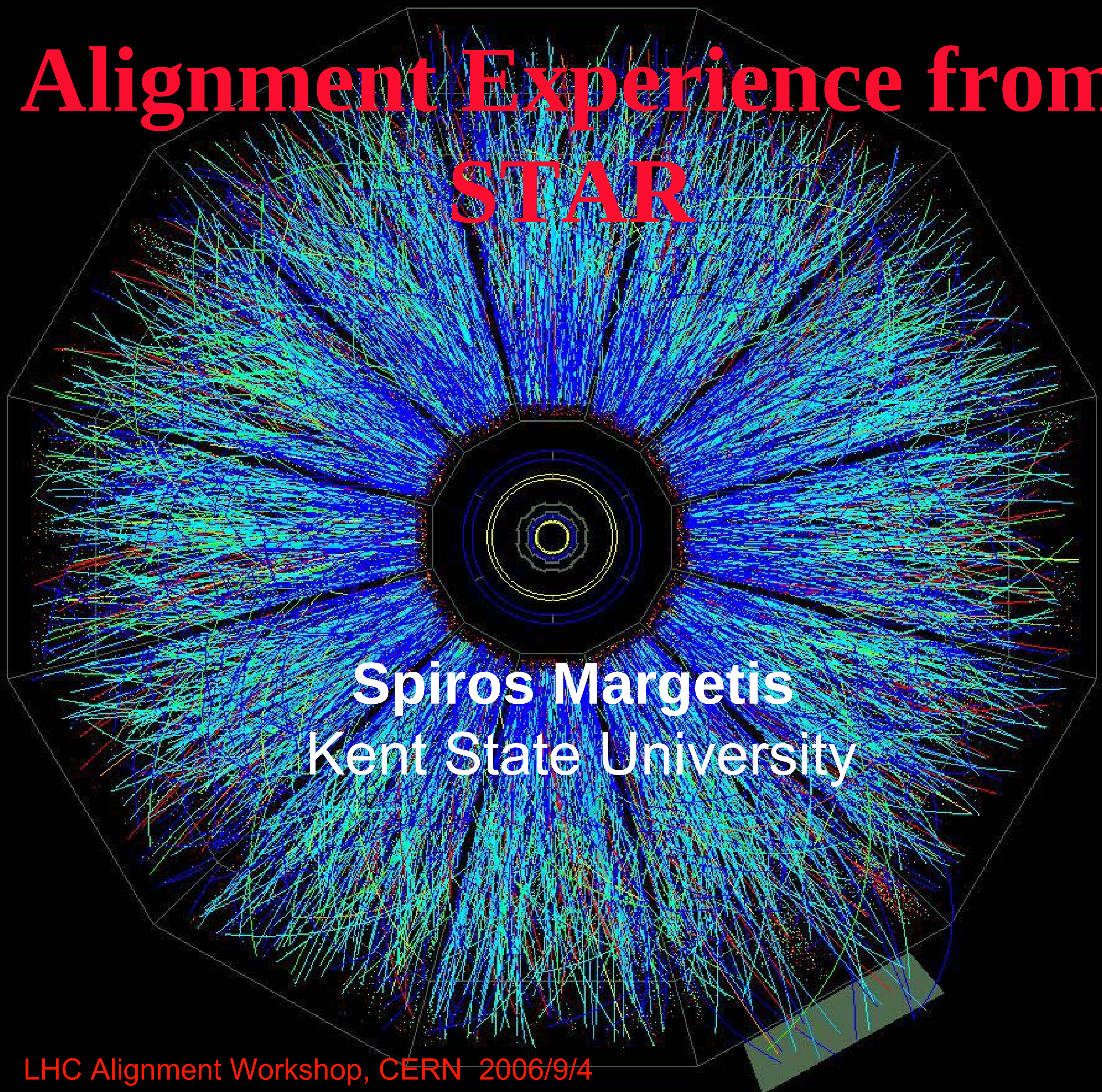
Alignment Experience from STAR



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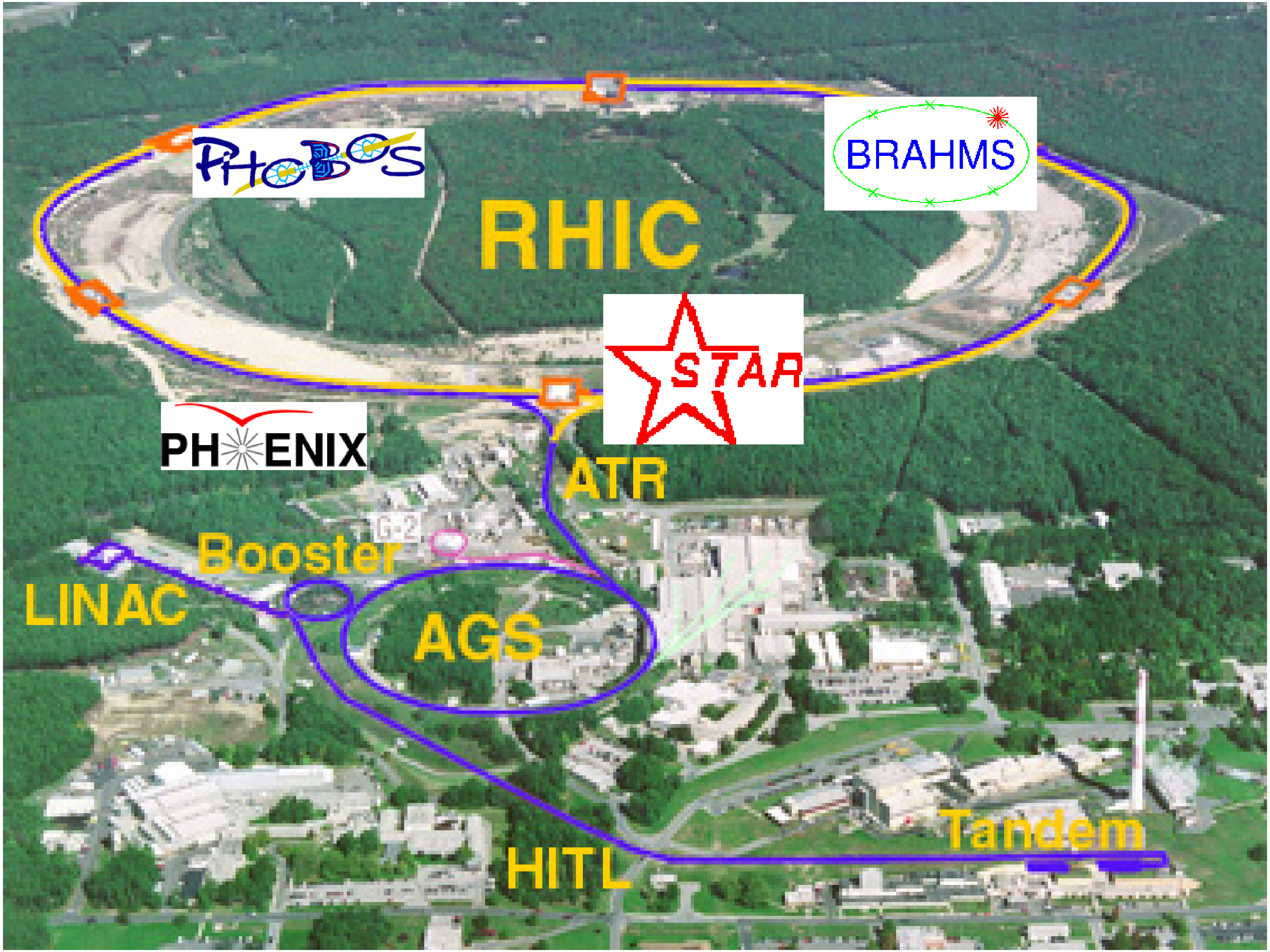
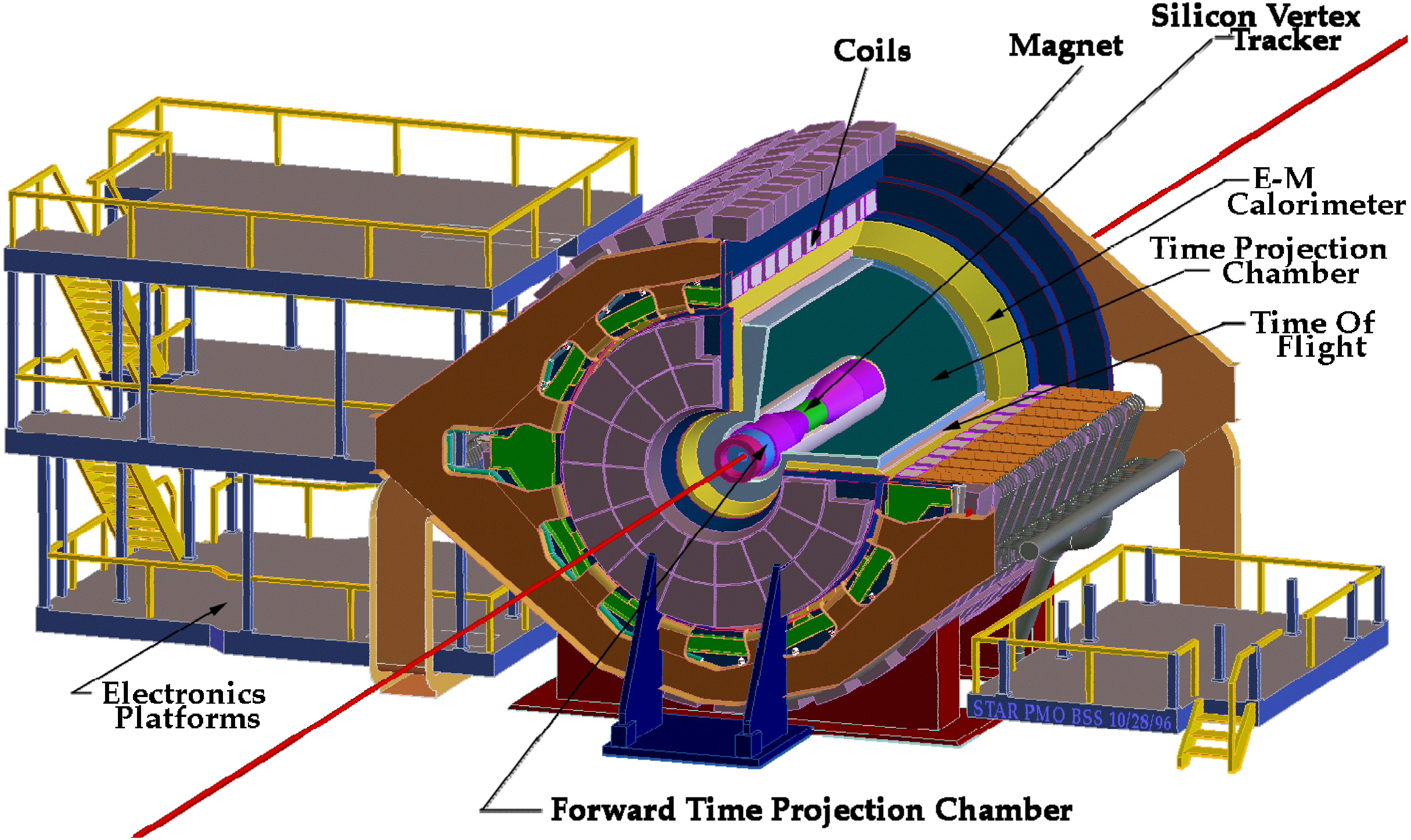
LHC Alignment Workshop, CERN 2006/9/4

