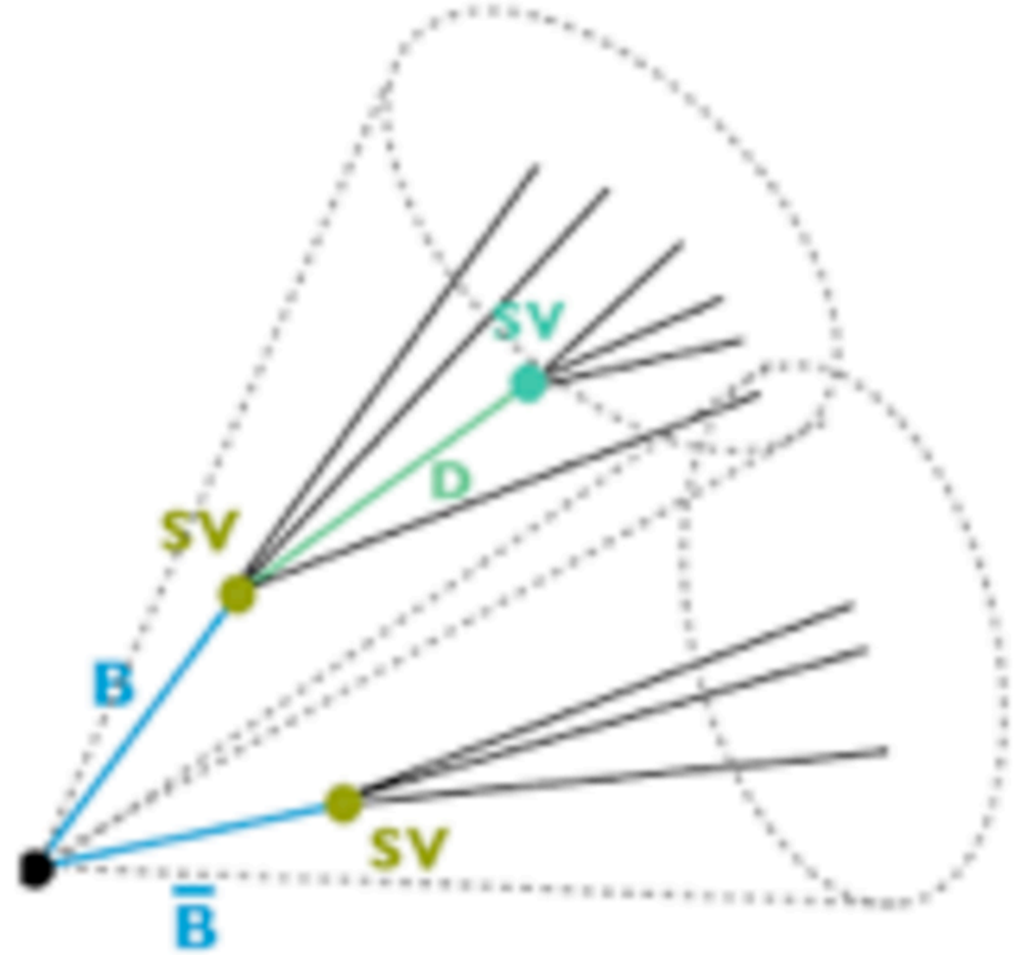
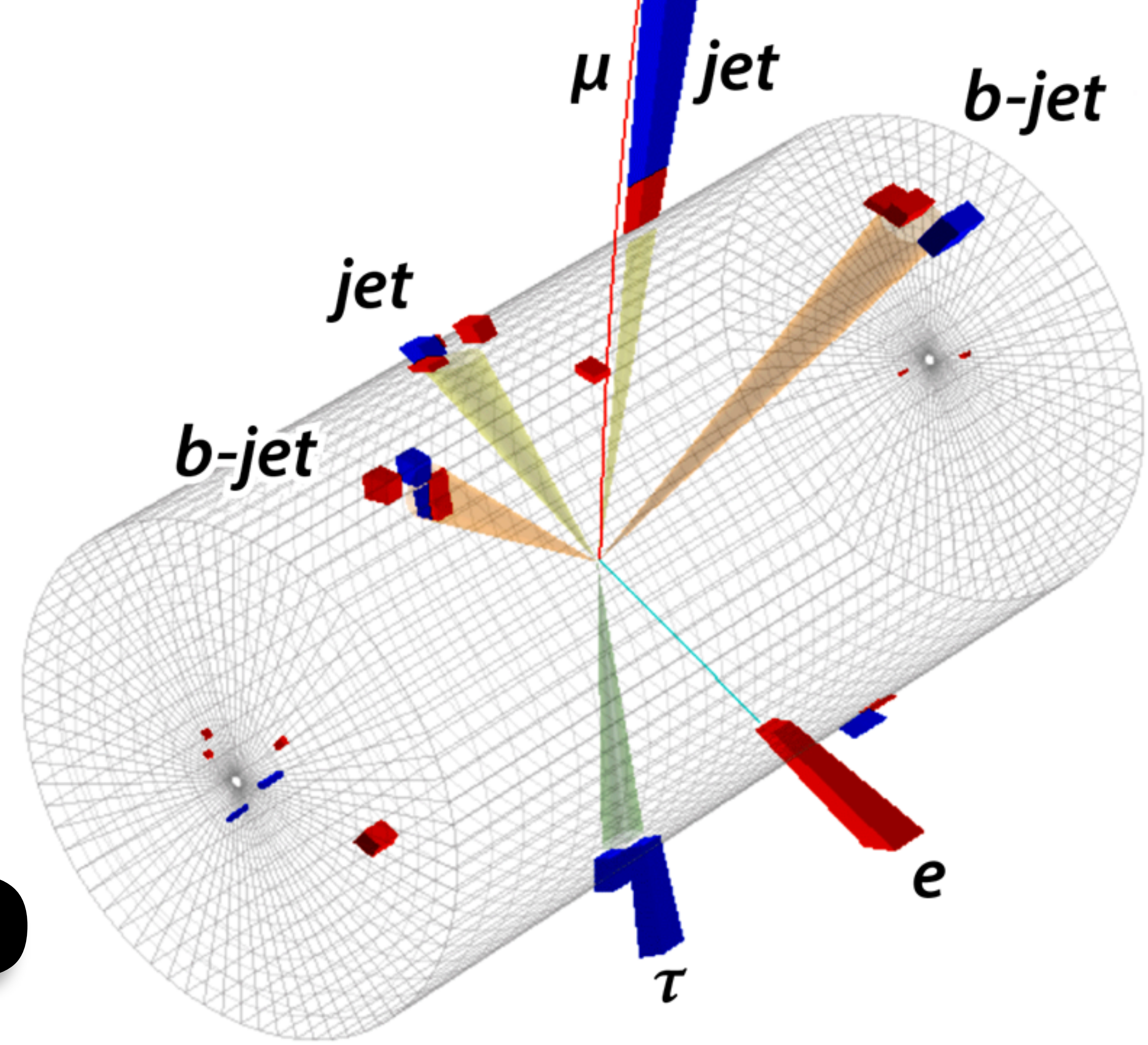
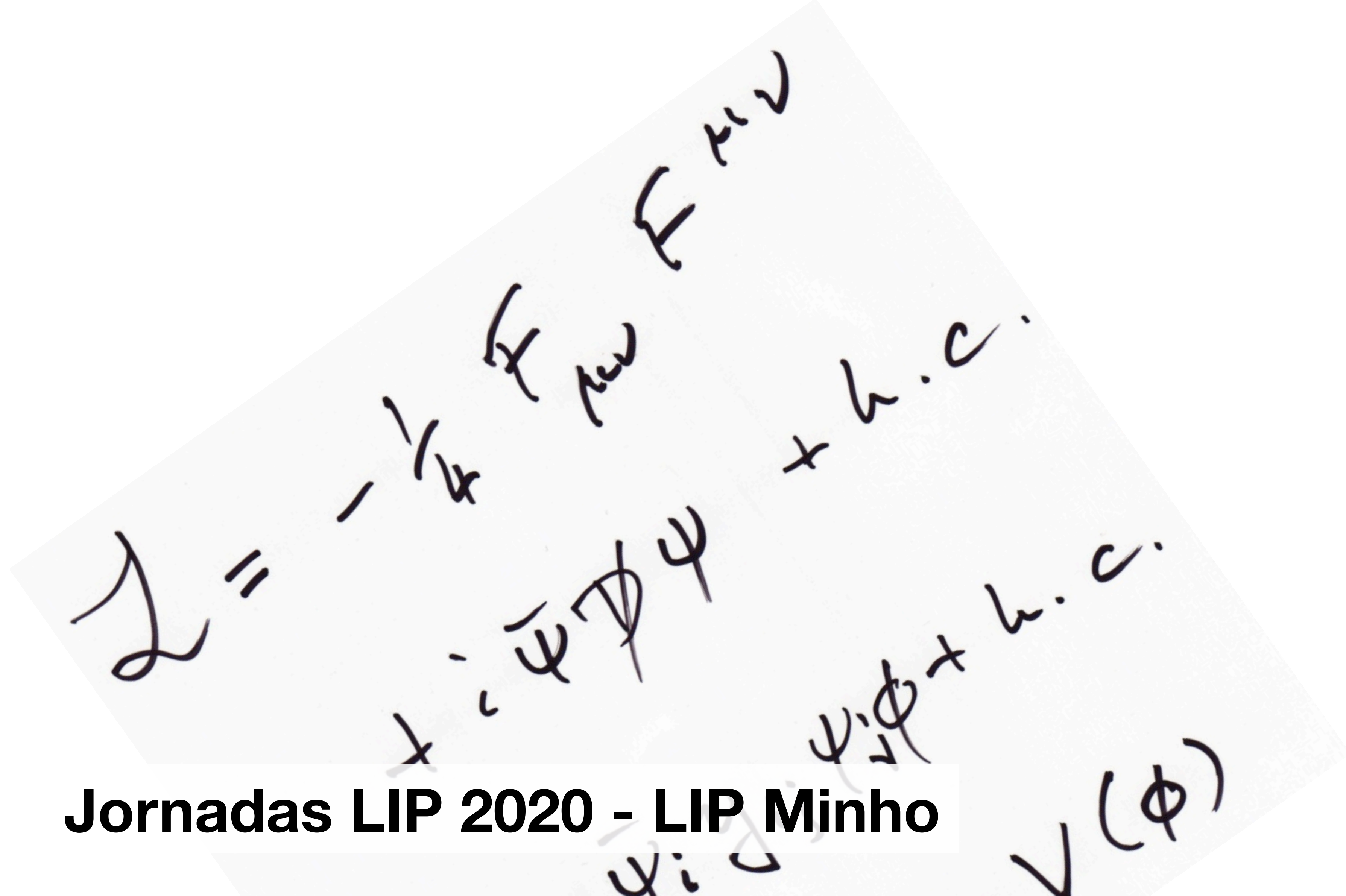
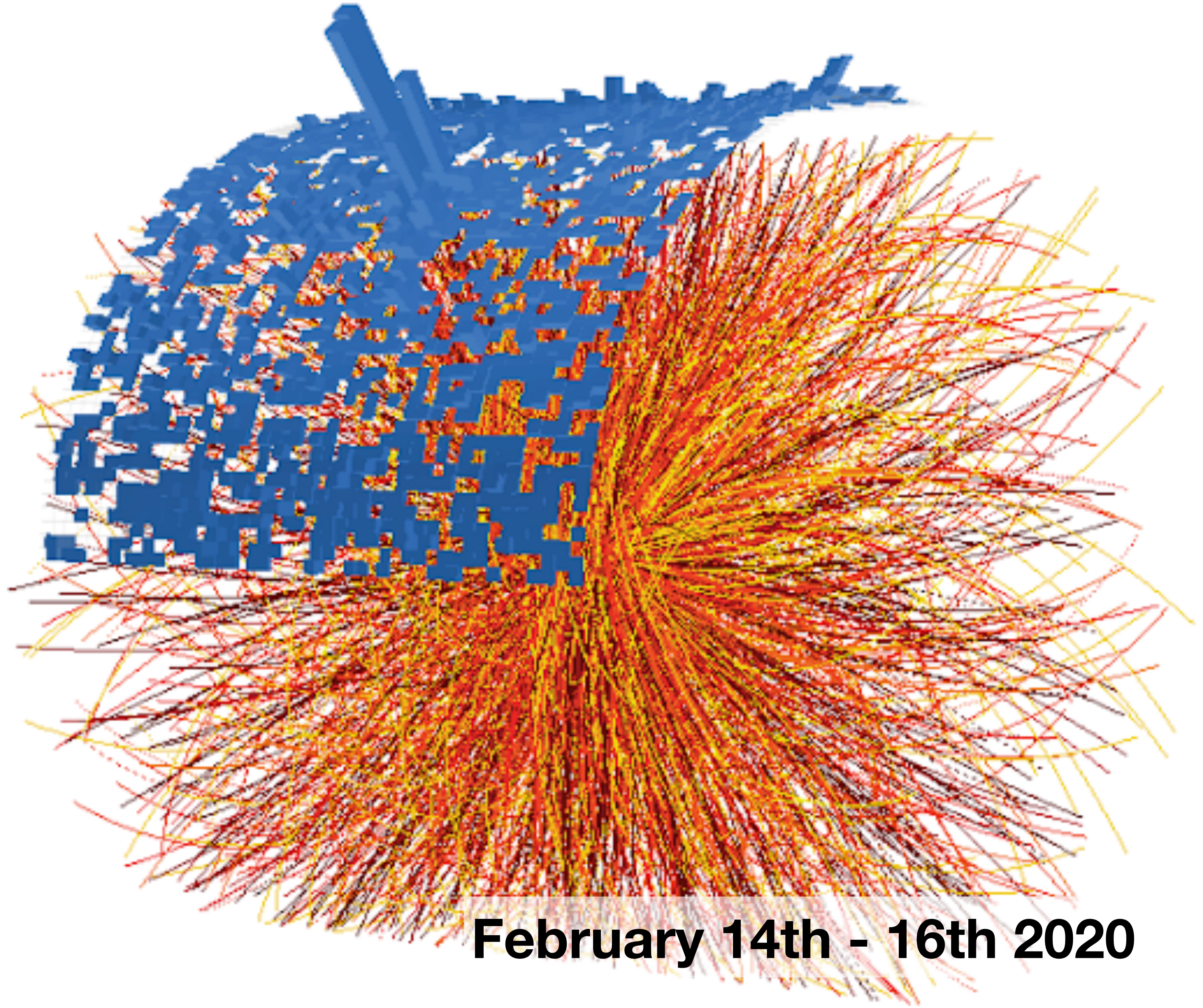




Report of the Pheno Group @ LIP

Liliana Apolinário





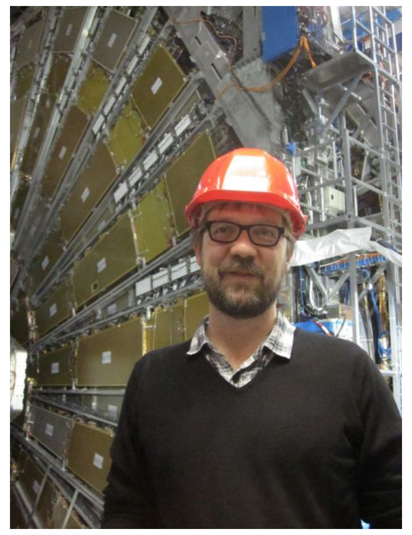
Who are we:

- Group of theoreticians, phenomenologists and experimentalists with focus on:
  - Link between experimental data and theoretical predictions
- Our work:
  - Develop models, to be tested at experiments
  - Create observables to constrain theoretical description
  - Withdraw meaningful quantities from experimental data

Our team:

Guilherme Milhano
Jet Physics, QGP

Liliana Apolinário
Jet Physics, QGP



Ricardo Gonçalo
SM/BSM [also ATLAS]

Ruben Conceição
Astroparticles [also Auger/LATTES]

Guilherme Guedes
PhD :: BSM/DM

Maria Ramos
PhD :: BSM/DM

Nuno Castro
SM/BSM [also ATLAS]

António Onofre
Top/Higgs Physics [also ATLAS]

Pietro Faccioli
Quarkonia [also CMS]

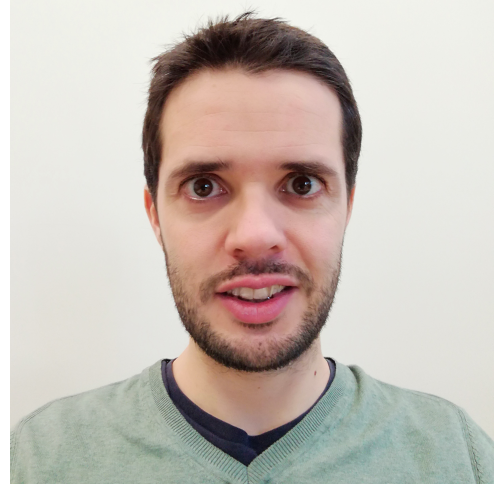
Miguel Fiolhais
Top/Higgs [also ATLAS]

Mariana Araujo
PhD :: Quarkonia [also CMS]

Susana Santos
PhD :: Top/Higgs [also ATLAS]

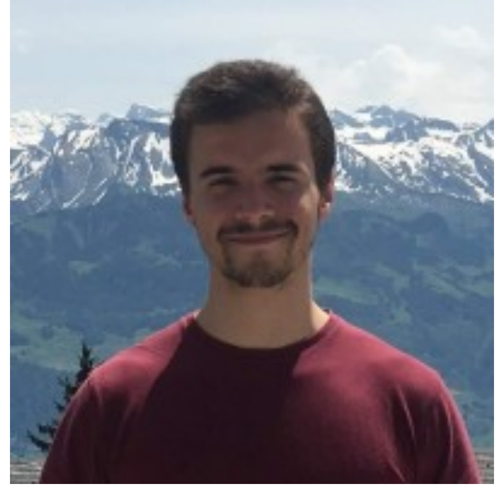
Grigorios Chachamis
QCD precision

João Pires
QCD precision



Miguel Romão
Machine Learning, SM/BSM

João Silva
MSc :: Jets in HI // ML



Our team:

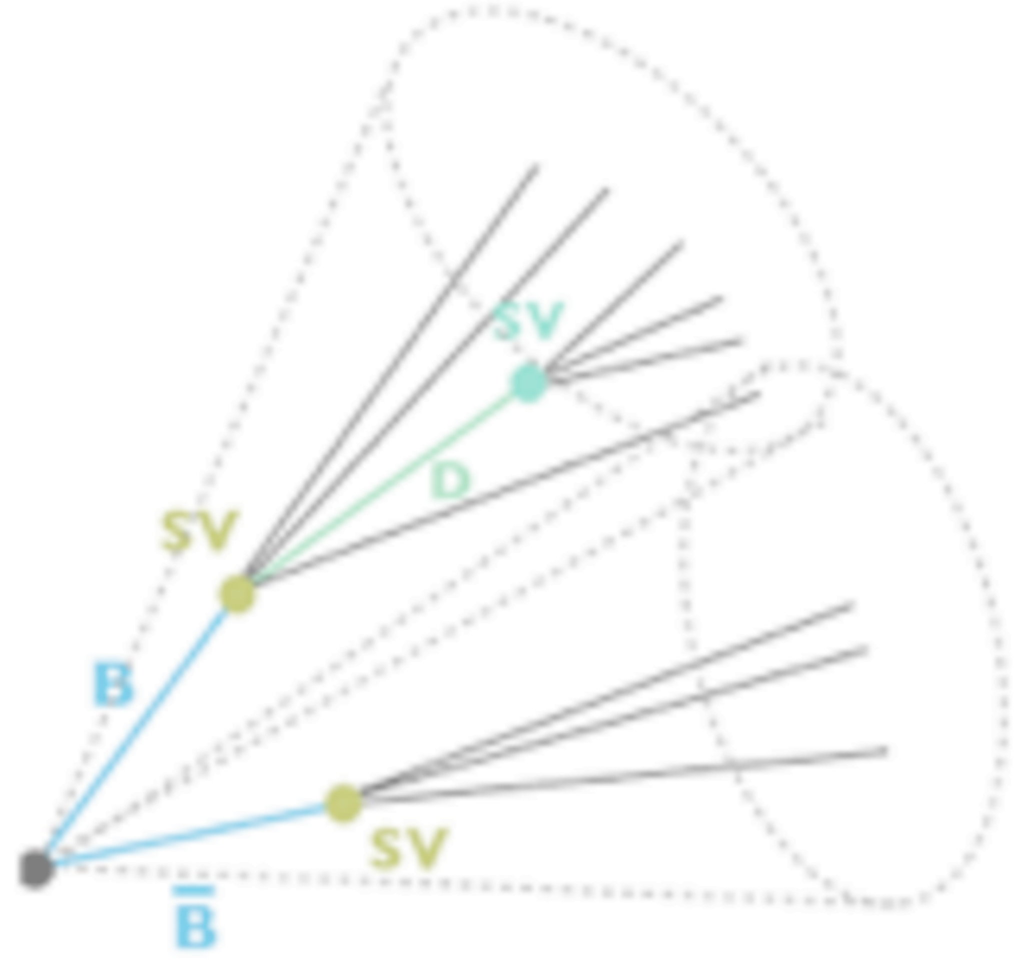
- Graduated at our group in the last two years:

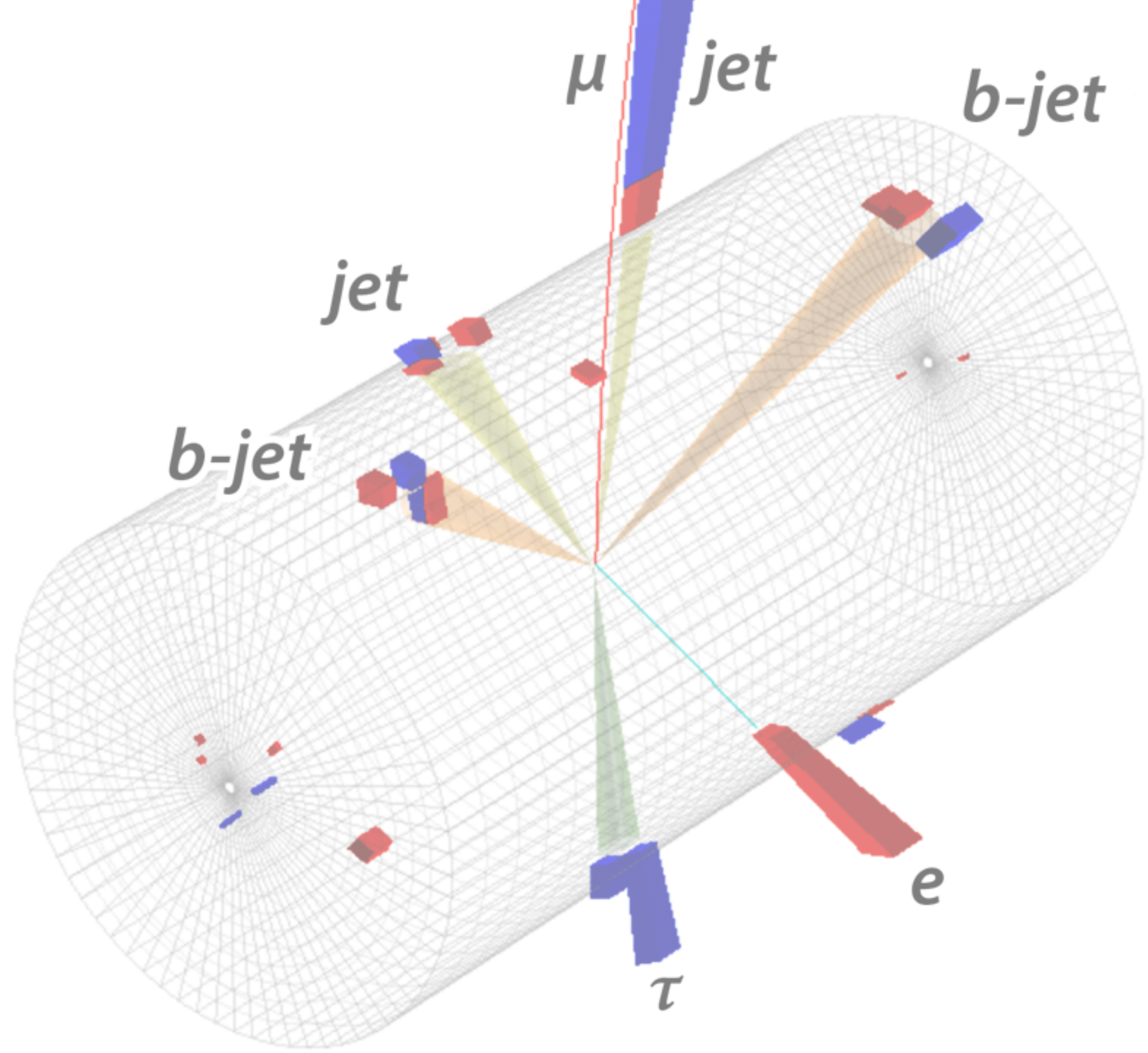
Bruno Silva
MSc :: Jets in small nuclei

Filipa Peres
MSc :: Jets in HI // ML

João Gonçalves
MSc :: Jets in HI // ML

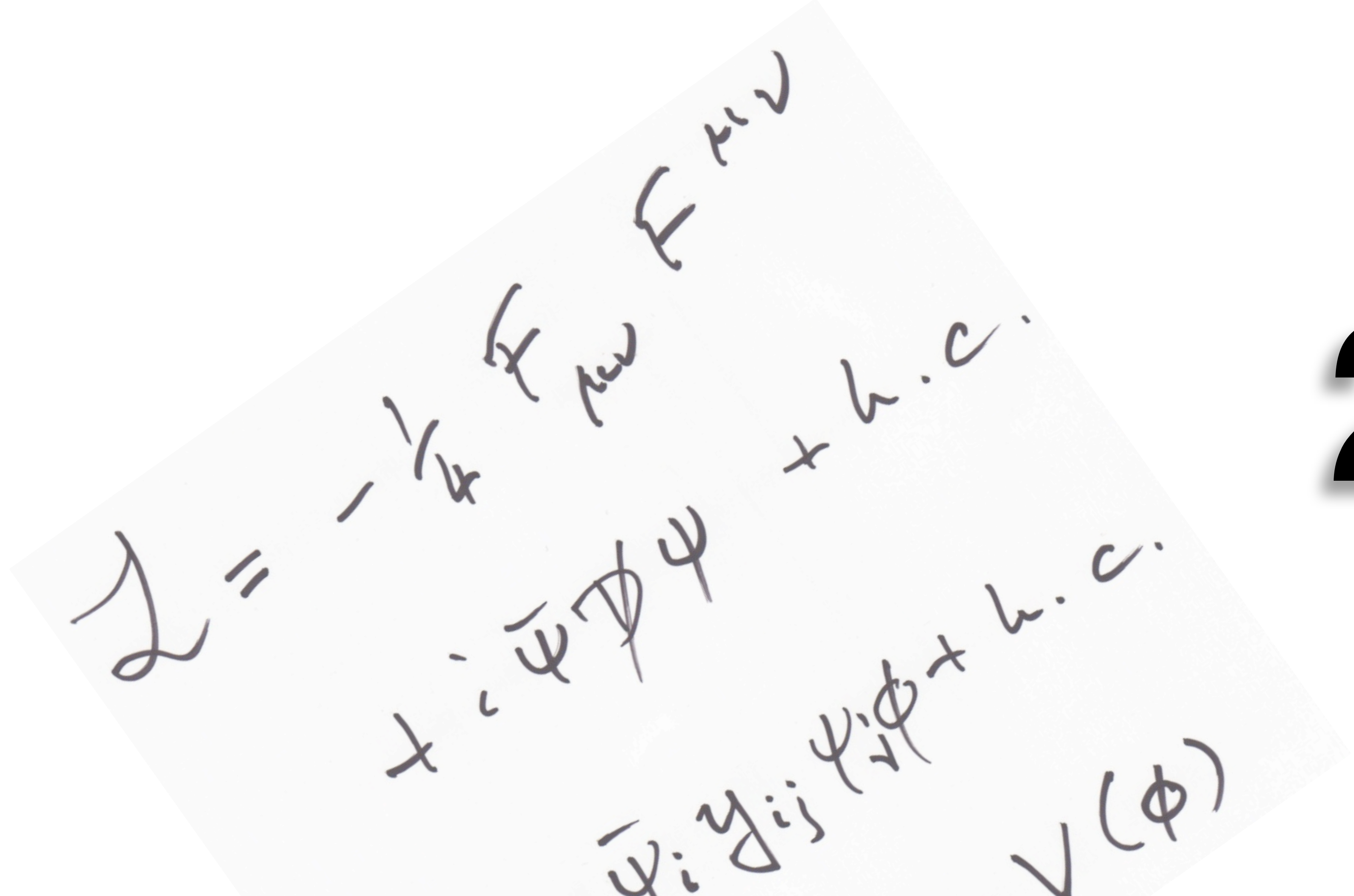
- External Collaborators:
  - F. del Aguila, J. Antonio Aguilar-Saavedra, N. Armesto, J. Casalderrey- Solana, M. Chala, P. Ferreira, A. Ferroglia, C. Lourenço, A. Morais, G. Salam, C.A. Salgado, J. Santiago, R. Santos, K. Rajagopal, U. Wiedemann.

