NNLL resummation
a novel approach

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In collaboration with
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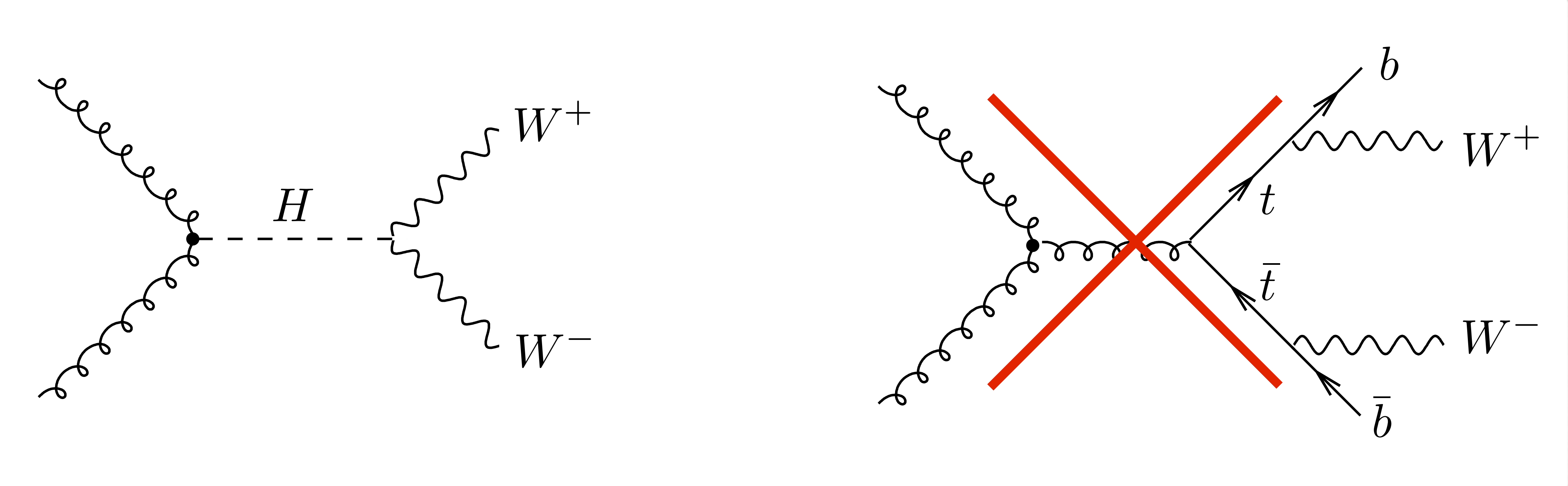
Outline

- Motivations
- State of the art of QCD resummations
- General technique for QCD resummations
  - Observable's properties
  - Amplitudes
  - Relevant phase space regions
- Applications in e^+e^- annihilation
- Current work in progress and outlook

An example: jet-veto

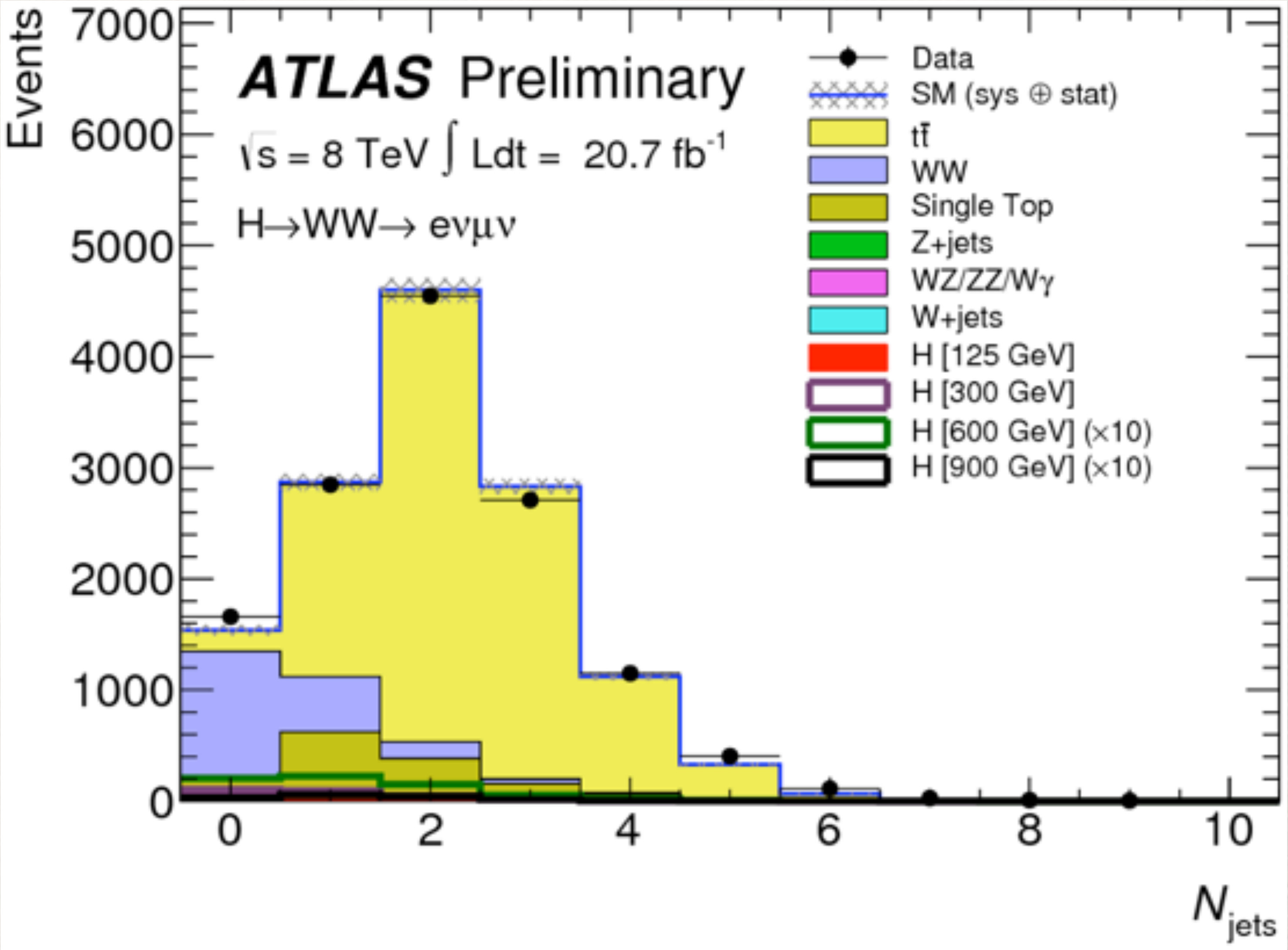
- Example: Higgs decaying into WW suffers from a large background from top-antitop production



- Each top quark decays into a b-jet $\Rightarrow$ veto events with jets in the final state
- Jet-vetoes are employed in many LHC analyses (e.g. vector-boson cross sections, boosted Higgs searches, etc.)

How do we veto jets?

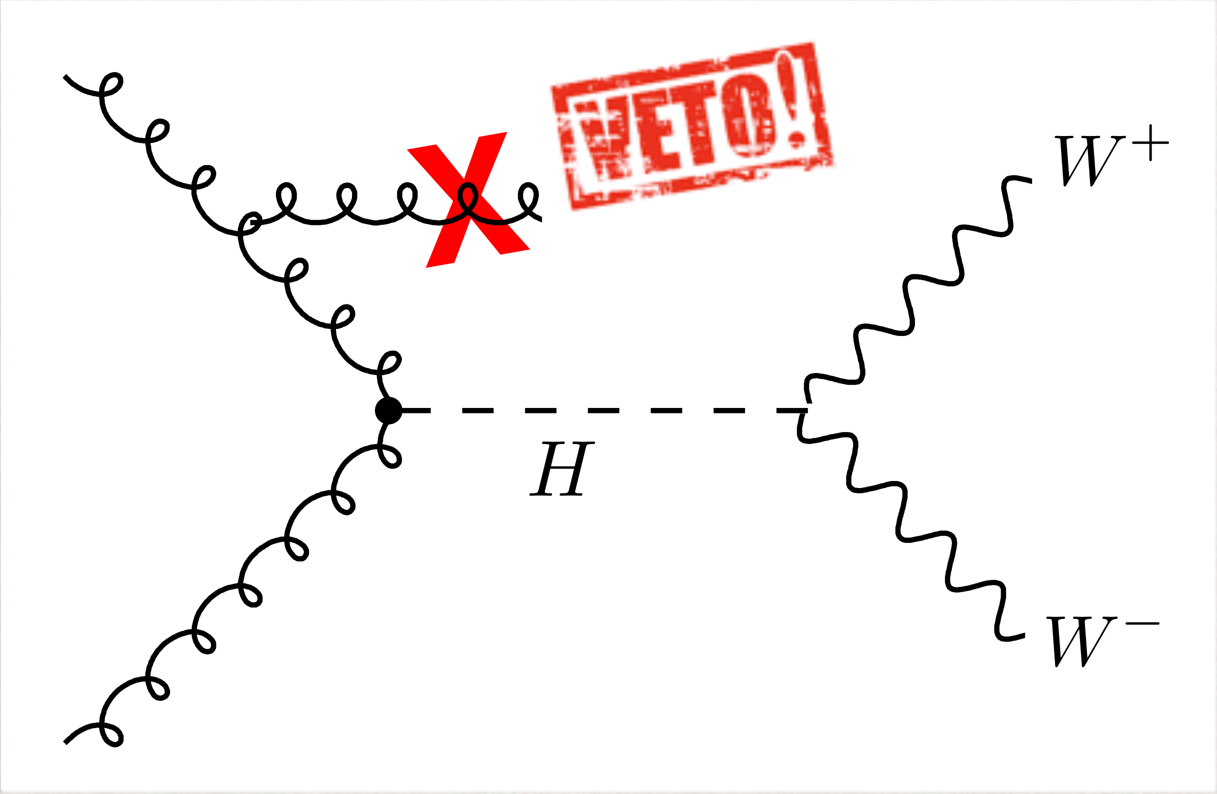
- We require that all jets with transverse momentum smaller than $p_{\mathrm{t,veto}}$



- The zero-jet cross section $\sigma_{0-\mathrm{jet}}$ is least contaminated by the huge (yellow) top-antitop background

