

Effective field theories and hadronic structures

Ignazio Scimemi

IPARCOS meeting, 16-17/06/2022

All physicists have a dream...

..and actually we have many..

- How do quarks and gluons move in hadrons in 3D? How are hadronic spins generated? How can we measure the hadron/quark or hadron/gluon spin-momentum distributions in 3D? Universality?
- How can we understand hadronic states (resonances) and their interactions at low energy? How do they affect heavy meson decays, CP-violation and EW physics?
- How are resonances generated and appear at EW scales? and in BSM physics?

...and effective field theories get us closer...

Features of EFT

- EFT combine QCD and kinematics symmetries to expand cross sections in easier and fundamental quantities/distributions (PDF, TMD, Jets, LDME,...)
- EFT are the low energy result of physics BSM
- EFT allow to connect physics phenomena at all energy (and build meaningful models if needed) with very **high precision**

Examples: *Chiral PT, Soft Collinear ET, Heavy Quark ET, Non Relativistic QCD, pNRQCD, vNRQCD, SMEFT, HEFT*

A practical result: All quark masses need an effective theory to be extracted from experiments

The theoretical particle physics group

In some order

Older Staff

- Antonio Dobado
- Angel Gómez Nicola
- Felipe Llanes Estrada
- José Ramón Peláez
- Juan José Sanz Cillero
- Ignazio Scimemi

New entries

- Clara Peset Martin
- Jacobo Ruiz de Elvira
- Alexey Vladimirov
- Patricia Magalhaes

PhD

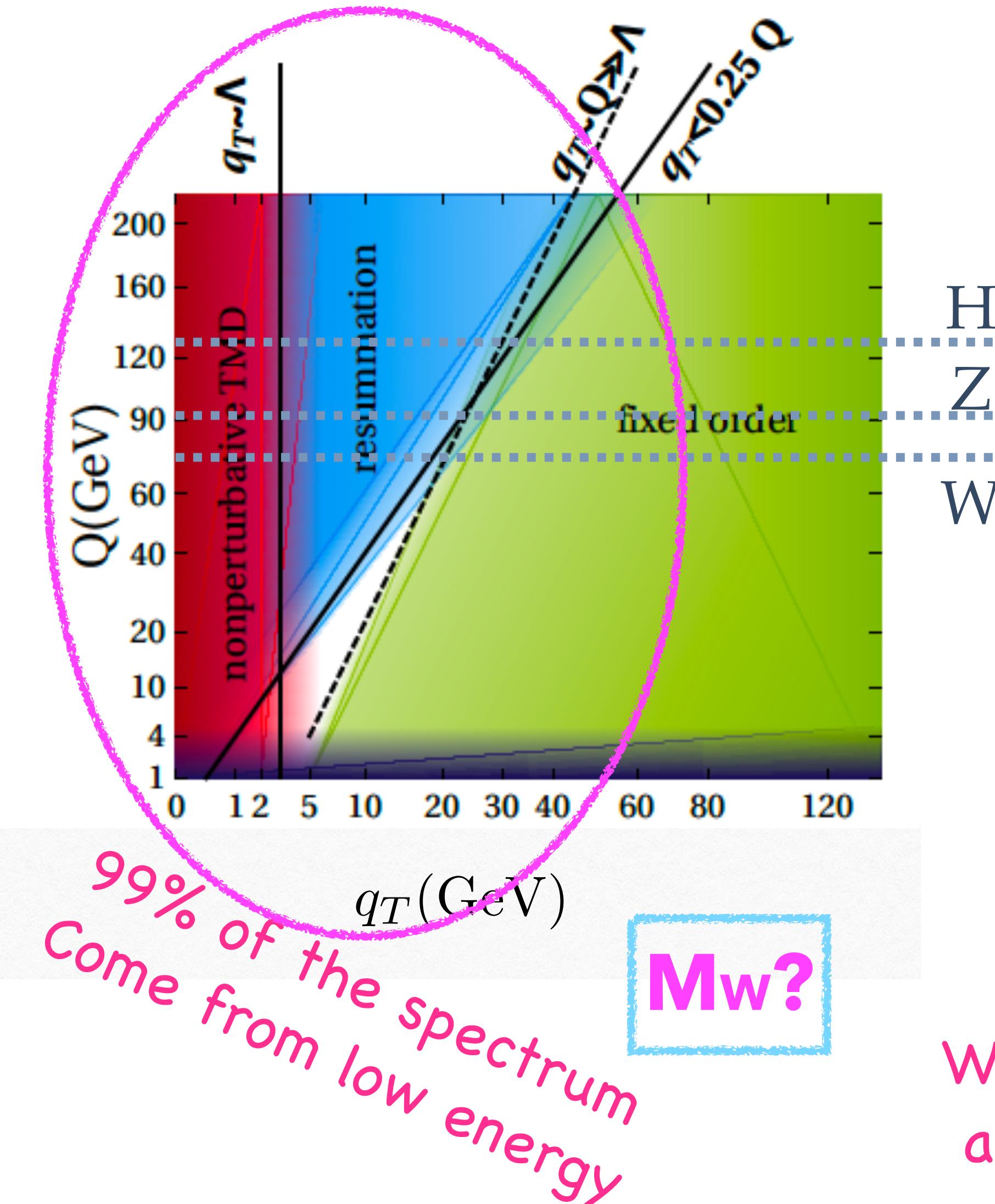
- Clara Álvarez Luna
- Adrian Casado Turrión
- Rafael Fernandez del Castillo
- Patricia Gutiérrez García
- Eva Lope Oter
- Carlos Quezada Calonge
- Oscar del Rio García
- Alexandre Salas Bernardez
- Andrea Vioque Rodriguez

3D hadron tomography: TMD

Why should we care?

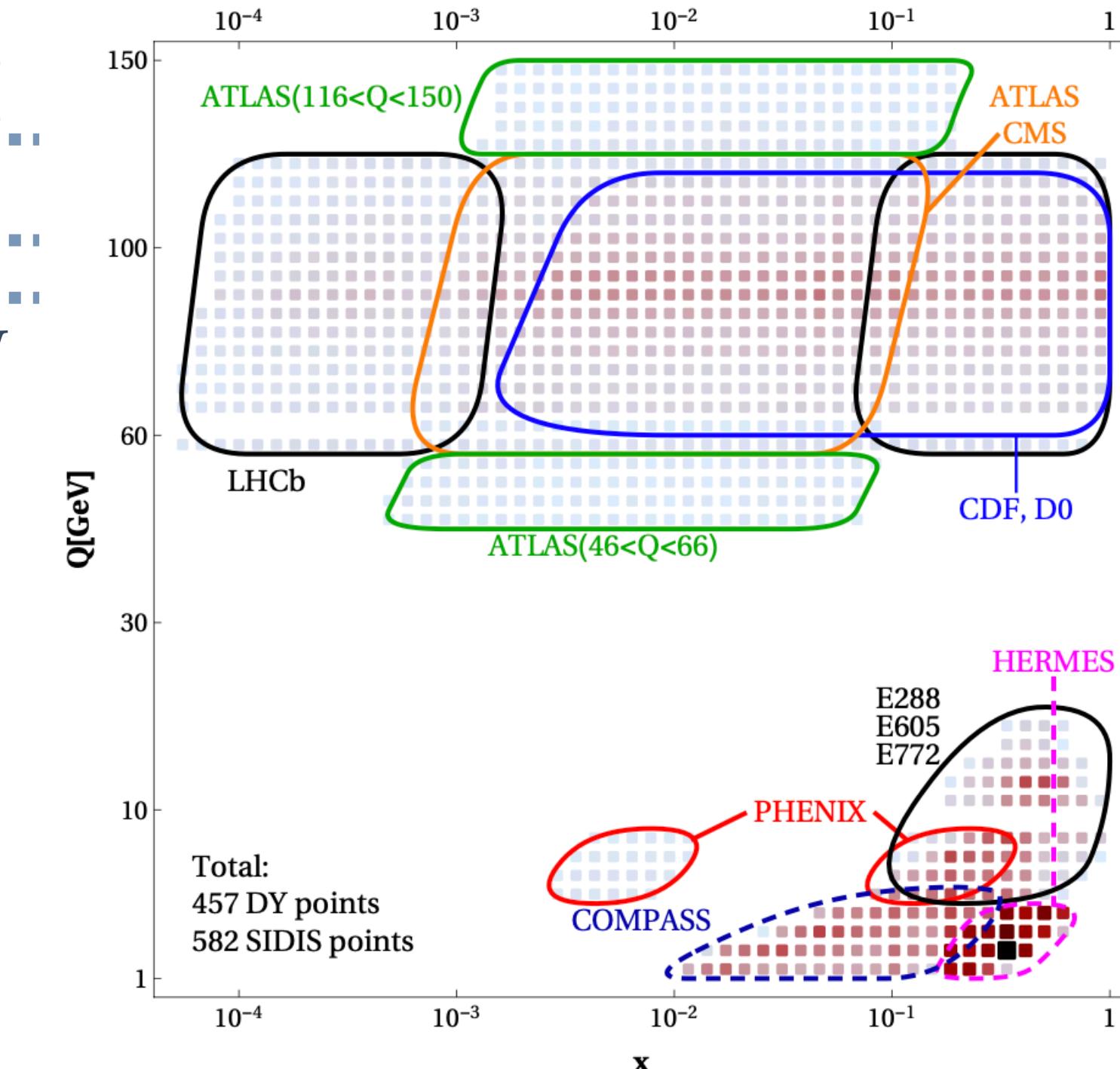
Ignazio Scimemi
Alexey Vladimirov
Rafael Fernandez del Castillo
Patricia Gutierrez
Oscar del Rio Garcia

