The search for the Higgs Boson at CERN

A story of one particle and 250’000 cores

UMK, Torun
March 18th 2013

Andrzej Nowak, CERN openlab
Andrzej.Nowak@cern.ch

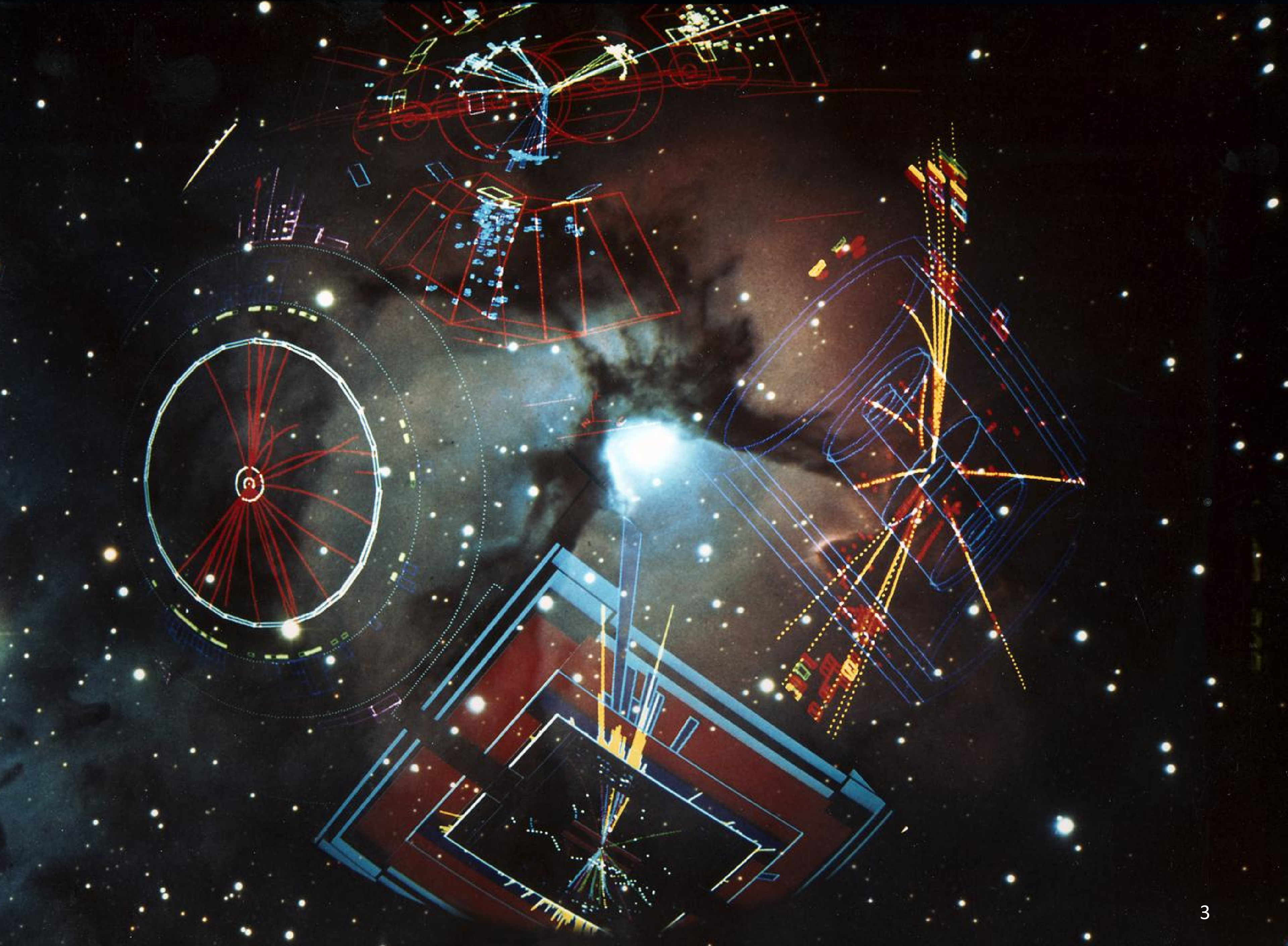
CERN openlab

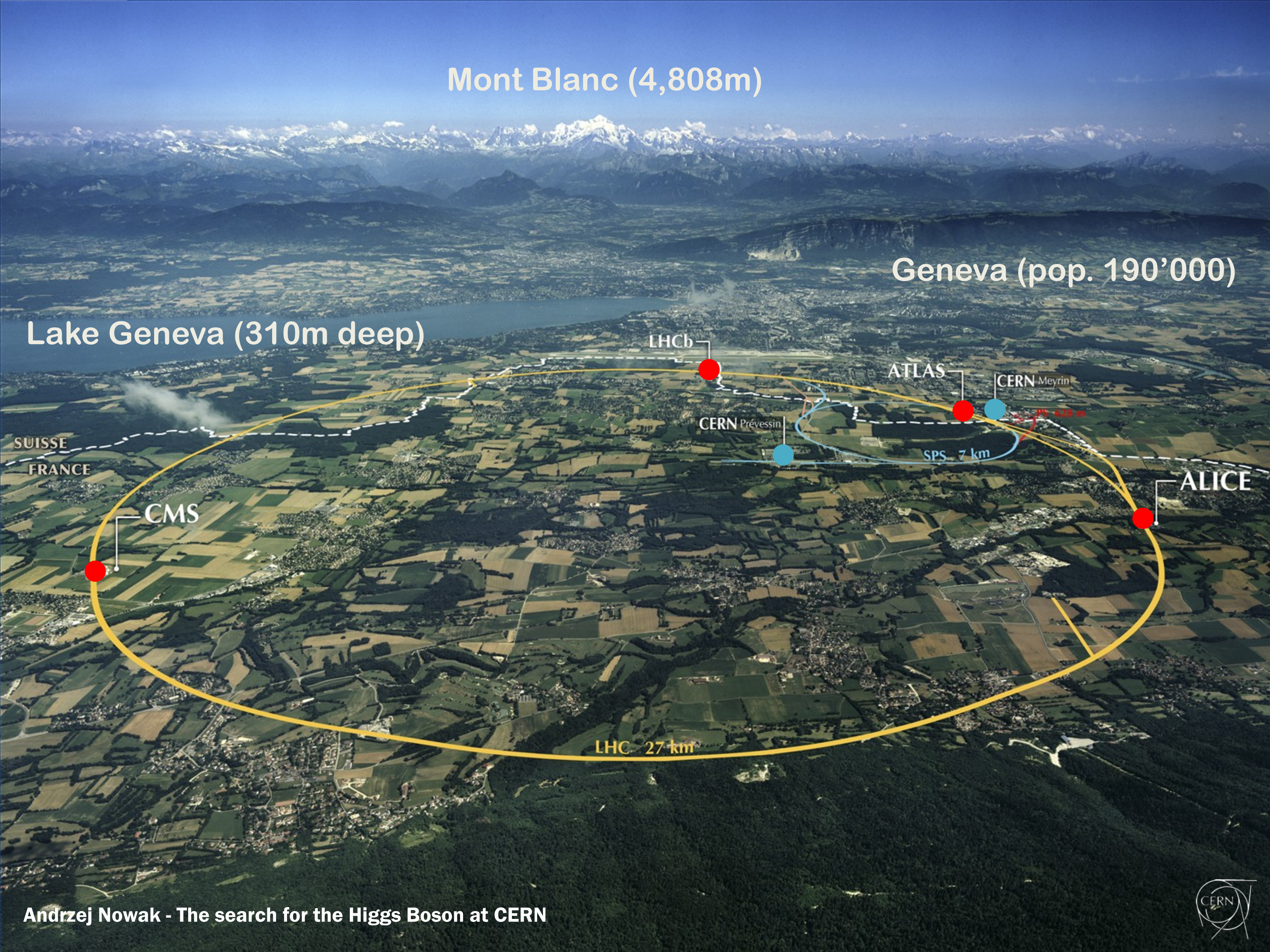
The European Particle Physics Laboratory based in Geneva, Switzerland

