Fully automated calculation in fermion scattering

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I. Motivation

Motivation: physics

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present few "experiment vs. theory" 2-3σ disagreements
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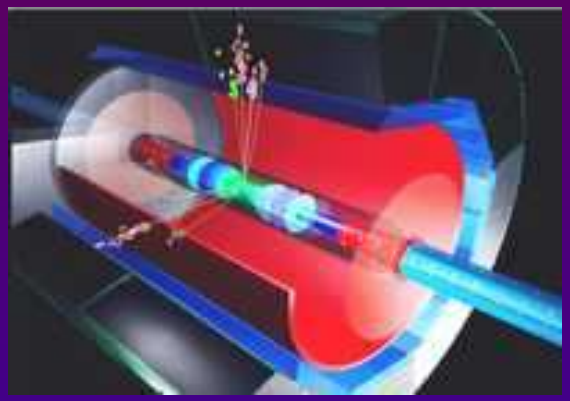
$$e^+e^- \text{ beam}, \quad E_{\mathrm{CM}} \approx 1\mathrm{TeV}, \quad ‰ \text{ precision}$$



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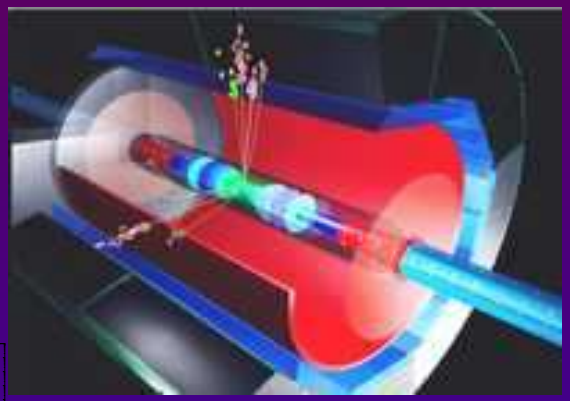
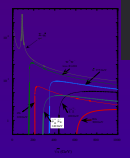


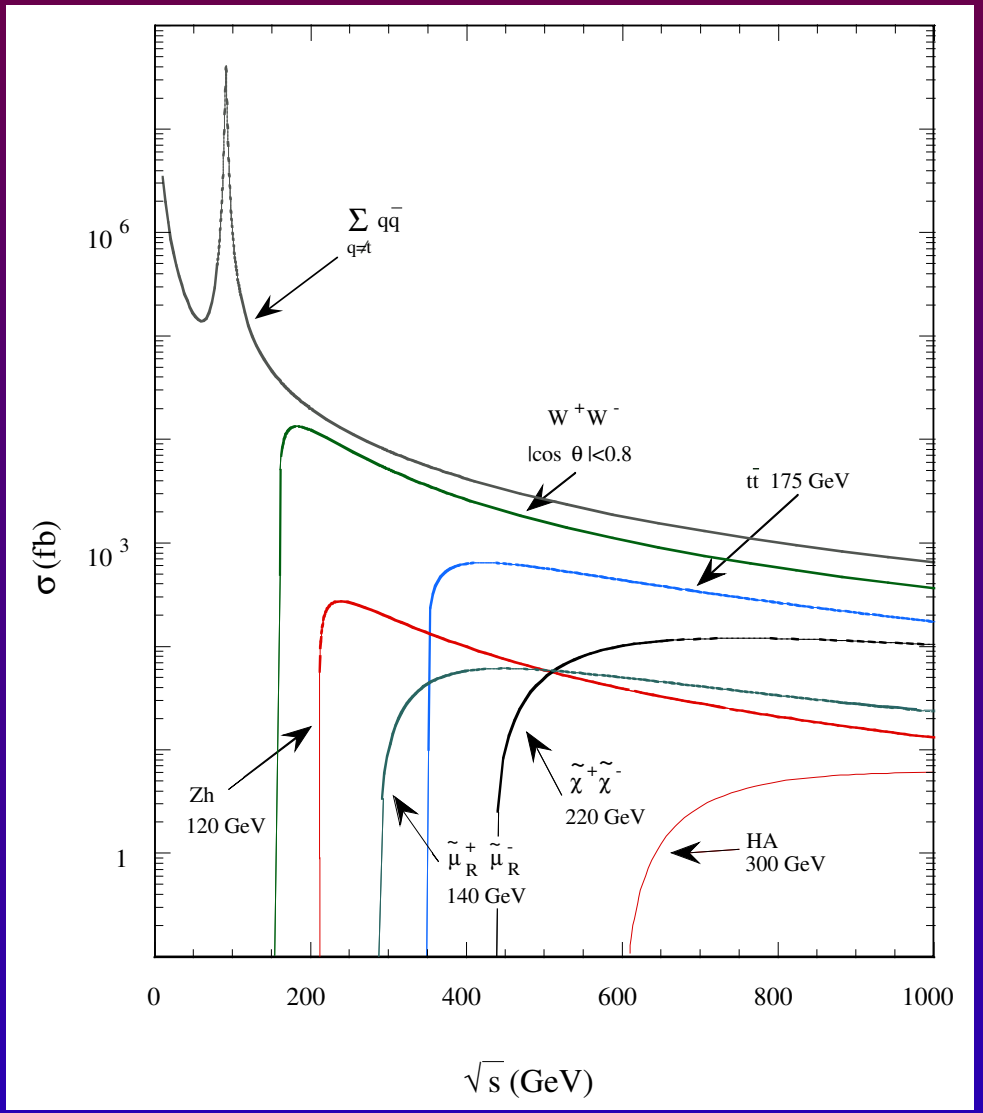
Fermion-pair production play a dominant role: Fig.



