Does the EIC need a muon detector for effective quarkonium studies?

Detection configurations

- $J/\psi \rightarrow e^+e^-$: BR = (5.971 ± 0.032) %
  - $J/\psi \rightarrow e^+e^-\gamma$: BR = (8.8 ± 1.4) × 10^{-3} (intrinsic Bremsstrahlung
- $J/\psi \rightarrow \mu^+\mu^-$: BR = (5.961± 0.033) %

Upsilon:

- BR is the same for e^+e^- and $\mu^+\mu^-$ channels

Detection configurations

- **J/ψ → e^+e^-**
  - Typically different electron ID at low and high p_T
  - Low p_T: Time-of-Flight, Ring Imaging Cherenkov, Transition Radiation Detector, High-p_T: E-M callorimeter
  - **No absorber**
  - Mass resolution sensitive to detector material budget due to Bremsstrahlung (important for ϒ(2S) and ϒ(3S) separation)
  - Combinatorial background sensitive detector material budget due to $\gamma \rightarrow e^+e^-$ conversion (mostly at low-p_T)

Detection configurations

- **J/ψ → $\mu^+\mu^-$**
  - Main background: misidentified pions
  - Setup with or without absorber (impact on background level)
  - Mass resolution insensitive to detector material budget, typically sufficient for Υ(1S)/Υ(2S) and Υ(3S) separation.

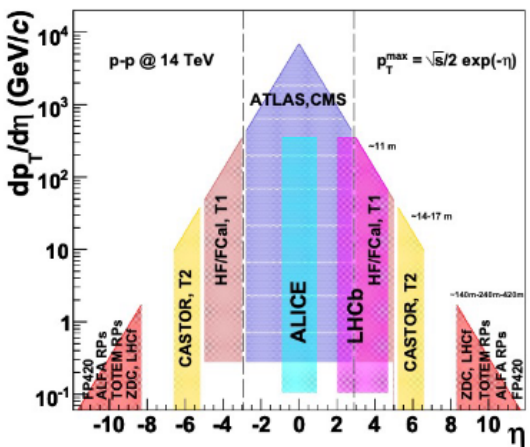
Example: LHC detectors

Quarkonium at LHC

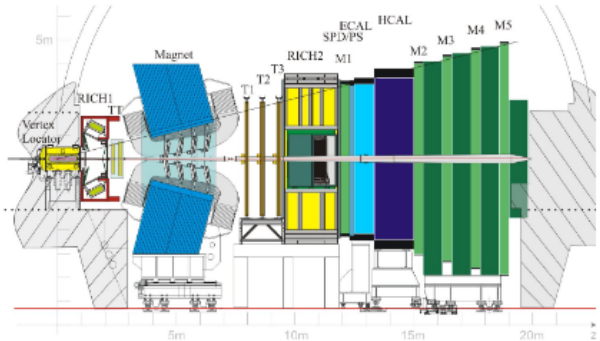
Li Xu, https://indico.cern.ch/event/1084752/contributions/4560675/attachments/2369997/4047563/LHC_Production_QaT22.pdf

- LHC energies: $\sqrt{s} = 2.76, 5, 7, 8, 13$ TeV
- Complementary kinematic ranges

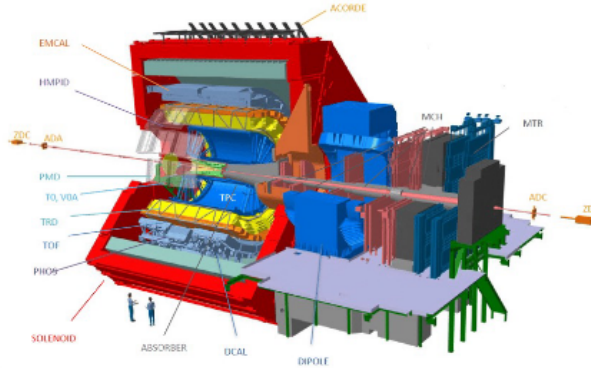
LHCb	forward-y	$2.0 < y < 4.5$	$\mu^+\mu^-$
ALICE	forward-y mid-y	$2.5 < y < 4.0$ $\|y\| < 0.9$	$\mu^+\mu^-$ e^+e^-
ATLAS	mid-y	$\|y\| < 2.0$	$\mu^+\mu^-$
CMS	mid-y	$\|y\| < 2.4$	$\mu^+\mu^-$



