Helmholtz Alliance

PHYSICS AT THE TERASCALE

Welcome, introduction and overview

Johannes Albrecht, Kevin Kröninger

(TU Dortmund)

Meinerzhagen, 21.9.2015

Organizing committee:
J. Albrecht (Co-chair), D.v. Dyk, J. Erdmann, G. Hiller, R. Klingenberg, K. Kröninger (co-chair), B. Spaan, P. Uwer

Organizers

Kevin Kröninger (Dortmund)

Johannes Albrecht (Dortmund)

Johannes Erdmann (Dortmund)

Danny van Dyk (Siegen)

Organizing committee: G. Hiller, R. Klingenberg, B. Spaan, P. Uwer

Meals & times

- Wireless is “everywhere, free and not protected”
  - Please leave your laptop closed during lectures

- We have two rooms, the plenum (here) & “Raum Lister”

- Lunch starts at 12:00, restart lectures at 14:00
  - Coffee breaks as indicated on the agenda

- Lunch for Friday, two options:
  - Normal lunch
  - Lunch-Pack to go

  → Please enter your choice in the lists

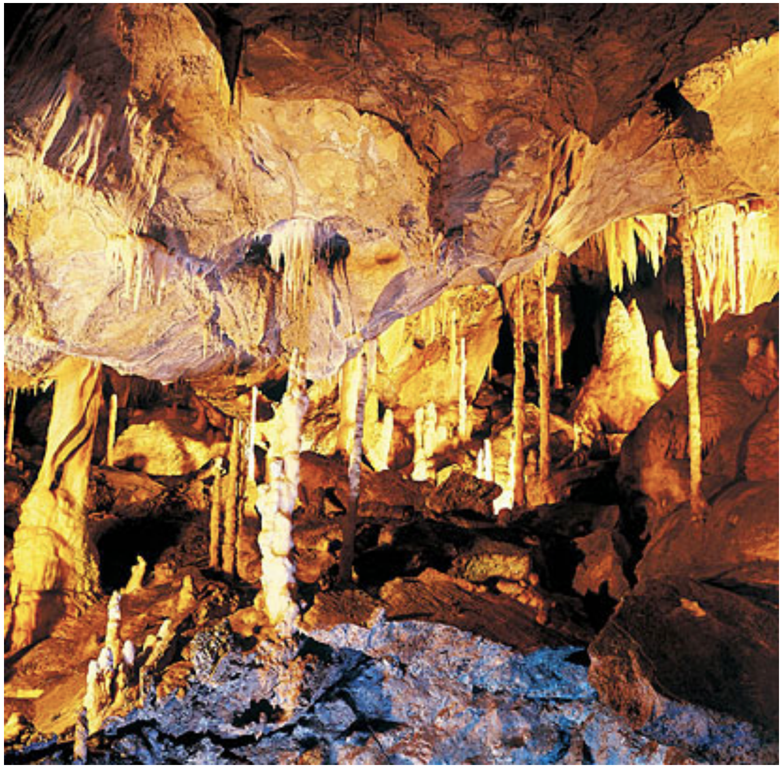
- Social event: Wednesday afternoon

Structure of school

- We have (in principle) added a exercise / discussion session to each lecture
  - Please use them and participate
- There are no stupid questions …. !
- Students come from very different backgrounds
  - This can be very beneficial if we profit from it

Social event: Tour to the Atta-Cave

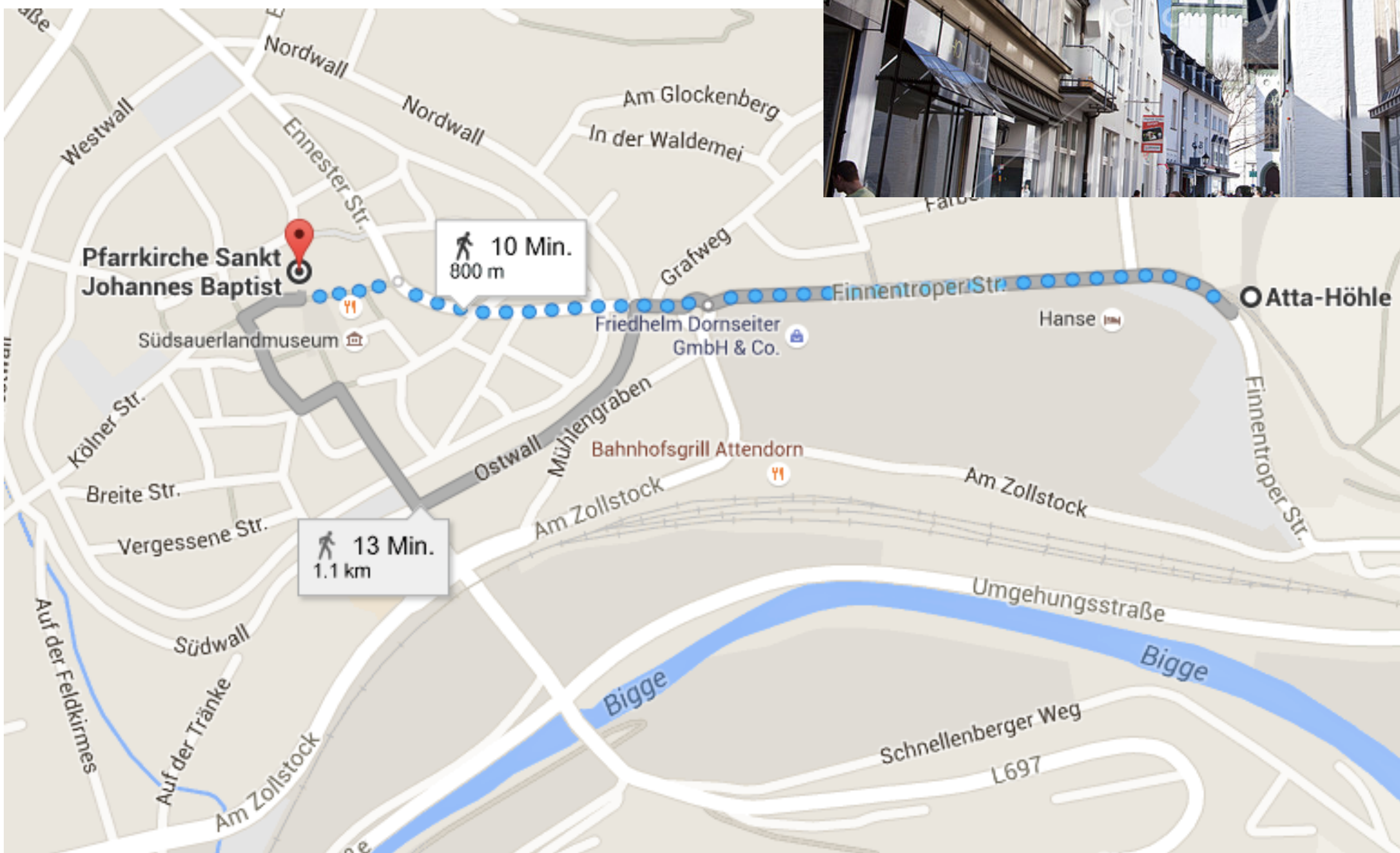
- trip to Attendorn Dripstone Cave
- 20 min. drive
- bus will leave Wednesday 2pm
- tour starts 3pm
- lasts ~ 1.5h including cheese tasting