- Luminosity monitoring and precise parameter determination
- Mass effects in heavy (t, b) quarks $\rightarrow$ test of Higgs sector (LHC)
- Disentangle limits on *New Physics* from SM predictions and backgrounds

Motivation: ILC cross sections

Integrated cross sections for different processes as expected for a linear collider. Aguilar Saavedra *et al*, TDR 2000 hep-ph/0106315 .



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The idea is to develop a tool for precise calculations. A must:

- Automatic beyond tree-level (1-loop or higher)
- Free software (also based upon)
- Documented and easy to install
- Profit from available good packages (DIANA, FORM and LOOPTOOLS)

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☛ Do other tools in the market satisfy these 3-4 points? ☹

Packages in the market to be mentioned:

FEYNARTS, GRACE, SANC, COMPHEP, MADGRAPH ...

II. Automated tool: $a\mathring{\mathrm{I}}\mathrm{TALC}$

aITALC overview

an Integrated Tool for Automated Loop Calculations

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- Restricted to automated $2 \longrightarrow 2$ fermions (EWSM and QED)
- GNU/LINUX tool, GPL licensed, free available since 29.10.04
- **http://www-zeuthen.desy.de/theory/aitalc**
- Submitted to CPC: Lorca and Riemann. hep-ph/0412047

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Three structural blocks:

Diagram generation	Algebra simplification	Numerical evaluation
DIANA 2.35 (QGRAF)	FORM 3.1	FORTRAN 77 LOOPTOOLS (FF)

