PHENIX upgrade –
Silicon Vertex Tracker

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for PHENIX collaboration

16/09/03 VERTEX2003

Outline

- The PHENIX experiment
- SVT overview
- Physics goals
- Technical options
- Plan
- Summary

PHENIX

12 Countries; 57 Institutions; 460 Participants

Brazil
- University of São Paulo, São Paulo

China
- Academia Sinica, Taipei, Taiwan
- China Institute of Atomic Energy, Beijing
- Peking University, Beijing

France
- LPC, University de Clermont-Ferrand, Clermont-Ferrand
- Dapnia, CEA Saclay, Gif-sur-Yvette
- IPN-Orsay, Universite Paris Sud, CNRS-IN2P3, Orsay
- LLR, Ecòle Polytechnique, CNRS-IN2P3, Palaiseau
- SUBATECH, Ecòle des Mines at Nantes, Nantes

Germany
- University of Münster, Münster

Hungary
- Central Research Institute for Physics (KFKI), Budapest
- Debrecen University, Debrecen
- Eötvös Loránd University (ELTE), Budapest

India
- Banaras Hindu University, Banaras
- Bhabha Atomic Research Centre, Bombay

Israel
- Weizmann Institute, Rehovot

Japan
- Center for Nuclear Study, University of Tokyo, Tokyo
- Hiroshima University, Higashi-Hiroshima
- KEK, Institute for High Energy Physics, Tsukuba
- Kyoto University, Kyoto
- Nagasaki Institute of Applied Science, Nagasaki
- RIKEN, Institute for Physical and Chemical Research, Wako
- RIKEN-BNL Research Center, Upton, NY
- University of Tokyo, Bunkyo-ku, Tokyo
- Tokyo Institute of Technology, Tokyo
- University of Tsukuba, Tsukuba
- Waseda University, Tokyo

S. Korea
- Cyclotron Application Laboratory, KAERI, Seoul
- Kangnung National University, Kangnung
- Korea University, Seoul
- Myong Ji University, Yongin City
- System Electronics Laboratory, Seoul Nat. University, Seoul
- Yonsei University, Seoul

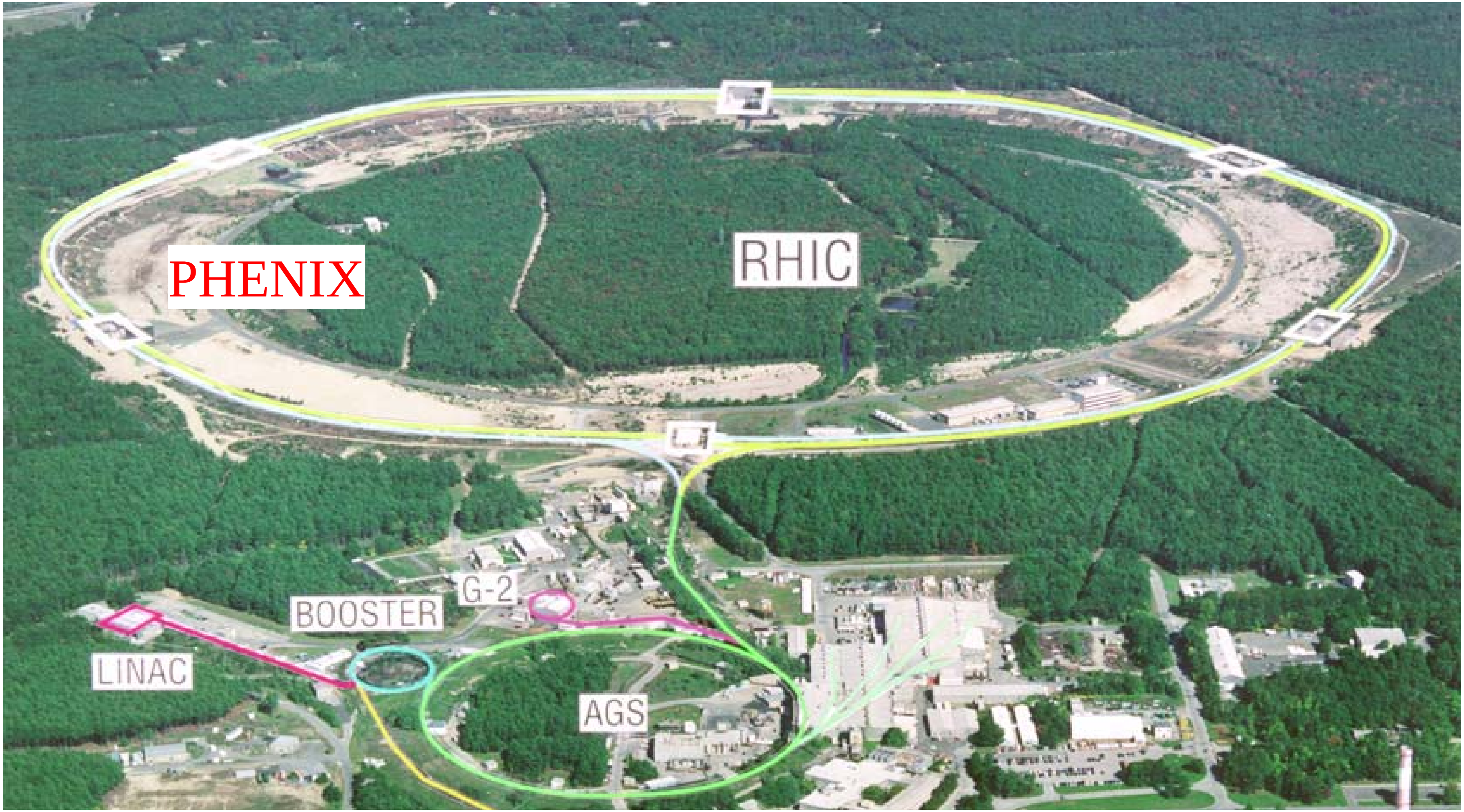
Russia
- Institute of High Energy Physics, Protovino
- Joint Institute for Nuclear Research, Dubna
- Kurchatov Institute, Moscow
- PNPI, St. Petersburg Nuclear Physics Institute, St. Petersburg
- St. Petersburg State Technical University, St. Petersburg

Sweden
- Lund University, Lund

USA
- Abilene Christian University, Abilene, TX
- Brookhaven National Laboratory, Upton, NY
- University of California - Riverside, Riverside, CA
- University of Colorado, Boulder, CO
- Columbia University, Nevis Laboratories, Irvington, NY
- Florida State University, Tallahassee, FL
- Georgia State University, Atlanta, GA
- University of Illinois Urbana Champaign, Urbana-Champaign, IL
- Iowa State University and Ames Laboratory, Ames, IA
- Los Alamos National Laboratory, Los Alamos, NM
- Lawrence Livermore National Laboratory, Livermore, CA
- University of New Mexico, Albuquerque, NM
- New Mexico State University, Las Cruces, NM
- Dept. of Chemistry, Stony Brook Univ., Stony Brook, NY
- Dept. Phys. and Astronomy, Stony Brook Univ., Stony Brook, NY
- Oak Ridge National Laboratory, Oak Ridge, TN
- University of Tennessee, Knoxville, TN
- Vanderbilt University, Nashville, TN

The PHENIX experiment

at BNL-RHIC



PHENIX program overview

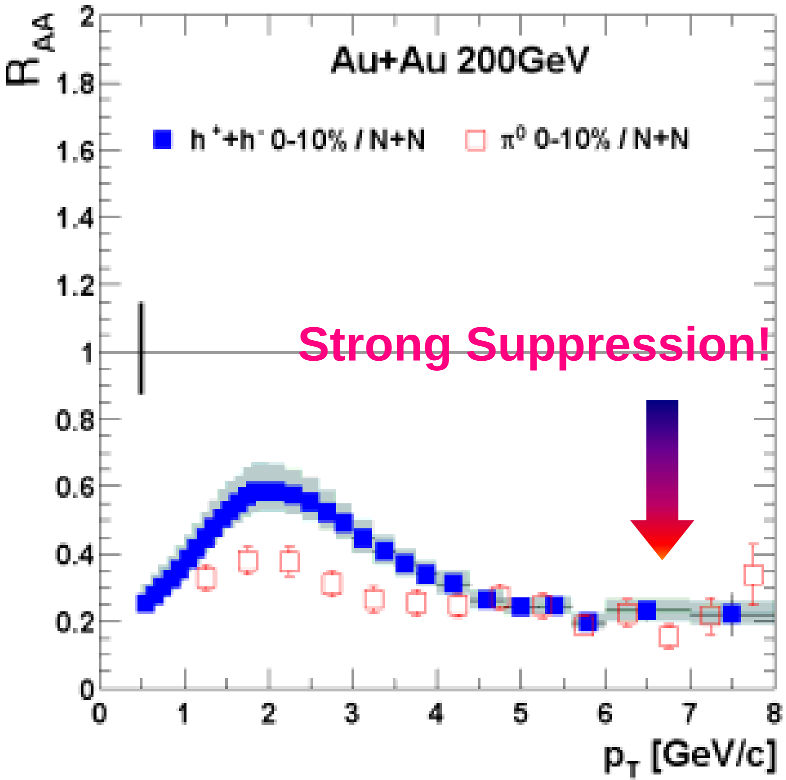
- Two physics programs
- Heavy Ion program
  - up to Au-Au with $\sqrt{s_{NN}} \leq 200$ GeV
  - search for Quark Gluon Plasma
- RHIC-spin program
  - polarized proton collision with $\sqrt{s} \leq 500$ GeV
  - study spin structure of proton, especially, gluon polarization.
- PHENIX focuses on rare probes, e.g., J/ψ, open charm/bottom, photons, etc., in addition to non-rare probes.

Heavy Ion program

- Many measurements
  - more than 10 physics talks in the JPS meeting last week
- Examples include
  - single/pair electron/muon
  - high p_T hadron suppression (jet quenching)
  - two-particle correlation
  - radial and elliptic flow
  - J/ψ
  - ...

