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Parametric Optimization with Evolutionary Strategies in Particle Physics

- Physics Motivation
- Tools
- Results
- Conclusion

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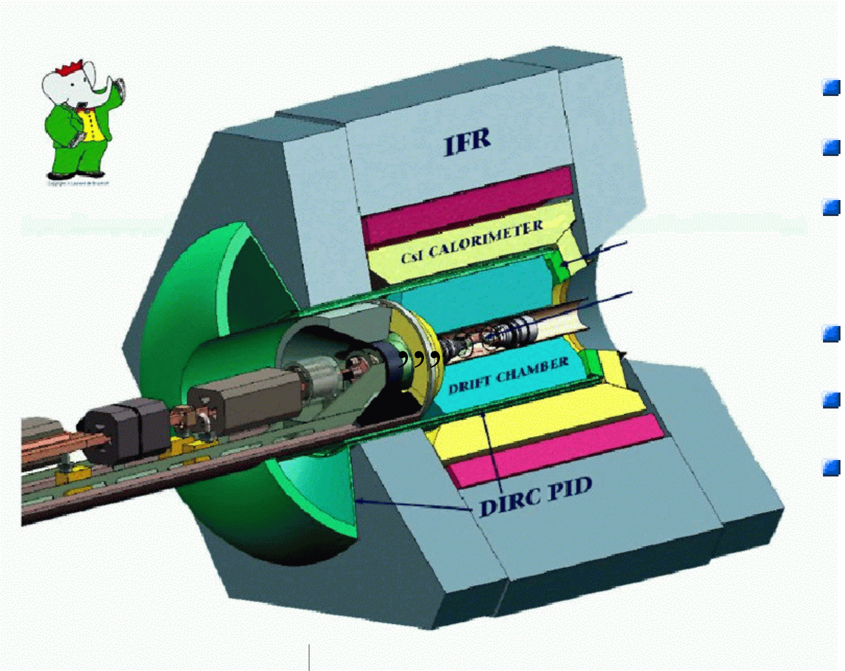
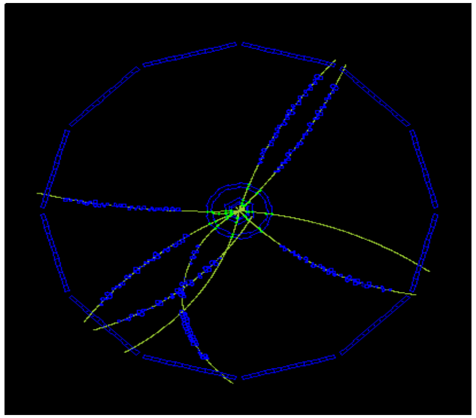
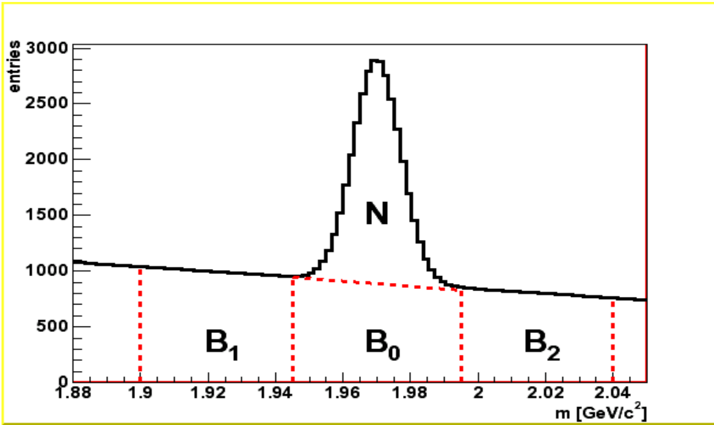
Tsukuba, Dec. 1st,.2003

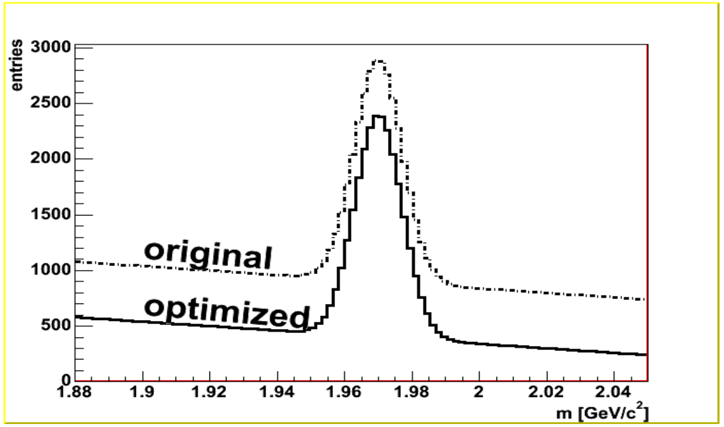
Physics Motivation – Optimization of Particle Signals



