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GÖTTINGEN

Machine learning for top reconstruction

Steffen Korn
II. Physikalisches Institut, Georg-August-Universität Göttingen
Lower Saxony – Scotland Joint Forum
22 November 2022

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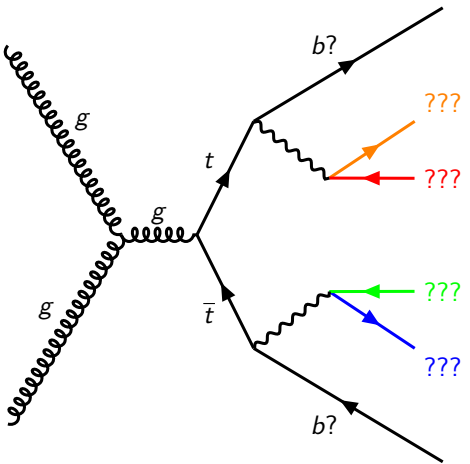
The Problem



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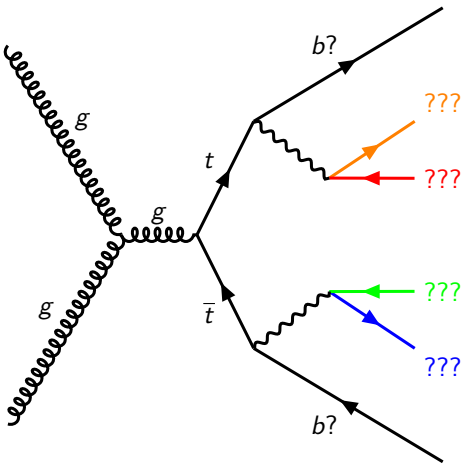

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  $\rightarrow$ Identify **electrons, muons**, (τ-leptons)

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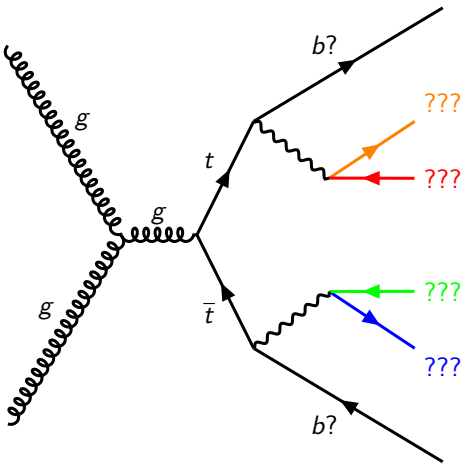

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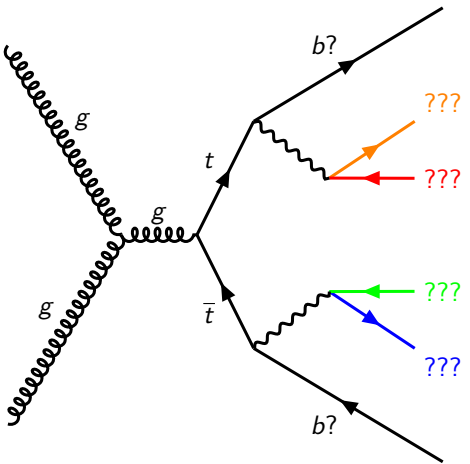

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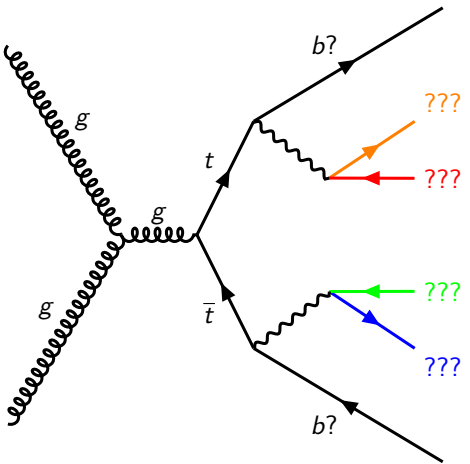

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We need performant top-reco algorithms for single-top, $t\bar{t}$, $t + X$, and $t\bar{t} + X$

The ML approach

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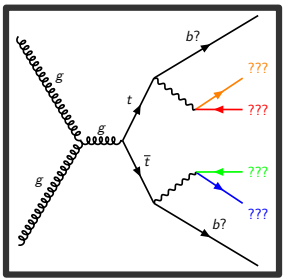
Ingredient 1



