Silicon Micro Vertex Detector

NSAC/DOE Review June 2, 2004

People involved

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  - Fred Bieser (Lead Electronic Engineer)
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  - Leo Greiner
  - Fabrice Retiere
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  - Robin Gareus (Univ. of Heidelberg)
- LEPSI/IReS (Strasbourg)
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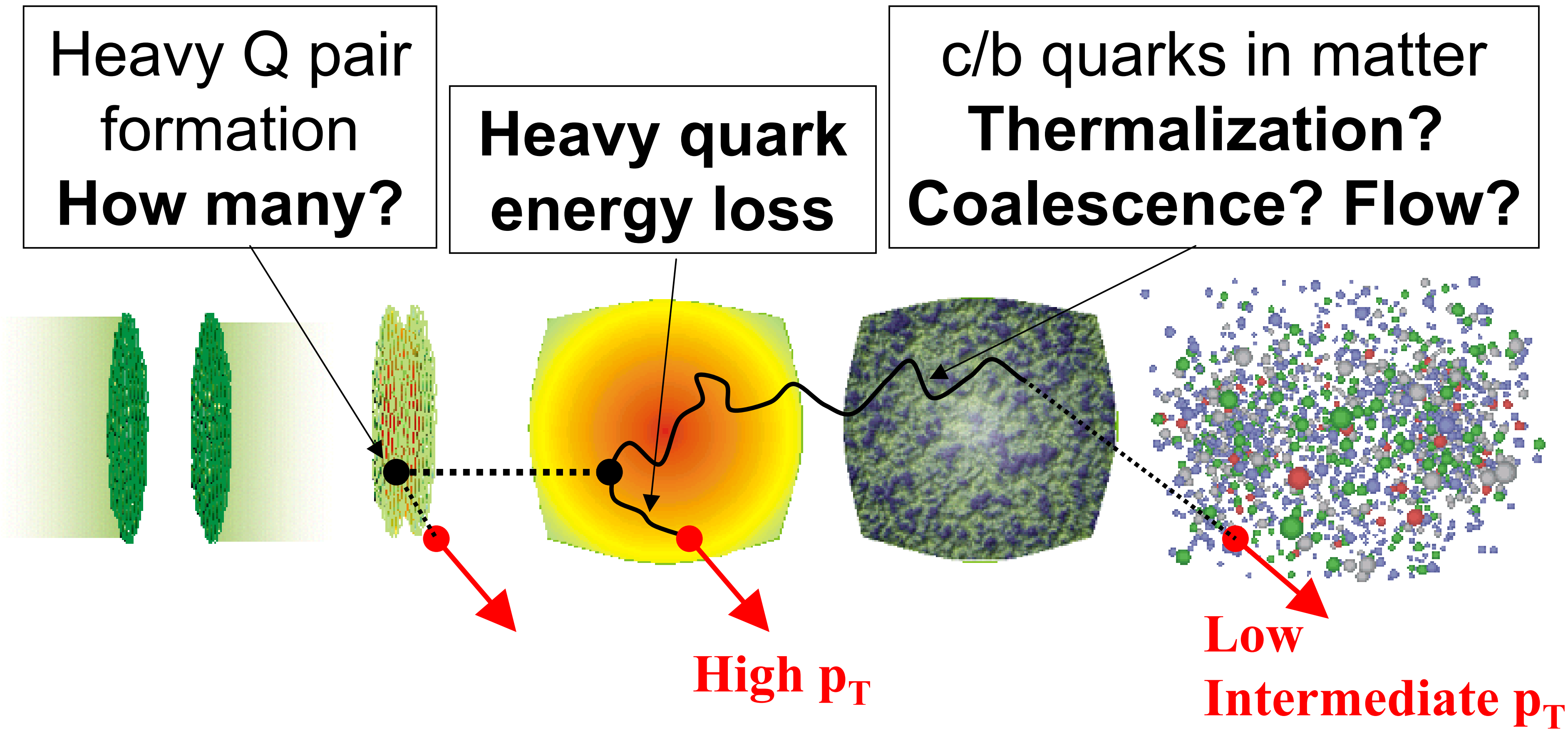
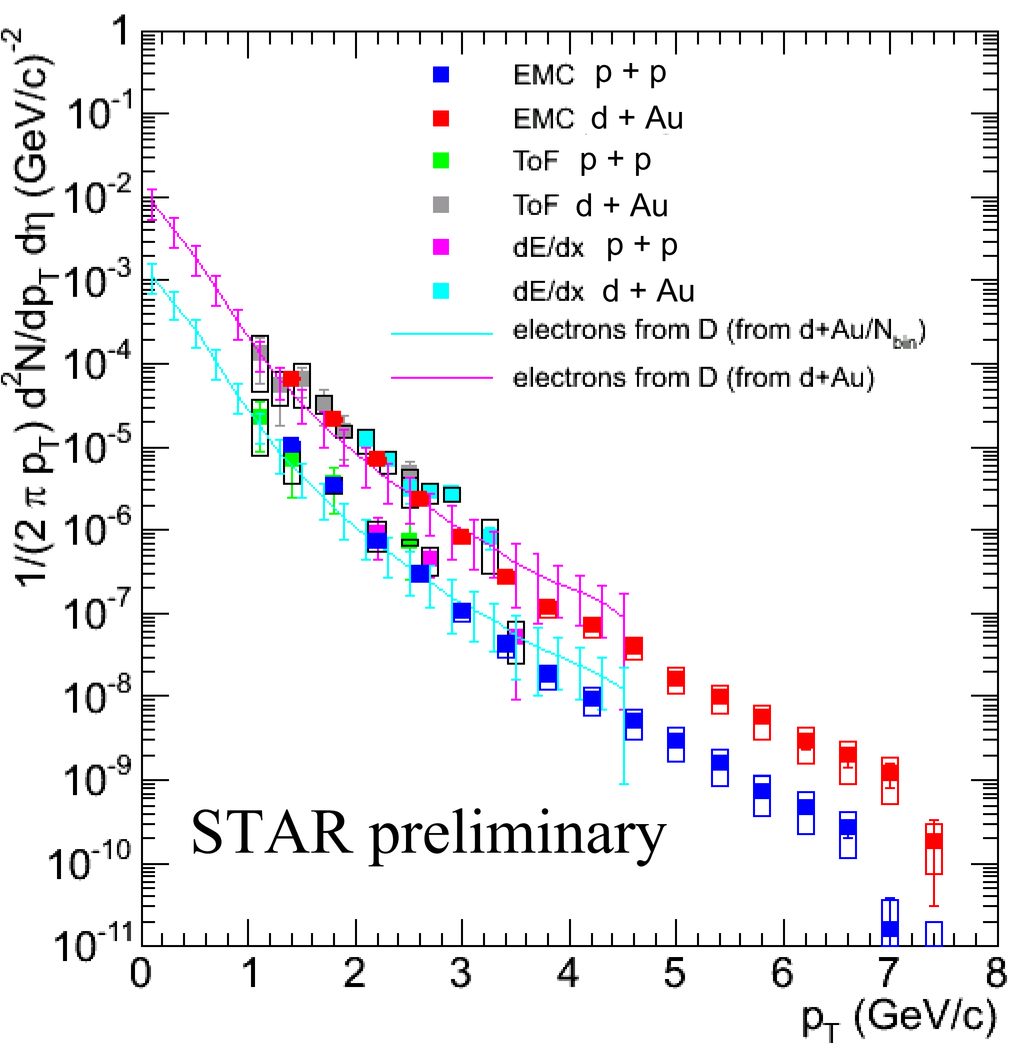
- UCIrvine
  - Stuart Kleinfelder + students
- LBNL Mechanical Engineering
  - Eric Anderssen (consultation – ATLAS Pixels)
  - Design works
- BNL Instrumentation Div (consulting)
- Ohio State U
  - Ivan Kotov

Heavy flavor in ultra-relativistic heavy-ion collisions



Heavy flavor hadrons to detectors

Heavy-quark energy loss

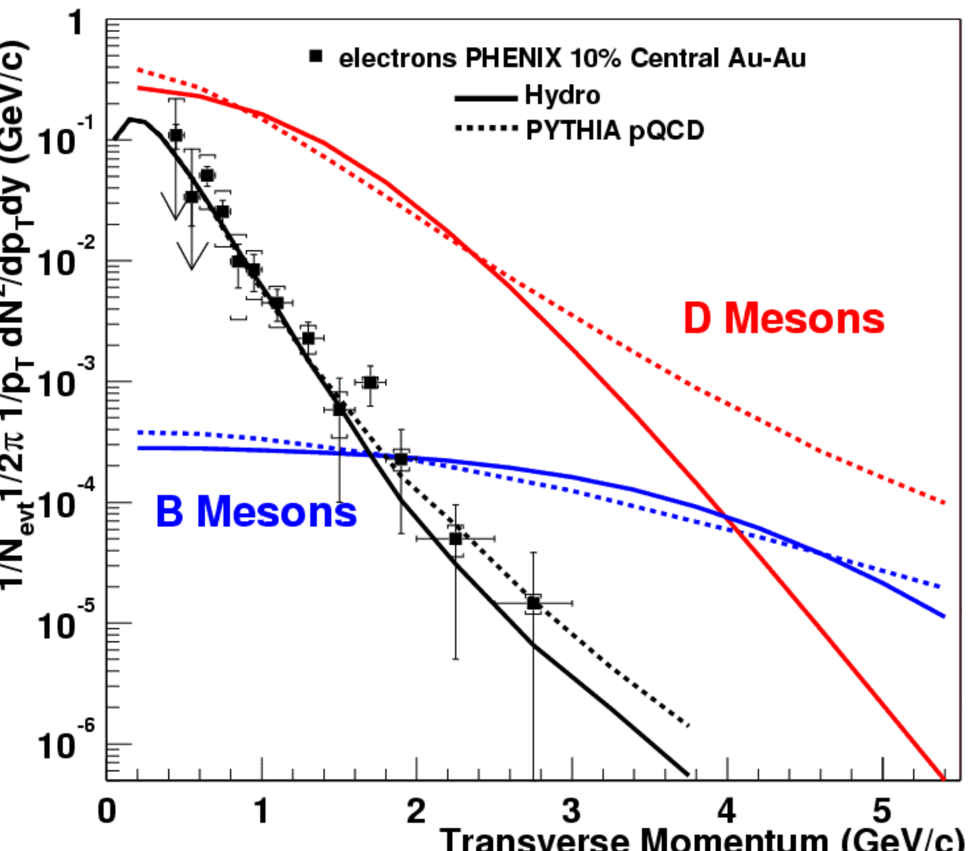


- Heavy quarks radiate less energy than light quarks (prediction)
  - Yield of charm and beauty (leading) hadrons less suppressed
  - May be measured by D → X+e- and B → X+e-
    - Without vertex information systematic error from background subtraction

