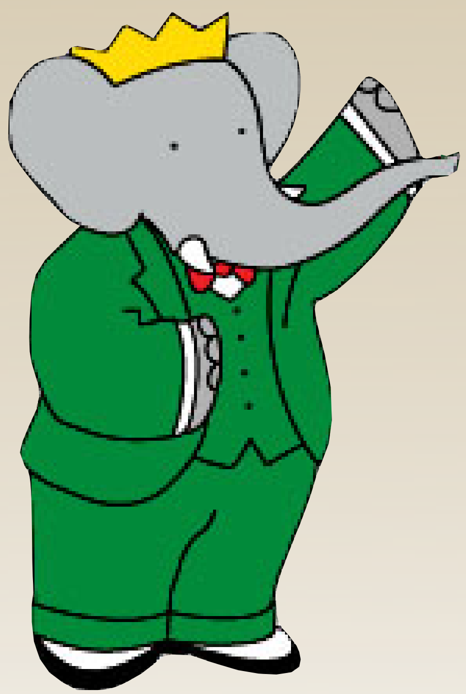
Measurements of $|V_{ub}|$ and $B \to D^{(*)}\tau\nu_\tau$ at BaBar

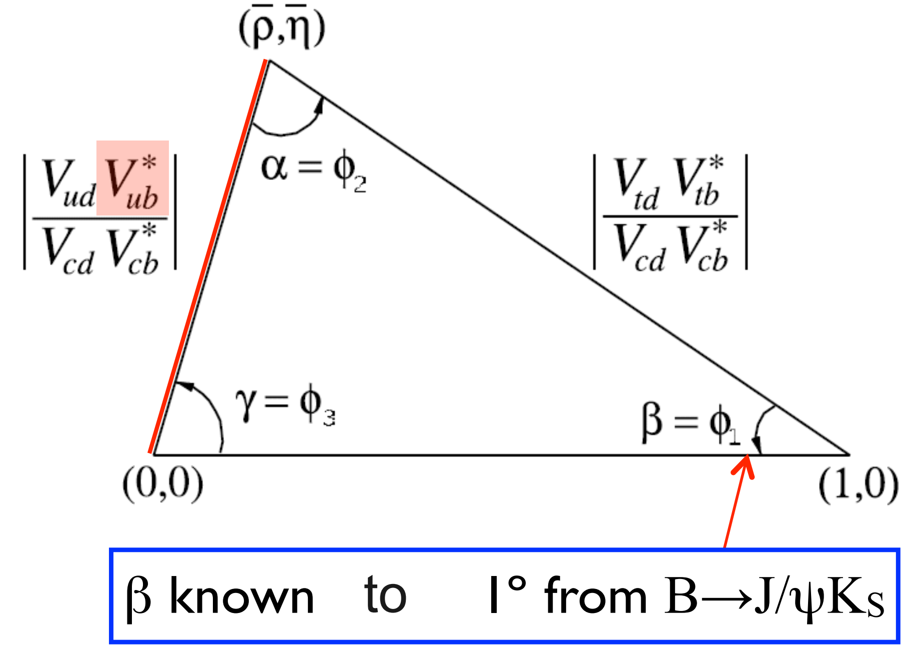


Manuel Franco Sevilla
on behalf of the BaBar collaboration
SLAC, Stanford University

<u>21st of July 2011</u>
Europhysics Conference on High Energy Physics
Grenoble, France

$|V_{ub}|$ status

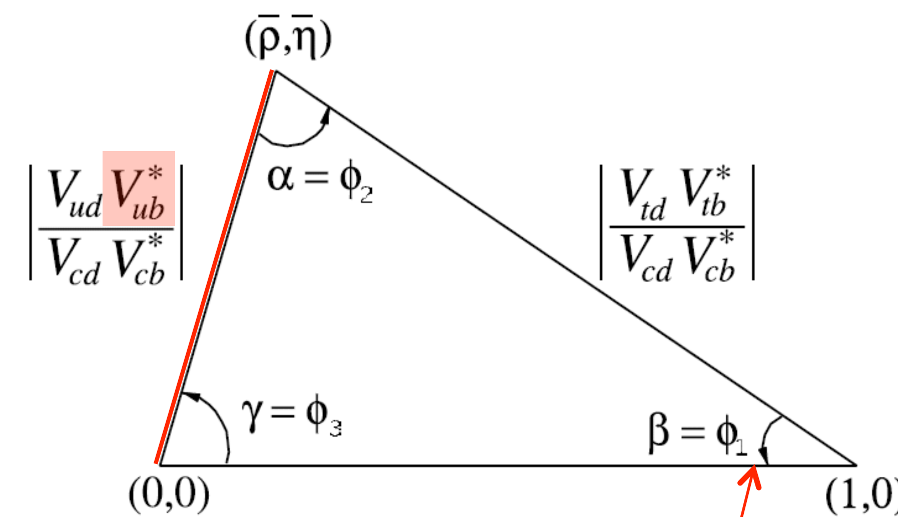
- $|V_{ub}|$ important **input** to the **SM**



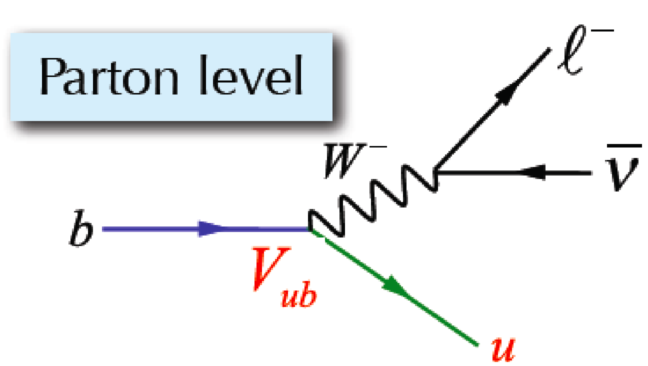
$|V_{ub}|$ status

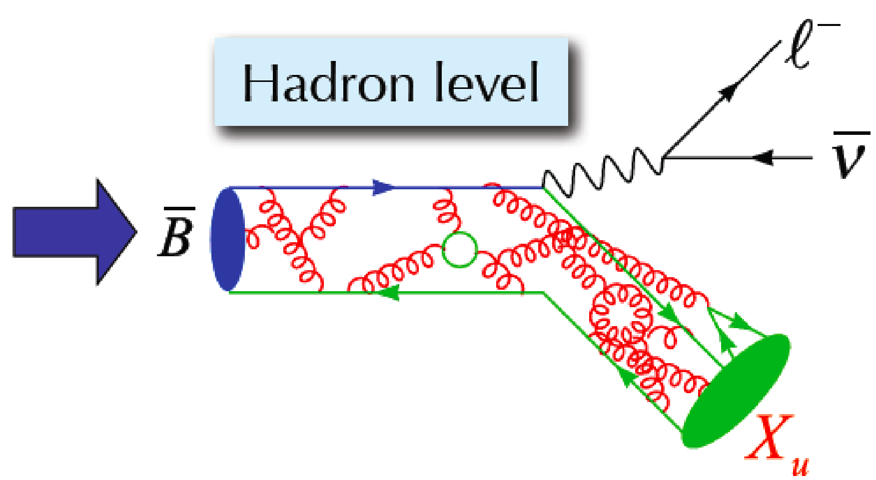
- $|V_{ub}|$ important **input** to the **SM**

$$\boxed{\Gamma_{B\to X_u \ell\nu} \propto |V_{ub}|^2 \times F^2_{\mathrm{had}}(q^2, M_X, \ldots)}$$



β known to 1° from $B\to J/\psi K_S$





$|V_{ub}|$ status

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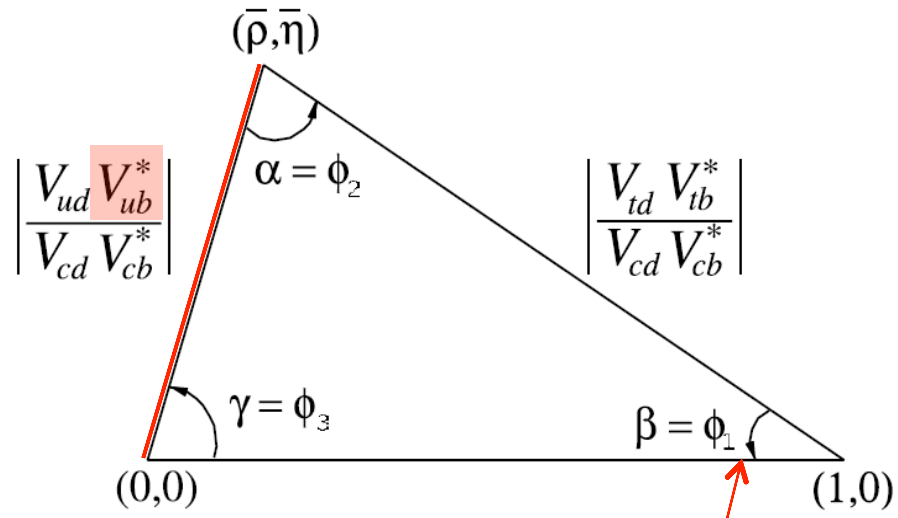
- **Complementary** measurements
  - **Inclusive** (reconstruct only lepton)
    - High $X_c\ell\nu$ background → Phase space restricted
    - Non-perturbative Shape function from QCD
  - **Exclusive** (reconstruct final decay)
    - Cleaner, lower statistics
    - Form factors from QCD



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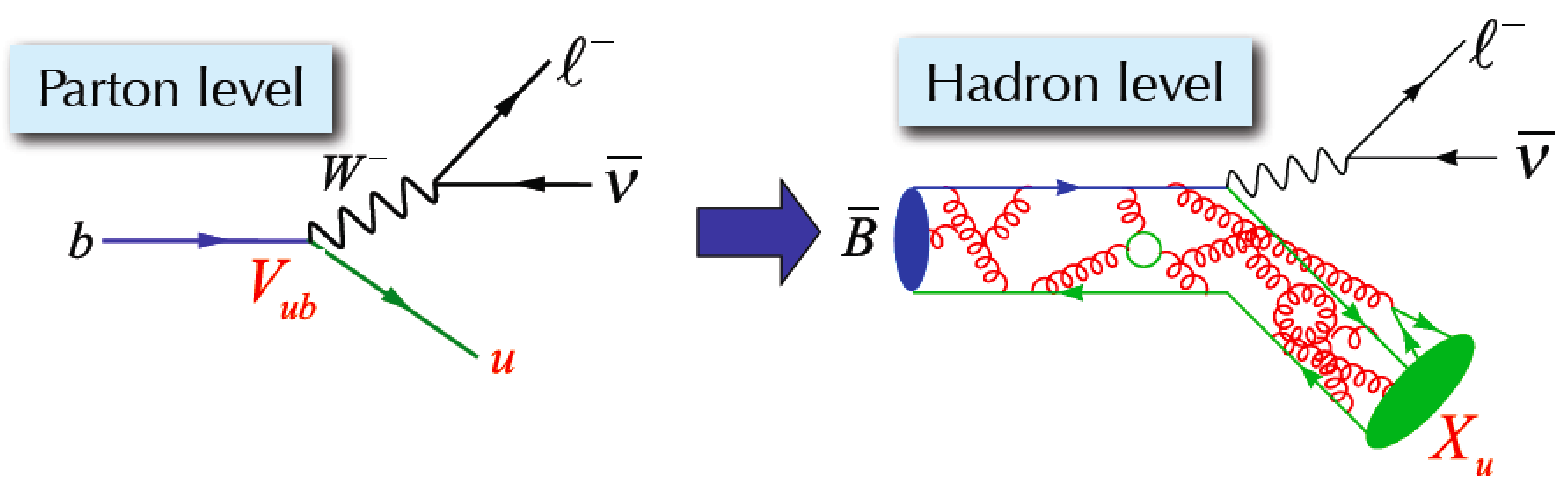

$|V_{ub}|$ status

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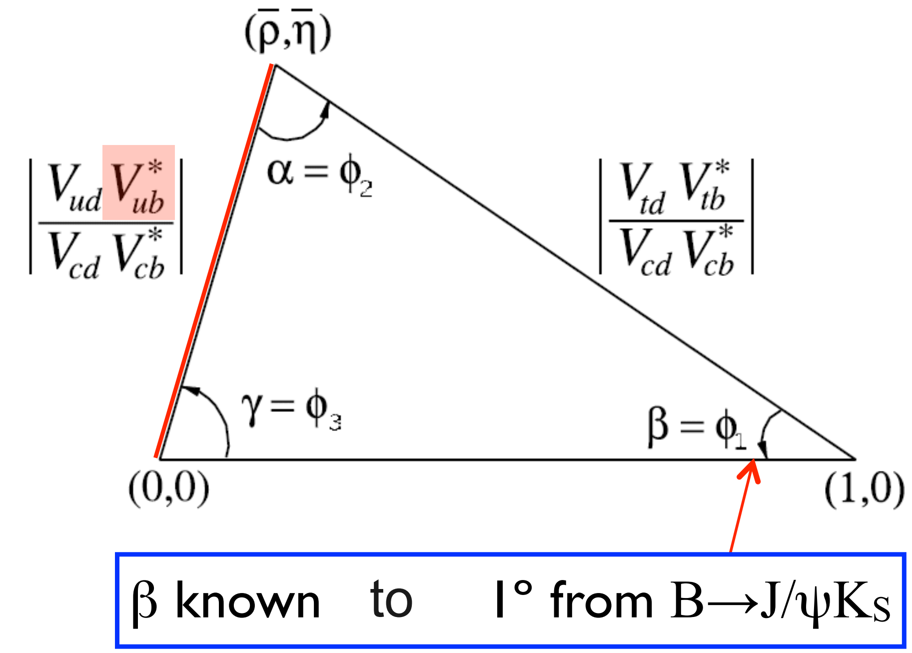

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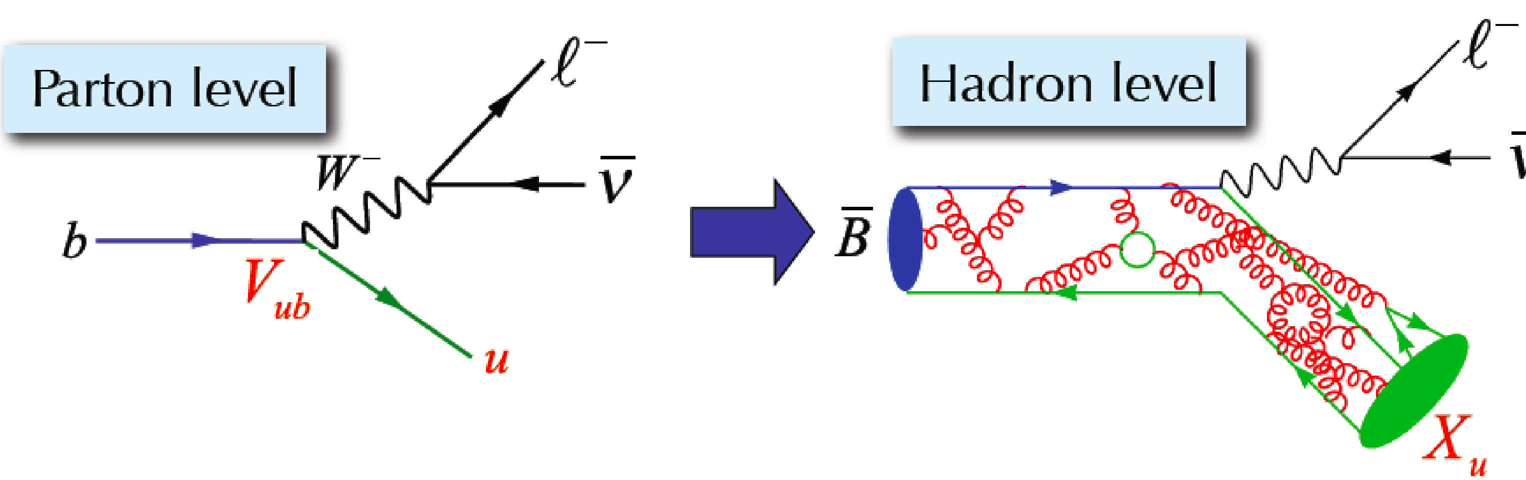


- Currently, **tension** between
  - **<u>Inclusive</u>**

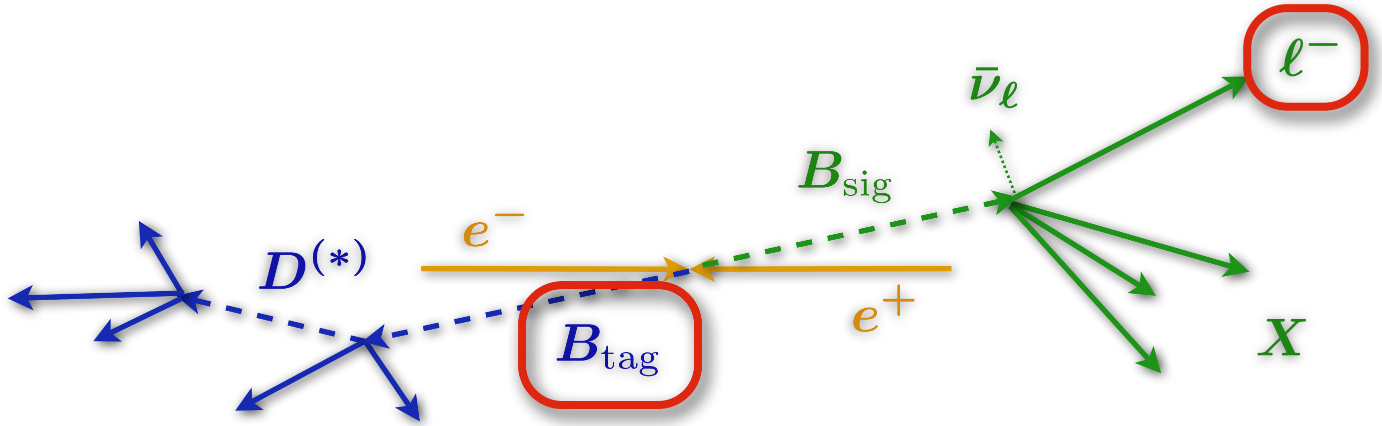
    $|V_{ub}| = (4.27 \pm 0.38) \times 10^{-3}$
  - **<u>Exclusive</u>**

