Heavy Flavor Tracker Pixel simulator

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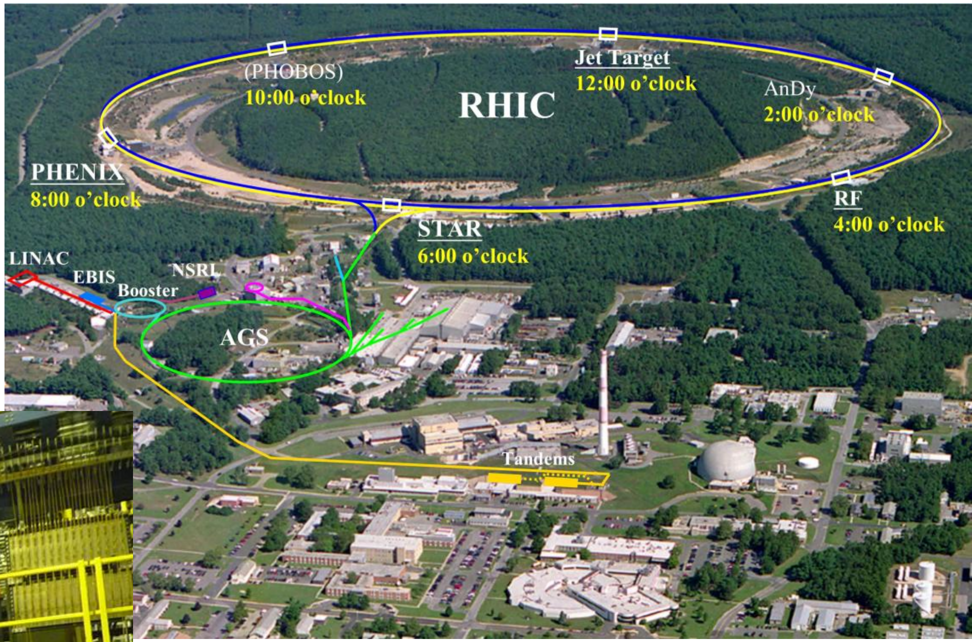
Outline

- RHIC, STAR
- HFT motivation
- Hybrid and Monolithic pixel sensors
- Pixel simulator - DIGMAPS
- Cosmic muon result
- Low luminosity data

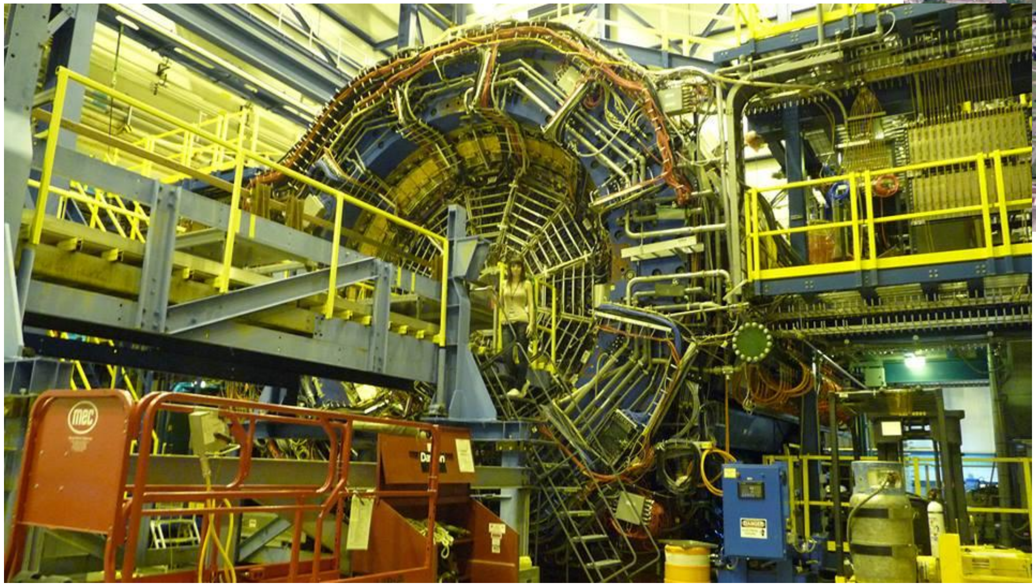
Relativistic Heavy Ion Collider

BROOKHAVEN NATIONAL LABORATORY

- ↑p+↑p, p+Al, p+Au, d+Au, He^3+Au, Cu+Cu, Cu+Au, Au+Au, U+U
- 7,7 – 200 GeV (500 GeV for protons)
- **STAR, PHENIX** – QGP, QCD phase diagram, proton spin

