



**IGFAE**  
Instituto Galego de Física de Altas Enerxías



**XUNTA  
DE GALICIA**

# QCD at IGFAE: Recent highlights

Néstor Armesto

for the SA1\_HQCD of the SA1: The Standard Model to the limits

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Santiago de Compostela, Spain*



FONDO EUROPEO DE DESENVOLVEMENTO REXIONAL "Unha maneira de facer Europa"

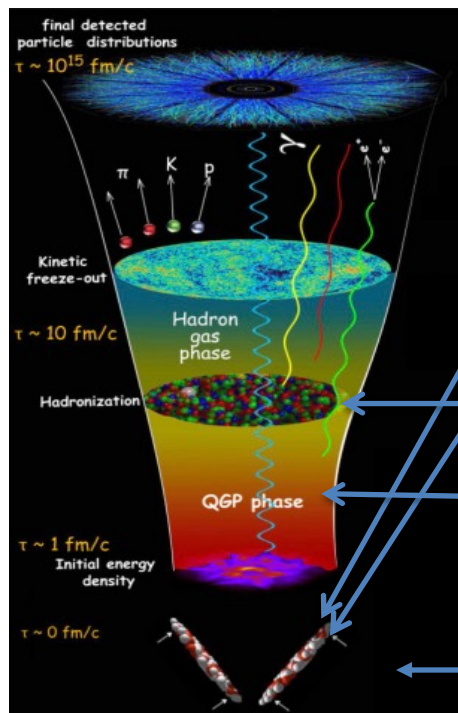
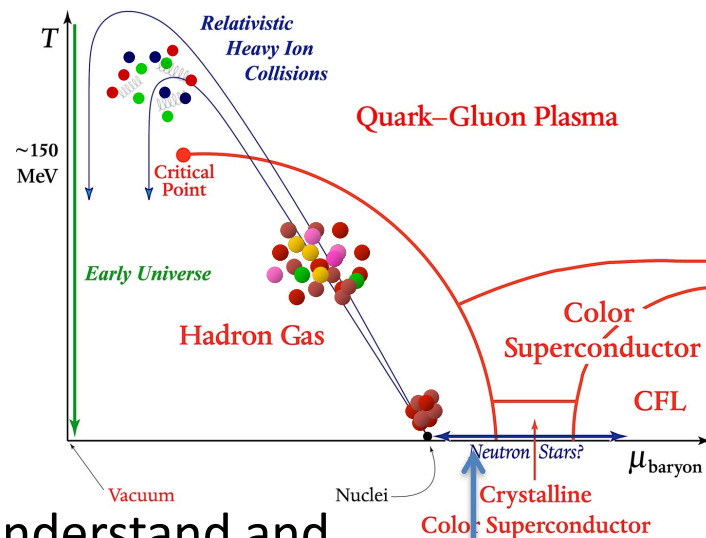


# SA1\_HQCD: QCD at IGFAE

- Our goal: The study of QCD under extreme conditions
- Strongly interacting matter (SIM): complex phase diagram  
 High  $T$ , high  $\rho$ : Quark Gluon Plasma (QGP)  
 Low  $T$ , high  $\rho$ : hadrons  $\rightarrow$  ? SC phase  $\rightarrow$  ? quark phase

Where?:

- in the Universe  $\approx 10^{-5}$  s after the Big-Bang
- in the core of neutron stars
- in high-energy hadronic collisions  
*from small ? to large systems*



## 4 Research activities to understand and characterise the properties of SIM:

- Parton structure and saturation
- QCD in the soft domain:  
 Phenomenological models and QCD based studies
- Hard probes in heavy-ion collisions:  
 jet quenching and quarkonium
- Skyrme model applied to nuclear physics and astrophysics

## Permanent staff:

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Tan Luo  
Yair Mulian  
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Xoan Mallo

