Future of Software and Computing
in the scope of the European Strategy for Particle Physics

Xinchou Lou
Institute of High Energy Physics, CAS, Beijing

Special Acknowledgement
Brigitte Vachon, Roger Jones, Emilia Leogrande, Ian Bird, Amber Boehnlein, Simone Campana, Maria Girone, Matthias Kasemann, Weidong Li, Graeme Stewart, authors of inputs to EPPSU, ...
Introduction to the European Particle Physics Strategy Update - EPPSU
The HEP experiment landscape and the demands for software and computing
Open Symposium in Granada
The Briefing Book – input to EPPSU
Summary
European Particle Physics Strategy Update - EPPSU

objectives, organization & schedule
assignment, contents
the Open Symposium in Granada
Briefing Book, input to be used by the European Strategy Group (ESG)
EPPSU decision, implementation by CERN (+national labs, funding agencies)
The European Strategy for Particle Physics is the cornerstone of Europe’s decision-making process for the long-term future of the field.

Mandated by the CERN Council, it is formed through a broad consultation of the grass-roots particle physics community, it actively solicits the opinions of physicists from around the world, and it is developed in close coordination with similar processes in the US and Japan in order to ensure coordination between regions and optimal use of resources globally.

Input from global HEP community

Open Symposium results in a Briefing book to be presented to the ESG for further deliberations
The composition of the ESG and the PPG is established by the CERN Council
Main document: Please prepare a pdf file containing a cover page (title, abstract, name of the contact person and his/her e-mail address) and a comprehensive and self-contained description of the proposed input (maximum 10 pages). This document should address (when applicable) the scientific context, objectives, methodology, readiness and expected challenges.

Addendum: Please also prepare a pdf file containing information on the following topics (where relevant): interested community, timeline, construction and operating costs, computing requirements. The name of this pdf file should be as follows: “Addendum-NN.pdf”, where NN is the file-name of your main document.

submission themes (tracks) to which your input relates:
- Large experiments and projects
- National road maps
- Accelerator Science and Technology
- Beyond the Standard Model at colliders (present and future)
- Dark matter and dark sector (accelerator and non-accelerator dark matter, dark photons, hidden sector, axions)

Instrumentation and computing
- Electroweak physics (physics of the W, Z, H bosons, of the top quark, and QED)
- Flavour Physics and CP violation (quarks, charged leptons and rare processes)
- Neutrino physics (accelerator and non-accelerator)
- Strong interactions (perturbative and non-perturbative QCD, DIS, heavy ions)

For confidential addenda: If you wish the addendum to be treated as confidential (i.e. limited to the PPG and ESG), you should send it to the following email address eppsu.addenda@espace.cern.ch by 18 December 2018
Scientific Input to the Strategy Update

- Call for inputs issued February 28, 2018 with deadline for submission December 18, 2018
- 160 submissions received

<table>
<thead>
<tr>
<th>Track ID</th>
<th>Granada sessions</th>
<th>Description</th>
<th>Conveners</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>Large experiments and projects</td>
<td>PPG/ESG</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>National road maps</td>
<td>ESG</td>
</tr>
<tr>
<td>7</td>
<td>B1</td>
<td>Electroweak Physics (physics of the W, Z, H bosons, of the top quark, and QED)</td>
<td>Keith Ellis, Beate Heinemann</td>
</tr>
<tr>
<td>8</td>
<td>B2</td>
<td>Flavour Physics and CP violation (quarks, charged leptons and rare processes)</td>
<td>Belen Gavela, Antonio Zoccoli</td>
</tr>
<tr>
<td>5</td>
<td>B3</td>
<td>Dark matter and Dark Sector (accelerator and non-accelerator dark matter, dark photons, hidden sector, axions)</td>
<td>Marcela Carena, Shoji Asai</td>
</tr>
<tr>
<td>3</td>
<td>B4</td>
<td>Accelerator Science and Technology</td>
<td>Caterina Biscari, Lenny Rivkin</td>
</tr>
<tr>
<td>4</td>
<td>B5</td>
<td>Beyond the Standard Model at colliders (present and future)</td>
<td>Gian Giudice, Paris Sphicas</td>
</tr>
<tr>
<td>10</td>
<td>B6</td>
<td>Strong Interactions (perturbative and non-perturbative QCD, DIS, heavy ions)</td>
<td>Krzysztof Redlich, Jorgen D’Hondt</td>
</tr>
<tr>
<td>9</td>
<td>B7</td>
<td>Neutrino Physics (accelerator and non-accelerator)</td>
<td>Stan Bentvelsen, Marco Zito</td>
</tr>
<tr>
<td>6</td>
<td>B8</td>
<td>Instrumentation and Computing</td>
<td>Xinchou Lou, Brigitte Vachon</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>Other (communication, outreach, strategy process, technology transfer, individual contributions,...)</td>
<td>ESG</td>
</tr>
</tbody>
</table>