Infrared sensitivity

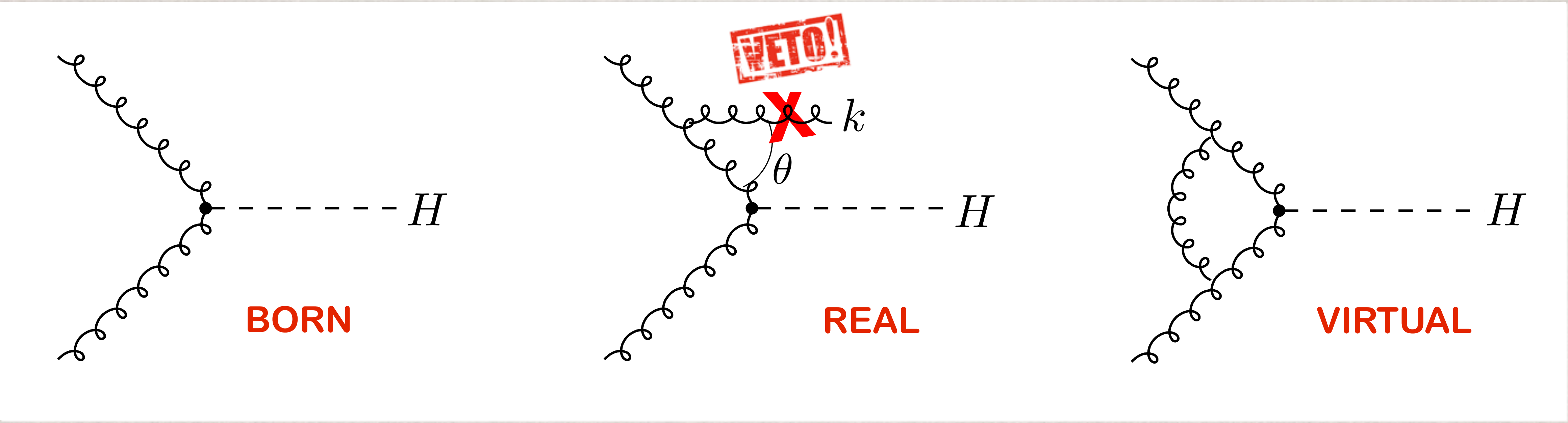
- The 0-jet cross section is characterised by two scales, the Higgs mass m_H and the jet resolution $p_{\mathrm{t,veto}}$



- In QCD, logarithms $\ln(m_H/p_{\mathrm{t,veto}})$ appear whenever the phase space for the emission of soft and/or collinear gluons is restricted

One gluon emission

- Example: veto one soft ($E \ll m_H$) and collinear ($\theta \ll 1$) gluon k



soft

collinear

$$\sigma_0 \left[1 \quad + \quad C_A \frac{\alpha_s}{\pi} \int \frac{dE}{E} \frac{d\theta^2}{\theta^2} \Theta\left(p_{\mathrm{t,veto}} - E\theta\right) \quad - \quad C_A \frac{\alpha_s}{\pi} \int \frac{dE}{E} \frac{d\theta^2}{\theta^2} \right]$$

factorisation of soft radiation

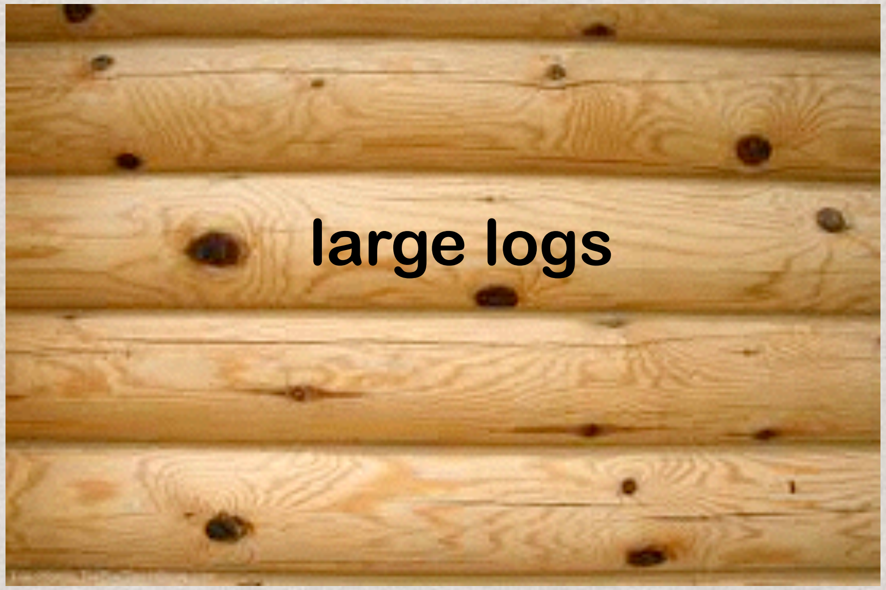
$$\boxed{\sigma_{0-\mathrm{jet}} = \sigma_0 \left[1 - C_A \frac{\alpha_s}{\pi} \ln^2 \left(\frac{m_H}{p_{\mathrm{t,veto}}} \right) \right]}$$

All-order 0-jet cross section

- The zero-jet cross section contains logarithmic contributions which can become large when $p_{\mathrm{t,veto}} \ll m_H$

$$\sigma_{0-\mathrm{jet}} \simeq \sigma_0 \left(\underset{\mathrm{LO}}{1} - \underset{\mathrm{NLO}}{2C_A \frac{\alpha_s(m_H)}{\pi} \ln^2 \frac{m_H}{p_{\mathrm{t,veto}}}} + \ldots \right)$$

breakdown of perturbation theory!



All-order 0-jet cross section

- All-order resummation of large logarithms $\Rightarrow$ reorganisation of the PT series in the region $\alpha_s L \sim 1$, with $L = \ln(m_H/p_{\mathrm{t,veto}})$

$$\sigma_{0-\mathrm{jet}} \sim \sigma_0 \exp\left[\underbrace{L g_1(\alpha_s L)}_{\mathrm{LL}} + \underbrace{g_2(\alpha_s L)}_{\mathrm{NLL}} + \underbrace{\alpha_s g_3(\alpha_s L)}_{\mathrm{NNLL}} + \ldots\right]$$

All-order 0-jet cross section

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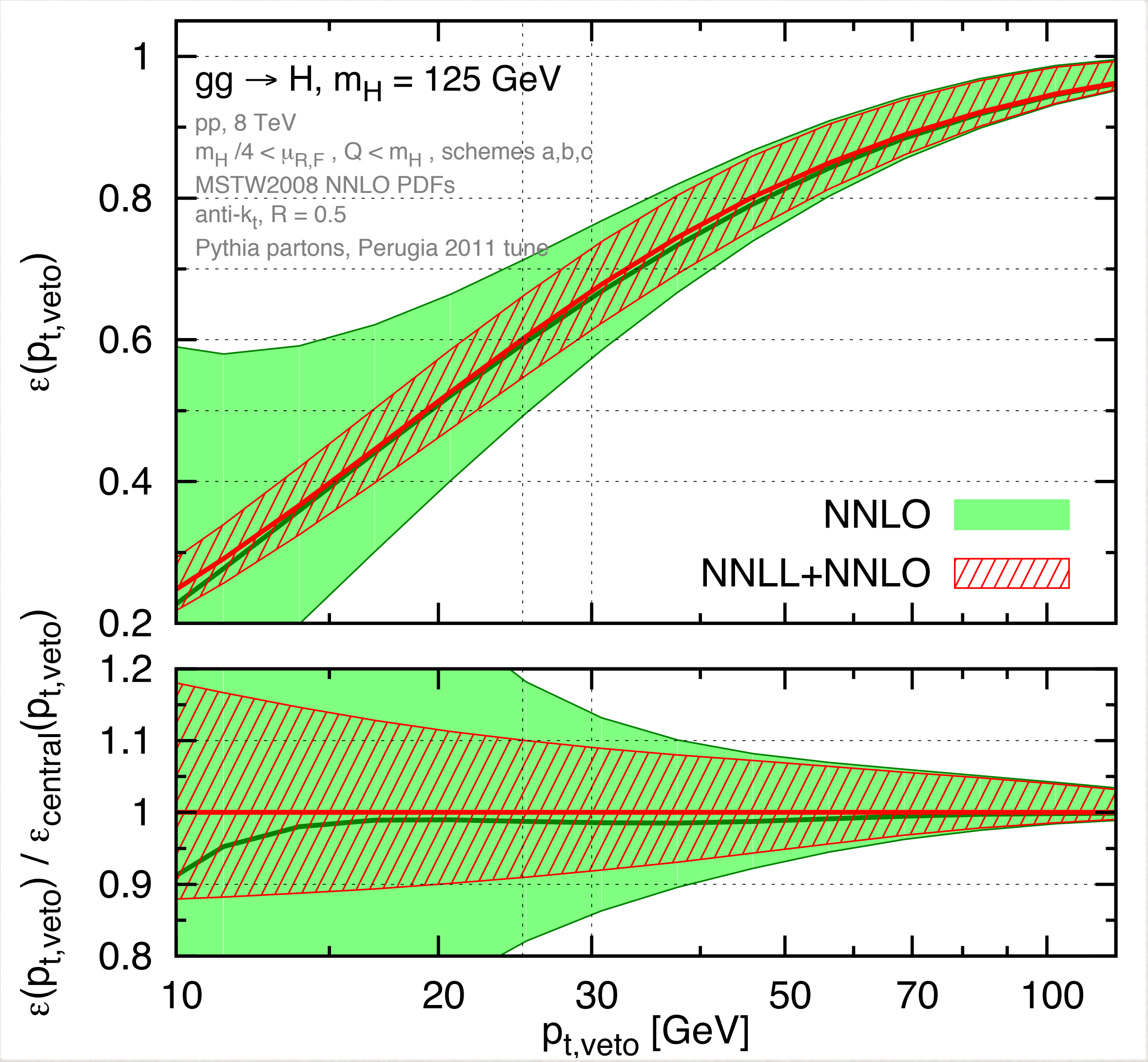
$$\sigma_{0-\mathrm{jet}} \sim \sigma_0\, e^{\overbrace{Lg_1(\alpha_s L)}_{\mathrm{LL}}} \times \left(\begin{array}{cccc} 1 & + & \alpha_s & + \dots \\ \underbrace{G_2(\alpha_s L)}_{\mathrm{NLL}} & + & \underbrace{\alpha_s G_3(\alpha_s L)}_{\mathrm{NNLL}} & + \dots \end{array} \right)$$

Predictions for jet-veto efficiency

- Jet-veto efficiency $\epsilon(p_{t,\text{veto}}) = \sigma_{0-\text{jet}}/\sigma_{\text{tot}}$

