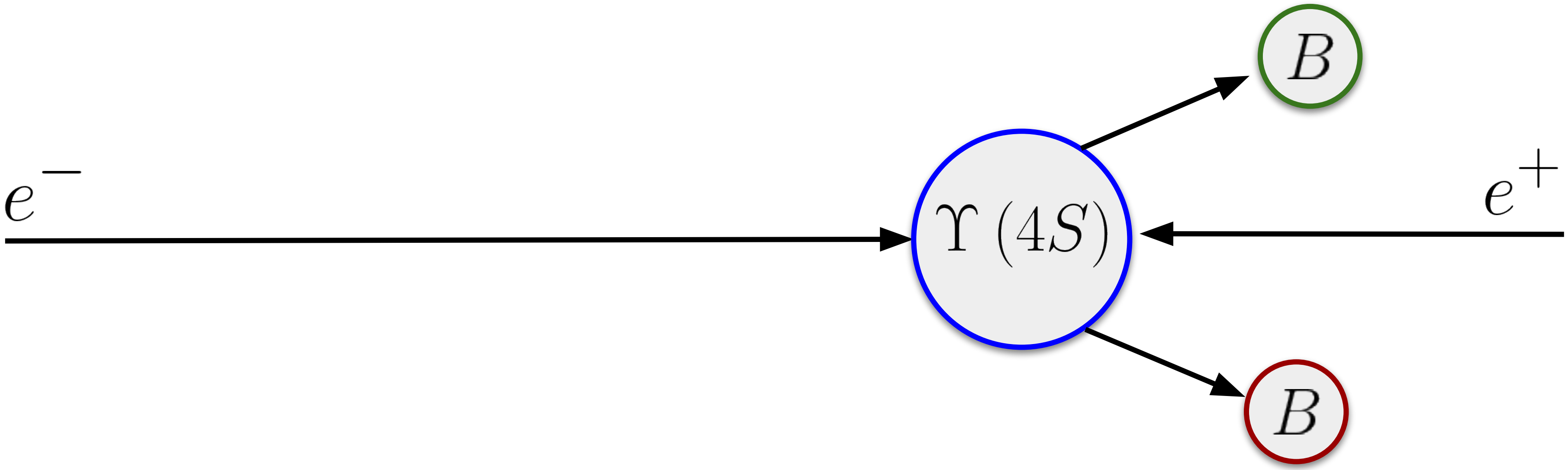
The forward-backward asymmetry in inclusive semileptonic B decays

Florian Herren

B-Factories



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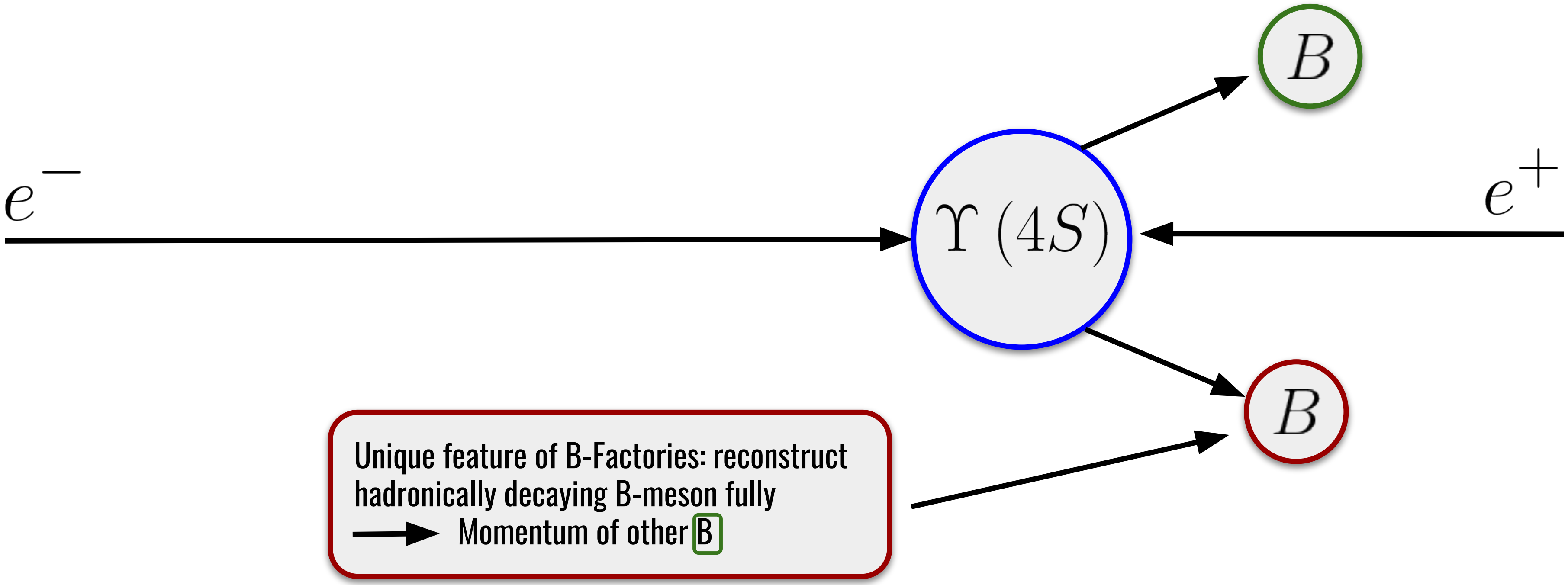

e^-
e^+
$\Upsilon(4S)$
B
B
Unique feature of B-Factories: reconstruct hadronically decaying B-meson fully
Momentum of other B

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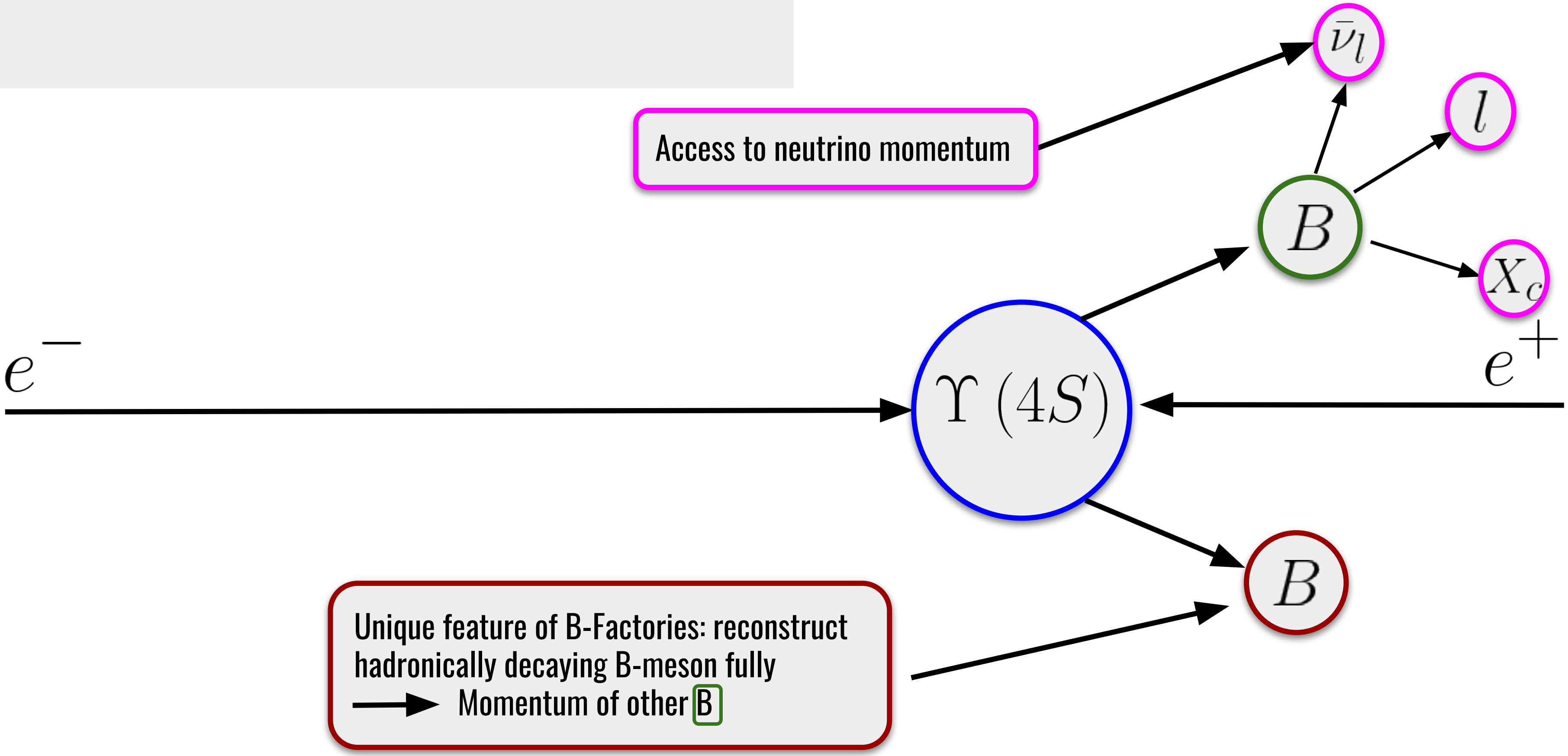
Access to neutrino momentum
$\bar{\nu}_l$
l
B
X_c
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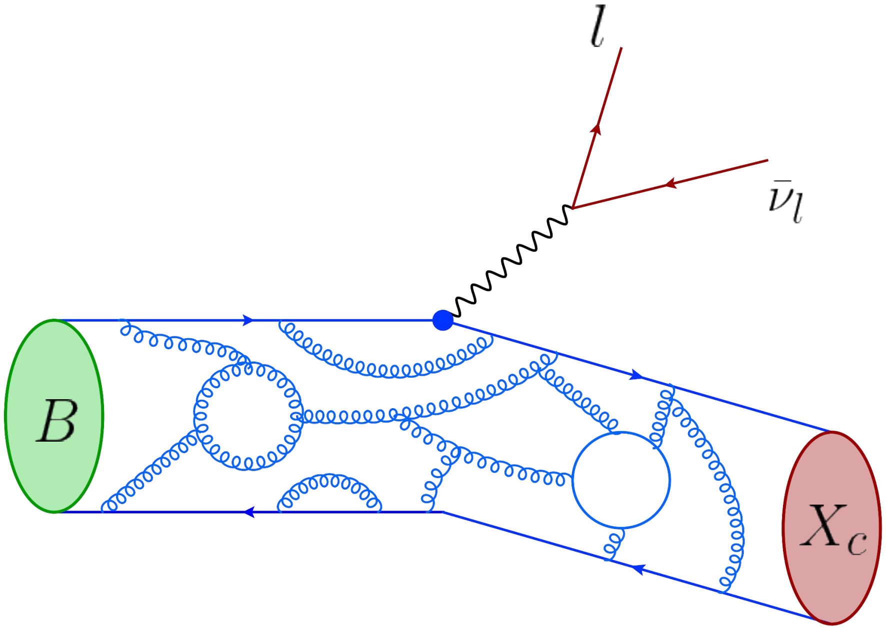
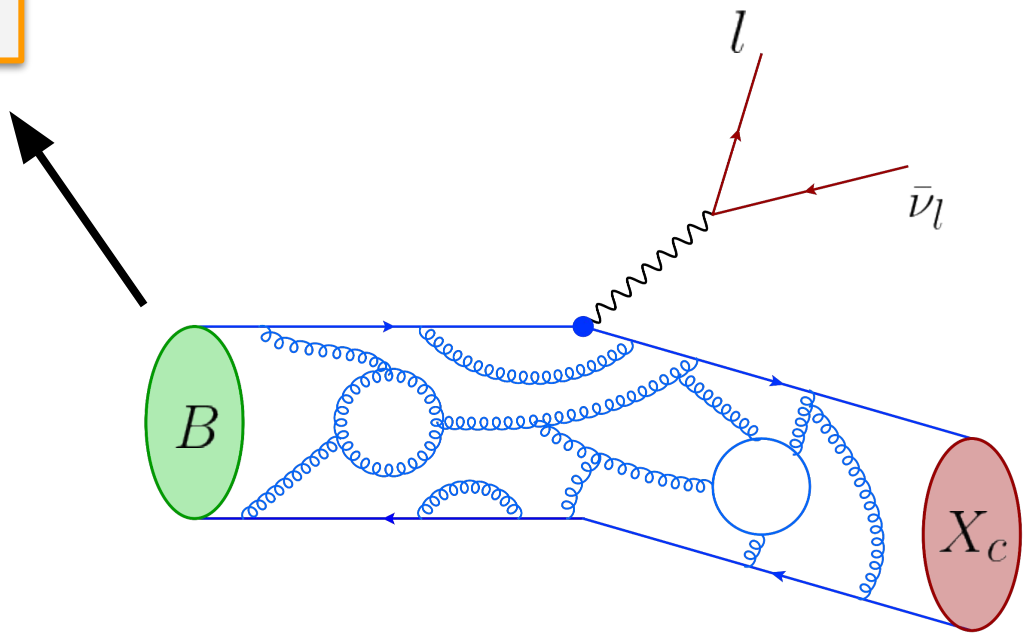
Inclusive semileptonic decays



