MONTE-CARLO EVENT GENERATOR LPPG

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Actual Problems of Microworld Physics
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GOALS

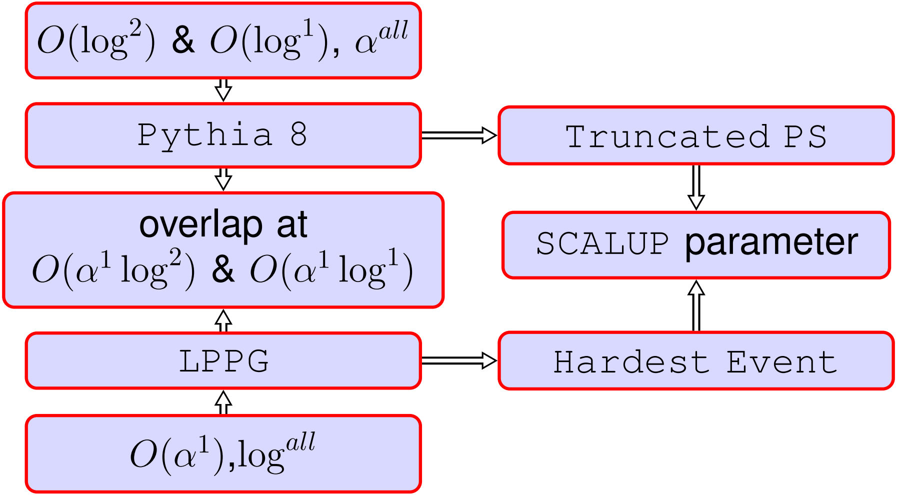
LPPG GENERATOR IS DESIGNED TO COMBINE THE MAIN ADVANTAGES OF THE EXISTING CODES

- Include loop corrections to arbitrary order;
- Positive event weight;
- Correct matching with parton shower generators;
- High generation efficiency;
- Short initialization time and minimum required memory/disk space;
- All interfaces to be included in analysis chain.

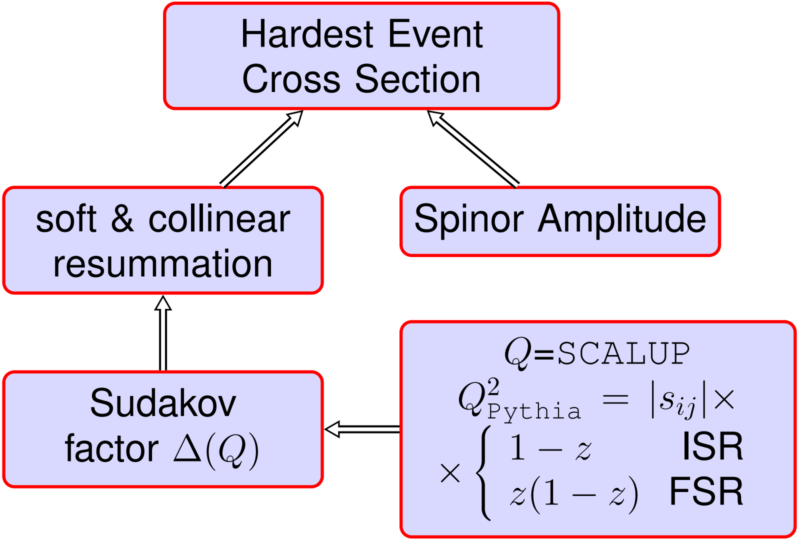
LPPG

- is generator for different processes at hadron and lepton colliders
- with one-loop electroweak corrections
- with exact hard QED Bremsstrahlung contribution
- with shower matching
- Les Houches Accord (LHA) event format
- LHAPDF interface for parton density functions

Hardest Event PS Matching



Hardest Cross Section



Properties

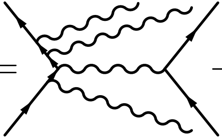
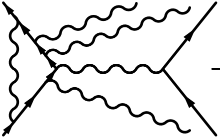
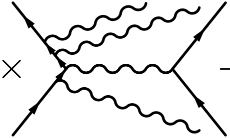
If calculations are organized in proposed way, then

- Infrared singularities are effectively regularized with Sudakov factor;
- Projection to lower phase-space are unnecessary. No off-shell extrapolation also;
- We deal with a positive-defined integrable distribution suitable for Monte-Carlo;
- Generator for multiplicity n effectively generates events for lower multiplicities;