(Luminosity upgrade adds capability for this case)

Flow and thermalization

- **Flow: spectra and v_2**



J. Nagle, S. Kelly, M. Gyulassy, S.B. JN, Phys. Lett. B 557, pp 26-32

- **Charm thermalization by chemistry**

	e-p & $e^+ e^-$	Thermal
$f(c\rightarrow D^0)$	0.557	0.483
$f(c\rightarrow D^+)$	0.232	0.21
$f(c\rightarrow D_s^+)$	0.101	0.182
$f(c\rightarrow \Lambda_c^+)$	0.076	0.080

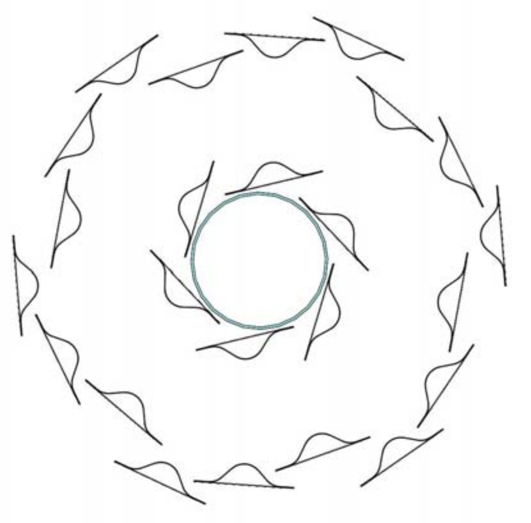
Measuring heavy flavor with the μVertex detector

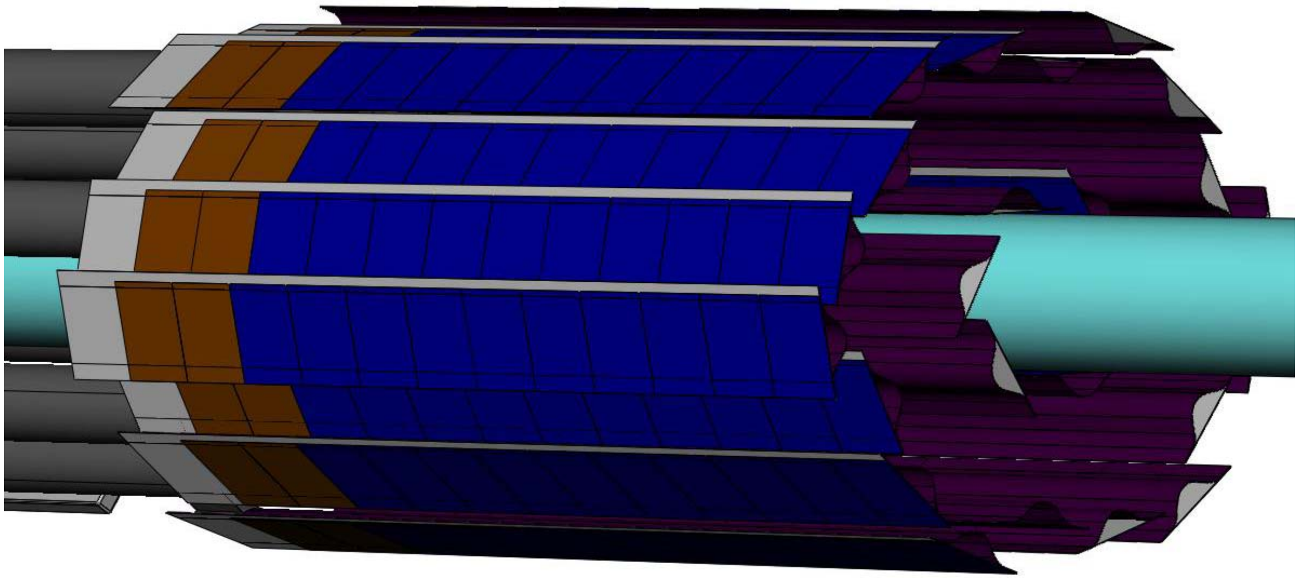
- **Goals**
  - Heavy flavor energy loss
    - Remove background
  - Charm flow
    - Precise D^0 spectra
    - D^0 v_2
  - Charm thermalization
    - Yield of D^+, D_s^+, Λ_c^+ (challenging 3 body decays)

- **μVertex strategy**
  - Separate charm and beauty decay product from primary tracks
    - Typically D^0 $c\tau = 124\ \mu m$
- **μVertex requirement: a very good vertex resolution**
  - Position resolution $< 10\ \mu m$
  - Thickness $< 0.2\%$ of rad length to limit multiple scattering

STAR Micro Vertex Detector

- Two layers
  - 1.5 cm radius
  - 4 cm radius
- 24 ladders
  - 2 cm X 20 cm each
  - < 0.2% X_0
  - ~ 100 Mega Pixels

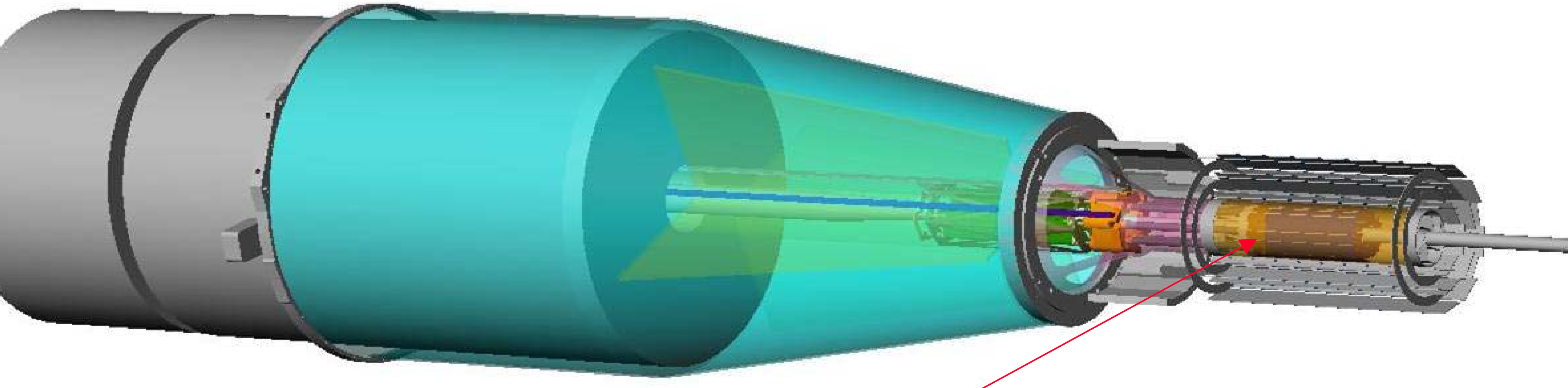




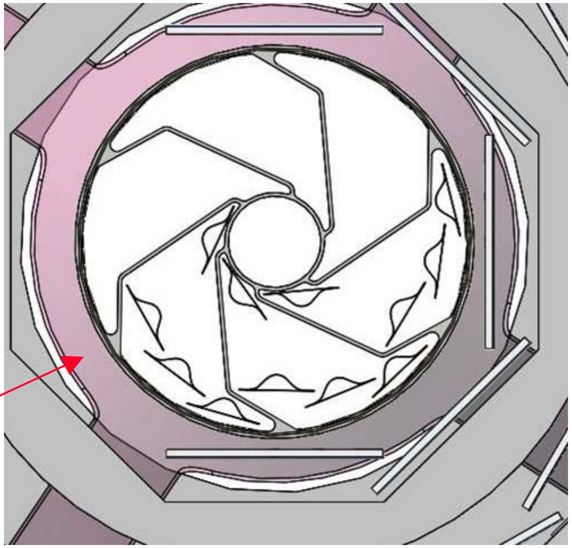
Charm hadron reconstruction performances (figure of merit)

System	N events for 3 σ D^0 signal	N events for 3 σ D^+_s signal *In progress*
TPC+SVT	12.6 M	
TPC+SVT+TOF	2.6 M	~1,000 M ($\phi+\pi^+$)
TPC+SVT+μVertex	100 K	~100 M ($\phi+\pi^+$)
TPC+SVT+μVertex+TOF	10 K	~1 M ($\phi+\pi^+$)