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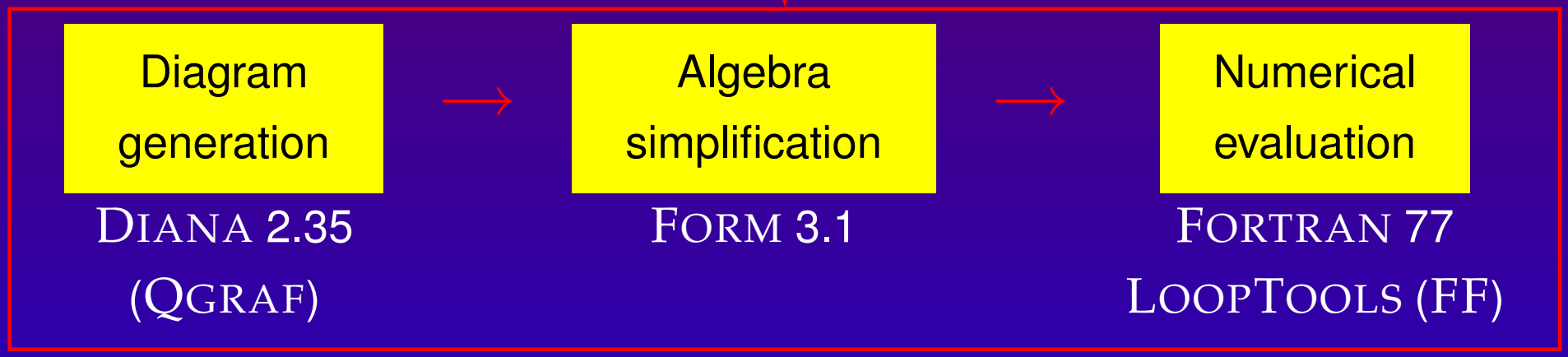
Three structural blocks: all running under MAKE environment



aITALC: Feynman Diagram Analizer DIANA

Developed at U.Bielefeld 1997-2004 (Fleischer and Tentyukov)

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- C program, based on Nogueira's FORTRAN generator QGRAF2
- Command line: requires a driver file and model file
- High portability, running in many UNIX systems
- Front-end topology editor (tedi) included for GNU/LINUX

`http://www.physik.uni-bielefeld.de/~tentukov/diana.html`

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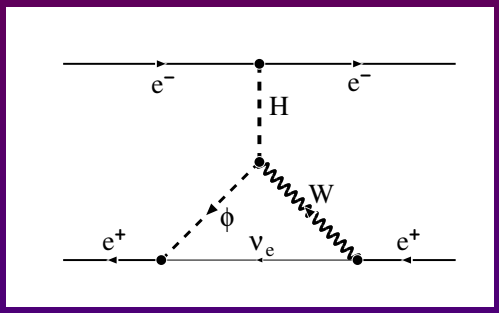
What do we ask?

```
SET _processname = Bhabha
---
\Begin(model,EWSM.model)
\Begin(process)
ingoing le(;p1),Le(;p4);
outgoing le(;-p2),Le(;-p3);
loops = 1;
---
options = onshell,notadp;
*\excludevertex(Le,le,H)
---
SET MakeEps = "!"
...
```

What does Diana answer?

Bhabha626.eps




```
G Amplitude =
(-1)*F(1,1,1,0,0)*(-i_)*e/2/sw*Mle/MW*F(2,2,1,-1,0)*
(-i_)*e/2/sqrt2/sw*Mle/MW*FF(3,2,+q,Mne)*i_*
F(3,2,mu1,1,-1,1)*(+i_)*e/2/sqrt2/sw*SS(4,0)*i_*
SS(1,2)*i_*VV(2,mu2,mu1,-q-k2,2)*i_*
V(4,mu2,+p1+p2-(+q+k1),1)*(-i_)*e/2/sw;
---
#define COUNTER "626" #define LINE "4"
#define LOOPTYPE "c" ...
```