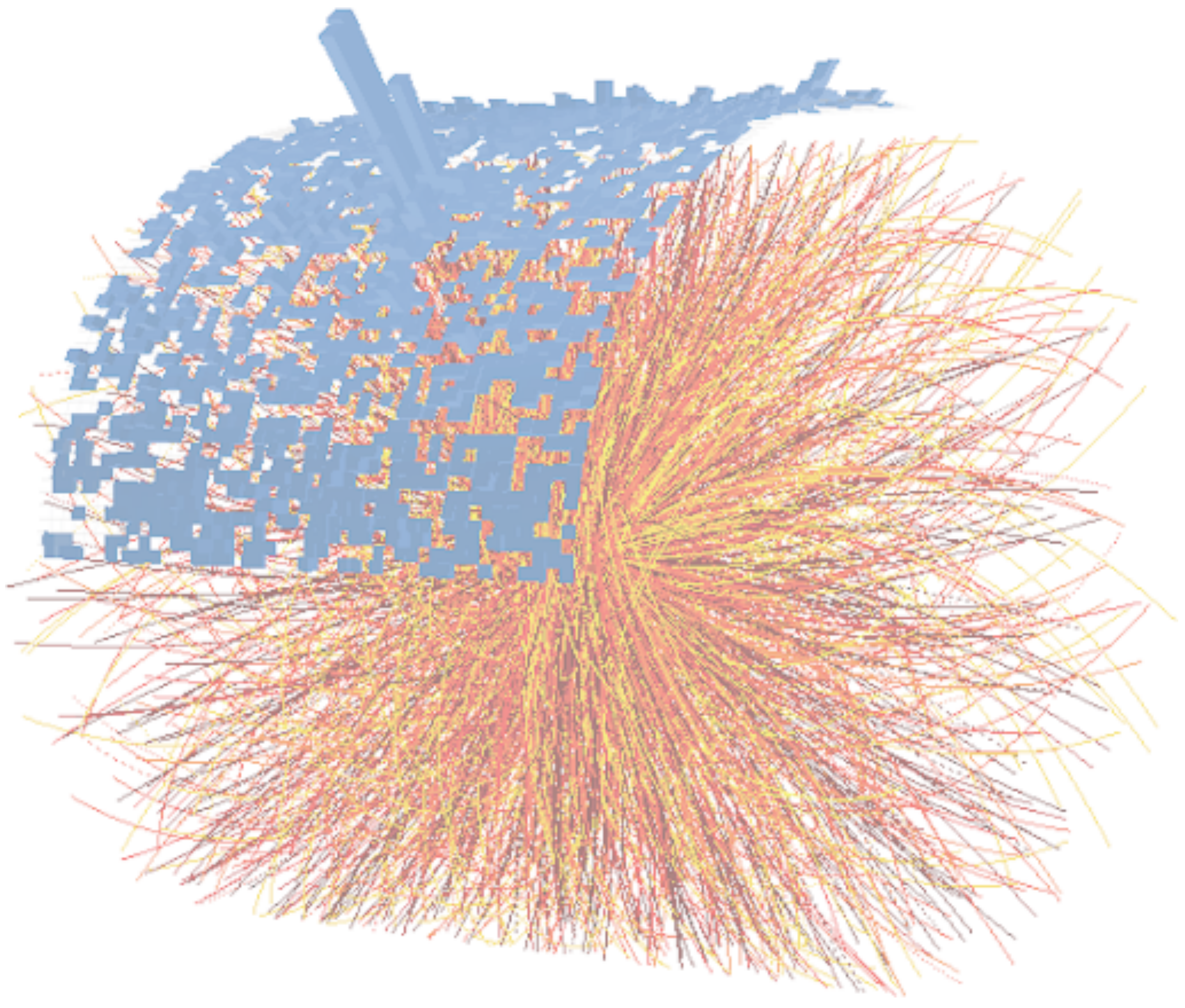




Going to the physics…

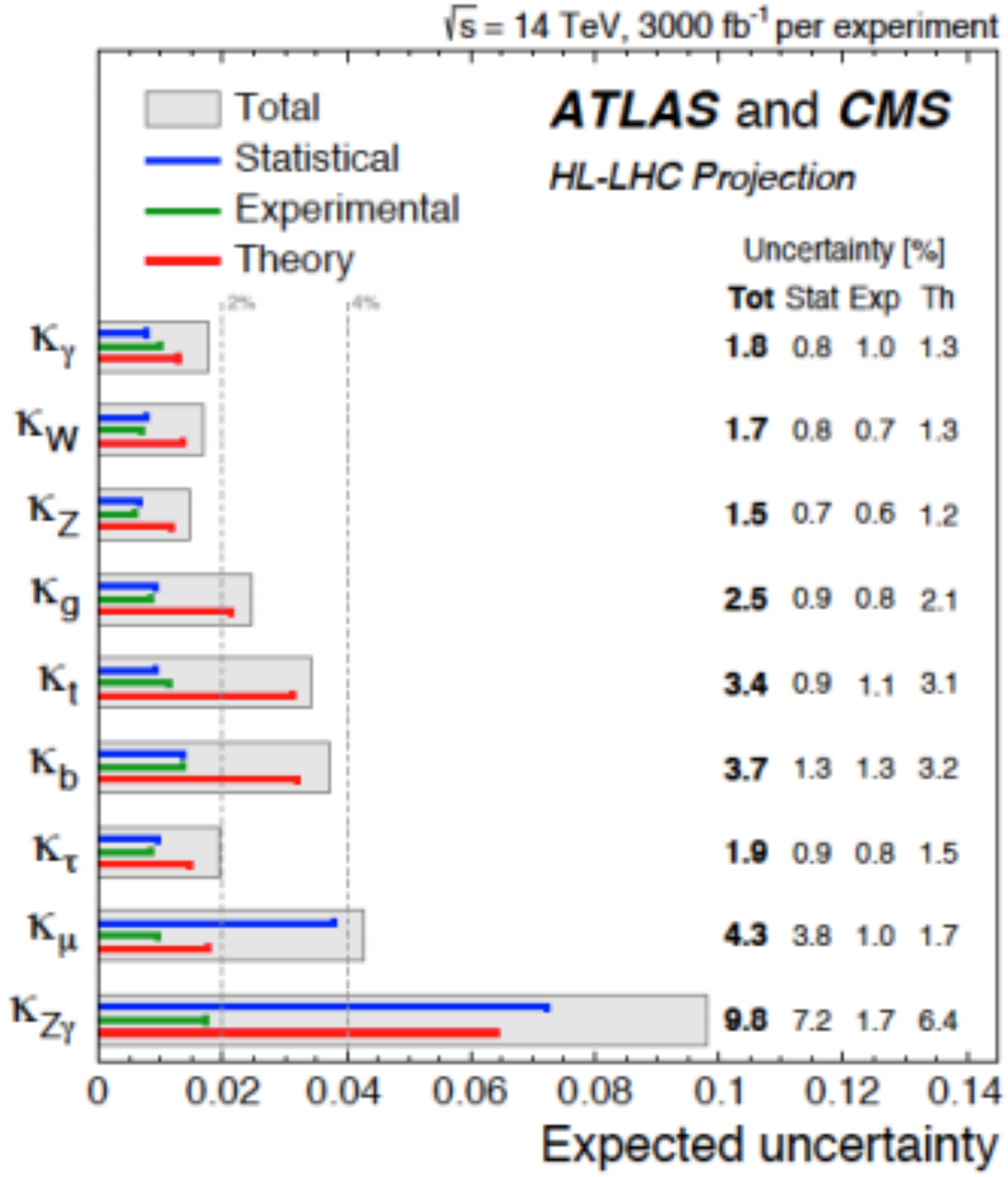
2018 - 2019





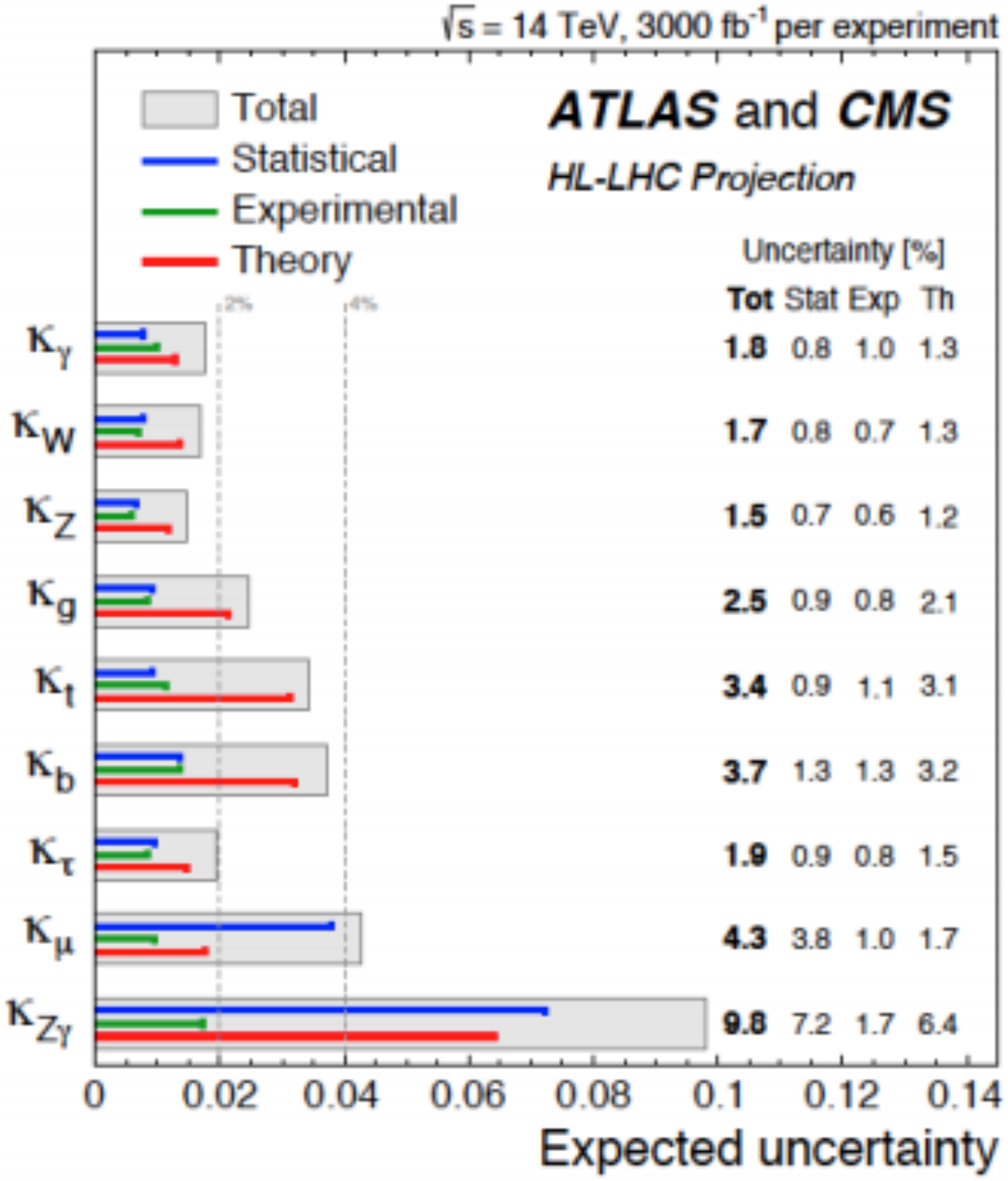
QCD Precision Physics

- Goal: Increase theory precision that currently limit physics analysis at the LHC
    - Example: Higgs couplings at the LHC measured today few % uncertainty, but the dominant one is is coming from the theory side.



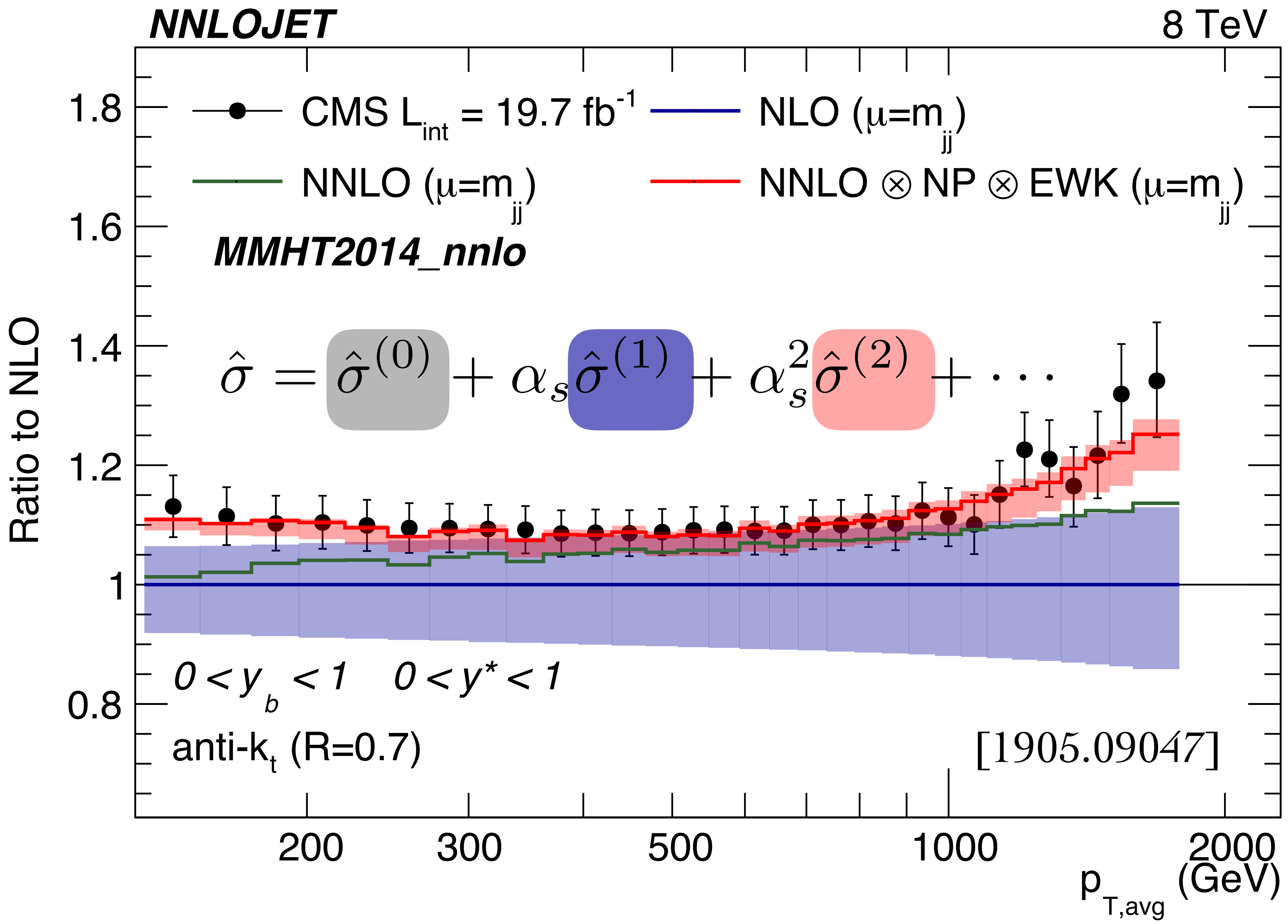
QCD Precision Physics

- Goal: Increase theory precision that currently limit physics analysis at the LHC
  - Example: Higgs couplings at the LHC measured today few % uncertainty, but the dominant one is is coming from the theory side.
- How?
  - Reach theoretical precision LHC phenomenology at NNLO
  - Development of a NNLO fully differential parton-level generator



QCD Precision Physics

- Calculation of the 2nd order pQCD correction
  - Reduction of theory uncertainties



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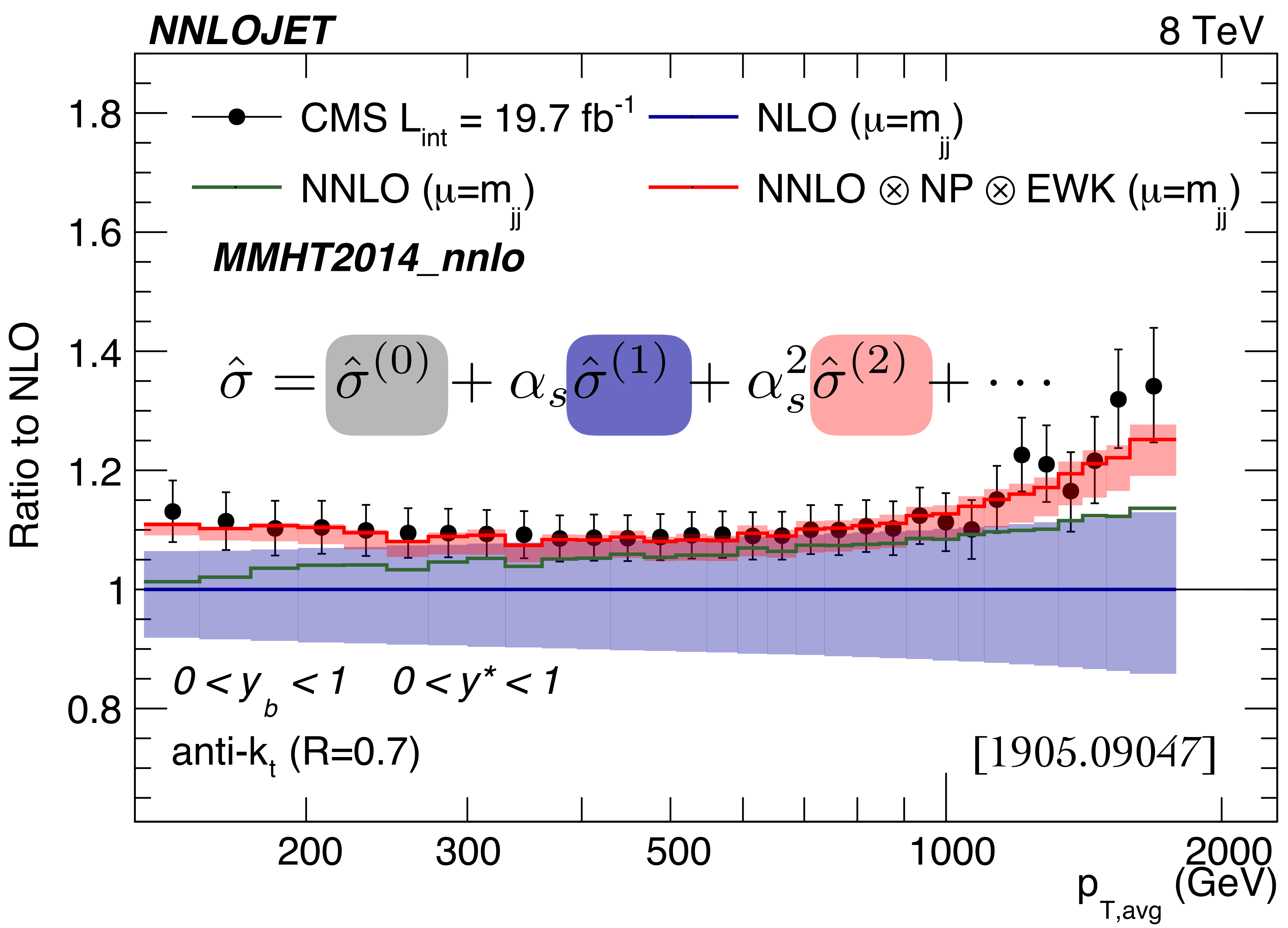
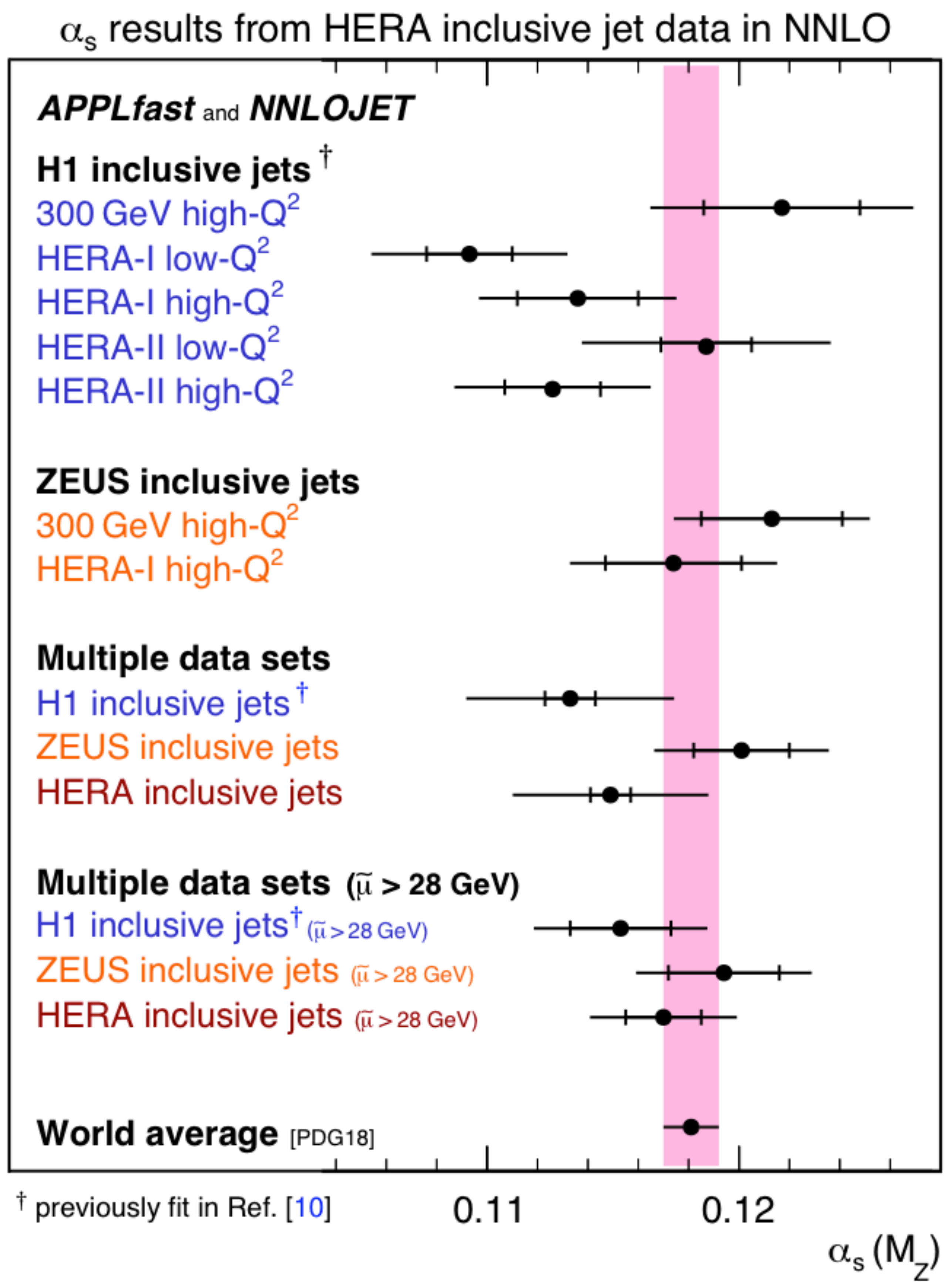


