Towards Pixel-Based Imaging of Transverse Momentum Distributions

Marco Zaccheddu- Jefferson Lab
In collaboration with: Nobuo Sato
Science at the Luminosity Frontier - Jefferson Lab at 22GeV

Jefferson Lab

Traditional model based approach “Model calibration”

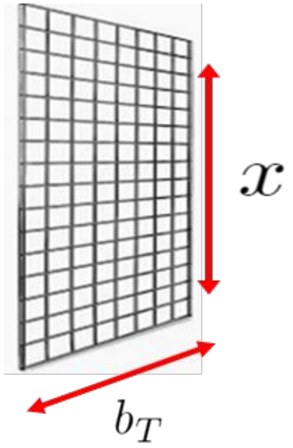
$$f_{1\,NP}(x, \boldsymbol{b}_T^2; \zeta, Q_0) = \frac{g_1(x)\, e^{-g_1(x)\frac{\boldsymbol{b}_T^2}{4}} + \lambda^2\, g_2^2(x) \left[1 - g_2(x)\frac{\boldsymbol{b}_T^2}{4}\right] e^{-g_2(x)\frac{\boldsymbol{b}_T^2}{4}} + \lambda_2^2\, g_3(x)\, e^{-g_3(x)\frac{\boldsymbol{b}_T^2}{4}}}{g_1(x) + \lambda^2\, g_2^2(x) + \lambda_2^2\, g_3(x)}$$

$$D_{1\,NP}(z, \boldsymbol{b}_T^2; \zeta, Q_0) = \frac{g_4(z)\, e^{-g_4(z)\frac{\boldsymbol{b}_T^2}{4z^2}} + \frac{\lambda_F}{z^2}\, g_5^2(z) \left[1 - g_5(z)\frac{\boldsymbol{b}_T^2}{4z^2}\right] e^{-g_5(z)\frac{\boldsymbol{b}_T^2}{4z^2}}}{g_4(z) + \frac{\lambda_F}{z^2}\, g_5^2(z)}$$

- Injects model biases
- Fitting TMDs are more about calibrating the model
- Uncertainties are a combination between data and TMD model

Pixel based approach

$$\tilde{f}_1(x, b_T; Q^2)$$
$$\tilde{D}_1(z, b_T; Q^2)$$



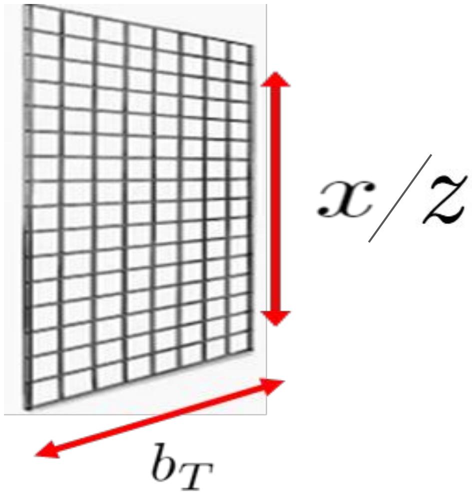
- TMDs as D-dimensional ‘’pictures’’
- Discretize using a grid
- Fit/tune each pixels of the grid
- Free of parametrization bias
- Well-suited for Neural Networks

Pixelization of TMDs

- Pixelization of non-perturbative part
- Q^2 dependence dictated by evolution equations

$$\widetilde{f}(x, b_T) = OPE \cdot Sudakov \cdot M_f(x, b_T) \qquad \widetilde{D}(z, b_T) = OPE \cdot Sudakov \cdot M_D(z, b_T)$$

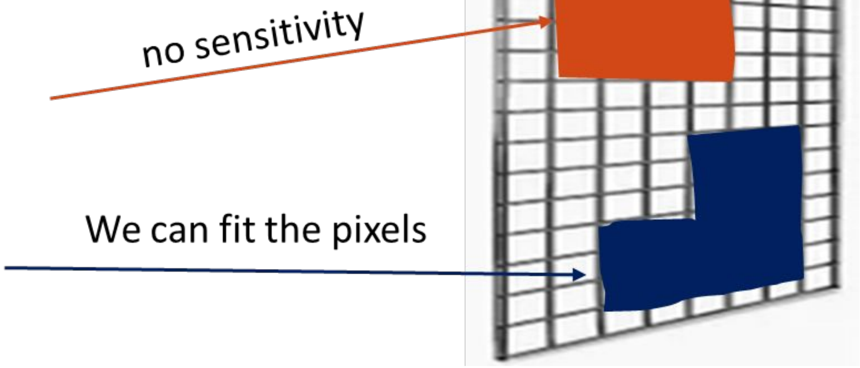
$$M_f(x, b_T) \big/ M_D(z, b_T) \longrightarrow$$