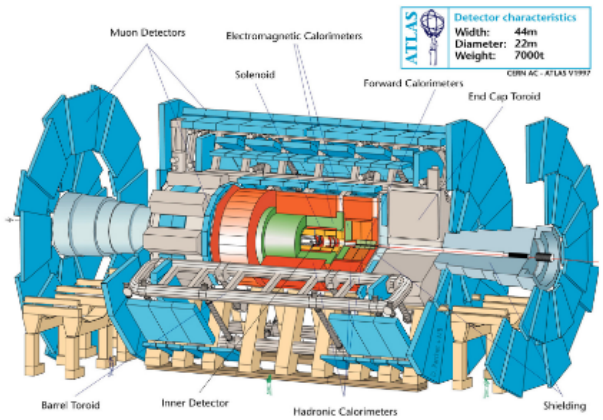
arXiv:0708.0551



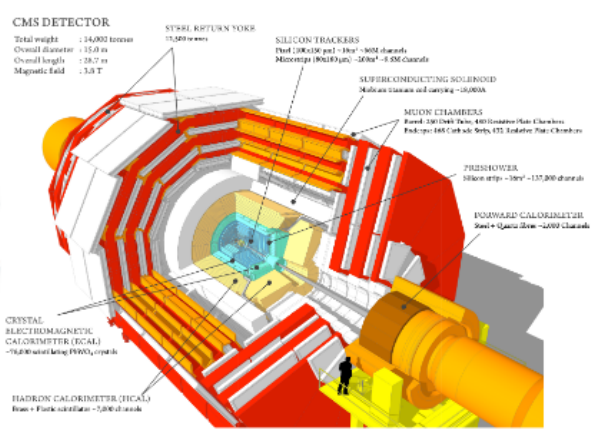
LHCb



ALICE

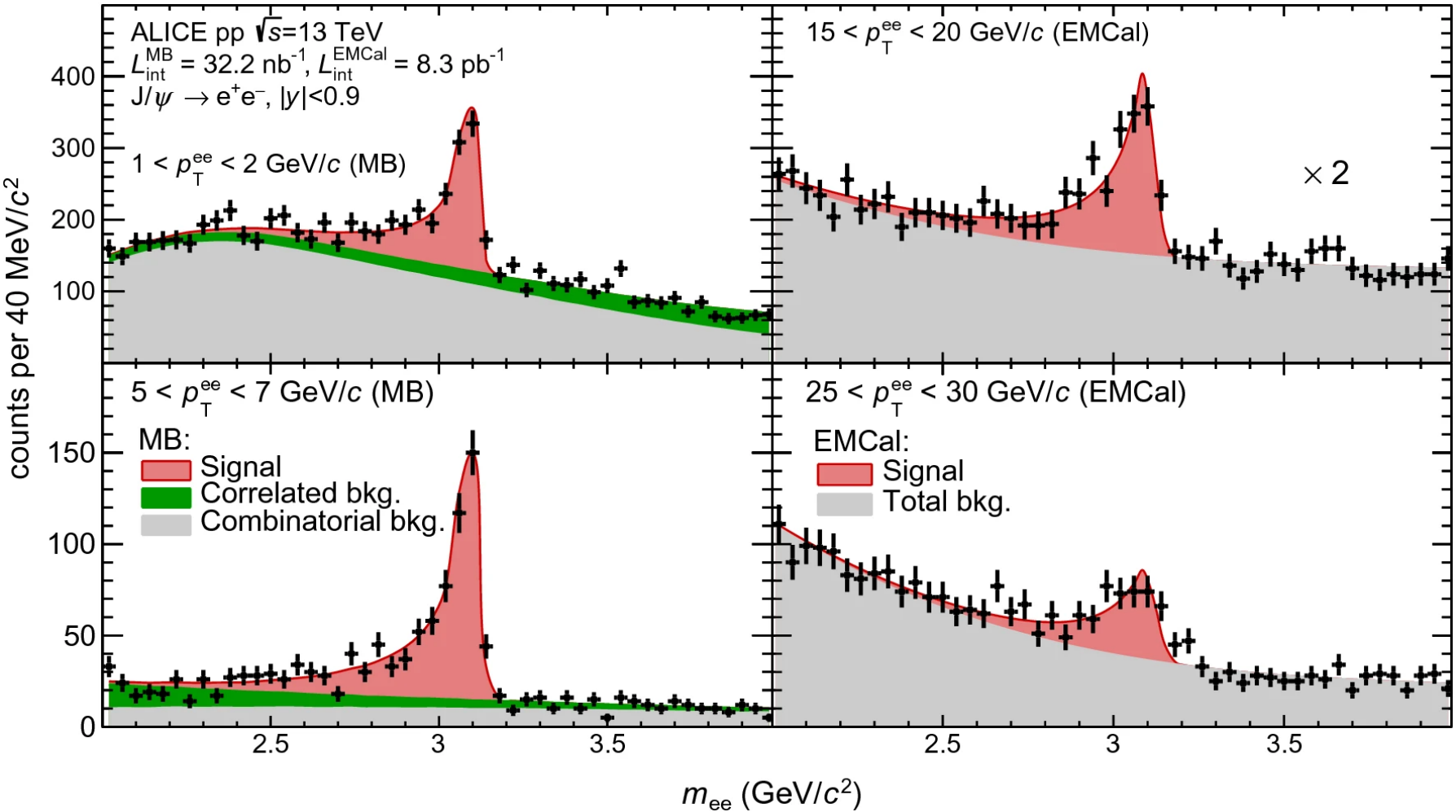


ATALS



CMS

Inclusive J/ψ production at midrapidity in pp collisions at √s = 13 TeV,