Outline

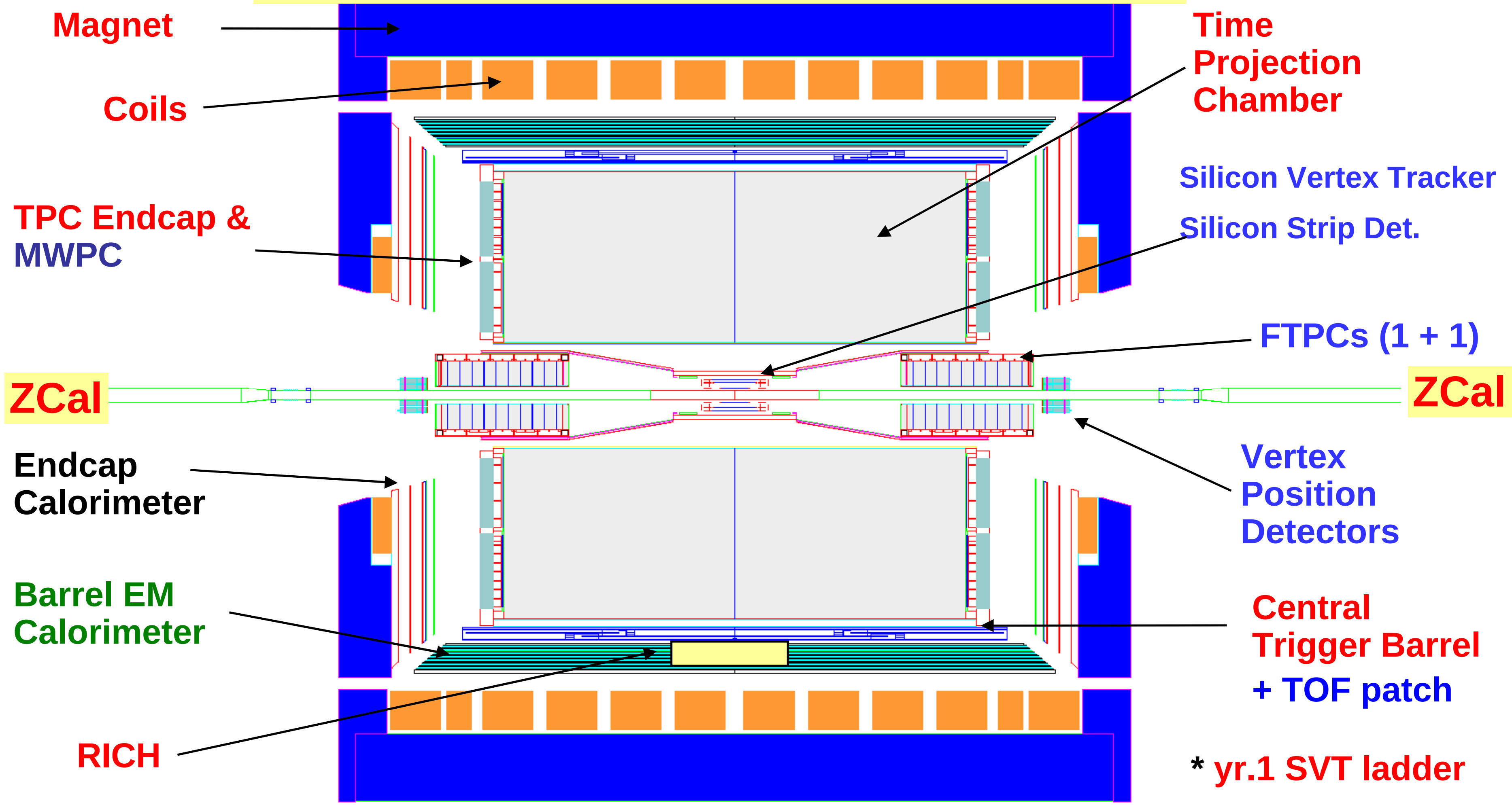
- The Detector(s) and the Physics Goals
- Recent work on Alignment
  - Strategies, Methods used
- Lessons learned so far
- Summary