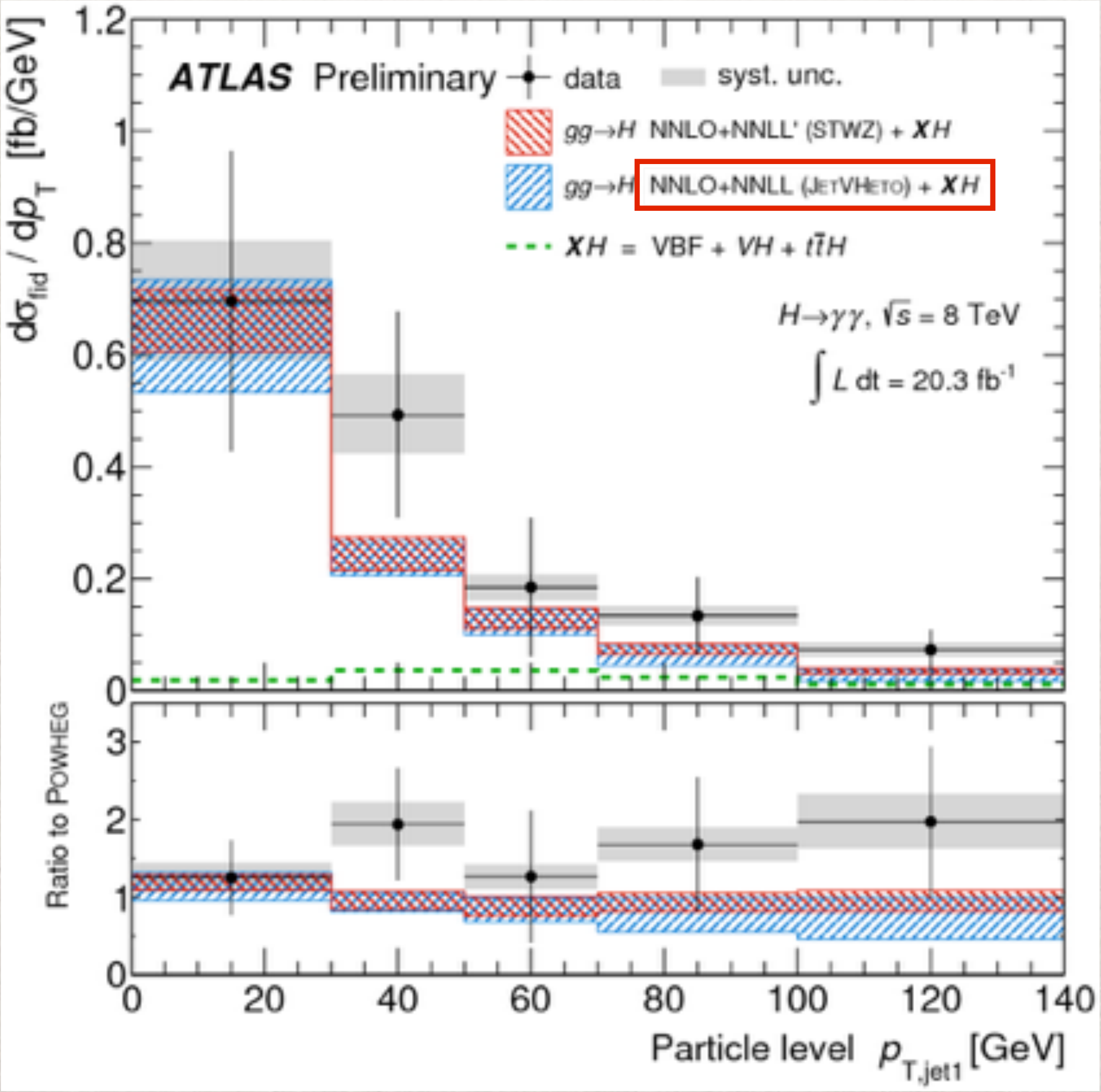
[AB Monni Salam Zanderighi]



- Reduction of theoretical uncertainty from NNLO to NNLL+NNLO

Comparison to data

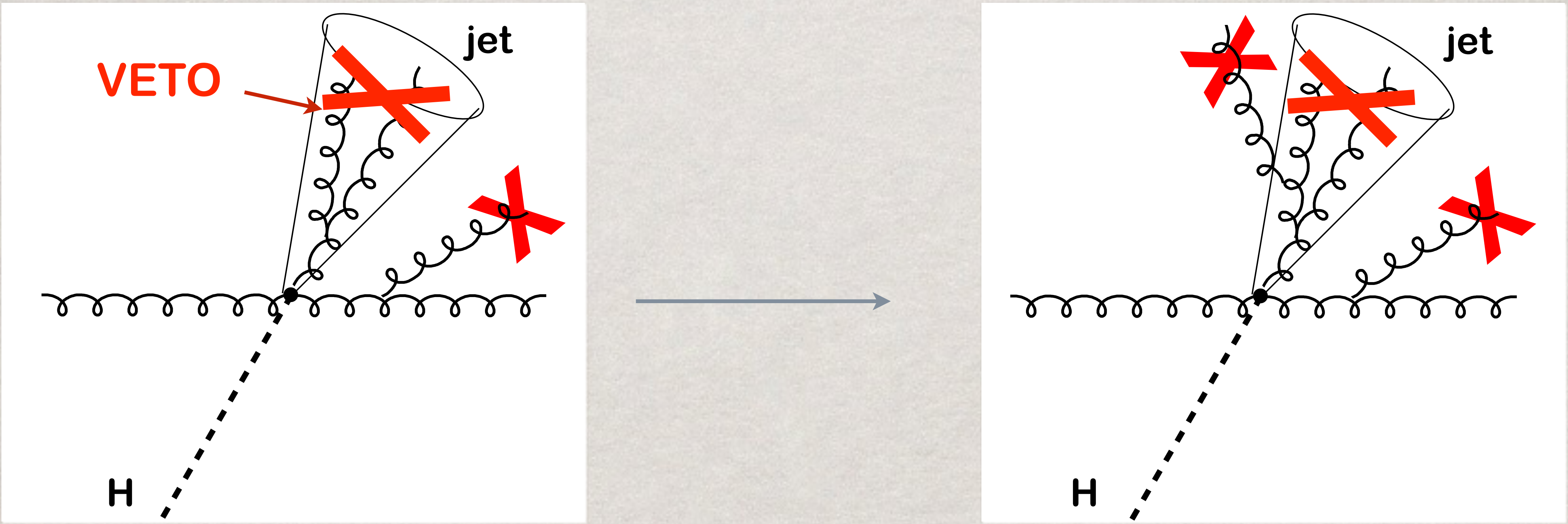
- With existing data it is already possible to have a measurement of $\sigma_{0-\mathrm{jet}}$



- Good agreement with data in the zero-jet bin
- The leading-jet p_t spectrum is underestimated at high p_t, but there VBF and NNLO corrections to Higgs+1jet are missing

Beyond zero jets

- The 0-jet cross section has the special property that is sensitive to soft and collinear gluons everywhere in the phase space



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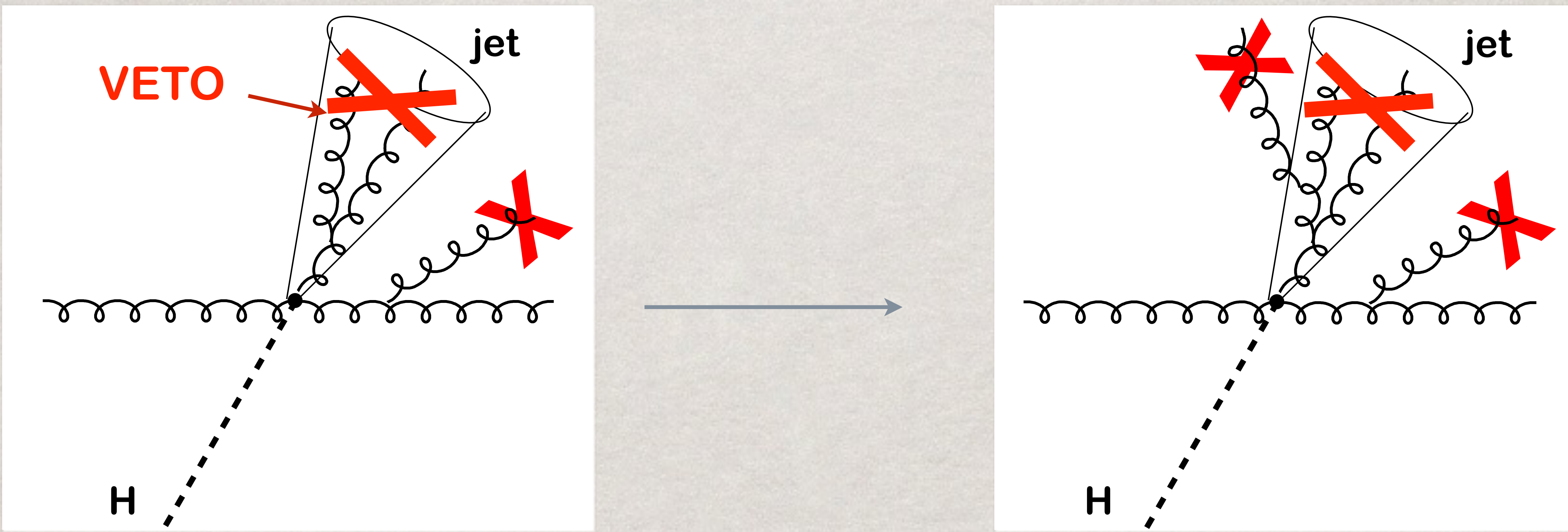
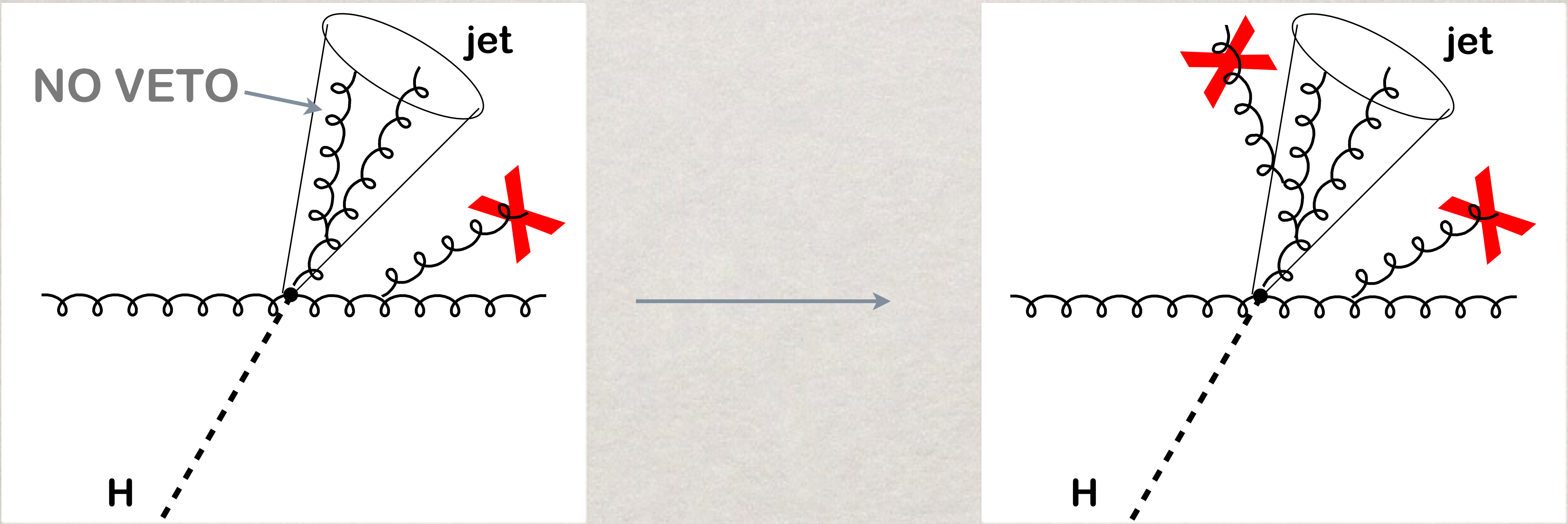