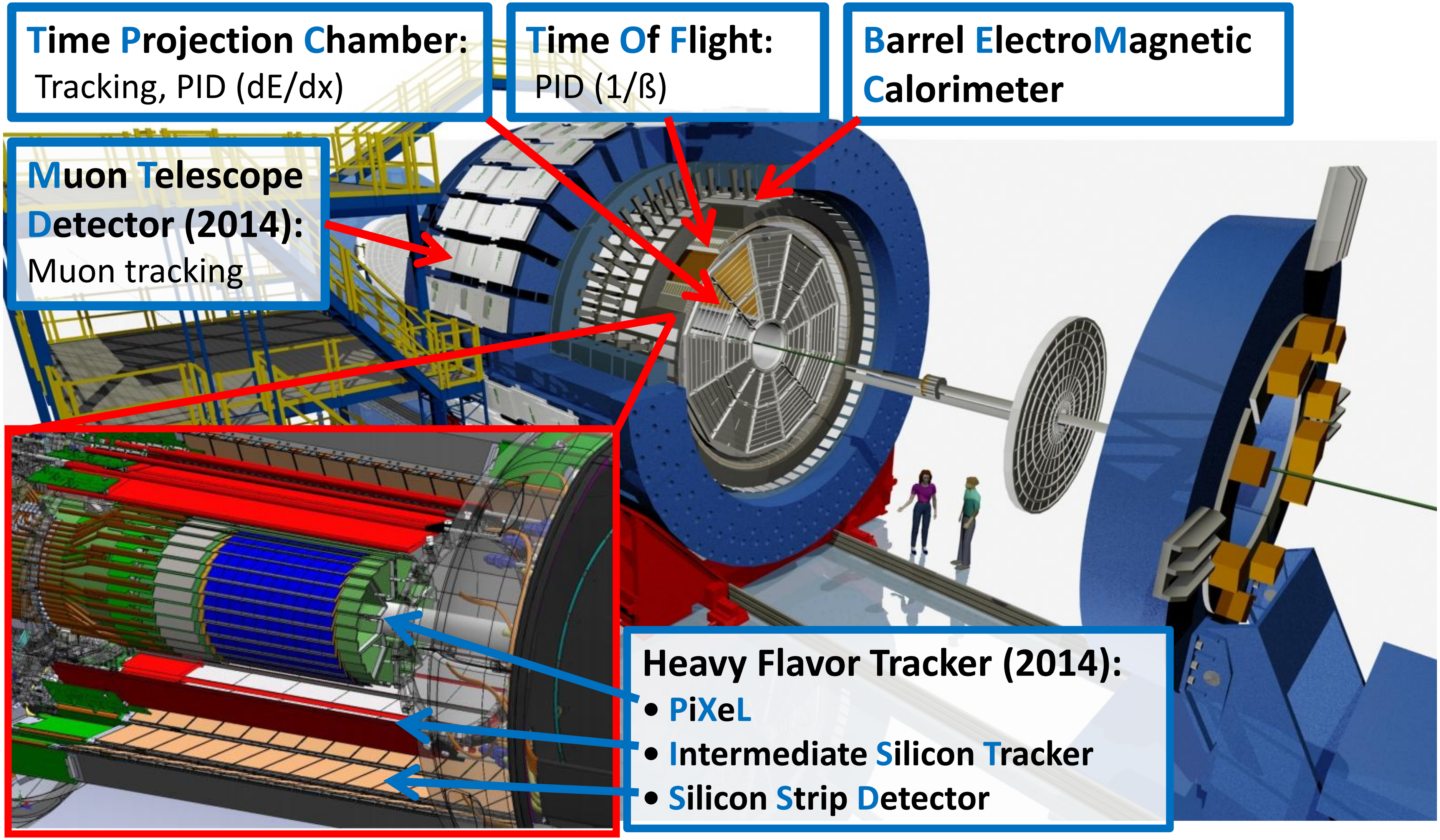


RHIC facility

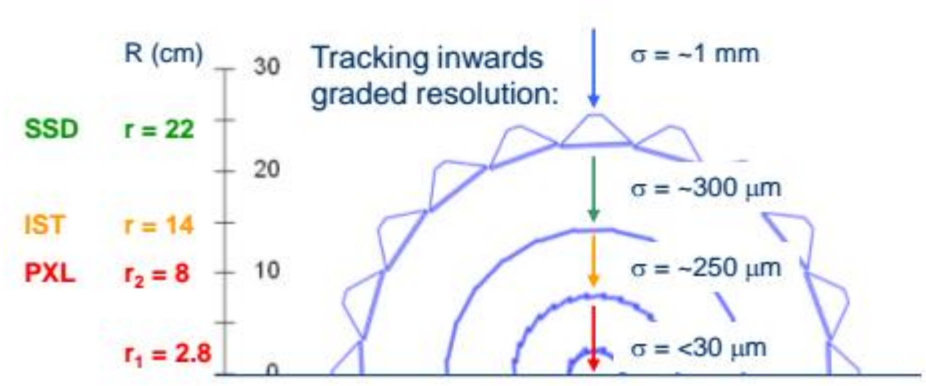


STAR detector

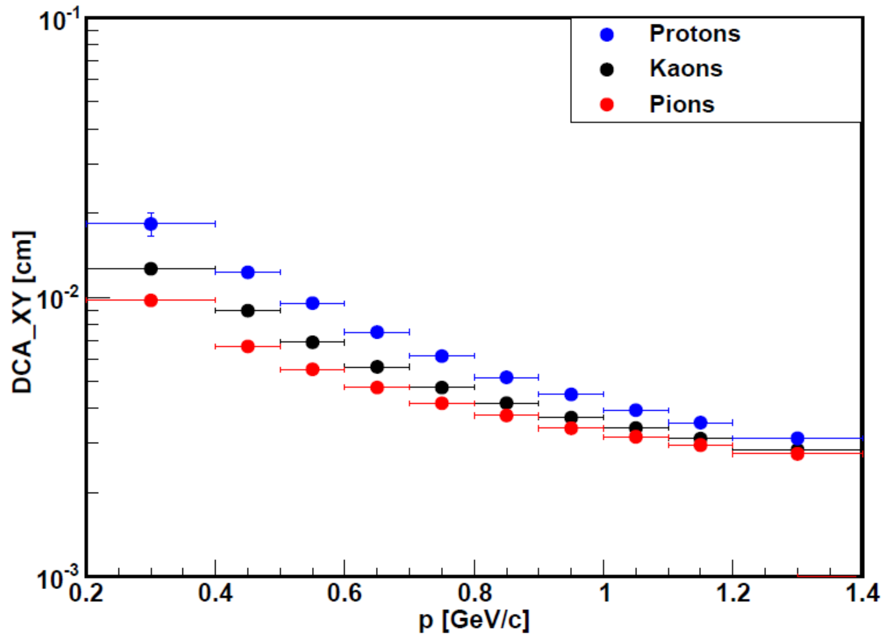
STAR Detector



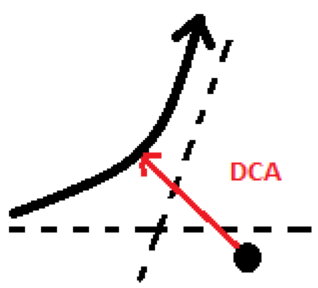
Heavy Flavor Tracker



DCA resolution



DCA resolution



DCA – Distance of closest approach

With all layers DCA resolution is better than 30 μm

HFT Motivation

- HFT is used for studying particles containing heavy quarks measuring decay vertices

D^0 $c\tau \approx 120$ μm

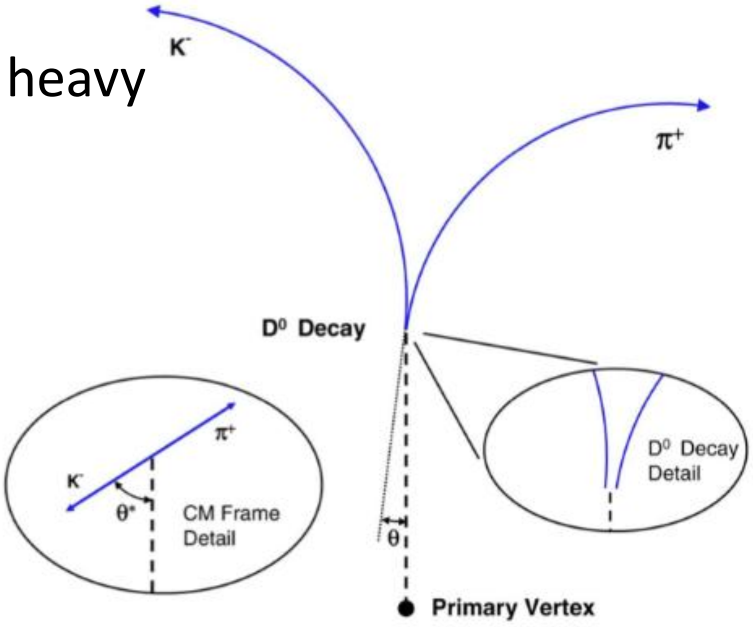
Λ_c^+ $c\tau \approx 60$ μm

B mesons $c\tau \approx 500$ μm

$D^0 \to K^-\pi^+$ (4%)

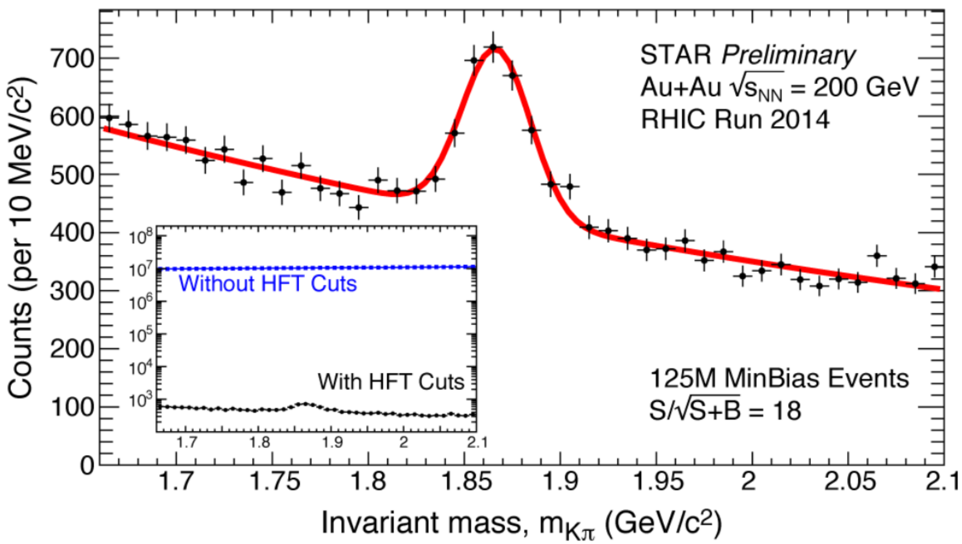
$\Lambda_c^+ \to pK^-\pi^+$ (5%)

$B \to J/\psi X$ or $B \to l^+\nu_l X$ (11%)



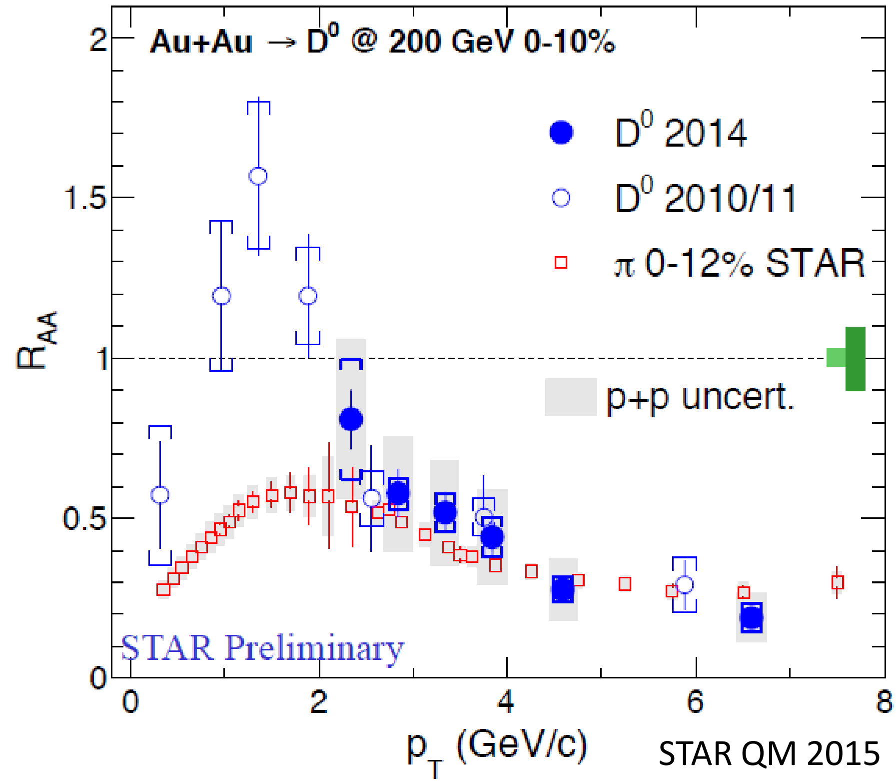
Decay of D^0

First results with HFT



First result of topological reconstruction of D^0

- 4 orders of magnitude suppression of combinatorial background
- More precise measurement of flavor dependence of energy loss



R_{AA} comparison between pions and D^0

Advantages of Monolithic Pixel sensor

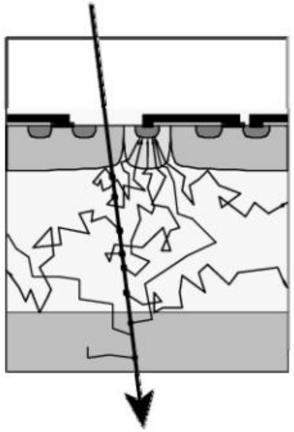
- First MAPS used in collider experiments
- First 2 layers of HFT are MAPS PXL
- Monolithic – 1 layer of silicon vs Hybrid – more layers connected

  + Smaller, Lower material budget, capacity and noise

  + Can measure higher particle density –> closer to interaction point

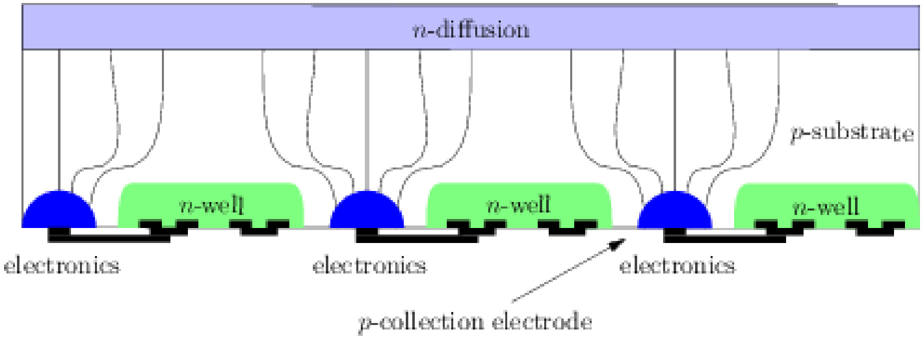
  - Different properties for each detector and electronics is needed

  - Lower radiation tolerance

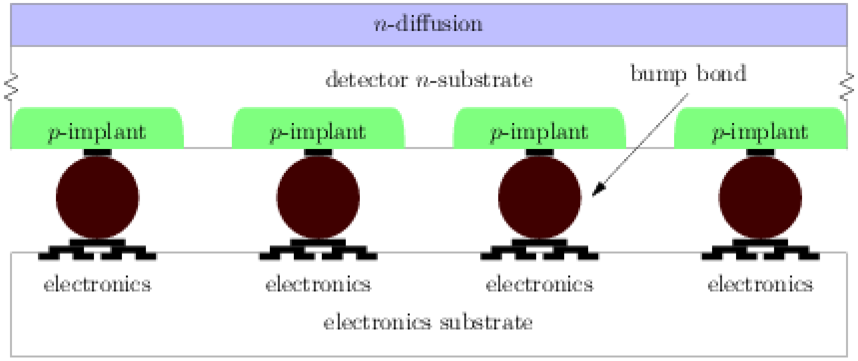


Electron diffusion

Pictures from: Hejtmánek, Diploma Thesis



Section view of monolithic active pixel sensor



Section view of hybrid pixel sensor

Charge collection:

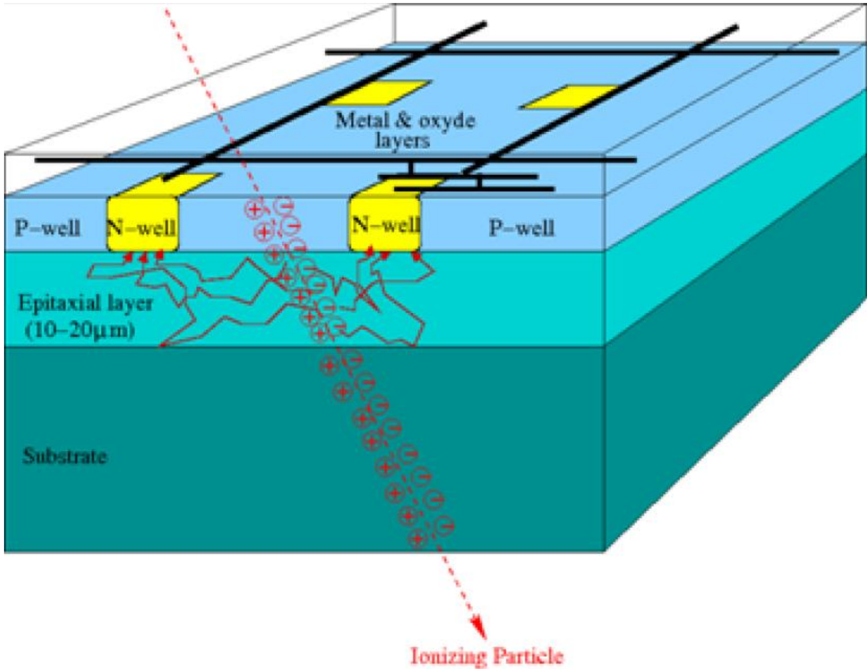
- MAPS: Charge diffusion to electrode
- Hybrid: Charge drift to closest bump and transfer to electronics

Pixel sensor simulator

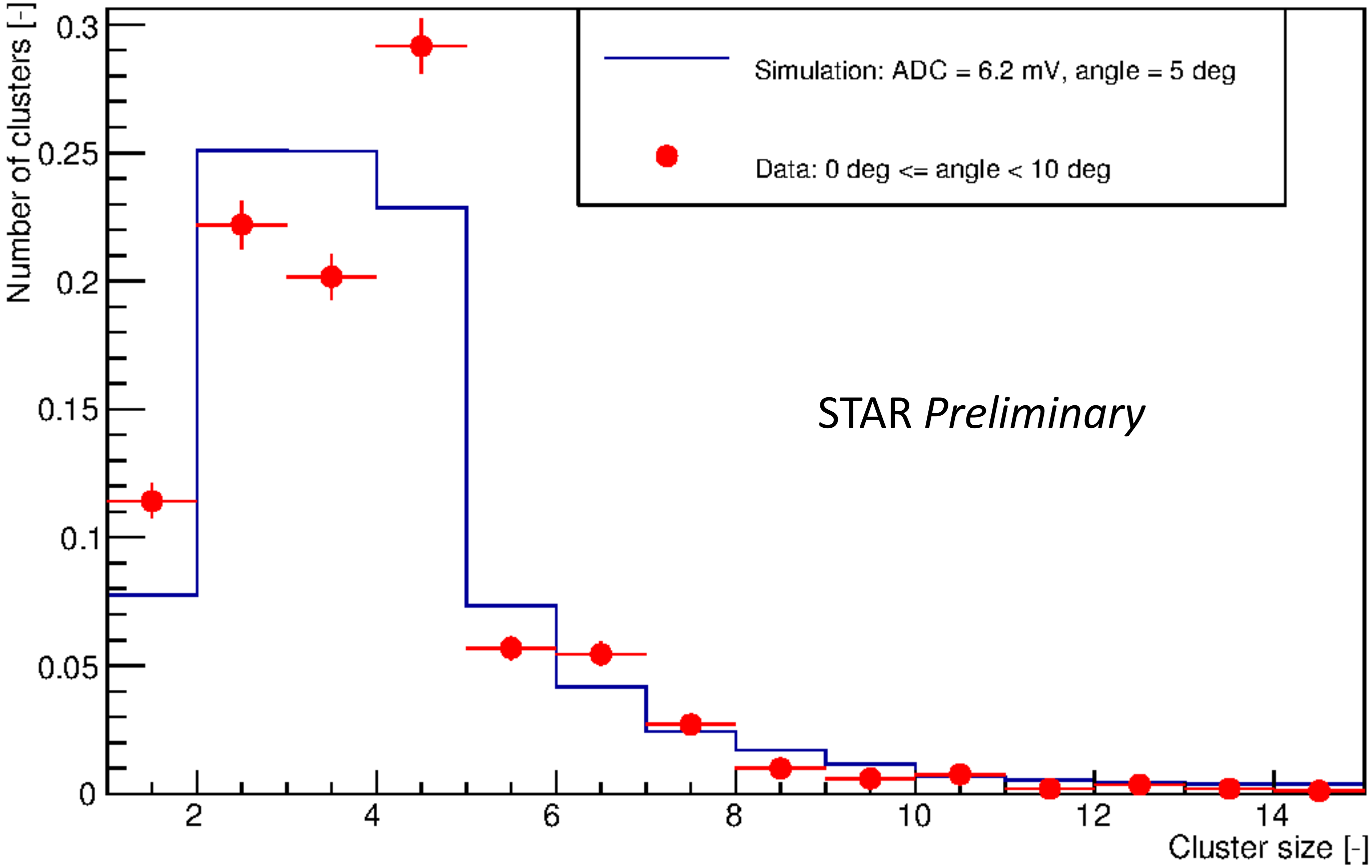
- **DIG**itizer tool for **MAPS** (A. Besson, Strasbourg)
- Slow simulator for MAPS pixel sensors
  - Input parameters, e.g. pitch, ionization energy, epitaxial layer thickness, ADC threshold
- What is it for?
  - Being able to describe the response of a chip including noise on the level of a single pixel
  - Test model for simulation
    - To provide model for full simulation for STAR-HFT

How simulations work

1. Incident particle generation
   - Angular dependence
2. Energy deposition – charge generation
   - Landau law (MPV = 80 e-/µm)
3. Charge transport up to the N-well diodes
   - Approximation by Lorentzian + Gaussian
4. Zero suppression and Clustering
   - Hit separation



First tests with cosmic data



Miroslav Šimko (STAR), Vertex 2014

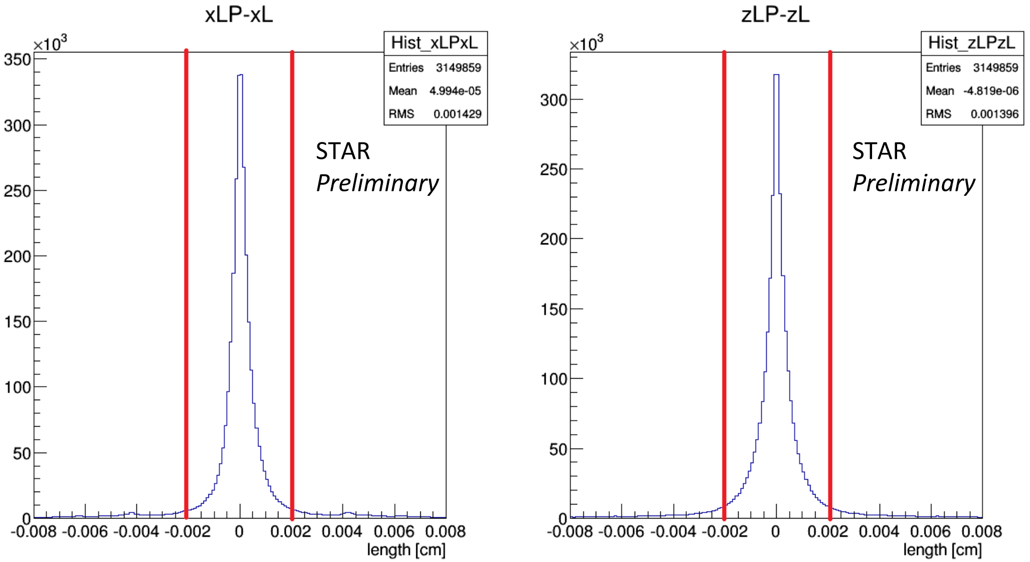
Simulator was tuned on the first cosmic data at STAR

