Future experiments and their impact on computing
Future experiments and their impact on computing
Future experiments and their impact on computing

Computing and their impact on future experiments
nuclear & particle experiments & myself
nuclear & particle experiments & myself
nuclear & particle experiments & myself
The days as a PhD student!
(1995-1999)
The days as a PhD student!
(1995-1999)
The days as a PhD student!
(1995-1999)
The days as a PhD student!
(1995-1999)
The days as a PhD student! (1995-1999)
The days as a PhD student!
(1995-1999)
Physics
Detector
Feature extraction
Online computing
GRID computing
Data interpretation
“If it was easy, it would have been studied before!”
“If it was easy, it would have been studied before!”

Exotic hadronic matter

“the holy grail of QCD”

(PANDA, BESIII, BELLE2, GlueX, Alice, ...)
Exp.&Theory: “Where are they?”

- tiny production cross sections
- huge background signals
- ambiguities in interpretation
- systematic analyses
- non-perturbative approaches
- Lattice calculations

“If it was easy, it would have been studied before!”

Exotic hadronic matter

“the holy grail of QCD”

(PANDA, BESIII, BELLE2, GlueX, Alice, ...)

\( \bar{p}p \rightarrow 3\pi^0 \)
"If it was easy, it would have been studied before!"

Quark Gluon Plasma

Phase Diagram of Strongly Interacting Matter
“If it was easy, it would have been studied before!”

Quark Gluon Plasma

Phase Diagram of Strongly Interacting Matter

(CBM, Alice, STAR, ...)
“If it was easy, it would have been studied before!”

Quark Gluon Plasma

Phase Diagram of Strongly Interacting Matter

Open charm:

Typical signal multiplicities: \(O(10^{-6})\)

“Needle in the haystack!”

(CBM, Alice, STAR, ...)

Volker Friese (CBM)
Experiments aim to cover a broad physics program.

Experiments need to become capable and flexible to accommodate versality.

Not one “golden” channel.

Era of large-scale facilities and huge collaborative efforts.

Versatile experiments
Challenge

- Required reduction factor: $\frac{1}{1000}$ (all triggers in total)
- e.g. 50 algorithms with a factor of $\frac{1}{50000}$ in average

Events/Data acquired by DAQ (temporarily buffered)

Software Trigger Algorithms

“Trickle” of events stored on disc

Required: online reduction by $\sim 1000$ with $>50$ algorithms

Klaus Goetzen, GSI
Trigger-less Data Acquisition

continuous data sampling with self-triggered detector
front-end ---> flexible event selection
### PANDA online computing

