Tracking at D0

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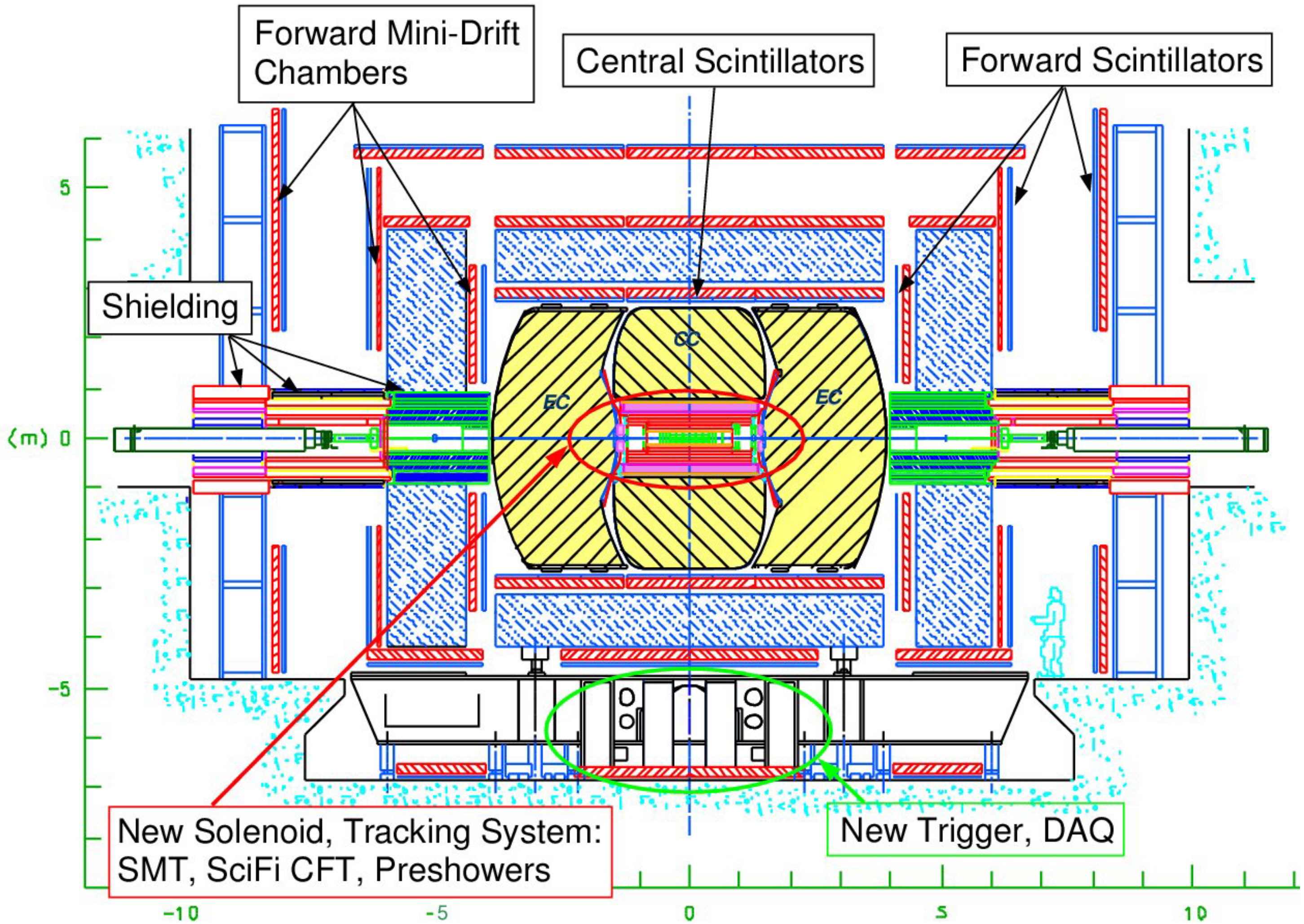
- Overview of the D0 detector
- Data taking
- D0 tracking system
- Tracking algorithms
- Alignment
- Tracking performance
- Examples of physics with tracking
- Conclusions

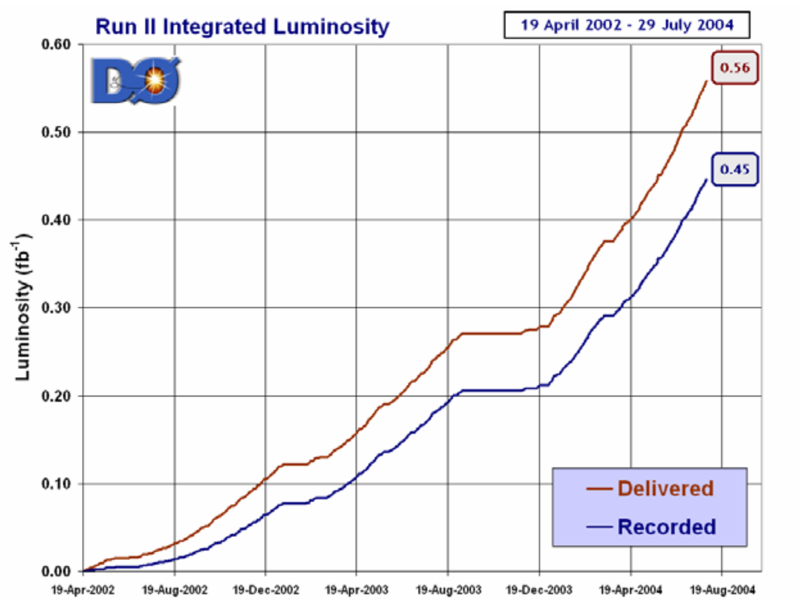
D0 Detector

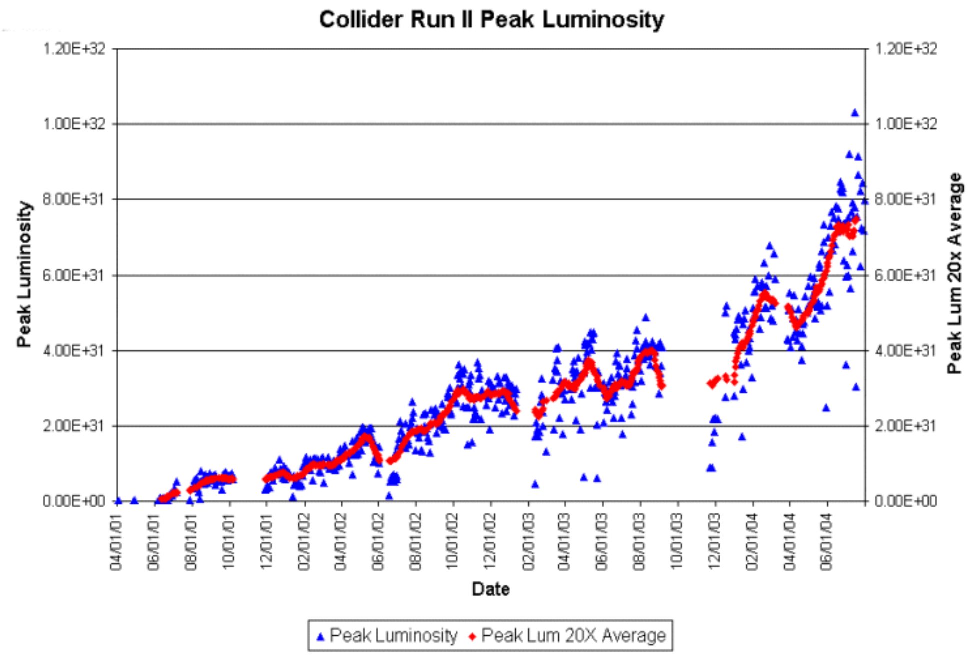


Forward Mini-Drift Chambers
Central Scintillators
Forward Scintillators
Shielding
CC
EC
EC
(m) 0
5
-5
-10
-5
0
5
10
New Solenoid, Tracking System: SMT, SciFi CFT, Preshowers
New Trigger, DAQ

