MadGraph and NLOAccess

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NLOAccess - the framework

The STRONG-2020 WP **VA1-NLOAccess**:

- a virtual access for automated perturbative calculation for collider physics, with emphasis on heavy ions and quarkonia

C. Flore, EPJ A 59 (2023) 46

- an online code library
- any code that could be compiled and launched via bash could be added

✓ HELAC-Onia and MadGraph5 are included

NLOAccess - facts and figures

Some facts and figures about NLOAccess:

- general information at `https://nloaccess.in2p3.fr`
- HELAC-Onia: `https://nloaccess.in2p3.fr/HO/`
- MG5: `https://nloaccess.in2p3.fr/MG5/`
- over 400 users from all over the world; over 4000 runs performed by the users
- features:
  - secure two-step registration process
  - protected OwnCloud storage is given
  - file input as first way to submit a run
  - live user run status and run history
  - almost zero computational cost for the users

NLOAccess - the tools

- HELAC-Onia — H.-S. Shao, CPC 184 (2013) 2562-2570 & CPC 198 (2016) 238-259
  - LO(+PS) automated event generator for quarkonia in the SM
  - based on the NRQCD framework, relies on off-shell recursion relations
  - approximate NLO calculation (*e.g.* NLO*, aNLO) feasible

    C. Flore *et al.*, Phys. Lett. B 811 (2020) 135926; H.-S. Shao, JHEP 01 (2019) 112

- MG5 — http://amcatnlo.web.cern.ch/amcatnlo/list_refs.htm
  - full NLO(+PS) matrix element and event generator in the SM and for BSM phenomenology
  - LO for any user-defined Lagrangian, and at the NLO for models supporting such a calculation
  - onium feasible within (I)CEM — J.-P. Lansberg *et al.*, Phys. Lett. B 807 (2020) 135559

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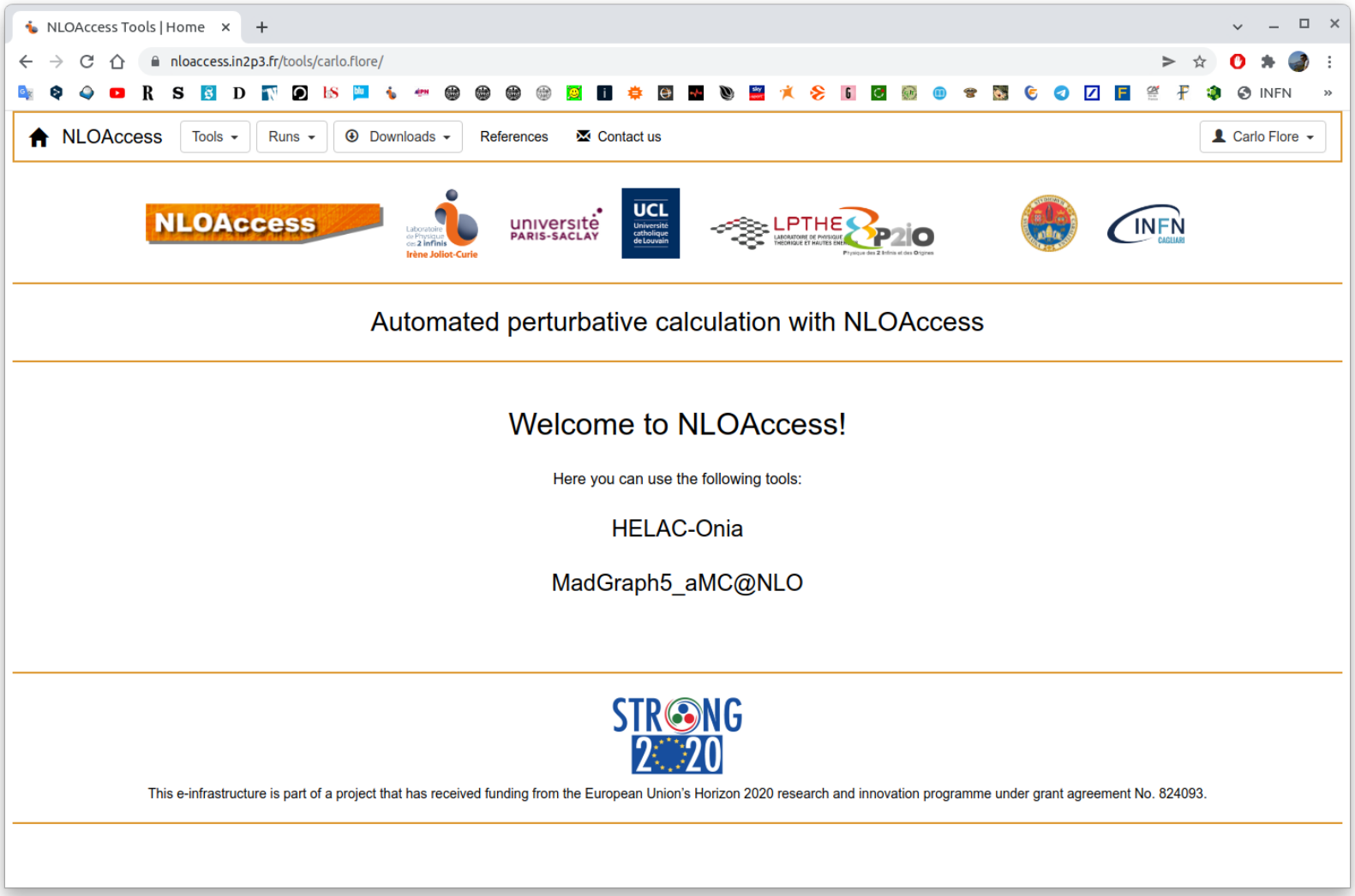
$\Rightarrow$ Les Houches Events available for both codes

