Pythia-PanScales Joint Session

PYTHIA contributions / discussions

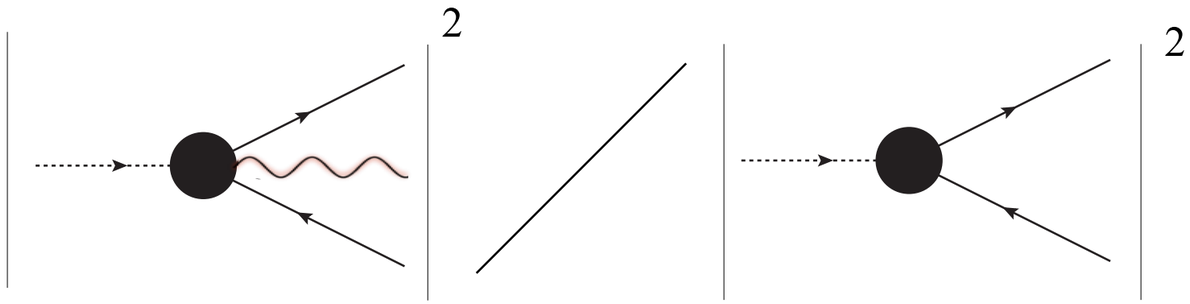
1. The Vincia QED Module
2. Interleaved MPI?
3. Pythia's Contrib

1. Types of (QED) Showers

Simple case:

neutral scalar → 2 charged fermions

= **A single QED dipole**



$$\boxed{\text{LO QED}} \quad \propto \quad \frac{2s_{e^-e^+}}{s_{e^-\gamma}s_{\gamma e^+}} + \frac{1}{M_0^2}\left(\frac{s_{\gamma e^+}}{s_{e^-\gamma}} + \frac{s_{e^-\gamma}}{s_{\gamma e^+}} + 2\right)$$

eikonal term — collinear terms

PYTHIA

DGLAP

e^--collinear limit

e^+-collinear limit

$$\frac{P_{e^-\to e^-\gamma}(z_1)}{s_{1\gamma}} + \frac{P_{e^+\to e^+\gamma}(z_2)}{s_{2\gamma}}$$

VINCIA

Antenna

All Singular Terms

$$\frac{2s_{e^-e^+}}{s_{e^-\gamma}s_{\gamma e^+}} + \frac{1}{M_0^2}\left(\frac{s_{\gamma e^+}}{s_{e^-\gamma}} + \frac{s_{e^-\gamma}}{s_{\gamma e^+}}\right)$$

Soft limit

HERWIG, SHERPA, PHOTOS

YFS

$$\frac{2s_{e^-e^+}}{s_{e^-\gamma}s_{\gamma e^+}}$$

Note: this is (intentionally) oversimplified. Many subtleties (recoil strategies, gluon parents, initial-state partons, and mass terms) not shown.

Beyond 2-body Systems: QED Multipoles

PYTHIA QED

Determines a "best" set of dipoles. No genuine multipole effects.

I.e., interference beyond dipole level only treated via "principle of maximal screening"

Works as a parton shower evolution (+ MECs) ➤ interleaved with QCD, MPI, …

YFS QED [Yennie-Frautschi-Suura, 1961 ➤ several modern implementations]

Allows to take full (multipole) soft interference effects into account

"Scalar QED"; no spin dependence.

I.e., starts from purely soft approximation; collinear terms not automatic

Is not a shower; works as pure afterburner, adding a number of photons to a final state with predetermined kinematics; no interleaving

VINCIA QED [Kleiss-Verheyen, 2017 ➤ Brooks-Verheyen-PS, 2020]