Data Taking

1) 36 bunches at a spacing of 396 ns (1.7 MHz interaction rate)
2) Peak luminosity ~10^{32}
3) Data taking efficiency ~85%
4) Have ~0.8 minimum bias events overlaid the "signal" event

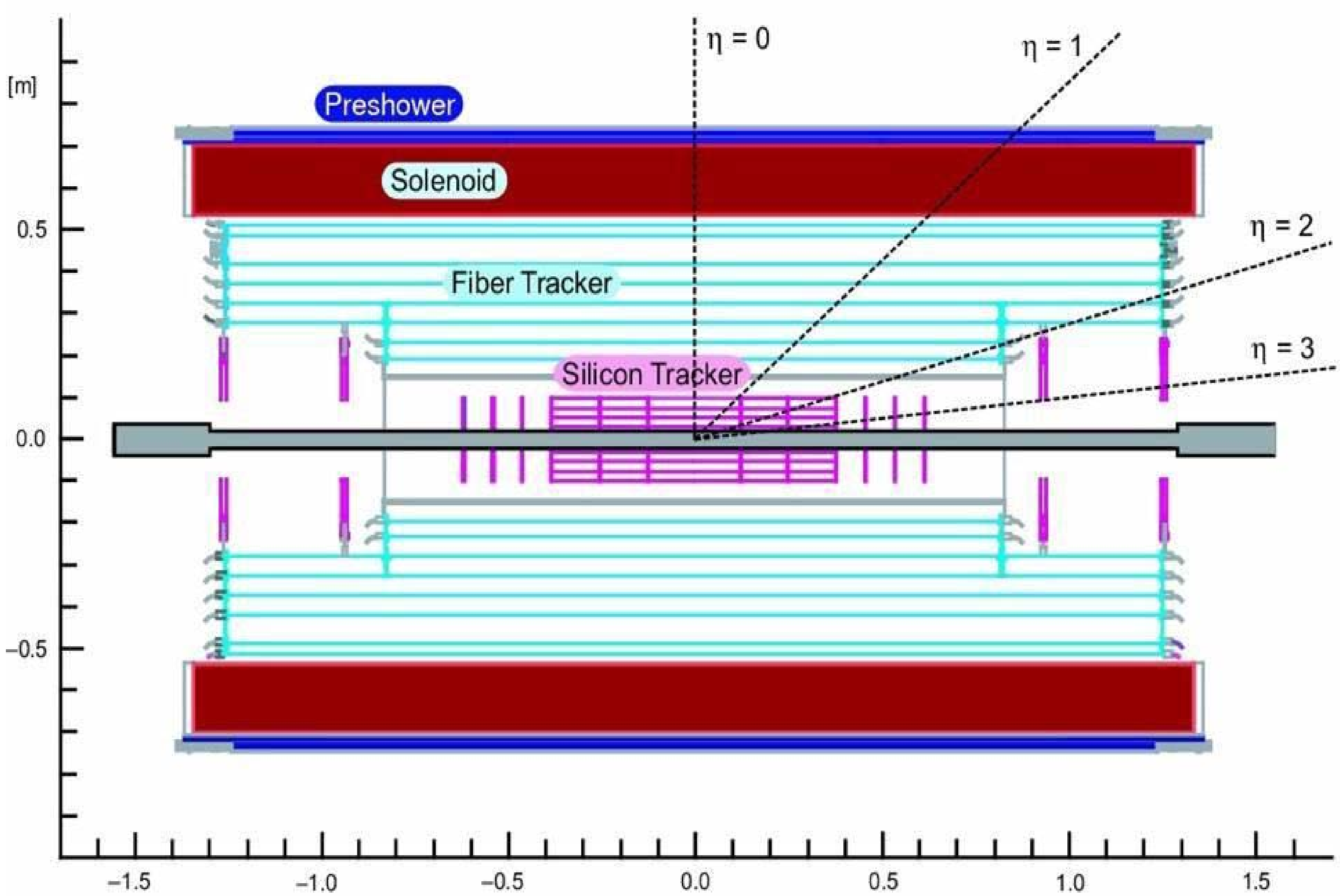




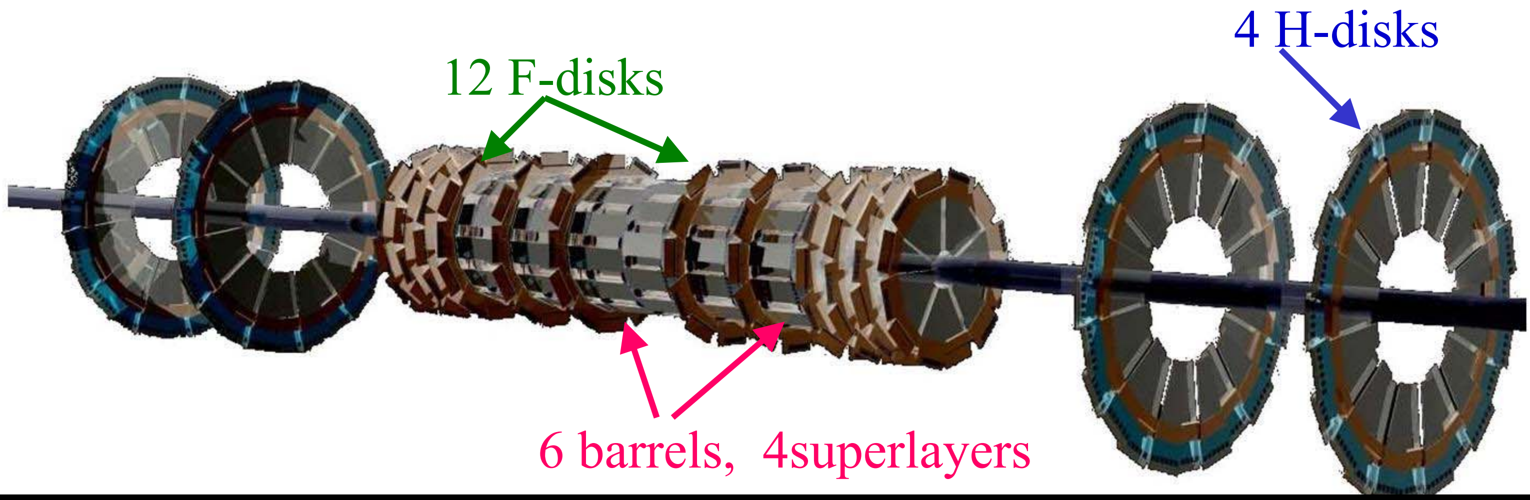
D0 Tracking System

Features:

1) Small number of measurements per track (max 12)
2) Small lever arm (2-52 cm)
3) High |η| coverage
4) Small amount of material



Silicon Microstrip Detector (SMT)



	Barrels	F-disks	H-disks
Type of ladders	Single, double-sided	Double-sided	Double-sided
Stereo angle	0^o, 2^o and 90^o	7.5^o	15^o
Inner radius	2.7 cm	2.6 cm	9.5 cm
Outer radius	9.5 cm	10.5 cm	26 cm
N of channels	400K	250K	150K

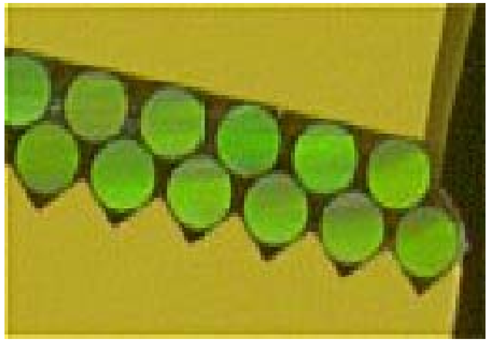
SMT (2)