NLOAccess Tools - homepage

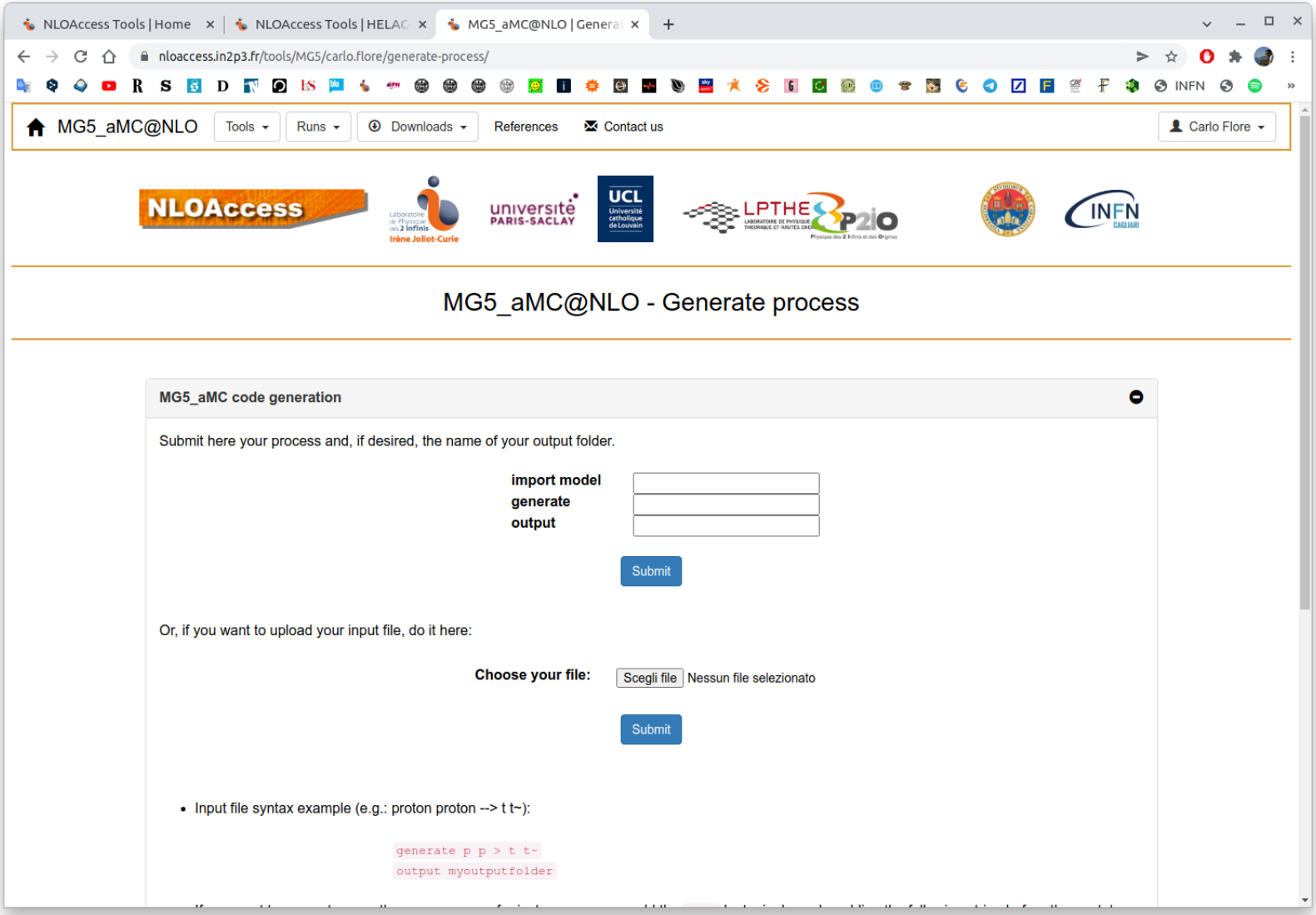
(https://nloaccess.in2p3.fr/tools/)



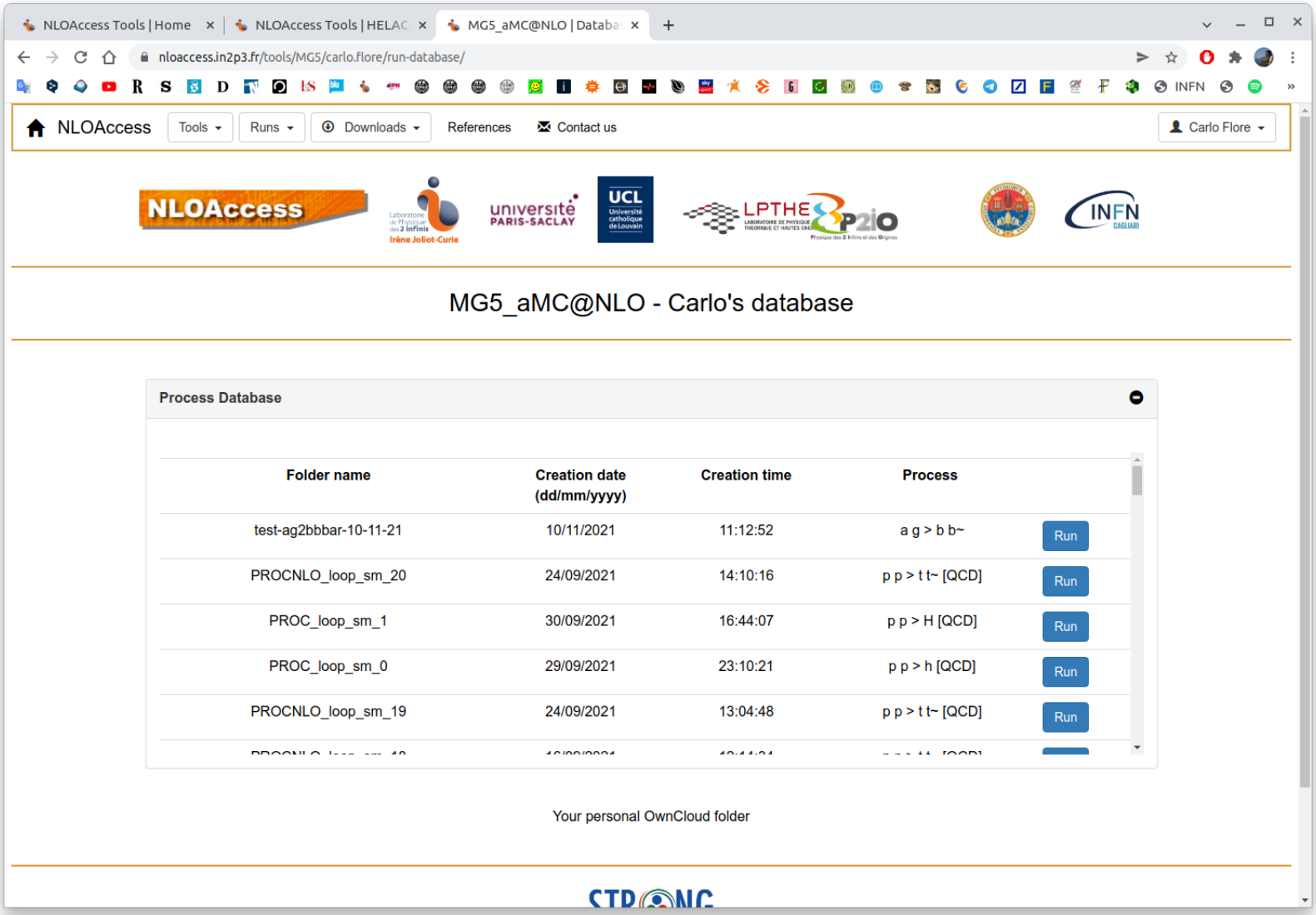
MG5 (https://nloaccess.in2p3.fr/MG5/)

