Annual Meeting 2024

VA2 – 3DPartons

Valerio Bertone, CEA/Irfu Paris-Saclay

Reminder

3DPartons gives access to **open-source code** necessary for high-precision phenomenology in the field of 3D hadron structure, with a specific emphasis on GPDs and TMDs with support also for PDFs and FFs.

It consists of **several libraries organised in a modular way**, which allows for continuous improvements and addition of new models, channels, and theoretical refinements.

Computing codes that contribute to 3DPartons

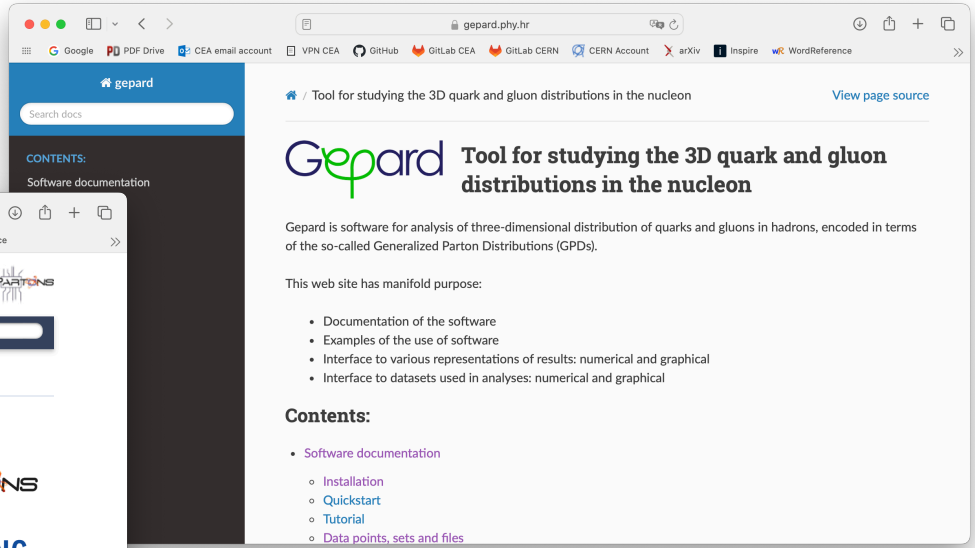
As of today, **3DPartons** is based on parts of, or offers interfaces to, various existing codes:

- **PDFs/FFs:** LHAPDF, APFEL/APFEL++, xFitter, MontBlanc, Denali,
- **GPDs:** PARTONS, EpIC, GeParD,
- **TMDs:** NangaParbat, arTeMiDe, TMDlib, CASCADE.

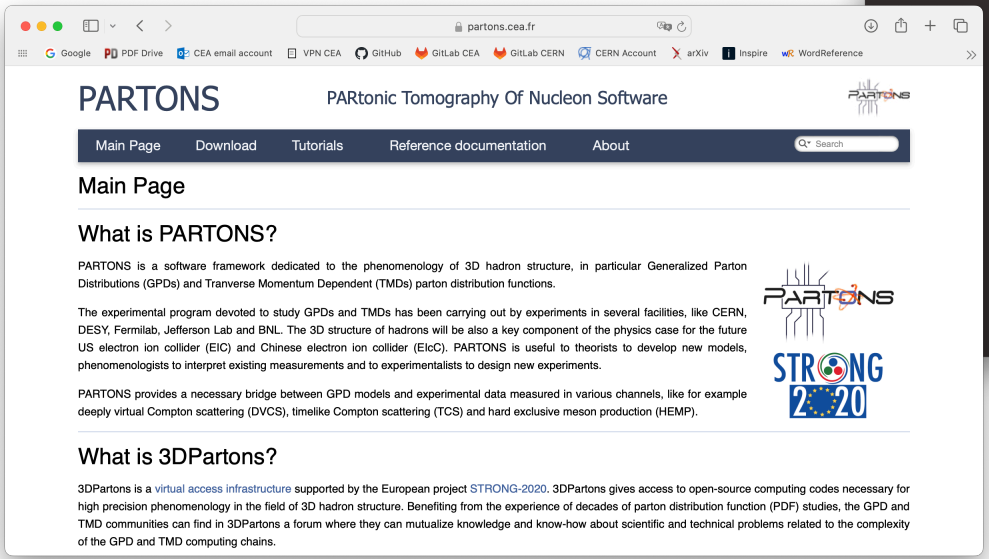
Progress during the last year

- Maintainance and support
- Development of new codes
- Several spin-offs
- Plenty of physics result already published and in the pipeline both internal to 3DPartons and by external users.