- Fast interpolation grid techniques at NNLO in QCD

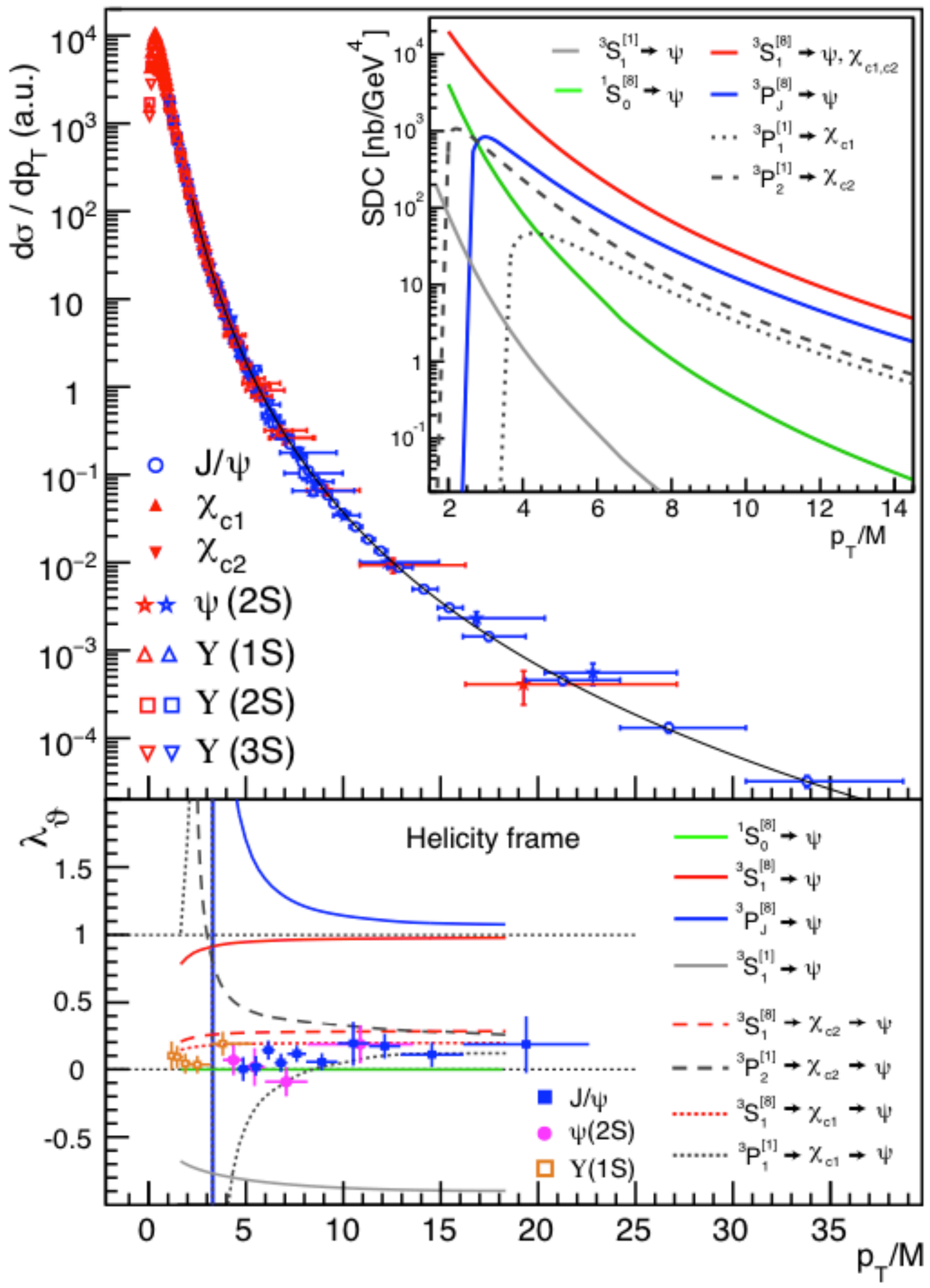
[1906.05303]



Accurate extraction of α_S

Heavy quarkonium

- Goal: Understand the production of quarkonium bound states (in pp and PbPb)
  - Heavy quark masses ⇒ Expansion in powers of (v/c)
- How? Non-relativistc QCD (NRQCD)
  - However, complicated structure masks our understanding of bound states QCD dynamics…
  - Need further phenomenological studies based on measured patterns (scaling laws)

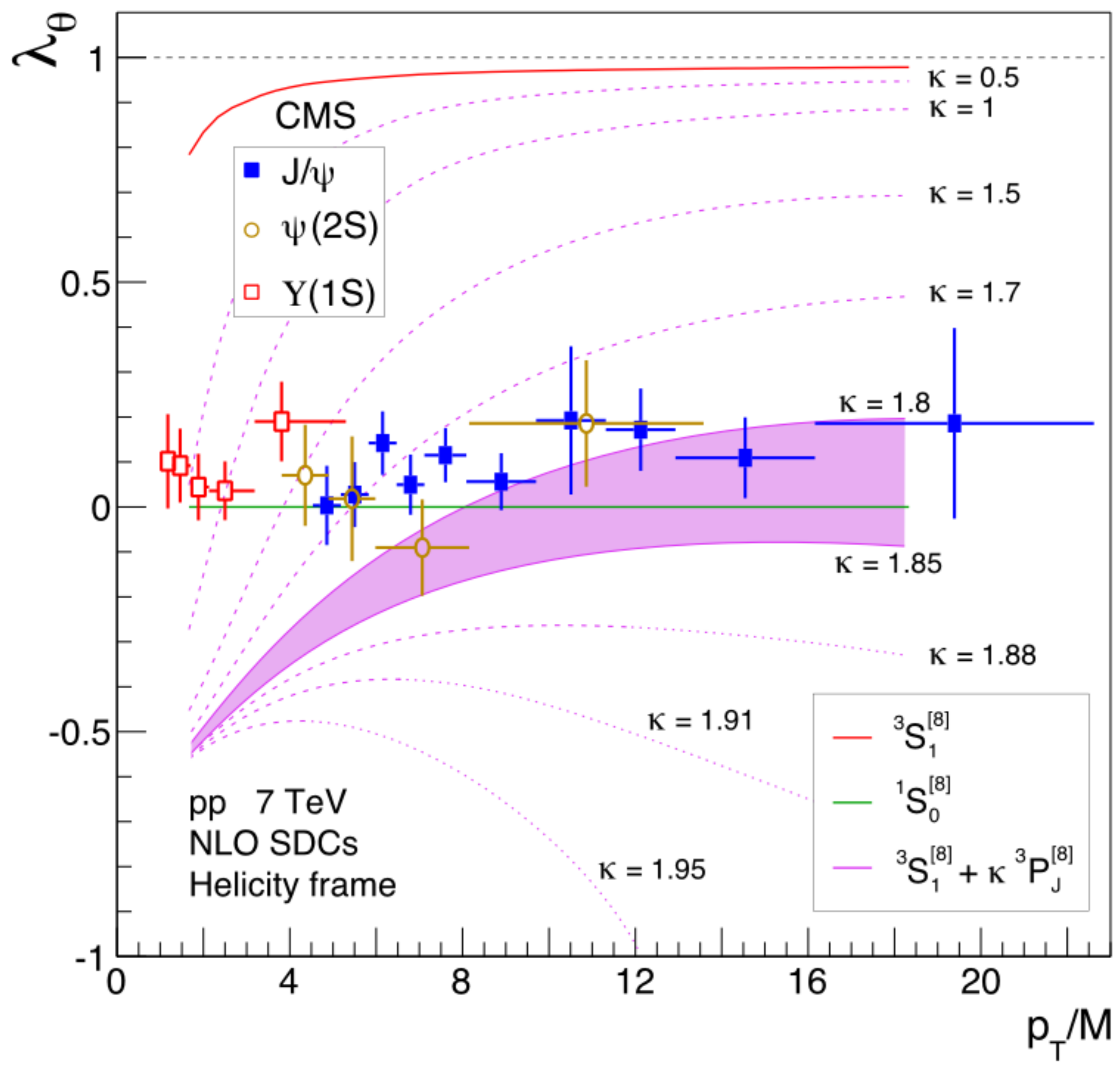


Heavy quarkonium

[PF. et al., EPJC (18)]
[PF, Lourenço, EPJC (19)]
[PhD. Thesis: M, Araujo]

- Deconstructing NRQCD complexity:
  - quarkonium states are produced as a superposition of many (colour singlet and octet) terms
    - J/ψ, ψ(2S) and Υ(nS): $^1S_0 + {}^3S_1 + {}^3P_J$
    - Data indicates: $^1S_0 \cong {}^3S_1 + \boldsymbol{\kappa}\, {}^3P_J$, with $\boldsymbol{\kappa} \cong 1.8$ (polarisation measurement λ_θ at large p_T/M)

[1905.09553]



In either case, zero and constant polarization is the biggest challenge to NRQCD.

More precise measurements are needed to reach a decisive conclusion.

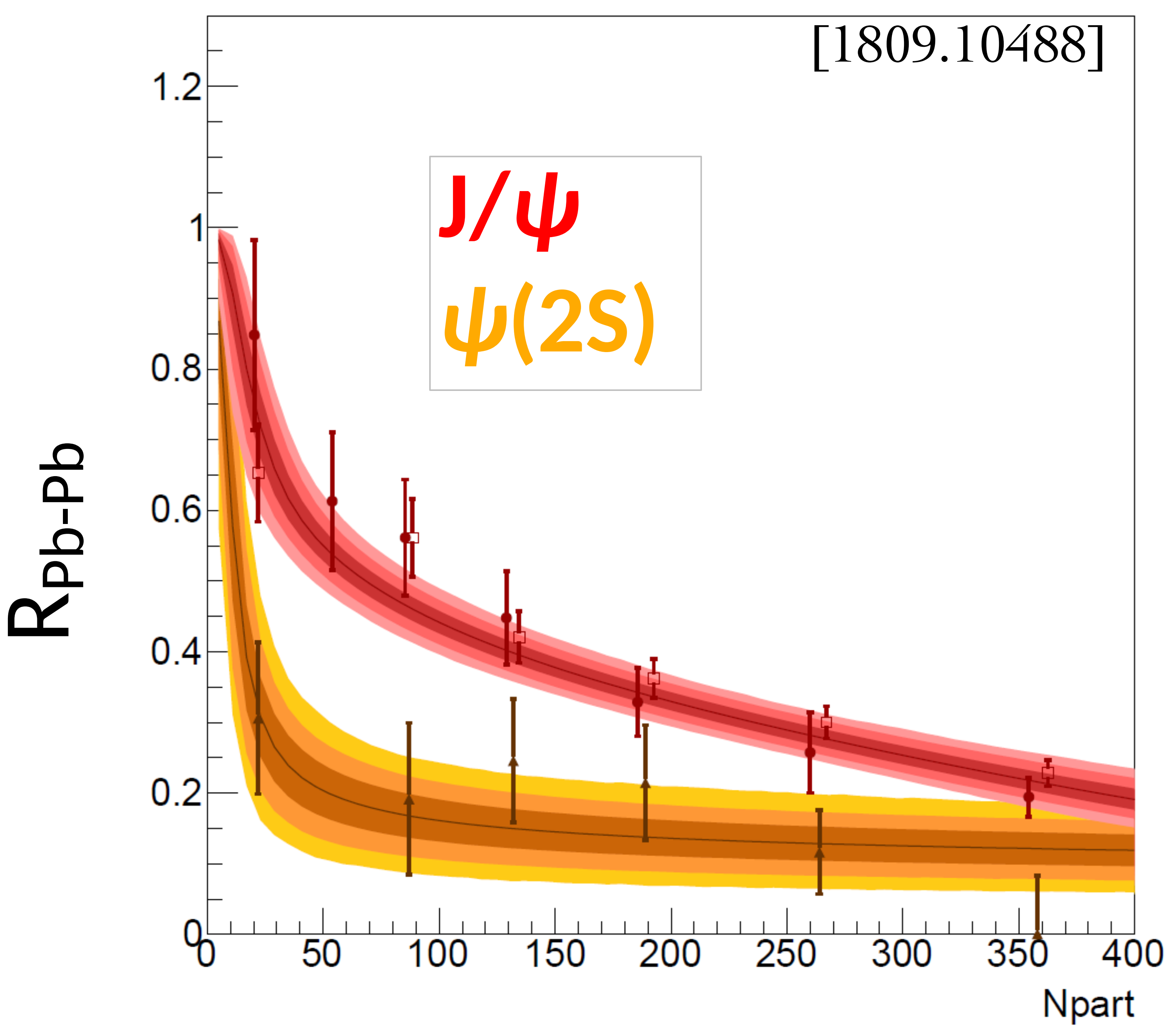
Heavy quarkonium

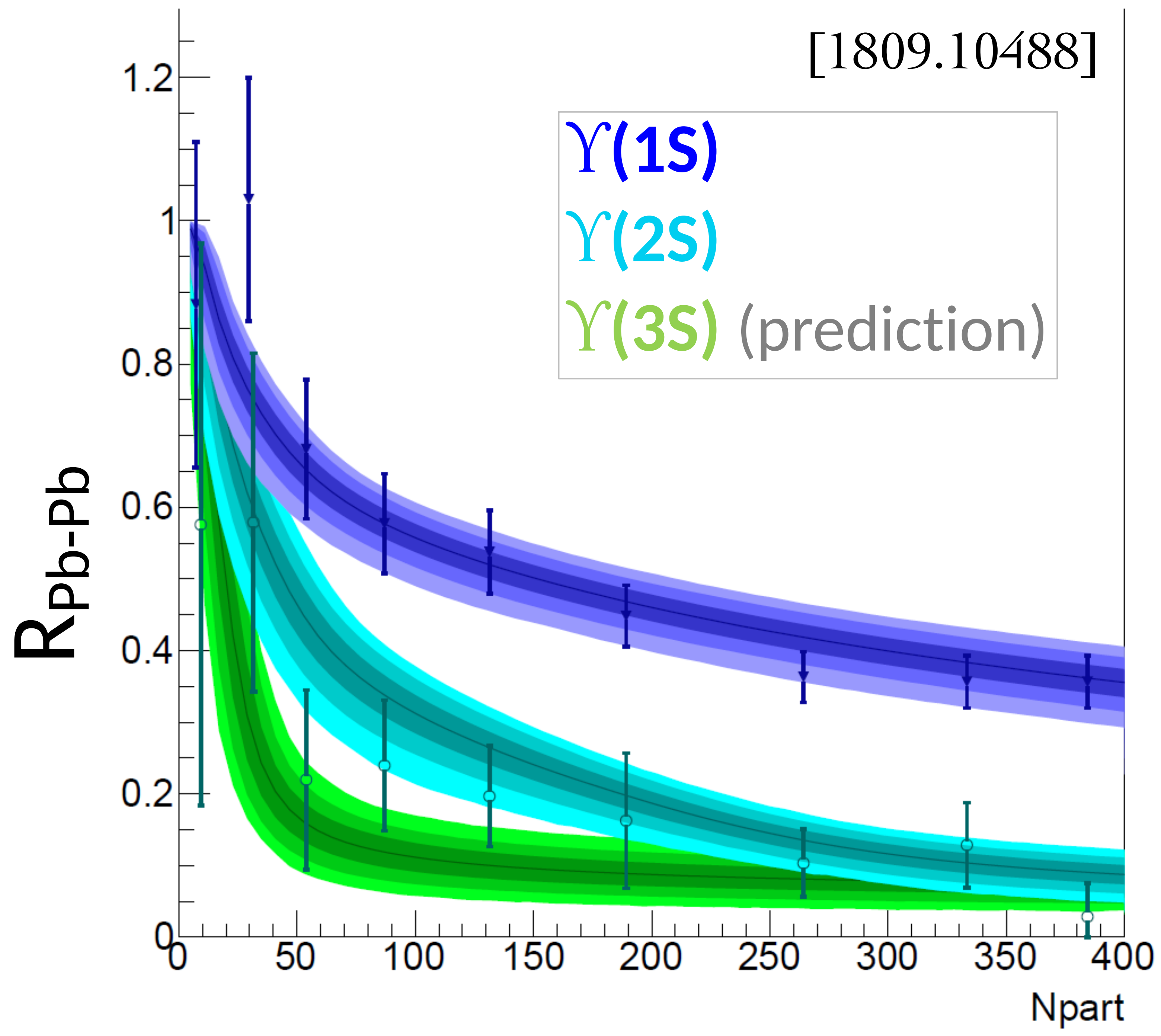
[PF, Lourenço, EPJC (18), FP, MA, et al EPJC (18)]

[PhD. Thesis: M, Araujo]

- Simple description of quarkonium suppression data, at PbPb collisions (LHC):
  - 3 parameter fitting model: $\frac{\sigma_{\psi|\Upsilon}}{\sigma_{Q\bar{Q}}} \propto (E_{binding} - \Delta E)^{\delta}$ with $\delta = 0.63 \pm 0.02$ and $\Delta E \propto \log(Npart)$, identical for all states.

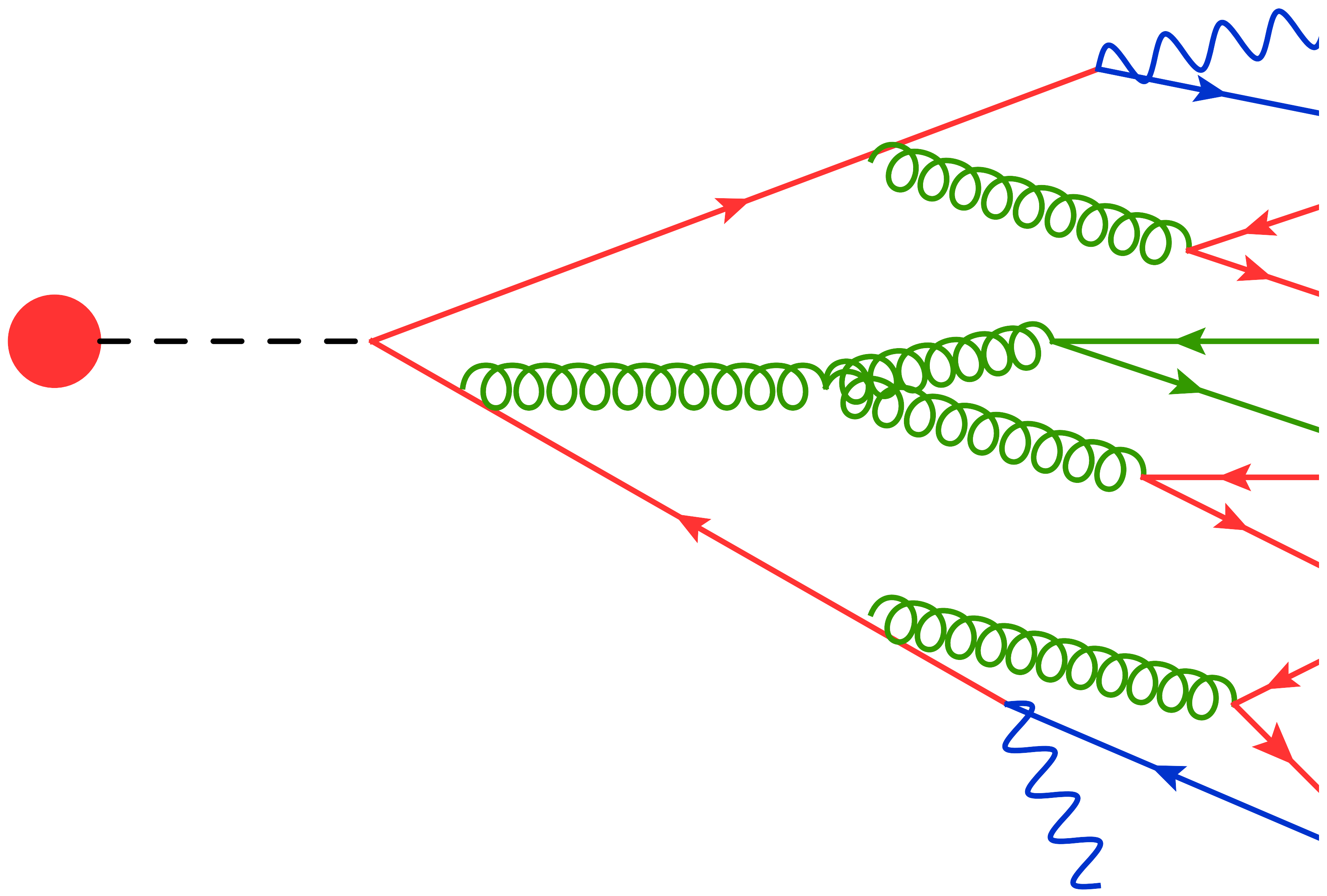
Suppression patterns depend exclusively on the binding energy of the states: the more weakly bound states are the most suppressed, as expected in the case of ("sequential") quark gluon plasma screening.





Heavy-Ions

- Goal: Understand QCD sector at extreme conditions
  - Quark-Gluon plasma constitution and dynamics
- How? Hard probes (mostly jets)
  - proton-proton collisions: jets very well understood
  - heavy-ion collisions: jets modified by its interaction with the QGP (?)



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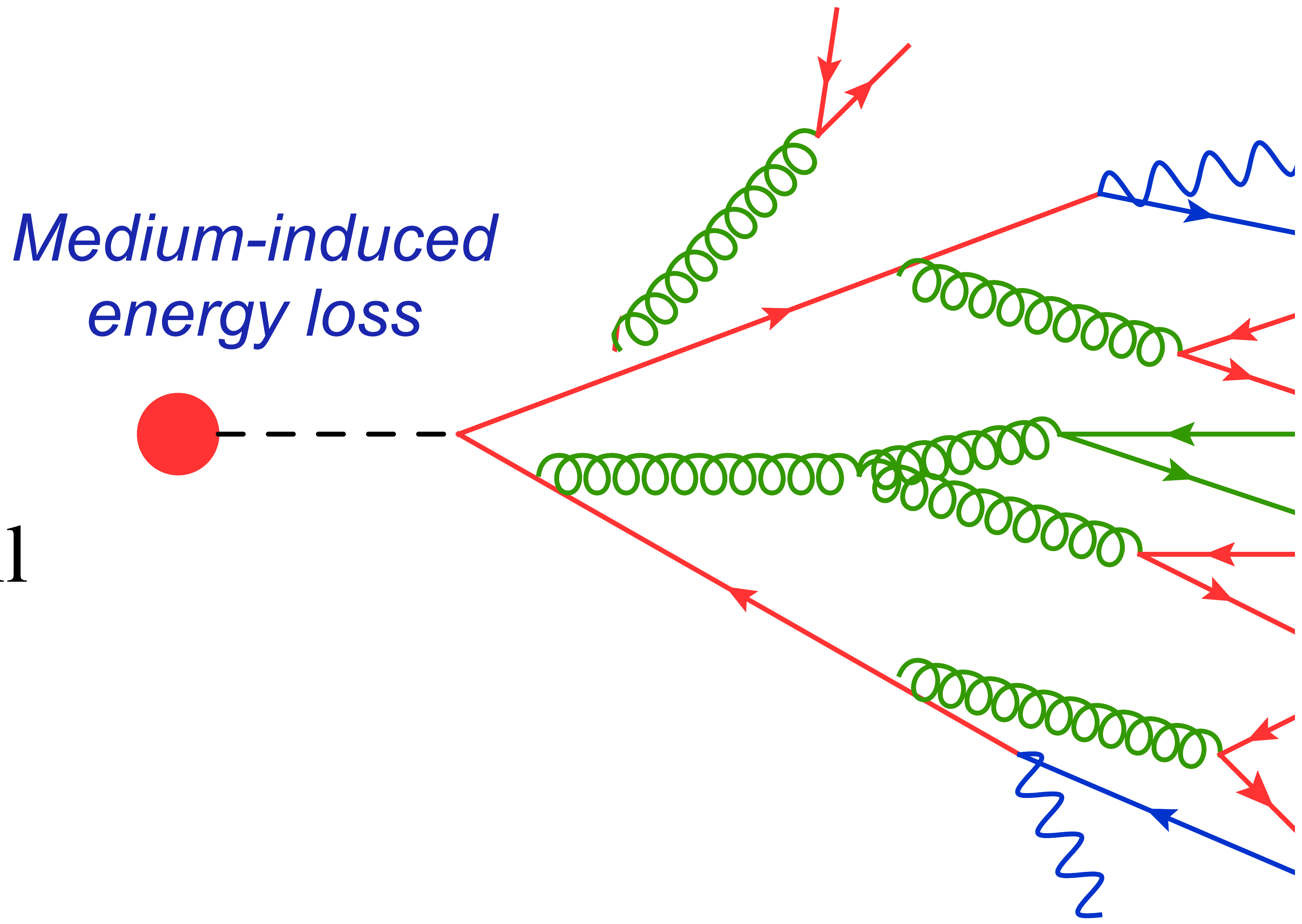

