High performance computing activities in hadron spectroscopy at BESIII

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For BESIII collaboration
ACAT 2013, IHEP, Beijing

Linac

Storage ring

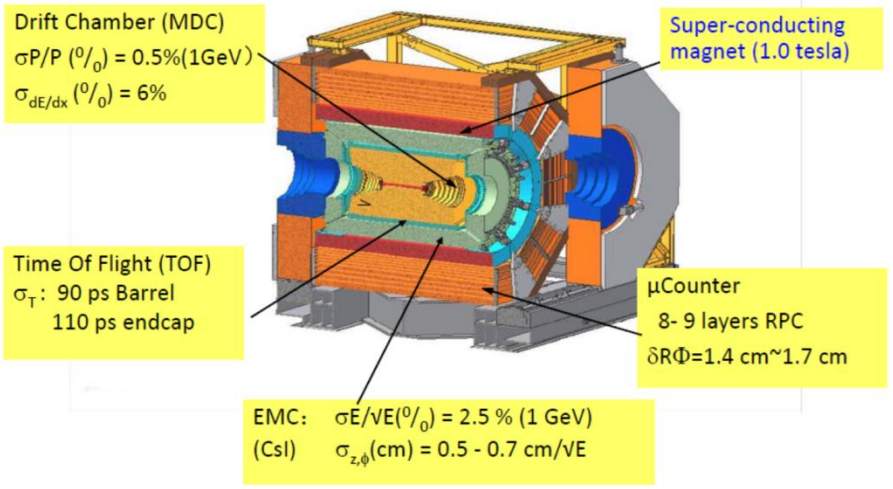
BES III
(Beijing Spectrometer)

Beam energy 1.0-2.3 GeV
Energy spread: 5.16×10^{-4}

Design luminosity
$1 \times 10^{33}/cm^2/s$ @ $\psi(3770)$

NIM A614, 345 (2010)

The BESIII Detector



BEPC II
(Beijing Electron-positron collider)
2004: started BEPCII upgrade,
BESIII construction
2008: test run
2009-now: BESIII physics run

Physics of τ-charm region

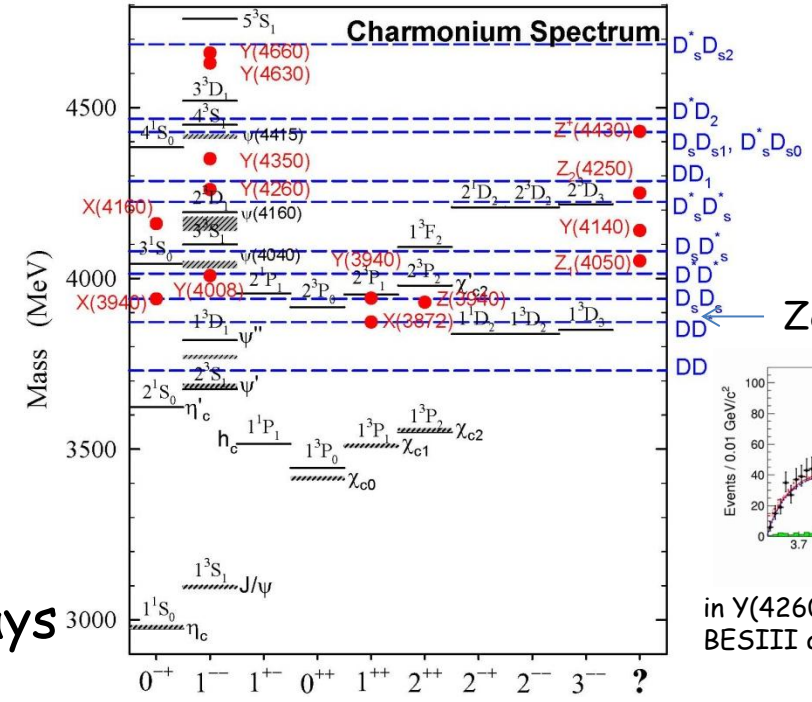
Charmonium physics:
- Spectroscopy
- transitions and decays

Light hadron physics:
- meson & baryon spectroscopy
- glueball & hybrid
- two-photon physics
- e.m. form factors of nucleon

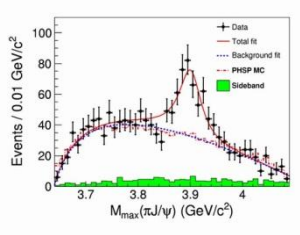
Open Charm physics:
- (semi)leptonic + hadronic decays
- decay constant, form factors
- CKM matrix: Vcd, Vcs
- D^0-D^0bar mixing and CP violation
- rare/forbidden decays

Tau physics:
- tau decays near threshold
- tau mass scan

…and many more.



