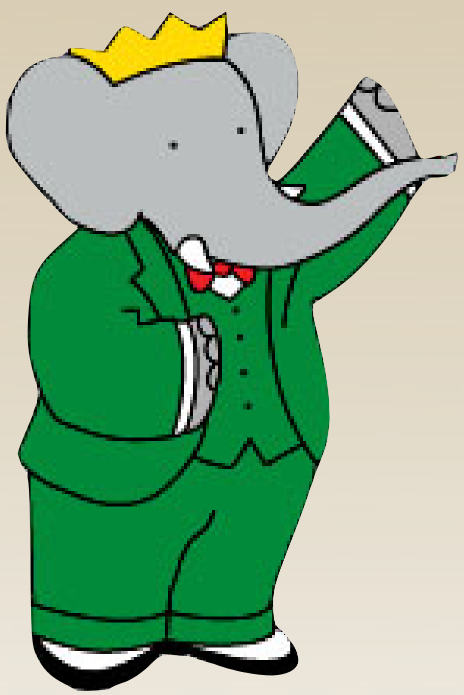
Evidence for an excess of $\overline{B} \to D^{(*)}\tau^- \overline{\nu}_\tau$ decays

PRL 109, 101802 (2012)
hep-ex: 1303.0571



Manuel Franco Sevilla
UC Santa Barbara

on behalf of the BaBar collaboration

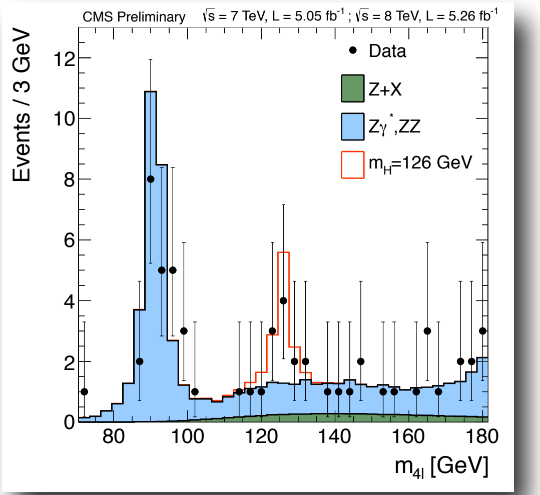
10th of May 2013
Cornell LEPP Journal Club
Ithaca, NY

Questions, questions

- **Standard Model** remarkably **successful theory**

<u>*Anomalous magnetic dipole moment*</u>

$$\frac{g_e - 2}{2} = 0.00115965218073(28)$$



<u>Fundamental Interactions</u>

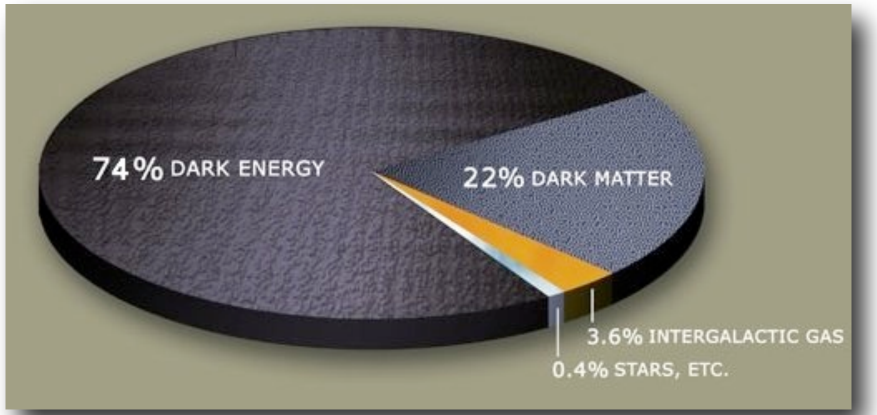
Strong

Electro-Magnetic

Weak

Gravitation??

- **Gravitation** does not fit in the SM framework
- **Dark matter, Dark energy**



- **Hierarchy problem, strong CP problem...**

Motivation

- **Charged Higgs** required in multiple **New Physics scenarios**

MSSM

SM h^0

A^0 H^0

H^+ H^-

Tevatron 1983-2011

LHC

$t \to bH^{\pm}$

$B \to X_s\gamma$ $B^- \to \tau^-\overline{\nu}_\tau$ $\overline{B} \to D^{(*)}\tau^-\overline{\nu}_\tau$

BABAR

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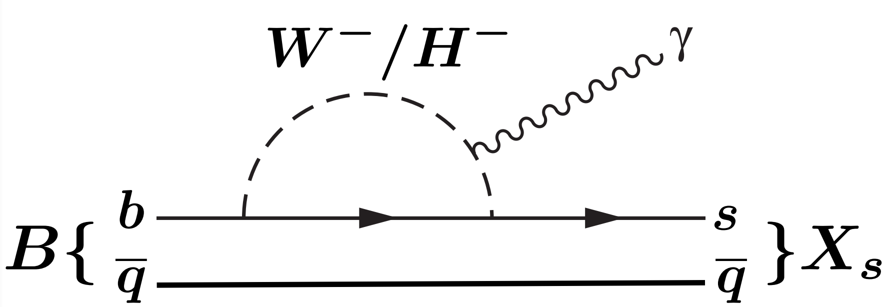
BELLE

Motivation

- Searches for a **charged Higgs** at **BaBar**

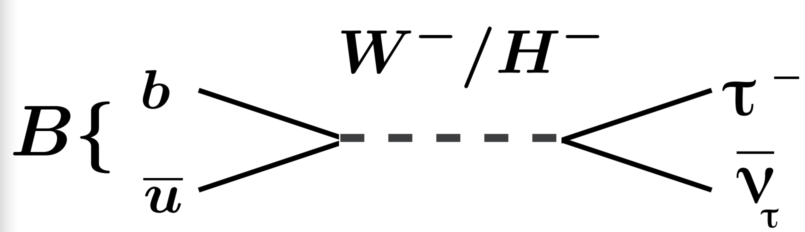
$B \to X_s \gamma$

- ☑ **Small σ_{SM}** ~ 7%
- ☐ H^- enters in a **loop**
- ☐ **BF ~ 0.03%**
- ☐ **Inclusive** measurement difficult



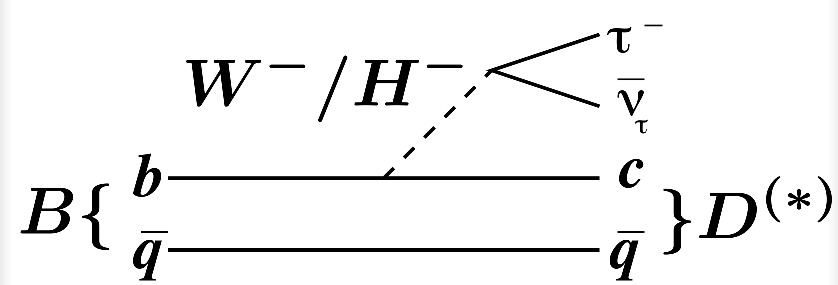
$B^- \to \tau^- \bar{\nu}_\tau$

- ☐ **Large σ_{SM}** ~ 25%
- ☑ H^- enters at **tree level**
- ☐ **BF ~ 0.01%**
  - ☐ Helicity suppressed



$\overline{B} \to D^{(*)} \tau^- \bar{\nu}_\tau$

- ☑ **Small σ_{SM}** ~ 2-5%
- ☑ H^- enters at **tree level**
- ☑ **BF ~ 1-2%**
- ☑ $D^{(*)}$ provides constraint



Measurements

- We measure **ratios** $$R(D^{(*)}) = \frac{\mathcal{B}(\overline{B} \to D^{(*)}\tau^-\overline{\nu}_\tau)}{\mathcal{B}(\overline{B} \to D^{(*)}\ell^-\overline{\nu}_\ell)}$$

Normalization
$(\ell^- = e^- \text{ or } \mu^-)$

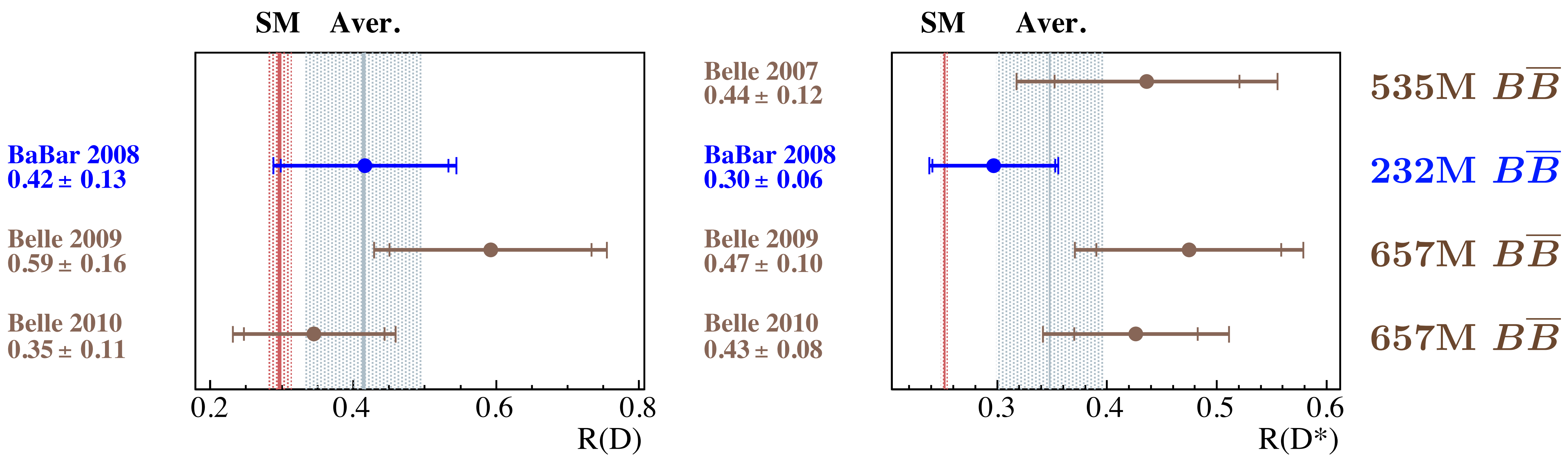
- Various **uncertainties cancel** in **ratio**
  - ✓ **Theoretical:** V_{cb}, FFs
  - ✓ **Experimental:** same final state particles

$$\tau^- \to \ell^-\overline{\nu}_\ell\nu_\tau$$

Measurements

- We measure **ratios**

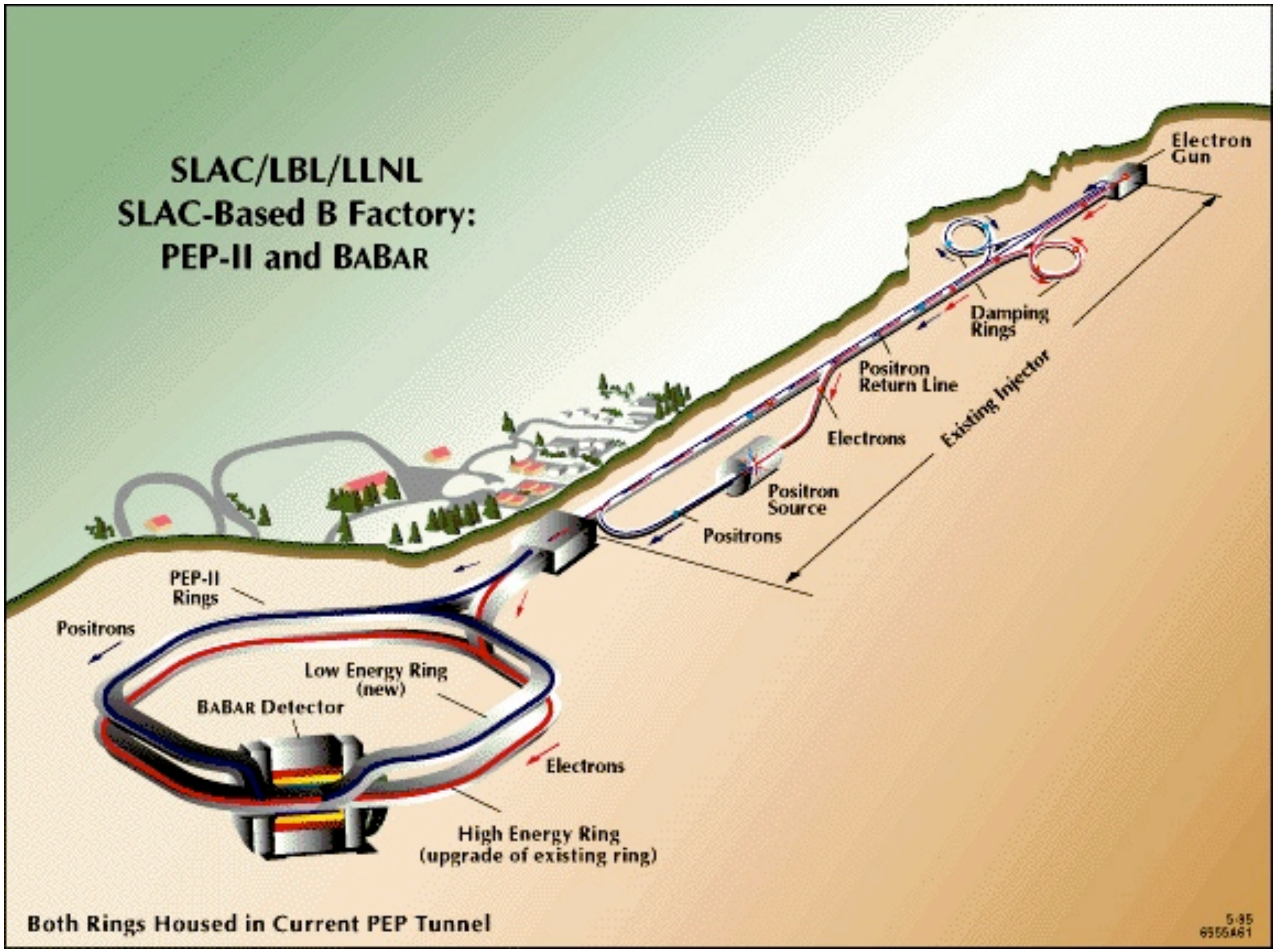
$$R(D^{(*)}) = \frac{\mathcal{B}(\overline{B} \to D^{(*)}\tau^-\overline{\nu}_\tau)}{\mathcal{B}(\overline{B} \to D^{(*)}\ell^-\overline{\nu}_\ell)} = \frac{N_{\rm sig}}{N_{\rm norm}} \times \frac{\varepsilon_{\rm norm}}{\varepsilon_{\rm sig}}$$



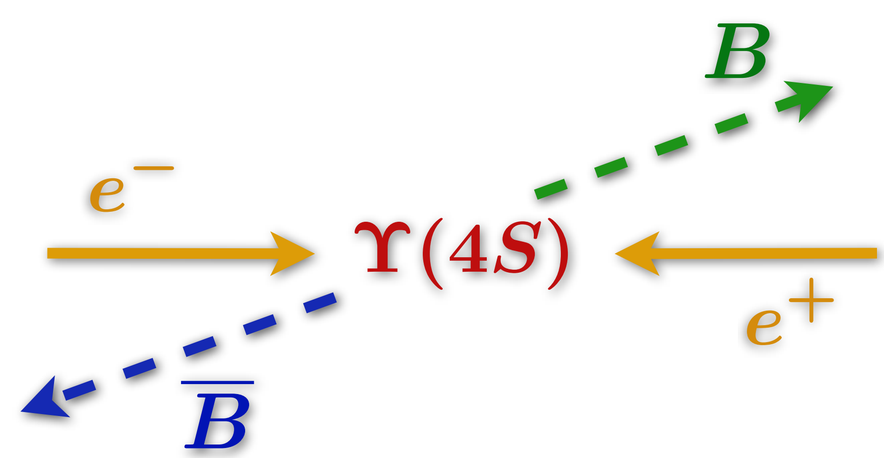
- **Previous** measurements **exceed SM** by **1-2 σ**

- We **update BaBar 2008** with **2x data** and **3x efficiency**

PEP-II storage rings



- **Operation 1999-2008**
- **Linear accelerator** injects in PEP-II ($\beta\gamma = 0.56$)
  - **9.0 GeV electrons e^-**
  - **3.1 GeV positrons e^+**



CM energy

$$m(\Upsilon(4S)) = 10.58\ \text{GeV}$$

The BaBar detector

- **Good lepton ID**
- **Good hadron ID** (π/K sep.)
- **91%** solid angle **coverage**

$$e^+e^- \to \Upsilon(4S) \to B^+B^-$$

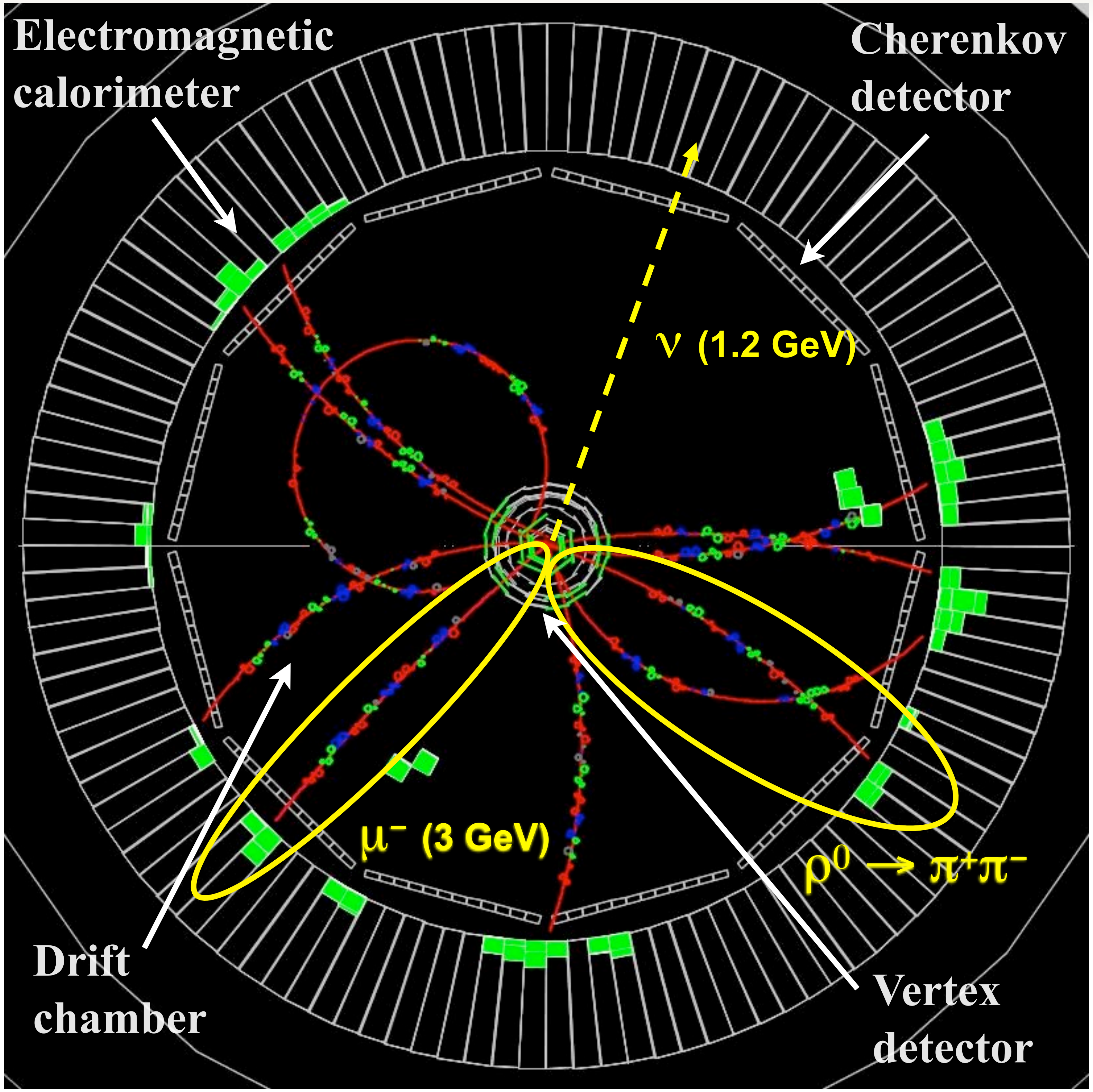
$$B^- \to \rho^0\mu^-\overline{\nu}_\mu$$

$$\rho^0 \to \pi^+\pi^-$$

Similar to normalization

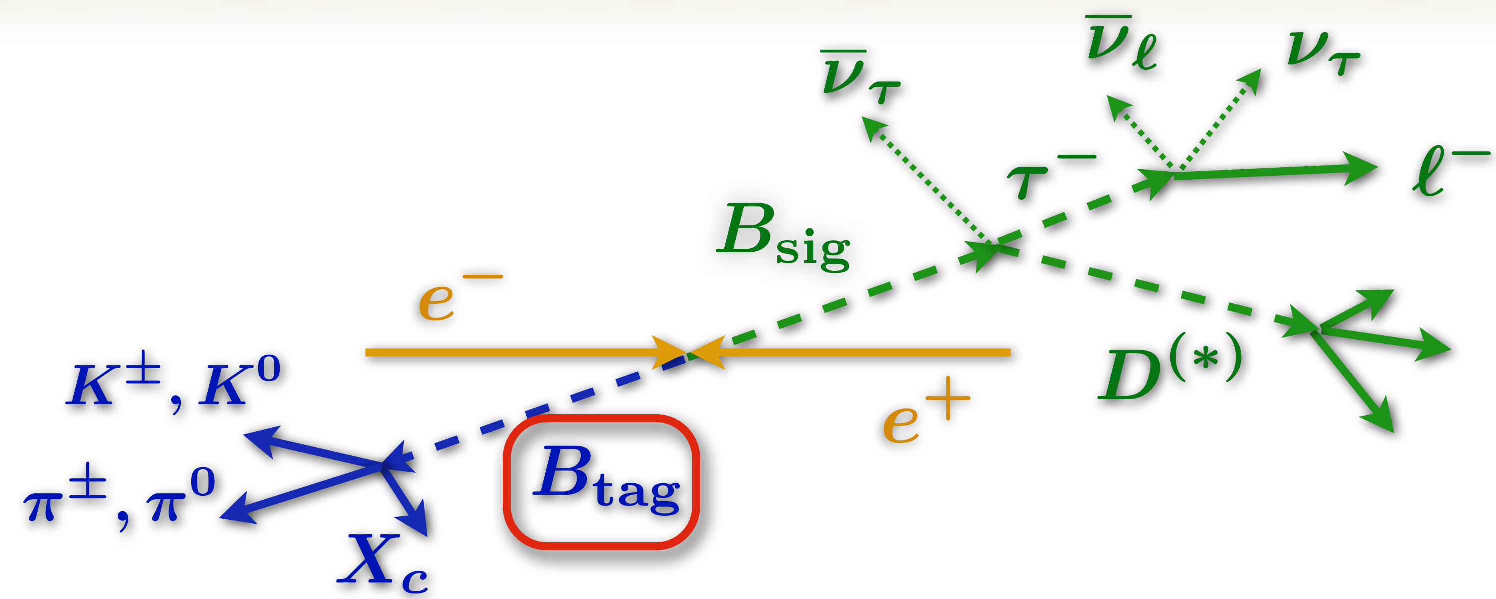
$$B^- \to D^0(\to K^-\pi^+)\mu^-\overline{\nu}_\mu$$

