Background Suppression

Background Reduction (I)

Until now, I only considered MET and $\Delta\varphi$:

1) MET

$$\frac{\int_{40}^{100} \boxed{f_{\mathrm{ZB}}(\mathrm{MET})}\,\mathrm{dMET}}{\int_{0}^{100} \boxed{f_{\mathrm{ZB}}(\mathrm{MET})}\,\mathrm{dMET}} = \frac{0.029}{1}$$

MET distribution in Zero Bias data.
Taken from https://arxiv.org/pdf/2005.09554 (https://www.hepdata.net/record/ins1796953)
Figure 1b shows the HLT MET distr. under Run-2 conditions, i.e. $\langle\mu\rangle \sim 55$

2) $\Delta\varphi$

$$\frac{\int_{0}^{1} \boxed{f_{\mathrm{ZB}}(\Delta\varphi)}\,\mathrm{d}\Delta\varphi}{\int_{0}^{\pi} \boxed{f_{\mathrm{ZB}}(\Delta\varphi)}\,\mathrm{d}\Delta\varphi} = \frac{1}{\pi}$$

Assume that $\Delta\varphi$ between MET (N-1)
and jet (N) is uncorrelated in ZB, i.e.
$f_{\mathrm{ZB}}(\Delta\varphi) = \mathrm{const}\,.$

Background Reduction (II)

We have an additional BG reduction because of the jet:

3) Jet

	B2F	CR, low ET
Level 1	40 GeV	30 GeV + displaced
HLT	20 GeV + displaced	30 GeV + displaced
combined	**40 GeV + displaced**	**30 GeV + displaced**

**displaced: jet origin in HCAL + Jet must be trackless*

For a given SM jet with some E_T, we can estimate the probability that it passes the E_T and displacement cuts, X and Y, respectively:

$$\mathscr{P}(E_T > X \wedge d > Y | E_T) = \mathscr{P}(d > Y | E_T) \times \Theta(E_T - X)$$

The SM jet background can therefore be estimated as

$$\int_X^\infty \boxed{\mathscr{P}(d > Y | E_T)} \times \boxed{f_{\mathrm{ZB}}(E_T)} \, \mathrm{d}E_T$$

Probability that a jet with given E_T is "displaced"

Leading jet E_T (p_T) distribution in ZB

Background Reduction (III)