- The Open Symposium aims to reach a consensus on the **scientific goals** of the community, based on the provided input, and assess the proposed projects and technologies to achieve those goals

- This is to ensure that the ESG is provided with all the necessary input to propose a realistic update of the Strategy – decisions on strategic choices are not expected to be taken this week
Organization of the Symposium

Granada Symposium: Plenary sessions, eight discussion sessions.

- The parallel sessions be convened by two members of the Physics Preparatory Group. The sessions are organized around topics covered by the submission tracks.

Preparation work leading up to the Open Symposium

- All inputs submitted to the EPPSU were reviewed
- EPPSU-PPG, EPPSU-ESG and ECFA initiated discussions with colleagues, communities, & heads of collaborations
- ECFA initiated several European community surveys
- ...
# HEP Computing

HEP Computing | 340 minutes of presentations, discussions and debates

## Plenary Session - García Lorca Room


CAMPANA, Simone (CERN)

## B8 - Instrumentation and Computing: Instrumentation - Picasso Room (09:00-13:30)

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
<th>Presenter</th>
</tr>
</thead>
<tbody>
<tr>
<td>09:00</td>
<td>Current HEP computing model (20+10 min)</td>
<td>BIRD, Ian (CERN)</td>
</tr>
<tr>
<td>09:30</td>
<td>Lessons (to be) learned from the development of the current HEP</td>
<td>JONES, Roger (Lancaster University (GB))</td>
</tr>
<tr>
<td></td>
<td>computing model (20+10 min)</td>
<td></td>
</tr>
<tr>
<td>10:00</td>
<td>Future challenges of HEP computing (20+10 min)</td>
<td>KASEMANN, Matthias (Deutsches Elekronen-Synchrotron Hamburg (DE))</td>
</tr>
<tr>
<td>10:30</td>
<td>Coffee break</td>
<td></td>
</tr>
<tr>
<td>11:00</td>
<td>HEP computing infrastructure R&amp;D (20+10 min)</td>
<td>GIRONE, Maria (CERN)</td>
</tr>
<tr>
<td>11:30</td>
<td>HEP Computing Software R&amp;D (20+10 min)</td>
<td>STEWART, Graeme A (CERN)</td>
</tr>
<tr>
<td>12:00</td>
<td>Panel discussion</td>
<td>BOEHNLEIN, Amber (Jefferson Lab) et. al.</td>
</tr>
</tbody>
</table>

## Plenary Session: Summaries, Discussion and Closeout - García Lorca Room (14:15-16:00)

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
<th>Presenter</th>
</tr>
</thead>
<tbody>
<tr>
<td>14:15</td>
<td>Instrumentation and Computing</td>
<td>VACHON, Brigitte (McGill University, (CA))</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LOU, Xinchou (Chinese Academy of Sciences (CN))</td>
</tr>
</tbody>
</table>
Computing – Panel Discussion

Panel members

- Ian Bird
- Amber Boehnlein
- Simone Campana
- Roger Jones
- Weidong Li
- Matthias Kasemann
- Graeme Stewart

Scope

1. Knowledge, training, career
2. HEP Computing evolution
3. Coordination of R&D

to make progress towards formulating constructive answers/suggestions to these questions, to bring forward to the EPPSU
The scientific outcomes of an experiment are made possible by the development of an efficient computing and software infrastructure

- Historically, the development of these infrastructures for particle physics has benefited from Moore’s law, the use of commodity hardware, and highly distributed systems.
- This, however, no longer holds true. Nowadays, the landscape of computing infrastructure for particle physics is rapidly changing and becoming more diverse.
- The particle physics community faces important challenges in this area and the current computing and software models must evolve to meet the needs of approved and future experiments
The science and technology drivers for software and computing in HEP

**HL-LHC**

**Belle-II**

Large ν exp.s

Theory,...