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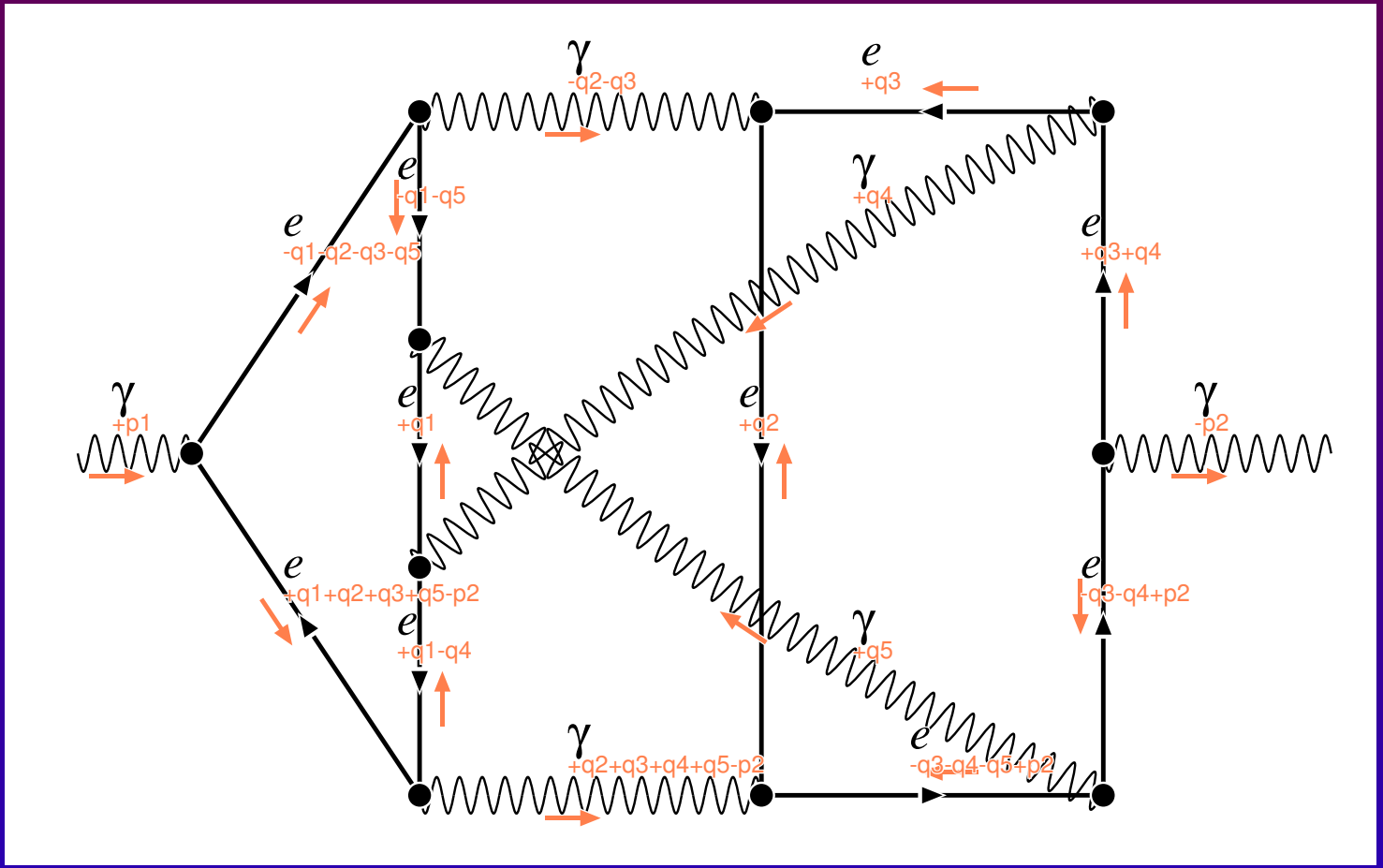
Do you imagine doing 5-loop QED calculations?



Computing: aITALC algebra

DIANA
(symbolic level)

¿¿¿ 1–Loop Library ???

FORTRAN
(numeric level)

Written in FORM

```
#call feynmanrules()
...
#call tracefermiloops()
#call integration()
#call chisholm()
#call dimensionfour()
#call gammaalgebra()
#call onshell()
#call diracequation()
#call massiveformfactors()
.end
```

These general procedures perform all algebra simplification

✓ Write automatically FORTRAN subroutines from DIANA output

Computing: aITALC numerical

For numerical evaluation language FORTRAN 77 is used

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The code is decomposed into different routines

- **Local**: Process-dependent automatically generated (`me, ff`)
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Executable file `main.out`

Input → parameter list, control flags.