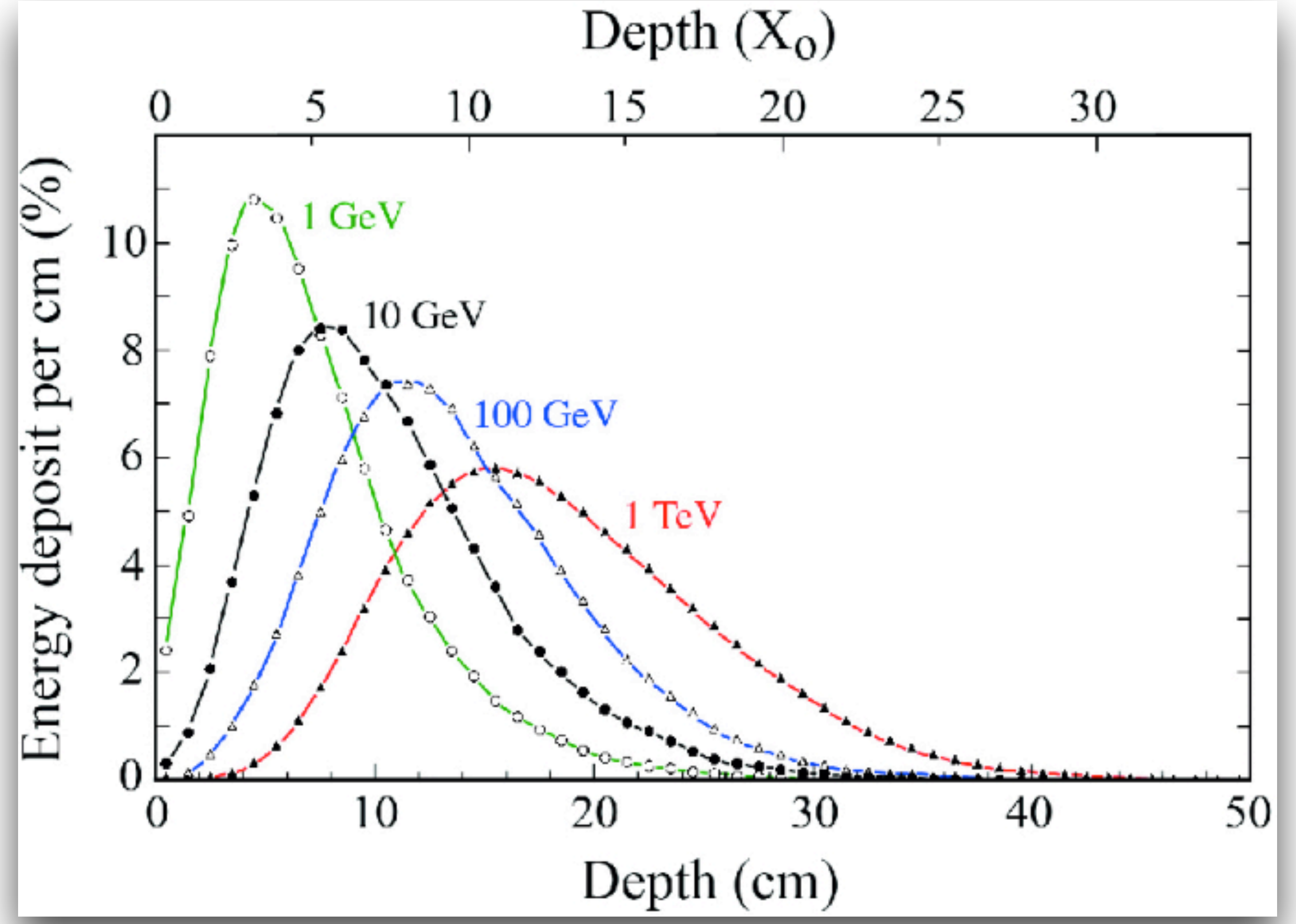
The SM jet background can therefore be estimated as

$$\int_X^\infty \boxed{\mathscr{P}(d > Y \mid E_T)} \times \boxed{f_{\text{ZB}}(E_T)}\, \mathrm{d}E_T$$