Public GPD analysis frameworks

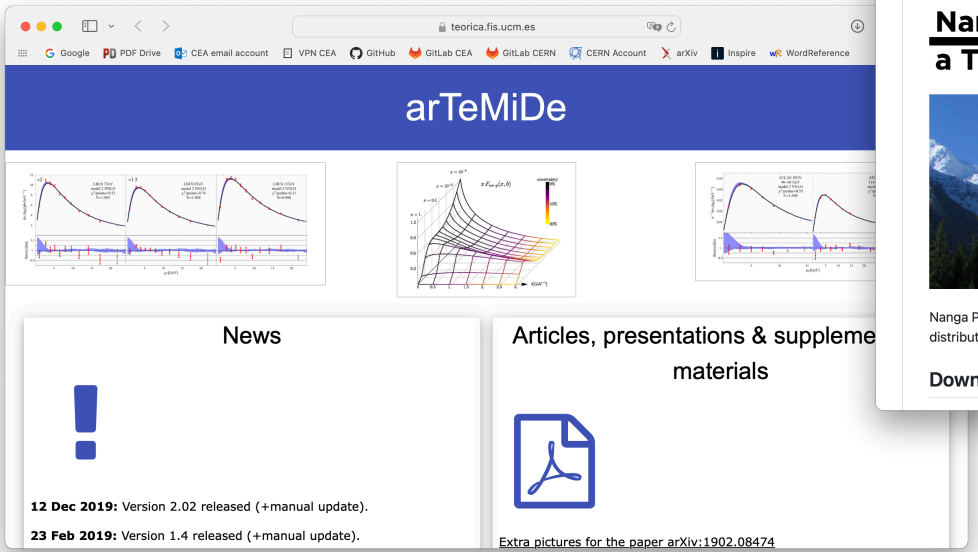


https://gepard.phy.hr/



https://partons.cea.fr/partons/doc/html/index.html

Public TMD analysis frameworks



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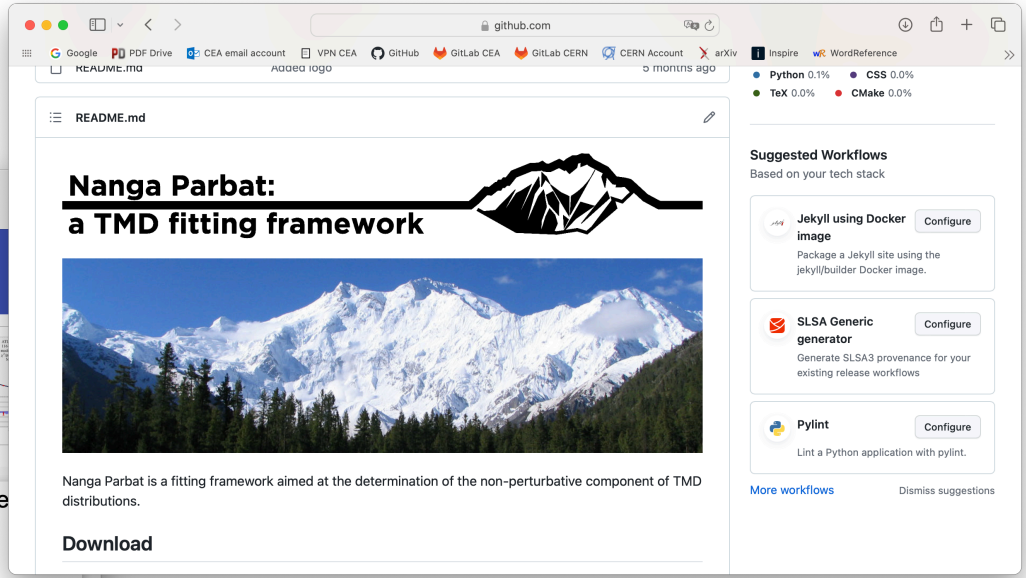
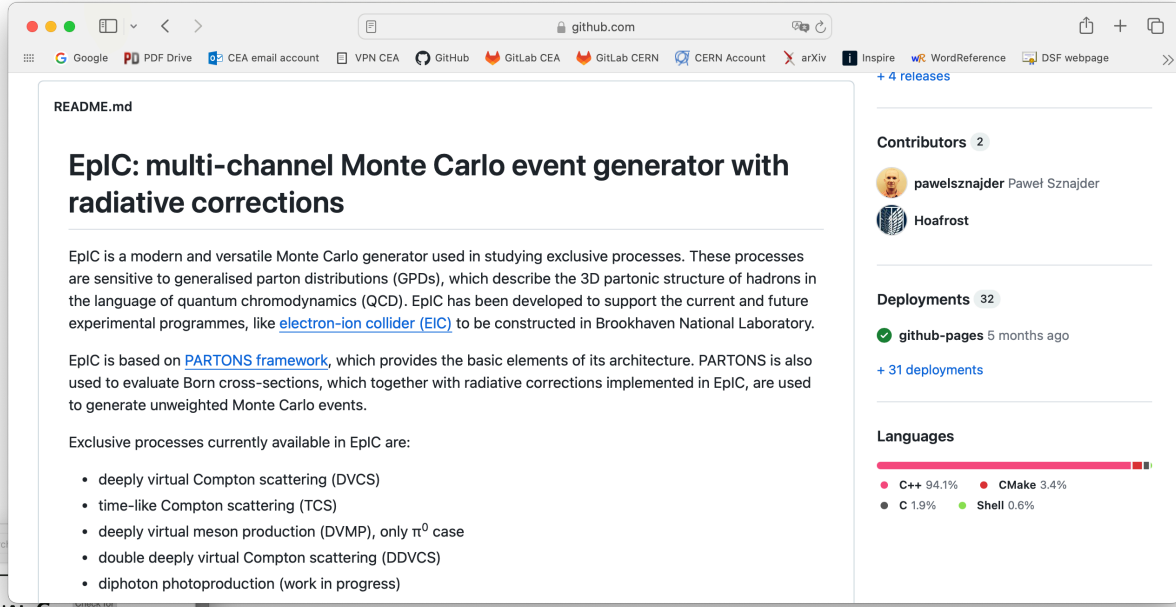
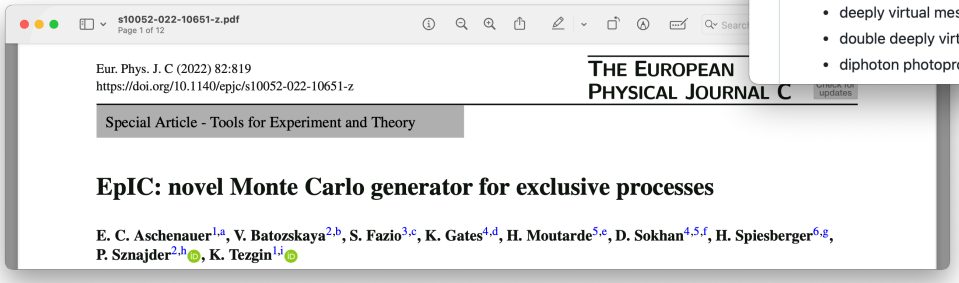


