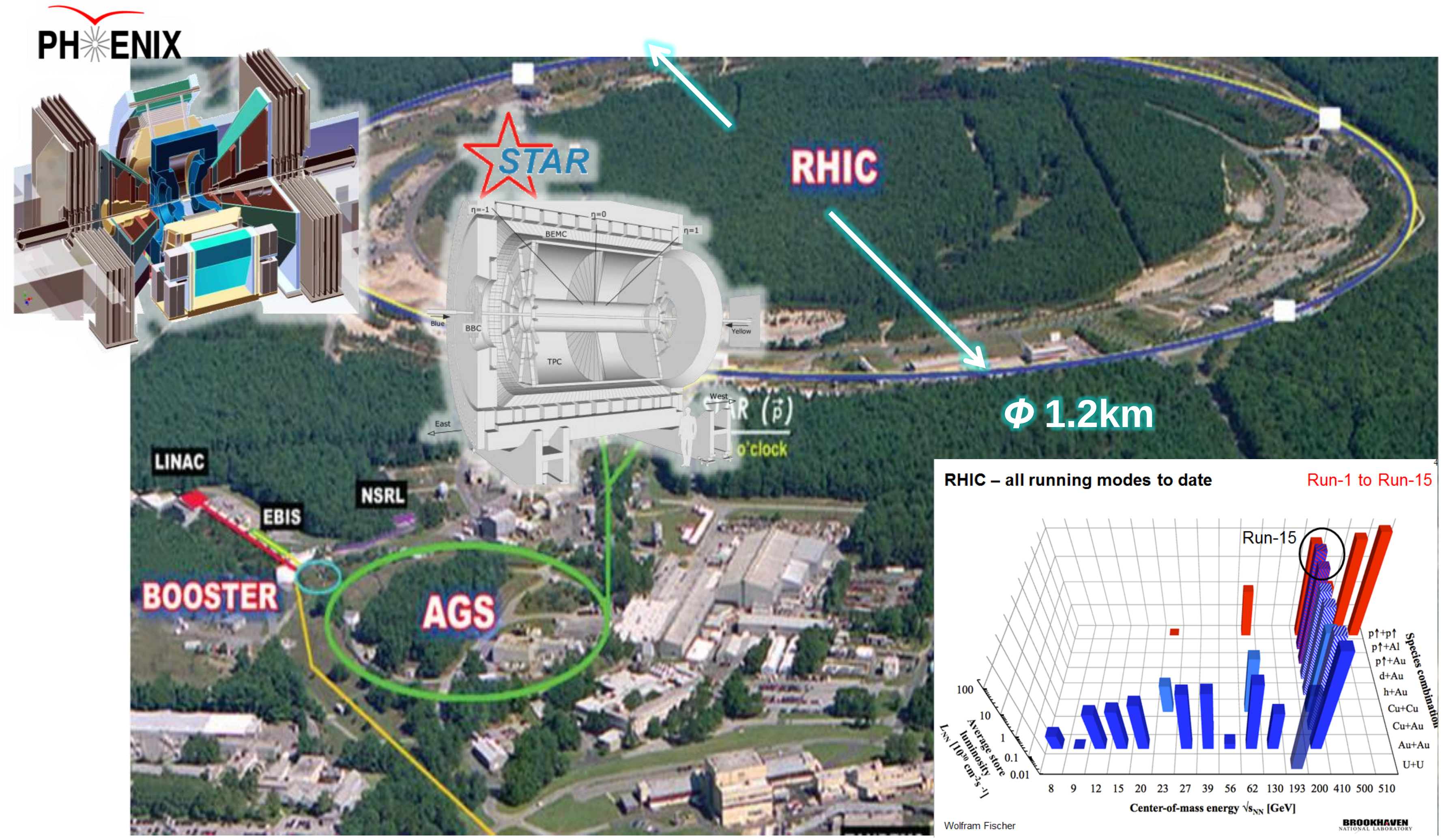
RHIC Experiments in Transition at Brookhaven National Laboratory

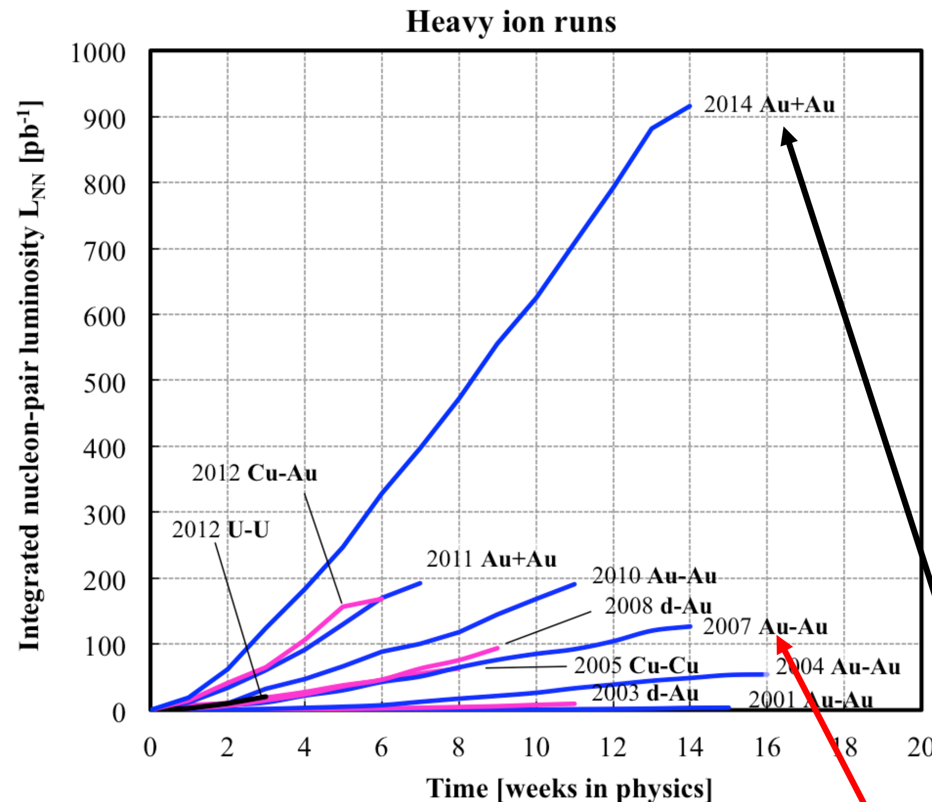
Outline: ● Today to 2022

Edouard Kistenev
Brookhaven National Laboratory
PHENIX Experiment

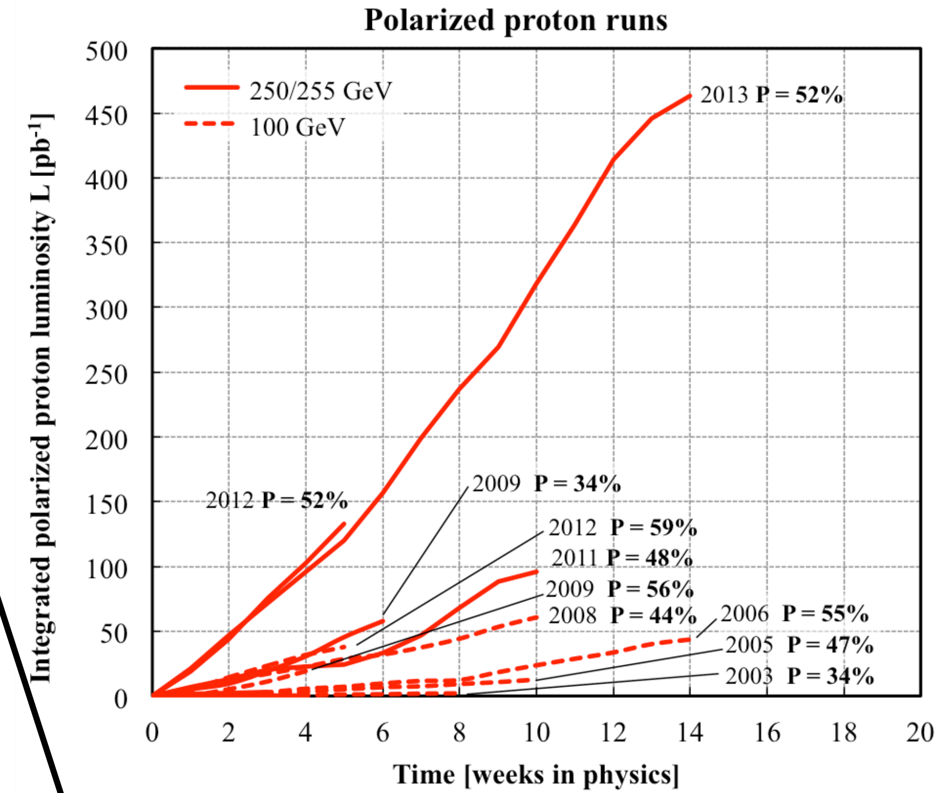
Brookhaven National Laboratory in Transition

Relativistic Heavy Ion Collider
Bird's eye view



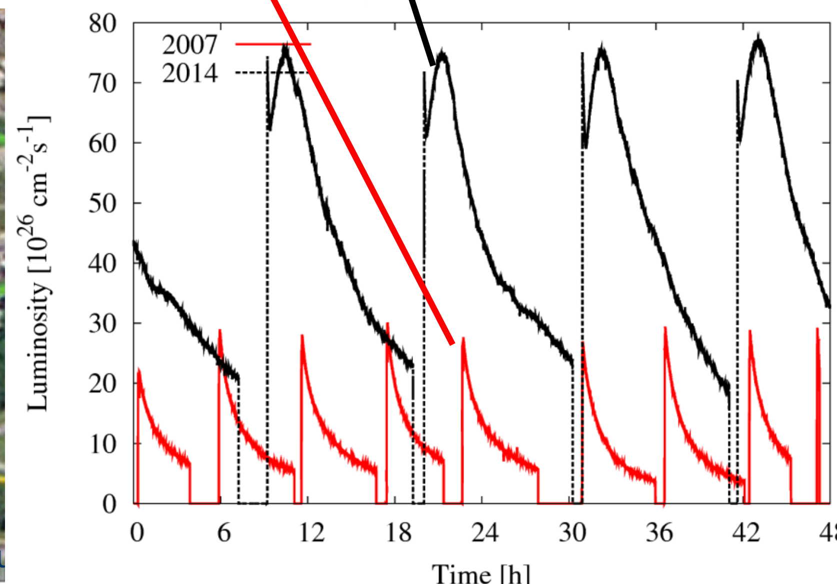


Heavy ion runs
Integrated nucleon-pair luminosity L_{NN} [pb^{-1}]
Time [weeks in physics]
2014 Au+Au
2012 Cu-Au
2012 U-U
2011 Au+Au
2010 Au-Au
2008 d-Au
2007 Au-Au
2005 Cu-Cu
2004 Au-Au
2003 d-Au
2001 Au-Au



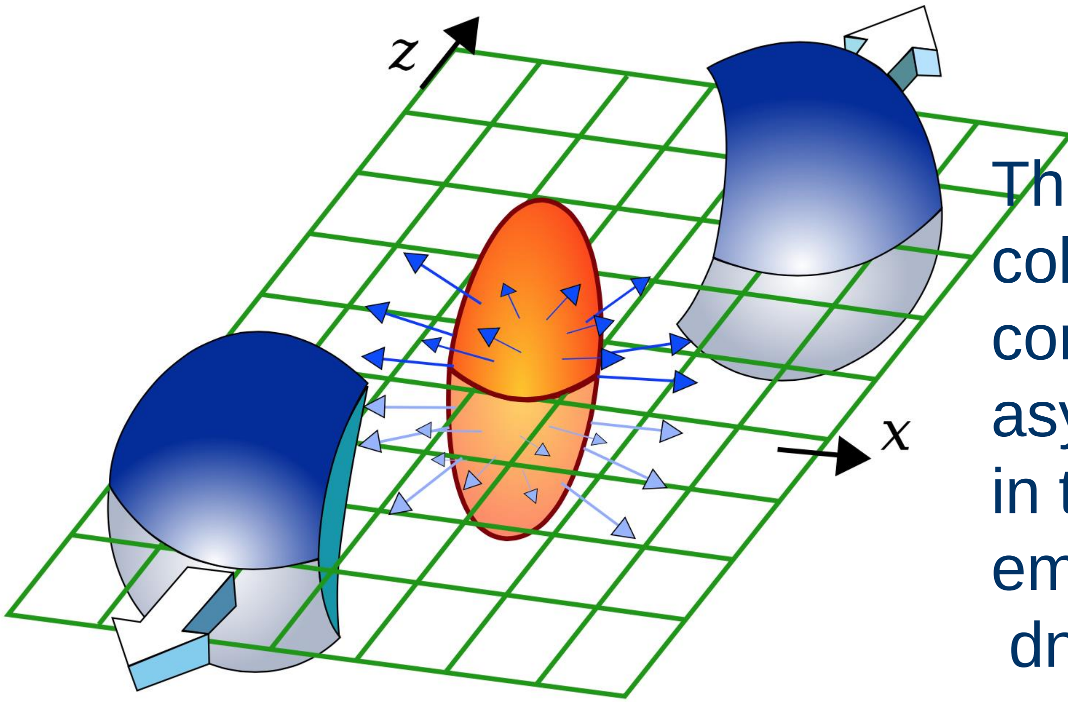
Polarized proton runs
Integrated polarized proton luminosity L [pb^{-1}]
Time [weeks in physics]
250/255 GeV
100 GeV
2013 P = 52%
2012 P = 52%
2009 P = 34%
2012 P = 59%
2011 P = 48%
2009 P = 56%
2008 P = 44%
2006 P = 55%
2005 P = 47%
2003 P = 34%

LINAC
NSRL
EBIS
BOOSTER
AGS



2007
2014
Luminosity [10^{26} cm^{-2}s^{-1}]
Time [h]