R_{AA} for π^0 and charged hadron

$$R_{AA} = \frac{\text{Yield}_{AuAu} / \langle N_{binary} \rangle_{AuAu}}{\text{Yield}_{pp}}$$

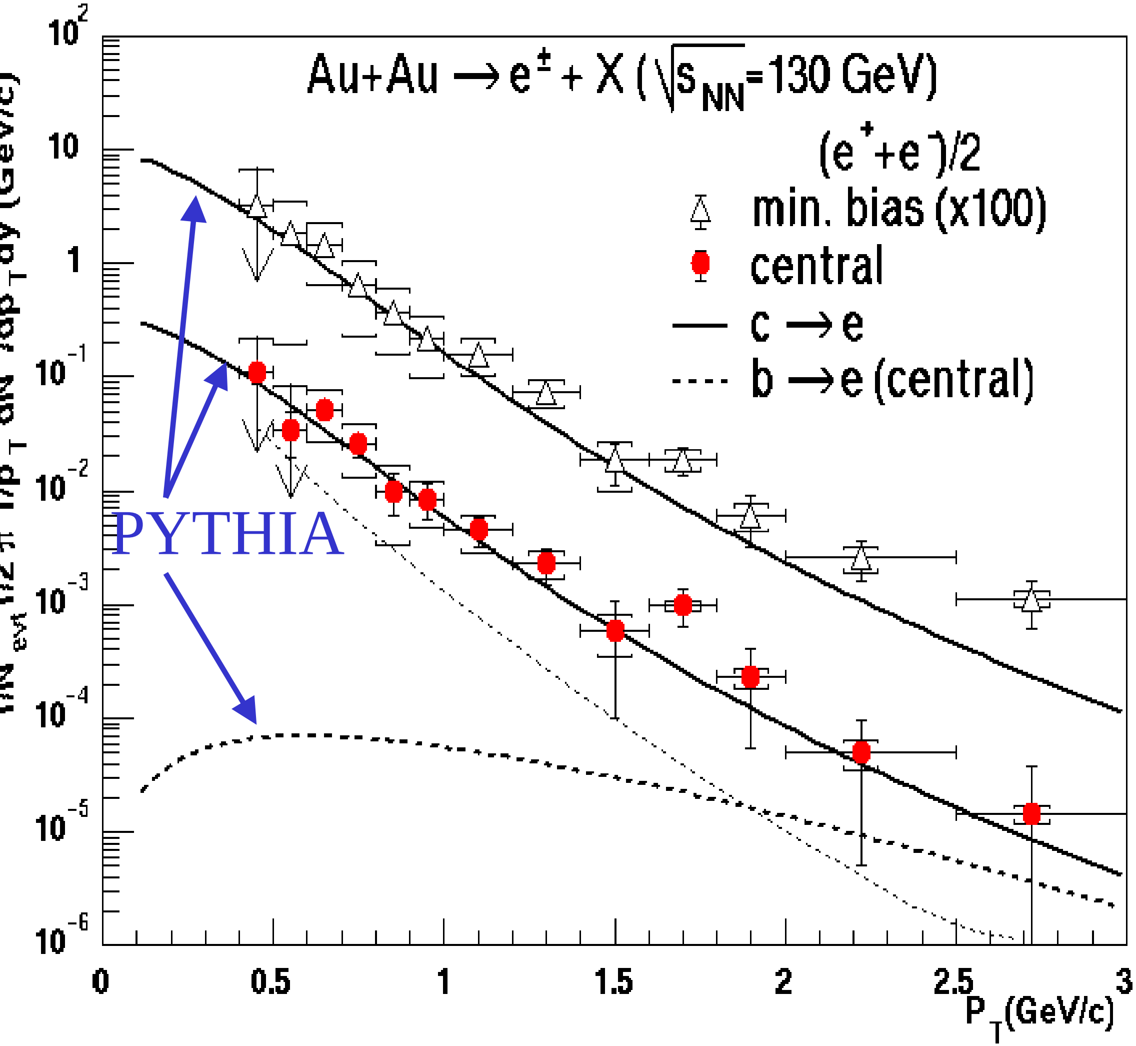


PHENIX AuAu 200 GeV
π^0 data: PRL 91 072301 (2003), nucl-ex/0304022.
charged hadron (preliminary) : NPA715, 769c (2003).

- $R_{AA} << 1$ for central events
- Suppression not observed in d-Au collisions
  [PRL 91, 072303 (2003) , hep-ex/0306021]
- Jet quenching models (partons lose energy by gluon radiation) can explain these.

→ How about heavy quarks?

Non-photonic electron



PHENIX: PRL 88(2002)192303

consistent with PYTHIA estimation for c,b → e

→ no suppression?

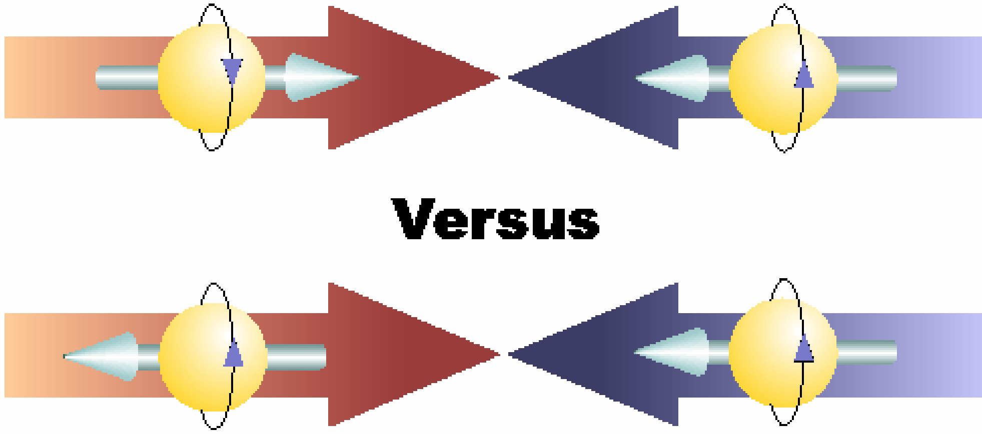
uncertainty for photo
conversion estimatio
is quite large

Spin program

- Polarized proton collider
  → Study of spin structure of proton
  $1/2 = 1/2\Delta\Sigma + \Delta G + L \quad (\Delta\Sigma \sim 0.25)$
- Gluon polarization → a possible answer to spin crisis.
- How to study?
  A_{LL} -- double spin asymmetry

$$= \frac{\sigma(++) - \sigma(+-)}{\sigma(++) + \sigma(+-)}$$

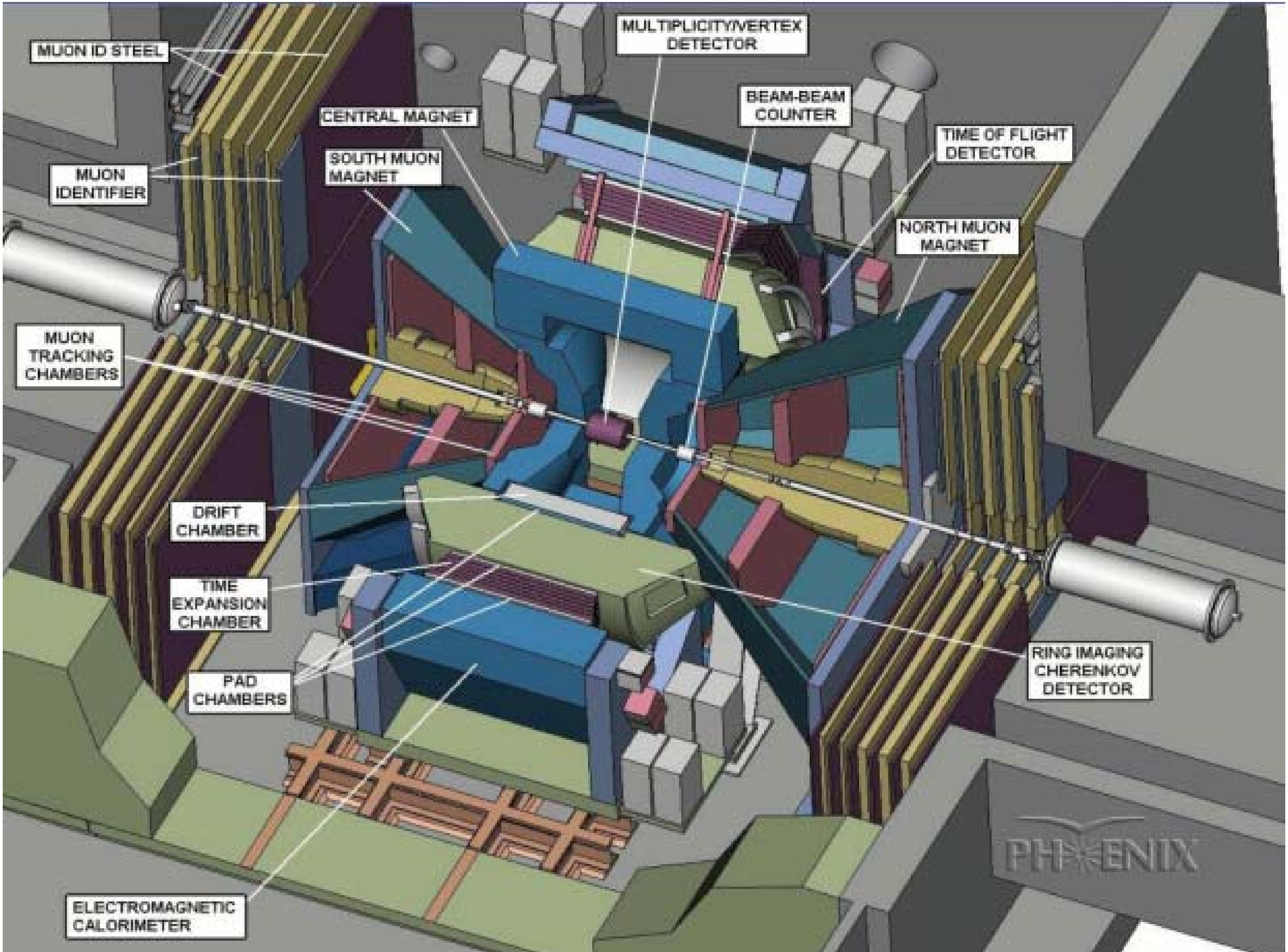
= (parton pol.)^2 × (a_{LL} in parton reaction)