    $|V_{ub}| = (3.38 \pm 0.36) \times 10^{-3}$

<u>PDG 2010</u>

Inclusive $|V_{ub}|$

To be submitted to Phys. Rev. D

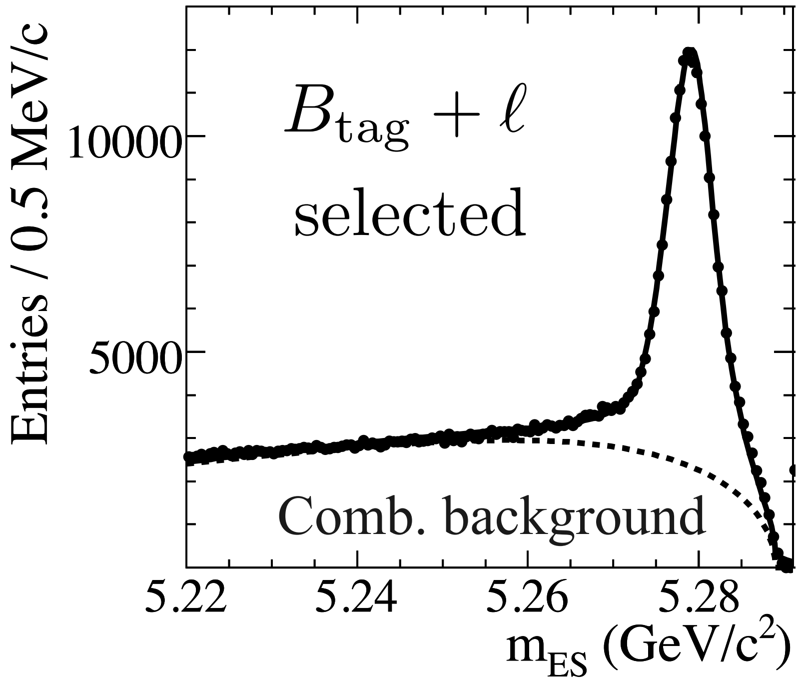


Kinematic variables

$$q^2 = (P_\ell + P_\nu)^2$$
$$M_X^2 = P_X^2 = E_X^2 - p_X^2$$
$$MM^2 = \left(P_{e^+e^-} - P_{B_{\text{tag}}} - P_X - P_\ell\right)^2$$

- **Hadronic <u>B$_{\text{tag}}$</u>** (ε = 0.3-0.5%) + **<u>e/μ</u>**
- **Combinatorial** background **subtracted**
- **$X_c\ell\nu$** background **reduced**
  - $D^*\ell\nu$, K_S, $K^\pm$ vetoes
- $MM^2 < 0.5\ \text{GeV}^2$

- **$X_c\ell\nu$ bkg. corrected** in signal depleted sample
  - Vetoes reversed

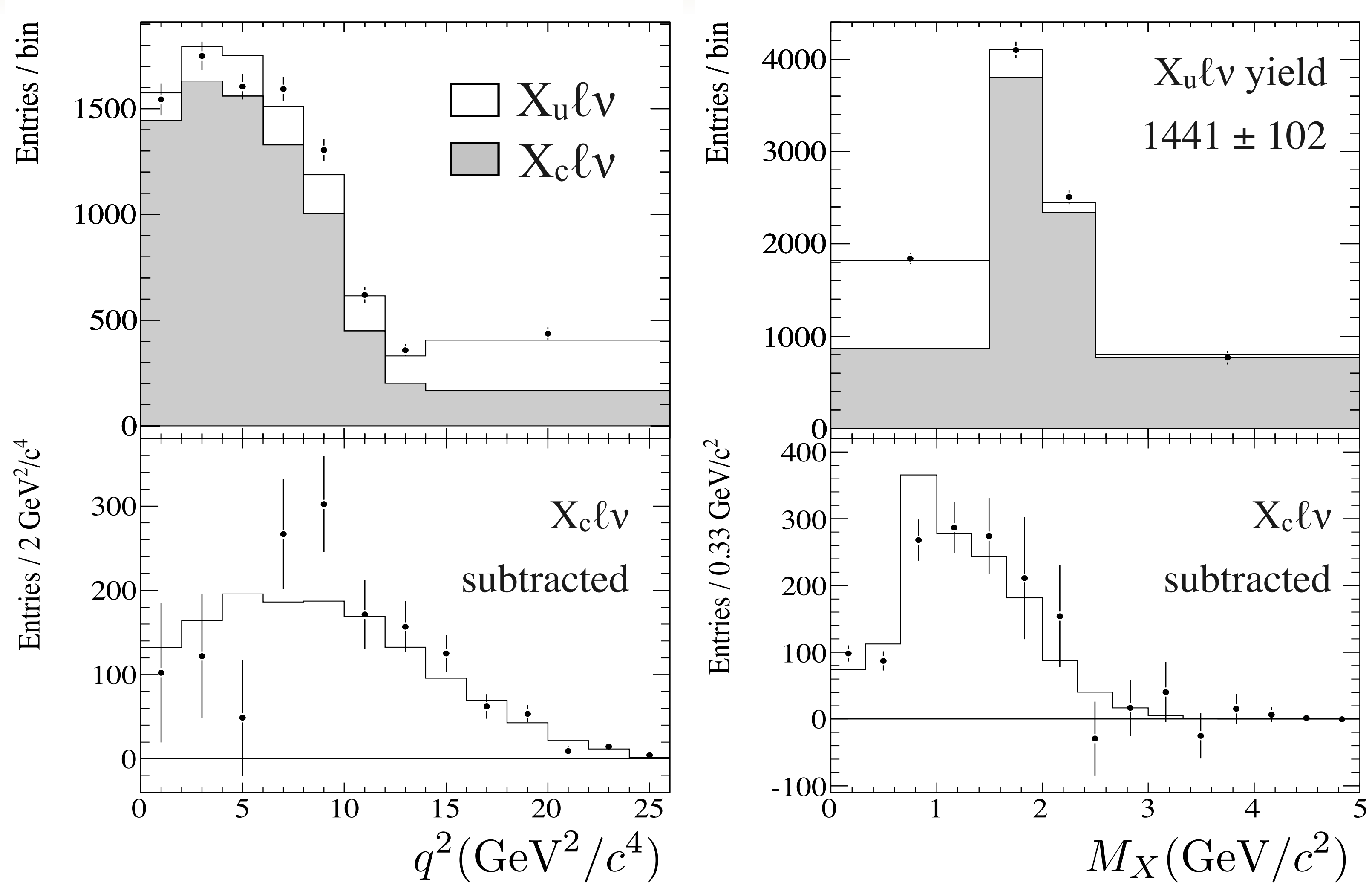


Inclusive $|V_{ub}|$

To be submitted to Phys. Rev. D

- Yields determined by fits to 7 phase space regions
  - **$X_u\ell\nu$** and **$X_c\ell\nu$ fitted**

- Most precise result
  - 2D: **q^2 - M_X**
  - **$p^*_\ell > 1$ GeV**
  - $\chi^2/\mathrm{ndof} = 31.0/29$



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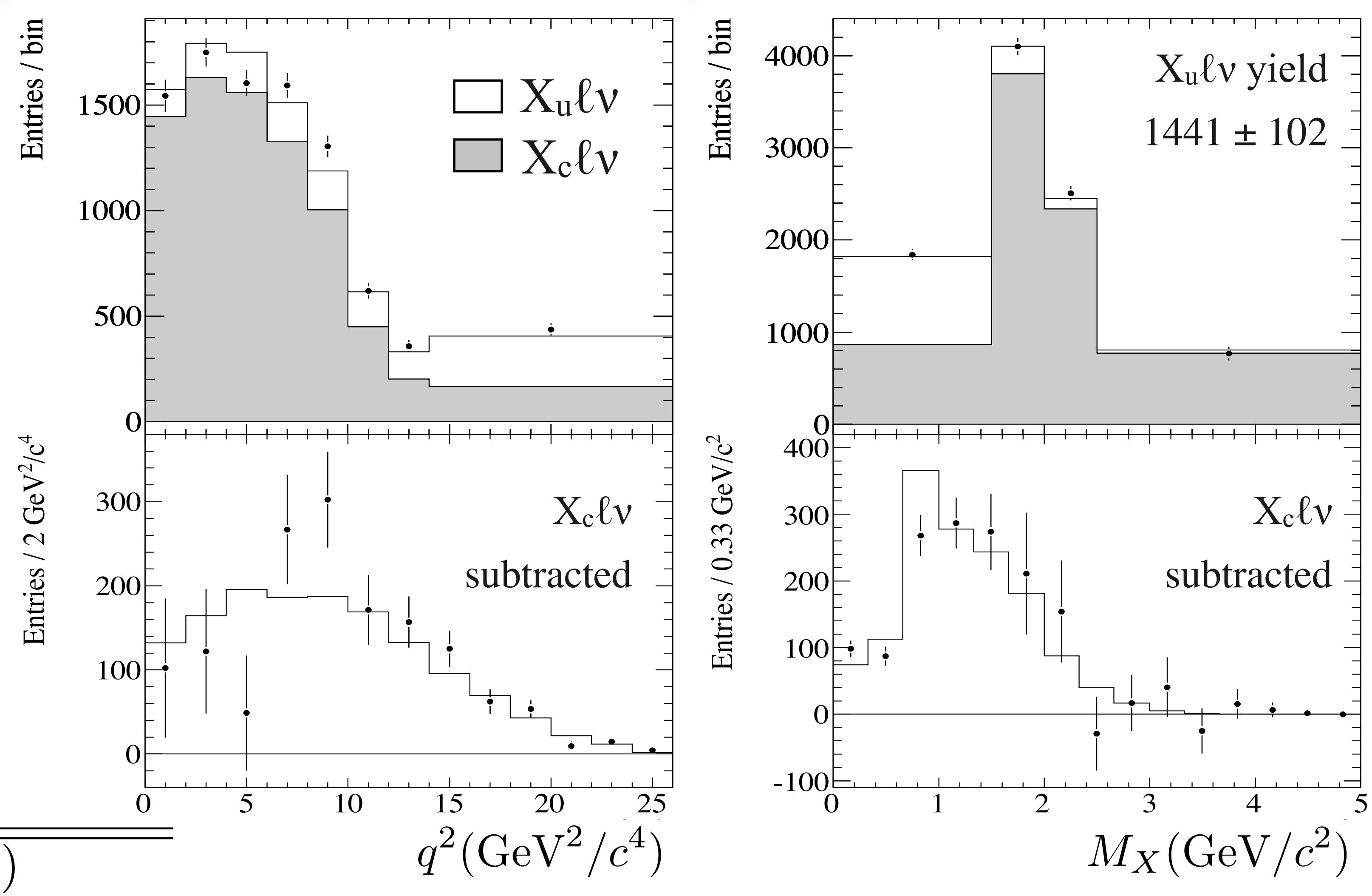


QCD Calculation	$\lvert V_{ub}\rvert(10^{-3})$
BLNP	$4.27 \pm 0.15 \pm 0.18^{+0.23}_{-0.20}$
DGE	$4.34 \pm 0.16 \pm 0.18^{+0.22}_{-0.15}$
GGOU	$4.29 \pm 0.15 \pm 0.18^{+0.11}_{-0.14}$
ADFR	$4.35 \pm 0.19 \pm 0.20^{+0.15}_{-0.15}$
Average	$4.31 \pm 0.25 \pm 0.16$

Uncertainty: **5.8% experimental, 3.7% theory**

Bosch *et al*. (BLNP), Phys. Rev. D **72**, 073006 (2005)
Andersen *et al*. (DGE), JHEP **0601**, 097 (2006)
Gambino *et al*. (GGOU), JHEP **0710**, 058 (2007)
Aglietti *et al*. (ADFR), Eur. Phys. J. C **59**, 831 (2009)

Exclusive $|V_{ub}|$: $B \to \pi \ell \nu$

<u>Two similar analyses</u>, but **small event overlap**

π + e/μ

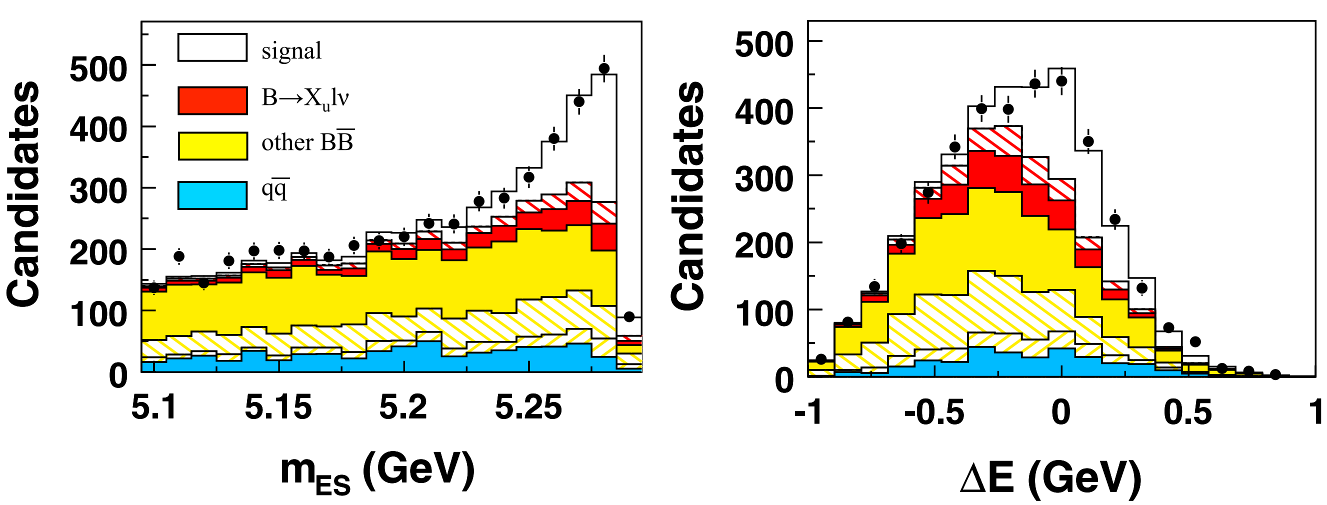
Untagged, **ν** from **rest of event**

m_{ES}-ΔE fit

Phys. Rev. **D83**, 032007 (2011)

- **Neural network**
- **S/B = 0.20 - Efficiency 7.0%**
- Combined fit to **$(\pi^-/\pi^0/\rho^-/\rho^0)\ell\nu$**
- **6 bins of q^2**

$8 < q^2 < 12$ GeV^2

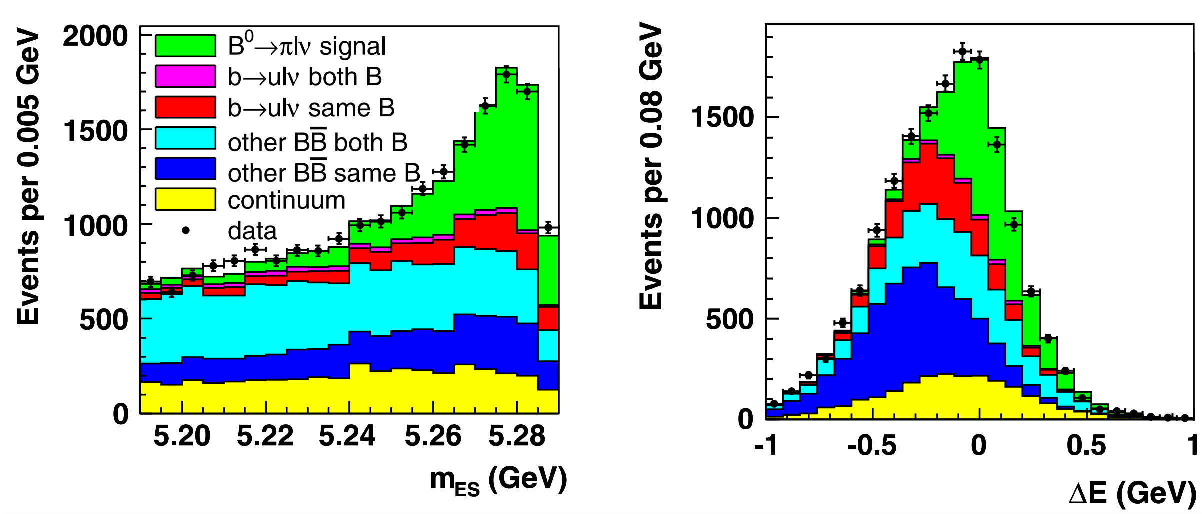


$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu_\ell) = (1.41 \pm 0.05 \pm 0.07) \times 10^{-4}$$

Phys. Rev. **D83**, 052011 (2011)

- **Cuts**
- **S/B = 0.09 - Efficiency 9.1%**
- Fit to **$\pi^-\ell\nu$**
- **12 bins of q^2**