RHIC
PHOBOS
BRAHMS
STAR
PHENIX
ATR
G-2
Booster
LINAC
AGS
Tandem
HITL

STAR - A multi-purpose barrel detector for Heavy Ions at RHIC



The STAR Detector



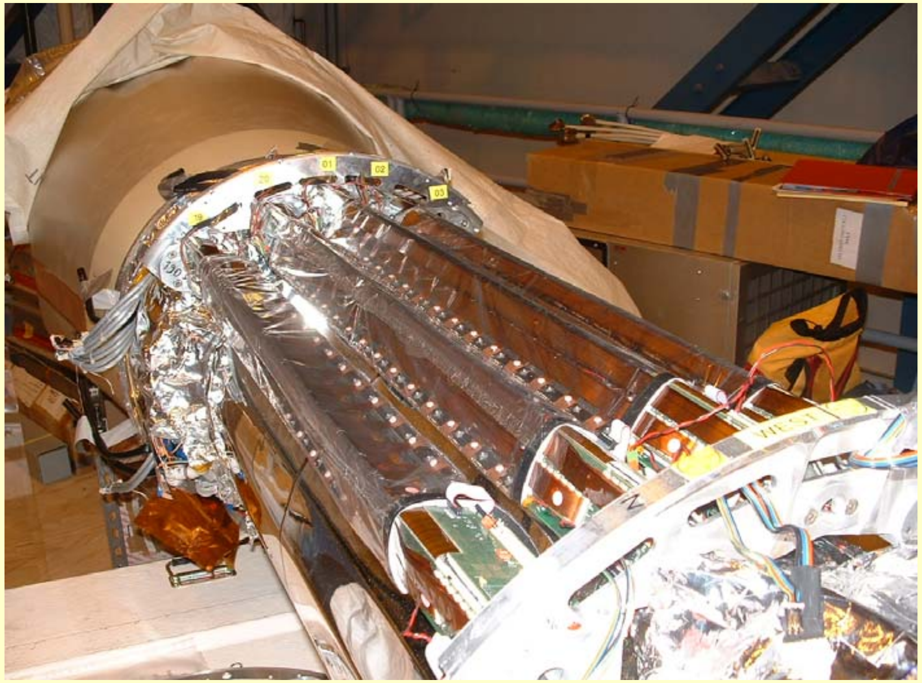
SVT- A 3 Layer Silicon Drift Detector

- A new technology at the time
- Primarily designed to do multi-strange particle physics
    - Relatively thick, far from vertex
- Arranged as 3 layers, at ~7,11,15 cm from vertex, on two rigid Clam-Shells

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

SSD - A single layer of 2-side Silicon Strip Detector

- It wraps around the SVT as a fourth layer
- It's primary purpose is to provide an intermediate point for track matching between the TPC and SVT
- Big Advantage: Non-drifting technology
- 20 ladders, at ~20cm from the beam, on 4 rigid Sectors



Initial remarks

- The initial goals for the SVT was to measure Ξ, Ω particles, not D-mesons!
  - but there is much interest in direct charm measurements now
  - A renewed effort started about a year ago to see if we can use the vertex trackers for charm. Alignment and Drift velocity calibrations were re-visited
  - See if we are able to do 'some/any' direct D-meson measurement and/or B-meson tagging
- Heavy Ion collisions is the toughest environment for this kind of work, about 2000 tracks in a single event, and with the fewest experts!

Figures of merit for SVT/SSD?

- **Pointing accuracy**, aka **Impact parameter** or **DCA** resolution
  - Combined resolution+calibrations must give better than TPC DCA-resolution (1-2 mm) [easy] and much better {~100um) for charm.
- **High efficiency** (Hit/Track finding/matching)
  - Interplay of good calibrations and good tracking algorithms
  - SSD is indispensable in Au+Au as a pointing/matching device
- **Low ghosting**

NOTE: Event Vertex Resolution should be better or comparable to pointing resolution of decay products. For central Au+Au collisions turns out to be better than 20 micron

Alignment/Calibrations affect everything

Procedure

- **Global Alignment**
  - **Step 1) Global SVT, SSD Alignment using SURVEY and TPC info,**
  - **Step 2) SSD Ladder tuning using TPC tracks,**
  - **Step 3) SVT Ladder Z-tuning using TPC+SSD tracks,**
- **SVT Drift velocities**
  - **Step 4) SVT Drift Velocity Calibration using TPC+SSD info**
  - **Step 5) Fine tuning SVT ladder alignment with updated drift velocities**
- **SVT Self-Alignment**

Alignment procedure

- Use:
  - Notations : Global X, Y,Z, Local u ≡ x (drift), v ≡ z, w ≡ y, α,β,γ are rotation around u, v, w or global X,Y,Z, respectively. Units are cm.
  - Rigid body model has been applied (ignore possible twists effects, etc for the moment).
  - A misalignment model (D0 alignment model): Taylor's expansion with respect to misalignment parameters (3D shifts (Δu,Δv,Δw) and 3D rotations(Δα, Δβ, Δγ)) for deviations of measured hit position from predicted (from other detectors) primary track position on a measurement plane
  - A misalignment parameter has been calculated as a slope with straight line fit of histogram of most probable values for above deviations versus corresponding track coordinates or inclination to detector plane (see examples below)
  - Frozen wafer position on ladder from survey data.
- Calibration sample:
  - ~250 Kevents of Cu+Cu at 62 GeV/nucleon at the end of fills (low luminosity, low space charge → low TPC distortions). TPC is drifting too!
  - Attempt to use NO Field data has failed because we found ~250 mkm displacement with respect to Full Field CuCu62 data and for which we don't have any model for now.

mkm=micron

Step 1) Global SVT, SSD Alignment using Survey and TPC info

- The SVT Clam-Shells and SSD Sectors were aligned using TPC tracking info only.
  - SVT and SSD ladder survey info was used/assumed at this point. Ladder-on-Shell accuracy of survey data estimated (hard/soft) 20-30 mkm
  - Proper math for Global shifts/rotations was developed (same procedure as in local)
  - Procedure checked for accuracy and limitations with Monte Carlo blind tests.

- In order to avoid drift velocity effects in the SVT, only the first 4mm of drift around the anodes were used (|u| in range [2.5,2.9] cm out of [0.0,3.0] cm total Si drift)

- Also excluded 1mm around readout anodes (due to variations in the focusing electric fields surrounding the anodes)

- When done Shells/Sectors were (on average) aligned to better than ~50 mkm in translations, and a few mrad in rotations.