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

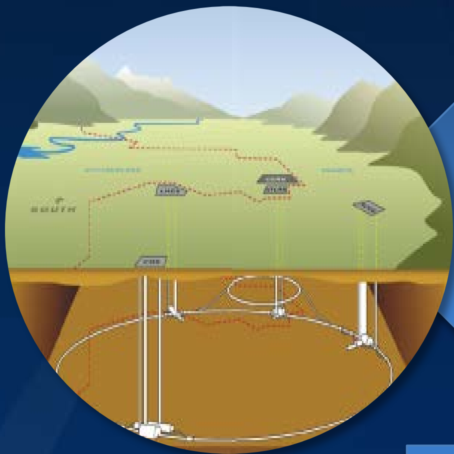
~2'500 personnel, > 15'000 users
~1 bln CHF yearly budget





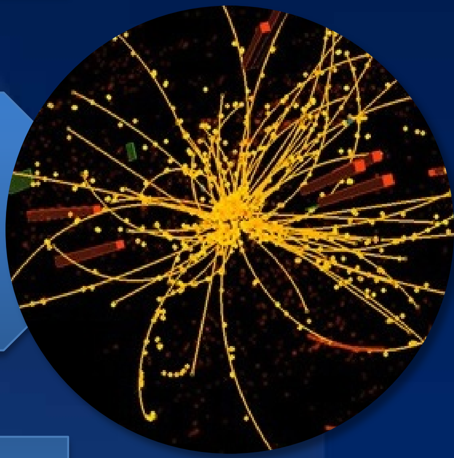
Mont Blanc (4,808m)
Geneva (pop. 190’000)
Lake Geneva (310m deep)
LHCb
ATLAS
CERN Meyrin
CERN Prévessin
SPS 7 km
SUISSE
FRANCE
ALICE
CMS
LHC 27 km

The Large Hadron Collider

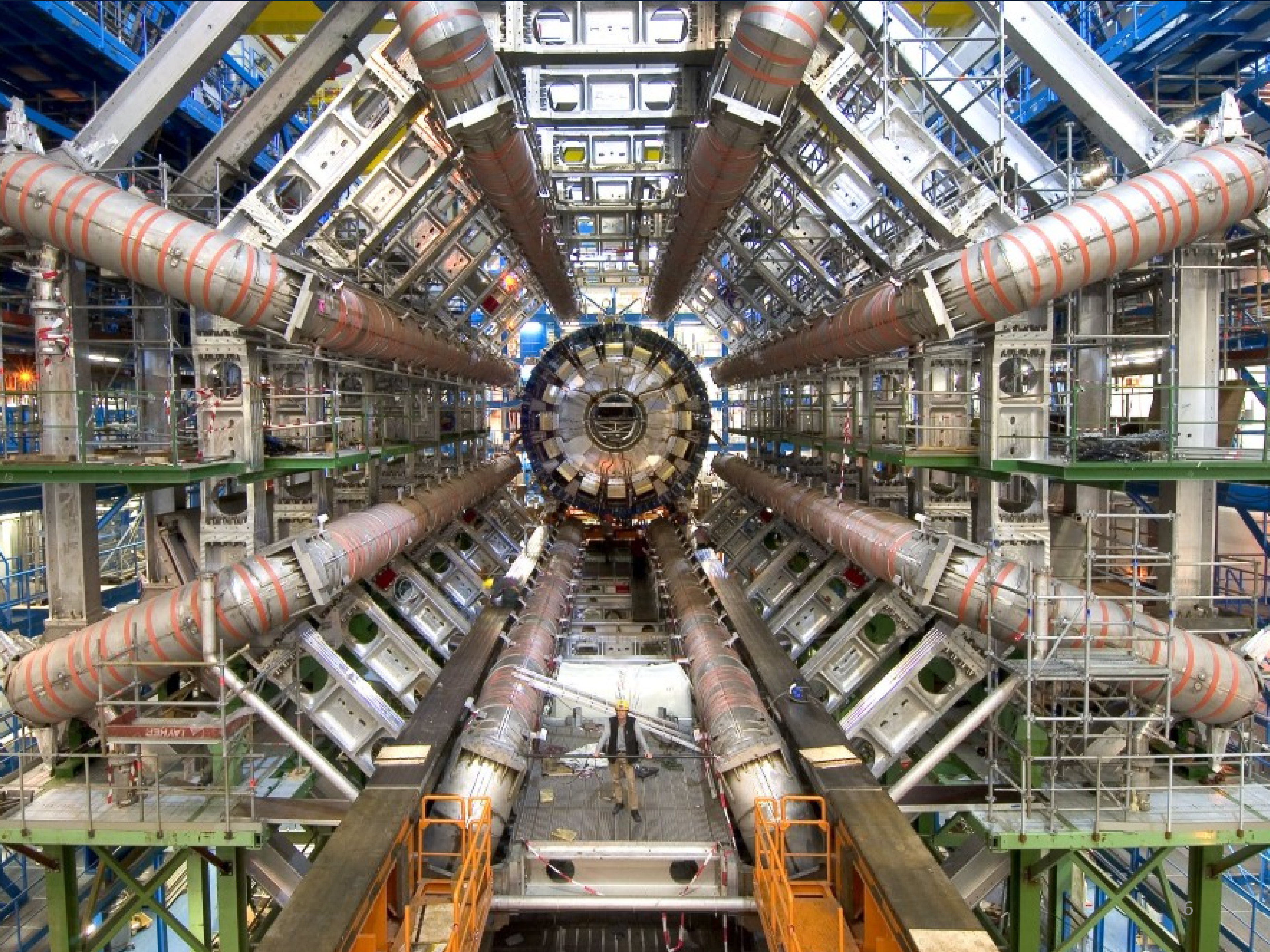


27 km underground superconducting ring – possibly the largest machine ever built by man

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

ARTICLE INFO

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

ABSTRACT

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.

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
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. Barberi
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
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.
L. Bouchami [93], J. Boudreau [122], E.V. Bouhova-Thacke

I.A. Christidi [77], A. Christov [48], D. Chromek-Burckhart
E. Cicalini [121a,121b], A.K. Ciftci [3a], R. Ciftci [3a], D. Cinca
A. Ciocio [14], M. Cirilli [87], M. Citterio [89a], A. Clark [49], P.J.
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
C.D. Cojocaru [28], J. Colas [4], B. Cole [34], A.P. Colijn [105], C.
J. Collot [55], G. Colon [84], R. Coluccia [72a,72b], G. Comune
M. Consonni [104], S. Constantinescu [25a], C. Conta [118a,11
B.D. Cooper [75], A.M. Cooper-Sarkar [117], N.J. Cooper-Smi
M. Corradi [19a], S. Correard [83], F. Corriveau [85,f], A. Corso

D. Fassouliotis [8], B. Fatholahzadeh [156], L. Fayard [114],
O.L. Fedin [120], I. Fedorko [29], W. Fedorko [29], L. Feligion
A.B. Fenyuk [127], J. Ferencei [143b], J. Ferland [93], B. Ferna
J. Ferrando [117], V. Ferrara [41], A. Ferrari [164], P. Ferrari
D. Ferrere [49], C. Ferretti [87], F. Ferro [50a,50b], M. Fiascar
A. Filippas [9], F. Filthaut [104], M. Fincke-Keeler [167], M.C
P. Fischer [20], M.J. Fisher [108], S.M. Fisher [128], H.F. Flach
P. Fleischmann [171], S. Fleischmann [20], F. Fleuret [78], T.
F. Föhlisch [58a], M. Fokitis [9], T. Fonseca Martin [76], J. Fo
D. Fortin [157a], J.M. Foster [82], D. Fournier [114], A. Fouss
P. Francavilla [121a,121b], S. Franchino [118a,118b], D. Franc
M. Fraternali [118a,118b], S. Fratina [119], J. Freestone [82], S