Inner vertex detector in STAR



New vertex detector centered in pointing detector, supported one end only

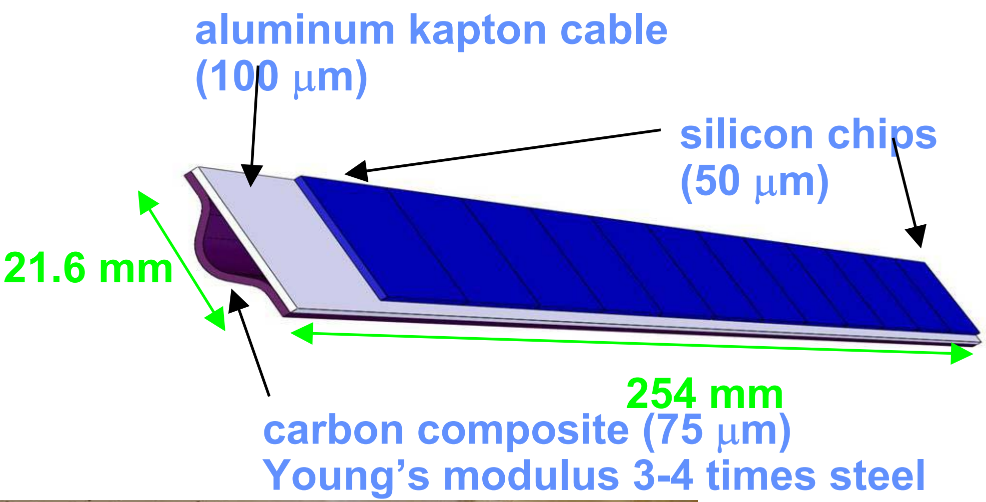


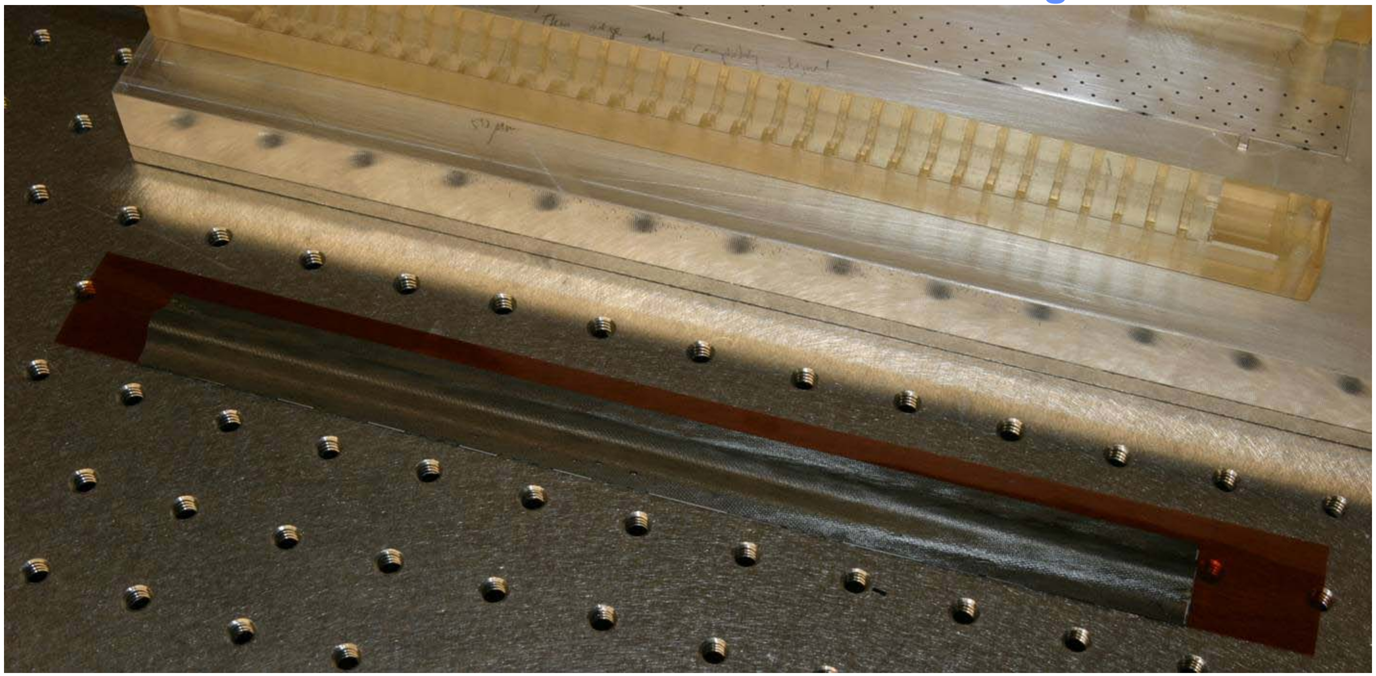
Conceptual design focused on rapid insertion and removal while preserving spatial mapping

End view showing 3 of 6 ladder modules

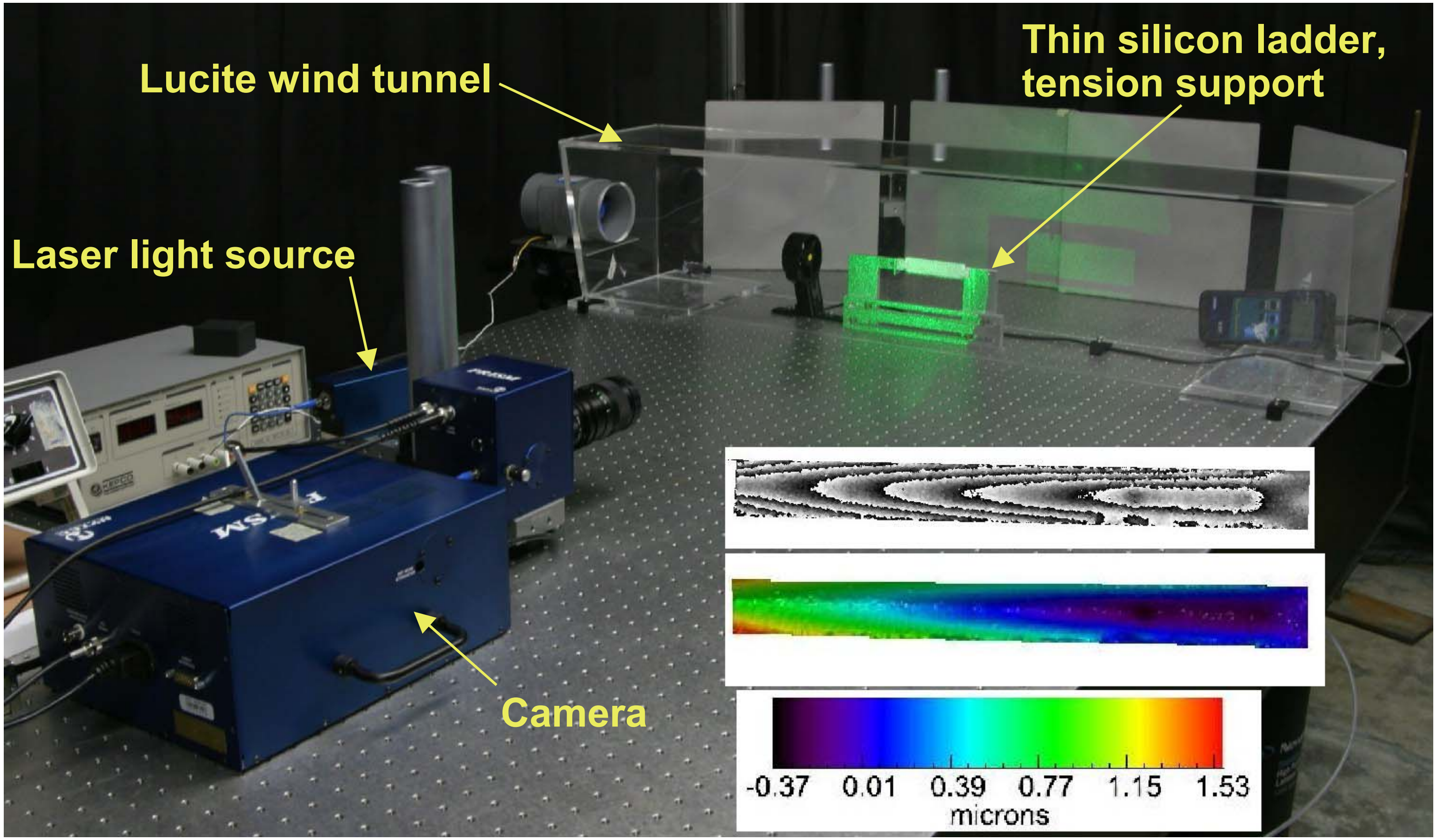
Support: Thin stiff ladder concept

- Under development
- Tested for thermal distortion
- Wind tunnel vibration tests