An experimentalist view of Heavy Ion Collisions



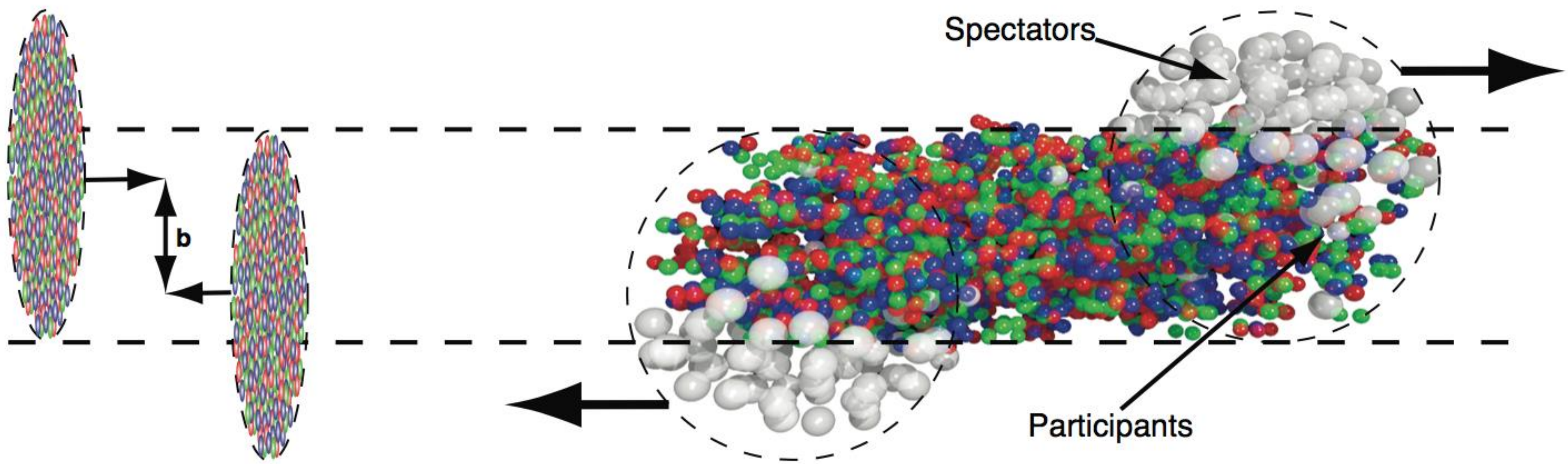
The collective nature of the the collision created medium converts initial state azimuthal asymmetry into a *strong* signal in the final state particle emission pattern

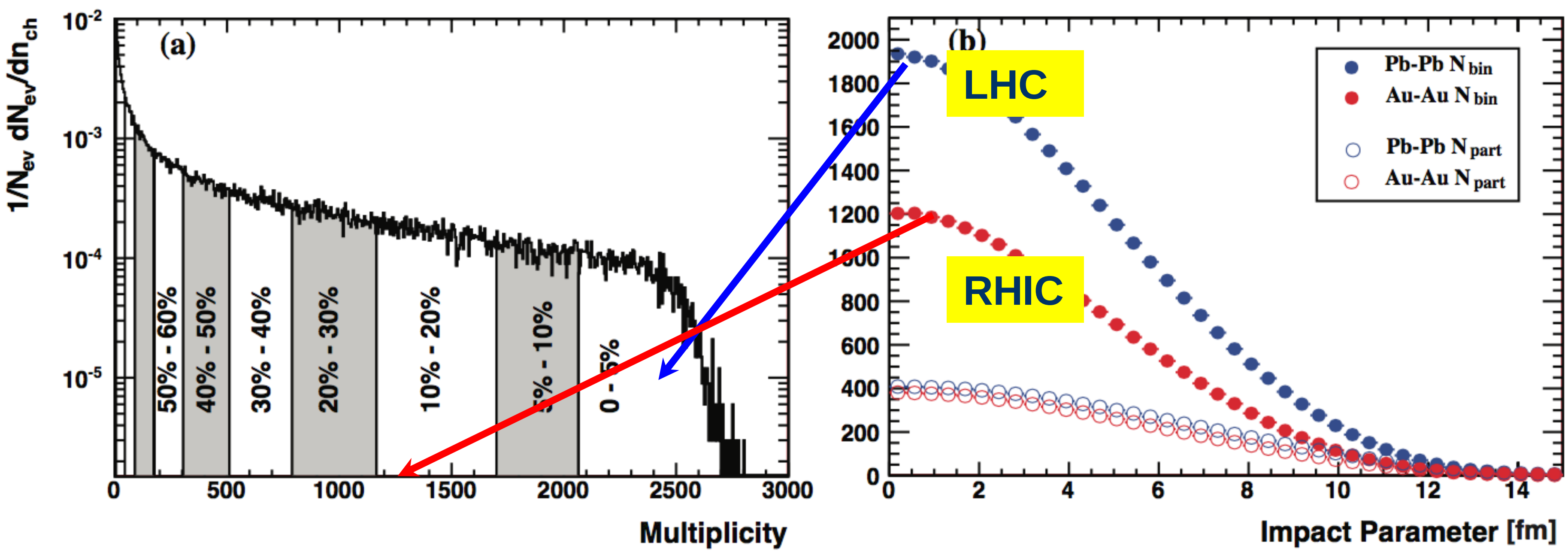
$dn/d\phi \sim 1 + 2\, v_2(p_T) \cos(2\phi)$

$$\frac{dN}{d(\phi - \Phi_n)} = N_0 \left[1 + 2 \sum v_n \cos\{n(\phi - \Phi_n)\}\right]$$

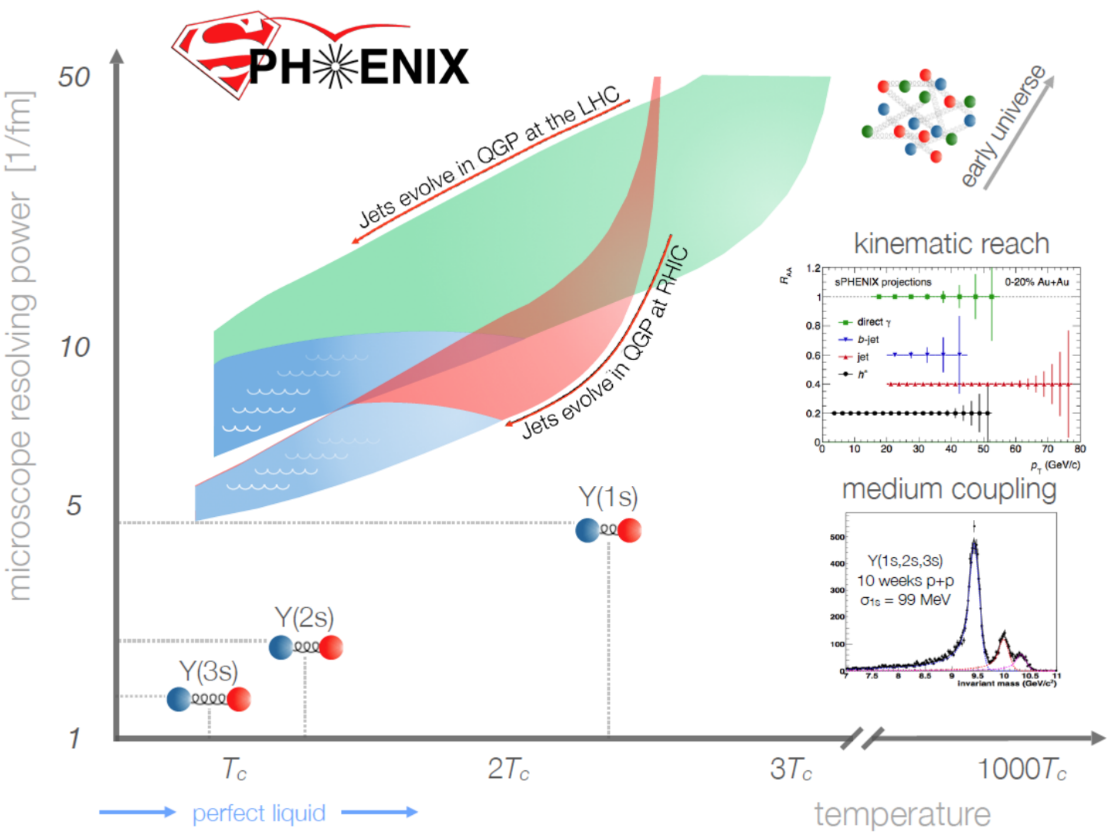
$$v_n = \langle \cos\{n(\phi - \Phi_n)\}\rangle$$

V3 and higher tells of fluctuations


b
Spectators
Participants

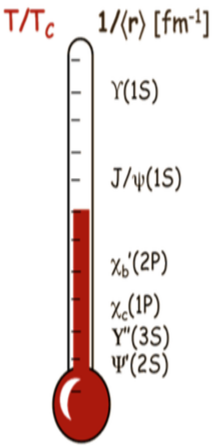

(a)
1/N_ev dN_ev/dn_ch
10^-2
10^-3
10^-4
10^-5
50% - 60%
40% - 50%
30% - 40%
20% - 30%
10% - 20%
5% - 10%
0 - 5%
0
500
1000
1500
2000
2500
3000
Multiplicity
(b)
LHC
RHIC
Pb-Pb N bin
Au-Au N bin
Pb-Pb N part
Au-Au N part
2000
1800
1600
1400
1200
1000
800
600
400
200
0
2
4
6
8
10
12
14
Impact Parameter [fm]

QGP program near Tc

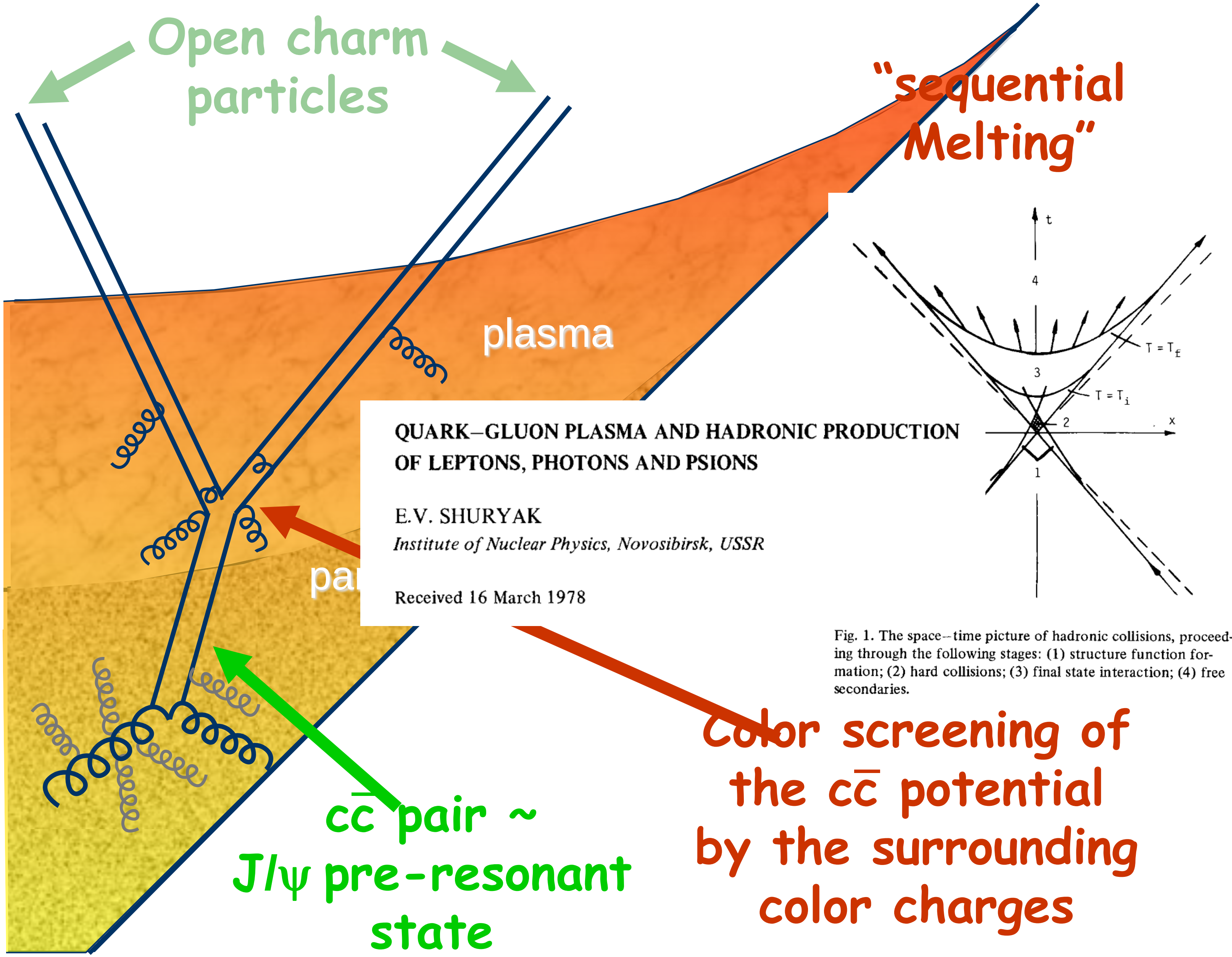


- **Detailed inspection of QGP near T_c using probes over a broad range of scales**
  - **Jet and Di-jet**
  - **γ-jet correlations**
  - **Heavy flavor jets**
  - **Separated ϒ(1s), ϒ(2s), ϒ(3s)**

J/ψ production and differential suppression



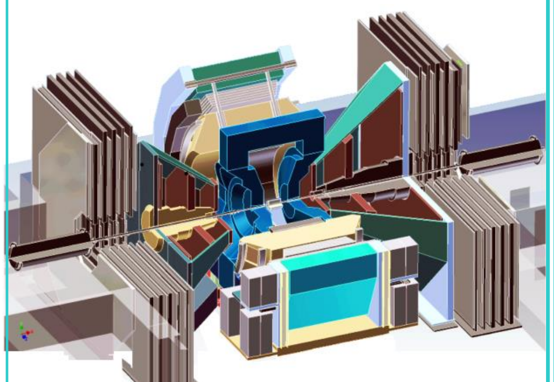
QGP thermometer based on sequential suppression of quarkonia. courtesy: A. Mocsy

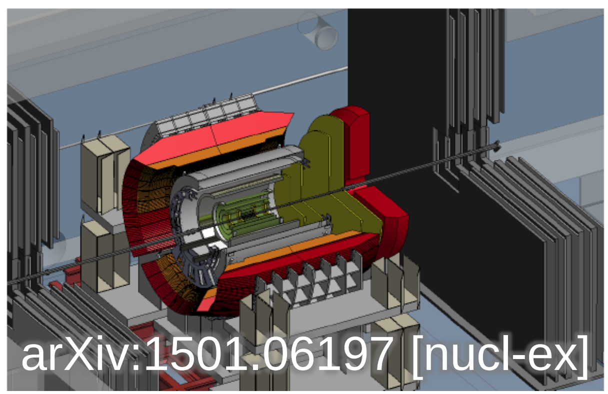


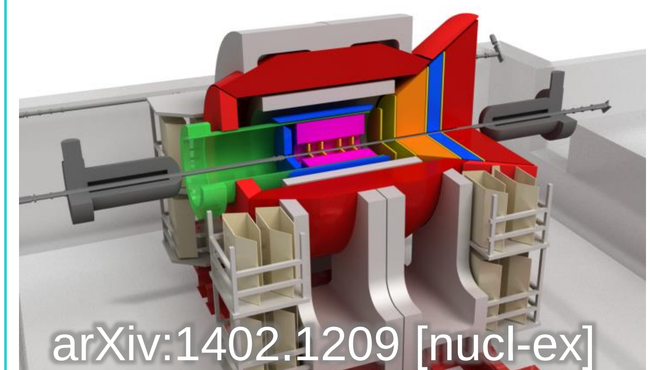
Evolution of the Experiment (PHENIX)

