The search for the Higgs Boson at CERN

Is there such a thing as too much compute power?

February 7th 2013

Andrzej Nowak, CERN openlab

Andrzej.Nowak@cern.ch

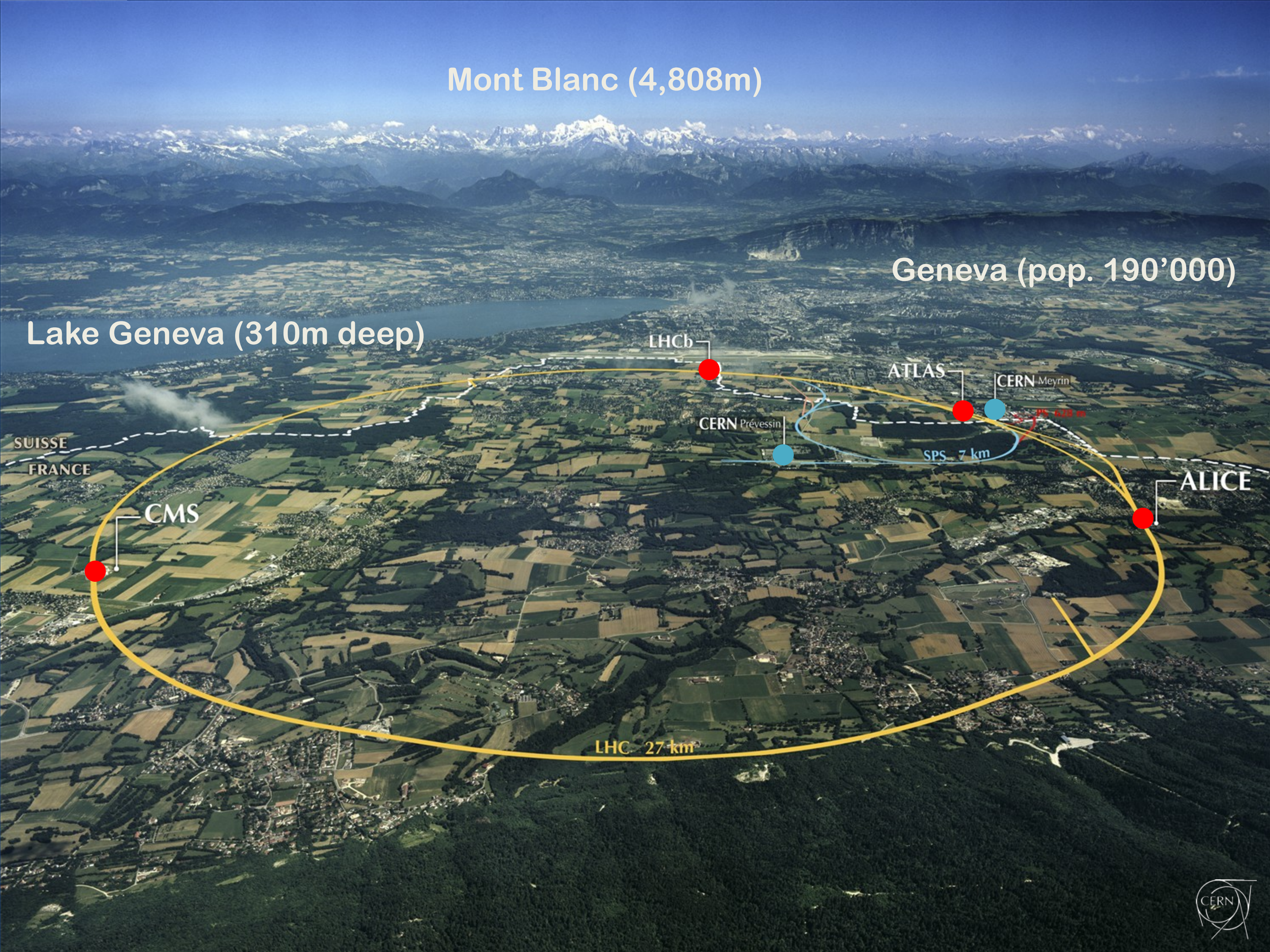
CERN openlab

The European Particle Physics Laboratory based in Geneva, Switzerland

Founded in 1954 by 12 countries for fundamental physics research in a post-war Europe

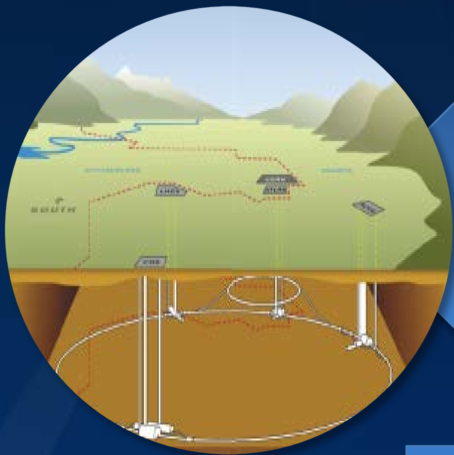
In 2012, it is a global effort of 20 member countries and scientists from 110 nationalities, working on the world’s most ambitious physics experiments

~2’500 personnel, > 15’000 users
~1 bln CHF yearly budget

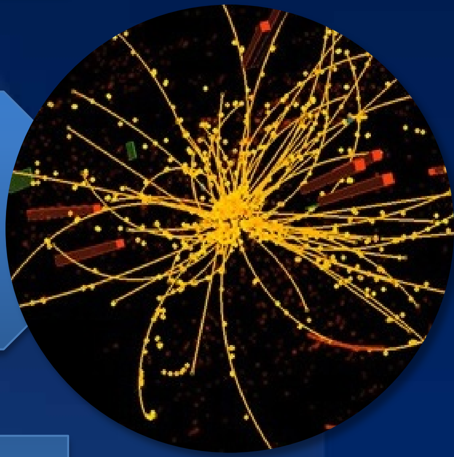


Mont Blanc (4,808m)
Geneva (pop. 190’000)
Lake Geneva (310m deep)
LHCb
ATLAS
CERN Meyrin
PS 628 m
CERN Prévessin
SPS 7 km
SUISSE
FRANCE
ALICE
CMS
LHC 27 km

The Large Hadron Collider

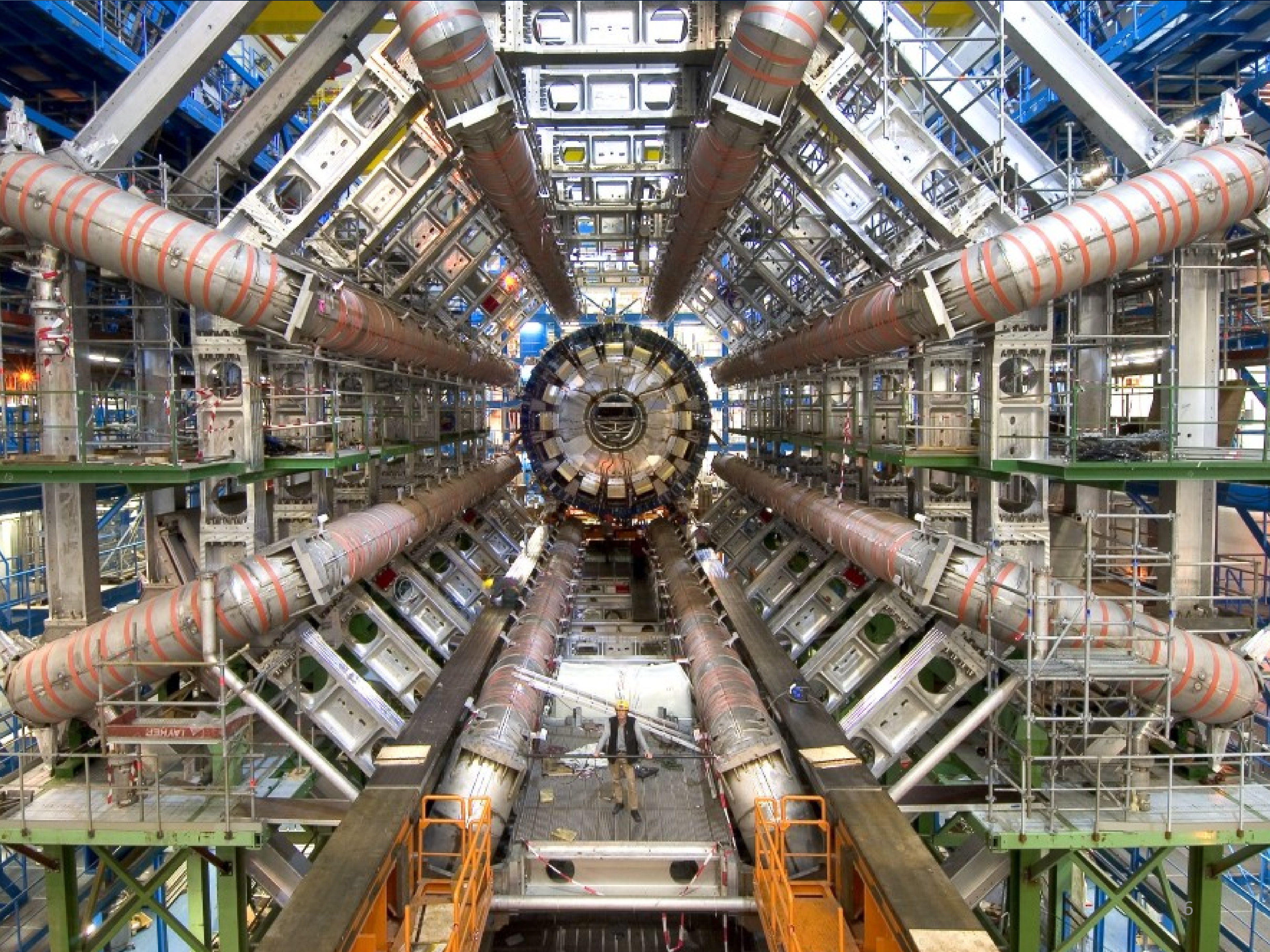


27 km underground superconducting ring – possibly the largest machine ever built by man



40 million collisions per second

150-200 MW power consumption



Charged-particle multiplicities in pp interactions at $\sqrt{s} = 900$ GeV measured with the ATLAS detector at the LHC [☆,☆☆]

ATLAS Collaboration

A R T I C L E   I N F O

Article history:
Received 16 March 2010
Received in revised form 22 March 2010
Accepted 22 March 2010
Available online 28 March 2010
Editor: W.-D. Schlatter

Keywords:
Charged-particle
Multiplicities
900 GeV
ATLAS
LHC
Minimum bias

A B S T R A C T

The first measurements from proton–proton collisions recorded with the ATLAS detector at the are presented. Data were collected in December 2009 using a minimum-bias trigger during coll at a centre-of-mass energy of 900 GeV. The charged-particle multiplicity, its dependence on trans momentum and pseudorapidity, and the relationship between mean transverse momentum and cha particle multiplicity are measured for events with at least one charged particle in the kinematic $|\eta| < 2.5$ and $p_T > 500$ MeV. The measurements are compared to Monte Carlo models of proton–p collisions and to results from other experiments at the same centre-of-mass energy. The charged-pa multiplicity per event and unit of pseudorapidity at $\eta = 0$ is measured to be 1.333 ± 0.003(st 0.040(syst.), which is 5–15% higher than the Monte Carlo models predict.