+ collaborations Bilbao, NIKHEF, LANL, JLAB

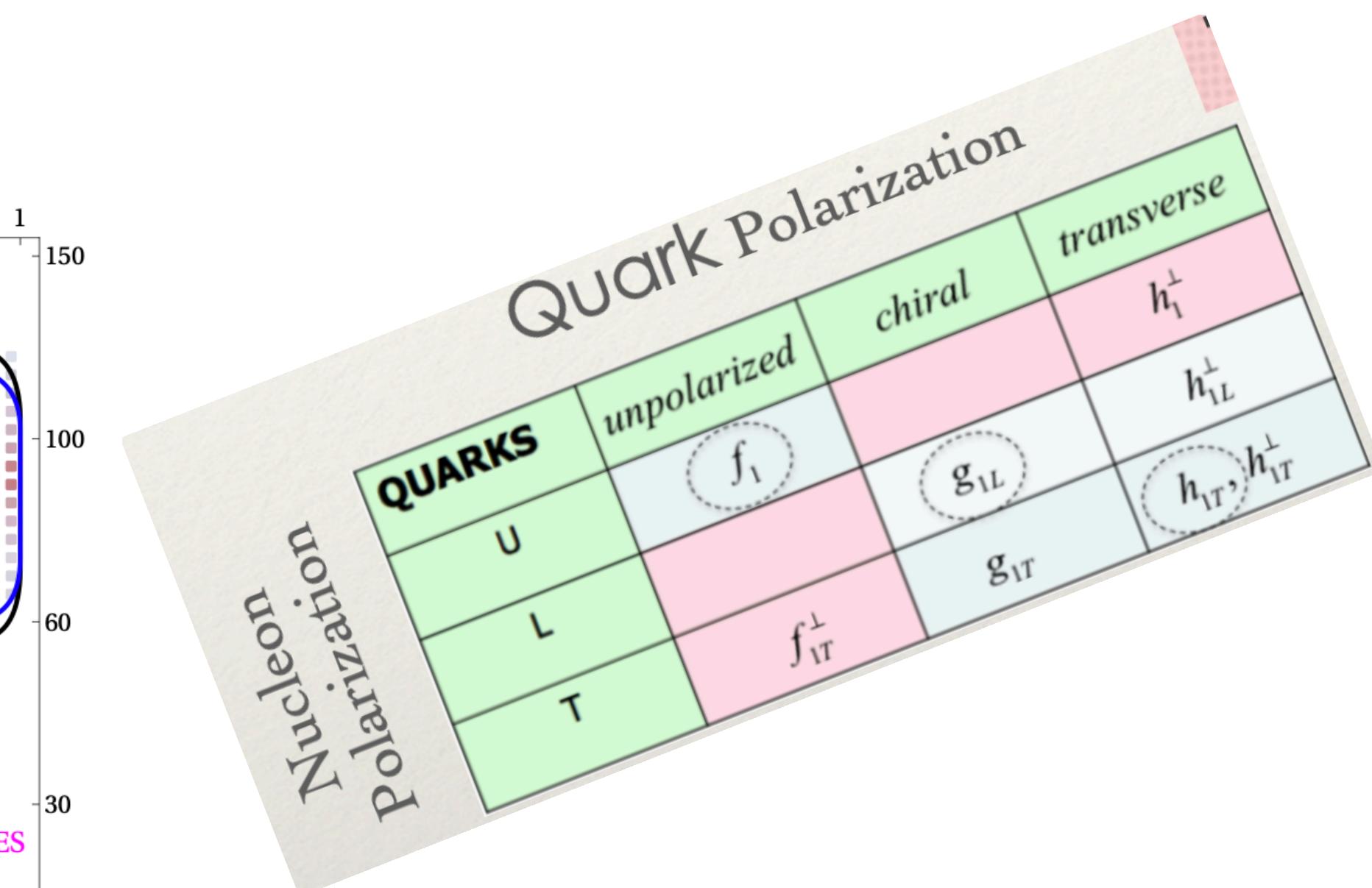


$$\ell(l) + H(P) \rightarrow \ell(l') + h(p_h) + X$$

$$h_1(P_1) + h_2(P_2) \rightarrow l(l) + l'(l') + X$$



We have a universal comprehension at all energies for DY, SIDIS, SIA

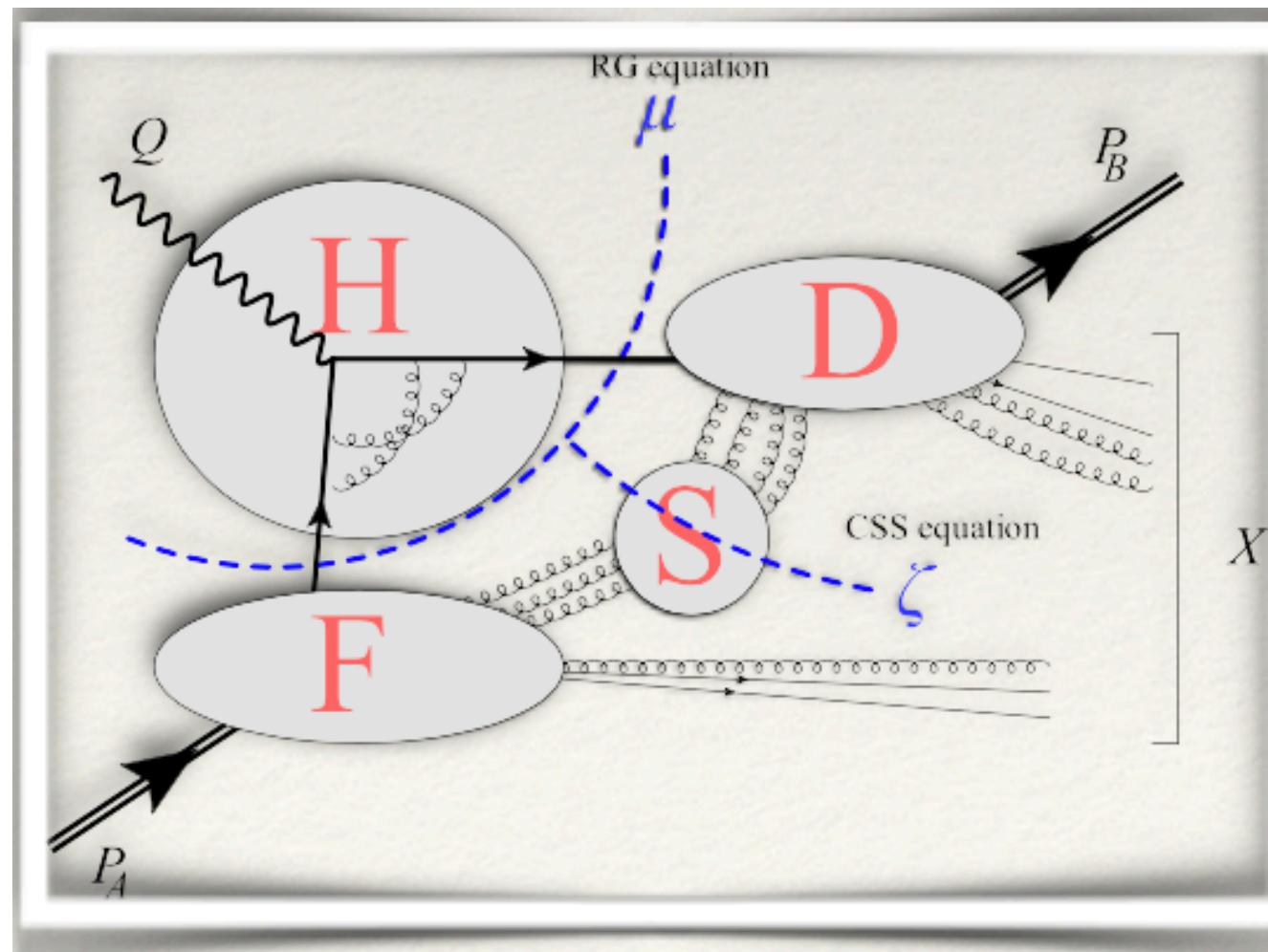


We understand the spin-momentum entanglement in hadrons

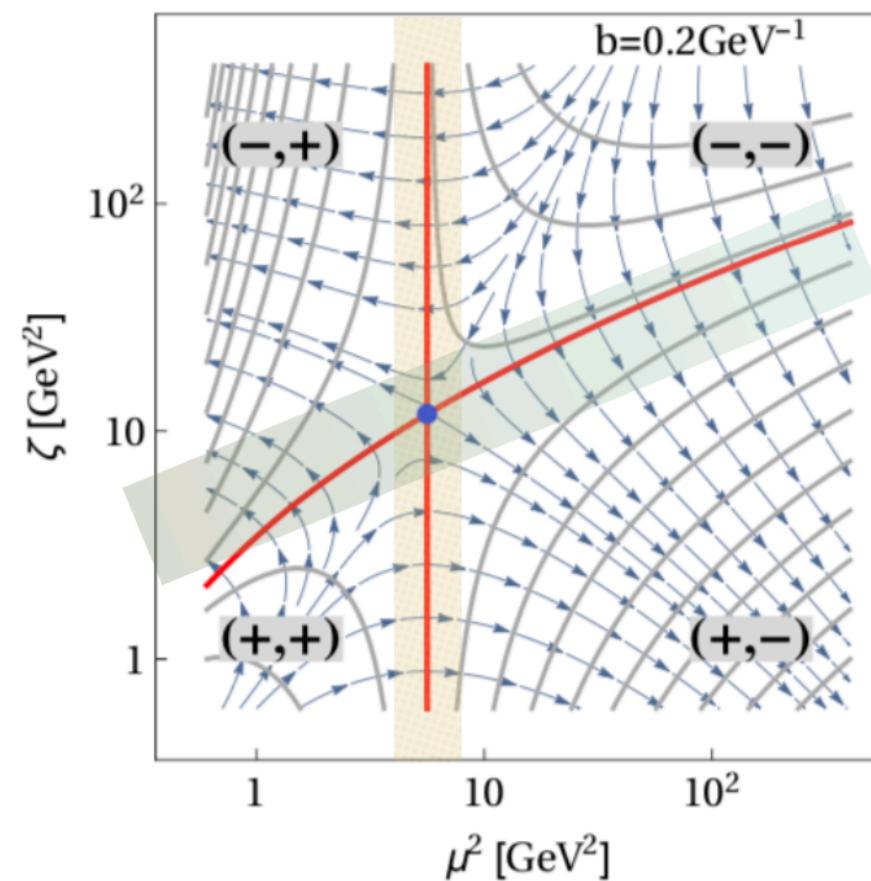
3D hadron tomography: Our Brand and Artemide

Why does the world care of us?

