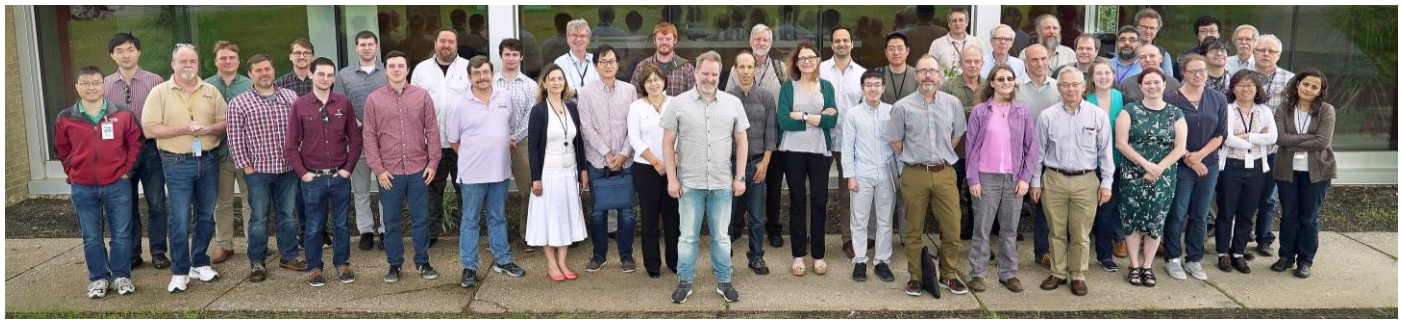
Heavy Flavor Physics with the sPHENIX MAPS Vertex Tracker Upgrade

Michael Peters
on behalf of
The sPHENIX Collaboration

The sPHENIX Collaboration



List of Recognized Experiments

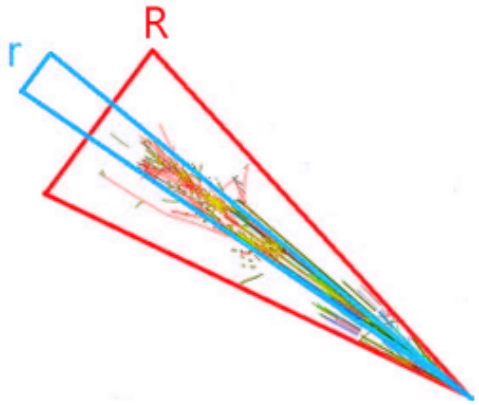
CERN

Ref.	Experiment	RE status at CERN since	until
RE 33	LIGO	2016	31-MAR-2022
RE 34	JUNO	2017	31-MAR-2020
RE 35	SNO+	2017	31-MAR-2020
RE 36	Mu3e	2018	31-MAR-2021
RE 37	DarkSide 20k	2018	31-MAR-2021
RE 38	DAMIC-M	2019	31-MAR-2022
RE 39	sPHENIX	2019	31-MAR-2022