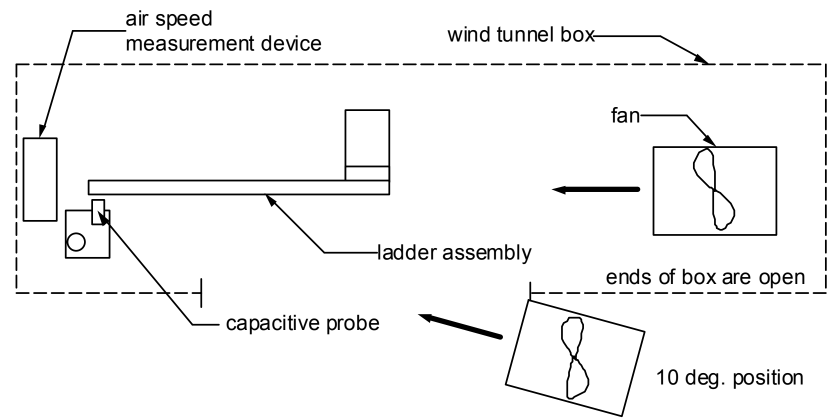


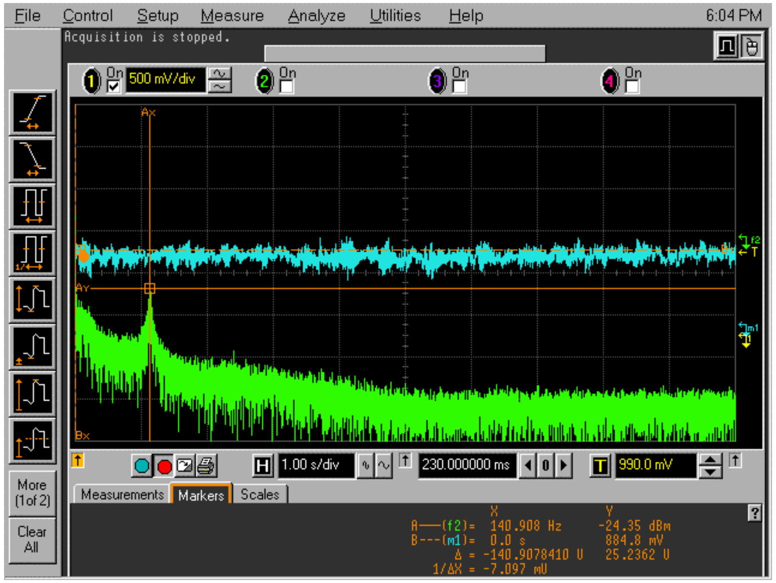


TV Holography from ATLAS, LBNL

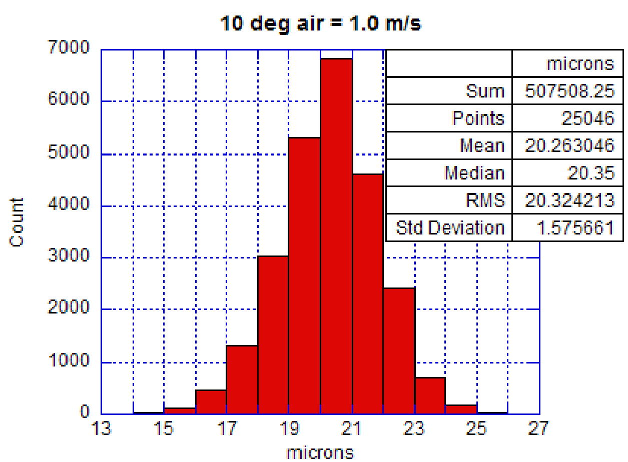


Capacitive Probe Measurement of Ladder Displacement and Vibration





1.6 μm vibration

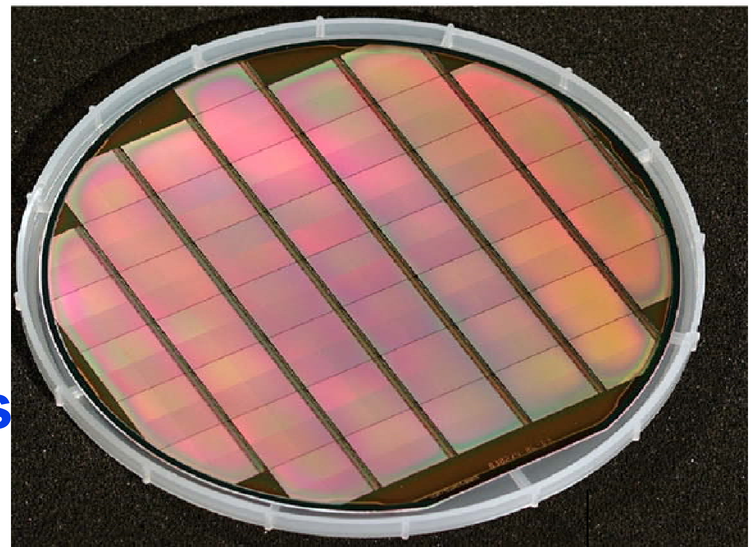


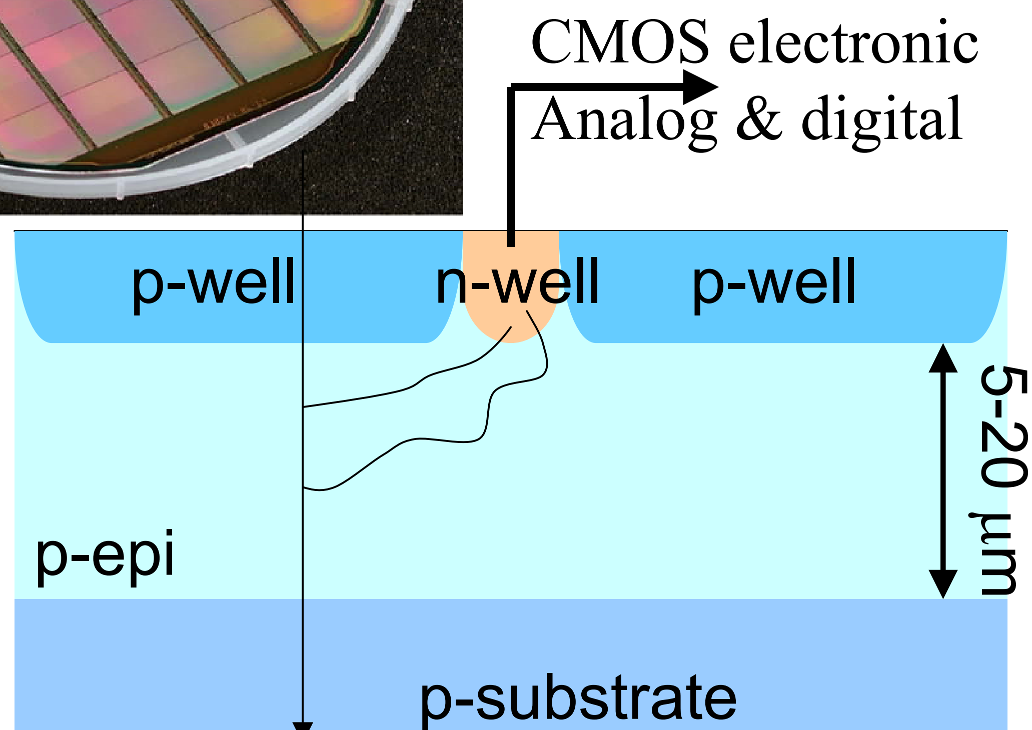
	microns
Sum	507508.25
Points	25046
Mean	20.263046
Median	20.35
RMS	20.324213
Std Deviation	1.575661

- **Additional vibration measurements: High sensitivity accelerometer place of the STAR inner detector support structure**

Sensors: Active Pixel Sensors

- **Advantages**
  - Precise
  - Can be thin
  - Rather fast
  - Low power
- **Disadvantages**
  - Small signal
  - Not that fast
  - New
    - Need R&D





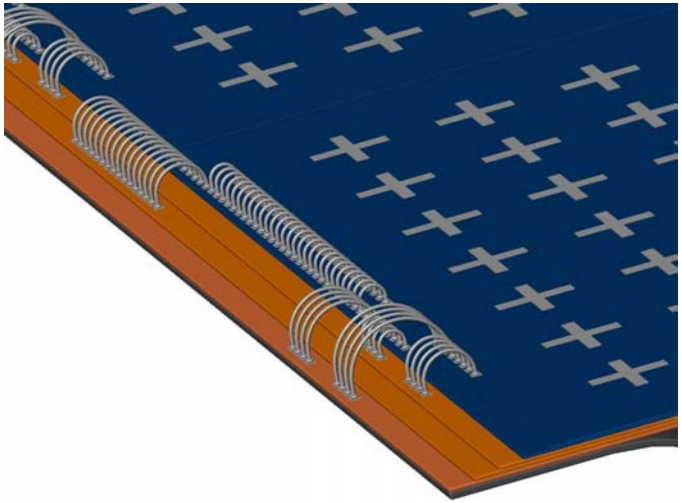
Sensors: 2 generations

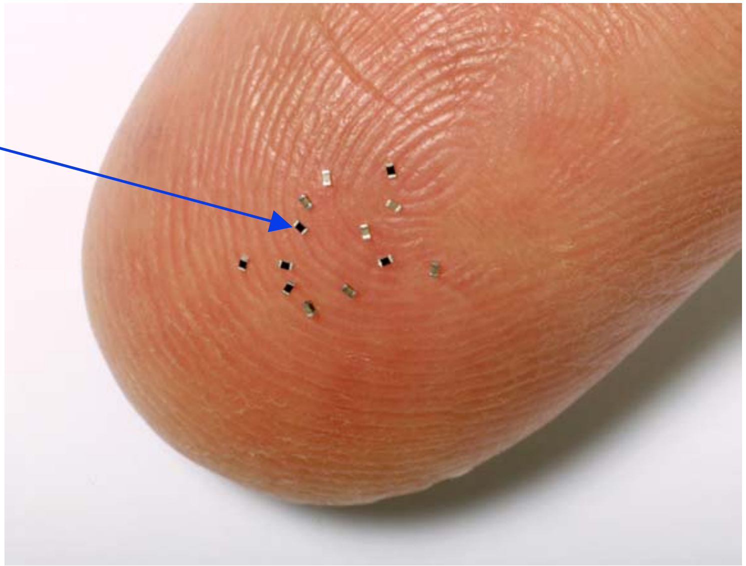
- 1^{st} Generation: 5-10 ms readout time
  - MIMOSTAR1 designed by LEPSI/IRES (Strasbourg)
    - 640×640 pixel of $30 \times 30\ \mu m^2$ pitch
  - Purely analog
  - Parallel readout on-chip multiplexed to 2 kind of outputs
    - $1 \times$ 100MHz driver
    - $10 \times$ 10 MHz drivers
- 2^{nd} Generation: Faster but need more R&D
  - R&D with UCIrvine and LEPSI/IRES
  - Improve charge collection
    - Photogate, Active reset, …
  - Some digital processing
    - Up to cluster-finder?

