8th mini-school on Particle and Astroparticle Physics, Oeiras 15-20 May, 2023

Particle Physics Phenomenology

Grigorios Chachamis, LIP
(on behalf of the LIP Pheno Group)

What is Particle Physics Phenomenology?

Wikipedia
https://en.wikipedia.org › wiki › Phenomenology_(ph...

Phenomenology (physics)

In physics, phenomenology is **the application of theoretical physics to experimental data by making quantitative predictions based upon known theories**.

Applications in particle physics · Standard M

Princeton University
https://phy.princeton.edu › research › research-areas

Particle Phenomenology | Department of Physics

Particle physics phenomenology is **the field of theoretical physics that focuses on the observable consequences of the fundamental particles of Nature** and ...

ub.edu
https://icc.ub.edu › research › particle-

Particle Physics Phenomenology

Particle physics phenomenology is **the part of theoretical physics that deals with the interpretation and understanding and of experiments involving** ...

Durham University
https://www.ippp.dur.ac.uk › phenomenology

Phenomenology - Institute for Particle Physics Phenomenology

Phenomenolgy is research on this boundary between theory and experiment. It is **concerned with identifying interesting physical observables**, making theoretical ...

What is Particle Physics Phenomenology?

- Philosophy

Phenomenology (from Greek: phenomenon = "that which appears" and logos = "study") is the philosophical study of the structures of subjective experience and consciousness.

- Physical Sciences

Observe "that which appears", a collection of phenomena that share a unifying principle, and try to find patterns to describe it. The patterns might or might not be of fundamental nature or they might be up to a certain degree.

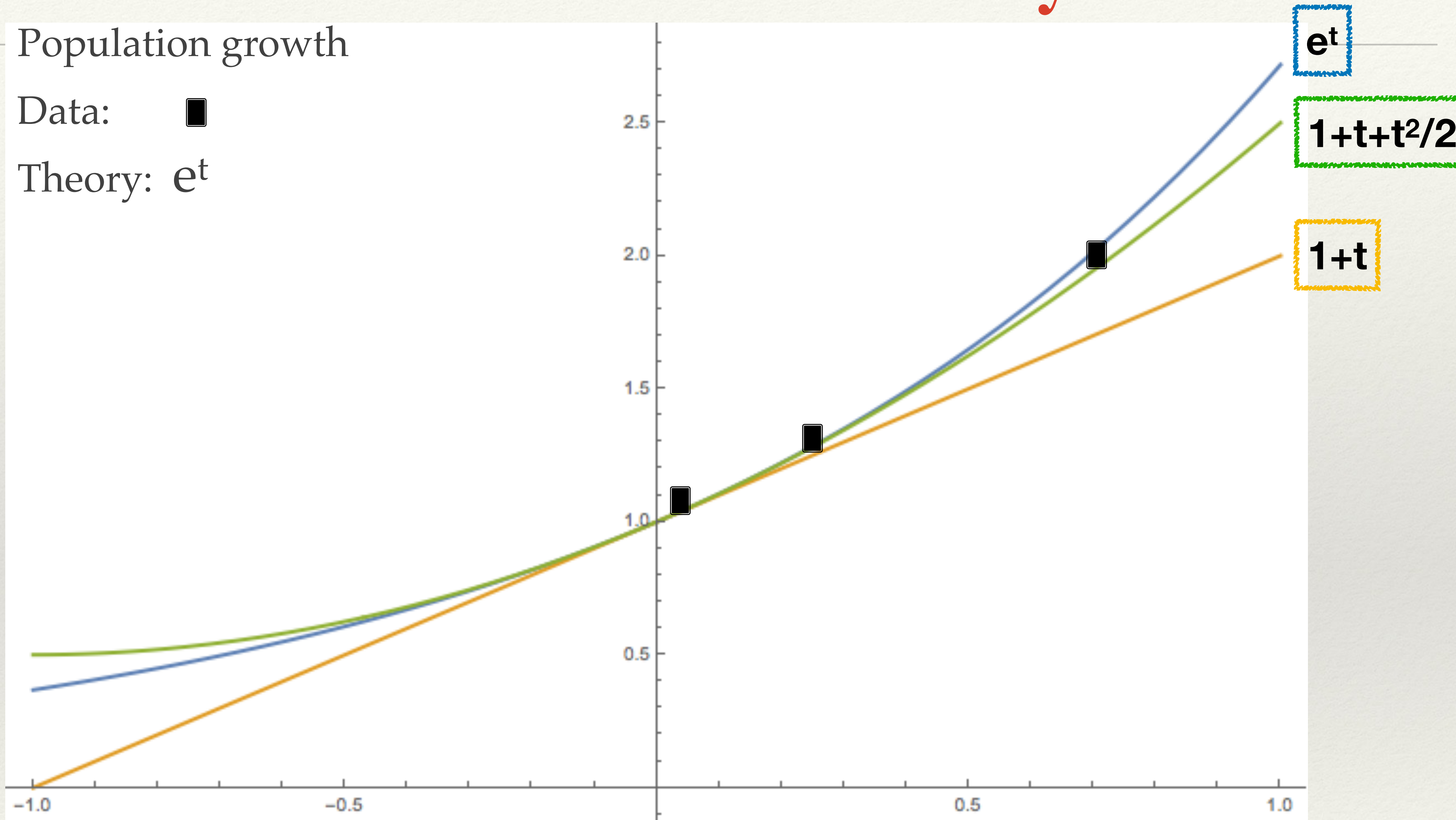
- Particle Physics

Use assumed **fundamental** laws (theory) to produce theoretical predictions for physical observables and then compare against experimental data to validate or falsify the assumed laws.

- What's the catch?