N. Massol [4], A. Mastroberardino [36a,36b], T. Mas
H. Matsunaga [153], T. Matsushita [67], C. Mattrave
J.K. Mayer [156], A. Mayne [138], R. Mazini [149], M.
F. Mazzucato [49], J. Mc Donald [85], S.P. Mc Kee [8
K.W. McFarlane [56], S. McGarvie [76], H. McGlone
T.R. McMahon [76], T.J. McMahon [17], R.A. McPhe
M. Medinnis [41], R. Meera-Lebbai [110], T.M. Meg
K. Meier [58a], J. Meinhardt [48], B. Meirose [48], C.
P. Mendez [98], L. Mendoza Navas [160], Z. Meng [1
P. Mermod [117], L. Merola [102a,102b], C. Meroni [89
J. Metcalfe [103], A.S. Mete [64], S. Meuser [20], J.-P.
W.T. Meyer [64], J. Miao [32d], S. Michal [29], L. Micu
A. Migliaccio [102a,102b], L. Mijović [74], G. Mikenb
D.W. Miller [142], R.J. Miller [88], W.J. Mills [166], C.M
D. Milstein [169], S. Mima [109], A.A. Minaenko [127
B. Mindur [37], M. Mineev [65], Y. Ming [129], L.M. M
S. Miscetti [47], A. Misiejuk [76], A. Mitra [117], J. Mi
P.S. Miyagawa [82], Y. Miyazaki [139], J.U. Mjörnma
P. Mockett [137], S. Moed [57], V. Moeller [27], K. Mö
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

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],
G. Unal [29], D.G. Underwood [5], A. Undrus [24], G. Unel [161], Y. Unno [66], D. Urbaniec [34], E. Urkovsky [151],
P. Urquijo [49,x], P. Urrejola [31a], G. Usai [7], M. Uslenghi [118a,118b], L. Vacavant [83], V. Vacek [126], B. Vachon [85],
S. Vahsen [14], C. Valderanis [99], J. Valenta [124], P. Valente [131a], S. Valentinetti [19a,19b], S. Valkar [125],
E. Valladolid Gallego [165], S. Vallecorsa [150], J.A. Valls Ferrer [165], R. Van Berg [119], H. van der Graaf [105],
E. van der Kraaij [105], E. van der Poel [105], D. Van Der Ster [29], B. Van Eijk [105], N. van Eldik [84],
P. van Gemmeren [5], Z. van Kesteren [105], I. van Vulpen [105], W. Vandelli [29], G. Vandoni [29], A. Vaniachine [5],
P. Vankov [73], F. Vannucci [78], F. Varela Rodriguez [29], R. Vari [131a], E.W. Varnes [6], D. Varouchas [14],

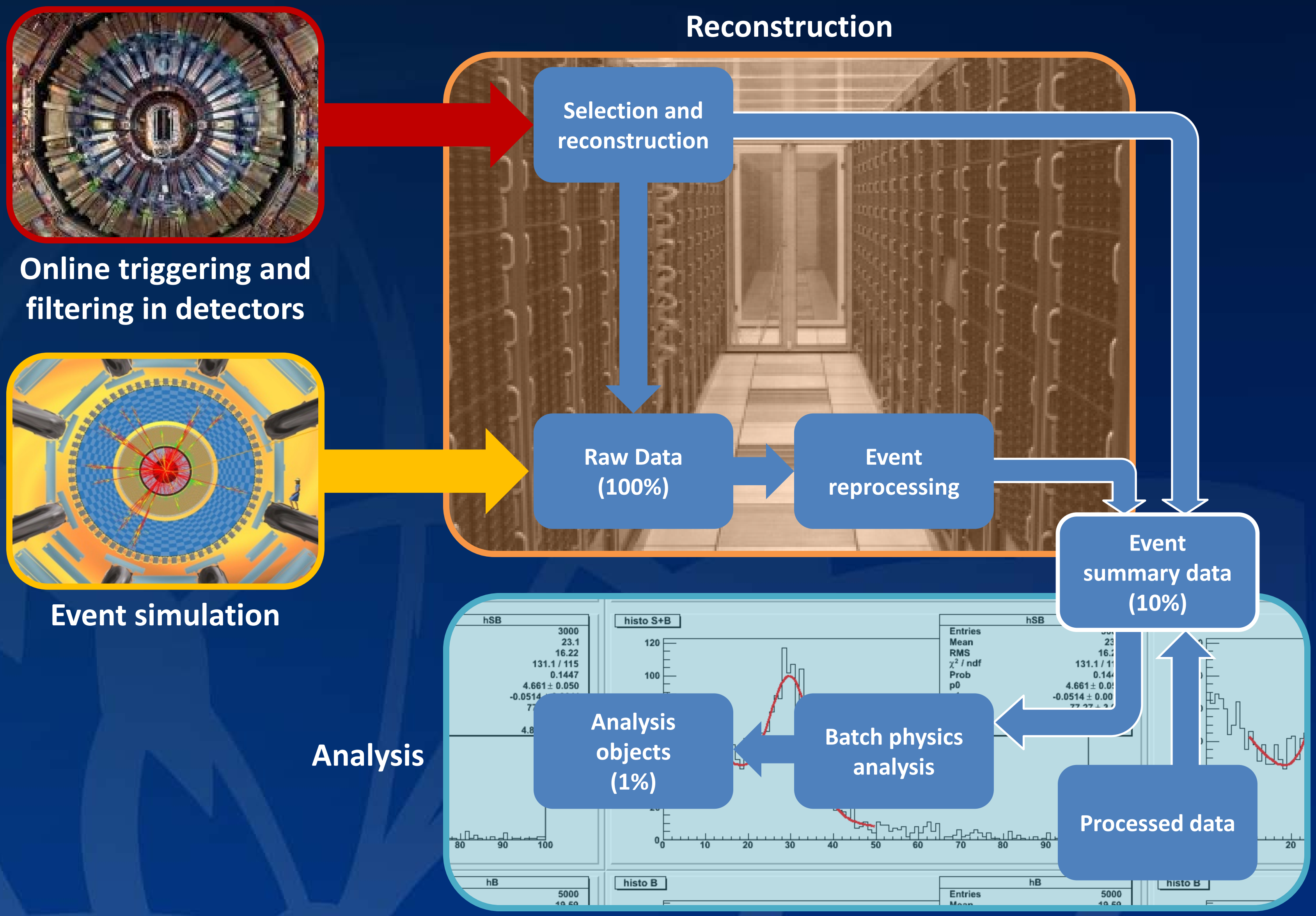
Z. Zhao [32b], A. Zhemchugov [65], S. Zheng [32a], J. Zhong [149,z], B. Zhou [87], N. Zhou [34], Y. Zhou [149], C.G. Zhu [32d],
H. Zhu [41], Y. Zhu [170], X. Zhuang [98], V. Zhuravlov [99], B. Zilka [143a], R. Zimmermann [20], S. Zimmermann [20],
S. Zimmermann [48], M. Ziolkowski [140], R. Zitoun [4], 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]

