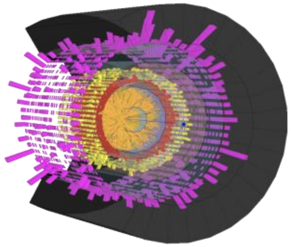
Probing QGP Properties with Upsilons at the sPHENIX Experiment

中国物理学会高能物理分会第十一届全国会员代表大会暨学术年会

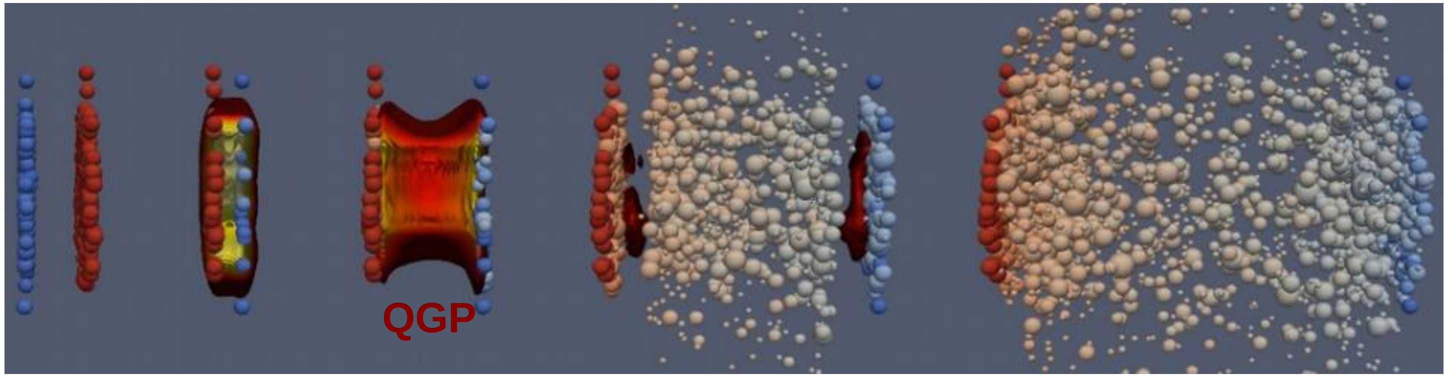
马维虎

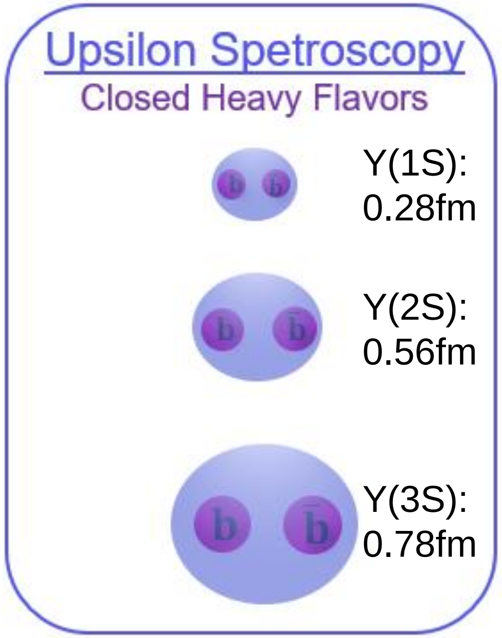
复旦大学

2022/08/11



Quarkonium probe in QGP Medium



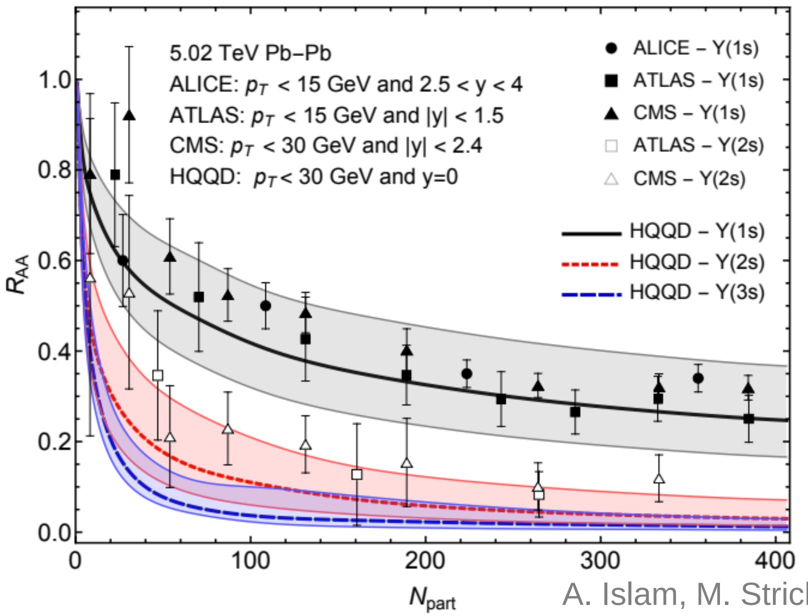


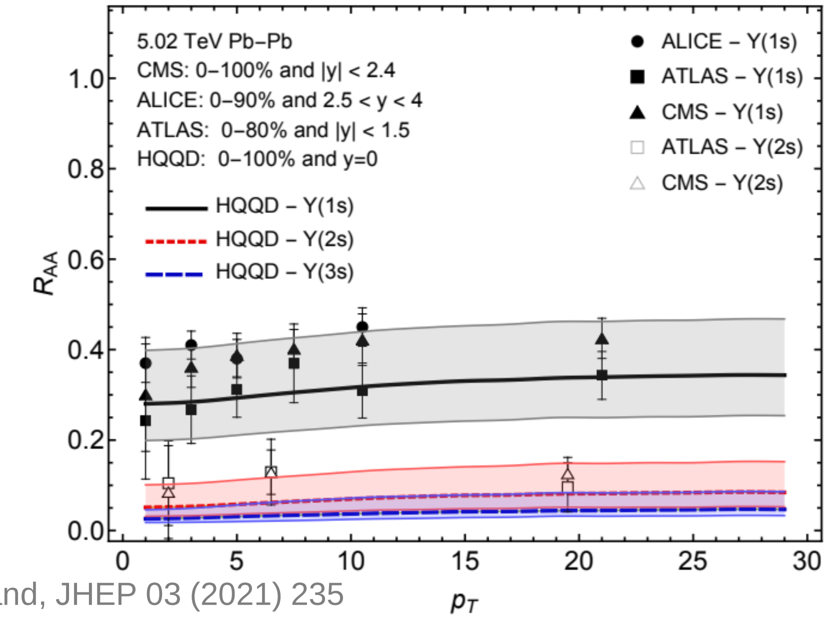
Quarkonia in relativistic heavy-ion collisions have been considered as golden probes for the study of strongly interacting matter of deconfined quarks and gluons, the quark-gluon plasma (QGP), at high energy density and temperature.

Bottomonia are produced by hard scattering in the early times of a relativistic heavy-ion collision, thus experience the entire evolution of the QGP.

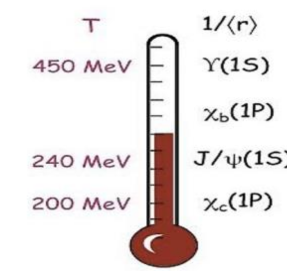
Its interacting with QGP medium (e.g. color screening) is the main motivation of measurement.