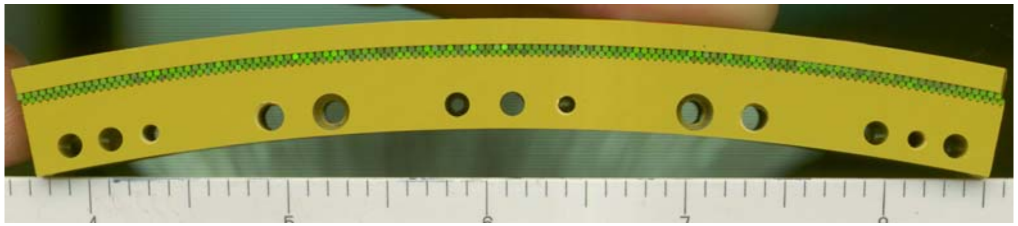
- **SMT design has unique features**:
  - Barrel part is short (±38cm) compared to the z beam spot size (σ = 30 cm), so tracking in disks is crucial;
  - Disks are partially embedded between barrels, cannot really separate tracking in barrels and disks;
  - Pattern recognition at high $|\eta|$ has to be done entirely in SMT, without any external support
  - $|\eta|$ coverage up to 3
- **Hardware Performance:**
  - 88% of channels are working now;
  - Running very stable – 99% uptime

Central Fiber Tracker (CFT)

- outer barrels are 2.5 meters long; inner/outer radius 20cm/52cm
- doublet position resolution ~ 100 mm, doublet efficiency > 98%
- Built in CMM, ribbons positioned within 30 mm of nominal

835 μm diameter scintillating fibers arranged into precisely positioned ribbons of interlocked fiber doublets



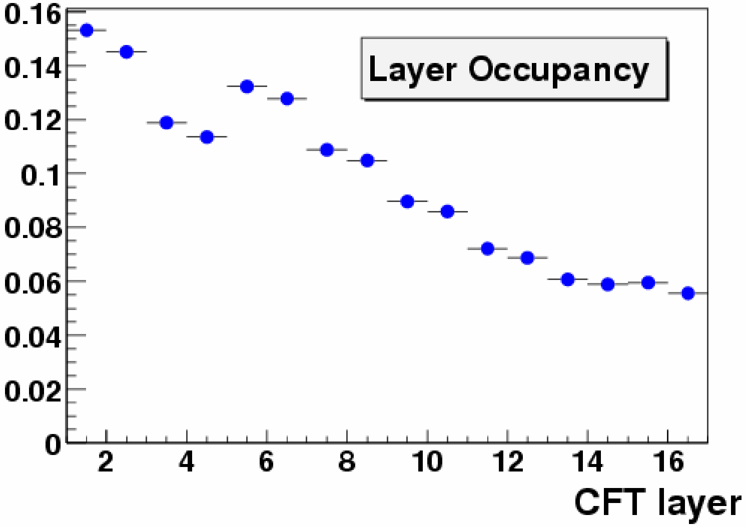


- 256 fibers per ribbon
- each barrel layer has axial and 3° stereo ribbons (XU, XV, XU…)

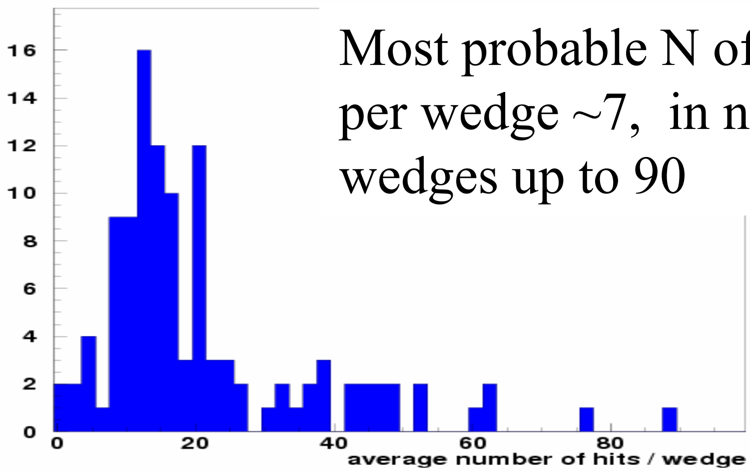
CFT (2)

- CFT design
  - 8 superlayers
  - Each superlayer consists of axial/stereo layers
  - $|\eta|$ coverage up to 2.0
- Hardware performance
  - 98% of channels are working
  - The rest almost certainly recoverable with care
  - Running very stable

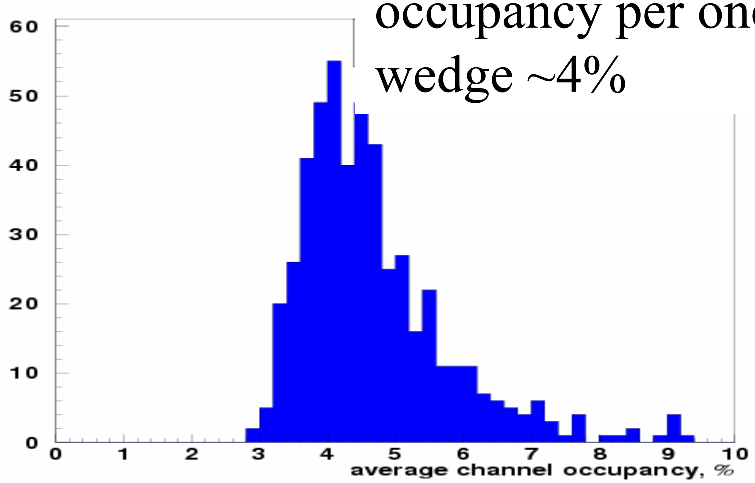
Occupancy in Tracker



- CFT occupancy is mostly due to hits from real tracks
- SMT occupancy is typically dominated by electronic noise



Most probable N of hits per wedge ~7, in noisy wedges up to 90



Average channel occupancy per one wedge ~4%

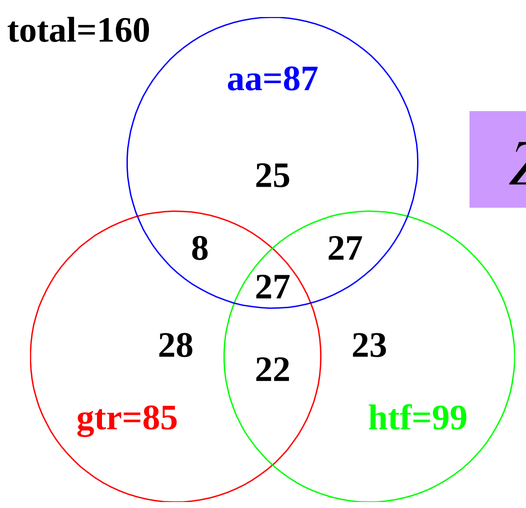
Tracking Algorithms (1)

- Before data taking, we had track reconstruction package developed on the Monte Carlo.
- When data arrived, it became clear that this code is inefficient (was not robust against misalignment, missing hits).
- Another two algorithms were developed essentially along the data taking.
- Benchmarks used for improving efficiency were numbers of found $J/\psi \rightarrow \mu\mu$, $Z \rightarrow ee$ and $Z \rightarrow \mu\mu$.
- Now, our track reconstruction software is combination of Histogramming Track Finder (HTF) and Alternative Algorithm (AA). We use final track refit code from the third algorithm.

Tracking Algorithms (2)

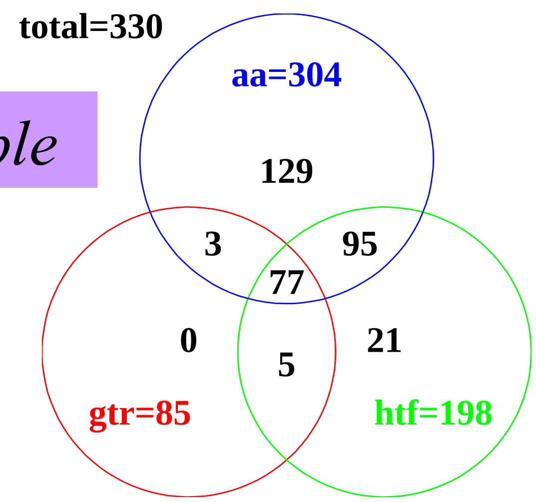
- It turned out, that having 3 different algorithms was extremely useful:
  – Why algorithm C did find $J/\psi \rightarrow \mu\mu$ in this event, while algorithm B did not find one track from $J/\psi \rightarrow \mu\mu$, and algorithm A did not find any tracks?