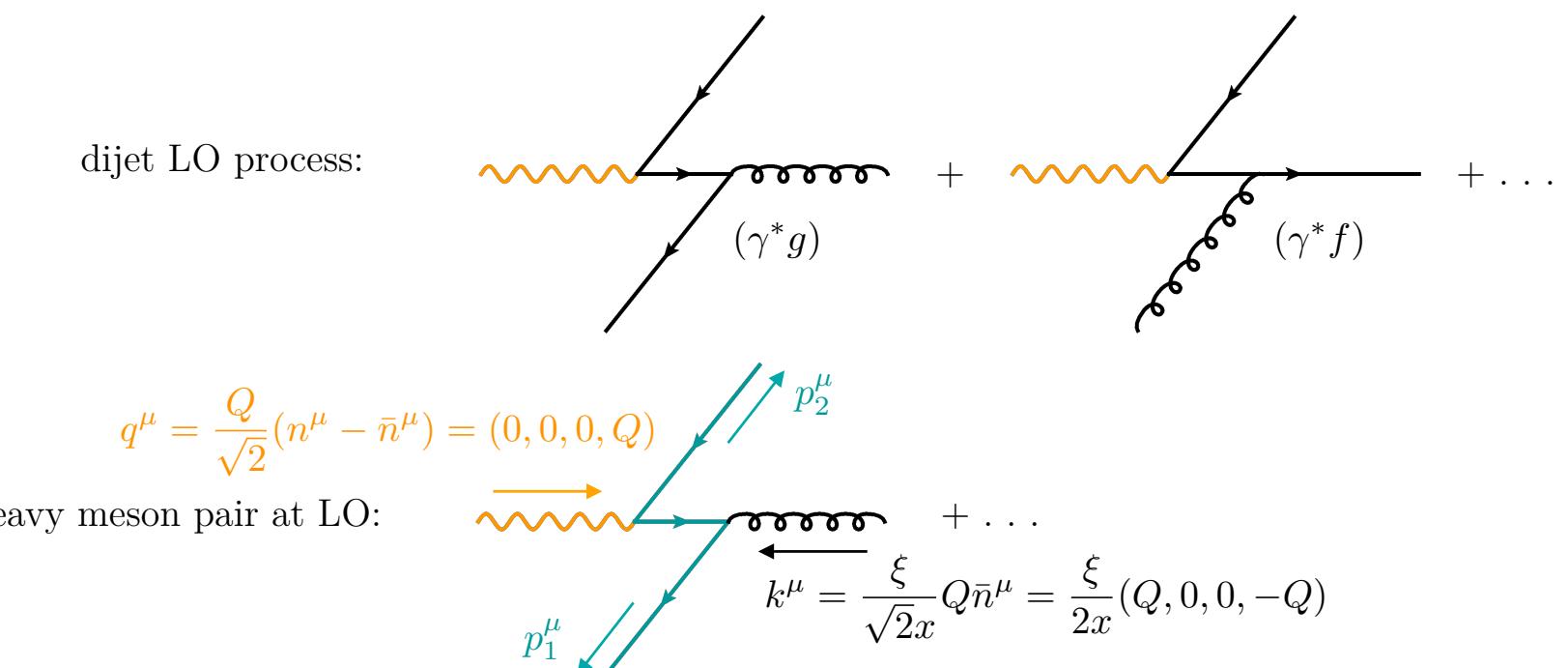
Factorization



Evolution

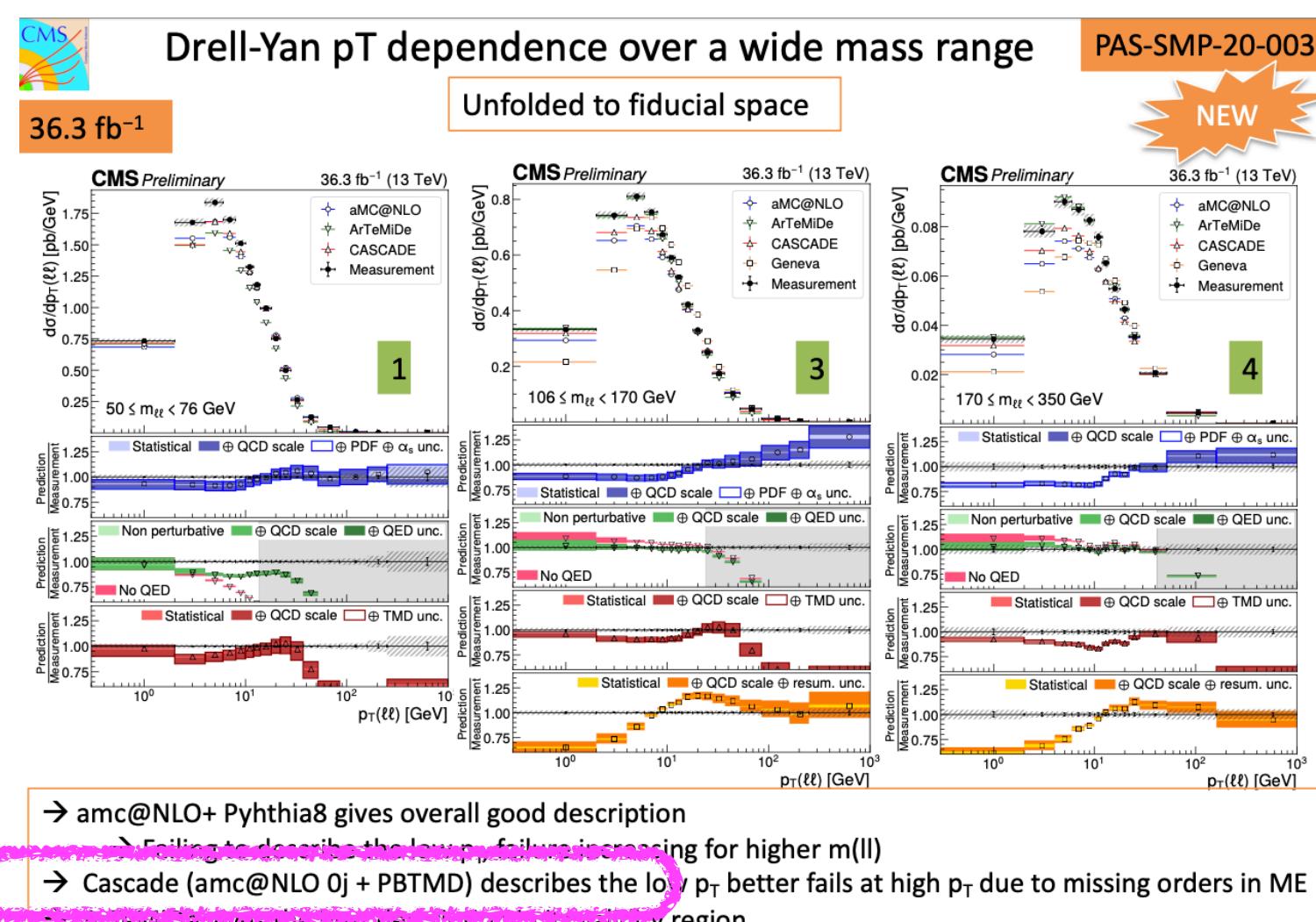
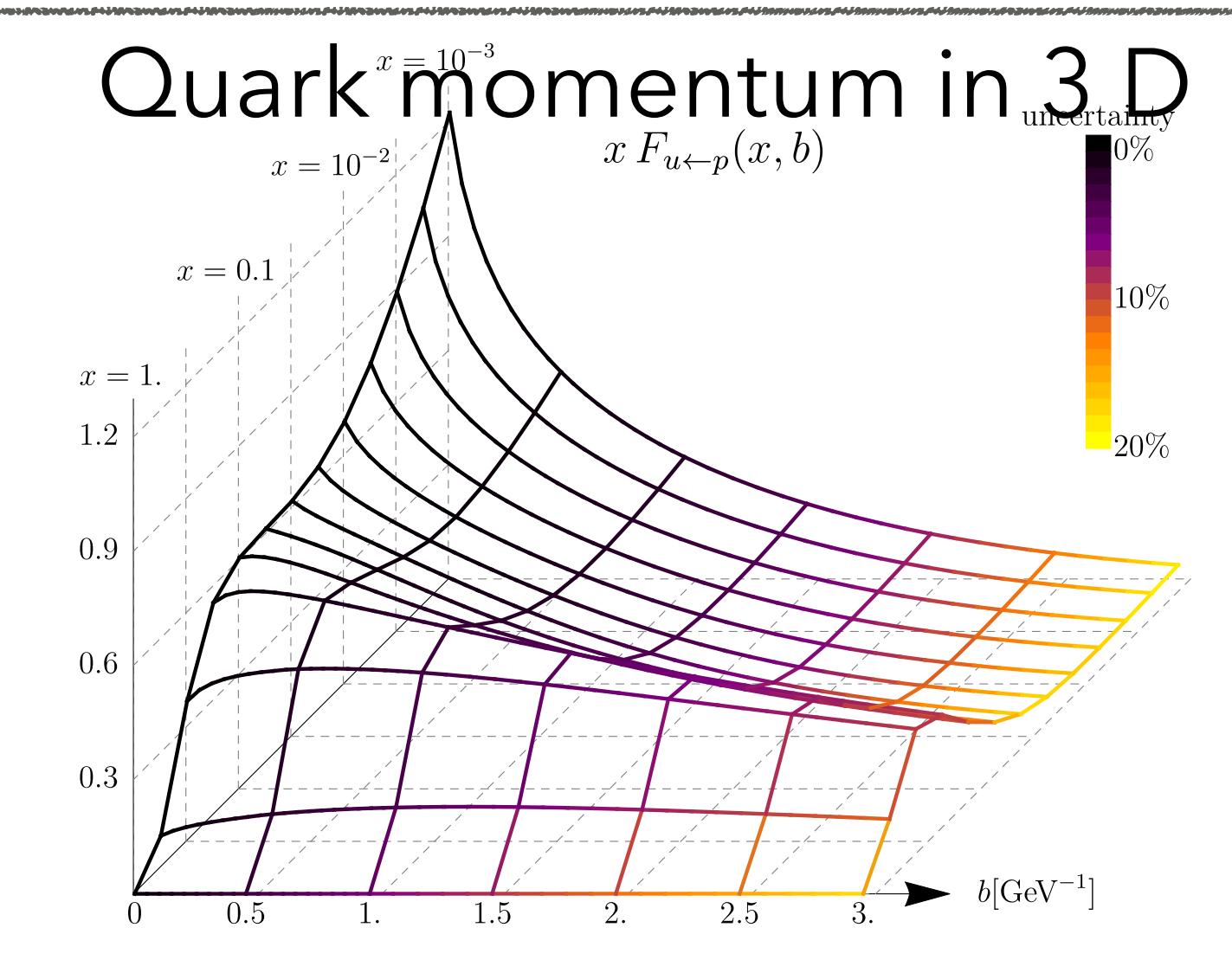
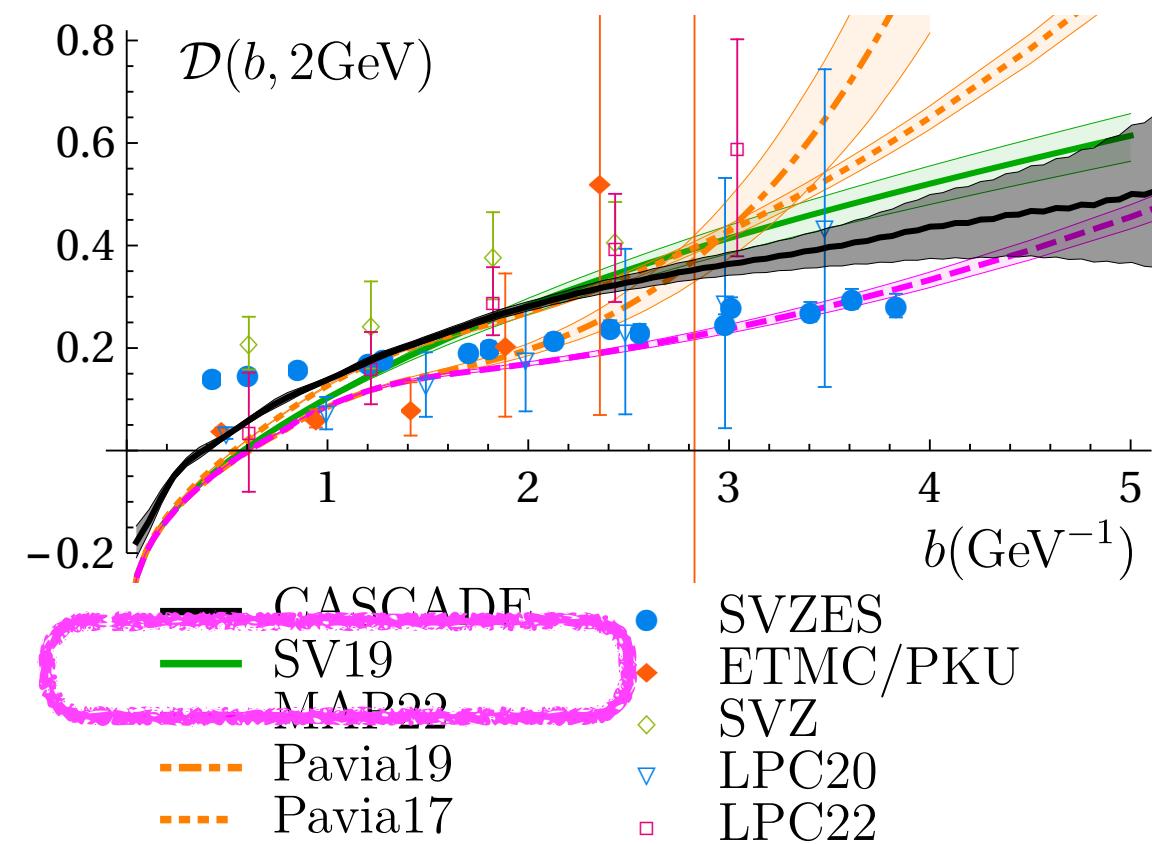


Jets and Heavy Hadrons



LHC, EIC, BELLE, ... data

Lattice





Theoretical Hadronic Physics @IPARCOS:

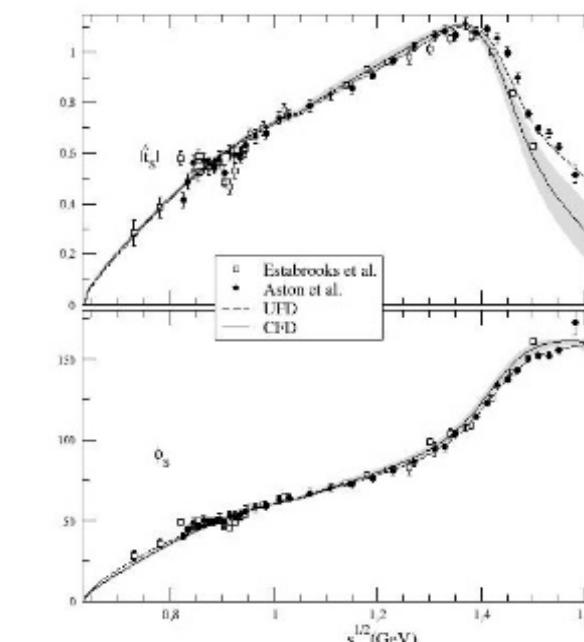
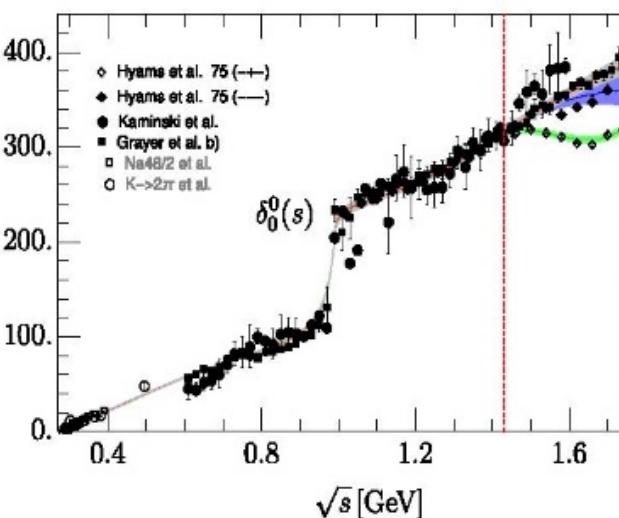
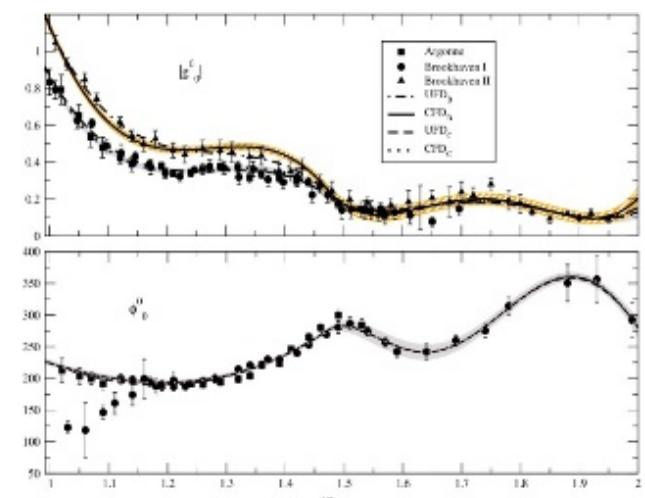
J.R. Peláez, A. Rodas, J. Ruiz de Elvira



