different channels.
- Technically: use exclusive sample and sort by Monte Carlo Truth.
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Cross Feed with Inclusive Reconstruction

Rec \MC	$D^{*0}\bar{D}^{*0}$	$D^{*+}D^{*-}$	$D^0\bar{D}^{*0}$	D^+D^{*-}	$\pi^0D^{*0}\bar{D}^{*0}$	$\pi^0D^{*+}D^{*-}$	$\pi^+D^{*0}D^{*-}$	$\pi^0D^0\bar{D}^{*0}$	$\pi^0D^+D^{*-}$	$\pi^+D^0D^{*-}$	$\pi^+D^-D^{*0}$
$D^{*0}\bar{D}^{*0}$	1932	4	2	0	0	1	0	53	1	2	0
$D^{*+}D^{*-}$	0	1009	0	0	0	0	0	0	13	10	0
$D^0\bar{D}^{*0}$	5	2	8486	0	0	0	1	2	0	1	1
D^+D^{*-}	1	0	2	6675	0	0	0	0	0	0	1
$\pi^0D^{*0}\bar{D}^{*0}$	1	0	0	0	1027	20	8	60	0	1	0
$\pi^0D^{*+}D^{*-}$	0	0	0	0	1	391	2	1	0	0	0
$\pi^+D^{*0}D^{*-}$	0	0	0	0	4	5	2548	1	0	2	0
$\pi^0D^0\bar{D}^{*0}$	684	7	3	0	20	0	9	3534	7	7	7
$\pi^0D^+D^{*-}$	0	243	0	1	0	1	8	1	2588	12	24
$\pi^+D^0D^{*-}$	2	555	1	1	0	2	11	4	25	5530	209
$\pi^+D^-D^{*0}$	1	5	2	0	0	0	4	23	19	142	5202

- Check for analysis algorithm: matrix almost diagonal.
- Large Cross feed between $D^{*0}\bar{D}^{*0}$ and $\pi^0D^0\bar{D}^{*0}$ ($D^{*0} \to D^0\pi^0$).
- Large Cross feed between $D^{*+}D^{*-}$ and $\pi^+D^0D^{*-}$ ($D^{*+} \to D^0\pi^+$).
- Large Cross feed between $\pi^+D^0D^{*-}$ and $\pi^+D^-D^{*0}$ (same final state for $D^{*-} \to D^-\pi^0$ and $D^{*0} \to D^0\pi^0$).
- Here: $\sqrt{s} = 4.42\,\mathrm{GeV}$.

Preliminary
Cross Section Measurement

Deconvolution of Cross Feed

For a single channel

$$N_i = \overbrace{\varepsilon_{ii} \cdot \sigma_i \cdot \mathcal{L}}^{\text{signal events}} + \sum_{\substack{j \\ j \neq i}} \overbrace{\varepsilon_{ij} \cdot \sigma_j \cdot \mathcal{L}}^{\text{background events}} = \sum_{\substack{i,j \\ i=j \text{ signal} \\ i \neq j \text{ background}}} \varepsilon_{ij} \cdot \sigma_j \cdot \mathcal{L}$$

