Study of Heavy Flavor Hadron Production in Heavy Ion Collisions

Zhaozhong Shi

Massachusetts Institute of Technology

06/02/2021

Outline

- **Beauty Hadrochemistry in Quark-Gluon Plasma at the LHC**
- **B and D meson Physics Simulation with sPHENIX**
- **sPHENIX EMCAL Studies and EIC EMCAL Simulations**
- **Future Outlook**

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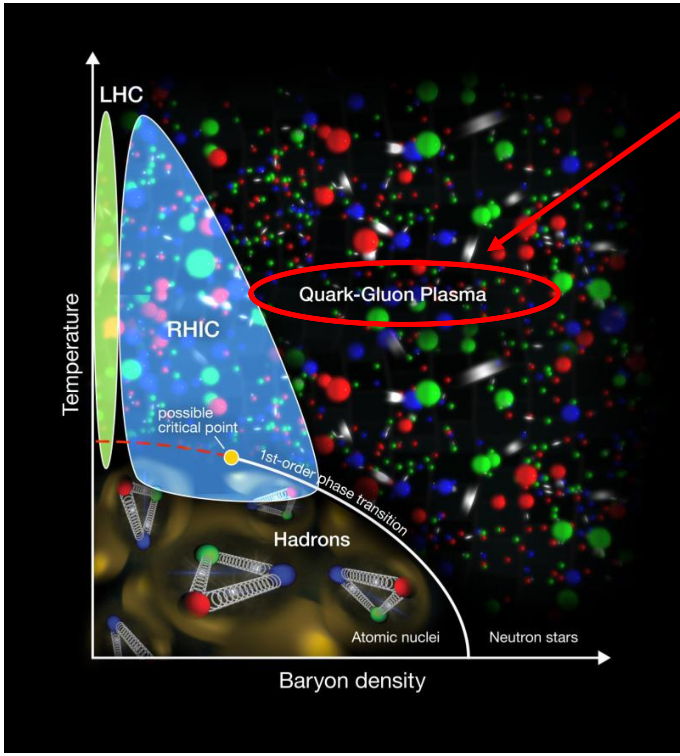
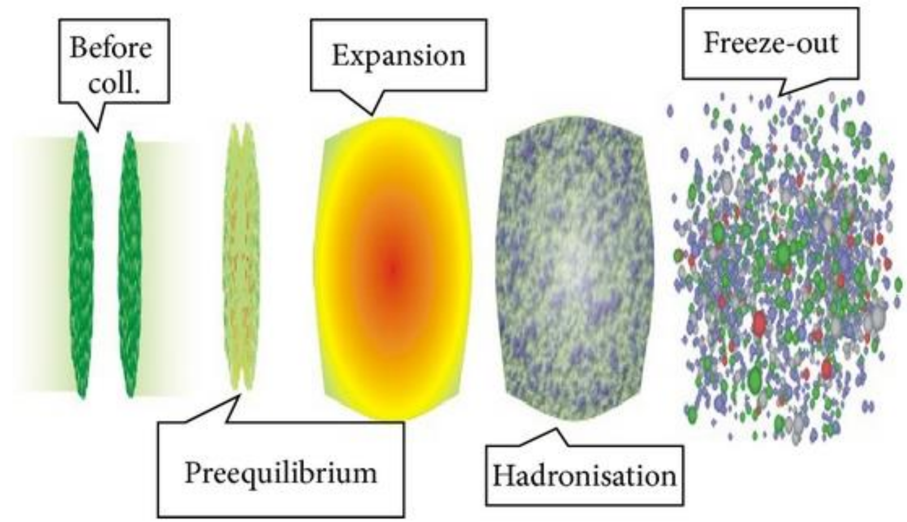
- Future Outlook

The Quest for the Quark-Gluon Plasma



My Research

Relativistic Heavy Ion Collision



Interesting Properties of Quark-Gluon Plasma

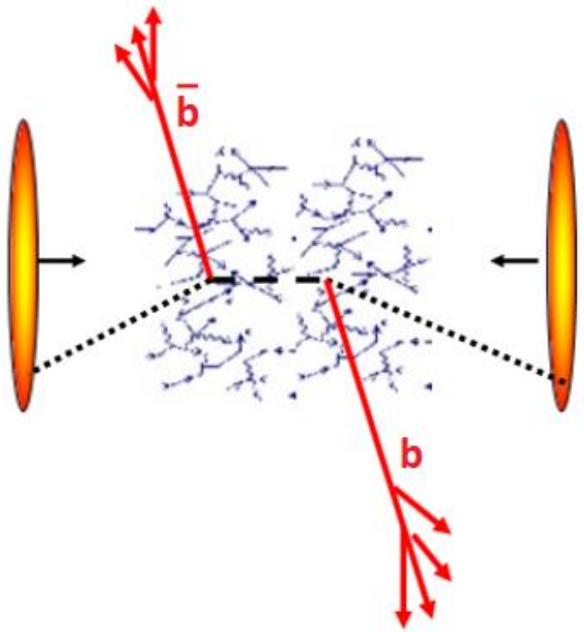
- Deconfined phase of QCD matter in extremely high temperature
- Strongly coupled ideal liquid with very short thermalization time and lifetime
- Can be created and studied in laboratory from relativistic heavy-ion collisions
- Believed to exist in the early universe, several microseconds after the Big Bang
- The inner workings and relevant degrees of freedom still under investigation

Physics

Heavy Quarks as Golden Hard Probes for QGP

Properties of Heavy Quarks

- Large mass (~ GeV/c^2) $m_Q \gg T_{QGP}$
- Predominantly produced in early hard scattering stage of heavy-ion collisions
- Long thermal relaxation time → generally do not thermalize with the QGP
- Retain their identities and propagate through the QGP medium → Excellent probes for the microscopic structure of QGP



Dynamics of Heavy Quarks in the QGP Medium

- $p_Q^{th} \simeq \sqrt{2m_Q T} > k \simeq T \rightarrow$ Brownian-Like Motion
- Planck-Fokker equation:

$$\frac{\partial}{\partial t} f_Q(t,p) = \frac{\partial}{\partial p} pA(p) f_Q(t,p) + \frac{\partial^2}{\partial p^2} B(p) f_Q(t,p)$$

- Transport properties of bulk medium via the spatial diffusion coefficient: $D_s = \frac{T}{m_Q A(p=0)} \sim \frac{1}{2\pi T} \frac{\eta}{s}$

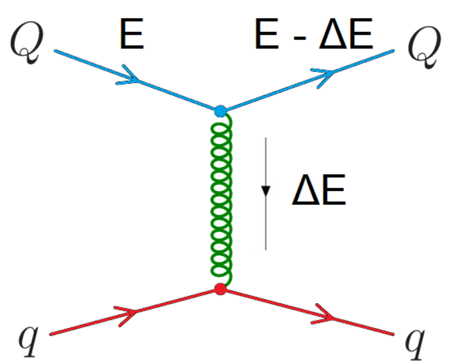
Experimental Observables

- Detect and study heavy flavor hadrons spectra
- Anisotropic flow via the Fourier analysis of the azimuthal distribution
- Hadron-hadron angular correlations

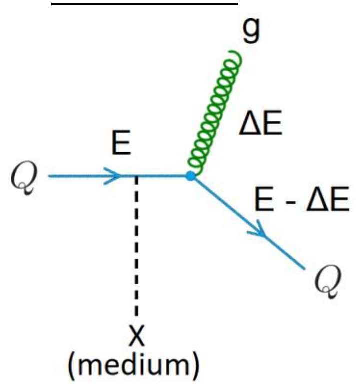
Heavy Quark Energy Loss Mechanism

pQCD: Weak Coupling

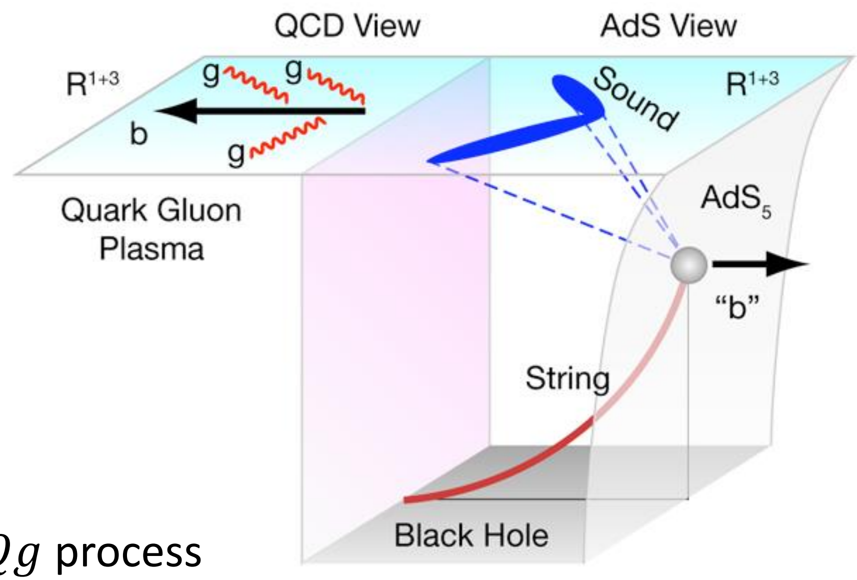
Collisional



Radiative



AdS/CFT: Strong Coupling

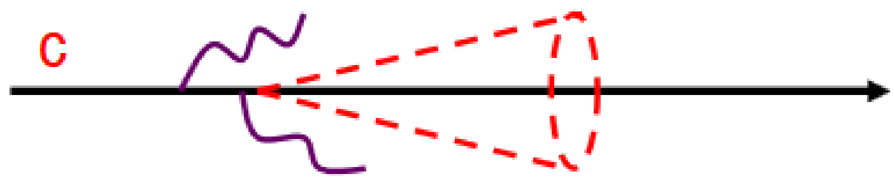


Dead Cone Effect:

- Lost energy by emitting gluons via inelastic $Q \rightarrow Qg$ process
- Gluon radiation spectra

$$dP = \frac{\alpha_s C_F}{\pi} \frac{d\omega}{\omega} \frac{k_\perp^2 dk_\perp^2}{\left(k_\perp^2 + \omega^2 \theta_0^2\right)^2} \quad \left(\theta_0 = \frac{m}{E}\right)$$

$$\Delta E_g > \Delta E_q > \Delta E_Q$$



- Flavor dependence of energy loss

Experimental Observables:

- **Traditional:** Heavy flavor hadron nuclear modification factor
- **More differential jet substructure:** Heavy flavor jet shape studies, jet-hadron correlation

Heavy Quark Hadronization Mechanism

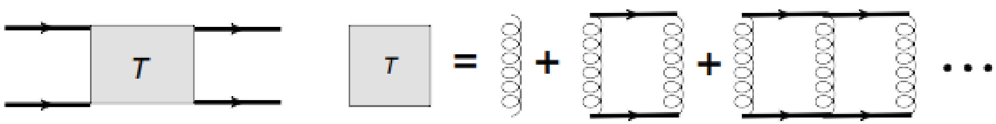
Theoretical Challenges

- Generally non-perturbative → first principle calculations not yet available
- Hadronization mechanisms: fragmentation and recombination
- Hadronization phenomenology with different assumptions: Lund String Model, Statistical Hadronization Model, Quark Coalescence Model → applicable in different conditions
- Inconsistency among hadronization models → limit our ability to interpret heavy flavor results

Beauty Hadrochemistry Models in Heavy-Ion Collisions

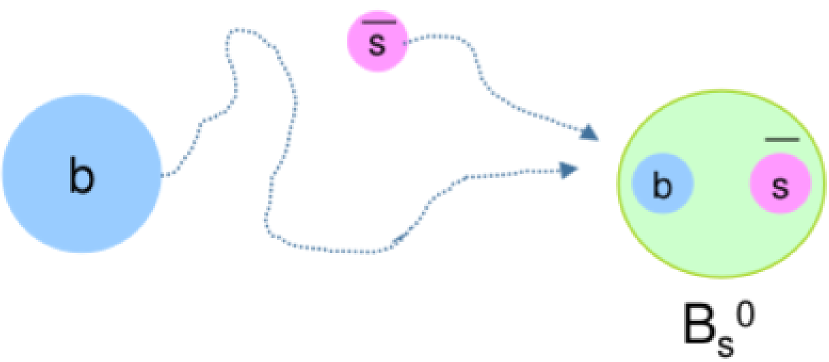
TAMU Model

- Many-body thermodynamic T-matrix approach
- Heavy quark in-medium diffusion
- Collision energy loss only
- Recombination hadronization mechanism



Cao, Sun, Ko Model

- Advanced Langevin hydrodynamics
- Both elastic and inelastic energy loss
- Comprehensive coalescence model + PYTHIA Peterson fragmentation model

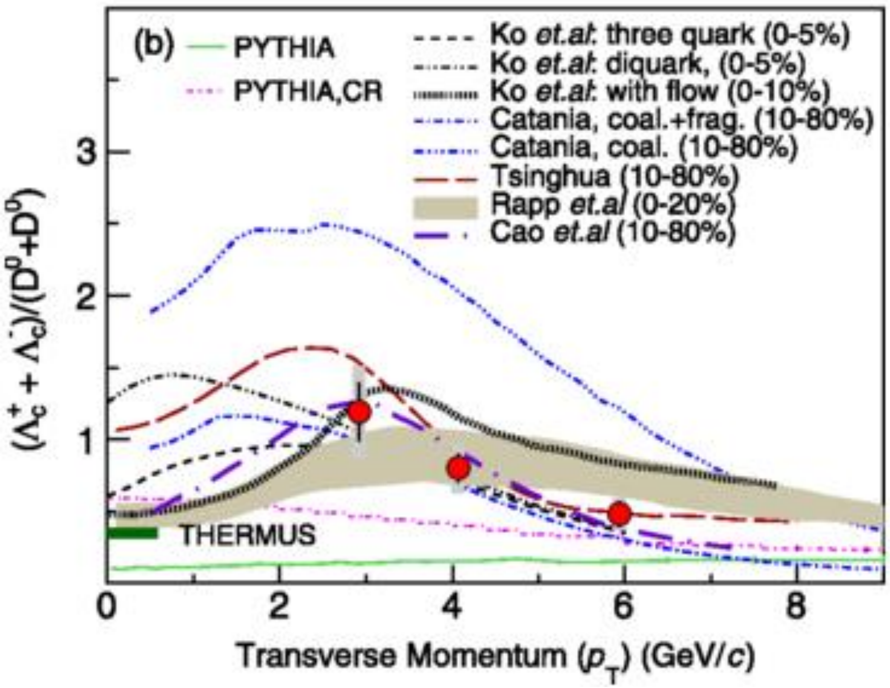


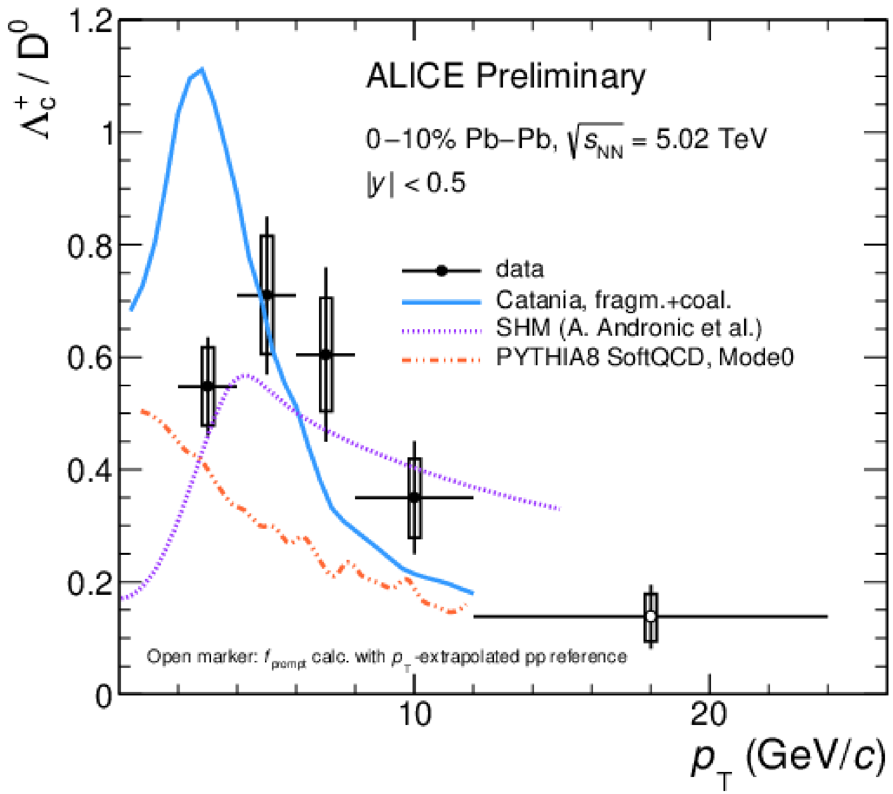
Experimental Observables

- Baryon-to-meson ratio
- Strange meson to non-strange meson ratio

Physics

Heavy Flavor Hadrochemistry in Heavy Ion Collisions

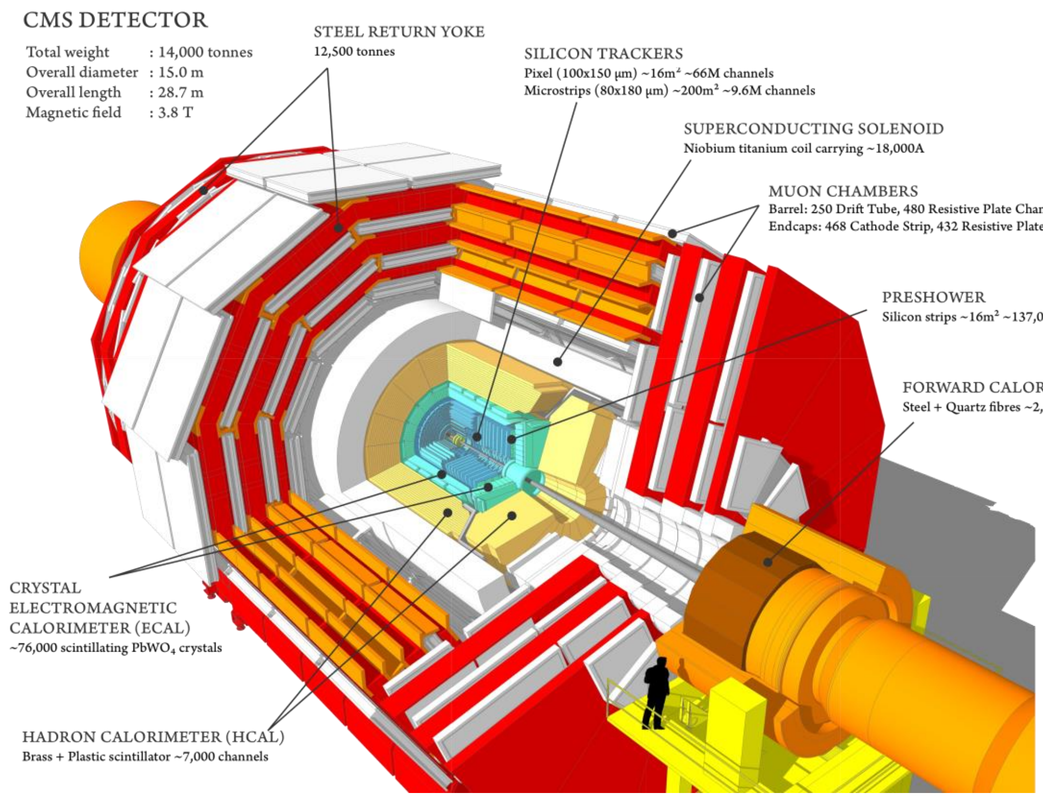




- Probing microscopic structure of QGP at different temperatures
- Extensive charm hadrochemistry studies at RHIC and LHC
- Fully reconstructed b hadrons via exclusive decays necessary to study beauty hadronization
- CMS and sPHENIX capable of fully reconstructing b hadrons from exclusive decays

Physics

CMS Detector

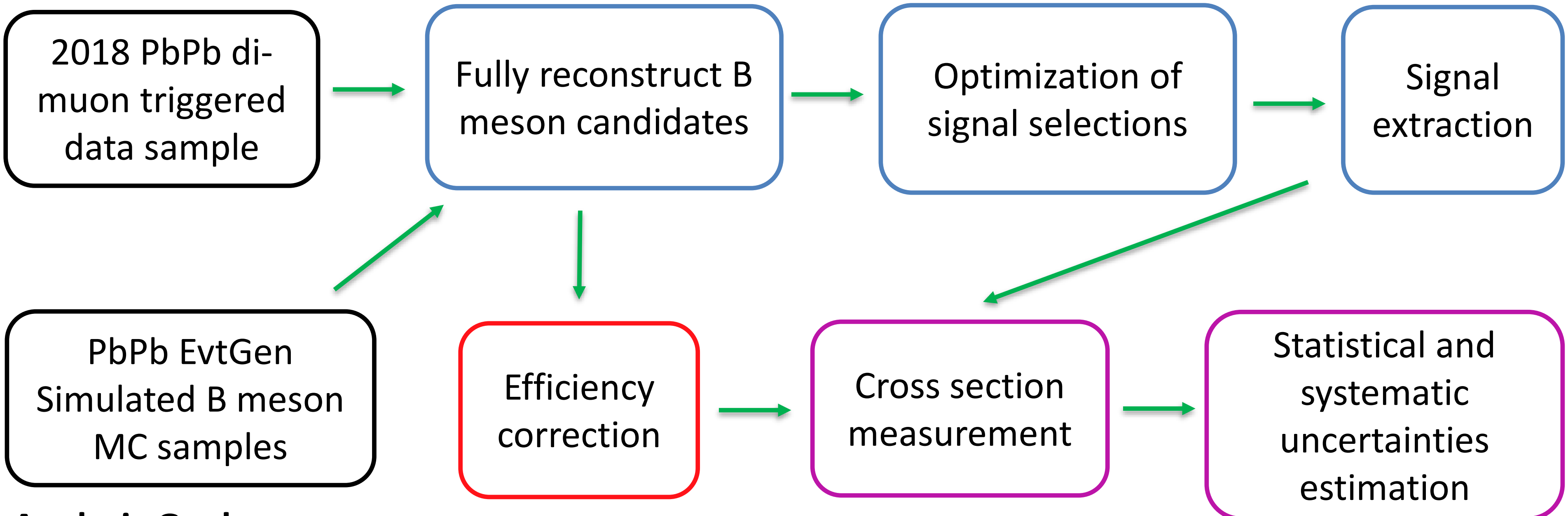


<u>Compact Muon Solenoid (CMS) Experiment at the LHC</u>

- State-of-the-art general-purpose detector with full 2π azimuthal and $|\eta| < 2.4$ coverage
- L1 hardware and HLT software triggers for efficient data acquisition
- Excellent vertexing and tracking capabilities
- Muon system with great performance for muon identification and reconstruction
- No dedicated hadronic particle identification

B-meson Measurement with CMS

Analysis Procedures:



Analysis Goals:

- Fully reconstruct B^+ and B_s^0 in a wide p_T range in central and peripheral collisions
- Measure the cross section of B_s^0 and B^+ and the B_s^0/B^+ ratio

Analysis Challenges

- Small decay branching ratio in the chosen channels → low statistics of B mesons
- No hadronic PID → huge combinatorial background, particular at low p_T
- Challenging for low p_T due to small muon and track acceptance → Low S/B ratio

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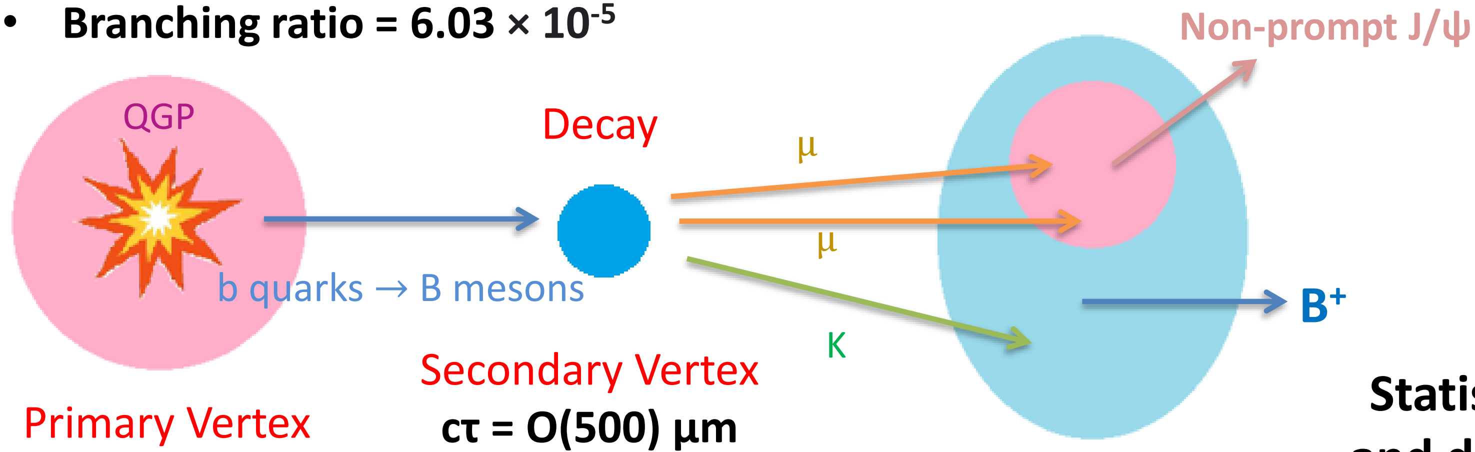
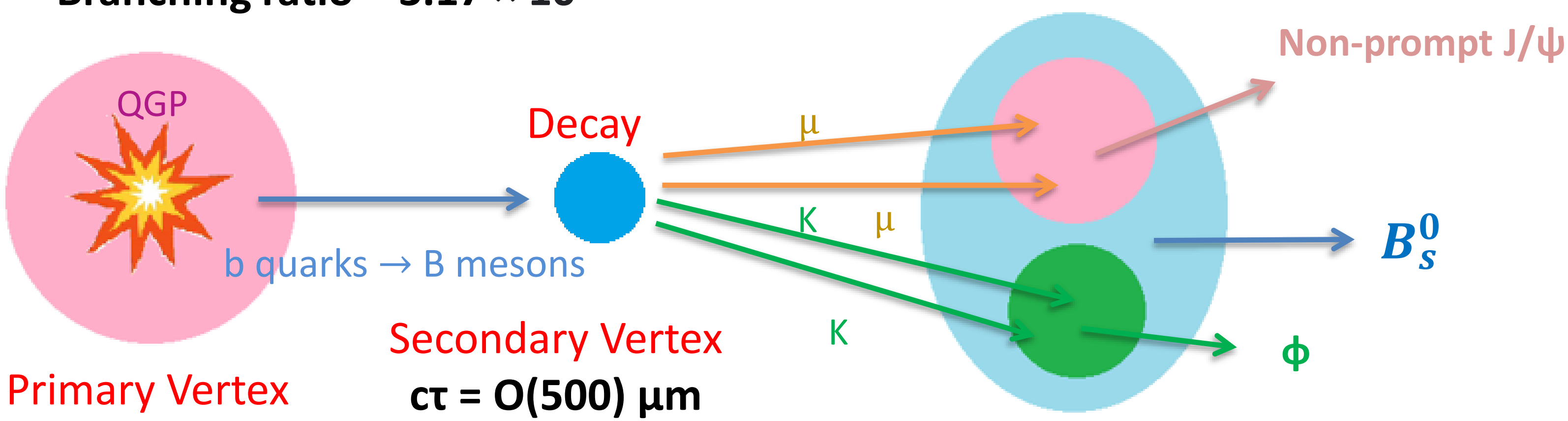
B-mesons Full Reconstruction Strategies

