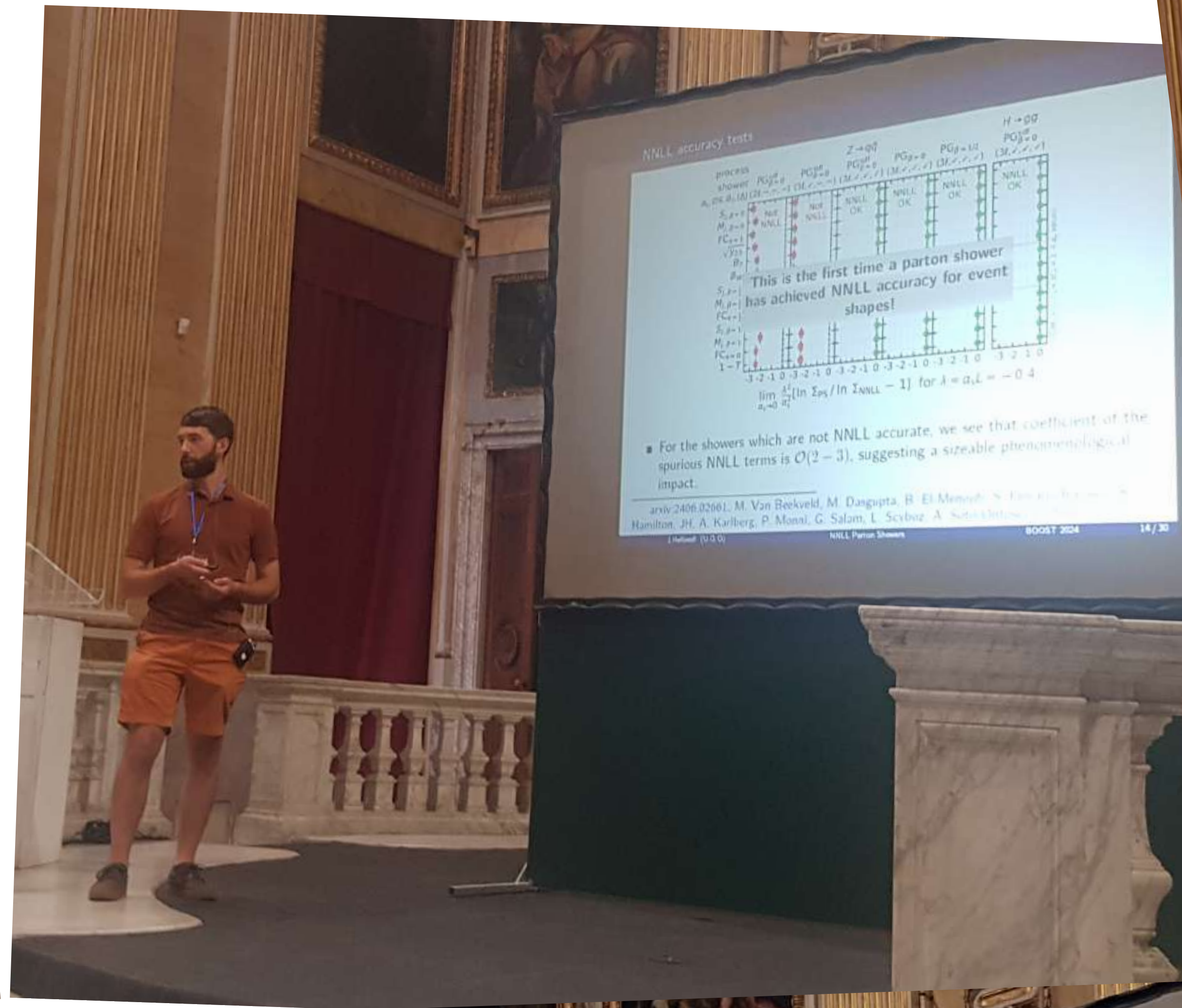
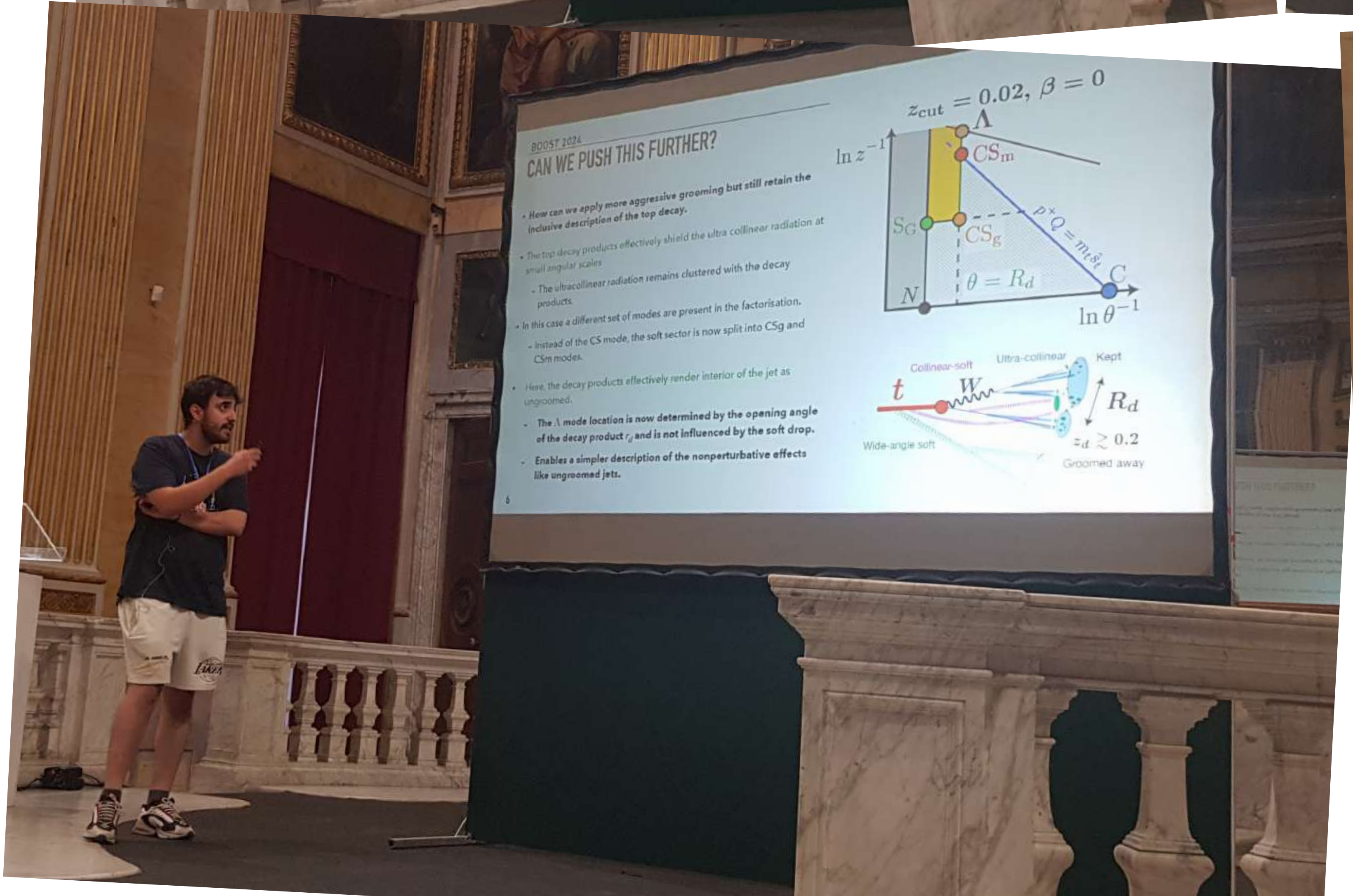
Theory summary boost 2024

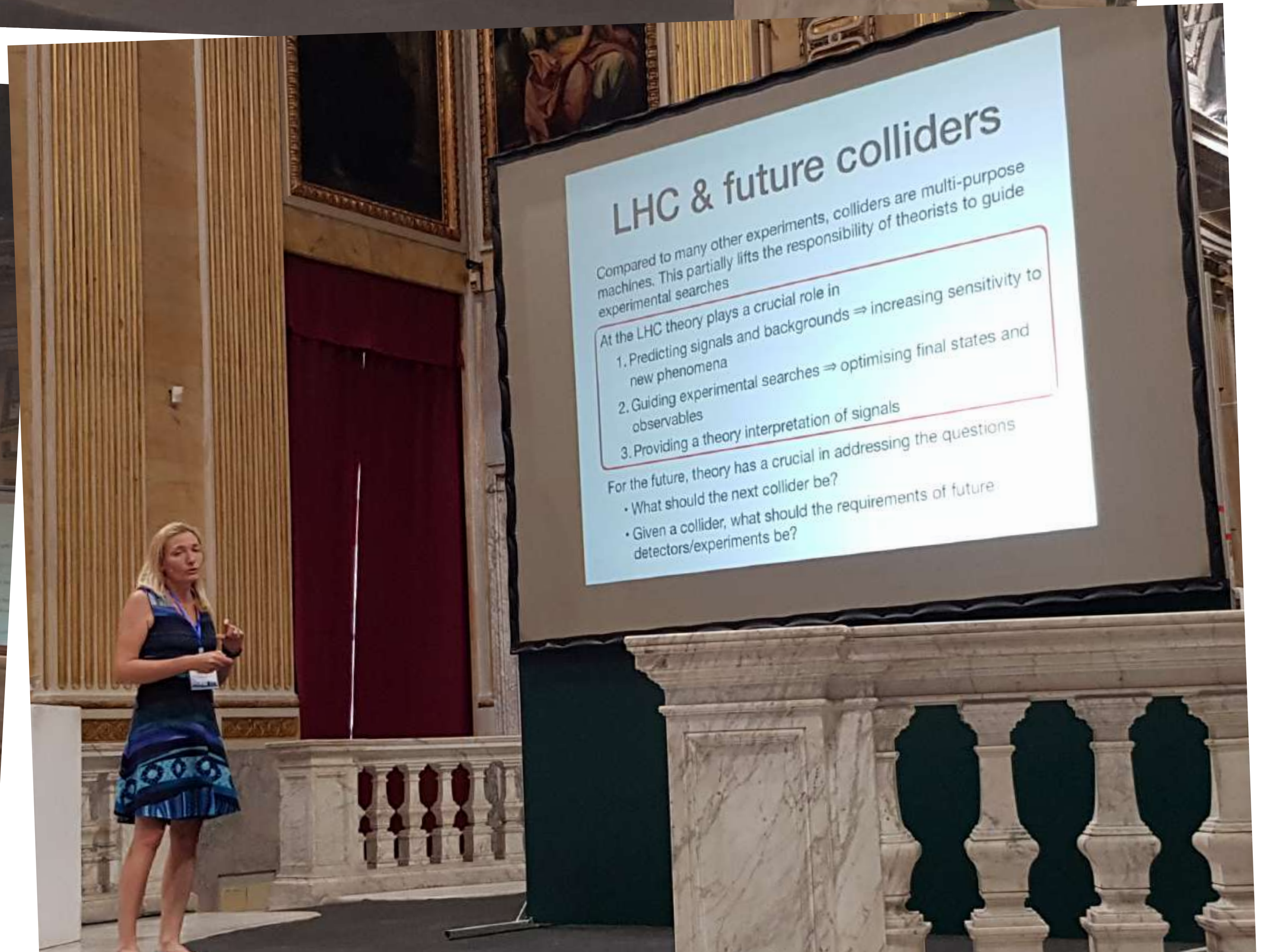
Melissa van Beekveld (Nikhef)

Thanks to all the speakers!

You are giving me a difficult job to summarise all of this great work…







All the credits are yours, all misinterpretations mine! Apologies for any omissions or misunderstandings…

History

4th theory summary of a PanScalaBooster

Boost Theory Summary

Gavin Salam

CERN, Princeton University & LPTHE/CNRS (Paris)

Boost 2012
Valencia, Spain, 23–27 July 2012

5 years

BOOST 2017 - Theory Summary

Gregory Soyez

July 21 2017

2 years

Theory Summary
26 July 2019, MIT

Frédéric Dreyer

My prediction: you'll get another one for Boost 2026

5 years

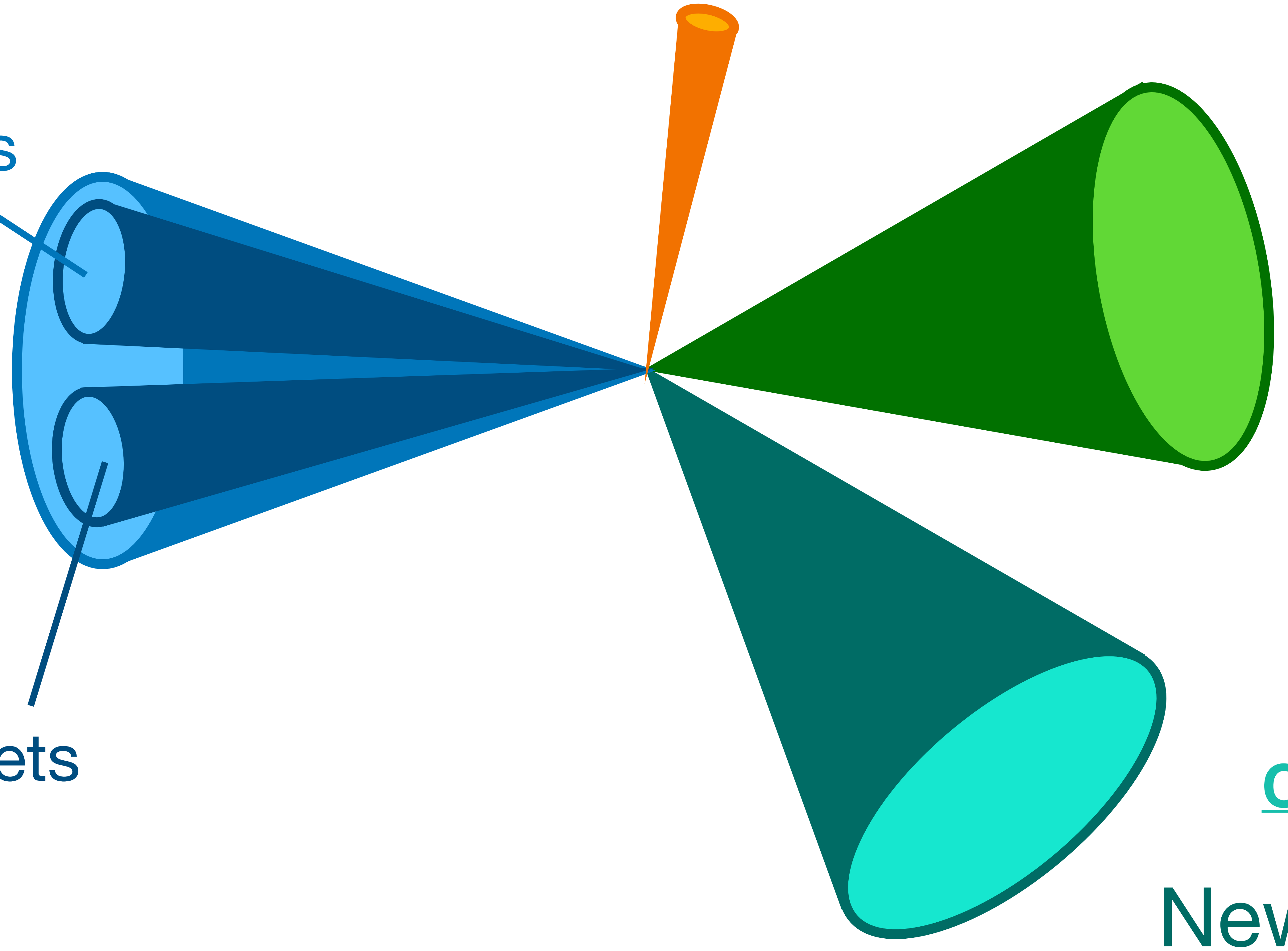
Boost 2024 theory summary

What is a jet?

Jets can be formed out of any 4-vector:

- Simulated particles from monte carlo
- ID tracks in the detector
- Other jets
- ....
- Boost abstracts!

My classification of boost theory talks



Can we take out the human bias?

1. Map boost abstracts to 3D vectors using NLP
2. Create massless 4-vectors of these
3. Cluster with CA, ask for 4 jets (ignore substructure…)

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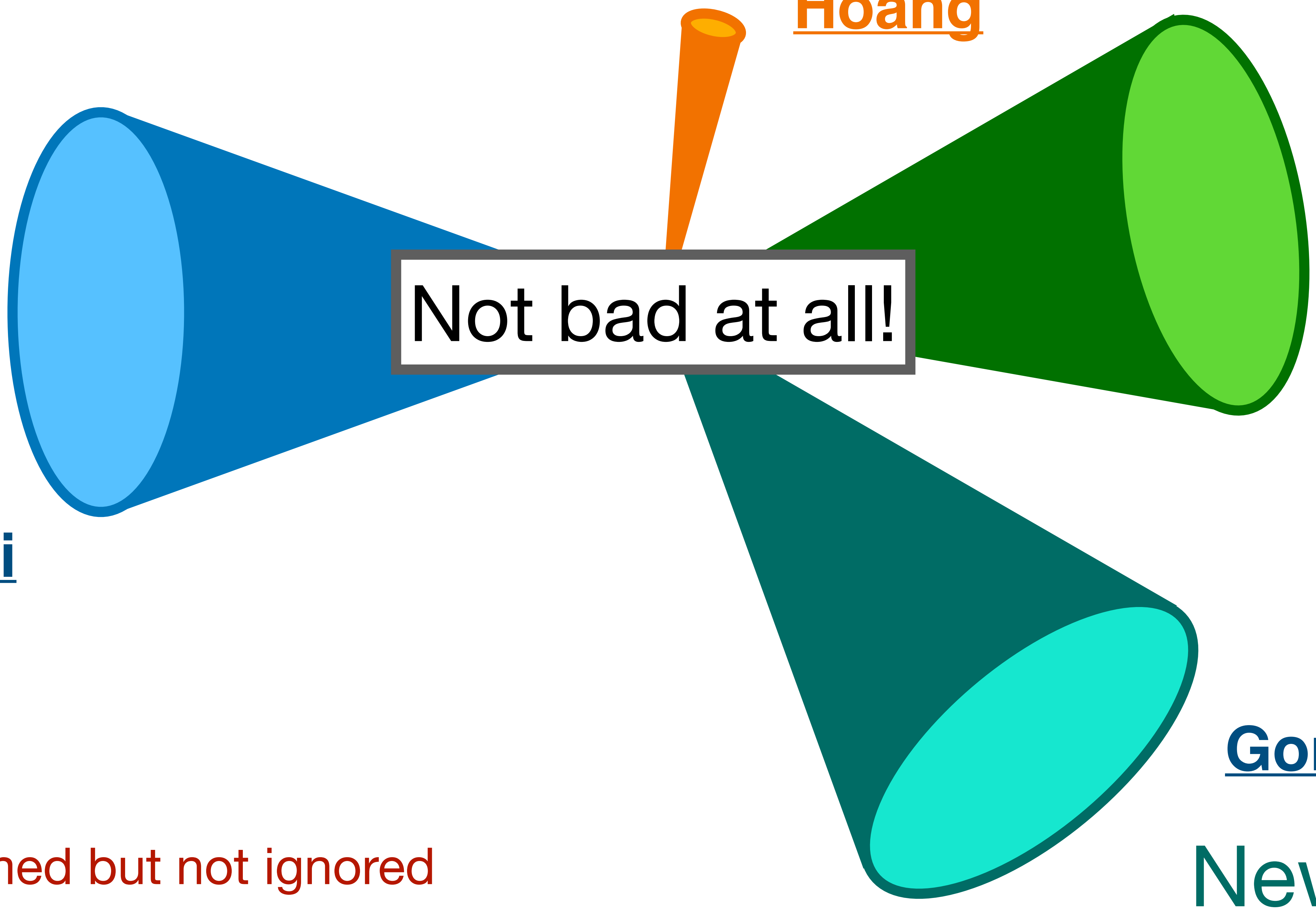

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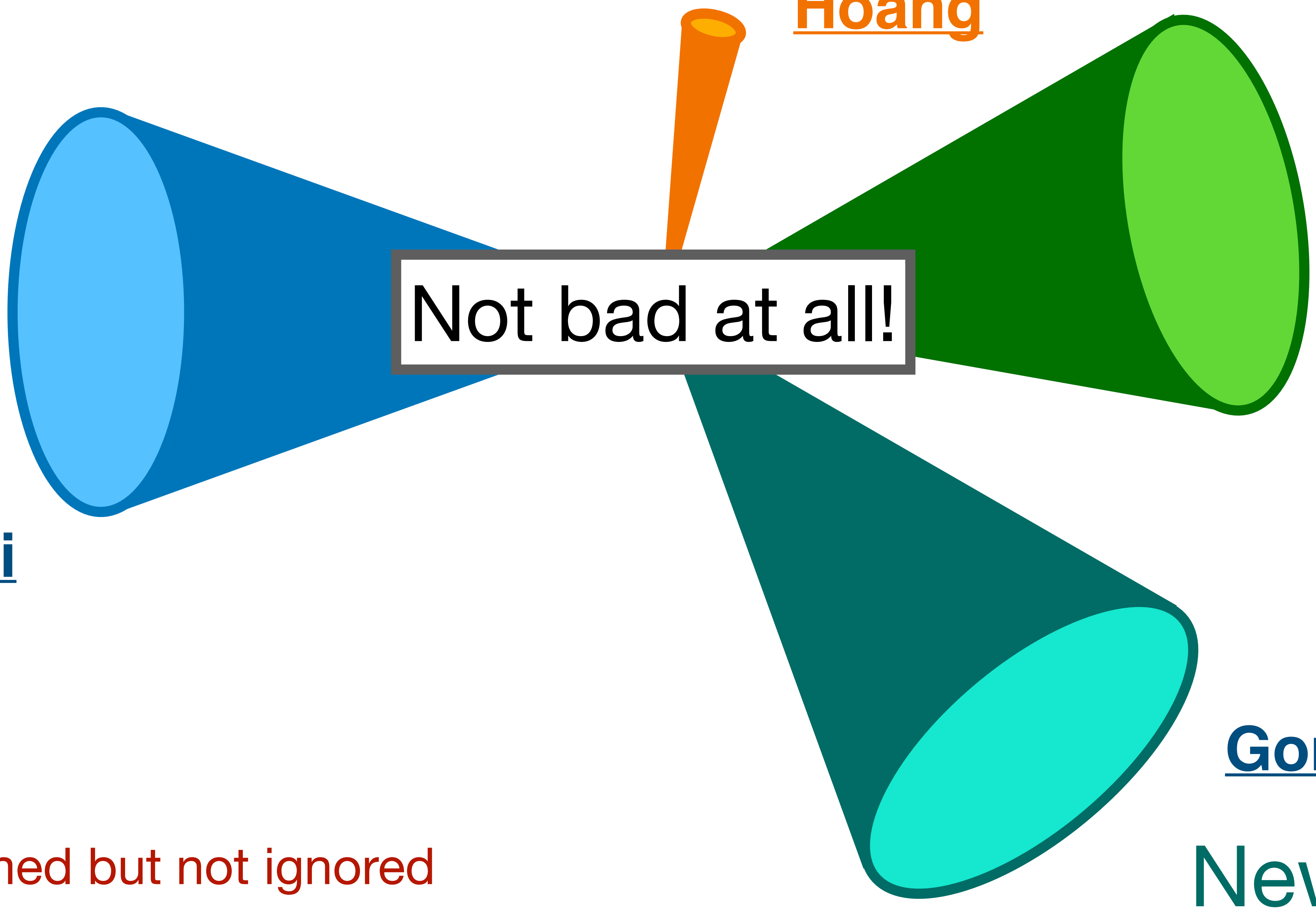
Bonus points for those who can guess the orange cluster

Generators
Helliwell
Hoang
Bouchhar



Advances in ML

Li
Letizia
Masełek
Qureshi
Schweitzer
Favaro
Mikuni
Nojiri
Reyes-Gonzalez
Bogatskiy
Liu

New calculations

Ghira
Wu
Caletti
Giachino
Bonino
Celiberto
Belov
Tecocoatzi

New observables

Craft
Cesarotti
Gonzalez
Silva
Pathak
Barrera
Alipour-fard

Groomed but not ignored
Gambhir

Using ML for BSM searches

ML

We know there is BSM physics… Can ML **boost** our search?

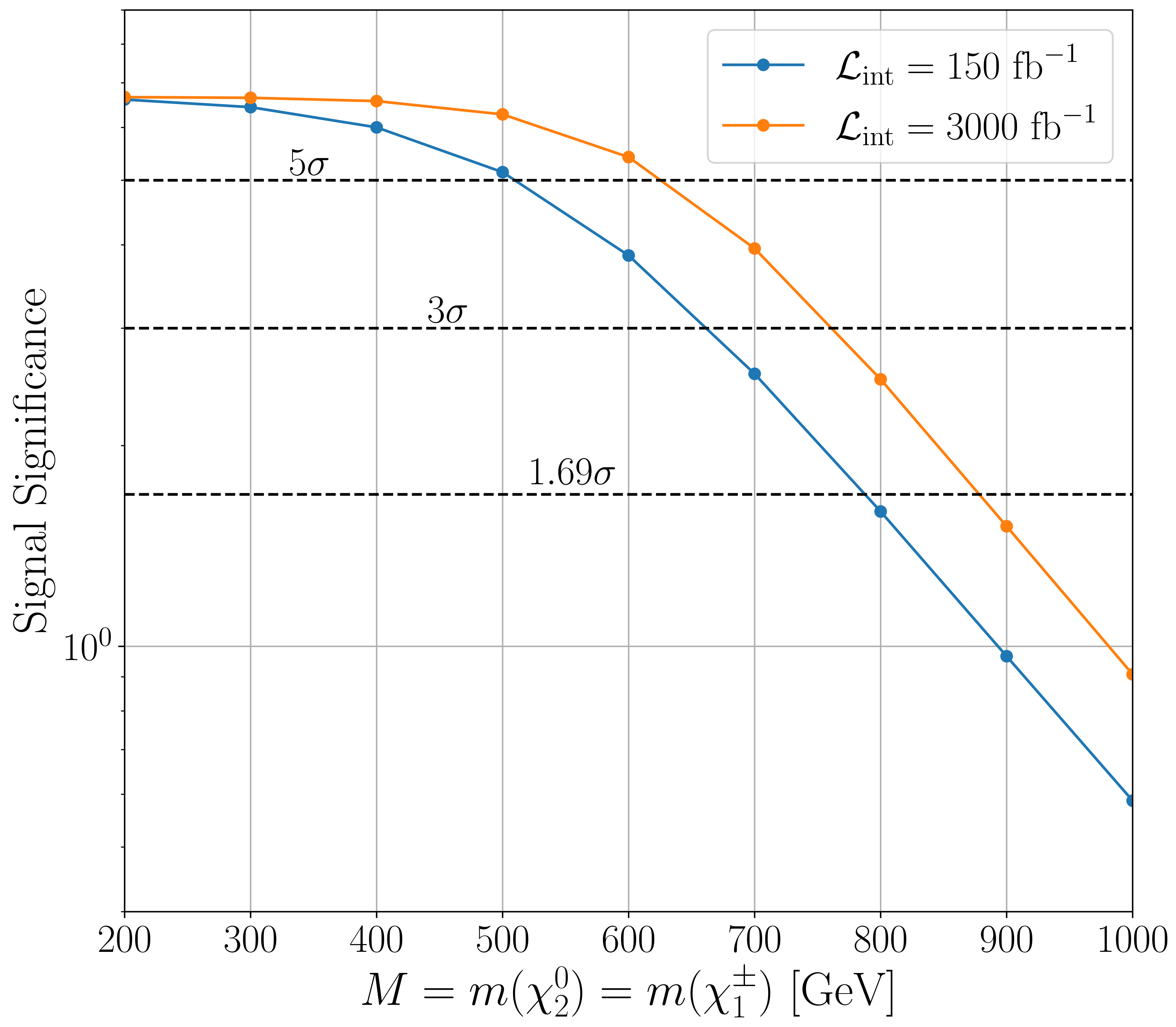
Probing the Supersymmetric Standard Model at the Large Hadron Collider through Vector Boson Fusion Processes and Machine Learning

Umar Qureshi

Can we improve our significance on a well-motivated BSM scenario?

Yes we can!

Using a BDT trained on kinematic variables selected with ‘expert knowledge’



Extending LHC Constrains to SUSY

Constraints to $\tilde{\chi}_2^0$ and $\tilde{\chi}_1^\pm$ masses at a:

- $\geq$ **5σ signal significance** for masses up to **660 (520) GeV**.
- $\geq$ **3σ signal significance** for masses up to **770 (620) GeV**.
- $\geq$ **95% confidence level** for masses up to **880 (750) GeV**.

Integrated luminosities of 3000 (150) fb^{-1}.

Using ML for BSM searches

ML

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Enhancing LHC searches for Dark Matter with Graph Neural Networks [Rafal Masełek]

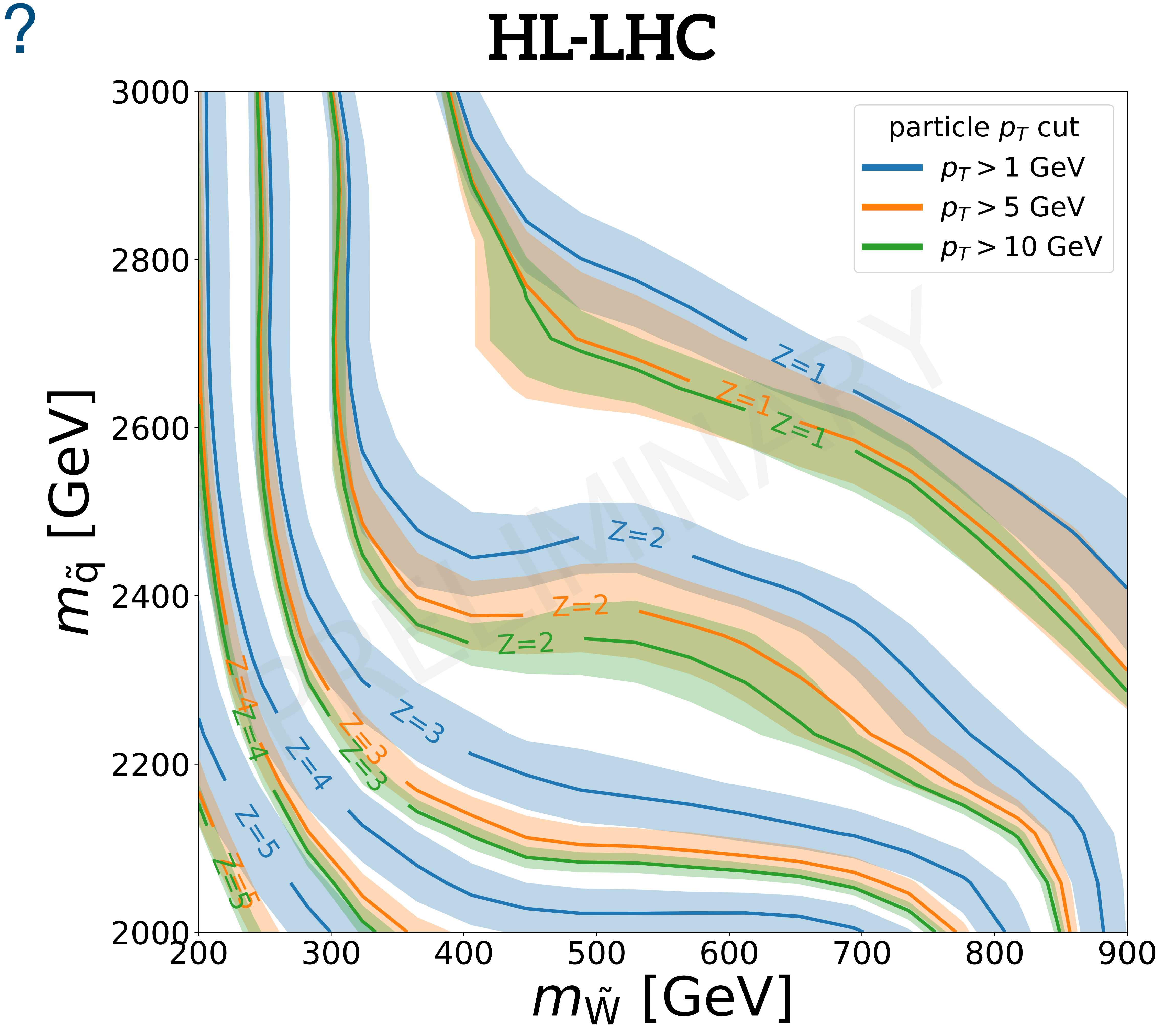
Can we re-analyse traditional BSM signatures?

Yes we can!

Train a GNN with both high level and particle-level input

Study of monojet SUSY search, aim for jet substructure

Depending on softness they find a good coverage of phase-space



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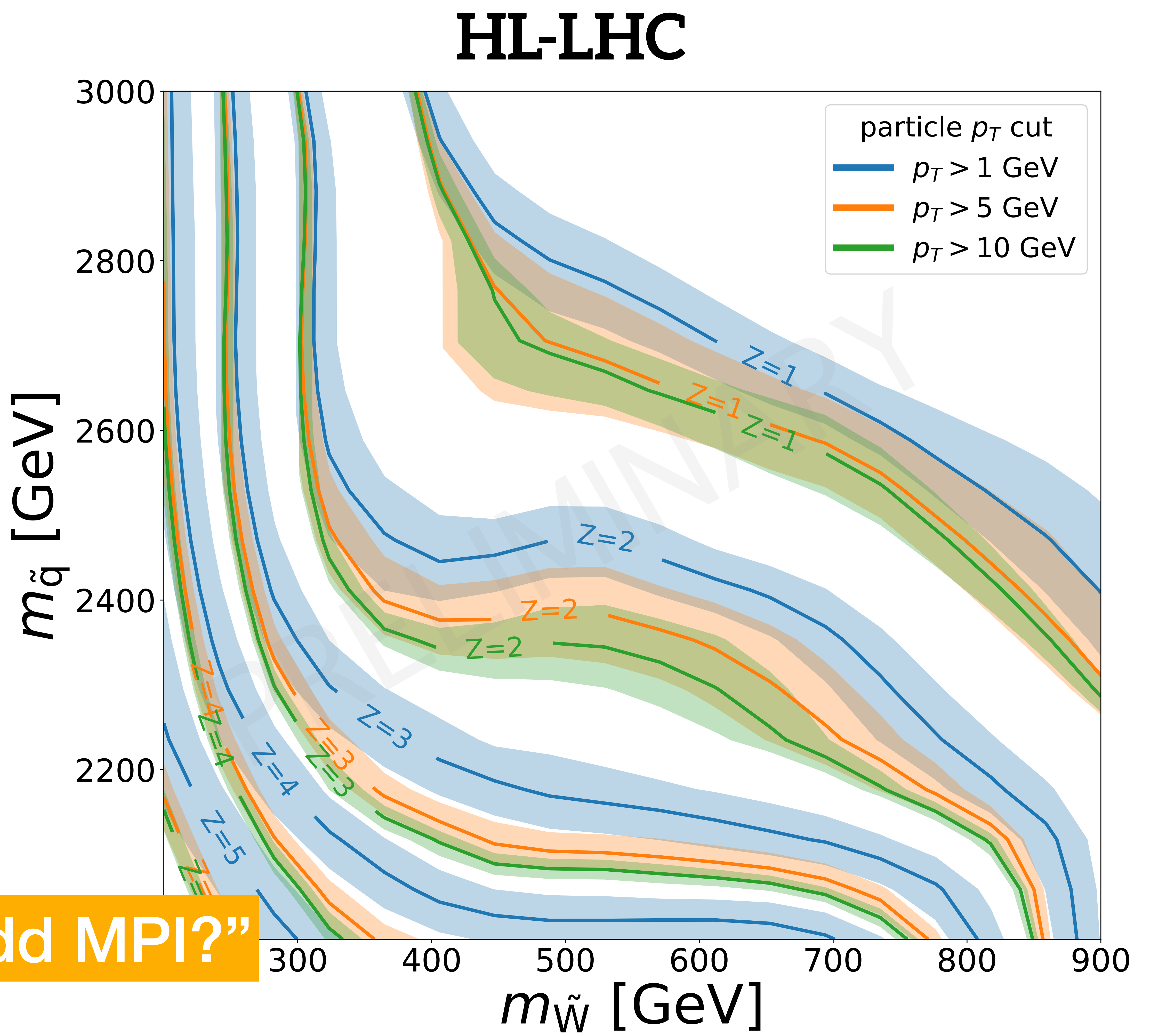


"What happens if we add MPI?"

Using ML for BSM searches

ML

We know there is BSM physics… Can ML **boost** our search?