https://github.com/MapCollaboration/NangaParbat

Highlights: EpIC Monte Carlo Event Generator

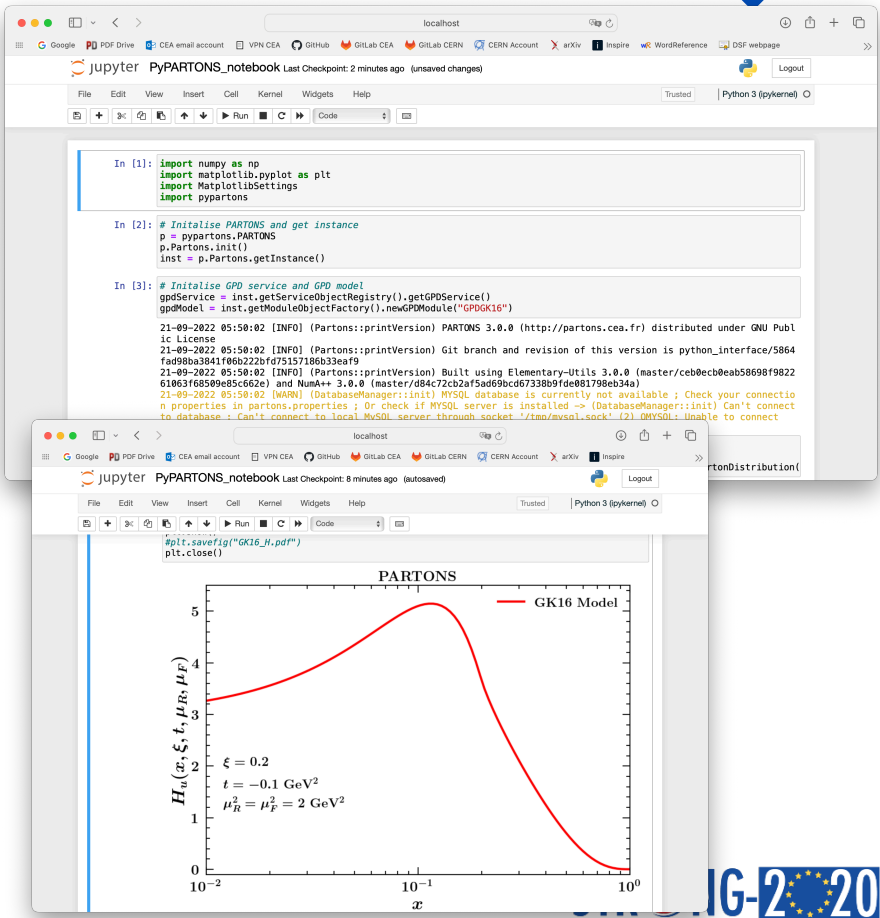
- **Based on PARTONS**: can use all provided exclusive channels in a transparent way.
- Includes treatment of radiative corrections.
- **Already used by** the EIC community and run at BNL.
- **Publicly available through GitHub.**
- Paper publish in EPJC.