Muon detector outside the plot



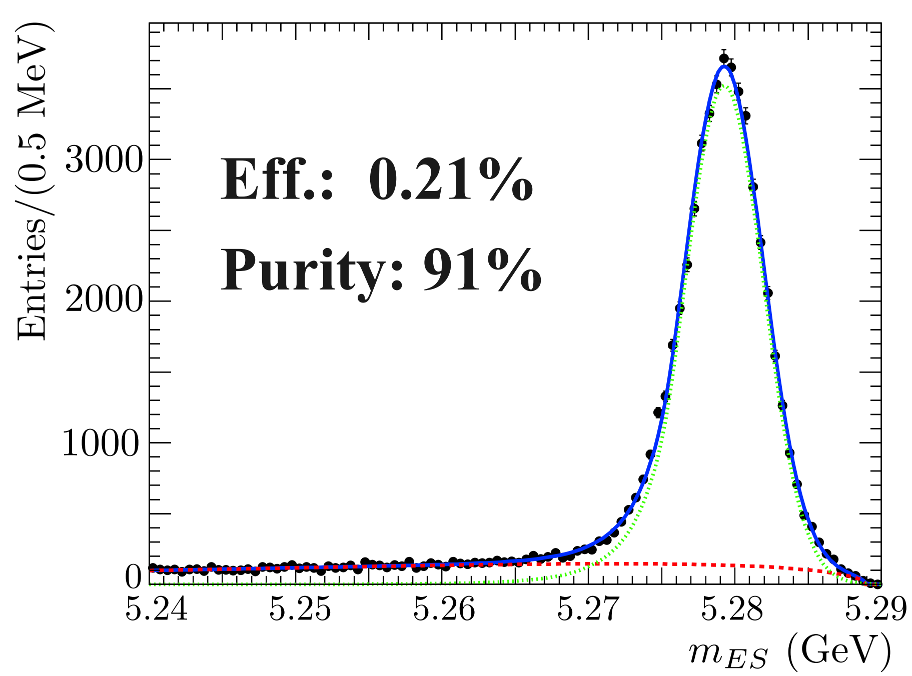
Event reconstruction

- **Fully reconstructed tag B**
  - Efficiency 2x previous analysis



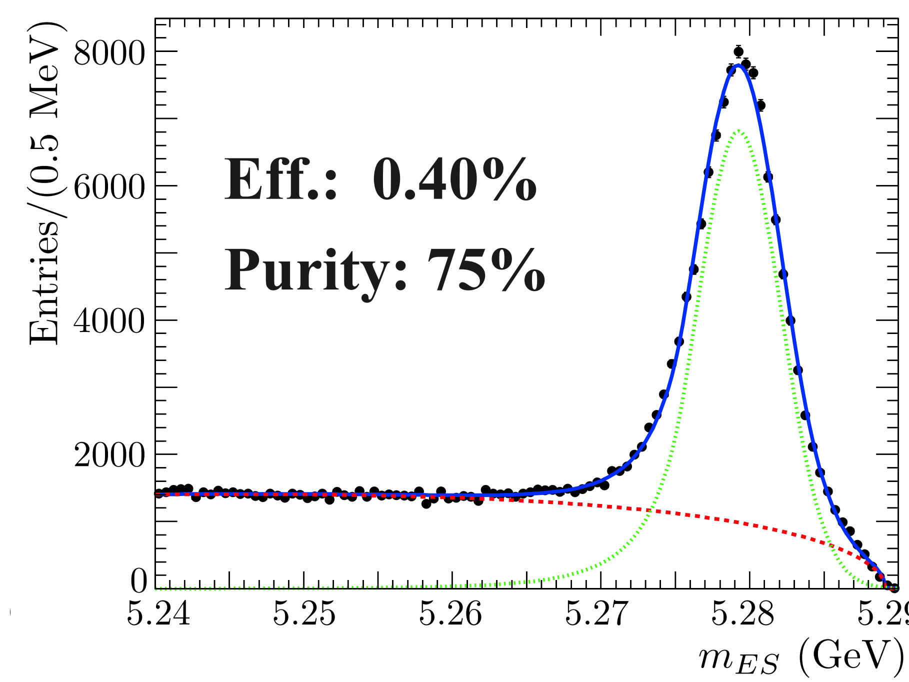
Old $B_{\rm tag}: X_c = D, D^*$

630 decay chains



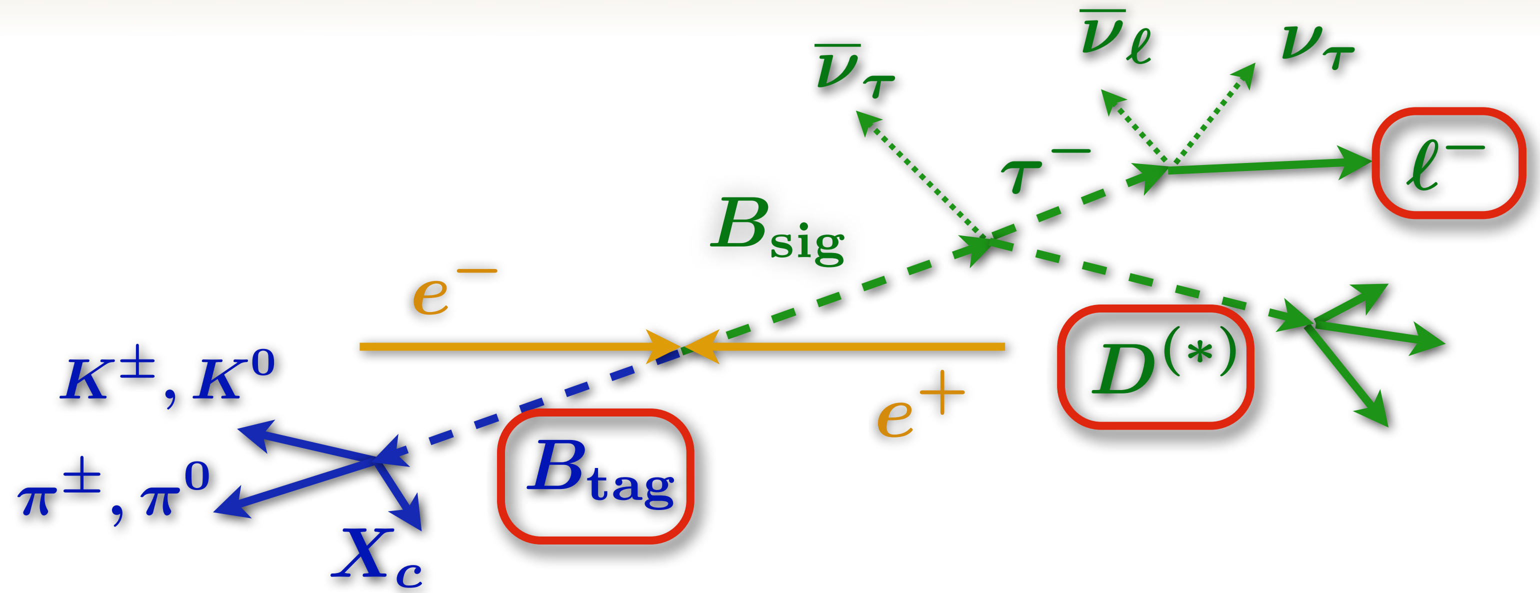
New $B_{\rm tag}: X_c = D, D^*, D_s^+, D_s^{*+}, J/\Psi$

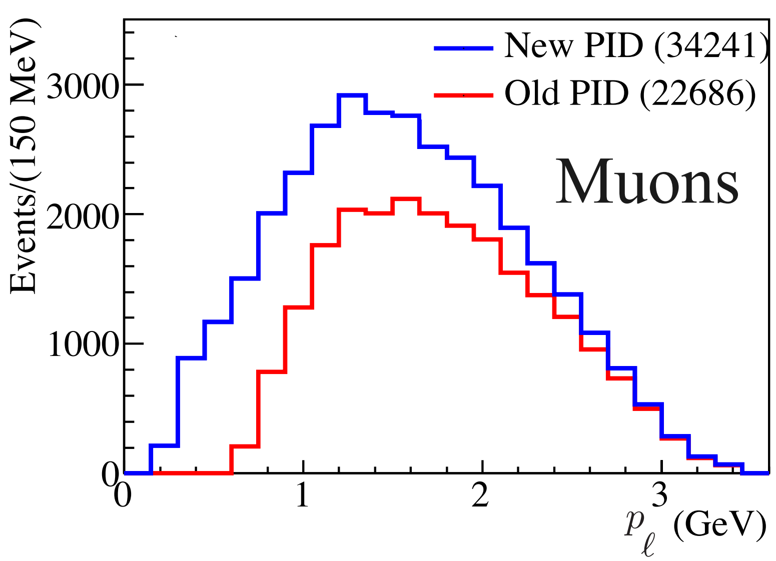
1,768 decay chains



Event reconstruction

- **Fully reconstructed tag B**
  - Efficiency 2x previous analysis
- D(*): D^0, D^{*0}, D^+, D^{*+}
- $\ell = e, \mu$ (improved PID)





- $q^2 > 4\ GeV^2$
- $p_{miss} > 200$ MeV

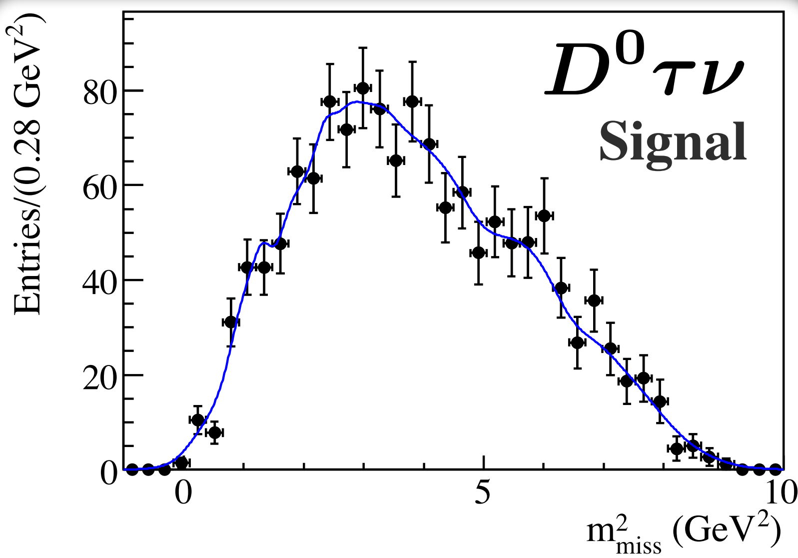
Backgrounds

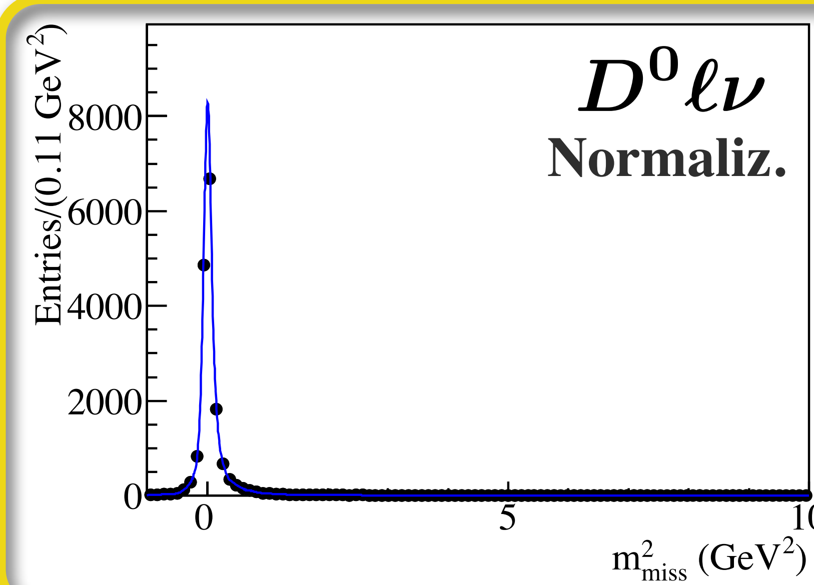
- **Boosted decision tree** to reject bkg.
- **BB/continuum** from **control samples**
  - $e^+e^- \to u\bar{u}, d\bar{d}, c\bar{c}, s\bar{s}$
- **Simultaneous fit** estimates **B→D**(ℓ/τ)ν**
  - **4 $D^{(*)}\pi^0$ control samples**

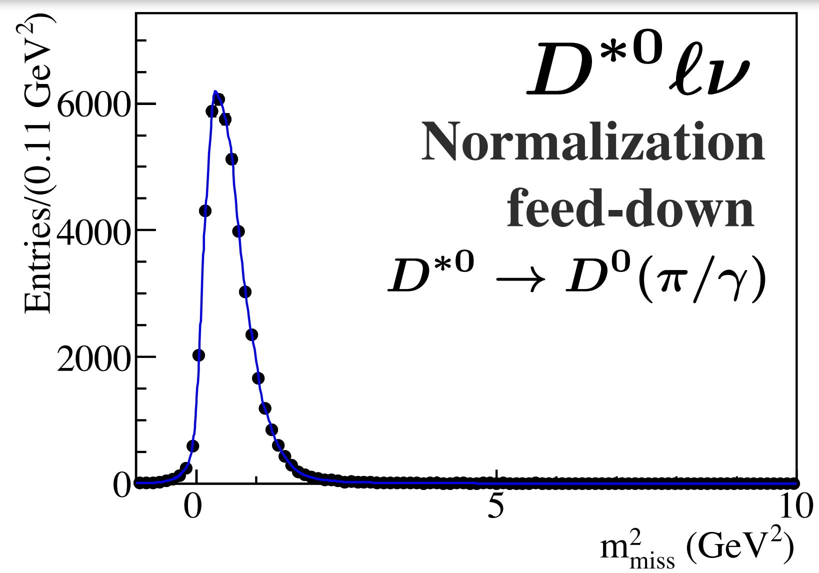
Missing mass

- Key variable to separate **signal** and **normalization**

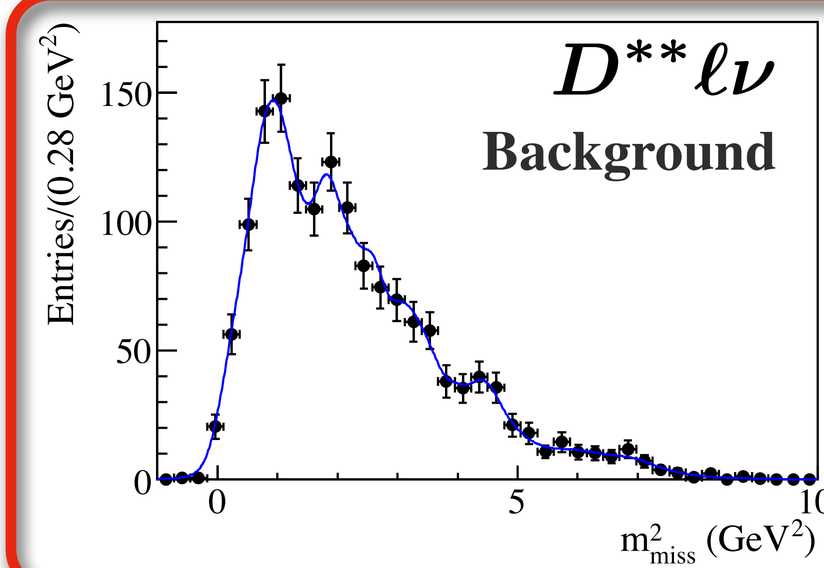
$$m^2_{\mathrm{miss}} = \left(p_{e^+e^-} - p_{B_{\mathrm{tag}}} - p_{D^{(*)}} - p_\ell\right)^2$$

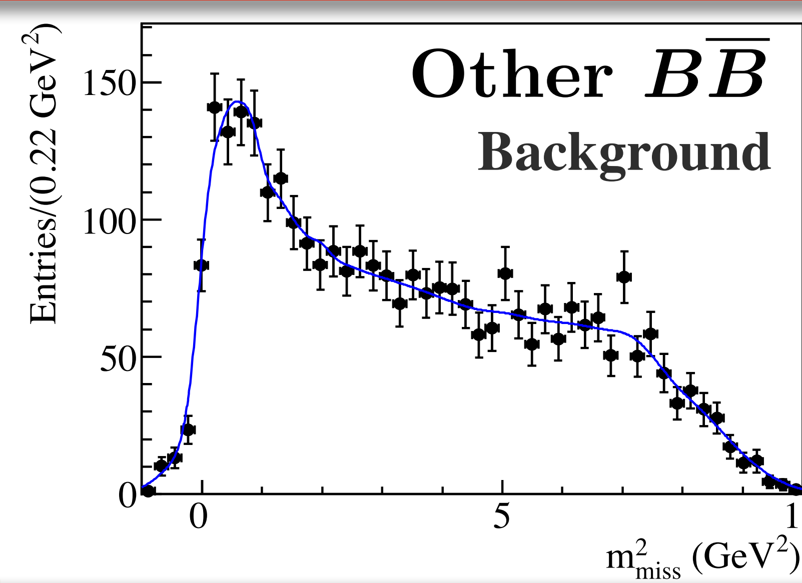






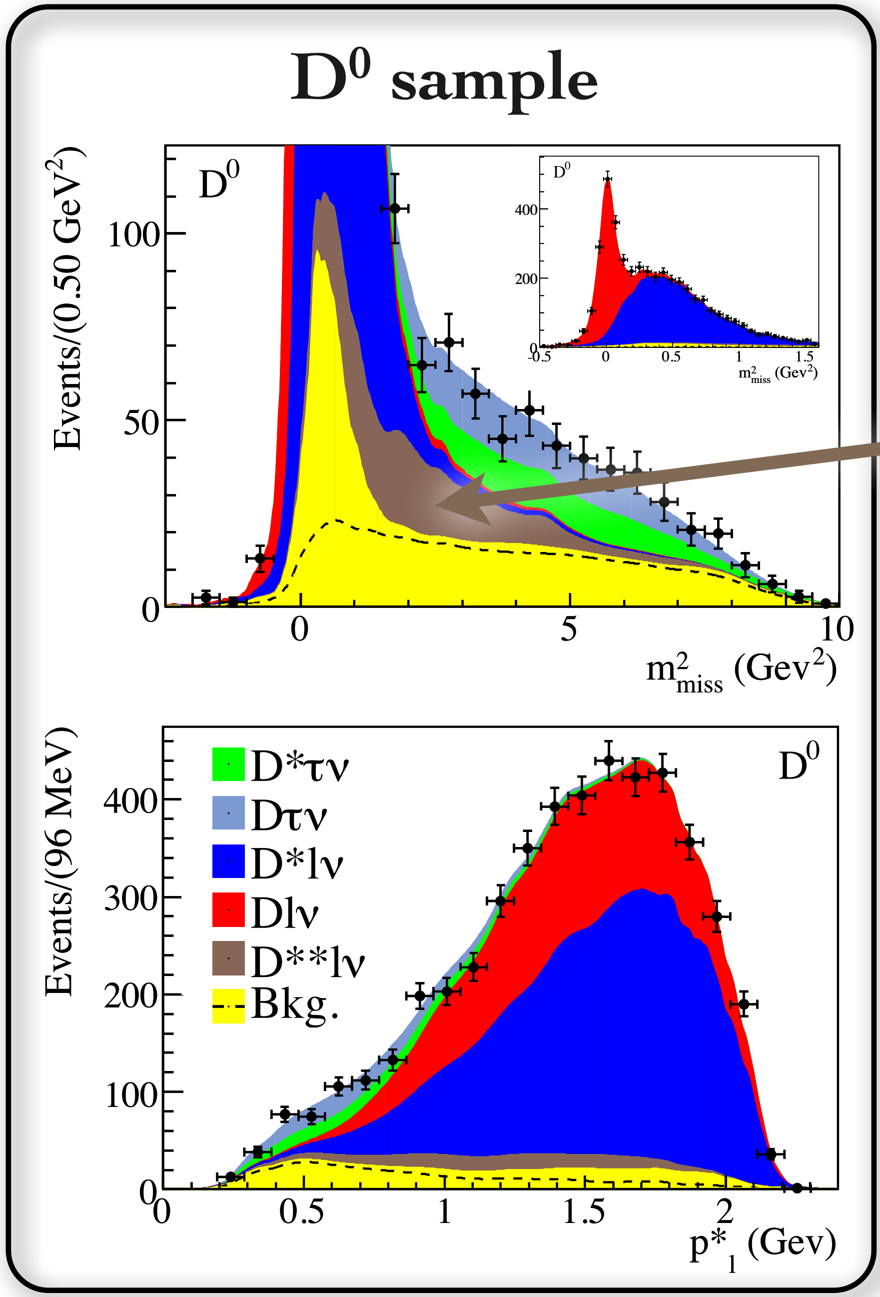
D^0 channel

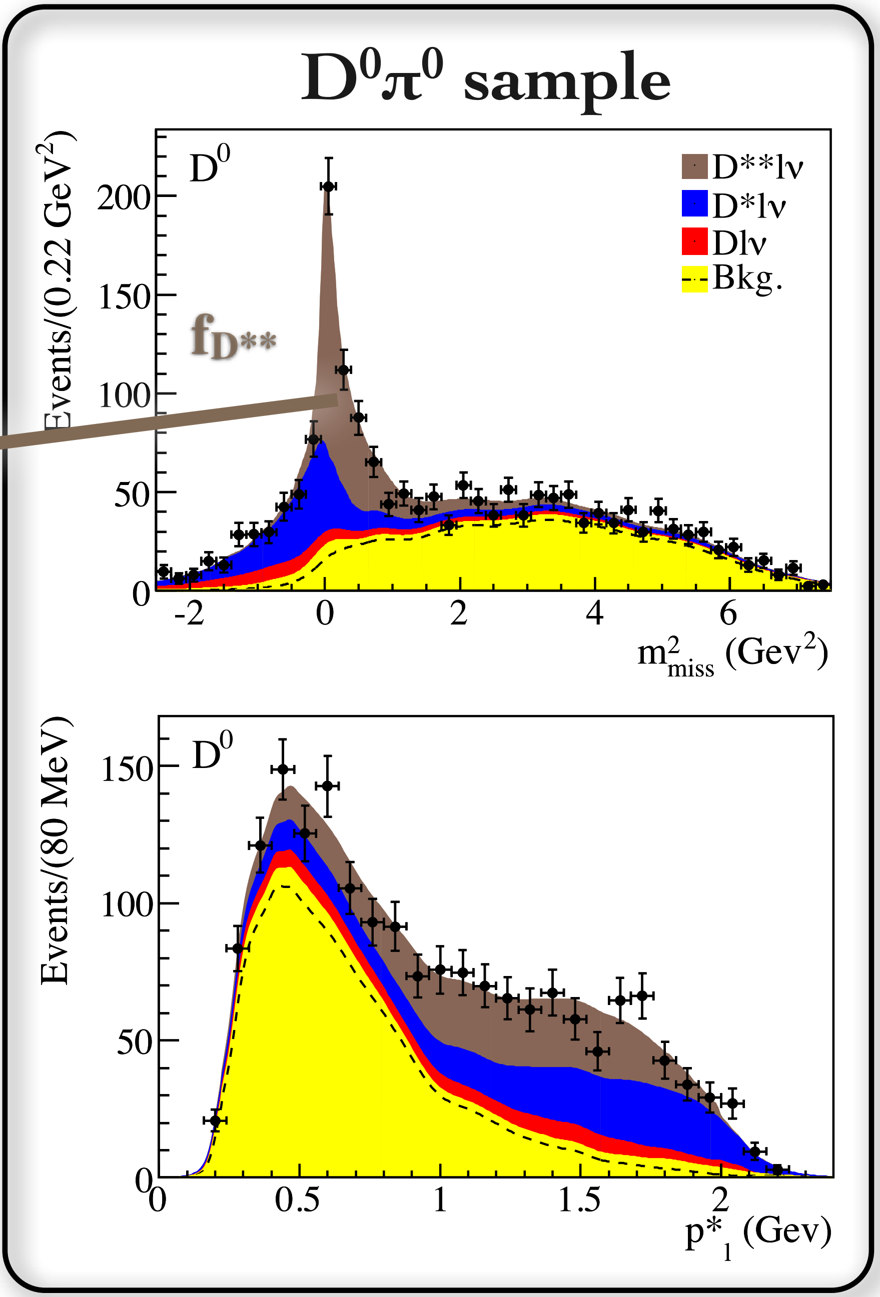




Fit structure

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

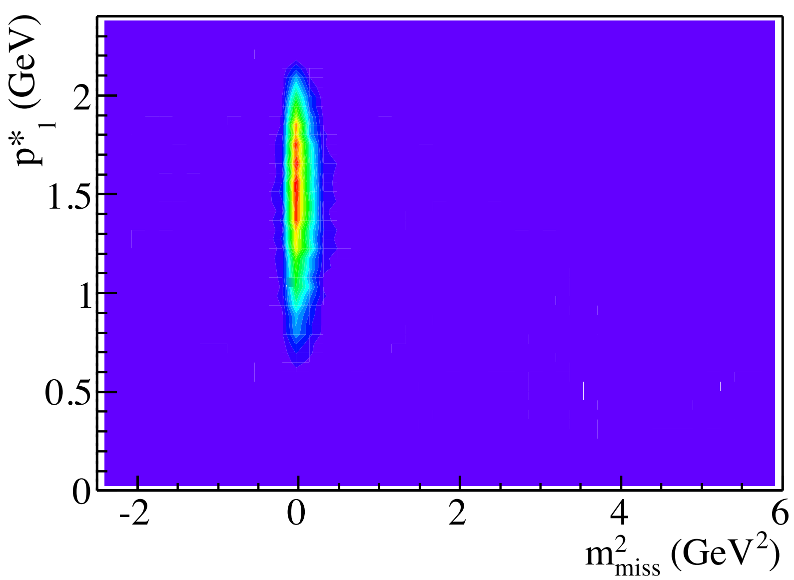


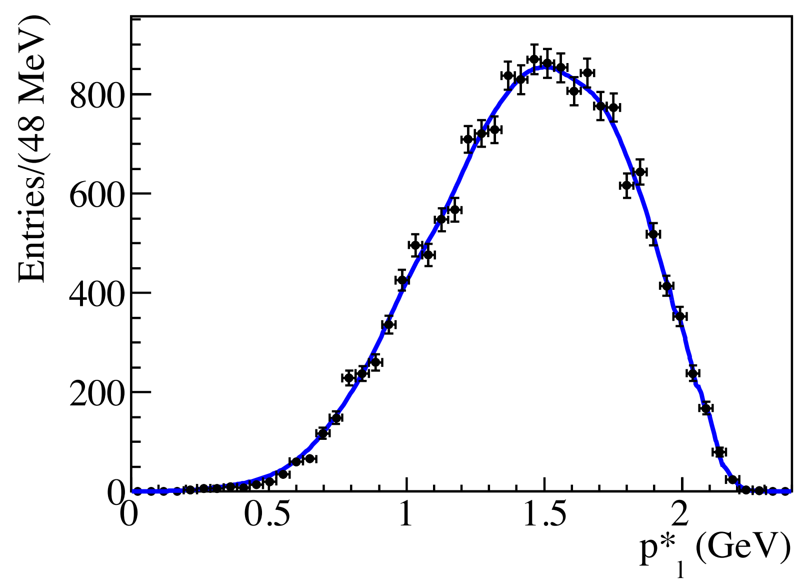


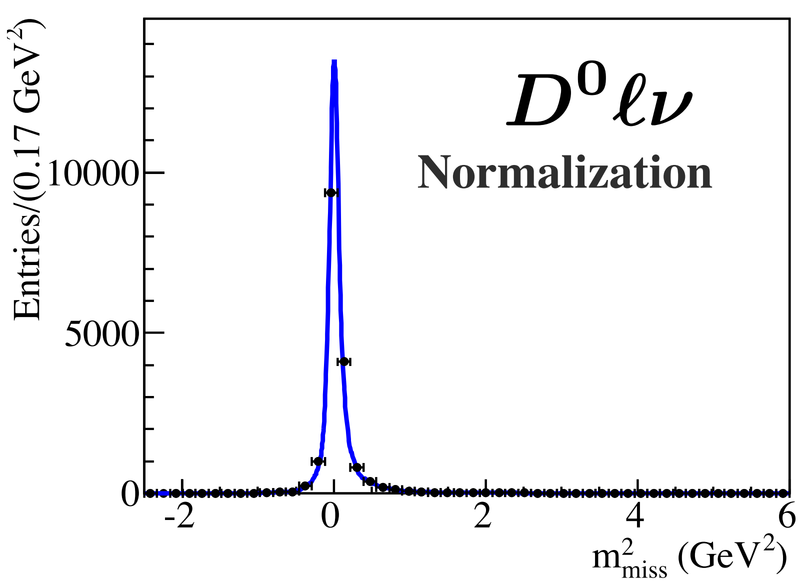
MC Simulation

Fit PDFs: 2D

- Fit uses **56** fully **two-dimensional Probability Density Functions**







- Irregular
- 2D correlations

} **Difficult to describe analytically**

Fit PDFs: Non-parametric

- We use **non-parametric Kernel estimators (KEYS)**
- $p(X)$ estimated by $\boldsymbol{\hat{p}(X; x_i)}$ using the sample $\{x_i\}$

