Nose Cone Calorimeter (NCC):
Next generation calorimetry for PHENIX

Ondrej Chvala, UC Riverside, PHENIX collaboration

BROOKHAVEN NATIONAL LABORATORY

PHENIX

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UNIVERSITY OF CALIFORNIA UC RIVERSIDE

Detector upgrades to PHENIX experiment

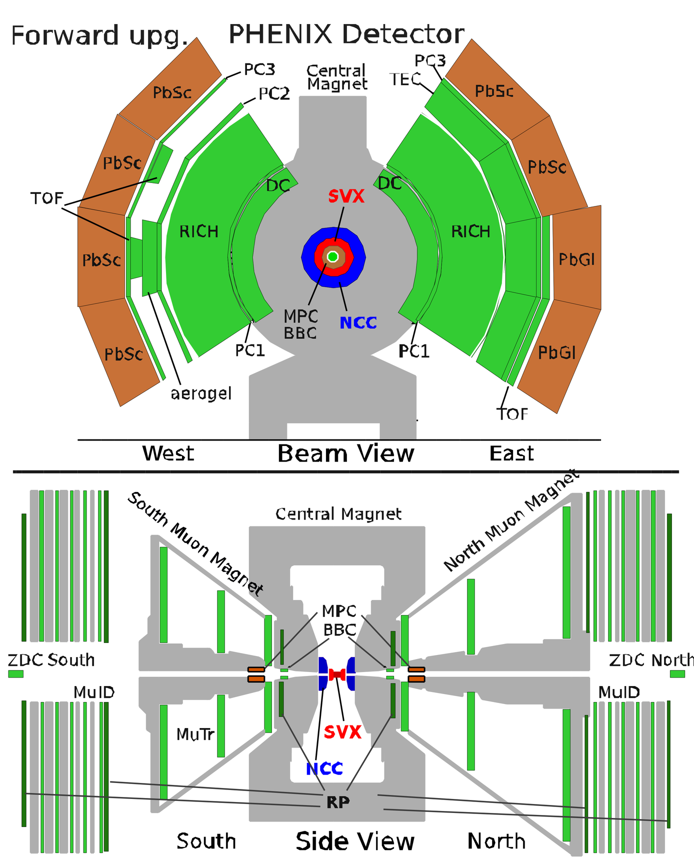


Figure 1: Location of PHENIX upgrades

PHENIX was designed specially to be efficient at measuring rare processes involving electromagnetic probes, both leptons and photons. PHENIX currently records events at a very high rate but has limited acceptance in both azimuth and rapidity.

Upgrades to the detector will improve coverage dramatically in both azimuth and rapidity. The Nose Cone Calorimeter (NCC) upgrade will permit high precision measurements of electromagnetic probes and jets in A+A, d+A, and p+p collisions.

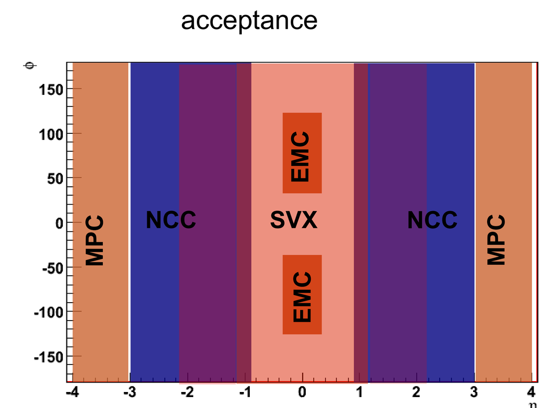


Figure 2: PHENIX acceptance after upgrades

Calorimetry:
EMC in central arms (PbSc, PbGl), original detector since Run 1, $|\eta| < 0.35$
MPC in forward directions (PbWo), added recently, since Run 6, $3 < |\eta| < 4$
NCC tracking calorimeter (W-Si), proposed, Run 11, $0.9 < |\eta| < 3$