Johannes Erdmann

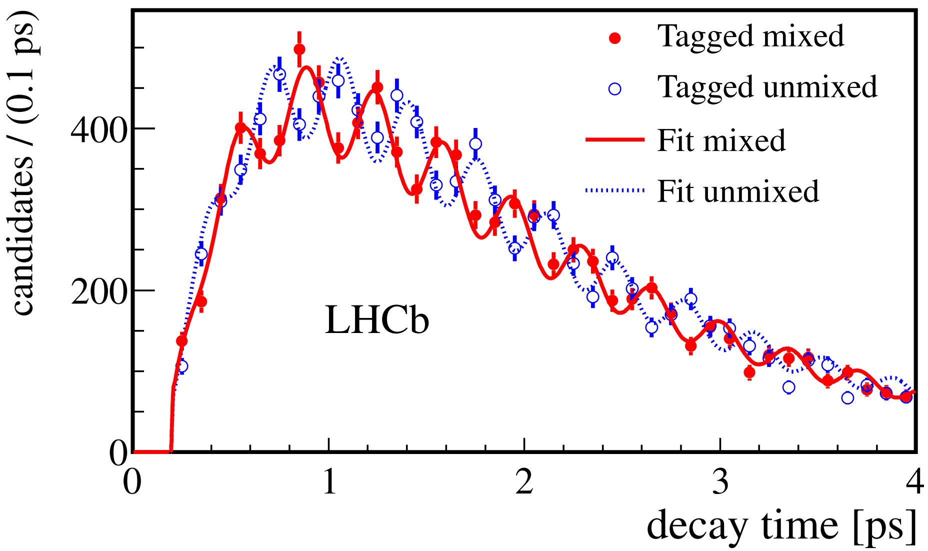
Social event: Tour to the Atta-Cave

- after that free time to spend in the old town
- bus will leave again 6:30pm at Atta-Höhle
- barbecue at haus nordhelle if weather permits

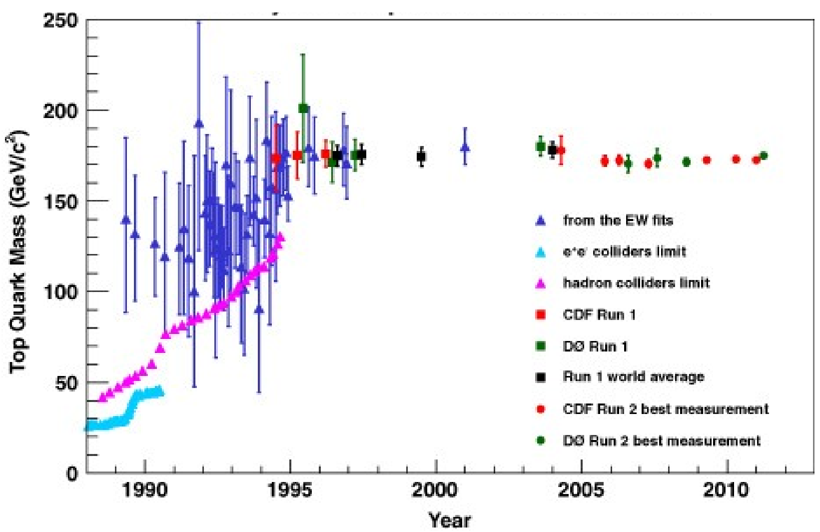


- Idea of the school:
  "how to make a precision measurement and how to interpret it?"

B_s -$\overline{B}_s$ oscillations



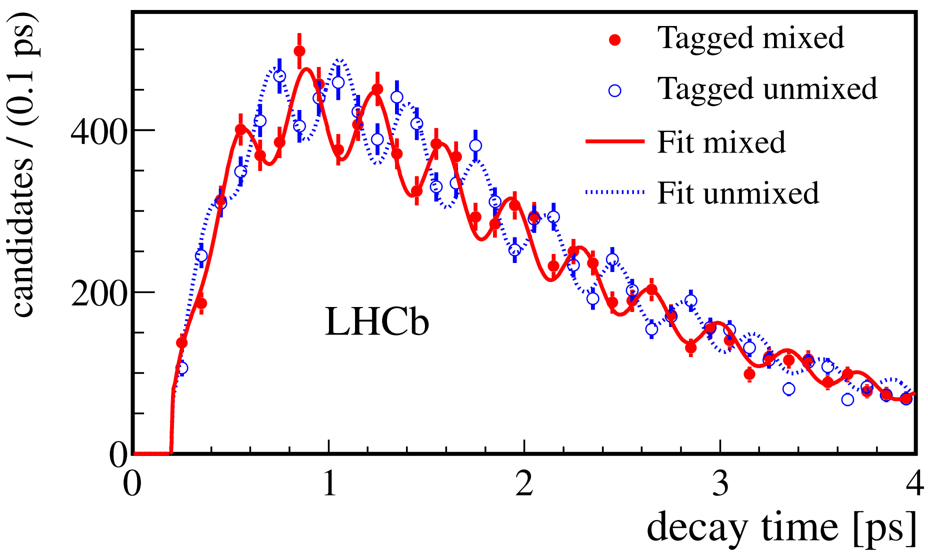
Top-Quark mass

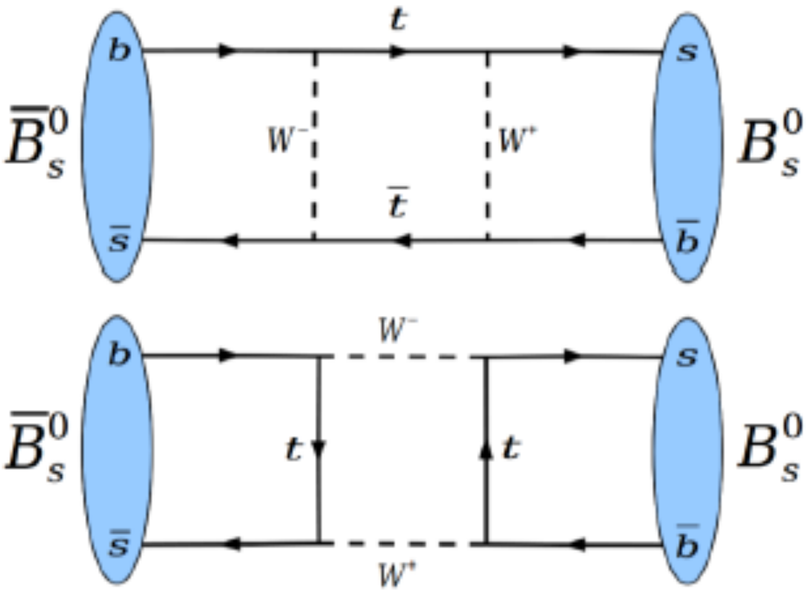


[Ann. Rev. Nucl. Part. Sci. **59** (2009) 505]

