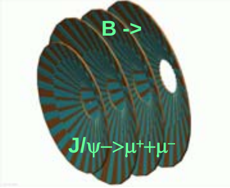


Silicon Tracker Upgrade for the Muon Arms

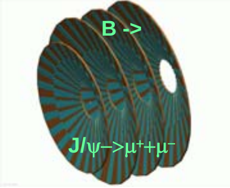
Goal is to provide for key measurements with the PHENIX detector:

Detailed study of Heavy Quark production

- **Beauty and Charm measurement in p+p, p-A and A-A collisions**
- **Energy loss of charm/beauty in hot matter**
- **ΔG (gluon polarization) measurement by heavy quark production over a wide Bjorken-x range.**
- **Gluon shadowing over a wide x range**

Measurements complement and enhance the present PHENIX physics program

- **Fully exploit existing rare event capabilities of PHENIX**
- **"Complete" the PHENIX central and muon spectrometers**



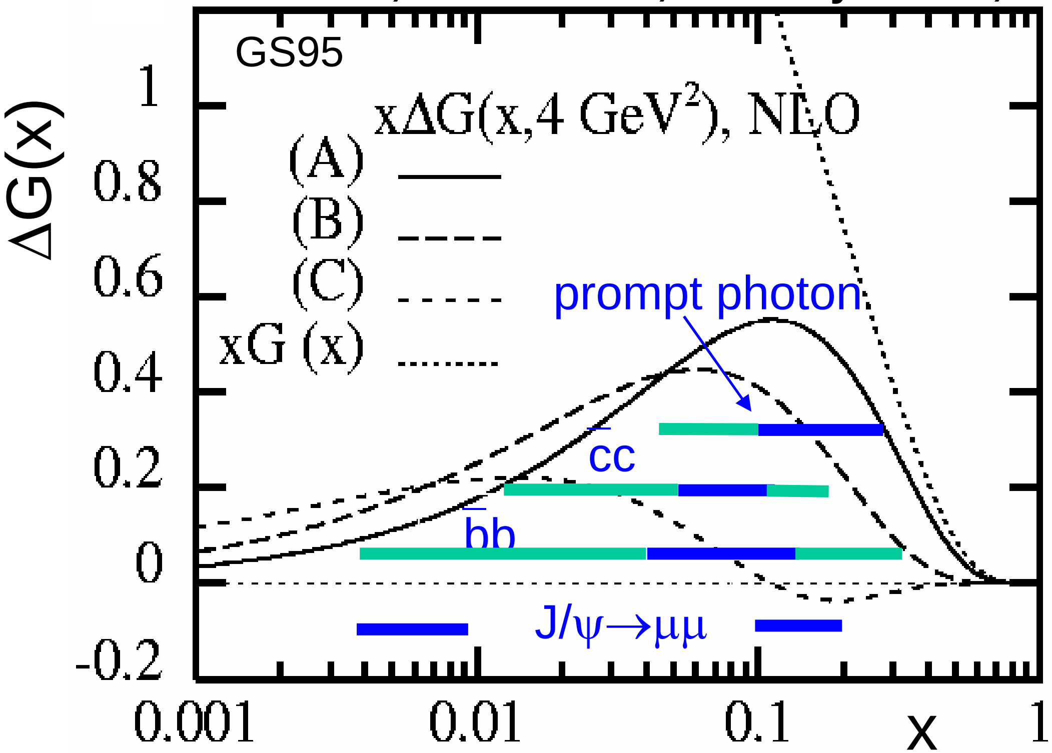
Quarkonium Measurements at RHIC

- pp
  - Certainly interesting in itself
    - no nuclear effects (production pure - pQCD)
    - close $\sqrt{s}$ gap (fixed target $\leftrightarrow$ CDF,D0)
  - needed as baseline for pA, AA
  - Spin: ΔG via J/Ψ
- pA
  - needed to study nuclear effects
  - Rate of rare processes increased by A^{α} compared to pp
- AA
  - the major goal: suppression as signature of QGP
  - Thermometer for early state:

    $T_{diss}(\Psi') < T_{diss}(\Upsilon(3S)) < T_{diss}(J/\Psi) \approx T_{diss}(\Upsilon(2S)) < T_{diss}(\Upsilon(1S))$

ΔG Before vs. with Silicon Endcap

L. Frankfurt, M. Strikman, Eur. Phys. J A5, 293



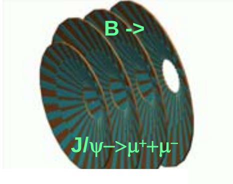
Before vertex upgrade

WITH vertex upgrade

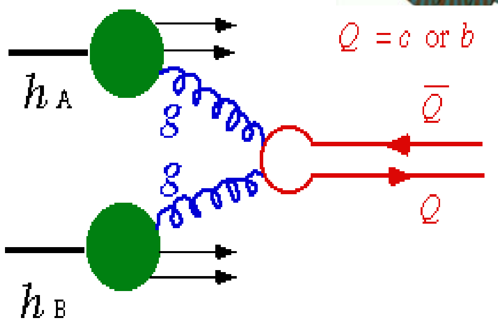
Nosecone Calorimeter

'Why gluon spin' see Matthias's talk

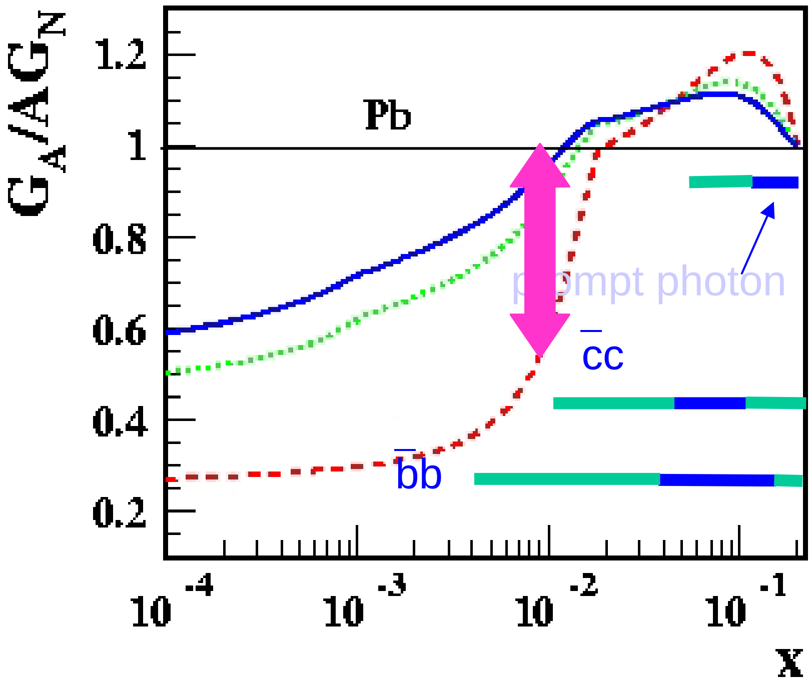
pA Charm, Beauty Production



- Heavy-flavor production via $gg \longrightarrow q + \bar{q}$
- Extracting gluon structure function nuclei, shadowing
  - Vertex detector provides broader range in x
    - into predicted shadowing region



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



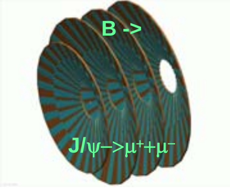
Q = 2 GeV

Q = 5 GeV

Q = 10 GeV

Before Vertex detector

WITH Vertex detector



AA at RHIC

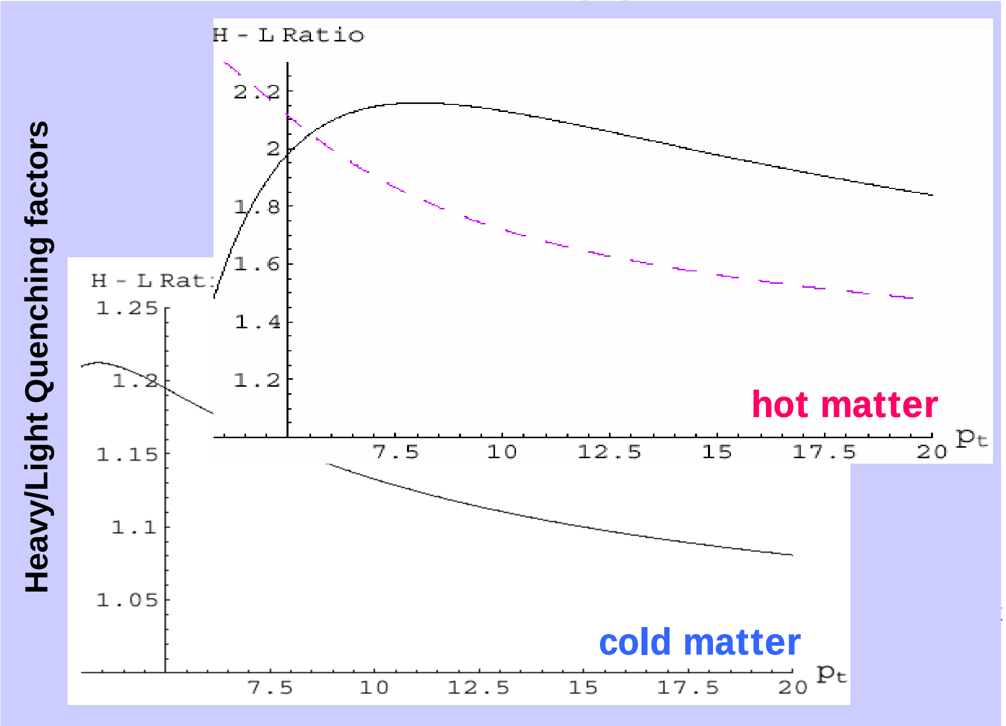
- For a full understanding of charmonium production/suppression:
  - understand nuclear effects
    - absorption, shadowing
    - from pA compared to pp
    - important: x_F, x_1, x_2 dependence
  - suppression vs. recombination
    - p_T, centrality dependence
  - contribution from feed-down (χ states)
    - measure at a minimum in pA
  - understand *co-mover* absorption
    - Υ less affected
    - centrality, reaction plane, and p_T dependence
  - need to understand charm production
  - *ultimate* measurements:

    v_2 - suppression vs. reaction plane

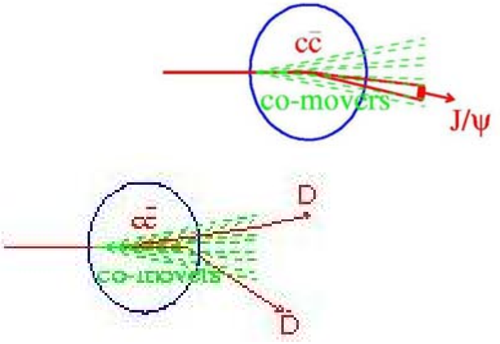
AA Collisions: Charm, Beauty Production

Kharzeev, hep-ph/0106202

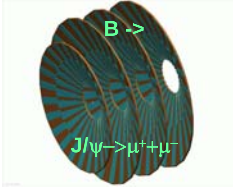
- Possible charm enhancement in earliest stage of reaction
- High-pt heavy-quarks may experience a smaller energy energy loss
  - Kharzeev et al. predict reduced gluon Bremsstrahlung
  - Magdalena's talk …