It may be that you cannot solve your theory exactly which means that you will need extra tools to compare against experimental data

Perturbation theory

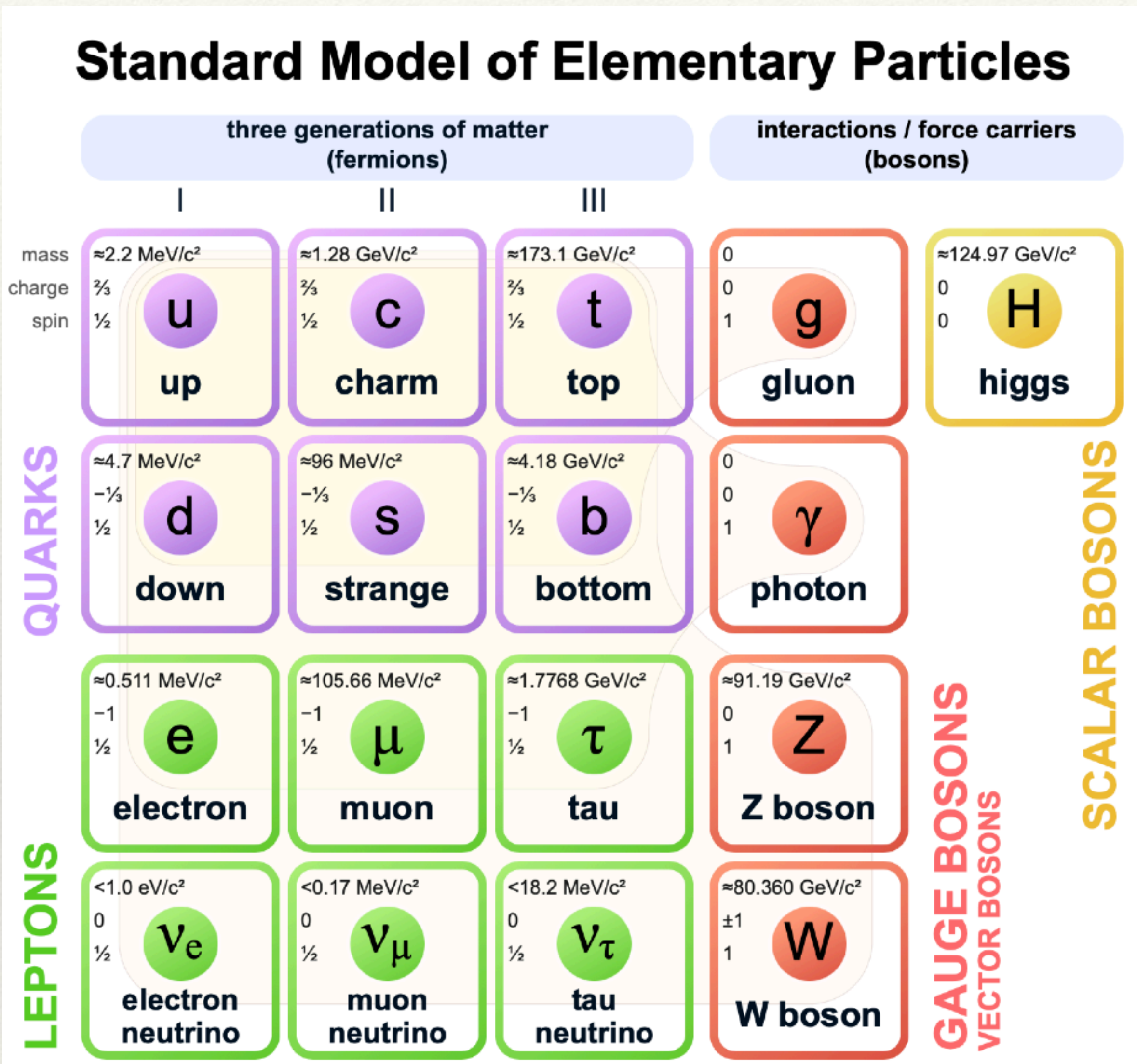


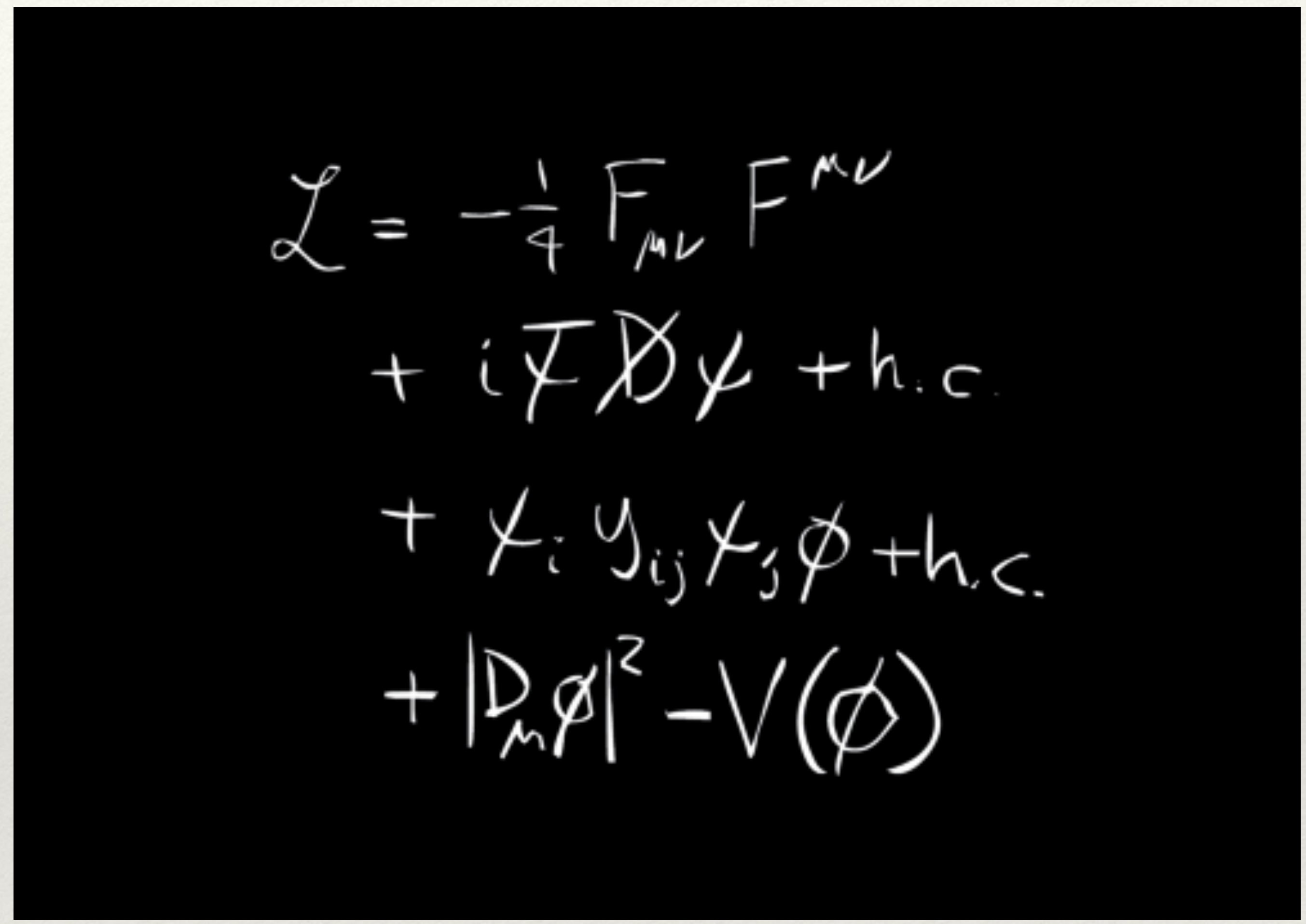
$$e^t = \sum_{n=0}^{\infty} \frac{t^n}{n!} = 1 + t + \frac{t^2}{2!} + \frac{t^3}{3!} + \cdots$$