Precision studies of meson-meson interactions using Dispersion Theory and Effective Field Theory

5-year highlights:

- Precise dispersive analysis of $\pi K \rightarrow \pi K$ and $\pi\pi \rightarrow K\bar{K}$ data
Constrained with 16 integral dispersion relations
- Analytic description of $\pi\pi \rightarrow \pi\pi$ data up to 2 GeV
Constrained with forward and coupled channel dispersive analyses



*Widely used by
theoreticians and
experimentalists*

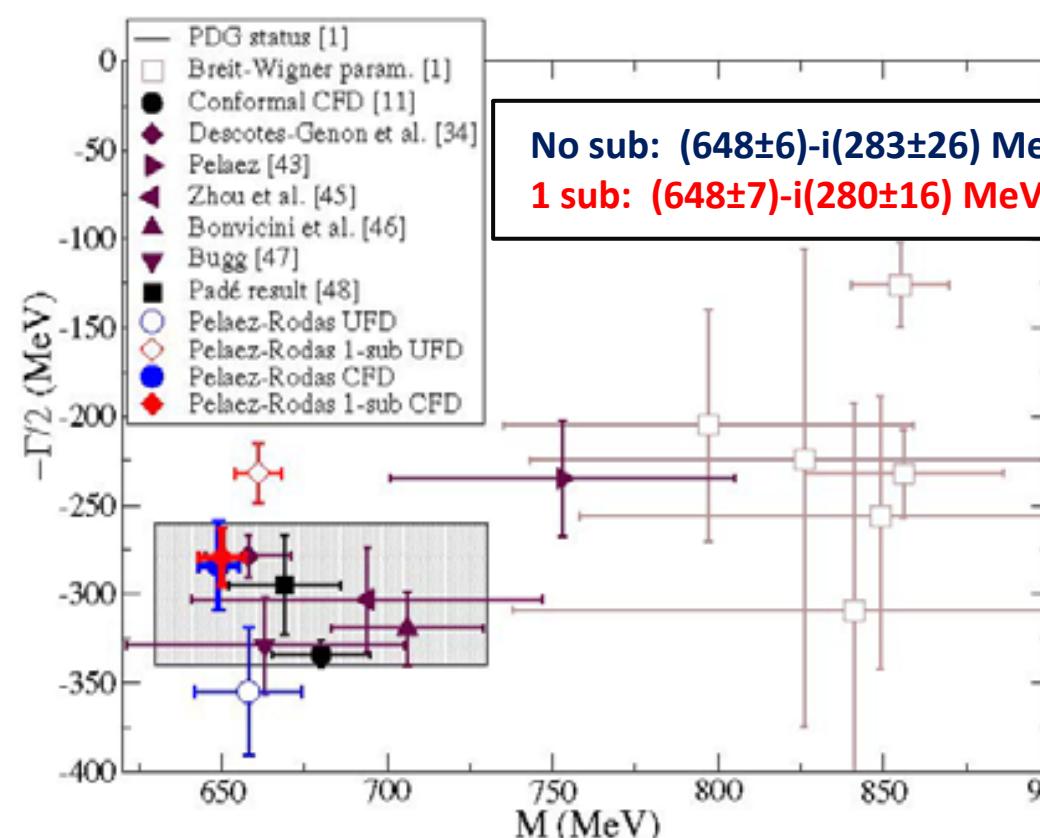
JRP & A.Rodas

- 1) Invited report: Phys.Rept. 969 (2022) 1-126
- 2) EPJ C78 (2018) no.11, 897

JRP, A.Rodas & J. Ruiz de Elvira:

- 3) EPJ C79 (2019) no.12, 1008
- 4) Invited report: EPJ.ST 230 (2021) 6, 1539

- Lightest strange resonance determination



From dispersion theory & data

Completes the
controversial
lightest scalar nonet
of QCD

JRP, A.Rodas. Phys.Rev.Lett. 124 (2020) 17

After decades of controversy:

- Name changed to $K_0^*(700)$
- “Needs Confirmation” to “Confirmed”
- Mass & width revised
in Review of Particle Properties



Theoretical Hadronic Physics: J.R. Peláez, A. Rodas

Precision studies of meson-meson interactions using Dispersion Theory and Effective Field Theory



5-year highlights (cont.):

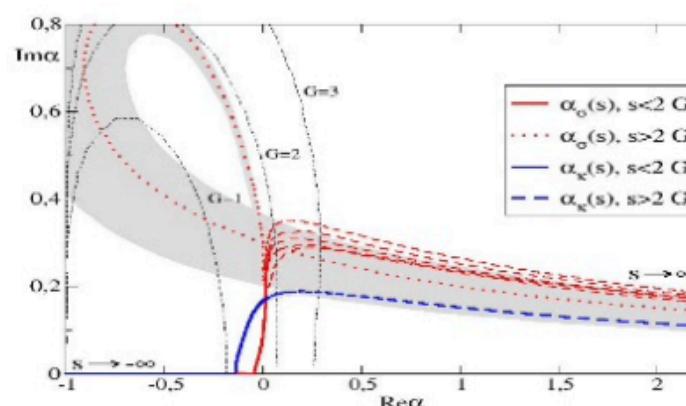
- Strange resonance poles from $K\pi$ scattering below 1.8 GeV



JRP, A.Rodas EPJ. C (2017) 77: 431

**Results added to
Review of Particle Physics**

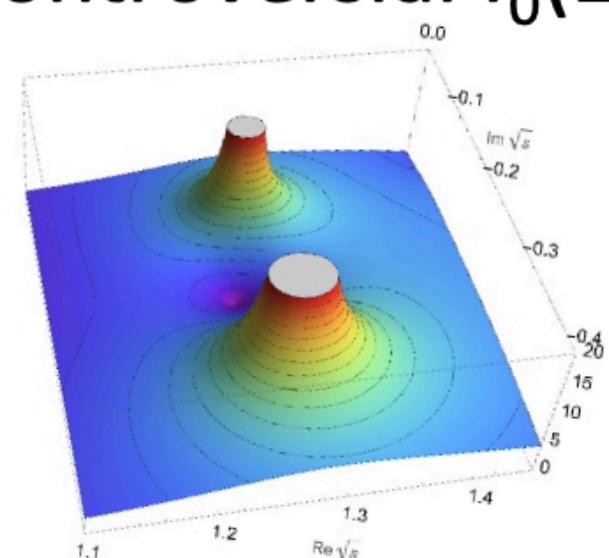
- $K_0^*(700)$ Regge trajectory
from dispersion theory



JRP, A.Rodas & J.Ruiz de Elvira.
EPJC (2017) 77: 91

**$K_0^*(700)$ is not an ordinary
quark-antiquark meson**

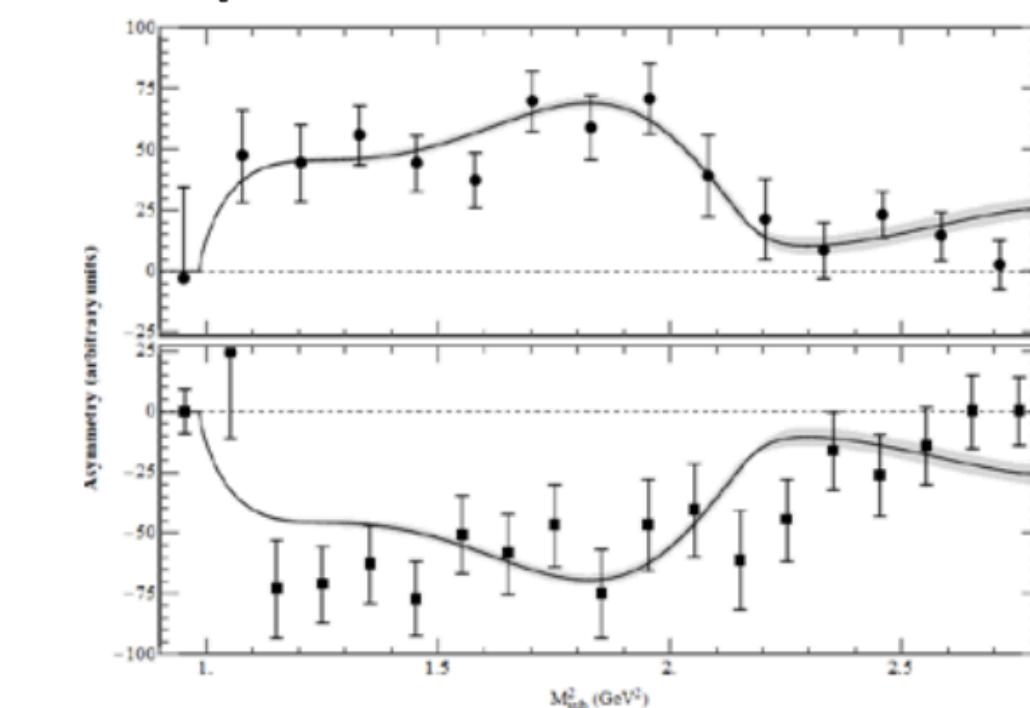
- Dispersive determination
of controversial $f_0(1370)$