Inclusive semileptonic decays

Γ_{SL}



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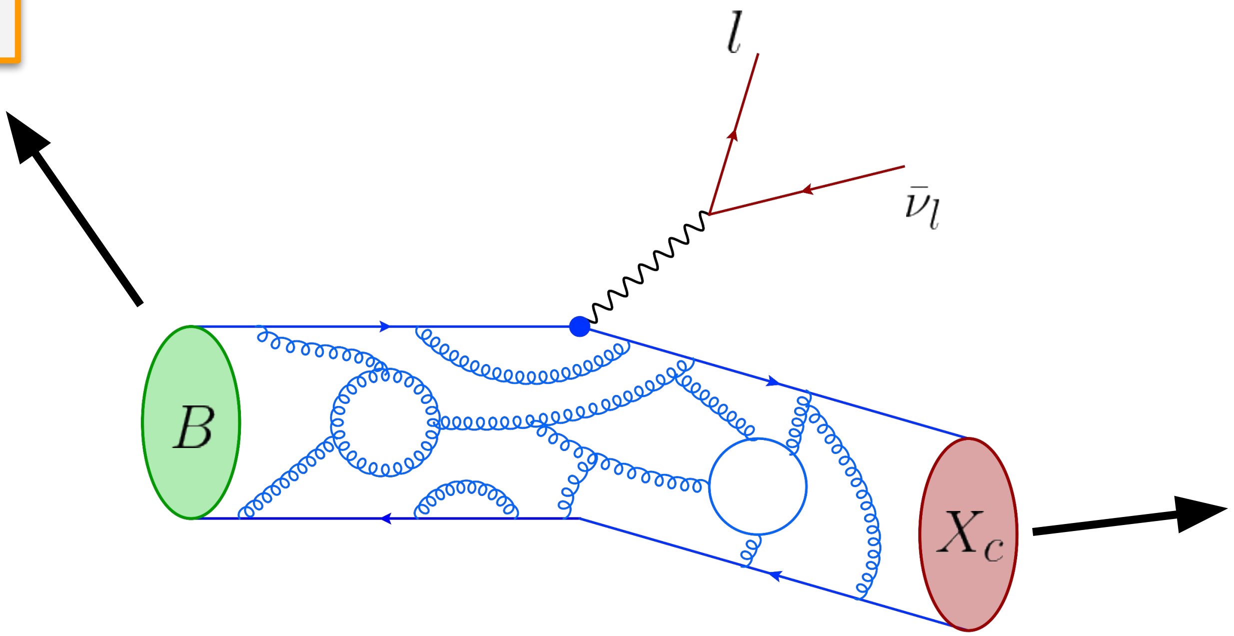
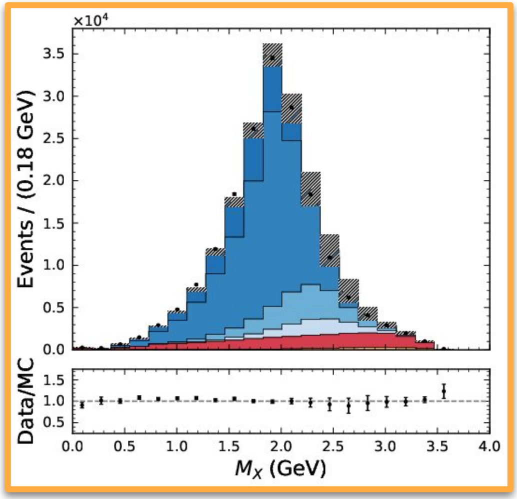


Phys.Rev.D 104 (2021) 11, 112011



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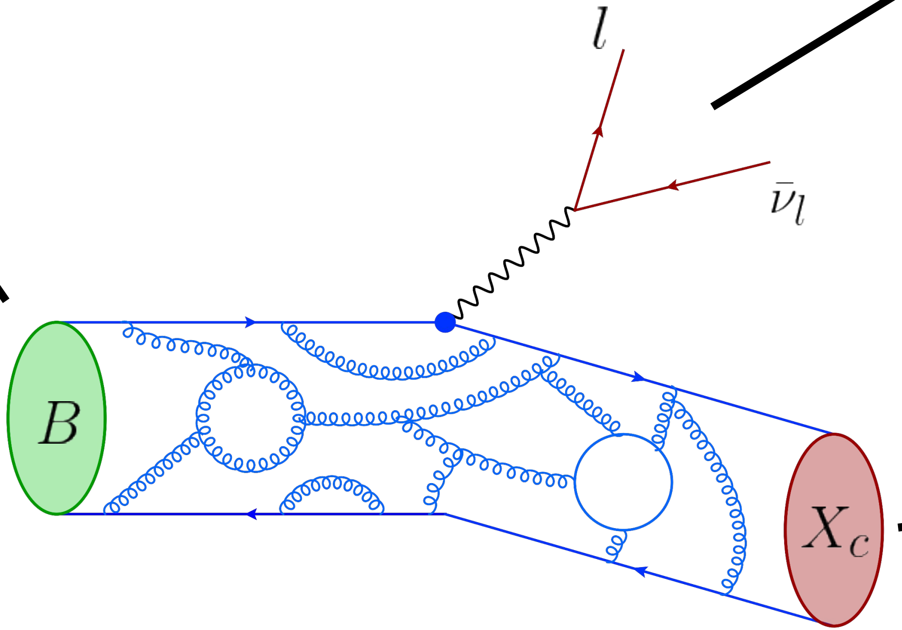

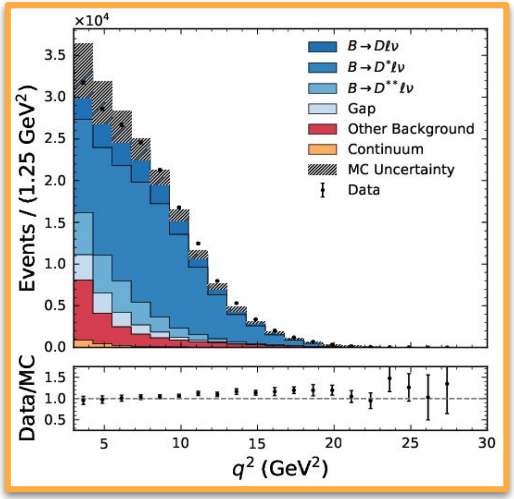

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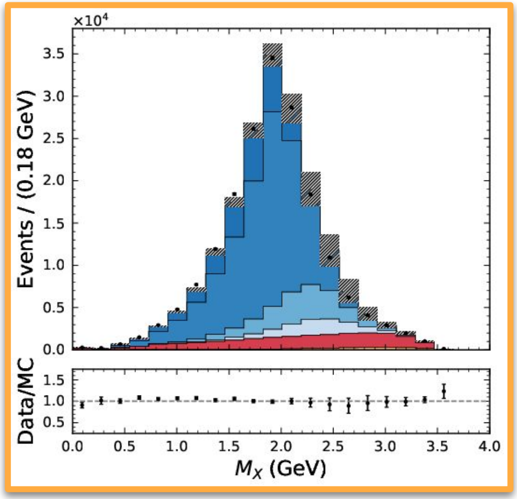
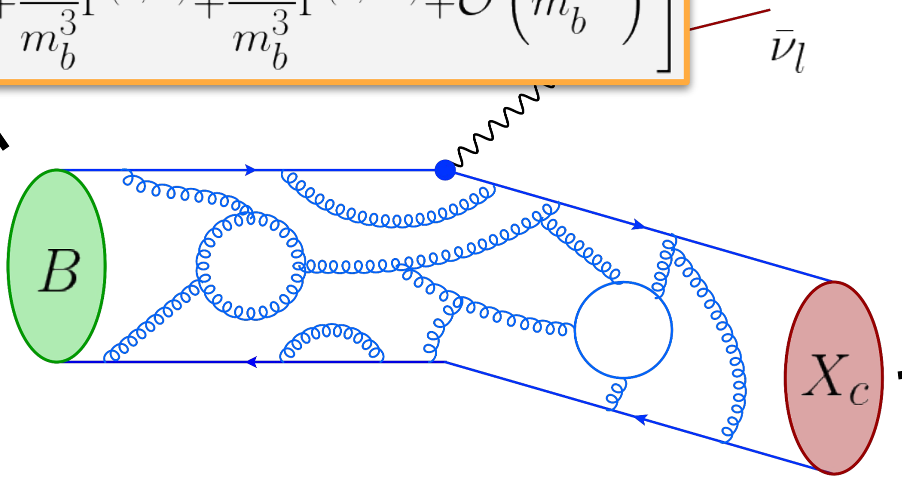
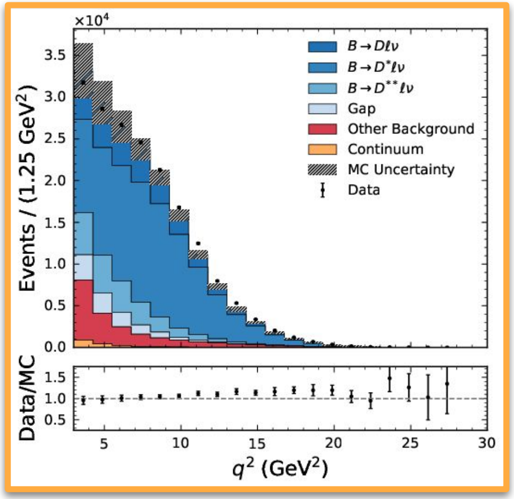


Inclusive semileptonic decays

$$\Gamma_{\mathrm{SL}} = \frac{G_F^2 |V_{cb}|^2}{192\pi^3 m_b^5}\left[\Gamma^{(0)} + \frac{\hat{\mu}_\pi^2}{m_b^2}\Gamma^{(2,\pi)} + \frac{\hat{\mu}_G^2}{m_b^2}\Gamma^{(2,\mathrm{G})} + \frac{\hat{\rho}_D^3}{m_b^3}\Gamma^{(3,\mathrm{D})} + \frac{\hat{\rho}_{LS}^3}{m_b^3}\Gamma^{(3,\mathrm{LS})} + \mathcal{O}\left(m_b^{-4}\right)\right]$$





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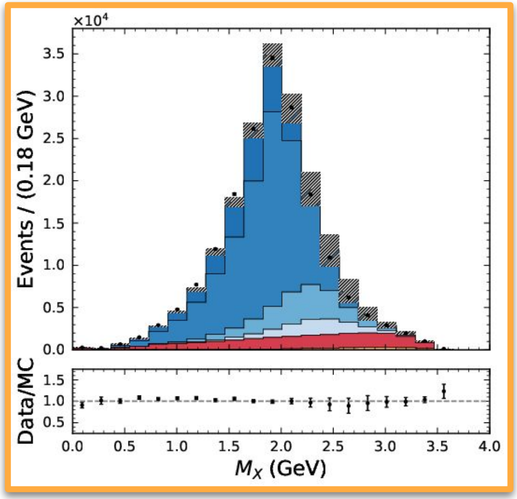

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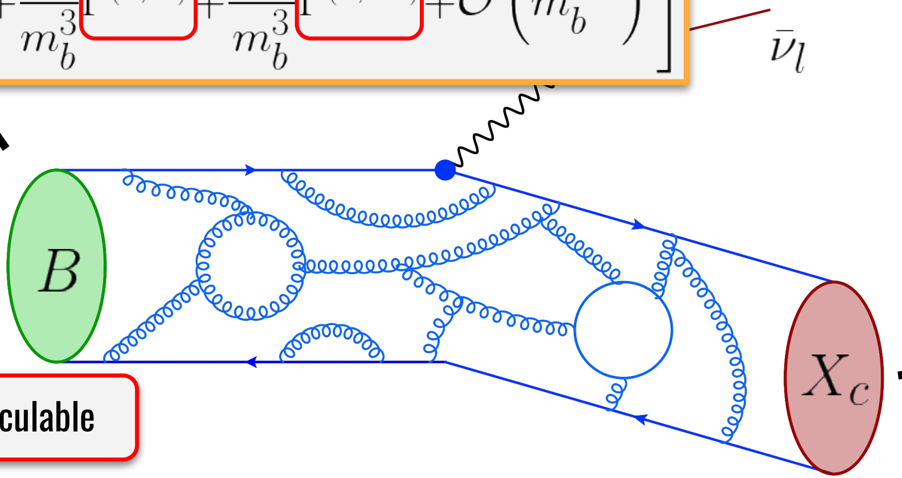
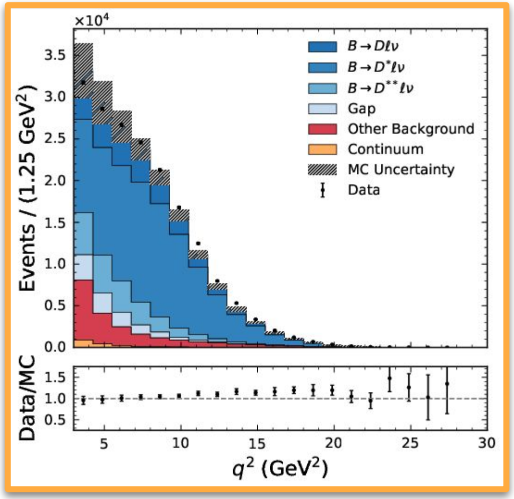