https://link.springer.com/article/10.1140/epjc/s10052-021-09873-4



https://arxiv.org/pdf/2109.15240.pdf

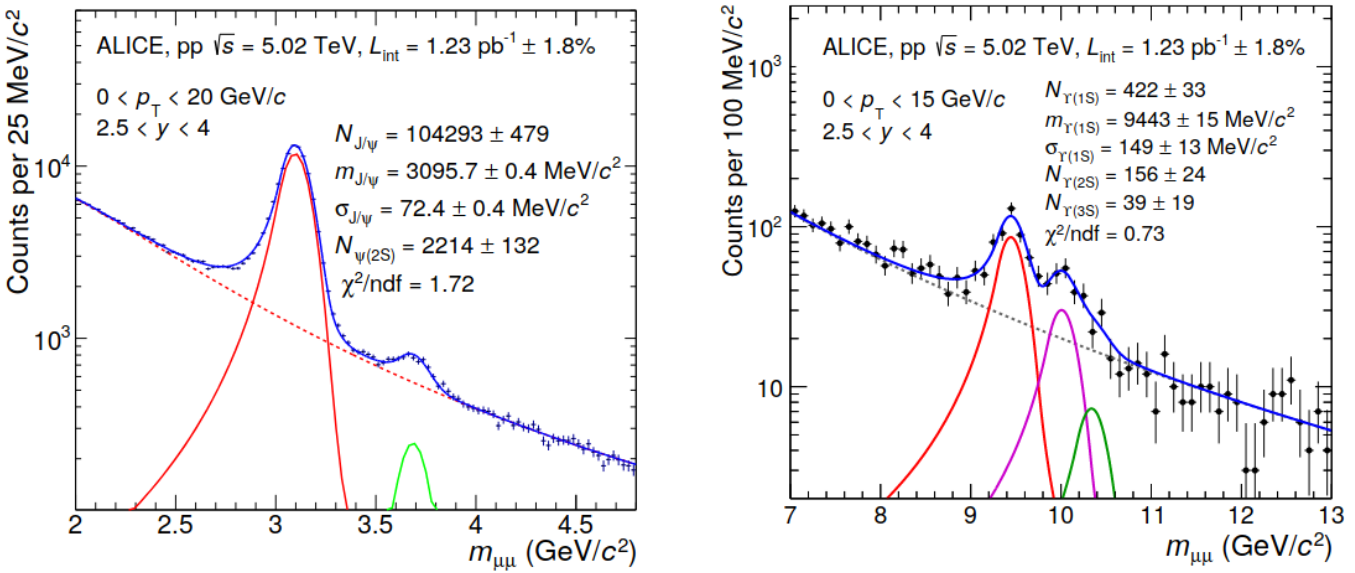
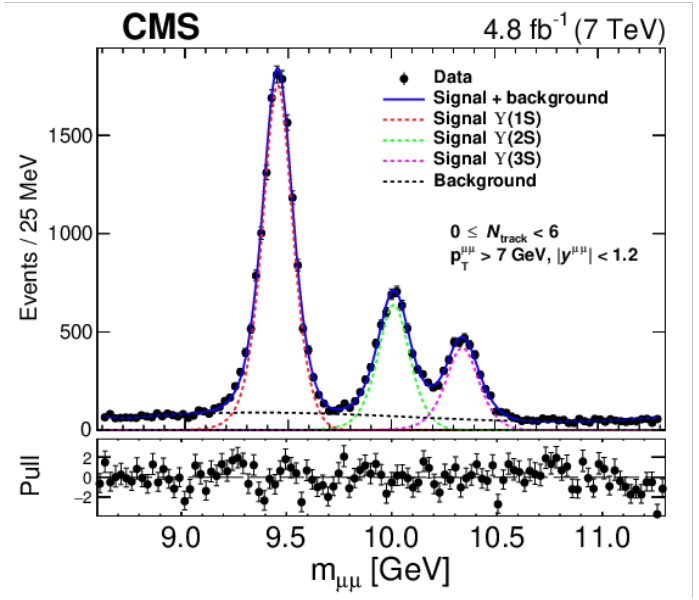