$0 < q^2 < 16$ GeV^2

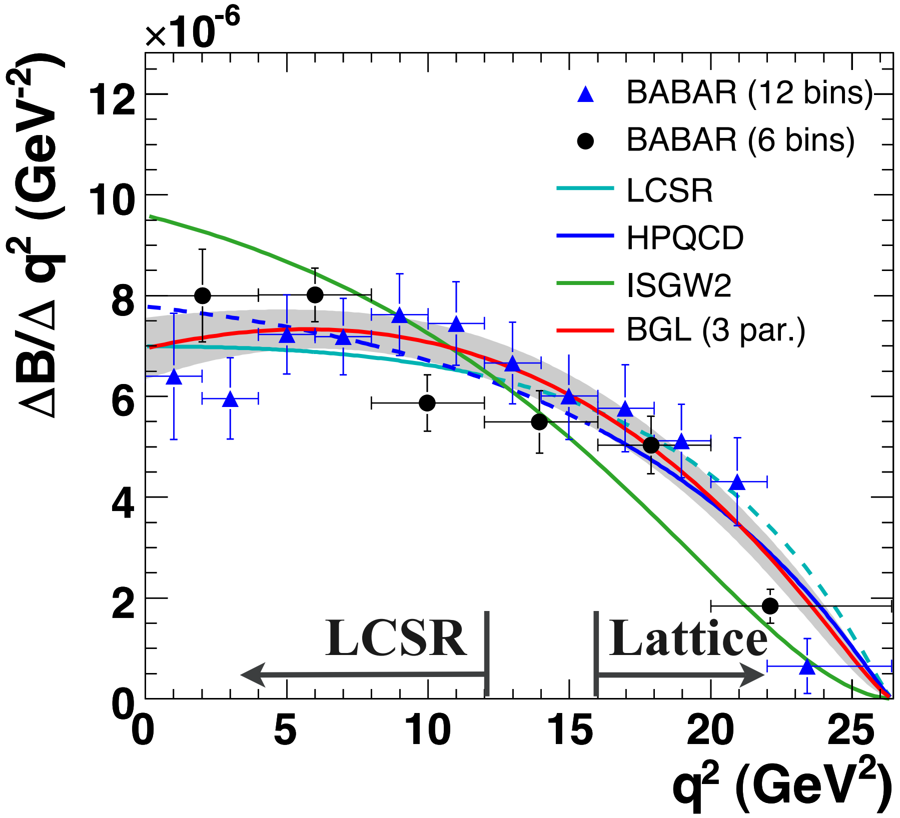


$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu_\ell) = (1.42 \pm 0.05 \pm 0.07) \times 10^{-4}$$

Exclusive $|V_{ub}|$: $B \to \pi \ell \nu$

Combined fit to data

$f_+(0)|V_{ub}| = (9.4 \pm 0.4) \times 10^{-4}$



- Data spectra agrees well with theory
- ISGW2 ruled out

Fits using BGL expansion with k_{max}=2

$$f_+(q^2) = \frac{1}{\mathcal{P}(q^2)\phi(q^2, q_0^2)} \sum_{k=0}^{k_{\max}} a_k(q_0^2)[z(q^2, q_0^2)]^k$$

Boyd, Grinstein, Lebed PRL **74**, 4603 (1995)

Fits provided by Jochen Dingfelder

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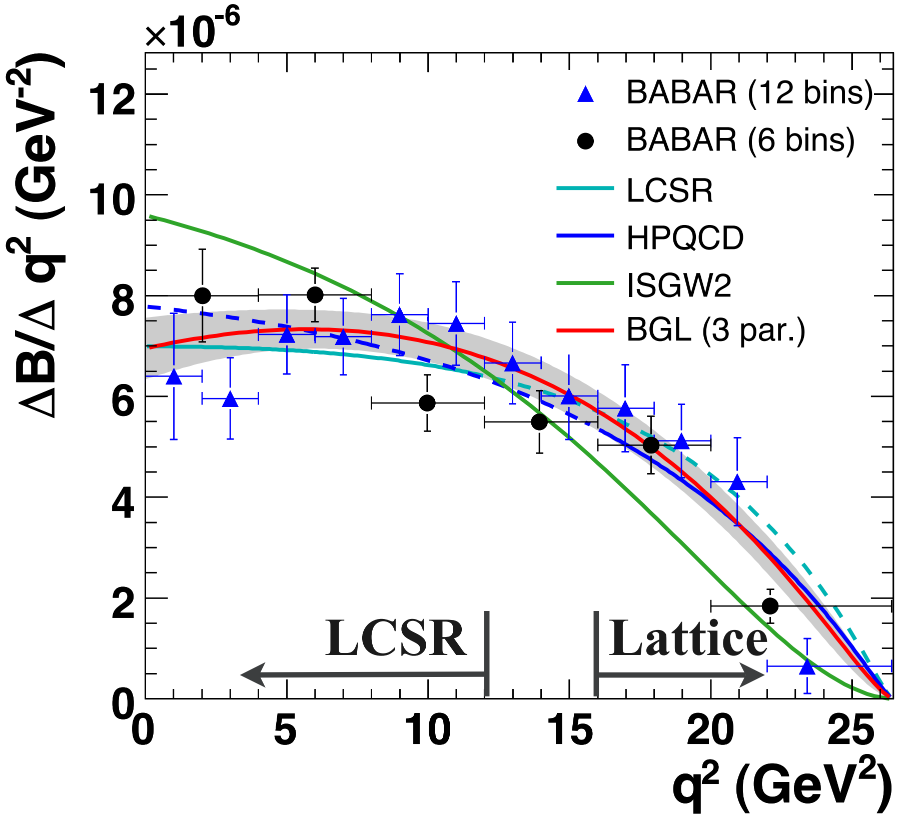

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$\times 10^{-3}$	12 bins	6 bins	Combined
$\lvert V_{ub}\rvert_{\mathrm{HPQCD}}$	3.28 ± 0.20	3.21 ± 0.18	$3.23 \pm 0.16^{+0.57}_{-0.37}$
$\lvert V_{ub}\rvert_{\mathrm{FNAL}}$	3.14 ± 0.18	3.07 ± 0.16	$3.09 \pm 0.14^{+0.35}_{-0.29}$
$\lvert V_{ub}\rvert_{\mathrm{LCSR}}$	3.70 ± 0.11	3.78 ± 0.13	$3.72 \pm 0.10^{+0.54}_{-0.39}$

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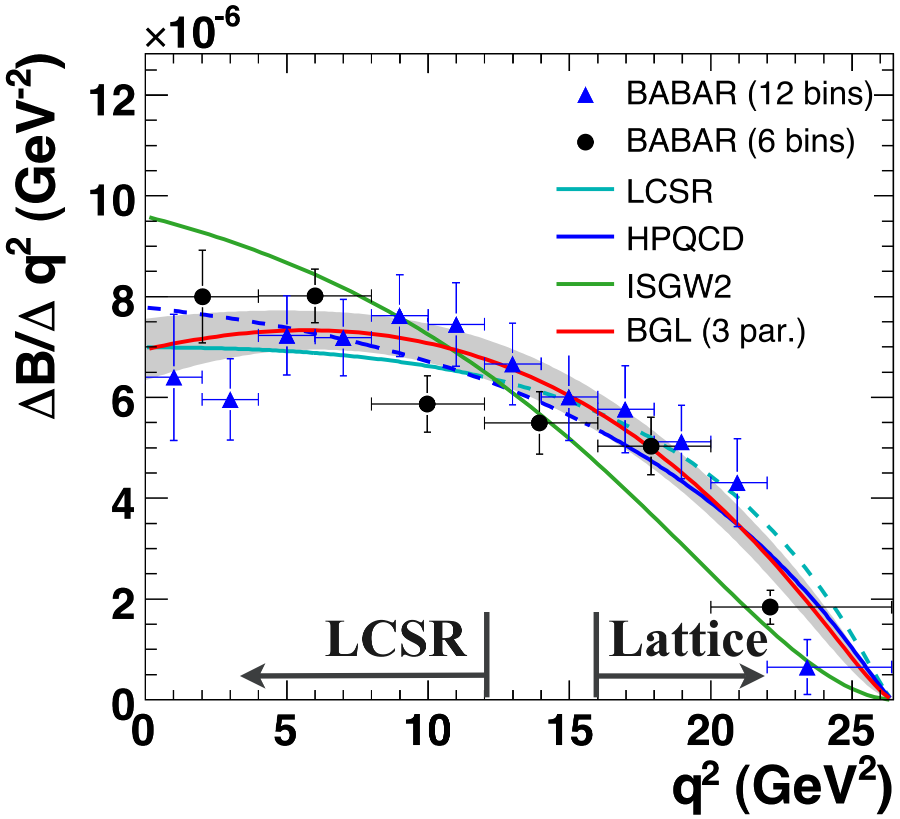

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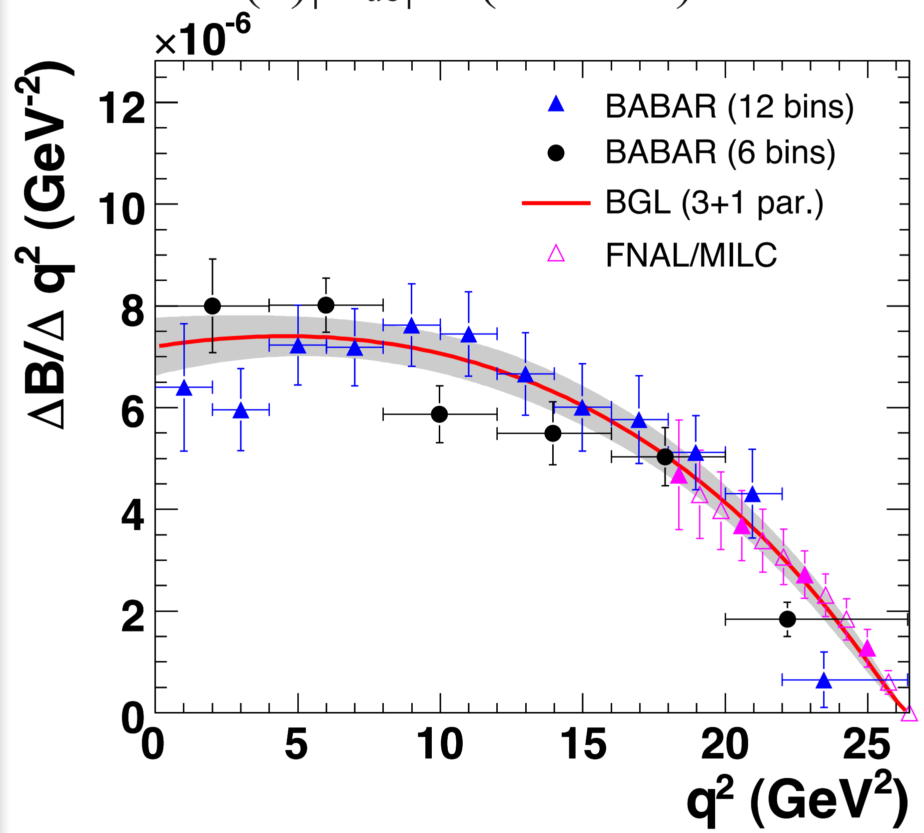
Combined fit + 4 FNAL points

$f_+(0)|V_{ub}| = (9.6\pm0.4)\times10^{-4}$



$$|V_{ub}| = (3.13\pm0.14\pm0.27)\times10^{-3}$$

Using shape information
uncertainty greatly reduced

Fits using BGL expansion with k_{max}=2

$$f_+(q^2) = \frac{1}{\mathcal{P}(q^2)\phi(q^2,q_0^2)}\sum_{k=0}^{k_{\max}} a_k(q_0^2)[z(q^2,q_0^2)]^k$$

Boyd, Grinstein, Lebed
PRL **74**, 4603 (1995)

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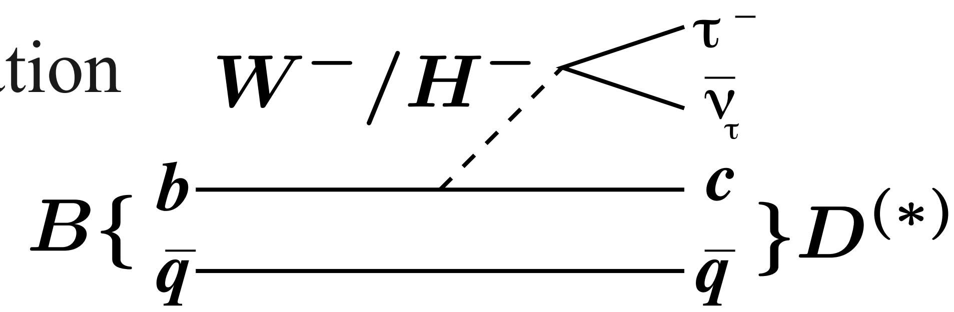
Measurement of

$B \to D\tau\nu_\tau$ and $B \to D^*\tau\nu_\tau$

Preliminary results

Motivation

- Decays sensitive to **charged Higgs** mediation
  - At **tree level**
  - Coupling proportional to m_τ



- **We measure** the ratios **R(D)** and **R(D*)** directly

$$\boxed{R(D^{(*)}) = \frac{\mathcal{B}\left(B \to D^{(*)}\tau\nu_\tau\right)}{\mathcal{B}\left(B \to D^{(*)}\ell\nu_\tau\right)}}$$

  - Several **theoretical** and **experimental uncertainties cancel**

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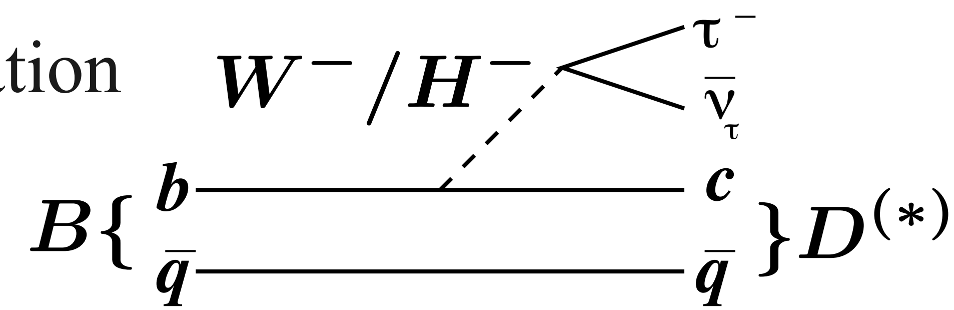

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  - Several **theoretical** and **experimental uncertainties cancel**

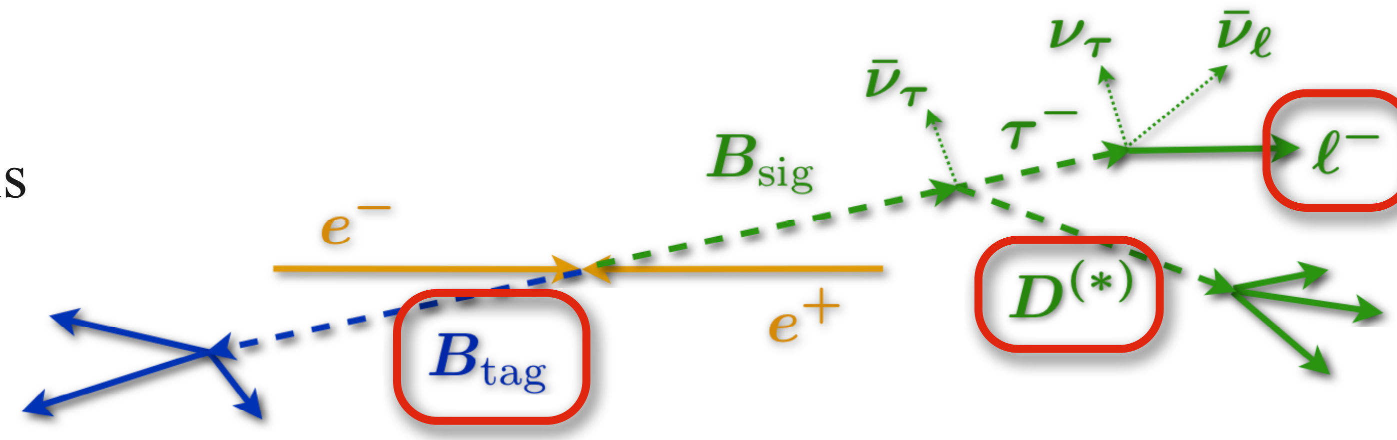
- **SM predictions**
  - **R(D) = 0.31 ± 0.02**
  - **R(D*) = 0.25 ± 0.02**

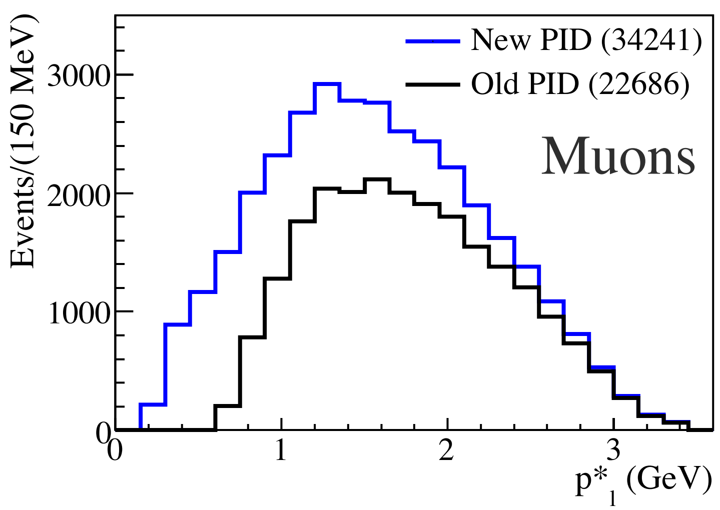
Nierste, Trine, Westhoff (2008)
Phys. Rev. **D78** 015066

- **Charged Higgs enhances** or **decreases R(D$^{(*)}$)**, depending on **tanβ/m$_H$**
  - Current measurements are **~1σ high**
- **Dτν** measured with **3.8σ**, **D*τν** with **8.1σ**