SVX: VTX Si tracker proposed, Run 10, $|\eta| < 2.2$

Motivation for NCC: new detailed physics

I. Heavy ions – hot nuclear matter
- R_{AA} in forward direction, esp. π^0 at high momentum
- γ-jet correlations to study opacity of sQGP
- Plasma temperature using charmonium suppression
- Open heavy flavor measurement via electrons (+FVTX)

II. d+Au collisions – cold nuclear matter
- Gluon structure function (saturation at low x?) by
  - Single hadrons via EM channels (π^0, η, ω, φ, J/ψ, …)
  - Direct photons, γ-jet correlations to fix kinematics
  - Dihadron production: π^0 or η in NCC and another in EMC
  - Open heavy flavor production
- Antiquark DF in nucleus at low x via Drell-Yan
- Cronin effect, x_F scaling of produced hadrons in p+A

III. Polarized p+p interactions – spin structure of nucleon
- Polarized gluon distribution ΔG via single hadrons, direct γ, heavy flavor
- Antiquark contribution to Δq via W
  - e measurement, BG reduction for μ
- Transverse physics
  - single spin asymmetry A_N – Sivers, Collins, higher twist
  - trasversity δq

NCC placement and structure

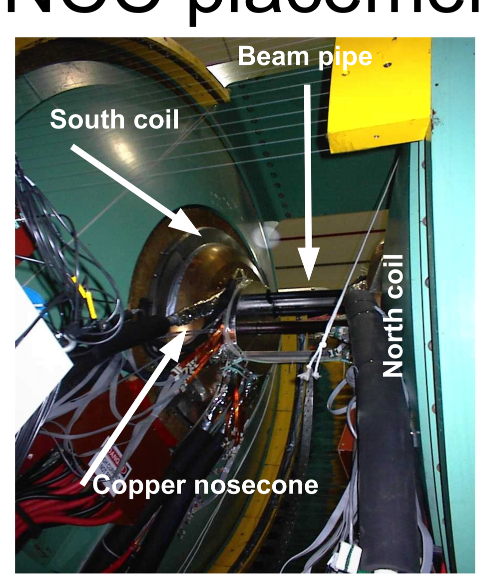


Figure 3: Design and placement of the NCC. Space between the magnet coils is limited

The NCC is a 19 cm thick W-Si sampling calorimeter with a radius of 50 cm. The detector is mounted on the magnet coils, with the front face 41 cm from nominal vertex.

Tungsten was chosen for its high density (19.3 g/cm^3) and small Molière radius (9mm). There are three longitudinal segments (EM1, EM2, HAD) and the total depth is 35 X_0 (1.3 L_{int}): (8 + 8 + 19 X_0).

Decay photons for π^0s with total momentum above 5-7 GeV merge into a single shower. To measure these "single shower" π^0s , 2 photon identifiers (PI1, PI2) are placed at (2, 3) X_0