Perturbatively calculable



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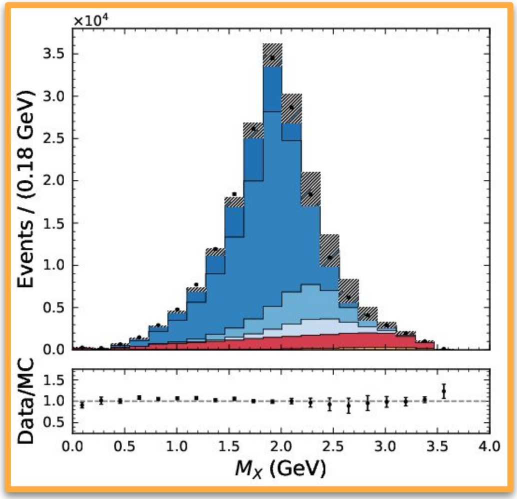

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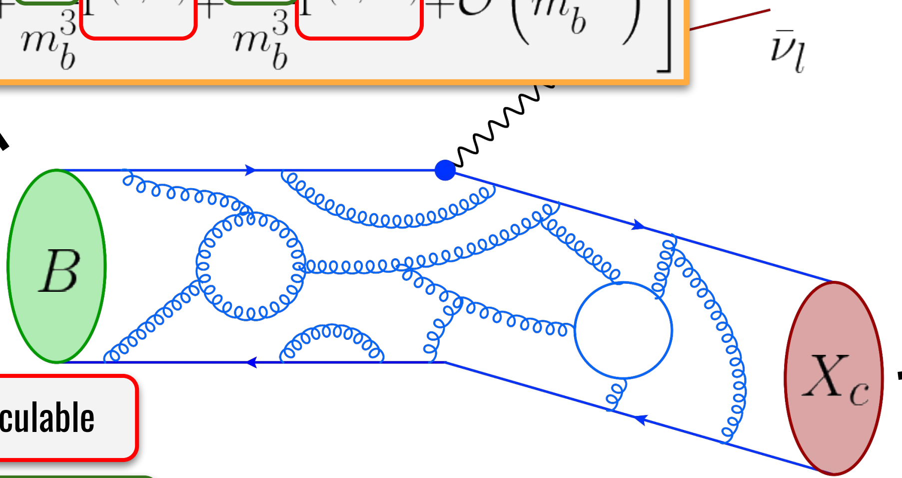

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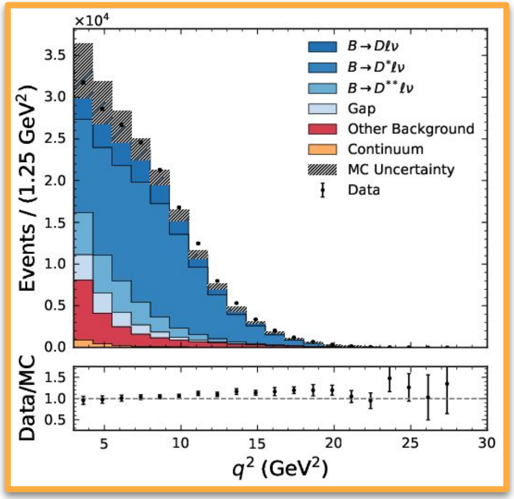
Nonperturbative parameter



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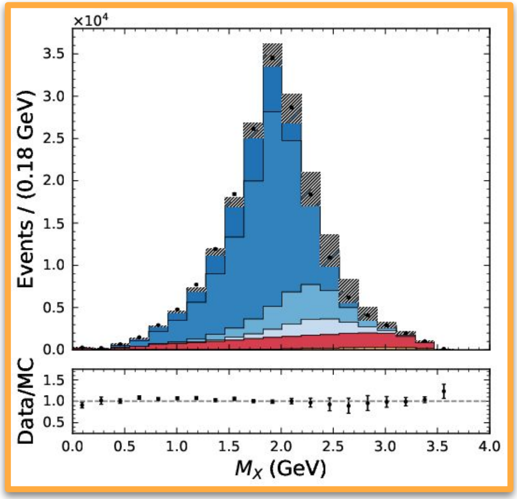

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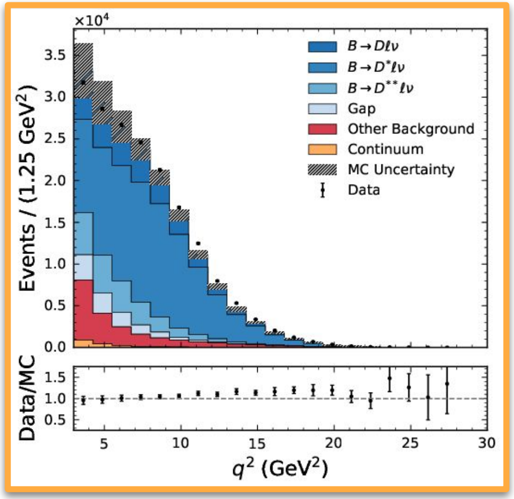

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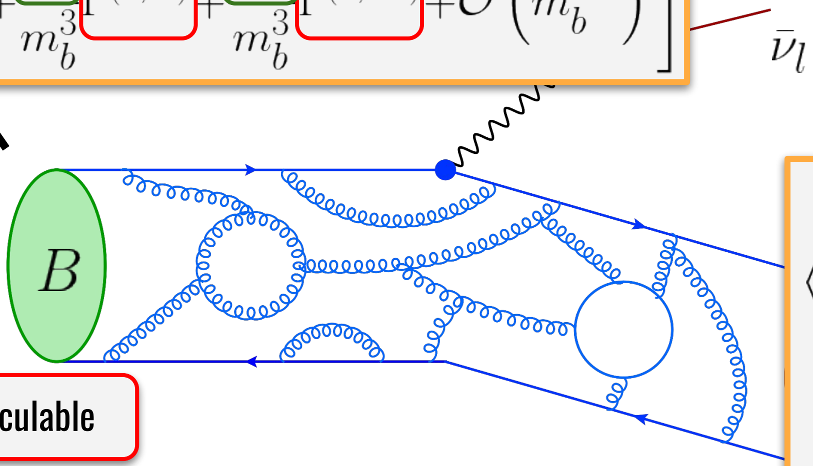

$$\left\langle q^2 \right\rangle = m_b^2\left[\mathcal{Q}^{(0)} + \frac{\hat{\mu}_\pi^2}{m_b^2}\mathcal{Q}^{(2,\pi)} + \frac{\hat{\mu}_G^2}{m_b^2}\mathcal{Q}^{(2,G)} + \frac{\hat{\rho}_D^3}{m_b^3}\mathcal{Q}^{(3,D)} + \frac{\hat{\rho}_{LS}^3}{m_b^3}\mathcal{Q}^{(3,LS)}\right]$$

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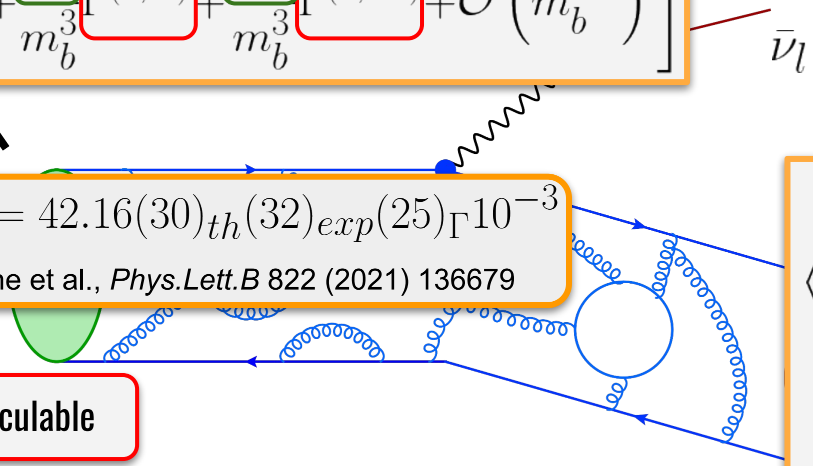
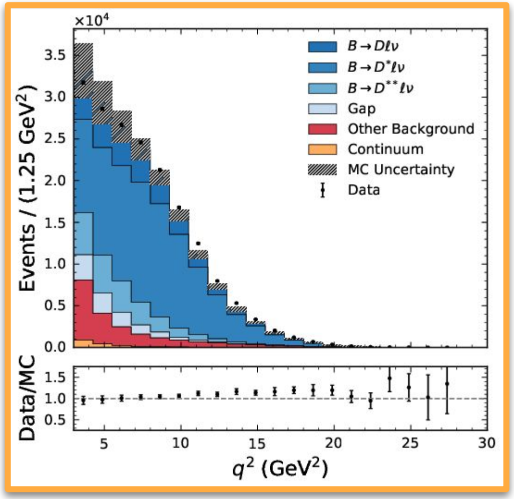


$$|V_{cb}| = 42.16(30)_{th}(32)_{exp}(25)_{\Gamma} 10^{-3}$$

Bordone et al., *Phys.Lett.B* 822 (2021) 136679



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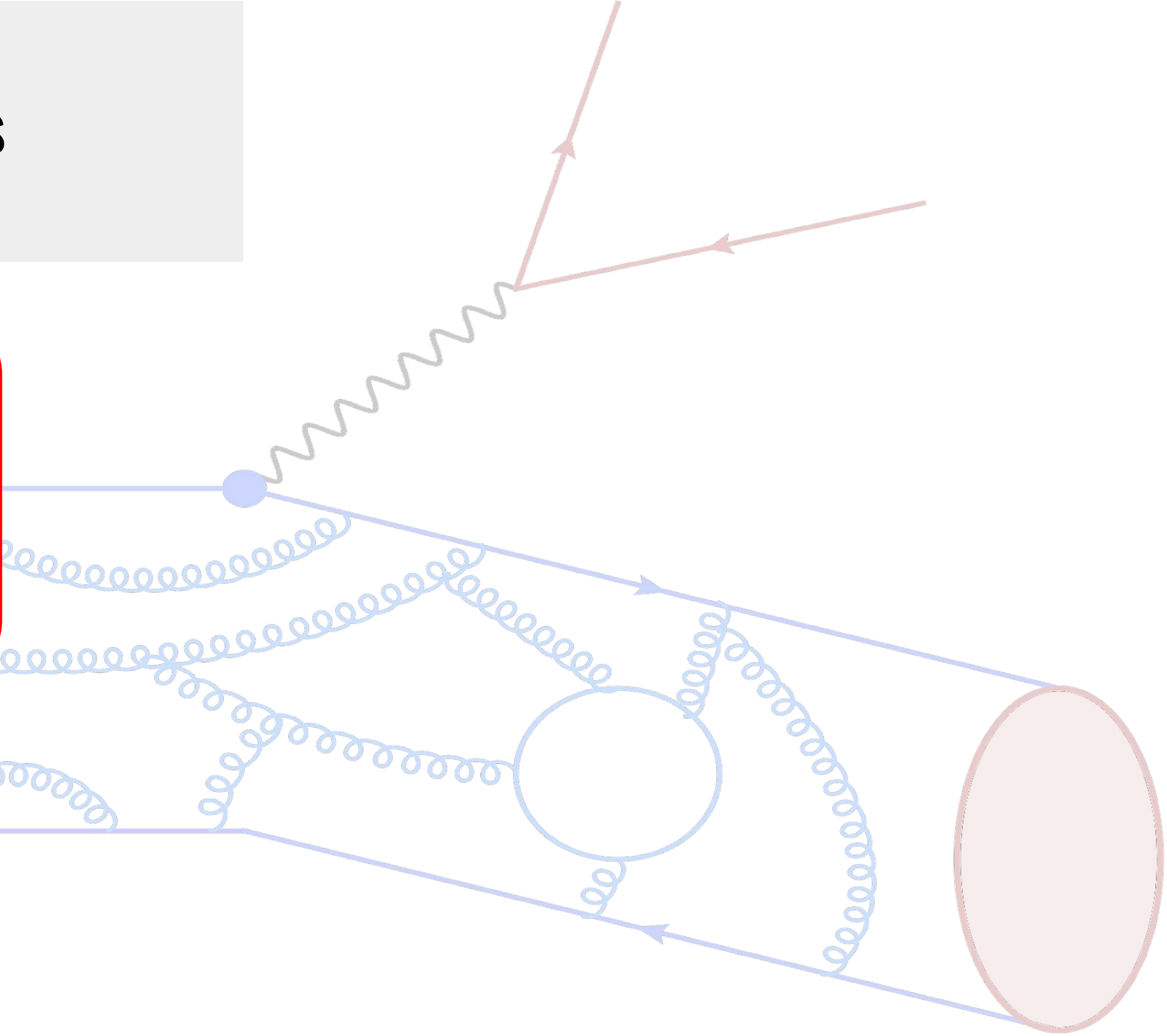
Need for new observables

