Track 3 Summary

19th International Workshop on Advanced Computing and Analysis Techniques in Physics Research (ACAT 2019)

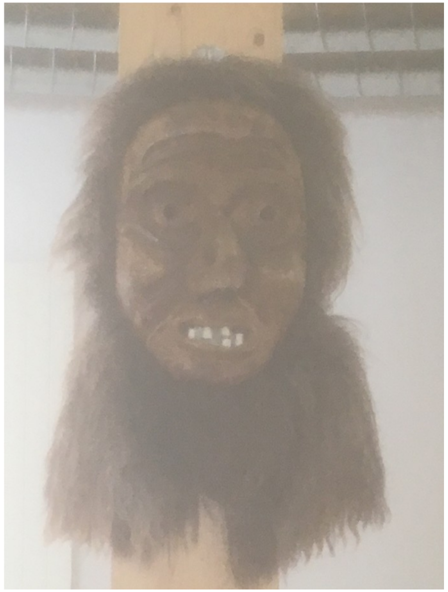
10-15 March 2019,
Saas Fee, Switzerland

Track 3

Computations in Theoretical Physics:
Techniques and Methods

This track focuses on computing techniques and algorithms used in the theoretical side of physics research

Rush summaries of 23 parallel talks
in 10 minutes

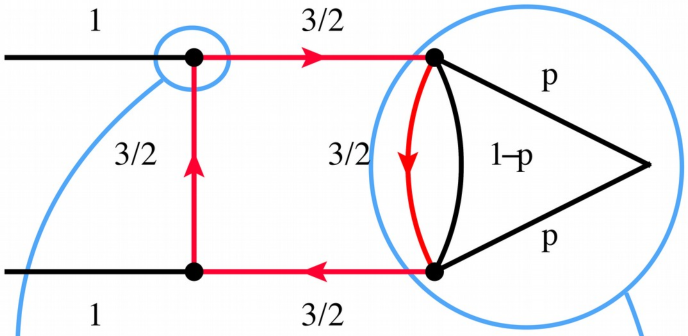


Face of ACAT

Multi-loop Calculations

STR: a Mathematica package for the method of uniqueness

Michelangelo Preti



We call the weight of the diagram (or of a portion of it) the sum of all the weights of the constituent lines.

Star of weight 4

Triangle of weight 1+p

A line, star and triangle are **unique** if their weights are 0, D and D/2 respectively

Method of uniqueness is a set of relations for unique portions of diagram

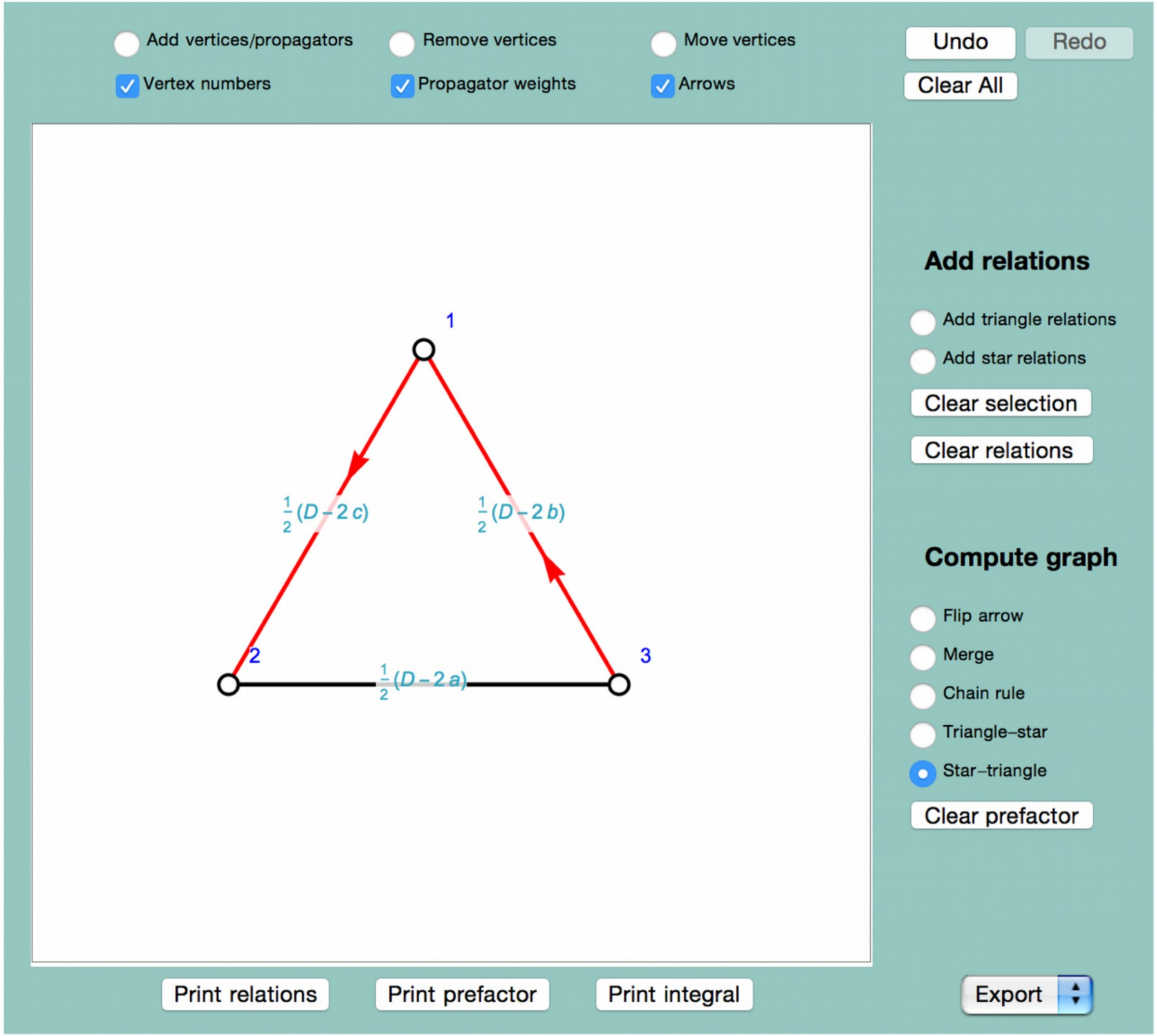
Merging rules

Star-Triangle relations

Chain rules

In[5]:= **STR[D]**

Out[5]=



STRrelations

$$\{a + b + c == D\}$$

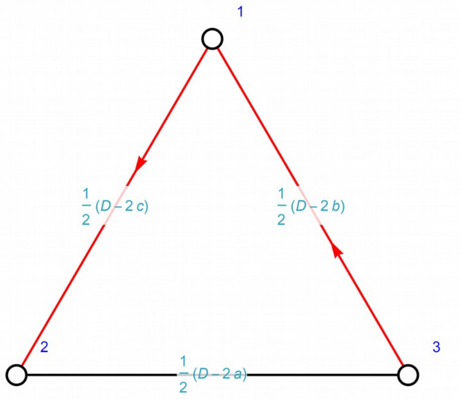
STRprefactor

$$\pi^{D/2}\, a_0[a]\, a_{\frac{1}{2}}[b, c]$$

STRintegral

$$\Delta_0[x_2, x_3]^{\frac{1}{2}(-2a+D)}\, \Delta_{\frac{1}{2}}[x_1, x_2]^{\frac{1}{2}(-2c+D)}\, \Delta_{\frac{1}{2}}[x_3, x_1]^{\frac{1}{2}(-2b+D)}$$

STRgraph



#292 de Doncker

Numerical multi-loop integration on heterogeneous many-core processors

E. de Doncker[1], A. Almulihi[1], F. Yuasa[2], N. Nakasato[3], H. Daisaka [4], T. Ishikawa [2]

Suiren2 at KEK, liquid immersion cooling, many-core supercomputer

$(m = 2)$ 5^{13} pts. LR results for 3-loop massless self-energy diagram L_0 on Suiren2

Diagram	N	#Pts. n	Times [s] on Suiren2, nXtY: X nodes, Y tasks 1 node	2 nodes	4 nodes	8 nodes
Fig [3ls] (t)	8	5^{13}	n1t1: 432.7			
			n1t2: 217.8	n2t1: 217.7		
			n1t4: 111.7	n2t2: 111.4	n4t1: 112.0	
			n1t8: 58.33	n2t4: 57.58	n4t2: 56.58	n8t1: 56.23
				n2t8: 30.68	n4t4: 29.70	n8t2: 29.01
					n4t8: 16.70	n8t4: 15.91
						n8t8: 9.857

Table: $(m = 2)$ 5^{13} pts. $(7D)$ results for 3-loop massless self-ene rgy diagram L_0 on Suiren2; Abs. err. = 1.71e-07, Rel. err. = 8.22e-09; Loop blocks of size $128 * 32$;

Compare to GPU: 390.6 s 2496 CUDA Cores

Numerical calculation of high-order QED contributions to the electron anomalous magnetic moment

#340 Volkov

Sergey Volkov
SINP MSU, Dubna branch (Russia)
DLNP JINR, Dubna (Russia)

AMM of the electron (theory and experiment)

The measured value [2011]:

a_e=0.00115965218073(28)

$A_1^{(2n)}$ calculations are still important...

Example

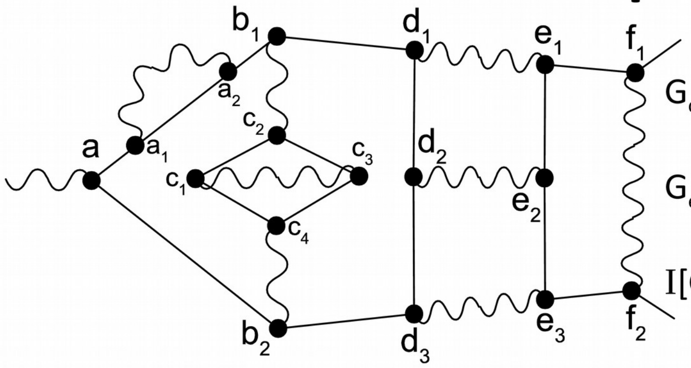


Diagram-specific probability density functions

#340 Volkov

- Integral: $\int_{z_1,\ldots,z_M>0} f(z_1,\ldots,z_M)\delta(z_1+\ldots+z_M-1)dz$
- Hepp sectors: $z_{j_1} \geq z_{j_2} \geq \ldots \geq z_{j_M}$
- Density: $C \cdot \frac{\prod_{l=2}^{M} (z_{j_l}/z_{j_{l-1}})^{Deg(\{j_l, j_{l+1}, \ldots, j_M\})}}{z_1 \cdot z_2 \cdot \ldots \cdot z_M}$,

Deg is defined on subsets of {1,…,M}

(the idea of E.Speer, J. Math. Phys. 9, 1404 (1968))

- My ideas are:

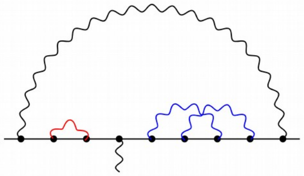
1) how to calculate *Deg*(s) for each set s

(taking into account the infrared behavior etc.)

2) how to generate samples fastly

$A_1^{(8)}$

Example of a diagram from (1,2,1):



Class	Value	Laporta, 2017
(1,3,0)	-1.96956(93)	-1.97107…
(2,2,0)	-0.1439(12)	-0.14248…
(1,2,1)	-0.6224(10)	-0.62192…
(3,1,0)	-1.04093(90)	-1.04054…
(2,1,1)	1.08594(76)	1.08669…
(4,0,0)	0.51185(34)	0.51246…

$A_1^{(10)}$: diagrams without electron loops

T. Aoyama, T. Kinoshita, M. Nio, 2019 (90% confidence): 7.668(159)

My result (1σ): **6.782(113)** 25797 GPU-hours, NVidia Tesla V100, supercomputer «Govorun», JINR

Calc 1: 6.739(132) 19515 GPU-hours, CURAND MRG32k3a generator

Calc 2: 6.905(220) 6282 GPU-hours, CURAND Philox_4x32_10 generator

- 3213 Feynman diagrams
- 13-dimensional integrals
- 807 classes of diagrams for comparison with the direct subtraction on the mass shell
- 9 gauge-invariant classes (k,m,n)
- 500 GB of the integrands code (compiled)
- $1.9 \cdot 10^{14}$ Monte Carlo samples

Class	Value	Calc 1	Calc 2	N_{diag}
(1,4,0)	6.172(42)	6.158(49)	6.209(80)	706
(2,3,0)	-0.724(54)	-0.746(63)	-0.66(10)	706
(1,3,1)	0.895(43)	0.854(50)	1.007(82)	148
(3,2,0)	-0.396(43)	-0.399(51)	-0.390(85)	558
(2,2,1)	-2.160(46)	-2.133(53)	-2.236(90)	370
(4,1,0)	-1.017(26)	-1.028(31)	-0.984(51)	336
(1,2,2)	0.301(25)	0.312(30)	0.267(50)	55
(3,1,1)	2.624(30)	2.628(35)	2.614(58)	261
(5,0,0)	1.0898(80)	1.0929(94)	1.081(15)	73

Three loop QCD corrections to heavy quark form factors

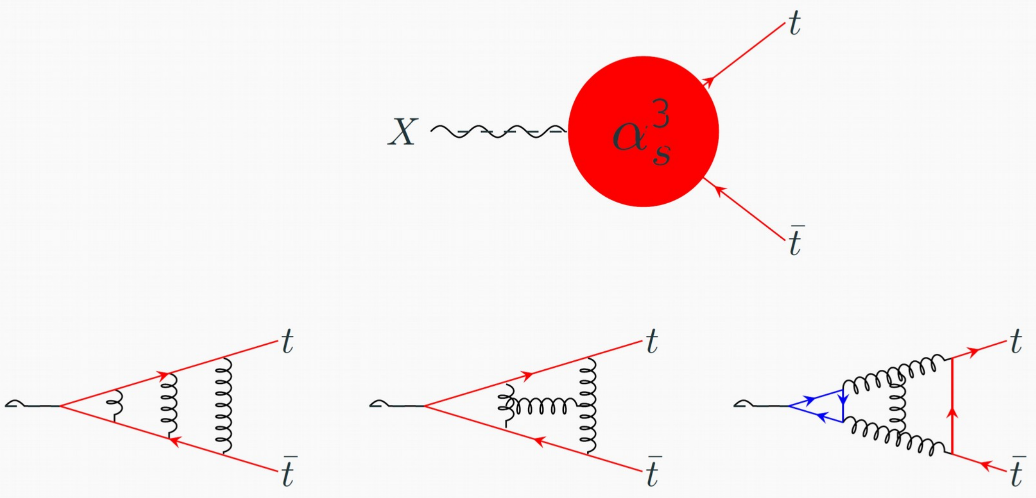
#484 Rana

Narayan Rana J. Ablinger, J. Blümlein, P. Marquard, C. Schneider

INFN Milan

In this talk, we present a brief overview on the generic procedure to compute top pair production at electron-positron colliders.