Allows to take full (multipole) soft interference effects into account

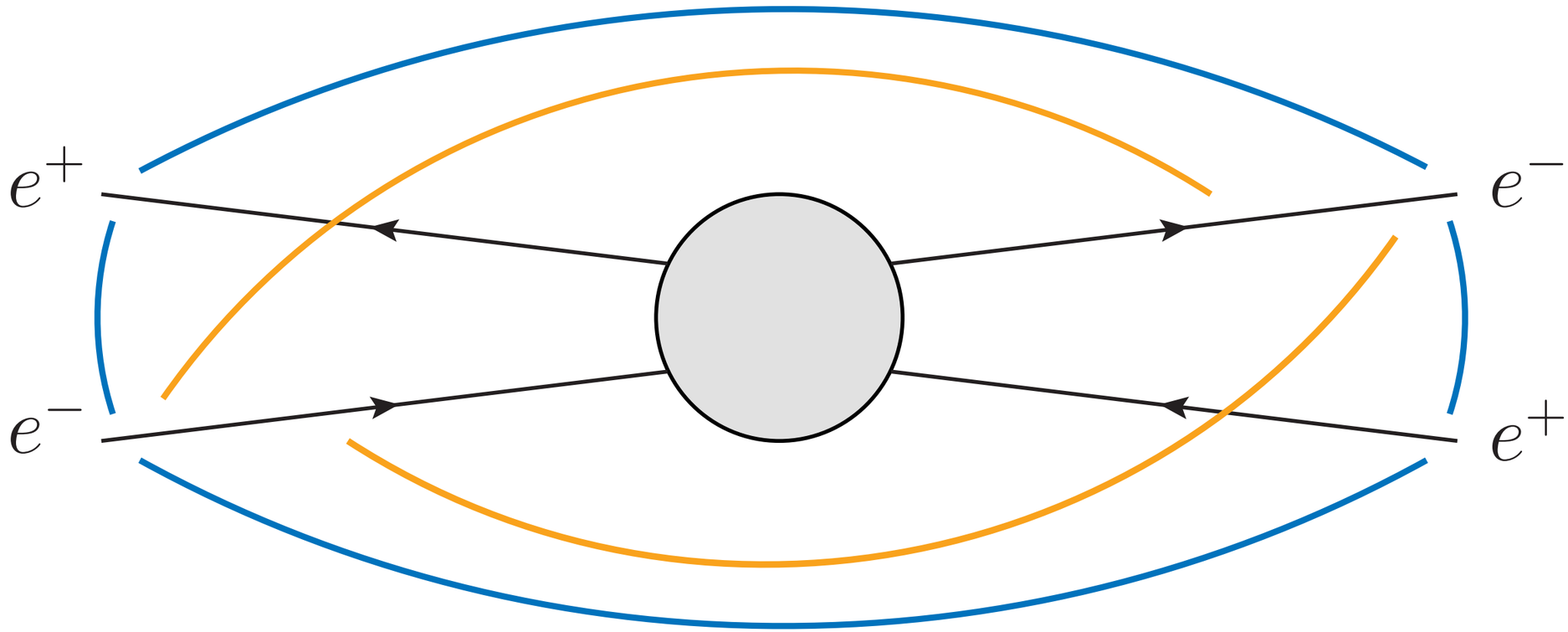
Not limited to scalar QED; includes spin dependence

I.e., starts from antenna approximation; including collinear terms

Works as a parton shower evolution; can be interleaved (+ MECs).

QED Multipole Radiation Patterns

Example: Quadrupole final state (4-fermion: $e^+e^+e^-e^-$)



Soft Photon Emission: $|M_{n+1}(\{p\},p_j)|^2 = -8\pi\alpha \sum_{x,y}^{n} \sigma_x Q_x \sigma_y Q_y \frac{s_{xy}}{s_{xj}s_{yj}} |M_n(\{p\})|^2$

