# Forward Tracking Upgrade and Silicon-Based Design R&D

STAR Upgrades Workshop 2015 @ USTC

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# Outline

- Physics Motivation
- Forward Tracking Consideration
- A Silicon-Based Design
- Summary

# Key measurements for polarized pp scattering in 2021-2022

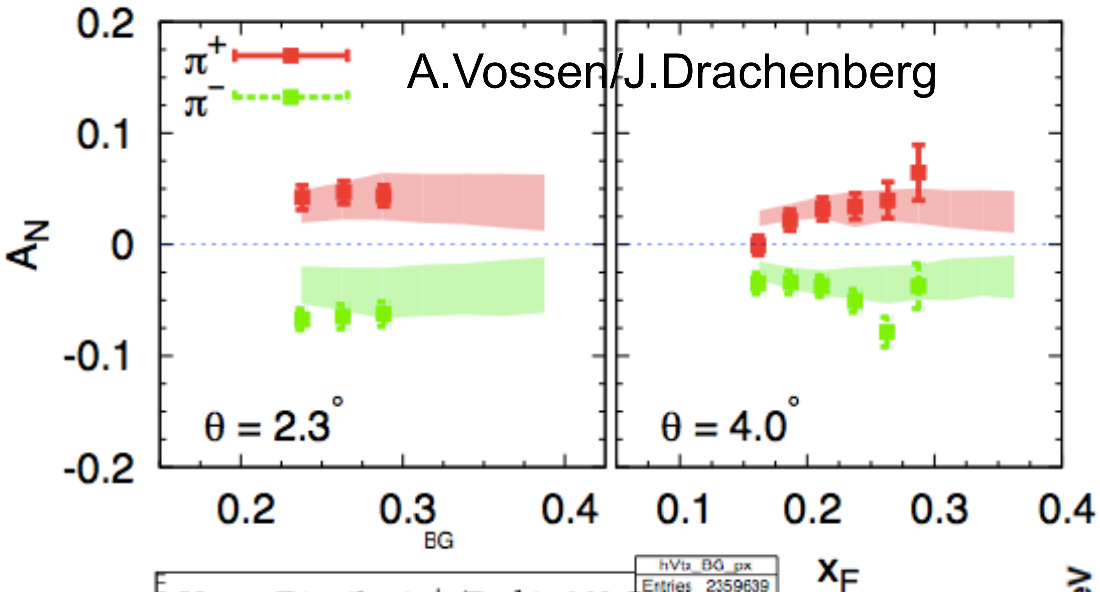
| deliverables | observables | what we learn | requirements | comments/competition |
|---|---|---|---|---|
| HP13 (2015) **Test unique QCD predictions for relations between single-transverse spin phenomena in p-p scattering and those observed in deep-inelastic lepton scattering.** | $A_N$ for $\gamma$ (?), $W^{+/-}$, $Z^0$, DY | Do TMD factorization proofs hold. Are the assumptions of ISI and FSI color interactions in pQCD are attractive and repulsive, respectively correct | high luminosity trans pol pp at $\sqrt{s}$=500 GeV DY: needs instrumentation to suppress QCD backgr. by $10^6$ at 3<y<4 | $A_N$ DY: >=2020 might be to late in view of COMPASS $A_N$W,Z: can be done earlier, i.e. 2016 |
| HP13 (2015) and flavor separation | $A_N$ for $\gamma$, charged identified(?) hadrons, jets and diffractive events in pp and pHe-3 | underlying subprocess causing the big $A_N$ at high $x_f$ and y | high luminosity trans pol pp at $\sqrt{s}$=200 GeV, (500 GeV jets ?) He-3: 2 more snakes; He-3 polarimetry; full Phase-II RP | the origin of the big $A_N$ at high $x_f$ and y is a legacy of pp and can only be solved in pp what are the minimal observables needed to separate different underlying subprocesses |
| transversity and collins FF | IFF and $A_{UT}$ for collins observables, i.e. hadron in jet modulations $A_{TT}$ for DY | TMD evolution and transversity at high x cleanest probe, sea quarks | high luminosity trans pol pp at $\sqrt{s}$=200 GeV & 500 GeV | how does our kinematic reach at high x compare with Jlab12 $A_{TT}$ unique to RHIC |
| flavour separated helicity PDFs polarization dependent FF | $A_{LL}$ for jets, di-jets, h/$\gamma$-jets at rapidities > 1 $D_{LL}$ for hyperons | $\Delta g(x)$ at small x $\Delta s(x)$ and does polarization effect fragmentation | high luminosity long. pol pp at $\sqrt{s}$=500 GeV Forward instrumentation which allows to measure jets and hyperons. Instrumentation to measure the relative luminosity to very high precision | eRHIC will do this cleaner and with a wider kinematic coverage |
| Searches for a gluonic bound state in central exclusive diffraction in pp | PWA of the invariant mass spectrum in pp→p'$M_X$p' in central exclusive production | can exotics, i.e. glue balls, be seen in pp | high luminosity pp at $\sqrt{s}$=200 GeV & 500 GeV full Phase-II RP | how does this program compare to Belle-II & PANDA |

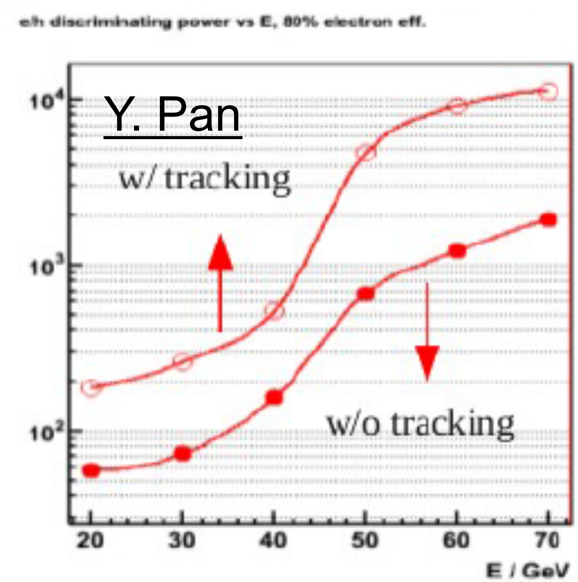

Z.Ye, 9/22/2015

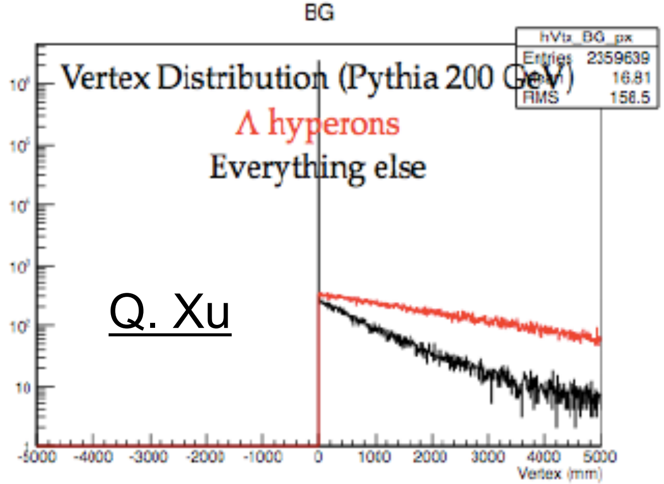
# Key measurements for p↑A scattering in 2021-2022

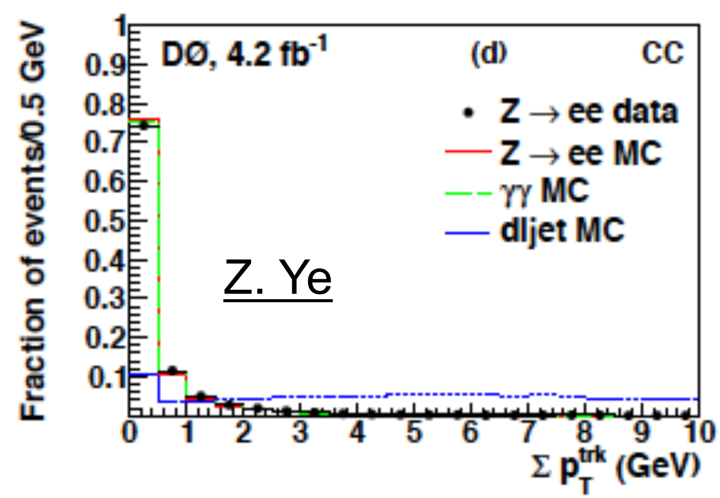
| deliverables | observables | what we learn | requirements | comments/competition |
|---|---|---|---|---|
| DM8 (2012)<br>determine low-x gluon densities via p(d) A | direct photon<br>potentially correlations, i.e. photon-jet | initial state g(x) for AA-collisions | A-scan | LHC and inclusive DIS in eA<br>eA: clean parton kinematics<br>LHC wider/different kinematic reach; NA61 |
| impact parameter dependent g(x,b) | c.s. as fct. of t for VM production in UPC (pA or AA) | initial state g(x,b) for AA-collisions | high luminosity,<br>clean UPC trigger | LHC and exclusive VM production in eA<br>eA: clean parton kinematics<br>LHC wider/different kinematic reach |
| "saturation physics" | di-hadron correlations, γ-jet, h-jet & NLO DY, diffraction<br><br>pT broadening for J/Ψ & DY -> $Q_s$ | is the initial state for AA collisions saturated<br><br>measurement of the different gluon distributions CNM vs. WW | capability to measure many observables precisely<br>large rapidity coverage to very forward rapidities<br>polarized pA<br>A scan | complementary to eA, tests universality between pA and eA |
| CNM effects | $R_{pA}$ for many different final states $K^0$, p, K, $D^0$, J/Ψ, .. as fct of rapidity and collision geometry | is fragmentation modified in CNM<br>heavy quarks vs. light quarks in CNM | A scan<br>to tag charm in forward direction → μ-vertex | separation of initial and final state effects only possible in eA |
| long range rapidty correlations "ridge" | two-particle correlation at large pseudo-rapidity $\Delta\eta$ | do these correlations also exist in pA as in AA | tracking and calorimetry to very high rapidities | interesting to see the √s dependence of this effect compared to LHC |
| is GPD $E_g$ different from zero | $A_{UT}$ for J/Ψ through UPC Ap↑ | GPD $E_g$ is responsible for $L_g$→ first glimpse | | unique to RHIC till EIC turns on |
| underlying subprocess for $A_N(\pi^0)$ | $A_N$ for $\pi^0$ and γ | underlying subprocess for $A_N(\pi^0)$<br>sensitivity to $Q_s$ | good $\pi^0$ and γ reconstruction at forward rapidities | resolving a legacy in transversely polarized pp collisions |

# What FTS Does – p+p and p+A



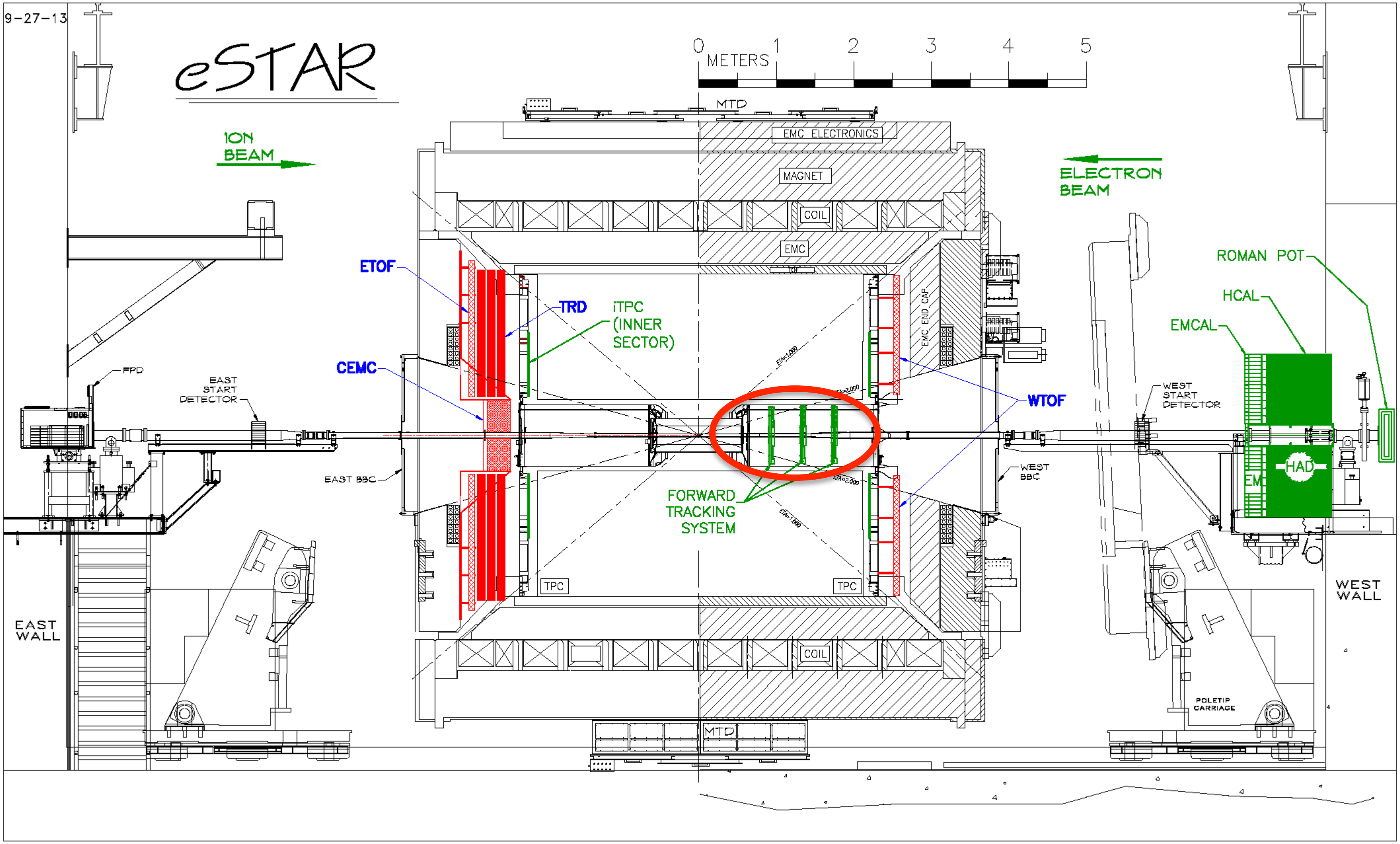



# Forward Tracking Requirements

- pp/pA/ep/eA physics - forward:
  - charge separation for $\pi^+/\pi^-$, di-hadron, Drell-Yan, J/psi
    ➔ low mass, good ϕ resolution
  - e/h discrimination for Drell-Yan, J/psi
    ➔ good ϕ resolution
  - e/γ discrimination for direct photon, Drell-Yan, J/psi
    ➔ low mass, high efficiency
  - vertex and reco for hyperon, jets
    ➔ large η coverage, good ϕ resolution
  - DCA for heavy flavor
    ➔ good r or ϕ resolution
- AA physics – forward :
  - Long range correlation
    ➔ good ϕ resolution, large η coverage
  - e/h discrimination for J/psi, Upsilon
    ➔ good ϕ resolution