`Specifically, what we compute`



+ many more

To solve such a system, it would be best to organize it in such a way that it diagonalizes, or at least it takes a block-triangular form.

#484 Rana

A glimpse of the result

$$
\begin{aligned}
F_{A,1}^{(3)} = C_F n_l^2 T_F^2 \Bigg[& \frac{1}{\varepsilon^3}\Big\{\frac{16}{27} - \frac{32}{27}\xi H_0\Big\} + \frac{1}{\varepsilon^2}\Big\{\frac{208}{81} + \xi\Big(-\frac{32}{9}H_{0,0} + \frac{64}{9}H_{-1,0} + \frac{32}{9}\zeta_2\Big) - \frac{16}{81}\Big(47 + 18x \\
& + 47x^2\Big)\eta H_0\Big\} + \frac{1}{\varepsilon}\Big\{\frac{688}{81} + \eta\Big(-\frac{16}{27}\Big(93+2x+93x^2\Big)H_0 - \frac{16}{27}\Big(47+18x+47x^2\Big)H_{0,0} + \frac{32}{27}\Big(47 \\
& + 18x + 47x^2\Big)H_{-1,0} + \frac{8}{27}\Big(121 + 36x + 67x^2\Big)\zeta_2\Big) + \xi\Big(-\frac{32}{3}H_{0,0,0} + \frac{64}{3}H_{0,-1,0} + \frac{64}{3}H_{-1,0,0} \\
& - \frac{128}{3}H_{-1,-1,0} + \Big(-\frac{16}{3}H_0 - \frac{64}{3}H_{-1}\Big)\zeta_2 + \frac{64}{3}\zeta_3\Big)\Big\} + \Big\{\frac{18224}{729} + \eta\Big(-\frac{16}{729}\Big(12475 - 3078x \\
& + 12475x^2\Big)H_0 - \frac{16}{9}\Big(93 + 2x + 93x^2\Big)H_{0,0} + \frac{32}{9}\Big(93 + 2x + 93x^2\Big)H_{-1,0} - \frac{16}{9}\Big(47 + 18x \\
& + 47x^2\Big)H_{0,0,0} + \frac{32}{9}\Big(47 + 18x + 47x^2\Big)H_{0,-1,0} + \frac{32}{9}\Big(47 + 18x + 47x^2\Big)H_{-1,0,0} - \frac{64}{9}\Big(47 \\
& + 18x + 47x^2\Big)H_{-1,-1,0} + \Big(\frac{8}{9}\Big(225 + 4x + 147x^2\Big) - \frac{8}{9}\Big(47 + 18x + 47x^2\Big)H_0 - \frac{32}{9}\Big(47 \\
& + 18x + 47x^2\Big)H_{-1}\Big)\zeta_2 + \frac{16}{27}\Big(319 + 108x + 245x^2\Big)\zeta_3\Big) + \xi\Big(-32H_{0,0,0,0} + 64H_{0,0,-1,0} \\
& + 64H_{0,-1,0,0} - 128H_{0,-1,-1,0} + 64H_{-1,0,0,0} - 128H_{-1,0,-1,0} - 128H_{-1,-1,0,0} + 256H_{-1,-1,-1,0} \\
& + \Big(-16H_{0,0} - 64H_{0,-1} + 32H_{-1,0} + 128H_{-1,-1}\Big)\zeta_2 + \frac{384}{5}\zeta_2^2 + \Big(\frac{544H_0}{27} - 128H_{-1}\Big)\zeta_3\Big)\Big\}\Bigg] \\
& + C_F^2 n_l T_F\Bigg[\frac{1}{\varepsilon^3}\Big\{-\frac{4}{3}\Big(17 + 10x + 17x^2\Big)x_+^2 + \frac{8\eta x_+^2}{3}\Big(1 + 20x + 14x^2 + 20x^3 + x^4\Big)H_0 \\
& - \frac{16}{3}\xi^2 H_{0,0}\Big\} + \frac{1}{\varepsilon^2}\Big\{\frac{1}{9}\Big(-187 + 706x - 187x^2\Big)x_+^2 + \eta x_+^2\Big(\frac{16}{9}\Big(7 + 167x + 77x^2 + 167x^3 \\
& + 7x^4\Big)H_0 - 8\Big(1 + 20x + 14x^2 + 20x^3 + x^4\Big)H_{-1,0} - 4\Big(1 + 20x + 14x^2 + 20x^3 + x^4\Big)\zeta_2\Big) \\
& + \xi^2\Big(-24H_{0,0,0} + 16H_{0,-1,0} + 32H_{-1,0,0} + 8H_0\zeta_2\Big) - \frac{4\eta^2 x_+}{9}\Big(65 - 61x + 238x^2 + 130x^3 \\
& + 281x^4 + 83x^5\Big)H_{0,0}\Big\} + \frac{1}{\varepsilon}\Big\{\frac{1}{54}\Big(-14071 + 13546x - 14071x^2\Big)x_+^2 + \xi^2\Big(-\frac{160}{3}H_{0,-1,-1,0} \\
& - \frac{256}{3}H_{1,0,1,0} + \frac{256}{3}H_{1,0,-1,0} + 144H_{-1,0,0,0} - 96H_{-1,0,-1,0} - 192H_{-1,-1,0,0} - 48H_{-1,0}\zeta_2
\end{aligned}
$$

Algorithm to find an all-order in the running coupling solution to an equation of the DGLAP type

#454 Kondrashuk

Igor Kondrashuk

UBB, Chillan, Chile

Gustavo Álvarez[1], Igor Kondrashuk[2]
(1) Hamburg DESY
(2) Departamento de Ciencias Basicas, Universidad del Bio-Bio (Chile)

The DGLAP IDE may be written in such a form

$$\int_{a-i\infty}^{a+i\infty} dN x^{-N} \phi_1(N) u^{\frac{\alpha}{2\pi}\gamma(N,\alpha)} \left[\gamma(N,\alpha) - \int_x^1 \frac{dy}{y} y^N P_{GG}(y,\alpha)\right]$$

$$= \int_{a-i\infty}^{a+i\infty} dN x^{-N} \phi_1(N) u^{\frac{\alpha}{2\pi}\gamma(N,\alpha)} \int_0^x \frac{dy}{y} y^N P_{GG}(y,\alpha) = 0$$

Toward an efficient evaluation of two-loop massive scalar integrals **#449 Guillet**

Renormalization of gauge theories at five loops

York Schröder

(UBB Chillán)

recent work with John Gracey, Ian Jack,
Thomas Luthe, Andreas Maier, Peter Marquard

and earlier work with
J. Möller, C. Studerus

#451 Schröder

result: 5-loop QCD β-function [with Luthe/Maier/Marquard]

- $\beta = \partial_{\ln\mu^2} a = -a\Big[\epsilon + \frac{11-4\,n_f}{3}\,a + b_1\,a^2 + b_2\,a^3 + b_3\,a^4 + b_4\,a^5 + \dots\Big]$
- $3^5\,b_4 = n_f^4\Big[c_1\,c_f + c_2\Big]$ [Gracey 1996]

  $+\,n_f^3\Big[c_3\,c_f^2 + c_4\,c_f + c_5\,d_{FF} + c_6\Big]$ [LMMS 2016]

  $+\,n_f^2\Big[\dots\Big] + n_f\Big[\dots\Big] + \Big[c_{22}\,d_{AA} + c_{23}\Big]$ [Herzog/Ruijl/Ueda/Vermaseren/Vogt 2017]
- the n_f^4 term agrees exactly with known result
- all c_i in terms of Zeta values,

  e.g. $c_6 = -3(6231 + 9736\zeta_3 - 3024\zeta_4 - 2880\zeta_5)$
- last row confirmed [LMMS 2017]

completion of 5-loop renormalization program

- besides β and γ_m, have also $Z_{\psi\psi}$, Z_{cc} and Z_{ccg} (Fy gauge + ξ^1) [LMMS 2017]
- all other RCs follow from these five, due to gauge invariance
- full gauge dependence now also available [Chetyrkin/Falcioni/Herzog/Vermaseren 2017]

Multi-leg Calculations

FUTURE e^+e^- COLLIDER PROJECTS

#360 Arbuzov

Linear Colliders

- ILC, CLIC
- ILC: technology is ready, to be built in Japan (?)

E_{tot}

- ILC: 91; 250 GeV — 1 TeV
- CLIC: 500 GeV — 3 TeV

$\mathcal{L} \approx 2 \cdot 10^{34}$ cm^{-2}s^{-1}

Stat. uncertainty $\sim 10^{-3}$

Beam polarization:
e^-beam: $P = 80 - 90\%$
e^+beam: $P = 30 - 60\%$

Circular Colliders

- FCC-ee, TLEP
- CEPC
- muon collider (?)

E_{tot}

- 91; 160; 240; 350 GeV

$\mathcal{L} \approx 2 \cdot 10^{36}$ cm^{-2}s^{-1} (4 exp.)

Stat. uncertainty $< 10^{-3}$

Beam polarization: desirable

QED and electroweak radiative corrections to polarized Bhabha scattering

#360 Arbuzov

Andrej Arbuzov

BLTP, JINR, Dubna

(on behalf of the SANC group)

SANC FOR PROCESSES WITH POLARIZED BEAMS

- NLO EW corrections for polarized e^+e^- scattering:
  - Bhabha scattering (PRD 2018)
  - $e^+e^- \to ZH$ (arXiv:1812.10965)
  - $e^+e^- \to \mu^+\mu^-$(or $\tau^+\tau^-$) (preliminary)
  - $e^+e^- \to Z\gamma$ (preliminary)
  - $e^+e^- \to \gamma\gamma$ (preliminary)
  - $e^+e^- \to t\bar{t}$ (in progress)
  - $e^+e^- \to ZZ$ (in progress)
  - $e^+e^- \to f\bar{f}\gamma$ (future plans)
  - $e^+e^- \to f\bar{f}H$ (future plans)
- NLO EW corrections for polarized $\gamma\gamma$ scattering:
  - $\gamma\gamma \to \gamma\gamma$ (future plans)
  - $\gamma\gamma \to Z\gamma$ (future plans)
  - $\gamma\gamma \to ZZ$ (future plans)

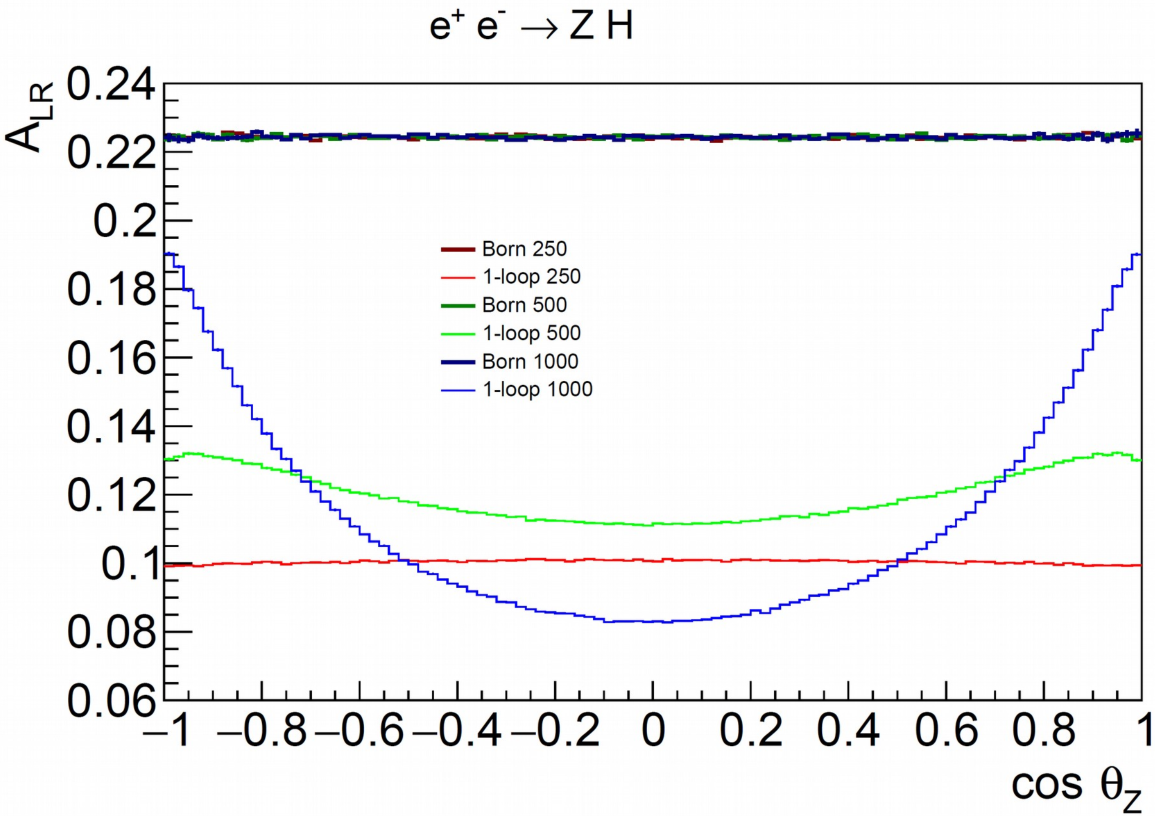
MCSANC$_{ee}$ – Event Generator for polarized e^+e^- scattering at one-loop EW