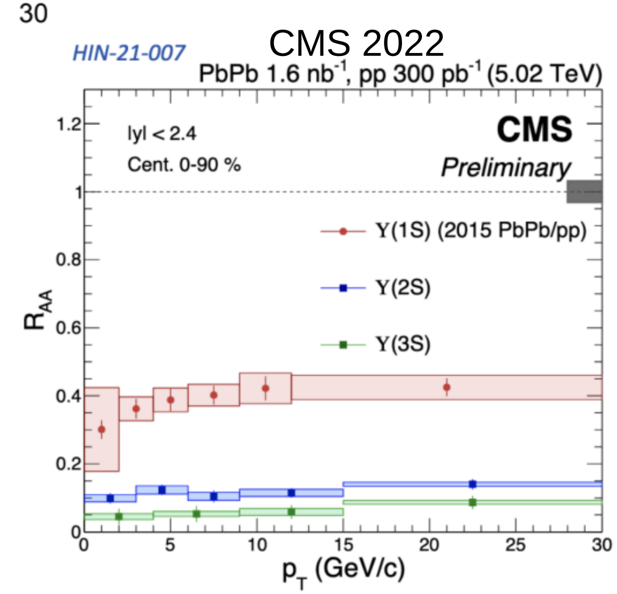
Bottomonium Suppression in QGP





A. Islam, M. Strickland, JHEP 03 (2021) 235

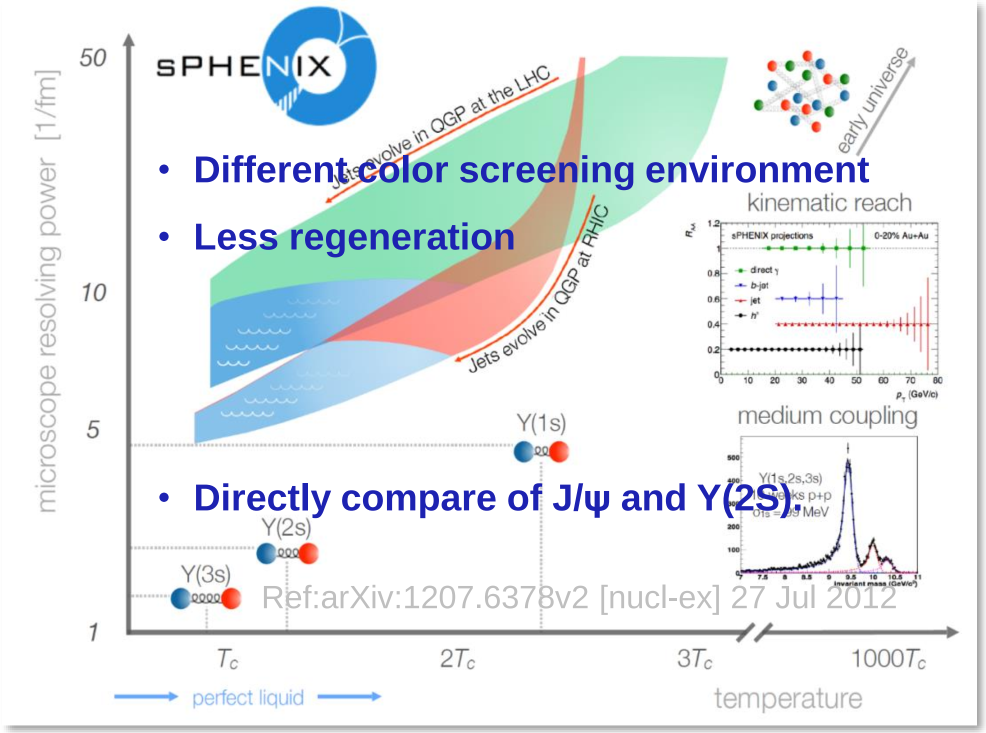




- Quarkonia are predicted to be suppressed in QGP, and previous measurements have revealed sizeable suppressions for the Υ(nS) states which increase with n.
- The LHC experiments CMS, ALICE, and ATLAS reported a significant suppression of the bottomonium states in Pb-Pb collisions
- At RHIC (STAR, PHENIX), Upsilon measurements have been hampered due to low yields and acceptance, and insufficient momentum resolution to resolve the three states.

Upsilon production at sPHENIX

The sPHENIX experiment is center on probing the strongly interacting Quark-Gluon Plasma with jets, heavy flavor, and Upsilon production.



Color screening and CNM become the primary effects.

High precision measurements of Upsilon production with sufficient accuracy for clear separation of the Υ(1S, 2S, 3S) states is a key deliverable of the sPHENIX physics program. Interacting with QGP medium (Color Screening effect) is the major motivation.

Advantages:

- Mainly produced at the early stage of the collisions.
- Negligible nonprompt fraction and less regeneration compared to charmonia.
- Three Υ(nS) states providing a opportunity to compare the effect of the medium simultaneously on the three states.

Run plan of sPHENIX

Scientific mission of sPHENIX can be achieved with 3 years of running.

Year	Species	$\sqrt{s_{NN}}$ [GeV]	Cryo Weeks	Physics Weeks	Rec. Lum. $\|z\| < 10$ cm	Samp. Lum. $\|z\| < 10$ cm
2023	Au+Au	200	24 (28)	9 (13)	3.7 (5.7) nb^{-1}	4.5 (6.9) nb^{-1}
2024	$p^{\uparrow}p^{\uparrow}$	200	24 (28)	12 (16)	0.3 (0.4) pb^{-1} [5 kHz] 4.5 (6.2) pb^{-1} [10%-*str*]	45 (62) pb^{-1}
2024	$p^{\uparrow}$+Au	200	–	5	0.003 pb^{-1} [5 kHz] 0.01 pb^{-1} [10%-*str*]	0.11 pb^{-1}
2025	Au+Au	200	24 (28)	20.5 (24.5)	13 (15) nb^{-1}	21 (25) nb^{-1}

Year-1 (Au+Au): Commissioning, calibration, collection of a Au+Au data

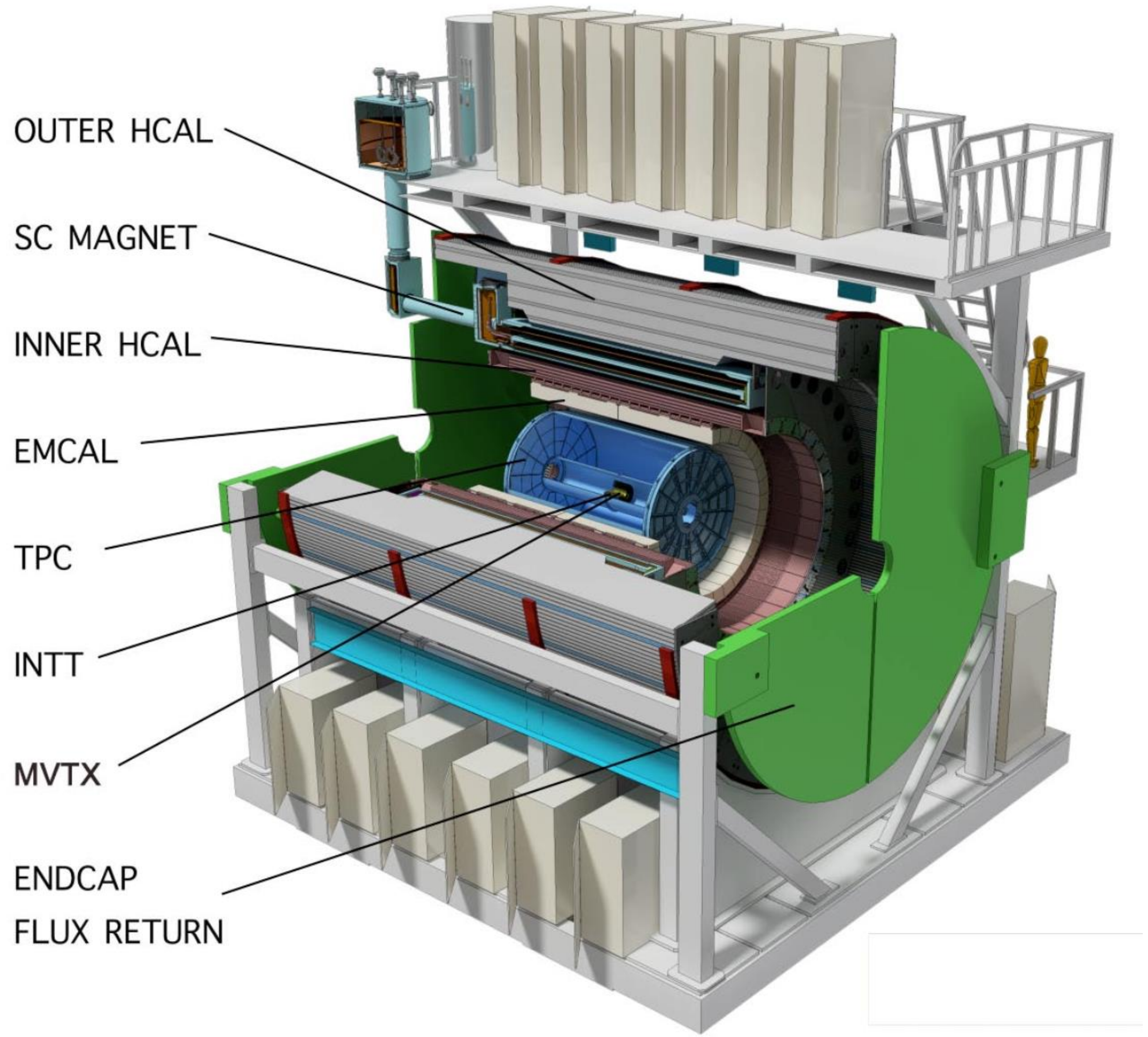
Year-2 (p+p & p+Au): Commissioning and pp reference data & cold QCD Measurements

Year-3 (Au+Au): High statistics data collection for jets, HF, and Quarkonia.