Examples of reaction channels

- Direct photon: $g + q \rightarrow \gamma + q$
  - ~10% contribution from other processes
    (e.g. $\bar{q}q \rightarrow \gamma\gamma$)
  → golden channel for gluon polarization
  - Need high luminosity (> 100 pb^{-1}).
- Inclusive high-p_T hadron production
  - mix of various processes, q+q, g+g, g+q, ...
  - feasible at relatively small luminosity (~pb^{-1})
- Heavy flavor
  - $g + g \rightarrow \bar{c}c,\ \bar{b}b$
- W -- spin-flavor structure

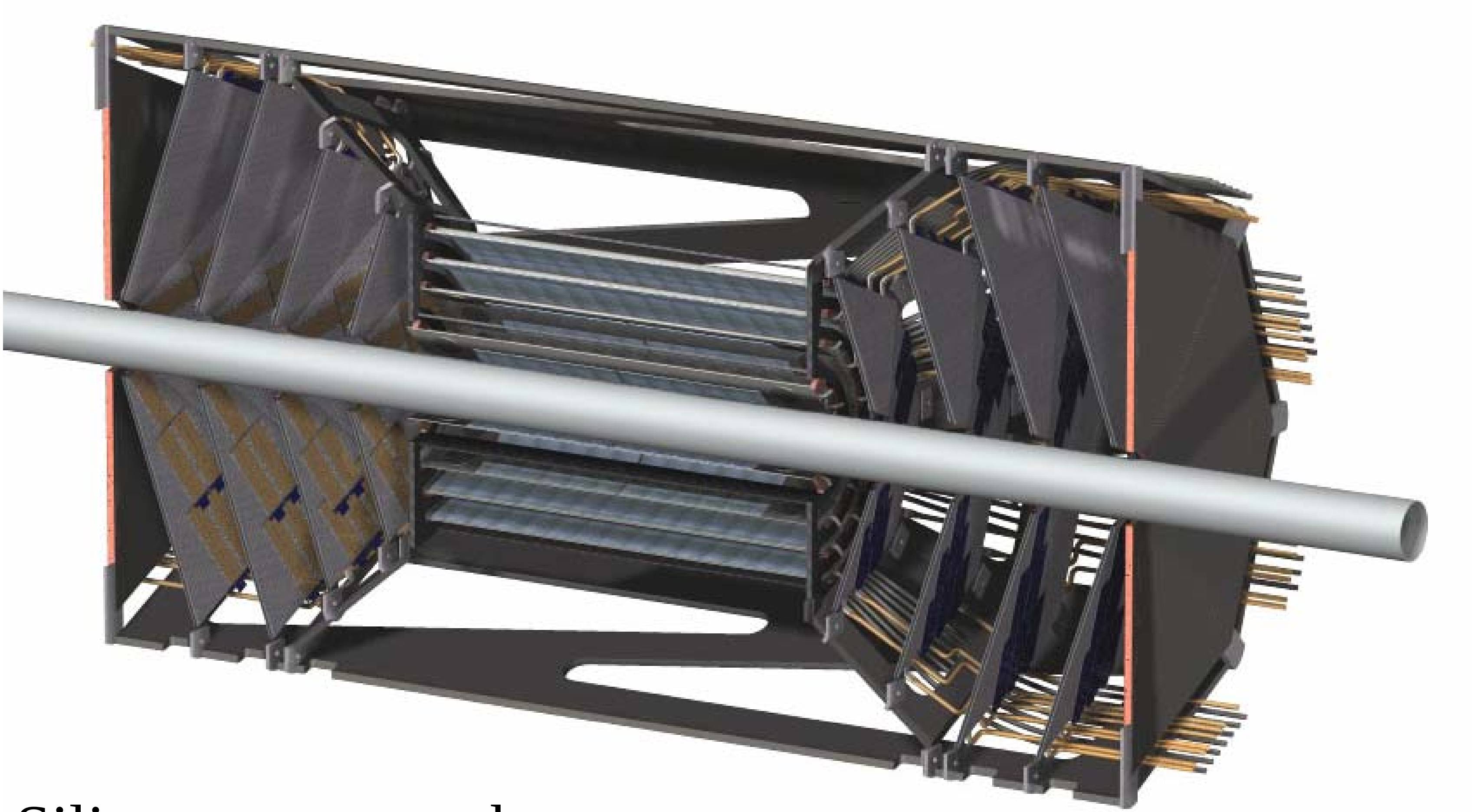
PHENIX detector



PHENIX detector (cont.)

- Global detectors (BBC, ZDC, NTC)
  - cover forward and backward region
  - triggering, event classification
- Central Arm ($|\eta| < 0.35$, $\Delta\phi$: π)
  - tracking, momentum measurement
  - RICH, TOF: PID (p,K,π,e)
  - EMcal.: photon, electron energy measurement.
- Muon Arm ($1.2 < |h| < 2.4$, $\Delta\phi \sim 2\pi$)
  - tracking, momentum measurement
- Limited capability for open heavy flavor
  - c,b → e,μ inclusive: suffers from severe background
    → Silicon Vertex Tracker upgrade

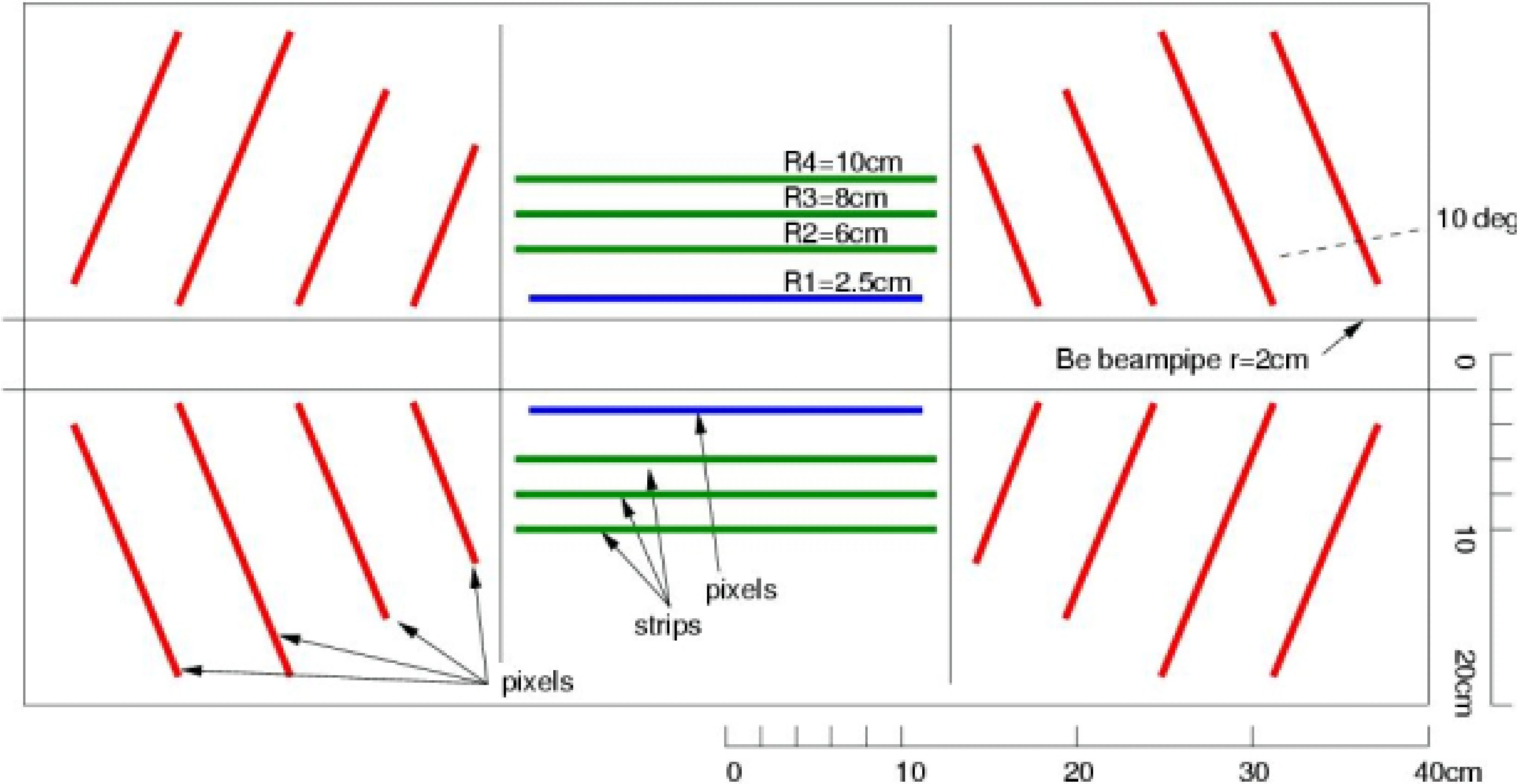
SVT Overview



Silicon vertex tracker

→ **detection of heavy flavors**

Strawman design



Barrel part + endcap part

Barrel ($|\eta| < 1.2$): Central Arm

Endcap ($1.2 < |\eta| < 2.4$): Muon Arm

Conceptual Mechanical Specs.