Hard cross-section

Infrared finite cross-section

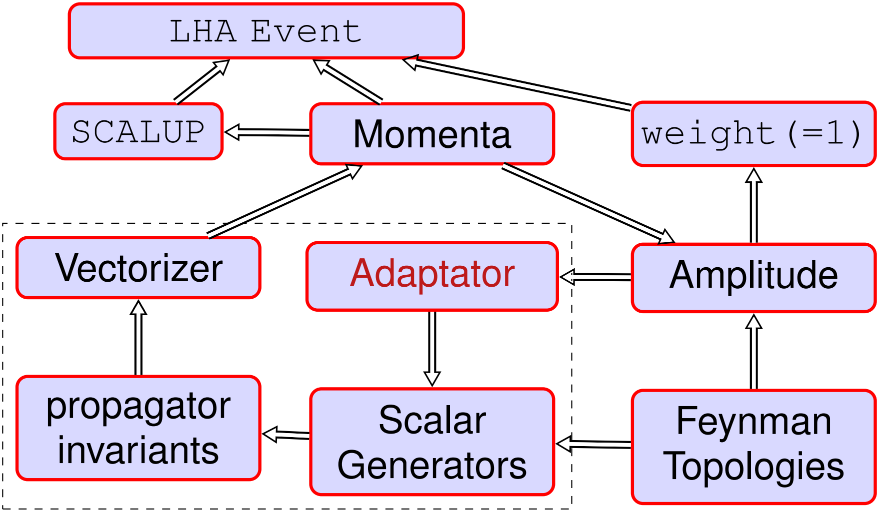
$$\sigma_n^H = \sigma_n^{H\,0\,\text{loop}} + \sigma_n^{H\,1\,\text{loop}} - \alpha B_n \sigma_n^{H\,0\,\text{loop}} + \cdots =$$

$=$  $+$  $-\alpha B_n \times$  $+\cdots$

Total cross-section

$$\sigma_n = \sigma_n^H \Delta_n(k^T_{\text{cut}})$$

Event Construction



Adaptive (Black box) approach

Adaptive MC able to sample from arbitrary function

General algorithm

split phase space (PS) onto smaller regions

No a-priori knowledge

have to build huge grids

Example: for DY+J

$d = 6$ dimensional phase space

for 30 splits over each axis

$\texttt{sizeof(grid)} = 30^6 \times \texttt{sizeof(double)} \approx 2.7\text{GB}$

Multi-channel approach

Approximate by "master" distributions

$$|A(x)|^2 \approx \sum_i c_i G_i(x) \;\Rightarrow\; w = \frac{|A(x)|^2}{\sum_i c_i G_i(x)} \approx 1$$

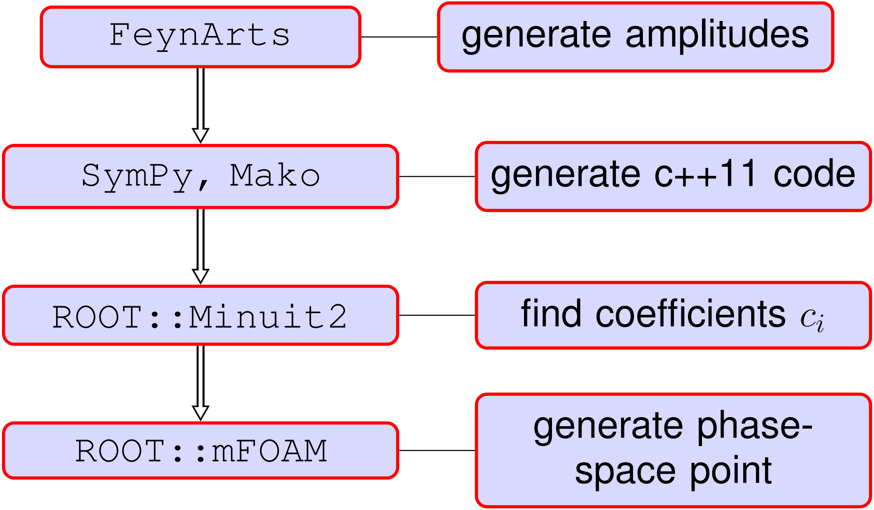
Iterative algorithm

[Kleiss, Pittau] coefficients c_i updated to minimize variance

Adaptator algorithm

we choose set of PS points $\{x_k\}$, and find $c_i > 0$ which minimize $\sum_k K\Big(\sum_i c_i G_i(x_k) - |A(x_k)|^2\Big)$
$K(x) = x^2 + r x^{10} \theta(x < 0)$, $r > 0$. We obtain $w \lessapprox 1$

Generation procedure



"Master" generators

The wider space of functions $G_i(x)$ the better adaptation

But non-wise **choice of variables** $x = \{x_1, x_2, \ldots, x_d\}$ can strongly complicate the job

In tree-level amplitude all peaks are due to **propagators**

Can we parametrize phase-space by **invariant** variables, which appear in **propagators**?