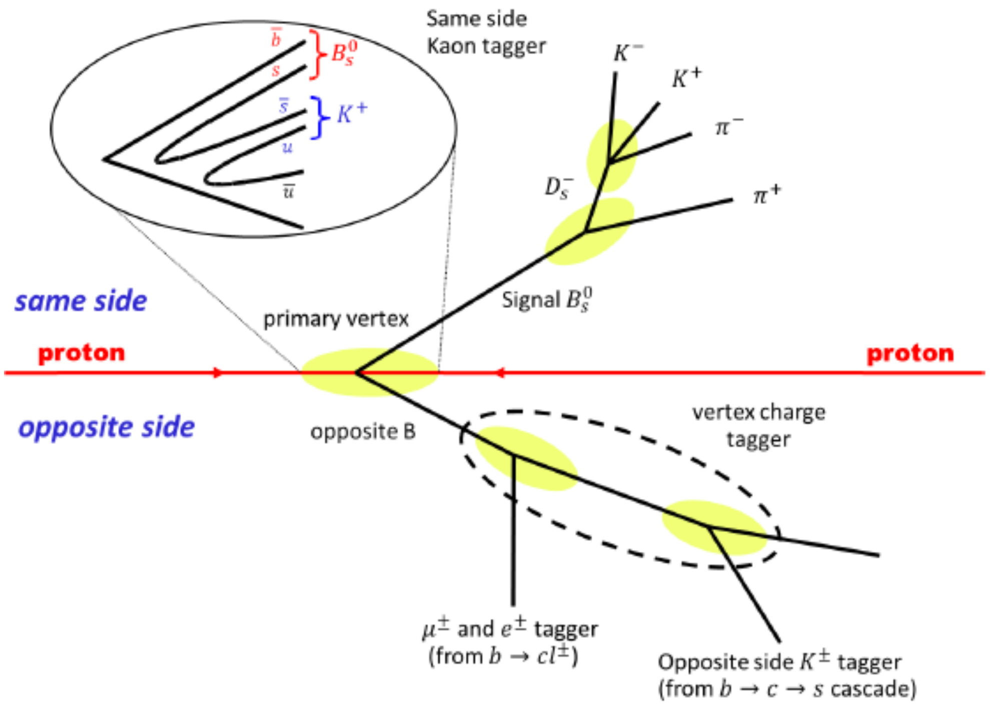
1st Example: Beauty Oscillations

B_s -$\overline{B}_s$ oscillations





Detour: Flavour tagging at hadron colliders



- Opposite side taggers
  - Partially reconstruct second b in event
    → conclude on production flavour
- Same sign taggers
  - Exploit hadronization remnants
- Combine all taggers
  - Combined tagging power:
    LHCb: $\varepsilon D^2 \sim 3.5\%$
    ATLAS: ~ 1.5%
    B-factories ~ 30%

Tagging efficiency

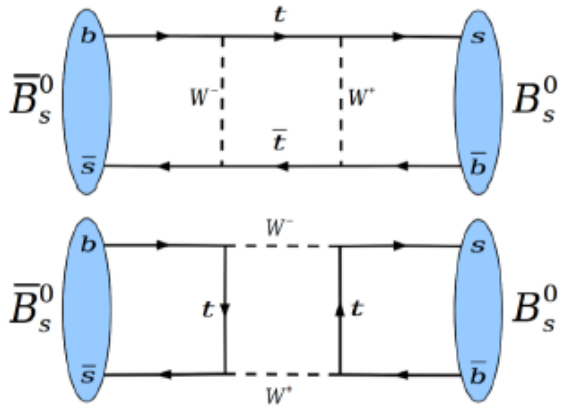
$$\varepsilon = \frac{\#\, tagged\ candidates}{\#\, all\ candidates}$$