Testing with low luminosity data

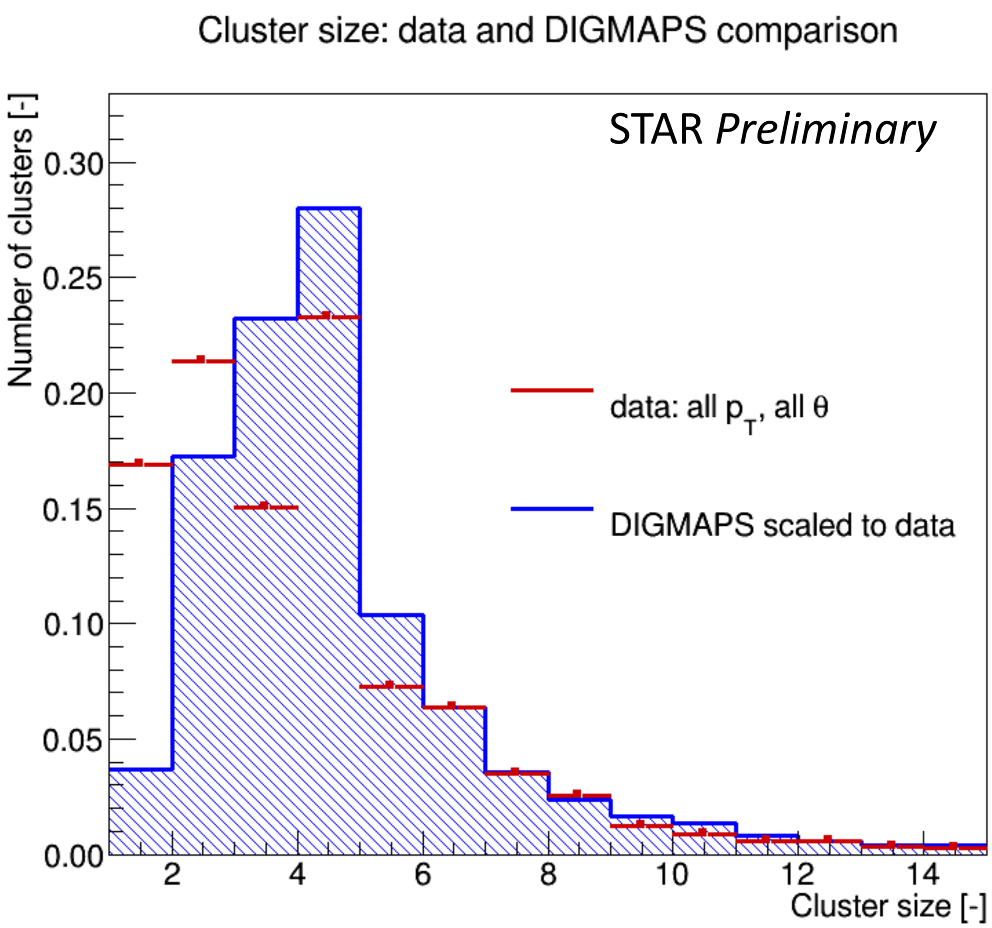
- DIGMAPS simulator is tuned for MIP
- Decide if it is usable for all particle species
  - If so, include DIGMAPS into STAR software as it is
  - If not, reprogram particle deposition energy from MIP to all particles
- How to do that?
  - Use Low luminosity Au+Au raw data
  - Reconstruct tracks
  - Look at cluster size at HFT
    - Most of them will be fake hits with 1-2 cluster size
    - Apply cuts to suppress fake hits in detector, the mean value of cluster size is expected around 3-4
    - Compare with DIGMAPS output

Applied cuts

- Run 14, Au+Au 200 GeV, low luminosity data
- PXL and IST used in tracking
- Required hit in each HFT layer
- Cuts applied to tracks
  - At least 1 cluster in IST 2σ-wide window (1 x 0,4 mm^2)
  - At least 1 cluster in inner PXL 2σ-wide window (20 x 20 μm^2)
  - At least 1 cluster in outer PXL 2σ-wide window (20 x 20 μm^2)



Clusters: all p_T, all angles



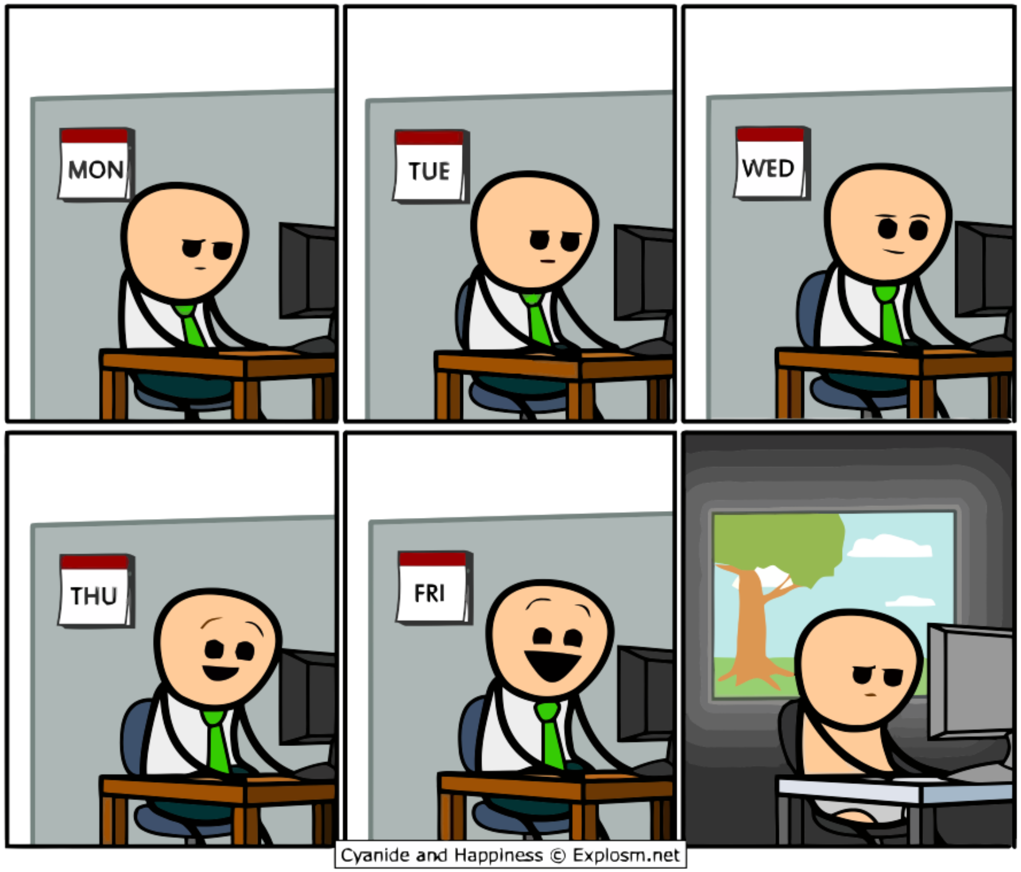
- Testing with low luminosity data started
- Behavior described excellent at large cluster sizes
- Effects of noise under study

ADC threshold: 6.2mV

Summary

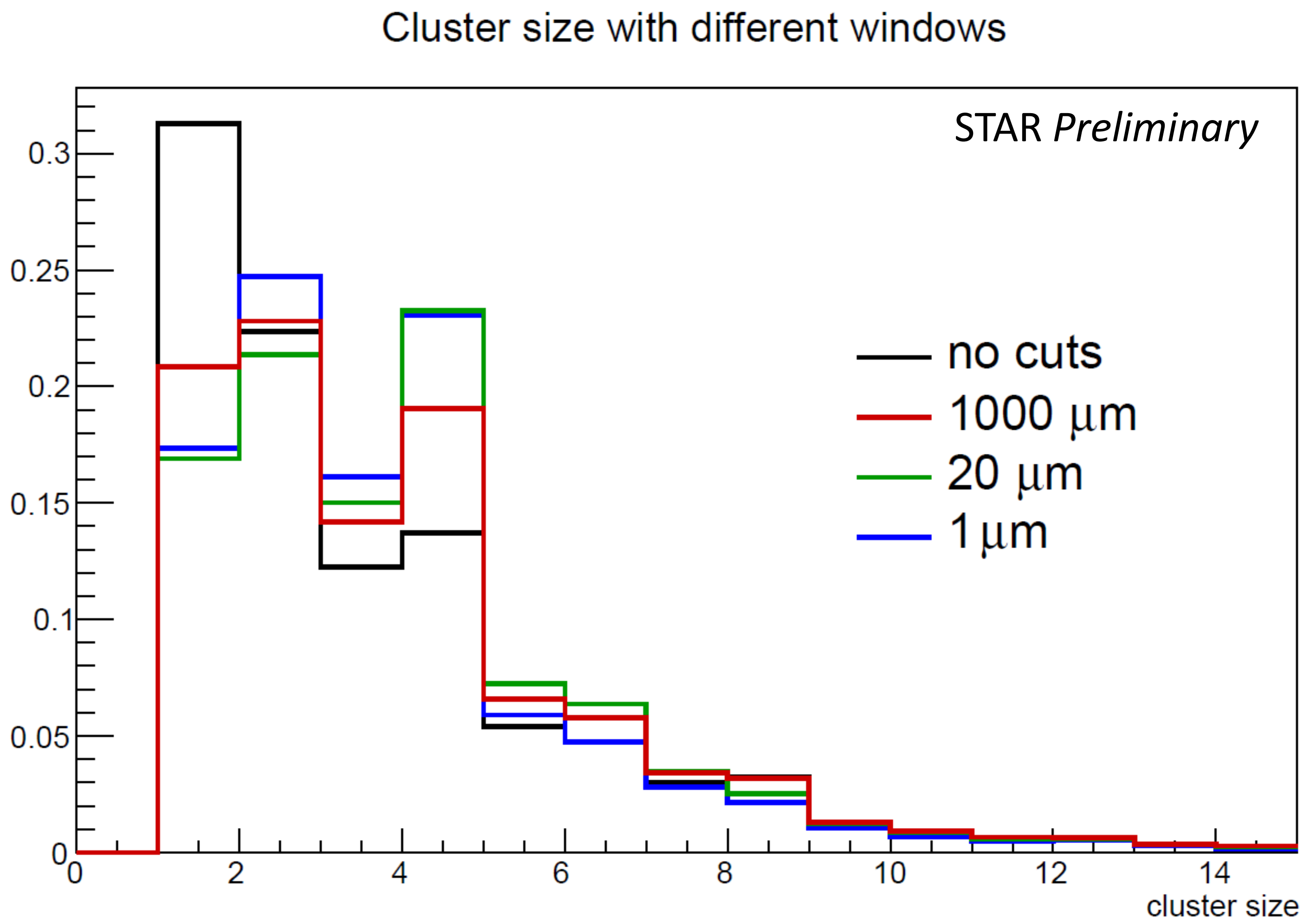
- HFT can be used for studying particles that contain heavy quarks by precisely measuring secondary decay vertices
- HFT was successfully installed at STAR. First MAPS used in collider experiments. First results are already available
- DIGMAPS was developed to simulate the response of the current pixel chips
- DIGMAPS has been tuned to cosmic data
- Ongoing tuning to low luminosity data
- Outlook:
  - Further tests and tuning with identified particles

THANK YOU FOR YOUR ATTENTION.