- Gluon splitting close to the jet boundary gives a small contribution, of relative order α_s, hence NNLL

[AB Salam Zanderighi]

Beyond zero jets

- The one-jet exclusive cross section is insensitive to emissions inside the tagged jet $\Rightarrow$ new logarithmic contributions for $p_{\mathrm{t,veto}} \ll p_{\mathrm{t,jet}}$



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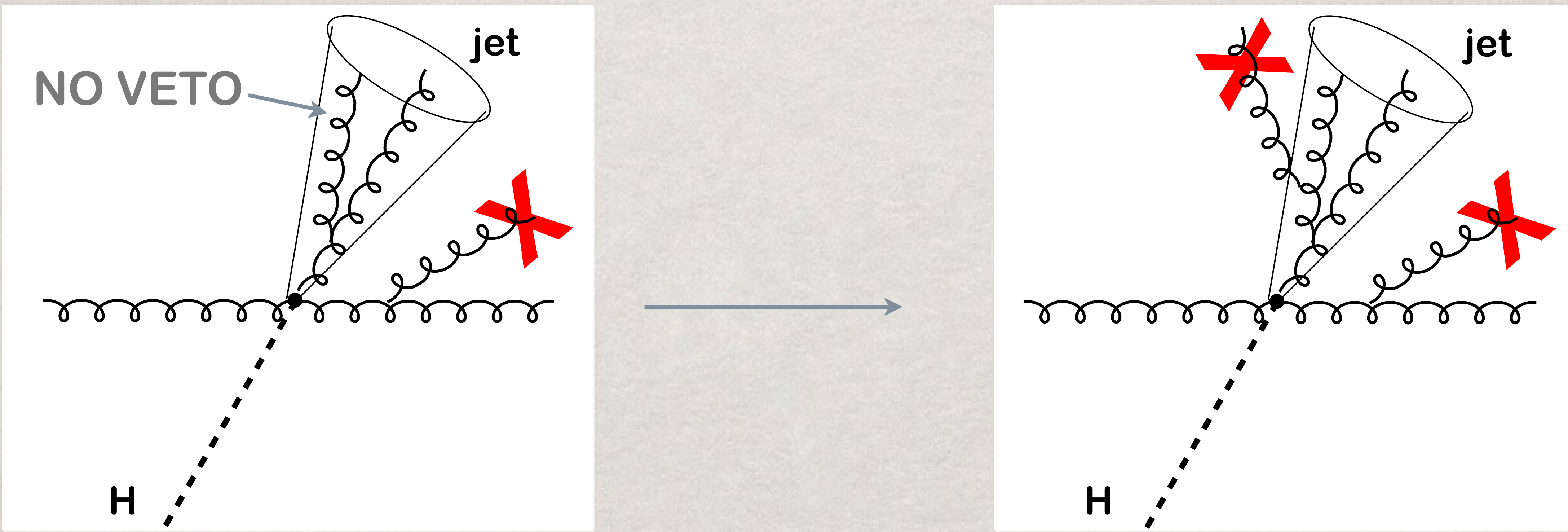


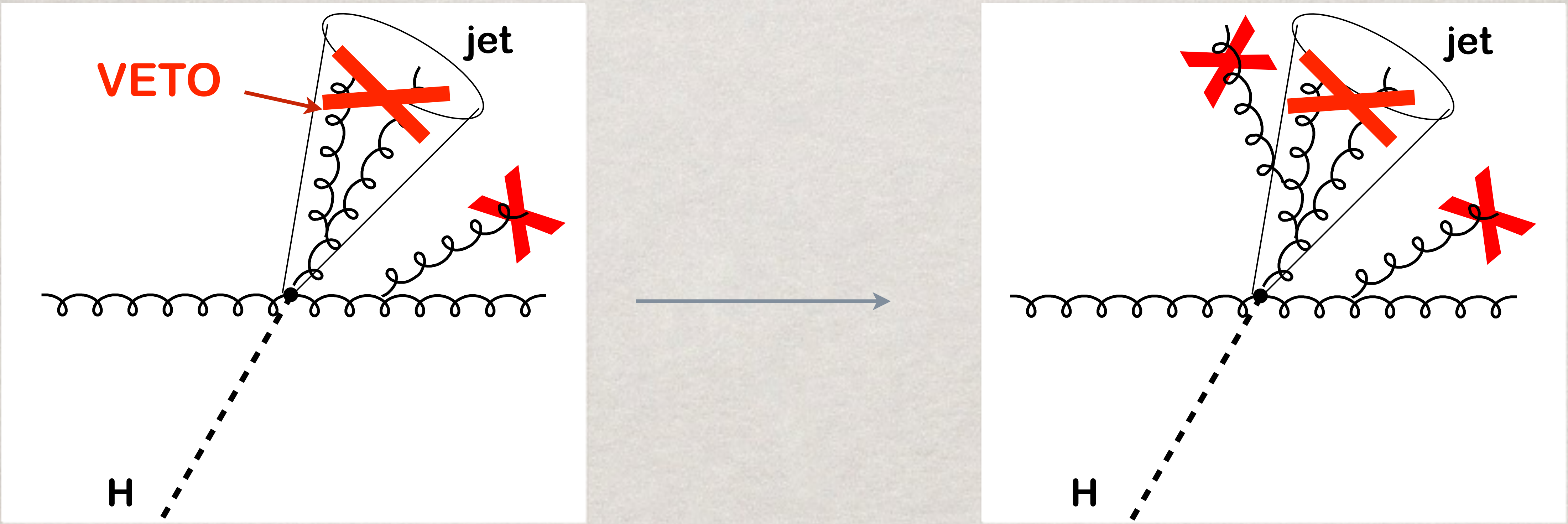
- Gluon splitting close to the jet boundary gives contributions of order $\alpha_s L$, called non-global and clustering logarithms, large for $p_{\mathrm{t,veto}} \ll p_{\mathrm{t,jet}}$

[Dasgupta Salam; Appleby Seymour; AB Dasgupta]

- Non-global logarithms known only in the large-N_c limit ⇒ we restrict ourselves to global observables

Beyond zero jets

- One can veto emissions inside the tagged jet as well, for instance imposing a cut on the resolution of sub-jets inside the leading jet



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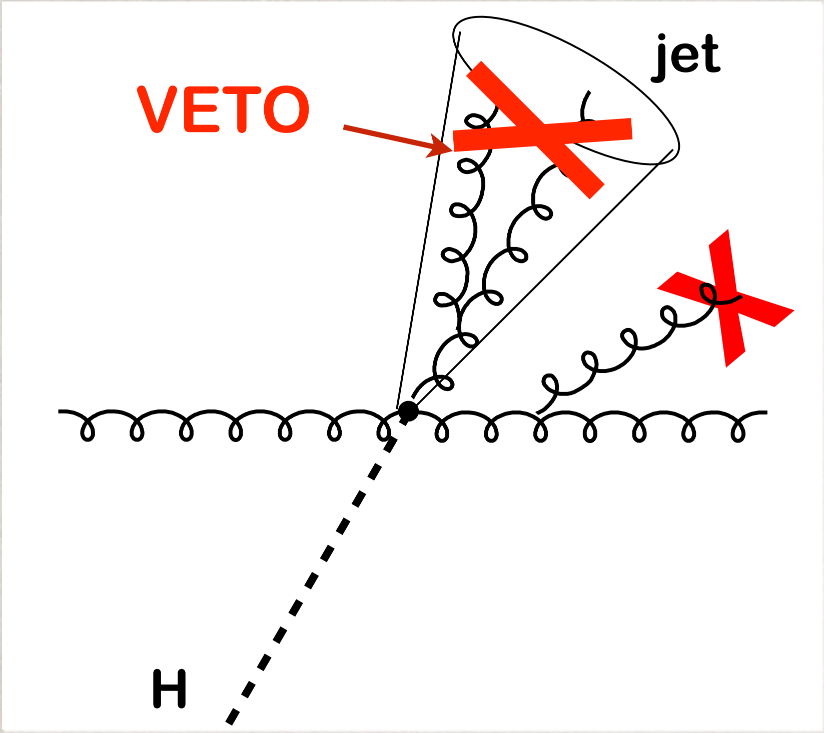
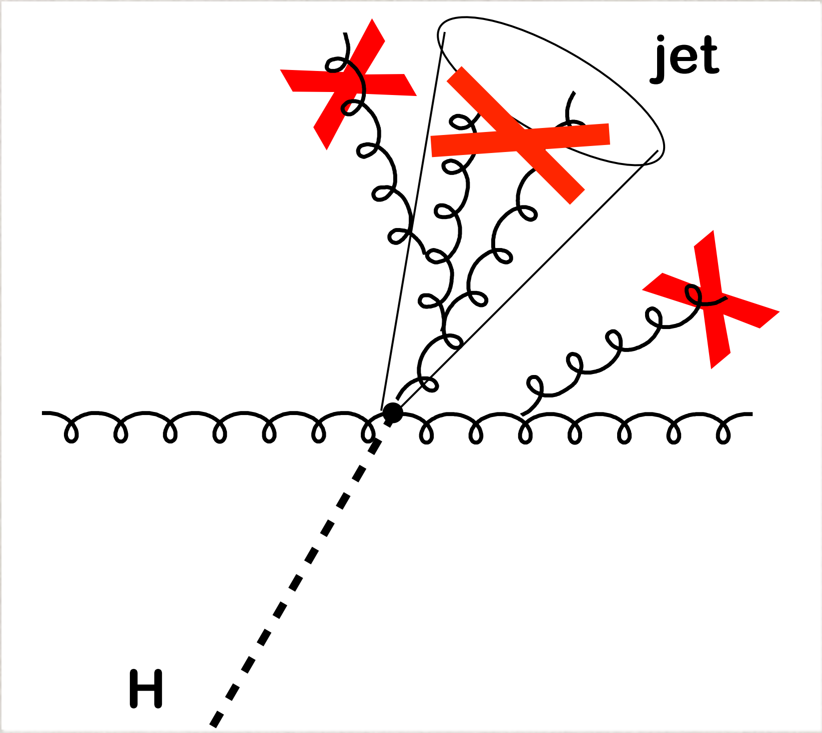