Documented: http://www.phenix.bnl.gov/plans.html

Current PHENIX	*s*PHENIX (+fsPHENIX)	An EIC detector
• 15y+ operation 100+M$ investment • Broad spectrum of physics (QGP, Hadron Physics, DM) • 150+ published papers to date • Last run in this form 2016	• Comprehensive central upgrade based on BaBar magnet • Rich jet and beauty quarkonia physics program → nature of QGP • fsPHENIX : forward tracking, e&h calorimetry and muon ID → Spin, CNM	• Path of PHENIX upgrade leads to a capable EIC detector • Large coverage of tracking, calorimetry and PID • Open for new collaboration/new ideas





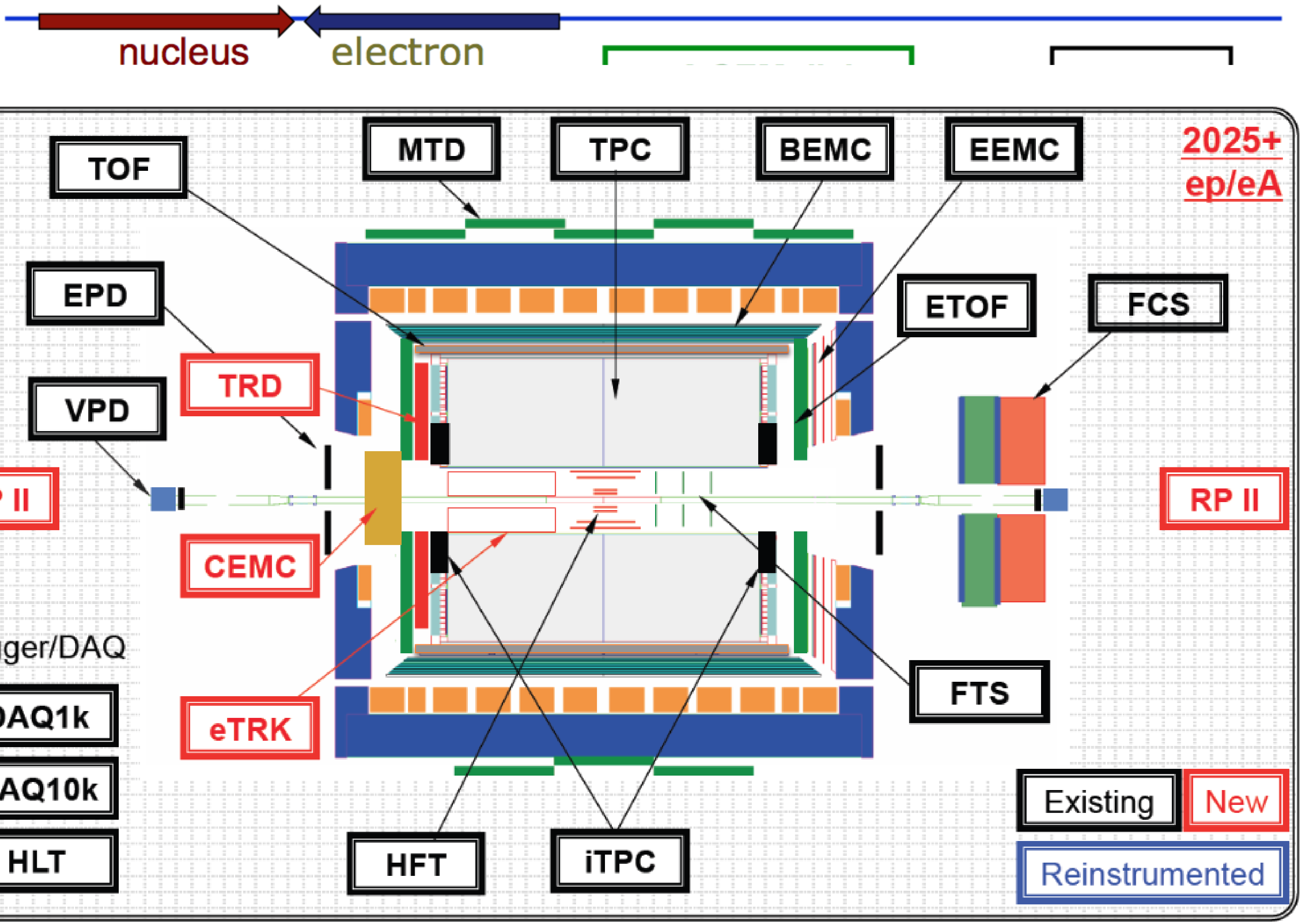


~2000 — 2017→2020 — ~2025 — Time

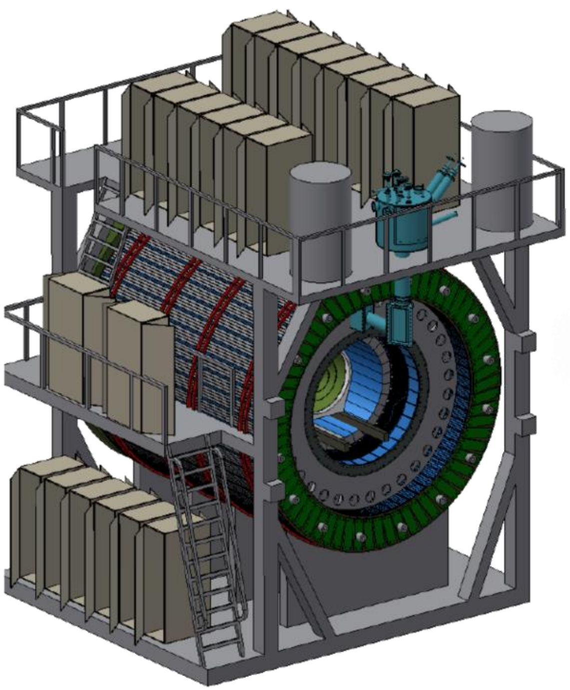
RHIC: A+A, spin-polarized p+p, spin-polarized p+A

EIC: e+p, e+A

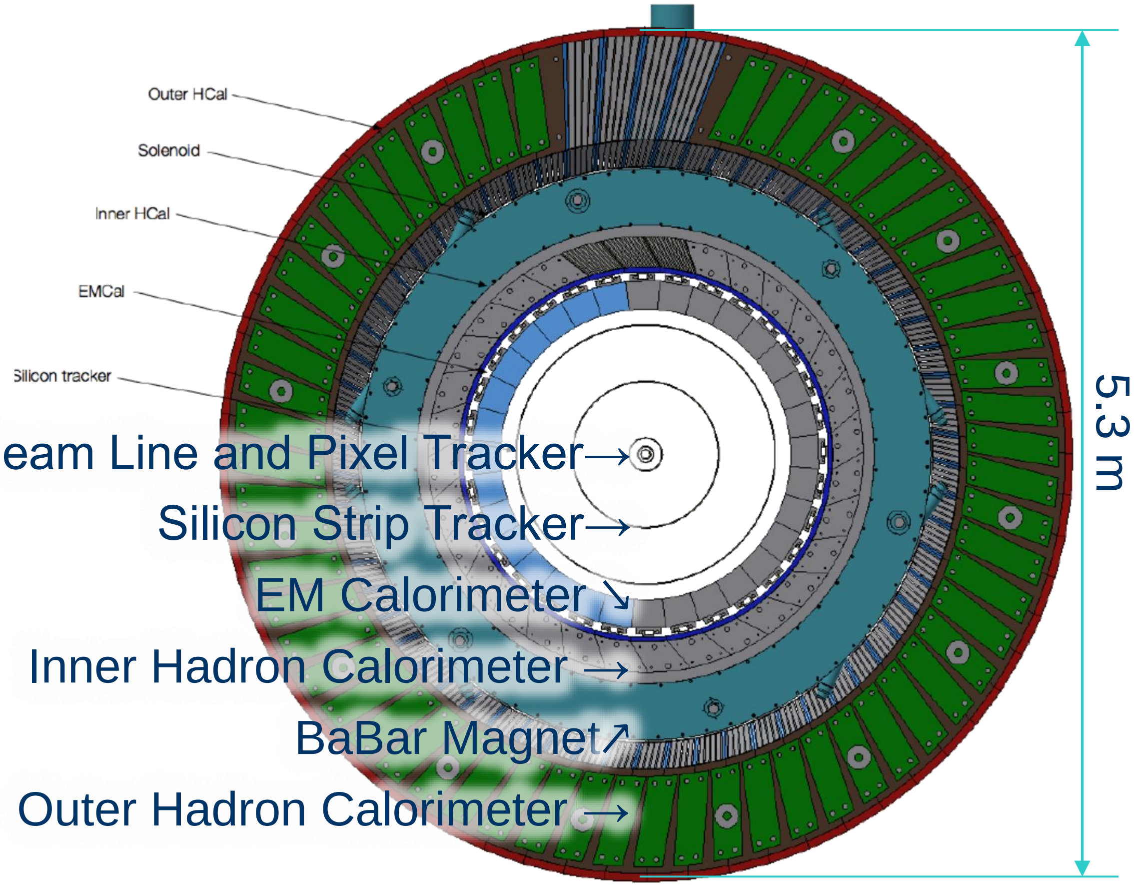
STAR forward instrumentation upgrade



sPHENIX experiment (already in construction stage …. illegal)



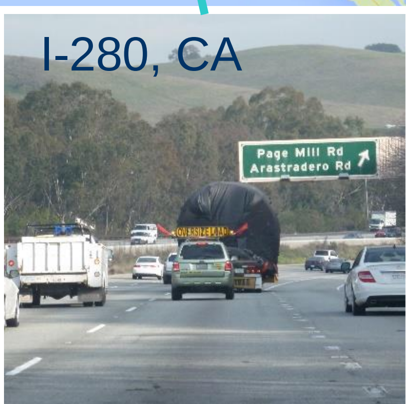
Detailed CAD model



Beam view

Move BaBar Magnet

Jan 16 -> Feb 3 2015



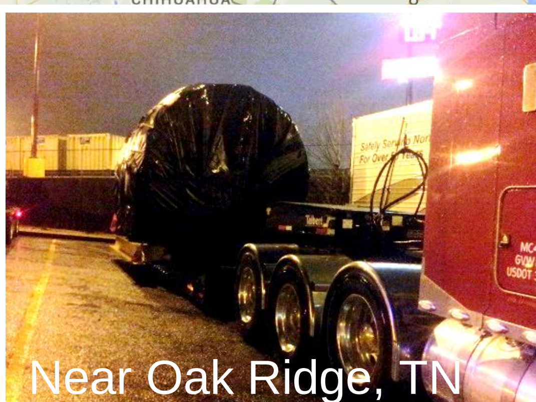


Photo by Andy Freeberg, SLAC National Accelerator Laboratory

breaking

January 16, 2015

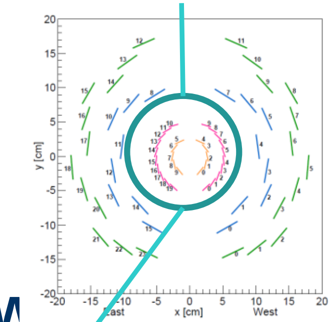
20-ton magnet heads to New York

A superconducting magnet begins its journey from SLAC laboratory in California to Brookhaven Lab in New York.

By Justin Eure

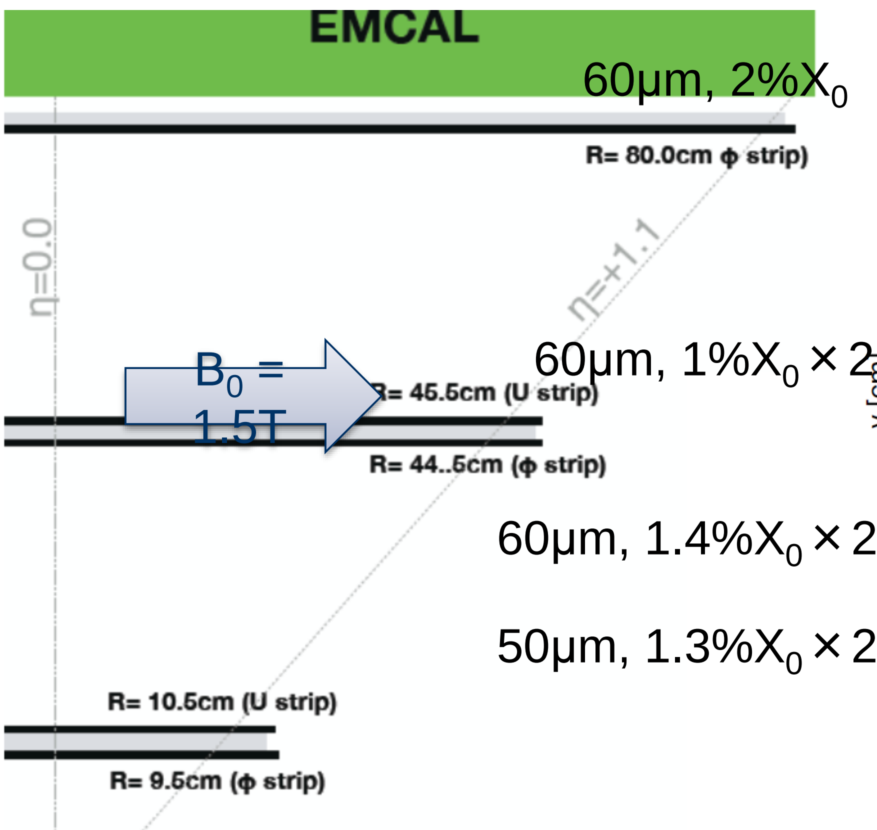
Tracking : Reconfigure existing Silicon Tracker