2010 Published by Elsevie

1. Introduction

Inclusive charged-particle distributions have been measured in pp and $p\bar{p}$ collisions at a range of different centre-of-mass energi 13]. Many of these measurements have been used to constrain phenomenological models of soft-hadronic interactions and to p properties at higher centre-of-mass energies. Most of the previous charged-particle multiplicity measurements were obtained by sel data with a double-arm coincidence trigger, thus removing large fractions of diffractive events. The data were then further correc remove the remaining single-diffractive component. This selection is referred to as non-single-diffractive (NSD). In some cases, desig as inelastic non-diffractive, the residual double-diffractive component was also subtracted. The selection of NSD or inelastic non-diffr charged-particle spectra involves model-dependent corrections for the diffractive components and for effects of the trigger selecti events with no charged particles within the acceptance of the detector. The measurement presented in this Letter implements a d strategy, which uses a single-arm trigger overlapping with the acceptance of the tracking volume. Results are presented as incl inelastic distributions, with minimal model-dependence, by requiring one charged particle within the acceptance of the measureme

This Letter reports on a measurement of primary charged particles with a momentum component transverse to the beam dire $p_T > 500$ MeV and in the pseudorapidity range $|\eta| < 2.5$. Primary charged particles are defined as charged particles with a mean lif $\tau > 0.3 \times 10^{-10}$ s directly produced in pp interactions or from subsequent decays of particles with a shorter lifetime. The distributi tracks reconstructed in the ATLAS inner detector were corrected to obtain the particle-level distributions:

$$\frac{1}{N_{ev}} \cdot \frac{dN_{ch}}{d\eta}, \quad \frac{1}{N_{ev}} \cdot \frac{1}{2\pi p_T} \cdot \frac{d^2 N_{ch}}{d\eta\, dp_T}, \quad \frac{1}{N_{ev}} \cdot \frac{dN_{ev}}{dn_{ch}} \quad \text{and} \quad \langle p_T \rangle \text{ vs. } n_{ch},$$

where N_{ev} is the number of events with at least one charged particle inside the selected kinematic range, N_{ch} is the total numb charged particles, n_{ch} is the number of charged particles in an event and $\langle p_T \rangle$ is the average p_T for a given number of charged par

ATLAS Collaboration

G. Aad [48], E. Abat [18a,*], B. Abbott [110], J. Abdallah [11], A.A. Abdelalim [49], A. Abdesselam [117], O. Abdinov
B. Abi [111], M. Abolins [88], H. Abramowicz [151], H. Abreu [114], E. Acerbi [89a,89b], B.S. Acharya [162a,162b],
M. Ackers [20], D.L. Adams [24], T.N. Addy [56], J. Adelman [173], M. Aderholz [99], C. Adorisio [36a,36b], P. Adrag
T. Adye [128], S. Aefsky [22], J.A. Aguilar-Saavedra [123b], M. Aharrouche [81], S.P. Ahlen [21], F. Ahles [48],
A. Ahmad [146], H. Ahmed [2], M. Ahsan [40], G. Aielli [132a,132b], T. Akdogan [18a], P.F. Åkesson [29], T.P.A. Åkes
G. Akimoto [153], A.V. Akimov [94], A. Aktas [48], M.S. Alam [1], M.A. Alam [76], J. Albert [167], S. Albrand [55],
M. Aleksa [29], I.N. Aleksandrov [65], M. Aleppo [89a,89b], F. Alessandria [89a], C. Alexa [25a], G. Alexander [151],
G. Alexandre [49], T. Alexopoulos [9], M. Alhroob [20], M. Aliev [15], G. Alimonti [89a], J. Alison [119], M. Aliyev
P.P. Allport [73], S.E. Allwood-Spiers [53], J. Almond [82], A. Aloisio [102a,102b], R. Alon [169], A. Alonso [79],
J. Alonso [14], M.G. Alviggi [102a,102b], K. Amako [66], P. Amaral [29], G. Ambrosini [16], G. Ambrosio [89a,a],
C. Amelung [22], V.V. Ammosov [127,*], A. Amorim [123a], G. Amorós [165], N. Amram [151], C. Anastopoulos
T. Andeen [29], C.F. Anders [48], K.J. Anderson [30], A. Andreazza [89a,89b], V. Andrei [58a], M.-L. Andrieux [55],
X.S. Anduaga [70], A. Angerami [34], F. Anghinolfi [29], N. Anjos [123a], A. Annovi [47], A. Antonaki [8], M. Anton
S. Antonelli [19a,19b], J. Antos [143b], B. Antunovic [41], F. Anulli [131a], S. Aoun [83], G. Arabidze [8], I. Aracena
Y. Arai [66], A.T.H. Arce [14], J.P. Archambault [28], S. Arfaoui [29,b], J.-F. Arguin [14], T. Argyropoulos [9], E. Arik
M. Arik [18a], A.J. Armbruster [87], K.E. Arms [108], S.R. Armstrong [24], O. Arnaez [4], C. Arnault [114],
A. Artamonov [95], D. Arutinov [20], M. Asai [142], S. Asai [153], R. Asfandiyarov [170], S. Ask [82], B. Åsman [144a,
D. Asner [28], L. Asquith [77], K. Assamagan [24], A. Astbury [167], A. Astvatsatourov [52], B. Athar [1], G. Atoian
B. Aubert [4], B. Auerbach [173], E. Auge [114], K. Augsten [126], M. Aurousseau [4], N. Austin [73], G. Avolio [161],
R. Avramidou [9], D. Axen [166], C. Ay [54], G. Azuelos [93,c], Y. Azuma [153], M.A. Baak [29], G. Baccaglioni [89a]
C. Bacci [133a,133b], A.M. Bach [14], H. Bachacou [135], K. Bachas [29], G. Bachy [29], M. Backes [49], E. Badescu
P. Bagnaia [131a,131b], Y. Bai [32a], D.C. Bailey [156], T. Bain [156], J.T. Baines [128], O.K. Baker [173], M.D. Baker [24]
S. Baker [77], F. Baltasar Dos Santos Pedrosa [29], E. Banas [38], P. Banerjee [93], S. Banerjee [167], D. Banfi [89a,
A. Bangert [136], V. Bansal [167], S.P. Baranov [94], S. Baranov [65], A. Barashkou [65], T. Barber [27], E.L. Barberio
D. Barberis [50a,50b], M. Barbero [20], D.Y. Bardin [65], T. Barillari [99], M. Barisonzi [172], T. Barklow [142],
N. Barlow [27], B.M. Barnett [128], R.M. Barnett [14], A. Baroncelli [133a], M. Barone [47], A.J. Barr [117], F. Barrei
J. Barreiro Guimarães da Costa [57], P. Barrillon [114], V. Bartheld [99], H. Bartko [99], R. Bartoldus [142],
D. Bartsch [20], R.L. Bates [53], S. Bathe [24], L. Batkova [143a], J.R. Batley [27], A. Battaglia [16], M. Battistin [29],

G. Battistoni [89a], F. Bauer [135], H.S. Bawa [142], M. Baza
R. Beccherle [50a], N. Becerici [18a], P. Bechtle [41], G.A. Be
A.J. Beddall [18c], A. Beddall [18c], V.A. Bednyakov [65], C.
M. Beimforde [99], G.A.N. Belanger [28], C. Belanger-Cha
G. Bella [151], L. Bellagamba [19a], F. Bellina [29], G. Bello
O. Beltramello [29], A. Belymam [75], S. Ben Ami [150], O.
M. Bendel [81], B.H. Benedict [161], N. Benekos [163], Y. Be
M. Benoit [114], J.R. Bensinger [22], K. Benslama [129], S. B
E. Bergeaas Kuutmann [144a,144b], N. Berger [4], F. Bergh
P. Bernat [114], R. Bernhard [48], C. Bernius [77], T. Berry [7
M.I. Besana [89a,89b], N. Besson [135], S. Bethke [99], R.M.
J. Biesiada [14], M. Biglietti [131a,131b], H. Bilokon [47], M.
C. Bini [131a,131b], C. Biscarat [178], R. Bischof [62], U. Bite
J.-B. Blanchard [114], G. Blanchot [29], C. Blocker [22], J. Bl
C. Boaretto [131a,131b], G.J. Bobbink [105], A. Bocci [44], D.
J. Boek [172], N. Boelaert [79], S. Böser [77], J.A. Bogaerts
V. Boisvert [76], T. Bold [161,d], V. Boldea [25a], A. Boldyre
M. Boonekamp [135], G. Boorman [76], M. Boosten [29], C
J.R.A. Booth [17], S. Bordoni [78], C. Borer [16], K. Borer [16
S. Borroni [131a,131b], K. Bos [105], D. Boscherini [19a], M.
J. Bouchami [93], J. Boudreau [122], E.V. Bouhova-Thacke

A. Tonazzo [133a,133b], G. Tong [32a], A. Tonoyan [13], C. Topfel [16], N.D. Topilin [65], E. Torrence [113],
E. Torró Pastor [165], J. Toth [83,u], F. Touchard [83], D.R. Tovey [138], T. Trefzger [171], J. Treis [20], L. Tremblet [29],
A. Tricoli [29], I.M. Trigger [157a], G. Trilling [14], S. Trincaz-Duvoid [78], T.N. Trinh [78], M.F. Tripiana [70],
N. Triplett [64], W. Trischuk [156], A. Trivedi [24,t], Z. Trka [125], B. Trocmé [55], C. Troncon [89a], A. Trzupek [38],
C. Tsarouchas [9], J.C.-L. Tseng [117], M. Tsiakiris [105], P.V. Tsiareshka [90], D. Tsionou [138], G. Tsipolitis [9],
V. Tsiskaridze [51], E.G. Tskhadadze [51], I.I. Tsukerman [95], V. Tsulaia [122], J.-W. Tsung [20], S. Tsuno [66],
D. Tsybychev [146], J.M. Tuggle [30], M. Turala [38], D. Turecek [126], I. Turk Cakir [3e], E. Turlay [105], P.M. Tuts [34],
M.S. Twomey [137], M. Tylmad [144a,144b], M. Tyndel [128], D. Typaldos [17], H. Tyrvainen [29], E. Tzamarioudaki [9],
G. Tzanakos [8], K. Uchida [115], I. Ueda [153], M. Ugland [13], M. Uhlenbrock [20], M. Uhrmacher [54], F. Ukegawa [158],
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P. Urquijo [49,x], P. Urrejola [31a], G. Usai [7], M. Uslenghi [118a,118b], L. Vacavant [83], V. Vacek [126], B. Vachon [85],
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P. Vankov [73], F. Vannucci [78], F. Varela Rodriguez [29], R. Vari [131a], E.W. Varnes [6], D. Varouchas [14],

