Eulogy for our friend and colleague Thomas Binoth

We are deeply saddened by Thomas' premature and unexpected death. Loosing him at the peak of his career was a terrible shock for us.
He was killed by an avalanche on 3rd of January, 2010, while skiing in the Diemtigtal Valley, south of Bern, Switzerland. A stunning series of accidental events. Two avalanches hit the same area within half an hour. The first hit only one member of his group. Thomas, his friends, Swiss tourists and rescue professionals started the rescue work immediately. The next avalanche hit eleven of them. For seven of them including Thomas the rescue came too late.

Born in Maulburg, Germany, in 1965.
Undergraduate and graduate studies at the University of Freiburg. PhD in 1997.
Number of postdoctoral appointments (Annecy, Edinburgh, Wuerzburg) (1997-2005).
Lectureship (2005) and Readership (2009) in Theoretical Particle Physics at the University of Edinburgh.
His results are published in more than 40 papers in referred journals and in more than 40 workshop and conference contributions.
His research has focused on the precision predictions of the Standard Model and their possible extensions for observables measured at high energy colliders with emphasis on Higgs search and LHC phenomenology

Messages of condolences and memories

http://www.ph.ed.ac.uk/news/thomas-binoth-memorial?page=3

friend: Lovely, warm-hearted friend, wonderful human being, kind, lovely, good man, great, warm person with good sense of humor, straightforward, upbeat, honest character; gentle smile under his mustache; ....

colleague: a first-class, solid, wonderful colleague; he was liked for his enthusiasm, openness, fairness, honesty. He was always approachable and was willing to help; he had a forceful voice and formed his opinion with clarity and honesty. He had friendly and straightforward manner and genuine curiosity, he was a real team player; ....

teacher: outstanding, has made an enormous contribution to the life and work of the Edinburgh School, not only supervisor but also friend of his diploma and graduate students, gifted, dedicated teacher, his enthusiasm and intensity was infectious

brilliant particle physicist:

Thomas: lovely, warm-hearted friend

Thomas: a first-class, wonderful colleague

Thomas: an outstanding teacher

Thomas: brilliant particle physicist

I met him first at Gudrun’s Heinrich PhD exam in Zurich in 1998

Thomas Binoth's brilliant science

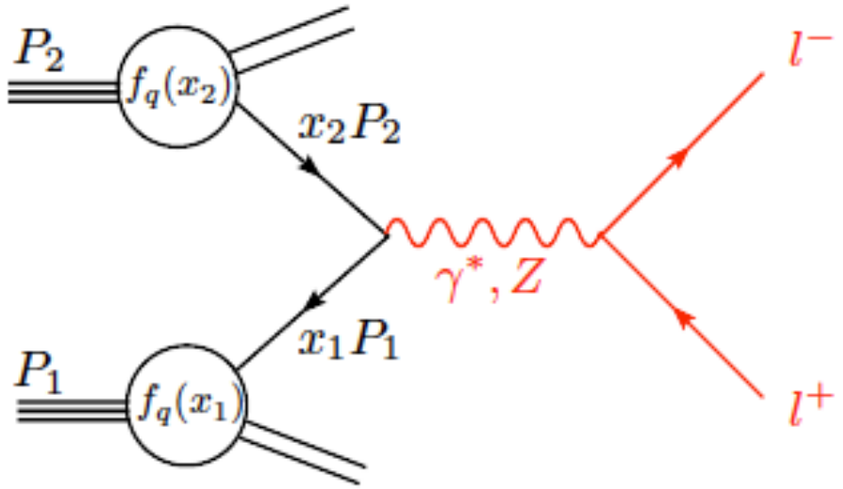
His vision was to give maximal theoretical support to the experimental effort at the Tevatron and LHC in testing the mechanism of the electro-weak symmetry breaking by

discovering the Higgs and/or New Physcis
measuring their properties (precision)
establishing the nature of the EWSB
....