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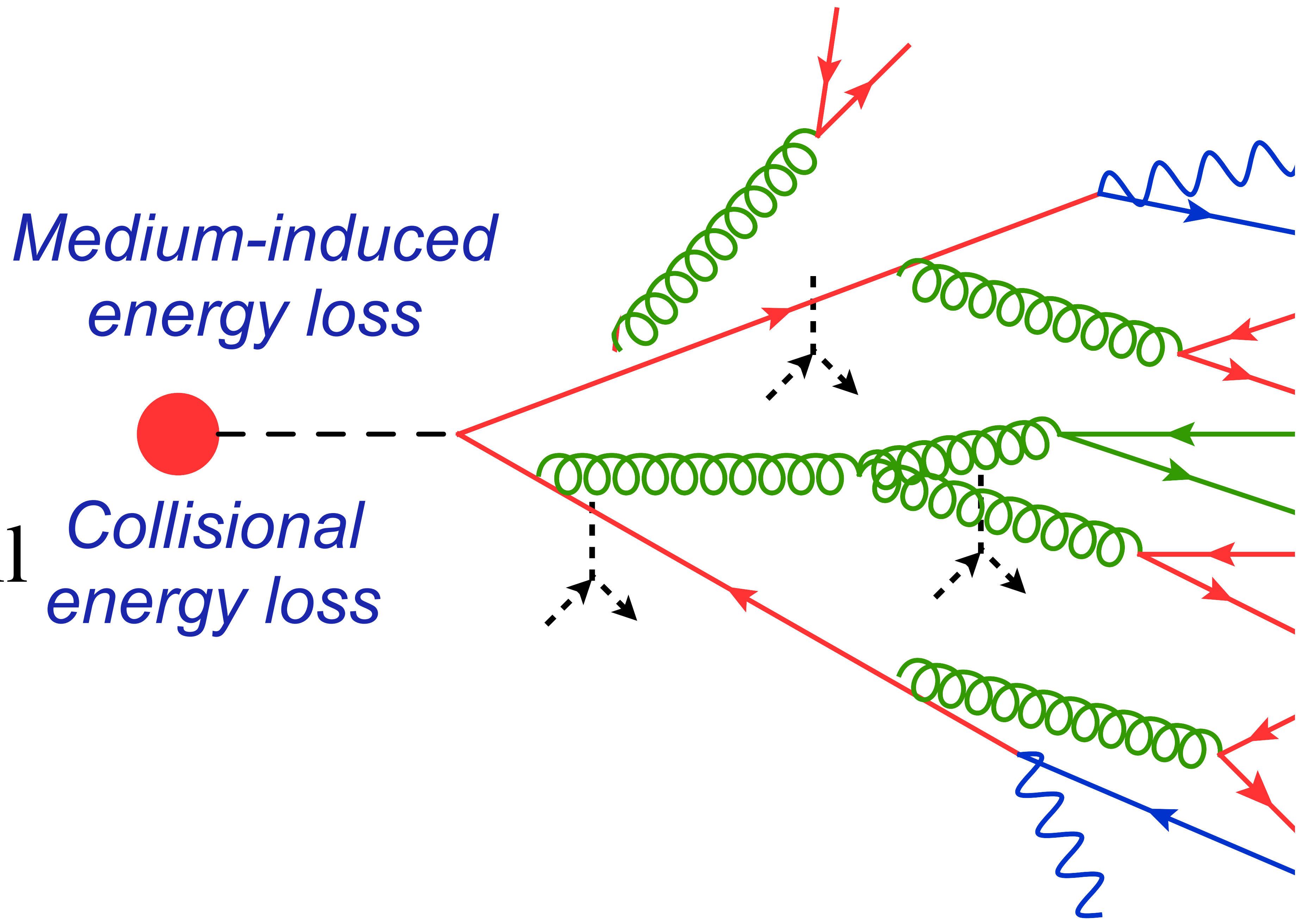

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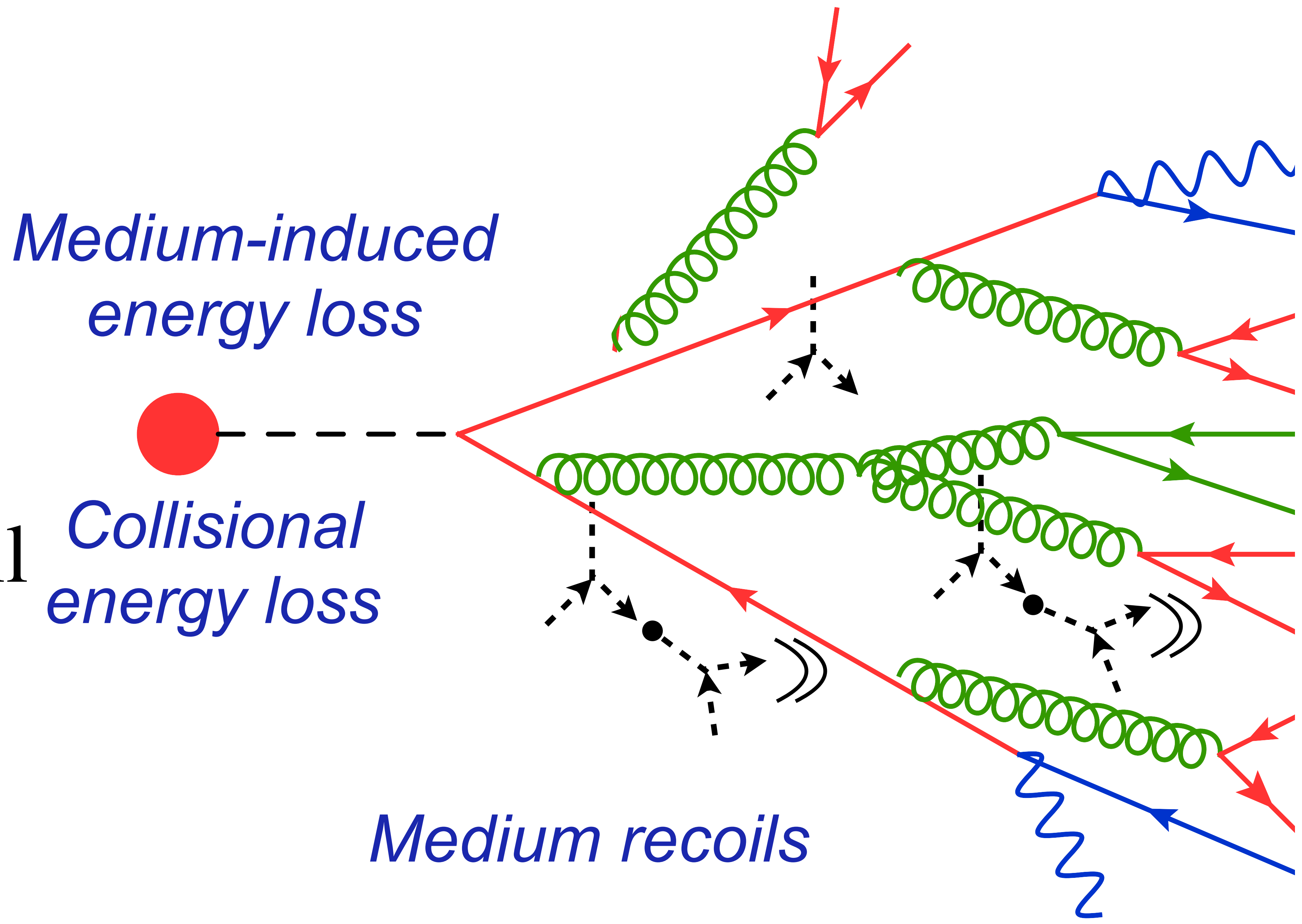

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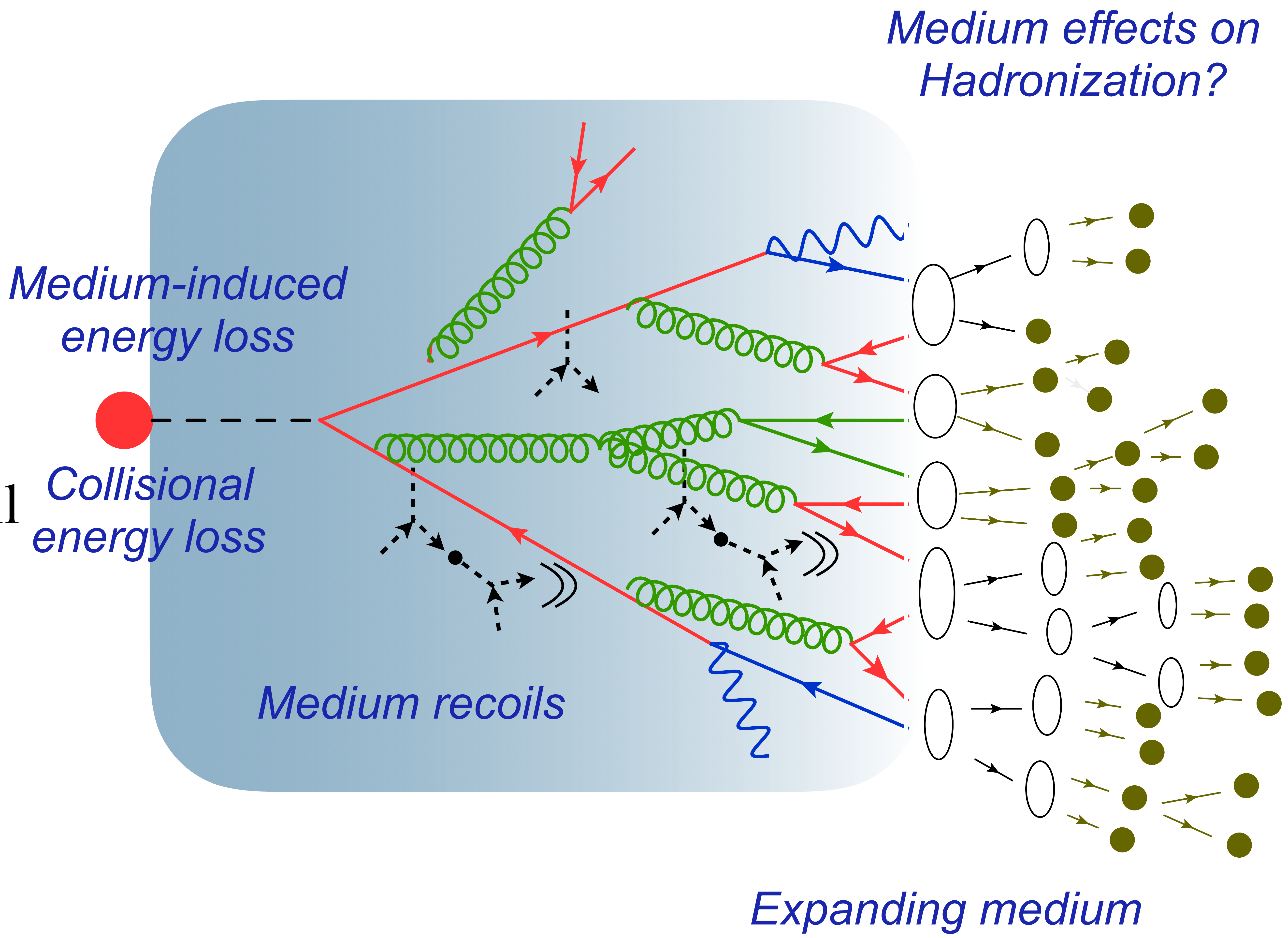

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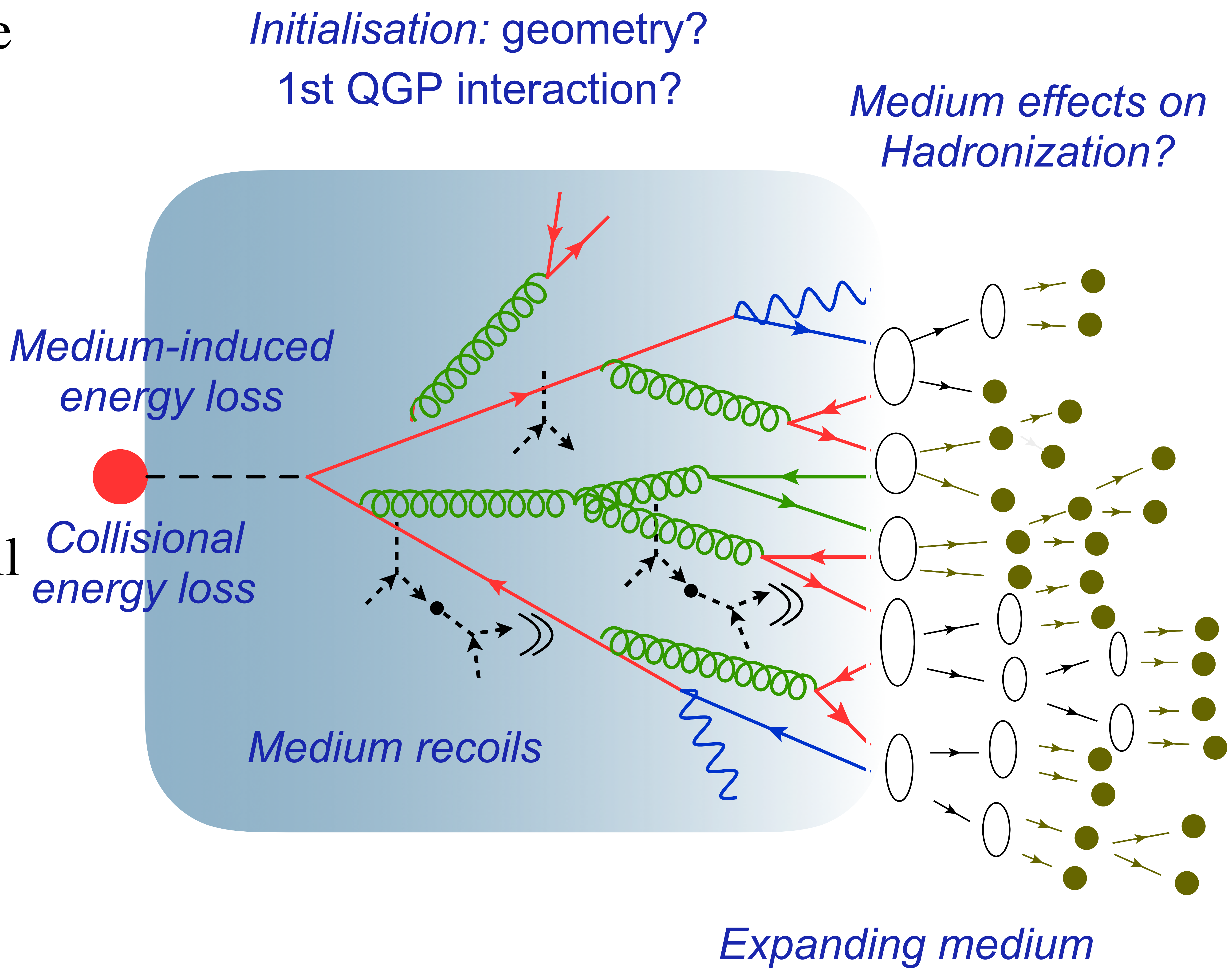
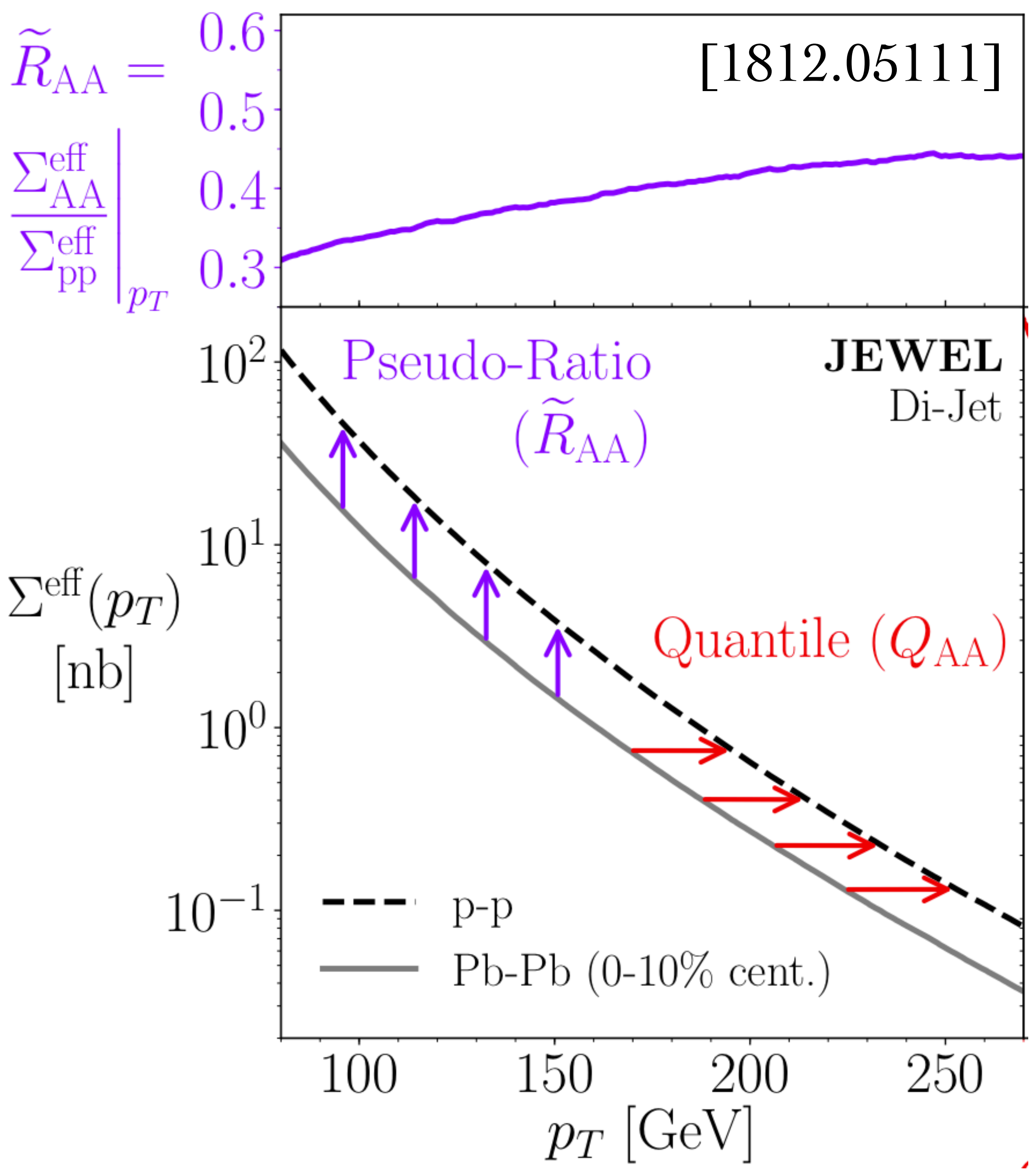
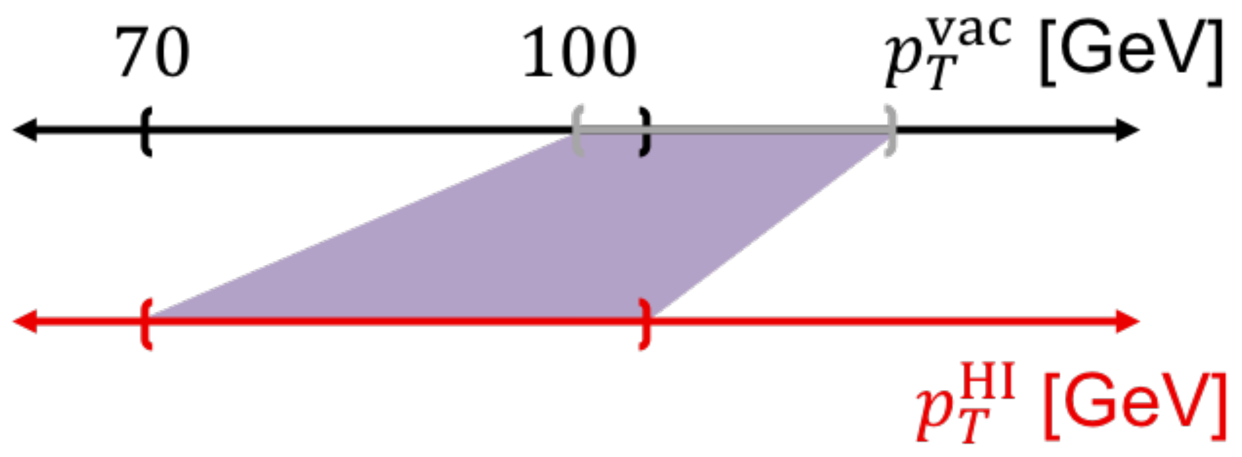


Heavy-Ions

- New jet observables to allow:
  - Accurate characterisation of the QGP





Jet p_T is modified by the QGP

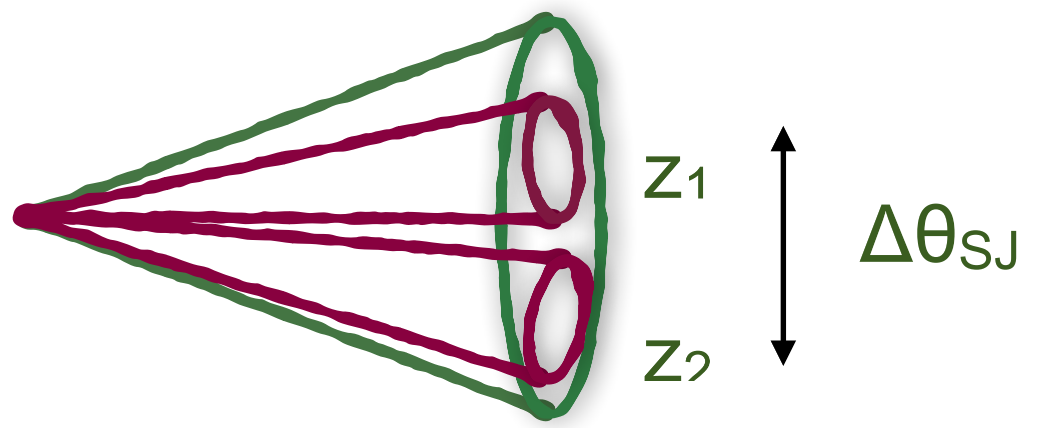
Instead of p_T, use quantiles binning: match p_T PbPb to p_T in pp

Heavy-Ions

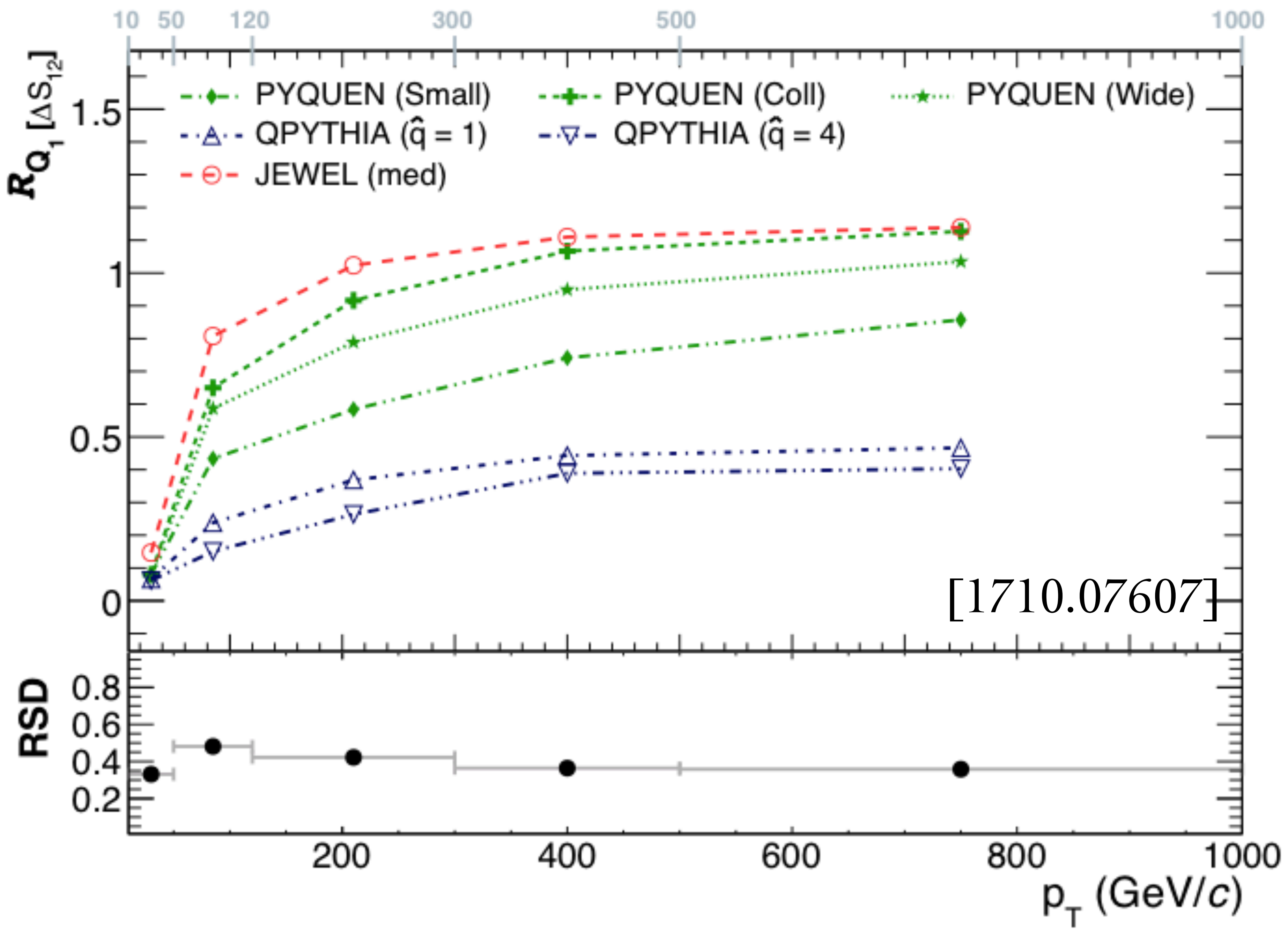
- New jet observables to allow:
  - Accurate characterisation of the QGP
  - Disentangle multiple medium-induced effects

Several QGP-induced effects contributing to the final jet observable

Use observables that are only sensitive to few effects to calibrate models



QM 2019: First measurements @ RHIC!



Heavy-Ions

[Andrews, LA, JGM et al EPJC (18), LA, JGM et al EPJC (18)]
[Casalderrey-Solana, JGM, et al, PRC (19), Brewer, JGM et al, PRL (19)]
[MsC. Thesis: J. Gonçalves, F. Peres]

- New jet observables to allow:
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How ML can help us in this quest?