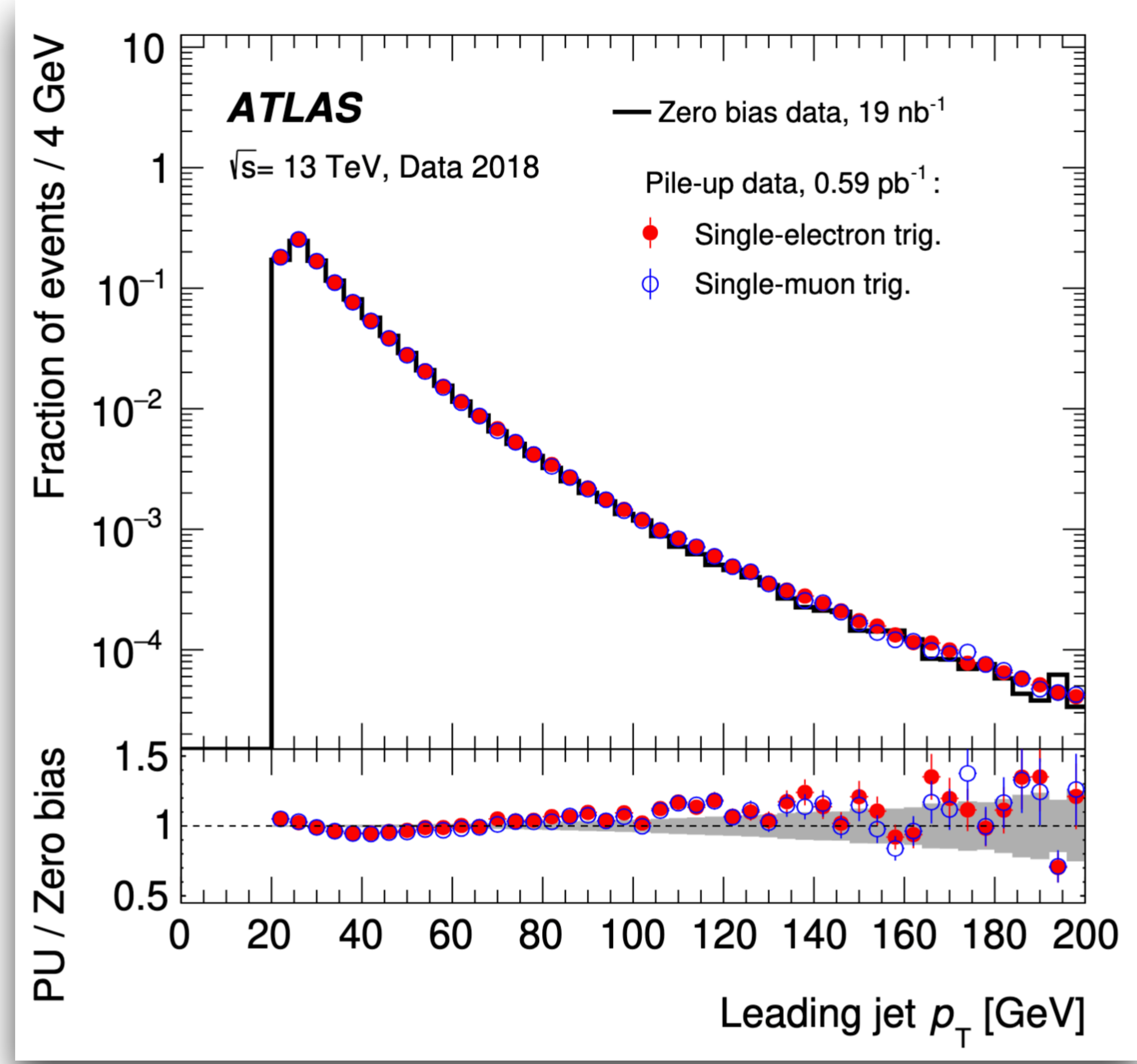
Probability that a jet with given E_T is "displaced"

Leading jet E_T (p_T) distribution in ZB → Can be extracted from e.g. https://doi.org/10.1007/JHEP12(2024)032 (unfortunately, no HEP Data link)

The shower depth depends logarithmically on the jet energy; also, the energy deposit per cm in the first Y cm is therefore somewhat anti-proportional to $\log E$



Given that $\log(E)$ is a rather weak dependence, it might be sufficient to assume $\mathscr{P}(d > Y \mid E_T) \approx \text{const}$.



Background Reduction (IV)