**Boson factories**

HE e+e- colliders

Cir. hh colliders

Larger ν exp.s

Theory,...

Example with large colliders

<table>
<thead>
<tr>
<th>T_{0}</th>
<th>+5</th>
<th>+10</th>
<th>+15</th>
<th>+20</th>
<th>...</th>
<th>+26</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILC</td>
<td>0.5/ab 250 GeV</td>
<td>1.5/ab 250 GeV</td>
<td>1.0/ab 500 GeV</td>
<td>0.2/ab 2M_{τ_{μ}}</td>
<td>3/ab 500 GeV</td>
<td></td>
</tr>
<tr>
<td>CEPC</td>
<td>5.6/ab 240 GeV</td>
<td>16/ab M_{Z}</td>
<td>2.6/ab 2M_{τ_{μ}}</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CLIC</td>
<td>1.0/ab 380 GeV</td>
<td>2.5/ab 1.5 TeV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FCC</td>
<td>150/ab ee, M_{Z}</td>
<td>10/ab ee, 2M_{τ_{μ}}</td>
<td>5/ab ee, 240 GeV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LHeC</td>
<td>0.06/ab</td>
<td>0.2/ab</td>
<td>0.72/ab</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HE-LHC</td>
<td>10/ab per experiment in 20y</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FCC eh/hh</td>
<td>20/ab per experiment in 25y</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Updates, Inputs from community, presentations and discussion at OS

Software and Computing
Hardware and network
Data preservation & regulation
Professional development and career for CHEP scientists and trainees
R&D – project based, blue sky, ...
Investment and meeting the needs
...

CHEP 2019
Open Symposium in Granada, Spain
Computing – evolution and current model

• Moore’s law is barely holding on
  • CMOS technology approaches fundamental limits

• Clock speed has been largely flat since 2007

• Number of cores continues to increase

Computing – evolution and current model

Today’s computing models

- HEP has always done distributed computing
- Scale of the challenge for LHC forced a more organized and formal structure
- Built a federated system – grid – to integrate and make easily usable pledged resources

Commodity components, distributed system (WLGC), other resources
Computing – challenges

LHC upgrade to High Luminosity

- The accelerator will be upgraded to provide ~3-4 times higher luminosity by 2026
- Luminosity:
  - Phase I: $< 2.2 \times 10^{34}$ cm$^{-2}$s$^{-1}$
  - Phase II: $(5)7.5 \times 10^{34}$ cm$^{-2}$s$^{-1}$
- Planned to deliver 3-4000 fb$^{-1}$ until 2037

<table>
<thead>
<tr>
<th></th>
<th>LHC</th>
<th>HL-LHC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pileup</td>
<td>~60</td>
<td>~140-200</td>
</tr>
<tr>
<td>Dataset</td>
<td>300/fb</td>
<td>3000-4000/fb</td>
</tr>
<tr>
<td>Instantaneous Lumi</td>
<td>~2x10$^{34}$</td>
<td>5-7.5x10$^{34}$</td>
</tr>
</tbody>
</table>

Matthias Kasemann
Computing – challenges + strategies

- Big challenges exist to meet the computing requirements for Run4
  - The current resources provisioning model is not sufficient
  - Collaboration with experiments beyond LHC beneficial

- Several other HEP/NP experiments require large amount of compute and storage resources
  - At smaller scale than ATLAS and CMS

- Technology, architecture changes
  - tracking is essential
  - $$$/resource unit is not a continuous and monotonic function, there will be surprises