Semi-visible jets, energy-based models, and self-supervision

Luigi Favaro

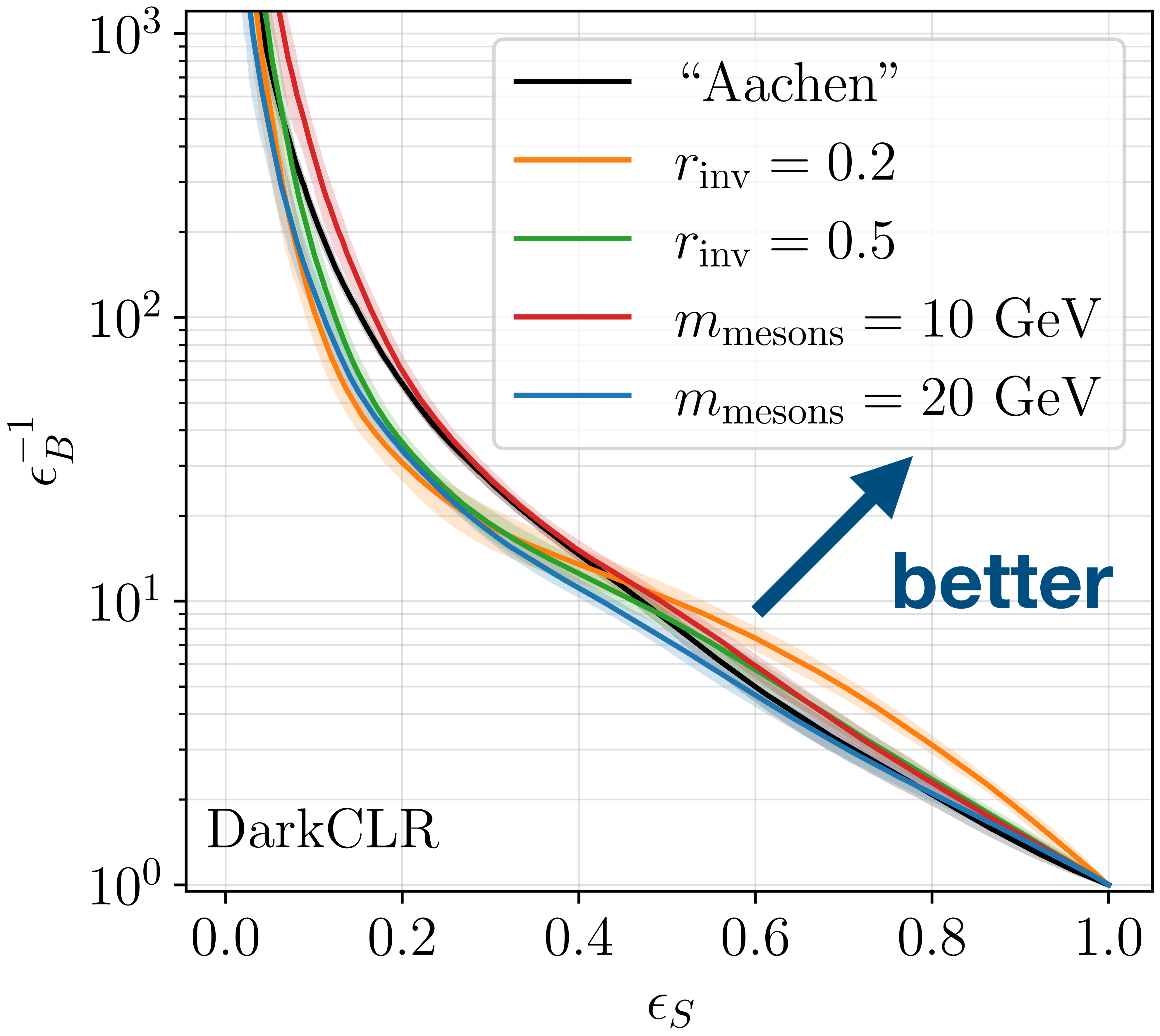
But we don't know what BSM model to look at! Can we be more model agnostic?

"Still early days, but we can try"

Use density estimation as model-agnostic anomaly scores with a NN

Representation is key → give the NN both real symmetries and BSM-inspired augmentations of the data

Robust method: train on one $r_{\rm inv}$, predict others



Using ML for BSM searches

ML

We know there is BSM physics… Can ML **boost** our search?

Efficient machine learning for model-independent tests

Marco Letizia

But we don't know what BSM model to look at! Can we be more model agnostic?

Use density estimation as model-agnostic anomaly scores but with a kernel function

Pro's: it is fast and versatile!

- Control data quality
- Test generative models
- Classification tasks

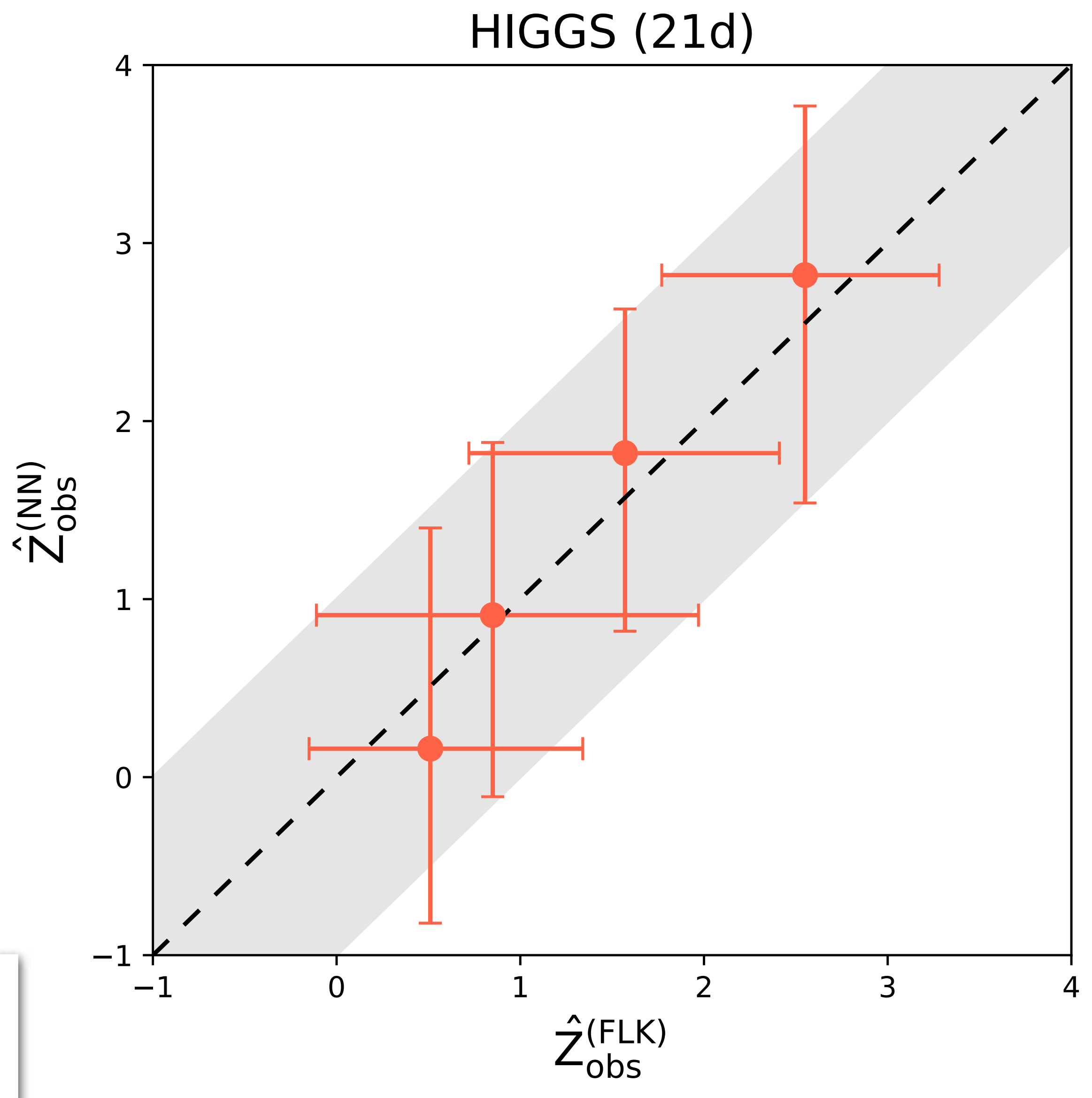


Table 1 Average training times per single run with standard deviations (low level features and reference toys). Note that time measured in hours (for NN) and seconds (for Falkon)

Model	DIMUON	SUSY	HIGGS
FLK	**(44.9 ± 3.4) s**	**(18.2 ±1.2) s**	**(22.7 ± 0.4) s**
NN	(4.23 ± 0.73) h	(73.1 ± 10) h	(112 ± 9) h

Also see invited contribution of Lorenzo Rosasco

The era of foundation models

ML

One model to rule them all

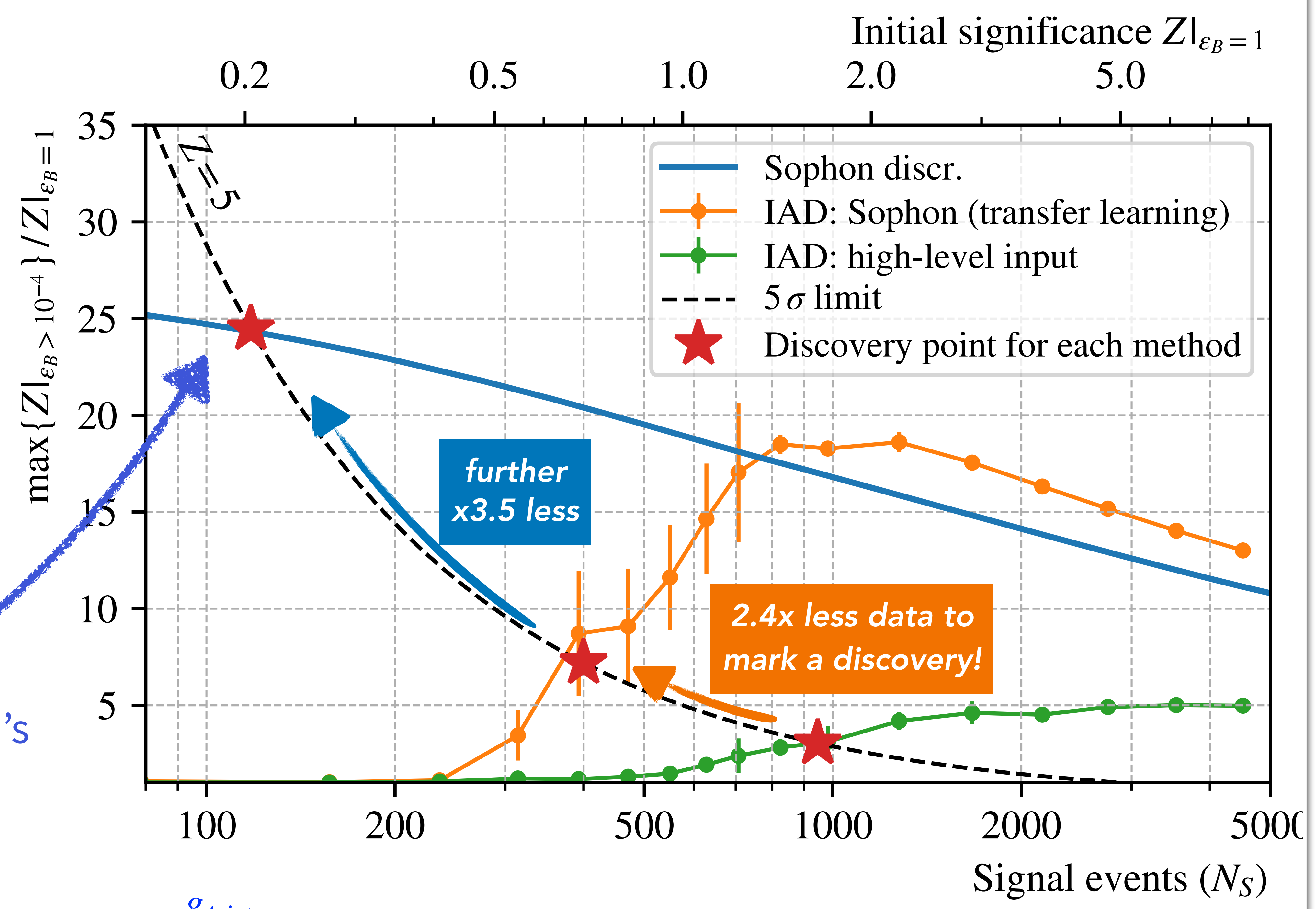
Accelerating resonance searches via signature-oriented pre-training Congqiao Li

Can we develop a tagger for all types of jets without losing performance?

A 'foundation classifier' with a simple task: connect the jet signature to NP or SM

Sophon: model based on particle transformer architecture

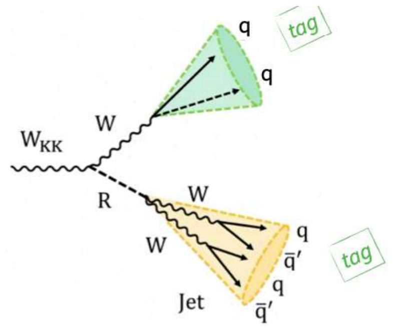
This pre-trained model can be fine-tuned to specific tasks i.e. classification by combining with CWoLa



using Sophon's constructed discriminant

$$\text{discr} = \sum_{\text{jet}=1,2} \frac{g_{A,\text{jet}}}{g_{A,\text{jet}} + \sum_{i=1}^{27} g_{\text{QCD}_i,\text{jet}}}$$

$$A = \begin{cases} 0.3 \times \{cs, qq\} \\ + 0.1 \times \{ccss, qqcs, qqqq\} \\ + 0.6 \times \{ccs, ccq, ssc, ssq, qqc, qqs, qqq\} \end{cases}$$



Byproduct: JetClass-II

The era of foundation models

ML

One model to rule them all

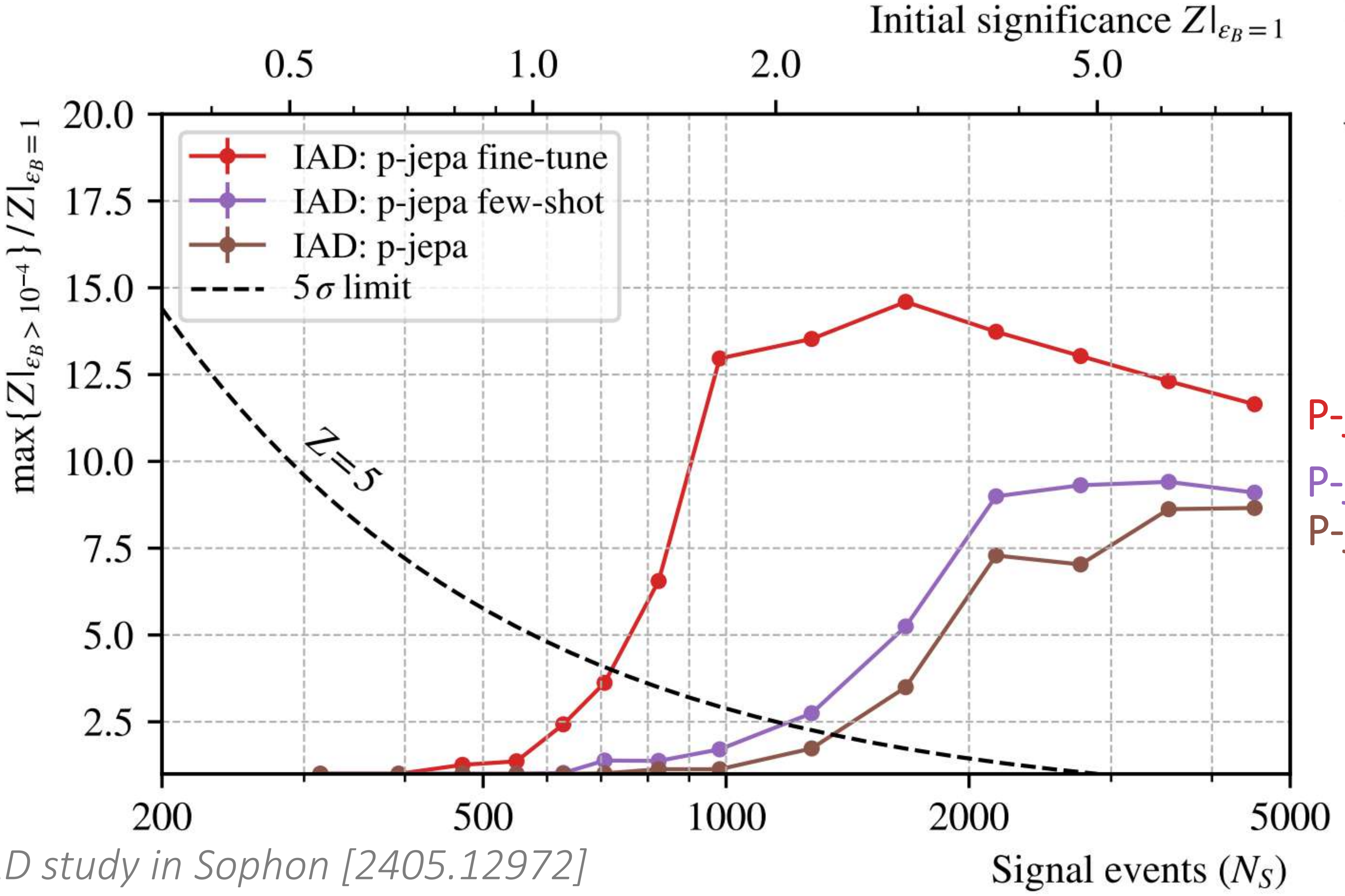
Learning powerful jet representations via self-supervision Qibin Liu

Can we go without labels, with the ultimate aim to directly learn from data?

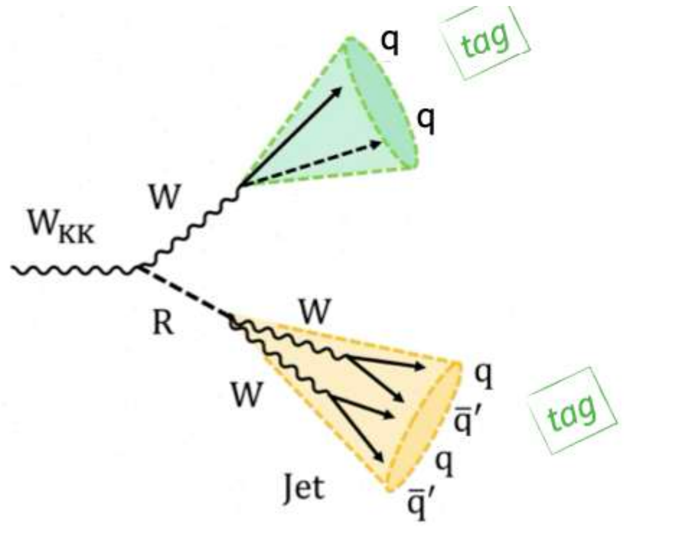
P-JEPA: transformer network that needs to learn how to fill in partial jet data in the latent space

Trained on Sophon's JetClass-II

Still underperforms w.r.t. supervised learning



AD study in Sophon [2405.12972]



P-jepa + finetune (10M)

P-jepa + few-shot (1k)

P-jepa

The era of foundation models

ML

One model to rule them all

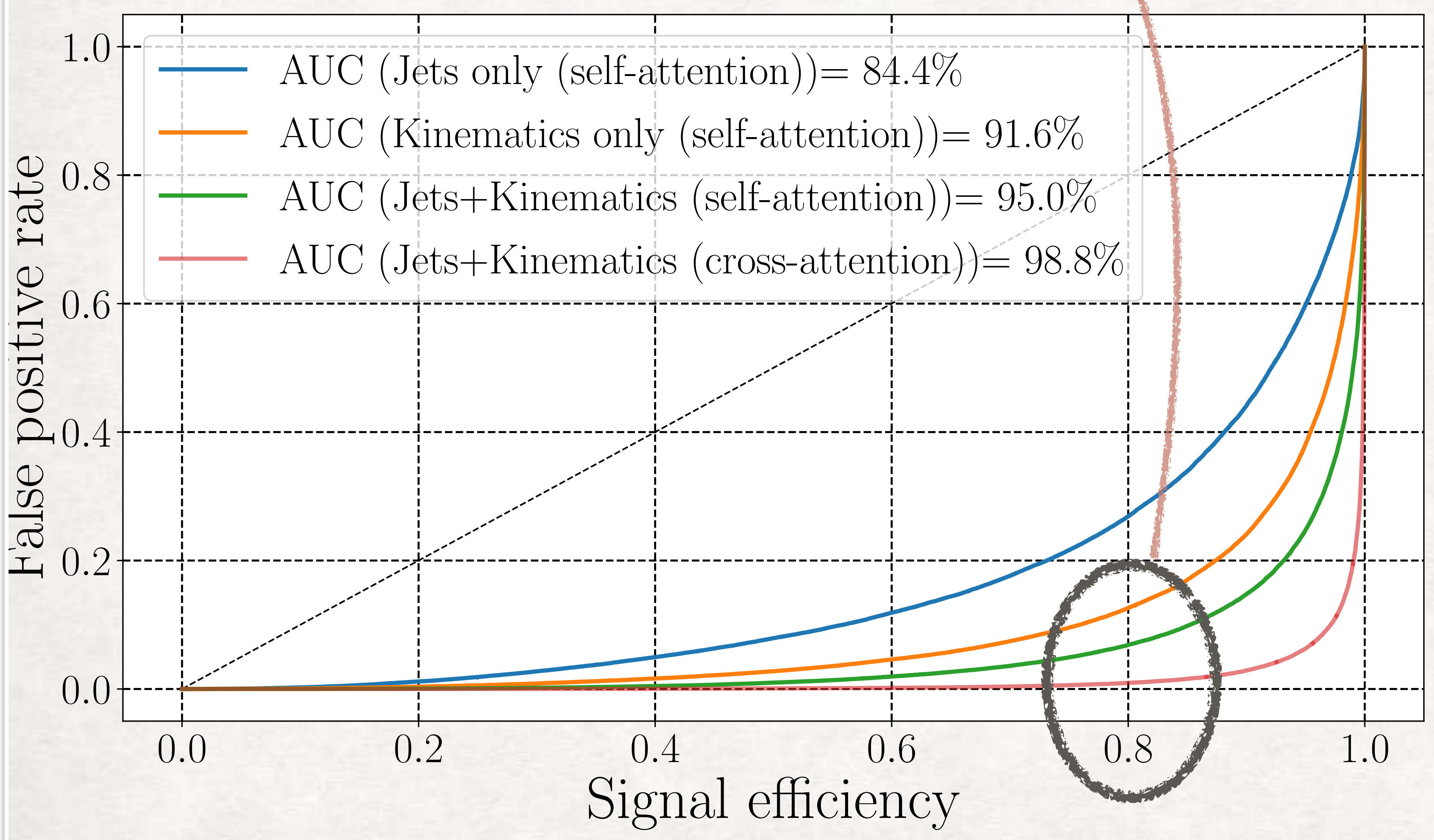
Streamlined jet tagging network assisted by jet prong structure

Mihoko Nojiri

Don't rule out the job of the expert!

Transformer network with a 'cross attention' mechanism: feed in both the subjets and the particles in the jets

factor 5 improvement at the same acceptance.



Cross attention improves the rejection efficiency significantly

The era of foundation models

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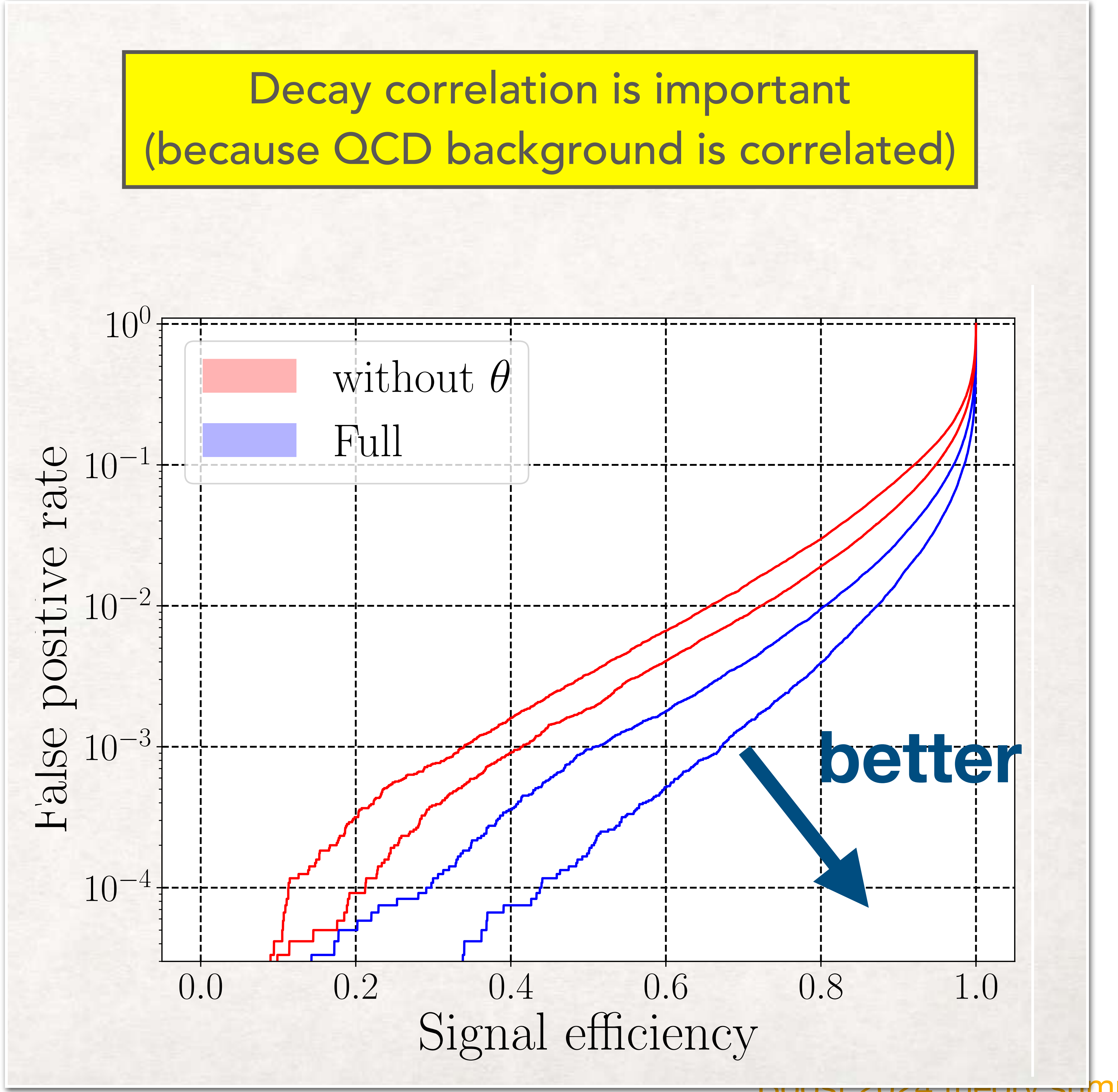
Another piece of expert knowledge: event orientation matters!



Does equivariance make better models?

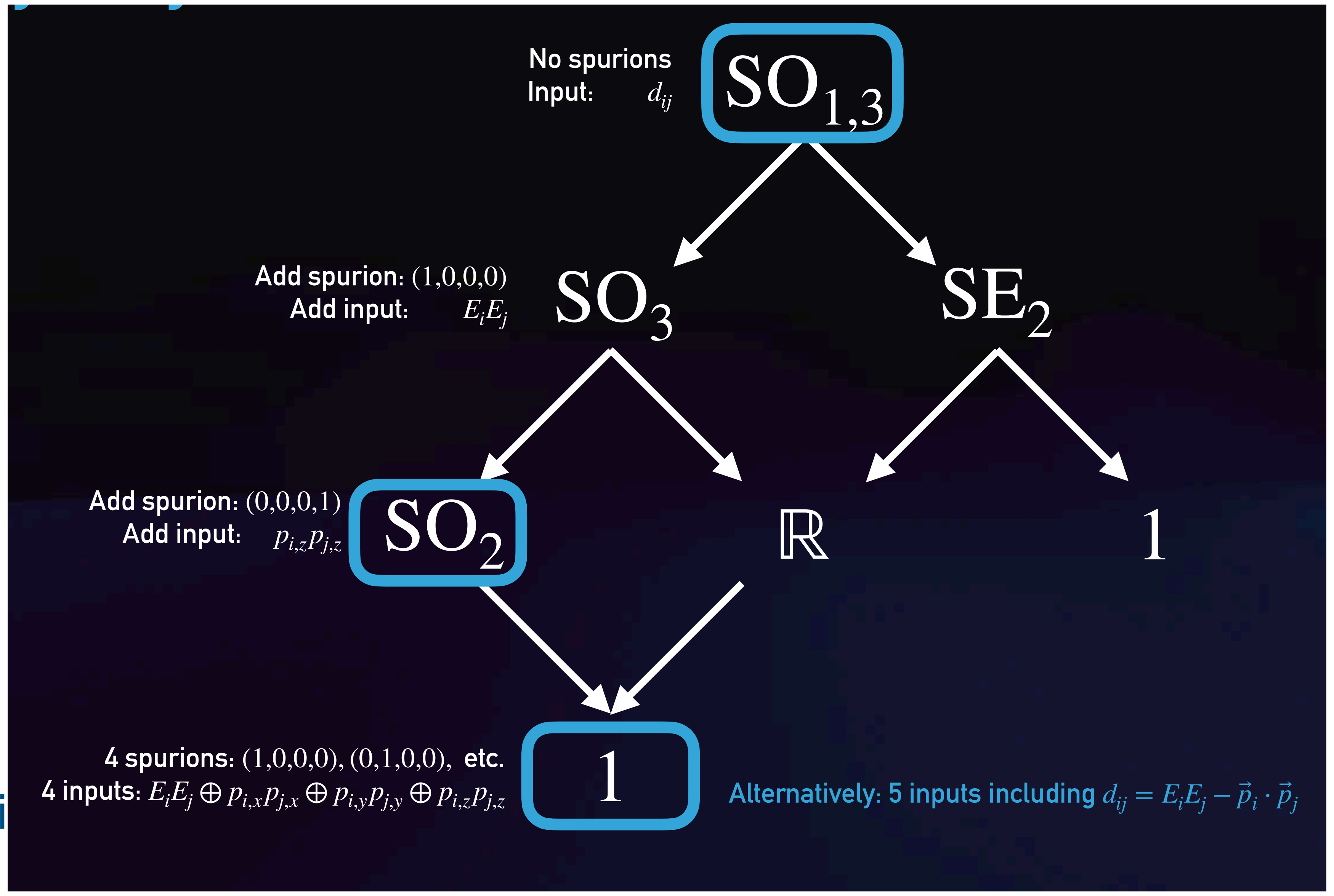
ML

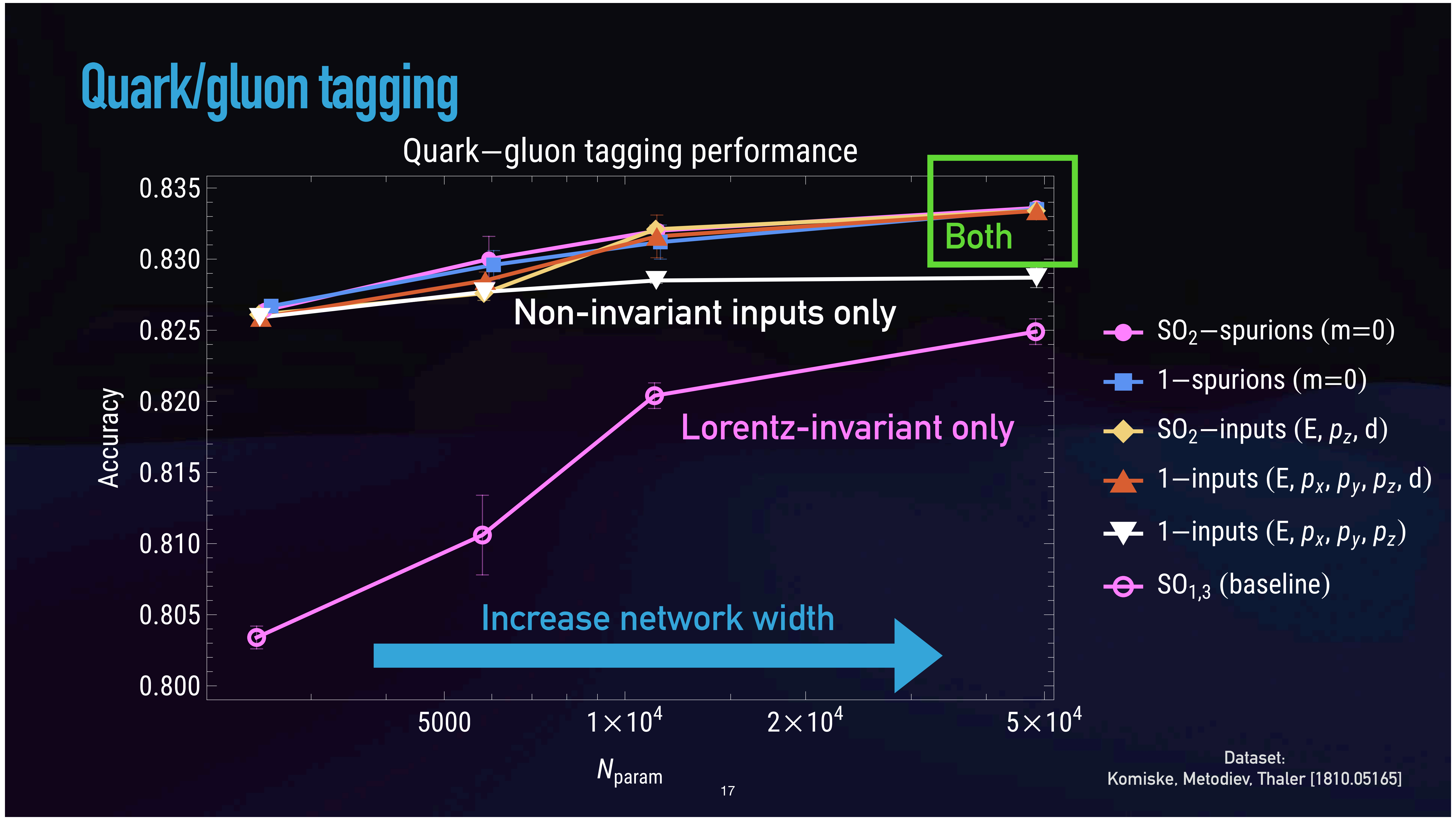
What is the ideal information to give to an architecture (PELICAN)?

Alexander Bogatskiy

Two methods to break the invariance:

- Spurion: explicitly add vectors that indicate a preferred direction
- Input: add energy/momenta components





Best networks: combination of both methods.

SPECTER: Efficient Evaluation of the Spectral EMD

Rikab Gambhir

The EMD provides a way to compare jets but it is hard to calculate

Solution: Spectral EMD

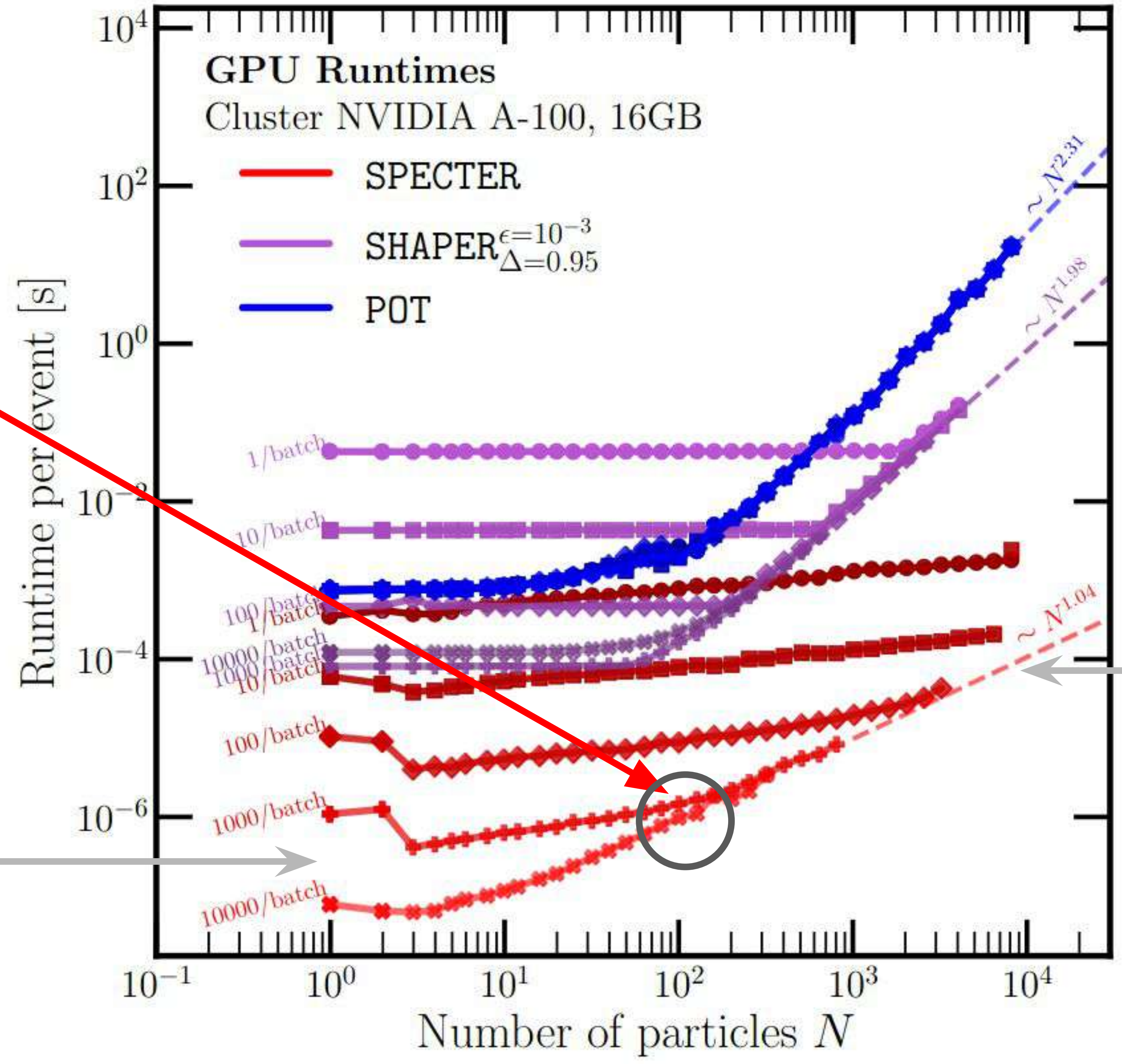
Respects symmetry properties, fast to evaluate

Bonus: some observables have a closed form → amenable to analytic calculations

Running on a single GPU on my local compute cluster …

SEMDs between jets with ~100 particles can be computed at a rate of **one million SEMDs per second**!