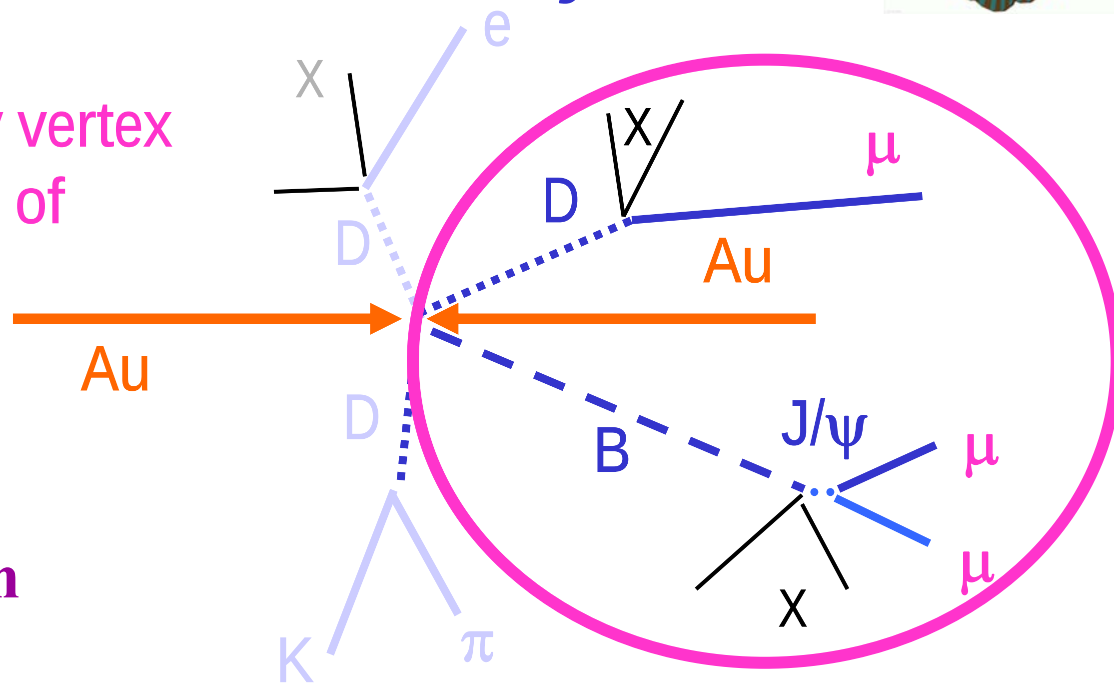
- Charm is critical baseline for J/ψ suppression
  - open vs. hidden charm
- Charm provides key info. for di-lepton continuum



Direct Observation of Open Charm and Beauty



Detection of displaced decay vertex will allow clean identification of charm and bottom decays



Central arm & barrel VTX

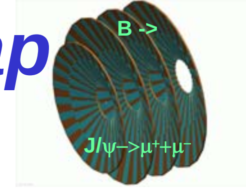
Muon Arms & Endcap VTX

Detection options:

- **Beauty and charm through displaced e and/or μ**
- **Beauty via displaced J/ψ**
- **Charm through D → π K**

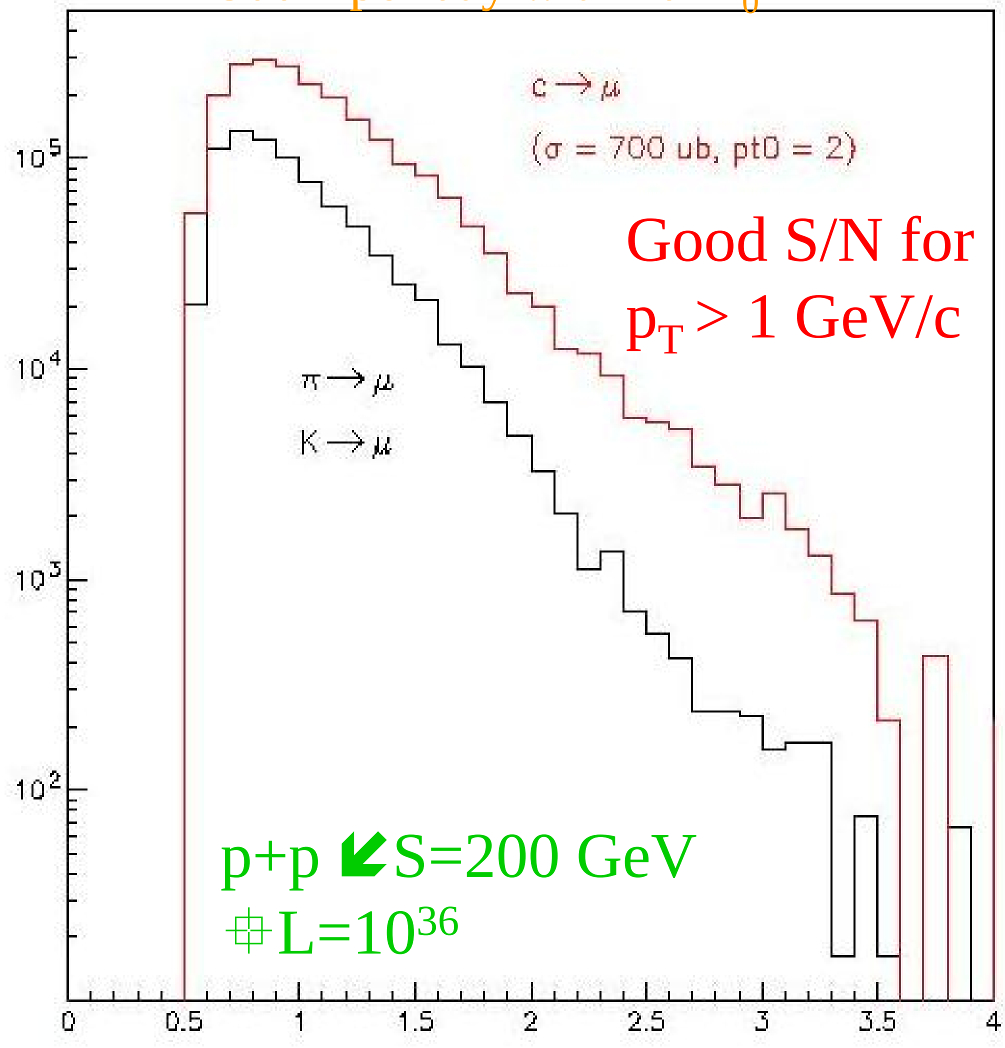
Need secondary vertex resolution < 50 μm (barrel), < ~150 μm (barrel)

Simulated S/N for D-> muon with Endcap



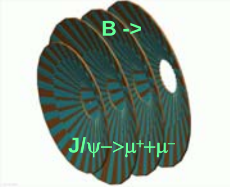
300K per day with 10*L_0

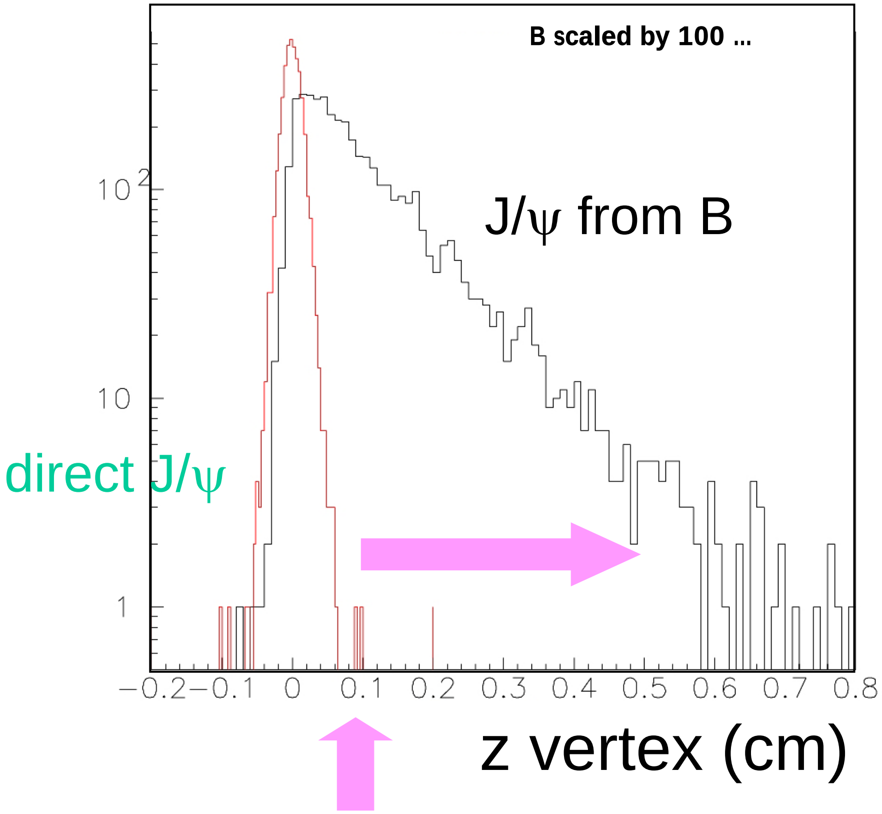
Events

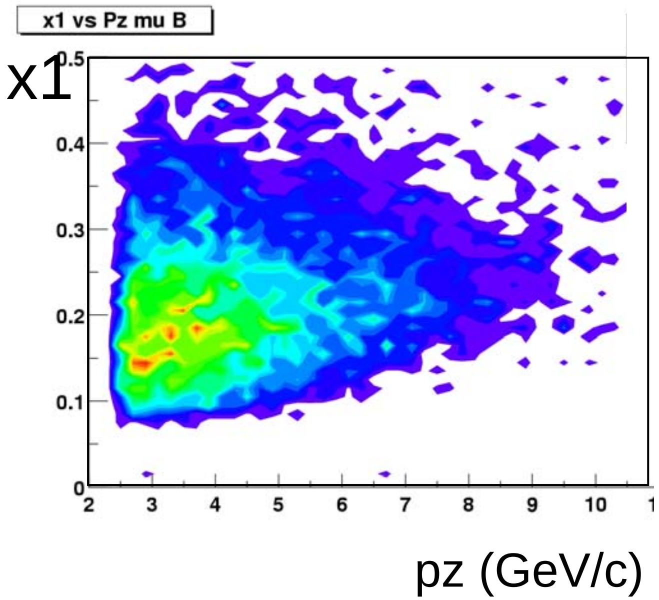


p_T GeV/c

Example, $B \rightarrow J/\psi \rightarrow \mu\mu$



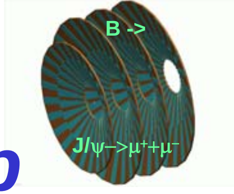




$B \rightarrow J/\psi$, utilizing large acceptance muon arms

Silicon Endcaps crucial !