Suppose now that you ask questions like:

- *What are the fundamental constituents of the Universe?*
- *How do they interact?*
- *What are the physical laws that govern their behaviour?*

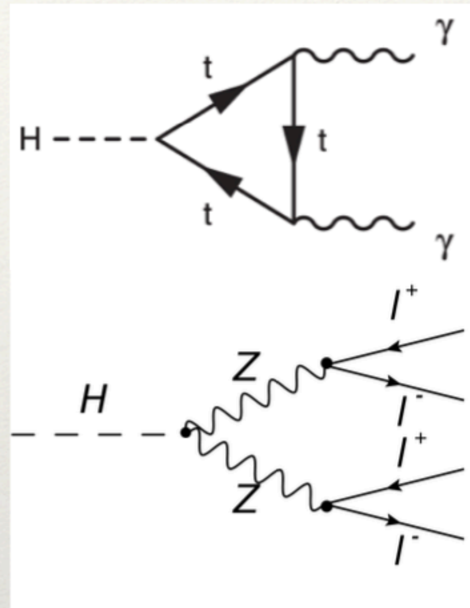
The Standard Model (SM)





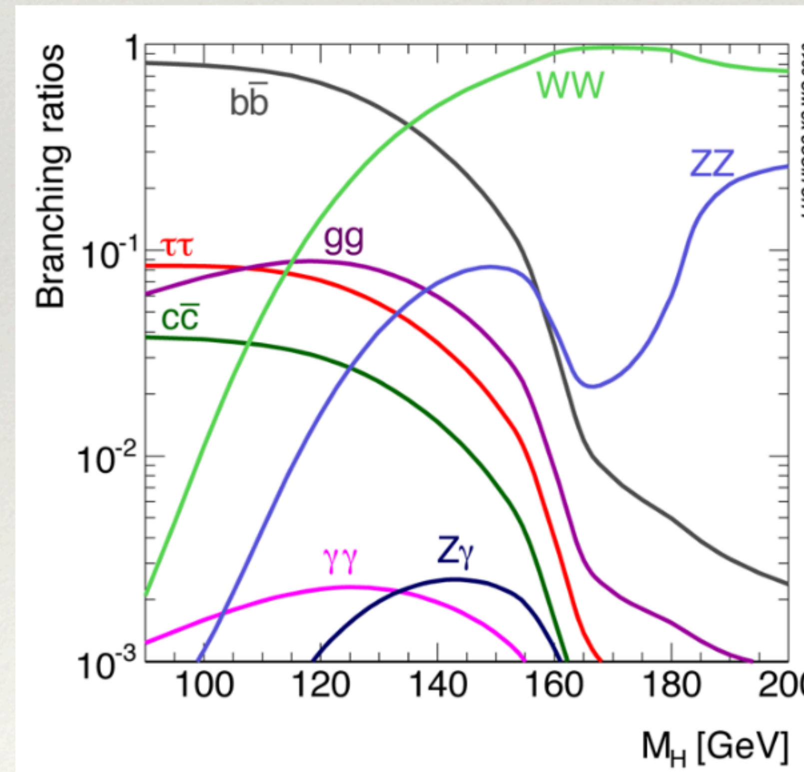
An example

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\Psi}\not{D}\psi + D_\mu\Phi^\dagger D^\mu\Phi - V(\Phi) + \bar{\Psi}_L\hat{Y}\Phi\Psi_R + h.c.$$

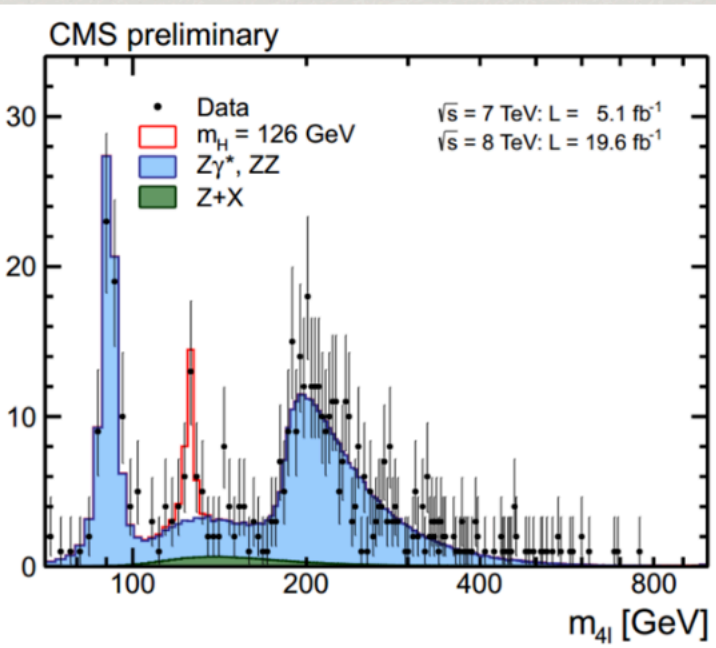


$$\Gamma(h^0 \to \gamma\gamma) = \frac{\alpha_{em}^3 m_h^3}{144\pi^2 m_W^2 \sin^2\theta_w}\left|\sum_f Q_f^2 N_c(f) I_f(\tau_f) - I_W(\tau_W)\right|^2$$