- Jets
- Leptons
- Neutrinos

Ingredient 2

More
- Jets
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The ML approach

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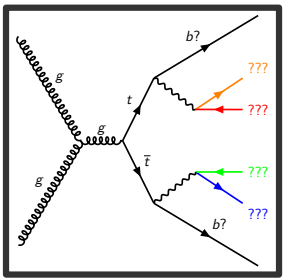

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- 2 major top quark reconstruction approaches:

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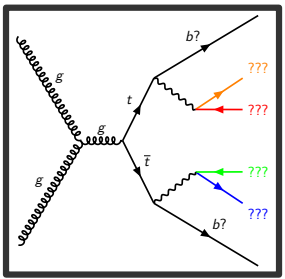

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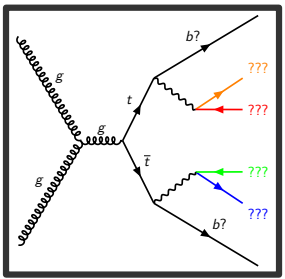

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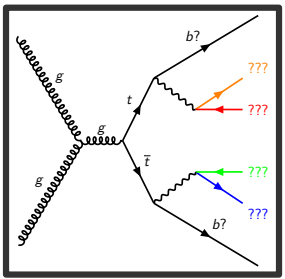

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- In Regression we search for $\hat{y}_{\text{top}p_T}$ directly $\rightarrow$ optimise cost$(\hat{y}_{\text{top}p_T}, y^{\text{true}}_{\text{top}p_T})$
- For jet-parton assignement we need $\hat{y}_{i \in \text{jets}} \rightarrow$ usually predict "jet labels"
- In addition we can do mixtures of both $\rightarrow$ global top variables & jet-parton assignement

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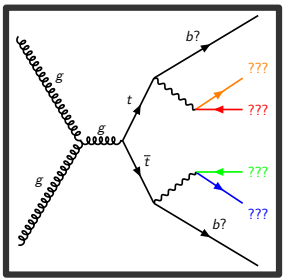

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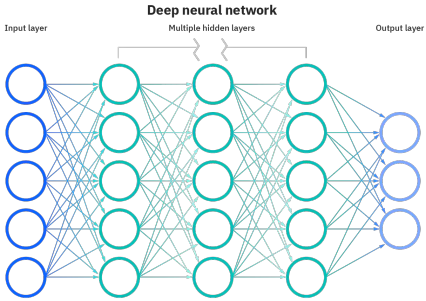
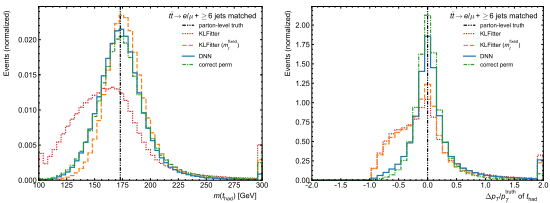
In this talk: some pointers to algorithms/methods out there

Reconstruction with DNN



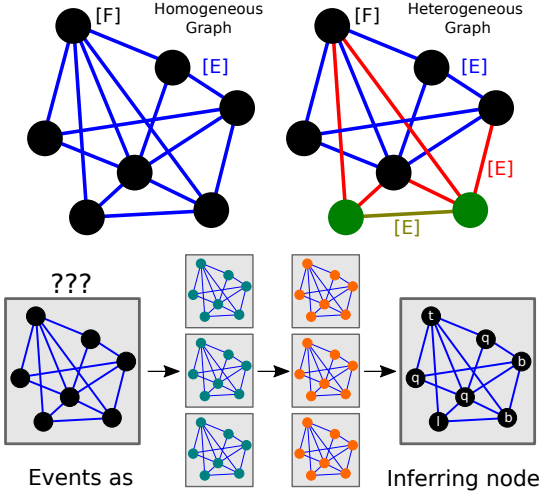


- Simple and quick to construct (e.g. using Tensorflow or Pytorch)
- Here: Prediction of jet labels in $t\bar{t}$ ℓ+jets final states $\rightarrow$ Classification w.r.t. to correct/incorrect jet-parton permutations.
- Direct regression of variable of interest also possible (but less common)
- Fixed input and output size $\rightarrow$ not very versatile