COMMON APPROACH: PS RECURSIVE BUILDING

Express PS as chain of decays and 2×2 scatterings [E. Byckling and K. Kajantie, Particle Kinematics]

LPPG'S GENERALIZATION

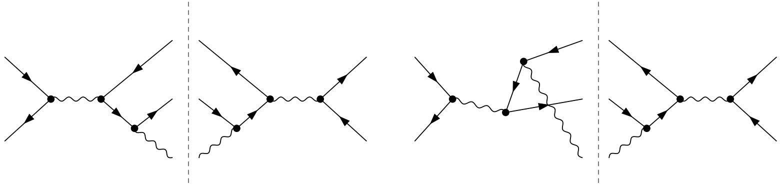
- changing of variables is as simple, as taking integrals with δ-functions:

$$\int dR_n \left(\frac{1}{p^2-m^2}\ldots\right) = \int ds' \frac{1}{s'-m^2}\left[\int dR_n \delta(p^2-s')\ldots\right]$$

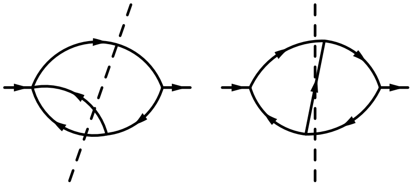
- problem now reduces to **generalized unitarity** integrals
- now formally all (intermediate and final) particles are **on-shell**