Low mass
Good phi resolution
Large eta coverage
High efficiency

# Forward Tracking System

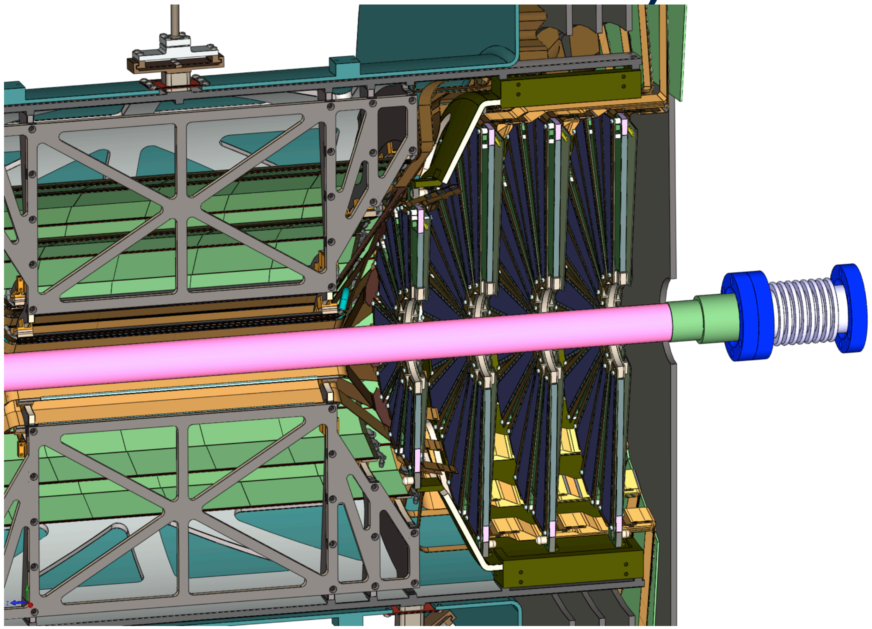




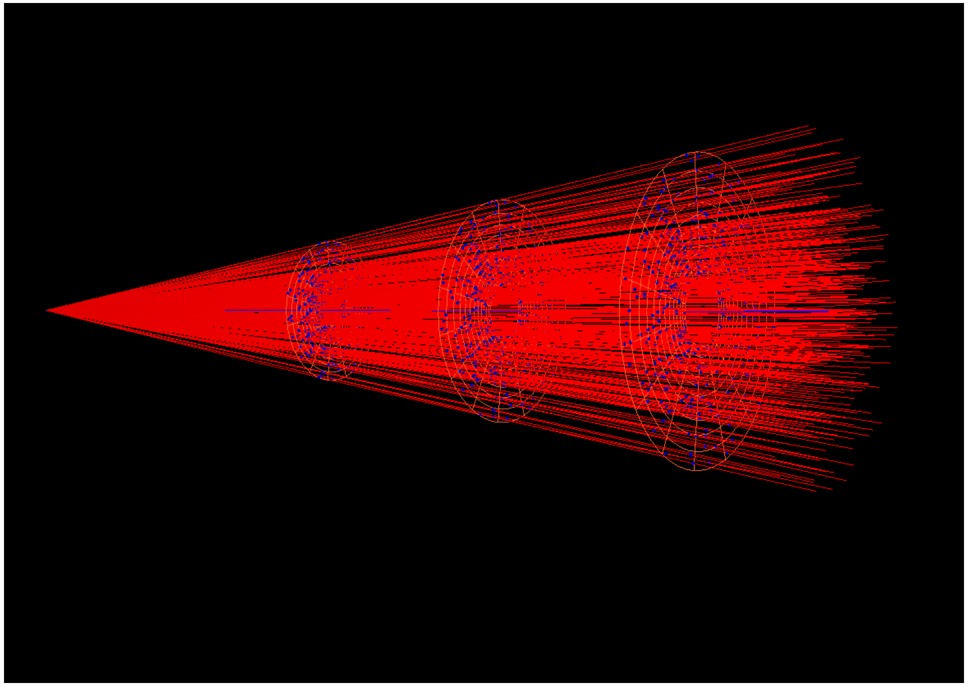

*Z.Ye, 9/22/2015*

# Forward Tracking Options

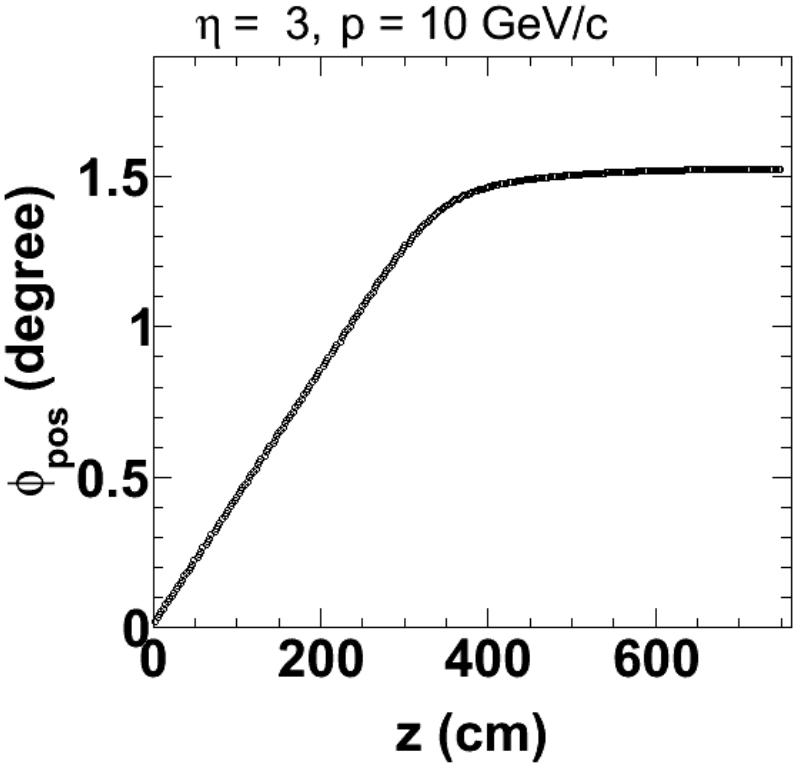
- Gas Electron Multiplier (STAR FGT-like)
- Silicon Pixel (HFT+ MAPS)
- Silicon Ministrip (PHENIX FVTX-like)



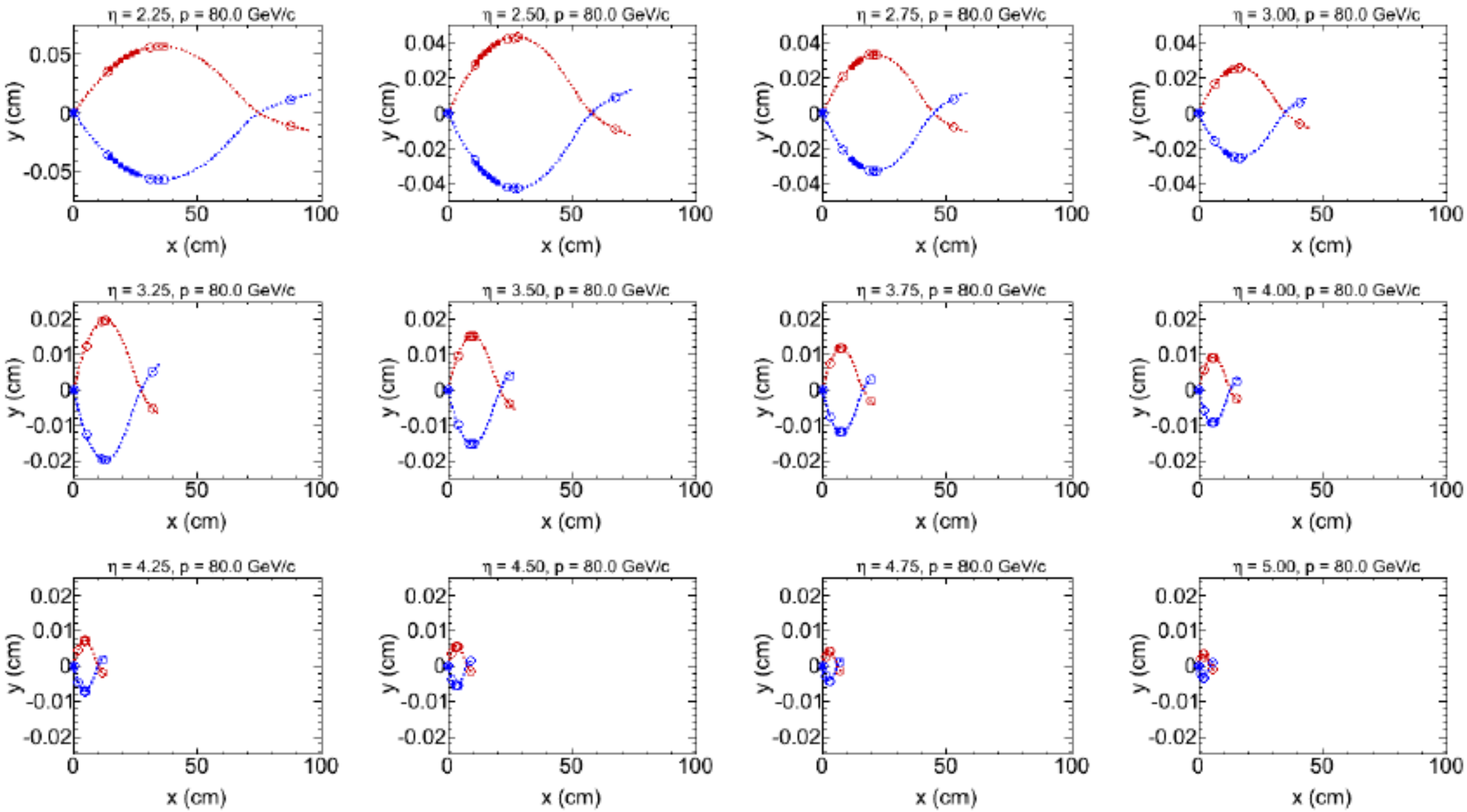
# Forward Tracking System (Alexander Schmah@LBNL)



STAR Magnetic Field Used for Tracking



# Forward Tracking System (Alexander Schmah@LBNL)



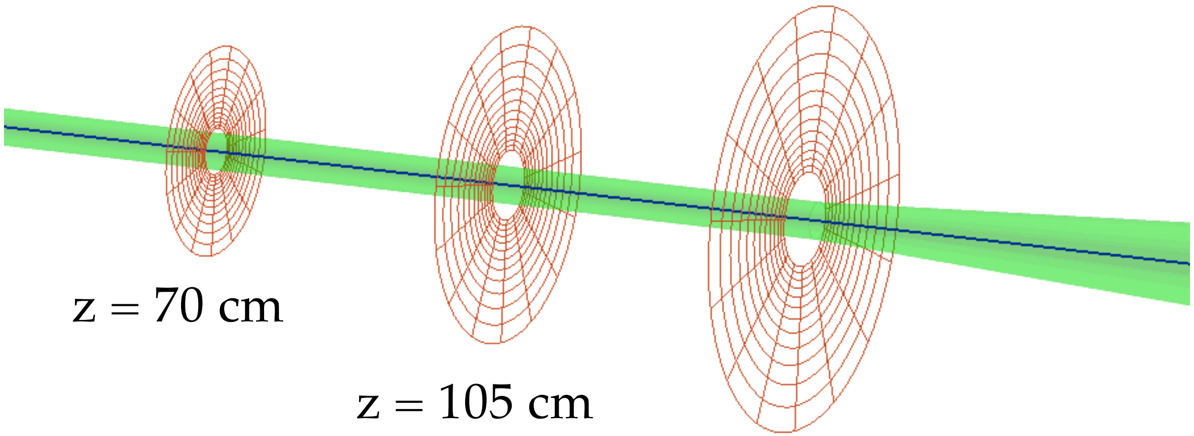

- Open symbols: hits at : z = 65 cm,145 cm,160 cm,170 cm, and 410 cm

filled symbols: FTS points



*Z.Ye, 9/22/2015*

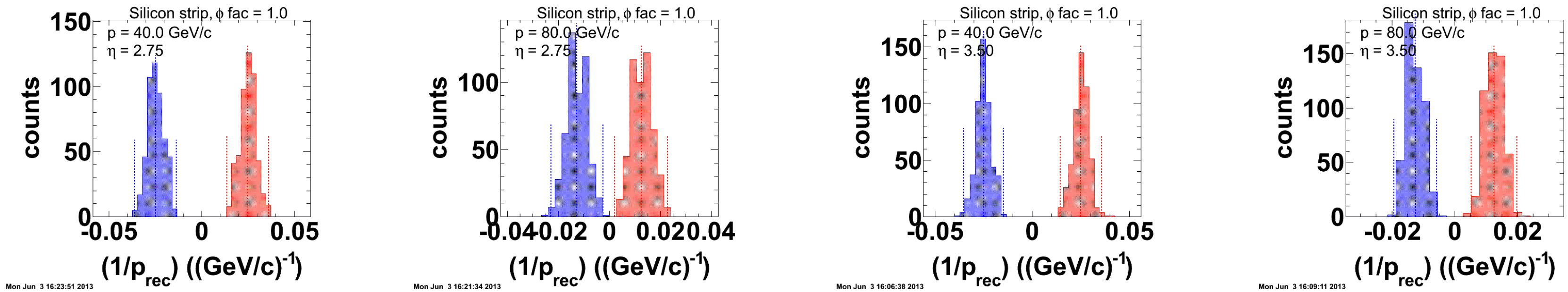
# A Three Plane Layout

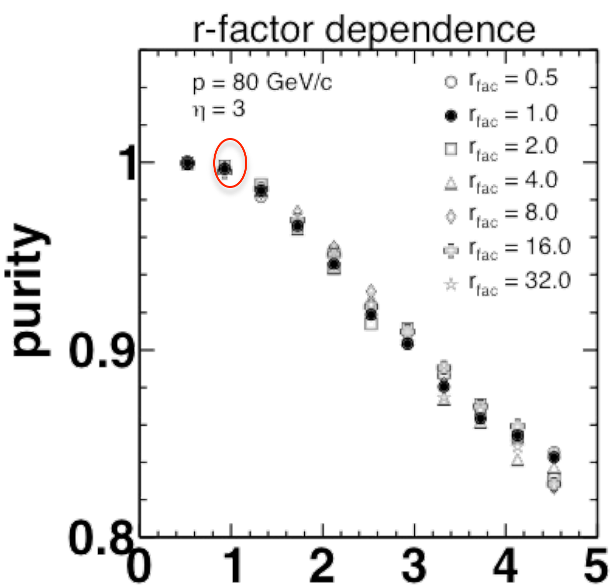


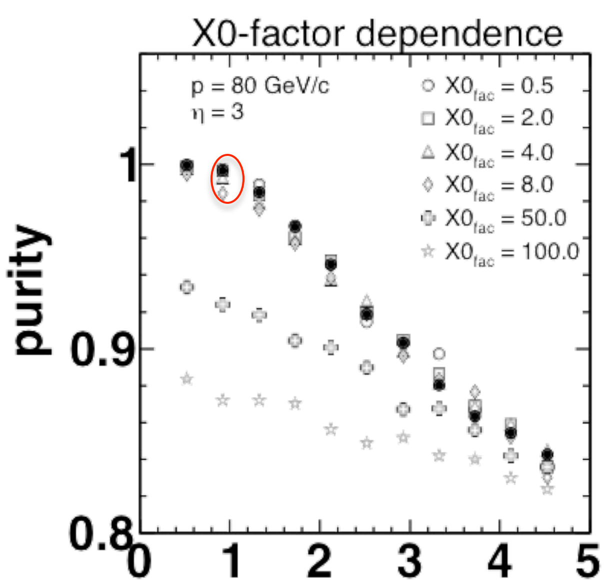

**Different from PHENIX FVTX which has pitch**:
~100 μm in r
~ a few mm in phi

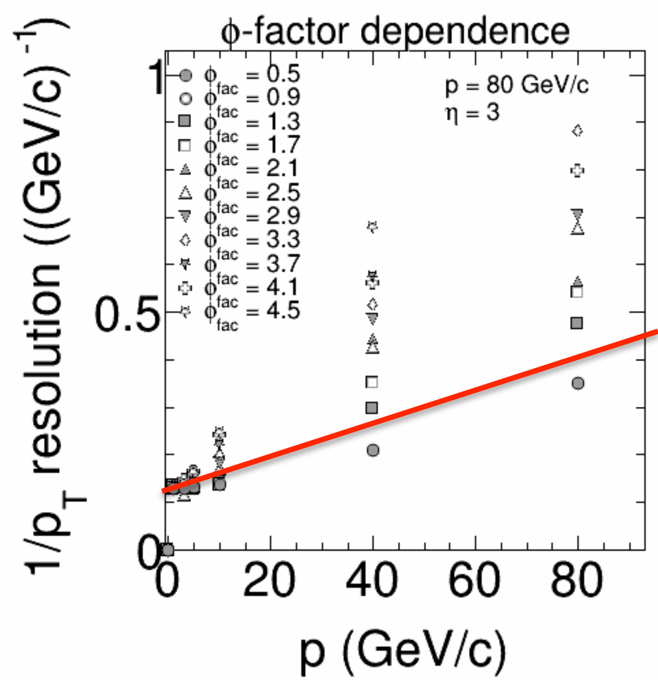
| in [mm] | $r_1$ | $r_2$ | $r_3$ | $r_4$ | $r_5$ | $r_6$ | $r_7$ | $r_8$ | $r_9$ | $r_{10}$ | $r_{11}$ | $r_{12}$ | $r_{13}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| plane 1 | 25.7 | 29.1 | 32.9 | 37.3 | 42.3 | 48.0 | 54.4 | 61.6 | 69.9 | 79.2 | 89.9 | 102.0 | 115.7 |
| ϕ pitch | 0.11 | 0.12 | 0.15 | 0.17 | 0.19 | 0.21 | 0.24 | 0.28 | 0.31 | 0.34 | 0.38 | 0.43 | |
| plane 2 | 38.5 | 43.6 | 49.4 | 56.0 | 63.5 | 71.9 | 81.5 | 92.4 | 104.8 | 118.9 | 134.8 | 152.9 | 173.5 |
| ϕ pitch | 0.17 | 0.18 | 0.22 | 0.26 | 0.28 | 0.32 | 0.36 | 0.42 | 0.46 | 0.51 | 0.56 | 0.64 | |
| plane 3 | 51.3 | 58.1 | 65.9 | 74.7 | 84.6 | 95.9 | 108.7 | 123.3 | 139.8 | 158.5 | 179.7 | 203.9 | 231.4 |
| ϕ pitch | 0.22 | 0.25 | 0.29 | 0.34 | 0.38 | 0.43 | 0.48 | 0.56 | 0.61 | 0.68 | 0.75 | 0.85 | |