Restacking PHENIX Pixel Tracker

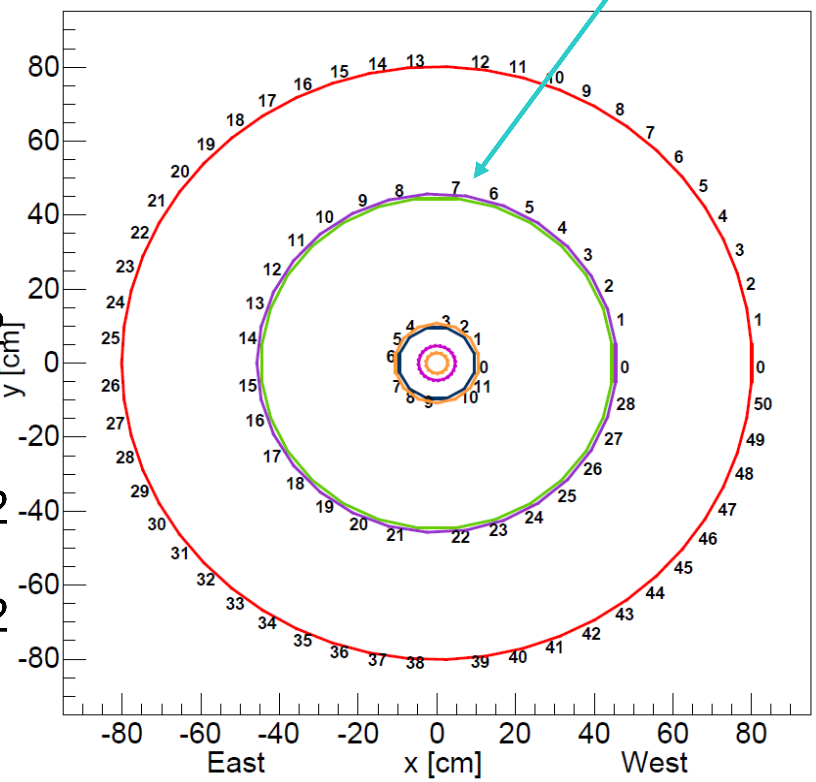


Also in study: a TPC for outer layer tracking

Side view

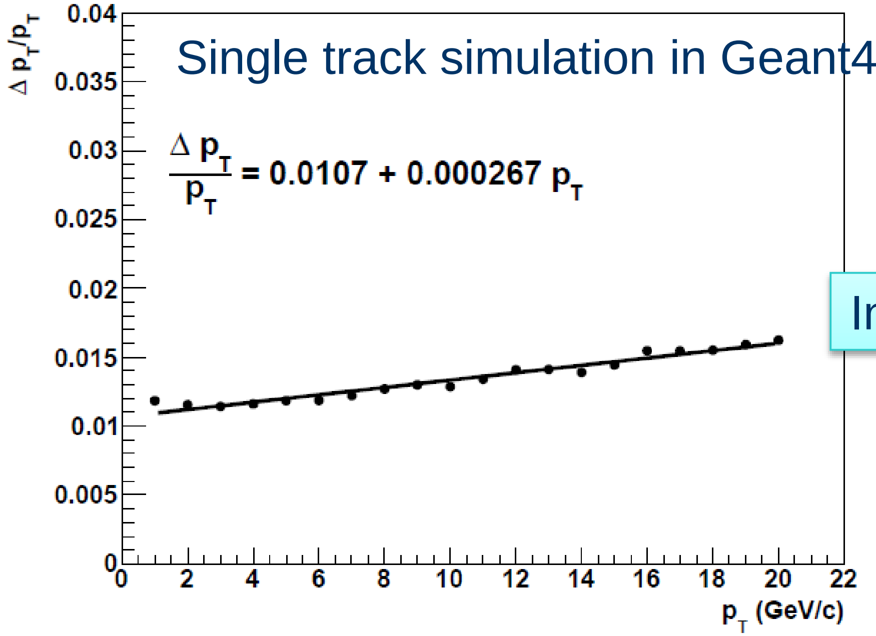


Beam View

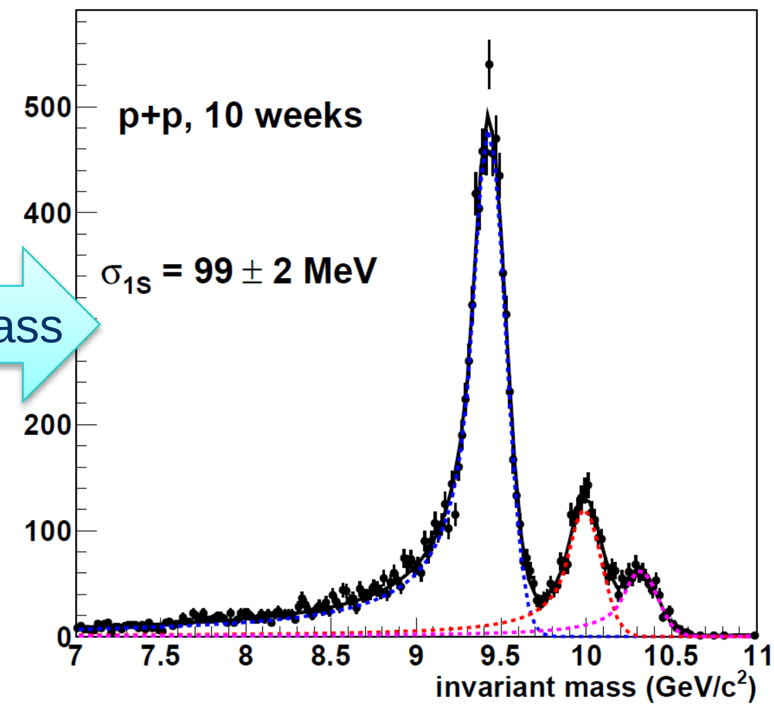


Tracking : Performance in Geant4

Invariant mass for e^+e^- pairs

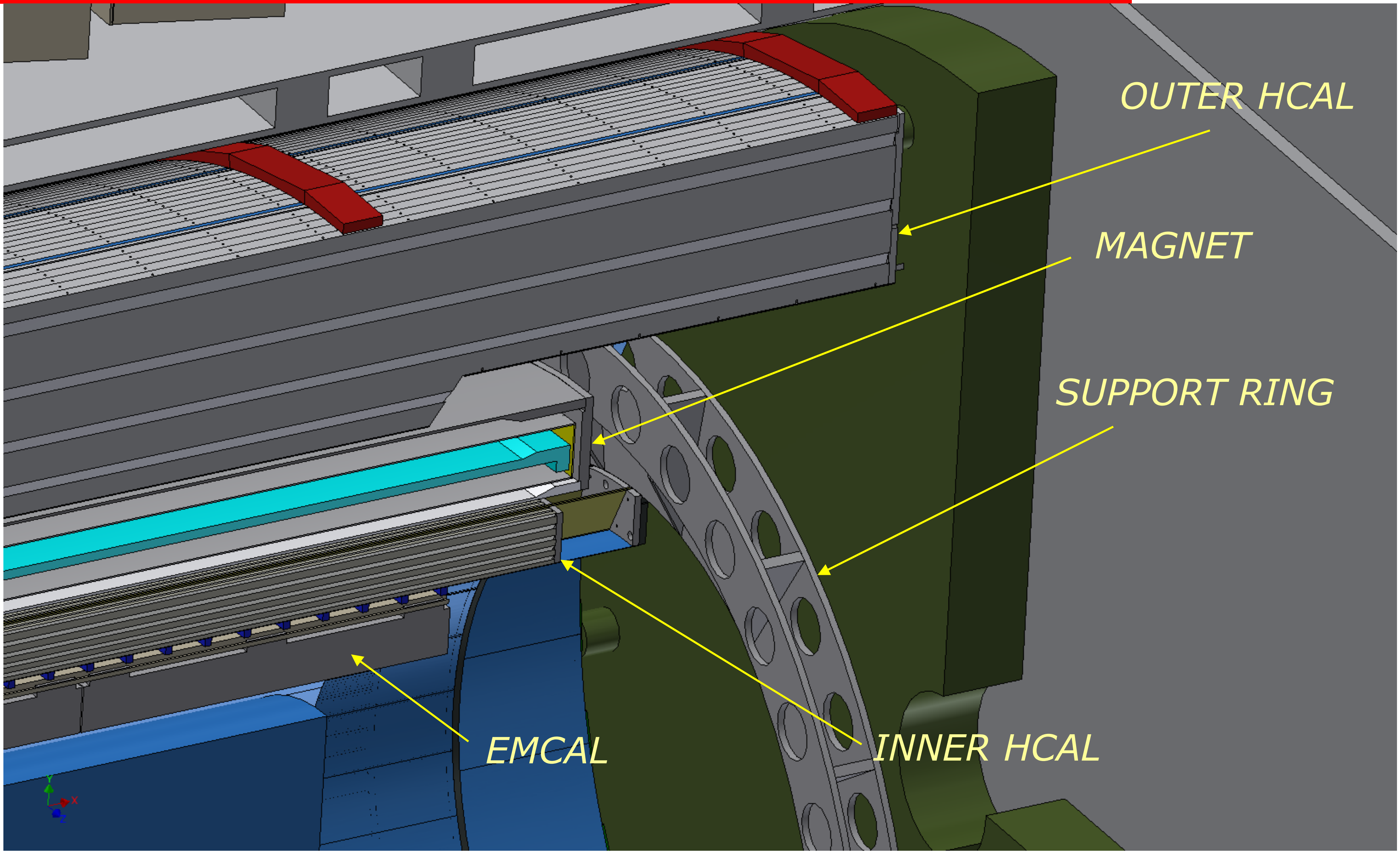


Inv. Mass



Also full detector HIJING simulation in Geant4
Eff. = 92% at 1 GeV/c and 97% at high p_T.

Backbone: New Jet and EM Id Calorimetry

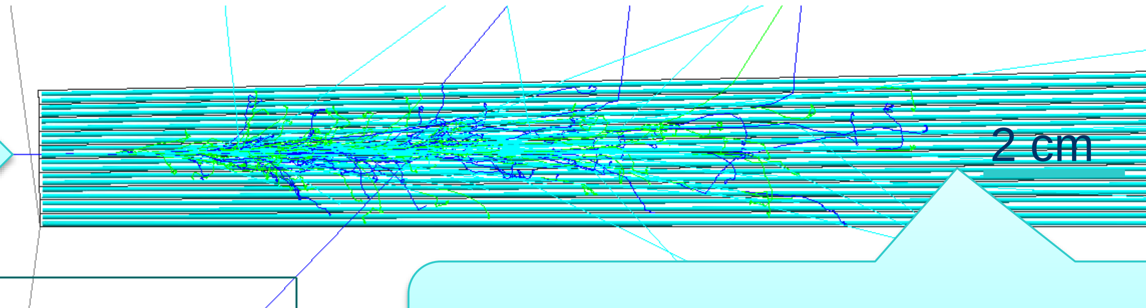


Electron ID: EM Calorimeter

- Electron ID using a compact EMCal with assistance from inner Hcal (|η|<1)
- Scintillation fiber-W powder sampling calorimeter (SPACAL), dE/E ~ 12%/√E

Side view

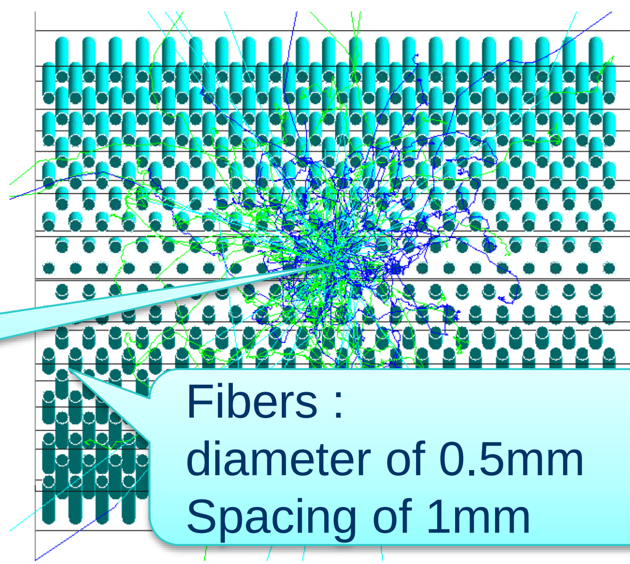
10GeV, e+



Tapered to form full cylinder
Azimuthally projective fibers

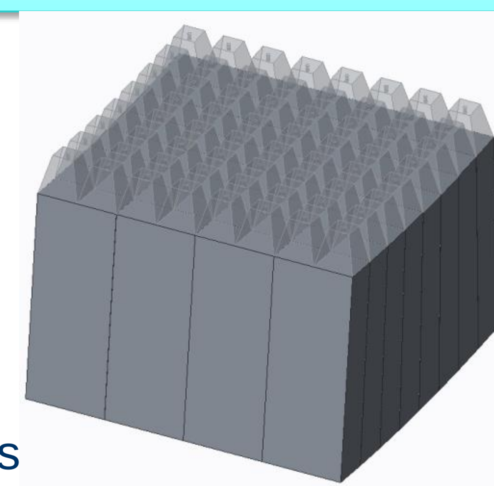
Particle view

1 cm



10GeV e

Fibers :
diameter of 0.5mm
Spacing of 1mm



E.Kis

Dealing with technological challenges

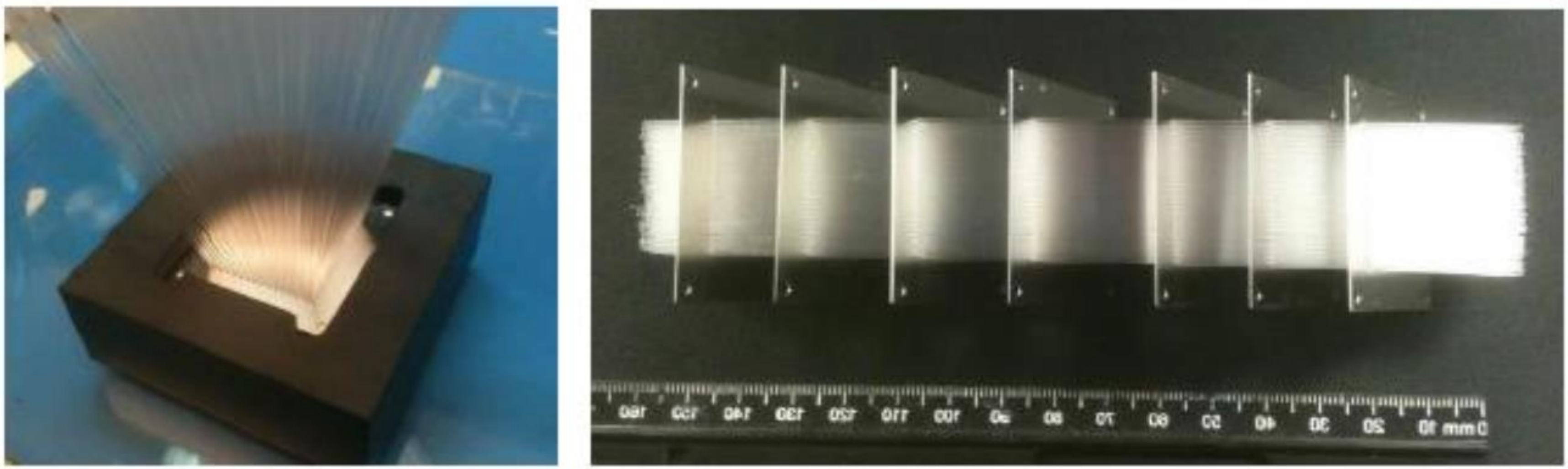


Figure 2.8: Left: Fibers filling a stack of tapered hold meshes which are separated by only a small amount to enable filling. Right: Fiber assembly after fully separating the meshes in preparation for insertion in the mold.