Figure 1: Examples of fit to the OS dimuon invariant mass distribution in the mass region $2 < m_{\mu^+\mu^-} < 5$ GeV/c^2 for $p_T < 20$ GeV/c (left), and $7 < m_{\mu^+\mu^-} < 13$ GeV/c^2 for $p_T < 15$ GeV/c (right).

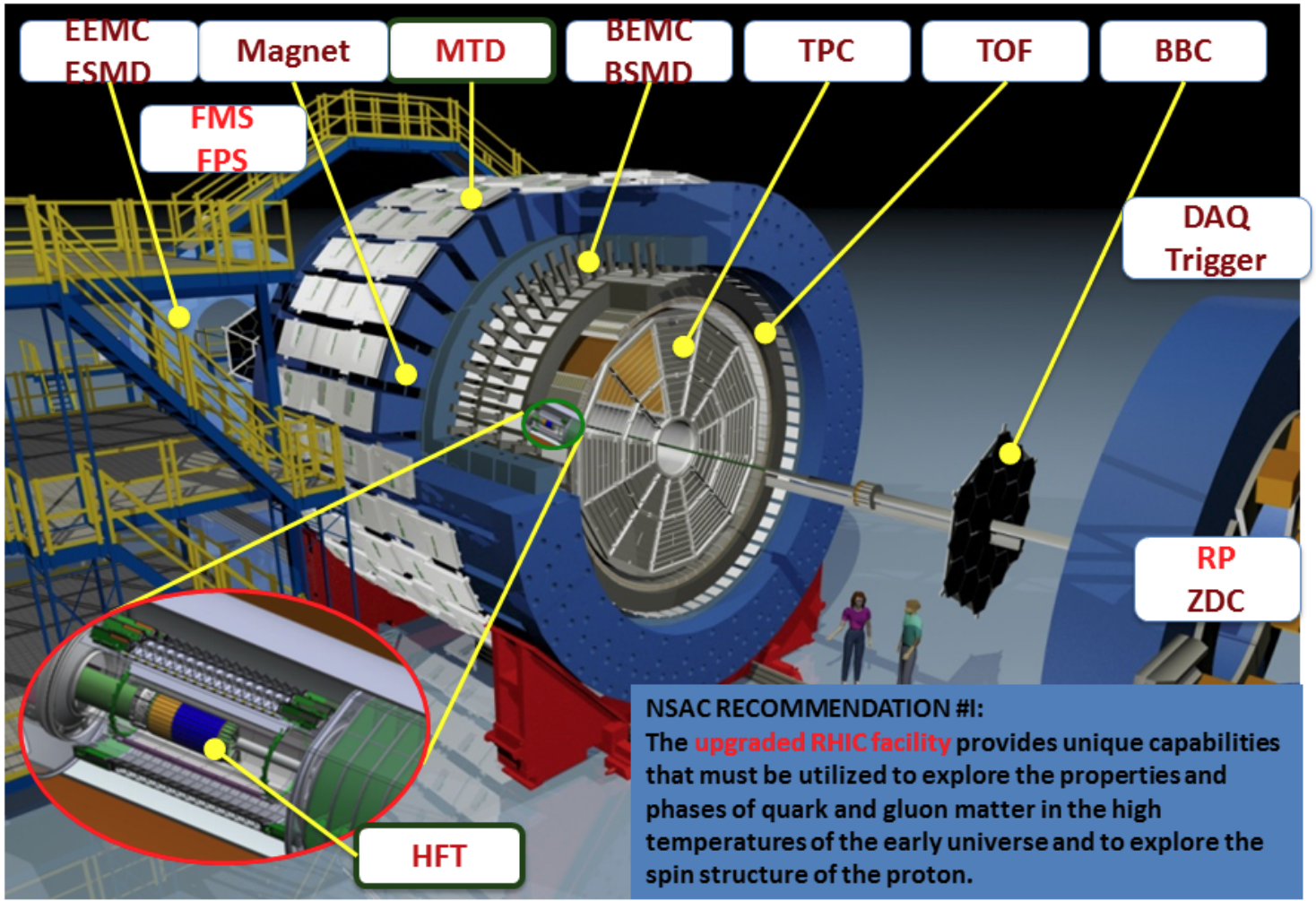