- MadGraph5 online version was only limited to LO calculation
- NLOAccess offers access for the first time to full NLO SM online calculation with MG5_aMC@NLO!

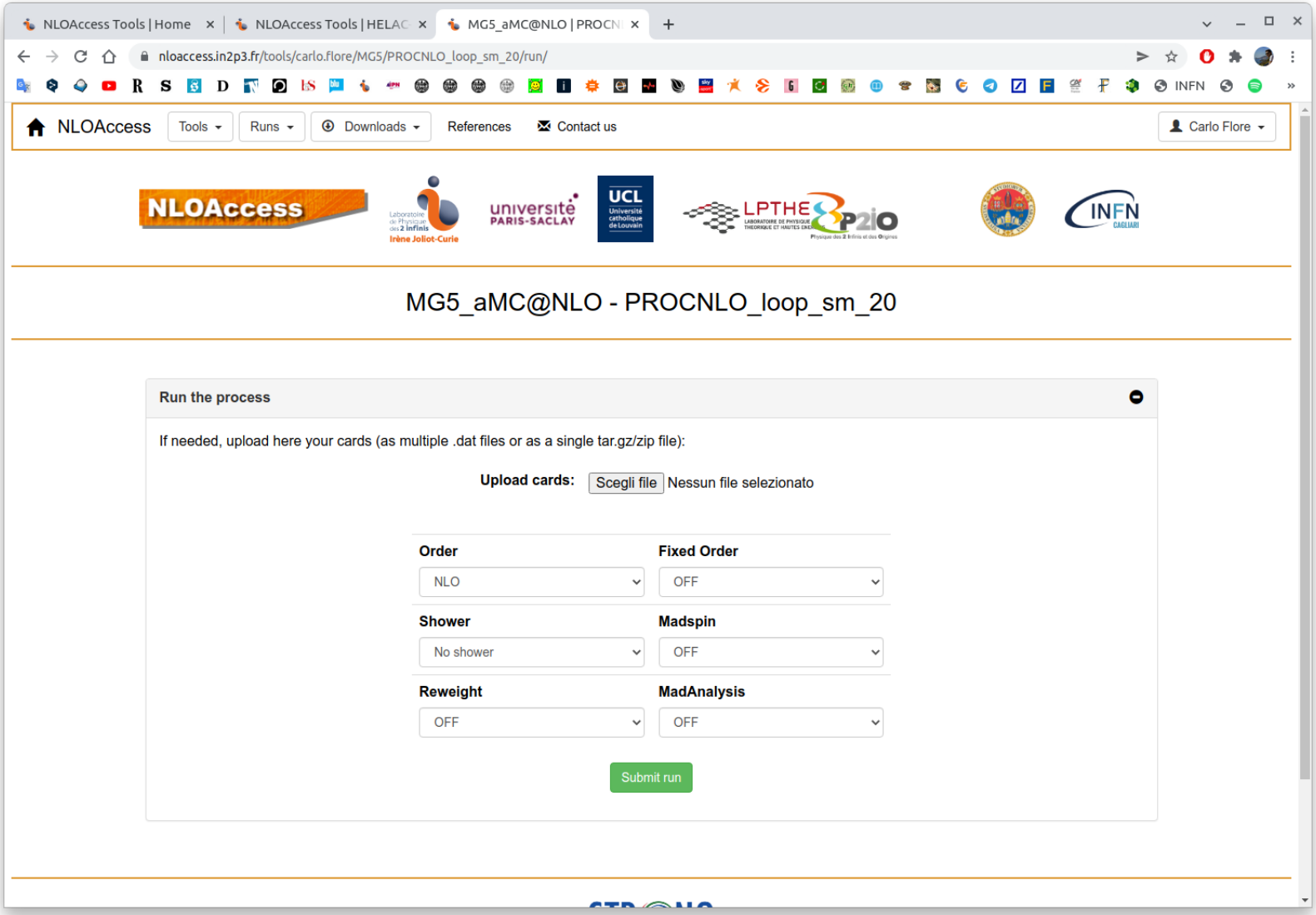
MG5 - code generation



MG5 - code database



MG5 - code running

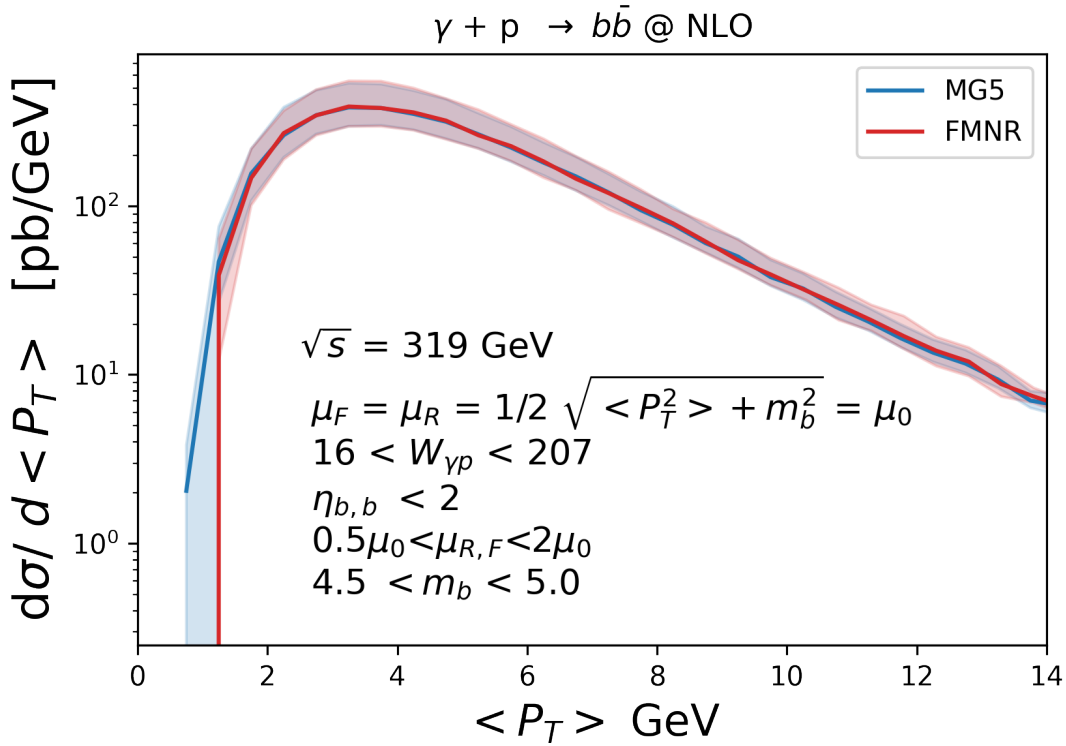


MG5 and NLOAccess - where are we?

- NLOAccess members highly involved in MG5 developement
- MG5 designed and validated at NLO for symmetric collisions, *i.e.* mostly LHC physics
- lepton-hadron collisions were not yet validated at NLO at fixed-order