# Performance Study from Simulation (Alexander Schmah@LBNL)



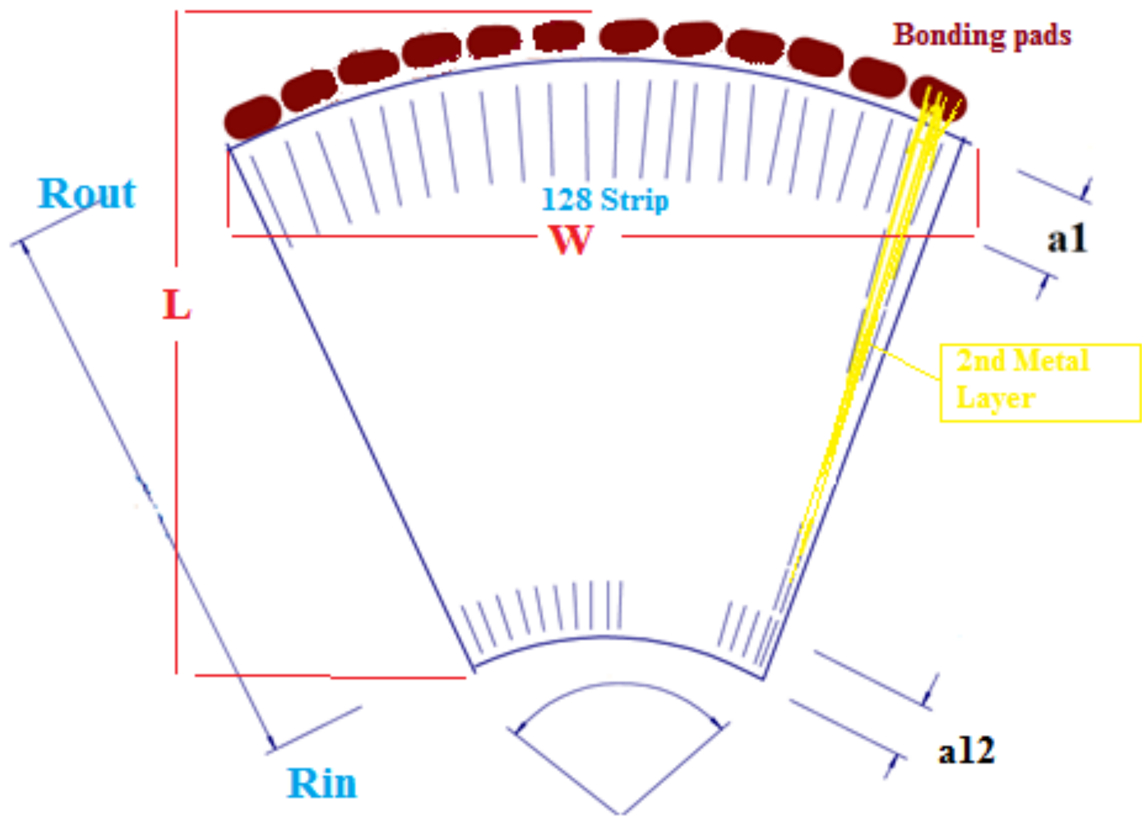




https://drupal.star.bnl.gov/STAR/system/files/aschmah_eSTAR_Forward_Tracking_ULCA_8_2013_V4.pdf

# Wedge Structure for Silicon FTS

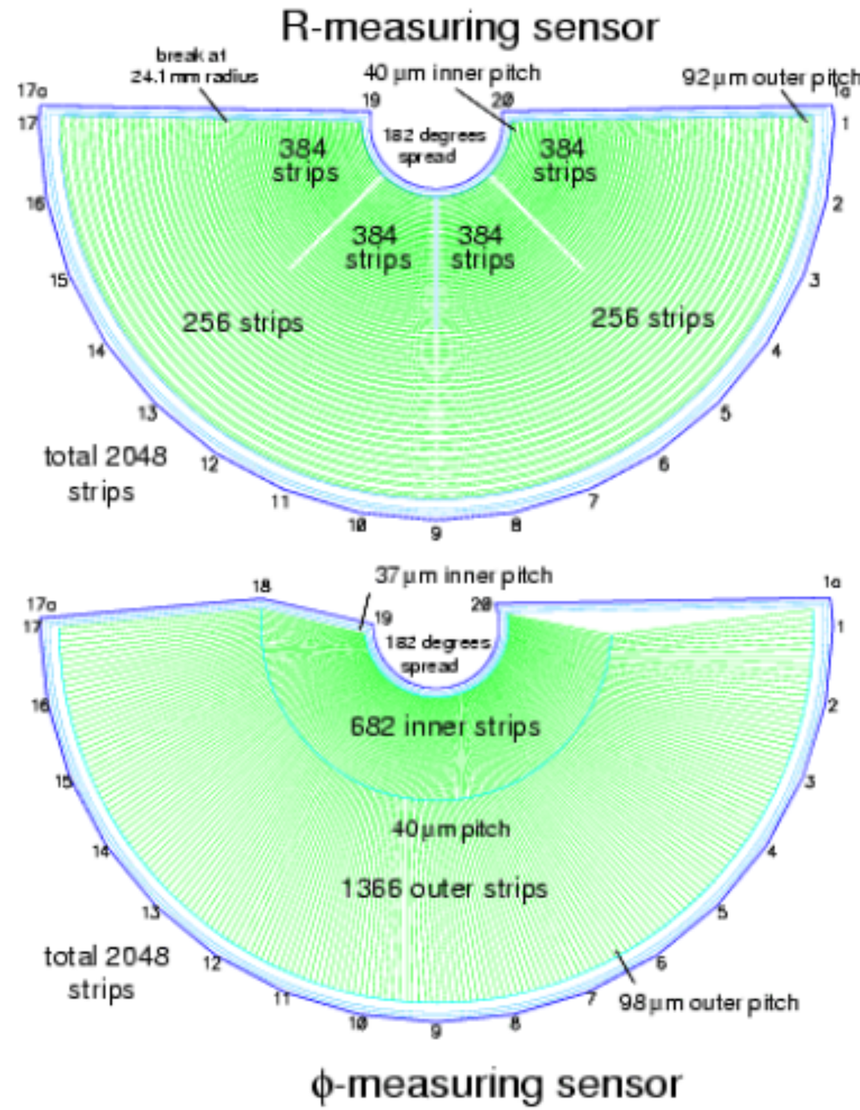


THE UNIVERSITY of LIVERPOOL

# Requirements (2)

- **Trigger** (see talk by Niels Tuning)
  - **FAST** 2D (***rz***) and 3D (***rz***$\phi$) standalone tracking for **L1 Trigger**: **Choose RΦ geometry!**
  - Rejection of multiple interactions
- **Baseline Sensor Design**
  - Sensors: 7mm>R>44mm (Active area 8mm to 43mm)
  - 182° angular coverage
  - R sensors
    - Pitch 40μm to 92μm
    - 45° inner, 90° outer sections
  - $\phi$ sensors
    - Pitch 37μm to 40μm and 40μm to 98μm
    - Double stereo angle

## LHCb VELO Detector



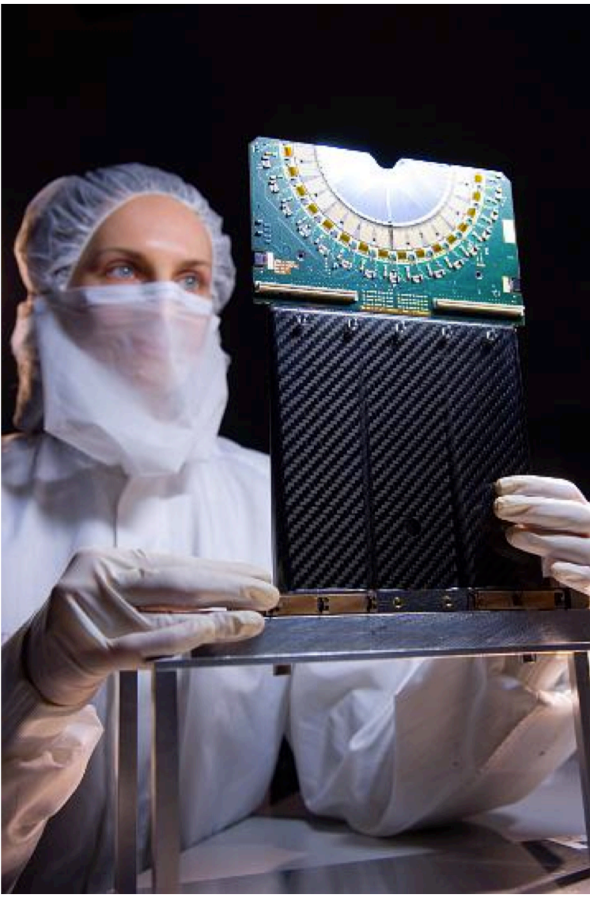
# Requirements (2)

- Trigger (see talk by Niels Tuning)
  - **FAST** 2D (*rz*) and 3D (*rzϕ*)

## LHCb VELO Detector

R-measuring sensor

ϕ-measuring sensor



98µm

- Double stereo angle

# R&D Timescale and Deliverable

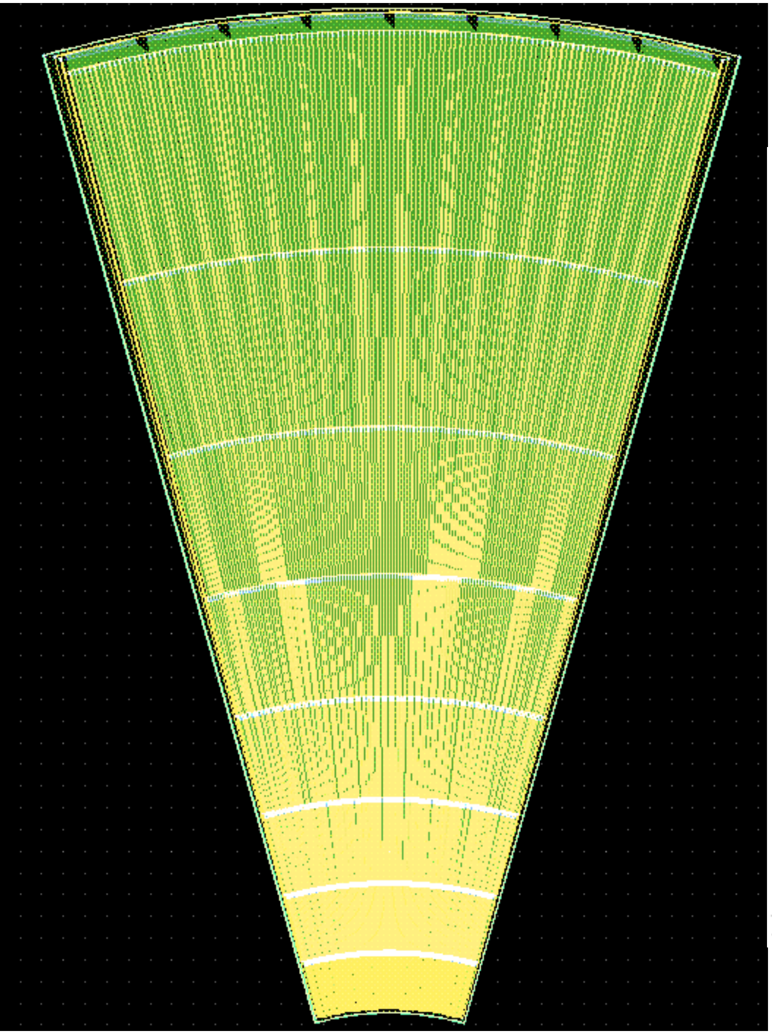
**Schedule**

- Finalize sensor wafer layout and place order – Spring 2016
- Sensor QA test – Fall 2016
- Prototype assembly ~ Winter 2016/Spring 2017
- Prototype full performance test ~ Summer/Fall 2017

**Deliverable**

- Proof-of-principle and optimized sensor design and FTS layout

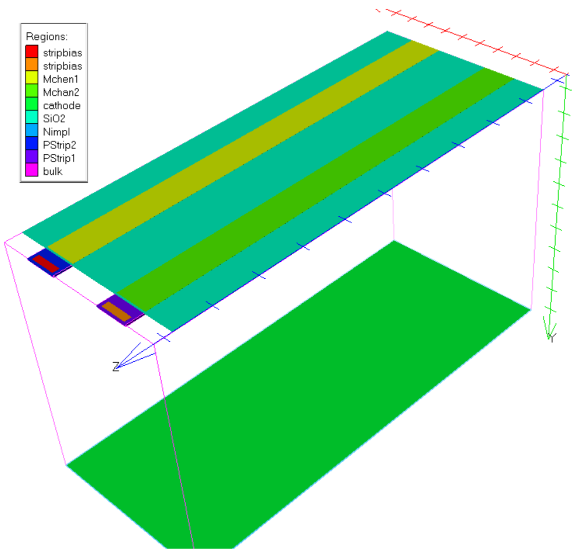
# FTS Sensor Design (ongoing@UIC)

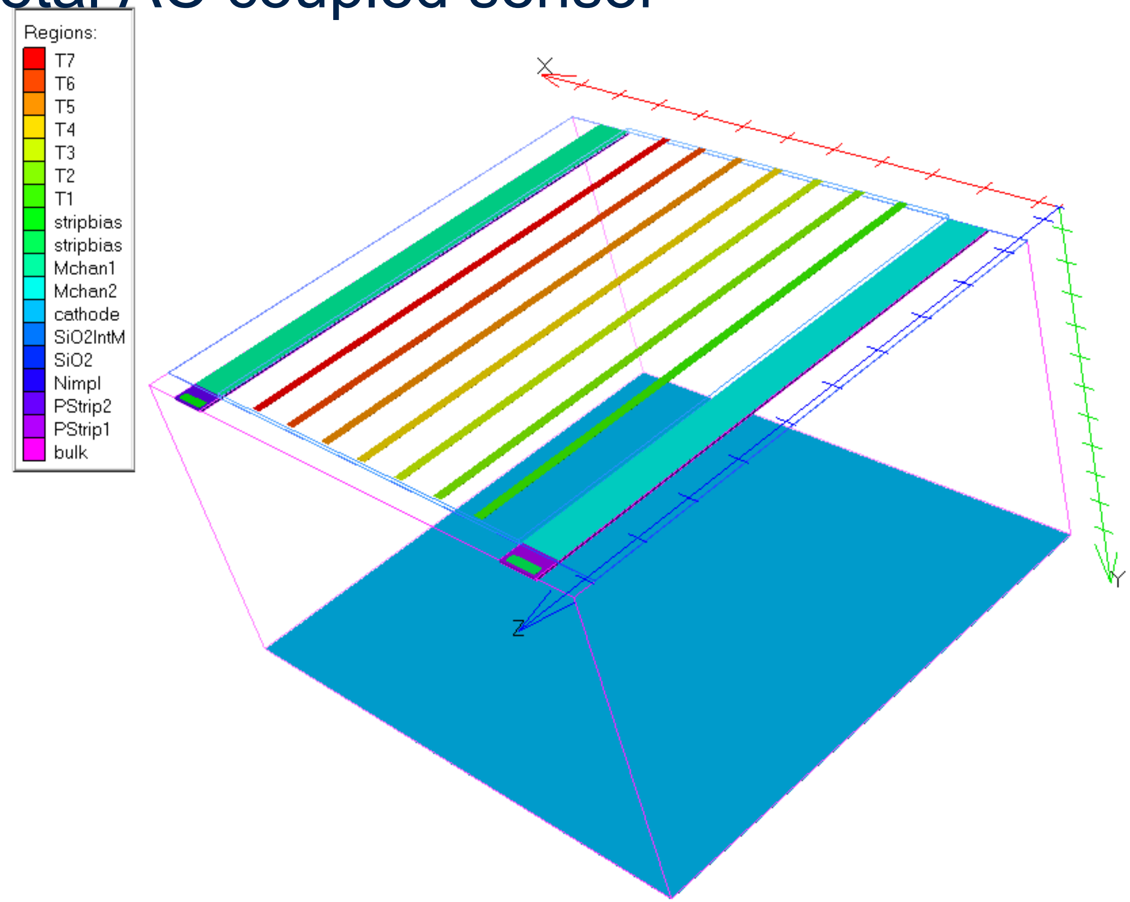


1. Layer **1** for Al layer at back-plane .
2. Layer 2 for N++ Implant at tailplane.
3. Layer 3 for N-Implant.
4. Layer **5** for P-implant .
5. Layer 7 for Poly-Silicon for Bias resistor .
6. Layer 9 for Metal-layer 1 over SiO2 layer.
7. Layer 10 for Metal Via 1 layer 10 to connect P-implant to Poly-Silicon bias resistor .
8. Layer 13 Metal layer 2 for routing to Bonding Pads at edge of wafer.
9. Layer 14 for Metal Via 2 layer to Connect Metal-layer 1 to 2 .
10. Layer 19 for Passive (protection) layer as negative mask.