For near future/ in progress

- Dispersive contributions to Giant CP violation @LHCb

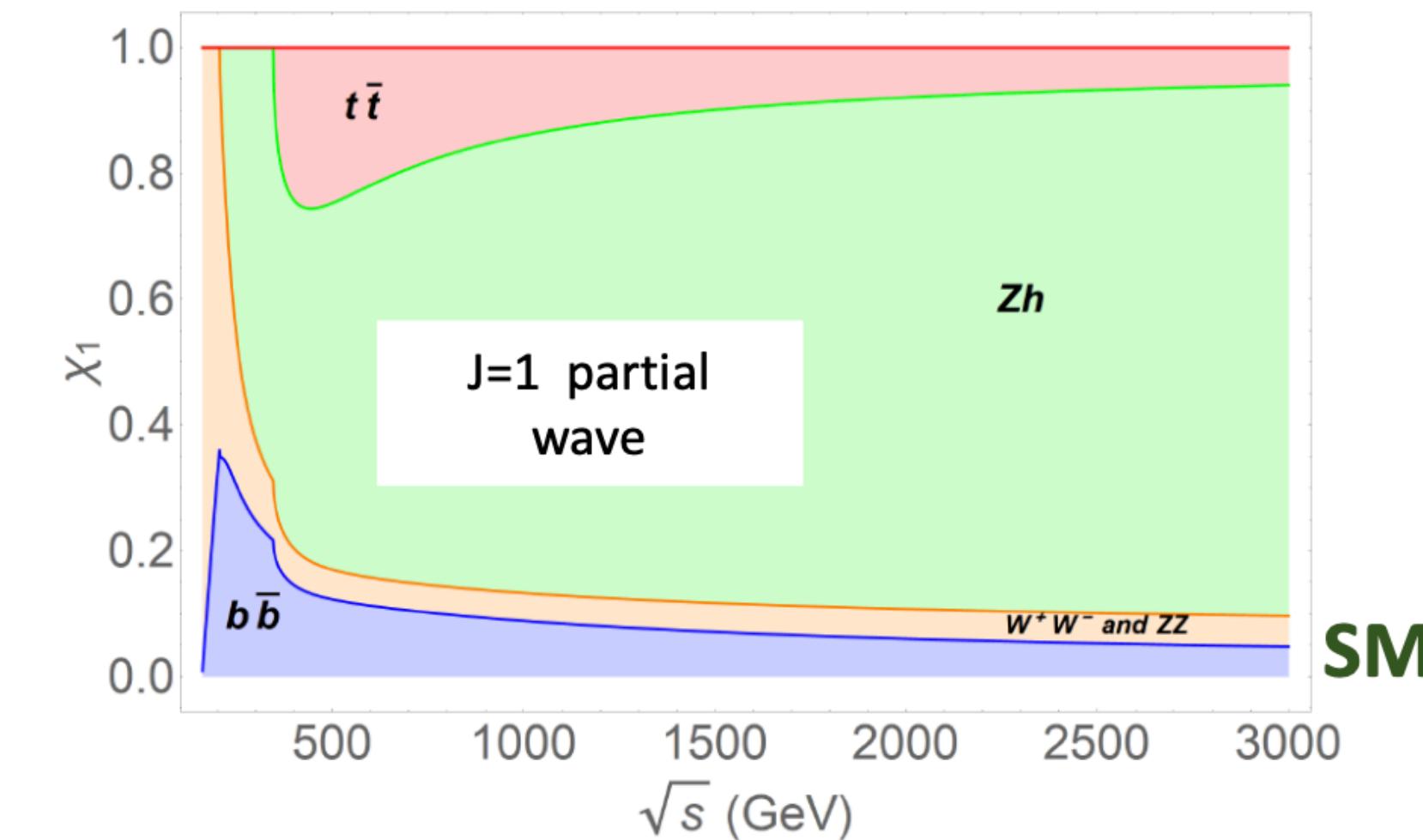
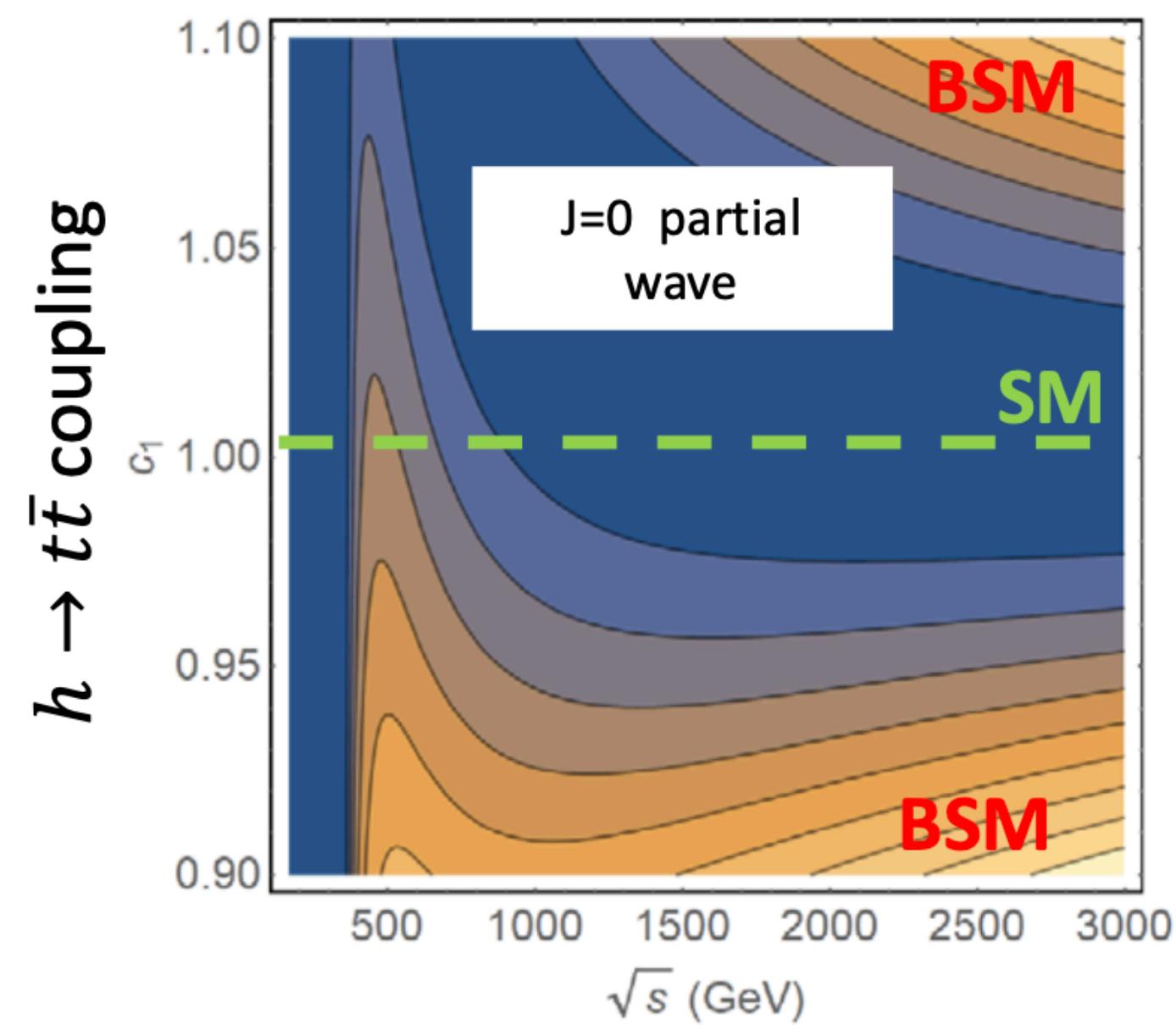
(already 2TFMs).
New Maria Zambrano postdoc:
Patricia Magalhaes



LHCb data vs. our dispersive amplitude

Higgs and EW Effective Theories

- Importance of fermion loops in WW scattering for SM & BSM
- Higgs Effective Theory (non-linear/chiral approach)
- Other theory aspects in EW physics:
 - Tests of the Equivalence Theorem (EW Goldstone \sim longit. EW gauge boson)
 - Custodial symmetry corrections ($g' \neq 0$)



Cumulative relative contribution of each channel to $J = 1$ PWA in the SM

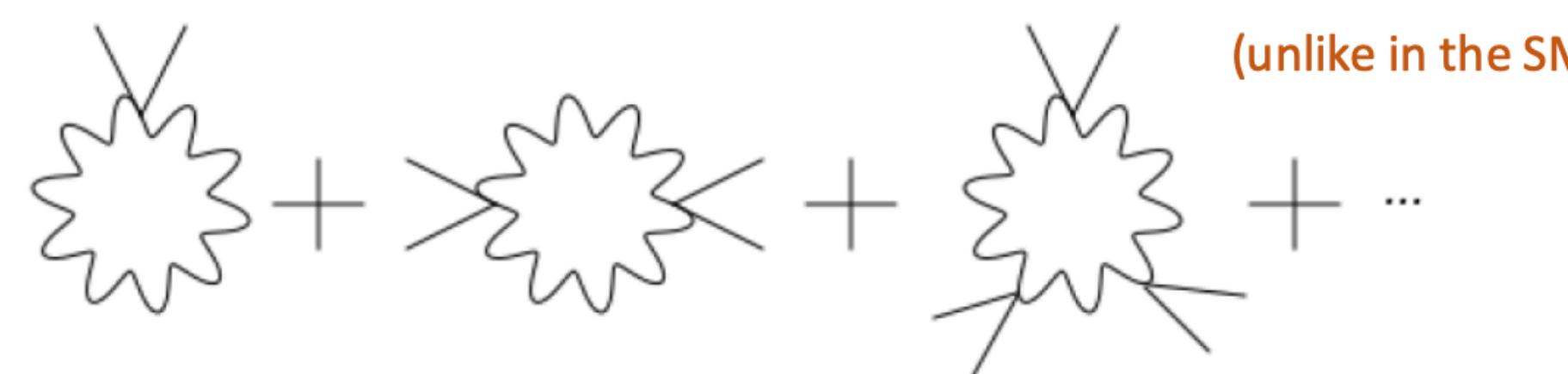
A Dobado, C Quezada-Calonge, JJ Sanz Cillero [2012.12242 \[hep-ph\]](#)

Study of large scale hierarchies

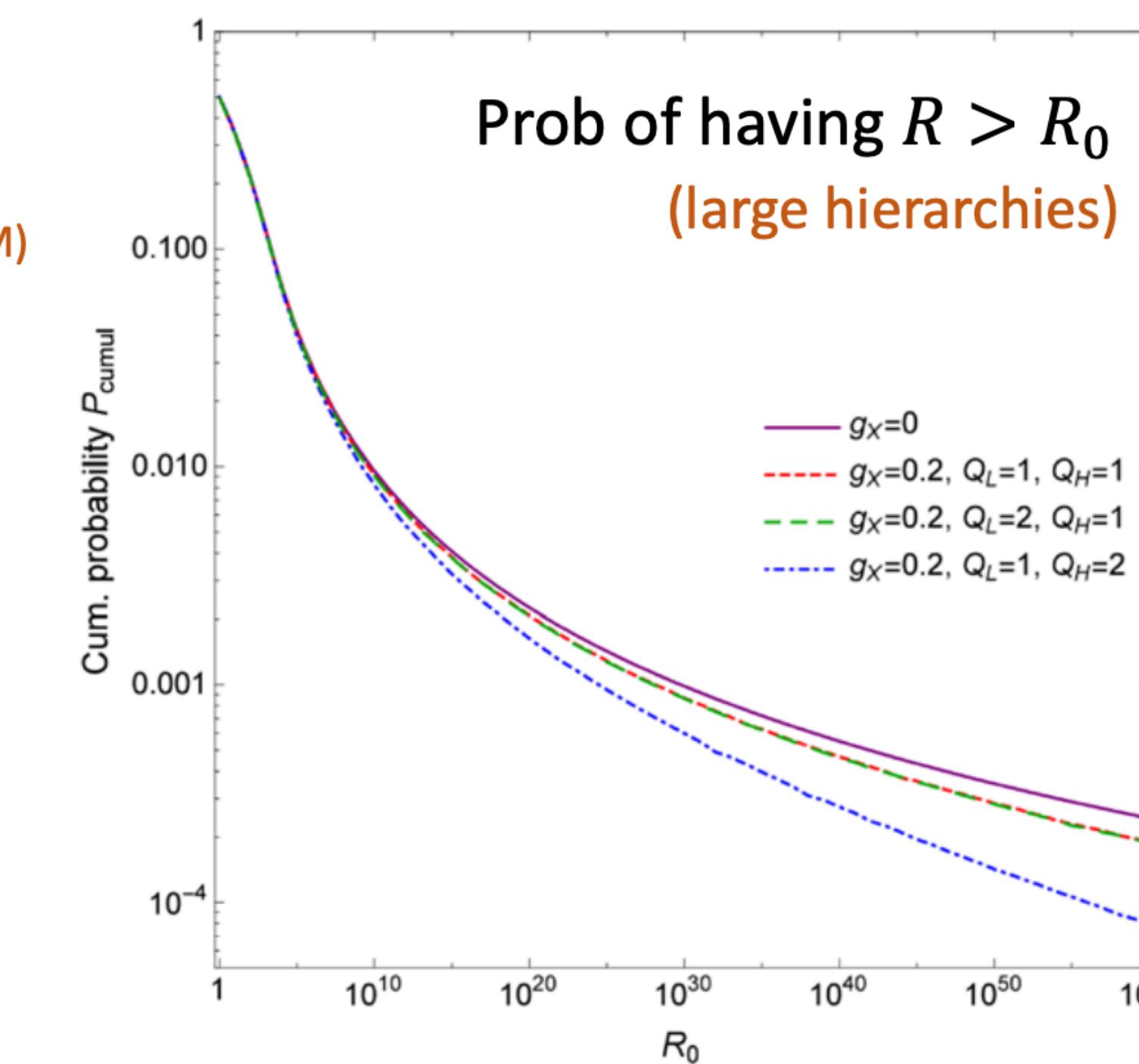
- Generation of large hierarchies through Coleman-Weinberg Eff.Potential
- Model building
- Generating sectors with very-large & very-small vev's
- Probabilistic analysis of the parameter phase-space
- Large hierarchies suppressed but log-like