Central Barrel

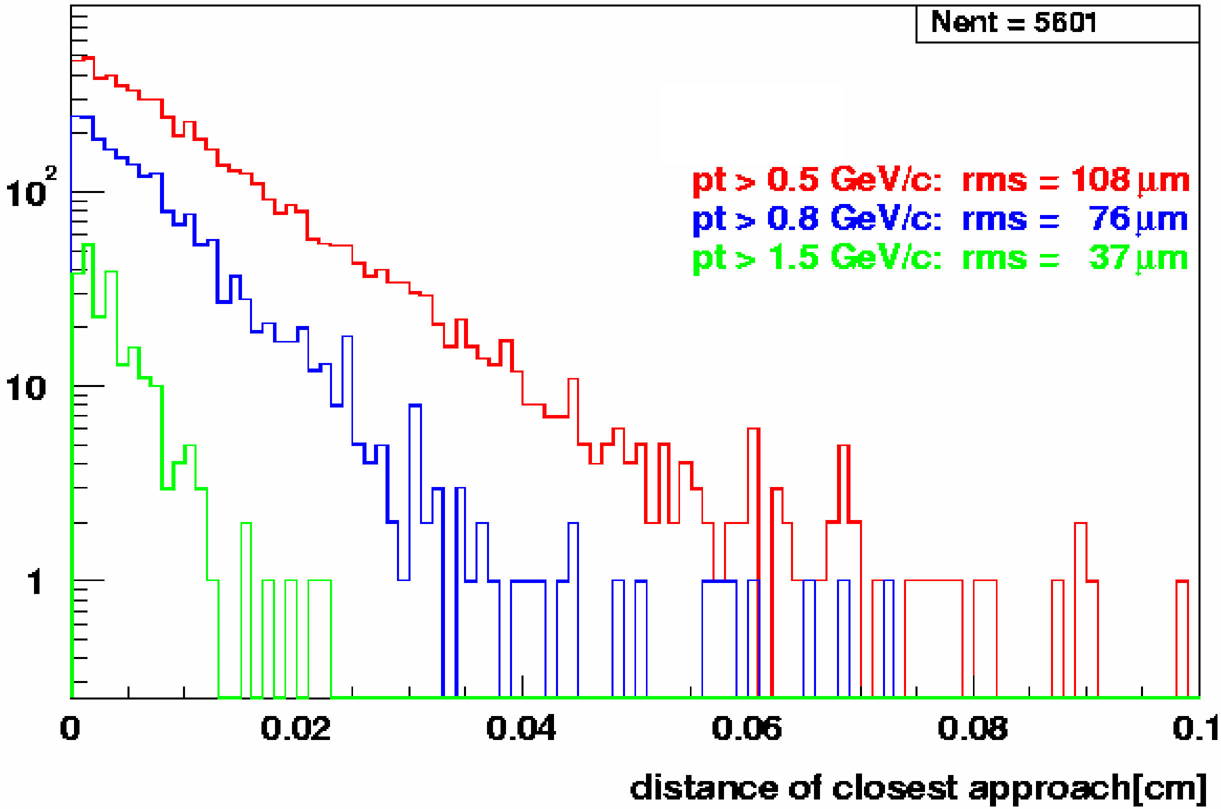
layer radius	2.5(pixel layer), 6, 8, 10(strip layers) cm
layer length	30 cm
pixel	50 µm x 425 µm x 1.3M channels
strips	80 µm x 3 cm x 370k channels
azimuthal coverage	320 deg

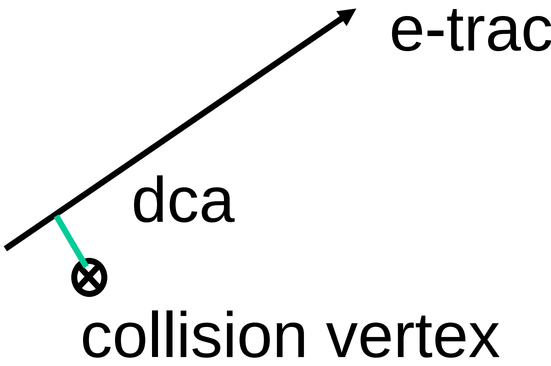
End Caps (each)

inner radius	3.0 cm
outer radius	18 cm
disk z pos.(at r_{in}= 3.0cm)	20,26,32,38 cm
pixel size	50 µm x 4 mm
total pixels	~2.8M
azimuthal coverage	320 deg

Electron DCA resolution

- Simulation for single electrons in central barrel
- Full multiple scattering included (X/X_0=1%/layer)
- DCA resolution < 50 μm at moderate p_T
- less than $c\tau$, D^0: 125μm, $D^{\pm}$: 317 μm → Charm, Bottom ID



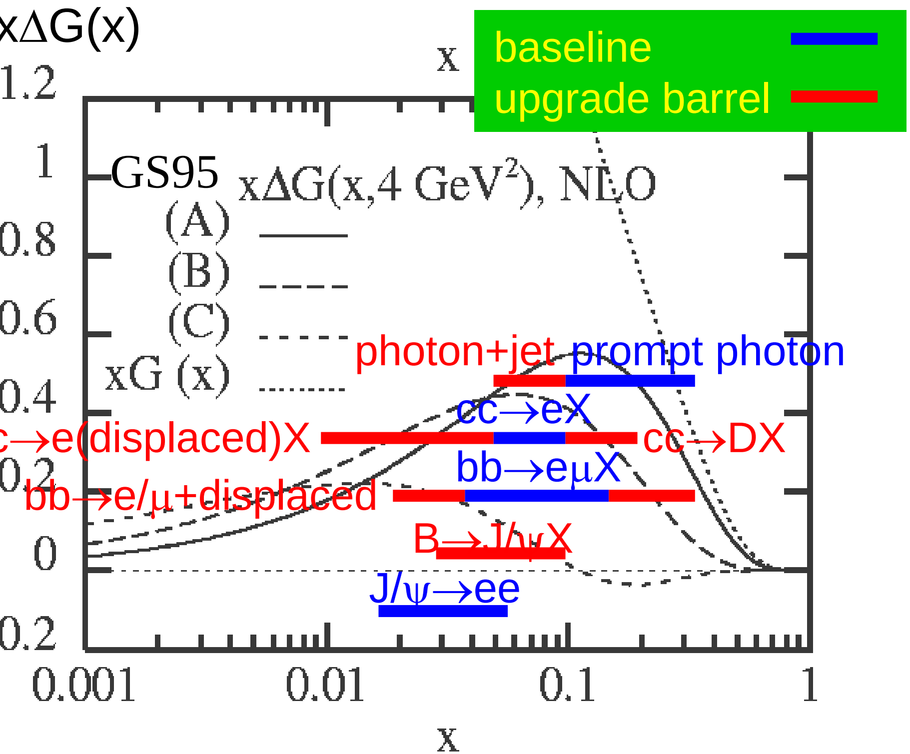


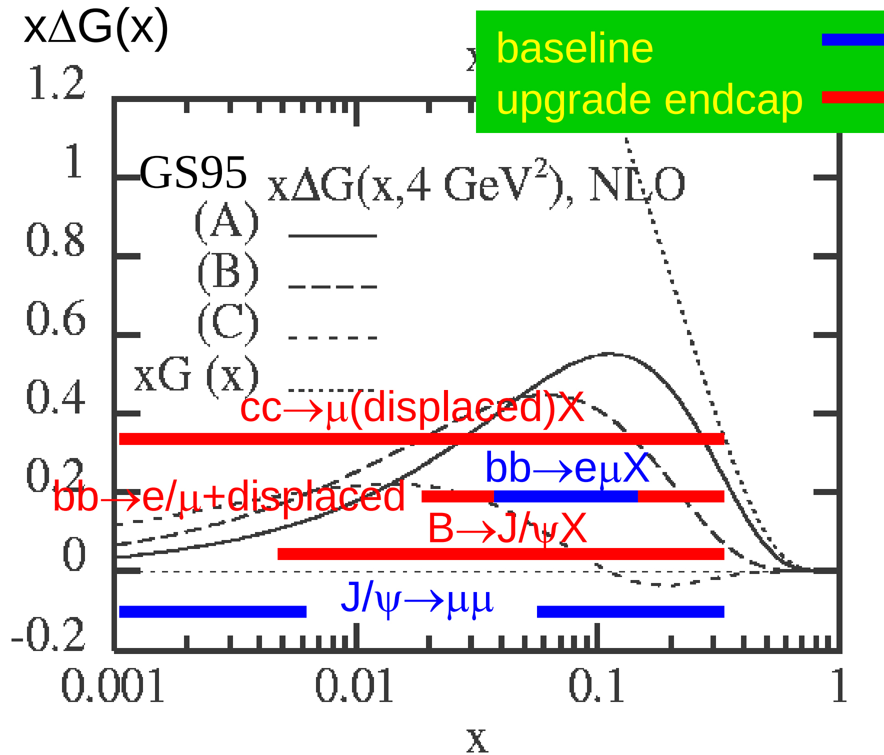
Physics goals

- heavy-ion physics
  - modification of gluon structure in nuclei
    - gluon shadowing
  - properties of earliest, densest stage of Au+Au
    - charm enhancement
    - charm baseline for J/ψ suppression
    - energy-loss of high-p_T heavy quarks
- spin physics
  - gluon polarization in broad x_{Bj} range
    - prompt photon + jet production: gluon Compton process
    - heavy flavor production: gluon fusion process
  - flavor contents of quark polarization
    - weak boson production
  - transversity
    - particle correlation

gluon polarization – x range

- Gluon fusion gg → $\bar{c}c$(bb) in polarized pp collision
- c,b → e(μ) and D → Kπ, Kππ
- Better S/N → wider x range coverage
  using low pT electrons/muons