- Signal in histogram resulting from cuts
- Varying cuts can lead to improved signal
- With figure of merit == f(cuts) :
  Accessible to computerized maximization techniques
- Often used : *Significance*^{2}: $S^2 = N^2 / (N + 2B_0)$
- In comparison: signal / background BAD !
- Problem : Testing quality of cuts in particle physics requires the processing of huge amounts of data for each set of cuts







„Events“ —Analysis / Cuts→ Histogram with signal —Optimization→ e.g. reduced Background

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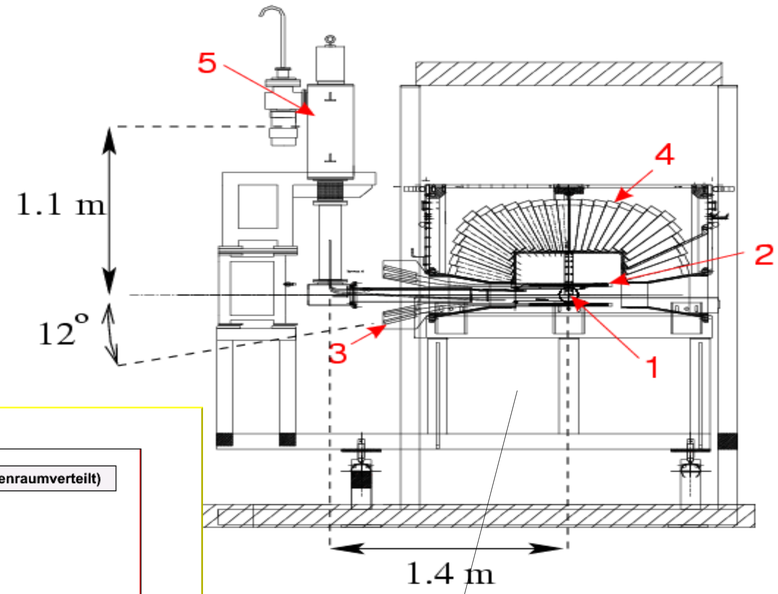
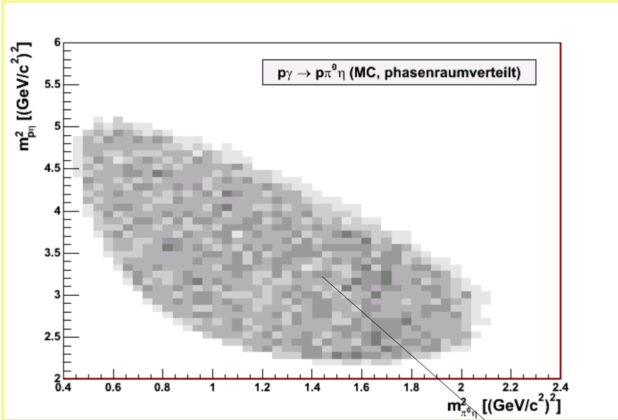
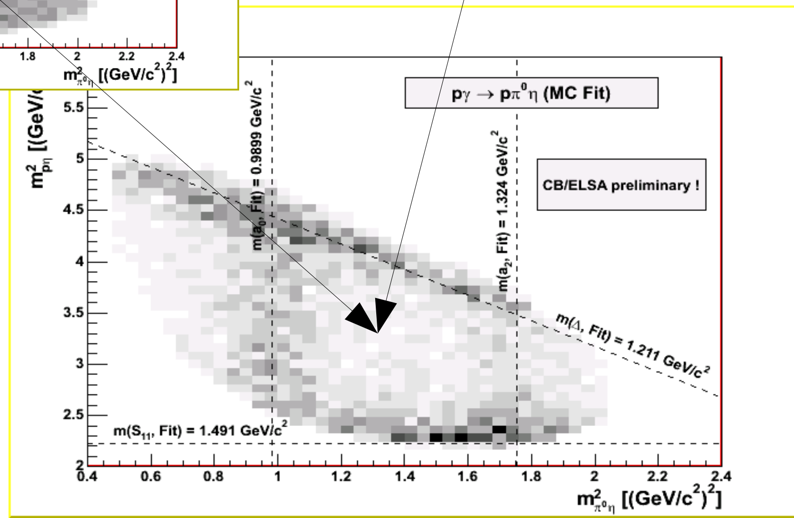
Physics Motivation – Dalitzplot Analysis at CB/ELSA (Bonn)

Dalitz plot analysis :

- In three-body final state : only two independent variables needed to describe final state; e.g. $p\gamma \rightarrow p\pi^0\eta$
- Choose squared invariant masses of each two of the three particles
- Information about resonant intermediate states can be deducted from band structures, e.g. $a_0 \rightarrow \pi^0\eta$