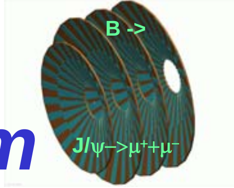
Open Charm and Beauty (muon arms) in pp



Era	Trigger	Lum avail	$D\rightarrow\mu X$ samp.	$D\rightarrow\mu X$ minb.	$B\rightarrow\mu X$ samp.	$B\rightarrow\mu X$ minb.	$B\rightarrow J/y\rightarrow\mu\mu$ samp.	$B\rightarrow J/y\rightarrow\mu\mu$ minb.
RHIC I	BBC	47.3 pb^{-1}	**$2.5\ 10^8$**	**$2.2\ 10^6$**	$5.5\ 10^5$	$5.0\ 10^3$	**1350**	**12**
	BBC	21.2 pb^{-1}	**$1.0\ 10^8$**	**$2.2\ 10^6$**	$2.5\ 10^5$	$5.0\ 10^3$	**600**	**12**
10cm	mVTX	21.2 pb^{-1}	**$1.4\ 10^8$**	**$1.4\ 10^6$**	$3.3\ 10^5$	$3.3\ 10^3$	**800**	**8**
RHIC II	BBC	946 pb^{-1}	**$4.5\ 10^9$**	**$2.7\ 10^6$**	$1.1\ 10^7$	$6.6\ 10^3$	**27000**	**16**
	BBC	424 pb^{-1}	**$2.0\ 10^9$**	**$2.7\ 10^6$**	$5.0\ 10^6$	$6.6\ 10^3$	**12100**	**16**
10cm	mVTX	424 pb^{-1}	**$2.7\ 10^9$**	**$1.9\ 10^6$**	$6.6\ 10^7$	$4.6\ 10^3$	**16100**	**11**

Assumes that BBC trigger efficiency is 0.75 for D, B production, while mVTX trigger efficiency is 1.0.

For **$B\rightarrow J/y\rightarrow\mu\mu$** a 1 mm vertex cut retains 39% of decays because of the Lorentz boost.



Other Benefits to the PHENIX muon program

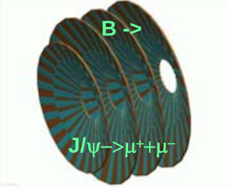
J/ψ, ψ' - VTX will improve mass resolution and background rejection.

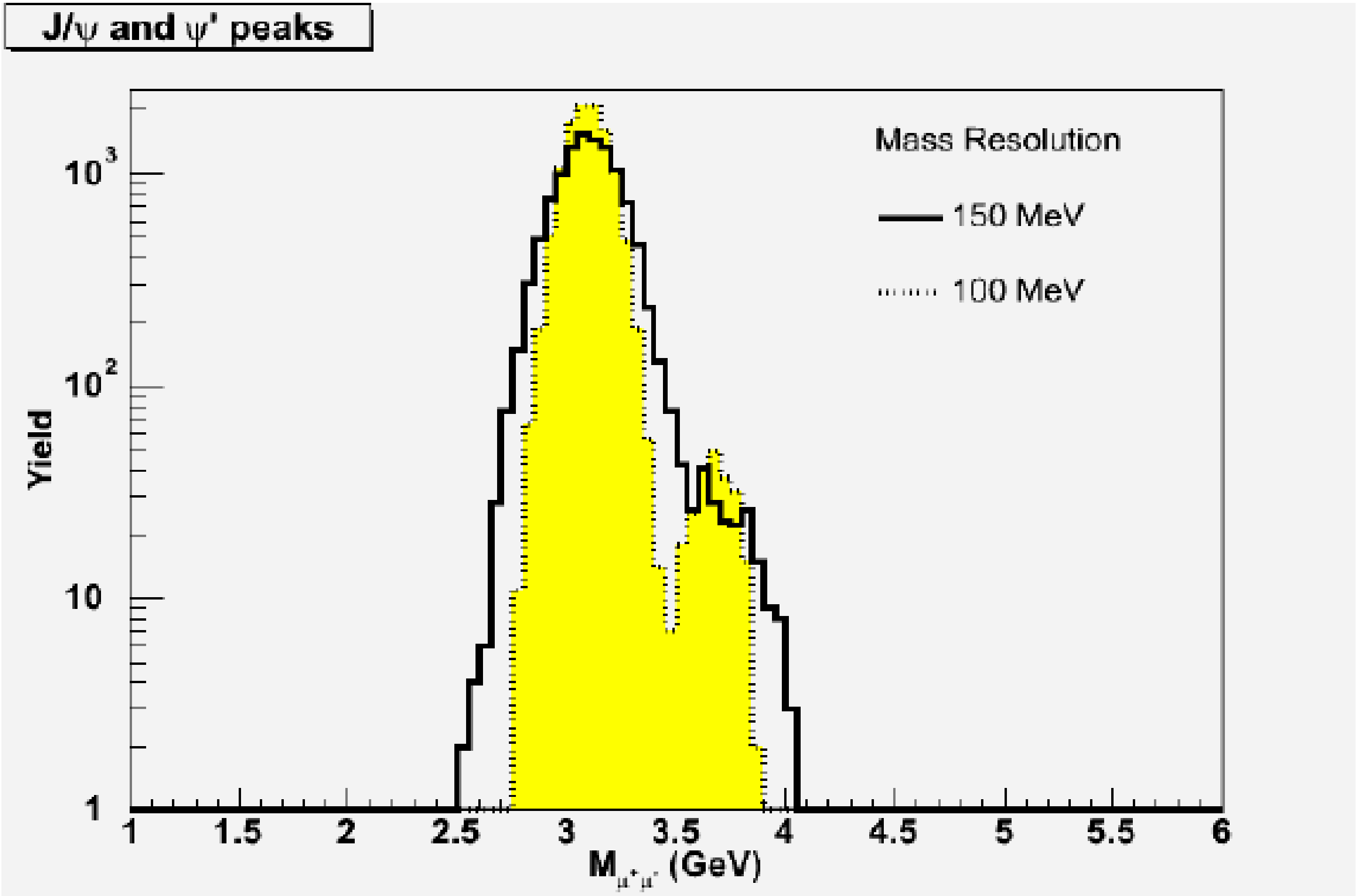
Ψ, Ψ', Ψ'' – VTX can improve detection of these at rapidities near zero.

$\mu^+ \mu^-$ Continuum - S/N can be greatly improved by VTX. Charm, beauty and Drell-Yan pairs can be separated.

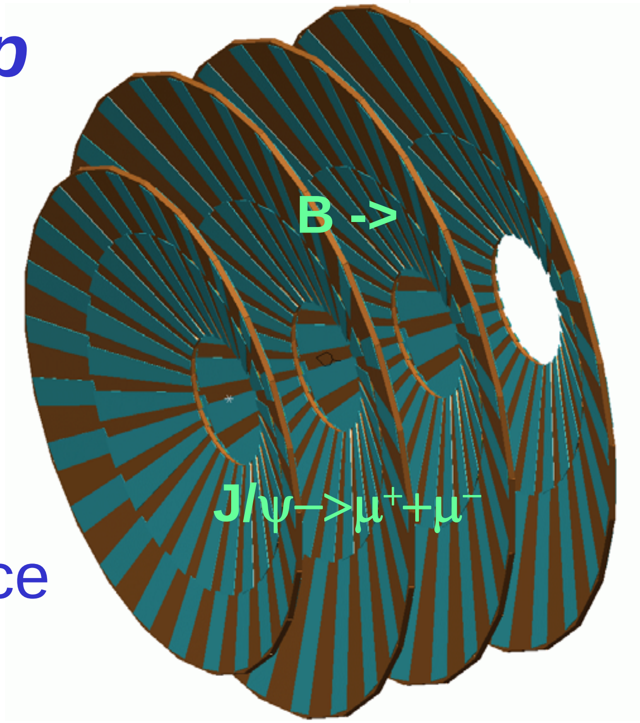
$e\ \mu$ pairs– VTX upgrade would improve S/N of these charm decays.

Improved Mass Resolution with VTX !!!!



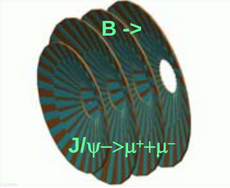


PHENIX Silicon Endcap

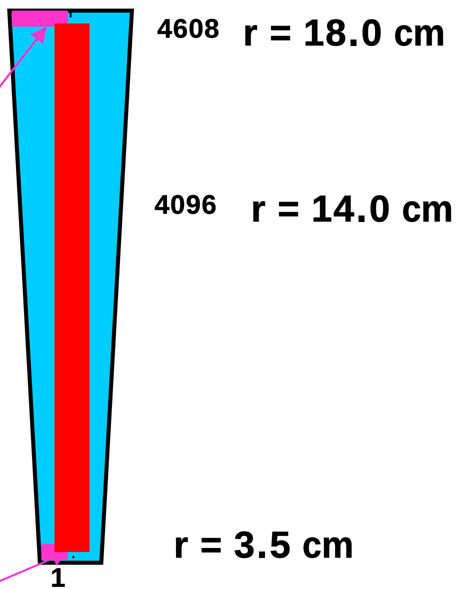


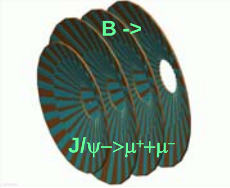
- Executive Summary
  - Four umbrella stations on each side matching the large MUON arm acceptace
  - Mini-strips of 50mu * 2.2 -13 mm
  - Readout via new PHX chip from Fermilab
    (based on existing FNAL chip architecture)
  - Data push via ~3 Gigabit optical links
  - Total channel count: 2 Million channels
  - Total chip count: 4000 chips

Si Umbrella Layout



- 50 mu radial pitch (z vertex reconstruction)
  - 4608 (4096) "mini-strips"
    - 3.5 cm < r < 18 (14) cm
    - < 1 % occupancy
  - 48 "double towers" in phi
    - mini-strips from
      13.0 mm
      to 2.2 mm
  - 2 rows of strips per "double tower", readout via one chip row



