Massimiliano Procura

Research Interests

CERN Theory Group Retreat, Les Houches, 4-6 November, 2015

Brief Curriculum Vitae

- PhD at the Technical University of Munich
- Postdocs: MIT, Munich, Bern
- Since November 2014, University Assistant (6 years) at the University of Vienna
- On leave for 2 years at CERN

Research Interests

Effective Field Theories of the Standard Model at high and low energies :

- Soft Collinear Effective Theory for hard QCD processes characterized by the presence of hadronic jets: factorization and resummation of large logarithms induced by restrictions on initial- and/or final-state radiation, to improve state-of-the-art calculations

- Chiral effective field theory for calculations of strong interaction effects at low energies (below 1 GeV): complementary information to lattice QCD

Jet physics: fragmentation

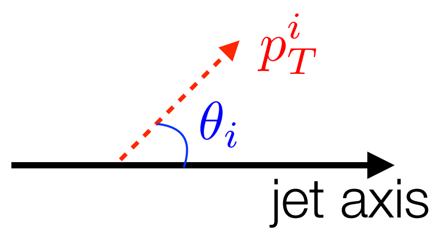
- Novel formalism to describe fragmentation of a parton into a hadron inside an identified jet (MP, Stewart 2010; Jain, MP, Waalewijn 2011, 2012): enables study of correlations between kinematic cuts and the fragmentation variable, and leads to complementary information on fragmentation functions from LHC data

- Novel framework to perform analytic QCD calculations for track-based observables, i.e. depending on kinematics of charged particles alone (Chang, MP, Thaler, Waalewijn 2013).
  At LHC tracking info used to improve jet measurements, study jet substructure and mitigate pileup. So far, theoretical studies rely on Monte Carlo event generators only.
  In our formalism hadronization effects are encoded in universal track functions; factorization theorems enable systematically improvable QCD calculations with reliable theory uncertainties.
  Goal: apply this framework to observables used by experimental collaborations, e.g. track N-subjettiness.

Jet physics: multidifferential resummation

- Double differential cross sections where both observables require resummations (MP, Waalewijn, Zeune 2015). Important to investigate correlations
  - jet cross sections: LHC analyses typically involve multiple cuts
  - jet substructure: ratio observables are common. Example: e_α / e_β

$$e_\alpha = \sum_{i \in \text{jet}} \frac{p_T^i}{p_T^{\text{jet}}} \left(\frac{\theta_i}{R} \right)^\alpha$$



$$\frac{d\sigma}{dr} = \int de_\alpha \, de_\beta \, \frac{d^2\sigma}{de_\alpha \, de_\beta} \, \delta\!\left(r - \frac{e_\alpha}{e_\beta} \right)$$

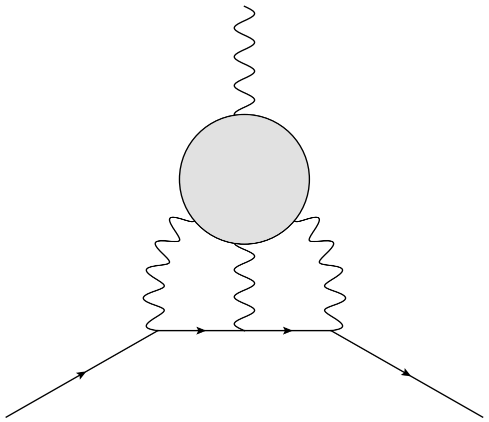
- At the phase-space boundaries different EFTs: we derived factorization formulae needed to achieve resummations in the bulk and provide an interpolation. Focus on:
  - Multiple angularity measurement on the same jet at NLL
  - Isolated Drell-Yan with a global veto on hard jets and measured transverse momentum of the vector boson (relations between fully unintegrated and standard pdfs, and various soft functions in different region of phase space)

Hadronic light-by-light scattering

- Limiting factor in the accuracy of SM predictions for $a_\mu = (g-2)_\mu$ is control over hadronic contributions, responsible for most of the theory uncertainty