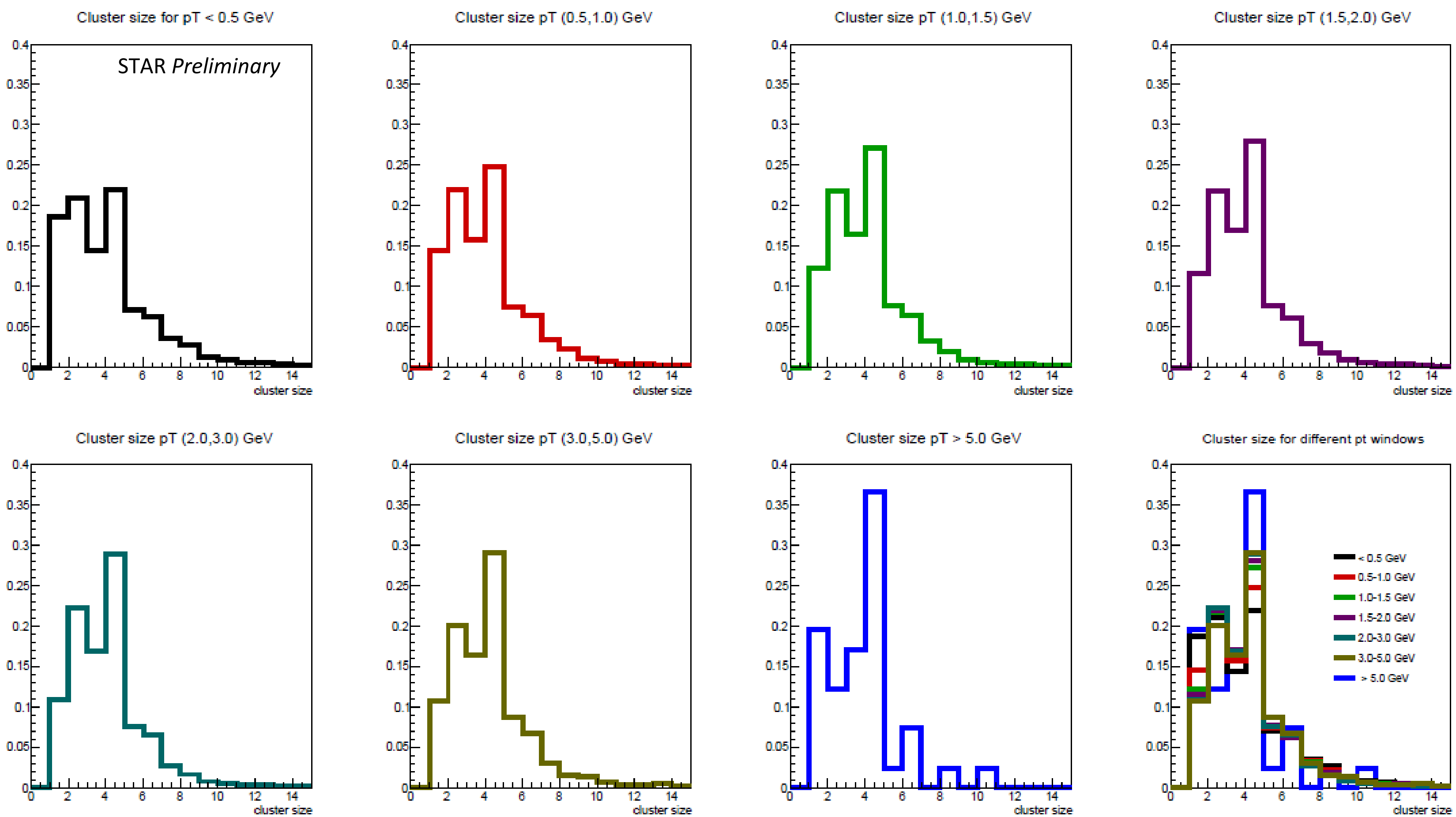


BACKUP

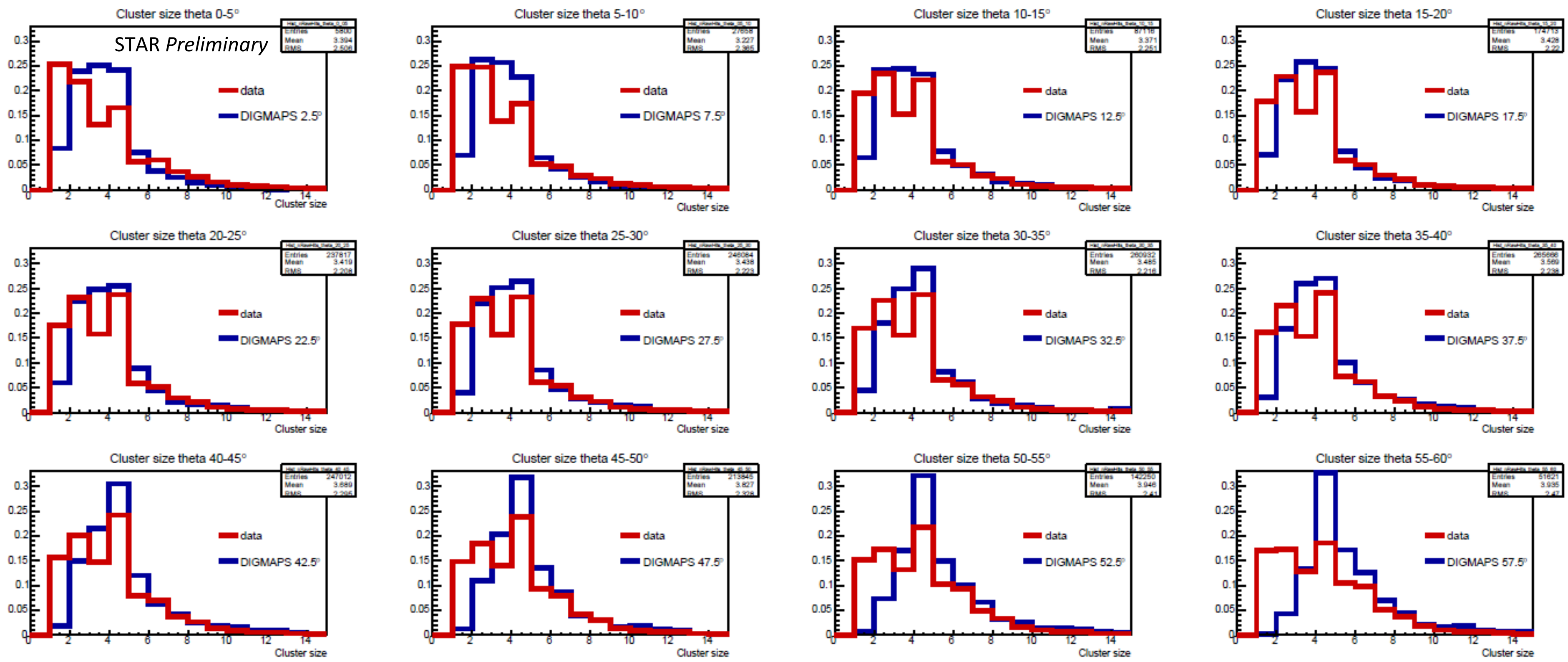
Clusters: window ranges



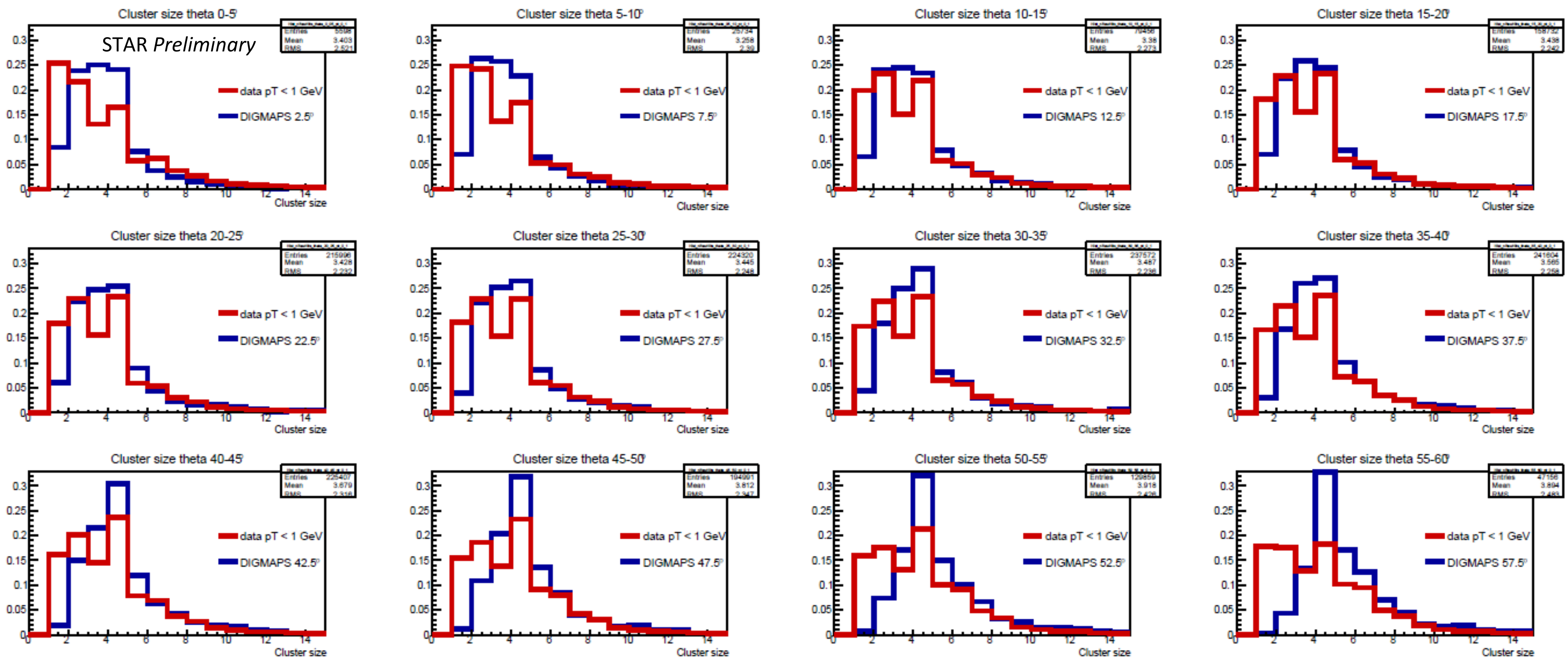
Cluster sizes: p_T ranges



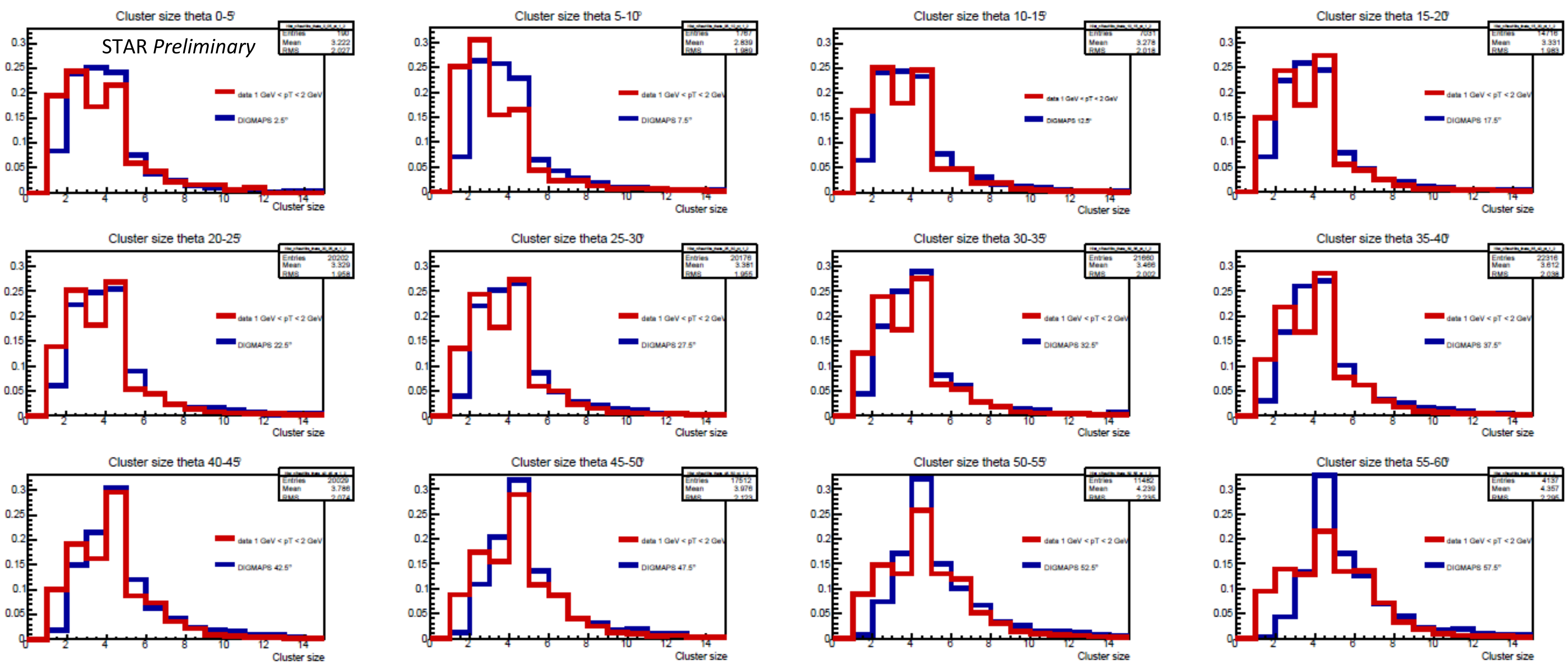
Clusters: angle ranges, all p_T



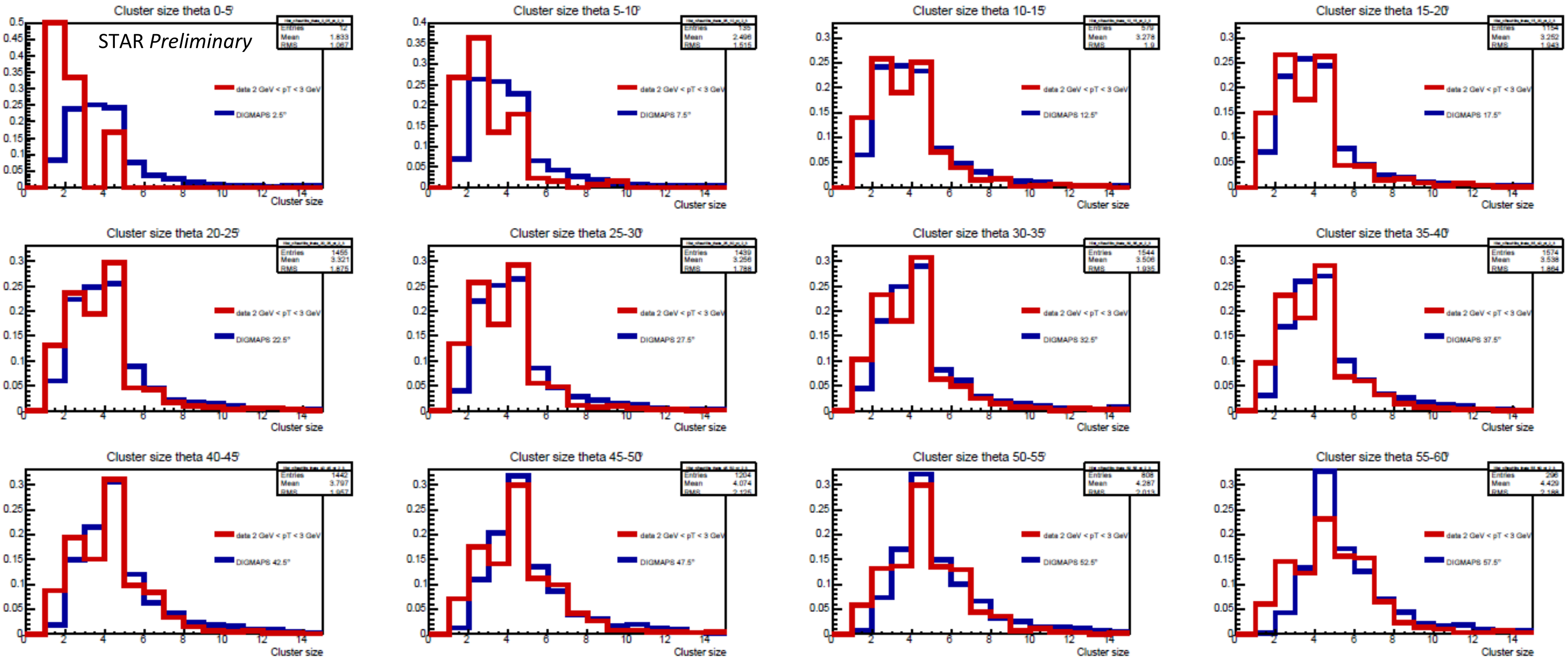
Clusters: angle ranges, p_T < 1 GeV



Clusters: angle ranges, 1 GeV < p_T < 2 GeV



Clusters: angle ranges, 2 GeV < p_T < 3 GeV



Simulations

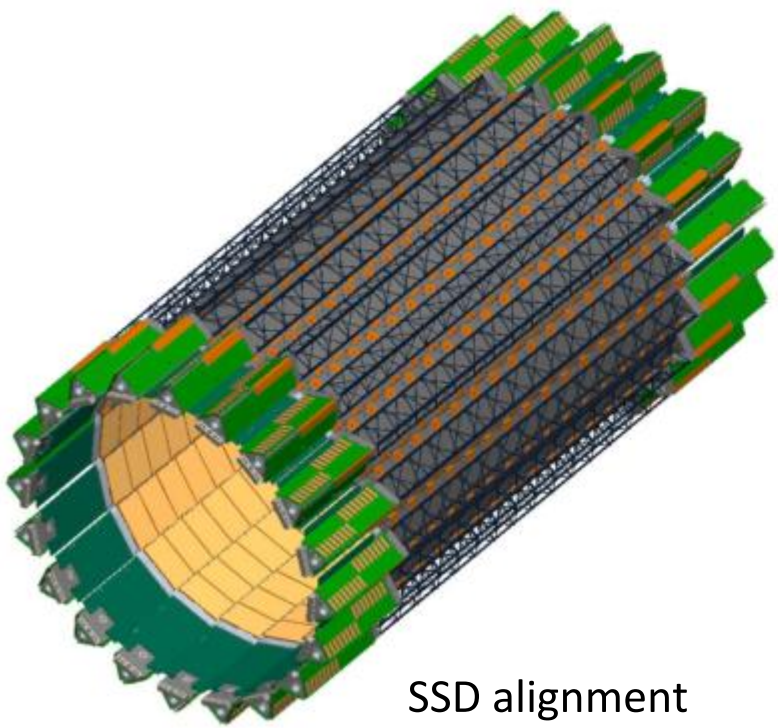
- DIGMAPS initial parameters corresponds to test beam
  - Pitch: 20.7 x 20.7 μm^2