Event reconstruction

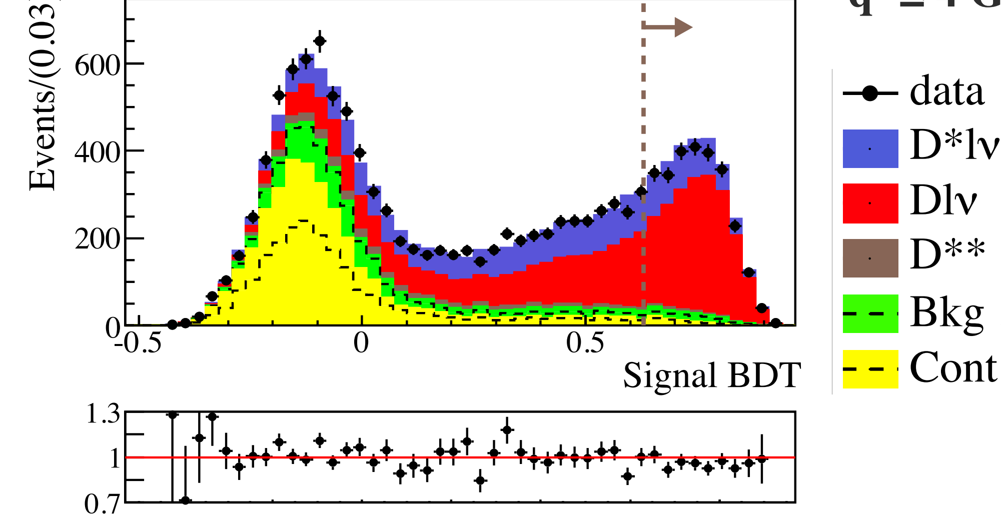
- **Improved B-tagging**
  - Efficiency 2x previous analysis
- **D(*) meson**: D^0, D^{*0}, D^+, D^{*+}
- **e or μ** (improved PID)





- **$q^2 = m_W^2 > 4$ GeV²**
- **Boosted Decision Tree (BDT)**
  - Backgrounds: **combinatorial** and **B→ D**ℓν**

Control sample
$q^2 \leq 4$ GeV²



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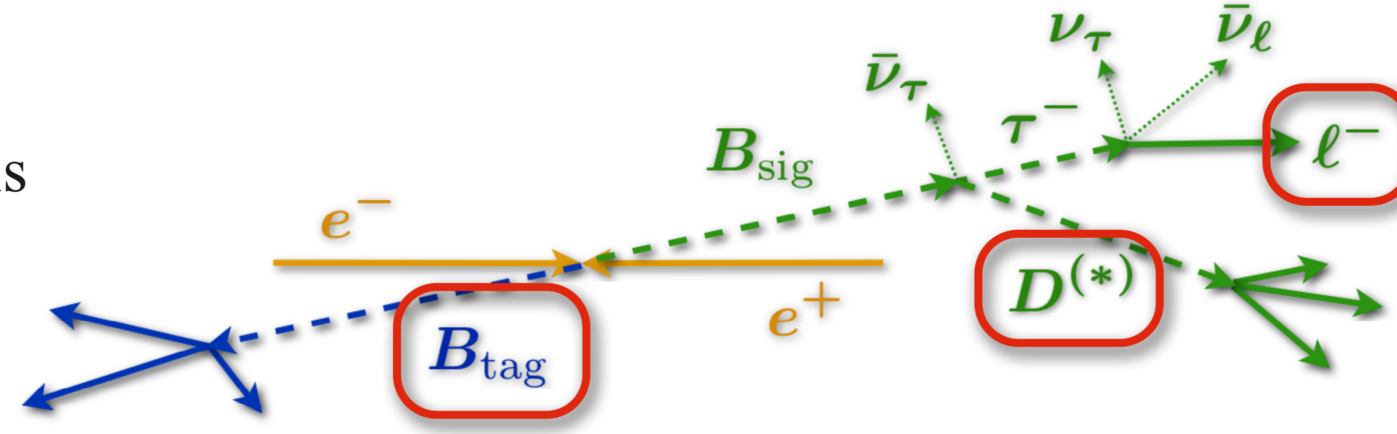

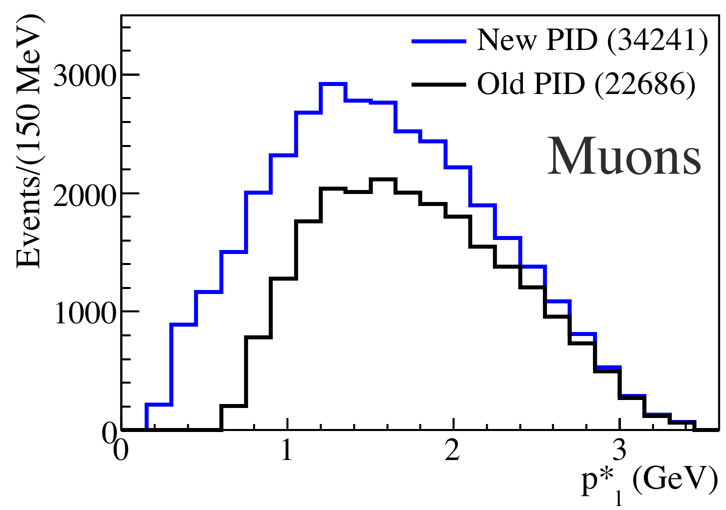

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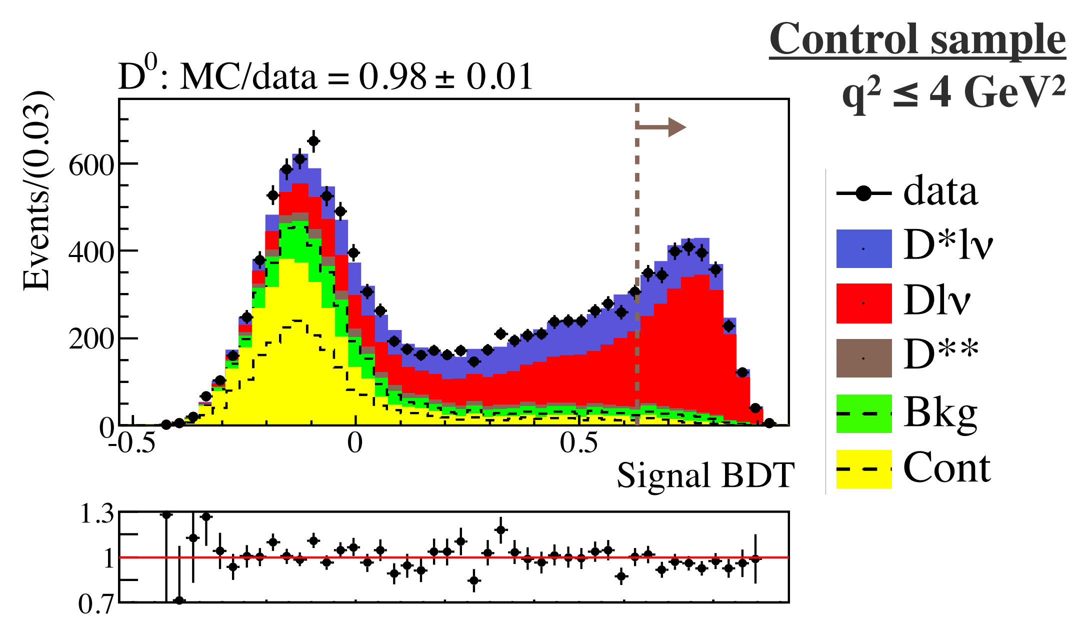
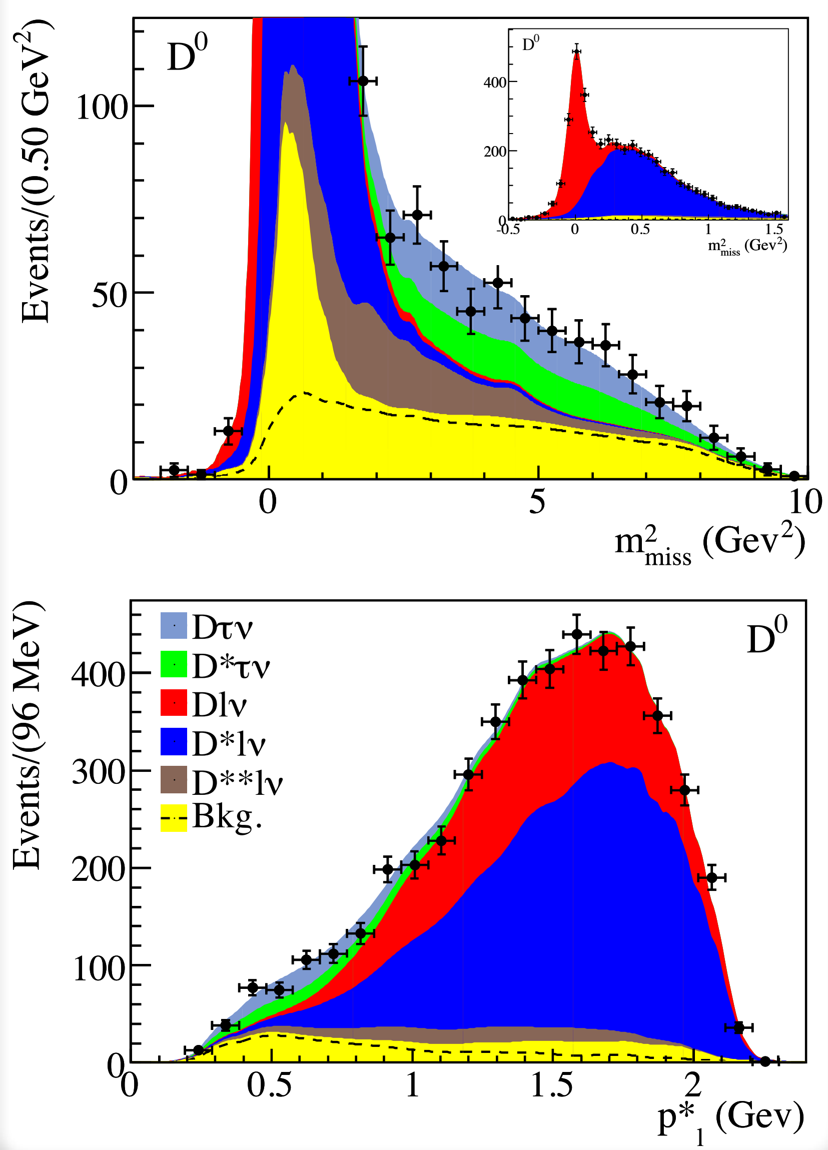


- **4 D$^{(*)}\pi^0$ℓν samples**
  - Because **B→ D**ℓν** has **large uncertainties**
  - Same selection as signal sample but
    - **Added π^0**: captures $D^{**} \to D^{(*)}\pi^0$ decays

Fit structure

- Unbinned ML fit
  - **2D: $m^2_{\text{miss}} - p^*_\ell$**
  - **4 Signal channels**
    - D^0, D^{*0}, D^+, D^{*+}

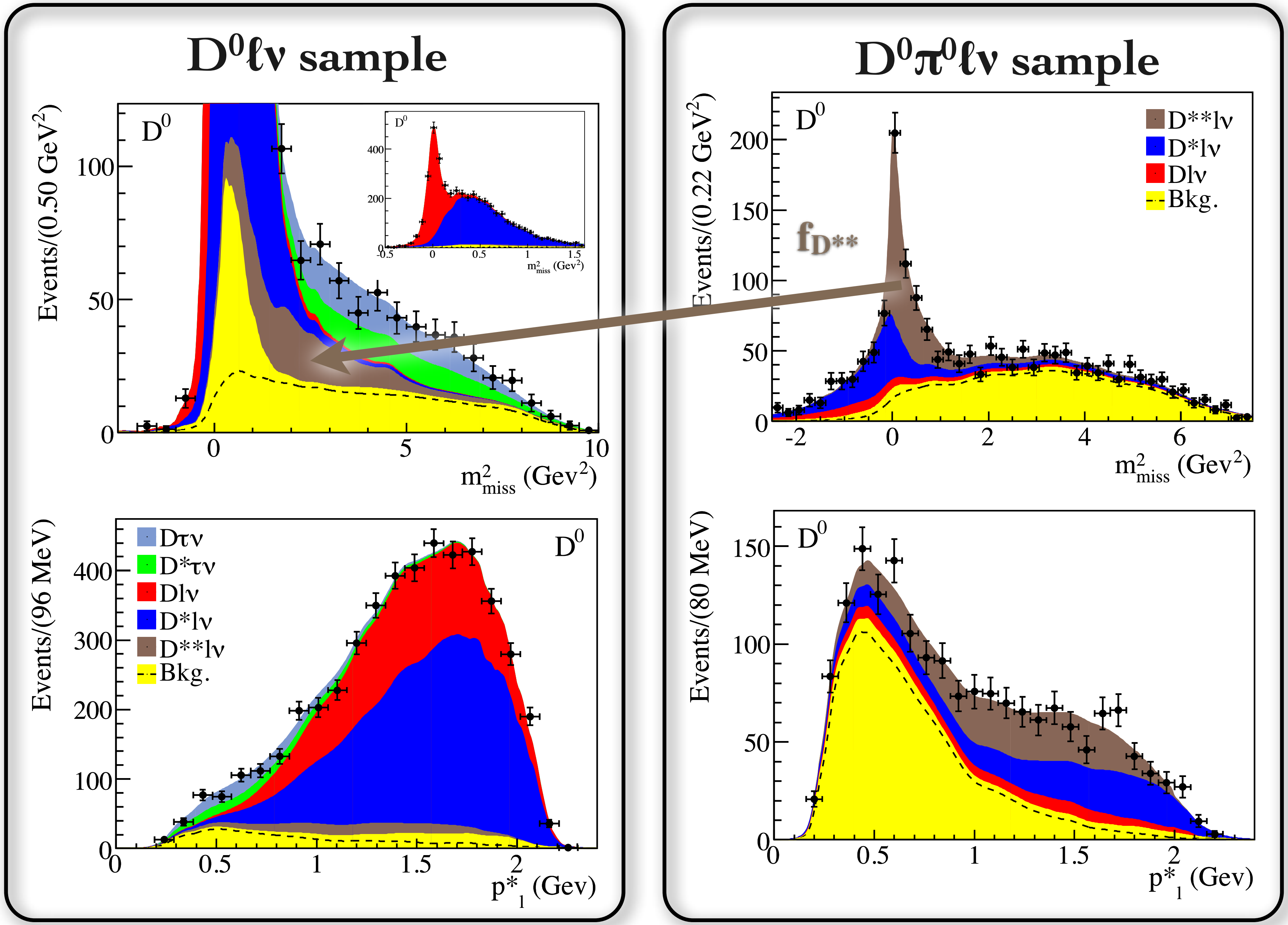
$D^0\ell\nu$ sample



MC Simulation

Fit structure

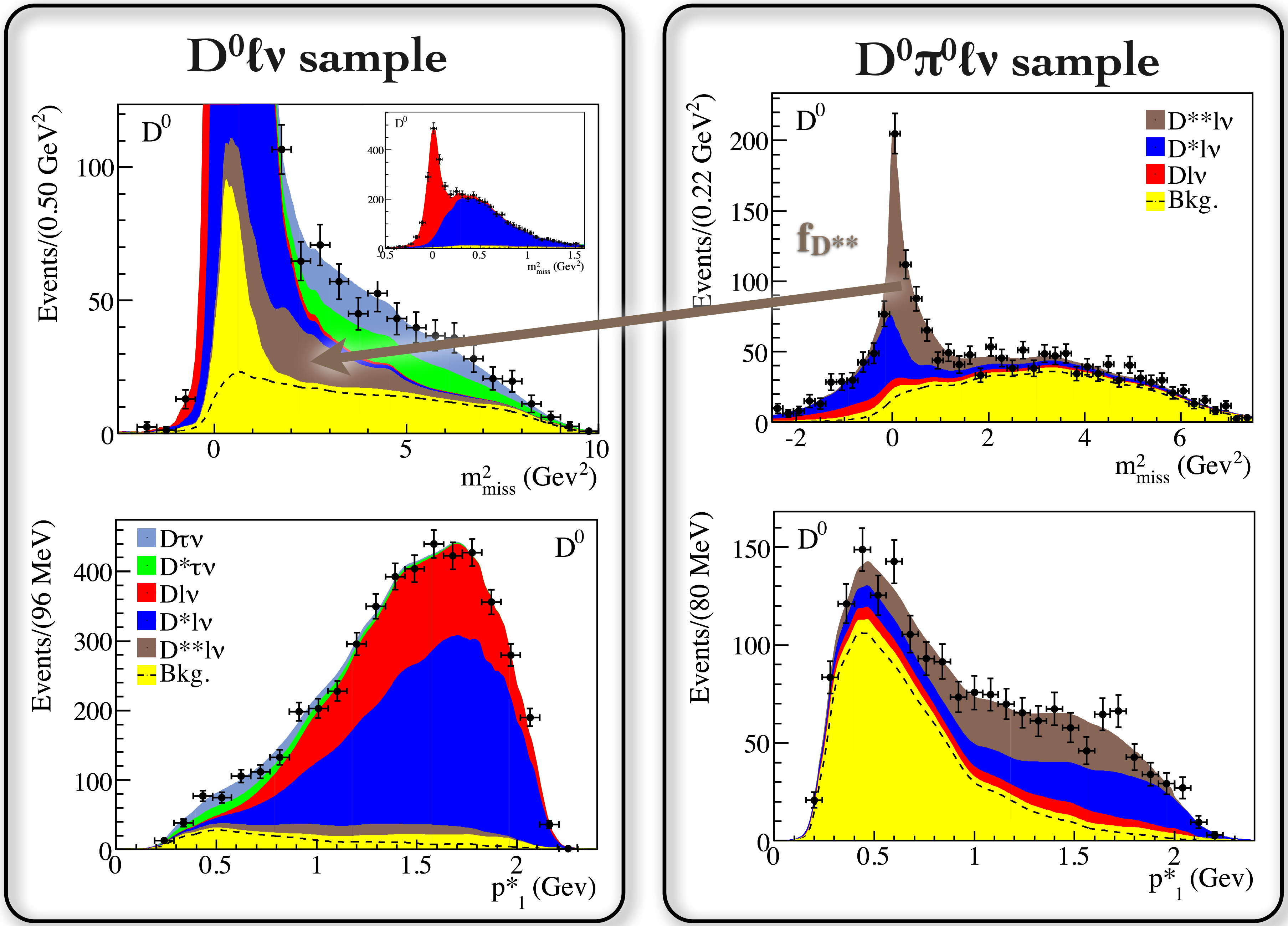
- Unbinned ML fit
  - **2D: $m^2_{\text{miss}} - p^*_\ell$**
  - **4 Signal channels**
    - D^0, D^{*0}, D^+, D^{*+}
  - **4 $D^{(*)}\pi^0\ell\nu$ channels**