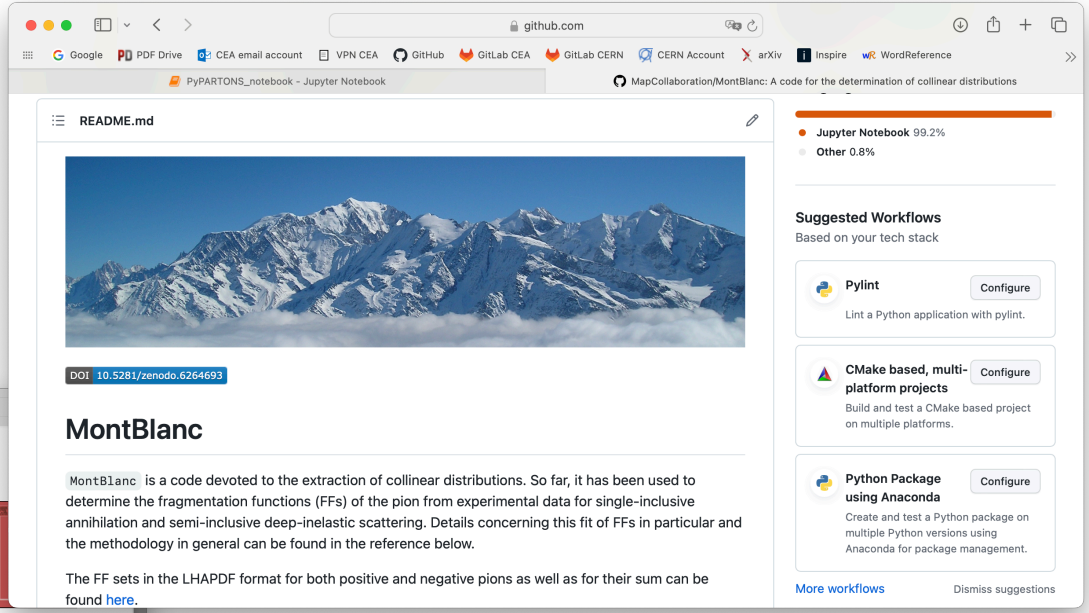
Highlights: PyPARTONS

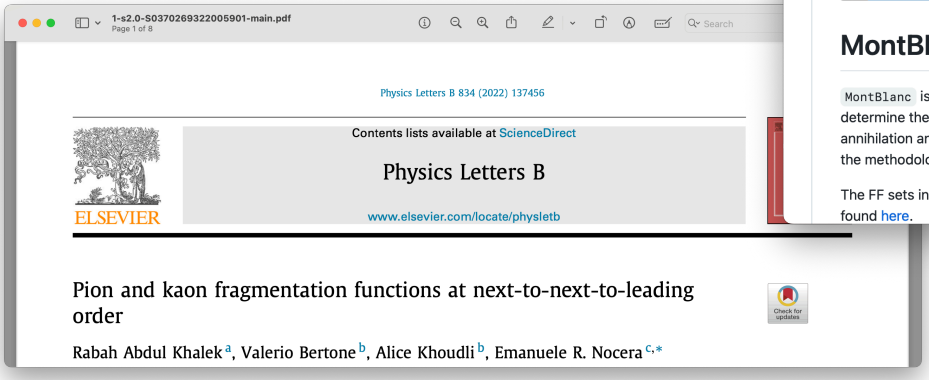
- Simplify interoperability with **popular libraries** on *e.g.*
  - machine learning (e.g. TensorFlow),
  - plotting (e.g. Matplotlib),
  - statistical data analysis (e.g. Pandas).
- Convenient for a **wide community of new (young) users**.
- **Facilitates dissemination of research** through e.g. Jupyter notebooks.
- Still working documentation.



Highlights: MontBlanc and FFs at NNLO

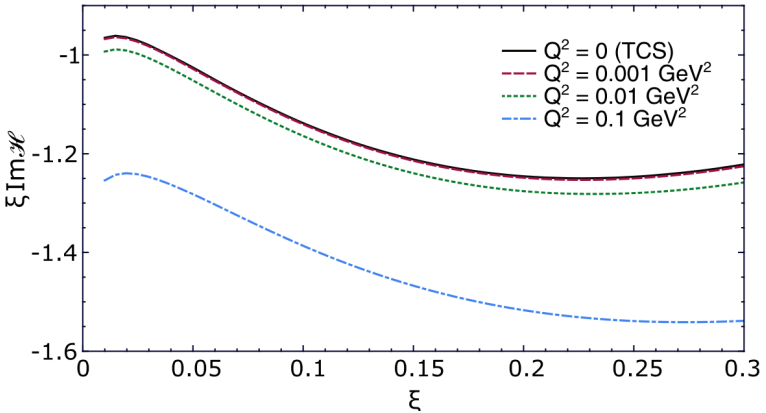
- First extraction of pion and kaon FFs at **NNLO** accuracy.
- **Code made publicly available**:
  - fully documented,
  - many spin-offs.
- FFs available through **LHAPDF**.
- Paper published in PLB.

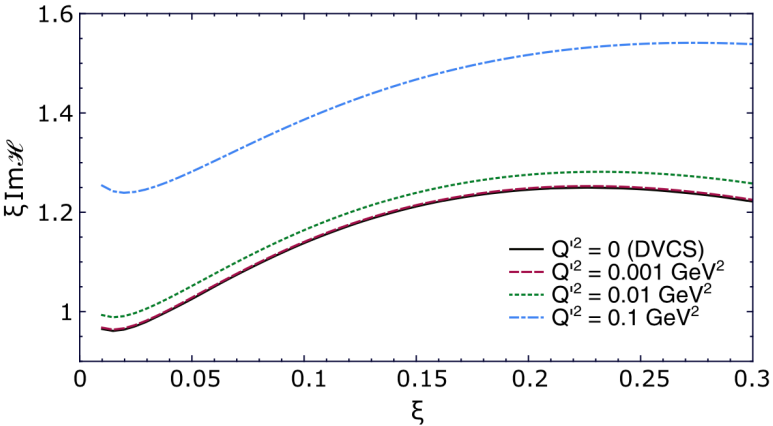


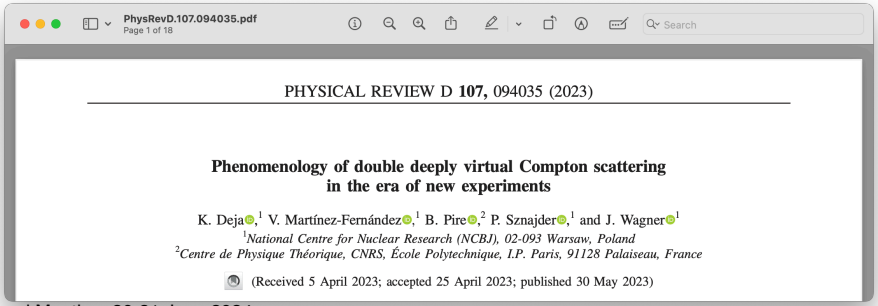


Highlights: DDVCS in PARTONS/EpIC

- Revisitation of DDVCS at leading order:
  - reformulation suitable for efficient numerical computation.
- **Code available through PARTONS**:
  - also available in EpIC
- Paper published in PRD.






PhysRevD.107.094035.pdf
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PHYSICAL REVIEW D **107,** 094035 (2023)

Phenomenology of double deeply virtual Compton scattering in the era of new experiments