Pixelization of TMDs

We can calculate the variation of the χ^2 w.r.t. the variation of each single pixel

$$\frac{\Delta\chi^2}{\Delta\text{pixel}} \begin{cases} = 0 \\ \neq 0 \end{cases}$$



SIDIS Multiplicities from Compass

- Case study: TMD fitting from SIDIS multiplicities from COMPASS experiment.
- What information can be extracted about PDFs and FFs?
- We will focus on a specific subset of the data.

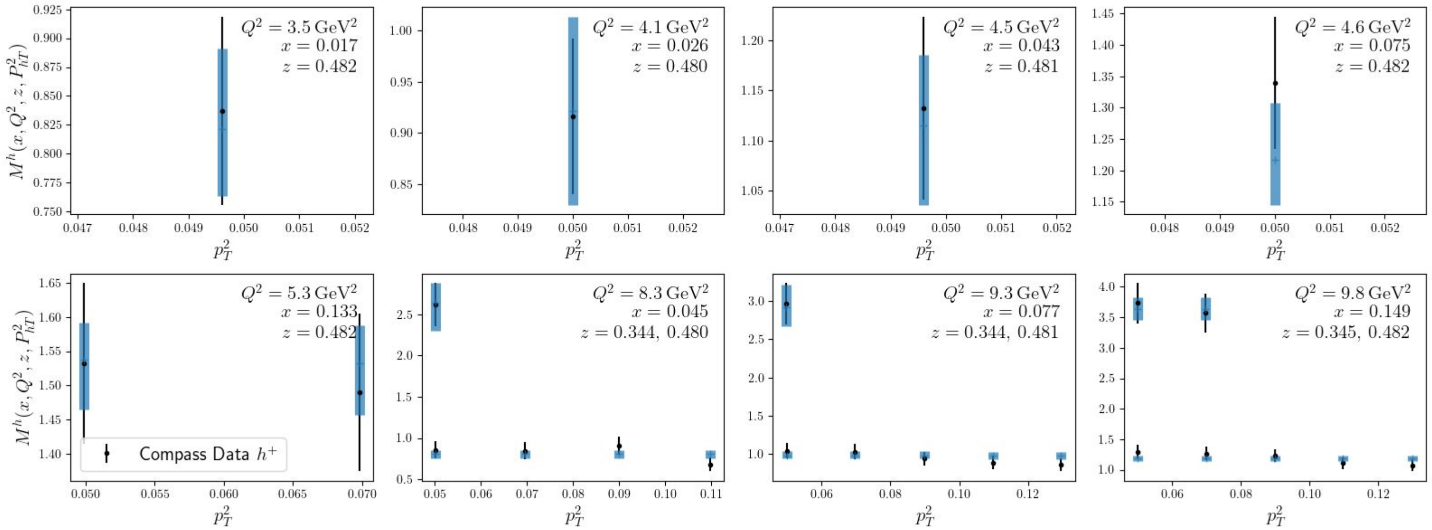
Q^2	$> 2.4\, GeV^2$
had	h^+
z	< 0.6
p_T	$> 0.2\, GeV$
q_T/Q	< 0.25

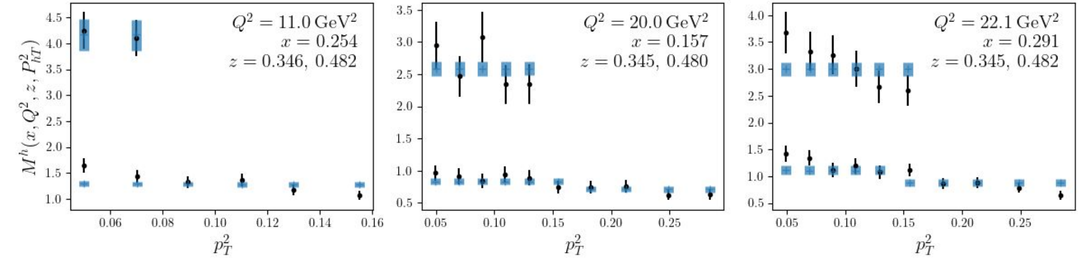
$$\frac{d^2 M^h(x, Q^2, z, P_{hT}^2)}{dz dP_{hT}^2} = \left(\frac{d^4\sigma^h}{dx dQ^2 dz dP_{hT}^2} \right) \Big/ \left(\frac{d^2\sigma^{DIS}}{dx dQ^2} \right)$$

