QCD corrections in the SM and Beyond

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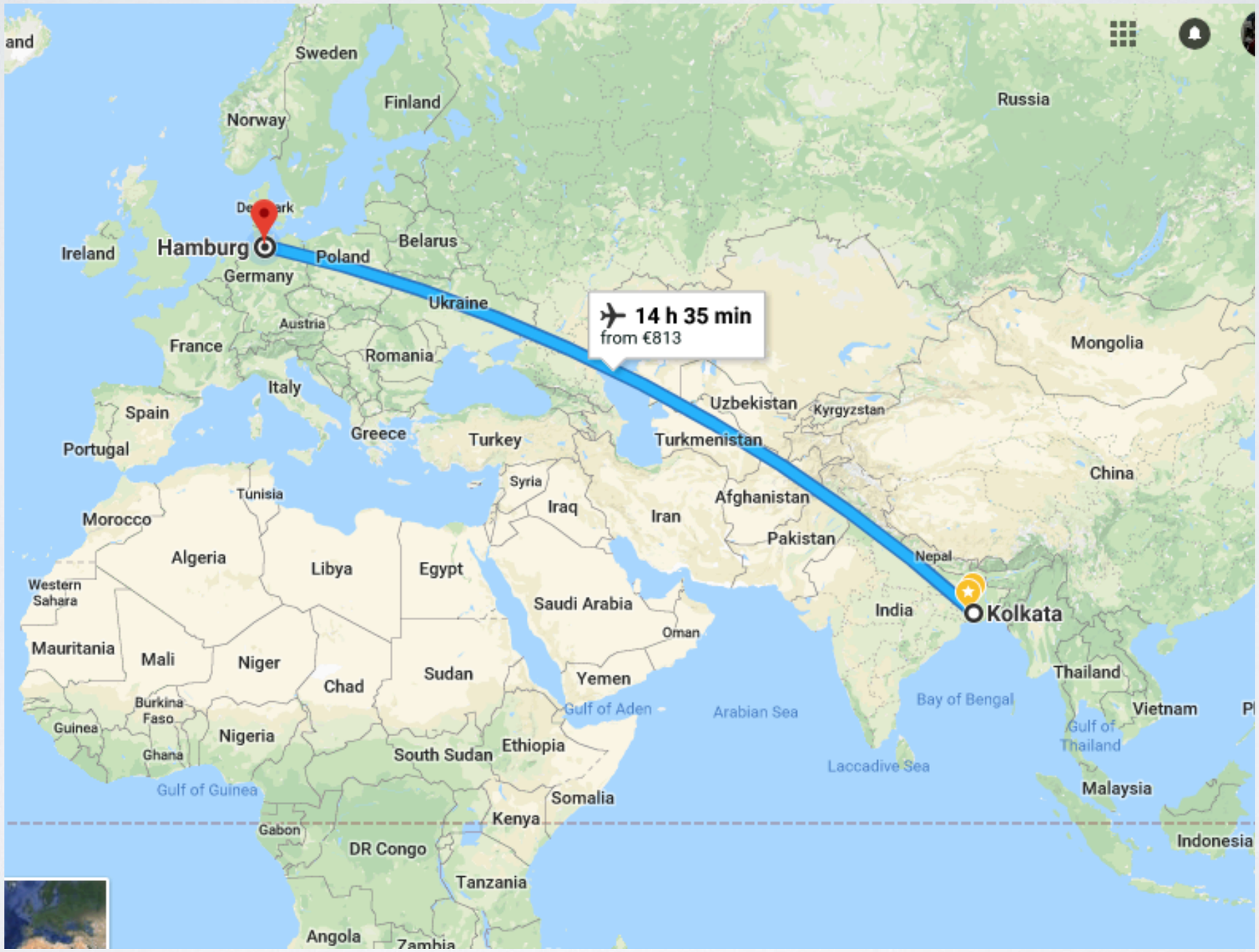
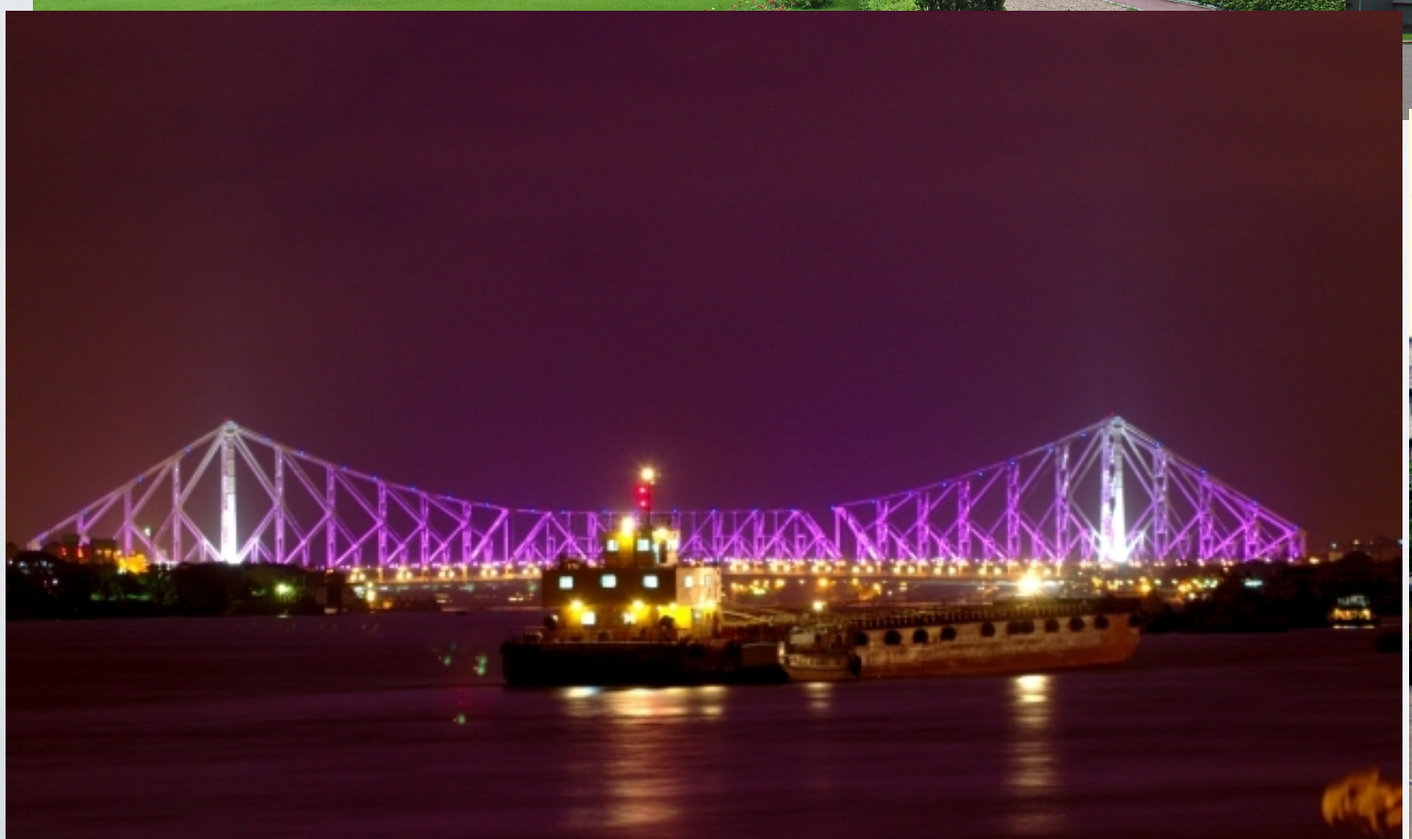
DESY, Hamburg