Readout

- **Analog to end of the ladder (~1 m away)**
  - **Challenge to drive analog signal at 100 MHz over 1m**
- **Piggy back chip**
  - **ADC and memory on a chip bounded to the pixel chip**

- **Analog Prototype with MIMOSA-5 Scheduled for Fall 04**
  - **To develop fabrication methods with aluminum cables and new small components**





Summary

- The micro vertex greatly improves heavy flavor capability before and after luminosity upgrade
- Design work progressing on MAPS by LEPSI/IReS (the 1st generation sensor for STAR inner vertex
- Developing Readout approaches
- R&D for 2nd generation sensors by UCI/LBNL and LEPSI/IRes
- R&D mechanical concepts for detector support system

- Installation in 2008 or 2009

backup

Selected Detector Parameters

Number of pixels	98,304,00
Pixel dimension	30 μm × 30 μm
Detector chip active area	19.2 mm × 19.2 mm
Detector chip pixel array	640 × 640
Number of ladders	24
Ladder active area	192 mm × 19.2 mm
Number of barrels	2
Inner barrel (6 ladders)	r = 1.5 cm
Outer barrel (18 ladders)	r = 4.5 cm
Frame read time	4 ms
Pixel read rate, after zero suppression	63 MHz
Ladder % X_0	0.26%

STAR Tracking Environment

Luminosity Au + Au	1×10^{27} Hz/cm^2
dN/dη (min bias)	170
min bias cross section	10 barns
interaction diamond size, σ	30 cm

STAR Tracking Environment

	MVD Outer Layer	MVD Inner Layer
Radius	4.5 cm	1.5 cm
Hit Flux	4,300 Hz/cm^2	18,000 Hz/cm^2
Hit Density 4 ms Integration	$17/cm^2$	$72/cm^2$
Projected Tracking σ, 1GeV/c	180 μm	100 μm
Background Hit Assignment	3.3%	4.4%

	MVD Outer Layer	MVD Inner Layer
Radius	4.5 cm	1.5 cm
Hit Density Au +Au Central Collision	$1.8/cm^2$	$7.4/cm^2$
Projected Tracking σ, 1 GeV/c	180 μm	100 μm
Background Hit Assignment	0.3%	0.5%

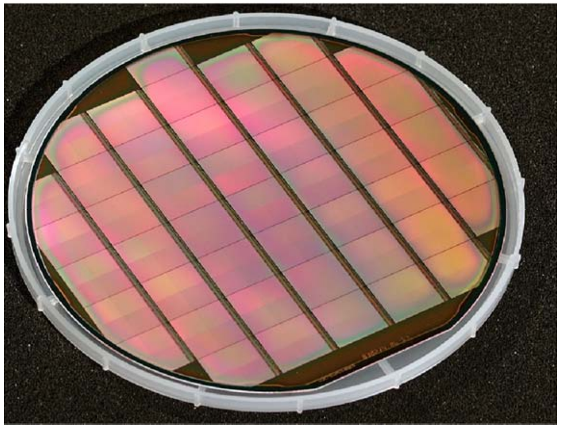
MAPS Silicon Schedule (LEPSI/IReS)

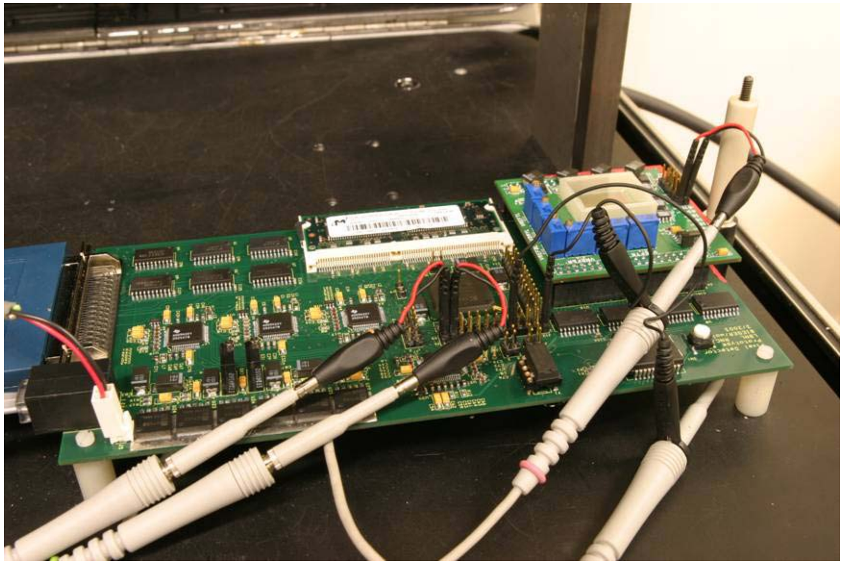
Jan – May '04	Design MIMOSTAR-1 Prototype
Sept '04 – Jan '05	Test MIMOSTAR-1
Sept '04 – Mar '05	Design MIMOSTAR-2 final prototype
Oct '05	MIMOSTAR-2 chips on final ladder prototype
2006	Receive and test final sensors

Detector installation 2008

MIMOSTAR LEPSI/IReS for first generation STAR detector

- **Based on MIMOSA-5, full wafer engineering run – significant readout infrastructure on chip**
- **LBNL test board works (Bieser and Gareus)**
  - 2 by 2 cm MIMOSA-5 chip
  - LBNL development using 4 commercial 50 MHz 14 bit ADCs
- **MIMOSTAR Design**
  - 1.9cmX1.9cm active
  - 30μmX 30μm pixels 409600 pixels/chip
  - Continuous frame read at 4-8ms per frame
  - 52 mW per chip
  - Analogue readout options
    - Single fast option 50 to100 MHz
    - 10 at 10 MHz option





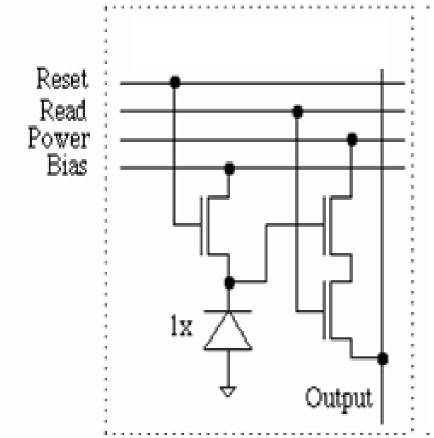
Advanced APS designs for generation 2

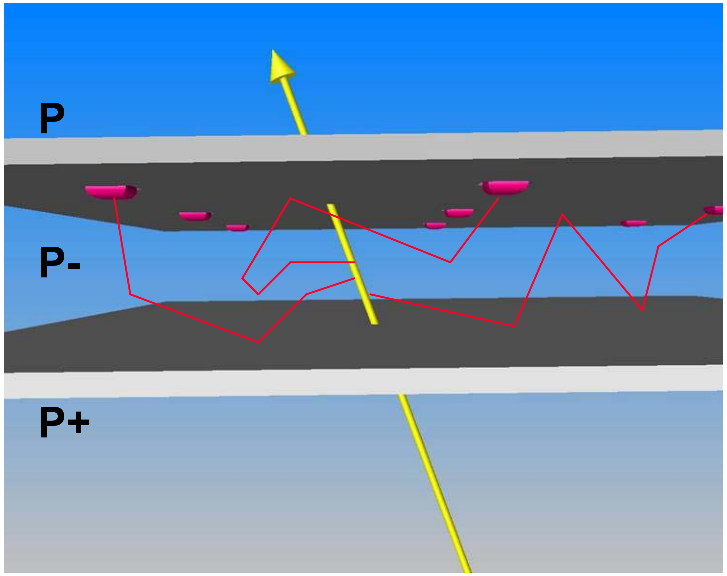
- Goal, increase speed with on detector chip zero suppress and by avoiding full frame readout
- Requires improvements in signal to noise
  - Noise sources
    - KTC reset noise
    - Fixed pattern noise, threshold variation, leakage current variation
- Programs at LEPSI/IReS
- Programs at UCI/LBNL (Stuart Kleinfelder, Yandong Chen)
  - Photogates
  - CDS clamp circuit
  - Active Reset