- need for extending MG5 to asymmetric collisions:
  - ℓh collisions (including photoproduction) $\Rightarrow$ EIC, EicC, LHeC, FCC-eh ...
  - pA, AB, πp, πA collisions

MG5 - photoproduction (I)

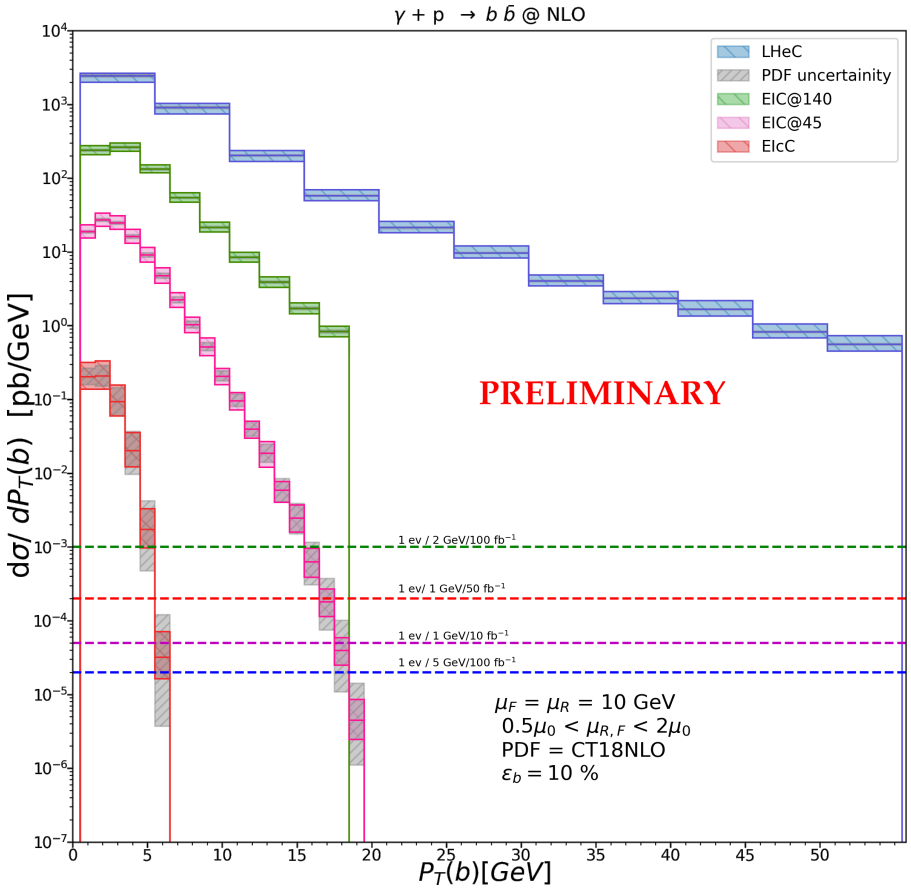
- Photoproduction processes will be important at the future lepton-hadron colliders
- what was done: fixed photon flux $Q^2_{\max}$, fixed boost routines, validated LO and NLO code at fixed order



FMNR code from private communication w/ S. Frixione; courtesy of L. Manna (WUT)

MG5 - photoproduction (II)