Theory Fellow Meeting, December 2017

Where did I come from?



Kolkata (Kalkutta)-City of Joy



Activities

Sports:

Cricket, Table Tennis.

Moto GP, F1

Others:

Movies, Music

Motorbiking, Foodie

Doglover

Academic Carrier

- PhD: Saha Institute of Nuclear Physics, Kolkata, (2017)

- PDF: The Institute of Mathematical Sciences, Chennai, 2017(Feb-Oct)

- PDF: DESY, Hamburg (2017, Oct- Present)

(Office: 204/1b)

Research So Far

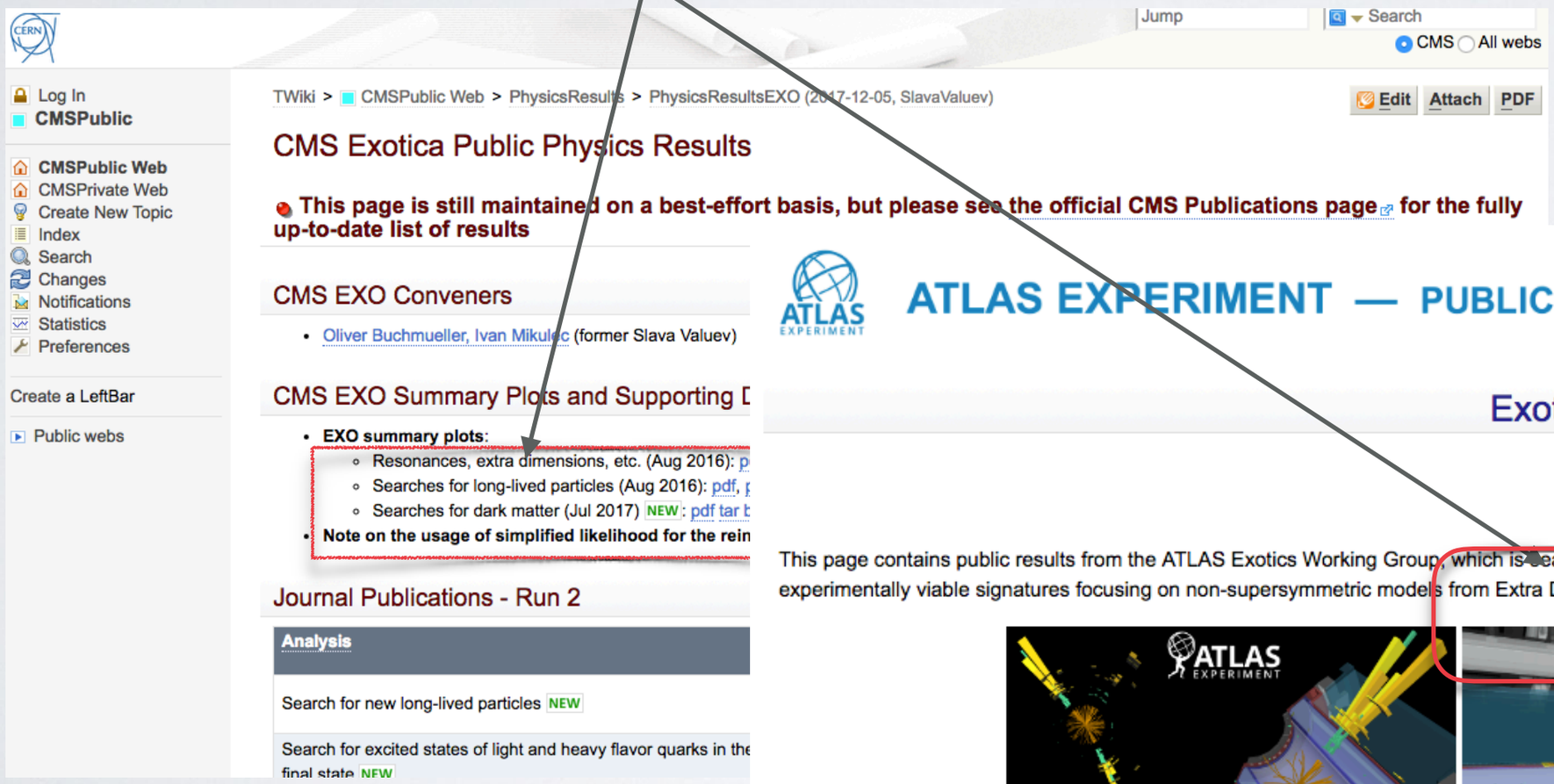
- Precision Spin-2 searches at the LHC

Automation MC tools Multiloop Computation

- Threshold Resummation

Precision Spin-2 study at LHC

Spin-2 in the context of LHC



Spin-2 at the LHC

Models:

- Generic Spin-2
- Arkani-Hamed-Dimopoulos-Dvali (ADD)
- Randall-Sundrum (RS)
- Universal Extra-Dimension (UED)

} Extra Dimensions

Spin-2 at the LHC

Idea:

- Built an EFT and study low energy phenomena
- Impact of gravity on quantum phenomena on first approximation, relying on semi-classical description of gravity.

Randall-Sundrum

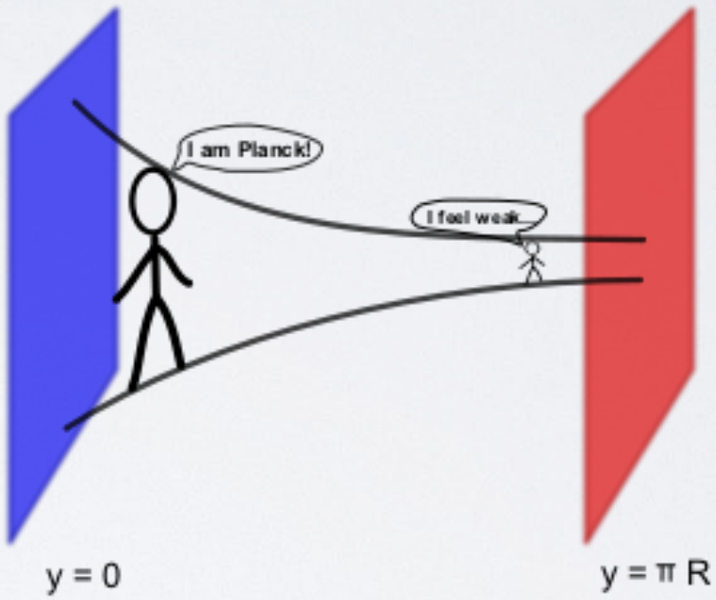
Naive description:

- One extra spatial dimension compactified on a S1/Z2 orbifold.
- SM is confined in TeV brane, Gravity propagates in 4+1 D
- 5-D gravity appears as a tower of Kaluza-Klein states from the SM brane.