- Strategies to meet future challenges are actively developed
  - In WCLG: resources provisions, coordination
    - Concepts for co-operation and coordination with other big data physics experiments is being developed
    - Data management, Middleware, networking
  - Experiments: software development, data models
    - New tools and concepts in triggering
    - Data management, algorithms, software frameworks
    - Adaptation to use more heterogenous resources

- Needs a huge investment of skilled developers
  - Not currently available at the required level

Matthias Kasemann
## Computing – R&D industry and HEP applications

<table>
<thead>
<tr>
<th>Technology</th>
<th>Industry Applications</th>
<th>HEP Experiments R&amp;D (see backup slides)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPUs</td>
<td>Machine learning, AI, block chain, signal processing, voice recognition, etc.</td>
<td>Online pattern recognition, object reconstruction, fast simulation, data quality monitoring, computing resource optimization, machine learning training and inference</td>
</tr>
<tr>
<td>TPUs</td>
<td>Machine learning inference and training, data processing, matrix multiplication</td>
<td>Machine Learning inference and training</td>
</tr>
<tr>
<td>FPGAs</td>
<td>Pattern recognition, inference application, low latency real-time applications</td>
<td>Triggering, machine learning inference, image recognition</td>
</tr>
<tr>
<td>ARM</td>
<td>Mobile applications, embedded systems, low power highly parallelized many core systems</td>
<td>Alternative low power general purpose architectures</td>
</tr>
</tbody>
</table>

Start with the detector-trigger, real time, online, AI, + software improvement

*Maria Girone*
Computing – R&D Computing Infrastructure

What shall we do?

- We need to better exploit the hardware on the market
  - Faster software will significantly reduce the resource gap
  - Vectorization, parallelization, CPU specific instruction sets and optimized libraries [Next talk]

- There is specialized accelerated hardware
  - GPUs, TPUs, FPGAs (new languages and programming paradigms)

- New techniques and methods
  - Machine Learning

- Disruptive technologies:
  - Neuromorphic, Quantum Computing

Improvements are flattening

- A very optimistic 15% growth is used for calculations!!

https://cacm.acm.org/magazines/2019/2/234352-a-new-golden-age-for-computer-architecture/fulltext

Maria.Girone@cern.ch
Computing – R&D Software

An Overview of HEP Software

- ~50 millions of lines of code, mainly C++
- Significant pieces of software are already shared
  - Event generators, Geant4, ROOT
- Poses the question, can we be doing better?

R&D-improvement

- Event generation
- Simulation
- Reconstruction-Software Triggers
- Analysis

Frameworks and Integration

- Increasingly heterogeneous world requires advanced software support infrastructure
  - Software frameworks support use of different devices as well as insulate developers from many of the details of concurrency and threading models
    - Latency hiding is critical to maintaining throughout
  - Framework development has traditionally been quite fragmented, but new experiments should offer a chance to increase convergence
    - Better to start off together than try to re-converge later (iLCSof, LA/Soft examples of success, albeit without concurrency)
- Actually software integration, into a working stack, is very desirable (‘Turnkey Stack’)
  - Integrate common components (geometry, simulation, reconstruction toolkits)
  - Saves time in conceptualisation and performance studies
    - Projects like AIDA/AIDA2020 have done this rather well
Organising for the Future

- HSF
  - Overarching umbrella organisation, at the international level (strongest in Europe and North America)
  - Builds community efforts, very inclusive; defined the [Community White Paper Roadmap](#)

- Software Institutes
  - IRIS-HEP in US
    - NSF funded at US$25M over 5 years
    - Machine Learning, DOMA, Innovative Advanced Algorithms, Analysis
  - Sizeable and funded
  - Should Europe do more here?
    - Traditionally labs (CERN, DESY) have played this role, but time to break out beyond HEP?
    - A lot of shared problems - critical architecture changes, new techniques affect us all
      - Value of the institute is in breaking boundaries (experiment, region, science)
    - Linking to *academic experts in software engineering* could be mutually very beneficial
    - Also helps us to tackle the training problem (pass on skills) and careers (better defined path) and solve practical software problems
Disruptive Technologies

Neuromorphic Computing
• Very large scale systems to mimic neuro-biological architectures present in the nervous system

Quantum Computing
• Computing systems relying on quantum properties/behaviors to perform calculations
  • Quantum Annealing like D-Wave systems
  • Quantum Gate models like IBM, Rigetti, Intel, Google

Maria Girone
Instrumentations and Computing

- A chapter on Instrumentation and Computing, intended for the Briefing Book for the European Strategy Group, has been prepared, after additional inputs and comments from the community have been incorporated.