- B^+: via the decay channel $B^+ \rightarrow J/\psi K^+ \rightarrow \mu^+\mu^- K^+$
- Branching ratio = 6.03×10^{-5}



Statistically enriched and dedicated dimuon triggered datasets from 2018 LHC PbPb run

- B_s^0: using the decay channel $B_s^0 \rightarrow J/\psi \phi \rightarrow \mu^+\mu^- K^+ K^-$
- Branching ratio = 3.17×10^{-5}

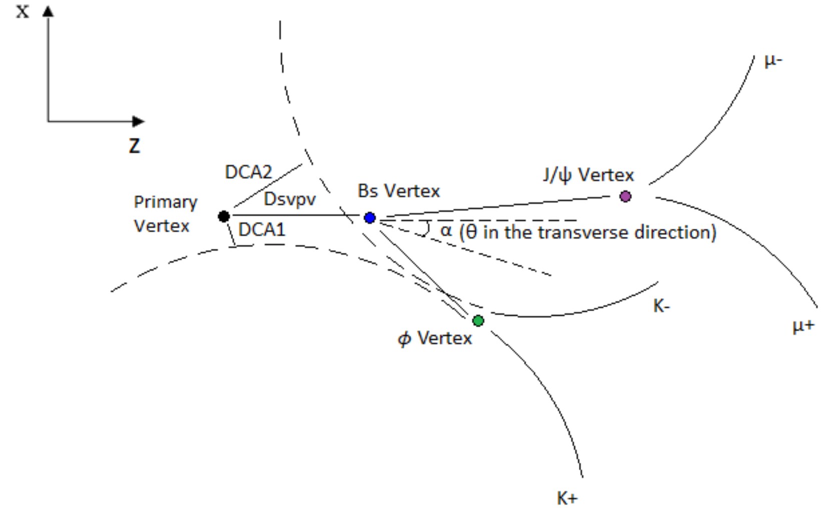


Physics

Machine Learning Techniques in B-meson Selections

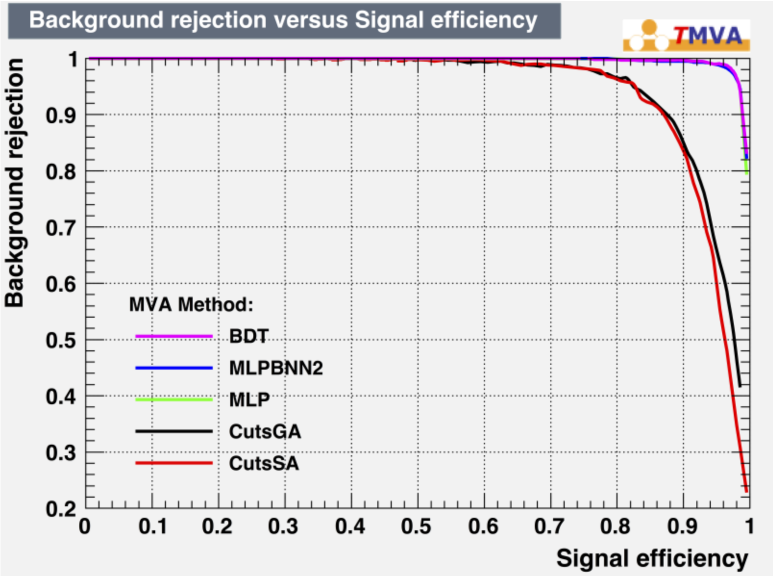
Topological variables in $B_s^0 \to J/\psi\phi \to \mu^+\mu^- K^+ K^-$ signal selections K^+K^- tracks

$|m_{KK} - m_{\phi}|$
The B_s^0 vertex probability
DCAxy1/DCAxy1Error
DCAxy2/DCAxy1Error
DCAz1/DCAz1Error
DCAz2/DCAz2Error
Dsvpv/DsvpvError
Opening angle α
Cosine of opening angle in xy: cos(θ)



Multivariate approach with machine learning

- Event, track, and muon quality preselection on the input samples
- MC generated B meson as signal and data B-meson mass sideband as background
- Boosted Decision Tree (**BDT**) best among other machine leaning algorithms under the optimal set of training parameters



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Machine Learning Techniques Application

Estimation of signal and background

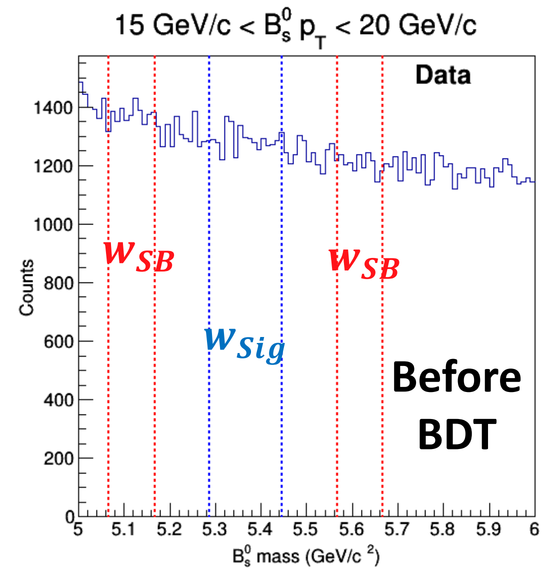
- **Data:** $B = N_{SB} w_{Sig} / w_{SB}$
- **MC:** $S = 2R_{AA}^{2015\ Ref} L\sigma_{FONLL}^{pp\to b\bar{b}} \varepsilon_{pre} \varepsilon_{S} f(b \to B) BR$

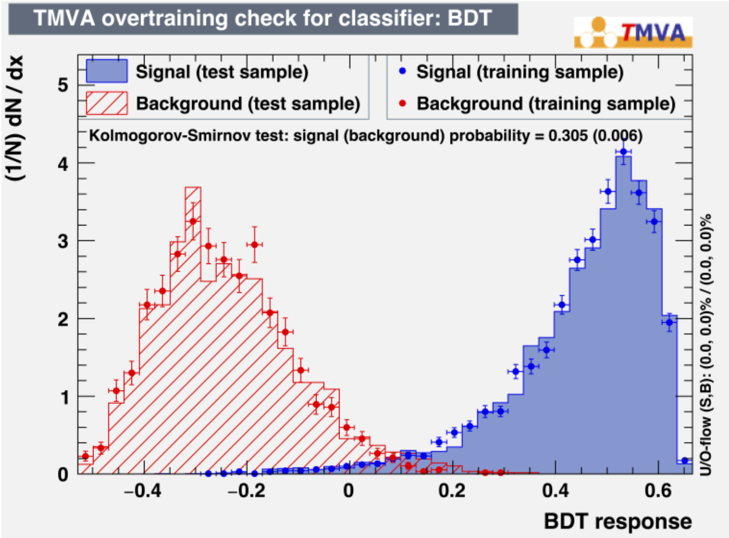
Analysis challenges:

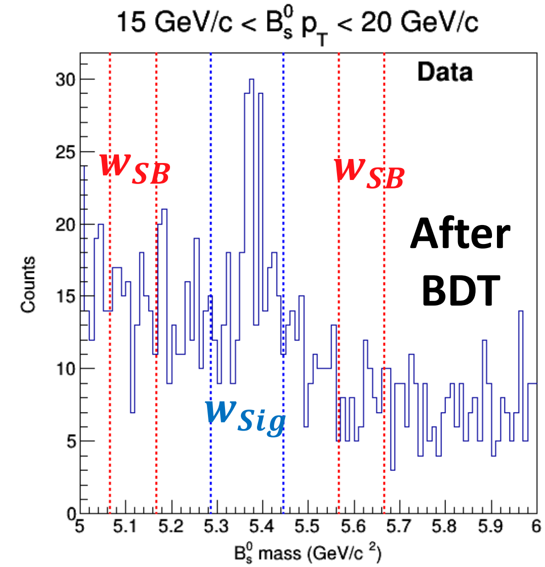
- Before selections, **B = 20672** and **S = 26**
- Need to achieve about **10^3** to **1** for the **B** to **S** rejection to observe B_s^0 signal in the PbPb data

BDT selections

- Excellent **Signal**/**Background** separation without overtraining
- A random BDT > 0.1 selection returns a visible signal

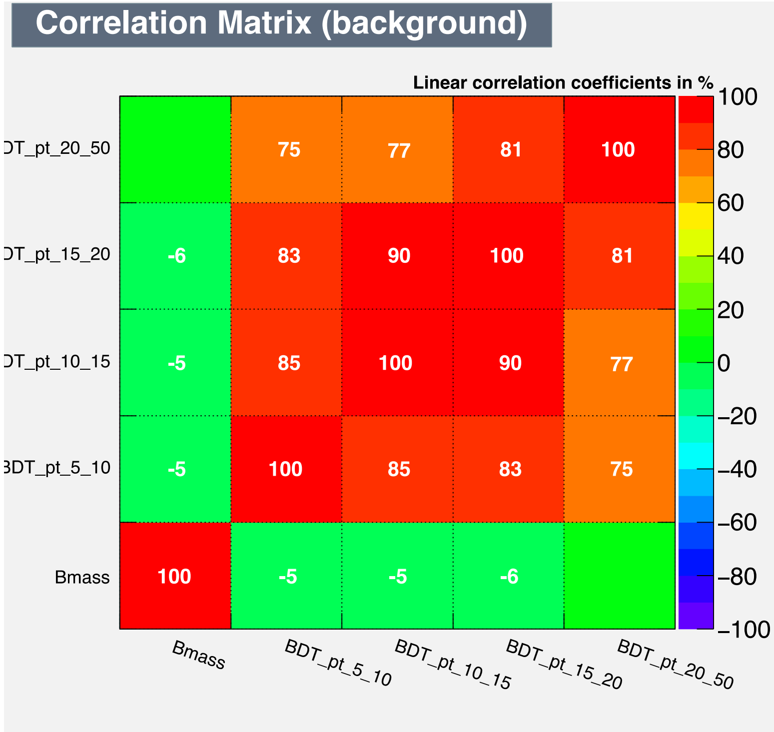


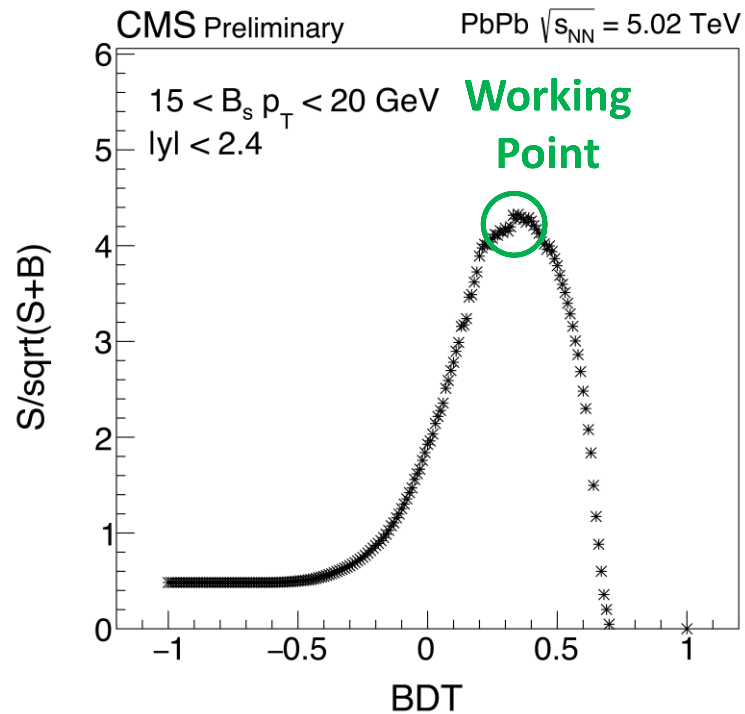




Physics

BDT Training Performance and Working Points



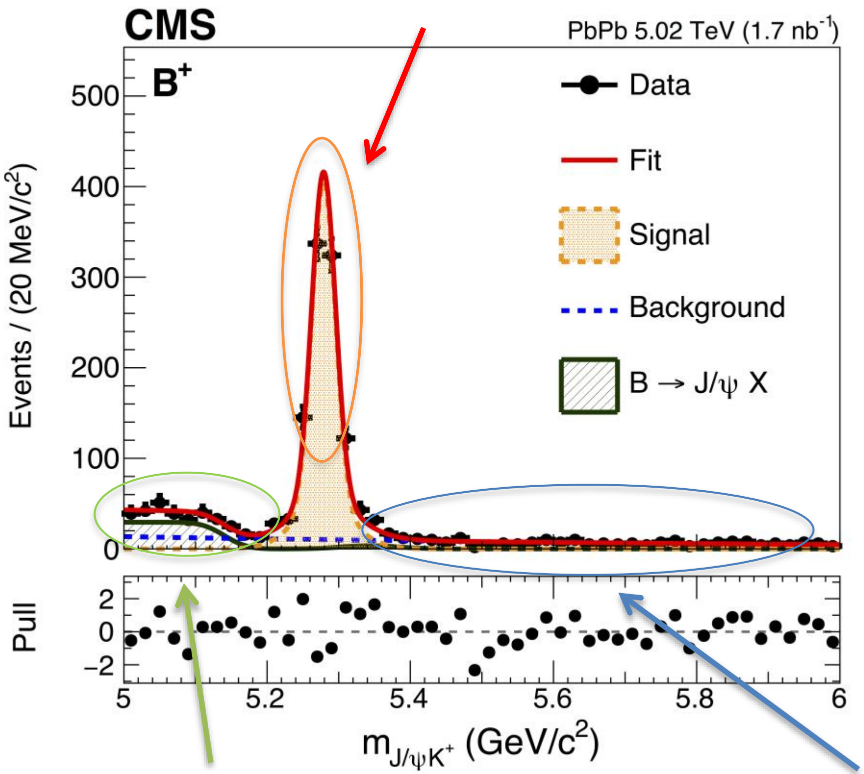


- Perform BDT training for each p_T bin
- No significant correlation between the BDT scores and the B_s^0 invariant mass → BDT cut valid to use in our analysis
- Maximize the statistical significance = $\frac{S}{\sqrt{S+B}}$ for BDT working point determination of each p_T bin in our analysis

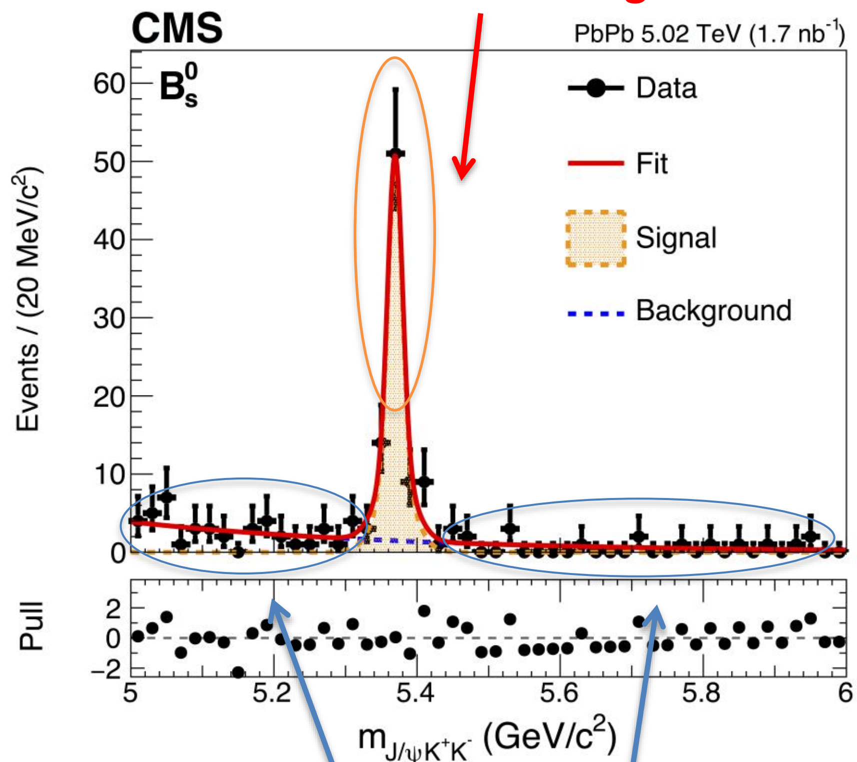
Physics

Fully Reconstructed B^+ and B_s in PbPb Collisions

Double Gaussian for signal



Double Gaussian for signal



Error function (shoulder) + 2 sided Gaussian (signal region) for Non-prompt background

Exponential decay for combinatorial background

Exponential decay for combinatorial background

- Clear B mesons signals after apply the BDT selections without applying hadronic PID
- Fully reconstructed B_s significance > 5σ → first observation of B_s^0 in nuclear collisions

Data-Driven Efficiency Correction Techniques

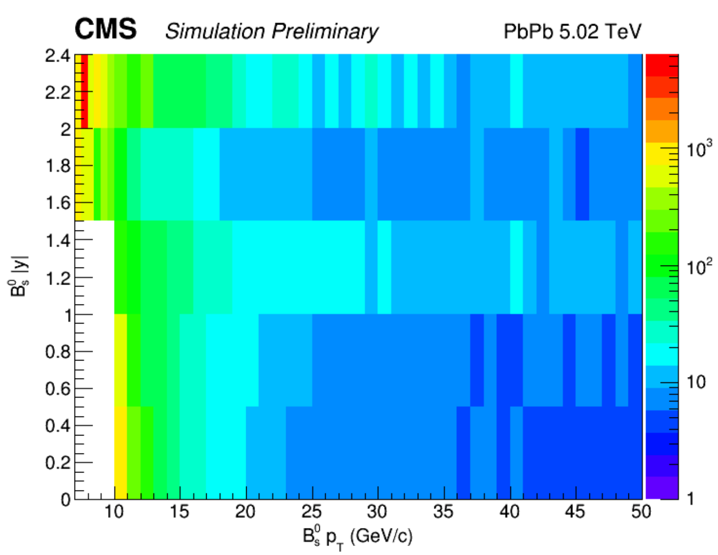
Analysis challenges:

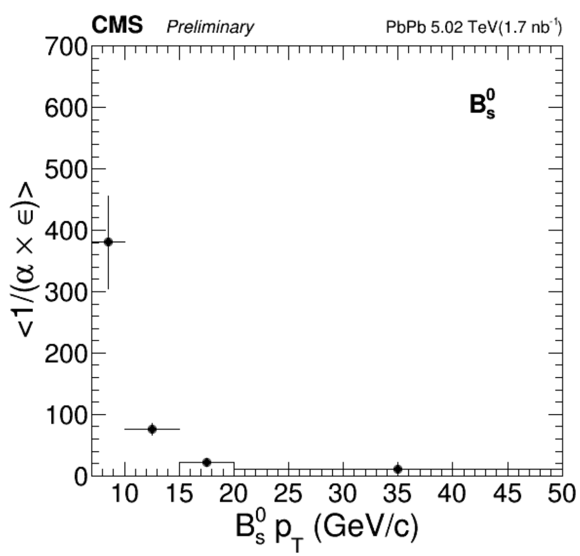
- Unknown B meson precise p_T and y distribution → huge systematics uncertainties on the efficiency correction, particularly over a large p_T and y range

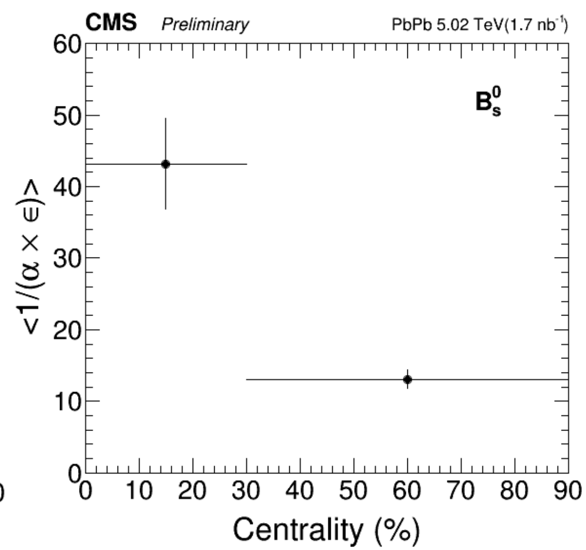
α: acceptance
ε: efficiency

Data-driven way of efficiency correction

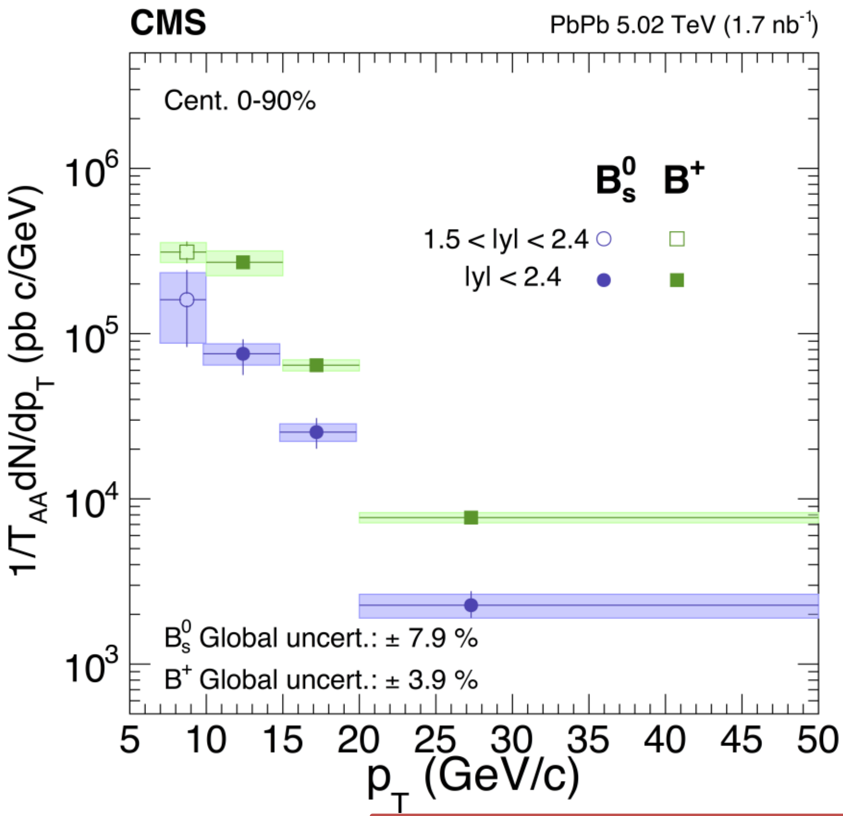
- **Fiducial region:** $|y| > 1.5$ for $p_T < 10$ GeV/c
- Finely grained $\frac{1}{\alpha \times \varepsilon}$ 2D B mesons p_T and $|y|$ efficiency maps to reduce the efficiency systematics
- **Tag-and-Probe Techniques:** Apply data-driven method for J/ψ efficiency corrections according to the identification, di-muon trigger, acceptance, and tracking selections of each muon
- **Data Driven:** Compute $\left\langle \frac{1}{\alpha \times \varepsilon} \right\rangle$ of data B mesons candidates in the signal region based on their p_T and $|y|$