Randall-Sundrum

- 5-D non-factorisable warped metric

$$ds^2 = e^{-2\kappa r_c|\phi|}\eta_{\mu\nu}dx^\mu dx^\nu - r_c^2 d\phi^2$$



- Interaction Lagrangian

$$\mathcal{L}_{RS} = -\frac{1}{\overline{M}_{Pl}} T^{\mu\nu}(x) G^{(0)}_{\mu\nu}(x) - \frac{\bar{c}_0}{m_0} T^{\mu\nu}(x) \sum_{n=1}^{\infty} G^{(n)}_{\mu\nu}(x)$$

Perturbative QCD

- N-particle scattering cross-section:

$$\sigma_N = \sigma_N^{(0)} + \left(\frac{\alpha_s}{2\pi}\right)\sigma_N^{(1)} + \left(\frac{\alpha_s}{2\pi}\right)^2 \sigma_N^{(2)} + \cdots$$

LO > NLO > NNLO

Precision Spin-2 Study at LHC

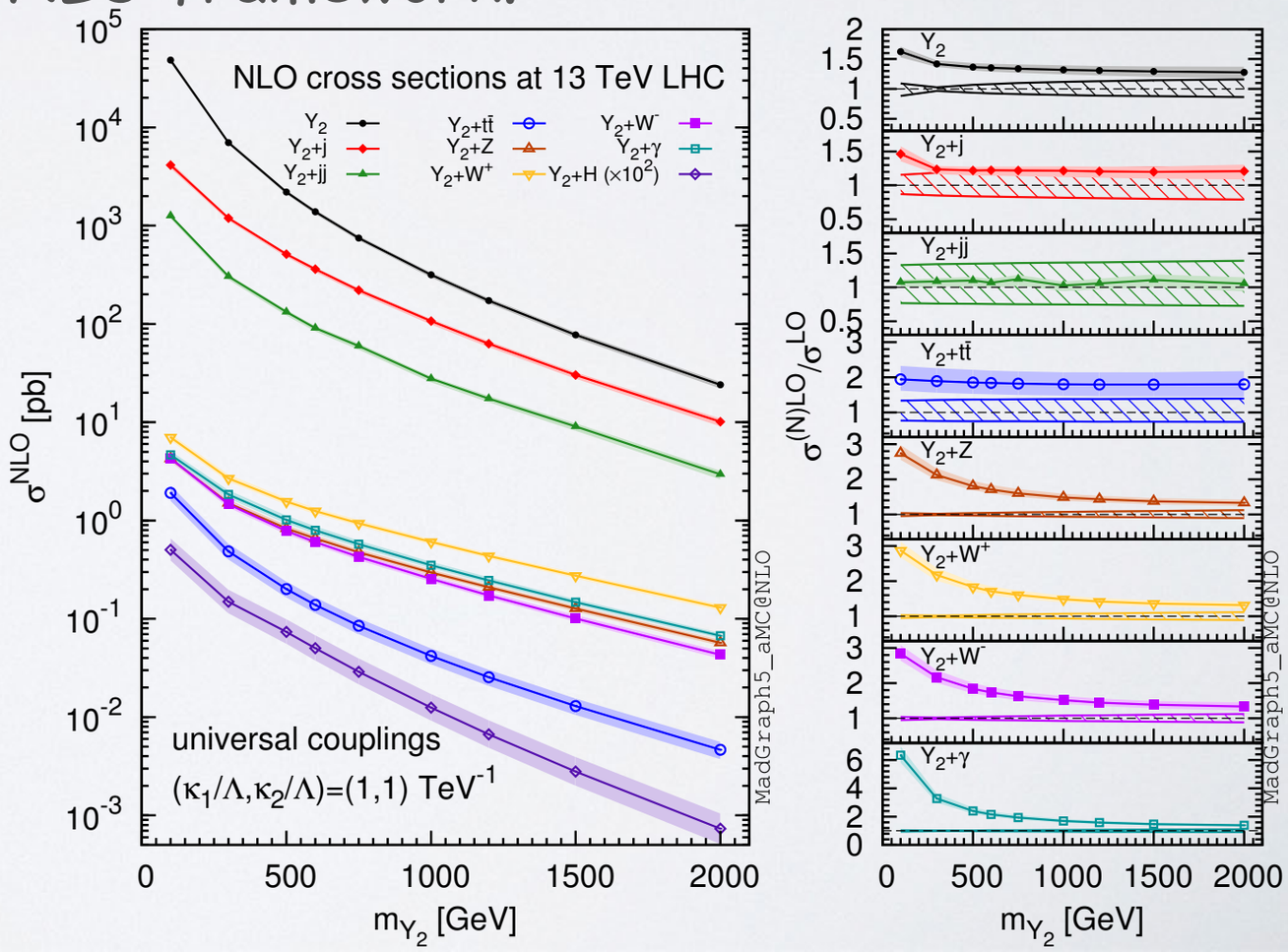
- Automation MC tools:

  Implementation of a generic spin-2 model in FeynRules - MadGraph5_aMC@NLO framework.