Started with:



Z→ee sample

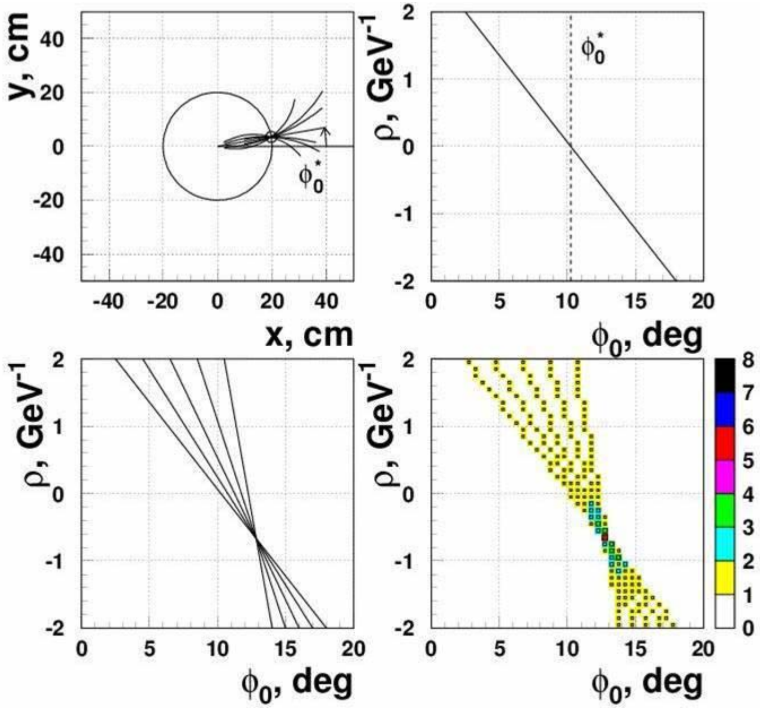
Came to:



HTF (1)

Uses all 3-D hits; allows missing hits

- Step 1: organize hits in patterns (templates)
  - Method: Hough transform + hisogramming
- Step 2: perform local pattern recognition
  - Method: Kalman filter



Histogramming:

Each hit is a point in conventional (x – y) space and line in track parameter space (ρ – φ)

Lines in the (ρ – φ) space corresponding to hits from the same track intersect at one point – track parameter point

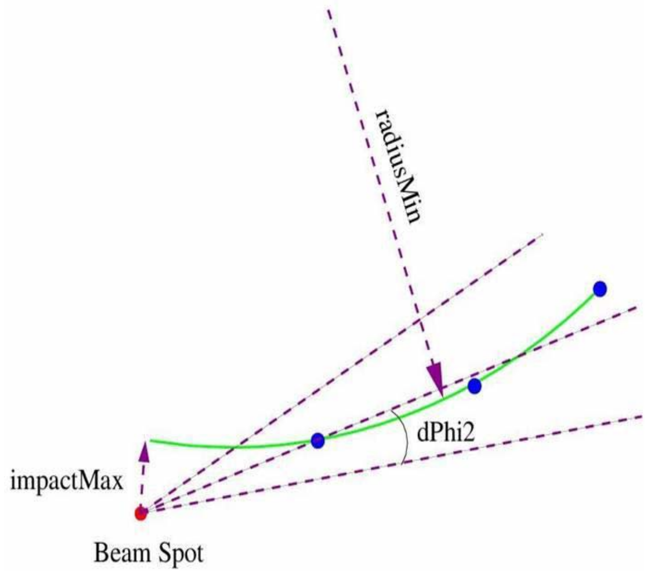
HTF (2)

- Strategies:
  - Perform pattern recognition in SMT (min 4 SMT hits)
    - Do histogramming in $(x,y \rightarrow \rho\varphi)$;
    - Do histogramming in $(z,r \rightarrow z_0,dz/dr)$;
    - Build 3d SMT tracks
    - Extrapolate to CFT
  - Perform pattern recognition in CFT (min 7 CFT hits)
    - Do histogramming in $(x,y \rightarrow \rho\varphi)$ and build CFT axial tracks;
    - Attach stereo, do histogramming in $(z,r \rightarrow z_0,dz/dr)$;
    - Build CFT 3d tracks
    - Extrapolate to SMT

Result: *tracks with ≥4 SMT hits + any # of CFT hits, or with ≥7 CFT hits + any # of SMT hits*

AA tracking algorithm

- Road following method;
- SMT → CFT:
  - Start from ≥3 stereo SMT hits
  - Extrapolate to the next layer, add hit if the increase of $\chi^2 <$ some threshold
  - *In each detector, use 1D hits to continue the track hypothesis*. It is very important for the D0 tracking, since some SMT ladders have only one operational side.
- CFT→ SMT
  - big combinatorics



- Heavily rely on the PV reconstructed with SMT tracks

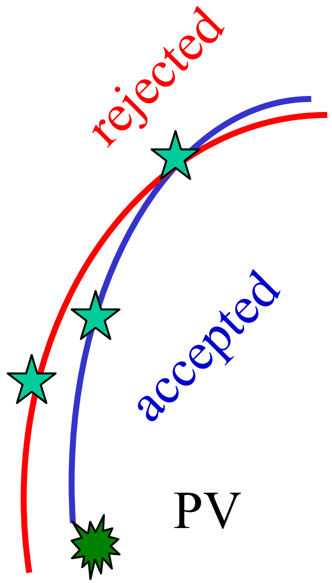
- Start with 3 CFT hits, extrapolate to the next layer…

Combination of HTF and AA (1)

- Each track finder works independently – how to combine results?
- Combination is not simply merging the final track pools;
- Merge "pre-final" lists of tracks;
- Ambiguities resolving is postponed up to the final procedure;

Combination of HTF and AA (2)

- Combining algorithm itself is not trivial: while resolving ambiguities, it takes into account:
  - Number of hits per track and its χ^2;
  - Number of missing hits and their positions (tracks with misses in the middle of the track have lower priority compared to the tracks with "back" misses, which might be tracks from K_s, for example);
  - It prefers combinations of tracks which are grouping in z – powerful tool against fake tracks.

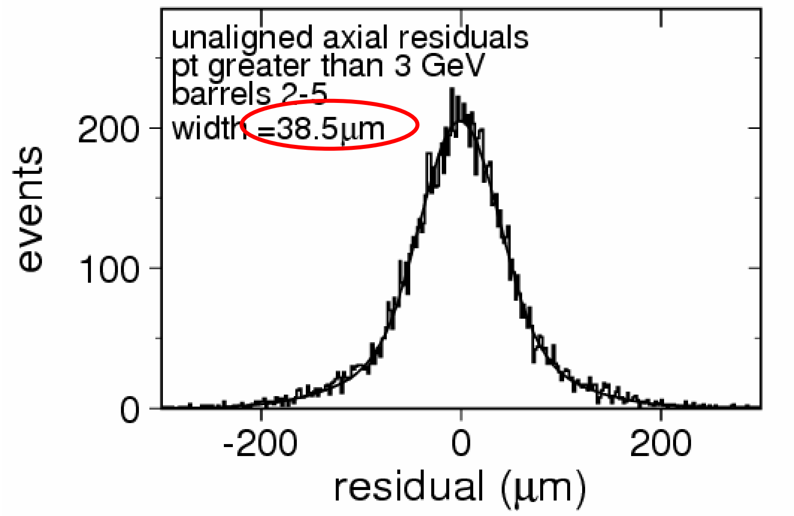


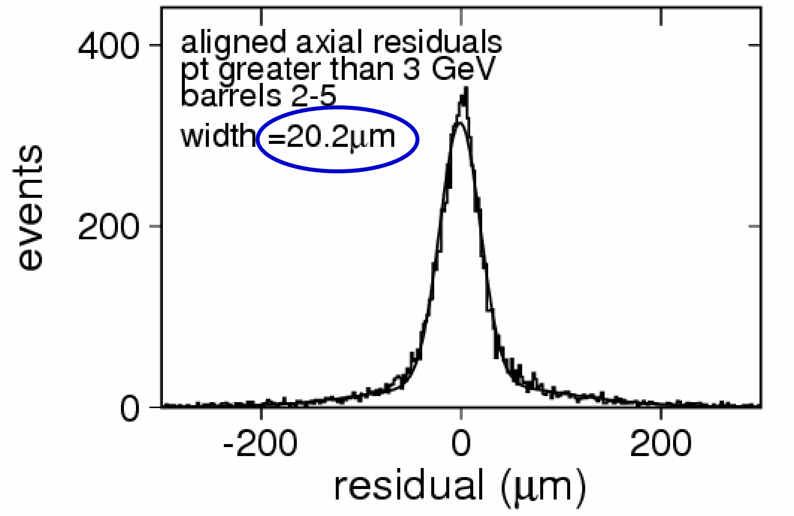
Alignment (1)