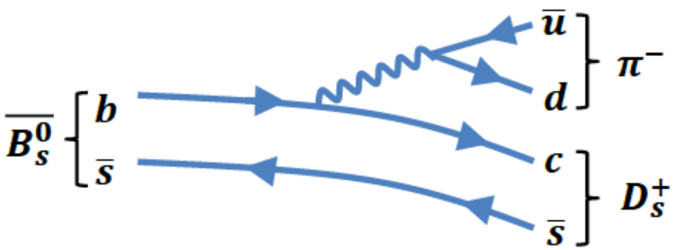
Mistag probability

$$\omega = \frac{\#\, tagged\ wrong}{\#\, tagged}$$

Dilution

$$D = (1 - 2\omega)$$

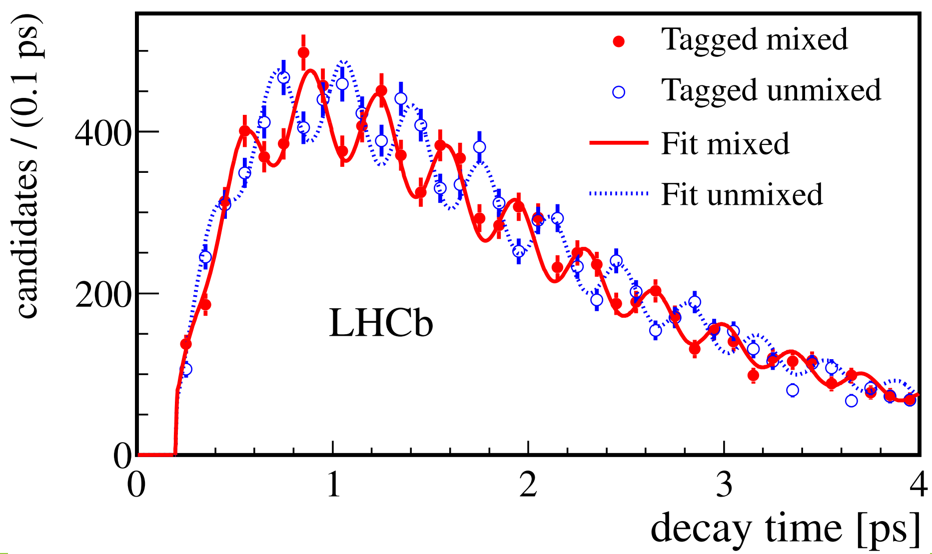




New J. Phys. 15 (2013) 053021

Know production flavour from tagging

Know decay flavour from charge

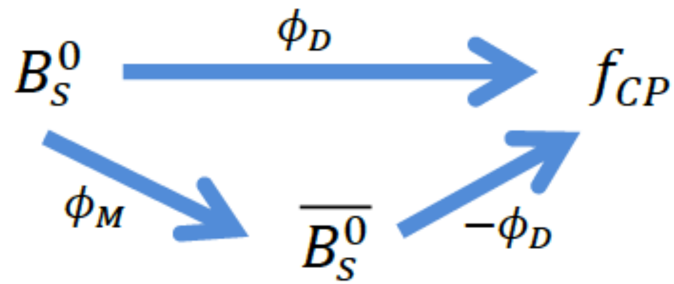


But: need clean theory to understand CP asymmetries

→ need other decay

Clean way to measure CP violation:
Interference between mixing and decay

$$\phi_s = \phi_M - 2\phi_D$$



B_s : $J^P = 0^{-1}$ (pseudo scalar)

J/ψ: : $J^{CP} = 1^{-1-1}$ (vector)

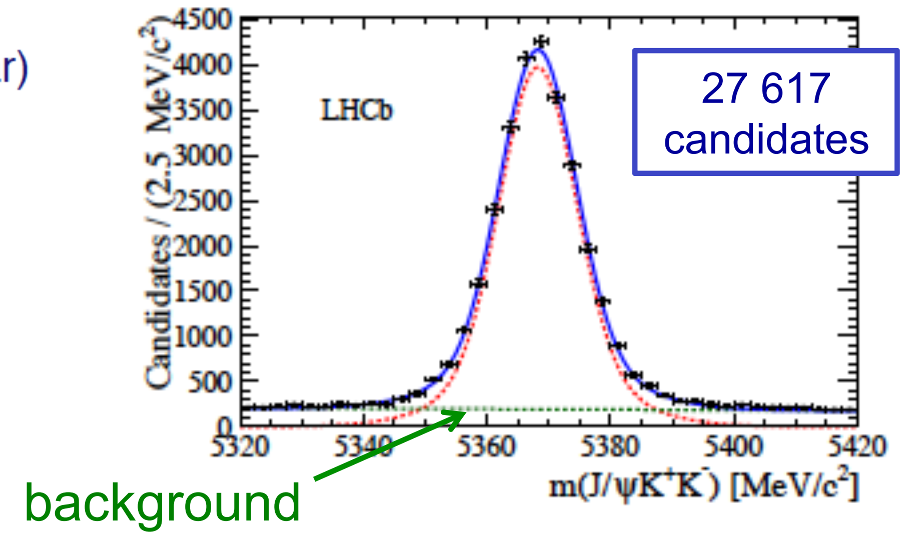
ϕ: : $J^{CP} = 1^{-1-1}$ (vector)

Angular momentum conservation:

$0 = J\,(J/\psi\phi) = |\vec{S} + \vec{L}|; \rightarrow L = 0,1,2$

$L = 0,2 \longrightarrow$ CP even final state

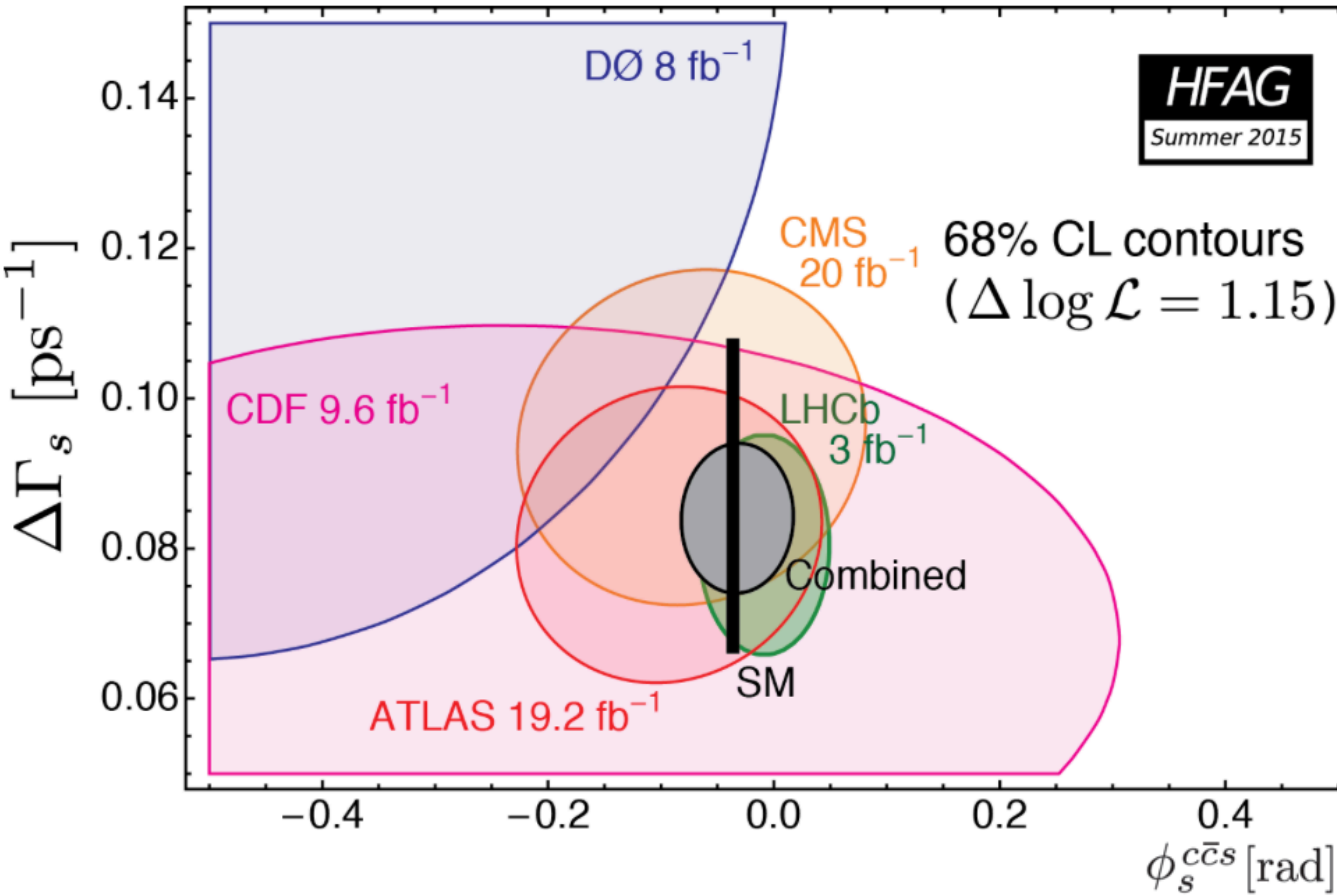
$L = 1 \longrightarrow$ CP odd final state



Final state no CP eigenstate but linear combination!