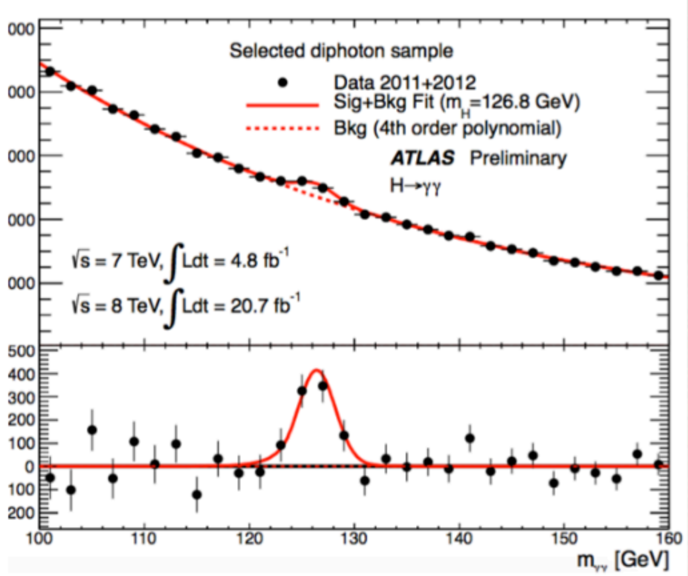
$$\Gamma(H \to ZZ) = \frac{1}{8\pi}\frac{M_Z^4}{M_H v^2}\left(1 - \frac{4M_Z^2}{M_H^2}\right)^{1/2}\left(3 + \frac{1}{4}\frac{M_H^4}{M_Z^4} - \frac{M_H^2}{M_Z^2}\right)$$



Higgs decay modes as function of M_H (Standard Model theory)



Higgs discovery plot in ZZ (CMS experiment at the LHC)



Higgs discovery plot in γγ (ATLAS experiment at the LHC)

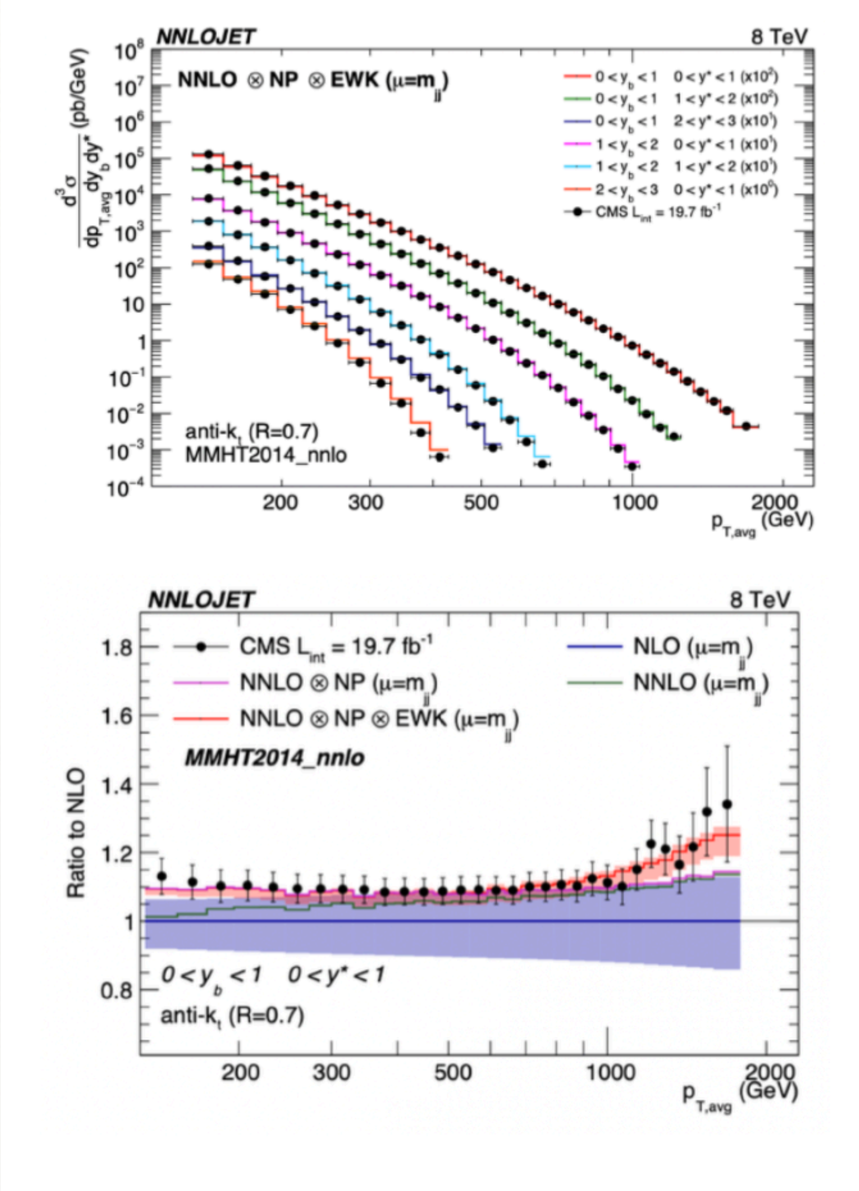
from a talk by J. Pires (LIP Lisbon)

Pheno Group at LIP

- SM/BSM observables for new Physics searches at colliders (Minho/Coimbra)
- QCD precision and automation (Lisbon)
- High energy limit of QCD resummation, Pomeron/ Odderon
- Quark Gluon Plasma, theory/Monte Carlo simulations/observables
- Machine Learning techniques are increasingly being used

Need of data from the Large Hadron Collider (LHC) at CERN

Precision Physics at the LHC

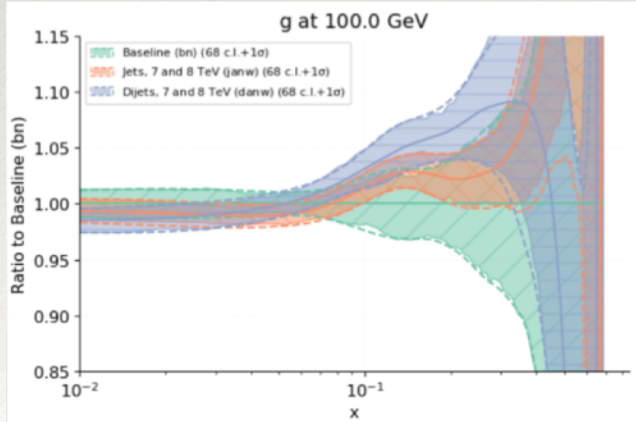


Triple differential dijet cross section at the LHC ***Phys. Rev. Lett. 123, 102001 (2019)***