Experimental accuracy of measured observables requires precise theoretical description.

proton beam $\approx$ beam of partons

For quantitative description: NLO QCD corrections are mandatory



Factorization

- asympotic freedom,
- DGLAP evolution
- perturbative expansion

$$\frac{d\sigma_{\mathrm{pp}\to\mathrm{hadrons}}}{dX} = \sum_{a,b} \int dx_1 dx_2 f_a(x_1,\mu_F) f_b(x_2,\mu_F) \times \frac{d\hat{\sigma}_{\mathrm{ab}\to\mathrm{partons}}(\alpha_s(\mu_R),\mu_R,\mu_F)}{dX} + \mathcal{O}\left(\frac{\Lambda^n_{\mathrm{QCD}}}{Q^n}\right)$$

1. The start: be well prepared for Higgs-search

Higgs signals modified by singlet scalars

T. Binoth, J.J. van der Bij

Freiburg–THEP–94/26.
hep–ph/9409332.

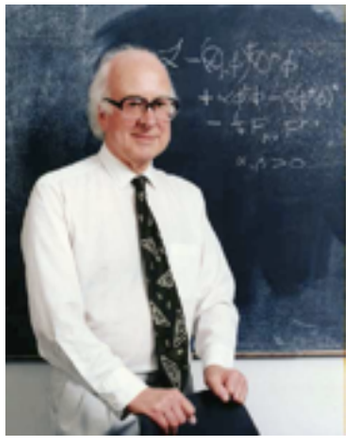
Nothing seen at LHC...

...due to undetectable invisible matter ?

- $H \rightarrow$ singlet matter and missing energy signal completely washed out
- Look for excess from $PP \rightarrow H + 2\,\text{jets} \rightarrow \not{E} + 2\,\text{jets}$

...due to heavy Higgs/no Higgs scenario?

- Look for excess in $W_L W_L \rightarrow W_L W_L$ scattering



What will we see?

- nothing
- Higgs + nothing
- Higgs + something

} NLO QCD

We are not well prepared!

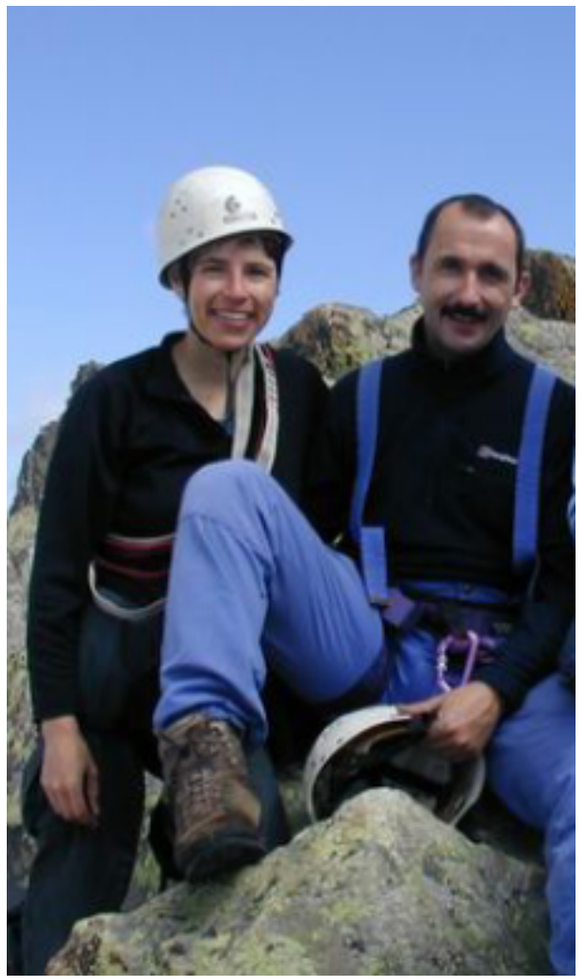
- NNLO is needed
- Complex final states require NLO prescription of multi-leg processes

experimental precision calls for

2. An automatized algorithm to compute infrared divergent multi-loop integrals

Binoth,T and Heinrich, G.
Nucl.Phys.B585:741-759,2000.

Iterative sector decomposition with decomposition strategies suitable for numerical treatment.



BREAKTHROUGH FOR NNLO CORRECTIONS TO SCATTERING
•PROCESSES

- Analytic calculations supported by the numerical approach
  Smirnov, Tausk, Remiddi, Gehrmann, Laporta, etc.

- Many more new ideas for improved numerical algorithms
  (contour deformation, automated Mellin-Barnes algorithm, new decomposition strategies (Melnilov,Petriello, Daleo, Anastasiou, Beerli, Czakon, Smirnov, Weinzierl ...)