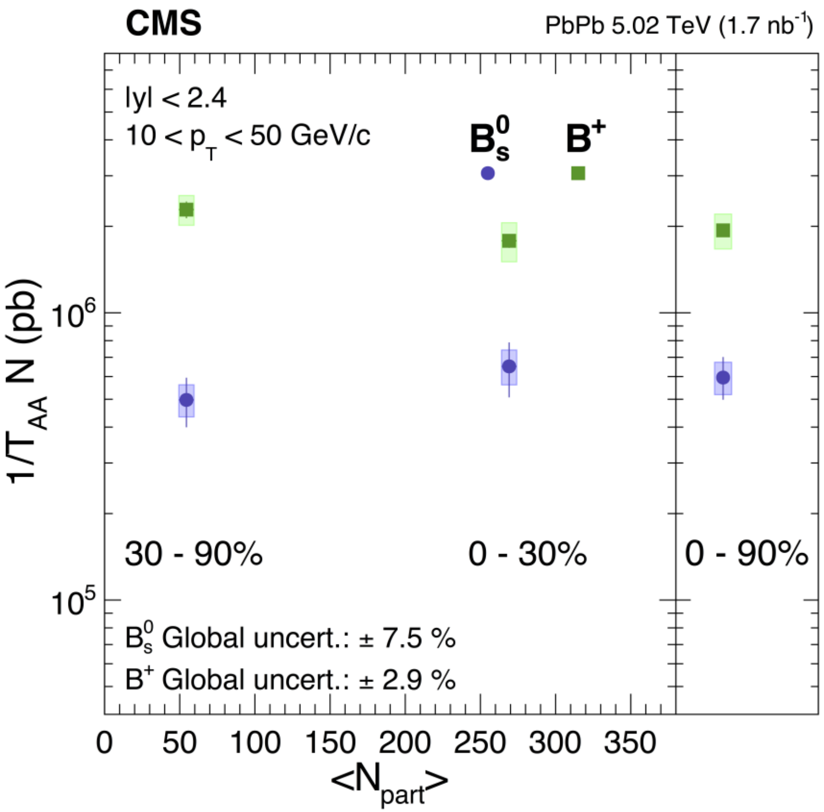






Cross Section as a Function of p_T and Centrality

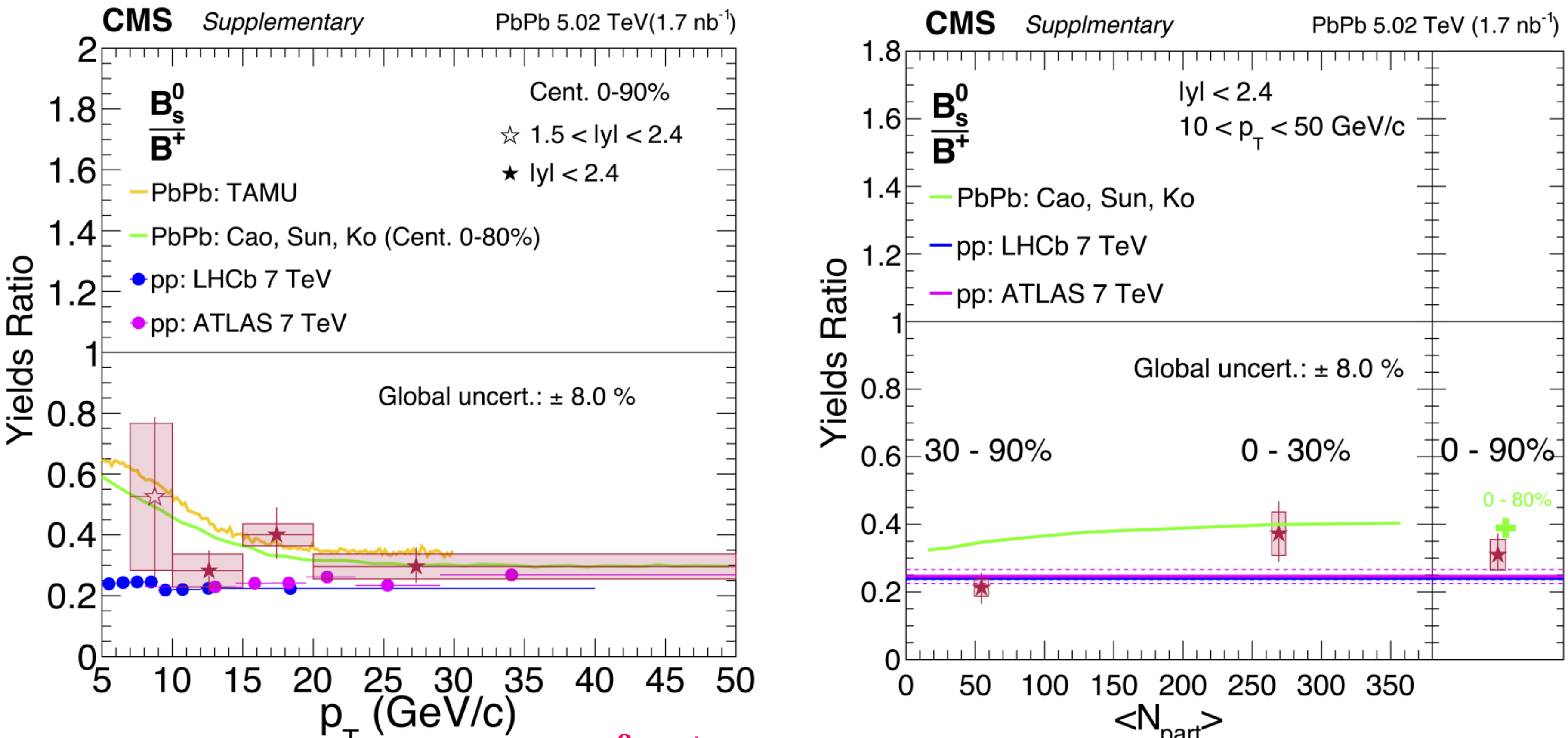




$$\frac{1}{T_{AA}}\frac{dN}{dp_T} = \frac{1}{T_{AA}}\frac{1}{2}\frac{1}{\Delta p}\frac{1}{BR \cdot N_{MB}} N^B \left\langle \frac{1}{\alpha \times \varepsilon} \right\rangle$$

- Precise p_T differential cross-section measurement of B^+ and B_s^0 mesons from 7 to 50 GeV/c
- First centrality differential cross-section measurement of B_s^0
- Substantial uncertainties of B_s^0 in the lowest p_T bin due to the limited statistics

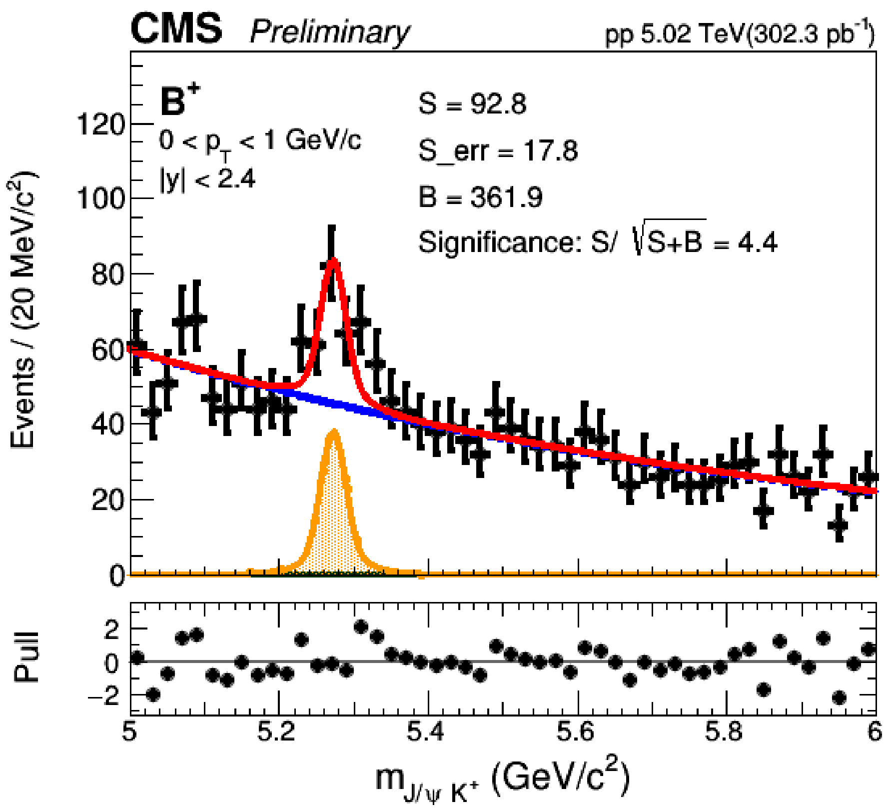
B_s^0/B^+ Ratio in PbPb

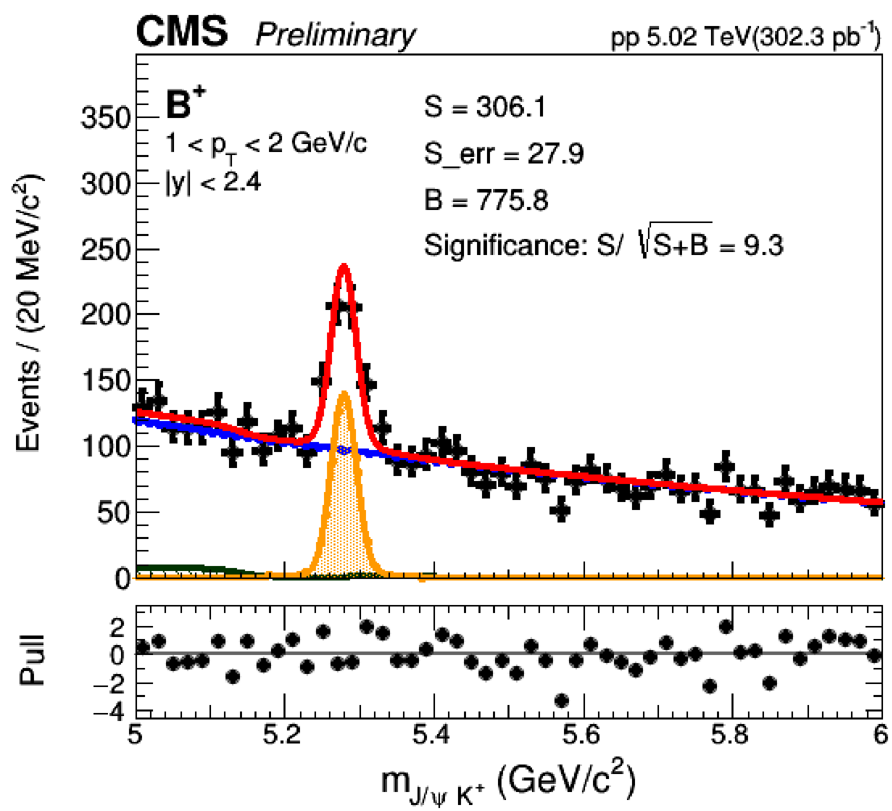


- No significant p_T dependence of B_s^0/B^+
- B_s^0/B^+ agrees reasonably well with **TAMU model** and **Cao, Sun, Ko. model**
- B_s^0/B^+ is compatible to the **LHCb pp 7 TeV** and **ATLAS pp 7 TeV** data
- No significant strangeness enhance observed
- **Pending submission to Physics Letters B Journal for publication within a few weeks**

MIT Physics

B⁺ in pp Down to $p_T = 0$ with BDT





- **BDT Capabilities:** Clear B^+ signal in 0 – 1 GeV/c with **>5σ significance without hadronic PID**
- Allow measurement of **inclusive beauty production cross section** and test pQCD
- **LHC Run 3 & Beyond:** precise measurements of b-hadron family (Λ_b^0, B_c^+, B_s^0, B^+, and B^0) over an extensive p_T, centrality, and multiplicity region to understand beauty hadronization
- **RHIC – sPHENIX:** leadership role in fully reconstructed B^+ and B_s^0 physics simulations

MIT Physics

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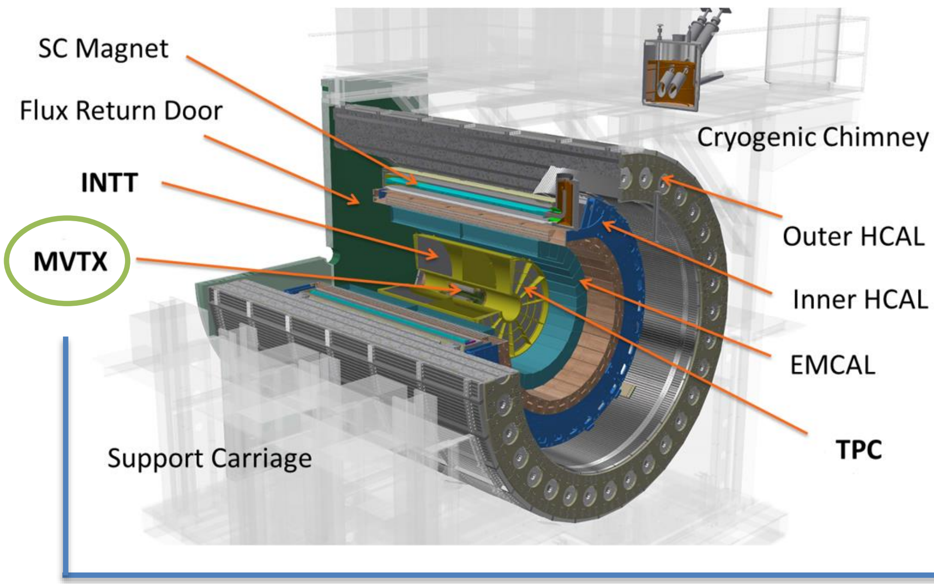
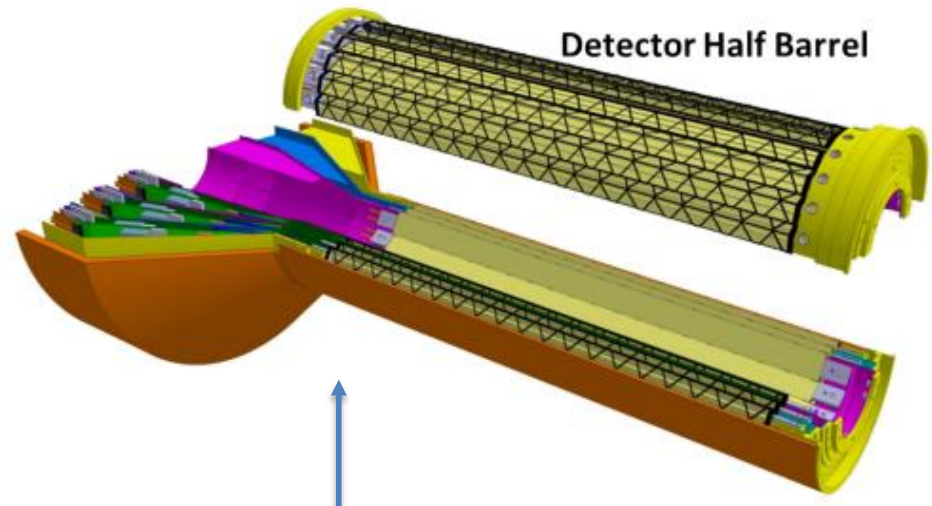
MIT Physics

sPHENIX Detector – MVTX





<u>The sPHENIX Detector</u>

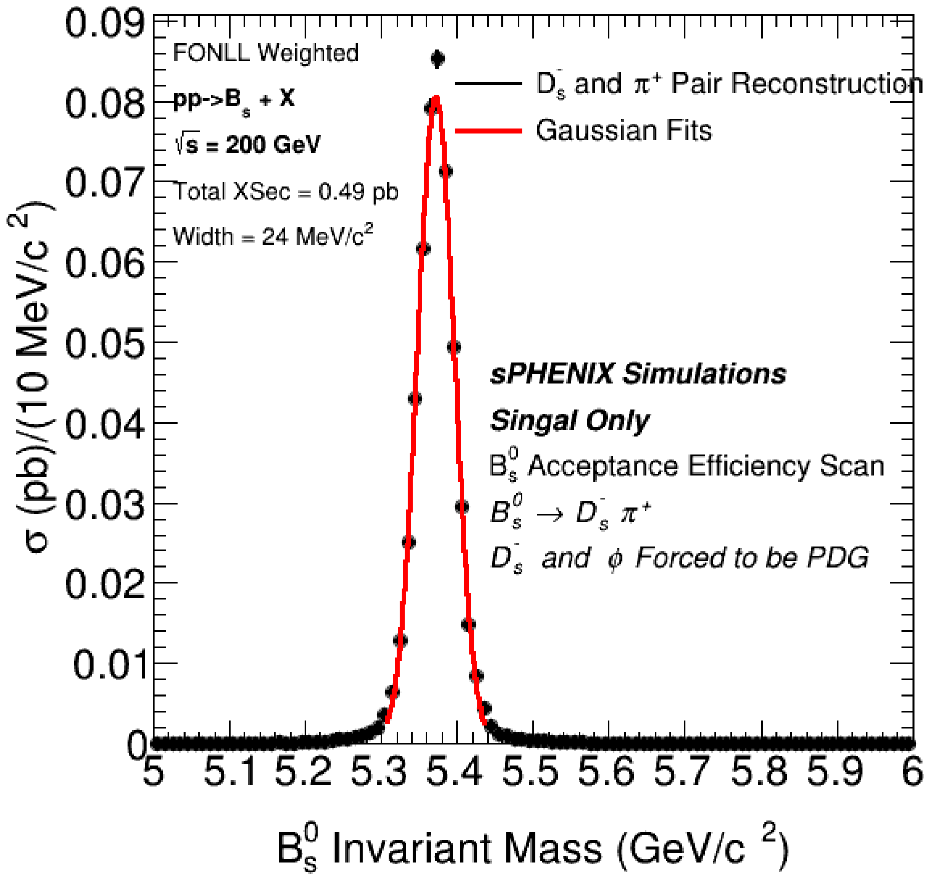
- State-of-the-arts jet detector with full 2π and |η| < 1.1 coverage upgraded from PHENIX
- Dedicated triggers to collect of large heavy-ion minimum biased datasets
- Excellent electron identification capability for heavy flavor studies
- No dedicated hadronic particle identification

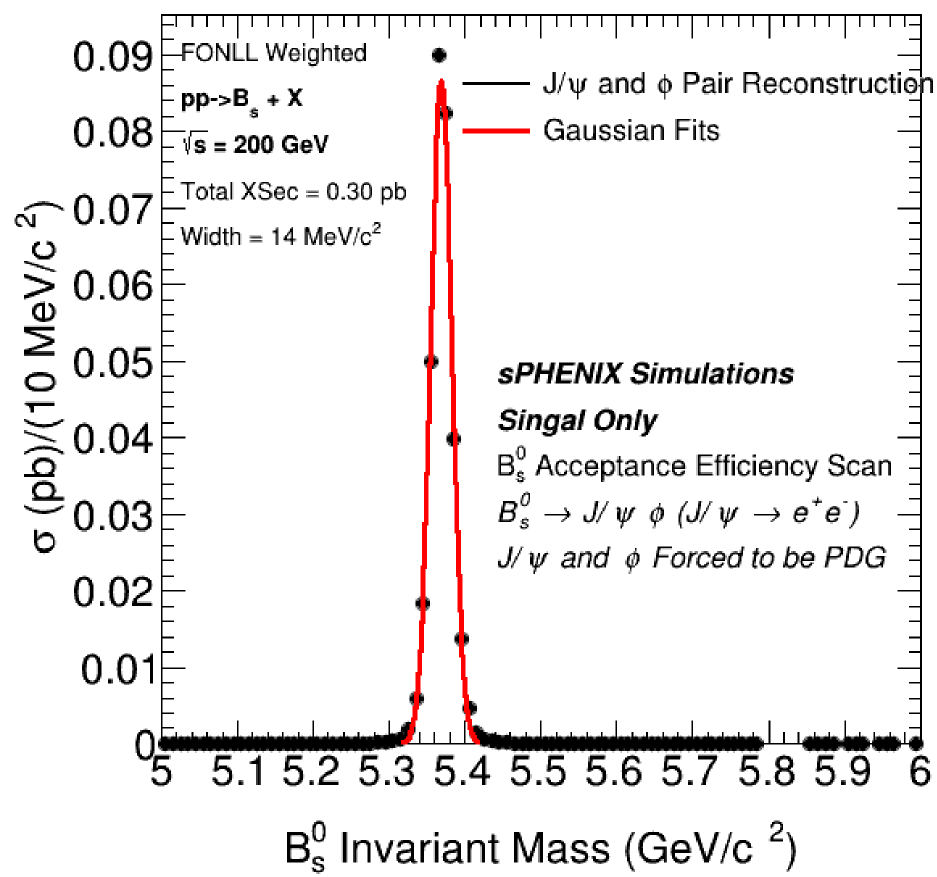
<u>MVTX</u>

- A copy from ALICE ITS with the inner three layers of silicon pixel detectors
- Excellent vertexing and tracking capabilities with MVTX and TPC

Physics

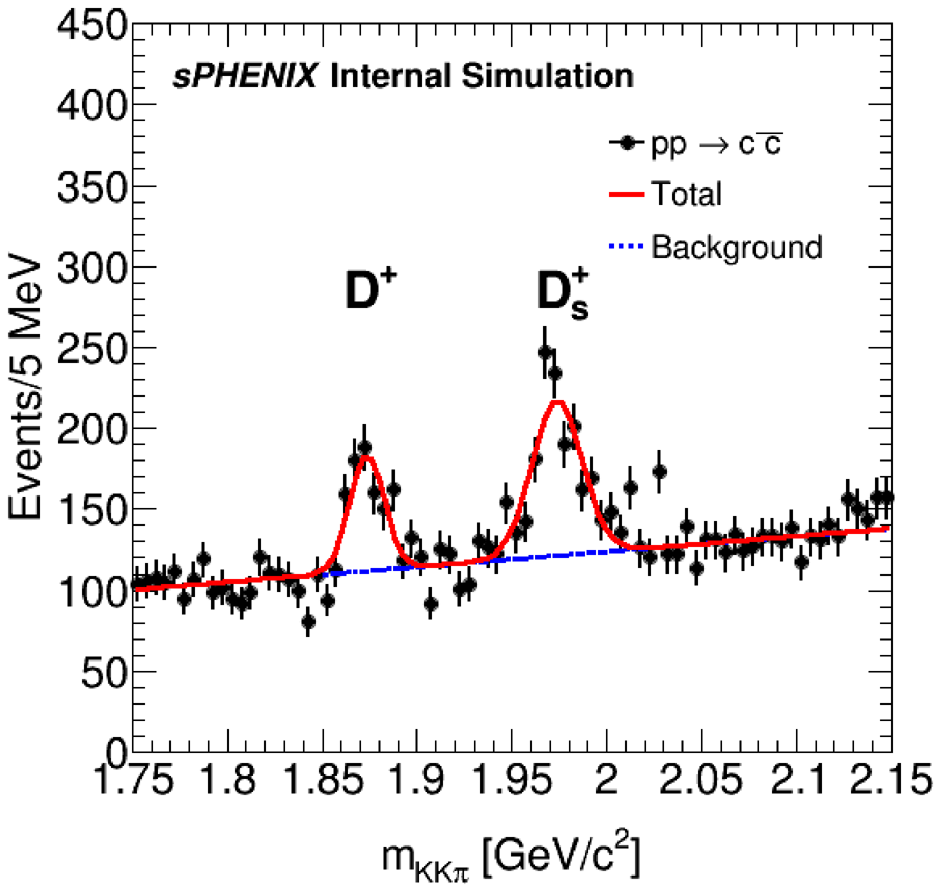
Full Signal B_s Simulations Performance

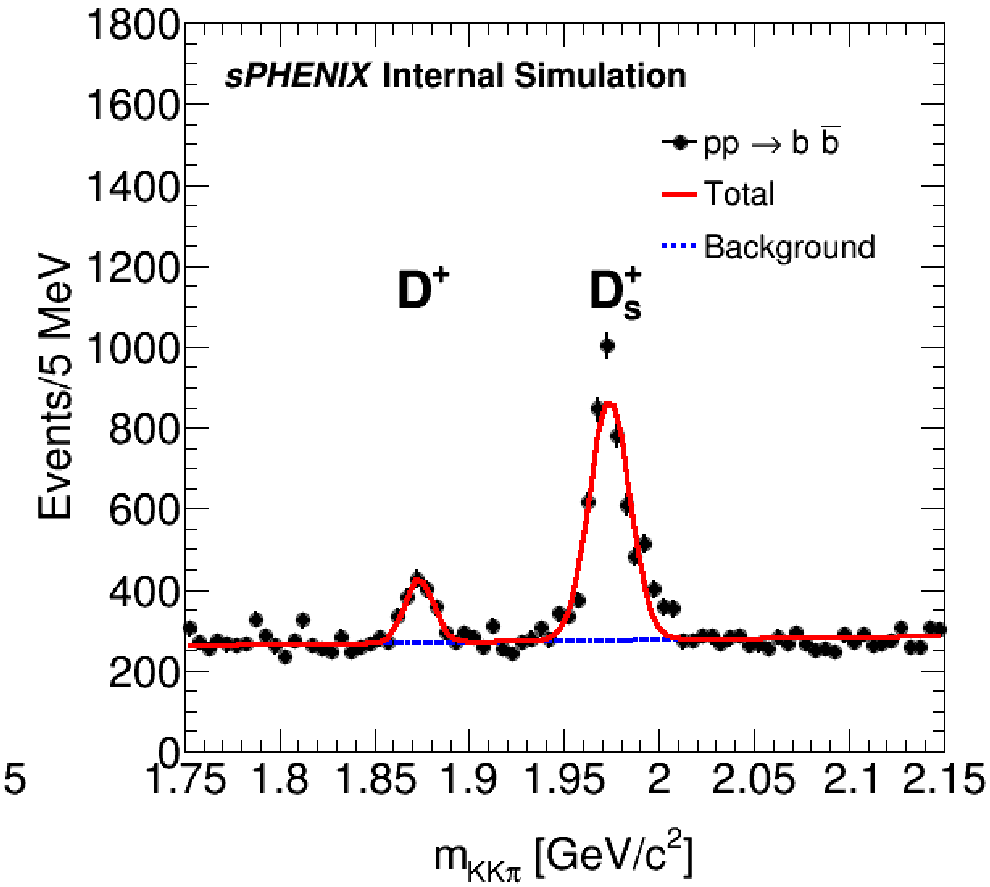




- Decay channels: $B_s^0 \rightarrow D_s^- \pi^+ \rightarrow \phi \pi^- \pi^+ \rightarrow K^+ K^- \pi^+ \pi^-$ and $B_s^0 \rightarrow J/\psi \phi \rightarrow e^+ e^- K^+ K^-$
- **Signal only simulation** considering acceptance and efficiency (weighted with FONLL)
- **Background:** Ongoing development of fast simulations with signal and background
- **Presented in ICHEP 2020 and Initial Stages 2021**

sPHENIX Mock Data Challenging Tests





- sPHENIX Mock Data Challenge: simulation of about 50 million $c\bar{c}$ and $b\bar{b}$ PYTHIA pp events
- Visible prompt and non-prompt D_s^+ signals in $c\bar{c}$ and $b\bar{b}$ sample with some simple selections
- **Presented in sPHENIX Software Computing Review and APS April Meeting**
- **sPHENIX analysis note: sPH-HF-2021-001**