Zc(3900)

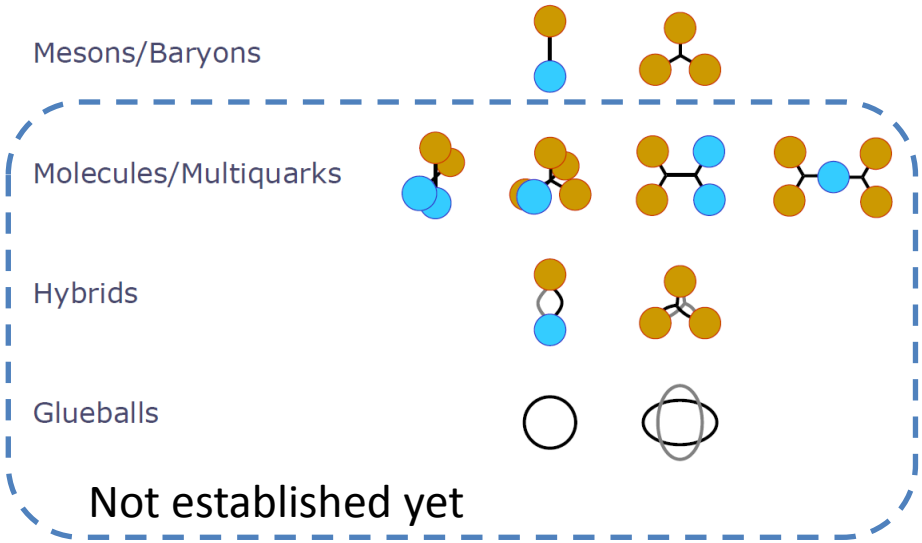


in Y(4260) decays
BESIII arxiv:1303.5949

	Previous data	BESIII present & future	Goal
J/ψ	BESII 58M	1.2 B 20* BESII	10 B
ψ'	CLEO: 28 M	0.5 B 20* CLEOc	3B
ψ"	CLEO: 0.8 /fb	2.9/fb 3.5*CLEOc	20 /fb
Above open charm threshold	CLEO: 0.6/fb @ ψ(4160)	2011: 0.4/fb @ ψ(4040) 2013: 1/fb@4260, 4360	5-10 /fb
R scan & Tau	BESII	2012: 12/pb@2.23,2.4,2.8,3.4 25/pb τ scan 2013, 2014: @4260, R scan, …	