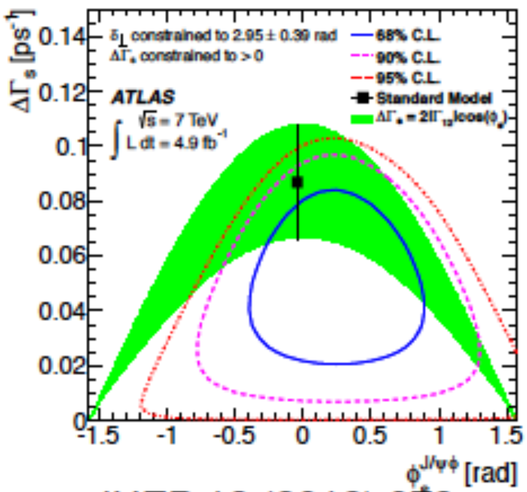
Angular analysis, to separate CP even/odd contributions.

World results combined



Detour: The importance of flavour tagging

ATLAS untagged result

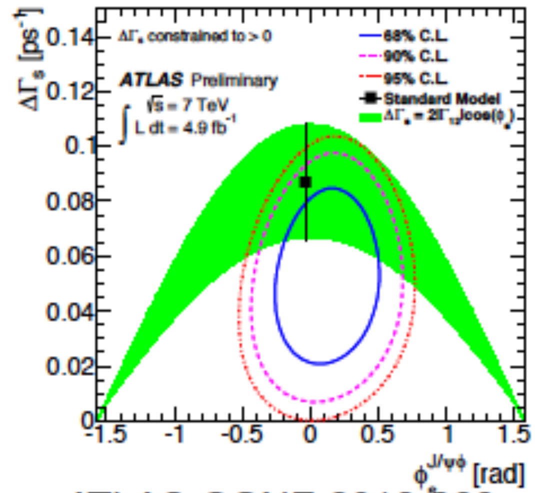


JHEP 12 (2012) 072

uncertainty on ϕ_s

improved by 40%

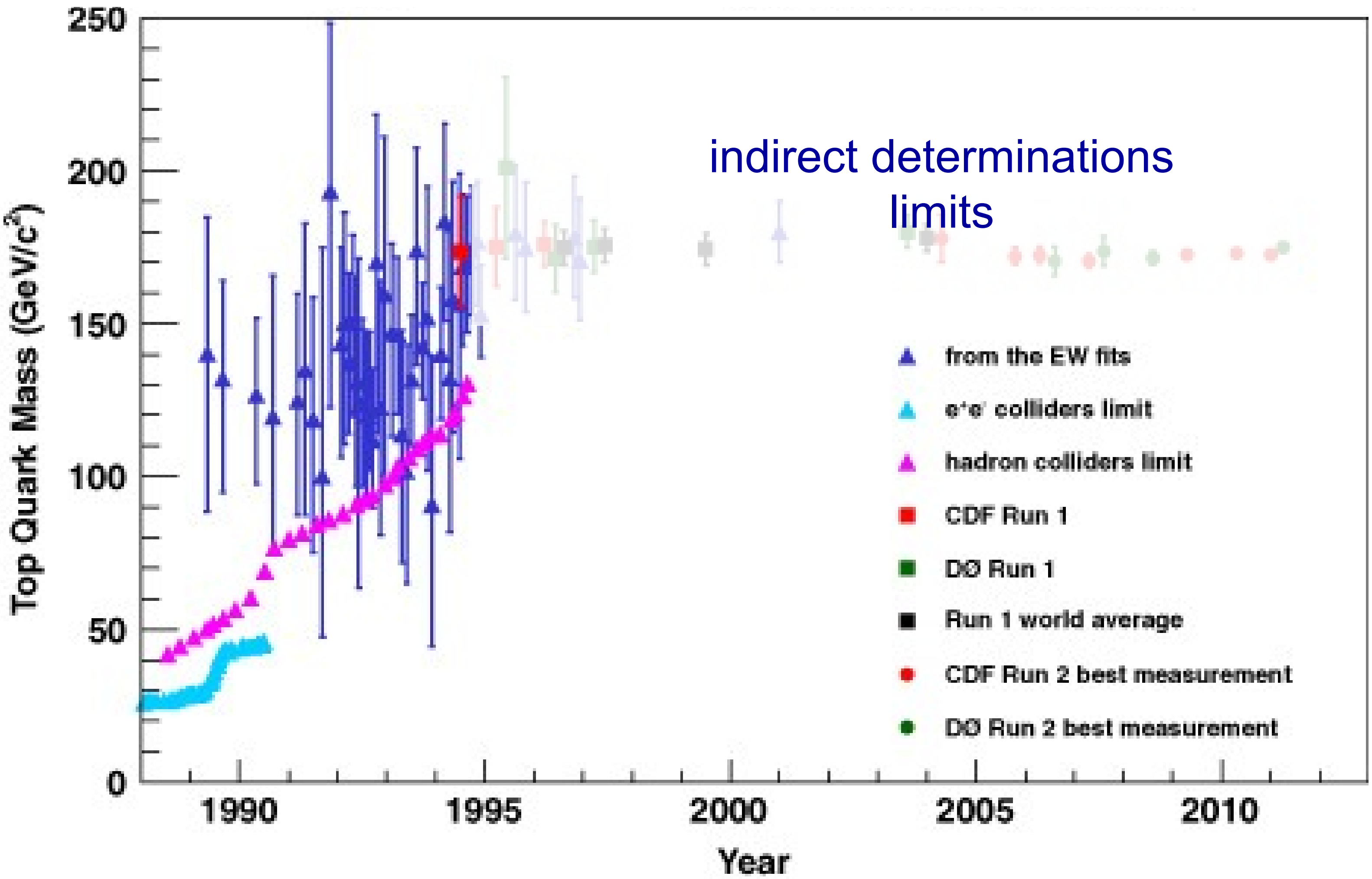
ATLAS tagged result



ATLAS-CONF-2013-039

The ATLAS collaboration managed to improve their sensitivity
by 40% with the inclusion of flavour tagging
(εD^2=1.45%, cf. ~3.5% @ LHCb)