- At a hadron-collider machine such as the LHC QCD radiative corrections are large and need to be computed in perturbation theory and be included in physics analysis

$$\hat{\sigma}(p_1,p_2) = \sigma_{LO}\left(1 + \frac{\alpha_s}{2\pi}\sigma_1 + \left(\frac{\alpha_s}{2\pi}\right)^2 \sigma_2 + \left(\frac{\alpha_s}{2\pi}\right)^3 \sigma_3 + \ldots\right) \qquad \alpha_s(M_Z) = 0.118$$

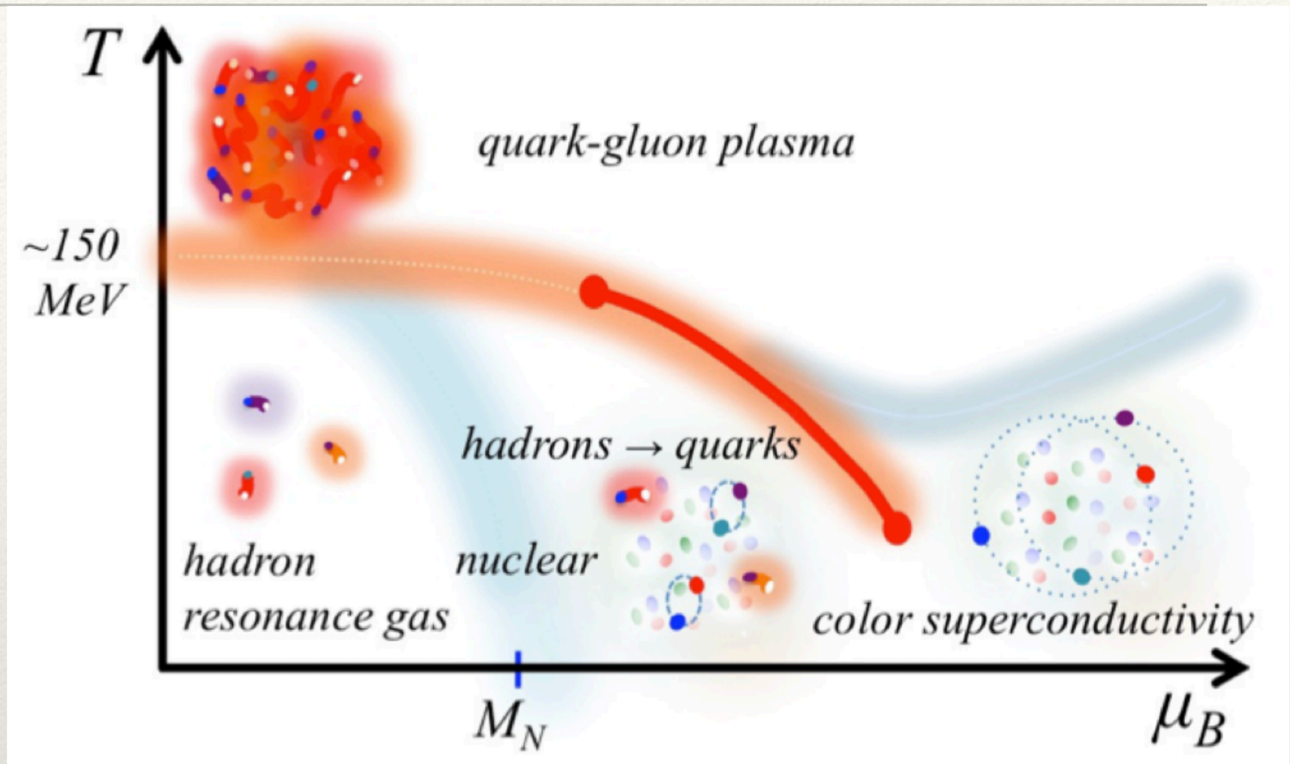
- NNLOJET: ongoing development of a Parton-level generator to compute cross sections and related observables in the Standard Model for the LHC through NNLO accuracy in the QCD perturbative expansion



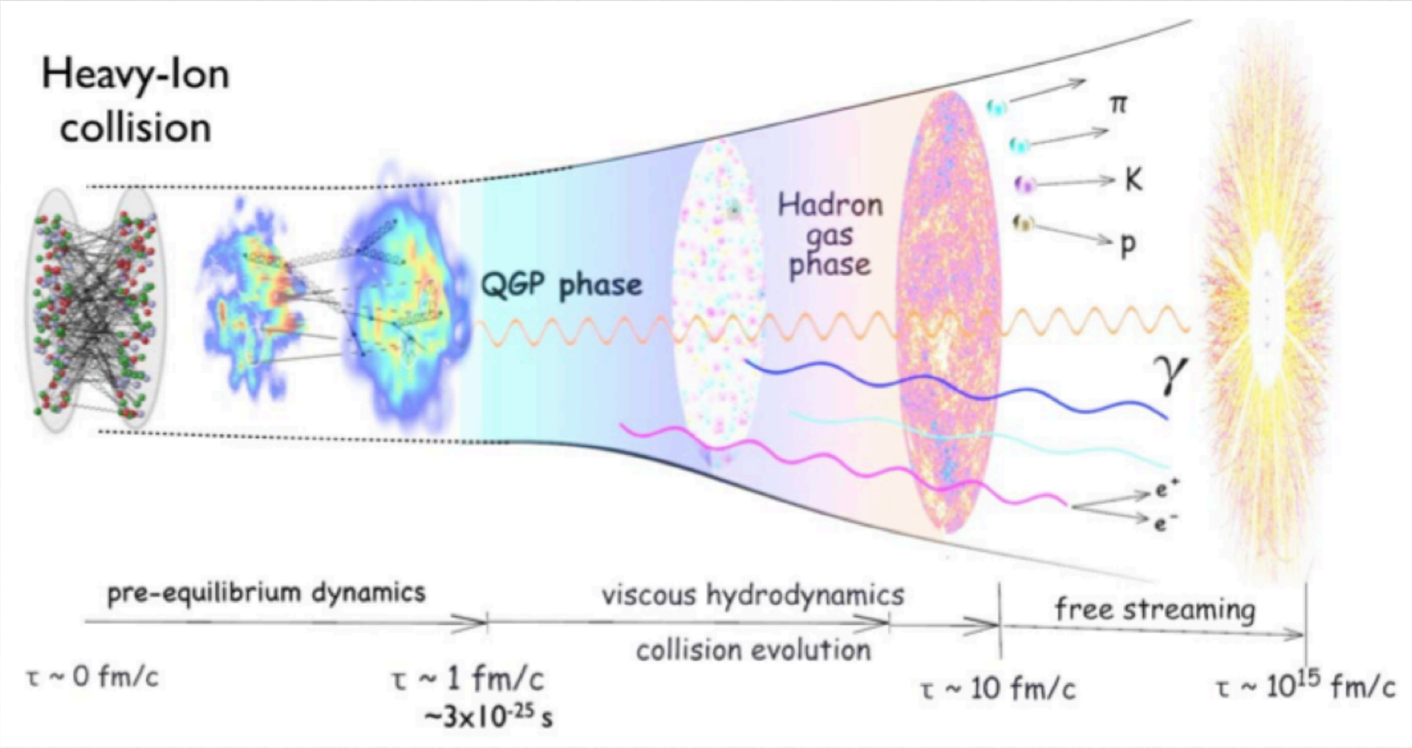
Phenomenology of NNLO jet production at the LHC and its impact on parton distributions ***Eur.Phys.J.C 80 (2020) 8, 797***