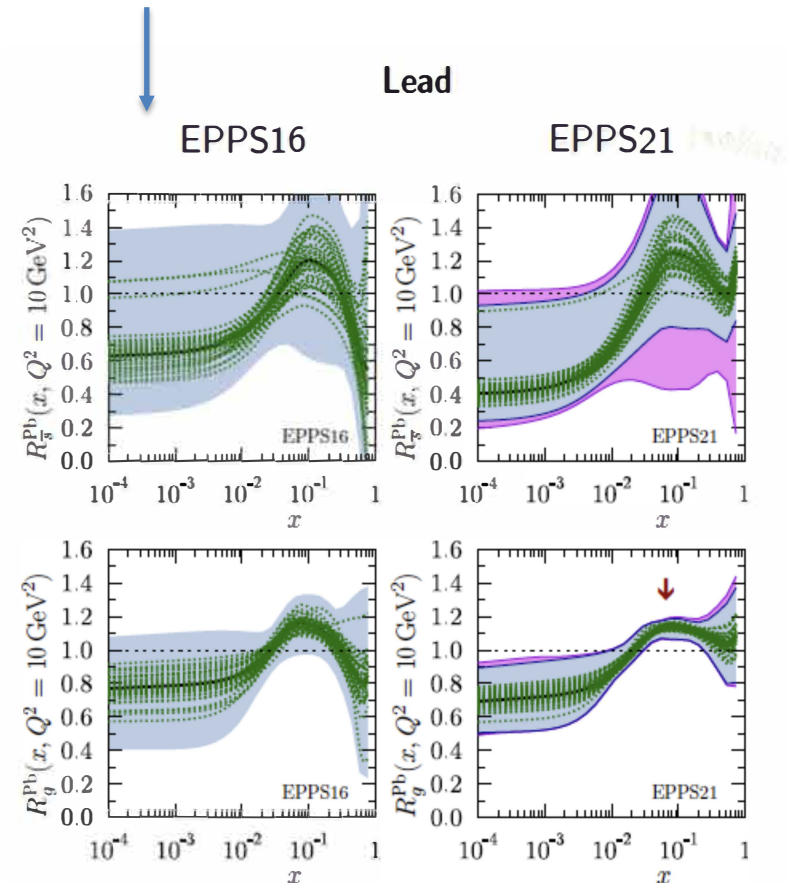
# RA1: Parton structure and saturation

Members: N. Armesto, E. G. Ferreiro, C. Pajares, C. Salgado, F. Dominguez, Bin Wu

## Global fits of nuclear PDFs: using linear DGLAP evolution => observable consequences

- nPDF analysis EPPS21: new set released in 2021 that supersedes EPS16
- Proton structure at the precision front  
Snowmass 2021 whitepaper, [arXiv:2203.13923](https://arxiv.org/abs/2203.13923)
- Diffractive PDFs in future ep/eA colliders:  
EIC YellowReport, [arXiv: 2103.05419](https://arxiv.org/abs/2103.05419)  
Conceptual Design Report of the LHeC  
J.Phys.G 48 (2021) 11, 110501
- QCD factorization:  
Factorization and transverse phase-space parton distributions. B. Wu, JHEP 07 (2021) 002  
Precision boson-jet azimuthal decorrelation at hadron colliders Y.-T. Chien, R. Rahn, D. Y. Shao, W. J. Waalewijn, B. Wu, [arXiv:2205.05104](https://arxiv.org/abs/2205.05104)

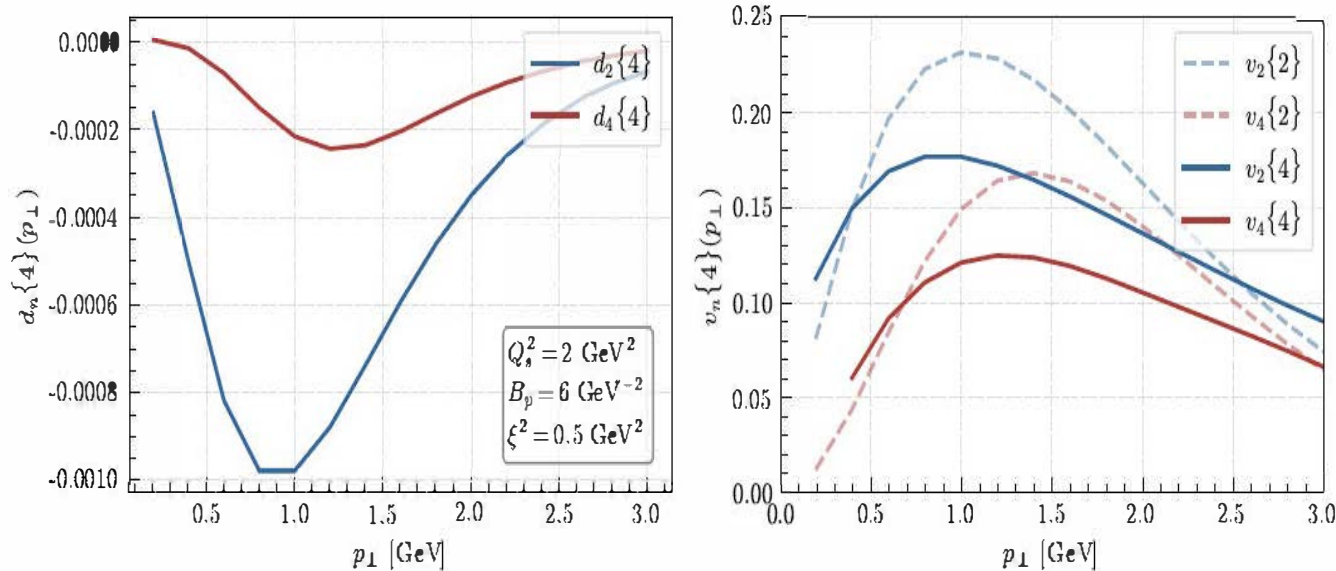
K. J. Eskola, P. Paakkinen, H. Paukkunen, C. A. Salgado, Eur. Phys. J. C82 (2022) 413