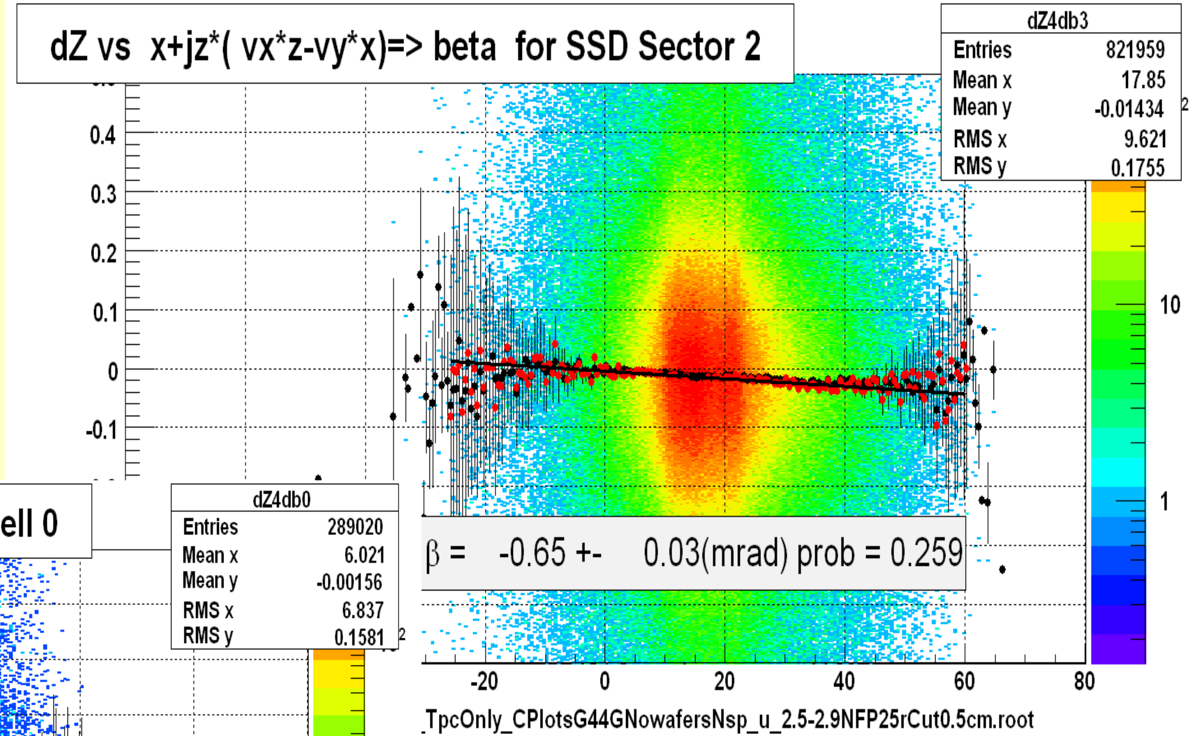
PTO ->

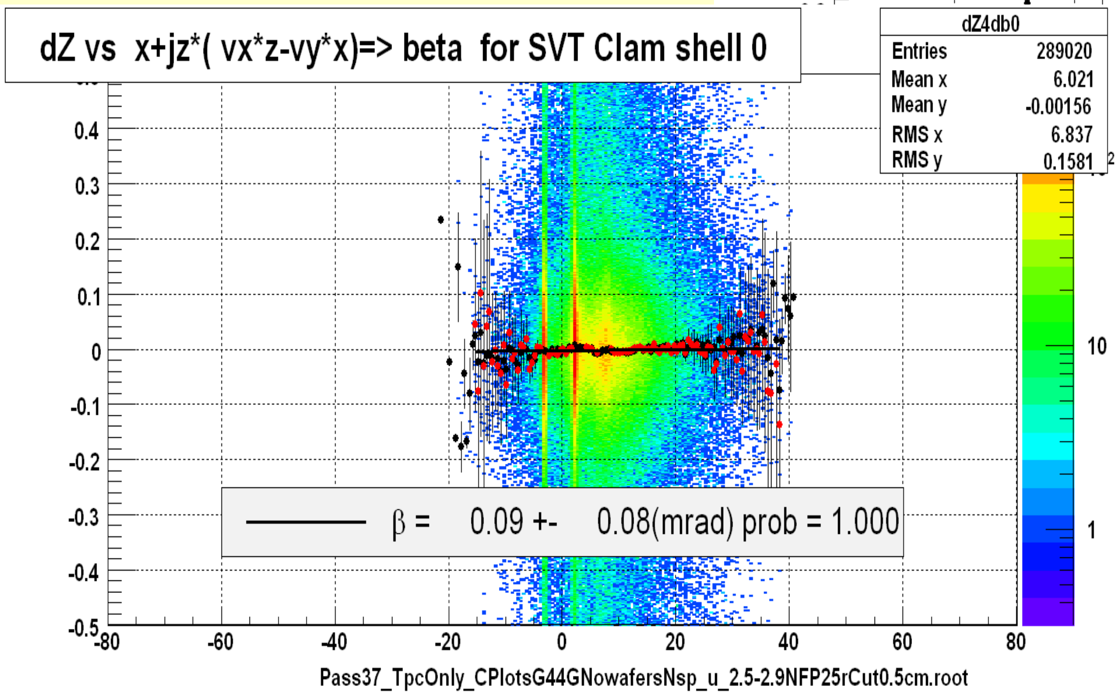
- **An example of results can be seen below and at:** http://www.star.bnl.gov/STAR/comp/reco/SVT/Alignment/Pass37_TpcOnly/C/Global/

and

http://www.star.bnl.gov/STAR/comp/reco/SVT/Alignment/Pass37_TpcOnly/C/Results.Sector_5FriApr2818:40:172006Pass37_TpcOnly_CPlotsG44GNowafersNsp_u_2.5-2.9NFP25rCut0.5cm

β is rotation around Y axis





Step 2) SSD Ladder tuning using TPC info

- Although SSD Sectors were good on the average, individual Ladders showed translations up to ~200mkms and rotations (especially around y-axis) of up to ~20mrad. A fine-tuning was performed.

http://www.star.bnl.gov/STAR/comp/reco/SVT/Alignment/Pass37_TpcOnly/C/Results.Pass37_TpcOnly_CPlotsG44GNoWafers_u_2.5-2.9NFP25rCut0.5cmFriApr2819:39:262006

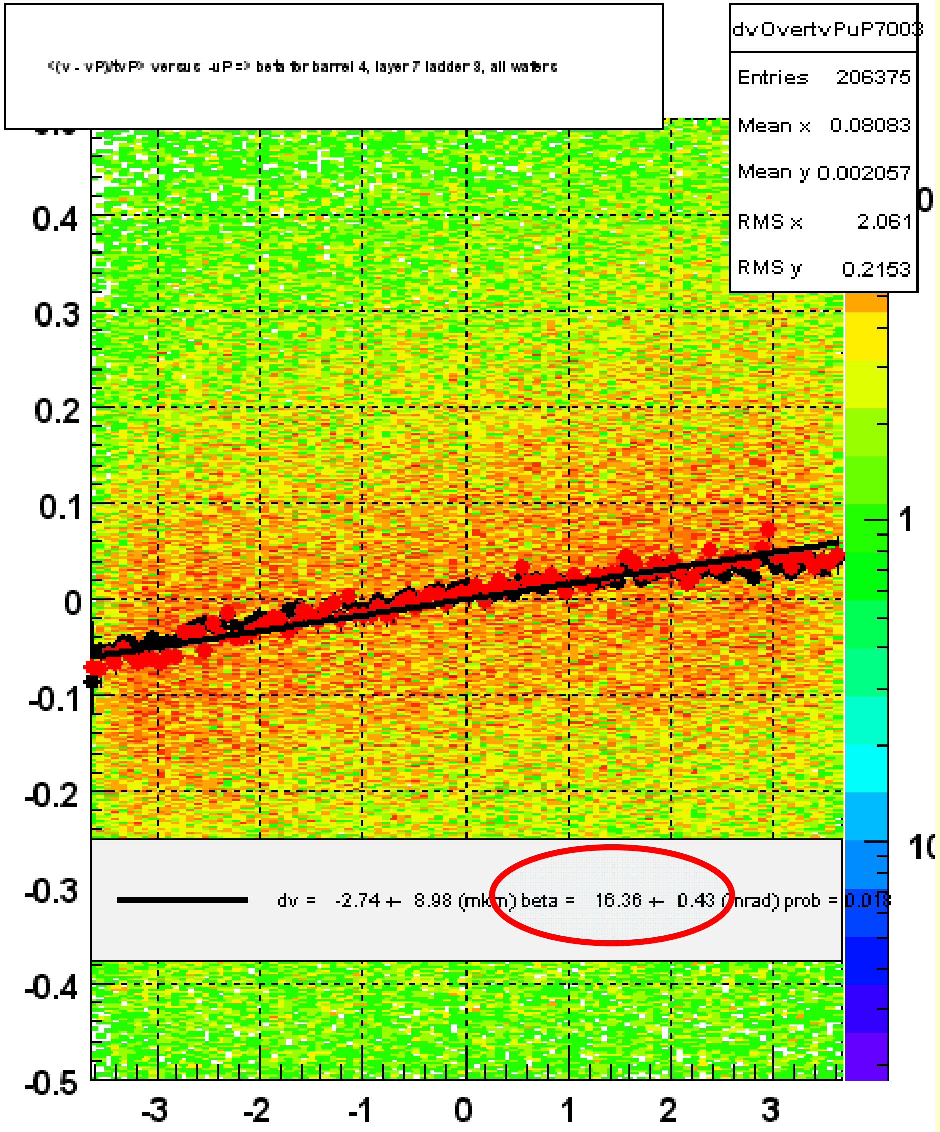
- After the SSD Ladder fine tuning the majority had translations of <20mkm and rotations <0.5mrad, all within errors.

http://www.star.bnl.gov/STAR/comp/reco/SVT/Alignment/Pass37_TpcOnly/J/Ssd/Results.Pass37_TpcOnly_JPlotsG44G_u_2.5-2.9NFP25rCut0.5cmSunApr3022:38:302006

