$B \to X\tau\bar{\nu}_\tau$

Challenges and Prospects

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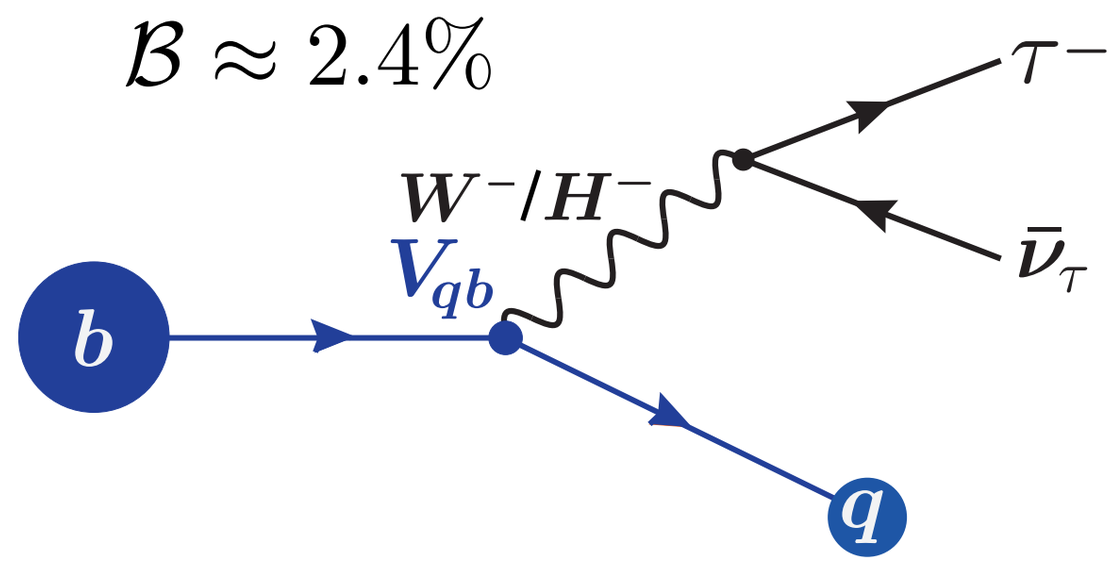
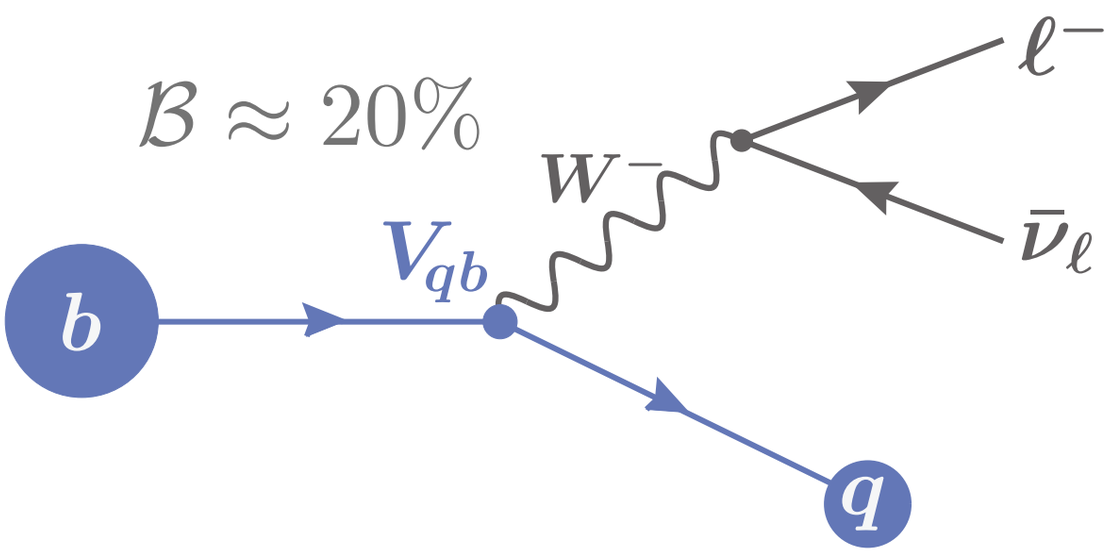
a Fantastic B: Semileptonic decays with τ





Observable of choice:

$$R = \frac{b \to q\,\tau\bar{\nu}_\tau}{b \to q\,\ell\bar{\nu}_\ell} \qquad \ell = e, \mu$$

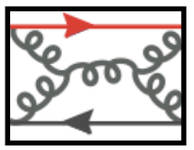
$$\downarrow$$

$$R(D^{(*)}, \pi, J/\psi)$$

Benefits:

- Experimental systematics **cancel in ratio**
- Theory uncertainties **cancel in ratio**

QCD:

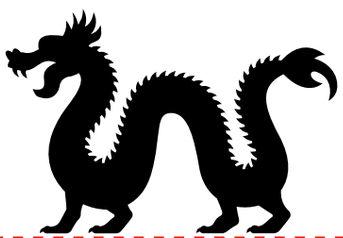


a Fantastic B: Semileptonic decays with τ

Two aspects:

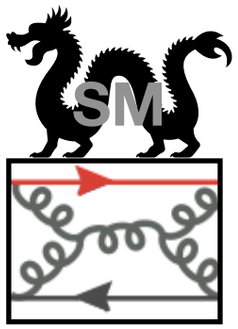
1) Precise determination of R

Need **excellent understanding** of semileptonic background decays



2) Precise prediction of R in the SM

Interplay of **theory** and **experiment** to measure non-perturbative dynamics



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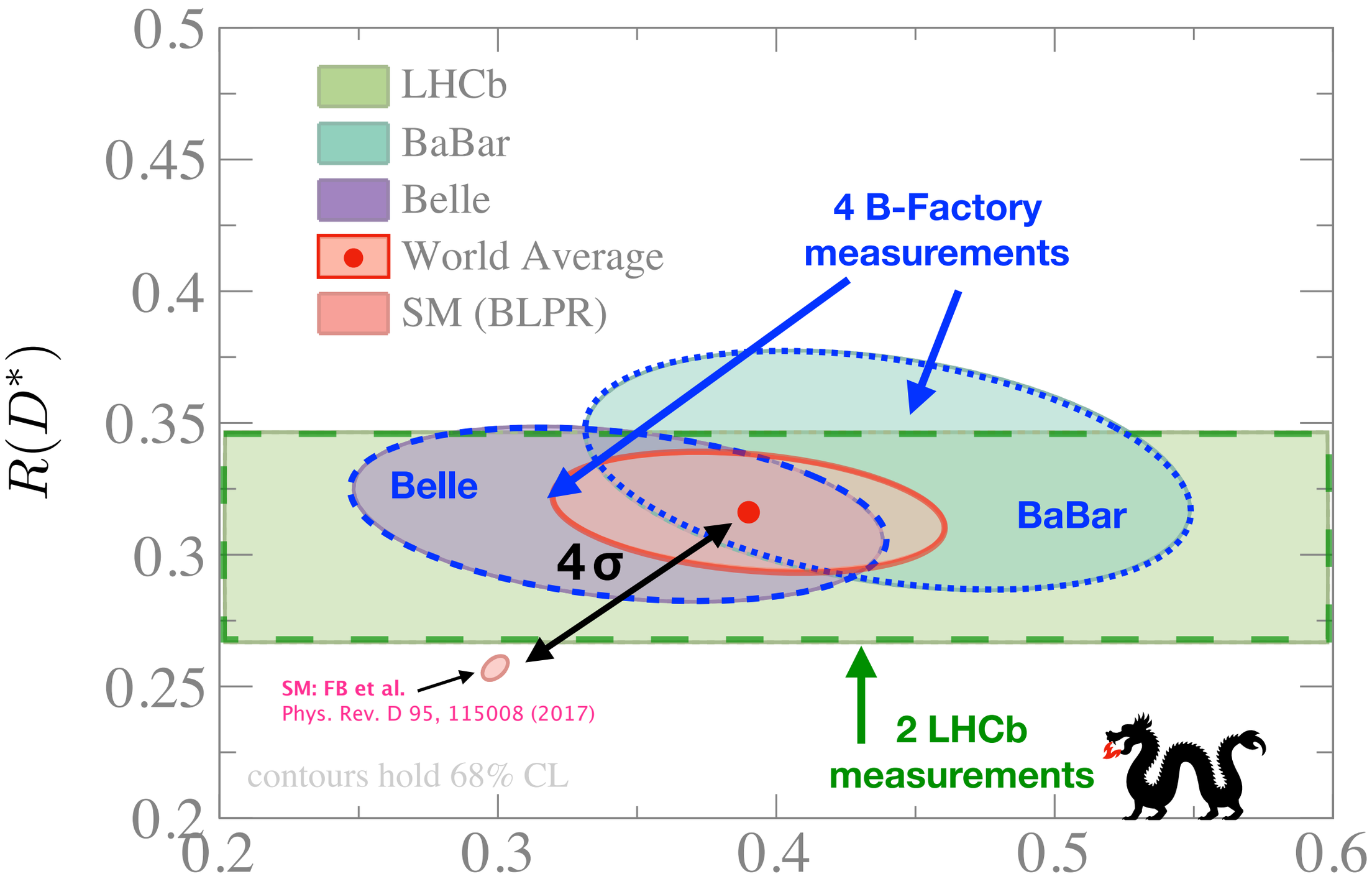
$$R(D^{(*)}, \pi, J/\psi)$$

Experimentally most important:

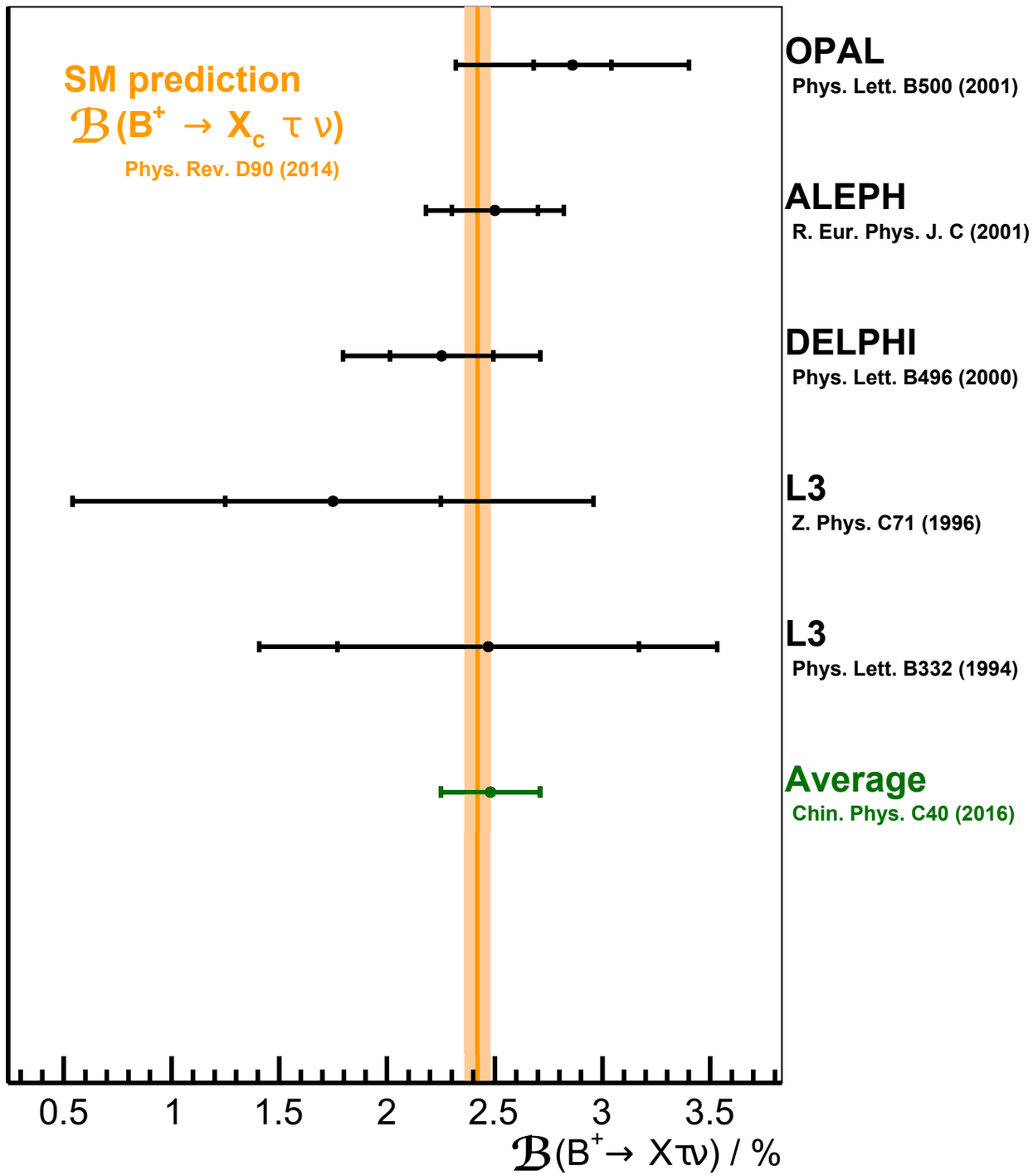
	D	D^*
Wave function	$\langle c\bar{q}\rangle \uparrow\downarrow$	$\langle c\bar{q}\rangle \uparrow\uparrow$

spin configuration



$$R(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\bar{\nu}_\tau)}{\mathcal{B}(B \to D^{(*)}\ell\bar{\nu}_\ell)}$$

Why measure $B \to X\tau\bar{\nu}_\tau$?



No one has measured it for ~ 18 years; no measurement from the B-factories

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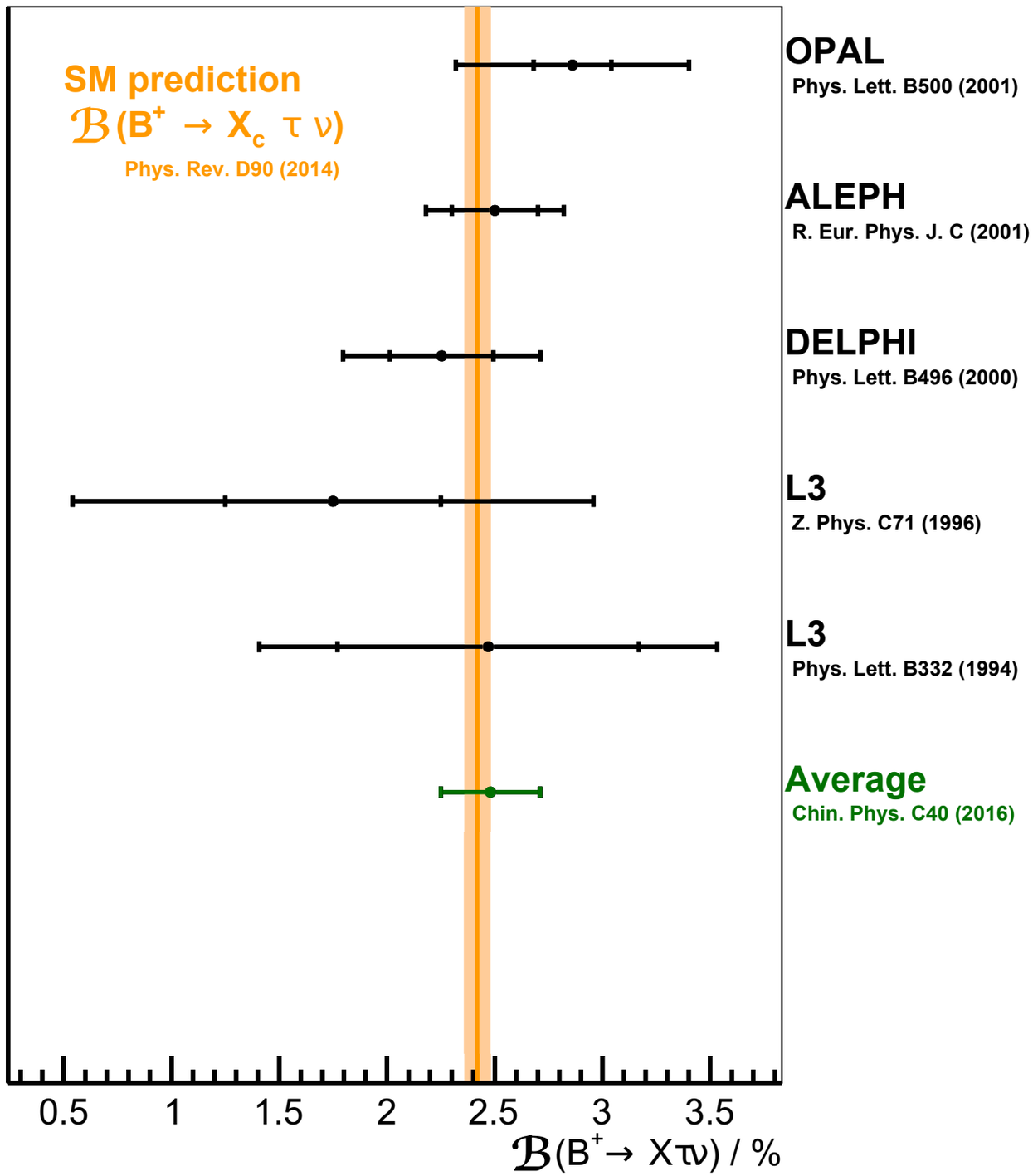

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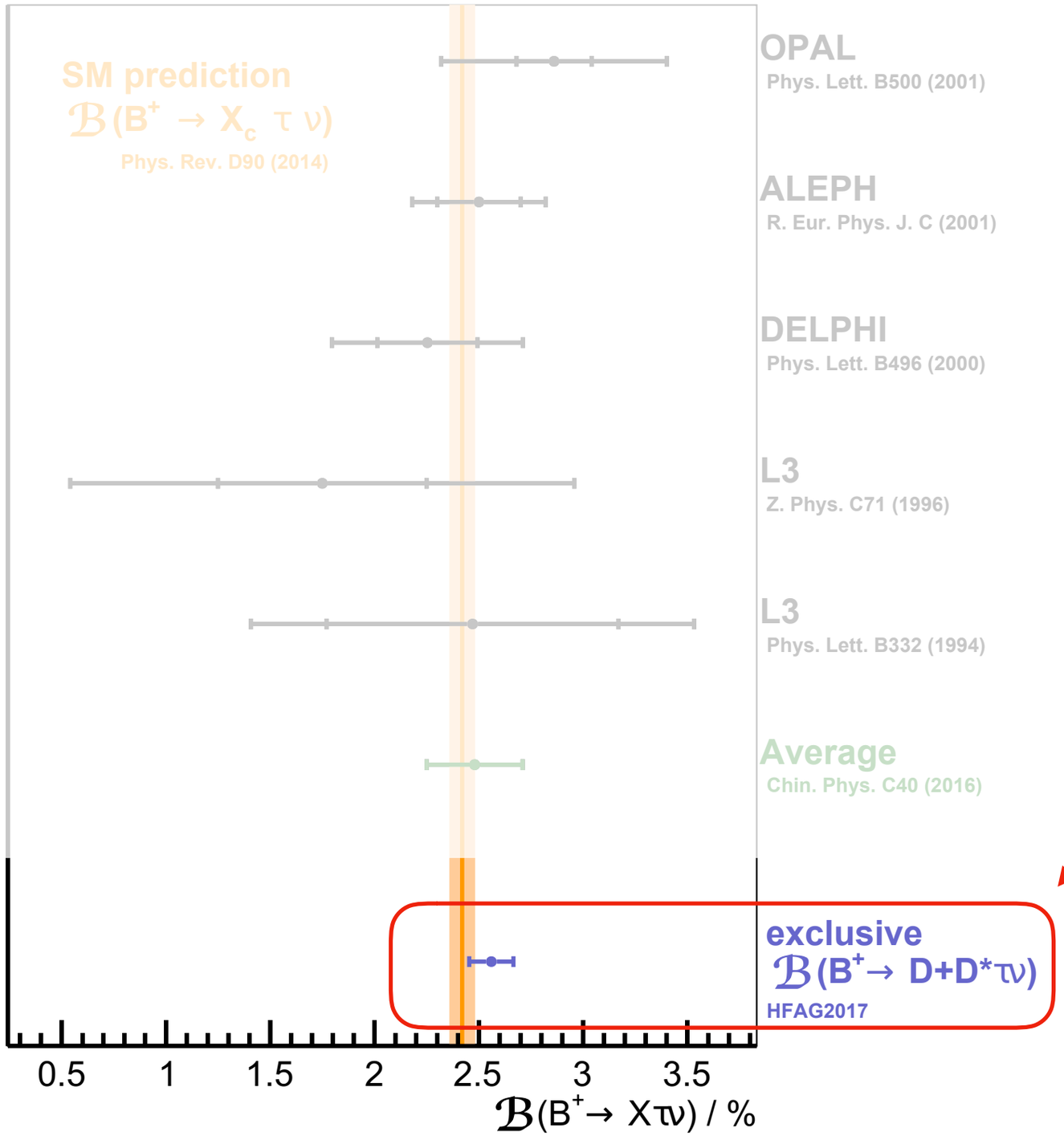