Limitations:

- Limited set of observables
- Higher moments of distributions highly correlated
- 9 additional nonperturbative parameters at $\mathcal{O}\left(m_b^{-4}\right)$

$$\langle \mathcal{O}^n \rangle = \frac{1}{\Gamma}\left(\int \mathrm{d}\mathcal{O} \frac{\mathrm{d}\Gamma}{\mathrm{d}\mathcal{O}} \mathcal{O}^n \right)$$



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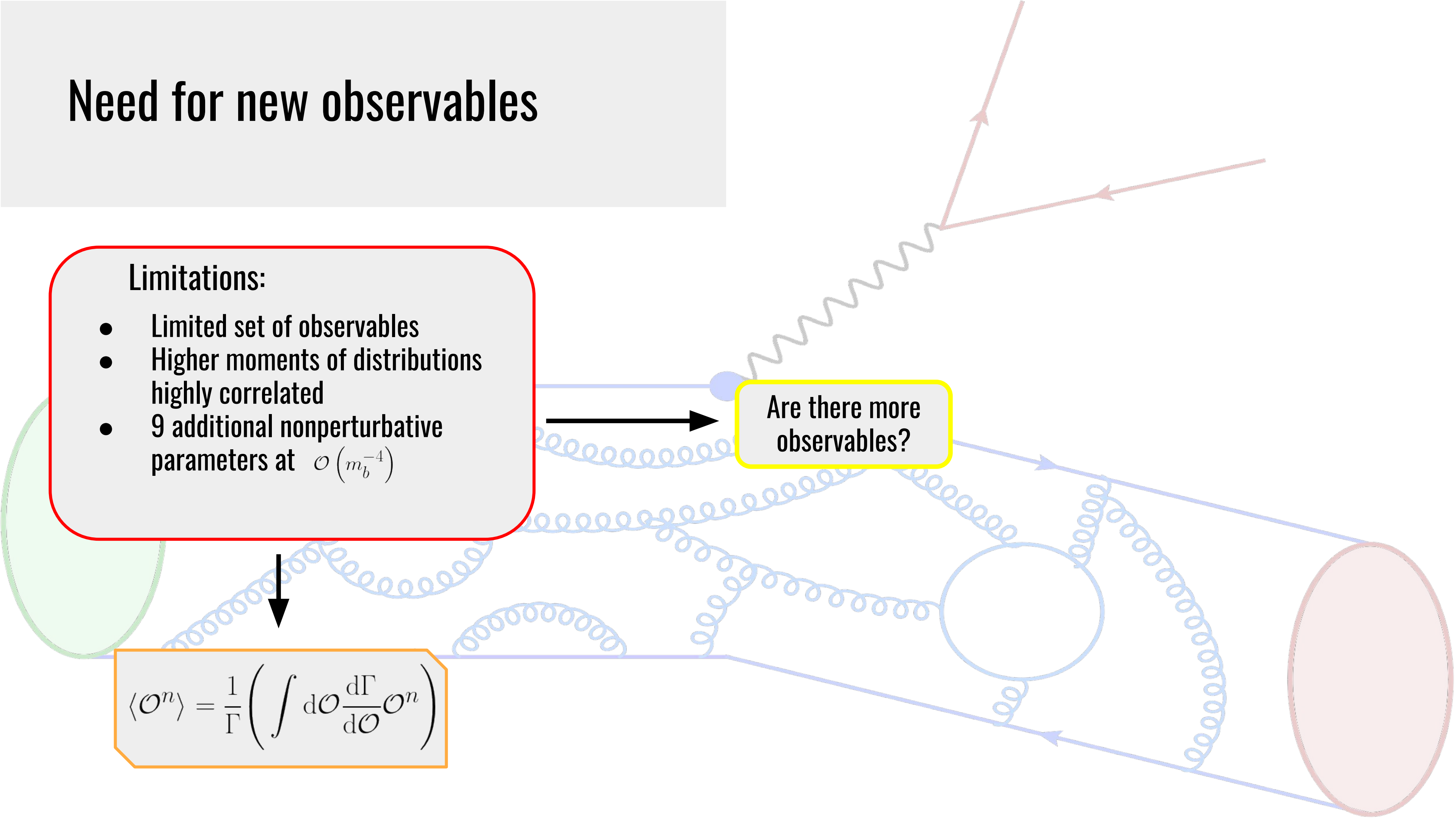

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Need for new observables

Yes!
The forward-backward asymmetry

S. Turczyk, *JHEP* 04 (2016) 131

$$\mathcal{A}_{FB} = \frac{1}{\Gamma}\left(\int_{-1}^{0} \mathrm{d}z \frac{\mathrm{d}\Gamma}{\mathrm{d}z} - \int_{0}^{1} \mathrm{d}z \frac{\mathrm{d}\Gamma}{\mathrm{d}z}\right)$$

$$z = \cos\theta_l = \frac{E_\nu - E_l}{\sqrt{(E_\nu + E_l)^2 - q^2}}$$

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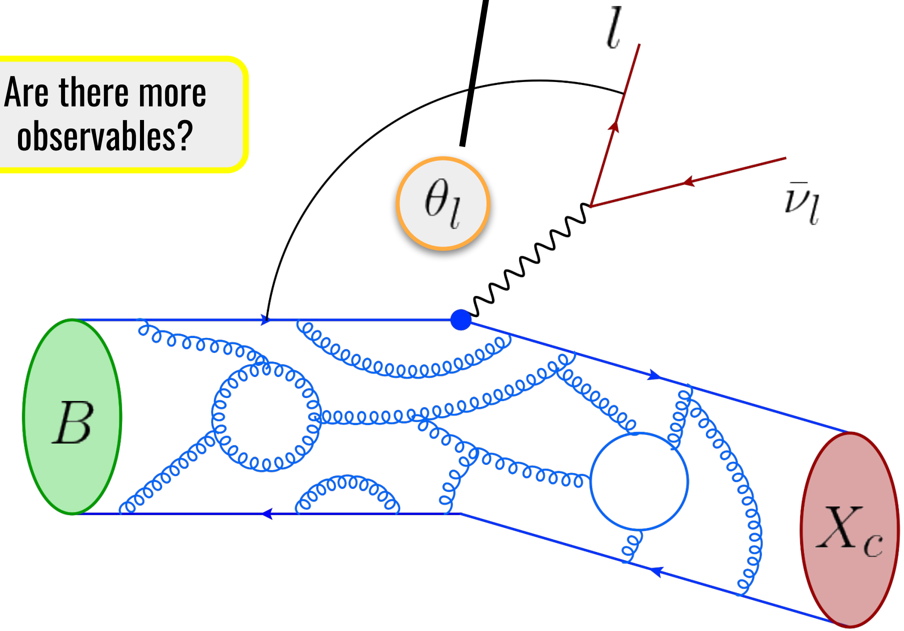

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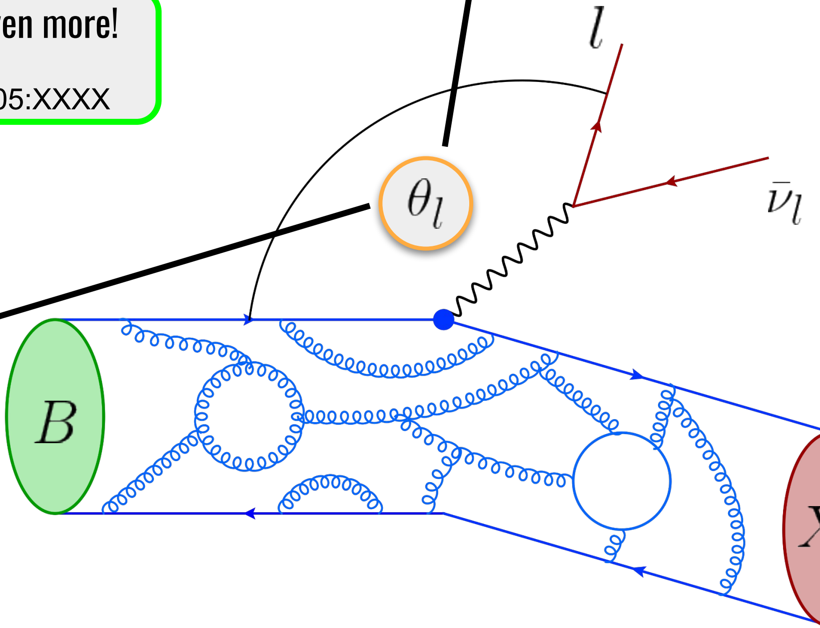
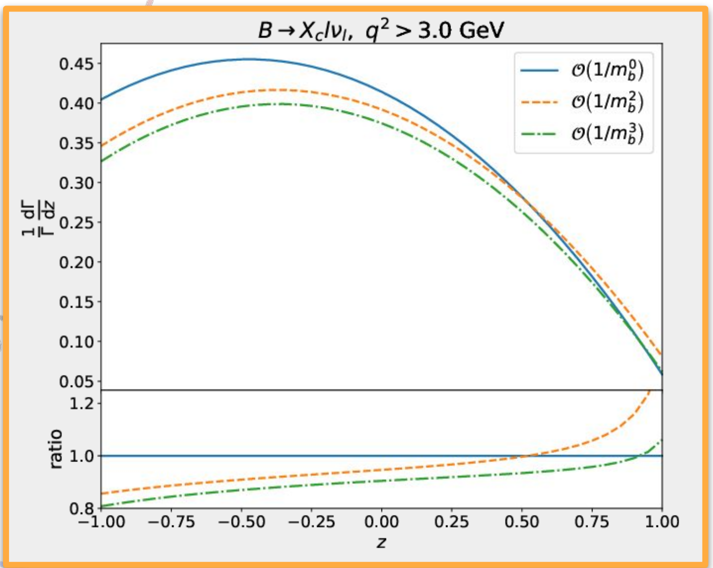
There are even more!

FH, arXiv:2205:XXXX



$$\langle \mathcal{O}^n \rangle_{\pm} = \frac{1}{\Gamma}\left(\int \mathrm{d}\mathcal{O}\left[\int_{-1}^{0} \mathrm{d}z \frac{\mathrm{d}\Gamma}{\mathrm{d}\mathcal{O}\mathrm{d}z}\mathcal{O}^n \pm \int_{0}^{1} \mathrm{d}z \frac{\mathrm{d}\Gamma}{\mathrm{d}\mathcal{O}\mathrm{d}z}\mathcal{O}^n\right]\right)$$

The angular spectrum



$$\Gamma \approx \frac{G_F^2\,|V_{cb}|^2\,m_b^5}{192\pi^3}\,0.706\left(1 - 0.011|_{\hat\mu_\pi^2} - 0.029|_{\hat\mu_G^2} - 0.031|_{\hat\rho_D^3} - 0.003|_{\hat\rho_{LS}^3} + \mathcal{O}\left(1/m_b^4\right)\right)$$

$$\mathcal{A}_{FB} \approx 0.192\left(1 - 0.051|_{\hat\mu_\pi^2} - 0.112|_{\hat\mu_G^2} + 0.024|_{\hat\rho_D^3} + 0.009|_{\hat\rho_{LS}^3} + \mathcal{O}\left(1/m_b^4\right)\right)$$

$$\langle M_X^2\rangle_+ \approx 0.202 m_b^2\left(1 - 0.076|_{\hat\mu_\pi^2} + 0.035|_{\hat\mu_G^2} + 0.040|_{\hat\rho_D^3} + 0.004|_{\hat\rho_{LS}^3} + \mathcal{O}\left(1/m_b^4\right)\right)$$

$$\langle E_l\rangle_+ \approx 0.316 m_b\left(1 + 0.011|_{\hat\mu_\pi^2} - 0.019|_{\hat\mu_G^2} - 0.011|_{\hat\rho_D^3} - 0.0004|_{\hat\rho_{LS}^3} + \mathcal{O}\left(1/m_b^4\right)\right)$$

$$\langle q^2\rangle_- \approx 0.056 m_b^2\left(1 - 0.081|_{\hat\mu_\pi^2} - 0.173|_{\hat\mu_G^2} + 0.014|_{\hat\rho_D^3} + 0.017|_{\hat\rho_{LS}^3} + \mathcal{O}\left(1/m_b^4\right)\right)$$

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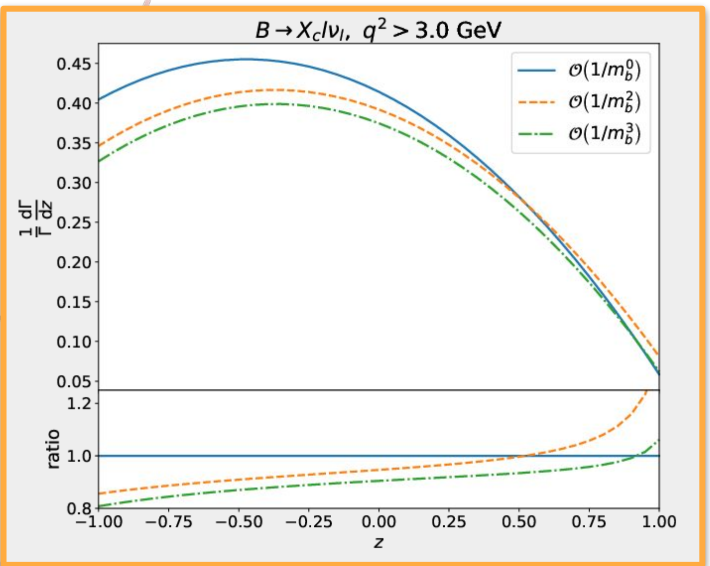