# FTS Sensor Simulation (ongoing@UIC)

- Simulation by SILVACO (3D Semi-conductor device simulation)
- Single-sided double metal AC coupled sensor
- 300μ, 5KΩ/cm PinN

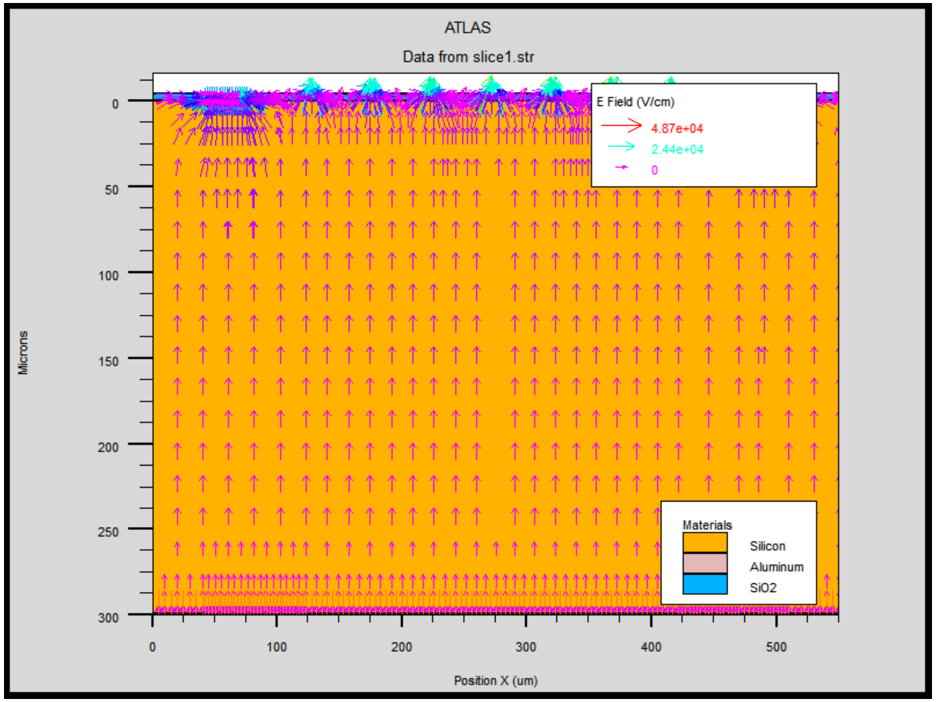


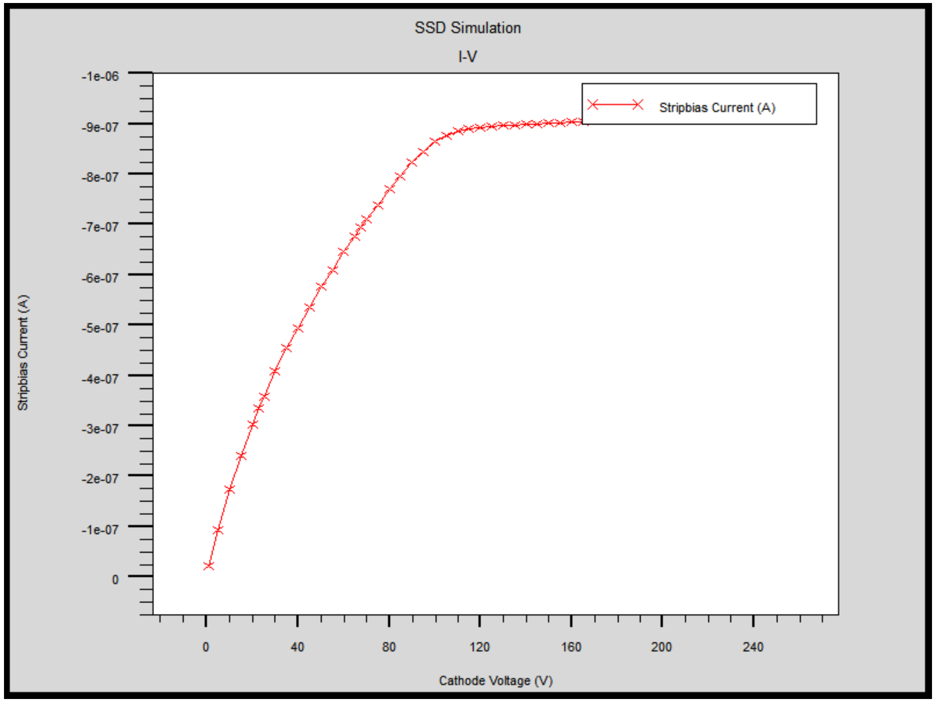






*Z.Ye, 9/22/2015*

# FTS Sensor Simulation (ongoing@UIC)



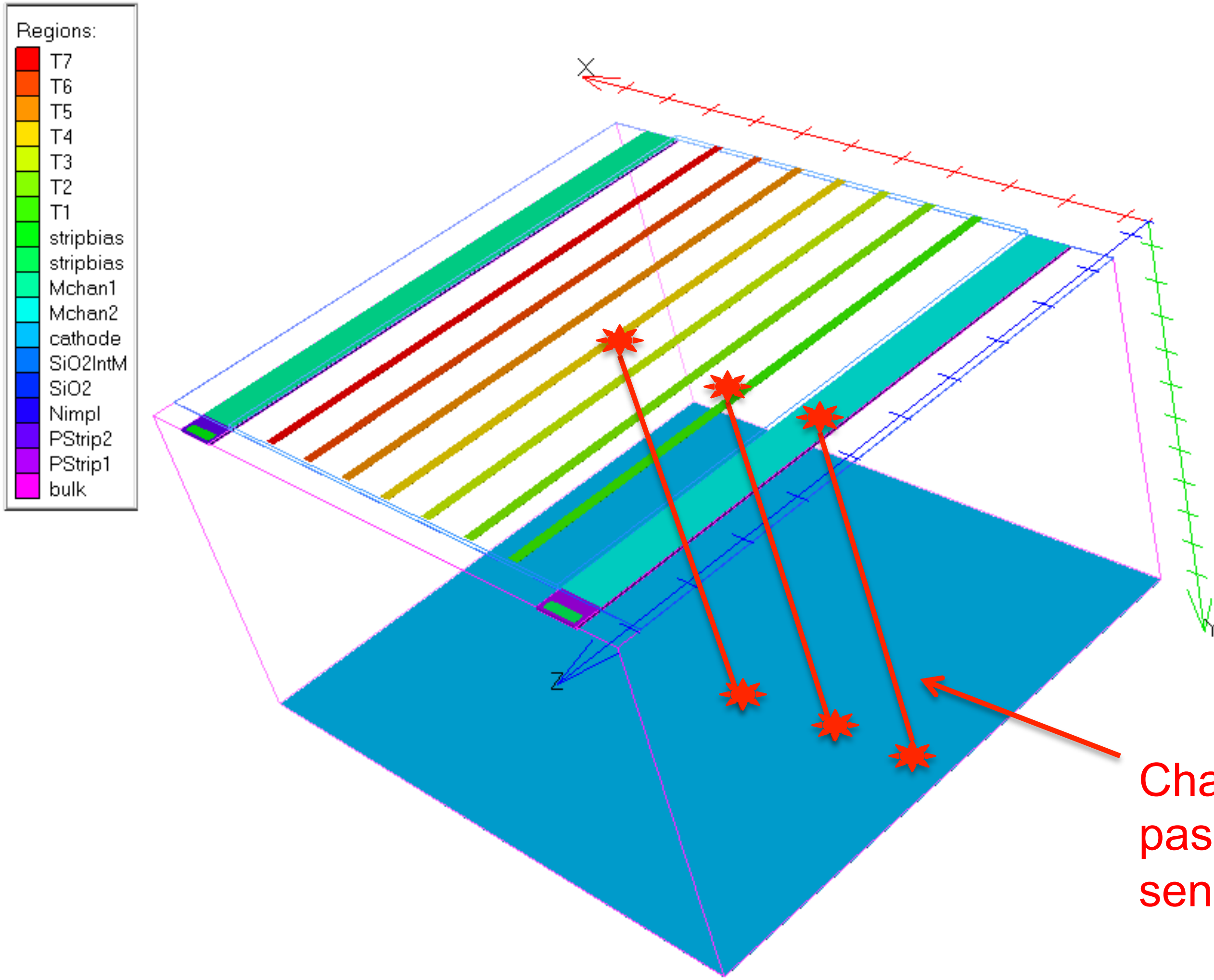




Good DC behavior, full depletion voltage ~ 100 V



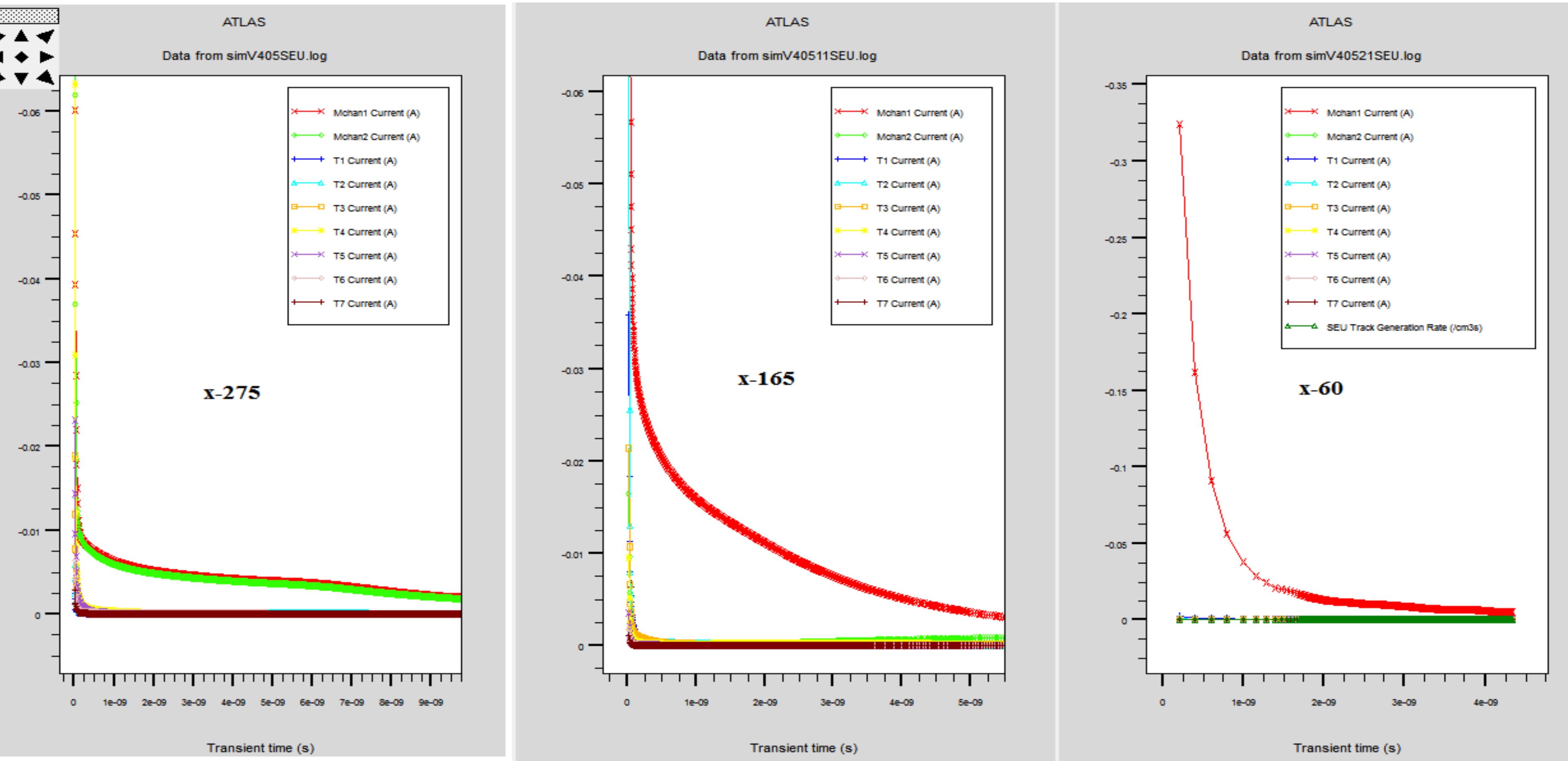
*Z.Ye, 9/22/2015*

# FTS Sensor Simulation (ongoing@UIC)




Charged particles passing through sensor

# FTS Sensor Simulation (ongoing@UIC)




Good signal behavior with small amount of cross-talk



*Z.Ye, 9/22/2015*

# D0 SMT Forward Disk Assembled at Fermilab

# R&D Timescale and Deliverable

**Schedule**

- Finalize sensor wafer layout and place order – Spring 2016
- Sensor QA test – Fall 2016
- Prototype assembly ~ Winter 2016/Spring 2017
- Prototype full performance test ~ Summer/Fall 2017

**Deliverable**

- Proof-of-principle and optimized sensor design and FTS layout

**Other important goals**

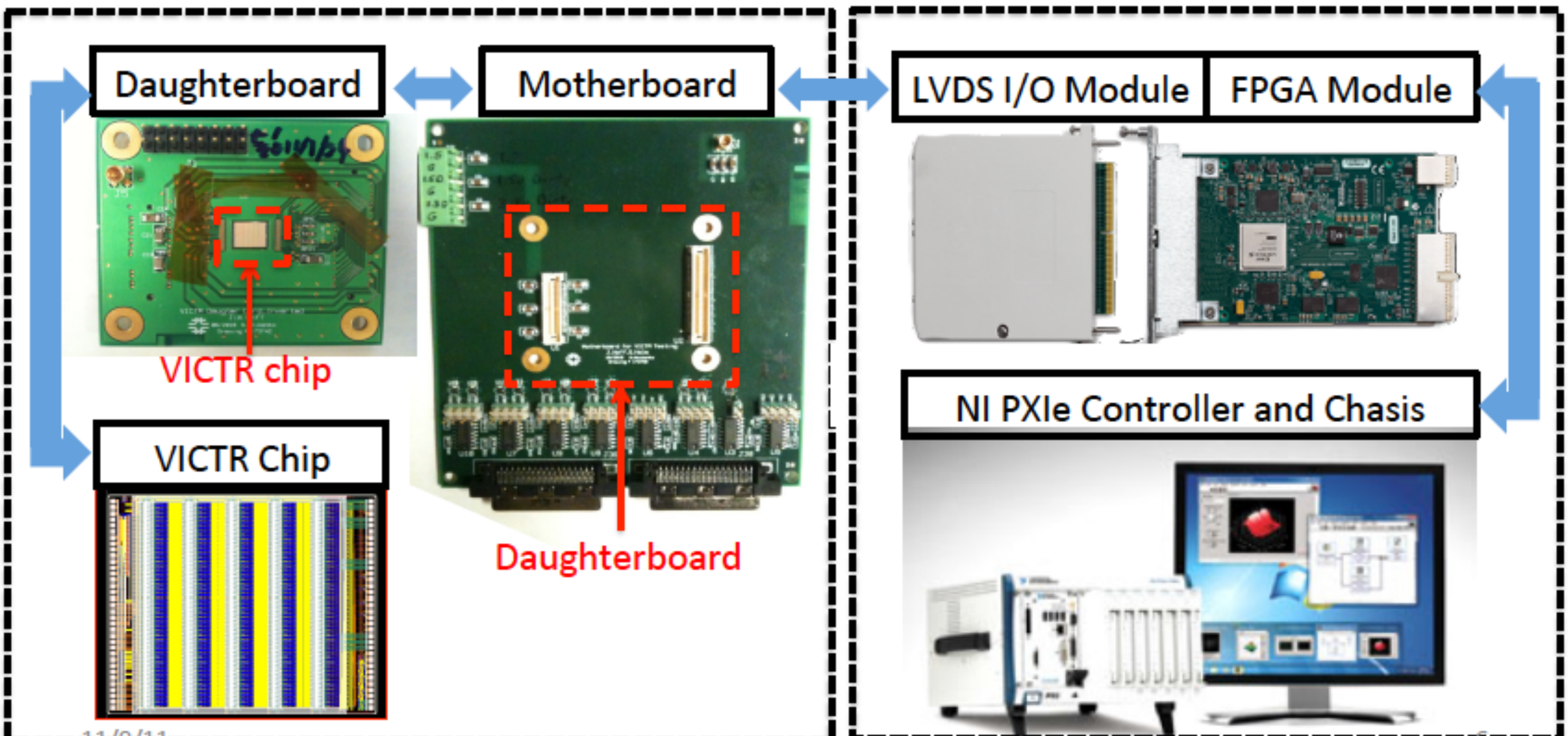
- Identify front-end readout chips, crucial for electrical and cooling system design
- Involve interested institutions to join **physics simulation** and R&D efforts towards a full detector system design by the end of year 2017

Have to act now!