MC Simulation

Fit structure

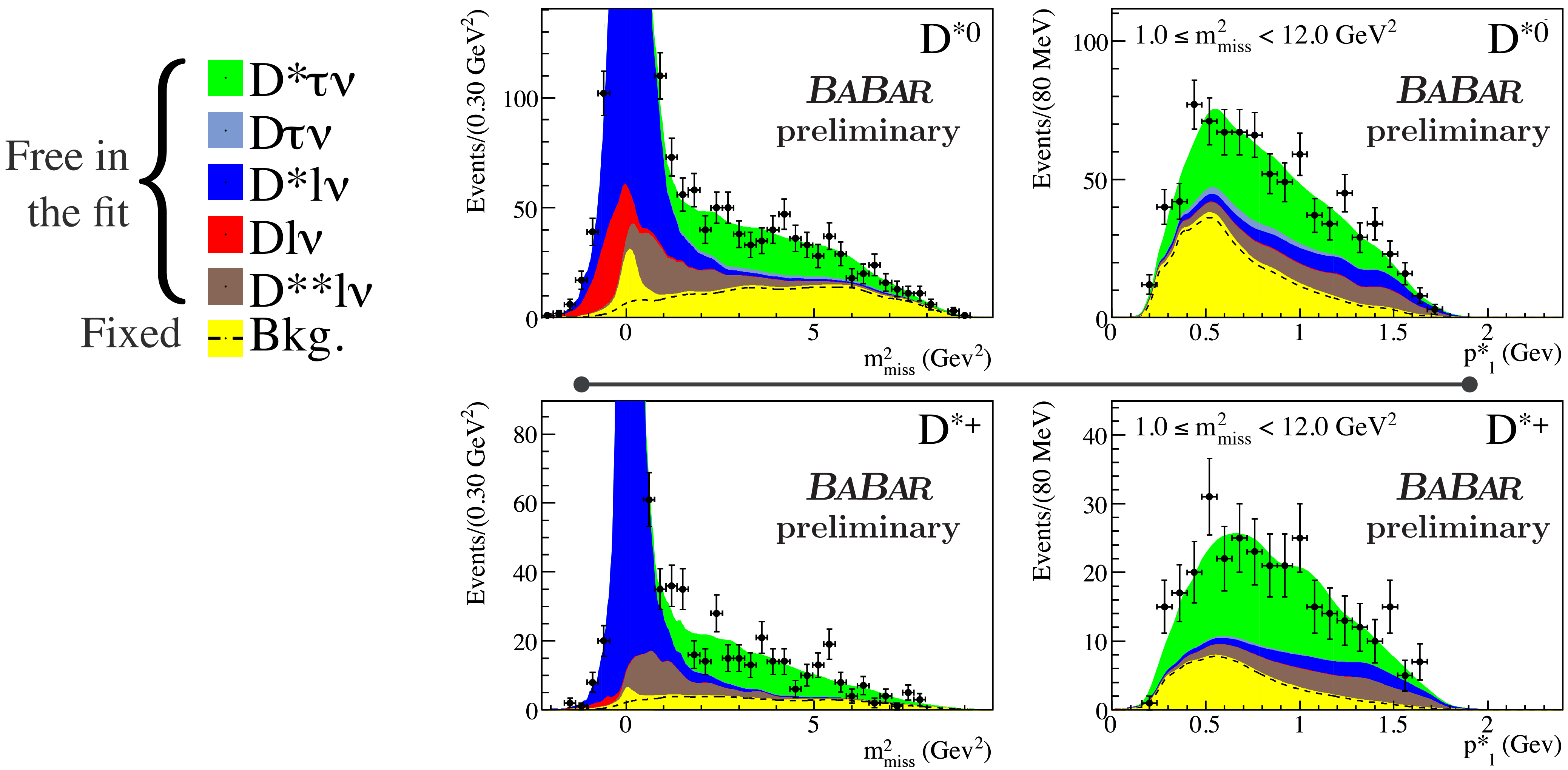
- Unbinned ML fit
  - 2D: $m^2_{\text{miss}} - p^*_\ell$
  - 4 Signal channels
    - D^0, D^{*0}, D^+, D^{*+}
  - 4 $D^{(*)}\pi^0\ell\nu$ channels
- Free parameters
  - 4 $D^{(*)}\tau\nu$
  - 4 $D^{(*)}\ell\nu$
  - 4 $D^{**}\ell\nu$
- Fixed yields (yellow)
  - Charge crossfeed
  - B combinatorial
  - Continuum



MC Simulation

Fit results: D^{*0} and D^{*+}

- Very **good fit**
- **R(D*) consistent**



Fit results: D^{*0} and D^{*+}

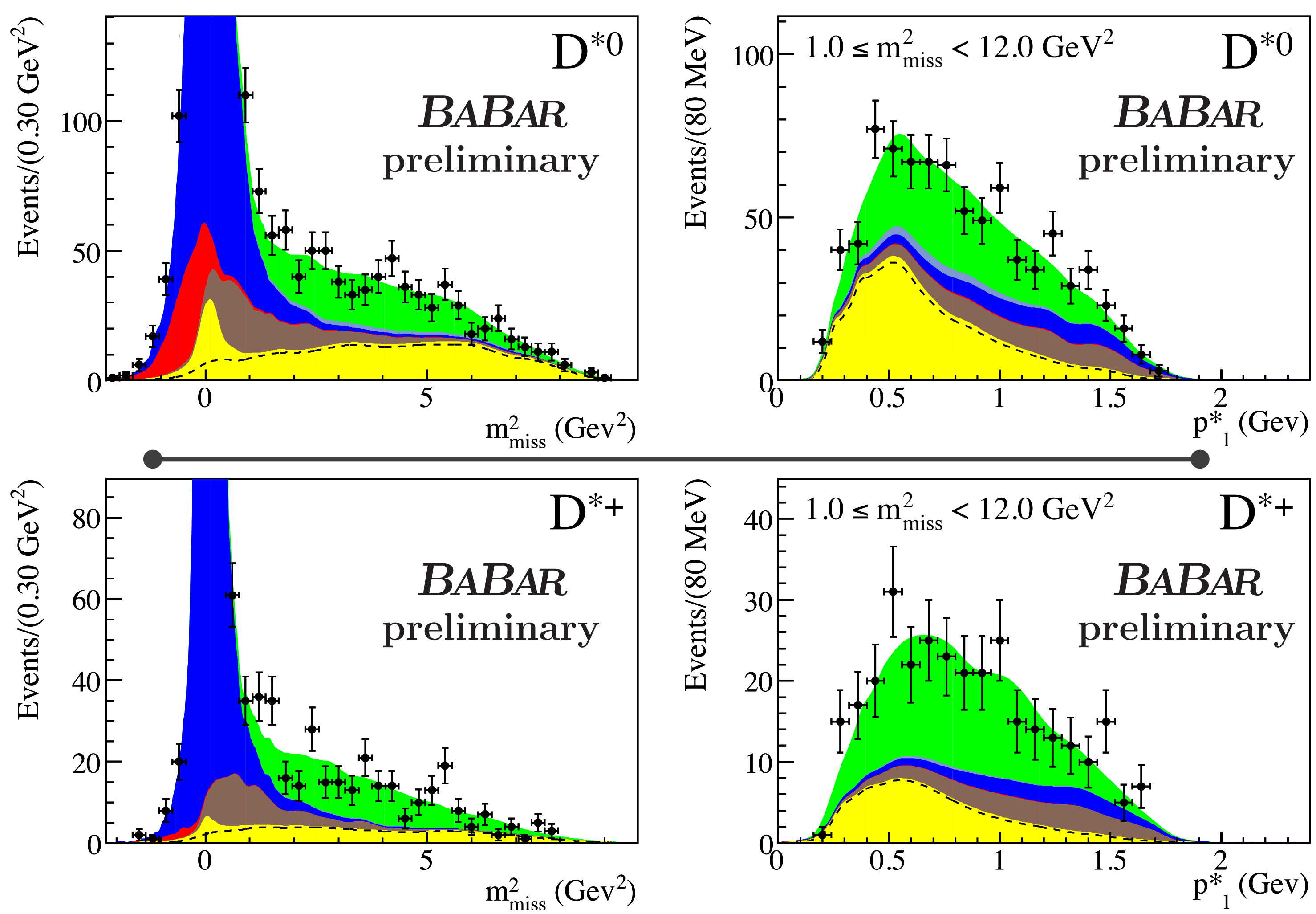
- Very **good fit**
- **R(D*) consistent**
- Uncertainties statistical

	D^{*0}	D^{*+}	D^{*}
N_{sig}	511 ± 48	220 ± 23	730 ± 50
Signif.	11.9	12.1	17.1
R(D*)	**0.314 ± 0.030**	**0.356 ± 0.038**	**0.325 ± 0.023**

Isospin constrained

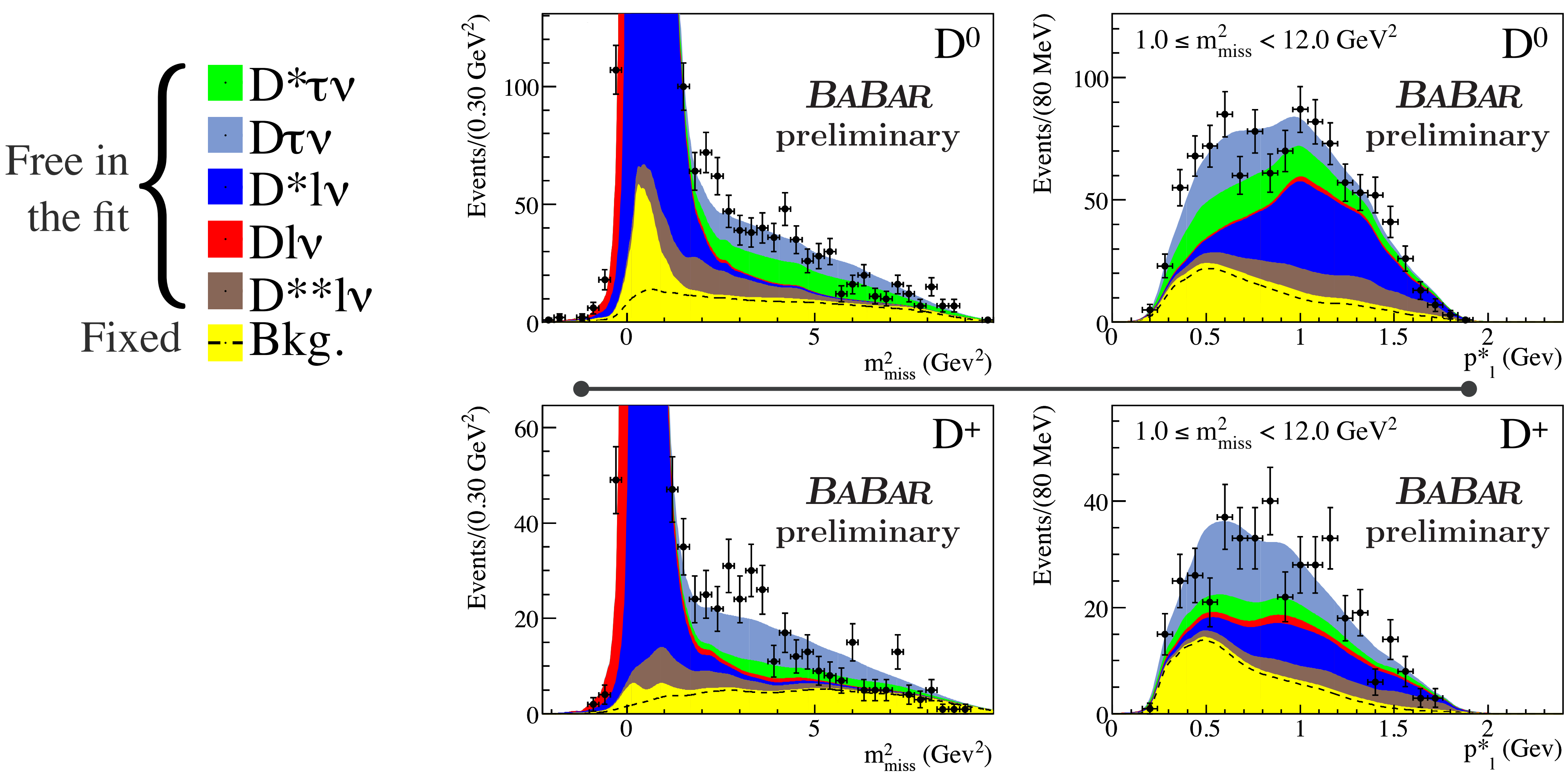
Free in the fit: $D^*\tau\nu$, $D\tau\nu$, $D^*l\nu$, $Dl\nu$, $D^{**}l\nu$

Fixed: Bkg.



Fit results: D^0 and D^+

- First **5σ observation**
- **Overestimation** for **$m^2_{miss} > 5$ GeV^2**
  - Dominated by **fixed Bkg.**



Fit results: D^0 and D^+

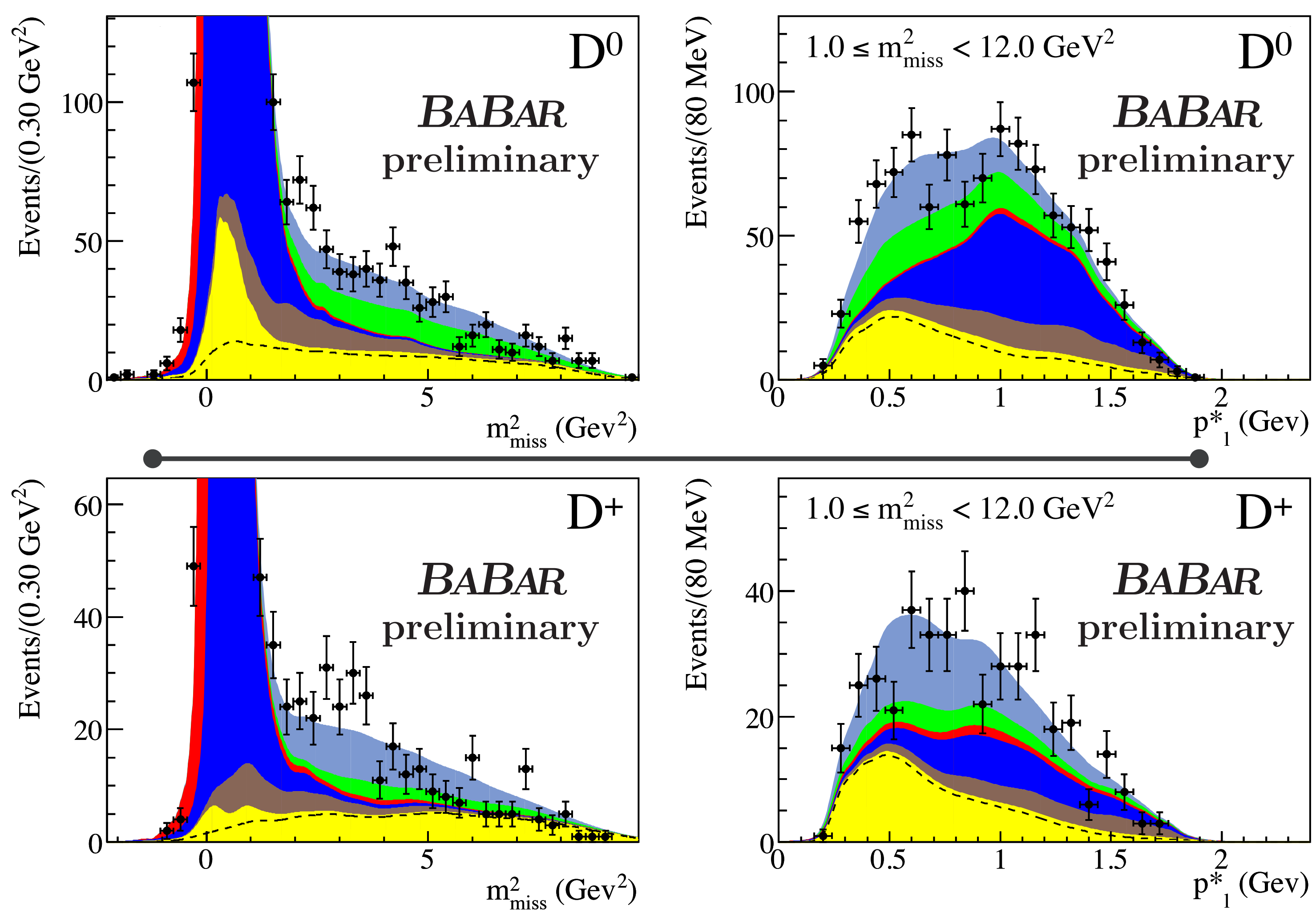
- First **5σ observation**
- **Overestimation** for **m^2_{miss} > 5 GeV^2**
  - Dominated by **fixed Bkg.**