- Alignment is iterative process
  - Minimization of residuals of reconstructed hit position resolution and reconstructed track intersection with the ladder plane
- Started from geometry provided by construction
  - Impact parameter resolution for high- p_T tracks was ~120 microns!
- Used 500K data with B = 0 magnetic field to align the tracker ;
- For the check of the alignment, use
  - Number of track found in the same run before and after alignment
  - Impact parameter resolution of tracks
    - p_T>3 GeV;
    - From primary vertex;
    - With at least 3 SMT hits
  - $Z \rightarrow \mu\mu$ mass peak resolution

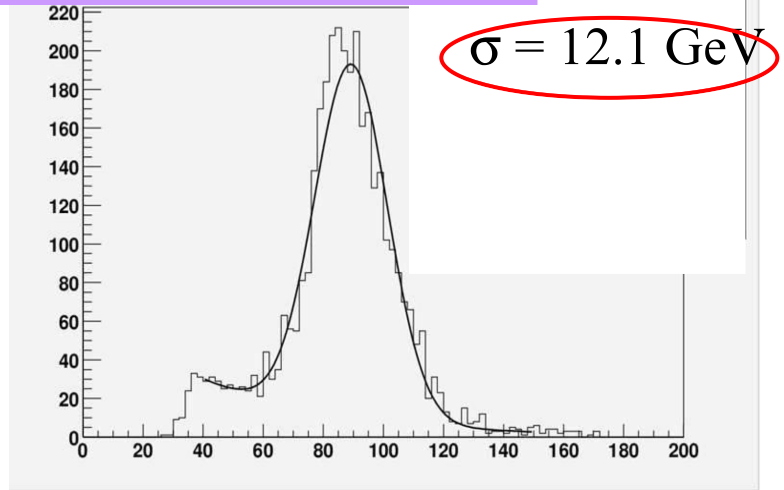
Alignment (2)

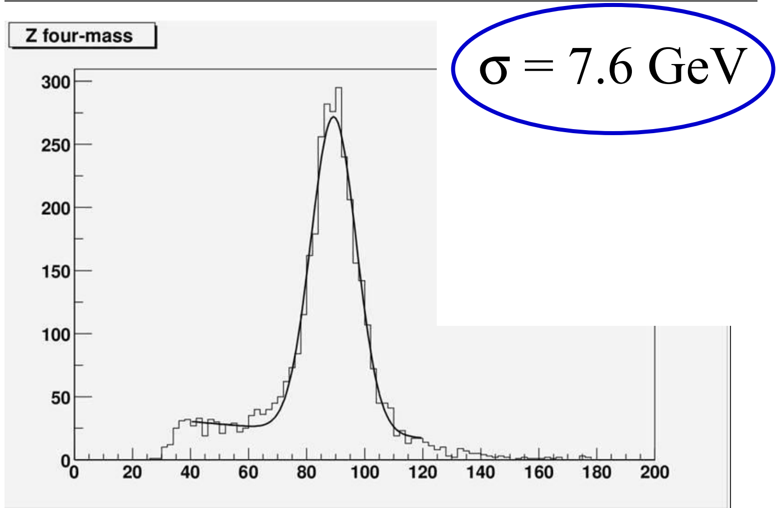
Track residuals





$Z \rightarrow \mu\mu$ invariant mass





Tracking Performance (1)

- Measurement of tracking efficiency in data – use muon sample
  - Select as clean muons as possible using local muon chambers information;
  - Look how often a global track can be found in a window around muon;
  - To the first order, $\varepsilon = N_{tracks} / N_{muons}$
  - If muon track is missed but another track is reconstructed, efficiency measurement would be biased high:

$$\varepsilon_M = \varepsilon_T + (1 - \varepsilon_T)\varepsilon_R$$

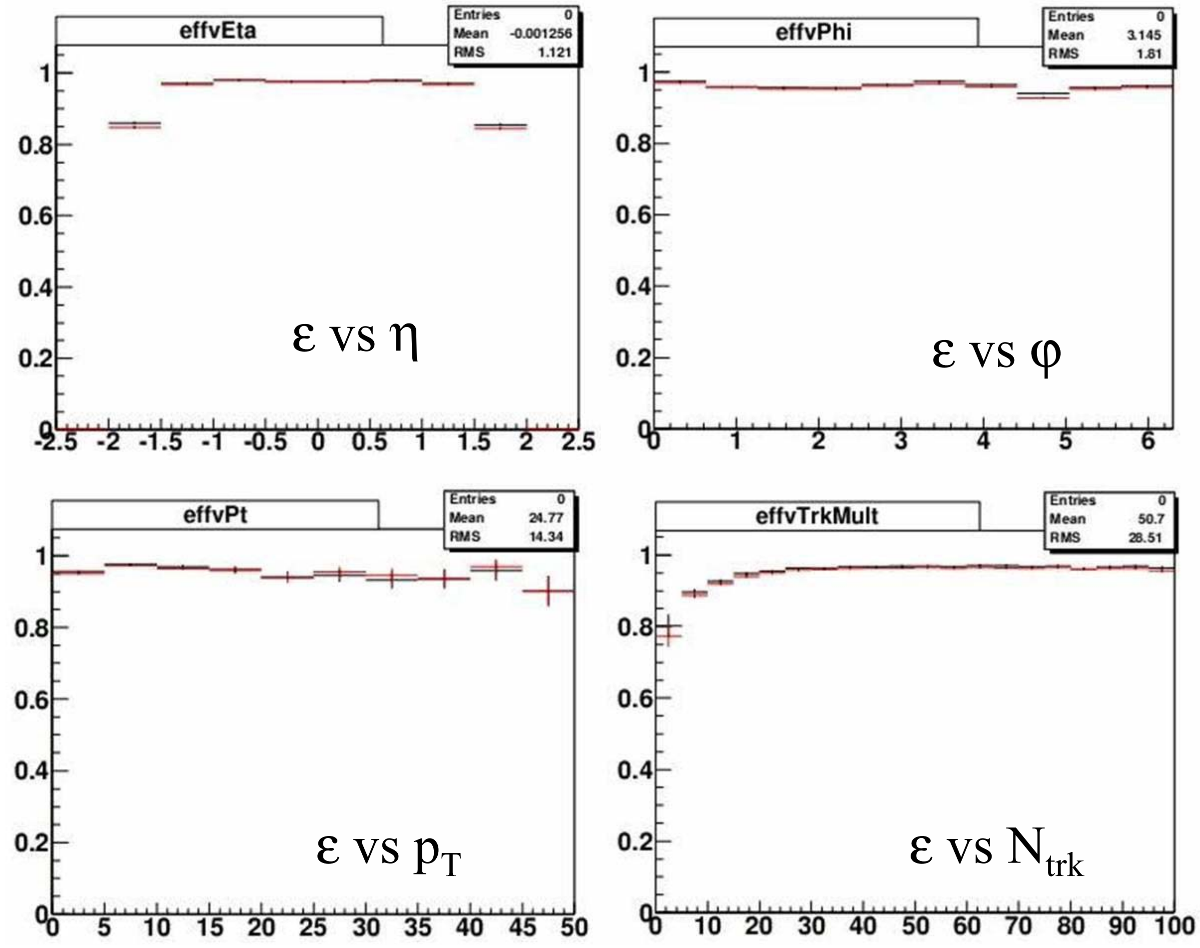
Measured efficiency (ε_M) **True efficiency** (ε_T) *Random probability* (ε_R)

  - Measure $\varepsilon_R \sim 5\%$ in control window of the same size but adjacent in φ.