I.A. Christidi [77], A. Christov [48], D. Chromek-Burckhart
E. Cicalini [121a,121b], A.K. Ciftci [3a], R. Ciftci [3a], D. Cinca [33]
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B. Clement [55], C. Clement [144a,144b], D. Clements [53], R.W
A. Coccaro [50a,50b], J. Cochran [64], R. Coco [92], P. Coe [117], S
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A. Migliaccio [102a,102b], L. Mijović [74], G. Mikenb
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S. Mohrdieck-Möck [99], A.M. Moisseev [127,*], R.
J. Monk [77], E. Monnier [83], G. Montarou [33], S. M
T.B. Moore [84], G.F. Moorhead [86], C. Mora Herre
G. Morello [36a,36b], D. Moreno [160], M. Moreno L
J. Morin [75], Y. Morita [66], A.K. Morley [86], G. Mor

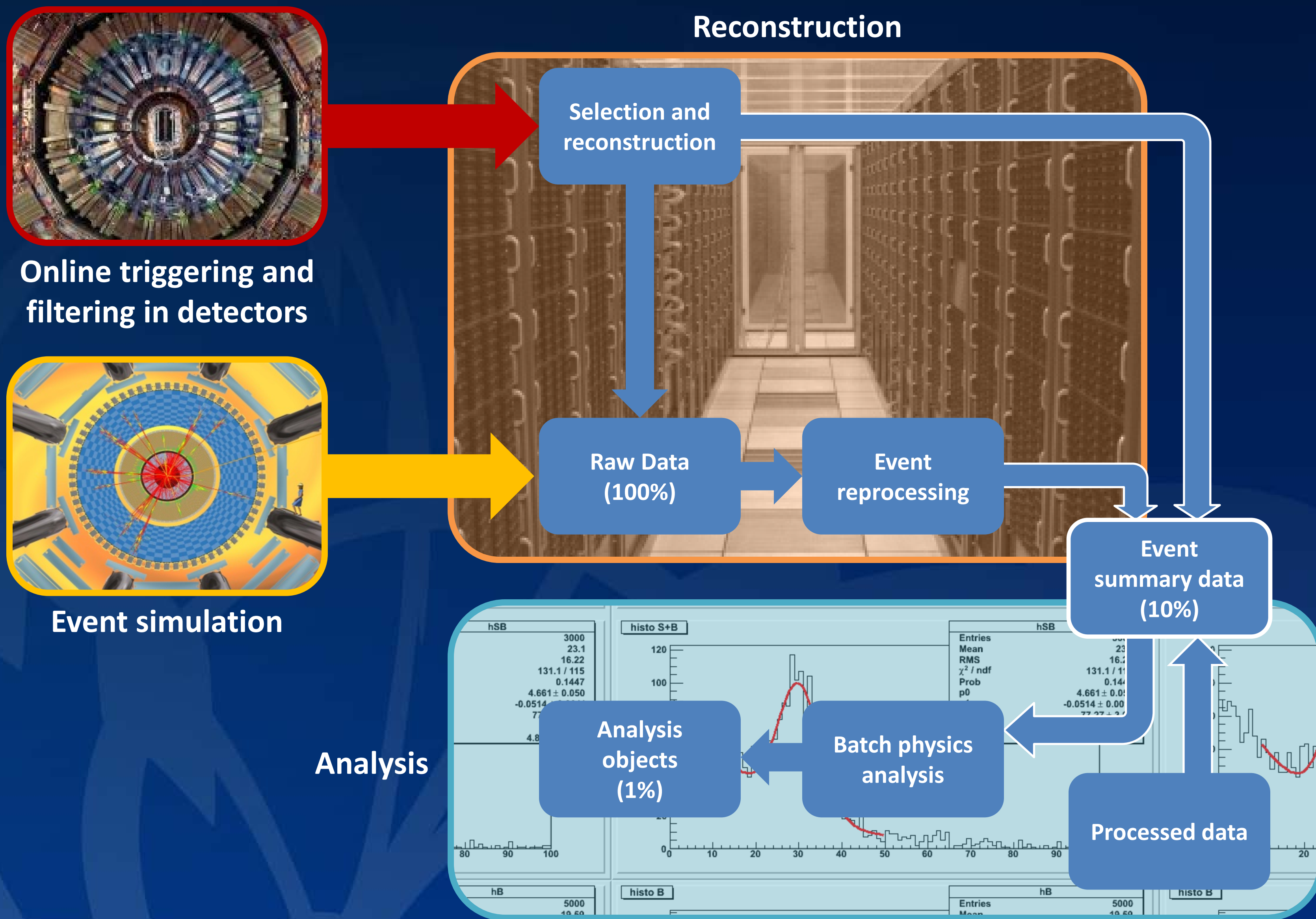
Z. Zhao [32b], A. Zhemchugov [65], S. Zheng [32a], J. Zhong [149,z], B. Zhou [87], N. Zhou [34], Y. Zhou [149], C.G. Zhu [32d],
H. Zhu [41], Y. Zhu [170], X. Zhuang [98], V. Zhuravlov [99], B. Zilka [143a], R. Zimmermann [20], S. Zimmermann [20],
S. Zimmermann [48], M. Ziolkowski [140], R. Zitoun [4], L. Živković [34], V.V. Zmouchko [127,*], G. Zobernig [170],
A. Zoccoli [19a,19b], Y. Zolnierowski [4], A. Zsenei [29], M. zur Nedden [15], V. Zutshi [5]

[1] University at Albany, 1400 Washington Ave, Albany, NY 12222, United States
[2] University of Alberta, Department of Physics, Centre for Particle Physics, Edmonton, AB T6G 2G7, Canada
[3] Ankara University[(a)], Faculty of Sciences, Department of Physics, TR 061000 Tandogan, Ankara; Dumlupinar University[(b)], Faculty of Arts and Sciences, Department of Physics, Kutahya; Gazi University[(c)], Faculty of Arts and Sciences, Department of Physics, 06500 Teknikokullar, Ankara; TOBB University of Economics and Technology[(d)], Faculty of Arts and Sciences, Division of Physics, 06560 Sogutozu, Ankara; Turkish Atomic Energy Authority[(e)], 06530 Lodumlu, Ankara, Turkey
[4] LAPP, Université de Savoie, CNRS/IN2P3, Annecy-le-Vieux, France
[5] Argonne National Laboratory, High Energy Physics Division, 9700 S. Cass Avenue, Argonne IL 60439, United States

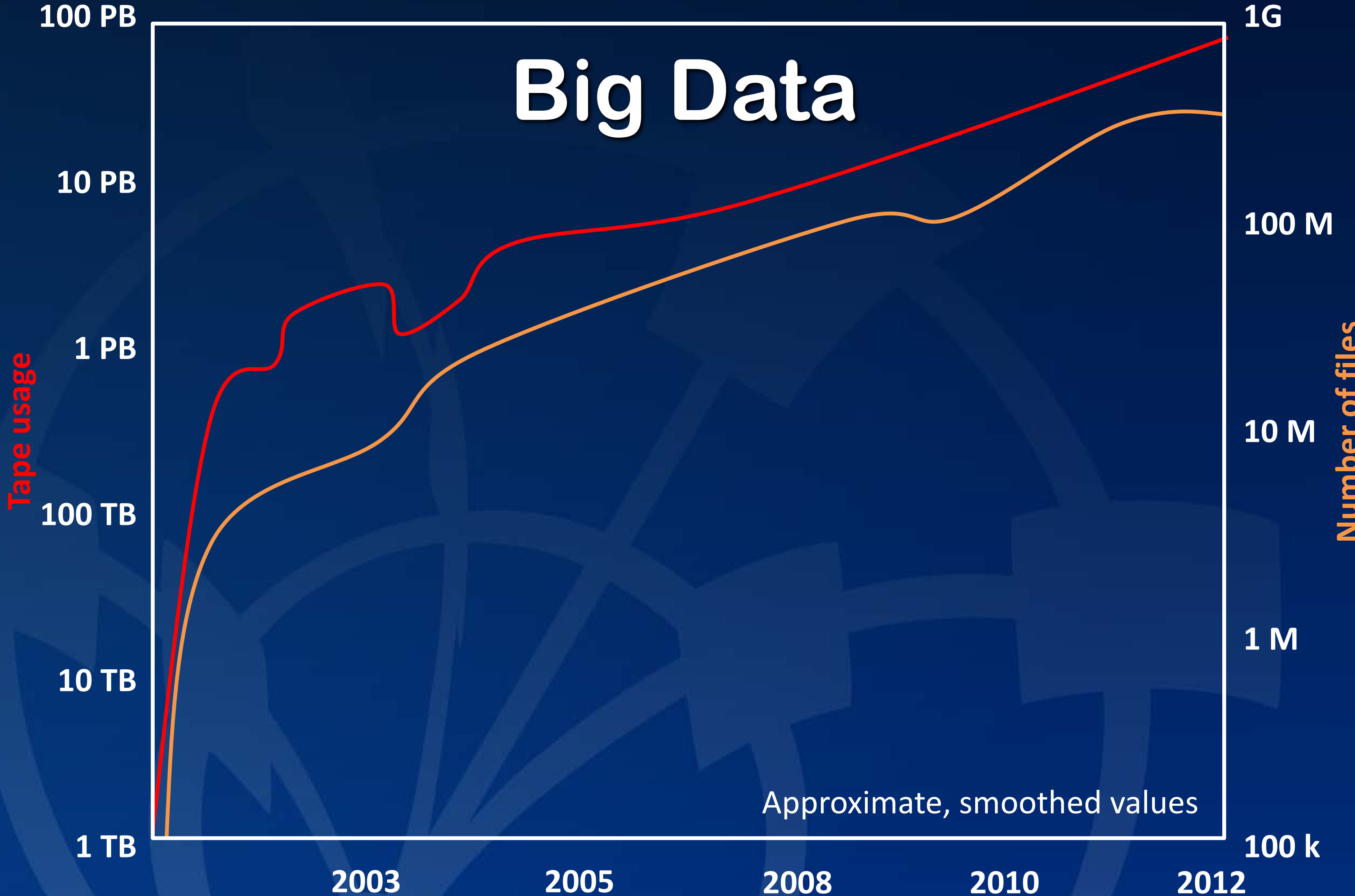
[63] University of Iowa, 203 Van Allen Hall, Iowa City, IA 52242-1479, United States
[64] Iowa State University, Department of Physics and Astronomy, Ames High Energy Physics Group, Ames, IA 50011-3160, United States
[65] Joint Institute for Nuclear Research, JINR Dubna, RU-141 980 Moscow Region, Russia
[66] KEK, High Energy Accelerator Research Organization, 1-1 Oho, Tsukuba-shi, Ibaraki-ken 305-0801, Japan
[67] Kobe University, Graduate School of Science, 1-1 Rokkodai-cho, Nada-ku, JP - Kobe 657-8501, Japan
[68] Kyoto University, Faculty of Science, Oiwake-cho, Kitashirakawa, Sakyou-ku, Kyoto-shi, JP - Kyoto 606-8502, Japan
[69] Kyoto University of Education, 1 Fukakusa, Fujimori, fushimi-ku, Kyoto-shi, JP - Kyoto 612-8522, Japan
[70] Universidad Nacional de La Plata, FCE, Departamento de Física, IFLP (CONICET-UNLP), C.C. 67, 1900 La Plata, Argentina
[71] Lancaster University, Physics Department, Lancaster LA1 4YB, United Kingdom
[72] INFN Sezione di Lecce[(a)]; Università del Salento, Dipartimento di Fisica[(b)], Via Arnesano, IT-73100 Lecce, Italy
[73] University of Liverpool, Oliver Lodge Laboratory, P.O. Box 147, Oxford Street, Liverpool L69 3BX, United Kingdom
[74] Jožef Stefan Institute and University of Ljubljana, Department of Physics, SI-1000 Ljubljana, Slovenia
[75] Queen Mary University of London, Department of Physics, Mile End Road, London E1 4NS, United Kingdom
[76] Royal Holloway, University of London, Department of Physics, Egham Hill, Egham, Surrey TW20 0EX, United Kingdom