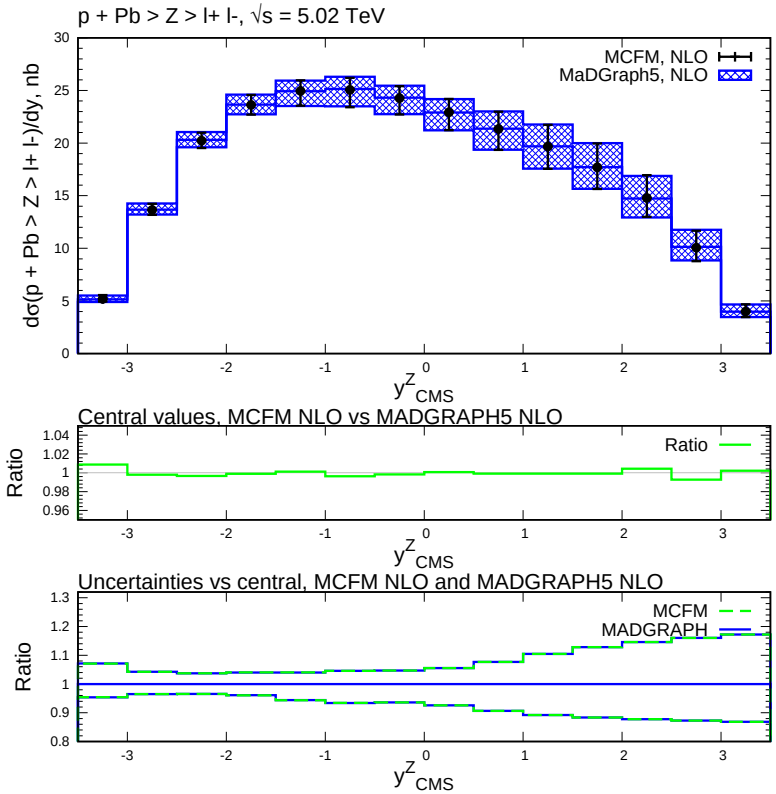
- Predictions for heavy-quark pair photoproduction for future experiments

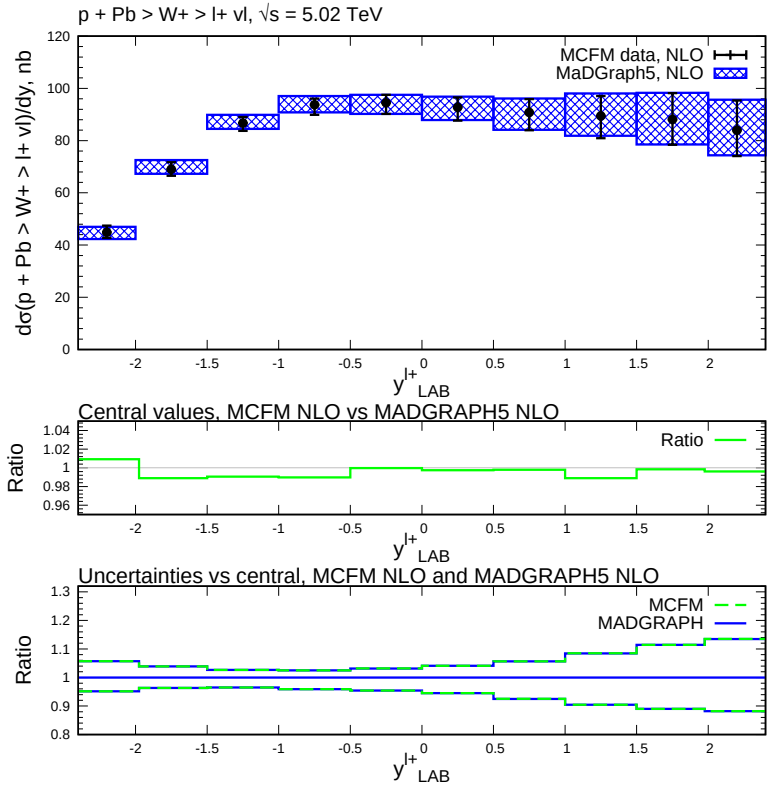


courtesy of L. Manna (WUT)

MG5 - *hA* collisions (I)

- MG5 integration of LHAPDF already allowed to compute *AA* collisions
- what was done: modification of parton luminosities functions and plotting routines to automatically compute nuclear modification factors R_{pA}

