# SPIF STATUS

Stefano Carrazza

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Università degli Studi di Milano and INFN Sezione di Milano

Machine Learning • PDFs • QCD

# Group overview

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- Local and national org.: **Alessandro Vicini**
- National network: Milano, Genova, Torino, Roma III
- CERN groups: PDF4LHC, LHeC, Higgs WG, EW WG
- National and international collaborations: +34 universities

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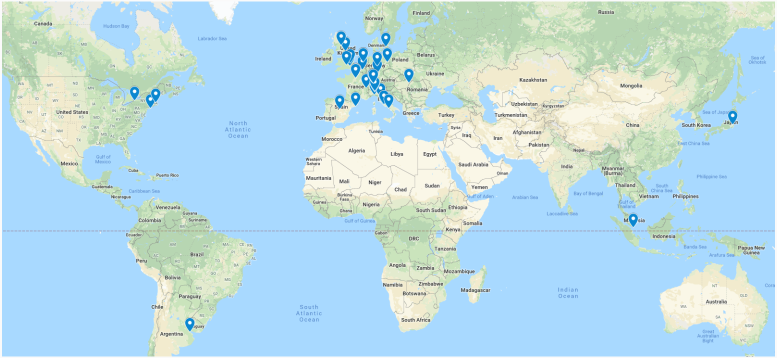


# Group members

| Name | INFN position | Time percentage | Details |
|---|---|---|---|
| Vito Antonelli | Associato | 30% | - |
| Stefano Carrazza* | Associato | 100% | RTD-B |
| Juan Cruz Martinez* | Associato | 100% | Assegnista |
| Stefano Di Vita | Associato | 100% | Assegnista INFN |
| Giancarlo Ferrera | Incarico di ricerca | 100% | Prof. |
| Stefano Forte | Incarico di ricerca | 100% | Prof. Ordinario |
| Tanjona Radonirina* | Associato | 100% | Dottorando |
| Narayan Rana | Associato | 100% | Assegnista INFN |
| Christopher Schwan* | Associato | 100% | Assegnista |
| Giovanni Stagnitto | Associato | 100% | Dottorando |
| Jesus Urtasun* | Associato | 100% | Dottorando |
| Alessandro Vicini | Incarico di ricerca | 100% | Prof. Associato |

**Table 1:** Current SPIF-MI members, * new members since 2019.

# Publications 2018 and 2019

| Publications | SPIF-MI | SPIF-all | % |
|---|---|---|---|
| 2018 | 6 | 21 | 29 |
| 2019 | 11 | - | - |

# Research topics

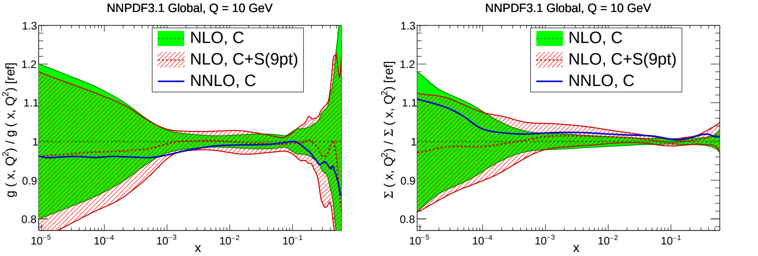
# Research Topics

- Parton distributions — *Forte, Carrazza, Cruz, Radonirina, Urtasun*
- Electroweak corrections — *Vicini, Ferrera, Rana, Carrazza, Schwan*
- Higher order corrections — *Vicini, Ferrera, Rana, Di Vita*
- Higgs and LHC phenomenology — *Forte, Vicini, Rana*
- Monte Carlo event generators — *Schwan, Ferrera*
- Machine learning for/from theoretical physics — *Carrazza*
- Neutrino physics — *Antonelli*

# Highlights

[arXiv:1905.04311 ‘19]

A first extraction of the proton PDFs that accounts for the missing higher order uncertainty (MHOU) in the fixed-order QCD calculations used in PDF determinations.

