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Status and prospects of (parton showers) and hadronization

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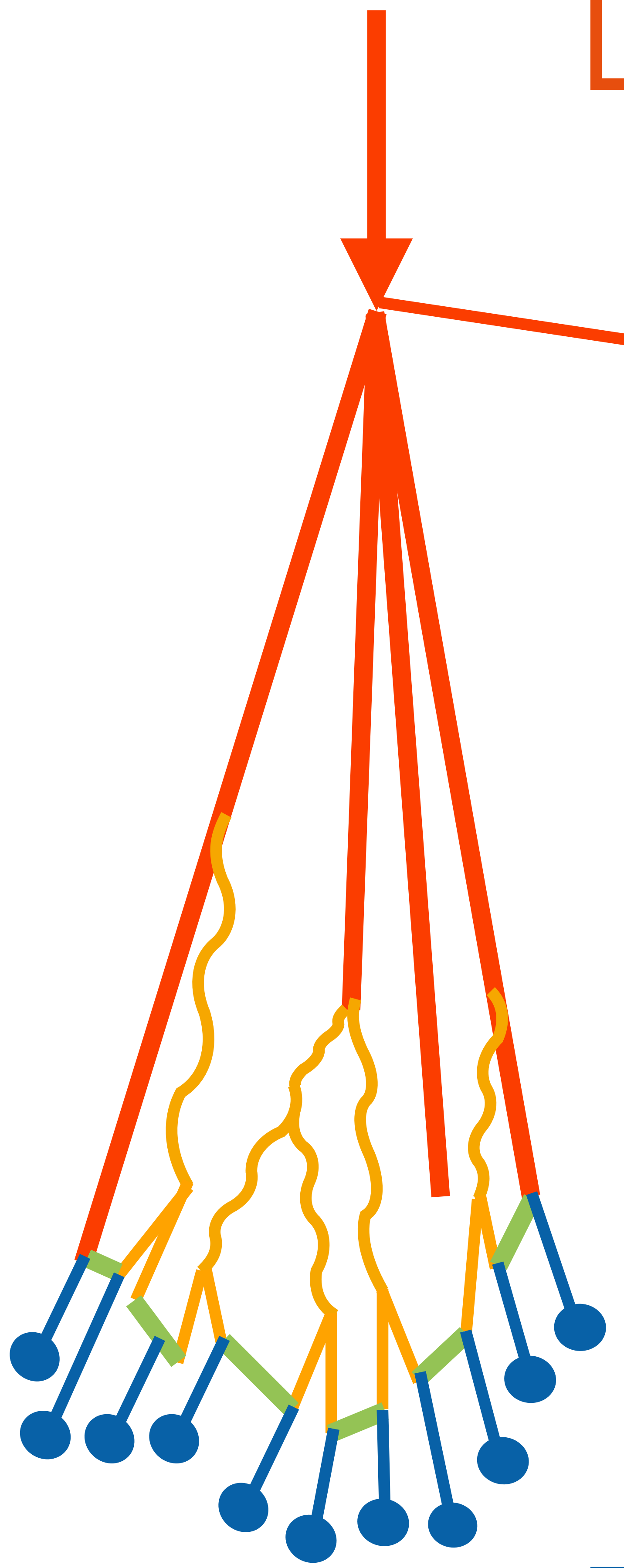
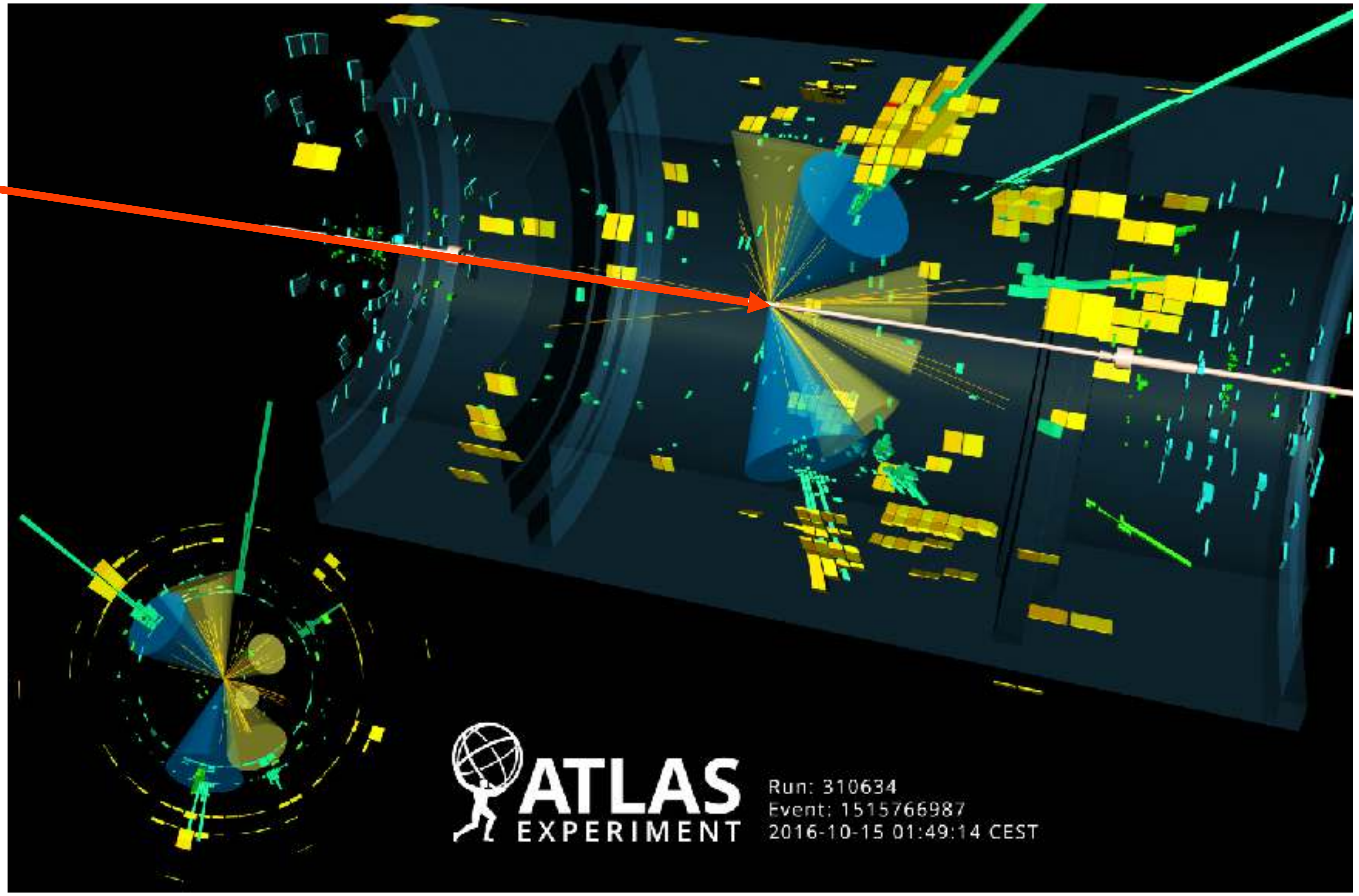
At the ACHT Workshop
Retzhof | 27 September 2023

The Complexity of Observations

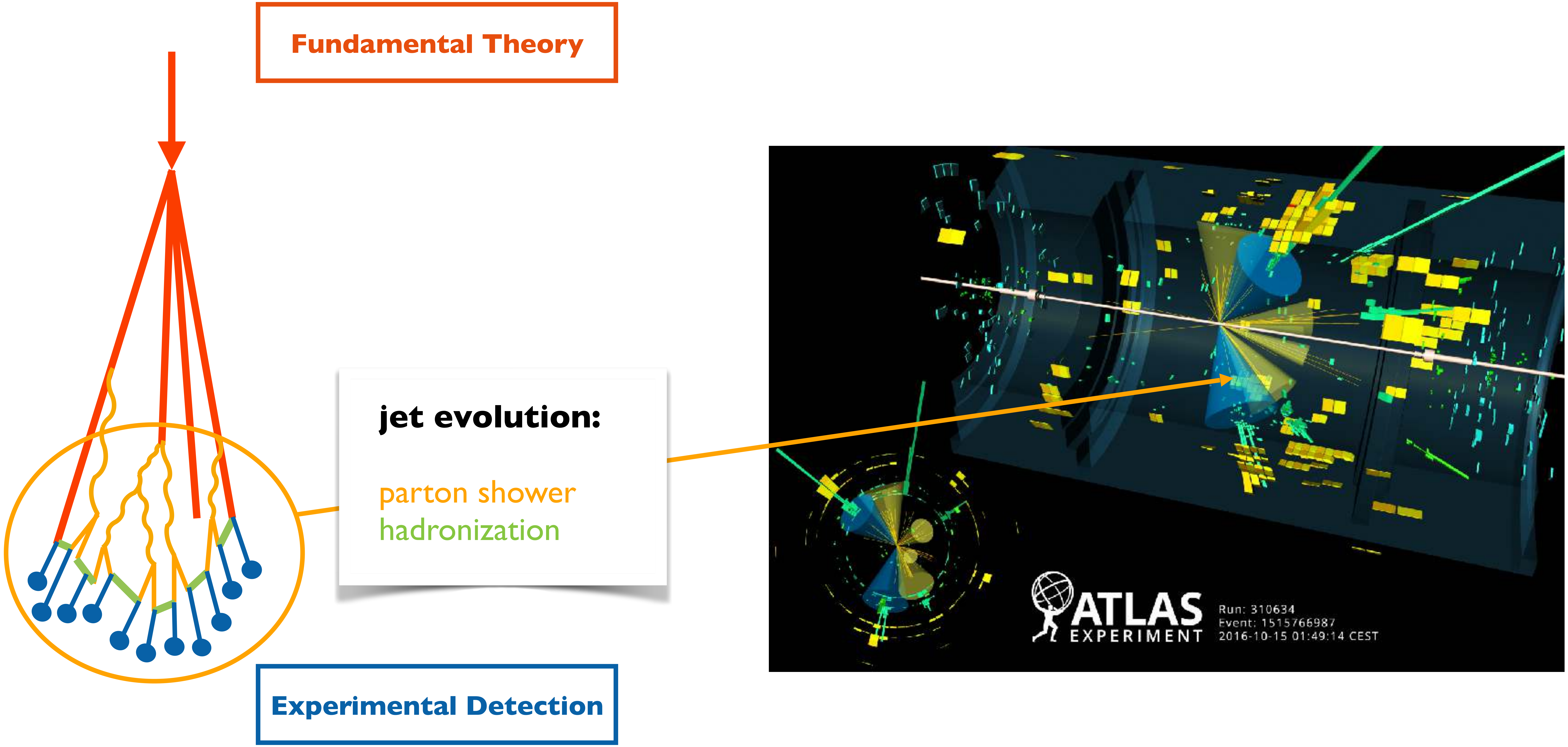
Fundamental Theory



Experimental Detection



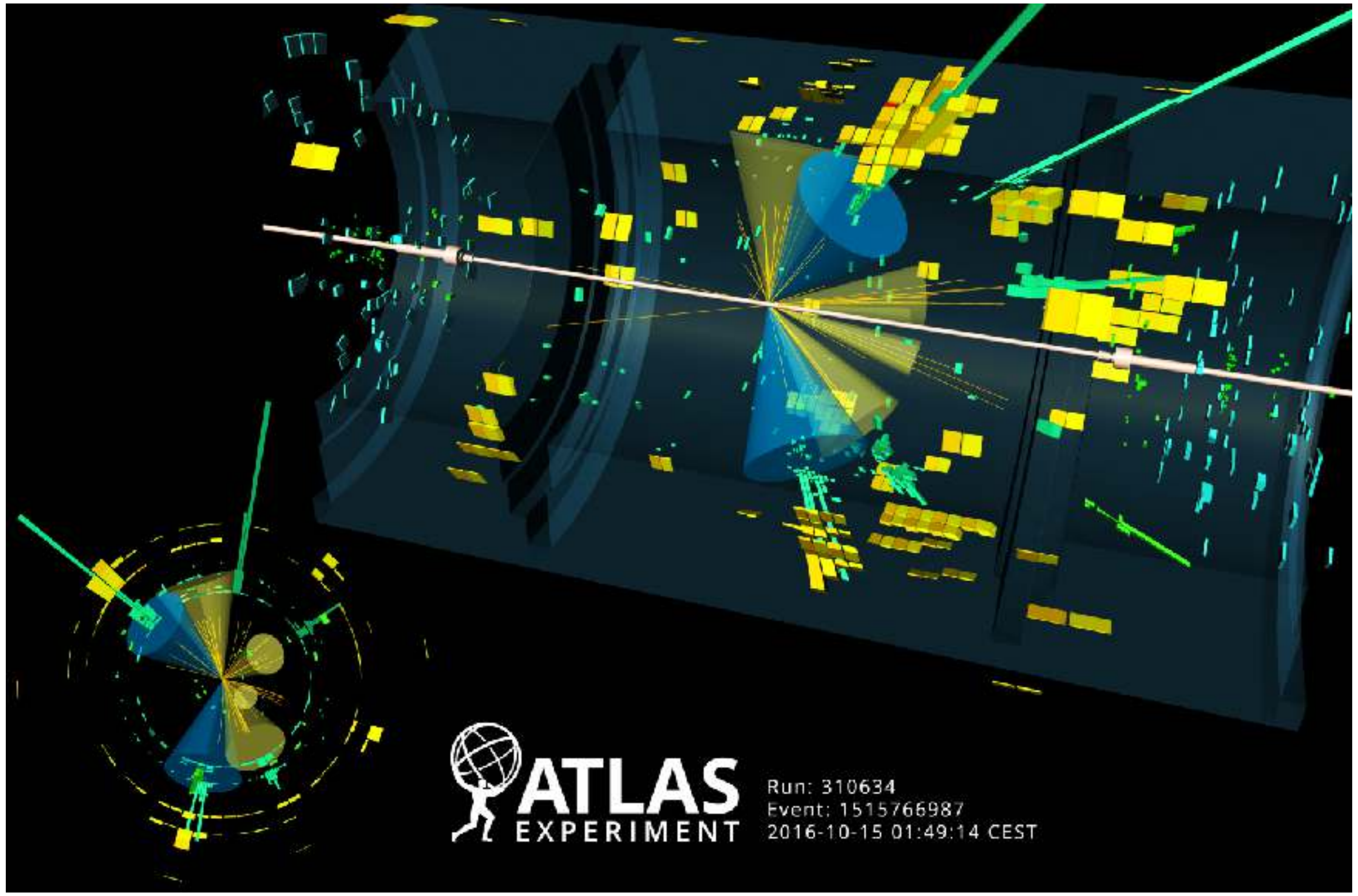
The Complexity of Observations



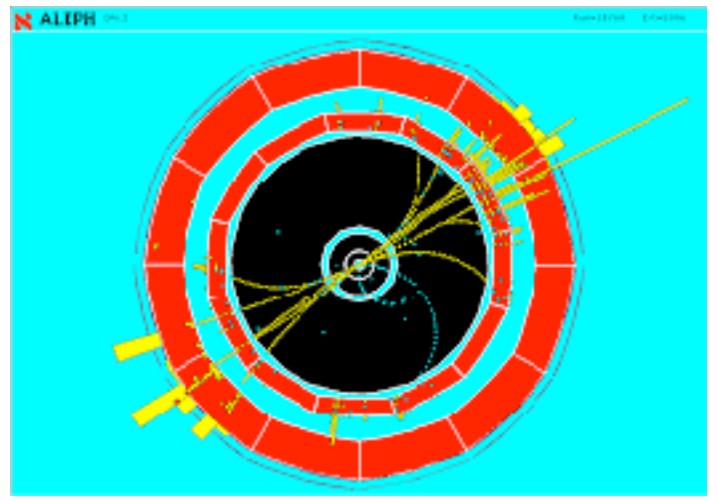
The Complexity of Observations

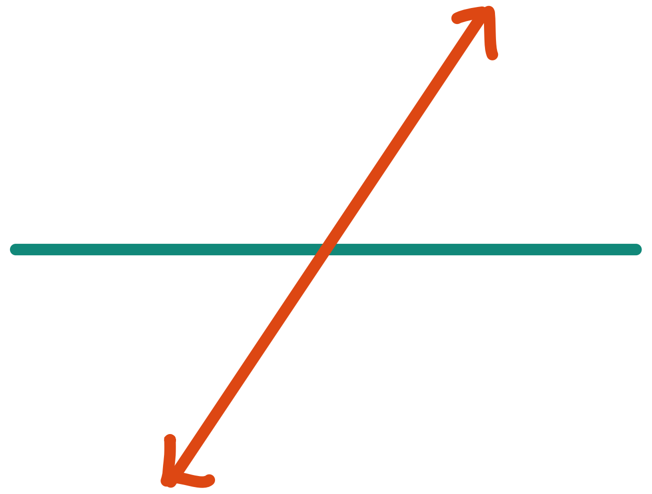
SCIENTIFIC AMERICAN TECHNOLOGY | OPINION

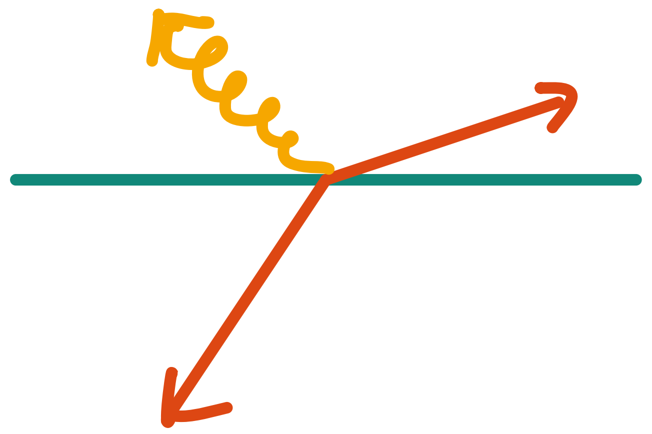
Confirmed! We ~~Live in~~ use a Simulation