Highly parallelized: Efficiency gains by processing many events at once!



Worst case SEMD scaling is $O(N^2 \log N)$ … SPECTER beats it in practical settings!

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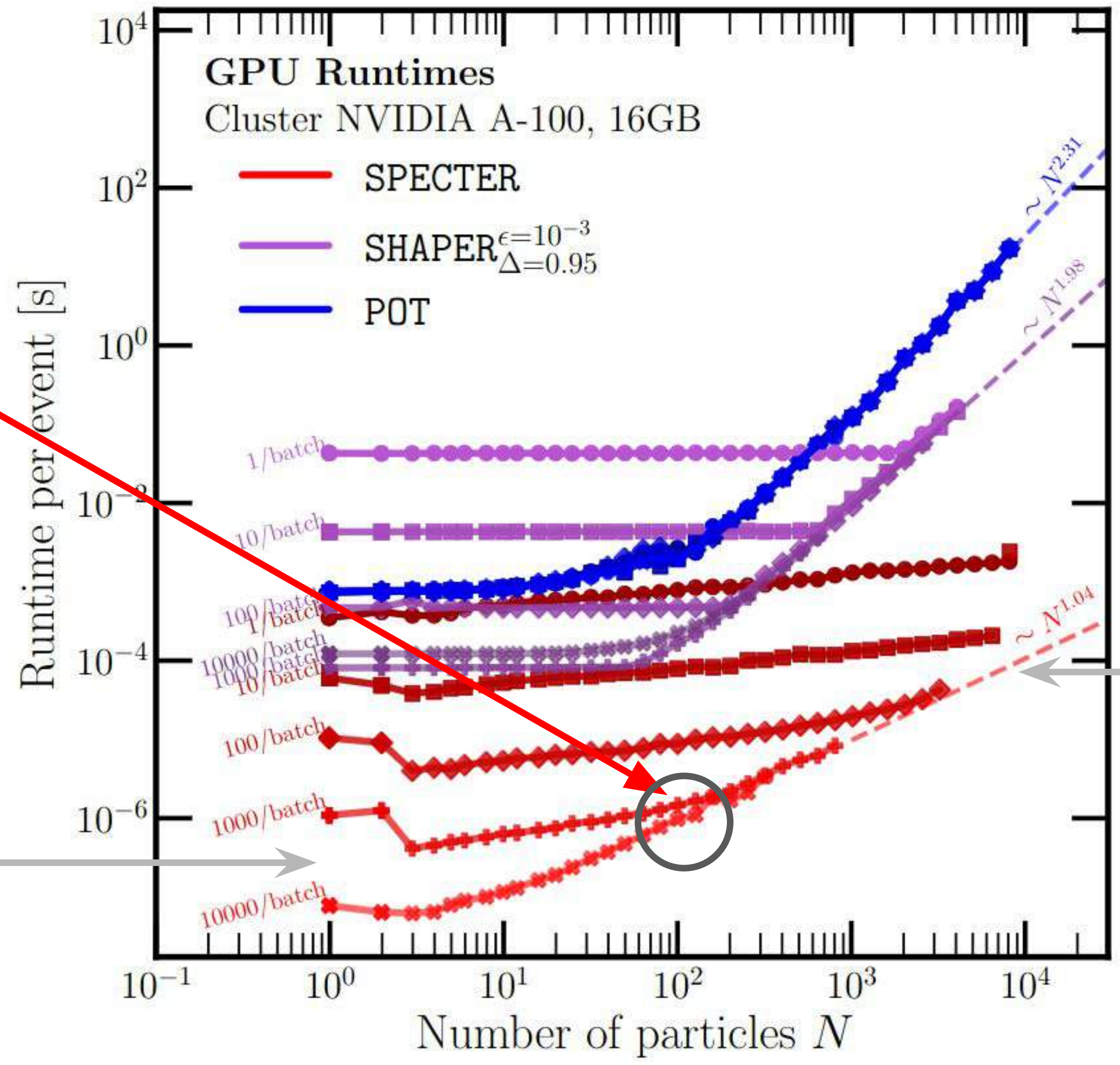

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Aren't we losing too much information? What do typical event-shape observables look like?

Jets physics

- Classification/tagging
- Anomaly detection
- Simulation
- Unfolding

Can we combine all tasks into one tool?

"Can we learn the language of jets?"

Reyes-Gonzalez

How to teach AI about jets?

Mikuni

Vinicius Mikuni

Supervised learning

Omnilearn

GGN + transformer network

Humerto Reyes-Gonzalez

ML

Self-supervised learning

The language of jets

Self-supervised transformer network

Vinicius Mikuni

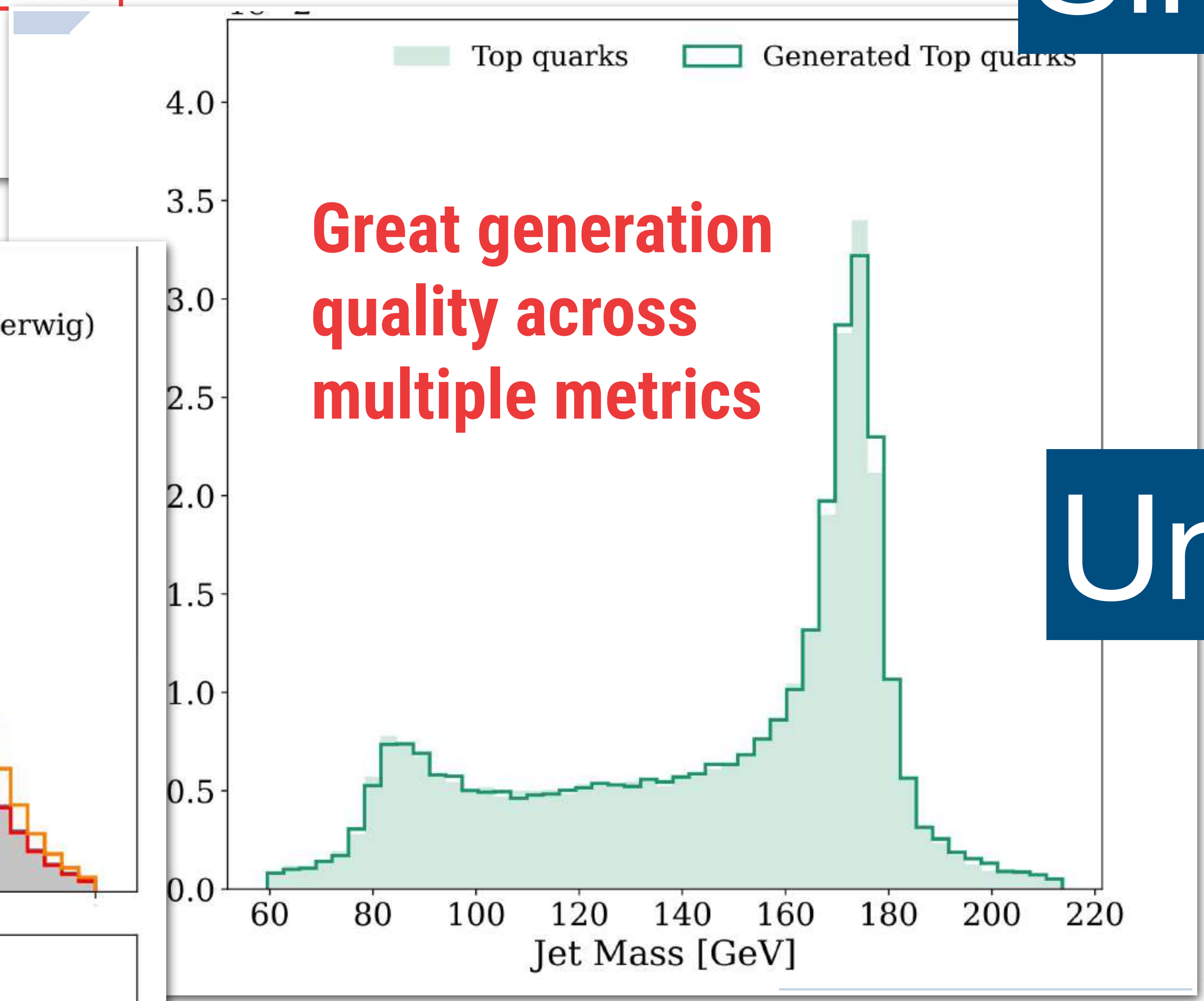
Supervised learning

Omnilearn

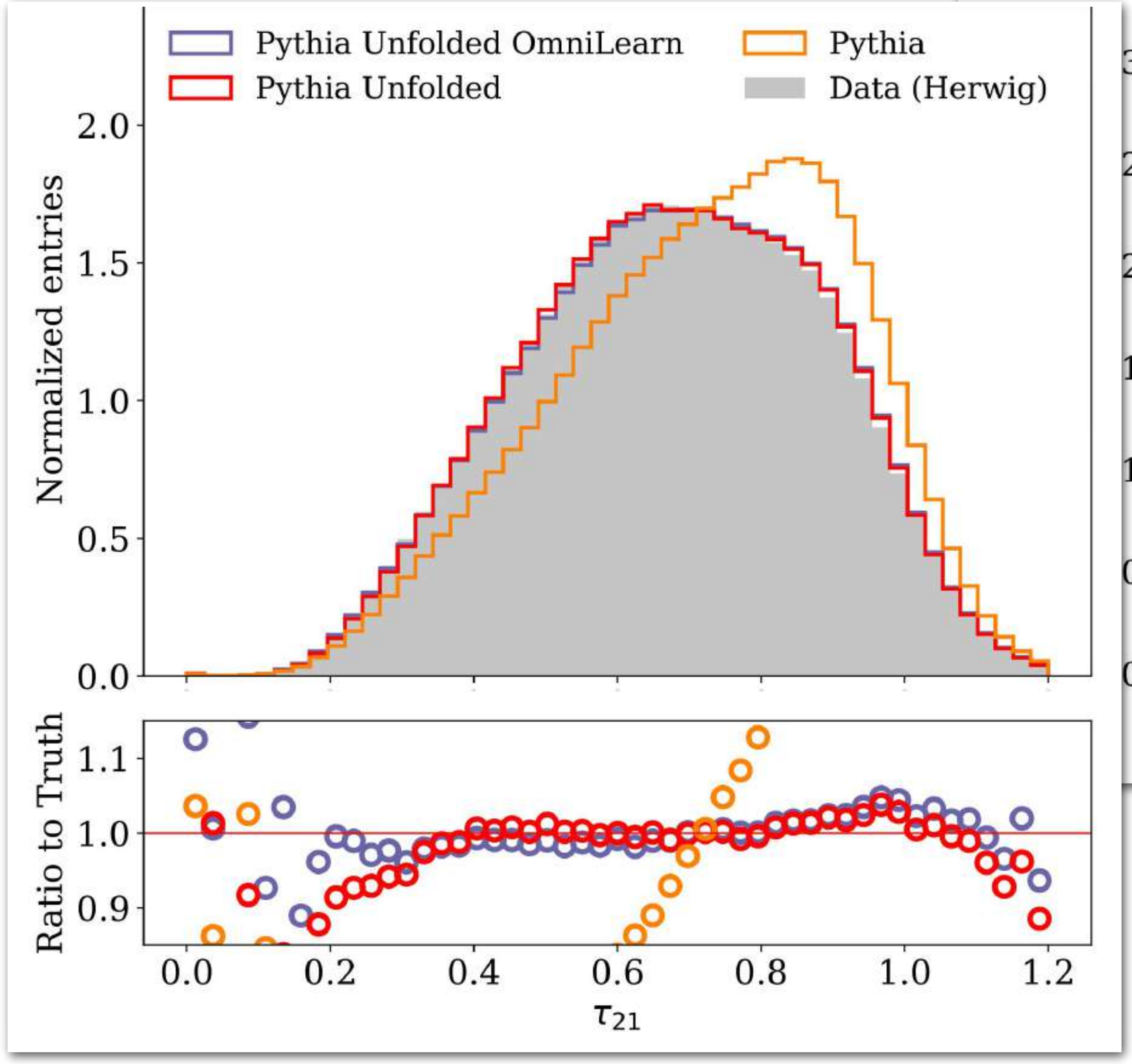
2 different jet categories, AK4 jets simulated in pp collisions with ~~Madgraph + Pythia8 with CMS Delphes detector simulation~~

	Acc	AUC	$1/\epsilon_B$	
			$\epsilon_S = 0.5$	$\epsilon_S = 0.3$
P-CNN [38]	0.827	0.9002	34.7	91.0
PFN [35]	-	0.9005	34.7±0.4	-
ParticleNet [38]	0.840	0.9116	39.8±0.2	98.6±1.3
rPCN [39]	-	0.9081	38.6 ± 0.5	-
ParT [42]	0.840	0.9121	41.3 ± 0.3	101.2 ± 1.1
ParT-f.t. [42]	0.843	0.9151	42.4 ± 0.2	**107.9 ± 0.5**
PET classifier	0.837	0.9110	39.92±0.1	104.9 ± 1.5
OmniLearn	**0.844**	**0.9159**	**43.7±0.3**	**107.7 ± 1.5**

Better than all non-fine-tuned models and similar to PartT performance



Great generation quality across multiple metrics



Tagging

Simulation

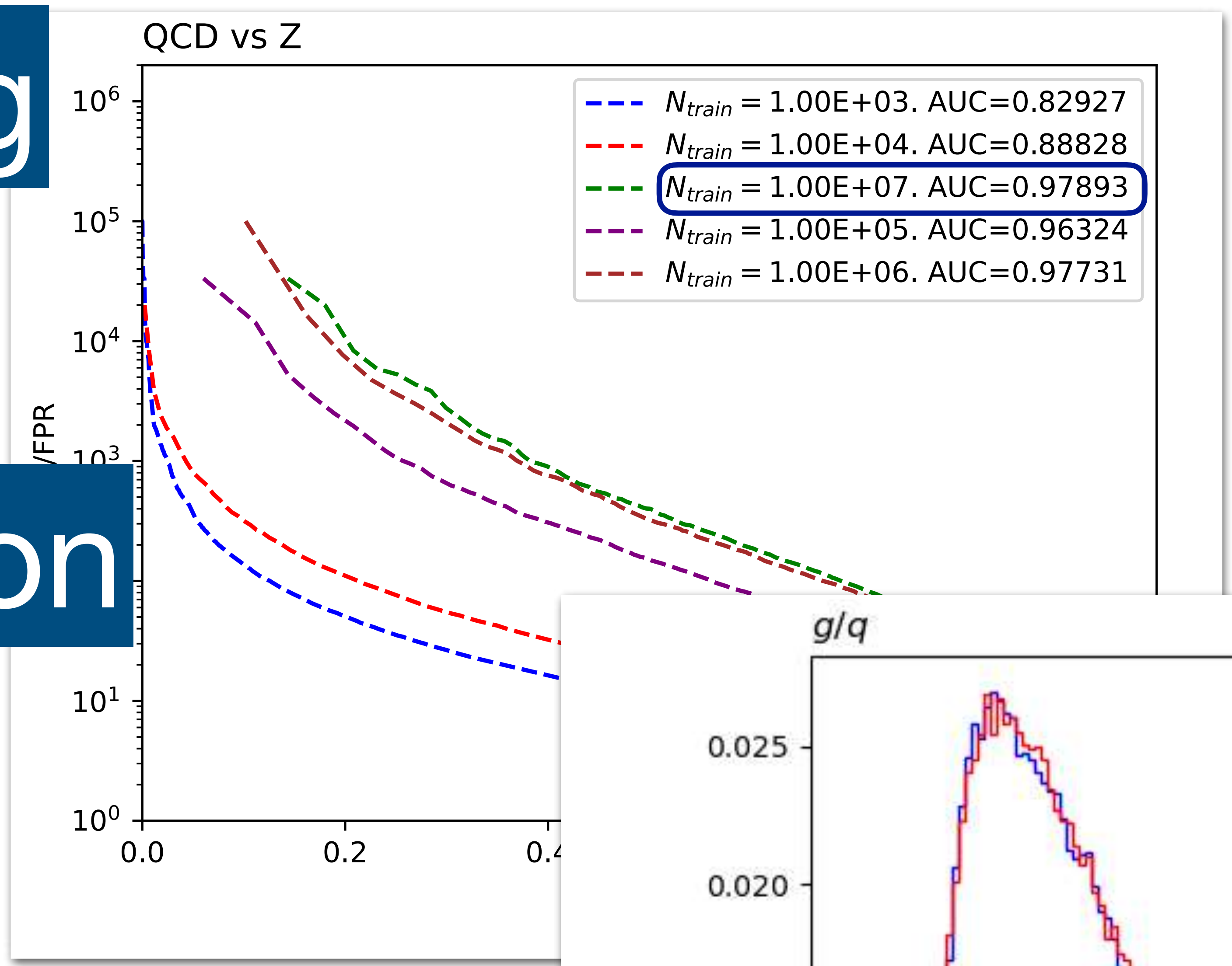
Unfolding

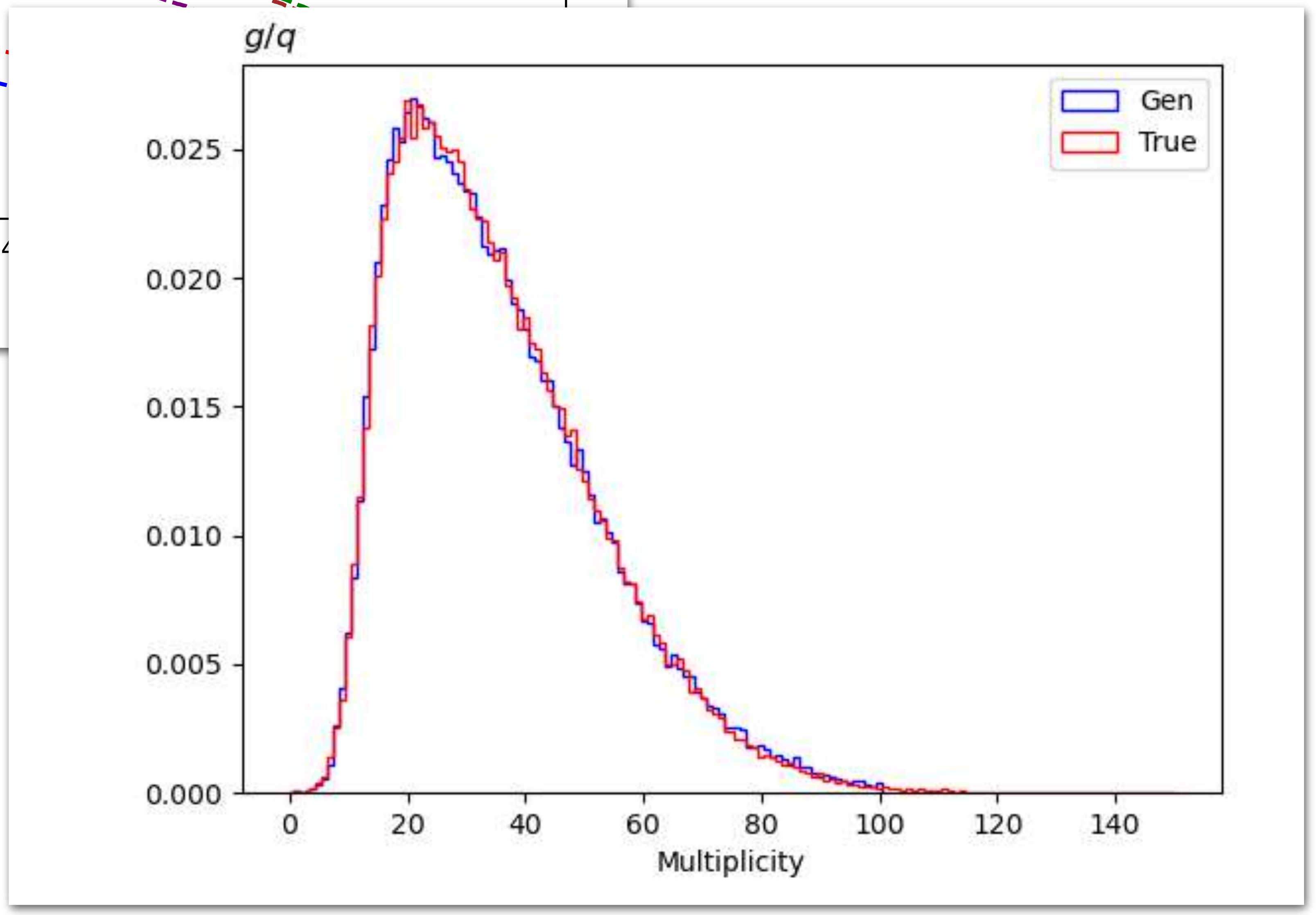
Humerto Reyes-Gonzalez

ML

Self-supervised learning

The language of jets





Vinicius Mikuni

Supervised learning

Omnilearn

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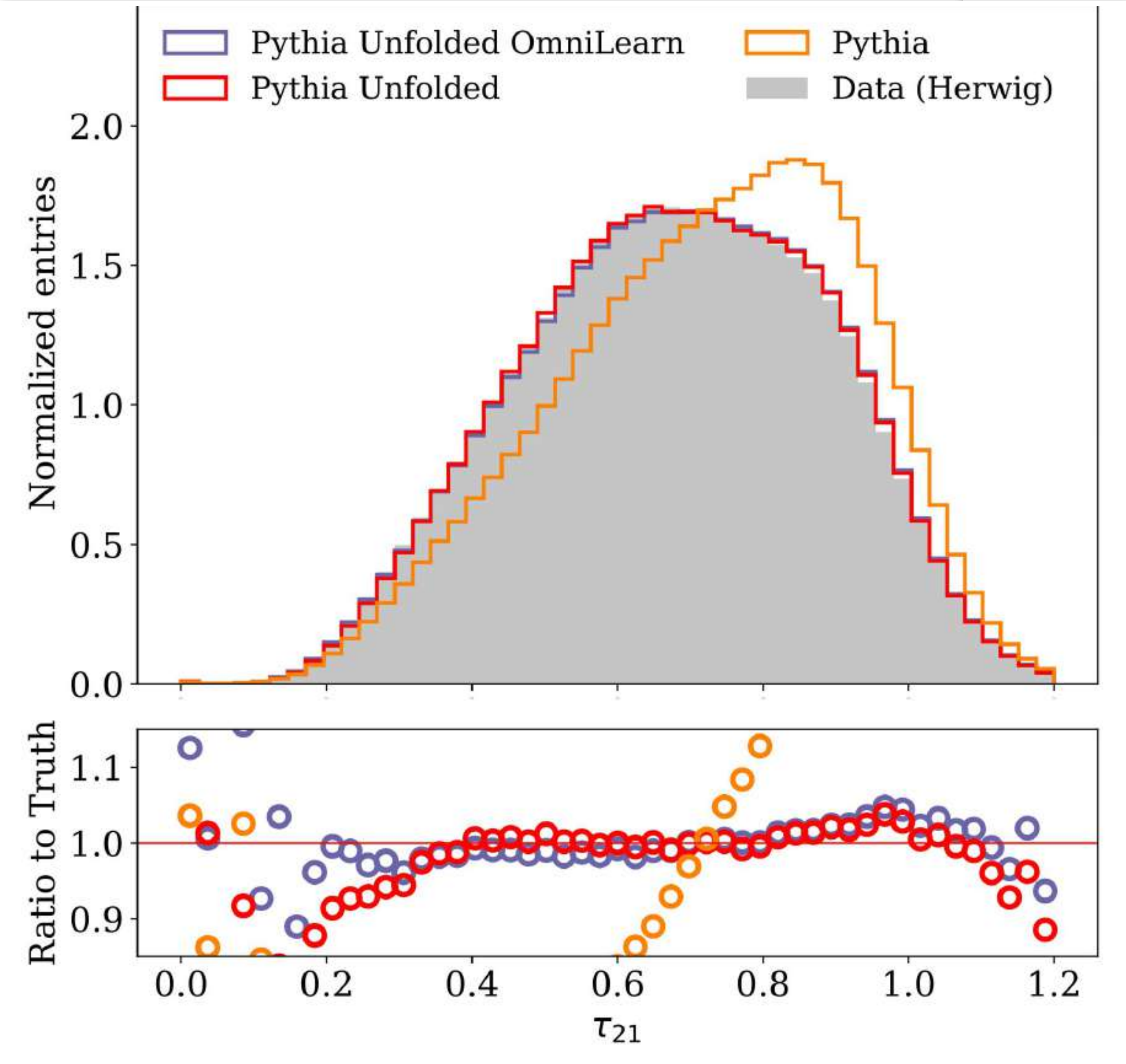

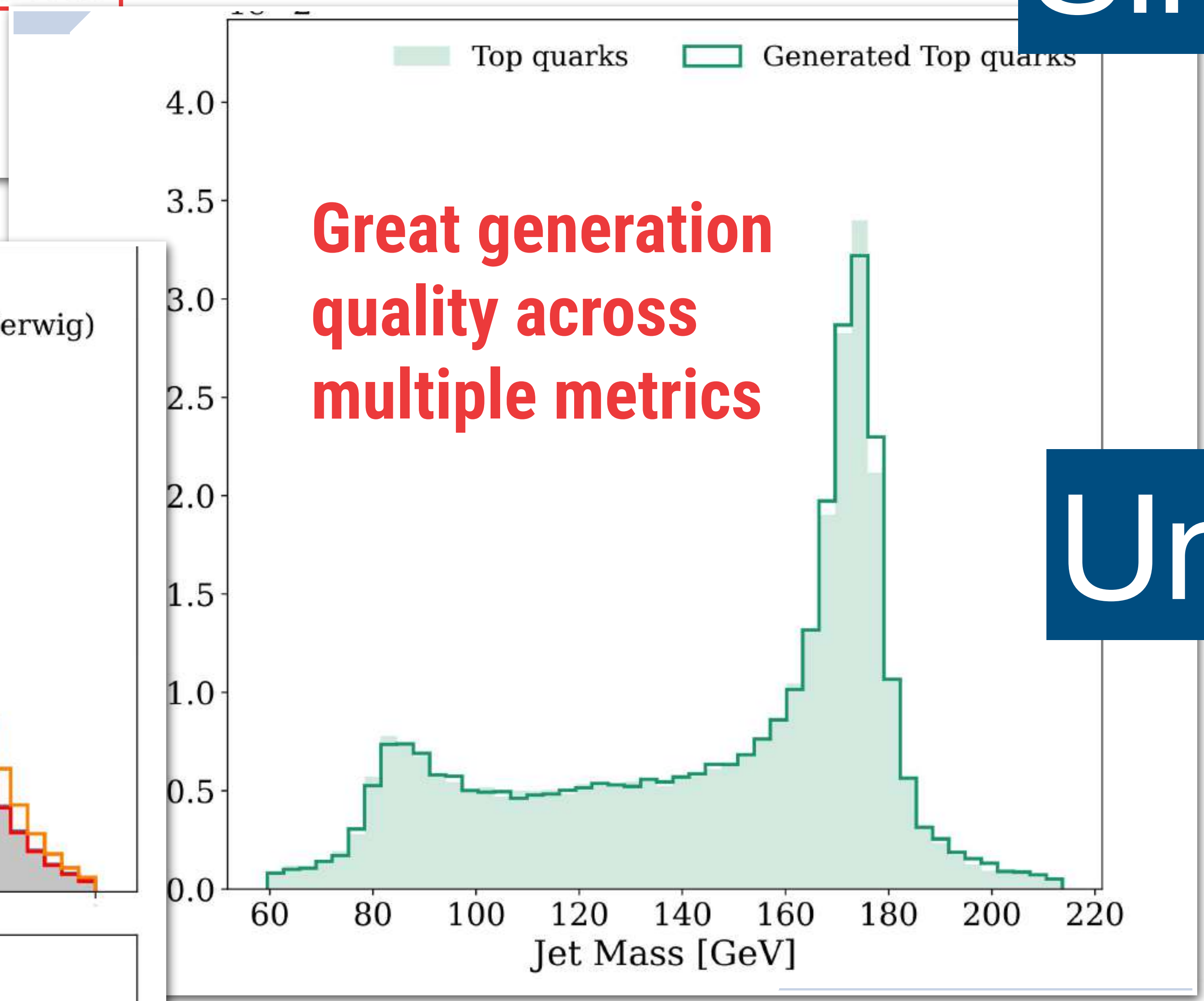

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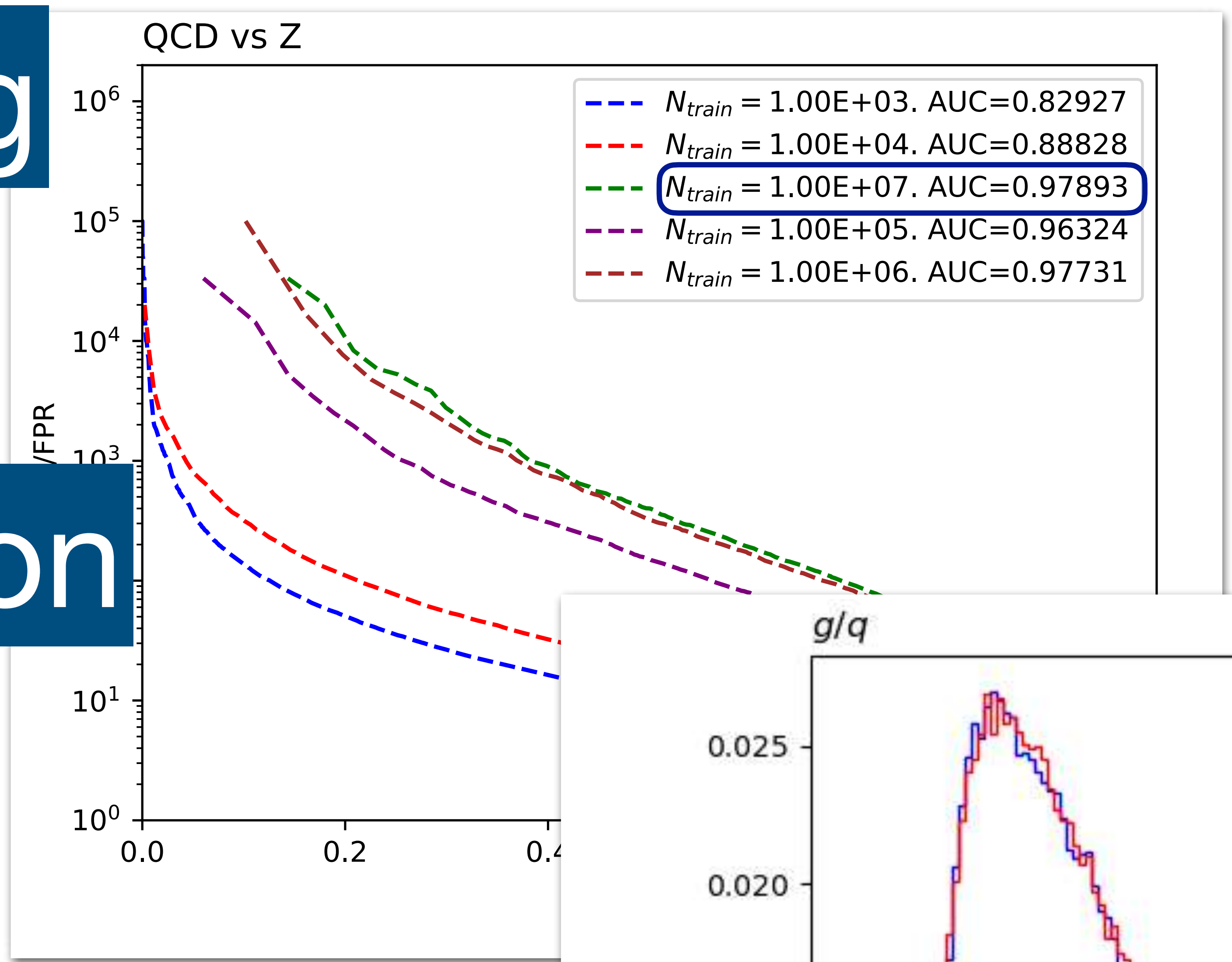
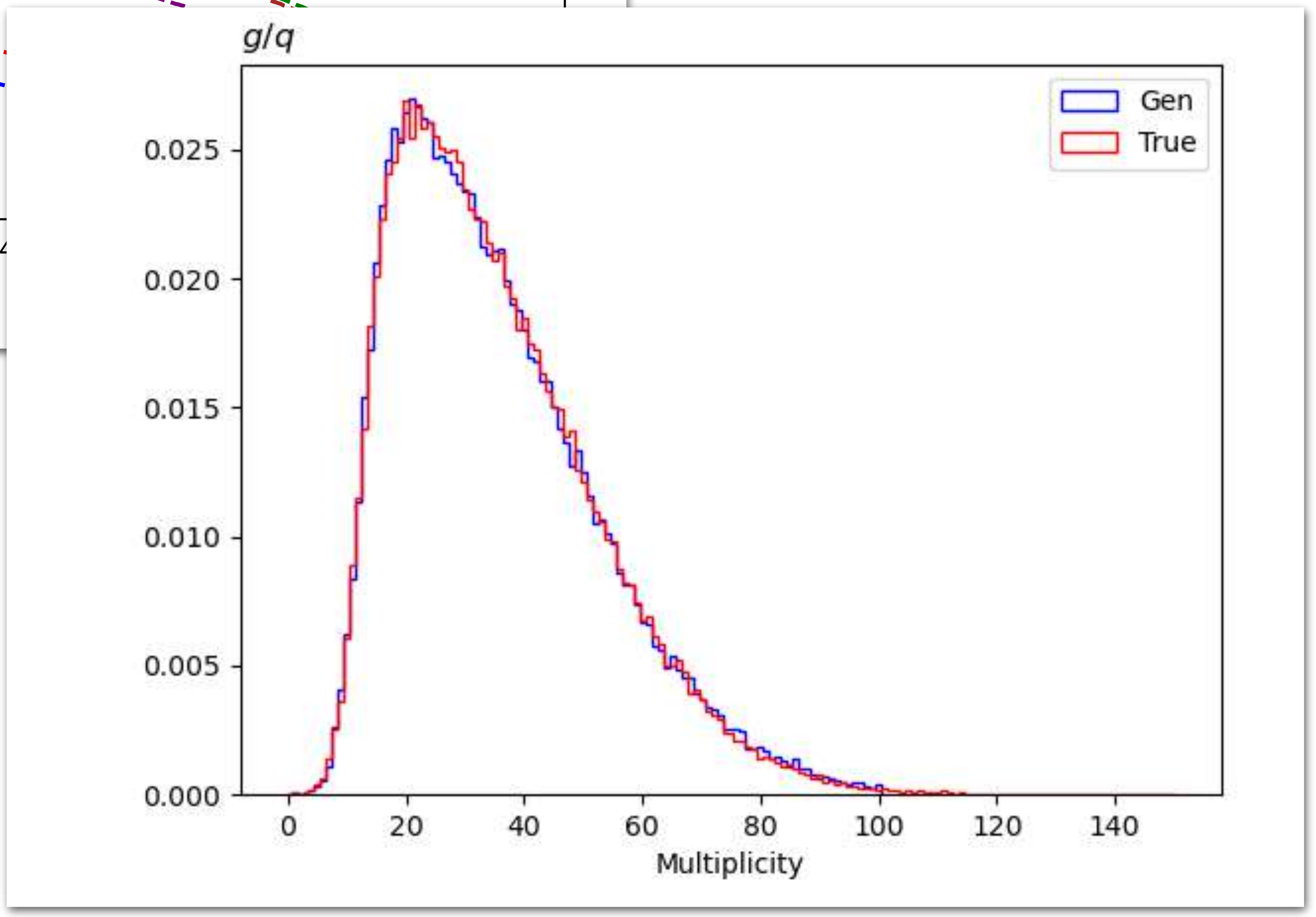




The fineprint: are we learning jet physics, or Pythia?