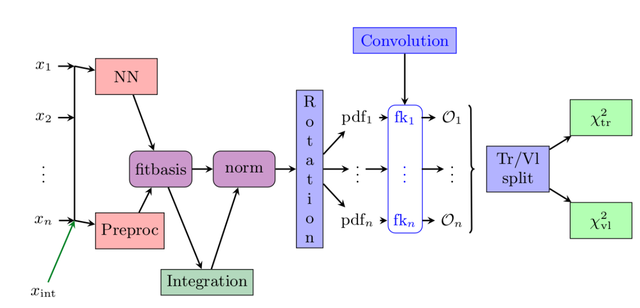



When including MHOU we observe:

- Moderate increate in PDF uncertainty,
- NLO-NNLO shift is fully compatible with the overall uncertainty,
- Central values are closer to the NNLO result.

# A new deep learning approach to PDFs (Carrazza, Cruz)

Fully revisited approach to the NNPDF fitting methodology based on stochastic gradient descent and deep learning architectures.

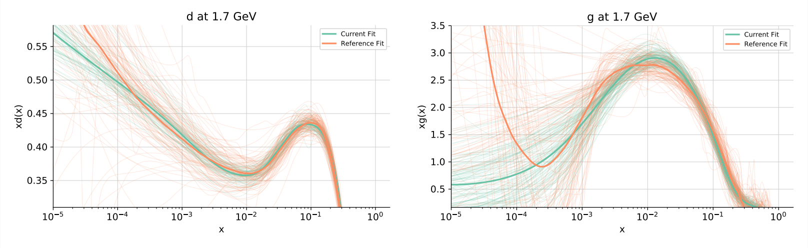



Benefits:

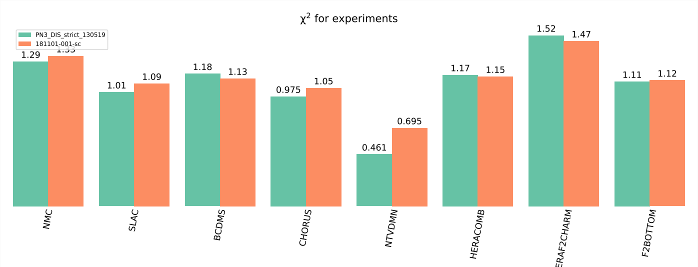
- Faster results
- Flexibility to test several architectures and optimizers
- Possibility to perform hyper-parametrization tuning

# A new deep learning approach to PDFs (Carrazza, Cruz)

Less complex PDF solutions:



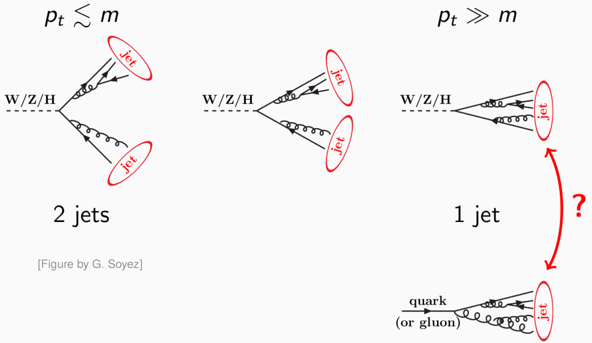

Good regression quality:



# Jet grooming with reinforcement learning (Carrazza)

Boosted objects at LHC energies, EW-scale particles ($W/Z/t$...) are often produced with $p_t \gg m$, leading to collimated decays.

**Problem:** hadronic decay products are often reconstructed into single jets. Identification of boosted objects by looking at the mass of the jet.




[Figure by G. Soyez]

Mass peak can be partly reconstructed by removing unassociated soft wide-angle radiation (grooming).

# Jet grooming with reinforcement learning (Carrazza)

**[arXiv:1903.09644 - S.C. and Dreyer '19]**

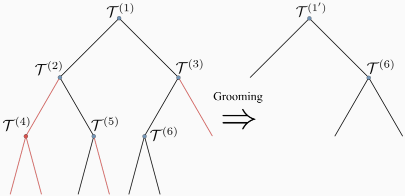
**ML idea:** use reinforcement learning to the problem of jet grooming.