sPHENIX Core Physics Program

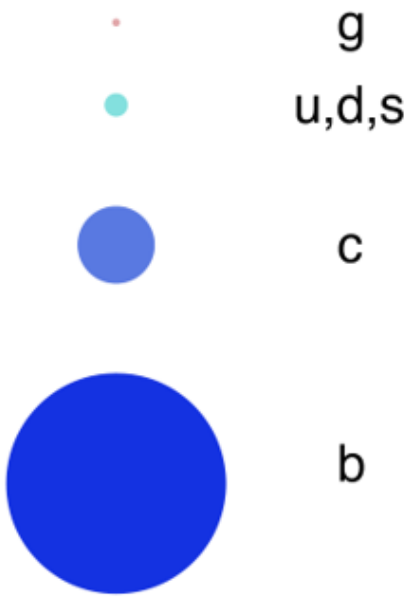
Jet cor. & substructure

Vary momentum/angular size of probe



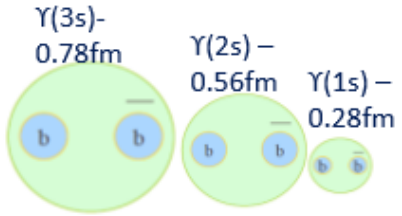
Parton energy loss

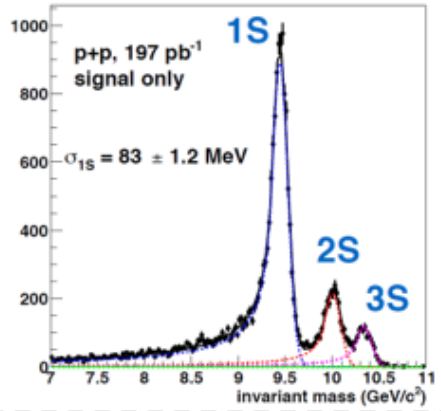
Vary mass/momentum of probe



Upsilon spectroscopy

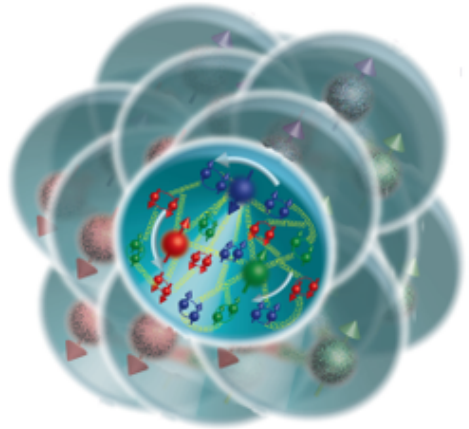
Vary size of the probe



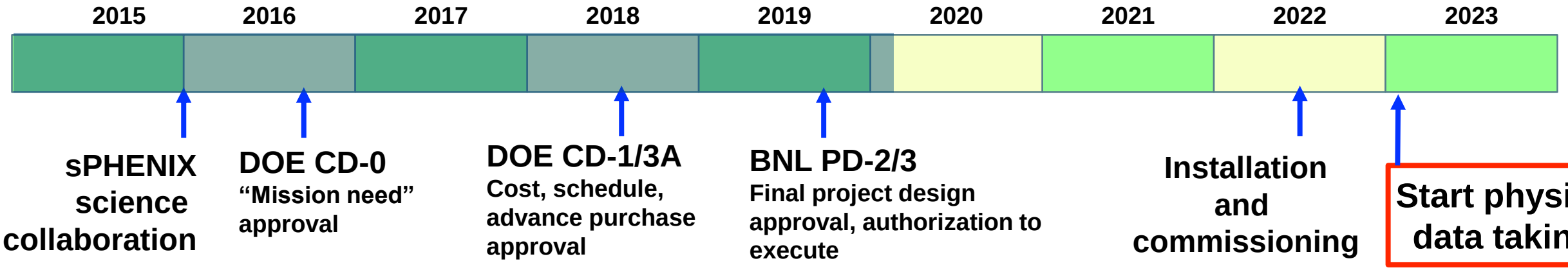


Cold QCD

Vary temperature of QCD matter

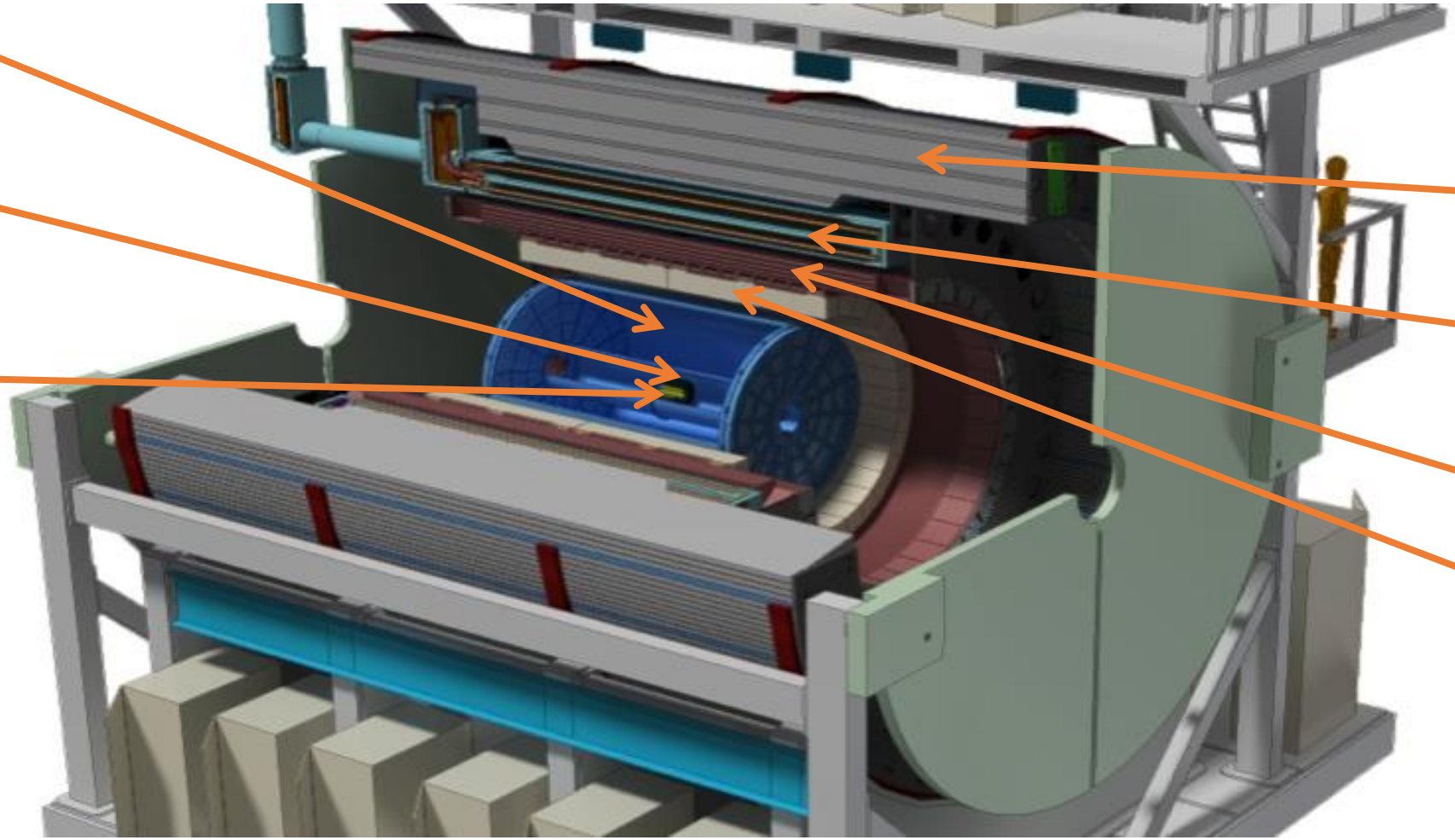


sPHENIX Schedule

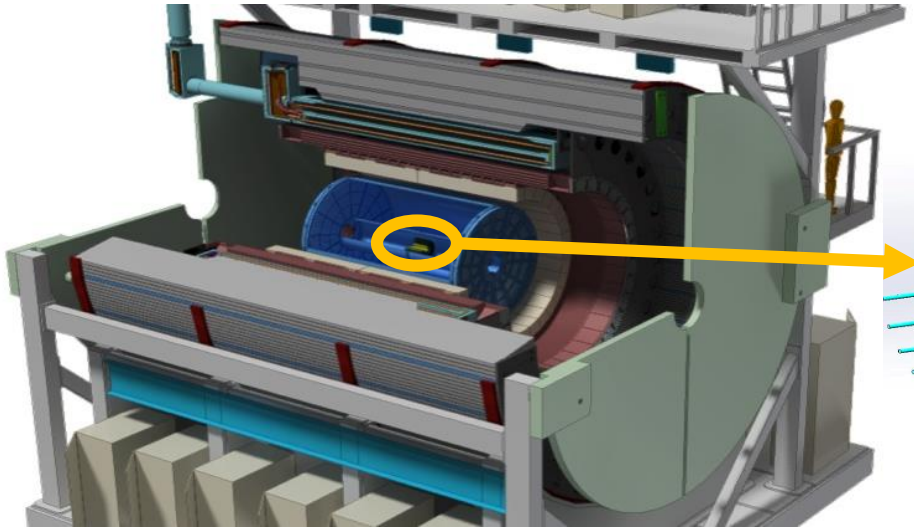


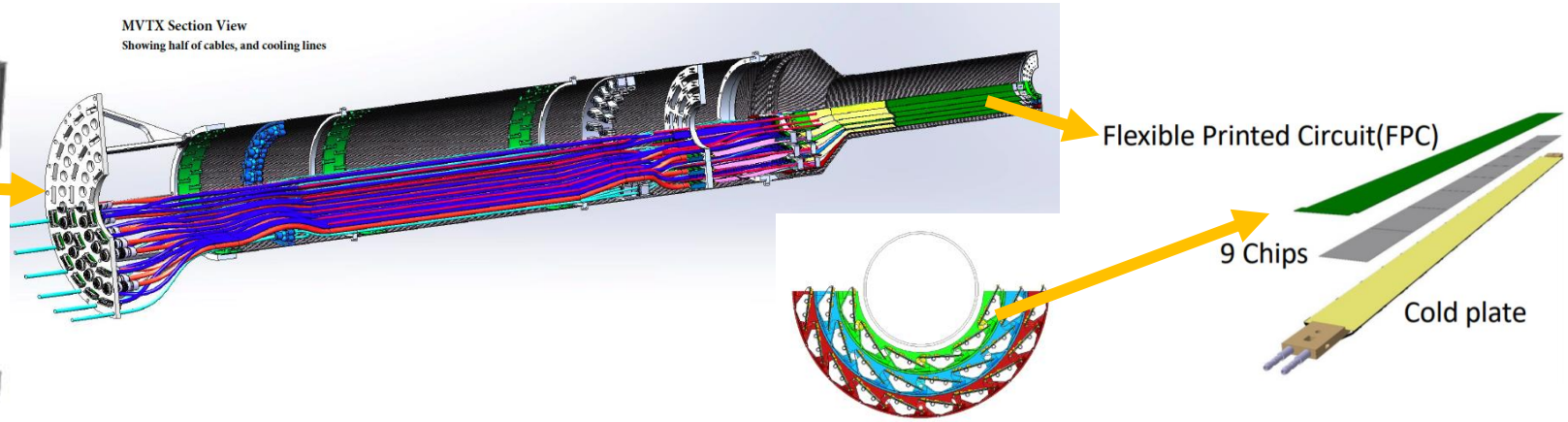
Year	Species	Energy [GeV]	Phys. Wks	Rec. Lum.	Samp. Lum.	Samp. Lum. All-Z
Year-1	Au+Au	200	16.0	7 nb^{-1}	8.7 nb^{-1}	34 nb^{-1}
Year-2	p+p	200	11.5	—	48 pb^{-1}	267 pb^{-1}
Year-2	p+Au	200	11.5	—	0.33 pb^{-1}	1.46 pb^{-1}
Year-3	Au+Au	200	23.5	14 nb^{-1}	26 nb^{-1}	88 nb^{-1}
Year-4	p+p	200	23.5	—	149 pb^{-1}	783 pb^{-1}
Year-5	Au+Au	200	23.5	14 nb^{-1}	48 nb^{-1}	92 nb^{-1}

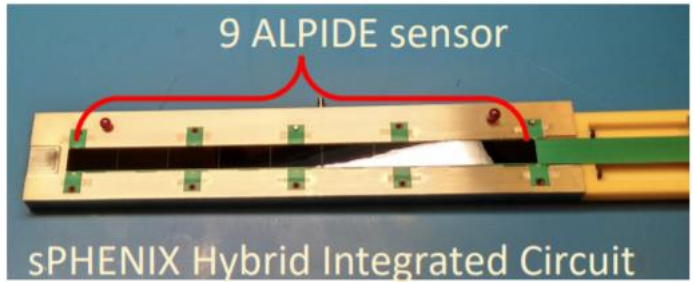
The sPHENIX Detector

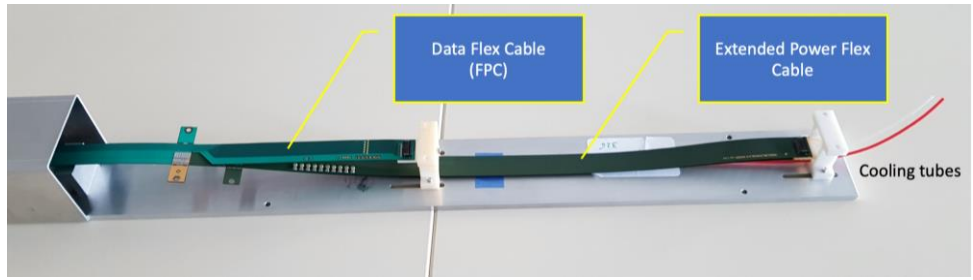


MVTX Overview: Layout







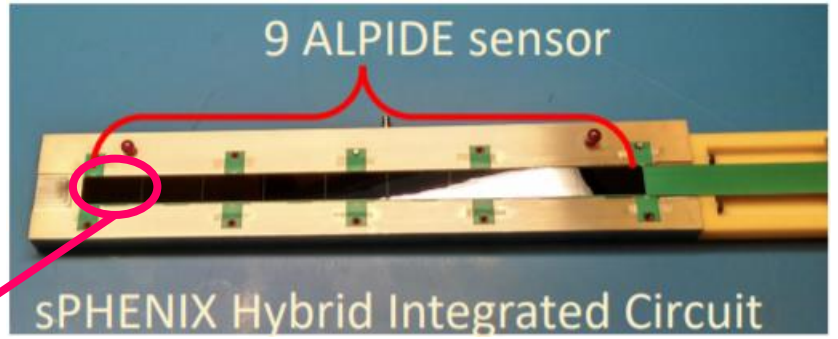


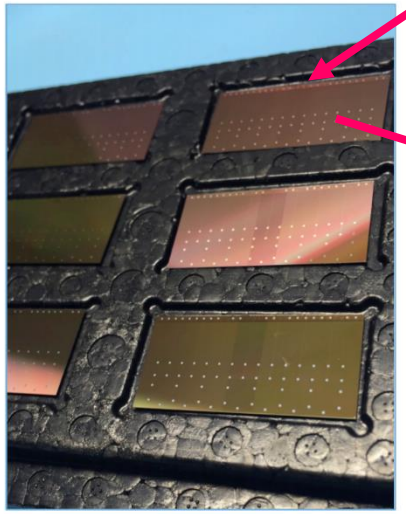
- Staves are identical to ALICE inner barrel staves, except for leads
- Produced in CERN facility operated by ALICE