- The ESG group has taken the delivery of the Briefing Book, and will work with CERN Council and CERN management to develop the European Strategy for the next cycle.

The CERN management is responsible for implementing the European Strategy for Particle Physics, in collaboration with the European national laboratories and institutes in the field

The Strategy document also acts as an important guide for the National Funding Agencies
Neutrino Physics & Cosmic Messengers: Stan Bentvelsen\textsuperscript{45}, Marco Zito\textsuperscript{46,47} (Conveners)
Albert De Roeck\textsuperscript{20}, Thomas Schwetz\textsuperscript{20} (Scientific Secretaries)
Bonnie Fleming\textsuperscript{48}, Francis Halzen\textsuperscript{49}, Andreas Haungs\textsuperscript{29}, Marek Kowalski\textsuperscript{5}, Susanne Mertens\textsuperscript{41}, Mauro Mezzetto\textsuperscript{50}, Silvia Pascoli\textsuperscript{50}, Bangalore Sathyaprakash\textsuperscript{19}, Nicola Serra\textsuperscript{57} (Convenors)

Beyond the Standard Model: Gian F. Giudice\textsuperscript{20}, Paris Spighics\textsuperscript{40,52} (Conveners)
Juan Alcaraz Maestre\textsuperscript{53}, Caterina Doglioni\textsuperscript{49}, Gaia Lanfranchi\textsuperscript{54}, Monica D’Onofrio\textsuperscript{43},
Matthew McCullough\textsuperscript{53}, Gitad Perez\textsuperscript{44}, Philipp Roloff\textsuperscript{55}, Veronica Sanz\textsuperscript{56}, Andreas Weiler\textsuperscript{44},
Andrea Wolter\textsuperscript{44,45,66} (Convenors)

Dark Matter and Dark Sector: Shojo Asai\textsuperscript{56}, Marcela Carena\textsuperscript{57} (Convenors)
Babette Dobrich\textsuperscript{50}, Caterina Doglioni\textsuperscript{51}, Joerg Jaeckel\textsuperscript{28}, Gordan Knjiga\textsuperscript{57},
Jocelyn Monroe\textsuperscript{48}, Konstantinos Petridis\textsuperscript{59}, Christoph Weniger\textsuperscript{50} (Scientific Secretaries/Convenors)

Accelerator Science and Technology: Caterina Biscari\textsuperscript{61}, Leonid Rivkin\textsuperscript{62} (Convenors)
Philip Burrows\textsuperscript{26}, Frank Zimmermann\textsuperscript{20} (Scientific Secretaries)
Michael Benedik\textsuperscript{20}, Pierluigi Campolina\textsuperscript{64}, Edda Gschwendtner\textsuperscript{38}, Erik Jensen\textsuperscript{20}, Mike Lamont\textsuperscript{20},
Wim Leemans\textsuperscript{20}, Luca Rossi\textsuperscript{20}, Daniel Schulte\textsuperscript{28}, Mike Seidel\textsuperscript{62}, Vladimir Shiltsev\textsuperscript{63},
Steinar Stapnes\textsuperscript{20}, Akira Yamamoto\textsuperscript{20,64} (Convenors)

Instrumentation and Computing: Xinchou Lou\textsuperscript{65}, Brigitte Vachon\textsuperscript{66} (Convenors)
Roger Jones\textsuperscript{67}, Emilia Leogrande\textsuperscript{20} (Scientific Secretaries)
Ian Bird\textsuperscript{20}, Simone Campana\textsuperscript{20}, Ariella Cattai\textsuperscript{20}, Didier Contardo\textsuperscript{68}, Cinzia Da Vi\textsuperscript{69}, Francesco Forti\textsuperscript{70},
Maria Giron\textsuperscript{69}, Matthias Kasemann\textsuperscript{20}, Lucie Linssen\textsuperscript{69}, Felix Sefkow\textsuperscript{20}, Graeme Stewart\textsuperscript{20} (Convenors)