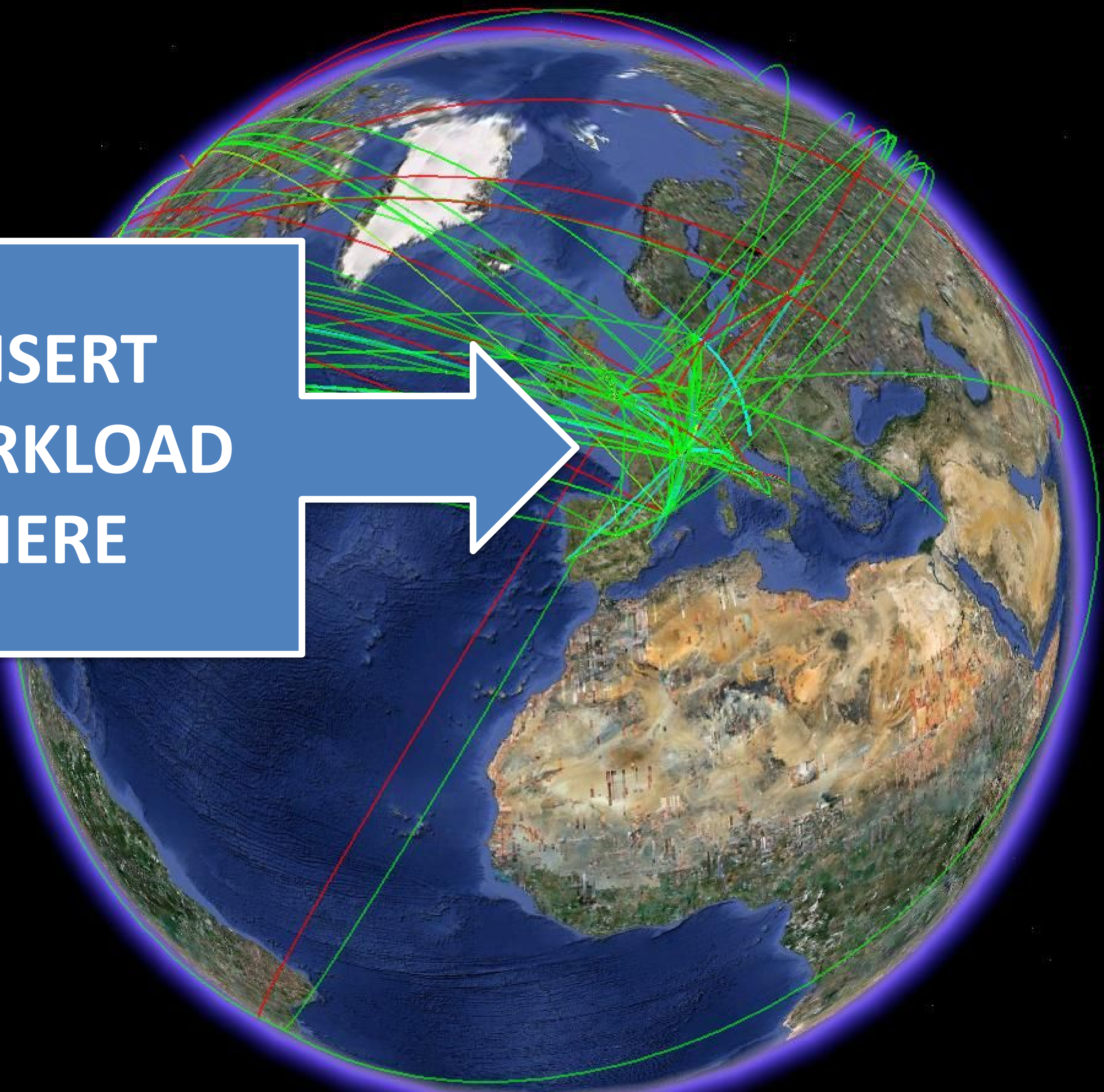
[138] University of Sheffield, Department of Physics & Astronomy, Hounsfield Road, Sheffield S3 7RH, United Kingdom
[139] Shinshu University, Department of Physics, Faculty of Science, 3-1-1 Asahi, Matsumoto-shi, JP - Nagano 390-8621, Japan
[140] Universität Siegen, Fachbereich Physik, D-57068 Siegen, Germany
[141] Simon Fraser University, Department of Physics, 8888 University Drive, CA - Burnaby, BC V5A 1S6, Canada
[142] SLAC National Accelerator Laboratory, Stanford, CA 94309, United States
[143] Comenius University, Faculty of Mathematics, Physics & Informatics[(a)], Mlynska dolina F2, SK-84248 Bratislava; Institute of Experimental Physics of the Slovak Academy of Sciences, Dept. of Subnuclear Physics[(b)], Watsonova 47, SK-04353 Kosice, Slovak Republic
[144] Stockholm University, Department of Physics[(a)]; The Oskar Klein Centre[(b)], AlbaNova, SE-106 91 Stockholm, Sweden
[145] Royal Institute of Technology (KTH), Physics Department, SE-106 91 Stockholm, Sweden
[146] Stony Brook University, Department of Physics and Astronomy, Nicolls Road, Stony Brook, NY 11794-3800, United States
[147] University of Sussex, Department of Physics and Astronomy, Pevensey 2 Building, Falmer, Brighton BN1 9QH, United Kingdom
[148] University of Sydney, School of Physics, AU - Sydney NSW 2006, Australia
[149] Insitute of Physics, Academia Sinica, TW - Taipei 11529, Taiwan
[150] Technion, Israel Inst. of Technology, Department of Physics, Technion City, IL - Haifa 32000, Israel
[151] Tel Aviv University, Raymond and Beverly Sackler School of Physics and Astronomy, Ramat Aviv, IL - Tel Aviv 69978, Israel
[152] Aristotle University of Thessaloniki, Faculty of Science, Department of Physics, Division of Nuclear & Particle Physics, University Campus, GR-54124 Thessaloniki, Greece
[153] The University of Tokyo, International Center for Elementary Particle Physics and Department of Physics, 7-3-1 Hongo, Bunkyo-ku, JP - Tokyo 113-0033, Japan
[154] Tokyo Metropolitan University, Graduate School of Science and Technology, 1-1 Minami-Osawa, Hachioji, Tokyo 192-0397, Japan
[155] Tokyo Institute of Technology, 2-12-1-H-34 O-Okayama, Meguro, Tokyo 152-8551, Japan
[156] University of Toronto, Department of Physics, 60 Saint George Street, Toronto M5S 1A7, Ontario, Canada
[157] TRIUMF[(a)], 4004 Wesbrook Mall, Vancouver, B.C. V6T 2A3; York University[(b)], Department of Physics and Astronomy, 4700 Keele St., Toronto, Ontario, M3J 1P3, Canada
[158] University of Tsukuba, Institute of Pure and Applied Sciences, 1-1-1 Tennoudai, Tsukuba-shi, JP - Ibaraki 305-8571, Japan
[159] Tufts University, Science & Technology Center, 4 Colby Street, Medford, MA 02155, United States
[160] Universidad Antonio Narino, Centro de Investigaciones, Cra 3 Este No.47A-15, Bogota, Colombia
[161] University of California, Irvine, Department of Physics & Astronomy, CA 92697-4575, United States
[162] INFN Gruppo Collegato di Udine[(a)]; ICTP[(b)], Strada Costiera 11, IT-34014 Trieste; Università di Udine, Dipartimento di Fisica[(c)], via delle Scienze 208, IT-33100 Udine, Italy
[163] University of Illinois, Department of Physics, 1110 West Green Street, Urbana, IL 61801, United States
[164] University of Uppsala, Department of Physics and Astronomy, P.O. Box 516, SE-751 20 Uppsala, Sweden
[165] Instituto de Física Corpuscular (IFIC), Centro Mixto UVEG-CSIC, Apdo. 22085 ES-46071 Valencia, Dept. Física At. Mol. y Nuclear, Univ. of Valencia, and Instituto de Microelectrónica de Barcelona (IMB-CNM-CSIC), 08193 Bellaterra Barcelona, Spain
[166] University of British Columbia, Department of Physics, 6224 Agricultural Road, CA - Vancouver, B.C. V6T 1Z1, Canada
[167] University of Victoria, Department of Physics and Astronomy, P.O. Box 3055, Victoria B.C., V8W 3P6, Canada
[168] Waseda University, WISE, 3-4-1 Okubo, Shinjuku-ku, Tokyo 169-8555, Japan
[169] The Weizmann Institute of Science, Department of Particle Physics, P.O. Box 26, IL 76100, Rehovot, Israel
[170] University of Wisconsin, Department of Physics, 1150 University Avenue, Madison, WI 53706, United States
[171] Julius-Maximilians-University of Würzburg, Physikalisches Institute, Am Hubland, 97074 Würzburg, Germany
[172] Bergische Universität, Fachbereich C, Physik, Postfach 100127, Gauss-Strasse 20, D-42097 Wuppertal, Germany
[173] Yale University, Department of Physics, P.O. Box 208121, New Haven, CT 06520-8121, United States
[174] Yerevan Physics Institute, Alikhanian Brothers Street 2, AM-375036 Yerevan, Armenia
[175] ATLAS-Canada Tier-1 Data Centre 4004 Wesbrook Mall, Vancouver, BC, V6T 2A3, Canada
[176] GridKA Tier-1 FZK, Forschungszentrum Karlsruhe GmbH, Steinbuch Centre for Computing (SCC), Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany
[177] Port d'Informacio Cientifica (PIC), Universitat Autonoma de Barcelona (UAB), Edifici D, E-08193 Bellaterra, Spain
[178] Centre de Calcul CNRS/IN2P3, Domaine scientifique de la Doua, 27 bd du 11 Novembre 1918, 69622 Villeurbanne Cedex, France
[179] INFN-CNAF, Viale Berti Pichat 6/2, 40127 Bologna, Italy
[180] Nordic Data Grid Facility, NORDUnet A/S, Kastruplundgade 22, 1, DK-2770 Kastrup, Denmark

Data flow from the LHC detectors



Big Data


100 PB
10 PB
1 PB
100 TB
10 TB
1 TB
Tape usage
1G
100 M
10 M
1 M
100 k
Number of files
2003
2005
2008
2010
2012
Approximate, smoothed values