#361 Sadykov

Renat Sadykov
DLNP JINR, Dubna
for the SANC/ARIeL team

$e^+e^- \to ZH$: A_{LR} distributions in $\cos\theta$

$$A_{LR} = \frac{\sigma_{LR}-\sigma_{RL}}{\sigma_{LR}+\sigma_{RL}}$$



Recent developments of GRACE system

Yoshimasa Kurihara (KEK)

#461 Kurihara

- Beam polarization
  - e^- (80%), e^+(30%)

Projection operator: $P_\lambda = \frac{1}{2}(1 + \lambda\gamma_5 \not{p}/m)$

Code optimization

$e^+e^- \to H\mu^+\mu^-$ 2235 loop diagrams

			Pol	
			0	1
Opt	0	src	1.0GB	5.9GB
		obj	4.9GB	31.5GB
	1	src		6.3GB
		obj		3.3GB

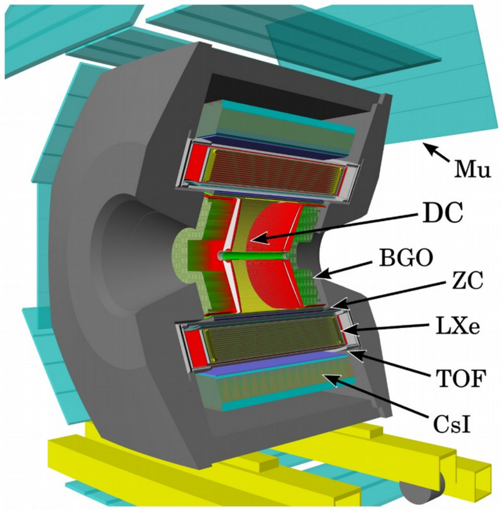
Data-driven low-energy generator for CMD-3

#486 Korobov

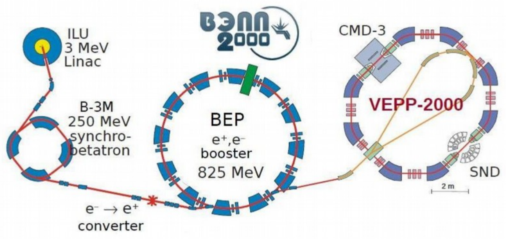
S. Eidelman, A. Korobov

Budker Institute of Nuclear Physics
NSU

CMD-3

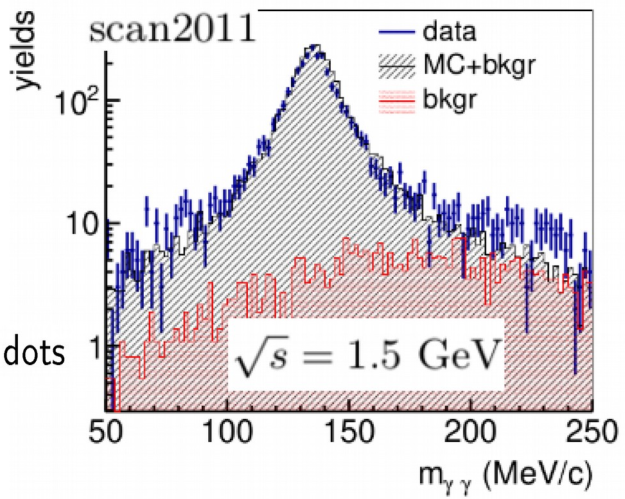


Collider VEPP-2000
$L = 4 * 10^{31} cm^{-2}s^{-1}$ at 2.0 GeV



- MHG2000-MultiHadronic Generator for VEPP-2000
- pQCD fails at the energy range $\sqrt{s} < 2$ GeV
- One of CMD-3's goals is the precision measurement of exclusive hadron cross section
- Evaluation of the background for hadronic processes
- It is data-driven generator based on the bulk of measured exclusive cross sections

Application at CMD-3: $\pi^+\pi^-\pi^0\pi^0$



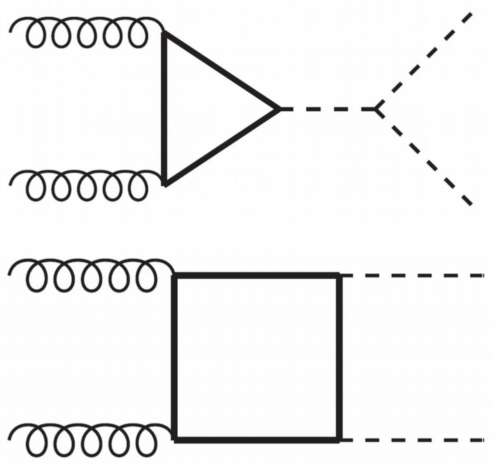
Red for MHG2000 without signal dots
Two photon invariant mass:
for data CMD-3 preliminary

Double Higgs Production in the high- and low-energy limits

#359 Davies

Joshua Davies, Go Mishima, Matthias Steinhauser, David Wellmann

Dominant channel at a hadron collider: gluon fusion.



$$\mathcal{M}^{\mu\nu} \sim \mathcal{A}_1^{\mu\nu}(\mathcal{F}_{tri} + \mathcal{F}_{box1}) + \mathcal{A}_2^{\mu\nu}(\mathcal{F}_{box2})$$

LO

- full result [Glover,van der Bij '88][Plehn,Spira,Zerwas '98]

NLO

- numerical result [Borowka,Greiner,Heinrich,Jones,Kerner,Schlenk,Zicke '16] [Baglio,Campanario,Glaus,Mühlleitner,Spira,Streicher '18]
- large-m_t limit [Dawson,Dittmaier,Spira '98] [Grigo,Hoff,Melnikov,Steinhauser '13] [Degrassi,Giardine,Gröber '16]
- Padé approx. (large-m_t + threshold) [Gröber,Maier,Rauh '17]

NNLO

- large-m_t limit [de Florian,Mazzitelli '13] [Grigo,Melnikov,Steinhauser '14] [Grigo,Hoff,Steinhauser '15]
- finite-m_t estimate [Grazzini,Heinrich,Jones,Kallweit,Kerner,Lindert,Mazzitelli '18]

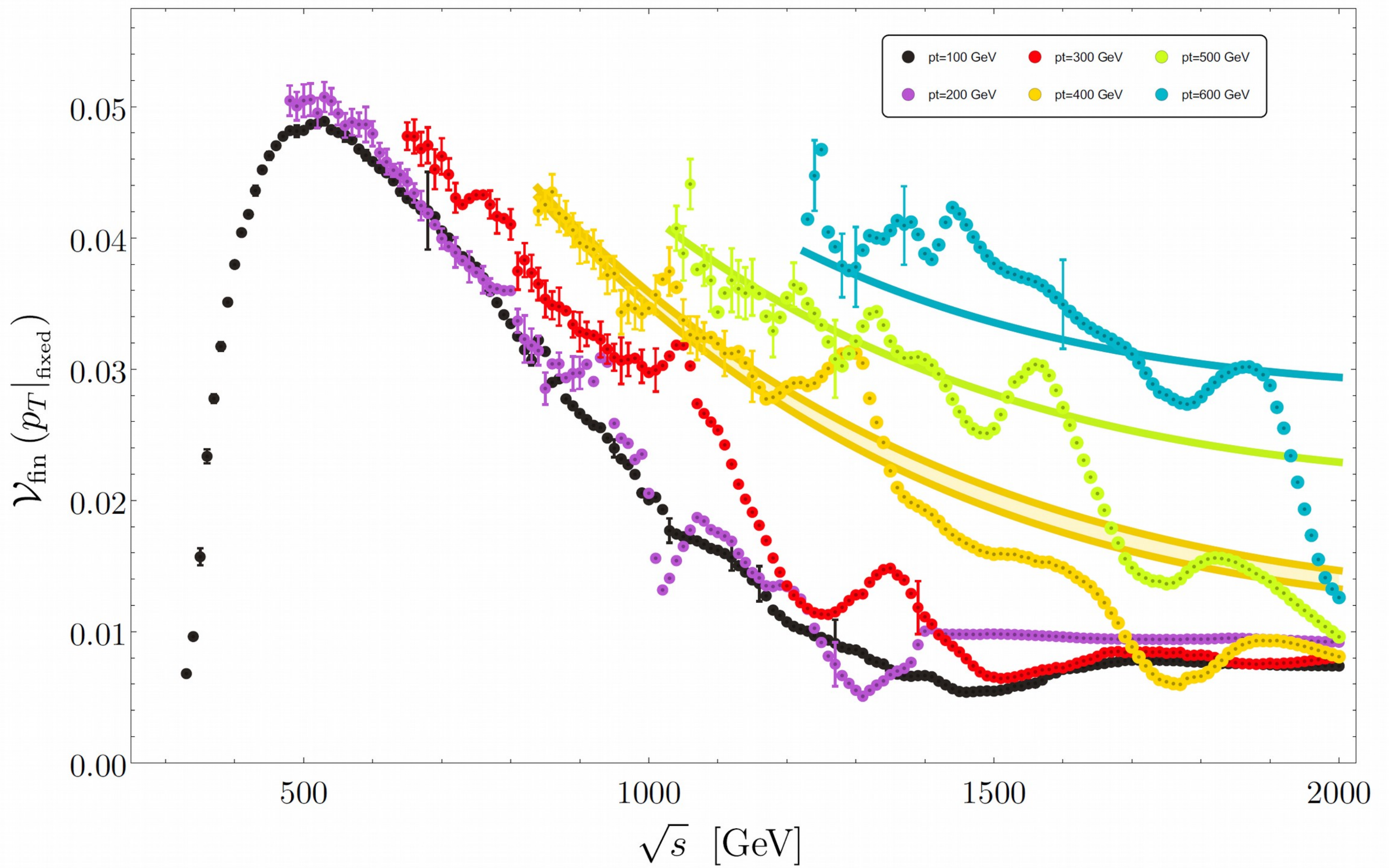
This talk:

- **NLO high-energy limit** [Davies,Mishima,Steinhauser,Wellmann '18,'19]
- **NNLO large-m_t limit**

Results: V_{fin}

#359 Davies

V_{fin}: IR finite (subtracted) virtual cross-section.