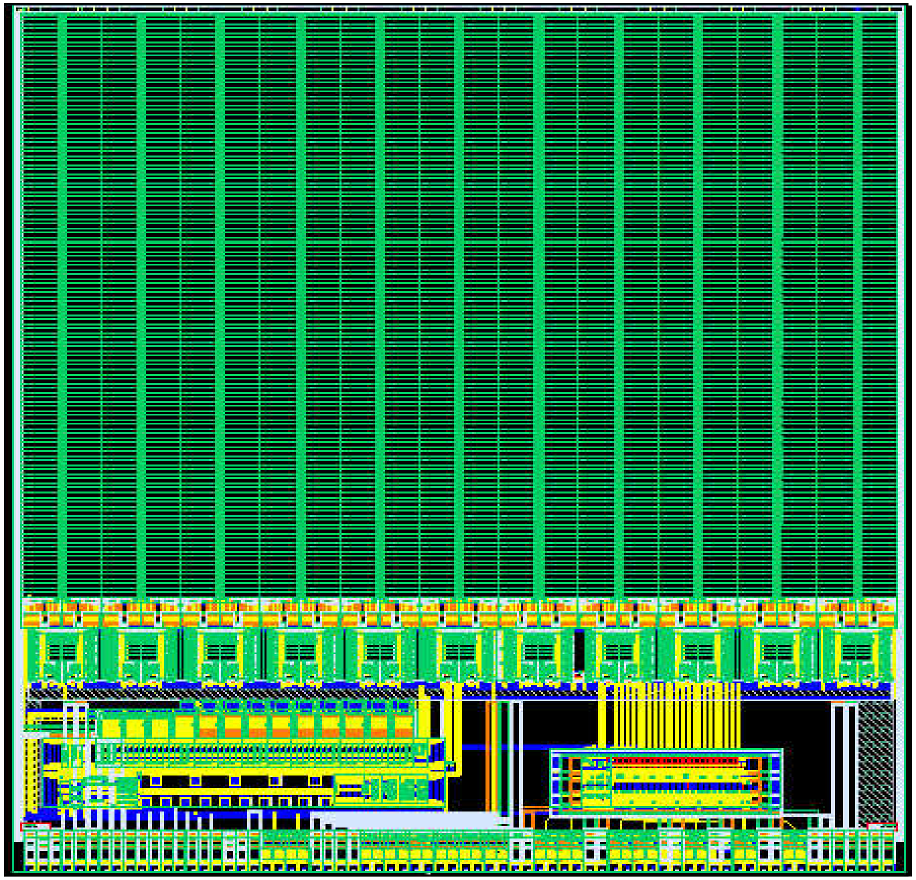


Collaboration with FNAL

- Started to work with Ray Yarema's group
  - They did D0 and CDF silicon readout (SVX#)
  - They developed BTEV prototype (FPIX)
  - Propose to build PHX, use existing developments …
  - First simulations for ministrips for PHENIX
  - Produced preliminary PHX chip layout
  - Solved Endcap bus challenge
  - Second/Third round of discussions at FEE2003/FNAL
    - Displaced Secondary Vertex Trigger via Data Push
    - (after muon trigger upgrade) matched two muon trigger ?
  - Propose to use FNAL infrastructure to prototype, test and assemble chips and detectors !!!!

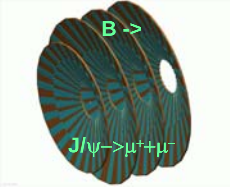
FPIX2 Features

- Very advanced mixed analog/digital design
- Low power (1/10th of ALICE chip)
- 128 rows x 22 columns (2816 channels)
- 50 µm x 400 µm pixels
- High speed readout intended for use in Level 1 trigger. 840 Mbits/sec data output.
- Very low noise
- Excellent threshold matching
- DC coupled input (pixel standart)
- Fully programmable device
- 3 bit ADC **-> basic dE/dx ?**

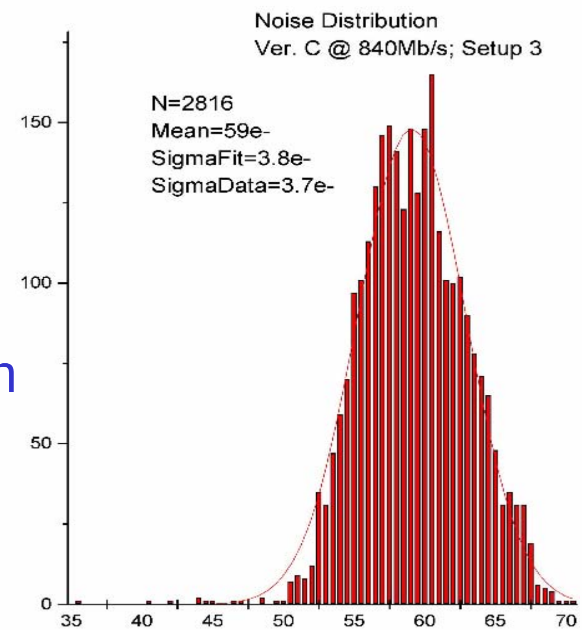


FPIX2

FPIX2 Measured Performance from Prototype Run in '03

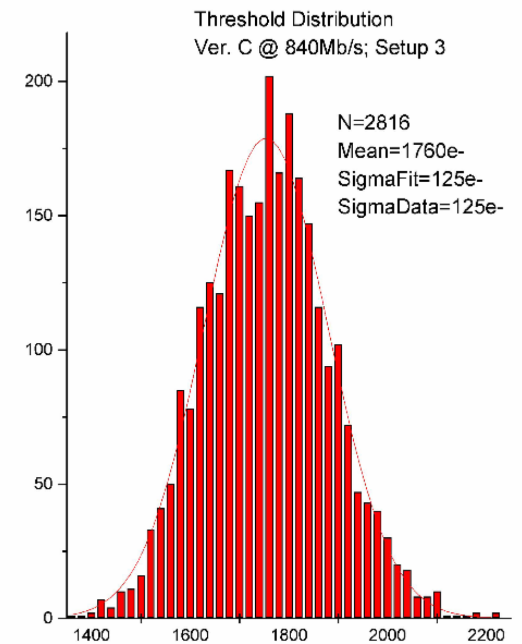


- Produced ~3000 chips in engineering run
- Mixed analog/digital design has excellent performance with insignificant interference and cross talk
- Chip size is 8.96 mm x 10.2 mm (91 mm^2)

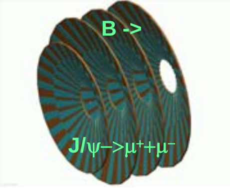


FPIX2 noise at C = 0 is about 60 erms

FPIX2 Threshold Distribution @ Cin= 0 pf is 125 erms



Reminder: MIP in 300 mu Silicon gives 24,000 electrons !!!!



FNAL Design for Phenix Chip - PHX -

- Modified FPIX2 front end (only 1 capacitor change)
- Same digital back end
- Relax bump bonding connections
- Backside contact for ground return (as done in SVX4)
- Slow programming control from FPIX2

PHX Chip Layout:

2 columns

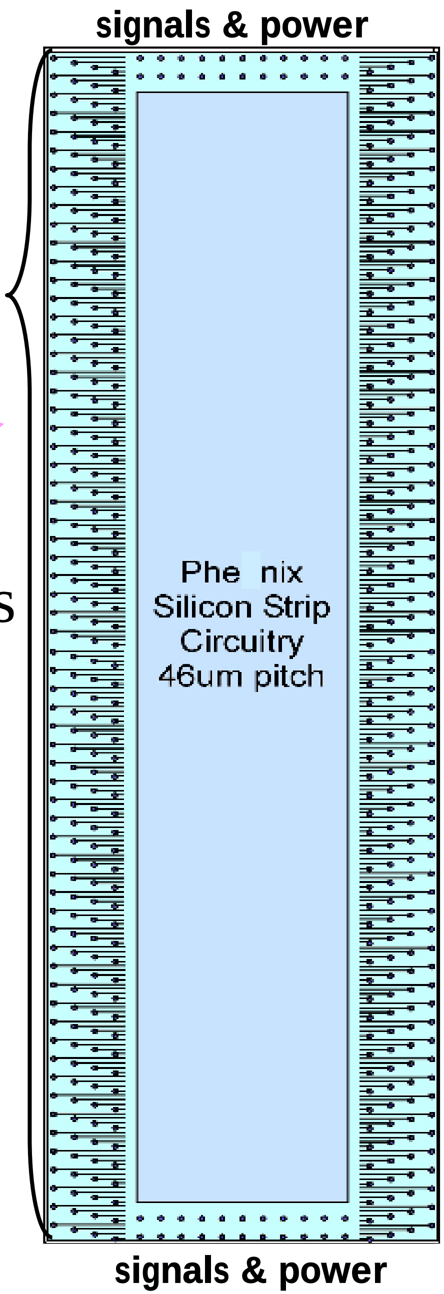
256 channels/column

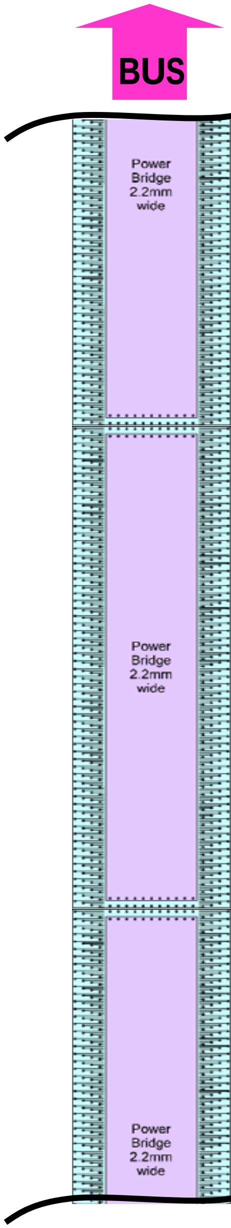
3.8 mm x 13 mm = 49.4 mm^2

Bump bonds on 200 um pitch

50 µm dia bumps

512 bumps plus inter-chip bumps for the BUS





FPIX2 Layout for comparison:

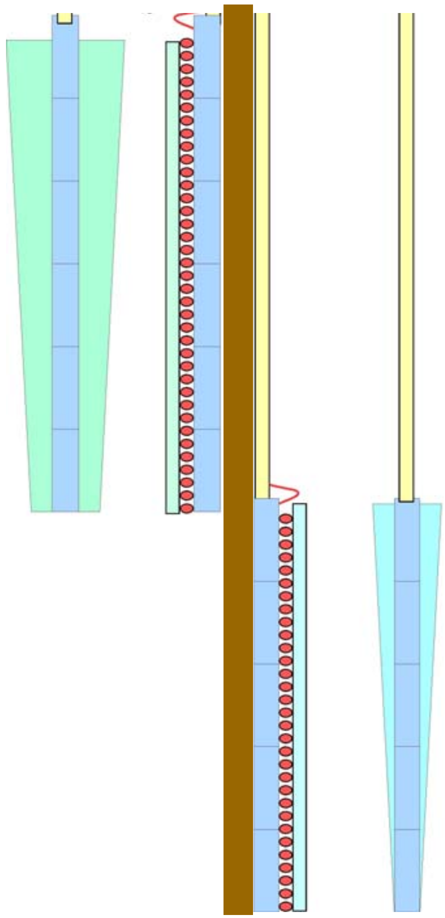
Chip area = 91 mm^2

Bump bonds on 50 µm pitch

12 µm dia bumps

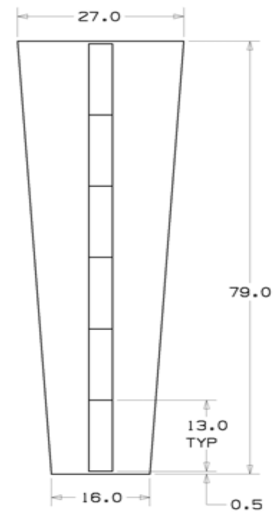
2816 bumps

Only '2 ½'Silicon Detector Styles



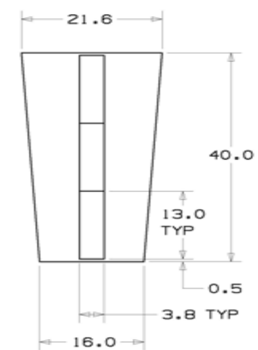
Carbon Cooling Wedge

Outside Detector (IIa)