**Online algorithms require track & kinematic fitting, particle ID, etc.**

### Physics Report

<table>
<thead>
<tr>
<th>Channel</th>
<th>TRK</th>
<th>NEUT</th>
<th>Excl.</th>
<th>mult</th>
<th>PID</th>
<th>p</th>
<th>E</th>
<th>ang.</th>
<th>inv M</th>
<th>dist cut</th>
<th>veto</th>
<th>4C</th>
<th>Vtx C</th>
<th>Mass C</th>
<th>Sig Eff [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>J/psi pi+ pi-</td>
<td>4</td>
<td>0</td>
<td>x</td>
<td></td>
<td>e, pi</td>
<td>p</td>
<td>E</td>
<td></td>
<td></td>
<td>x</td>
<td>J/psi pi+ pi-</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J/psi pi0 pi0</td>
<td>2</td>
<td>4</td>
<td>x</td>
<td></td>
<td>e</td>
<td>g</td>
<td>x</td>
<td>J/psi eta pi0</td>
<td>J/psi</td>
<td>17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>chi_c1,2 gam</td>
<td>2</td>
<td>2</td>
<td>x</td>
<td></td>
<td>e</td>
<td>g</td>
<td>x</td>
<td></td>
<td></td>
<td>J/psi</td>
<td>J/psi</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J/psi gam</td>
<td>2</td>
<td>1</td>
<td>x</td>
<td></td>
<td>e</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td>J/psi</td>
<td>J/psi</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>J/psi eta</td>
<td>2</td>
<td>2</td>
<td>x</td>
<td></td>
<td>e</td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td>J/psi</td>
<td>J/psi</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>h_c -&gt; 3gam</td>
<td>0</td>
<td>3</td>
<td>x</td>
<td>3n</td>
<td>g</td>
<td>h_c</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>h_c -&gt; 2phi gam</td>
<td>4</td>
<td>1</td>
<td>x</td>
<td></td>
<td>K</td>
<td>g</td>
<td>x</td>
<td>pi0</td>
<td></td>
<td></td>
<td></td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D+ D-</td>
<td>6</td>
<td>0</td>
<td>x</td>
<td></td>
<td>?</td>
<td>D</td>
<td>x</td>
<td>z(D)</td>
<td>x</td>
<td>D+D-</td>
<td>D+D-</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D*+ D*-</td>
<td>6</td>
<td>0</td>
<td>x</td>
<td></td>
<td>?</td>
<td>D*</td>
<td>x</td>
<td>z(D*)</td>
<td>x</td>
<td>D*+D*</td>
<td>D*+D*</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>eta_c1 eta</td>
<td>2</td>
<td>7</td>
<td>x</td>
<td></td>
<td>e</td>
<td></td>
<td>x</td>
<td>&lt;1 comb/ev</td>
<td></td>
<td></td>
<td></td>
<td>chi, pi0, eta</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>eta_c1 eta</td>
<td>4</td>
<td>8</td>
<td>x</td>
<td></td>
<td>K, pi</td>
<td></td>
<td>x</td>
<td>&gt;1 comb/ev</td>
<td></td>
<td></td>
<td></td>
<td>K pi, D0, D0*, eta, pi0</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J/psi omega</td>
<td>4</td>
<td>2</td>
<td>x</td>
<td></td>
<td>e, pi</td>
<td></td>
<td>x</td>
<td>&lt;1 comb/ev</td>
<td></td>
<td></td>
<td>J/psi pi+pi-</td>
<td>J/psi, pi0</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>f2(2230) -&gt; 2phi</td>
<td>4</td>
<td>0</td>
<td>x</td>
<td></td>
<td>K</td>
<td></td>
<td>x</td>
<td></td>
<td>phi</td>
<td></td>
<td></td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ds Ds(2317)</td>
<td>3</td>
<td>0</td>
<td>K, pi</td>
<td></td>
<td></td>
<td>K</td>
<td>x</td>
<td></td>
<td>Ds, phi</td>
<td></td>
<td></td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Xi- Xi+ pi0</td>
<td>6</td>
<td>2</td>
<td>x</td>
<td></td>
<td>p, pi</td>
<td>g</td>
<td>x</td>
<td>d(IP-Xi)</td>
<td>&gt;1 comb/ev</td>
<td>Lam, Xi-+ Xi Xi pi0</td>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lam Lam</td>
<td>6</td>
<td>0</td>
<td>x</td>
<td></td>
<td>p, pi</td>
<td></td>
<td>x</td>
<td>d(IP-Xi)</td>
<td></td>
<td>Lam, Lam pi</td>
<td>19</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Selection criteria used in the Physics Report Analyses**
  - **no multiplicity cuts**
  - **PID!**
  - **few kinematic cuts (except mass)**
  - **a lot of fitting!**
10^7 /sec.

kinematic reco

10^4 events/sec.

Distributed computing?
Hell yes, heavily! But...
Which tool for what job?
Software development?
Smart algorithms?

feature extraction

track finding

event ordering

vertex fitting

10^7 /sec.

10^4 events/sec.

10^7 /sec.

10^4 events/sec.

