Heavy Quark Detection with a Forward Silicon Micro-vertex Detector at PHENIX

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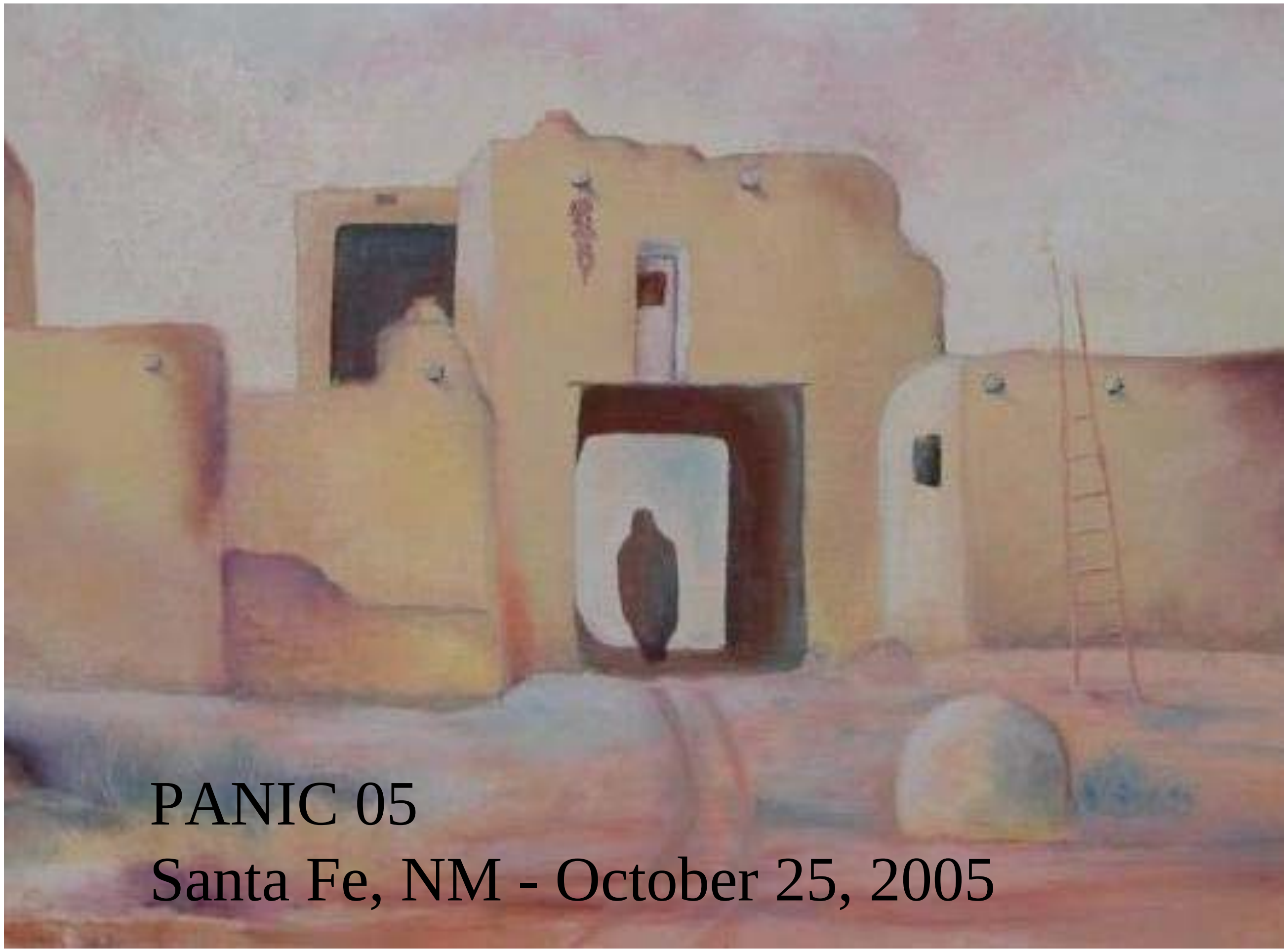
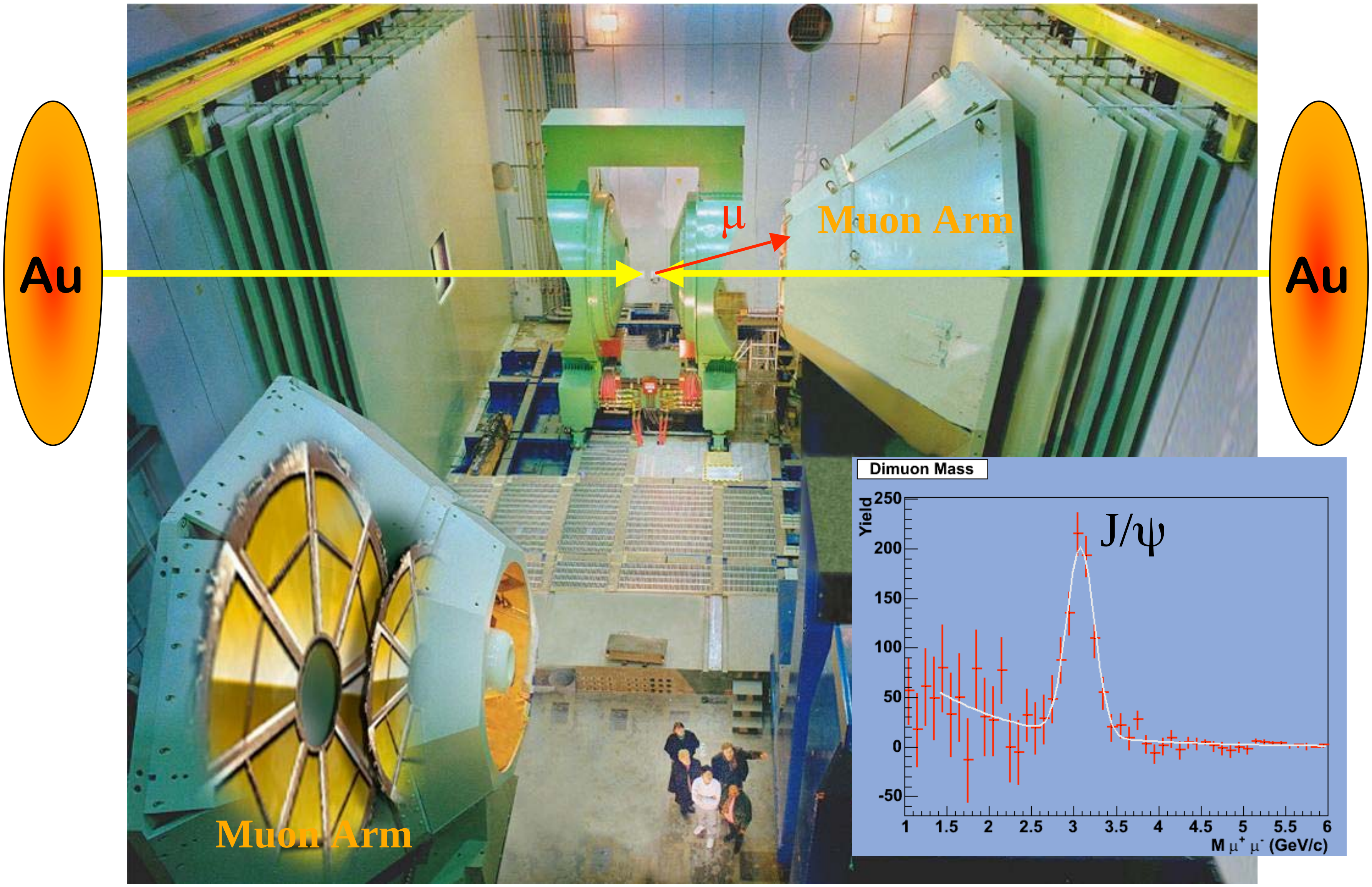