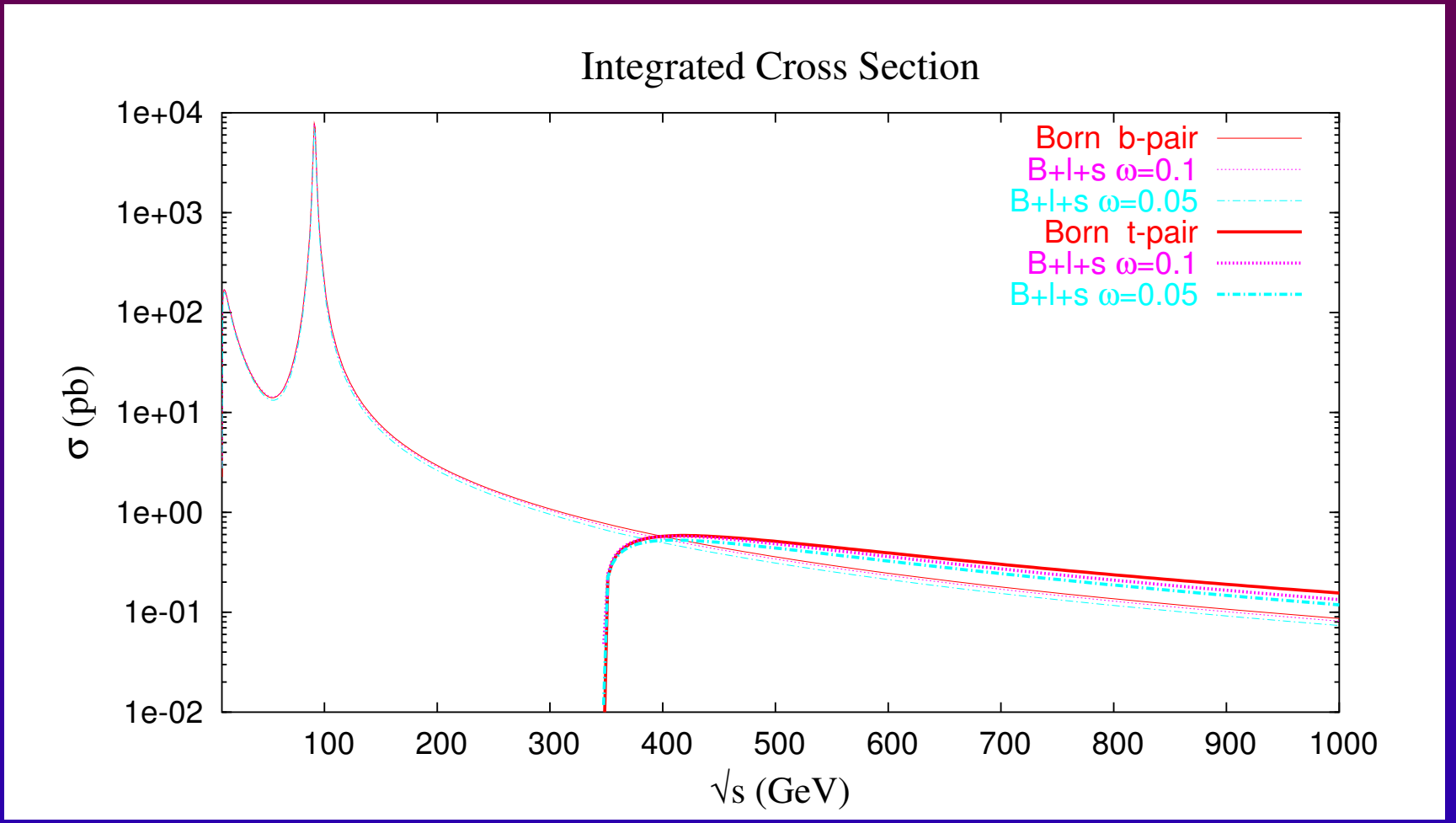
Output ← tables for differential and integrated cross sections and forward-backward asymmetries

Tests ✔ ultraviolet and infrarred finiteness against parameter variation. Quadruple precision

III. Results

Results: Fermion-pair production

We confirmed results on fermion production distributions,
also integrated cross sections. . .