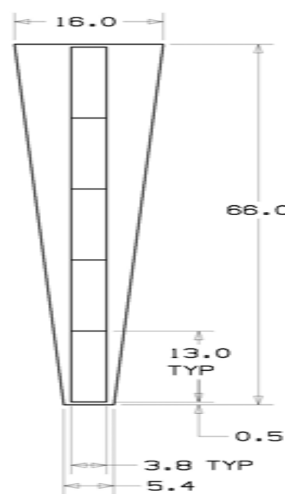
6 chips= 3072 strips

Outside Detector (IIb)

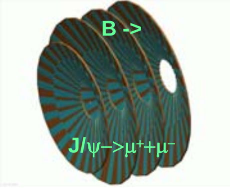


3 chips= 1536 strips

Inside Detector (I)



5 chips= 2560 strips

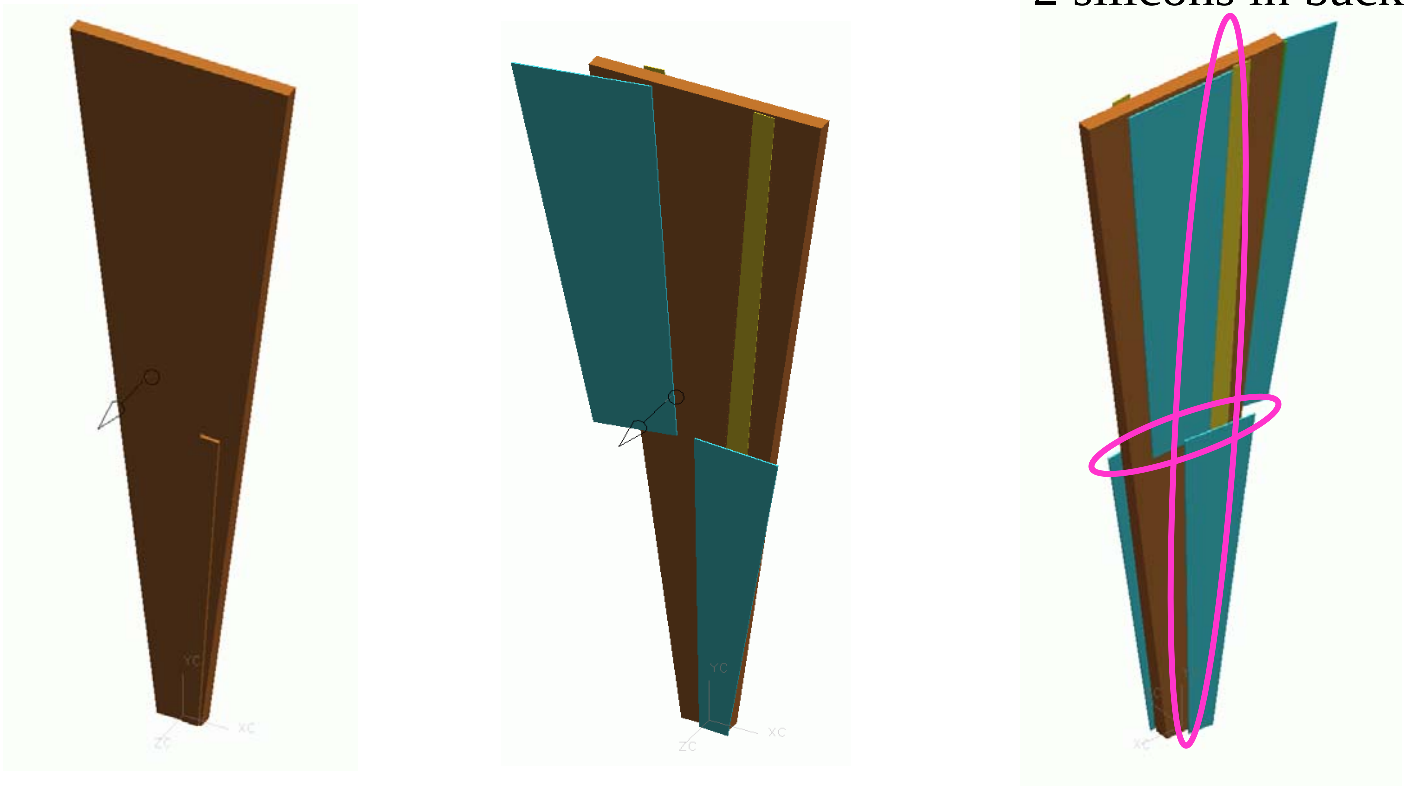


Wedge Assembly Concept

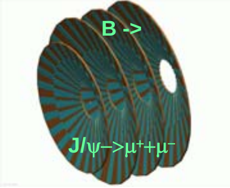
3 mm carbon wedge for
assembly and cooling

2 silicons in front

2 silicons in back

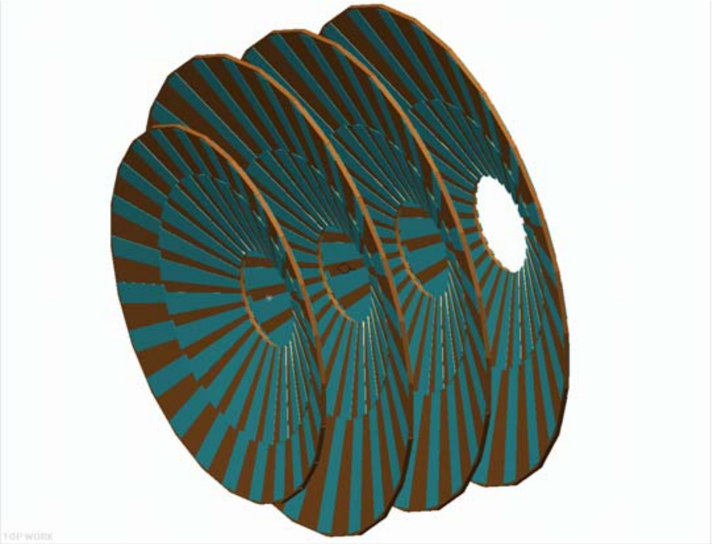


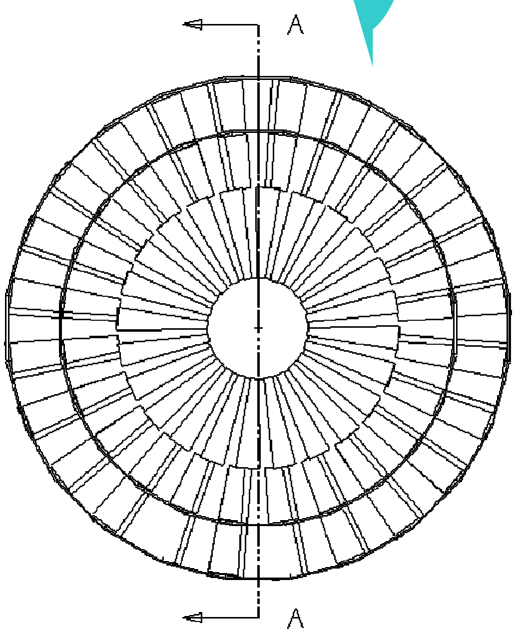
Reason: Eliminate dead silicon areas by overlapping 1 mm along edges ….