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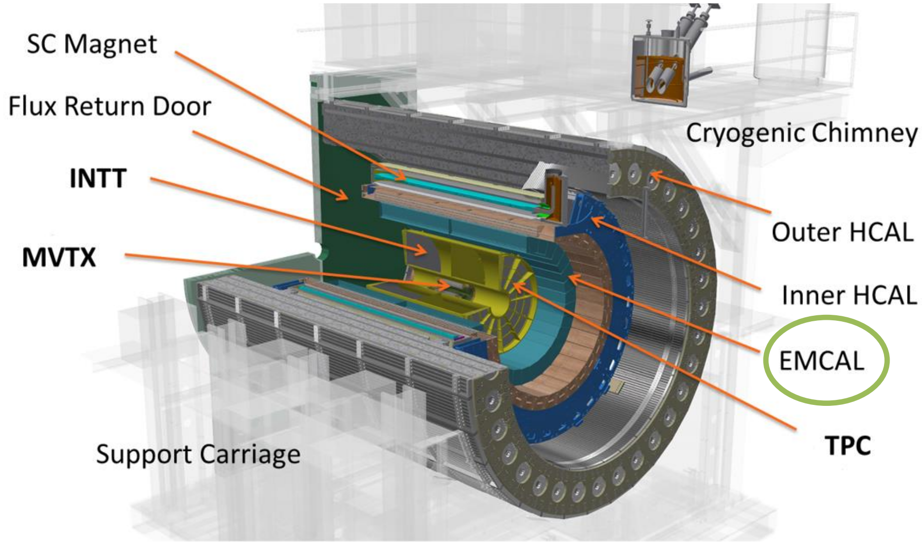
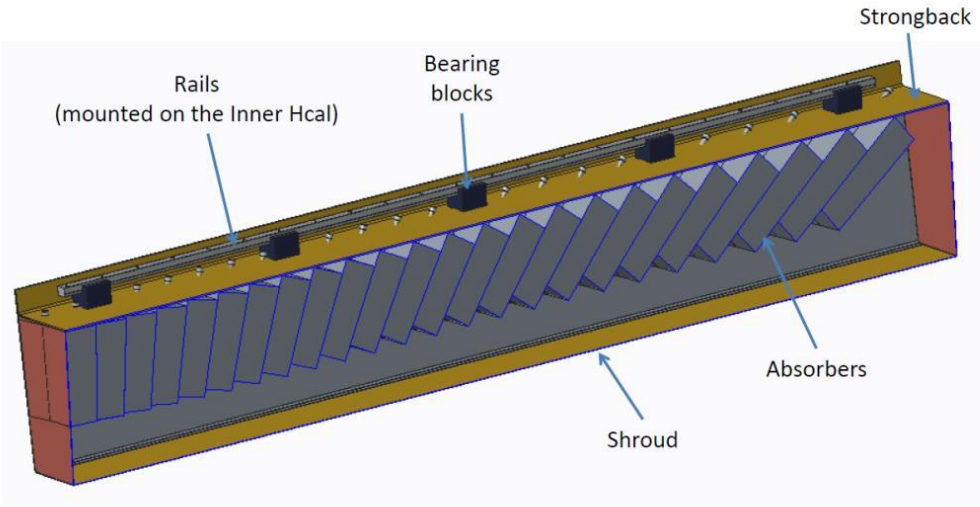
Physics

sPHENIX Detector – EMCAL

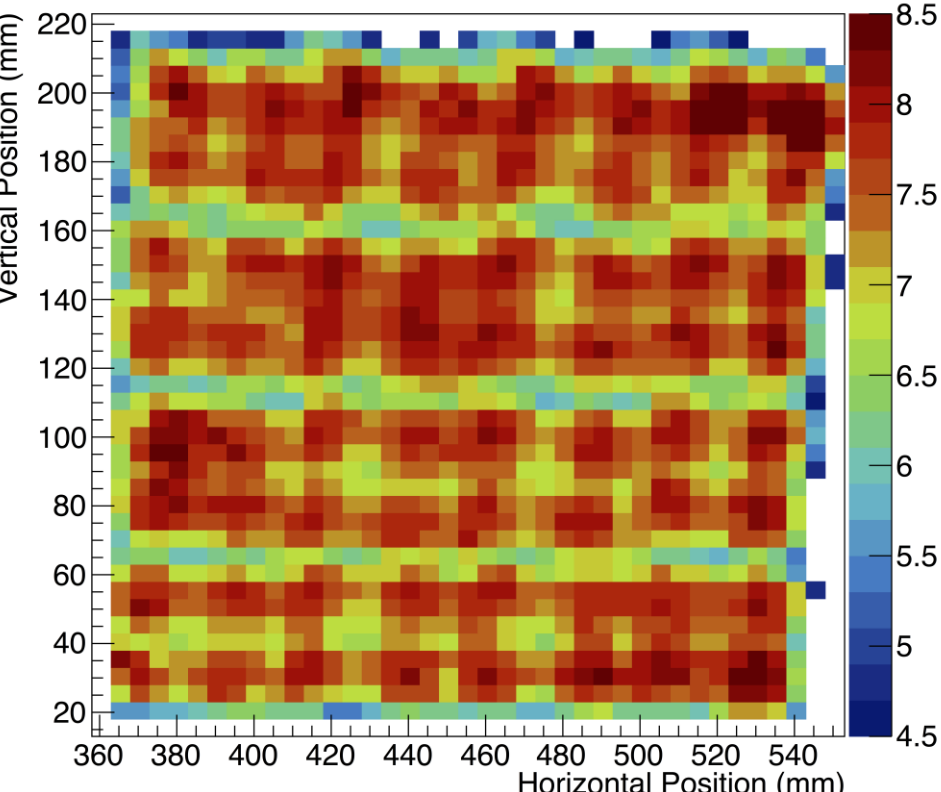




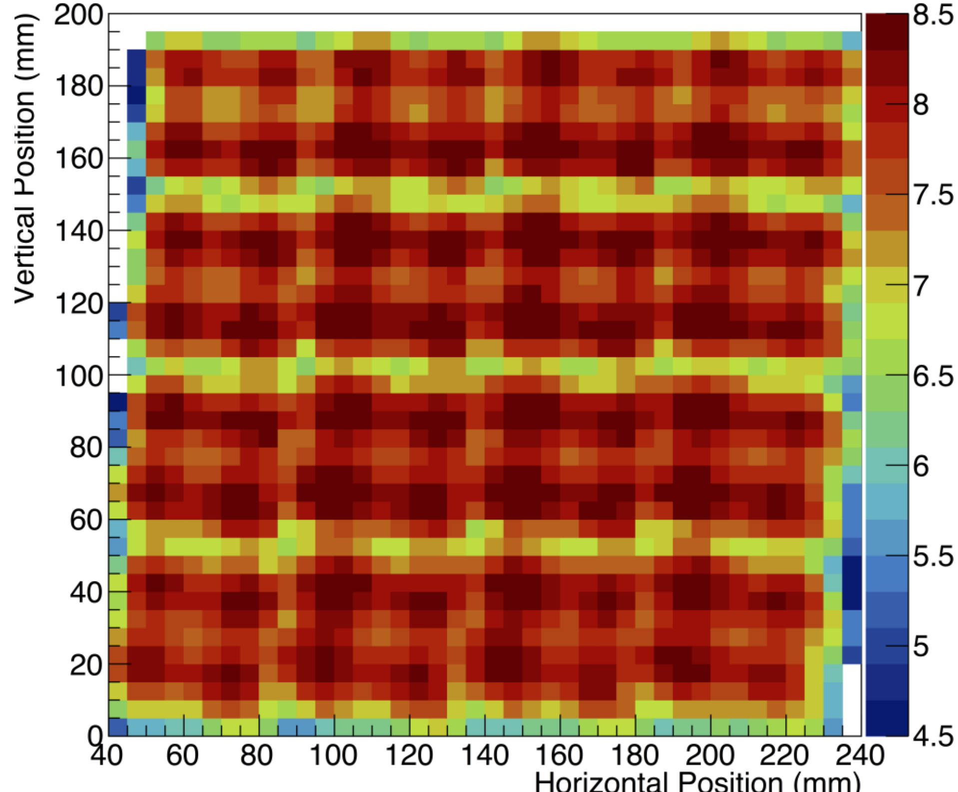
- W/scintillating fiber sampling EMCAL with 2D project SPACAL block design
- Acceptance coverage: 2π and $|\eta| < 1.1$
- Total radiation length: 18 X0 with $\Delta\eta \times \Delta\phi = 0.2 \times 0.2$
- Energy resolution: $\frac{\Delta E}{E} = 2.8\% \oplus \frac{15.5\%}{\sqrt{E}}$
- Good electron identification capabilities

sPHENIX EMCAL Uniformity Studies

Data



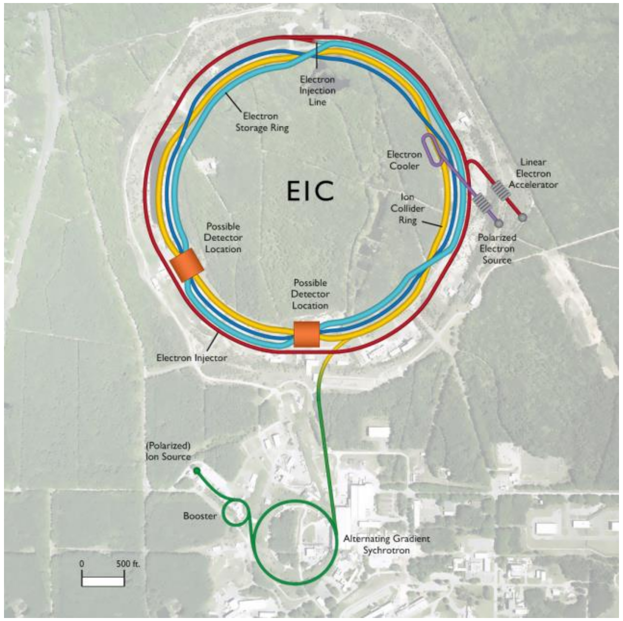
Simulation

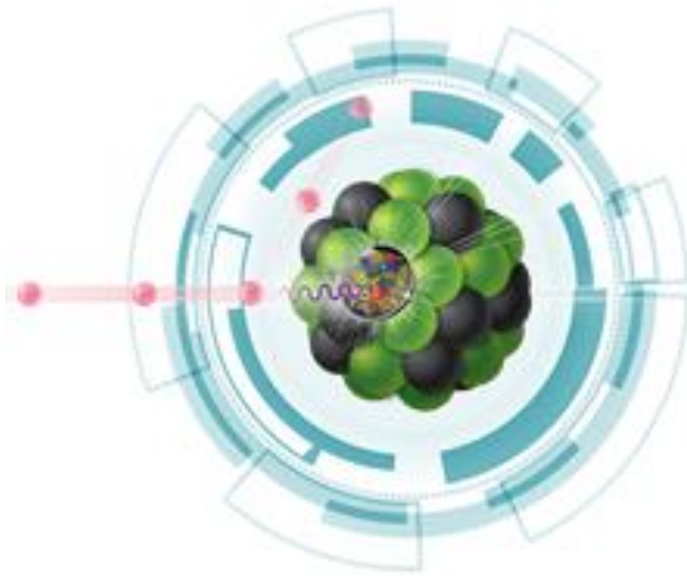


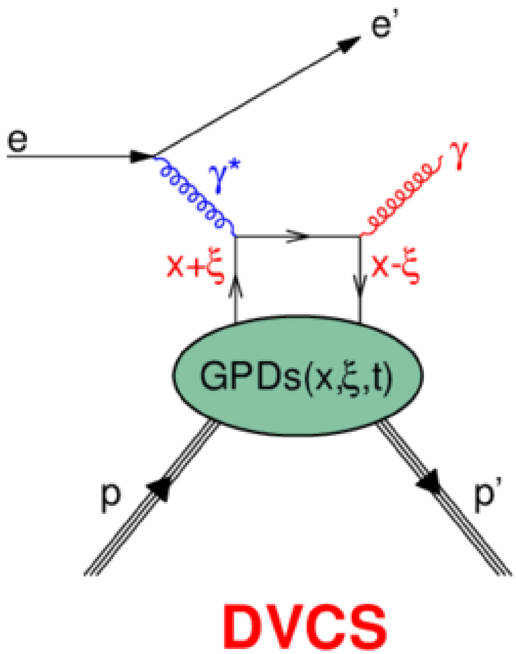
- Excellent consistency between data and simulation
- Solution to non-uniformity: position dependent correction with simulations
- **Published on IEEE Transaction on Nuclear Science Journal**
- **Connection to future EIC EMCAL R&D:** enhance with novel SiPM and large photocathode coverage as one of design options for EIC EMCAL

Physics

EIC Physics and Detector R&D







EIC Machine Capabilities

- Highly polarized beams with high luminosity
- Extensive kinematic phase space (x, Q^2) coverage with a large range of ion species
- Precision 3D imaging of nuclei via Deeply Virtual Compton Scattering (DVCS) experiments

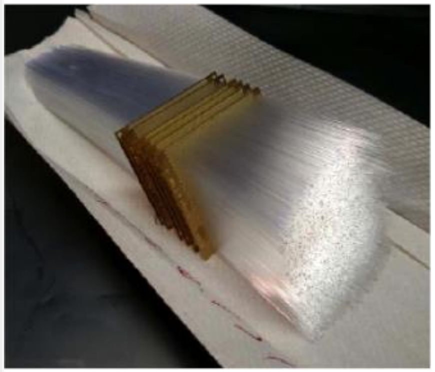
EIC Scientific Programs

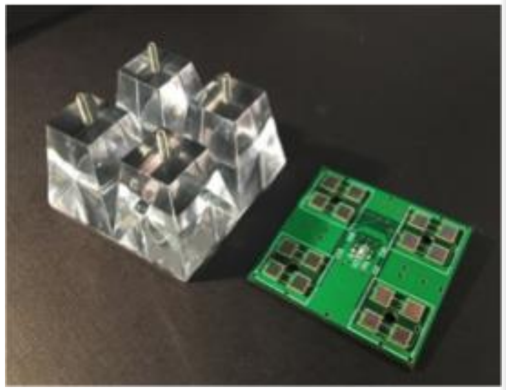
- Cold QCD: color confinement, partonic structure of hadrons, hadronization mechanisms
- ***Detector development: apply novel technologies to develop detectors for future EIC experiments to achieve EIC Physics Goals***

EMCAL Development for EIC Experiments

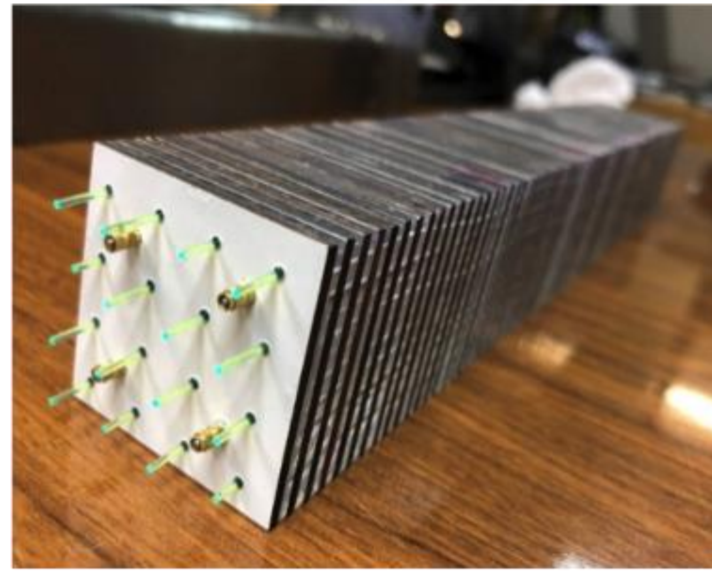
EMCAL Design Options

W/scintillating fiber with more SiPM and large photocathode coverage





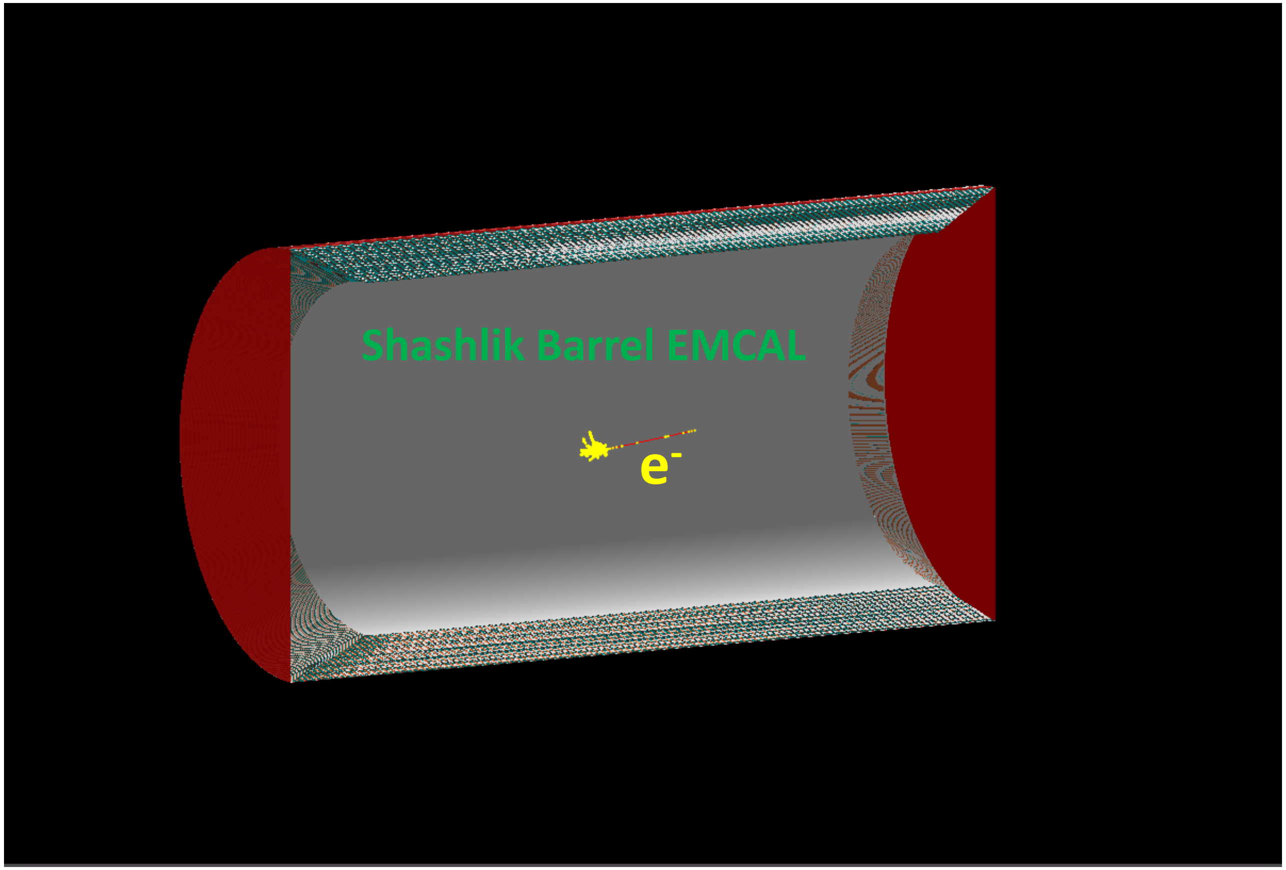
W/Shashlik tower design with high granularity and efficient readout



Novel Technologies Proposed

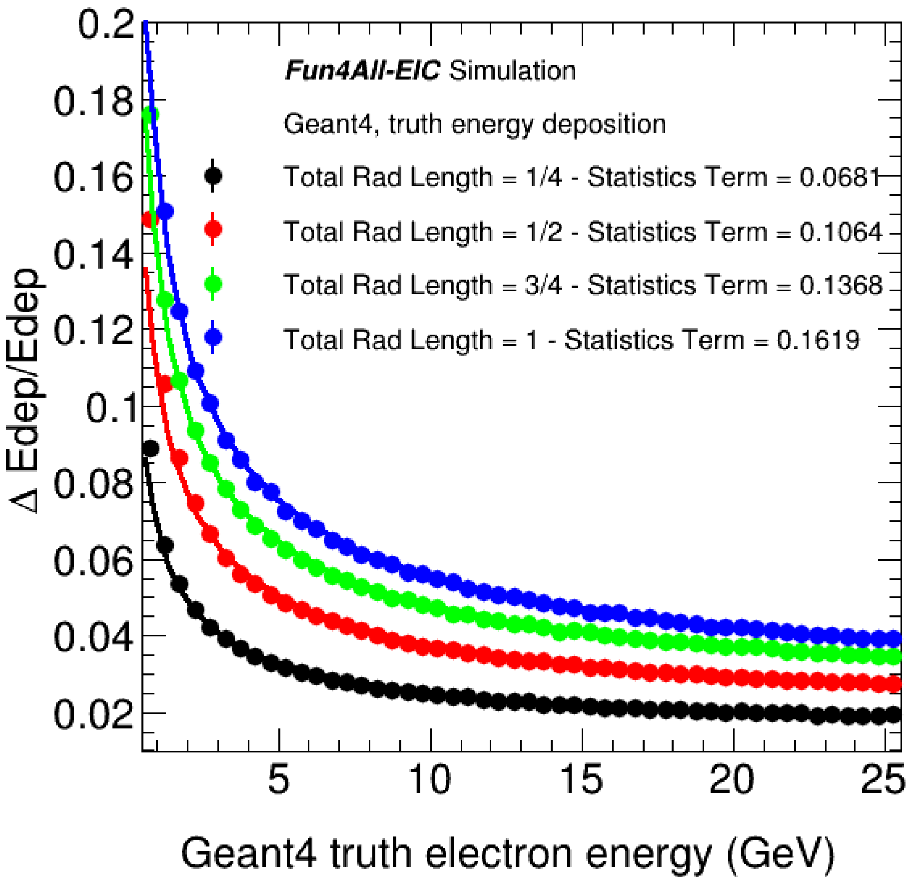
- Novel silicon photon-multiplier (SiPM) with $6 \times 6\ mm^2$ $15\ \mu m$ pixel size
- Application of EMCAL readout electronics with digitizing the calorimeter signal "Radio Frequency system on chip" (RFSoC) analogy to digital converter (ADC)
- Explore the possibility of high granularity (tower size < Moliere radius) EMCAL to measure DVCS and DVMP experiments in an extended kinematic regime

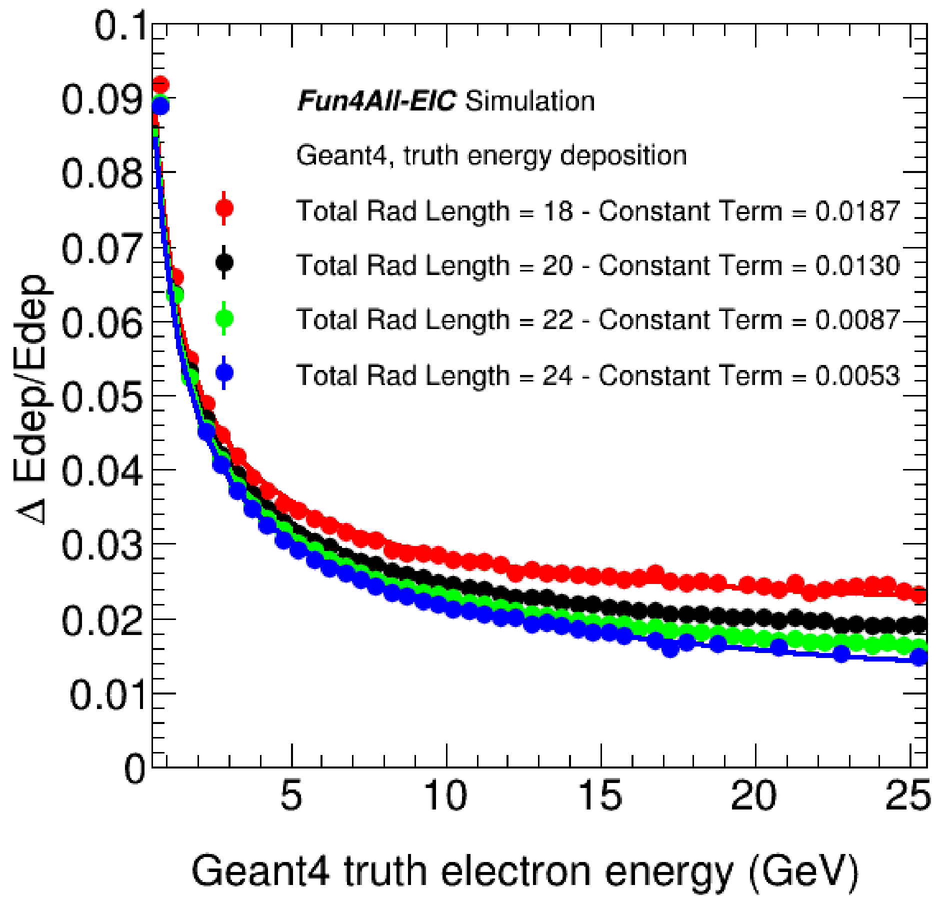
EIC Barrel EMCAL Simulations Setup



- GEANT 4 simulation of W/Cu (80/20 alloy) shashlik barrel EMCAL (r ~ 1 m)
- Event above: 1 GeV electron at η = 0 producing an electromagnetic shower
- Vary scintillator thickness and number of plates to study the effects of sampling frequency and total radiation length on EMCAL energy resolution