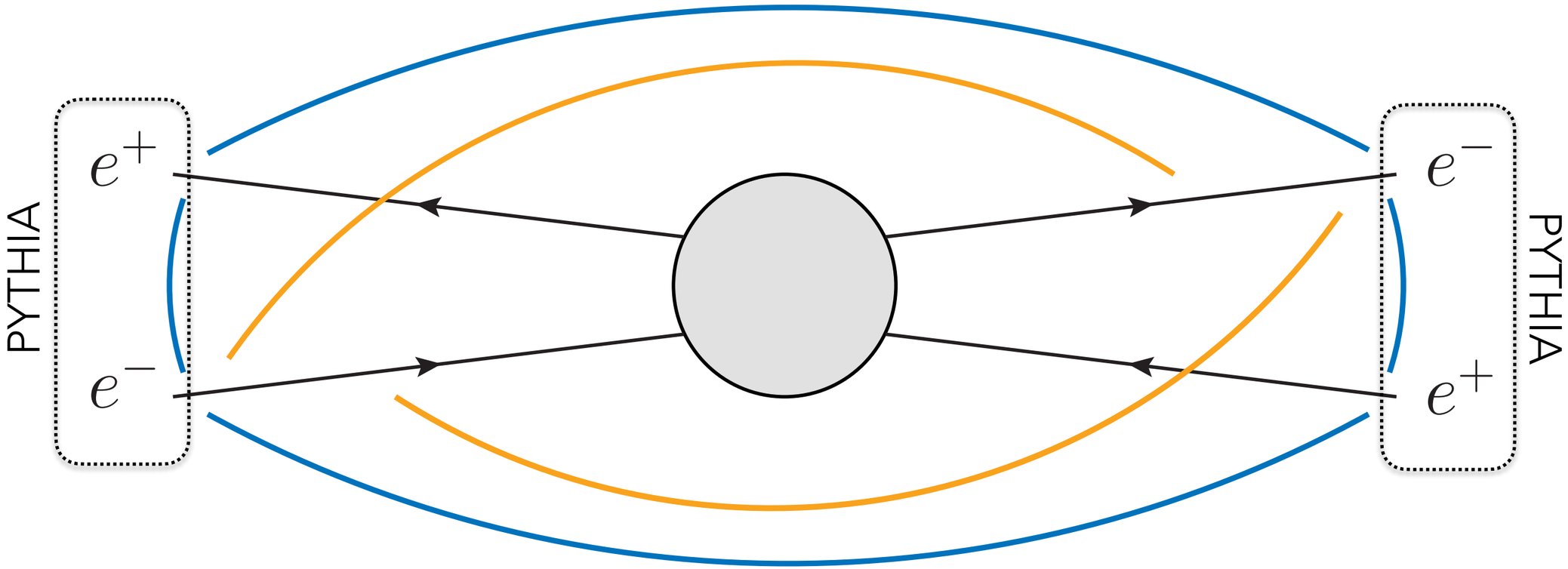
[Dittmaier, 2000]

Opposite-charge pairs ➤ positive terms

Same-charge pairs ➤ negative terms

What's the problem?

Example: Quadrupole final state (4-fermion: $e^+e^+e^-e^-$)



Why was this not done as a shower before?

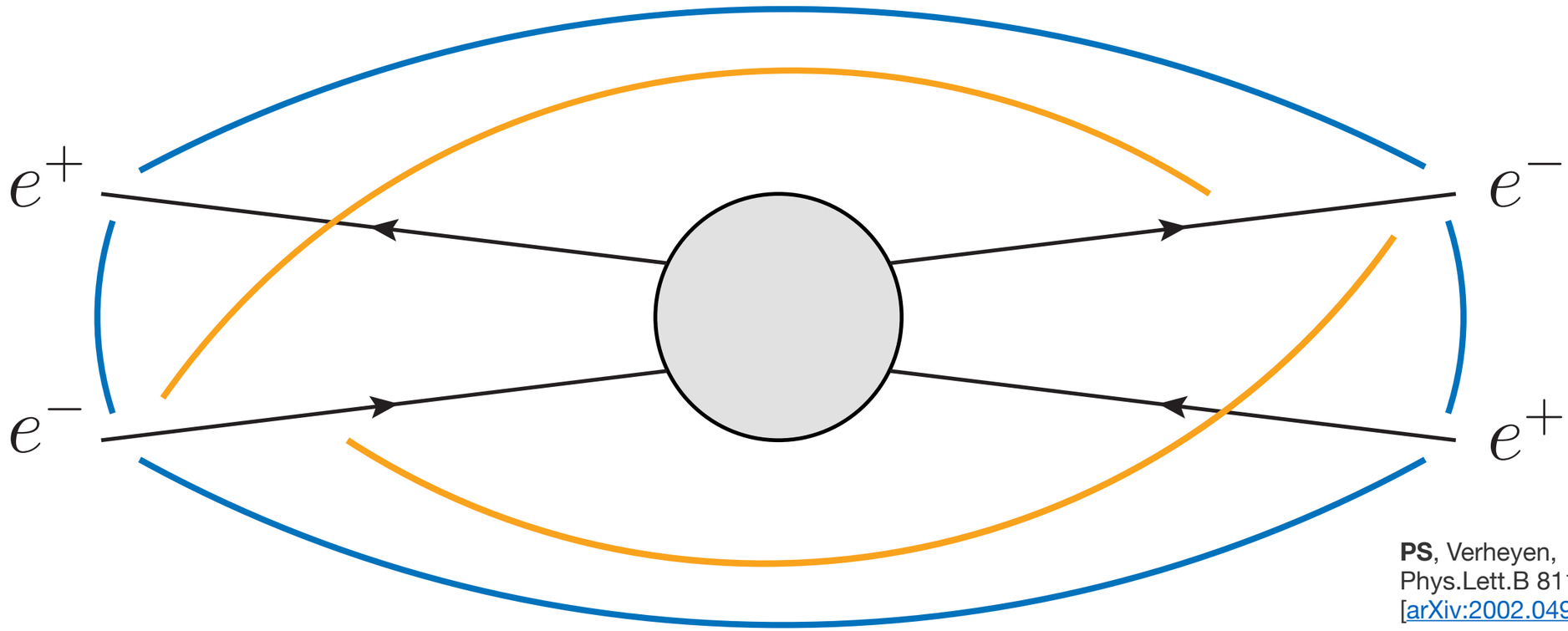
The orange terms are negative ➤ negative weights (+ big cancellations)

