Event generator LePaProGen for the Drell-Yan process

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Calculations for Modern and Future Colliders
20-30 July 2015

Outline

LePaProGen

- is generator for Drell-Yan process: $pp \to \gamma, Z \to \mu^+\mu-$
- for charged-current Drell-Yan: $pp \to W^+ \to \mu + \nu$
- with one-loop electroweak corrections
- with exact hard QED Bremsstrahlung contribution: $pp \to l^+l^- + \gamma$
- QCD and double-Bremsstrahlung are in development: $pp \to l^+l^- + \gamma/g + \gamma/g$

LePaProGen Interfaces

- can be Pythia8 plug-in;
- Les Houches Accord (LHA) event format;
- LHAPDF interface for parton density functions;
- variety of renormalization schemes;
- POWHEG-like matching.

LePaProGen code structure

python — Python module: processing of input settings, precalculation of all constants

mako — Mako template: optimized code generation for process chosen by user

C++ — C++ code: modular architecture, high performance

Impotance Sampling

- to flatten a peak change variable:

$$\frac{f(x)dx}{(x-x_0)^2+a^2} = \frac{f(x_0 + a\tan\psi)d\psi}{a}$$

- in tree-level amplitude all peaks are due to **propagators**
- Can we parametrize phase-space by invariant variables, which appear in propagators?

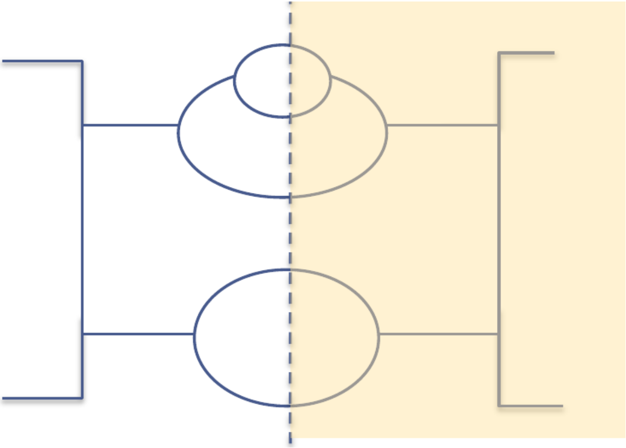
Cutting lines

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

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

- problem now reduces to **generalized unitarity** integrals
- now all (intermediate and final) particles are **on-shell**
- what about simple unitarity?