Towards NNLL accurate parton showers

Generators

Jack Helliwell

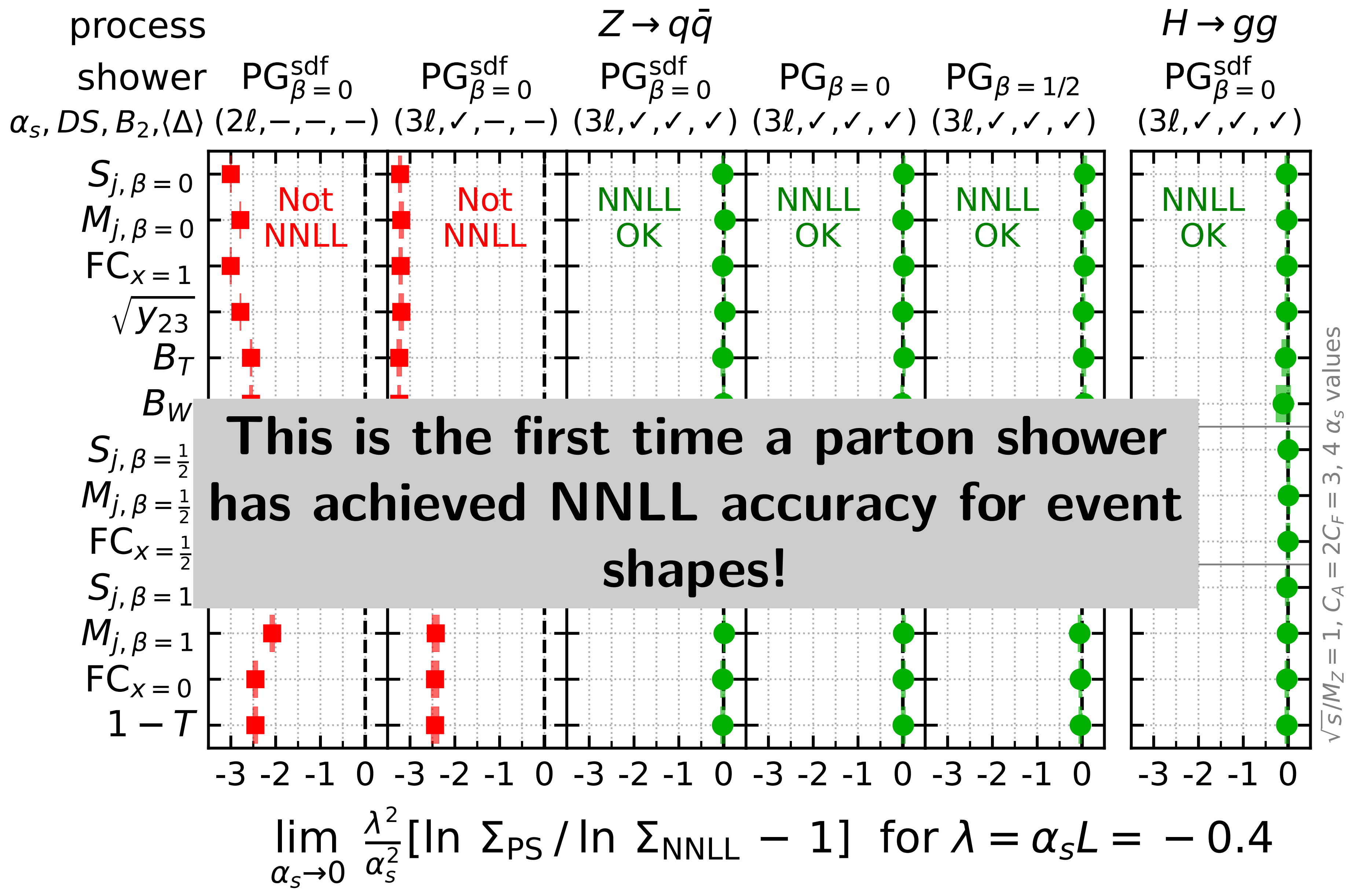
We saw:

1. Many ML models trained on MC data
2. Many data-MC discrepancies

We want AI to learn nature, not MC

The era of parton showers that achieve a higher formal accuracy

NNLL accuracy tests



- For the showers which are not NNLL accurate, we see that coefficient of the spurious NNLL terms is $\mathcal{O}(2-3)$, suggesting a sizeable phenomenological impact.

arxiv:2406.02661, M. Van Beekveld, M. Dasgupta, B. El-Menoufi, S. Ferrario Ravasio, K. Hamilton, JH, A. Karlberg, P. Monni, G. Salam, L. Scyboz, A. Soto-Ontoso, G. Soyez

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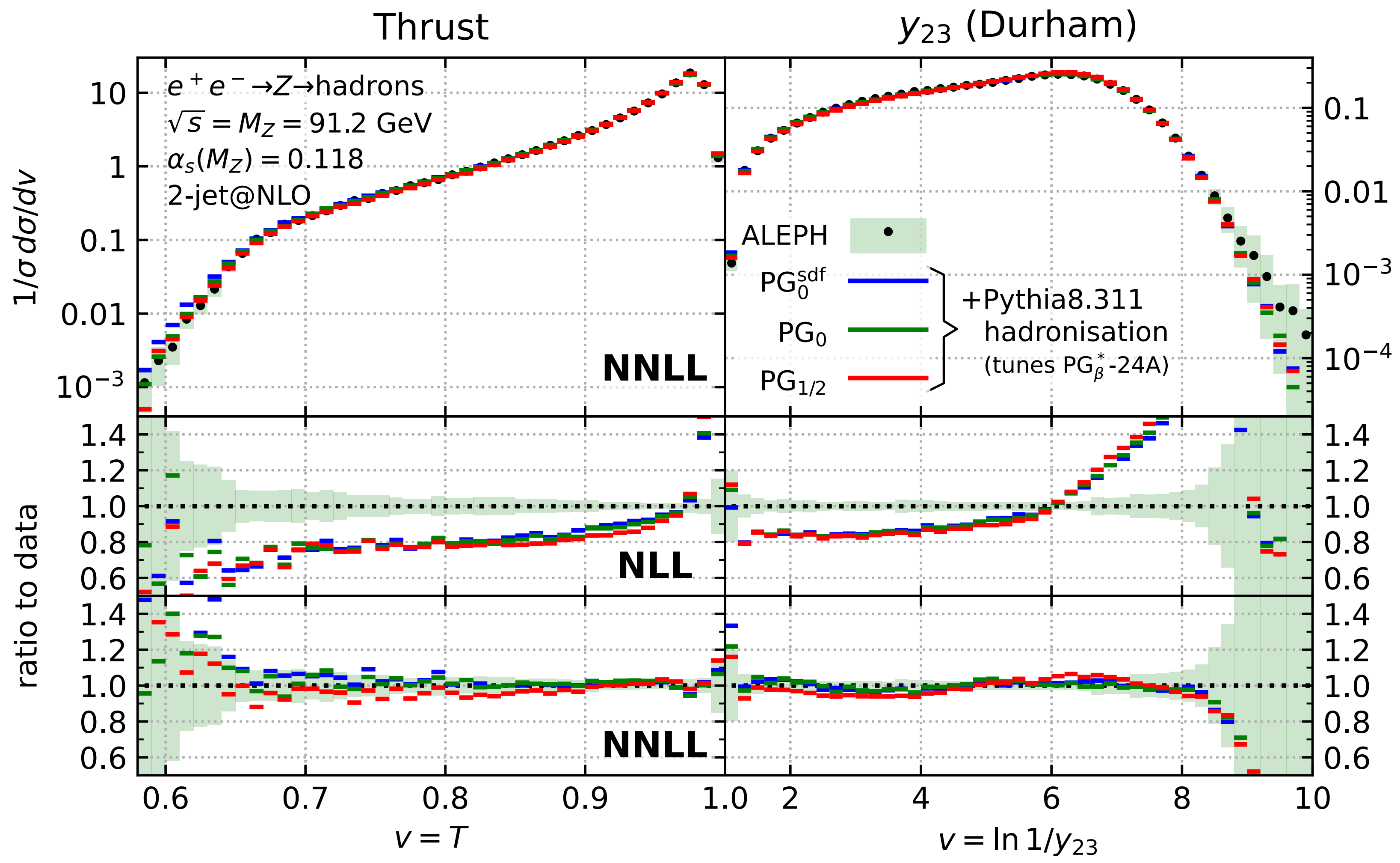
Comparison to LEP data



$$\alpha_s(m_Z) = 0.118$$

Colour is handled using the NODS scheme which gives full colour accuracy at NLL for global observables (includes those shown)

- Inclusion of NNLL potentially resolves the issue of needing an anomalously large value of $\alpha_s(m_Z)$ to achieve good agreement with LEP data. ($\alpha_s(m_Z) = 0.137$ in Pythia's Monash 13 tune * arxiv:1404.5630, Skands, Carrazza, Rojo)
- Some caution needed as no 3-jet NLO matching, which is known to be relevant away from the 2-jet region.
- A comprehensive study of shower uncertainties is still to be done.

*This should be taken as an average α_s^{eff} not an $\alpha_s^{\overline{MS}}$

Work towards pp is ongoing

High-purity gluon jet showers using secondary Lund jet planes

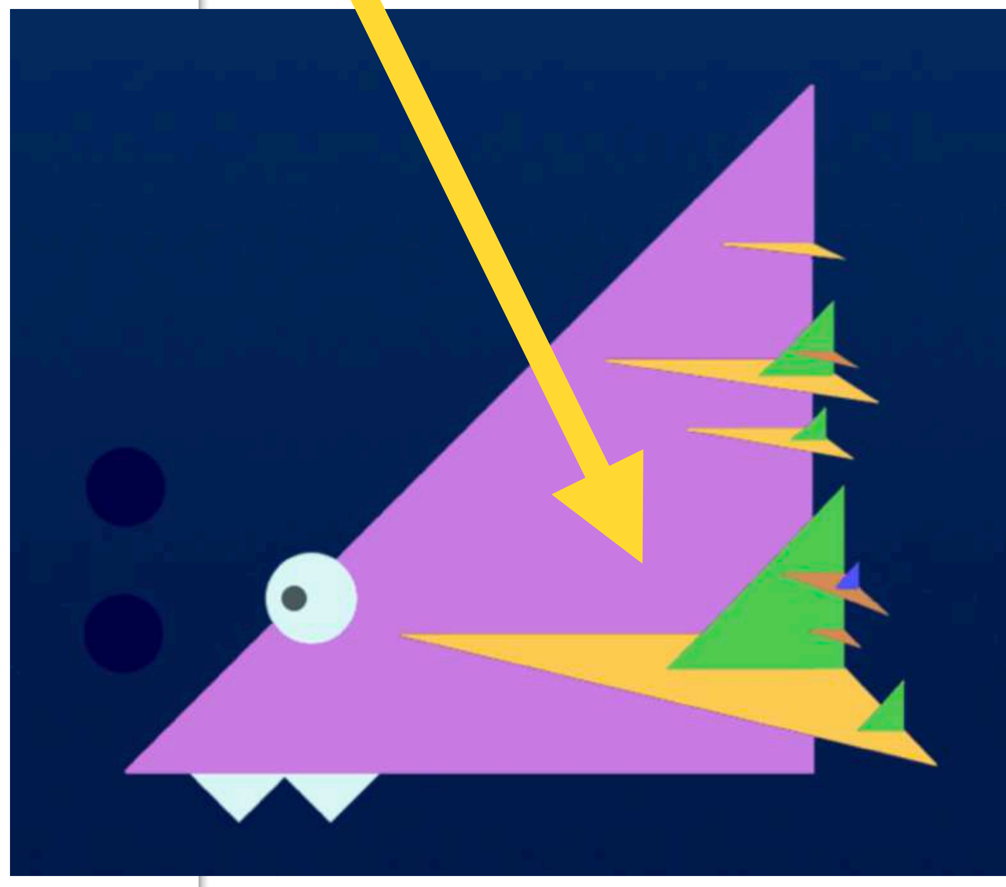
New observables

Cristian Barrera

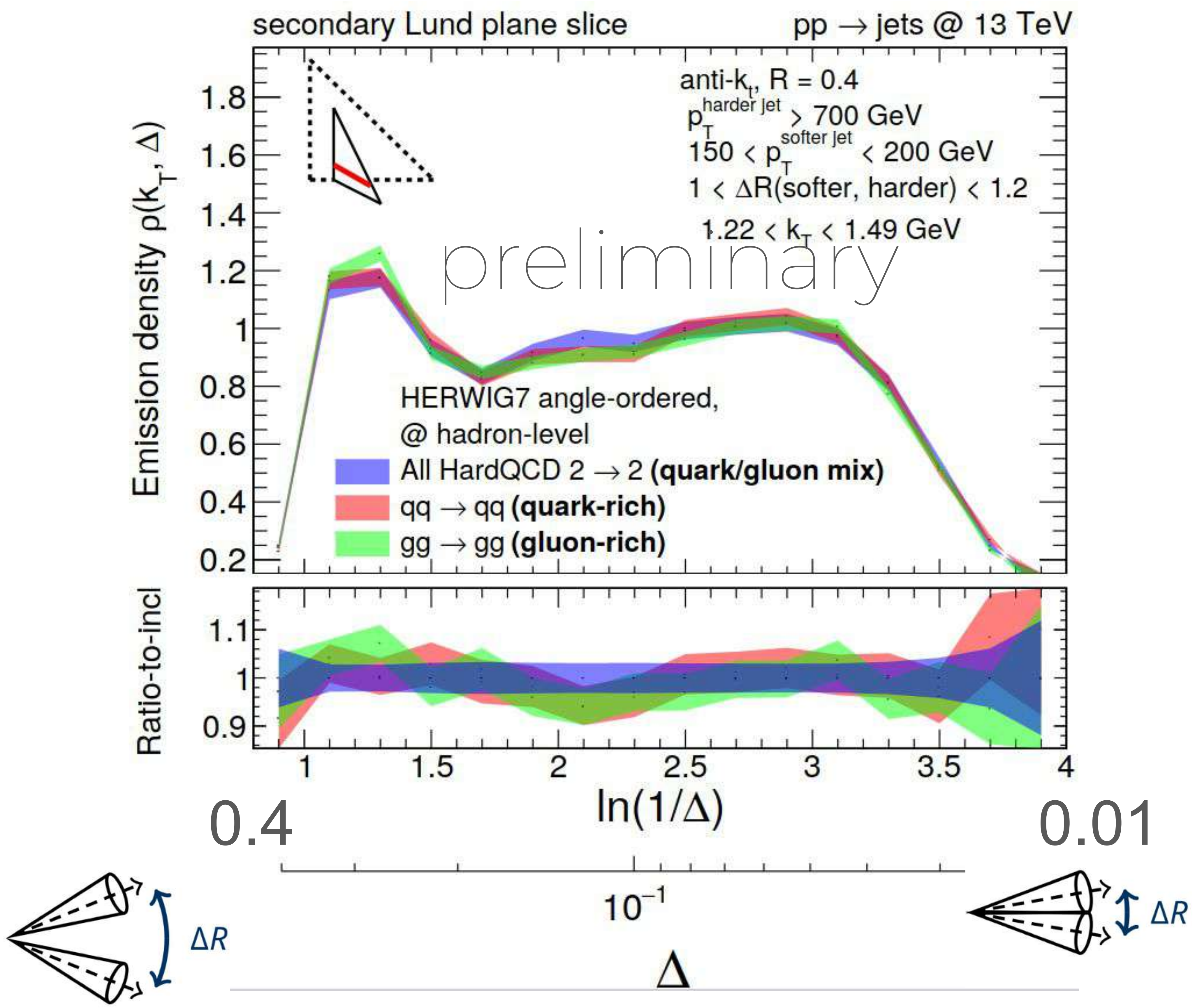
Can we constrain the gluon shower better?

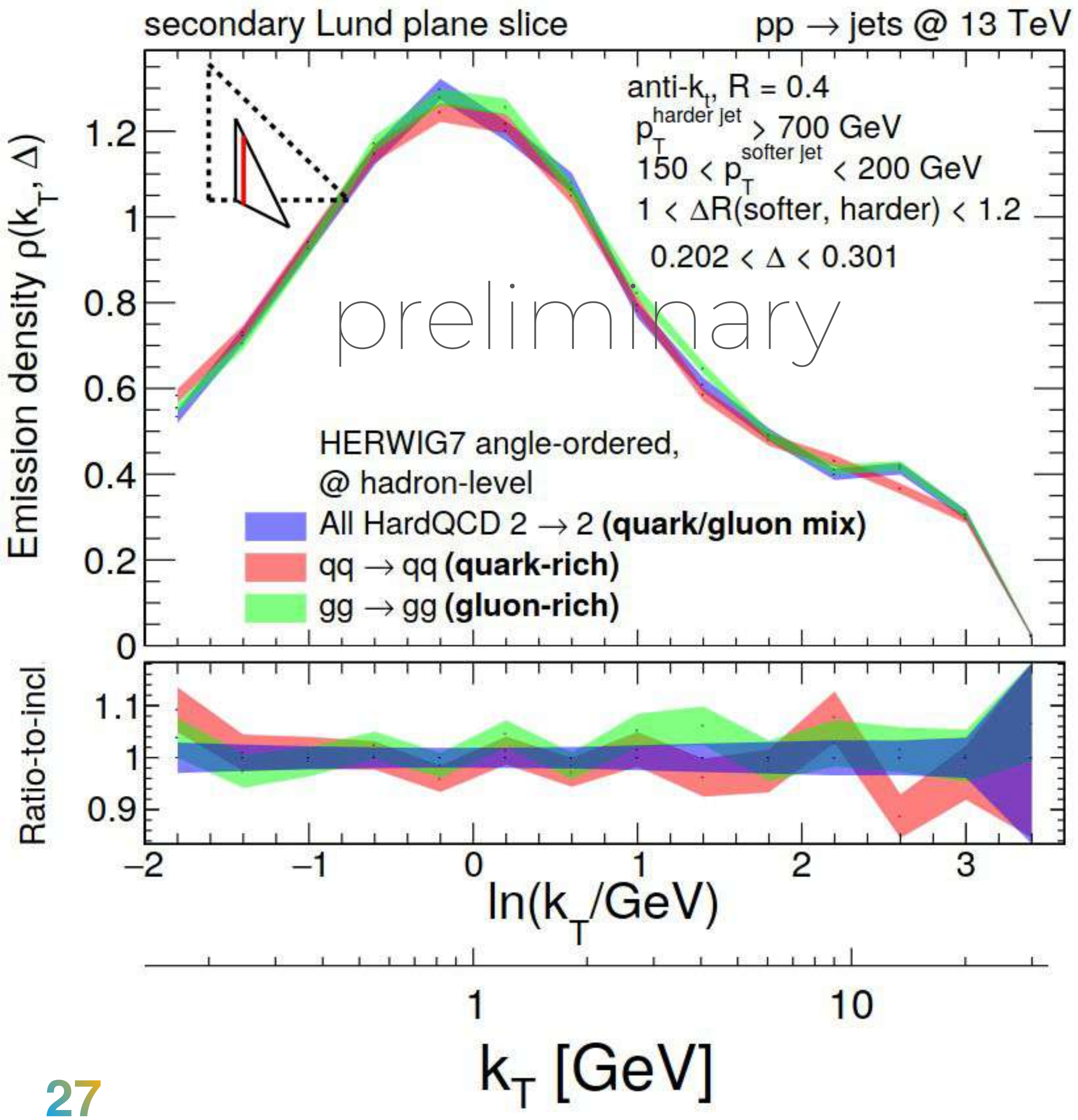
Input for e.g. heavy-ion studies and jet calibration

Use the secondary Lund jet plane



Process-independence, PDF-independence





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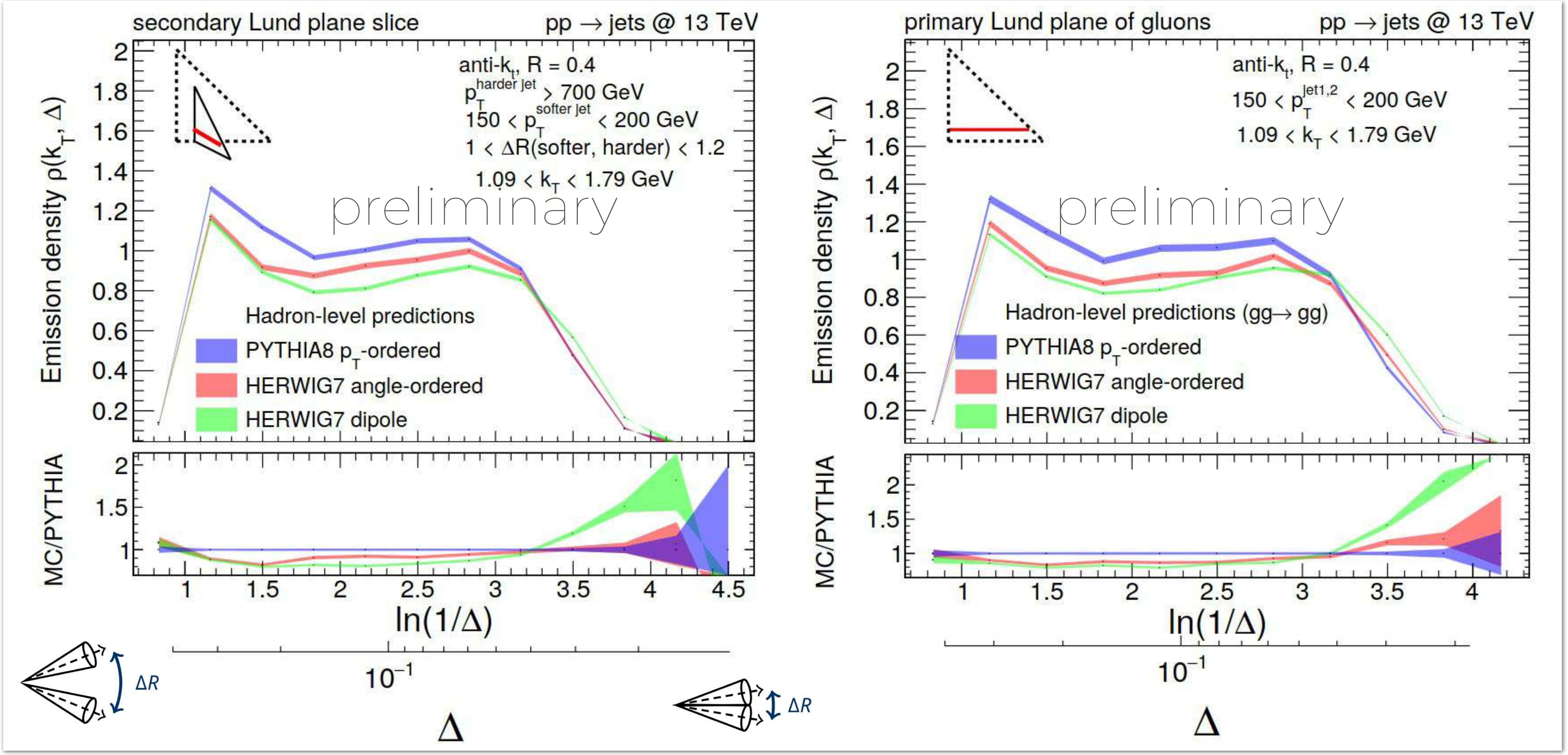

Can we understand this generator-dependence? Is any of them correct?

New calculations

Leonardo Bonino

How do heavy quarks fragment into hadrons (w one heavy quark)?

- $$\frac{1}{\sigma_{\mathcal{Q}}^{tot}}\sigma_{\mathcal{Q}}\left(Q,m\right)=\frac{1}{\sigma_{\mathcal{Q}}^{tot}}\sigma^{(0)}\sum_{i,j}C_i\left(Q,\mu,\mu_F\right)E_{ij}\left(\mu_F,\mu_{0F}\right)D_{j\to\mathcal{Q}}\left(\mu_{0F},m\right)$$

2 factorisation scales: μ_F and μ_{0F}

  - Initial conditions $D_{j\to\mathcal{Q}}$ @ NNLO **[Melnikov, Mitov '04] [Mitov '04] [Maltoni et al. '22]**
  - DGLAP Evolution (ZM-VFNS @ NLO) E_{ij} with MELA **[Bertone et al. '15] [Ridolfi et al. '19]**
  - Coefficient functions C_i @ NNLO **[Rijken, van Neerven '97] [Blümlein, Ravindran '06] [Mitov, Moch '06]**
- Poor behaviour in large-N $(x\to 1)$ region (Sudakov region)
  - Need resummation @ NNLL in initial conditions and coefficient functions **[Cacciari, Catani '01] [Aglietti et. al '06] [Maltoni et al. '22] [Czakon et al. '22]**

Heavy Quark Fragmentation in e+e- Collisions to NNLO+NNLL Accuracy in Perturbative QCD

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Leonardo Bonino

How do heavy quarks fragment into hadrons (w one heavy quark)?

- $\frac{1}{\sigma_{\mathcal{Q}}^{tot}} \sigma_{\mathcal{Q}}(Q, m) = \frac{1}{\sigma_{\mathcal{Q}}^{tot}} \sigma^{(0)} \sum_{i,j} C_i ($
  - Initial conditions $D_{j \to \mathcal{Q}}$ @ NNLO
  - DGLAP Evolution (ZM-VFNS @
  - Coefficient functions C_i @ NNLO
- Poor behaviour in large-N $(x \to 1)$
  - Need resummation @ NNLL in i

et. al '06] [Maltoni et al. '22] [Czakon et al. '22]

Flashback to 2017

When will NNLO be relevant

- we want $2 \to 3$ e.g. W/Z+jet or dijets (so as to have at least 2 particles in the jet!)
- $2 \to 2$ is availale
- rule of thumb adding one loop or one leg takes $\mathcal{O}(10)$ years

$\Rightarrow$ NNLO meets BOOST around 2025

Only one year off!

- Note 1: large community effort so we may hope for better
- Note 2: Boost=small angles $\Rightarrow$ delicate corner of phase space

Gregory Soyez | BOOST 2017 - Theory Summary | July 21 2017 | 26 / 42

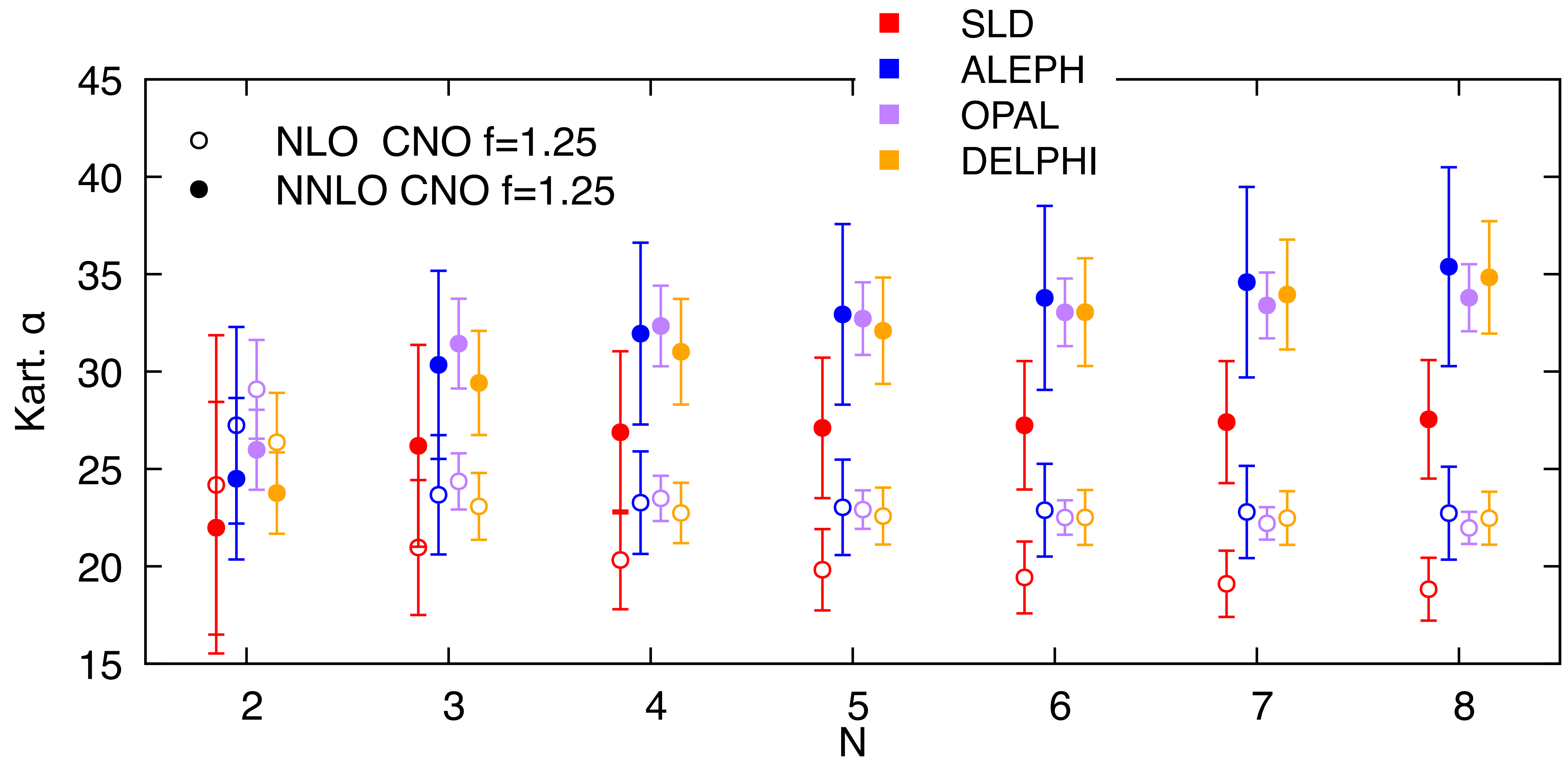
Heavy Quark Fragmentation in e+e- Collisions to NNLO+NNLL Accuracy in Perturbative QCD

New calculations

Leonardo Bonino

How do heavy quarks fragment into hadrons (w one heavy quark)?

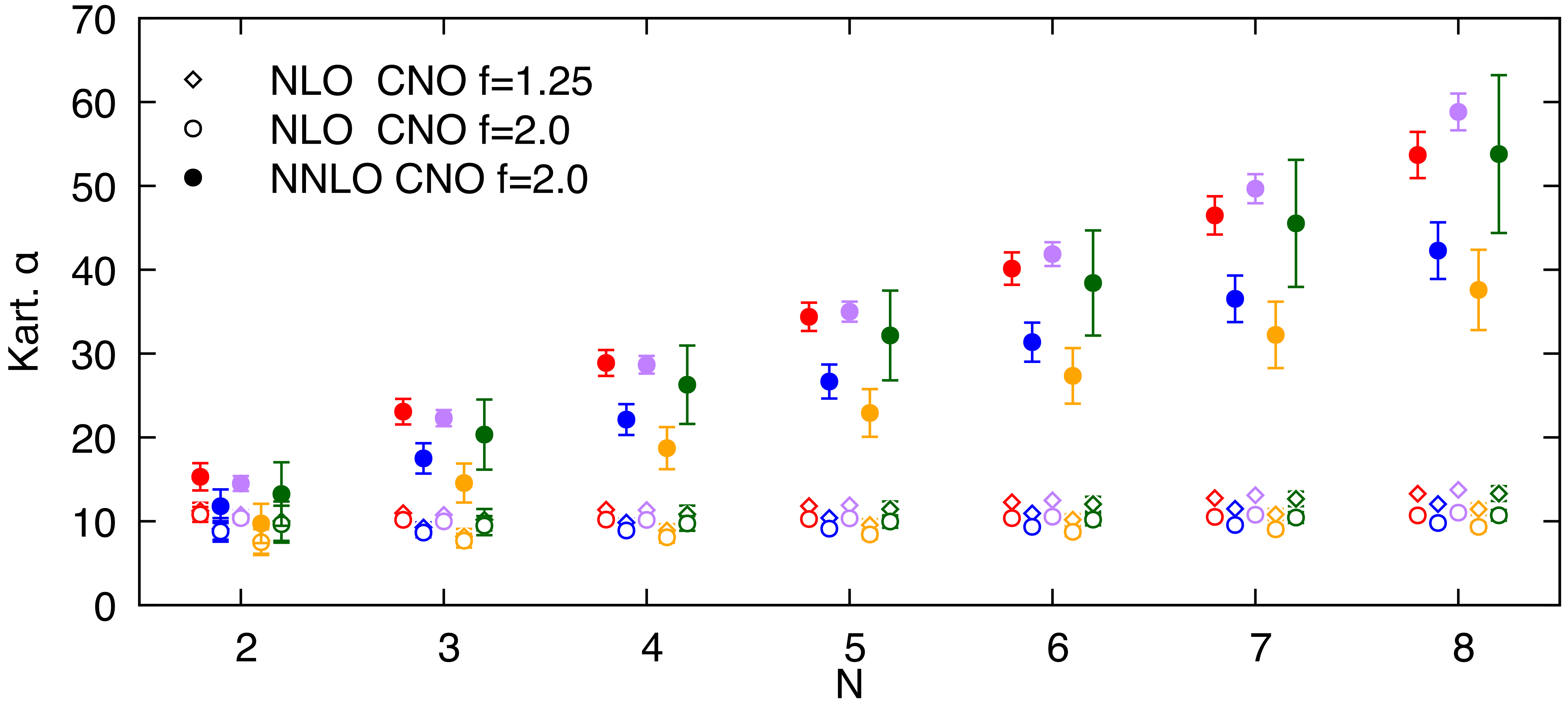
Extraction of FF is OK for bottom…



Which regularisation scheme is more sensible? Do we need to come up with something new?

- Single parameter non-perturbative function

$$D_K^{np}(x) = (\alpha+1)(\alpha+2)x^{\alpha}(1-x)$$ [Kartvelishvili et al. '78]



… but not so much for charm

Towards Quarkonium Fragmentation from Heavy-Flavor Non-Relativistic Evolution

New calculations

Francesco Celiberto

How do heavy quarks fragment into hadrons (w ~~one~~ two heavy quark)?

HADRONIC STRUCTURE

QUARKONIUM THEORY

PRECISION QCD

COLLINEAR FACTORIZATION

Guiding principle ⇒ ¡ Use the best of the Two Worlds as much as we can !