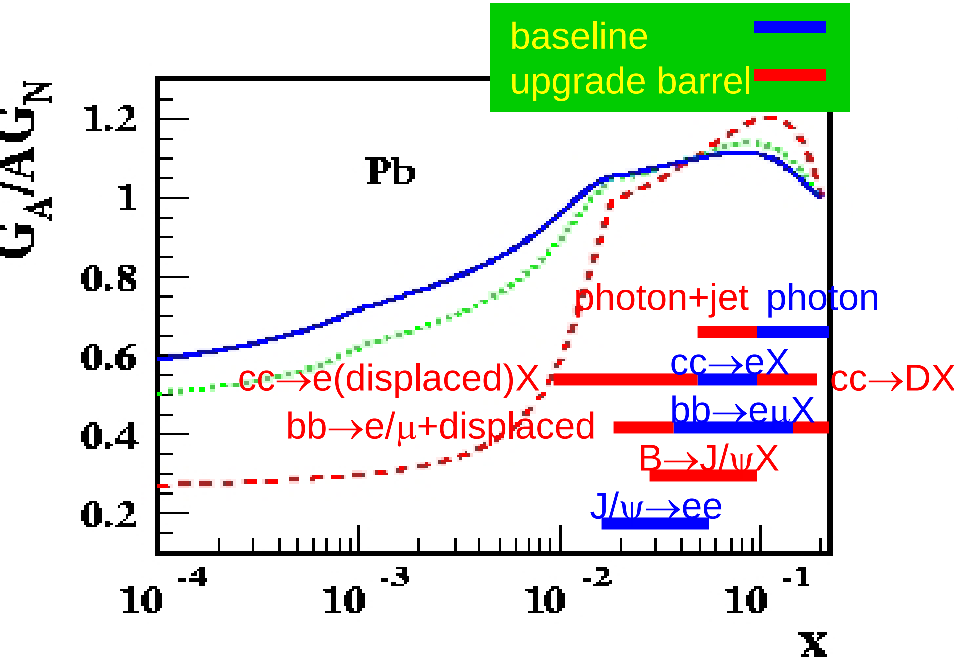


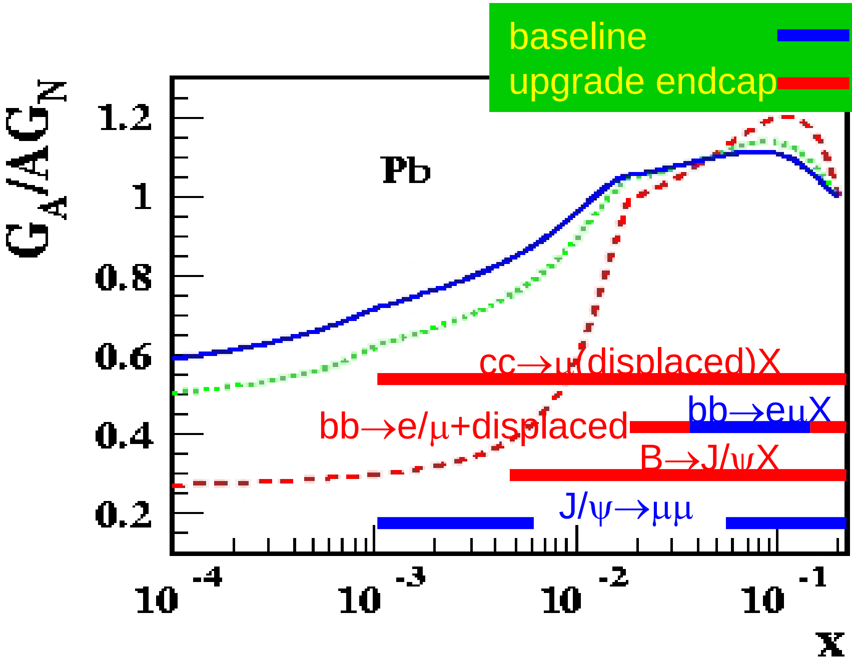
Gluon structure of nuclei

- Using pA → cc(bb)
  - – broader range in x
    - → into predicted shadowing region

L. Frankfurt,
M. Strikman
ur. Phys. J A5, 293 (99)

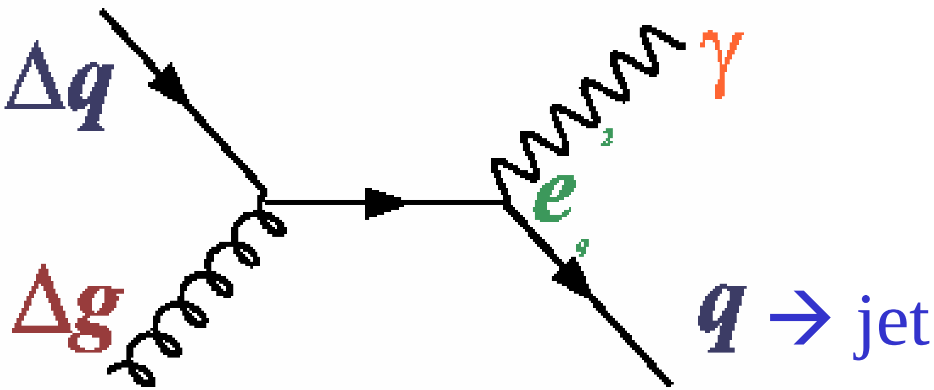
Q = 2 GeV
Q = 5 GeV
Q = 10 GeV





Direct photons

- gluon compton scattering



- SVX: jet detection on the other side
  - provides more kinematical information
    → better S/N, lower p_T,
    → lower x range (0.1 ~ 0.4 → 0.05 ~ 0.4)

Open heavy quarks in HI program

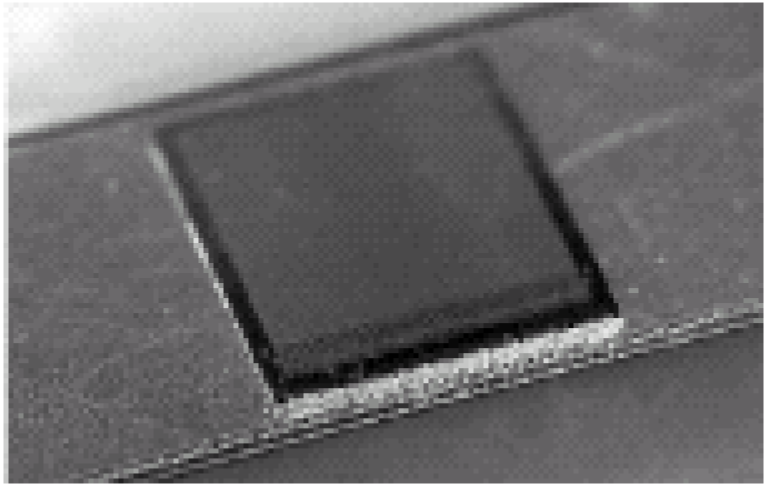
- More data on p_T spectra of open heavy flavors
  - if gluon radiation, energy loss is smaller for heavy quarks
- Open charm enhancement?
  - possible in pre-equilibruim stage via gluon fusion.
- J/ψ suppression
  - should be discussed on J/ψ to (open charm) ratio
  - we need to know yield of $\overline{c}c$ pair via open charm measurement
  - especially important if enhancement is observed.
- Does charm flow?
- ...

Technical options

Current choices

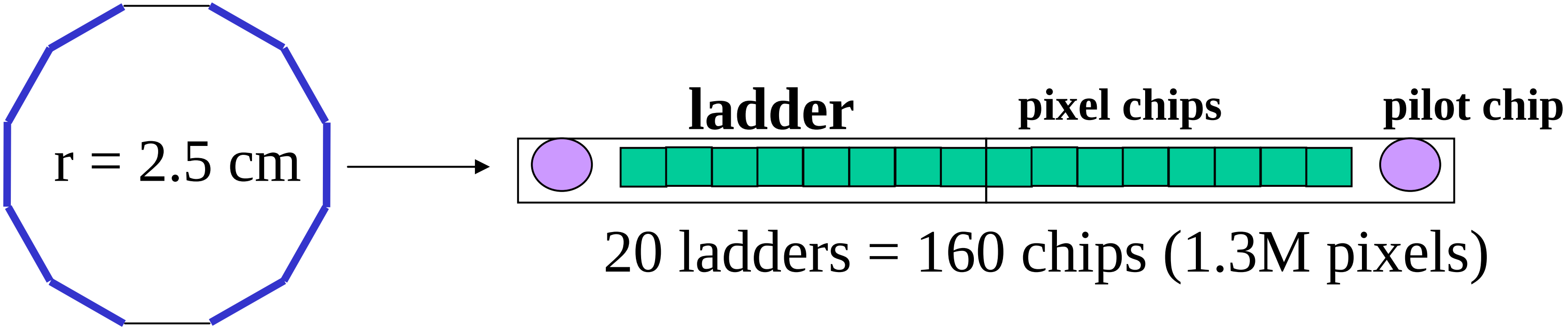
- 1st barrel layer
  - hybrid pixels using ALICE1 chip
  - modify peripherals (bus, pilot, ...) to match PHENIX environment
- Outer barrel layers
  - strips (pixel-strip)
  - readout: SVX4 chip from FNAL
- endcap
  - mini-strips or hybrid pixels
  - readout: planning new chip in collaboration with FNAL.

Hybrid pixel layer



ALICE1 readout chip

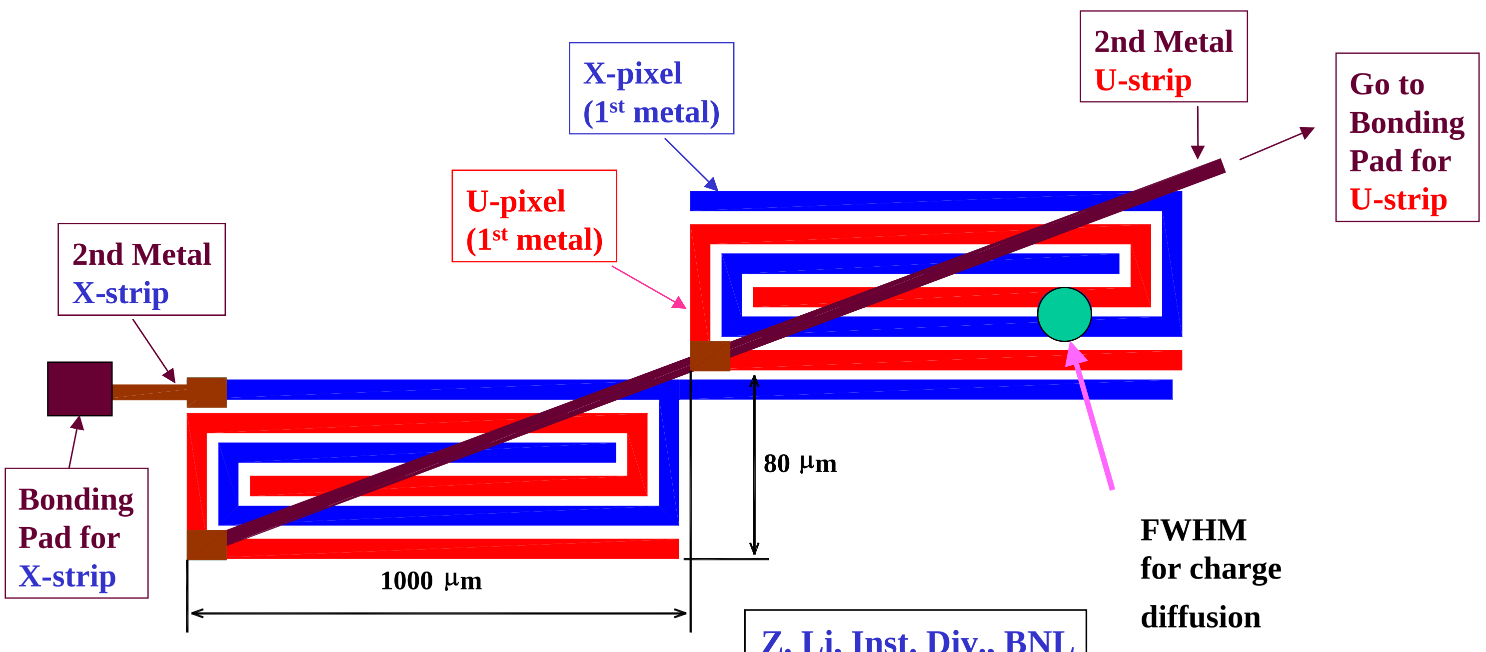
- 32 x 256 pixels of
  425 μm (z) x 50 μm (rϕ)
- Size: 13.6 mm x 15.95 mm
- Binary output
- Readout speed: 25.6 μs/chip @10MHz