[Andrews, LA, JGM et al EPJC (18), LA, JGM et al EPJC (18)]
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Heavy-Ions

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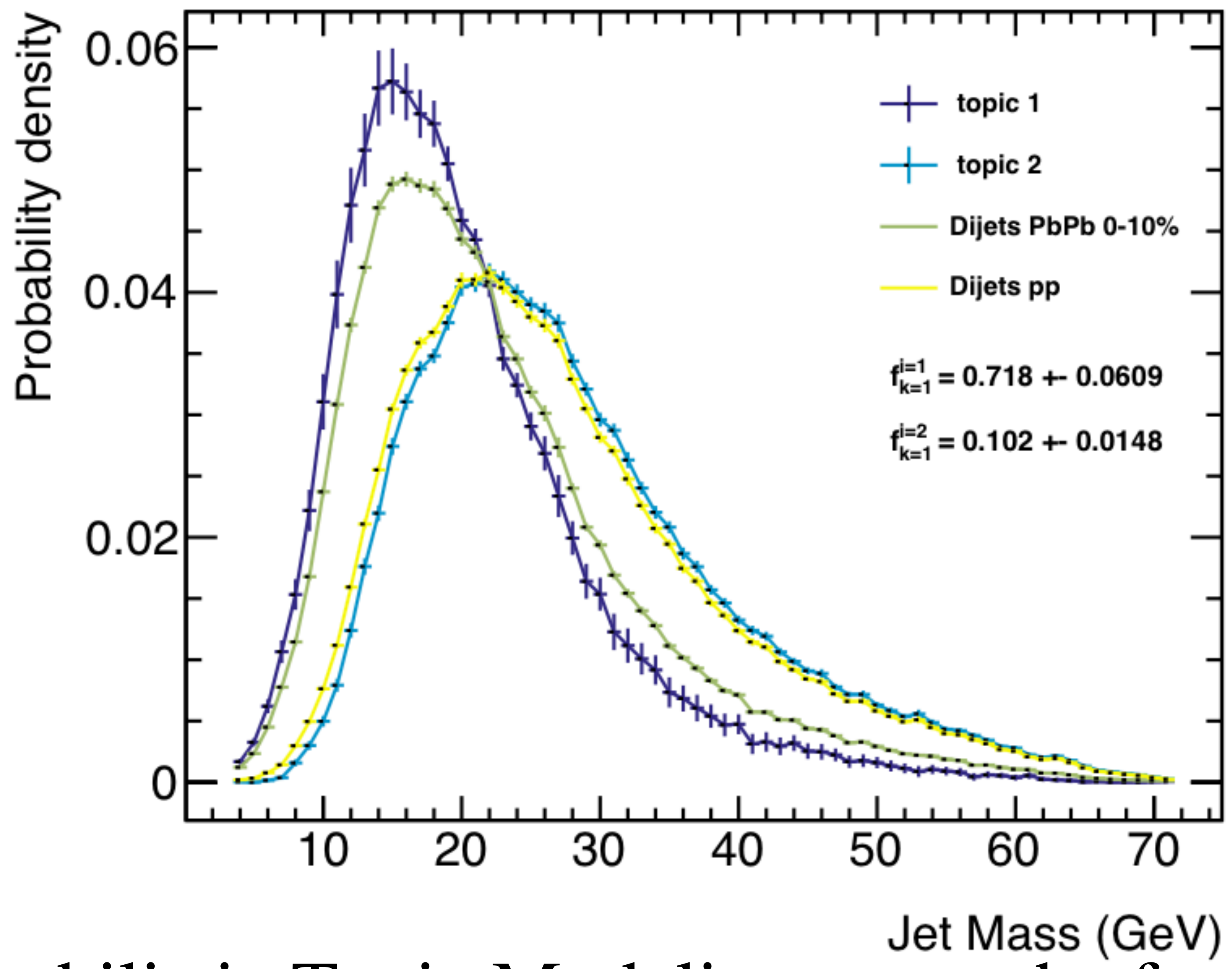
[MsC. Thesis: J. Gonçalves]



How ML can help us in this quest?

Probabilistic Topic Modeling to get the fraction of jets modified by the QGP

[Andrews, LA, JGM et al EPJC (18), LA, JGM et al EPJC (18)]
[Casalderrey-Solana, JGM, et al, PRC (19), Brewer, JGM et al, PRL (19)]

Heavy-Ions

[MsC. Thesis: J. Gonçalves, F. Peres]

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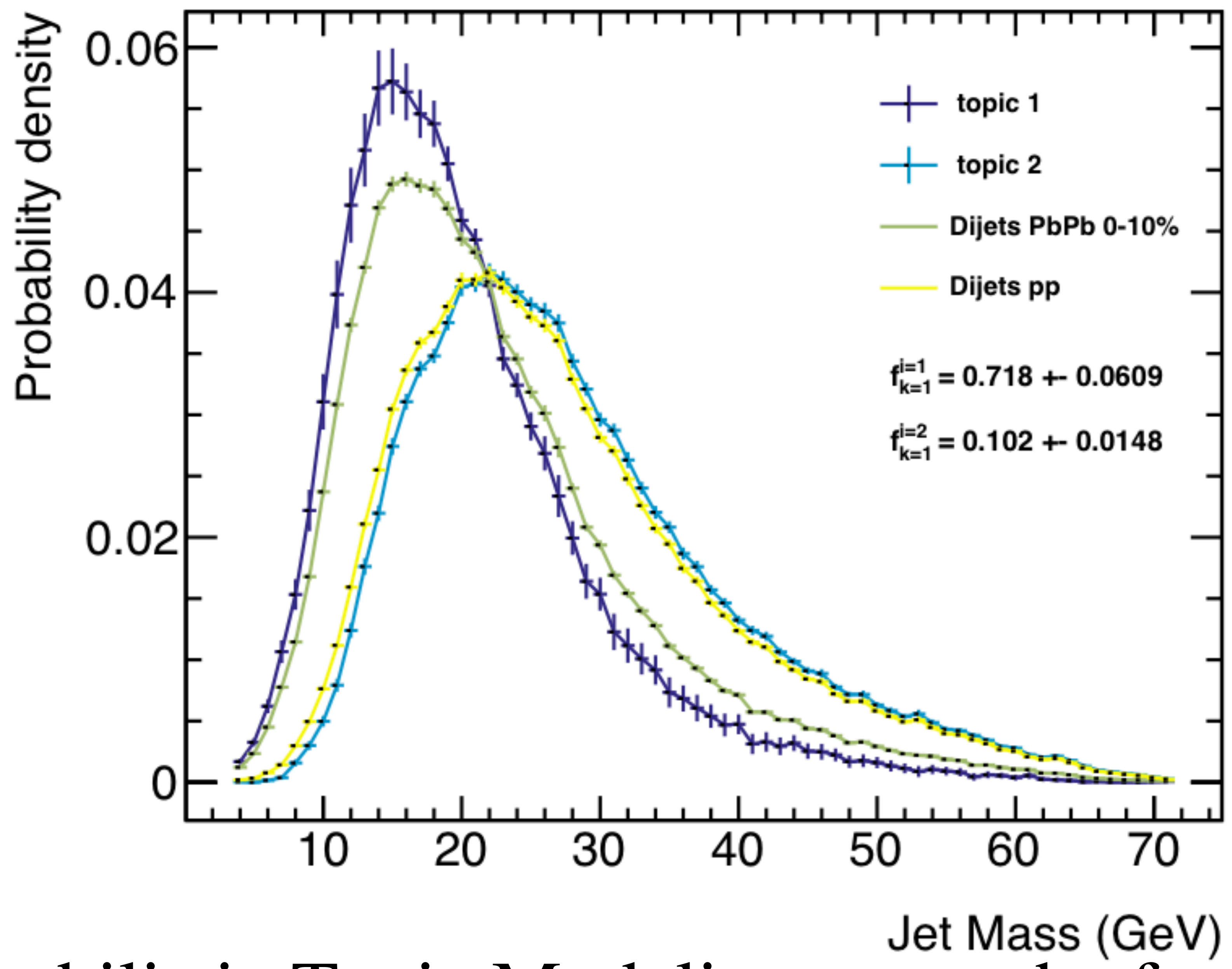
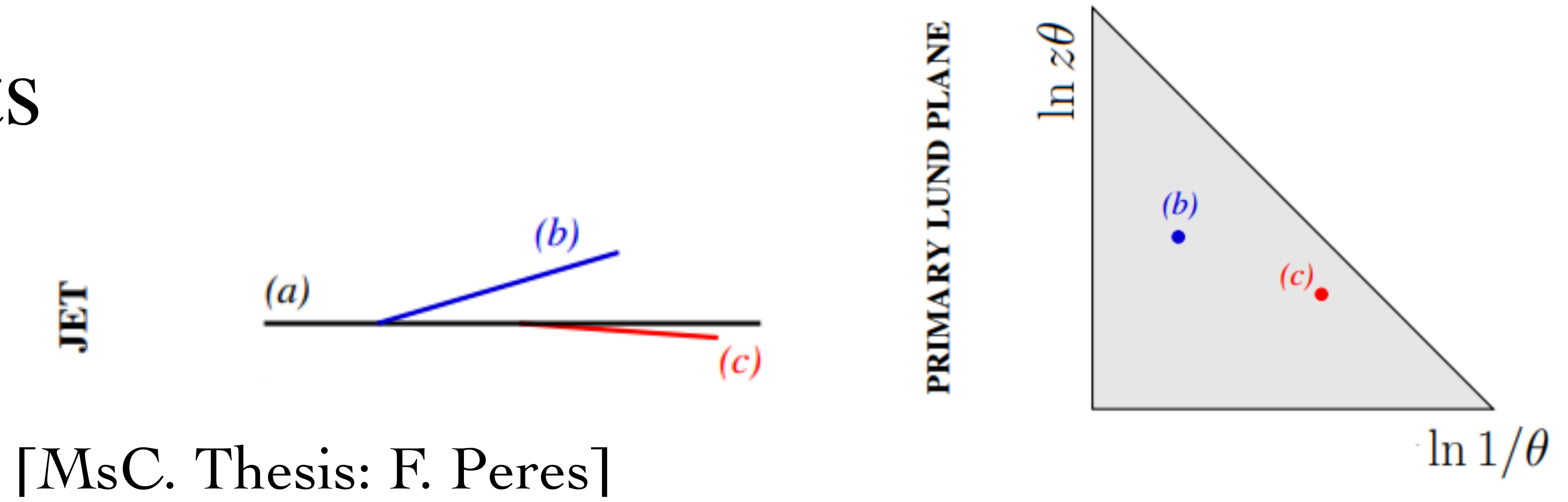
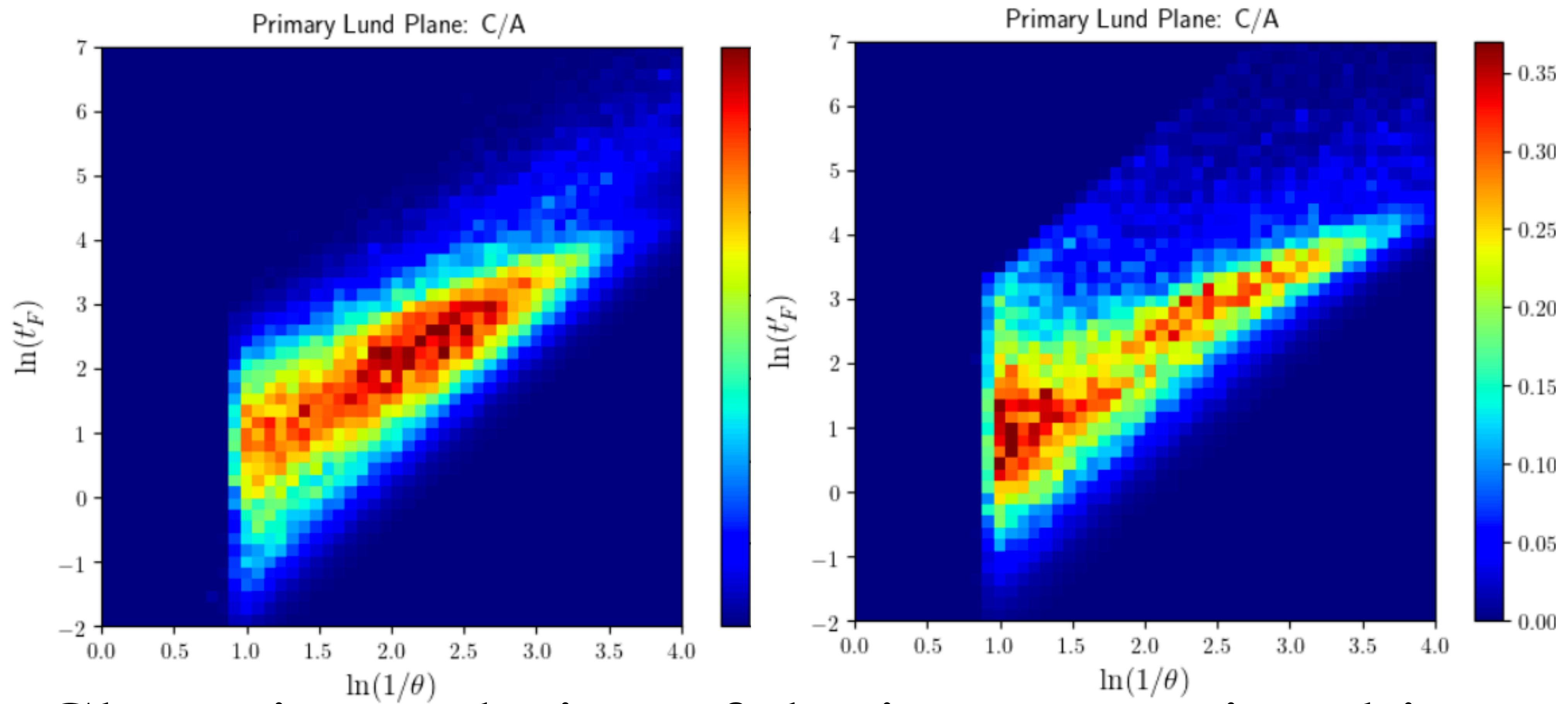


Probabilistic Topic Modeling to get the fraction of jets modified by the QGP



[MsC. Thesis: F. Peres]



Clustering ordering of the jet tree to signal jets modified by the QGP

[Andrews, LA, JGM et al EPJC (18), LA, JGM et al EPJC (18)]
[Casalderrey-Solana, JGM, et al, PRC (19), Brewer, JGM et al, PRL (19)]

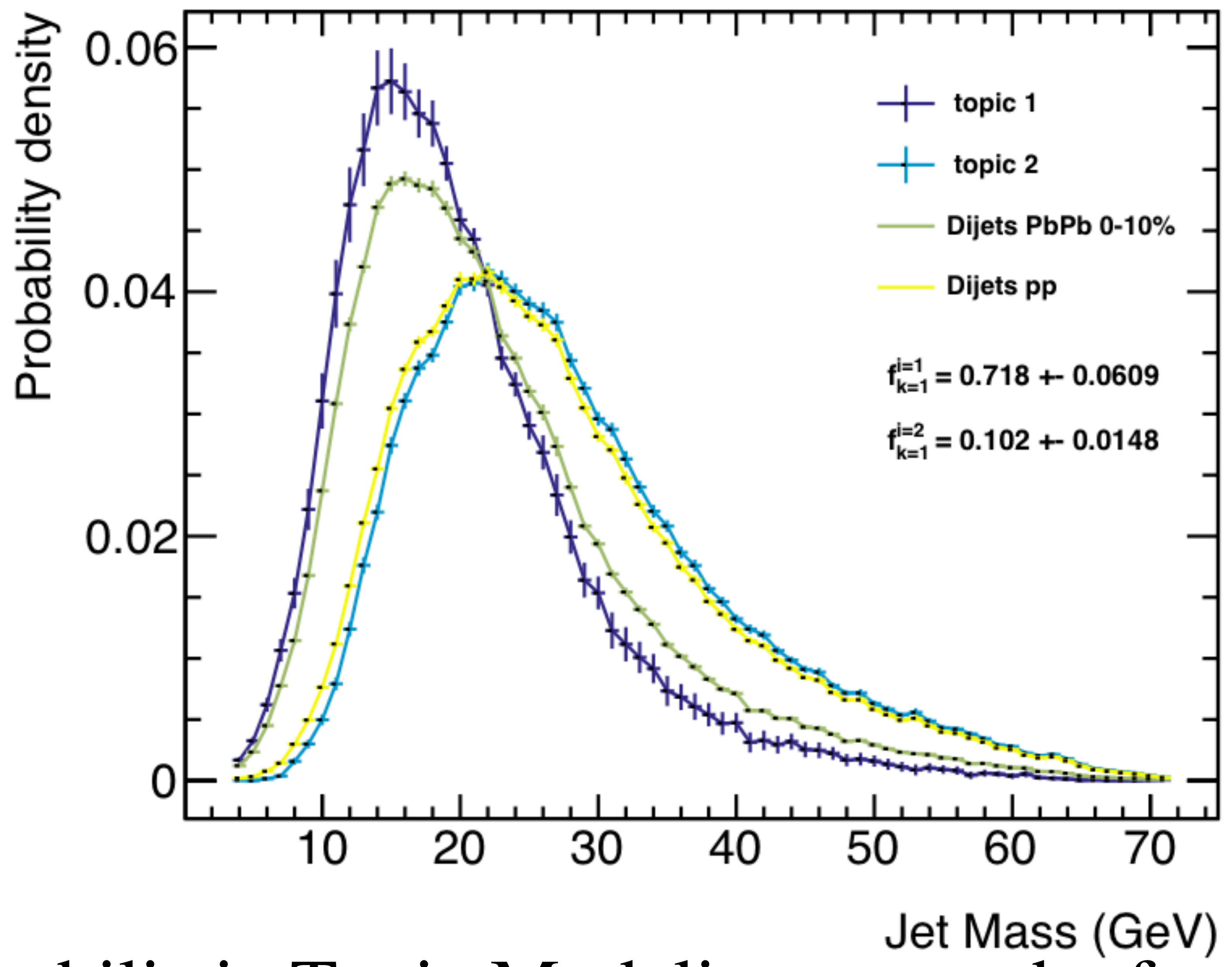
Heavy-Ions

[MsC. Thesis: J. Gonçalves, F. Peres]

- New jet observables to allow:

On-going ML work: See M. Romão presentation

- Accurate characterisation of the QGP [MsC. Thesis: J. Gonçalves]
- Disentangle multiple medium-induced effects



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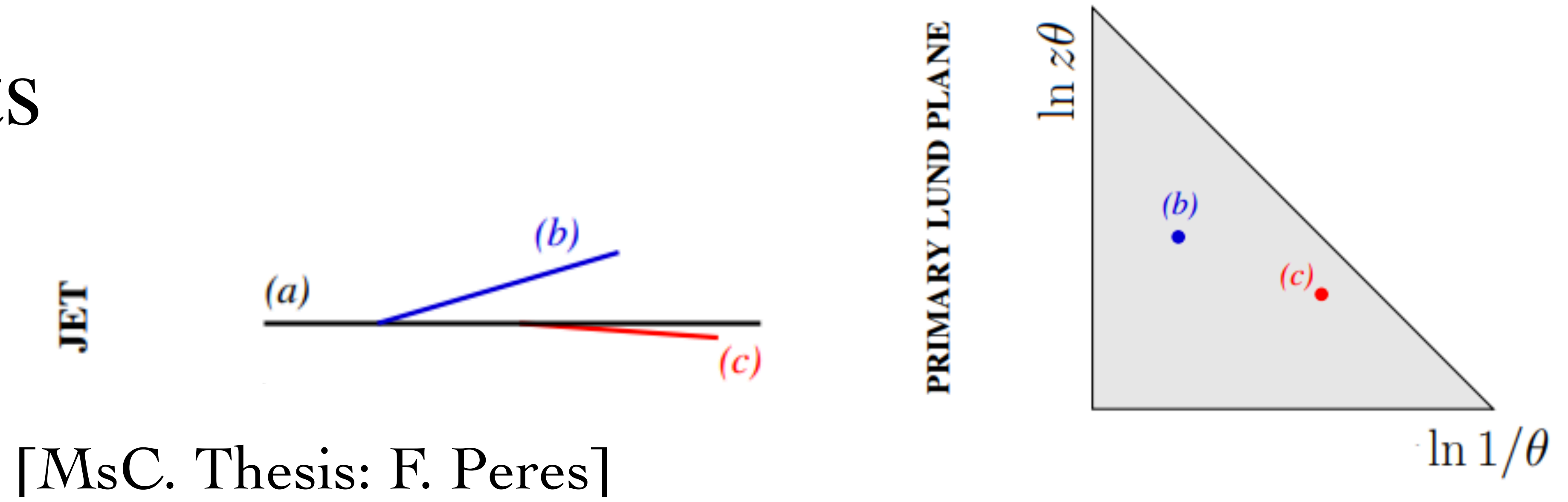
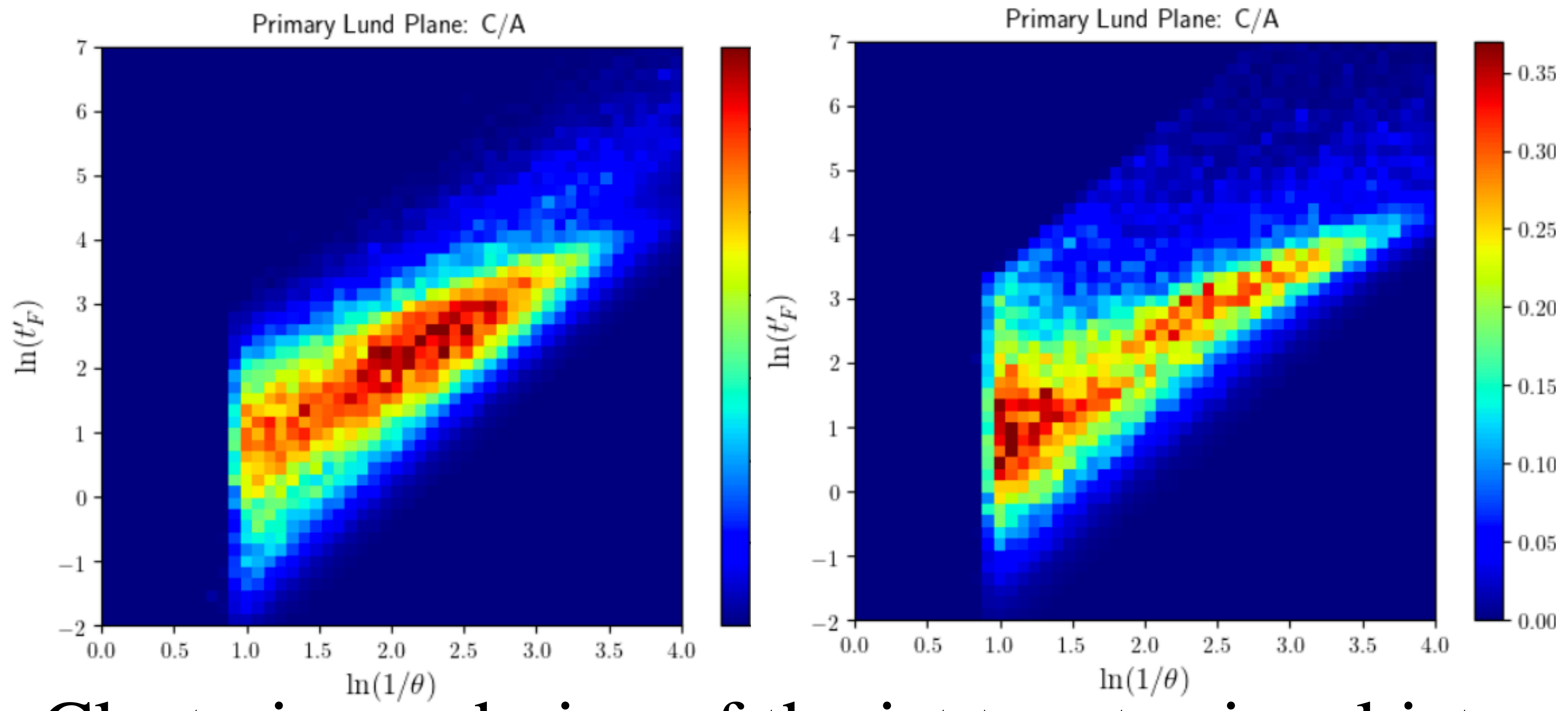


[MsC. Thesis: F. Peres]