Heavy flavor non relativistic evolution

Towards Quarkonium Fragmentation from Heavy-Flavor Non-Relativistic Evolution

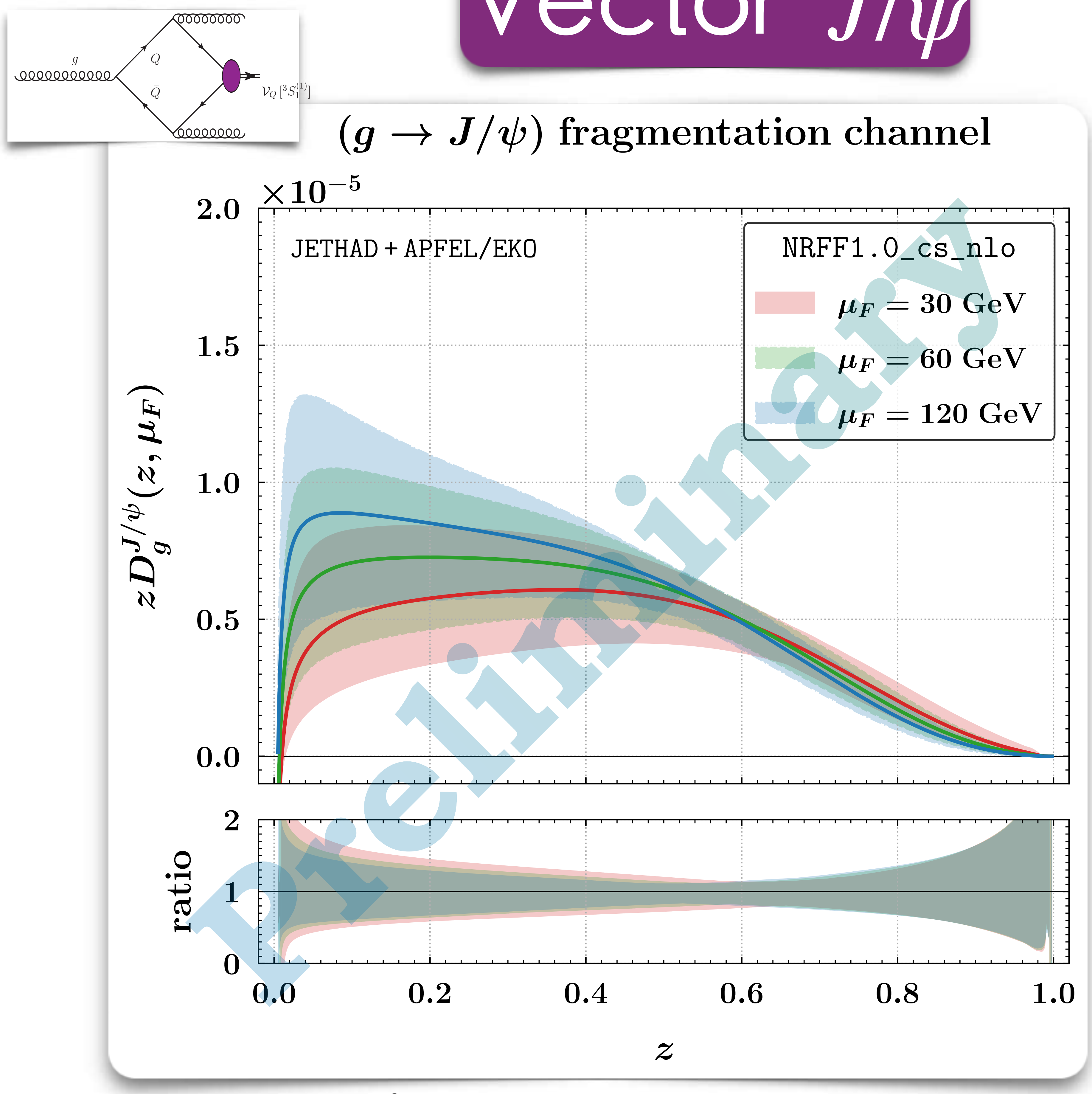
New calculations

Francesco Celiberto

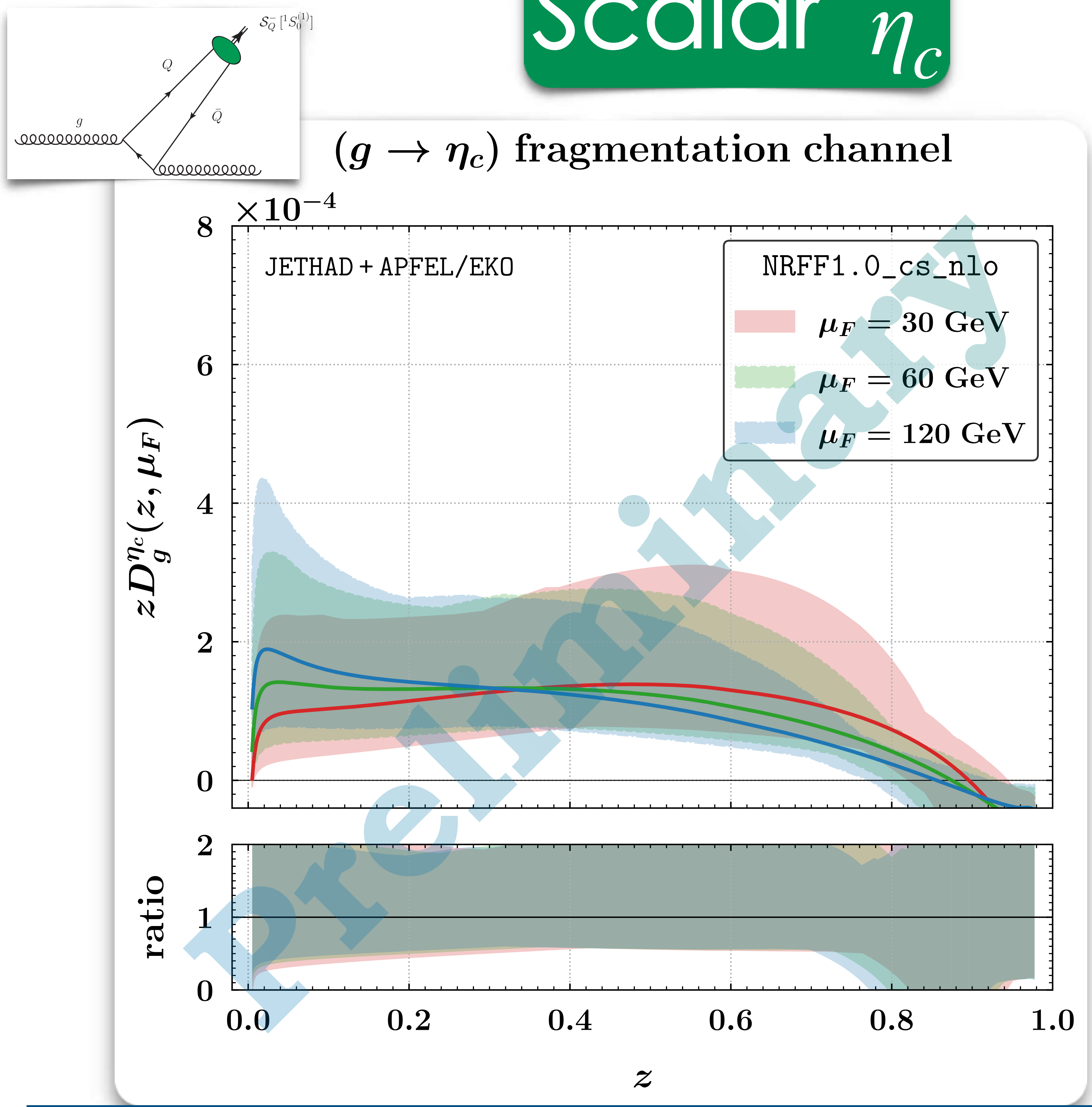
How do heavy quarks fragment into hadrons (w ~~one~~ two heavy quark)?

NRFF1.0: Gluon fragmentation to charmonia

Vector J/ψ



Scalar η_c



"next up: quarkonium jet substructure"

One-loop gauge invariant amplitudes with a spacelike gluon in hybrid kT-factorization

New calculations

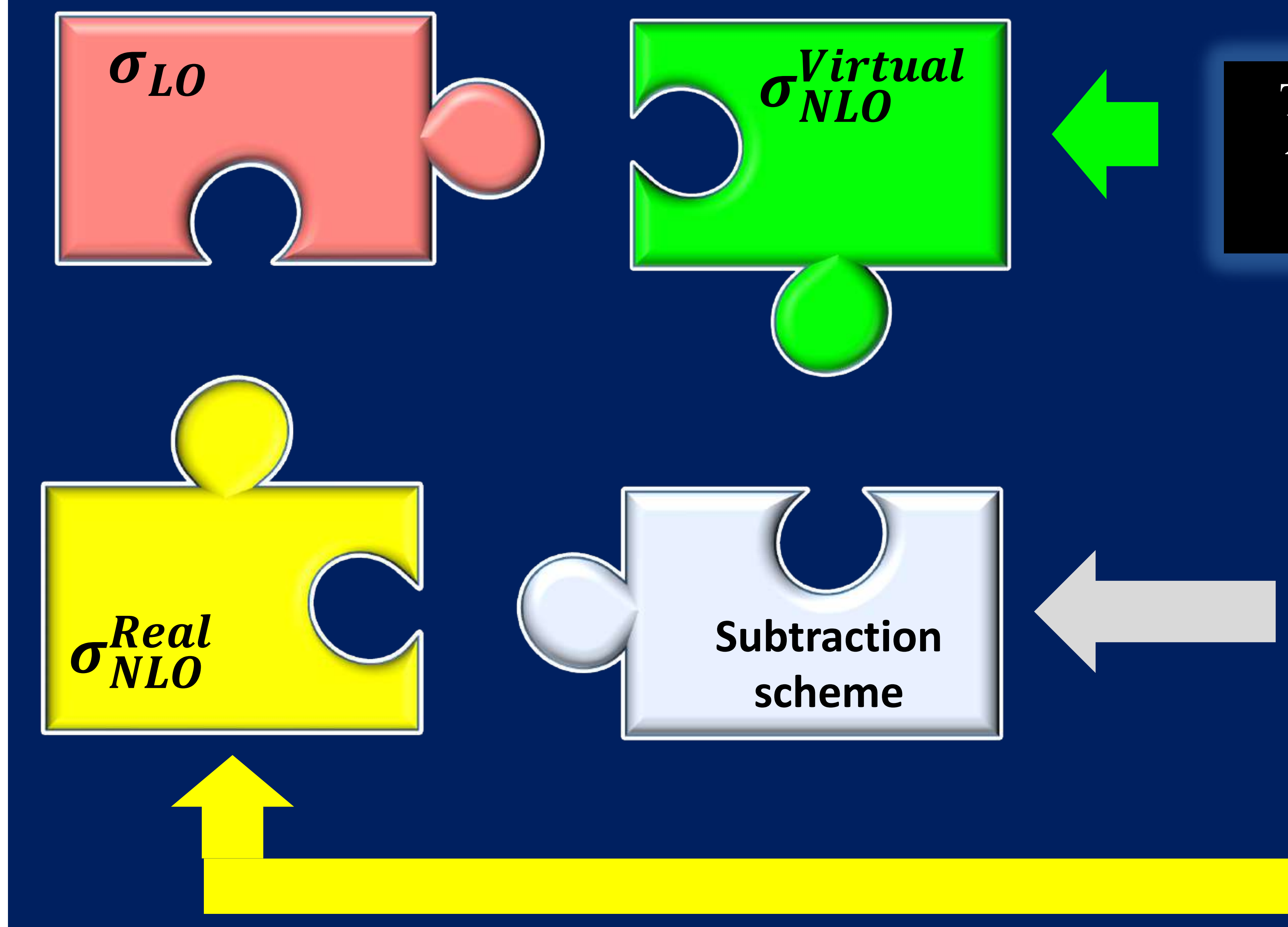
Alessandro Giachino

k_T factorisation naturally describes small-x / forward physics better

Issue: difficult to formulate beyond LO

Let's start with a hybrid approach first!

$$\sigma^{NLO} = \sigma_{LO} + \sigma^{Real}_{NLO} + \sigma^{Virtual}_{NLO}$$



The Λ dependent contributions have UNIVERSAL structure: this is a fundamental step to calculate NLO cross sections in hybrid kT-factorization! [*]

We presented a subtraction scheme for the calculation of the real-radiation contribution. We did implement the scheme and performed calculations for all processes relevant for 2-jet production as NLO, and found that the subtracted real-radiation integrals indeed converge [**]

[*] E. Blanco, A. G., A. van Hameren, P. Kotko, Nucl. Phys. B 995 (2023).
[**] A. G., A. van Hameren and G. Ziarko, *J. High Energ. Phys.* 2024, 167 (2024

"Stay tuned for automated NLO calculations"

Heavy flavour jet substructure

New calculations

Heavy flavour jet substructure

New calculations

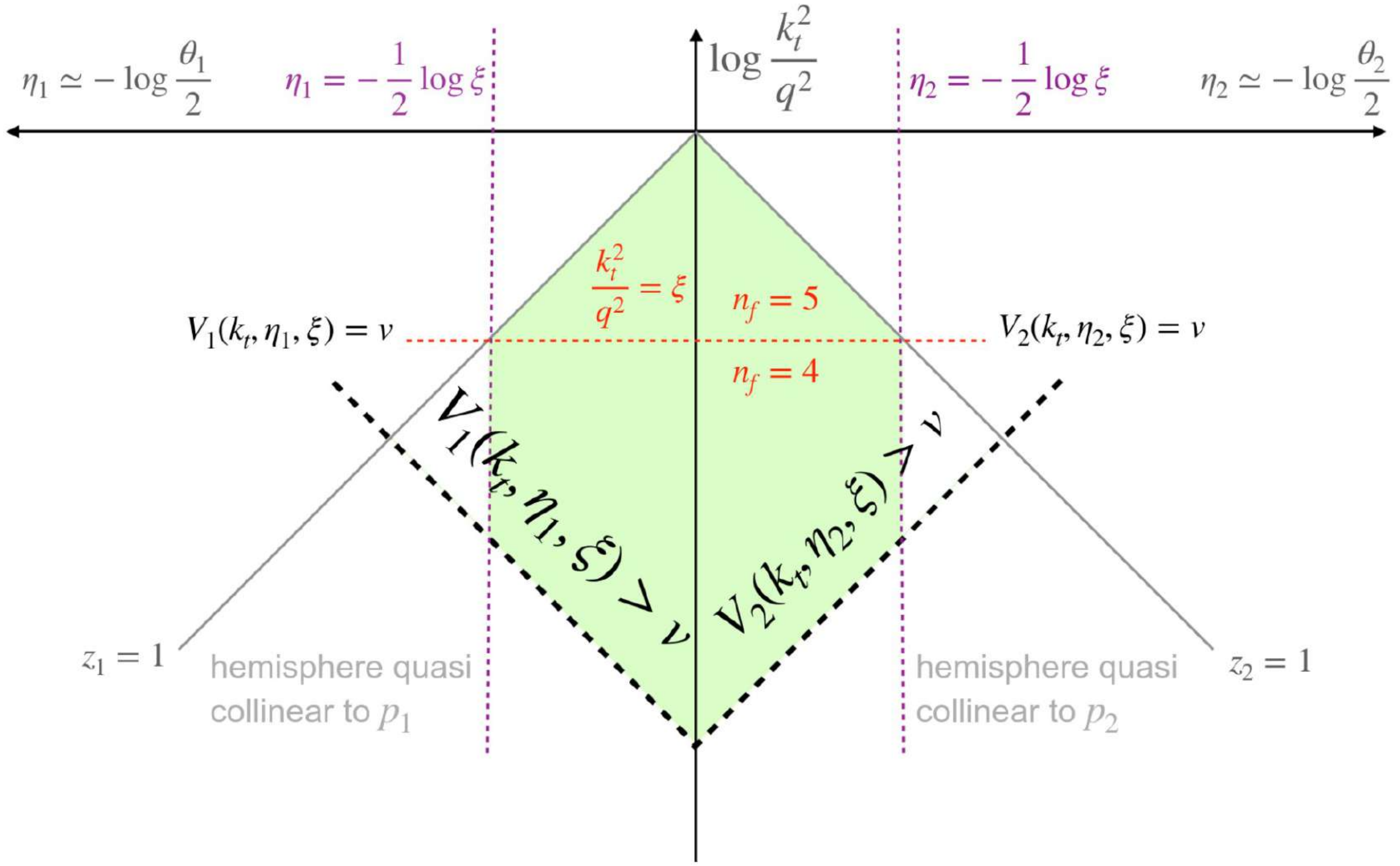
Reuse the massless resummation techniques for the massive case

Lund Plane for massive particles

[Ghira, Marzani, Ridolfi (2309.06139)]

In the massive case the following we have

- to consider the quasi-collinear splitting function $P_{Qg \leftarrow Q}$
- to modify the PS (aka the Lund Plane) introducing a new boundary (dead cone effect)
  ➞ new vertical lines
- to introduce boundaries corresponding to 4 and 5 active flavour treshold (or 3 and 4)
  ➞ new horizontal lines
- to take into account that the observable might explicitly depends on the HQ mass
  ➞ dashed lines are deformed



Observables studied (or under investigation) exploiting this framework: Andrea Ghira

θ_g z_g Simone Caletti this talk

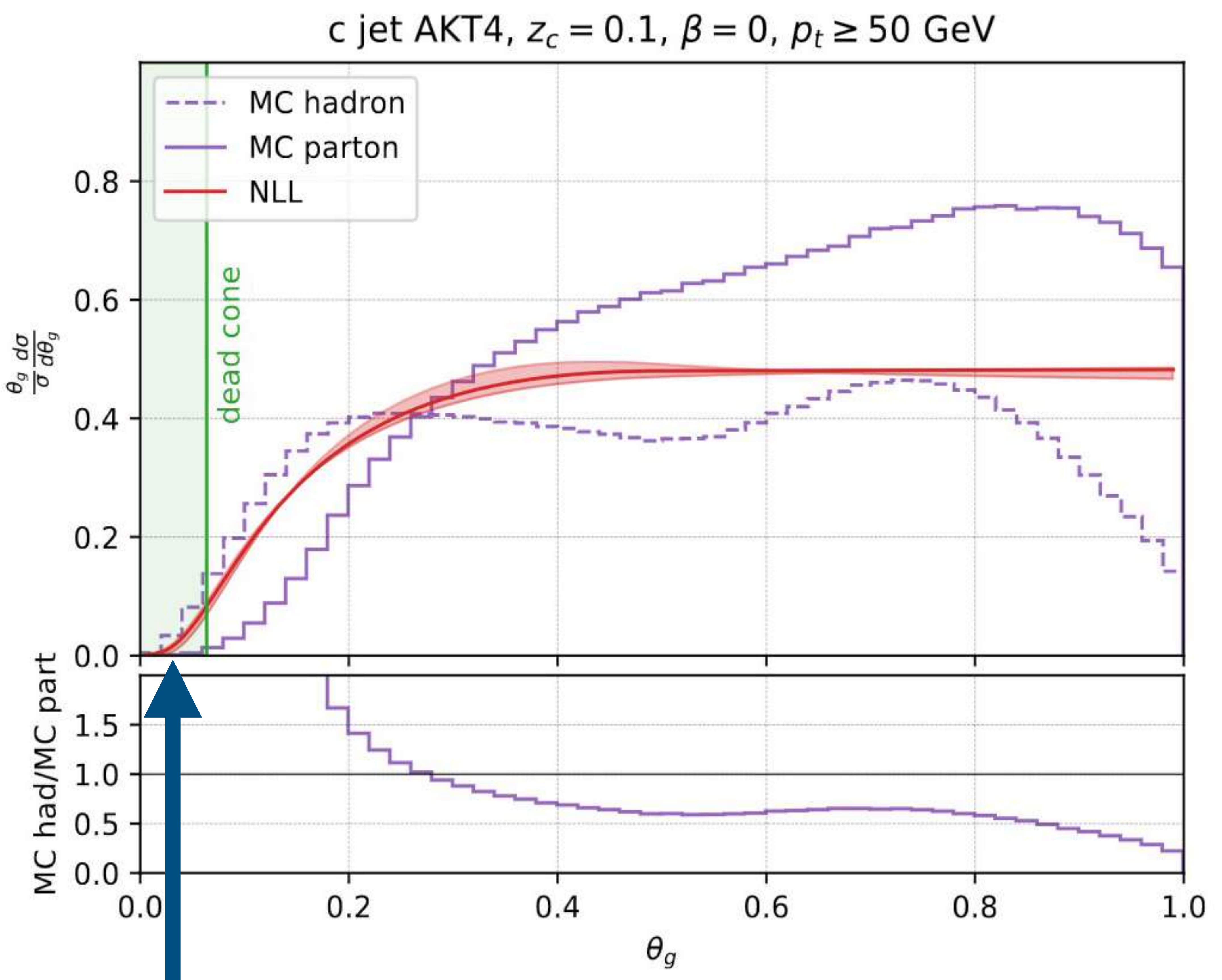
λ_α see Andrea's talk

ECF

7

Simone Caletti

Soft-drop z_g and θ_g



Deadcone suppression

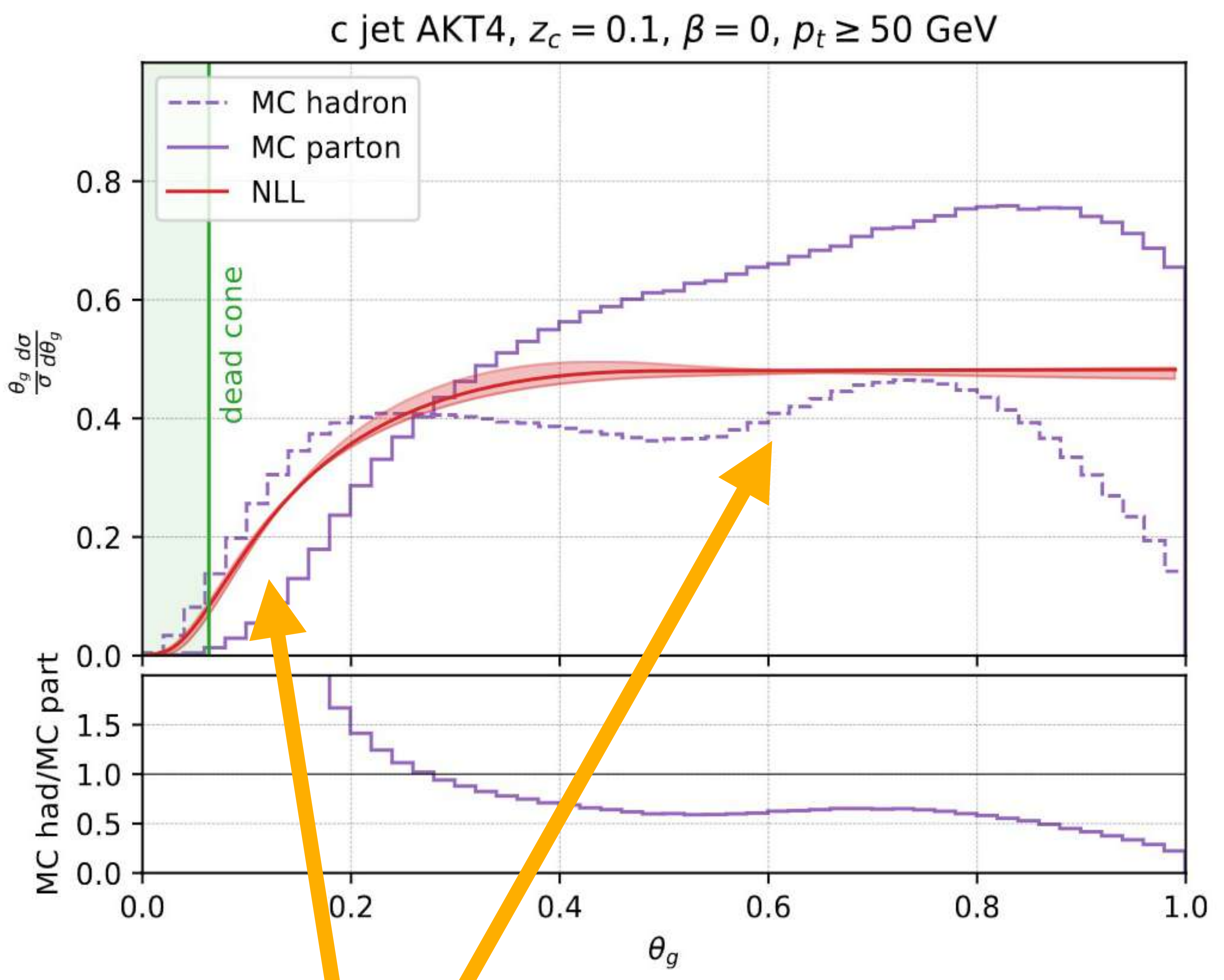
Andrea Ghira

Jet angularities

New calculations

Simone Caletti

Soft-drop z_g and θ_g



Large non-perturbative effects, no agreement with NLL

Andrea Ghira

Jet angularities

New calculations

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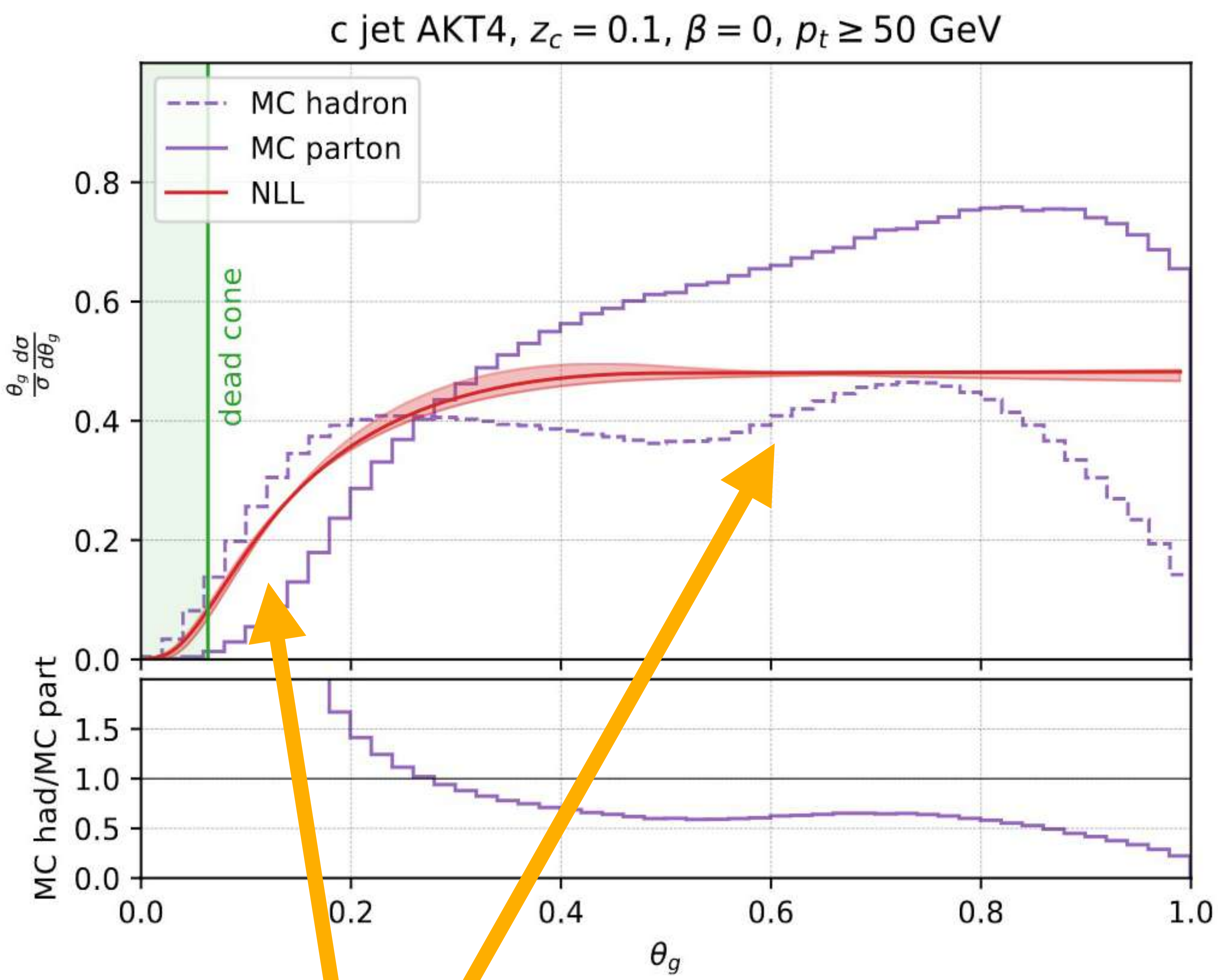


Large non-perturbative effects, no agreement with NLL

Andrea Ghira

New calculations

Jet angularities

What definition to take?

WTA axis (massless)

WTA axis (massive)

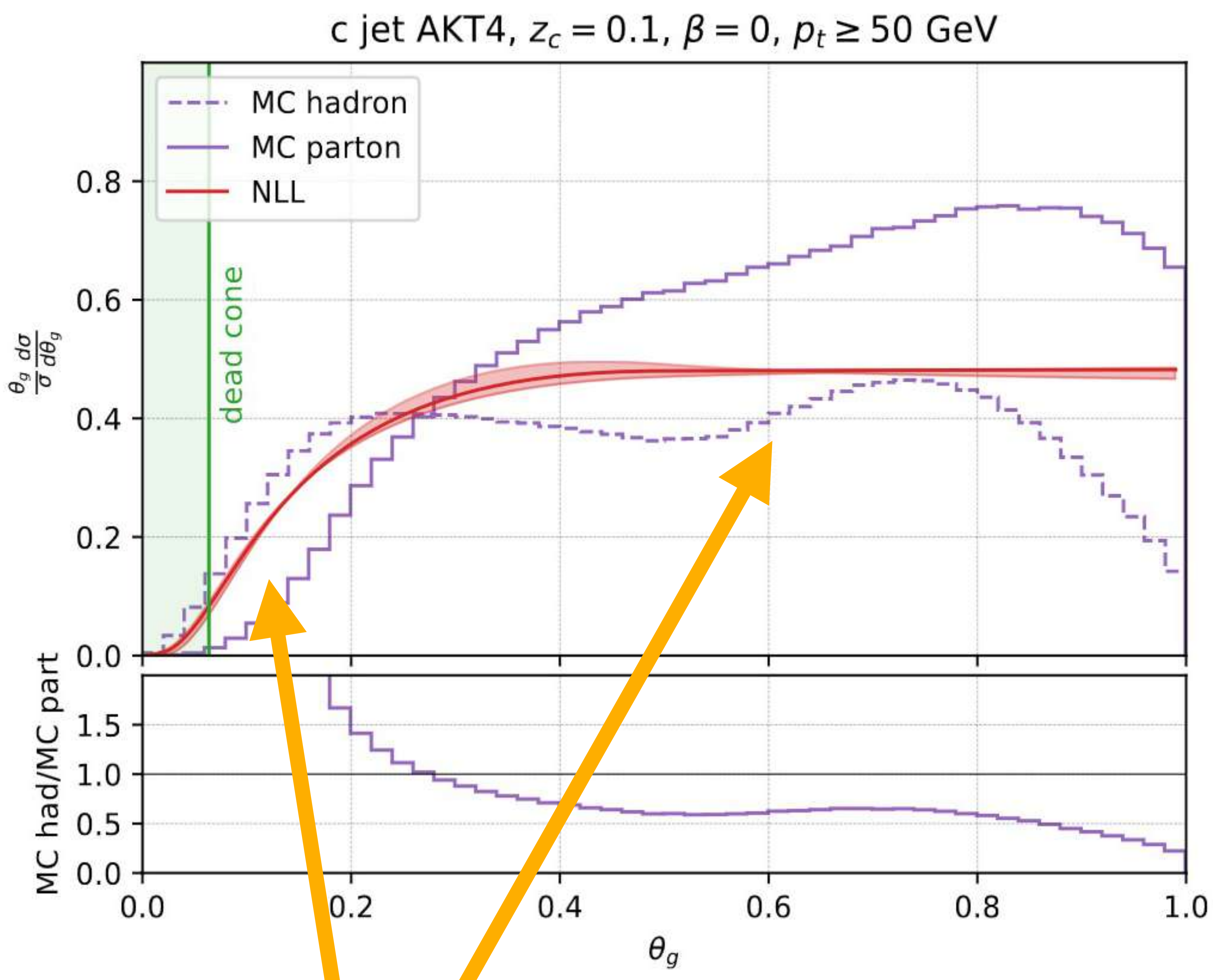
$$\dot{\lambda}_0^{\alpha} = \sum_i \frac{p_{t_i}}{p_t}\left(\frac{2p_i\cdot\bar{n}}{p_{t_i}R_0^2}\right)^{\frac{\alpha}{2}}, \quad \dot{\lambda}^{\alpha} = \sum_i \frac{p_{t_i}}{p_t}\left(\frac{2p_i\cdot n}{p_{t_i}R_0^2}\right)^{\frac{\alpha}{2}}$$

$$\lambda^{\alpha} = \sum_i \frac{p_{t_i}}{p_t}\left(\frac{\Delta R_i}{R_0}\right)^{\alpha}, \quad \mathring{\lambda}_0^{\alpha} = \sum_{i\neq n} \frac{p_{t_i}}{p_t}\left(\frac{2p_i\cdot\bar{n}}{p_{t_i}R_0^2}\right)^{\frac{\alpha}{2}}, \quad \mathring{\lambda}^{\alpha} = \sum_{i\neq n} \frac{p_{t_i}}{p_t}\left(\frac{2p_i\cdot n}{p_{t_i}R_0^2}\right)^{\frac{\alpha}{2}}$$

Goal: highest sensitivity to deadcone effect

Simone Caletti

Soft-drop z_g and θ_g



Large non-perturbative effects, no agreement with NLL

Andrea Ghira

Jet angularities

New calculations

What definition to take?

Don't resum well

$$\cancel{\dot{\lambda}_0^\alpha = \sum_i \frac{p_{t_i}}{p_t}\left(\frac{2p_i \cdot \bar{n}}{p_{t_i} R_0^2}\right)^{\frac{\alpha}{2}}, \quad \dot{\lambda}^\alpha = \sum_i \frac{p_{t_i}}{p_t}\left(\frac{2p_i \cdot n}{p_{t_i} R_0^2}\right)^{\frac{\alpha}{2}}}$$

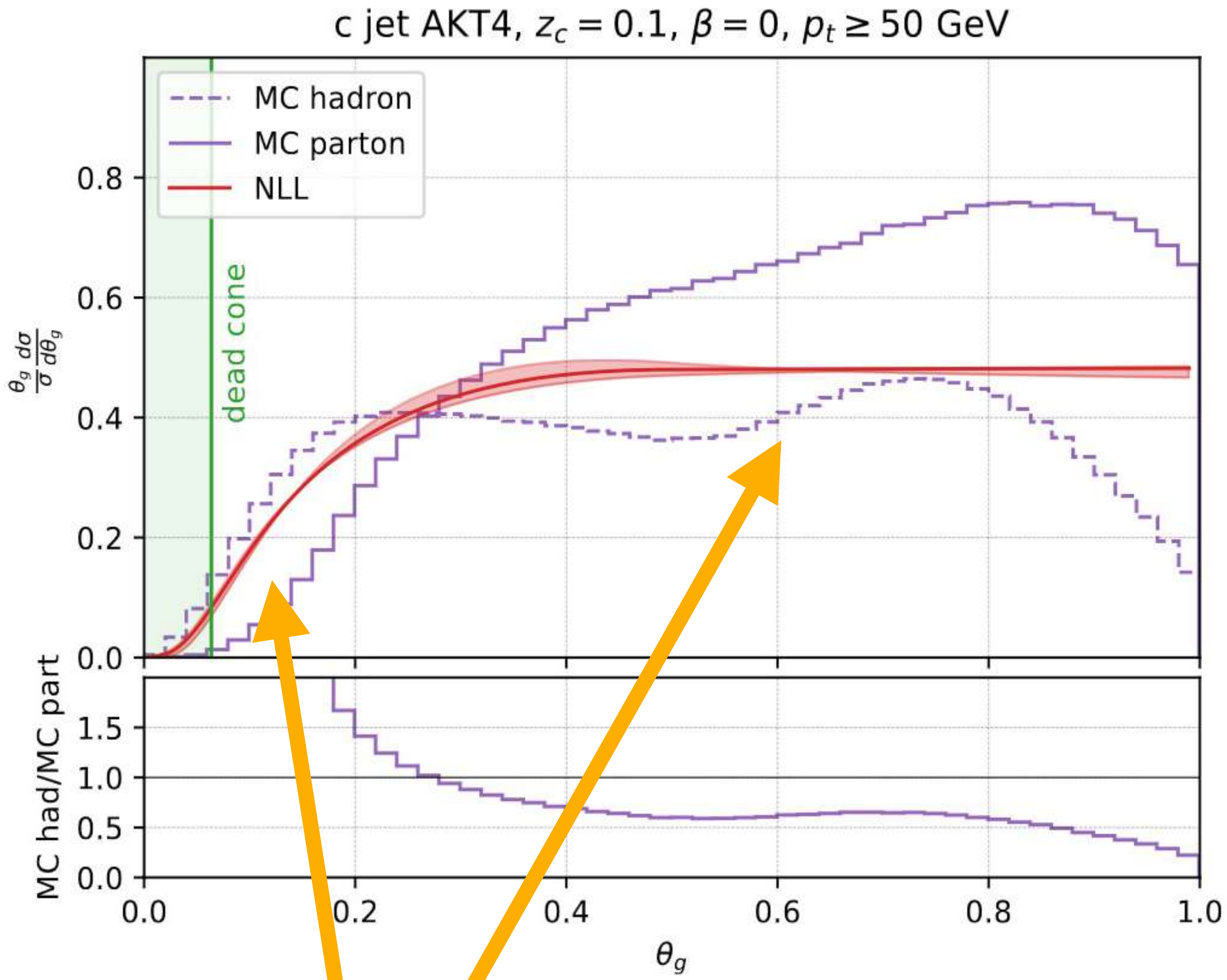
$$\lambda^\alpha = \sum_i \frac{p_{t_i}}{p_t}\left(\frac{\Delta R_i}{R_0}\right)^{\alpha}, \quad \cancel{\mathring{\lambda}_0^\alpha = \sum_{i\neq n} \frac{p_{t_i}}{p_t}\left(\frac{2p_i \cdot \bar{n}}{p_{t_i} R_0^2}\right)^{\frac{\alpha}{2}}, \quad \mathring{\lambda}^\alpha = \sum_{i\neq n} \frac{p_{t_i}}{p_t}\left(\frac{2p_i \cdot n}{p_{t_i} R_0^2}\right)^{\frac{\alpha}{2}}}$$

Have larger NP corrections

Take $\alpha = 1$

Soft-drop z_g and θ_g

Simone Caletti

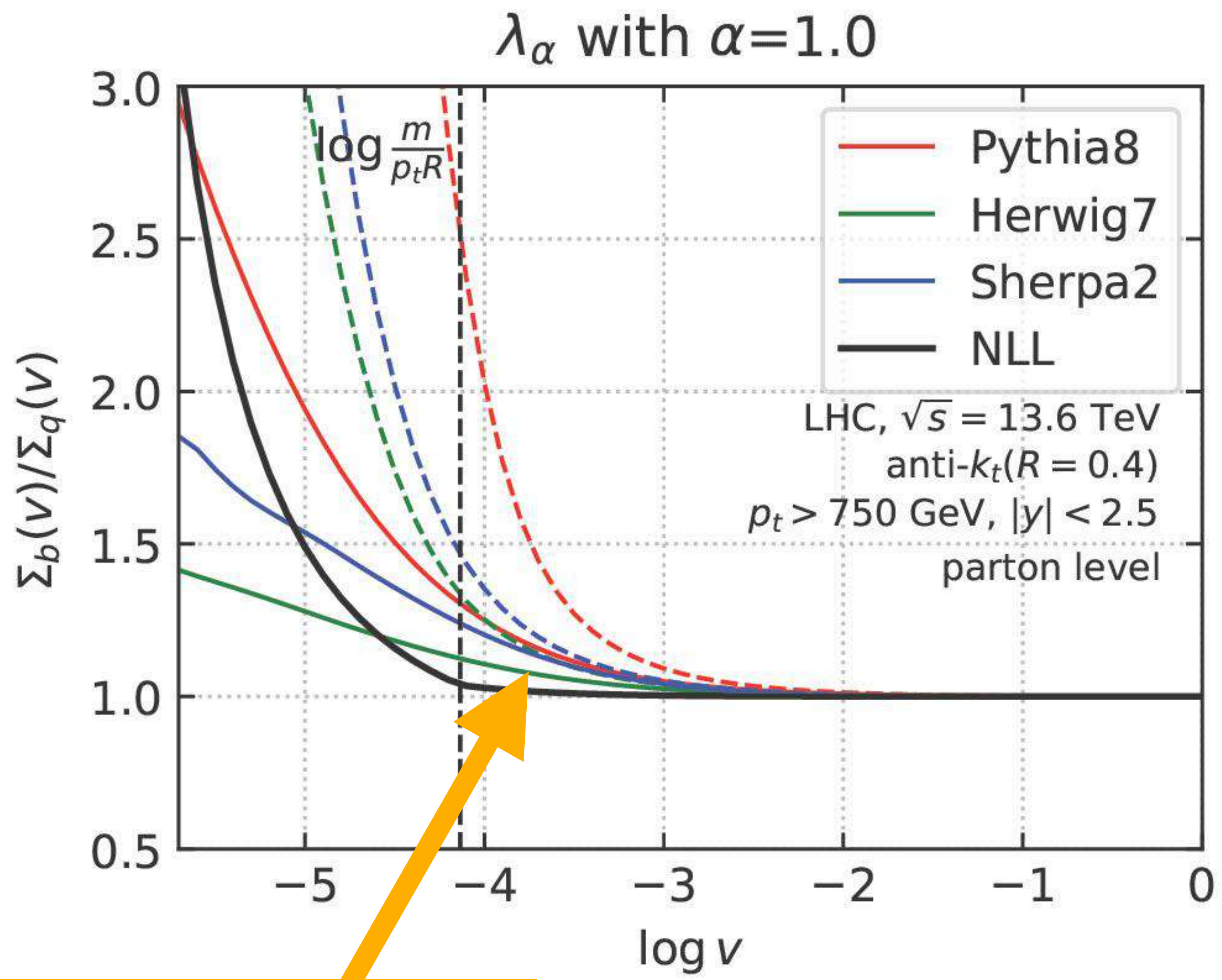


Large non-perturbative effects, no agreement with NLL

Jet angularities

Andrea Ghira

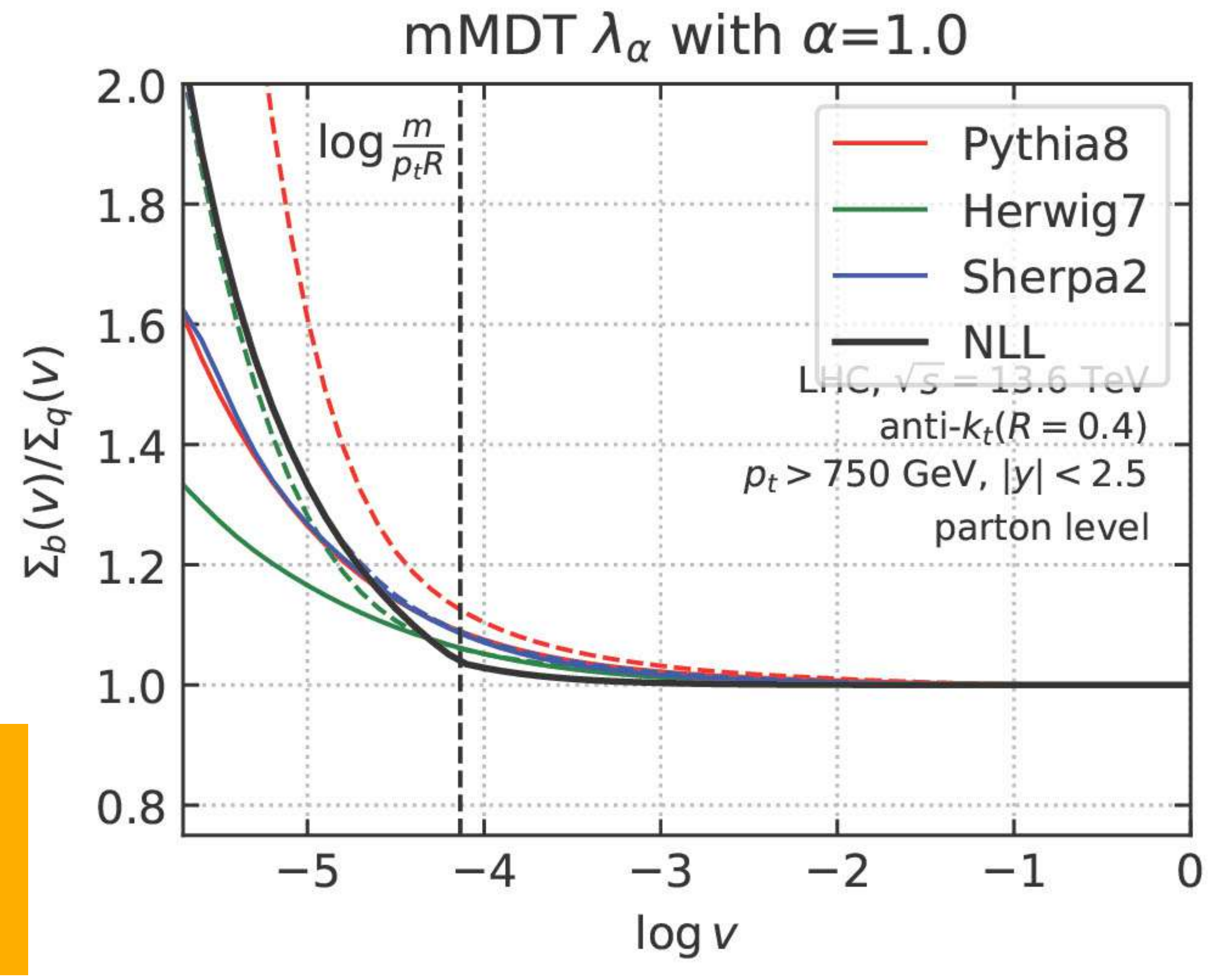
New calculations



Dashed:

$$\frac{\Sigma_b^{hadron}}{\Sigma_q^{hadron}}$$

Too early onset of the deadcone effect?