Bricksmanship in modern physics

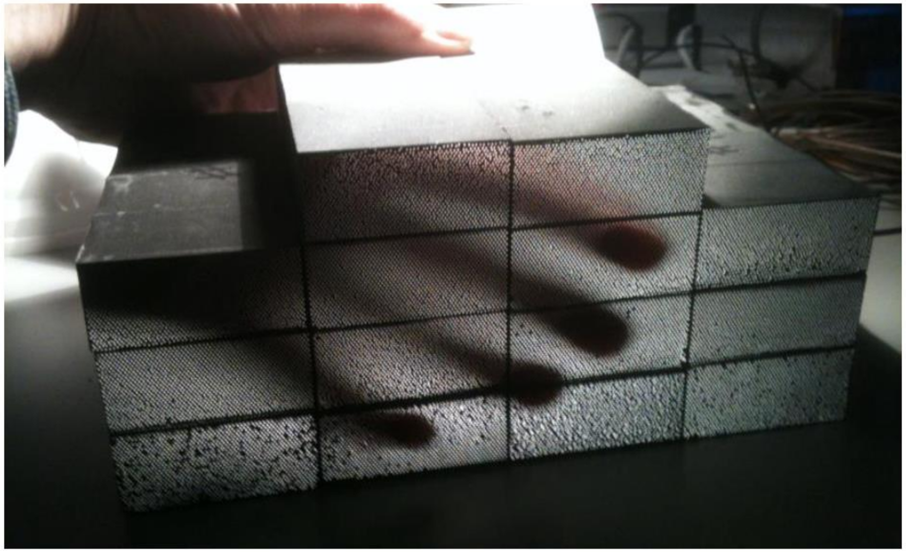


Figure 2.4. Modules produced at UIUC for the 8x8 tower prototype

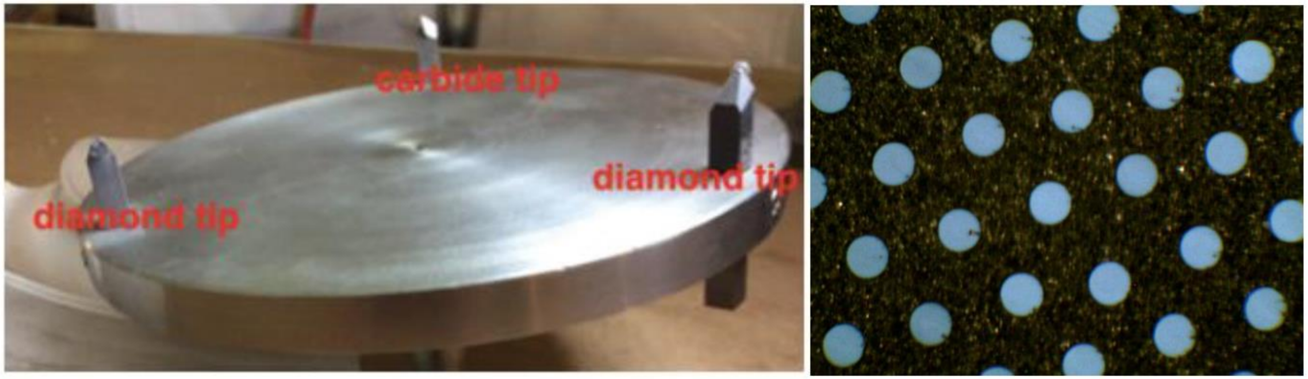
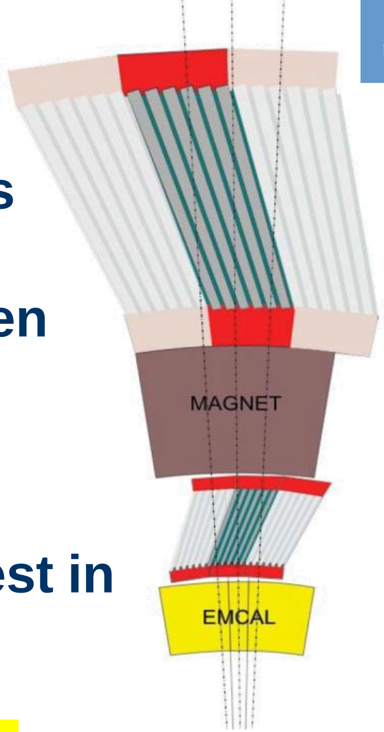
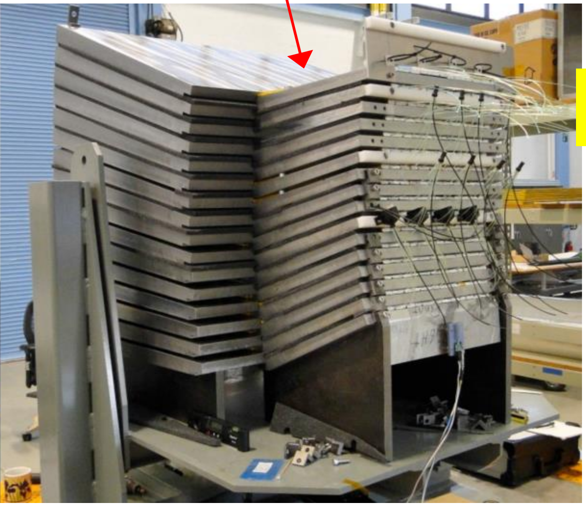


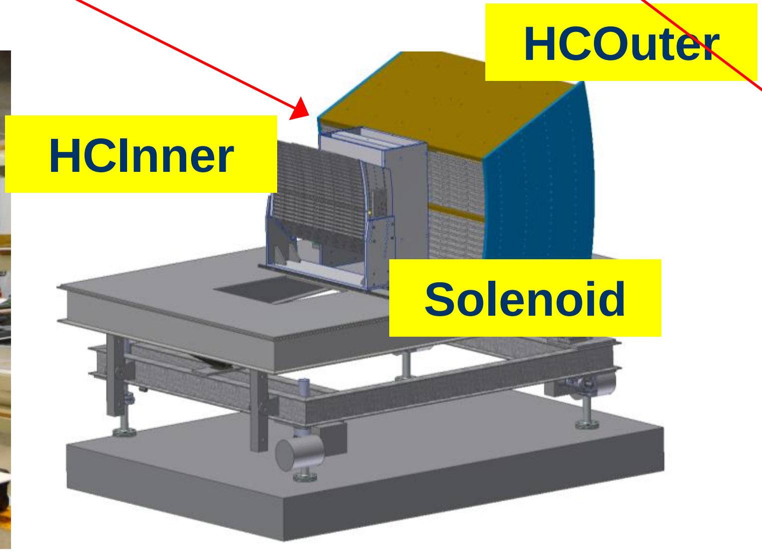
Figure 2.5. Left: Fly cutting tool used at UIUC to finish the ends of the fibers. Right: Fibers ends after fly cutting step.

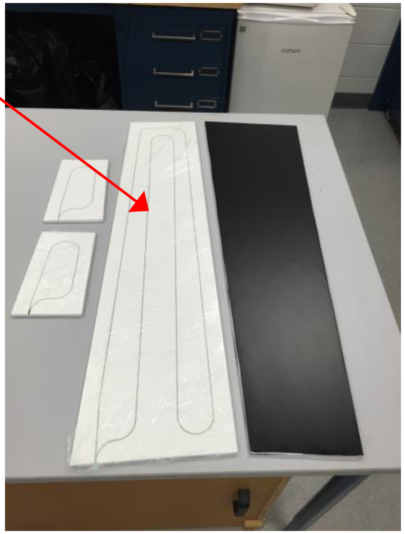
Hadron Calorimeter



- Novel design using tilted iron plates doubling as field return
- Active medium – scintillators in the gaps between plates
- Optical readout (WLS fibers and SiPM's);
- PoP Prototype tested in FermiLab in 2014
- System prototype is in assembly stage. Beam test in April 2016 at FNAL

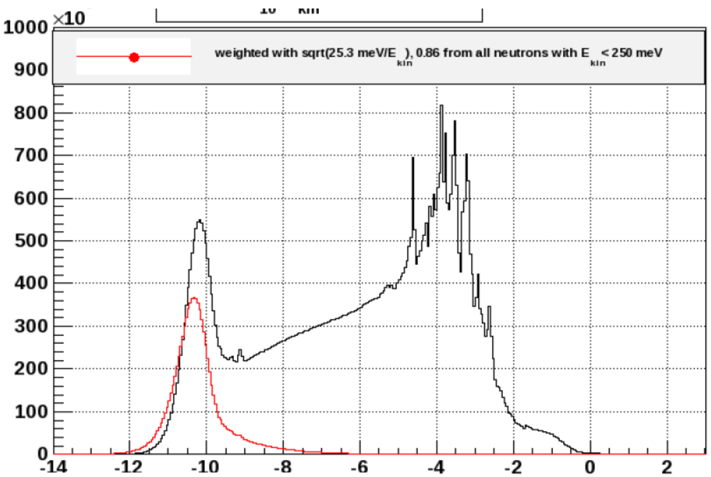






Radiation Damage in SiPMs

Estimated neutron flux in the STAR IR



Y. Fisak et.al. NIM A756 (2014) 68-72

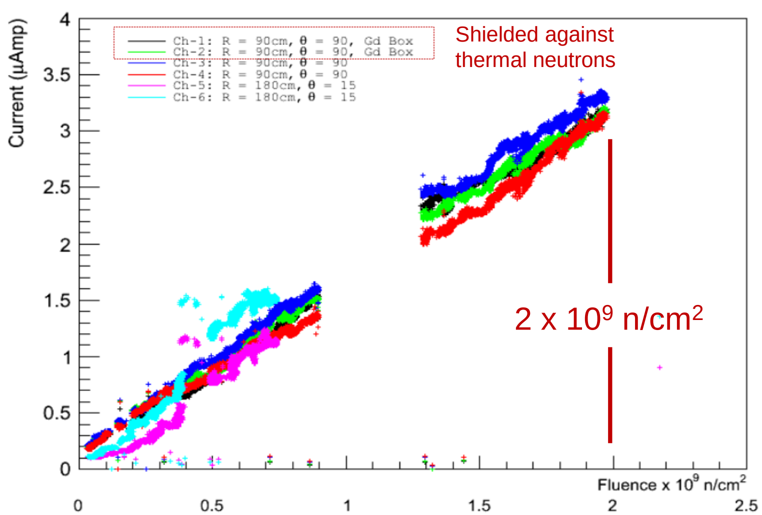
Damage is caused mainly by neutrons (E ~ MeV)

Measure thermal neutron flux in RHIC IR and estimate MeV equivalent neutrons using MC

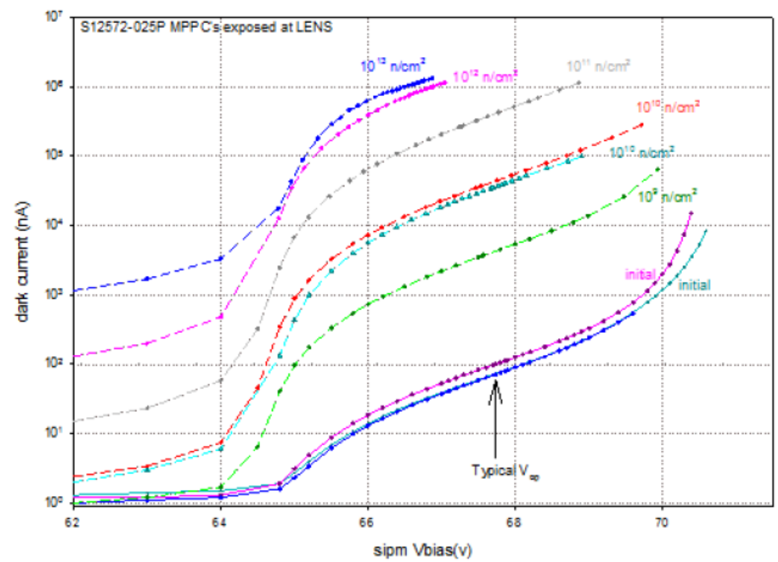
Estimates in STAR for 2013 run (L=526 pb^{-1}):

R= 3-8 cm, |Z| < 10 cm : $\Phi_{eq} \sim 8 \times 10^{10}$ n/cm^2
R= 100 cm, Z = 675 cm : $\Phi_{eq} \sim 2.2 \times 10^{10}$ n/cm^2

Measured neutron flux in the PHENIX IR

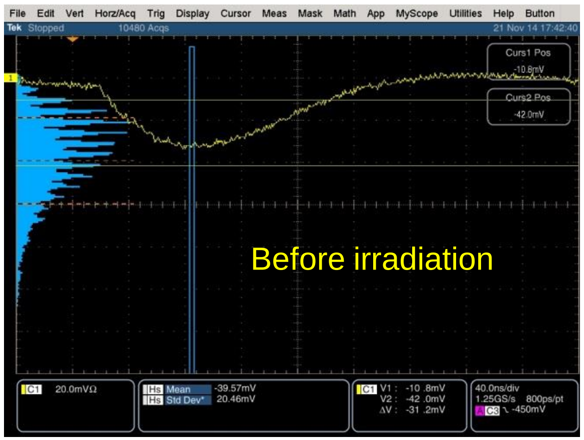


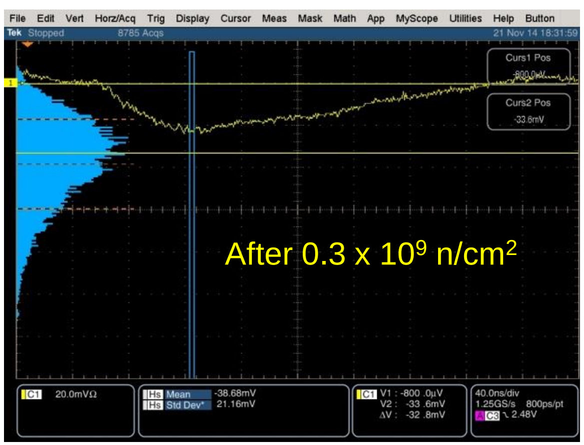
Neutron measurements at the Indiana University LENS Facility