World's largest samples

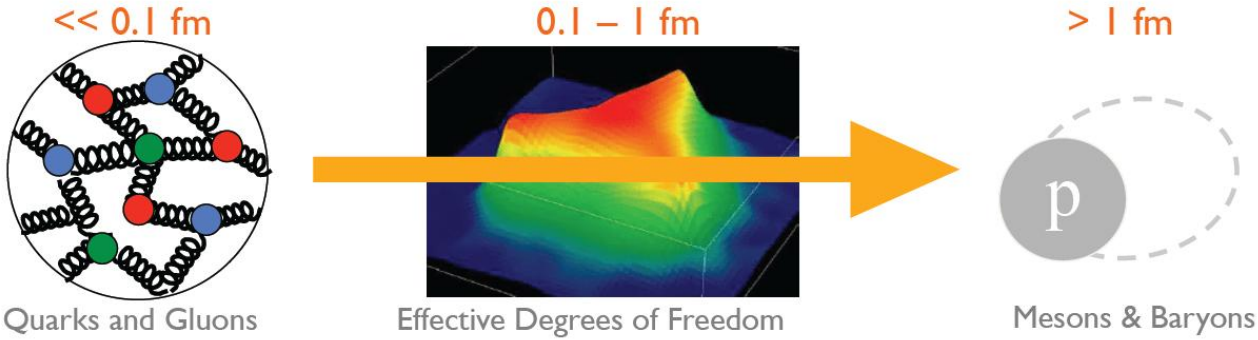
Hadron spectrum



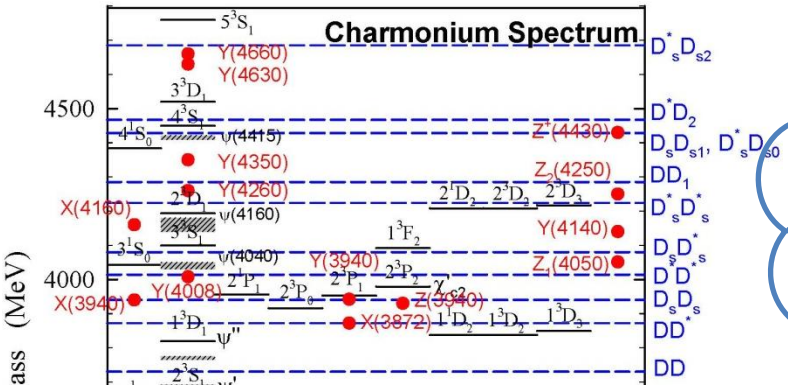
Continuous efforts in experiment and theory

- Hadron spectroscopy is a key tool to investigate QCD

- testing QCD in the confinement regime
- providing insights into the fundamental degrees of freedom



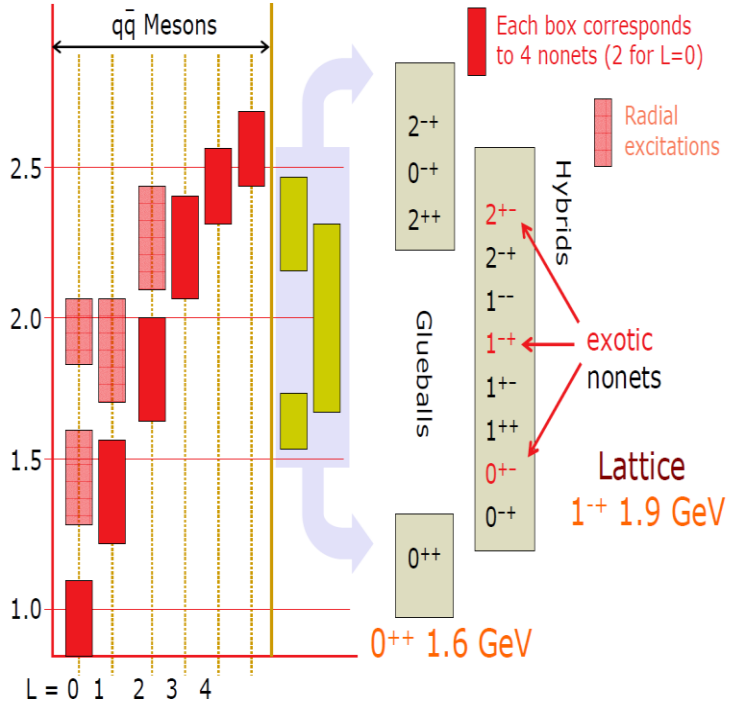
Where are the QCD exotics

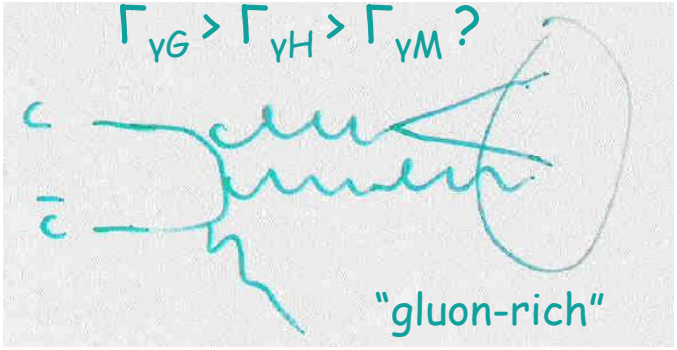


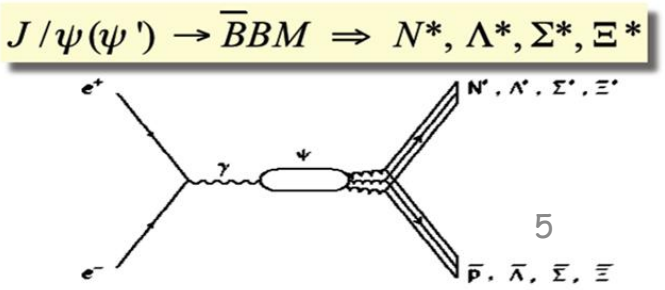
hybrids
molecules
hadrocharmonium
tetraquarks
threshold effects