Editors: Halina Abramowicz\textsuperscript{21}, Roger Forty\textsuperscript{20}, and the Convenors
The Briefing Book as input to ESPPU

Physics Briefing Book
Input for the European Strategy for Particle Physics Update 2020

11 Instrumentation and Computing
11.1 Particle physics instrumentation
11.2 Computing and software for particle physics
11.3 Interplay between instrumentation and computing
11.4 Developing and preserving knowledge and expertise
11.5 Summary of key points
Computing and software – challenges

- **Cost**: Predictability of hardware cost has become difficult as the price trends are driven by commercial markets and the increased performance that was seen for the same amount of money due to Moore’s Law no longer hold.

- **Hardware evolution**: Computing resources are nowadays becoming increasingly heterogeneous, placing requirements on both the code base and on the experiment computing systems.

- **Data storage, management and preservation**: Data storage needs of future projects exceed the predicted capacity and affordability of the current data storage and management model. The current model also does not provide the adaptability required to efficiently exploit heterogeneous compute infrastructures. There is also an uncertainty in the future availability of tape storage which could have a significant impact on the data storage capacity available to experiments. The tape market now depends on a single manufacturer, increasing the risk of market collapse. Data preservation (reproducibility, accessibility) and Open access both lack consistent policies in the experiments and across the funding agencies. This must be addressed urgently, and new proposals must include data management plans. Open access is also typically not explicitly funded although expected by many funding agencies.
Computing and software – challenges

Software challenges: The large volume of legacy software used in particle physics requires important improvements in memory usage and throughput. The software must also be upgraded to make the most efficient use of different computing platforms, e.g. to take advantage of increased processing power from accelerators and GPU use, tuning on CPUs, etc. The current legacy software also offers many opportunities for algorithmic enhancement, and should also be upgraded to take advantage of developments in machine learning and AI applications [ID5].

Increasing skills gap between early career physicists and the profile needed for programming on new compute architectures [ID114] necessitates the needs for professional training, development and career opportunities for computing-software professionals [ID5, ID34, ID53, ID59, ID68, ID69, ID114, ID127, ID150].

As approved projects enter into operation and future projects are being developed, it is clear that there will be unprecedented pressure on computing resources availability for particle physics in the 2020s. Past experience has shown that development time-scales are long, and therefore, these challenges must be addressed now to maximize the scientific outputs of tomorrow.
Computing and software – R&D

To meet the challenges, the particle physics community must invest in more skilled developers, and carry out carefully planned and coordinated R&D programs that will

- Adopt new hardware
- Take advantage of industrial trends and emerging technologies,
- Improve the software
- Position HEP computing and software for revolutionary and disruptive technologies

Nature of the R&D: a balanced portfolio that includes activities targeted at the immediate needs of running experiments, activities focused on addressing the needs of future experiments, and pure R&D activities that anticipate the use of disruptive technologies
Computing and software – R&D

- **Tools and applications development** for effective use of capacity provided by heterogeneous tools.
- **Application and data access tools development** at HPC facilities and using commercial Clouds, which can deliver extra capacity to particle physics.
- **Software R&D**, which is expected to provide one of the biggest opportunities to address the needs of the particle physics community. For the HL-LHC experiments, the software and the data formats will be improved to allow for more efficient processing and storage. Common software framework, turnkey stacks can be developed through the inter-experiment collaboration for the HL-LHC and future collider projects.
- **Hardware infrastructure development and support**. The particle physics community should seize the opportunity to be involved in the planning stage of future multidisciplinary research infrastructures, such as large HPC systems and Clouds.
- **Preparation and follow-up for the innovative, new technologies** on the horizon, such as quantum computing and neuromorphic computing.
Computing and software – Synergies and opportunities

In order to provide a sustainable future for software and computing in the field, synergies with the experiments, other disciplines and with industry are. Having led the field of data intensive science, driven by the needs of the LHC and others, the subject must transition to being an important player in a wider ecosystem.