Jet Selection	Reconstruction Efficiency			
	all	W_{had}	b_{had}	b_{lep}
$\geq$4	80.2%	85.0%	82.2%	89.9%
$\geq$5	66.6%	75.8%	76.7%	83.6%
$\geq$6	57.1%	68.3%	72.7%	79.3%

arXiv:1907.11181

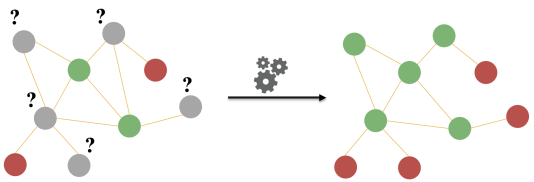
Reconstruction with GNNs

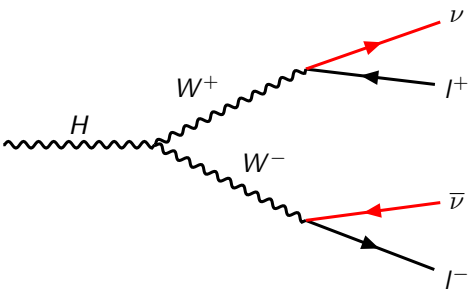


- Wideley used outside HEP, e.g. for social networks, drug/molecule classification, ...
- Independent of jet multiplicity $\rightarrow$
- Similar to 2D conv. networks $\rightarrow$ convolutions along edges in "graph-space"
- Events can be described by adjacency matrix, A, node features ($[F]$), and edge features ($[E]$).
- Usually done with PYG

$$\mathcal{G}_1 = (\mathbf{X}_1, \mathbf{A}_1)$$
$$\mathcal{G}_2 = (\mathbf{X}_2, \mathbf{A}_2)$$
$$\mathrm{GNN}\left(\begin{bmatrix} \mathbf{A}_1 & \\ & \mathbf{A}_2 \end{bmatrix}, \begin{bmatrix} \mathbf{X}_1 \\ \mathbf{X}_2 \end{bmatrix}\right) = \begin{bmatrix} \mathbf{X}'_1 \\ \mathbf{X}'_2 \end{bmatrix}$$

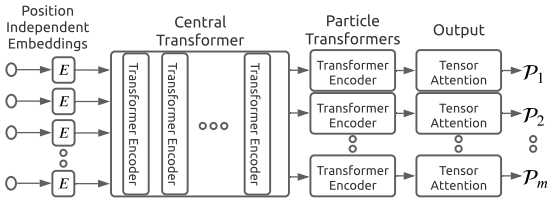
Difficult/Invisible objects





- Often we have to work with incomplete information (e.g. from neutrinos)
- E.g. in $H \to W^+W^- \to \ell^+\ell^-\bar{\nu}\nu$
- Need for algorithms that are "agnostic" to this problem
- GNN could help here through node classification/regression $\to$ attempt to reconstruct neutrino four momenta as features of nodes
- Common problem outside HEP, not really used in HEP yet

Reconstruction with SPANet

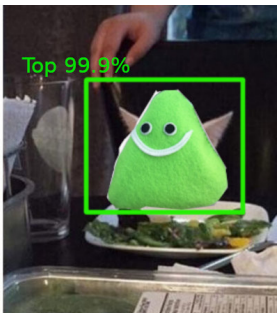


	N_{jets}	Event Fraction	SPA-NET Efficiency Event	SPA-NET Efficiency Top Quark	χ^2 Efficiency Event	χ^2 Efficiency Top Quark
All Events	== 6	0.245	0.643	0.696	0.424	0.484
	== 7	0.282	0.601	0.667	0.389	0.460
	≥ 8	0.320	0.528	0.613	0.309	0.384
	Inclusive	**0.848**	**0.586**	**0.653**	**0.392**	**0.457**
Complete Events	== 6	0.074	0.803	0.837	0.593	0.643
	== 7	0.105	0.667	0.754	0.413	0.530
	≥ 8	0.145	0.521	0.662	0.253	0.410
	Inclusive	**0.325**	**0.633**	**0.732**	**0.456**	**0.552**

- SPANet = *Symmetry Preserving Attention Networks*
- Aims at jet-parton assignment in $t\bar{t} + (X)$
  1. NN attempts to solve jet-parton assignment sub-problems
  2. Combination of sub-problens into final jet-parton assignment
- Avoiding calculation of all permutations → run-time improvement
- Able to reconstruct partial events

arXiv:2106.03898, Github

Summary and Conclusion



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