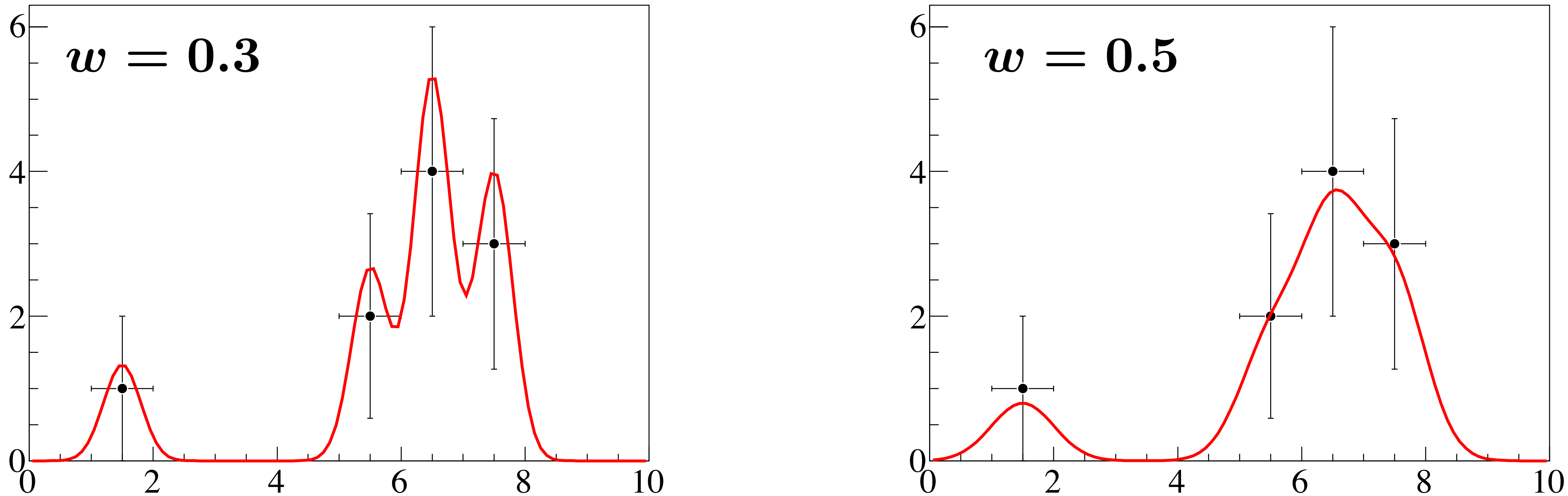
Gaussian kernels

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

Simulated events

Smoothing

With **non-parametric, easy to trade Bias for Variance**

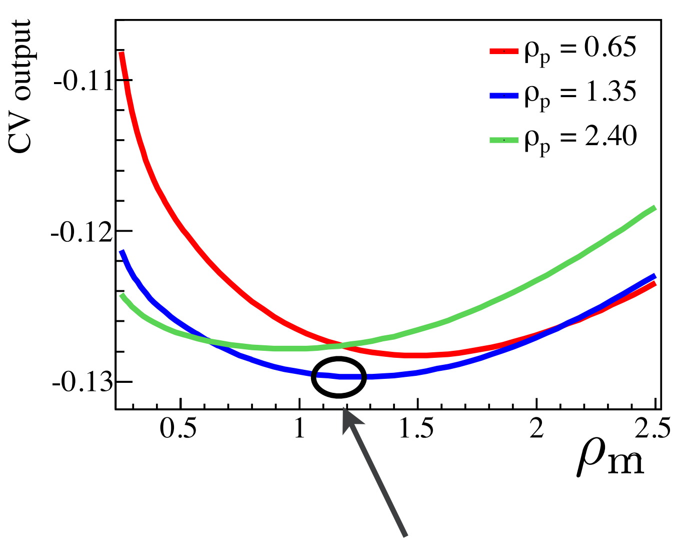


Fit PDFs: Uncertainty

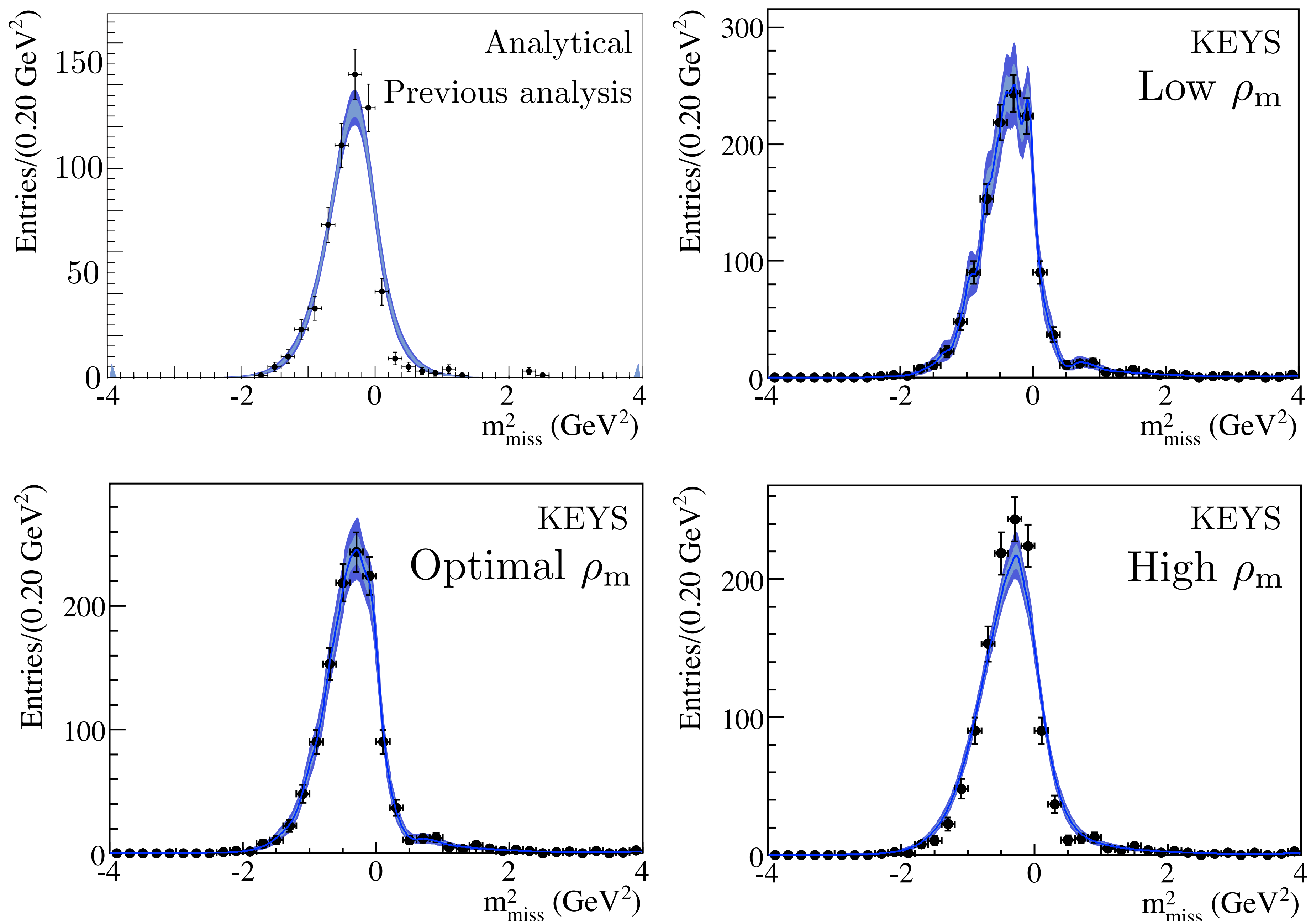
- Uncertainties estimated with **Bootstrap algorithm**
  - For same statistics ⇒ **larger uncertainty than analytical** (parametric) PDF

Cross-validation algorithm

$$\mathrm{CV} = \frac{1}{n}\sum_{i=1}^{n}\int \hat{p}^{2}_{-i}(X)\mathrm{d}X - \frac{2}{n}\sum_{i=1}^{n}\hat{p}_{-i}(x_i)$$

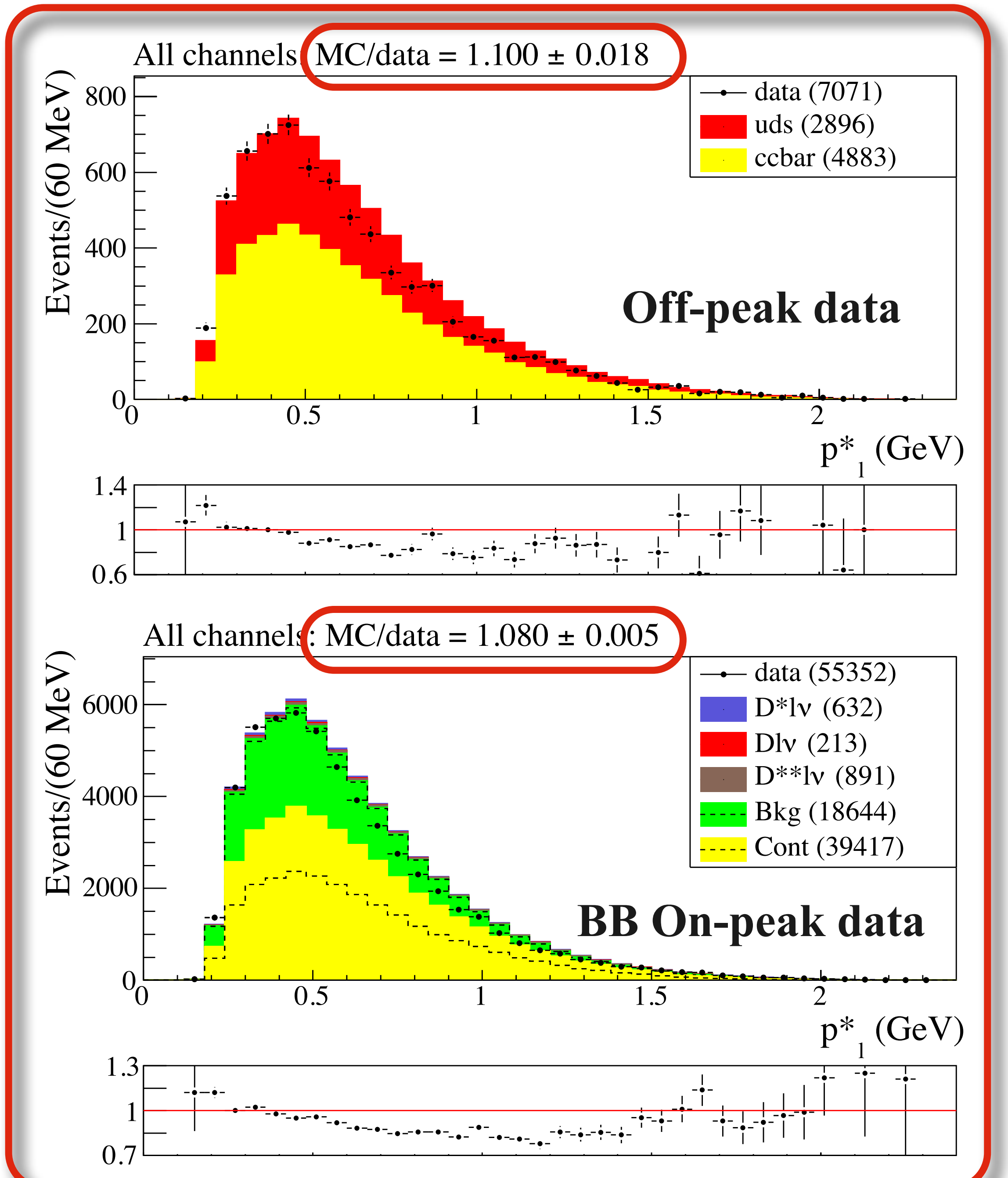


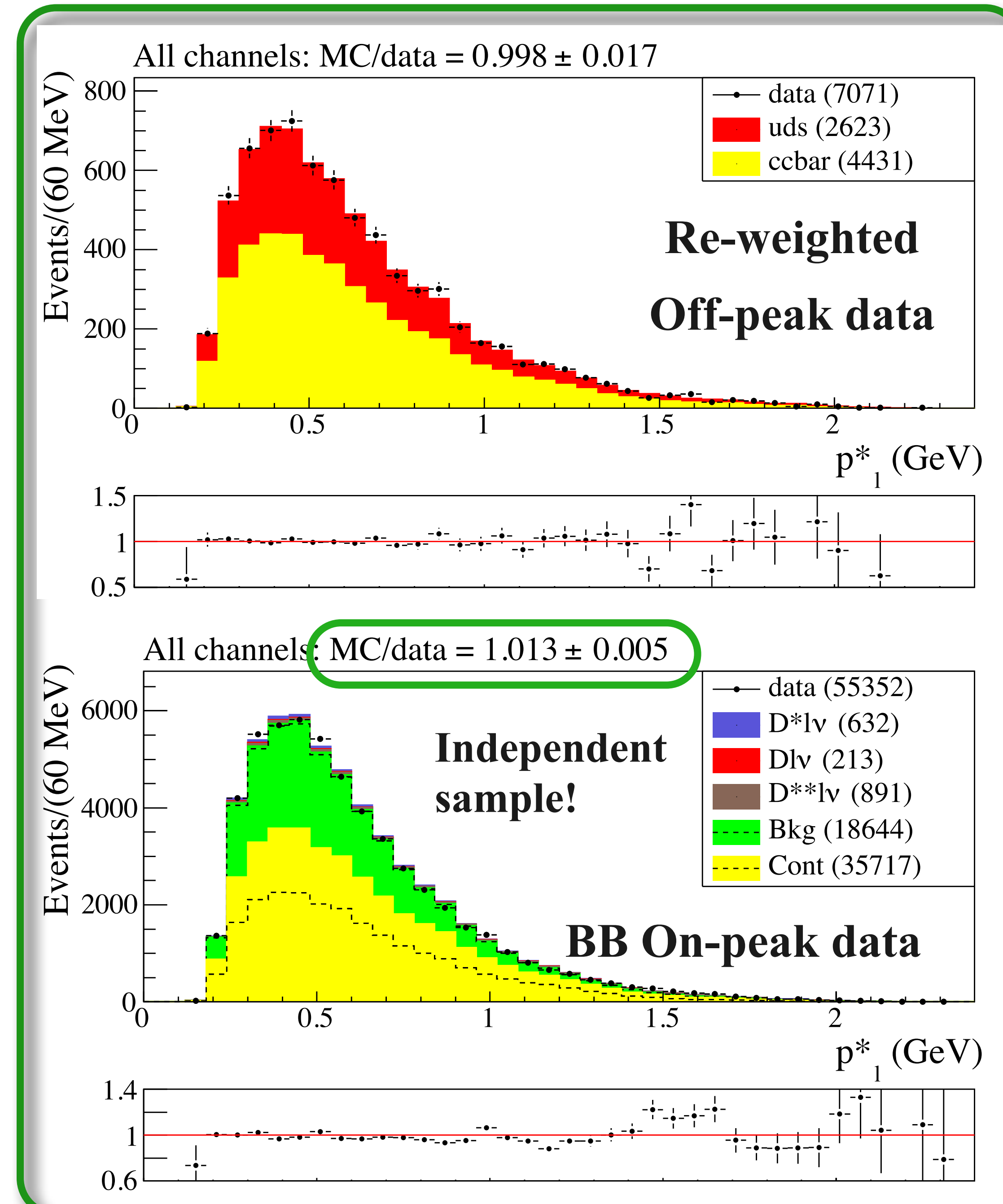
Optimal



Continuum bkg.

- Simulation does not reproduce **p*$_l$** and **yields** of $e^+e^- \to u\bar{u}, d\bar{d}, c\bar{c}, s\bar{s}$

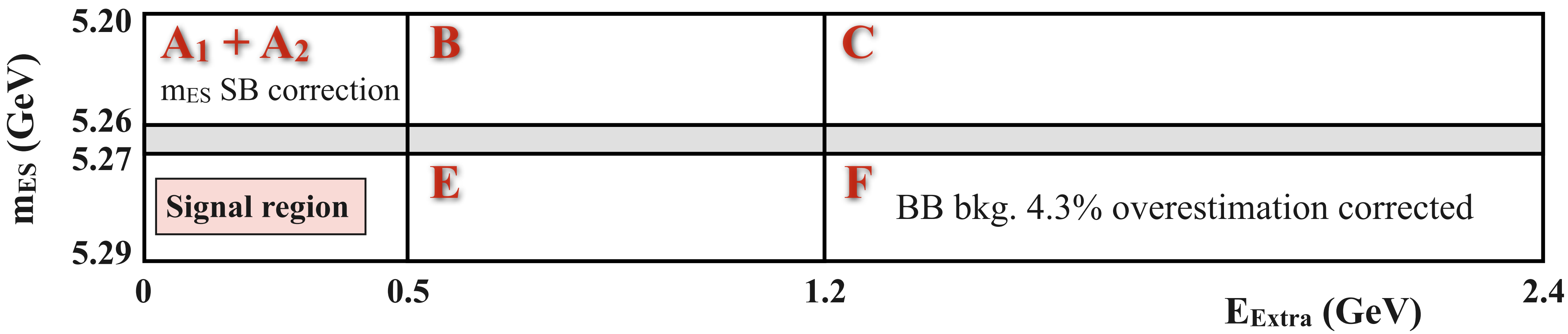


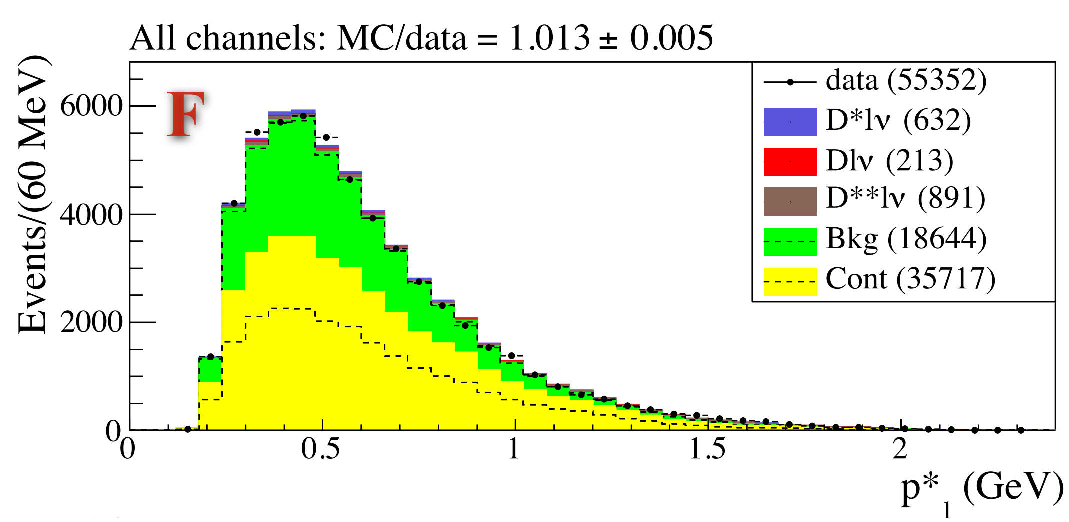


1.2 < E_{Extra} < 2.4 GeV

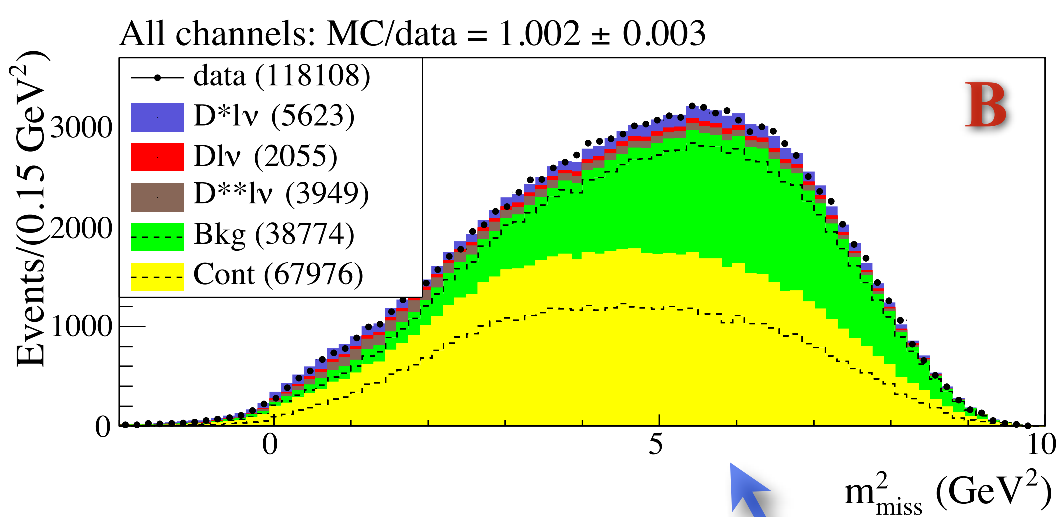
BB Background

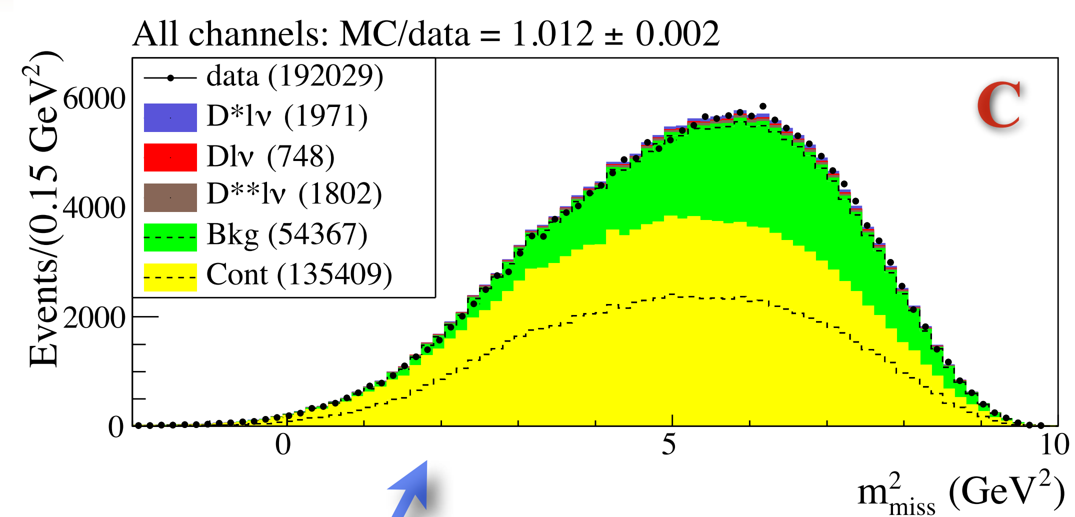
- **BB background** estimated from **control samples**
  - $5.20 < m_{ES} < 5.26$ GeV
  - $E_{\text{Extra}} = \sum_{\text{unused } \gamma} E_\gamma > 0.5$ GeV





BB Background

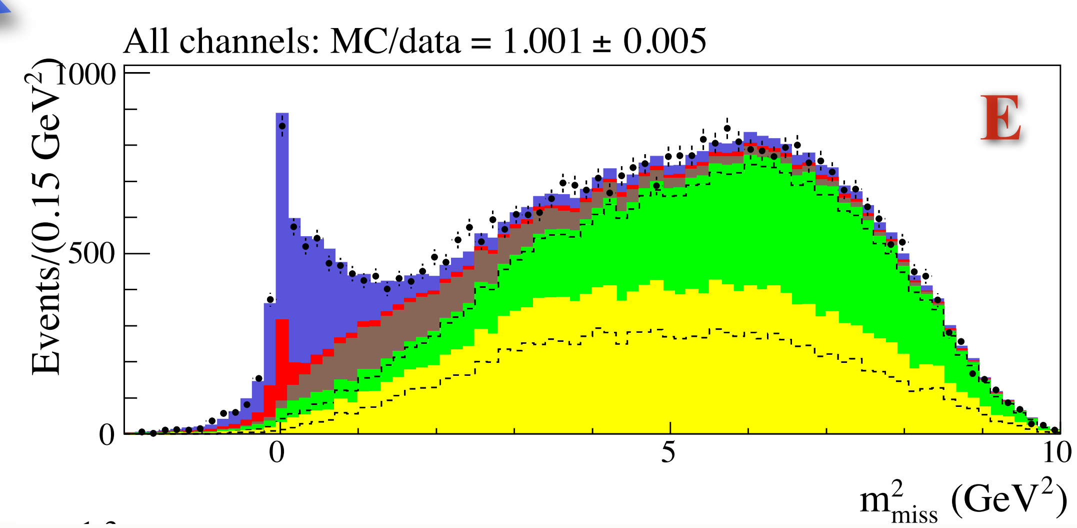




m_{ES} (GeV)	E_{Extra}: 0 – 0.5	0.5 – 1.2	1.2 – 2.4
5.20 – 5.26	**$A_1 + A_2$** m_{ES} SB correction	**B** 1.000 ± 0.003	**C** 1.011 ± 0.003
5.27 – 5.29	**Signal region**	**E** 0.998 ± 0.006	**F** BB bkg. 4.3% overestimation corrected

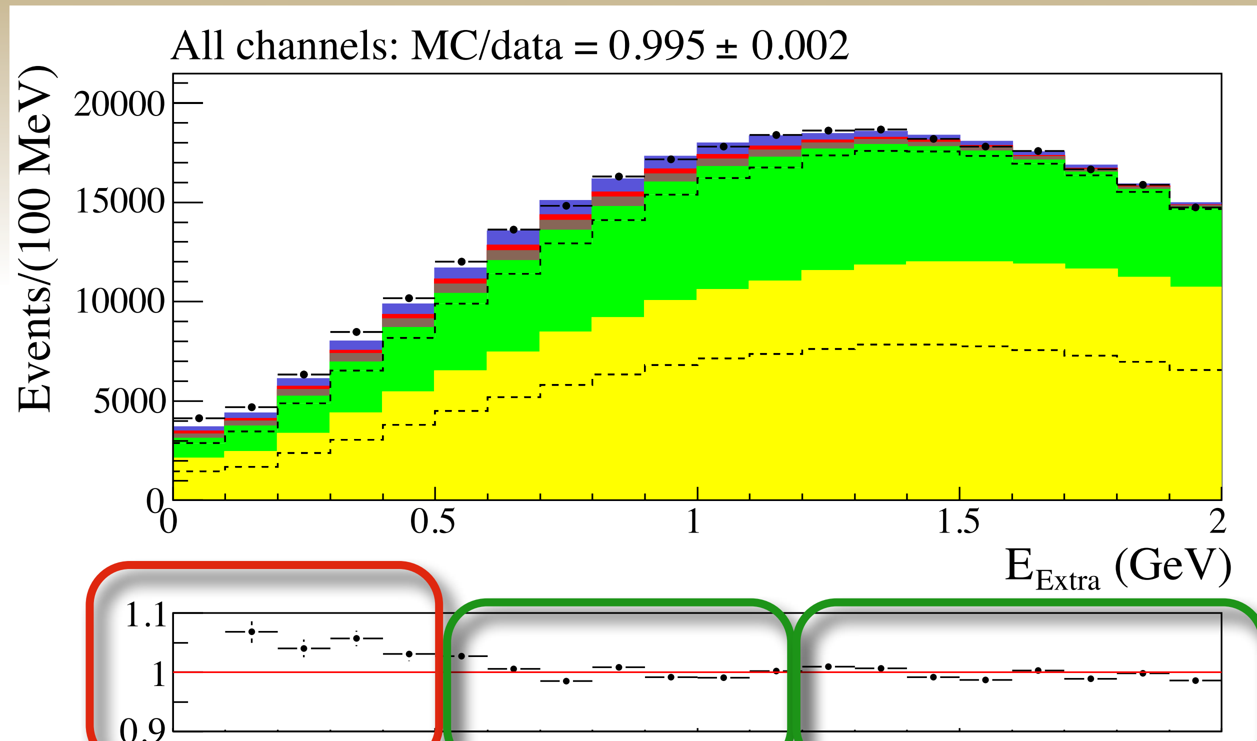
E_{Extra} (GeV)