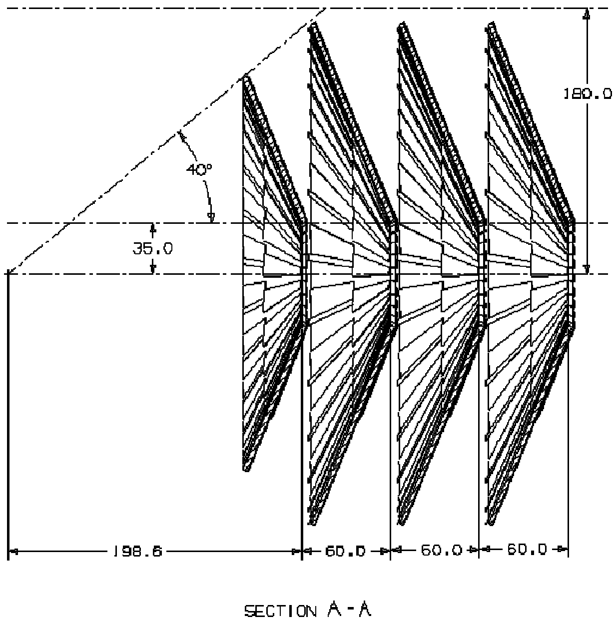


From Wedges to Umbrellas

X 24

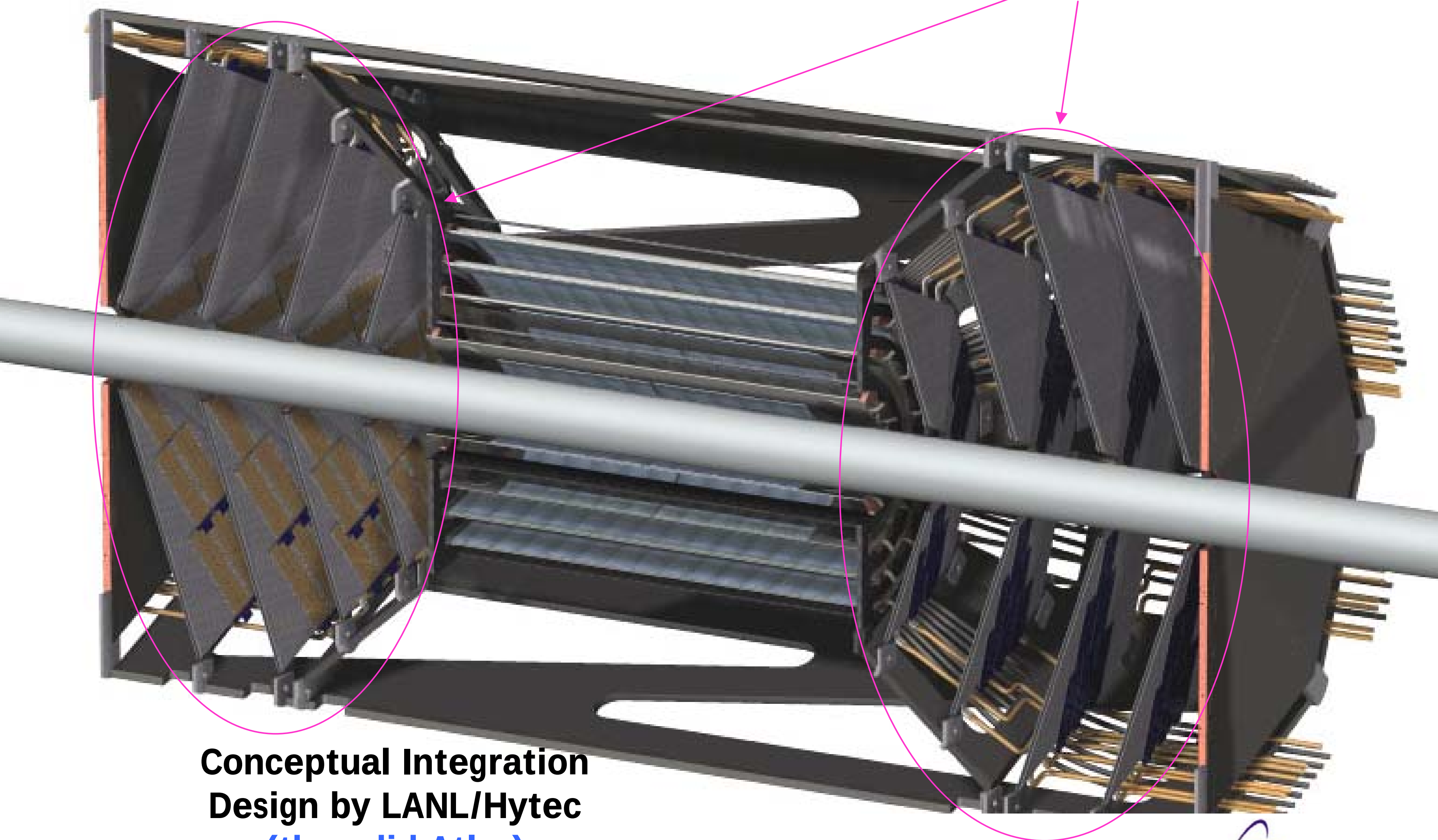




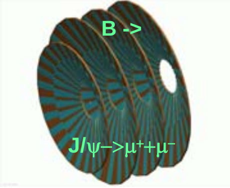


Si Vertex – Purchased Design Study

Si-Umbrellas



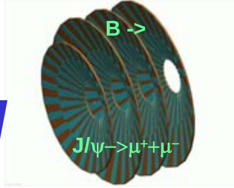
Conceptual Integration Design by LANL/Hytec (they did Atlas)



Progress Report as of June '04

- Collaboration with V.Lindenstruth/Heidelberg concerning OASE chip and computer topologies for fast Level I and II
- Extended LANL visit by Ivan Kisel (LHCb tracking specialist)
  - Cellular automaton tracking adapted to endcap configuration
  - Confirmation of P.McGaughey's earlier results on resolution
  - Ongoing effort to fine tune the geometry for the endcap and implement it into PISA (crossed pixels ??)
- Contact with BTEV intensified
  - Erik Gottschalk (Level I leader came to LANL on April 7th
    - Endcap trigger discussion that day with Craig, John, Vince, Tony, Chi etc.
  - Discussion with Simon Kwan and W. Wester about BTEV/FPIX2
    - Current plan for PHX has same digital interface as FPIX2
- Capitol money received from LANL for SiEndcap LDRD
  - Flip-chip assemblies from BTEV/FNAL; FPIX2 bump bonded to silicon detector (same pixel size as ALICE but faster and less power and 3 bit adc …) plus their test DAQ

Endcap Readout with Trigger Capability: Front End



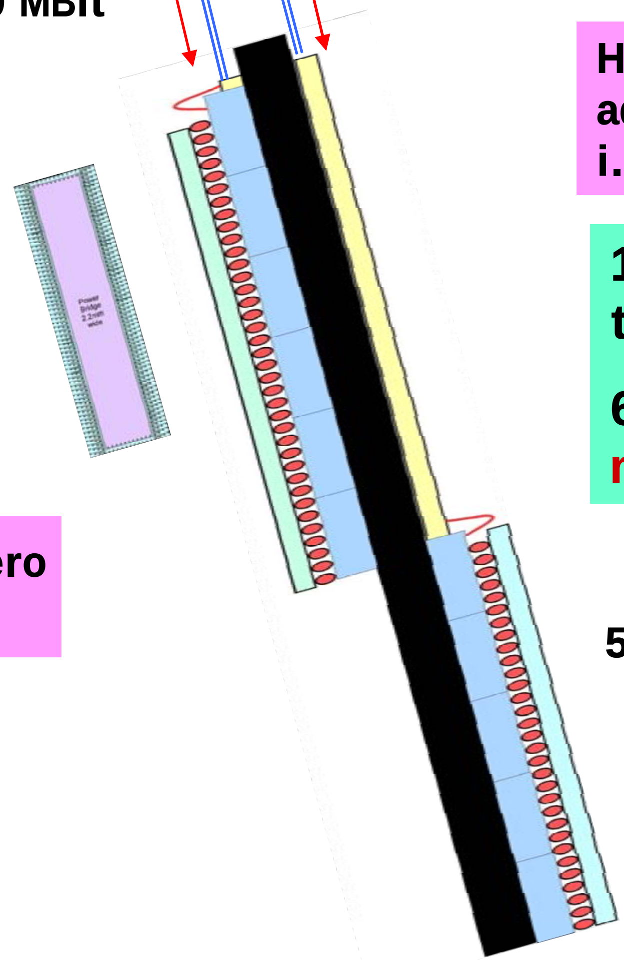
RISC onboard

OASE chip

Fiber 2.5 Gbit/s

Slow Control ~100 Hz

LVDS 6 x 160 MBit



6 x 512 channels

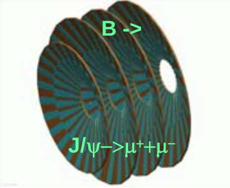
Hit: 9 bit address ,3 bit adc, 4 bit chip-id, tag 8bit, i.e.24 bits

1 % Occupancy translates into:

60 x 24-bits in <0.6 micro seconds !

PHX/FPIX2 is zero supressed !!!

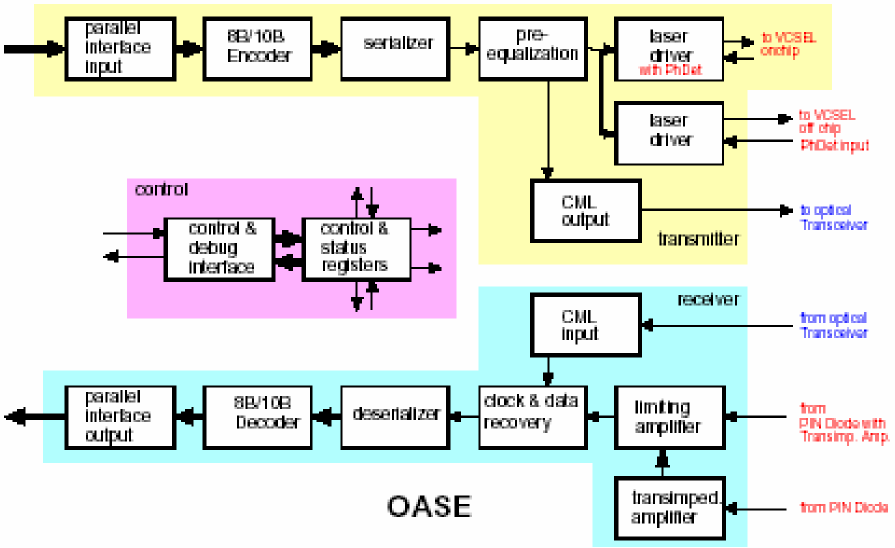
5 x 512 channels



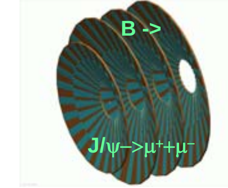
Optical Advanced Serialiser (OASE from HD)

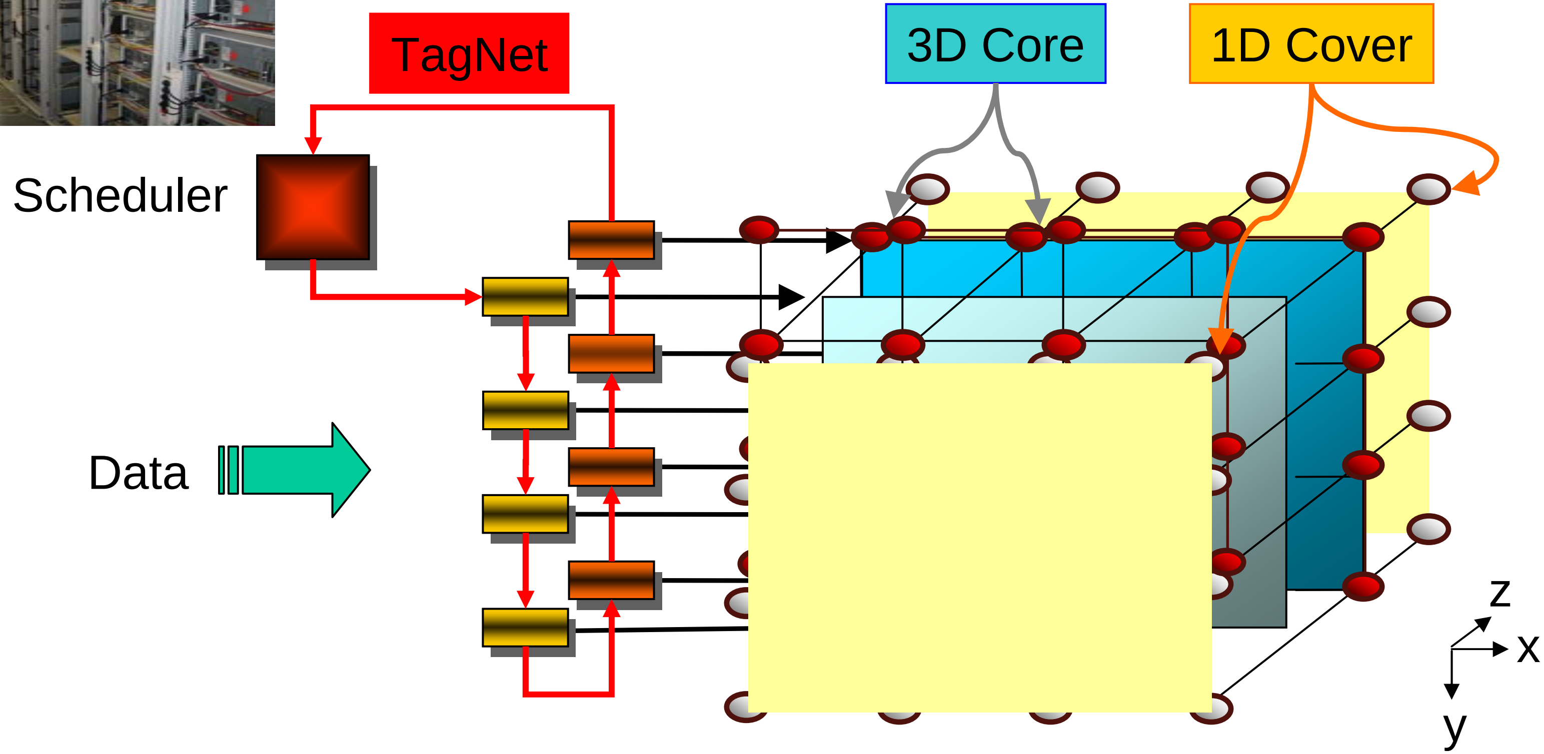
*The **OASE** device is a flexible serial transceiver, delivering high-speed, bidirectional, point-to-point data transmission to provide up to 2.5 Gbit/s of data transmission capacity per channel. The device performs the parallel to serial, serial to parallel conversion and provides a selectable 8-bit/10-bit encode/decode function. Each transmit section of the OASE device contains LVDS drivers and on-chip mounted fiber interface.*

- *All components on chip (15mm^2)*
- Power 200mA at 1.8 V,i.e 0.4 Watt
- More info in May ….