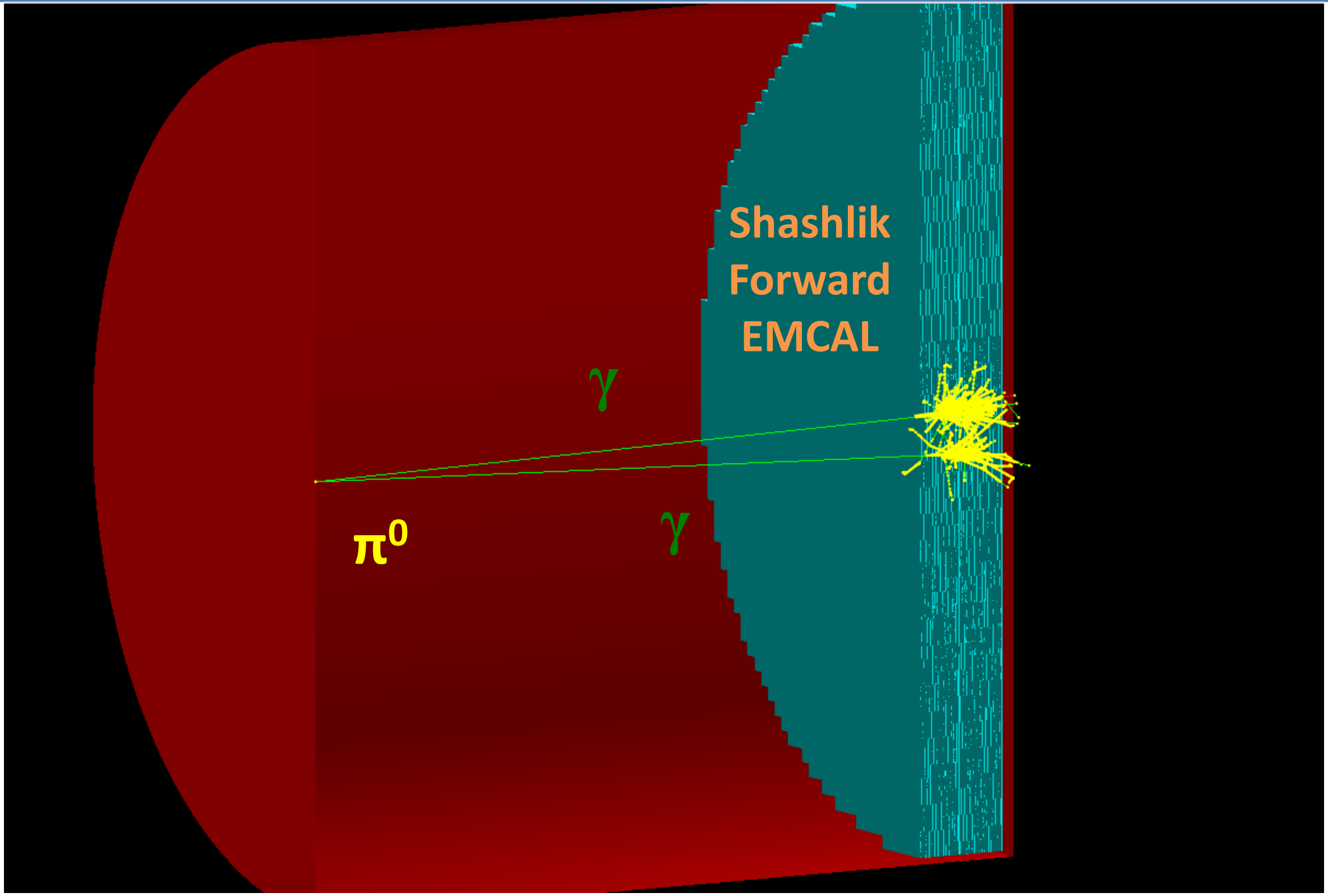
Barrel Shashlik EMCAL Energy Resolution





- The statistical term gets better as we goes to thinner scintillators
- The constant term gets better as the number of plates increases
- **Presented in eRD1 Yellow Report and ECCE and EIC Calorimetry Workshops**

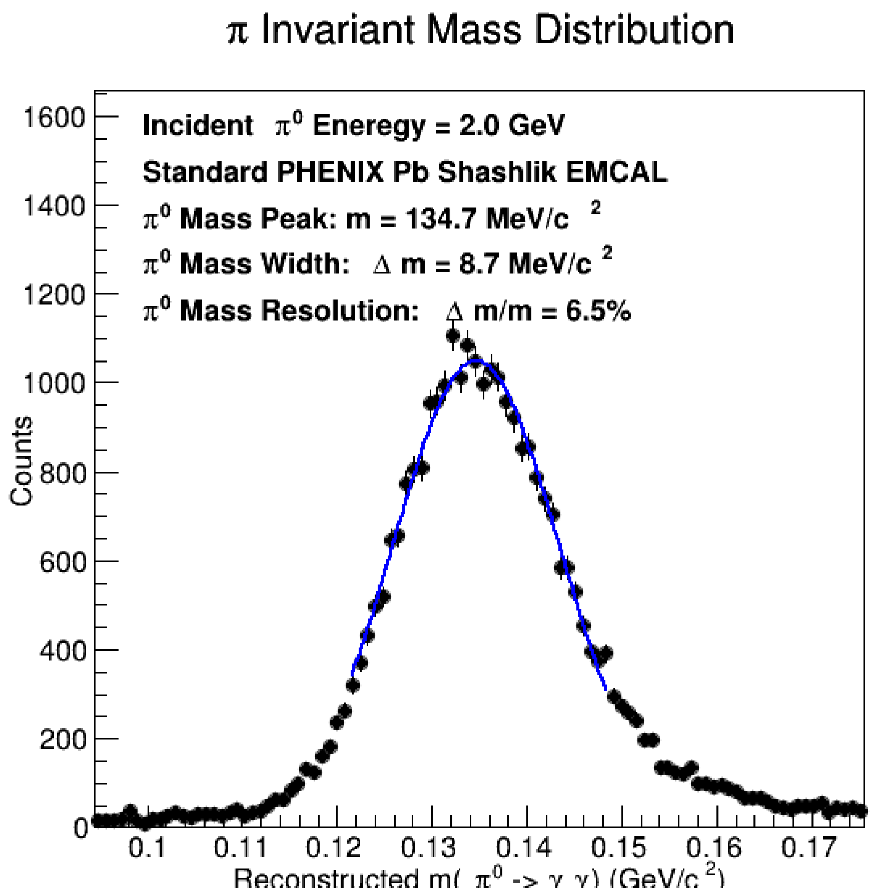
π^0 Merging Probability Setup

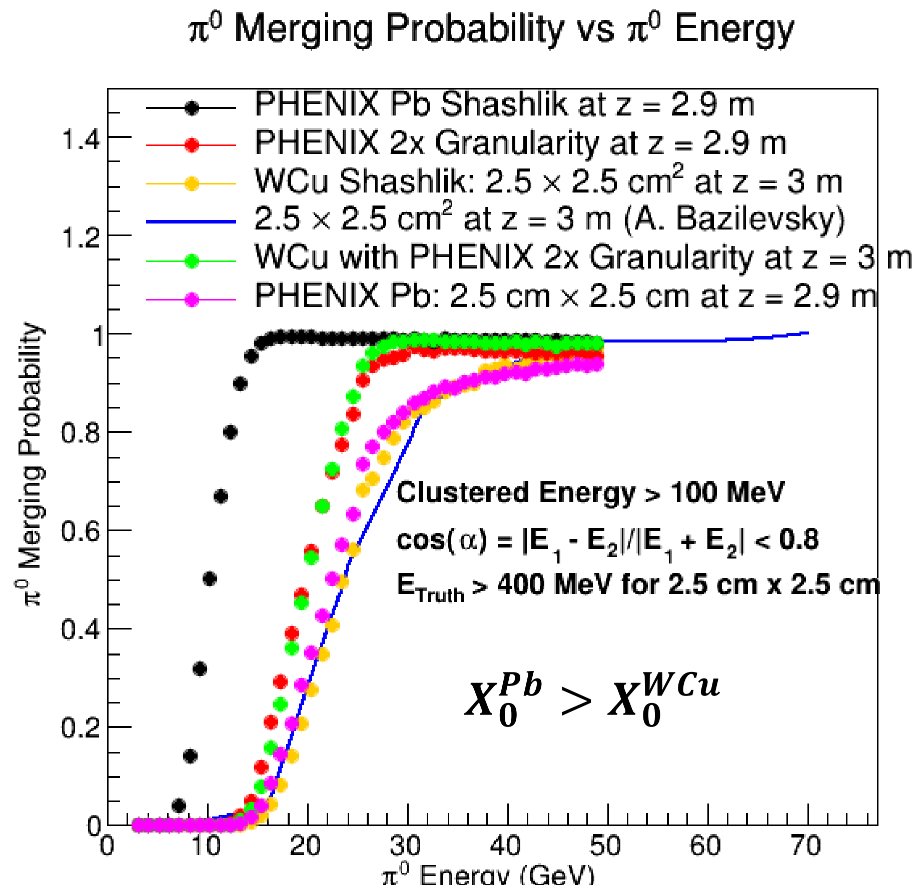


- Above shows a horizontal 1 GeV $\pi^0 \rightarrow \gamma\gamma$ decay events creating two EM clusters in the forward PHENIX Pb shashlik EMCAL
- Study π^0 merging probability of two clusters into one with various EMCAL granularities

MIT Physics

π^0 Merging Probability Studies





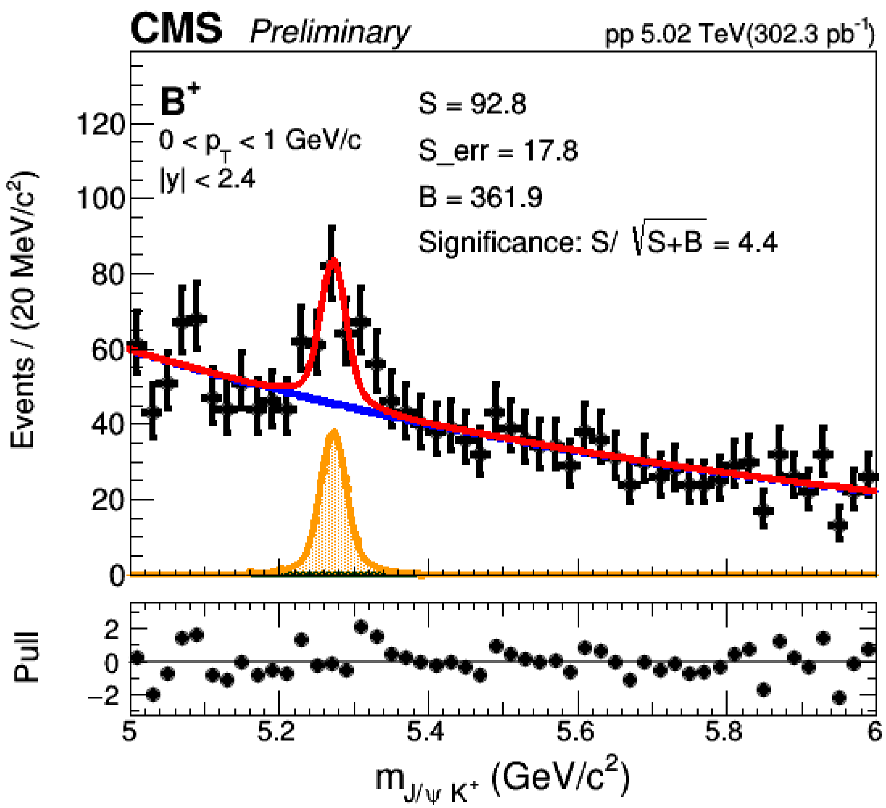
- π^0 merging probability decreases with finer granularity, allowing to reconstruct π^0 at higher energy
- π^0 merging probability has strong dependence on granularity and weak dependence on Moliere radius of the absorber materials at the parameter range
- Extend the kinematic acceptance of Deeply Virtual Meson Production measurements for GPD
- **Presented in EIC eRD1 Report and EIC Calorimetry workshops**

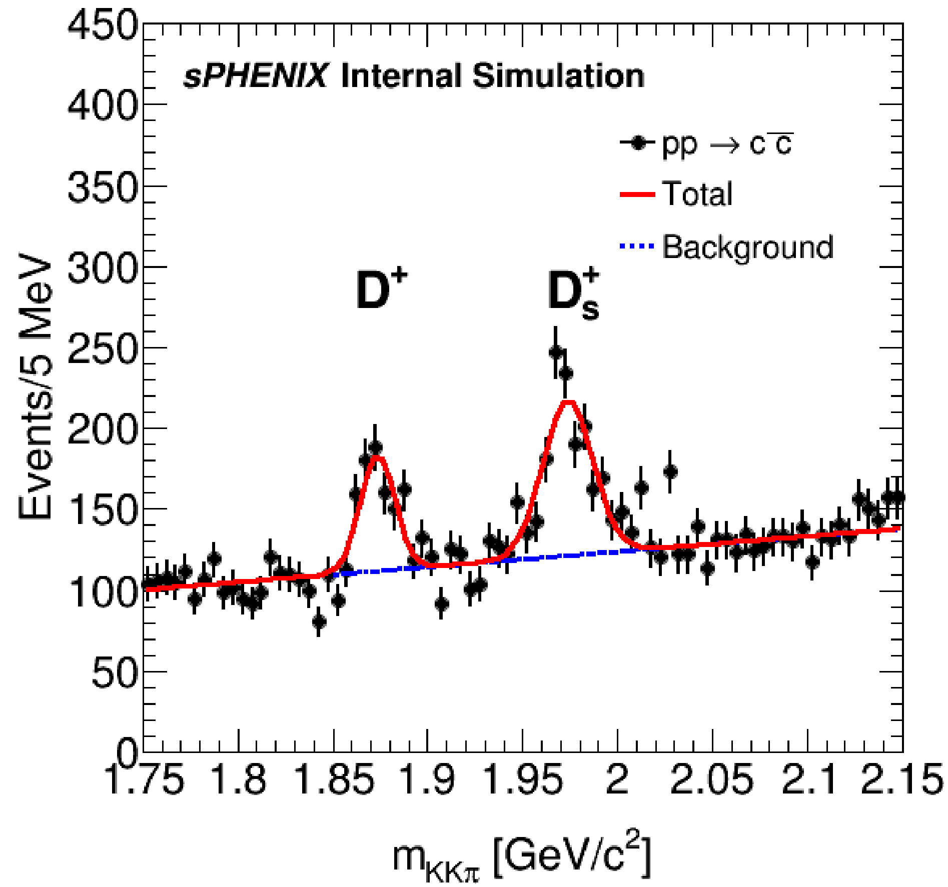
MIT Physics

Outline

- Beauty Hadrochemistry in Quark-Gluon Plasma at the LHC
- B and D meson Physics Simulation with sPHENIX
- sPHENIX EMCAL Studies and EIC EMCAL Simulations
- **Future Outlook**

Heavy Flavor Physics with Machine Learning

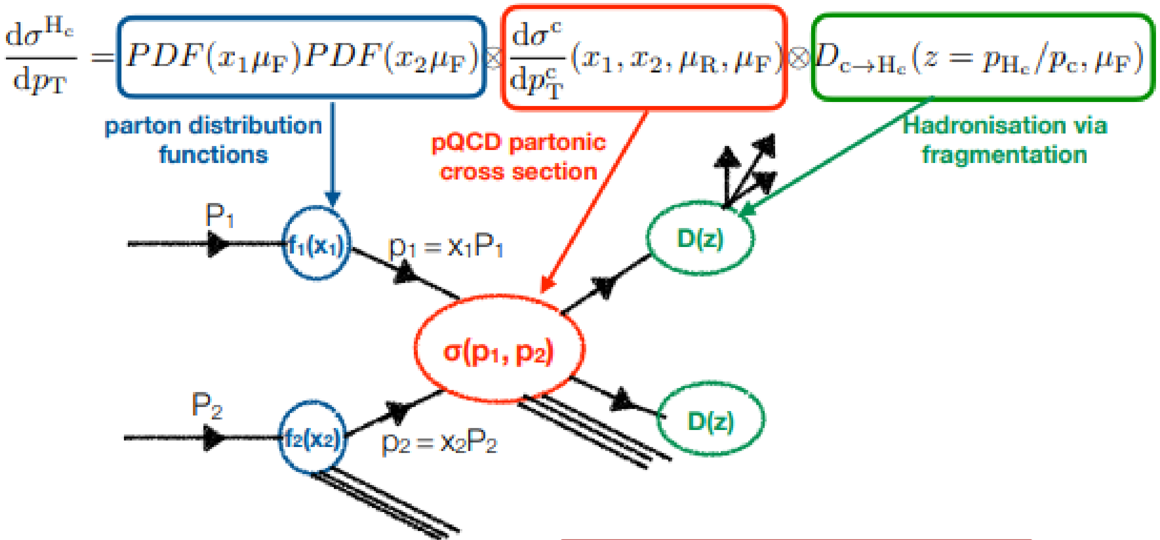


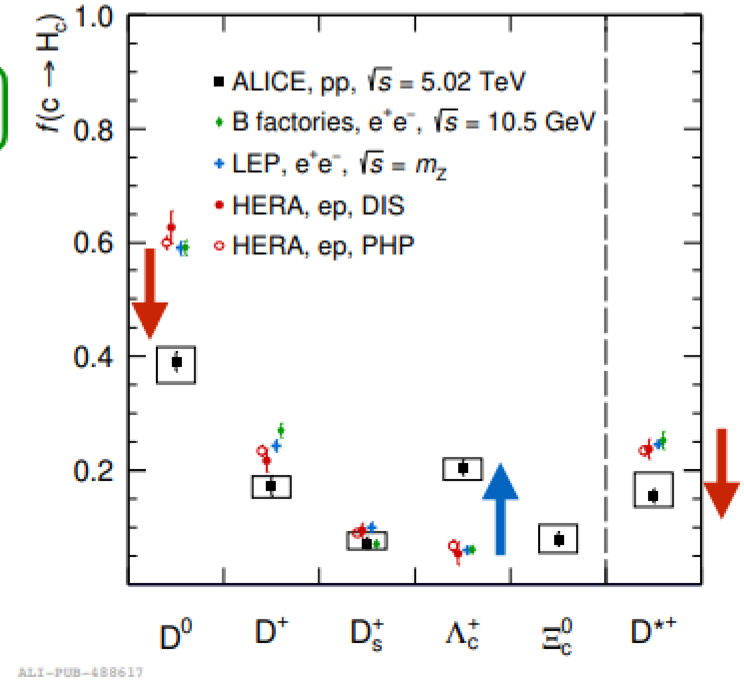


Opportunities with machine learning

- Applied in the full reconstruction of STAR and ALICE $D_s^{\pm}$, CMS B^+, B_s^0 and Λ_c^+
- Applicable as well for sPHENIX $D_s^{\pm}$ and B_s^0 and potentially in Λ_c^+ and Λ_b^+ studies
- Extend to low p_T and high multiplicity measurements thanks to machine learning and MVTX

Hadronization Universality Breaking





Innocenti: SQM 2021

- QCD Factorization Theorem: PDF ⊗ pQCD Diagrams ⊗ Fragmentation Function $D(z, Q^2)$
- Hadronization Universality: $D(z, Q^2) = D_{e^+e^-}(z, Q^2) = D_{ep}(z, Q^2) = D_{pp}(z, Q^2)$
- Broken due to quark coalescence mechanism? Additional dependence on color charge density: $D_{pp}(z, Q^2) \rightarrow D_{pp}(z, Q^2, n_c)$?
- Future opportunities: RHIC energy? EIC energy and collision systems? Beauty sector at RHIC and the LHC? Differential studies on Hadronization Universality Breaking?

Tentative Research Plans

- **Application of Machine Learning in Simulation and Analysis**

- **RHIC – sPHENIX Experiment**
- Physics simulations for B and D mesons
- MVTX quality control system software development and noise calibration
- Create and test analysis modules for general heavy flavor physics within the KF Particle and sPHENIX Fun4All software framework
- Add RHIC data points to test the hadronization universality
- B and D mesons data analysis with sPHENIX pp, pAu, and AuAu datasets

- **LHC – LHCb Experiment**
- LHCb Run III data analysis: heavy-ion program on B_c^+ and Λ_b^0 with LHCb
- Study hadronization universality in the beauty sector at LHC energy with LHCb
- Collaboration with the LHCb experts on exotic hadrons measurement in heavy-ion collision

Physics

Back Up

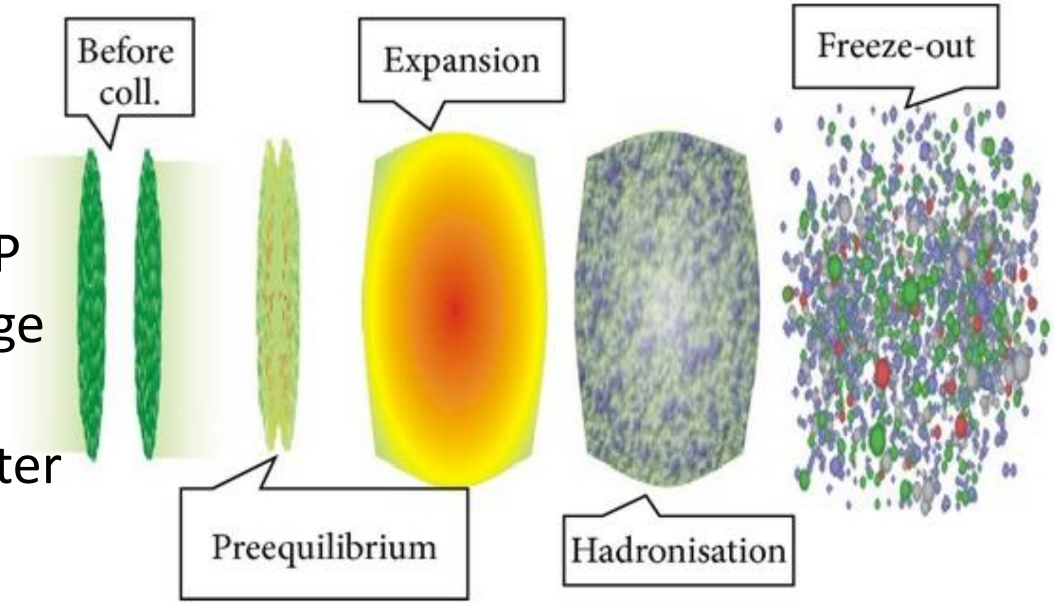
Laboratory for Relativistic Heavy-Ion Physics

Relativistic Heavy Ion Collisions:

- Use accelerators to collide heavy nuclei at high energy to create an extreme hot and dense environment (170 MeV -> Trillion degrees Kelvin)
- Experimental variables to control (knobs to turn):
  - Collision energy
  - Nuclei species
  - Impact parameter
  - Nuclei spin polarization

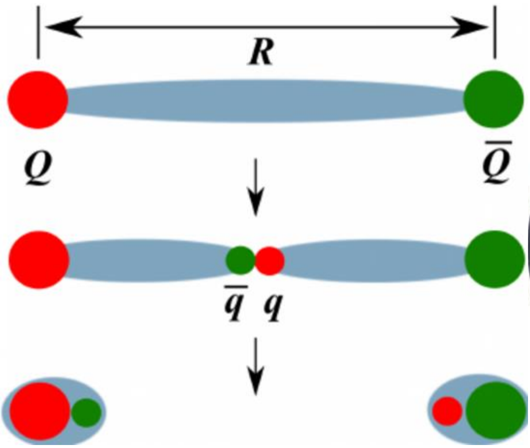
Stages in Heavy Ion Collisions:

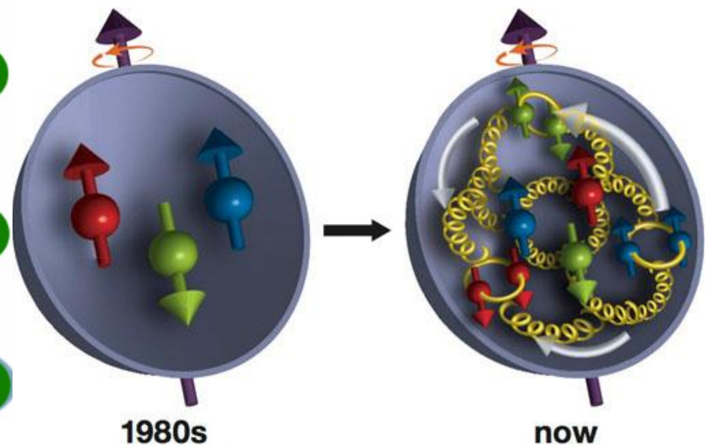
- Hot and dense QCD matter QGP exists during the expansion stage (lifetime ~ 10 fm/c ~ 10^{-23} s)
- Final state hadrons detected after the freeze-out stage