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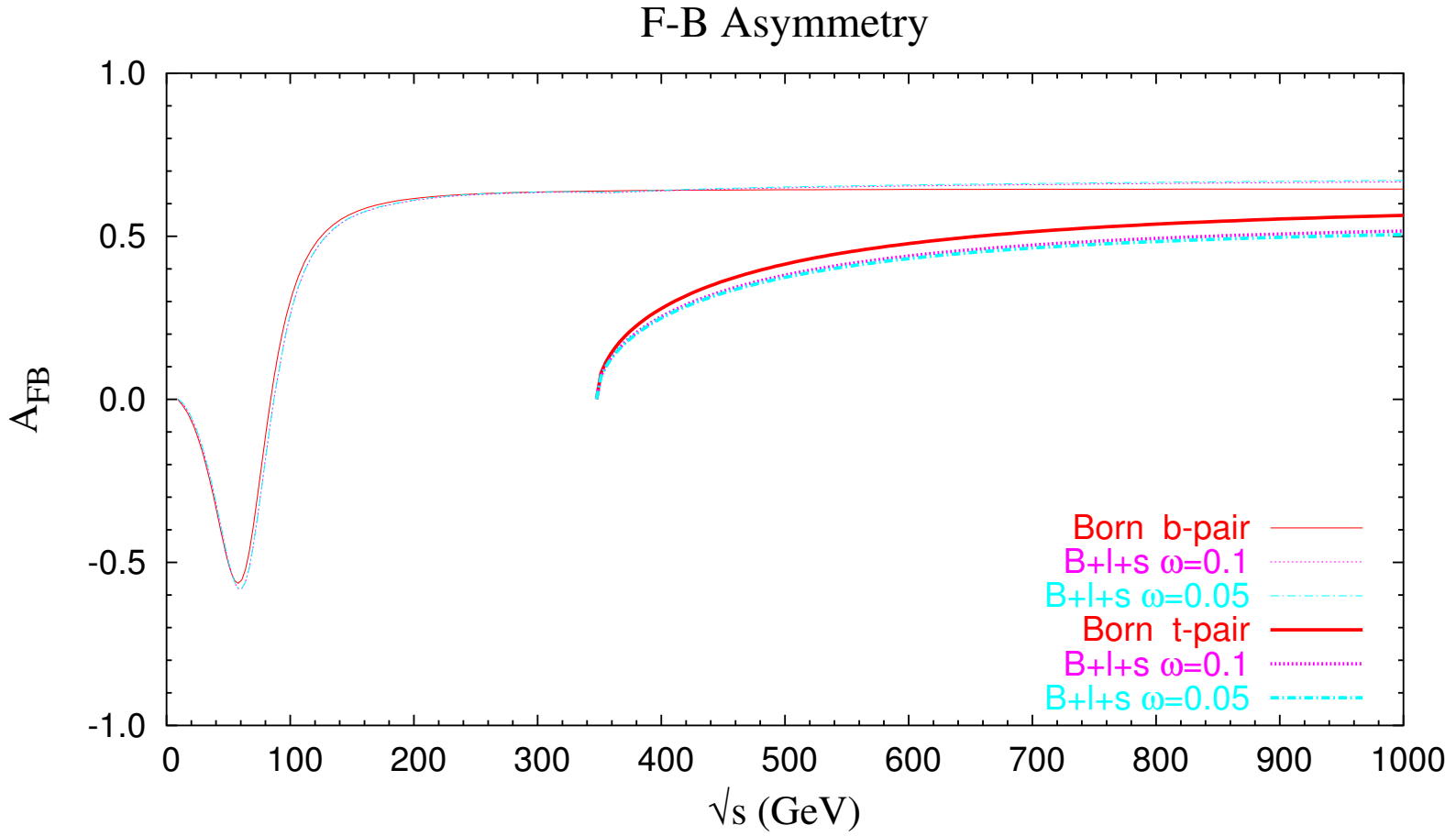