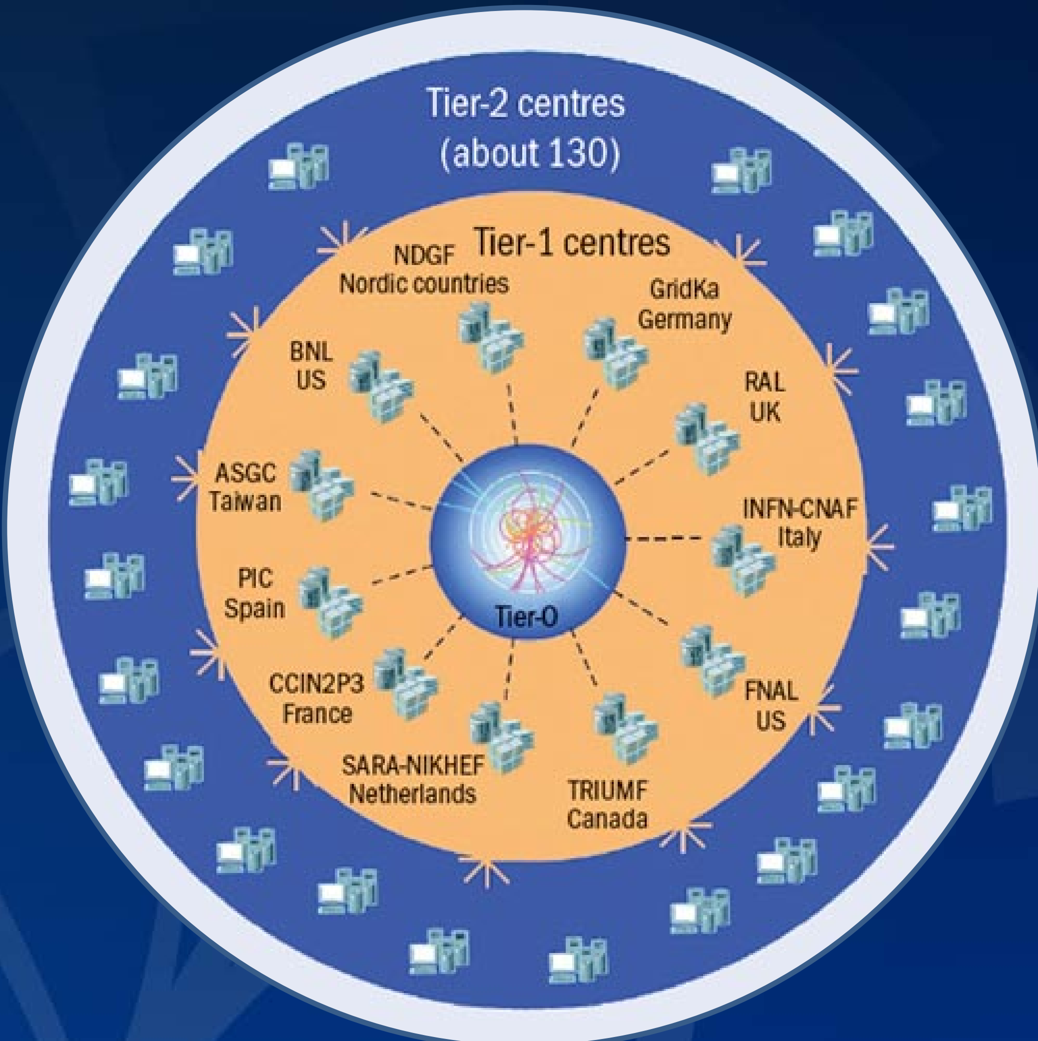
INSERT WORKLOAD HERE

Collaboration on big data and computing
The Worldwide LHC Computing Grid

Tier-0 (CERN): data recording, reconstruction and distribution

Tier-1: permanent storage, re-processing, analysis

Tier-2: Simulation, end-user analysis

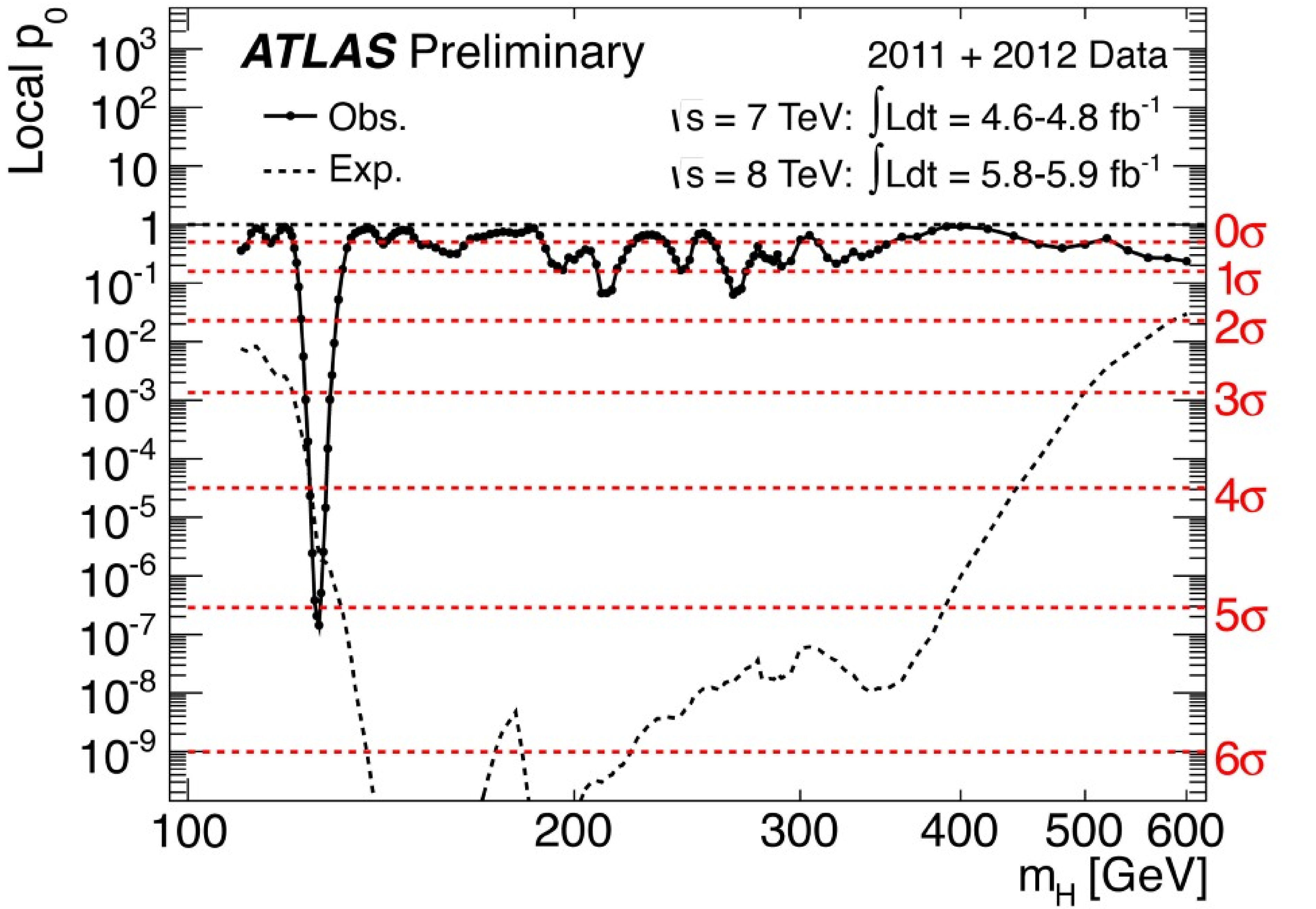


nearly 160 sites

~250’000 cores

173 PB of storage

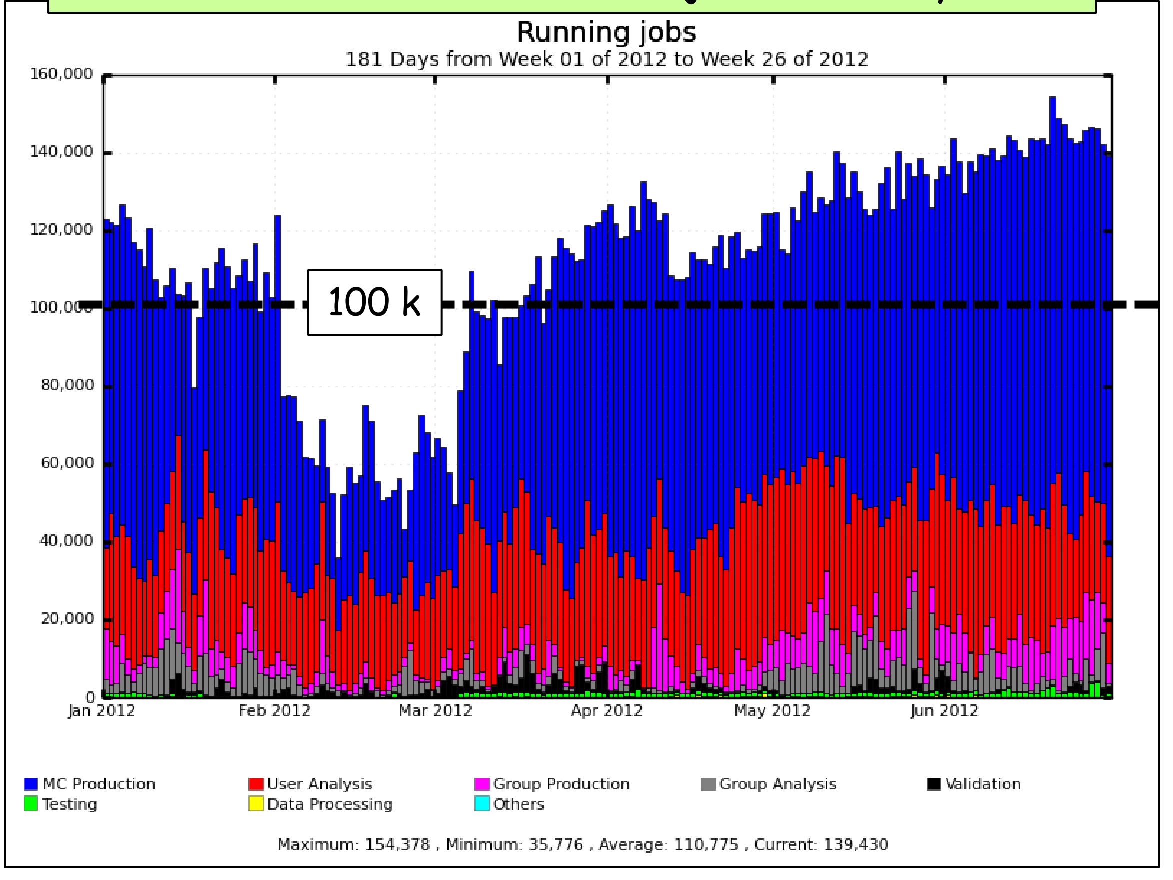
> 2 million jobs/day



ATLAS Preliminary
2011 + 2012 Data
Obs.
Exp.
√s = 7 TeV: ∫Ldt = 4.6-4.8 fb⁻¹
√s = 8 TeV: ∫Ldt = 5.8-5.9 fb⁻¹
Local p0
mH [GeV]
0σ
1σ
2σ
3σ
4σ
5σ
6σ