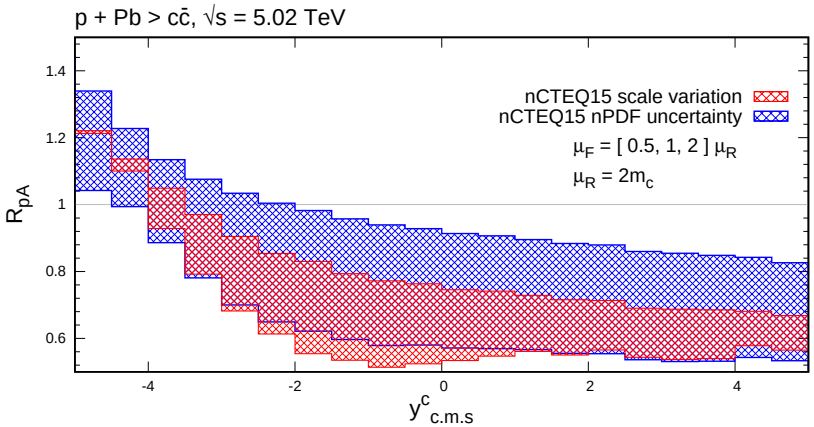


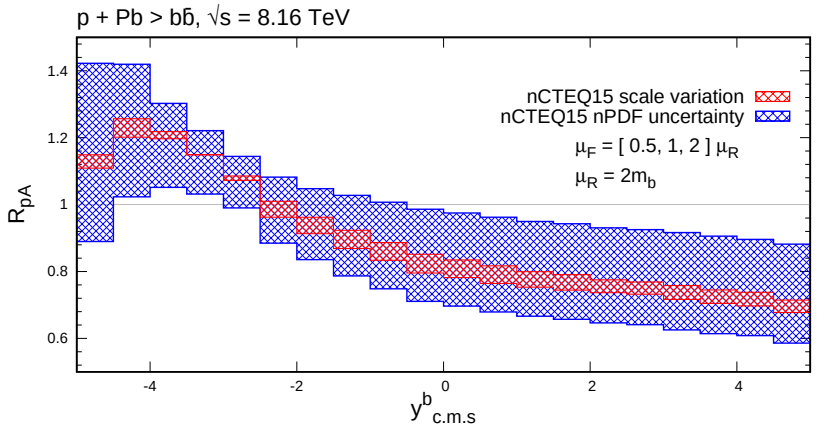


A. Safronov *et al.*, **PoS ICHEP2022 (2022) 494**

MG5 - *hA* collisions (II): R_{hA}

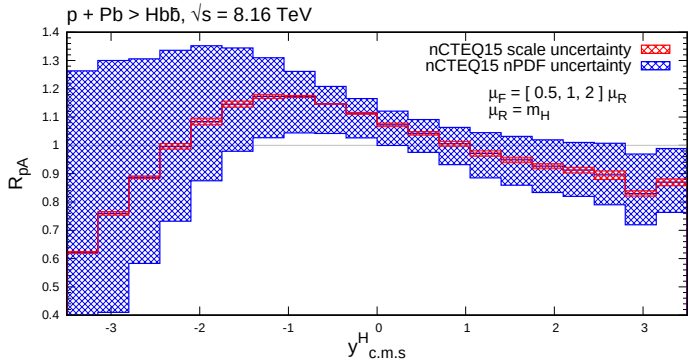
- only needed to specify the proton and ion LHAPDF id in the run card
- Predictions for R_{pPb} at the LHC





A. Safronov *et al.*, **PoS ICHEP2022 (2022) 494**

- A fancier prediction: Higgs + $b\bar{b}$ at the LHC



Courtesy of A. Safronov (WUT)

Conclusions and outlook

- NLOAccess: an online platform for automated perturbative calculation for collider physics
- MG5 now available online in its full NLO version on NLOAccess
- validated and developed MG5 for asymmetric collisions
  - photoproduction in ℓh collisions
  - nuclear modification factors in pA and AB collisions

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- next:
  - extension to pion beams and to (N)LO+PS
  - automation of onium production computations at (N)LO in MG5

    [A. Abdul-Hameed, LPTHE Paris, C. Flett, IJCLab Orsay]
  - automation of spin and transverse momentum effects for quarkonium production

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Thank you

Backup

Quarkonium Production Model

Phys.Rept. 889 (2020) 1-106 & EPJC (2016) 76:107 for reviews

- No agreement on which mechanism is dominant
- Differences in the treatment of the hadronization
- 3 common models:
  1. Color Singlet Model:
     hadronization w/o gluon emission; colour and spin are preserved during the hadronization
  2. NRQCD and Color Octet Mechanism:
     higher Fock states of the mesons taken into account; $Q\bar{Q}$ can be produced in octet states with different quantum number as the meson;
  3. Color Evaporation Model:
     based on quark-hadron duality;
     only the invariant mass matters; semi-soft gluons emissions;
     color-wise decorrelated $c\bar{c}$ prod. and hadr.

HELAC-Onia

H.-S. Shao, CPC 184 (2013) 2562-2570 & CPC 198 (2016) 238-259

HELAC-Onia is an automatic matrix element and event generator for quarkonium physics

- based on NRQCD framework
- based on off-shell recursion relations

NRQCD factorisation:

$$\sigma(pp \to \mathcal{Q} + X) = \sum_{i,j,n} \int dx_1 dx_2 \, f_{i/p}(x_1) \, f_{j/p}(x_2) \, \hat{\sigma}(ij \to Q\bar{Q}[n] + X) \, \langle \mathcal{O}_n^{\mathcal{Q}} \rangle$$

- $f_{i/p}(x_1), f_{j/p}(x_2)$ are the PDFs
- $\hat{\sigma}(ij \to Q\bar{Q}[n] + X)$ is the partonic cross section for producing a heavy quark pair in the Fock state n
- $n = {}^{2S+1}L_J^c$, with $c = 1, 8$ (color singlet or color octet)
- $\langle \mathcal{O}_n^{\mathcal{Q}} \rangle$ are the LDMEs

Code vs metacode

What is the main difference between HELAC-Onia and MG5_aMC@NLO?

HELAC-Onia is a code

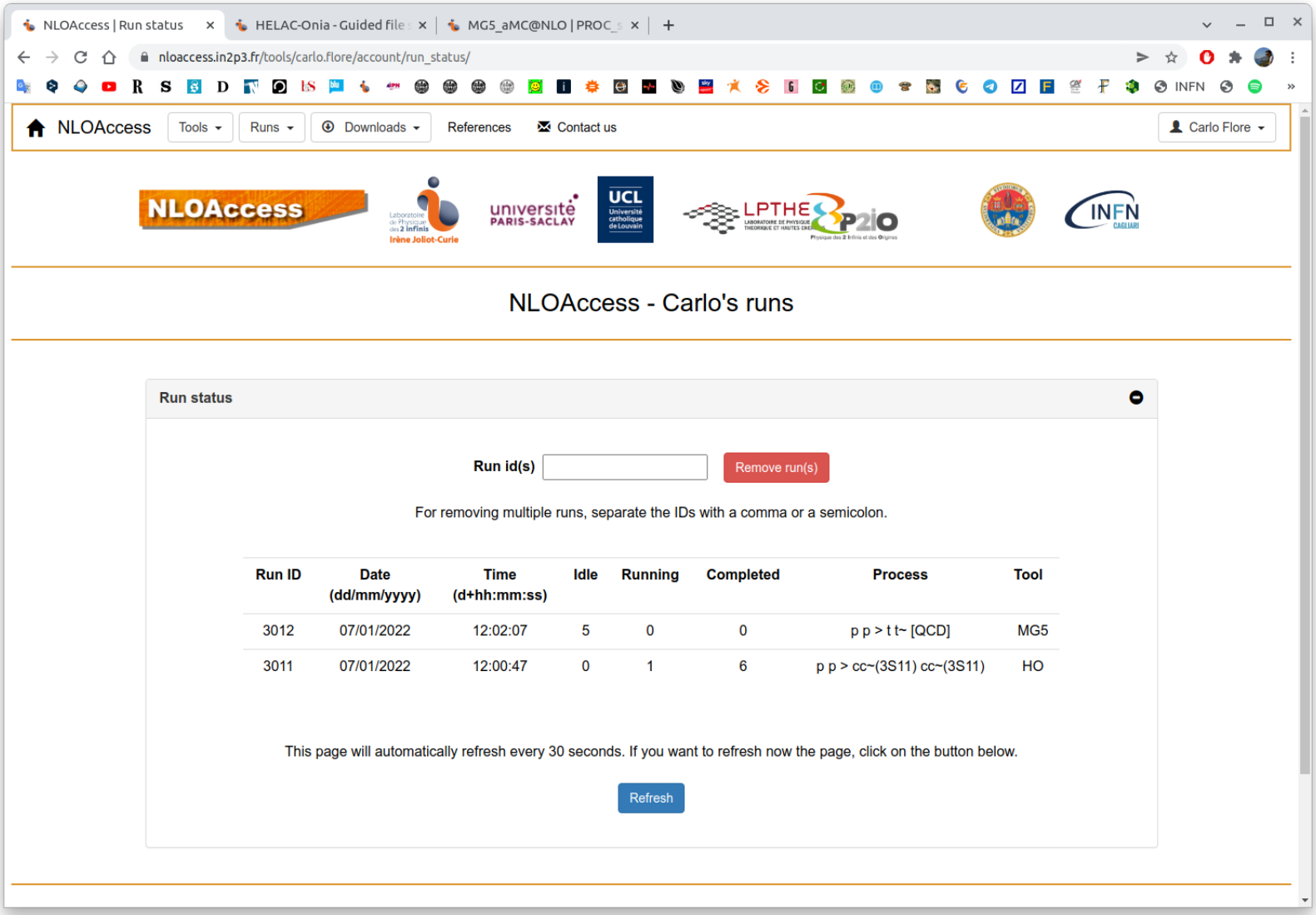
MG5_aMC@NLO is a metacode, *i.e.* a code generating another code

