Experience with D0 Tracking and Other Software Development

In Respect of STAR's Upgrades

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Relevant Experience Highlights

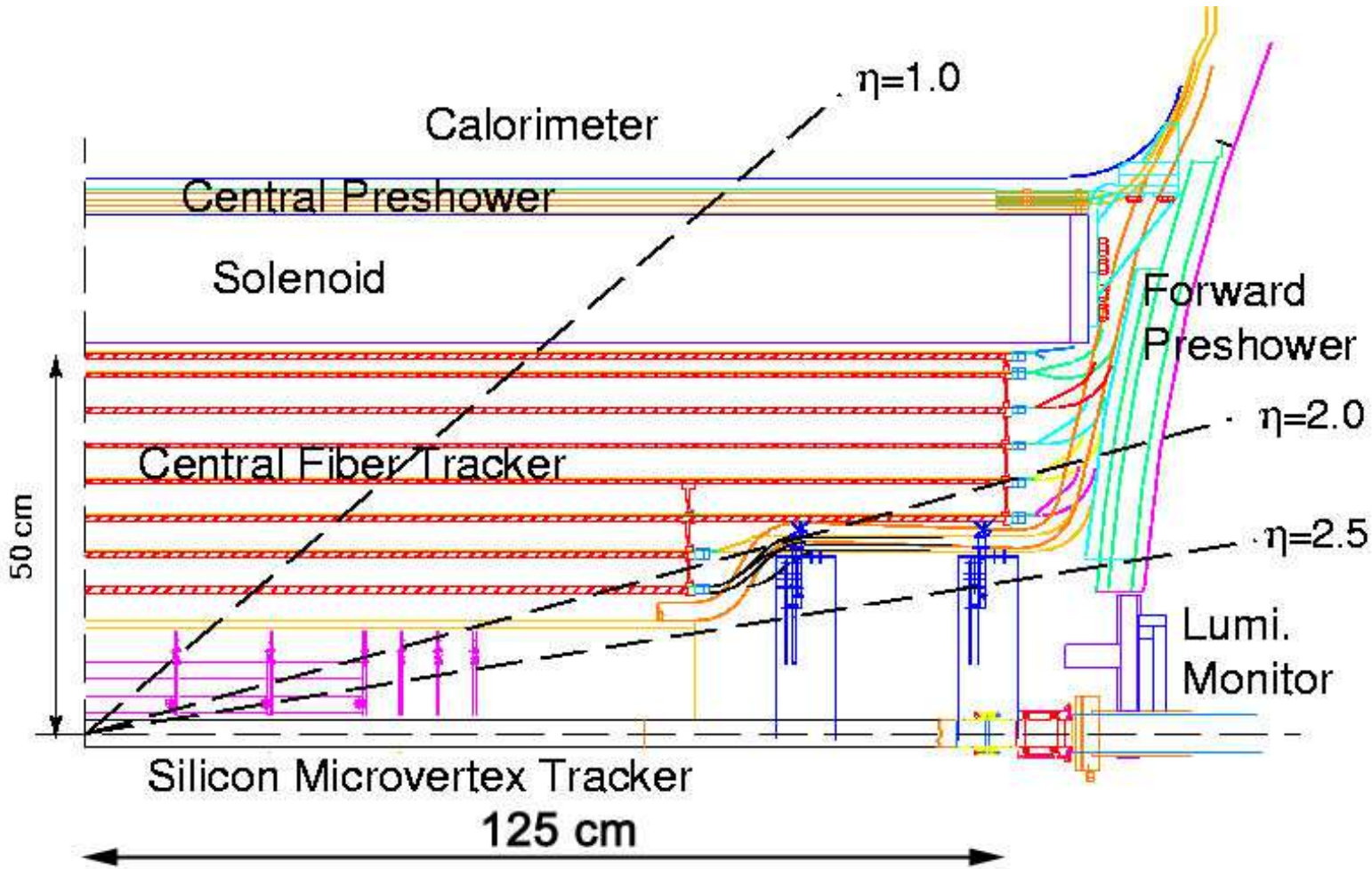
Nov, 2005 – Aug, 2010 **University of Notre Dame**
Fermi National Accelerator Lab

- Diversified support of the **scintillating fiber tracker** of the D0 experiment at Fermilab
  - Hardware testing, online and offline calibrations, detector performance monitoring, integration with event reconstruction software

Aug, 2010 – present **Brookhaven National Lab**

- Complete life cycle support for regular measurements of proton beam polarization with **RHIC CNI polarimeters**
- Physics analysis of STAR data with STAR software libraries