No one has measured it for ~ 18 years; no measurement from the B-factories

R(D) and R(D*) saturate the predicted inclusive rate, so no D contributions?**

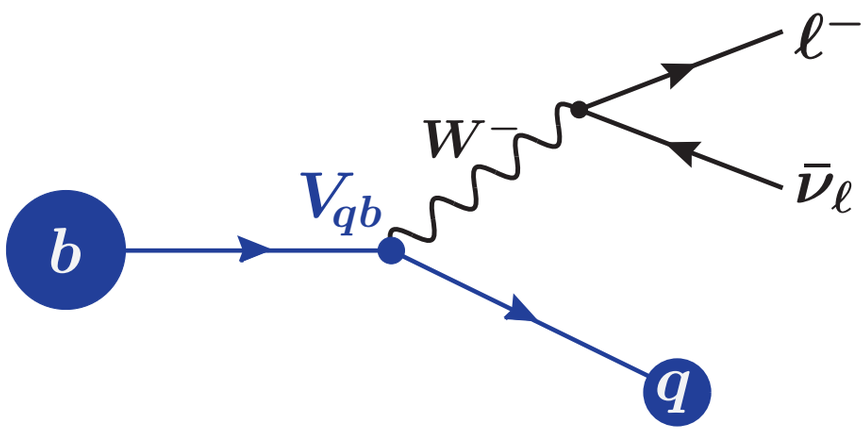
Experimental aspects

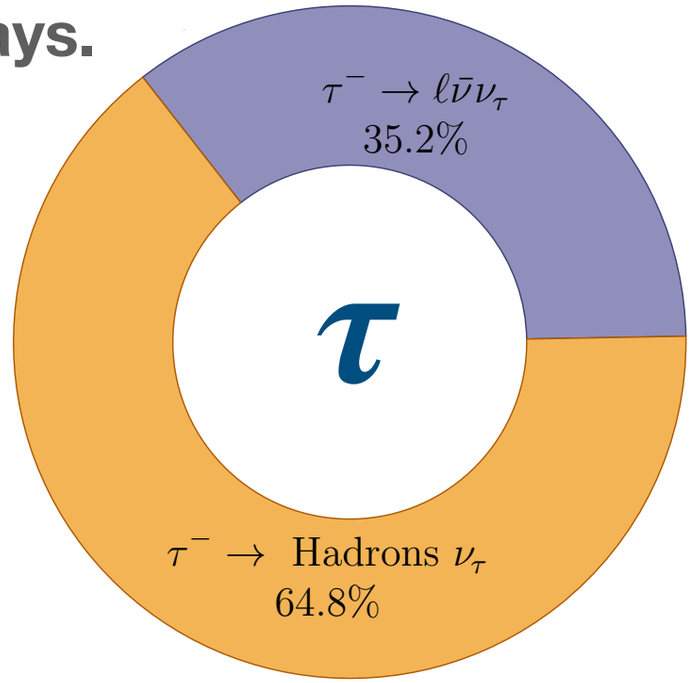
$$\frac{\mathcal{B}(B \to D^{(*)}\tau\bar{\nu}_\tau)}{\mathcal{B}(B \to D^{(*)}\ell\bar{\nu}_\ell)}$$

$\ell = e, \mu$

1. Leptonic or Hadronic τ decays?

Some properties (e.g. τ **polarisation**) **only accessible** in **hadronic decays.**





2. Albeit not necessarily a rare decay of O(%) in BF, difficult to separate from normalisation and backgrounds

LHCb: **Isolation** criteria, **displacement** of $D^{(*)}$ and τ, **kinematics**

B-Factories: Full reconstruction of event (**Tagging**), **matching topology, kinematics**

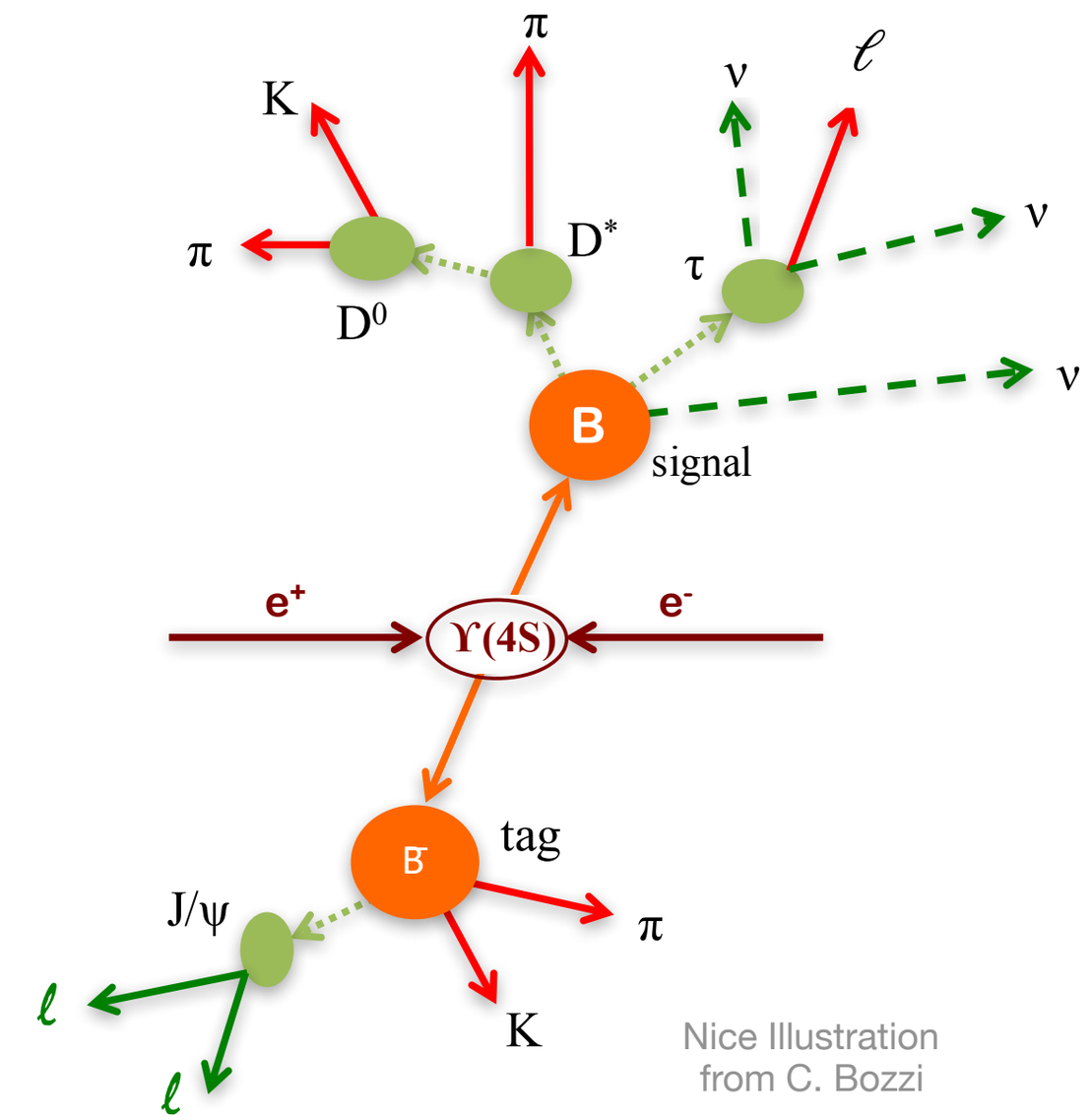
How does one measure R(D/D*) at a B-factory?

Tagging approach in a nut-shell:

- e^+/e^- collision produces ***Y(4S)*** → ***B$\bar{B}$***
- Fully reconstruct one of the two B-mesons ('tag') → **possible** to measure **momentum** of signal B
- **Missing four-momentum (neutrinos)** can be reconstructed with high precision

$$p_{\mathrm{miss}} = (p_{\mathrm{beam}} - p_{B\mathrm{tag}} - p_{D^{(*)}} - p_{\ell})$$

✓ **Small efficiency (~0.2-0.4%) compensated by large integrated luminosity**



Nice Illustration from C. Bozzi

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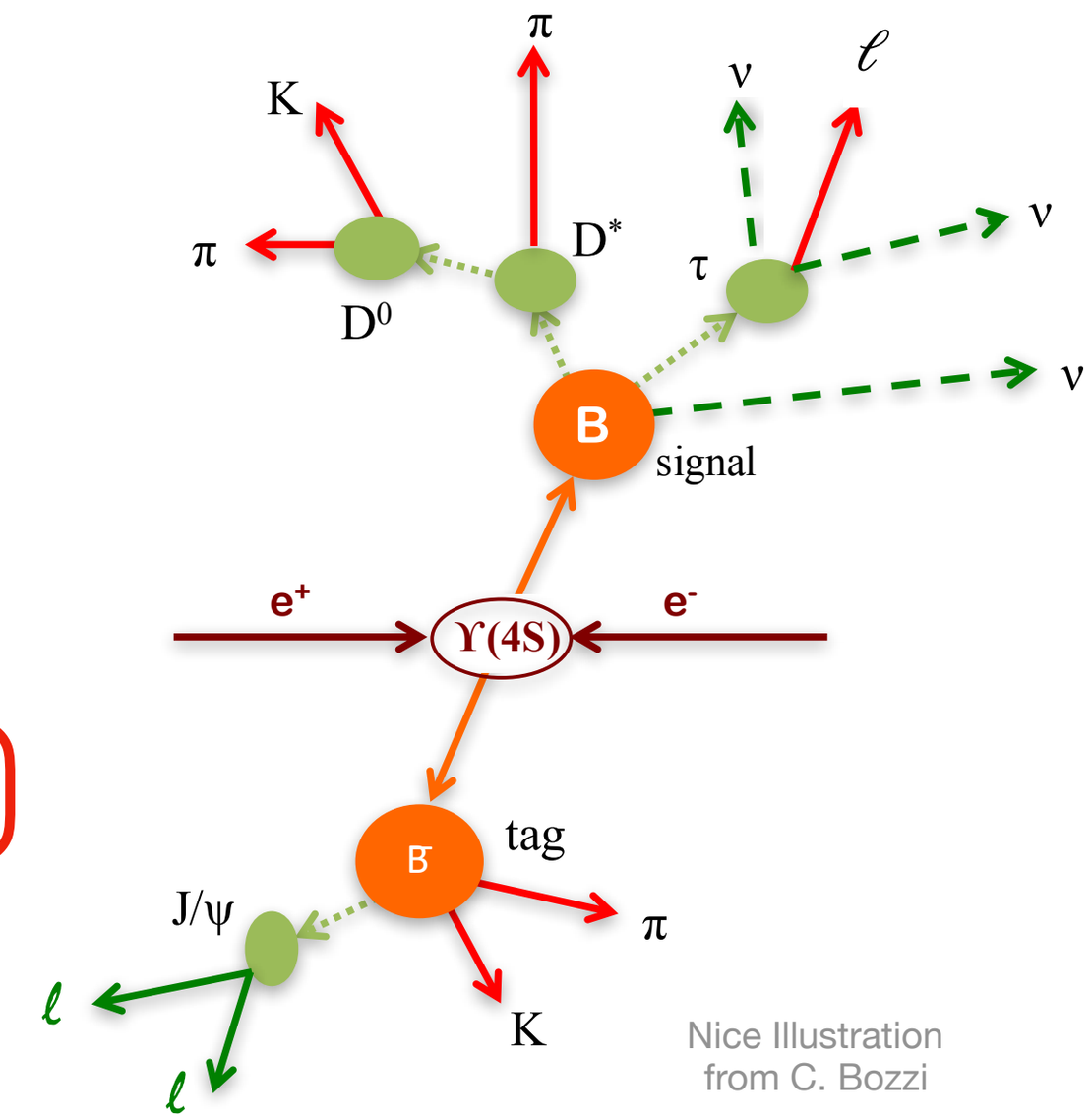