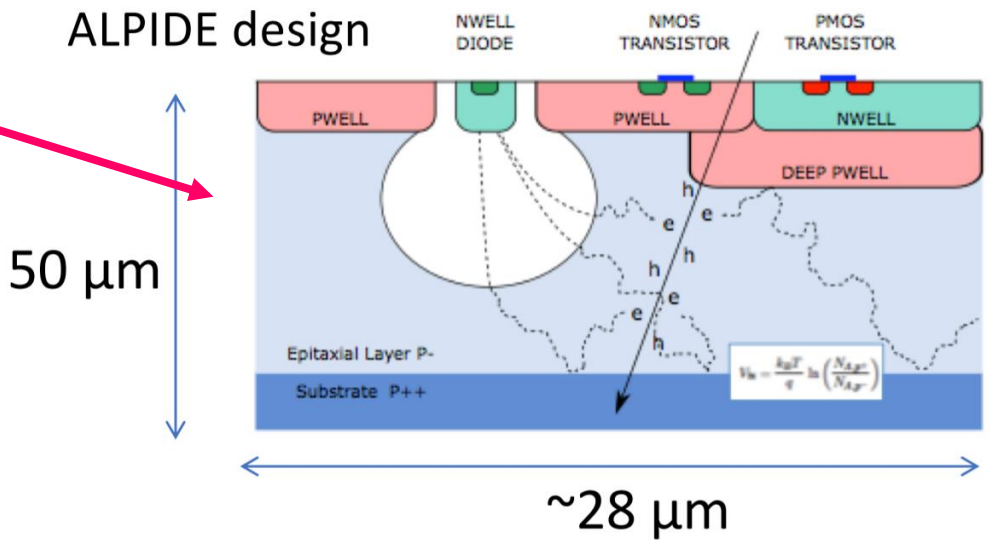
MVTX Overview: ALPIDE

- Monolithic Active Pixel Sensor (MAPS)-based detector
- Basic unit: ALPIDE sensors
  - 27 x 29 μm pitch
  - <5 μs time resolution
  - 1024 x 512 pixels
  - Efficiency > 99%
  - Fake rate $<10^{-6}$
  - Thin (<50 μm, 0.3% X_0)
  - On-chip digitization
  - Low-power (50 mW/cm^2)

M. Van Leeuwen
Jun 4, 11:15
https://indi.to/pJY6Z

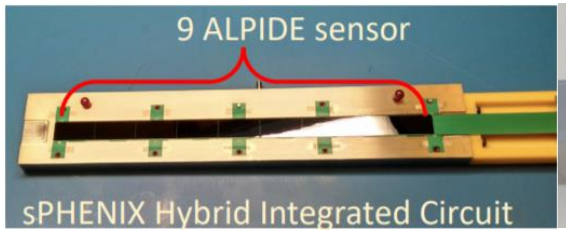


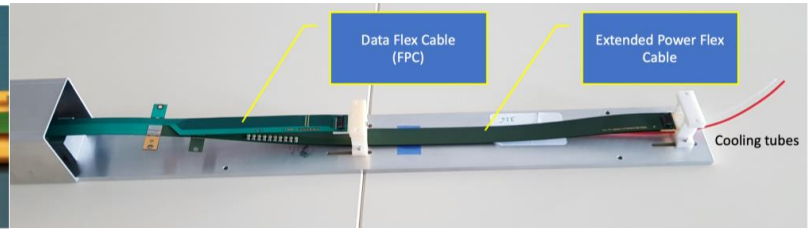




Recent News: Production

- 5 staves ready, 15 awaiting final analysis over next 2 weeks
- 48 staves completed by end of year
- 60 Readout Units awaiting testing at CERN
- 6 FELIX cards in production (ATLAS hardware)
- Preparing for stave testing and metrology at LBNL
- Services (racks and power): preliminary design finalized for MVTX

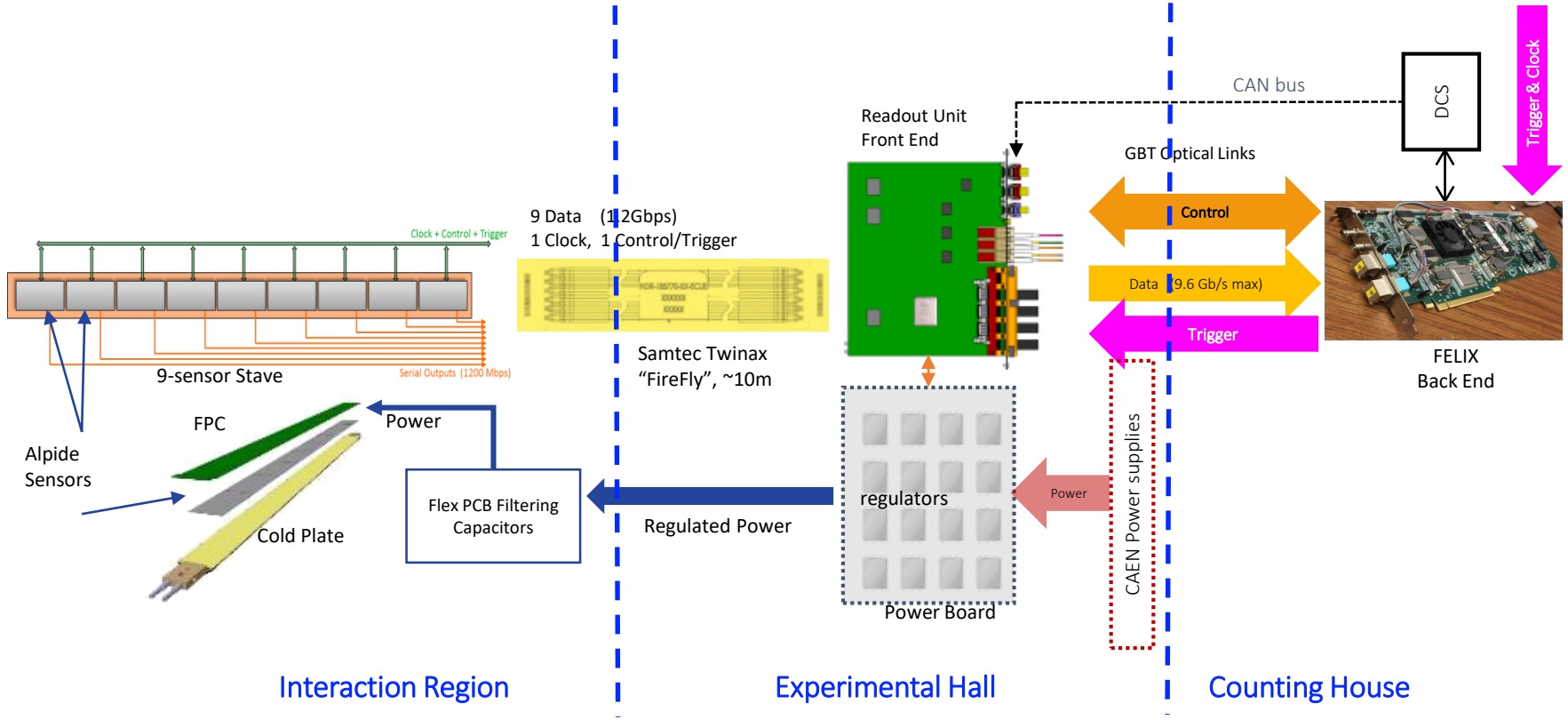




Readout Unit v2

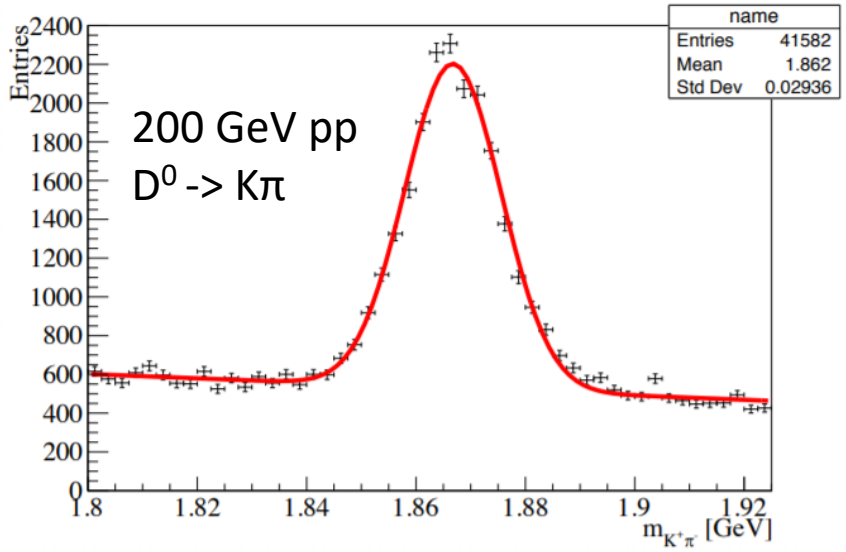
Data Assembly Module (FELIX v2)