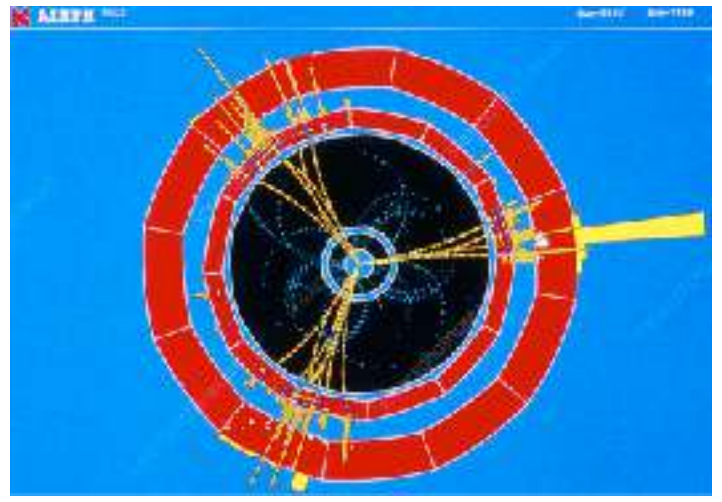


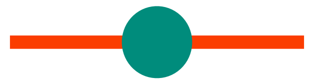
Jets & hadronization





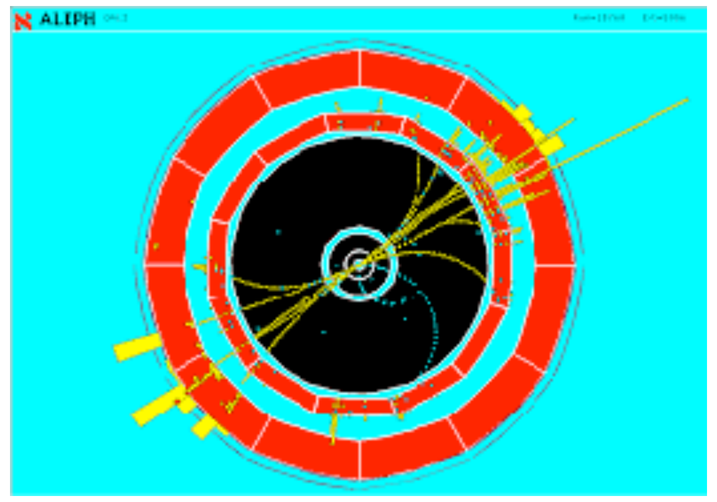


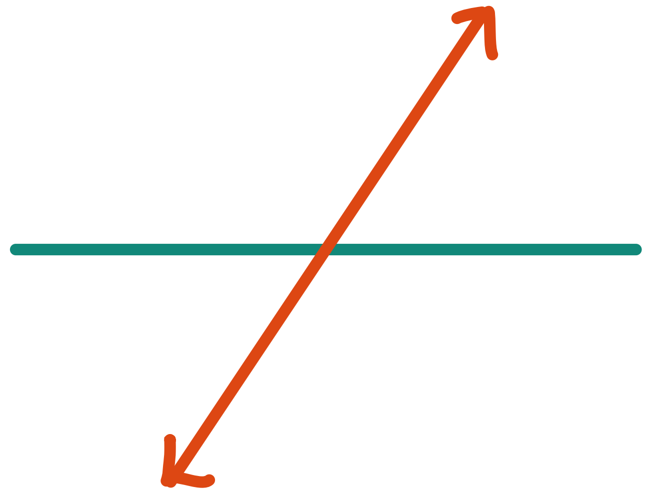


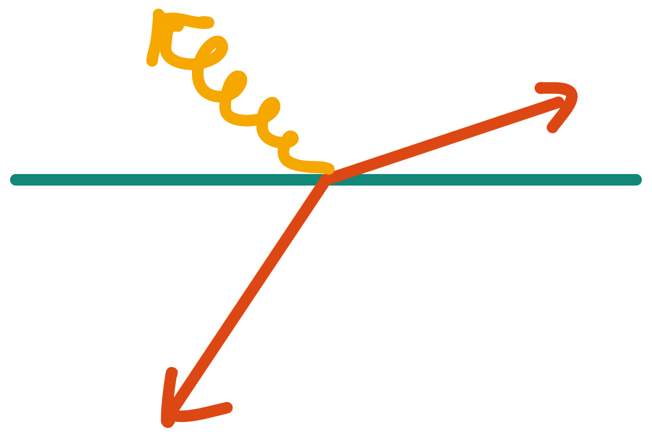


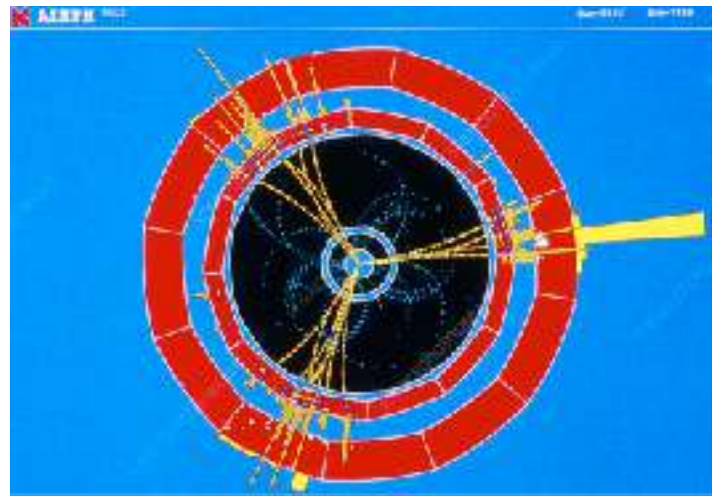
t ~ 1/Q

Jets & hadronization







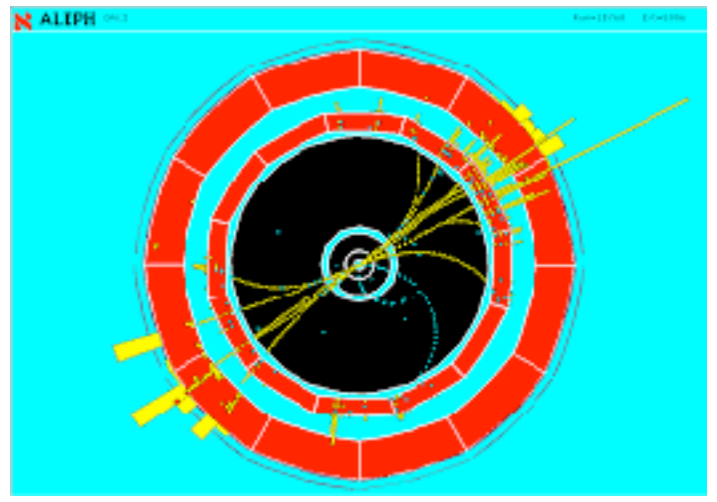


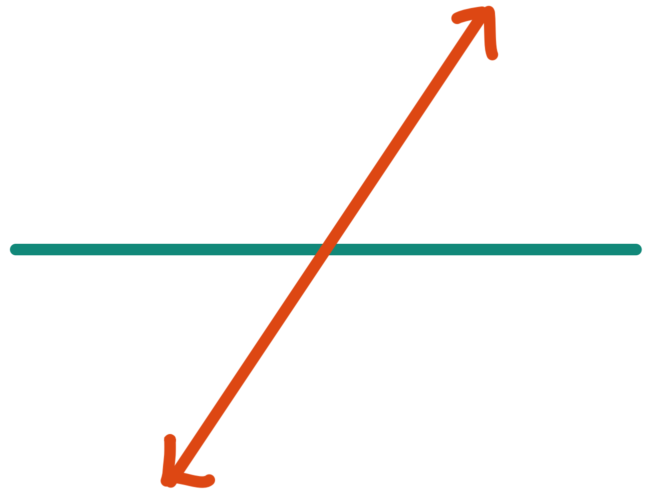
$R \sim 1$ fm

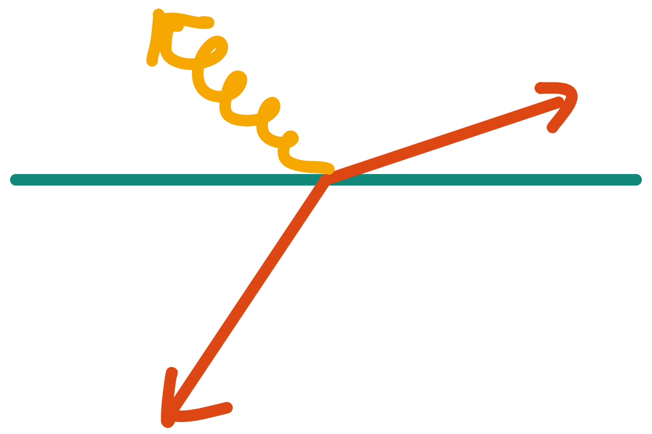
$t_{\text{hadronization}} \sim Q\, R^2$

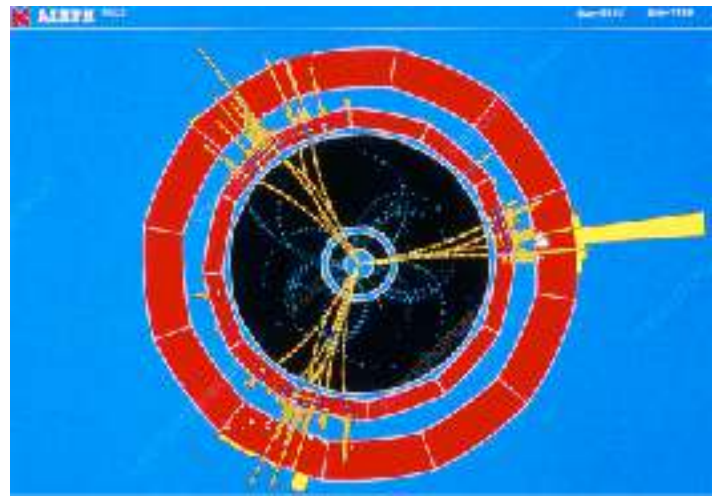
$t \sim 1/Q$

Jets & hadronization









$t_{formation} \sim E/p_t^2$

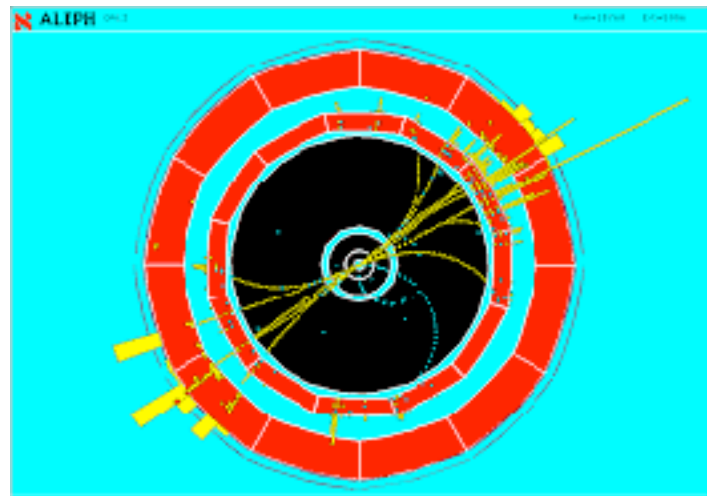
$t_{hadronization} \sim E\ R^2$

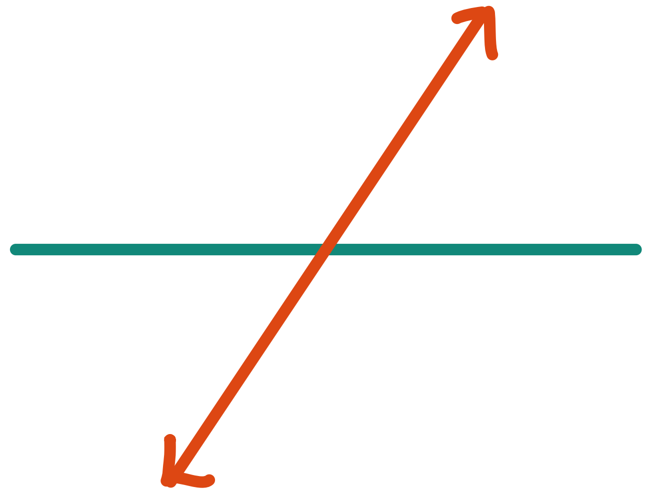
R ~ 1 fm

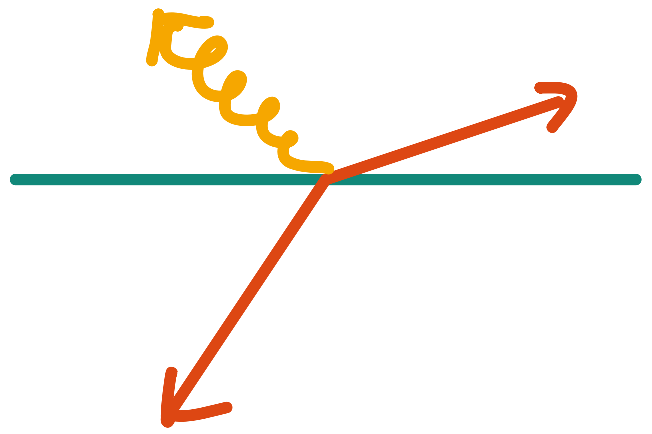
$t_{hadronization} \sim Q\ R^2$

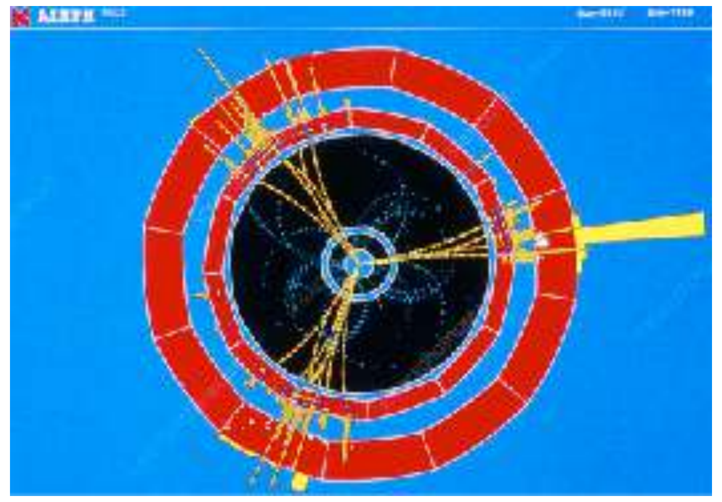
t ~ 1/Q

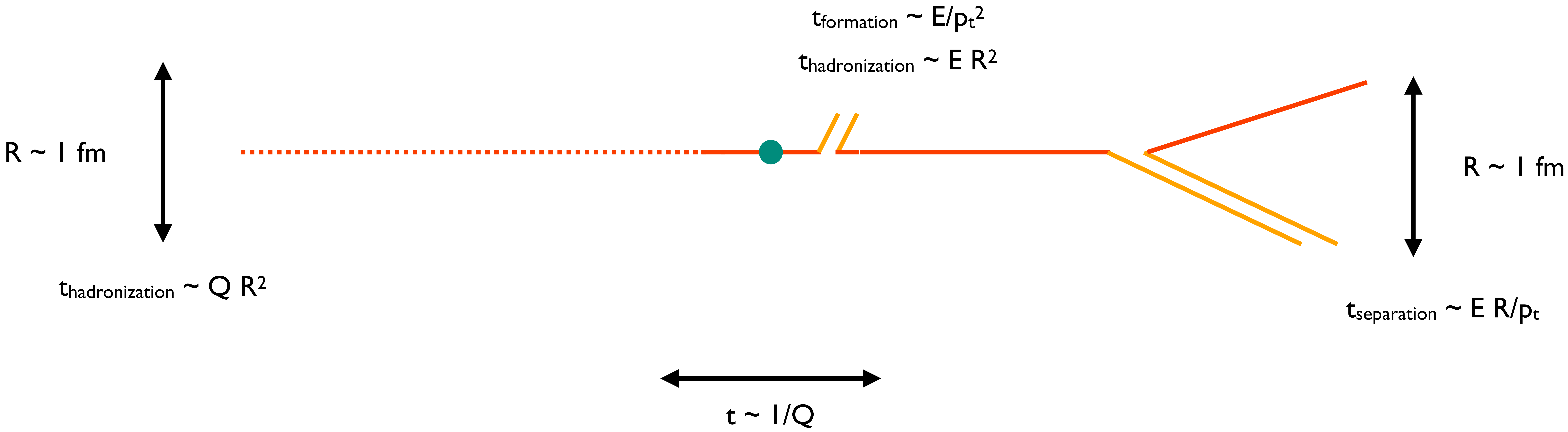
Jets & hadronization



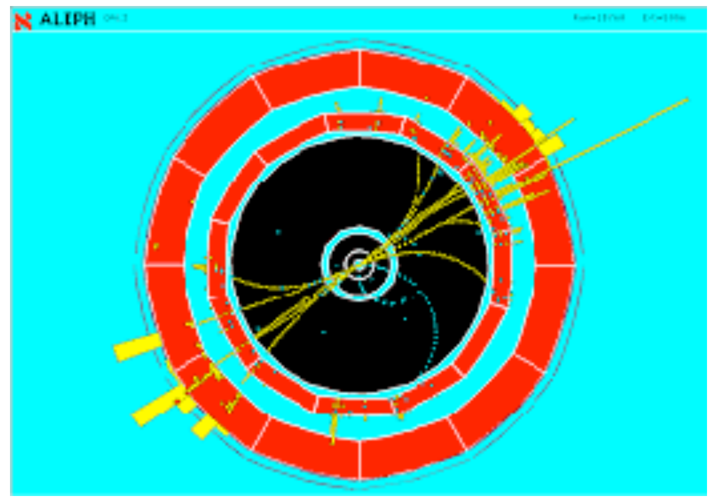


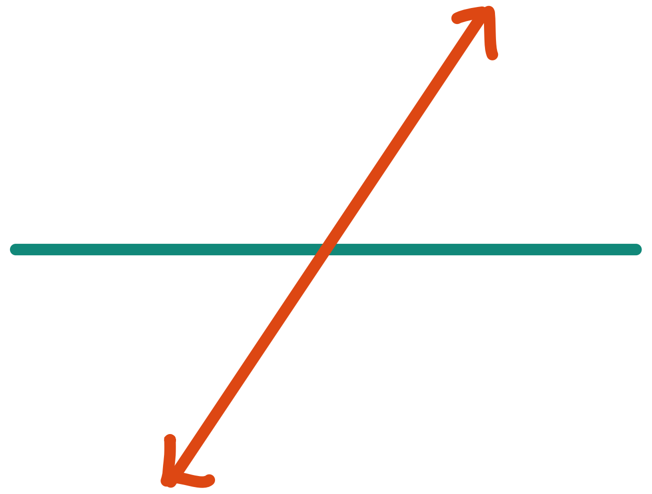


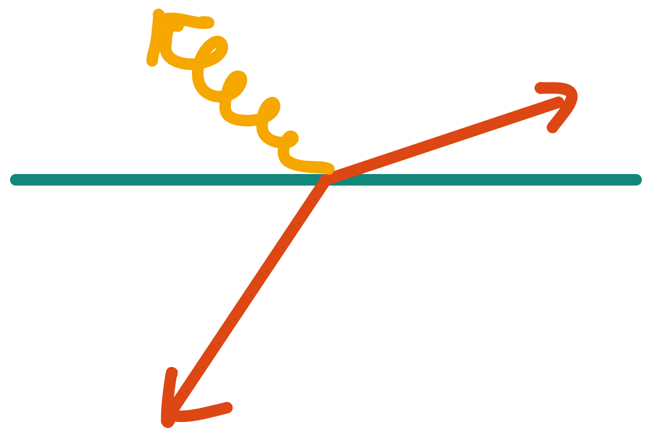


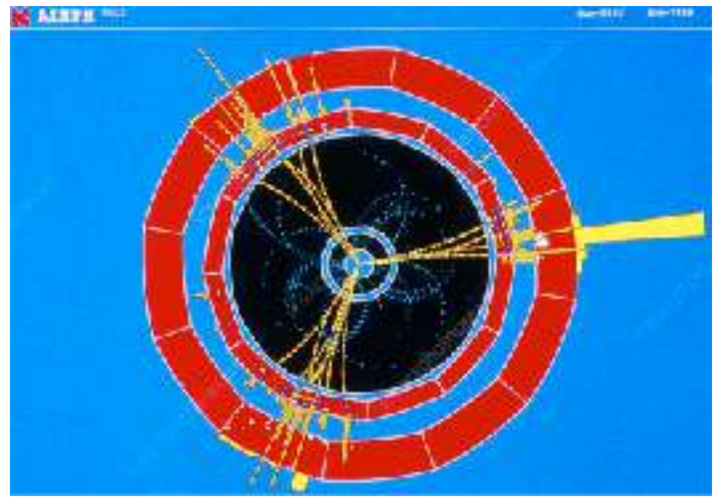


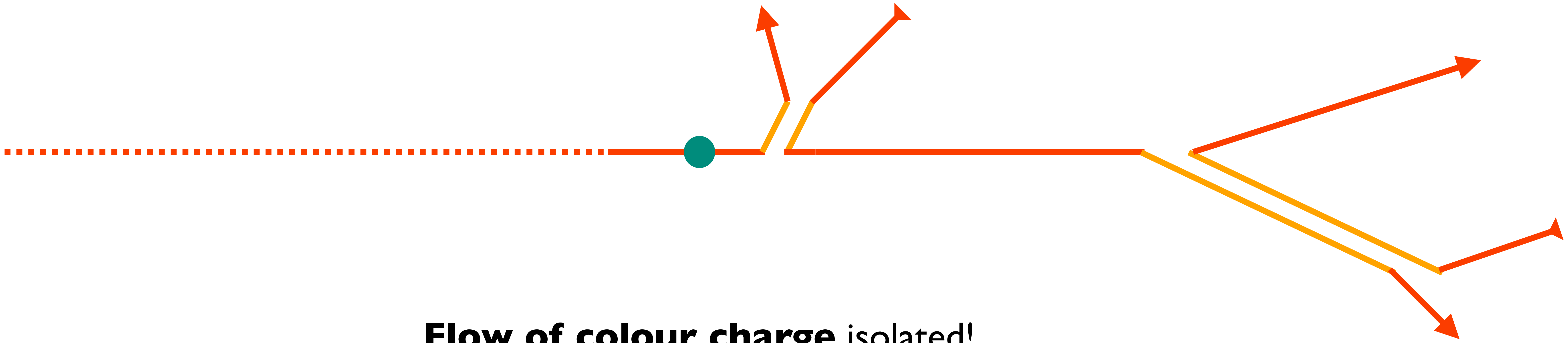
Jets & hadronization







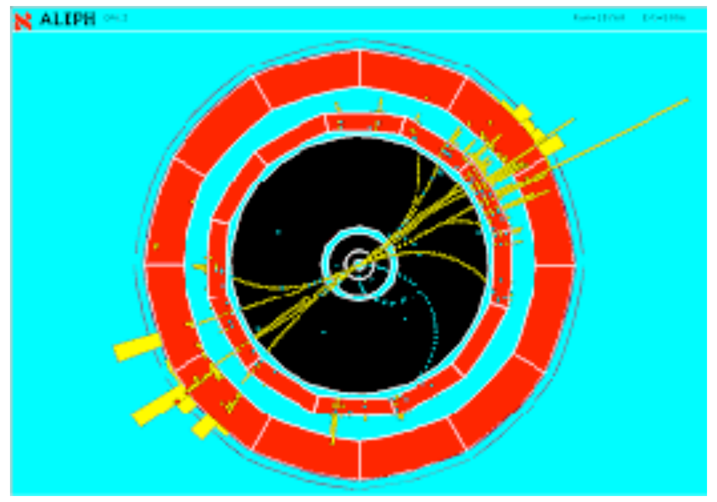


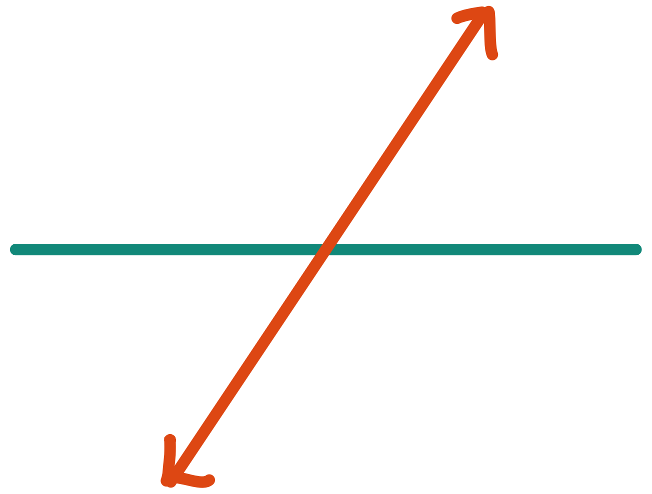


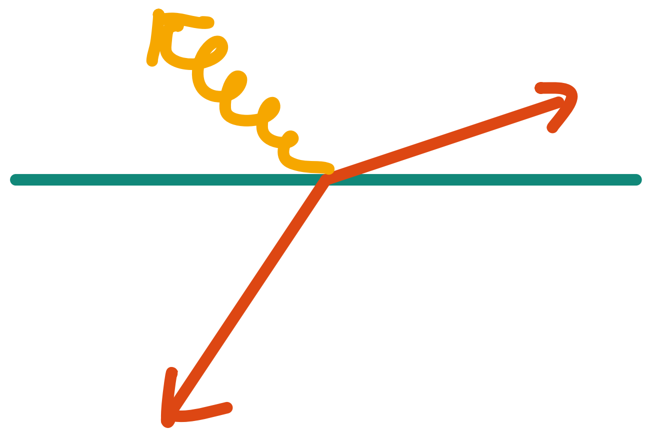
Flow of colour charge isolated!

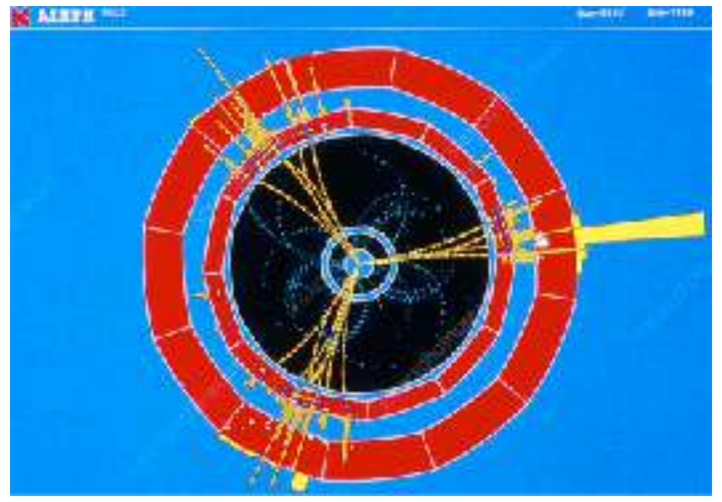
t ~ 1/Q

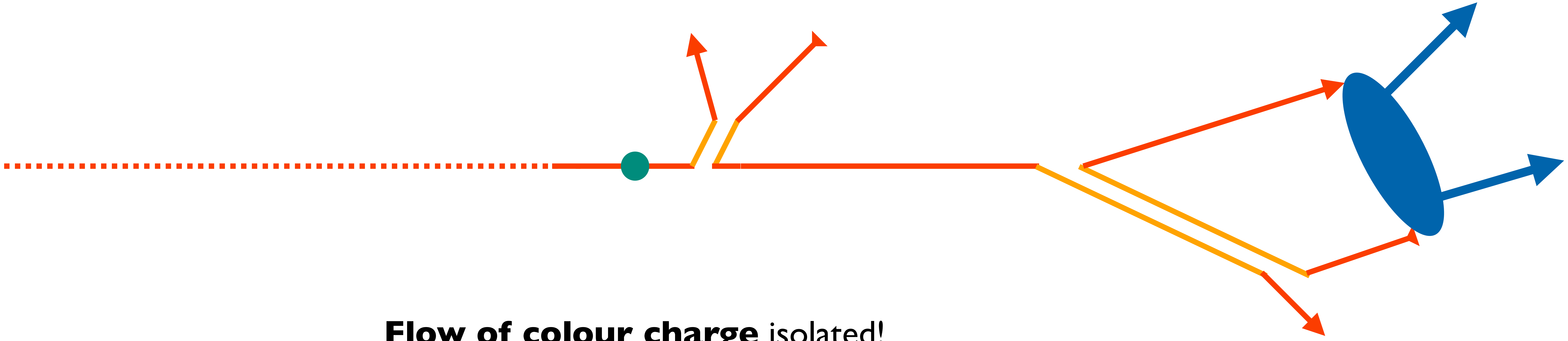
Jets & hadronization











Flow of colour charge isolated!

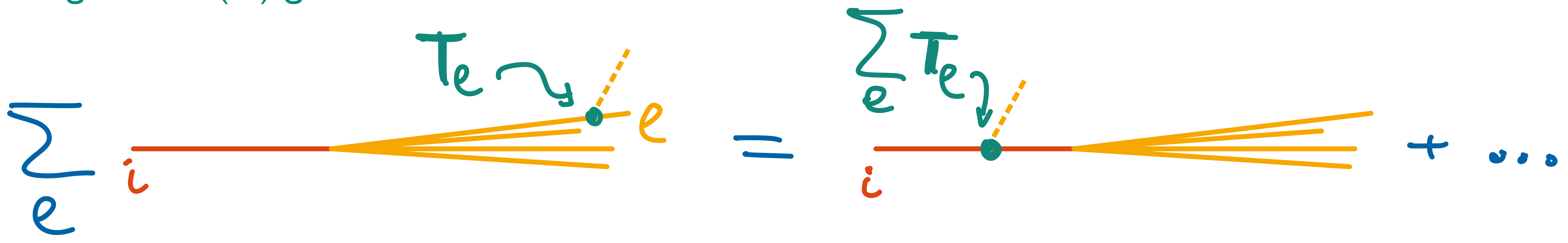
t ~ 1/Q

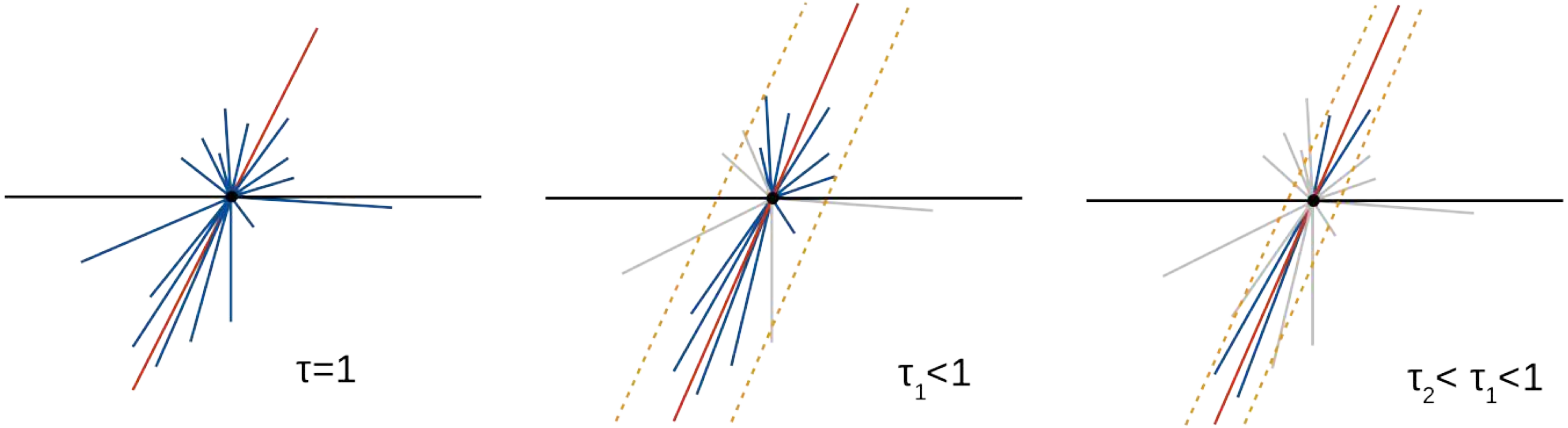
[Cluster models — Gottschalk, Webber, …]

Jets in momentum space: coherence

Flow of colour charge is a statement at the level of scattering amplitudes.

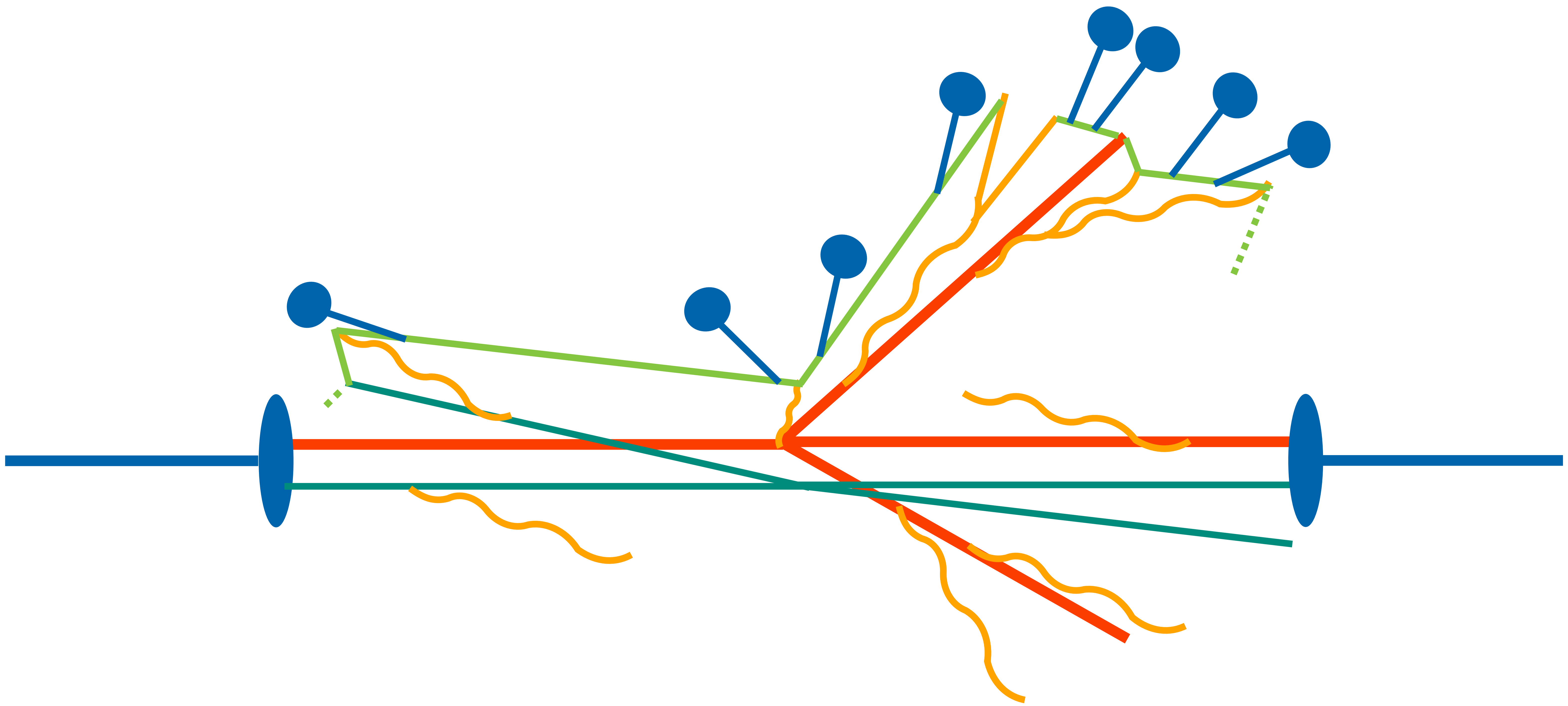
Colour charge — SU(N) generator





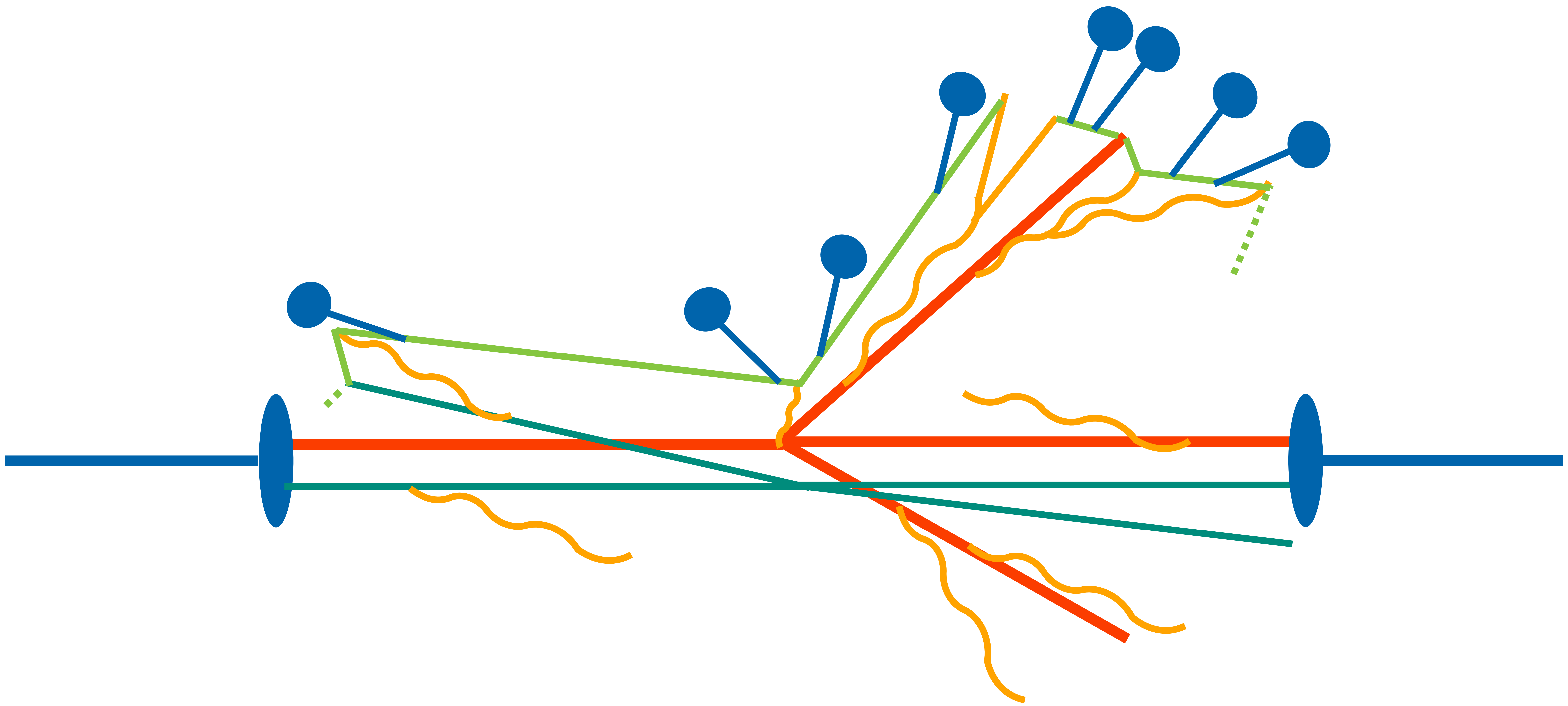
[EARWIG, HERWIG, and all that — Catani, Doskhitzer, Marchesini, Webber, …]

Complexity, factorized.



$$d\sigma \sim L \times d\sigma_H(Q) \times PS(Q \to \mu) \times MPI \times Had(\mu \to \Lambda) \times \ldots$$

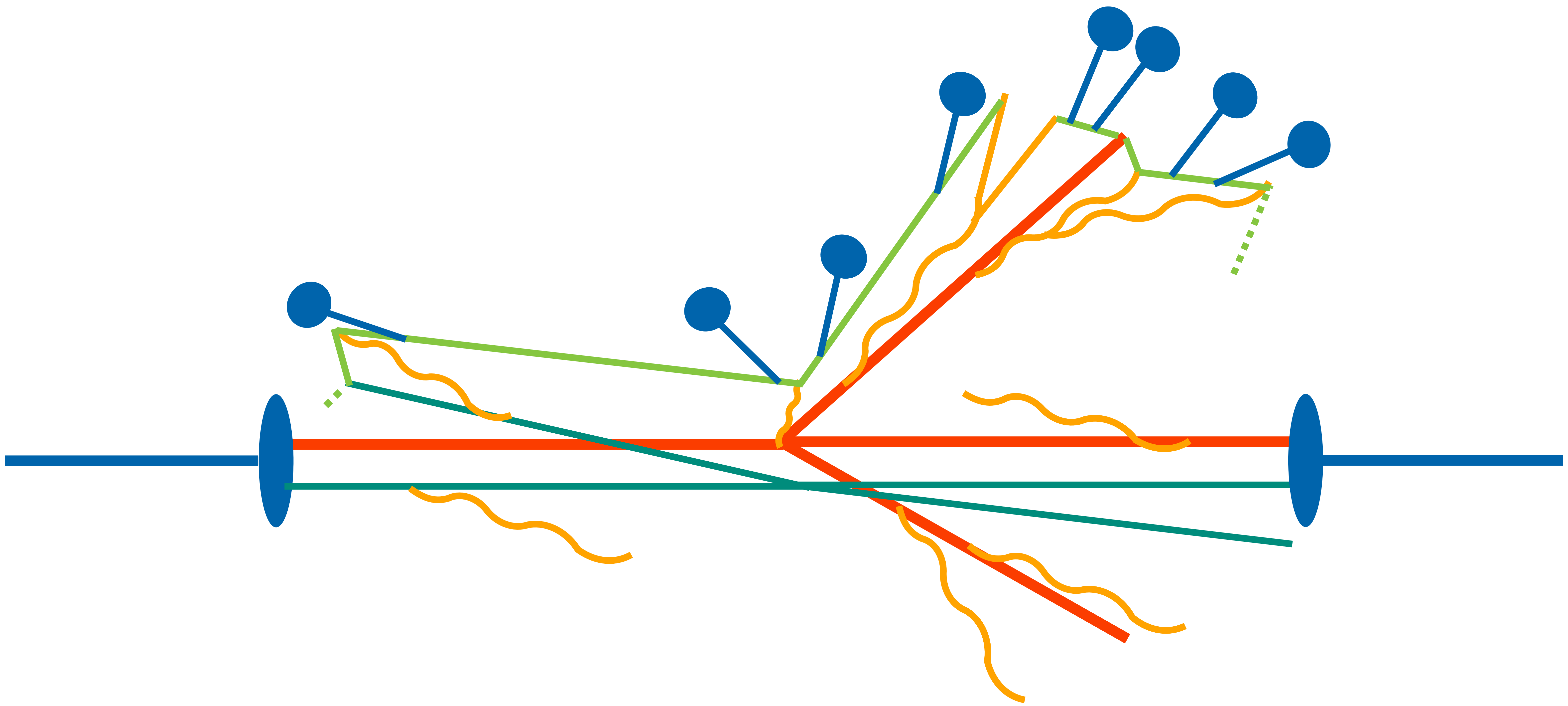
Complexity, factorized.



100's of GeV

$$d\sigma \sim L \times d\sigma_H(Q) \times PS(Q \to \mu) \times MPI \times Had(\mu \to \Lambda) \times \ldots$$

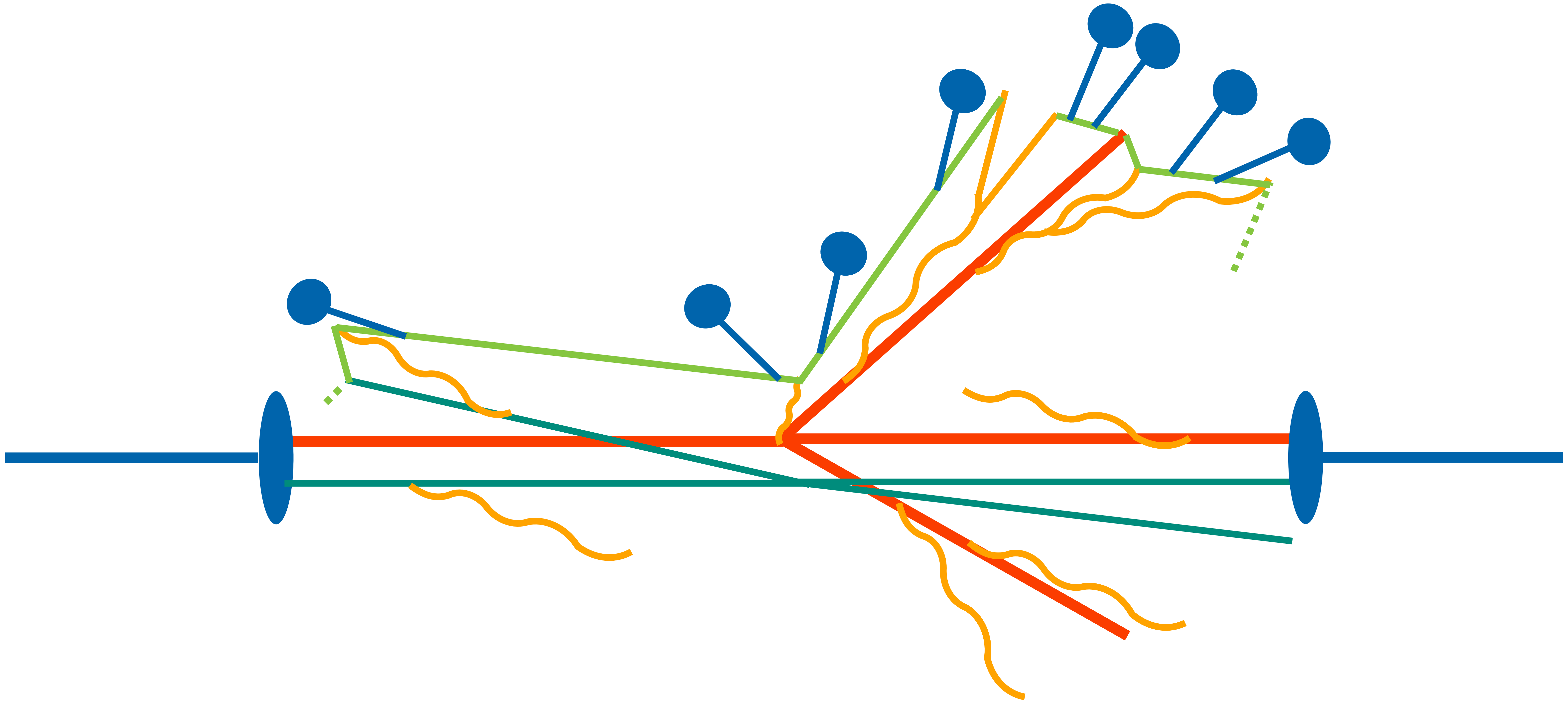
Complexity, factorized.



100's of GeV   1-2 GeV

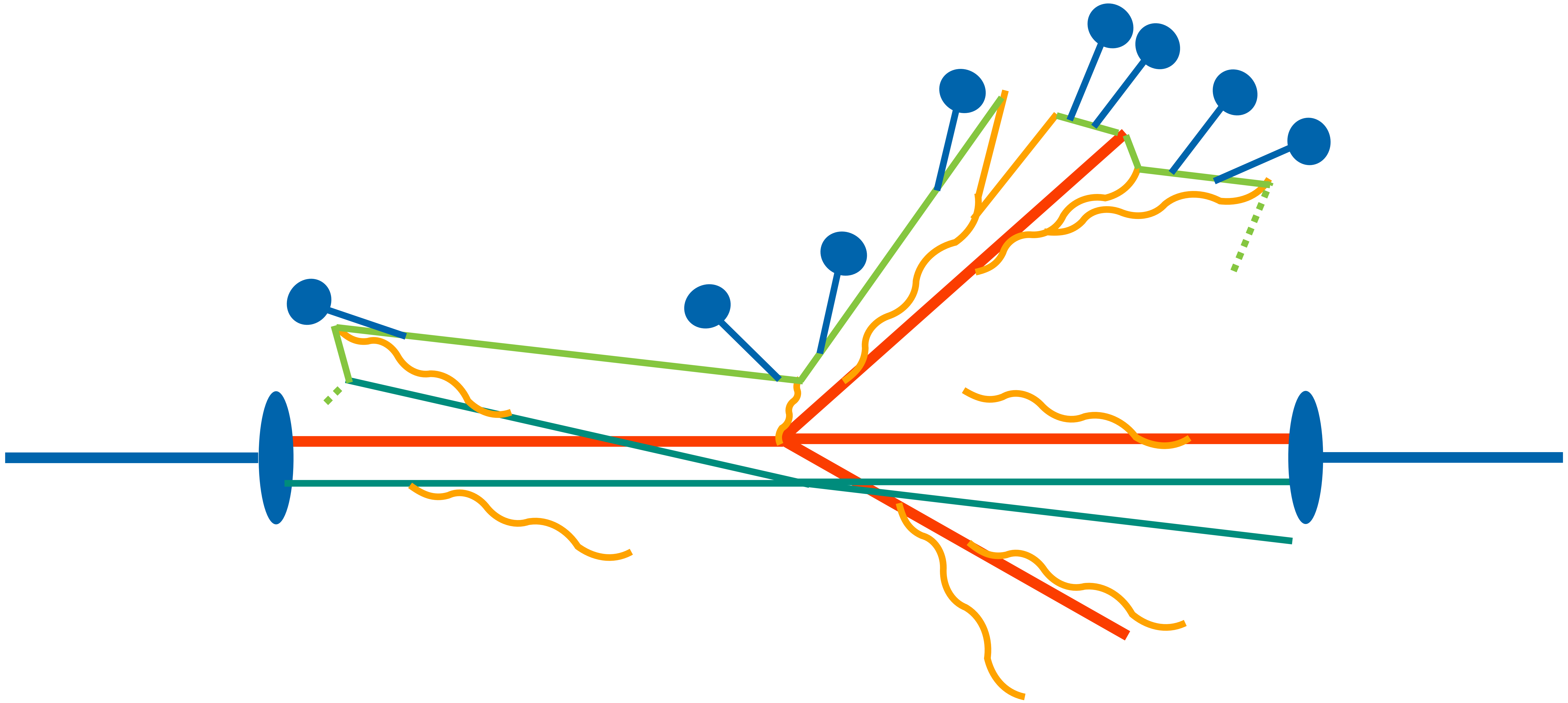
$$d\sigma \sim L \times d\sigma_H(Q) \times PS(Q \to \mu) \times MPI \times Had(\mu \to \Lambda) \times \ldots$$

Complexity, factorized.



$$\mathrm{d}\sigma \sim \mathrm{L} \times \mathrm{d}\sigma_H(Q) \times \mathrm{PS}(Q \to \mu) \times \mathrm{MPI} \times \mathrm{Had}(\mu \to \Lambda) \times \ldots$$

Complexity, factorized.