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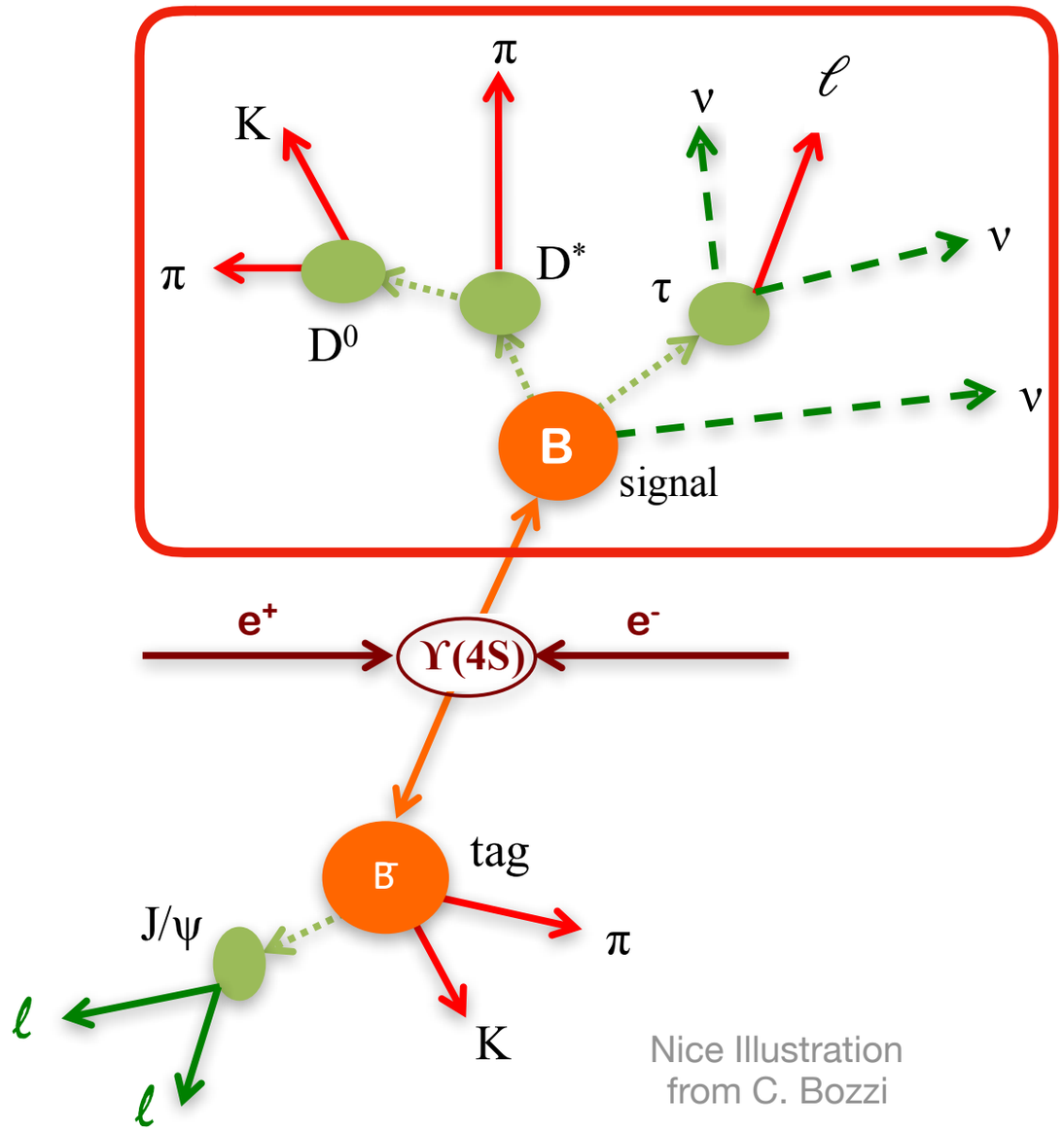
~~✓ Demand matching topology~~



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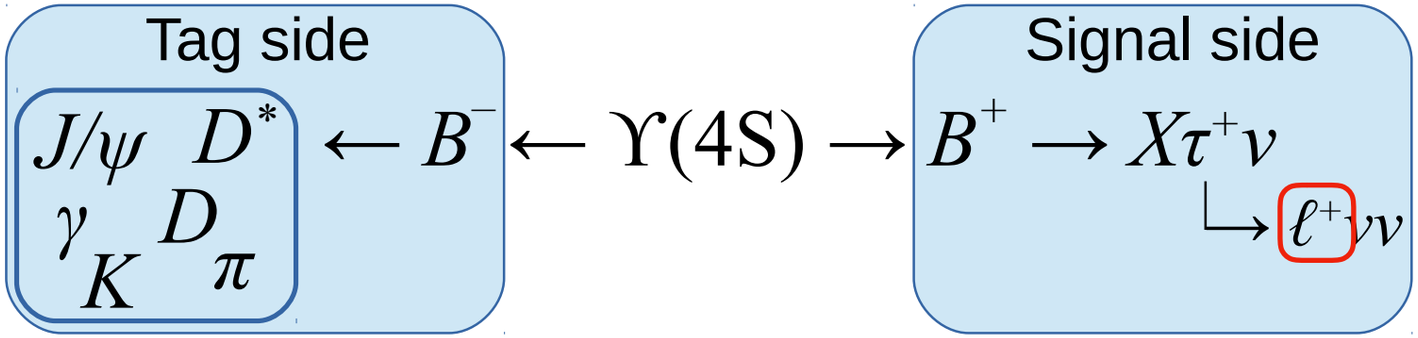
Measurement by Belle (PhD thesis Jan Hasenbusch, Uni Bonn)

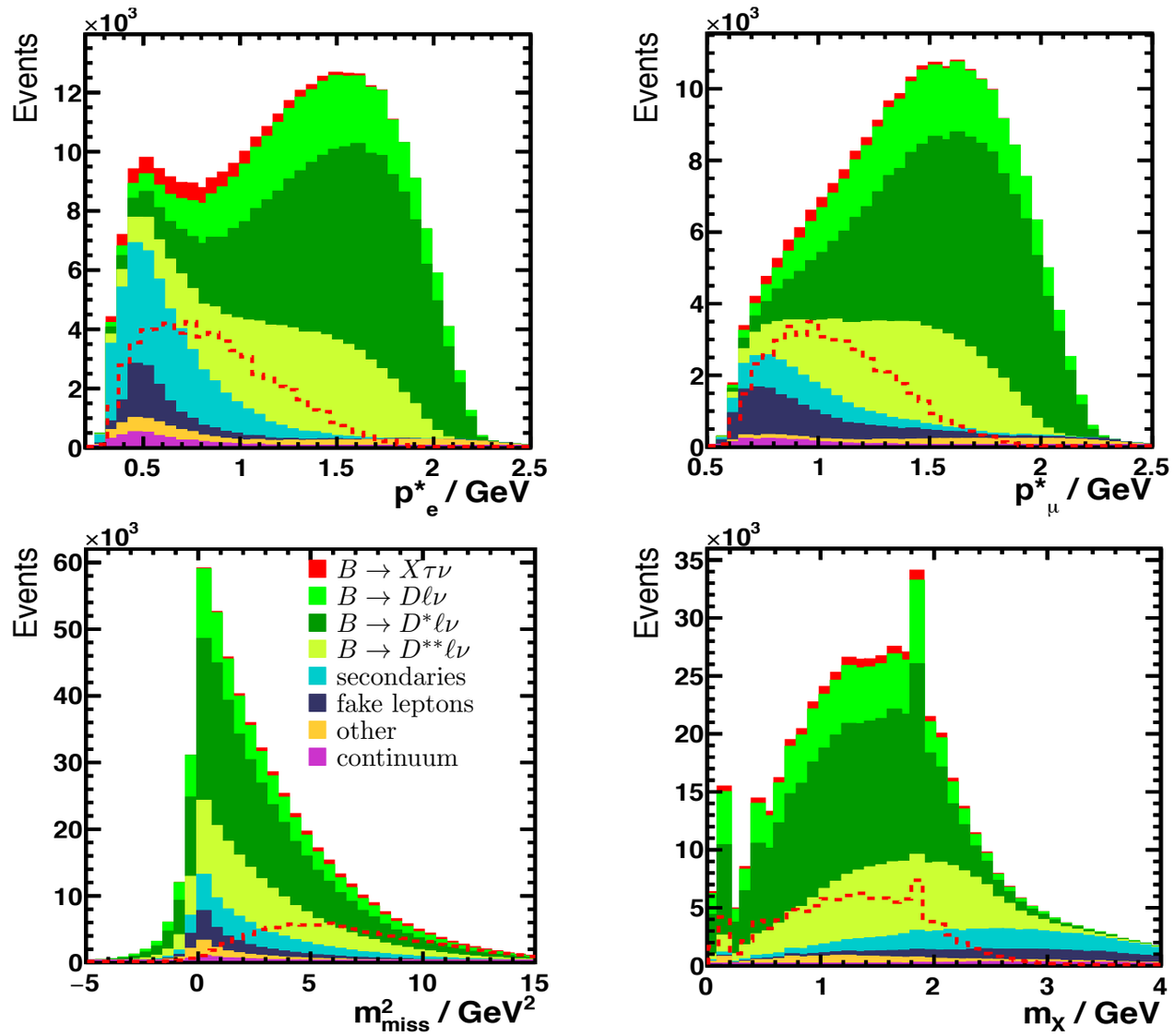
FR (pre-FEI)



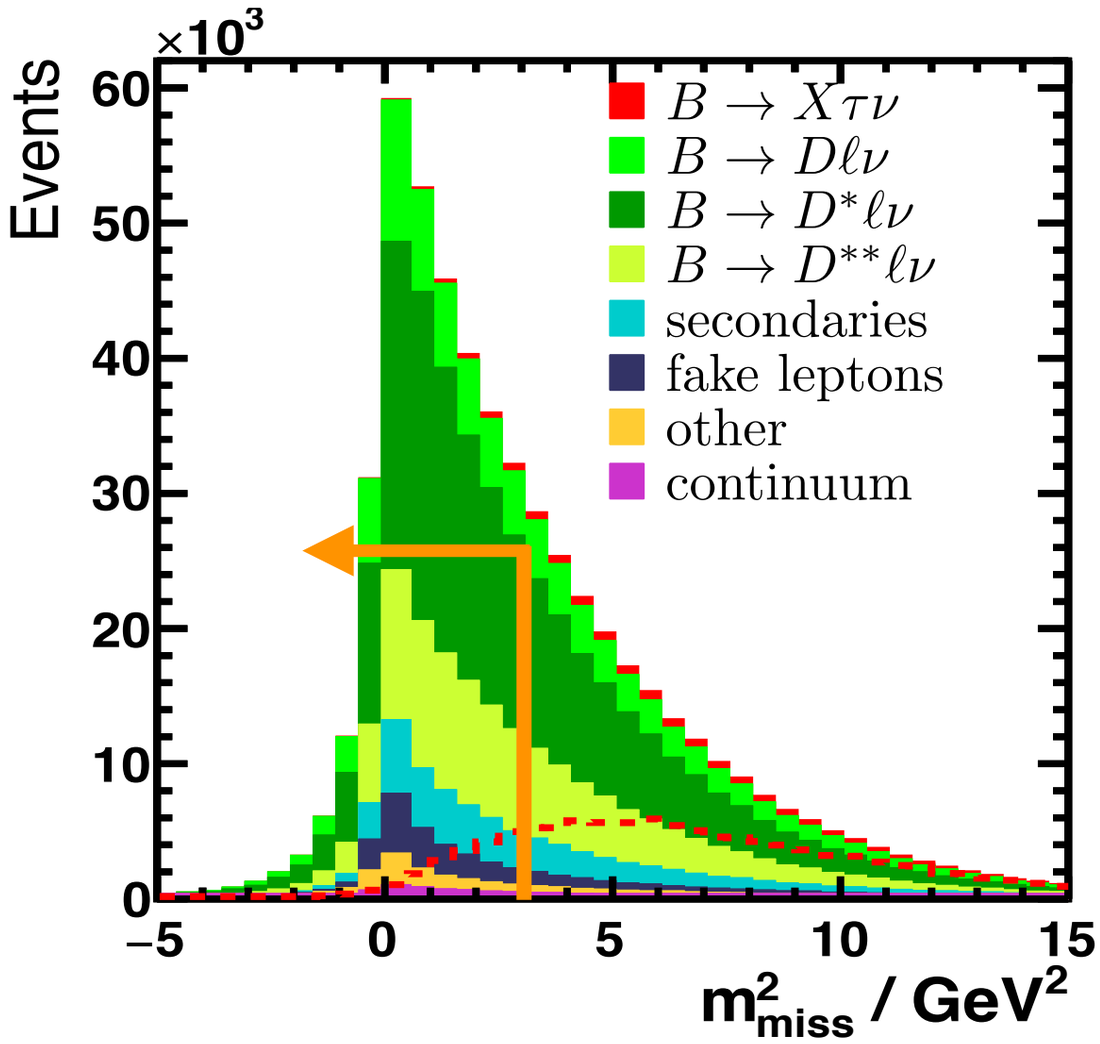
Cuts:

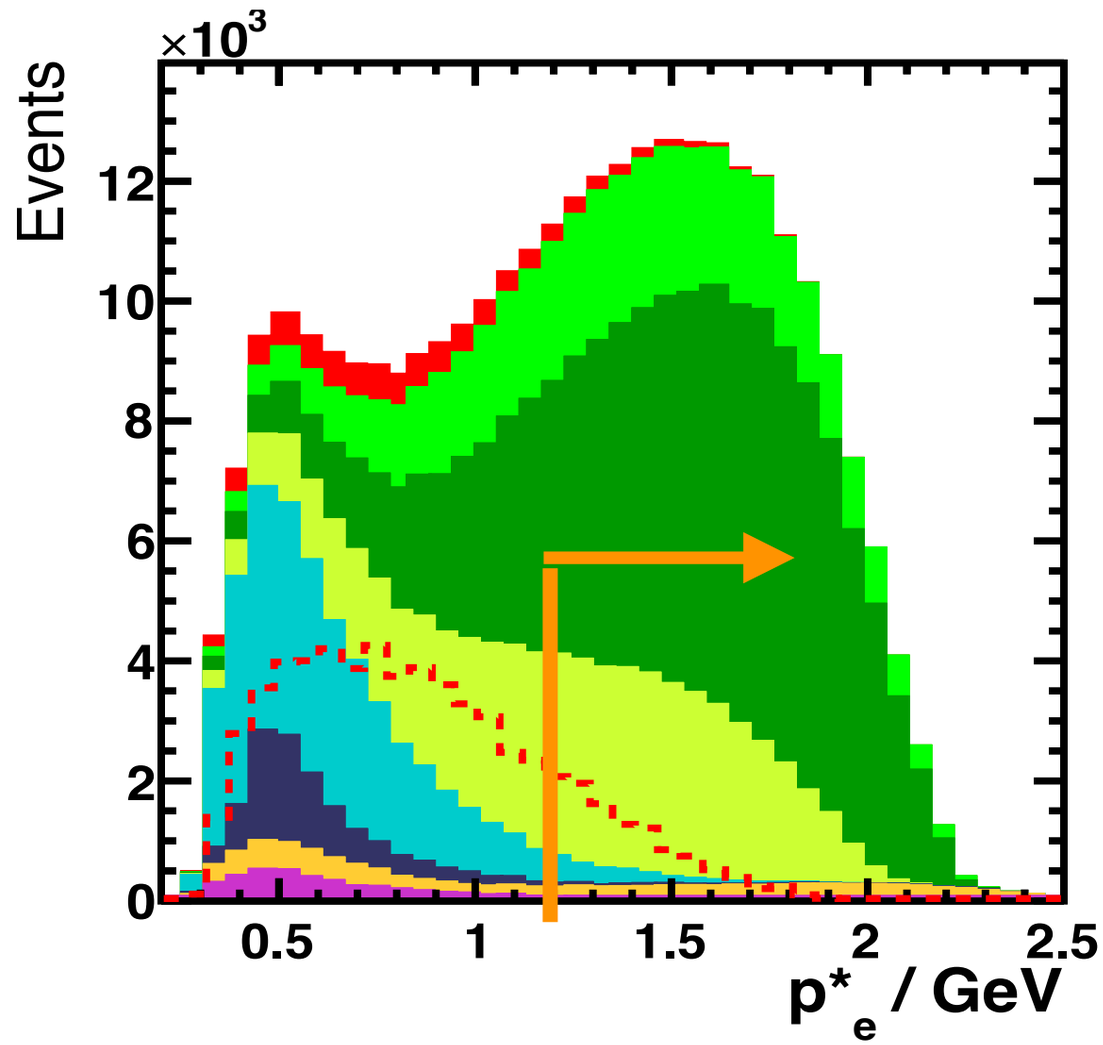
- lepton ID
- lepton charge correlation with Btag candidates (this rejects mixed events in case of neutral Btags)
- build X from left-over clusters and tracks on signal side
  - reject curlers and clean up ROE

$$m^2_{\mathrm{miss}} = p^2_{\mathrm{miss}} = \left(p^{\mu}_{e^+e^-} - p^{\mu}_{\mathrm{visible}}\right)^2 .$$



Sidebands and troubles





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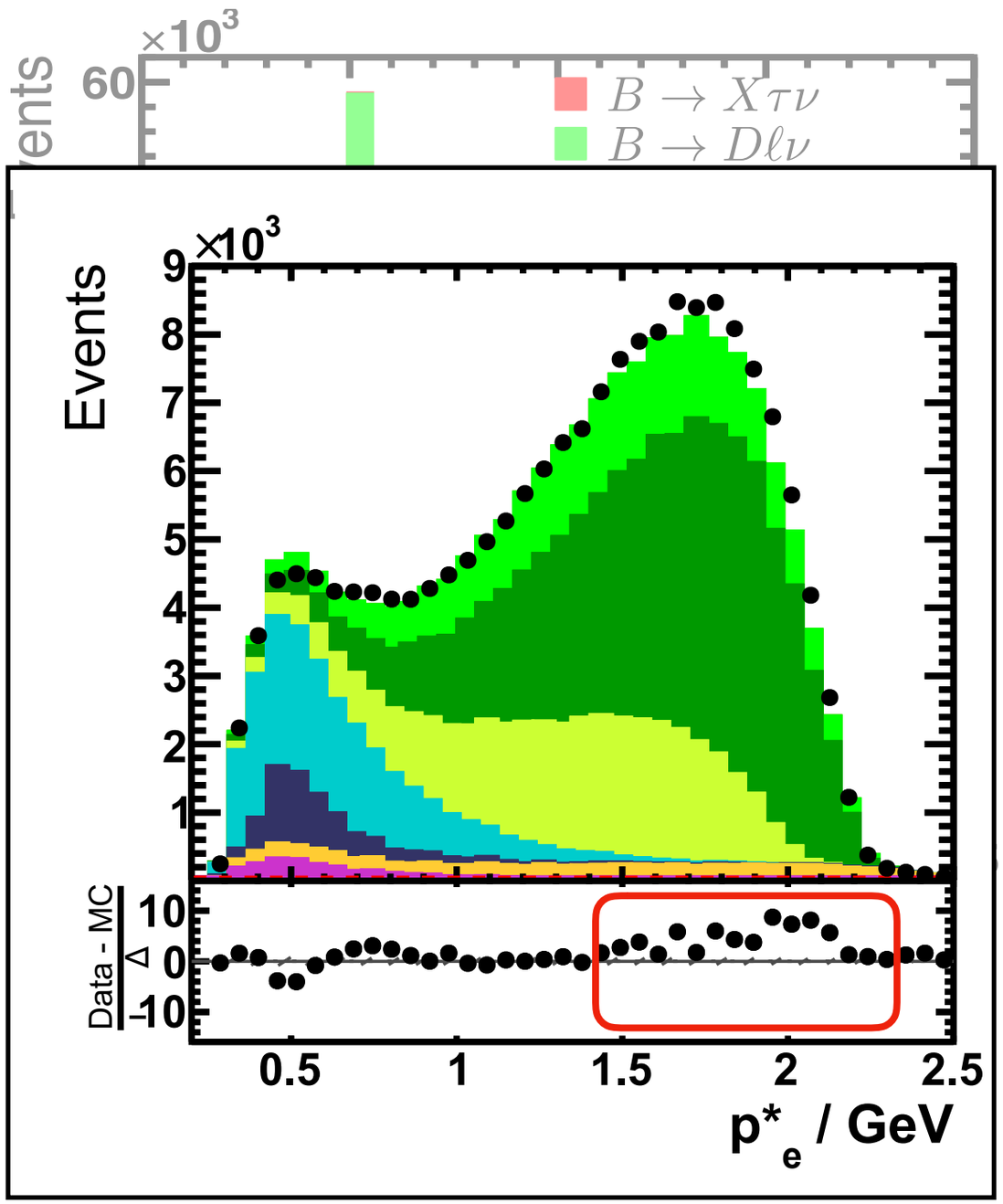
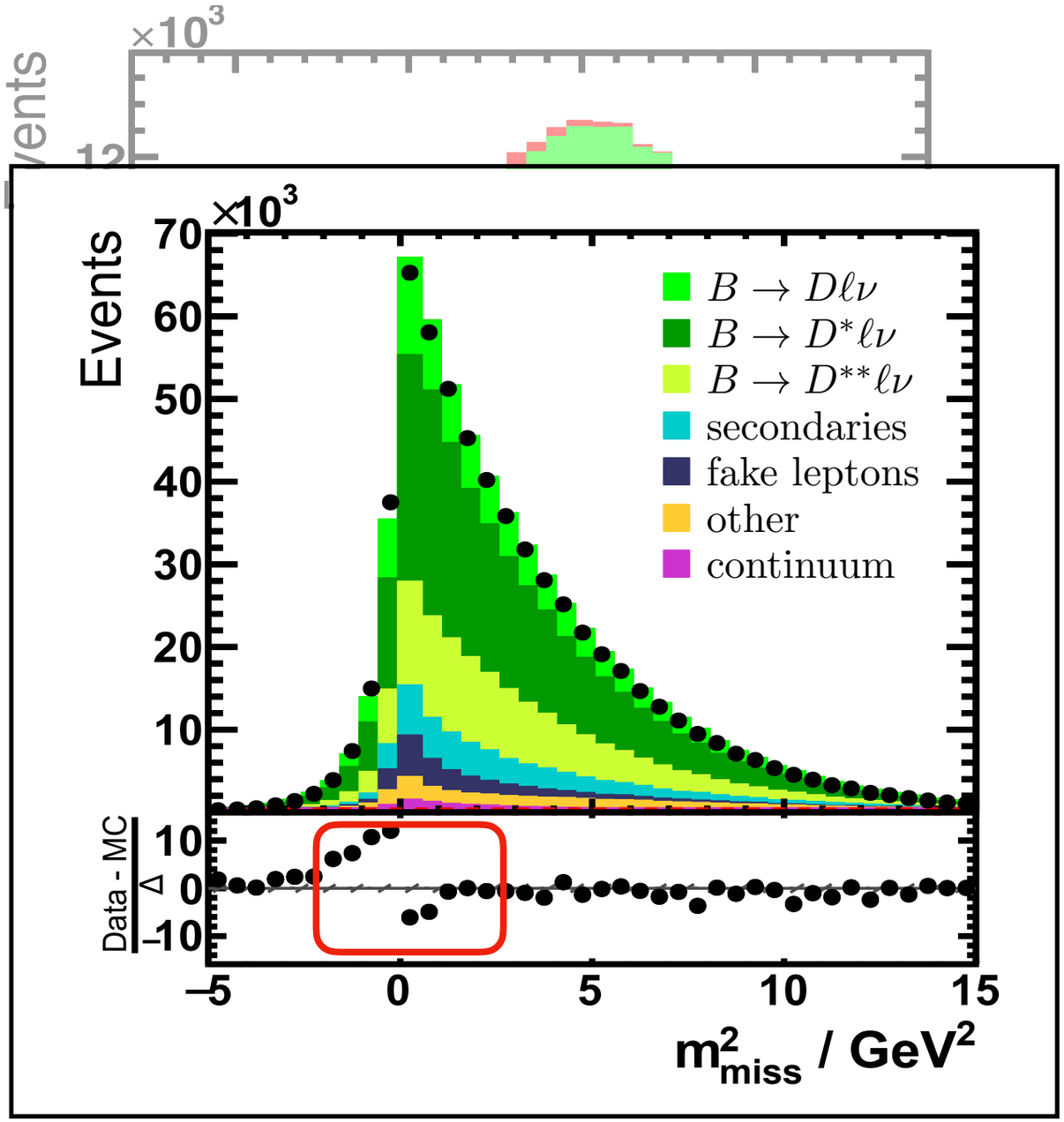