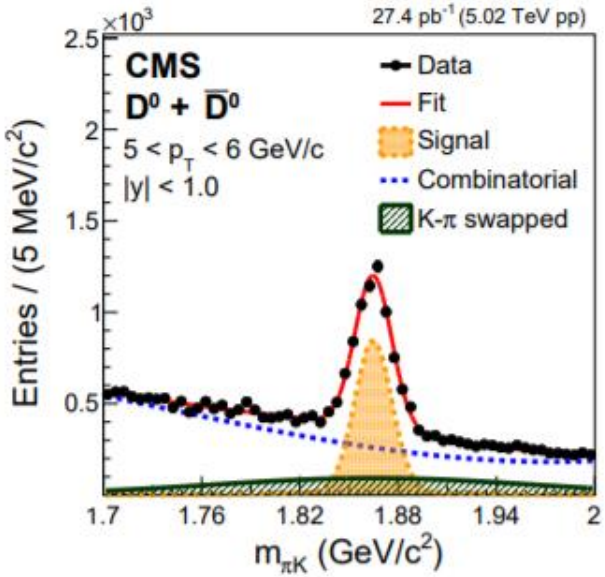
Recent News: Slow Control

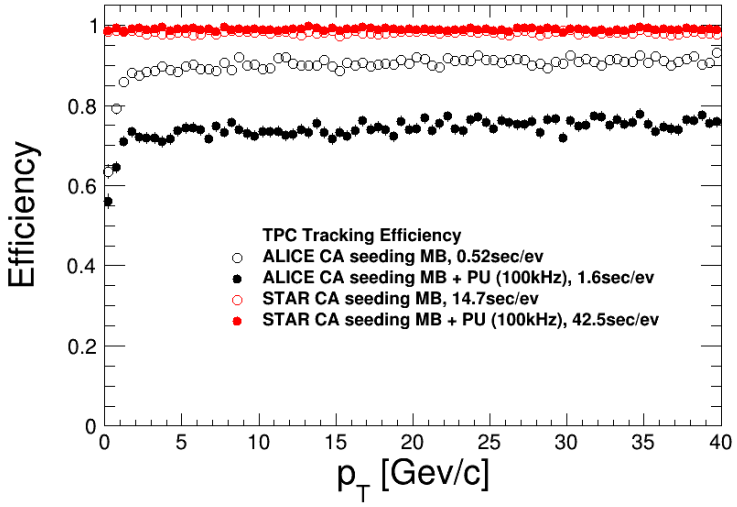


- Readout Unit firmware and software identical to ALICE
- Firmware design in progress for GigaBit Transceiver (GBT) communication:
  - Slow Control Adapter (SCA)
  - Single Word Transaction (SWT)

Recent News: Simulation and Software



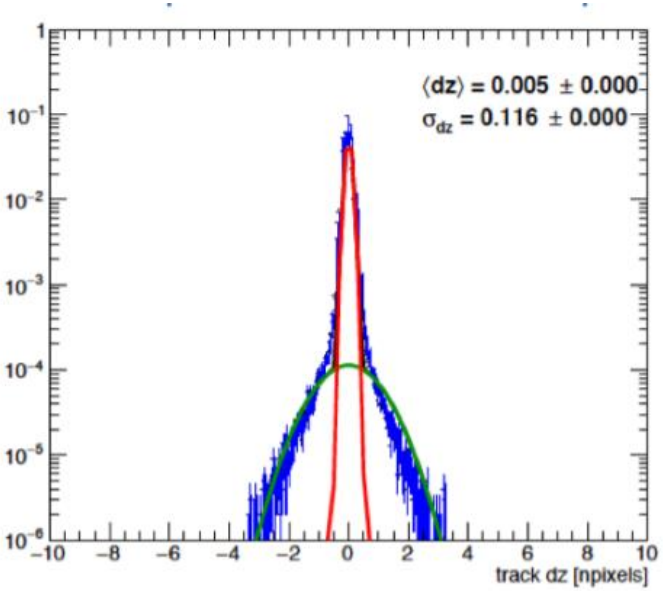


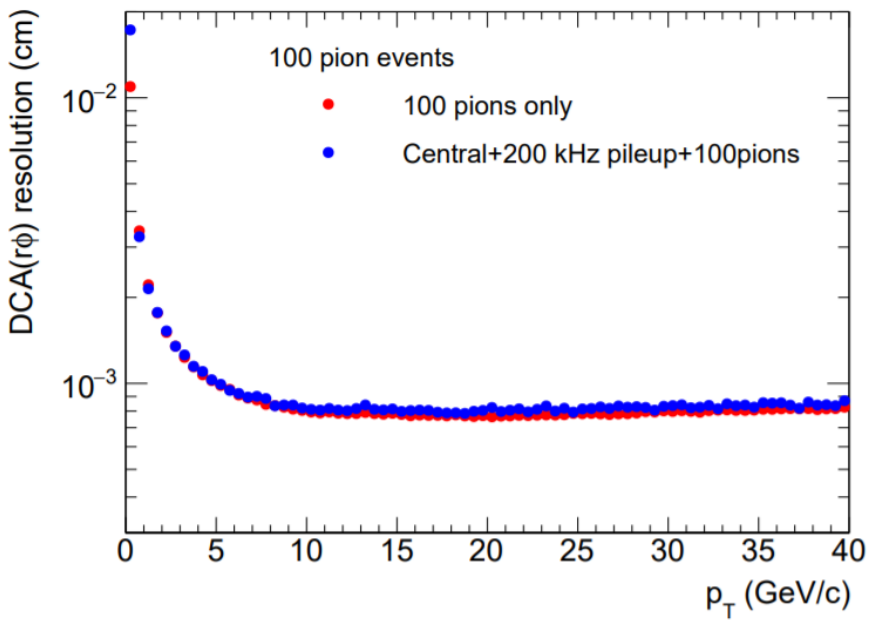


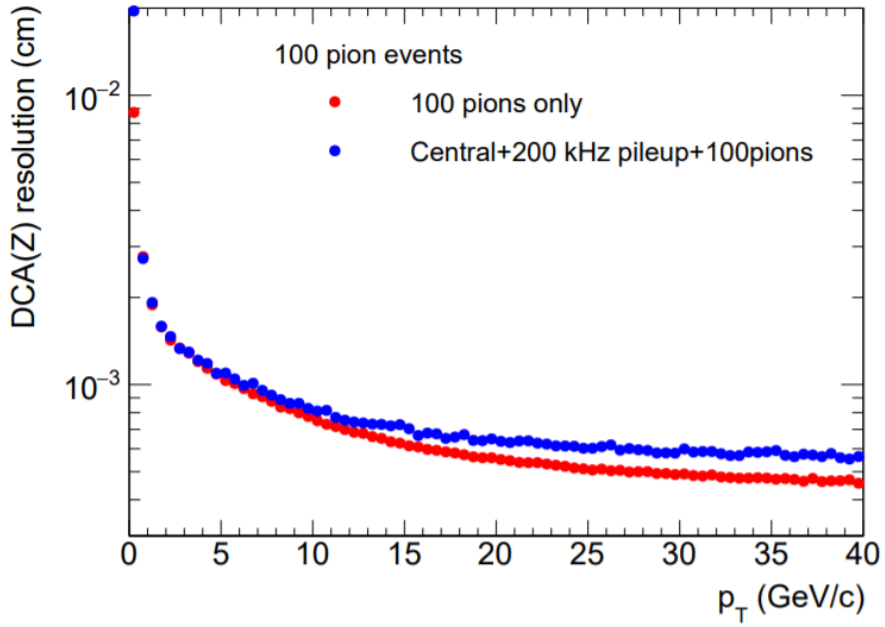
Phys. Lett. B 782 (2018) 474

- KFParticle (Kalman Filter decay reconstruction) successfully implemented for two-pronged D^0 decay
- Cellular Automaton (CA) track seeding: optimizing for efficiency, approaching goal of 5 seconds/event
- ACTS (ATLAS open source tracking software) implementation in progress

General Tracking Impact







Hit spatial resolution

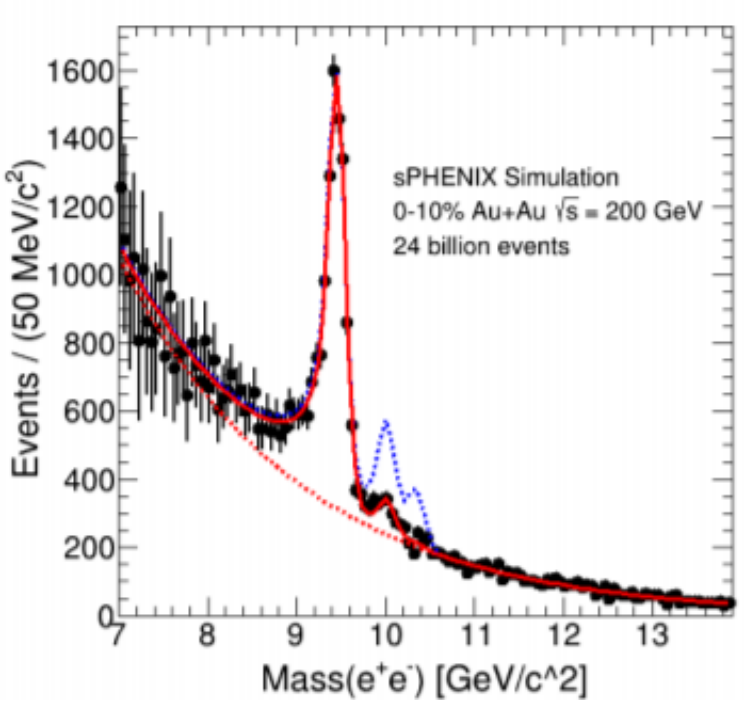
rϕ DCA resolution

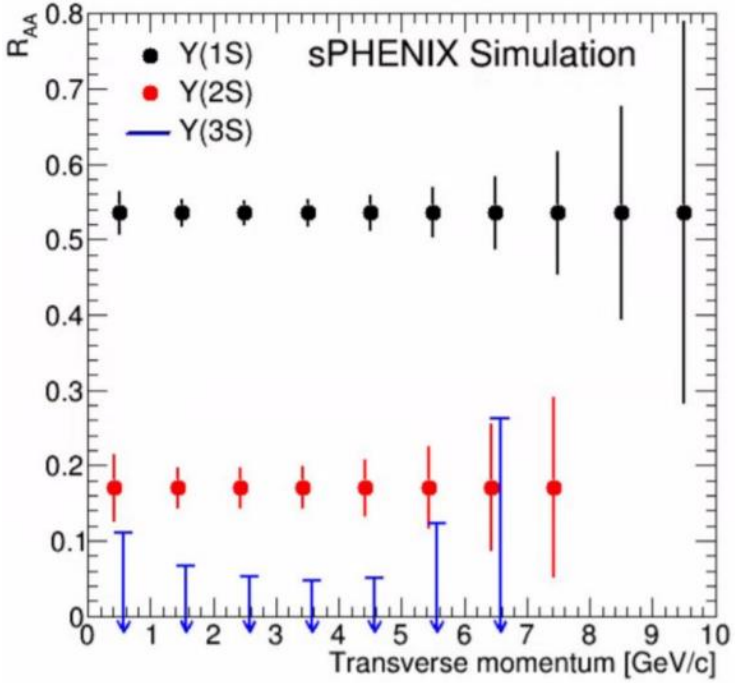
Z DCA resolution

- Hit spatial resolution of < 5 μm
- Contributes high-performance vertexing to integrated tracking program