- R&D for modification of pilot chip and bus is ongoing.
- Mass production will include PHENIX chips (CERN-RIKEN contract

Strip layers

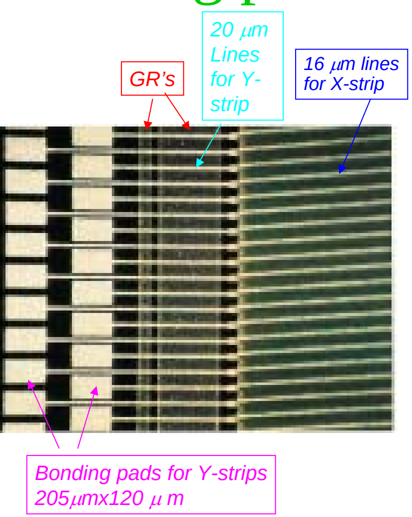
- New sensor prototype v1
  - by Zheng Li (BNL instrumentation div.)
  - spiral shape: divide one pixel (80 μm x 1000 μm) to two regions and connect them → x and u strips
  - single sided, yet 2-dimensional

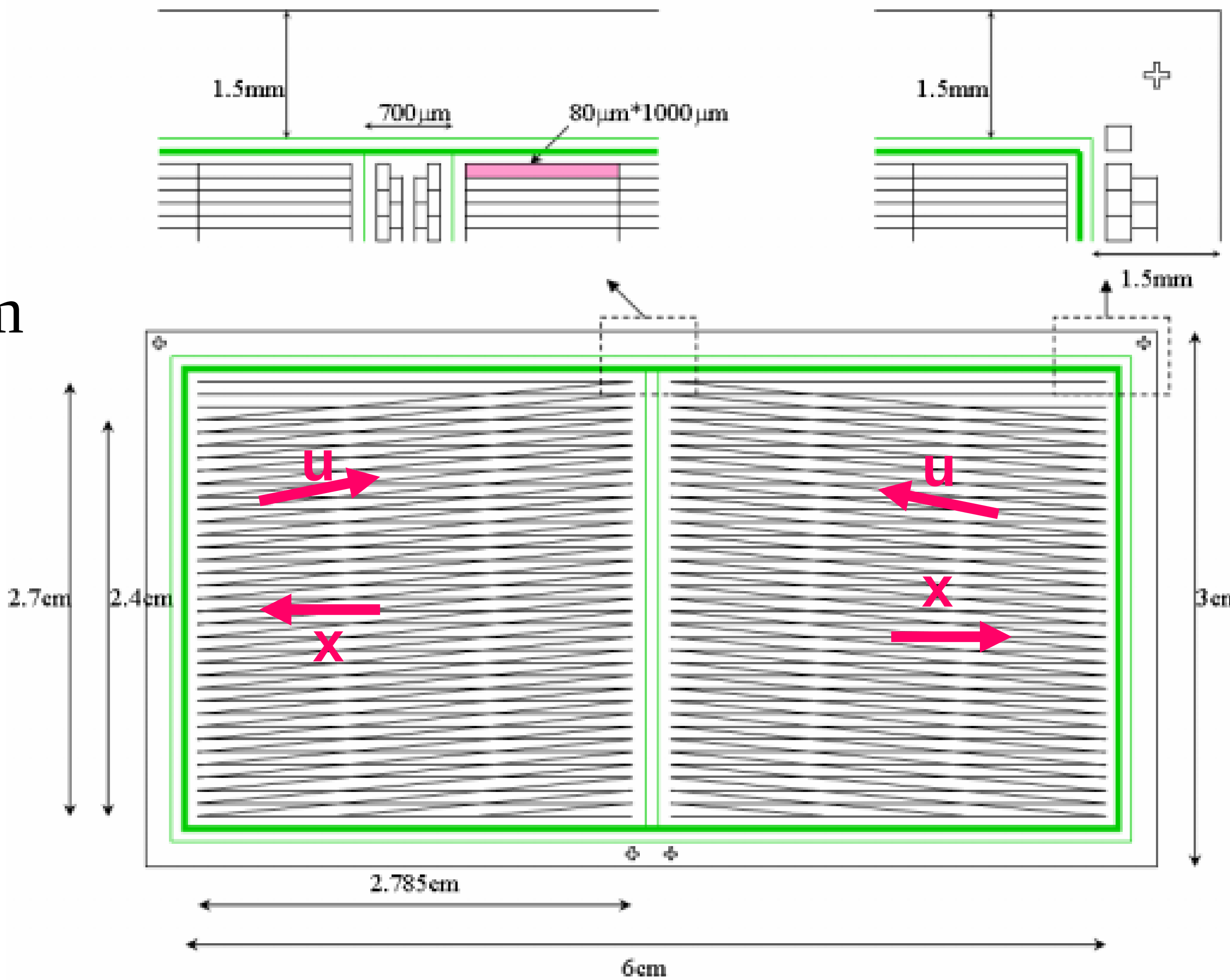


Strip sensor

sensor size:
 3 cm x 6 cm
strip size:
 3 cm x 80 µm

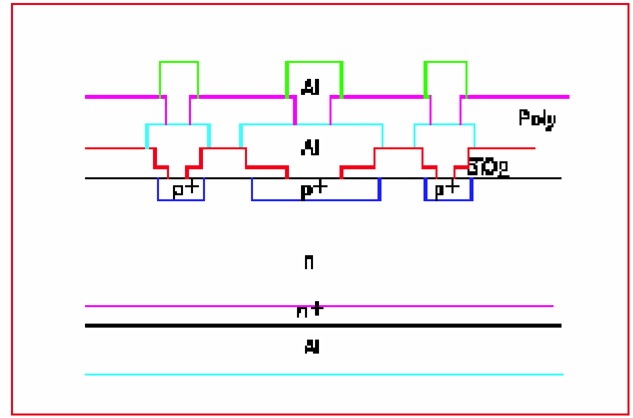
bonding pads

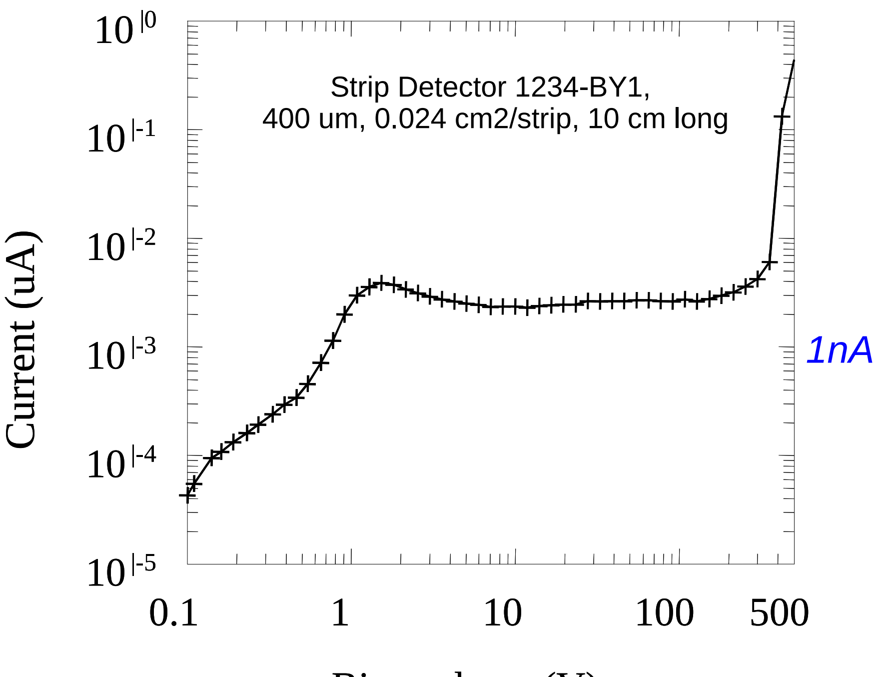


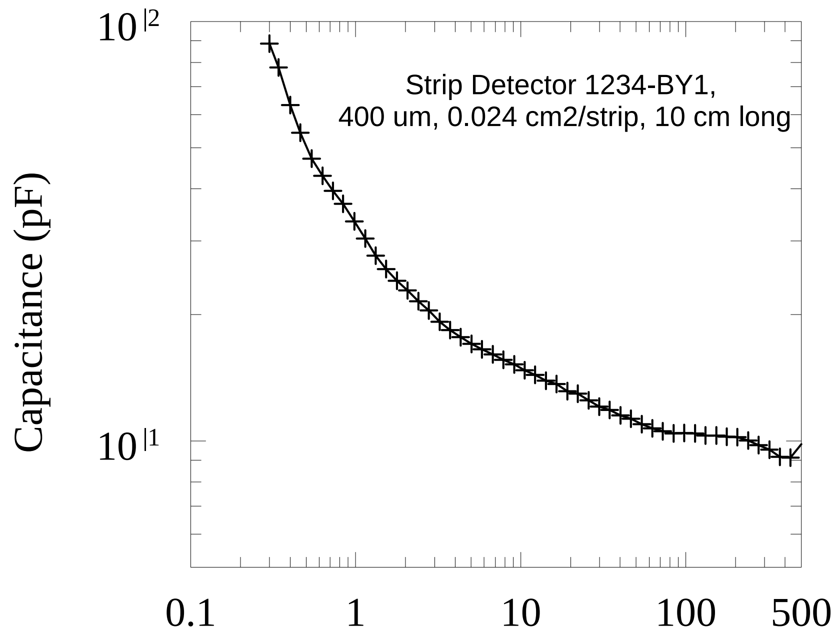


Strip sensor (cont.)