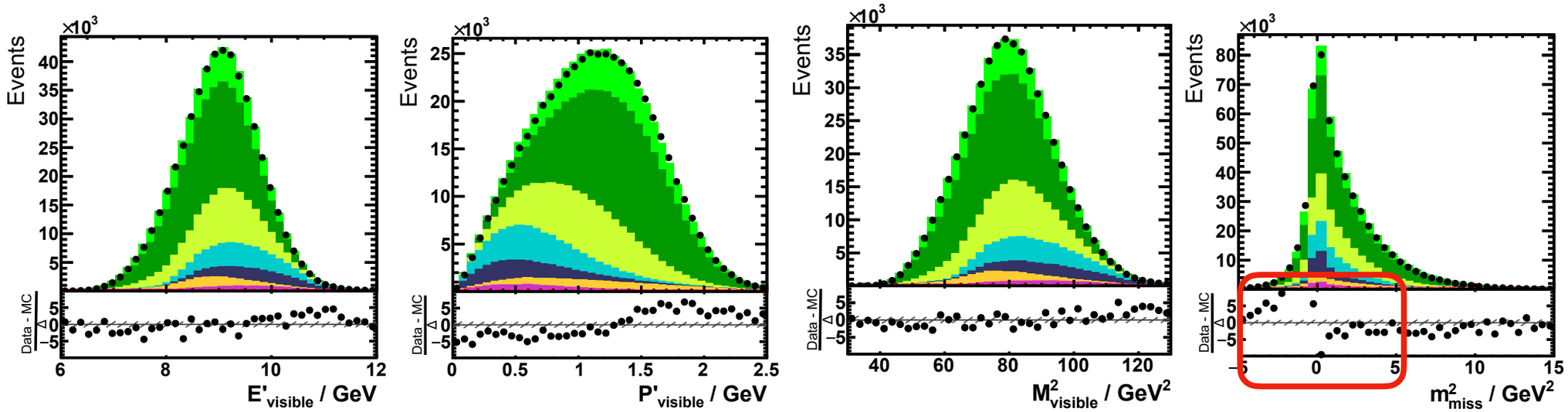
Tighter?

tight

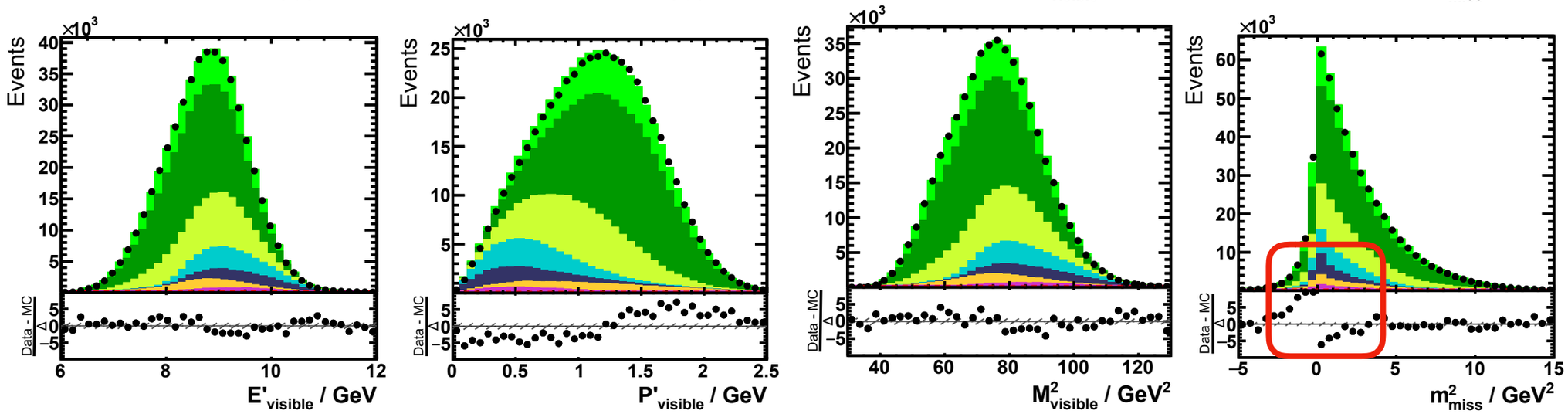
	PID	min $\lvert\vec{p}\rvert$/ MeV	max $(\mathrm{d}r, \mathrm{d}z)$/cm	θ
Electron	> 0.90	300	$(0.5, 1.5)$	$17° < \theta < 150°$
Muon	> 0.97	600	$(0.5, 1.5)$	$25° < \theta < 145°$
Kaon	< 0.60	100	$(0.5, 1.5)$	-
Pion	> 0.60	100	$(0.5, 1.5)$	-
Photon	-	150	-	-