PANDA 8

CN/ATCA

Status


track fitting

event ordering

particle ID

track fitting

kinematic reco

Distributed computing?
Hell yes, heavily! But...
Which tool for what job?
Software development?
Smart algorithms?
Moore’s law and its limitations
Moore’s law and its limitations

Let's admit! We were spoiled by the frequency-scaling era

Cores don’t get faster, but more parallel! Requires new approaches!

Even then, not all jobs are easy parallelizable (Amdahl’s law)
Moore’s law and its limitations

Let's admit! We were spoiled by the frequency-scaling era.

Cores don't get faster, but more parallel! Requires new approaches!

Even then, not all jobs are easy parallelizable (Amdahl’s law)

Long live innovation!!

Try to find the most efficient and cost-effective solution to your problem...

... with the right tool for the job!
“Intelligence” in practice: GPUPWA

Resonance searches with BESIII data

Partial-wave analyses for a **huge** data samples are extremely time consuming

Innovative idea! Use SIMT capabilities on cheap graphic cards

Massive parallel floating point operations and lookup tables ideally suited for the fitting problem

\[ \mathcal{L} \propto \prod_{i=1}^{n} \frac{I(\Omega)}{\eta(\Omega) I(\Omega) d\Omega} \]

Likelihood, given \( n \) data points at \( \Omega \)

Product over data events

Normalisation integral over phase space

Detection efficiency

\[ \prod_{i=1}^{n} I(\Omega) \]

Normalisation integral over phase space

\[ \eta(\Omega) I(\Omega) d\Omega \]

Detection efficiency

\[ J/\psi \rightarrow \gamma K^+K^- \]

\[ \times 150 \text{ Speedup} \]
### Track Finder+Fitting for PANDA Central Tracker

<table>
<thead>
<tr>
<th>Method</th>
<th>CPU (ms)</th>
<th>GPU (ms)</th>
<th>Improvement</th>
<th>Occupancy</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total runtime</td>
<td>117138</td>
<td>590</td>
<td><strong>199</strong></td>
<td></td>
<td><a href="https://example.com">[2]</a> runs (num_points) times</td>
</tr>
<tr>
<td><code>startUp()</code></td>
<td>0.25</td>
<td>0.0122</td>
<td>20</td>
<td>2%</td>
<td>runs (num_points) times</td>
</tr>
<tr>
<td><code>setOrigin()</code></td>
<td>0.25</td>
<td>0.0119</td>
<td>21</td>
<td>25%</td>
<td>runs (num_points) times</td>
</tr>
<tr>
<td>Clear Hough and Peaks (memset on GPU)</td>
<td>3</td>
<td>0.0463</td>
<td>65</td>
<td>100%</td>
<td>runs (num_points) times</td>
</tr>
<tr>
<td><code>conformalAndHough()</code></td>
<td>73</td>
<td>0.8363</td>
<td>87</td>
<td>25%</td>
<td>runs (num_points) times</td>
</tr>
<tr>
<td><code>findPeaksInHoughSpace()</code></td>
<td>51</td>
<td>0.497</td>
<td>103</td>
<td>100%</td>
<td>runs (num_points) times</td>
</tr>
<tr>
<td><code>findDoublePointPeaksInHoughSpace()</code></td>
<td>4</td>
<td>0.0645</td>
<td>62</td>
<td>100%</td>
<td>runs (num_points) times</td>
</tr>
<tr>
<td><code>collectPoints()</code></td>
<td>4</td>
<td>0.066</td>
<td>61</td>
<td>100%</td>
<td>runs (num_points) times</td>
</tr>
<tr>
<td><code>sortPeaks()</code></td>
<td>0.25</td>
<td>0.0368</td>
<td>7</td>
<td>2%</td>
<td>runs (num_points) times</td>
</tr>
<tr>
<td><code>resetOrigin()</code></td>
<td>0.25</td>
<td>0.0121</td>
<td>21</td>
<td>25%</td>
<td>runs (num_points) times</td>
</tr>
<tr>
<td><code>countPointsCloseToTrackAndTrackParams()</code></td>
<td>22444</td>
<td>0.9581</td>
<td>23426</td>
<td>33%</td>
<td>runs once</td>
</tr>
<tr>
<td><code>collectSimilarTracks()</code></td>
<td>4</td>
<td>2.3506</td>
<td>2</td>
<td>67%</td>
<td>runs once</td>
</tr>
<tr>
<td><code>collectSimilarTracks2()</code></td>
<td></td>
<td></td>
<td></td>
<td>2%</td>
<td>runs once</td>
</tr>
<tr>
<td><code>getPointsOnTrack()</code></td>
<td>0.25</td>
<td>0.0187</td>
<td>13</td>
<td>33%</td>
<td>runs (num_tracks) times</td>
</tr>
<tr>
<td><code>nullifyPointsOfThisTrack()</code></td>
<td>0.25</td>
<td>0.0106</td>
<td>24</td>
<td>33%</td>
<td>runs (num_tracks) times</td>
</tr>
<tr>
<td>Clear Hough space (memset on GPU)</td>
<td>2</td>
<td>0.0024</td>
<td>833</td>
<td>100%</td>
<td>runs (num_tracks) times</td>
</tr>
<tr>
<td><code>secondHough()</code></td>
<td>0.25</td>
<td>0.0734</td>
<td>3</td>
<td>4%</td>
<td>runs (num_tracks) times</td>
</tr>
<tr>
<td><code>findPeaksInHoughSpaceAgain()</code></td>
<td>290</td>
<td>0.2373</td>
<td>1222</td>
<td>66%</td>
<td>runs (num_tracks) times</td>
</tr>
<tr>
<td><code>collectTracks()</code></td>
<td>0.25</td>
<td>0.0368</td>
<td>7</td>
<td>2%</td>
<td>runs (num_tracks) times</td>
</tr>
</tbody>
</table>