Probing the trilinear Higgs boson coupling in di-Higgs production at NLO QCD in Powheg

#356 Scyboz

G. Heinrich[1], S. Jones[2], M. Kerner[3], G. Luisoni[1], **L. Scyboz**[1]

Varying the Higgs couplings

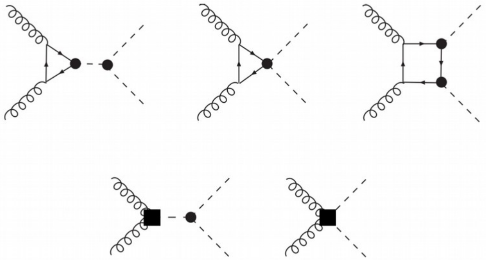
JHEP09 (2018) 057

Full m_t−dependence:

- Full NLO QCD for hh within a non-linear EFT
  [Buchalla, Capozi, Celis, Heinrich, LS '18]
- 5 anomalous couplings:

$$\mathscr{L} \supset -m_t \left(y_t \frac{h}{v} + c_{tt} \frac{h^2}{v^2} \right) \bar{t}\, t - \kappa_\lambda \frac{m_h^2}{2v} h^3 + \frac{\alpha_s}{8\pi} \left(c_{ggh} \frac{h}{v} + c_{gghh} \frac{h^2}{v^2} \right) G^a_{\mu\nu} G^{a,\mu\nu}$$

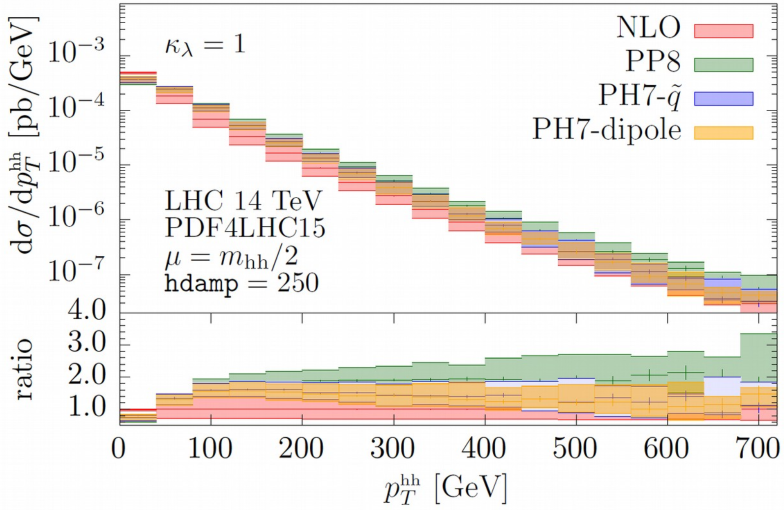
LO diagrams



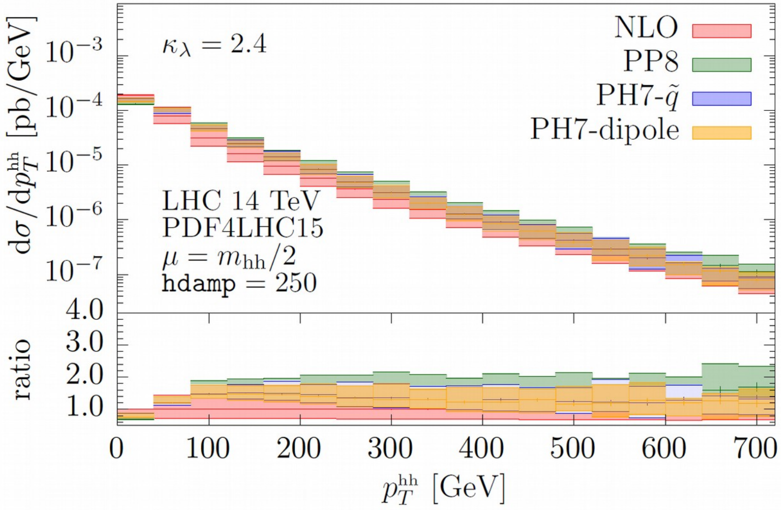
Showered results

#356 Scyboz

- Pythia8 generates much harder radiation in the high-p_T^{hh} tail
- Very similar results for both Herwig showers



$\kappa_\lambda = 1.0$



$\kappa_\lambda = 2.4$

New Features in FeynArts & Friends, and how they got used in FeynHiggs

#347 Hahn

Thomas Hahn
Max-Planck-Institut für Physik
München

Many small functions/additions to FeynArts, FormCalc, & LoopTools, mostly triggered by FeynHiggs development.

Together significant improvements, in particular in code generation:

- **Convenience of Code Generation:**
  `DeclIf`, `Enum`, `ClearEnum`
- **Variable/Abbreviation handling:**
  `ToVars`, `MakeTmp`, `Abbreviate`
- **Generic Amplitudes:**
  persistent names, propagator-type-dependent particle properties, mixing fields
- **Mixing precision** within the same code

Update on

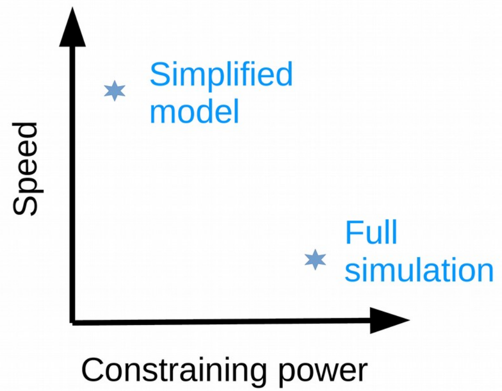
#378 Waltenberger

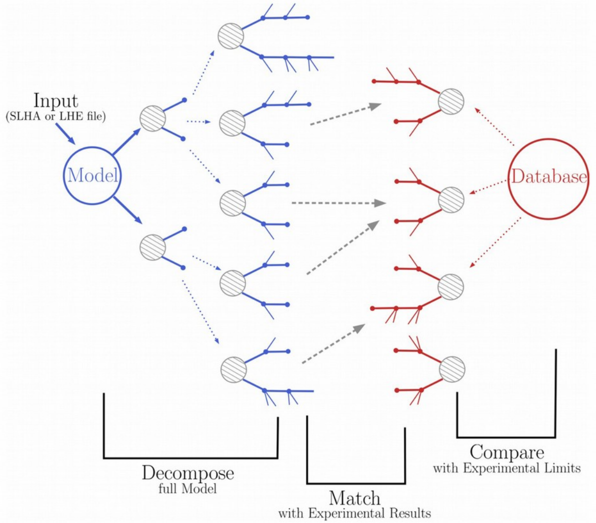
Recap: the Idea behind SModelS

Wolfgang Waltenberger
HEPHY and Vienna University

for the SModelS group

SModelS confronts theories beyond the Standard Model (BSM) with LHC search results by decomposing full models into their simplified models topologies, and comparing the cross section predictions of these individual topologies with a database of SMS results.





SModelS database

#378 Waltenberger

#	ID	pretty name	Topologies	Type	$\mathcal{L}$ [fb^{-1}]
1	ATLAS-SUSY-2015-01	2 b-jets + $\not{E}_T$	1: T2bb	ul	3.2
2	ATLAS-SUSY-2015-02	single l stop	1: T2tt	ul	3.2
	ATLAS-SUSY-2015-02	single l stop	1: T2tt	eff	3.2
3	ATLAS-SUSY-2015-06	0 l's + 2-6 jets + $\not{E}_T$	2: T1, T2	eff	3.2
4	ATLAS-SUSY-2015-09	jets + 2 SS l's or >=3 l's	1: T1tttt	ul	3.2
5	ATLAS-SUSY-2016-14	2 SS or 3 l's + jets + $\not{E}_T$	3: T1tt[off]tt, T1tttt[off]...	ul	36.1
6	ATLAS-SUSY-2016-17	2 opposite sign l's + $\not{E}_T$	2: T2bbWW[off], T2tt[off]...	ul	36.1
7	ATLAS-SUSY-2016-19	stops to staus	1: T4bnutaubnutau...	ul	36.1
8	ATLAS-SUSY-2016-26	>=2 c jets + $\not{E}_T$	1: T2cc	ul	36.1
9	ATLAS-SUSY-2016-33	2 OSSF l's + $\not{E}_T$	2: T5ZZ, T6ZZ	ul	36.1
10	ATLAS-SUSY-2017-03	multi-l EWK searches	1: TChiWZ	ul	36.1
11	ATLAS-CONF-2012-105	2 SS l's + >= 4 jets + $\not{E}_T$	1: T1tttt	ul	5.8
12	ATLAS-CONF-2012-166	1 l + 4(1 b-)jets + $\not{E}_T$	1: T2tt	ul	13.0
13	ATLAS-CONF-2013-001	0 l's + 2 b-jets + $\not{E}_T$	1: T6bbWW[off]	ul	12.8
14	ATLAS-CONF-2013-007	2 SS l's + 0-3 b-jets + $\not{E}_T$	4: T1btbt, T1tttt...	ul	20.7
15	ATLAS-CONF-2013-024	0 l + 6 (2 b-)jets + $\not{E}_T$	1: T2tt	ul	20.5
	ATLAS-CONF-2013-024	0 l + 6 (2 b-)jets + $\not{E}_T$	21: T1bbbb, T1bbbt...	eff	20.5
16	ATLAS-CONF-2013-025	>= 5 (>=1 b-)jets + 2, 3 SFOS l's + $\not{E}_T$	1: T6ZZtt	ul	20.7
17	ATLAS-CONF-2013-035	3 l's (e,mu) + $\not{E}_T$	2: TChiChipmSlepL...	ul	20.7
18	ATLAS-CONF-2013-037	1 l + >= 4(1 b-)jets + $\not{E}_T$	1: T2tt	ul	20.7
	ATLAS-CONF-2013-037	1 l + >= 4(1 b-)jets + $\not{E}_T$	18: T1bbbb, T1bbbt...	eff	20.7
19	ATLAS-CONF-2013-047	0 l's + 2-6 jets + $\not{E}_T$	3: T1, T5WW[off]...	ul	20.3
	ATLAS-CONF-2013-047	0 l's + 2-6 jets + $\not{E}_T$	24: T1, T1bbbb, T1bbbt...	eff	20.3
20	ATLAS-CONF-2013-048	2 l's + (b-)jets + $\not{E}_T$	2: T2bbWW, T6bbWW[off]...	ul	20.3
	ATLAS-CONF-2013-048	2 l's + (b)jets + $\not{E}_T$	11: T1bbtt, T1btbt...	eff	20.3
21	ATLAS-CONF-2013-049	2 l's (e,mu) + $\not{E}_T$	1: TSlepSlep	ul	20.3
22	ATLAS-CONF-2013-053	0 l's + 2 b-jets + $\not{E}_T$	1: T2bb	ul	20.1
	ATLAS-CONF-2013-053	0 l's + 2 b-jets + $\not{E}_T$	17: T1bbbb, T1bbbt...	eff	20.1
23	ATLAS-CONF-2013-054	0 l's + >= 7-10 jets + $\not{E}_T$	24: T1, T1bbbb, T1bbbt...	eff	20.3
24	ATLAS-CONF-2013-061	jets + >= 3 b-jets + $\not{E}_T$	3: T1bbbb, T1btbt...	ul	20.1
	ATLAS-CONF-2013-061	jets + >= 3 b-jets + $\not{E}_T$	21: T1bbbb, T1bbbt...	eff	20.1
25	ATLAS-CONF-2013-062	1 l + jets + $\not{E}_T$	21: T1, T1bbbb, T1bbbt...	eff	20.3
26	ATLAS-CONF-2013-065	2 l's + (b-)jets + $\not{E}_T$	2: T2tt, T6bbWW	ul	20.3
27	ATLAS-CONF-2013-089	2 l's (e,mu) + $\not{E}_T$	1: T6WW	ul	20.3
28	ATLAS-CONF-2013-093	1 l + 2 b-jets + $\not{E}_T$	1: TChiWH	ul	20.3
	ATLAS-CONF-2013-093	1 l + 2 b-jets + $\not{E}_T$	6: T1bbbt, T2bt, T2tt...	eff	20.3
29	ATLAS-SUSY-2013-02	0 l's + 2-6 jets + $\not{E}_T$	5: T1, T2, T5WW[off]...	ul	20.3
	ATLAS-SUSY-2013-02	jets and met	4: T1, T2, T3GQ, T5...	eff	20.3
30	ATLAS-SUSY-2013-04	0 l's + >= 7-10 jets + $\not{E}_T$	1: T1tttt	ul	20.3
	ATLAS-SUSY-2013-04	0 l's + >= 7-10 jets + $\not{E}_T$	8: T1bbbb, T1btbt...	eff	20.3
31	ATLAS-SUSY-2013-05	0 l's + 2 b-jets + $\not{E}_T$	2: T2bb, T6bbWW[off]...	ul	20.1
	ATLAS-SUSY-2013-05	0 l's + 2 b-jets + $\not{E}_T$	1: T2bb	eff	20.1
32	ATLAS-SUSY-2013-08	Z + b-jets + $\not{E}_T$	1: T6ZZtt	ul	20.3
33	ATLAS-SUSY-2013-09	2 SS l's + $\not{E}_T$	1: T1tttt	ul	20.3
34	ATLAS-SUSY-2013-11	2 l's (e,mu) + $\not{E}_T$	4: TChiWW, TChiWZ...	ul	20.3
	ATLAS-SUSY-2013-11	2 l's (e,mu) + $\not{E}_T$	3: TChiWW[off], TChipChimSlepSnu...	eff	20.3
35	ATLAS-SUSY-2013-12	3 l's (e,mu,tau) + $\not{E}_T$	4: TChiChipmSlepL...	ul	20.3
36	ATLAS-SUSY-2013-15	1 l + 4 (1 b-)jets + $\not{E}_T$	1: T2tt	ul	20.3
	ATLAS-SUSY-2013-15	1 l + 4 (1 b-)jets + $\not{E}_T$	1: T2tt	eff	20.3
37	ATLAS-SUSY-2013-16	0 l + 6 (2 b-)jets + $\not{E}_T$	1: T2tt	ul	20.1
	ATLAS-SUSY-2013-16	0 l + 6 (2 b-)jets + $\not{E}_T$	1: T2tt	eff	20.1
38	ATLAS-SUSY-2013-18	0-1 l's + >= 3 b-jets + $\not{E}_T$	2: T1bbbb, T1tttt...	ul	20.1
	ATLAS-SUSY-2013-18	0-1 l's + >= 3 b-jets + $\not{E}_T$	2: T1bbbb, T1tttt...	eff	20.1
39	ATLAS-SUSY-2013-19	2 OS l's + (b-)jets + $\not{E}_T$	2: T2bbWW, T2tt	ul	20.3
40	ATLAS-SUSY-2013-21	monojet or c-jet + $\not{E}_T$	3: T2bb, T2bbWW[off]...	eff	20.3
41	ATLAS-SUSY-2013-23	1 l + 2 b-jets (or 2 γs) + $\not{E}_T$	1: TChiWH	ul	20.3
42	ATLAS-SUSY-2014-03	>= 2(c-)jets + $\not{E}_T$	1: TScharm	eff	20.3