# Backup

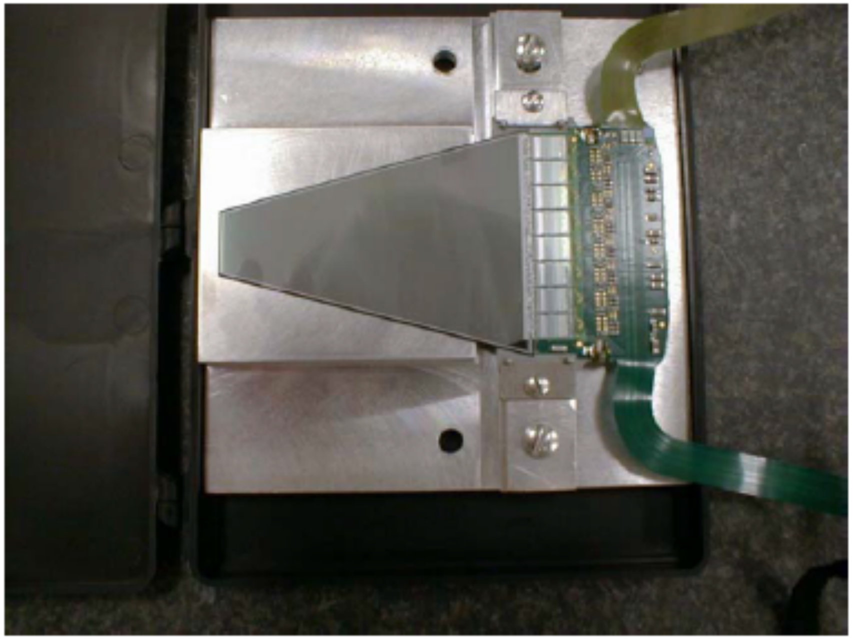
# Test Stand

- Two customized PCB boards (passive components+LVDS/CMOS drivers).
- Nantional Instruments FlexRIO system (PC, on-board FPGA module, LVDS I/O adapter module) and Labview.

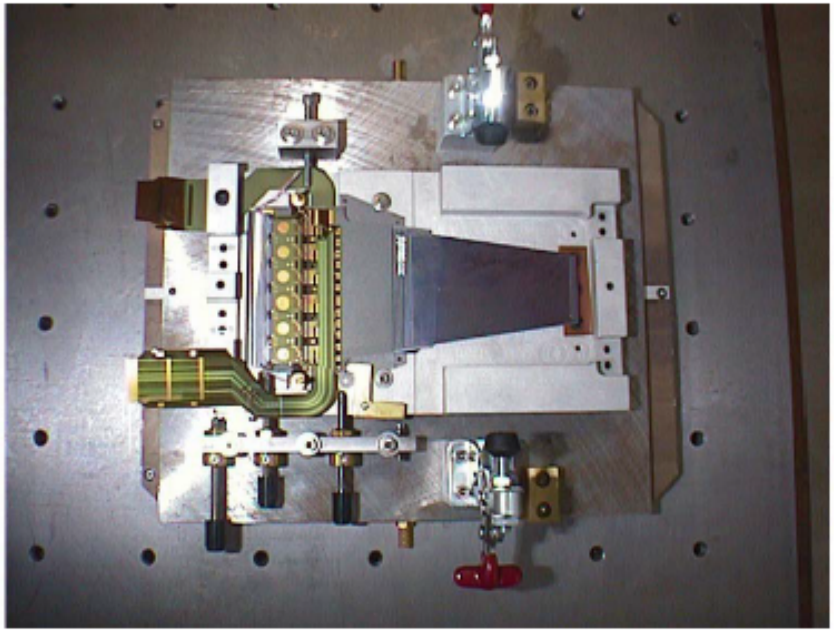


# Disk Detectors

F-Wedge Detectors (144)
- 8+6 chip readout
- 2.6 cm < r < 10 cm
- Double sided wedges with ±15$^0$
- 50 μm (p-side), 62.5 μm (n-side)
- Variable strip length



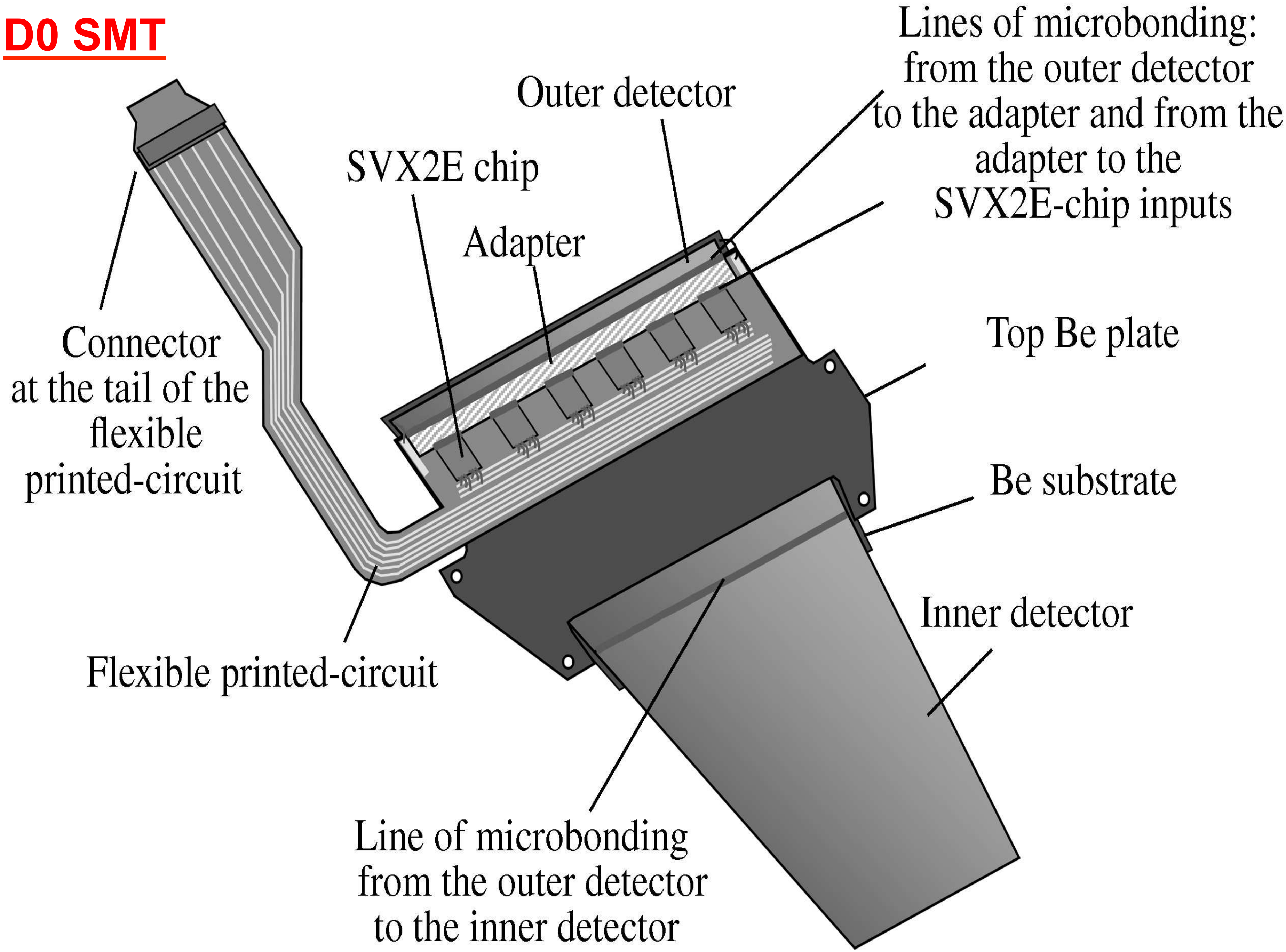
**D0 SMT**

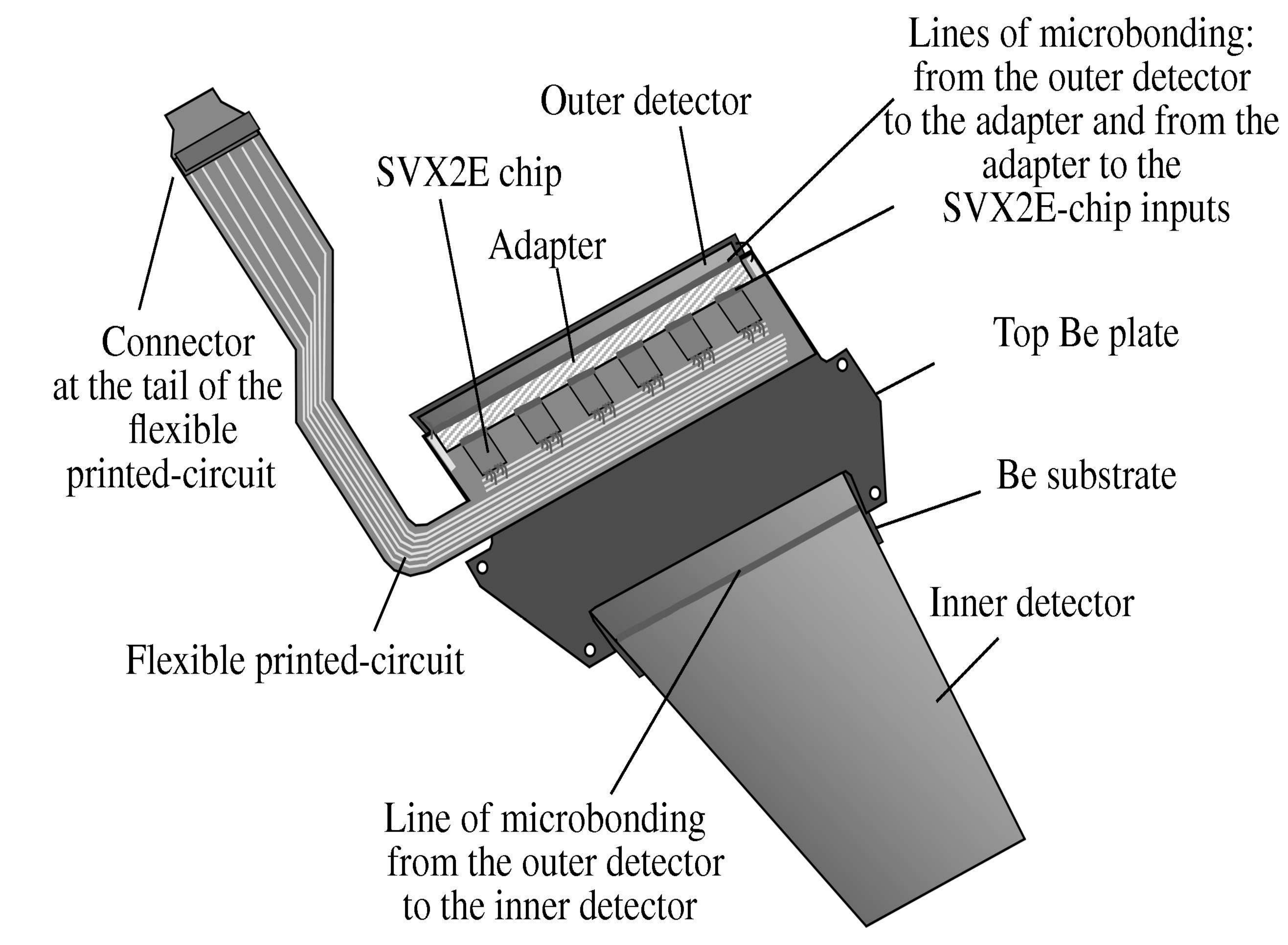


H-Wedge Detectors (384)
- 6+6 chip readout
- 9.6 cm < r < 23.6 cm
- Single sided glued back-to-back with ±7.5$^0$
- 40 μm (p-side) strip pitch
- 80 μm readout pitch
- Variable strip length

*Cecilia Gerber, Fermilab*

# D0 SMT


Lines of microbonding: from the outer detector to the adapter and from the adapter to the SVX2E-chip inputs
Outer detector
SVX2E chip
Adapter
Top Be plate
Connector at the tail of the flexible printed-circuit
Be substrate
Inner detector
Flexible printed-circuit
Line of microbonding from the outer detector to the inner detector



Lines of microbonding: from the outer detector to the adapter and from the adapter to the SVX2E-chip inputs
Outer detector
SVX2E chip
Adapter
Connector at the tail of the flexible printed-circuit
Top Be plate
Be substrate
Inner detector
Flexible printed-circuit
Line of microbonding from the outer detector to the inner detector

# Previous Talks

Silicon Strip Option Discussion (Zhenyu Ye@UIC):

http://drupal.star.bnl.gov/STAR/system/files/yezhenyu_eSTAR_20130423_3.pdf

https://drupal.star.bnl.gov/STAR/system/files/yezhenyu_eSTAR_20130829.pdf

https://drupal.star.bnl.gov/STAR/system/files/yezhenyu_eSTAR_20131015.pdf

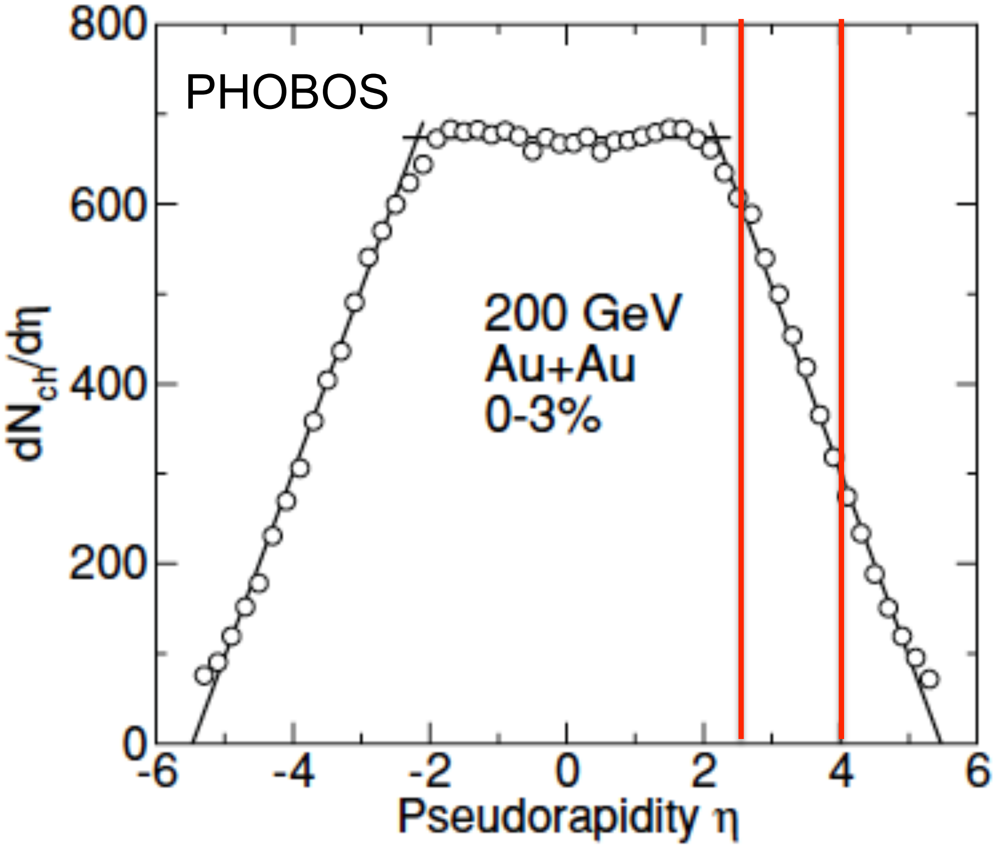
https://drupal.star.bnl.gov/STAR/system/files/yezhenyu_eSTAR_20140111.pdf