Can we understand these differences better?

Melissa van Beekveld

Heavy flavour jet substructure for heavy ion collisions

New calculations
Chang Wu

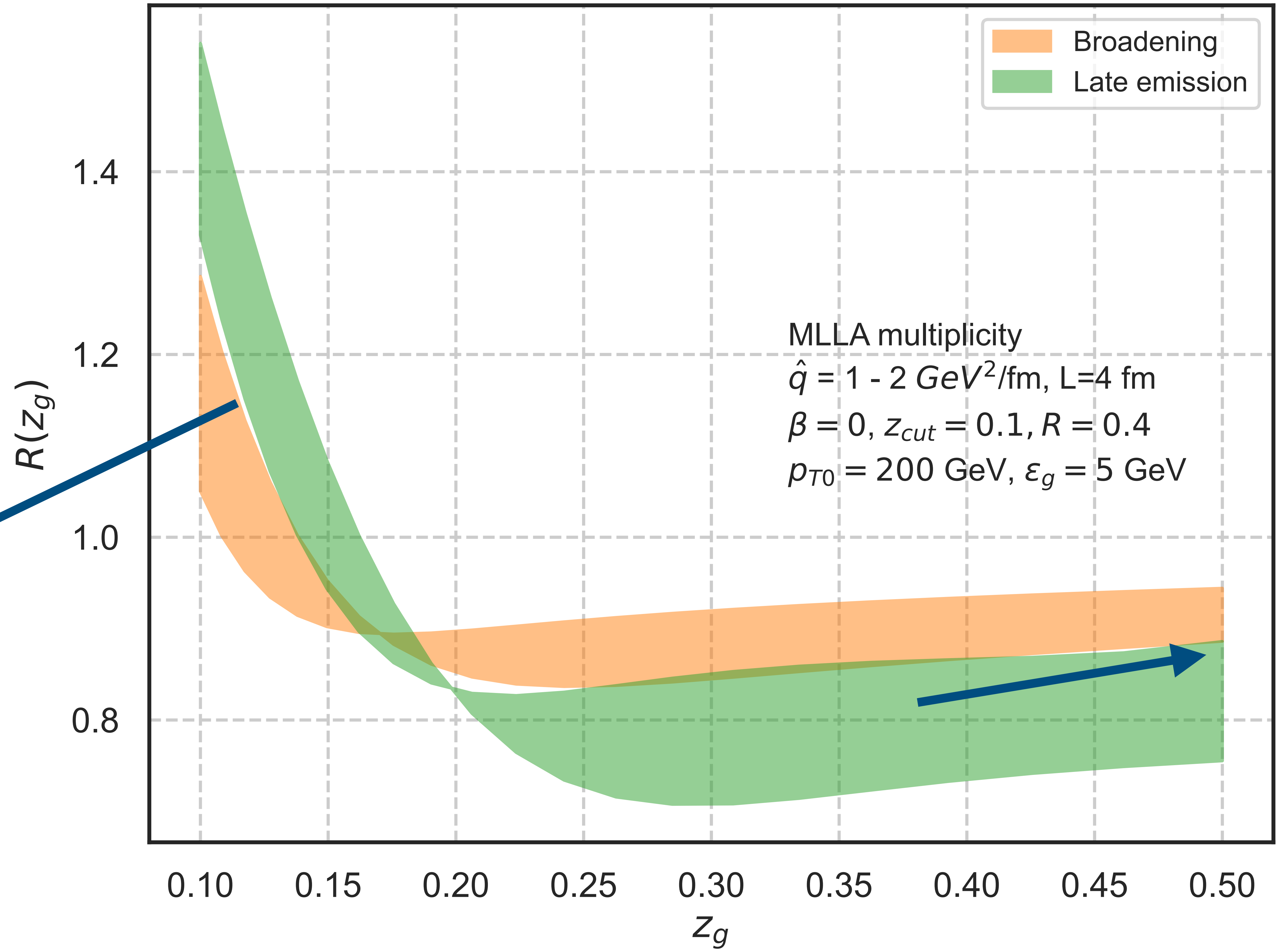
Can we get a pure measurement of emissions originating from medium?

Medium-induced emissions appear at angles < deadcone → isolate this region!

Caucal, Iancu, Soyez

Vacuum emissions happen fast, medium dynamics happen later → extend this picture to account for quark masses

Ratio medium over vacuum z_g distribution



medium-induced emissions

vacuum-induced emissions

Unbiased quantification of jet energy loss

New observables

João Silva

Can we estimate jet energy loss when they travel through a medium?

We want to compare vacuum and medium predictions, but hard because of pT migration → we need to calculate this migration (or have a hard probe)

(Pseudo-)Quantiles, introduced by J. Brewer, J. Milhano, J. Thaler can do this for you

Energy loss dependence on color charge

q ~ C_F g ~ C_A

See ATLAS

γ+jet ~ q init. jets

dijet ~ mixture of q and g init. jets

$\Rightarrow R_{AA}^{\gamma j} > R_{AA}^{jj}$

=

Casimir scaling in jets ?

Unbiased quantification of jet energy loss

New observables

[João Silva](#)

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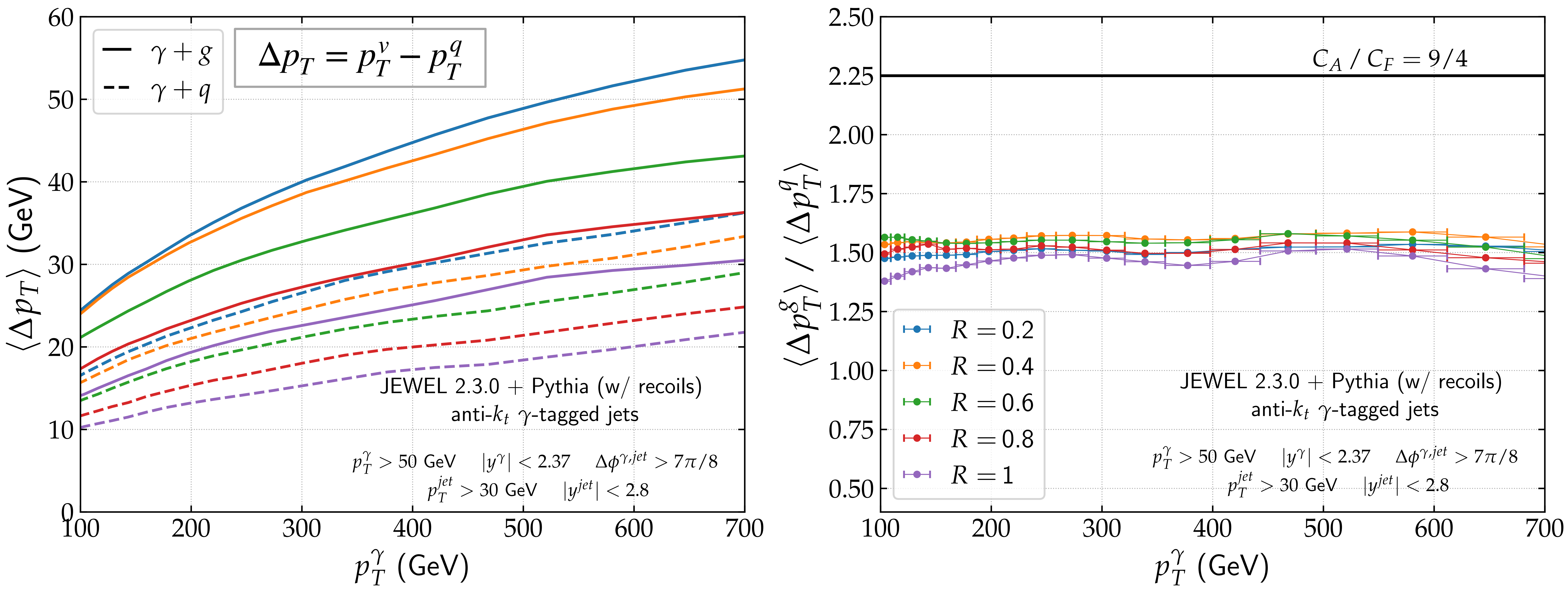


Casimir scaling is significantly reduced with respect to naive single parton scaling

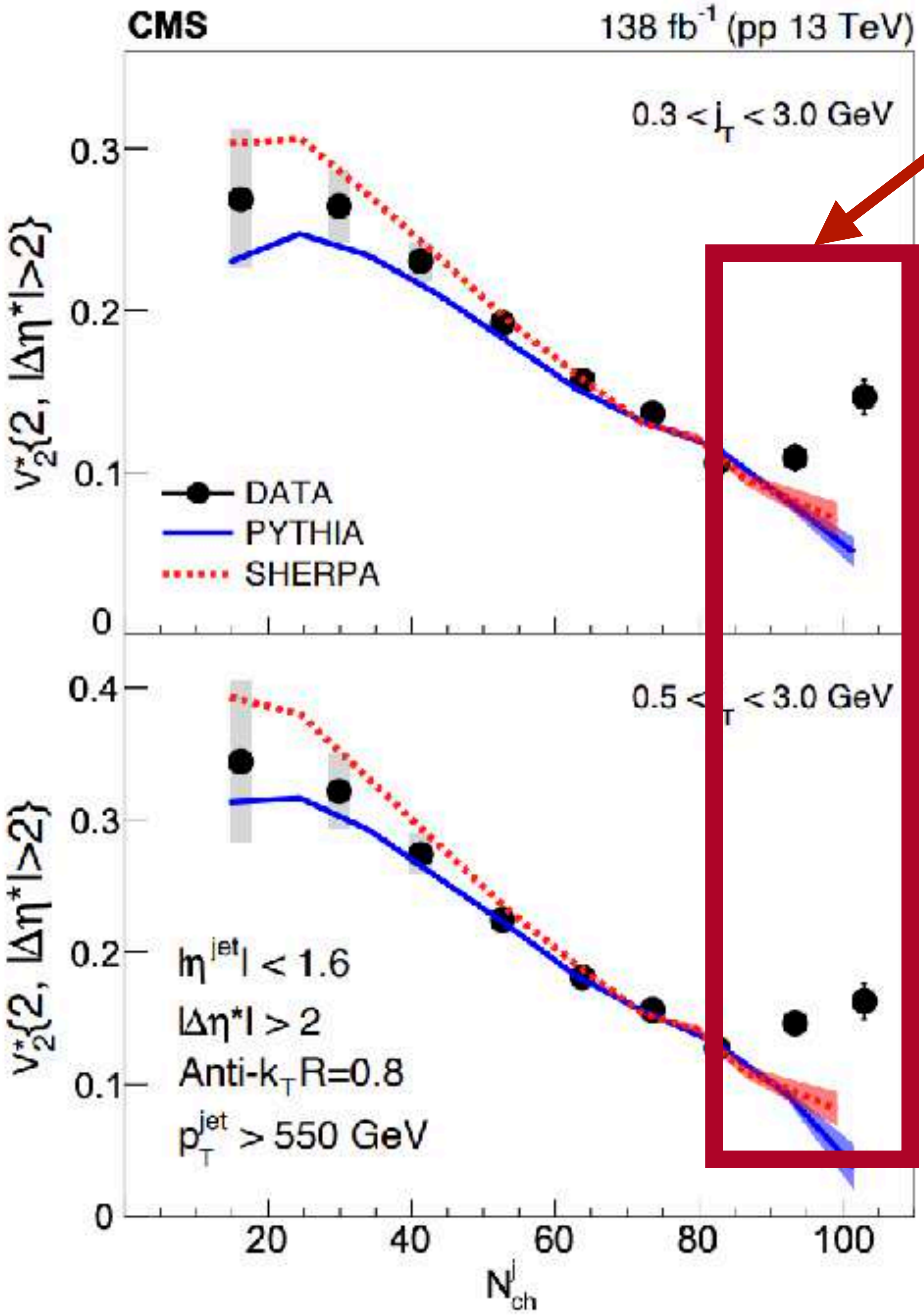
Event shapes of High Multiplicity Jets

New observables

Cari Cesarotti

Intrigued by an experimental observation…

Elliptic anisotropy coefficient for large η separation



Are we seeing new QCD dynamics?

Can we build a MC chain that predicts this?

Pipeline for studying hydrodynamics in jets (Work in progress)

Pythia 8 → Trajectum → Compute Event Shapes

Simulate CMS jet samples

Apply hydrodynamics to jet constituents

See if with hydro we can better match data

Compare v_2 to ring EMD? (See ATLAS 2305.16930)

Could reveal more about the nature of QCD!

Single heavy baryon study via spectra and decay width

New calculations
Hugo Tecocoatzi

Where do we need to look to find new hadrons and their excitations?

To get full info: calculate their mass spectrum AND their decay widths

- The masses of the heavy singly baryon states are calculated as the eigenvalues of the Hamiltonian , E. Santopinto, A. Giachino, J. Ferretti, H. Garcia-Tecocoatzi, M.A. Bedolla, R. Bijker, E. Ortiz-Pacheco, EPJC 79(12), 1012 (2019), which is modeled as:

$$H = H_{\mathrm{h.o.}} + P_s\,\mathbf{S}^2 + P_{sl}\,\mathbf{S}\cdot\mathbf{L} + P_I\,\mathbf{I}^2 + P_f\,\mathbf{C_2}(\mathrm{SU}(3)_{\mathrm{f}}), \qquad (1)$$

- The two-body strong decay widths are calculated with the predicted masses and their predicted quantum numbers
- The $^3P_0$ model is used for calculating the strong-decay widths of a singly heavy baryon A into a singly heavy baryon B plus a meson C, or a singly heavy baryon A into a light baryon B plus a heavy meson C, $A \to BC$

$$\Gamma = \frac{2\pi\gamma_0^2}{2J_A+1}\,\Phi_{A\to BC}(q_0)\sum_{M_{J_A},M_{J_B}}|\mathcal{M}^{M_{J_A},M_{J_B}}|^2 \qquad (4)$$

Single heavy baryon study via spectra and decay width

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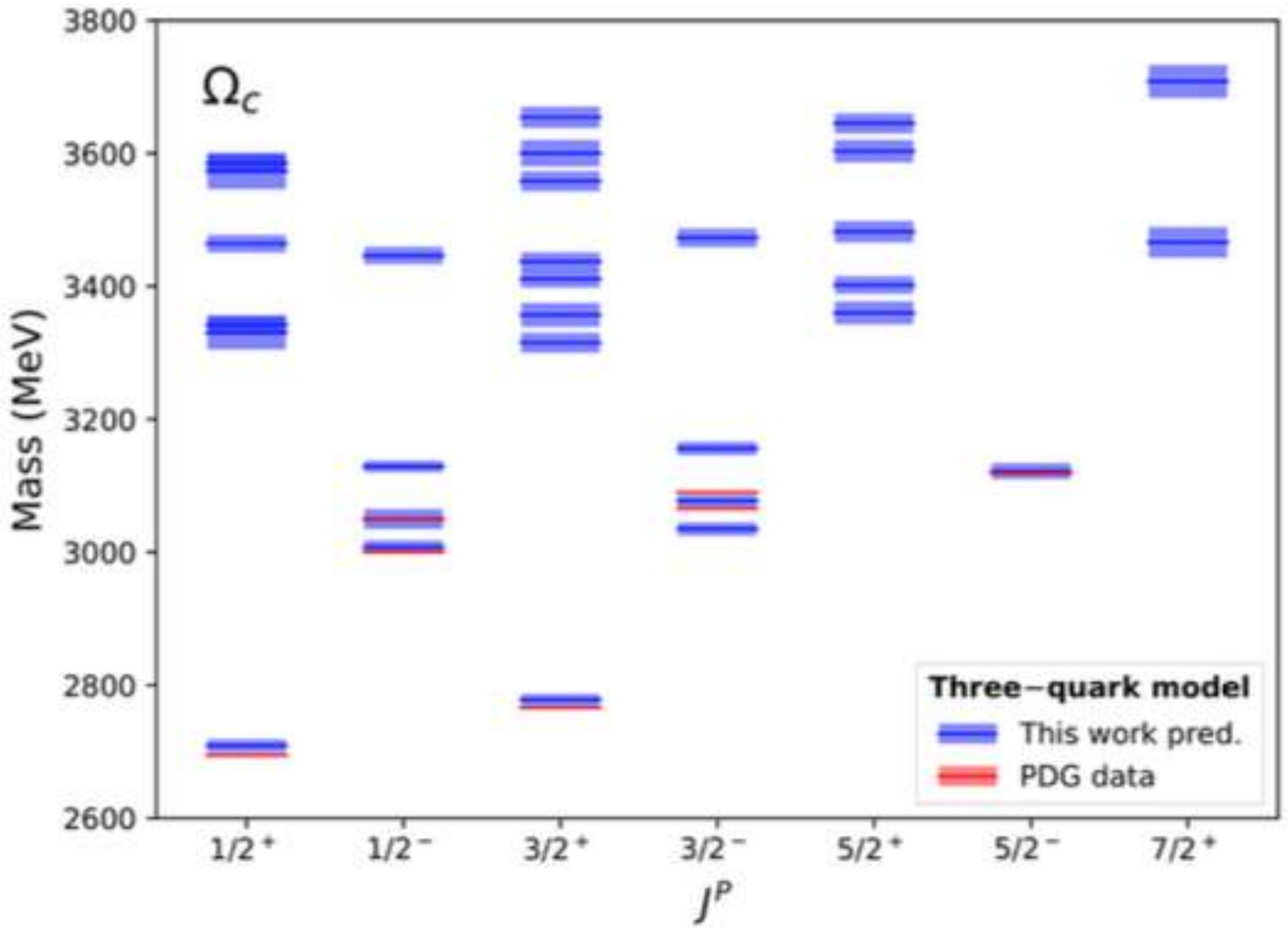
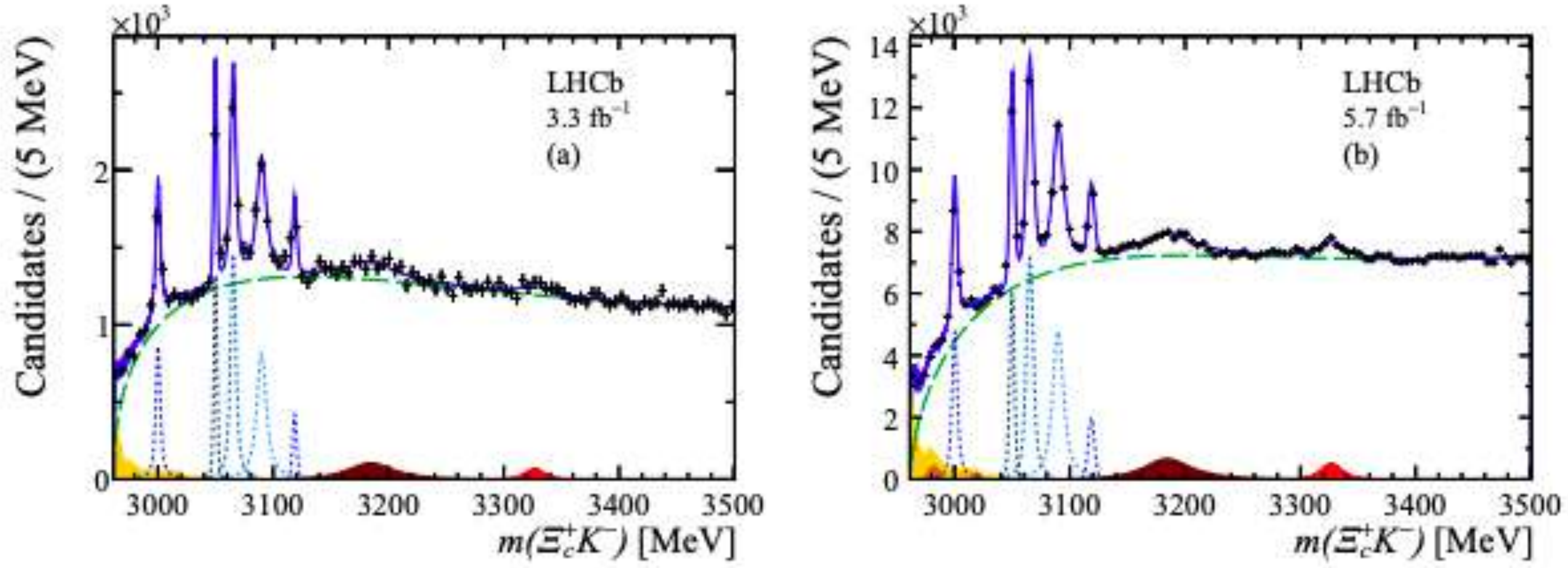
Predicted spectrum for Ω_c



LHCb new observed state agrees

New state $\Omega_c(3327)$ with mass$=3327.1 \pm 1.2$ MeV and $\Gamma = 20 \pm 5$ MeV



$\vert l_\lambda = 2, l_\rho = 0, k_\lambda = 0, k_\rho = 0\rangle$	$^2D_{3/2}$	3315^{+15}_{-14}	3306^{+14}_{-14}	†	11^{+5}_{-5}
$\vert l_\lambda = 2, l_\rho = 0, k_\lambda = 0, k_\rho = 0\rangle$	$^2D_{5/2}$	3360^{+17}_{-16}	3348^{+17}_{-17}	†	24^{+12}_{-12}
$\vert l_\lambda = 2, l_\rho = 0, k_\lambda = 0, k_\rho = 0\rangle$	$^4D_{1/2}$	3330^{+25}_{-25}	3328^{+24}_{-23}	†	16^{+8}_{-8}

Single heavy baryon study via spectra and decay width

New calculations
Hugo Tecocoatzi

Where do we need to look to find new hadrons and their excitations?

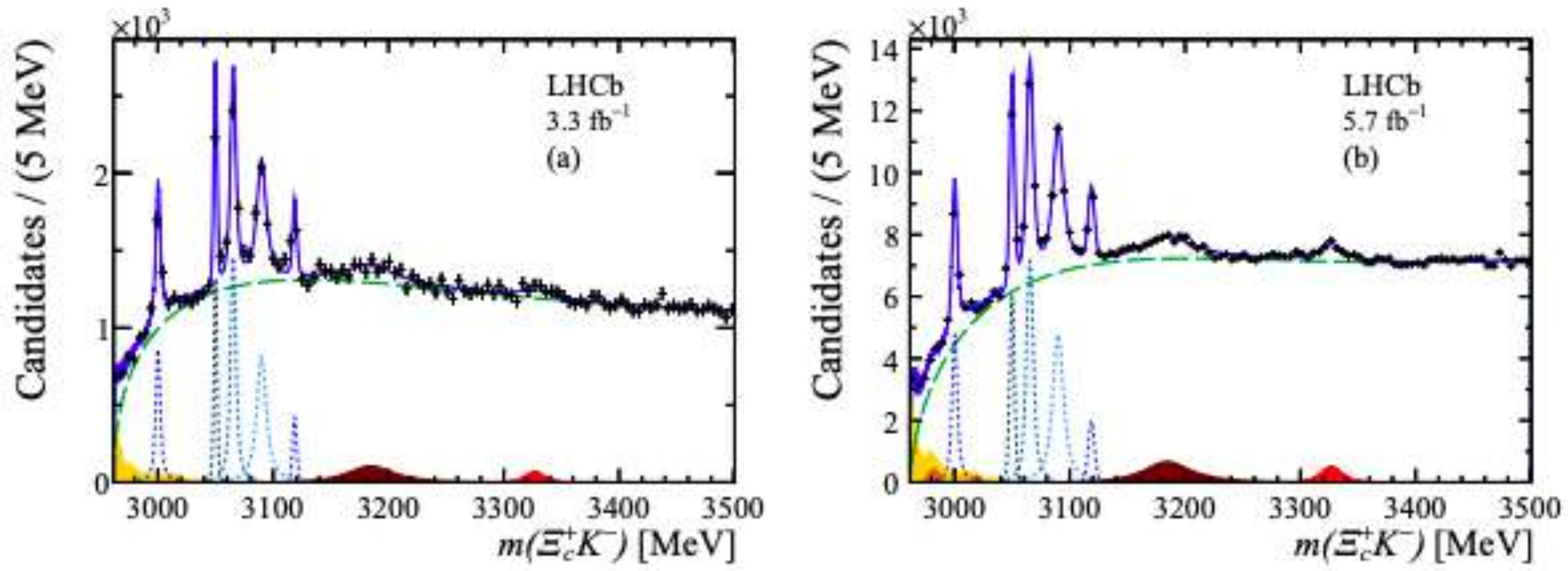
To get full info: calculate their mass spectrum AND their decay widths

$\Omega_c(ssc)$ $\mathcal{F}=\mathbf{6}_f$	$\Xi_c K$	$\Xi_c' K$	$\Xi_c^* K$
$\Omega_c(2709)^2S_{1/2}$	0	0	0
$\Omega_c(2778)^4S_{3/2}$	0	0	0
$\Omega_c(3008)^2P_{1/2}$	4.1	0	0
$\Omega_c(3050)^4P_{1/2}$	7.5	0.1	0
$\Omega_c(3035)^2P_{3/2}$	26.3	0	0
$\Omega_c(3077)^4P_{3/2}$	6.3	0.4	0
$\Omega_c(3122)^4P_{5/2}$	40.9	8.9	0.3
$\Omega_c(3129)^2P_{1/2}$	—	8.9	5.5
$\Omega_c(3156)^2P_{3/2}$	—	61.1	10.5
$\Omega_c(3315)^2D_{3/2}$	1.9	1.8	2.3
$\Omega_c(3360)^2D_{5/2}$	5.4	5.1	0.5
$\Omega_c(3330)^4D_{1/2}$	0.2	0.2	3.3
$\Omega_c(3357)^4D_{3/2}$	2.0	0.5	5.2
$\Omega_c(3402)^4D_{5/2}$	5.0	1.2	5.0
$\Omega_c(3466)^4D_{7/2}$	7.8	2.0	5.0
$\Omega_c(3342)^2S_{1/2}$	0.2	0.3	0.1
$\Omega_c(3411)^4S_{3/2}$	0.2	0.1	0.4
$\Omega_c(3585)^2S_{1/2}$	0.3	1.0	0.7
$\Omega_c(3654)^4S_{3/2}$	0.1	0.1	1.2
$\Omega_c(3437)^2D_{3/2}$	—	6.5	107.0

We need to look in different channels to find all excitations

LHCb new observed state agrees

New state $\Omega_c(3327)$ with mass$=3327.1 \pm 1.2$ MeV and $\Gamma = 20 \pm 5$ MeV



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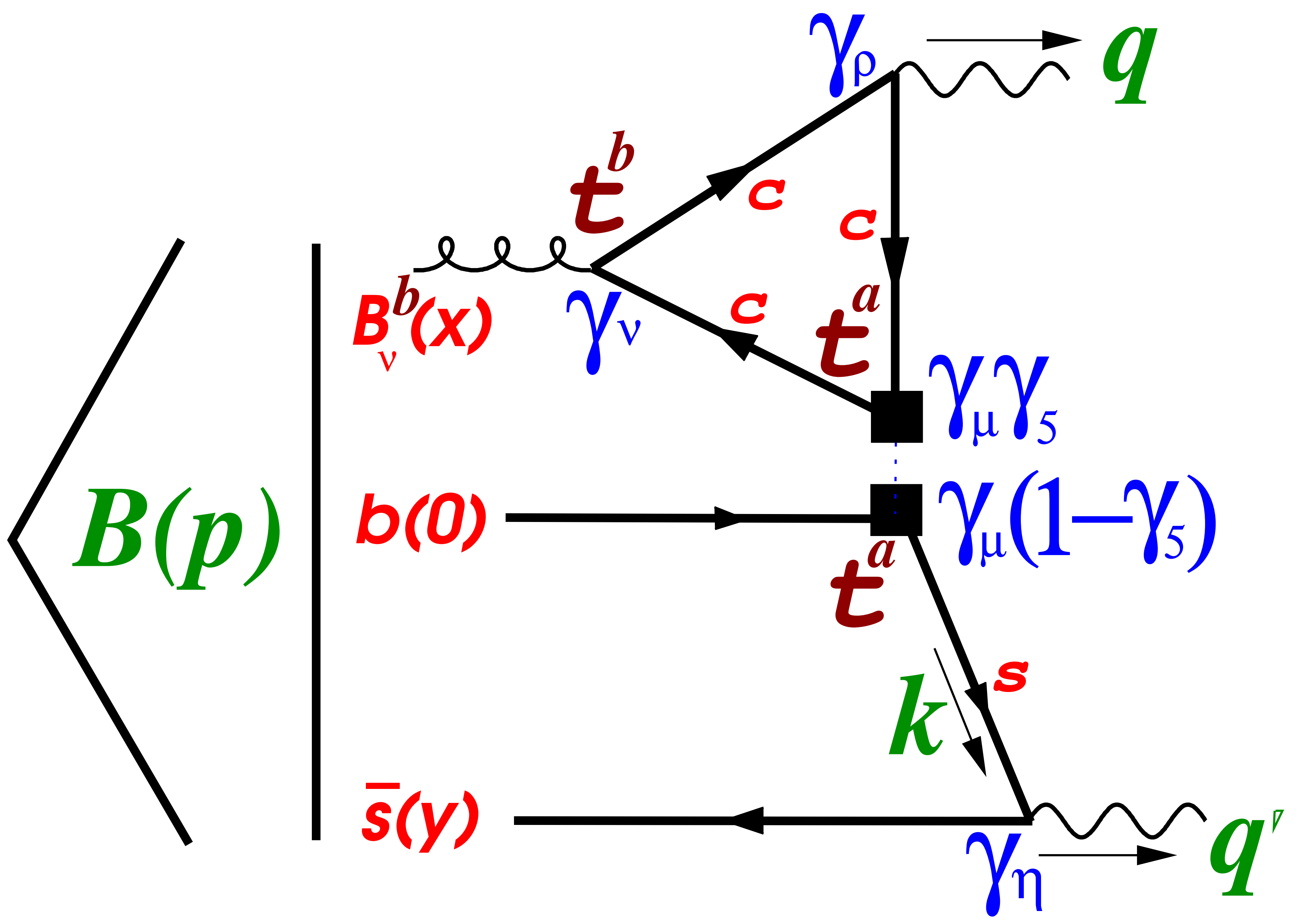
Nonfactorizable charm loop in rare Bs → γ l+l– decay

New calculations

Ilia Belov

Flavour-changing neutral currents are suppressed in the SM

We don't want to falsely claim new physics →
we need to have an accurate SM prediction