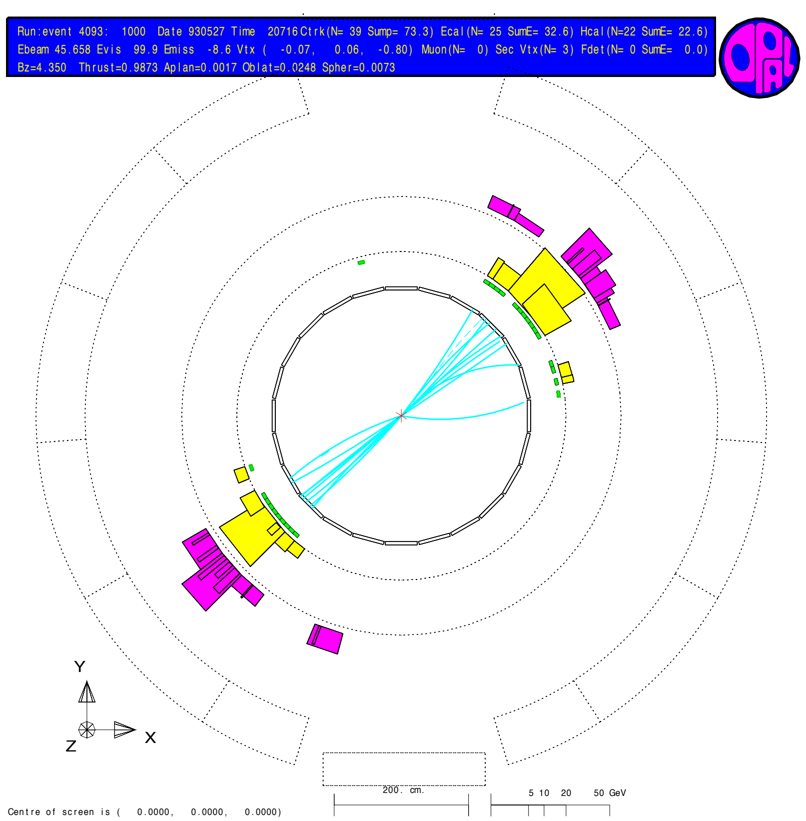
- Besides its theoretical interest, a NNLL resummation of a global one-jet exclusive cross section has important applications
  - measurements of the QCD coupling
  - matching of parton-shower event generators with exact NNLO

[Hamilton Nason Zanderighi; Hoeche et al]

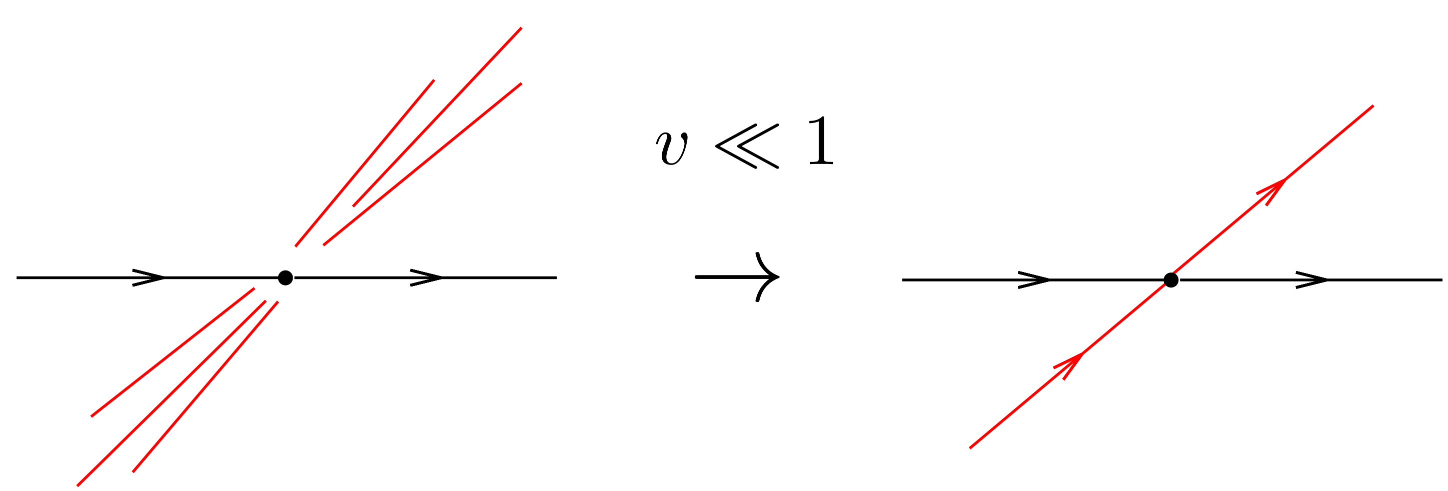
Final-state observables

- We consider a generic final-state observable, a function $V(p_1, \ldots, p_n)$ of all possible final-state momenta $p_1, \ldots, p_n$
- Examples: leading jet transverse momentum in Higgs production or thrust in $e^+e^- \to \text{hadrons}$

$$\frac{p_{\mathrm{t,max}}}{m_H} = \max_{j \in \mathrm{jets}} \frac{p_{t,j}}{m_H} \qquad\qquad T \equiv \max_{\vec{n}} \frac{\sum_i |\vec{p}_i \cdot \vec{n}|}{\sum_i |\vec{p}_i|}$$



$$\Sigma(v) = \mathrm{Prob}[V(p_1, \ldots, p_n) < v]$$



NLL resummation

- Several NLL exist for a number of observables (extensive literature ~1 observable per article)
- (~) 4 approaches to Sudakov resummation are available
  - Branching algorithm

    [Catani Marchesini Webber et al.]
  - Soft Collinear Effective Theory (SCET)

    [Bauer Fleming Pirol Stewart Beneke Becher Neubert et al.]
  - Collins-Soper-Sterman factorisation theorems

    [Collins Soper Sterman Kidonakis Laenen Magnea et al.]
  - CAESAR approach

    [Banfi Salam Zanderighi]

Resummation achieved through factorisation of cross section into leading kinematic subprocesses and subsequent RGE evolution

Resummation achieved by simulating (numerically) the QCD radiation to all orders in perturbation theory

- From CAESAR onwards,NLL resummation is a solved problem (at least for rIRC safe observables)

Resummation beyond NLL

- How many approaches to resummations survive beyond NLL?
  - Branching algorithm
    [Catani Marchesini Webber et al.]
  - Soft Collinear Effective Theory (SCET)
    [Bauer Fleming Pirol Stewart Beneke Becher Neubert et al.]
  - Collins-Soper-Sterman factorisation theorems
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  - CAESAR approach
    [Banfi Salam Zanderighi]
- Only SCET and CSS formalism are able to go beyond NLL accuracy, but with factorisation formulae that are observable dependent
- Is it possible to devise a synergy for a new, more powerful approach?

State of the art

- NNLL corrections are often sizeable and important for precision physics
- Few results exist in e^+e^- annihilation, and even fewer in hadron collisions
- The most important limitation is the analytical treatment of the observable in some (smartly defined) conjugate space $\Rightarrow$ resummation often leads to very tedious calculations (~ 14-16 years to go from NLL to NNLL)
- GOAL: devise a semi-numerical approach that:
  - does not rely on analytical properties of the observable
  - is NNLL accurate and extendable to higher orders
  - is fully general for a very broad category of observables (~ all that can be possibly resummed at NNLL accuracy)
  - is flexible and automated (only input: observable's routine)

Definition of the problem

- The problem consists in computing all-order logarithmic enhanced contributions to a generic final-state observable (e.g. event shape or jet resolution parameter)
- We need to control the behaviour of QCD matrix elements and the observable in the presence of an arbitrary number of soft and/or collinear emission
- We divide the problem (and its solution) in three parts
  - observable’s properties
  - amplitudes in the soft/collinear limit
  - relevant phase space regions

Observable's properties

- We consider an infrared and collinear (IRC) safe observable normalised as

$$v = V(\{\tilde{p}\}, k_1, \ldots, k_n) \leq 1$$

- We study the limit $v \to 0$

- In this limit, radiative corrections are just virtual corrections and soft/and or collinear emissions $\Rightarrow$ QCD amplitudes factorise

$$|\mathcal{M}(\{\tilde{p}\}, k_1, ..., k_n)|^2 \simeq |M_{\mathrm{Born}}(\{\tilde{p}\})|^2 |M(k_1, ..., k_n)|^2 + \ldots$$

- Standard approach: full factorisation is achievable only if the constrained phase space (including the observable's definition) factorises $\Rightarrow$ resummation can be achieved once a factorisation theorem is available (and a lot of patience to carry out the calculations)

Observable's properties

- Final-state observables (e.g. event shapes) do not trivially factorise in products of terms $\Rightarrow$ integral transforms needed
- Successful for simple very inclusive observables (e.g. thrust in e^+e^-)

$$1 - T \simeq \sum_{i=1}^{n} \frac{k_{ti}}{Q} e^{-\eta_i} \qquad \to \qquad \Theta(1 - T < \tau) = \int \frac{d\nu}{2\pi i \nu} e^{\nu\tau} \prod_{i=1}^{n} e^{-\nu \frac{k_{ti}}{Q} e^{-\eta_i}}$$