  (http://feynrules.irmp.ucl.ac.be/wiki/Spin2)

Phenomenology study at NLO+PS for inclusive and associated production with

$$j, jj, \gamma, Z, W^{\pm}, t\bar{t}$$



Precision Spin-2 Study at LHC

- Automation MC tools:

  Implementation of RS model in MadGraph5_aMC@NLO at NLO+PS

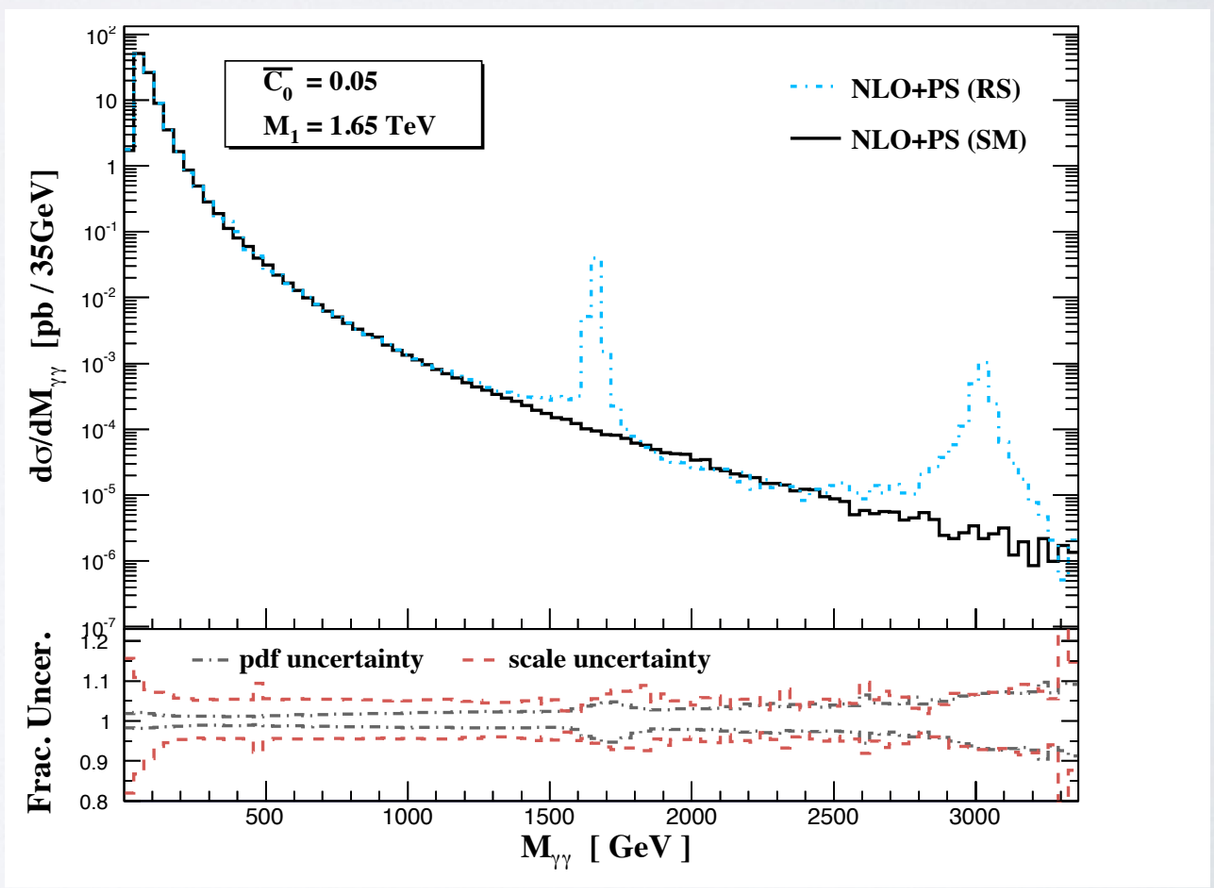
  Standalone codes:

  (http://amcatnlo.web.cern.ch/amcatnlo/)

  Phenomenology study for

  $$\gamma\gamma, \ell^+\ell^-, ZZ, W^+W^-$$

  $$\gamma\gamma\gamma, \gamma\gamma Z, \gamma ZZ, ZZZ$$



Precision Spin-2 Study at LHC

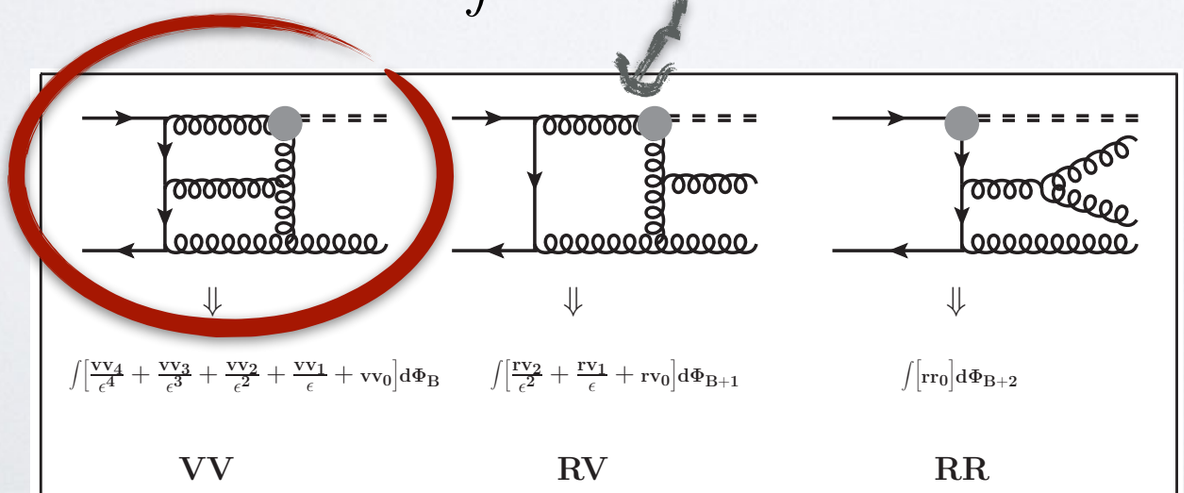
- Multiloop computation:

  N-particle cross-section

$$\sigma_N = \sigma_N^{(0)} + \left(\frac{\alpha_s}{2\pi}\right)\sigma_N^{(1)} + \left(\frac{\alpha_s}{2\pi}\right)^2\sigma_N^{(2)} + \left(\frac{\alpha_s}{2\pi}\right)^3\sigma_N^{(3)} + \cdots$$

LO > NLO > NNLO > NNNLO

$$\sigma_N^{(2)} = \int 2\,\mathrm{Re}\langle M_N^{(0)}|M_N^{(2)}\rangle\, d\phi_N + \int 2\,\mathrm{Re}\langle M_{N+1}^{(0)}|M_{N+1}^{(1)}\rangle\, d\phi_{N+1} + \int \langle M_{N+2}^{(0)}|M_{N+2}^{(0)}\rangle\, d\phi_{N+2}$$



Precision Spin-2 Study at LHC

- Multiloop computation:

Processes Studied

q, g Form-Factor (3-loop)

$Y_2 \to q + \bar{q} + g$ (2-loop)

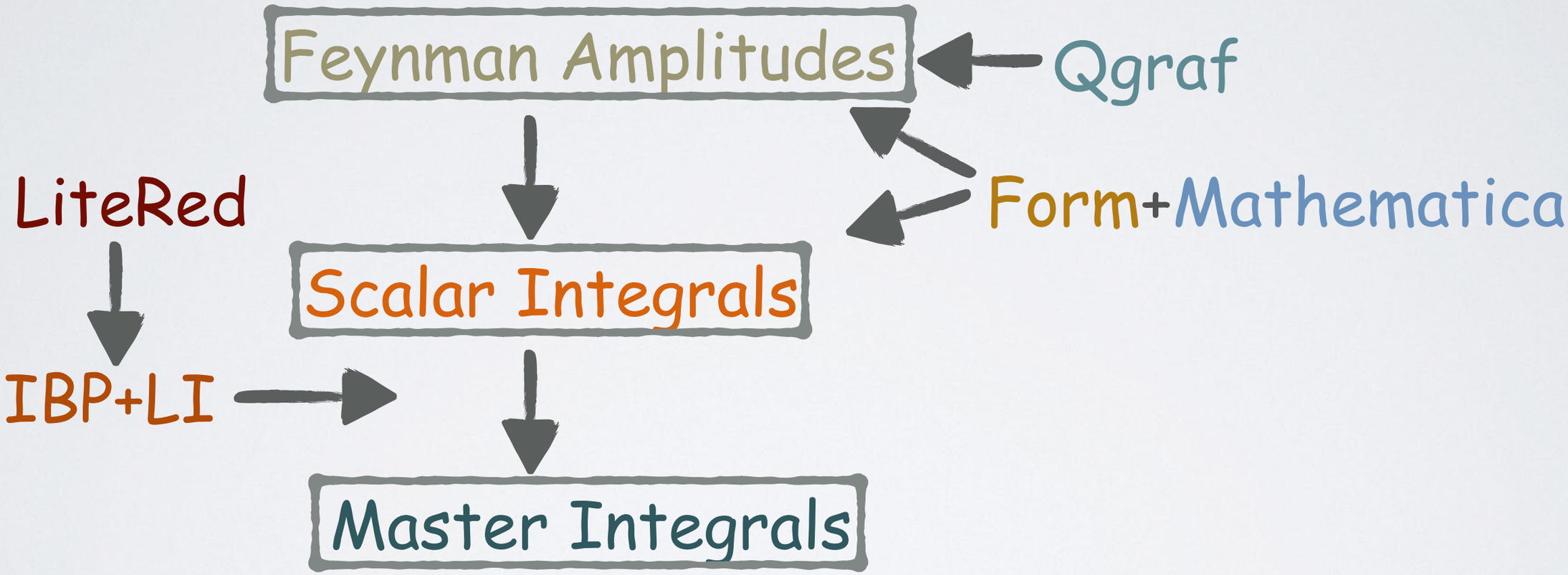
Inclusive Spin-2 production at NNNLO

Mono-jet at NNLO

Thousands of diagrams!!