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Difference of $\hat{\mu}_\pi^2$ and $\hat{\mu}_G^2$

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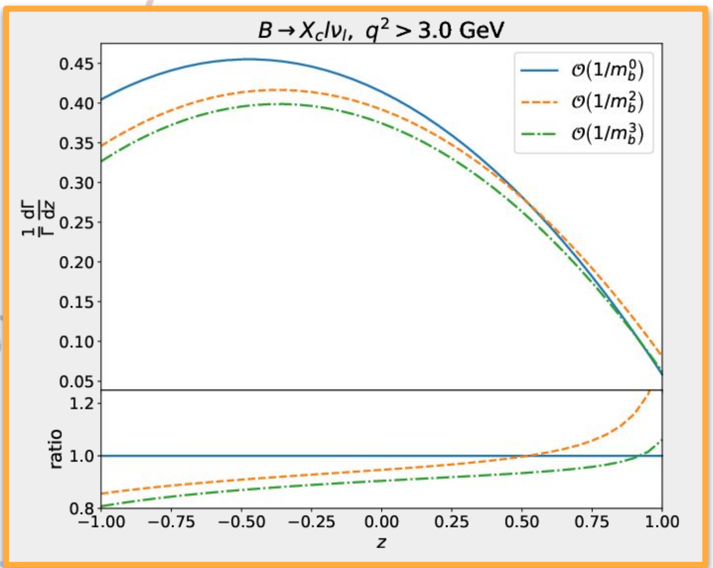
Sum of $\hat{\mu}_\pi^2$ and $\hat{\mu}_G^2$

The angular spectrum



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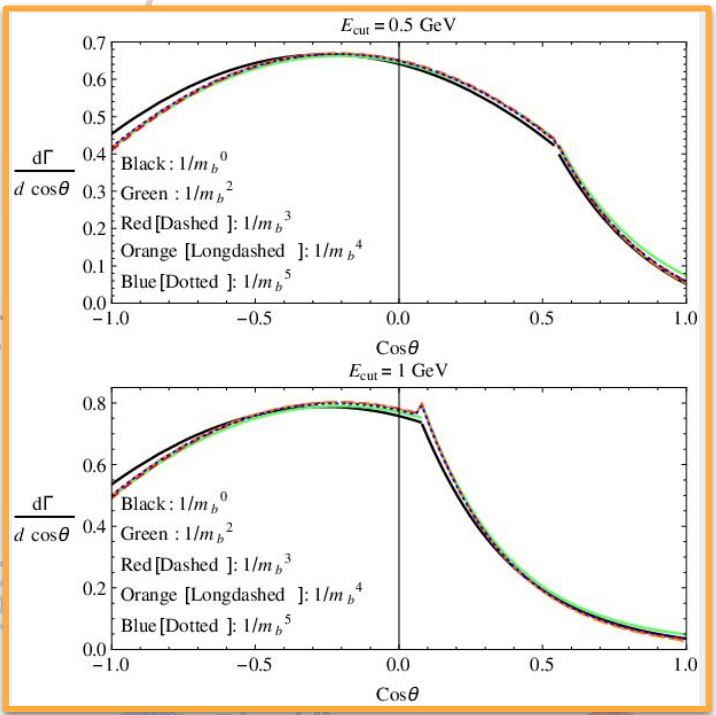
Strongest dependence on $\hat{\rho}_D^3$

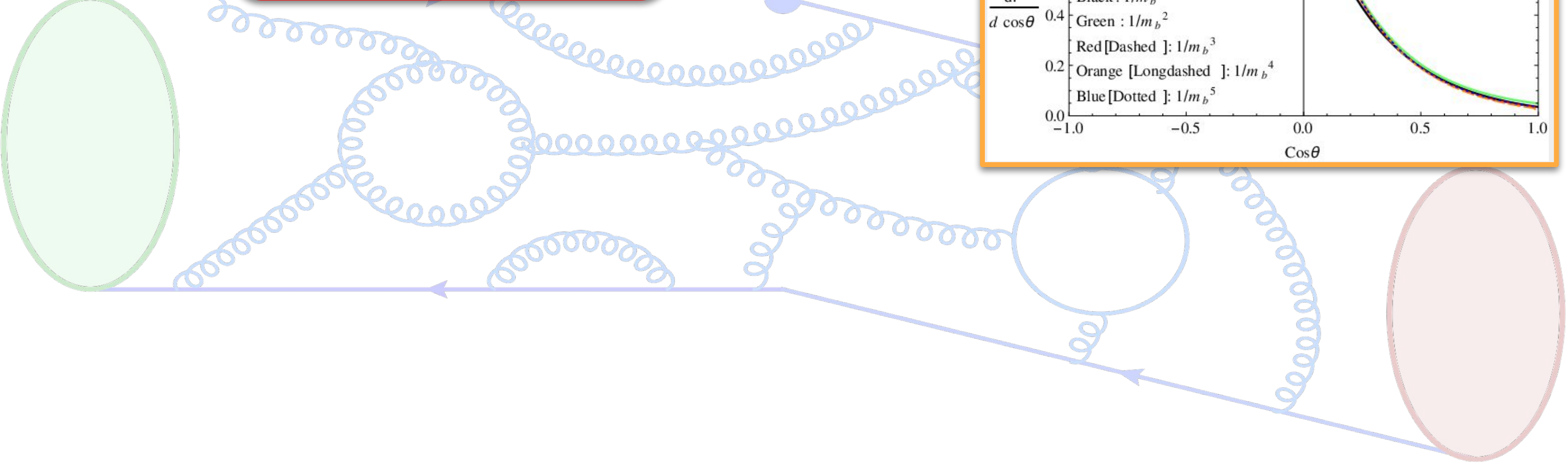
Possibility to determine $\hat{\rho}_{LS}^3$ more precisely?

No measurement without cuts

Original idea: cut on lepton energy

S. Turczyk, *JHEP* 04 (2016) 131





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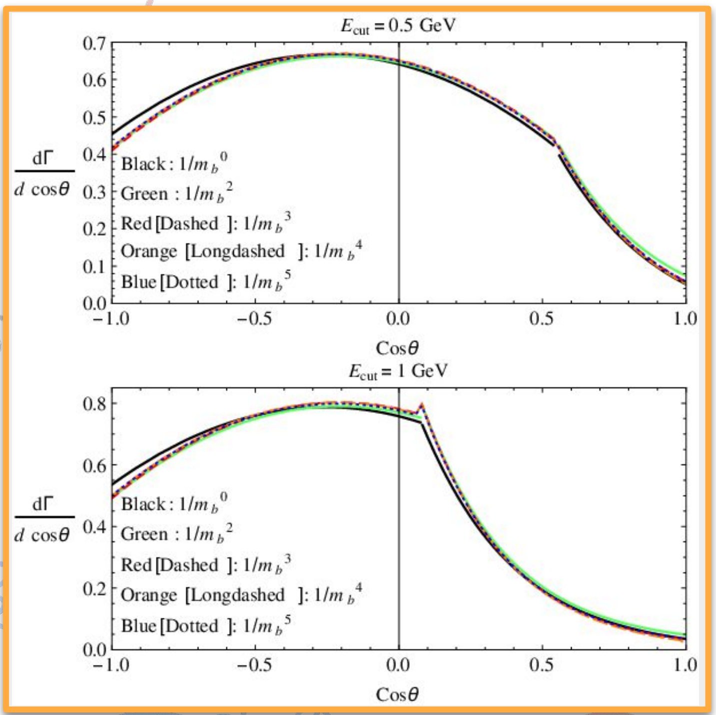

- Discontinuity in spectrum
- Cut of 0.5 GeV unrealistic for muons

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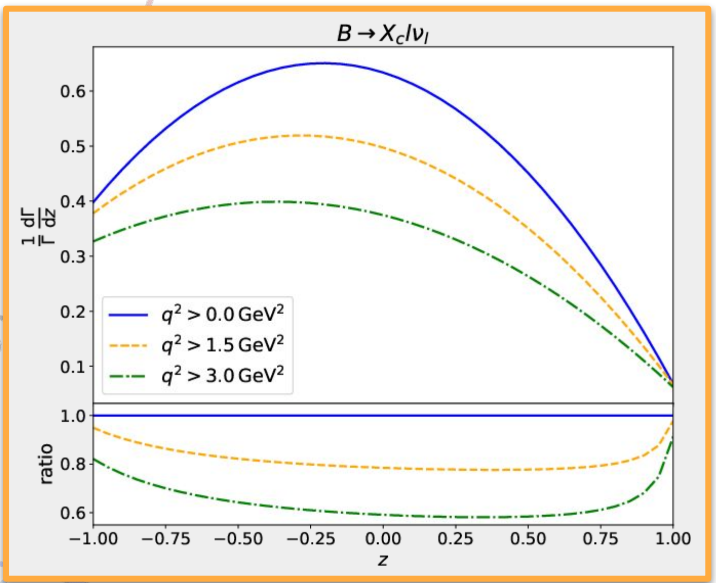

Better idea: cut on q^2

FH, arXiv:2205:XXXX

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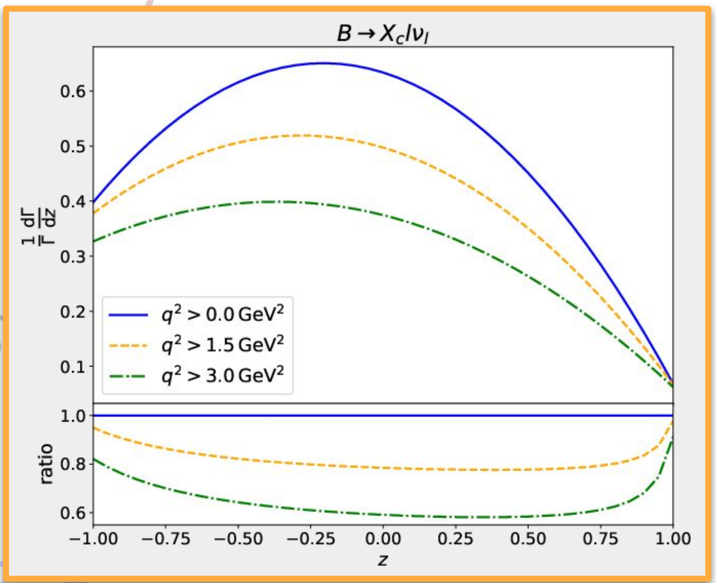
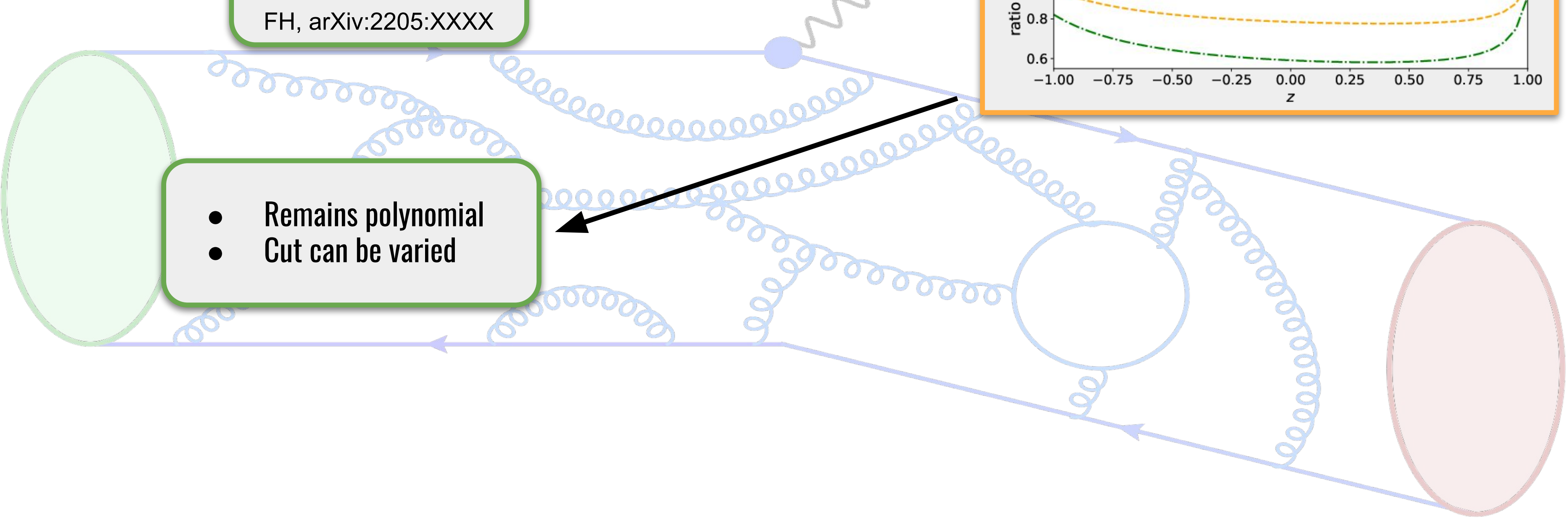