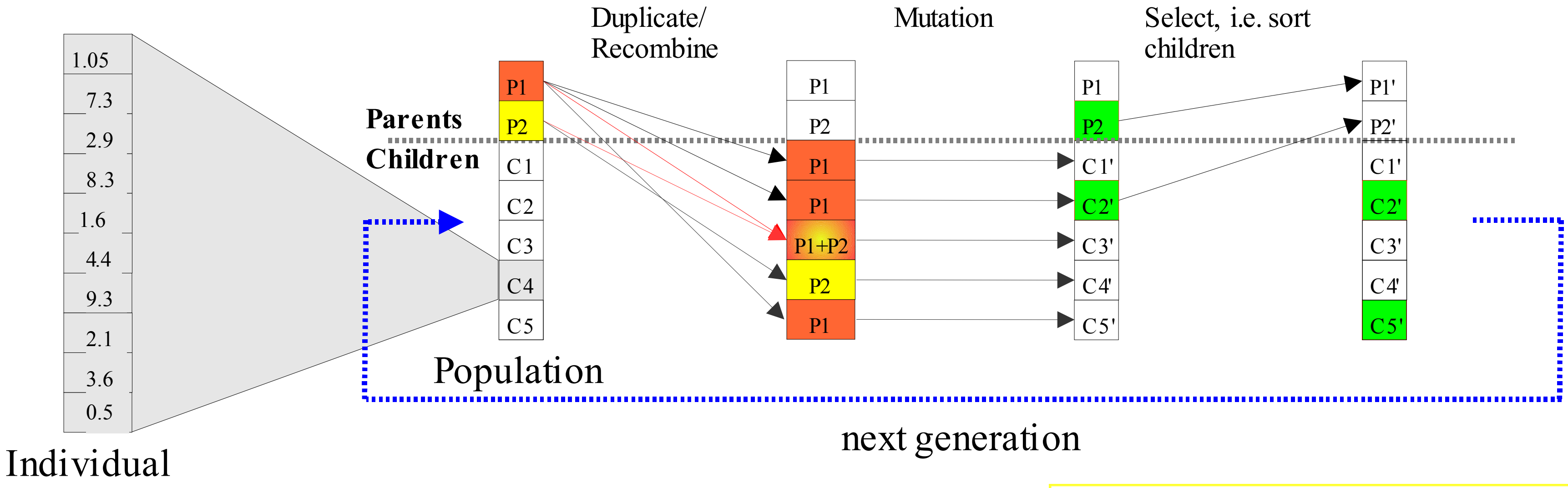




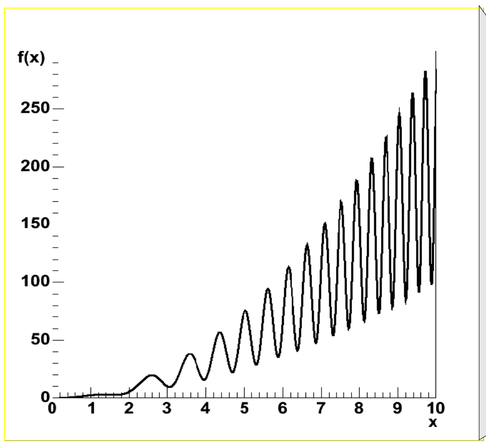
Procedure

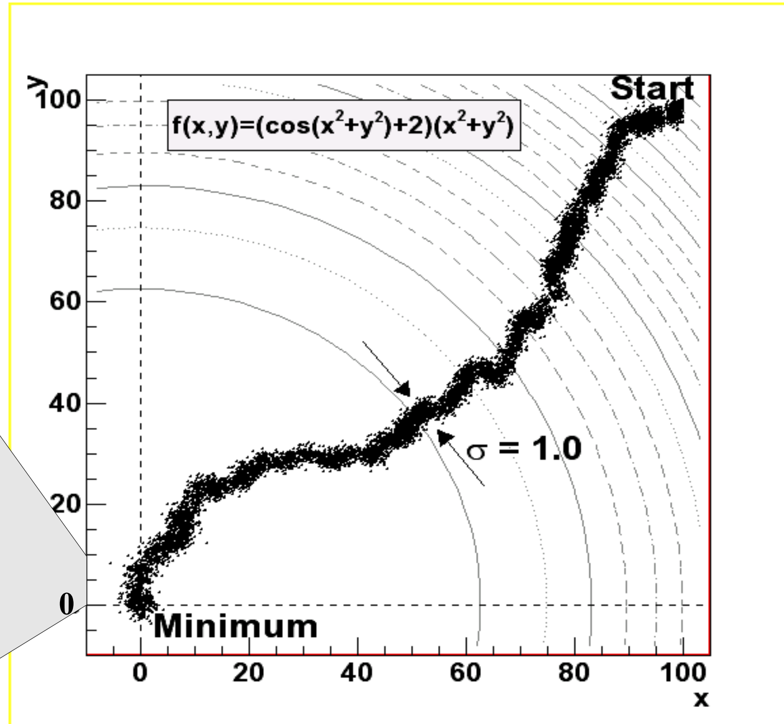
- Start with measured data + phase space distributed MC events
- Fill weight=f(masses, widths, ...) into Dalitz plot for each MC event
- Vary free parameters, minimize χ^2 (masses, widths, ...) - i.e. „difference“ between data- and MC plot; extract parameters
- Problem : large amounts of data make calculation computationally expensive