- Numerical approach for loop integrals with many important applications

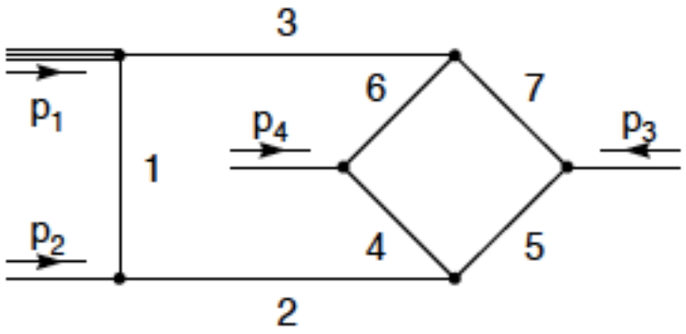


Figure 2: *The non-planar double box with leg 1 off-shell.*

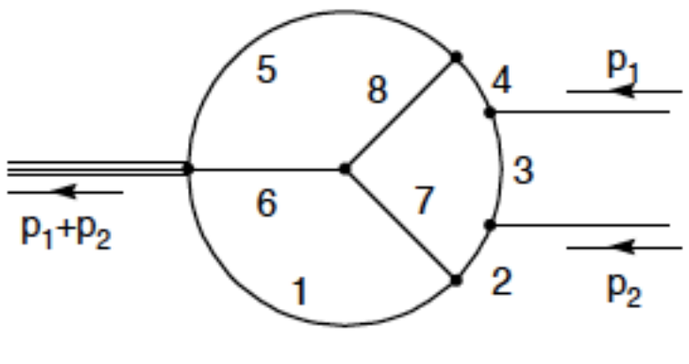


Figure 4: *A 3–loop Mercedes-Star (MS) topology.*

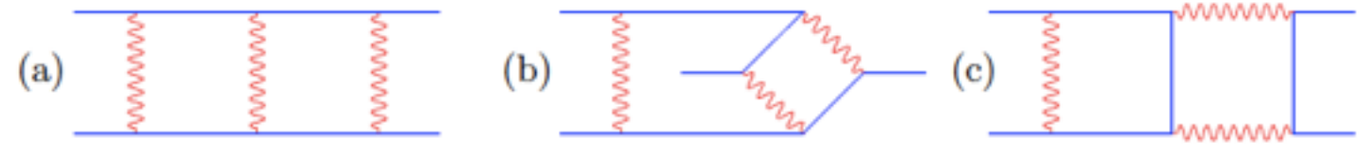
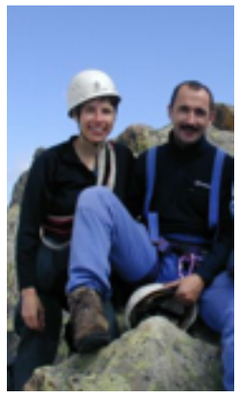


Figure 2: *The two-loop four point master topologies relevant for Bhabha scattering.*

Figure 6: *Planar triple-box graph*



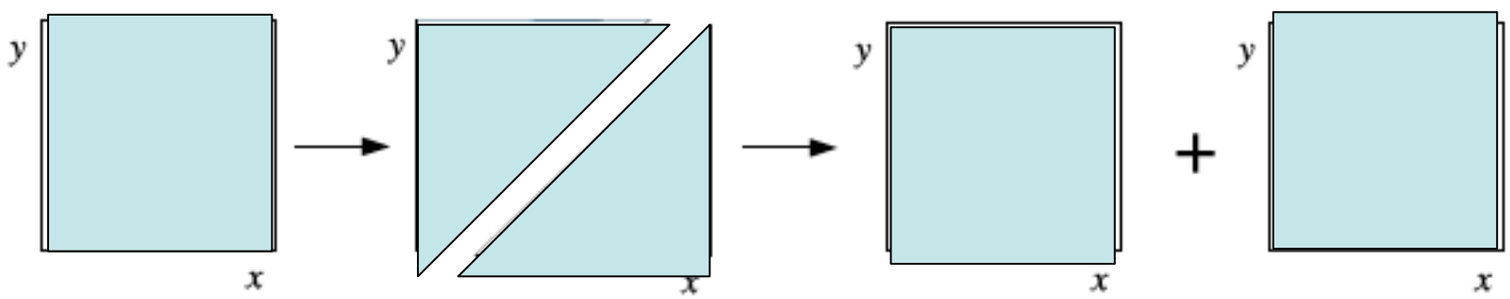
$$TB(-1,-3) = \Gamma(4+3\epsilon)\Big[\frac{0.09874}{\epsilon^6} - \frac{0.7669}{\epsilon^5} - \frac{1.977}{\epsilon^4} - \frac{0.7534}{\epsilon^3} - \frac{4.747}{\epsilon^2} + \frac{2.010}{\epsilon} + 21.48\Big]$$