	D^0	D^+	D
N_{sig}	226 ± 39	139 ± 21	368 ± 42
Signif.	6.2	7.5	9.6
R(D)	**0.422 ± 0.074**	**0.513 ± 0.081**	**0.456 ± 0.053**

Isospin constrained

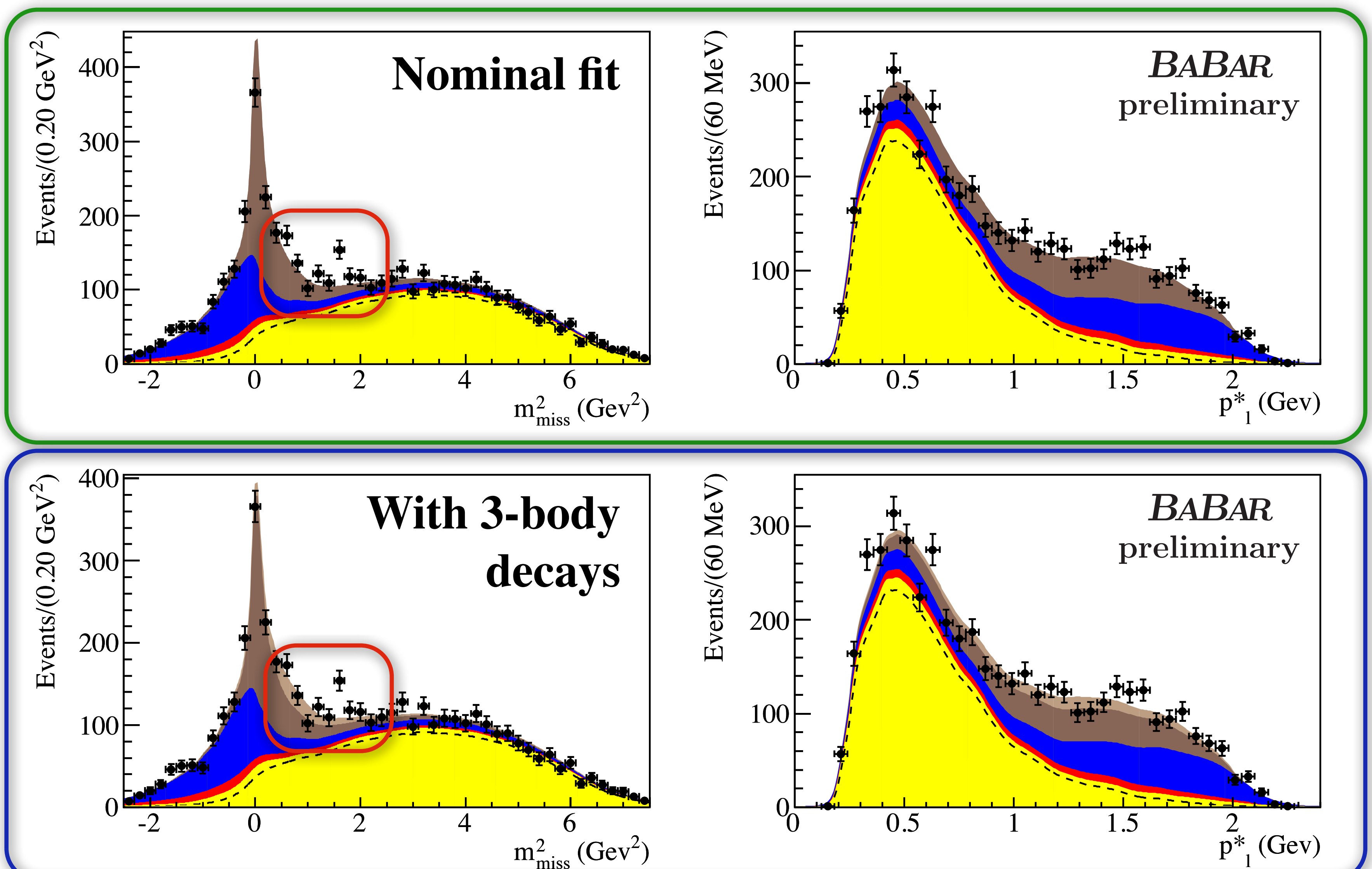
Free in the fit: $D^*\tau\nu$, $D\tau\nu$, $D^*l\nu$, $Dl\nu$, $D^{**}l\nu$

Fixed: Bkg.



Systematics: $D^{**}\ell\nu$

- **$D^{**}\ell\nu$ fitted** in $D^{(*)}\pi^0\ell\nu$ samples
- **Peaks** are **well described**
  - There might be an **excess** at **$1 \leq m^2_{miss} \leq 2$ GeV^2**
  - **3-body decays of D^{**}** included as a systematic uncertainty



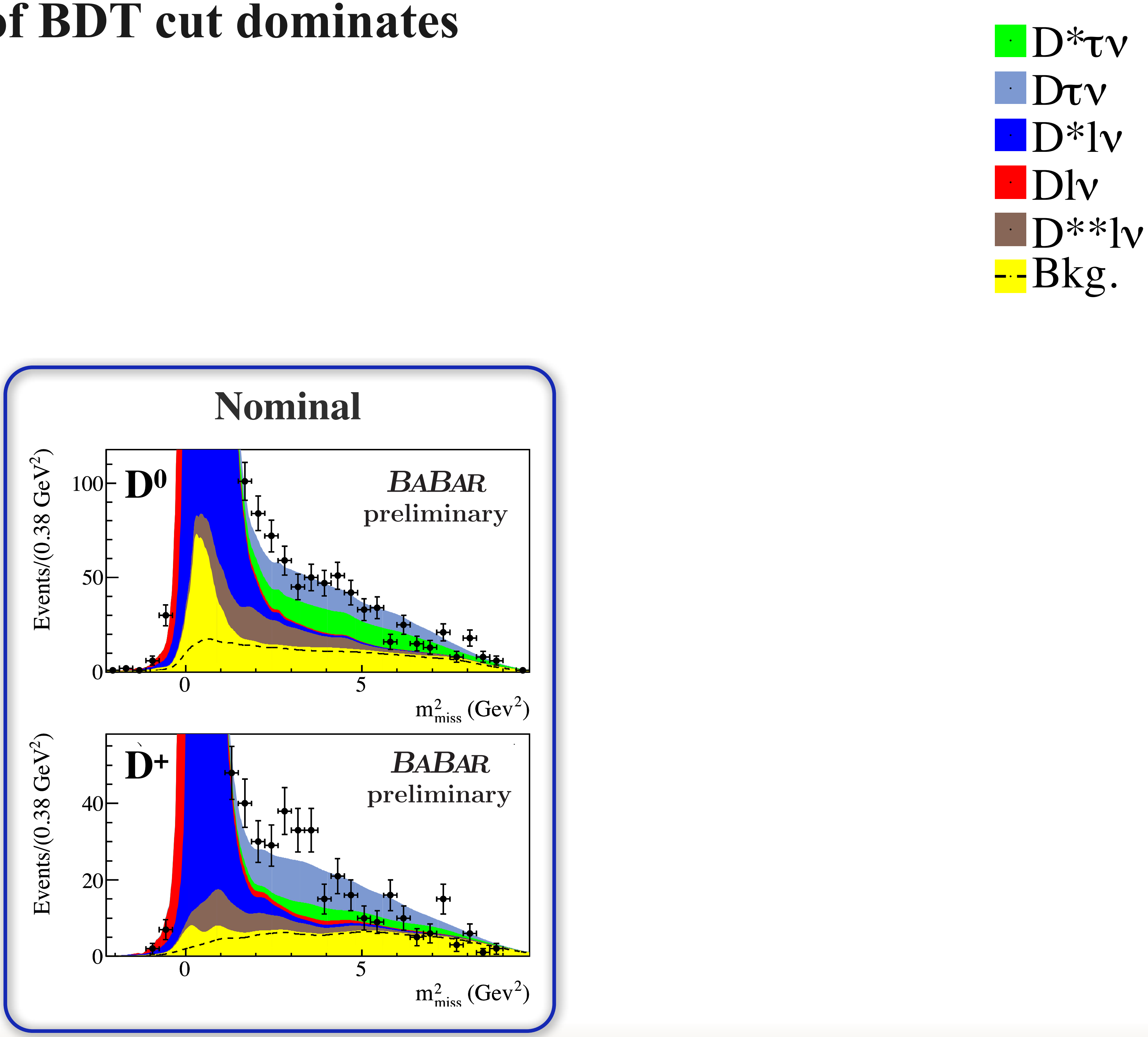
Sum 4 $D^{(*)}\pi^0\ell\nu$ samples

- $D^{**}(\rightarrow D^{(*)}\pi)\ell\nu$
- $D^{**}(\rightarrow D^{(*)}\pi\pi)\ell\nu$
- $D^*\ell\nu$
- $D\ell\nu$
- Combinatorial

- **B combinatorial floated**
  - Expected 1553 events
  - Fitted 1570 ± 60 → Good agreement

Systematics: BDT

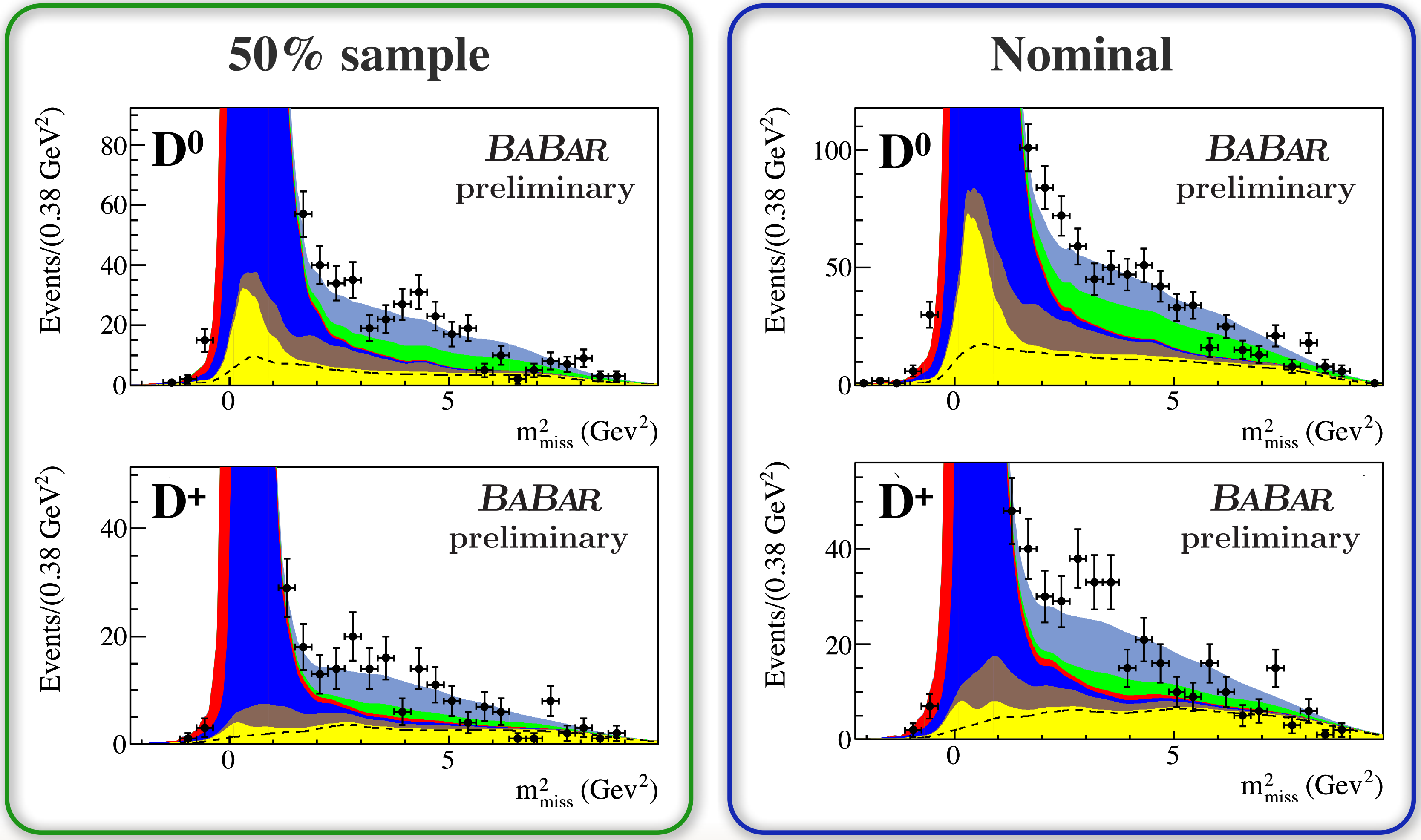
- Currently, **variation of BDT cut dominates**



Systematics: BDT

- Currently, **variation of BDT cut dominates**
  - **Tight BDT cut**: 50% nominal sample

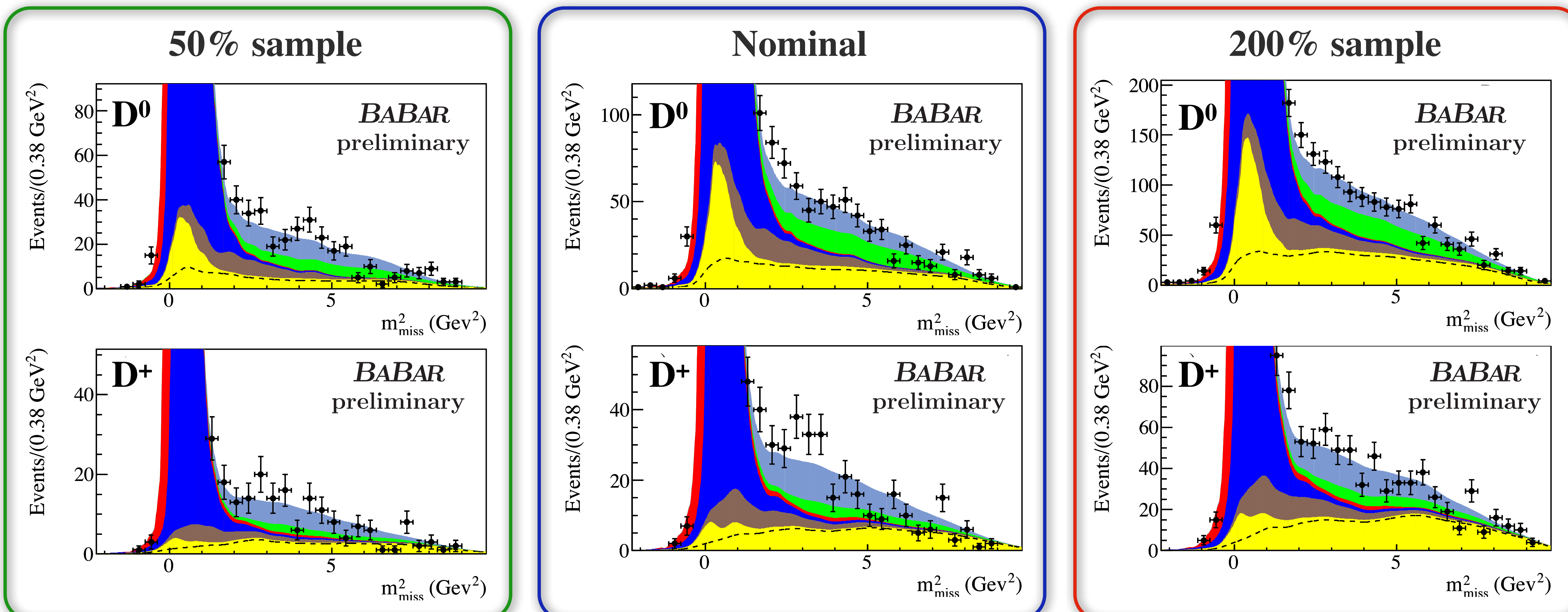
$D^*\tau\nu$
$D\tau\nu$
$D^*l\nu$
$Dl\nu$
$D^{**}l\nu$
Bkg.