Corrections to the potential:

Spont. Sym. Breaking triggered by gauge boson loops



$$V(\varphi, \eta) = V_0(\varphi, \eta) + \frac{3}{64\pi^2} \sum_{j=1}^7 m_j^4 \left[\ln \left(\frac{m_j^2}{\mu^2} \right) - \frac{5}{6} \right]$$

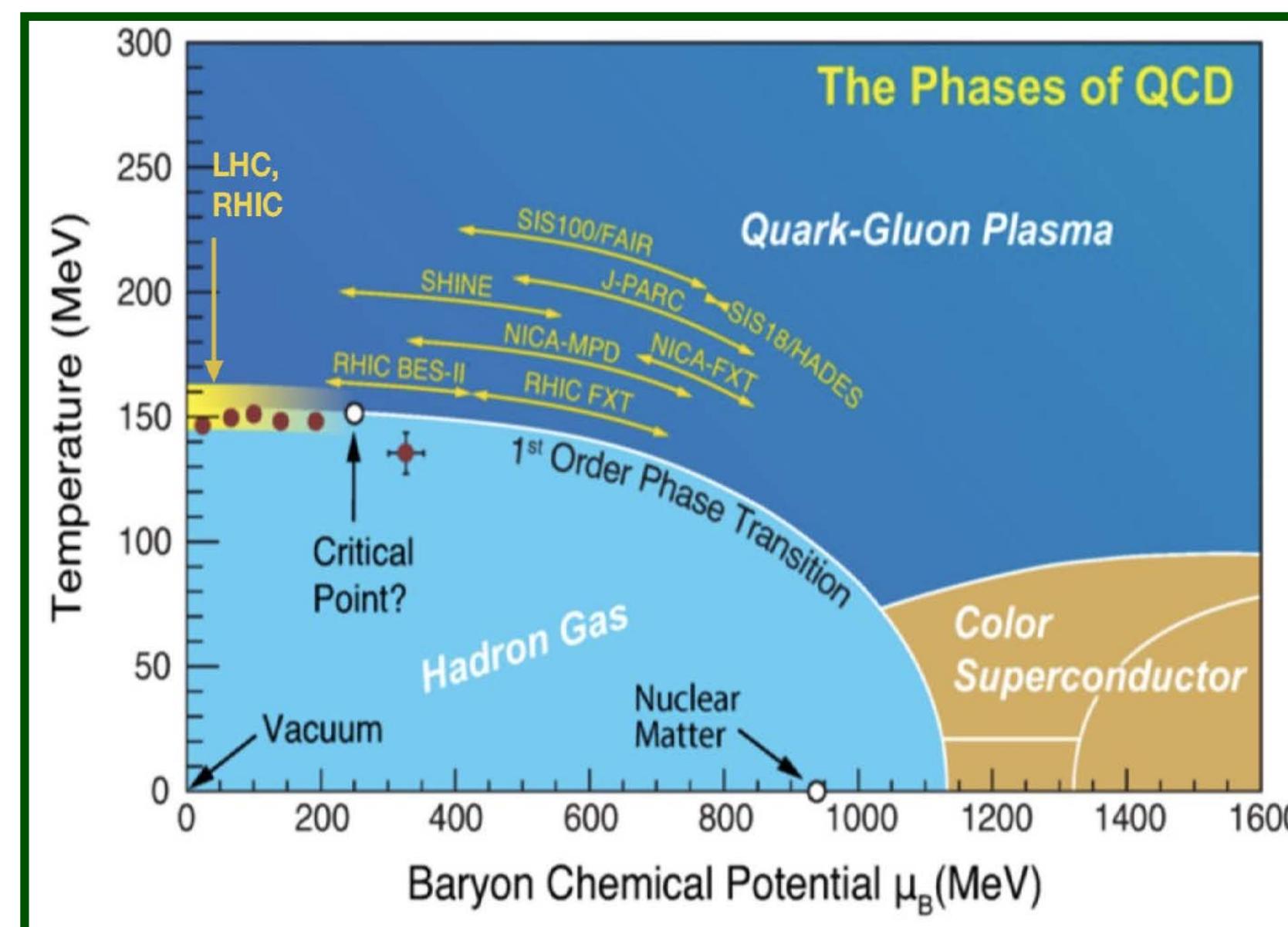


C Álvarez Luna, JA Ruiz Cembranos, JJ Sanz Cillero [2109.04955](https://arxiv.org/abs/2109.04955) [hep-ph]

$$\mathfrak{R} = \frac{m_{W_H}^2}{m_{W_L}^2} = \frac{g_H^2 \langle \eta \rangle^2}{g_L^2 \langle \varphi \rangle^2}$$

Effective Theories in Hadron Physics at extreme conditions (temperature, chemical potentials,...) with applications to the QCD phase diagram

A. Gómez Nicola
J. Ruiz de Elvira
Andrea Vioque-Rodríguez



Recent review

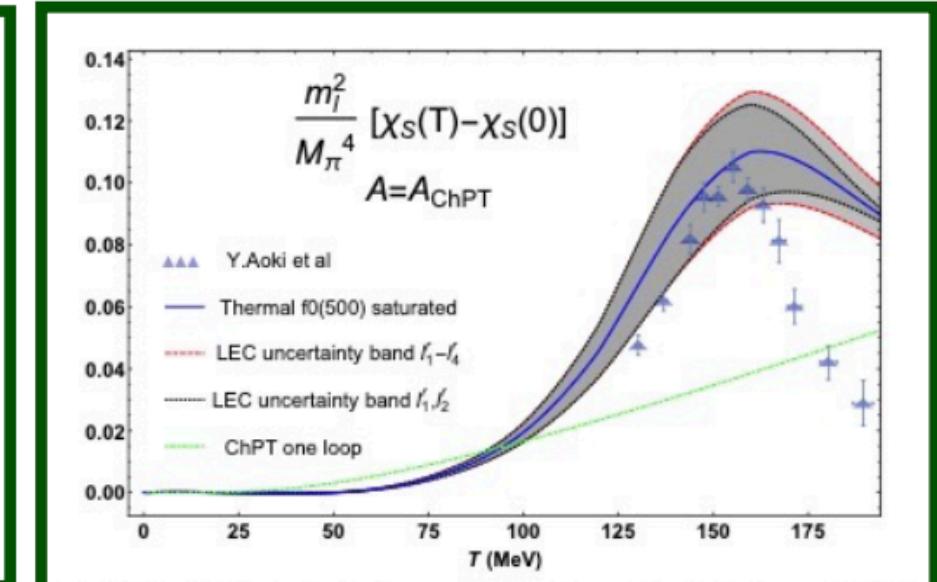
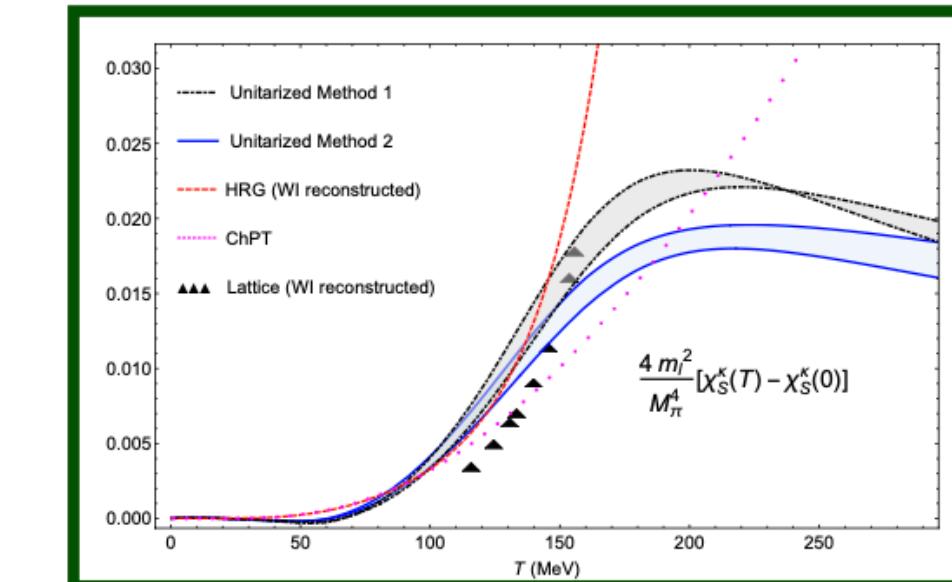
→ A. Gómez Nicola, Eur.Phys.J.ST 230 (2021) 6, 1645

Effective Theories in Hadron Physics at extreme conditions

- Role of thermal resonances in chiral & $U(1)_A$ symmetry restoration

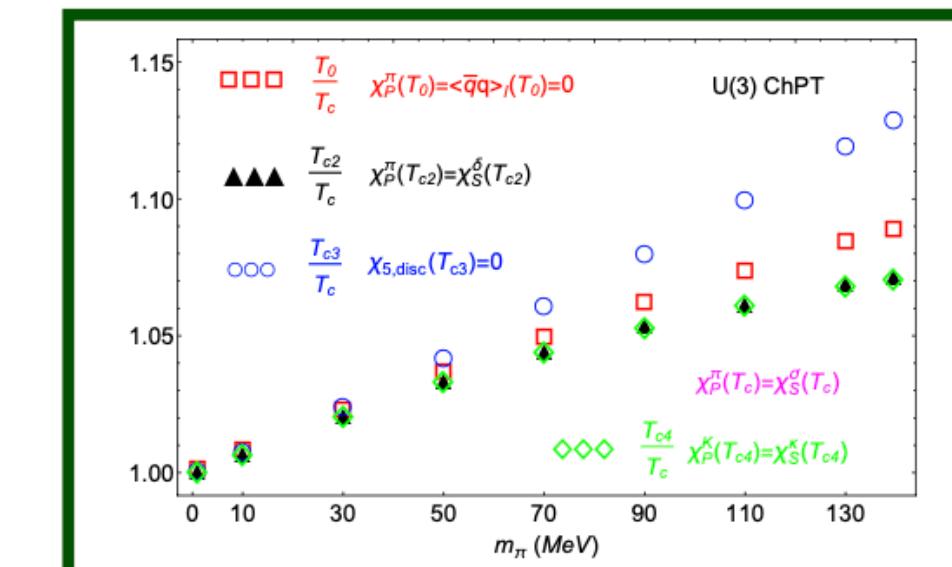
S. Ferreres-Solé, A. Gómez Nicola, A. Vioque Rodríguez, Phys.Rev.D99 (2019) 036018

A. Gómez Nicola, J.Ruiz de Elvira, A. Vioque Rodríguez, D.Álvarez-Herrero, Eur.Phys.J.C 81 (2021) 637



- Symm.rest. patterns and partners through Eff.Theo. & Ward Id.