**M. Al-Turany**

**this afternoon @ 5:25 @ event processing**

NVidia GeForce 480 vs Intel Xeon CPU W3505@2.53 GHz
General Purpose FPGA Compute Node

High Performance and scalable CN for FEE

5 FPGAs: Virtex-4 FX60

Lots of buffer memory: 10Gb DDR2 RAM

Flexible I/O connectivity ~32 Gbps bandwidth

2 PowerPC for SC

HP backplane interconnection: ATCA compliant!

University of Giessen, Germany
IHEP, Beijing, China
Consolidating the reconstruction efforts

- **Uni-Frankfurt/FIAS:** Vector classes, GPU implementation
- **GSI:** Algorithms development, Many-core optimization
- **OpenLab (CERN):** Many-core optimization, Benchmarking
- **HEPHY (Vienna)/Uni-Gjovik:** Kalman Filter track fit, Kalman Filter vertex fit
- **Intel:** Ct implementation, Many-core optimization, Benchmarking

**Common Reconstruction Package**

**CBM (FAIR/GSI)**

**ALICE (CERN)**

**PANDA (FAIR/GSI)**

**STAR (BNL)**

Volker Friese, Ivan Kisel (GSI)
Offline software developments anno 2012

“Don’t re-invent the wheel”

Base on LHC code and experiences

Re-use existing and well-tested code

Framework, modularity, virtualization & versatility
Example of a large-scale software project

**ROOT**
- Since 1995

**FairRoot**
- M. Al-Turany, F. Uhlig, R. Karabowicz, D. Bertini
- Since 2001

**PandaRoot**
- Stefano Spataro
- Since 2003

**Panda Code**
- STT, TOF, EMC, MUO, MVD, DIRC, FTS, GEM
- DPM, EvtGen, ASCII, Pythia
- Hit Producers (digitizers, track finding)
- Dipole Map, Solenoid Map, const. field