# RA1: Parton structure and saturation

Members: N. Armesto, E. G. Ferreiro, C. Pajares, C. Salgado, F. Dominguez, Bin Wu

## Partonic structure of the nucleus in the non-linear parton saturated regime: studies on particle production and correlations



- Multi-particle production in pA collisions in the CGC  
P. Agostini, T. Altinoluk, N. Armesto, Eur. Phys. J. C 81 (2021) 760  
+ NLO calculations, non-eikonal corrections,...
- Angular correlations in pA collisions from CGC  
T. Altinoluk, N. Armesto, A. Kovner, M. Lublinsky, and V. Skokov, Eur. Phys. J. C 81 (2021) 583

# RA2: QCD in the soft domain

Members: Carlos Merino, Carlos Pajares, Ricardo Vázquez, Xabier Feal, Bin Wu

## Multiparton interactions: non-perturbative string and Regge models

Models applicable from proton-proton to nucleus-nucleus collisions

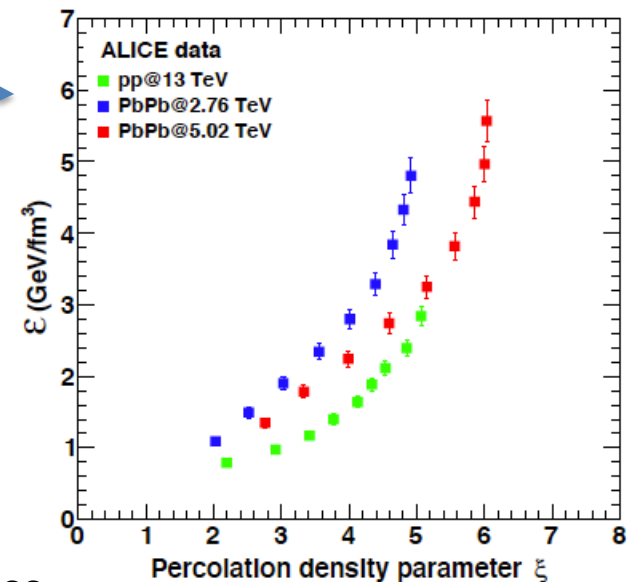
- Studies on experimental observables usually considered as signatures of collectivity

M. A. Braun and C. Pajares, *Flow coefficients in O-O Al-Al and Cu-Cu collisions at 200 GeV in the fusing color string model*, Phys. Rev. C 103 (2021) 5, 054902

### Relation between soft models and deconfinement

N. Mishra, G. Paić, C. Pajares, R. P. Scharenberg, and B. K. Srivastava, *Deconfinement and degrees of freedom in pp and AA collisions at LHC energies*, Eur. Phys. J. A 57 (2021) 245

G.H. Arakelyan, C. Merino, Y.M. Shabelski, *Multistrange hyperon production on nuclear targets*, Phys. Rev. D 105 (2022) 114013



- QCD matter

Thermalization of gluons in spatially homogeneous systems,  
S. Barrera Cabodevila, C.A. Salgado, B. Wu, arXiv:2206.12376