	HELAC-Onia	MG5_aMC@NLO
compilation	once	once for each `generate` command
running	run single executable each time	(re-)run the generated code for the requested process
code re-usage	✖	✓

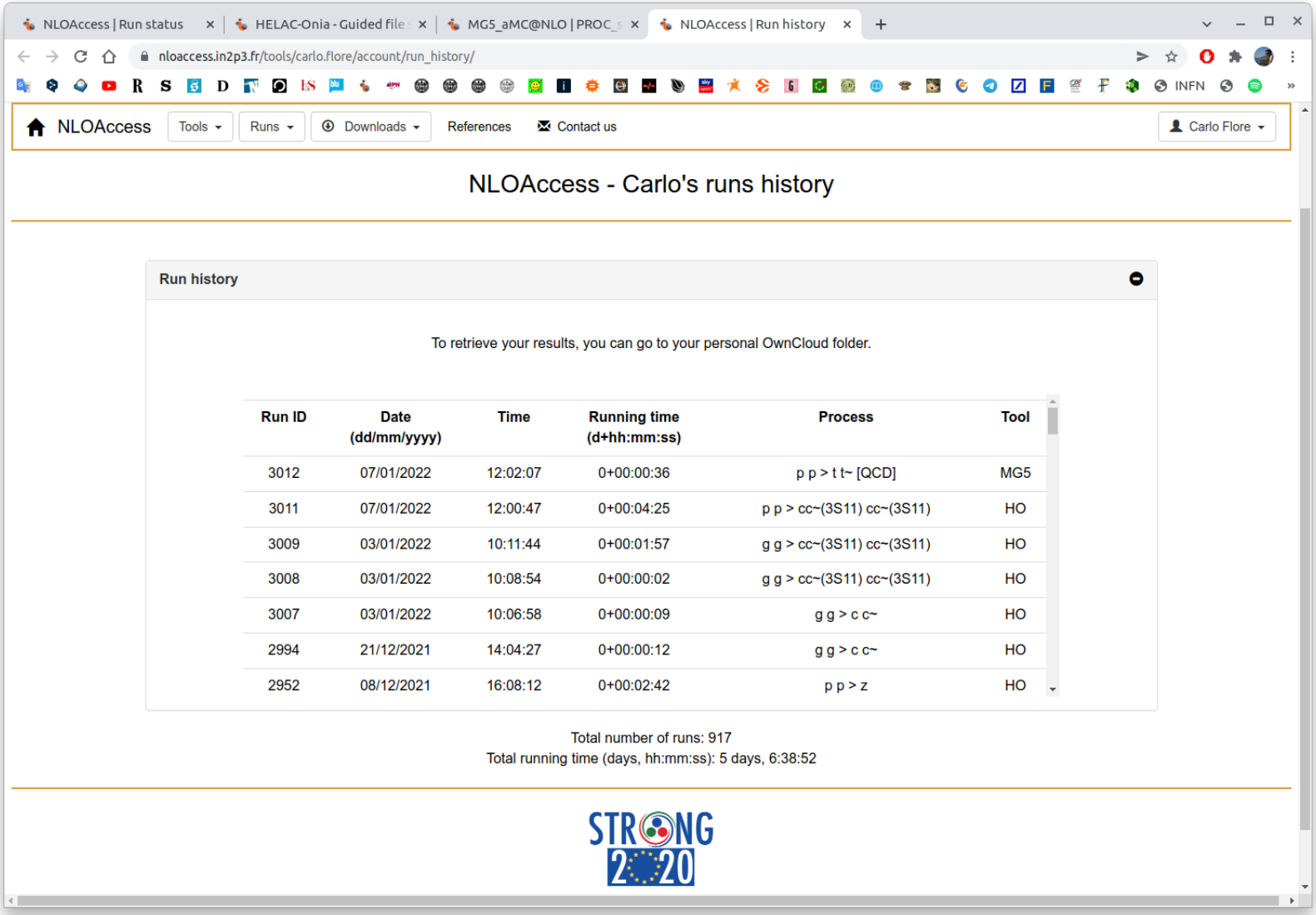
NLOAccess - homepage

(https://nloaccess.in2p3.fr)