YFS is able to get around that by not being formulated as a shower.

Utilises that the sum is always non-negative.

What does VINCIA do differently?

Example: Quadrupole final state (4-fermion: $e^+e^+e^-e^-$)



PS, Verheyen,
Phys.Lett.B 811 (2020) 135878
[arXiv:2002.04939]

Sectorize phase space: for each possible photon emission kinematics p_γ, find the 2 charged particles with respect to which that photon is softest ➤ "Dipole Sector"

Use dipole *kinematics* for that sector, but sum **all** the positive and negative *antenna* terms (w spin dependence) to find the **coherent emission *probability***.

Further Details

Antenna phase-space factorisation is exact, also for massive particles

+ Universal mass corrections are included in the eikonals

➤ Should have faithful representation of "dead cone" effect (radiation from massive particles strongly damped for $\theta_\gamma \lesssim E/m$) [Gehrmann-de Ridder, Ritzmann, PS, 2012]

Also automatically includes $\gamma \to e^+e^-, \mu^+\mu^-, \ldots$ splittings

➤ **First steps towards application of VINCIA QED to Hadron Decays**

PhD project of Giacomo Morgante (in collaboration with Warwick)
[Giele, Kosower, PS, 2011, + more recent]

Generic spin structures, generic Matrix-Element Corrections

So far ignoring: Form Factors, VMD contributions, BRs, …

+ Can be interleaved with event evolution, e.g., with **Resonance Decays** Brooks, **PS**, Verheyen, SciPost Phys. 12 (2022) 3, 101 [arXiv:2108.10786]

Technical Structure & Comments

Rob Verheyen wrote VinciaQED to be largely modular, standalone.

Only relies on a few common Vincia utilities like kinematics maps

Inherits from a base class he called **VinciaModule**.

(Could be relabelled PerturbativeModule or something like that)

In Vincia, we ask our QCD evolution for a trial scale, and also the QED module for a trial scale, then pass the highest back to Pythia.