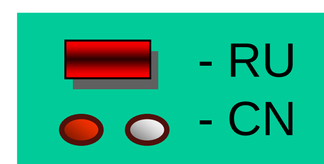


3D Torus Topology 4x4x(1+2+1)

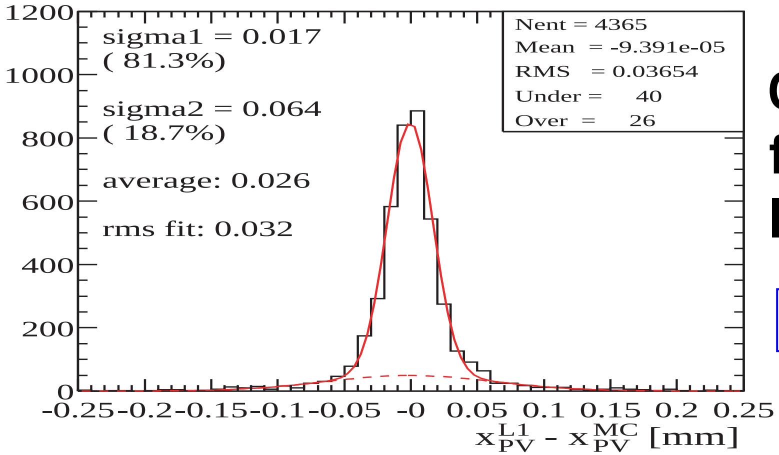




- TagNet – schedule and send small data packets
- Core network – distribute data to the target compute nodes
- Cover network – increase number of compute nodes
- X->Y->Z routing path

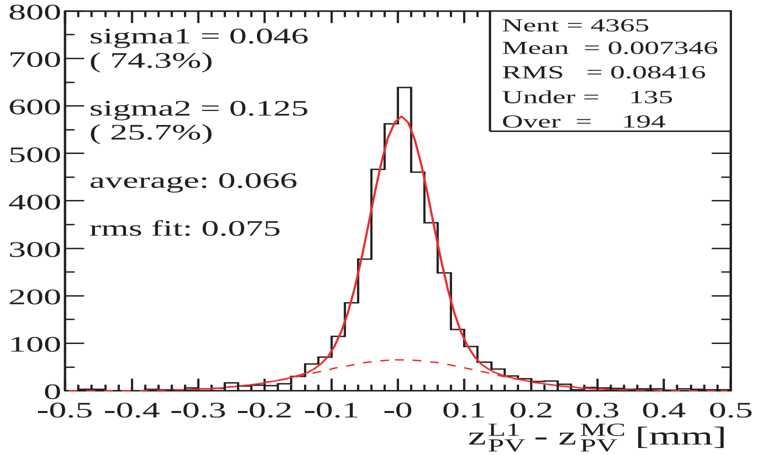


Ivan Kisel: LHCb Tracking Efficiency and Primary Vertex Resolution



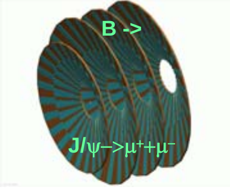
Cellular Automaton Tracking for the LHCb with many more layers ...

$X/Y_{core} \approx$ **17 μm**

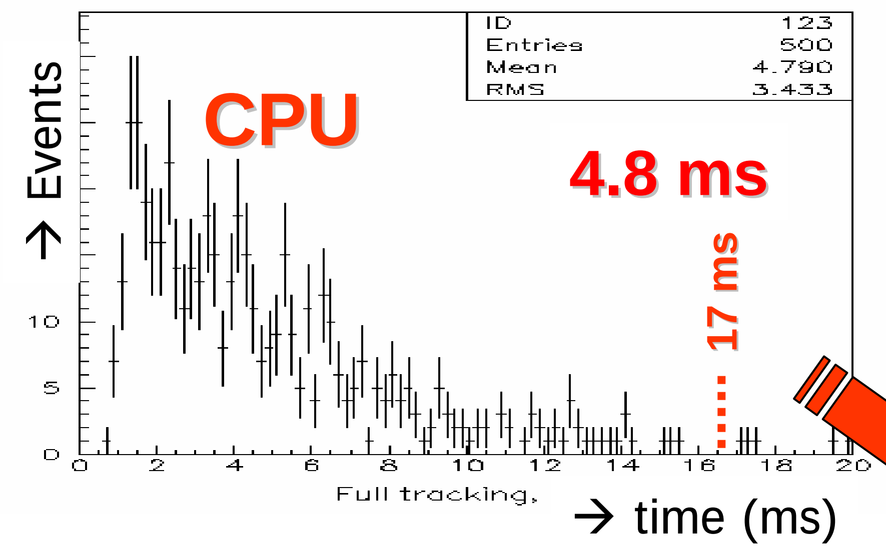


$Z_{core} \approx$ **46 μm**

Ivan Kisel: Trigger Performance



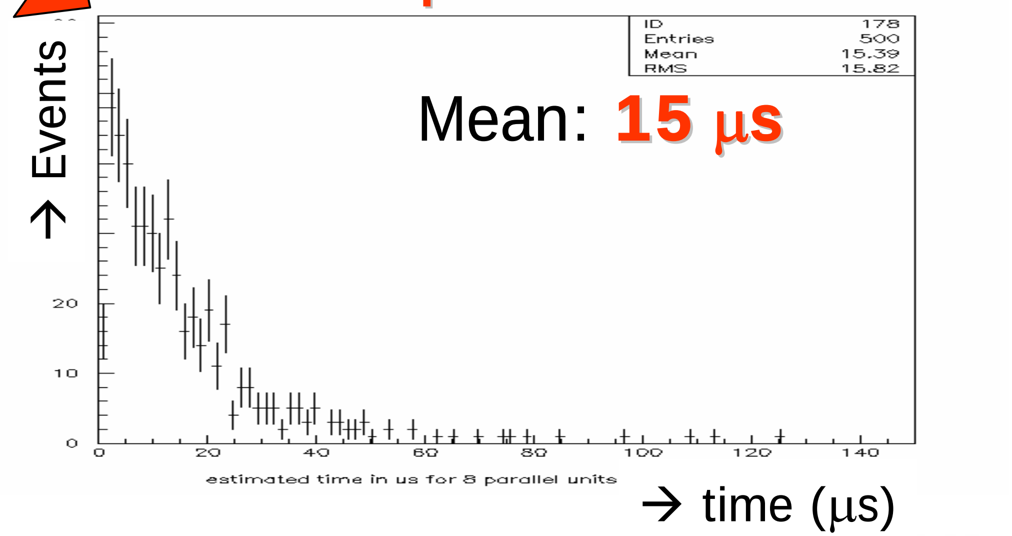
1) Tracking efficiency 97—99% 2) PV resolution 46 μm 3) Timing 4.8 ms



Expect a factor 7—8 in CPU power in 2007 (PASTA report)

=> we are already within 1 ms !

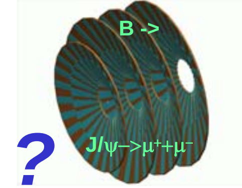
FPGA co-processor



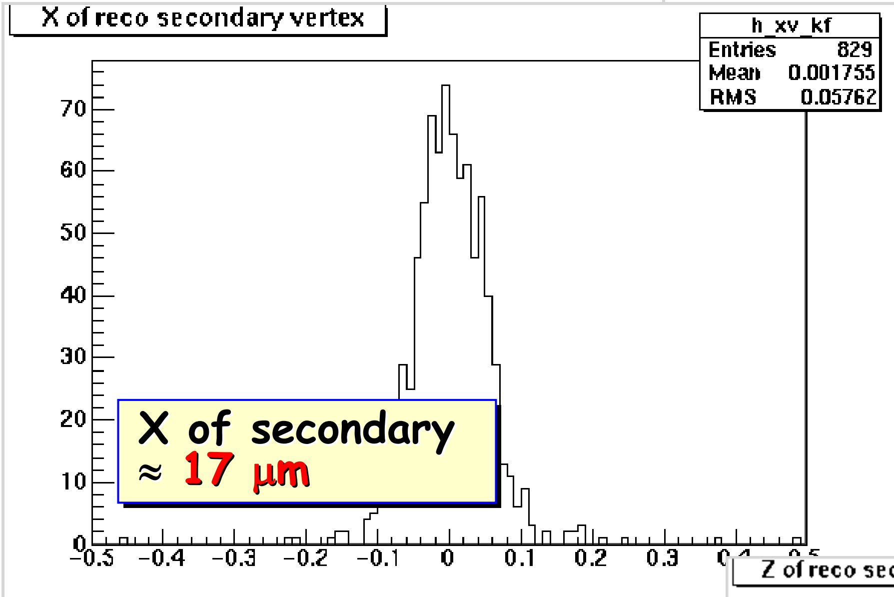
- Cellular Automaton algorithm
- FPGA co-processor at 50 MHz
- 8 processing units running in parallel

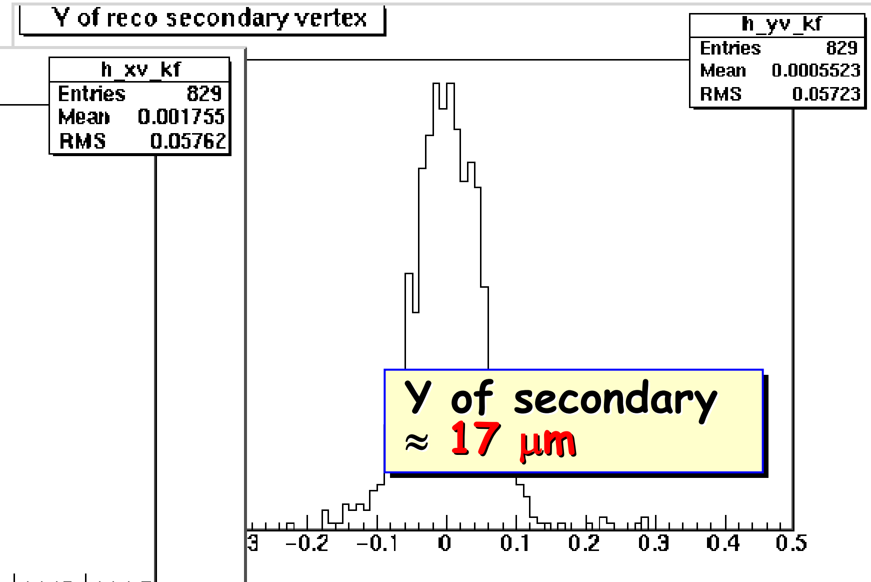
=> 15 μs !