Radiation Damage in SiPMs

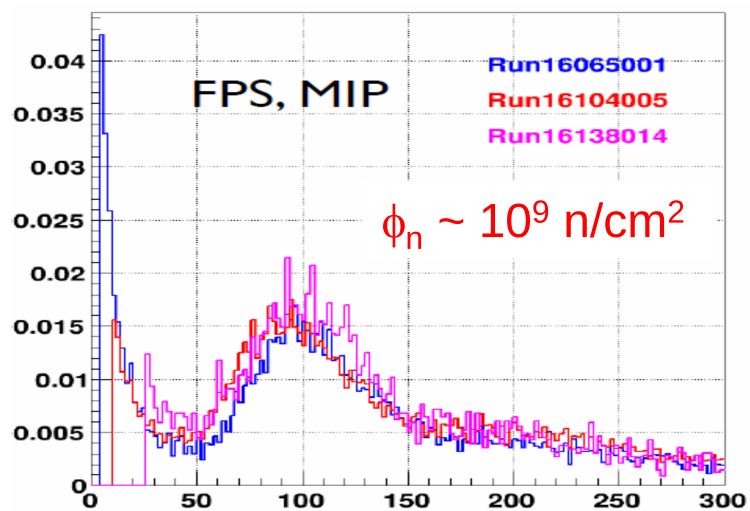
Hamamatsu S12572-025P





Primary effect seems to be increase in noise and not loss of PDE

MIP peak for STAR Forward Preshower detector during RHIC Run 15



O. Tsai, EIC R&D Report, July 2015

Operationally we plan to keep V_b constant for currents up to ~ 1 mA

Will require cooling to maintain ~ 20° C

EM Calorimeter Energy resolution

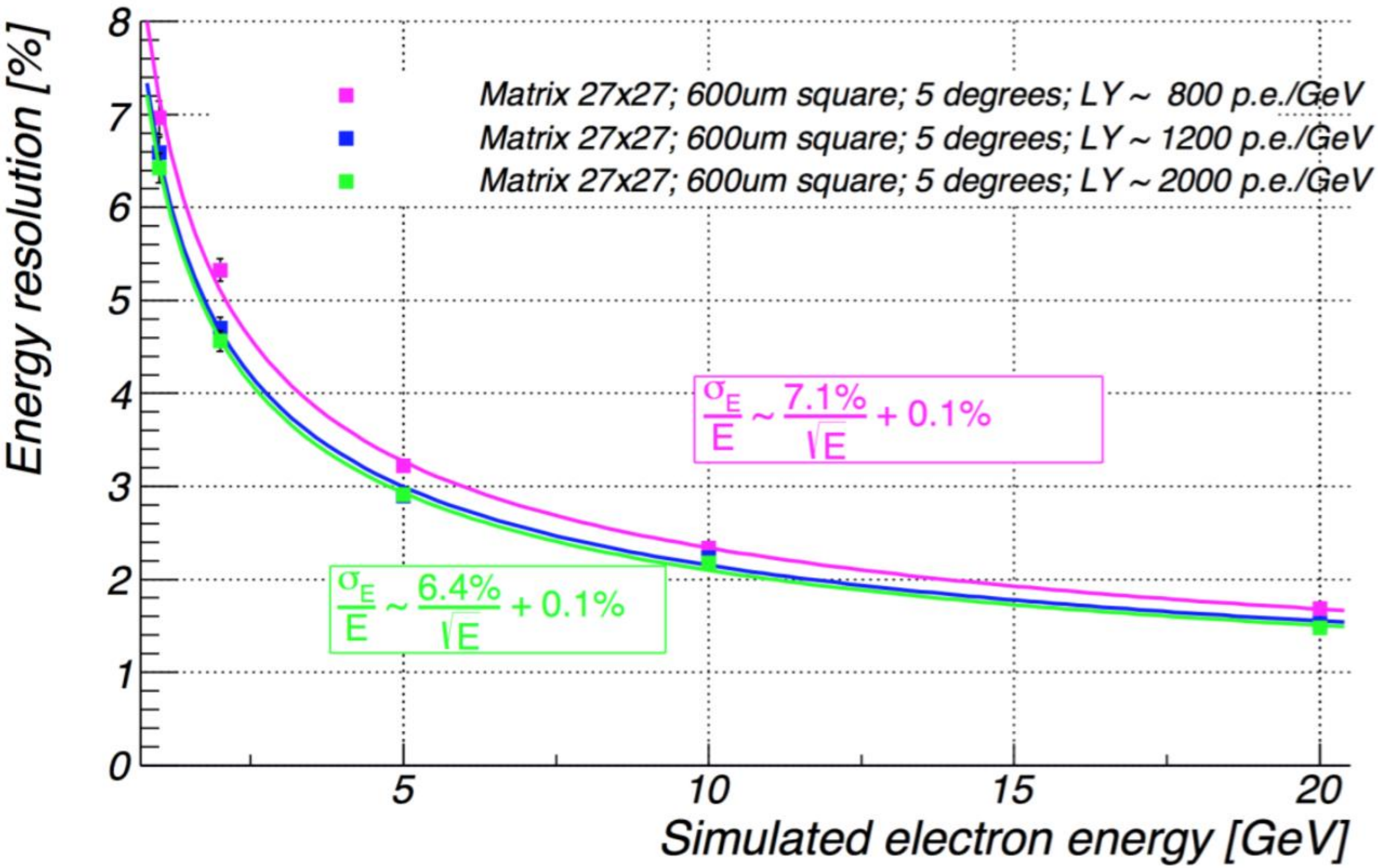
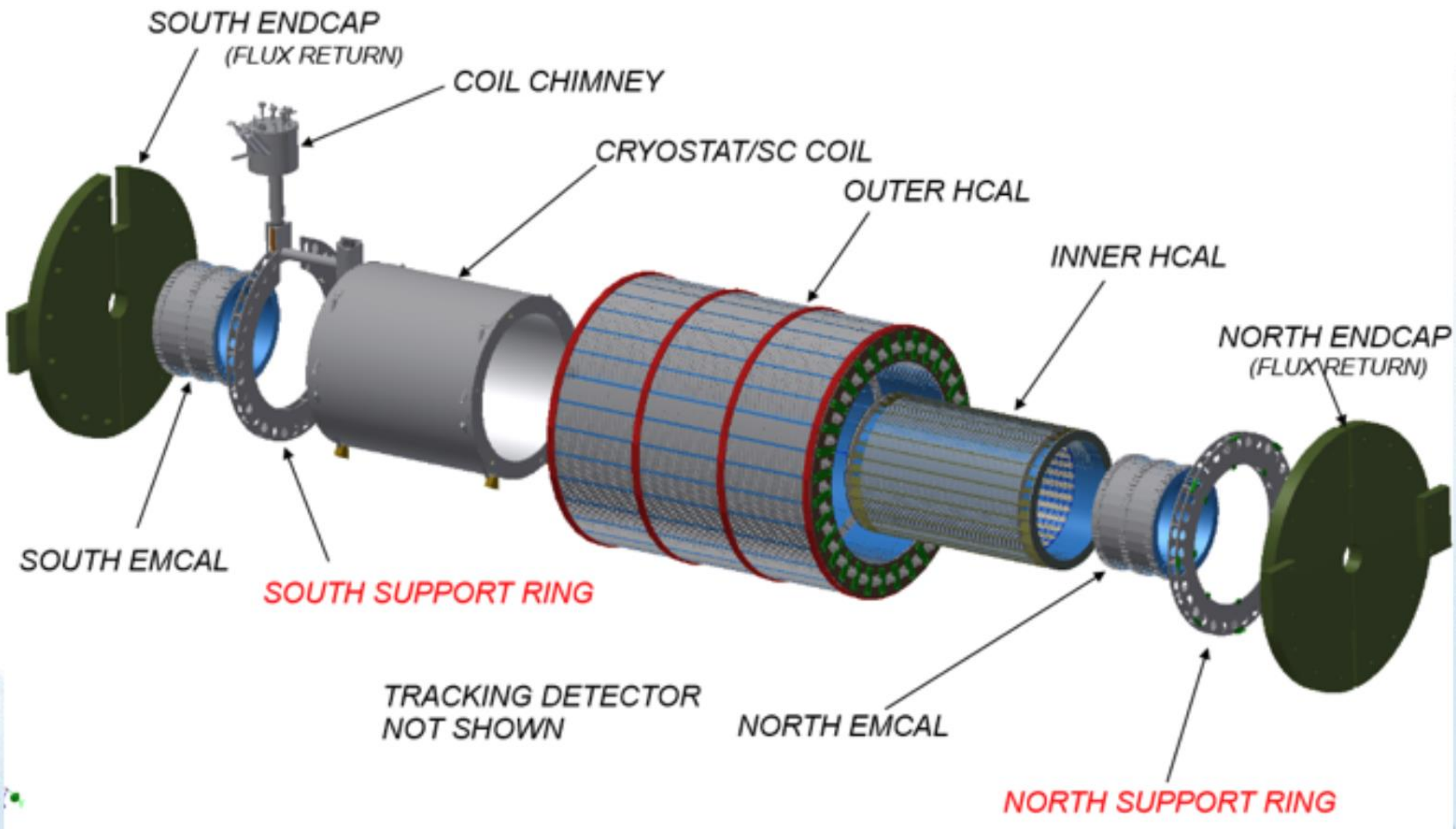


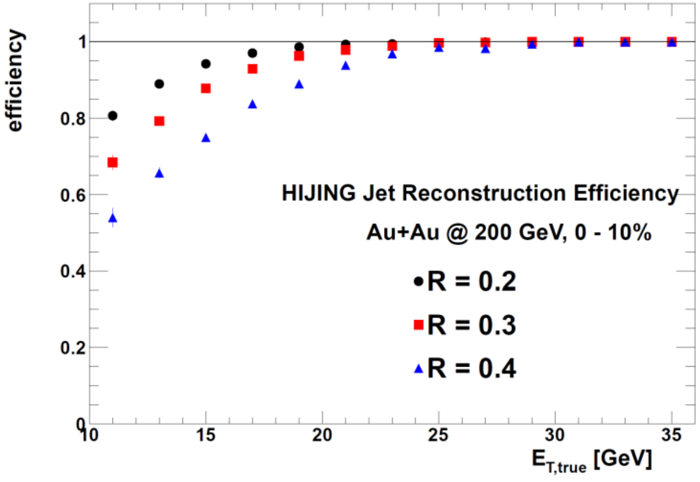
Figure 1.3. Expected energy resolution of new BEMC

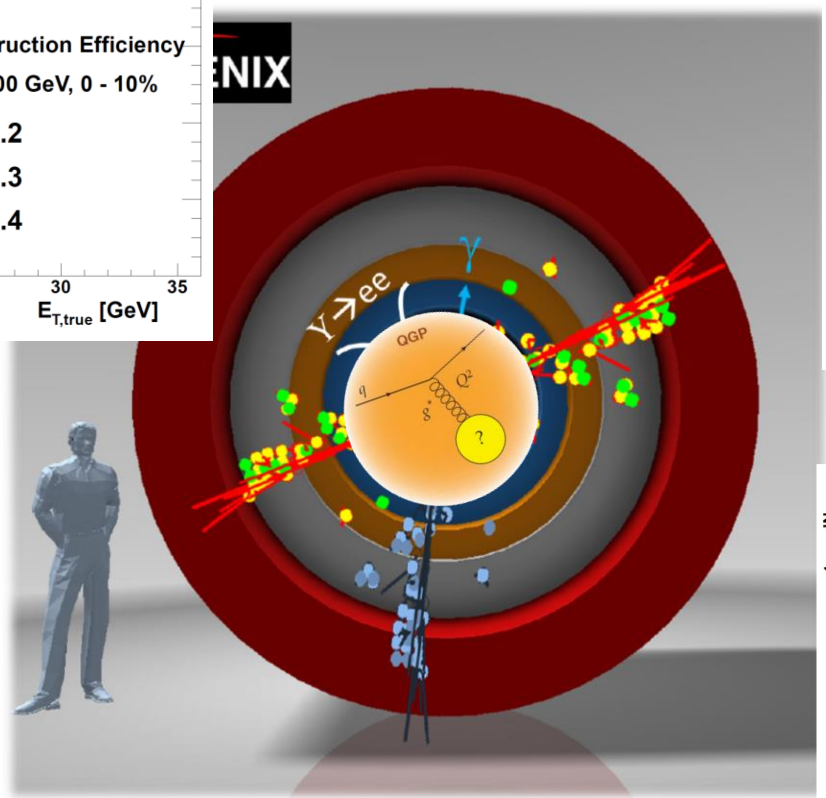
sPHENIX exploded view



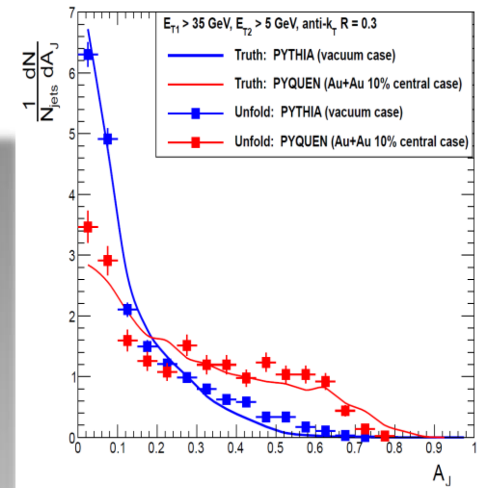
Use jets as probe of QGP in sPHENIX

Efficiency

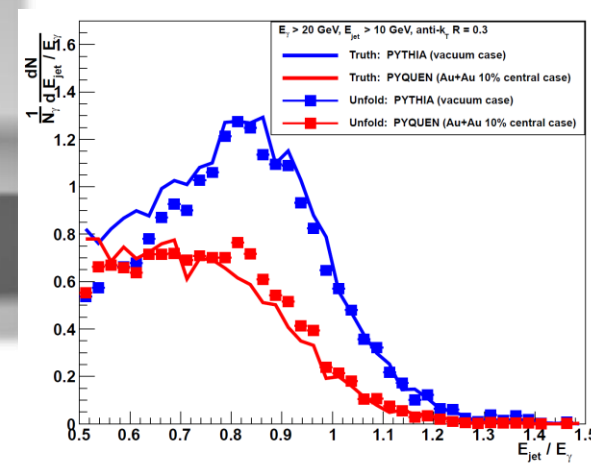




Di-jets



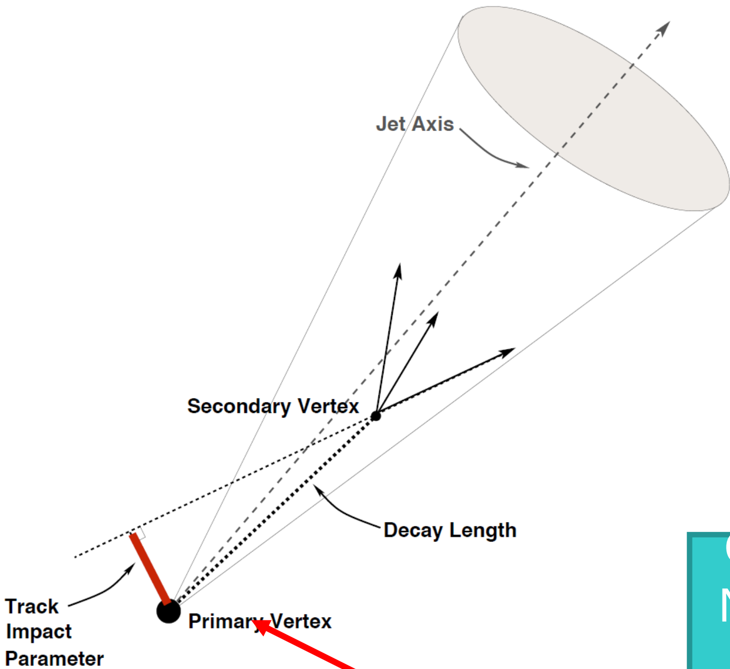
Photon-jet



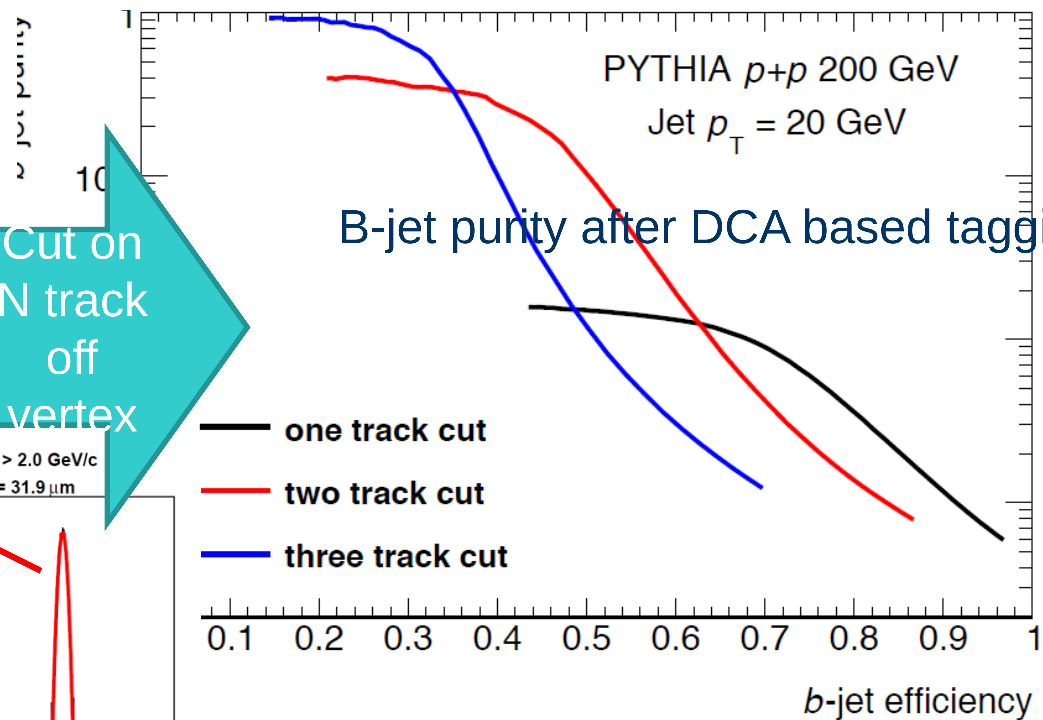
B-quark jet tagging

Heavy quark provide very different
Sensitivity to collision and radiative energy
Loss in QGP from light quark/gluon