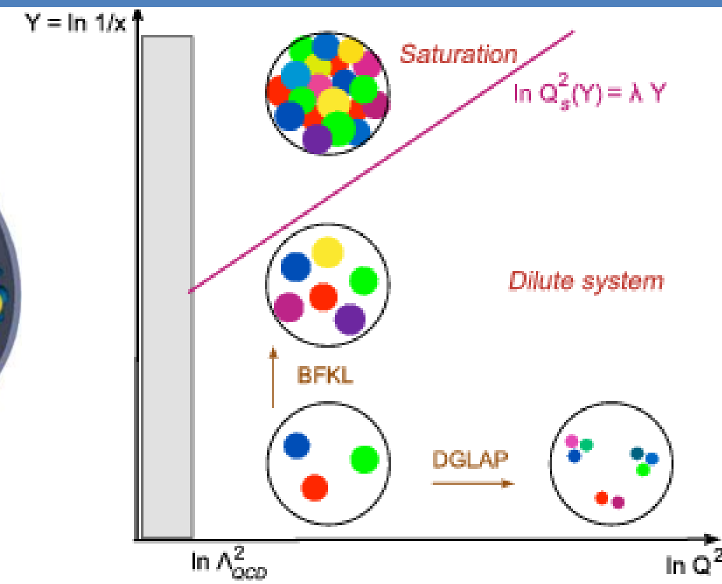


Physics

Cold QCD Physics

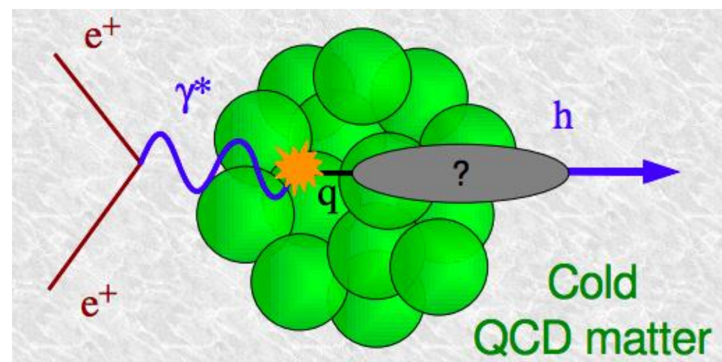






Color Confinement:

- Feature of non-abelian gauge theory
- Quarks and gluons are confined and form QCD bound states



Partonic Structure of Hadrons:

- Non-perturbative QCD at low temperature
- The spin structure of proton: angular momentum carried quarks and gluons in proton
- Gluon Saturation at small x: nuclear shadowing effect

Parton - Hadron Interaction and Hadronization Mechanism:

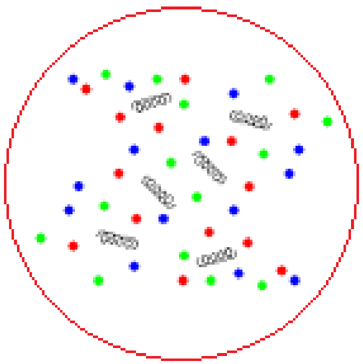
- Parton propagation in cold nuclear matter: modification of parton energy loss
- Parton hadronize in color environment: cold nuclear matter effects on hadronization

Physics

Research Interests

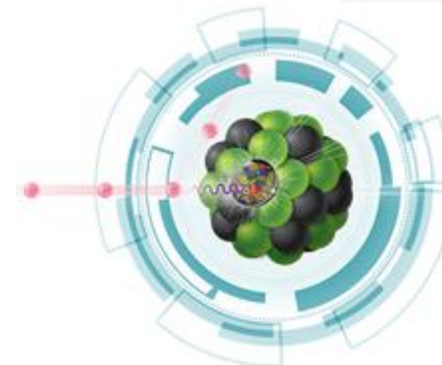
Hot QCD

Quark Gluon Plasma



- QCD at very high temperature
- Deconfined quarks and gluons

Cold QCD

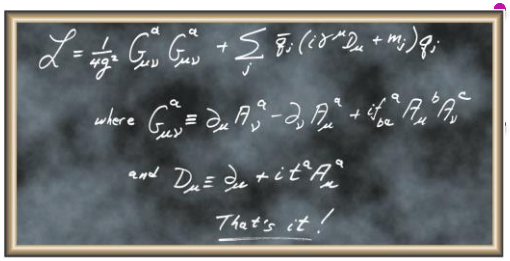


- QCD at lower temperature
- Quarks and gluons are confined and form hadrons

EIC Detector R&D

- Precision 3D imaging of nucleons
- Application of novel technologies to detector R&D

Nuclear Phenomenology



- Cold QCD model development
- Propose new experimental observables and ideas for EIC

Physics

Physics Motivations

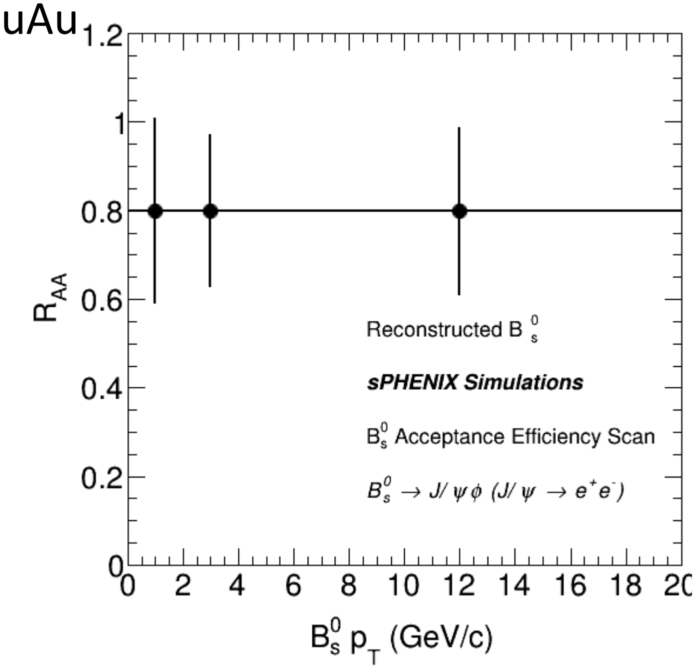
Physics Motivations

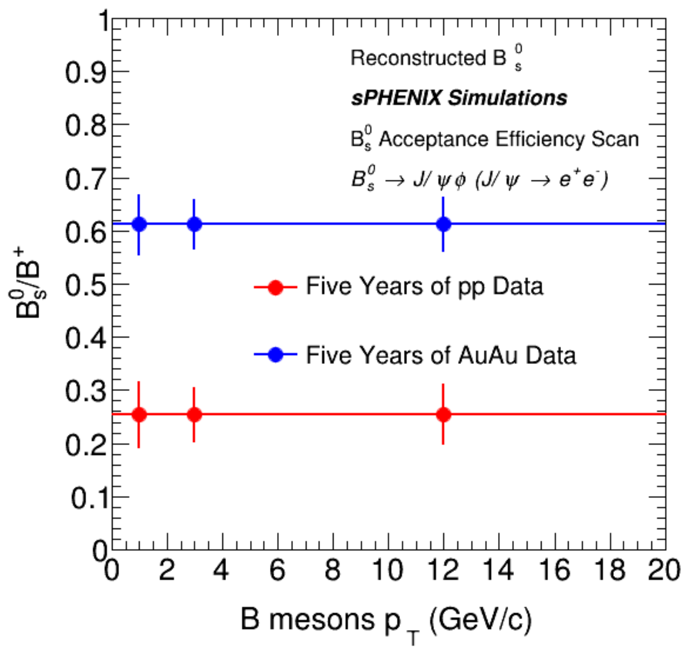
- Complementary heavy flavor measurements to LHC experiments
- Probing QGP at different temperatures and baryon chemical potentials
- More comprehensive understanding beauty hadronization mechanism
- Measurement of inclusive beauty cross section in pp and AuAu at RHIC energy

Experimental Observables:

- B_s and B^+ nuclear modification factor
- B_s/B^+ Ratio in pp and AuAu

Lumi = 1.4 fb^{-1}





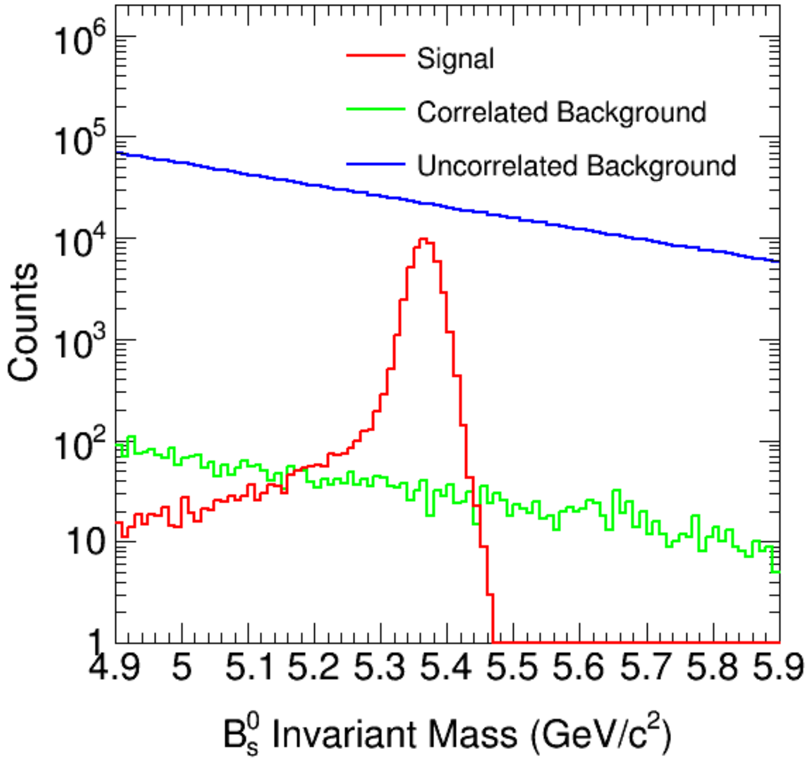
Physics

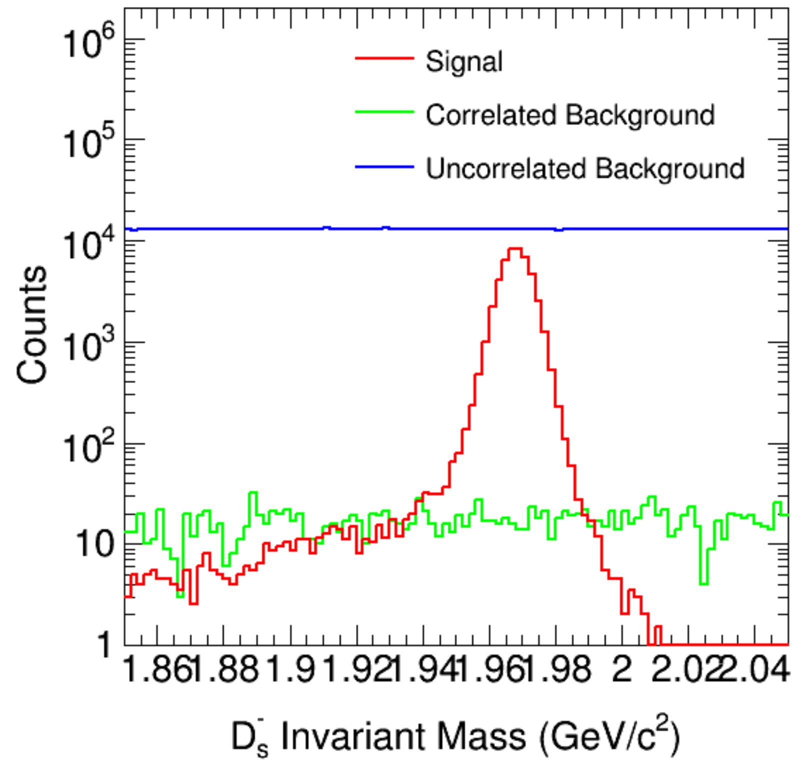
Machine Learning Techniques in B-meson Selections

Muon acceptance

$\|\eta\|$	0 – 1.2	1.2 – 2.1	2.1 – 2.4
p_T (GeV/c)	> 3.5	> 5.47 – 1.89 $\|\eta\|$	> 1.5

sPHENIX Fast Simulations (Ongoing)





Fast simulation Machinery:

- Simulation sample: total 480000 events filtered with some event and track quality selections
- Signal: EvtGen package to force B_s -> D_s decay channel
- Correlated background: $pp \rightarrow b\bar{b}$ with PYTHIA 8
- Uncorrelated background: randomly sample identified p, K, π spectra from primary vertex

Everything is still in the beginning!!! More validations and improvements still ongoing!

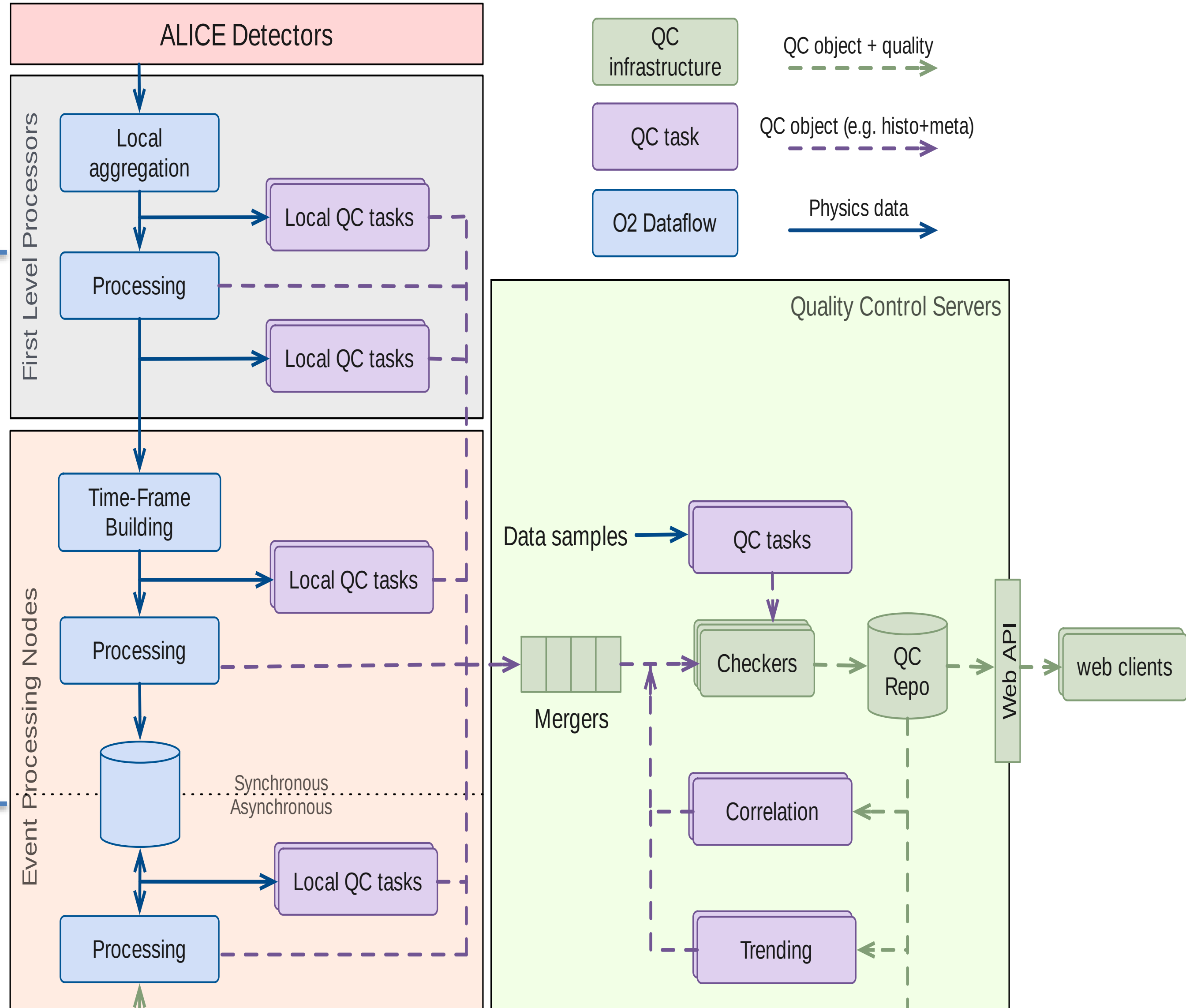
Physics

Quality Control Software System for ALICE ITS Upgrade

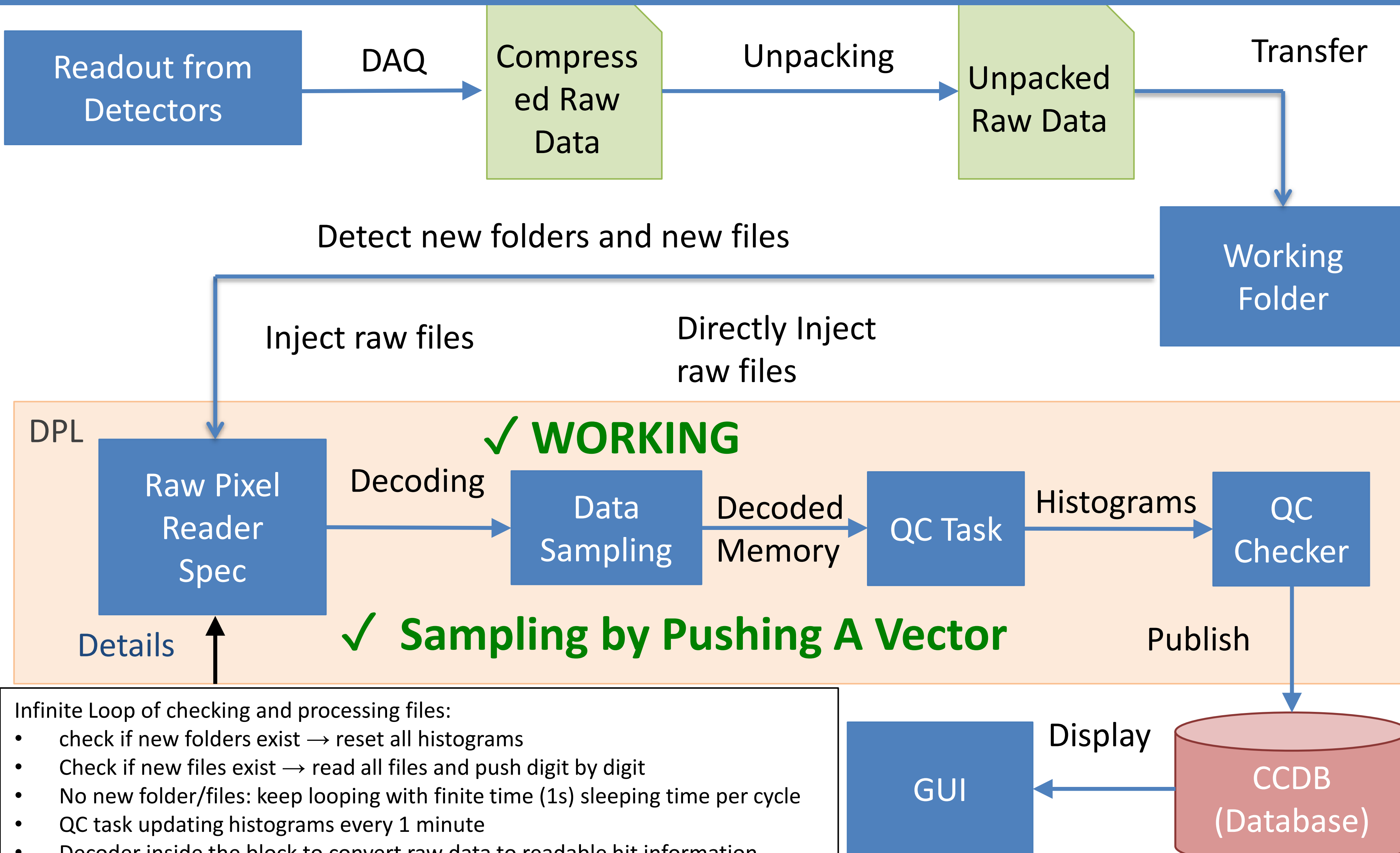
General ALICE QC Framework

Currently, in ALICE ITS commissioning, the QC are all installed in the FLP machines

In principle, QC can also be installed at EPN if needed



QC Workflow



Infinite Loop of checking and processing files:

- check if new folders exist → reset all histograms
- Check if new files exist → read all files and push digit by digit
- No new folder/files: keep looping with finite time (1s) sleeping time per cycle
- QC task updating histograms every 1 minute
- Decoder inside the block to convert raw data to readable hit information

MIT Physics

CCDB Database

- **System**
- CCDB is a database that stores the histograms of the analysis results
- CCDB will only clean up every hour and keep the one histogram in a hour
- CCDB has a total storage of about 700 GB
- CCDB for ALICE ITS commissioning website: http://ccdb-test.cern.ch:8080/browse/ITSRAWDS

- **Features**
- Tree structure of the analysis results
- Metadata (RunID + FileID) has been implemented along with the tree structure on CCDB

ID	Valid from	Valid until	Initial validity limit	Created at	Last modified	MD5	File name	Content type	Size	Path	Metadata	Replicas
d75ed4d0-be9d-11e9-a7a5-808d5c675566	1565792074393 14 Aug 2019 16:14	1881152074393 11 Aug 2029 16:14	1881152074393 11 Aug 2029 16:14	1565792074397 14 Aug 2019 16:14	1565792074397 14 Aug 2019 16:14	91bfe25031a229cf0e31b7bae37afebf	ITSQC/General/ErrorPlots_1565792074393.root	application/octet-stream	833	ITSRAWDS/ITSQC/General/ErrorPlots	partName send Run 1621 File 0 quality 10	• 0
77de5380-bdff-11e9-a7a4-808d5c675566	1565724053684 13 Aug 2019 21:20	1565792074392 14 Aug 2019 16:14	1881084053684 10 Aug 2029 21:20	1565724053688 13 Aug 2019 21:20	1565724053688 13 Aug 2019 21:20	322875321099bf55611c76b417b65537	ITSQC/General/ErrorPlots_1565724053684.root	application/octet-stream	833	ITSRAWDS/ITSQC/General/ErrorPlots	UpdatedFrom 2001:1458:202:28:0:0:100:35 partName send Run 1610 File 3 quality 10	• 0

- Retrieving old data based on the metadata is available from metadata for further analysis

Physics

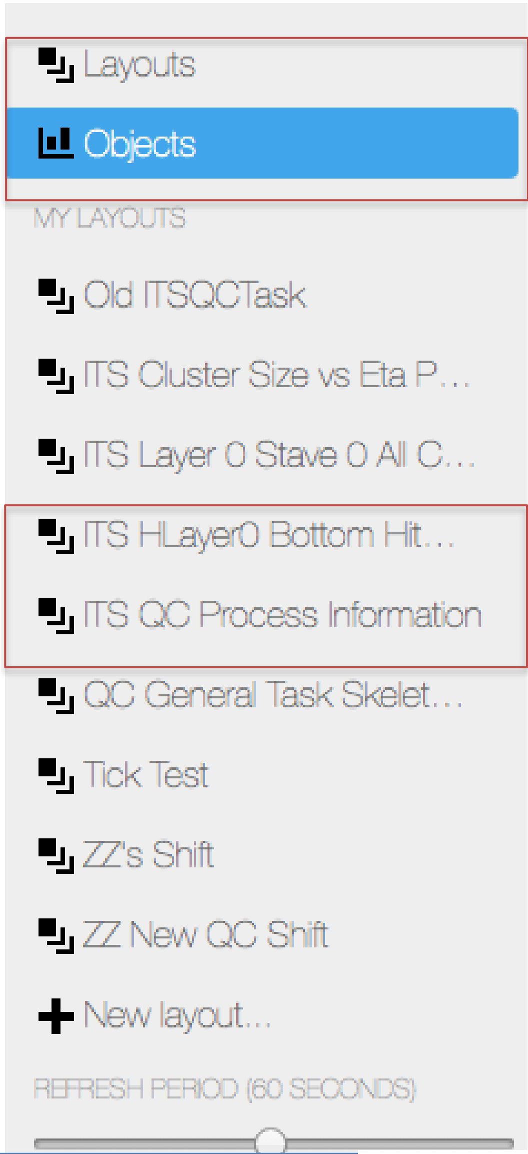
GUI

- **System**

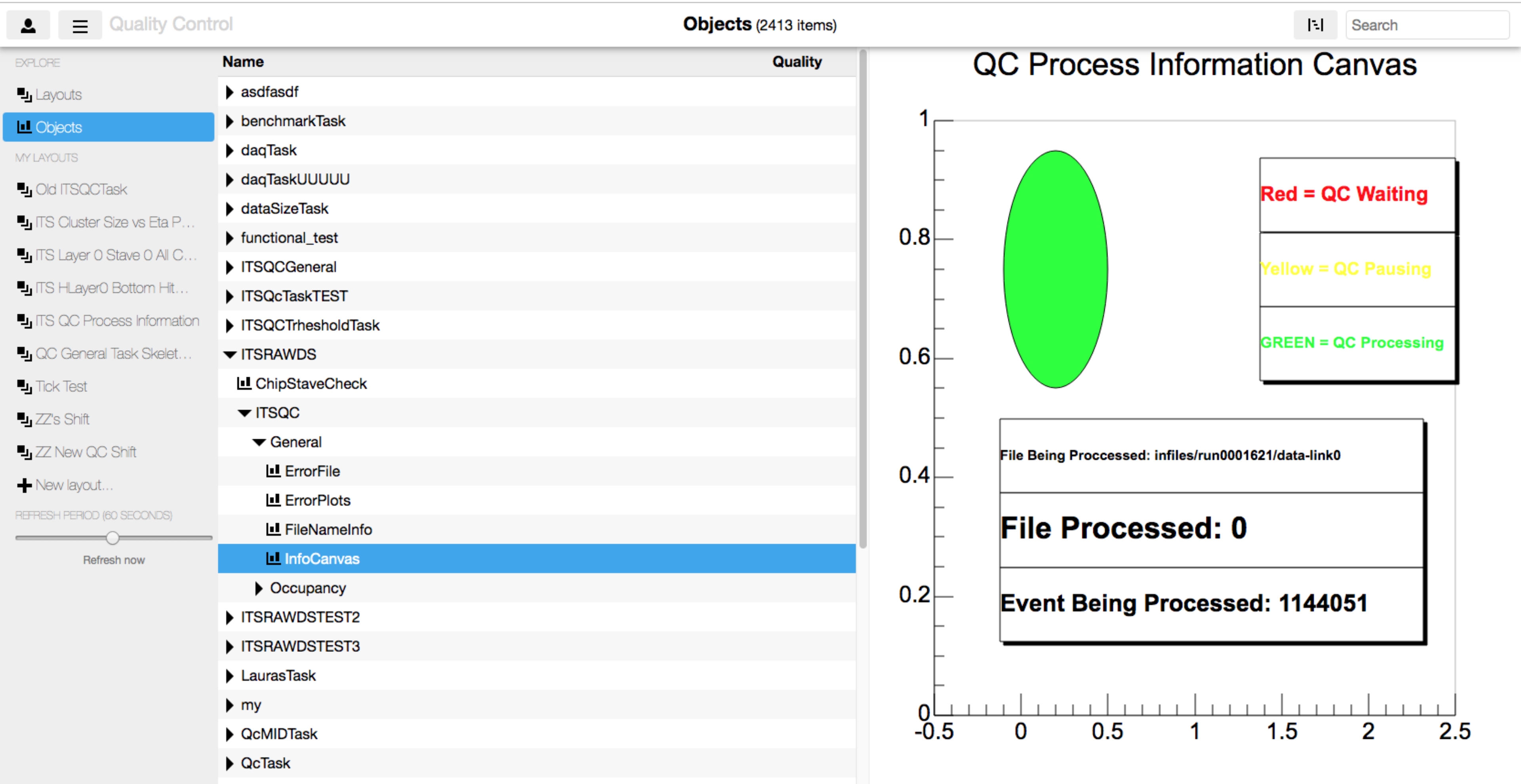
- GUI for ALICE ITS commissioning website (ALICE Access Required): https://qcg-test.cern.ch/?page=layoutList
- GUI will automatically refresh every 60 second
- GUI has objects and layouts
- Histogram plots are stored at the objects under the Task name folder. The GUI also has a tree structure similar to the CCDB