**Run Manager**
- Tasks, Magnetic Field, Event Generator

**Virtual MC**
- G3VMC, G4VMC, Geant3, Geant4

**RTDatabase**
- Root files, Hits, Digits, Tracks

**IO Manager**
- TSQLServer

**Event Display**
- Detector base, Application, Cuts, processes

**Track propagation**

**Geometry**
- Since 1995

**Root files**
- Oracle, MySQL, Postgresql

**Virtual MC**
- Since 1994

**CBM**
- CbmRoot, R3BRoot, MPDRoot, ASYEOSRoot, EICRoot

**Since 2005**

**Since 2006**

**Since 2009**

**Since 2010**

**Since 2011**

**Since 2011**
Offline software developments anno 2012

“Learn along the way”

Early deployment, continuous involvement of “users”

Open environment and collaborative tools
Offline software developments anno 2012

“MC studies & data”

Driven by detailed MC studies...

... and by prototype tests for validation and code testing/optimization/tuning
Offline software developments anno 2012

“Innovative ideas”
(very very incomplete list!)
Offline software developments anno 2012

“Innovative ideas”
(very very incomplete list!)

“Framework and versatility”

“Simulating details”

“Towards many cores”

“Software trigger”

“Unified PWA”

FairDBInterface

Denis Bertini, Mohammad Babai

Genfit

Pavia group

FairGeane

Tobias Stockmanns (poster this afternoon)

Step2Root

TUM group (poster this afternoon)

FairLink

Tobias Stockmanns, Mohammad Al-Turany

FairCuda

Mohammad Al-Turany, talk at 5:25

Time-based framework

PAWIAN

RUB+TUM groups
GRID/Cloud computing for FAIR

PANDAGrid

computing center for high-energy, hadron, nuclear, and atomic physics

serve >20 collaborations

FAIR computing 2018

CBM
PANDA
NuSTAR
APPA
LQCD
300,000 cores + Grid sites
40 PB disk
40 PB archive

Kilian Schwarz
Radek Karabowicz, Rene Rosdall, et al.

Mainz
Dubna
Orsay
Data, data, and even more data
Data, data, and even more data

“Waterfall”
Data, data, and even more data
Data, data, and even more data

How do we manage, preserve and extract knowledge from the overwhelming flood of data efficiently, reliably and sustainably?

(yesterday: David South, Jacek Becla, ...)
Data Processing,
Publishing, and Mining

Edwin Valentijn et al.
(Astrowise, Target)
“Waterfall” forward chaining “tier” architecture driven by raw data process in pipeline operators push data results in releases static archive raw data is obsolete

Edwin Valentijn et al. (Astrowise, Target)
Data Processing, Publishing, and Mining

**“Waterfall”**
- forward chaining
- “tier” architecture
- driven by raw data
- process in pipeline
- operators push data
- results in releases
- static archive
- raw data is obsolete

**“Target”**
- backward chaining
- “target” architecture
- driven by user query
- process on-the-fly
- users pull data
- information system
- dynamic archive
- raw data is sacred

HEP (old style)

Astronomy

Edwin Valentijn et al. (Astrowise, Target)
Future experiments and their impact on computing
Future experiments and their impact on computing

The development of future experiments are based on the successes of LHC
Future experiments and their impact on computing

The development of future experiments are based on the successes of LHC

Demanding physics goals and versatile facilities count heavily on Moore’s law
Future experiments and their impact on computing

The development of future experiments are based on the successes of LHC

Demanding physics goals and versatile facilities count heavily on Moore’s law

Innovative approaches are pursued in this era of many cores & data mining
Future experiments and their impact on computing

The development of future experiments are based on the successes of LHC

Demanding physics goals and versatile facilities count heavily on Moore’s law

Innovative approaches are pursued in this era of many cores & data mining

.... with the aim to place the physics goals and researcher at the center
Future experiments and their impact on computing

The development of future experiments are based on the successes of LHC

Demanding physics goals and versatile facilities count heavily on Moore’s law

Innovative approaches are pursued in this era of many cores & data mining

.... with the aim to place the physics goals and researcher at the center