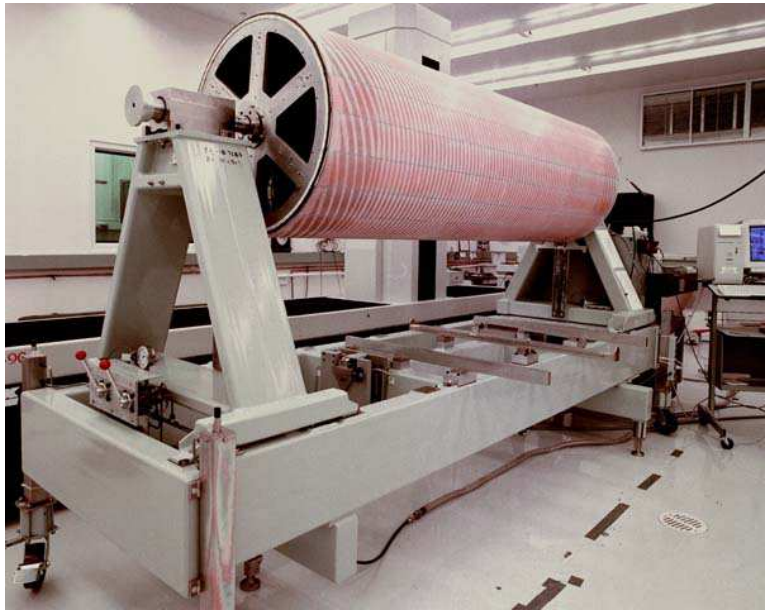
D0 Central Fiber Tracker & Preshower Detectors

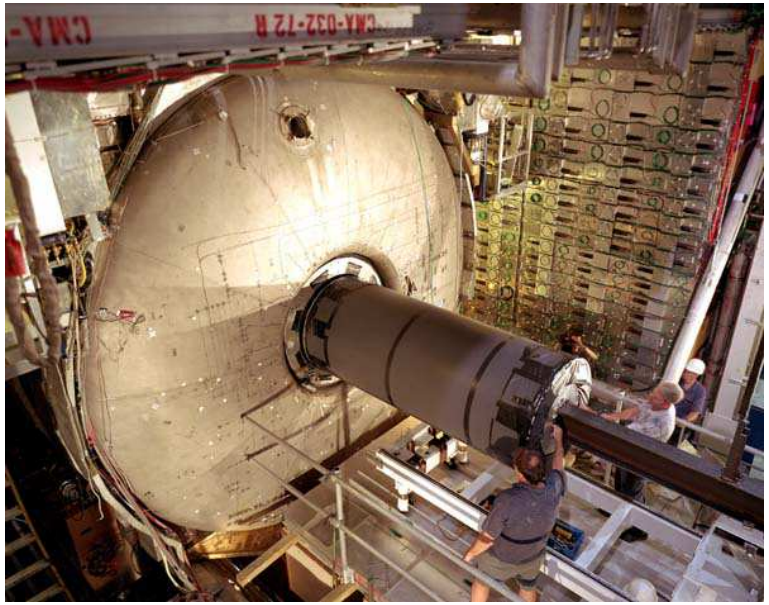


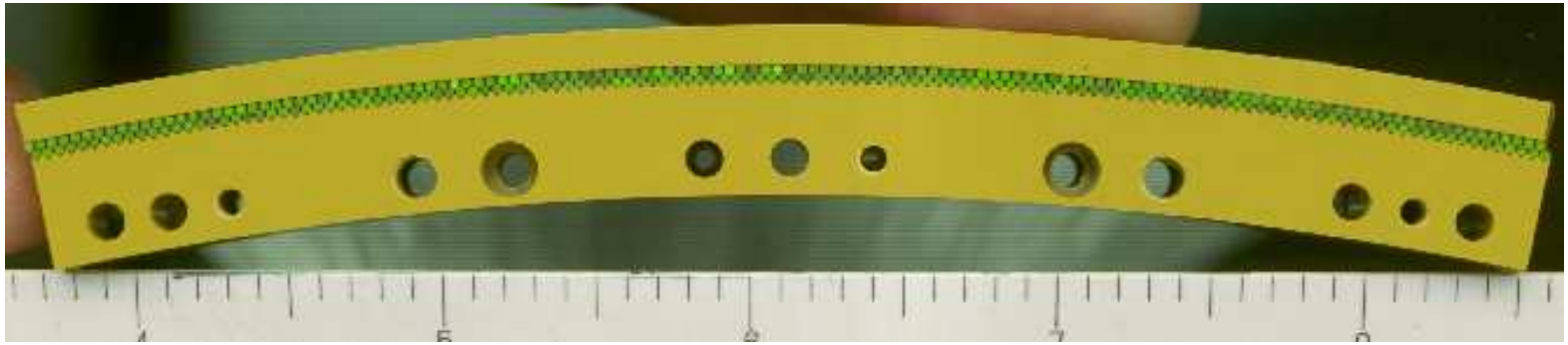
- **Central Fiber Tracker** (CFT), Central and Forward Preshower (CPS, FPS) detectors utilize a similar readout
- Particles crossing scintillating fibers generate light which propagates to solid state diodes, **Visible Light Photon Counters** (VLPCs)