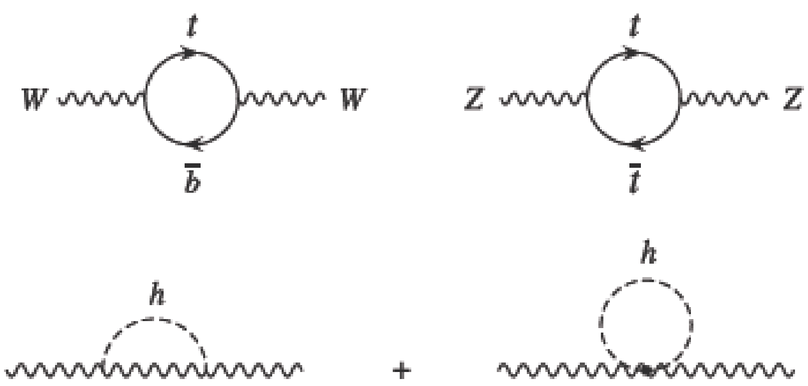
2nd Example: Top mass

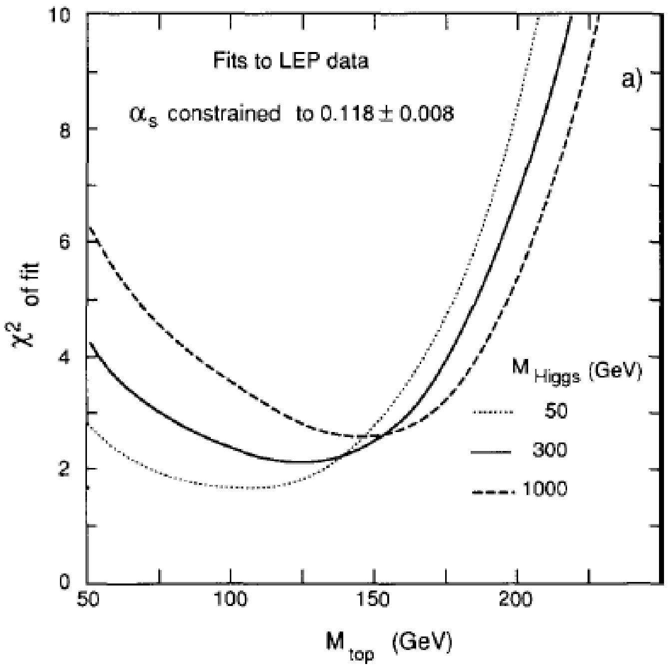


[Ann. Rev. Nucl. Part. Sci. **59** (2009) 505]

Example: the top mass

- Before discovery: top mass from EW fits

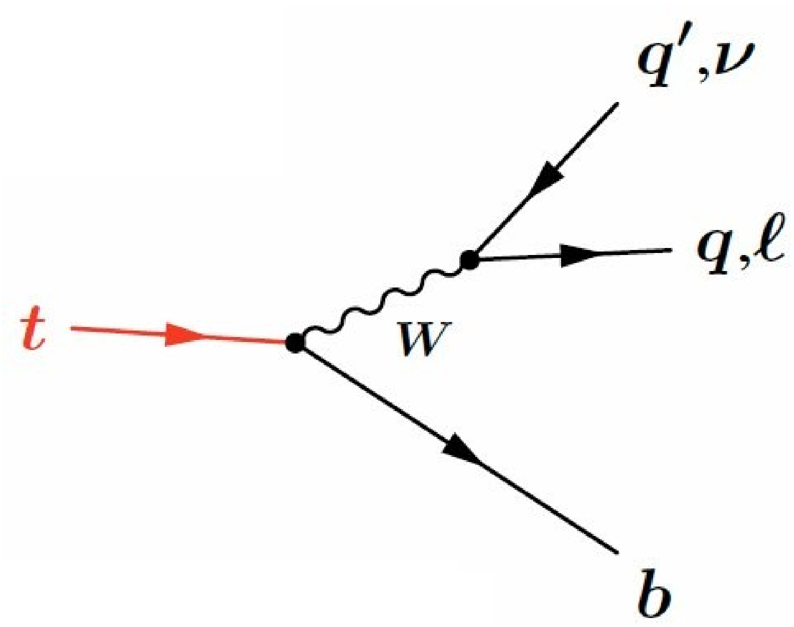




[Phys. Lett. B **276** (1992) 247]

- Measurement: Properties of $W^\pm$, Z^0
  → Processes influenced by top and Higgs mass
  (plus other SM Parameters)

Discovery (1995)



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NEWS RELEASE

News Release - March 2, 1995

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Judy Jackson, 708/840-4112 (Fermilab)
Gary Pitchford, 708/252-2013 (Department of Energy)
Jeff Sherwood, 202/586-5806 (Department of Energy)

PHYSICISTS DISCOVER TOP QUARK

Batavia, IL--Physicists at the Department of Energy's Fermi National Accelerator Laboratory today (March 2) announced the discovery of the subatomic particle called the top quark, the last undiscovered quark of the six predicted by current scientific theory. Scientists worldwide had sought the top quark since the discovery of the bottom quark at Fermilab in 1977. The discovery provides strong support for the quark theory of the structure of matter.

Two research papers, submitted on Friday, February 24, to Physical Review Letters by the CDF and DZero experiment collaborations respectively, describe the observation of top quarks produced in high-energy collisions between protons and antiprotons, their antimatter counterparts. The two experiments operate simultaneously using particle beams from Fermilab's Tevatron, world's highest energy particle accelerator. The collaborations, each with about 450 members, presented their results at seminars held at Fermilab on March 2.

"Last April, CDF announced the first direct experimental evidence for the top quark," said William Carithers, Jr., cospokesman, with Giorgio Bellettini, for the CDF experiment, "but at that time we stopped short of claiming a discovery. Now, the analysis of about three times as much data confirms our previous evidence and establishes the discovery of the top quark."

The DZero collaboration has discovered the top quark in an independent investigation. "The DZero observation of the top quark depends primarily on the number of events we have seen, but also on their characteristics," said Paul Grannis, who serves, with Hugh Montgomery, as DZero cospokesman. "Last year, we just did not have enough events to make a statement about the top quark's existence, but now, with a larger data sample, the signal is clear."

Physicists identify top quarks by the characteristic electronic signals they produce. However, other phenomena can sometimes mimic top quark signals. To claim a discovery, experimenters must observe enough top quark events to rule out any other source of the signals.

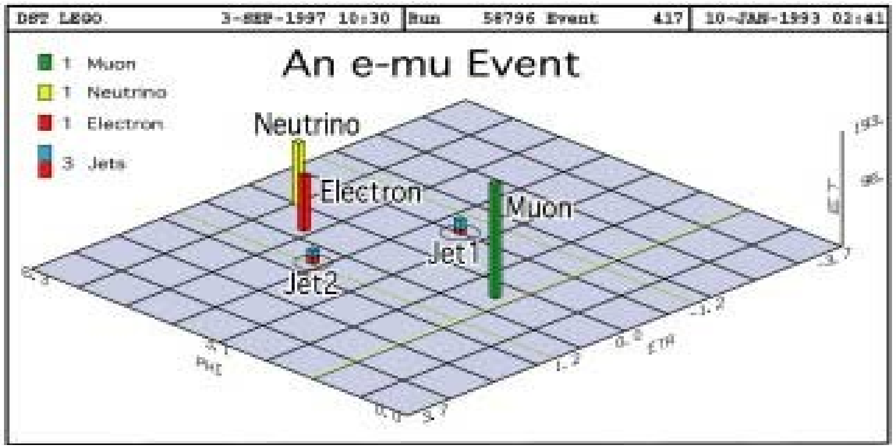
"This discovery serves as a powerful validation of federal support for science," said Secretary of Energy Hazel R. O'Leary. "Using one of the world's most powerful research tools, scientists at Fermilab have made yet another major contribution to human understanding of the fundamentals of the universe."