- prototype v1
  - 2 metal (Al) layers
  - thickness: 400μm and 250μm
  - DC coupling
  - full depletion at ~80 V
  - capacitance ~10 pF
  - leakage current ~10 nA

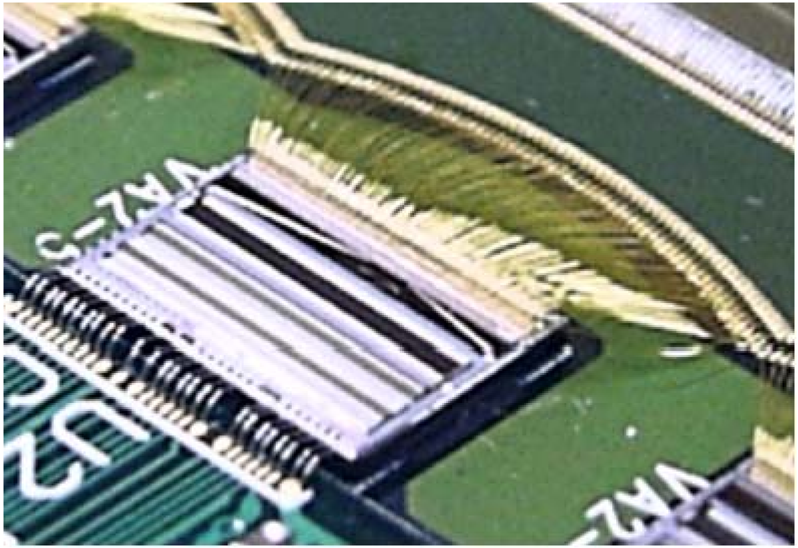


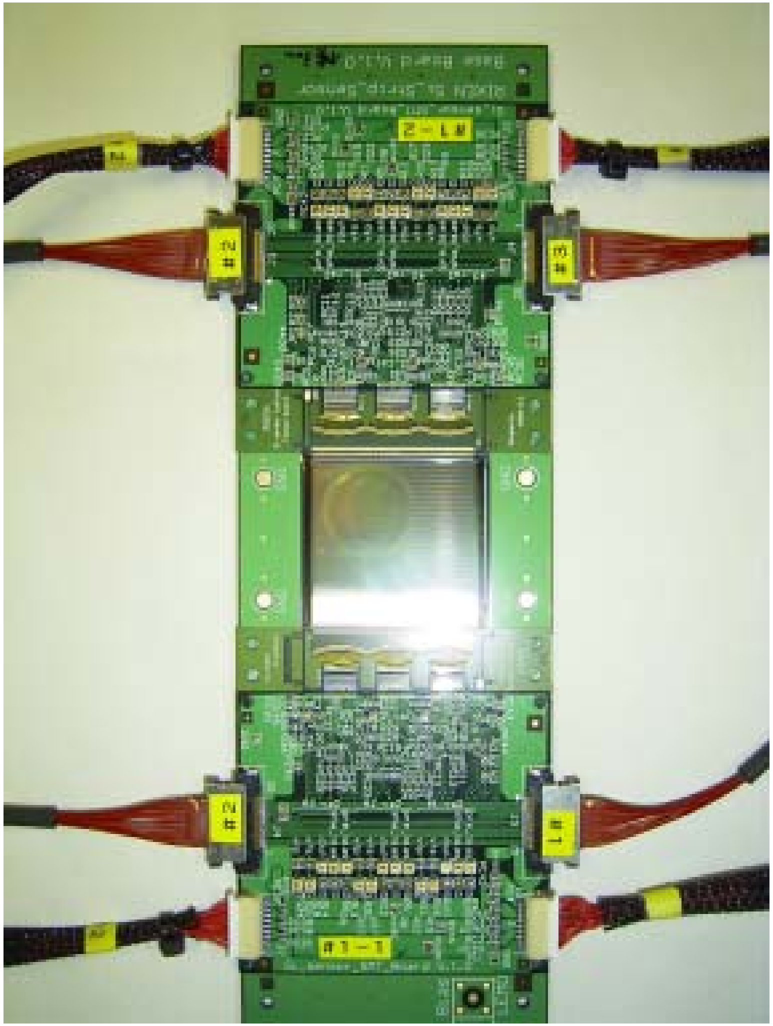




Sensor test board

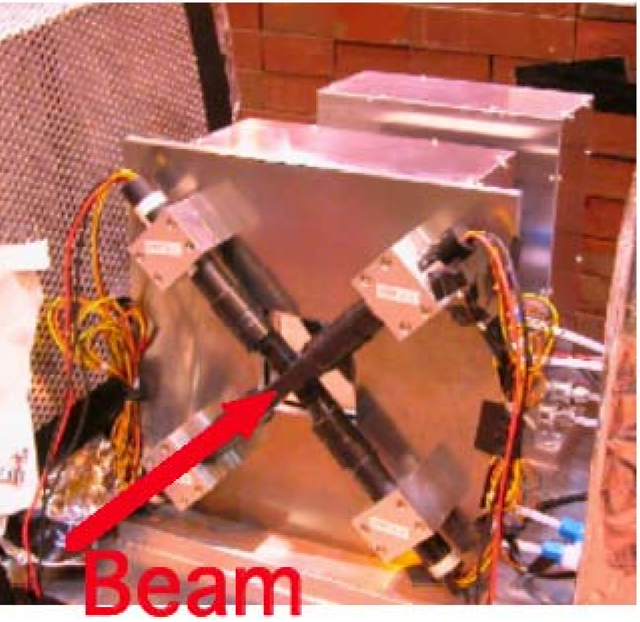
- R&D items
  - charge division
  - noise level
  - position resolution
  - efficiency
- test readout with VA2

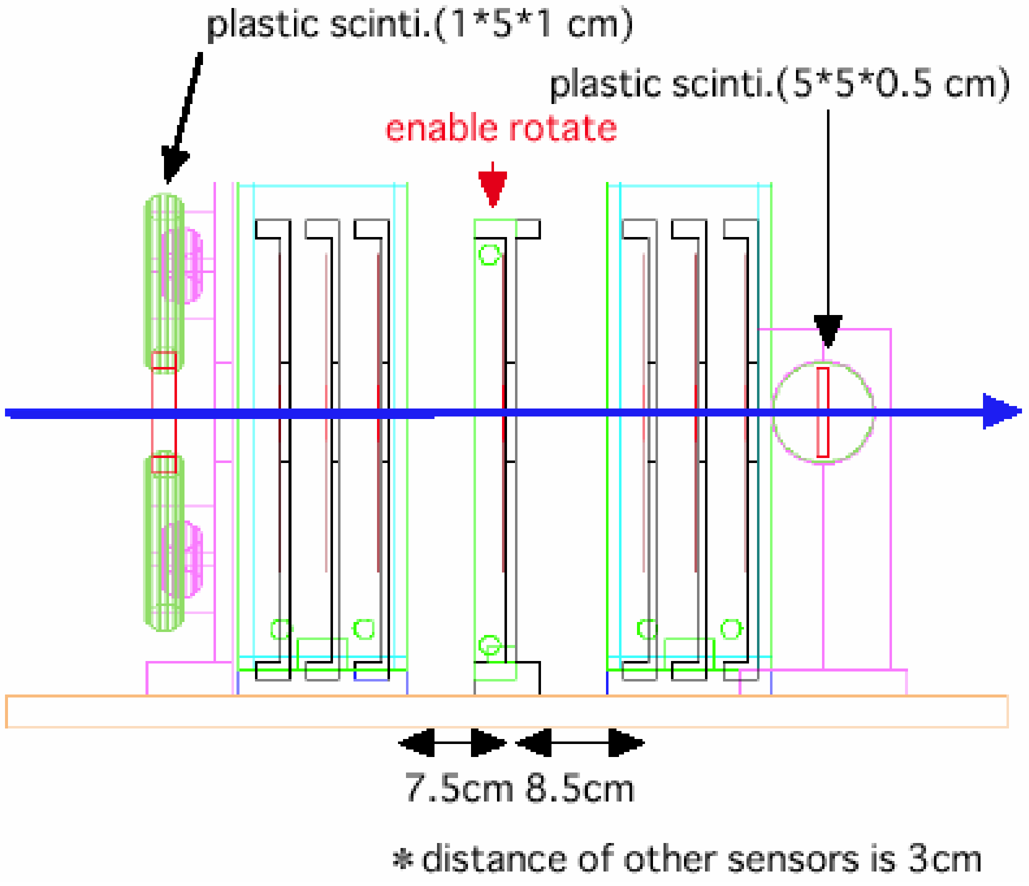




KEK beam test

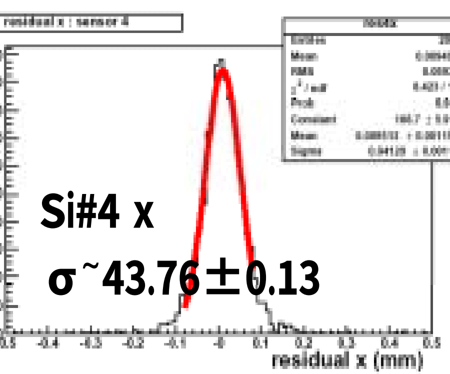
- KEK-PS T1 beam line
  - 0.5-2.0 GeV/*c* charged particles
  - tracking with clusters on 2nd-6th board