MC/data for $m^2_{miss} > 1.5$ GeV²



- **Background** very **well described** for **large E_{Extra}**
  - m_{miss} shapes
  - Yields

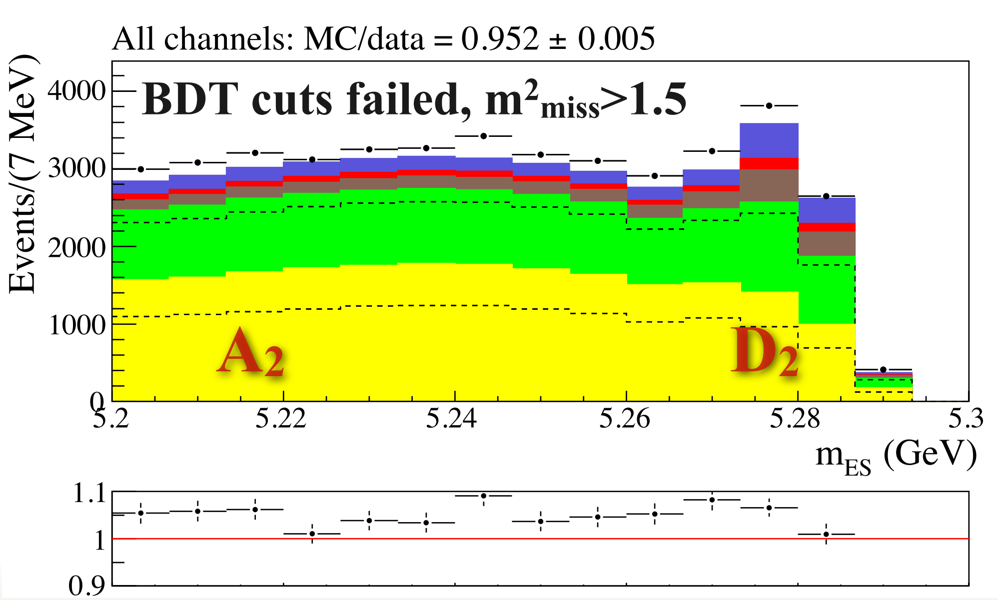
E_{Extra}

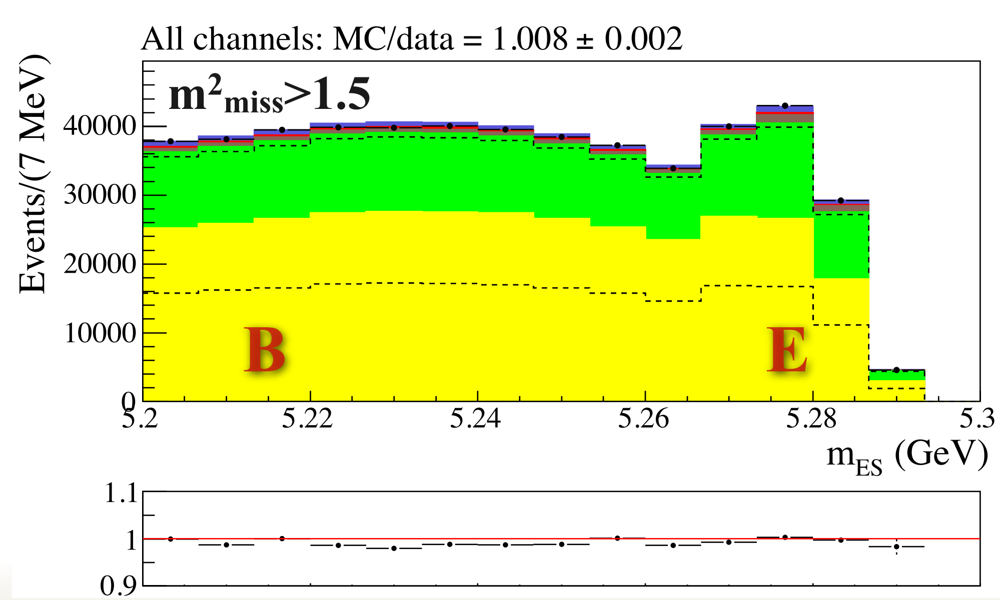


- **Background** very **well described** for **large E_{Extra}**
- 5-10% diff. for $E_{Extra} < 0.5$ GeV
  - **Corrected with m_{ES} sideband**
  - Significant uncertainty

m_{ES} (GeV) \ E_{Extra} (GeV)	0 – 0.5	0.5 – 1.2	1.2 – 2.4
5.20 – 5.26	**$A_1 + A_2$** m_{ES} SB correction	**B** **1.000 ± 0.003**	**C** **1.011 ± 0.003**
5.26 – 5.27			
5.27 – 5.29	**Signal region**	**E** **0.998 ± 0.006**	**F** BB bkg. 4.3% overestimation corrected

MC/data for $m^2_{miss} > 1.5$ GeV^2





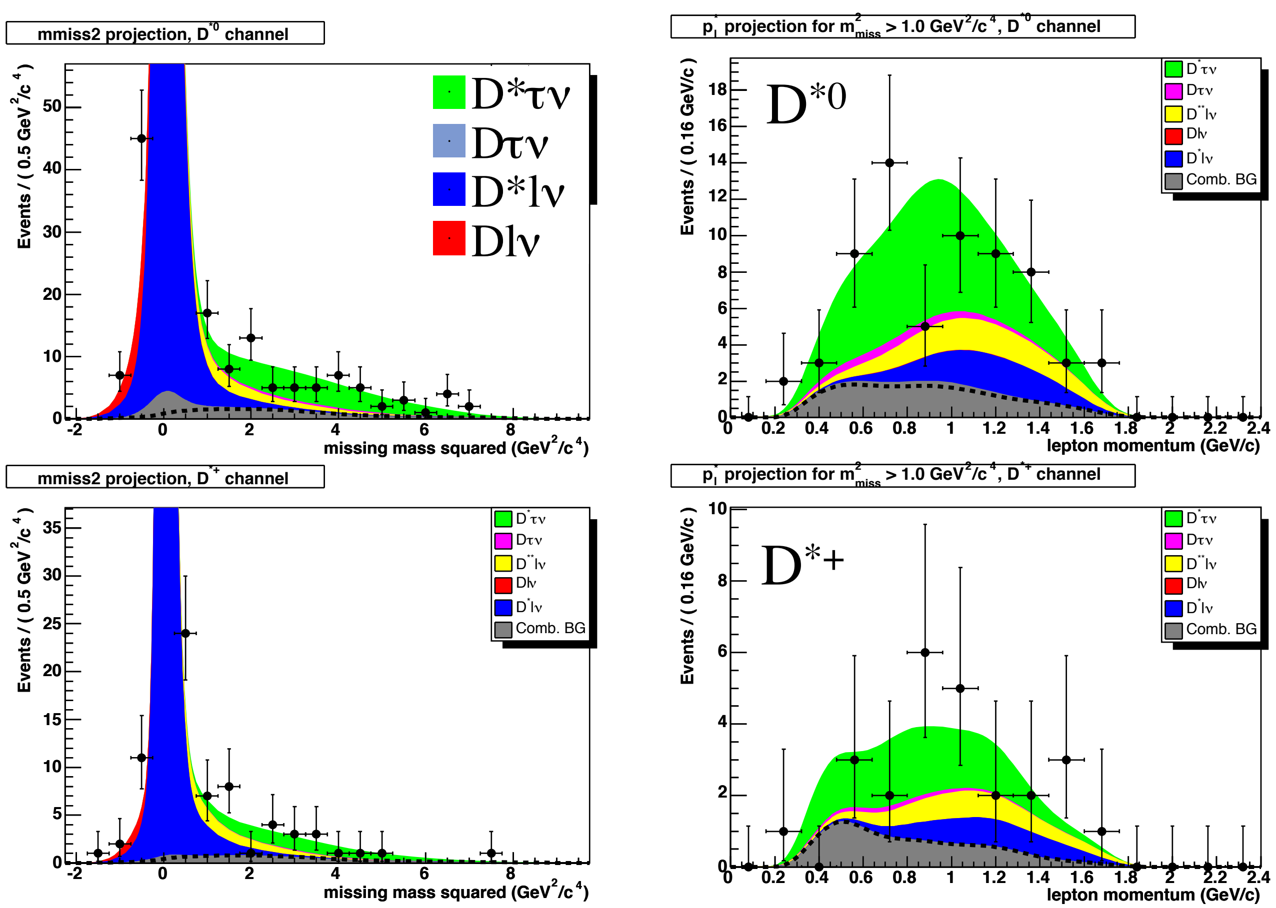
MC/data flat in $m_{ES} \Rightarrow$ Extrapolation of the correction OK

D* channels: 1/2 data

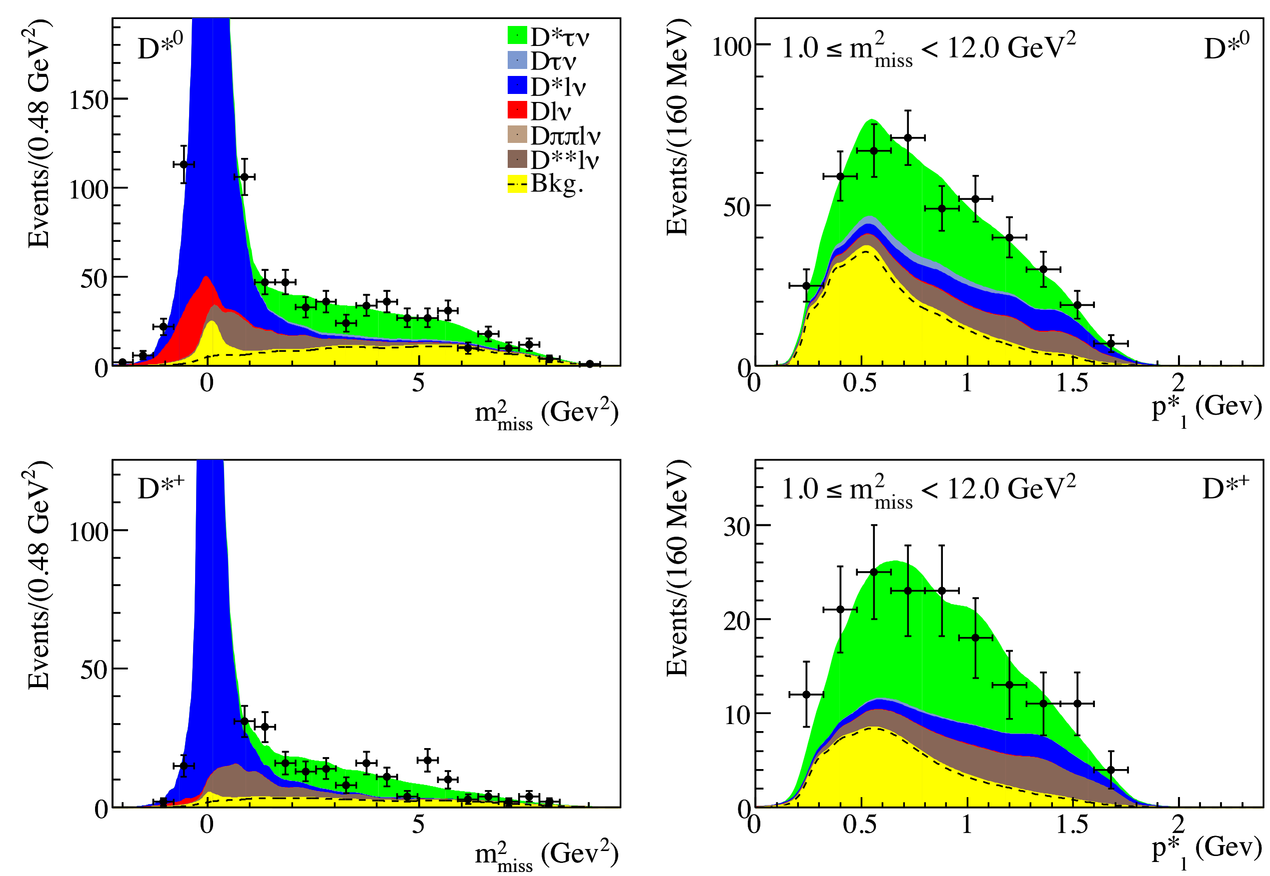
- **Efficiency 3x**
- **Good agreement** with previous analysis

	2008		2012	
	$D^{*0}\tau\nu$	$D^{*+}\tau\nu$	$D^{*0}\tau\nu$	$D^{*+}\tau\nu$
N_{sig}	92 ± 20	16 ± 7	267 ± 35	107 ± 17
Signif.	5.8 σ	2.7 σ	8.6 σ	8.0 σ
R(D*)	**0.35 ± 0.07**	**0.21 ± 0.10**	**0.31 ± 0.04**	**0.32 ± 0.05**

2008



2012



Fit results: $D^*\tau\nu$

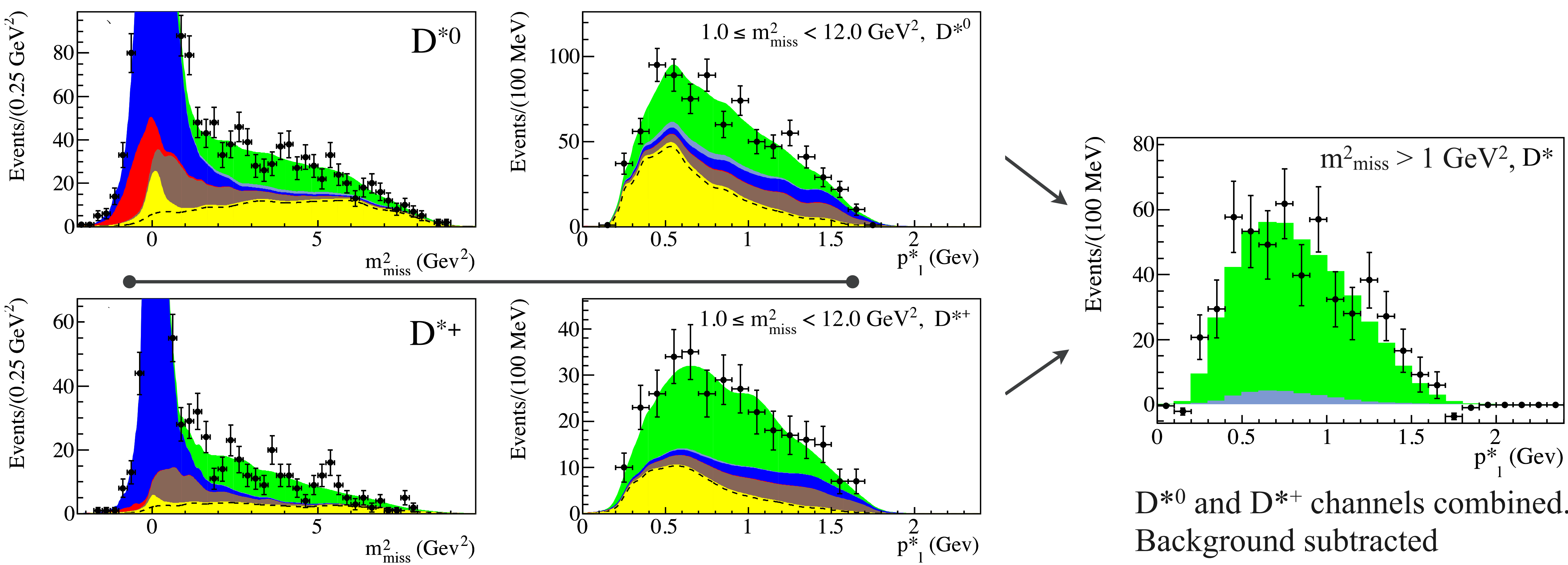
- **Good fit** agreement
- Uncertainties statistical

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

Fixed: Bkg.

	$D^{*0}\tau\nu$	$D^{*+}\tau\nu$	$D^*\tau\nu$
N_{sig}	639 ± 62	245 ± 27	888 ± 63
Signif.	11.3 σ	11.6 σ	16.4 σ
R(D^*)	**0.322 ± 0.032**	**0.355 ± 0.039**	**0.332 ± 0.024**

Isospin constrained



D^{*0} and D^{*+} channels combined. Background subtracted

Fit results: Dτν

- First 5σ observation
- Uncertainties statistical

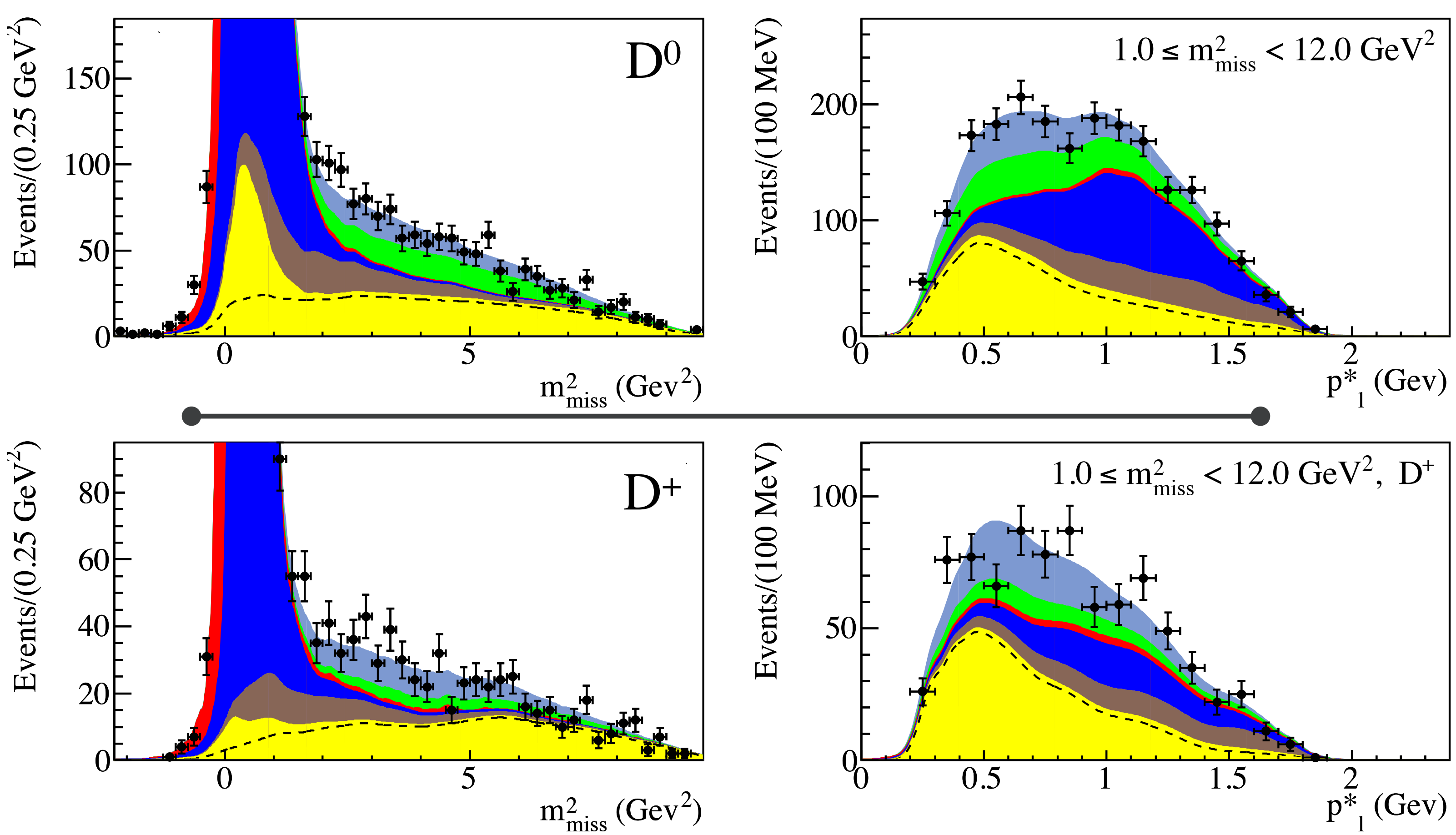
Free in the fit: D*τν, Dτν, D*lν, Dlν, D**lν

Fixed: Bkg.

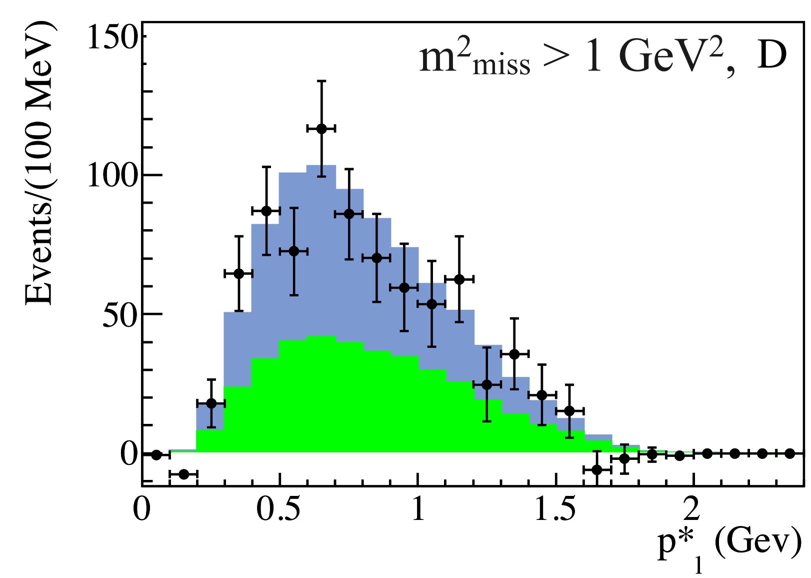
	$D^0\tau\nu$	$D^+\tau\nu$	$D\tau\nu$
N_{sig}	314 ± 60	177 ± 31	489 ± 63
Signif.	5.5 σ	6.1 σ	8.4 σ
R(D)	**0.429 ± 0.082**	**0.469 ± 0.084**	**0.440 ± 0.058**

First observation!

Isospin constrained



-45% correlation D-D*



D^0 and D^+ channels combined.
Background subtracted

Systematic uncertainties

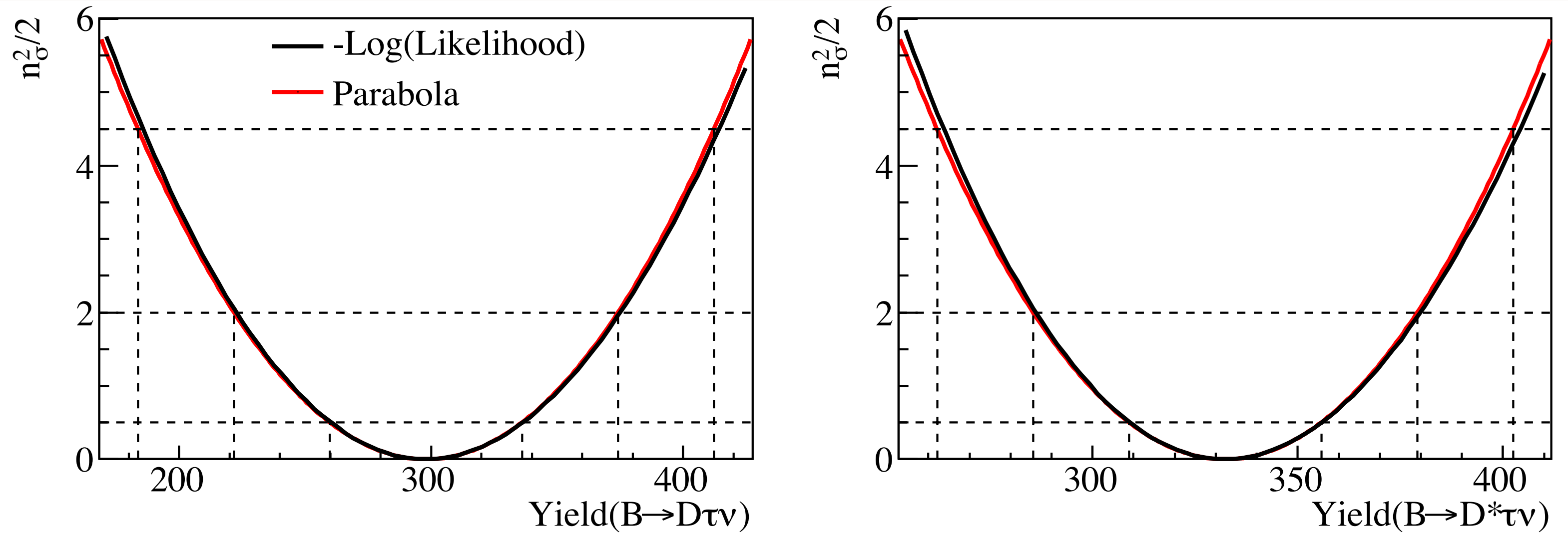
Source	Uncertainty (%) $R(D)$	Uncertainty (%) $R(D^*)$	ρ
$D^{**}\ell\nu$ background	5.8	3.7	0.62
MC statistics	5.0	2.5	-0.48
Cont. and $B\overline{B}$ bkg.	4.9	2.7	-0.30
$\varepsilon_{\rm sig}/\varepsilon_{\rm norm}$	2.6	1.6	0.22
Systematic uncertainty	9.5	5.3	0.05
Statistical uncertainty	13.1	7.1	-0.45
Total uncertainty	**16.2**	**9.0**	**-0.27**

Correlation between $R(D)$ and $R(D^*)$

- **Largest syst.** due to **backgrounds**
- **Small** uncertainty on **efficiency ratio $\varepsilon_{sig}/\varepsilon_{norm}$**
- **Statistical** uncertainty **dominates**