It would have been impossible to release physics results so quickly without the outstanding performance of the Grid (including the CERN Tier-0)

Number of concurrent ATLAS jobs Jan-July 2012



Includes MC production, user and group analysis at CERN, 10 Tier1-s, ~ 70 Tier-2 federations → > 80 sites

> 1500 distinct ATLAS users do analysis on the GRID

- Available resources fully used/stressed (beyond pledges in some cases)
- Massive production of 8 TeV Monte Carlo samples
- Very effective and flexible Computing Model and Operation team → accommodate high trigger rates and pile-up, intense MC simulation, analysis demands from worldwide users (through e.g. dynamic data placement)

A wealth of knowledge

- Academic Training program
- Summer Student program
- Physics and computing schools
- Technical Training program
- CERN Teacher schools
- Outreach programs
- EU FP7 programs

Innovation in science

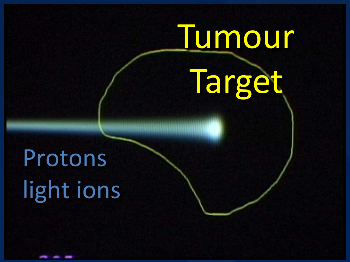
Medical Applications as an Example of Particle Physics Spin-off

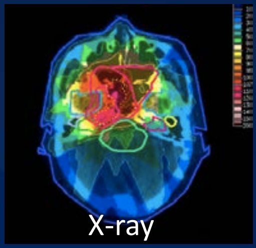
Accelerating particle beams

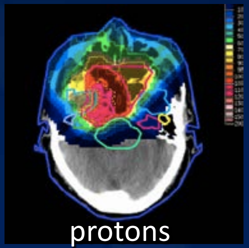
~30’000 accelerators worldwide

~17’000 used for medicine

Hadron Therapy



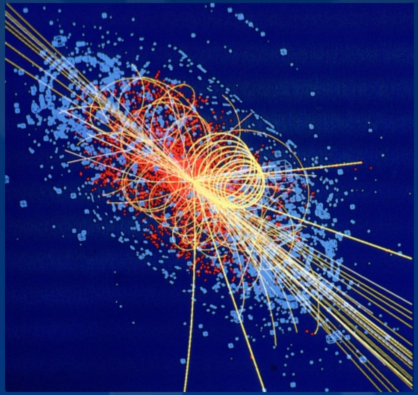




Leadership in Ion Beam Therapy now in Europe and Japan

>70’000 patients treated worldwide (30 facilities)

>21’000 patients treated in Europe (9 facilities)

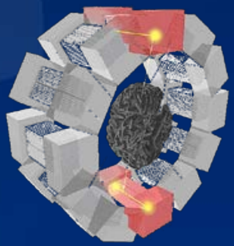


Detecting particles

Imaging

Clinical trial in Portugal for new breast imaging system (ClearPEM)

PET Scanner



From F.Hemmer

Innovation in computing

- 1989: First high bandwidth transatlantic links
- 1991: The World Wide Web is born at CERN
- 1999: The Grid vision materializes
- 2001: CERN wins Computerworld’s 21st Century Achievement Award for SHIFT
- 2003: Several Internet2 land speed records
- 2008: The WLCG is the world’s largest grid
- 2012: LHC delivering intense data challenges

A European Cloud Computing Partnership: big science teams up with big business

HELIX NEBULA
THESCIENCECLOUD

Strategic Plan

- Establish multi-tenant, multi-provider cloud infrastructure
- Identify and adopt policies for trust, security and privacy
- Create governance structure
- Define funding schemes

CERN

To support the computing capacity needs for the ATLAS experiment

EMBL

Setting up a new service to simplify analysis of large genomes, for a deeper insight into evolution and biodiversity

esa

DLR cnes

To create an Earth Observation platform, focusing on earthquake and volcano research

Atos, Capgemini, CloudSigma, CSA cloud security alliance, egi, interoute, logica, OpenNebula.org, orange Business Services, SAP, the SERVER LABS, sixsq, Telefónica, terradue 2.0, THALES, Trust it, T-Systems

From B.Jones

Accelerating Science and Innovation

Continued support of the worldwide physics community and the European population

Great science and engineering + great partners = great innovation

Challenges in computing

Big(ger) Data

- LHC upgrades
- New paradigms, science

Exascale

- Computing evolution
- Next-gen interconnect

Society

- Scientific leadership
- Sustainable computing

Big(ger) data

Data rates at the LHC to increase by ~100x

Raw data: an exabyte per second?

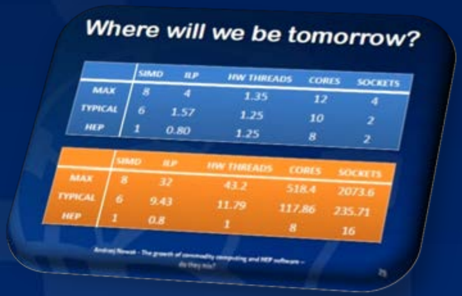
Exabytes stored yearly?

Millions of computing cores?

“Sustainable computing”

Future directions in computing

- **Software replacing hardware**
  - Programmability replaces rigid structures
- **Intensive compute**
  - Local farms must have much higher processing capacity
- **Accelerators**
  - Experiments with Intel MIC and GPUs
- **Silicon photonics**



The CERN openlab

A unique research partnership of CERN and the industry

Objective: The advancement of cutting-edge computing solutions to be used by the worldwide LHC community

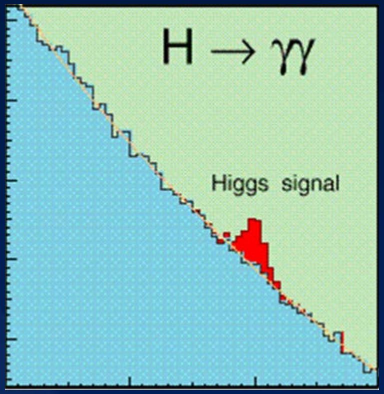
- Partners support manpower and equipment in dedicated competence centers
- openlab delivers published research and evaluations based on partners' solutions – in a very challenging setting
- Created robust hands-on training program in various computing topics, including international computing schools; Summer Student program
- Past involvement: Enterasys Networks, IBM, Voltaire, F-secure, Stonesoft, EDS; Future involvement: Huawei
- Now in phase IV: 2012-2014

http://cern.ch/openlab

CERN openlab

PARTNERS

Physics jobs



- **Independent events (collisions of particles)**
  - trivial (read: pleasant) parallel processing
- **Bulk of the data is read-only**
- **Very large aggregate requirements:**
  - computation, data, input/output
- **Chaotic workload**
  - research environment - physics extracted by iterative analysis: Unpredictable, Unlimited demand
- **Compute power scales with combination of SPECint and SPECfp**
  - Good double-precision floating-point (10%-20% of total) is important!
  - Good transcendental math libraries needed
- **Key foundation: Linux together with GNU C++ compiler**

Where are we now? (software)

- **Large C++ frameworks with millions of lines of code**
  - Thousands of shared libraries in a distribution, gigabytes of binaries
  - Low number of key players but high number of brief contributors
- **Large regions of memory read only or accessed infrequently**
- **Characteristics:**
  - Significant portion of double precision floating point (10%+)
  - Loads/stores up to 60% of instructions
  - Unfavorable for the x86 microarchitecture (even worse for others)
    - Low number of instructions between jumps (<10)
    - Low number of instructions between calls (several dozen)
- **For the most part, code won't fit accelerators in its current shape**

Where are we now? (hardware)

- Very limited or no vectorization
  - Online has somewhat better conditions to vectorize
- Sub-optimal instruction level parallelism (CPI at >1)
- Hardware threading unused, but often beneficial
- Cores used well through multiprocessing – bar the stiff memory requirements
  - However, systems put in production with delays
- Sockets used well
- Multiple systems used very well
- Relying on in-core improvements and # cores for scaling

Where are we now?

	SIMD	ILP	HW THREADS	CORES	SOCKETS
TOP	4	4	1.35	8	4
OPTIMIZED	2.5	1.43	1.25	8	2
HEP	1	0.80	1	6	2

	SIMD	ILP	HW THREADS	CORES	SOCKETS
TOP	4	16	21.6	172.8	691.2
OPTIMIZED	2.5	3.57	4.46	35.71	71.43
HEP	1	0.80	0.80	4.80	9.60

Using a low single digit percentage of raw machine power available today

_%

Write your percentage here

The Platform Competence Center

Focus on efficient computing

Technology monitoring

- Tracking
- Analysis
- Forecasting

Research and experimentation

- Benchmarking
- Parallelization
- Optimization

Results and dissemination

- Recommendations
- Papers, conferences
- Education

Close collaboration with the Physics department

PCC - particular interests

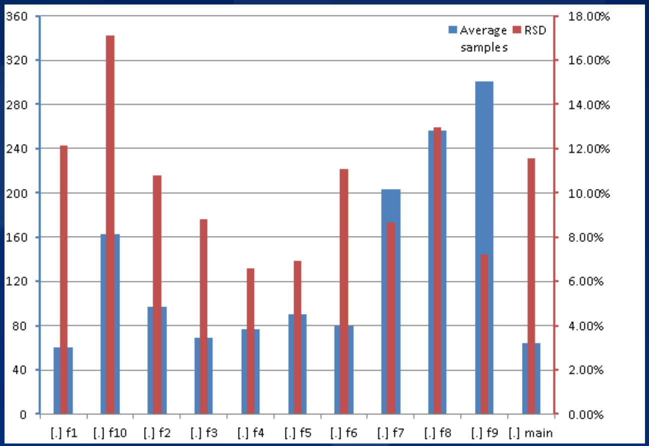
- **Compute optimization**
  - Absolute, per CHF, per Watt
  - Optimization tools
- **Compilers**
- **Parallelization**
  - x86 compatible technologies spanning the whole range from OpenCL to MPI
- **Accelerators**
  - Intel MIC, limited interest in GPUs, combos
- **Storage**
- **Next phase V in 2015-2018 (Exascale era)**

Compiler project

- Main emphasis is on Intel64, even though some experiments still work in 32-bit mode for various reasons
- Regular benchmarking and evaluations – both compilers and hardware
  – Long-term participation in the beta program
- Closely following vectorization features and advanced optimization

Tuning

- **Another long standing program**
  - Work with perfmon2, linux-perf
- **Alpha-tested new "XE" tools**
  - Feedback implemented in products
  - Still in the program
- **PMU research with Intel Israel**
- **Own profiling tools**



Parallelization

- 6 major collaborations at CERN still run heavily object oriented, sequential code
- High level problems are more painful than technical ones
  - How do you create a working collaboration?
  - Which model to choose?
  - Who is responsible for what?