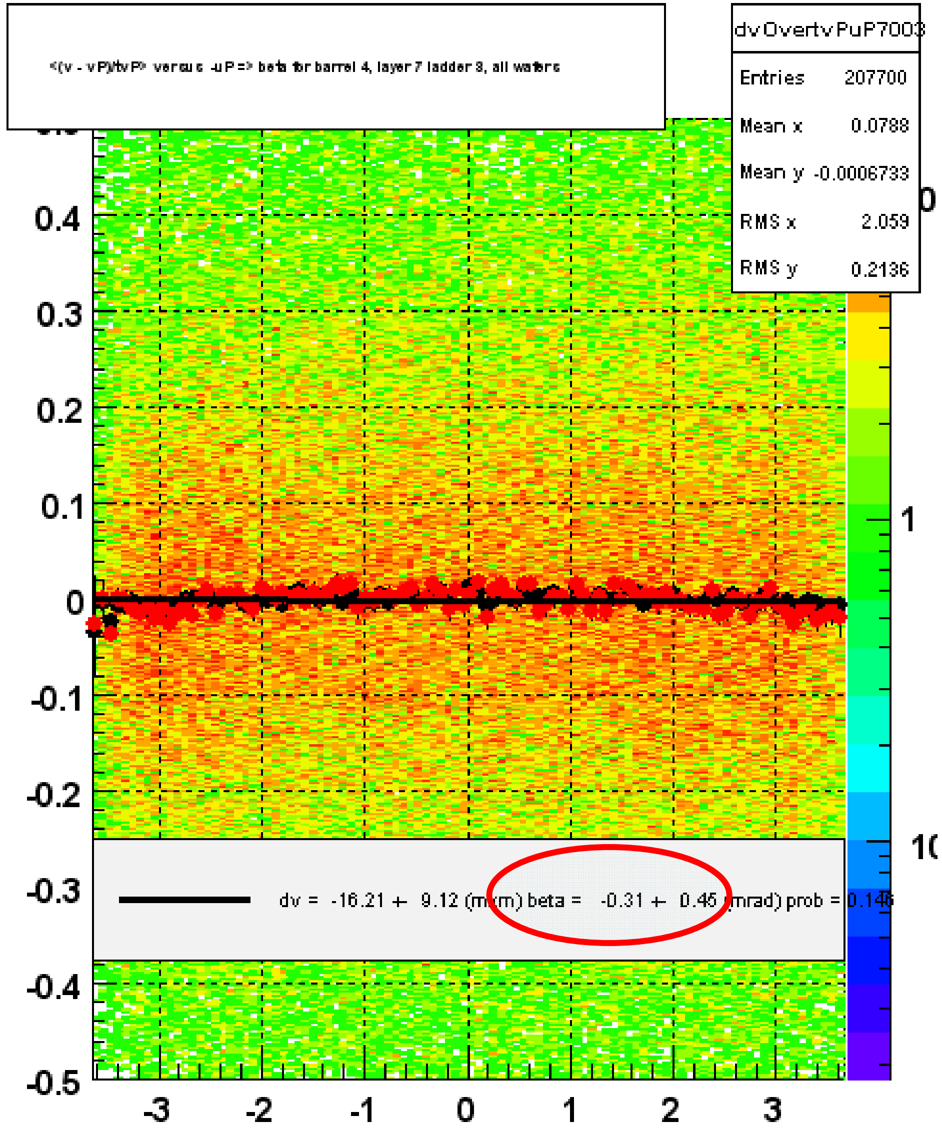
(see also next slide)

- After this step the SSD Geometry was frozen and SSD info was put on tracking with proper errors (specs) (200 mkm or R-Phi and 700 mkm in Z)

BEFORE



AFTER



Example of correcting a SSD individual ladder rotation around the z-axis

Step 3) SVT Ladder Z-tuning using TPC+SSD info

- Although SVT Shells, as a whole, were good on the average, individual Ladders showed Z-translations up to ~400mkms (but the bulk around 100mkms). We believe that this discrepancy between survey and in-situ positions is due to work done on Shells after the survey was completed (water pipe leakage). Also 2 Ladders were replaced and serviced.

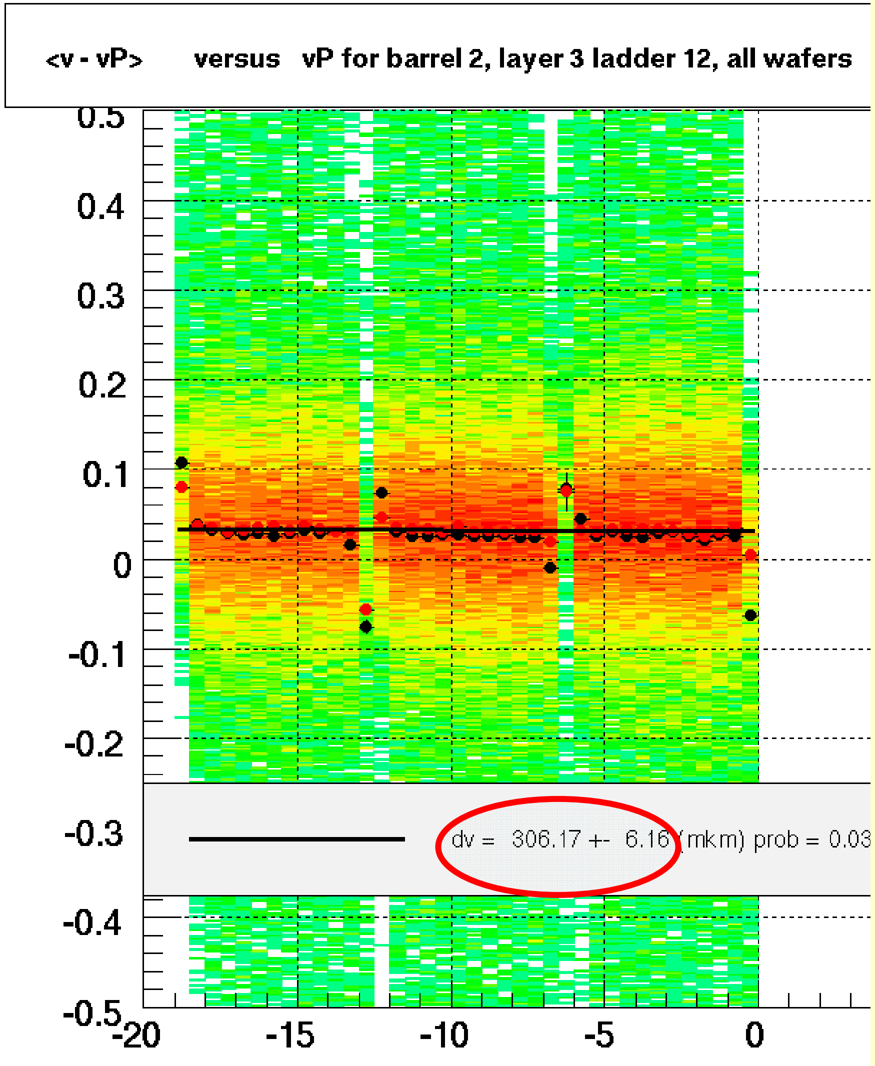
- *Touching the detector after the survey is done should be avoided!!*

- After the SVT Ladder fine Z-tuning the majority has translations of <20mkm

http://www.star.bnl.gov/STAR/comp/reco/SVT/Alignment/Pass49_Q/Ladders

- See next slide for example

BEFORE



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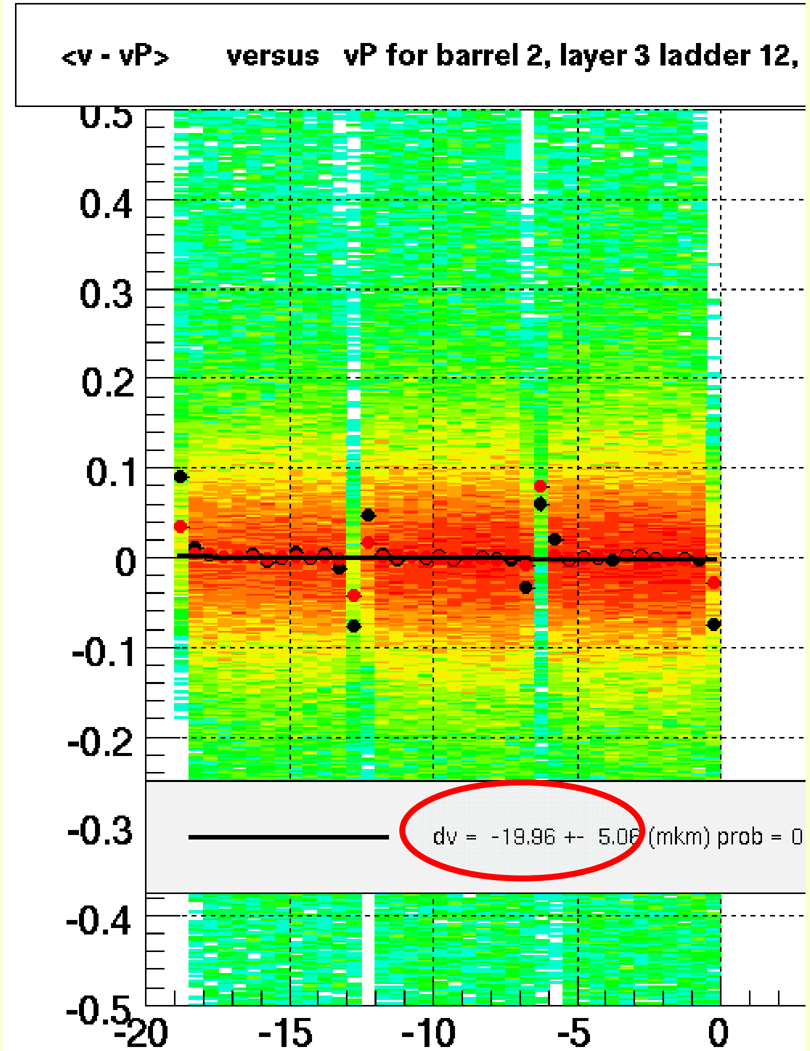