Simulation Discussion (Alexander Schmah@LBNL):

http://www.star.bnl.gov/protected/heavy/aschmah/Presentations/aschmah_eSTAR_Silicon_Strip_May_2013_V2.pdf

https://drupal.star.bnl.gov/STAR/system/files/aschmah_eSTAR_Forward_Tracking_ULCA_8_2013_V4.pdf

# Occupancy

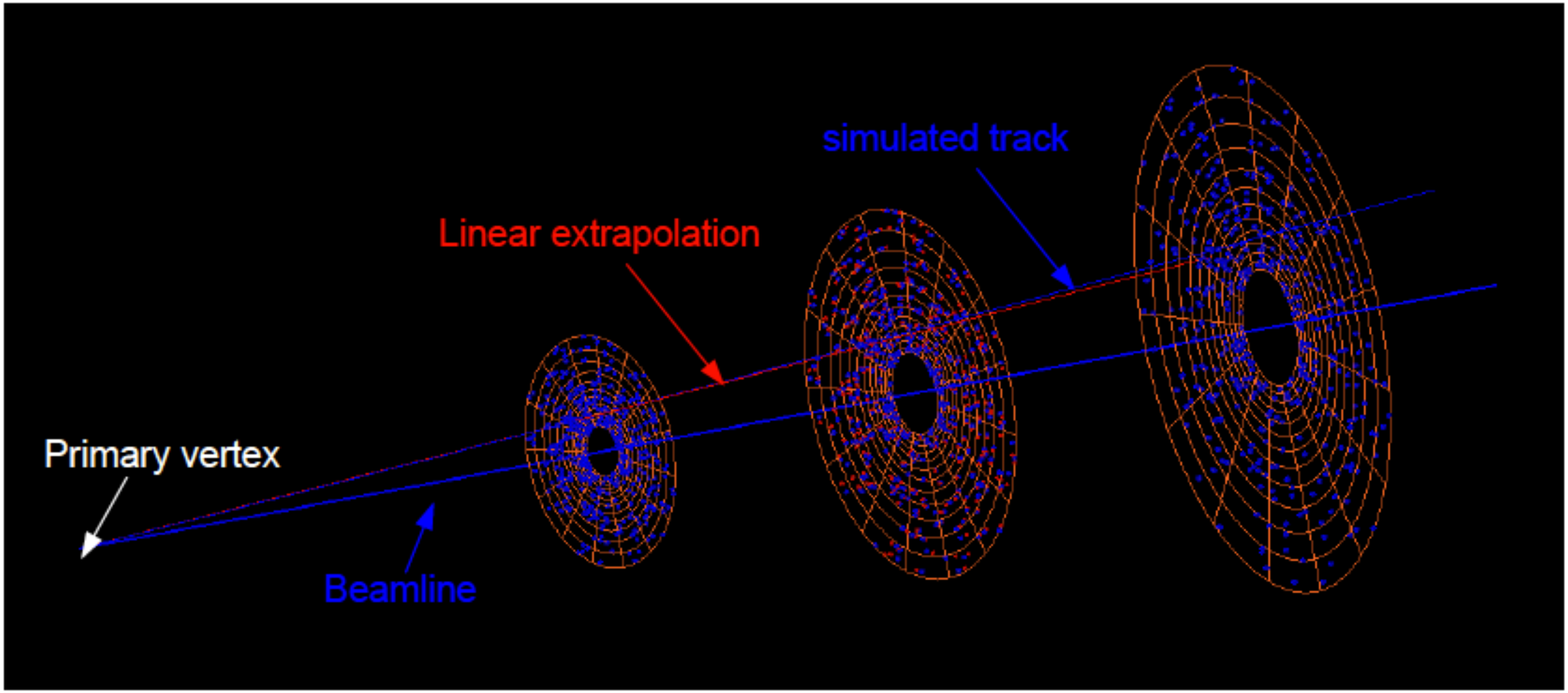



Assume total track=2*primary tracks:

Occupancy ≤ 5% (inner)
10% (outer)

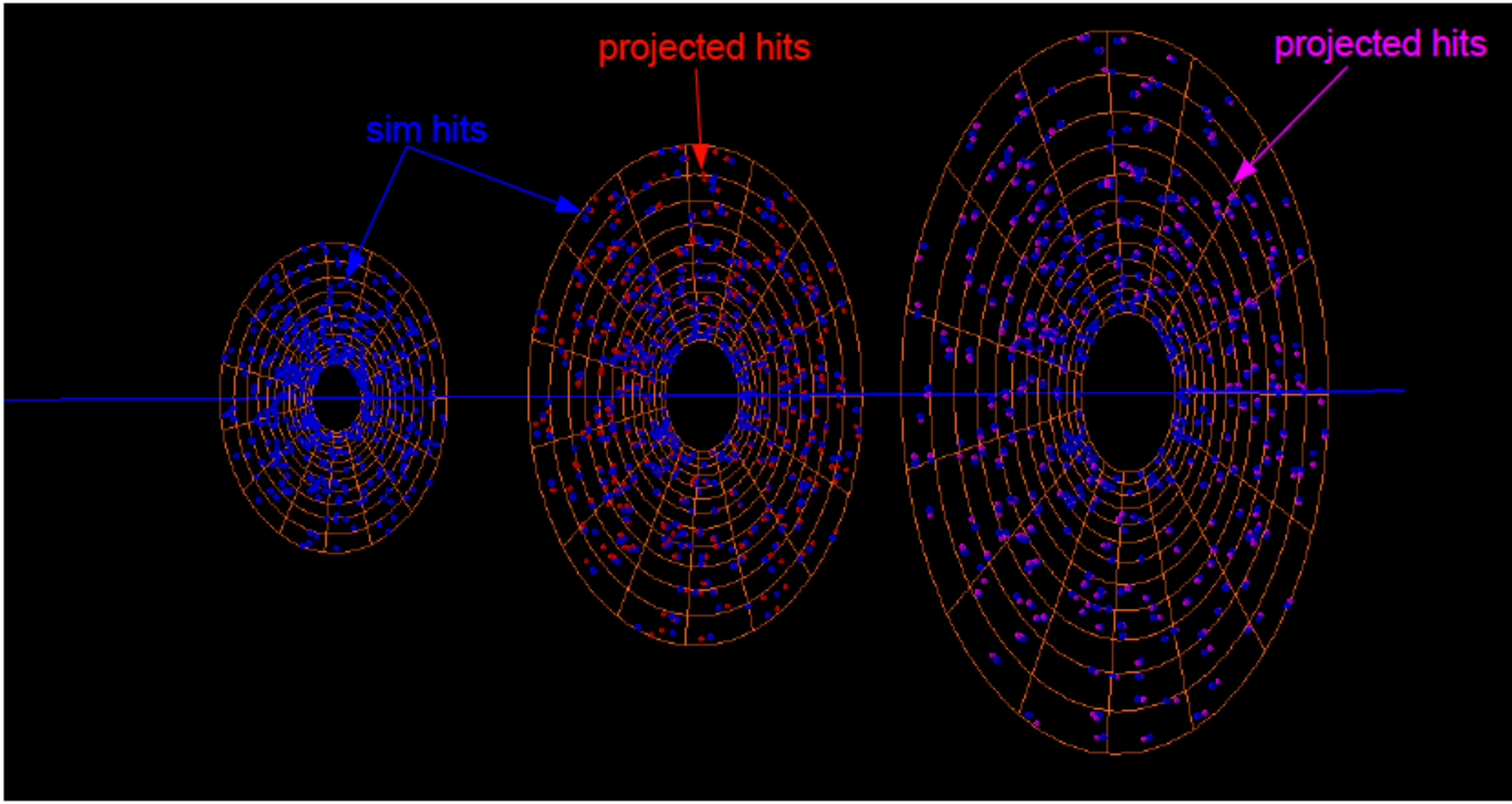
for 0-3% Au+Au collisions at 200 GeV

# Hit Matching: 2$^{nd}$ Plane



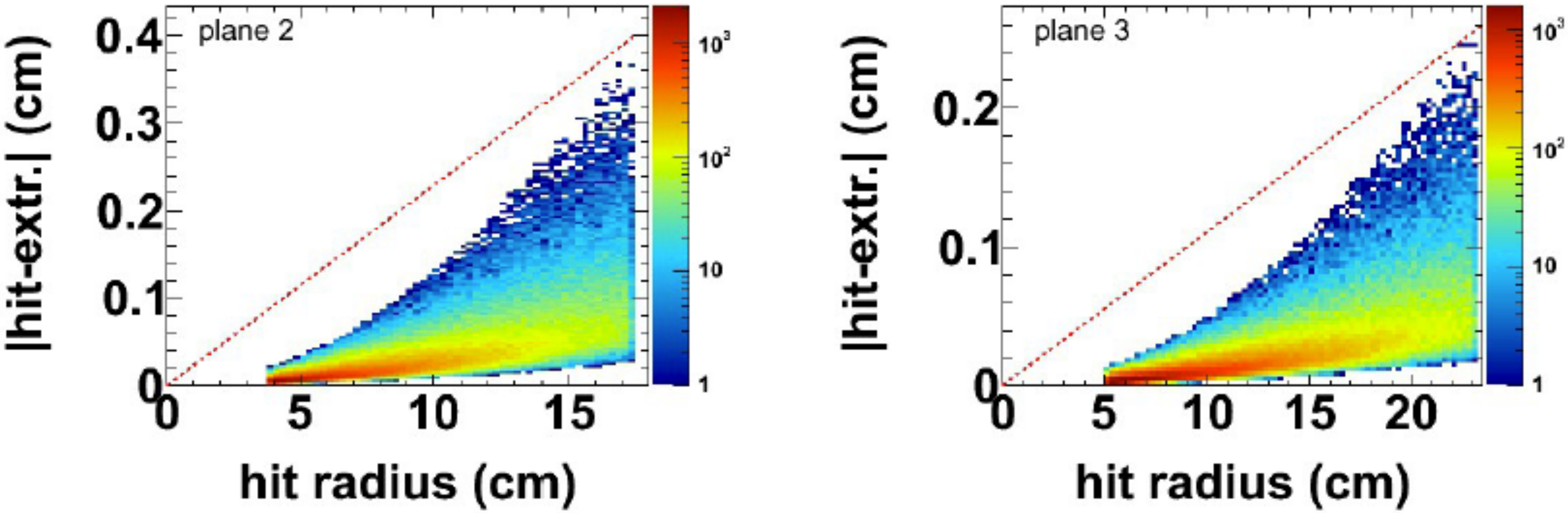

- First step: Simple hit matching for tracking
- Linear projection from primary vertex, first hit point to 2$^{nd}$ plane
- Red: linear extrapolation (tracks and hits points)
- Blue: simulated tracks and hit points

# Hit Matching: 3rd Plane



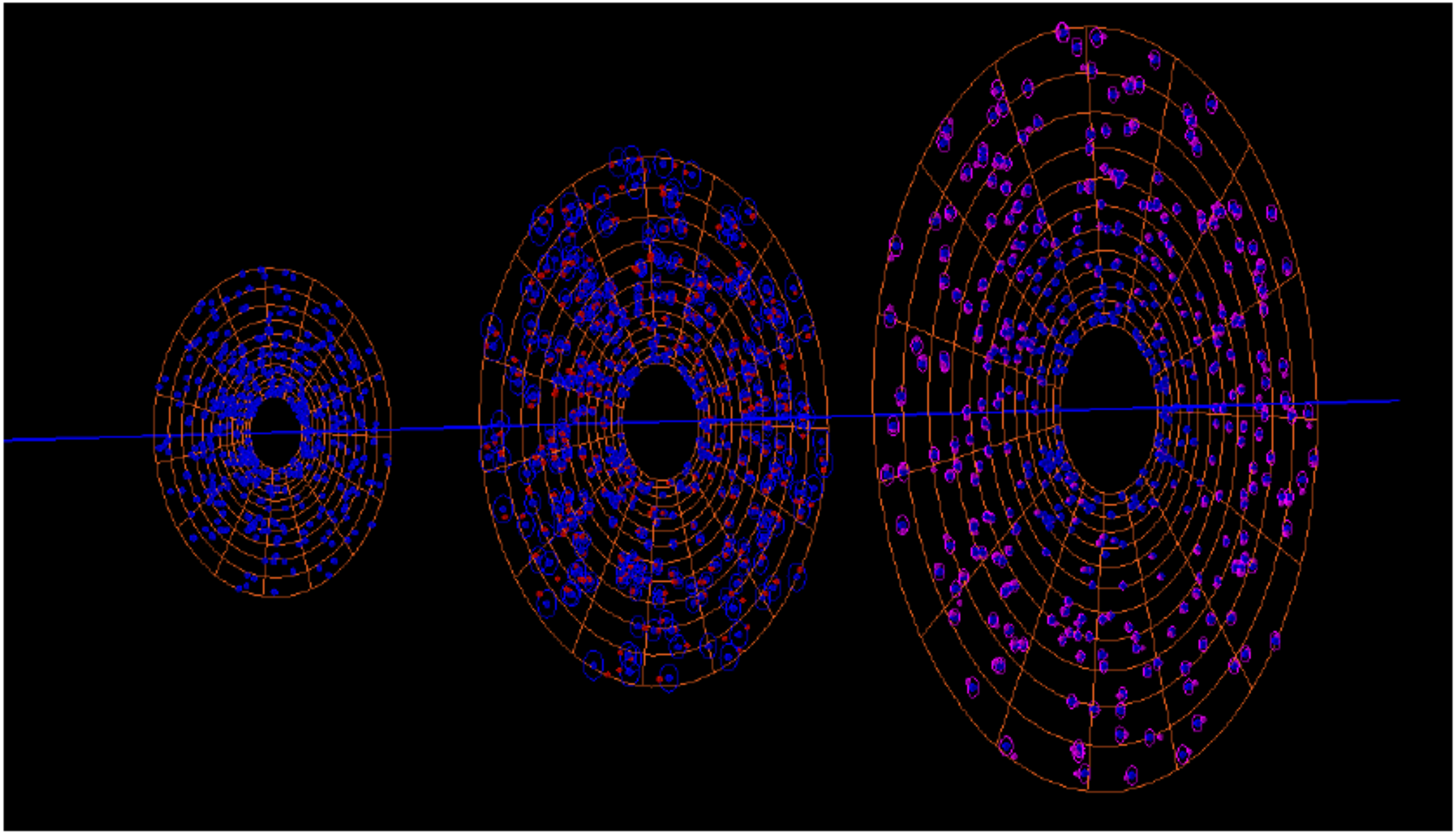

- Linear extrapolation from first and second plane to third plane (magenta hit points)
- Blue: simulated hit points