Heavy Flavor Physics Performance Projections

Upsilon Spectroscopy

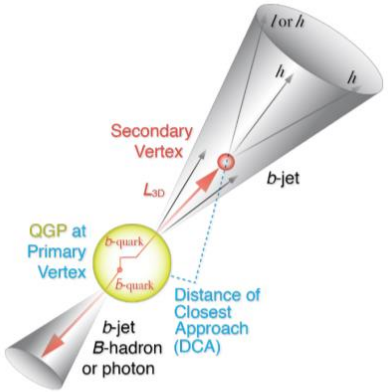




- Mass resolution of sPHENIX tracking allows clear separation of ϒ states for the **first time** at RHIC!
- Makes possible precision measurements of ϒ(1S) and ϒ(2S) R_{AA}
  - Upsilon melting observations for $0<p_T<7$ GeV

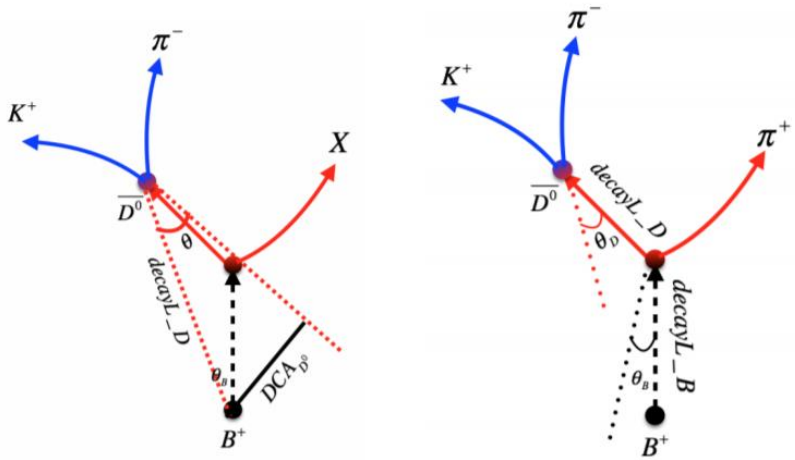
Open Heavy Flavor with MVTX

Inclusive tagging



b-jet

Exclusive tagging



$B \rightarrow \overline{D^0} + X$ (B.R. 60%)

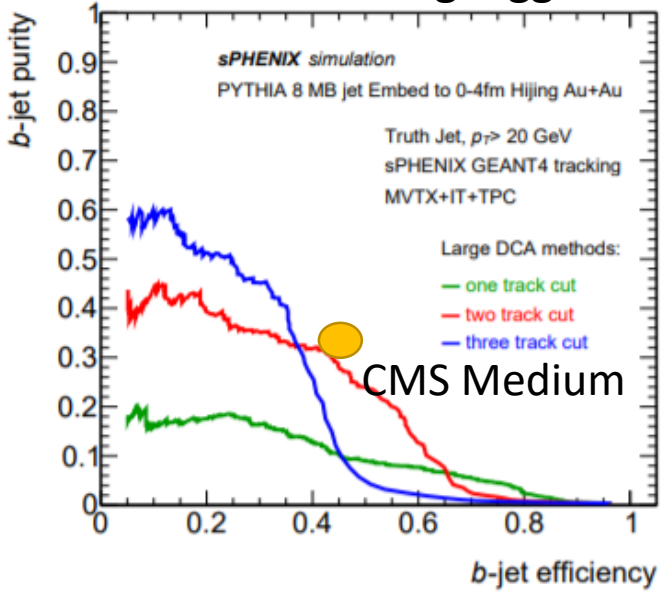
$B^+ \rightarrow \overline{D^0}\,\pi^+$(B.R. 0.5%)

- Precise identification of secondary vertex allows high-purity b-jet samples
- Heavy flavor decays: marked by **distinctive decay topology**
  - High-resolution DCA, precise vertexing, high rate
  - Detection of heavy-flavor mesons possible even without p/K/π PID