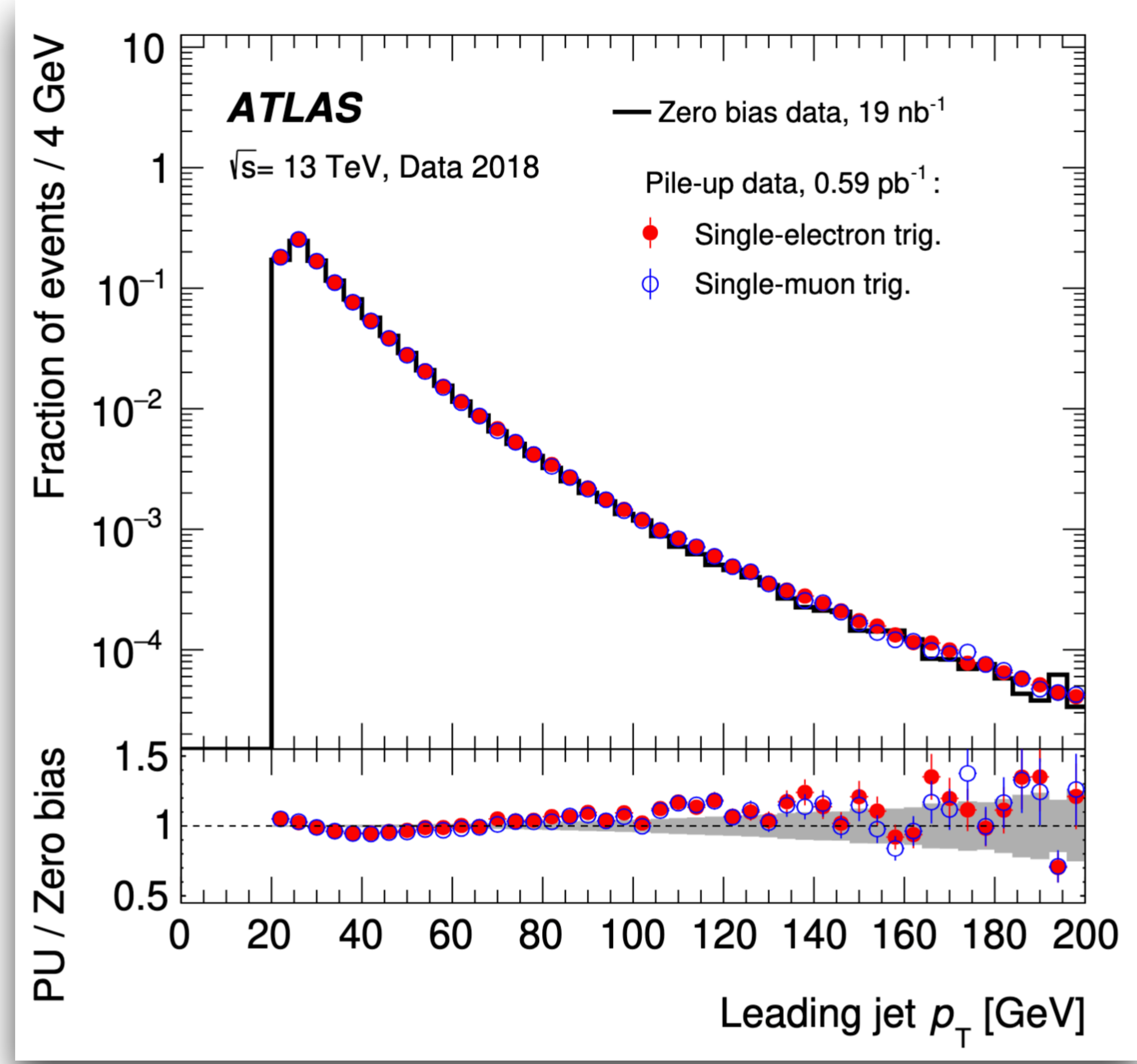
This simplifies the jet background reduction to

$$\frac{\int_{40}^{\infty} f_{\mathrm{ZB}}(E_T)\,\mathrm{d}E_T}{\int_{30}^{\infty} f_{\mathrm{ZB}}(E_T)\,\mathrm{d}E_T} = \frac{?}{?}$$

I'm reading from the graph (roughly):

pT	Frac
20 24	0.15
24 28	0.22
28 32	0.15
32 36	0.10
36 40	0.08
40 44	0.06
44 48	0.04
48 52	0.03
52 56	0.02
56 60	0.015
60 64	0.010
64 68	0.009
68 72	0.006
72 76	0.005

Splitting the 3rd bin into
[28,30]: 0.10
[30,32]: 0.05



This allows to make a rough estimate for our background suppression:

$$\int_{30}^{40} f_{\mathrm{ZB}}(p_T)\,\mathrm{d}p_T \approx 0.23$$

$$\int_{40}^{76} f_{\mathrm{ZB}}(p_T)\,\mathrm{d}p_T \approx 0.20$$

$$\Rightarrow \int_{30}^{\infty} f_{\mathrm{ZB}}(p_T)\,\mathrm{d}p_T \approx 0.43, \qquad \int_{40}^{\infty} f_{\mathrm{ZB}}(p_T)\,\mathrm{d}p_T \approx 0.20$$

Background Reduction (V)

In summary:

1) MET
$$\frac{\int_{40}^{100} f_{\mathrm{ZB}}(\mathrm{MET})\,\mathrm{dMET}}{\int_{0}^{100} f_{\mathrm{ZB}}(\mathrm{MET})\,\mathrm{dMET}} = \frac{0.029}{1}$$