Project Overview

- A new state of matter, the quark-gluon plasma (QGP), is being probed in collisions of heavy ions at RHIC.
- Heavy quarks (charm and beauty) are the cleanest probe of QGP. Next frontier of QGP physics. Want to measure their energy loss and flow in QGP.
- We will construct a forward silicon micro-vertex detector → unique heavy quark experimental capability at RHIC ($|y| > 0$).
- Close collaboration between theory, simulation and experiment.
- Quantitative determination of QGP properties.

The PHENIX Muon Arms

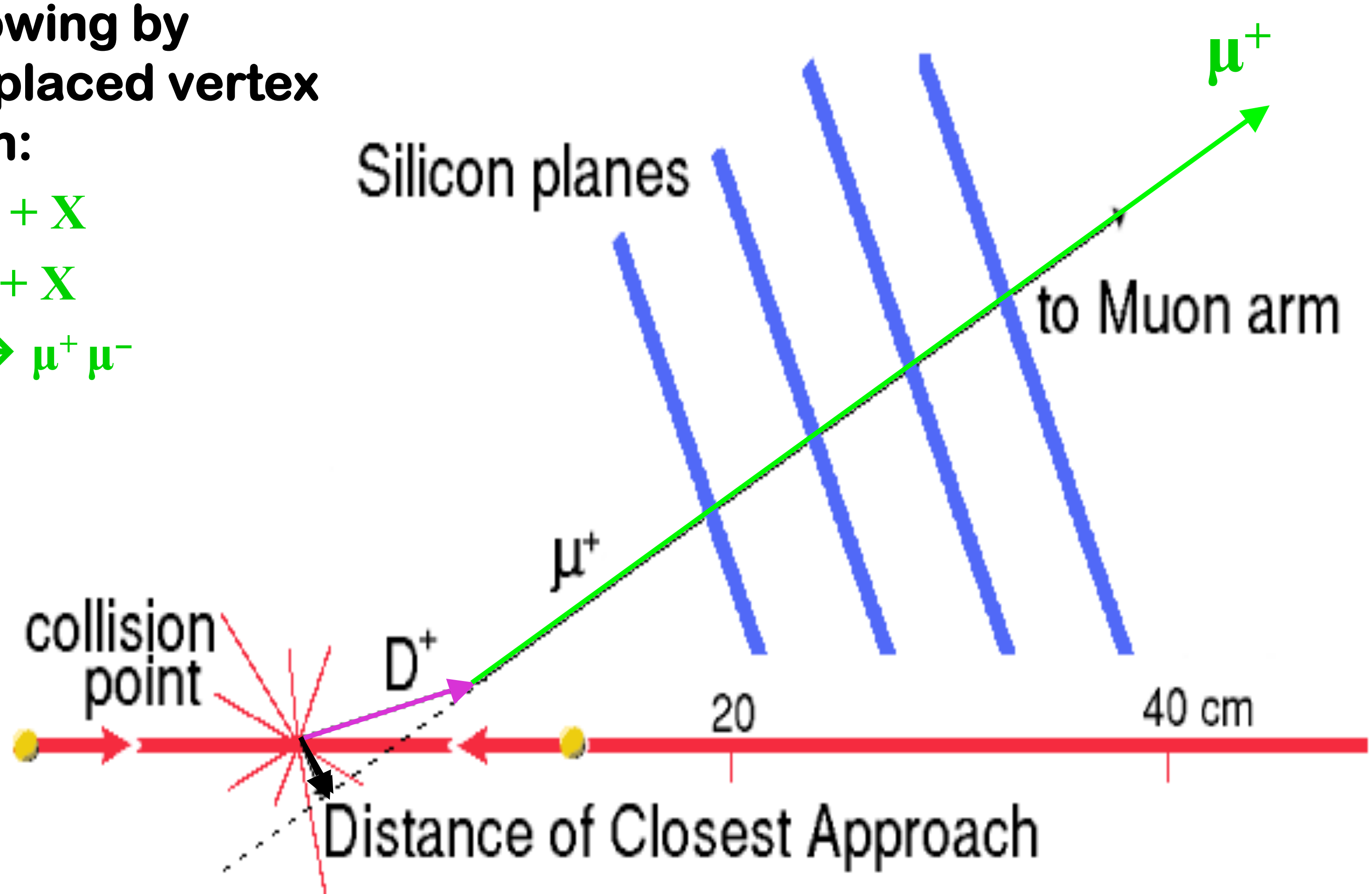


Muon Arms were designed for heavy quark measurements!

Forward Micro-Vertex Detector

Can detect following by observing a displaced vertex (DCA) of a muon:

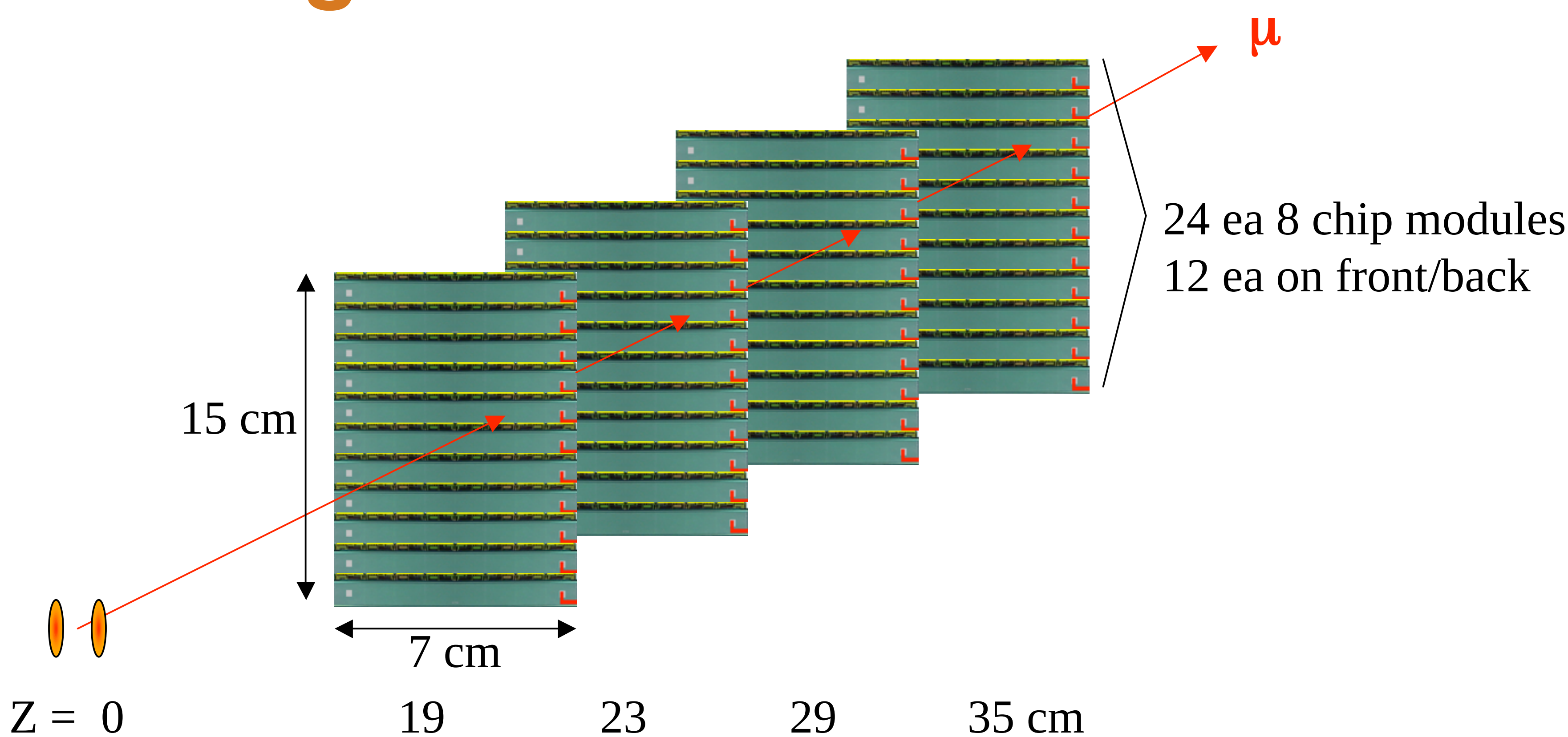
- D (charm) → μ + X
- B (beauty) → μ + X
- B → J/ψ + X → $\mu^+ \mu^-$