- Cumbersome for more involved observables, like the jet broadening in e^+e^- or the vector boson transverse momentum in hadron collisions
- Impossible for observables in which all emissions cooperate in a non-trivial way (e.g. two-jet rate or thrust minor in e^+e^-
- Factorisation is a unnecessary request for resummation, all is needed is some scaling properties of the observable

Observable requirements

- Parametrisation for a single soft/collinear emission

$$V(\{\tilde{p}\}, k_i) = \zeta_i v$$

- Standard requirement of IRC safety

$$\lim_{\zeta_{n+1}\to 0} V(\tilde{p}, k_1(\zeta_1), \ldots, k_n(\zeta_n), k_{n+1}(\zeta_{n+1})) = V(\tilde{p}, k_1(\zeta_1), \ldots, k_n(\zeta_n))$$

soft and/or collinear

- An analogous condition holds for secondary collinear splittings

Observable requirements

- Parametrisation for a single soft/collinear emission

$$V(\{\tilde{p}\}, k_i) = \zeta_i v$$

- Further requirements of recursive IRC safety

[Banfi Salam Zanderighi]

$$\lim_{v\to 0} \frac{V(\tilde{p}, k_1(\zeta_1), \ldots, k_n(\zeta_n))}{v} = \text{finite (non-zero)}$$

all emissions simultaneously soft and/or collinear

- This conditions means that the observable scales in the same fashion in the present of one or many emissions

- It is necessary for the exponentiation of double logarithms at all orders

Observable requirements

- Parametrisation for a single soft/collinear emission

$$V(\{\tilde{p}\}, k_i) = \zeta_i v$$

- Further requirements of recursive IRC safety

[Banfi Salam Zanderighi]

$$\lim_{\zeta_{n+1}} \lim_{v\to 0} \frac{V(\tilde{p}, k_1(\zeta_1), \ldots, k_n(\zeta_n), k_{n+1}(\zeta_{n+1}))}{v} = \lim_{v\to 0} \frac{V(\tilde{p}, k_1(\zeta_1), \ldots, k_n(\zeta_n))}{v}$$

all emissions simultaneously soft and/or collinear

one emission softer or more collinear than the others

- This conditions ensures that there exists $\epsilon \gg v$ such that we can neglect all emissions with $V(\{\tilde{p}\}, k_i) < \epsilon v$

- An analogous condition holds for secondary collinear splittings

Virtual and (unresolved) real

- Virtual corrections to the underlying Born process (e.g. $e^+e^- \to q\bar{q}$) exponentiate

  [Parisi; Magnea Sterman]

- We define a subset of (unresolved) emissions such that $V_{\mathrm{sc}}(\{\tilde{p}\}, k_i) < \epsilon v$

  - The soft-collinear approximation for V is enough to ensure the cancellation of infrared singularities with virtual corrections (a different prescription can be used, leaving the final result unchanged)

  - By rIRC safety, these emissions do not generate new logarithms, and can be neglected

$$V(\{\tilde{p}\}, k_1, \ldots, k_n, \ldots, k_m) \simeq V(\{\tilde{p}\}, k_1, \ldots, k_n) + \epsilon^p v$$

  - Unresolved emissions are largely unconstrained $\Rightarrow$ exponentiation

    [Frenkel Gatheral Taylor; Altarelli Parisi]

  - Using rIRC safety and renormalisation group it is possible to show that unresolved emissions and virtual corrections exponentiate at all orders

    [known for simple observables + work in progress…]

Virtual and (unresolved) real

- Unresolved real and virtual corrections give rise to an exponential factor, interpreted as the no emission probability up to the scale ϵv

$$P(\text{no emissions}) \sim e^{-R(\epsilon v)}$$

- Different logarithmic contributions are isolated by expanding around v

$$P(\text{no emissions}) \sim e^{-\underbrace{R(v)}_{\text{LL}} - \underbrace{R'(v)}_{\text{NLL}} \ln\frac{1}{\epsilon} - \frac{1}{2}\underbrace{R''(v)}_{\text{NNLL}} \ln^2\frac{1}{\epsilon} + \dots}$$

- Owing to the definition of unresolved emissions, the radiator $R(v)$ is the same for all observables that scale in the same way with respect to a single soft-collinear emission

- The remaining terms in the exponent cancel the ϵ-dependence of resolved real emissions

Resolved real emissions

- General expression of the cumulative distribution of $V(\{\tilde{p}\}, k_1, \ldots, k_n)$

$$\Sigma(v) = \mathrm{Prob}[V(\{\tilde{p}\}, k_1, \ldots, k_n) < v] \sim e^{-R(v)}\mathcal{F}(v)$$

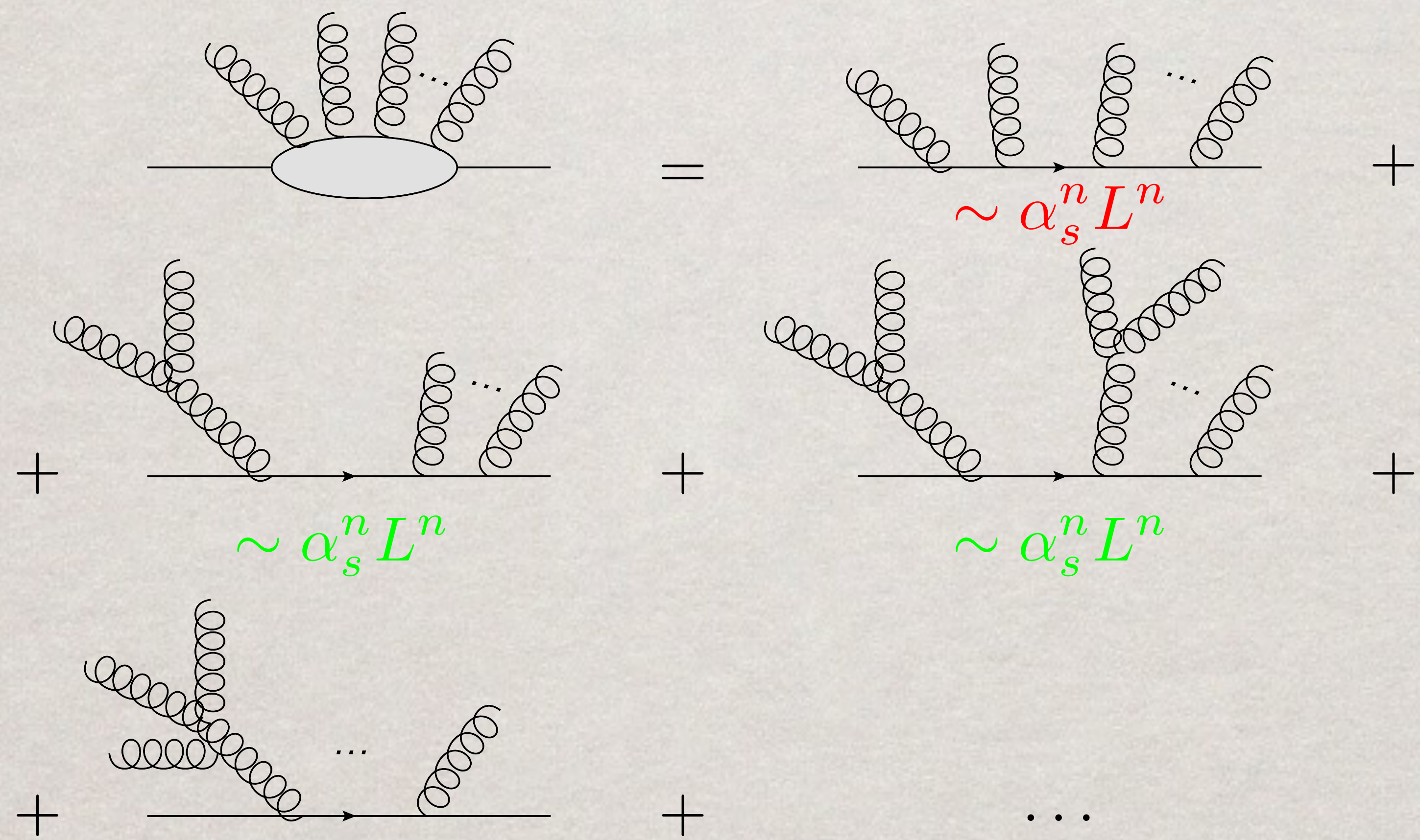
- rIRC safety ensures that
  - all double logarithms are contained in the radiator $R(v)$
  - resolved real emissions are constrained in the region $\epsilon v \lesssim V(\{\tilde{p}\}, k_i) \lesssim v$

$$\Downarrow$$

resolved real emissions lose one logarithm $\Rightarrow \mathcal{F}(v)$ starts at NLL

Soft matrix element

- Cluster decomposition of the matrix element for n soft emissions into terms with increasing number of colour correlations



- Which diagrams do we need to achieve NNLL accuracy (i.e. neglect terms of order $\alpha_s^n L^{n-2}$?)