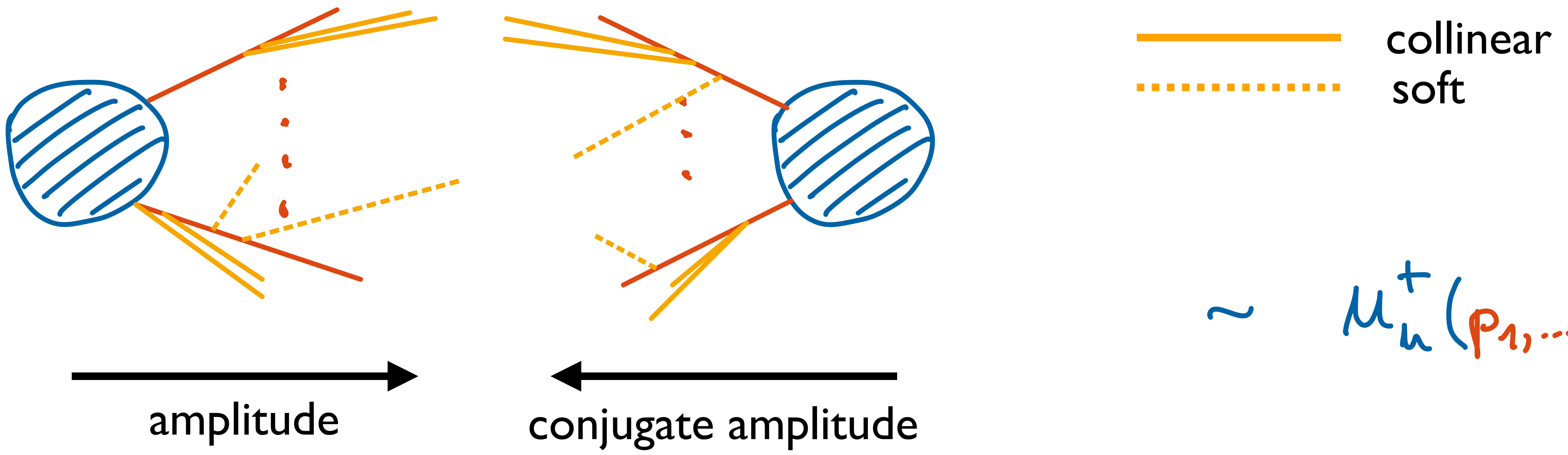


$$d\sigma \sim L \times d\sigma_H(Q) \times PS(Q \to \mu) \times MPI \times Had(\mu \to \Lambda) \times \ldots$$

100's of GeV — 1-2 GeV — 1-10 GeV — few 100's MeV

Building parton showers

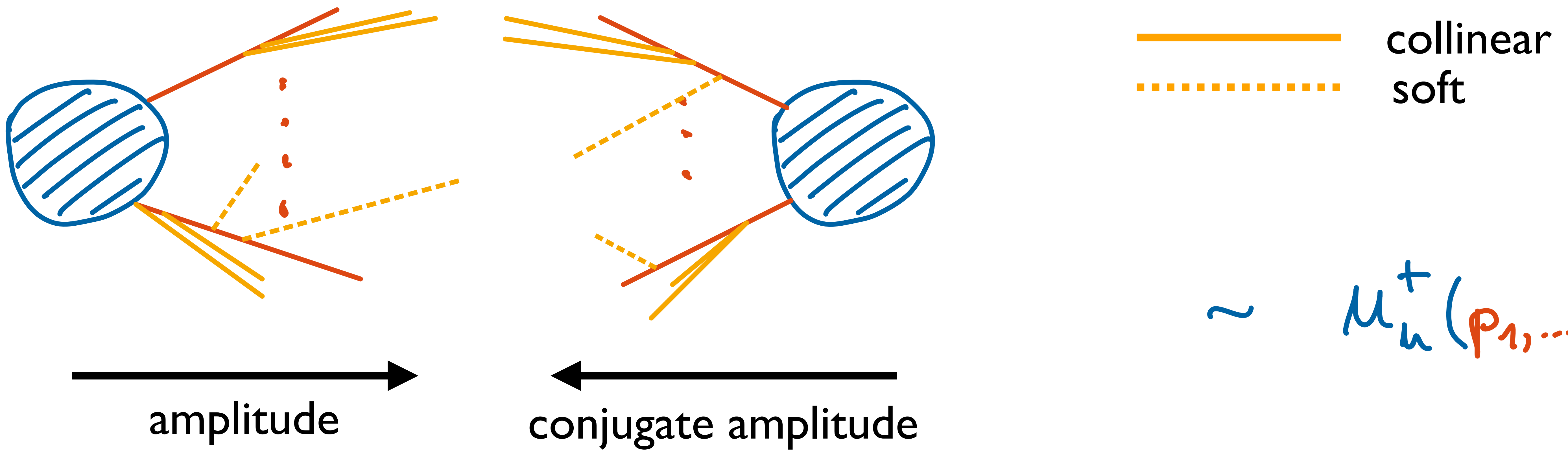
$$\mathrm{d}\sigma \sim \mathrm{L} \times \mathrm{d}\sigma_H(Q) \times \mathrm{PS}(Q \to \mu) \times \mathrm{MPI} \times \mathrm{Had}(\mu \to \Lambda) \times \ldots$$



$$\sim \mathcal{M}_n^{\dagger}(p_1, \ldots, p_n)\, T \cdots T \circ T \cdots T\, \mathcal{M}_n(p_1, \ldots, p_n)$$

Building parton showers

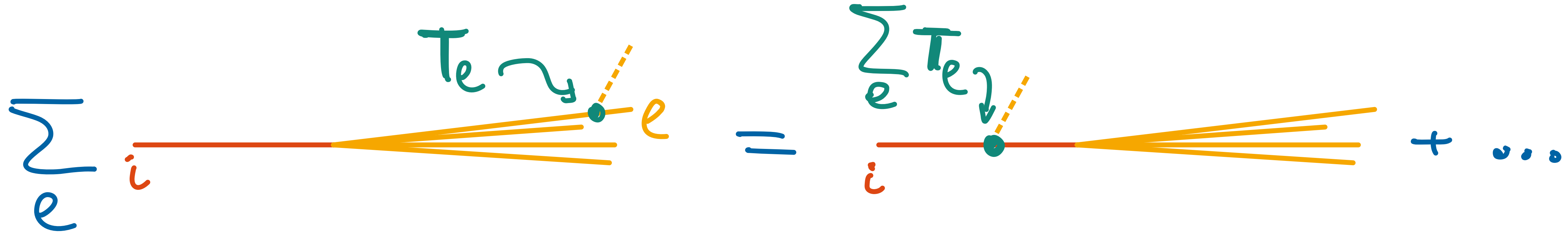
$$d\sigma \sim \mathrm{L} \times d\sigma_H(Q) \times \mathrm{PS}(Q \to \mu) \times \mathrm{MPI} \times \mathrm{Had}(\mu \to \Lambda) \times \ldots$$



$$\sim \mathcal{M}_n^\dagger(p_1,\dots,p_n)\, \mathbf{T}\cdots\mathbf{T}\cdot\mathbf{T}\cdots\mathbf{T}\, \mathcal{M}_n(p_1,\dots,p_n)$$

Exploit QCD coherence:

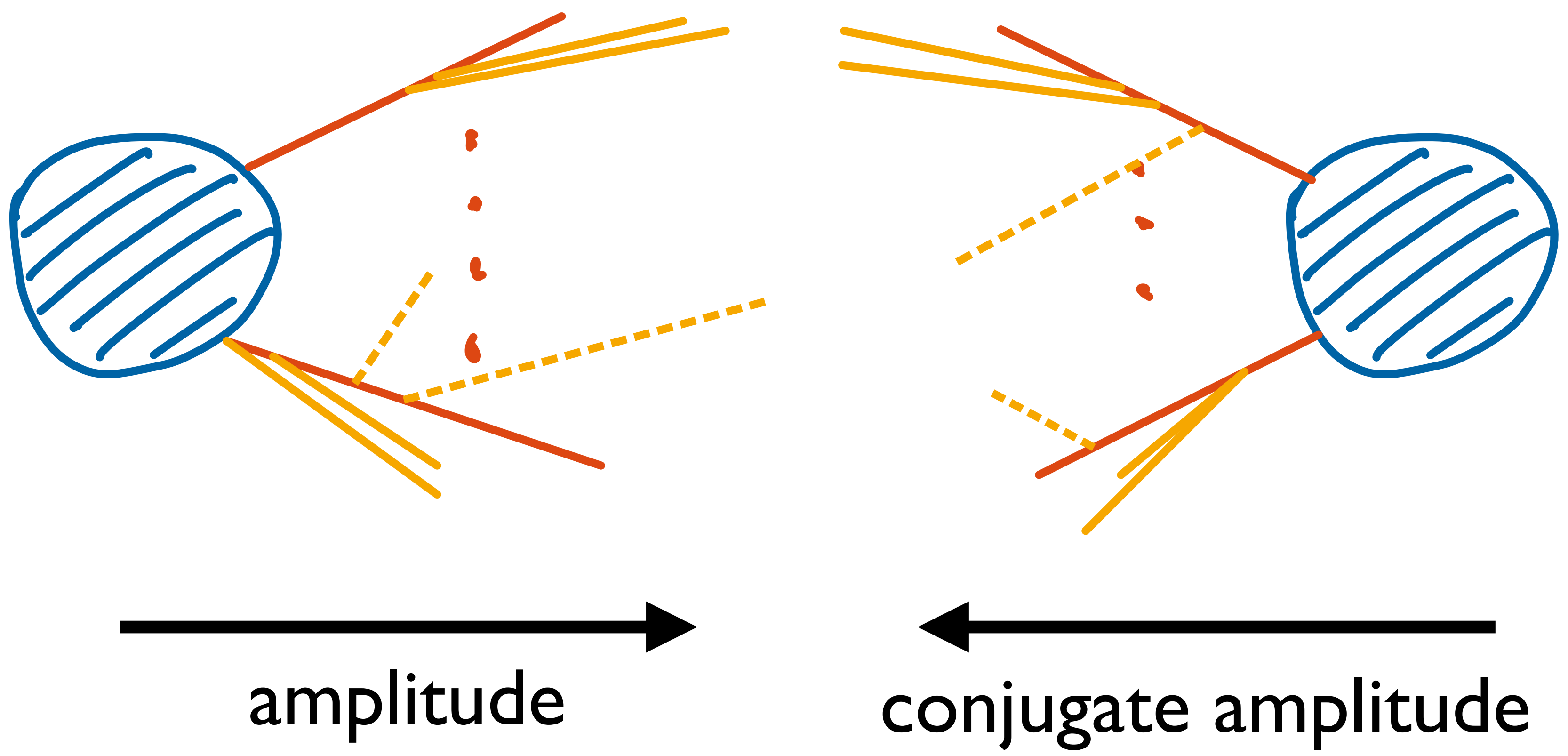
Colour correlations are simple in the collinear limit.

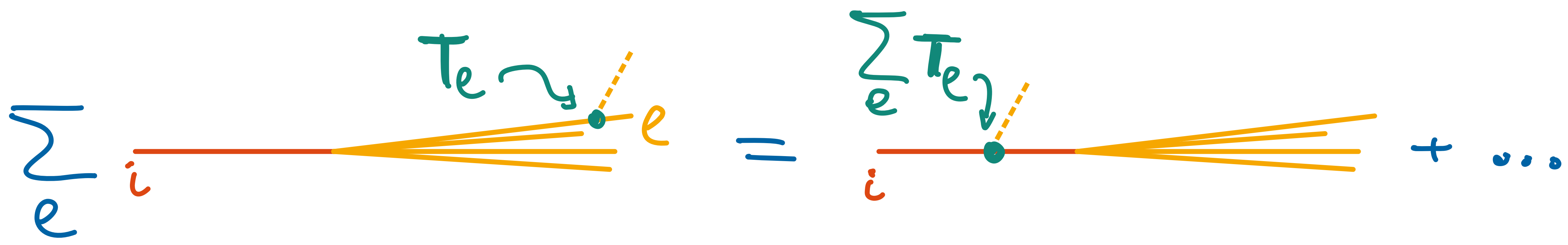


$$\mathbf{T}_j \mathbf{T}_l \mathbf{T}_i\cdot\mathbf{T}_i \mathbf{T}_m \mathbf{T}_j = C_i\, \mathbf{T}_j \mathbf{T}_l\cdot\mathbf{T}_m \mathbf{T}_j$$

Coherent branching parton showers

$$d\sigma \sim \mathrm{L} \times d\sigma_H(Q) \times \mathrm{PS}(Q \to \mu) \times \mathrm{MPI} \times \mathrm{Had}(\mu \to \Lambda) \times \ldots$$





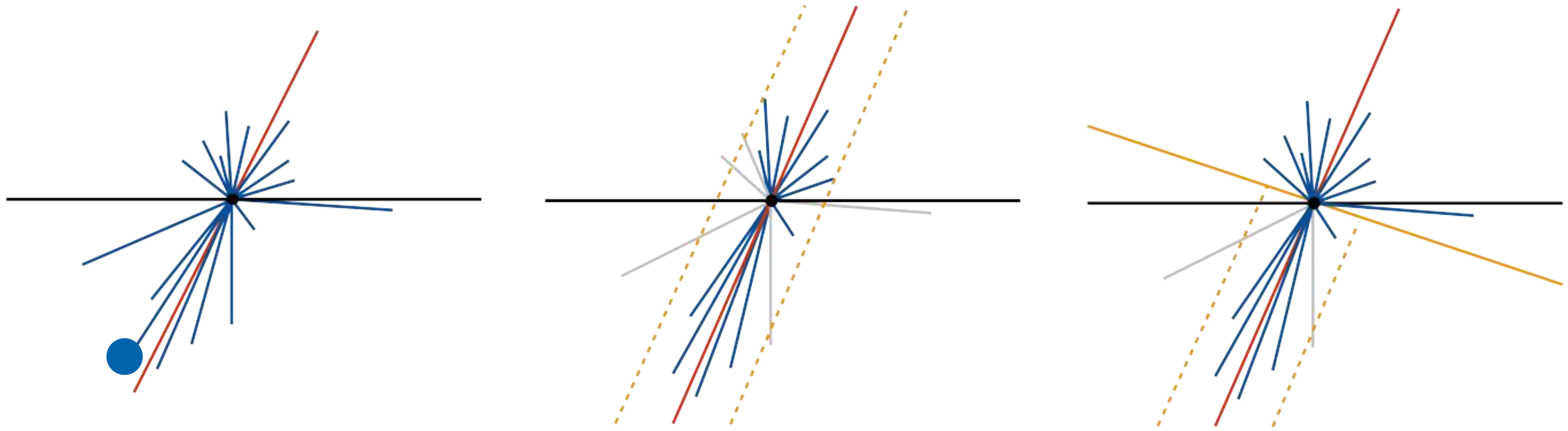
$$dS = \frac{\alpha_s}{2\pi}\frac{d\tilde{q}_i^2}{\tilde{q}_i^2} dz P(z_i) \exp\left(- \int_{\tilde{q}_i^2}^{Q^2} \frac{dq^2}{q^2} \int_{z_-(k^2)}^{z_+(k^2)} d\xi \frac{\alpha_s}{2\pi} P(z) \right)$$

emission rate

no emission probability

All probabilistic algorithms determine the effect of gluon exchange and virtual corrections by unitarity.

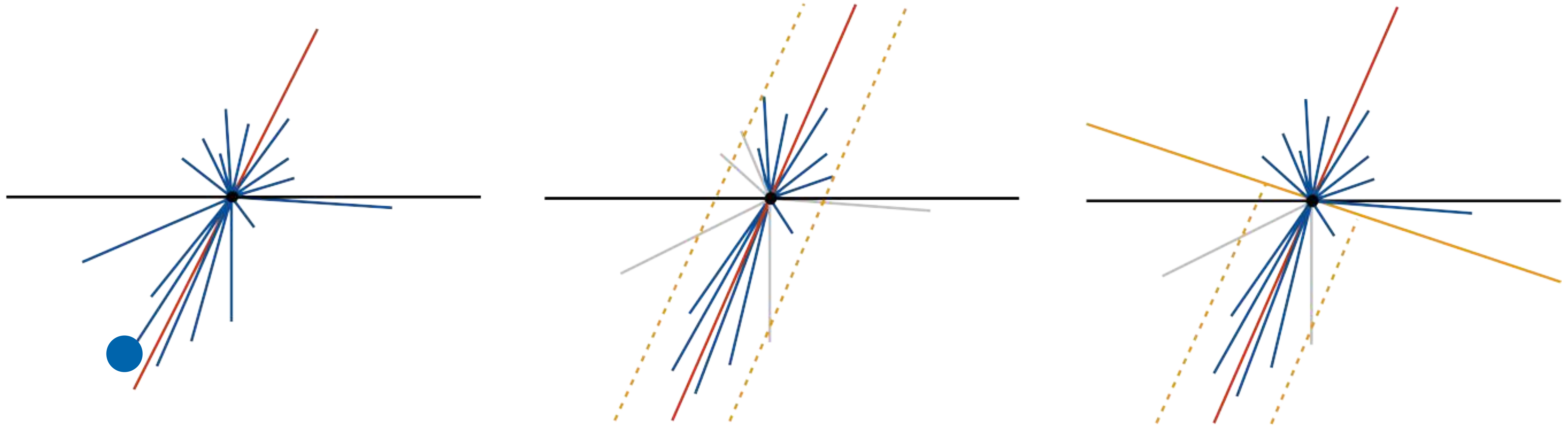
Accuracy of Parton Showers



Fragmentation is fine if we get collinear physics right.

Accuracy of Parton Showers

[Catani, Trentadue, Webber, Marchesini ….]



Fragmentation is fine if we get collinear physics right.

Global event shapes from coherent branching — for two jets.

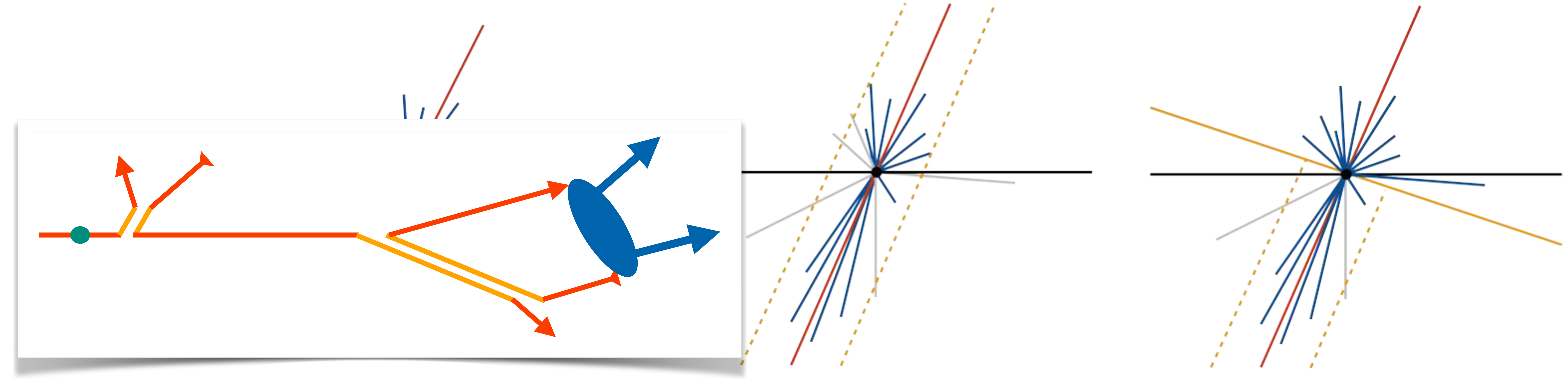
$$H(\alpha_s) \times \exp\left(Lg_1(\alpha_s L) + g_2(\alpha_s L) + \alpha_s g_3(\alpha_s L) + \ldots\right)$$

LL — qualitative   NLL — quantitative   NNLL — precision

$\alpha_s L \sim 1$

Accuracy of Parton Showers

[Catani, Trentadue, Webber, Marchesini ….]



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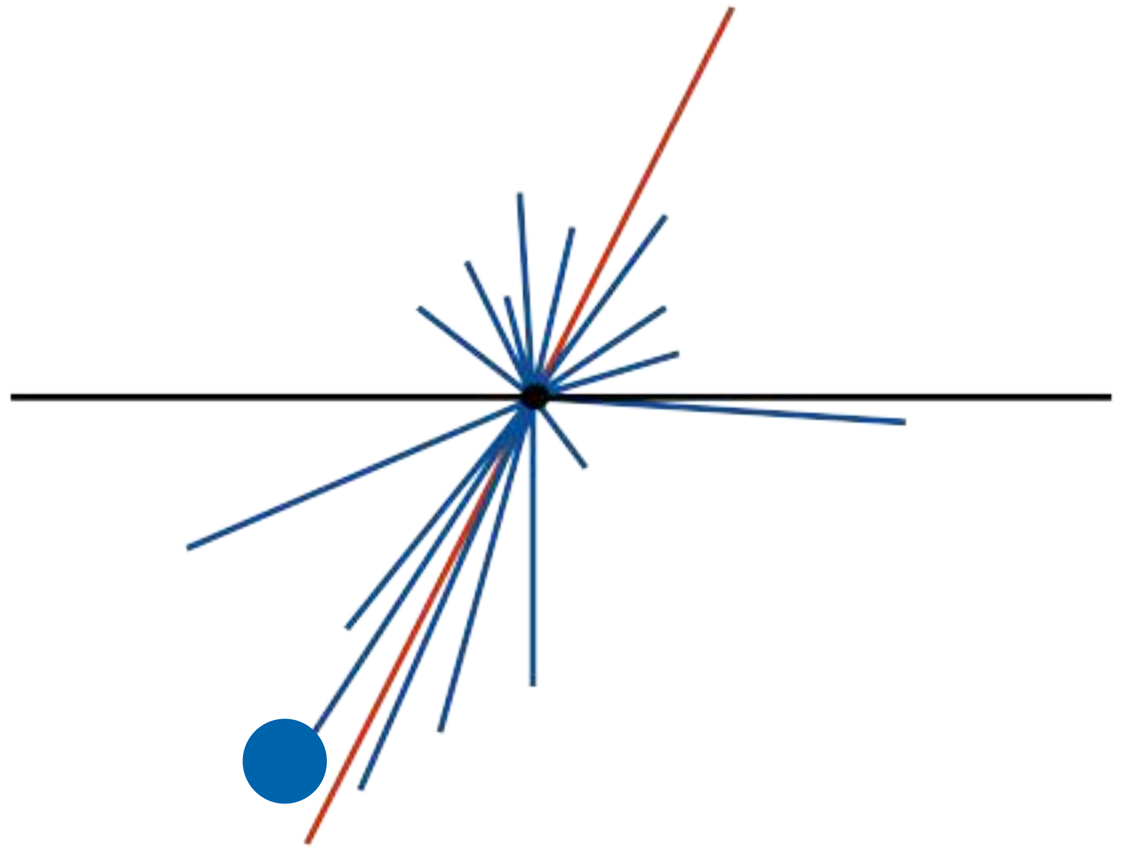
LL — qualitative   NLL — quantitative   NNLL — precision

$$\alpha_s L \sim 1$$

Accuracy of Parton Showers



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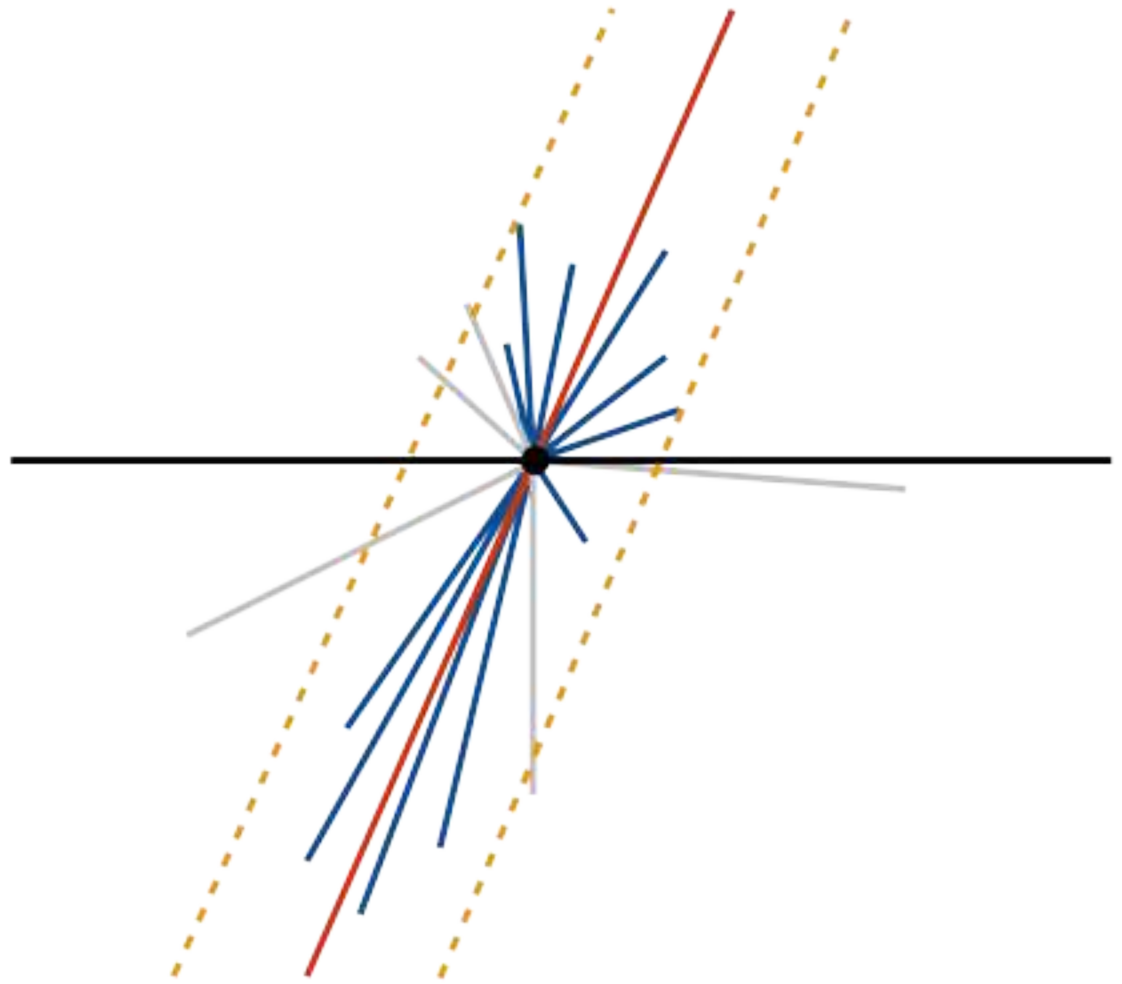

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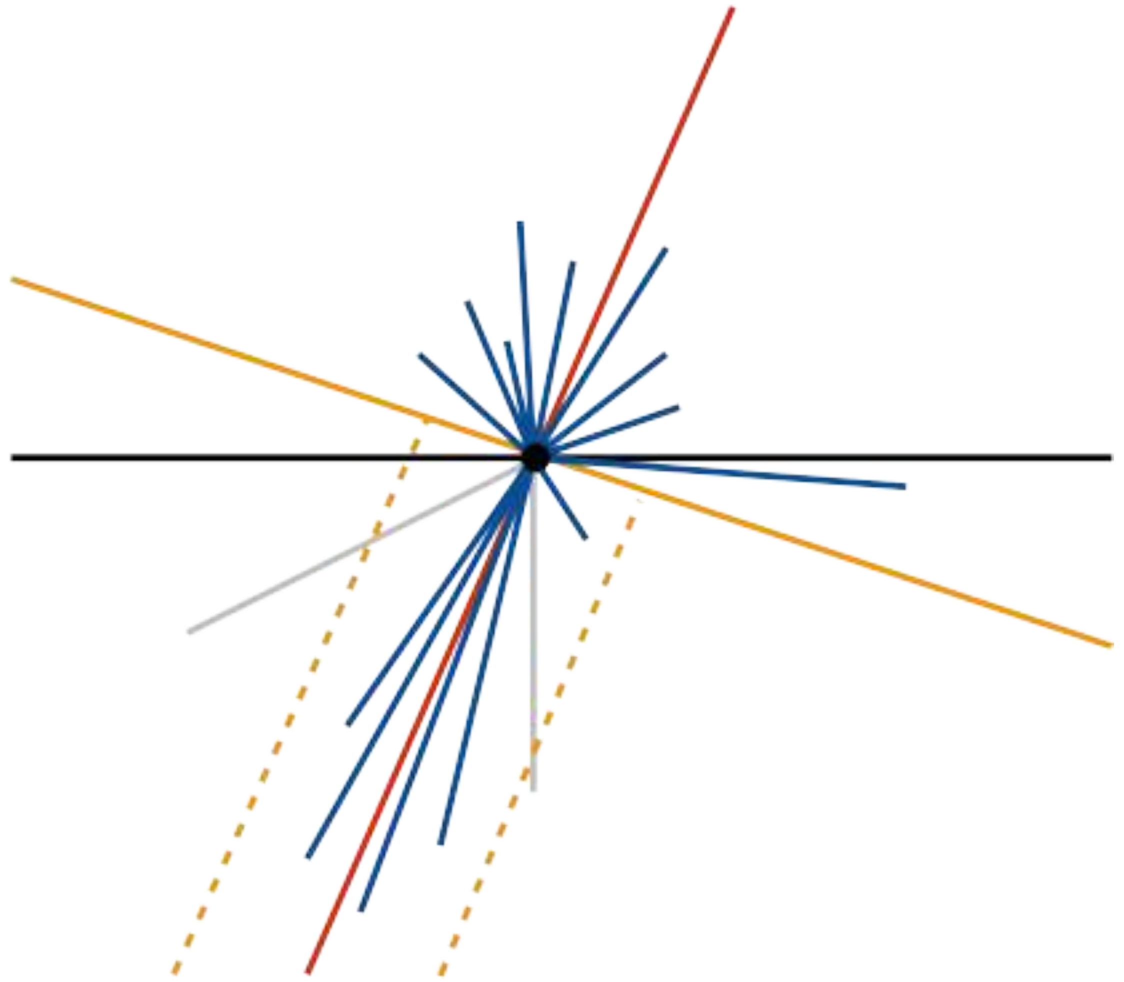


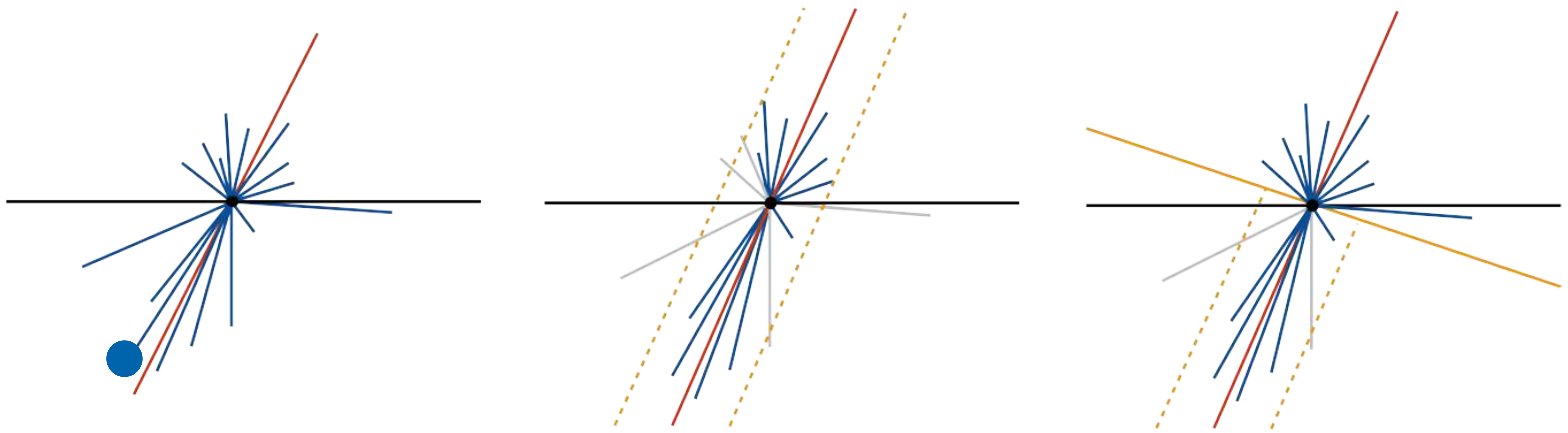
Coherence breaks down for non-global observables.

$T_k T_l T_i \cdot T_j T_m T_n$

↓

large-N limit

Event generator accuracy



(N)NLO with matching

NLL with coherent branching
Issues in dipole showers

Issues in coherent branching
LL with dipole showers

Can we push this to $\text{NLL}_{\text{global}}$ / $\text{LL}_{\text{non-global}}$ in one (dipole) algorithm? $\alpha_s L \sim 1$ $\alpha_s N^2 \sim 1$

Event generator accuracy

Progress in improving the PS accuracy

- **Assessing the logarithmic accuracy of a shower**
  Herwig [1904.11866, 2107.04051], Deductor [2011.04777], Forshaw, Holguin, Plätzer [2003.06400]
  PanScales [1805.09327, 2002.11114], Alaric [2110.05964], …
- **Triple collinear / double soft splittings**
  Dulat, Höche, Krauss, Gellersen, Prestel [1705.00982, 1705.00742, 1805.03757, 2110.05964]
  Li & Skands [1611.00013], Löschner, Plätzer, Simpson Dore [2112.14454], …
- Matching to fixed-order **see Alexander's talk**
  NLO; i.e. Frixione & Webber [0204244], Nason [0409146], …
  NNLO; i.e. UNNLOPS [1407.3773], MiNNLOps [1908.06987], Vincia [2108.07133], …
  NNNLO; Prestel [2106.03206], Bertone, Prestel [2202.01082]
- Colour (and spin) correlations **see Simon's talk**
  Forshaw, Holguin, Plätzer, Sjödahl [1201.0260, 1808.00332, 1905.08686, 2007.09648, 2011.15087]
  Deductor [0706.0017, 1401.6364, 1501.00778, 1902.02105], Herwig [1807.01955], Plätzer & Ruffa [2012.15215]
  PanScales [2011.10054, 2103.16526, 2111.01161], …
- Electroweak corrections
  Vincia [2002.09248, 2108.10786], Pythia [1401.5238], Herwig [2108.10817], …

Super-active field of research:
taken from Melissa van Bleekveld's talk at the CERN workshop on parton showers for future colliders.

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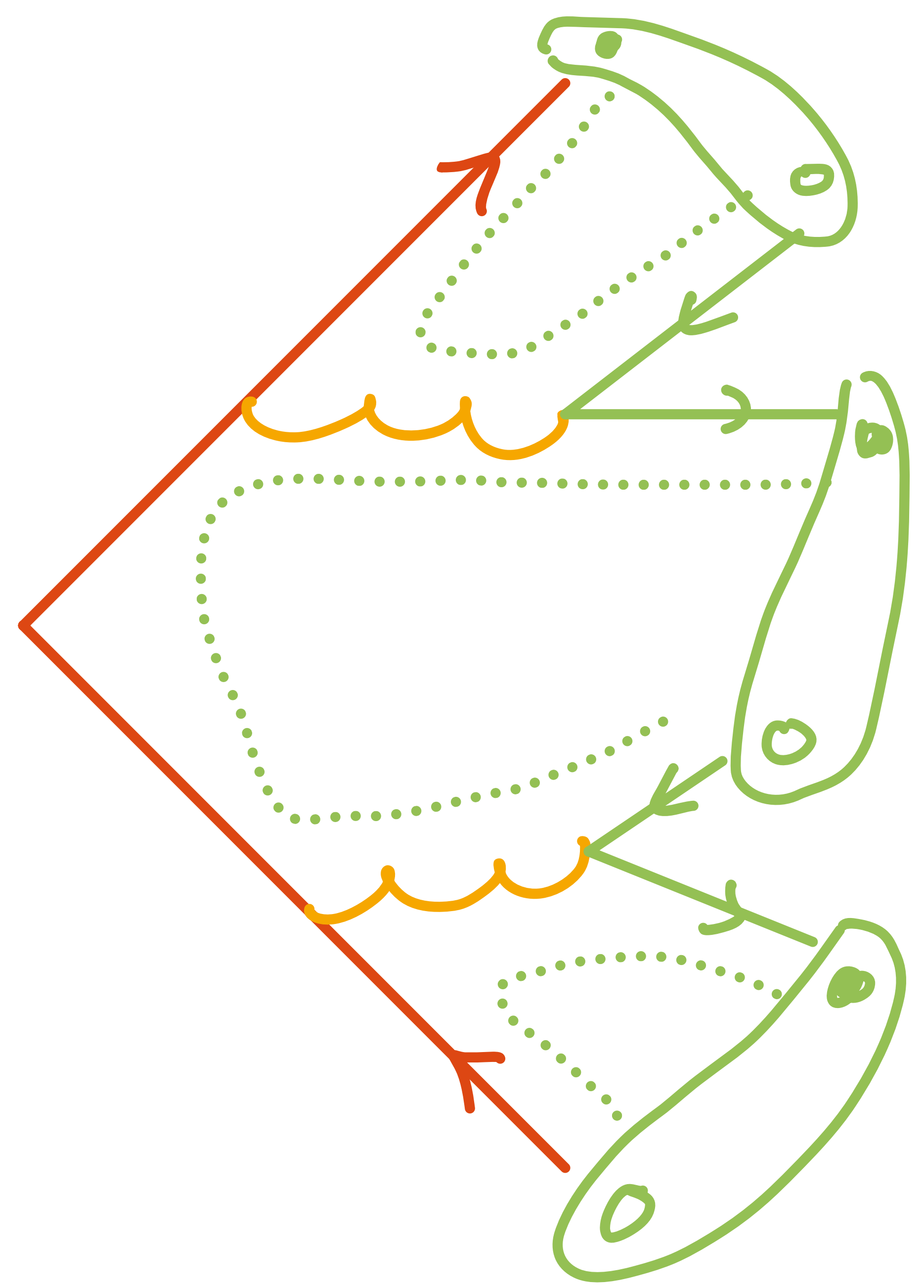
$L \sim 1 \qquad \alpha_s N^2 \sim 1$

Hadronization: the cluster model

$$\mathrm{d}\sigma \sim \mathrm{L} \times \mathrm{d}\sigma_H(Q) \times \mathrm{PS}(Q \to \mu) \times \mathrm{MPI} \times \mathrm{Had}(\mu \to \Lambda) \times \ldots$$