Produce Y's directly
e+e- @4260/4360/…

BES provides some ideal hunting grounds *Power of high statistics*

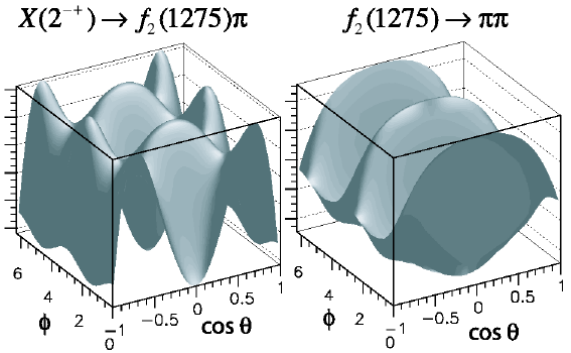






Partial wave analysis

"Holography"



Tasks:

- **Map out the resonances**
- **Systematic determination of resonance properties:**
  spin-parity,
  resonance parameters,
  production properties,
  decay properties, …
  - resonances tend to be broad and plentiful, leading to intricate interference patterns, or buried under a background in the same and in other waves.

Event-wise ML fit to all observables simultaneously

dynamic angular

$$\omega(\xi) \equiv \frac{d\sigma}{d\Phi} = \left| \sum_i c_i R_i B(p,q) Z(L) \right|^2$$

Event-wise efficiency correction

$$P(\xi) = \frac{\omega(\xi)\epsilon(\xi)}{\int \omega(\xi)\epsilon(\xi)}$$

Tools: PWA

- ✓ **Decompose to partial wave amplitudes**
- ✓ **Make full use of data**
- ✓ **Handle the interference**
- ✓ **Extract resonance properties with high sensitivity and accuracy**

How to run it faster

--in the era of $O(10^9)$ data sets

Computing bottlenecks in BES analysis

Algorithmic Analysis	Reduction: event selection, record useful information	Processing DST Bottle neck: **I/O, CPU**
Interactive Analysis	Final selection, plotting, "studies"	Processing Ntuple/Tree Bottle neck: **I/O**
Statistical Analysis	Extract physics	Fit (e.g. PWA, …) Bottle neck: **CPU**

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1, TAG-based preselection

$J/\psi(1S)$ $I^G(J^{PC}) = 0^-(1^{--})$ PDG2012

Mass $m = 3096.916 \pm 0.011$ MeV
Full width $\Gamma = 92.9 \pm 2.8$ keV (S = 1.1)
$\Gamma_{ee} = 5.55 \pm 0.14 \pm 0.02$ keV

$J/\psi(1S)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
…			
$\gamma f_2(1270)$	$(1.43 \pm 0.11) \times 10^{-3}$		1286
$\gamma f_0(1710) \to \gamma K\overline{K}$	$(8.5\ ^{+1.2}_{-0.9}) \times 10^{-4}$	S=1.2	1075
$\gamma f_0(1710) \to \gamma\pi\pi$	$(4.0 \pm 1.0) \times 10^{-4}$		–
$\gamma f_0(1710) \to \gamma\omega\omega$	$(3.1 \pm 1.0) \times 10^{-4}$		–

Phys. Rev. Lett. 110, 021601 (2013)
"the partial width of J/ψ radiatively decaying into the pure gauge scalar glueball is predicted to be 0.35(8) keV"

How to access the 0.1% events of interests efficiently

- Typically, in an exclusive analysis @BES
  - events of interest are **O(1/1000)** in a data set
  - Event size is **O(100) kB** for a hadronic event
- Column-wise accessing