  - Pixels: 980 x 921
  - Epitaxial Thickness: 9 μm
  - Charge transport model: 1D gaus+lorenz
  - ADC threshold: 6.2mV

CMOS, APS

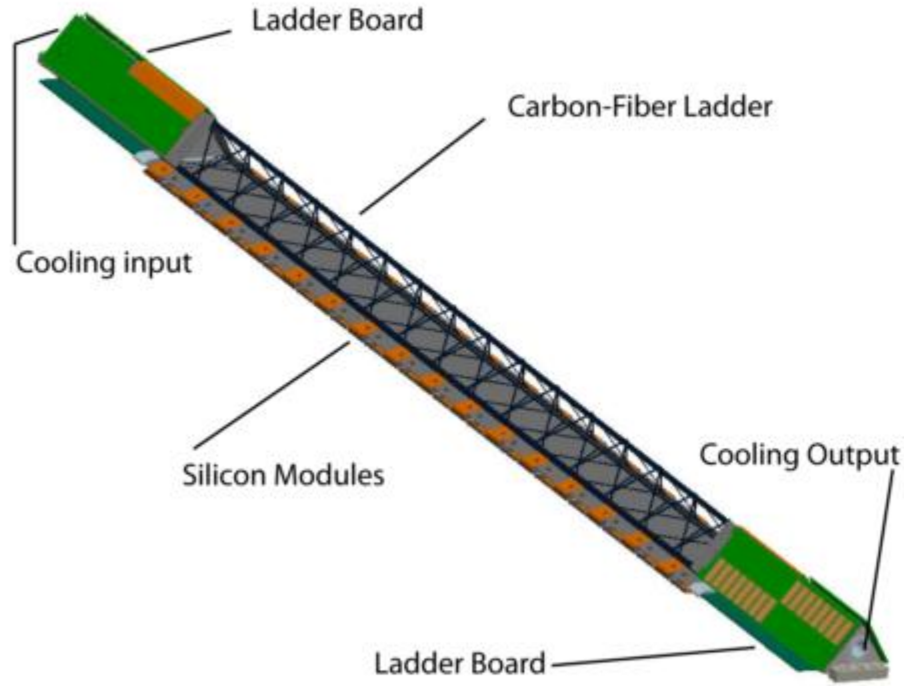
- **C**omplementary **M**etal–**O**xide–**S**emiconductor
  - technology for constructing integrated circuits
  - Microprocessors, SRAM
  - high noise immunity, low power consumption
  - Intel: Sandy Bridge, Ivy Bridge
- **A**ctive **P**ixel **S**ensor
  - array of pixel sensors
  - each pixel containing a photodetector and an active amplifier
  - cell phone cameras, web cameras, digital pocket cameras