#	ID	pretty name	Topologies	Type	$\mathcal{L}$ [fb^{-1}]	$\sqrt{s}$
1	CMS-PAS-EXO-16-036	hscp search	3: THSCPM1b, TRHadGM1...	ul	12.9	13
	CMS-PAS-EXO-16-036	hscp search	8: THSCPM1b, THSCPM2b...	eff	12.9	13
2	CMS-PAS-SUS-15-002	>= 4jets + $\not{E}_T$, HT, HTmiss	2: T1, T1bbbb	ul	2.2	13
3	CMS-PAS-SUS-16-014	jets + $\not{E}_T$, HT	6: T1, T1bbbb, T1tttt[off]...	ul	12.9	13
4	CMS-PAS-SUS-16-015	jets + $\not{E}_T$, MT2	6: T1, T1bbbb, T1tttt[off]...	ul	12.9	13
5	CMS-PAS-SUS-16-016	>= 1 jet + $\not{E}_T$, α_T	4: T1bbbb, T1tttt[off]...	ul	12.9	13
6	CMS-PAS-SUS-16-019	jets + 1 l	1: T1tttt[off]	ul	12.9	13
7	CMS-PAS-SUS-16-022	>= 3 l's + $\not{E}_T$	1: T1tttt[off]	ul	12.9	13
8	CMS-PAS-SUS-16-052	soft l, <= 2 jets	2: T2bbWW[off], T6bbWW[off]...	ul	35.9	13
9	CMS-PAS-SUS-16-052-agg	soft l, <= 2 jets	2: T2bbWW[off], T6bbWW[off]...	eff	35.9	13
10	CMS-PAS-SUS-17-004	multi-l EWK searches	2: TChiWH, TChiWZ[off]...	ul	35.9	13
11	CMS-SUS-15-002	multijets + $\not{E}_T$, HT	3: T1, T1bbbb, T1tttt[off]...	ul	2.2	13
12	CMS-SUS-15-008	SS dil	1: T1tttt[off]	ul	2.3	13
13	CMS-SUS-16-032	Sbottom and compressed stop	2: T2bb, T2cc	ul	35.9	13
14	CMS-SUS-16-033	0L + jets + $\not{E}_T$	6: T1, T1bbbb, T1tttt[off]...	ul	35.9	13
15	CMS-SUS-16-034	2 OSSF l's	2: T5ZZ, TChiWZ	ul	35.9	13
16	CMS-SUS-16-035	2 SS l's	7: T1tttt[off], T5WW[off]...	ul	35.9	13
17	CMS-SUS-16-036	0L + jets + $\not{E}_T$	8: T1, T1bbbb, T1tttt[off]...	ul	35.9	13
18	CMS-SUS-16-037	1L + jets + $\not{E}_T$ with MJ	3: T1tttt[off], T5tt[off]tt...	ul	35.9	13
19	CMS-SUS-16-039	multi-l EWK searches	5: TChiChipmSlepL...	ul	35.9	13
20	CMS-SUS-16-041	multi-ls + jets + $\not{E}_T$	6: T1tttt[off], T6HHtt...	ul	35.9	13
21	CMS-SUS-16-042	1L + jets + $\not{E}_T$	2: T1tttt[off], T5WW[off]...	ul	35.9	13
22	CMS-SUS-16-043	EWK WH	1: TChiWH	ul	35.9	13
23	CMS-SUS-16-045	Sbottom to bHbH and H $\rightarrow \gamma\gamma$	2: T6bbHH, TChiWH...	ul	35.9	13
24	CMS-SUS-16-046	γ + $\not{E}_T$	2: T5gg, T6gg	ul	35.9	13
25	CMS-SUS-16-047	γ + HT	2: T5gg, T6gg	ul	35.9	13
26	CMS-SUS-16-049	All hadronic stop	4: T2cc, T2ttC, T2tt[off]...	ul	35.9	13
27	CMS-SUS-16-050	0L + top tag	4: T1tttt[off], T2tt[off]...	ul	35.9	13
28	CMS-SUS-16-051	1L stop	2: T2tt[off], T6bbWW...	ul	35.9	13
29	CMS-SUS-17-001	Stop search in dil + jets + $\not{E}_T$	2: T2tt[off], T6bbWW...	ul	35.9	13
30	CMS-EXO-12-026	hscp search	3: THSCPM1b, TRHadGM1...	ul	18.8	8
31	CMS-EXO-13-006	hscp search	8: THSCPM1b, THSCPM2b...	eff	18.8	8
32	CMS-PAS-SUS-12-022	multi-l + $\not{E}_T$	6: TChiChipmSlepL...	ul	9.2	8
33	CMS-PAS-SUS-12-026	>= 3 l's (+jets) + $\not{E}_T$	1: T1tttt	ul	9.2	8
34	CMS-PAS-SUS-13-015	>= 5(1b-)jets + $\not{E}_T$	1: T2tt[off]	eff	19.4	8
35	CMS-PAS-SUS-13-016	2 OS l's + >= 4 (2 b-)jets + $\not{E}_T$	1: T1tttt[off]	ul	19.7	8
	CMS-PAS-SUS-13-016	2 OS l's + >= 4 (2b-)jets + $\not{E}_T$	1: T1tttt[off]	eff	19.7	8
36	CMS-PAS-SUS-13-018	1-2 b-jets + $\not{E}_T$, M_CT	1: T2bb	ul	19.4	8
37	CMS-PAS-SUS-13-023	hadronic stop	2: T2tt[off], T6bbWW[off]...	ul	18.9	8
38	CMS-PAS-SUS-14-011	razor with b-jets	3: T1bbbb, T1tttt[off]...	ul	19.3	8
39	CMS-SUS-12-024	0 l's + >= 3 (1b-)jets + $\not{E}_T$	1: T1tttt[off]	ul	19.4	8
	CMS-SUS-12-024	0 l's + >= 3 (1b-)jets + $\not{E}_T$	2: T1bbbb, T1tttt[off]...	eff	19.4	8
40	CMS-SUS-12-028	jets + $\not{E}_T$, α_T	5: T1, T1bbbb, T1tttt...	ul	11.7	8
41	CMS-SUS-13-002	>= 3 l's (+jets) + $\not{E}_T$	1: T1tttt	ul	19.5	8
42	CMS-SUS-13-004	>= 1 b-jet + $\not{E}_T$, Razor	3: T1bbbb, T1tttt[off]...	ul	19.3	8
43	CMS-SUS-13-006	EW prod, to l's, W, Z, and H	5: TChiChipmSlepL...	ul	19.5	8
44	CMS-SUS-13-007	1 l + >= 2 b-jets + $\not{E}_T$	2: T1tttt[off], T5tttt...	ul	19.3	8
	CMS-SUS-13-007	1 l + >= 2 b-jets + $\not{E}_T$	1: T1tttt[off]	eff	19.3	8
45	CMS-SUS-13-011	1 l + >= 4 (1b-)jets + $\not{E}_T$	2: T2tt[off], T6bbWW[off]...	ul	19.5	8
	CMS-SUS-13-011	1 l + >= 4 (1b-)jets + $\not{E}_T$	1: T2tt[off]	eff	19.5	8
46	CMS-SUS-13-012	n_{jets} + HTmiss	3: T1, T1tttt[off]...	ul	19.5	8
	CMS-SUS-13-012	n_{jets} + HTmiss	19: T1, T1bbbb, T1btbt...	eff	19.5	8
47	CMS-SUS-13-013	2 SS l's + (b-)jets + $\not{E}_T$	2: T1tttt[off], T6ttWW[off]...	ul	19.5	8
	CMS-SUS-13-013	2 SS l's + (b-)jets + $\not{E}_T$	1: T1tttt[off]	eff	19.5	8
48	CMS-SUS-13-019	>= 2 jets + $\not{E}_T$, MT2	6: T1, T1bbbb, T1tttt[off]...	ul	19.5	8
49	CMS-SUS-14-010	b-jets + 4 Ws	1: T1tttt[off]	ul	19.5	8
50	CMS-SUS-14-021	soft l's, low n_{jets}, high $\not{E}_T$	1: T2bbWW[off]	ul	19.7	8

We collect the results of the experimental collaborations, and augment them with recast analyses (MadAnalysis5, CheckMATE), creating our own efficiency maps. In addition, fastlim kindly allowed us to also use their efficiency maps. SModelS v1.2.2 ships with results of almost 100 different analyses.

https://smodels.github.io/docs/ListOfAnalyses

HepMC3 Event Record Library for Monte Carlo Event Generators

http://hepmc.web.cern.ch/hepmc/

#462 Verbytskyi

Andrii Verbytskyi[1], Andy Buckley[2], David Grellscheid[3], Dmitri Konstantinov[4], Leif Lönnblad[5], James Monk[5,6], Witold Pokorski[4] and Tomasz Przedziński[7]

HepMC3 I/O is easily extendable for different purposes

- See **30 LOCs** to write events for ZEUS detector simulation.
- Writing events into dot format is given in git repository. To be used with GraphViz:

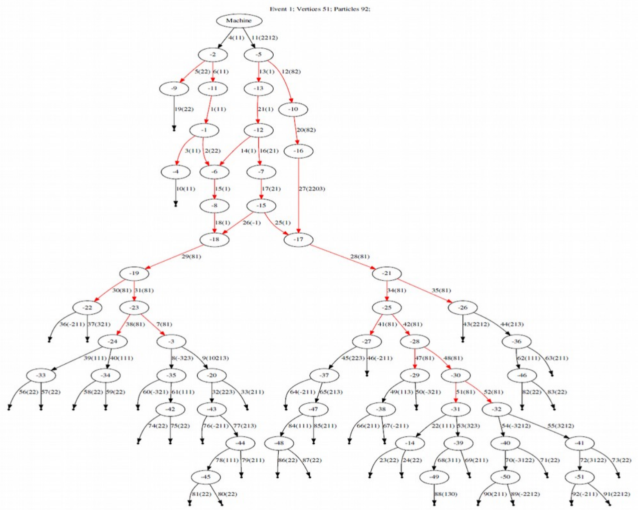


Figure: $e^- p$ collision in Herwig 7.1.4

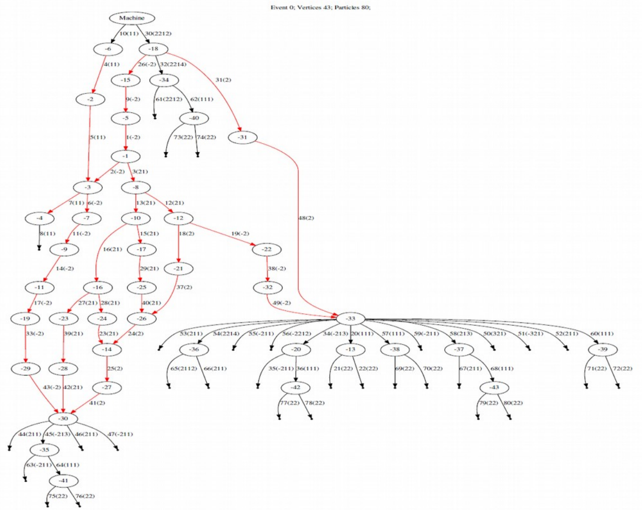


Figure: $e^- p$ collision in Pythia 8.2.40

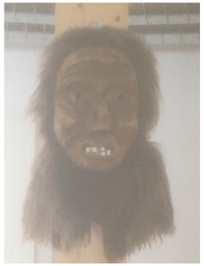
Current usage

#462 Verbytskyi

Code	Type	Implementation
SHERPA-MC	MCEG	3.1/3.0 in SHERPA-MC master/2.2.5
JetScape	MCEG	3.0 in JetScape 1.0
ThePEG	MCEG Toolkit	3.1 in ThePEG master
Herwig7	MCEG	3.1 via ThePEG
Pythia8	MCEG	3.1/3.0 in HepMC3
Pythia6	MCEG	3.1 in HepMC3 examples
Tauola	MCEG	3.1/3.0 in HepMC3
Photos	MCEG	3.1/3.0 in HepMC3
WHIZARD	MCEG	3.0?
EvtGen	MCEG	in touch with authors
GeantV	Simulation	3.0
pyhepmc-ng/scikit-hep	Utility	3.1/3.0 in scikit-hep master
MC-ANALYSER	Analysis/Ploting	HepMC3
Rivet	Analysis/Ploting	work in progress

Note: HepMC3 3.1.0 and HepMC2 can co-exist in one installation → painless migration from HePMC2. +We will help you to find out how to implement HepMC3 support → hepmc-dev@cern.ch.