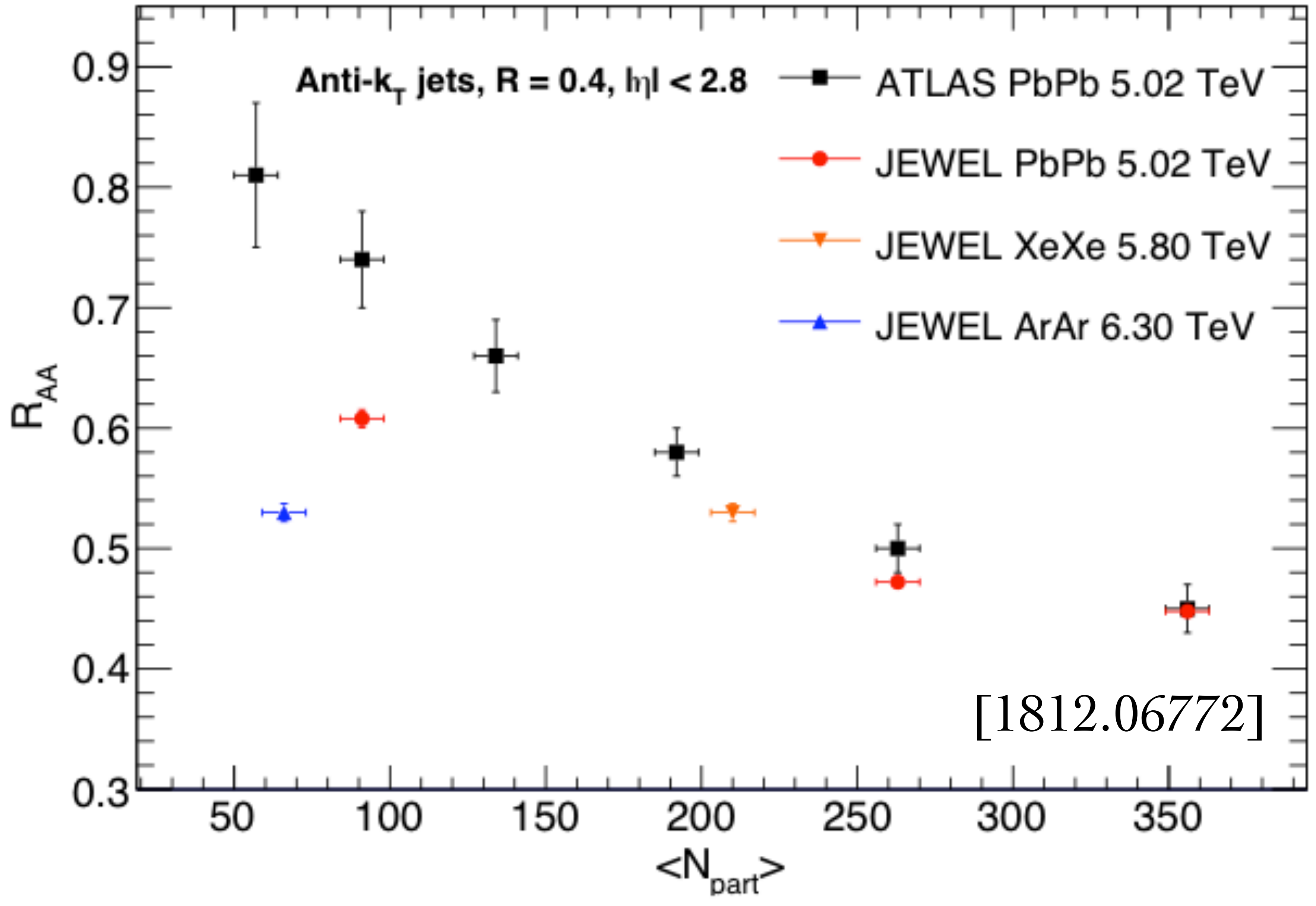
Probabilistic Topic Modeling to get the fraction of jets modified by the QGP

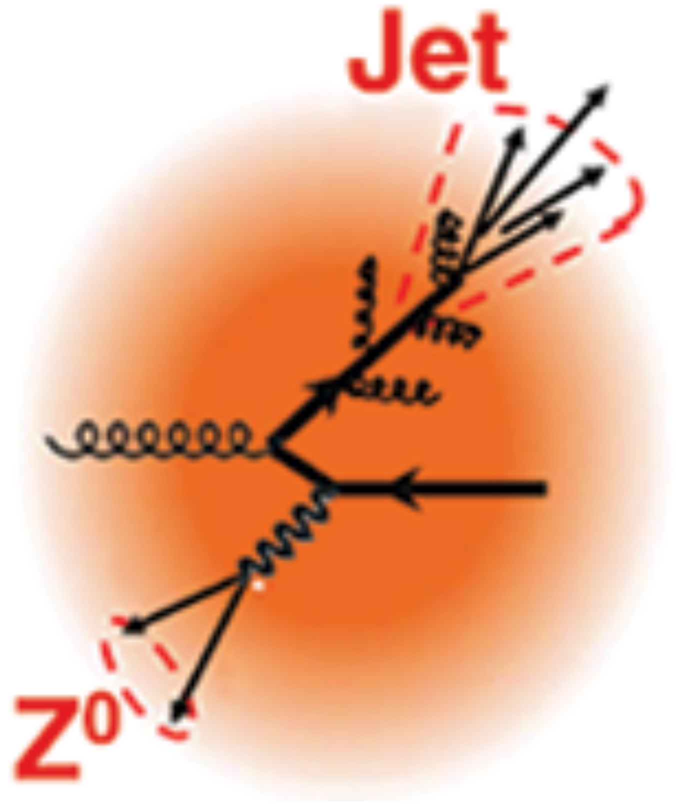
Clustering ordering of the jet tree to signal jets modified by the QGP

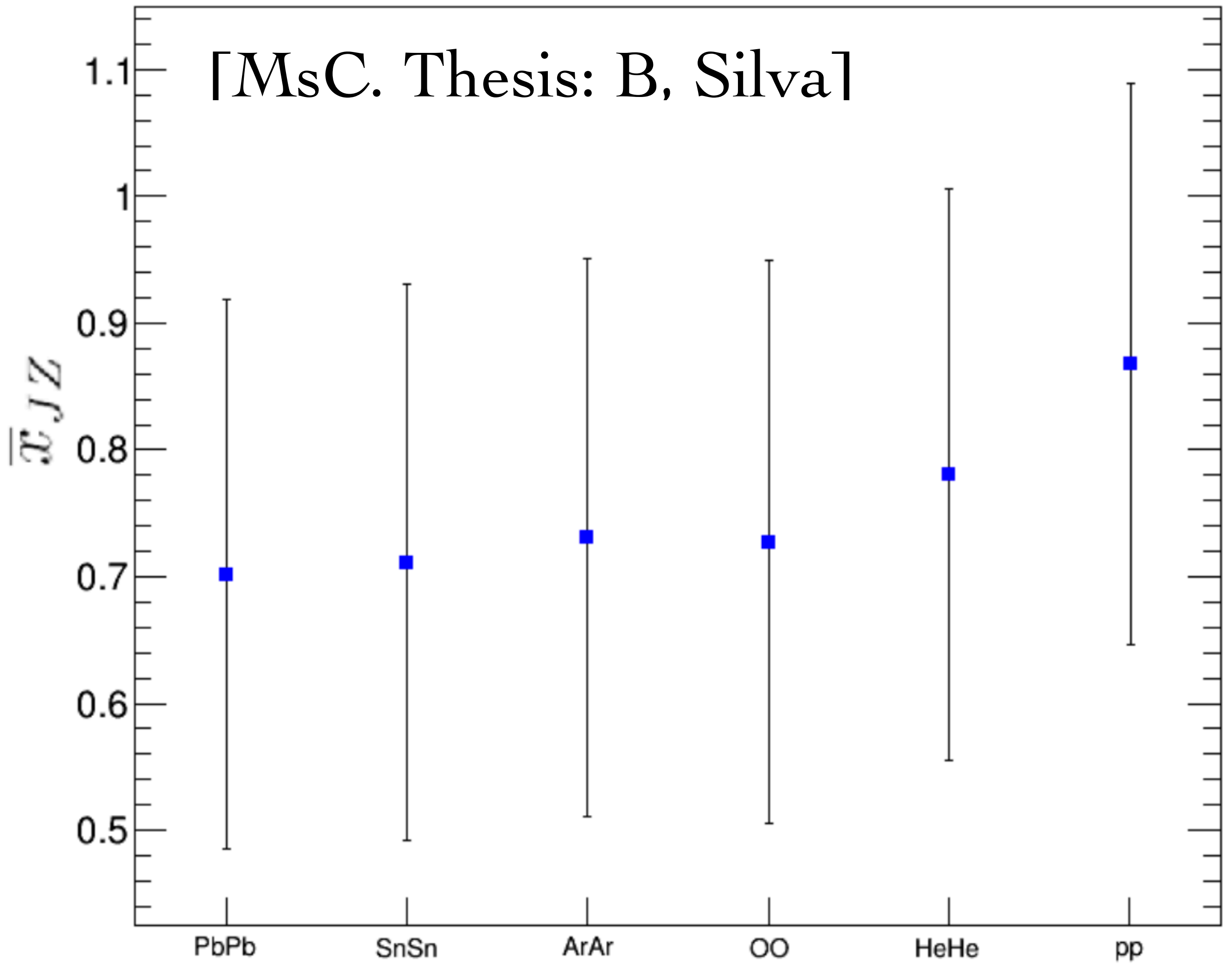
Heavy-Ions

[LA, JGM et al PRL (18), FCC Collab. (18)]
[Citron, LA, JGM et al YRep (19)]

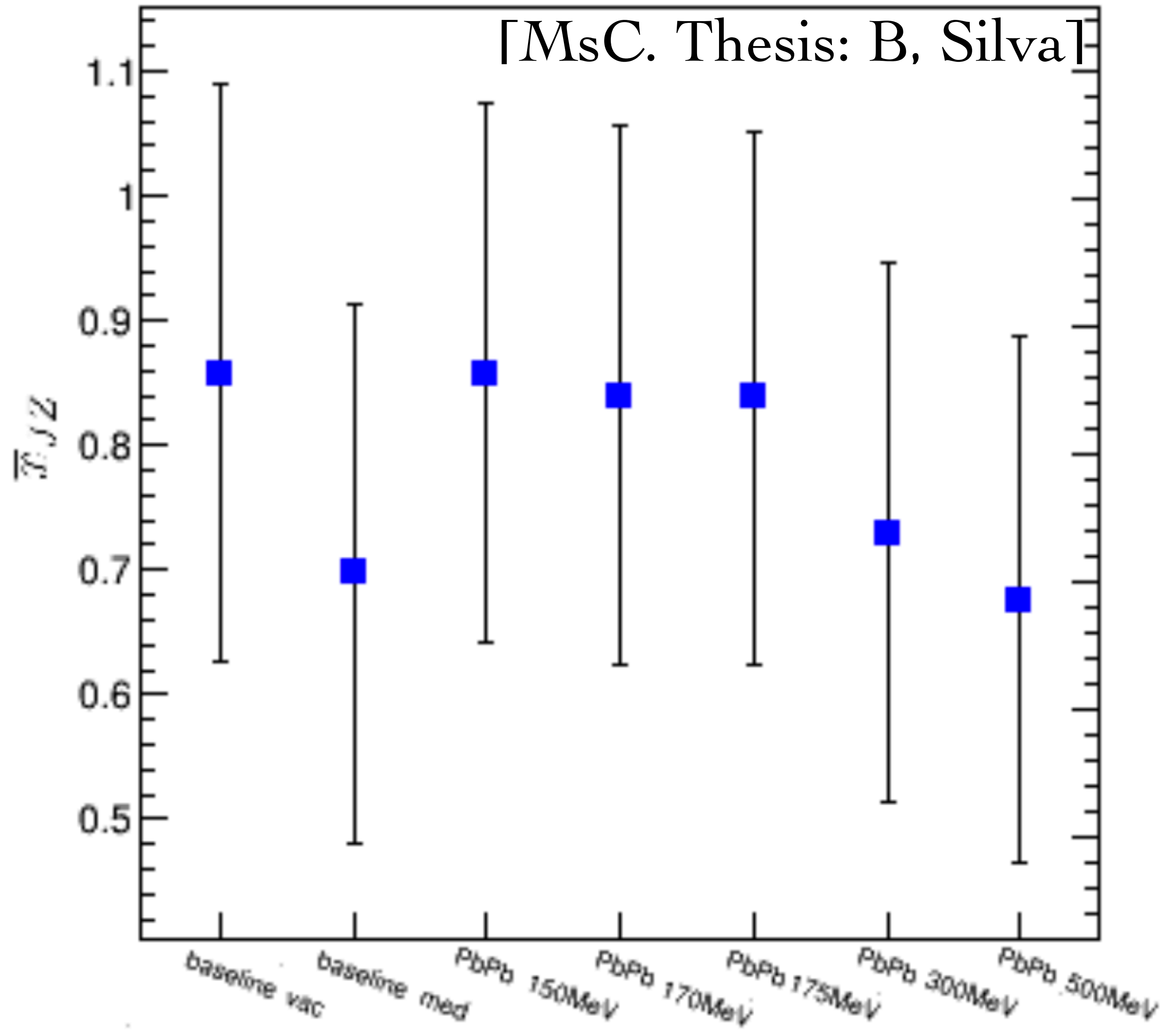
- Future upgrades:
  - To be or not to be QGP? (Small systems):







[MsC. Thesis: B, Silva]



What is the lighter system where QGP is still present (measurable amount of energy loss)?

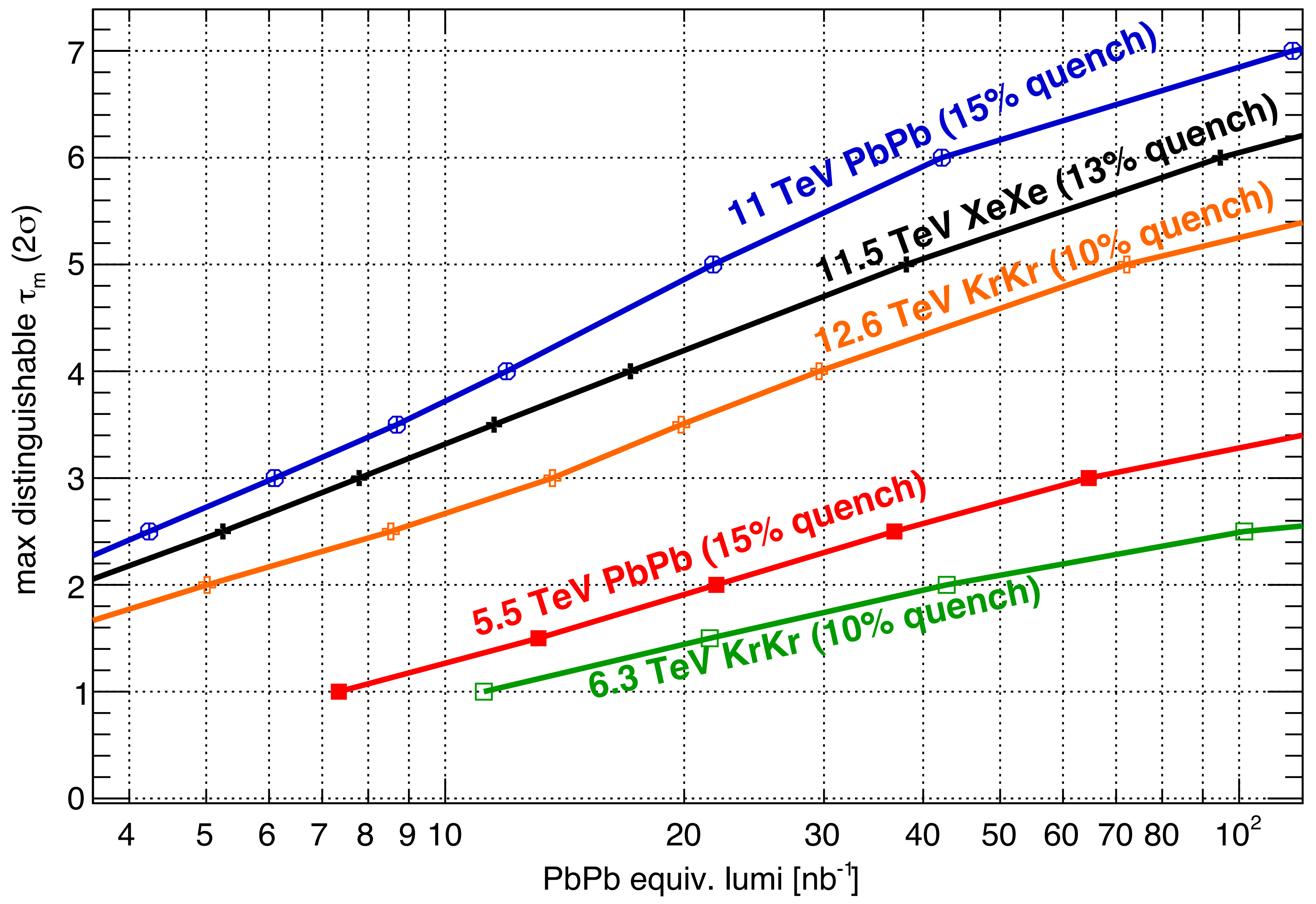
Heavy-Ions

[LA, JGM et al PRL (18), FCC Collab. (18)]
[Citron, LA, JGM et al YRep (19)]
[MsC. Thesis: B, Silva]

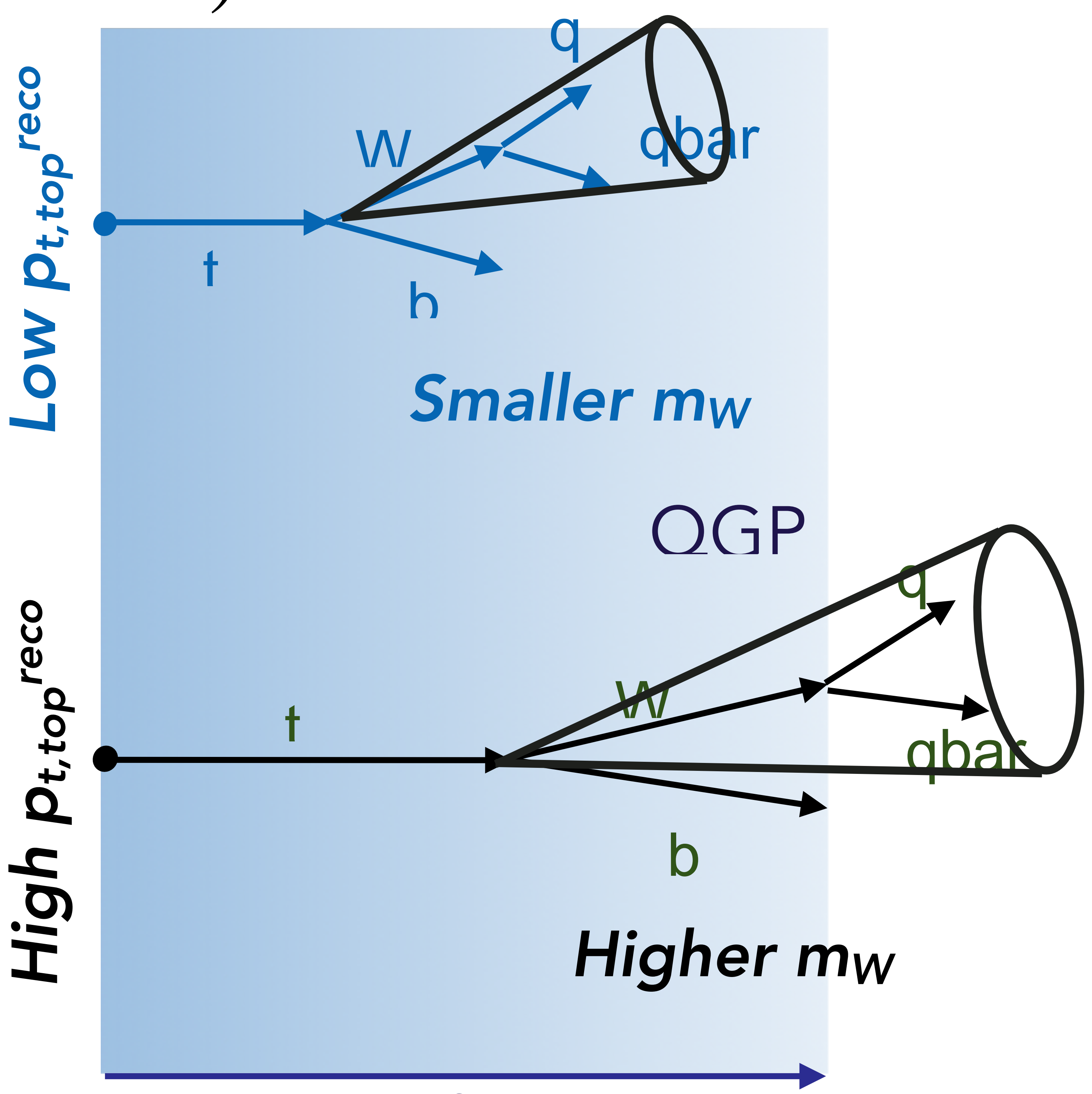
- Future upgrades:
  - To be or not to be QGP? (Small systems):

Top quark evidence PbPb $\sqrt{(s_{NN})}$ = 5.02 TeV CMS: 4.0 σ (lepton + b-tagged)

[1812.06772]



- Future facilities:
  - Novel QGP probes @ FCC (QGP time structure)

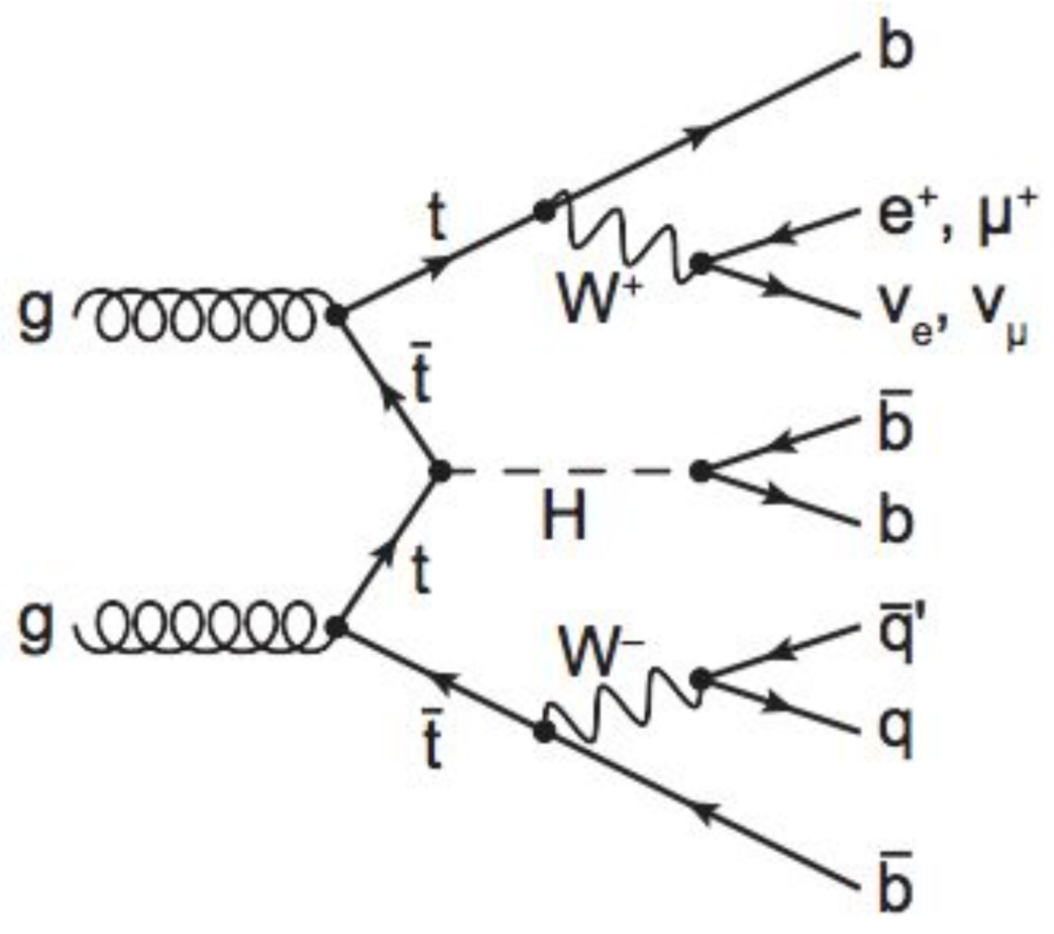


Reconstructed W mass: m_W

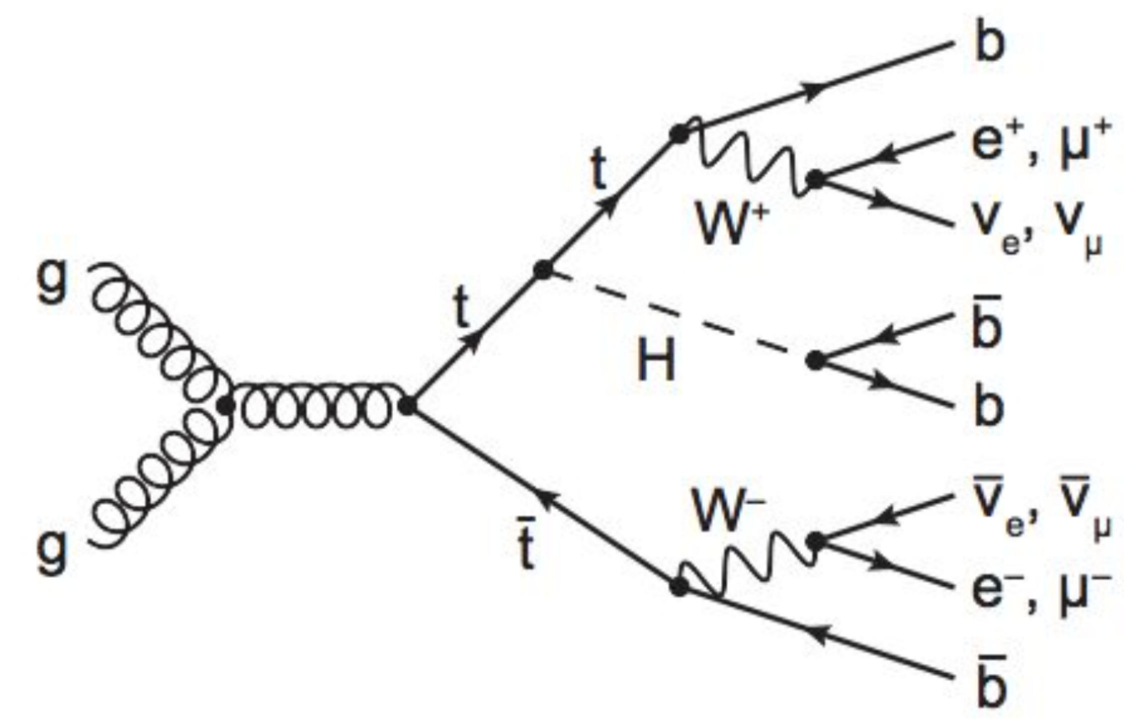
Depends on the medium length that the jet is able to "see"

Top Physics

- Goal: Top quark is the strongest coupling to the SM Higgs boson (Y_t ~1)
  - Precision measurements of top quark properties are an important test of the SM.
  - Important role for the electroweak symmetry breaking and sensitive probe for physics beyond the SM.