https://cds.cern.ch/record/2723301/plots#0

Example: STAR detector

STAR Detector System

15 fully functioning detector systems

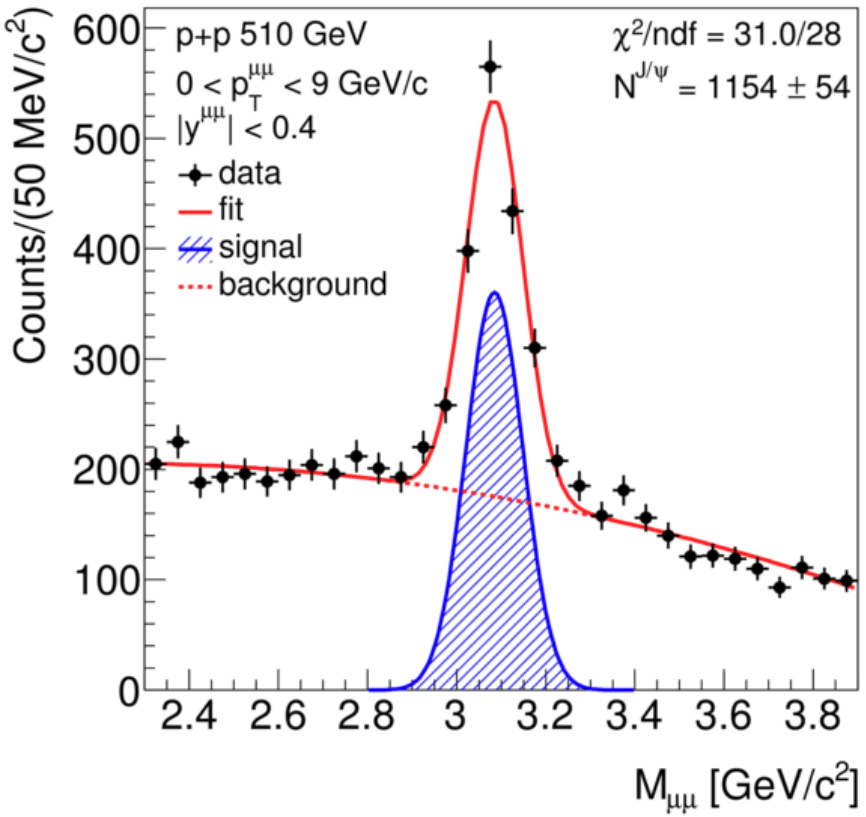


X10^3 increases in DAQ rate since 2000, most precise Silicon Detector (HFT)