Example of fine tuning the z position of an SVT ladder using TPC+SSD info

Step 4) SVT Drift Velocity Calibration using TPC+SSD info

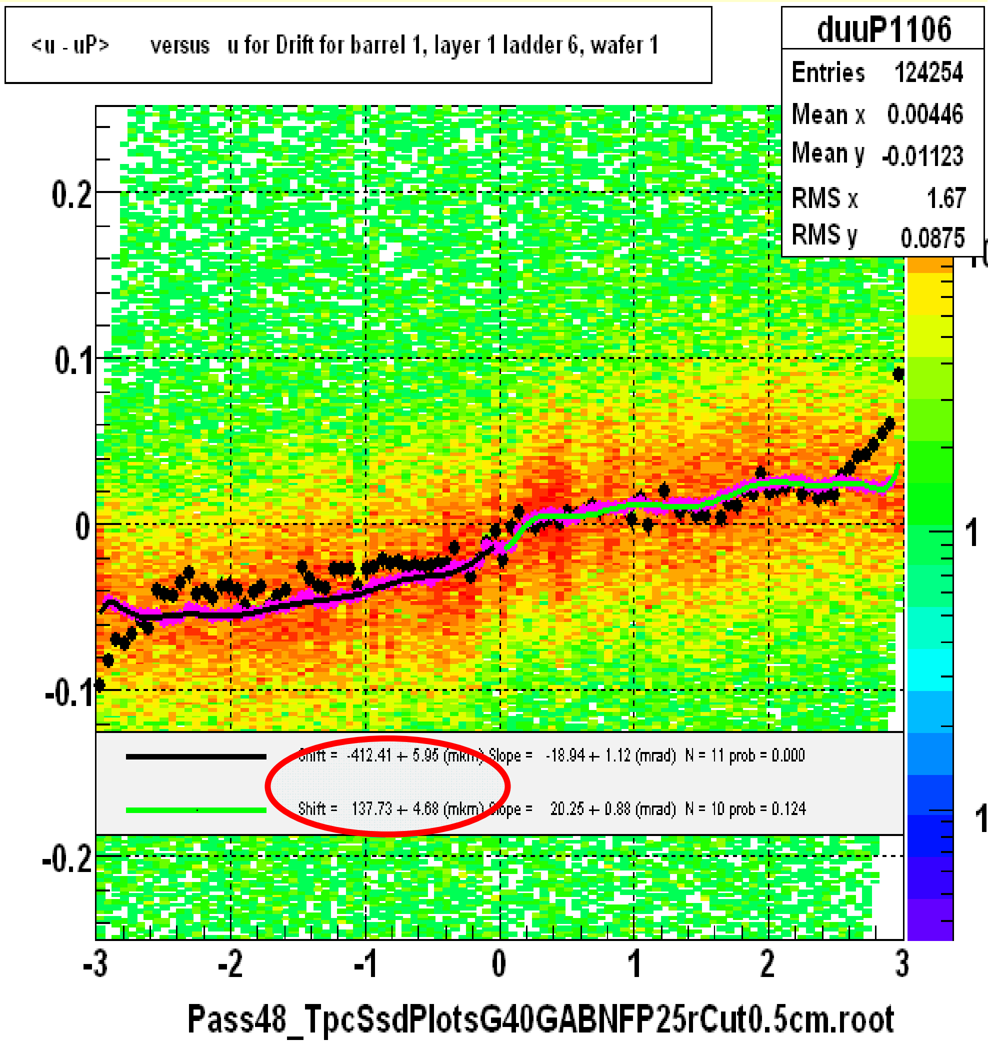
- For drift velocities (as starting point) we used earlier 9th degree polynomial parameterization of bench test results which accounts for the anode dependence of drift velocities.
- This parameterization does not work for the data sample we used (see plots below). The most important deviation is an offset at zero drift length (t_0) which cannot be explained by geometrical misalignment because these offsets are different within a ladder.
- Initial (very important) question was: Whether the above deviation patterns are stable in time ?
  - Visual comparison of Runs for a few days (CuCu 62) checked out fine:
    - 2 hybrids showed inconsistency in a small drift region (can be masked out)
    - One Ladder showed complex drift patterns but half of it in a consistent way.
  - Otherwise patterns are very similar among ladders/wafers/hybrids
  - Thus the drift velocity is stable within a period of about a week.

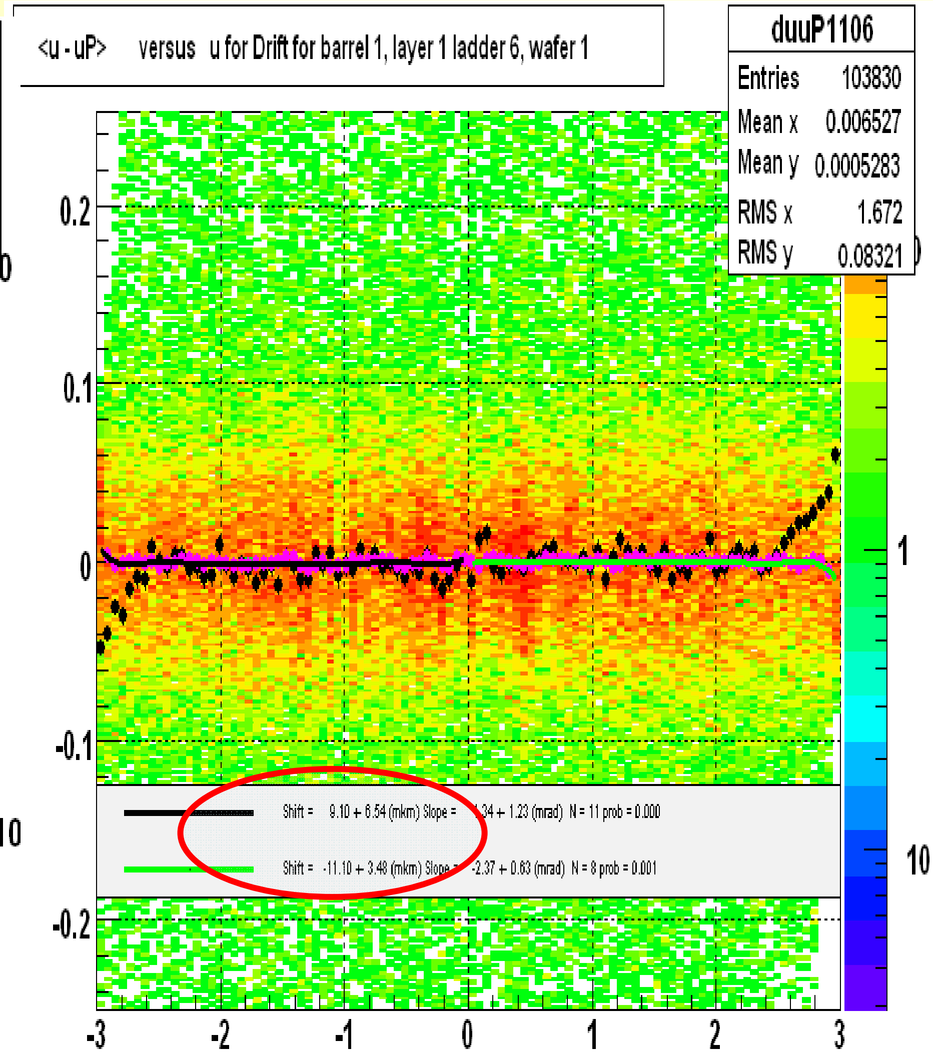
- Tchebyshev polynomials as (hack because of SVT drift model lack) drift correction were estimated and applied on top of the parameterization.