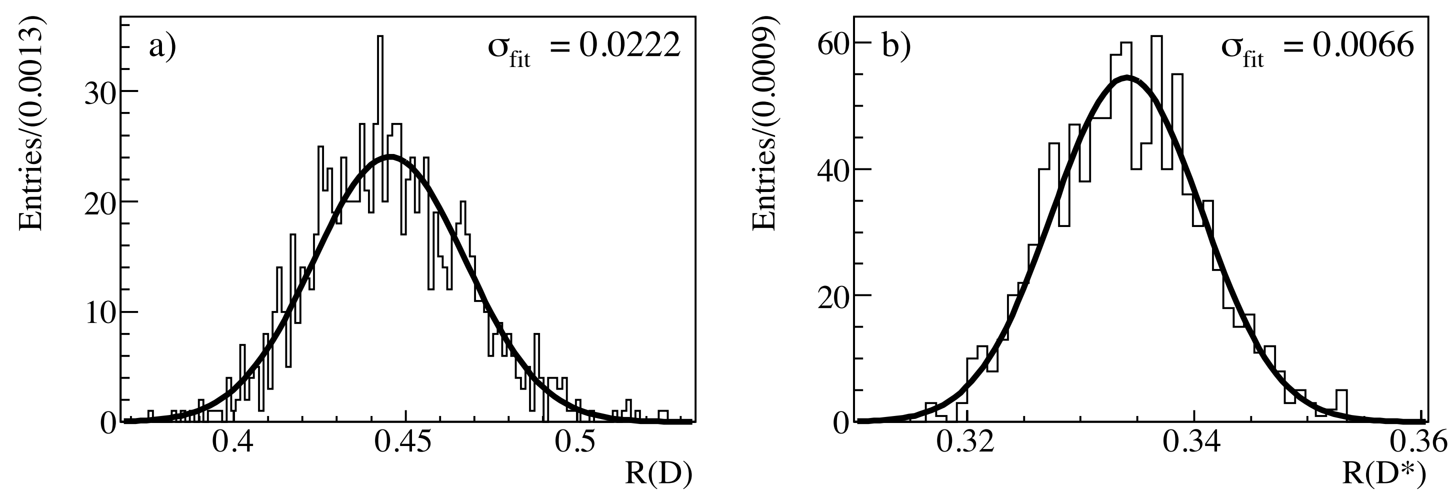
Gaussian uncertainties

- **Statistical uncertainty**

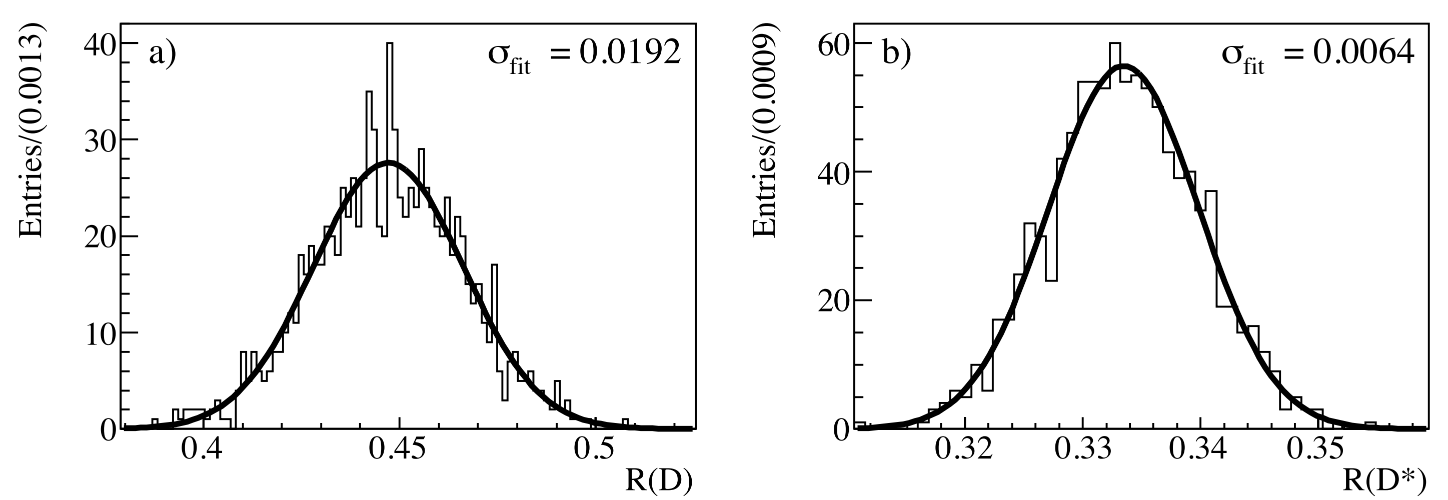


Likelihood scan

- Largest **systematic uncertainties**



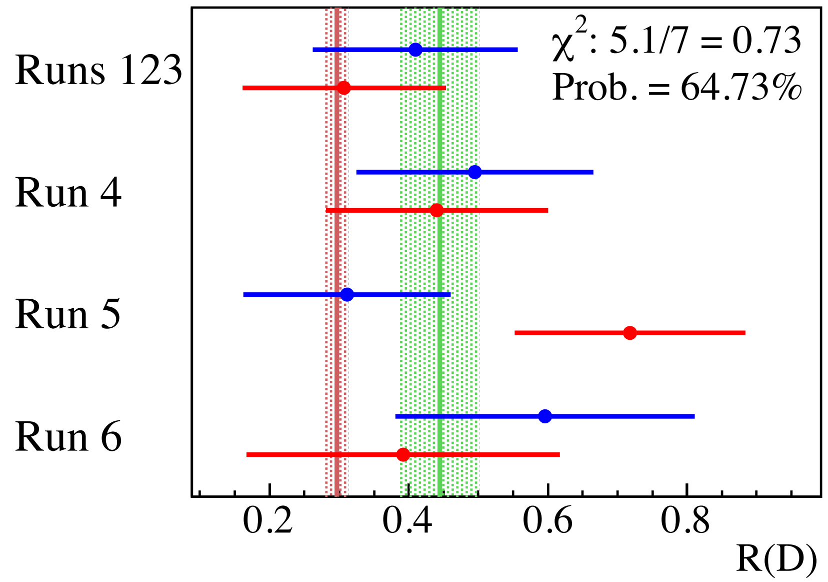
Variations of the **$D^{**}\ell\nu$ rate** from the $D\pi^0$ into the signal samples

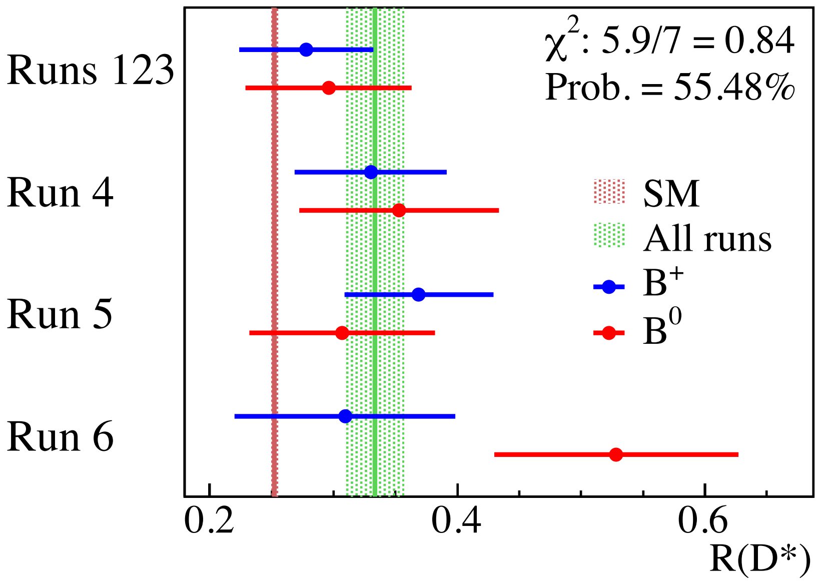


Variations of the **PDFs** due to MC statistics

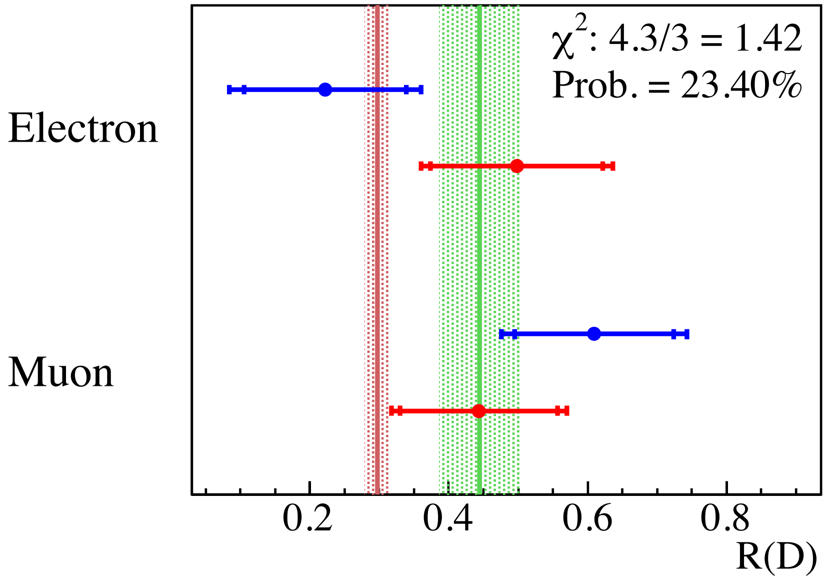
Stability checks

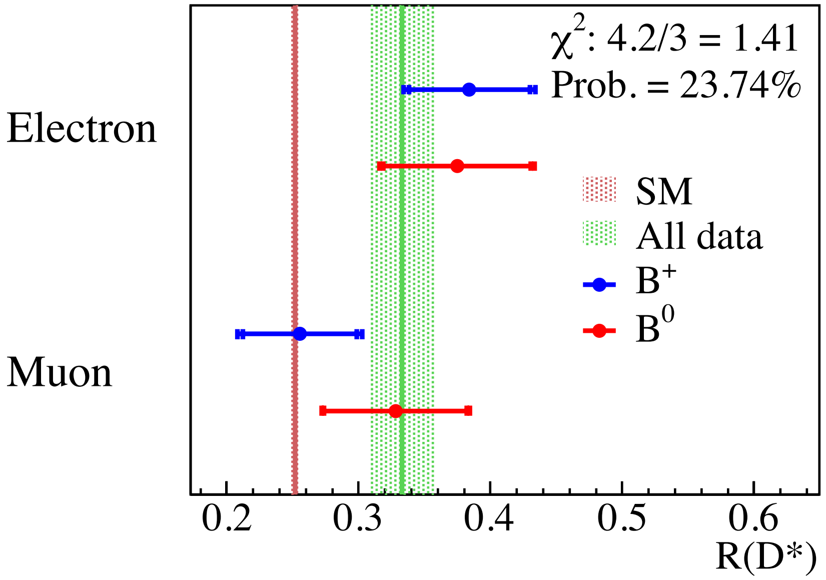
- **Results** are **consistent for different run periods**



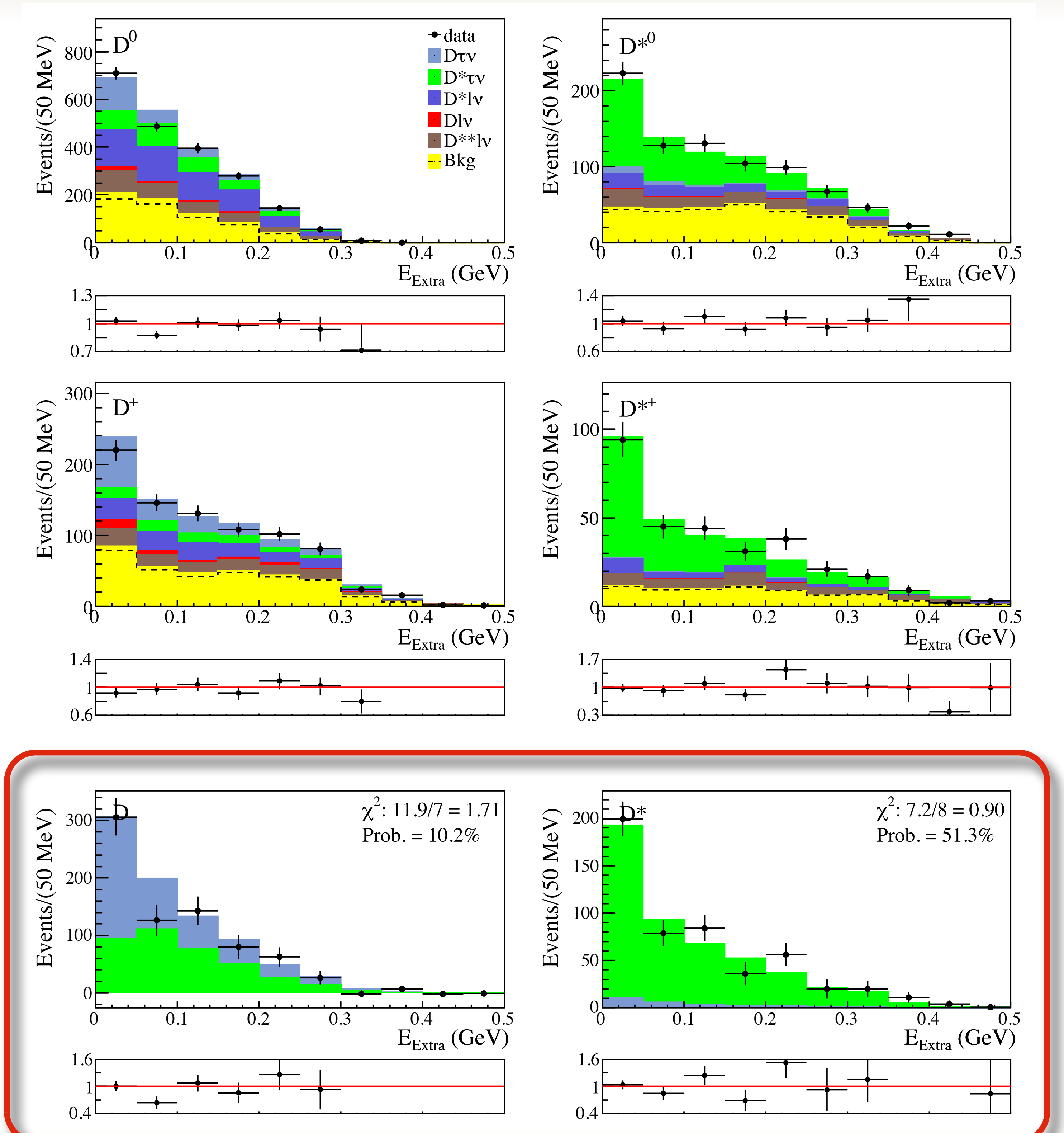


- **Results** are **consistent for e Vs μ**, within the large uncertainties





E_{Extra} after the fit



- **Key variable** in the **BDT**

$$E_{\mathrm{Extra}} = \sum_{\mathrm{unused}\ \gamma} E_\gamma$$

- **Signal peaks in E_{Extra}**
  - Re-scaled to the results of the fit
  - $m^2_{\mathrm{miss}} > 1.5\ \mathrm{GeV}^2$

$D^{(*)0}$ and $D^{(*)+}$ channels combined
Background subtracted

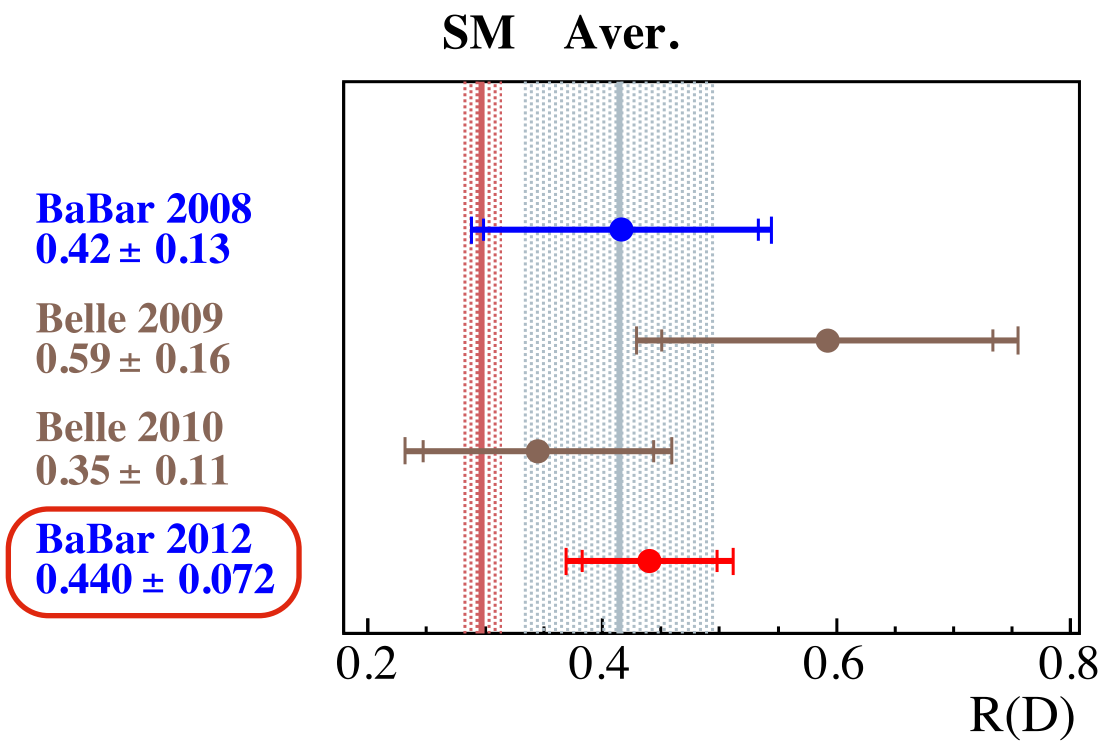
Results

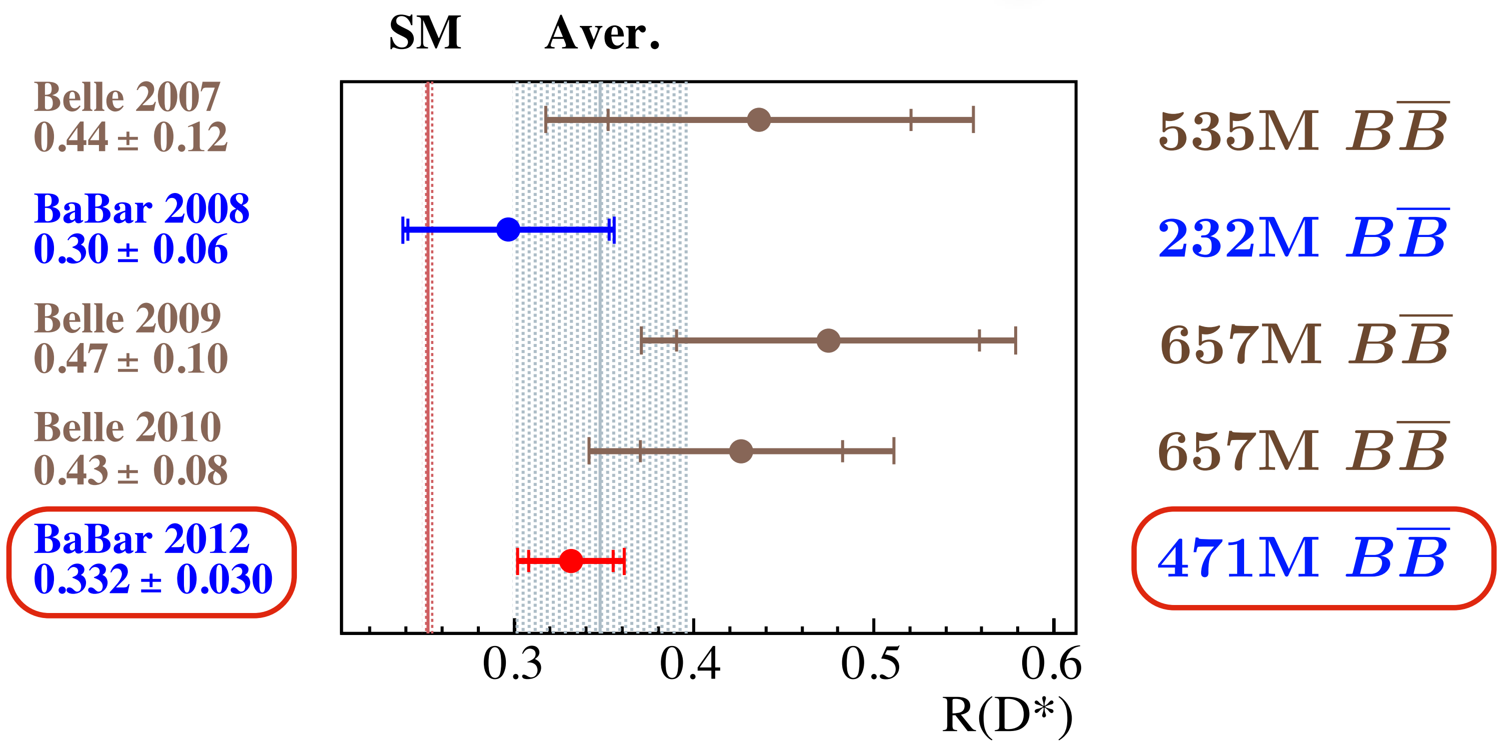
PRL 109, 101802 (2012)

Decay	N_{sig}	N_{norm}	$R(D^{(*)})$	$\mathcal{B}(B \to D^{(*)}\tau\nu)$ (%)	$\Sigma_{tot}(\sigma)$
$D\tau^-\overline{\nu}_\tau$	489 ± 63	2981 ± 65	$0.440 \pm 0.058 \pm 0.042$	$1.02 \pm 0.13 \pm 0.11$	6.8
$D^*\tau^-\overline{\nu}_\tau$	888 ± 63	11953 ± 122	$0.332 \pm 0.024 \pm 0.018$	$1.76 \pm 0.13 \pm 0.12$	13.2

- **First 5σ observation** of **B→Dτν**
- **Agreement** with **previous measurements**

Average does not include this analysis





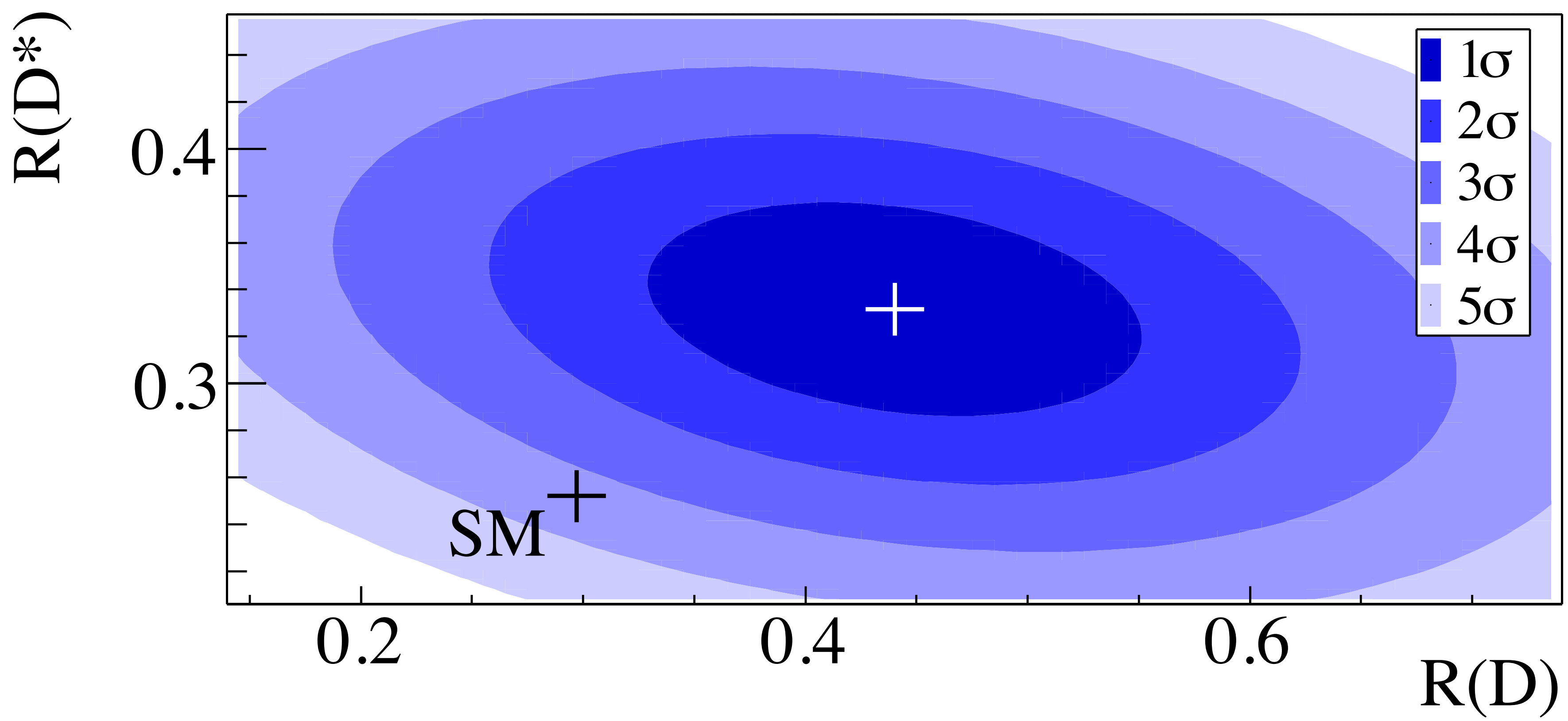
Disagreement with SM

$$R(D) = \begin{cases} 0.440 \pm 0.072 & \text{BABAR} \\ 0.297 \pm 0.017 & \text{SM} \end{cases} \quad \mathbf{2.0\sigma}$$

$$R(D^*) = \begin{cases} 0.332 \pm 0.030 & \text{BABAR} \\ 0.252 \pm 0.003 & \text{SM} \end{cases} \quad \mathbf{2.7\sigma}$$

Combined: **3.4σ**

3.2σ with largest $R(D)_{SM}$
PRL 109, 071802 (2012)

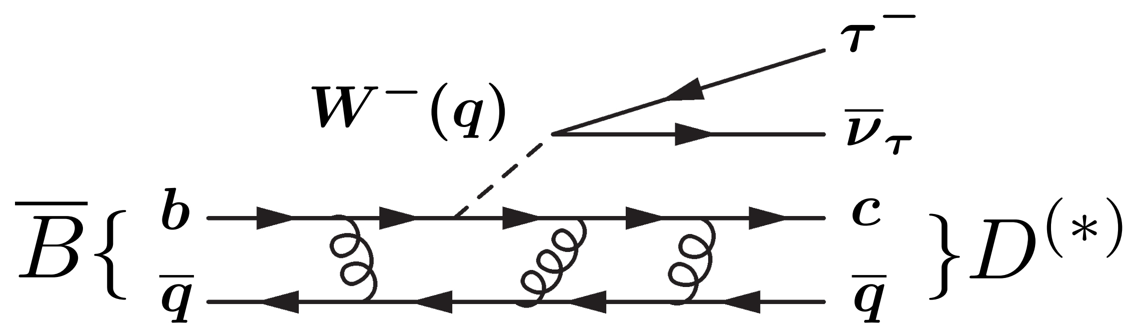


R(D) and **R(D*)** **not independent**

-27% correlation

Type II 2HDM calculation

- **SM matrix element** $$\mathcal{M}^{\lambda_\ell}_{\lambda_M}(q^2,\theta_\ell)\Big|_W = \frac{G_F V_{cb}}{\sqrt{2}} \sum_{\lambda_W} L^{\lambda_\ell}_{\lambda_W} H^{\lambda_M}_{\lambda_W}$$
  - $L^{\lambda_\ell}_{\lambda_W}$ are the **leptonic currents**
    - Simple functions of q^2 and θ_l
  - $H^{\lambda_H}_{\lambda_W}$ are the **hadronic currents**
    - Parameterized by Form Factors