Precision Spin-2 Study at LHC

- Multiloop computation:



- Form-Factors satisfy Sudakov integro-differential equation
- Universal infrared pole behaviour.

Threshold resummation

- Developed a formalism to resum threshold logarithms for Rapidity distribution of any colorless particle.

- Resummation in two-dimensional Mellin space.

Threshold resummation

- Rapidity distribution

$$\frac{d\sigma^I}{dy} = \sigma^I_{\rm B}(x_1^0, x_2^0, q^2, \mu_R^2) \sum_{ab=q,\overline{q},g} \int_{x_1^0}^1 \frac{dz_1}{z_1} \int_{x_2^0}^1 \frac{dz_2}{z_2}\, \mathcal{H}^I_{ab}\left(\frac{x_1^0}{z_1}, \frac{x_2^0}{z_2}, \mu_F^2\right) \Delta^I_{d,ab}(z_1, z_2, q^2, \mu_F^2, \mu_R^2).$$

Hadronic rapidity: $y = \frac{1}{2}\ln(x_1^0/x_2^0)$

Scaling variable: $z_i = x_i^0/x_i$

Soft-Virtual part: $\left[\frac{\ln^{m-1}(1-z_i)}{(1-z_i)}\right]_+ \qquad \delta(1-z_i)$ $\qquad m \leq 2n$

Exponentiates the threshold logs through
cusp anomalous dimension and collinear functions

Threshold resummation

- Double Mellin transformation

$$\tilde{\Delta}_d^{I,\mathrm{SV}}(\omega) = \int_0^1 dz_1 z_1^{N_1-1} \int_0^1 dz_2 z_2^{N_2-1} \Delta_d^{I,\mathrm{SV}}(z_1, z_2)$$

Resumed rapidity distribution

$$\tilde{\Delta}_d^{\mathrm{SV},I}(\omega) = \tilde{g}_{d,0}^I(a_s) \exp\left(g_d^I(a_s, \omega)\right)$$

Ni dependent

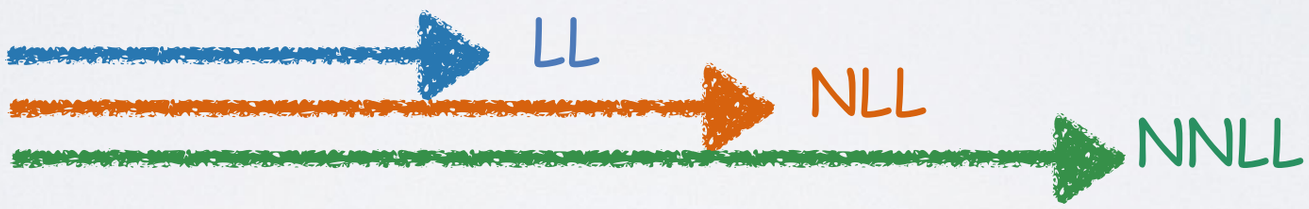
Ni independent

$$\omega = a_s \beta_0 \ln\left(\overline{N}_1 \overline{N}_2\right)$$

Threshold resummation

Resumed rapidity distribution

$$g_d^I(a_s,\omega) = g_{d,1}^I(\omega)\ln(\overline{N}_1\overline{N}_2) + \sum_{i=0}^{\infty} a_s^i g_{d,i+2}^I(\omega)$$
$$= g_{d,1}^I(\omega)\ln(\overline{N}_1\overline{N}_2) + g_{d,2}^I(\omega) + a_s g_{d,3}^I(\omega) + \cdots$$



Resumed Logs

LL $\longrightarrow$ $\alpha_s^n \ln^{n+1}(\bar{N}_1\bar{N}_2)$

NLL $\longrightarrow$ $\alpha_s^n \ln^{n}(\bar{N}_1\bar{N}_2)$

NNLL $\longrightarrow$ $\alpha_s^{n+1} \ln^{n}(\bar{N}_1\bar{N}_2)$

$$\delta(1-z_i) \to 1$$
$$\frac{\ln^i(1-z_j)}{1-z_j} \to \ln^i \bar{N}_j$$

Threshold resummation

Logarithms that are resumed

	LL	NLL	NNLL
$\mathcal{O}(a_s)$	$\ln^2(\bar{N}_1\bar{N}_2)$	$\ln(\bar{N}_1\bar{N}_2)$	$\ln(\bar{N}_1\bar{N}_2)$
$\mathcal{O}(a_s^2)$	$\ln^3(\bar{N}_1\bar{N}_2)$	$\ln^2(\bar{N}_1\bar{N}_2)$	$\ln^2(\bar{N}_1\bar{N}_2)$
$\mathcal{O}(a_s^3)$	$\ln^4(\bar{N}_1\bar{N}_2)$	$\ln^3(\bar{N}_1\bar{N}_2)$	$\ln^2(\bar{N}_1\bar{N}_2)$
Resumed terms:	$a_s^m \ln^{m+1}(\bar{N}_1\bar{N}_2)$	$a_s^m \ln^m(\bar{N}_1\bar{N}_2)$	$a_s^{m+1} \ln^m(\bar{N}_1\bar{N}_2)$
Functions that resums:	$g^I_{d,1} \ln(\bar{N}_1\bar{N}_2)$	$g^I_{d,2}$	$a_s g^I_{d,3}$