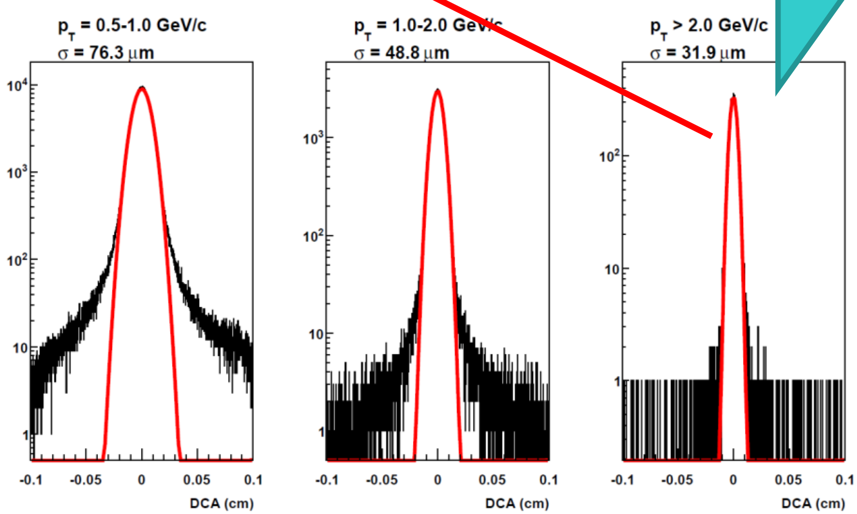
Probed by heavy quark jets at sPHENIX



Cut on N track off vertex



B-jet purity after DCA based tagging



E.Kistenev, UTFSM, 2016

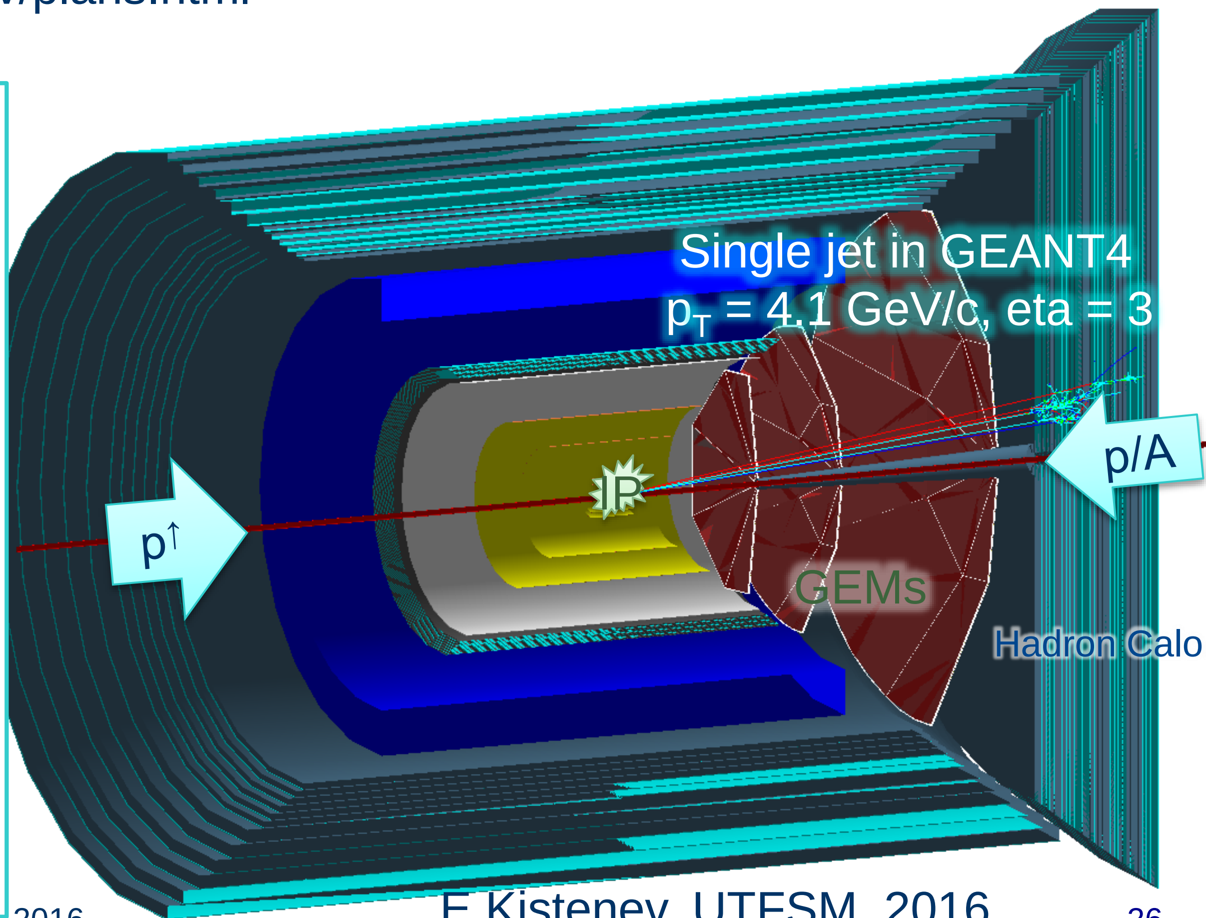
Forward spectrometer of sPHENIX: *fs*PHENIX

BROOKHAVEN NATIONAL LABORATORY

- Shared detector with future eRHIC program and deliver an unique forward program with RHIC's pp/pA collision
- white paper submitted to BNL in Apr 2014: http://www.phenix.bnl.gov/plans.html

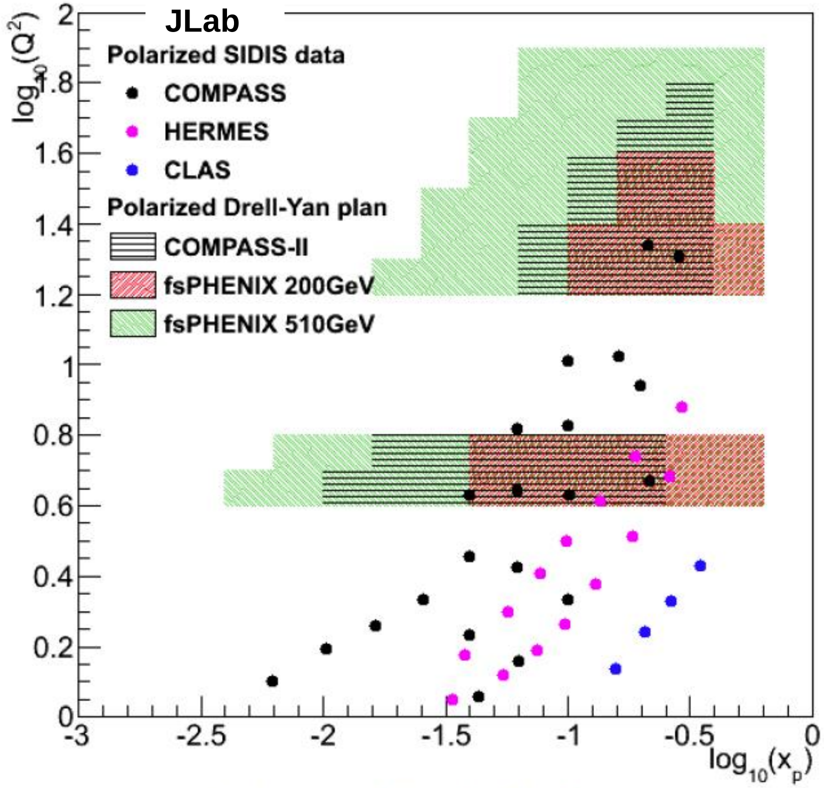
EIC detector GEM + H-Cal
→ Forward jet with charge sign tagging
→ A_N in hadron collisions
→ polarized Drell-Yan with muons
→ Forward-central correlations

+ central detector (sPHENIX)
+ reuse current forward silicon tracker & Muon ID detector

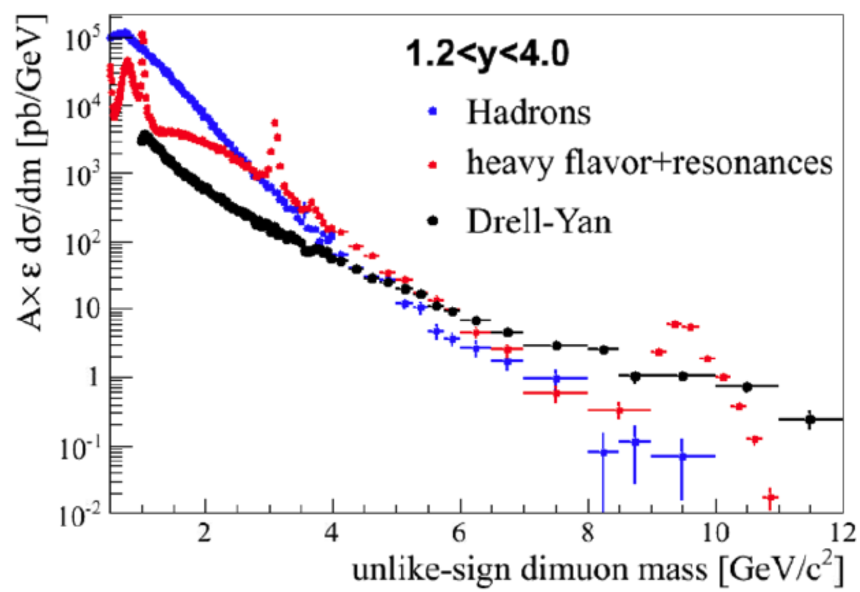


*fs*PHENIX DY – challenging and very interesting

Statistics-kinematic coverage comparisons



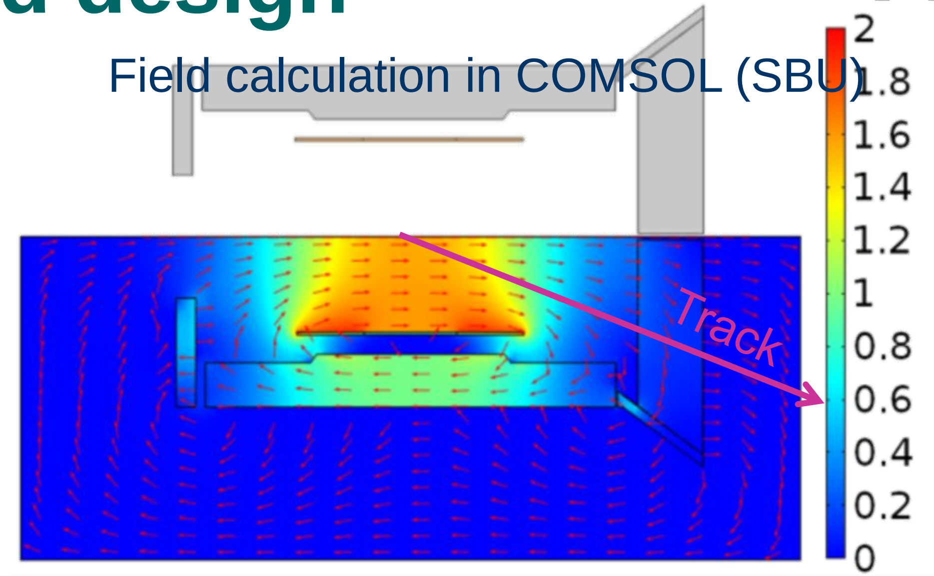
Major challenge on background and potential improvement

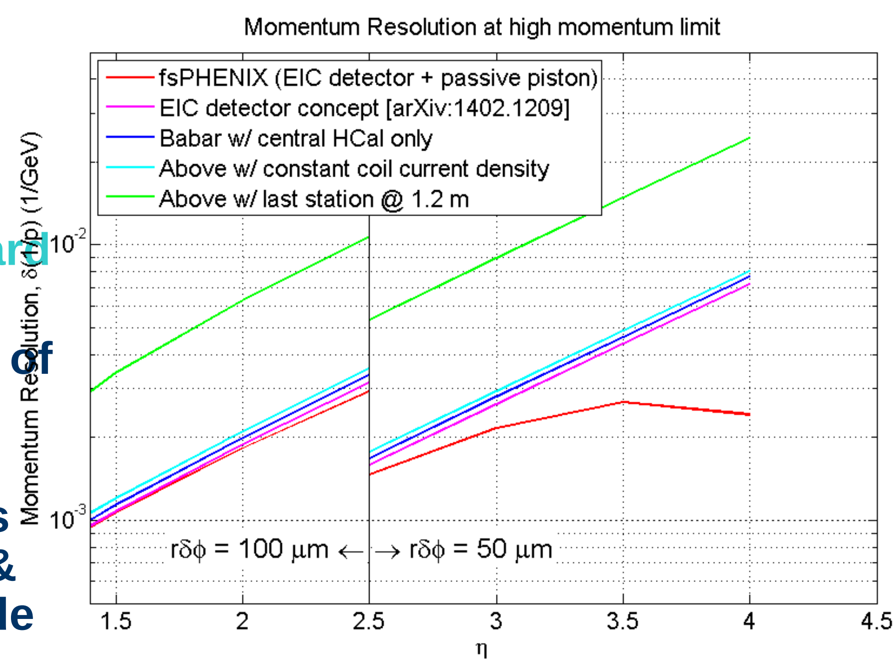


Challenge: Forward field design

- **BaBar superconducting magnet**
  - **Length: 385 cm**
  - **Nominal field: 1.5T**
  - **Designed for homogeneous B-field in central tracking**
- **Field calculation and yoke tuning**
  - **Field calculated and cross checked: POISSION, FEM, OPERA and COMSOL**
- **For forward spectrometer**
  - **Longer field volume for forward tracking**
  - **Higher current density at end of the magnet -> better forward bending**
  - **To work well with RICH needs field-shaping yoke: Forward & central Hcal + Steel lampshade**