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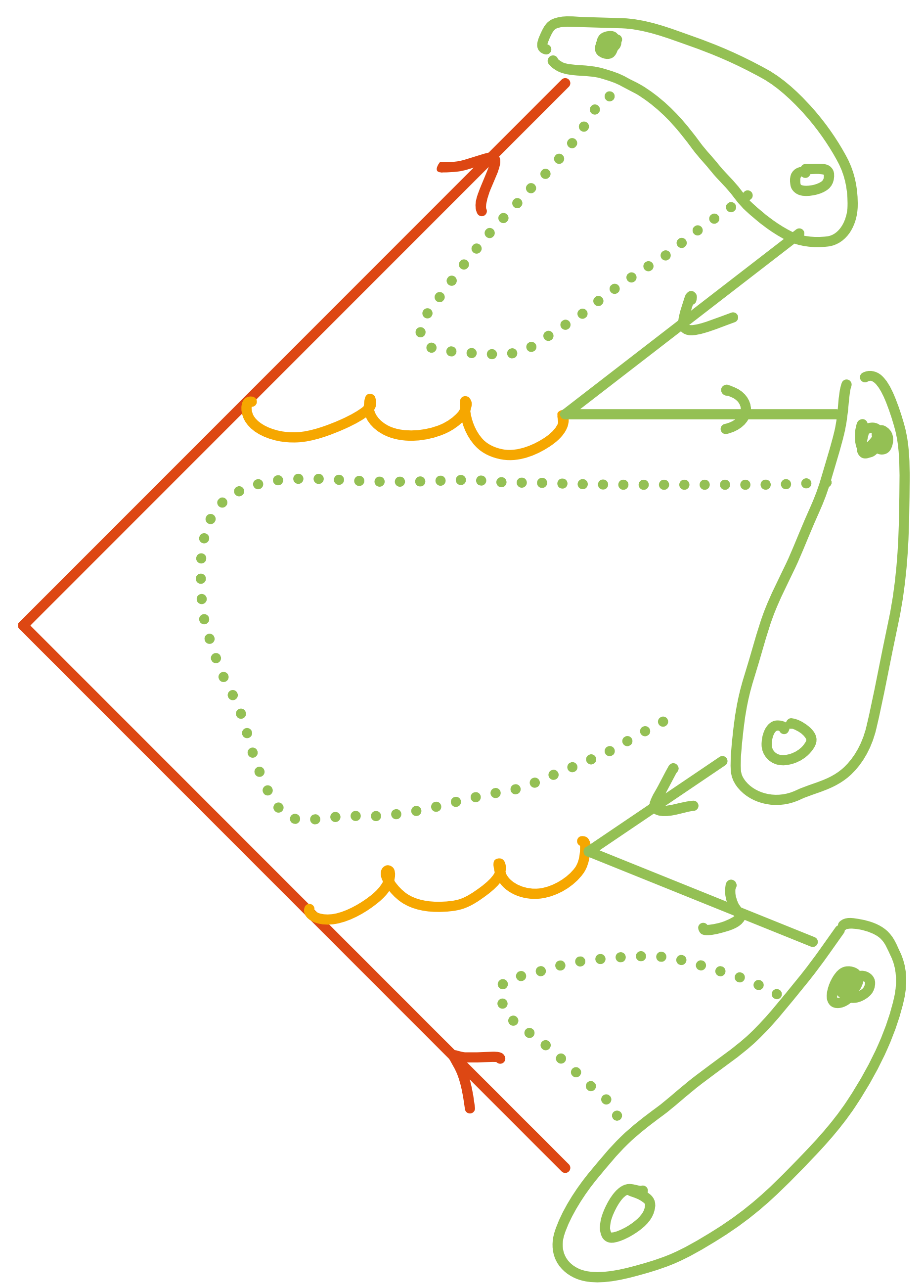
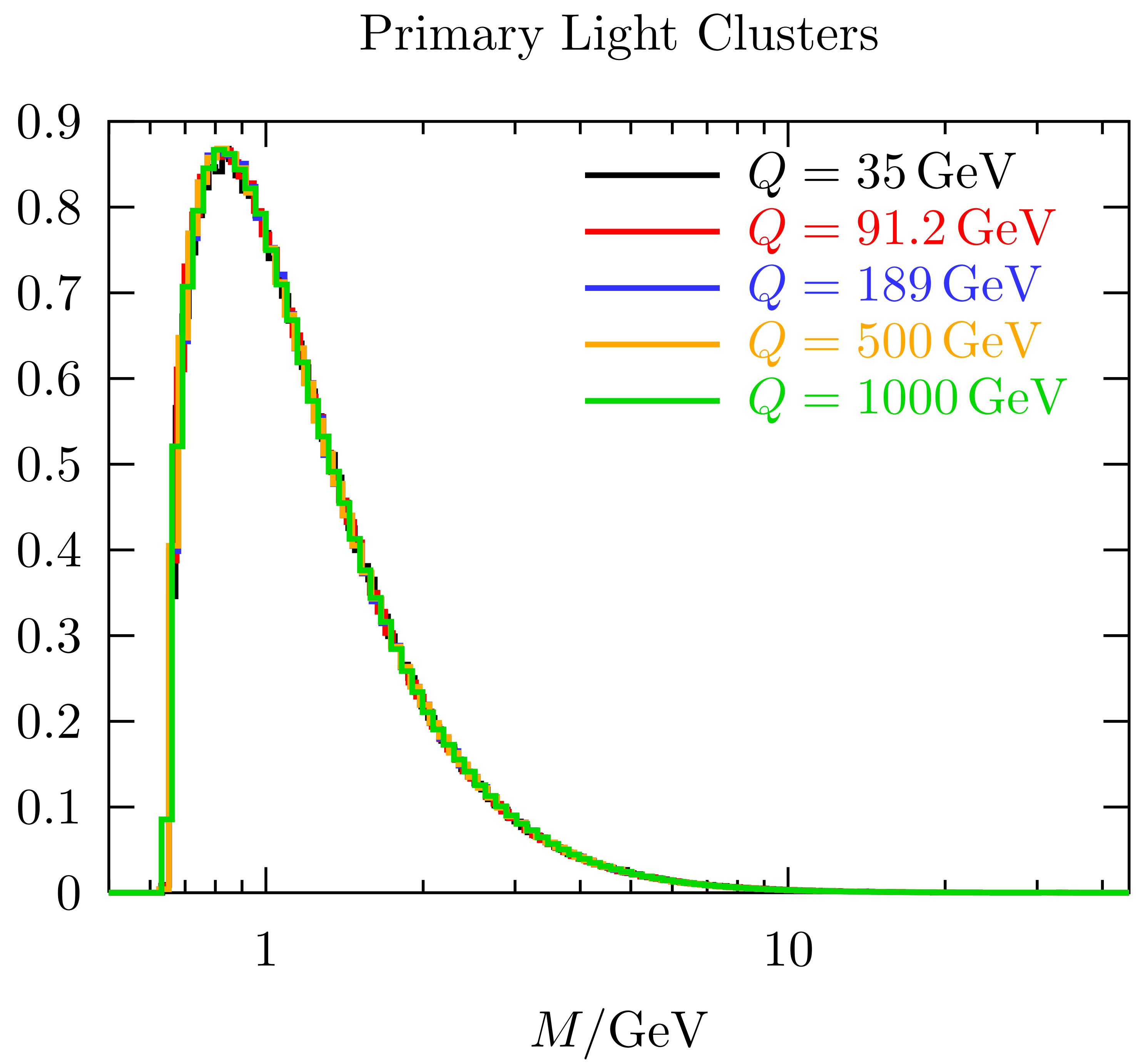


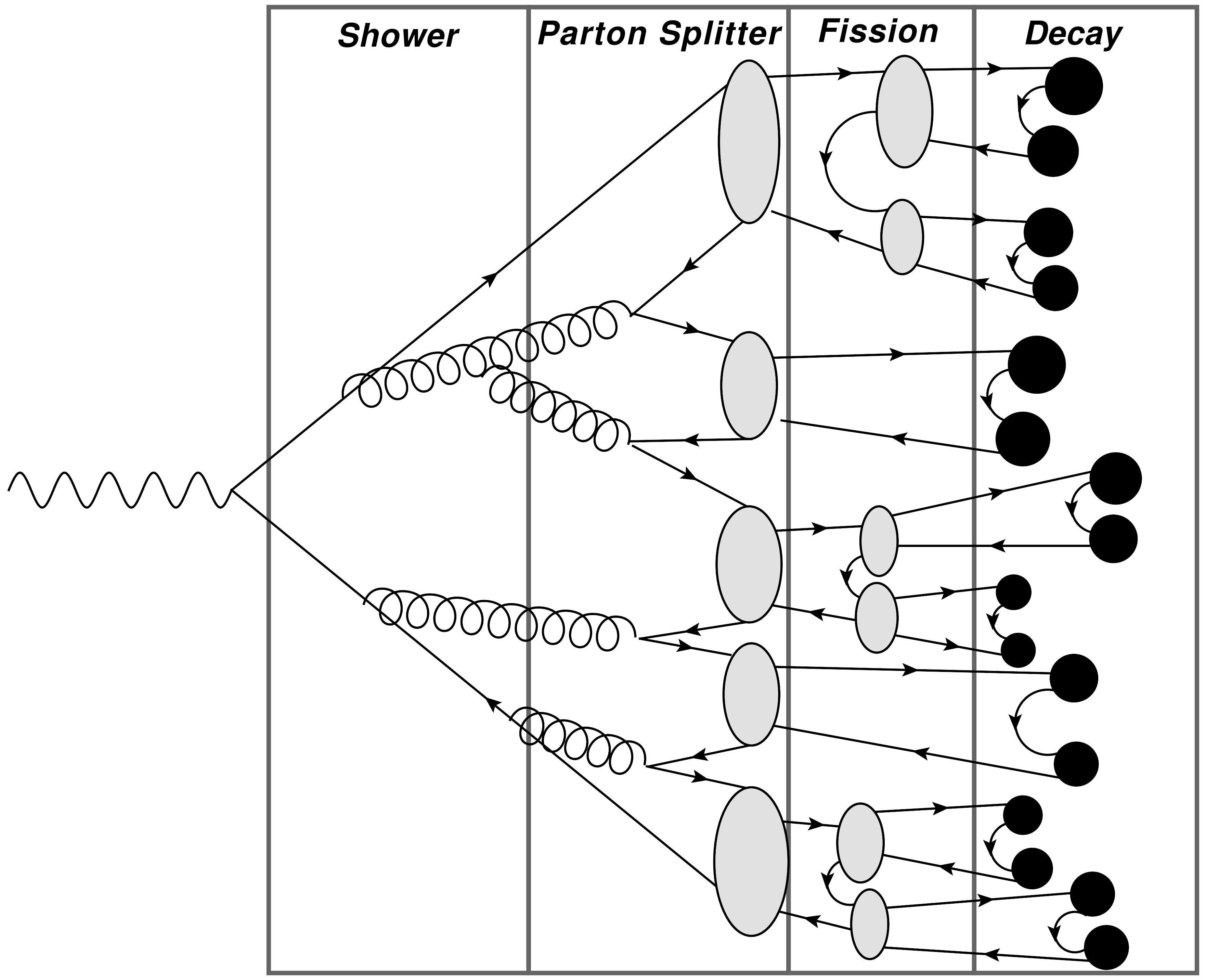
Universal cluster spectrum: pre-confinement.



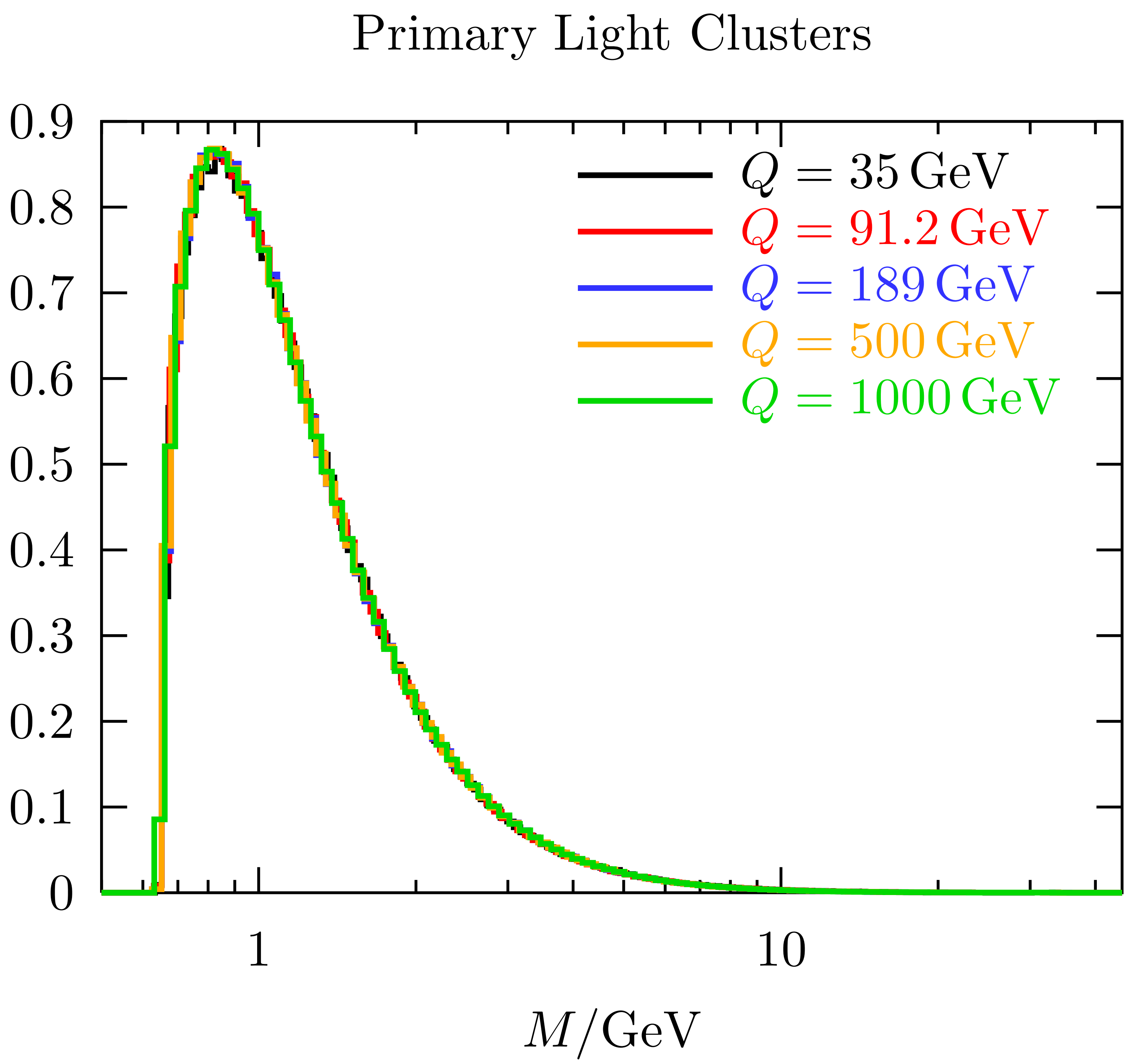
[Herwig++ 1.0 release — Gieseke et al. '04]

Hadronization: the cluster model

$$d\sigma \sim L \times d\sigma_H(Q) \times PS(Q \to \mu) \times MPI \times Had(\mu \to \Lambda) \times \ldots$$



Universal cluster spectrum: pre-confinement.



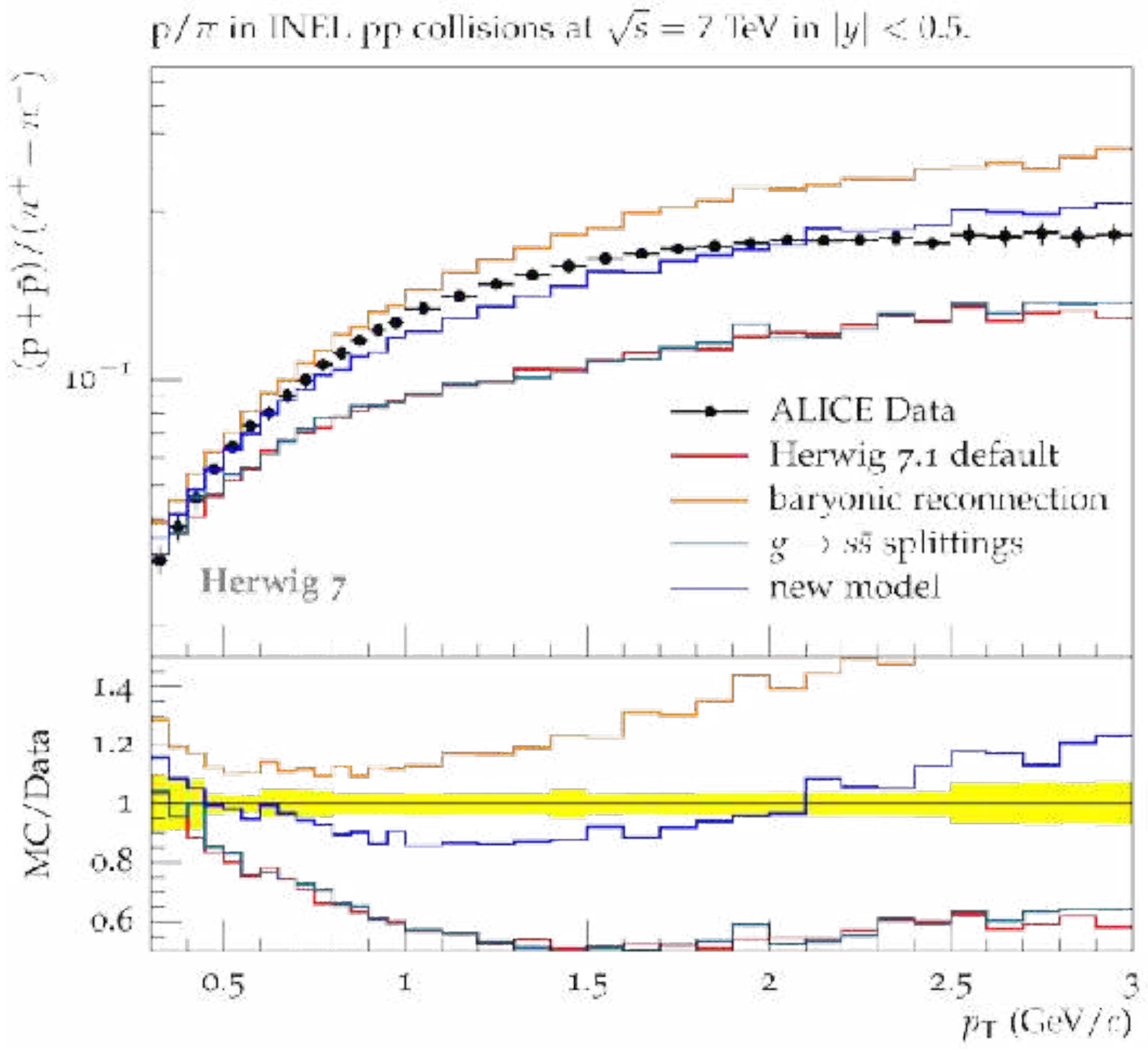
[Figure by Patrick Kirchgaesser]

[Herwig++ 1.0 release — Gieseke et al. '04]

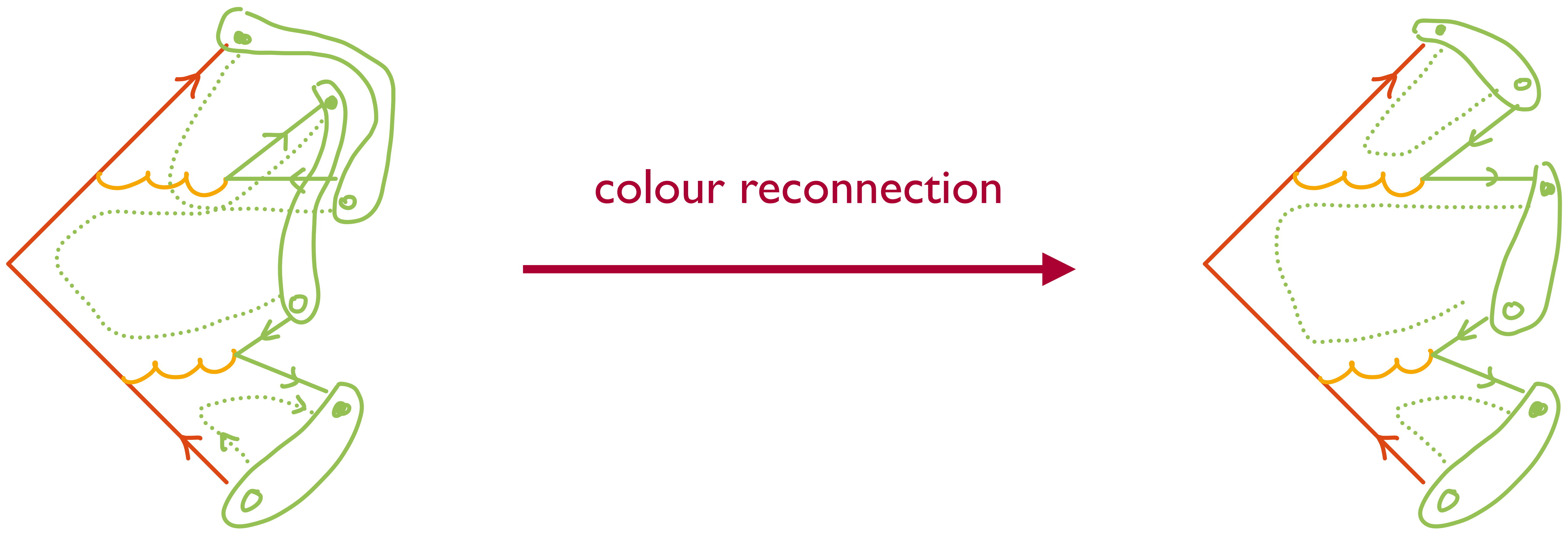
Colour Reconnection

Ignorance about colour correlations results in clusters which are too heavy.

proton yield



pt

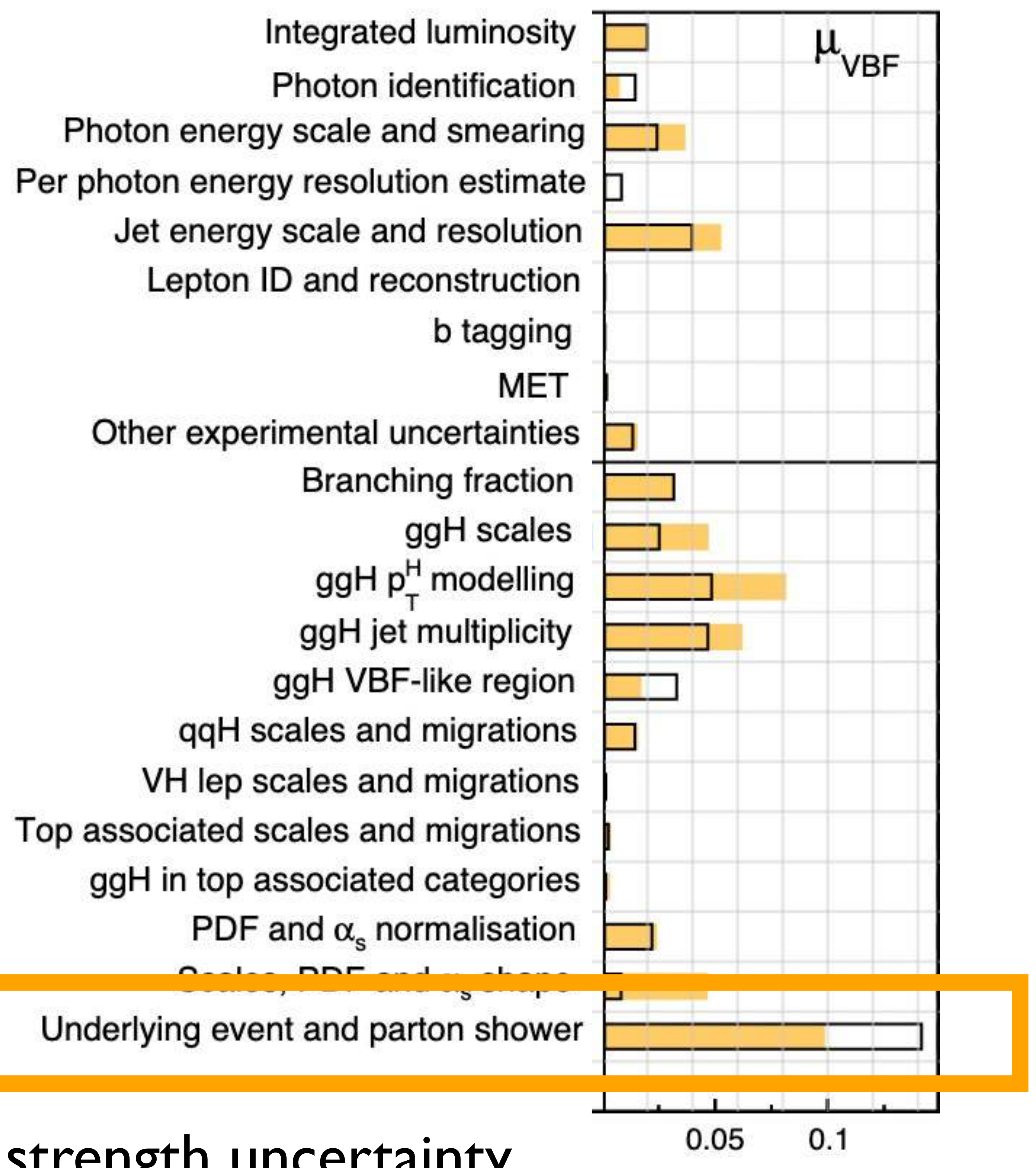


Most sophisticated algorithms in the cluster model now include baryons and non-trivial momentum information.

[Gieseke, Kirchgaesser, Plätzer – '18]
[Gieseke, Kirchgaesser, Plätzer, Siodmok – '18]

Challenges

[CMS at Higgs working group — '21]

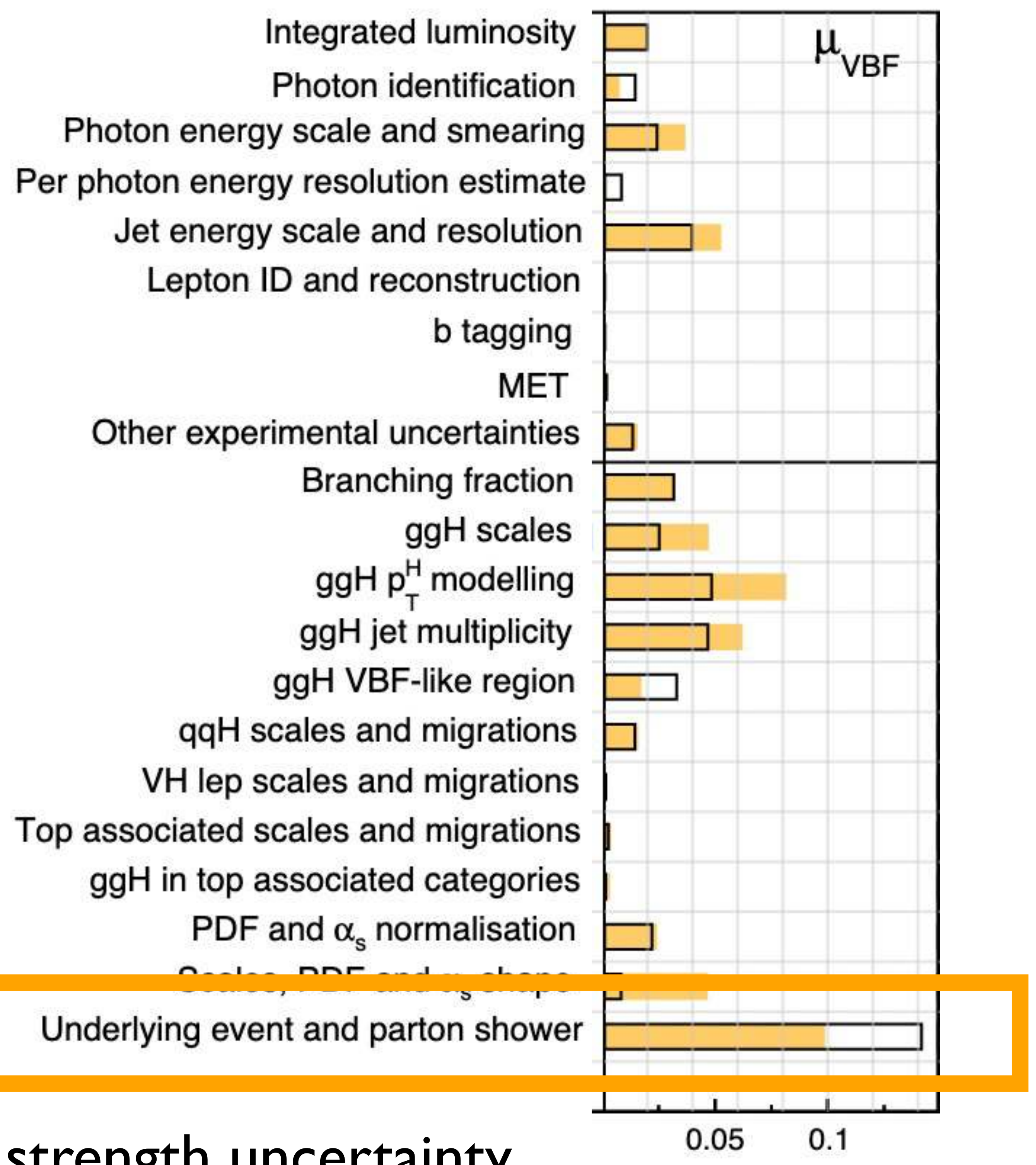


signal strength uncertainty

$$\mathrm{d}\sigma \sim \mathrm{L} \times \mathrm{d}\sigma_H(Q) \times \mathrm{PS}(Q \to \mu) \times \mathrm{MPI} \times \mathrm{Had}(\mu \to \Lambda) \times \ldots$$

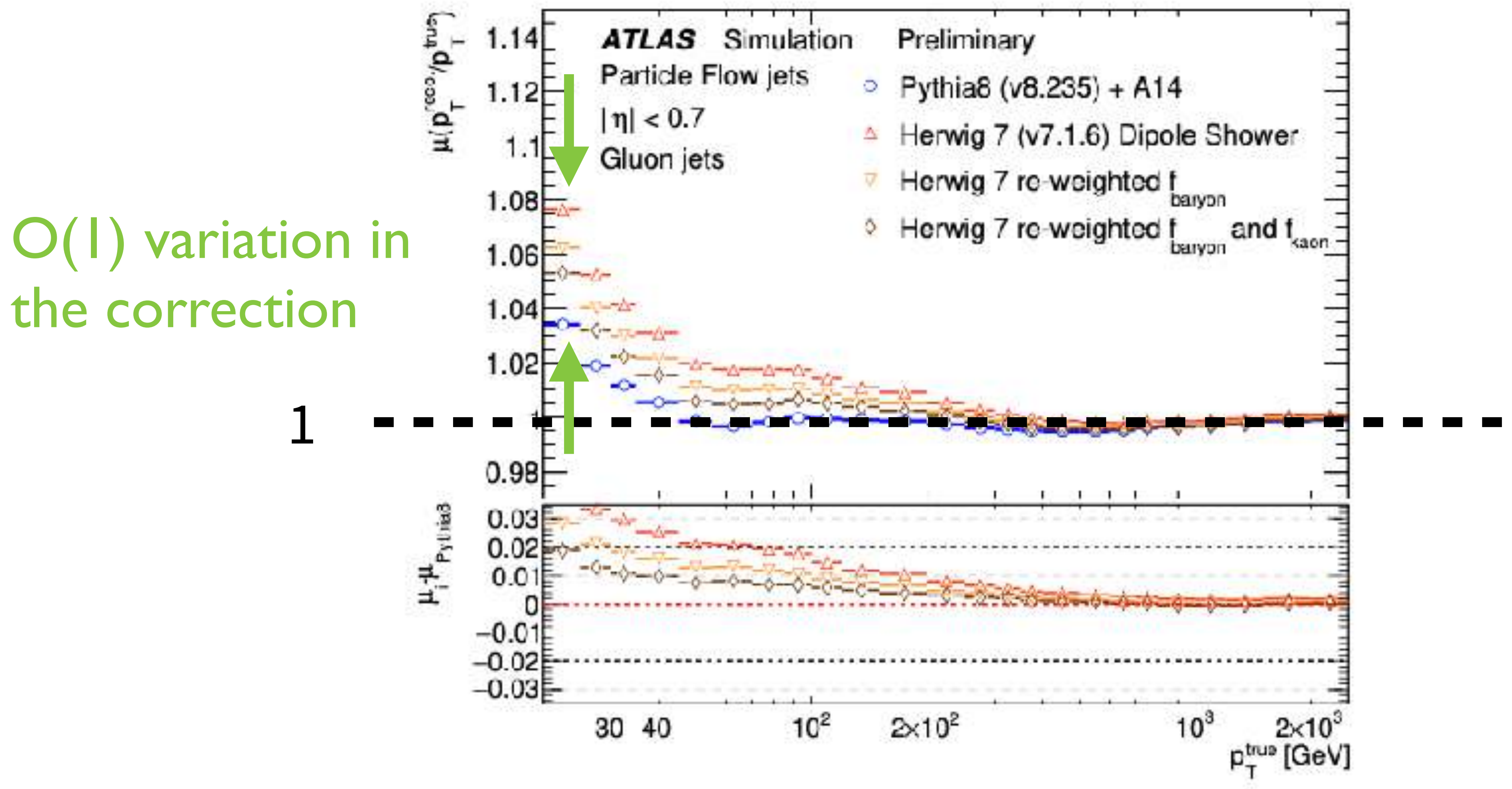
Challenges

[CMS at Higgs working group — ’21]



signal strength uncertainty

deviation of reconstructed pt



simulated pt

[ATLAS-PUB-2022-021]

$$d\sigma \sim L \times d\sigma_H(Q) \times PS(Q \to \mu) \times MPI \times Had(\mu \to \Lambda) \times \dots$$

Challenges

Perturbative precision is far from the last word:

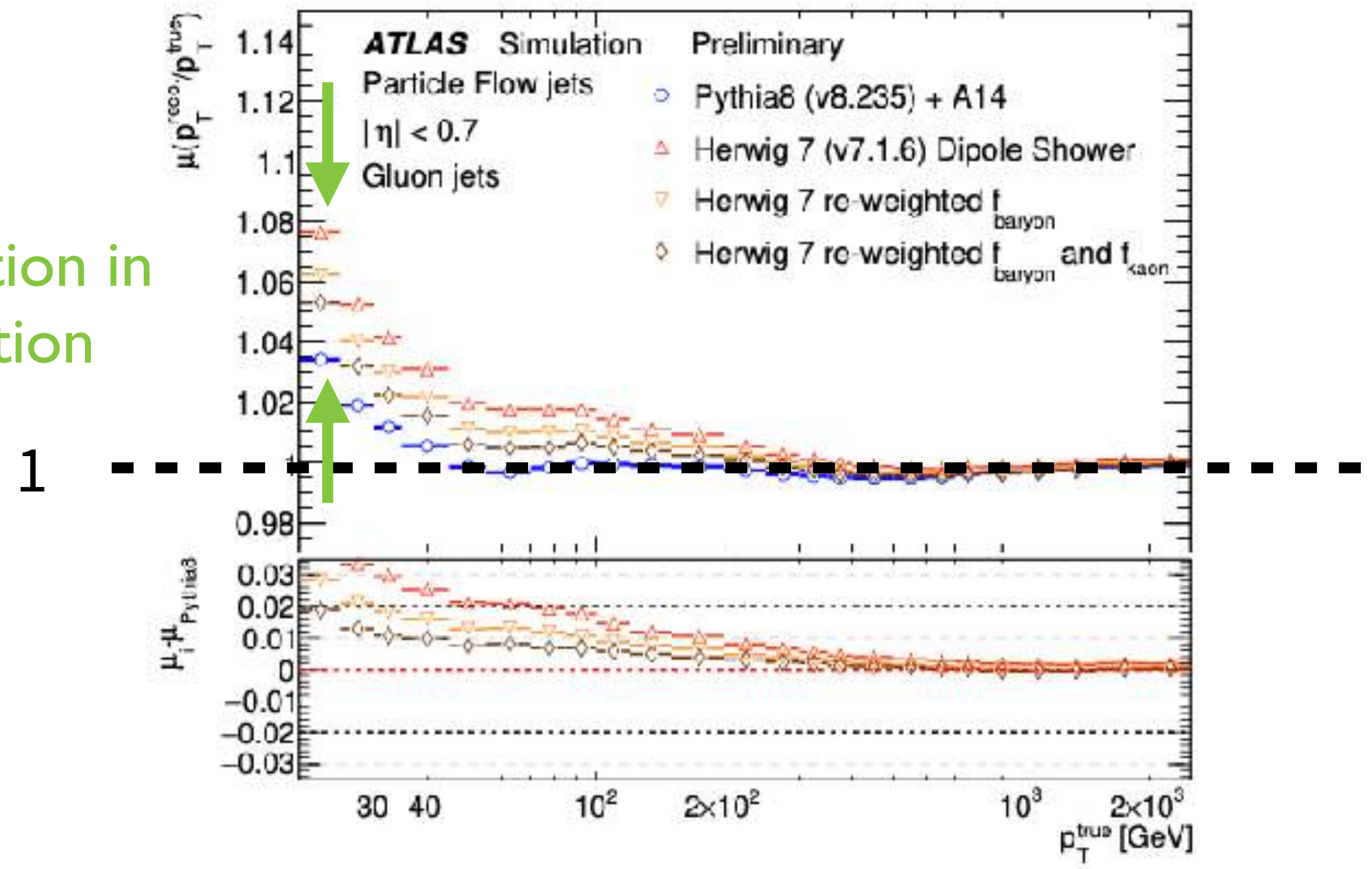
E.g. lack of understanding of baryon production is limiting the power of q/g discrimination.

Can we systematically address parton showers, hadronization and their interface taking into account quantum mechanical interference from the start?