- Remains polynomial
- Cut can be varied



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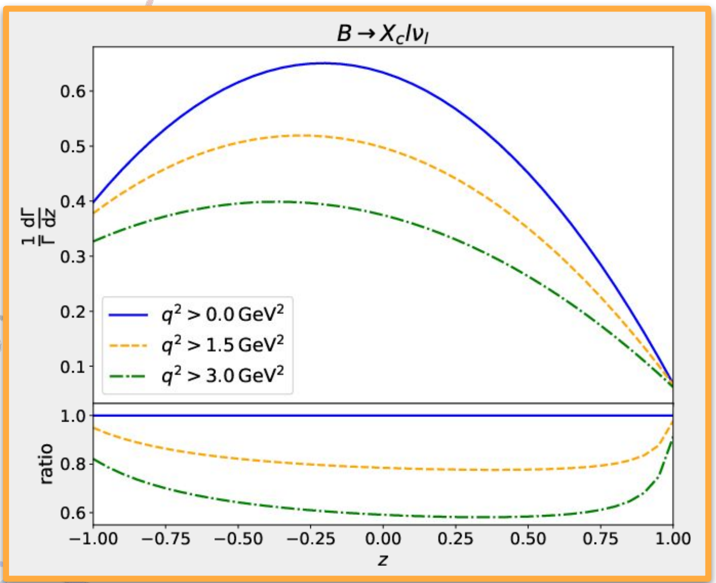

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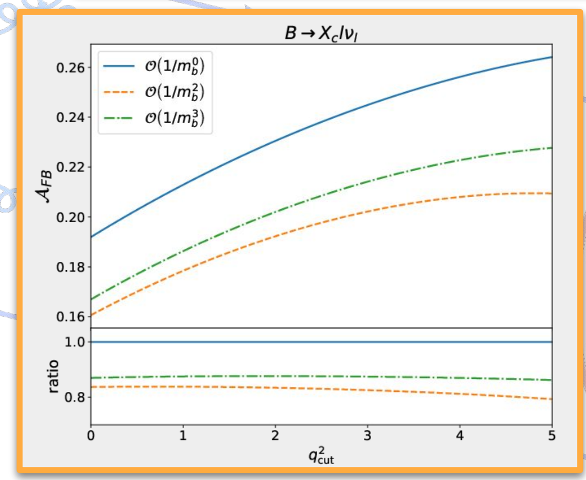

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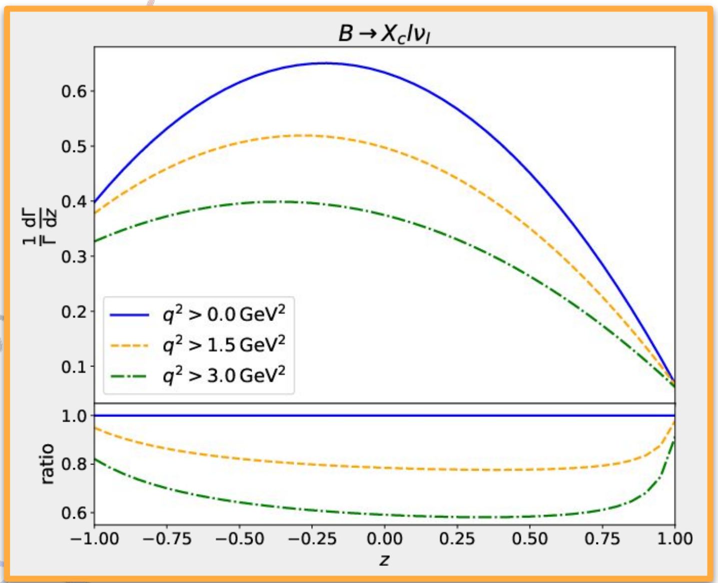
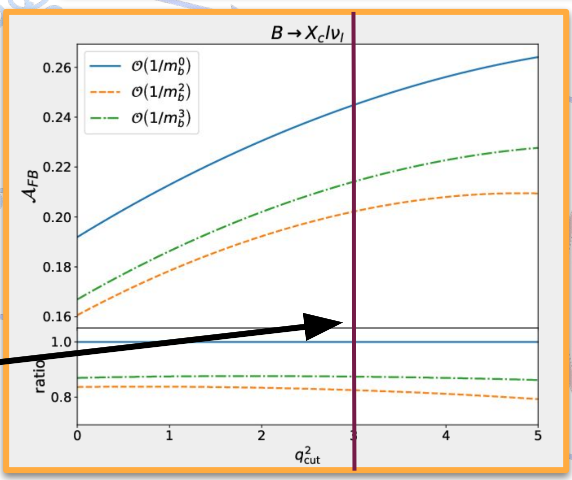
FH, arXiv:2205:XXXX



- Remains polynomial
- Cut can be varied



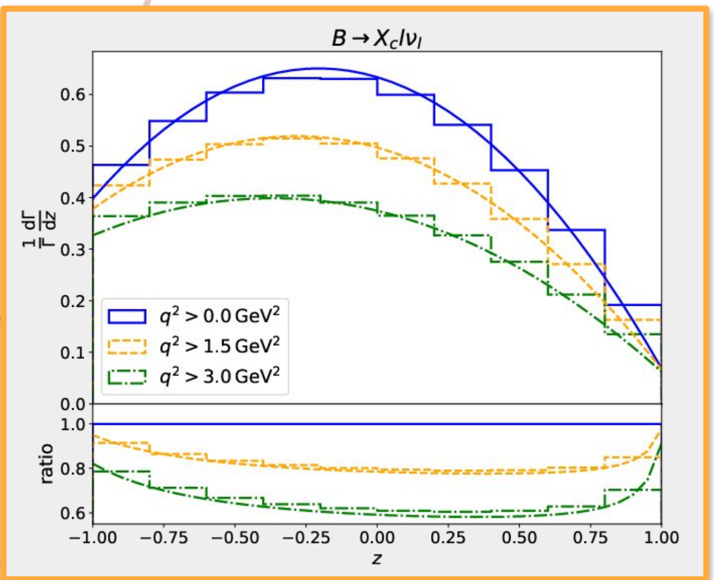
A cut of 3 GeV^2 realistic

Phys.Rev.D 104 (2021) 11, 112011

No measurement without cuts

Compare to Sherpa

FH, arXiv:2205:XXXX



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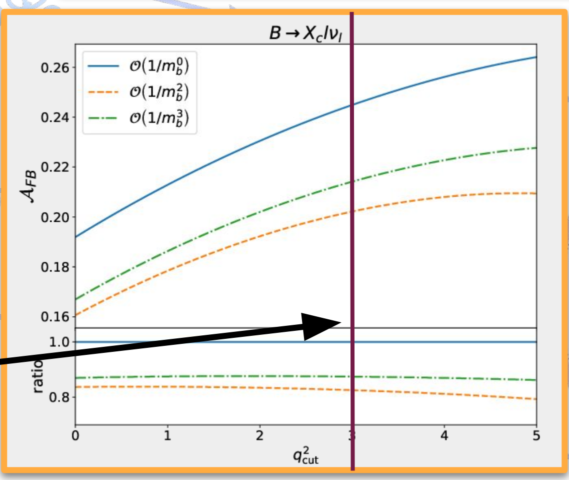

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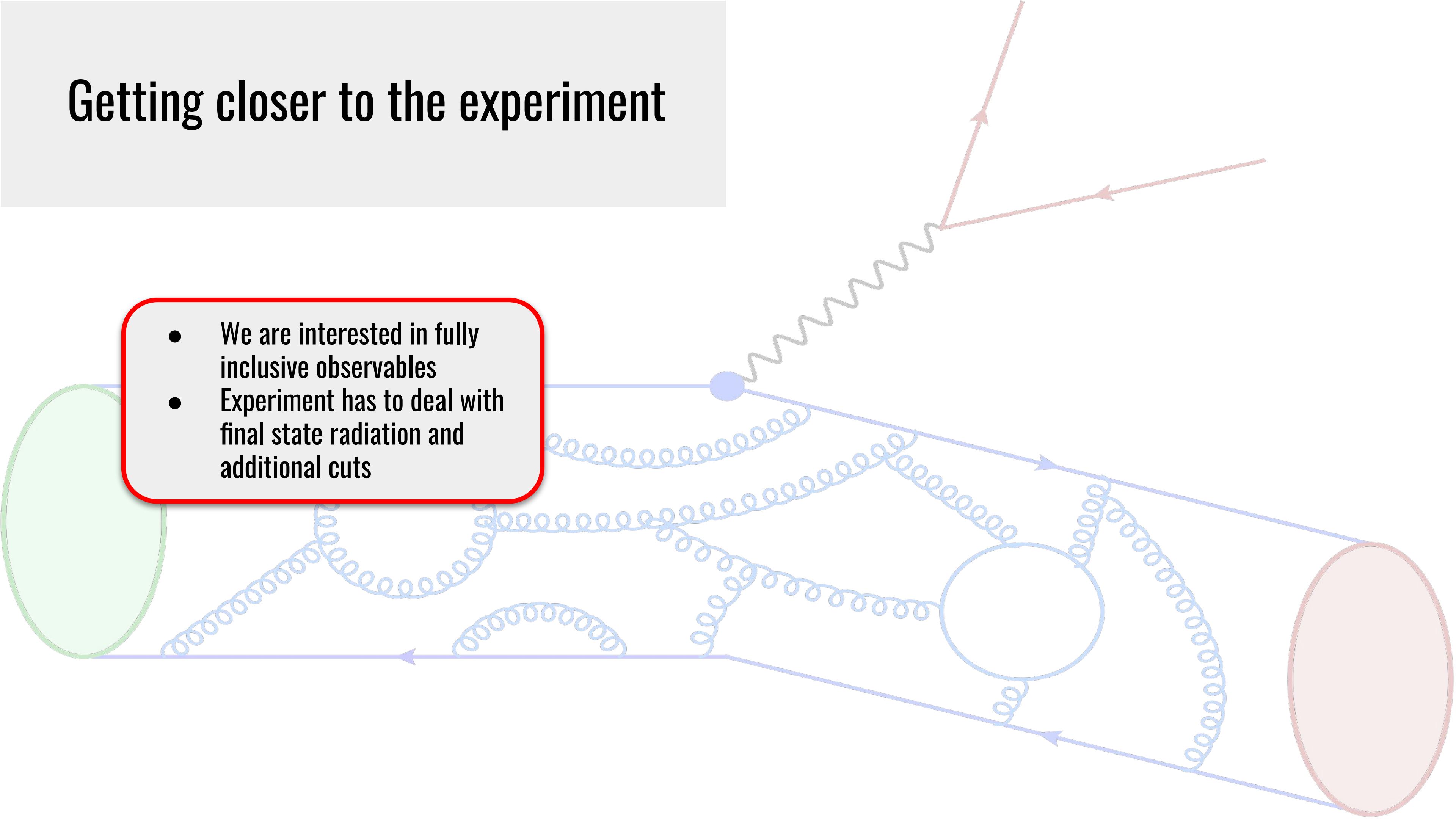
Getting closer to the experiment



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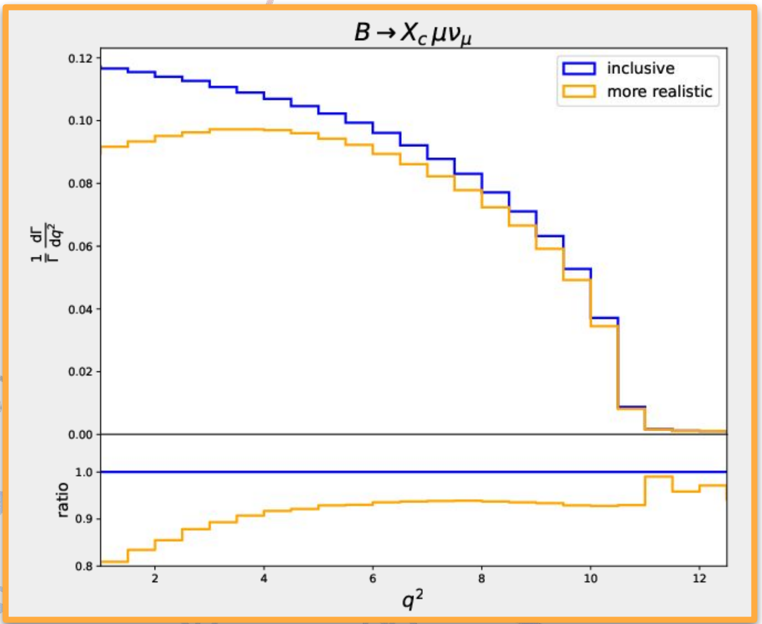