Species	Events	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$	Total Υ
p+p	8300B	10800	2820	1570	15200
p+p after eID		9755	2540	1400	13680
Au+Au (0-10% central)	24B	27120	7050	3930	38100
Υ in Au+Au (0-10% central) after suppression from [ref].	Nucl. Phys. A879 25, (2012)	14500	1200	137	15840
Υ in Au+Au (0-10% central) after suppression and eID		11750	970	111	12830

Estimated yields of $\Upsilon \rightarrow e^+e^-$ in the sPHENIX. eID efficiency is assumed to be 90% in Au+Au and 95% in p+p.

sPHENIX Detector

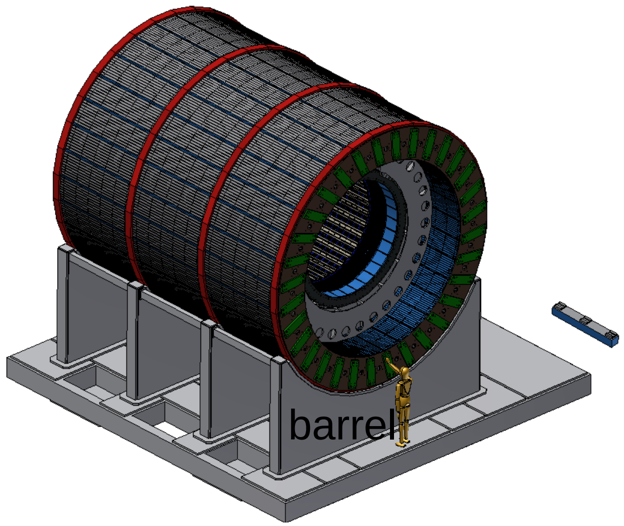


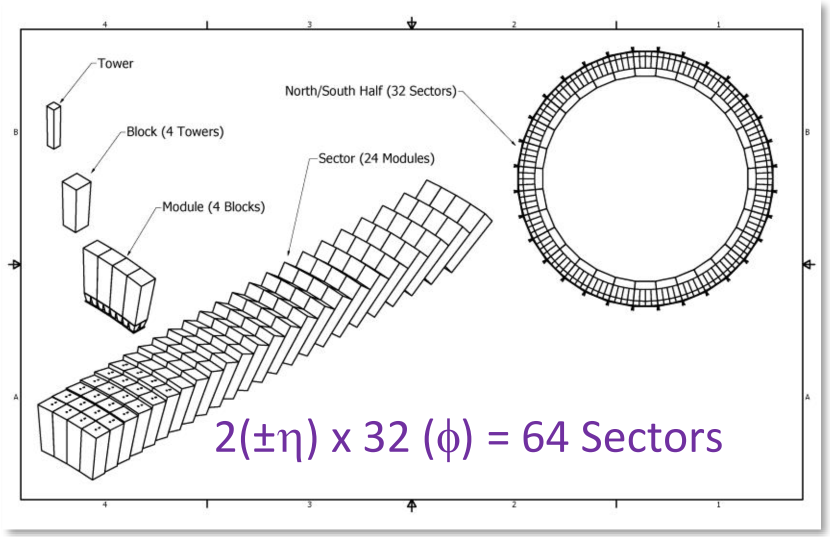
EMCal Design Performance

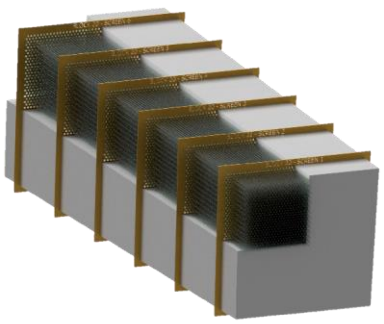
The EMCal performance is central to the direct photon and Upsilon measurements and it is also a key component, along with the HCal, of the jet reconstruction.

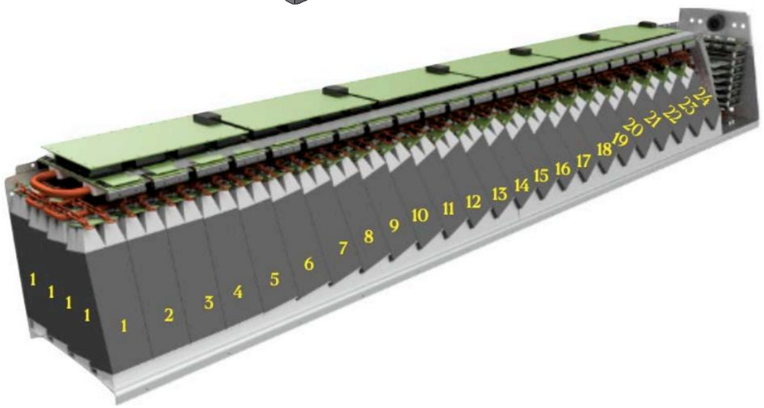
W/SciFi EMCal block

EMCal covering $\pm$ 1.1 in η and 2π in ϕ. $\Delta\phi$ x $\Delta\eta$ ~ 0.025x 0.025



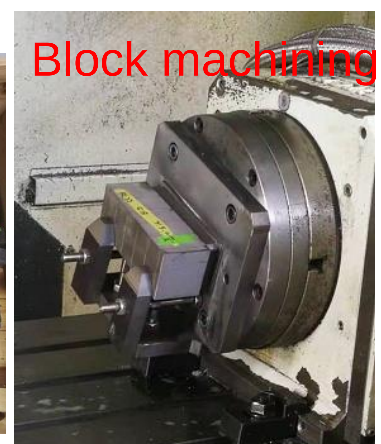




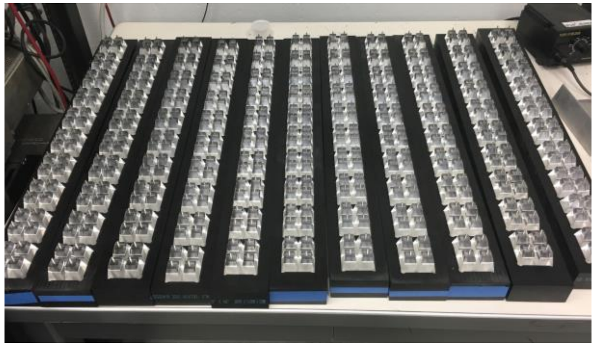


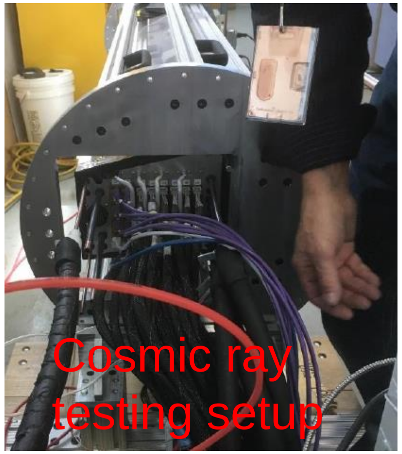
- High density (9-10 g/cm^3), low radiation length (~7 mm), small Molière radius (~ 2 cm), compact structure and low cost.
- The readout system adopts light guide combined with SiPM.