What algorithms do we need?

deviation of reconstructed pt

O(1) variation in the correction



simulated pt

[ATLAS-PUB-2022-021]

$$d\sigma \sim L \times d\sigma_H(Q) \times PS(Q \to \mu) \times MPI \times Had(\mu \to \Lambda) \times \ldots$$

Full colour and interferences are central

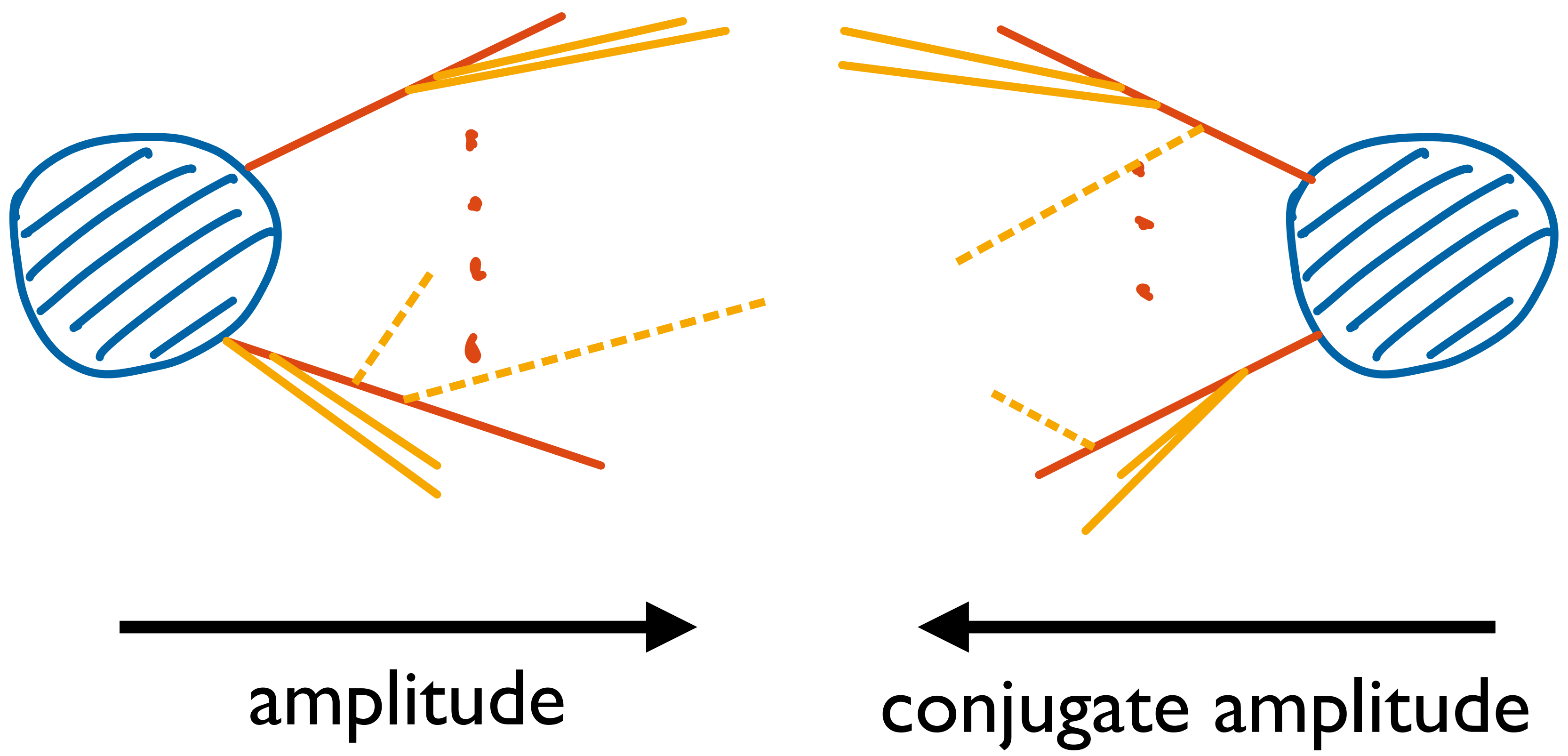
Colour reconnection and hadronization is about subleading-N.
So are shower accuracy and interference terms.

Colour factor algorithms	Colour ME corrections	Full amplitude evolution
Coherent, NLL-accurate dipole showers	Colour-exact real emissions as far as possible	Colour-exact real and virtual corrections
[Gustafson] [PanScales ‘21] [Forshaw, Holguin, Plätzer ’21]	[Plätzer, Sjödahl ’12,‘18] [Höche, Reichelt ’20]	[Forshaw, Plätzer + … ’13 …] [Nagy, Soper ’12 …]

$$\mathrm{d}\sigma \sim \mathrm{L} \times \mathrm{d}\sigma_H(Q) \times \mathrm{PS}(Q \to \mu) \times \mathrm{MPI} \times \mathrm{Had}(\mu \to \Lambda) \times \ldots$$

Reminder: Building parton showers

$$d\sigma \sim \mathrm{L} \times d\sigma_H(Q) \times \mathrm{PS}(Q \to \mu) \times \mathrm{MPI} \times \mathrm{Had}(\mu \to \Lambda) \times \ldots$$

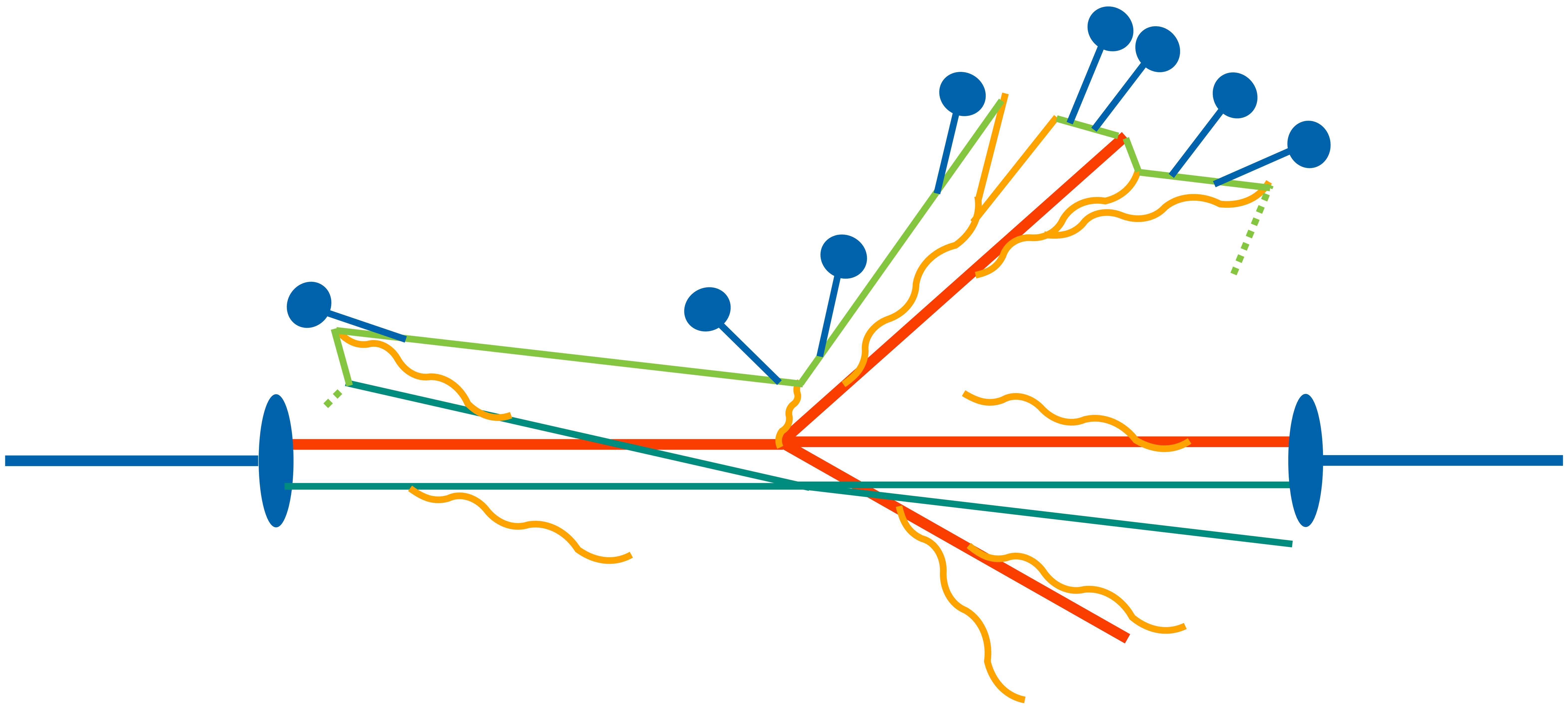


collinear
soft

$$\sim \mathcal{M}_n^+(p_1,\ldots,p_n)\, \mathbf{T}\cdots\mathbf{T} \;\vdots\; \mathbf{T}\cdots\mathbf{T}\, \mathcal{M}_n(p_1,\ldots,p_n)$$

Suggests an iterative procedure to build amplitude and conjugate amplitude with many emissions.

Complexity, factorized?



$$d\sigma \sim \mathrm{Tr}\left[\mathbf{PS}(Q \to \mu)\mathrm{d}\mathbf{H}(Q)\mathbf{PS}^\dagger(Q \to \mu)\mathbf{Had}(\mu \to \Lambda)\right]$$

Amplitude evolution

Colour reconnection and hadronization is about subleading-N.
So are shower accuracy and interference terms.

Colour factor algorithms	Colour ME corrections	Full amplitude evolution
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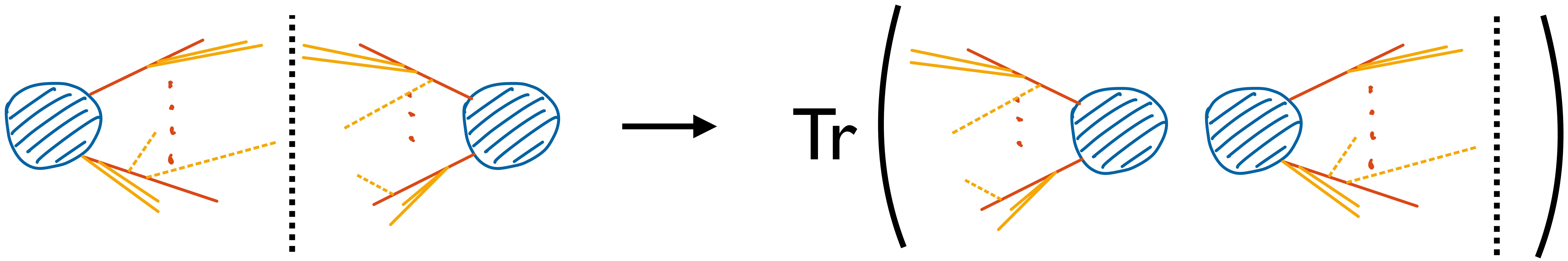
$$\mathrm{d}\sigma \sim \mathrm{Tr}\left[\mathbf{PS}(Q \to \mu)\mathrm{d}\mathbf{H}(Q)\mathbf{PS}^\dagger(Q \to \mu)\mathbf{Had}(\mu \to \Lambda)\right]$$

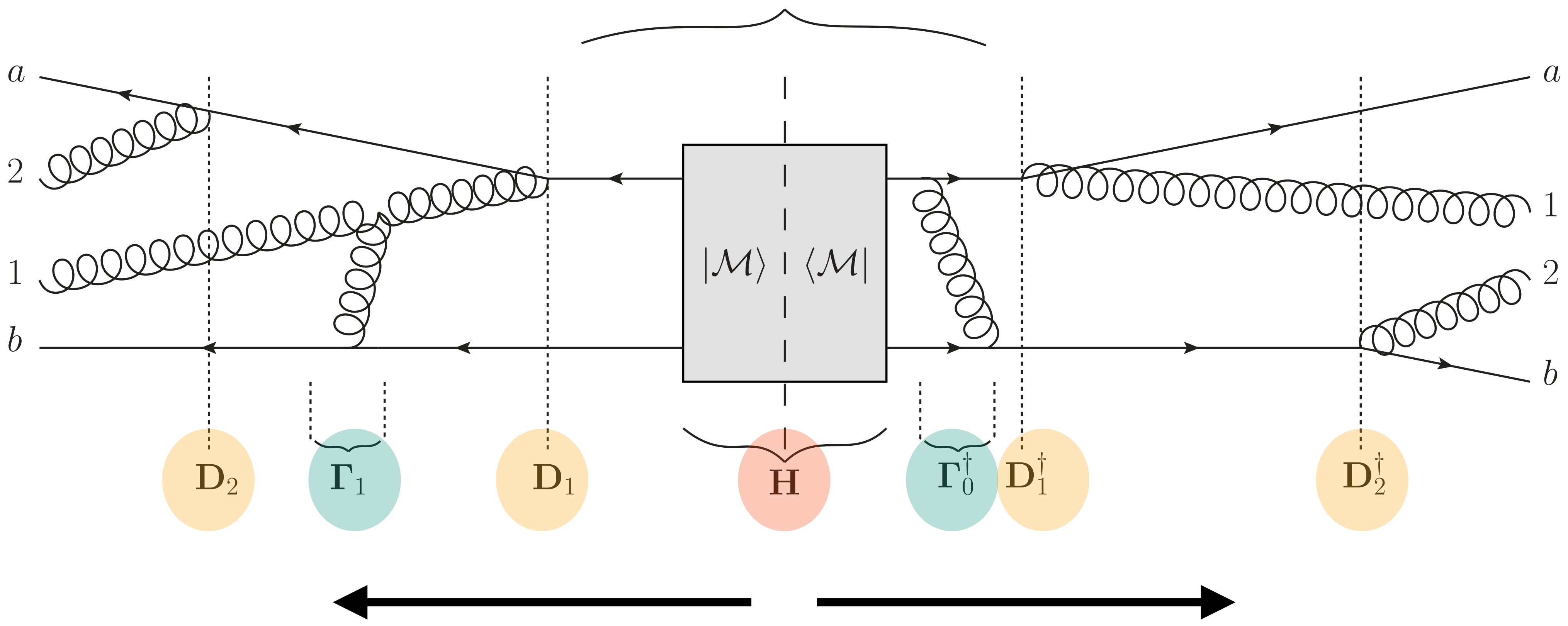
Amplitude evolution



$$\mathbf{A}_n(q) = \int_q^Q \frac{\mathrm{d}k}{k}\, \mathrm{P}e^{-\int_q^k \frac{\mathrm{d}k'}{k'}\boldsymbol{\Gamma}(k')}\, \mathbf{D}_n(k)\, \mathbf{A}_{n-1}(k)\, \mathbf{D}_n^\dagger(k)\, \overline{\mathrm{P}}e^{-\int_q^k \frac{\mathrm{d}k'}{k'}\boldsymbol{\Gamma}^\dagger(k')}$$

Markovian algorithm at the amplitude level:
Iterate gluon exchanges and emission.

Different histories in amplitude and conjugate amplitude needed to include interference.

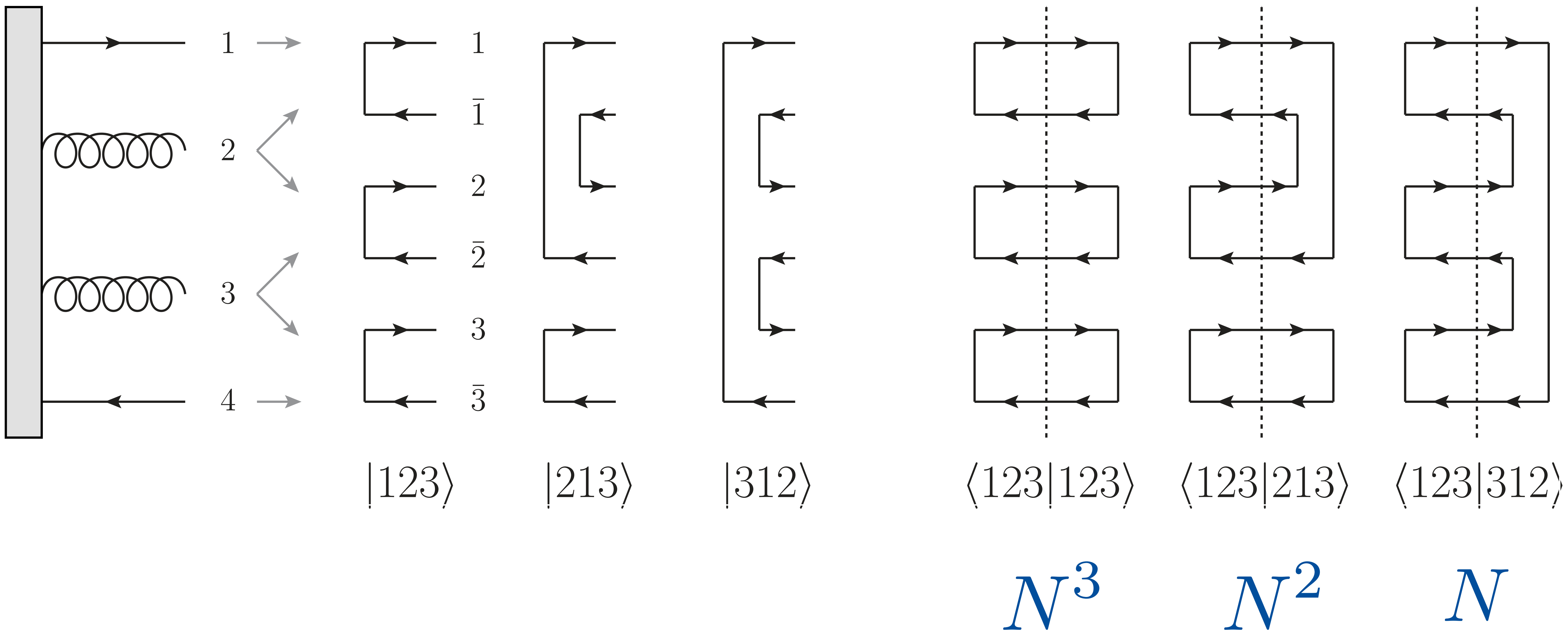


amplitude conjugate amplitude

[Angeles, De Angelis, Forshaw, Plätzer, Seymour – '18]
[Forshaw, Holguin, Plätzer – '19]

Tracking colour flow

Decompose amplitudes in flow of colour charge. $(t^a)^i{}_k (t^a)^j{}_l = T_R \left(\delta^i_l \delta^j_k - \frac{1}{N} \delta^i_k \delta^j_l \right)$



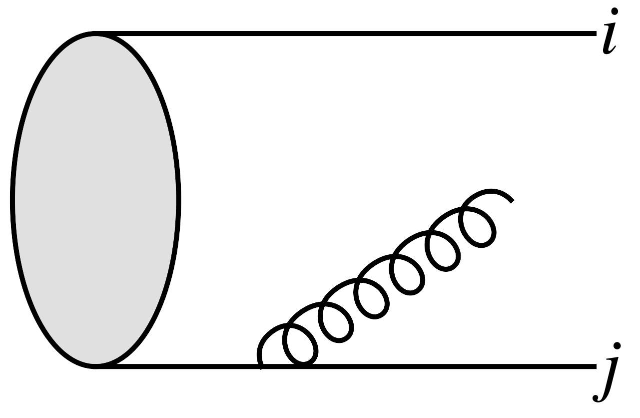
Suppression of interferences outside of colour connected dipoles.

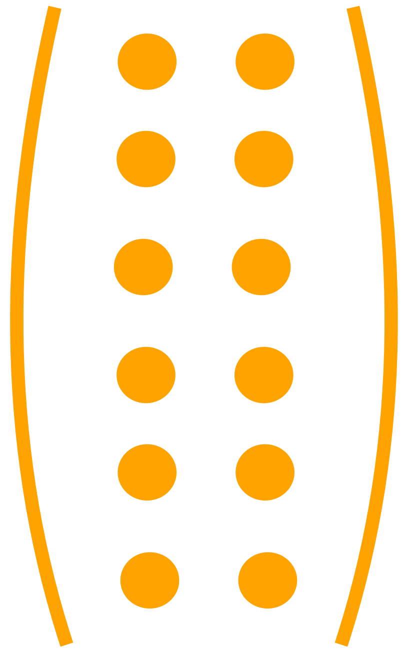
[Plätzer '13]
[Angeles, De Angelis, Forshaw, Plätzer, Seymour '18]

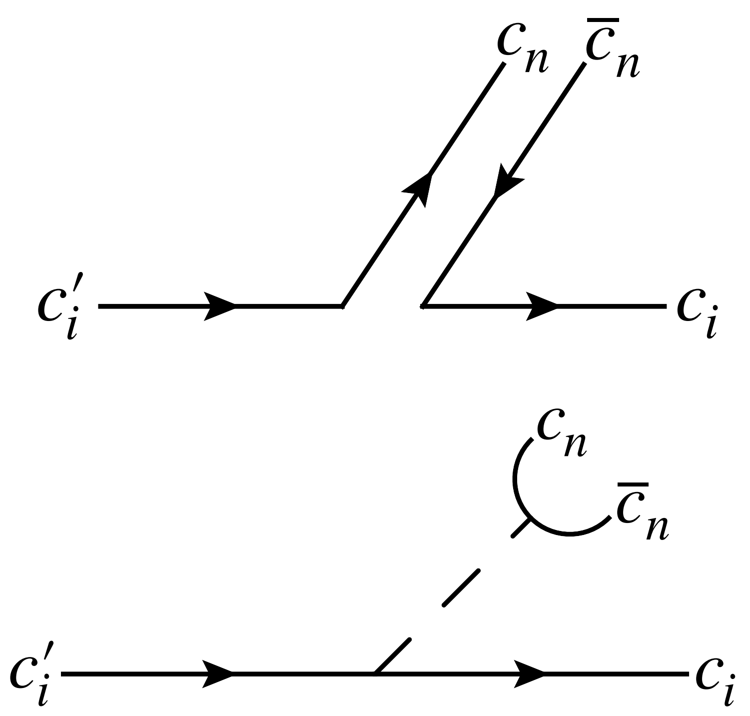
Tracking colour

Gluon emission

$$\mathbf{D}_n(k)$$



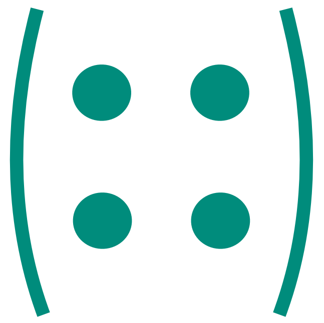


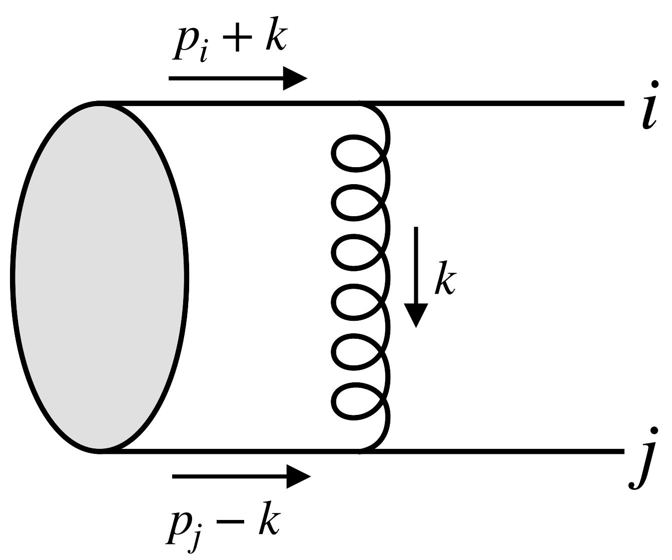


Explicit suppression in 1/N

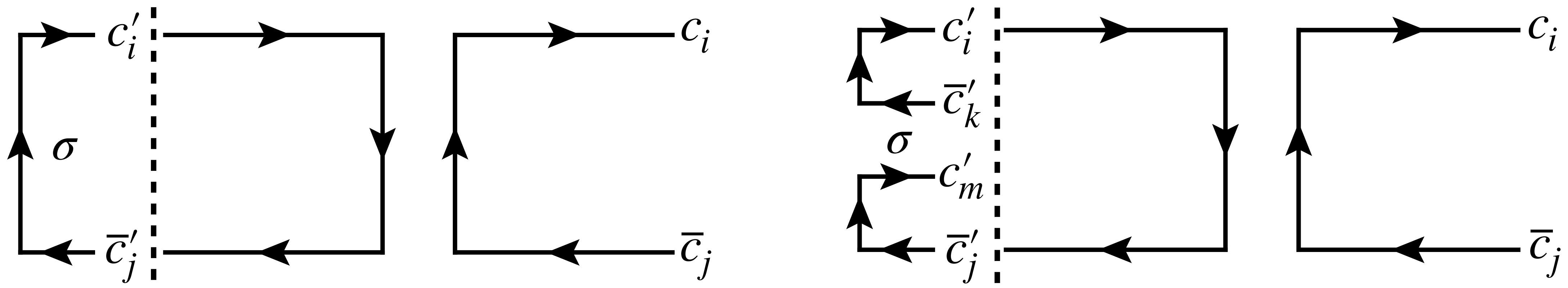
Gluon exchange

$$\mathrm{P}e^{-\int_q^k \frac{\mathrm{d}k'}{k'}\mathbf{\Gamma}(k')}$$





$$[\tau|\mathbf{\Gamma}|\sigma\rangle = (\alpha_s N)[\tau|\mathbf{\Gamma}^{(1)}|\sigma\rangle + (\alpha_s N)^2[\tau|\mathbf{\Gamma}^{(2)}|\sigma\rangle + \ldots$$



$$[\tau|\mathbf{\Gamma}^{(1)}|\sigma\rangle = \left(\Gamma_\sigma^{(1)} + \frac{1}{N^2}\rho^{(1)}\right)\delta_{\sigma\tau} + \frac{1}{N}\Sigma_{\sigma\tau}^{(1)}$$

dipole flips — implicit suppression in 1/N

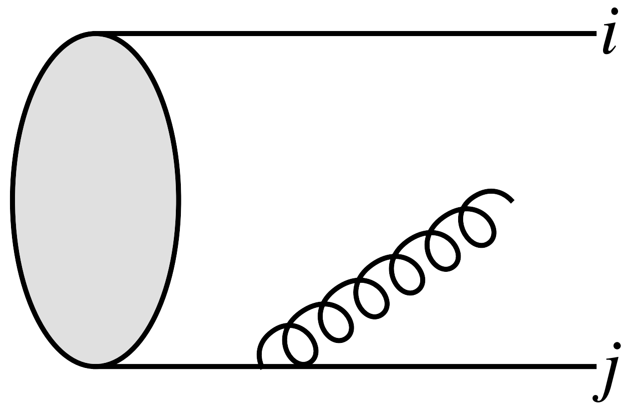
Systematically expand around large-N limit summing towers of terms enhanced by $\alpha_S N$

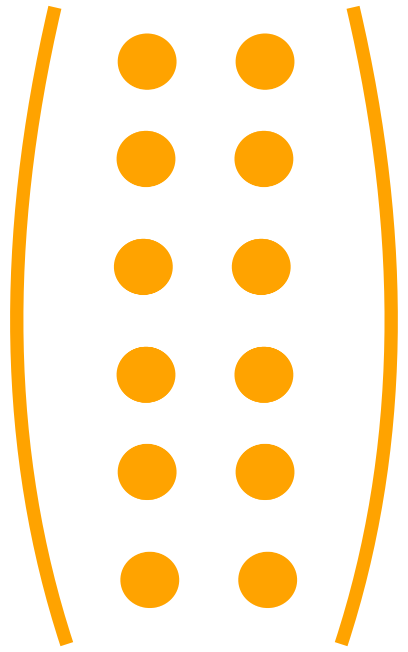
[Plätzer – '13] — diagrams from [Ruffa, MSc thesis 2020]

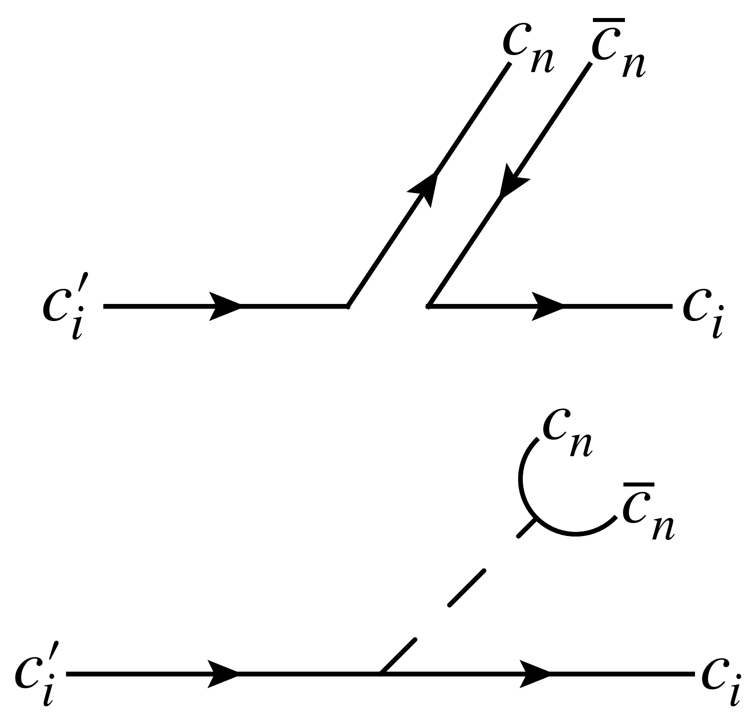
Tracking colour

Gluon emission

$$\mathbf{D}_n(k)$$







Explicit suppression in 1/N

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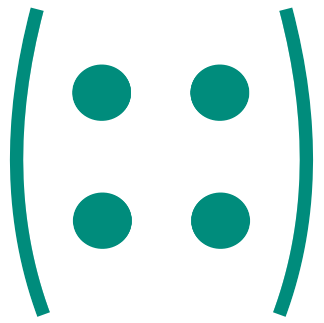
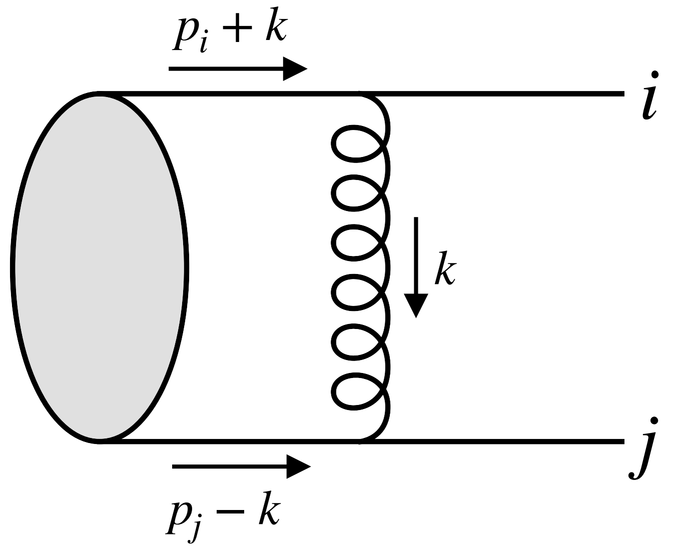
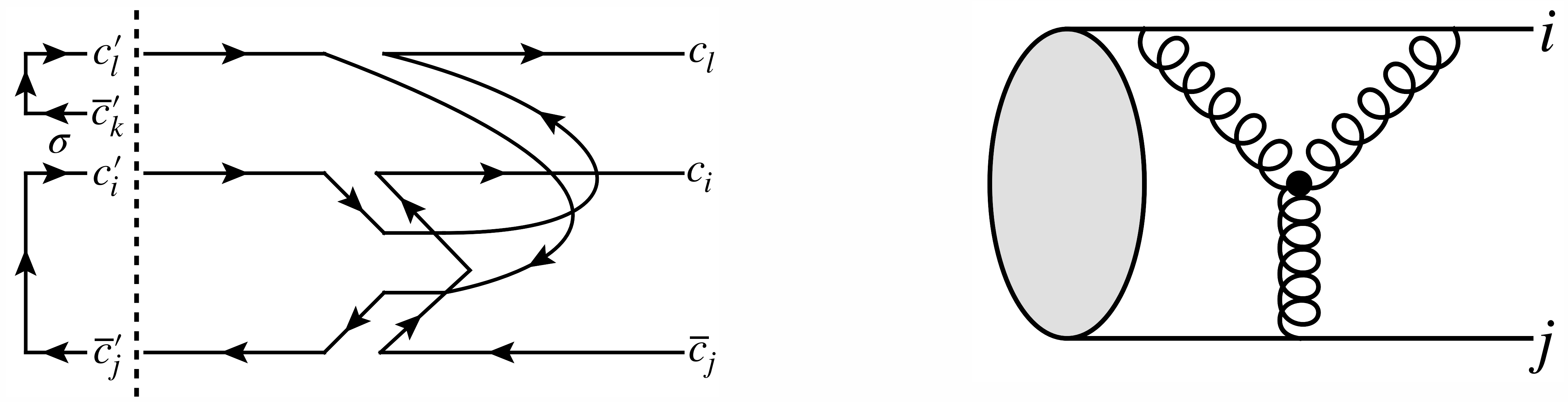




$$[\tau|\mathbf{\Gamma}|\sigma\rangle = (\alpha_s N)[\tau|\mathbf{\Gamma}^{(1)}|\sigma\rangle + (\alpha_s N)^2[\tau|\mathbf{\Gamma}^{(2)}|\sigma\rangle + \ldots$$



[Plätzer, Ruffa — '21]

dipole flips — implicit suppression in 1/N

Systematically expand around large-N limit summing towers of terms enhanced by $\alpha_S N$

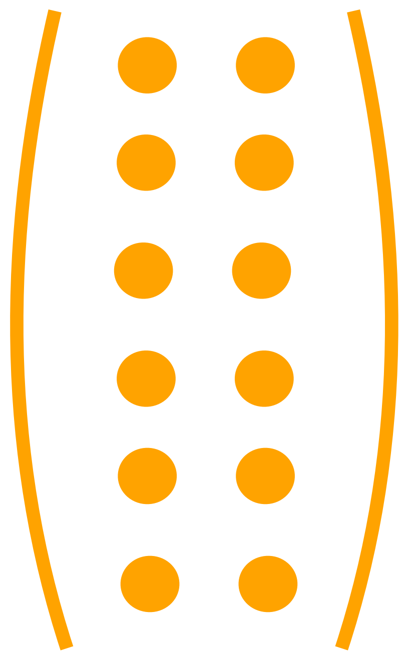
[Plätzer – '13] — diagrams from [Ruffa, MSc thesis 2020]

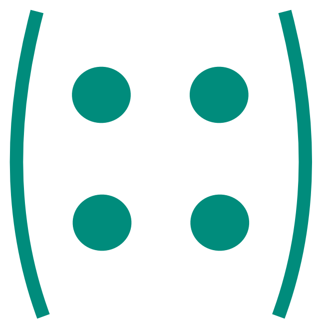
Amplitude evolution — CVolver

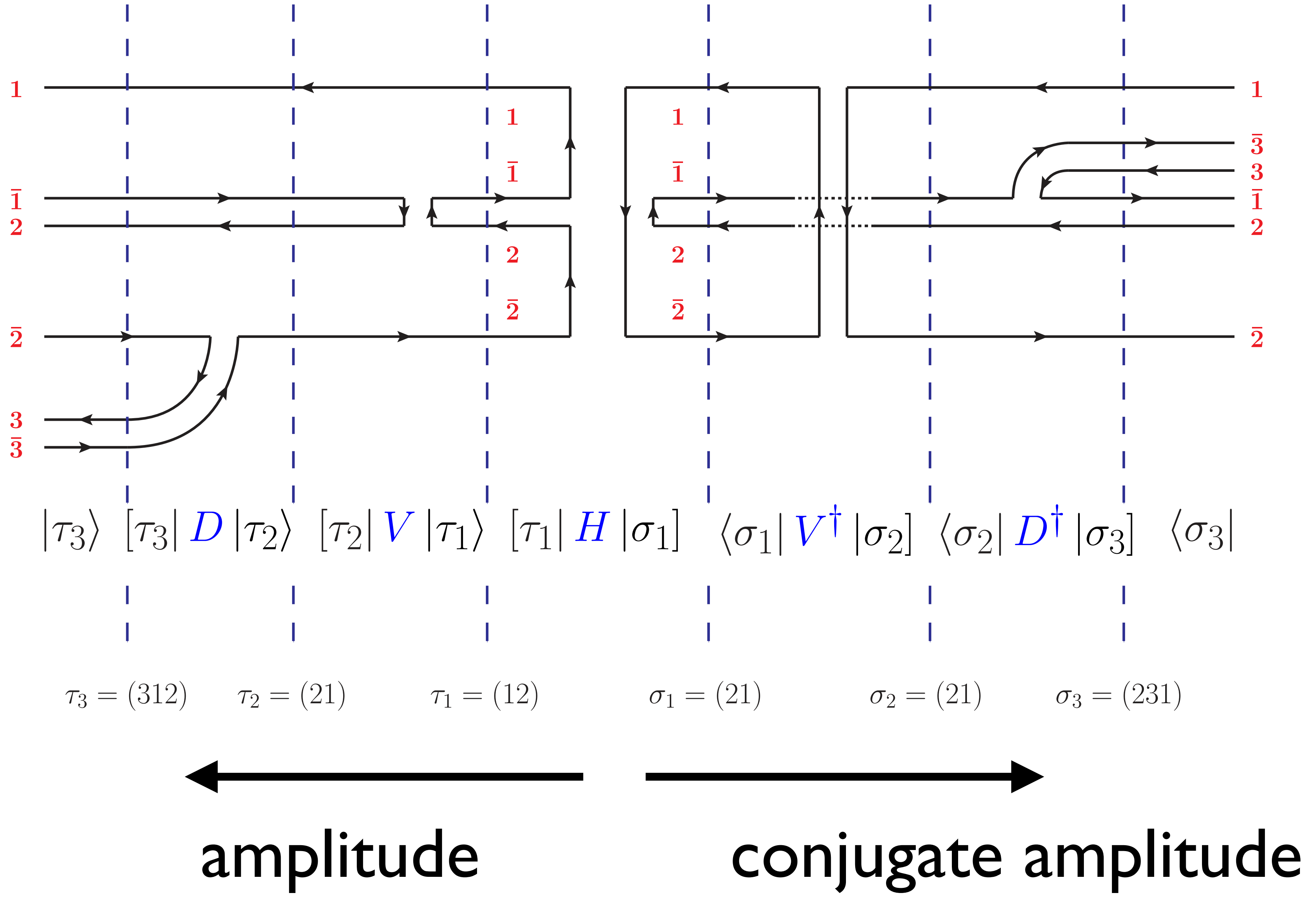
CVolver solves evolution equations in colour flow space