- Related to **RA1**, approach to the thermalisation process

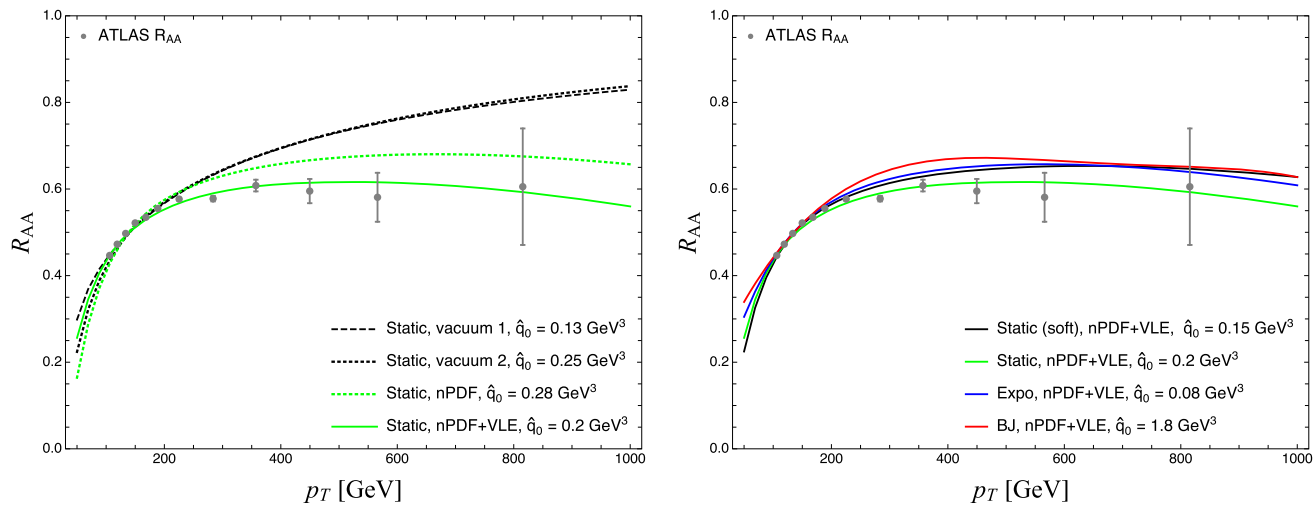
X. Feal, C. Pajares and R. Vazquez, *Thermal and hard scales in transverse momentum distributions, fluctuations, and entanglement*, Phys. Rev. C 104 (2021) 4, 044904

# RA3: Hard probes in heavy-ion collisions

Members: N. Armesto, E.G. Ferreiro, C. Salgado, R. Vázquez, F. Domínguez, J. Barata, X. Feal, M.A. Escobedo

**Jet quenching:** to study the initial stages of HI collisions, ERC AdG “Yoctosecond Imaging of QCD collectivity using jet observables (YoctoLHC)” (C. Salgado 2019)

Main topic: time evolution of the in-medium parton cascade and how it is affected by the early stages of the collision.



S. P. Adhya, , C. A. Salgado, M. Spousta, K. Tywoniuk, *Multi-partonic medium induced cascades in expanding media*, Eur.Phys.J.C 82 (2022) 20

J. Barata, F. Dominguez, C. A. Salgado, V. Vila, *A modified in-medium evolution equation with color coherence*, JHEP 05 (2021) 148

# RA3: Hard probes in heavy-ion collisions

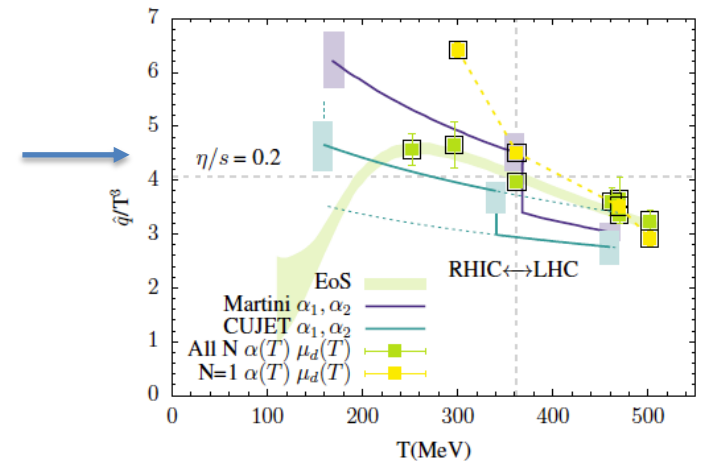
Members: N. Armesto, E.G. Ferreiro, C. Salgado, R. Vázquez, F. Domínguez, J. Barata, X. Feal, M.A. Escobedo

**Jet quenching:** to study the initial stages of HI collisions, ERC AdG “Yoctosecond Imaging of QCD collectivity using jet observables (YoctoLHC)” (C. Salgado 2019)

Other topics:

- correct interpolation between multiple-soft and single-hard scatterings.