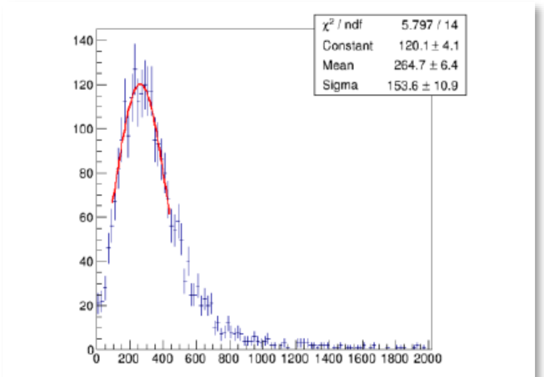
Mass of Block Production at Fudan



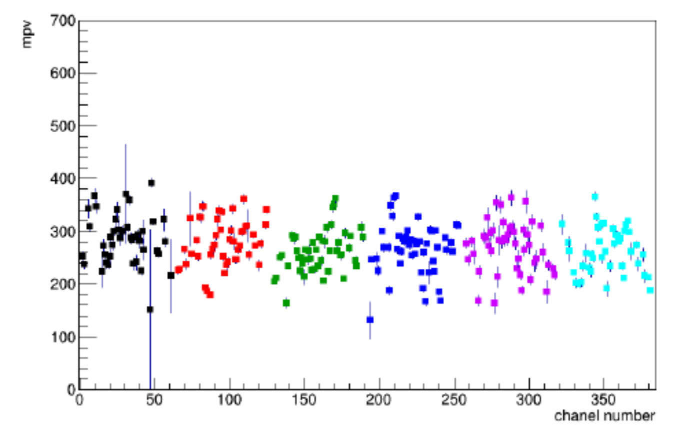
EMCal Modules and Sectors Assembly





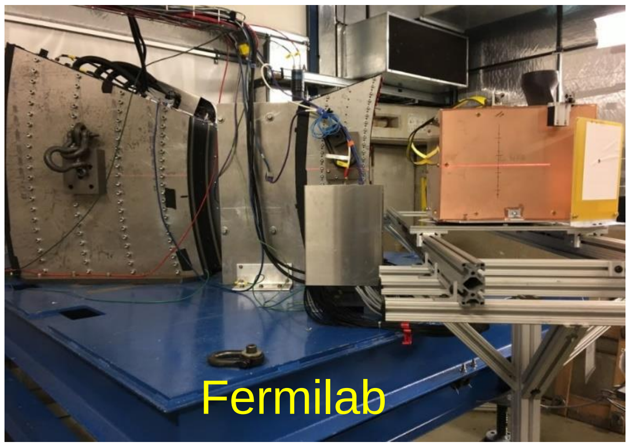


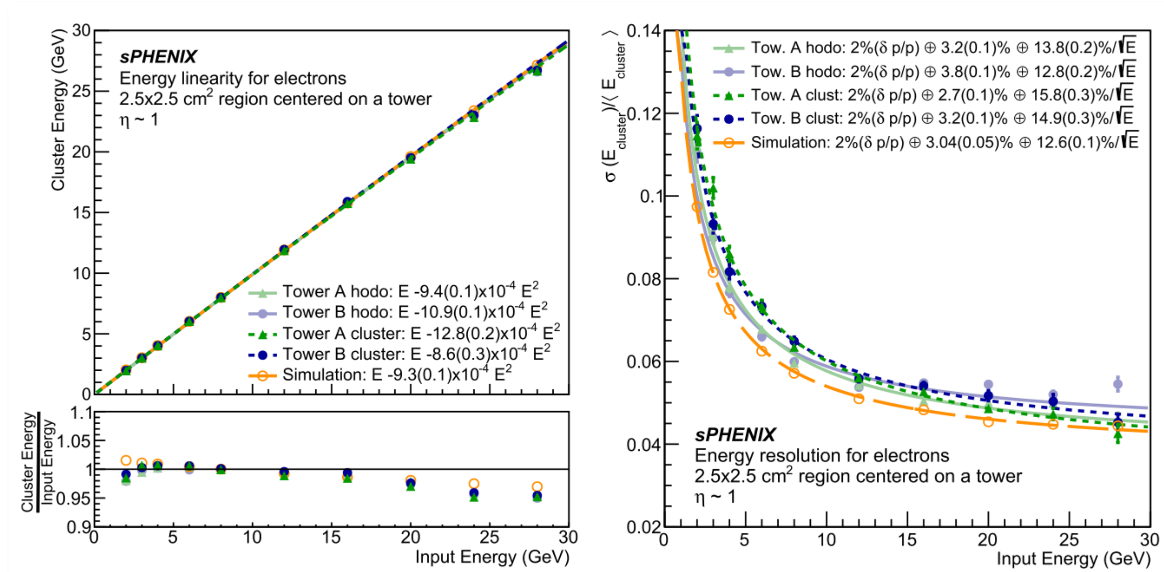
Cosmic ray spectrum for a single tower

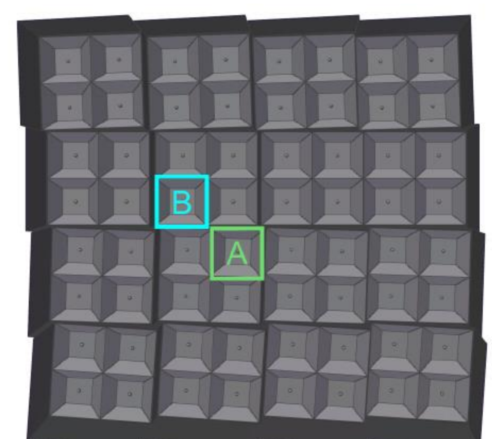


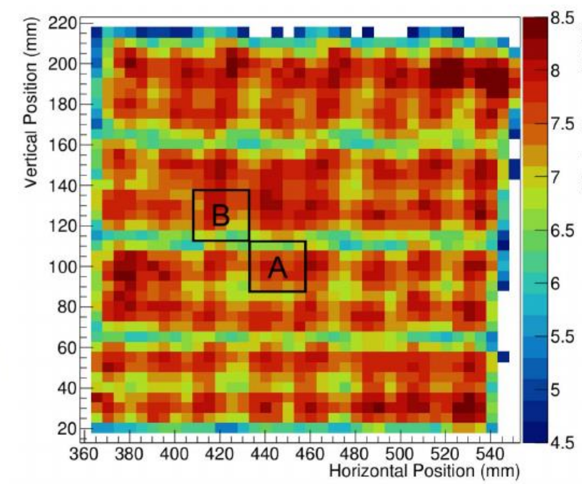
MIP peaks for all towers in a sector

EMCal Prototyping and Testing





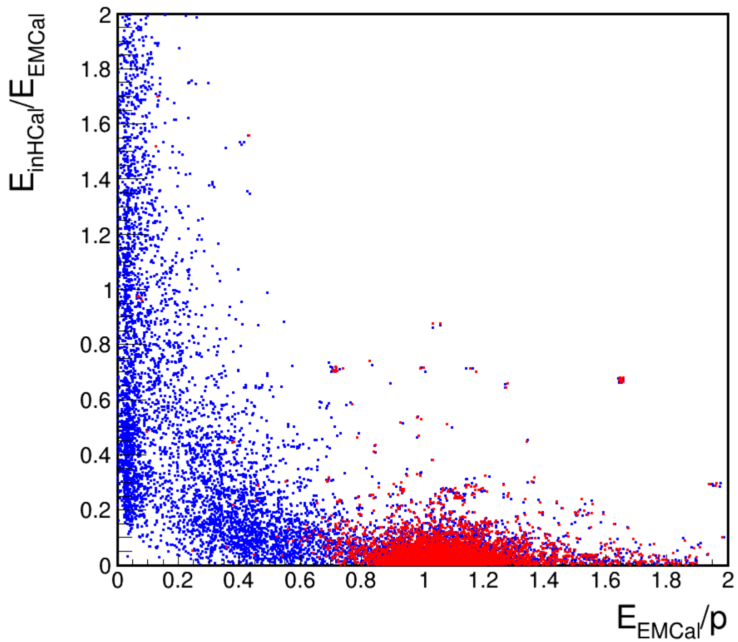


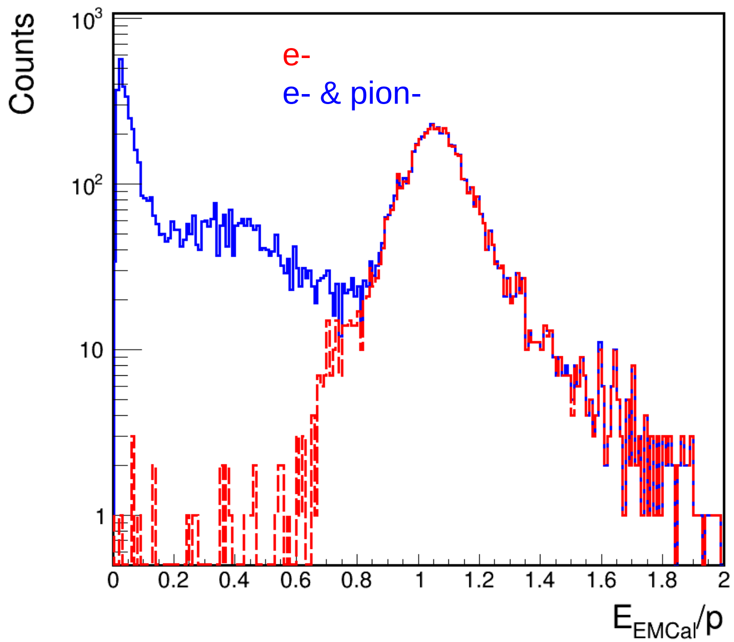


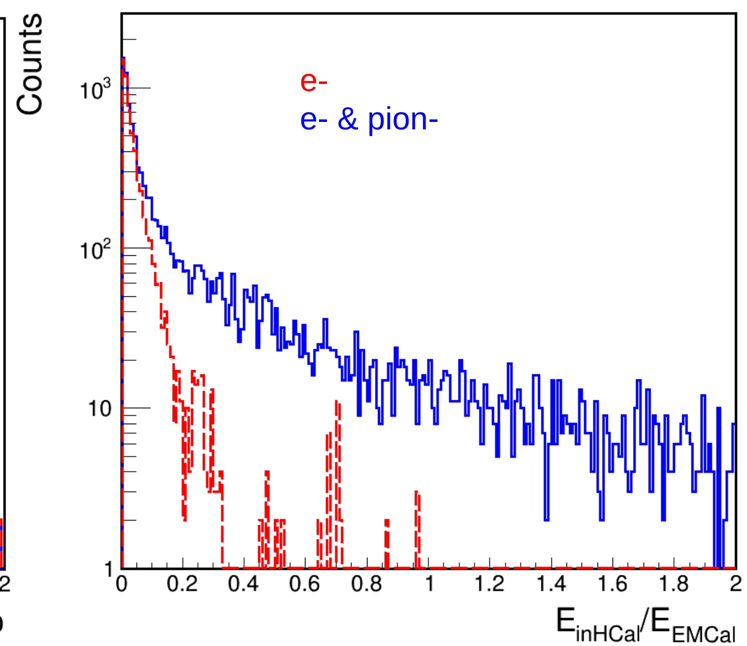
Electron identification

- Reconstruction of Upsilon invariant mass by e+e- pairs.
- Background sources: misidentified charged hadrons, irreducible (physics) background.
- The background should be removed to extract the signal pairs.
- Event mixing method can be used to estimate combined background.

eID strategies: individual variable analysis & multiple variable analysis.
Variable: E_{EMCal}/p; E_{inHCal}/ E_{EMCal}; shower shape; vertex information.