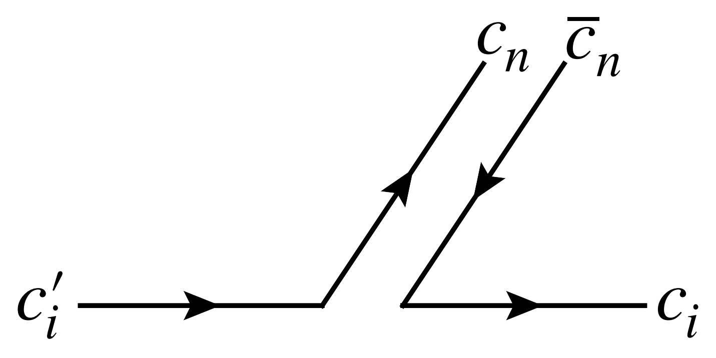
[De Angelis, Forshaw, Plätzer '21]
[Plätzer '13]

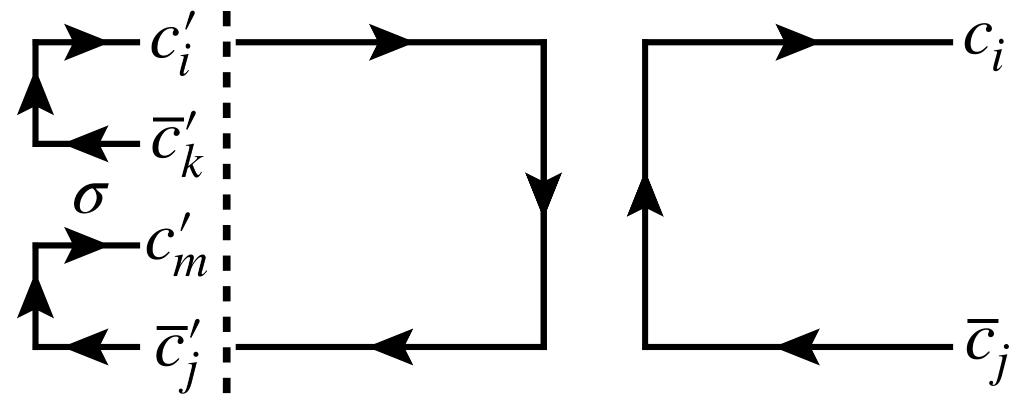
$$\mathbf{A}_n(q) = \int_q^Q \frac{\mathrm{d}k}{k}\, \mathrm{P}e^{-\int_q^k \frac{\mathrm{d}k'}{k'}\mathbf{\Gamma}(k')}\, \mathbf{D}_n(k)\, \mathbf{A}_{n-1}(k)\, \mathbf{D}_n^\dagger(k)\, \overline{\mathrm{P}}e^{-\int_q^k \frac{\mathrm{d}k'}{k'}\mathbf{\Gamma}^\dagger(k')}$$









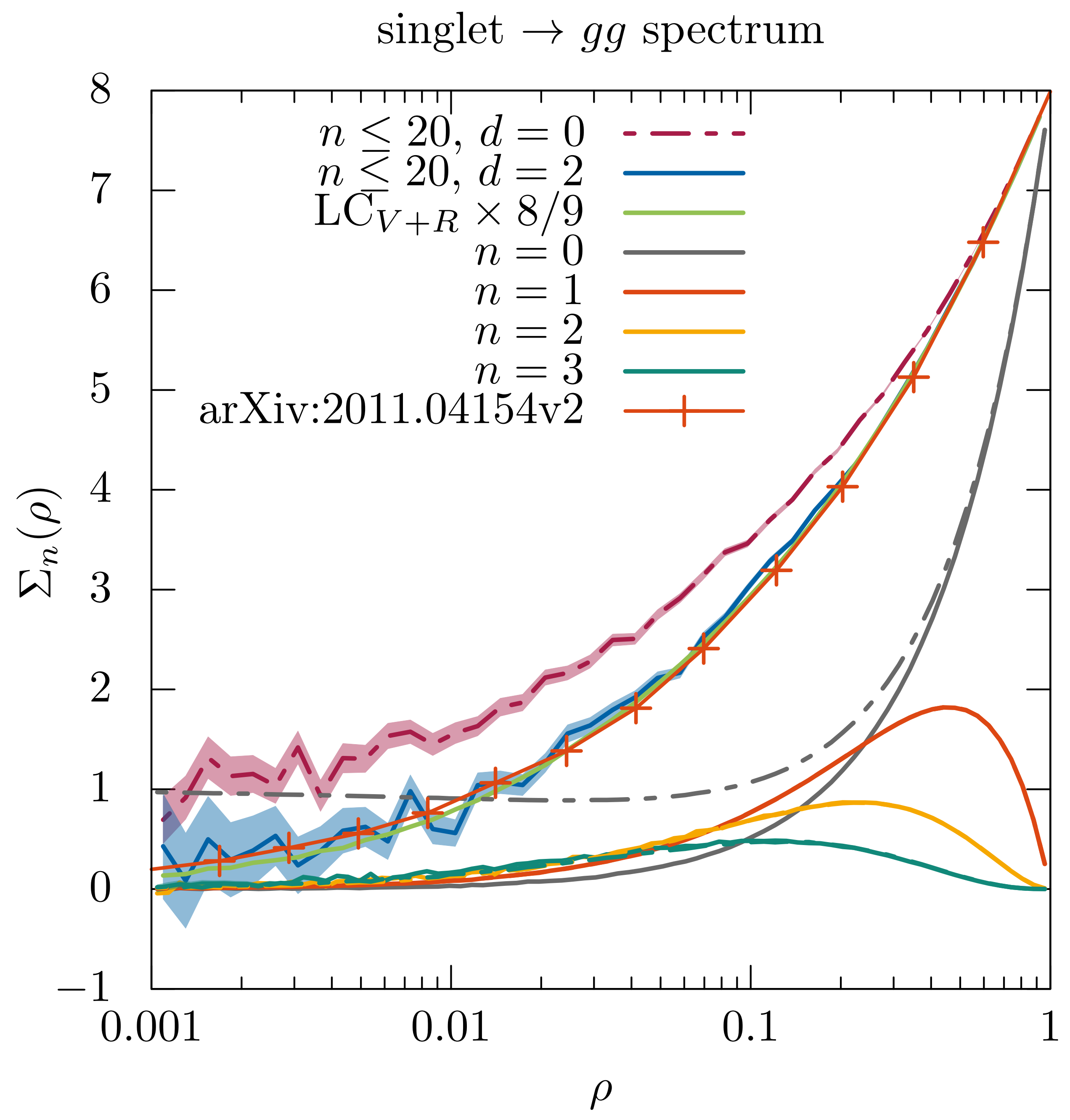


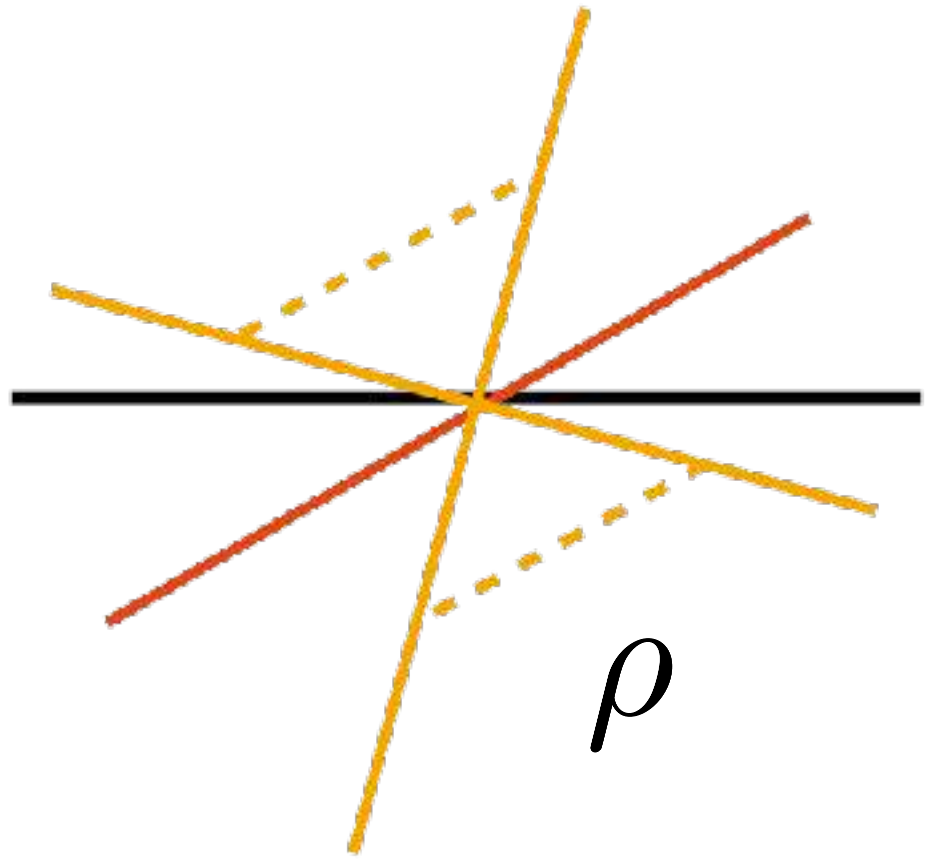
Amplitude evolution — CVolver

CVolver solves evolution equations in colour flow space

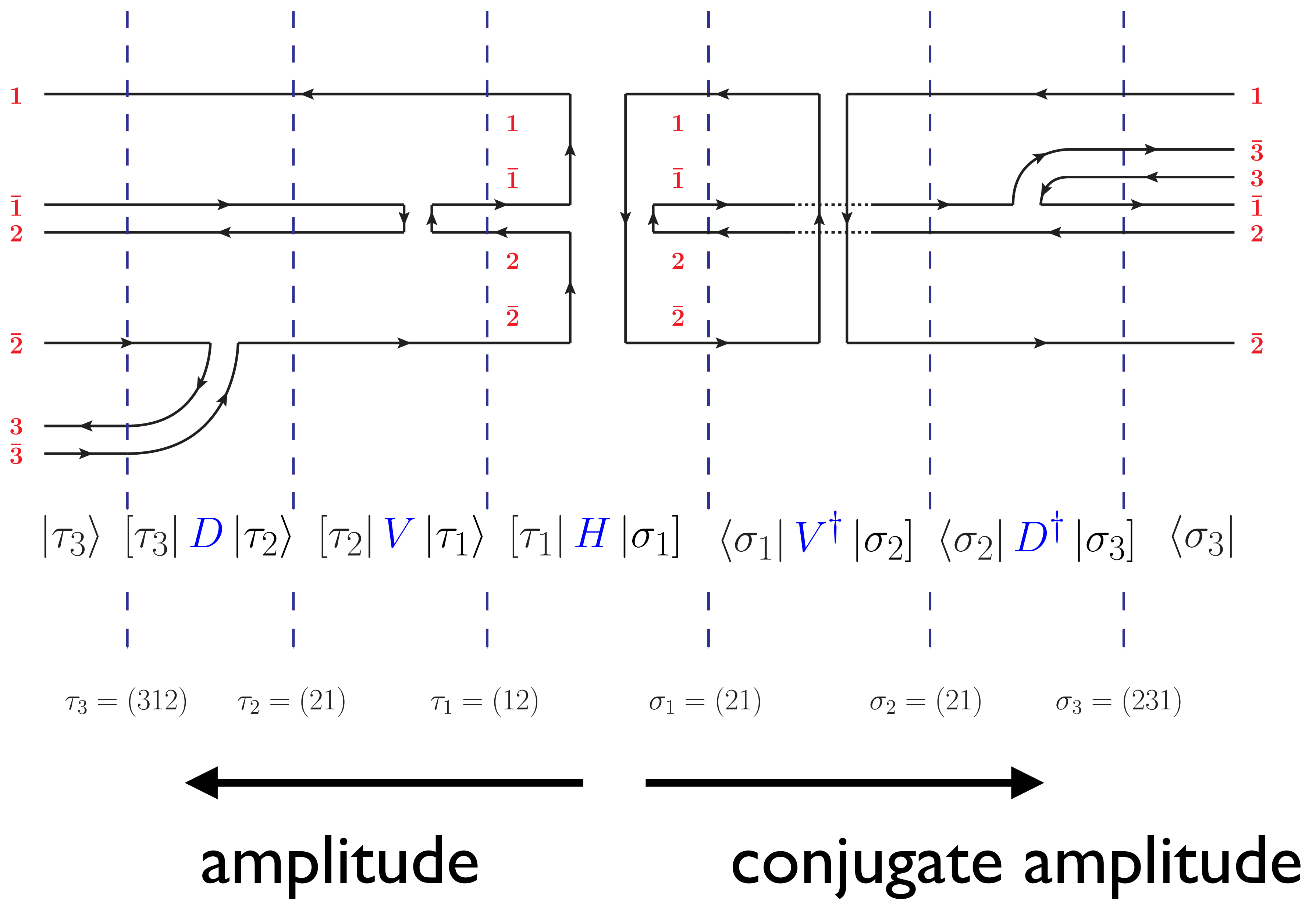
[De Angelis, Forshaw, Plätzer '21]
[Plätzer '13]

$$\mathbf{A}_n(q) = \int_q^Q \frac{\mathrm{d}k}{k}\; \mathrm{P}e^{-\int_q^k \frac{\mathrm{d}k'}{k'}\boldsymbol{\Gamma}(k')}\; \mathbf{D}_n(k)\; \mathbf{A}_{n-1}(k)\; \mathbf{D}_n^\dagger(k)\; \overline{\mathrm{P}}e^{-\int_q^k \frac{\mathrm{d}k'}{k'}\boldsymbol{\Gamma}^\dagger(k')}$$





$$\Sigma(\rho) = \sum_n \int \mathrm{d}\sigma(\{p_i\}) \prod_i \theta_{\mathrm{in}}(\rho - E_i)$$



Agrees with Hatta & Ueda using equivalent Langevin formulation by Weigert.

Factorisation and evolution

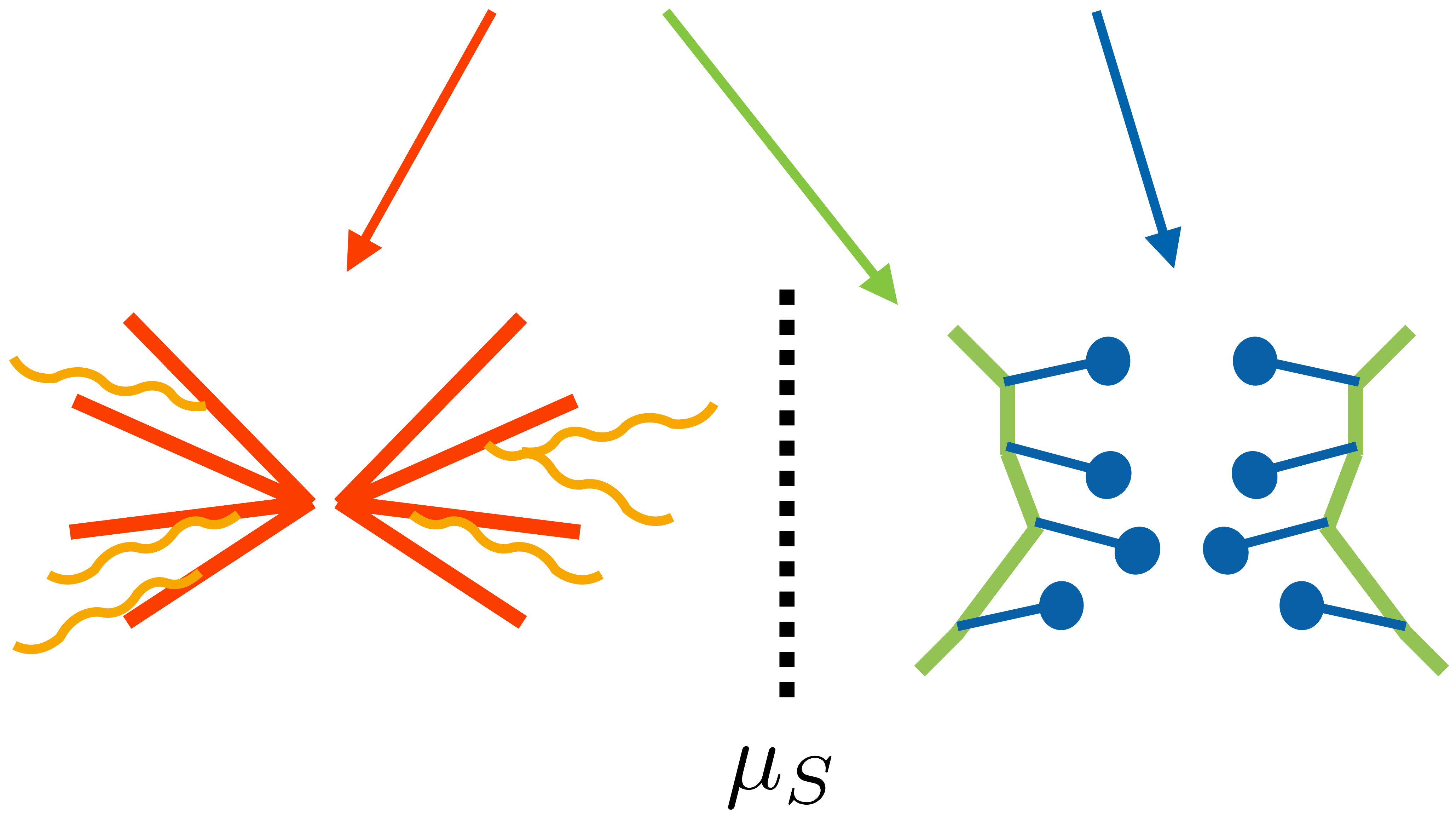
$$\sigma = \sum_{n,m} \int \int \mathrm{Tr}_n \left[\mathbf{M}_n \mathbf{U}_{nm}\right] \mathrm{d}\phi_m u(\phi_m)$$

[Plätzer – '22]

Factorisation and evolution

$$\sigma = \sum_{n,m} \int \int \mathrm{Tr}_n \left[\mathbf{M}_n \mathbf{U}_{nm} \right] \mathrm{d}\phi_m u(\phi_m)$$

$$0 = \frac{\mathrm{d}}{\mathrm{d}\mu_S}$$



[Plätzer – '22]

Factorisation and evolution

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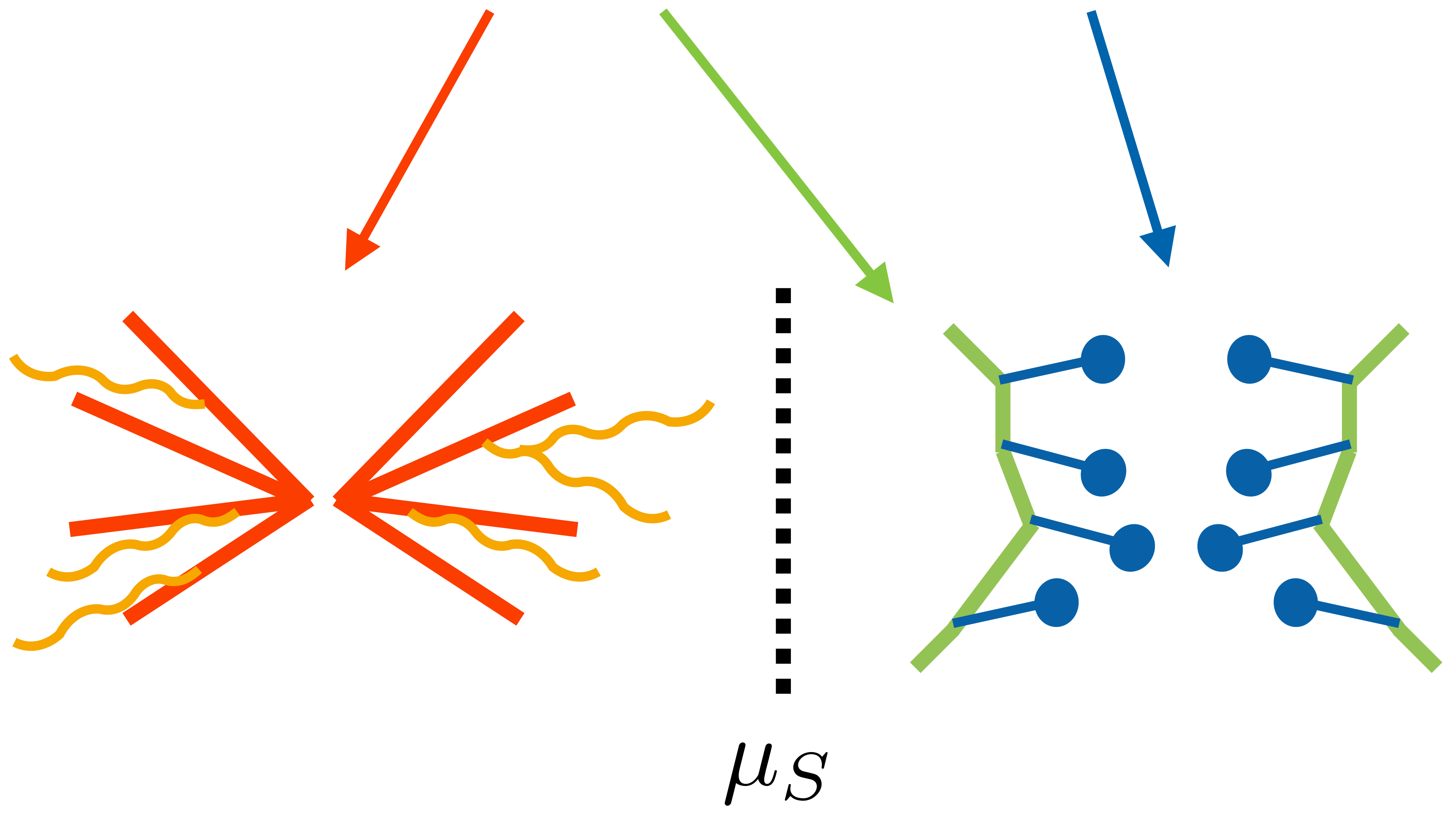


calculate building blocks

derive evolution

construct model response

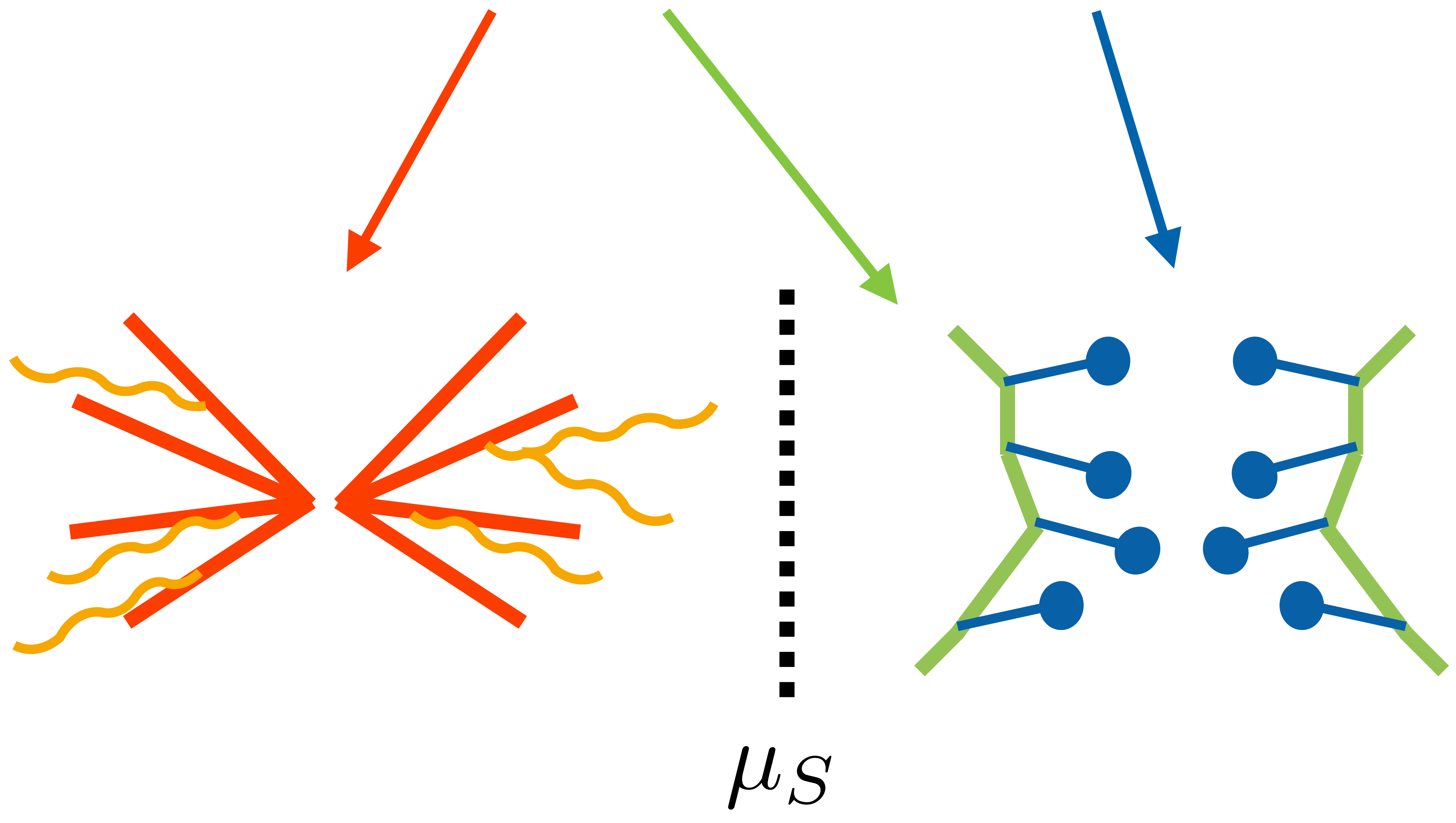
constrain by data

[Plätzer – '22]

Factorisation and evolution

$$\sigma = \sum_{n,m} \int \int \mathrm{Tr}_n \left[\mathbf{M}_n \mathbf{U}_{nm}\right] \mathrm{d}\phi_m u(\phi_m)$$

$$0 = \frac{\mathrm{d}}{\mathrm{d}\mu_S}$$



Not limited to a hadronization model — can also re-arrange partonic observables in this way.

[e.g. resummation of NGL in SCET — Becher, Neubert et al.]

[Plätzer – '22]

Redefinitions of "bare" operators

How do we consistently hadronize in light of (improved) shower algorithms?

How to do this at subleading N and higher order shower evolution?

$$\sigma = \sum_{n,m} \int \int \mathrm{Tr}_n \left[\mathbf{M}_n \mathbf{U}_{nm}\right] \mathrm{d}\phi_m u(\phi_m)$$

Remove UV divergencies

$$\alpha_0 \left(4\pi\mu^2\right)^\epsilon = \alpha_S(\mu_R)\mu_R^{2\epsilon} Z_g$$

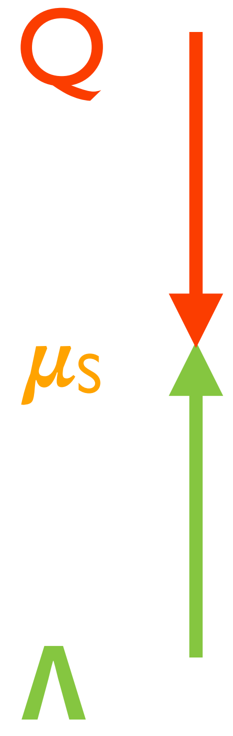
Subtract IR divergencies in unresolved regions

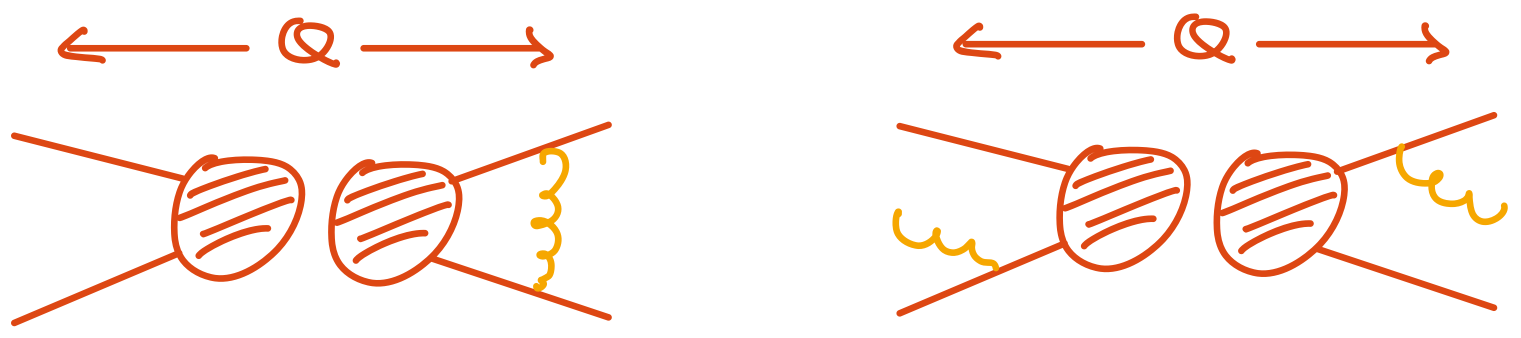
$$\mathbf{U}_n = \mathcal{X}_n \left[\mathbf{S}(\mu_S), \mu_S\right]$$

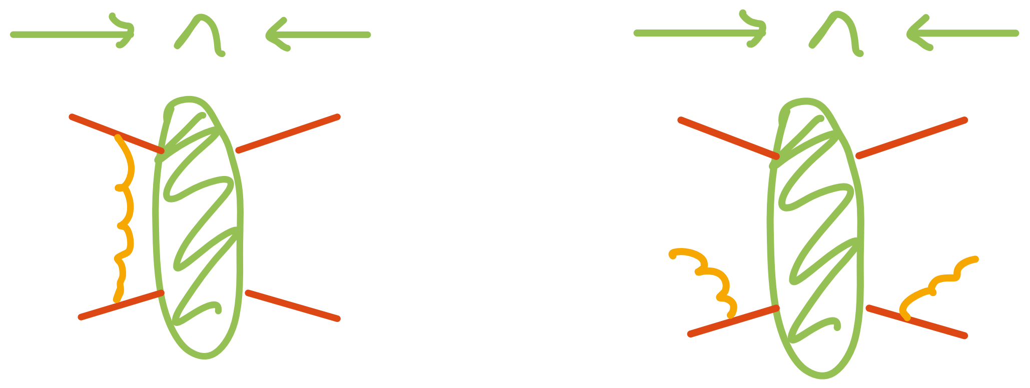
Re-arrange to resum IR enhancements

$$\mathbf{M}_n Z_g^n = \mathcal{Z}_n \left[\mathbf{A}(\mu_S), \mu_S\right]$$

Implies evolution equations,
cross section invariant after redefinition.







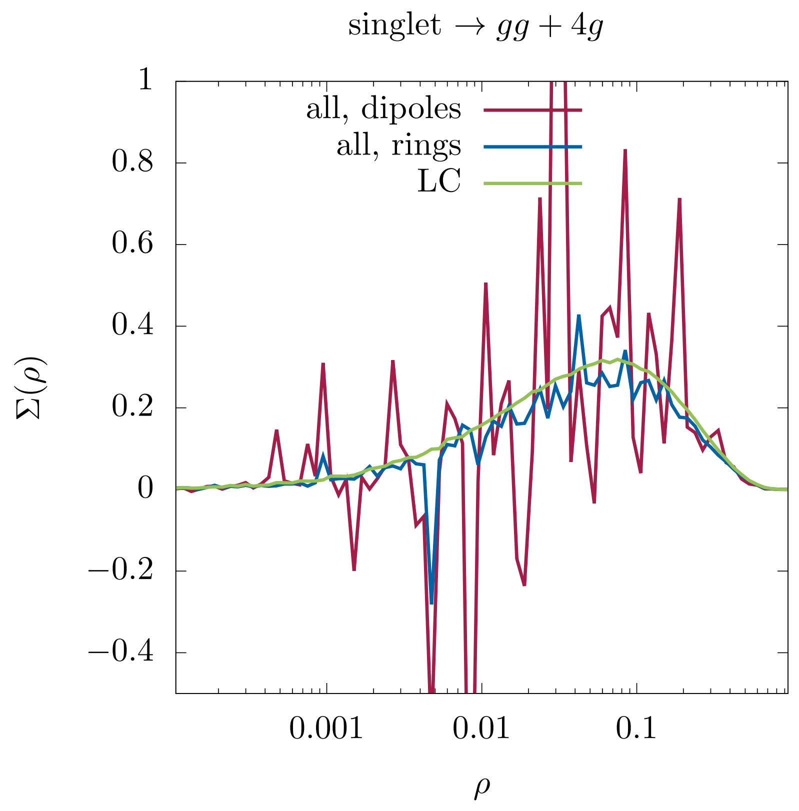
Cross section is RG invariant

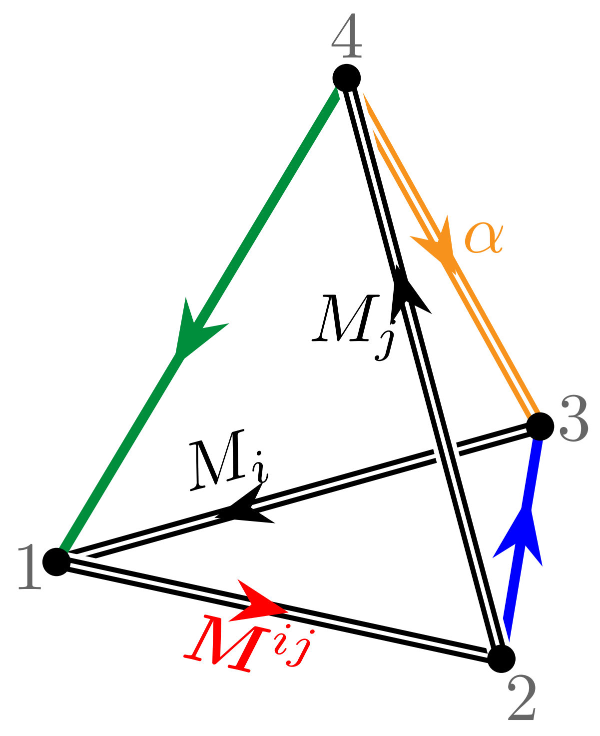
$$\sigma = \sum_n \alpha_S^n \int \mathrm{Tr}\left[\mathbf{A}_n(\mu_S)\mathbf{S}_n(\mu_S)\right] \mathrm{d}\phi_n$$

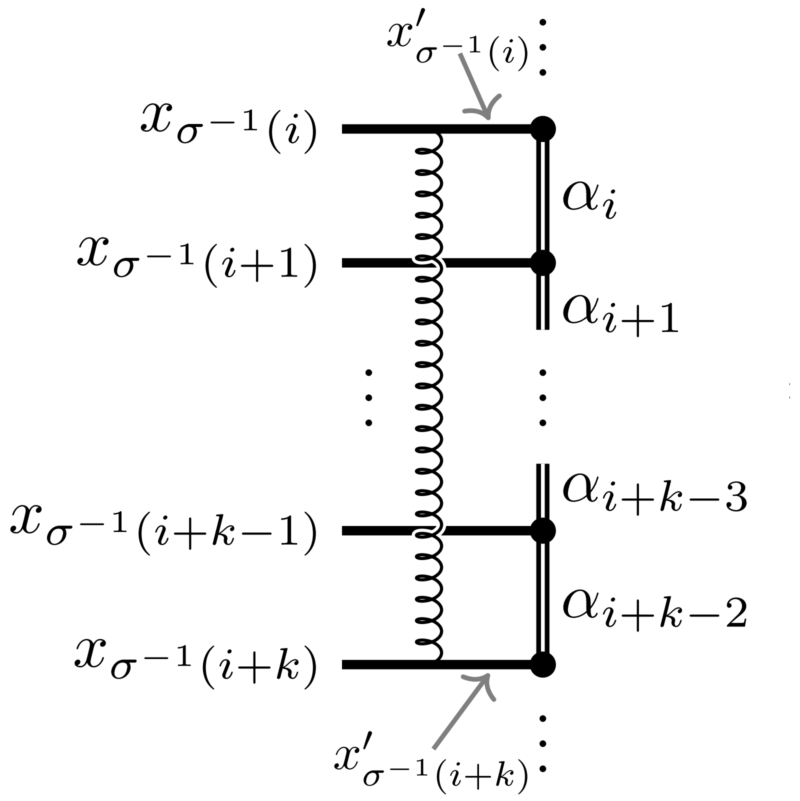
A plethora of activities …

Understand basis functions beyond large-N and colour flow importance sampling.