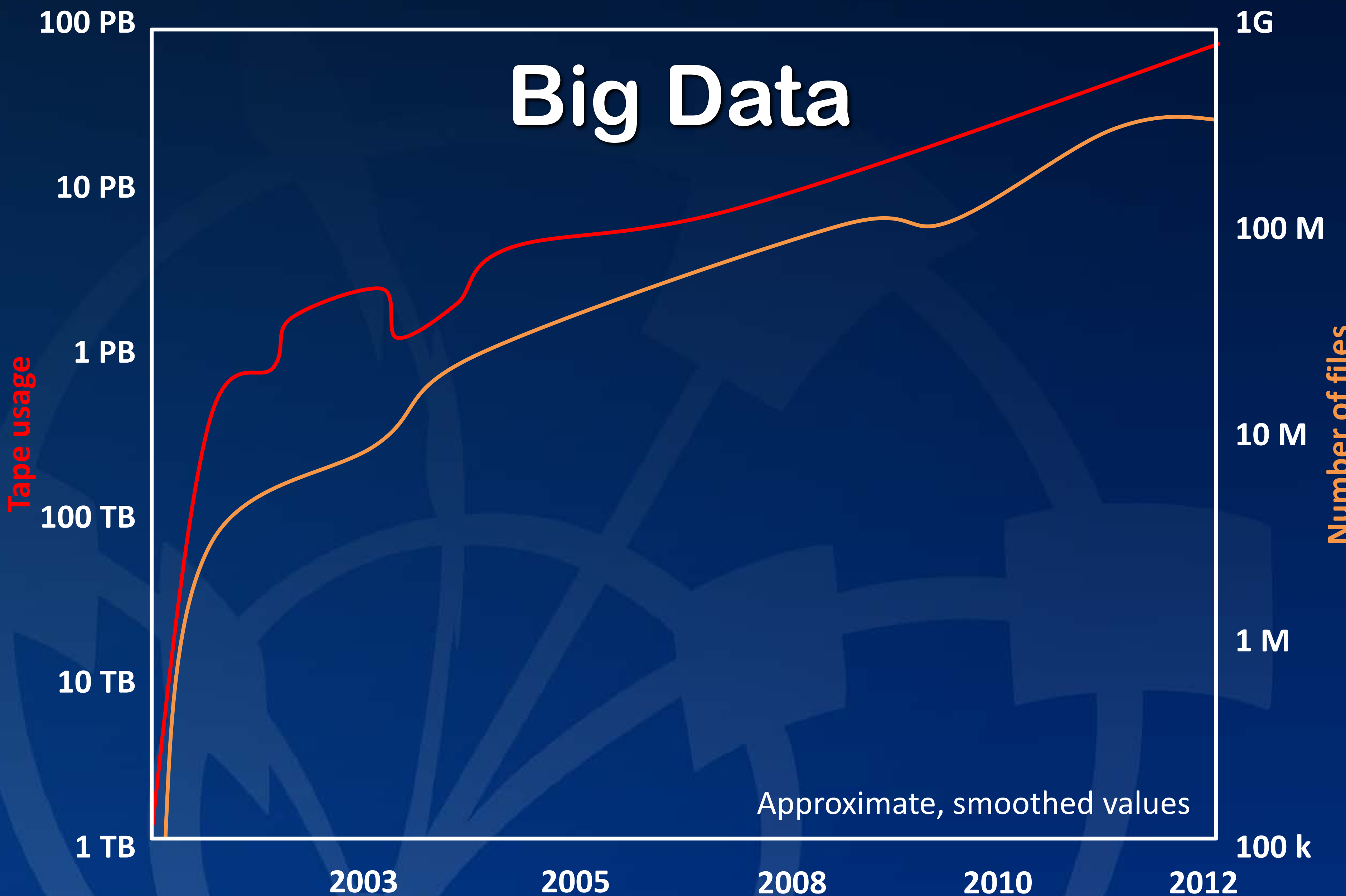
[1] University at Albany, 1400 Washington Ave, Albany, NY 12222, United States
[2] University of Alberta, Department of Physics, Centre for Particle Physics, Edmonton, AB T6G 2G7, Canada
[3] Ankara University[(a)], Faculty of Sciences, Department of Physics, TR 061000 Tandogan, Ankara; Dumlupinar University[(b)], 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

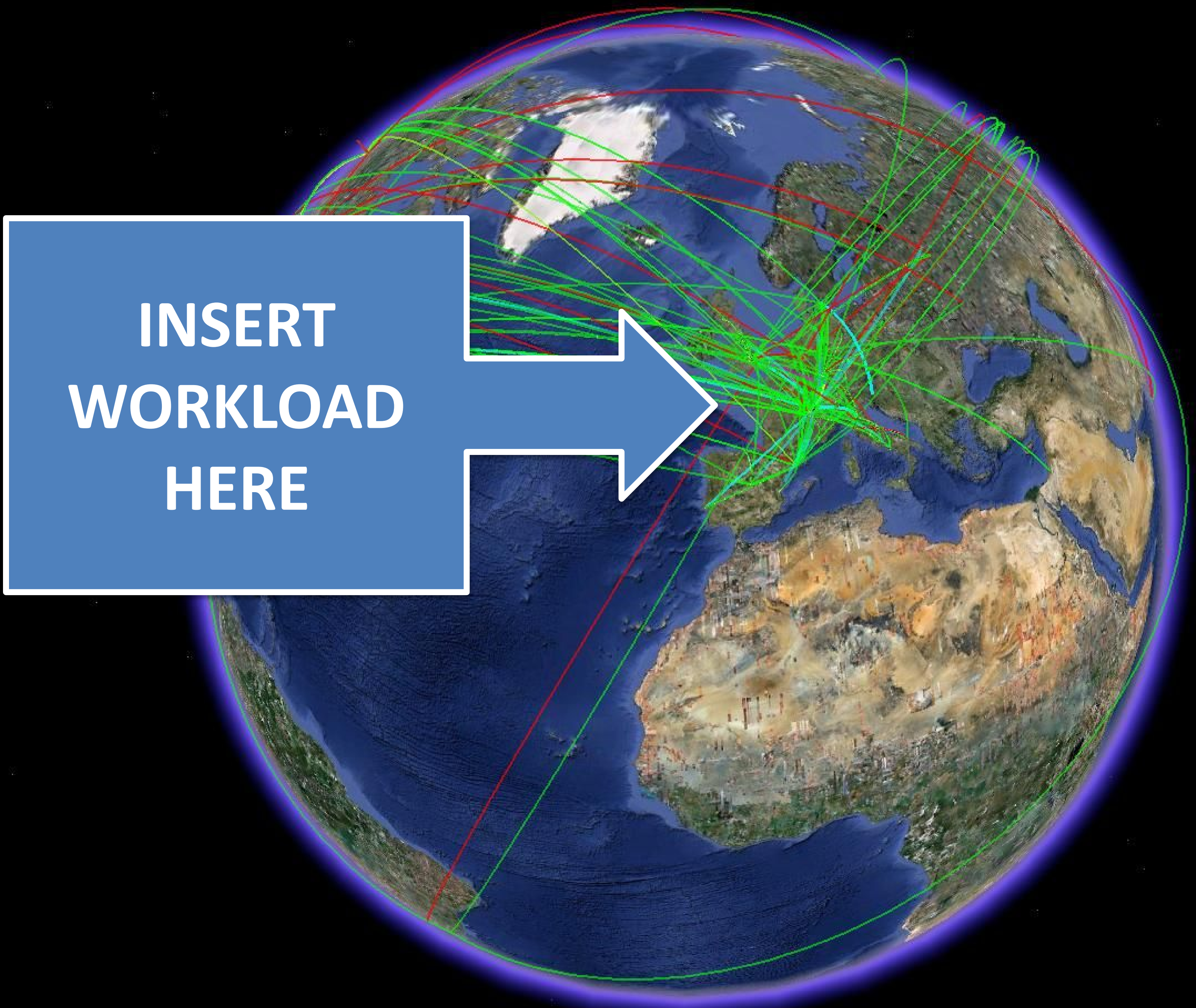
[63] University of Iowa, 203 Van Allen Hall, Iowa City, IA 52242-1479, United States
[64] Iowa State University, Department of Physics and Astronomy, Ames High Energy Physics Group, Ames, IA 50011-3160, United States
[65] Joint Institute for Nuclear Research, JINR Dubna, RU-141 980 Moscow Region, Russia
[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