Field calculation in COMSOL (SBU)

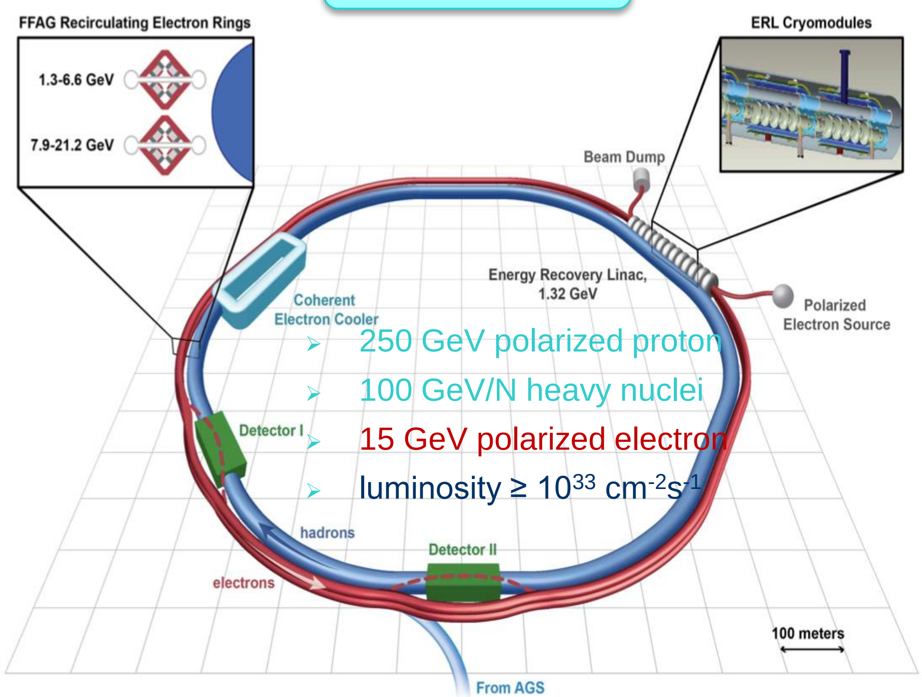




High energy polarized EIC concepts

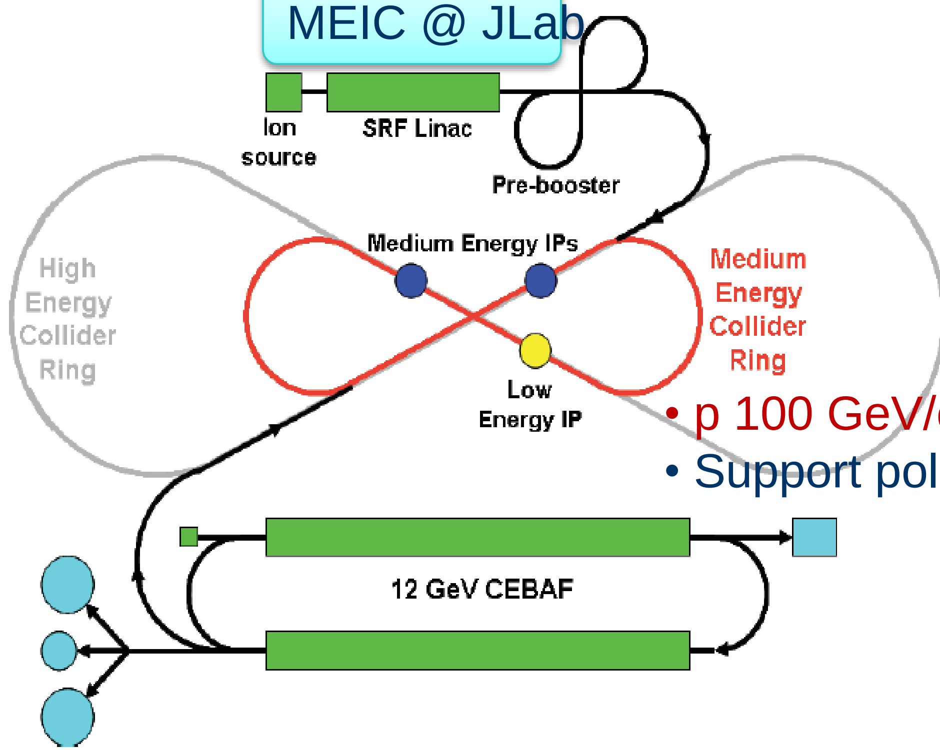
- Highly polarized electron and nucleon beams
- Ion beams from D-> U or Pb
- Variable C.M. energy from 20 -> 100 GeV (150 upgradable)
- High collision luminosity 10^{33}-10^{34} $cm^{-2}s^{-1}$
  (HERA luminosity ~ $5x10^{31}$ cm^{-2} s^{-1})
- Possibility of more than one interaction regions

eRHIC @ BNL



- 250 GeV polarized proton
- 100 GeV/N heavy nuclei
- 15 GeV polarized electron
- luminosity ≥ 10^{33} $cm^{-2}s^{-1}$

MEIC @ JLab

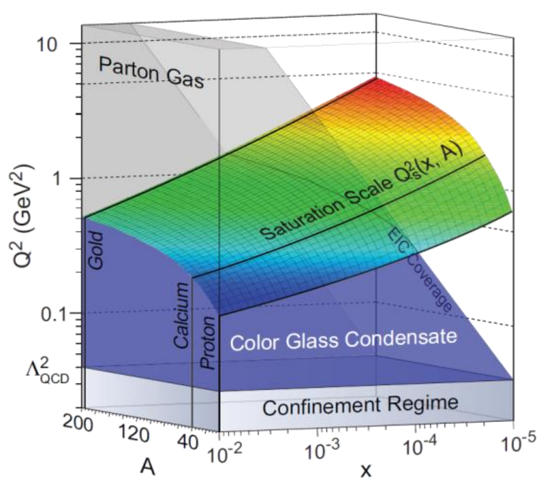


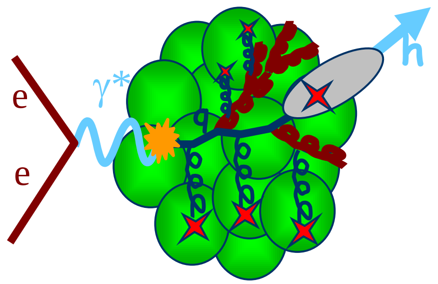
- p 100 GeV/c
- Support pol.

Physics goals: nucleus as a laboratory for QCD

Outlined in EIC white paper, arXiv:1212.1701

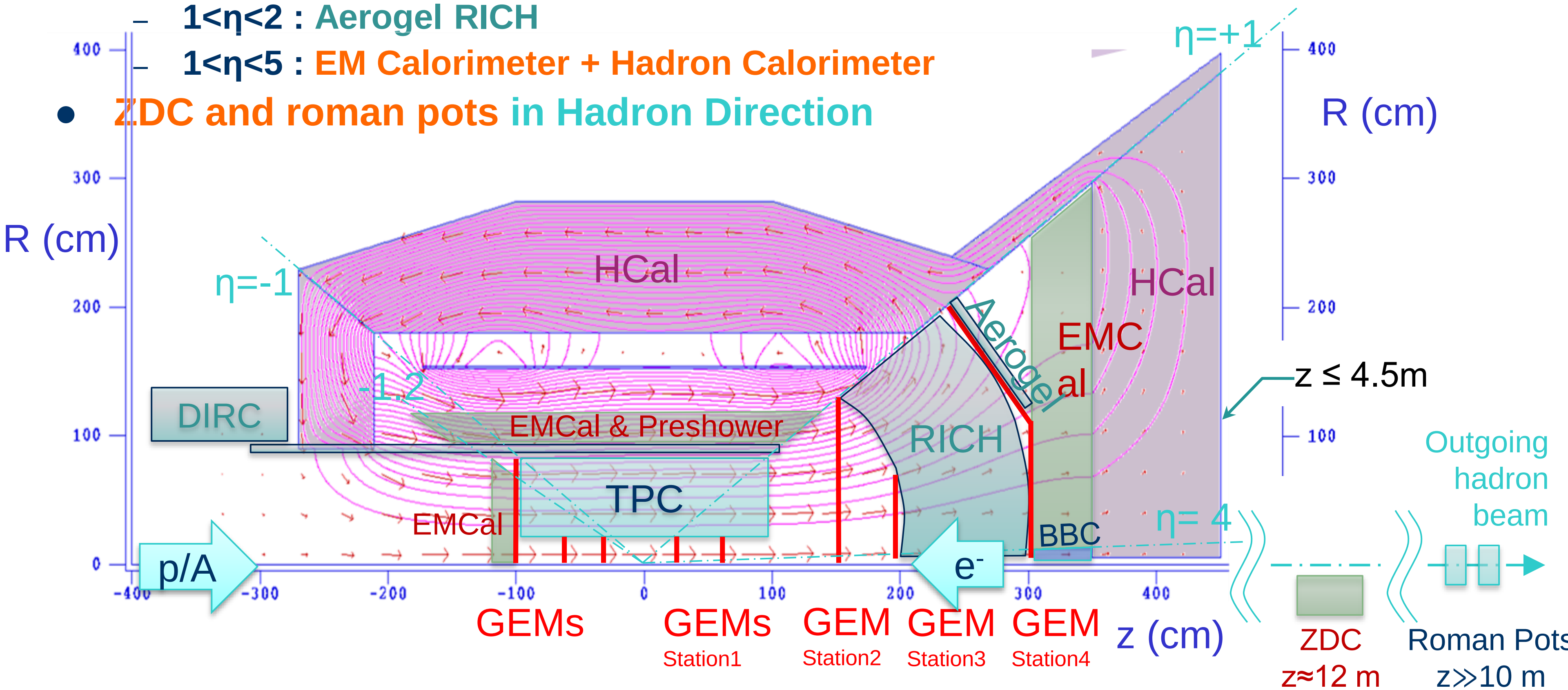
- The compelling questions:
  - Where does the saturation of gluon densities set in?
  - How does the nuclear environment affect the distribution of quarks and gluons and their interactions in nuclei?
- Deliverable measurement using electron-ion collisions
  - Probing saturation of gluon using diffractive process and correlation measurements
  - Nuclear modification for hadron and heavy flavor production in DIS events; probe of nPDF
  - Exclusive vector-meson production in eA
- Leading detector requirement:
  - ID of hadron and heavy flavor production
  - Large calorimeter coverage to ID diffractive events
  - Detection/rejection of break-up neutron production in eA collisions



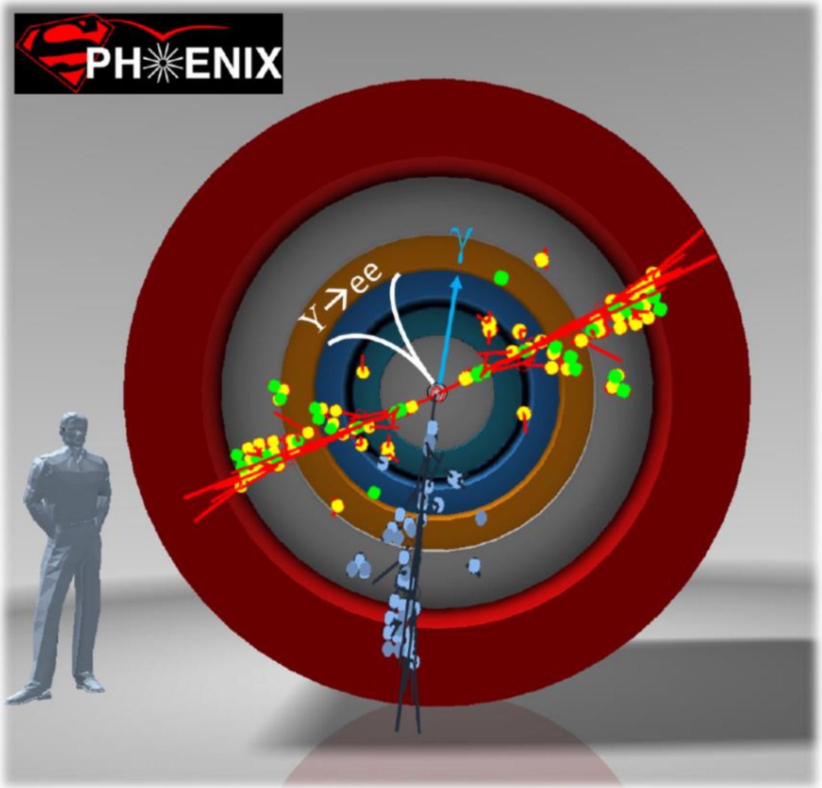


eRHIC era: sPHENIX based concept for an EIC Detector

- **-1<η<+1 (barrel) : sPHENIX + Compact-TPC + DIRC**
- **-4<η<-1 (e-going) :**
  High resolution calorimeter + GEM trackers
- **+1<η<+4 (h-going) :**
  - **1<η<4 : GEM tracker + Gas RICH**
  - **1<η<2 : Aerogel RICH**
  - **1<η<5 : EM Calorimeter + Hadron Calorimeter**
- **ZDC and roman pots in Hadron Direction**



Summary



- RHIC program in this decade is about quantitatively studies of QGP near T_C using probes over a broad range of scales
- Initial stage of this program – sPHENIX – just underwent successful DOE scientific review;
- It got substantial bust from the shipment of BaBar magnet to BNL
- Both sPHENIX and STAR are developing forward upgrades aimed towards transverse spin physics;
- Both upgrade paths could lead to a capable EIC detector and broad ep/eA program

Plenty of opportunities for Universities and good students

Motto of experimentalist (violated daily)

As forthwith declared on this day,
Physics Experiment Electronics shall contain no:

- Blueberry Pies
- Raspberry Pi's
- Legos
- Tamagotchis
- Arduinos
- Game Controllers
- Garage Door Openers

Or any other such technologies deemed to be unworthy of the professional and reliable operation of a world-class physics detector.

The control devices that we are using are the type found in military, medical equipment and automobile engines. That's why your car doesn't just shut off in the middle of the Long Island Expressway. ***SB, 1/14/2016***