Silicon Strip Detector

- 20 ladders
- 16 wafers per ladder
- 768 strips per wafer side

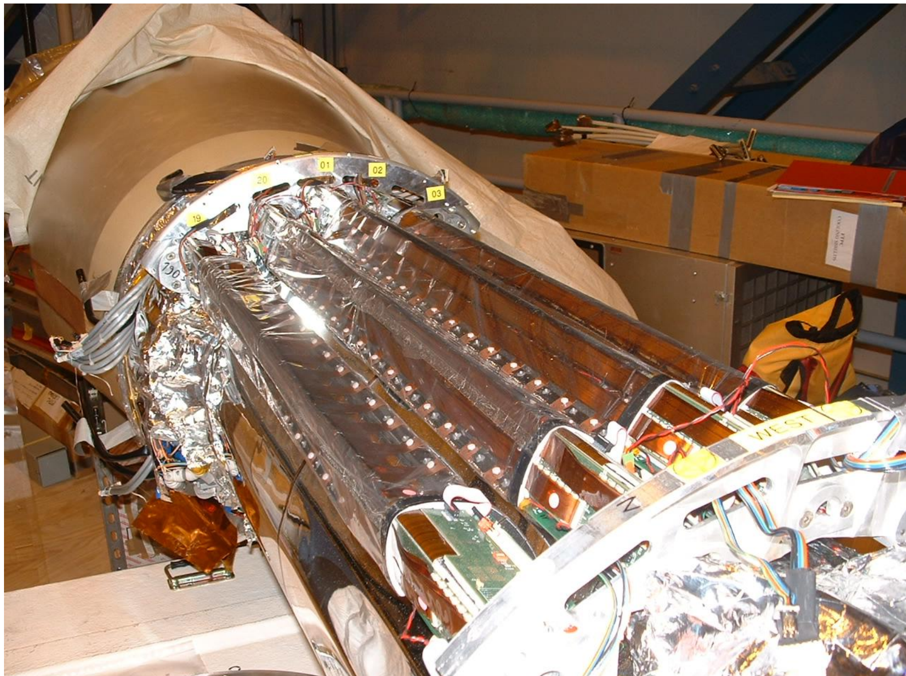


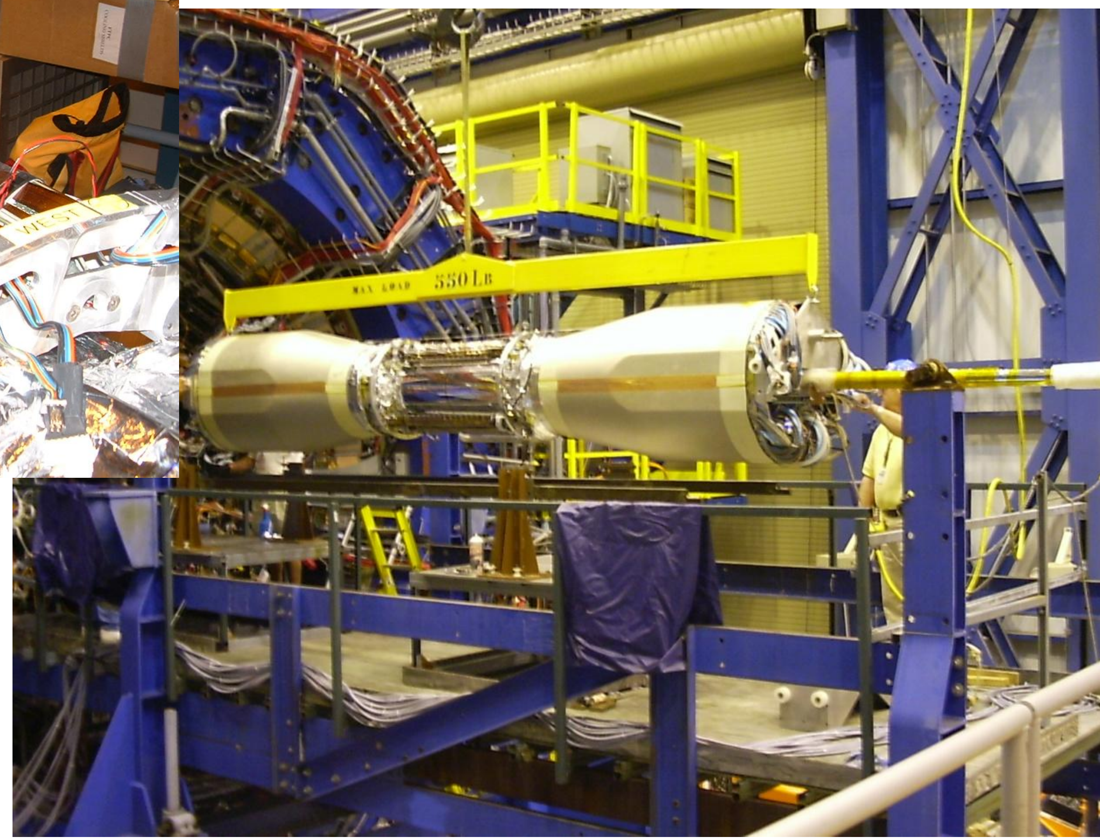
SSD alignment



SSD ladder

Silicon Strip Detector





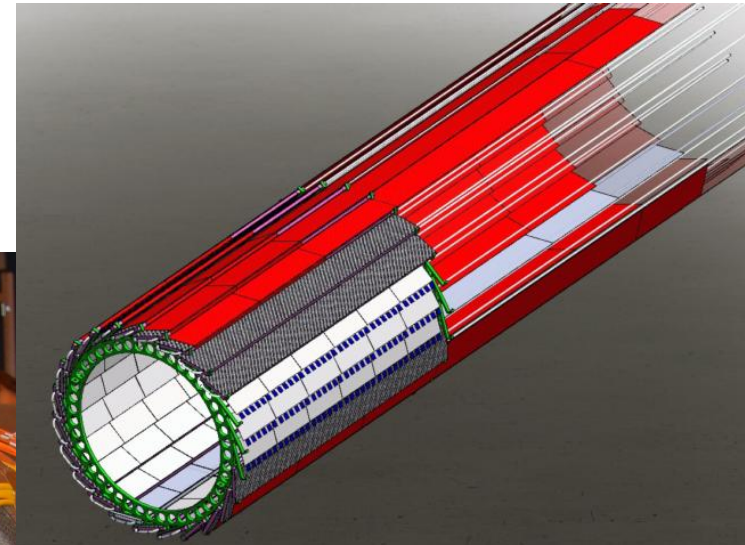
Silicon Strip Detector

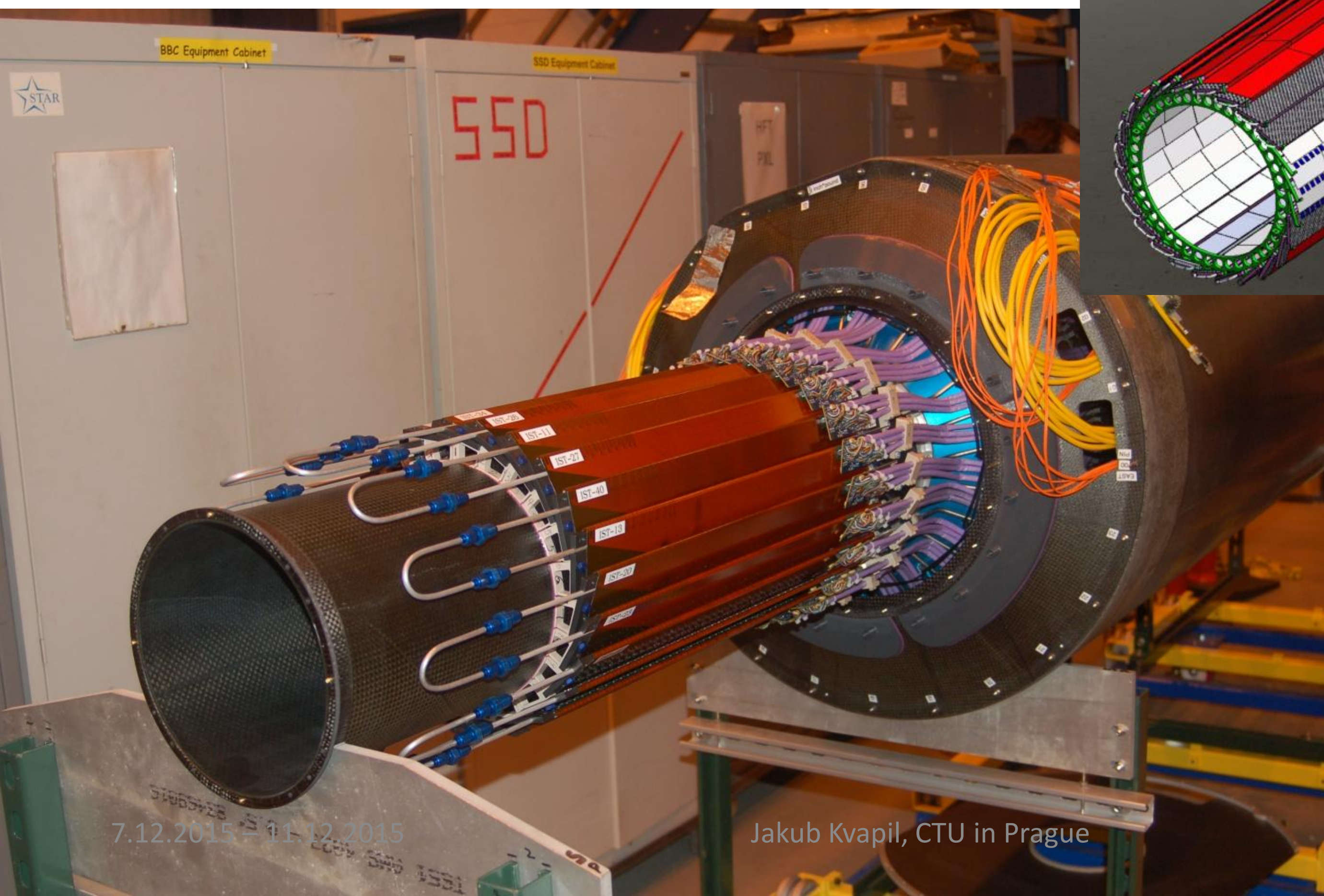
Radius	22 cm
Length	106 cm
Strip size	95 μm X 73 mm
R-Φ, Z resolution	20 μm X 740 μm
Number of channels	500 k
Heat dissipation	500 W, air cooling
Radiation length	X/X_0 = 1%