Heavy Ion Physics

- Access the high temperature and density domain of QCD: the QGP
- In the time interval of 10^{-10}–10^{-6} s after the Big Bang, matter existed in the form of a quark–gluon plasma

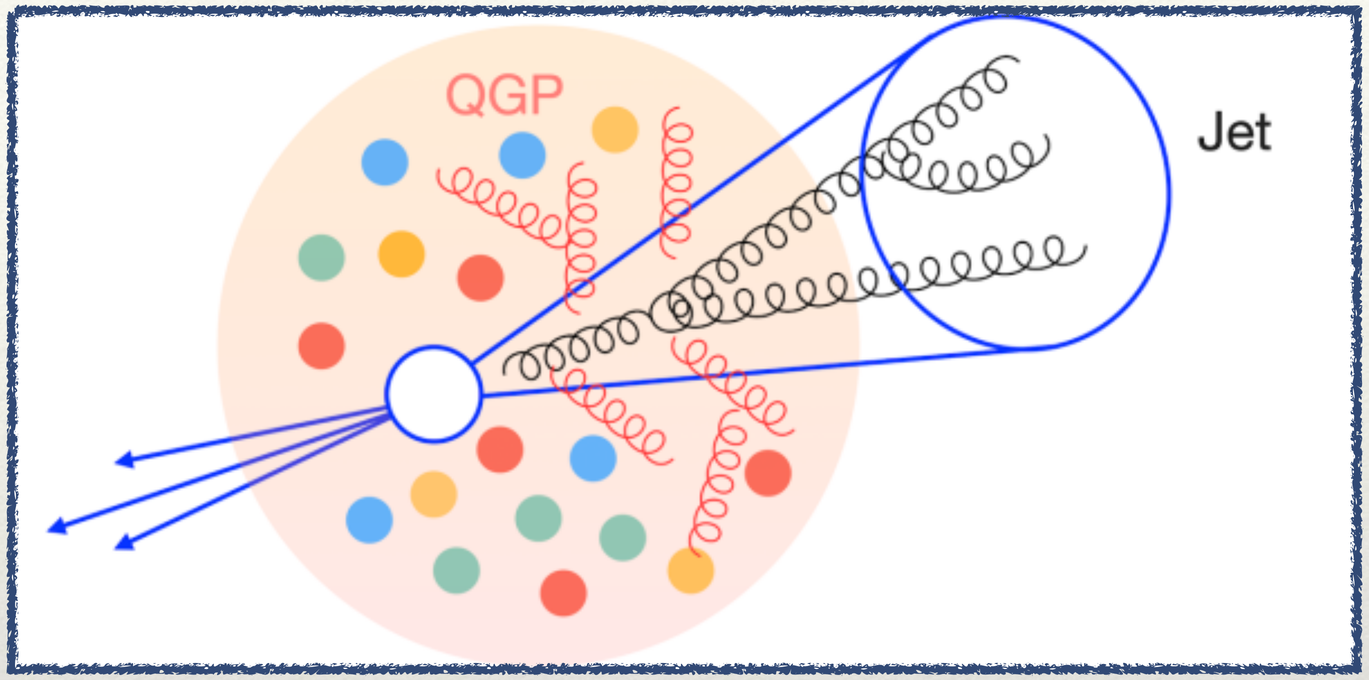


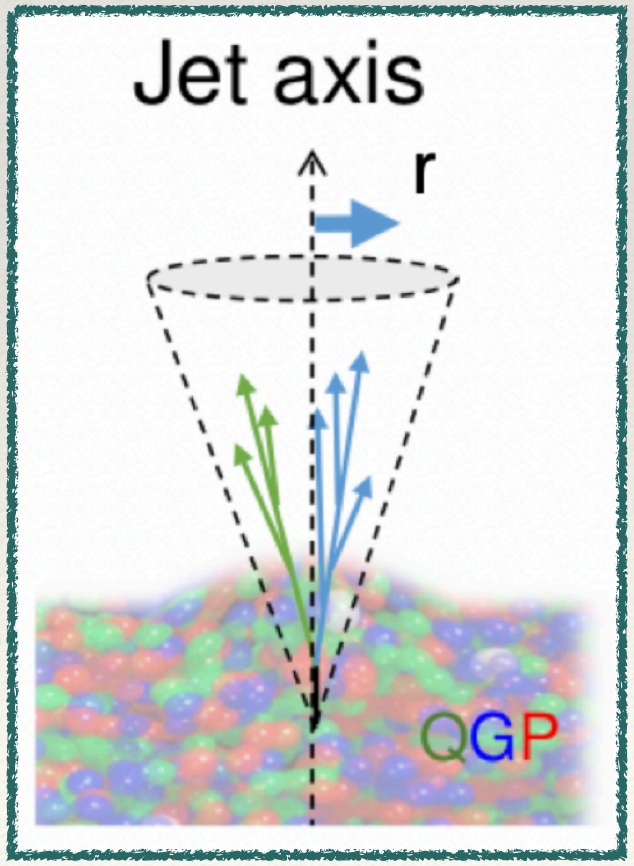
- Early conditions after the Big Bang recreated at the LHC via the collisions of an heavy-ion Pb-Pb system accelerated to $\sqrt{s}$=5.02 TeV
- In the presence of the quark-gluon plasma jets will loose energy as they propagate through the medium: → jet quenching