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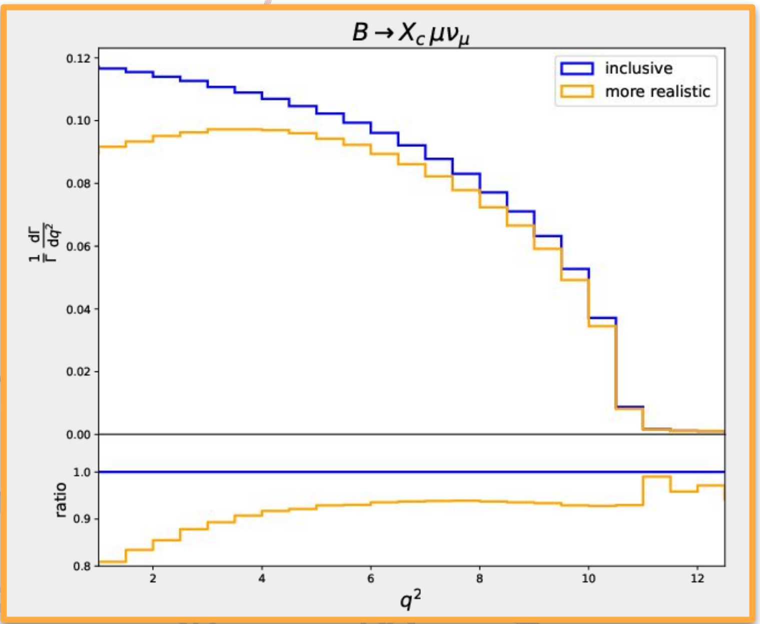
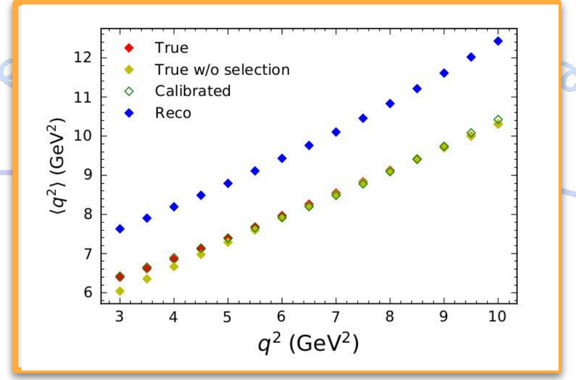
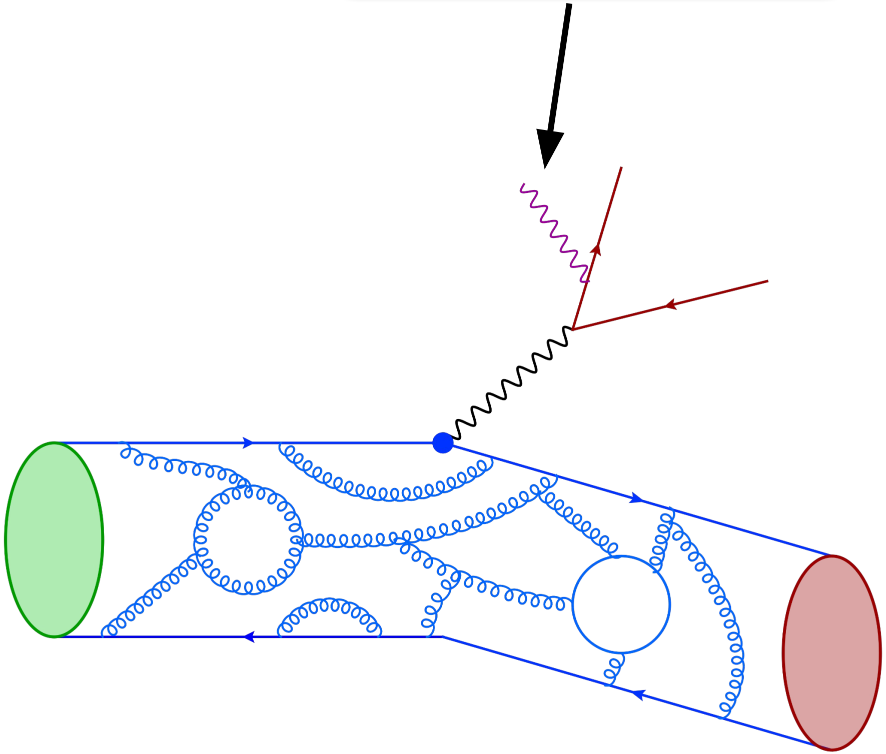




R. van Tonder, PhD Thesis, 2021

Finally: Some Radiation (FSR)

- FSR affects electrons more than muons
- Possibly larger impact on angular observables



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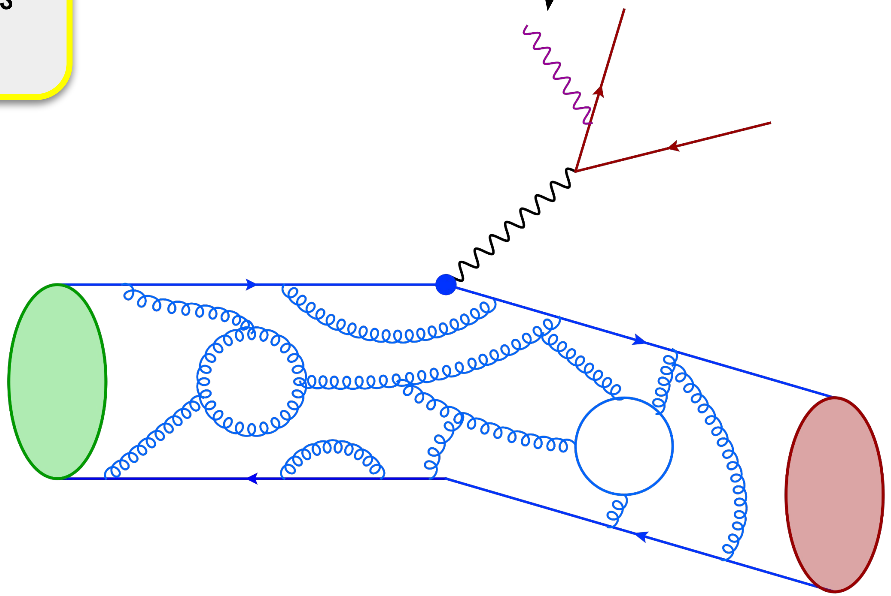

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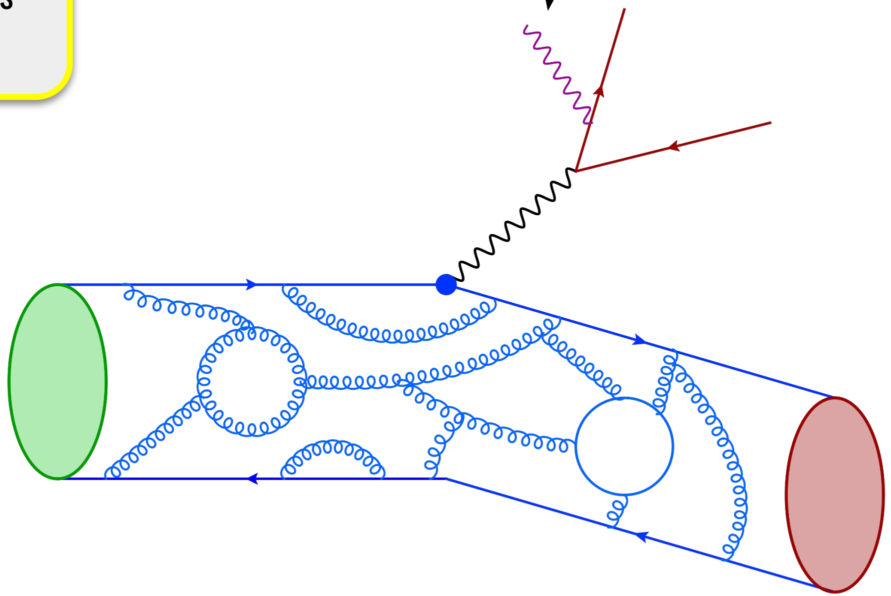

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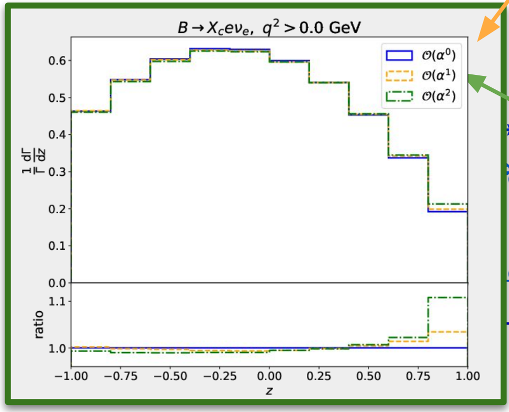
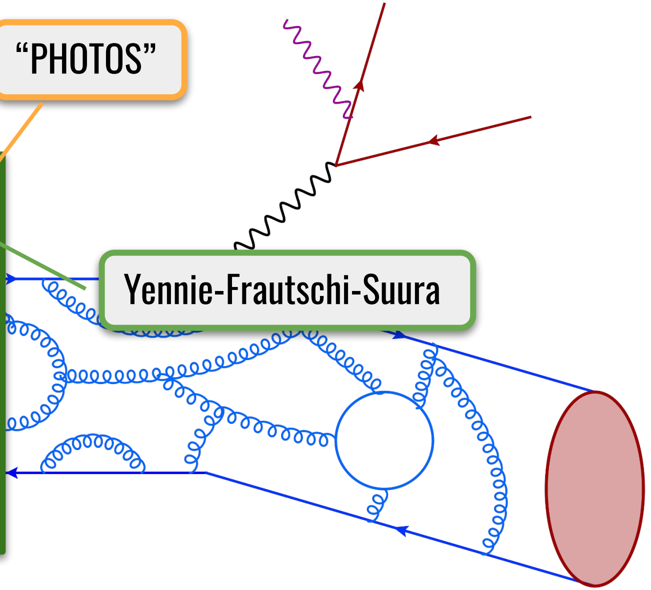


Yennie-Frautschi-Suura



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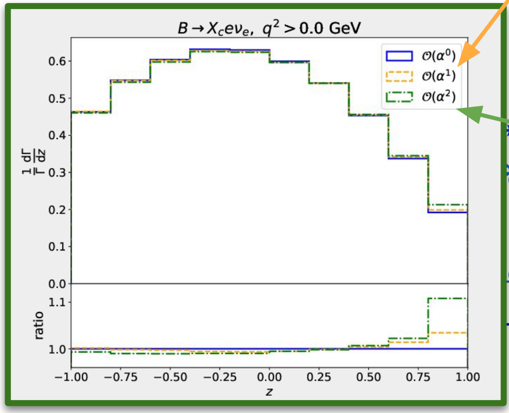

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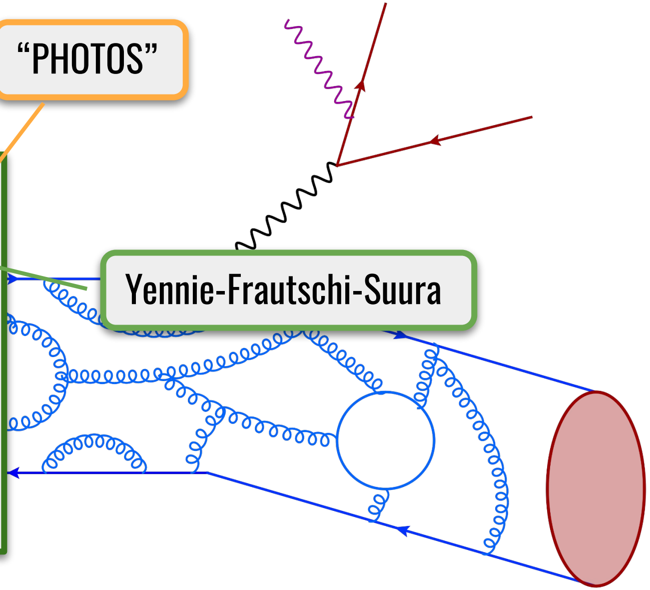

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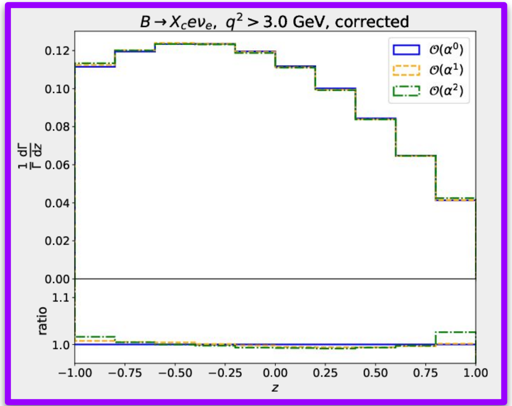
Finally: Some Radiation (FSR)