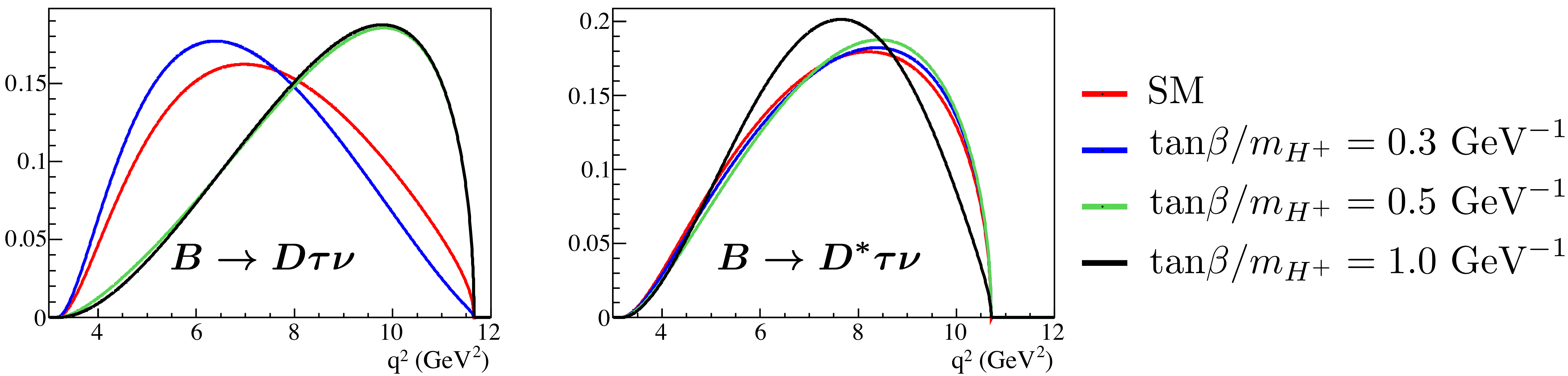


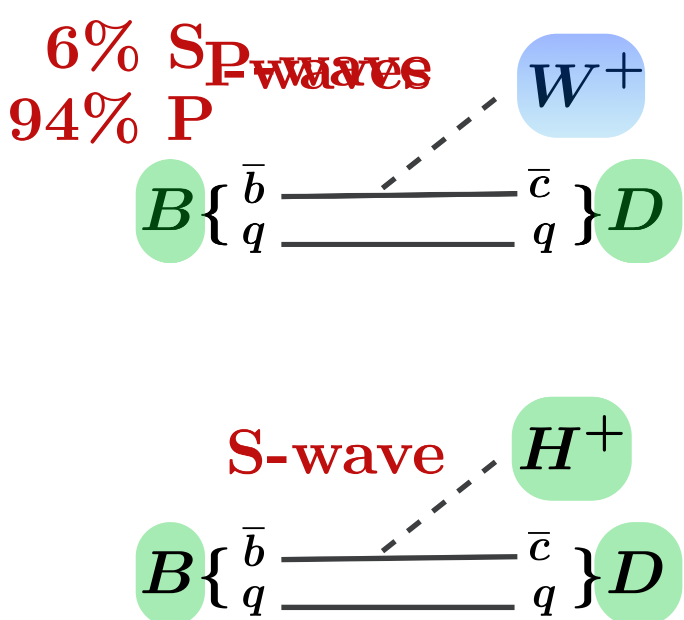
- **H⁻** enters through the **scalar current** $H_s^{2\mathrm{HDM}} \approx H_s^{\mathrm{SM}} \times \left(1 - \frac{\tan^2\beta}{m^2_{H^+}} \frac{q^2}{1 \mp m_c/m_b}\right)$
  - We re-weight the simulation to account for it

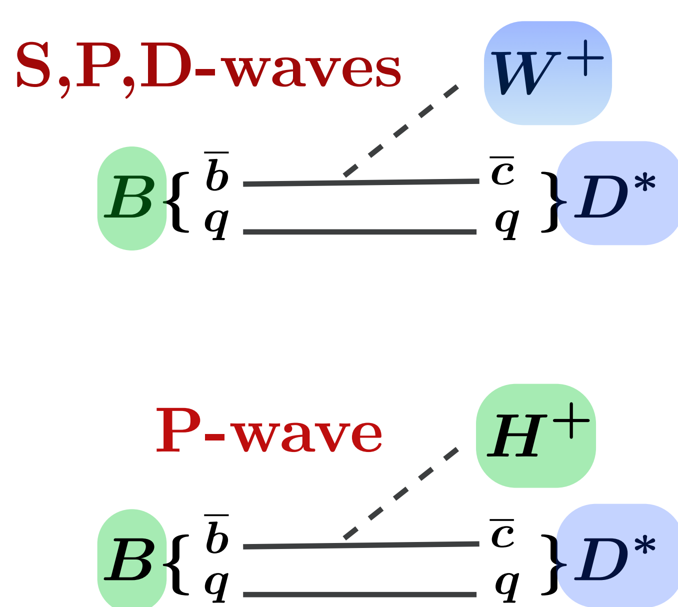
Type II Two-Higgs-Doublet Model

Type II 2HDM: q^2

- **q^2 spectrum** impacted by $H_s^{2HDM} \approx H_s^{SM} \times \left(1 - \frac{\tan^2\beta}{m^2_{H^+}} \frac{q^2}{1 \mp m_c/m_b}\right)$

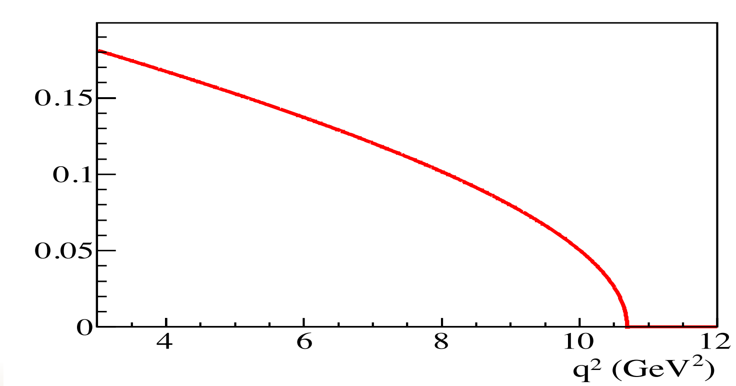






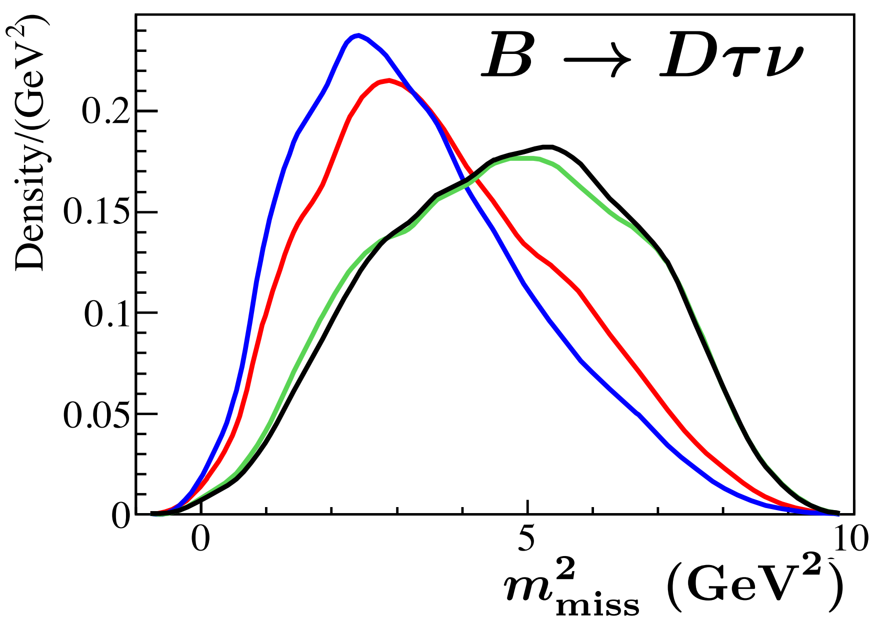
Spin 0 **Spin 1**

P-waves pick up a factor of $p_{D^{(*)}}$



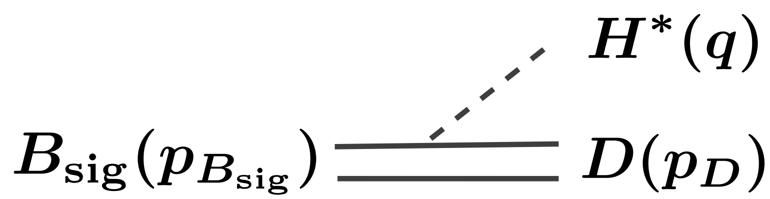
Type II 2HDM: PDFs

PDFs re-calculated in the **2HDM** context



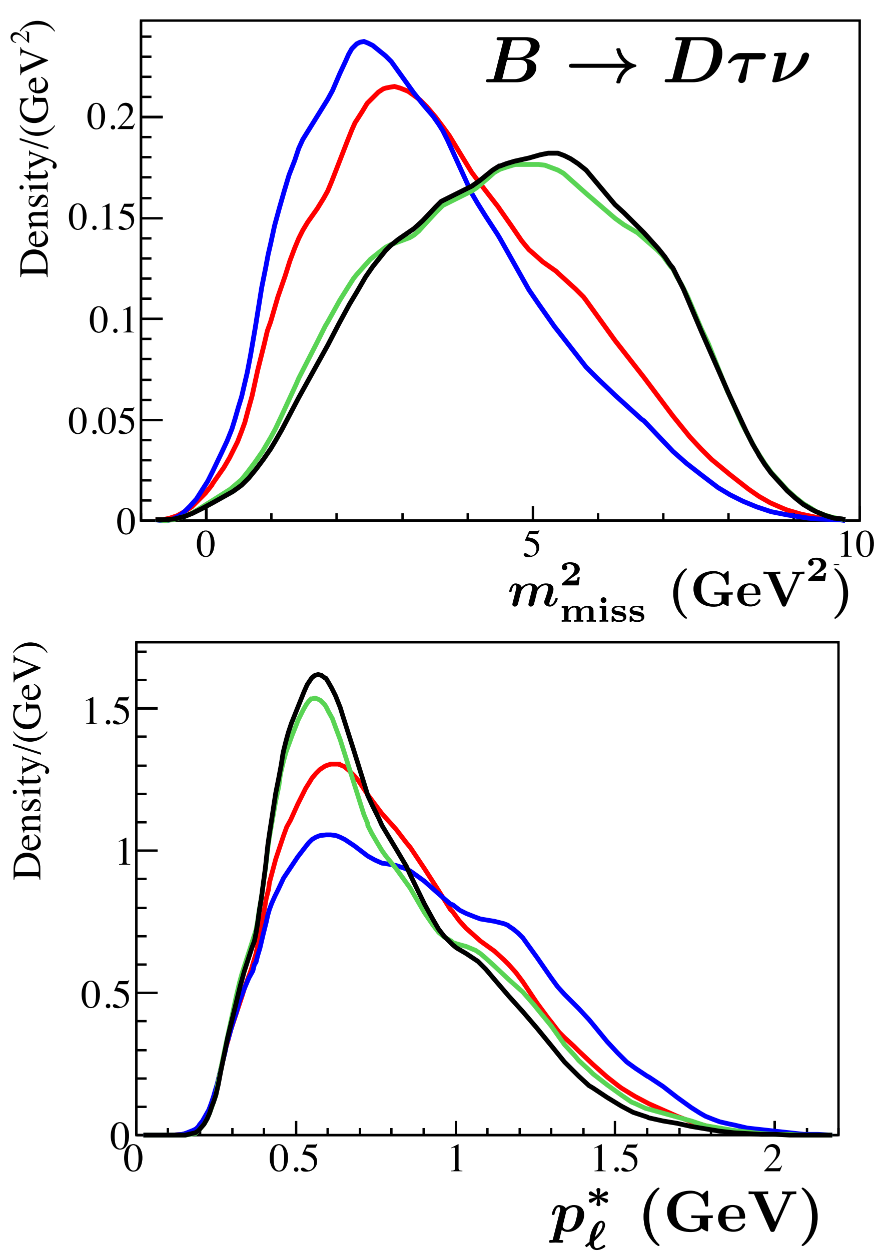
Higgs impact on m^2_{miss} similar to q^2

$$m^2_{\rm miss} = \Big(\overbrace{\underbrace{p_{e^+e^-} - p_{B_{\rm tag}}}_{\text{}}}^{p_{B_{\rm sig}}} - p_{D^{(*)}} - p_\ell\Big)^2 = (q - p_\ell)^2, \qquad q = p_{B_{\rm sig}} - p_{D^{(*)}}$$

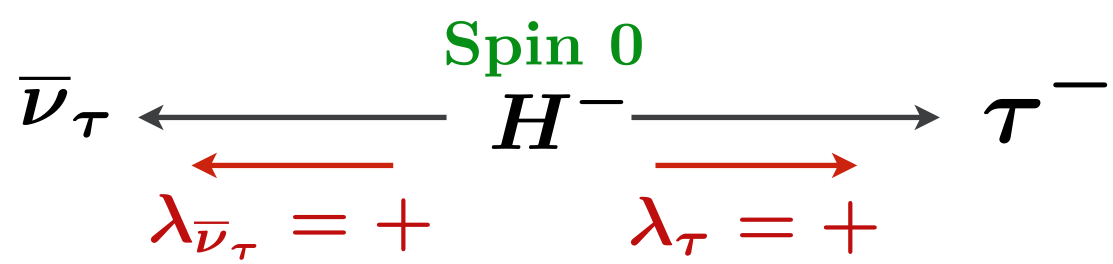


Type II 2HDM: PDFs

PDFs re-calculated in the **2HDM** context

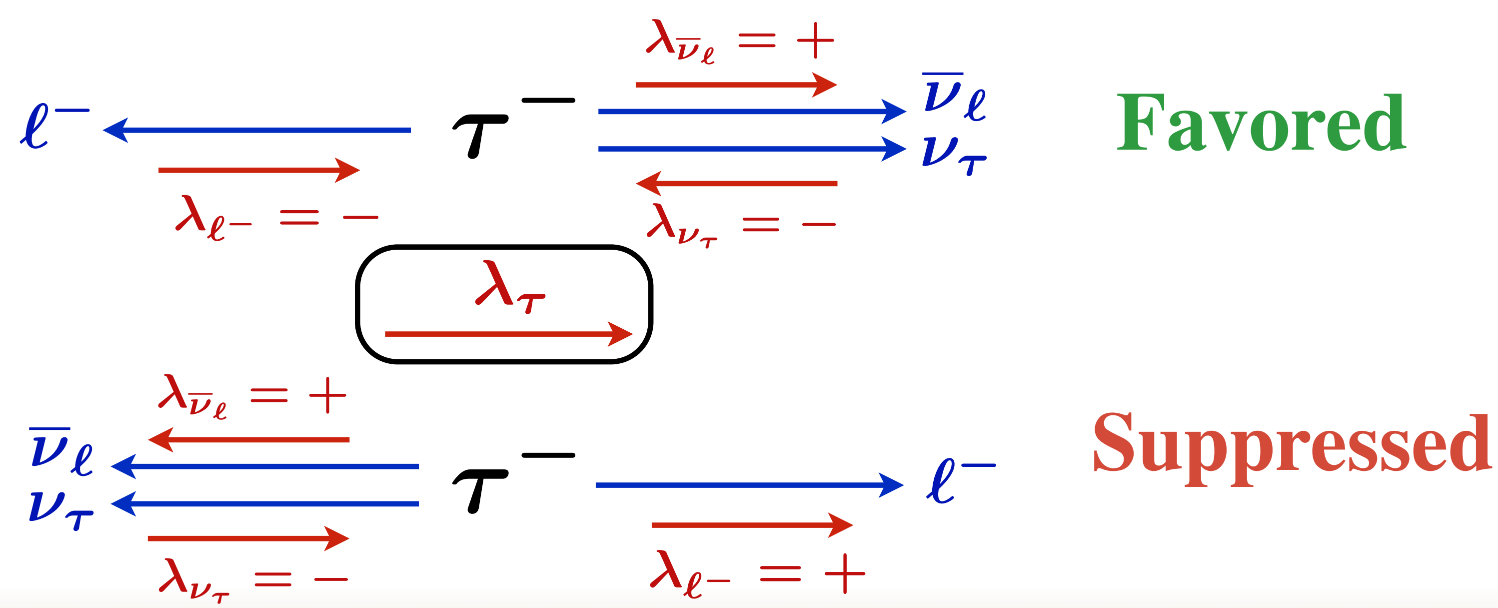


- **τ^- polarization in $\overline{B} \to D^{(*)}\tau^-\overline{\nu}_\tau$**
  - **<u>SM:</u>** Left-handed **30-80%,** Right-handed **70-20%**
    - **τ spin points back (partially) to B meson**



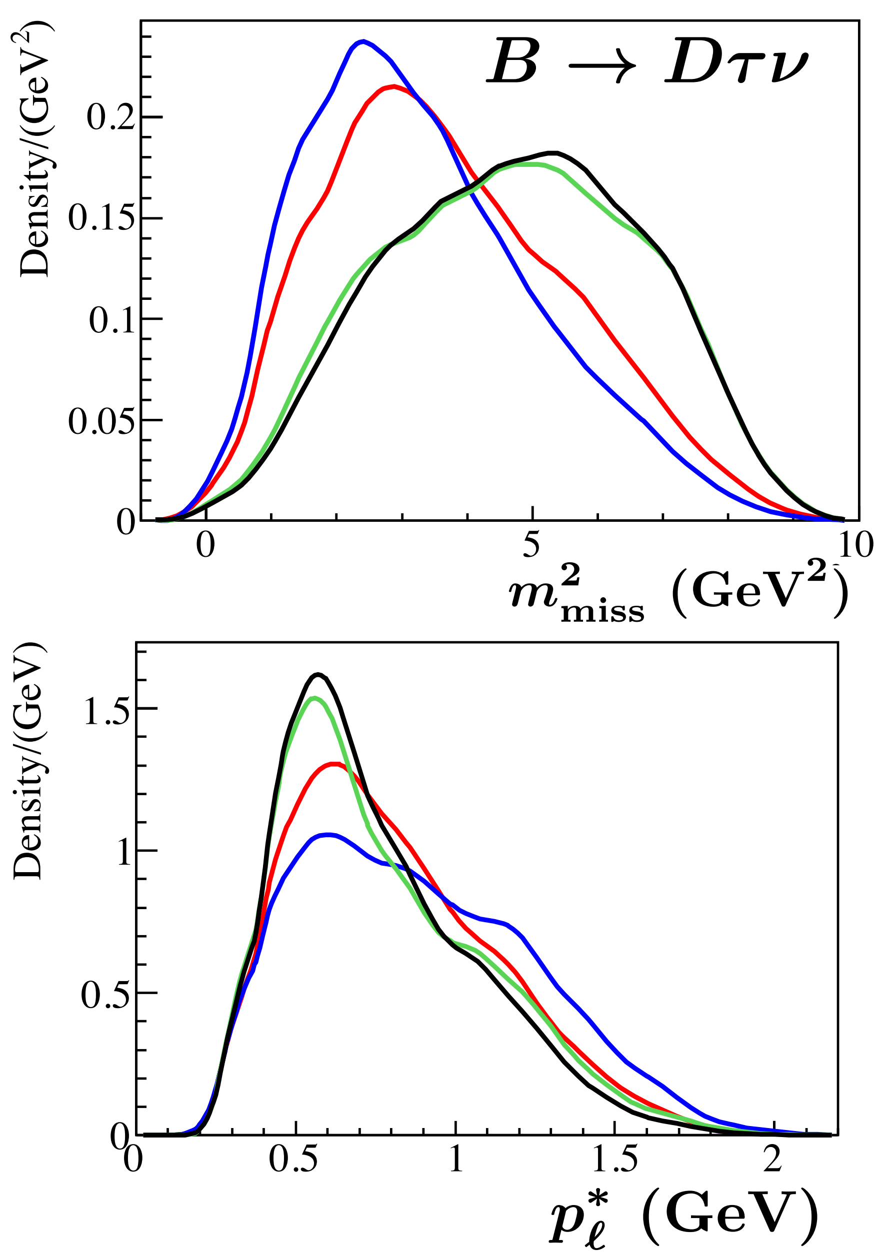
  - **<u>2HDM:</u>** Left-handed **0%,** Right-handed **100%**
    - **τ spin away from B meson**

p^*_ℓ is the momentum of the secondary lepton from $\tau^- \to \ell^-\overline{\nu}_\ell\nu_\tau$ decays in B frame

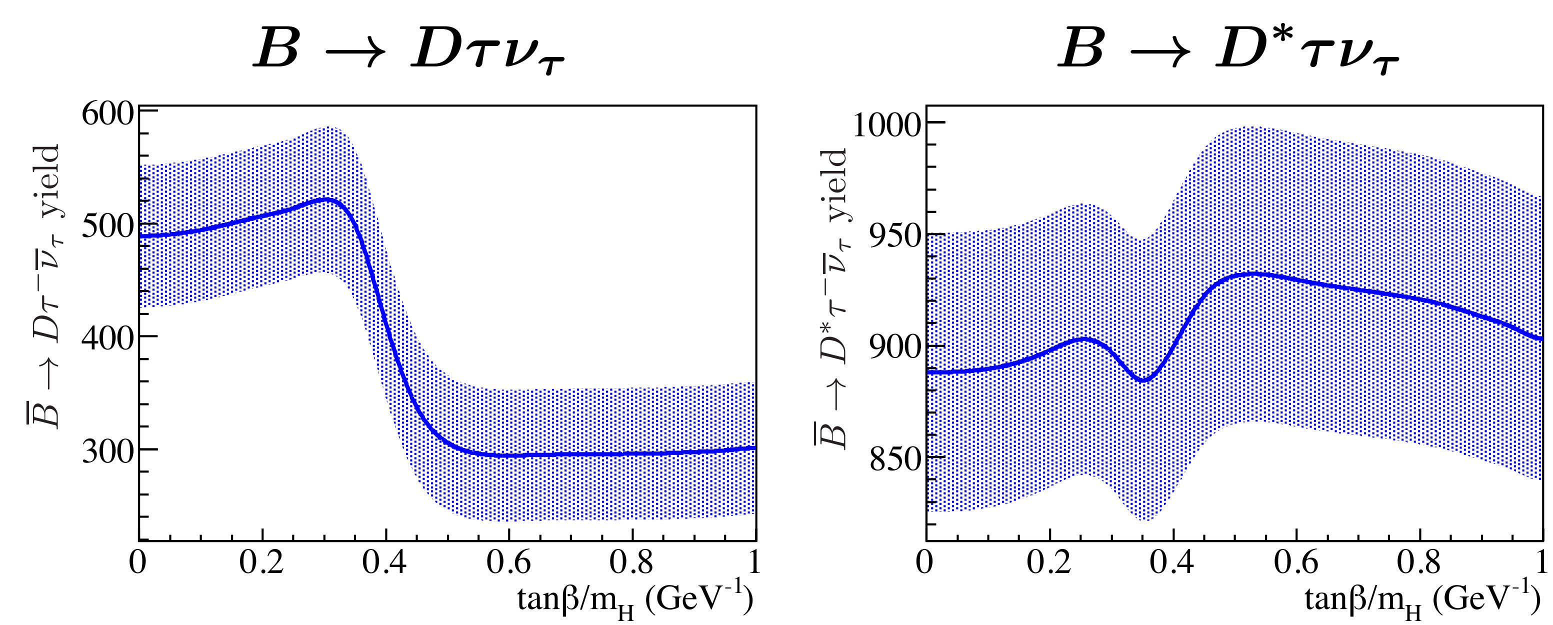


Type II 2HDM scan

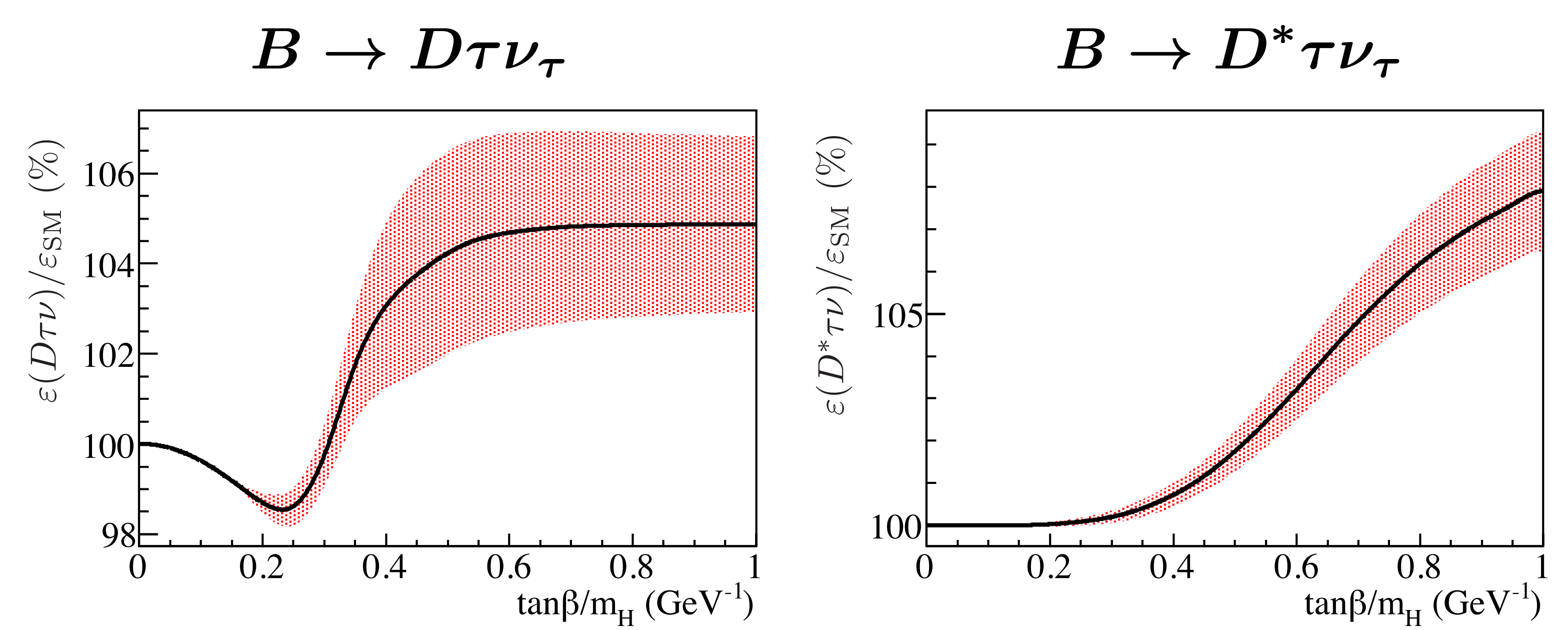
PDFs re-calculated in the **2HDM** context