Bes Offline Software System (Gaudi) has a large overhead

Column ~ Attribute of events

A_1	B_1	…	X_1
A_2	B_2	…	X_2
…	…	…	…
A_n	B_n	…	X_n

Row ~ Event

row-wise accessing

Read every entire row

column-wise accessing

Access every element of column_A

Selectively access column_B according A_i

Selectively access column …

Selectively access column_X

How to access the 0.1% events of interests efficiently

- TAG: meta-data (thumbnail) of an event

A small and flat event data model for pre-selection
run#, rec#, run type, EventFilter result, Multiplicity of tracks/photons/e/μ/π/K/p, …

- ✓ Every event has a TAG (very small, 1/400 of a reconstructed event--DST)
- ✓ Make cuts on TAG without opening DST
- ✓ Only access the selected DST events

Development

- BEAN: a light weighted ROOT-based analysis framework designed for the **BE**S3 **AN**alysis (by Dubuna group, BES3).
- Hadoop: (http://hadoop.apache.org) distributed computing + distributed storage with high performance, low cost

(CPU directly access data on the local disks)

  - Selective accessing requires better disk performance
  - A test-bed is set up in IHEP's computing center
  - 7 nodes, with 8 cores and 3T hard disk for each
  - "Ready-for-use" (no re-development)
- We successfully run BOSS and BEAN jobs on the test-bed.

Implementation

- TagCreator:
  - create TAG from DST
  - Like a normal analysis, loop all the events, get the information for pre-selection of all the events
- TagCuts: interface to user's pre-selection cuts

```
//In the begin
m_tagcuts->SetNGoodGamRange(2,10);
…
selector-> SetPreselection(m_tagcuts);
//In the event loop
m_tagCuts->IsAccepted(m_TTag)
…
```

Implementation

- Approach A:
  - individual TAG files (ROOT tree)→analysis TAG files →an index of selected events→access DST according to the index

Non-trivial for Hadoop

- high performance I/O for the tiny TAGs
- indexing the small tags
- locating the file/event on HDFS

- Approach B: (our current choice)
  - Append TAG as a branch of the "Event" tree in DST files.
  - Get the TAG for each event first to make a pre-selection
  - If pass, get the DST event

Performance

A typical case: event selection of $J/\psi \rightarrow K^+ K^- \pi^0$
K+, K-, N>=2 photon candidates,
(~1/1000 of the total events)
Kinematic fit of tracks and photons to the J/ψ with mass constraint of π^0

Loop a DST Data file (127223 events)

Tool	Timing result
BOSS	89.3 s
BEAN	26.0 s
BEAN TAG-based pre-selection	2.2 s

- BEAN analysis is much faster than BOSS.
- TAG-based pre-selection can improve the performance by O(10).
- I/O performance can be improved by tuning the settings and by pre-skimming the data files.