- Hadronic vacuum polarization can be systematically improved: unitarity and analyticity relate it directly to $\sigma_{\rm tot}(e^+e^- \to \gamma^* \to \text{hadrons})$

- Hadronic light-by-light (HLbL) is more problematic. Only model calculations have been performed so far and they are characterized by large uncertainties in the individual contributions and discrepancies



  - a reliable uncertainty estimate is still an open issue

- How to reduce model dependence ? Recent strategies for an improved calculation :

  - lattice QCD
  - dispersion theory to make the evaluation as data driven as possible

Hadronic light-by-light scattering

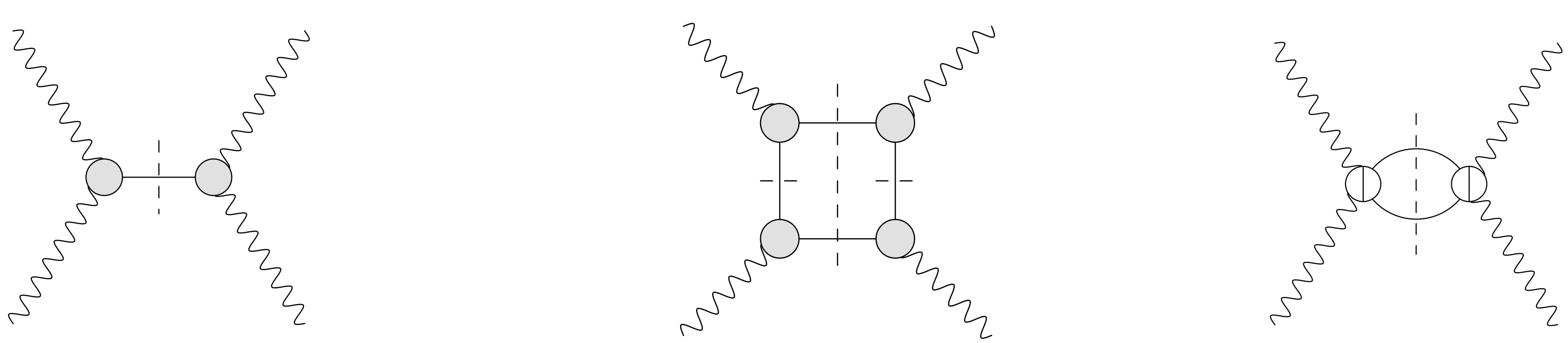
(Colangelo, Hoferichter, MP, Stoffer 2013, 2014, 2015)

- The hadronic light-by-light tensor

$$\Pi^{\mu\nu\lambda\sigma}(q_1,q_2,q_3) = -i\int d^4x\, d^4y\, d^4z\, e^{-i(q_1\cdot x+q_2\cdot y+q_3\cdot z)}\langle 0|T\{j^\mu_{\rm em}(x)j^\nu_{\rm em}(y)j^\lambda_{\rm em}(z)j^\sigma_{\rm em}(0)\}|0\rangle$$

has a very complex analytic structure: approximations are required. We order the contributions according to the mass of intermediate states: the lightest states are expected to be the most important (in agreement with model calculations).

- We therefore split $a_\mu^{\rm HLbL}$ into: ``pion'' pole term (one-pion intermediate state), box topologies (2-pion intermediate states in direct- and crossed-channel), $\pi\pi$ rescattering contribution (2 pion intermediate state only in direct channel), and higher-mass intermediate states (so far neglected).



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- We therefore split $a_\mu^{\rm HLbL}$ into: ``pion" pole term (one-pion intermediate state), box topologies (2-pion intermediate states in direct- and crossed-channel), ππ rescattering contribution (2 pion intermediate state only in direct channel), and higher-mass intermediate states (so far neglected).

- Input for our dispersion relations at fixed photon virtualities are singly- and doubly-virtual pion transition form factors, pion vector form factors, and helicity partial waves for $\gamma^*\gamma^*\to\pi\pi$.
  Ongoing work: dispersive reconstruction of transition form factors and helicity partial waves (constraints from chiral EFT), numerical analysis.