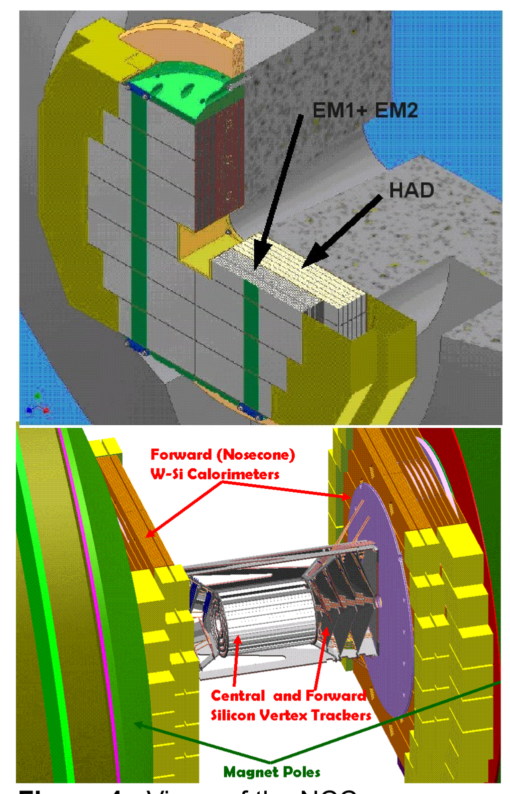


Figure 4: Views of the NCC

NCC tower composition

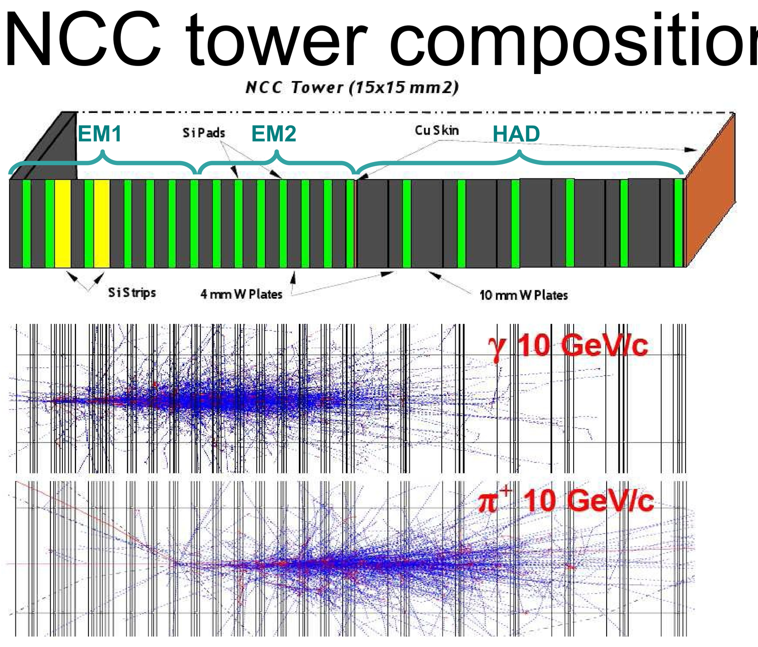


Figure 5: A cross section of the NCC showing the different sections (above) and simulations of an electromagnetic and a hadronic shower expected in the detector.

The composition of the NCC towers are shown to the right. Each tower consists of EM1, EM2, HAD sub-towers. These sum signals from individual Si pads.

Longitudinal segmentation allows for EM shower (e, γ, π^0) identification and hadron rejection thanks to different physics of electromagnetic versus hadronic showers.

Merged π^0 identification

Two photon showers from a π^0 decay start to overlap for $p_{Tot}(\pi^0)$ > 5-7 GeV/c forming a "single track π^0". Photon Identifiers (PI1, PI2) contain two layers of Si strips (pitch 0.5 mm) along X and Y direction each.

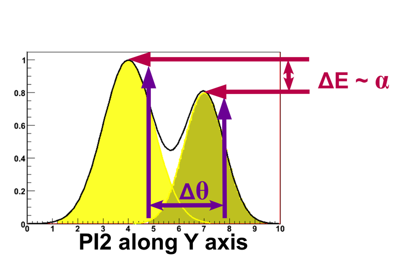


Figure 6: Schematics of single shower π^0 identification by separation angle $\Delta\theta$ and energy asymmetry α measurement via Photon Identifiers (PI1, PI2).

$$m_\pi^2 = E^2 (1 - \alpha)\,(1 - \cos(\Delta\theta))$$

NCC energy resolution

Energy resolution of electromagnetic showers σ_E/E [%] can be parametrized by: ($1 < \eta < 2.5$)

$$\sigma_E/E = \frac{\alpha}{\sqrt{E\,[\text{GeV}]}} + \beta \quad [\%]$$

To reduce hadronic contamination, it may be useful to use EM1+EM2 for energy measurement only.