	Layers	Coverage	Num. of Channels
CFT	8 axial and 8 stereo	$\lvert\eta\rvert < 2.0,\ 0 < \phi < 2\pi$	$\approx 77,000$
CPS	1 axial and 2 stereo	$\lvert\eta\rvert < 1.25,\ 0 < \phi < 2\pi$	$\approx 7,700$
FPS	2 MIP and 2 shower	$1.4 < \lvert\eta\rvert < 2.5,\ 0 < \phi < 2\pi$	$\approx 15,000$

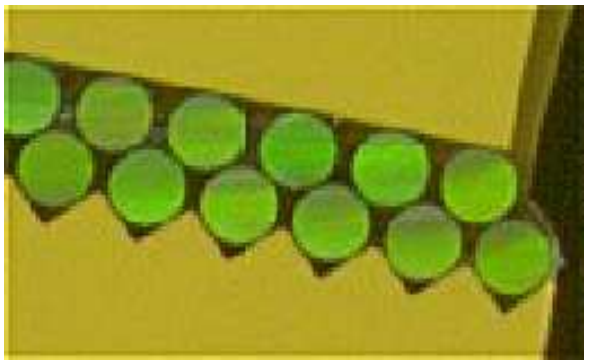
D0 Central Fiber Tracker Details







- Fibers arranged into ribbons of interlocked doublets
- Fiber diameter is 0.8 mm



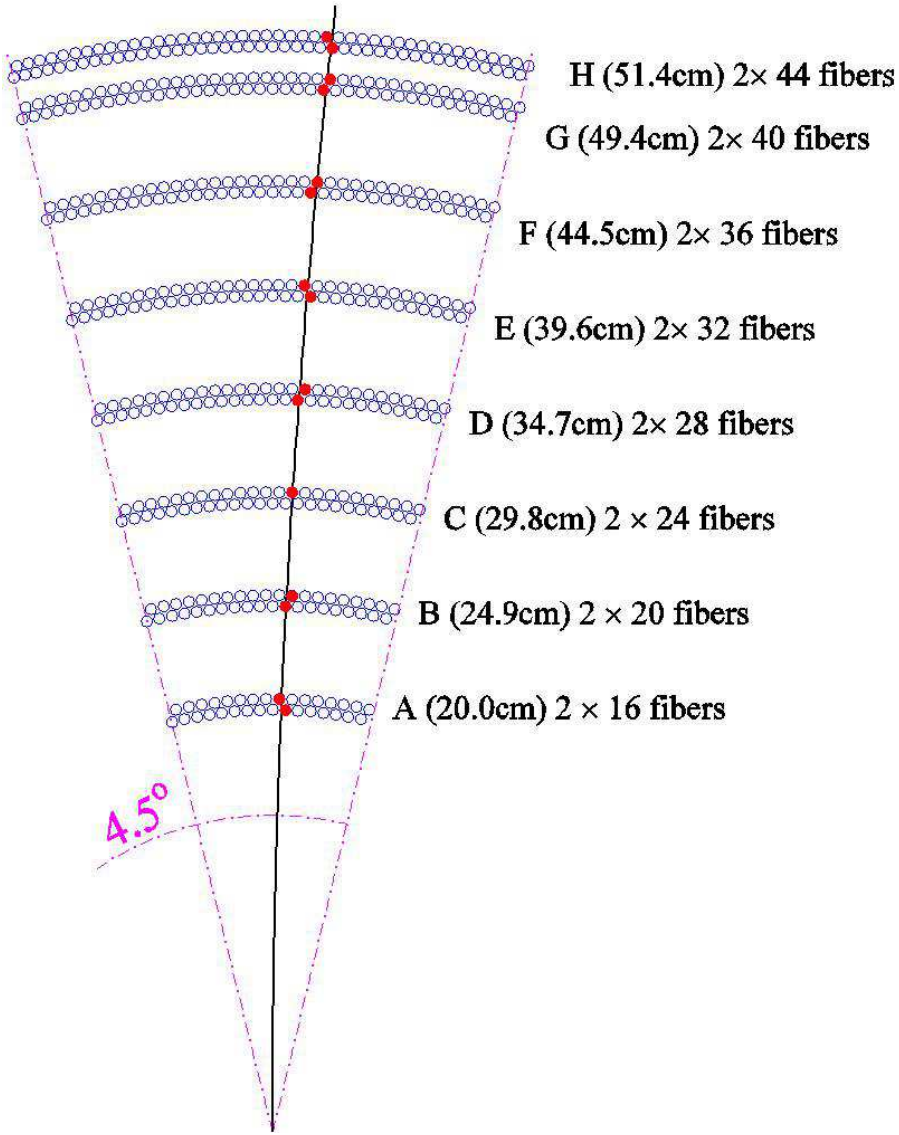
- In 8 axial layers fibers oriented along the cylinder axis
- In 8 stereo layers fibers oriented at $+3^\circ$ and -3° stereo angle