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

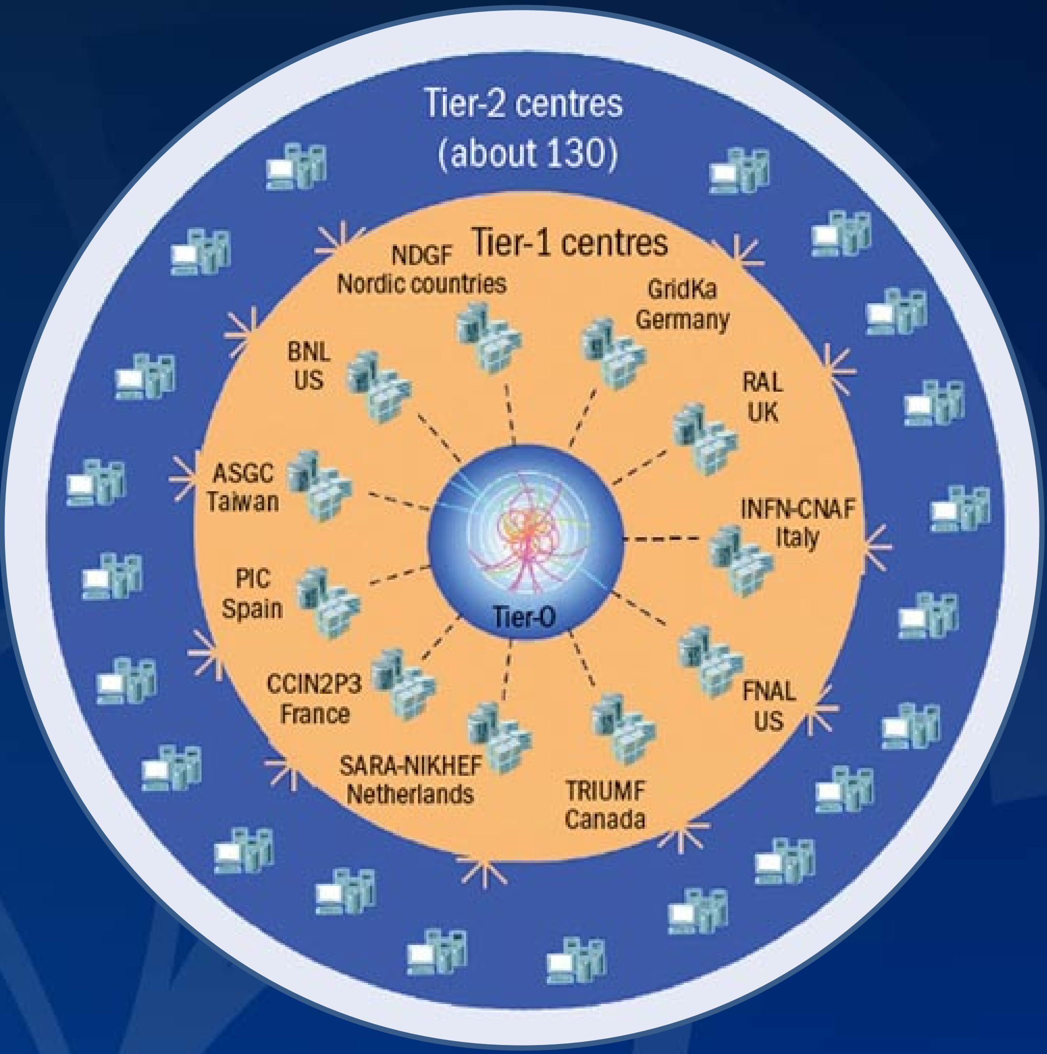

INSERT
WORKLOAD
HERE

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

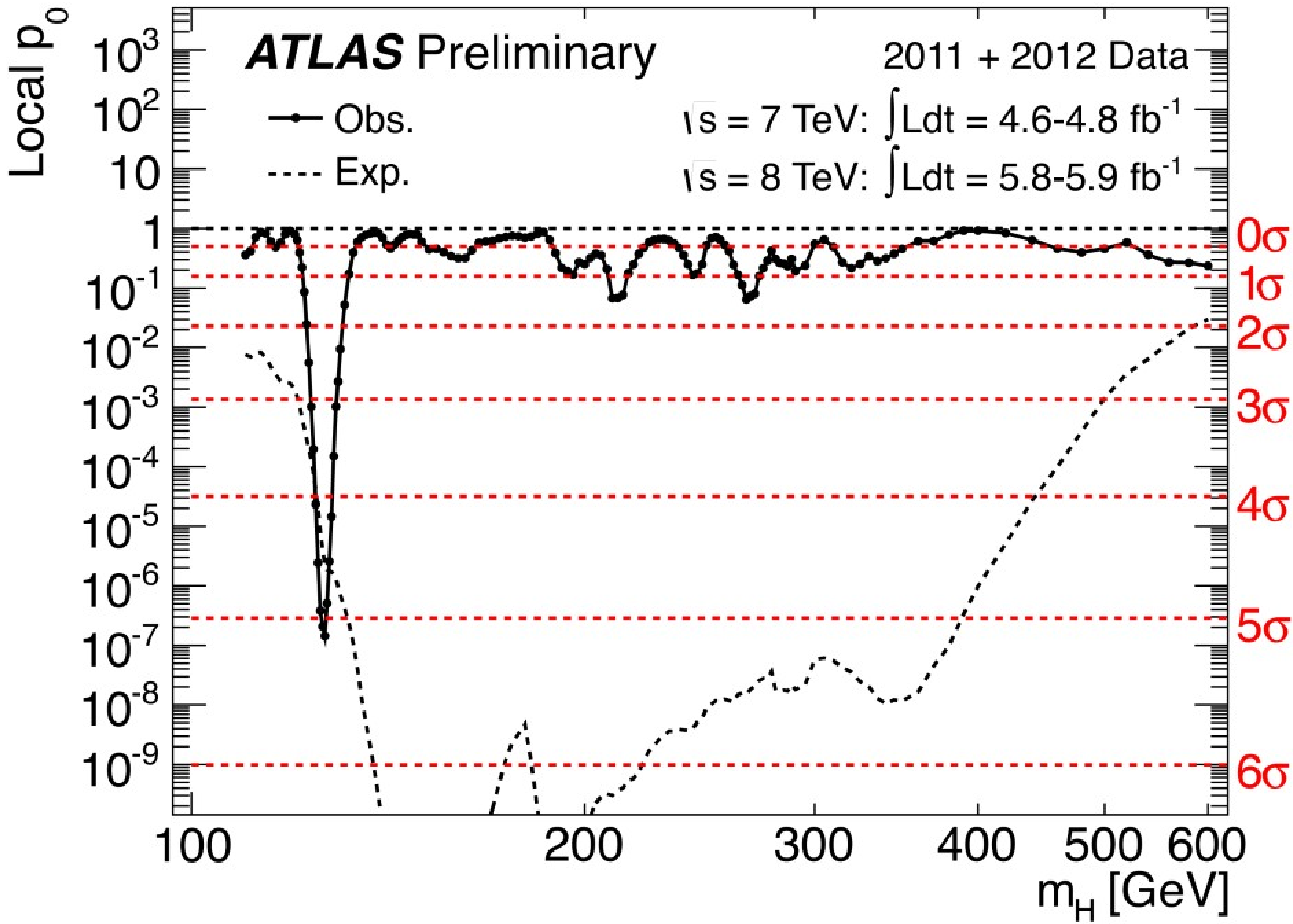


nearly 160 sites

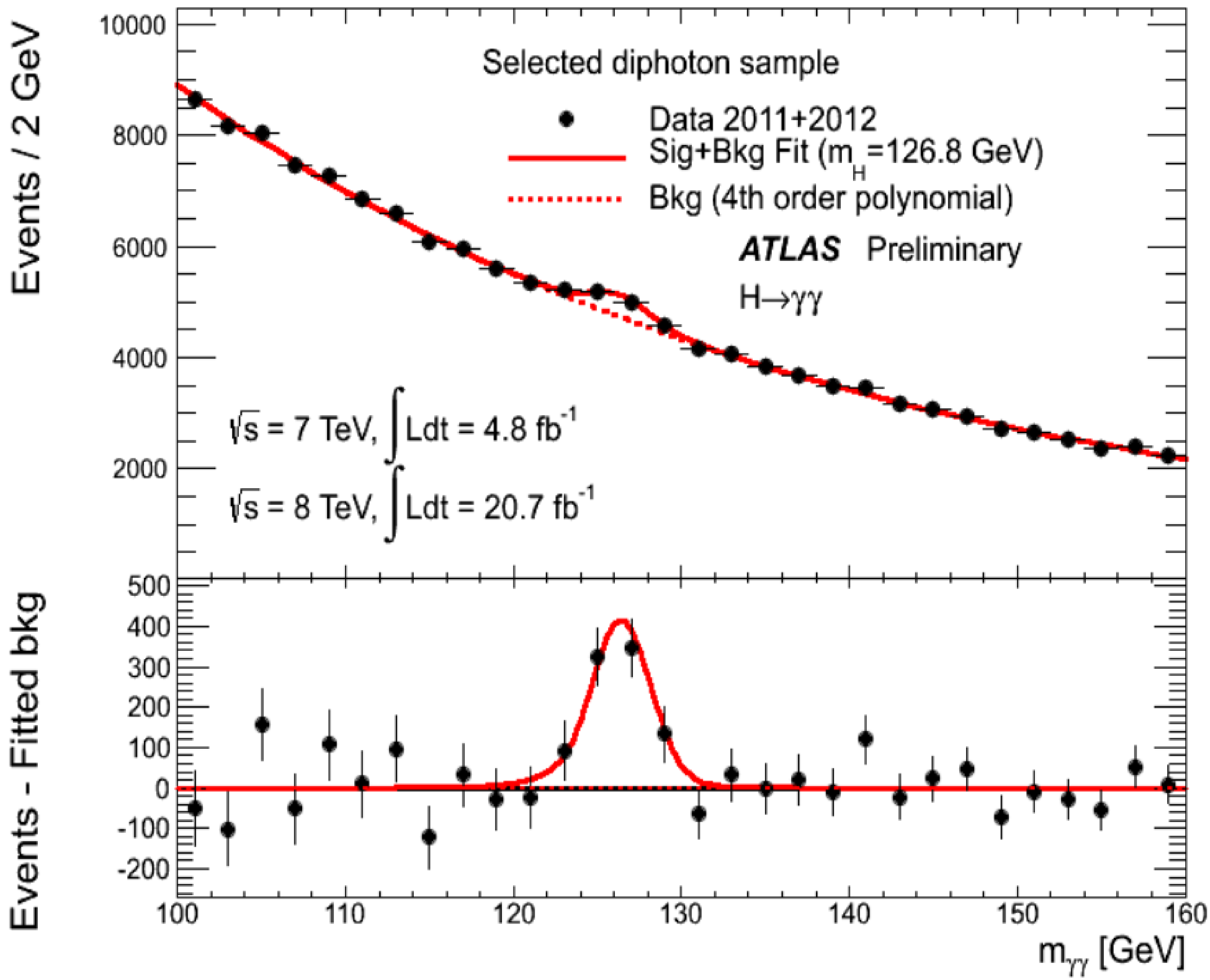
~250’000 cores

173 PB of storage

> 2 million jobs/day