Photo gate purpose - addresses standard diode limitations

- Correlated Double Sample on chip
- Improved charge collection

Standard APS diode structure

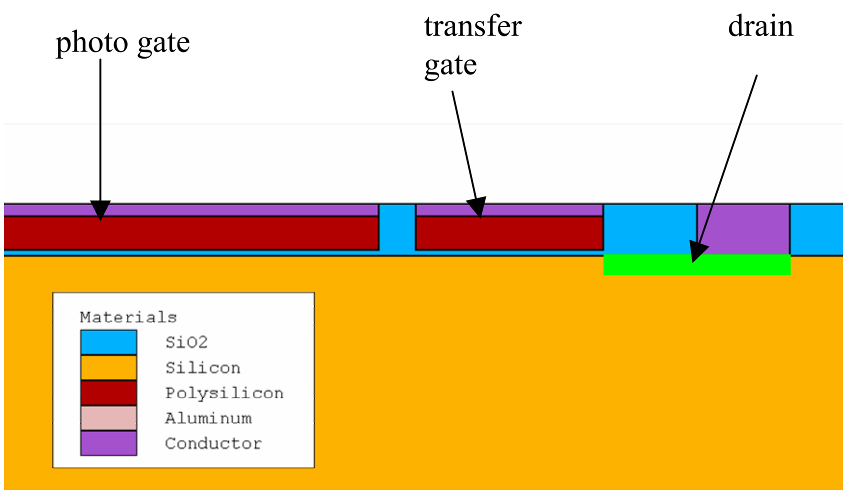


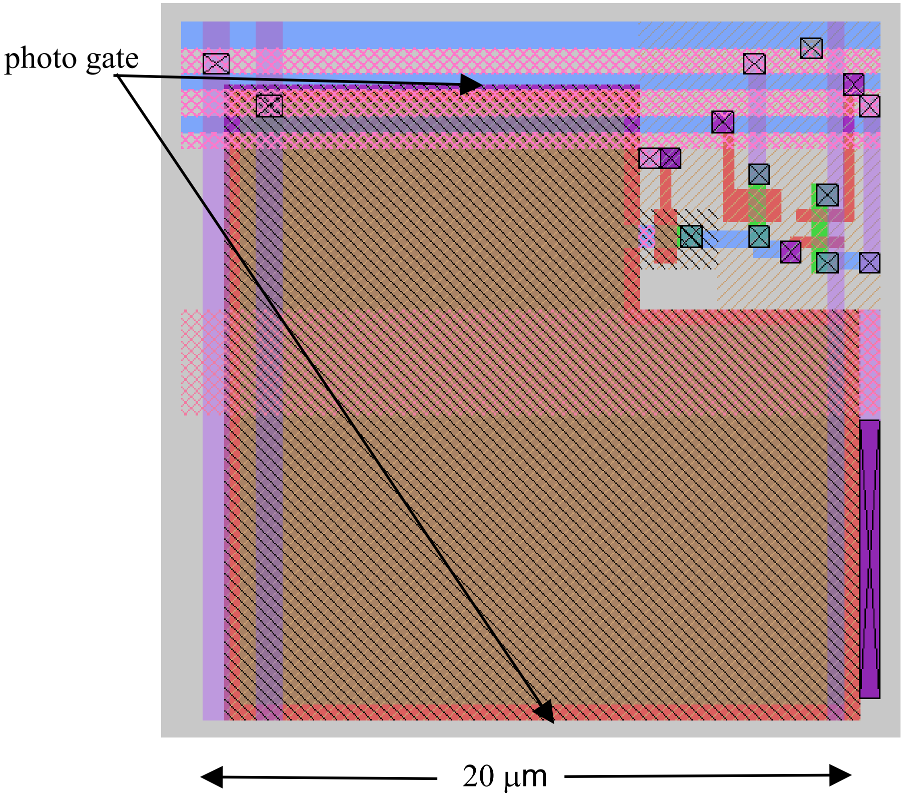


Standard diode geometry

Photo-gate geometry

- Large photo gate area for collection
- Transfer to small capacitance node

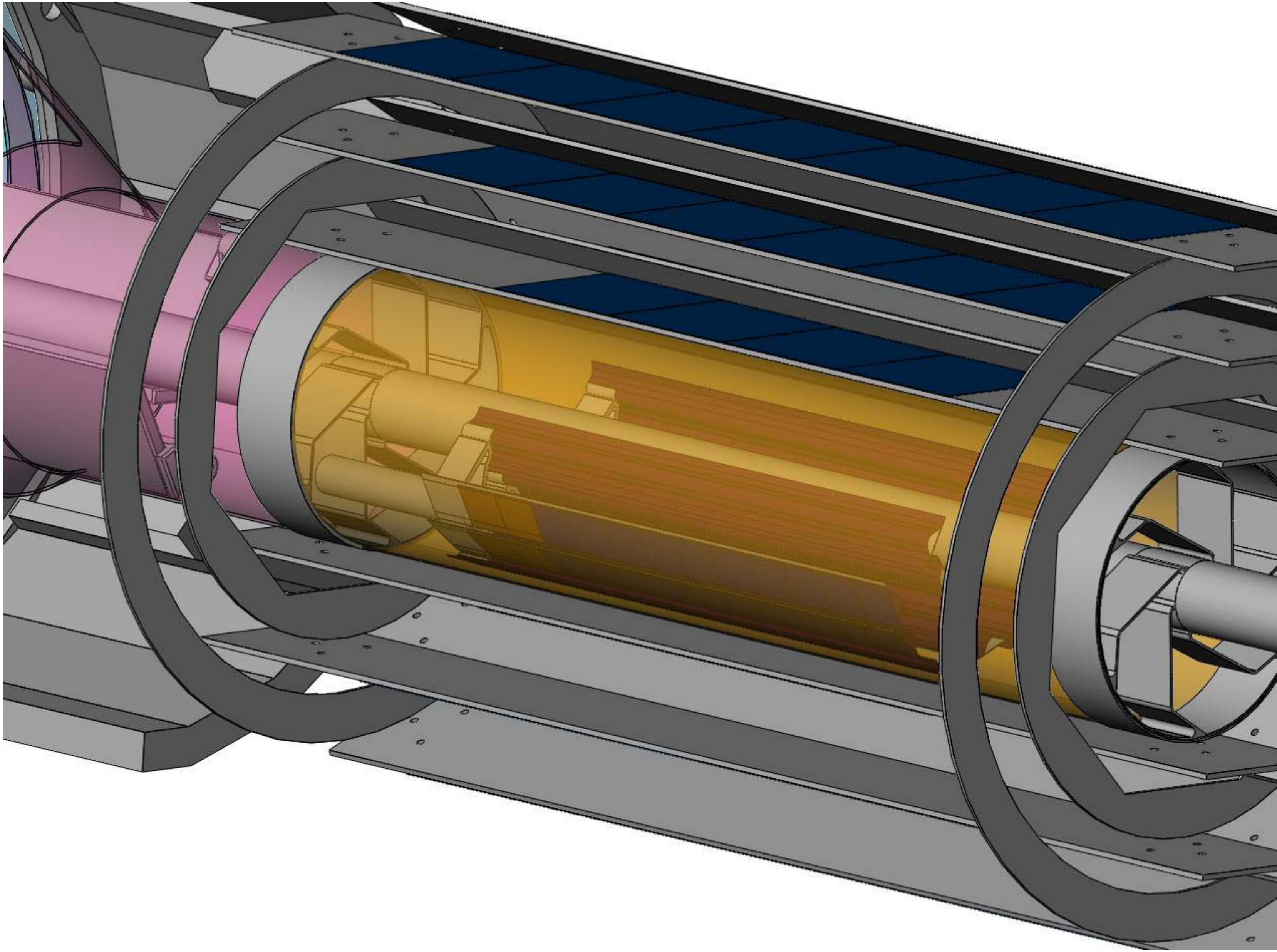




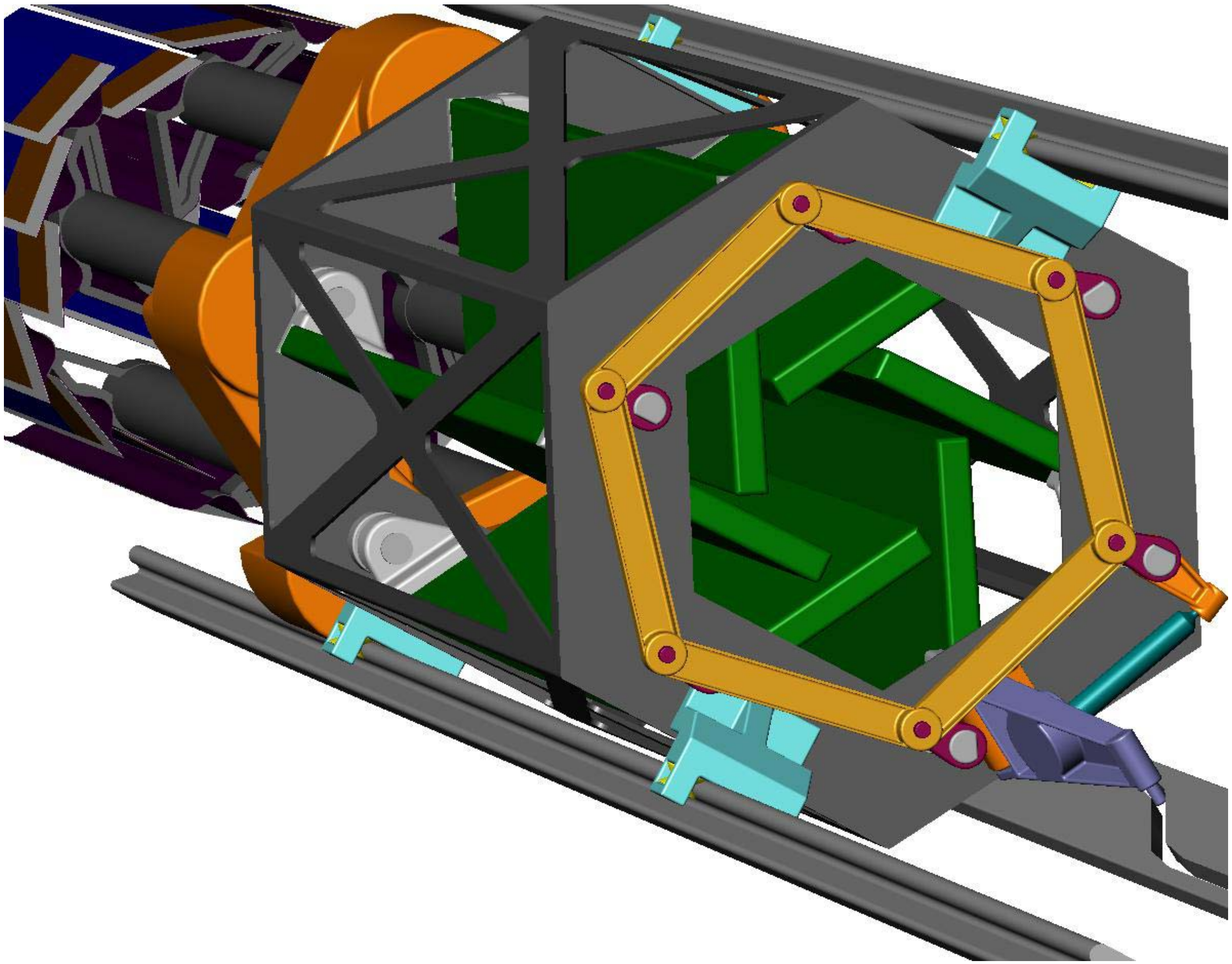
Mechanical

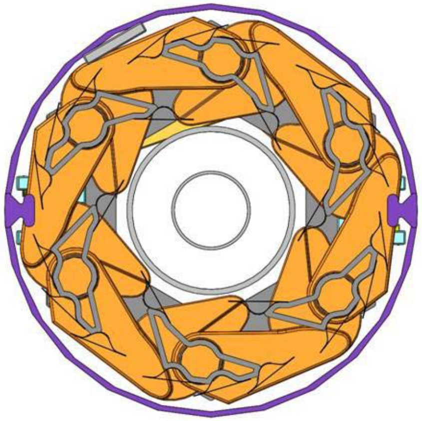
- Rapid insertion and removal
  - Rapid replacement - insurance for beam excursion damage