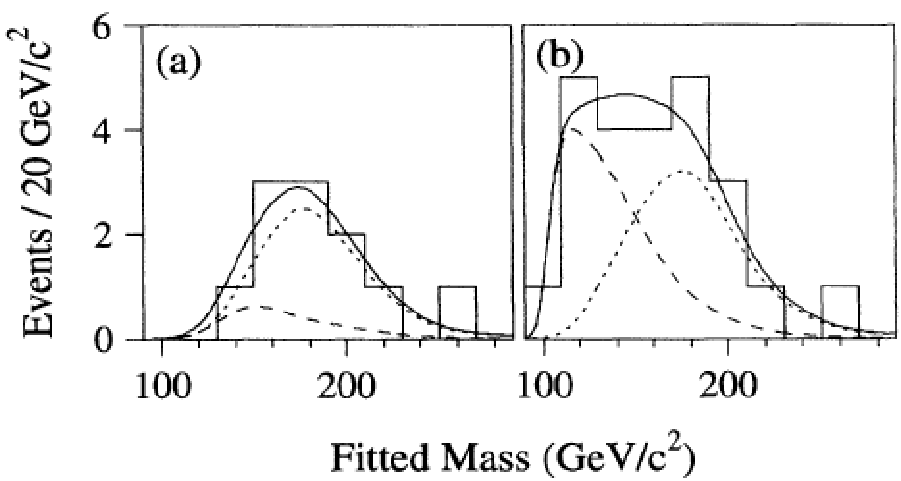
The Department of Energy, the primary steward of U.S. high-energy physics, provided the majority of funding for the research. The Italian Institute for Nuclear Physics and the Japanese Ministry of Education, Science and Culture made major contributions to CDF. Support for DZero came from Russia, France, India, and Brazil. The National Science Foundation contributed to both collaborations. Collaborators include scientists from Brazil, Canada, Colombia, France, India, Italy, Japan, Korea, Mexico, Poland, Russia, Taiwan, and the U.S.

"The discovery of the top quark is a great achievement for the collaborations," said Fermilab Director John Peoples, "and also for the men and women of Fermilab who imagined, then built, and now operate the Tevatron accelerator. We have much to learn about the top quark, and more of nature's best-kept secrets to explore. We look forward to beginning a new era of research with the Tevatron, making the best use of the world's highest-energy collider."

Fermilab, 30 miles west of Chicago, is a high-energy physics laboratory operated by Universities Research Association, Inc. under contract with the U.S. Department of Energy.

Discovery (1995)





[Phys. Rev. Lett. **74** (1995) 2632]

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News Release - March 2, 1995

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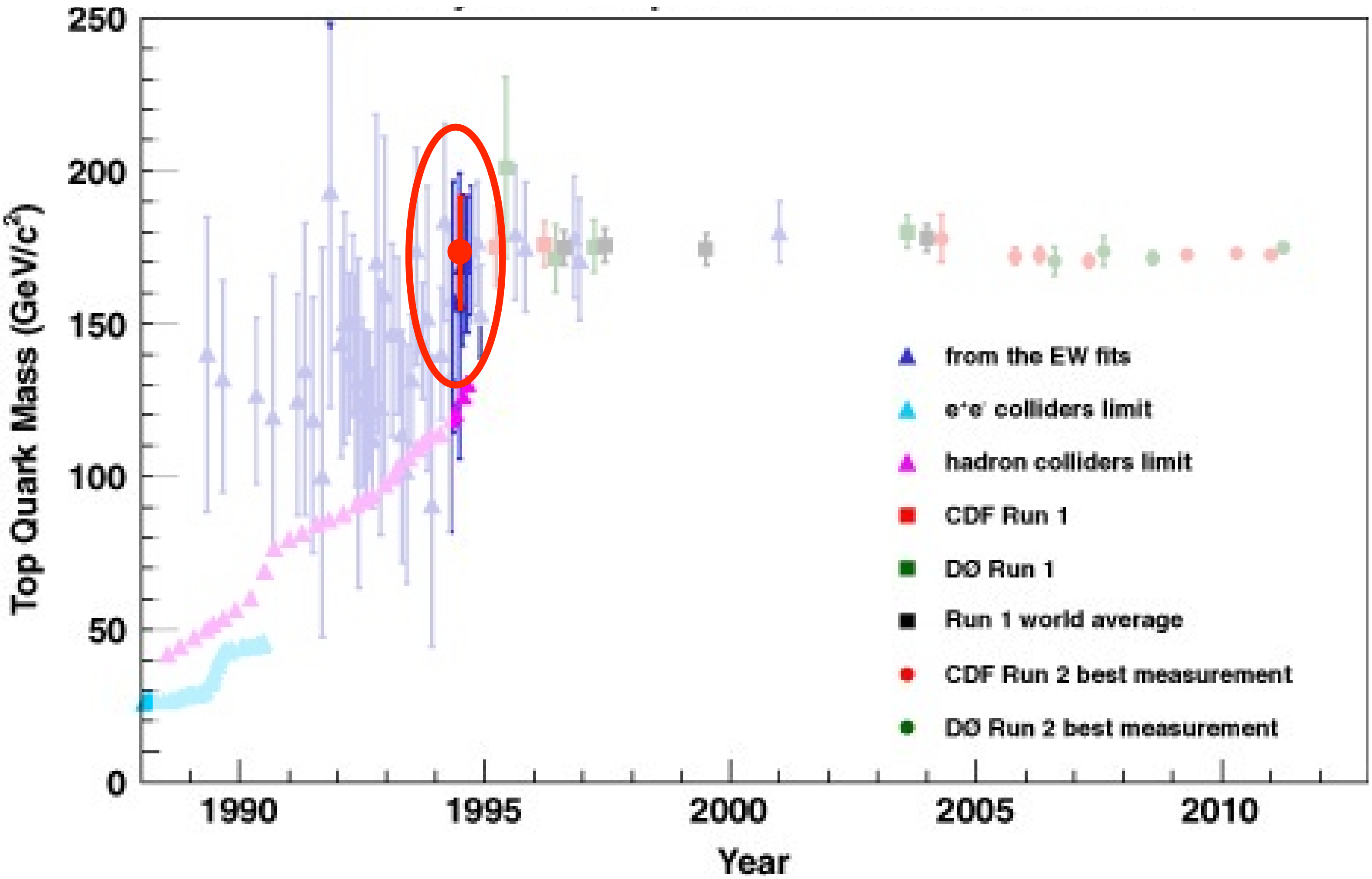
Evolution of top mass