K. Deja,[1] V. Martínez-Fernández,[1] B. Pire,[2] P. Sznajder,[1] and J. Wagner[1]
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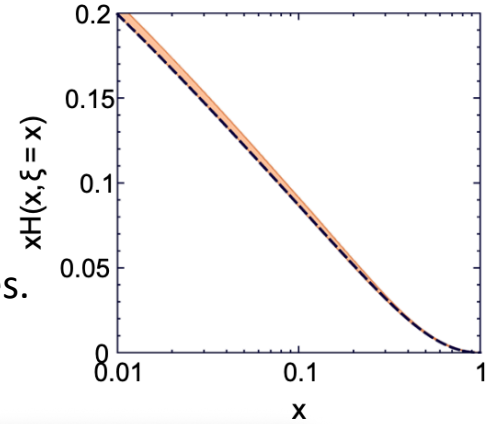
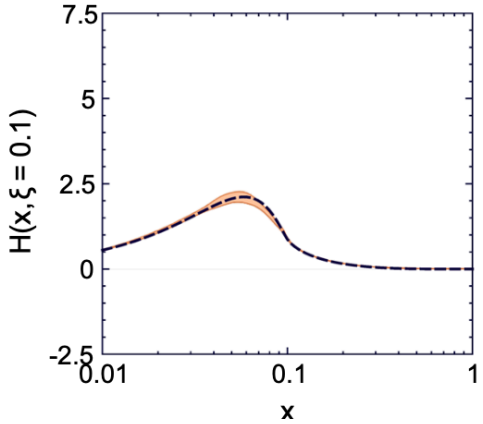
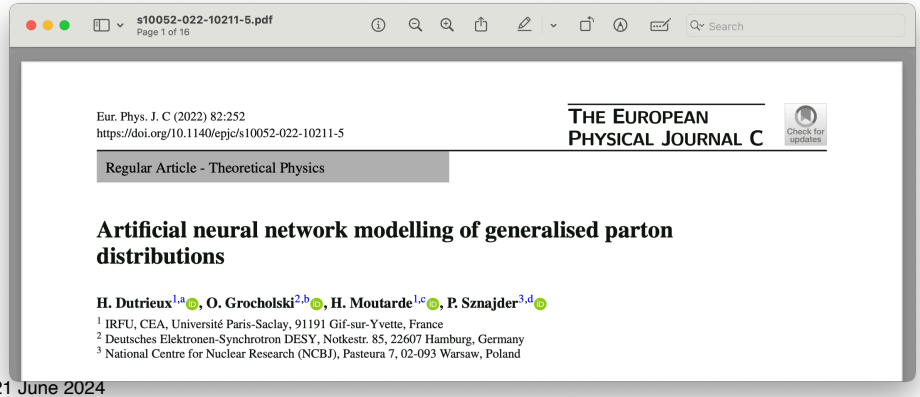
(Received 5 April 2023; accepted 25 April 2023; published 30 May 2023)

Highlights: ANN modelling of GPDs

- Study of the parameterisation of GPDs:
  - in direct (momentum) space
  - in double-distribution space.
- All relevant symmetries satisfied.
- Exploitation of machine learning techniques.
- Paper published in EPJC.



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Eur. Phys. J. C (2022) 82:252
https://doi.org/10.1140/epjc/s10052-022-10211-5

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Theoretical Physics

Artificial neural network modelling of generalised parton distributions

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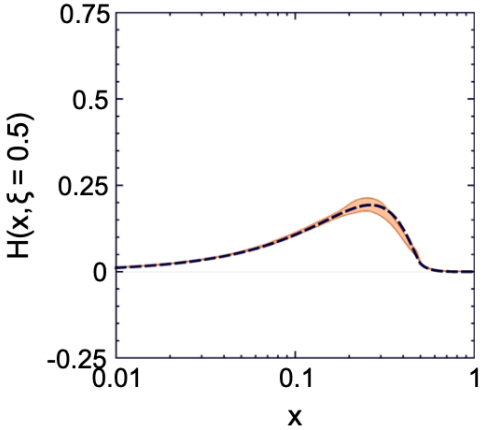
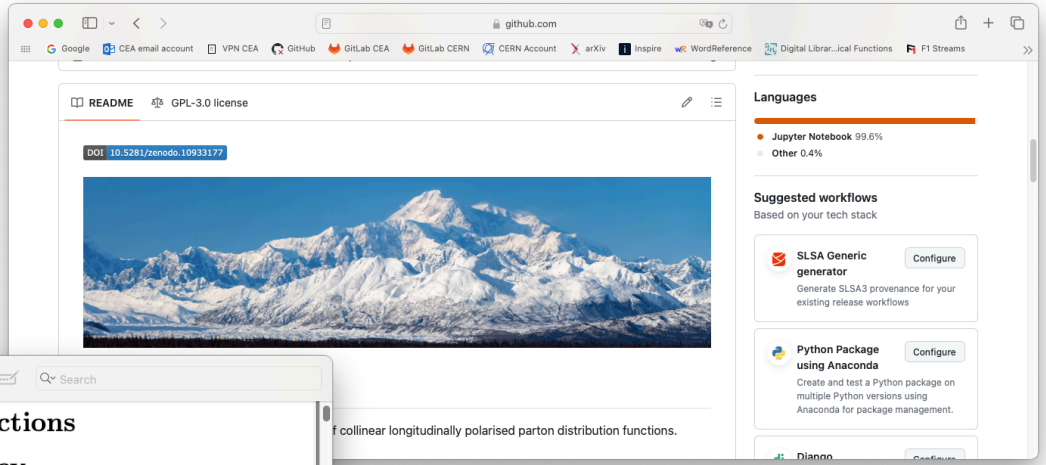
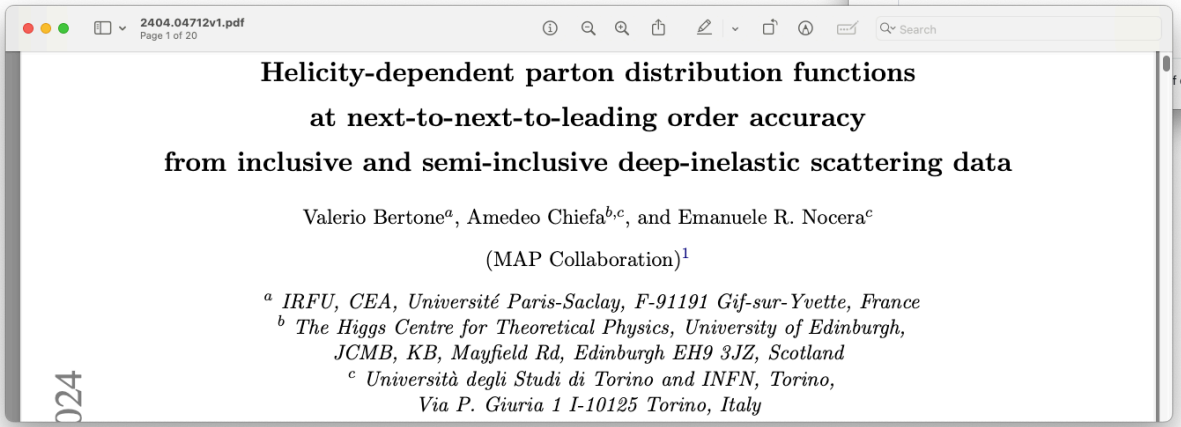


Highlights: Denali and polarised PDFs at NNLO

- First extraction of polarised proton PDFs at **NNLO** accuracy.
- **Code publicly available**:
  - fully documented,
- PDFs will be made available through **LHAPDF**.
- Paper soon on the arXiv.