BEFORE

Most Ladders

AFTER





Example of drift residual vs. drift distance before and after the correction. Ignore profile Points (black). Fitted profile points (pink) are the right ones. From 400 down to ~10mkm means

What did we learn from this calibration sample?

- We have evidence of relative detector movement for different magnetic field settings for which we don’t have any control and any model.
  - After we verify the effect for all setting we will need to install motion sensors to control relative positions of Magnet, TPC, SVT and SSD with precision ~10 mkm in order to use NO Field data (and any other field setting, Reversed Full Field, Half Field,…)

- We do need to check for deviations of our geometrical model from rigid body (twist/sagging of SSD ladders, …)

- But in the first approximation (and up to SVT drift velocity) the approach we used for geometrical alignment looks reasonable and usable.

- We are close to our goal for SVT ($\sigma_X = \sigma_Z$= 80 mkm) and

SSD (σ_X=30mkm and σ_Z=700 mkm) resolution but we are not yet there.

SVT drift velocity -> Avoid drifting technologies if possible!

- **Drifting complicates the Alignment process**
  - **We might need to redo drift velocities starting with measured time-bins and anode raw information (bypassing bench measurements).**
  - **We need to understand the origin of an observed "two band" structure in drift (detector is still in burn-in stage, some other pathology in detector status ? Trips? Changing resistance due to high ionization particle ?)**
  - **We have to develop SVT drift velocity model which should include:**
    - **A possibility to have trap centers in silicon,**
    - **Temperature dependence, Voltage variations, variation of silicon resistance, …**
    - **Integrated radiation effects (short range ~ hours, long range ~years)**
    - **Space charge, dependence on how long SVT was irradiated and for how long it was switched off**
  - **…**

If you have drift detectors make sure you have plenty of redundant monitoring systems (lasers, charge injectors etc.

SVT Internal Alignment Effort

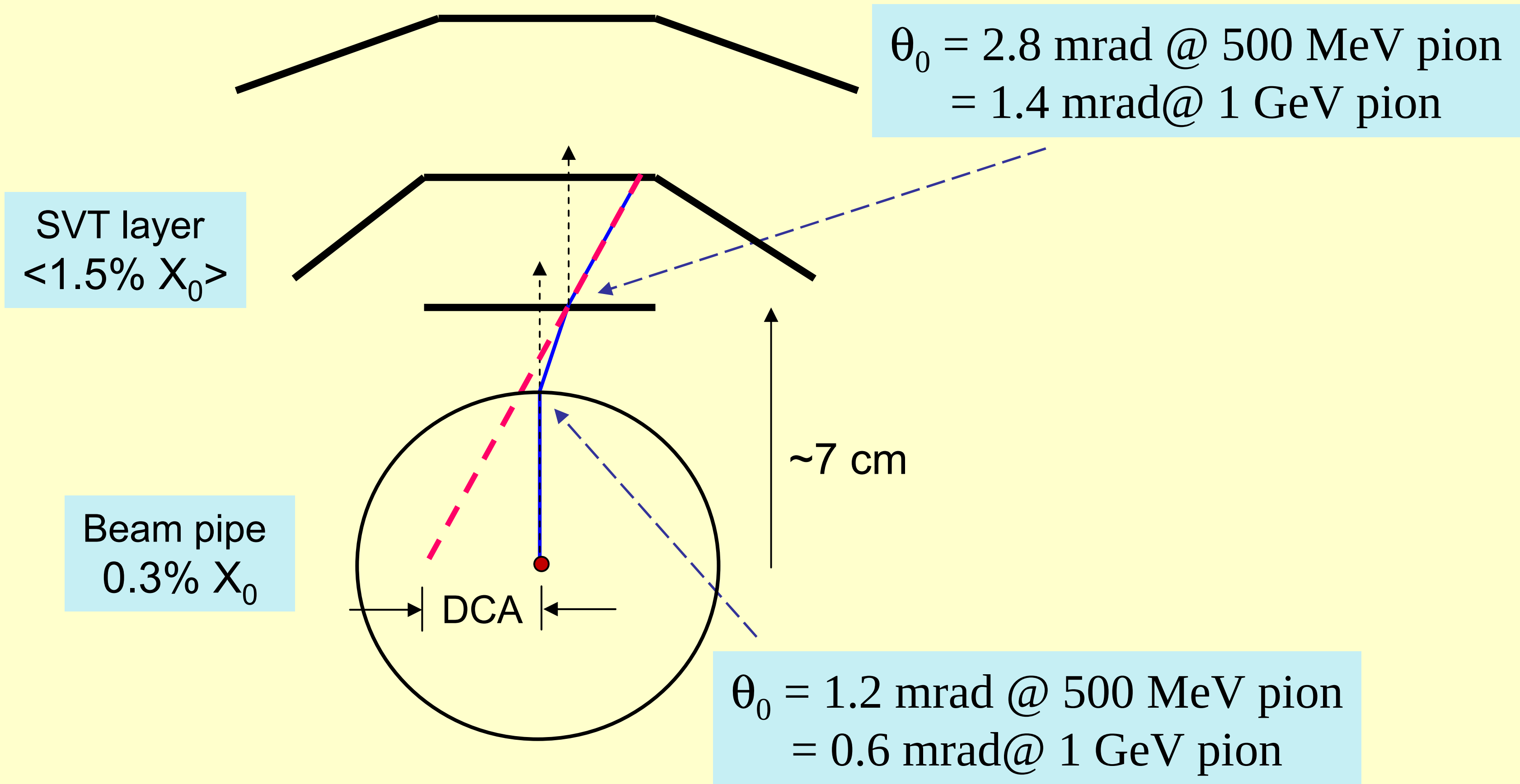
- Though not a ‘must have’ we would like to have this done for consistency checks
- This is an ongoing effort since currently we do not have a successful method
- We have worked so far on several approaches:
  - An iterative method on track/vertex fitting
    - The SVT/SSD hits are associated with tracks using the TPC tracks and then fitted.
    - The event vertex is determined, the tracks refitted with the vertex and the hit residuals determined
    - A correction is determined and the process starts again with the new hit positions
    - Initial convergence followed by oscillations around 20mkm which is not quite acceptable
  - The Millipede code was also tried as is
    - Problem of strong correlation of parameters is still not resolved
    - A modified version of this approach is currently under investigation

Some results: DCA Resolution

- The main factors determining the DCA resolution of the SVT/SSD is the mass (scattering) and the distance of the first layer from the vertex

- The following figures show that we are close to the limits of the device which indirectly shows that Alignment/Calibration errors are a subset of the overall errors

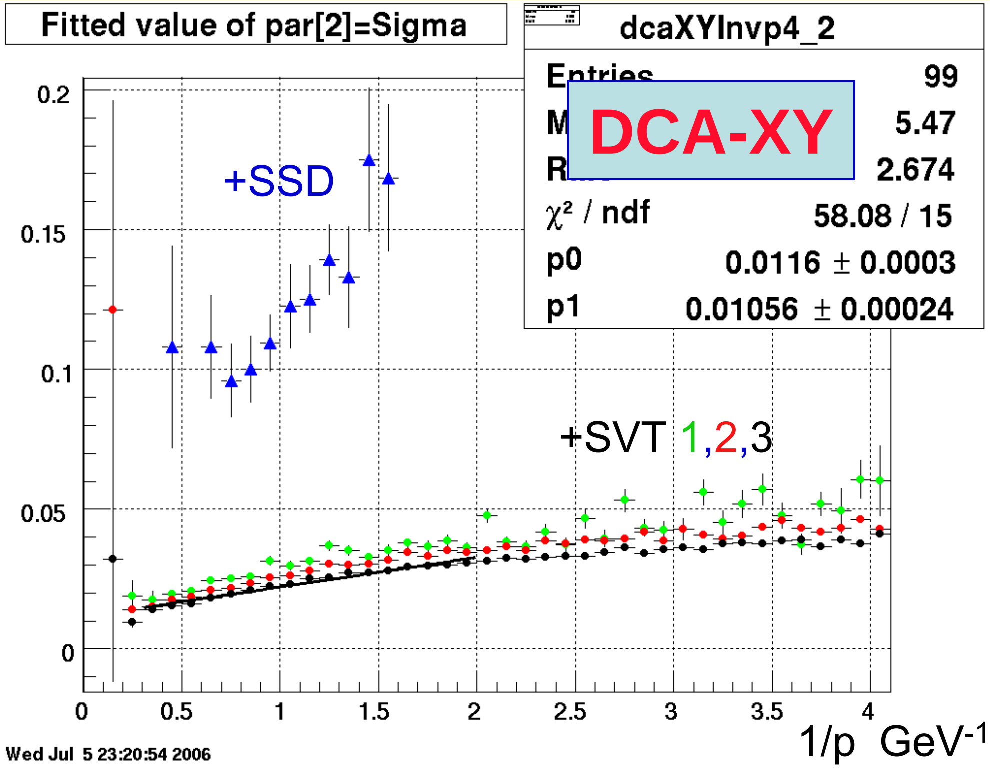
LIMITATIONS: DCA-XY Resolution due to MCS only