\+



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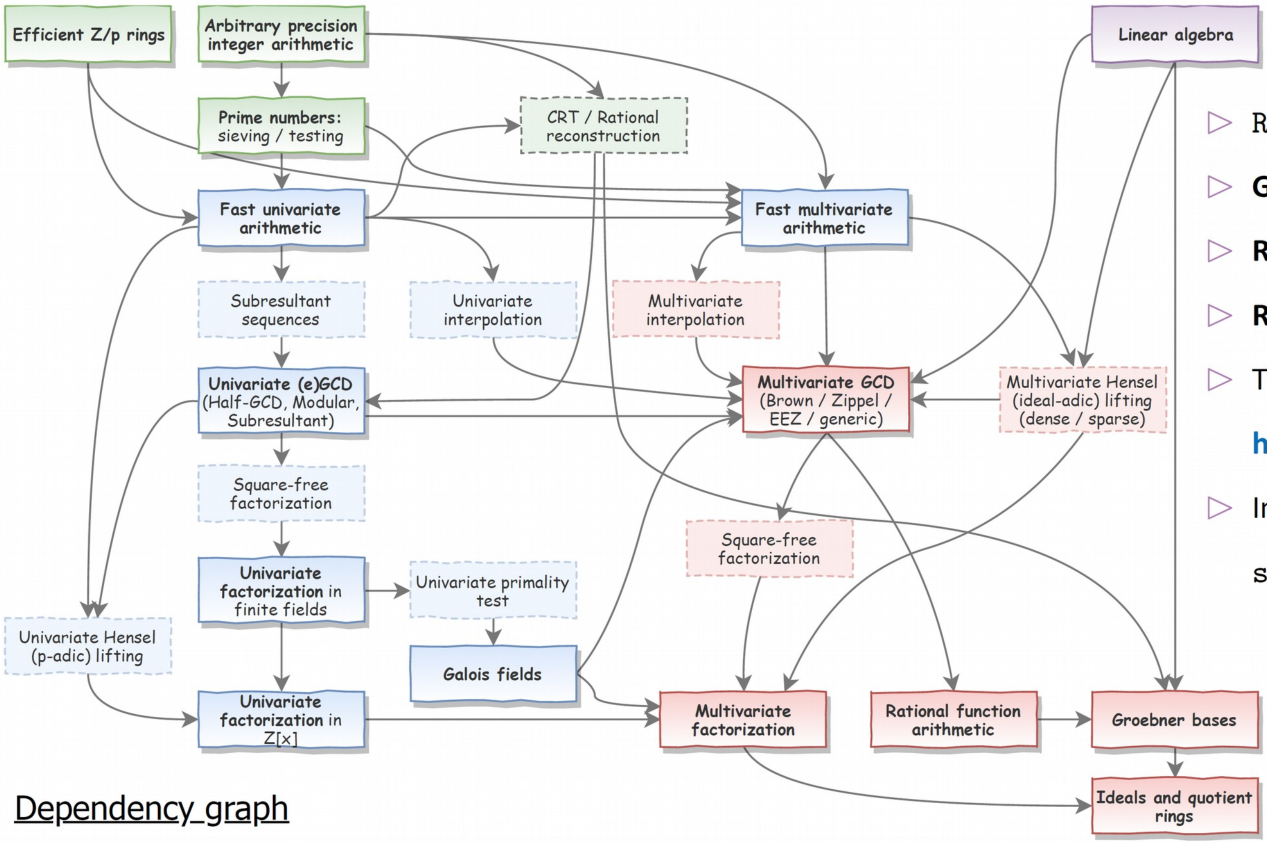
Computer Algebra

Rings: *efficient Java/Scala library for polynomial rings*

#284 Poslavsky

Stanislav Poslavsky

Institute for High Energy Physics NRC "Kurchatov Institute", Protvino, Russia



Dependency graph

- Rings is **93,137** (.java) + **8,386** (.scala) lines of code
- **GitHub**: https://github.com/PoslavskySV/rings
- **RT*D**: https://rings.readthedocs.io
- **Ref:** CPC, Vol. 235, 2019, pp. 400-413, arXiv:1712.02329 [cs.SC]
- Thousands of unit and integration:

  http://circleci.com/gh/PoslavskySV/rings (CI)
- Interactive **REPL**:

```
sh> brew install PoslavskySV/rings/rings.repl
```

Benchmarks: *polynomial GCD*

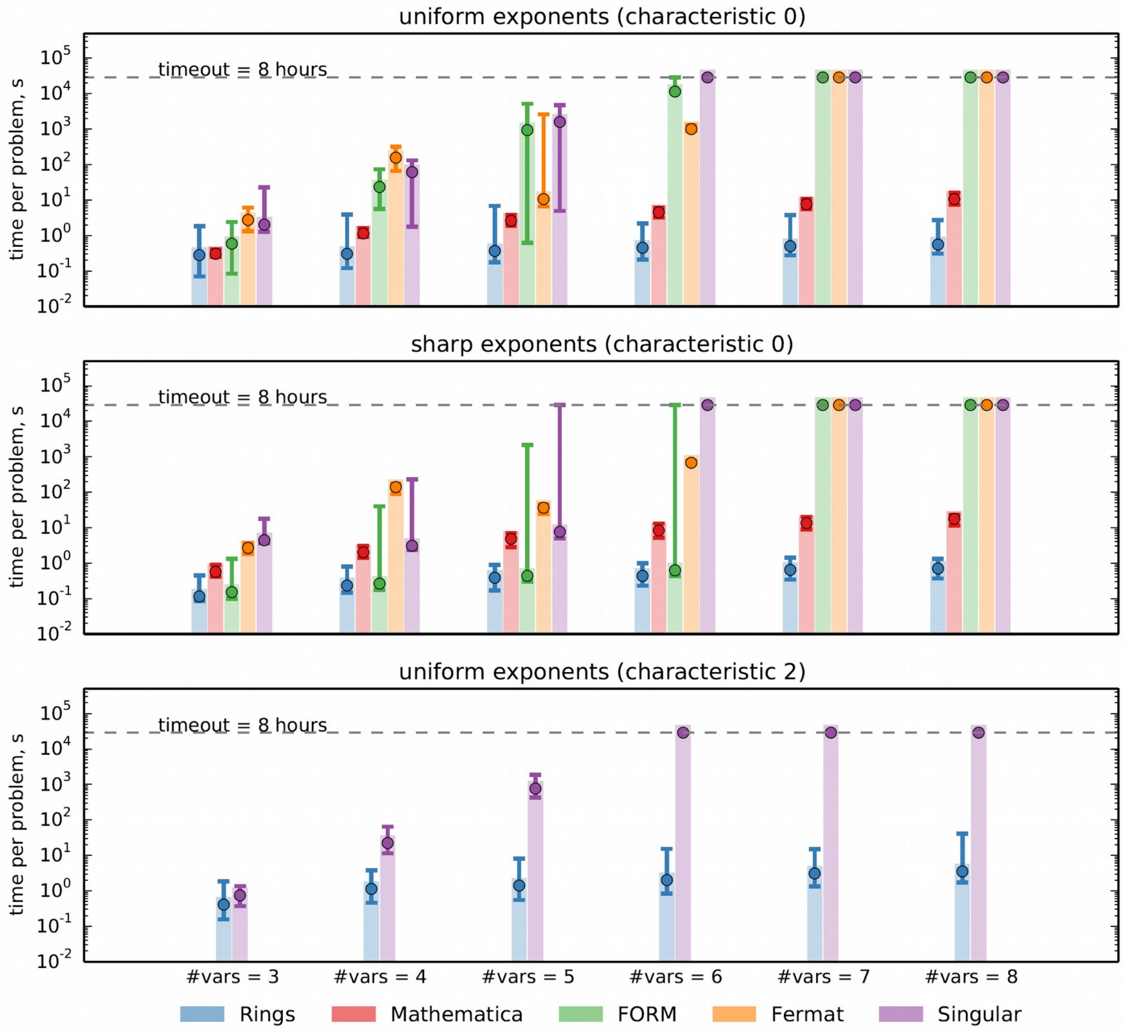
#284 Poslavsky

Params (a,b,g):

#terms = 40
#bits = 32
exp_{min} = 0
exp_{max} = 30

#terms = 40
#bits = 32
exp_{tot} = 50

#terms = 40
#bits = 1
exp_{min} = 0
exp_{max} = 30



▷ reFORM (see Ben's talk) seems has comparable performance

Ben Ruijl

ETH Zurich

Internals

- Almost every operation is an iterator, since the result may not fit in memory
- Expansion operation:

$$\left(x + (1+y)^{10}\right)\left(3 + (x+y)z\right)$$

- Product of factors: Cartesian product iterator
- Subexpressions: sequence iterator
- Powers of positive integer: binomial iterator

Python API for polynomials


```python
import reform

vi = reform.VarInfo()

a = reform.Polynomial("1+x*y+5", vi)
b = reform.Polynomial("x^2+2*x*y+y", vi)
g = a + b

ag = a * g
bg = b * g
print(gcd(ag, bg))

rat = reform.RationalPolynomial(ag, bg)
print(rat)
```

Further developments of FORM

#409 Ueda

Takahiro Ueda
Seikei University, Tokyo

with Toshiaki Kaneko, Ben Ruijl, Jos Vermaseren
KEK, Tsukuba · ETH Zürich · Nikhef, Amsterdam

a toolkit for formula manipulation

`https://github.com/vermaseren/form`
Vermaseren *et al.*

Efficient, especially for very big expressions

e.g.,

TU's talk in ACAT 2016
Ruijl's talk in ACAT 2017

Parallelisation available with `Pthreads` or `MPI`

4.2.1

Latest release

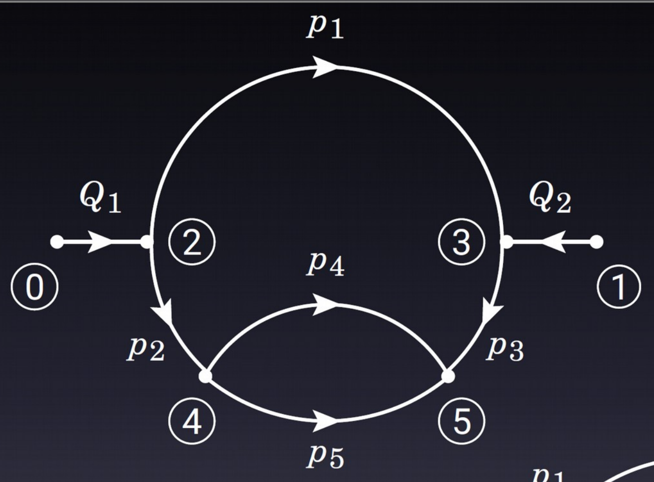
v4.2.1 eaf85a7

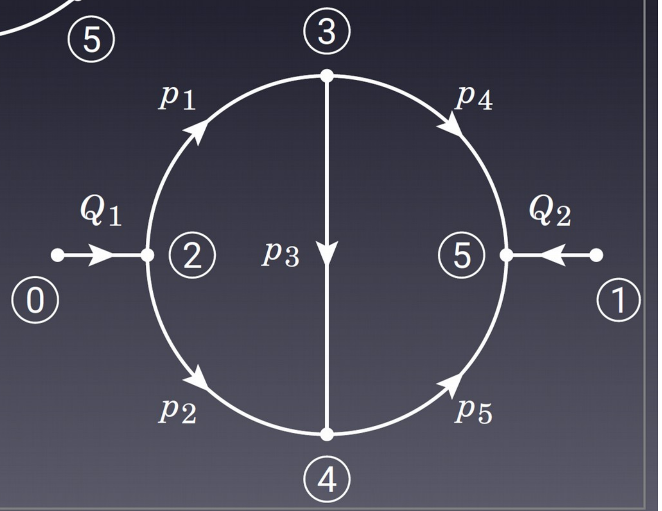
benruijl released this on Feb 2

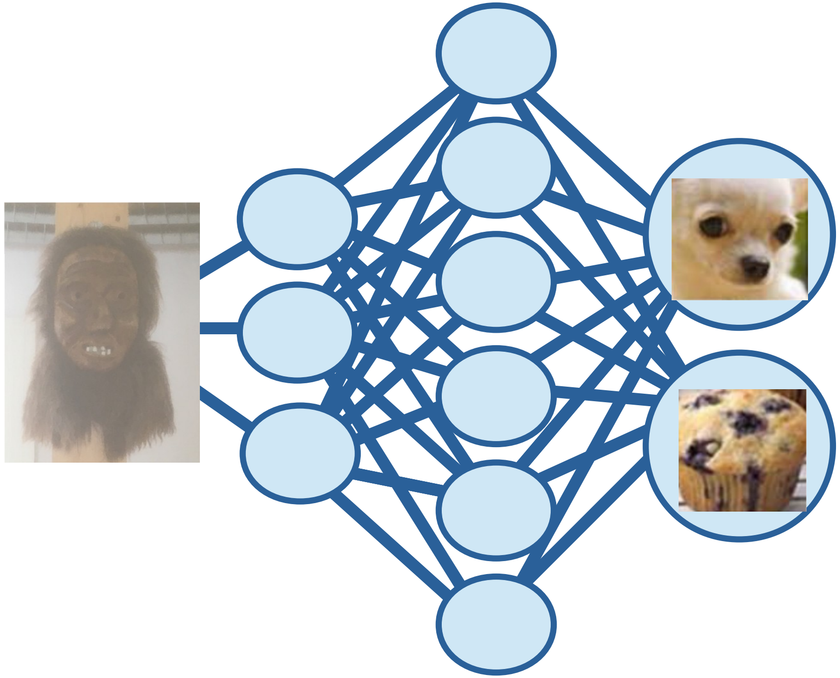
This release is a minor update from 4.2.0 and mostly contains bug fixes. For an overview of the changes, see the full release notes.