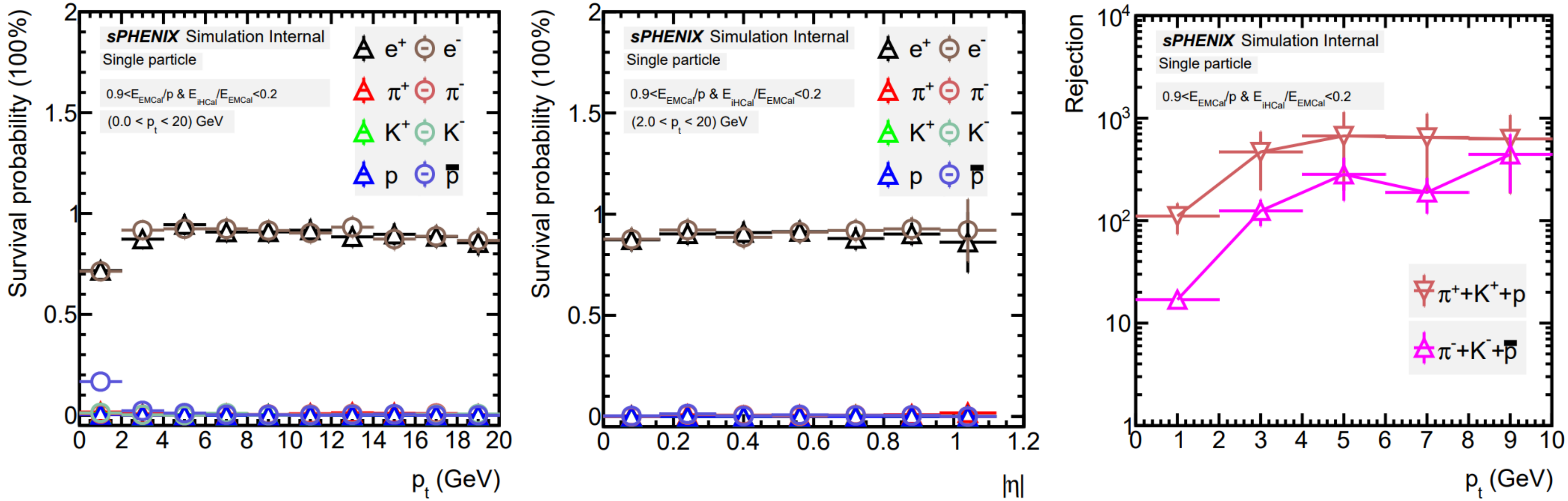






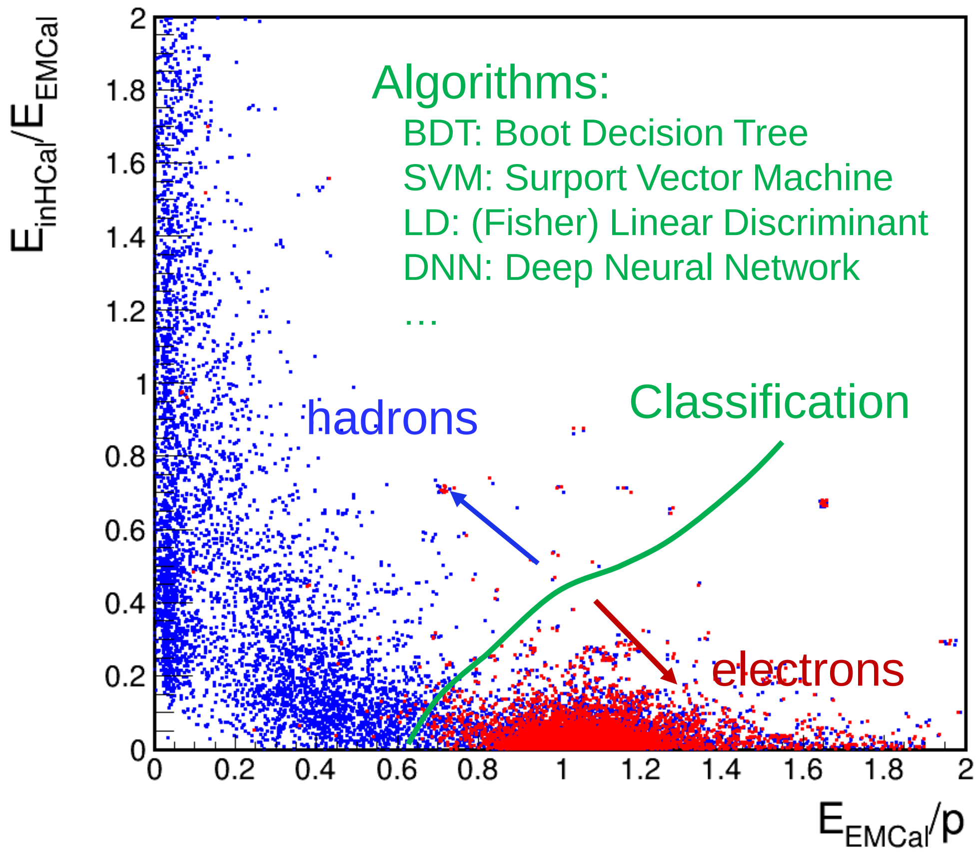
Electron identification

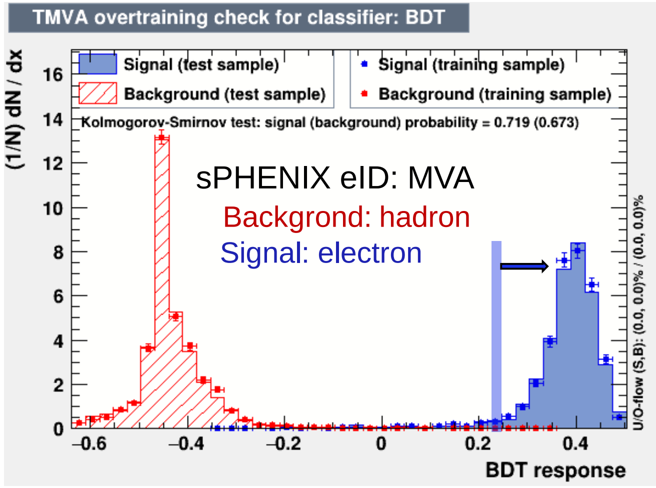
Electron identification efficiency and hadron rejection ability for single particle samples.

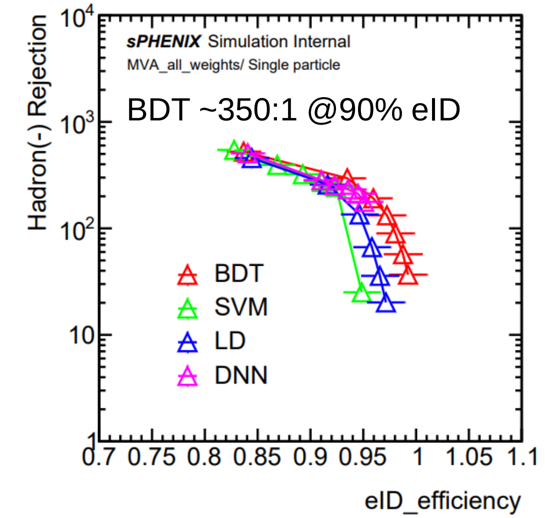


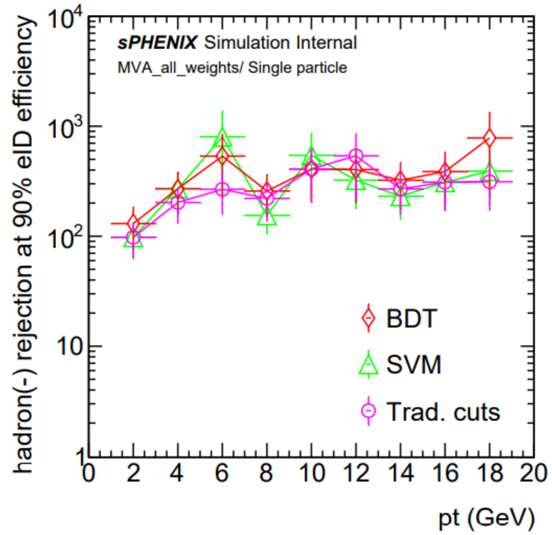
Electron identification

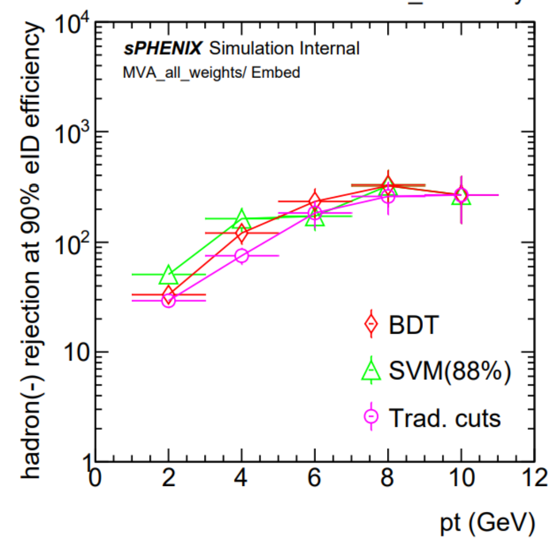
Classification with Multiple Variable Analysis (machine learning)