2) $\Delta\varphi$
$$\frac{\int_{0}^{1} f_{\mathrm{ZB}}(\Delta\varphi)\,\mathrm{d}\Delta\varphi}{\int_{0}^{\pi} f_{\mathrm{ZB}}(\Delta\varphi)\,\mathrm{d}\Delta\varphi} = \frac{1}{\pi}$$

3) Jet
$$\frac{\int_{40}^{\infty} f_{\mathrm{ZB}}(p_T)\,\mathrm{d}p_T}{\int_{30}^{\infty} f_{\mathrm{ZB}}(p_T)\,\mathrm{d}p_T} = \frac{0.20}{0.43}$$

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4) Symmetry factor

Do we need to account that CR can fire in N-1 and N
(hence twice the possibility to get a fake jet)?

Signal Simulation

The `DipoleDM2_minimalH_UFO` generation seems to run for the following benchmark:

```
define p = g u c d s u~ c~ d~ s~
define j = g u c d s u~ c~ d~ s~
define c1 = ~chi1 ~chi1bar
define c2 = ~chi2 ~chi2bar
define c0 = ~chi0 ~chi0bar
generate p p > c1 c2 / h, (c1 > b b~ c0), (c2 > b b~ c0)
add process p p > c1 c2 j  / h,  (c1 > b b~ c0), (c2 > b b~ c0)
```

With the following settings

- `WS = w2 = w1 = w0 = auto`
- `MSd = 500, M2 = 250, M1 = 244, M0 = 154`
- `sina = 0.2`
- `ychi20 = 1`
- `ychi21 = 1`
- `Chxx10 = 0.1`
- `LambdaUV = 5000`

Previously, I was setting `ychi1 = 1`*, but I removed this option*

LLP boost and lifetime

$$t_{\text{readout}} = t_{\text{lab}} - \frac{L_{\text{lab}}}{c} = \frac{L_{\text{lab}}}{\beta c} - \frac{L_{\text{lab}}}{c}$$

$$\Rightarrow \beta = \frac{L_{\text{lab}}}{ct_{\text{readout}} + L_{\text{lab}}}$$

We're sensitive to LLP decays in the second BCs inside the HCAL, i.e.

- $t_{\text{readout}} \in (25 - 8, 25 + 8)\,\text{ns} = (17, 33)\,\text{ns}$
- $L_{\text{lab}} \in (2, 5)\,\text{m}$

That is, we're sensitive to $\beta \in (\beta_{\min}, \beta_{\max})$ with

- $\beta_{\min} = \min\left(\frac{L_{\min}}{ct_{\max} + L_{\min}}, \frac{L_{\max}}{ct_{\max} + L_{\max}}\right)$
- $\beta_{\max} = \max\left(\frac{L_{\min}}{ct_{\min} + L_{\min}}, \frac{L_{\max}}{ct_{\min} + L_{\max}}\right)$

N.B. LLP decay in 2nd BC and inside HCAL $\Rightarrow \beta \in (\beta_{\min}, \beta_{\max})$,
but not $\beta \in (\beta_{\min}, \beta_{\max}) \Rightarrow$ LLP decay in 2nd BC and inside HCAL

LLP decay probability

$$P(t) = \exp\left(-\frac{t_{\text{lab}}}{\gamma\tau_0}\right) = \exp\left(-\frac{t_{\text{readout}} + L_{\text{lab}}/c}{\gamma\tau_0}\right)$$
$$= \exp\left(-\frac{t_{\text{readout}}}{\gamma\tau_0}\right) \times \exp(-\beta)$$

Integrated from $t_{\min}$ to $t_{\max}$ and normalised, this becomes

$$\mathscr{P}(\gamma, \tau_0) = \exp\left(-\frac{t_{\min}}{\gamma\tau_0}\right) - \exp\left(-\frac{t_{\max}}{\gamma\tau_0}\right)$$

$$\mathscr{P}(\gamma, \tau_0) = \exp\left(-\frac{t_{\min}}{\gamma\tau_0}\right) - \exp\left(-\frac{t_{\max}}{\gamma\tau_0}\right)$$ with

$t_{\mathrm{readout}} \in (25-8, 25+8)\,\mathrm{ns} = (17, 33)\,\mathrm{ns}$ and

$\beta \in (\beta_{\min}, \beta_{\max})$