$((\mathrm{d}r, \mathrm{d}z) < (0.5, 1.5)\,\mathrm{cm}).$

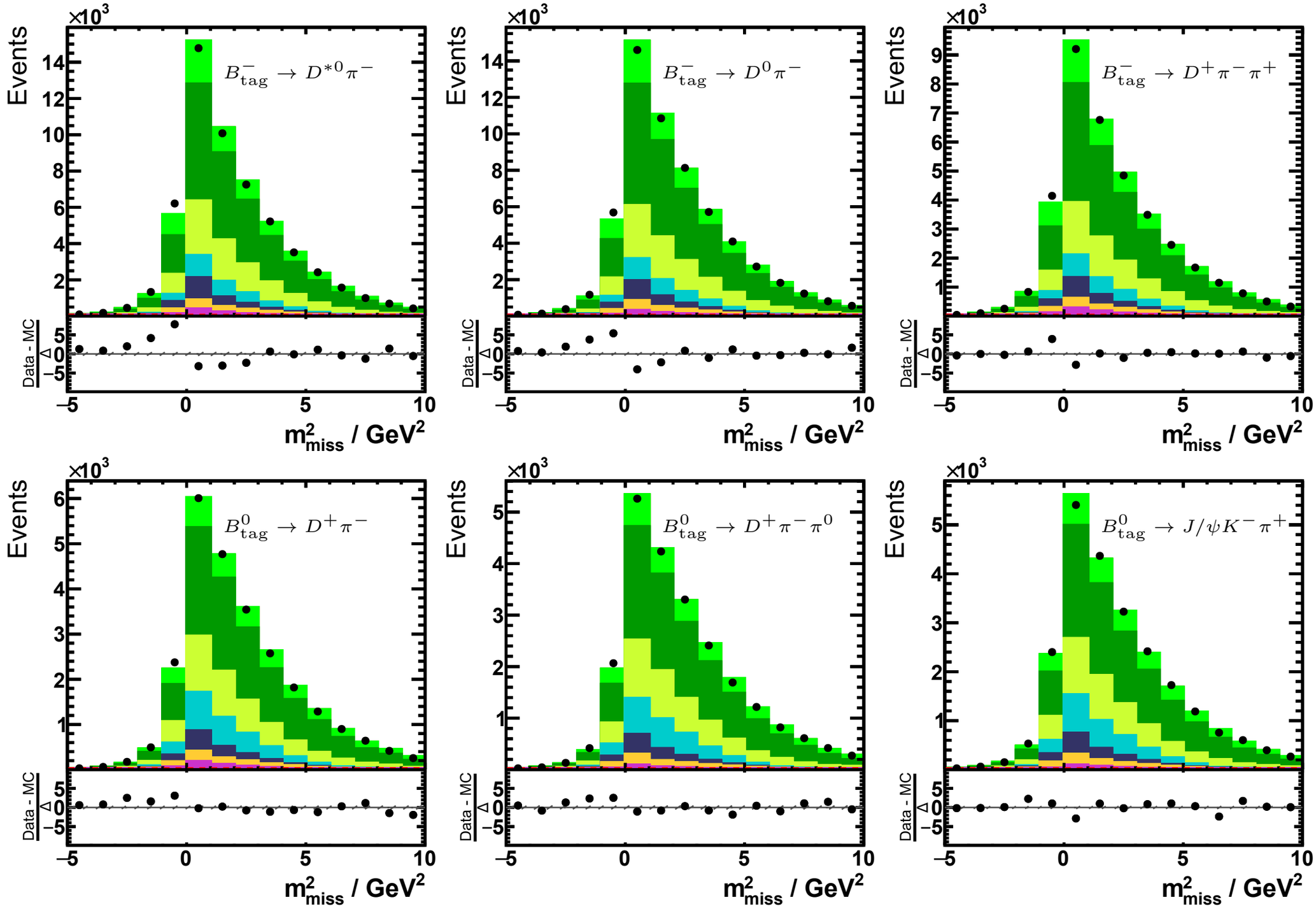
loose



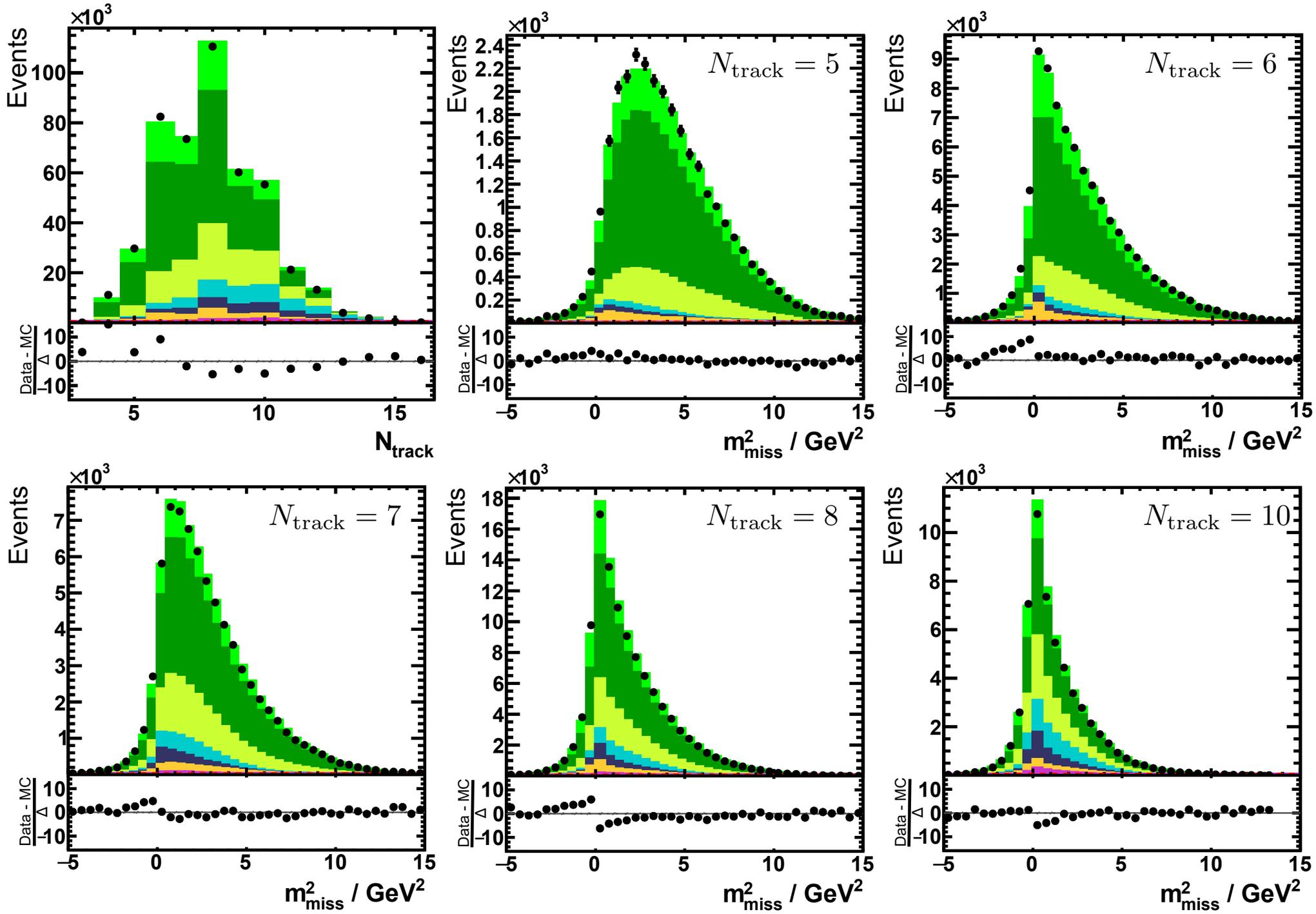
tight



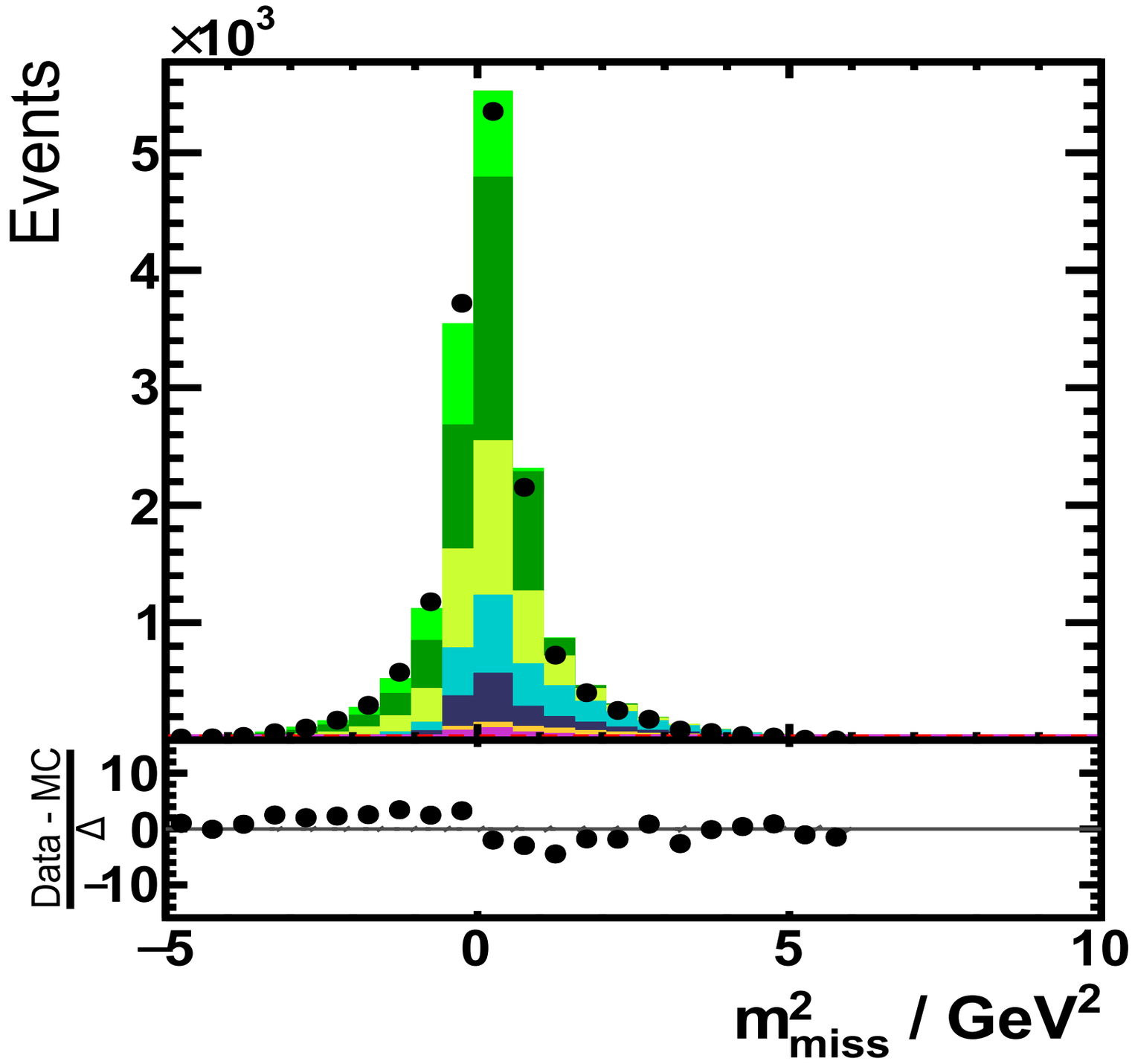
MM2 versus Tagging Mode



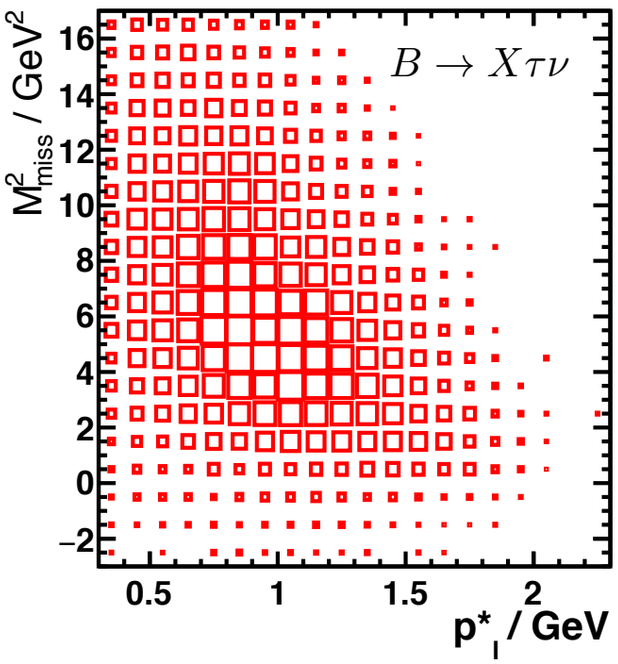
MM2 versus # of tracks

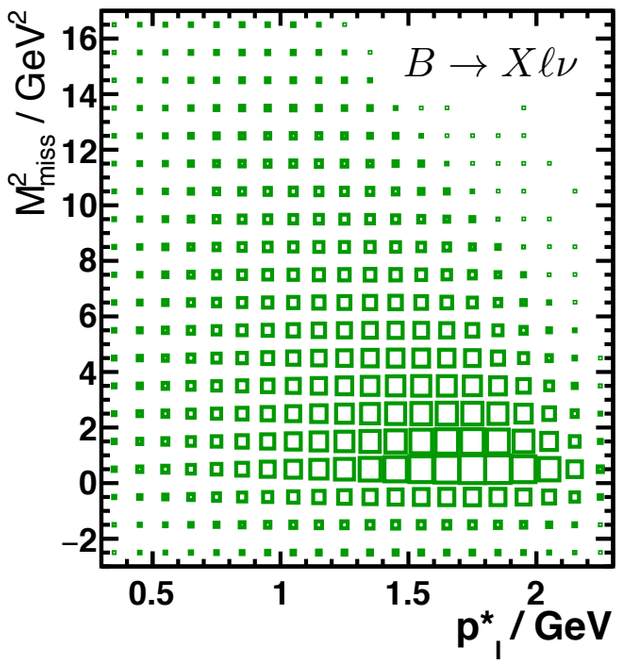


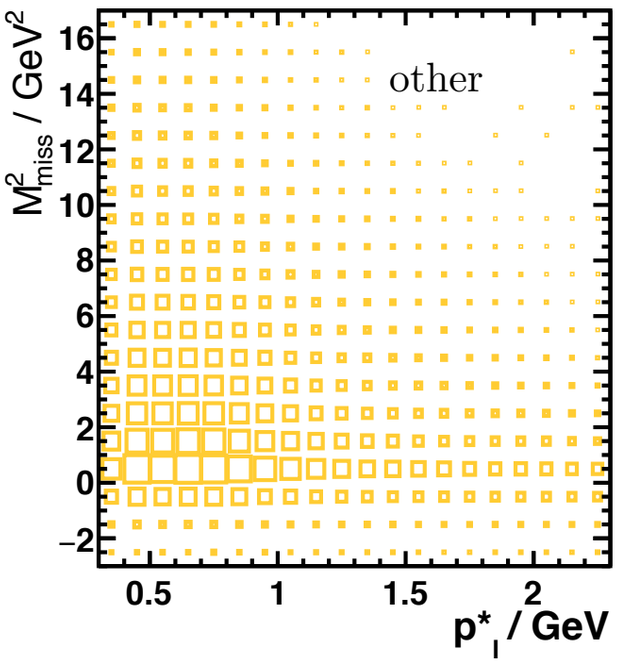
Semi-Inclusive $B \to DX\ell\bar{\nu}_\ell$