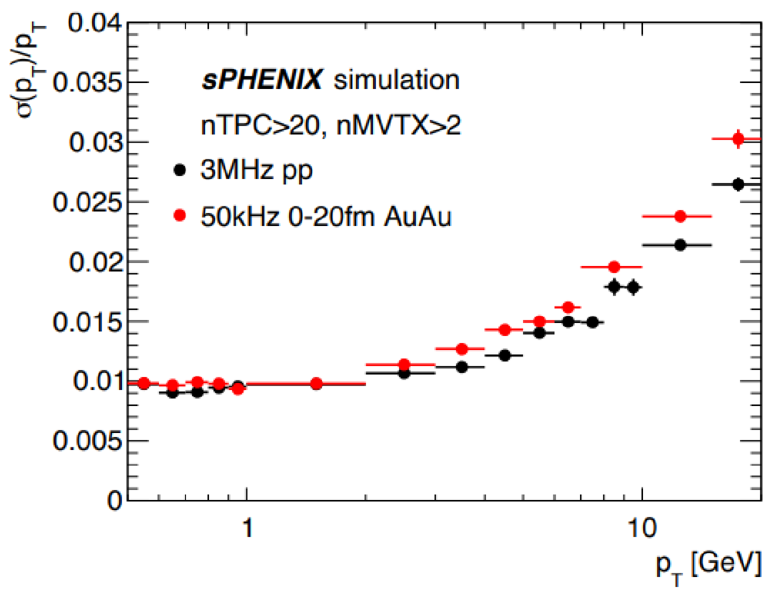


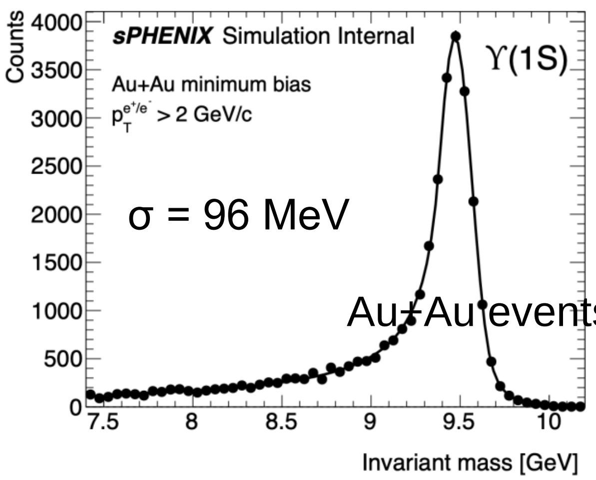
BDT gets 80% improvement for pt in range of (2,10) GeV