*X. Feal, C. A. Salgado, R. A. Vazquez, Jet quenching test of the QCD matter created at RHIC and the LHC needs opacity-resummed medium-induced radiation, Phys.Lett.B 816 (2021) 136251*



- Exploration of the possibilities of quantum simulation in computing quantities of interest for high-energy and nuclear physics, including transport coefficients.

*J. Barata, N. Mueller, A. Tarasov, R. Venugopalan, Single-particle digitization strategy for quantum computation of a  $\phi^4$  scalar field theory, Phys.Rev.A 103 (2021) 4, 042410*

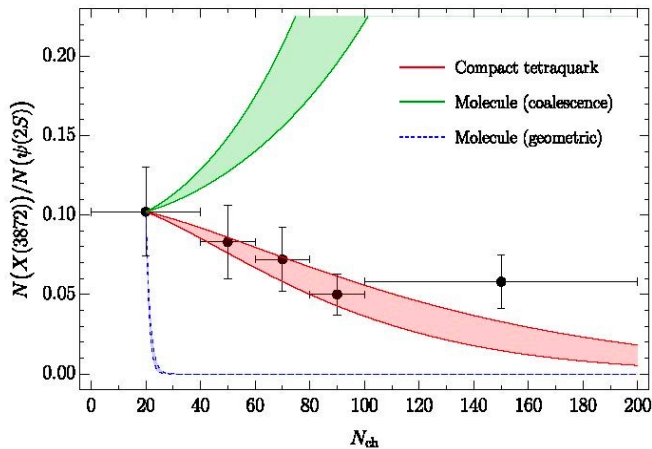
*J. Barata, C. A. Salgado, A quantum strategy to compute the jet quenching parameter  $q_{hat}$ , Eur.Phys.J.C 81 (2021) 862*



# RA3: Hard probes in heavy-ion collisions

Members: N. Armesto, E.G. Ferreiro, C. Salgado, R. Vázquez, F. Domínguez, J. Barata, X. Feal, M.A. Escobedo

## Quarkonium: understanding the suppression pattern of different quarkonia states in various colliding systems



- Especially relevant is the possibility to use the suppression pattern in pp collisions to identify the structure of exotic new states

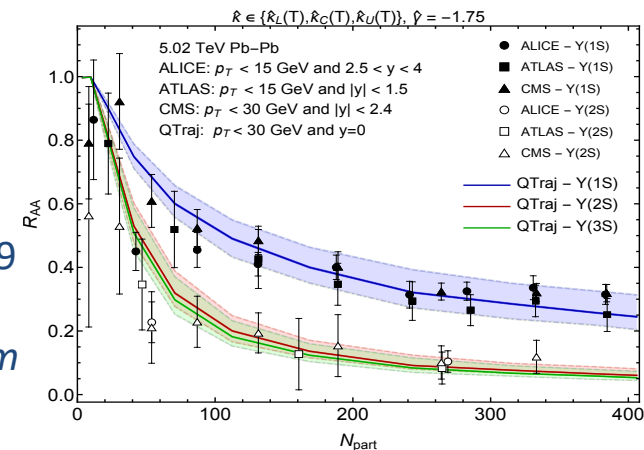
Angelo Esposito, Elena G. Ferreiro, Alessandro Pilloni, Antonio D. Polosa, Carlos A. Salgado, *The nature of X(3872) from high-multiplicity pp collisions*, Eur.Phys.J.C 81 (2021) 669

- Different approaches for the quarkonium-medium interaction:

M. A. Escobedo and E. G. Ferreiro, *Initial-state & hot-medium effects*, Phys. Rev. D 105 (2022) 014019

N. Brambilla, M. A. Escobedo, M. Strickland et al, *Bottomonium production in heavy-ion collisions ...*, Phys. Rev. D 104 (2021) 094049