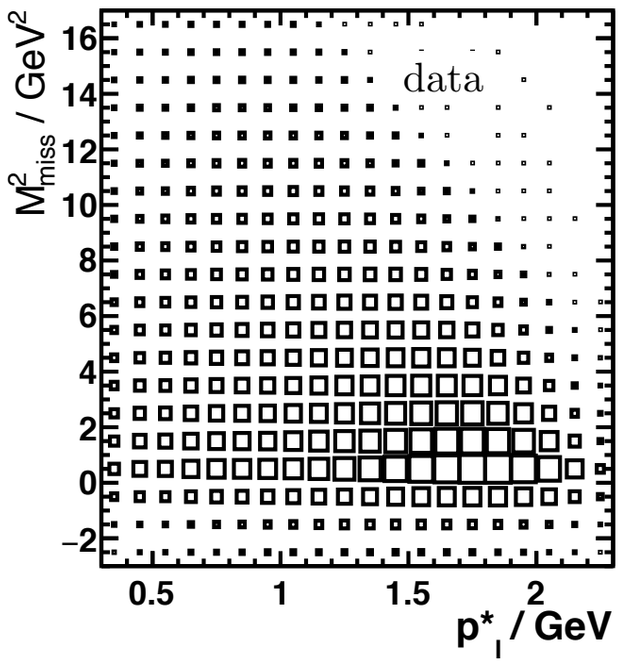


2D Fit





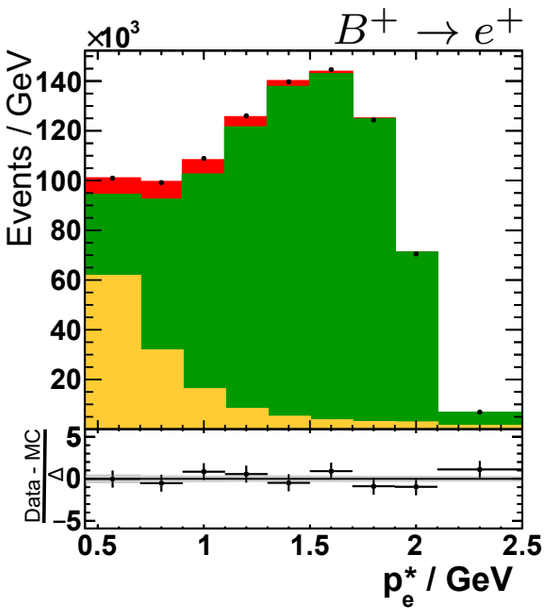


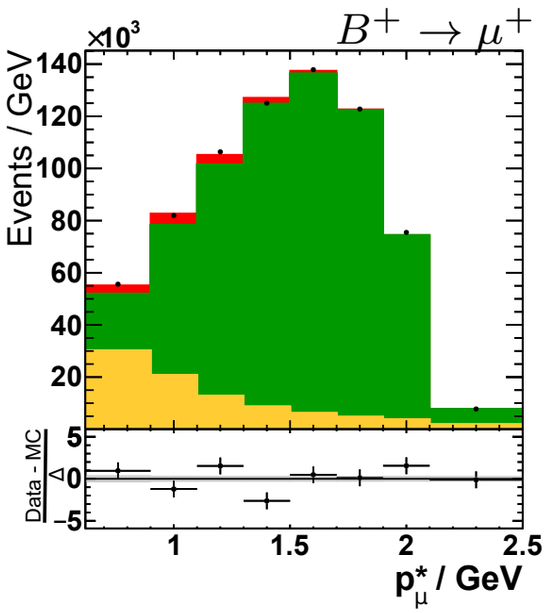


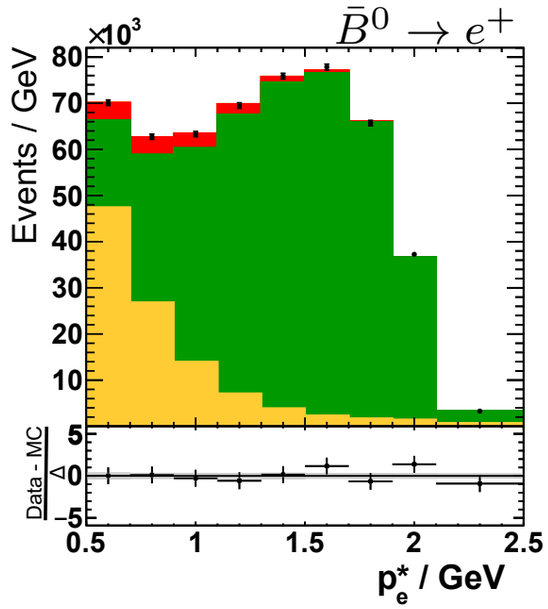
$$\chi^2(\vec{\theta}) \to \chi^2(\vec{\theta}, \vec{\lambda}) = \chi^2(\vec{\theta}) + \chi^2_{\mathrm{NP}}(\vec{\lambda}),$$

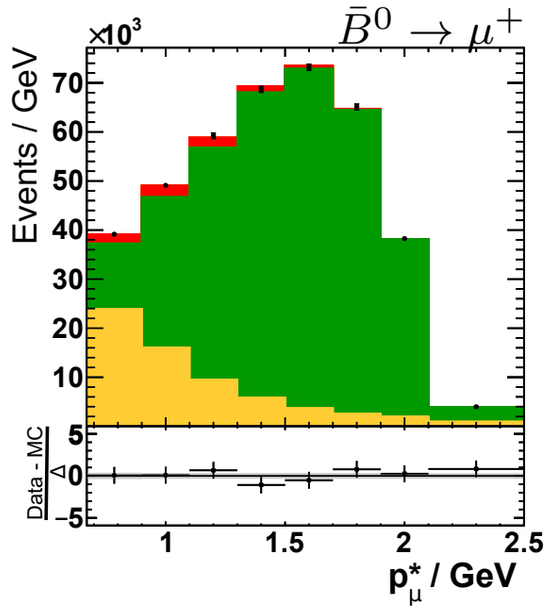
	Rel. uncertainty $\delta R(X)/\%$
Statistical	± 5.2
PID	± 1.1
$\mathcal{B}(B \to X\tau\nu)$ composition	± 0.6
$\mathcal{B}(B \to D\ell\nu)$	± 0.2
$\mathcal{B}(B \to D^*\ell\nu)$	$^{+5.5}_{-5.0}$
$\mathcal{B}(B \to D^{**}\ell\nu)$ composition	± 3.7
$\mathcal{B}(D \to X\ell\nu)$	± 4.7
D^{**} decay model	± 0.2
$\mathrm{FF}_{\mathrm{CLN}}(B \to D^{(*)}\ell\nu)$	± 0.7
$\mathrm{FF}_{\mathrm{LLSW}}(B \to D^{**}\ell\nu)$	$^{+5.5}_{-5.1}$
MC statistics	± 2.6
Total systematic	$^{+8.2}_{-7.9}$
Total	$^{+9.7}_{-9.4}$

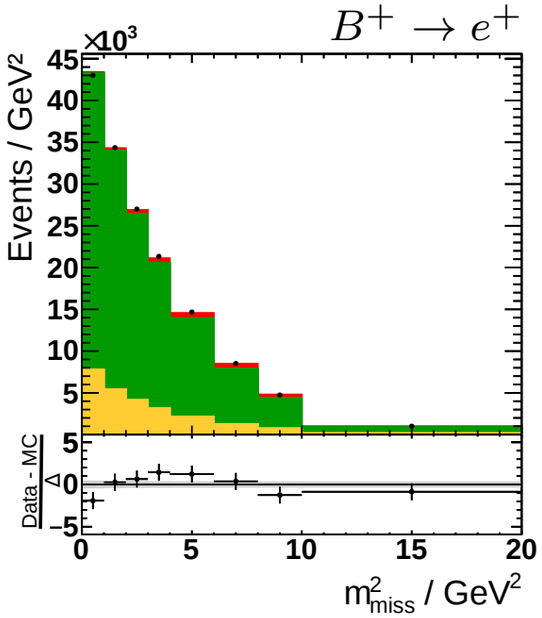
Post-Fit

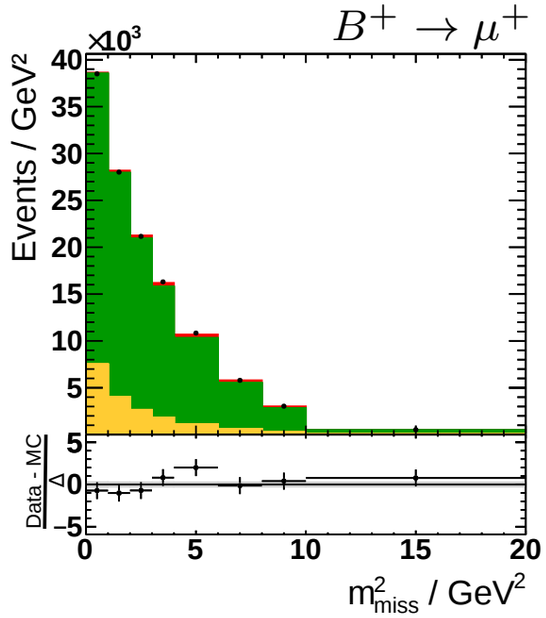


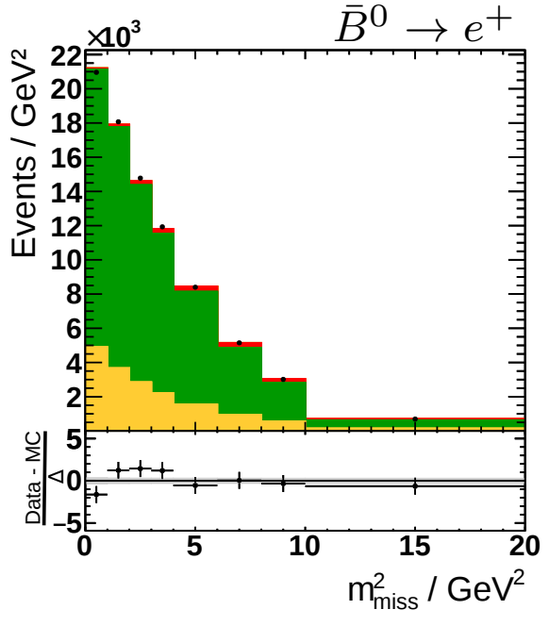


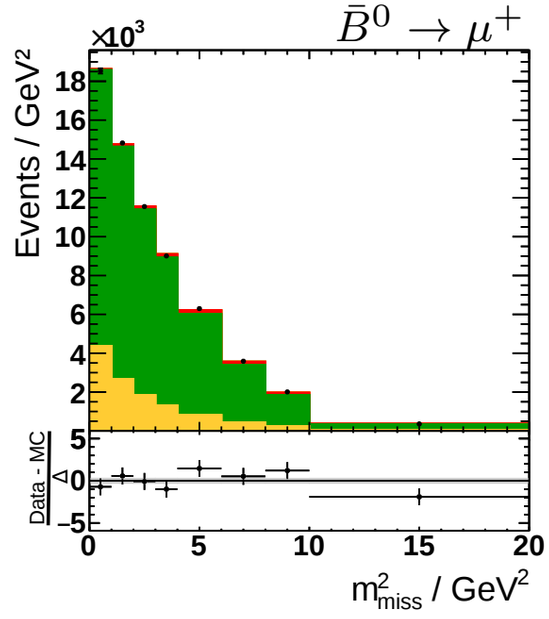












$$R(X) = 0.298 \pm 0.012_{\text{stat}} \pm 0.018_{\text{sys}}.$$

Fit prob. inkl. systematics 4.9%

Putting it all together