Use finite DCA cut to eliminate backgrounds from π or K → μ + X

Four Si planes constructed of pixels 50 um high x 400 um long

Design of micro-Vertex Detector

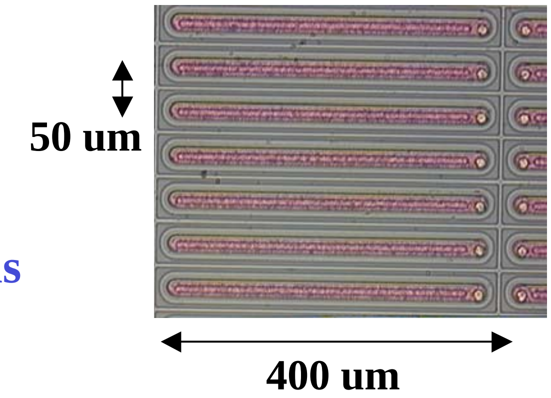


- 2 Sectors of 4 Tracking stations composed of Si pixels, 50 by 400 um
- Cover ~ 1/8 of one muon arm (one octant) with 200 detector modules
- Electronics recently developed by FNAL for BTeV, ~4M pixels.
  Low power, high speed and high resolution pixel detector.
- Can detect large numbers of D and some B decays per year at RHIC.

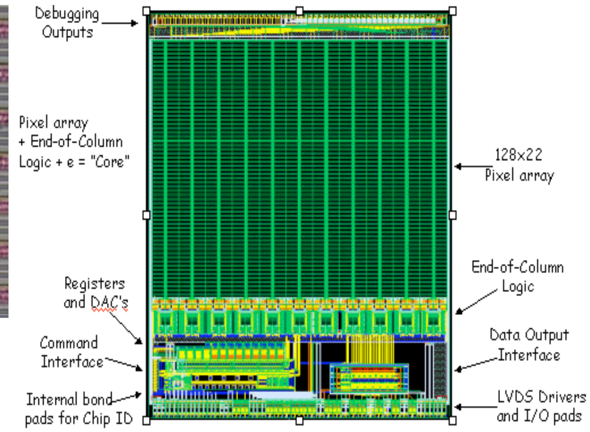
BTeV Pixel Detector Module

- **Pixel Sensor bump-bonded to Readout chip**
- **Fine segmentation**
  - **50 µm x 400 µm**
  - **Large number of channels**
  - **Electronics in the active tracking volume**
  - **High power density**
    → cooling system required
- **Basic building block – Multichip Module (MCM)**
  - **8 readout chips / module**
  - **HDI and flex cables**
- **Assemble modules on both sides of substrate to form pixel plane; providing a high resolution radius measurement plus a good phi measurement.**