$$\frac{d\sigma}{dx dy d\psi dz d\phi_h dP_{h\perp}^2} = \frac{\alpha^2}{xyQ^2} \frac{y^2}{2(1-\epsilon)} \left(1 + \frac{\gamma^2}{2x}\right) F_{UU,T}$$

$$F_{UU}(x, z, q_T) = x \sum_q e_q^2 \int \frac{db_T}{2\pi} b_T J_0(b_T q_T) \tilde{f}_1(x, b_T) \tilde{D}_1(z, b_T)$$

SIDIS Multiplicities from Compass





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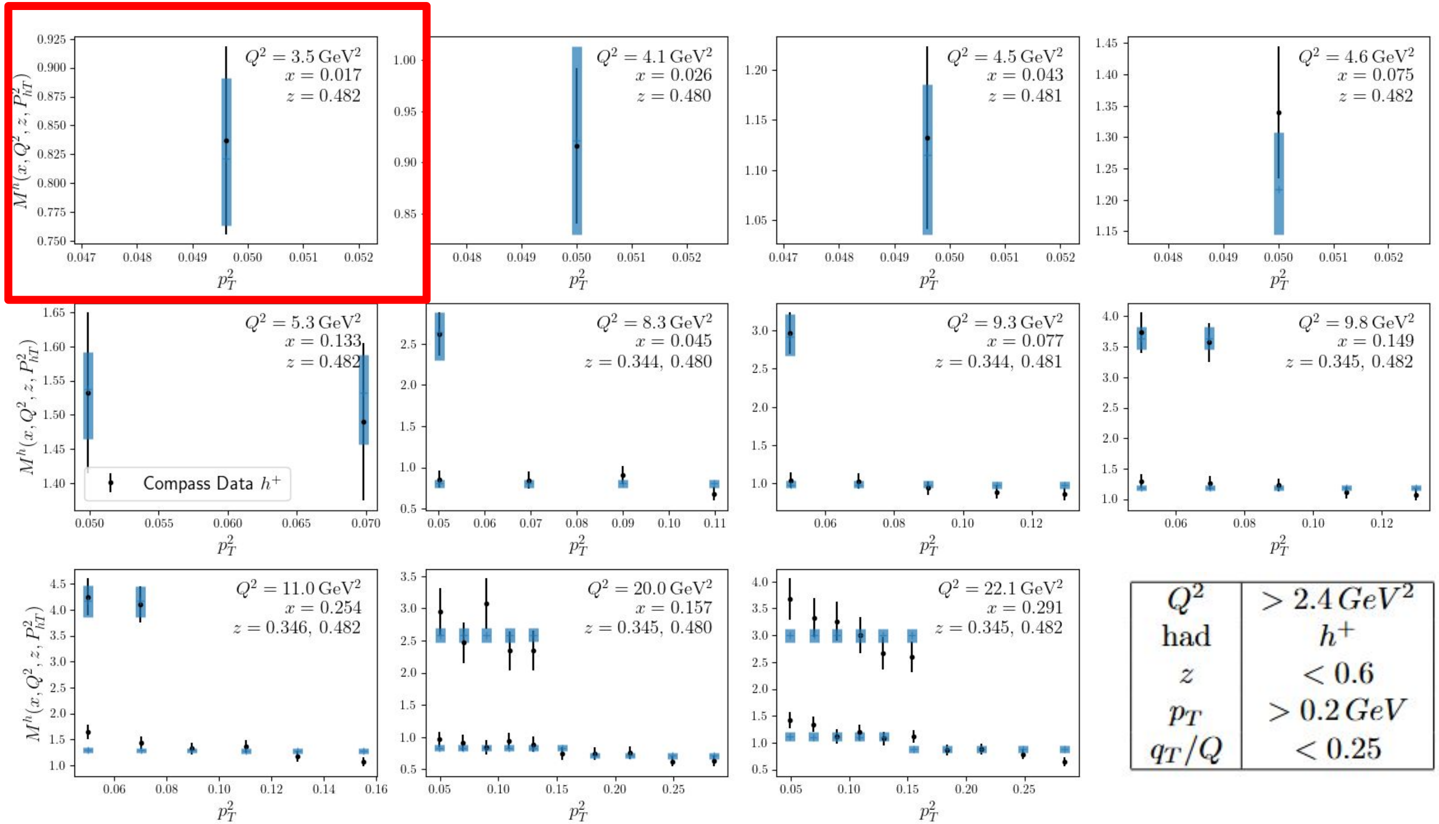
$$\chi^2_{pts} \approx 1$$