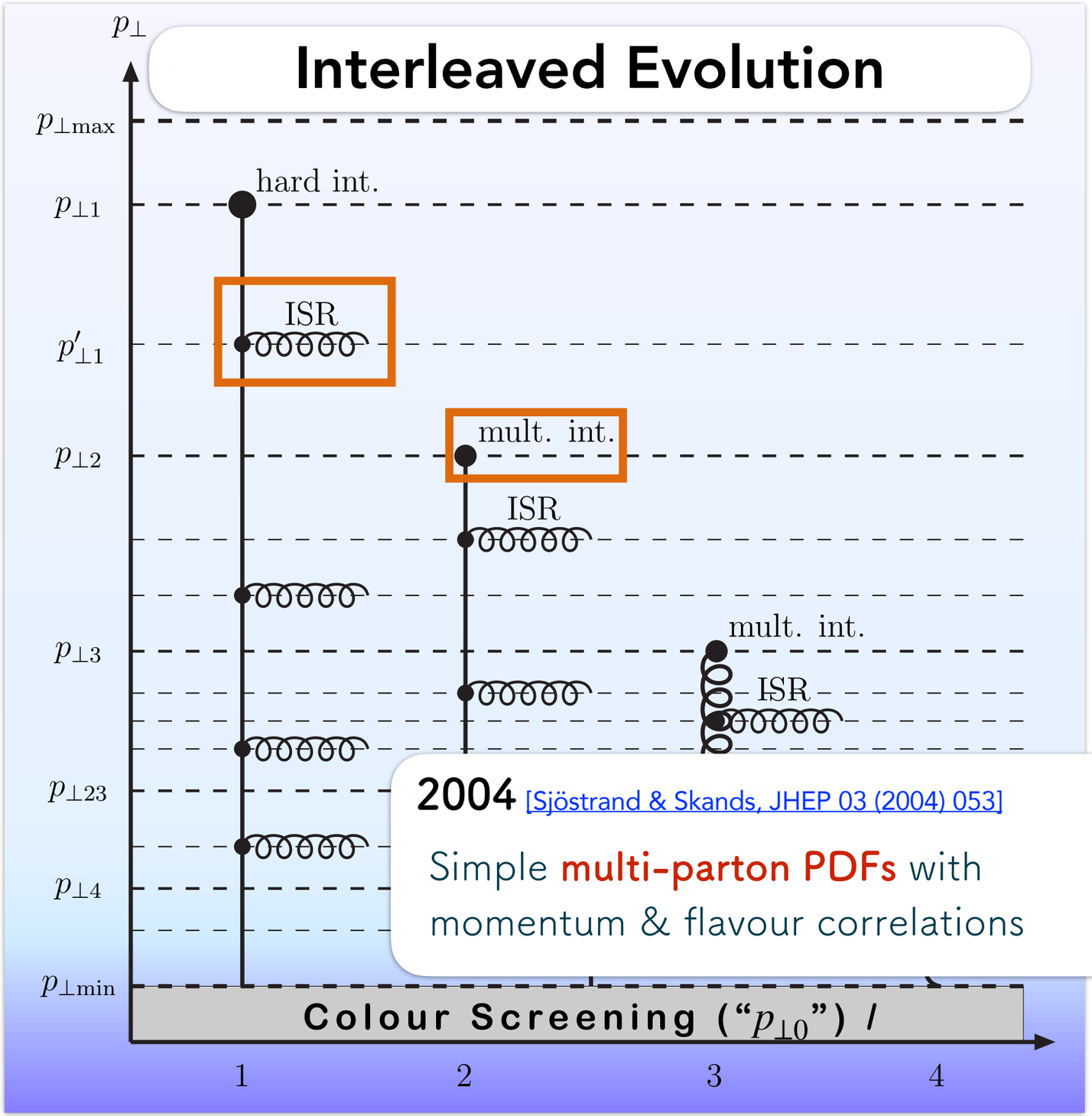
The QED module simply looks at the current event and constructs all needed branchers etc on the fly.

$\Longrightarrow$ Automatically picks up new charges from $g \to q\bar{q}$ branchings and/or MPI, without any need for dedicated update methods.

Note: **interfacing** and **porting** are very different.

I would vastly prefer **interfacing**, and would be happy to discuss & collaborate on any modifications of the module that would be needed to make that happen.

Discussion of interleaving with MPI



Already in Pythia (& Vincia), MPI and shower pT definitions are not exactly the same

In PanScales, main question would presumably be about rapidity dependence?

1. Poor man's solution: just treat as global "clock"? Always pass a large scale back to Pythia -> you go first

2. Rapidity-dependent evolution eqs could open possibility for new treatments of saturation?

And would you like Pythia to *handle* the MPI showers?

Reminder and Discussion of Pythia Contrib

Over to Phil …

+ Melissa raised the issue that they have trouble passing the total cross section, due to weights issues. Sounds like this ties into our weights discussion.