Tools – Evolutionary Strategies



- Local optima not a problem (e.g. noisy input data ...)
- Can be easily parallelized
- Suitable even for very large optimization tasks
- Non-continuous evaluation functions possible
- More function calls than standard procedures for low number of variables and easy evaluation function





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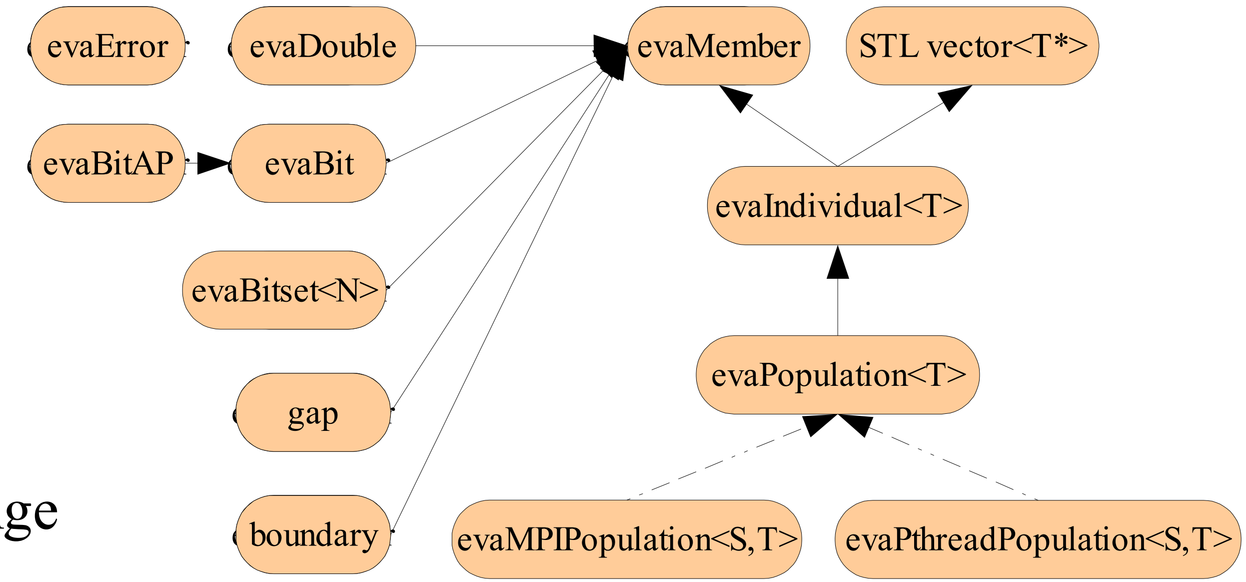
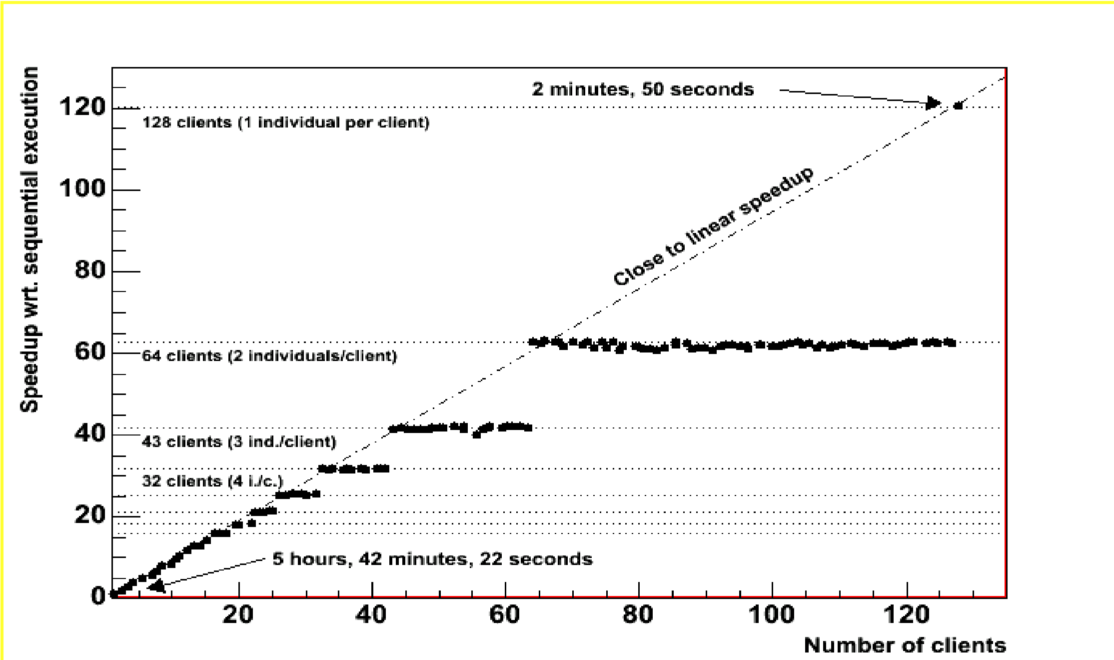
Tools – The EVA library