- Cast jet as clustering tree where state of each note $\mathcal{T}^{(i)}$ is a tuple with kinematic information on splitting

$$s_t = \{z, \Delta_{ab}, \psi, m, k_t\}$$

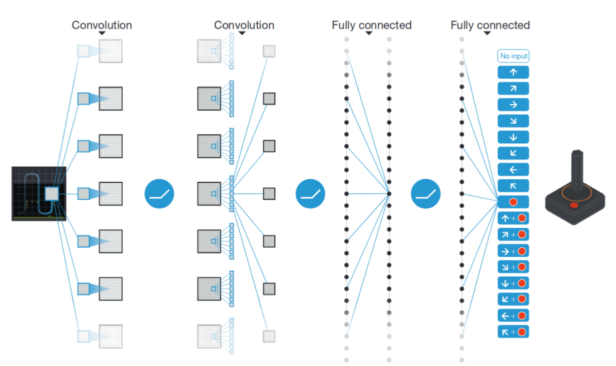
- Grooming algorithm defined as a function $\pi_g$ observing a state and returning an action $\{0, 1\}$ on the removal of the softer branch, *e.g.*

$$\pi_{\text{RSD}}(s_t) = \begin{cases} 0 & \text{if} \quad z > z_{\text{cut}}\left(\frac{\Delta_{ab}}{R_0}\right)^{\beta}, \\ 1 & \text{else} \end{cases}$$



# Jet grooming with reinforcement learning (Carrazza)

We use a Deep Q-Network as a RL algorithm which uses a table of $Q(s,a)$, determining the next action as the one that maximizes $Q$.

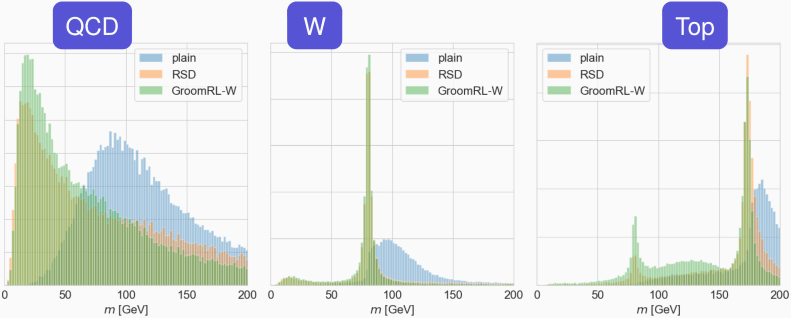



A NN is used to approximate the optimal action-value function:

$$Q^*(s,a) = \max_{\pi} \mathbb{E}[r_t + \gamma r_{t+1} + ...|s_t = s, a_t = a, \pi]$$

# Jet grooming with reinforcement learning (Carrazza)

- To test the grooming algorithm derived from the DQN agent, we apply our groomer to three test samples: QCD, $W$ and Top jets.
- Improvement in jet mass resolution compared to heuristic methods (RSD)
- Algorithm performs well on data beyond its training range such as the top sample.



# Precise theoretical predictions for the LHC (Ferrera)

Higher-order (NNLO) and all-order (NNLL) QCD calculations extremely important at the LHC: precise theoretical predictions and robust estimate of uncertainties.

NNLO calculations are not an easy task due to infrared singularities (not possible direct use of numerical techniques): developments of subtraction formalisms at NNLO order and beyond.

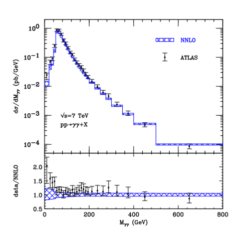



**Figure 1:** Diphoton production at LHC. Comparison between ATLAS data for diphoton invariant mass spectrum and NNLO QCD results (including uncertainty band) [Catani,Cieri,de Florian,Ferrera,Grazzini('18)].

# Precise theoretical predictions for the LHC (Ferrera)

At small transverse-momenta fixed-order calculations are not reliable: the resummation of large logarithmic contributions at all order in QCD is necessary.

Interplay of QCD and QED effects in transverse-momentum resummation is important for precision measurements at the LHC (e.g. W boson mass).