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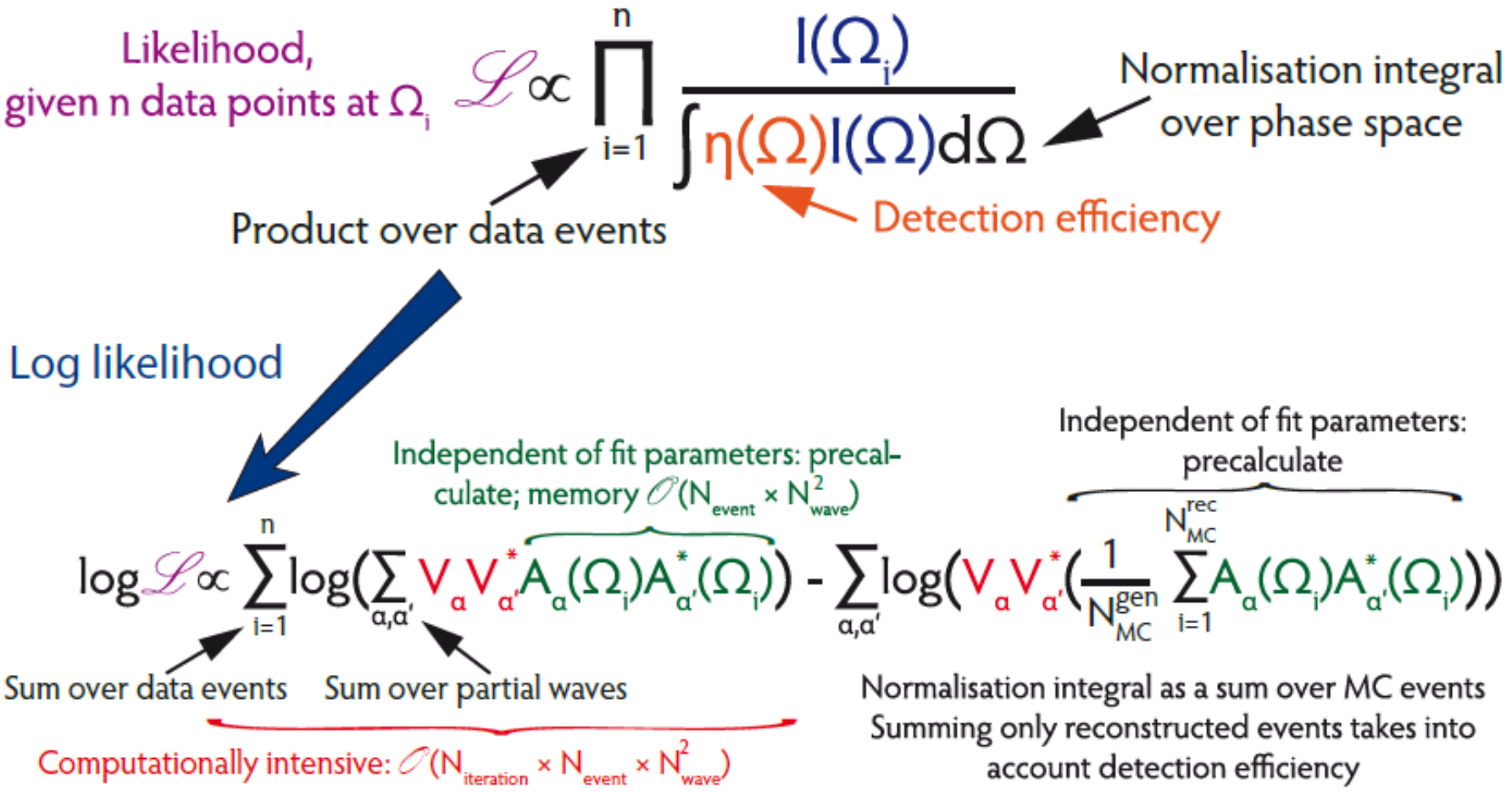
1, TAG-based preselection