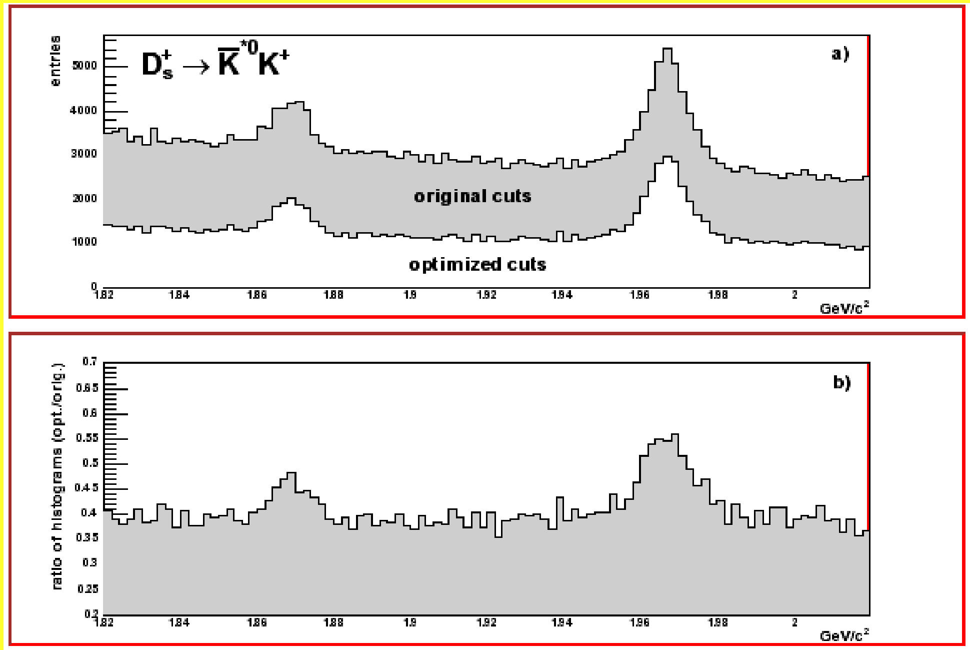
- Implementation of Evolutionary Strategies and Genetic Algorithms
- Parallel Execution on SMP (POSIX threads), clusters and Grid (through MPICH) possible
- In MPI-mode : data exchange through XML
- Seemless parallelization – no change of user code required
- Serial mode allows easy debugging
- Implemented in C++
- Derivative of STL vector class, hence fully templatized
- Open Source
- Interface to ROOT
- In idealized environment : reduction of compute time from over 5 hours to under 3 minutes (1+128 ES)
- Almost linear speedup