- **Features**

- User can create (and name), modify (and rename) and delete a layout and selection plots from the objects to put in the layout
- The plots size on the layout can be adjusted to 1 × 1, 1 × 2, 2 × 2, 3 × 3, ect. The layout page size is 4 × 4
- The draw options such as “COLZ” and log x and y options are also available
- Currently, we have two layout for the ALICE ITS commissioning shift: ITS QC Process information and ITS HLayer0 Bottom Hit



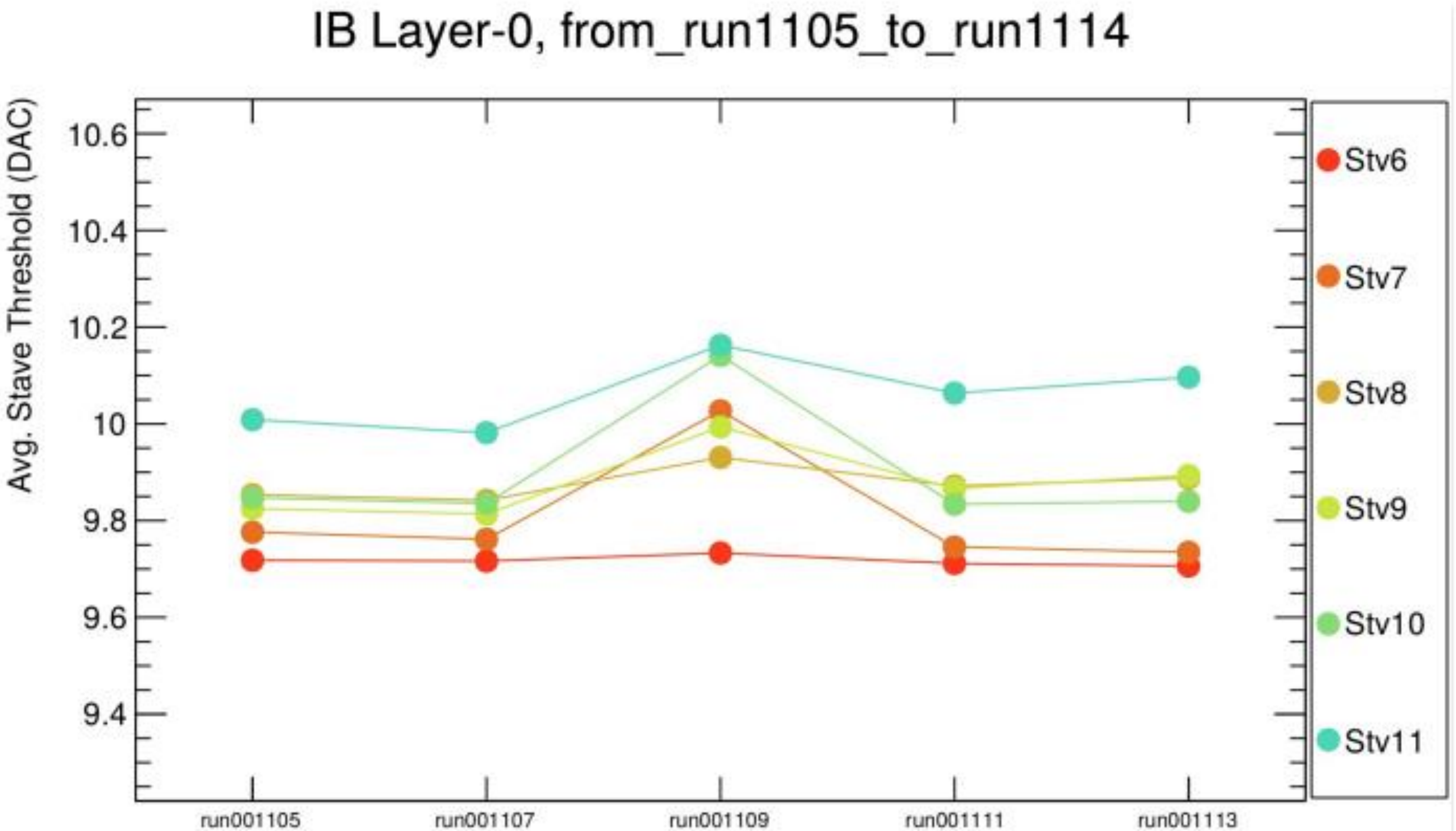
Object Examples on the GUI



- Tree structure for ALICE ITS commissioning QC
- Many other ALICE QC tasks are also saved in the GUI

QC Shift Results

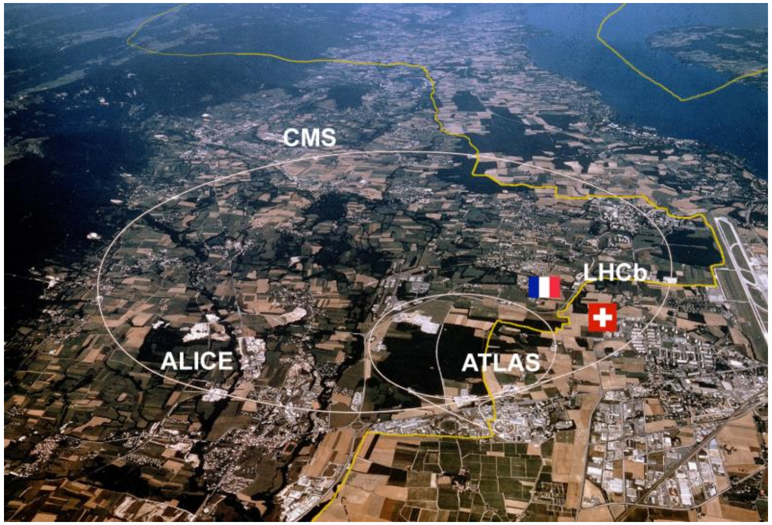
- We also create a weekly QC shift to perform the analysis on the ITS performance on larger time scale based on the QC output retrieved from CCDB
- We can visualize the ITS performance over a week for different runs



Physics

Current Experimental Facilities

LHC (Large Hadron Collider – CERN, Meyrin, Switzerland)



Higher collision energy

- Higher temperature
- Lower baryon chemical potential

Quark-gluon Plasma is discovered at SPS at CERN in Feb 2000

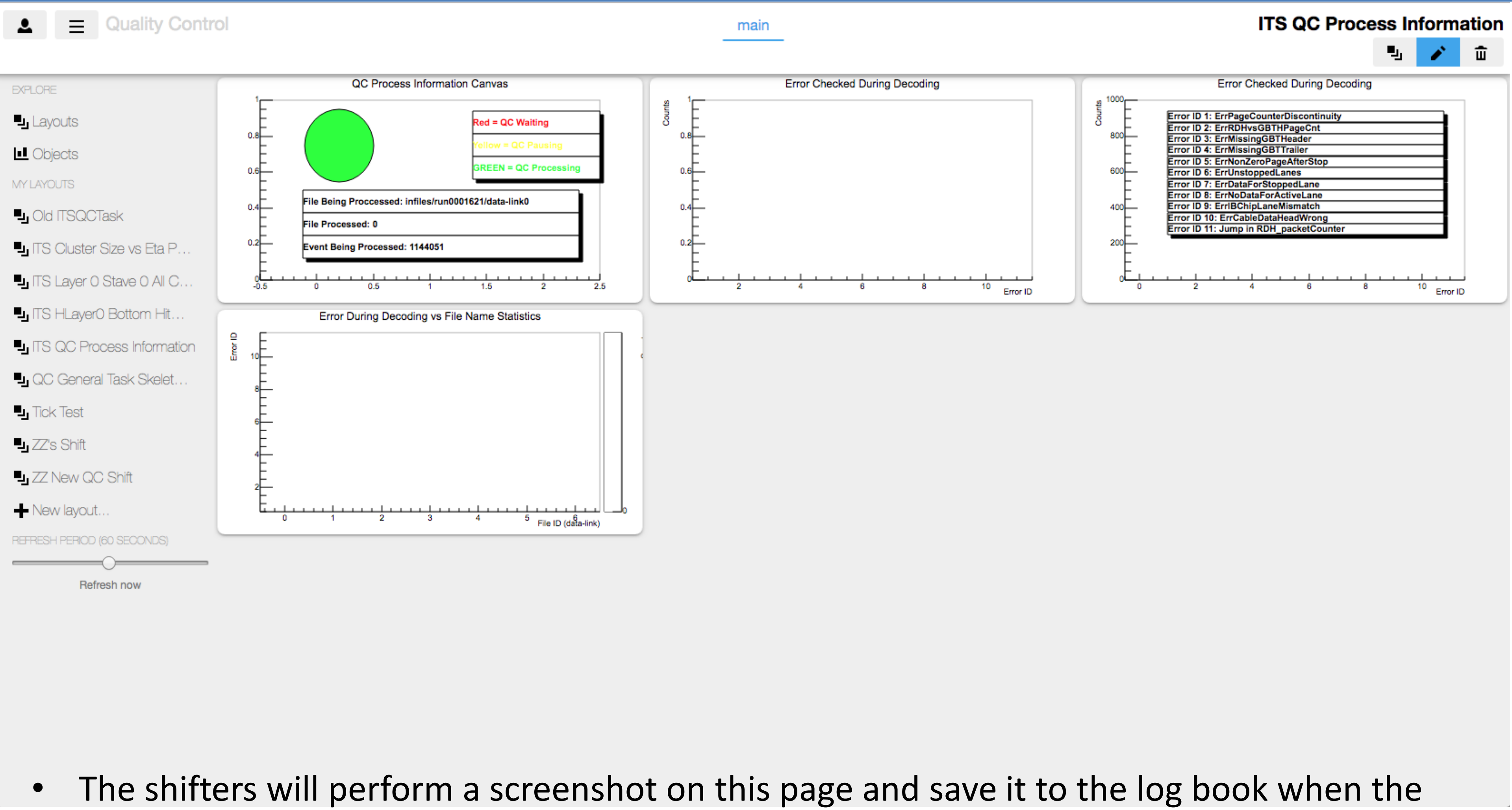
RHIC (Relativistic Heavy Ion Collider – BNL, New York, USA)

More colliding nuclei species and various collision energies

- Different temperature and baryon chemical potential
- Different system size

Physics

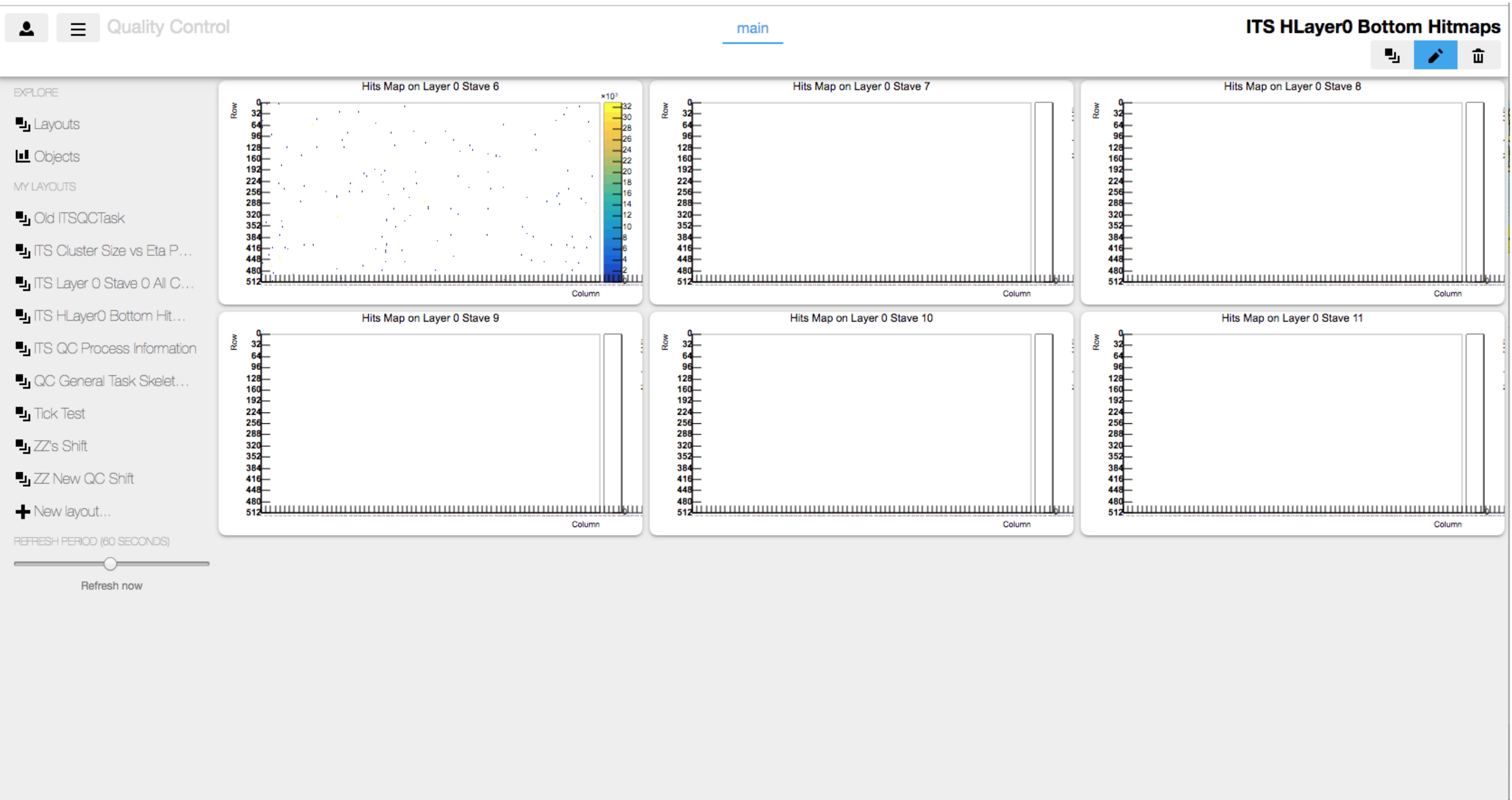
General QC Information Canvas



- The shifters will perform a screenshot on this page and save it to the log book when the green light turns red
- **Will develop similar quality control software system for sPHENIX MVTX**

Physics

2D Hit Maps for ITS Layer 0



- The shifters will perform a screenshot on also this page and save it to the log book when the green light turns red

QC for sPHENIX MVTX

- We have developed the QC system for ALICE ITS Commissioning. It has been stable and currently still in use for not only ITS but also other parts of the ALICE detector

- The general workflow of the QC can be ported from ITS to MVTX

- The systems codes and performance plots can be just directly copied from ITS. Many other functions will need to adjust and integrated to the Fun4All software framework

- We need to have some other parts of the components ready for the QC such as the decoder, data sampling, database, and GUI

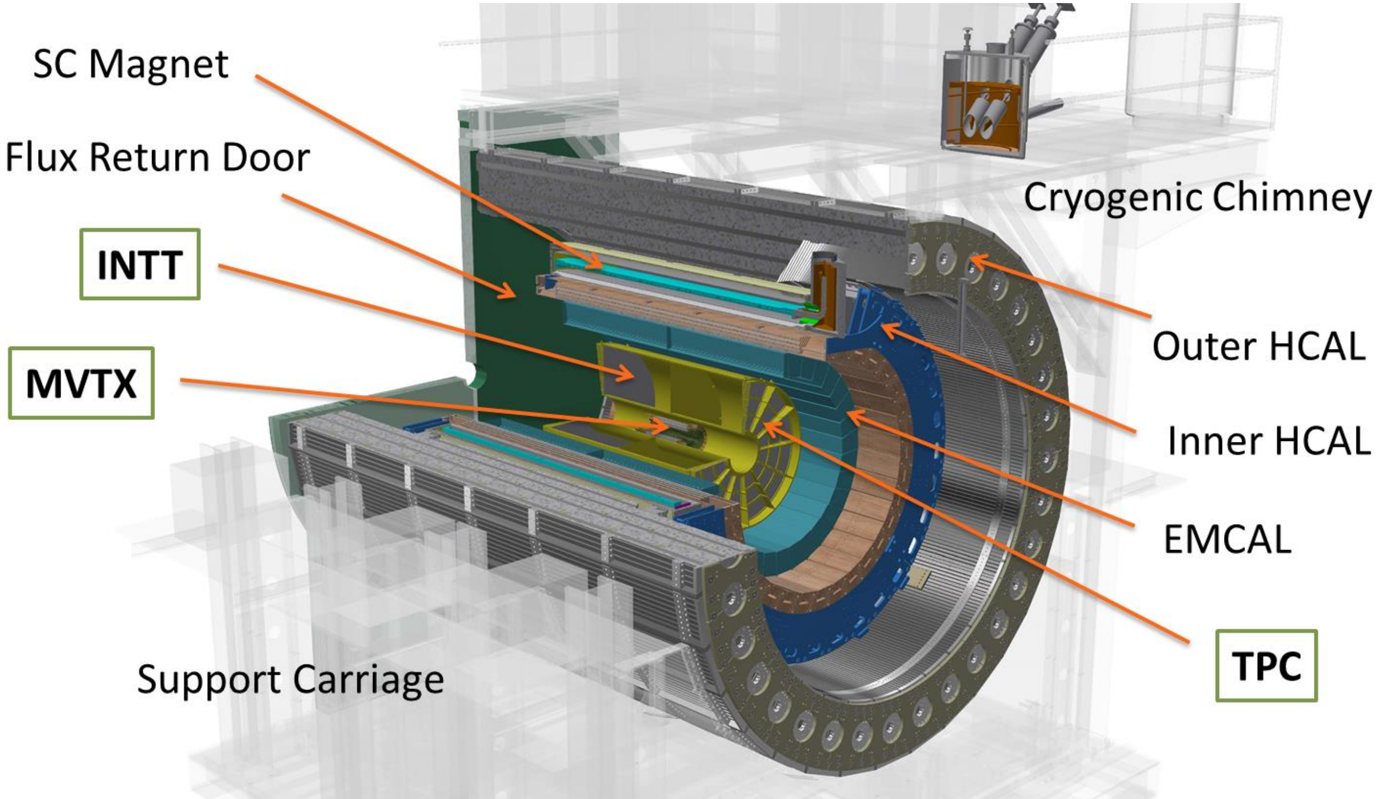
- Currently, I start to get actively involved in the sPHENIX MVTX team and get familiar with the test beam online monitoring and offline analysis codes to get some first results

First Glance at sPHENIX MVTX Codes

- Start to get familiar with the test beam QC codes and have
- Connect all component and transfer the ALICE QC to sPHENIX MVTX for commissioning shift at BNL

sPHENIX EMCAL Characterization at Test Beam

sPHENIX Detector



The Super Pioneering High Energy Nuclear Interaction eXperiment (sPHENIX) at RHIC

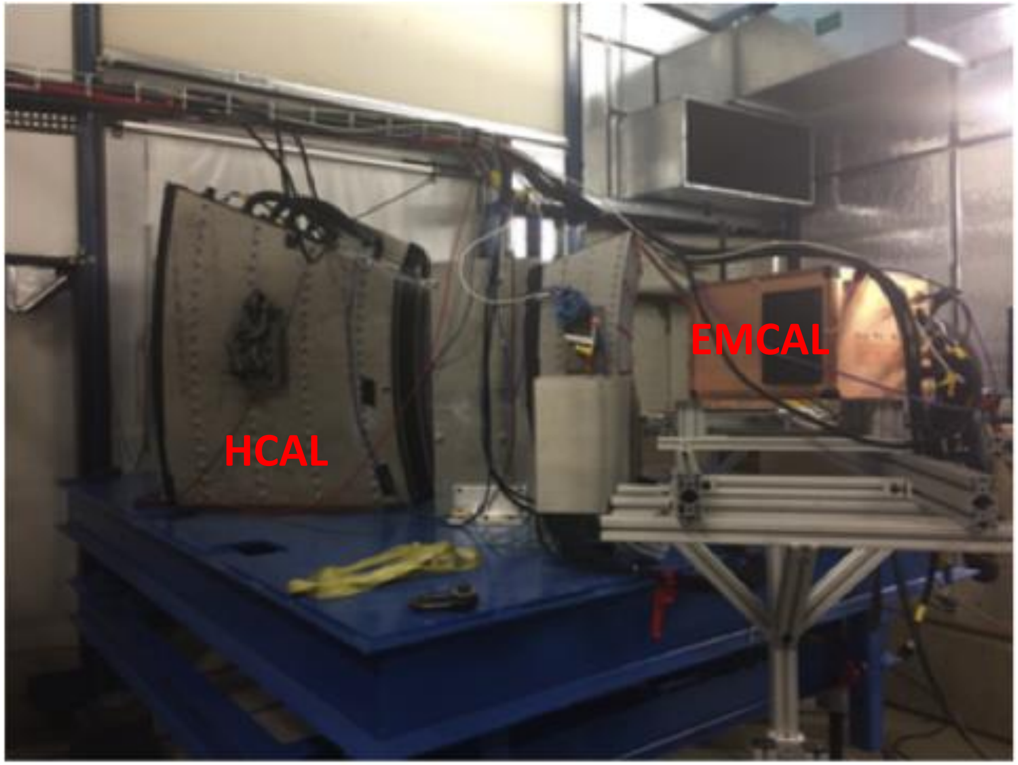
- State-of-the-arts jet detector with full 2π and $|\eta| < 1.1$ coverage upgraded from PHENIX
- Dedicated triggers to collect of large heavy-ion minimum biased datasets
- Excellent vertexing and tracking capabilities with MVTX and TPC
- Excellent electron identification capability for heavy flavor studies
- No dedicated hadronic particle identification

MIT Physics

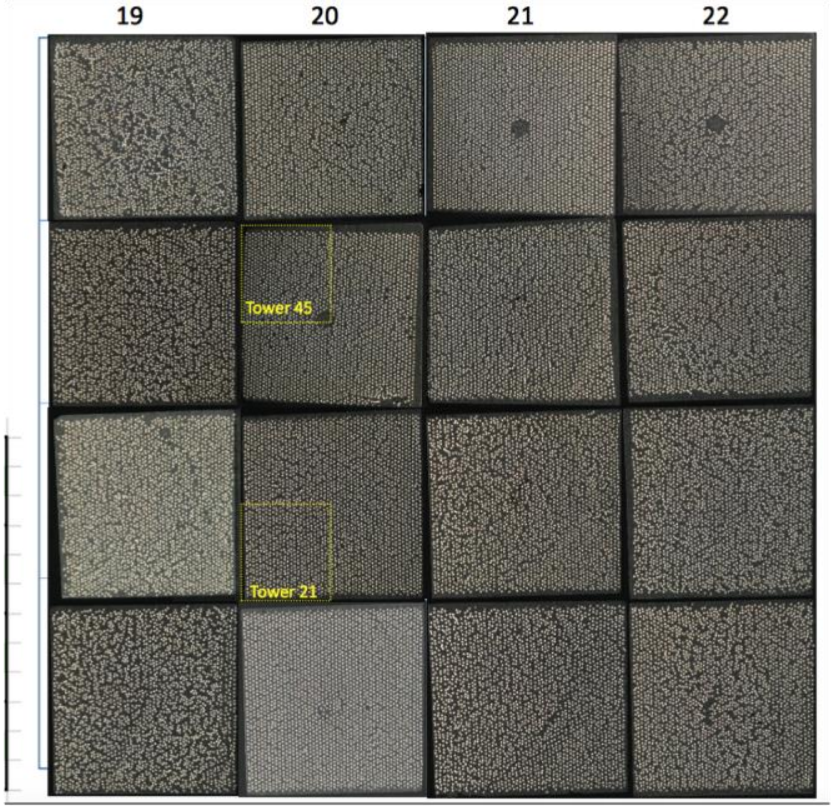
sPHENIX Calorimeter Test Beam at Fermilab