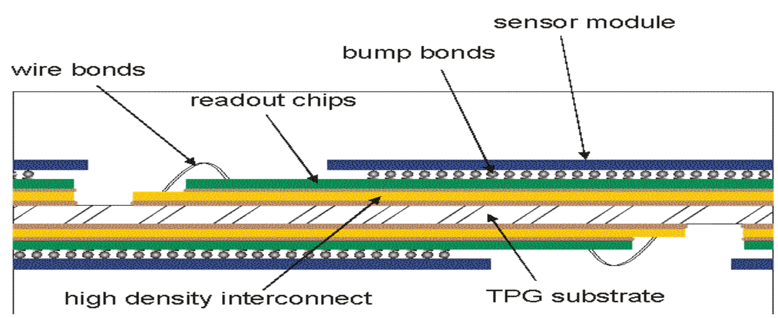
Si pixel sensors



FPIX 2 Pixel Readout chip

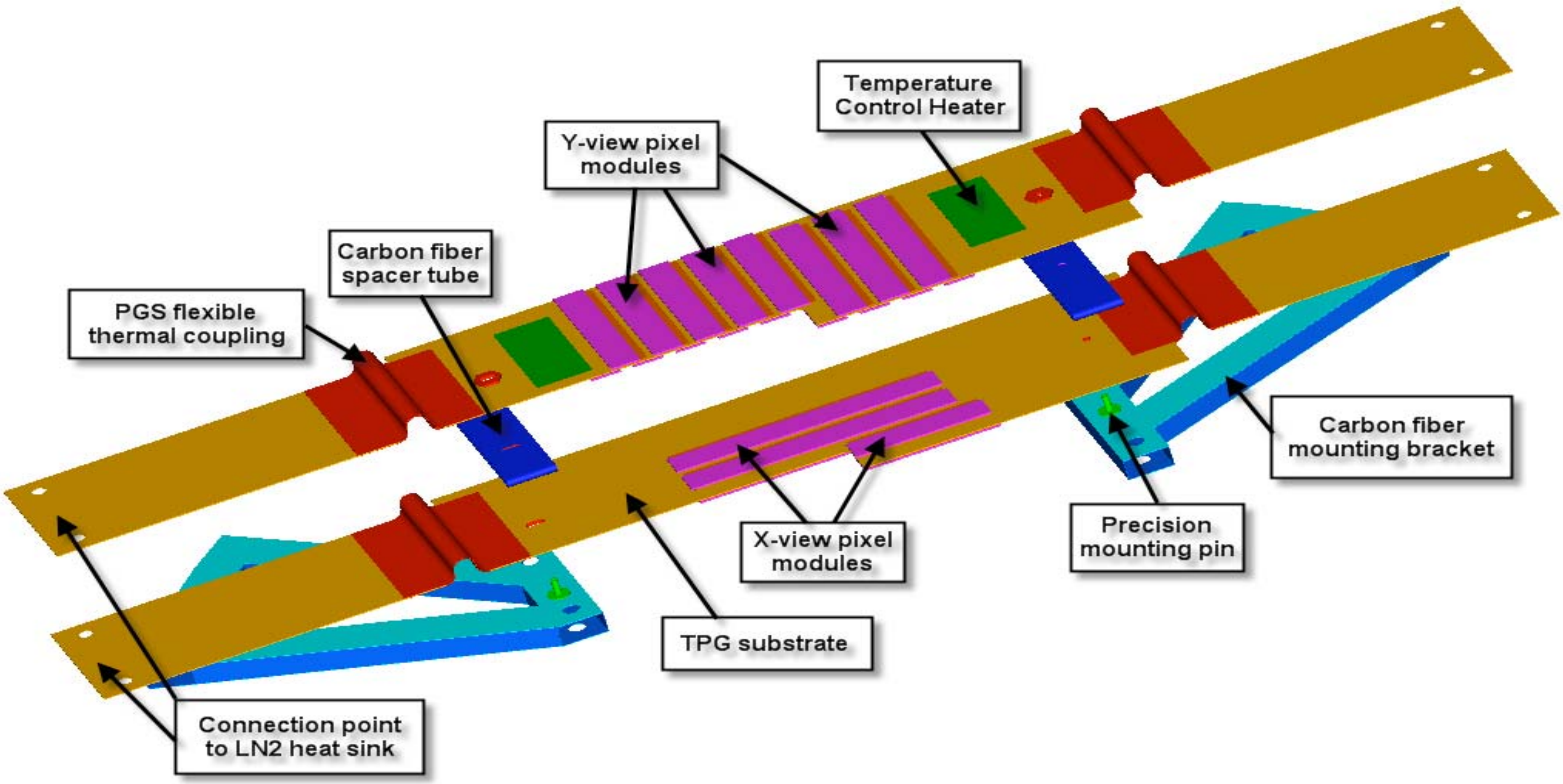


Multichip module



Module Assembly

BTeV Ladder Design



We will build ladders containing only Y-view modules.
Zero degree C liquid cooling instead of LN_2.