20 ladders
16 wafers per ladder
768 strips per wafer side
Double sided silicon pad sensors

Intermediate Silicon Tracker

- 24 staves
- each 6 silicon pad sensors and 36 readout chips





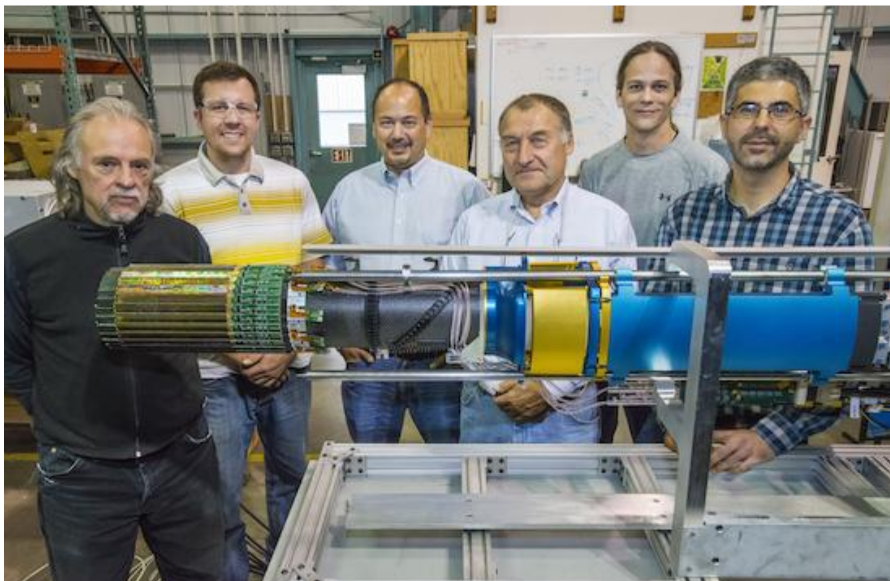
Intermediate Silicon Tracker

Radius	14 cm
Length	50 cm
Strip size	600 μm X 6 mm
R-Φ, Z resolution	172 μm X 1.8 mm
Number of channels	110 k
Integration time	185.6 μs
Heat dissipation	264 W, liquid cooling
Radiation length	X/X_0 = 1.5%
Radiation environment	30 kRad / year

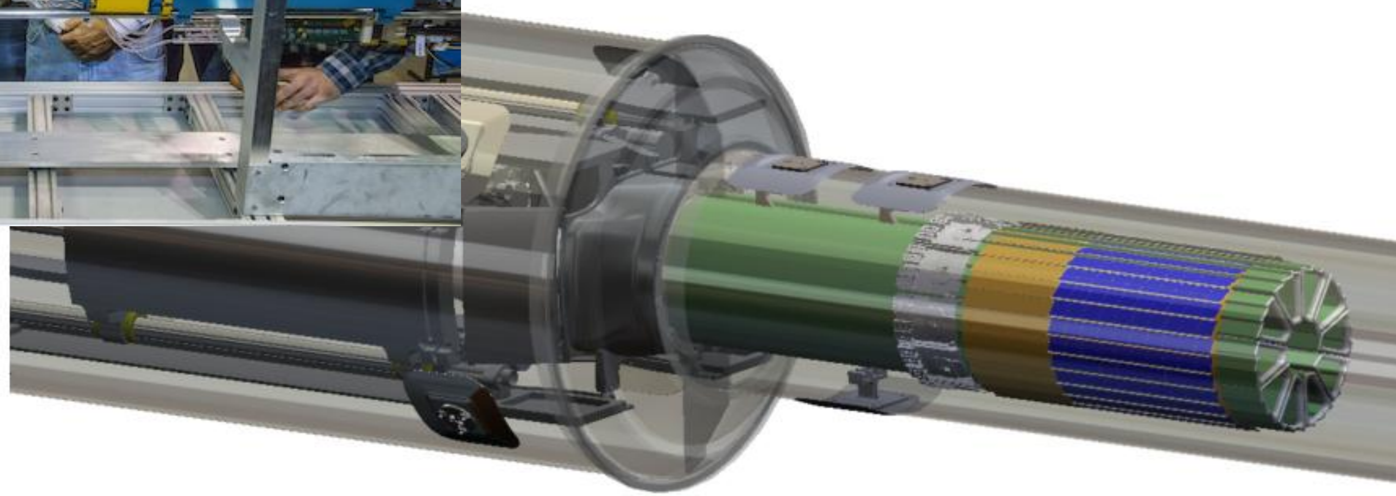
Single sided silicon pad sensors
24 staves, each with 6 silicon pad sensors and 36 readout chips

PiXeLs

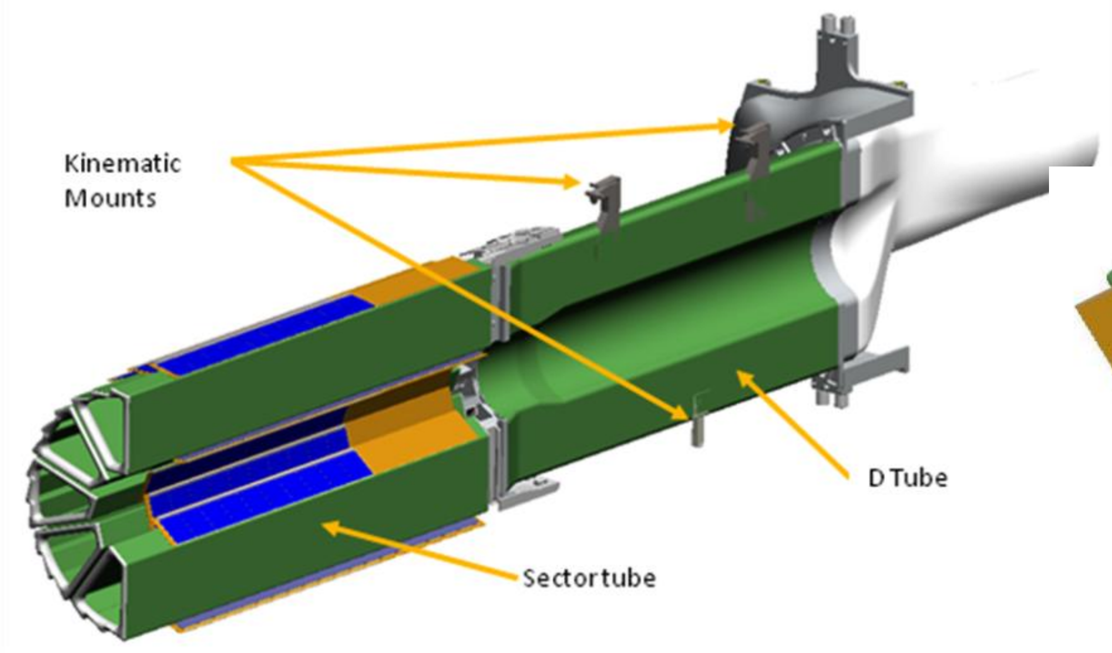
- 10 carbon fiber sector tubes
- each supporting four 10-sensor ladders (1 inner layer, 3 outer layer)
- Sensor: CMOS MAPS – 1000 x 1000 pixels

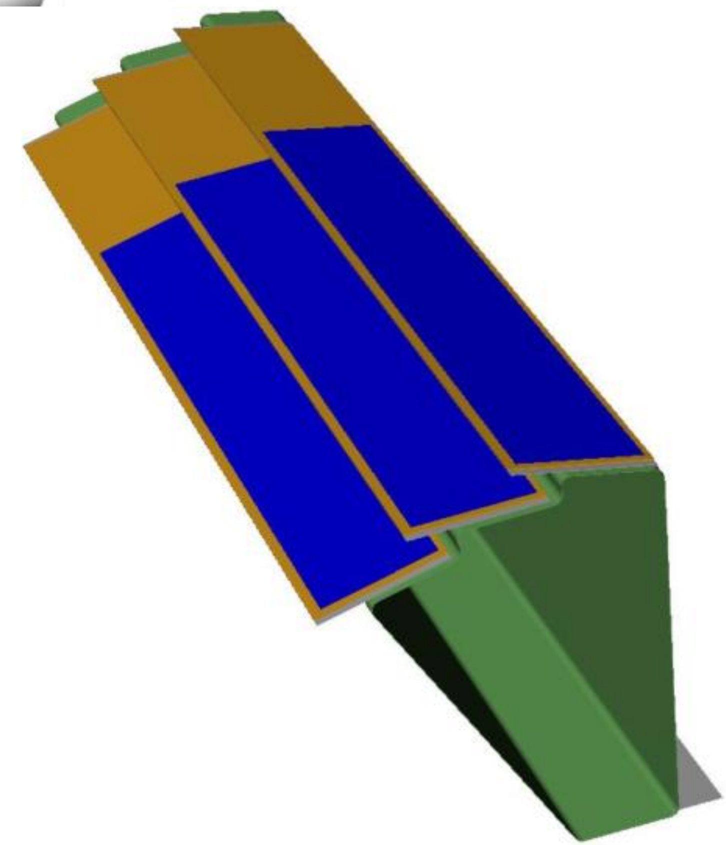


First monolithic sensor used in particle experiment



PiXeLs





PiXeLs

Layers	Layer 1 at 2.8 cm radius Layer 2 at 8 cm radius
MAPS sensors	400
Pixel size	20.7 μm X 20.7 μm
Total number of pixels	361 M
Integration time	185.6 μs
Heat dissipation	< 200mW/cm^2, air cooling
Radiation length	Layer 1 X/X_0 = 0.4% Layer 2 X/X_0 = 0.5%
Radiation environment	90 kRad / year (267 kRad / 12 w) 2*10^{11} to 10^{12} 1MeV n eq/cm^2

[10]