- Minimum thickness: 50 Micron Si Detector – 50 Micron Si Readout chip
- Air cooling
- Composite beam pipe?

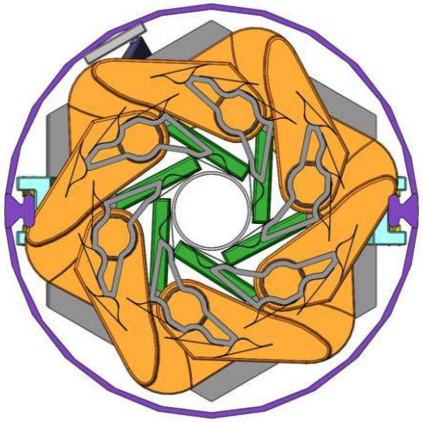
Inner STAR model – SVT and micro-vertex



Cam driven iris concept for fast insertion and removal



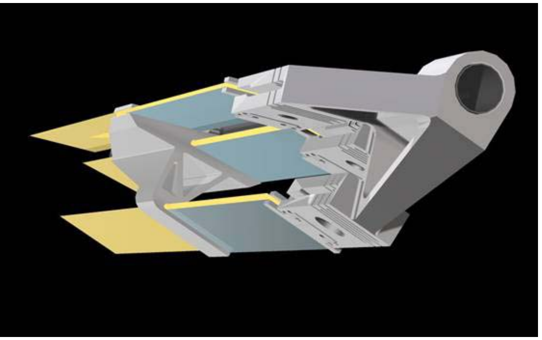


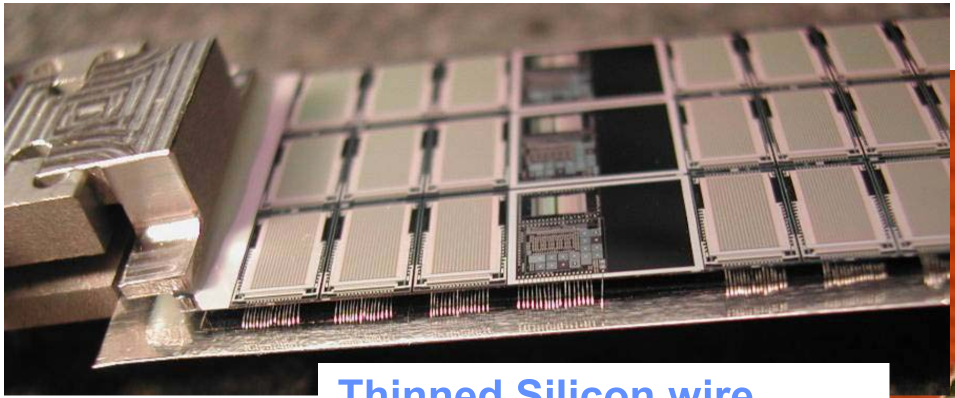


1^{st} layer radiation length fraction

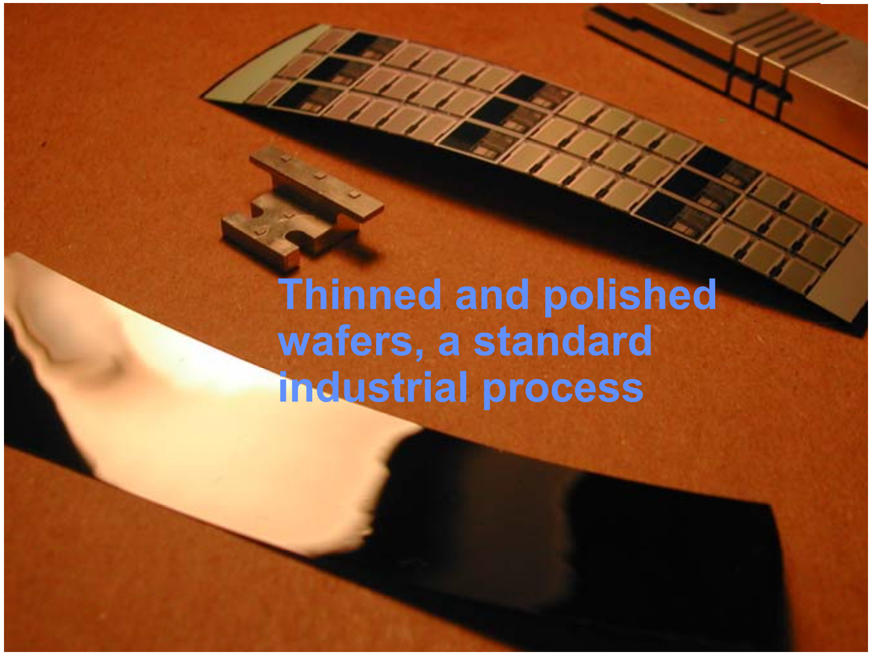
material	X_0 (cm)	material thickness (μm)	$\%X_0$
Beryllium (beam pipe)	35	500	0.14
Aluminum (conductors)	9.0	10	0.007
Silicon (detector + readout)	9.4	112	0.12
Kapton (cable)	35	170	0.05
Adhesive	35	85	0.024
Carbon Composite	28	174	0.062