Readout Electronics Chain

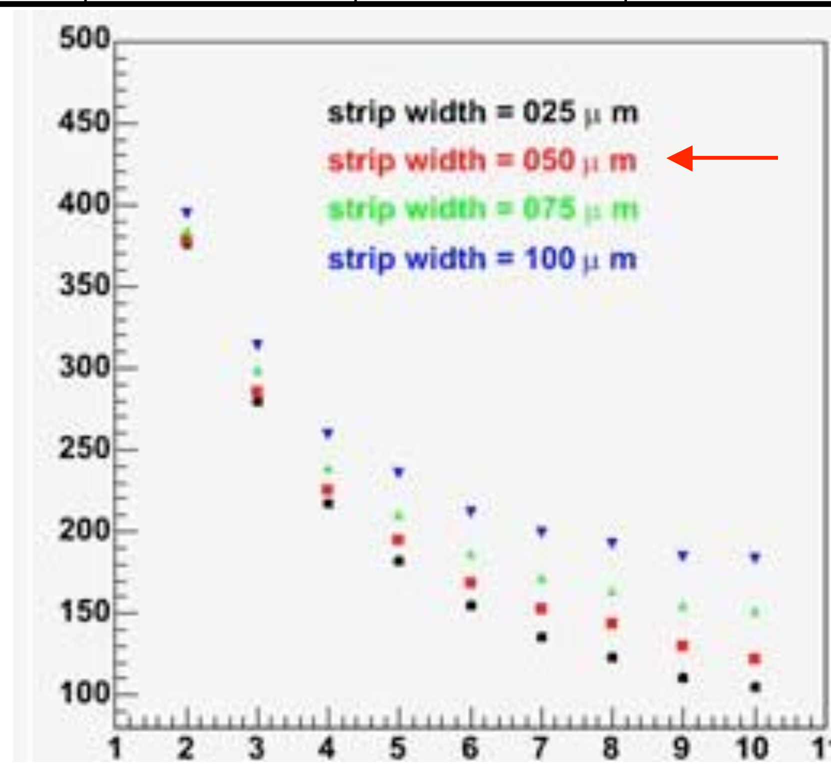
- Silicon Detector
  - Array of 50 x 400 micron pixels
  - Bump bonded to 8 front end chips
- Front End Chip
  - FPIX2 with data push, LVDS output, 840 Mb/sec
  - Wire bonded to high density interconnect, 10m cable with digital output and control lines
- Receiver / Controller Board
  - Xilinx FPGA emulates PHENIX readout standard
  - Interface to PHENIX fast and slow controls
  - Possible Level I trigger
- Optical Fiber Interface and Cable to Counting House
- PHENIX Data Collection Module

Heavy Quark Yields*, for 1/8 of a Muon Arm

Run	Ions	Luminos. on tape	D → μ triggered counts	B → μ triggered counts	B→J/ψ→ μ with 1 μ in SiVTX
2007	p+p	67 pb^{-1}	$28*10^6$	$24*10^3$	240
2008	Au+Au	760 ub^{-1}	$8*10^6$	$6*10^3$	160

- Rates before application of a vertex cut.