Tracking Performance (2)

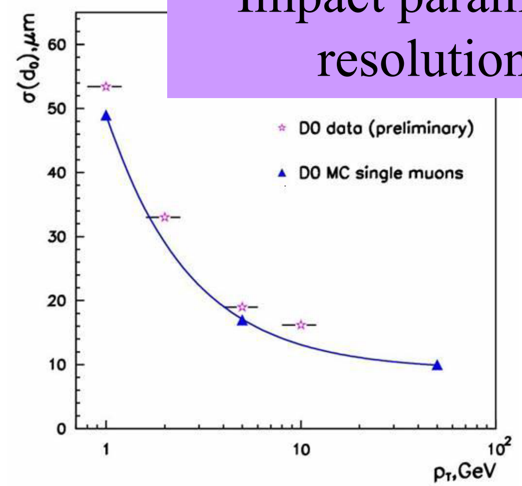
Tracking performance for muons with p_T>1.5 GeV, data

"True" efficiency

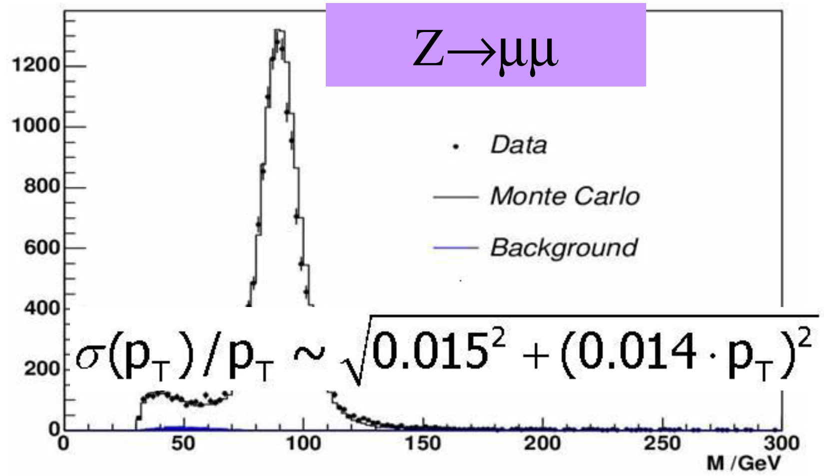


Tracking Performance (3)