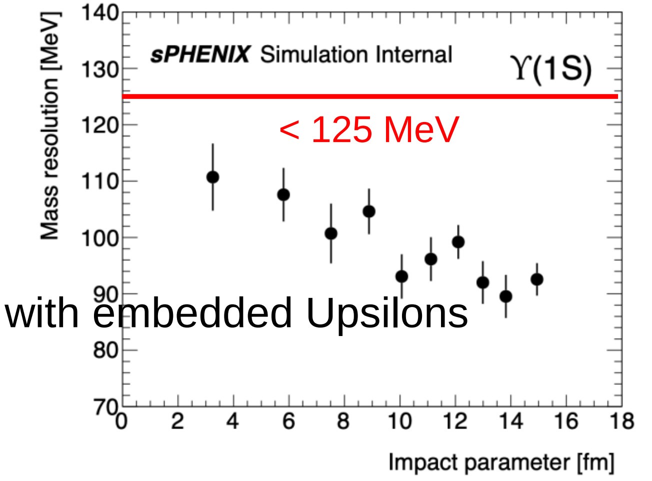
Upsilon Reconstruction from e+e- pairs

sPHENIX provides excellent mass resolution

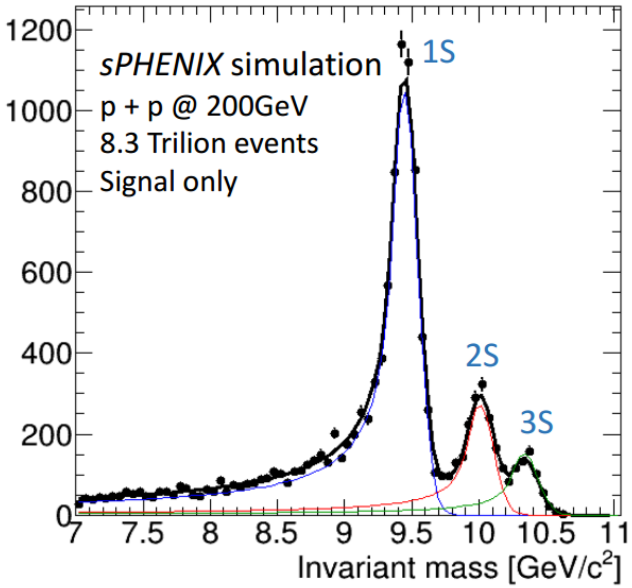
Y(nS)->e+e-

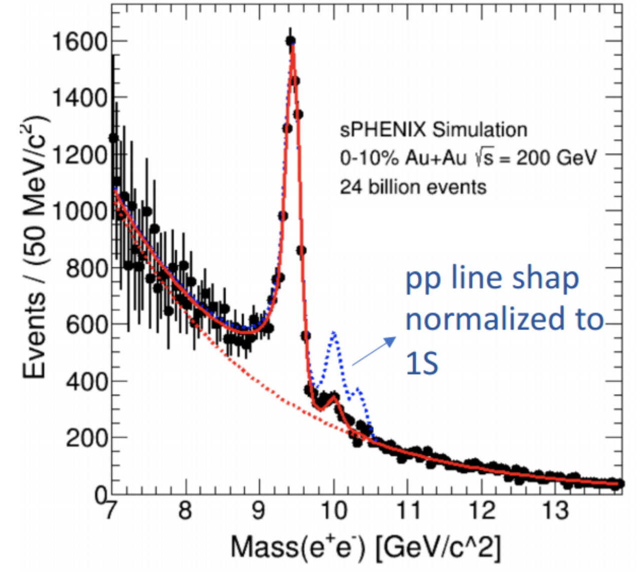




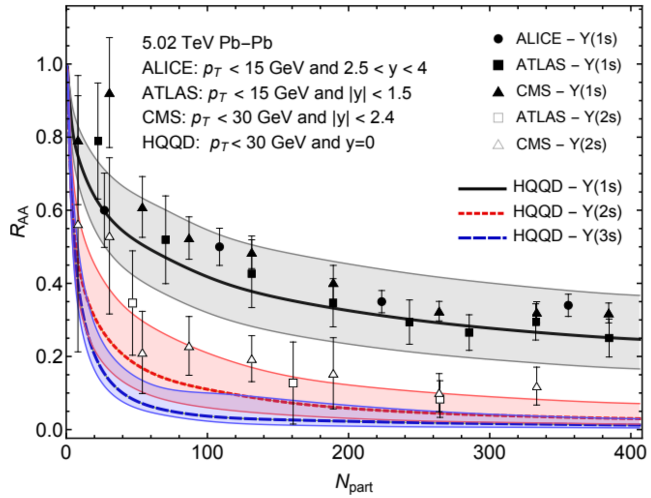


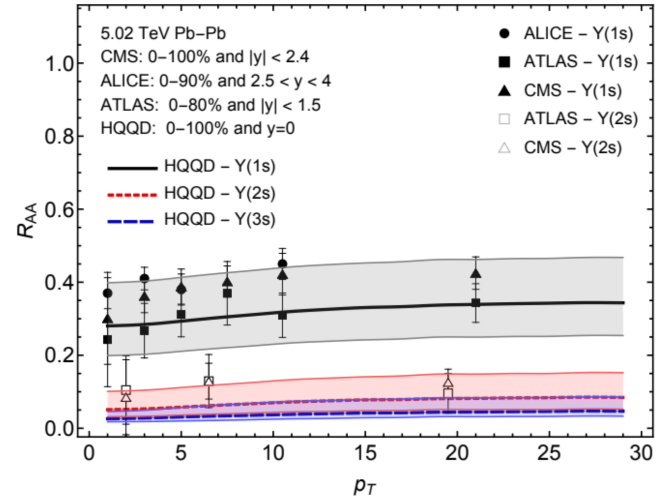
Au+Au events with embedded Upsilons

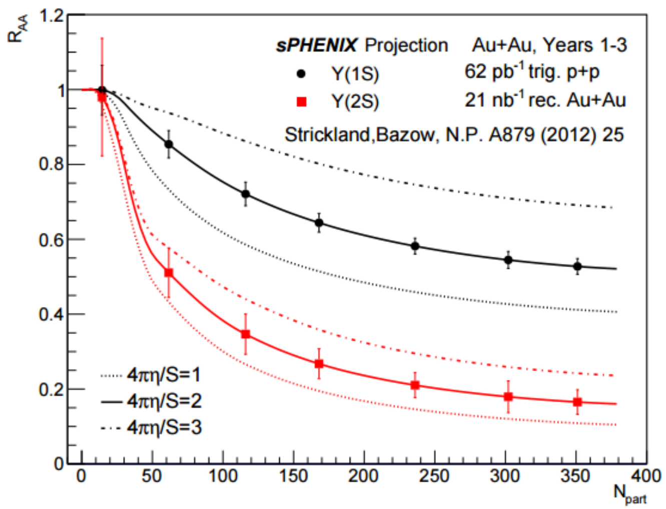


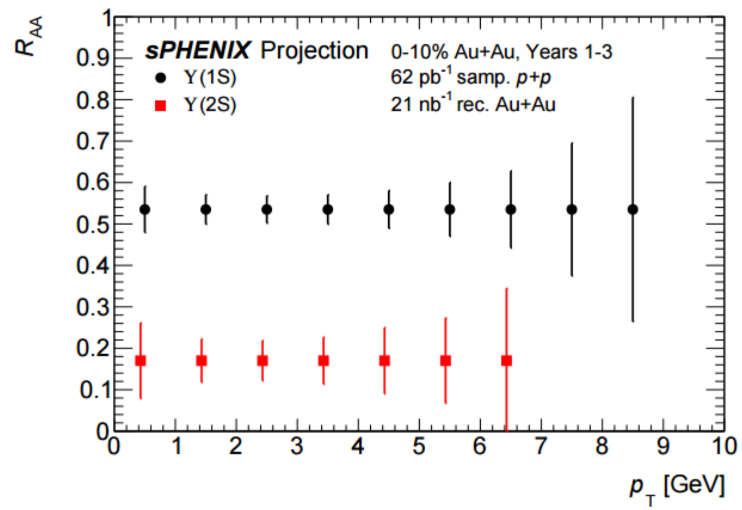


The estimation of Upsilon suppression









- ➢ Measuring centrality & p_t dependence of R_{AA} is critical to compare with LHC.
- ➢ Measuring Υ(3S) modification will be challenging due to the large suppression.

Summary

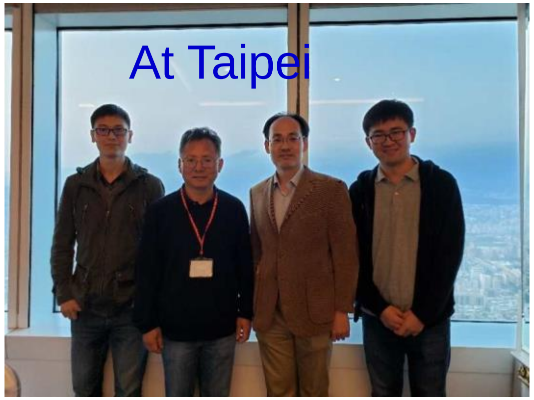
- With large acceptance, good momentum resolution, and high hadron rejection ability, the upgrade to sPHENIX would provide better mass resolution and high yields for upsilon measurements. This would substantially enhance the ability of RHIC to provide upsilon data of comparable quality to the LHC data.
- The EMCal detector is an essential subsystem for Upsilon measurements via its di-electron decay.
- sPHENIX electron identification capability can be improved by MVA method.
- Chinese sPHENIX Consortium contributing to EMCal blocks covering the pseudo-rapidity region of 0.8-1.1, which will greatly enhanced the physics capability of sPHENIX for jets and Upsilon measurements.
- W/SciFi EMCal and its light guide coupling SiPM readout technology have promising application in EIC and other experiments.

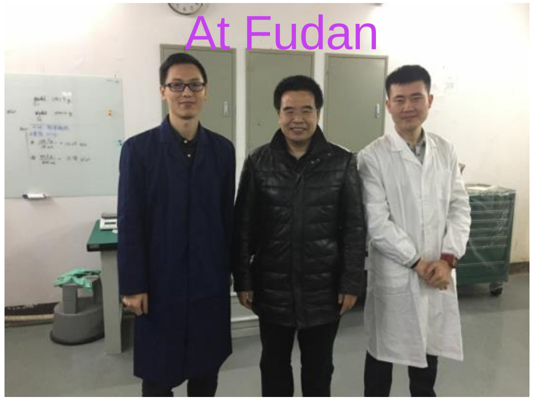
Thanks！

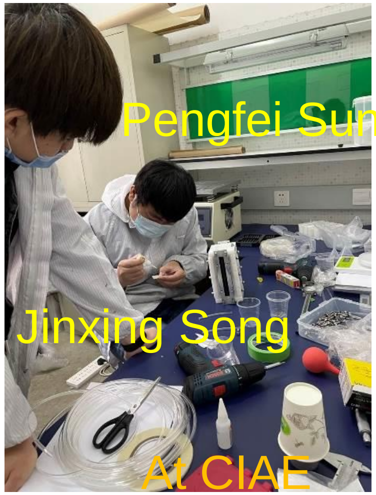
中国物理学会高能物理分会第十一届全国会员代表大会暨学术年会

Questions and Comments?

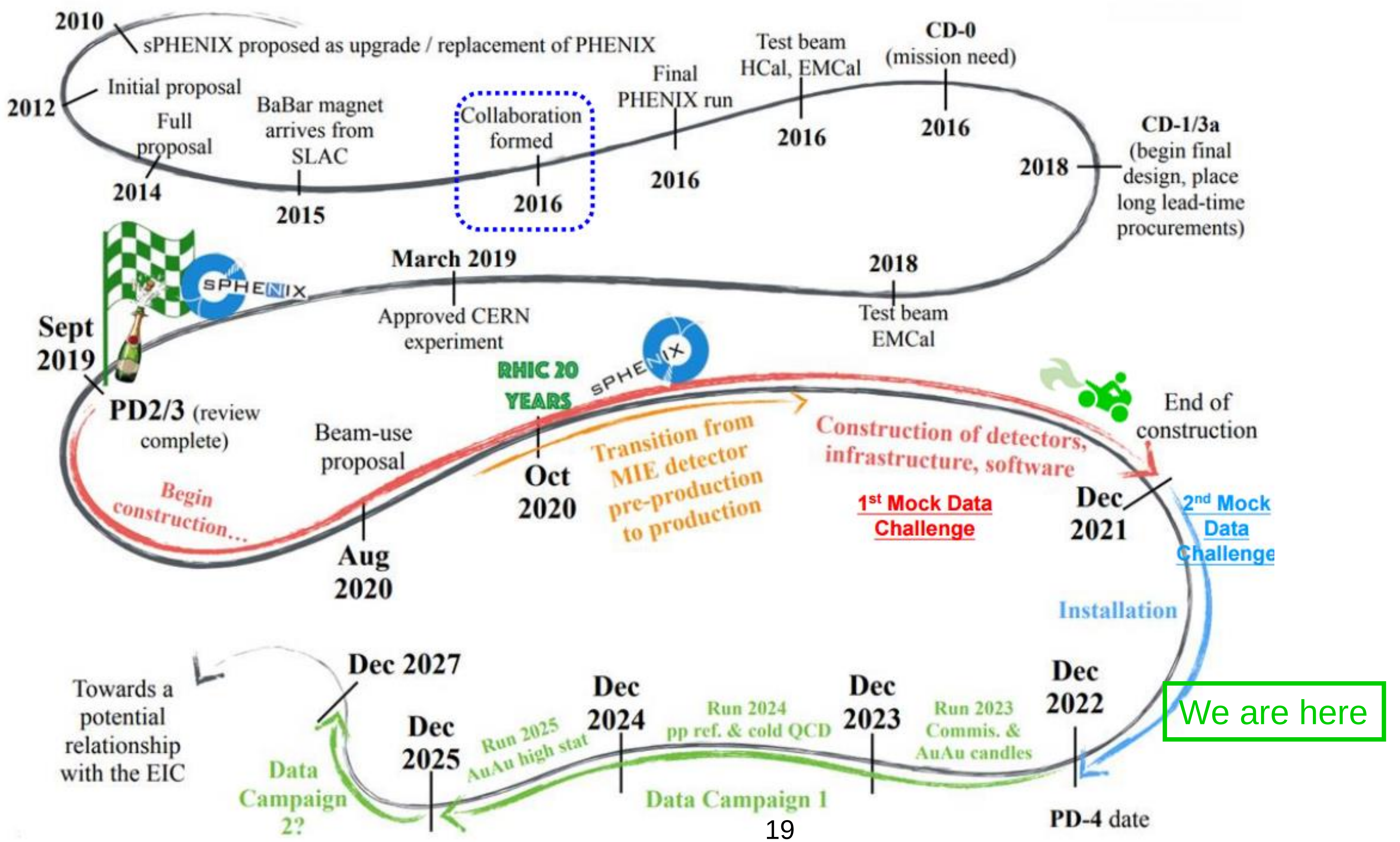
Collaboration Consortium and Production Scenario