Cutting on q^2 improves situation



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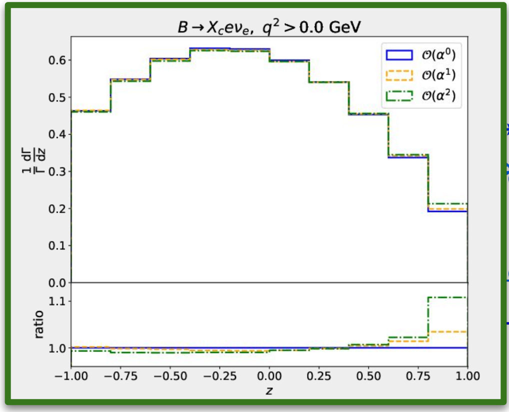

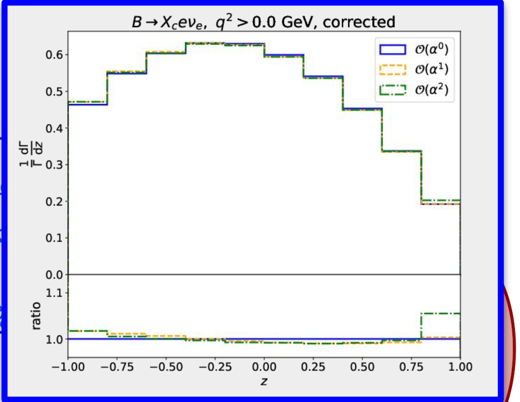

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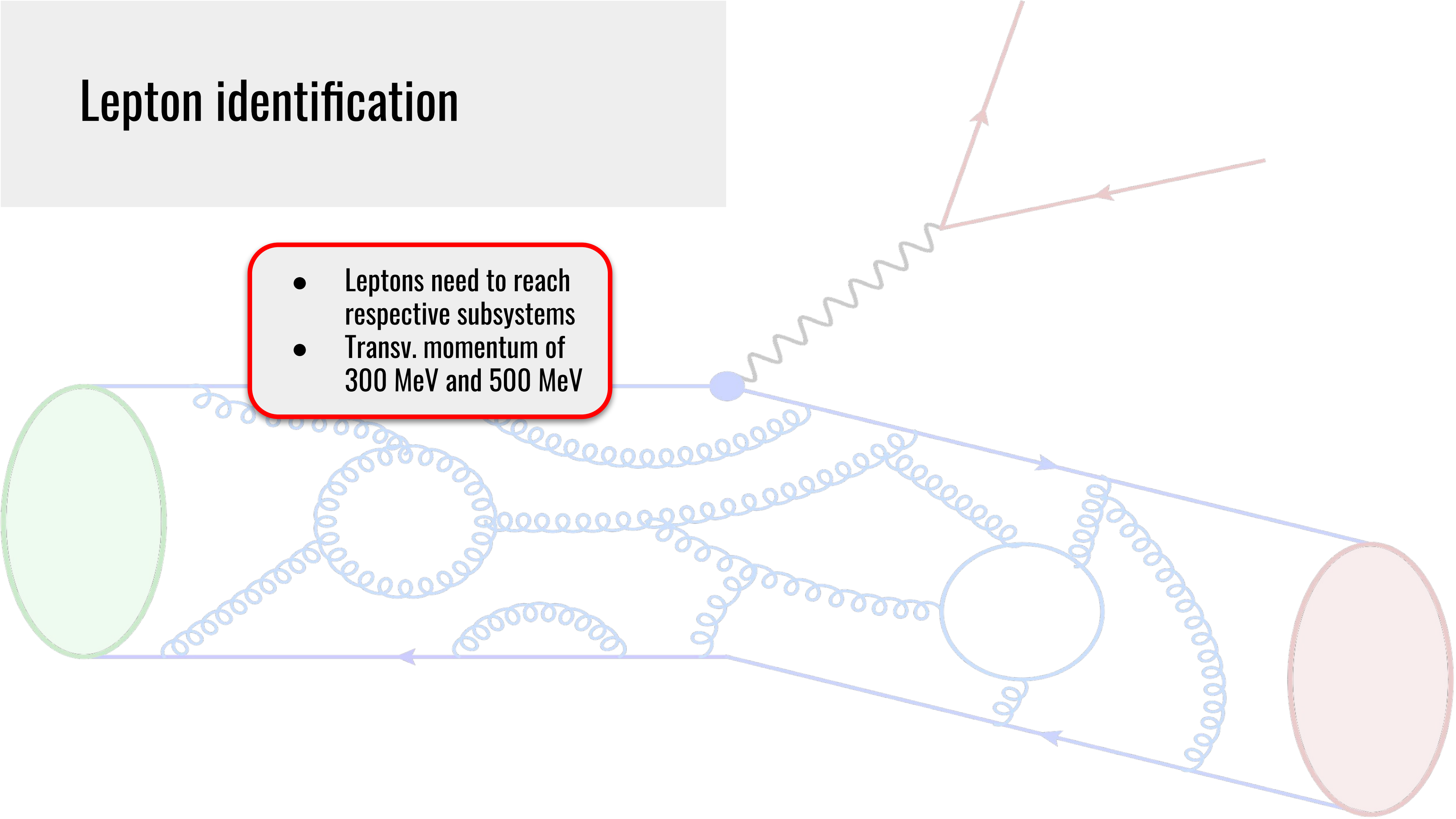
Lepton identification



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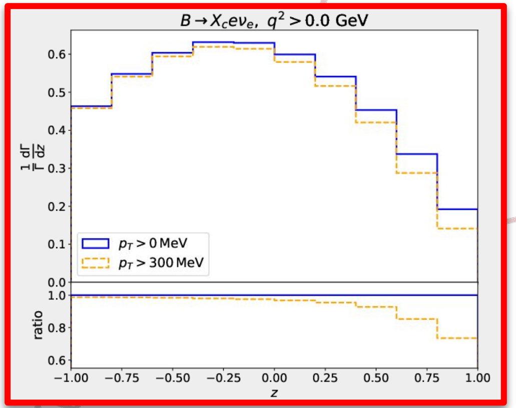

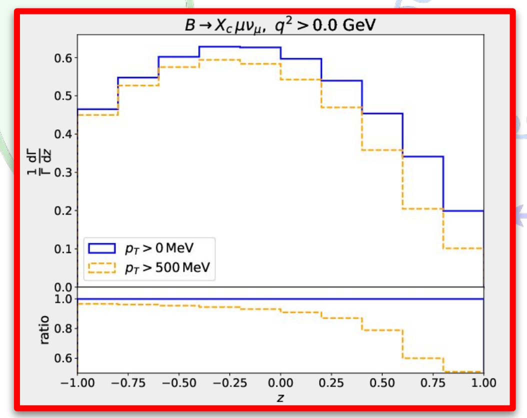

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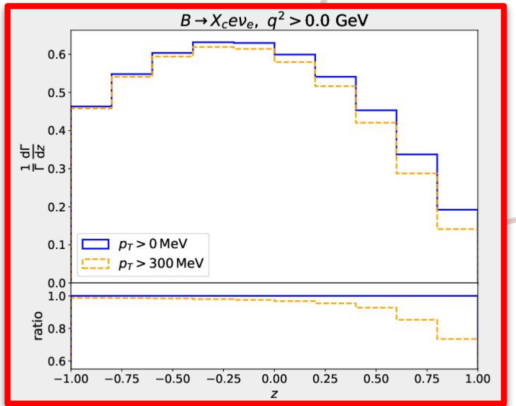
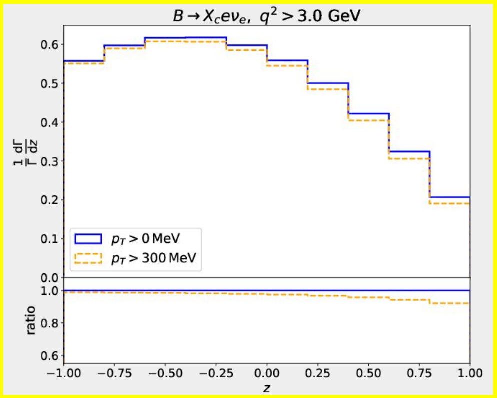
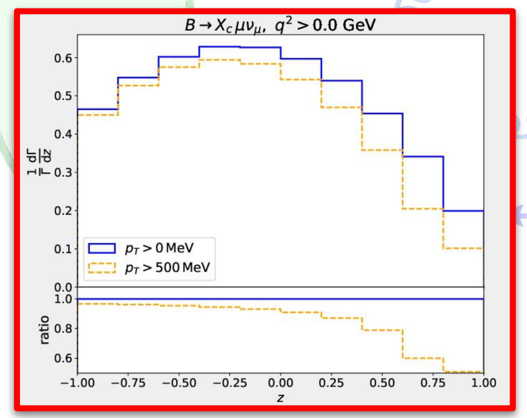
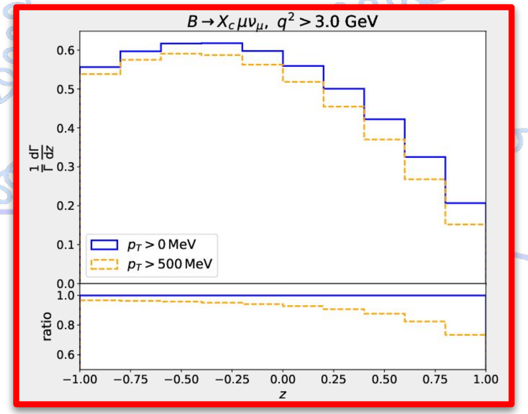


Cut on q^2







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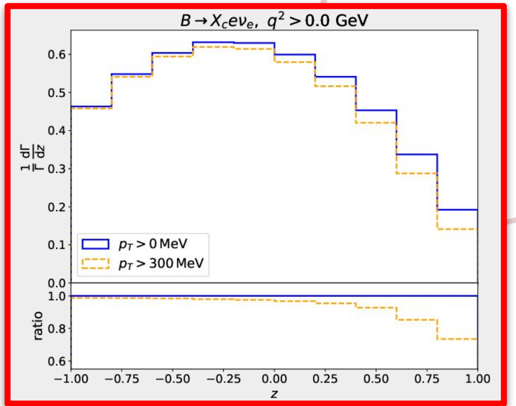

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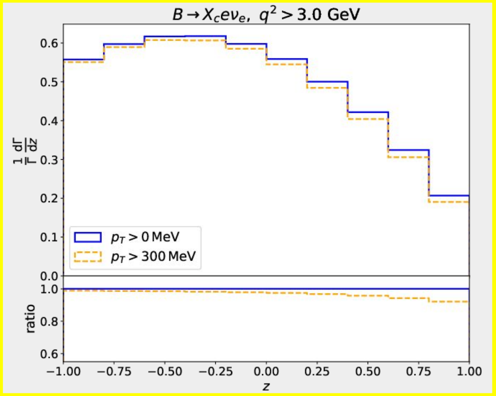

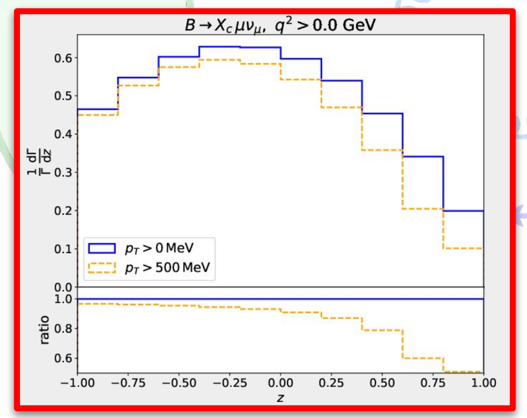

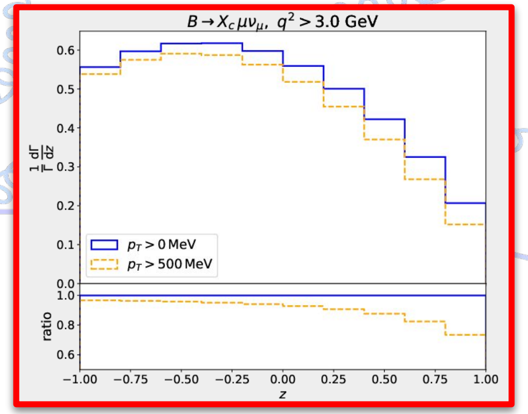

- Shifts $\mathcal{A}_{FB}$ for electrons by 6%
- Shifts $\mathcal{A}_{FB}$ for muons by 20%

→ Unfolding the distribution?

Conclusions & Outlook

Paper out later today!

Conclusions:

- Belle II has the unique ability to study angular observables in inclusive decays
- Angular observables provide additional information on nonperturbative parameters
- A cut on the invariant mass of the lepton-neutrino system is advantageous
- Final state radiation is under control
- Experimental analyses need to carefully correct for lepton identification requirements

Outlook:

- Inclusive decays can cross-check tensions with the SM in exclusive decays
- Measurement of the forward-backward asymmetry could be done already
- Need higher order radiative corrections to take full advantage of a measurement
- Can we do this for the tau?
  Need mass effects in the calculation
- Are there additional observables that could benefit CKM element determinations?