A. Gómez Nicola, J. Ruiz de Elvira, JHEP 1603 (2016) 186, Phys.Rev. D97 (2018) 074016, Phys.Rev.D98 (2018) 014020

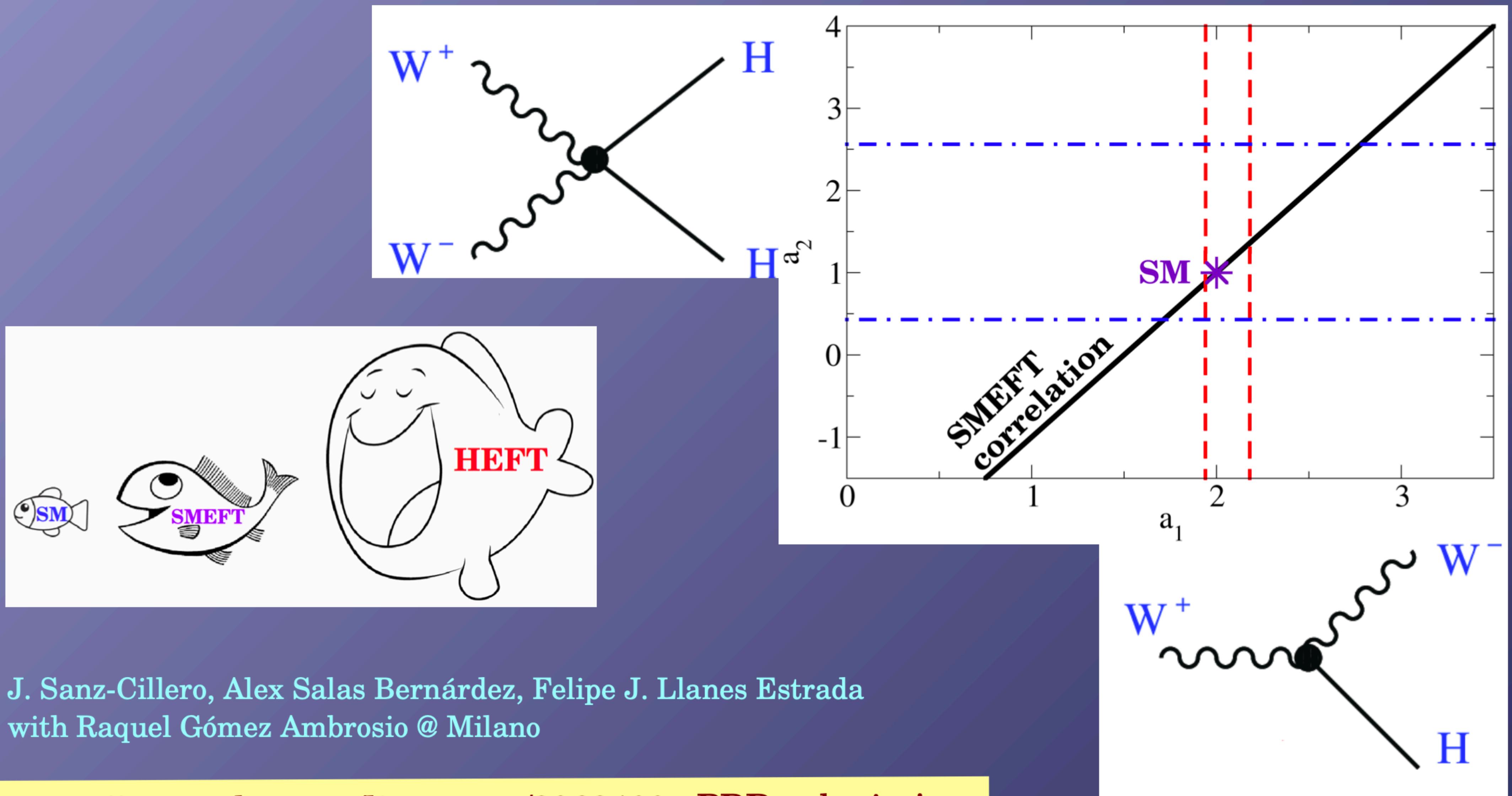


- Bose-Einstein cond. ($\mu_{I,S}$) and chiral imbalance (μ_5) phases

D. Espriu, A. Gómez Nicola, A. Vioque Rodríguez, JHEP 06 (2020) 062

A. Gómez Nicola, A. Vioque Rodríguez, 2205.14609 [hep-ph]

New: correlations among HEFT parameters to falsify SMEFT with data

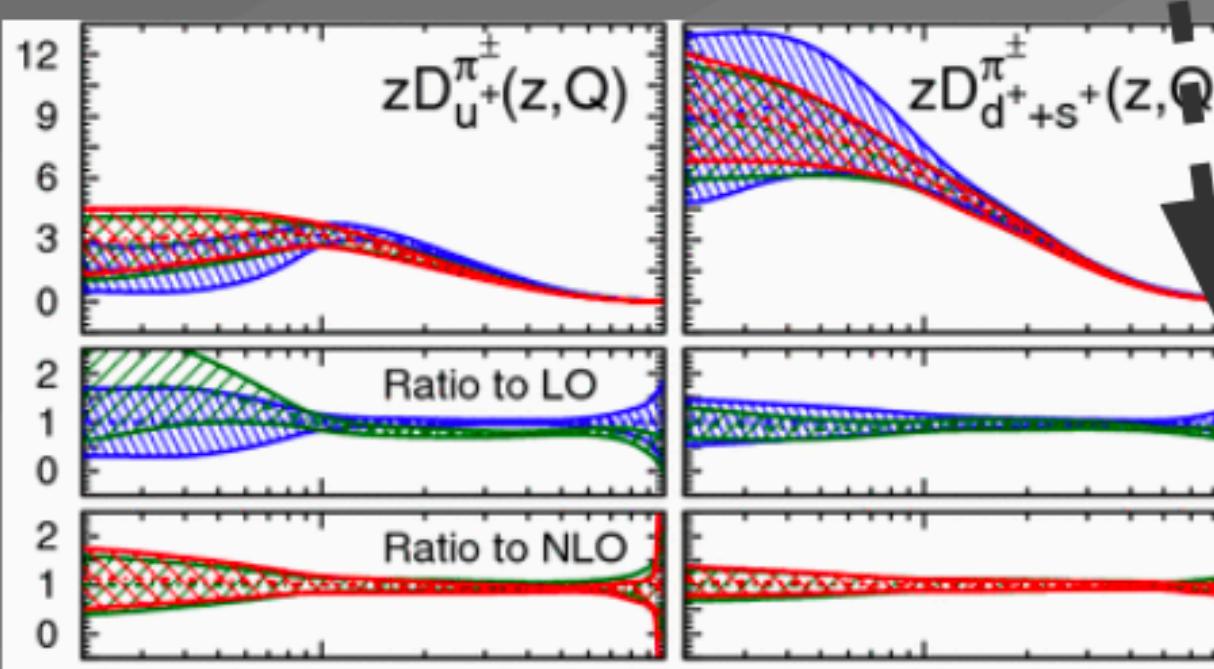
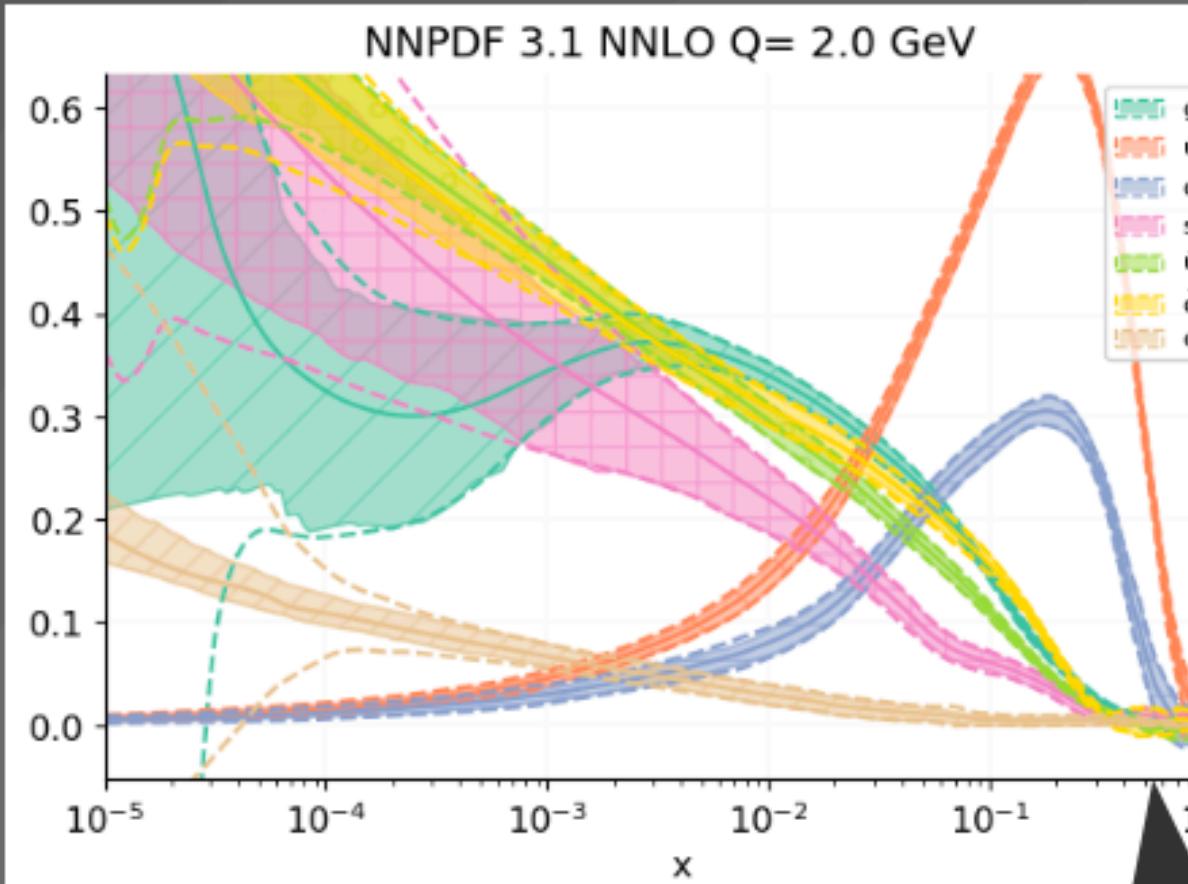


J. Sanz-Cillero, Alex Salas Bernárdez, Felipe J. Llanes Estrada
with Raquel Gómez Ambrosio @ Milano

<https://inspirehep.net/literature/2063400> PRD submission

Research line: hadron spectroscopy and structure at quark level

Currently playing with:
Barone-Drago-Ma relation



$$D(z) \simeq z f(1 - 2/z)$$

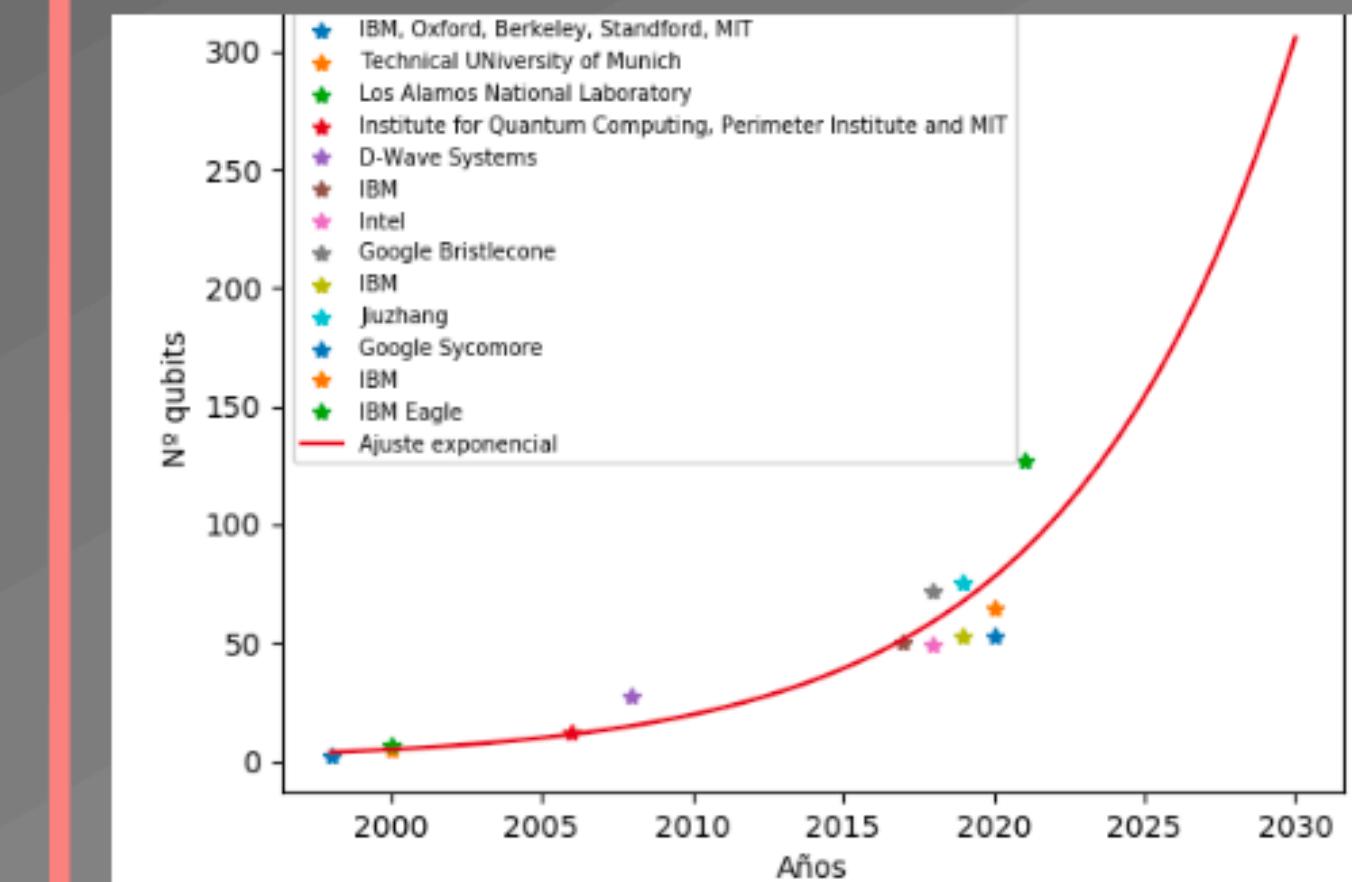
Students: Guillermo Benito & Javier García Olivares
with Felipe J. Llanes Estrada