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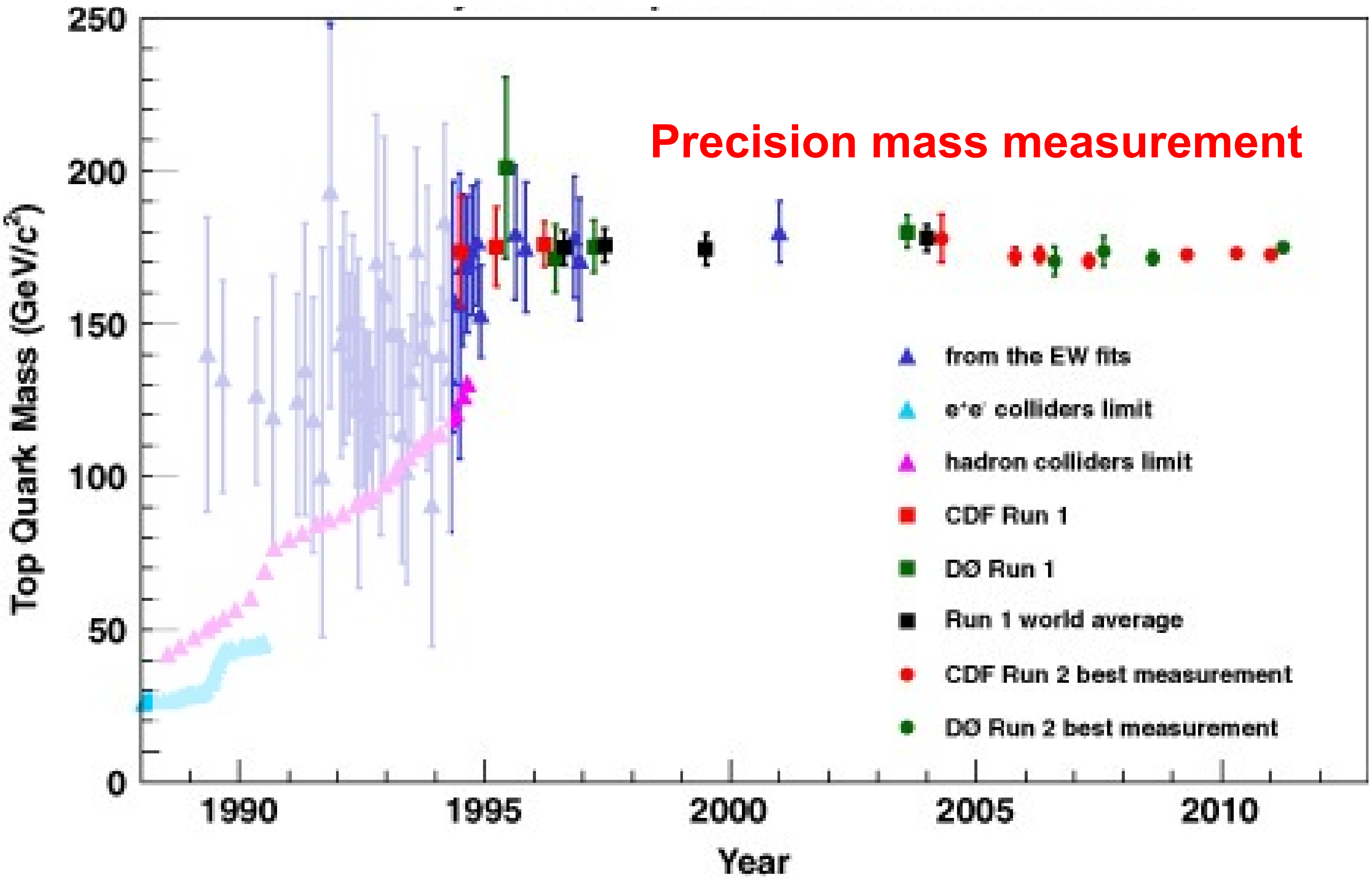

[Ann. Rev. Nucl. Part. Sci. **59** (2009) 505]

What was used?

- Parameter / Observables
  - Top mass used as parameter in Electroweak fits
    → also after discovery: parameter “top mass”, observable jet-mass

- What are uncertainties, statistical and systematical?
    - Often the systematic uncertainties govern the measurement done
    - What is a theory uncertainty

- Statistical interpretation of results
  - What are “limits” and how to interpret not seeing a signal
  - How to combine several measurements?
  - How to do “fits” and how to interpret them in Standard Model (or beyond Standard Model) quantities?
    - Methods used: template method, (un)-binned likelihood fits, Matrix Element method

Content of the school

- Idea of the school:
  "how to make a precision measurement
  and how to interpret it?"

1) Components: what is measured and what is estimated
   → P. Uwer: Observables and Parameters

2) Example measurements, these will use what you will learn
   → U. Uwer: Measurements with bottom quarks
   → D. Hirschbühl: Measurements with top quarks

Content of the school

3) How do we analyse data,
   → M. Schmelling: Statistical methods

4) How precise are our measurements? (more than statistics)
   → M. Kenzie: Systemtatic uncertainties

5) Why is it necessary to use effective theories to increase precision?
   → B. Lange: Introduction to effective field theory

6) Example analysis of current flavour data
   → D. Straub: Interpretation of measurements

Many thanks to the Terascale Alliance for support!

Helmholtz Alliance

PHYSICS AT THE TERASCALE

PHYSICS AT THE TERA SCALE Helmholtz Alliance

Deutsches Elektronen-Synchrotron DESY + + + Karlsruher Institut für Technologie - Großforschungsbereich + + + Max-Planck-Institut für Physik München + + + Rheinisch-Westfälische Technische Hochschule Aachen + + + Humboldt-Universität zu Berlin + + + Rheinische Friedrich-Wilhelms-Universität Bonn + + + Technische Universität Dortmund + + + Technische Universität Dresden + + + Albert-Ludwigs-Universität Freiburg + + + Justus-Liebig-Universität Gießen + + + Georg-August-Universität Göttingen + + + Universität Hamburg + + + Ruprecht-Karls-Universität Heidelberg + + + Karlsruher Institut für Technologie - Universitätsbereich + + + Johannes Gutenberg-Universität Mainz + + + Ludwig-Maximilians-Universität München + + + Universität Regensburg + + + Universität Rostock + + + Universität Siegen + + + Julius-Maximilians-Universität Würzburg + + + Bergische Universität Wuppertal + + +