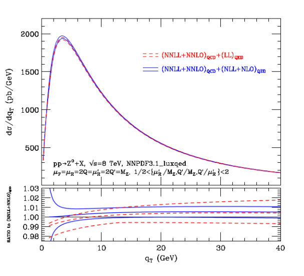
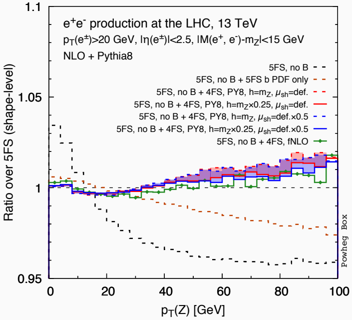
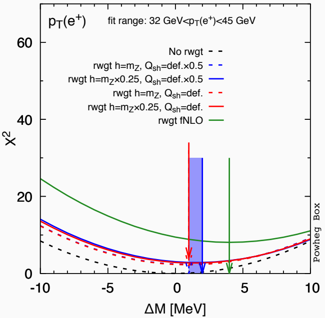



**Figure 2:** Transverse-momentum spectrum of the Z boson at the LHC. Resummed QCD results at NNLL accuracy combined with the QED effects at leading (red dashed) and next-to-leading (blue solid) logarithmic accuracy (including QED uncertainty bands) [Cieri,Ferrera,Sborlini('18)].

# Massive $b$ impact on $Z$ $p_T$ spectrum (Vicini)

Studies about the impact of the massive bottom quark on $Z$ $p_T$ spectrum, and related impact propagation at the level of the $M_W$ mass determination.



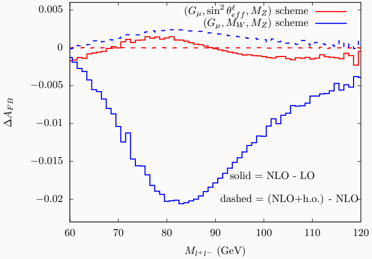



# New electroweak scheme (Vicini)

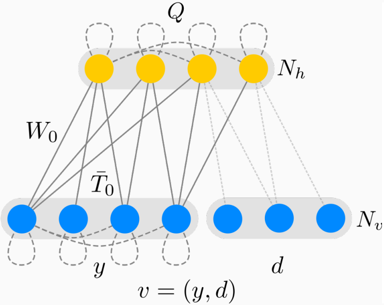
New electroweak scheme which takes as input the leptonic effective sinus

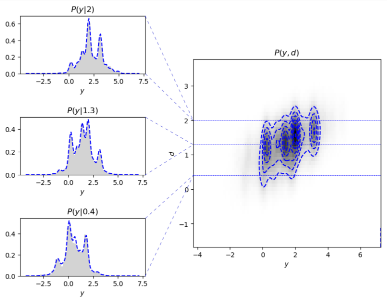
$$(G_\mu, M_Z, \sin^2(\theta^l_{eff}))$$

which allows its measurement via template fit. Such scheme has a optimal convergence, so the sinus determination should suffer from very small uncertainties due to missing higher orders.



New Riemann-Theta Boltzmann Machine architecture for density estimation and conditional probability extraction.




Applications in MC simulation, experimental physics and statistical fields.

# Interazioni deboli e forti a diverse scale di energia (Antonelli)

1. Possibile Violazione di Lorentz invarianza (LIV) e studi fenomenologici (V. Antonelli, M. Torri e L. Miramonti)
   • Costruzione di modello con simmetrie interne di Modello Standard in presenza di **LIV isotropica**: **arXiv:1906.05595**;
   • **LIV e oscillazioni dei neutrini: EPJC** 78 (2018) n.8, 667;
   • **Deep Inelastic Scattering e interazioni forti** in presenza di **LIV**: analisi in corso di svolgimento.
2. Fenomenologia dei neutrini ($\nu$) (collaborazione con JUNO-gr.II)
   • **Potenzialità di JUNO e di esperimenti da reattore**: gerarchia di massa dei neutrini, parametri di oscillazione, etc. Vedi contributo di V. Antonelli a **arXiv:1812.06739**, report di **"CERN European Neutrino Town Meeting"** e di ESSP 2019 ( **European Strategy Discussion**).

   Vedi anche: V. A. : **PosNeutel2017** (2018) 056 e **Nuovo Cim. C** 41 (2018) n.1-2, 55

   • **Studio dei neutrini solari** con **JUNO** e **"Non Standard $\nu$ Interactions"**: articolo in fase di completamento
   • **Aspetti di fenomenologia e analisi dati.** 3 lavori in '18-19: **JINST** 13 (2018) n.12 P02008 (analisi dati); **JGR Solid Earth** 124(4) (2019) 4231 (geoneutrini); **Nucl. Instrum. Meth. A** 925 (2019) 6 (problematiche scintillatore)
3. Altri aspetti di interazioni forti ad alte E

**Thank you!**