Results: Bhabha comparisons

$e^-e^+ \to e^-e^+ (\gamma)$ at ILC: $\sqrt{s} = 500\ \mathrm{GeV}, \quad E_{\max}(\gamma_{\mathrm{soft}}) = \frac{\sqrt{s}}{10}$

$\cos\theta$	$\left[\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta}\right]_{\mathrm{Born}}$ (pb)	$\left[\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta}\right]_{\mathcal{O}(\alpha^3)=\mathrm{Born+QED+weak+soft}}$ (pb)	Tool
-0.9	0.21699 88288 10920	0.19344 50785 26862 70315 89…	aITALC
-0.9	0.21699 88288 10920	0.19344 50785 26862	FEYNARTS
-0.9	0.21699 88288 41513	0.19344 50785 62638	$m_e = 0$
$+0.0$	0.59814 23072 50331	0.54667 71794 69423 03528 77…	aITALC
$+0.0$	0.59814 23072 50329	0.54667 71794 69422	FEYNARTS
$+0.0$	0.59814 23072 88584	0.54667 71794 99961	$m_e = 0$
$+0.9$	$0.18916\,03223\,32271 \cdot 10^3$	$0.17292\,83490\,66508\,29307\,47\ldots \cdot 10^3$	aITALC
$+0.9$	$0.18916\,03223\,32271 \cdot 10^3$	$0.17292\,83490\,66508 \cdot 10^3$	FEYNARTS
$+0.9$	$0.18916\,03223\,31849 \cdot 10^3$	$0.17292\,83490\,61347 \cdot 10^3$	$m_e = 0$
$+0.9999$	$0.20842\,90676\,46391 \cdot 10^9$	$0.19140\,17861\,11883\,04292\,09\ldots \cdot 10^9$	aITALC
$+0.9999$	$0.20842\,90676\,46436 \cdot 10^9$	$0.19140\,17861\,11979 \cdot 10^9$	FEYNARTS

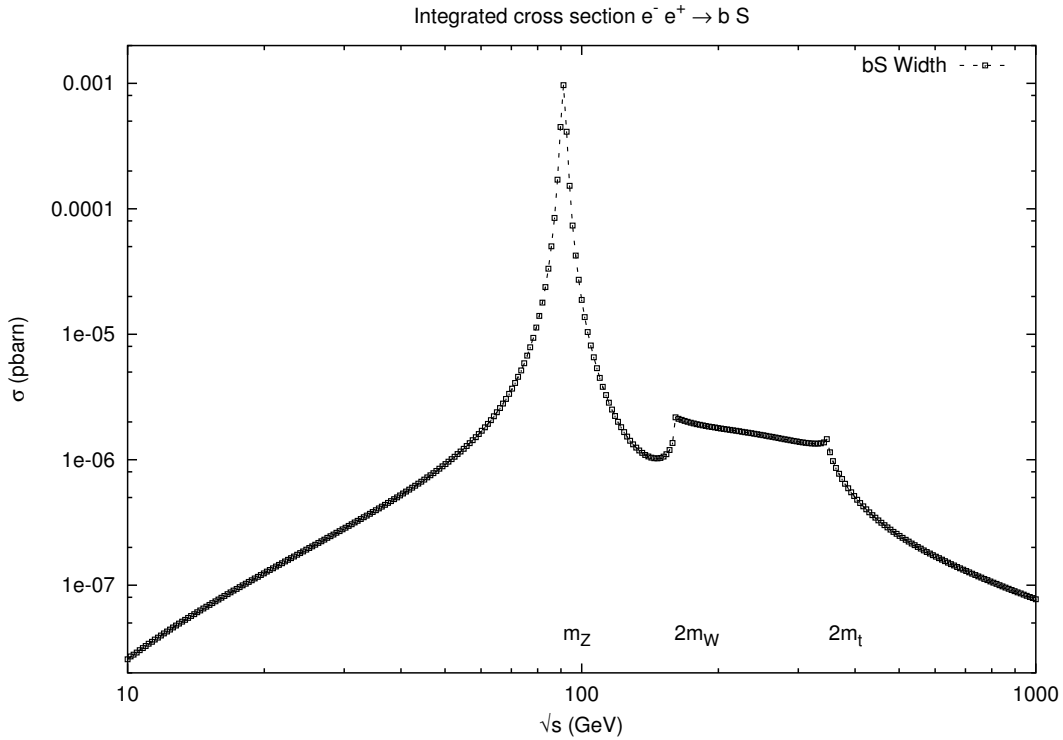
Great independent agreement saturating limit in double precision