For calorimeter simulations, resolution depends on tracking cutoff energies.
10 keV – closest to the nature with standalone GEANT3
1 MeV - used in PISA simulations, 10 central Au+Au events / hour / CPU of PISA tracking

Energy cutoff	NCC segments used	$\alpha \pm \sigma_\alpha$ [%]	$\beta \pm \sigma_\beta$ [%]
10 keV	EM1+EM2+HAD	18.0 ± 1.6	4.5 ± 1.0
10 keV	EM1+EM2	18.5 ± 1.7	3.6 ± 1.0
1 MeV	EM1+EM2+HAD	20.1 ± 1.7	4.8 ± 1.1
1 MeV	EM1+EM2	22.3 ± 1.7	3.3 ± 0.9

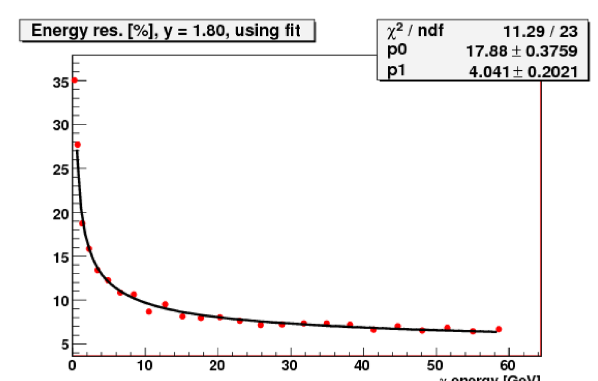


Figure 7: Energy resolution as a function of energy for single photons at η = 1.8

NCC jet resolution

HAD segment L_{abs} = 1.3 allows to measure jets
σ_E/E = 45 % / $\sqrt{E}$

PYTHIA jets using cone algorithm (dR < 0.5)
Further improvements are expected from
- sampling fractions corresponding to hadrons
- advanced jet finding algorithms

Jet angular resolution is critical for determination of x. In high multiplicity events, leading particle will be used as a good proxy, see plot in the right panel.

Angular resolution < 0.1 rad → x resolution < 10 %
(less than NLO radiative effects)

Jet energy

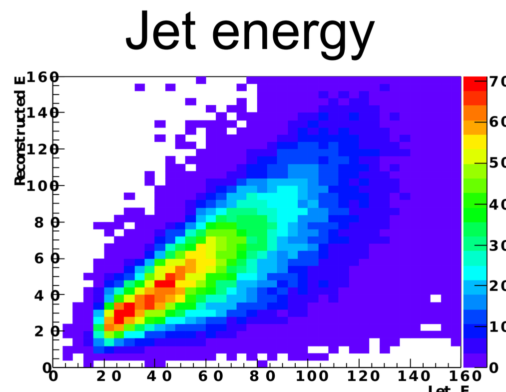


Figure 8: Reconstructed jet energy from a cone within dR < 0.5 vs. PYTHIA jet energy [GeV]

Jet angle

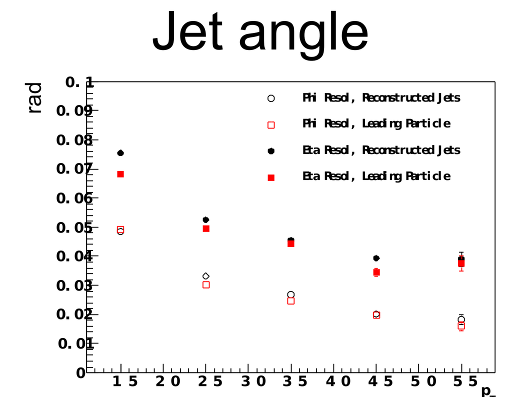


Figure 9: Angular resolution of reconstructed jets and leading particles in azimuthal angle φ and pseudorapidity θ

Occupancy in central Au+Au collisions

NCC will be able to measure physics signals even in the most central Au+Au interactions in rapidity region up to 2