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Helicity-dependent parton distribution functions at next-to-next-to-leading order accuracy from inclusive and semi-inclusive deep-inelastic scattering data

Valerio Bertone[a], Amedeo Chiefa[b,c], and Emanuele R. Nocera[c]

(MAP Collaboration)[1]

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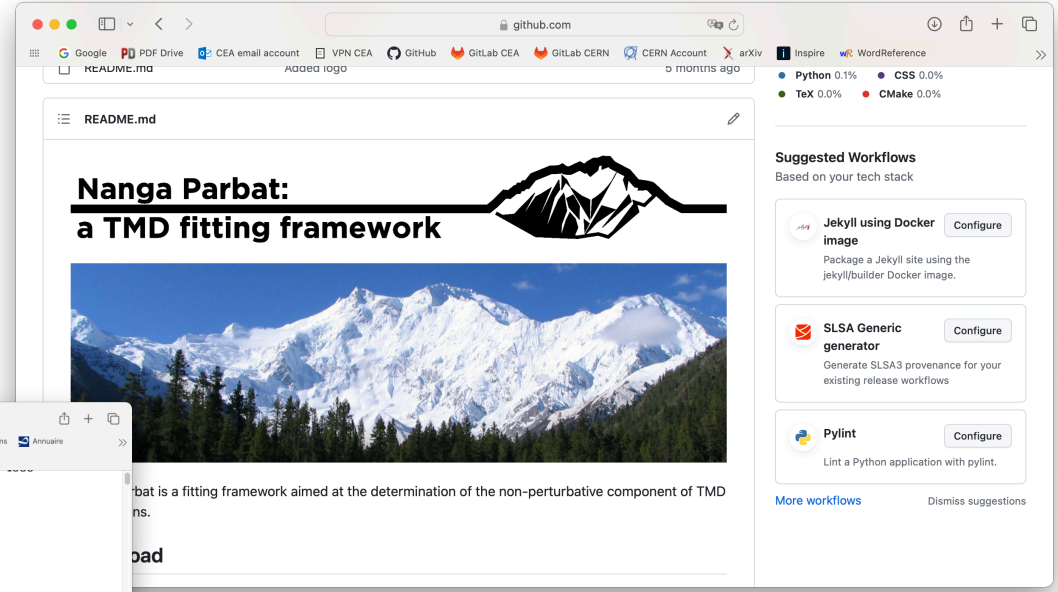
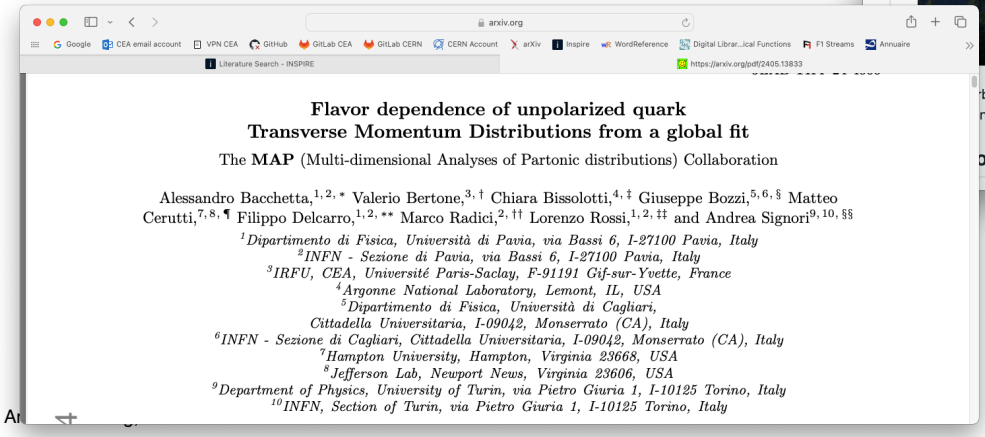
[e-Print: 2404.04712]
Paper under review

Highlights: NangaParbat and global TMDs

- Global extraction TMD PDFs and FFs at **N3LL** accuracy and with **flavour dependence**.
- **Code publicly available**:
  - fully documented.
- **TMDs** available through **TMDlib**.





Flavor dependence of unpolarized quark Transverse Momentum Distributions from a global fit

The **MAP** (Multi-dimensional Analyses of Partonic distributions) Collaboration

Alessandro Bacchetta,[1,2,*] Valerio Bertone,[3,†] Chiara Bissolotti,[4,‡] Giuseppe Bozzi,[5,6,§] Matteo Cerutti,[7,8,¶] Filippo Delcarro,[1,2,**] Marco Radici,[2,††] Lorenzo Rossi,[1,2,‡‡] and Andrea Signori[9,10,§§]