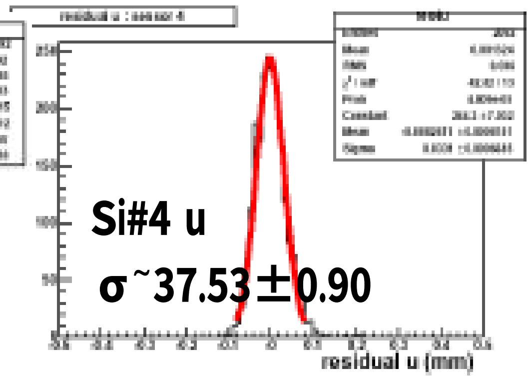




Position resolution & efficiency

- position resolution (after subtracting multiple scattering)
  - 23μm-26μm
  - expected: 80μm/√12=23μm





Si number	Residual x(μm)	Residual x(μm)
2(250um)	52.66±0.21	50.99±0.20
3(400um)	35.73±0.08	43.08±0.13
4(400um)	43.76±0.13	37.53±0.90
5(400um)	34.45±0.08	43.49±0.13
6(250um)	48.66±0.17	45.63±0.15

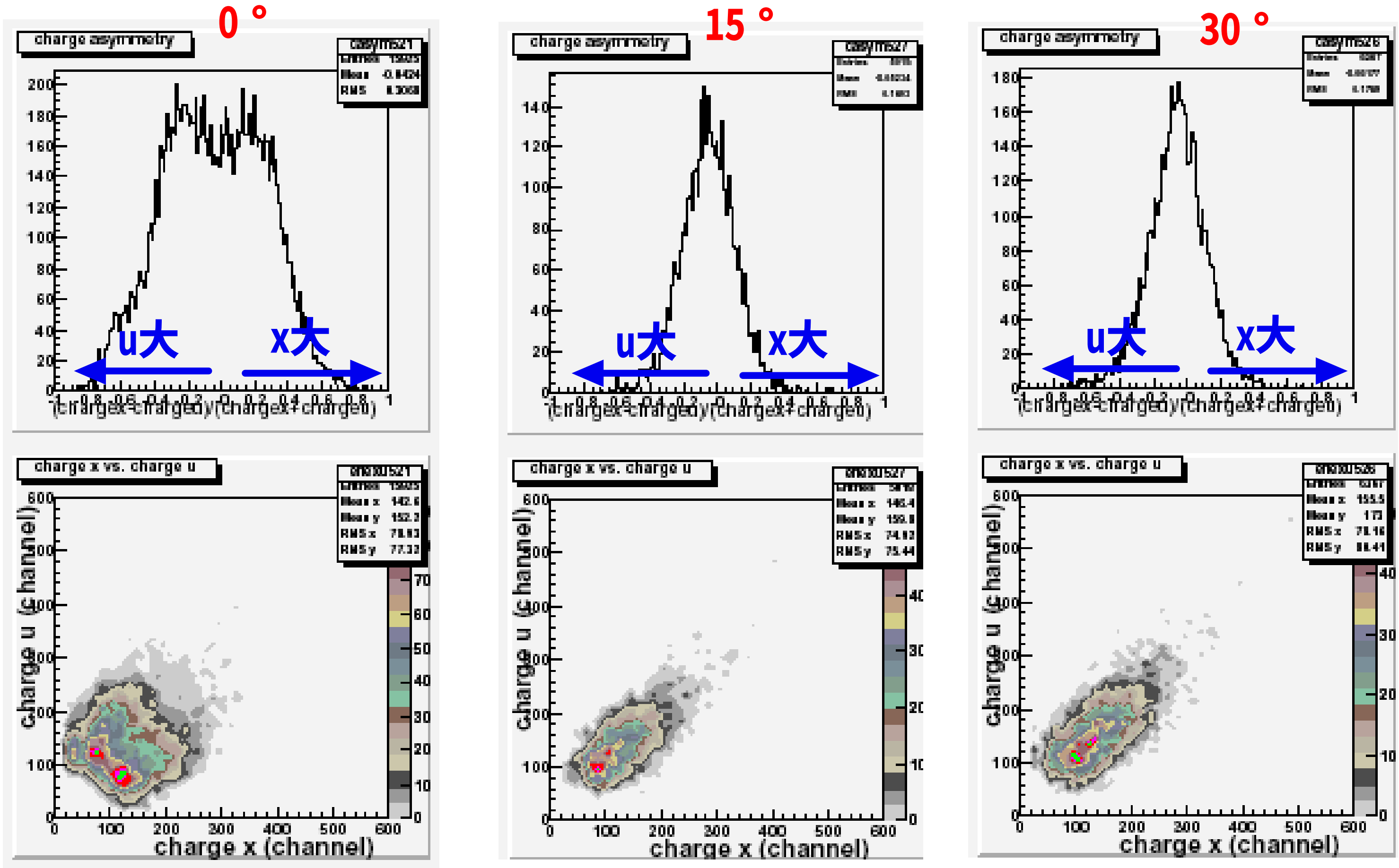
- efficiency

$$4^{th}\text{ board efficiency} = \frac{\#\text{track with clusters on } 2^{nd}\text{-}6^{th}\text{ boards}}{\#\text{track with clusters on } 2^{nd}, 3^{rd}, 5^{th}, 6^{th}\text{ boards}}$$

Si number	efficiency
2(250um)	61.45±1.91
3(400um)	96.41±2.87
4(400um)	98.23±2.88
5(400um)	87.29±2.66
6(250um)	58.33±1.82

OK for 400 μm sensors

Charge division



Not very good at small angle

- spiral pitch not fine enough to accomodate diffusion?

→ making 2nd prototype (pitch 13 μm → 8 μm)

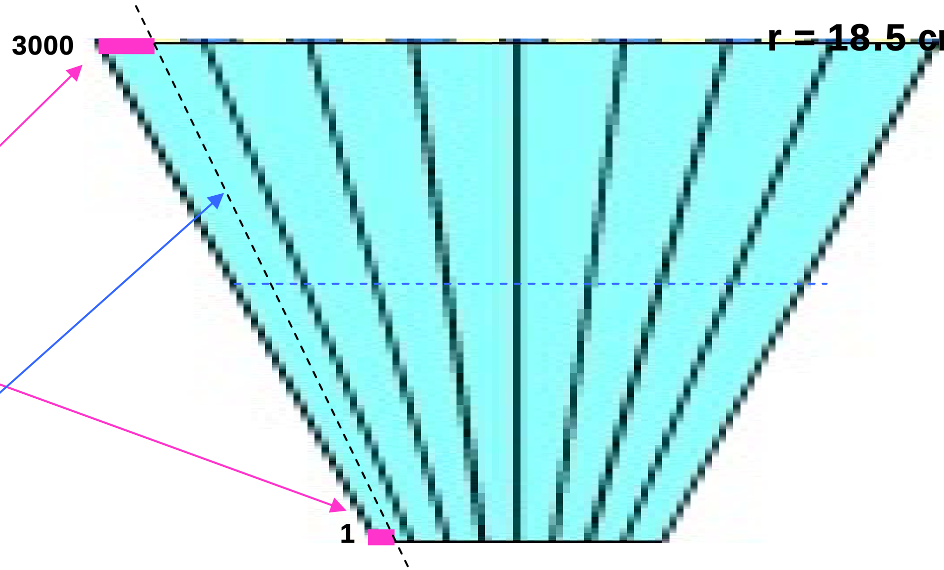
SVX4 readout chip

- 128-channel Si-strip readout chip developed by FNAL/LBNL.
- Pipelined digitization and readout (42-deep pipeline for analog samples).
- 4-event LVL1-accept buffering.
- On-board zero-suppression available.
- Multi-stage pedestal subtraction.
- Designed for AC-coupled device (Z. Li sensors DC-coupled). Two handles:
  - Frequent storage-cap resets.
  - Cool sensors to 0 degrees C to reduce leakage current.
  - Certainly able to do first. May suffice, but may want to cool anyway.
- Integration time (~80 ns) much shorter than sensors have been tested at. Possibly worse S/N.
- FNAL indicated willingness to do wafer-testing.

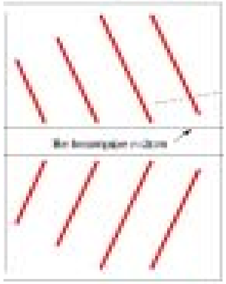
Endcap mini-strips (preliminary)

- 50 μm radial pitch (z vertex reconstruction)
  - 3000 mini-strips
    - 3.5 cm < r < 18.5 cm
  - 128 towers in phi
    - mini-strips from

      2.2 mm to 11.6 mm



  - 2 rows of strips in one double-tower
  - 8 (16) wedges in one lampshade(layer)
  - 8 lampshades (~ 20 degree tilt)



- R&D for readout chip is planned with FNAL group (R. Yarema et al.)

Support & cooling

- Mechanical support
  - preliminary design ongoing at LANL/Hytec
  - single barrel shape with GFRP was chosen

Figure 4.2-1: Various PHENIX Tracker Support Structure Concepts Studied for Structural Stiffness.

- Cooling
  - R&D for cooling pipe embedded print circuit board (~ 100 μm thick) is starting at Soliton R&D company in Japan in collaboration with RIKEN

Plan/schedule

- LOI submitted to DOE in Mar. 2003, proposal will be submitted in this month.
- Barrel
  - R&D: 2003-2004
  - construction: 2005-2006
  - Actual use from 2007.
- Endcap
  - R&D: 2004-2005
  - construction: 2006-2007
  - Actual use from 2008.

Summary

- Silicon Vertex Tracker is an important part of PHENIX upgrade program.
- Physics with SVT include
  - gluon spin structure function by open charm (bottom) in polarized proton collision.
  - various measurement related to charm and bottom quarks in heavy ion collision.
- Barrel: 1 pixel + 3 strip (stripixel) layers
  Endcap: mini-strips
- Plan to start data taking in 2007/2008
  R&D is ongoing.