[Holguin, Forshaw, Plätzer — '21]
[Löschner, Plätzer, Majcen — in preparation]



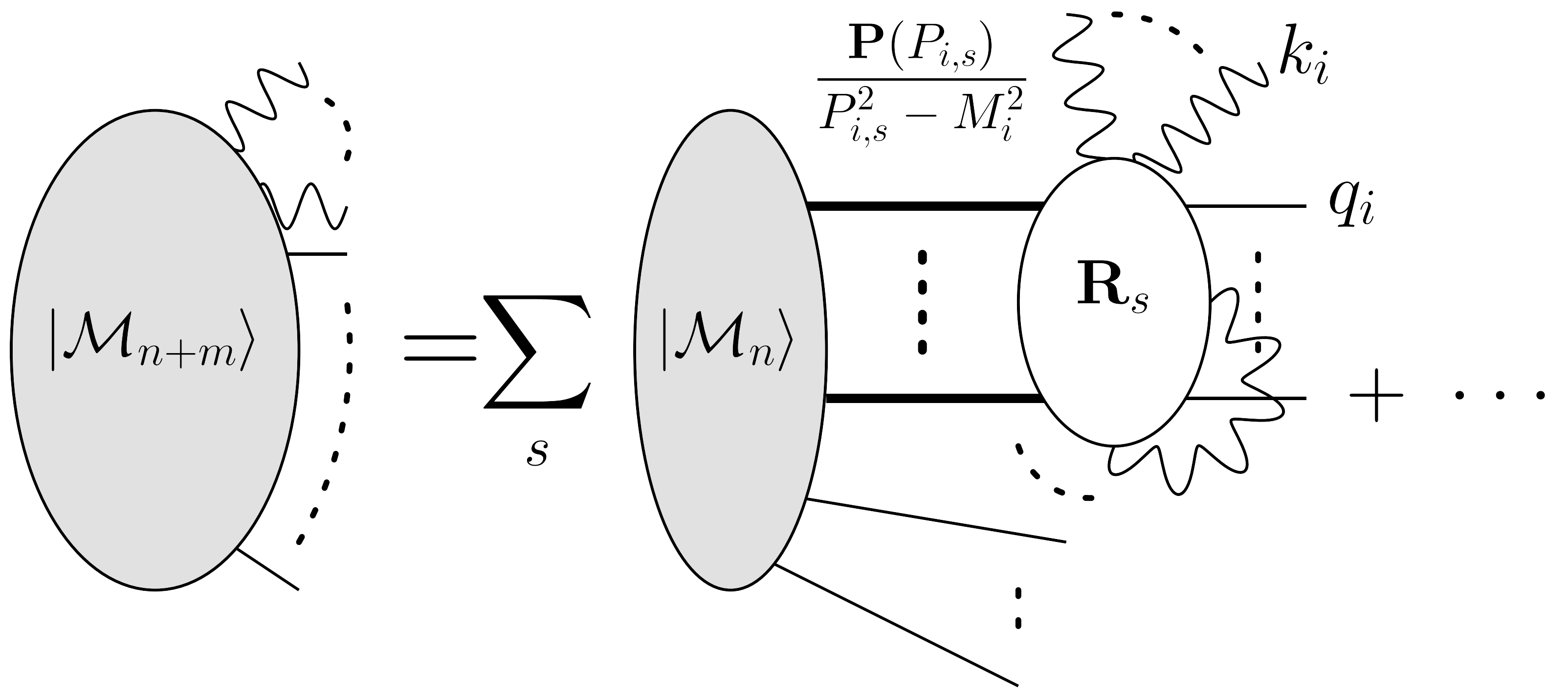




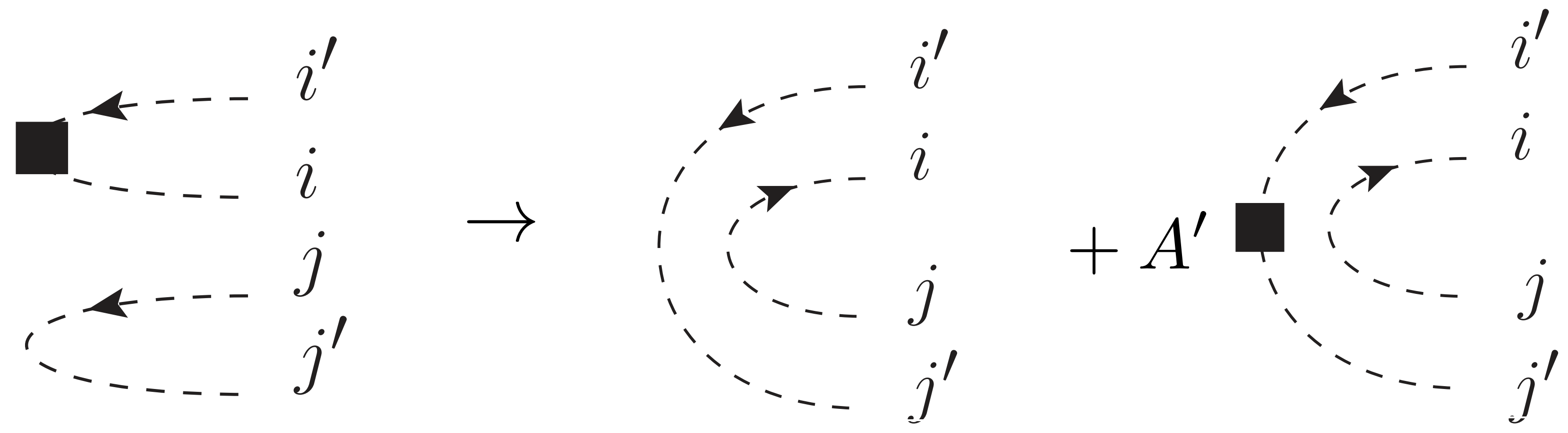
Understand colour multiplets for many legs.

[Alcock-Zeilinger, Keppeler, Plätzer, Sjödahl – '22 & in progress]

Construct electroweak evolution.
Measurement projection is ubiquitous.



Factorisation and kinematics.



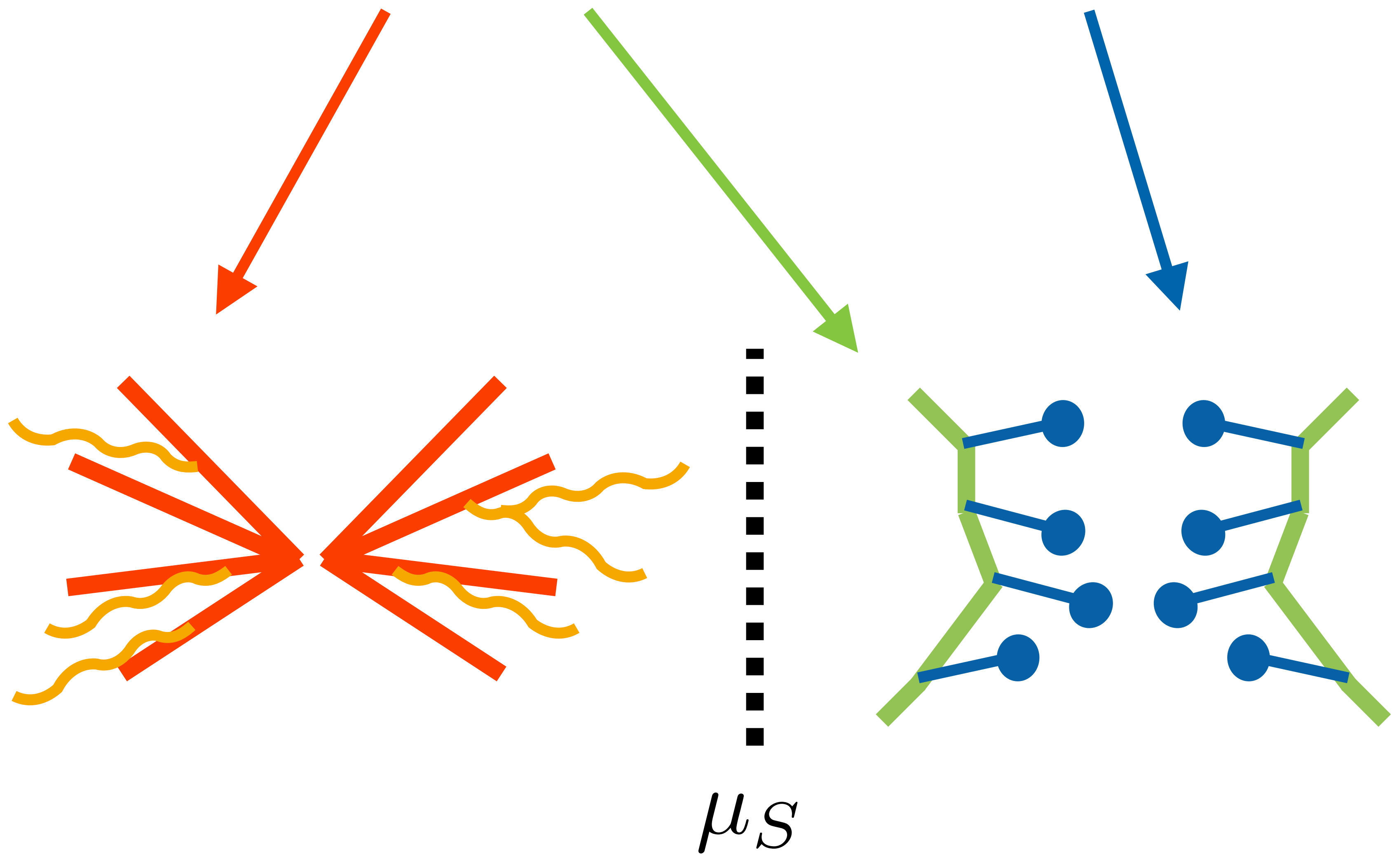
Basis and mixing of chirality structures and propagation of spin information.

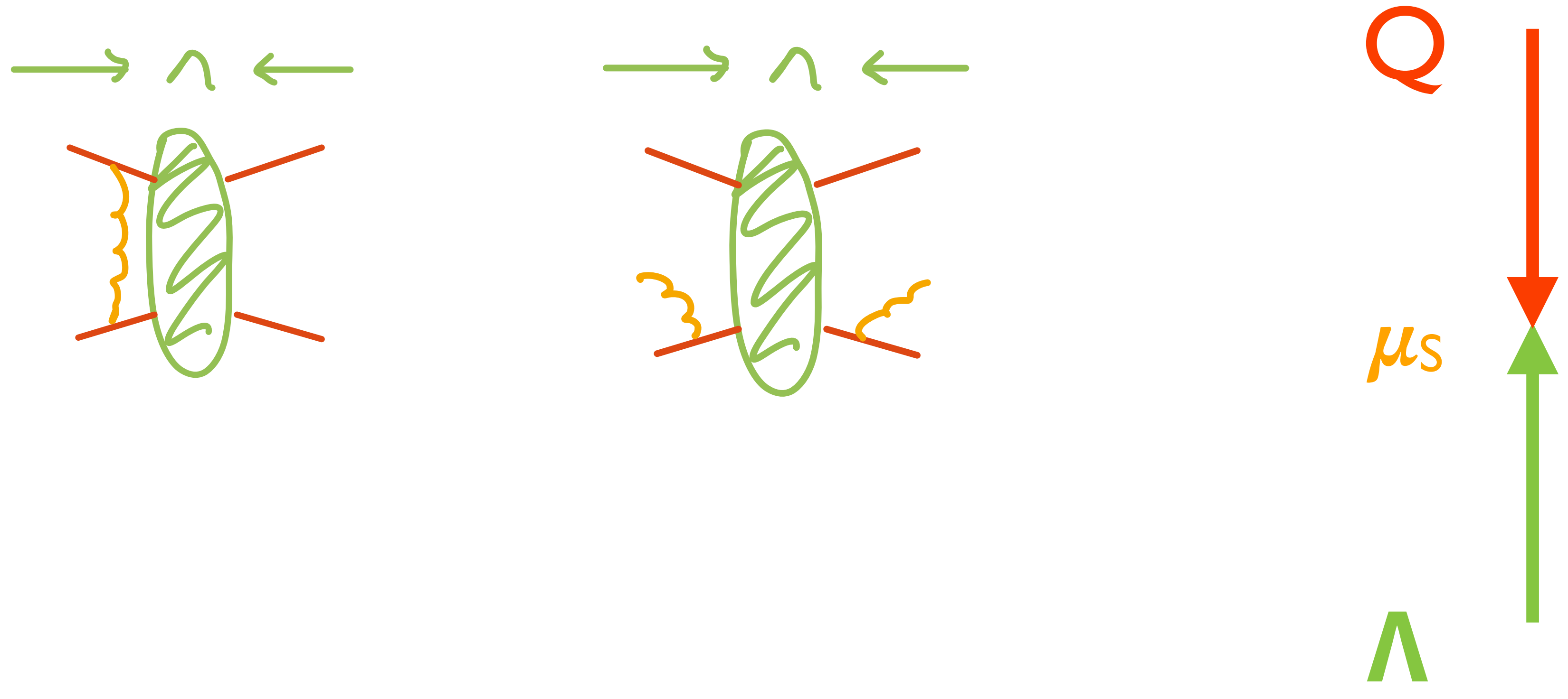
[Plätzer, Sjödahl — '21]

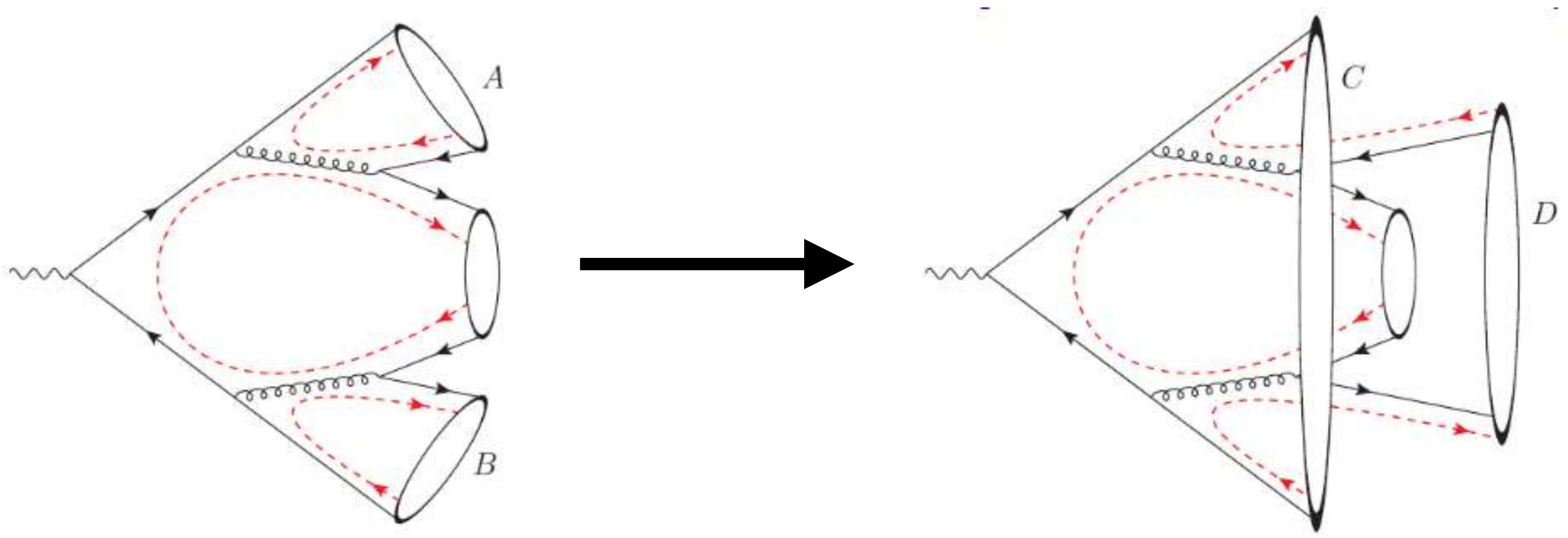
Constructing hadronization models

$$\sigma = \sum_{n,m} \int \int \mathrm{Tr}_n \left[\mathbf{M}_n \mathbf{U}_{nm} \right] \mathrm{d}\phi_m u(\phi_m)$$

$$0 = \frac{\mathrm{d}}{\mathrm{d}\mu_S}$$





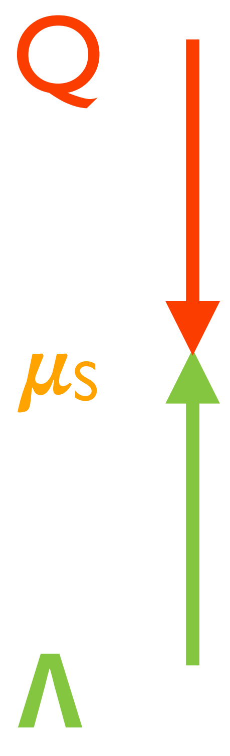


Construct perturbative end of hadronization.
Genuine non-perturbative effects only in initial condition at low scale.

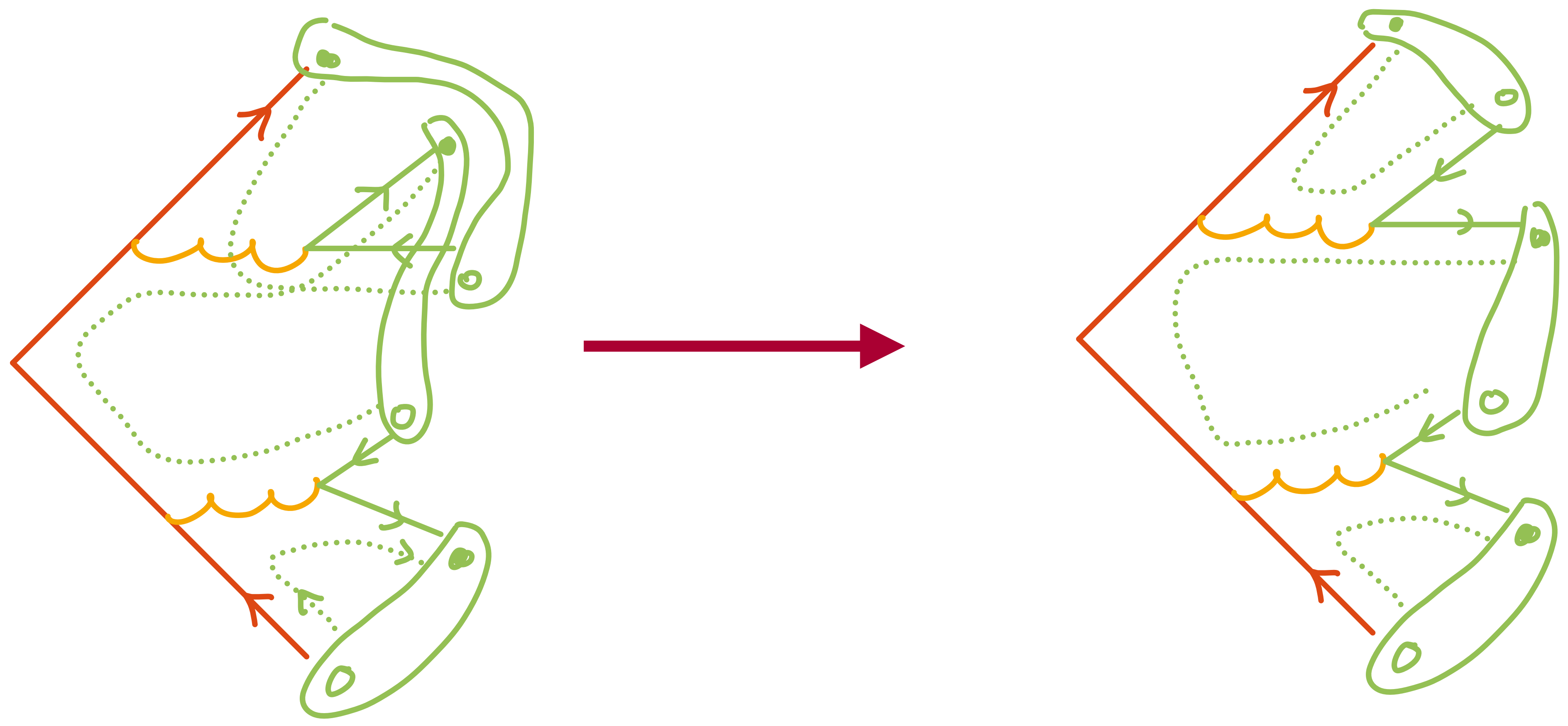
e.g. colour reconnection *implied* just as observed in [Gieseke, Kirchgaesser, Plätzer – '18 …]

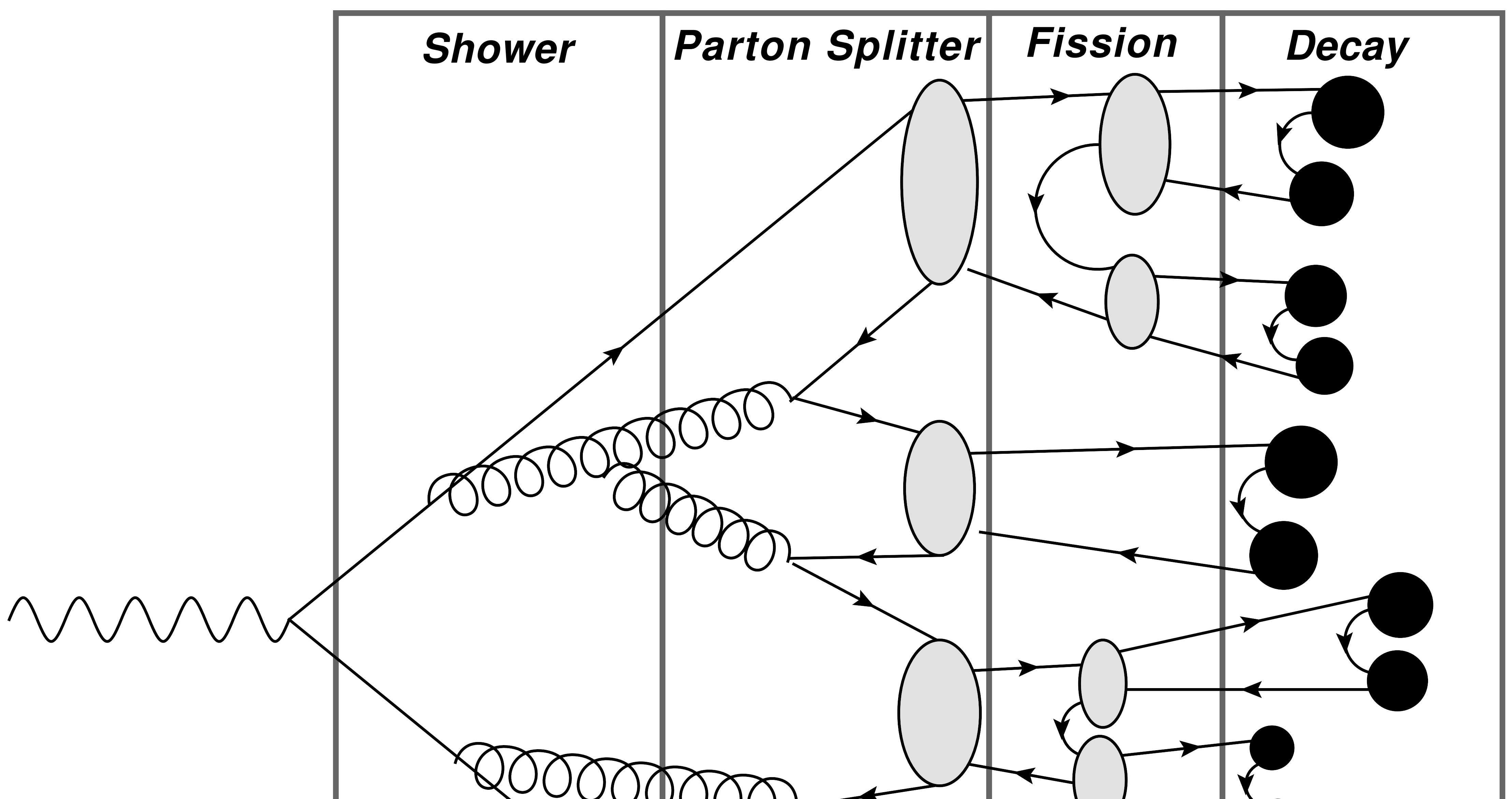
Hadronization models

$$\mathrm{d}\sigma \sim \mathrm{Tr}\left[\mathbf{PS}(Q \to \mu)\mathrm{d}\mathbf{H}(Q)\mathbf{PS}^\dagger(Q \to \mu)\mathbf{Had}(\mu \to \Lambda)\right]$$



$$\partial_S \mathbf{S}_n = -\tilde{\mathbf{\Gamma}}^\dagger_{S,n}\mathbf{S}_n - \mathbf{S}_n\tilde{\mathbf{\Gamma}}_{S,n} + \sum_{s\geq 1}\alpha_S^s \int \tilde{\mathbf{R}}^{(s)\dagger}_{S,n+s}\mathbf{S}_{n+s}\tilde{\mathbf{R}}^{(s)}_{S,n+s}\prod_{i=n+1}^{n+s}[\mathrm{d}p_i]\tilde{\delta}(p_i)$$





Hadronization models

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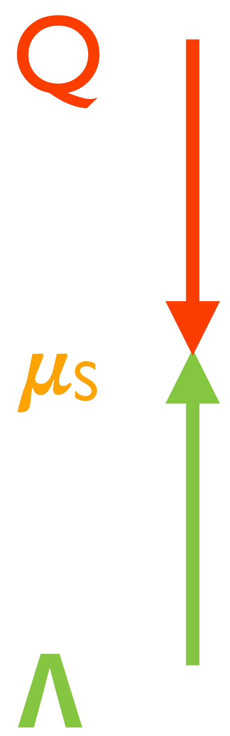
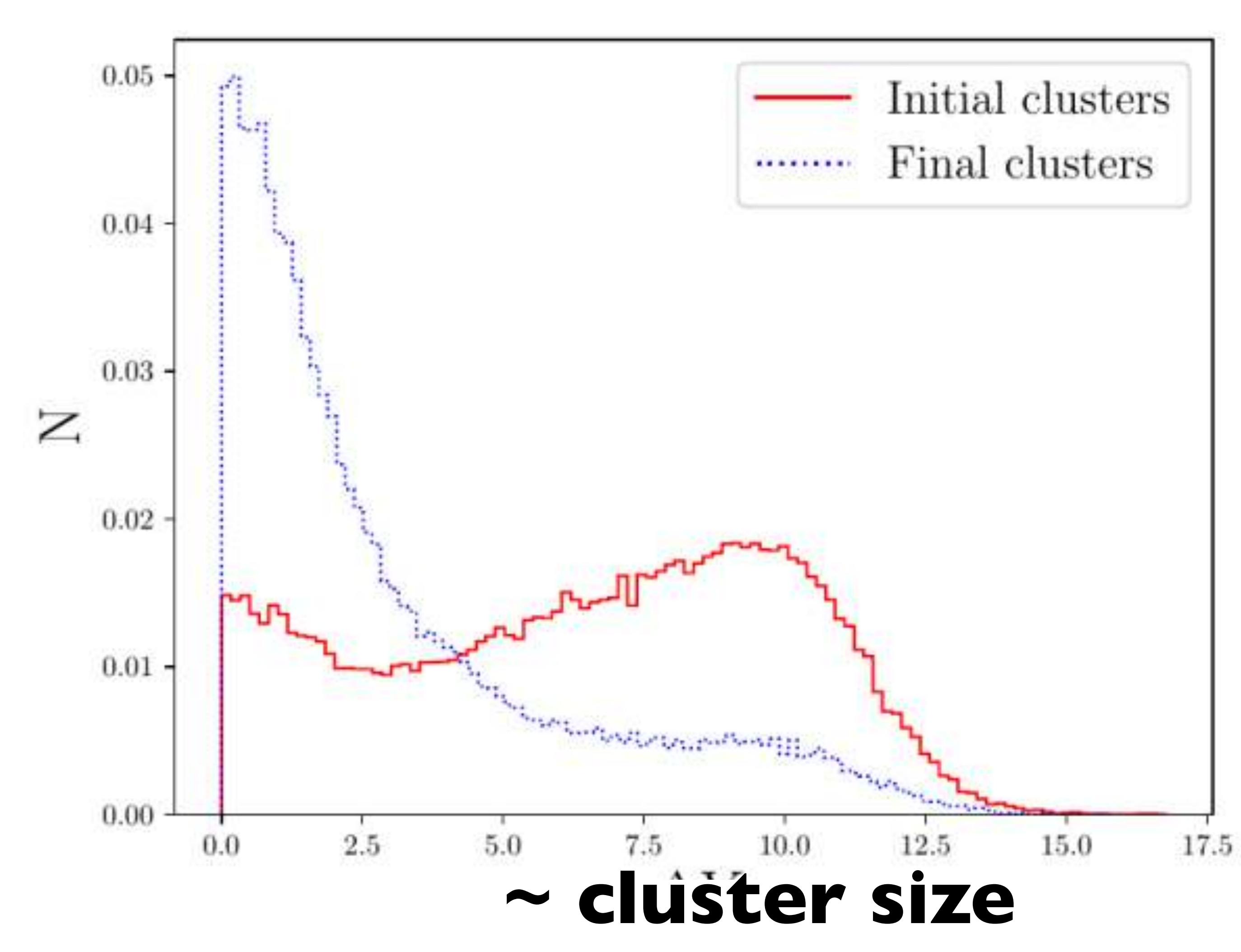


$\partial_S \mathbf{S}$



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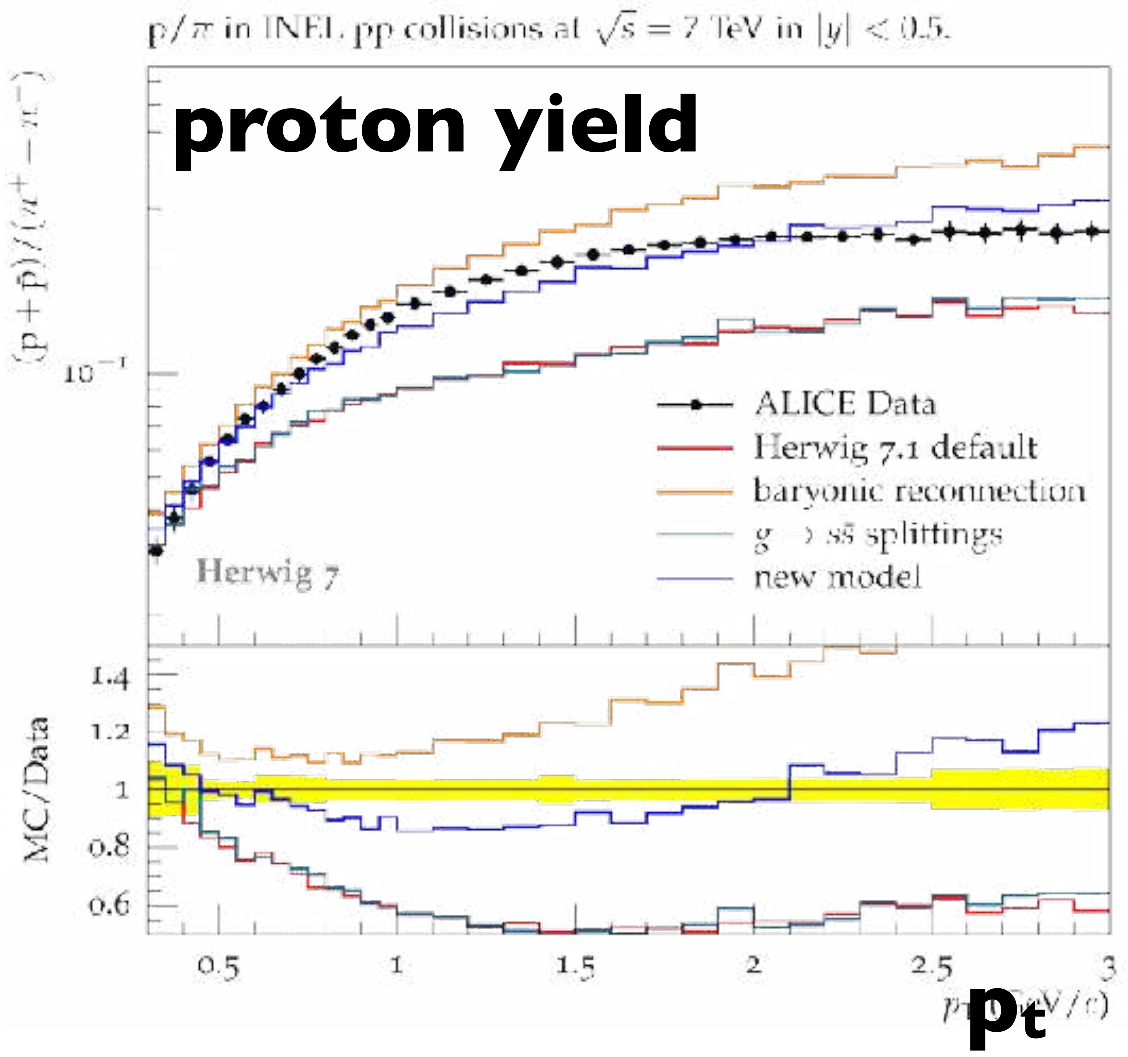
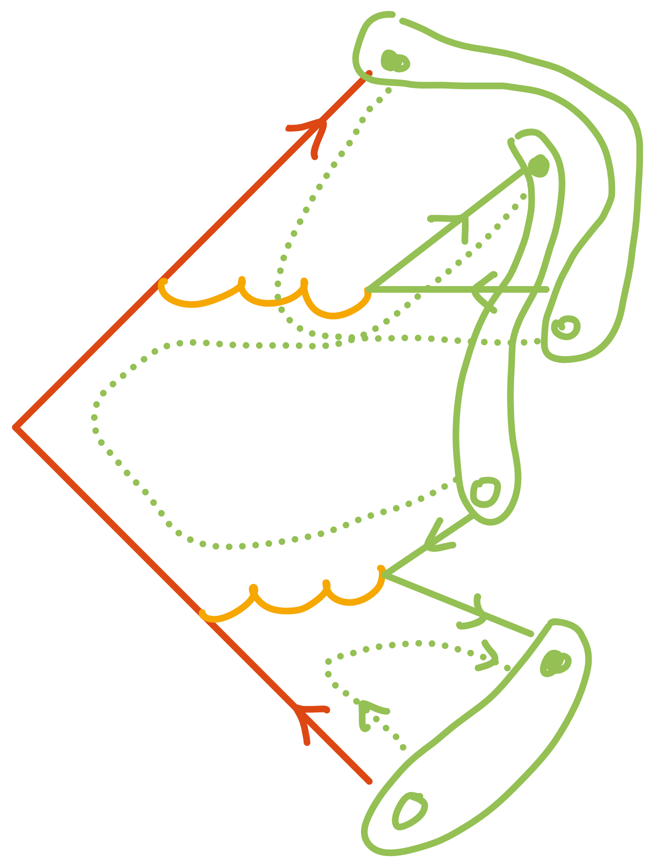
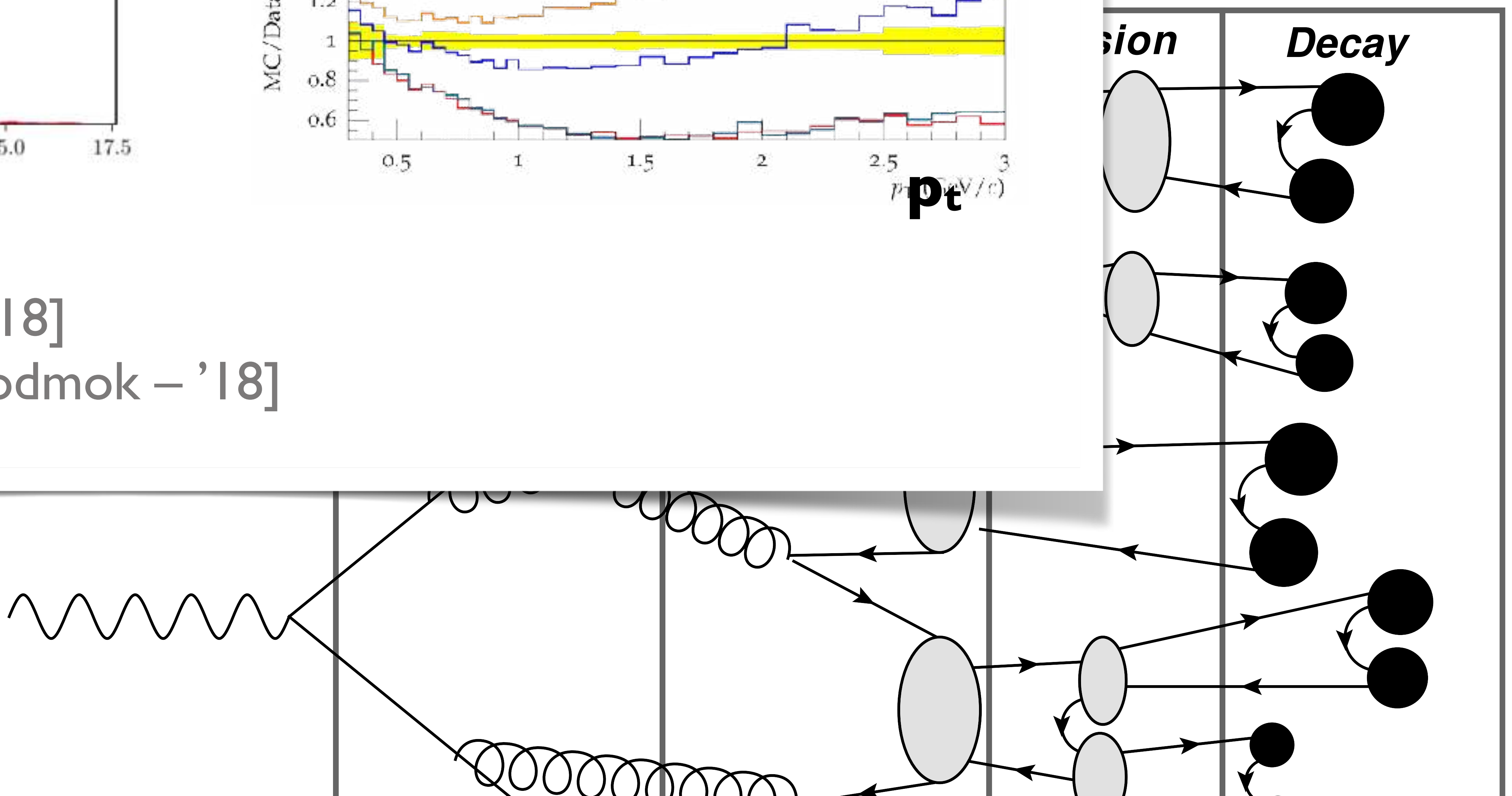