Non-factorizable charm loops have not been taken into account to far

Nonfactorizable charm loop in rare Bs → γ l+l− decay

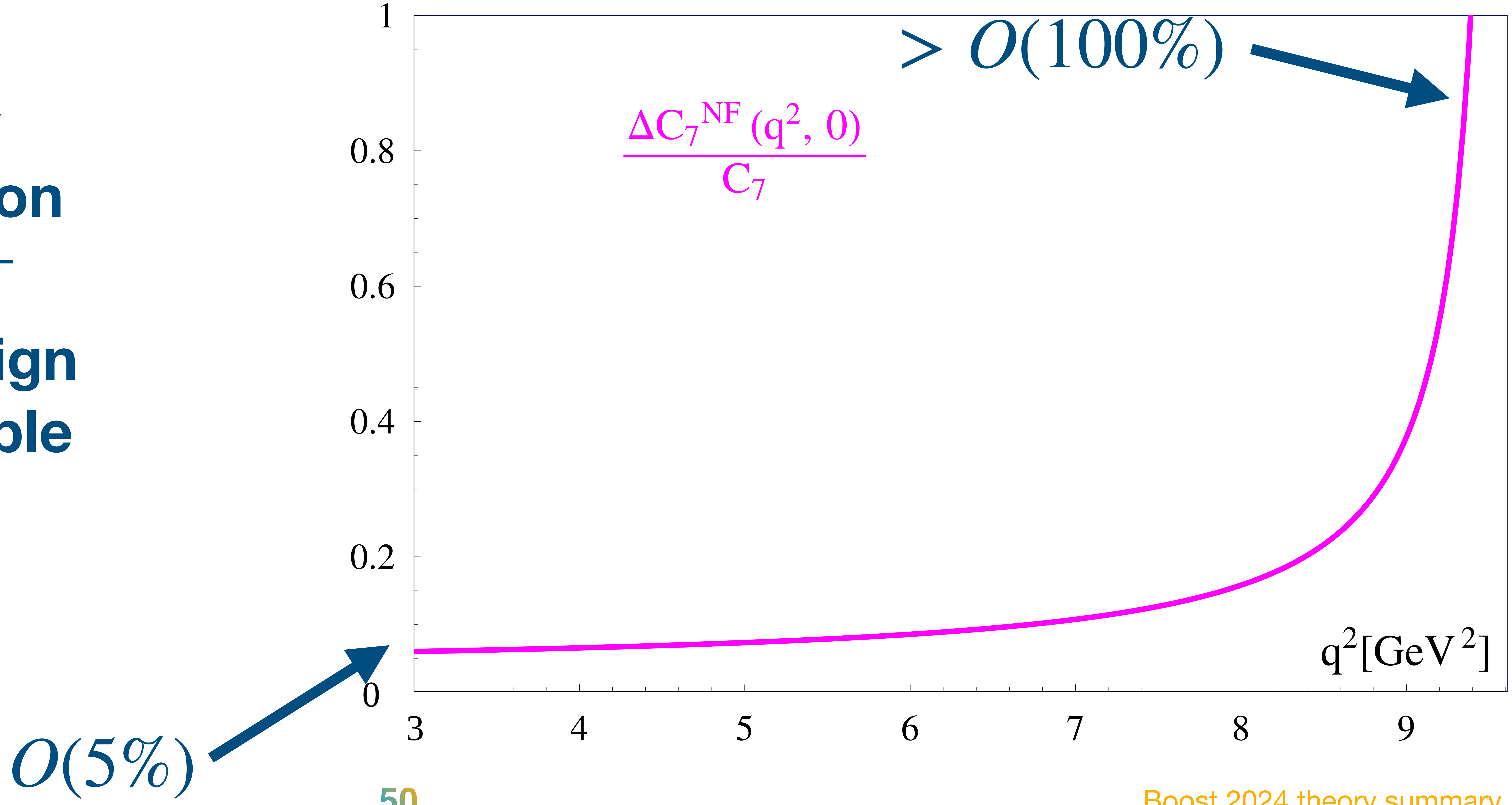
New calculations

Ilia Belov

Flavour-changing neutral currents are suppressed in the SM

We don't want to falsely claim new physics →
we need to have an accurate SM prediction

Results show sizable correction for $B_s \to \gamma l^+ l^-$ that has same sign as the factorisable contributions



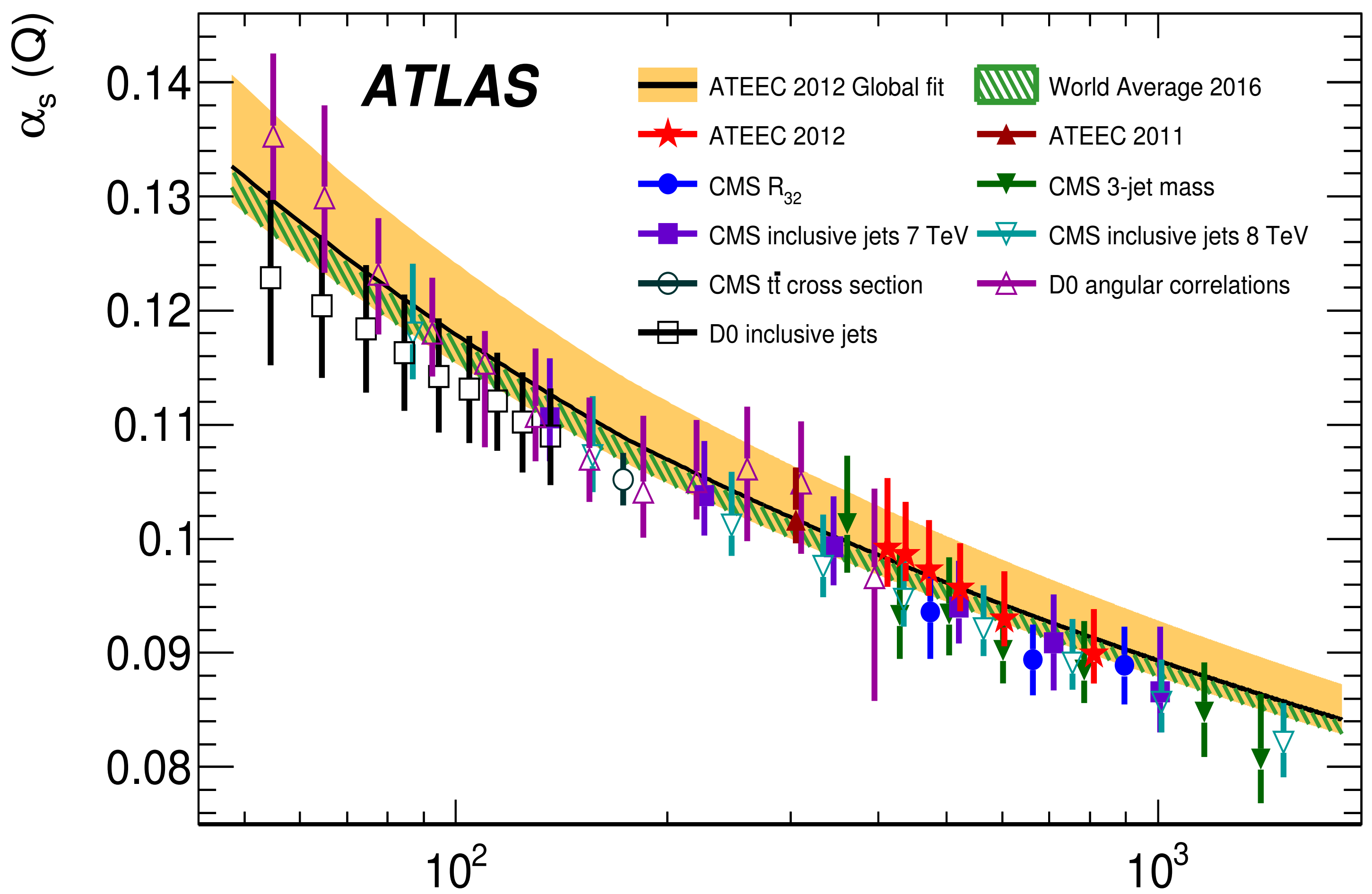
EEC: success story

The EEC: What makes it special?

The **EEC** addresses several important goals of QCD phenomenology, including:

$$\left\langle \sum_{\substack{\text{pairs } (i,j):\\ \theta_{ij}=\theta}} E_i \, E_j \right\rangle$$

- Measurements of α_s;



ATLAS [1707.02562]

ATLAS:[1508.01579]
[1707.02562]

[CMS PAS SMP-22-015]

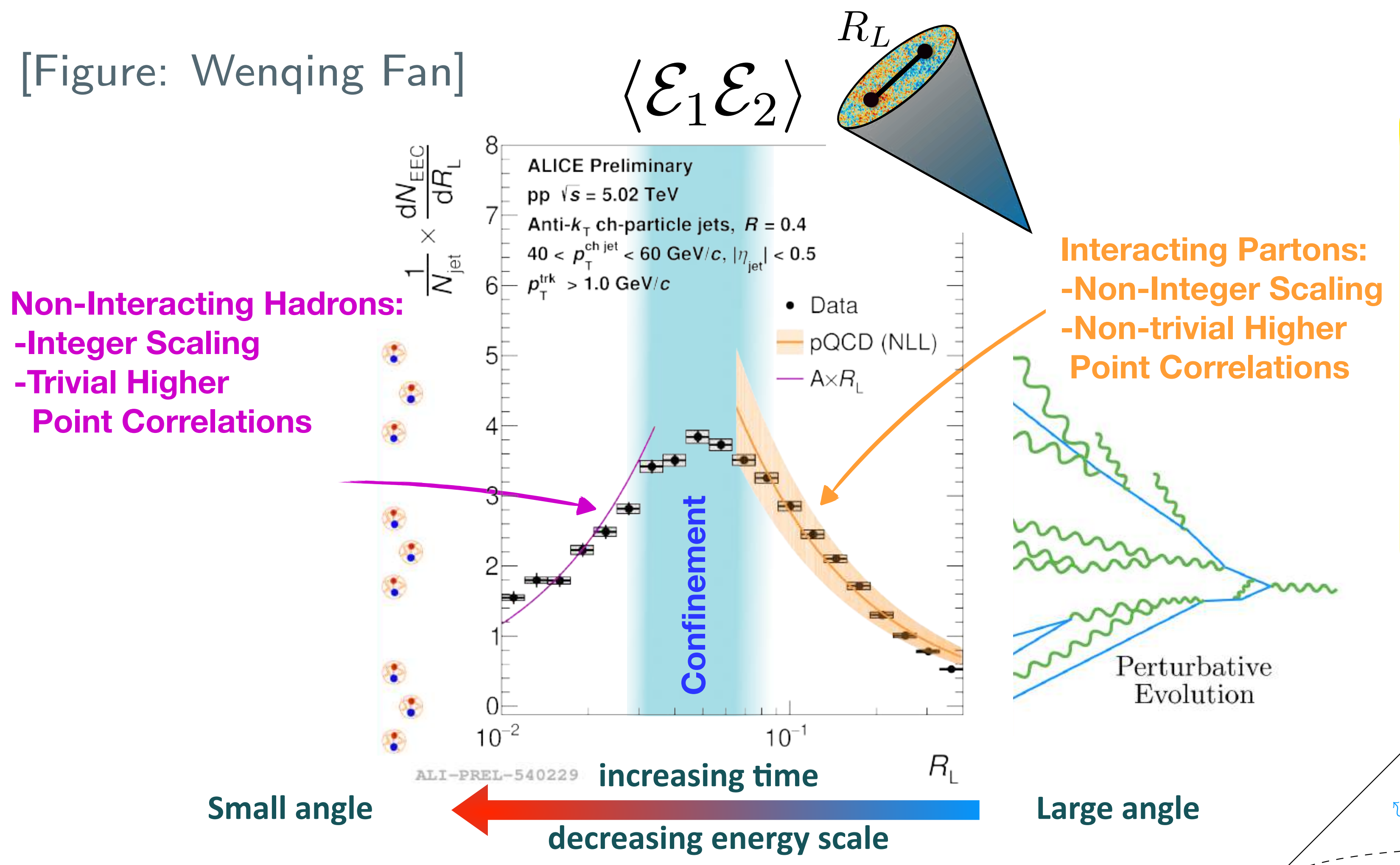
HERA:[2008.00271]

LEP+:[1804.09146]

Samuel Alipour-fard

Mark Gonzalez

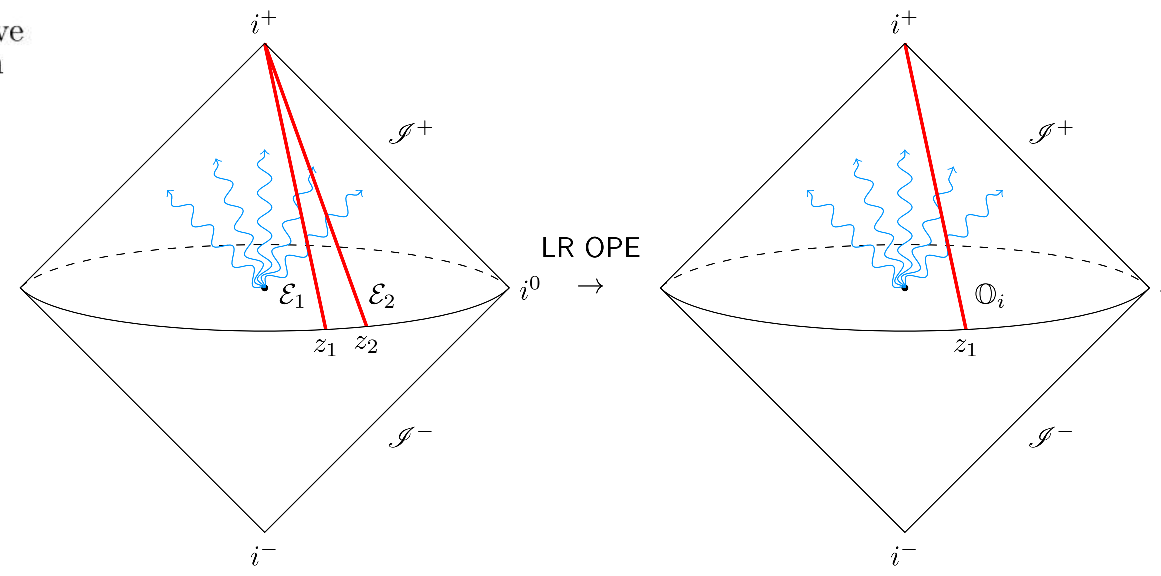
[Figure: Wenqing Fan]



Correlation function of detectors $\Rightarrow$ jet substructure observable

A clear link between theory and experiment!

- Evolution of the jet goes from right to left
  - Distinct scaling regimes corresponding to partonic and hadronic physics
  - Transitions image the physical scales of QCD



Perturbative scaling predicted by the light-ray OPE

$\Rightarrow$ **Universal scaling behavior!**

$$\mathcal{E}(\hat{n}_1)\mathcal{E}_2(\hat{n}_2) \sim \sum_i \theta^{\tau_i - 4} \mathbb{O}_i^+(\hat{n}_1)$$

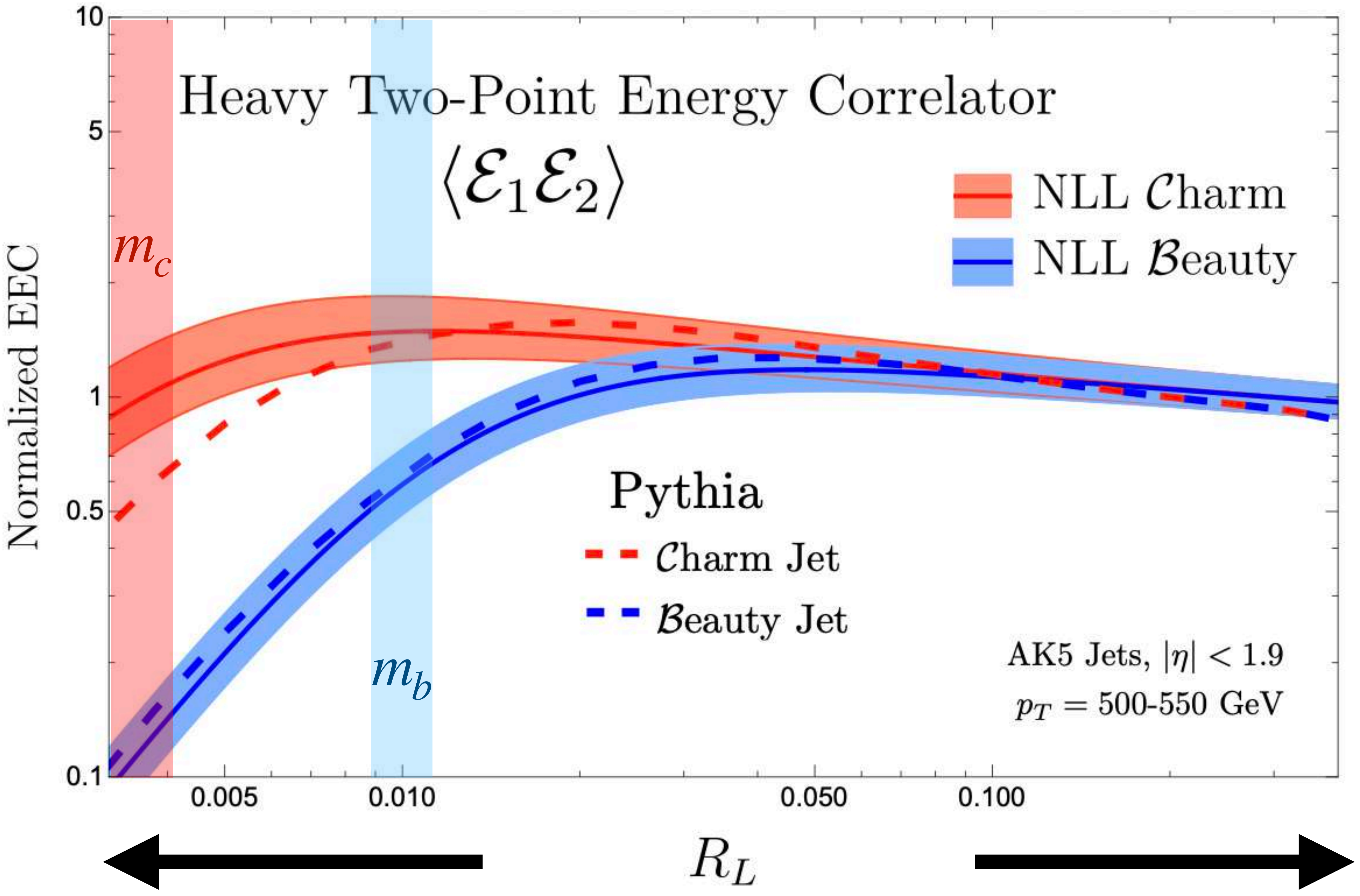
What else can we do?

Energy Correlators, Heavy Flavor, and Precision QCD

New observables

Evan Craft

Can we use a 2-point EEC to measure the deadcone?



Sensitivity to the quark mass scale at $R_L \sim m_Q/p_T$

Scaling identical to that of massless quarks

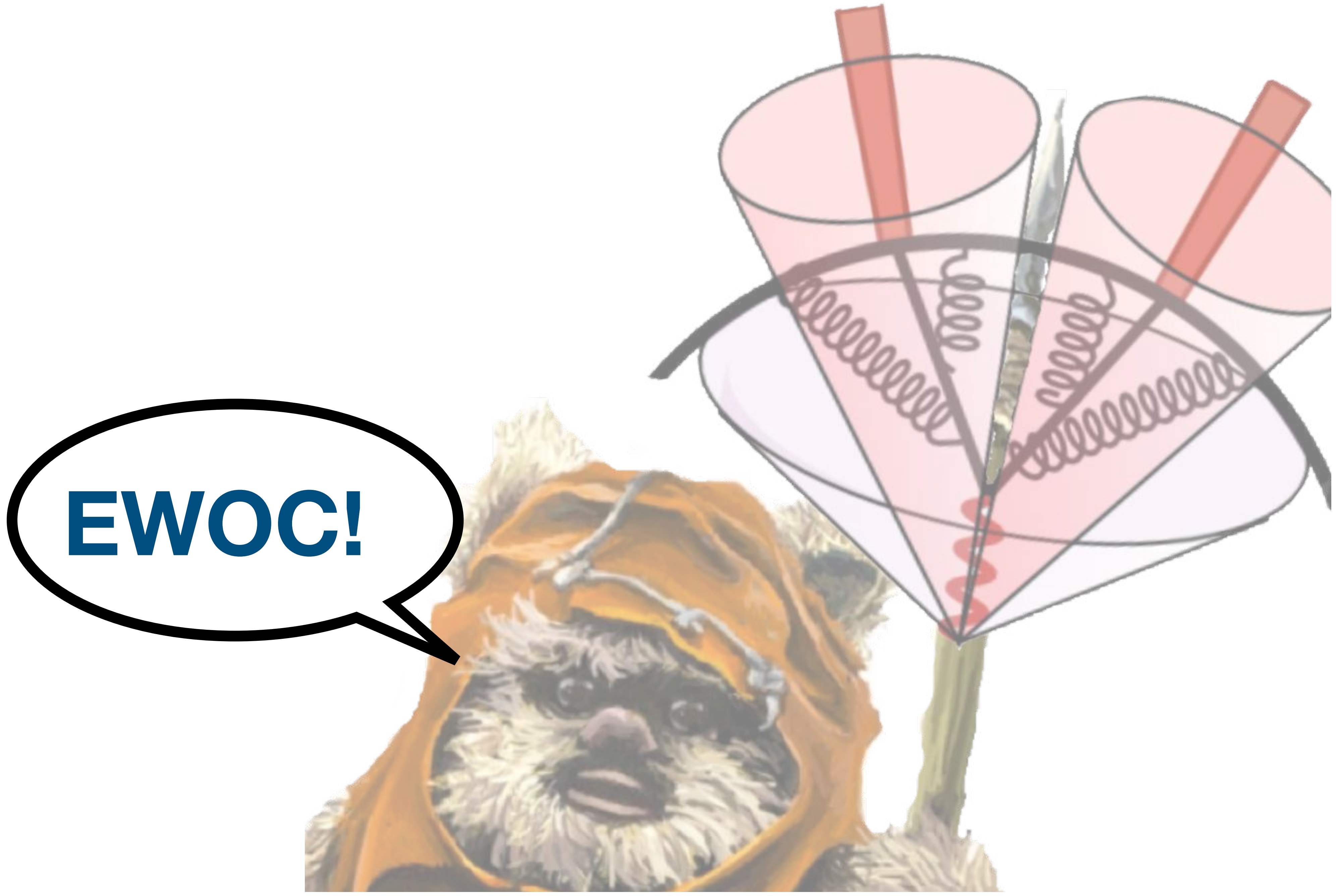
Next boost: a measurement of the deadcone using EECs?

Energy Correlators Beyond Angles

New observables

Samuel Alipour-fard

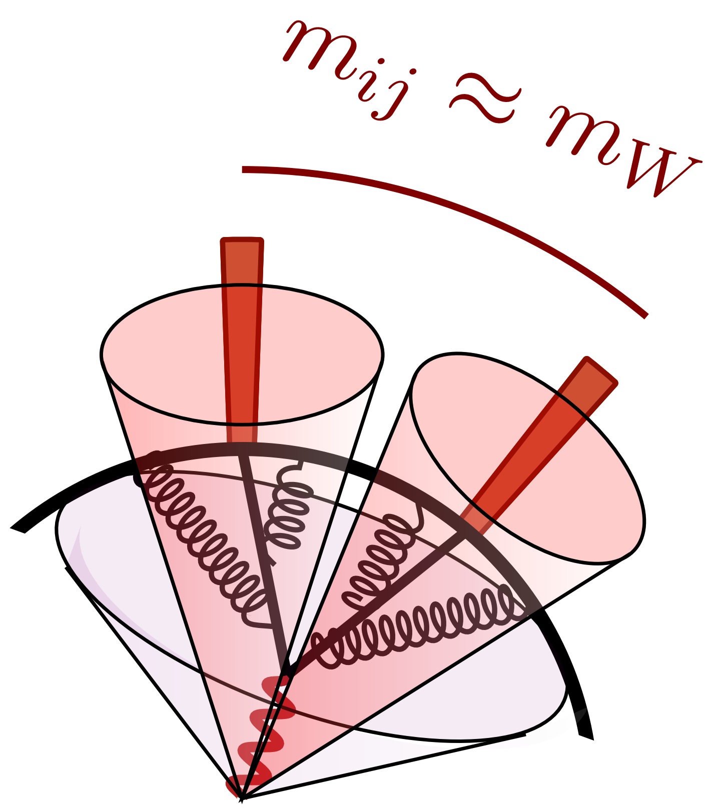
Can we use a 2-point EEC to measure m_W?

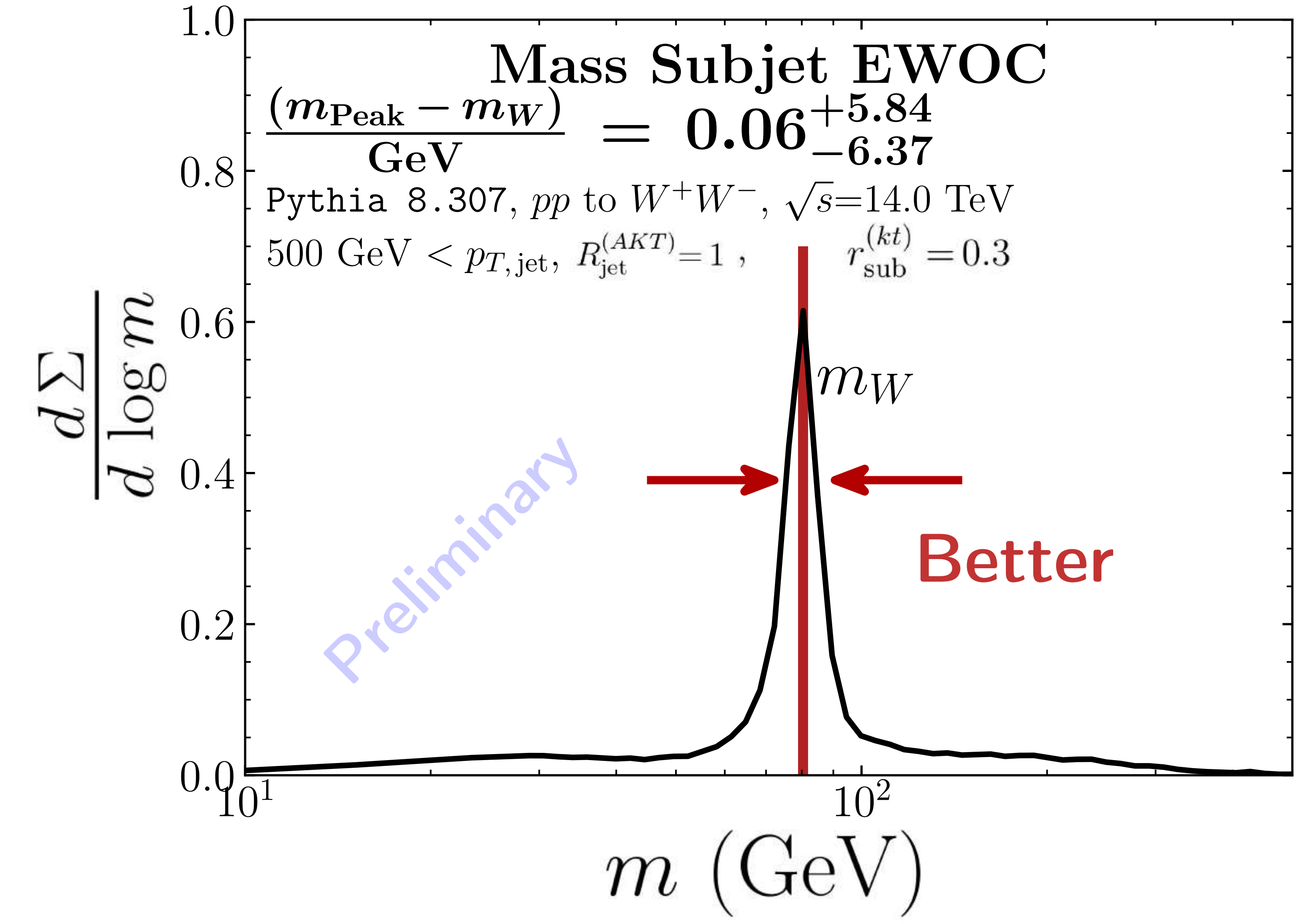


1. Take subjets instead of points
2. Measure mass instead of angle

$\Longrightarrow$

Mass EWOC:





Energy Correlators Beyond Angles

New observables

Samuel Alipour-fard

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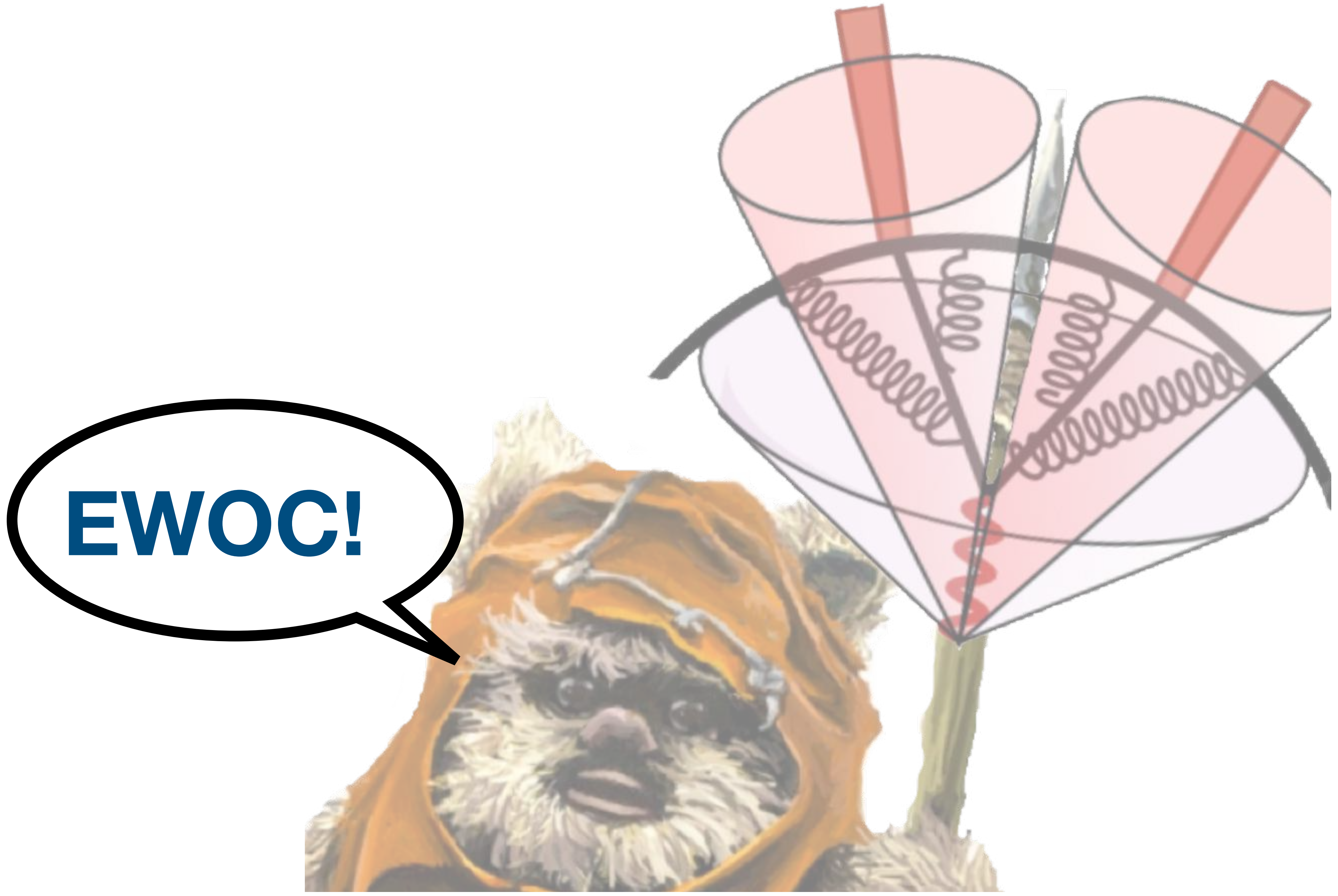

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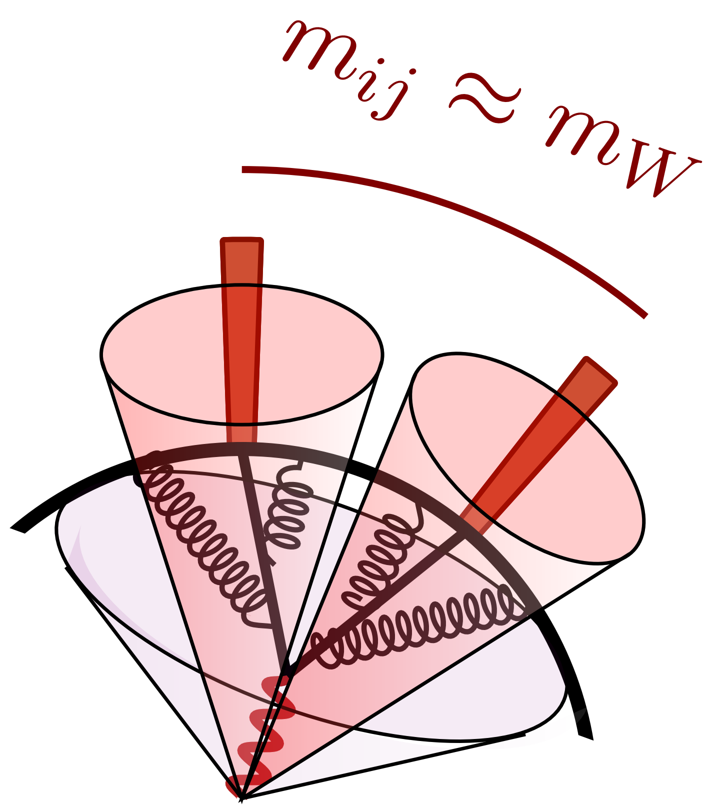
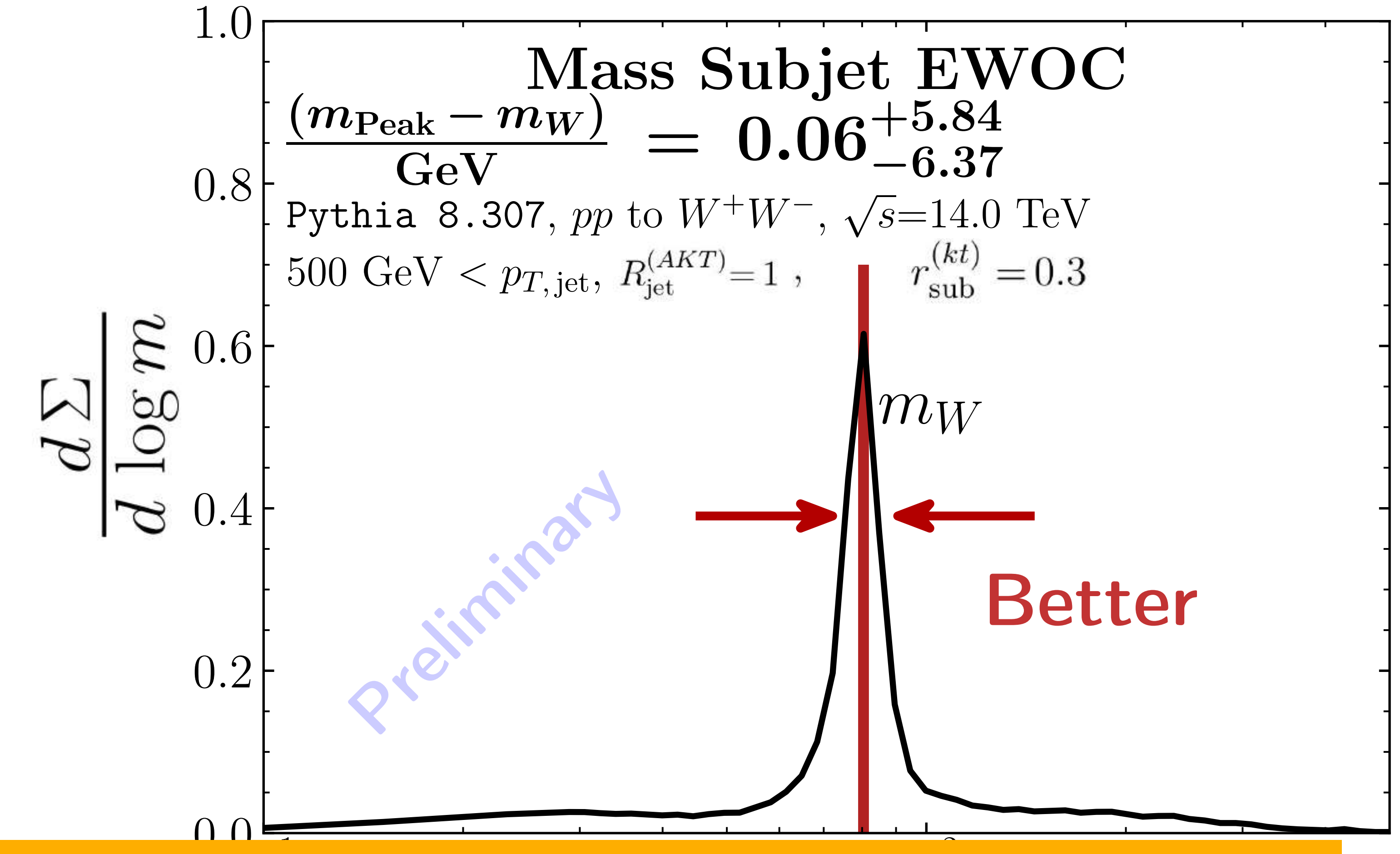
Mass EWOC:





What are the mass shifts when hadronisation/MPI is turned on?

Using the W as a Standard Candle to Reach the top

New observables

Aditya Pathak

Can we use m_W to measure m_t directly without modeling bias?