SIDIS Multiplicities from Compass



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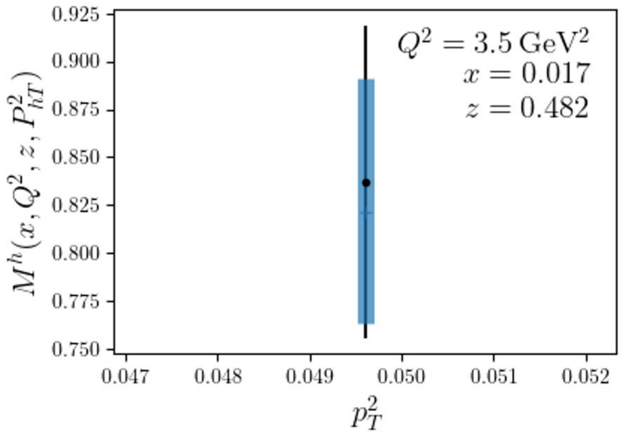
SIDIS Multiplicities from Compass

What information can we extract from this single data point?

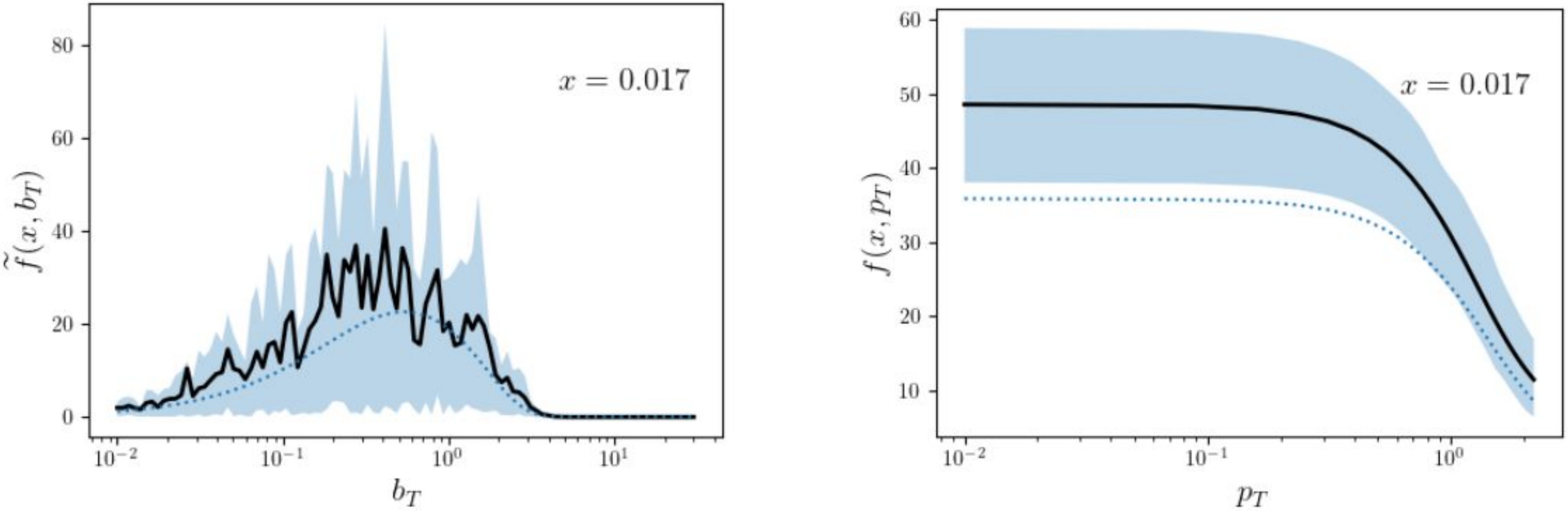


$$F_{UU}(x,z,q_T) = x\sum_q e_q^2 \int \frac{db_T}{2\pi} b_T J_0(b_T q_T)\tilde{f}_1(x,b_T)\tilde{D}_1(z,b_T)$$

- We can obtain information about the area of this integral.
- We can extract information about the PDF at this specific x-value and the FF at this specific z-value.