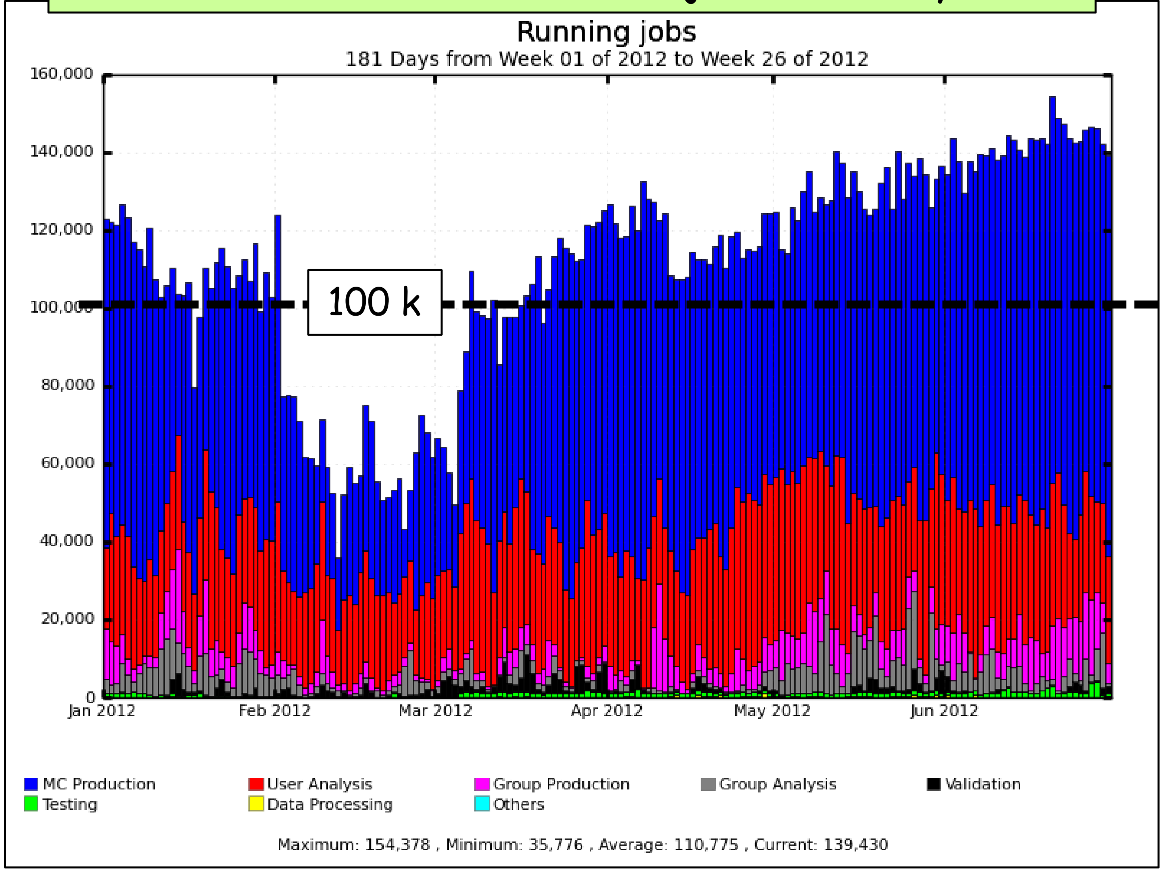
ATLAS Preliminary
2011 + 2012 Data
Obs.
Exp.
√s = 7 TeV: ∫Ldt = 4.6-4.8 fb⁻¹
√s = 8 TeV: ∫Ldt = 5.8-5.9 fb⁻¹
Local p0
0σ
1σ
2σ
3σ
4σ
5σ
6σ
100
200
300
400
500
600
mH [GeV]



http://blog.vixra.org/2013/03/06/moriond-higgs-update/

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)