Typical Feynman parameter integral for overlapping divergences

$$I = \int_0^1 dx dy x^{-1-\epsilon} y^{-\epsilon} \left(x + (1-x)y\right)^{-1}$$

$$I = \int_0^1 dx dy x^{-1-\epsilon} y^{-\epsilon} \left(x + (1-x)y\right)^{-1} \left(\Theta(x-y) + \Theta(y-x)\right)$$

$$I = \int_0^1 dx \int_0^x dy\, x^{-1-\varepsilon} y^{-\varepsilon} \left(x + (1-x)y\right)^{-1} + \int_0^1 dy \int_0^y dx\, x^{-1-\varepsilon} y^{-\varepsilon} \left(x + (1-x)y\right)^{-1}.$$



two sectors

$$S_1 + S_2 \equiv I = \int_0^1 dx\, dy\, x^{-1-2\varepsilon} y^{-\varepsilon} \left(1 + (1-x)y\right)^{-1} + \int_0^1 dx\, dy\, x^{-1-\varepsilon} y^{-1-2\varepsilon} \left(1 + (1-y)x\right)^{-1}.$$

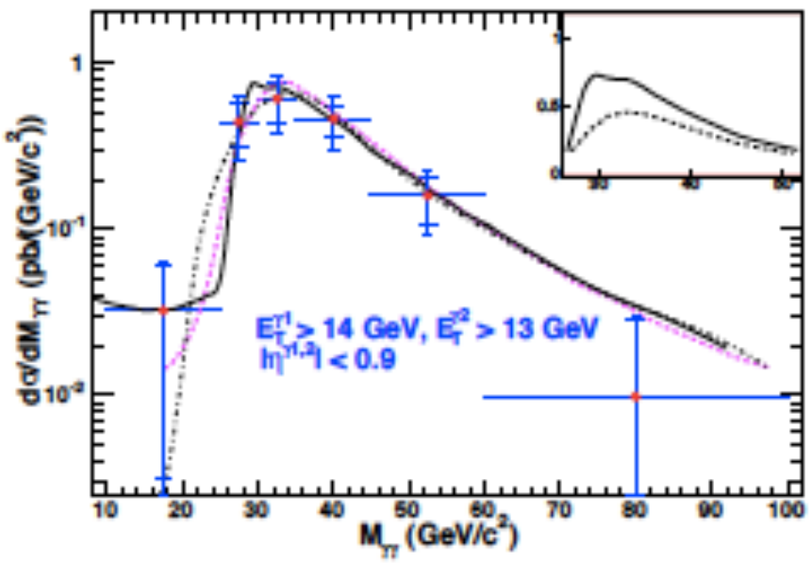
The $1/\varepsilon$ poles can be extracted by Taylor-expanding around $\varepsilon = 0$ using

$$x^{-1+\kappa\varepsilon} = \frac{1}{\kappa\varepsilon}\delta(x) + \sum_{n=0}^{\infty} \frac{(\kappa\varepsilon)^n}{n!} \left[\frac{\log^n x}{x}\right]_+.$$