3-pronged decay → use EEEC

Production mechanism:

- PDF uncertainty ☑
- Hard scattering corrections ☑

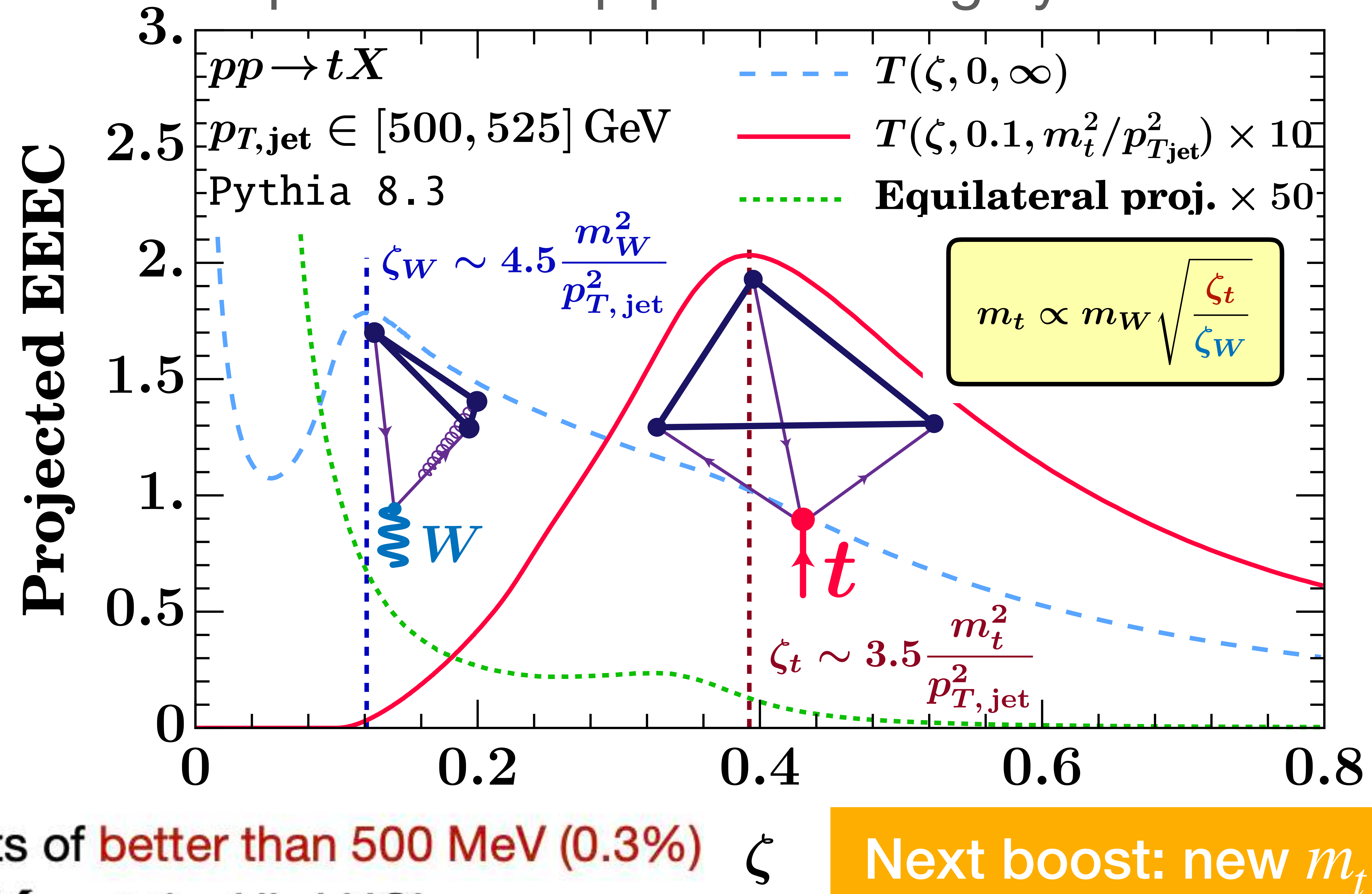
Jet substructure:

- Jet radius dependence ☑
- Hadronization effects ☑
- Impact of underlying event ☑
- Wide angle soft physics ☑
- Perturbative uncertainty ☑

Experimental feasibility:

- Statistical sensitivity ☑
- Jet energy scale ☑
- Constituent energy scale ☑
- Track efficiency ☑
- Heavy flavor dependence ☑

W peak and top peak are highly correlated



Prospects of better than 500 MeV (0.3%) precise M_{top} at the HL-LHC!

Next boost: new m_t measurement?

Interpretation of the MC top mass parameter with the soft-dropped groomed jet mass

New calculations

Naseem Bouchhar

Back to soft drop, not all is forgotten

Can we understand the m_t^{MC}?

Resurrect an 'old' idea but with more aggressive grooming → reduces impact MPI

- Model uses three parameters, $\mathbf{m_t}^{Pole}$, $\mathbf{\Omega_1^{had}}$, and $\mathbf{x_2}$ associated with **first-** and **second-moment non-perturbative corrections.**
- Idea is to obtain **value of parameters in NNLL theory** calculation that **best describe MC prediction.**

What happens with a different shower model?

Mass relation (pp):

$$\Delta^{Pole} = m_t^{MC} - m_t^{Pole} = 590^{+375}_{-320}\ \text{MeV}$$

Mass relation (e^+e^-):

$$\Delta^{Pole} = m_t^{MC} - m_t^{Pole} = 600^{+275}_{-215}\ \text{MeV}$$

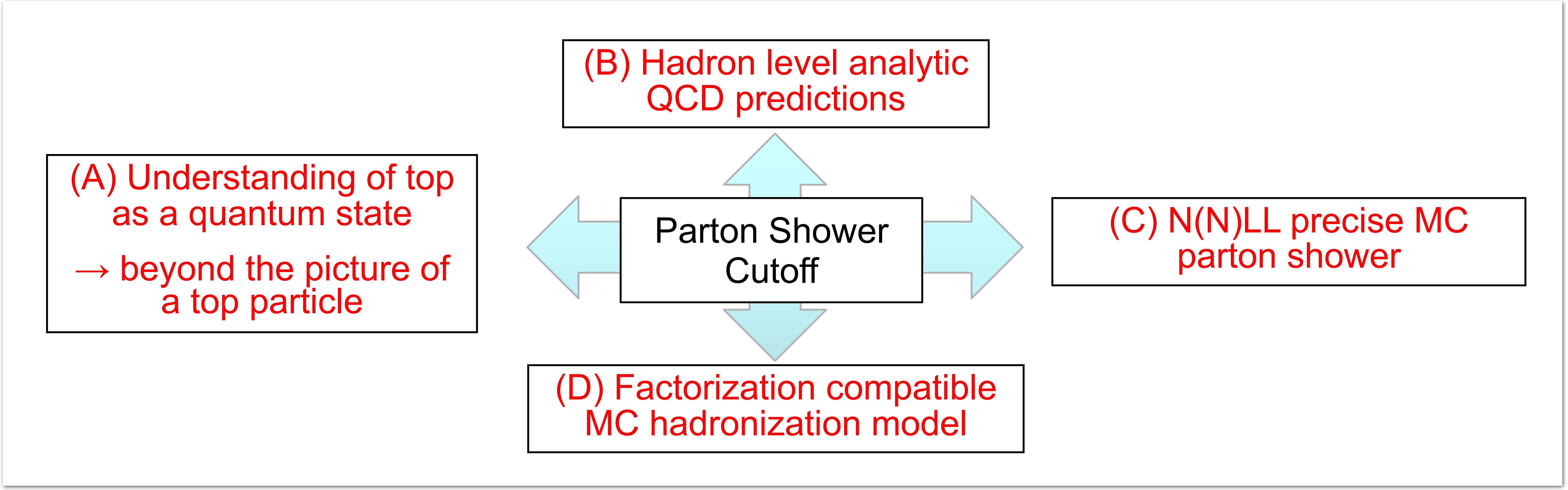
Suggests universality between the e^+e^- and pp processes.

An approach to pin down the top quark mass parameter in MC event generators

Can we make m_t^{MC} more physical?

Can we promote m_t^{MC} to a renormalisation scheme (such that it can be translated to other schemes)?

Yes, but you need quite a list of ingredients

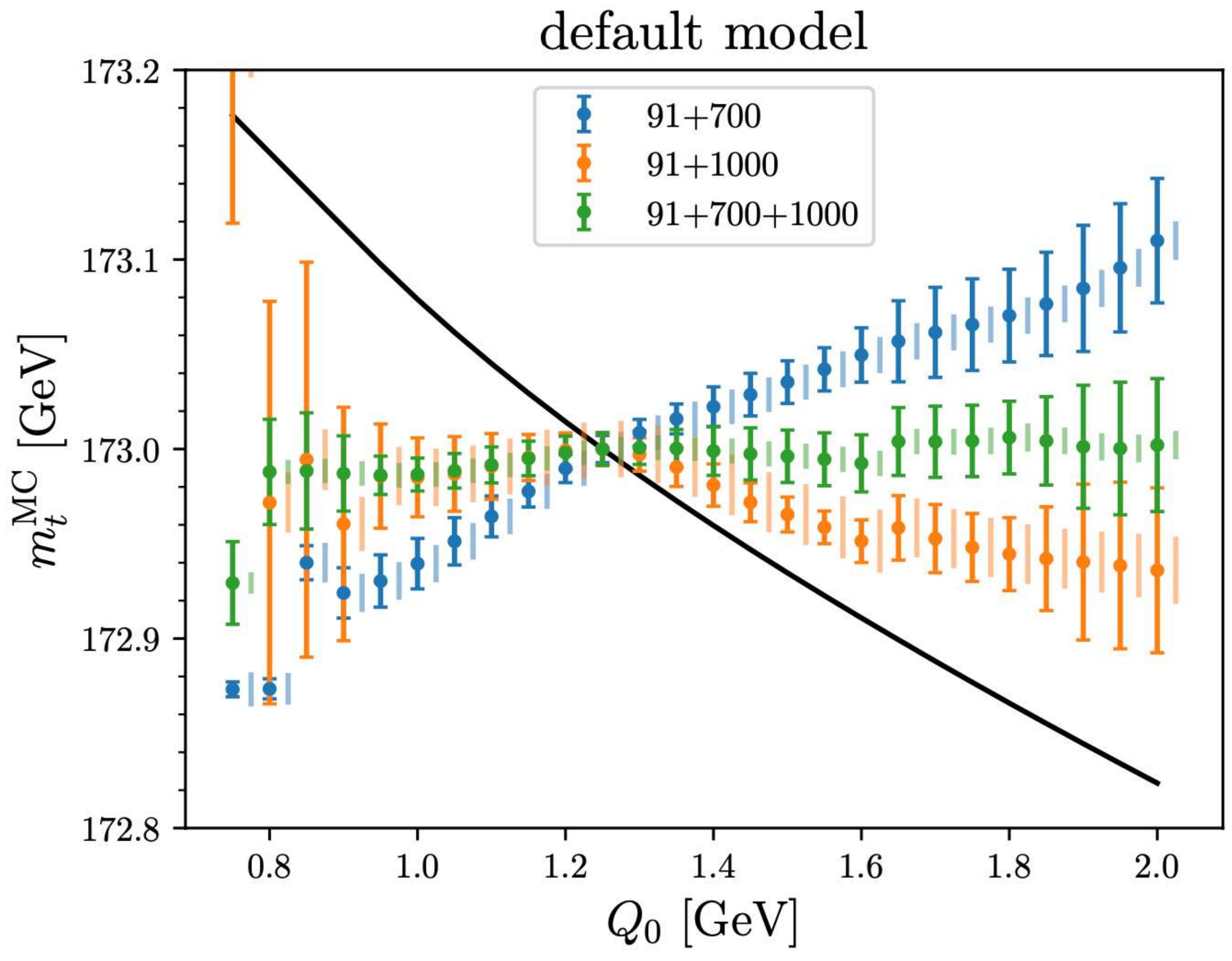


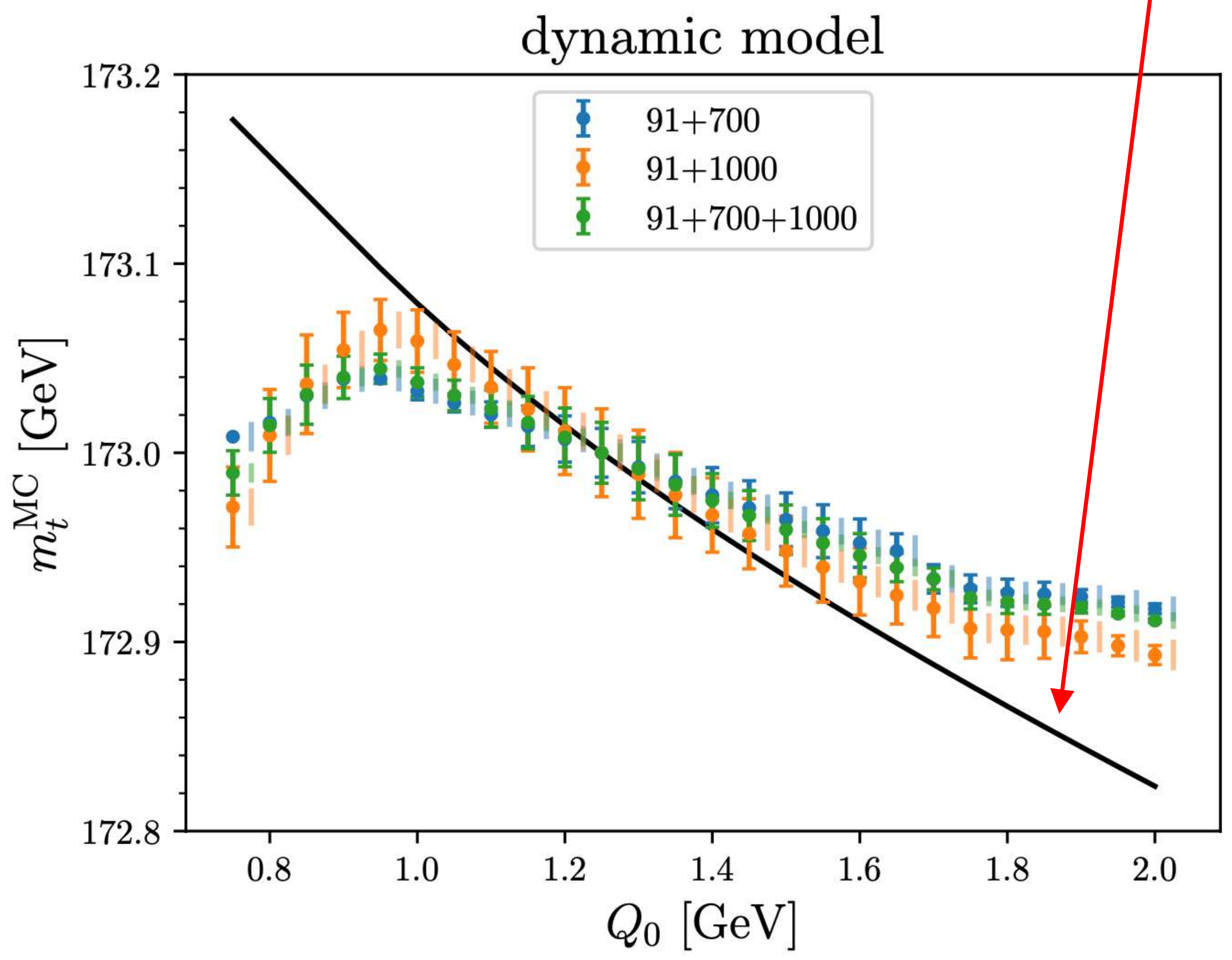
An approach to pin down the top quark mass parameter in MC event generators

Can we make m_t^{MC} more physical?

Tune m_t^{MC} for different values of Q_0 to ref. data for $Q_0 = 1.25$ GeV

Q_0 dependence expected from $m_t^{\mathrm{CB}}(Q_0)$





Default Herwig hadronization model modifies m_t^{MC} in an unphysical way incompatible with QCD factorization: uncertainty ~ 0.5 GeV

Agreement of m_t^{MC} with $m_t^{\mathrm{CB}}(Q_0)$ within 50 MeV !

An approach to pin down the top quark mass parameter in MC event generators

André Hoang

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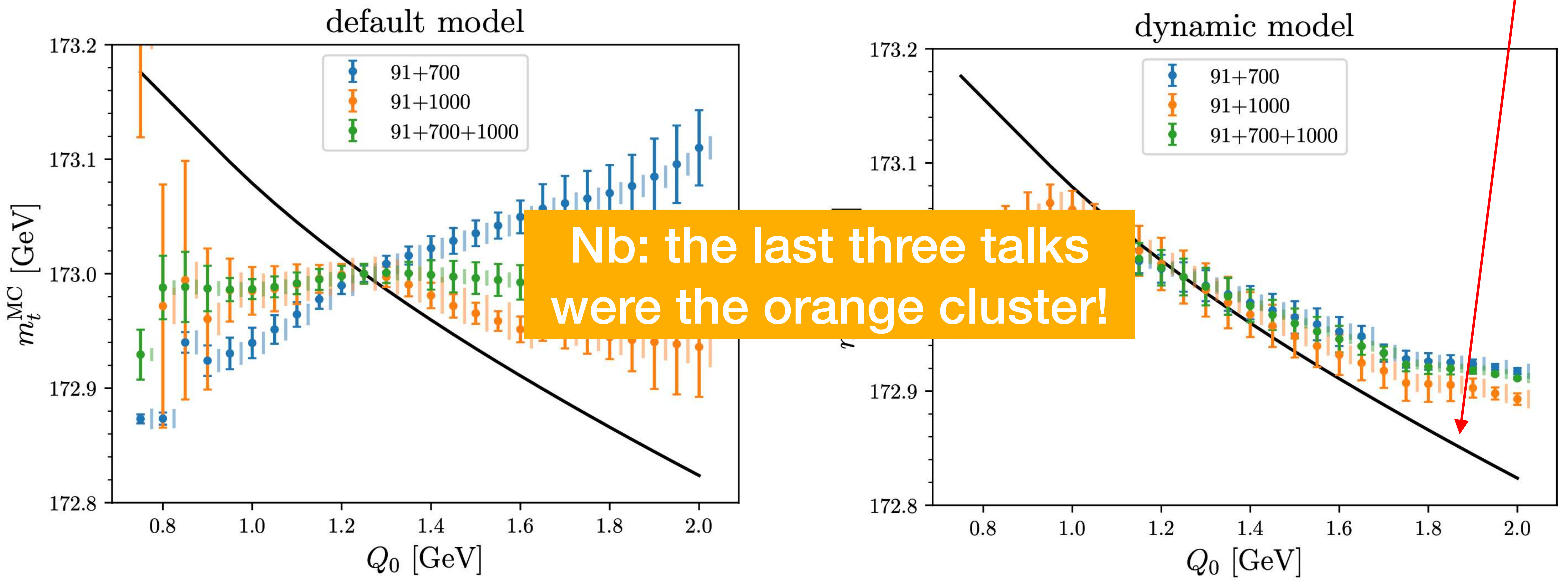

Nb: the last three talks were the orange cluster!

Default Herwig hadronization model modifies m_t^{MC} in an unphysical way incompatible with QCD factorization: uncertainty ~ 0.5 GeV

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How to unfold top decays

ML

Sofia Schweitzer

Can we learn how to unfold top decay products?

Goal: learn transformation latent → gen phase space conditioned on reco event

During training, use paired events of forward simulation

After training, repeated sampling from latent space with constant condition allows probabilistic single event unfolding

Sofia's prediction: "I'm not gonna tell you about the generative model, this will change anyway in two years or so"

How to unfold top decays

ML

Sofia Schweitzer

Can we learn how to unfold top decay products?

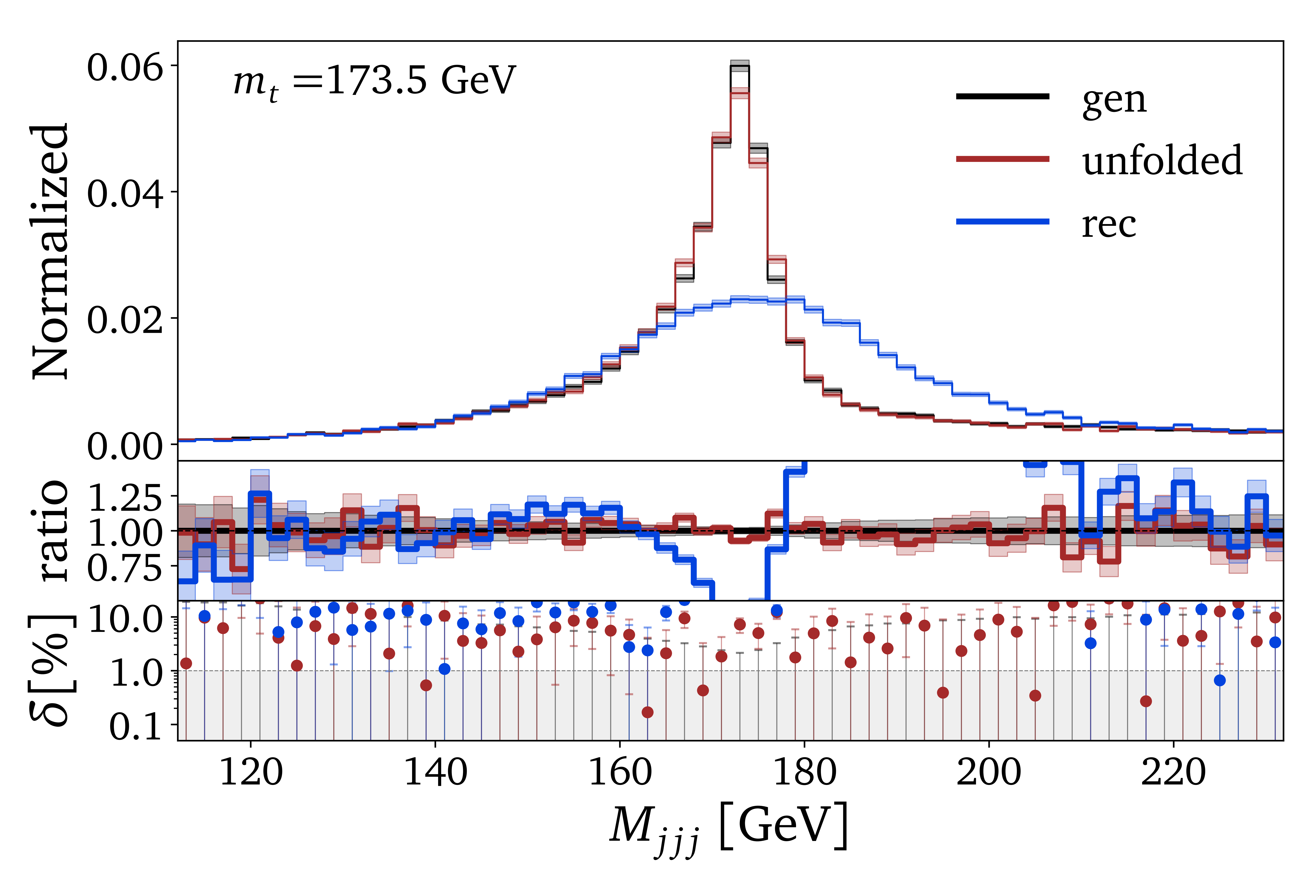
Be careful with:

1. Mapping the resonances

→ pick the right input

2. Dependence on the model

→ train on different masses



How to unfold top decays

ML

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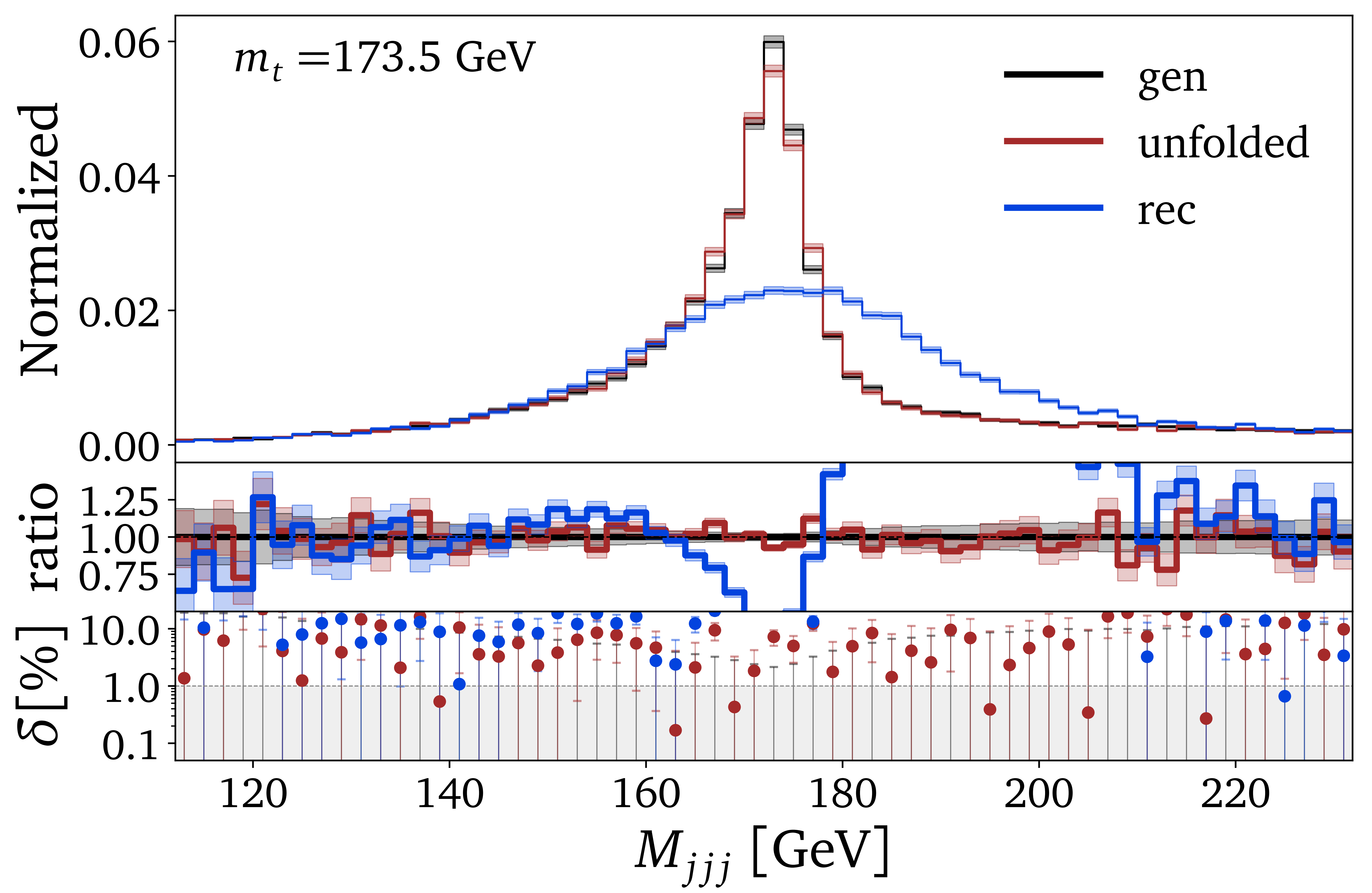
What happens with different tunes/ hadronisation/shower?



Detectorology and its Phenomenological Applications

New observables

Back to the EEC.. Can we generalise it?

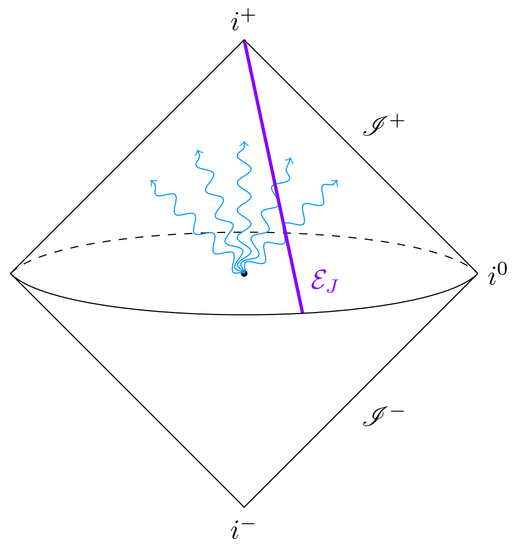
Mark Gonzalez

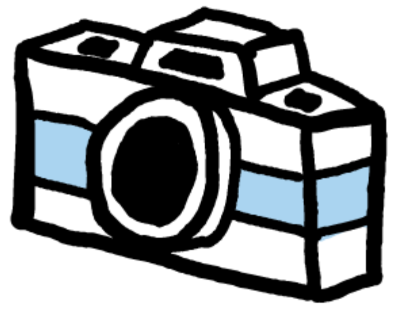
$\mathcal{E}_J$ Detectors

A new camera which measures the energy flux to an arbitrary power, E^{J-1} with $J \in \mathbb{C}$

$$\mathcal{E}_J(\hat{n})|X\rangle = \sum_i E_{k_i}^{J-1}\delta^{d-2}(\Omega_{\hat{n}} - \Omega_{\hat{k}_i})|X\rangle$$

- Formally: $\mathcal{E}_J(z) \sim \mathbb{O}_J^+(\infty, z)$
  - Analytically continued twist-2, spin-J light-ray operator
  - Energy weighting is related to spin





As an operator in a perturbative scalar field theory

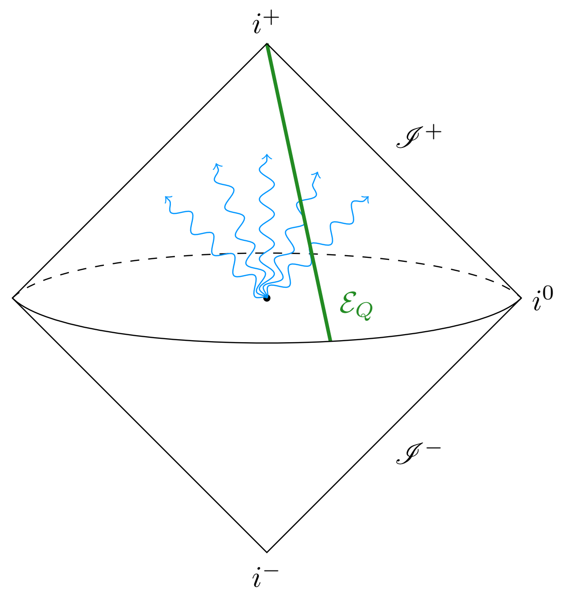
$$\mathcal{D}_{J_L}^+(z) = \frac{1}{C_{J_L}} \int d\alpha_1\, d\alpha_2 : \overline{\varphi}(\alpha_1, z)\varphi(\alpha_2, z) :$$
$$\times \left[(\alpha_1 - \alpha_2 + i\epsilon)^{2(\Delta_\varphi - 1)+J_L} + (\alpha_2 - \alpha_1 + i\epsilon)^{2(\Delta_\varphi - 1)+J_L}\right]$$

- Twist-2, spin-J_L, and “charge/spin even”
- Observables are no longer collinear safe due to energy weighting
  - Access to universal non-perturbative physics through multi-hadron fragmentation functions

[Kravchuk Simmons-Duffin '18]

[Caron-Huot Kologlu Kravchuk Meltz…

$\mathcal{E}_Q$ Detectors



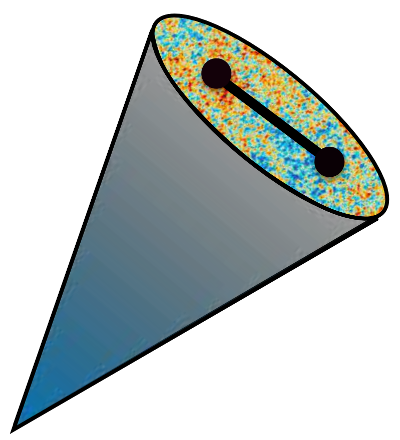
We can also build cameras that probe different quantum numbers!

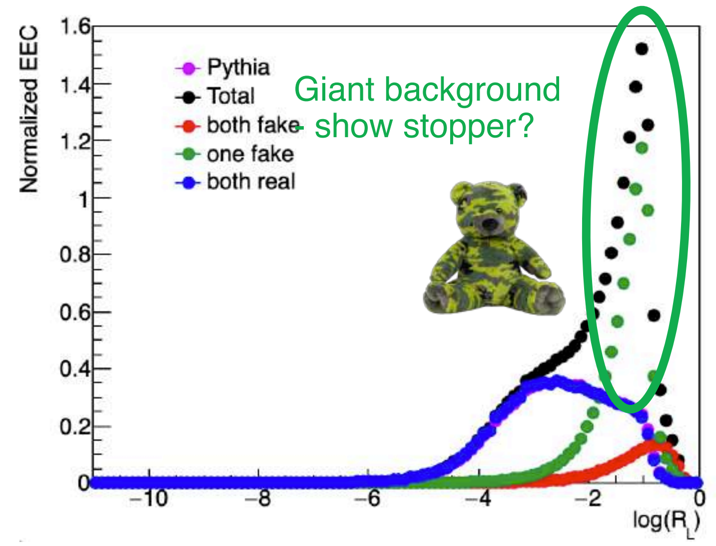
Sensitivity to a charge Q (times the energy)

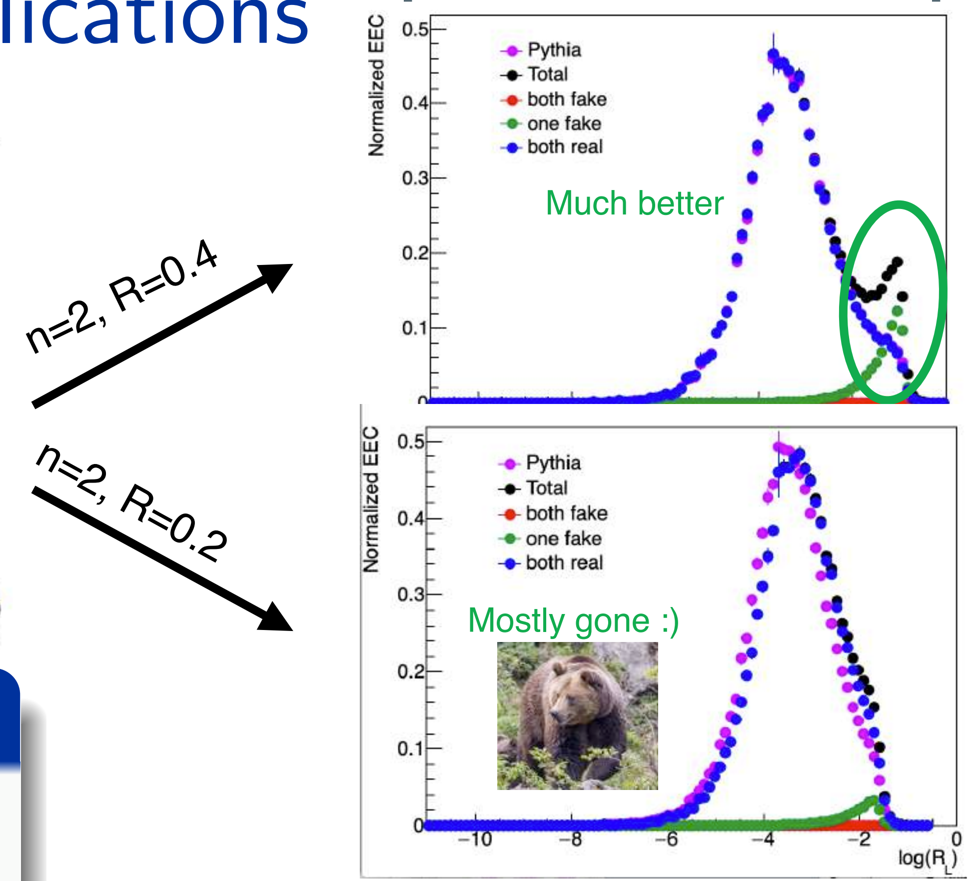
$$\mathcal{E}_Q(\hat{n})|X\rangle = \sum_i E_{k_i}^{J-1} Q_{k_i}\delta^{d-2}(\Omega_{\hat{n}} - \Omega_{\hat{k}_i})|X\rangle$$

Detector Applications

[Figure: L Havener, A Rai]



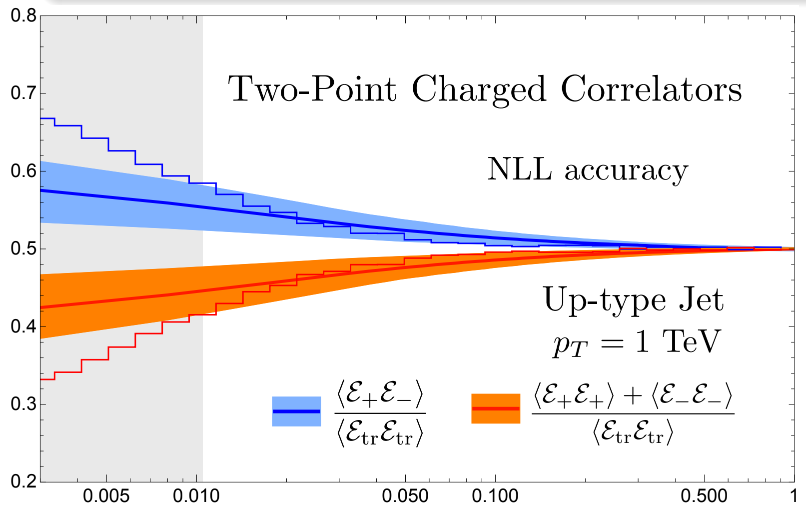




$\mathcal{E}_J$ Detectors

Large (small) powers of energy suppress (enhance) soft physics:

Applications in hot and cold QCD



[Lee Moult '23]

$\mathcal{E}_Q$ Detectors

- Great resolution on charged tracks
- **More hadronization/ non-perturbative information**

Plus these operators are ‘renormalisable’ in conformal theories

→ we can do calculations

My (biased) hopes/predictions for 2025

- Can we understand better what ML tools are learning: is it physics or generators?
- We will see the first full NNLO-meets-boost calculation
- A better representation of the Monte Carlo community (I want a fat MC jet)

Jing: “showers are everywhere”

- Can we understand better differences between showers that we are seeing all across different measurements?
- And of course new cool calculations, measurements, novel techniques, and all the enthusiasm I saw this week!

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BOOS-TI-AMO!!