The D0 Fiber Tracker Timeline

- **1992:** Compact D0 scintillating fiber tracker proposed
- **2000:** CFT installed
- **2002:** Data taking begins in Run 2
- **2006:** Start testing new readout prototypes. Develop new calibration procedures
- **2007:** All channels instrumented. Detector performance verified. New data format tested and implemented. Fiber tracker trigger electronics upgraded
- **2008:** Implement online and offline time calibrations. Study tracking efficiency and high luminosity effects
- **2009–2010:** Continue support and monitoring of the detector. Stable operation continues
  - Fraction of unresponsive channels is $\approx 1.6\%$
  - Was $\approx 0.3\%$ in 2001; Increased due to error in cryostat operation in 2004
- **2011:** The Tevatron program is over

Track Reconstruction

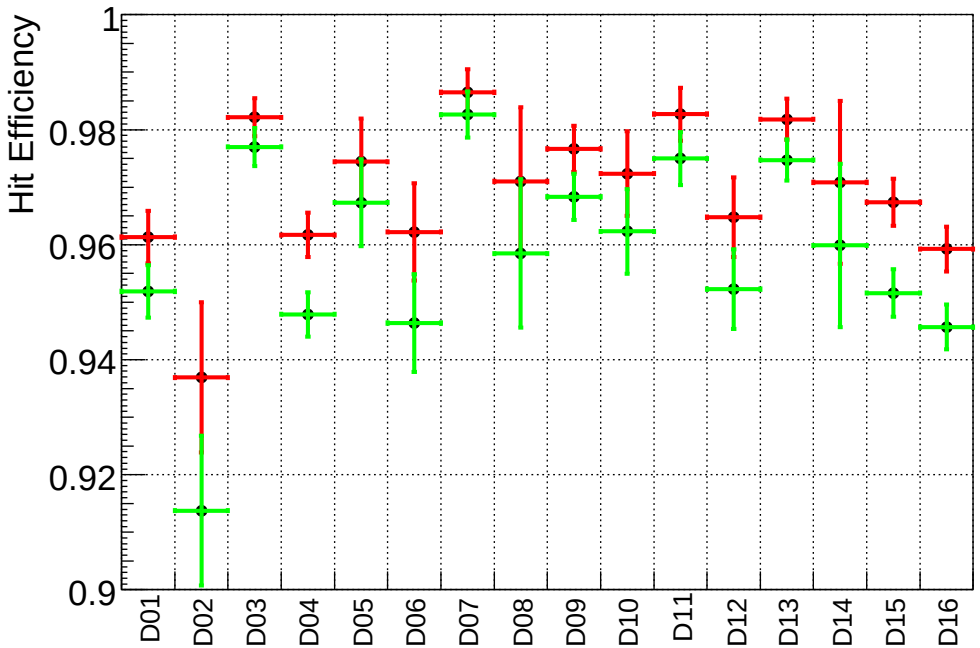
- Clusters formed from axial and stereo hits
- Fast Histogramming Track Finder is used to find track roads in CFT and vertex detector (SMT)
- Kalman filter is applied to find track states at every detector surface
- Tracks started from SMT and CFT are then merged