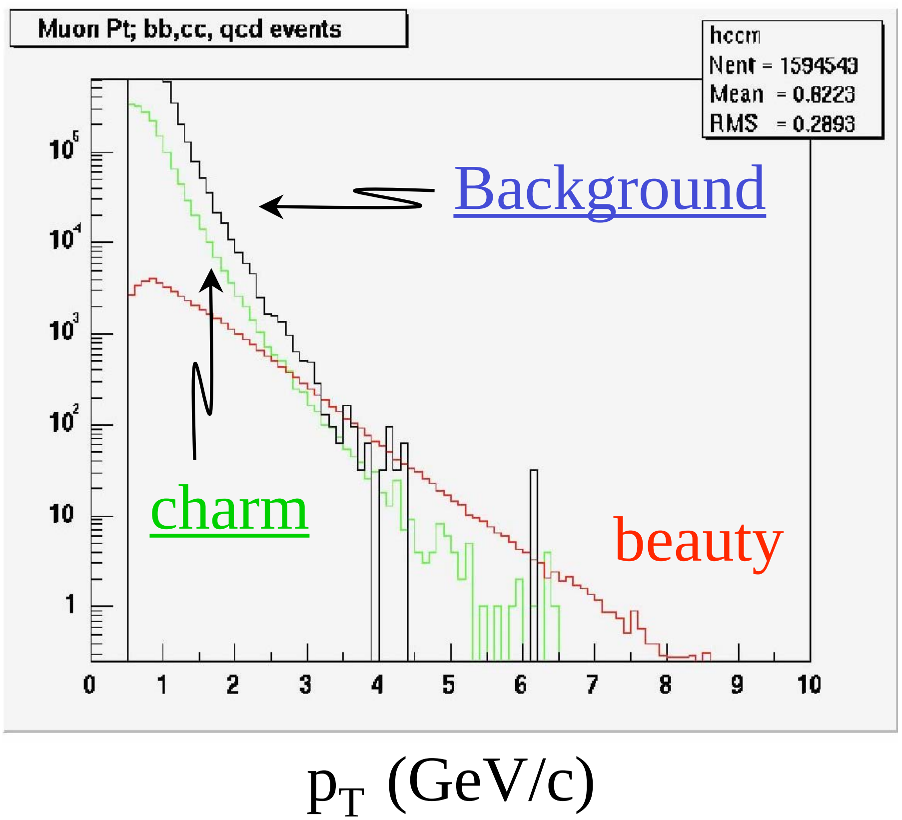
Z-Vertex Resolution, μm

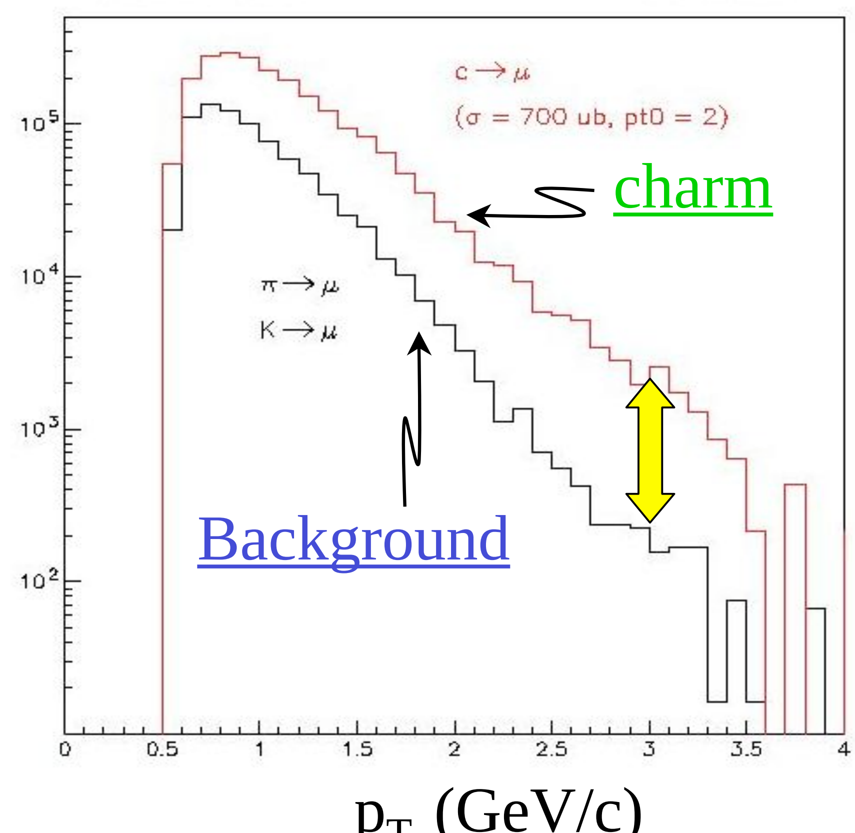


Muon Momentum, GeV

Dramatic Signal / Background Improvement for Heavy Quarks

Before vertex cuts Muon Events **After vertex cuts**





Simulated Signal to Noise for D→ μ+X without SVD and with SVD, 10 X improvement is signal / background → accurate yield, slope of charm

Hardware Cost and Schedule

Silicon Sensors	Front End Chips	Wire Bonding Bumping	Flex Cables, Hybrids	Fiber Optics	Receiver	Power Supplies + Cables	Support Structure	Total + 30%
$130 K	$90 K	$75 K	$152 K	$25 K	$40 K	$30K	$60 K	$785 K

Cost estimates for SVD Hardware covering ~1/8 of a PHENIX Muon Arm
Labor not included, expect similar labor and hardware costs.

- **FY06 : Complete readout chip production with FNAL**
  Procure Si detectors and bump-bond to readout chips
  Design and procure readout bus (HDI)
  Design support structure and cooling
  Design FPGA board
- **FY07 : Assemble and test detector modules, mount on substrate**
  Construct FPGA board, cabling, power and cooling
  Install 4 layer vertex detector in PHENIX
- **FY08 : Record p+p or Au+Au data for charm decays**

Theory Program

QCD Theory of Plasma (E. Mottola and I. Vitev) :

- **Calculate transport coefficients - viscosity, conductivity + diffusion**
- **Study approach to thermalization and equilibration**
- **Determine collective degrees of freedom and equation of state**
- **Calculate energy loss of heavy quarks due to gluon radiation, suppression of high p_T charm and beauty in QGP**

Lattice QCD (R. Gupta) :

- **Study Debye screening effects leading to dissociation of heavy quark bound states versus temperature (e.g. J/ψ yield versus T)**
- **Calculate equation of state versus temperature for QGP**
- **Lattice is only non-perturbative way to address QCD equilibrium properties**

Participants + Support

LANL, P. McGaughey, E. Mottola, et al.
Fermilab, D. Christian, et al.
Iowa State Univ., J. Lajoie, C. Ogolvie, et al.
NMSU, S. Pate and V. Papavasiliou, et al.
UNM, D. Fields, et al.
BNL, PHENIX upgrade team
Hytec, Inc. of Los Alamos
Columbia Univ., B. Cole, et al. ?
We're looking for additional collaborators!

LANL Budget : ~1.25 M$/year for 3 years
LANL project approved during summer '05.
Funding began in FY06.

Summary

Definitive Physics of New State of Matter:

- Charm and beauty production cross sections
- Energy loss and flow of charm and beauty in QGP
- Measurement of QGP properties – energy density, temperature, transport properties, viscosity, conductivity

State-of-the-Art Silicon Vertex Detector:

- Si end cap covering 1/8 muon arm (4 pixel layers)
- Leverage DOE funds for full detector ($5M)
  DOE Proposal to be submitted in CY 2006.