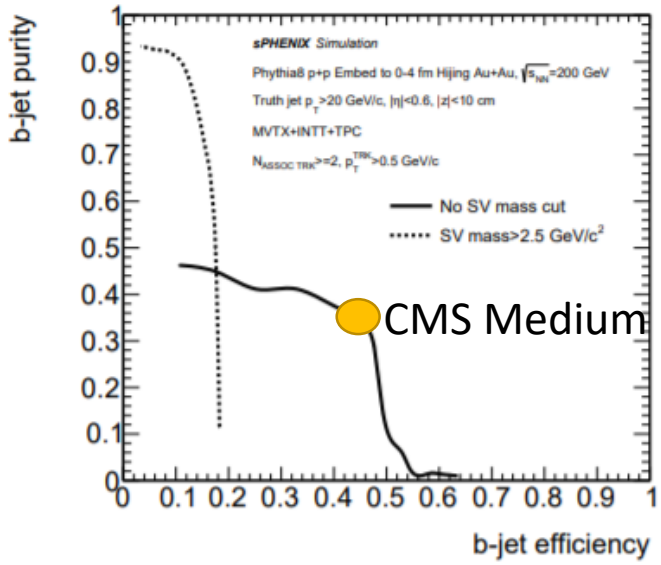
sPH-HF-2018-001

HF-Jet Tagging

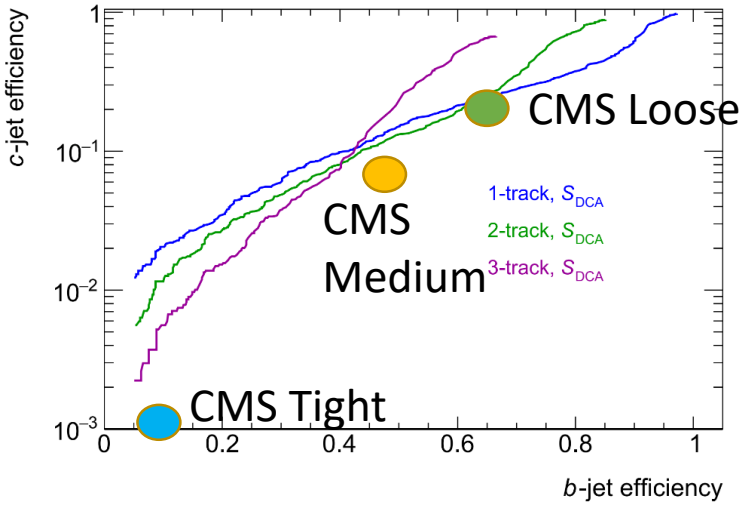
Track counting tagger



Secondary vertex tagger

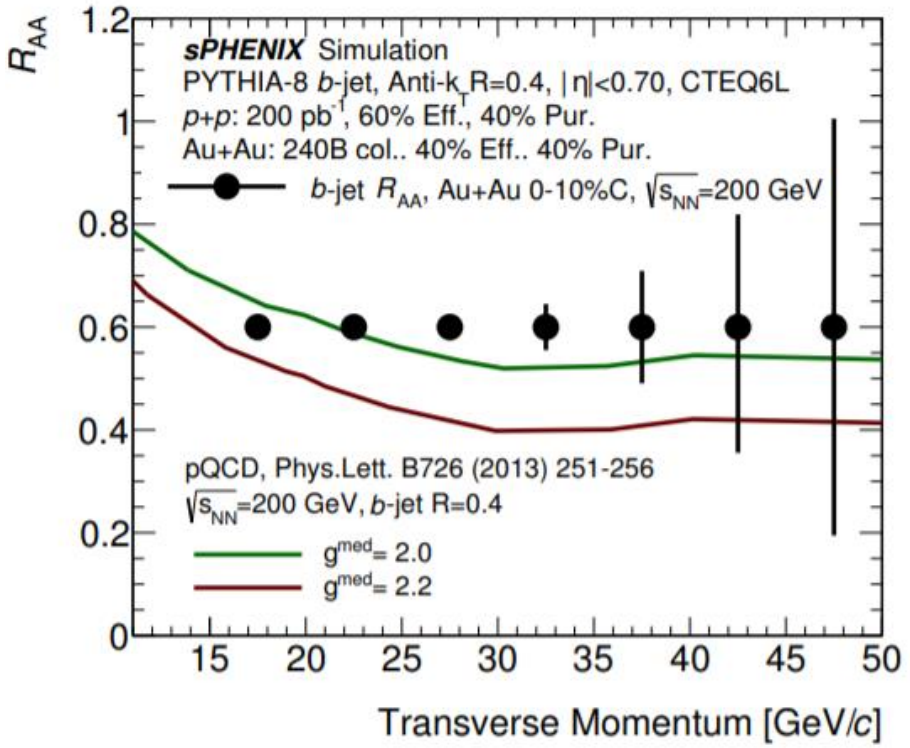


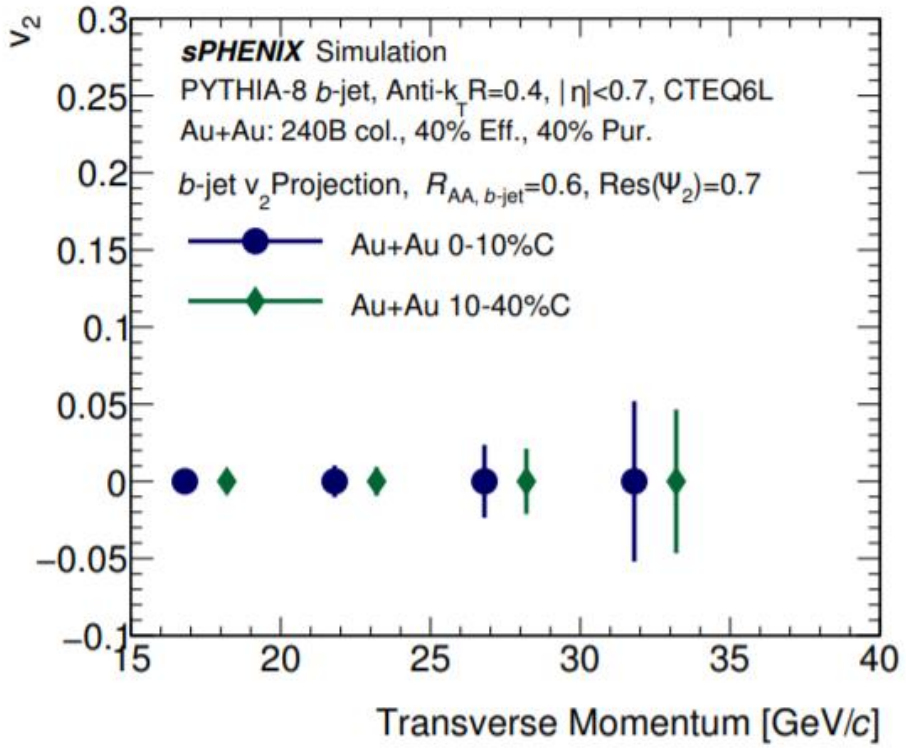
Track counting c vs. b jet efficiency



- Track counting and secondary vertex taggers implemented
- Similar performance to CMS typical PbPb working point
- Plan to use combined tagging scheme incorporating both
  - Leptonic tagger also included in combined scheme

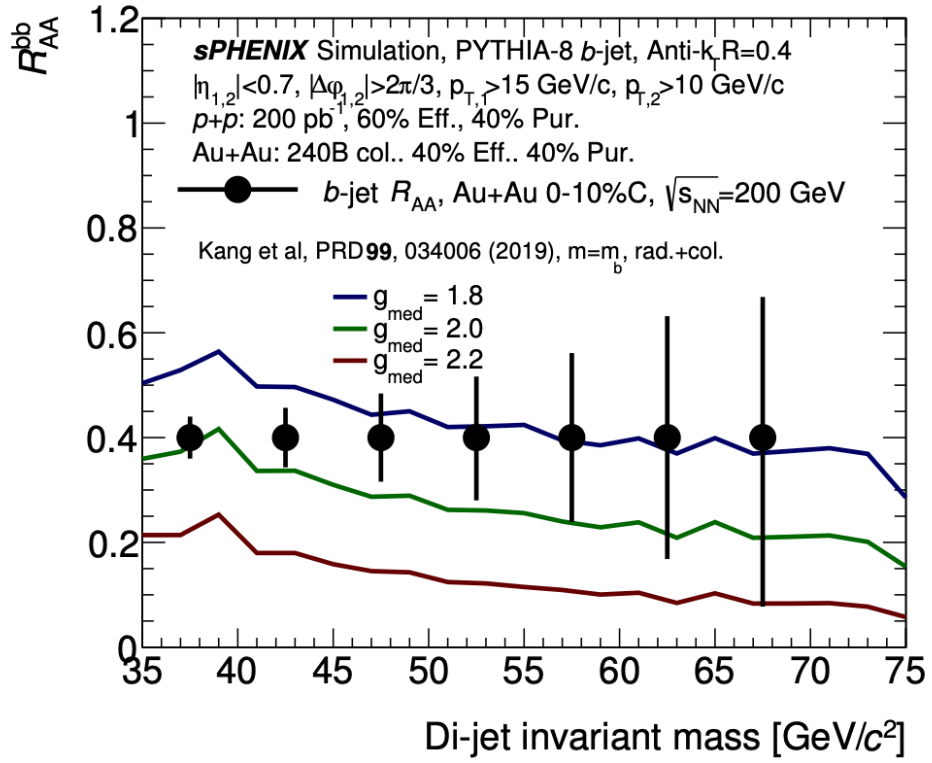
b-Jet R_{AA} and v_2

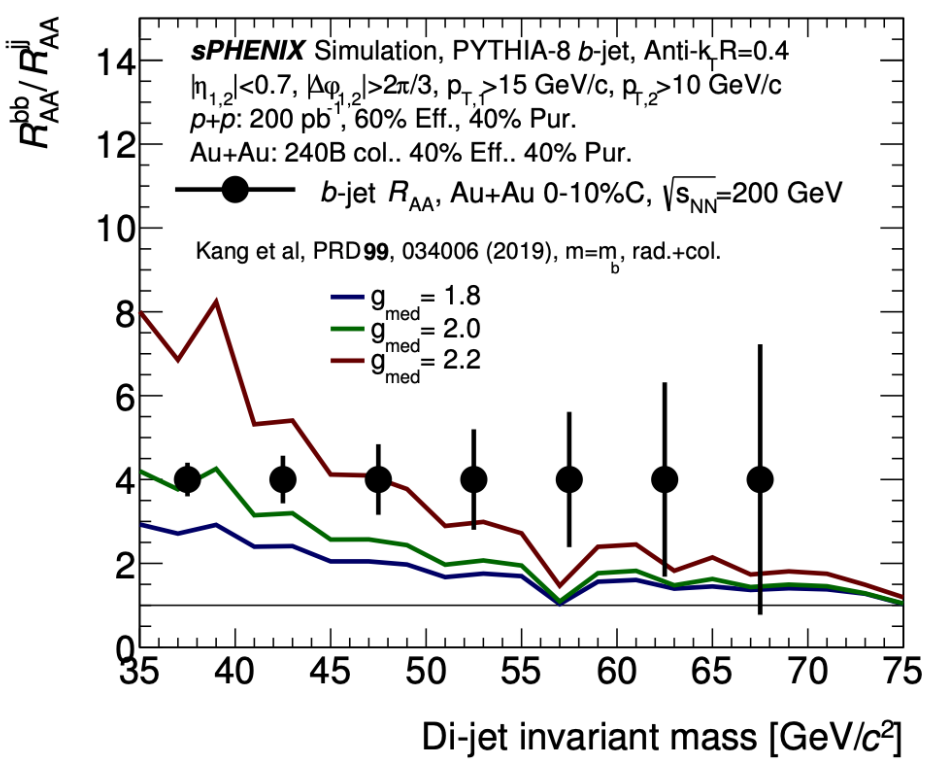




- Collisional and radiative components of medium interaction both contribute to medium coupling g^{med}
- Heavy flavor mesons: different kinematics, therefore different medium coupling
- B-jet observables coupled with light-jet observables: two measurements of g^{med}

Di-(b-Jet) Observables

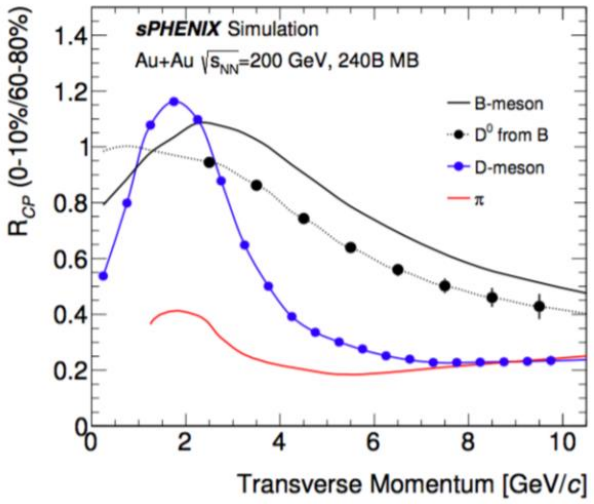


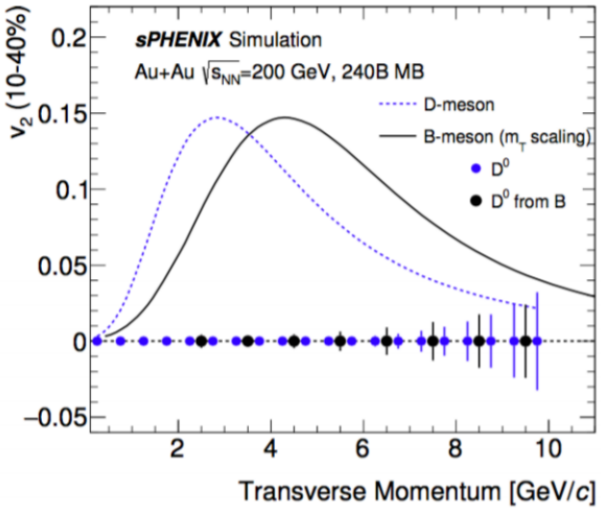


- Novel jet observable for RHIC, supported via LANL LDRD (20170073DR)
- Di-(b-jet) R_{AA} allows more precise measurement of g^{med}
- Mass effect enhanced in heavy-to-light double ratio