NLOAccess - run status



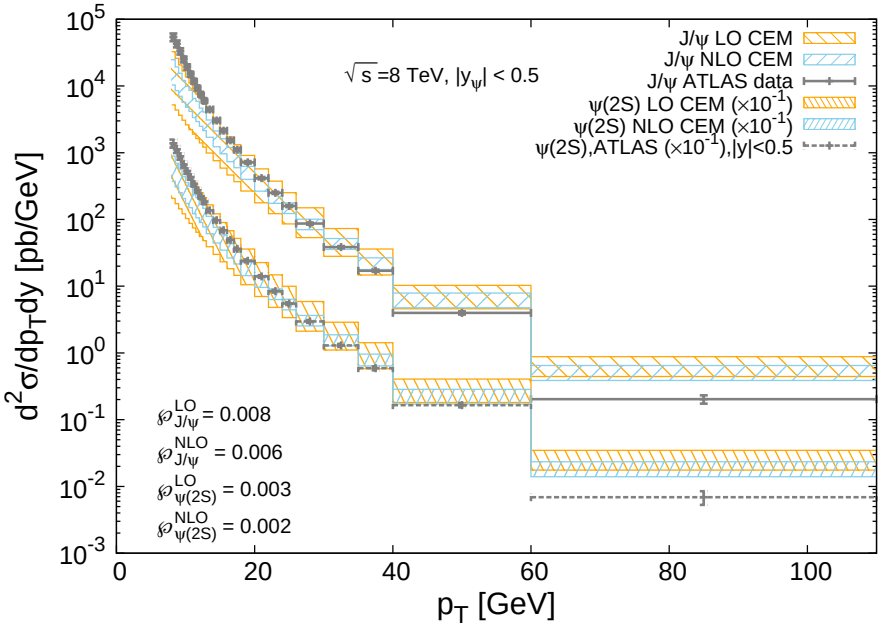
NLOAccess - run history

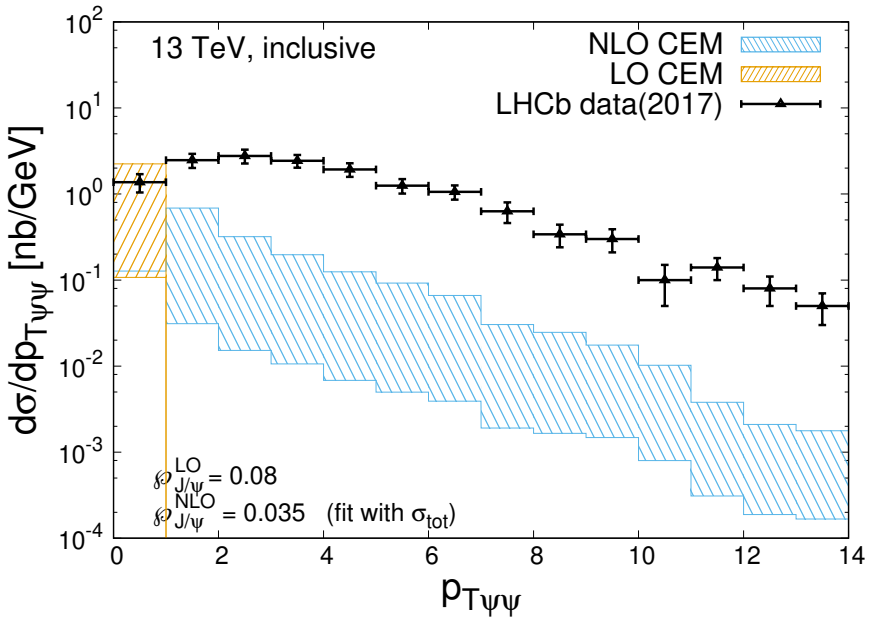


Run ID	Date (dd/mm/yyyy)	Time	Running time (d+hh:mm:ss)	Process	Tool
3012	07/01/2022	12:02:07	0+00:00:36	p p > t t~ [QCD]	MG5
3011	07/01/2022	12:00:47	0+00:04:25	p p > cc~(3S11) cc~(3S11)	HO
3009	03/01/2022	10:11:44	0+00:01:57	g g > cc~(3S11) cc~(3S11)	HO
3008	03/01/2022	10:08:54	0+00:00:02	g g > cc~(3S11) cc~(3S11)	HO
3007	03/01/2022	10:06:58	0+00:00:09	g g > c c~	HO
2994	21/12/2021	14:04:27	0+00:00:12	g g > c c~	HO
2952	08/12/2021	16:08:12	0+00:02:42	p p > z	HO

Bonus - NLO (di-)onium production in MG5

J.-P. Lansberg, H.-S. Shao, N. Yamanaka, Y.-J. Zhang, C. Noûs, PLB 807 (2020) 135559





All the computations were done with MG5_aMC@NLO **[J. Alwall *et al.*, JHEP 07 (2014) 079]**.

- Good description of the P_T spectrum for single J/ψ (still some issues at large P_T)
- di-J/ψ production cannot be described by NLO CEM

The Color Evaporation Model

- In the CEM, an onium production cross section is obtained from the one for $Q\bar{Q}$ production, with a cut on the invariant mass of the pair:

$$d\sigma_{\mathcal{Q}}^{(\mathrm{N})\mathrm{LO}} = \mathcal{P}_{\mathcal{Q}}^{(\mathrm{N})\mathrm{LO}} \int_{2m_Q}^{2m_H} dm_{Q\bar{Q}} \frac{d\sigma_{Q\bar{Q}}^{(\mathrm{N})\mathrm{LO}}}{dm_{Q\bar{Q}}}$$

- its Improved version (ICEM), momenta are rescaled:

$$d\sigma_{\mathcal{Q}}^{(\mathrm{N})\mathrm{LO}} = \mathcal{P}_{\mathcal{Q}}^{(\mathrm{N})\mathrm{LO}} \int_{2m_Q}^{2m_H} dm_{Q\bar{Q}} \frac{d\sigma_{Q\bar{Q}}^{(\mathrm{N})\mathrm{LO}}}{dm_{Q\bar{Q}}}\Big|_{p_{Q\bar{Q}}=\frac{m}{M_{\mathcal{Q}}}p_{\mathcal{Q}}}$$