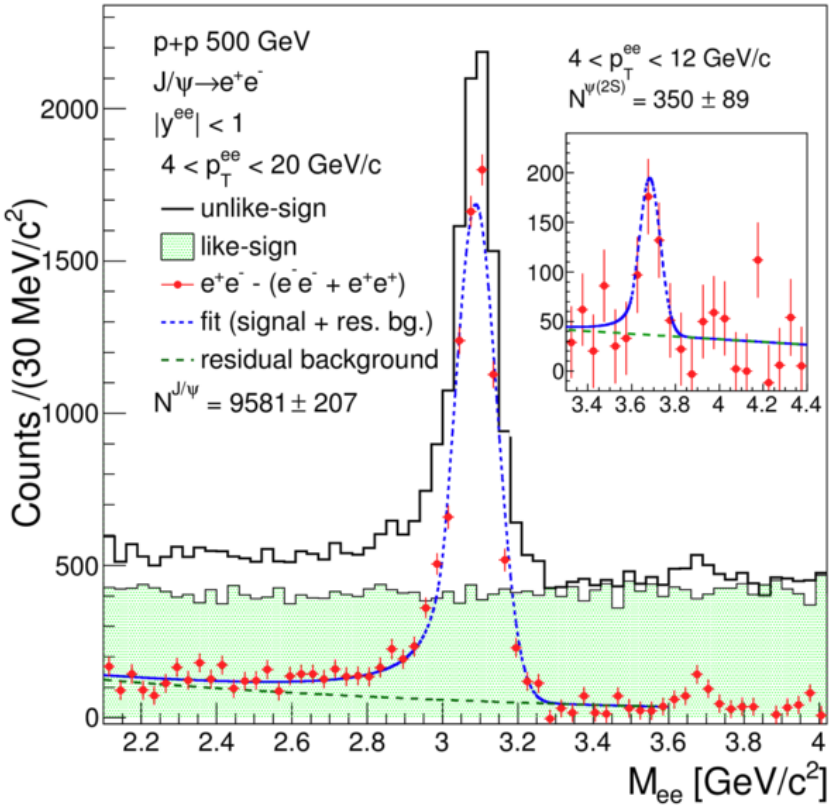
Muon Telescope Detector (MTD) added as an upgrade to improve detection capabilities at low-p_T and Υ(2S) and Υ(3S) separation

Measurements of the transverse-momentum-dependent cross sections of J/psi production at mid-rapidity in proton+proton collisions at √s = 510 and 500 GeV with the STAR detector, Phys. Rev. D 100 (2019) 52009