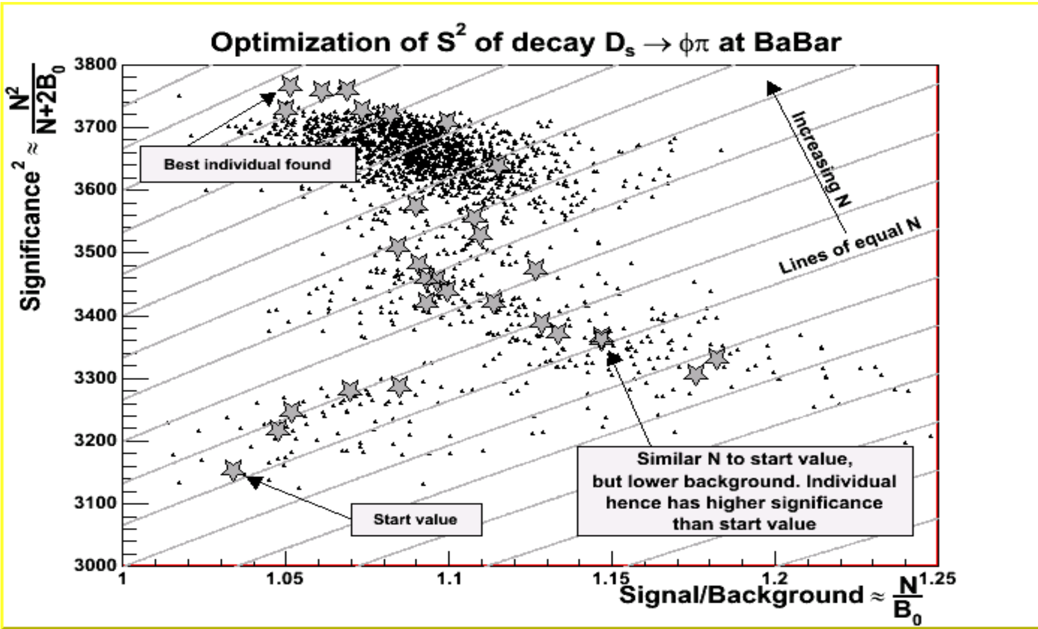


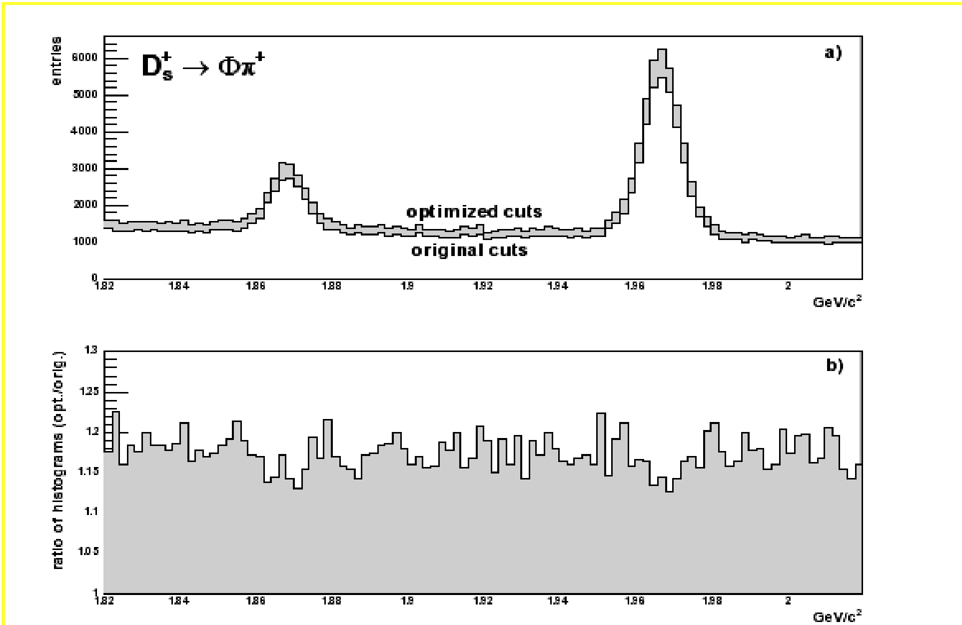


Results – BaBar / Optimizing Significance

- Variation of 4 parameters ($\cos(\Theta_h)$, D_s momentum, mass constraints, fit probability)
- Improved significance of D_s peaks between 19.4 % and 45 % in different decay channels
- Reduction of compute time from 38 to under 3 hours by parallelization (1+20 ES)