# Hit Matching



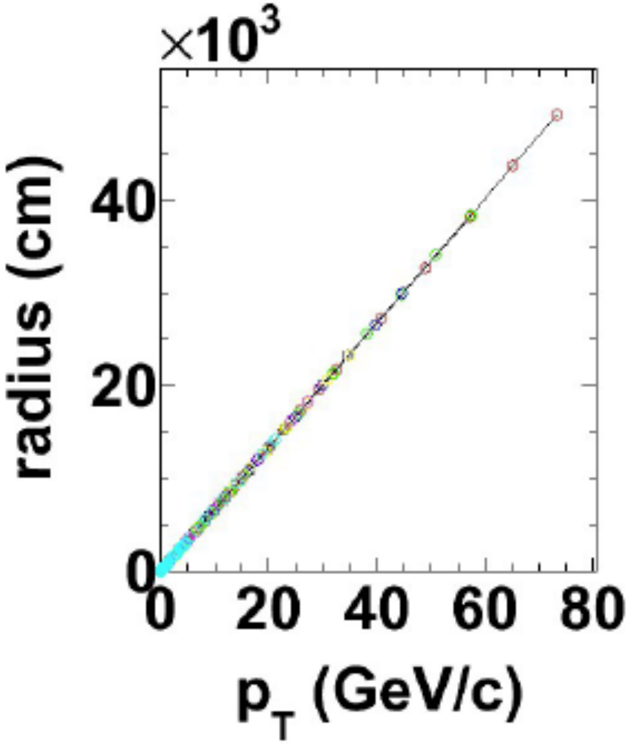

- Distance to linear extrapolations calculated for 2nd and 3rd plane
  → distance between blue and red/magenta hit points
- 500 mb events used
- No ambiguities due to noise yet
- Red line: all hits included for hit matching window

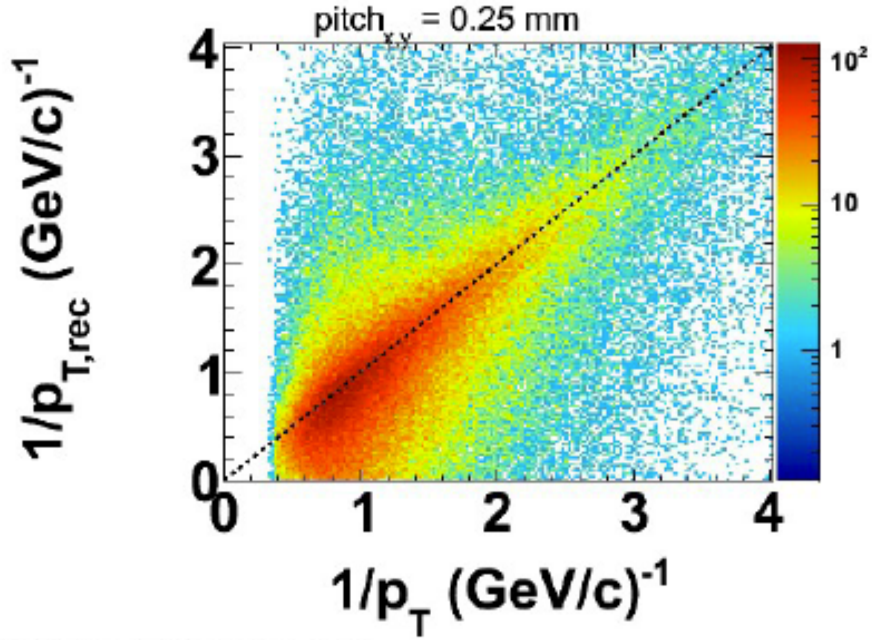
# Hit Matching Windows



- Hit search radii as a function of hit radius calculated for 2nd and 3rd plane

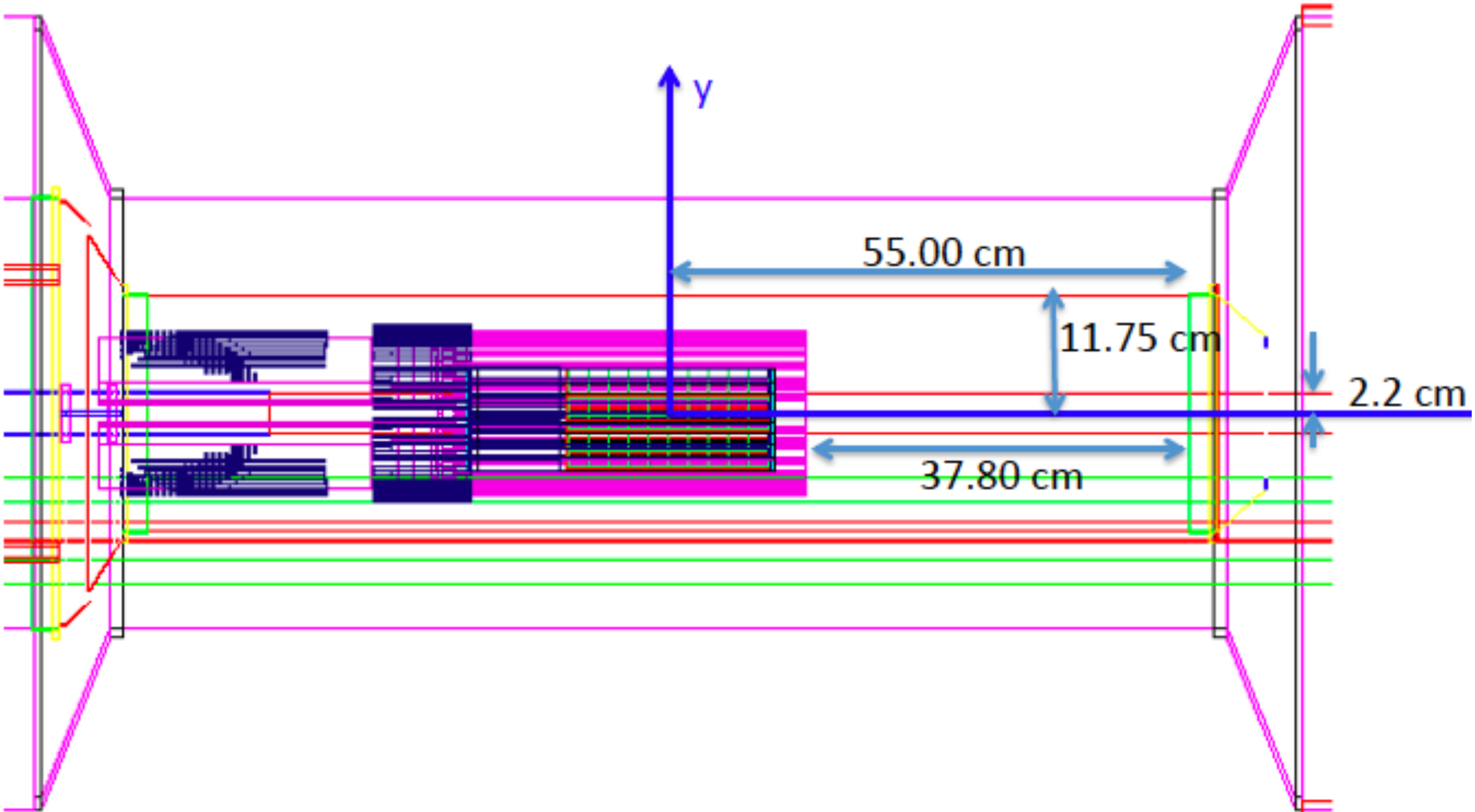
# Momentum Reconstruction

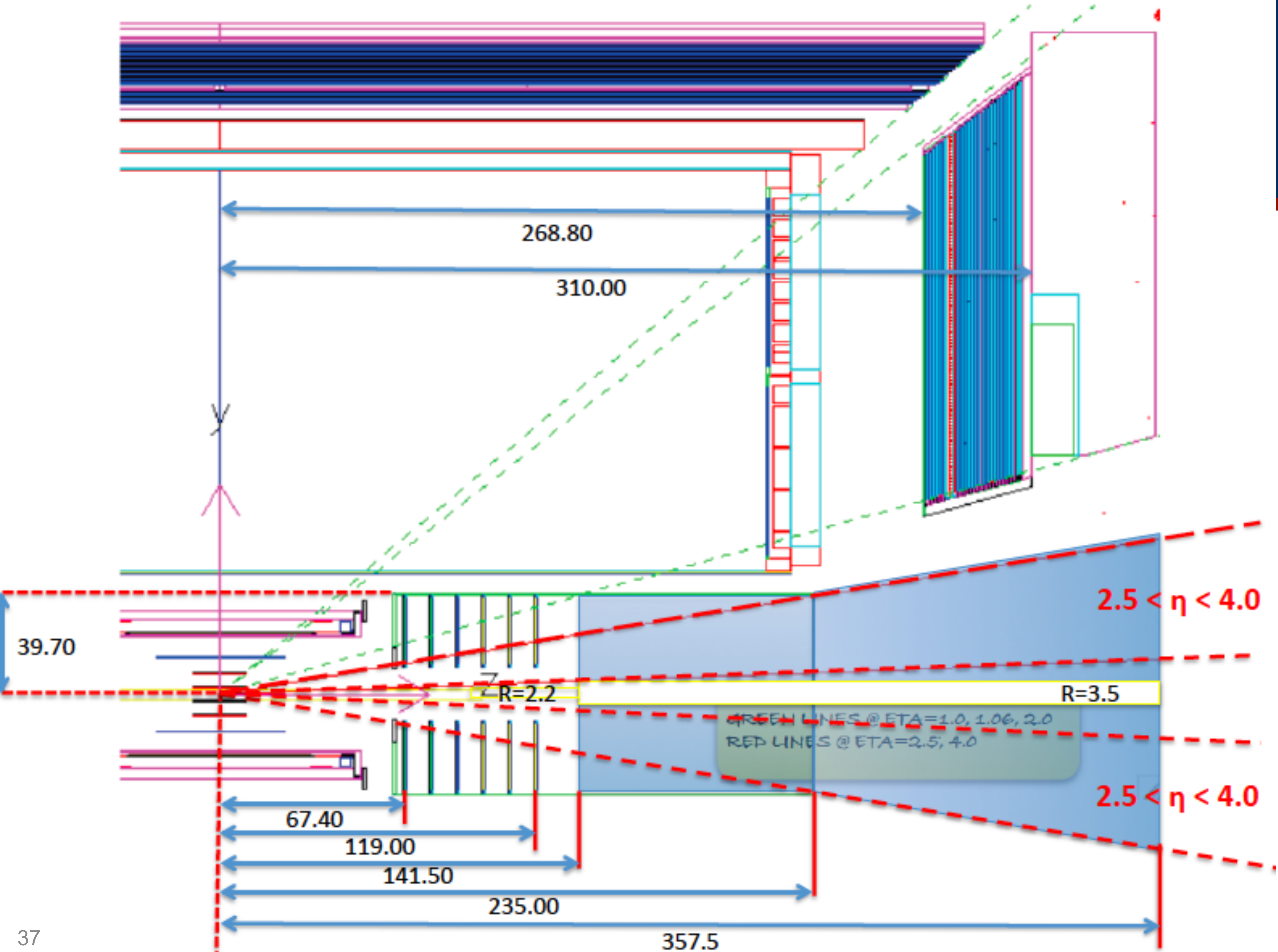



- Circle fits to hit points in transverse plane
  → linear correlation between circle radius and $p_T$
- Good correlation between reconstructed $p_T$ and input $p_T$
- Tendency to larger reconstructed $p_T$ values

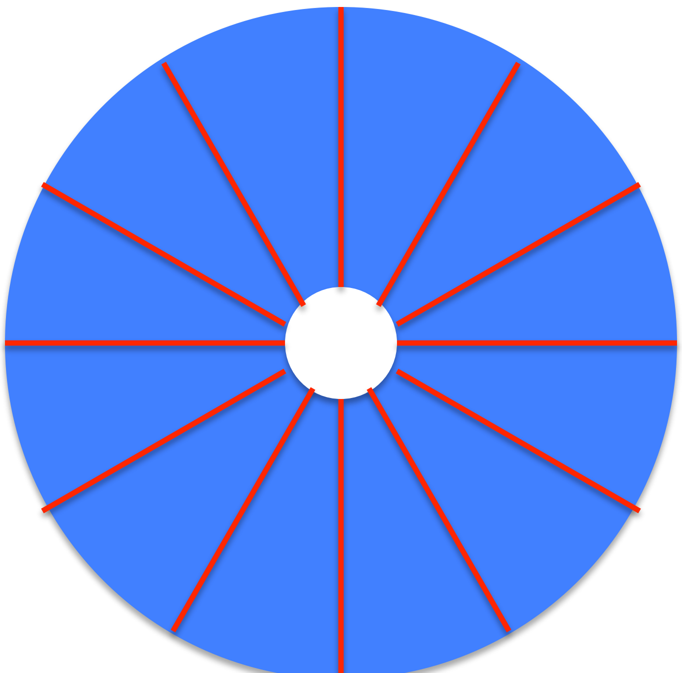
# Locations



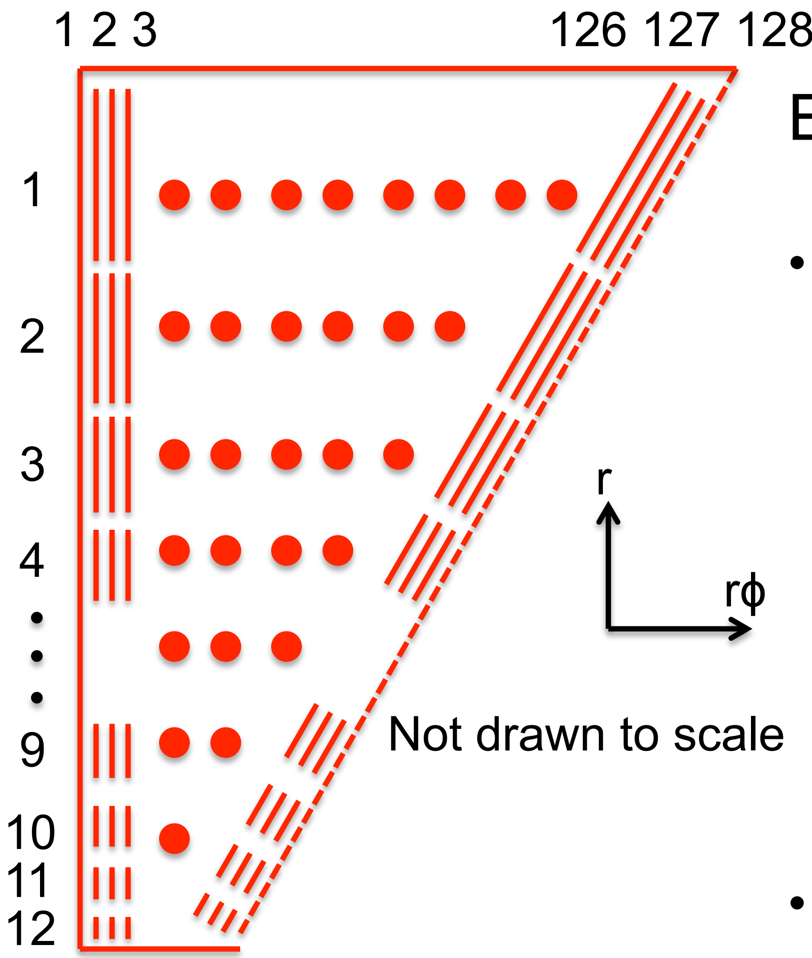

268.80
310.00
Y
39.70
Z
R=2.2
R=3.5
2.5 < η < 4.0
GREEN LINES @ ETA=1.0, 1.06, 2.0
RED LINES @ ETA=2.5, 4.0
2.5 < η < 4.0
67.40
119.00
141.50
235.00
357.5

# Silicon Strip Disk

- 3 Silicon strip disks at Z=70,105,140 cm
- Inner/outer radius 25/115, 38/175, 50/230mm for η=[2.5-4] coverage



# Silicon Mini-Strip Sensor




Each disk has

- 12 single-sided double metal silicon mini-strip sensors, with12*128 strips:

  Z=700mm
  0.11*3.4 (inner)-…-0.43*13.7 (outer)
  Z=1050mm
  0.165*5.1 (inner)-…-0.64*20.1 (outer)
  Z=1400mm
  0.22*6.8 (inner)-…-0.85*27.5 (outer)