Impact parameter resolution

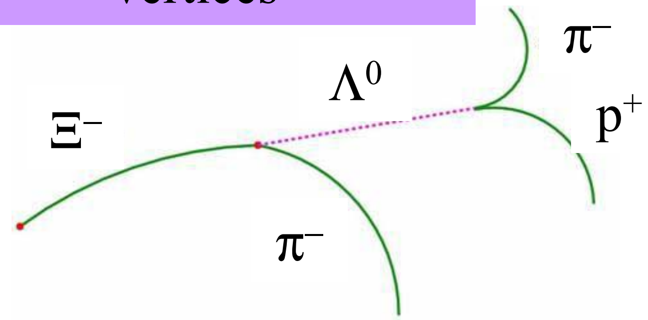


$Z \rightarrow \mu\mu$

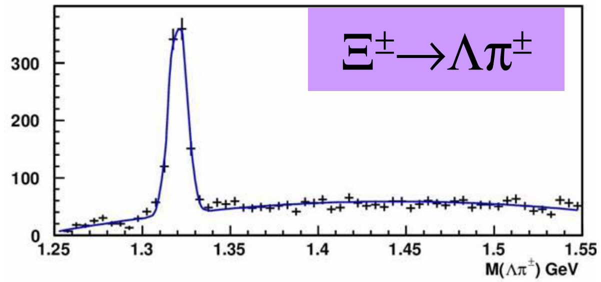


$$\sigma(p_T)/p_T \sim \sqrt{0.015^2 + (0.014 \cdot p_T)^2}$$

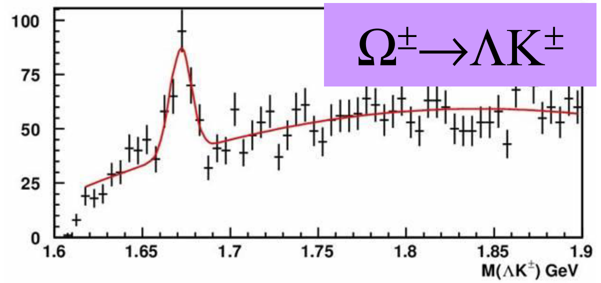
Tracks from secondary vertices



$\Xi^{\pm} \rightarrow \Lambda\pi^{\pm}$

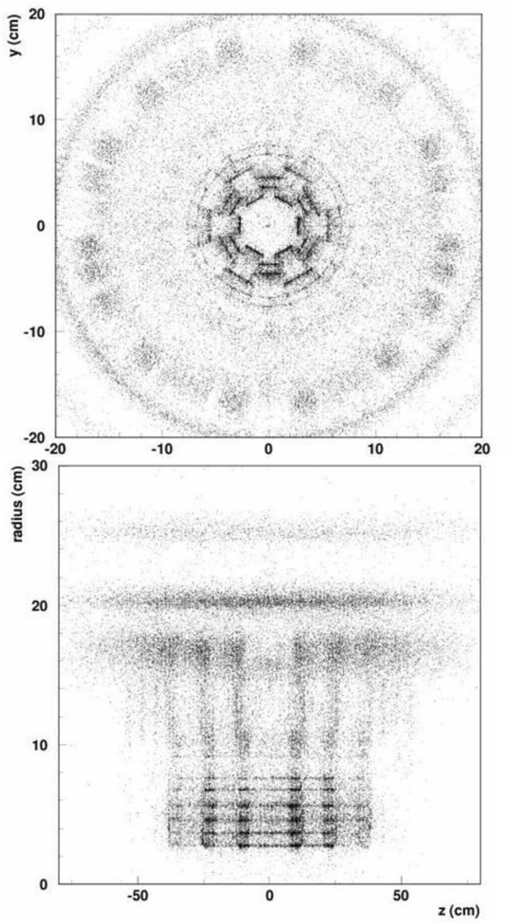


$\Omega^{\pm} \rightarrow \Lambda K^{\pm}$

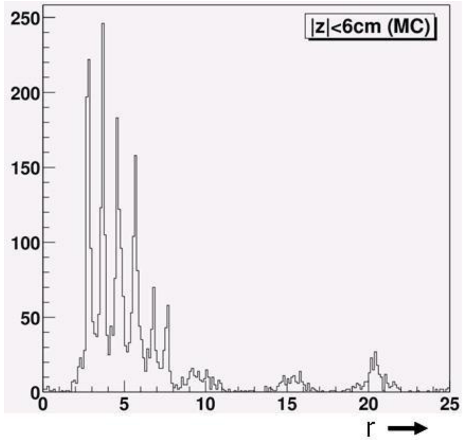


Material Studies on Data

Good: photon conversions found with high efficiency

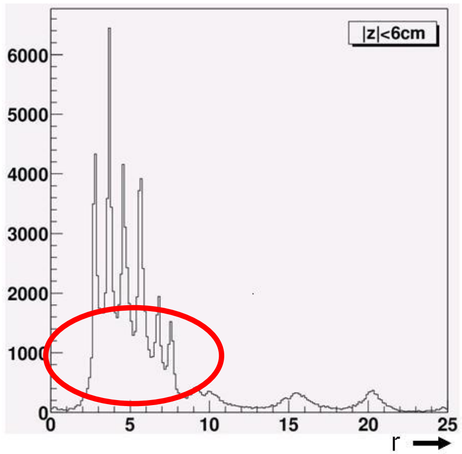


Bad: expose large difference in material description…



location of photon conversions in the MC

location of photon conversions in the data



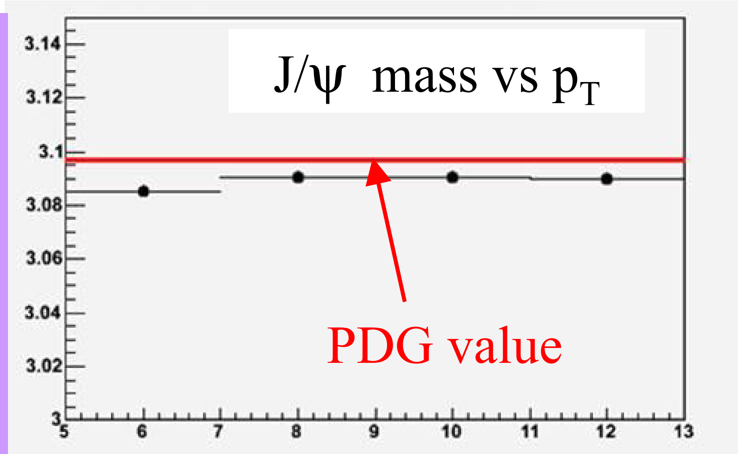
We are working on it

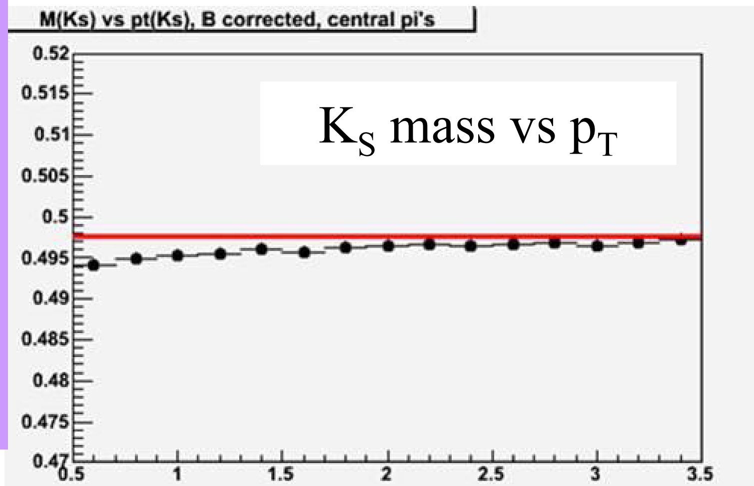
Preliminary Corrections

First pass of corrections with tuned material representation

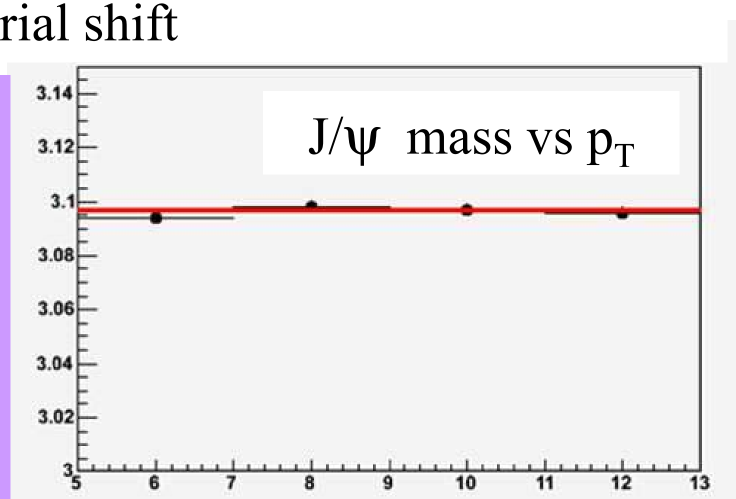
Still interplay between B-field and material shift

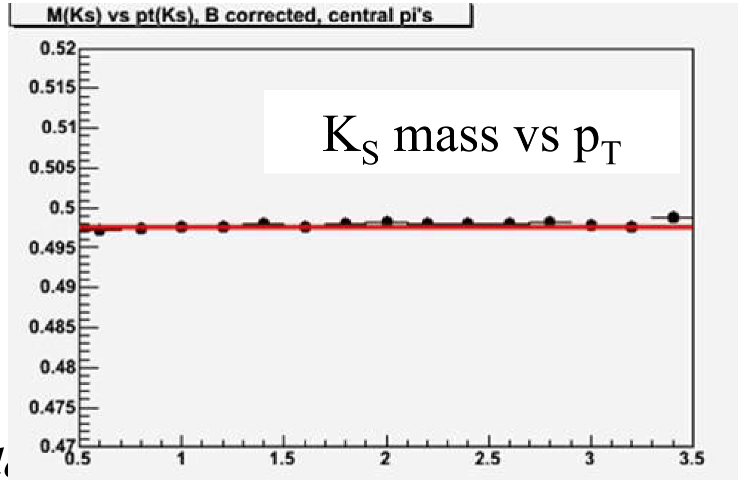
Before corrections



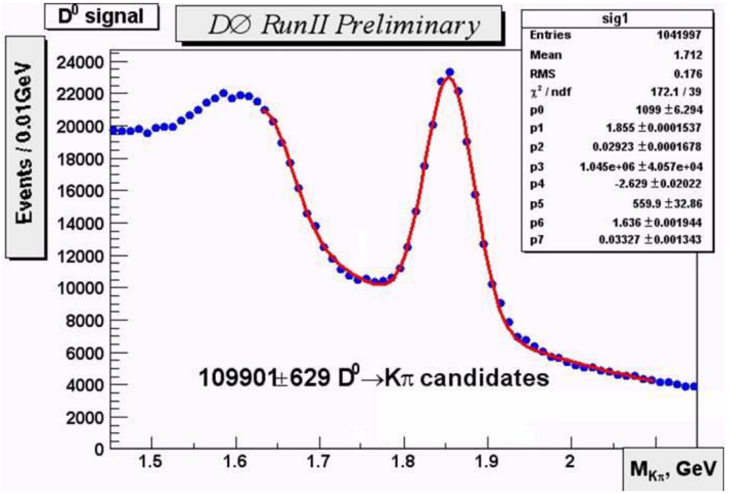


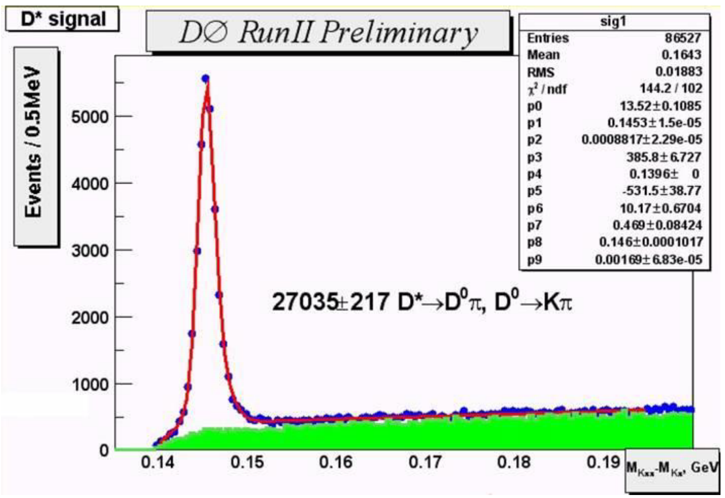
After corrections





B-physics at D0 (1)