Technical preview: topologies_ function

```
F =
     +
        node_(0,-Q1)
       *node_(1,-Q2)
       *node_(2,Q1,-p1,-p2)
       *node_(3,Q2,p1,-p3)
       *node_(4,p2,-p4,-p5)
       *node_(5,p3,p4,p5)
     +
        node_(0,-Q1)
       *node_(1,-Q2)
       *node_(2,Q1,-p1,-p2)
       *node_(3,p1,-p3,-p4)
       *node_(4,p2,p3,-p5)
       *node_(5,Q2,p4,p5)
   ;
```







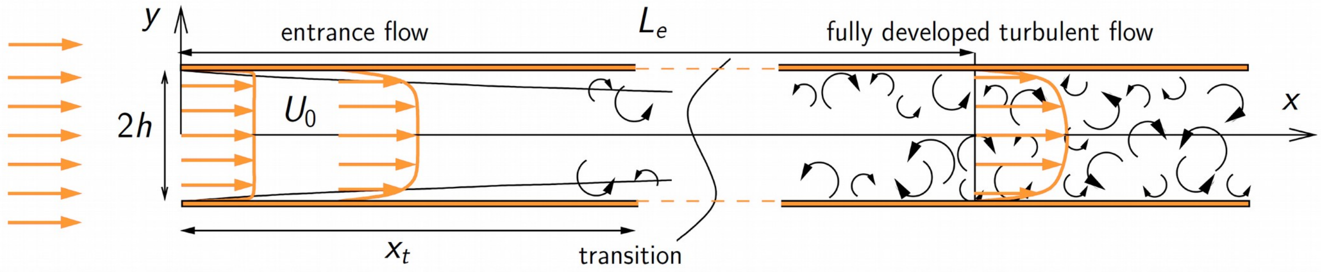
Simulations and Machine Learning

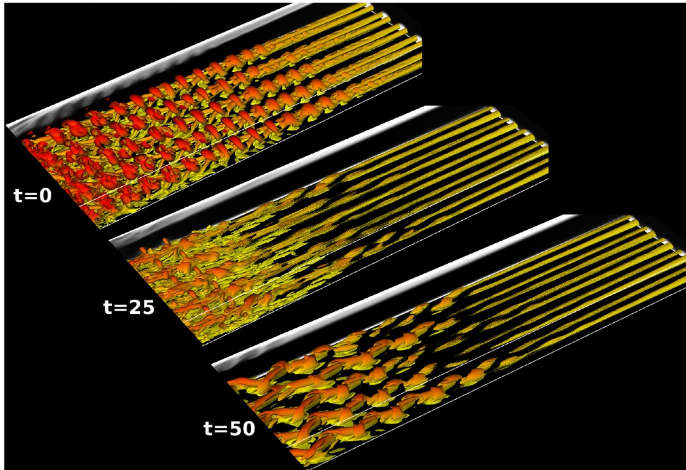
In-situ analysis and visualization of massively parallel computations of transitional and turbulent flows

#307 Cadiou

Anne Cadiou, Marc Buffat, Christophe Pera*
Bastien Di Pierro, Frédéric Alizard, Lionel Le Penven

"High-Performance Computing is the **use of super computers** and **parallel processing** techniques for solving complex computational problems." *(from Techopedia)*



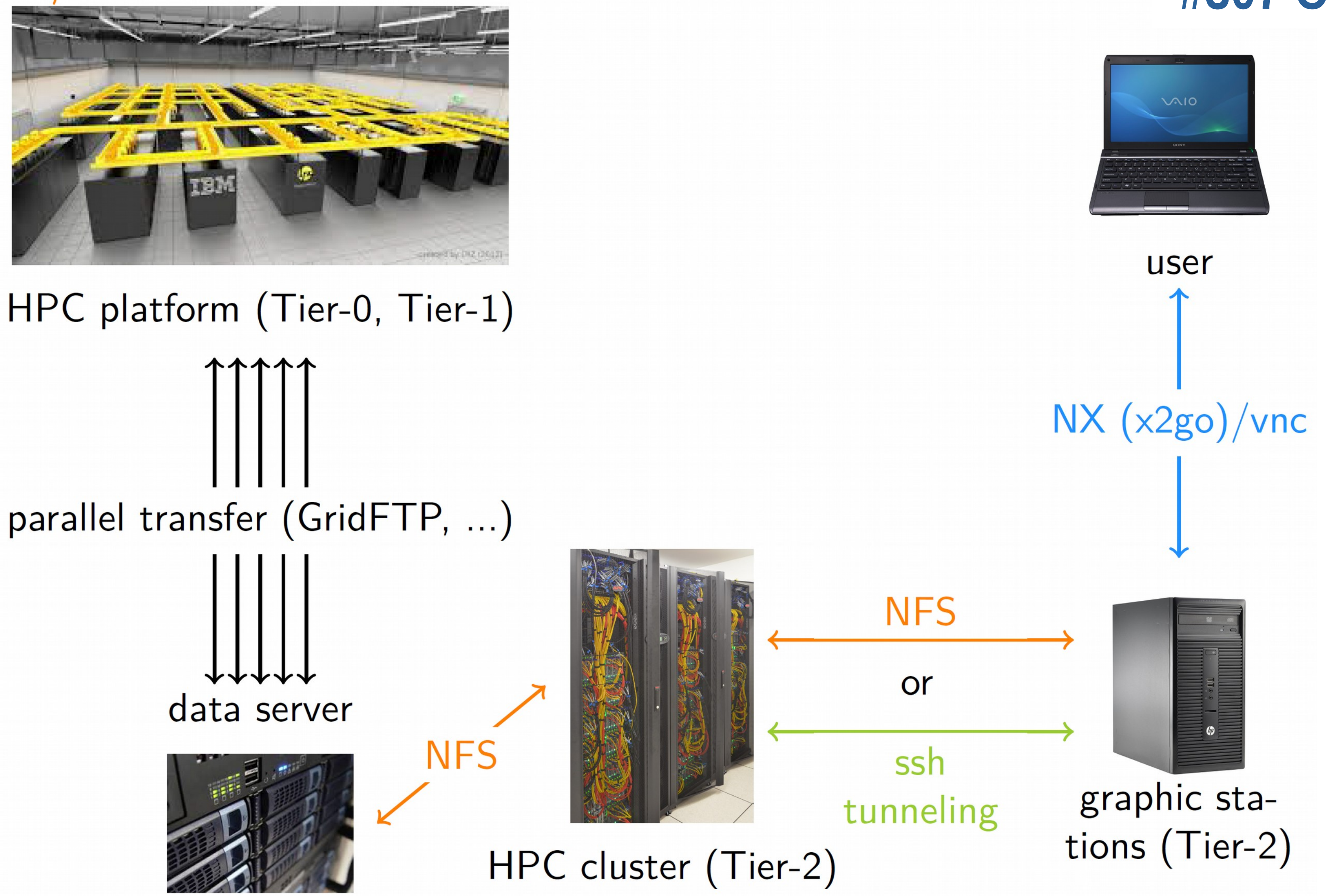


Constraints

- Numerical experiments require spectral accuracy
- Efficiency (follow flow development during long time)

Client/server workflow

#307 Cadiou



N-Tuples and compact matrix element representations

Daniel Maître, IPPP Durham

- A nTuple file is a weighted sample to represent the integral

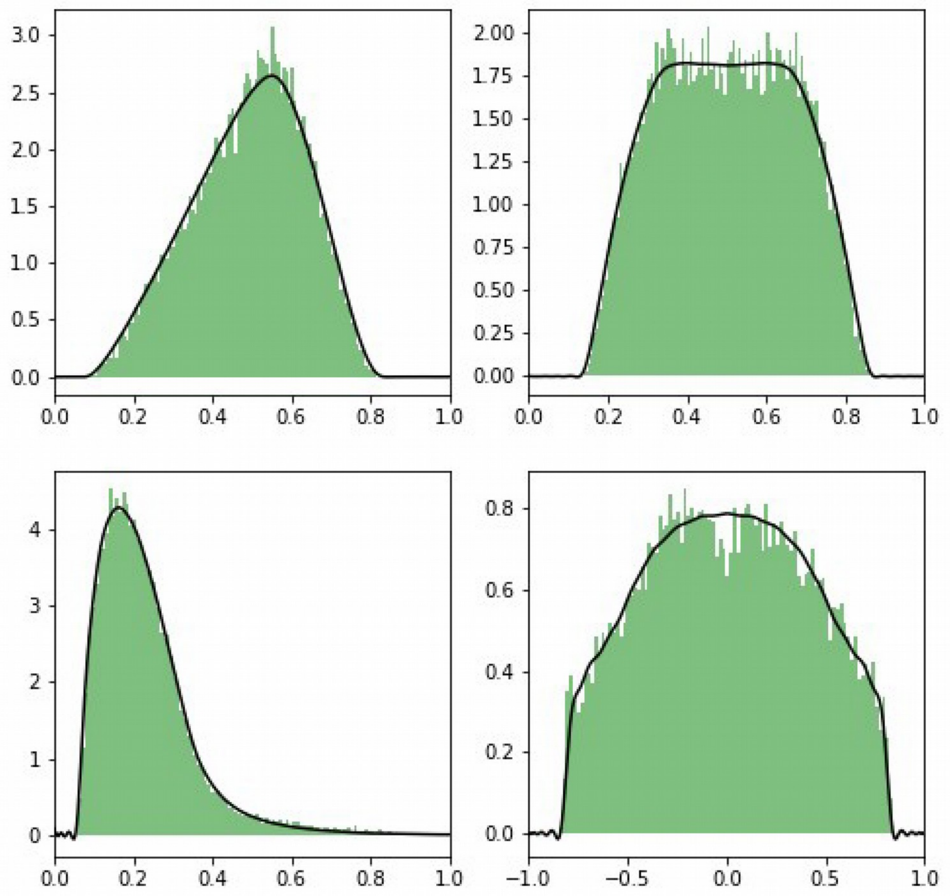
$$\sigma = \int d\phi_n \frac{d\sigma}{d\phi} C(\phi)$$

- Where *C* is a set of cuts designed to be as inclusive as possible
- ϕ is the phasespace, and also include the integration over the PDFs for hadronic initial states
- For hadronic initial states we need to create new nTuples
  - For new collider energies
  - For different jet pt cuts

Unweighted events

#439 Maître

- Using the Gibbs sampling method we generate an unweighted sample:



Riemann-Theta Boltzmann machine

#312 Carrazza

Stefano Carrazza Universit degli Studi di Milano (UNIMI and INFN Milan)

RTBM **[Krefl, S.C., Haghighat, Kahlen '17]**

Novel very generic probability density:

$$P(v) \equiv \sqrt{\frac{\det T}{(2\pi)^{N_v}}} e^{-\frac{1}{2}v^tTv - B_v^t v - B_v^t T^{-1} B_v} \frac{\tilde{\theta}(B_h^t + v^t W | Q)}{\tilde{\theta}(B_h^t - B_v^t T^{-1} W | Q - W^t T^{-1} W)}$$

Damping factor

Riemann-Theta function

The Riemann-Theta definition:

$$\theta(z, \Omega) := \sum_{n \in \mathbb{Z}^{N_h}} e^{2\pi i \left(\frac{1}{2} n^t \Omega n + n^t z\right)}$$

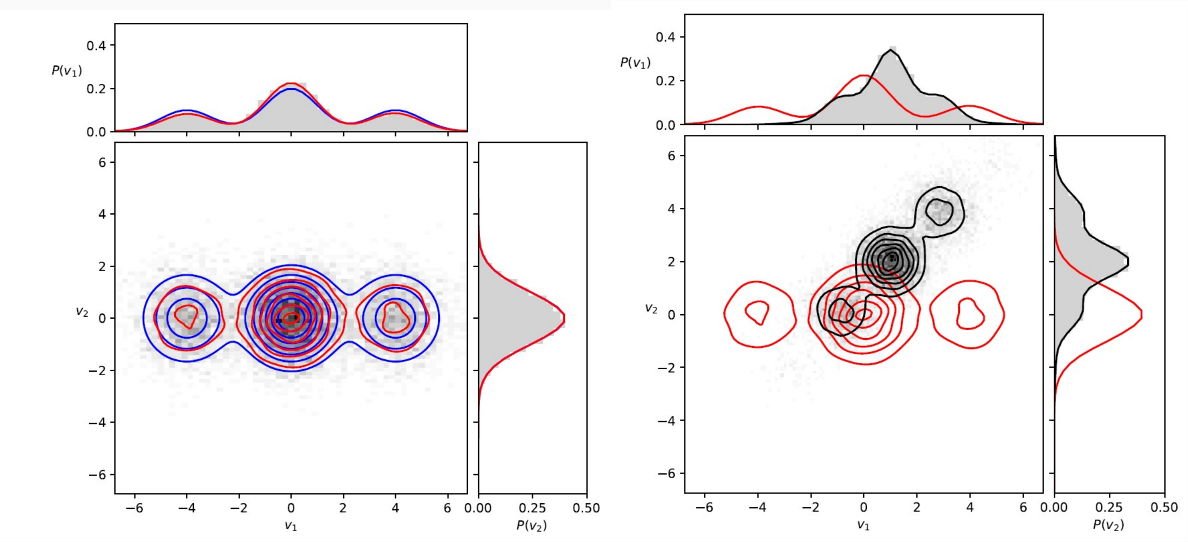
Key properties: Periodicity, modular invariance, solution to heat equation, etc.

Note: Gradients can be calculated analytically as well so gradient descent can be used for optimization.