[Gieseke, Kirchgaesser, Plätzer – '18]
[Gieseke, Kirchgaesser, Plätzer, Siodmok – '18]

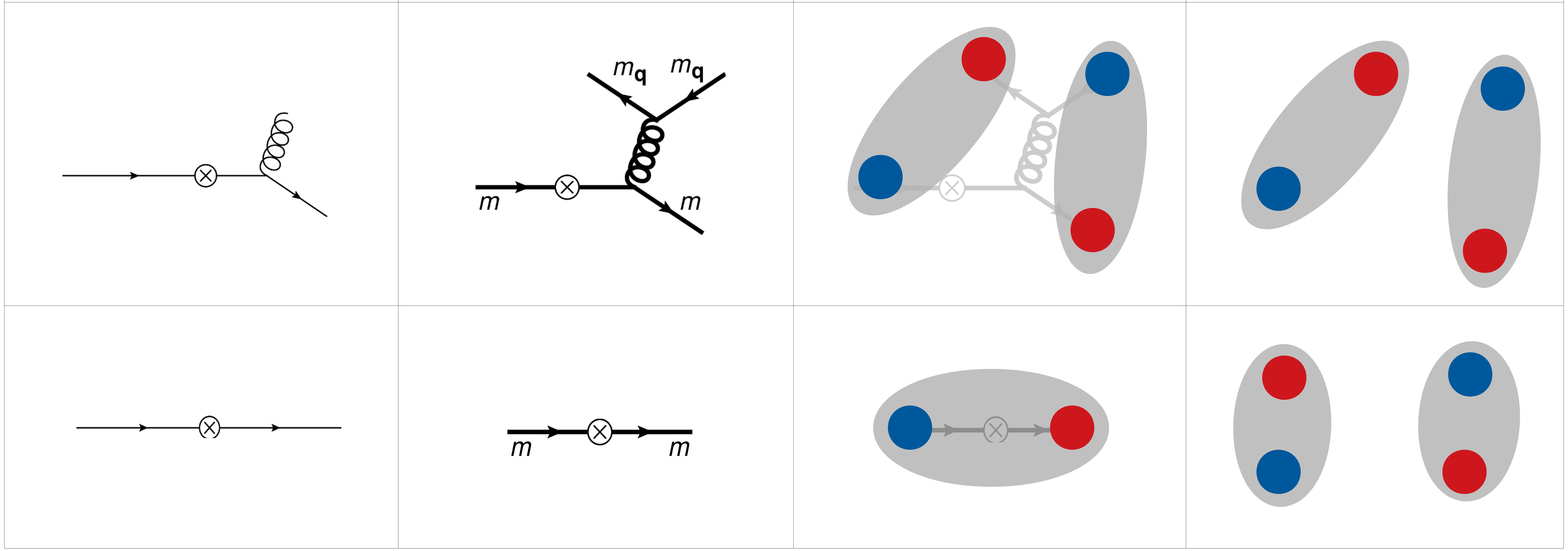




Stepping stone: match clusters to shower

UV limit of hadronization needs to reproduce soft limit of (angular ordered) shower.

parton shower	forced splitting and constituent masses	cluster formation	cluster fission

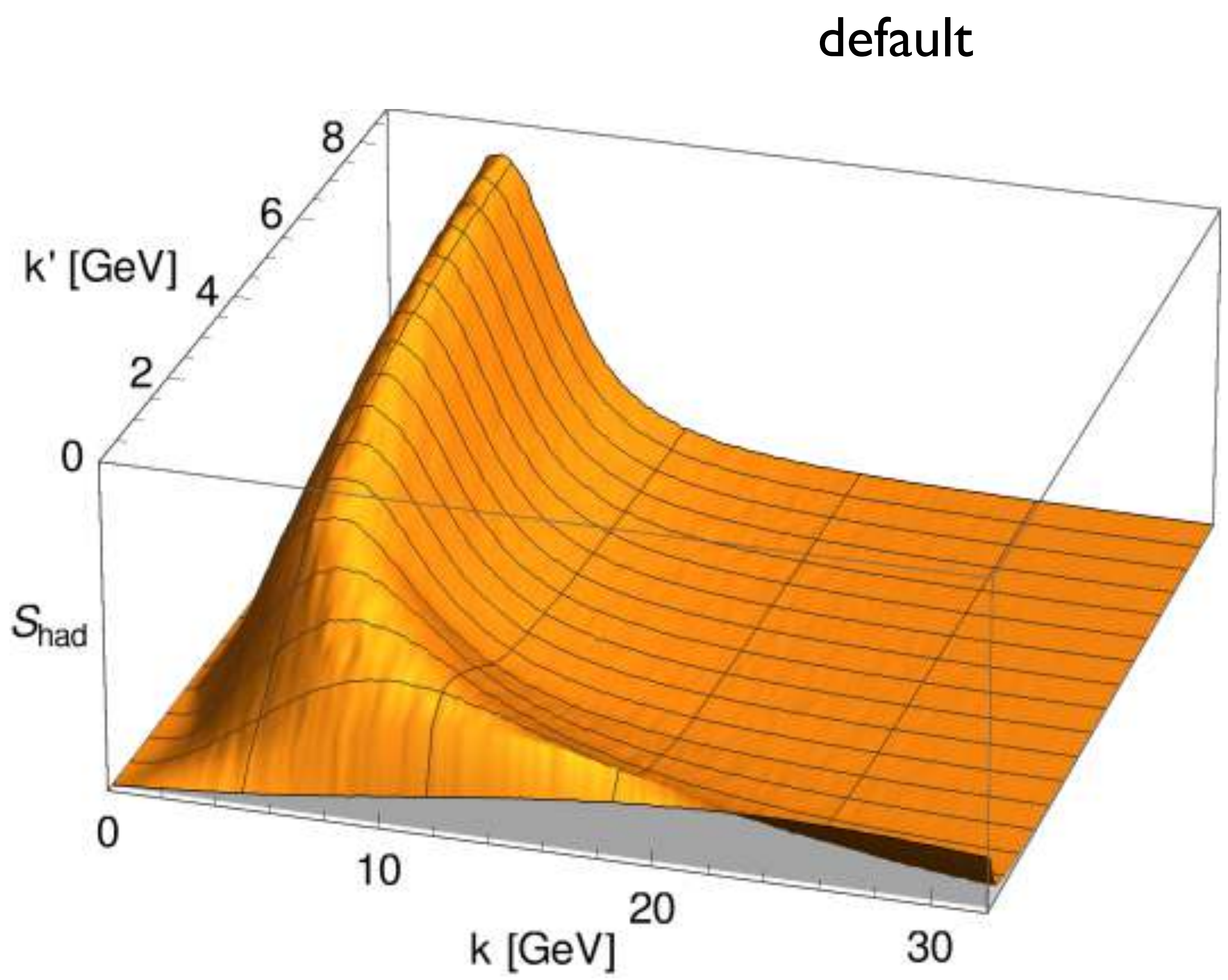


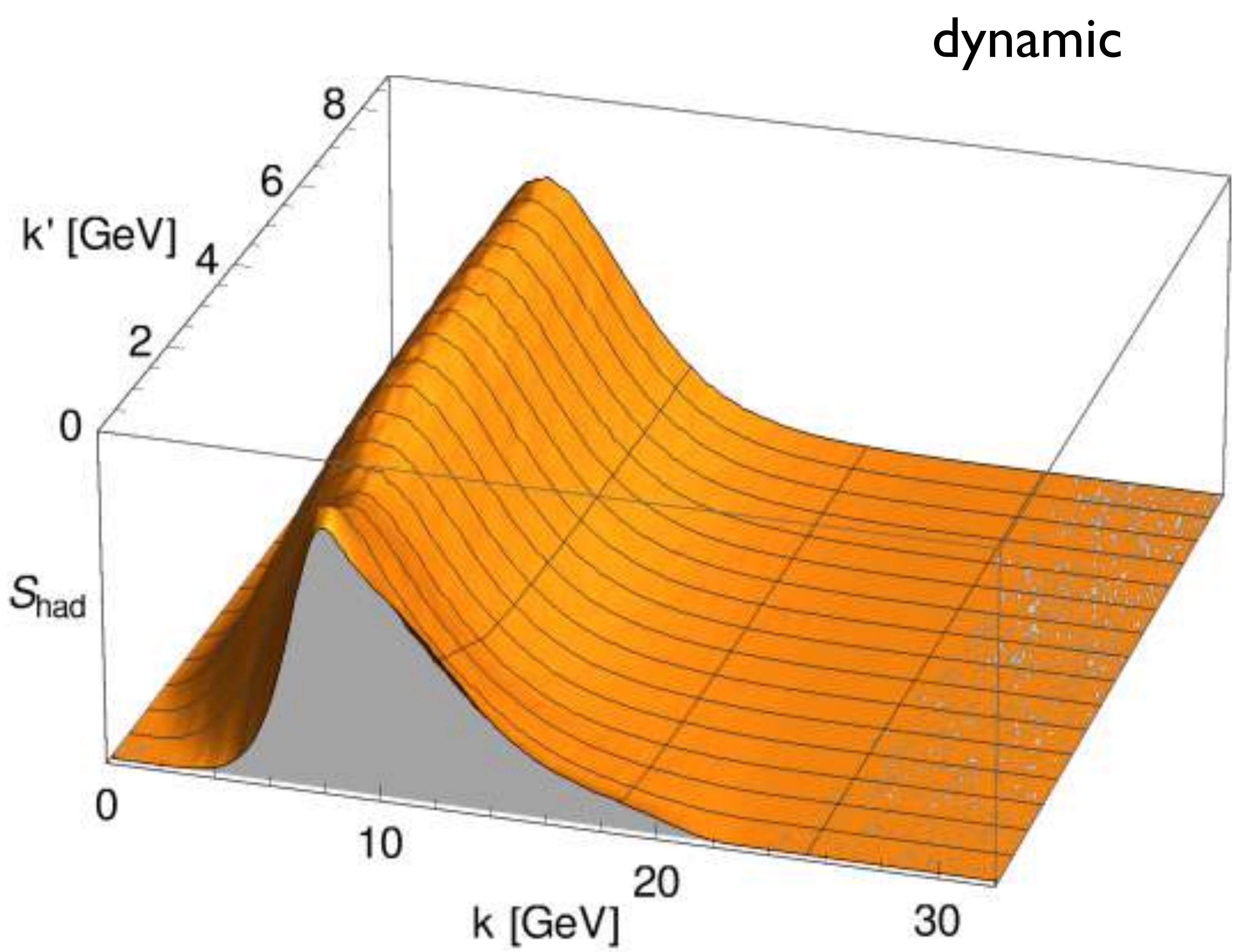
figures by Daniel Samitz

[Hoang, Plätzer, Samitz — in progress]
[Kiebacher, Plätzer, Priedigkeit — in progress]

Tuning and hadronization corrections

Significantly different shapes of hadronization corrections (extracted bin by bin from Herwig)



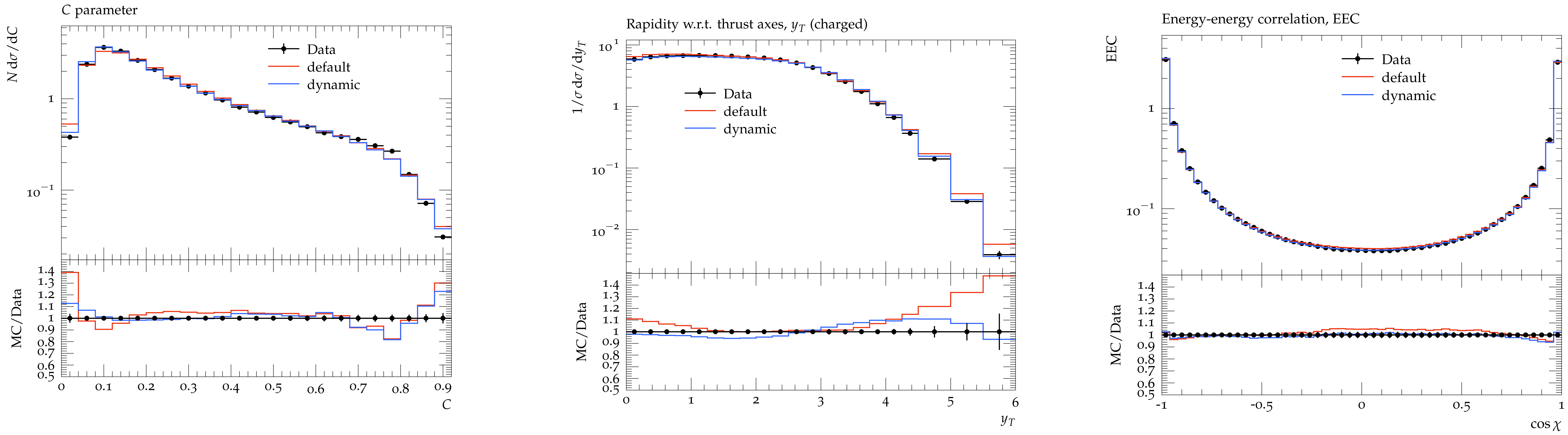


C parameter parton versus hadron level

[Hoang, Plätzer, Samitz — in progress]

Tuning and hadronization corrections

Significantly different shapes of hadronization corrections (extracted bin by bin from Herwig)



C parameter

rapidity wrt thrust

EEC

C parameter parton versus hadron level

[Hoang, Plätzer, Samitz — in progress]

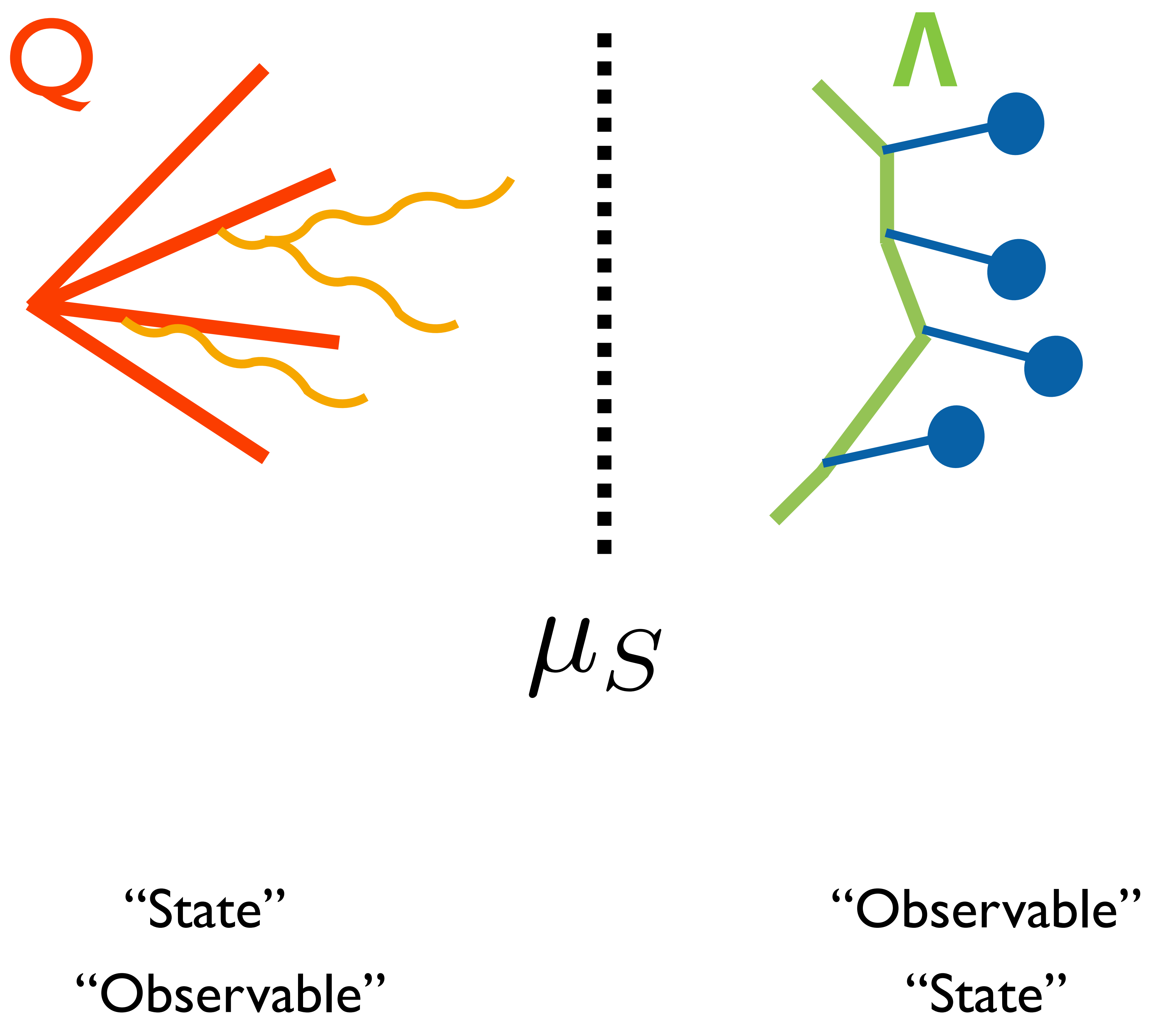
Summary

As we aim to use more and more of the complex structures, shower accuracy becomes the bottleneck.

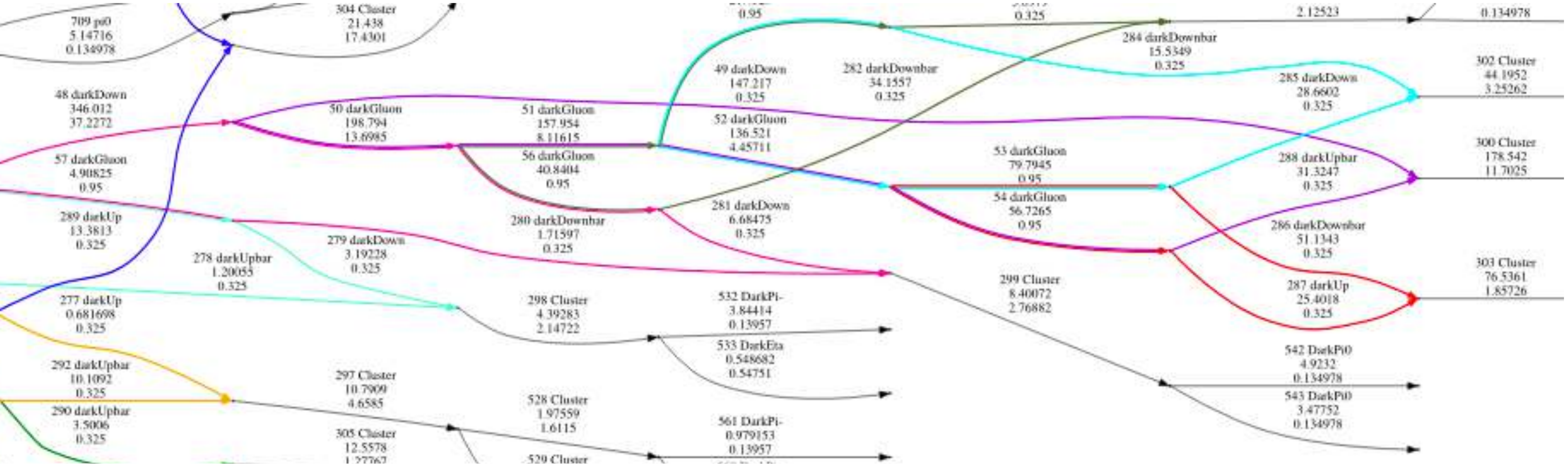
Resummation and design of parton showers needs to go hand in hand: amplitude evolution can serve as a theoretical tool and an algorithm in its own right.

The understanding of hadronization effects and models, and their interplay with parton showers will be one of the main topics for precise simulations.

Quantum mechanical propagation of **colour and spin**, and the account of interference will be crucial and can be accounted for by **amplitude evolution** algorithms.



Why would we care?



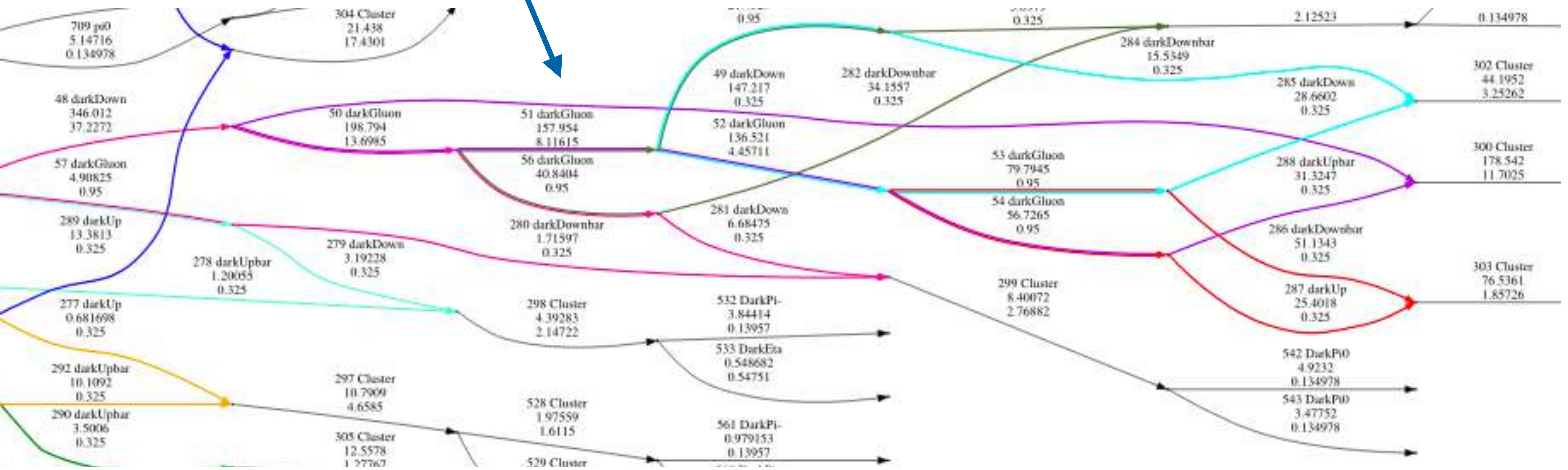
No data better no model …

Hidden valley angular ordered shower, based on new shower interactions framework

[Masouminia]

More flexible cluster hadronization

[Plätzer, Stafford]

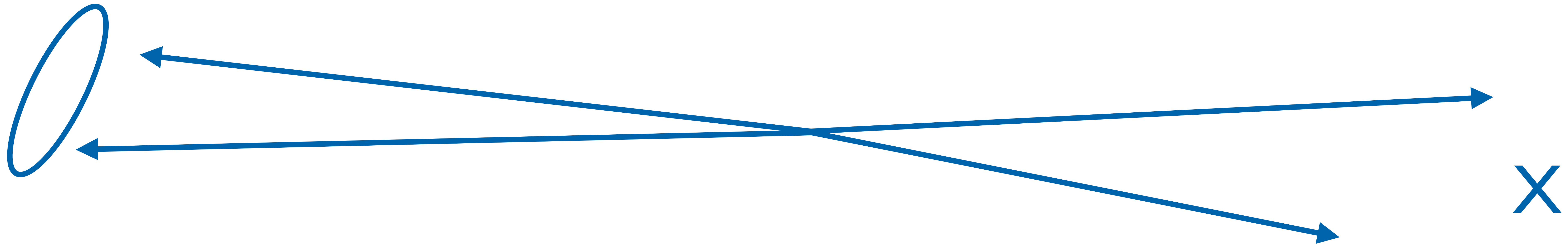


[Kulkarni, Masouminia, Plätzer, Stafford — in progress]

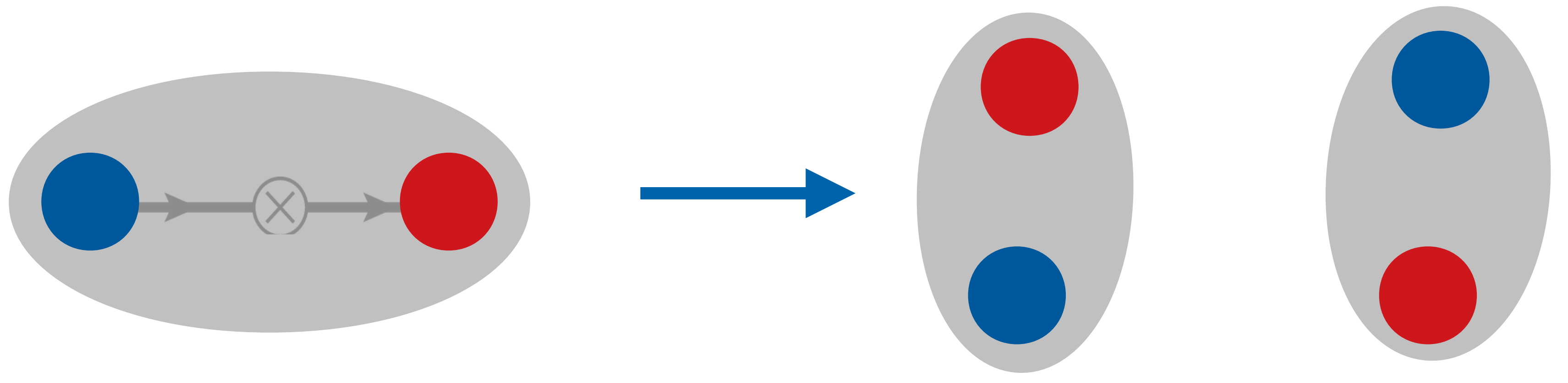
Herwig package complementing Pythia's hidden valley model.

Blindly relying on validity of coherence and quasi-collinear limit … among many other questions.

Seen a lot of improvements, but is this the right physics?



Rather exclusive events at low 1-Thrust.
BELLE @ 10.45 GeV ~ no shower evolution.



[Kiebacher, Plätzer, Priedigkeit — in progress]

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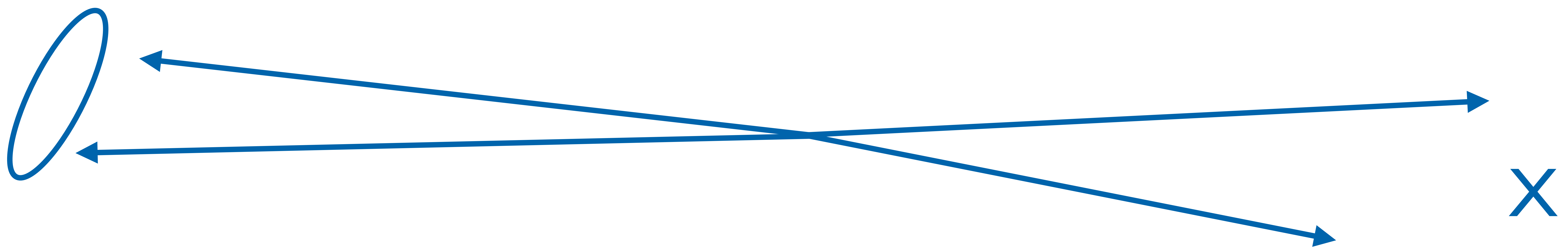

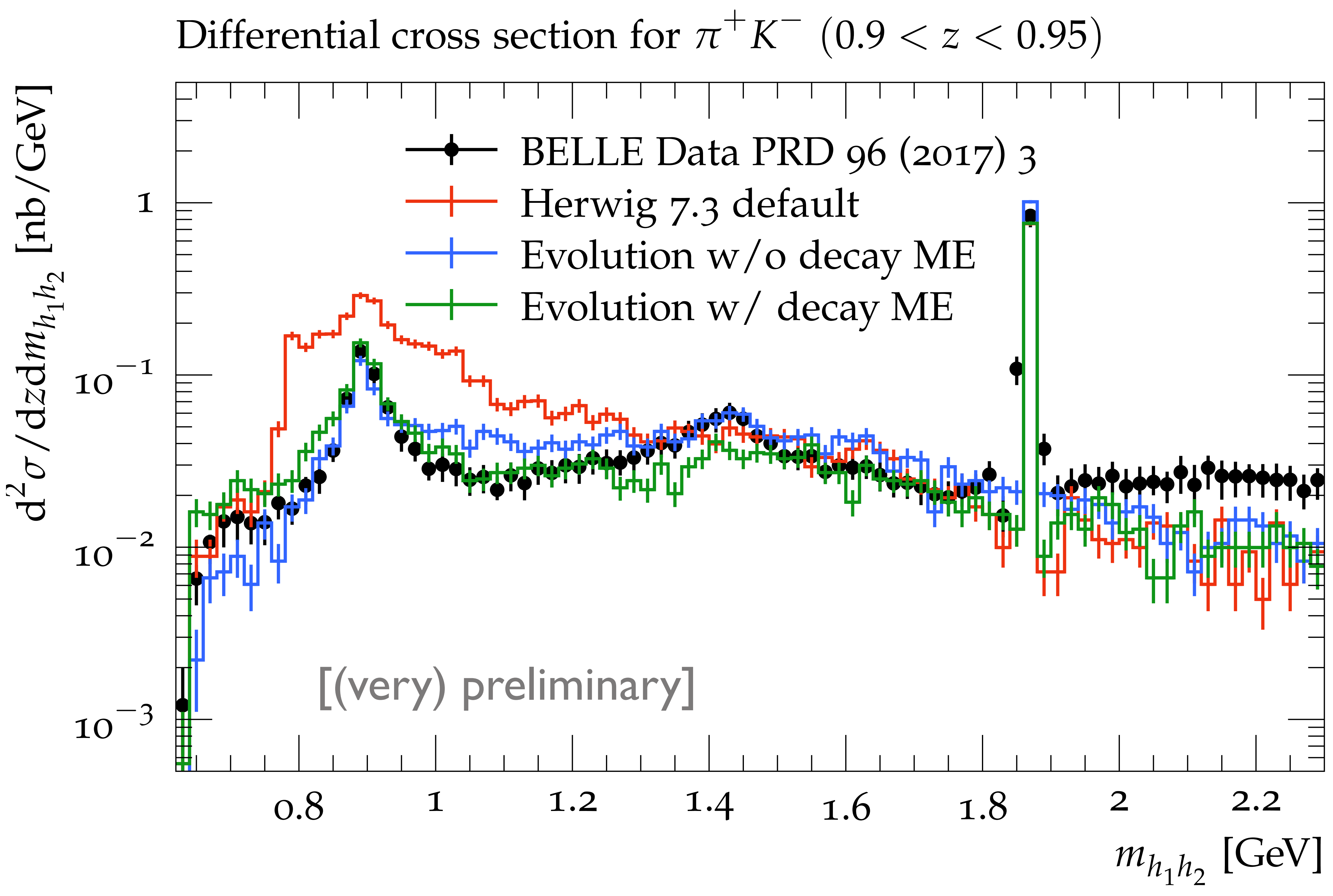

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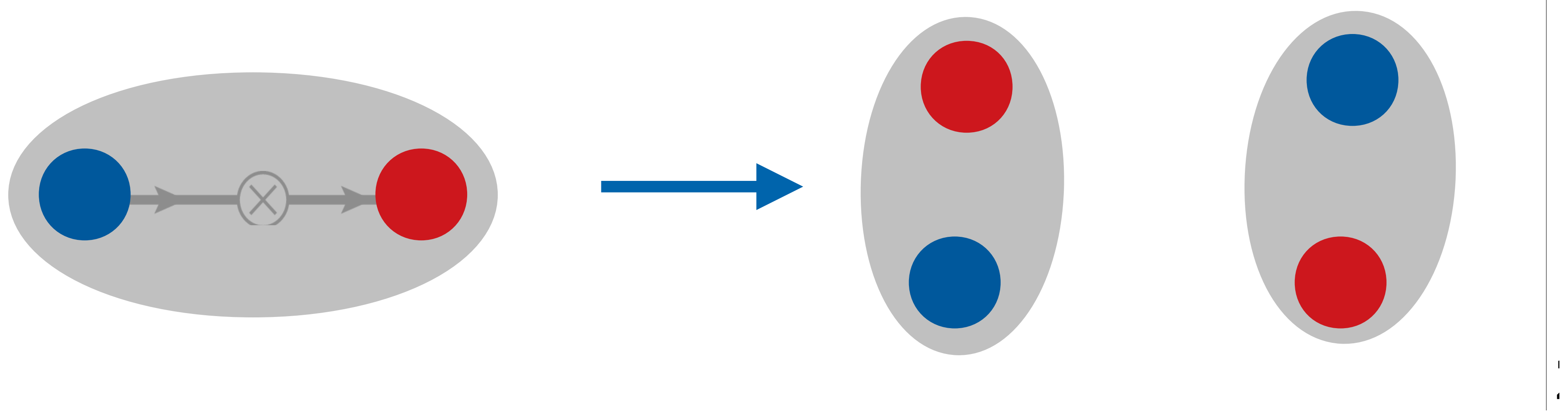

[Kiebacher, Plätzer, Priedigkeit — in progress]

Thank you.