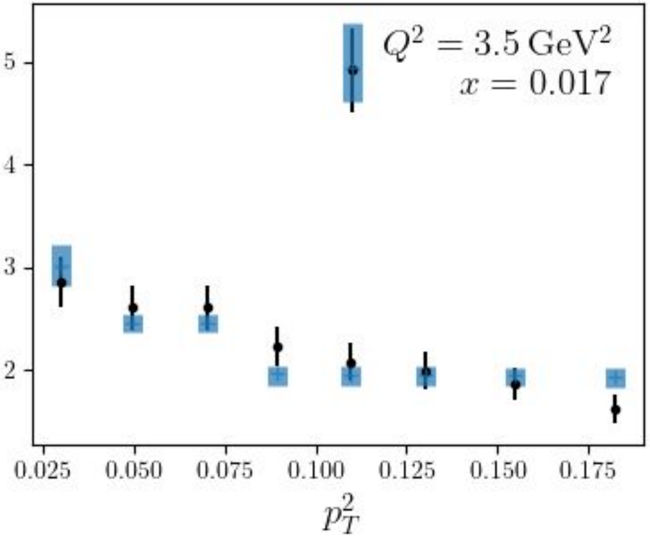
SIDIS Multiplicities from Compass

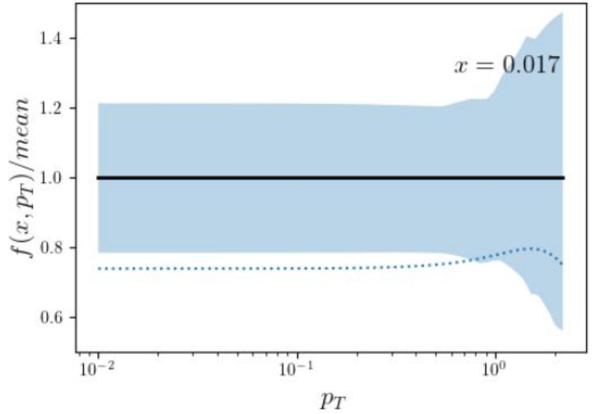
The TMD PDF is not well-constrained at this specific x, and a more robust reconstruction requires additional data points at different pT values.

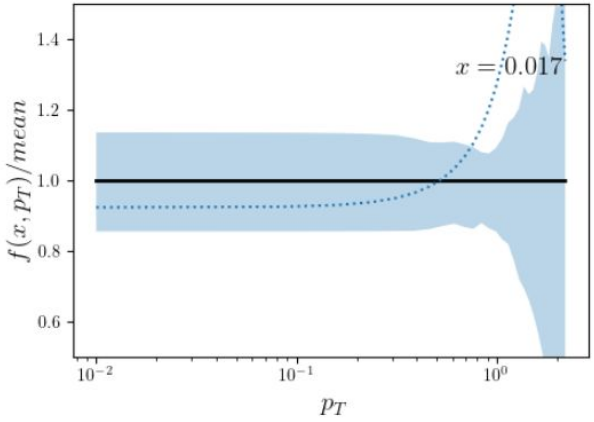


SIDIS Multiplicities from Compass

By adding more points in pT,
we can better constrain the PDF.







Why do we need multidimensional analysis?