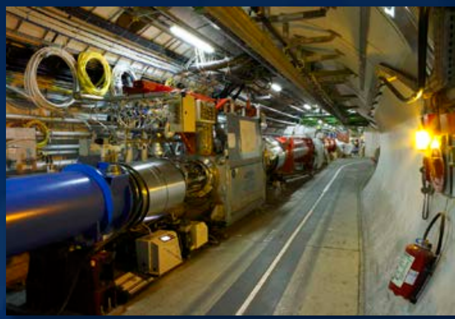
A wealth of knowledge

- 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

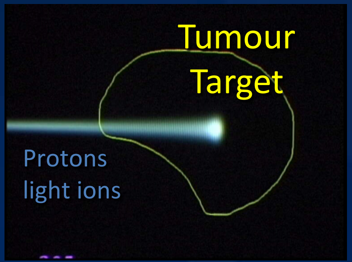


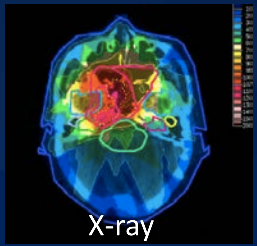
Accelerating particle beams

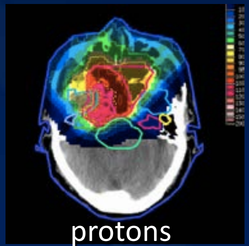
~30’000 accelerators worldwide

~17’000 used for medicine

Hadron Therapy



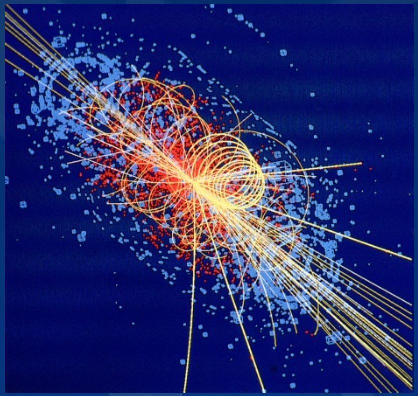




Leadership in Ion Beam Therapy now in Europe and Japan

>70’000 patients treated worldwide (30 facilities)

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

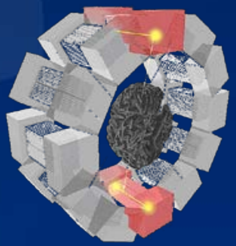


Detecting particles

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

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

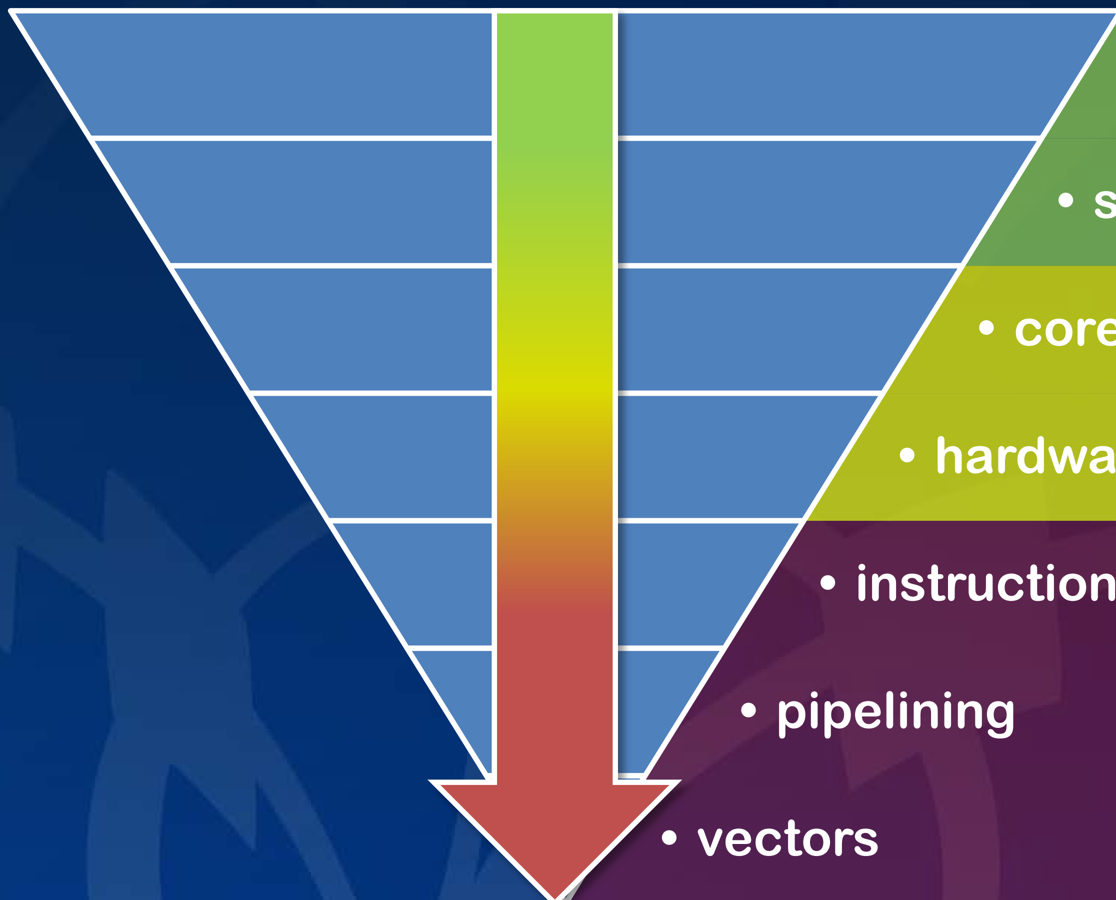
Big(ger) data

Data rates at the LHC to increase by ~100x

- Raw data: an exabyte per second?
- Exabytes stored yearly?
- Millions of computing cores?

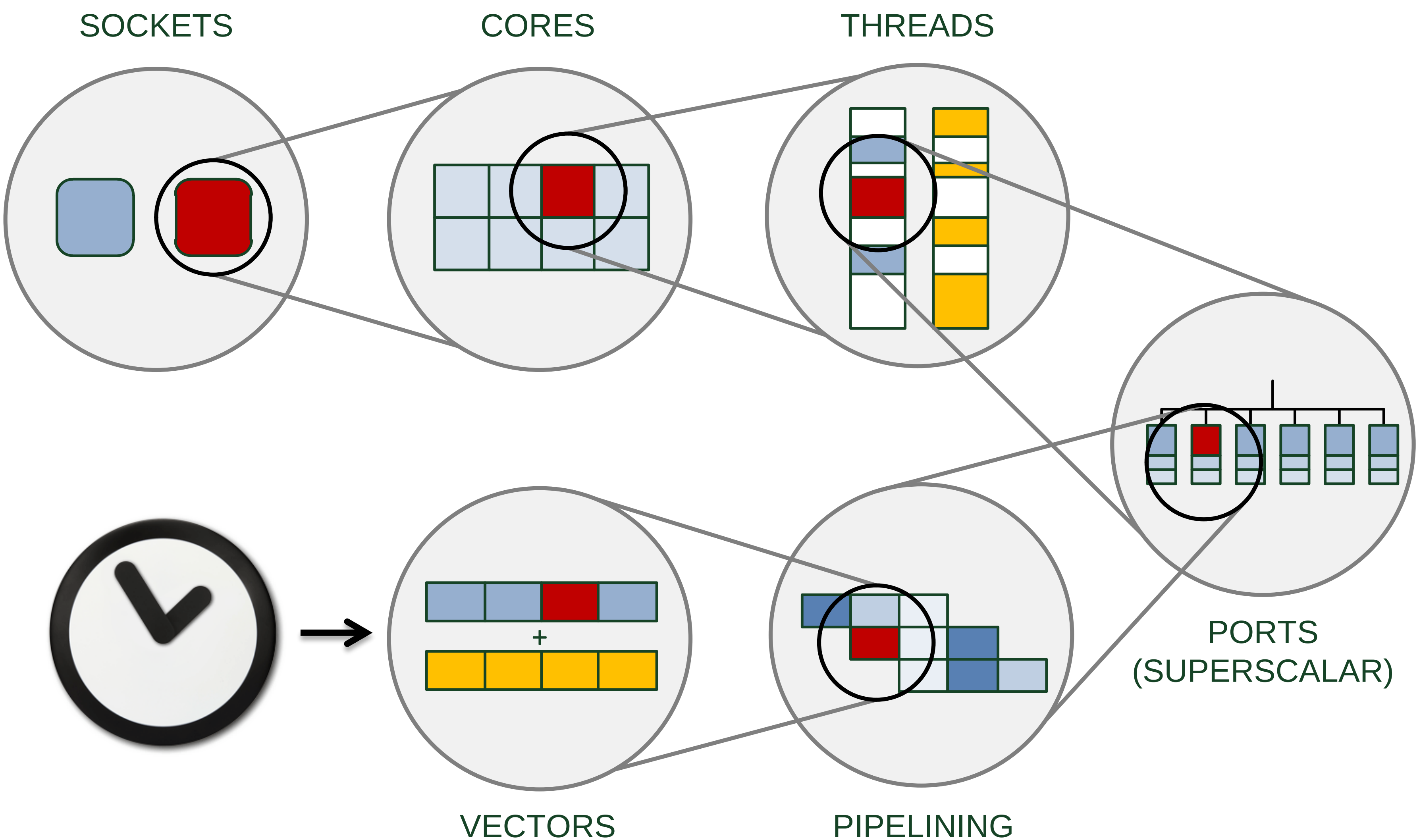
"Sustainable computing"