Fitted yields

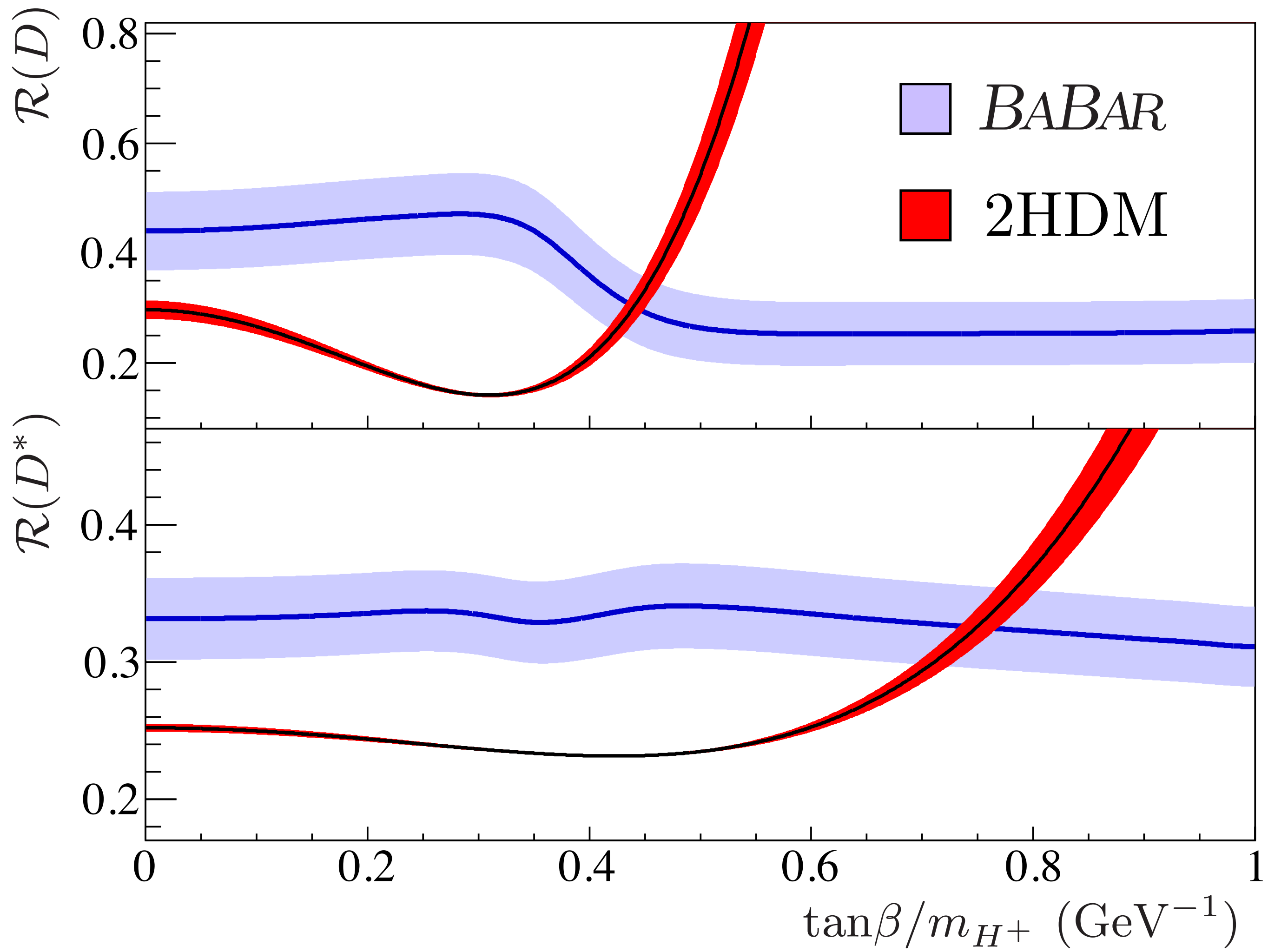


Efficiency



Type II 2HDM scan

- Measured $R(D^{(*)}) = \frac{\mathcal{B}(\overline{B} \to D^{(*)}\tau^- \overline{\nu}_\tau)}{\mathcal{B}(\overline{B} \to D^{(*)}\ell^- \overline{\nu}_\ell)} = \frac{N_{\rm sig}}{N_{\rm norm}} \times \frac{\varepsilon_{\rm norm}}{\varepsilon_{\rm sig}}$ in the **full 2HDM parameter space**



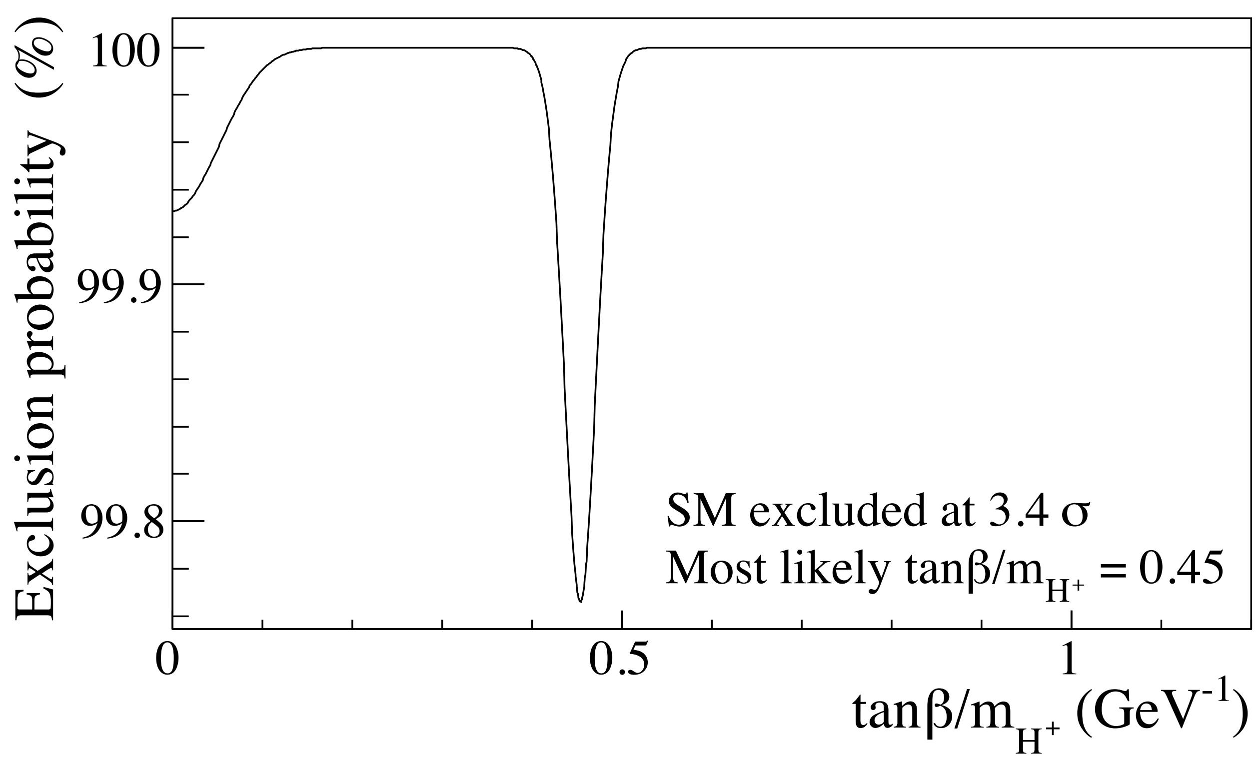
$\tan\beta/m_{H^+} = 0.44 \pm 0.02$ GeV^{-1}

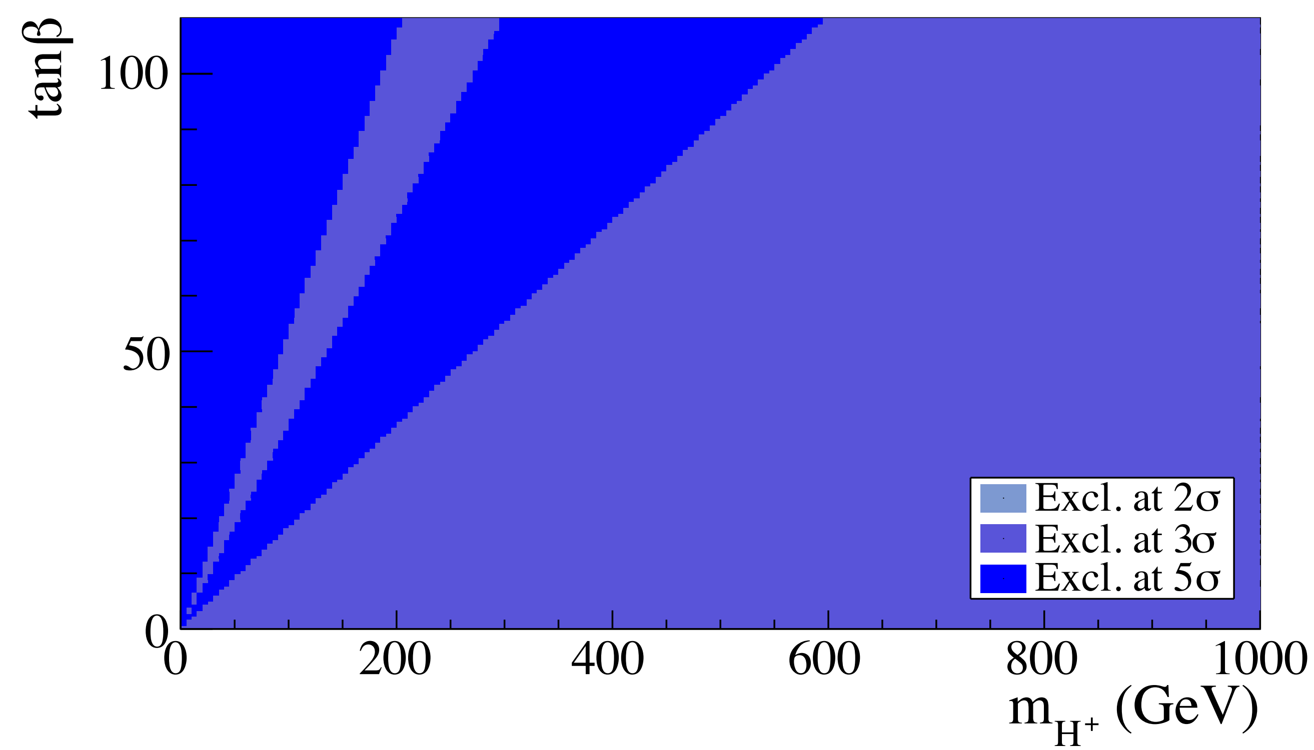
$\tan\beta/m_{H^+} = 0.75 \pm 0.04$ GeV^{-1}

Type II 2HDM

- Compatibility of $\boldsymbol{\Delta(D^{(*)}) = R(D^{(*)})_{\mathrm{exp}} - R(D^{(*)})_{\mathrm{2HDM}}}$ given by a χ^2 for each 2HDM point

$$\chi^2(\tan\beta/m_{H^+}) = (\Delta(D), \Delta(D^*)) \begin{pmatrix} \sigma^2_{\mathrm{exp}} + \sigma^2_{\mathrm{th}} & \rho\,\sigma_{\mathrm{exp}}\sigma^*{}_{\mathrm{exp}} \\ \rho\,\sigma_{\mathrm{exp}}\sigma^*{}_{\mathrm{exp}} & \sigma^*{}^2_{\mathrm{exp}} + \sigma^*{}^2_{\mathrm{th}} \end{pmatrix}^{-1} \begin{pmatrix} \Delta(D) \\ \Delta(D^*) \end{pmatrix}$$





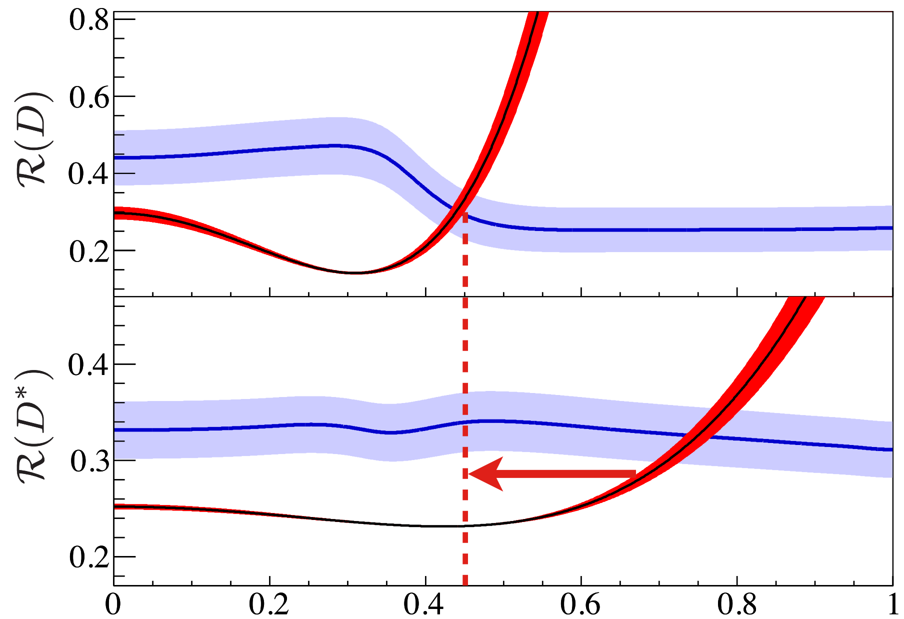
Type II 2HDM <u>excluded at 99.8%</u>, or equivalently, **<u>3.1σ</u>**

Type III 2HDM

- General **spin-0 interactions** — Datta et al, PRD 86, 034027 (2012)

$$\mathcal{H}_{\rm eff} = \frac{4G_F V_{cb}}{\sqrt{2}} \left[(\overline{c}\gamma_\mu P_L b)\,(\overline{\tau}\gamma^\mu P_L \nu_\tau) + S_R (\overline{c} P_R b)\,(\overline{\tau} P_L \nu_\tau) + S_L (\overline{c} P_L b)\,(\overline{\tau} P_L \nu_\tau) \right]$$

Type II 2HDM



$\tan\beta/m_{H^+} = \sqrt{\frac{-S_R}{m_b m_\tau}}$ (GeV^{-1}) $[S_L = 0]$

No solutions

- **R(D) - R(D*)** depend on **independent NP parameters**

$$\mathcal{R}(D) = \mathcal{R}(D)_{\rm SM} + A'_D {\rm Re}(S_R + S_L) + B'_D |S_R + S_L|^2$$

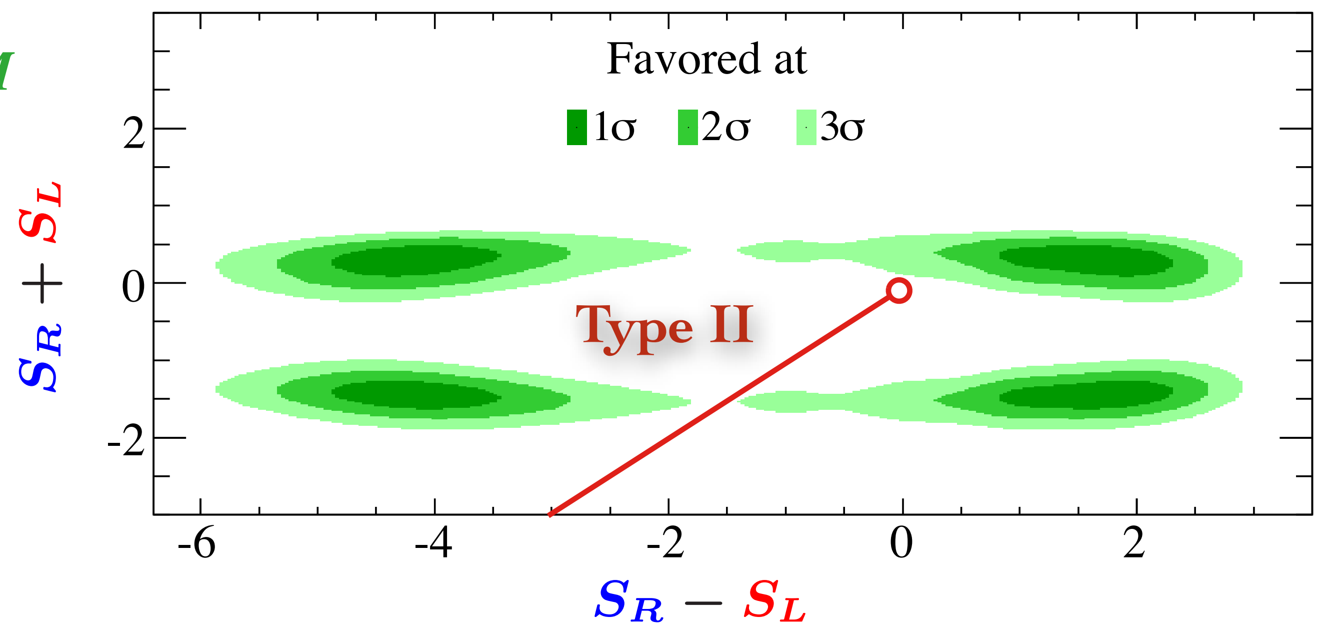
$$\mathcal{R}(D^*) = \mathcal{R}(D^*)_{\rm SM} + A'_{D^*} {\rm Re}(S_R - S_L) + B'_{D^*} |S_R - S_L|^2$$

Type III 2HDM

- General **spin-0 interactions** — **Datta et al, PRD 86, 034027 (2012)**

$$\mathcal{H}_{\rm eff} = \frac{4G_F V_{cb}}{\sqrt{2}}\left[(\bar{c}\gamma_\mu P_L b)(\bar{\tau}\gamma^\mu P_L \nu_\tau) + S_R(\bar{c}P_R b)(\bar{\tau}P_L\nu_\tau) + S_L(\bar{c}P_L b)(\bar{\tau}P_L\nu_\tau)\right]$$

Type III 2HDM



4 solutions for real S_R - S_L and more for complex values

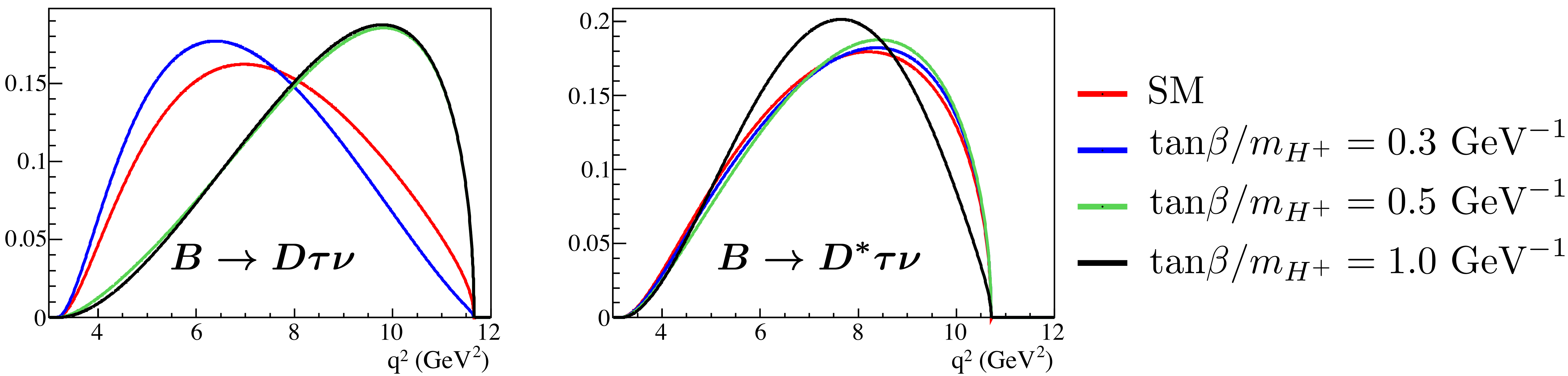
- **R(D) - R(D*)** depend on **independent NP parameters**

$$\mathcal{R}(D) = \mathcal{R}(D)_{\rm SM} + A'_D {\rm Re}(S_R + S_L) + B'_D|S_R + S_L|^2$$

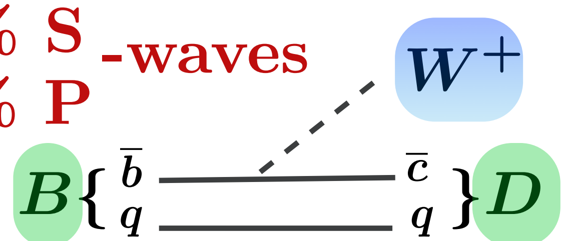
$$\mathcal{R}(D^*) = \mathcal{R}(D^*)_{\rm SM} + A'_{D^*} {\rm Re}(S_R - S_L) + B'_{D^*}|S_R - S_L|^2$$

q^2 spectra

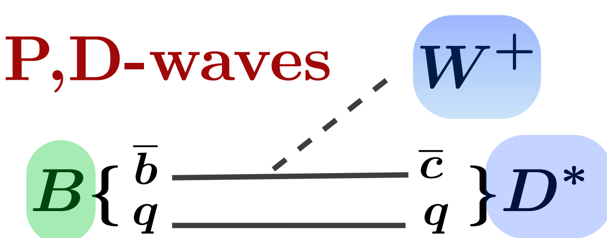
- **q^2 spectrum** impacted by $H_s^{2HDM} \approx H_s^{SM} \times \left(1 - \frac{\tan^2\beta}{m^2_{H^+}} \frac{q^2}{1 \mp m_c/m_b}\right)$



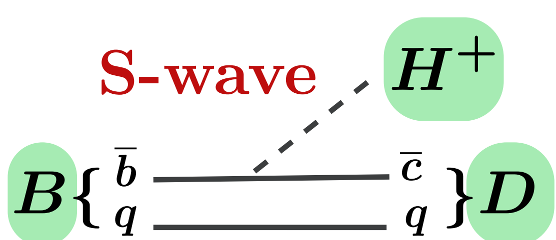
6% S -waves
94% P



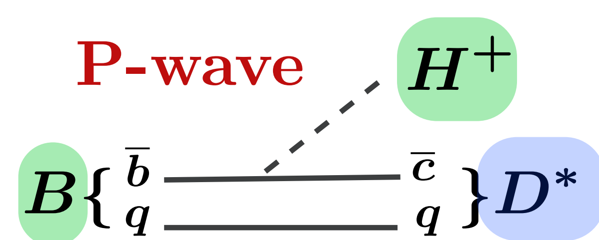
S,P,D-waves



S-wave

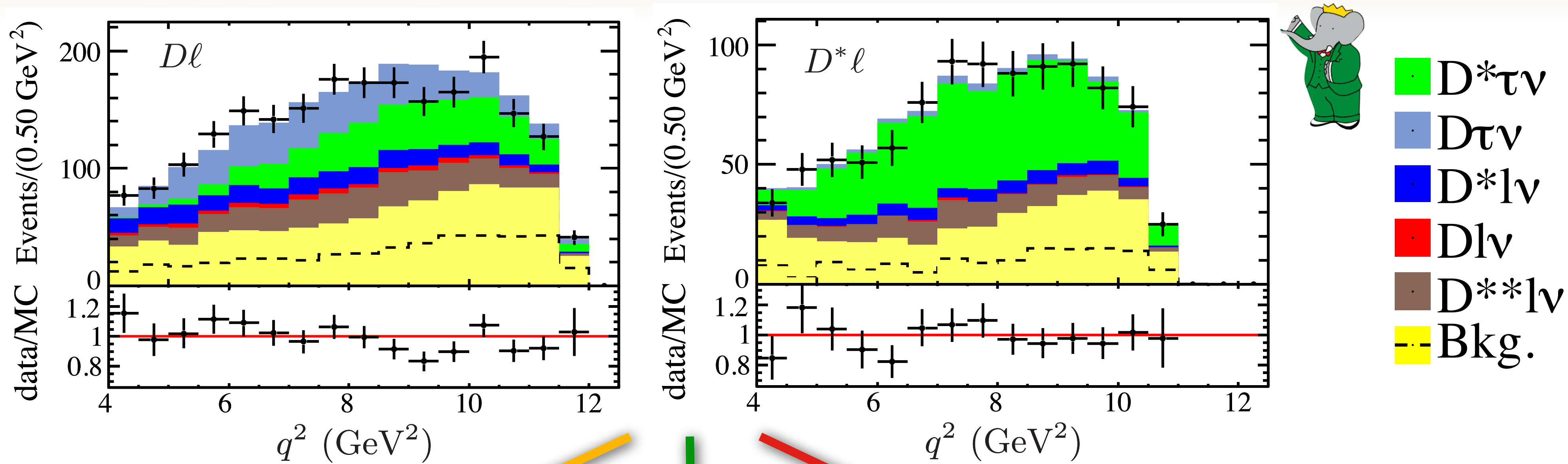


P-wave



- **P-waves** have **lower q^2 spectra,** due to p^2_D
- **B→Dτν more affected** by NP than **B→D*τν**

q^2 spectra



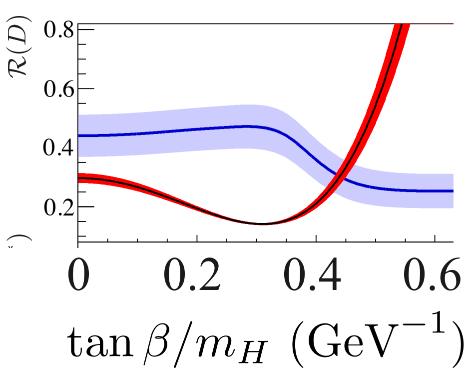
hep-ex 1303.0571

$m^2_{\text{miss}} > 1.5\ \text{GeV}^2$

SM shape

Yields from fit

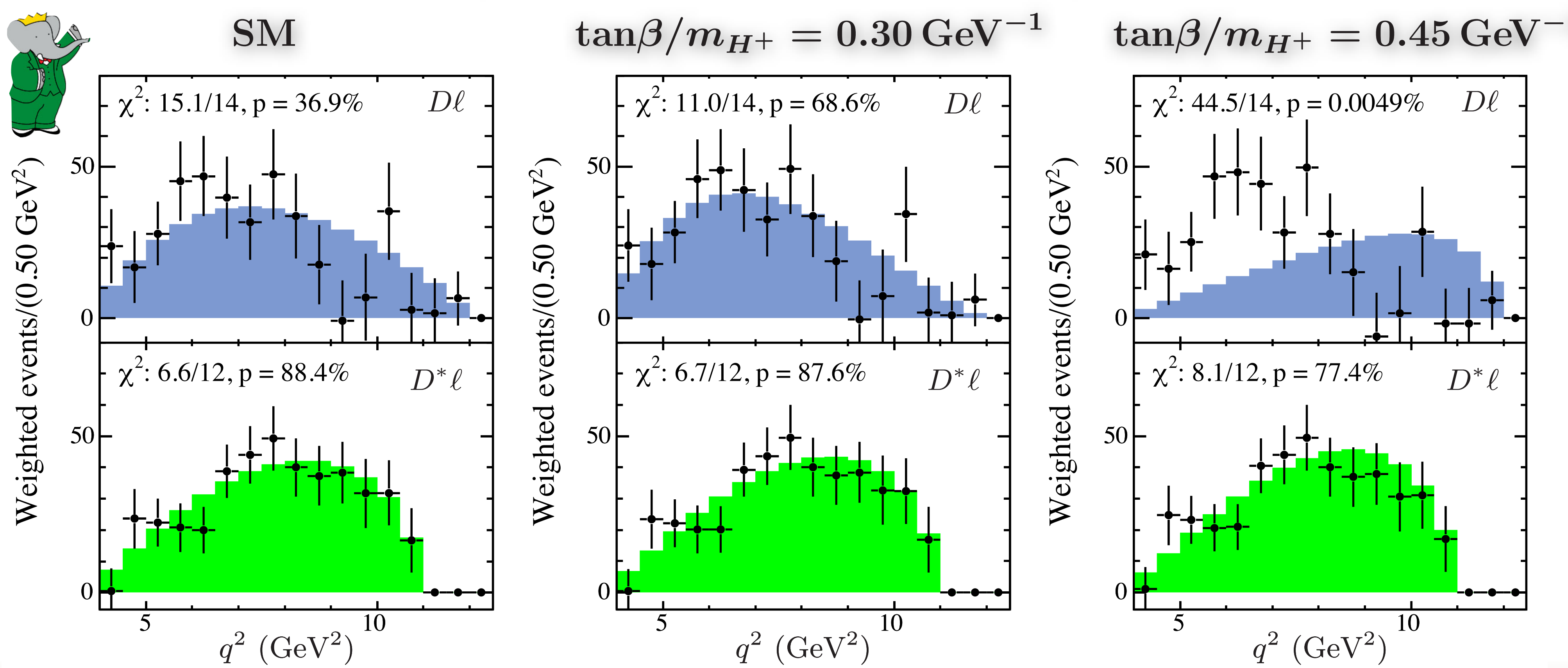
(40% over SM)