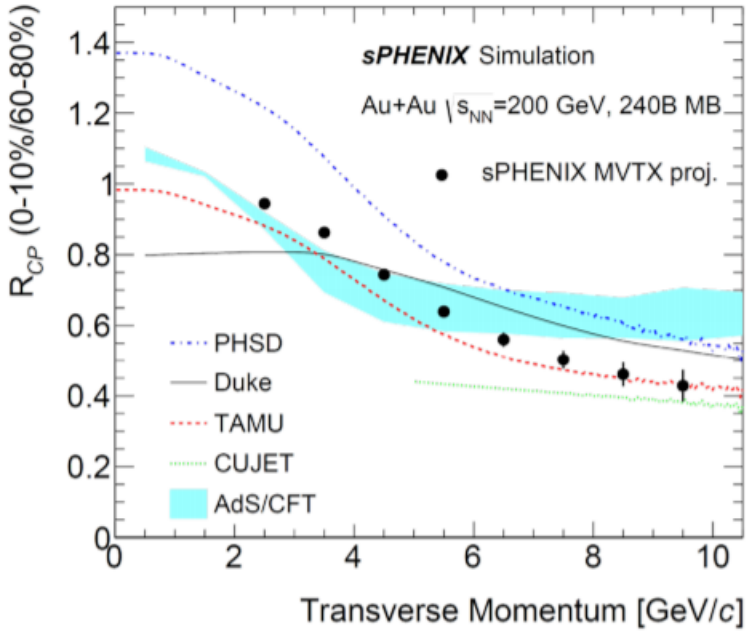
Phys. Rev. D99 034006 (2019)

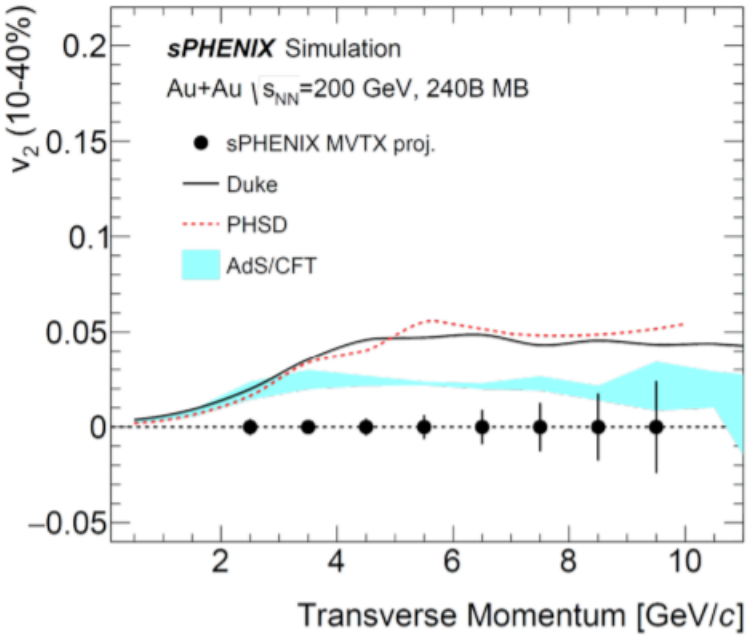
D^0 and B^0 R_{CP} and v_2





Non-prompt D^0 R_{CP} and v_2

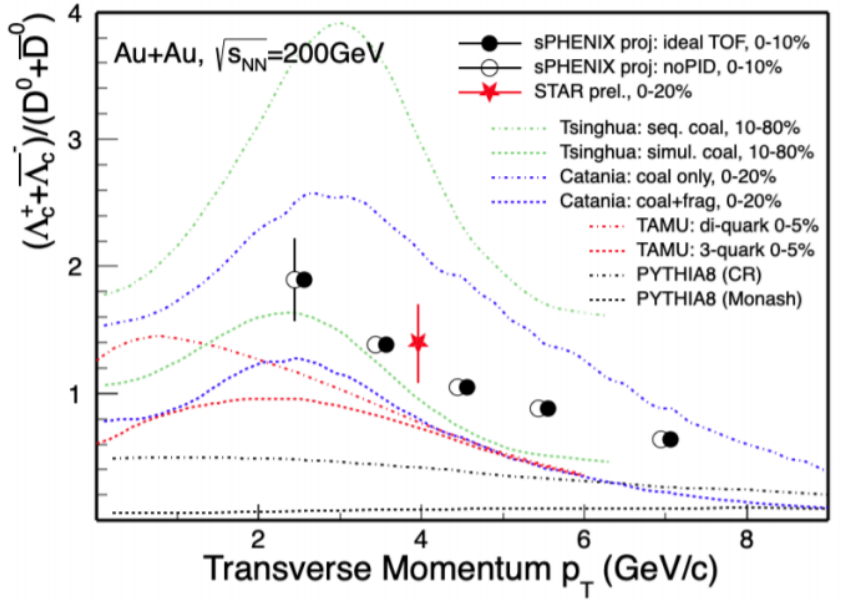


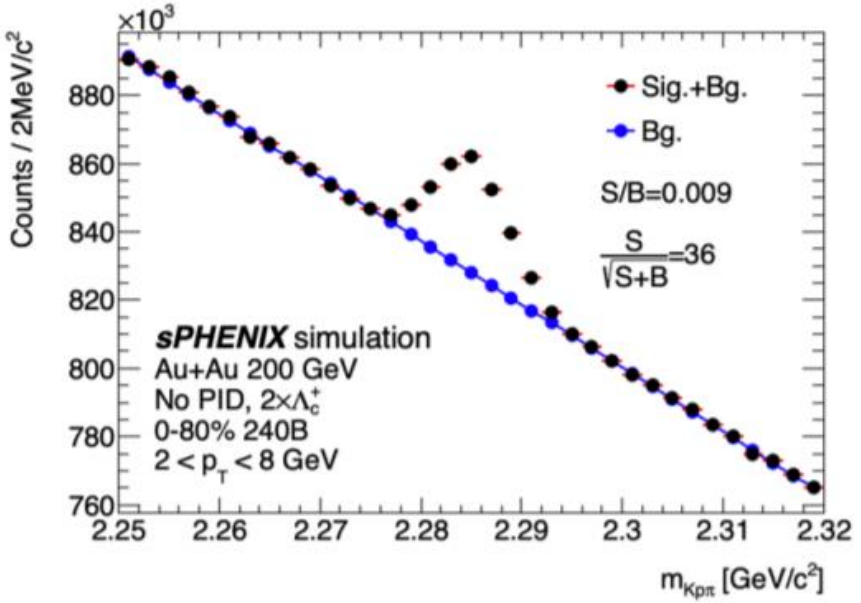


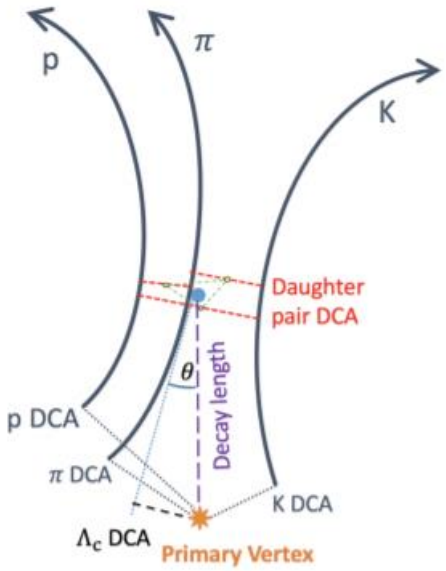
- Non-prompt D^0 meson proxy for B meson
- Precision of R_{CP} and v_2 measurements can discriminate between transport model projections

Λ_c and Λ_c/D^0 Ratio

Phys. Rev. Lett. **124**, 172301 (2020)

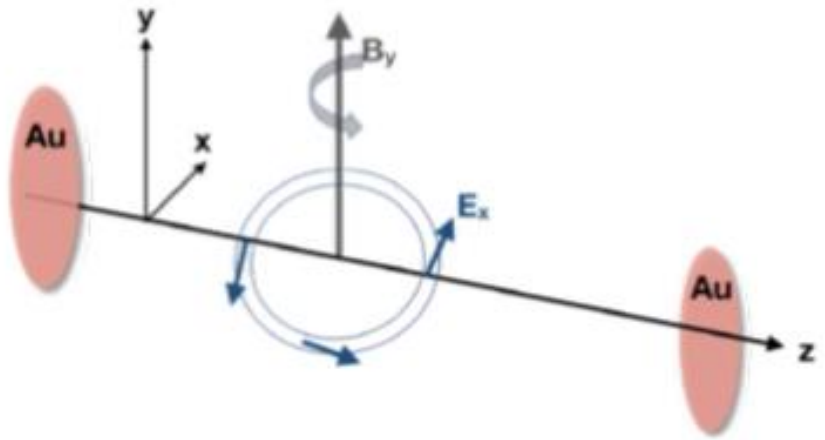


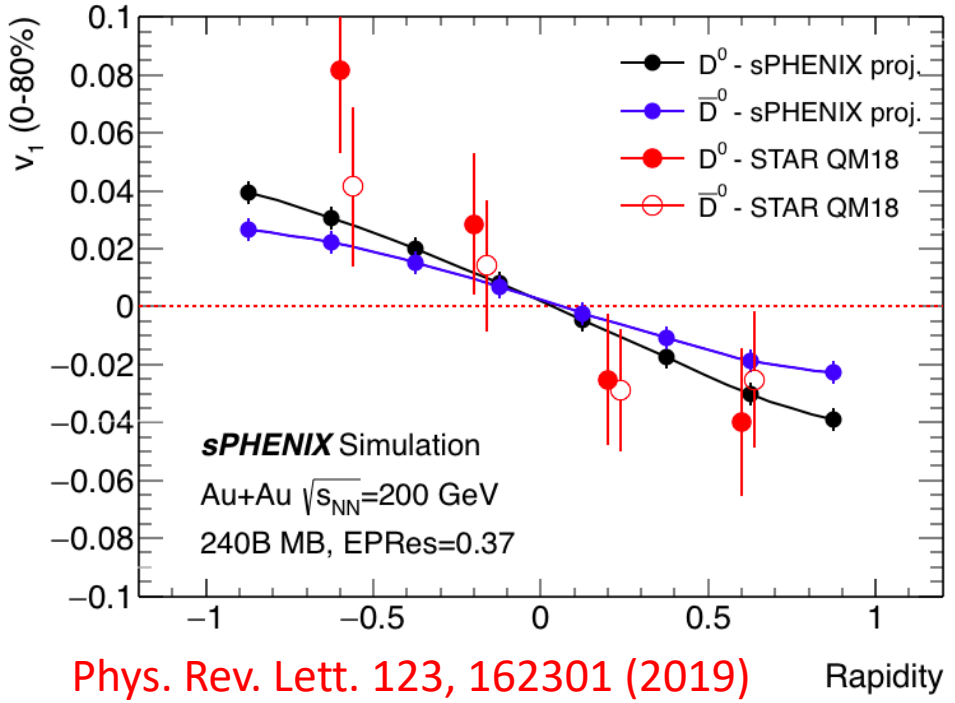




- Ratio provides window into HF hadronization mechanisms
- Provides input for B meson yield measurements and b cross section
- Ingredient for total charm cross section