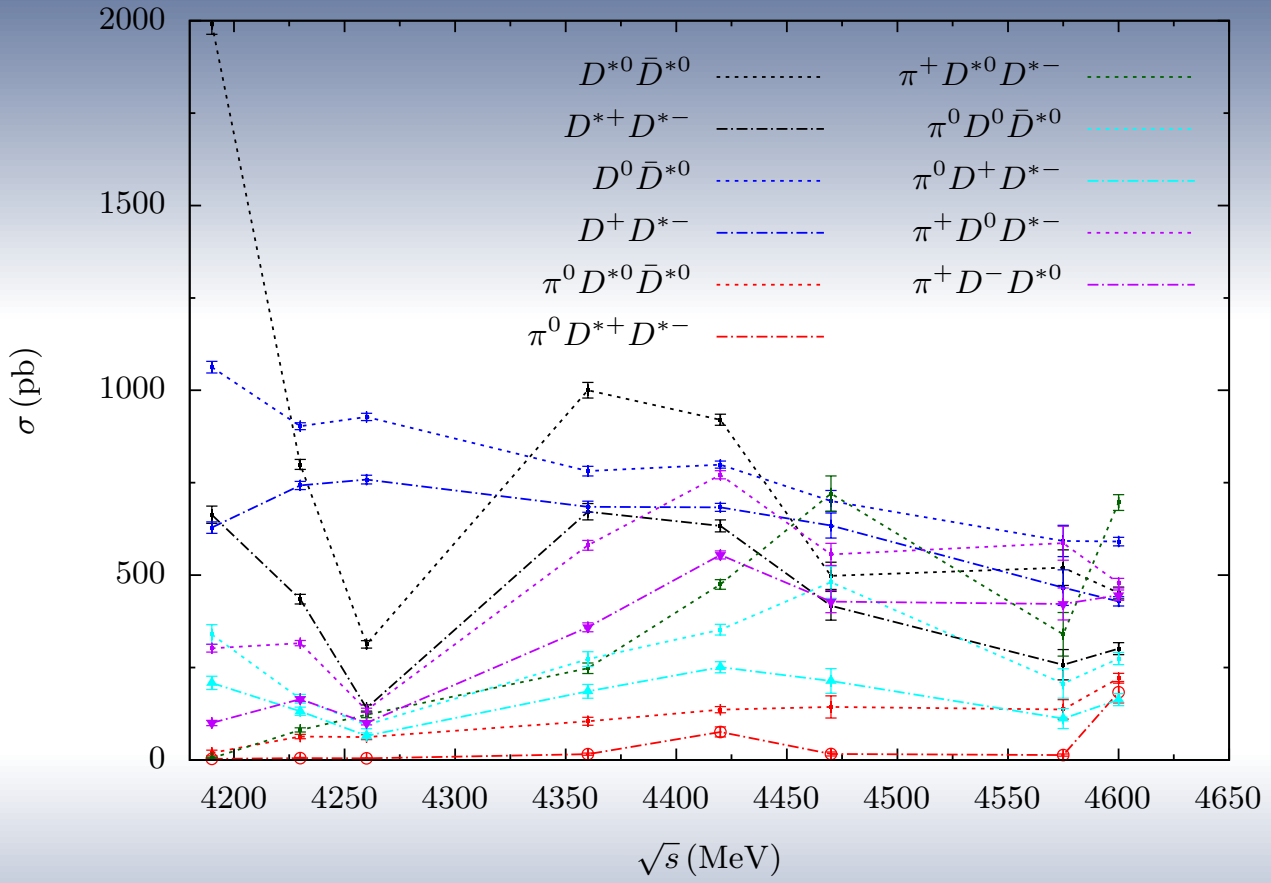
Example for two channels

$$\overbrace{\begin{pmatrix} N_{D^{*+}D^{*-}} \\ N_{\pi^+D^0D^{*-}} \end{pmatrix}}^{\text{measured}} = \overbrace{\begin{pmatrix} \varepsilon_{D^{*+}D^{*-}} & \varepsilon^{\pi^+D^0D^{*-}}_{\to D^{*+}D^{*-}} \\ \varepsilon^{D^{*+}D^{*-}}_{\to \pi^+D^0D^{*-}} & \varepsilon_{\pi^+D^0D^{*-}} \end{pmatrix}}^{\text{from MC}} \cdot \overbrace{\begin{pmatrix} \sigma_{D^{*+}D^{*-}} \\ \sigma_{\pi^+D^0D^{*-}} \end{pmatrix}}^{\text{to be extracted}} \cdot \mathcal{L}$$

Calculation of Cross Sections

- Including cross feed leads to a linear equation system that can be solved approximately for σ.
- Method works beacause background to open charm channels are other open charm channels.
- Second: All open charm channels relevant to the problem are measured.

Preliminary Result for Cross Sections



- For time reasons: the efficiency matrix was determined at $\sqrt{s} = 4.42\,\mathrm{GeV}$ and used for all $\sqrt{s}$.
- For channels πDD^*, D^*D^* dip at $Y(4260)$.
- No dip for πD^*D^* and DD^*.

Summary

What has been done

- As sideproduct of the background analysis of the channels $\pi^+ D^0 D^{*-}$ and $\pi^+ D^- D^{*0}$ a method was developed to reconstruct all open charm channels of type $(\pi) D^{(*)} D^{(*)}$.
- The method allows to extract all 16 cross sections of type $(\pi) D^{(*)} D^{(*)}$ from data.

Some questions

- Is the ansatz with the efficiency matrix justified?
- Is a method relying so heavily on kinematic fitting suitable for a cross section measurement?