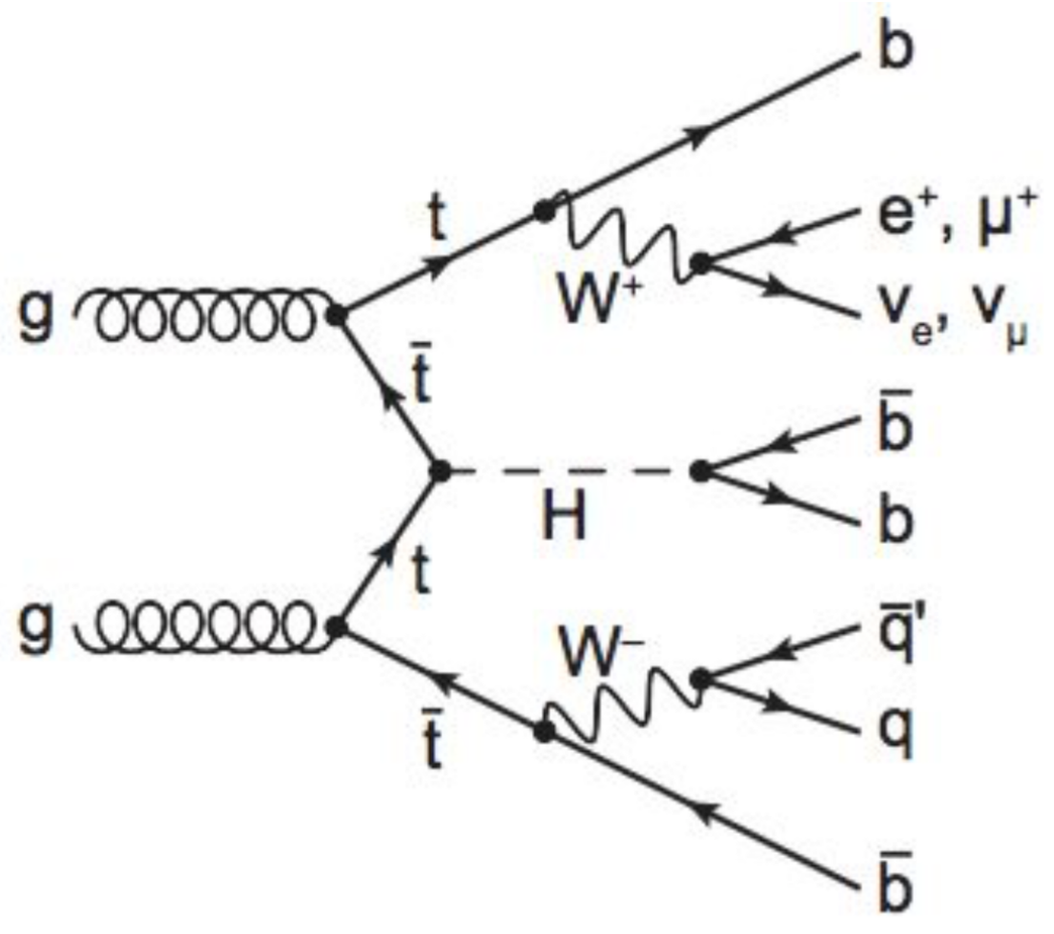
semileptonic decay



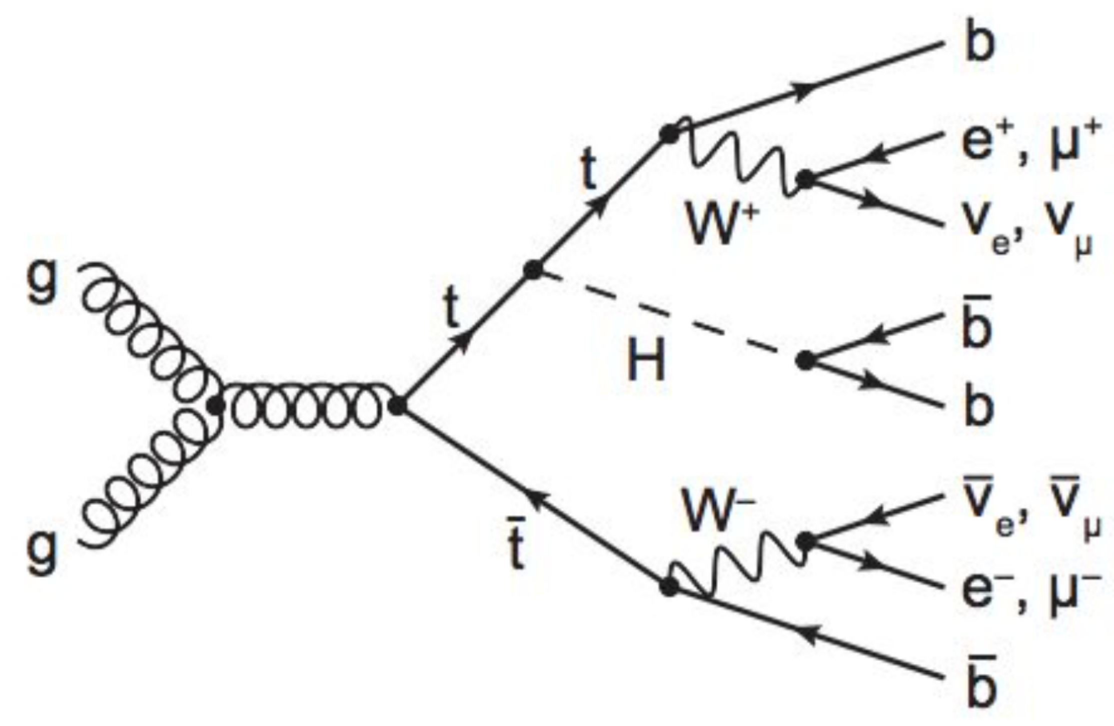
dileptonic decay

Top Physics

- Goal: Top quark is the strongest coupling to the SM Higgs boson ($Y_t \sim 1$)
  - Precision measurements of top quark properties are an important test of the SM.
  - Important role for the electroweak symmetry breaking and sensitive probe for physics beyond the SM.
- How?
  - Find new observables to test the CP nature of the coupling in ttH events at the LHC with best precision
  - Look for anomalous couplings in the top-W coupling



semileptonic decay



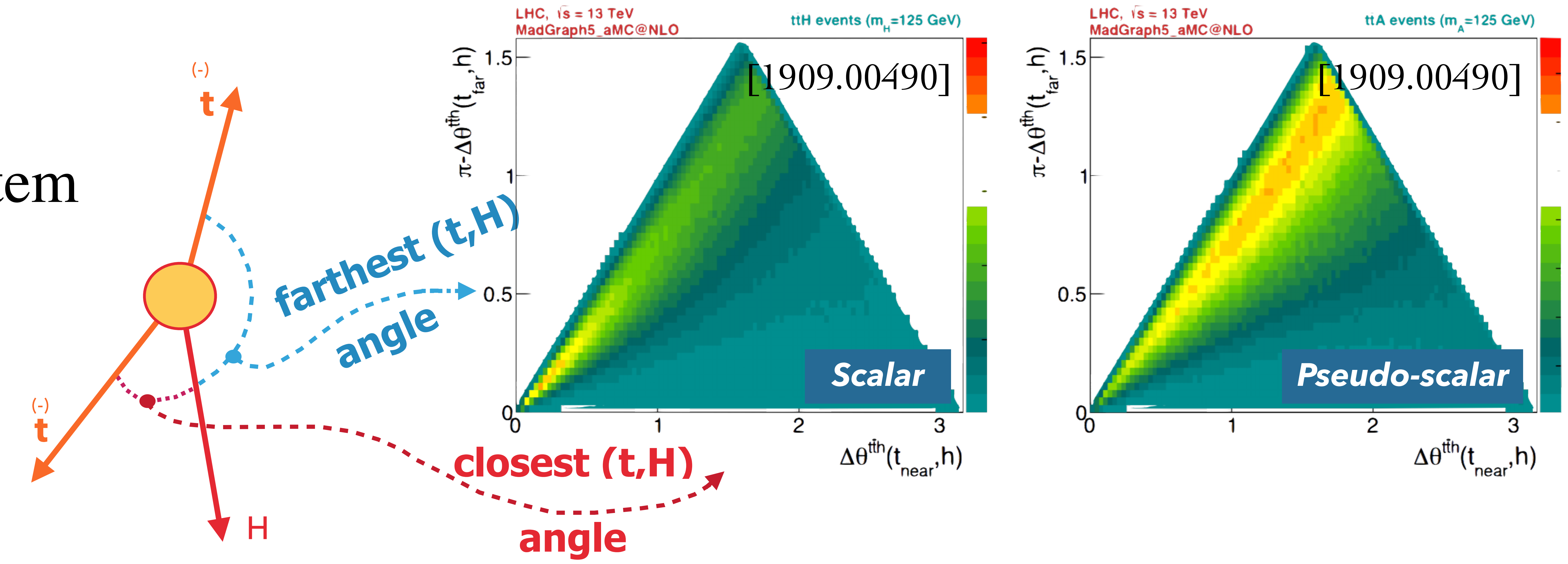
dileptonic decay

Top Physics

[Ferroglia, AO, et al PRD (19), Cepeda, AO, et al YRep (19)]

[PhD.. S. Santos (see Poster!!!)]

- New possibilities to directly measure a hypothetical CP-odd (pseudoscalar) component in the top-quark Yukawa coupling
  - Role of ttH centre-of-mass system



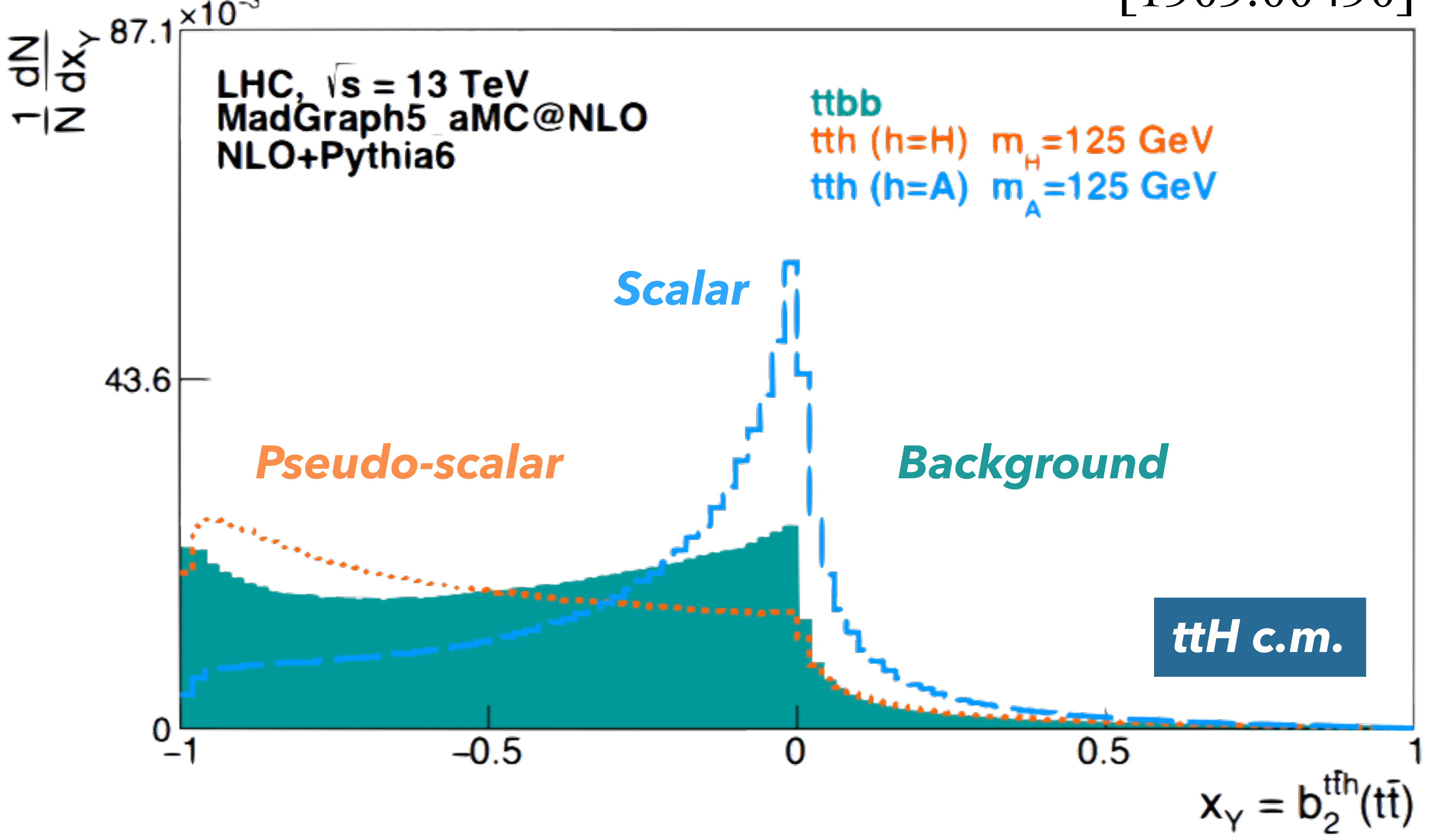
Top Physics

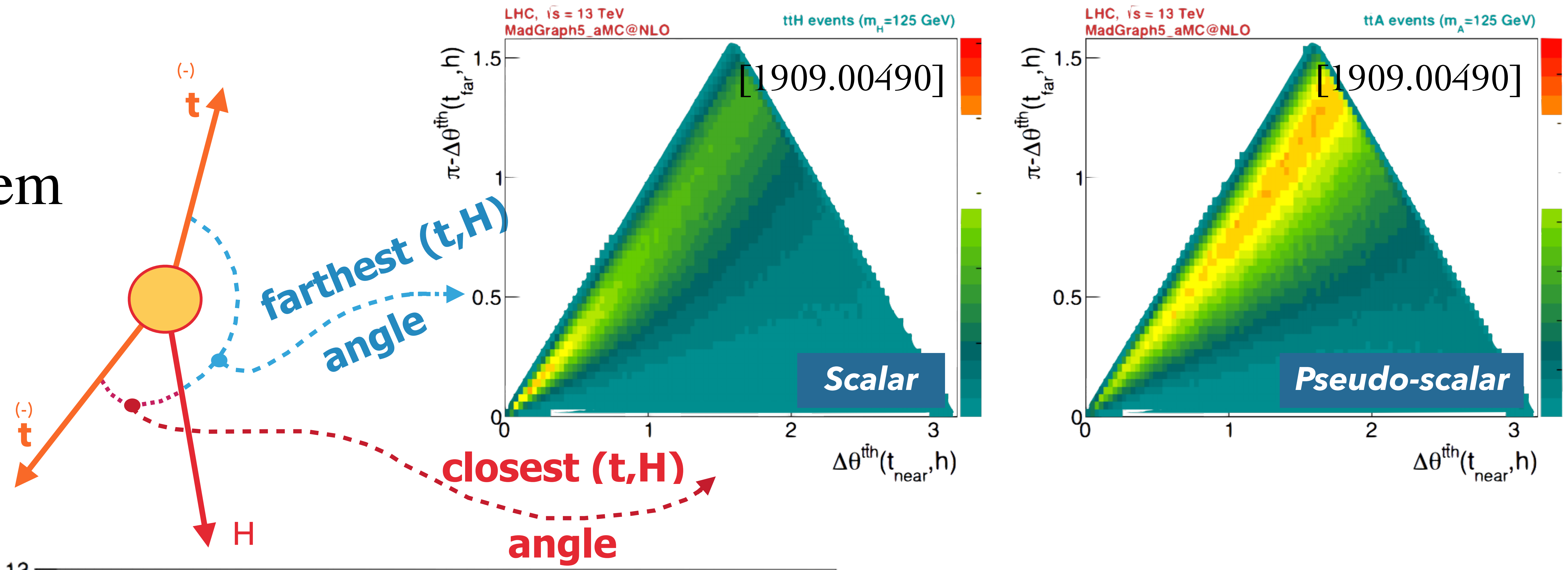
[Ferroglia, AO, et al PRD (19), Cepeda, AO, et al YRep (19)]

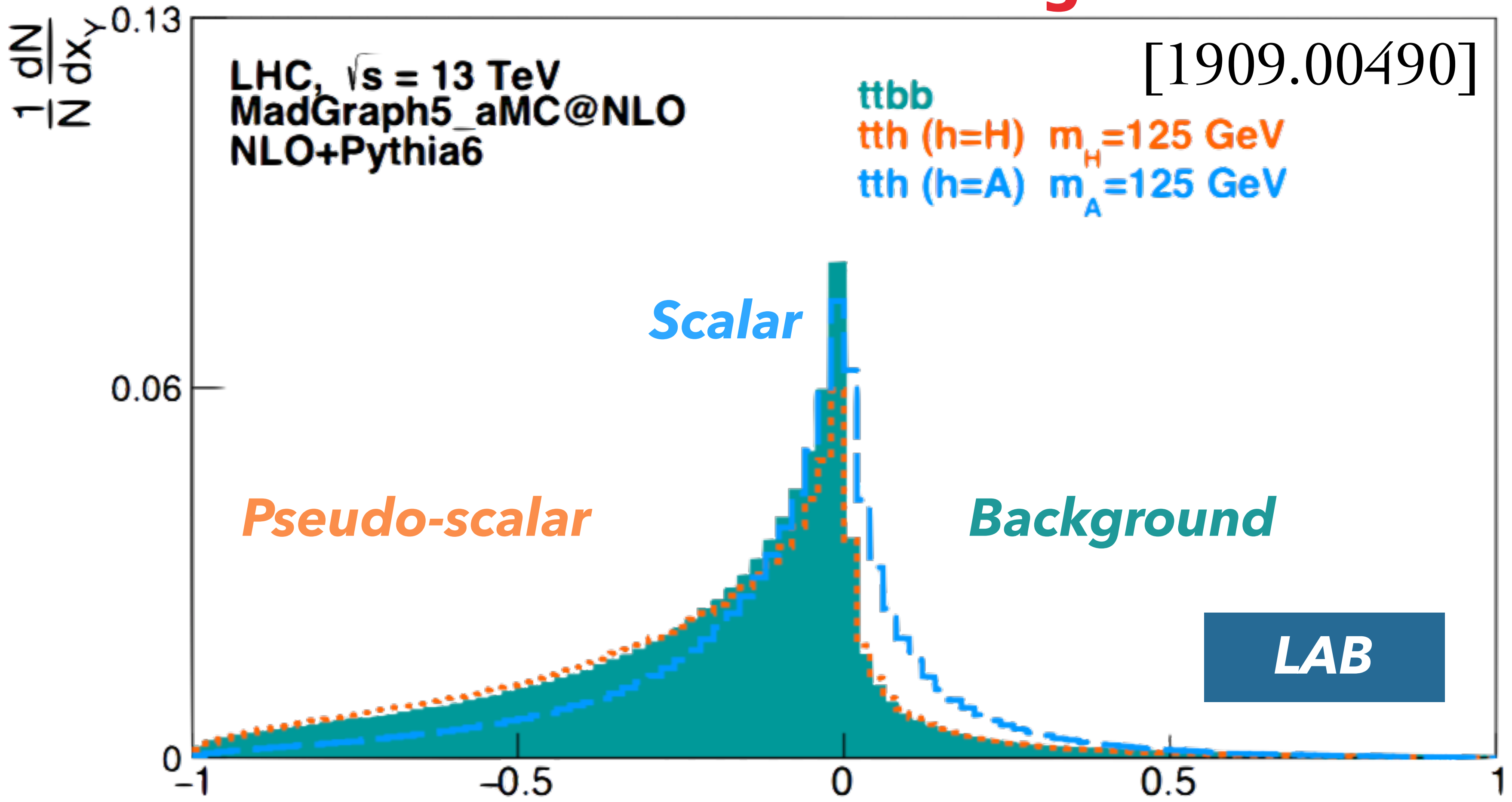
[PhD.. S. Santos (see Poster!!!)]

- New possibilities to directly measure a hypothetical CP-odd (pseudoscalar) component in the top-quark Yukawa coupling
  - Role of ttH centre-of-mass system

[1909.00490]







Visible in the b2 variable:

$$b_2^f(i,j) = \frac{(\vec{p}_i^{\,f} \times \hat{k}_z).(\vec{p}_j^{\,f} \times \hat{k}_z)}{|\vec{p}_i^{\,f}||\vec{p}_j^{\,f}|}$$

Top Physics

[Azzi, AO, et al YRep (19)]

General Wtb vertex:

$$\mathcal{L} \;=\; -\frac{g}{\sqrt{2}}\bar{b}\,\gamma^{\mu}\left(V_L P_L + V_R P_R\right) t\, W_{\mu}^{-}$$
$$-\frac{g}{\sqrt{2}}\bar{b}\,\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}\left(g_L P_L + g_R P_R\right) t\, W_{\mu}^{-} + \text{h.c.}\,,$$

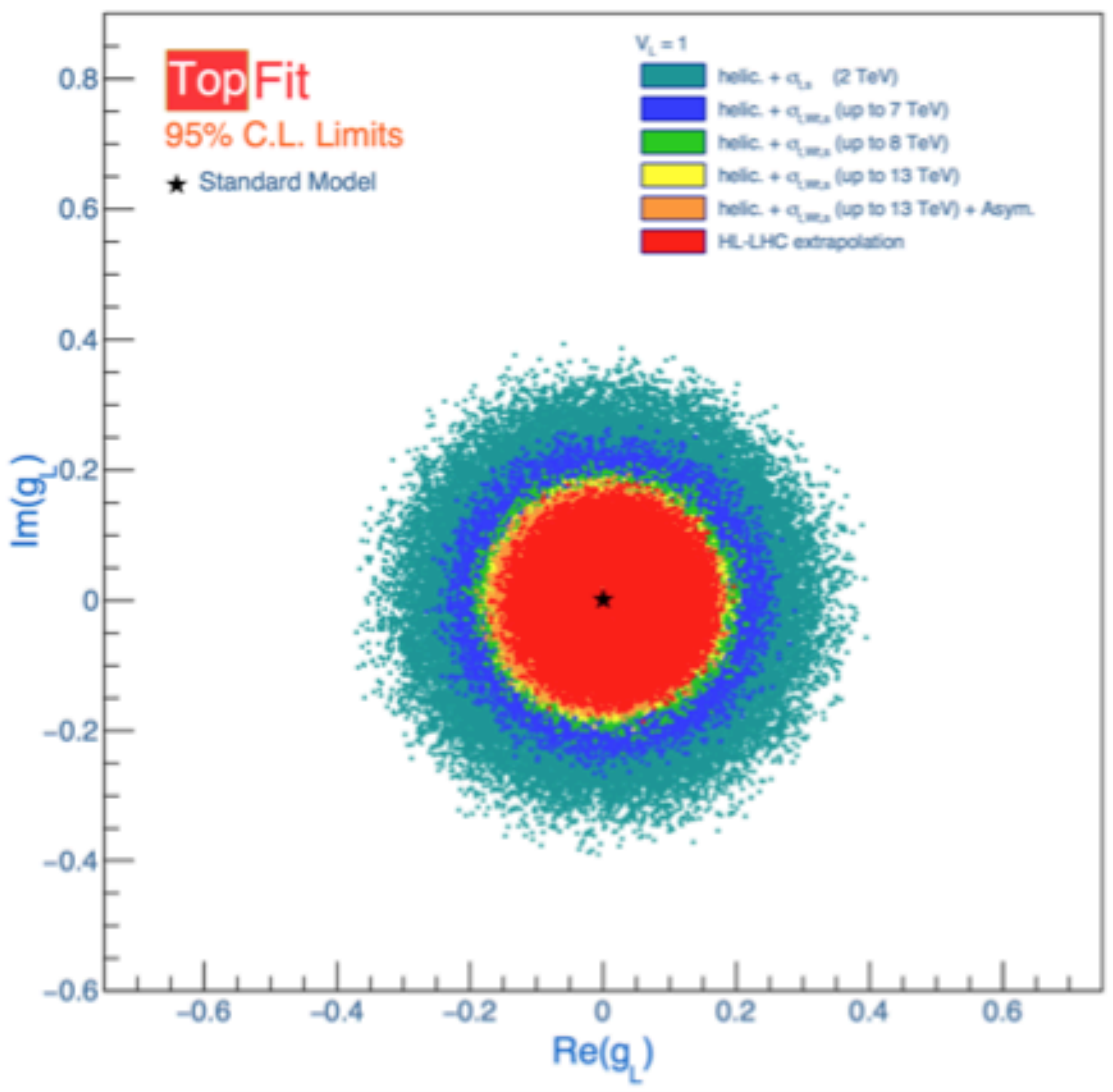
- Future upgrades:
  - The top quark couplings to the W boson:
    - Allowed regions of the new couplings (based on an extrapolation of the results to the HL-LHC phase)

Table 50: Allowed regions for anomalous couplings.