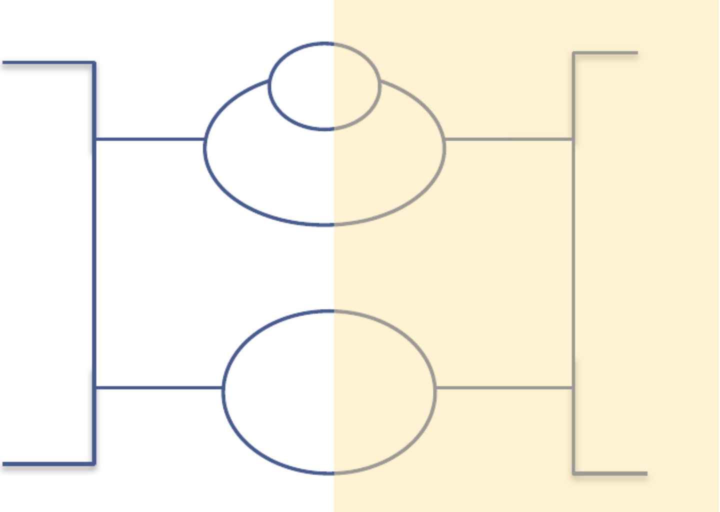
Optical Theorem



- squared amplitude is imaginary part of multi-loop diagram

Loop Contraction

- we are going to integrate loop-by-loop



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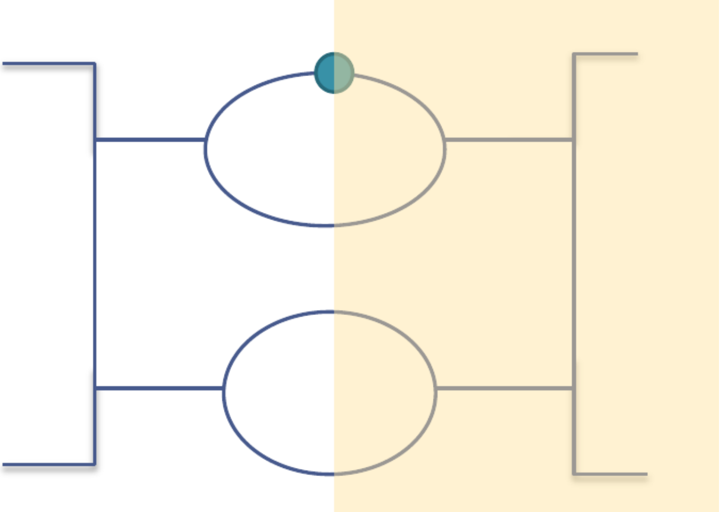

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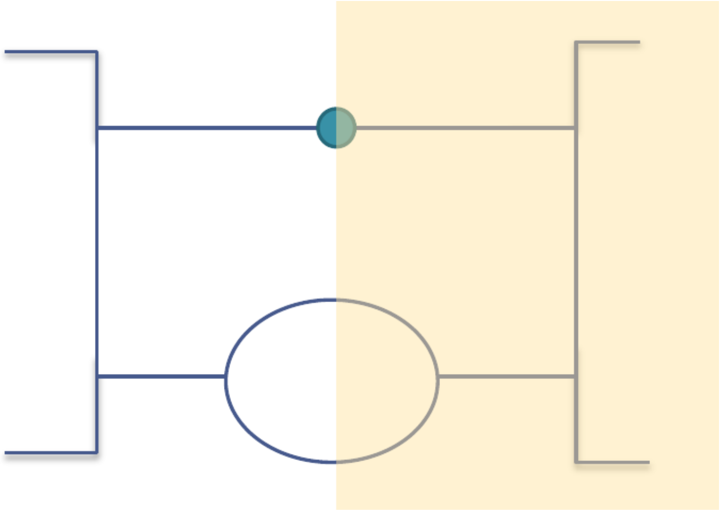

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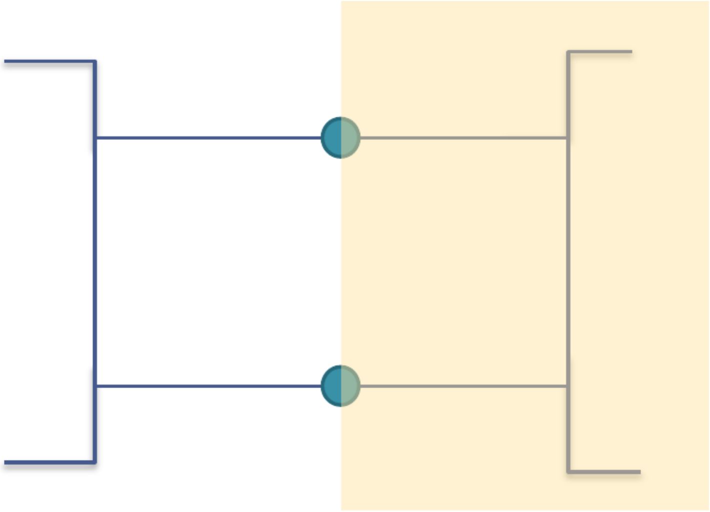