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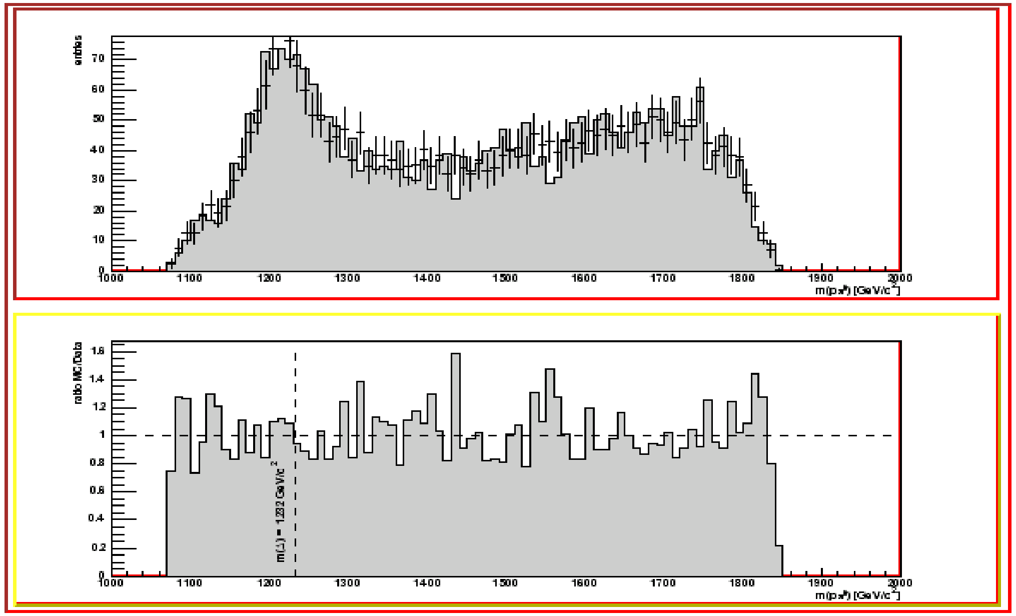
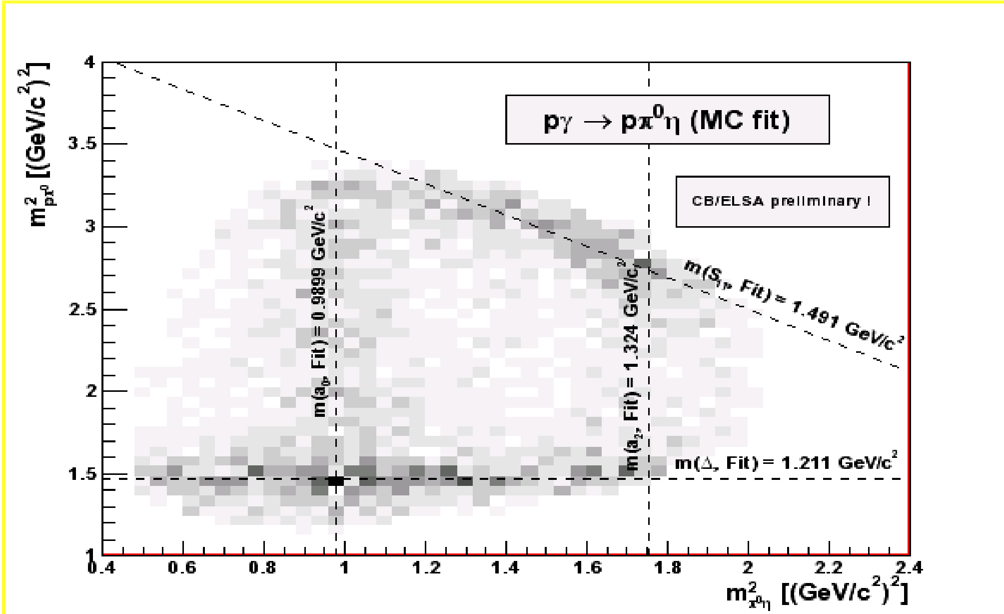
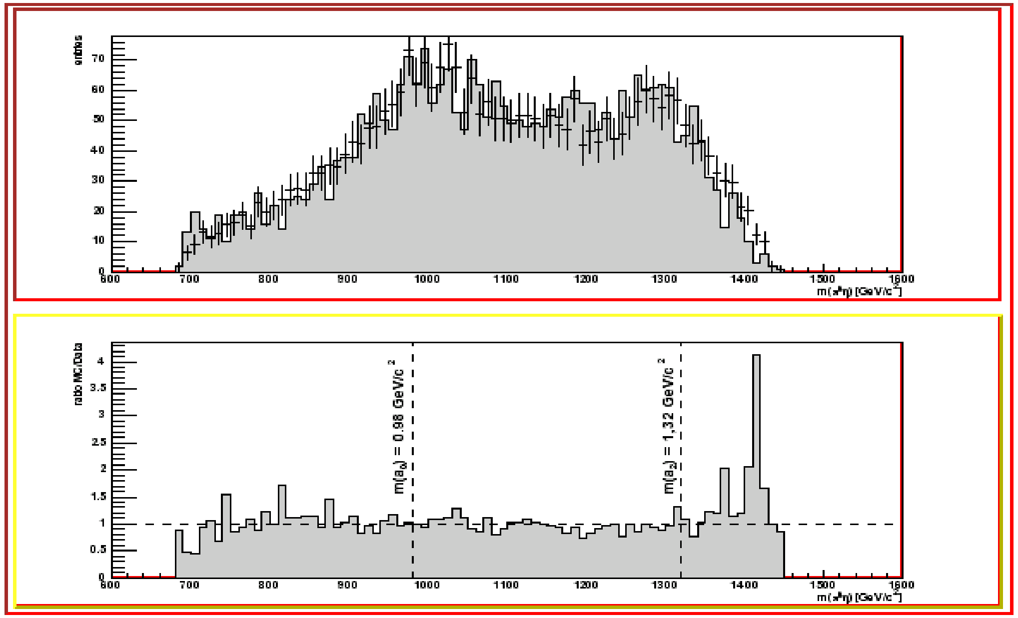
Results – CB/Elsa / Dalitz plot analysis





- Variation of 16 free parameters of (simplified) weight funtion

$$
\begin{aligned}
W \;=\;& R^2_{ph.sp.} + R^2_{\Delta_{10}} \left| BW\left(m_\Delta, \Gamma_\Delta\right) Y^0_1\left(\Theta_{p\Delta}, \Phi_{p\Delta}\right)\right|^2 \\
+\;& R^2_{\Delta_{11}} \left| BW\left(m_\Delta, \Gamma_\Delta\right) Y^1_1\left(\Theta_{p\Delta}, \Phi_{p\Delta}\right)\right|^2 + R^2_{S_{11}} \left| BW\left(m_{S_{11}}, \Gamma_{S_{11}}\right)\right|^2 \\
+\;& R^2_{a_0} \left| BW\left(m_{a_0}, \Gamma_{a_0}\right)\right|^2 + R^2_{a_2^{20}} \left| BW\left(m_{a_2}, \Gamma_{a_2}\right) Y^0_2\left(\Theta_{\eta a2}, \Phi_{\eta a2}\right)\right|^2 \\
+\;& R^2_{a_2^{21}} \left| BW\left(m_{a_2}, \Gamma_{a_2}\right) Y^1_2\left(\Theta_{\eta a2}, \Phi_{\eta a2}\right)\right|^2 + R^2_{a_2^{22}} \left| BW\left(m_{a_2}, \Gamma_{a_2}\right) Y^2_2\left(\Theta_{\eta a2}, \Phi_{\eta a2}\right)\right|^2
\end{aligned}
$$