50 μm Silicon

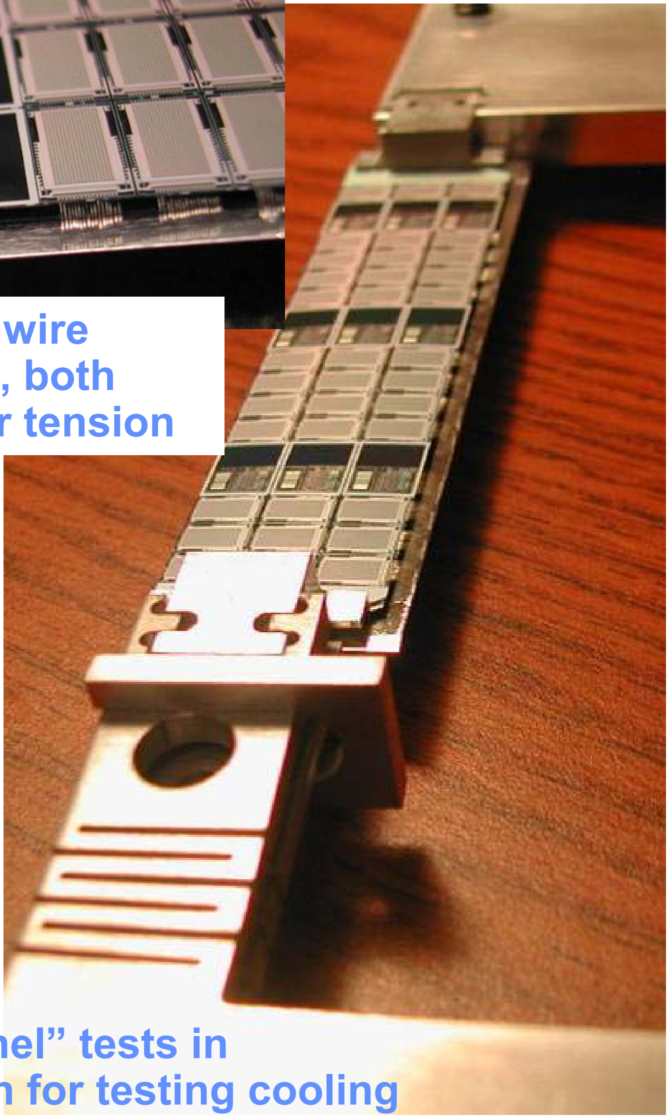




Thinned Silicon wire bonded to cable, both supported under tension



Thinned and polished wafers, a standard industrial process



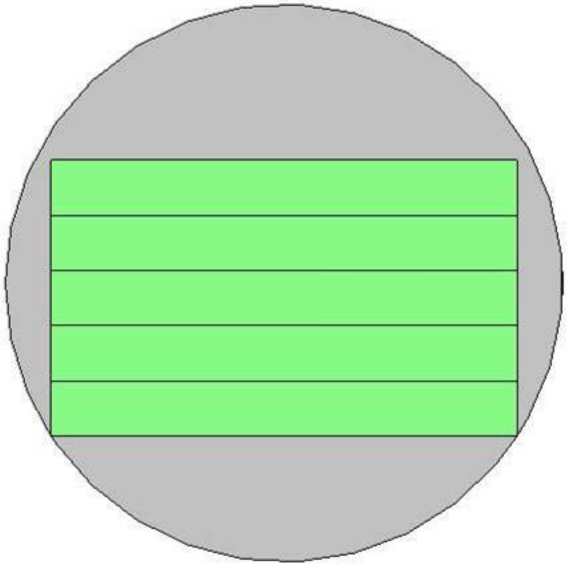
"Wind tunnel" tests in preparation for testing cooling and vibration stability

Silicon Cost

Ladders per Wafer	5
Ladders per Detector	24
Yield	60%
Number of Detector Copies	4
Number of Wafers	32
Wafer Cost Each	2-5 k$
Wafer Costs	64-160 k$
Mask Cost	150-200 k$
Total	**214-360 k$**

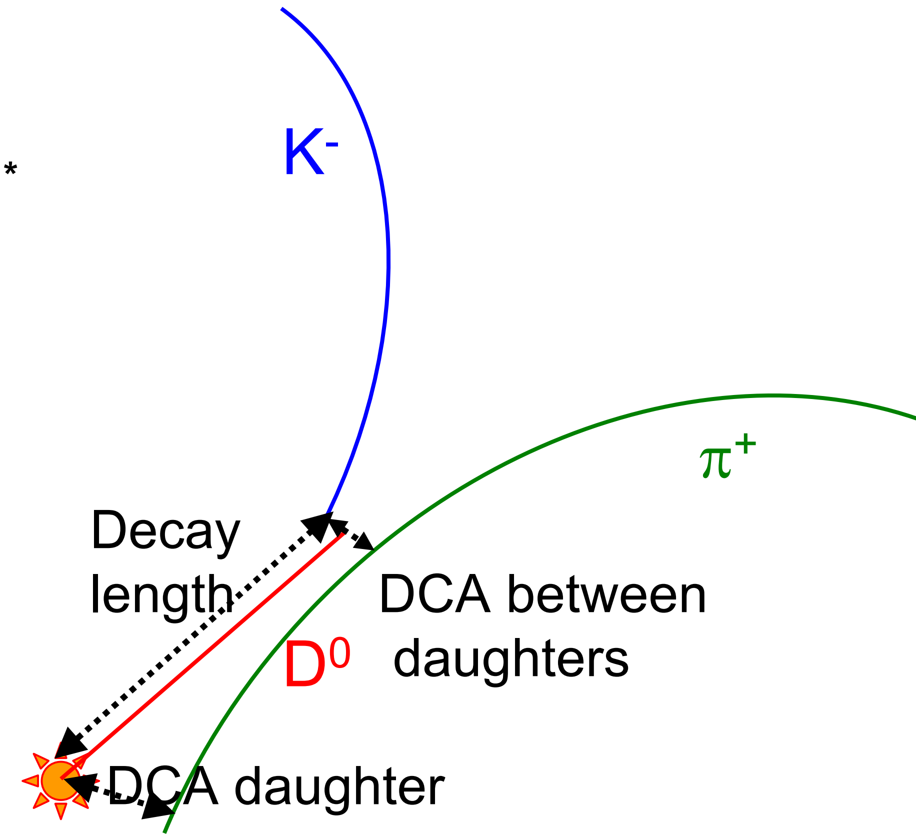
8 inch wafers

20 mm x 170 mm ladders



Cuts tuned by optimizing Signal²/Background

- **Daughter**
  - **Dca daughter > (200 μm – momentum / 2GeV/c * 200 μm)**
  - **Good quality TPC tracks**
- **D^0**
  - **Decay length > 100 μm**
  - **Cos(θ) > 0.96**
  - **Dca between daughters < 100 μm**
  - **|Minv-1.865| < 2 σ = 40 MeV**
  - **|cos(θ*)| < 0.8**



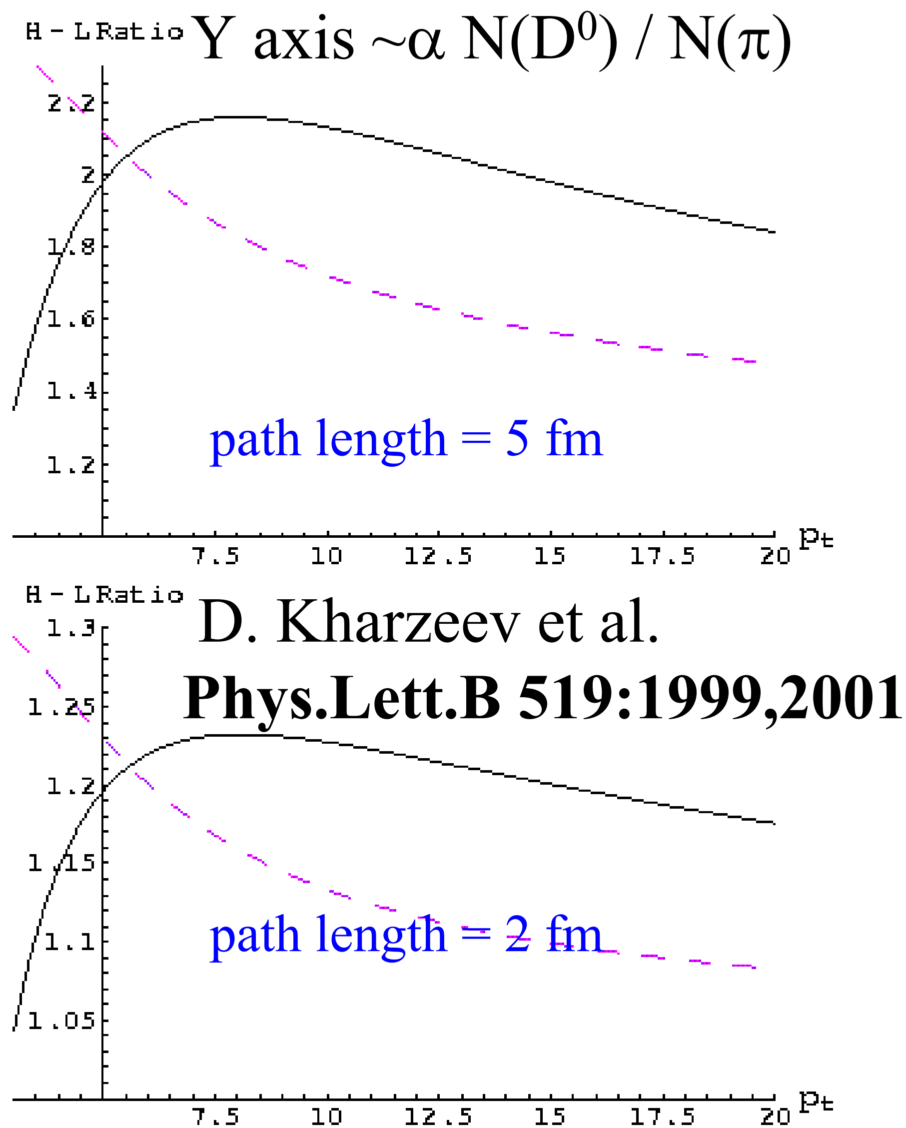
$$\cos(\theta) = \frac{\vec{V} \cdot \vec{P}}{|\vec{V}| \cdot |\vec{P}|}$$

$$\vec{P} = \vec{P}_K + \vec{P}_\pi$$

$$\vec{V} = \text{DVertex} - \text{PrimaryVertex}$$

Heavy quark energy loss

- Energy loss smaller for heavy than light quarks due to
  - Dead cone effect
  - Ter-Mikayelian effect
    - Gluon radiation smaller in-medium than in vaccum (nucl-th/0305062)
- Heavy quark allow differential study of energy loss



Trigger on e+/e- from open beauty (charm?) and clean up with mVertex

- $B \rightarrow e^{+/-}$ + hadron + X
  - High pt $e^{+/-}$ triggered by EMC
  - Remove hadronic background by associating the e+/- with a hadron at a displaced vertex