- High rapidity ($\eta = 1$)
- 2D projective EMCAL towers
- Orientations: 0, 5°, and 10° tilted in the ϕ direction

Test Beam Experiment Setup



EMCAL Block Configuration



sPHENIX EMCAL

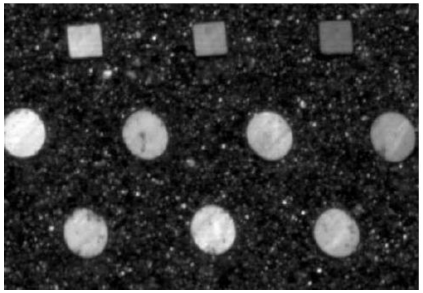
sPHENIX EMCAL Technical Information:

- W/scintillating fiber sampling EMCAL
- Acceptance coverage: 2π and $|\eta| < 1.1$
- Total radiation length: 18 X0
- 2D project SPACAL block design
- Tower size: 2.5 cm $\times$ 2.5 cm
- Energy resolution: $\frac{\Delta E}{E} = \boxed{2.8\%} \oplus \frac{\boxed{15.5\%}}{\sqrt{E}}$

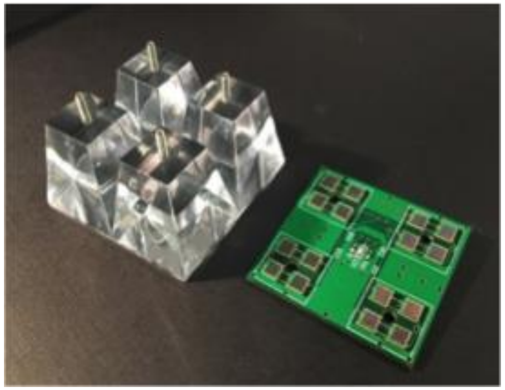
Constant Term

Statistical Term

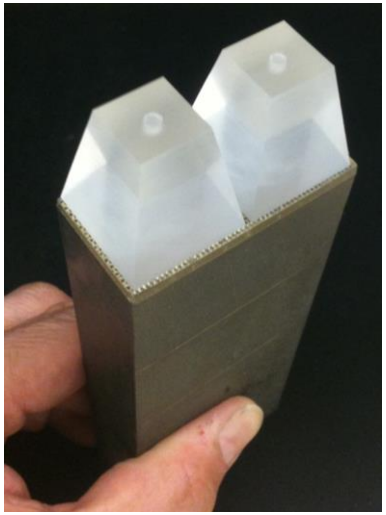
W/Scintillating Fiber



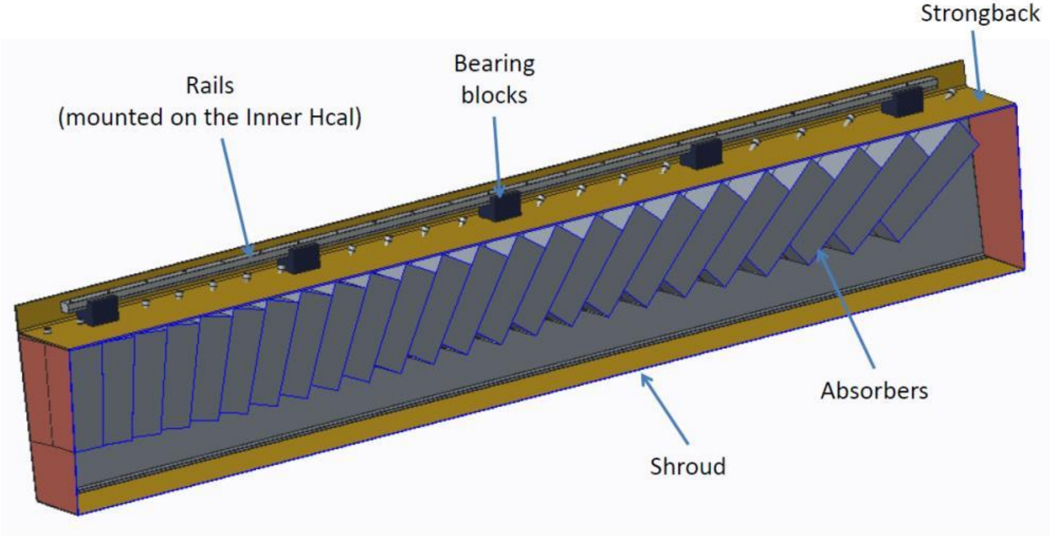
Light Guides and SiPMs



EMCAL Tower



2D project SPACAL Blocks Design

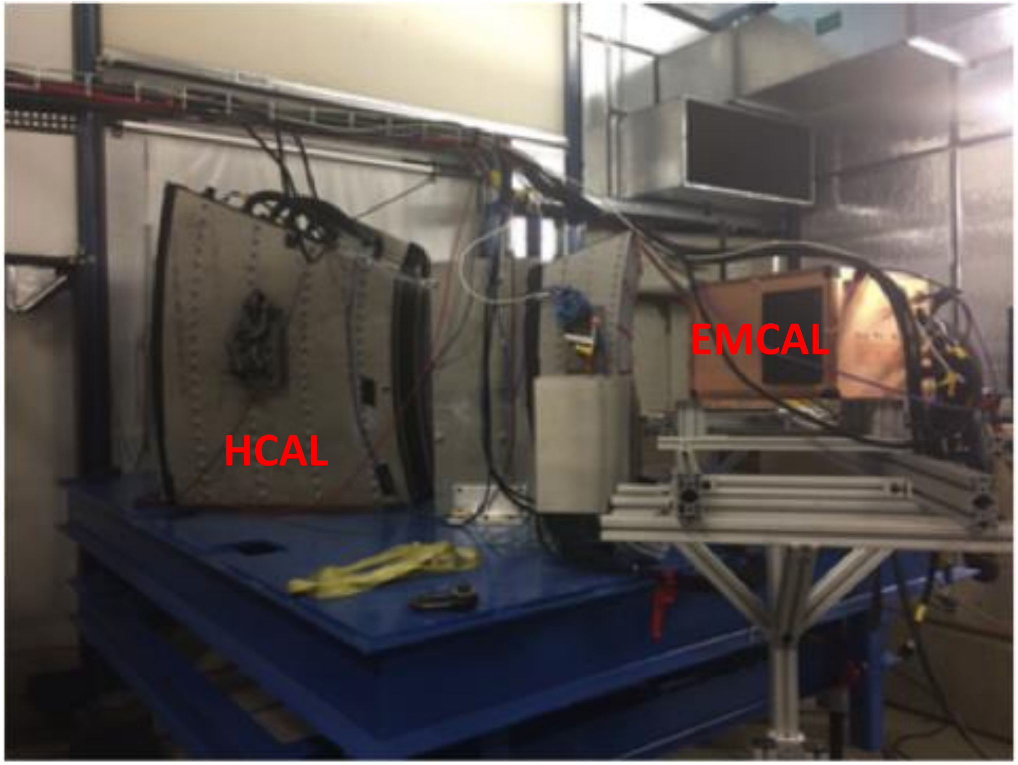


Physics

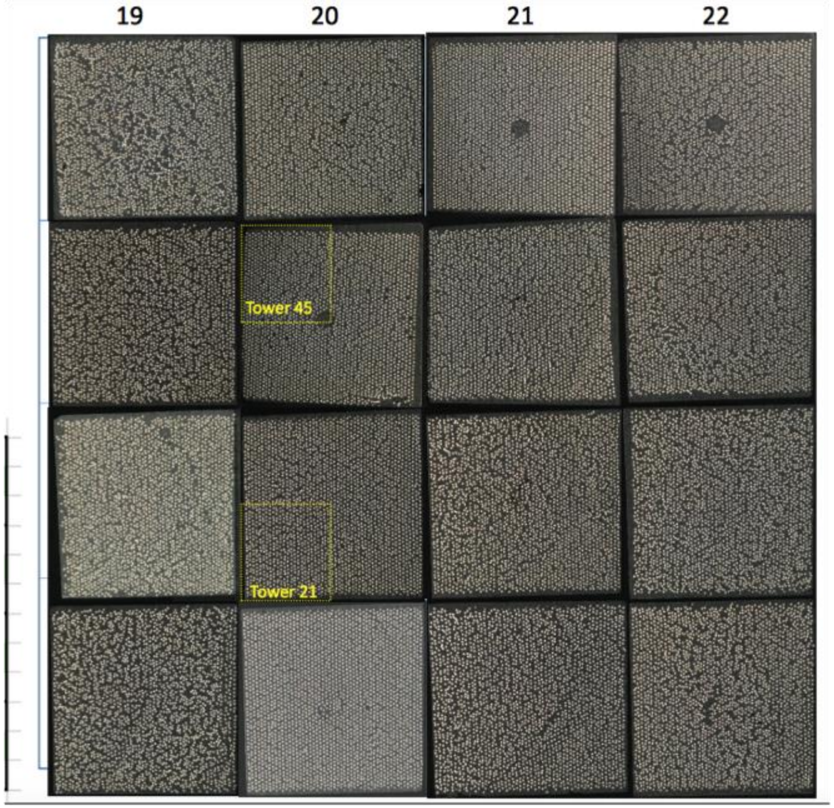
Fermilab Test Beam

- High rapidity ($\eta = 1$)
- 2D projective EMCAL towers
- Orientations: 0, 5°, and 10° tilted in the ϕ direction

Test Beam Experiment Setup

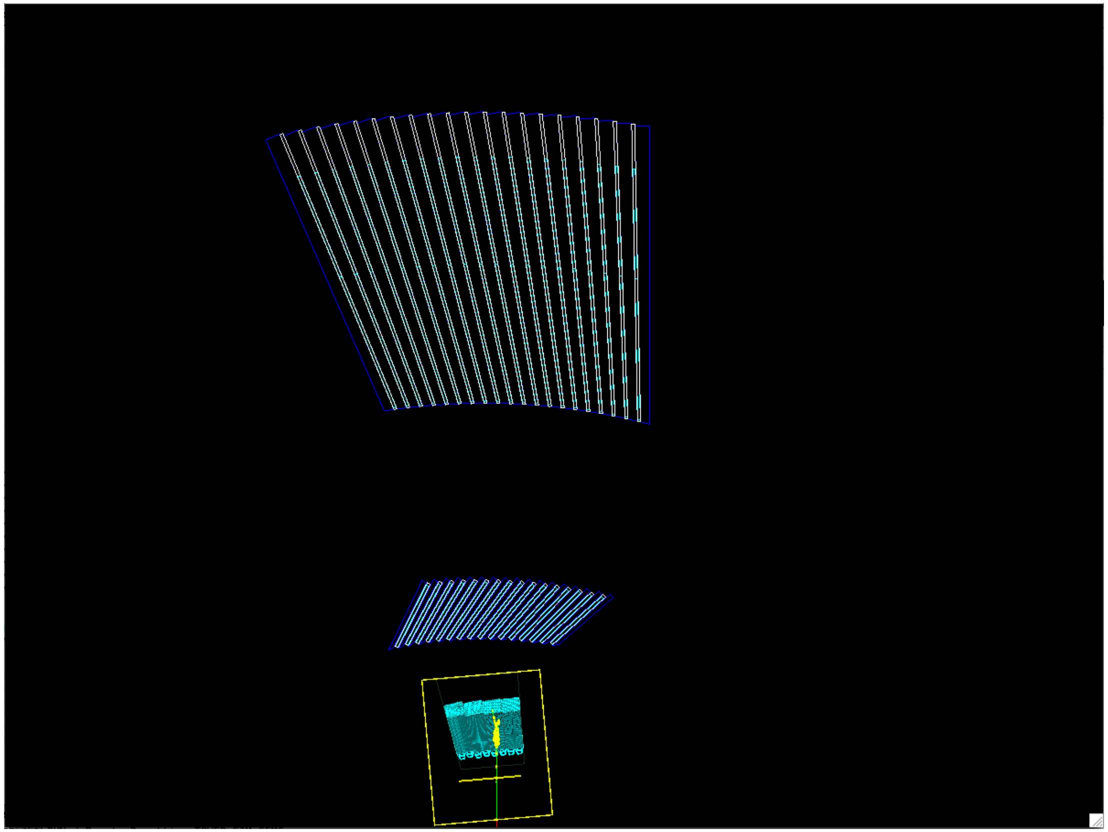


EMCAL Block Configuration



Physics

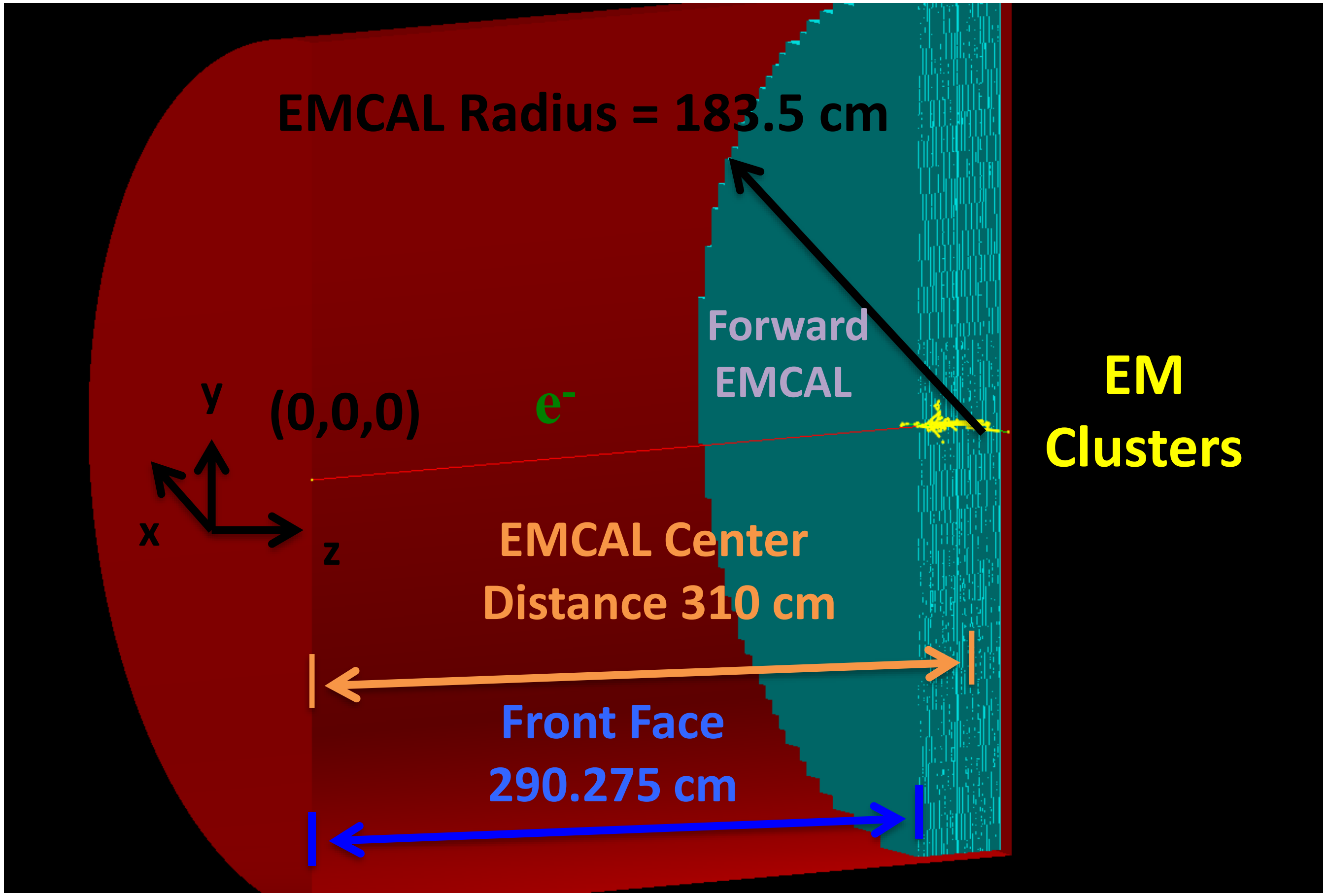
GEANT 4 Simulations



- GEANT 4: a software toolkit for the simulation of the passage of particles through matter
- Up-to-date EMCAL detector geometry and light collection efficiency maps as the inputs for the simulations to model the EMCAL prototype used in the test beam experiment
- 8 GeV electron beam with Gaussian beam profile scanning through the EMCAL

Physics

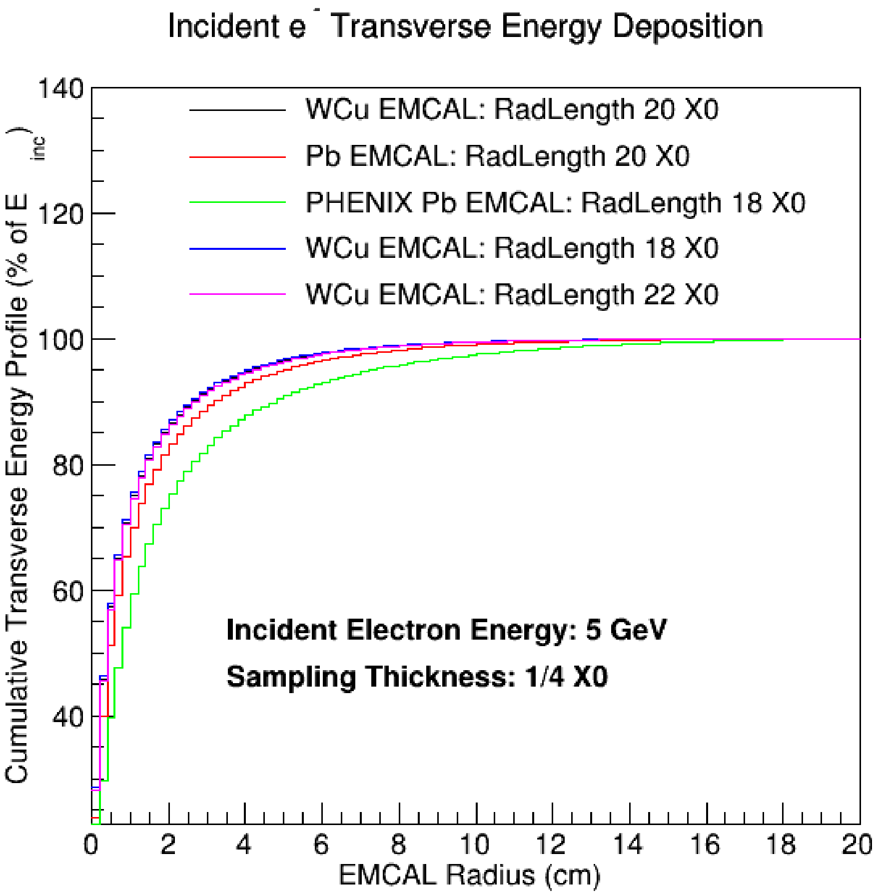
EIC Forward Endcap EMCAL Simulations Setup

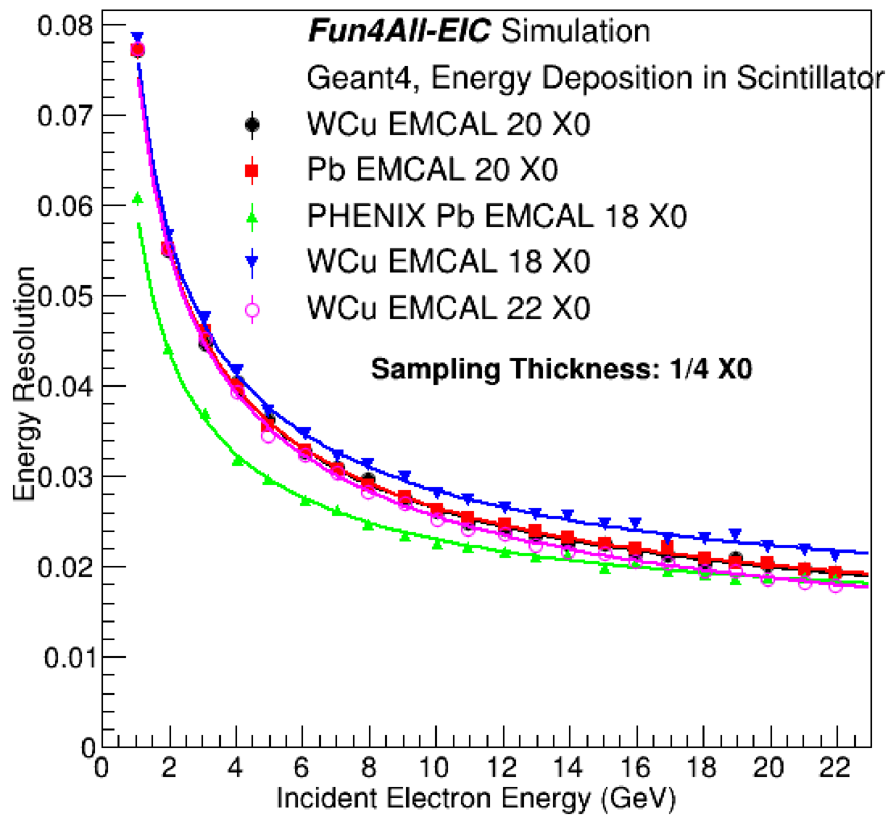


- A 1 GeV electron beam created at (0,0,0) entering the EMCAL in the +z direction
- Will use these setup to compare the performance of W/Cu and Pb EMCALs

Physics

Transverse Shower Profile and Energy Resolution

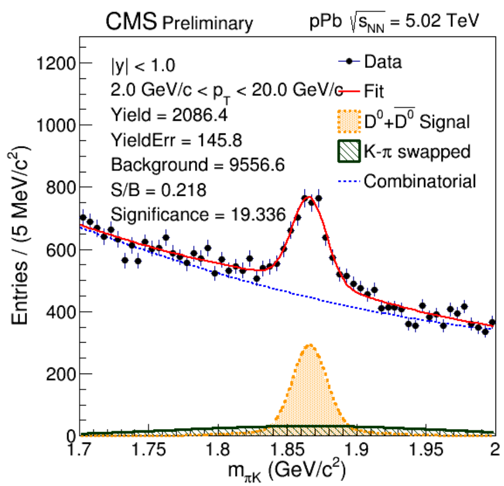




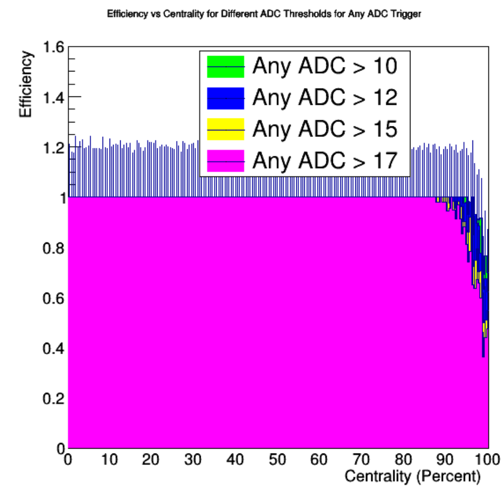
- Moliere Radius: WCu = 2.5 cm, Pb = 3.3 cm, sPHENIX = 4.5 cm, consistent with the left figure
- Sampling fraction: PHENIX > Pb > WCu
- The energy resolution: PHENIX configuration EMCAL is overall slightly better than the published results because we ignore actual detector electronics effects

Other PhD Research Trainings and Service Work

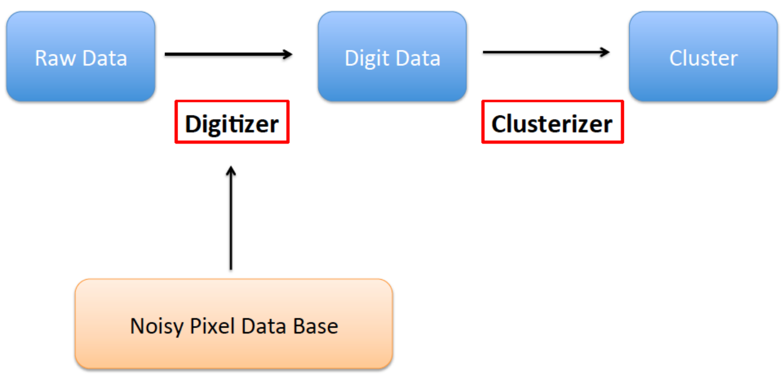
D^0 R_{pA} in pp and pPb at 5.02 TeV with CMS



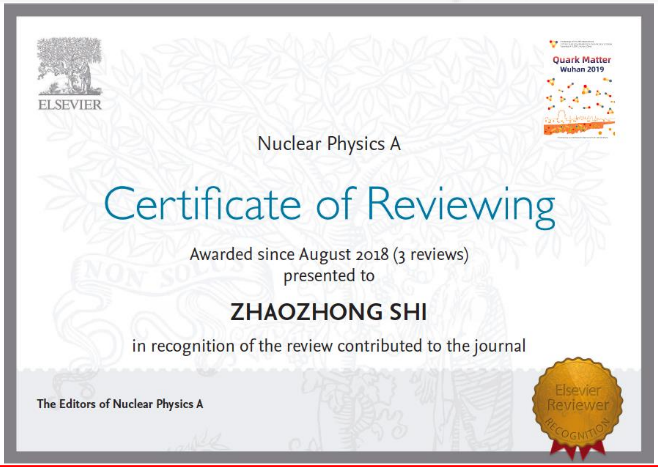
CMS 2018 PbPb MB Trigger Development



Noisy Pixel Calibration for ALICE ITS Upgrade



Peer Reviewer for Nuclear Physics A Journal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Quark Matter
Wuhan 2019

Nuclear Physics A

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Awarded since August 2018 (3 reviews)
presented to

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in recognition of the review contributed to the journal

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