Parallelization

- We now have a very practical understanding of various options for parallelism on x86
- Extensive whitepaper published, based on 2 years of research – as a part of the collaboration with Intel SSG
- Optimization of the MLFit application with:
  - TBB
  - MPI
  - Cilk
  - OpenMP
  - Vectorization (both autovectorization and CEAN explicit syntax)

Comparison of Software Technologies for Vectorization and Parallelization

Sverre Jarp, Alfio Lazzaro, Andrzej Nowak, Liviu Valsan
CERN openlab, September 2012 – version 1.0
White-paper as part of the collaboration between CERN openlab and Intel SSG

Executive Summary

This paper demonstrates how modern software development methodologies can be used to give an existing sequential application a considerable performance speed-up on modern x86 server systems. Whereas, in the past, speed-up was directly linked to the increase in clock frequency when moving to a more modern system, current x86 servers present a plethora of “performance dimensions” that need to be harnessed with great care. The application we used is a real-life data analysis example in C++ analyzing High Energy Physics data. The key software methods used are OpenMP, Intel Threading Building Blocks (TBB), Intel Cilk Plus, and the auto-vectorization capability of the Intel compiler (Composer XE). Somewhat surprisingly, the Message Passing Interface (MPI) is successfully added, although our focus is on single-node rather than multi-node performance optimization. The paper underlines the importance of algorithmic redesign in order to optimize each performance dimension and links this to close control of the memory layout in a thread-safe environment. The data fitting algorithm at the heart of the application is very floating-point intensive so the paper also discusses how to ensure optimal performance of mathematical functions (in our case, the exponential function) as well as numerical correctness and reproducibility. The test runs on single-, dual-, and quad-socket servers show first of all that vectorization of the algorithm (with either auto-vectorization by the compiler or the use of Intel Cilk Plus Array Notation) gives more than a factor 2 in speed-up when the data layout in memory is properly optimized. Using coarse-grained parallelism all three approaches (OpenMP, Cilk Plus, and TBB) showed good parallel speed-up on the available CPU cores. The best one was obtained with OpenMP, but by combining Cilk Plus and TBB with MPI in order to tie processes to sockets, these two software methods nicely closed the gap and TBB came out with a slight advantage in the end. Overall, we conclude that the best implementation in terms of both ease of implementation and the resulting performance is a combination of the Intel Cilk Plus Array Notation for vectorization and a hybrid TBB and MPI approach for parallelization.

Intel MIC at openlab

Early access

- Work since MIC alpha (under RS-NDA)
- ISA reviews in 2008

Results

- 3 benchmarks ported from Xeon and delivering results: ROOT, Geant4, ALICE HLT trackfitter

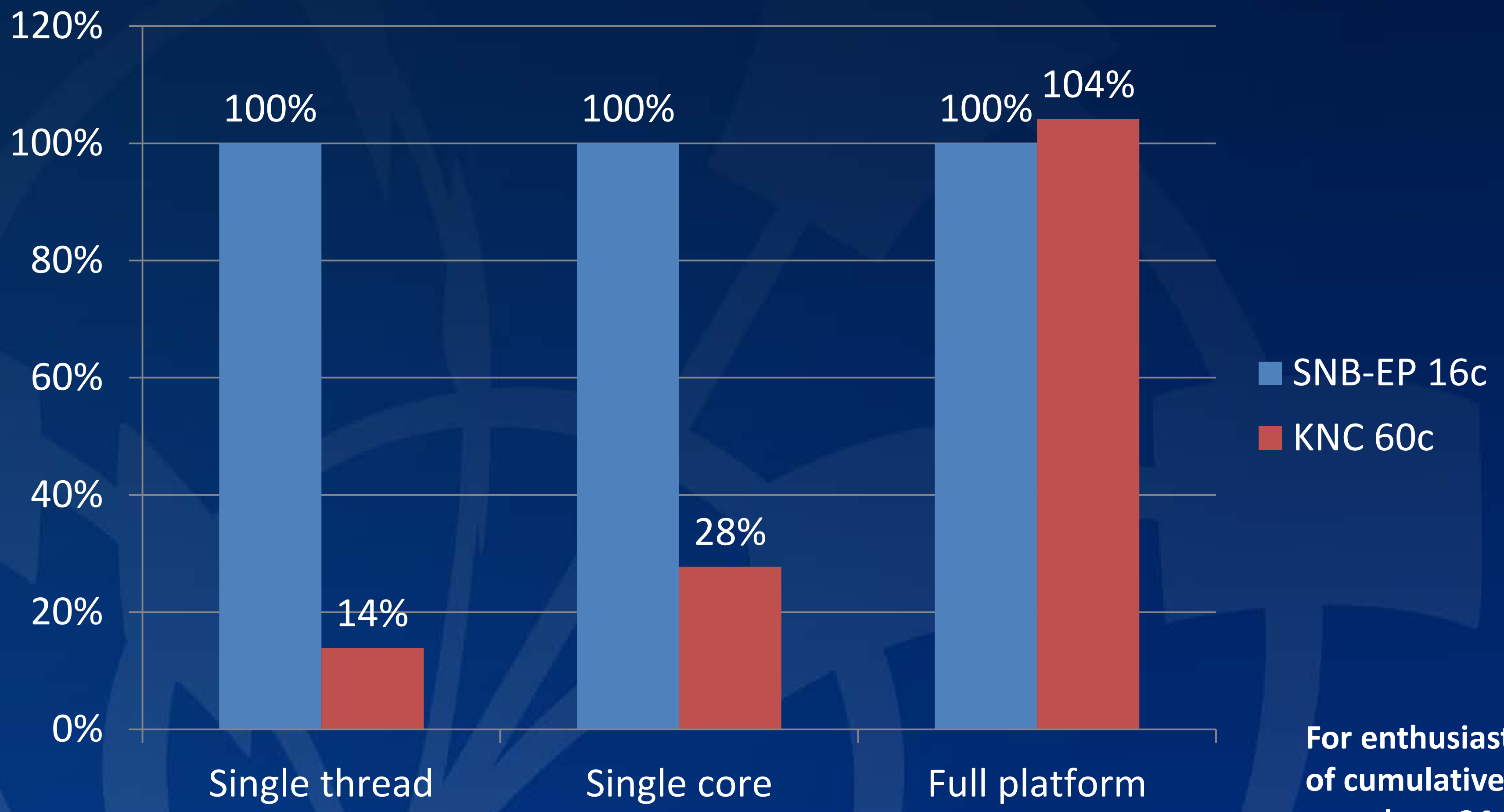
Expertise

- Understood and compared with Xeon
- **Post-launch dissemination**

Intel MIC

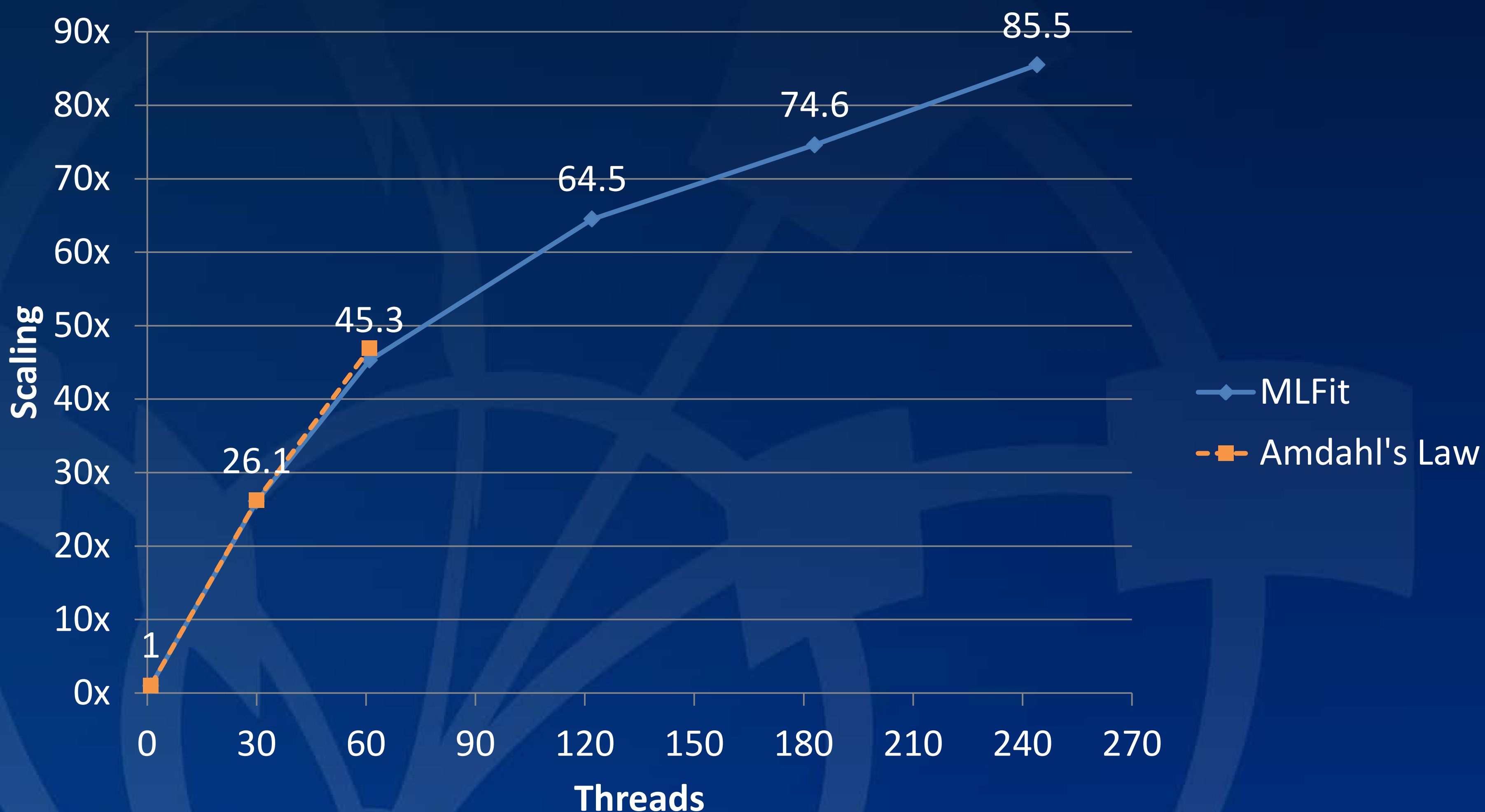
- **ALICE/CBM track fitter prototype**
  - Threaded
  - Explicitly vectorized, vectors wrapped in C++ classes
- **MLFit**
  - Threaded (pthreads, MPI, OpenMP, TBB)
  - Vectorized (Cilk+)
- **Early multi-threaded Geant4 prototype**
  - Threaded (pthreads)
  - No vectorization
- **Test hardware**
  - Pre-production Knights Corner – 61 cores @ 1.1 GHz
  - Sandy Bridge-EP – 16 cores @ 2.7 GHz, Turbo on
  - Frequency unscaled results reported (1:1 comparison)