Systematics: BDT

- Currently, **variation of BDT cut dominates**
  - **Tight BDT cut**: 50% nominal sample
  - **Loose BDT cut**: 200% nominal sample

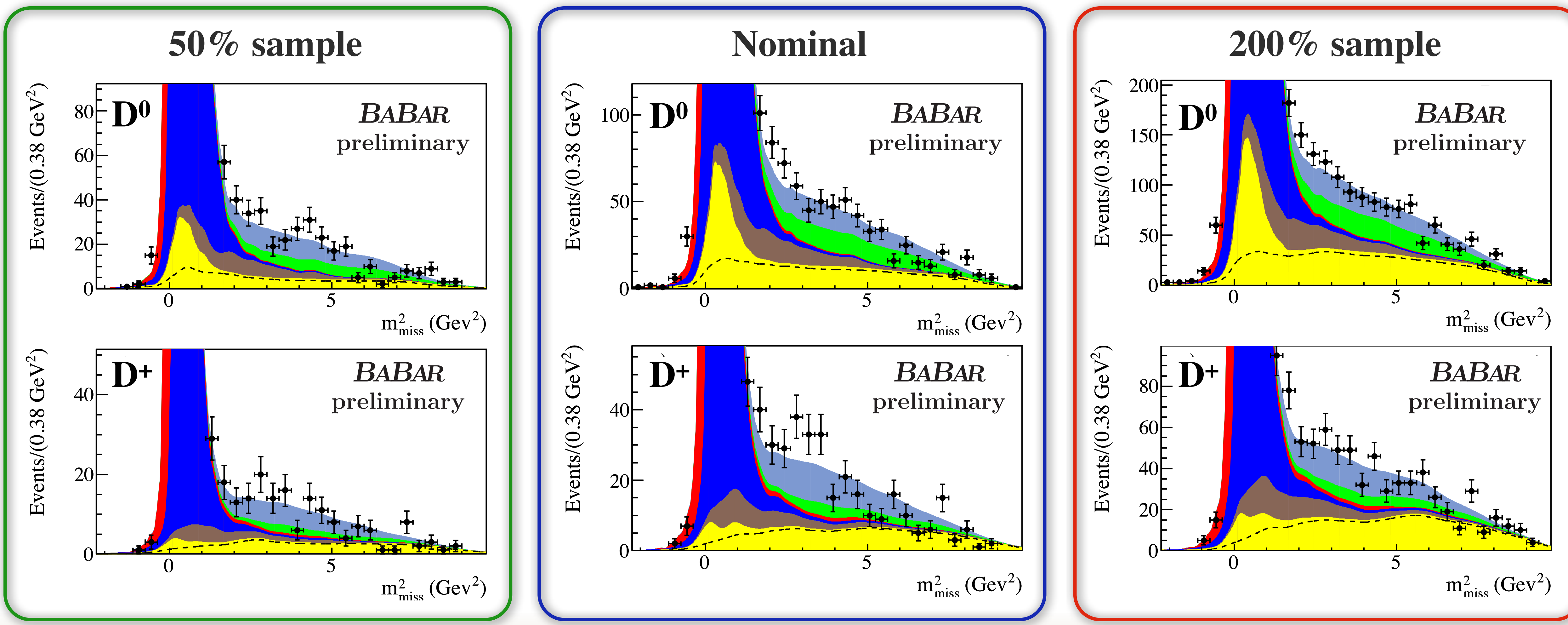
$D^*\tau\nu$
$D\tau\nu$
$D^*l\nu$
$Dl\nu$
$D^{**}l\nu$
Bkg.



Systematics: BDT

- Currently, **variation of BDT cut dominates**
  - **Tight BDT cut**: 50% nominal sample
  - **Loose BDT cut**: 200% nominal sample
  - $R(D^{(*)})$ change due to **statistical and systematic** sources
    - Assigned **half of the maximum variation (9.5% on R(D), 6.5% on R(D*))**

- $D^*\tau\nu$
- $D\tau\nu$
- $D^*l\nu$
- $Dl\nu$
- $D^{**}l\nu$
- Bkg.



Results

Mode	N_{sig}	N_{norm}	$\mathcal{R}(D^{(*)})$	$\mathcal{B}(B \to D^{(*)}\tau\nu)$ (%)	Σ_{tot} (Σ_{stat})
$D^0\tau^-\overline{\nu}_\tau$	226 ± 39	1433 ± 46	$0.422 \pm 0.074 \pm 0.059$	$0.96 \pm 0.17 \pm 0.14$	5.0 (6.2)
$D^{*0}\tau^-\overline{\nu}_\tau$	511 ± 48	6839 ± 90	$0.314 \pm 0.030 \pm 0.028$	$1.73 \pm 0.17 \pm 0.18$	8.9 (11.9)
$D^+\tau^-\overline{\nu}_\tau$	139 ± 21	704 ± 29	$0.513 \pm 0.081 \pm 0.067$	$1.08 \pm 0.19 \pm 0.15$	6.0 (7.5)
$D^{*+}\tau^-\overline{\nu}_\tau$	220 ± 23	2802 ± 56	$0.356 \pm 0.038 \pm 0.032$	$1.82 \pm 0.19 \pm 0.17$	9.5 (12.1)
$D\tau^-\overline{\nu}_\tau$	368 ± 42	2140 ± 54	$0.456 \pm 0.053 \pm 0.056$	$1.04 \pm 0.12 \pm 0.14$	6.9 (9.6)
$D^*\tau^-\overline{\nu}_\tau$	730 ± 50	9639 ± 107	$0.325 \pm 0.023 \pm 0.027$	$1.79 \pm 0.13 \pm 0.17$	11.3 (17.1)

Last two rows: Isospin constrained fit

- Systematics still **preliminary**
- **5σ** in **all channels**
- **1.8σ excess** over SM
  - Result favors **large tanβ**

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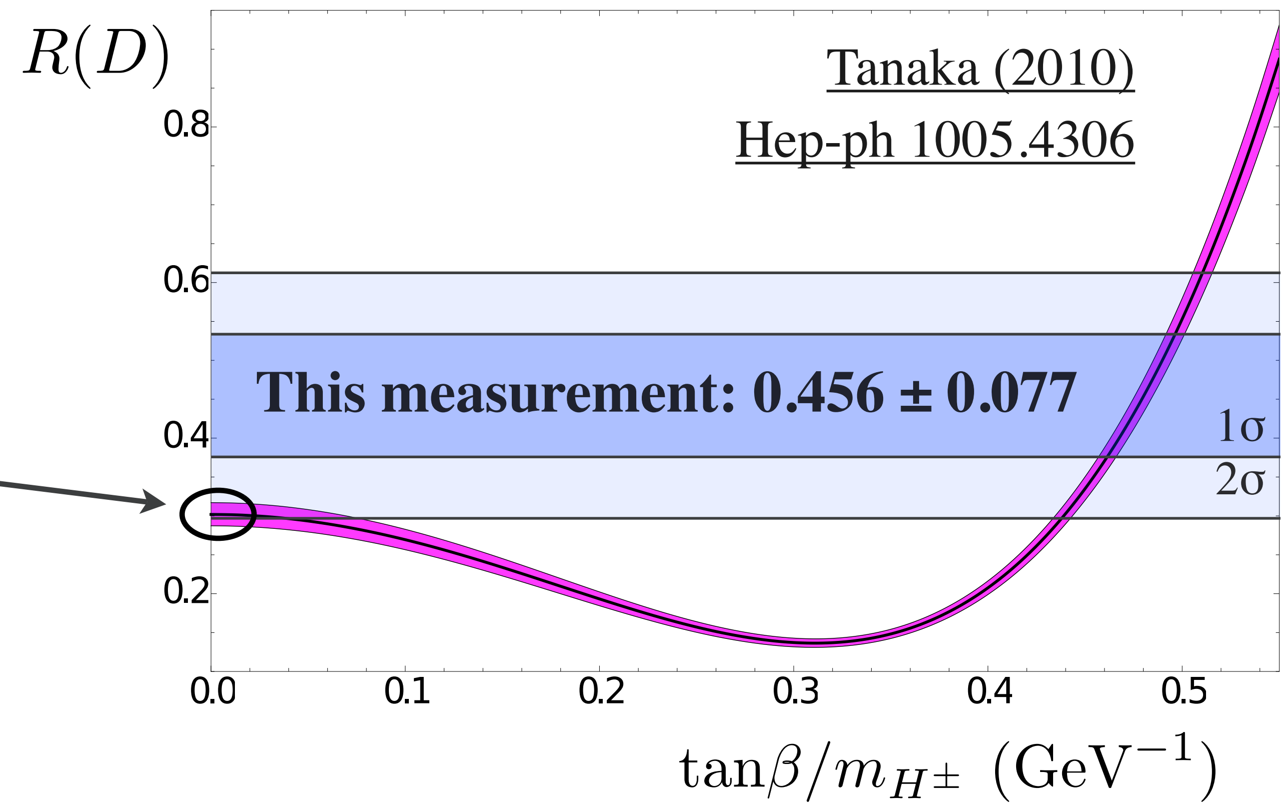
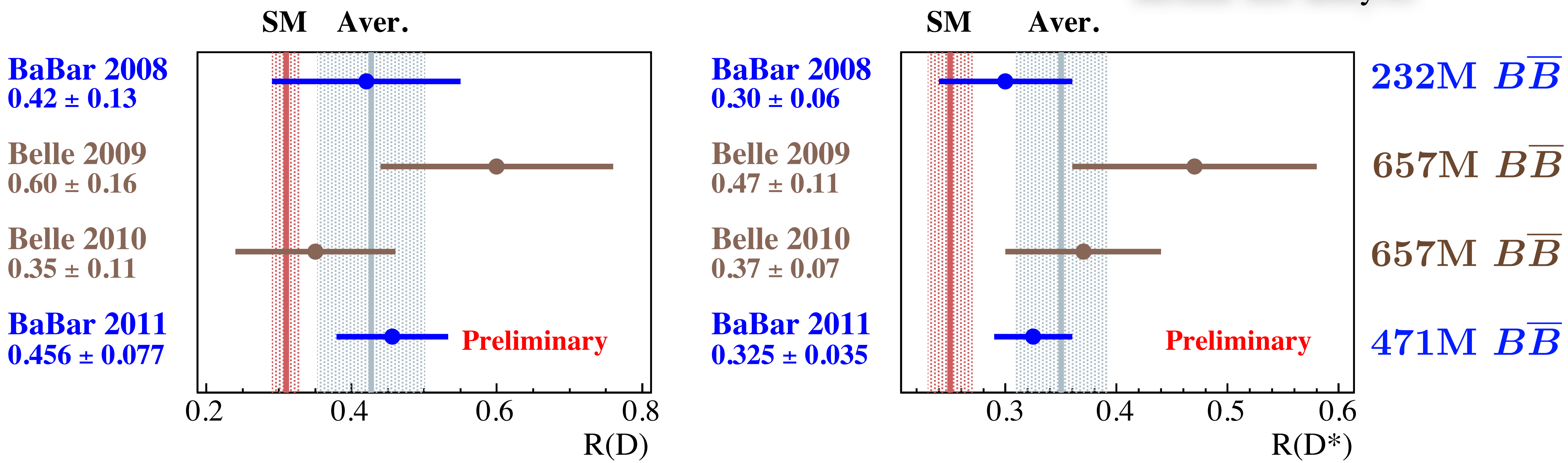


Summary

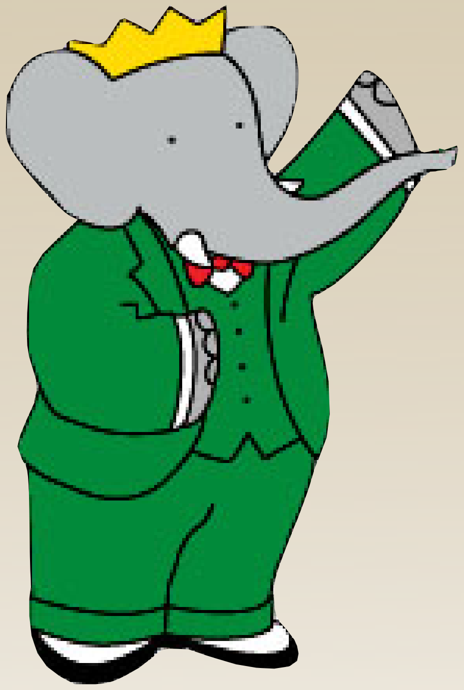
- **Final $|V_{ub}|$ results at BaBar**
  - **Inclusive measurement** $|V_{ub}| = (4.31 \pm 0.25 \pm 0.16) \times 10^{-3}$
  - **Combined exclusive measurements** $|V_{ub}| = (3.13 \pm 0.14 \pm 0.27) \times 10^{-3}$
- Inclusive Vs Exclusive **discrepancy persists**

- **$B \to D\tau\nu$** and **$B \to D^*\tau\nu$** measurements **improved**
  - **Uncertainty down almost a factor of 2**
  - **$D^0\tau\nu$** and **$D^+\tau\nu$ observed**
  - **1.8 σ** excess **over SM**

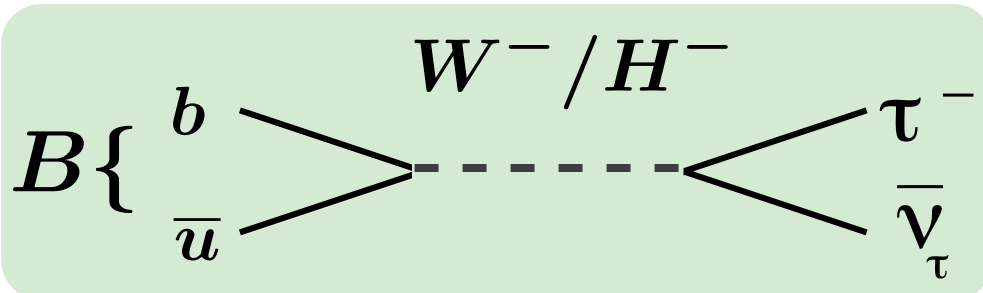
Average does not include this analysis

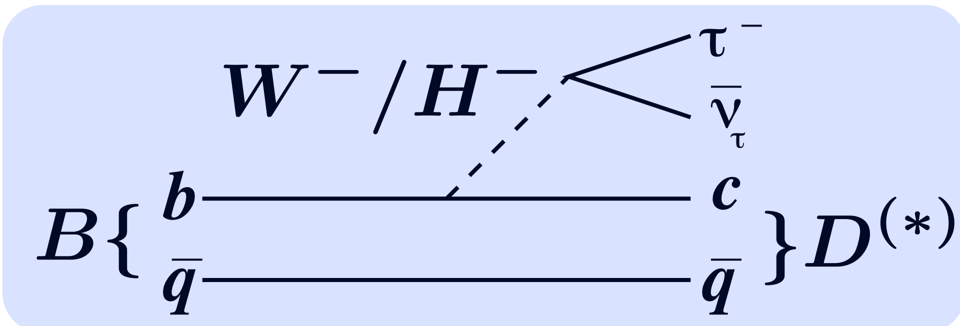


Back up



Motivation





- Alternative to $B^- \to \tau^- \bar{\nu}_\tau$
  - $\mathcal{B}(B \to D^{(*)}\tau\nu_\tau) \sim 50 \times \mathcal{B}(B \to \tau\nu_\tau)$
  - V_{cb} uncertainty ~**3.5** times **smaller** than V_{ub}
  - $\mathcal{B}(B \to \tau\nu_\tau)$ depends on **non-perturbative** f_B ~ **30% uncertainty**
  - $\mathcal{B}(B \to D^{(*)}\tau\nu_\tau)$ depends on 4 FF ~ as low as **10% uncertainty**

Current status

- First observation of $B^0 \to D^{*-}\tau^+\nu_\tau$ by Belle
  - 60 ± 12 events, 5.2σ significance
  - PRL **99**, 191807 (2007)
- Latest measurements

	BaBar, 2008 232M $B\overline{B}$ pairs		Belle, 2009 657M $B\overline{B}$ pairs		Belle, 2010 657M $B\overline{B}$ pairs	
Mode	Events	Significance	Events	Significance	Events	Significance
$B^- \to D^0\tau^-\overline{\nu}_\tau$	35 ± 19	1.8	99 ± 26	3.8	146 ± 42	3.5
$B^- \to D^{*0}\tau^-\overline{\nu}_\tau$	99 ± 20	5.3	100 ± 22	3.9	446 ± 57	8.1
$\overline{B}^0 \to D^+\tau^-\overline{\nu}_\tau$	23 ± 8	3.3	17 ± 8	2.6	—	—
$\overline{B}^0 \to D^{*+}\tau^-\overline{\nu}_\tau$	16 ± 7	2.7	25 ± 7	4.7	—	—

  - $B \to D\tau\nu_\tau$ **not yet observed**

PRL **100**, 021801 (2008)
Hep-Ex 0910.4301 (2009)
PRD **82**, 072005 (2010)

- This analysis **updates BaBar 2008** with **471M of BB pairs**

B_{tag} decay modes

- *Seed* decay modes
  - Branching fractions are for $B_{tag} \rightarrow Seed + \pi^{\pm}/K^{\pm}$

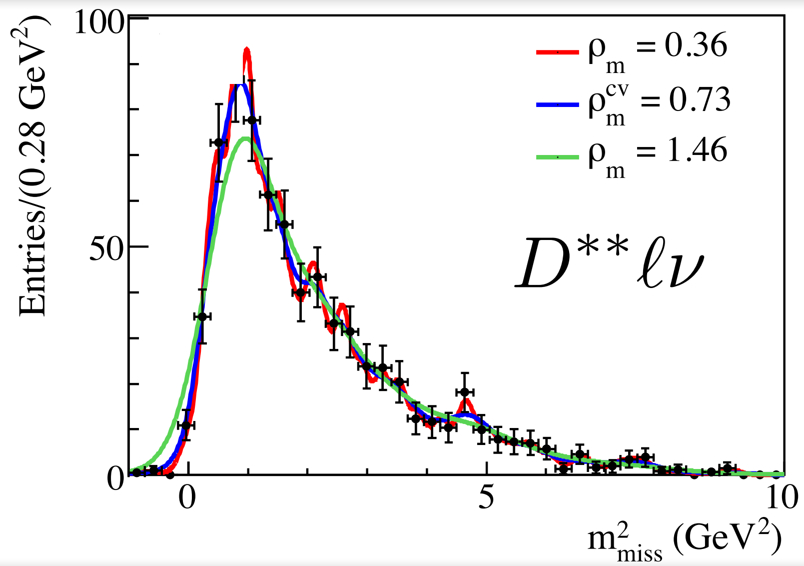
BSemiExcl(Add) seeds			$\mathcal{B}(10^{-5})$
D^0	$\rightarrow$	$K^-\pi^+\pi^0$	72.9
	$\rightarrow$	$K^-\pi^+\pi^-\pi^+$	42.5
	$\rightarrow$	$K^-\pi^+$	20.4
	$\rightarrow$	$K^0_S\pi^+\pi^-$	15.7
D^+	$\rightarrow$	$K^-\pi^+\pi^+$	26.6
	$\rightarrow$	$K^0_S\pi^+\pi^0$	19.6
	$\rightarrow$	$K^-\pi^+\pi^+\pi^0$	17.3
	$\rightarrow$	$K^0_S\pi^+\pi^+\pi^-$	8.7
	$\rightarrow$	$K^0_S\pi^+$	4.2
D^{*0}	$\rightarrow$	$D^0\pi^0$	100.2
	$\rightarrow$	$D^0\gamma$	61.7
D^{*+}	$\rightarrow$	$D^0\pi^+$	53.3
		Total	442.9