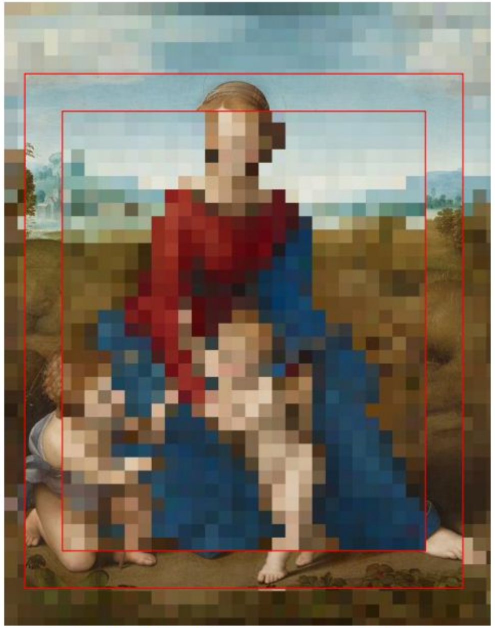
- SIDIS cross sections, multiplicities, and asymmetries involve multiple variables (x, Q^2, P_T, z).
- A one-dimensional analysis might overlook crucial dependencies
- Multi-dimensional analysis allows for more comprehensive understanding of these dependencies.

- It allows us to better constrain TMDs and understand them for a wider range of x, z values, as well as test evolution equations.
- It allows us to better disentangle FFs from PDFs.

Why do we need multidimensional analysis?

From Bakur's talk

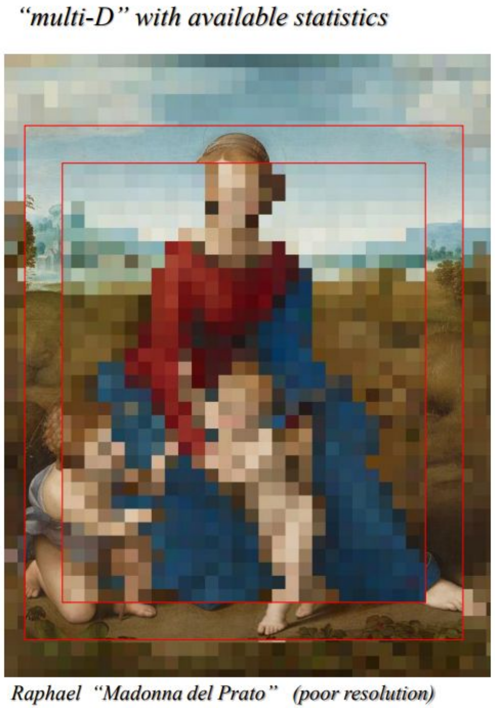
"multi-D" with available statistics

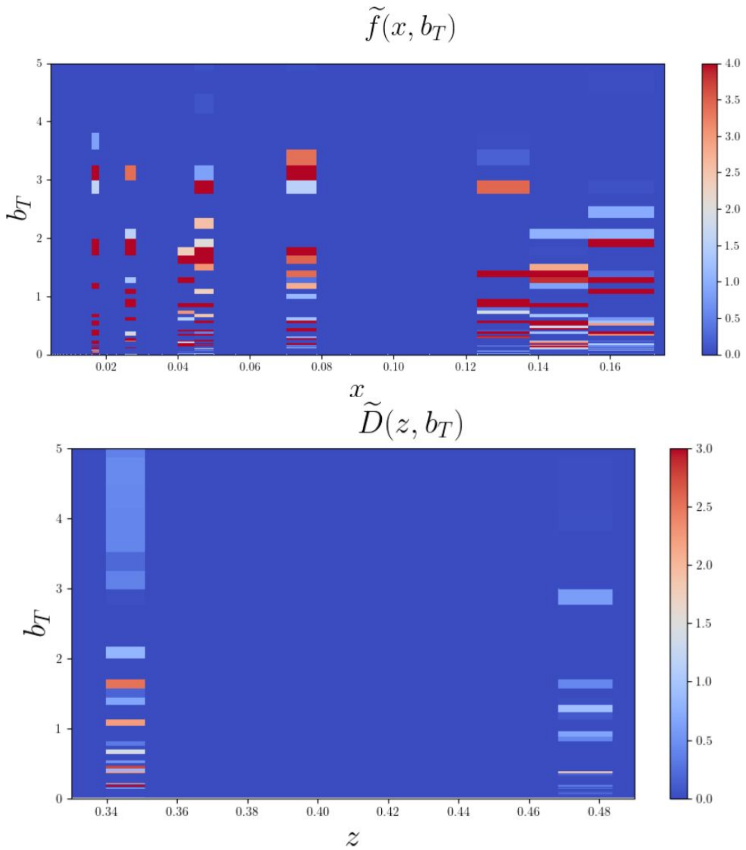


Raphael "Madonna del Prato" (poor resolution)

Why do we need multidimensional a

From Bakur’s talk





Thanks for the attention!