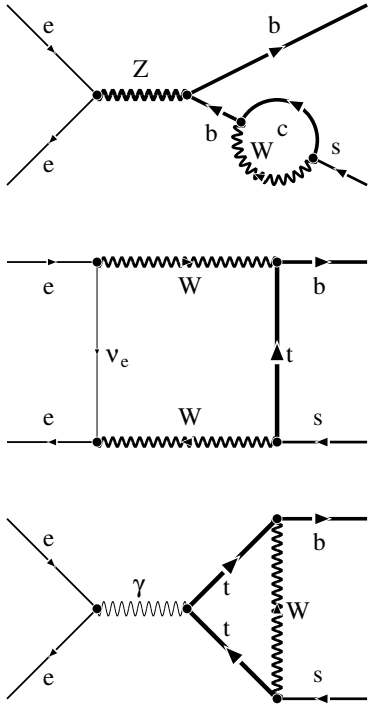
Thanks to T. Hahn for supplying FEYNARTS' numbers

Results: Flavour Changing NC

Process $e^+e^- \to b\bar{s}$ only possible at one-loop level!

Quantum resonances at $\sqrt{s} = 2m_W$ (boxes) and at $2m_t$ (vertices)





In agreement up to a overall factor with Huang *et al.* hep-ph/9902474

Conclusions & Outlook

- Complete $\mathcal{O}(\alpha)$ electroweak corrections to different $2 \to 2$ fermion processes: $e^+e^- \to f\bar{f}, e^+e^-, b\bar{s}$ ($t\bar{c}$ or Møller not shown)
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  - *Potential extension to other models (QCD or SUSY), to* parallelization *or to higher loops through* DIANA

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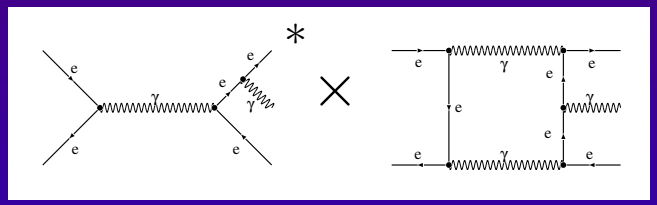
  2-loop Bhabha scattering + 

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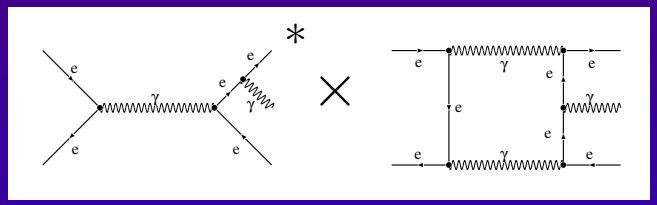

? Should we join into a project in loop calculations for colliders?