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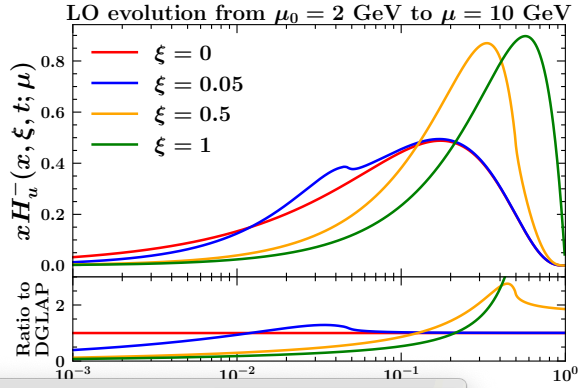
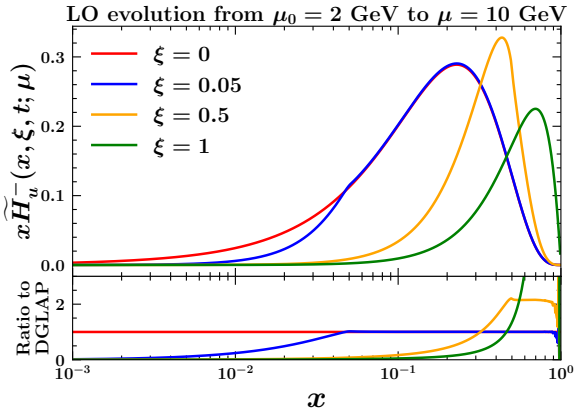
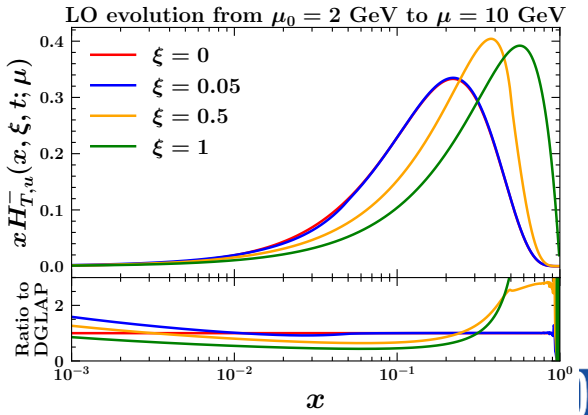
[e-Print: 2405.13833]
Paper under review

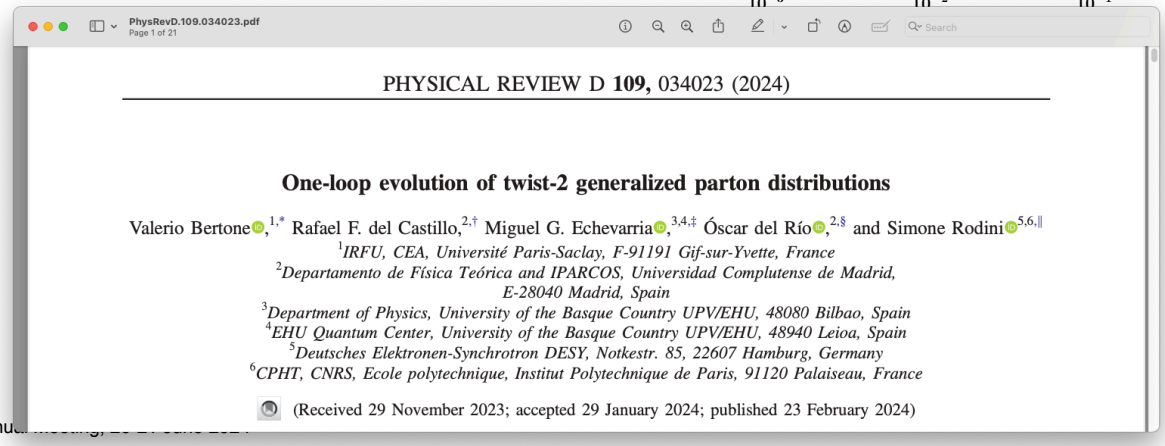
Highlights: GPD evolution in APFEL++/PARTONS

- Revisit and implement GPD evolution for all twist-2 polarisations
- **Code publicly available within PARTONS.**
- One paper already published in EPJC.
- Paper published in PRD.









PhysRevD.109.034023.pdf
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PHYSICAL REVIEW D **109,** 034023 (2024)

One-loop evolution of twist-2 generalized parton distributions

Valerio Bertone,[1,*] Rafael F. del Castillo,[2,†] Miguel G. Echevarria,[3,4,‡] Óscar del Río,[2,§] and Simone Rodini[5,6,‖]

[1]*IRFU, CEA, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France*
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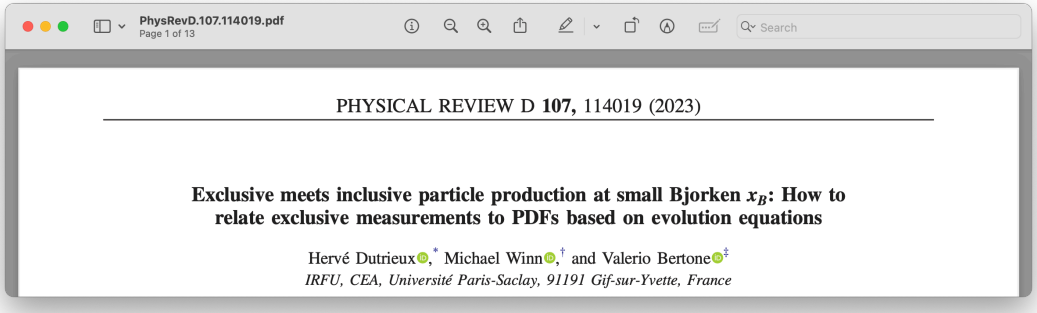
(Received 29 November 2023; accepted 29 January 2024; published 23 February 2024)

Highlights: Connecting PDFs and GPDs

- Investigate the **connection between GPDs and PDFs**.
- A method to established the connection and gauge its accuracy is put forward.
- It made use of **PARTONS**.
- Published in PRD.