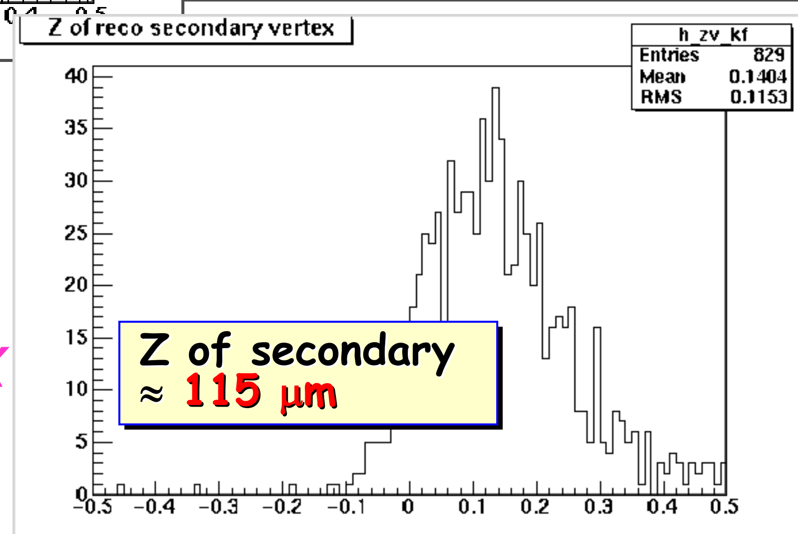
Physics

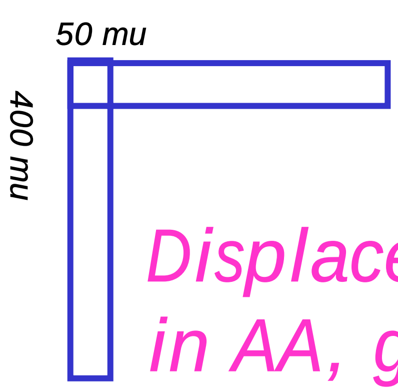


3-d Tracking in Phenix with Crossed Pixels ?





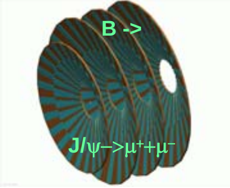




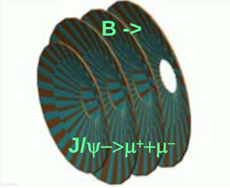
Use 'stock' BTEV pixels

Displaced Vertex in AA, ghosts ?

FPIX Silicon Tracker at LANL



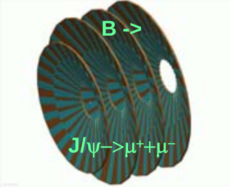
- Got LANL capitol money to build tracker prototype at LANL
  - Flip-chip assembles from BTEV
    - Acquire completely tested components
    - Participate in the test beam program
    - Inherit their test beam PC based DAQ
  - Build cosmic ray tracking test stand at LANL
  - Gain experience and evaluate performance
  - Study capabilities of BTEV test daq
    - Btw. it is commercially available and reads FPIX or SVX into a PCI card, comes complete with soft and firm ware !
  - Develop more detailed trigger plans
  - Use OASE chip for fiber link between detector and readout
- Build *COMPLETE* system from detector to reading it into PHENIX minidaq for proof of principle



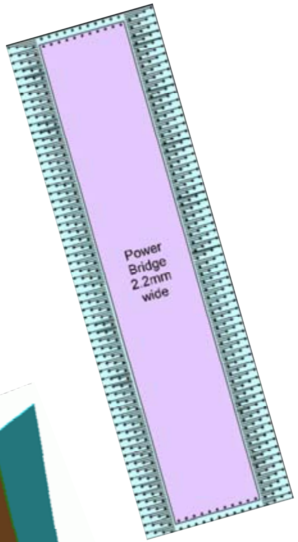
Endcap Summary

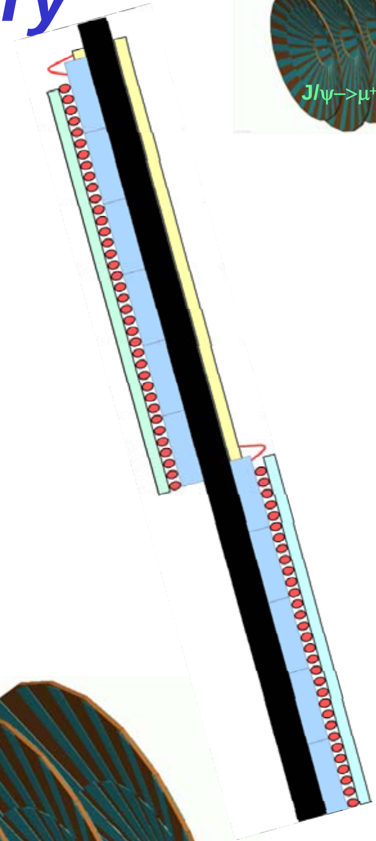
- PHX chip with 840 Mbit/s asynchronous readout
- OASE chip with LVDS input, fiber output 2.5 Gbit/s
  - Located on the nose cone
- For central Au-Au <0.6 micro second readout !!!!
- Dual Path
  - Emulate *normal* PHENIX standard
  - Level I or II for Primary and Secondary vertices
- 3d LINUX toroidal network structure
- Collaboration with BTEV
- Established MOU with FNAL on PHX
- Tracking test stand at LANL (complete proof of principle)

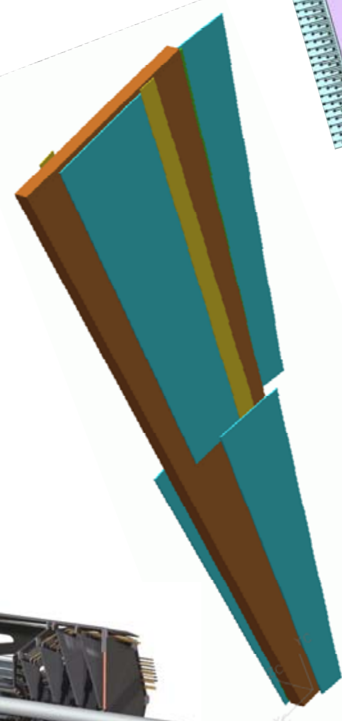
Endcap Technology Summary

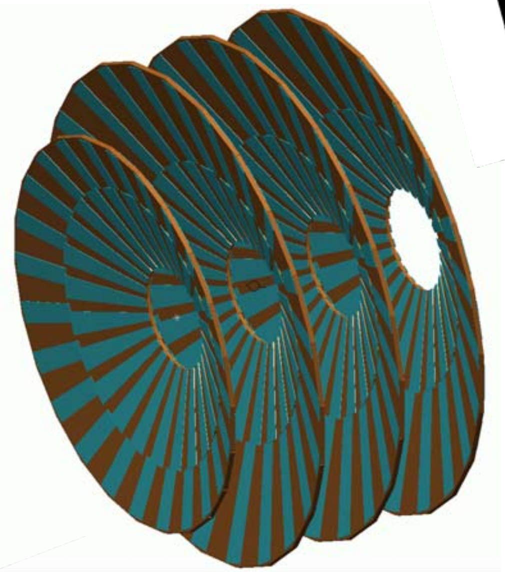


- Readout and bus via PHX from Fermilab
  - R&D plan exists
- Bump bonded assemblies
  - Relaxed requirements
  - Following industry standard
- Wedge design
  - Conceptual design for cooling and assembly
- Umbrella endcap
- Integration by LANL/Hytec

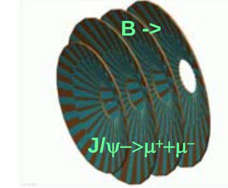








PHENIX Silicon Endcap Physics

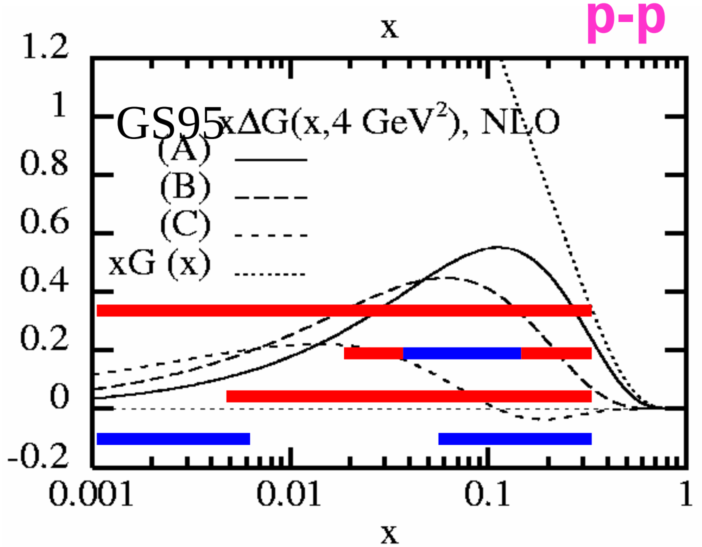


p-p

cc→μ(displaced)X

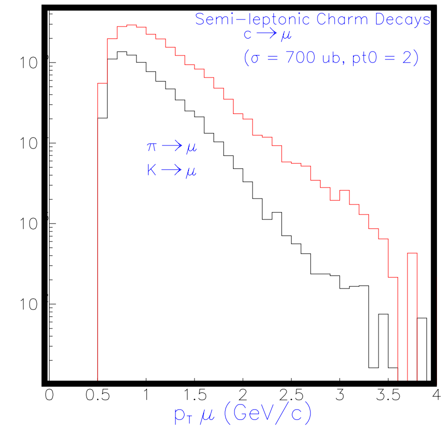
bb→e/μ+displaced

B→J/ψXg



Open Charm Measurement

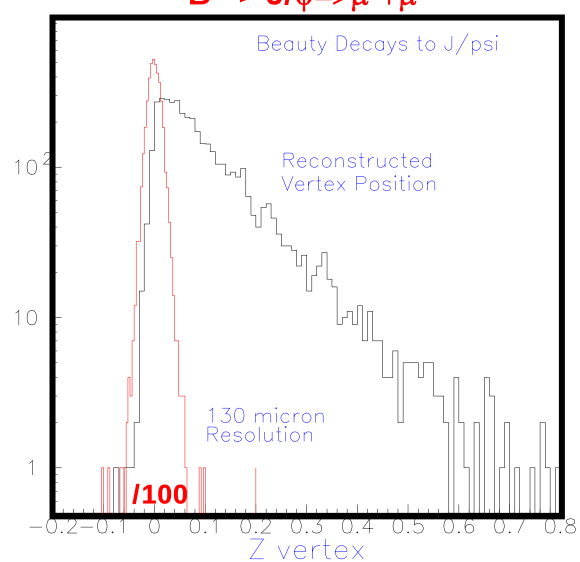
D=>μ+X, D D̄=>μ+e+X, D D̄=>μ⁺ +μ⁻ +X



A-A

Beauty Measurement

B => J/ψ=>μ⁺+μ⁻



p-A

cc→μ(displaced)X

bb→e/μ+displaced

B→J/ψX