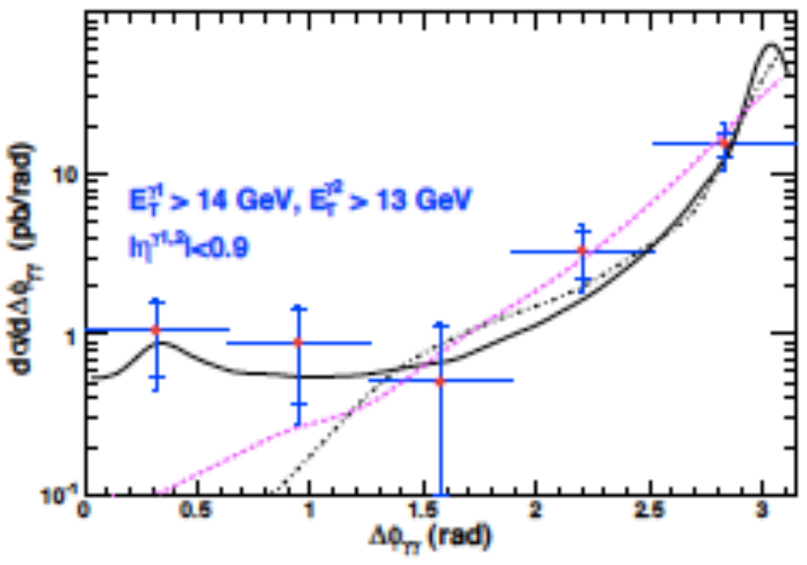
3. DIPHOX: NLO code for $\gamma\gamma\,,\pi^0\gamma\,,\pi^0\pi^0$ production

$\gamma\gamma$ rate at Tevatron Run II [hep-ex/0412050]

$M_{\gamma\gamma}$ distribution



$\Delta\phi_{\gamma\gamma}$ distribution



DIPHOX (solid), RESBOS (dashed), PYTHIA$\times 2$!!! (dot-dashed)

4. An algebraic/numerical formalism for one-loop multi-leg amplitudes

theoretical formalism for

The GOLEM project

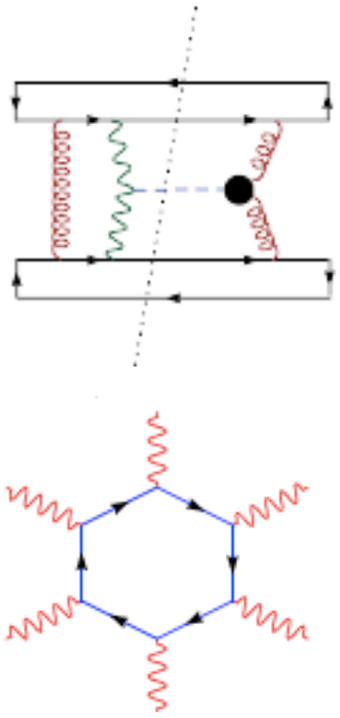
General One Loop Evaluator for Matrix elements

- Evaluation of 1-loop amplitudes bottleneck for LHC@NLO
- Combinatorial complexity ↔ numerical instabilities
  ⇒ switching between algebraic/numerical representations
- Aim: Automated evaluation of numerically stable one-loop amplitudes for multi-leg processes
- The GOLEM team: T.B., A. Guffanti, J.Ph. Guillet, G. Heinrich, S. Karg, N. Kauer, E. Pilon, T. Reiter, G. Sanguinetti

He was a distinguished young leader of the field of the radiative correction especially for the LHC physics. The "Golem" being developed by Thomas Binoth and his collaborators is one of the most advanced system of the automatic calculation system for NLO-QCD.

Results obtained by Golem

- $gg \to W^*W^* \to l\nu l'\nu'$, GG2WW code
  http://hepsource.sourceforge.net/programs/GG2WW
  T.B., M. Ciccolini, M. Krämer, N. Kauer (2006)
- $gg \to HH, HHH$
  T.B., S. Karg, N. Kauer, R. Rückl (2006)
- $pp \to Hjj$ GF/WBF NLO interference $\mathcal{O}(\alpha^2\alpha_s^3)$
  J.R. Andersen, T.B., G. Heinrich, J. Smillie (2007)
- $\gamma\gamma \to \gamma\gamma\gamma\gamma$
  T.B., G. Heinrich, T. Gehrmann, P. Mastrolia (2007)