Soft (resolved) matrix element

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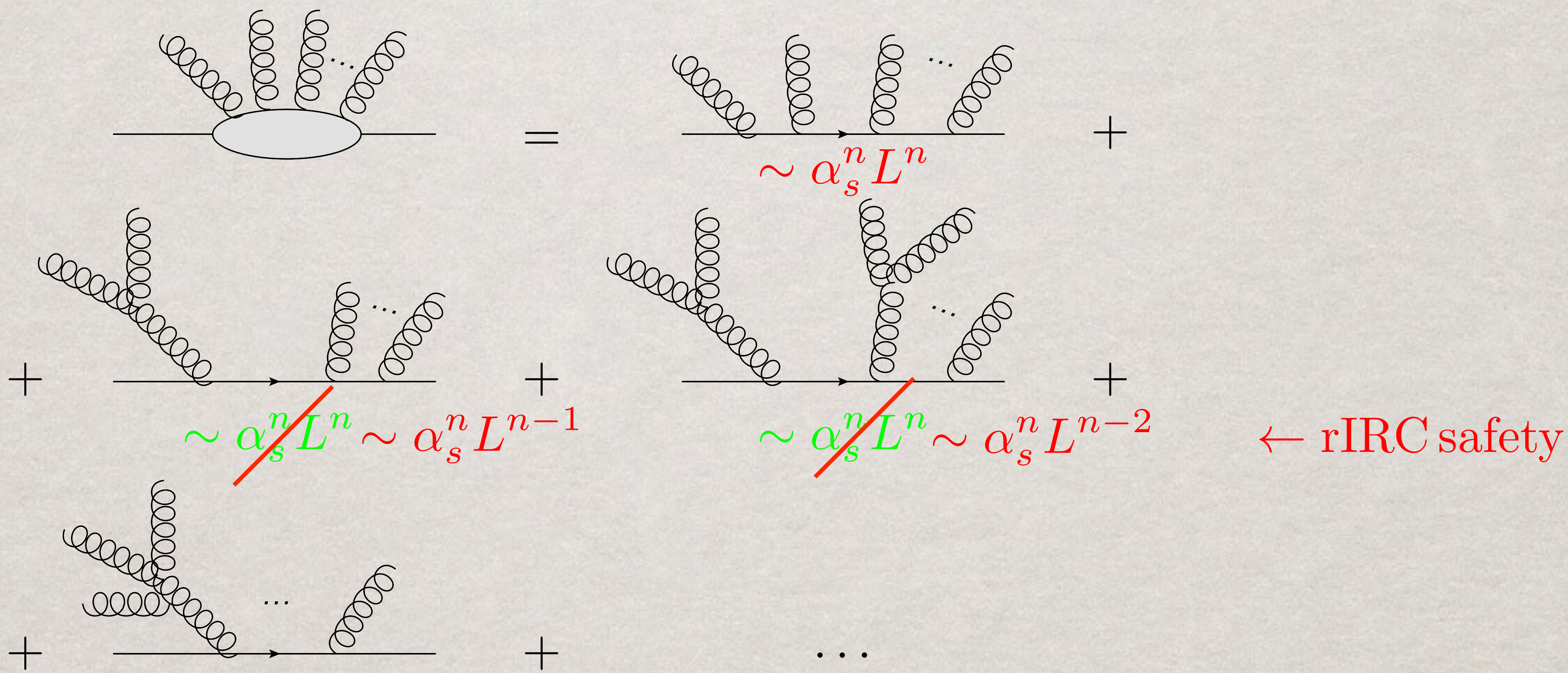
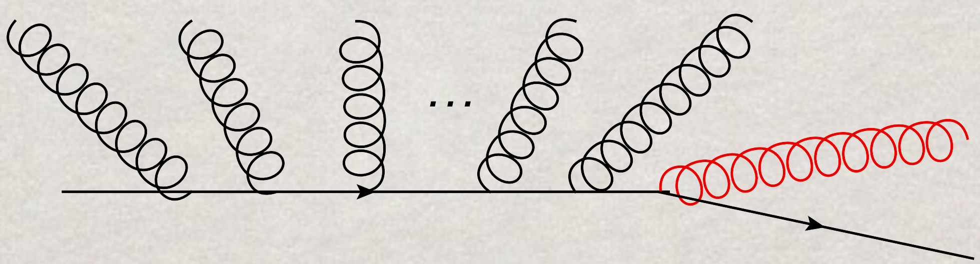


- Which diagrams do we need to achieve NNLL accuracy (i.e. neglect terms of order $\alpha_s^n L^{n-2}$?)

Collinear (resolved) matrix element

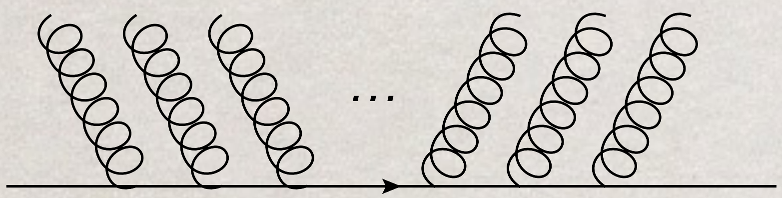
- From the previous analysis, at NNLL, we need to keep only configurations with an arbitrary number of independent soft-collinear emissions, and a single gluon branching
- Similarly, repeating the same analysis in the collinear limit, at NNLL only a single hard emission can be emitted collinear to any Born leg



- Further gluon branchings or more collinear emissions can be included for extensions to higher logarithmic orders

Phase space at NLL

- At NLL the multiple emission function $\mathcal{F}(v)$ is given by an ensemble of soft and collinear gluons, widely separated in rapidity (angle)



Measure defined by the soft-collinear ensemble

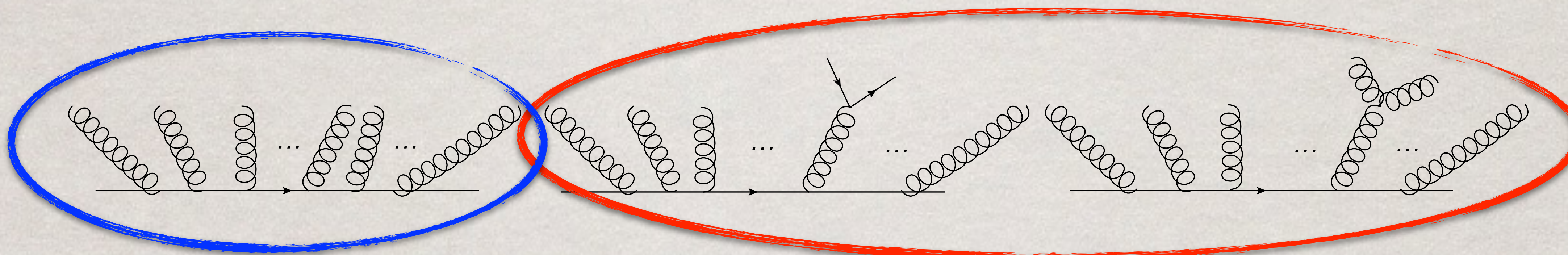
$$= \int \mathcal{Z}[\{R'_{\ell_i}, k_i\}]\, \Theta\left(1 - \lim_{v\to 0} \frac{V_{\rm sc}(\{\tilde{p}\},\{k_i\})}{v}\right)$$

$$\mathcal{F}_{\rm NLL}(v) = \langle \Theta(1 - \lim_{v\to 0} \frac{V_{\rm sc}(\{\tilde{p}\},\{k_i\})}{v}) \rangle$$

- The exact rapidity bound for each emission can be neglected at this order (but does contribute at NNLL)

Phase space at NNLL

- At most two soft-collinear emissions can get close in rapidity



Clustering correction
(jet algorithms only)

Correlated corrections

$$\delta F_{\mathrm{correl}}(\lambda) = \int_0^\infty \frac{d\zeta_a}{\zeta_a} \int_0^{2\pi} \frac{d\phi_a}{2\pi} \sum_{\ell_a=1,2} \left(\frac{2C_{\ell_a}\lambda}{\beta_0} \frac{R''_{\ell_a}}{\alpha_s} \right) \int_0^\infty \frac{d\kappa}{\kappa} \int_{-\infty}^{\infty} \int_0^{2\pi} \frac{1}{2!} C_{ab}(\kappa,\eta,\phi) \times$$

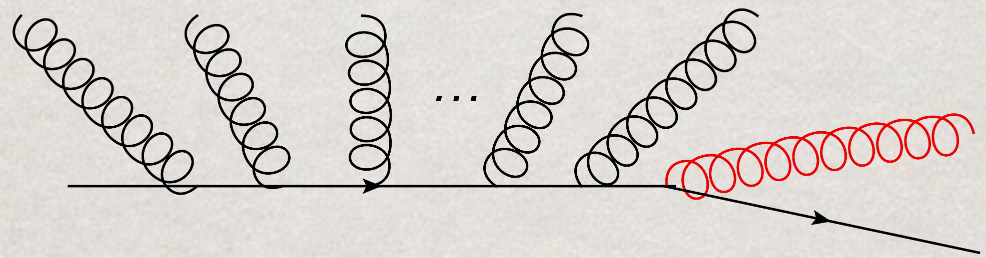
$$\times \int d\mathcal{Z}[\{R'_{\ell_i}, k_i\}] \left[\Theta(v - V_{\mathrm{sc}}(\{\tilde{p}\}, k_a, k_b, \{k_i\})) - \Theta(v - V_{\mathrm{sc}}(\{\tilde{p}\}, k_a + k_b, \{k_i\})) \right]$$

$$C_{ab}(\kappa,\eta,\phi) = \frac{\tilde{M}^2(k_a,k_b)}{M^2_{\mathrm{sc}}(k_a) M^2_{\mathrm{sc}}(k_b)}$$

All corrections in terms of four-dimensional integrals

Phase space at NNLL

- At most one collinear emission that carries a significant fraction of the energy of the emitter, which recoils against it



- We have split this contribution into a hard-collinear and recoil correction

$$\delta\mathcal{F}_{\mathrm{hc}}(\lambda) = \sum_{\ell=1,2} \frac{\alpha_s(v^{1/(a+b_\ell)}Q)}{\alpha_s(Q)(a+b_\ell)} \int_0^\infty \frac{d\zeta}{\zeta} \int_0^{2\pi} \frac{d\phi}{2\pi} \int d\mathcal{Z}[\{R'_{\ell_i}, k_i\}] \times$$
$$\times \int_0^1 \frac{dz}{z}(zp_\ell(z) - 2C_\ell) \left[\Theta\left(1 - \lim_{v\to 0} \frac{V_{\mathrm{sc}}(\{\tilde{p}\}, k, \{k_i\})}{v}\right) - \Theta\left(1 - \lim_{v\to 0} \frac{V_{\mathrm{sc}}(\{\tilde{p}\}, \{k_i\})}{v}\right) \Theta(1-\zeta)\right]$$

$$\delta\mathcal{F}_{\mathrm{rec}}(\lambda) = \sum_{\ell=1,2} \frac{\alpha_s(v^{1/(a+b_\ell)}Q)}{\alpha_s(Q)(a+b_\ell)} \int_0^\infty \frac{d\zeta}{\zeta} \int_0^{2\pi} \frac{d\phi}{2\pi} \int d\mathcal{Z}[\{R'_{\ell_i}, k_i\}] \times$$
$$\times \int_0^1 dz\, p_\ell(z) \left[\Theta\left(1 - \lim_{v\to 0} \frac{V_{\mathrm{hc}}(\{\tilde{p}\}, k', \{k_i\})}{v}\right) - \Theta\left(1 - \lim_{v\to 0} \frac{V_{\mathrm{sc}}(\{\tilde{p}\}, k, \{k_i\})}{v}\right)\right]$$