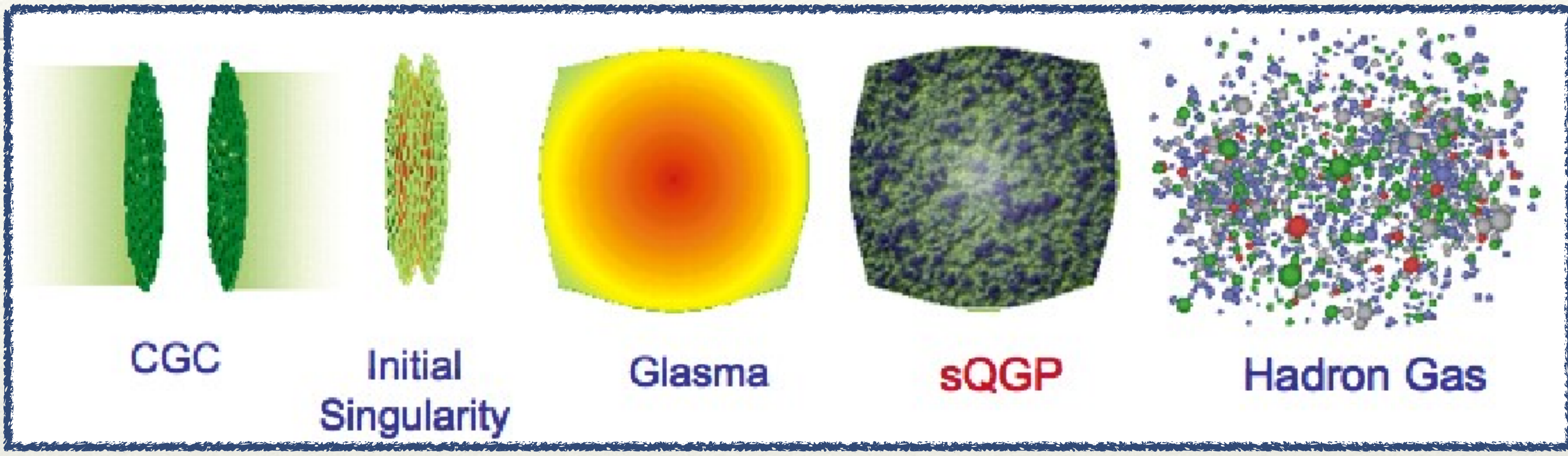
Heavy Ion Physics

- Jet quenching theory development
- Jet quenching Monte Carlo studies & jet observables
- Pre-QGP (Glasma) theory & phenomenology
- Machine learning application
- Quark-Gluon Plasma and Cosmic Rays





Heavy Ion Physics



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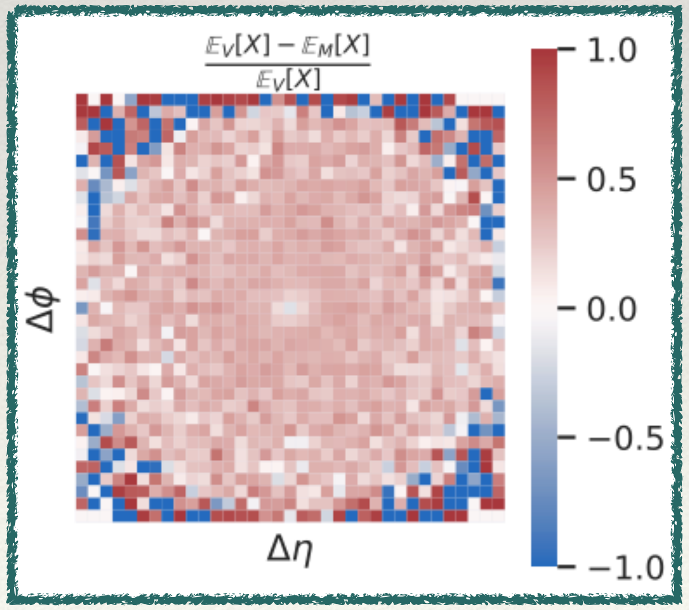
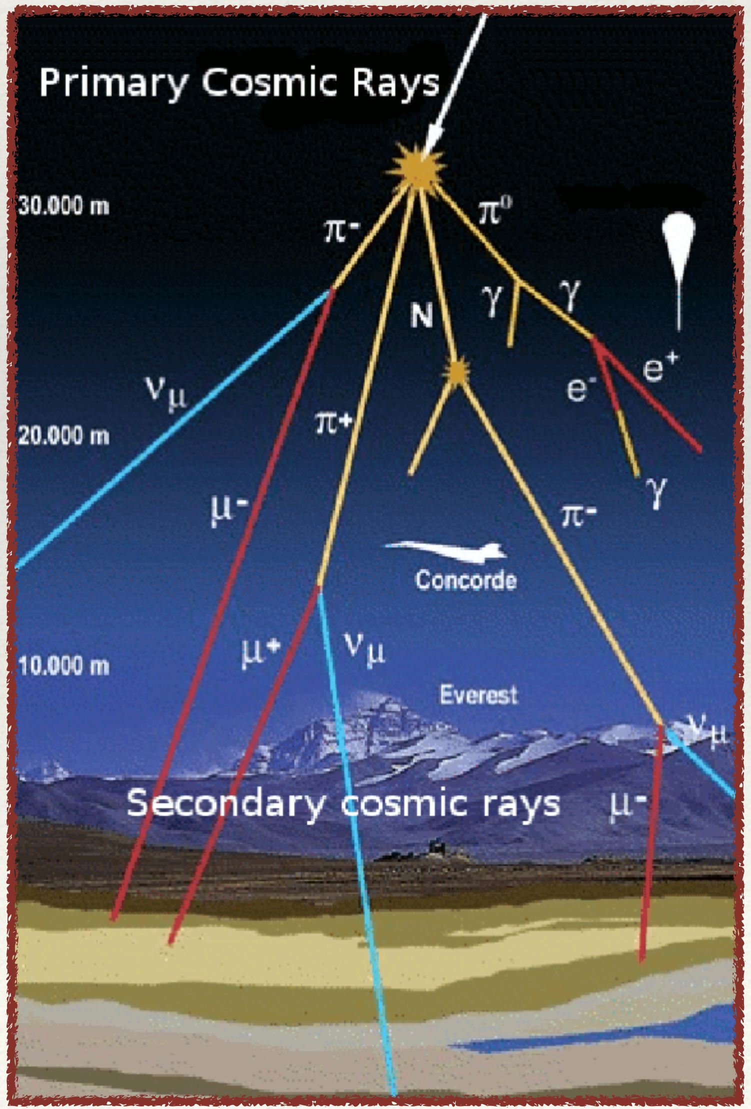
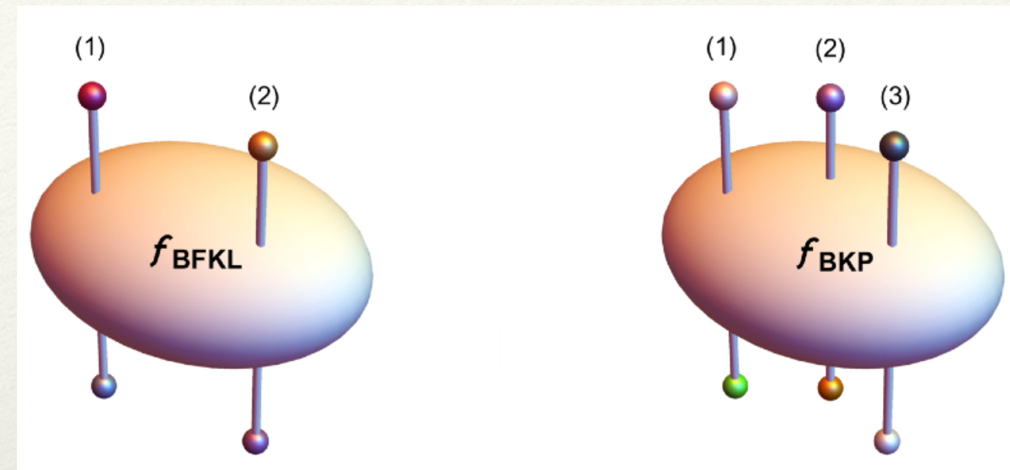
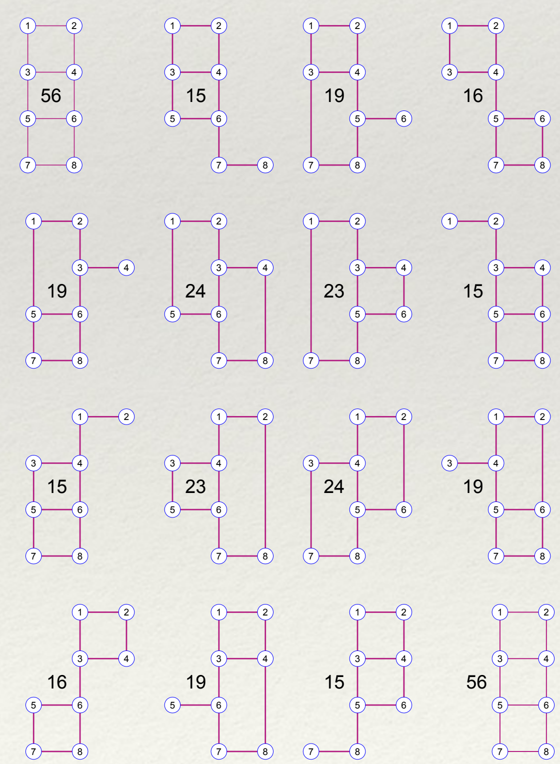