D^0 Meson v_1





Phys. Rev. Lett. 123, 162301 (2019)

- Internal magnetic field of QGP splits D0 and D0bar directed flow
- Significantly more precise v_1 measurement
- Larger, finer-grained rapidity coverage

Summary

- sPHENIX heavy flavor program poised to make several precision measurements with significant discriminating power
- MVTX plays integral role in providing necessary precision

sPHENIX Posters

sPHENIX capabilities for measuring Λc_cc production in Au+Au collisions
Yuanjing Ji (University of Science and Technology of China)
https://indi.to/dM2t8

The sPHENIX heavy flavor jet physics program
Jin Huang BNL
https://indi.to/jkjJ4

The sPHENIX open heavy flavor hadron physics program
Sitong Peng pengst3@mail2.sysu.edu.cn
https://indi.to/ff8vF

Beam test results of the sPHENIX HCal prototype
Uttam Acharya (Georgia State University)
https://indi.to/BGp75

Cold QCD physics with sPHENIX and potential forward upgrades
Desmond Mzamo Shangase (University of Michigan (US))
https://indi.to/xFzFG

sPHENIX capabilities for jet-based observables
Dennis Perepelitsa (University of Colorado Boulder)
https://indi.to/tdVxW

sPHENIX EMCal design, construction and test beam results
Anabel Romero (Univ. Illinois at Urbana Champaign (US))
https://indi.to/z5P4z

sPHENIX EMCal module prototyping and production plan in China
Weihu Ma (Fudan University)
https://indi.to/9ZVzj

sPHENIX MAPS prototype test beam results
Cameron Dean (Los Alamos National Laboratory (US))
https://indi.to/FT6p8

Testbeam Results for the sPHENIX TPC Prototype
Henry Klest (Stony Brook University)
https://indi.to/2k3dY

The sPHENIX MAPS-based vertex detector
Dr Yasser Corrales Morales (Los Alamos National Laboratory (US))
https://indi.to/fnksd

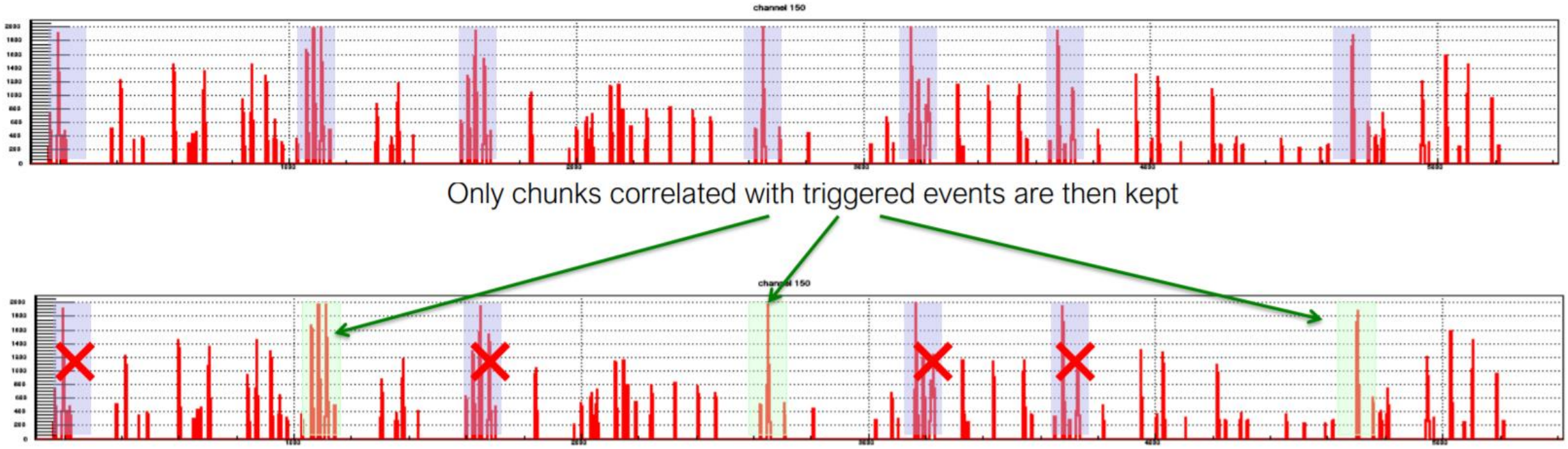
Backup

CMS B-jet Working Point

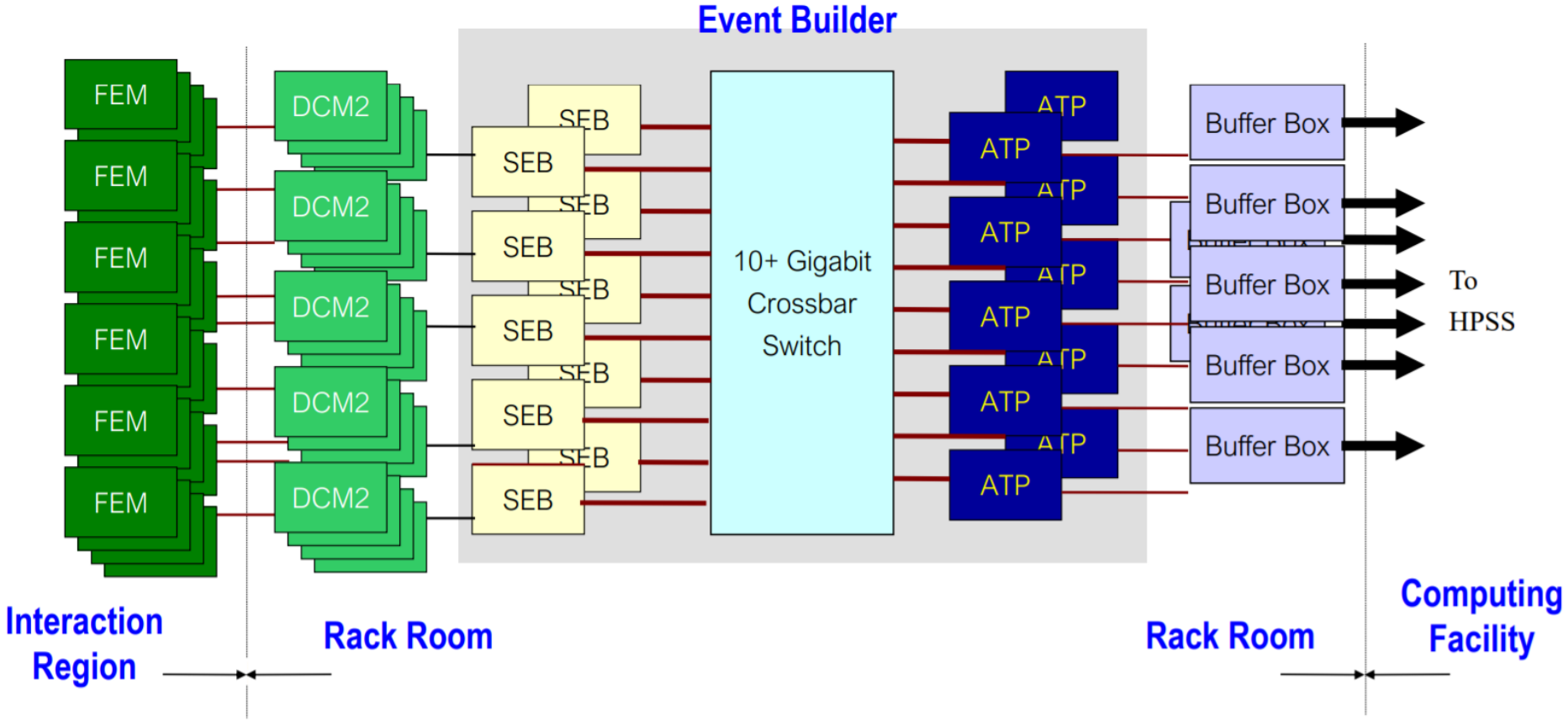
WP	b-discriminant	b eff	c eff	light eff
Loose	> 0.519	67%	20%	10%
Medium	> 0.856	47%	4.6%	1%
Tight	> 0.994	11%	0.1%	0.05%

Streaming Readout

The streaming data are recorded all the time, and broken up in chunks above threshold



Streaming Readout



- DCM-2 receives data from digitizer, zero-suppresses and packages
- SEB collects data from a DCM group (~35)
- ATP Assembles events and compresses data (~60)
- Buffer Box data interim storage before sending to the computing center (7)

Heavy Flavor in pp Collisions with Streaming Readout