Between
parton
dist.
functions

and

Fragmen-
tation
functions

Next period:
new computational methods



Moore's
law for
quantum
chips
now
working

$$\mathcal{L}_{\text{QCD}} \rightarrow \mathcal{H}_{\text{QCD}} \\ \rightarrow (\uparrow \downarrow)$$

Formulate fixed-gauge QCD for
simulation in quantum computers

New student: Juan J. Gálvez Viruet & María Rocha
& Felipe J. Llanes-Estrada

Conclusions

..only a few of them..

- Effective field theories allow to study Nature at very different energy scales: There are opportunities and challenges
- New tools are continuously considered to solve old and new problems, i.e. new theoretical results, machine learning and quantum information for data analysis
- Our group is well consolidated and with a large and international experience, and covering many important topics for the physics community. We can do much better with stronger PhD and postdoctoral programs
- We need expertises in different subjects to improve altogether

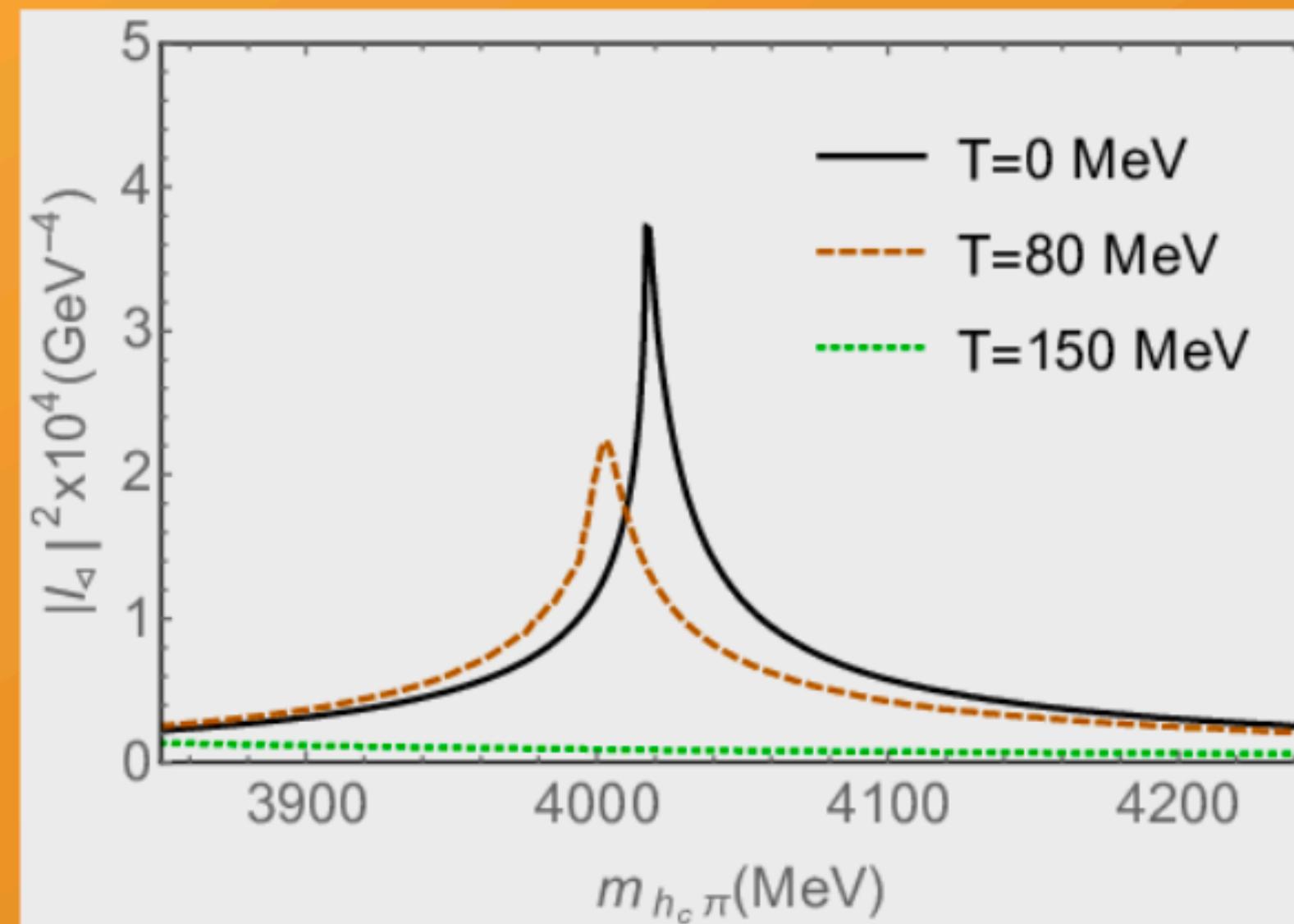


...Eppur si muove...

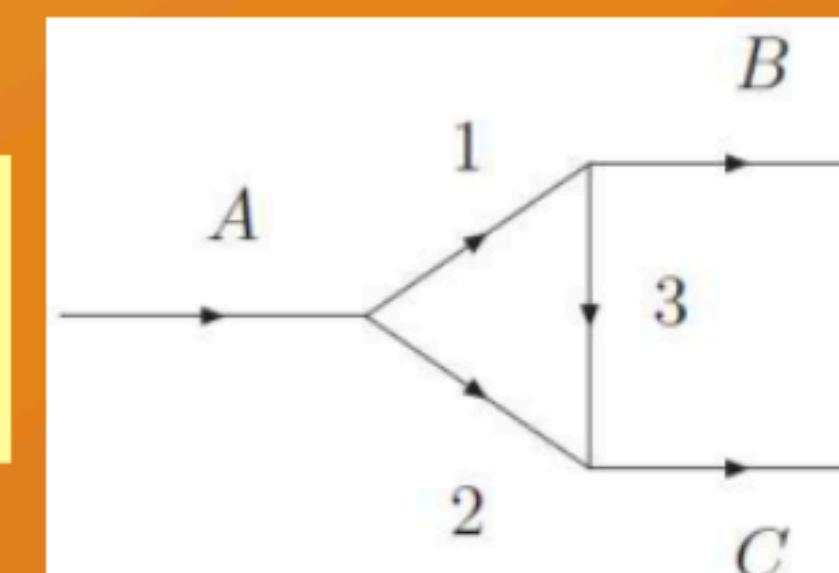
Galileo Galilei

Research line: Strong interactions in extreme environments

Result for LHC heavy ion collisions:
use to distinguish new mesons



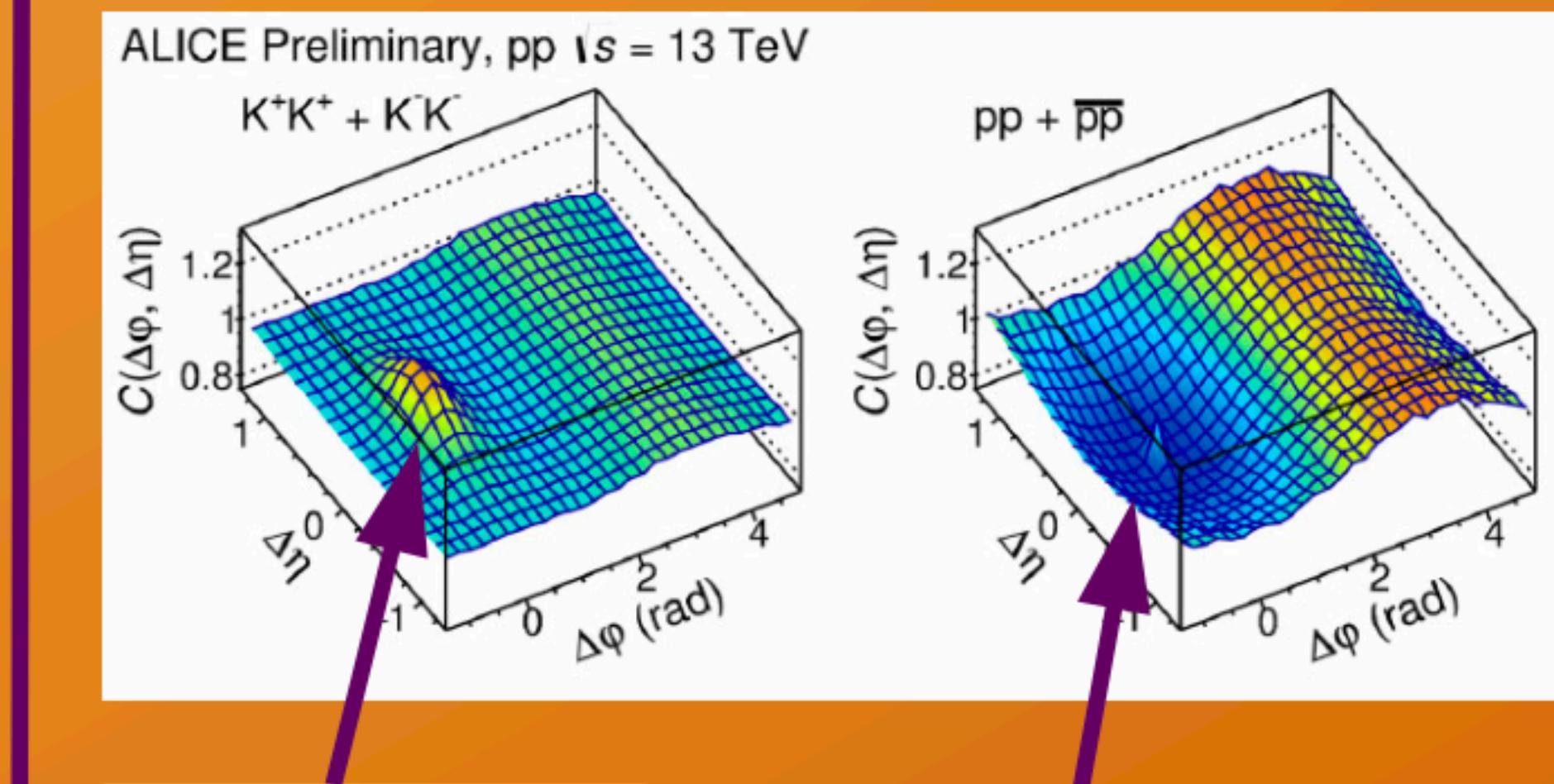
from Landau
singularities



Felipe J. Llanes Estrada & Luciano Abreu

<https://inspirehep.net/literature/1813614>

Currently addressing:
baryon anticorrelation problem



Mesons fly
together
(same jet,
correlation)

Perhaps: Pauli exclusion @ quark level
Not in Pythia (classical algorithm)
trying to figure out how to fix it

Noe Demazure & Víctor González
with Felipe J. Llanes Estrada