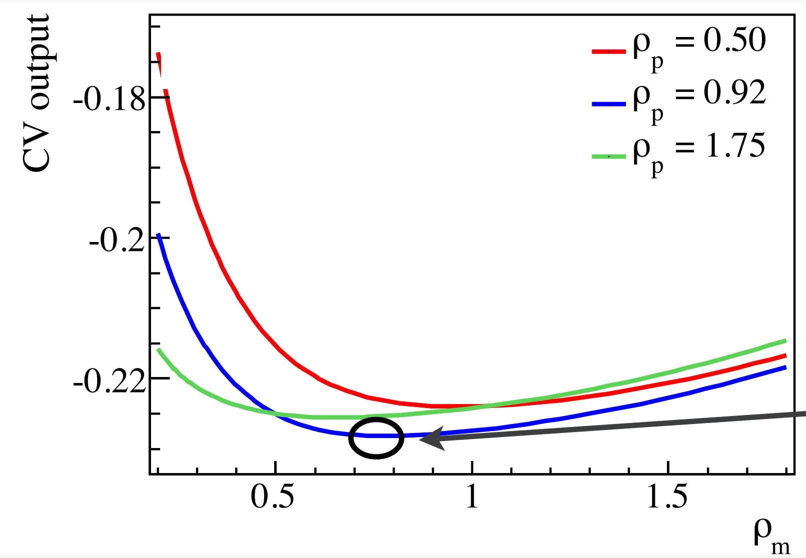
BSemiExclAdd seeds			$\mathcal{B}(10^{-5})$
D^0	$\rightarrow$	$K^0_S\pi^+\pi^-\pi^0$	28.3
	$\rightarrow$	$\pi^+\pi^-\pi^0$	7.5
	$\rightarrow$	$K^0_S\pi^0$	6.4
	$\rightarrow$	K^+K^-	2.1
	$\rightarrow$	$\pi^+\pi^-$	0.7
D^+	$\rightarrow$	$K^+K^-\pi^+\pi^0$	7.8
	$\rightarrow$	$K^+K^-\pi^+$	2.8
D^{*0}	$\rightarrow$	Extra D^0	48.2
D^{*+}	$\rightarrow$	$D^+\pi^0$	27.5
	$\rightarrow$	Extra D^0	32.6
D_s^+	$\rightarrow$	$\phi\pi^+$	0.2
	$\rightarrow$	$K^0_S K^+$	0.1
D_s^{*+}	$\rightarrow$	$D_s^+\gamma$	0.3
J/ψ	$\rightarrow$	e^+e^-	6.3
	$\rightarrow$	$\mu^+\mu^-$	6.3
		Total	177.0

Fit PDFs

- **56 PDFs** taken from simulation
  - **We use non-parametric Gaussian Kernel estimators (KEYS)**

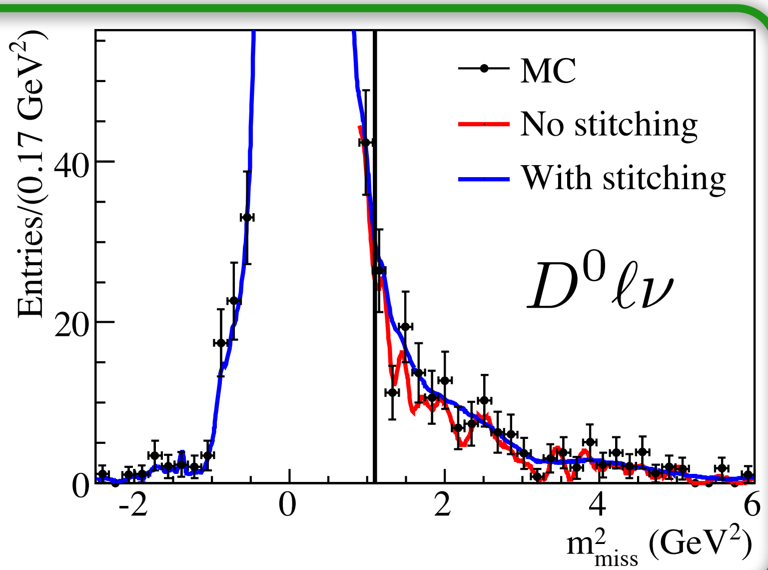
$$\hat{p}(X; x_i) = \frac{1}{nw} \sum_{i=1}^{n} K\left(\frac{X - x_i}{w}\right)$$

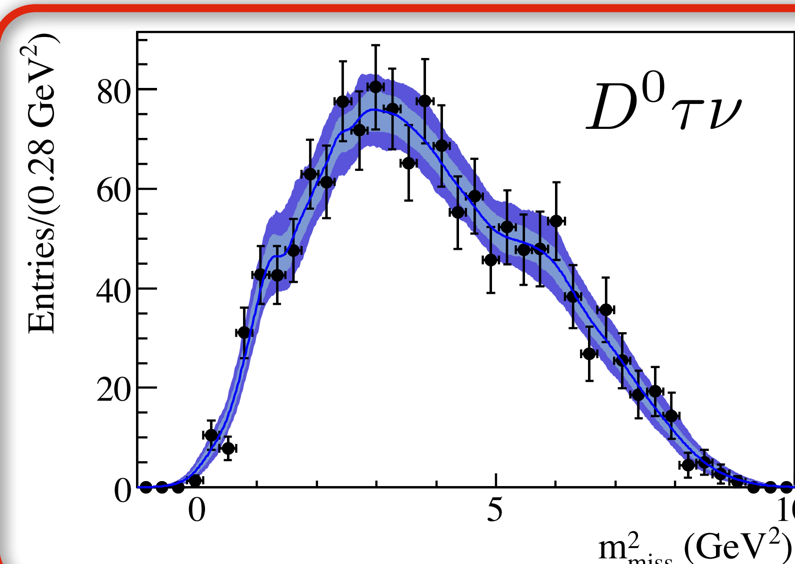




Cross-validation algorithm to choose optimal smoothing

Stitching to combine smoothing factors

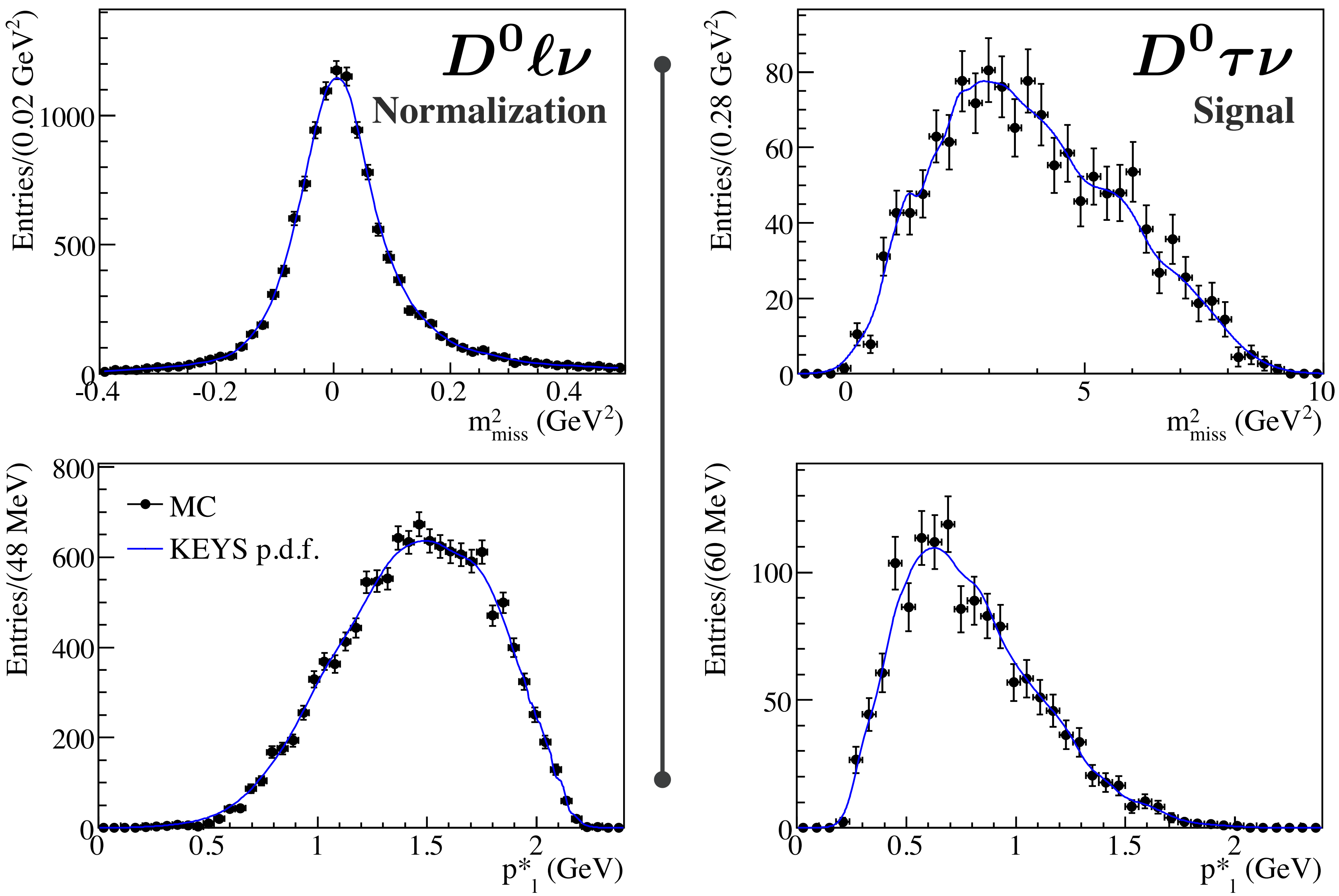




Bootstrap algorithm to estimate uncertainty

Fit PDFs

- **Probability Density Functions** taken from simulation
  - **2D KEYS functions**
    - Cross-validation to choose smoothing
    - 4 KEYS functions per PDF describing different regions



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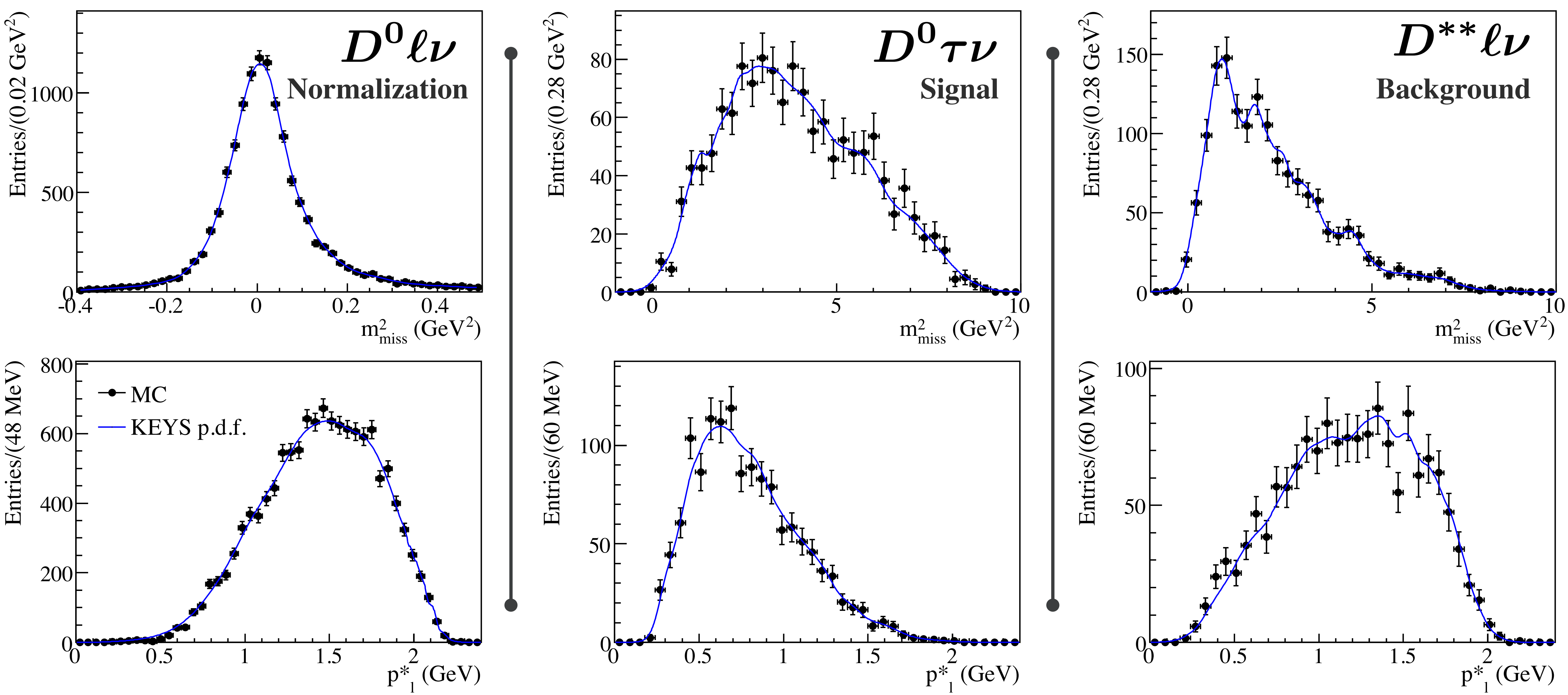
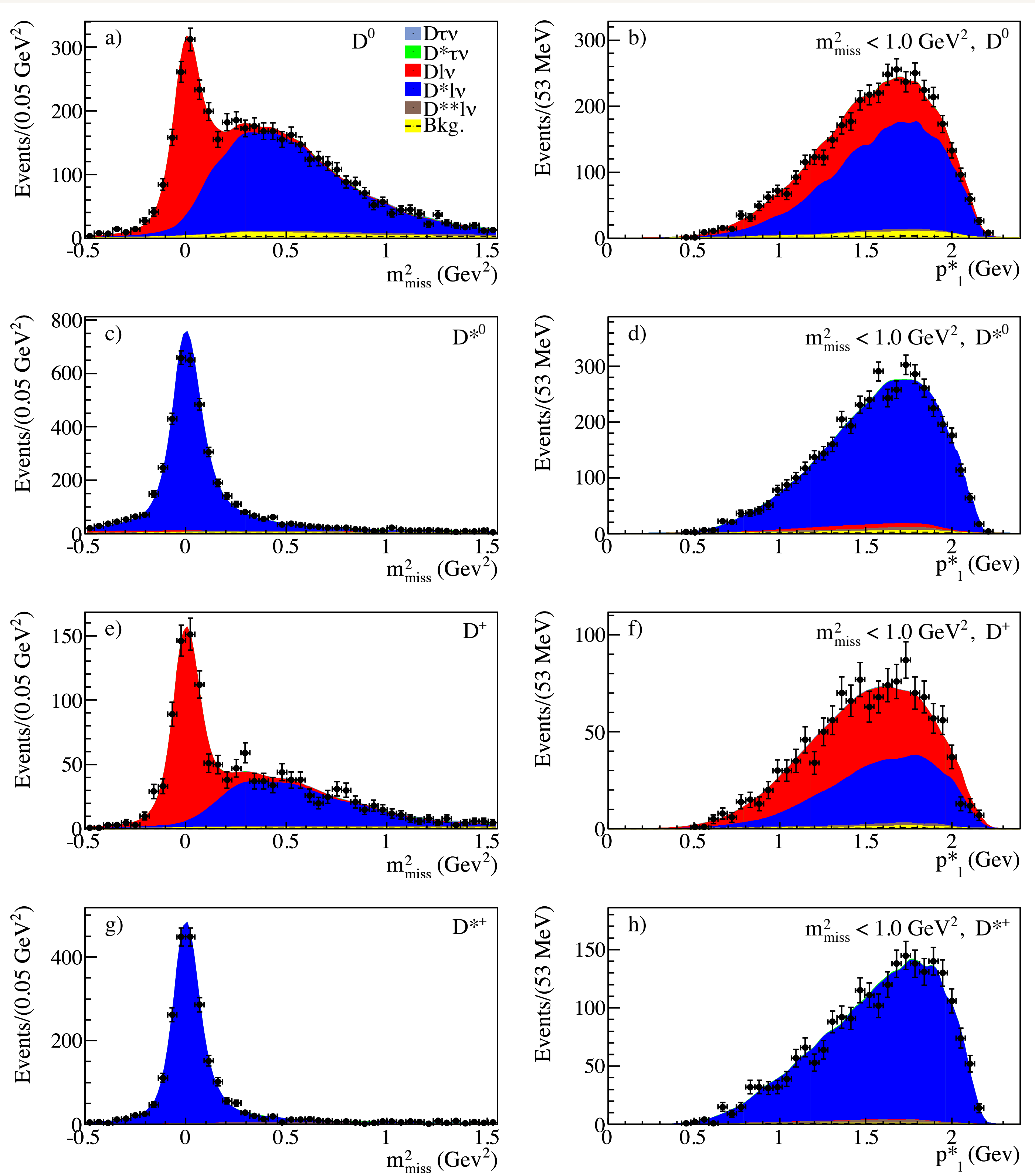


Results: Normalization



- Normalization (**D$^{(*)}\ell\nu$) well fitted**
- Yields agree with expectations
  - After $q^2 \leq 4$ GeV^2 correction