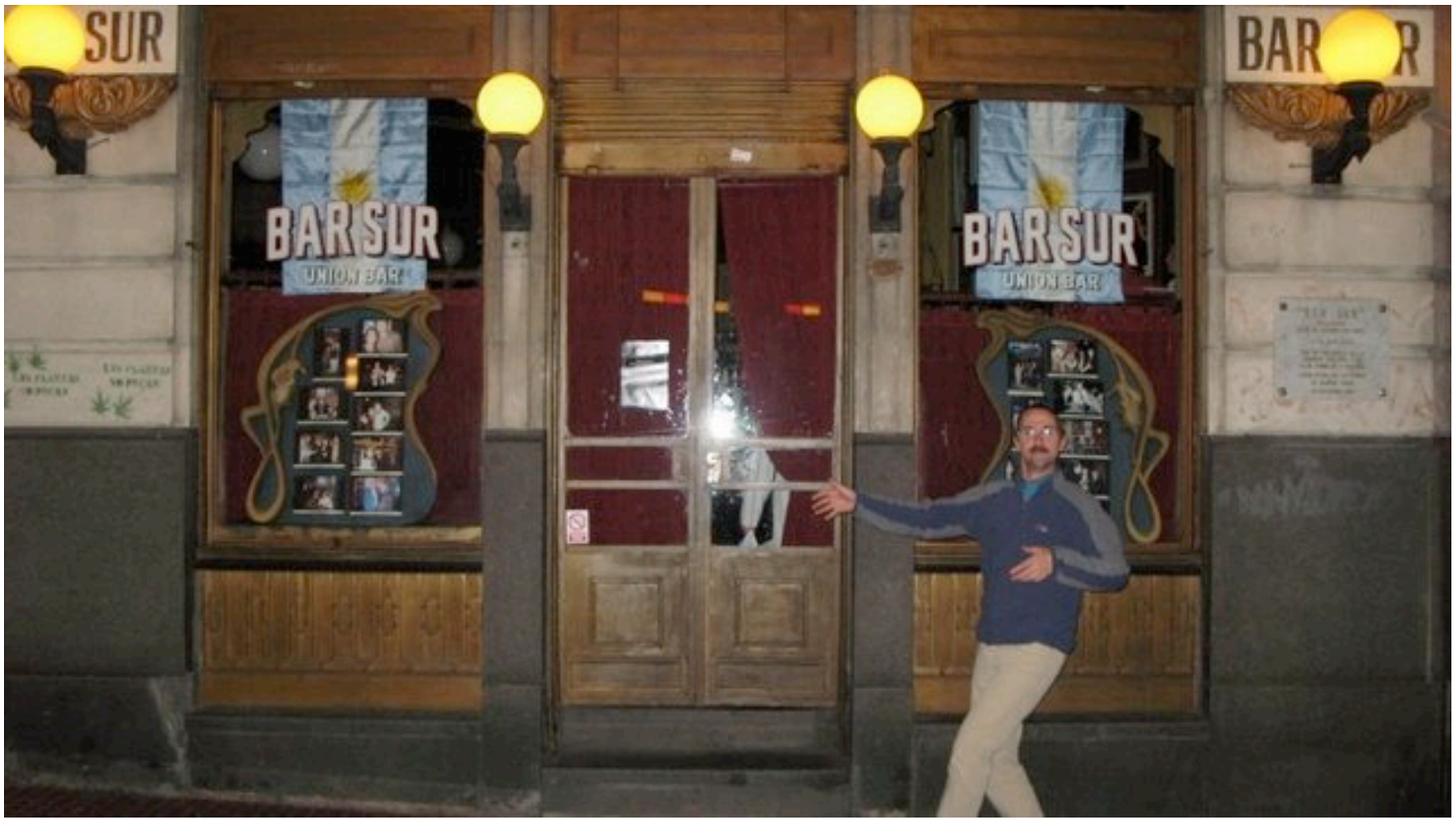


- $gg \to Z^*Z^*, \gamma^*Z^*, \gamma^*\gamma^* \to l\bar{l}l'\bar{l}'$, GG2ZZ code
- $pp \to WWj, ZZj$, $gg \to WWg, ZZg$
- $pp \to bbbb$

5. A proposal for a standard interface between Monte Carlo tools and one loop programs

Dedicated to the memory of, and in tribute to, Thomas Binoth, who led the effort to develop this proposal for Les Houches 2009. Thomas led the discussions, set up the subgroups, collected the contributions, and wrote and edited this paper. He made a promise that the paper would be on the arXiv the first week of January, and we are faithfully fulfilling his promise. In his honor, we would like to call this the Binoth Les Houches Accord.

- Combining codes of calculating one-loop matrix elements with existing Monte Carlo tools.
- First attempt of standardisation of NLO calculations
- Binoth Les Houches Accord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“ Dearest Thomas,

with all the enthusiasm you put into your work, the dedication, the hard work and the unmatched skills, I just hope that, from where you are now, you can finally get a clear picture of how nature really works, something which we earthlings are left down here struggling to find out. we'll miss you. “

Michelangelo Mangano