N. Brambilla, M. A. Escobedo, M. Strickland et al, *Heavy quarkonium dynamics ...*, arXiv 2205.10289



# RA4: Skyrme model applied to nuclear physics and astrophysics

Members: Christoph Adam, Joaquín Sánchez-Guillén, Ricardo Vázquez

## Generalized Skyrme models applied to nuclear physics and astrophysics

### • Skyrme matter at high density and neutron stars

C. Adam, A. García Martín-Caro, M. Huidobro, R. Vázquez, A. Wereszczynski,  
*Quasiuniversal relations for generalized Skyrme stars*, Phys. Rev. D103 (2021) 023022;

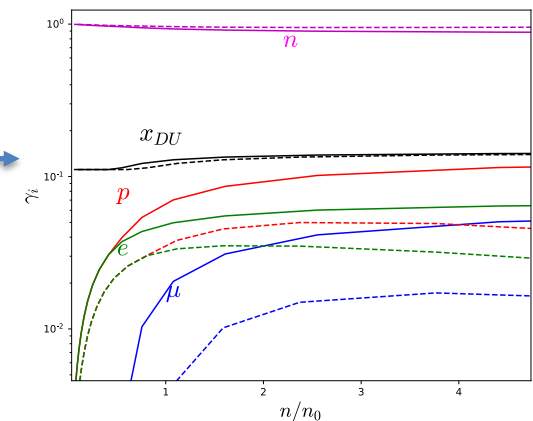
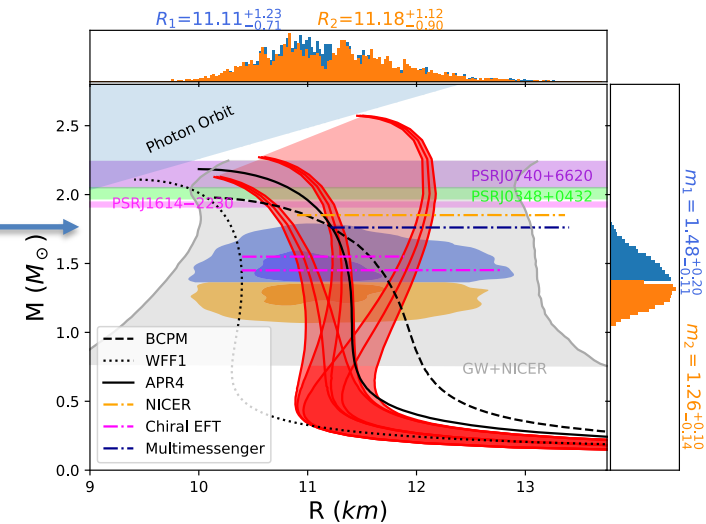
*Dense matter equation of state and phase transitions from a generalized Skyrme model*, Phys. Rev. D105 (2022) 074019;

*Quantum Skyrmion crystals and the symmetry energy of dense matter*, arXiv: 2202.00953.

#### Spin-off:

C. Adam, J. Castelo, A. García Martín-Caro, M. Huidobro, R. Vázquez, A. Wereszczynski,  
*Universal relations for rotating boson stars*,  
arXiv: 2203.16558

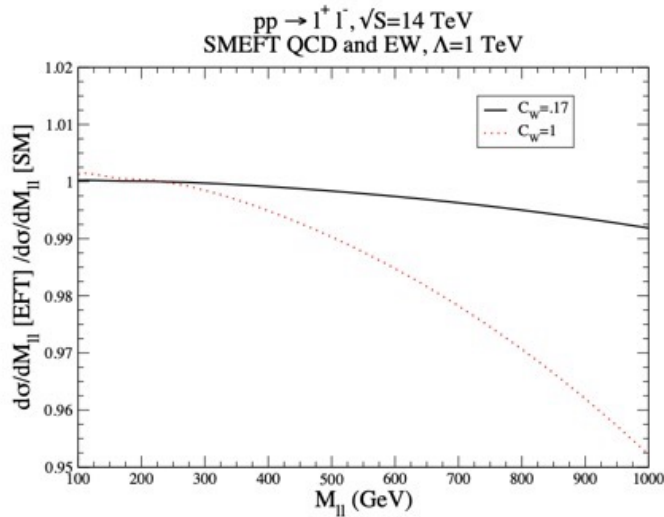
Applicability for GW, relation with **SA2\_GRWA**