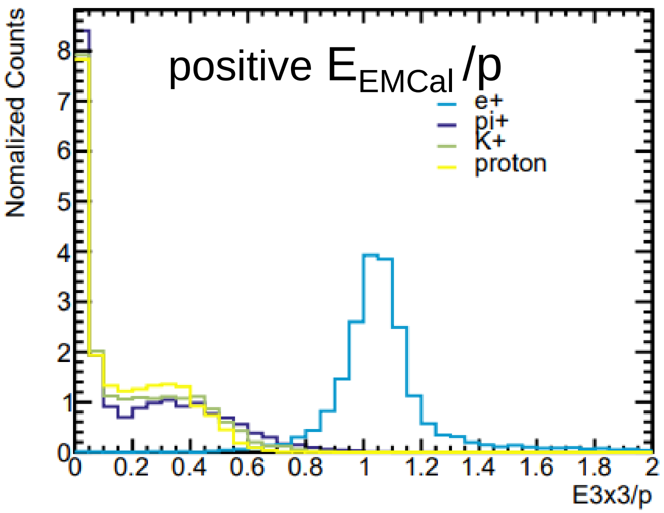


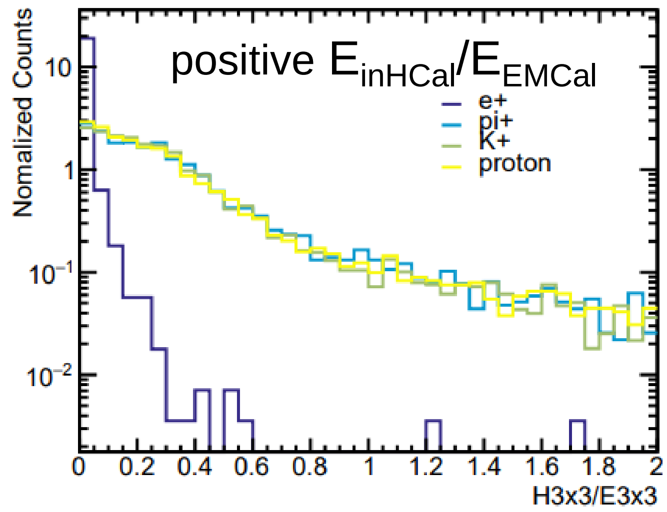


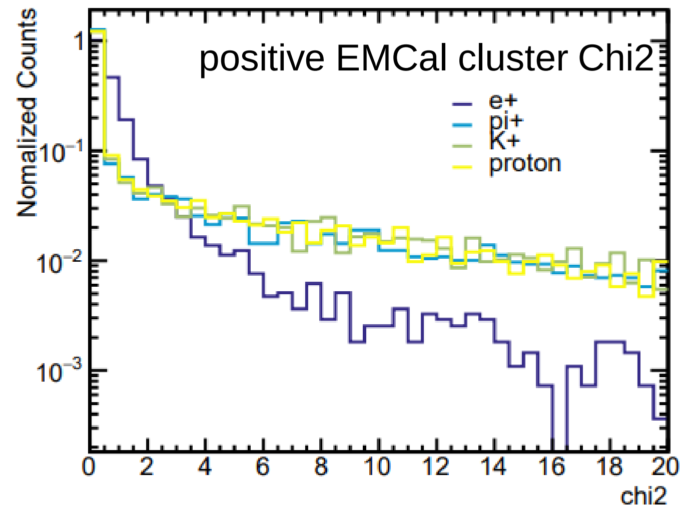
sPHENIX Schedule



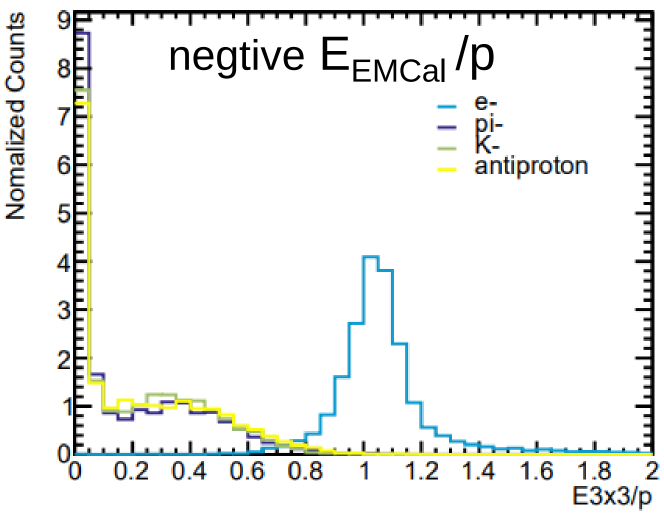
eID-MVA Classification

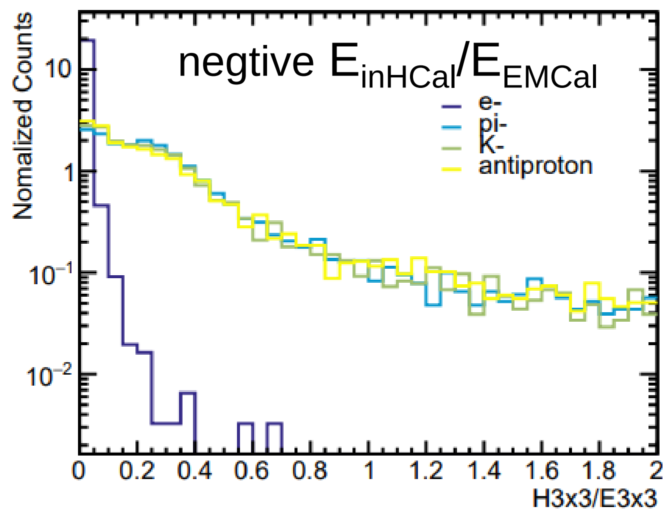


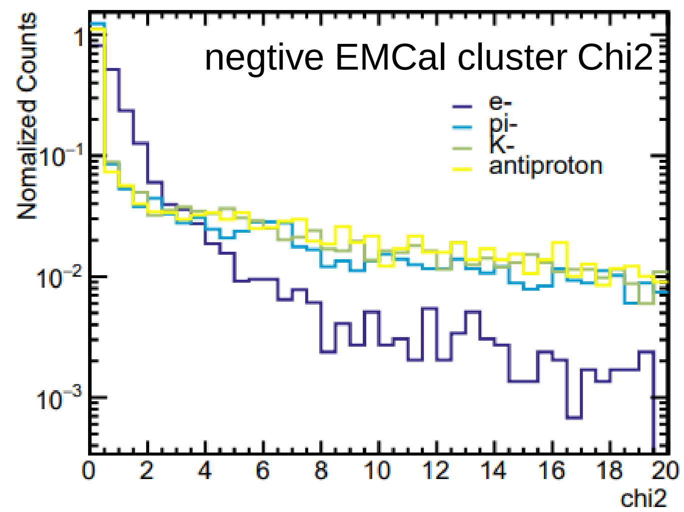




nmaps>0 & nintt>0 & ntpc>20 & quality<10 & pt>2.0 GeV





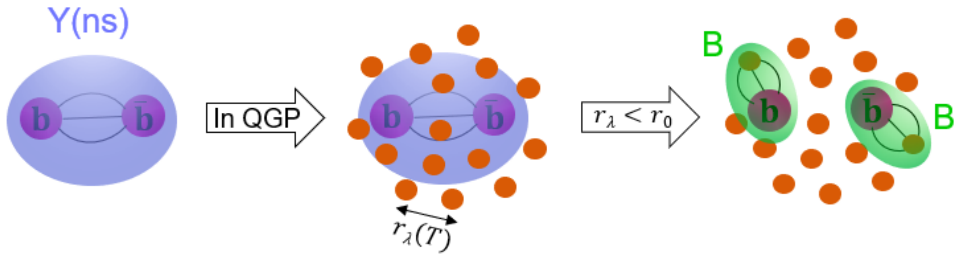


Suppression of Heavy Quarkonium in QGP

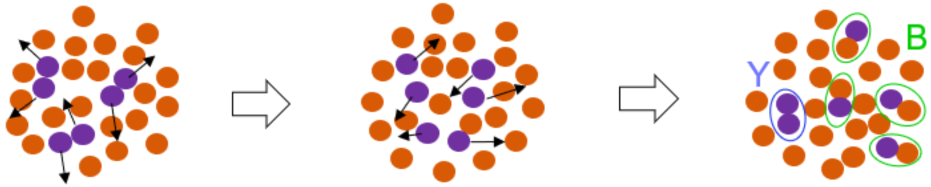
Physical effects:

- **Debye screening**: The color screening of the surrounding medium prevent the heavy quark and anti-quark pairs from forming their bound states
- **Cold nuclear matter effects**: modification of parton distribution function of nuclei relative to proton and nuclear absorbtion.
- **Regeneration**: coalescence of uncorrelated quarks or recombination of heavy-quark pairs from an original dissociated quarkonium.
- Feed-down production of ground state and sequential suppression of higher states.
- Comoving effects and dissociation
- Parton energy loss(e.g. nonprompt J/ψ R_{AA} reflects b-quark energy loss)

Color screening:



Regeneration:



TMVA BDT (Boosted Decision Trees)

- Sequential application of cuts splits the data into nodes, where the final nodes (leafs) classify an event as signal or background.
  - Start with Root node
  - Split training sample according to cut on best variable at this node
  - Splitting criterion: e.g., maximum "Gini-index": purity $\times$ (1– purity)
  - Continue splitting until min. number of events or max. purity reached
  - Classify leaf node according to majority of events, or give weight; unknown test events are classified accordingly