MLFit performance
OpenMP, no block splitting, higher is better



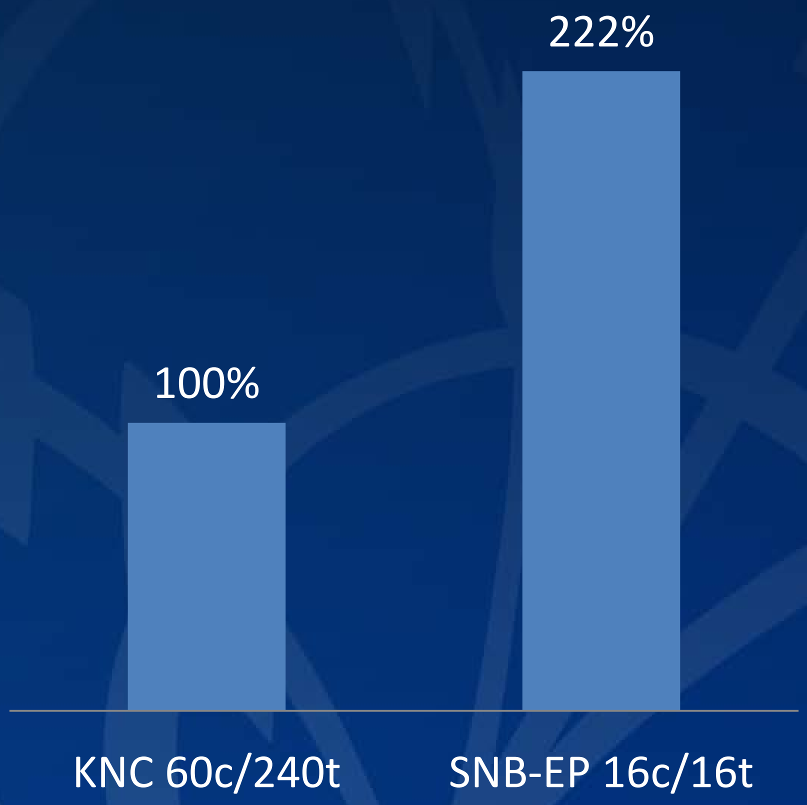
For enthusiasts of cumulative speed-up: 34x

MLFit scaling
(OpenMP)

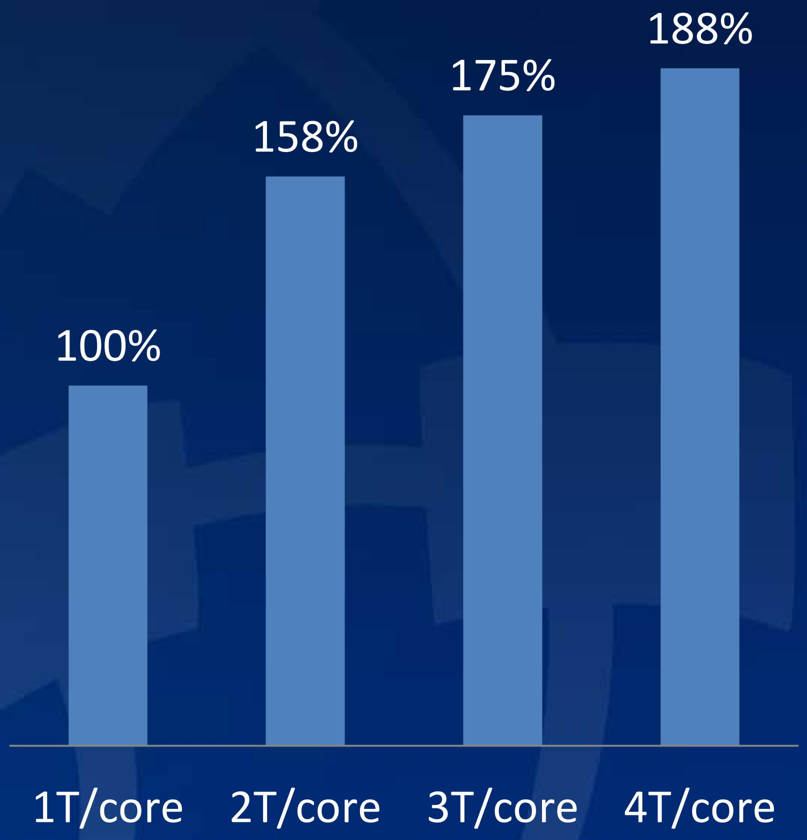


MTG4 performance
(higher is better, no vectorization)

Full platform performance



HW threading throughput



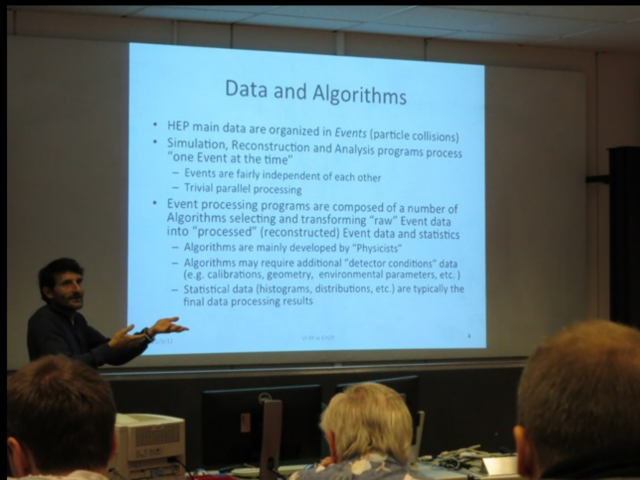
MTG4 – example profile

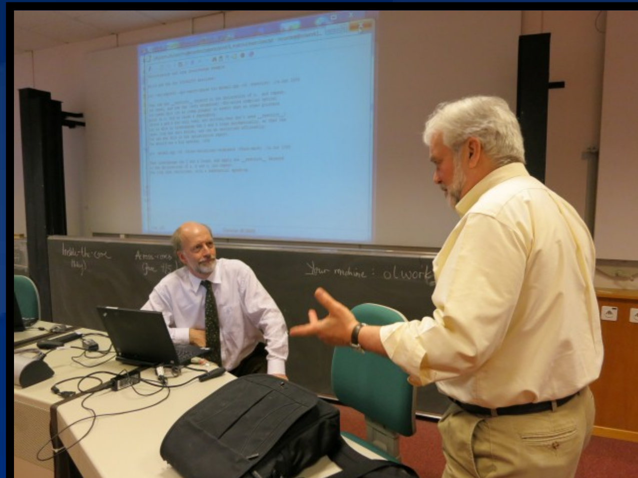
Function / Call Stack	CLK %	INST %
sqrt	14.35%	22.16%
exp	6.47%	9.47%
atan2	4.22%	6.31%
CLHEP::RanluxEngine::flat	3.24%	5.60%
G4ElasticHadrNucleusHE::HadronNucleusQ2_2	3.01%	2.41%
G4PhysicsVector::Value	2.76%	0.95%
log	2.22%	2.85%
G4VoxelNavigation::LevelLocate	2.05%	0.66%
G4VoxelNavigation::ComputeStep	1.64%	1.10%
G4ClassicalRK4::DumbStepper	1.59%	2.96%
G4SteppingManager::DefinePhysicalStepLength	1.54%	1.39%
G4Navigator::ComputeStep	1.40%	1.01%

Teaching

- International computing schools
- Workshops
  - 10 workshops in 2012
  - >350 participants

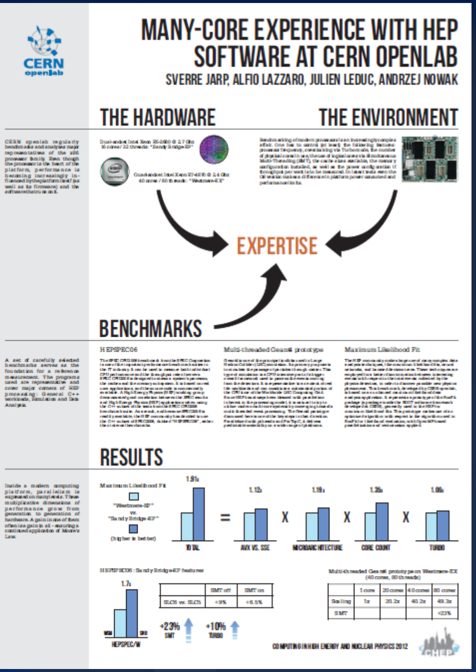
Numerical computing workshops





Dissemination

- International conferences
- CERN whitepapers
- CERN-Intel whitepapers
- Industry events
  - ISC 2010 keynote with Kirk Skaugen
  - IDF 2011 keynote with Justin Rattner
  - ERIC 2012 keynote (Andrzej Nowak)



Dissemination

ICE-DIP

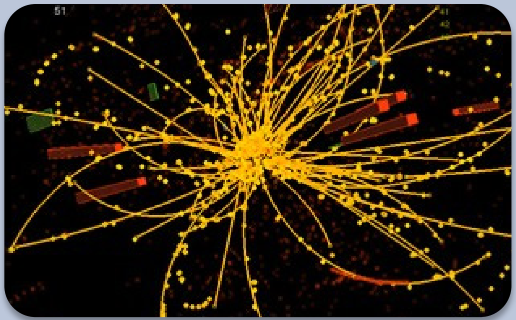
- **EU Framework Program 7 project looking for (amongst other things) efficient methods of accelerator/co-processor use**
- **Focus on data taking past 2016**
- **Of particular interest**
  - Getting data into the platform
  - Getting data into the accelerator/co-processor
  - Efficient processing
  - Efficient distribution of results
- **What role for software?**
- **Funded**

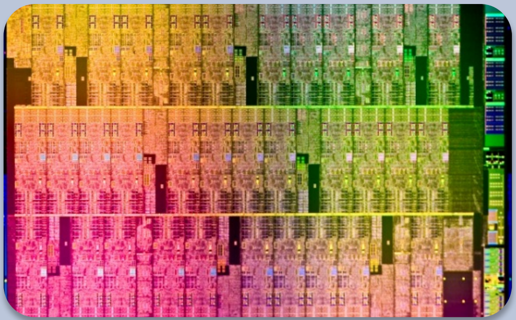
MARIE CURIE ACTIONS

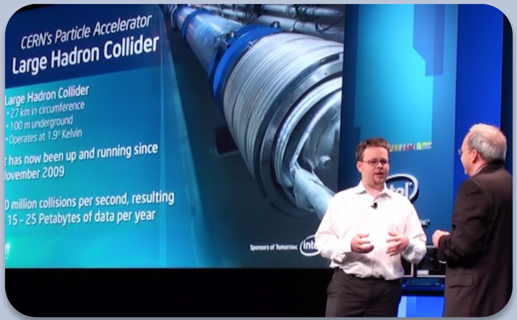
BIG-DATA

- **How can Big Science work with Big Data?**
- **Planned project:**
  - 16 partners
  - Foresees 14 new personnel spread across multiple labs
  - 4 years
- **Another related collaboration proposal submitted to Intel**
- **Funding decision in Spring**

Summary







New challenges ahead of CERN

Upcoming new era for LHC computing

openlab and Intel actively contribute

THANK YOU

Q & A

Questions? Andrzej.Nowak@cern.ch