# RA5: Probing new physics with EFT

Members: Pier P. Giardino

## Probing new physics with EFT: Drell Yan, Z & W and Higgs production



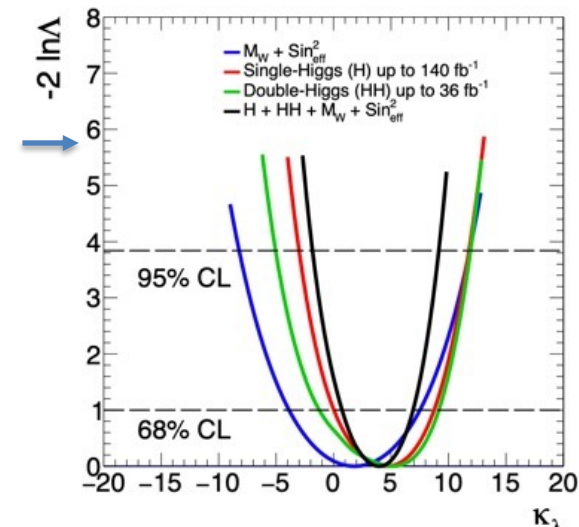
- Drell Yan production as a sensitive probe of new physics calculated to high order in both the electroweak and QCD sectors

← Sally Dawson, Pier Paolo Giardino New physics through Drell-Yan standard model EFT measurements at NLO Phys.Rev.D 104 (2021) 7, 073004

- SMEFT implications for Higgs:

G. Degrassi, B. Di Micco, P.P. Giardino, E. Rossi, *Higgs boson self-coupling constraints from single Higgs, double Higgs and Electroweak measurements*, Phys.Lett.B 817 (2021) 136307

S. Dawson, P.P. Giardino, S. Homiller, *Uncovering the High Scale Higgs Singlet Model*, Phys.Rev.D 103 (2021) 075016



Strong implication in the elaboration of **new experimental proposals**:

- Ions at the HL-LHC in Runs 3 and 4 and beyond  
*Perspectives for quarkonium studies at the high-luminosity LHC*, Prog. Part. Nucl. Phys. 122 (2022) 103906
- Fixed Targets experiments at LHC (AFTER@LHC): coordination & organisation  
*A fixed-target programme at the LHC: Physics case and projected performances for heavy-ion, hadron, spin and astroparticle studies*, Phys. Rept. 911 (2021) 1-83
- ep and eA colliders (LHeC and EIC): coordination and convenerships  
*Conceptual Design Report of the LHeC*, J.Phys.G 48 (2021) 11, 110501  
  
*Science Requirements and Detector Concepts for the Electron-Ion Collider: EIC Yellow Report*  
e-Print: 2103.05419 [physics.ins-det]
- Boards of the LHeC/FCC/EIC

# SA1\_HQCD: Other highlights

- Plenary talks, convenorship, IACs
  - Hard Probes 2022, Deep Inelastic Scattering 2021, International Conference on High Energy Physics (ICHEP) 2022
- Organisation
  - Deep Inelastic Scattering 2022 with SA1\_LHCB
  - European Nuclear Physics Conference 2022 with SA3
- Participation in multiple Boards
  - Nuclear Physics Board European Physical Society
  - Executive & Governing Board STRONG2020
  - Plenary ECFA European Committee for Future Accelerators
  - Management Committee COST Action
  - Board members from European institutions EIC
  - AEI - Agencia Estatal de Investigación
- Research projects
  - ERC Advanced Grant:
    - Yoctosecond imaging of QCD collectivity using jet observables (YoctoLHC)*
  - Others: AEI-Agencia Estatal, Xunta de Galicia, STRONG2020

# SA1\_HQCD : Relation with the other research fields of IGFAE

SA2 COSMIC PARTICLES AND FUNDAMENTAL PHYSICS  
**Extremely energetic cosmic rays and neutrinos**

SA1 THE STANDARD MODEL TO THE LIMITS  
**SA1\_STRI String theory and relation with other fields**

SA1 THE STANDARD MODEL TO THE LIMITS  
**SA1\_HQCD Hot and dense QCD in the LHC era and beyond**  
RA1 Parton structure and saturation  
RA2 Phenomenological models for QCD in the soft domain  
RA3 Hard probes in heavy-ion collisions: jet quenching & quarkonium  
RA4 Skyrme model applied to nuclear physics and astrophysics

SA1 THE STANDARD MODEL TO THE LIMITS  
**SA1\_LHCB Beyond the Standard Model searches with**

SA3 NUCLEAR PHYSICS;  
SA2\_GRWA **gravitational wave astronomy**