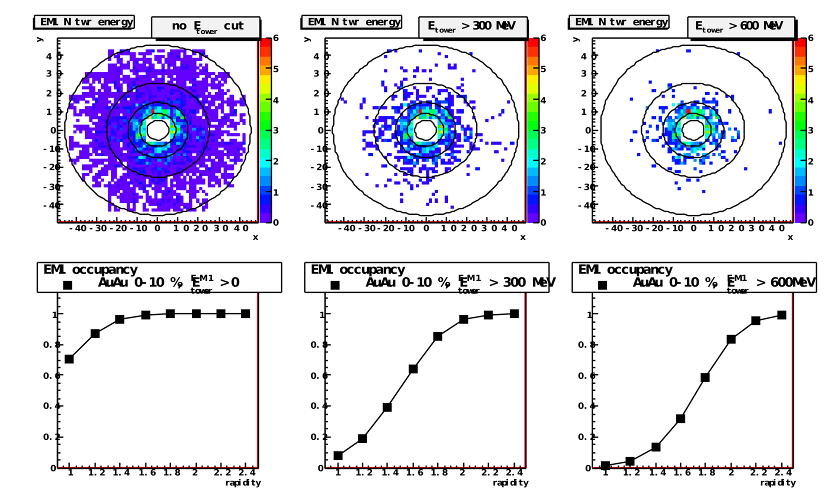


Figure 10: Energy deposits [GeV] in EM1 segment for a central (0-10%) HIJING Au+Au event with no threshold (left), 300 MeV (middle) and 600 MeV (right) thresholds. MIP corresponds to ~ 200 MeV.

Circles indicate $d\eta$ = 0.5 starting at η = 1 down to η = 3.

NB: occupancy in the most central Au+Au events stays below 50 % at η < 1.5 for E > 300 MeV

Occupancy similar to EMC for η < 2

Expected performance of the NCC detector

All estimates are based on 12 week run at RHIC II luminosity. Error bars indicate expected measurement precision. The studies were performed by merging signal particles with HIJING generated p+p, d+Au and Au+Au events

I. π^0 R_{AA} in Au+Au

Figure 11: Two track invariant mass method for low momentum π^0, several centralities.

R_{AA} values are taken from central arms measurement

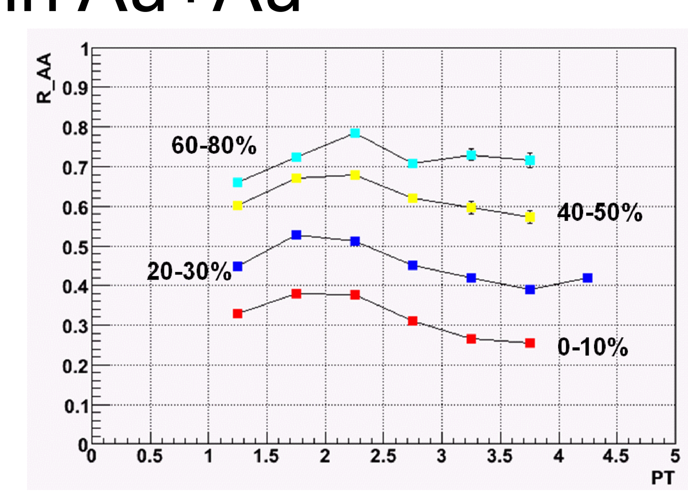
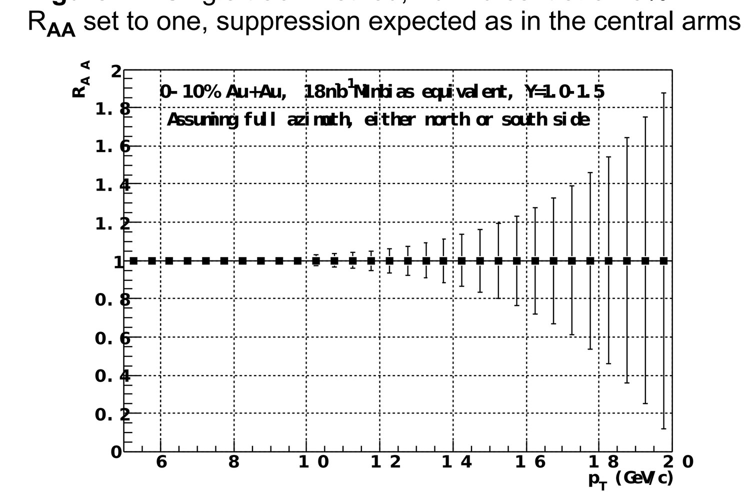


Figure 12: Single track method, Au+Au central 0-10% R_{AA} set to one, suppression expected as in the central arms