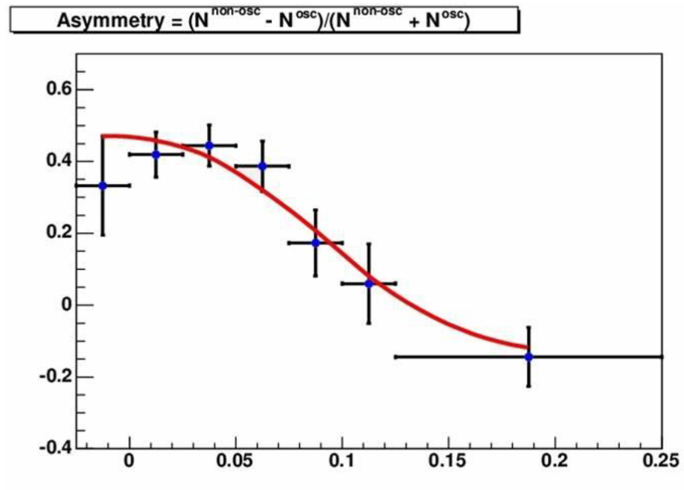




Exclusively reconstructed B→ D (D^0, D*) final states

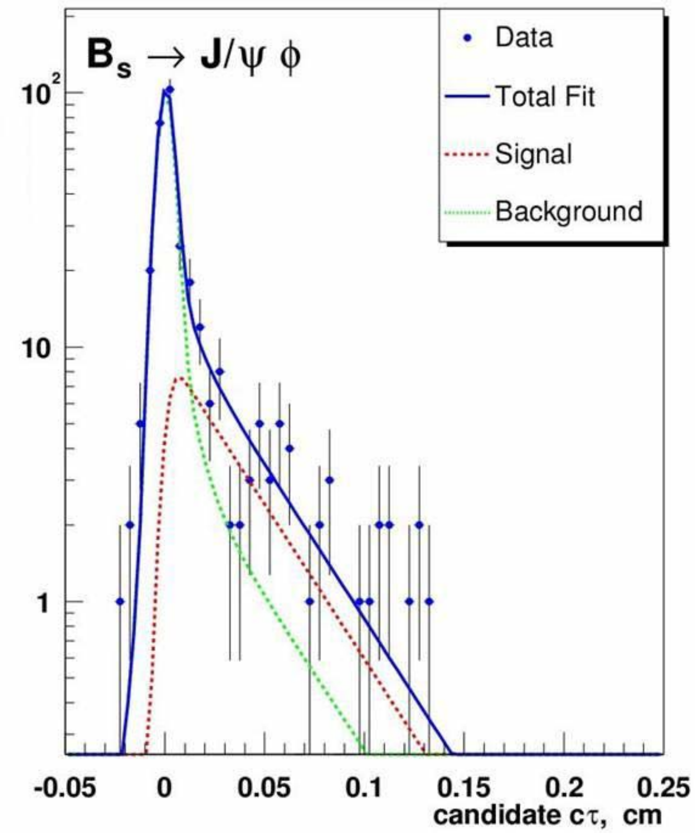
Opposite side muon used to determine initial b flavor

$$\Delta m_d = 0.506 \pm 0.055(stat) \pm 0.049(syst)\,ps^{-1}$$

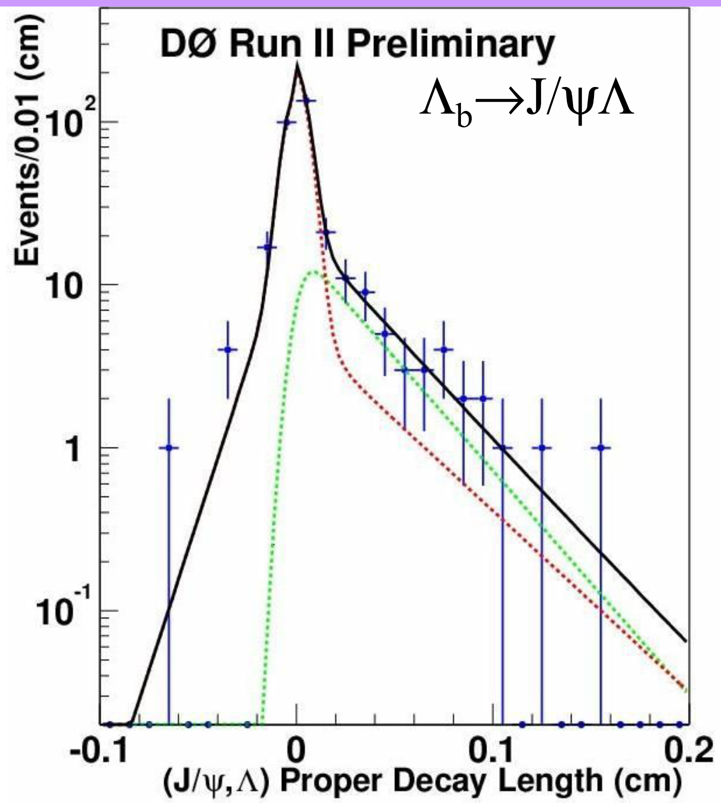


B-physics at D0 (2)

Can be studied only at the Tevatron



$\tau(B_s) = 1.19^{+0.19}_{-0.16}(stat) \pm 0.14(syst)\text{ps}$



$\tau(\Lambda_b) = 1.05^{+0.21}_{-0.18}(stat) \pm 0.12(syst)\text{ps}$

b-tagging

Three methods developed:

1) Secondary Vertex Tagger (SVT)

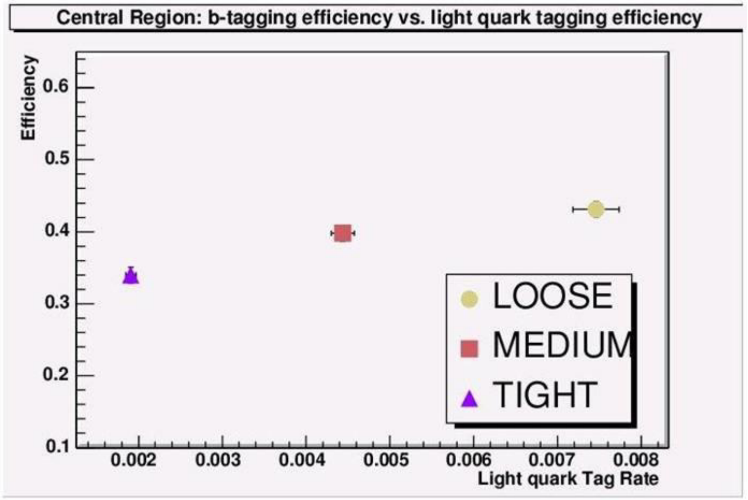
2) Jet Lifetime Probability (JLIP)

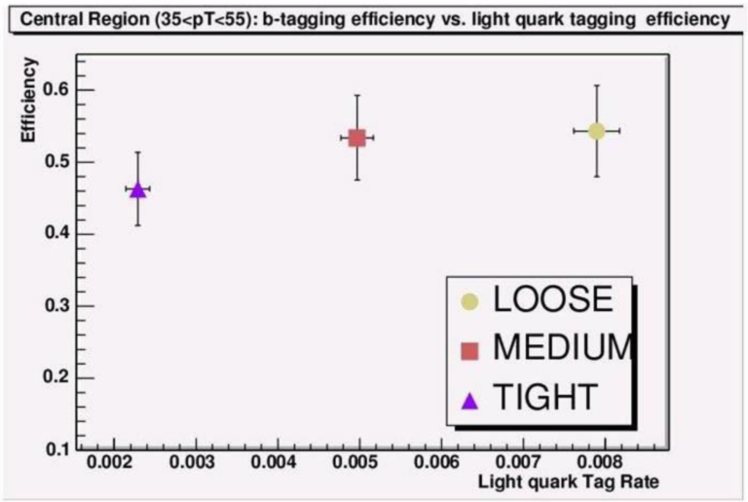
3) Counting Signed Impact Parameter tagger (CSIP)

Performance was measured on data

All of them have been used in various analyses (Higgs and new physics searches, Wbb and tt cross section measurements)

Probability to tag a tt event is P(ntags≥1)~60%; P(ntags≥2) ~15%





Conclusions

- D0 tracking works well
  - Essentially, all of the hardware functions for now;
  - Software is also functional (could be faster);
- Lessons from D0
  - Flexibility is key;
  - Hardware and software experts should talk years before;
  - Calibration/databases need to be available before/early data taking;
  - Having more than one tracking algorithms is a good idea