Computing: omnipresent multiplicative parallelism

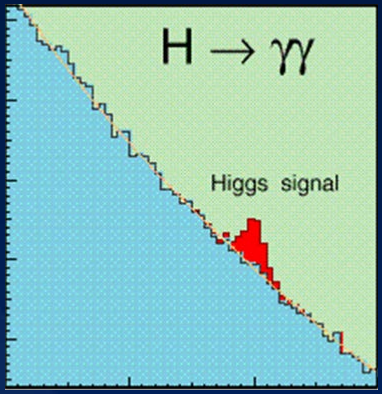


- systems
- sockets
- cores
- hardware threading
- instruction level (superscalar)
- pipelining
- vectors

Inside a modern PC platform



CERN's 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**

Mainstream compute uses a low single digit percentage of raw machine power available today

_%

Write your percentage here

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

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

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

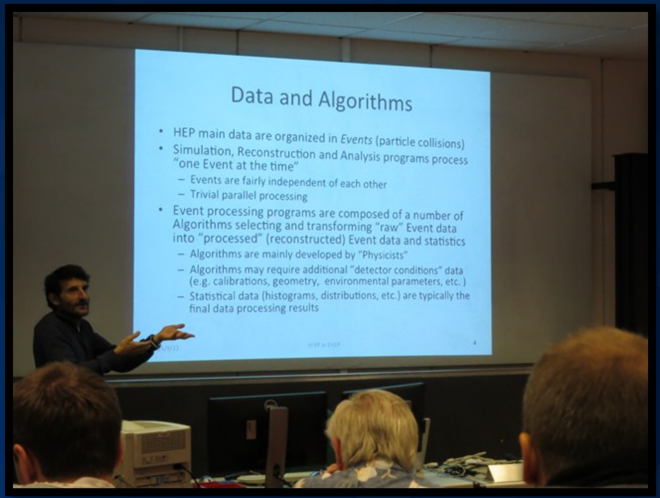
Expertise

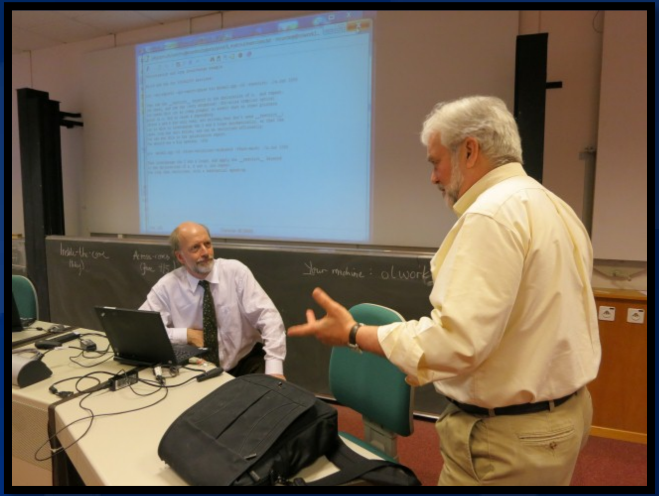
- Understood and compared with Xeon
- **Post-launch dissemination**

Teaching

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

Numerical computing workshops





ICE-DIP

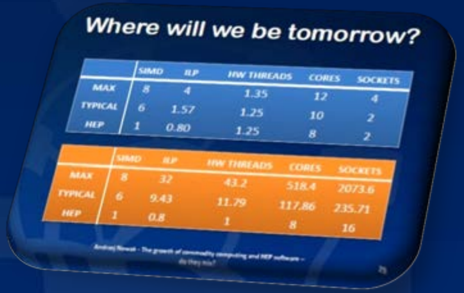
- **EU Framework Program 7 project looking for (amongst other things) efficient methods of accelerator/co-processor use**
- **Focus on data taking past 2016**
- **Of particular interest**
  - Getting data into the platform
  - Getting data into the accelerator/co-processor
  - Efficient processing
 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

  We will employ 5 PhD students to work on Si Photonics, FPGAs, networks, many-core

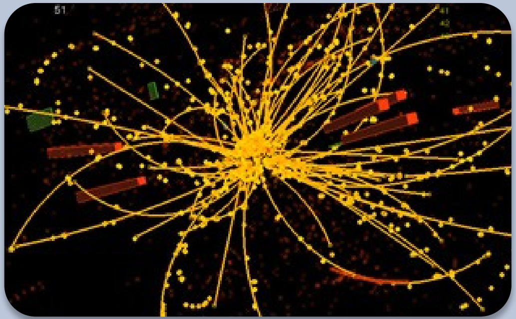
MARIE CURIE **ACTIONS**

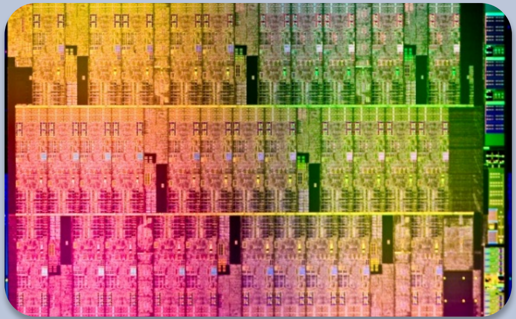
Future directions in computing

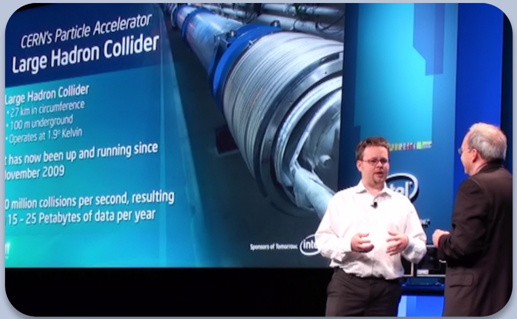
- **Software replacing hardware**
  - Programmability replaces rigid structures
- **Intensive compute**
  - Local farms must have much higher processing capacity
- **Accelerators/co-processors**
  - Experiments with Intel MIC and GPUs
- **Silicon photonics**



Summary







New challenges ahead of CERN

Upcoming new era for LHC computing

openlab actively contributes

THANK YOU

Q & A

CERN
openlab

Questions? Andrzej.Nowak@cern.ch