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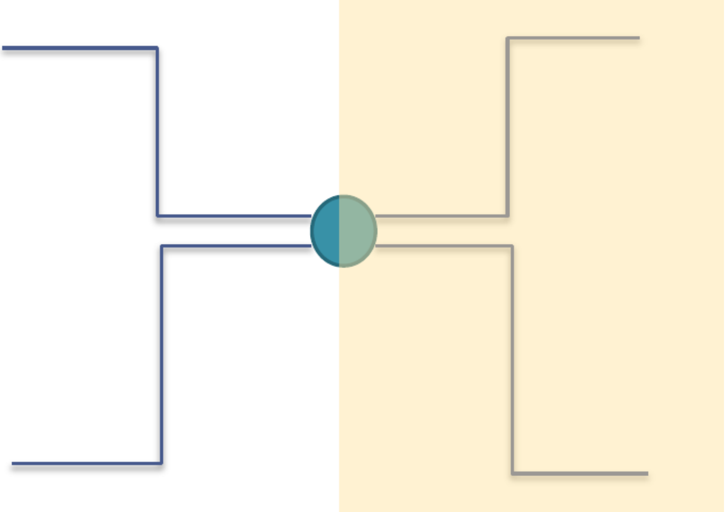


Loop Contraction

- It is generalization of recurrence relation for phase-space volume from [E. Byckling and K. Kajantie, Particle Kinematics (John Wiley, London; New York; Sydney; Toronto, 1973)]

Reconstruction

- 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 of reconstraction

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

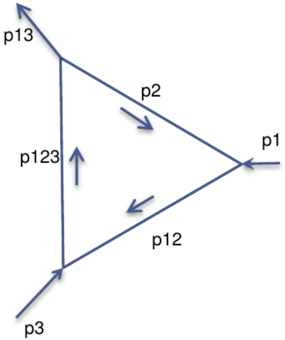
$$G = p_1 \wedge p_{13}$$

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 of reconstraction

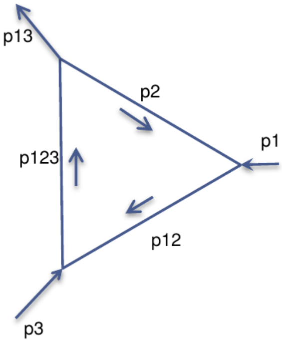
Random vector:

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

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

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
- limits can be modified by applying user **cuts**
- we adopt **interval arithmetic** package for doing this job

Amplitudes

- The complete EW corrections at one-loop is calculated for single W and Z production.
- Supports different EW-schemes: $\alpha(0)$, $\alpha(M_Z)$, $G\mu$.
- Bremsstrahlung amplitudes are generated using *Clifford algebra* technique.

Singularities handling

- Need handling soft and collinear singularities suitable for generator.

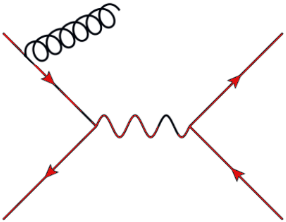
Sudakov form factor:

$$\Delta(Q^2, p_t^2) \propto e^{-A \log^2 \frac{Q^2}{p_t^2}}$$

$$\underbrace{\frac{1}{p^2}}_{\text{coll., IR}} \rightarrow \underbrace{\frac{1}{p^2}\Delta(Q^2, p_t^2)}_{\text{Integrable,suitable for MC}}$$

Matching with shower

- In soft limit R-correction contains information about born.

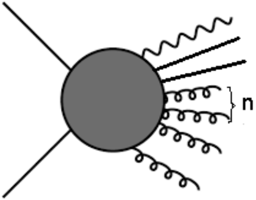


$$\sigma^B + \sigma^R$$

$$\sigma^B \cdot \Delta(Q^2, p_t^2) \xrightarrow[p_t^2 \to 0]{resum} 0$$

Semiinclusive process

- Consider first *n* hardest gluon(photon) exclusively.
- The other are resummed inclusively with Sudakov form factor.



Parton shower (like PYTHIA, Herwig) make further *exclusivisation* of process.

Conclusion

- proposed method of generation and reconstruction is proved to be efficient
- all necessary interfaces for inclusion into CMS analysis infrastructure
- matching with parton shower MCs

next steps:

- comparison against other existing codes (FEWZ, HORACE, SANC etc.)