- one disk is read out by 144 readout chips

R&D needed

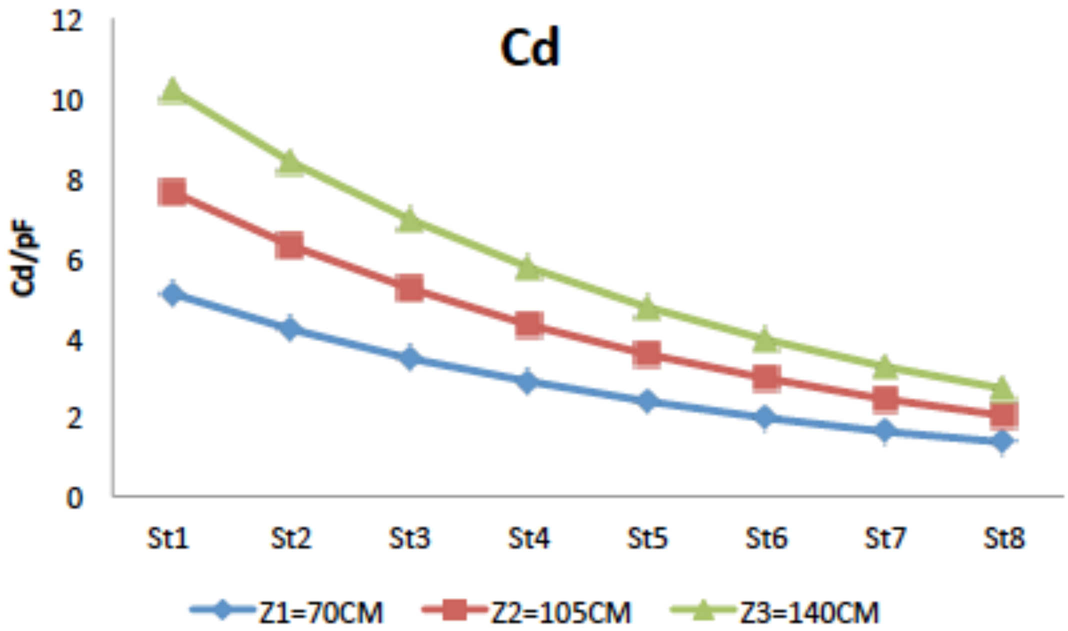
# Very Rough Cost Estimation (Design/Prototype+Production)

- Detector module
  - Silicon sensor: 120+400 k
  - Front-end readout chip: 5+25 k
  - Carbon-fiber core: 50+150 k
  - Flexible Kapton PCB: 80+150 k
  - Ladder assembly: 40+240 k
- Mechanical
  - Cooling: 20+100 k
  - Mechanical Support: 50+150 k
- Readout electronics
  - Readout crate: 20+100 k
  - Sensor bias power supply: 10+100 k
  - Readout boards: 50+120 k
  - Cables: 20+80 k

Subject to large uncertainties

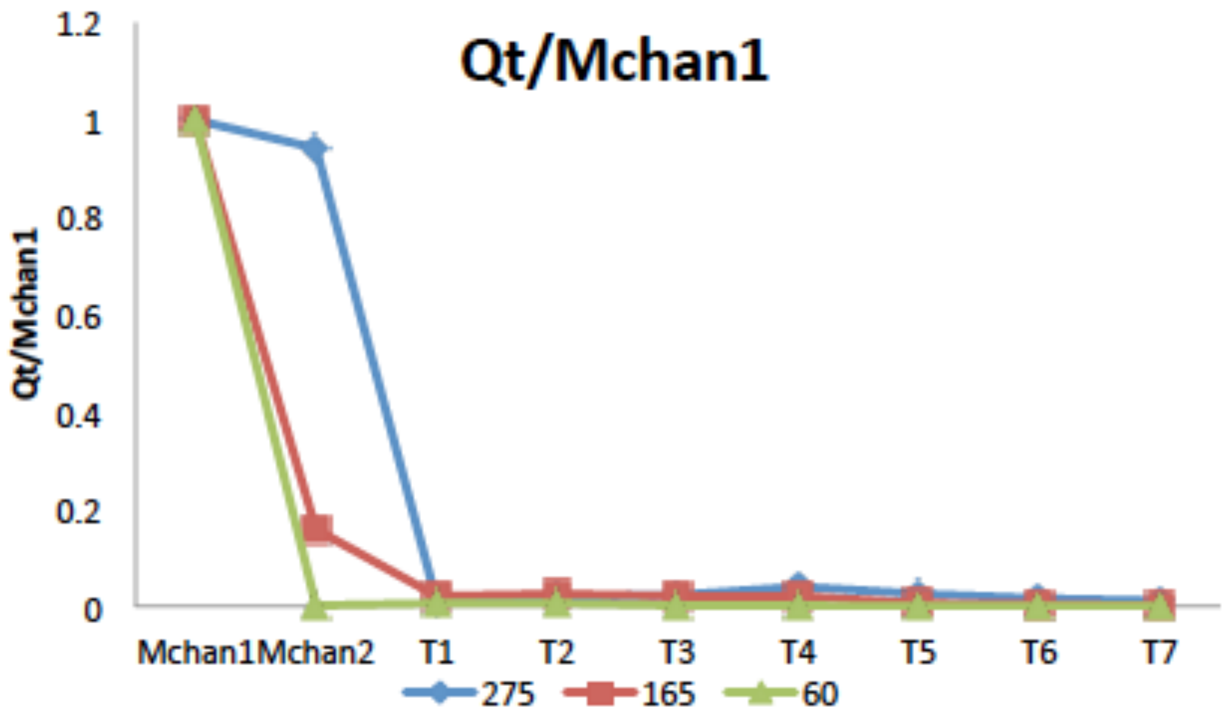
| | |
|---|---|
| Prototyping | 365-440k |
| Production | 1745-2050k |
| 40% contingency | 840-1000k |
| Sum | ~2970-3500k for 3 disks |

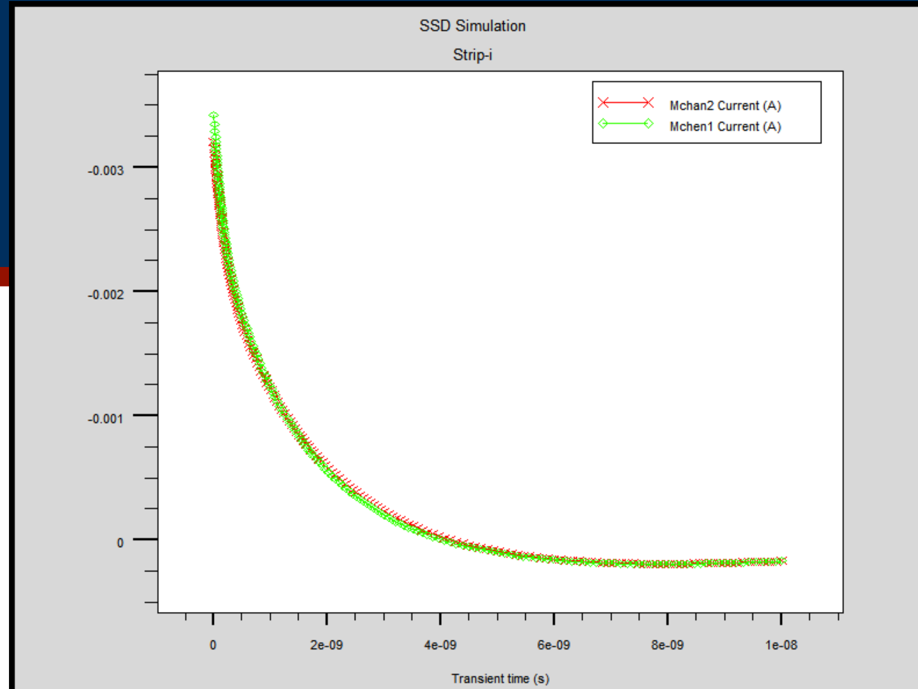
If there is need for more precise r (η) resolution

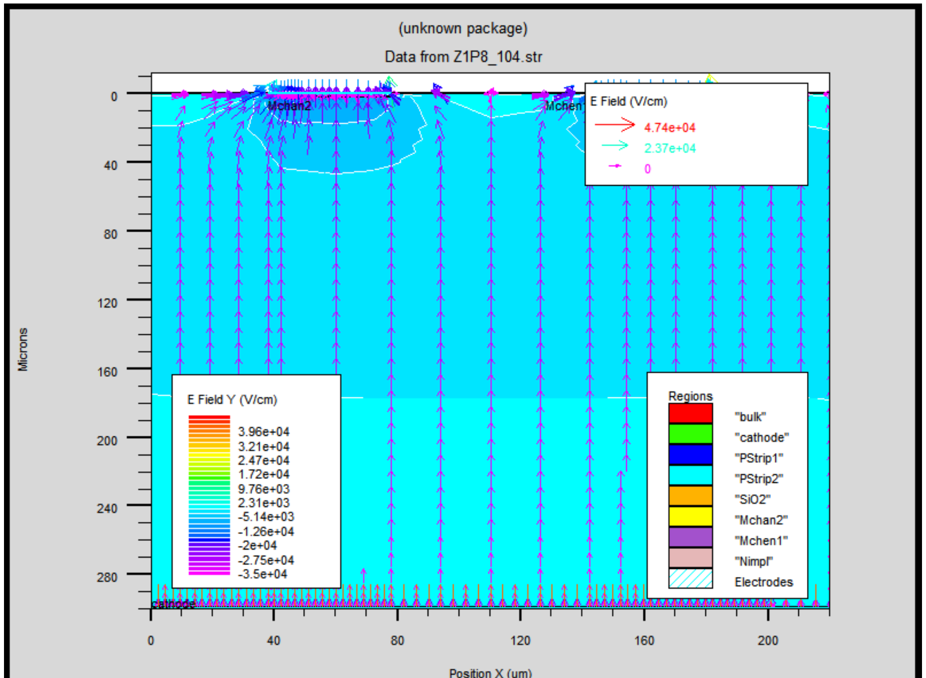


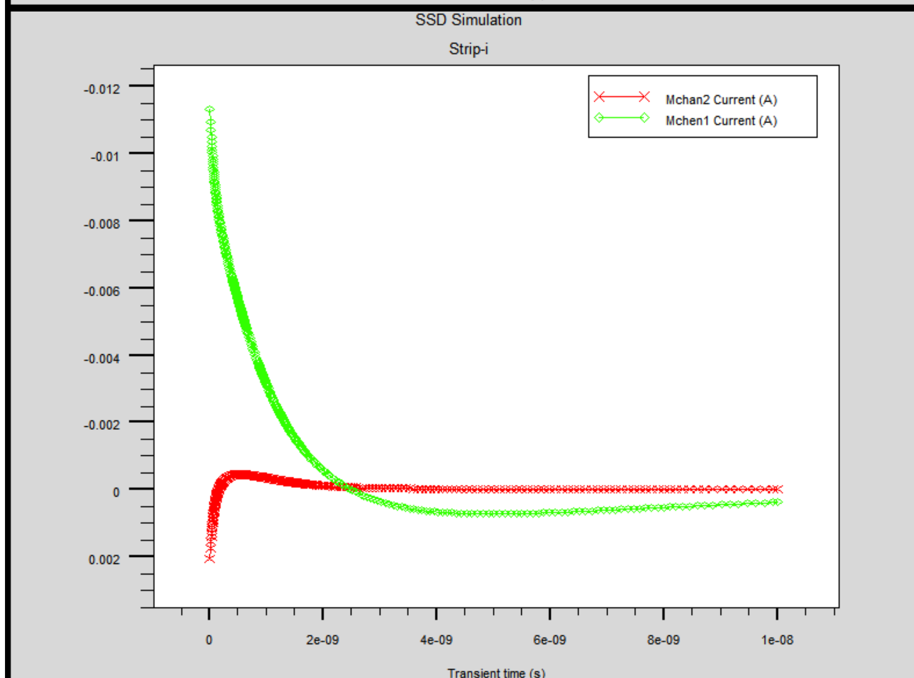

Noise = 270 +38 * Cd    $e^-$
Signal = 24000    $e^-$

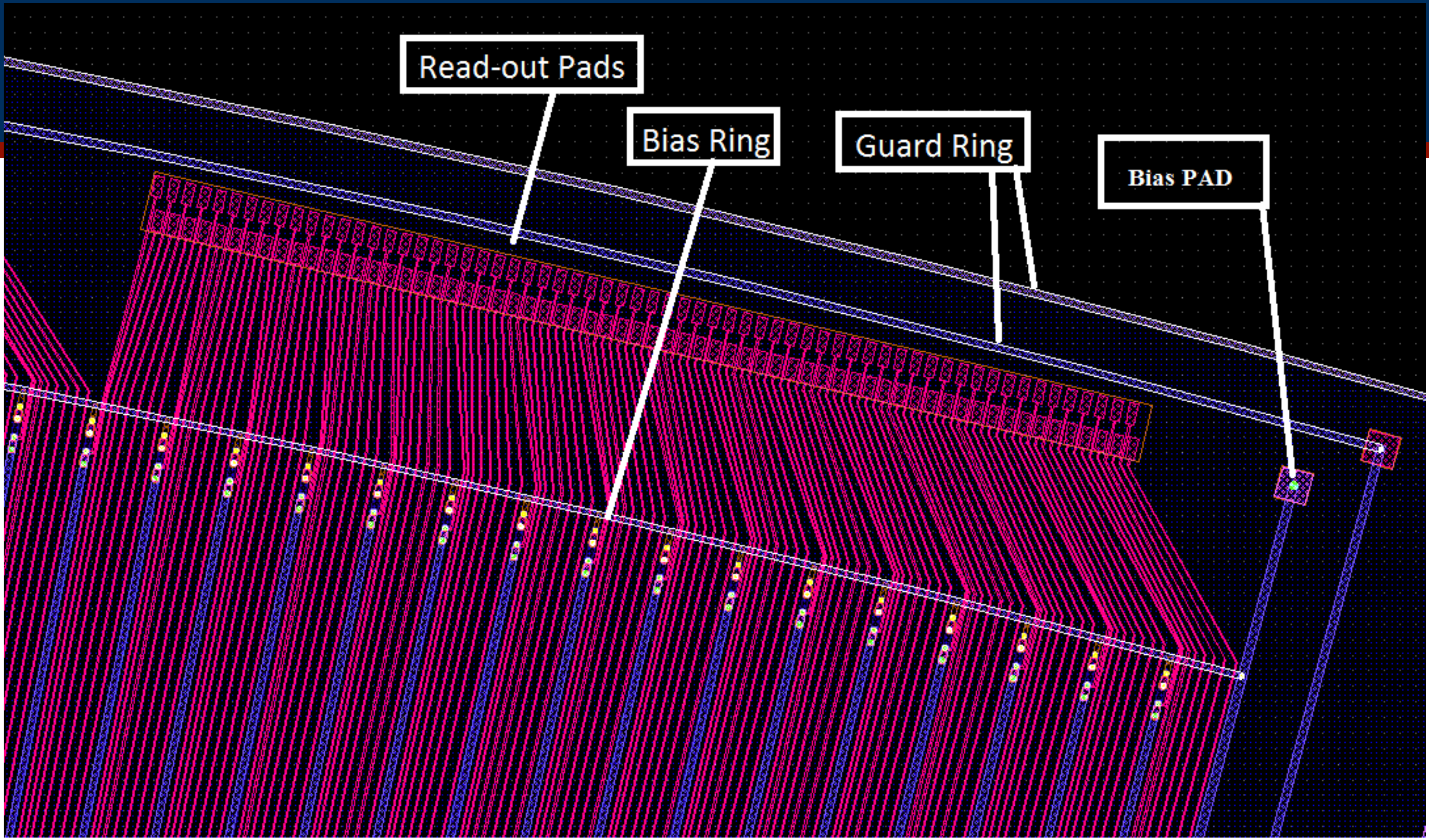
# Sensor Characteristics from Silvaco Simulation (Babak@UIC)




SSD Simulation
Strip-i
Mchan2 Current (A)
Mchen1 Current (A)
-0.003
-0.002
-0.001
0
0
2e-09
4e-09
6e-09
8e-09
1e-08
Transient time (s)


(unknown package)
Data from Z1P8_104.str
Microns
Position X (um)
Mchan2
Mchen1
cathode
E Field (V/cm)
4.74e+04
2.37e+04
0
E Field Y (V/cm)
3.96e+04
3.21e+04
2.47e+04
1.72e+04
9.76e+03
2.31e+03
-5.14e+03
-1.26e+04
-2e+04
-2.75e+04
-3.5e+04
Regions
"bulk"
"cathode"
"PStrip1"
"PStrip2"
"SiO2"
"Mchan2"
"Mchen1"
"Nimpl"
Electrodes


SSD Simulation
Strip-i
Mchan2 Current (A)
Mchen1 Current (A)
-0.012
-0.01
-0.008
-0.006
-0.004
-0.002
0
0.002
0
2e-09
4e-09
6e-09
8e-09
1e-08
Transient time (s)


Read-out Pads
Bias Ring
Guard Ring
Bias PAD