Unique Opportunity for Convergence of:

- Theory, simulation and experiment of quark-gluon plasma formation and decay in the laboratory

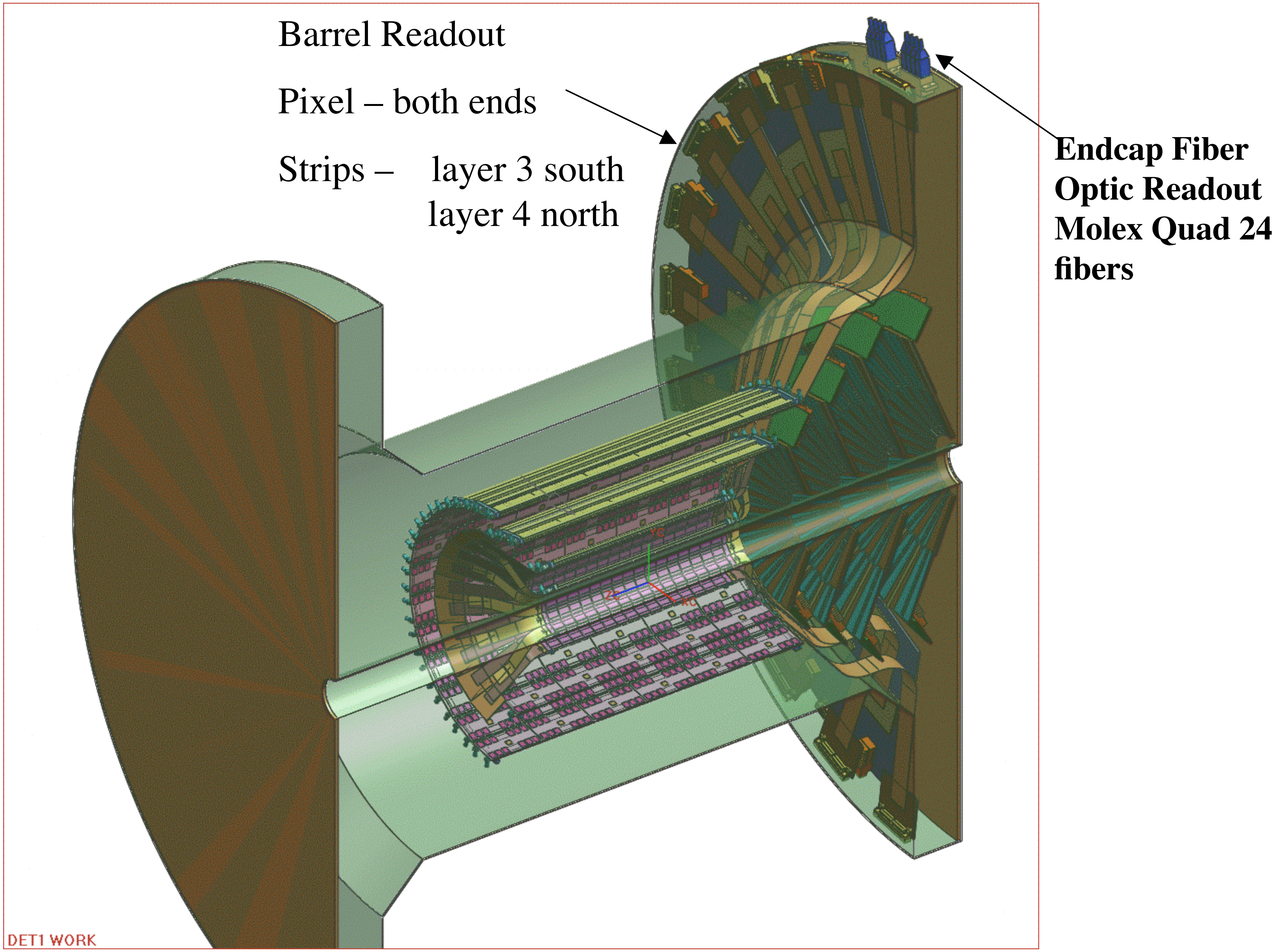
Backup slides

Why Heavy Quarks ?

- Have mainly qualitative evidence for QGP formation - can make quantitative measurements with heavy quarks
- Heavy quarks (charm and beauty) - produced early in the collision. Live long enough to sample the plasma
- Intrinsic large mass scale allows precise calculations
- Mass dependence of diffusion of heavy quarks determines plasma properties, e.g. viscosity and conductivity
- Yields of charm and beauty pairs compared to first principle lattice simulations determine the energy density and temperature
- Comparison between light and heavy quark suppression distinguishes between theoretical models of energy loss in the QGP

Heavy quarks can provide an <u>order of magnitude</u> better determination of the properties of the plasma!

Si Vertex Detector Mechanical Layout



FNAL Readout Chip Comparison

Chip All 50 μm spacing	Noise Threshold σ	Ministrip	Readout type speed	Trigger possible	Power per chan	Geometry r-phi
SVX4 128 ch	S/N -12/1	yes	Pipeline 53 MHz	no	2 mW	yes
FSSR 128 ch	250 e 440 e	yes	Data push 840 Mb	yes	3 mW	yes
FPIX 2816 ch	220 e 125 e	no	Data Push 840 Mb	yes	90 μW	no

FSSR and FPIX chip are good candidates for LDRD project

Signal = 24000 e for 300 μm Si Sensor.