LOOP CONTRACTION

FSR

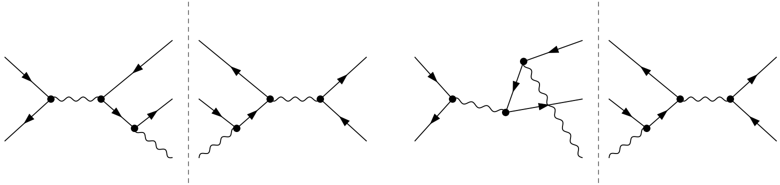


"MASTER" GENERATORS

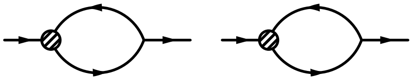


LOOP CONTRACTION

FSR

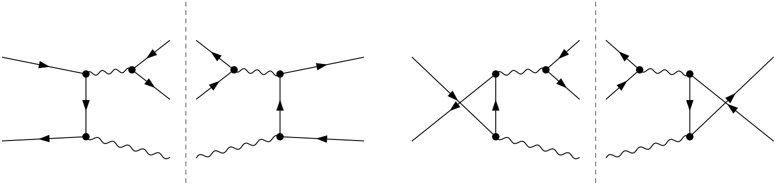


"MASTER" GENERATORS

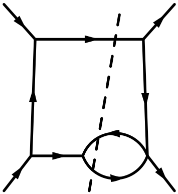


Loop Contraction

ISR

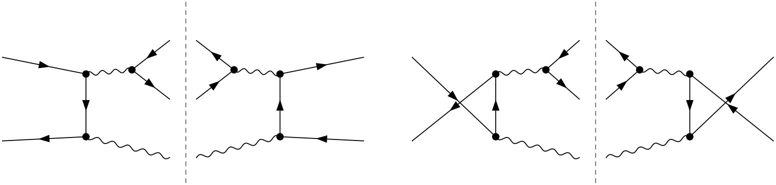


"Master" Generator

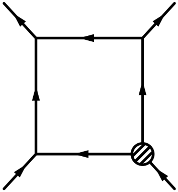


Loop Contraction

ISR

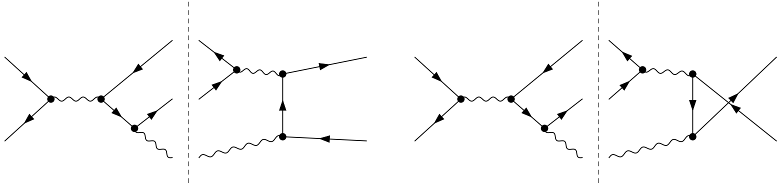


"Master" Generators

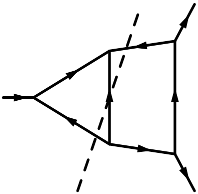


Loop Contraction

ISR-FSR interference

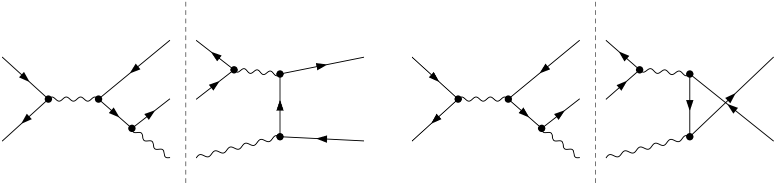


"Master" Generator

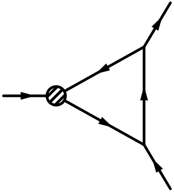


Loop Contraction

ISR-FSR interference

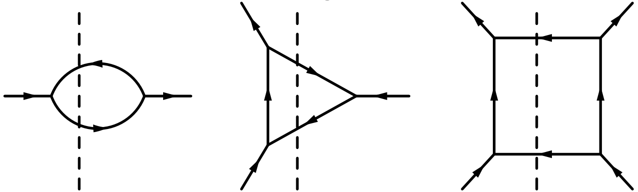


"Master" Generators



ELEMENTARY LOOPS

In our simple case only ”self-energy”, ”vertex” and ”forward-box” diagrams are needed



The same diagrams are used by vectorizer to construct particles momenta in desired reference frame

MOMENTA CONSTRUCTION

- one-loop sub-diagrams used for reconstruction of the momentum, running in the loop
- reference frame and axes directions are fixed by external legs
- boosts and rotations can easily be performed by operators from Clifford algebra [Doran, Lasenby Geometric Algebra for Physicists]

Example for "vertex"

$$p_1 \cdot p_2 = \frac{s_{12} - s_1 - s_2}{2} \qquad p_2 \cdot p_{13} = \frac{s_{123} - s_{13} - s_2}{2}$$

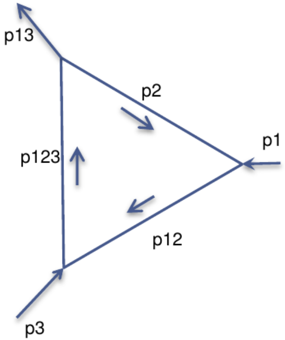
$$G = p_1 \wedge p_{13}$$

Reciprocal basis:

$$\tilde{p}_1 = p_{13} G^{-1}$$

$$\tilde{p}_{13} = -p_1 G^{-1}$$

$$p_{2L} = (p_1 \cdot p_2)\,\tilde{p}_1 + (p_2 \cdot p_{13})\,\tilde{p}_{13}$$



Example for "vertex"

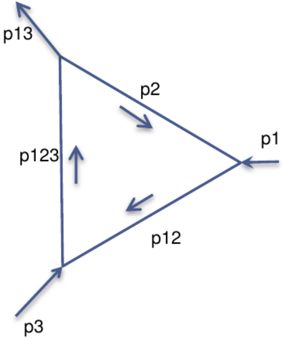
Random vector:

$$n = \gamma_1 \sin\alpha + \gamma_2 \cos\alpha$$

$$p_{2T}^2 = s_2 - p_{2L}^2$$

Rotor $R = \sqrt{G\gamma_0 \wedge \gamma_3}$

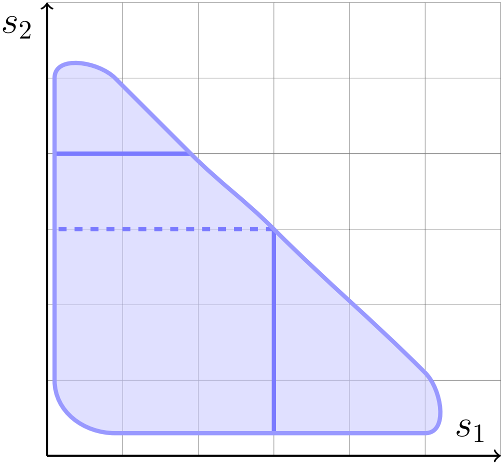
$$p_2 = p_{2L} + \sqrt{p_{2T}^2} R n R^{-1}$$



CUTS AND LIMITS

- for each propagator variable there are **limits**, which *must* be determined
- they **depend** on inner-loop masses and outer-loop variables $\Rightarrow$ Kinematic-Reflection effects
- limits can be modified by applying user **cuts** (absolute or relative)
- we adopt **interval arithmetic** package for doing this job

Kinematic Reflection



Treatment of kinematic reflections

General solution

Include in list of "master" generators $\{G_i(x)\}$ all possible orderings of normalization:

$$p(x) \otimes q(y) = \frac{p(x)}{P(x_{max}) - P(x_{min})} \cdot \frac{q(y)}{Q(y_{max}(x)) - Q(y_{min}(x))}$$

$$q(y) \otimes p(x) = \frac{q(y)}{Q(y_{max}) - Q(y_{min})} \cdot \frac{p(x)}{P(x_{max}(y)) - P(x_{min}(y))}$$

Conclusion

- proposed method of generation with multi-channel optimization approach and wise phase space parametrization
- matching with parton shower MCs implemented

Thank you!