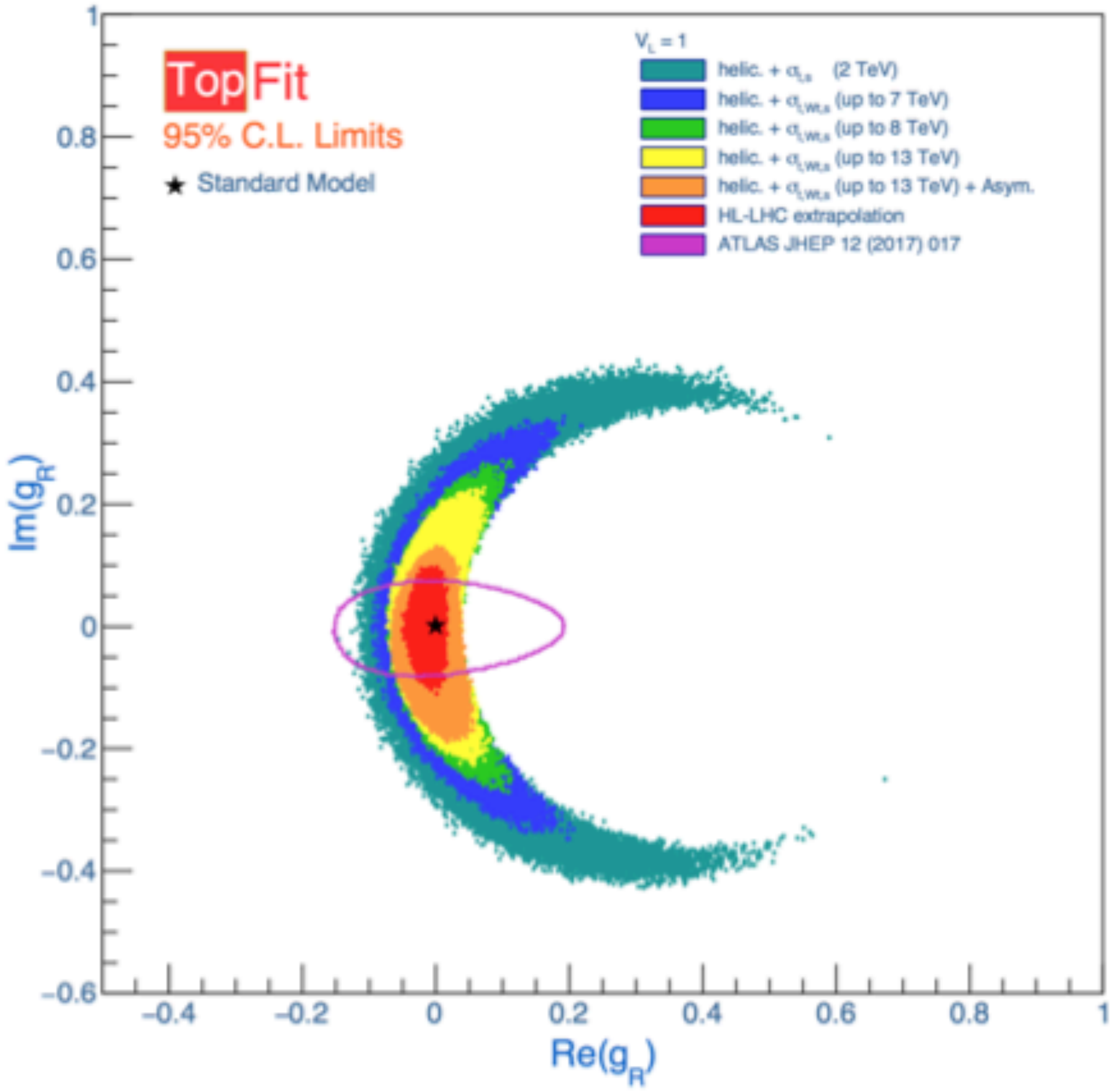
HL-LHC	$g_{\rm R}$	$g_{\rm L}$	$V_{\rm R}$
Allowed Region (Re)	[-0.05 , 0.02]	[-0.17 , 0.19]	[-0.28 , 0.32]
Allowed Region (Im)	[-0.11 , 0.10]	[-0.19 , 0.18]	[-0.30 , 0.30]

Gains from run 2 to the HL-LHC exist but…
new data analysis strategies to improve
sensitivity need to be considered

[1902.04070]



[1902.04070]

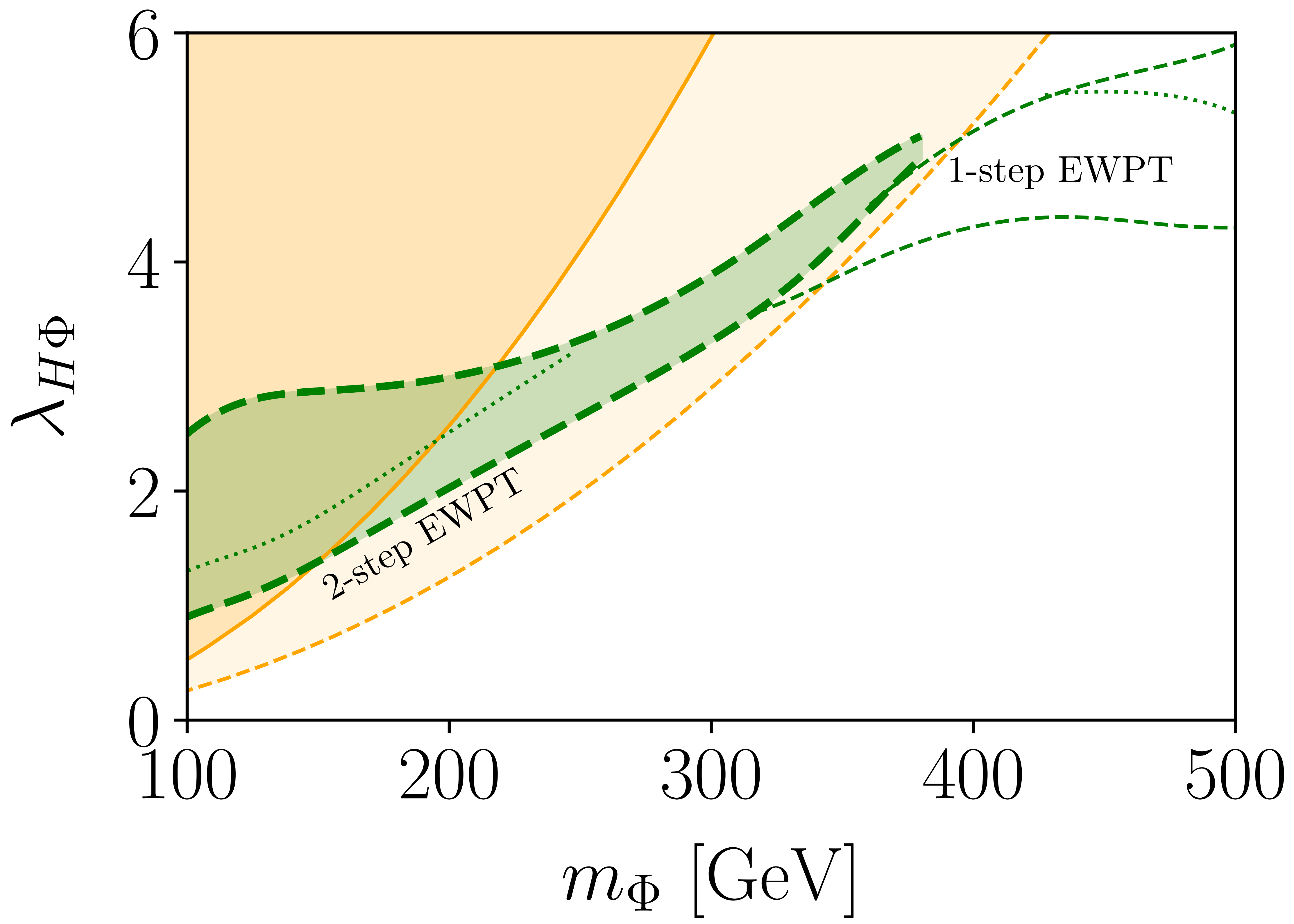


Composite Higgs models

[M. Chala, MR , M. Spannowsky, EPJC (19)]

[PhD. Thesis: M. Ramos; G. Guedes (see posters!!)]

- BSM Physics to address hierarchy problem:
  - Reach of the LHC in ongoing searches and HL-LHC



Exclusion at 95 % CL with current measurements H→γγ

Possible exclusion with HL-LHC (H→γγ)

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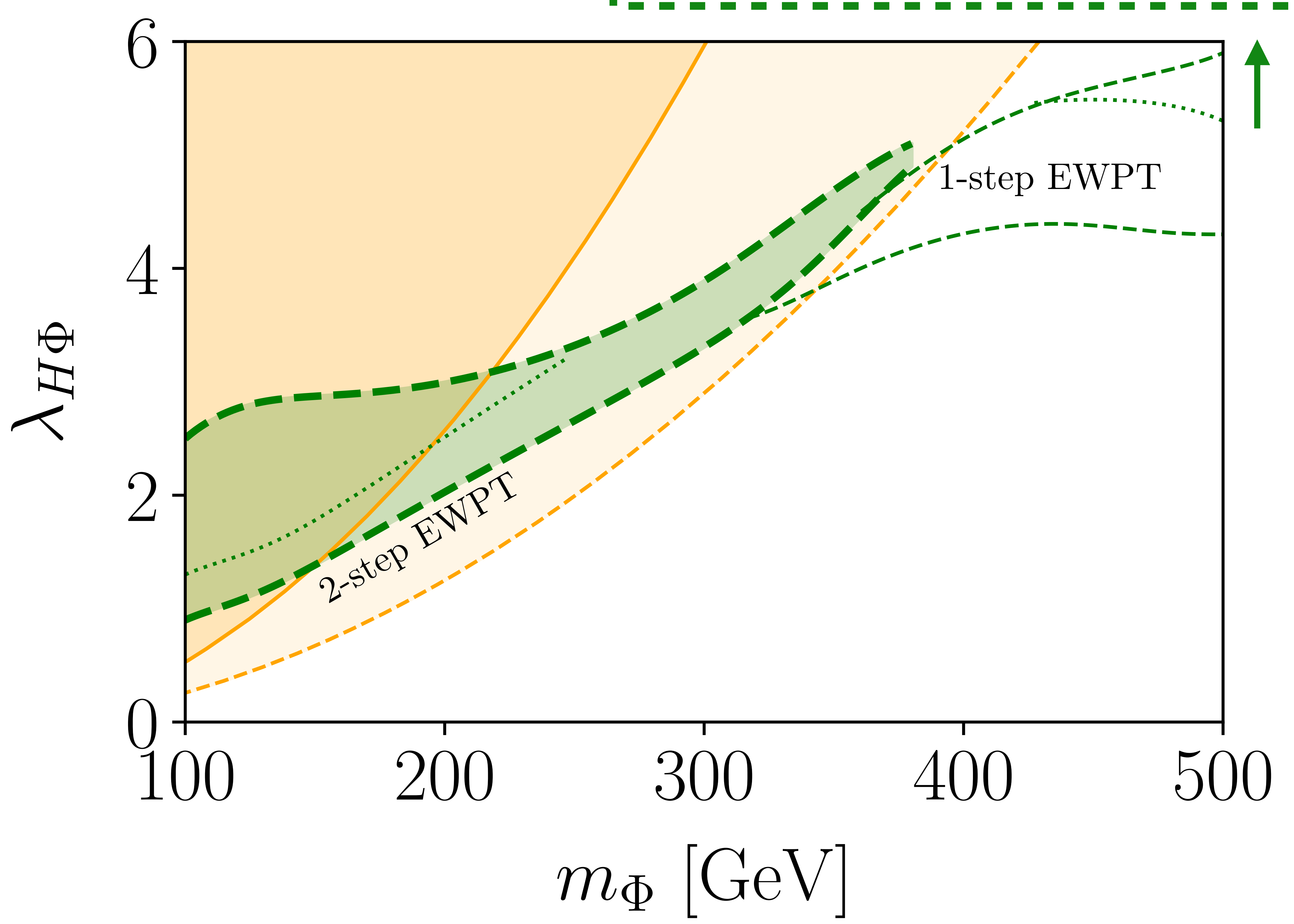
- BSM Physics to address hierarchy problem:
  - Reach of the LHC in ongoing searches and HL-LHC
  - Reach of LISA to test the parameter space region of the scalar potential
    - Signal: production of gravitacional waves
- <u>More info: next talk by Maria Ramos</u>

Larger scalar masses can be probed at LISA



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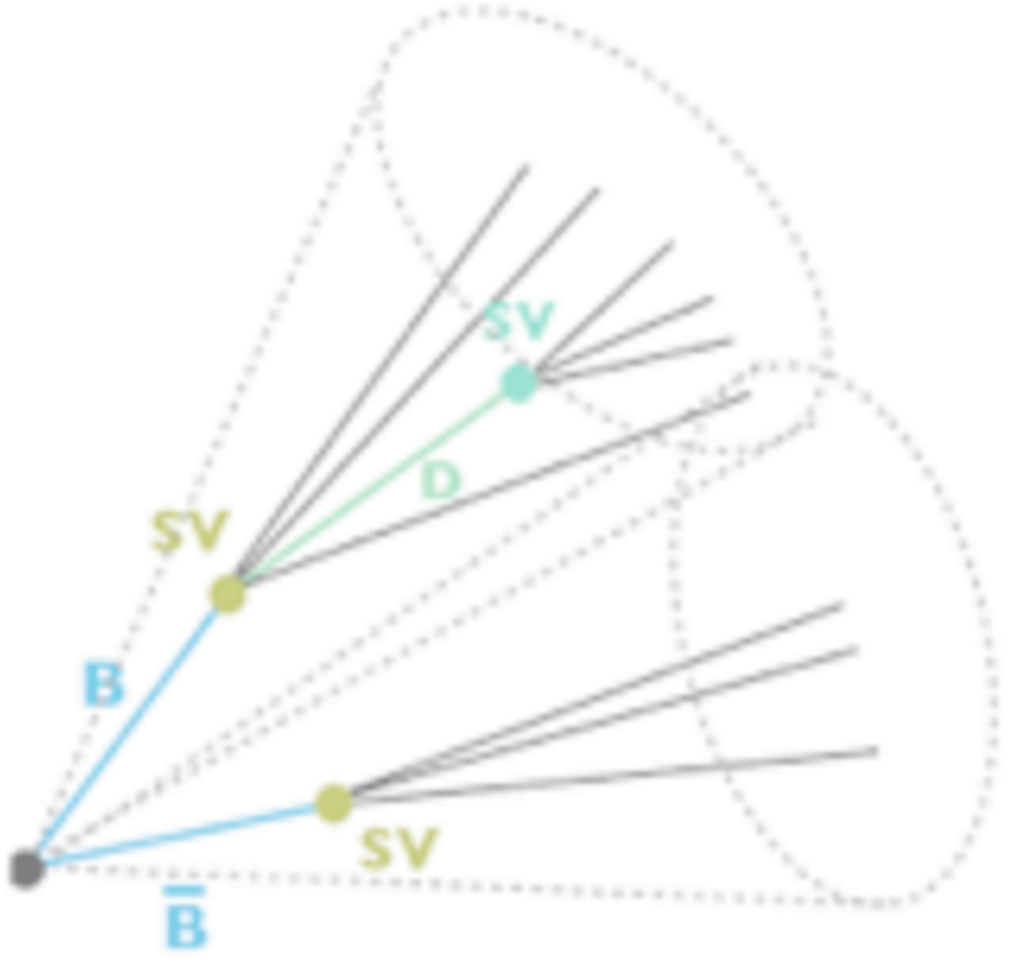
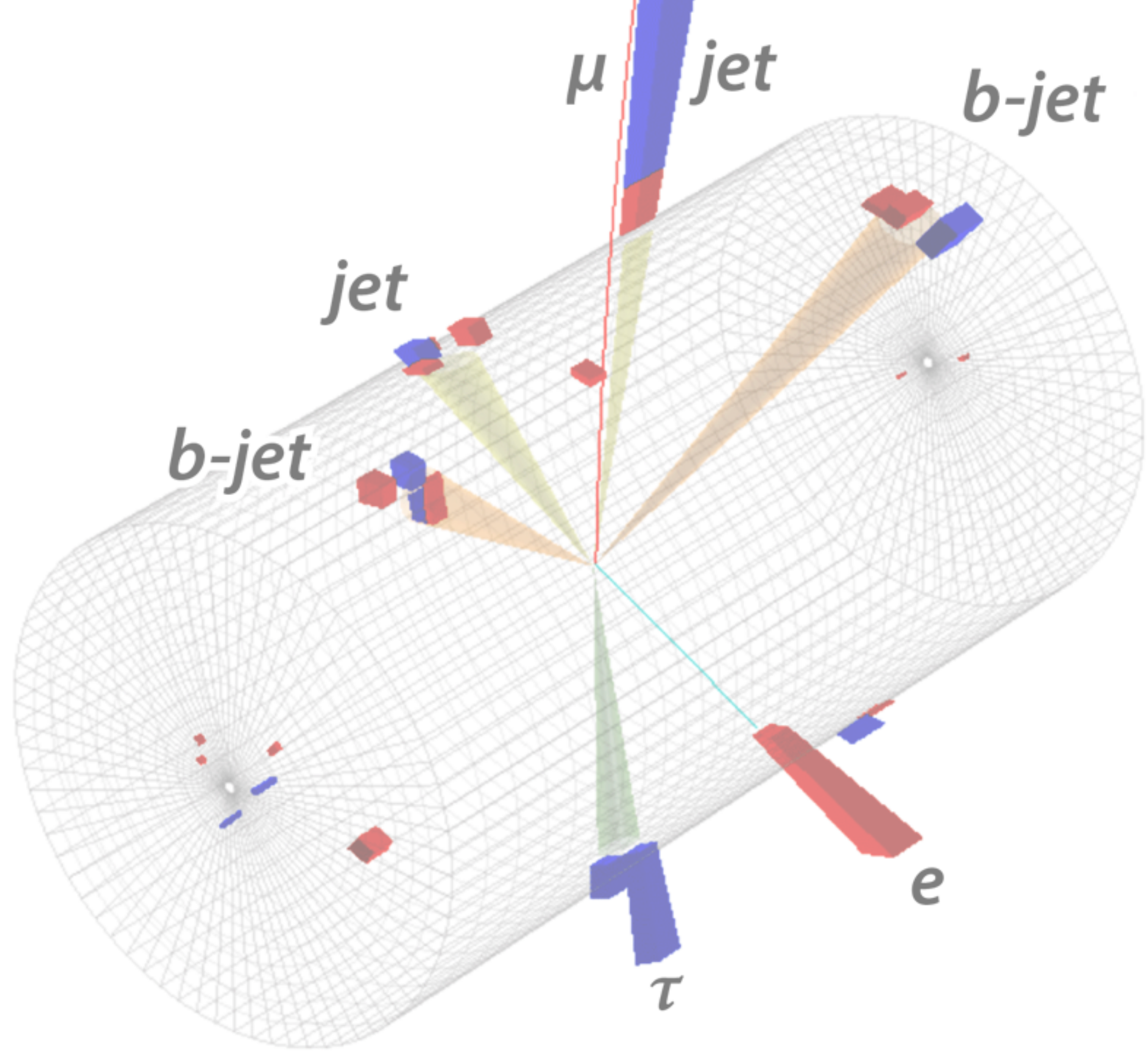
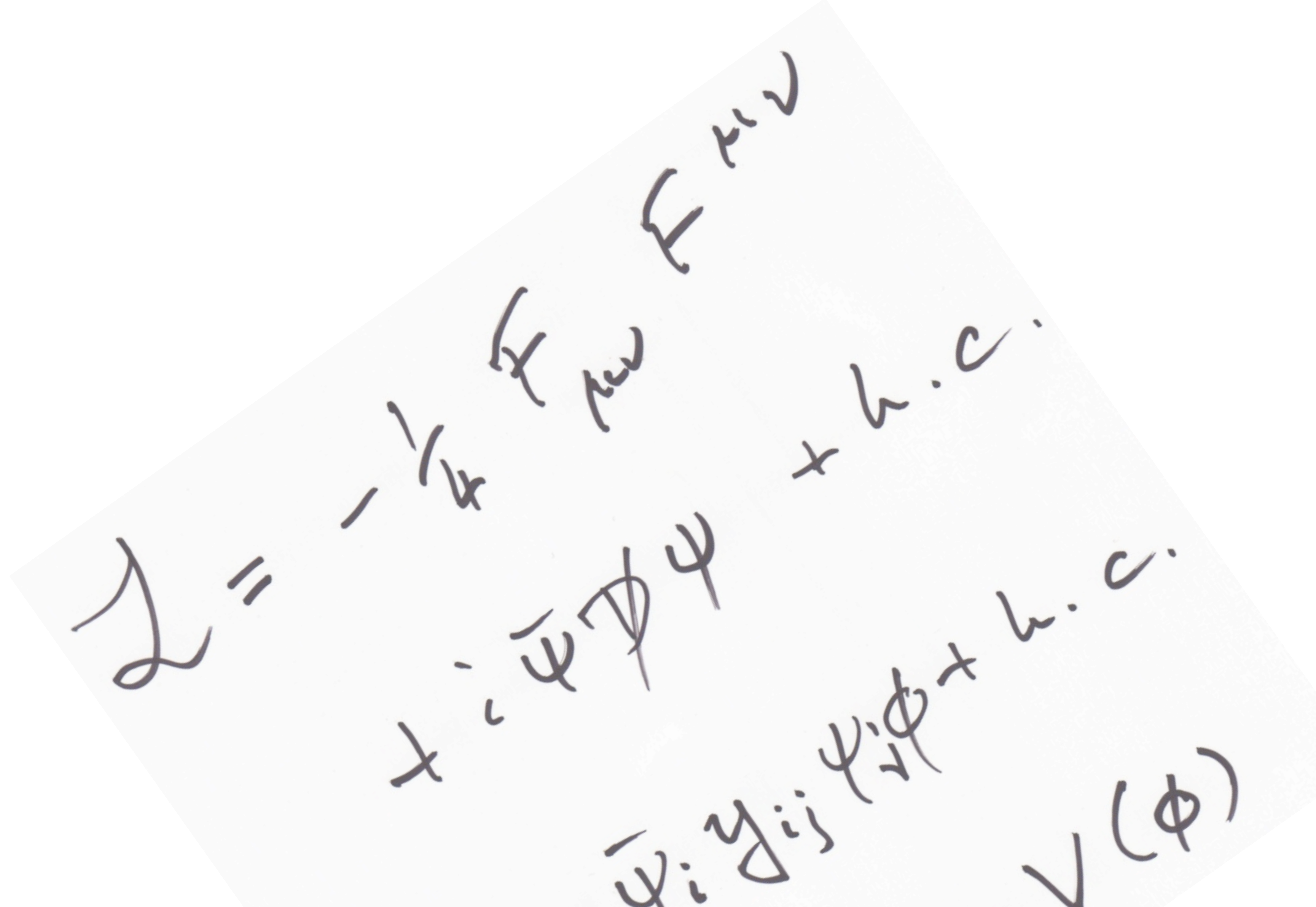
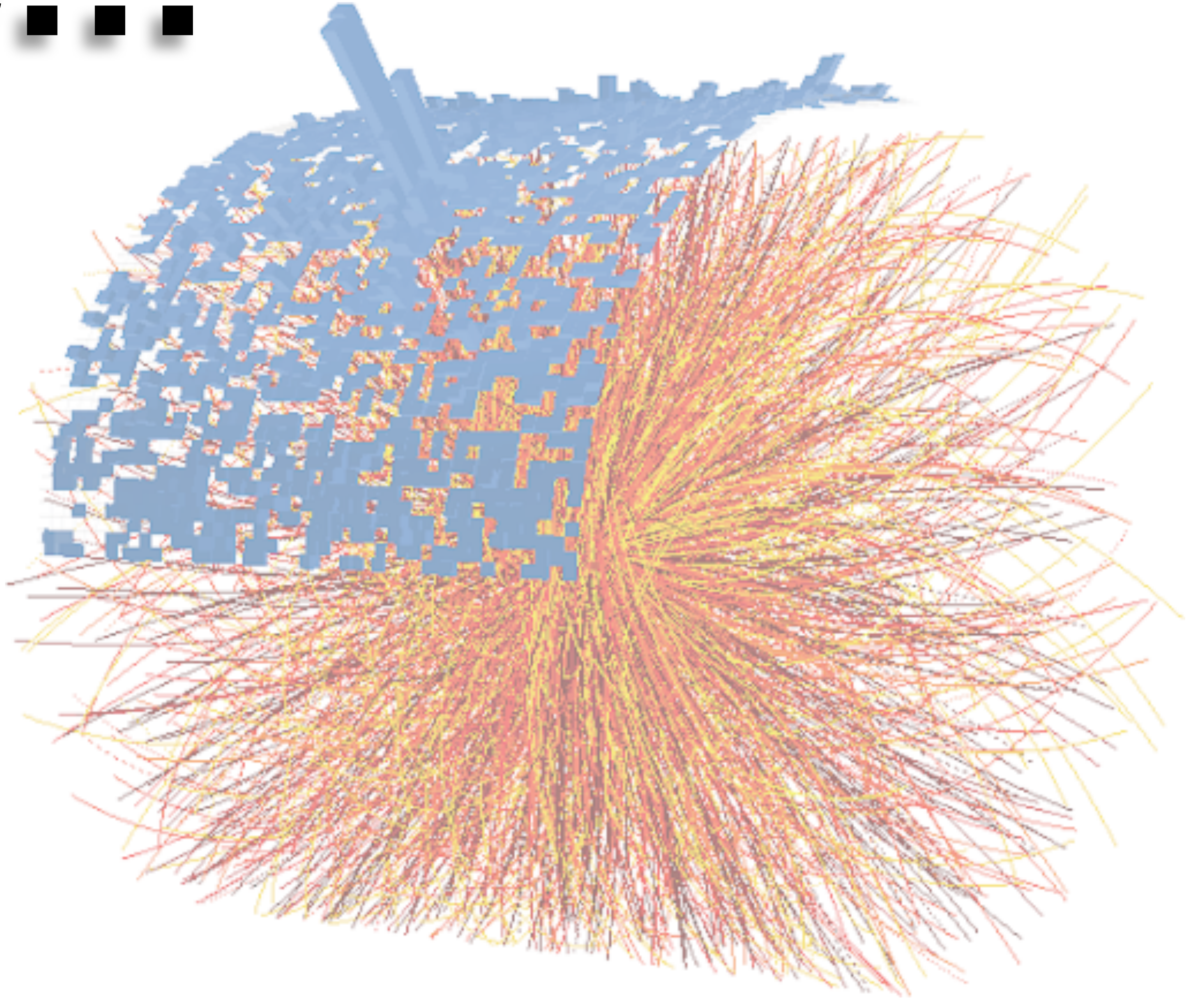




For the future…

2020 - 2021





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  - Maintain existing collaborations and foster new partnerships.

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Thank you!

Acknowledgments

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