- Very good agreement of MC and data after the ES-based fit

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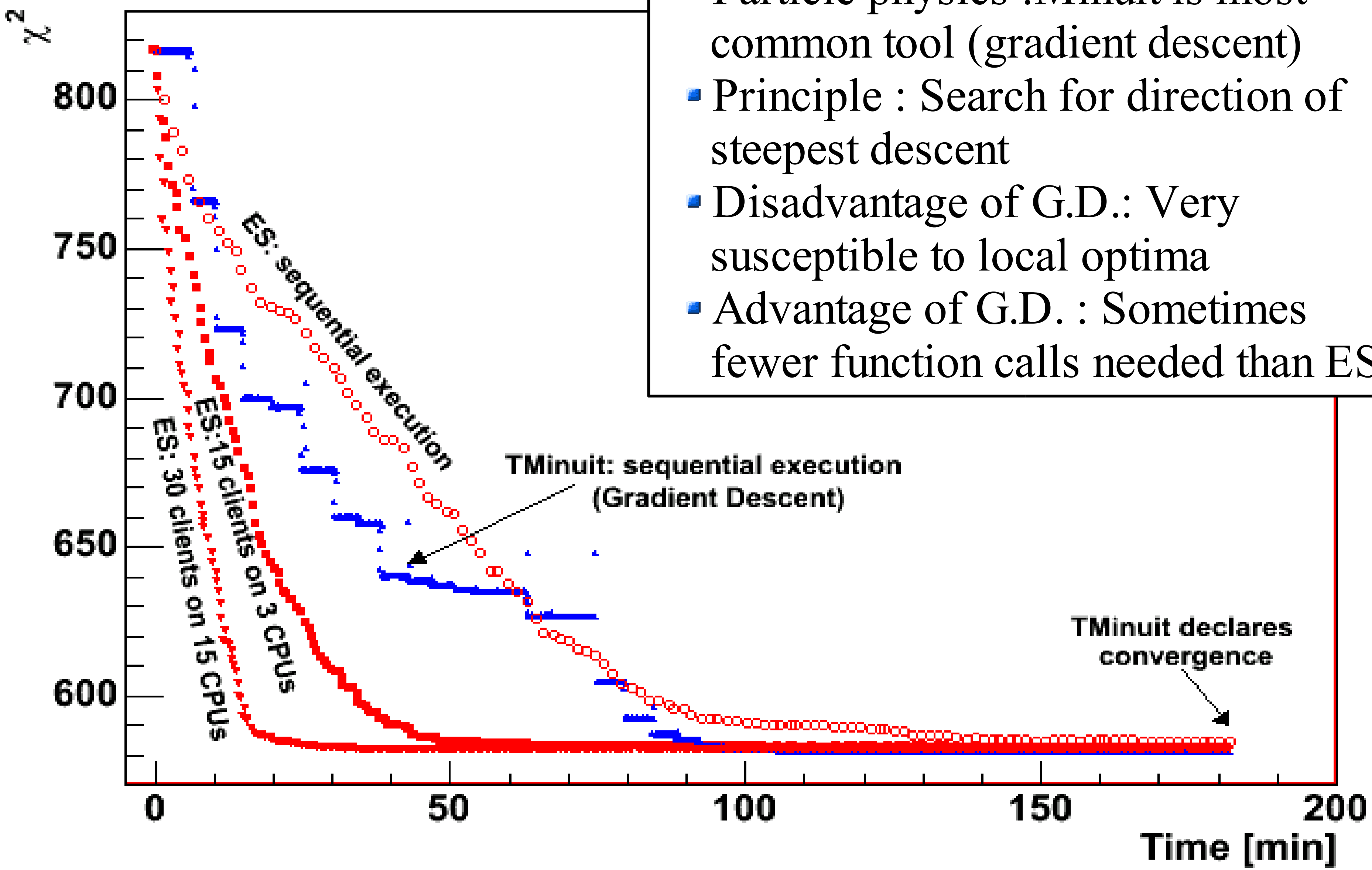
Results – Comparison with Gradient Descent (D.P. analysis)



- Particle physics :Minuit is most common tool (gradient descent)
- Principle : Search for direction of steepest descent
- Disadvantage of G.D.: Very susceptible to local optima
- Advantage of G.D. : Sometimes fewer function calls needed than ES

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Conclusion

- Automated optimization of particle signals shows very good results even when starting with hand-optimized cuts
- Dalitz plot analysis benefits from parallel execution
- The EVA library, by virtue of parallel execution, makes also those problems accessible to optimization that so far were deemed too computationally expensive
- The EVA library can be used for almost generic small or large optimization problems, in- or outside physics (example : optimization of urban traffic)
- Code will be made available under an Open Source license in a few weeks

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bmb+f - Förderschwerpunkt

Hadronen - und Kernphysik

Großgeräte der physikalischen Grundlagenforschung