High energy limit of QCD/Resummation

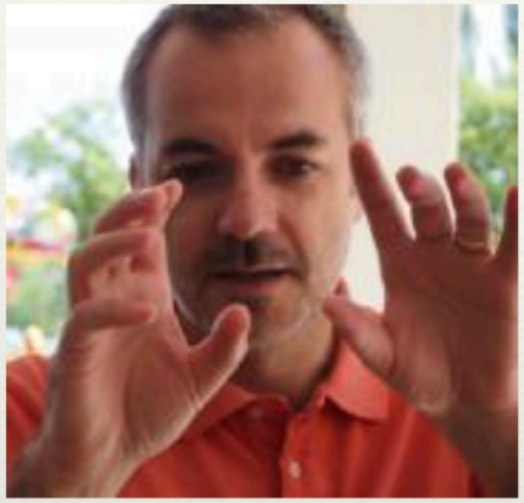


- In the high energy limit, new degrees of freedom arise, (gluons , quarks) —> Reggeons
- 2 interacting Reggeons —> Pomeron
- 3 interacting Reggeons —> Odderon
- Saturation



n rungs	Number of diagrams
2	9
3	27
4	81
5	243
6	729
7	2187
8	6561
9	19683
10	59049
11	177147
12	531441
13	1594323
14	4782969.

Some of the LIP Pheno Group members



Guilherme Milhano [LIP-Lisboa]
Jet Physics, QGP

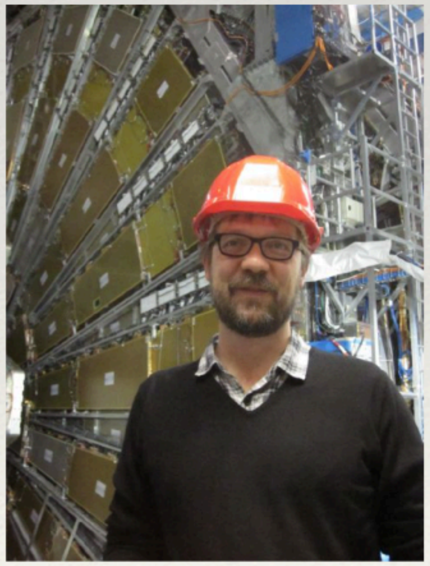
Liliana Apolinário [LIP-Lisboa]
Jet Physics, QGP

João Pires [LIP-Lisboa]
QCD precision

Grigorios Chachamis [LIP-Lisboa]
QCD precision

Nuno Castro [LIP-Minho]
SM/BSM [also ATLAS]

Miguel Romão [LIP-Minho/Lisboa]
Machine Learning, SM/BSM



Ricardo Gonçalo [LIP-Coimbra/Lisboa]
SM/BSM [also ATLAS]

Some of the LIP Pheno Group members

António Onofre [LIP-Minho]
SM/BSM [also ATLAS]

Ruben Conceição [LIP-Lisboa]
QGP, Cosmic Rays

Pietro Faccioli [LIP-Lisboa]
QCD quarkonium production

Pablo Rodriguez [LIP-Lisboa]
Jet Physics, QGP

https://www.lip.pt/?section=research&page=research-group-details&details=project&area=physics&line=LHC-experiments-and-phenomenology&projectid=90

The Pheno Group members and I will be happy to get your questions and have a chat whenever you feel like learning more about our activities

chachamis@gmail.com