II. direct γ R_{AA} in Au+Au

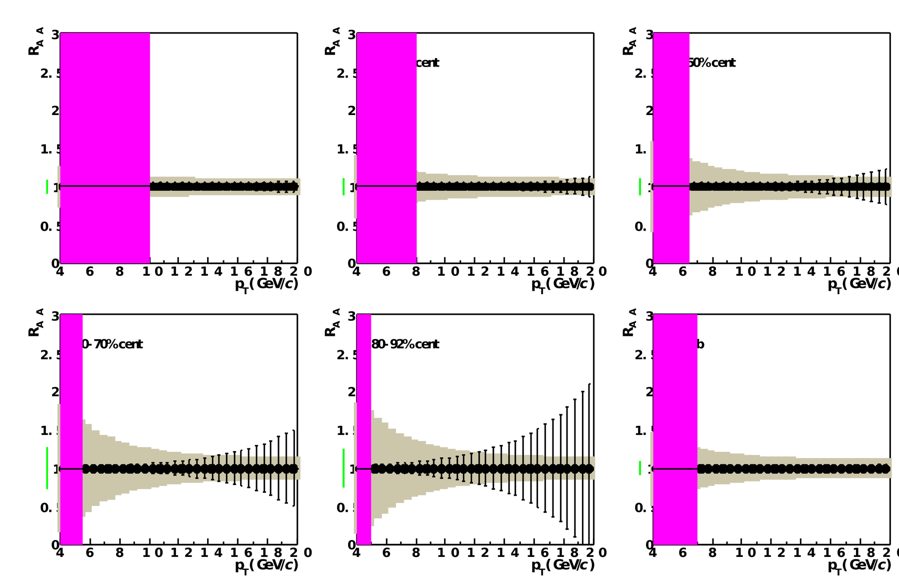


Figure 13: R_{AA} values are set to one. In purple areas current ambiguities in determining efficiencies are too large.

III. χ_c R_{AA} in Au+Au

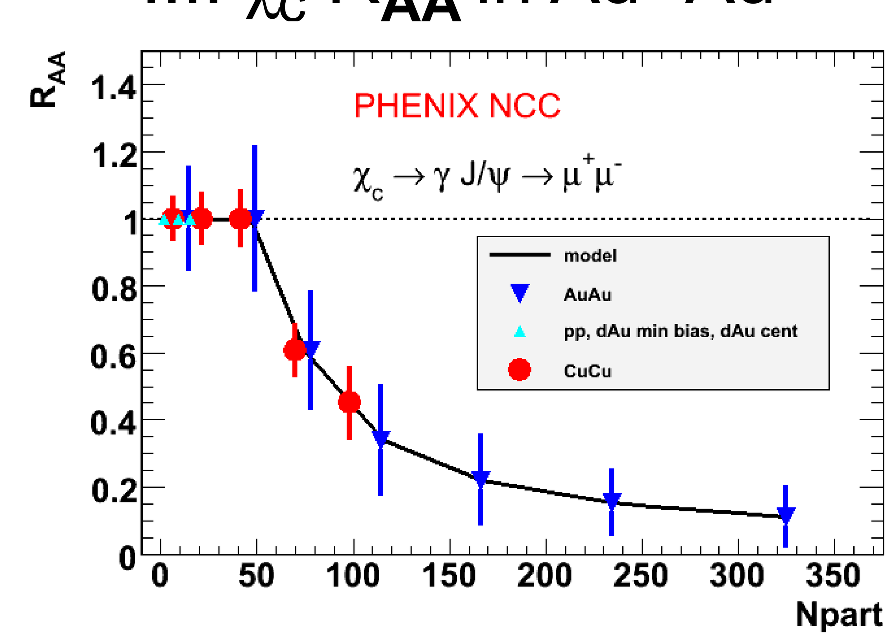


Figure 14: NCC enables χ_c measurement up to the highest centrality in Au+Au collisions. R_{AA} values taken from a model.