Phase space at NNLL

- At most one soft-collinear emission has exact phase space

$$\delta\mathcal{F}_{\rm sc}(\lambda) = \frac{\pi}{\alpha_s}\int_0^\infty \frac{d\zeta}{\zeta}\int_0^{2\pi}\frac{d\phi}{2\pi}\sum_{\ell=1,2}\left(\delta R'_\ell + R''_\ell \ln\frac{d_\ell g_\ell(\phi)}{\zeta}\right)\int d\mathcal{Z}[\{R'_{\ell_i}, k_i\}]\times$$
$$\times\int_0^1 dz\, p_\ell(z)\left[\Theta\left(1-\lim_{v\to 0}\frac{V_{\rm sc}(\{\tilde{p}\},k,\{k_i\})}{v}\right)-\Theta\left(1-\lim_{v\to 0}\frac{V_{\rm sc}(\{\tilde{p}\},\{k_i\})}{v}\right)\Theta(1-\zeta)\right]$$

- At most one soft emission can have small rapidity (large angle)

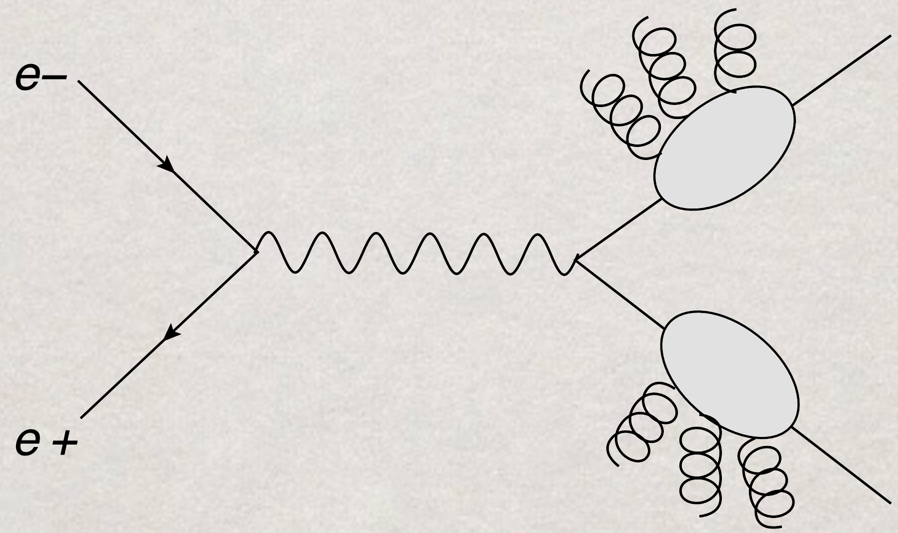
$$\delta\mathcal{F}_{\rm wa}(\lambda) = \frac{2C_F}{a}\frac{\alpha_s(v^{1/a}Q)}{\alpha_s(Q)}\int_0^\infty\frac{d\zeta}{\zeta}\int_{-\infty}^{\infty}d\eta\int_0^{2\pi}\frac{d\phi}{2\pi}\int d\mathcal{Z}[\{R'_{\ell_i},k_i\}]\times$$
$$\times\left[\Theta\left(1-\lim_{v\to 0}\frac{V_{\rm wa}(\{\tilde{p}\},k,\{k_i\})}{v}\right)-\Theta\left(1-\lim_{v\to 0}\frac{V_{\rm sc}(\{\tilde{p}\},k,\{k_i\})}{v}\right)\right]$$

- With more than two legs there are additional contributions due to colour correlations between hard legs

[Botts Sterman; Kidonakis Oderda Sterman]

Application to 2-leg process

- Event shapes in $e^+e^- \to 2\ \mathrm{jets}$



- Relevant for precise determination of the strong coupling, through deviations from the 2-jet limit
- Toy model for final-state radiation (conceptually complete)
- Clean experimental environment to study non-perturbative corrections (hadronisation)

Application to 2-leg process

- Reproduced old results and presented new ones
  - thrust and heavy-jet mass (known)

$$T \equiv \max_{\vec{n}} \frac{\sum_i |\vec{p}_i \cdot \vec{n}|}{\sum_i |\vec{p}_i|} \qquad \rho_H \equiv \max_{i=1,2} \frac{M_i^2}{Q^2} \qquad M_i^2 = \left(\sum_{j \in \mathcal{H}_i} p_j \right)^2$$

  - total and wide-jet broadening(known)

$$B_L \equiv \sum_{i \in \mathcal{H}_1} \frac{|\vec{p}_i \times \vec{n}_T|}{2Q}, \quad B_R \equiv \sum_{i \in \mathcal{H}_2} \frac{|\vec{p}_i \times \vec{n}_T|}{2Q}$$

$$B_W \equiv \max\{B_L, B_R\}$$

$$B_T \equiv B_L + B_R$$

  - C-parameter (new)

$$C \equiv 3 \left(1 - \frac{1}{2} \sum_{i,j} \frac{(p_i \cdot p_j)^2}{(p_i \cdot Q)(p_j \cdot Q)} \right)$$

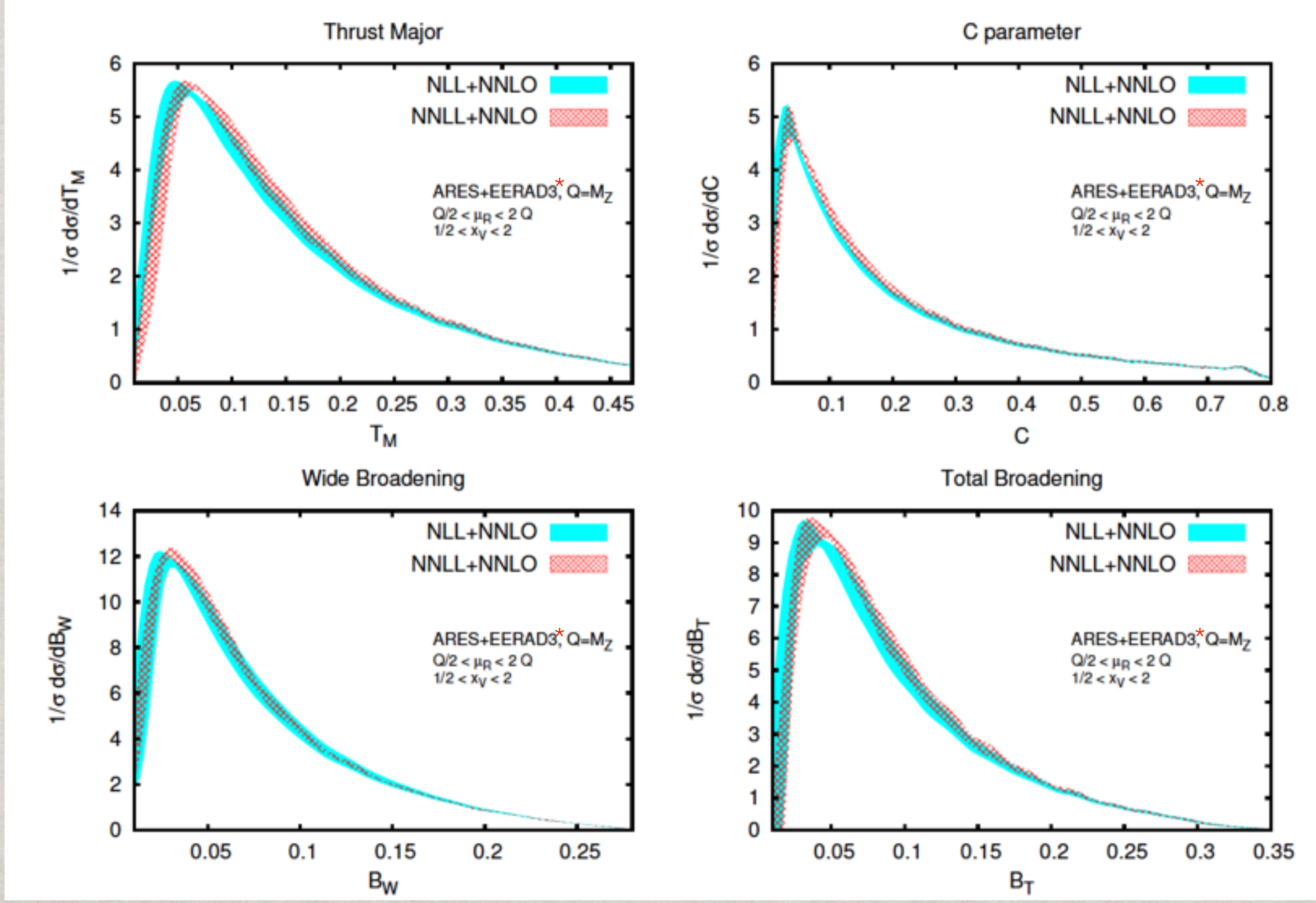
  - thrust major and oblateness (new)

$$T_M \equiv \max_{\vec{n} \cdot n_T} \frac{\sum_i |\vec{p}_i \cdot \vec{n}|}{\sum_i |\vec{p}_i|} \qquad T_m \equiv \frac{\sum_i |\vec{p}_{x,i}|}{\sum_i |\vec{p}_i|} \qquad O \equiv T_M - T_m$$

Application to 2-leg process

- Event-shapes distributions at NNLL matched to exact NNLO

[AB McAslan Monni Zanderighi]



[* Gehrmann-De Ridder Gehrmann Glover Heinrich]

Application to 2-leg process

- Observables with different logarithmic structures can be resummed with the same method (fully general)

correction type	$p_{\mathrm{t,veto}}$	$1-T$	B_T	B_W	C	ρ_H	T_M	O
$\mathcal{F}_{\mathrm{NLL}}$	✓	✓	✓	✓	✓	✓	✓	✓
$\delta\mathcal{F}_{\mathrm{rap}}$	x	✓	✓	✓	✓	✓	✓	✓
$\delta\mathcal{F}_{\mathrm{wa}}$	x	x	x	x	✓	x	x	x
$\delta\mathcal{F}_{\mathrm{hc}}$	x	✓	✓	✓	✓	✓	✓	✓
$\delta\mathcal{F}_{\mathrm{rec}}$	x	✓	✓	✓	✓	✓	✓	✓
$\delta\mathcal{F}_{\mathrm{clust}}$	✓	x	x	x	x	x	x	x
$\delta\mathcal{F}_{\mathrm{correl}}$	✓	x	✓	✓	x	x	✓	✓

Conclusions

- Novel general method for the resummation of any rIRC safe (global) observable in the two-scale regime
  - weak applicability conditions
  - cancellation of poles between real and virtual corrections performed analytically in dimensional regularisation
  - contributions of resolved real emissions formulated in terms of four-dimensional integrals (suitable for Monte Carlo implementation)
- Modulo technical work the NNLL resummation for any rIRC safe observable in the two-scale regime is a theoretically solved problem
- Application to jet cross sections in e^+e^- (Durham and Cambridge 2-jet rate) and in hadron collisions (H+1jet) is under way

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Thank you for your attention!