2. GPUPWA

Likelihood calculation

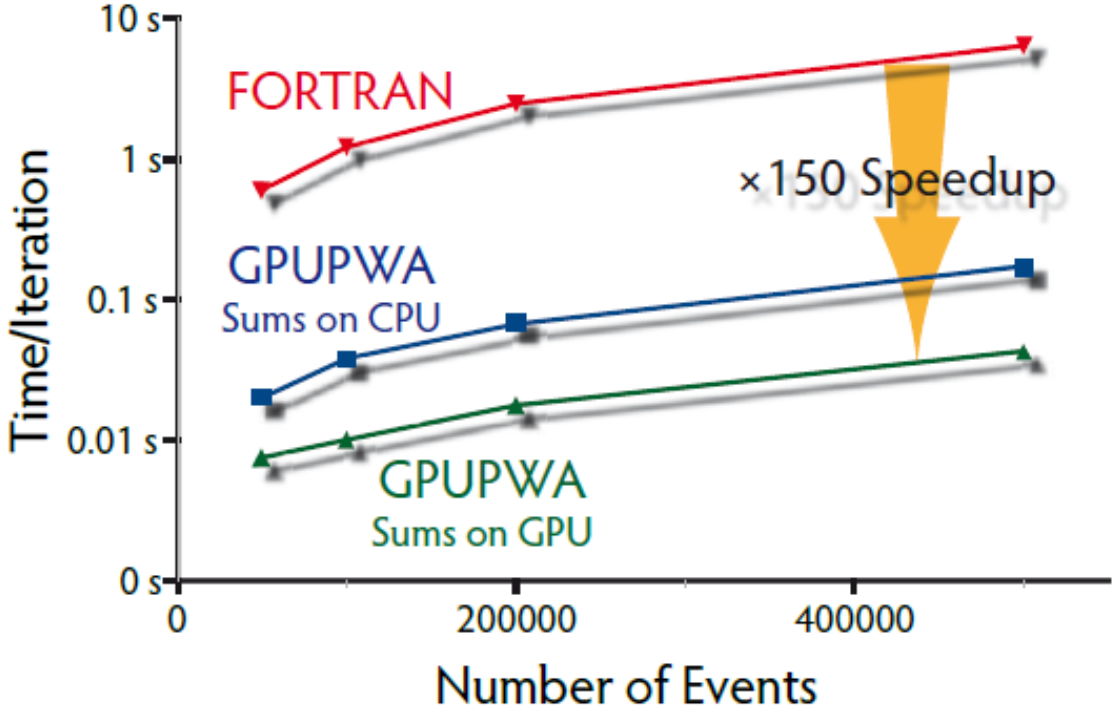


Data parallelism: do the calculation for every event simultaneously

GPUPWA

N. Berger, B.J. Liu and J.K. Wang, J.Phys.Conf.Ser., 219, 042031
http://gpupwa.sourceforge.net

OpenCL



Data parallelism in event-wise likelihood PWA fit

GPUPWA

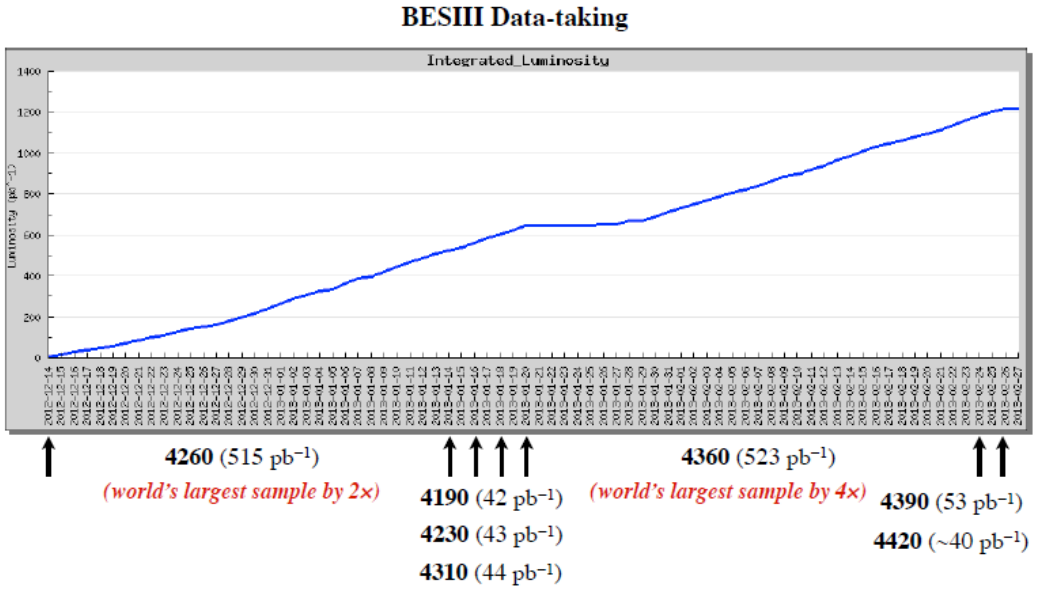
GPUPWA is our running framework

- Management of partial waves
- Interface to user defined amplitudes
- Interface to stream computing (OpenCL)
- GPU based tensor manipulation
- GPU based normalization integrals
- GPU based likelihoods
- GPU based analytic gradients
- Interface to ROOT::Minuit2 fitters
- Projections and plots using ROOT

- We build a cluster for BES3 PWA in computing center @IHEP
  (35 nodes X 4 GPUs, there will be an upgrade this year)
- Partial wave analysis of $J/\psi \rightarrow \gamma\eta\eta$, arXiv:1301.0053 to appear in PRD
- Spin-Parity Analysis of ppbar Mass Threshold Structure in J/psi and psi' Radiative Decays, Phys. Rev. Lett. 108, 112003 (2012)

Summary

- BESIII took 1.2 billion J/ψ events and 0.5 billion ψ' events.



Look forward to many new results from BESIII!

And we are right now collecting 3× more Y(4260) decays...

子曰 工欲善其事 必先利其器

When a craftsman wants to do a nice piece of work, he will always sharpen his tools first.
-- Confucius

Thank you