IV. A_{LL} p+p 500 GeV using direct photons

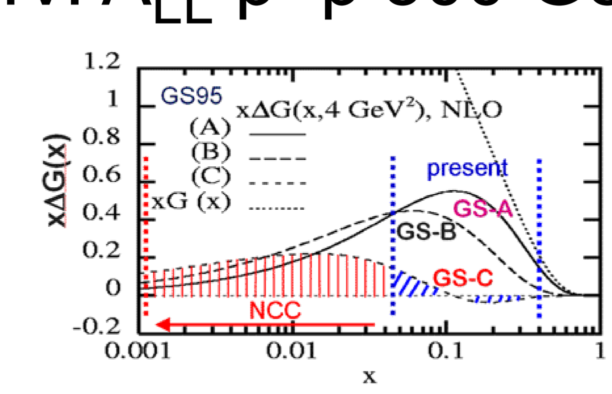


Figure 15: NCC coverage of forward rapidity (small x) increases sensitivity of A_{LL} measurement.

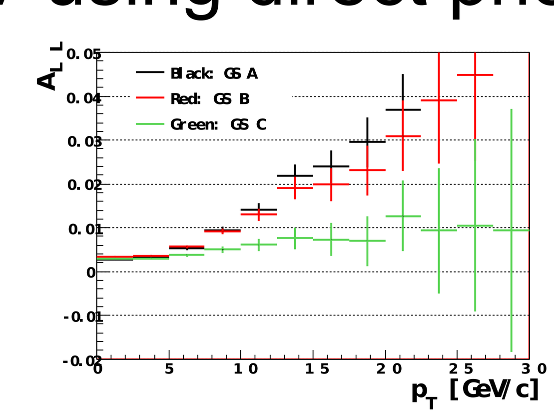


Figure 16: NCC measurement of A_{LL}

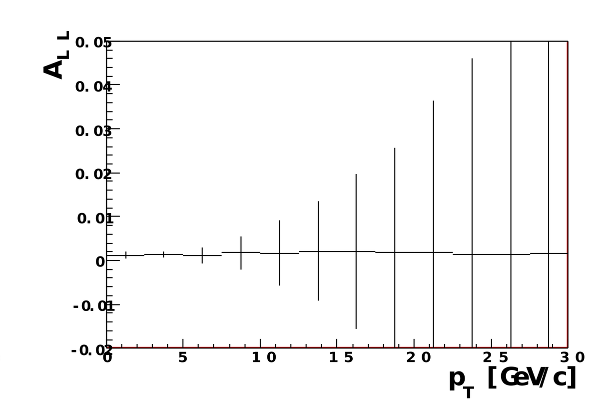


Figure 17: EMC measurement

Both assume a 12 week long run at RHICII luminosity, 70% beam polarization

NCC prototype tests

1) proof of principle device

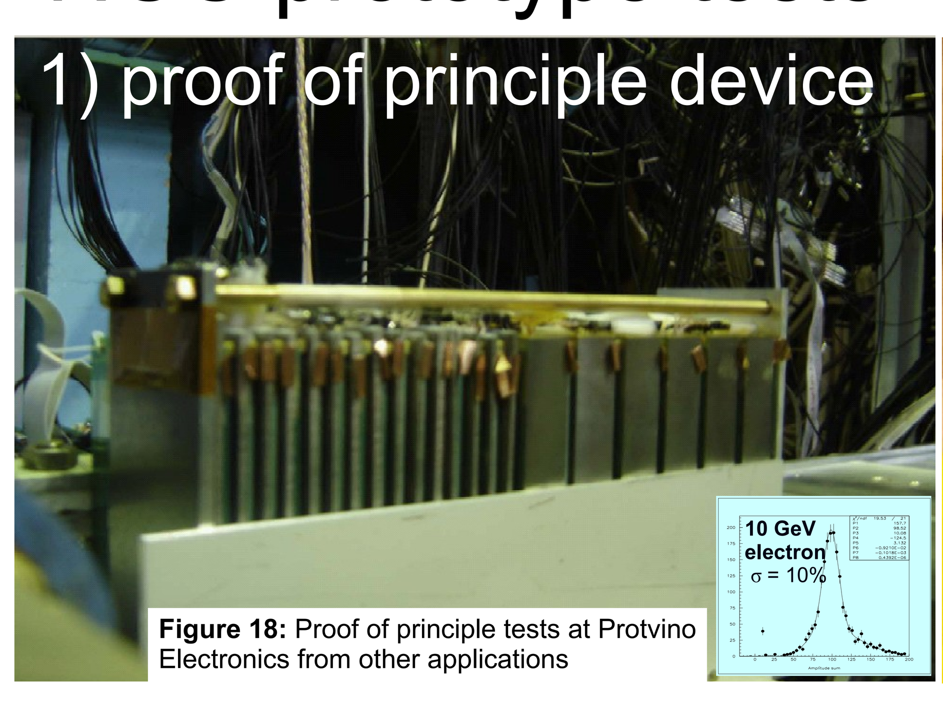


Figure 18: Proof of principle tests at Protvino. Electronics from other applications

2) 2x2 sensor prototype

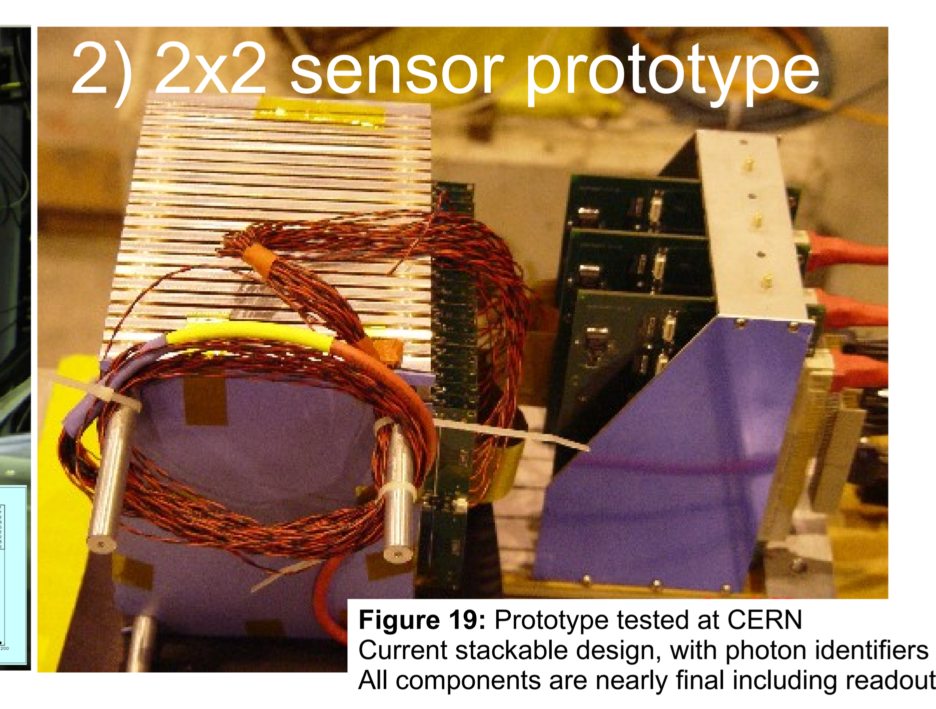


Figure 19: Prototype tested at CERN. Current stackable design, with photon identifiers. All components are nearly final including readout

NCC summary

- NCC: dense W-Si tracking calorimeter with small Molière radius
- 10x larger acceptance than central arms allows new physics studies
- Installation expected in 2010, physics measurements starting in Run 11

NCC provides:
- Precision measurements of EM showers in forward rapidity region(s)
- γ/π^0 discrimination similar to central arms
- additional γ/hadron discrimination
- jet finding, jet energy and rapidity measurements
- data for fast LL1 triggering

Allows for studies:
- **Heavy ions**
  - suppression in fwd region
  - opacity and temperature of sQGP
  - heavy flavor
- **d+Au collisions**
  - sea distribution at low x
  - Cronin effect
- **Spin program**
  - sea contribution to proton spin
  - transverse physics