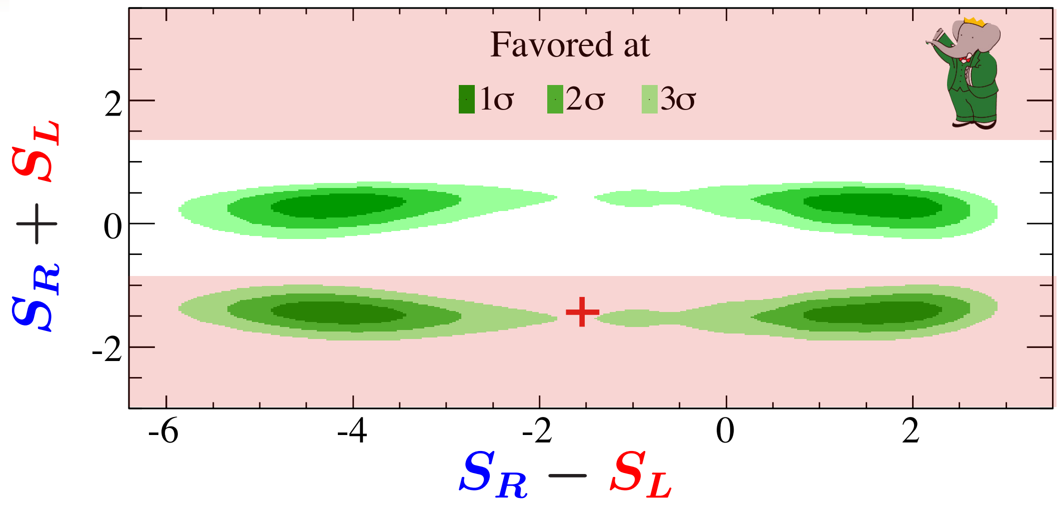
$m^2_{\text{miss}} > 1.5\ \text{GeV}^2$

Corrected for relative efficiency

Background sub.



q^2 spectra



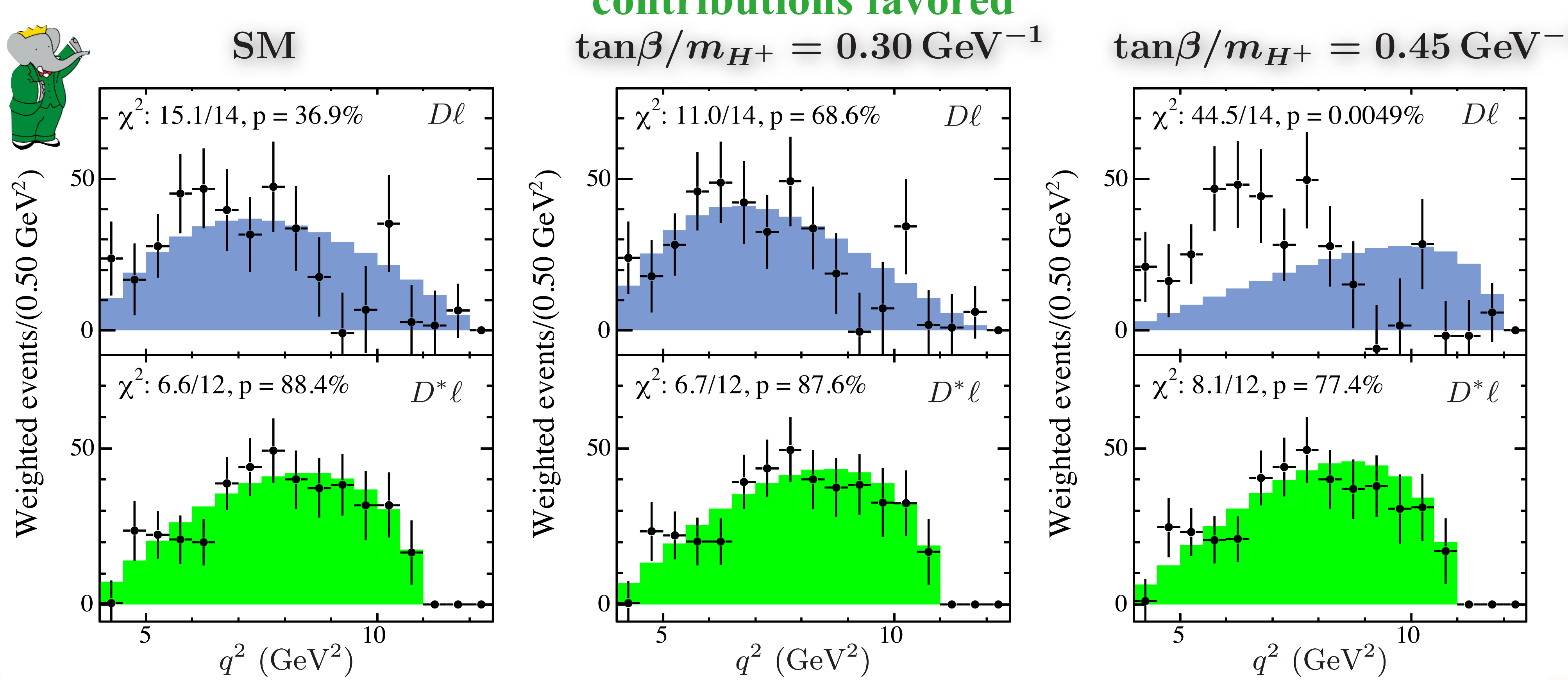
q^2 spectra excludes 2 solutions

p-values including conservative systematics

	SM	$\frac{\tan\beta}{m_{H^+}} = 0.30\ \mathrm{GeV}^{-1}$	$\frac{\tan\beta}{m_{H^+}} = 0.45\ \mathrm{GeV}^{-1}$
$\overline{B} \to D\tau^-\overline{\nu}_\tau$	83.1%	95.7%	0.4%
$\overline{B} \to D^*\tau^-\overline{\nu}_\tau$	98.8%	98.9%	97.9%

$$\left.\begin{array}{l} S_R = -m_b m_\tau \tan^2\beta / m^2_{H^+} = -1.51 \\ S_L = 0 \end{array}\right\} S_R \pm S_L = -1.51$$

Non-zero spin contributions favored



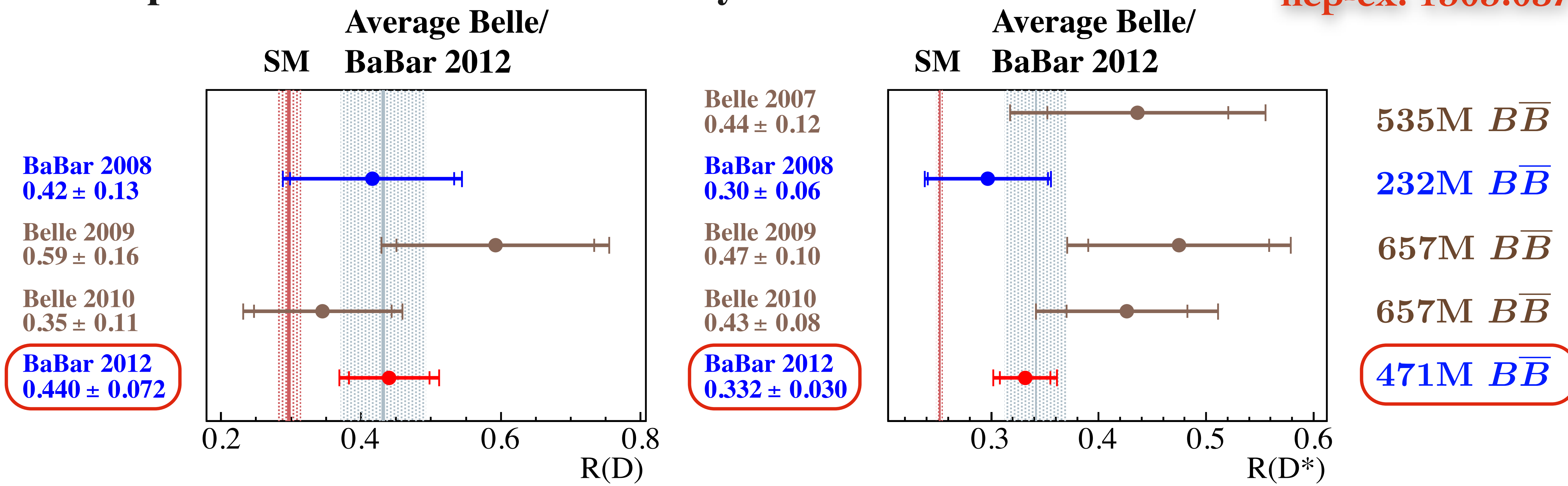
$m^2_{\mathrm{miss}} > 1.5\ \mathrm{GeV}^2$

Corrected for relative efficiency Background sub.

Summary

PRL 109, 101802 (2012)
hep-ex: 1303.0571

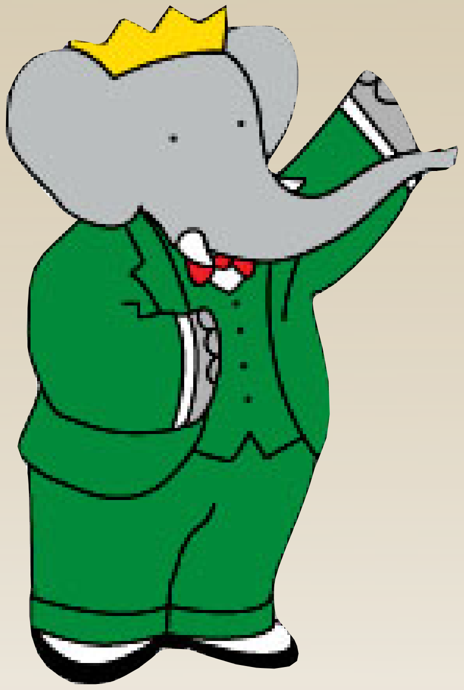
- **Improved $B \to D^{(*)}\tau\nu$ uncertainty** more than **2x**



	R(D)	R(D*)	R(D)/R(D*)	q² spectrum
SM	✗ (2.0 σ)	✗ (2.7 σ)	✗ (3.4 σ)	✓
Type II 2HDM	✓	✓	✗ (3.1 σ)	~
Type III 2HDM	✓	✓	✓	~
Non-0 spin NP	✓	✓	✓	✓

- **New Belle/BaBar** results (semileptonic tag, $\tau \to \pi\nu_\tau$) **soon: confirmation?**

Back up



Fit PDFs: Uncertainty

- In PDF estimation, **Mean Squared Error**

$$\mathbf{MSE}[\hat{\boldsymbol{p}}(\boldsymbol{X};\boldsymbol{X_i})] = E\left[\left(\hat{p}(X;X_i) - p(X)\right)^2\right]$$

- **Variance term** due to **limited** amount of **statistics**

$$\boxed{\mathbf{Var}[\hat{\boldsymbol{p}}]} = E\left[\left(\hat{p}(X) - E[\hat{p}(X)]\right)^2\right]$$

- **Bias term** due to **inadequacies** of your **model**

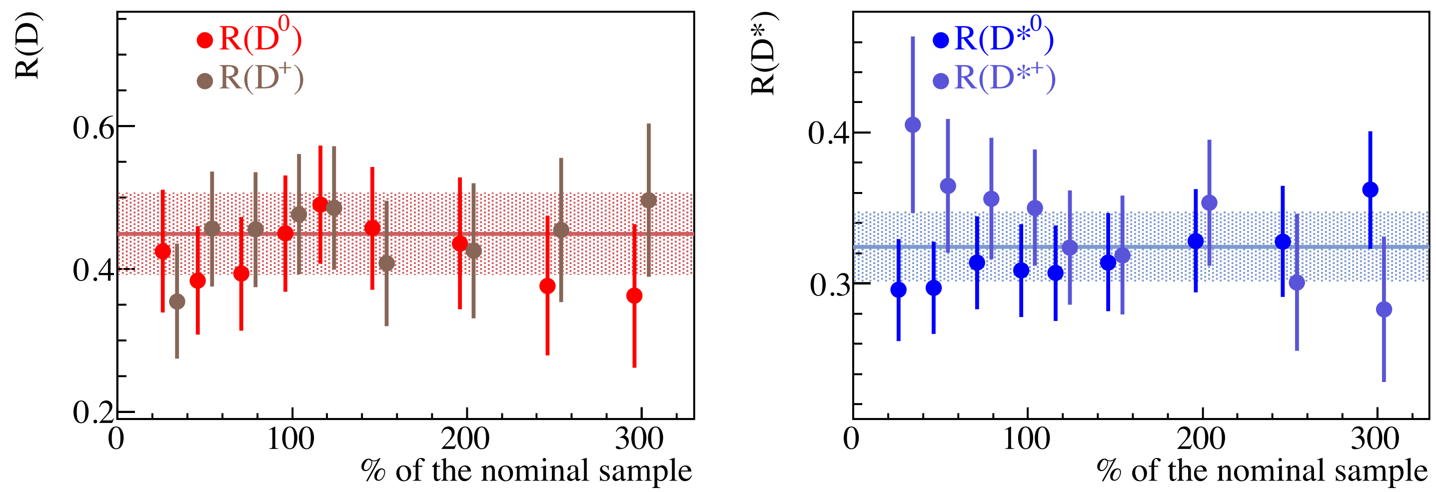
$$\boxed{\mathbf{Bias}[\hat{\boldsymbol{p}}]} = E\left[\hat{p}(X)\right] - p(X)$$

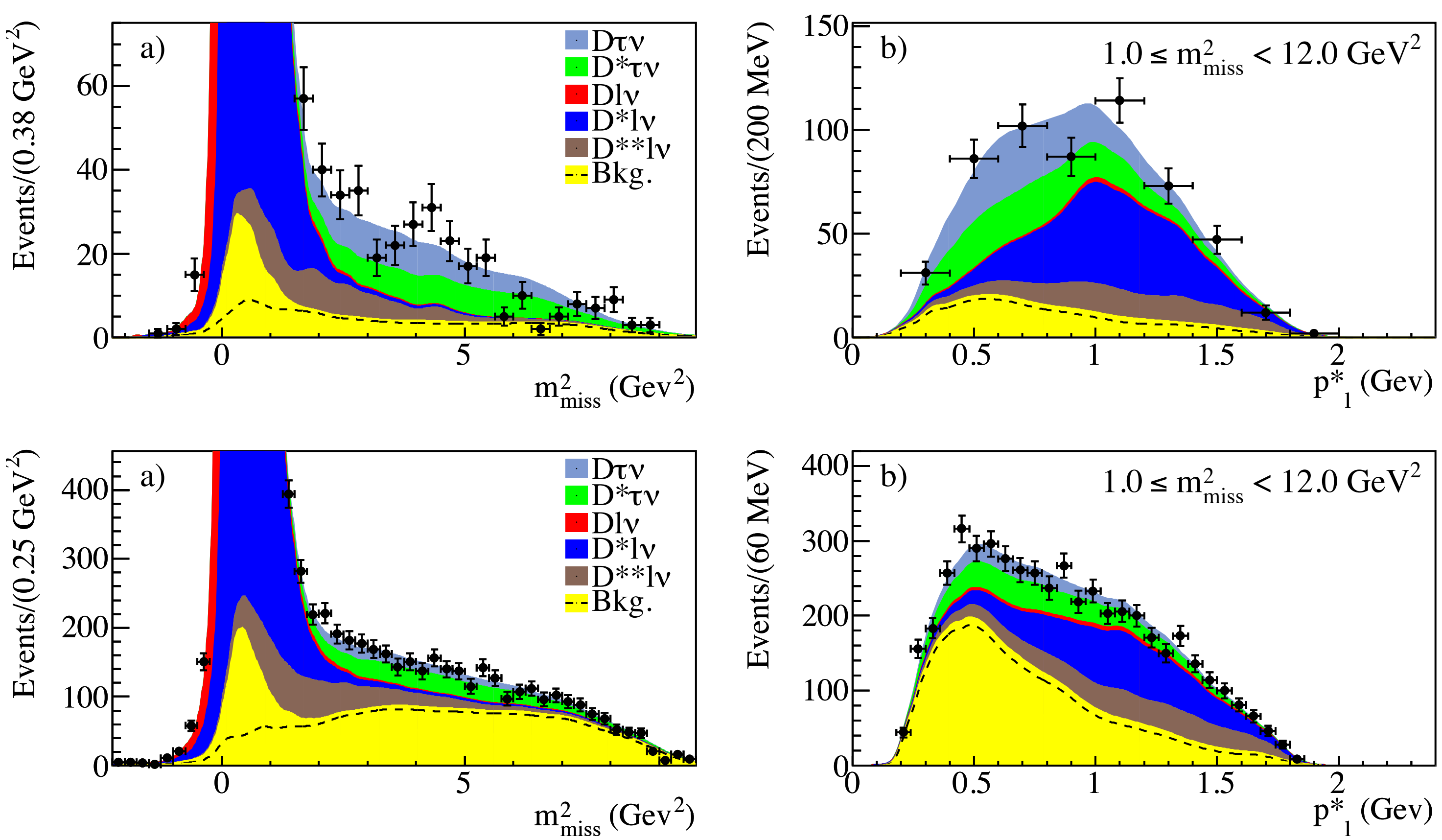
  - Difficult to estimate

- With **non-parametric, easy to trade Bias for Variance**
  - Estimate **Variance** with **Bootstrap algorithm**

Stability checks

- **Results consistent** for large **variations** of **BDT requirements**





Fit to 30% sample

$R(D^0) = 0.42 \pm 0.09$

$S/B = 1.3$

Fit to 100% sample (nominal)

$R(D^0) = 0.43 \pm 0.08$

$S/B = 0.8$

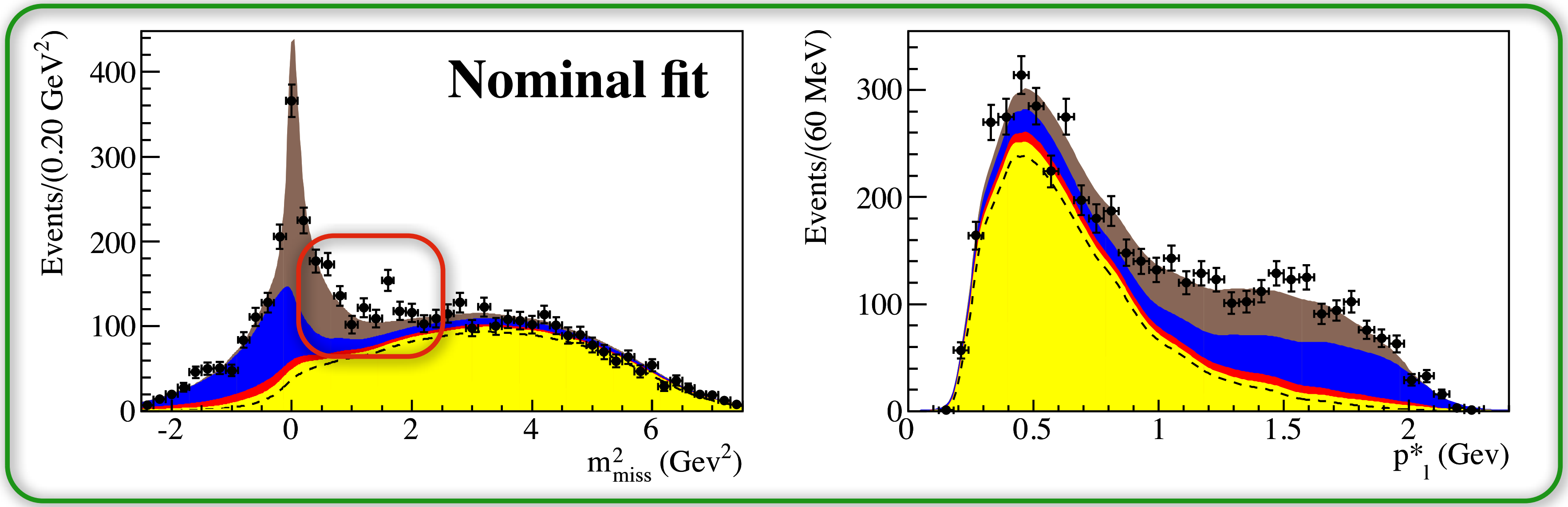
Fit to 300% sample

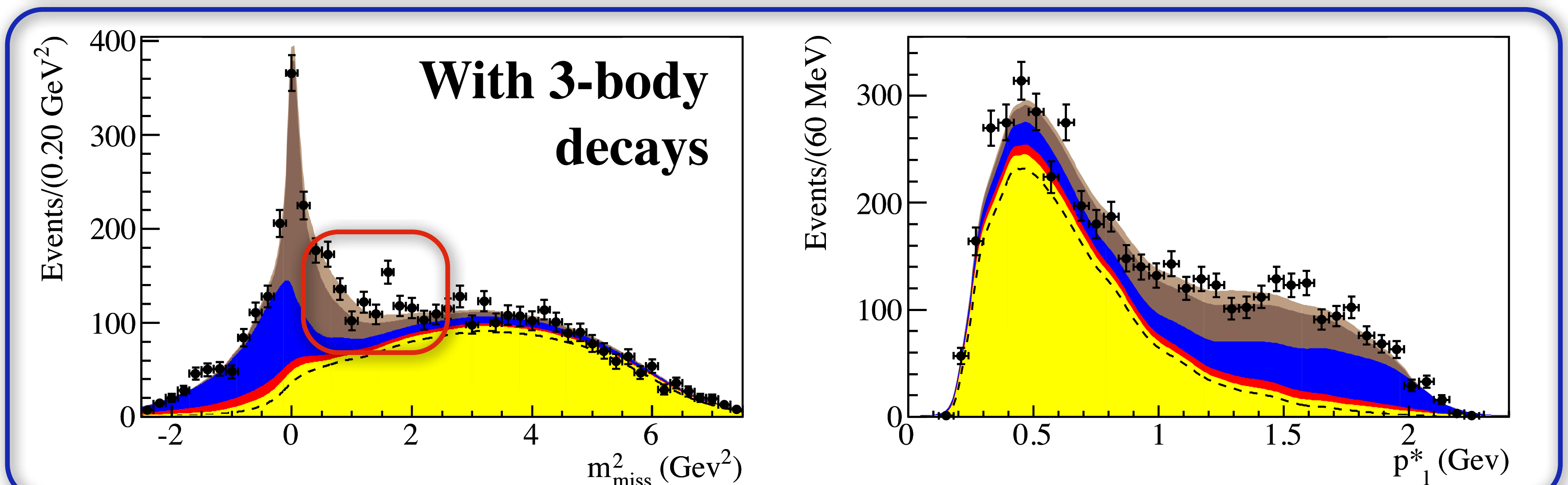
$R(D^0) = 0.35 \pm 0.10$

$S/B = 0.3$

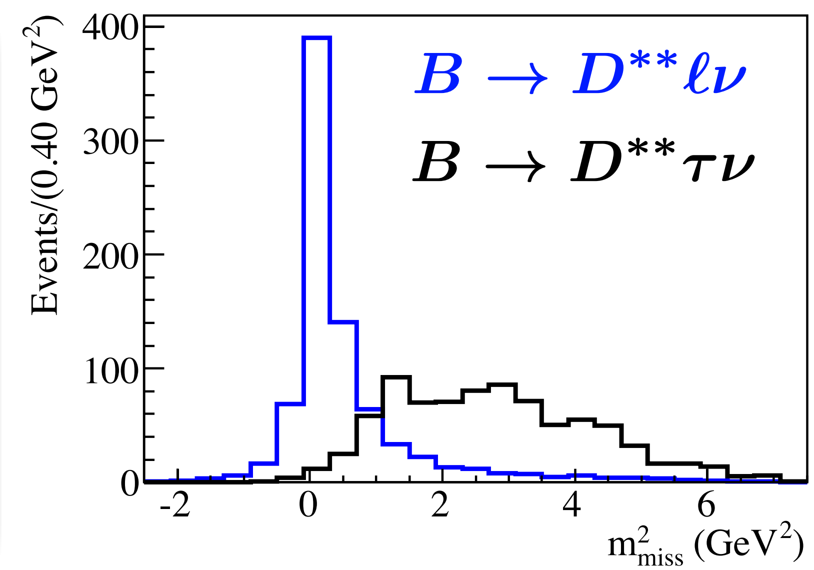
Systematic uncertainties

- **Largest uncertainty** due to **B→D**(ℓ/τ)ν background**
- **Peaks** are **well described**
  - **Some excess** at m^2_{miss} ~ 1-2 GeV^2





50% uncert. on **B→D**τν**



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

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

Systematics on q^2