- **Internal synergies** are illustrated by the number of submissions that highlight the intention to leverage computing and software developments from the LHC. The diversity of development projects in the various LHC experiments was useful to prototype various ideas, but the transition to the use of common tools now the experiments are mature must continue to reduce the operational and development

- **Synergies exist with other science disciplines.** With new big astronomy projects, ...

- **Synergies also exist with the commercial world** between commercial Cloud providers and individual experiments, ...
Computing and software – Interplay between instrumentation and computing

The requirement of efficiency to extract the maximum physics potential from the available computing resources requires an increasingly “holistic” approach to the design of experiments and their associated computing and software systems.

- **detector design decisions** design & evaluation of the detector design must include the computing burden as a metric
- It would be desirable that projects view computing and software responsibilities on an equal footing with sub-detector responsibility.
- **Online processing** moving more complex algorithmic processing into the online systems; use of detector electronics to do processing and data reduction at an early stage; offline-like reconstruction is increasingly possible in online triggering systems, with further reductions in the offline data volume without loss of physics performance, …
Computing and software – Developing and preserving knowledge and expertise

Human factors need to be carefully considered; an adequate level of development and preservation of expertise in computing-related R&D activities; a major change in paradigm in the community about computing

- **Recruitment** it is essential to attract brilliant young physicists to the interesting challenges of computing-related R&D
- **Training** investment in the specialized education of young physicists in the form of schools in scientific computing
- **Expertise preservation and career opportunities** recognition of these research areas in universities’ hiring plans, possibly exploiting synergies and potential interests with engineering and computing science departments, specialized and attractive grants for computing R&D, as well as prizes recognizing computing scientists, …
In the scope of EPPSU and the Briefing Book as input to EPPSU:

- Computing & Software is part of the input to EPPSU
- HEP Computing & Software is vital to the success of particle physics
- Many challenges and opportunities for HEP Computing & Software
- Place Computing & Software at the right level — planning-R&D-funding,…
- Talent recruitment, professional development and career path need real enhancement and investment
- Well organized/coordinated efforts to improve efficiency are critical
- Interplay with detector-DAQ — to be even smarter to reach the goals
- A balanced portfolio of R&D should be supported
Additional Slides
Computing – Panel Discussion  

Knowledge, training, career

- What key area(s) of knowledge/expertise in community need(s) to be further developed?
- How to attract and retain the best and the brightest to the challenges of HEP computing (within HEP, from other research fields, from industry)?
- What initiatives already exist to train new experts?
  - How effective are these initiatives?
  - What new initiatives could be considered?
- How can the profile, visibility and employment perspectives of HEP computing scientists be improved?
Computing – Panel Discussion

HEP Computing evolution

• How should HEP computing evolve in order to support future scientific programs and their specific needs?
  - E.g. issues related to this evolution include: cost associated with CPU/storage, data management plan, data format optimization, policy viz computing cost and commitments, how to ensure efficient use of different types of resources (e.g. heterogenous, exascale, etc.) available in the future, etc...

• What areas of computing R&D activities should the community be involved in, at what level of efforts, and on what timescale?
  - Use/development of emerging technologies (e.g. quantum computing, different accelerators (GPU, FPGAs))?
  - Community involvement in the design/development of future exascale computer systems?
  - Learning from advances made in other fields and/or industry (e.g SKA, ...)
  - Work related to issues of OpenAccess, OpenData, data preservation, and analysis preservation.
  - etc...
• How to best coordinate computing R&D in particle physics?
  - within Europe and abroad?
  - across different disciplines (astroparticle, neutrino, cosmology...)?

• How to fund different types of computing R&D programs?

• What kind of resources can be shared between institutions and laboratories, and how?
Computing – R&D Services Ecosystem

There is an opportunity to leverage commonality across HEP and beyond. This is happening already. Compromise between experiment specific and common solutions.

Compromise in adopting products from open source community projects and in-house development.

Openness and collaboration are the key. Watch for sustainability!

Common access layers to HPC and Clouds.