Sampling examples with affine transformation

#312 Carrazza

RTBM $P(v)$ sampling with affine transformation: [S.C. and Krefl '18]



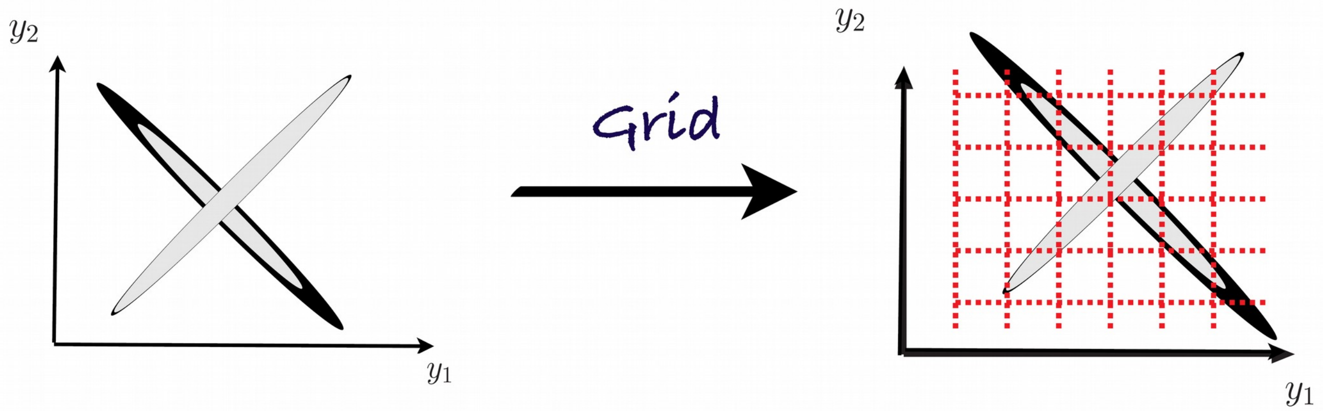
For a rotation of $\theta = \pi/4$ and scaling of 2 ($N_v = 2$, $N_h = 2$).

Machine learning for Monte-Carlo integration

Valentin Hirschi

VEGAS

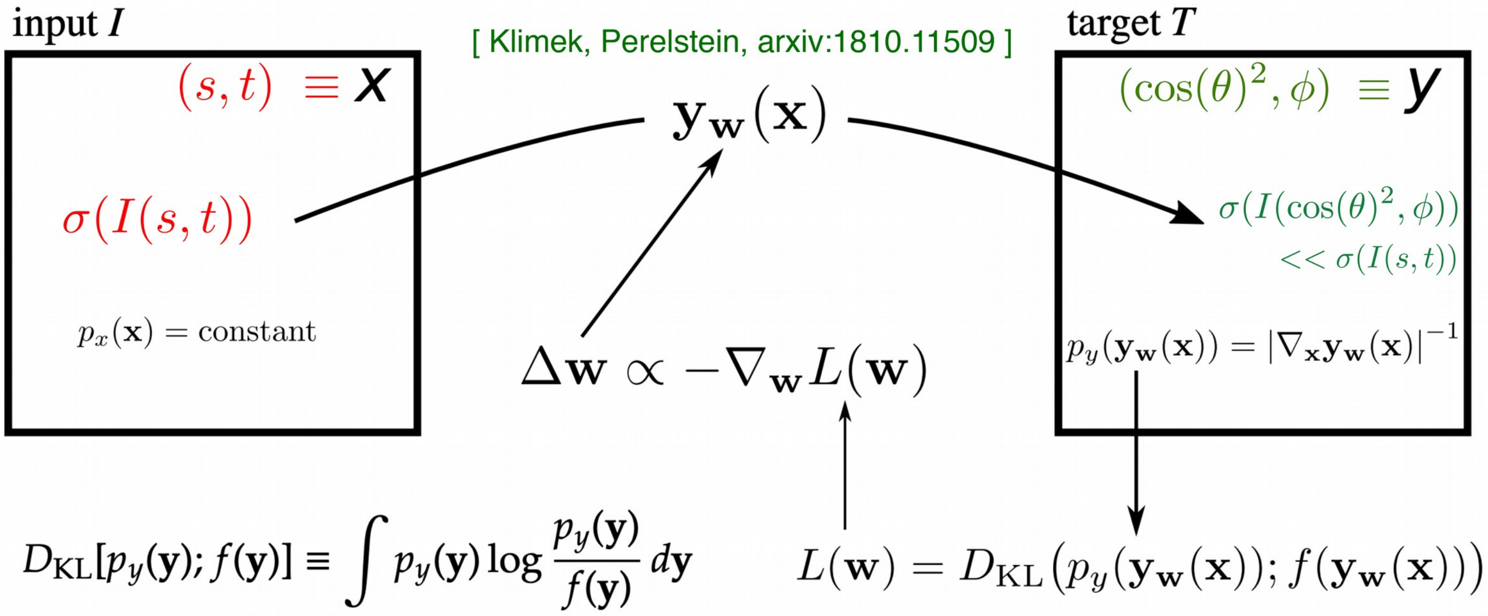
- The choice of the parameterisation has a strong impact on the efficiency



NN Integration replacing VEGAS

#463 Hirschi

If **integrand faster than NN inference** then all is not lost:

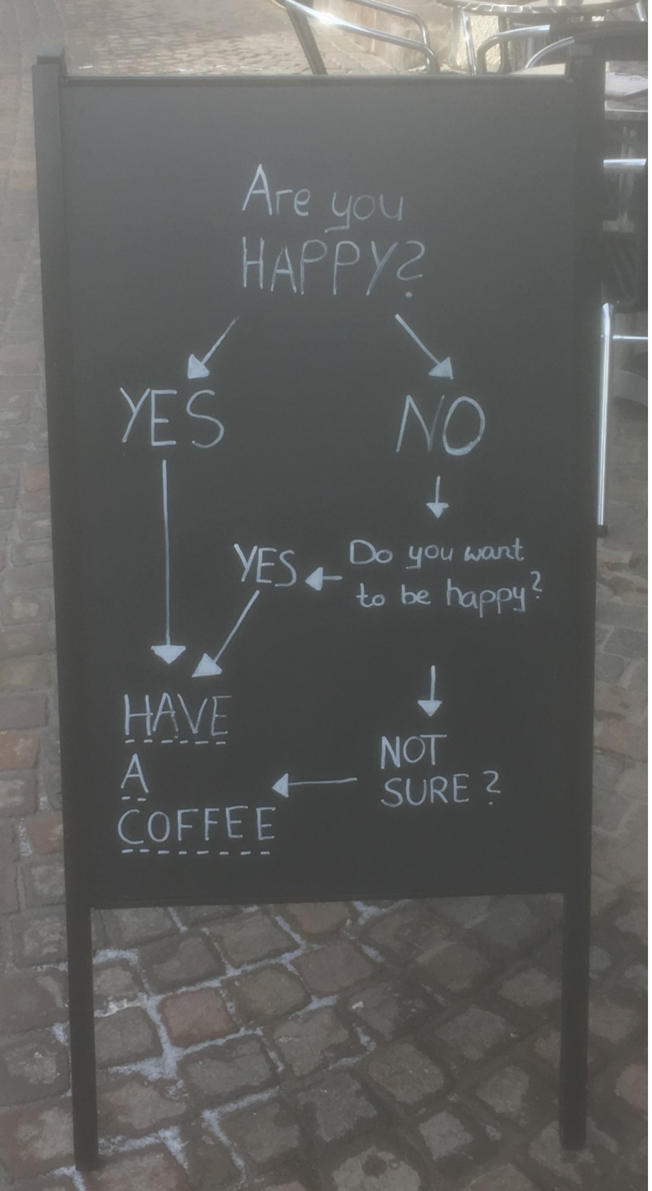


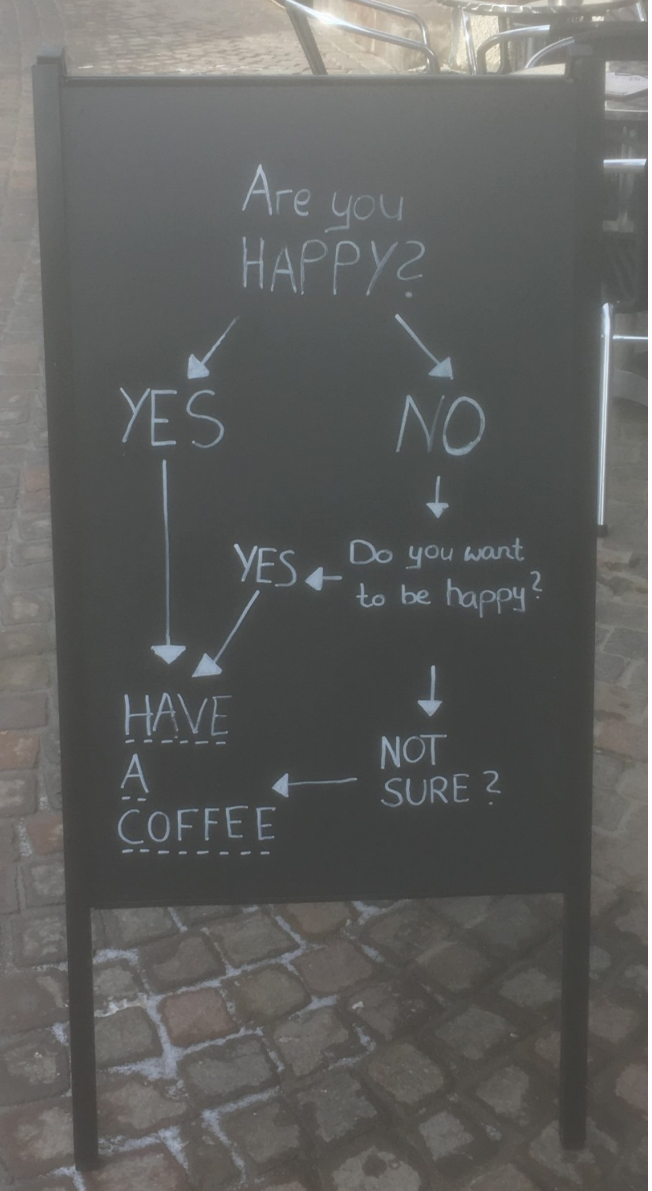
Consider **a generative NN model** effectively learning a change of variables.

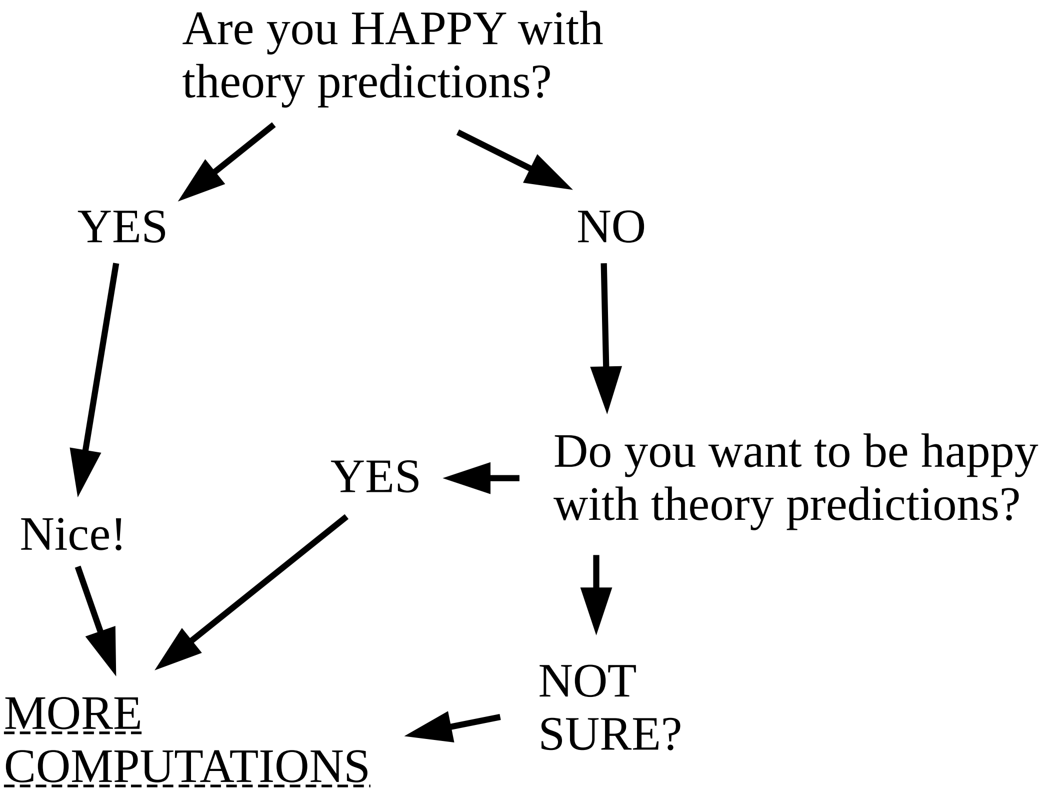
Contrary to **VEGAS**, it is not a piece-wise ansatz: no factorised approx.

Saturation of the **variance reduction** much delayed.

If perfectly trained, then V=0 and a single evaluation yields the exact integral.


Are you HAPPY?
YES
NO
Do you want to be happy?
YES
NOT SURE?
HAVE A COFFEE





See more computations in the next ACAT

T3 Conveners: Claude Duhr, Takahiro Ueda, Ben Ruijl
Apologies for the biased summary by Teen-agers++(++)