Threshold resummation

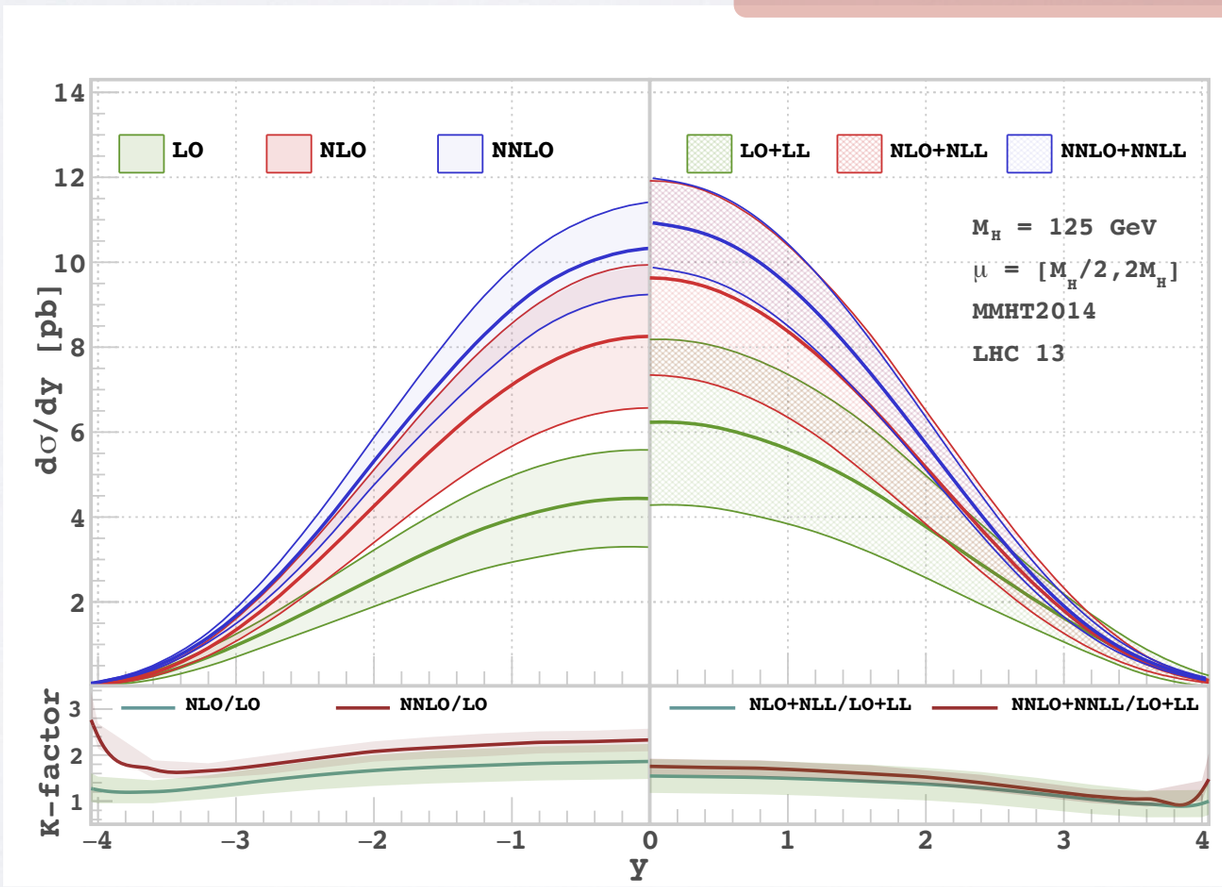
- Matching at NNLO+NNLL:

$$\frac{d\sigma^{g,\mathrm{res}}}{dy} = \frac{d\sigma^{g,\mathrm{f.o.}}}{dy} + \sigma_B^I \int_{c_1-i\infty}^{c_1+i\infty} \frac{dN_1}{2\pi i} \int_{c_2-i\infty}^{c_2+i\infty} \frac{dN_2}{2\pi i} e^{y(N_2'-N_1')}$$
$$\times (\sqrt{\tau})^{-2-N_1'-N_2'} \tilde{f}_g(N_1') \tilde{f}_g(N_2') \left[\tilde{\Delta}_{d,g}^{\mathrm{SV},N_1',N_2'} - \left(\tilde{\Delta}_{d,g}^{\mathrm{SV},N_1',N_2'} \right)_{\mathrm{trunc}} \right]$$

Matching with FO

Case study: Higgs rapidity

1. Resum result gives better perturbative convergence.
2. NNLO+NNLL result stabilises with respect to the choice of central scale.



Current Research

- Study DY threshold resummation.
- qT resummation.
- Resummation in Soft-Collinear Effective theory.
- N-Jettiness
- …

thank you!