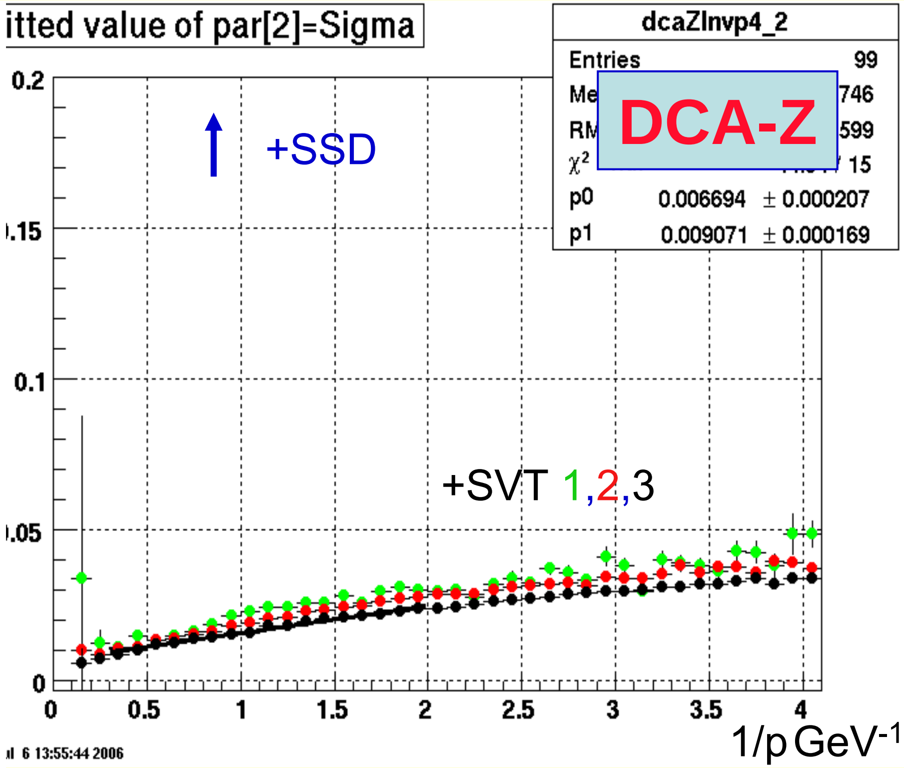


DCA-XY ~ 140μm / p(GeV) ← Remember this number

NOTE: Non-Gaussian tails at ~2% level

Hijing Monte Carlo Simulation

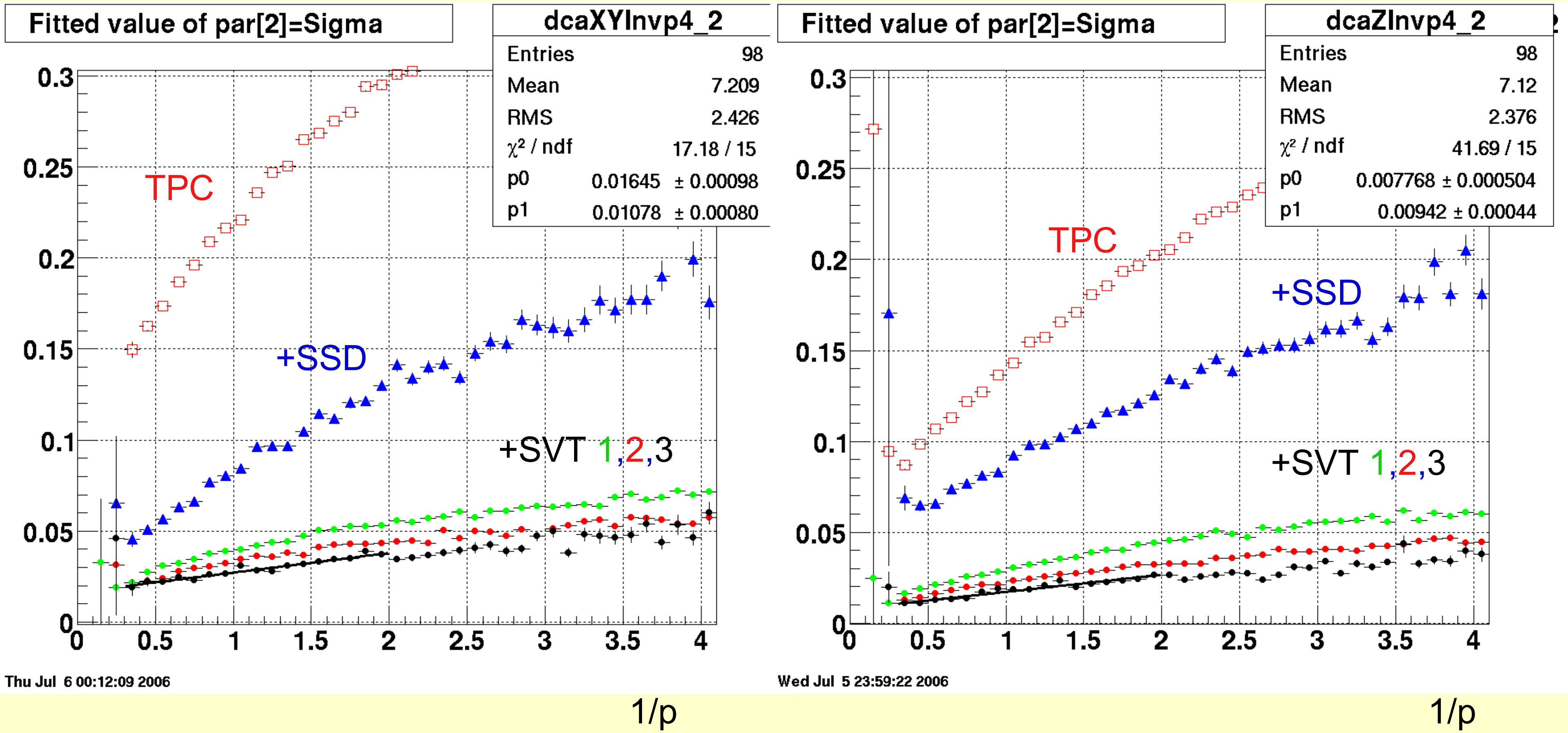




- **Resolution here includes vertex and hit resolutions**
- **Real values ~20% smaller due to presence of non-gaussian tails**

- At infinite momentum limit is ~120um in XY and 70um in Z
- At 1 GeV/c it is 200um in XY and 150 in Z
- Z is our good (not drifting) coordinate!
- **This is an IDEAL case scenario where there Alignment/Calibrations are perfect**

DATA



- **Resolution here includes vertex and hit resolutions. Real values 20% smaller**

- At infinite momentum limit is ~150um in XY and 80um in Z (~vertex resolution in CuCu)
- At 1 GeV/c it is 220um in XY and 150 in Z
- Z is our good (not drifting) coordinate!
- **We are on a good path**

Summary

• Recent interest in charm physics re-focused STAR's interest in its vertex detectors

• The presence of drift silicon technology (like in ALICE) complicates the task of Alignment

  • but also presence of non-drifting detectors (strips or pixels) will prove invaluable

• Our Global Alignment approach and techniques were successful to overall shifts better than 20 mkm

  • which for this device is sufficient

• The Self-Alignment methods are still under development.

• STAR has a funded R&D active pixel effort for an ultra thin device @ 2cm from the vertex