Muon detector

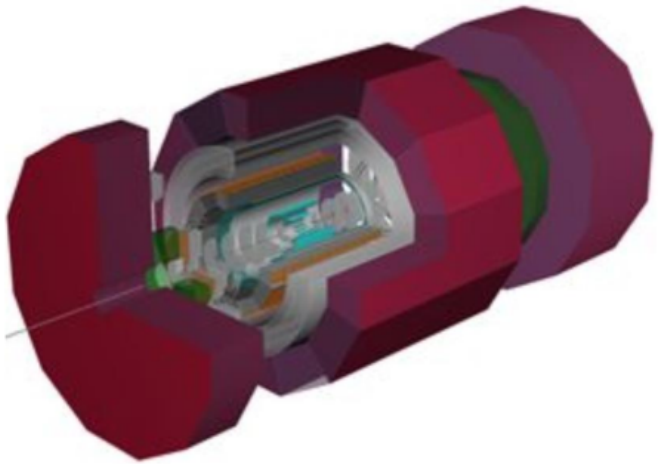


ToF + E-M calorimeter

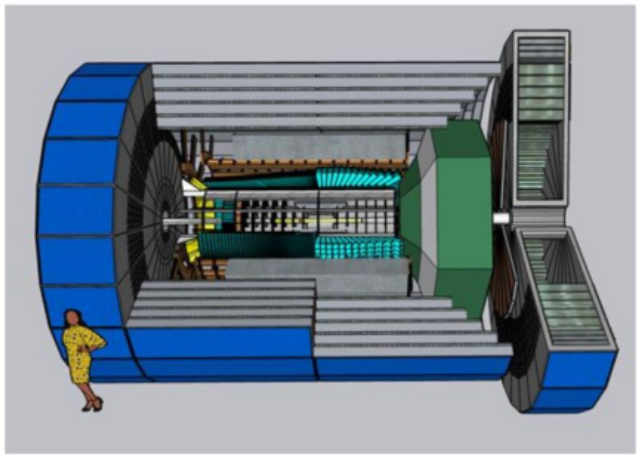


The candidates of detector system at EIC

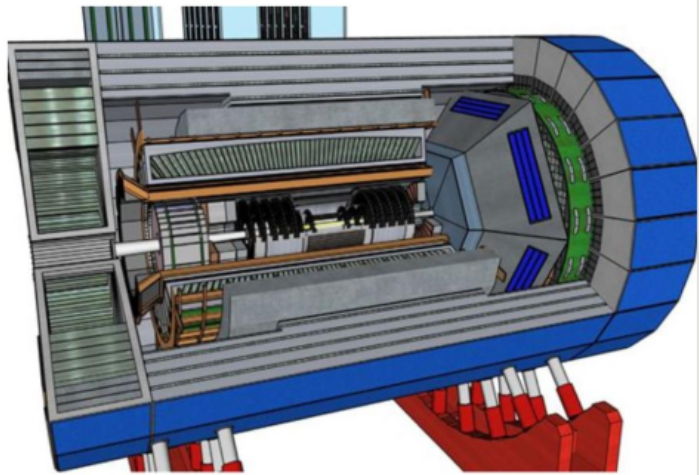
ATHENA: athena-eic.org



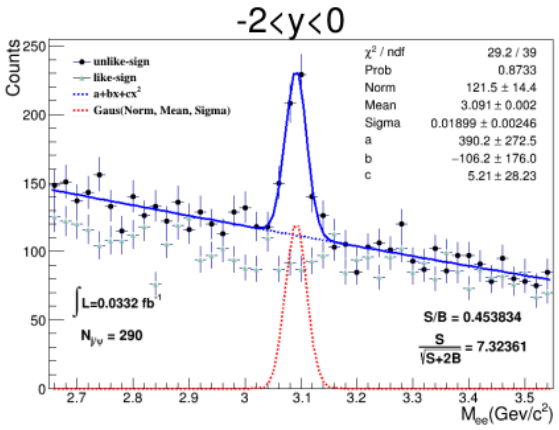
CORE: eic.jlab.org/core

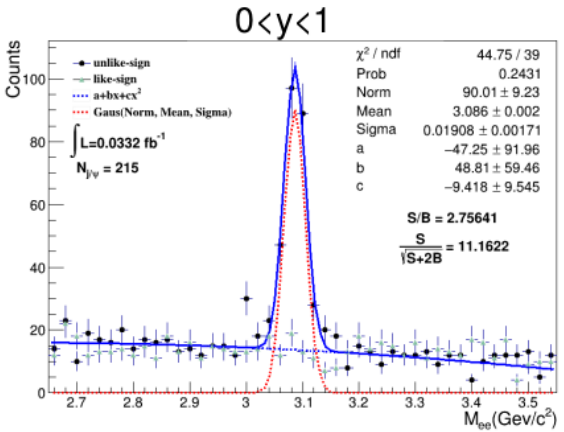


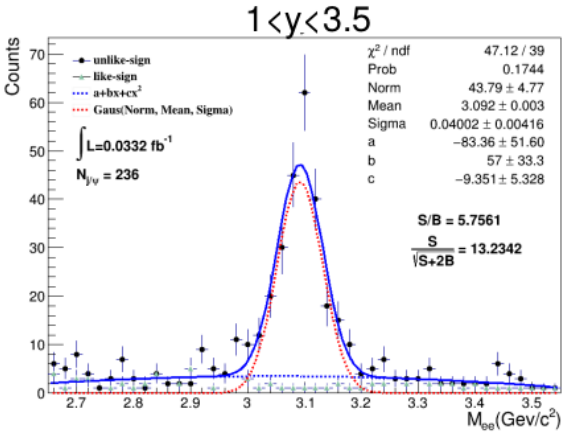
ECCE: ecce-eic.org



J/ψ Reconstruction



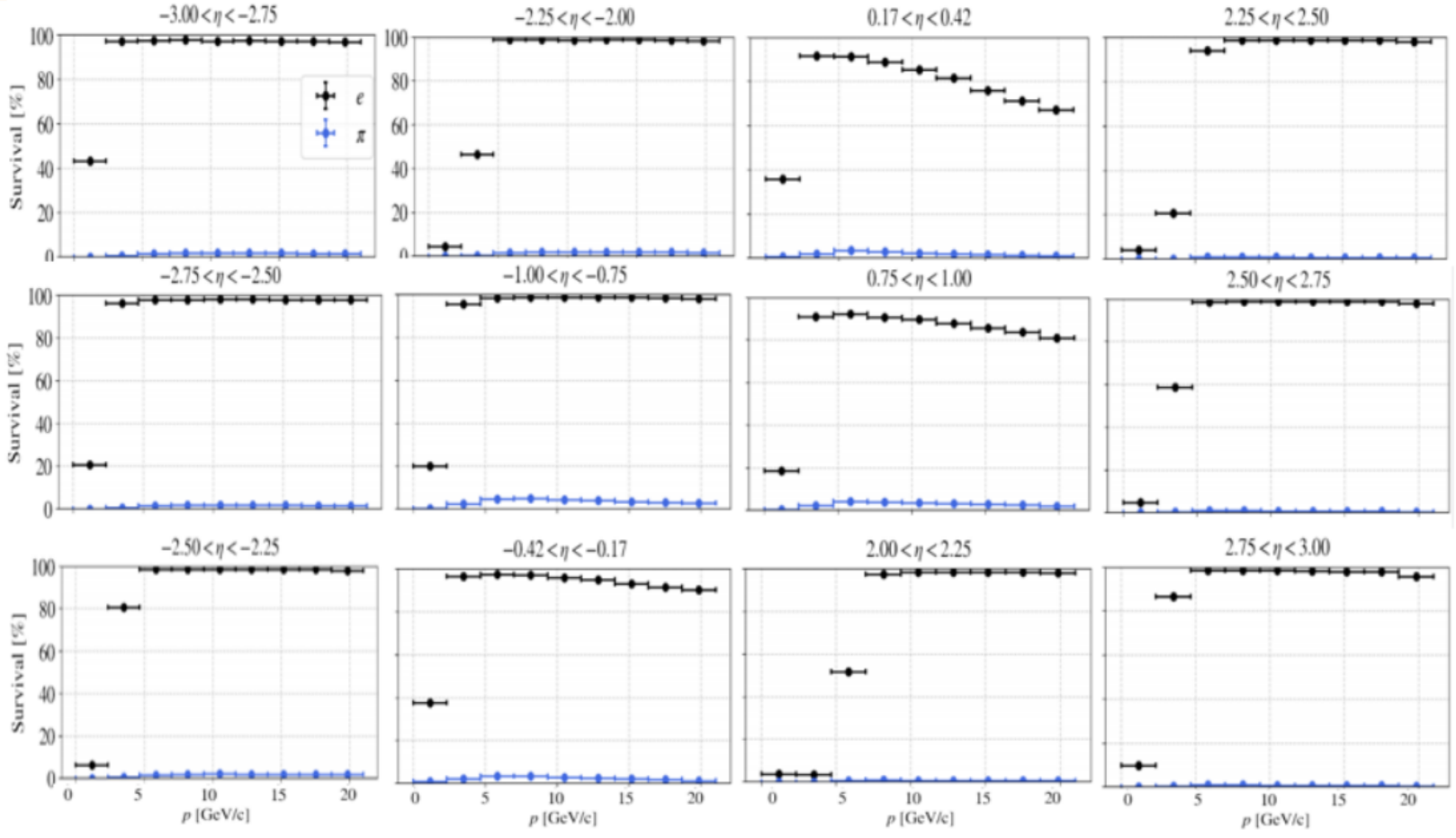




Central region with better mass width.

From e-going to h-going, signal backround ratio turns better.

Electron identification capability at ECCE—EMCal+Tracking



Does the EIC need a muon detector?

- In general e^+e^- channel is sufficient for spectra/asymmetry studies

- **EIC** may need muon detector for
  - Low-p_T and mid-rapidity measurements
  - Statistic-hungry studies (double the yields)
  - Measurement of Υ(1S), Υ(2S) and Υ(3S) and their separation
  - Studies of associated production: J/ψ + charmed meson

    (vertex detector need for charm reconstruction is a source of additional background)