PhysRevD.107.114019.pdf
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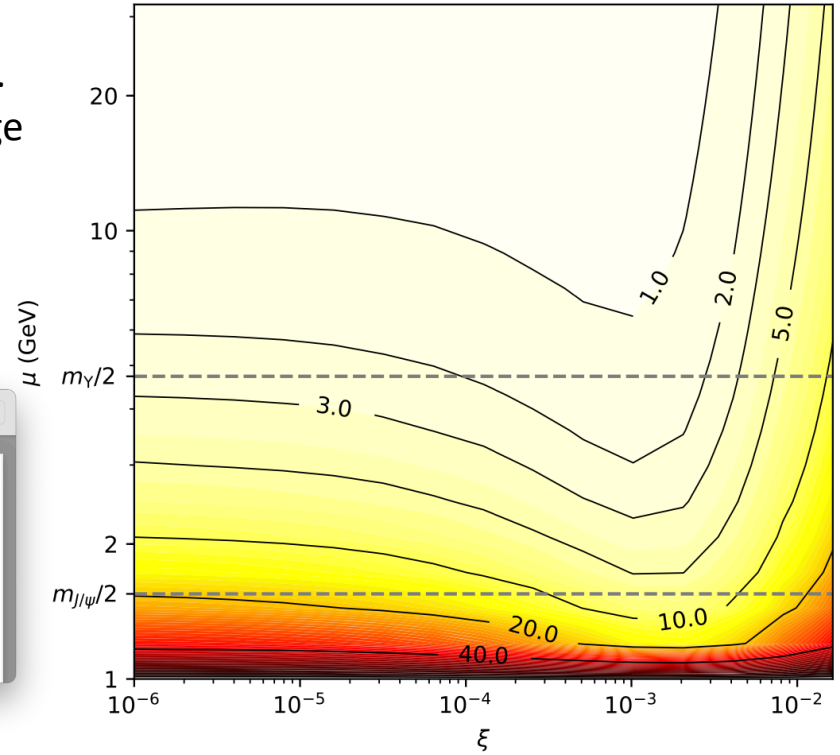
PHYSICAL REVIEW D **107,** 114019 (2023)

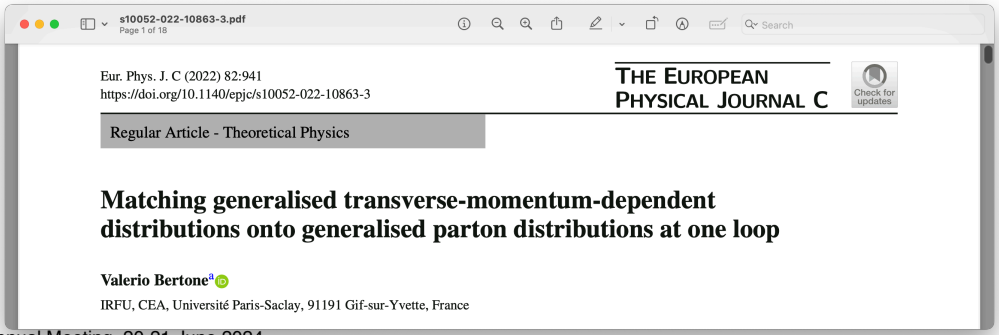
Exclusive meets inclusive particle production at small Bjorken x_B: How to relate exclusive measurements to PDFs based on evolution equations

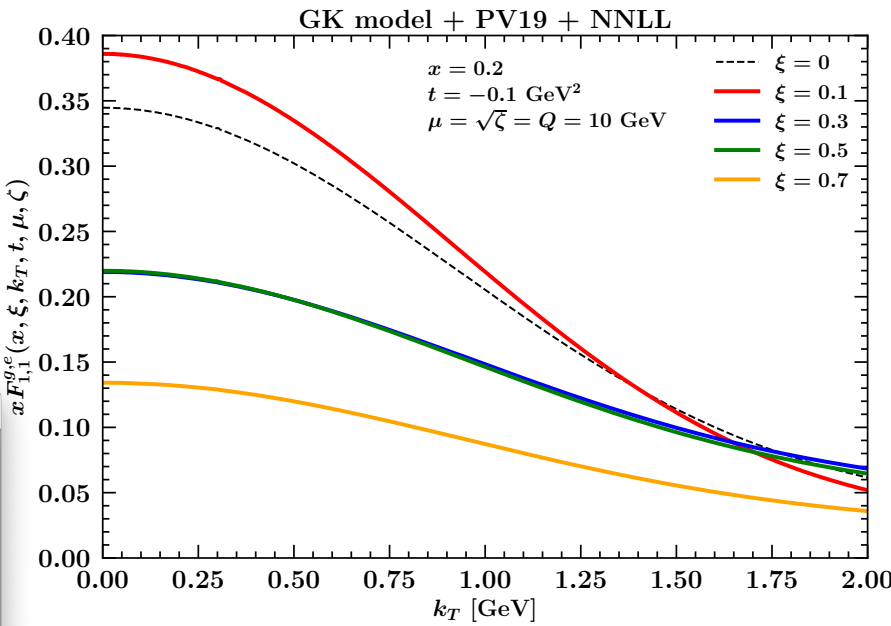
Hervé Dutrieux,* Michael Winn,† and Valerio Bertone‡
IRFU, CEA, Université Paris-Saclay, 91191 Gif-sur-Yvette, France



An example of interoperability: reconstructing GTMDs

- Interoperability of codes belonging to 3DPartons allowed us to reconstruct GTMDs:
  - **PARTONS** (GPD model)
  - **NangaParbat** (TMD model)
  - **APFEL++** (perturbative input)
- **Code publicly available through GitHub.**
- Paper published in EPJC.





Summary

- **3DPartons** delivered **impactful results** in many areas of **hadronic structure,** in some respects **beyond the original plans**.
- It is built upon a **solid code infrastructure** that consistently incorporates the resulting developments making them **publicly available**.
- 3DPartons in a unique position to exploit **present and future opportunities**:
  - current and future experimental facilities,
  - theoretical developments,
  - technological advances.