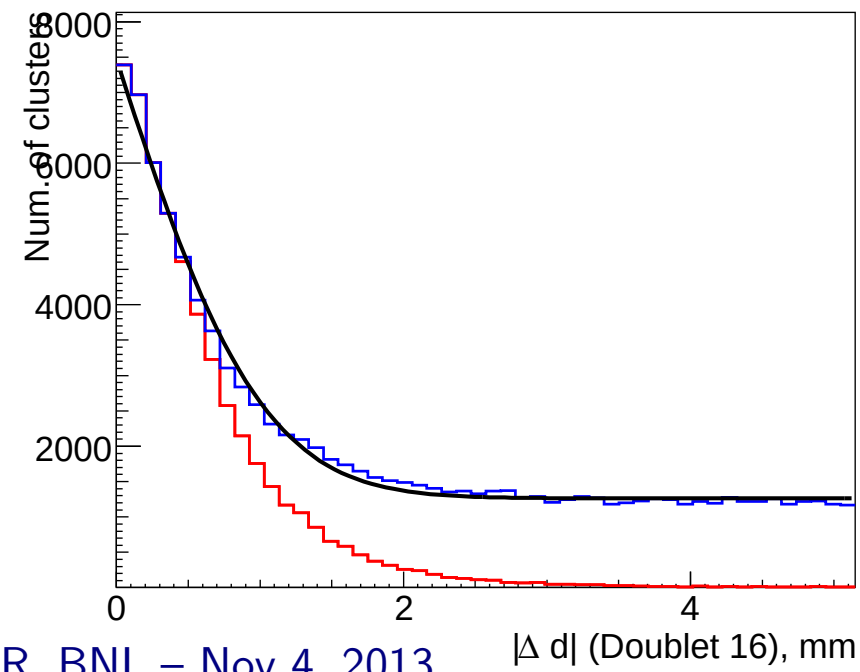
Project Goals and Resolutions

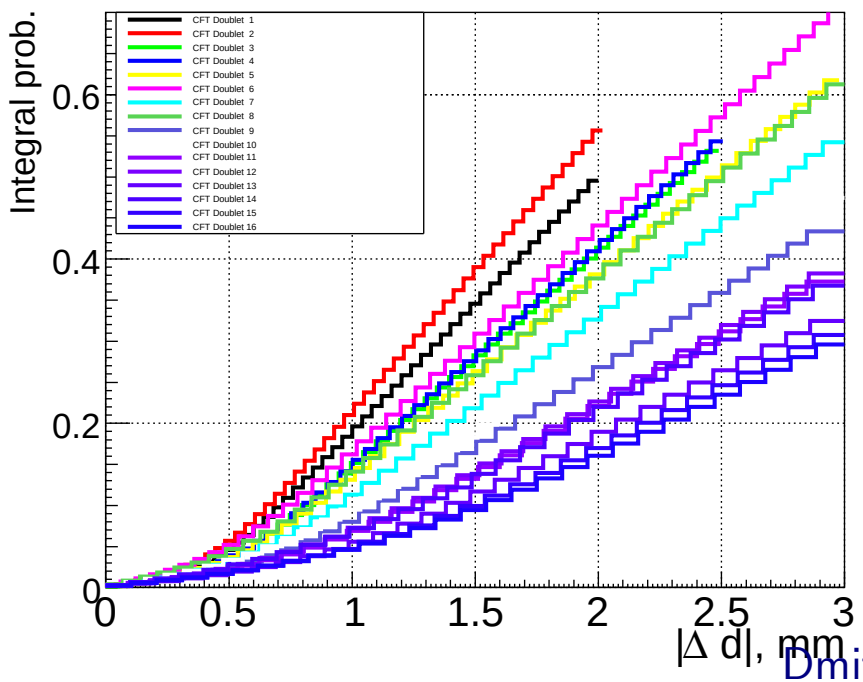
- **Replace the readout electronics unnoticeably to the experiment**
  - Gradually replaced old boards with software development and hardware debugging on the way
  - Integrated new raw data format seamlessly into the existing reconstruction software
- **Make sure detector efficiency is not degraded after the hardware upgrade**
  - Developed and implemented a method to measure efficiency in an unbiased way
- **Deal with ever-increasing instantaneous luminosities (similar to RHIC)**
  - More hits in the tracker mean more fake clusters and fake tracks
  - Made new features of the new boards available in the standard event reconstruction

Single Hit Efficiency

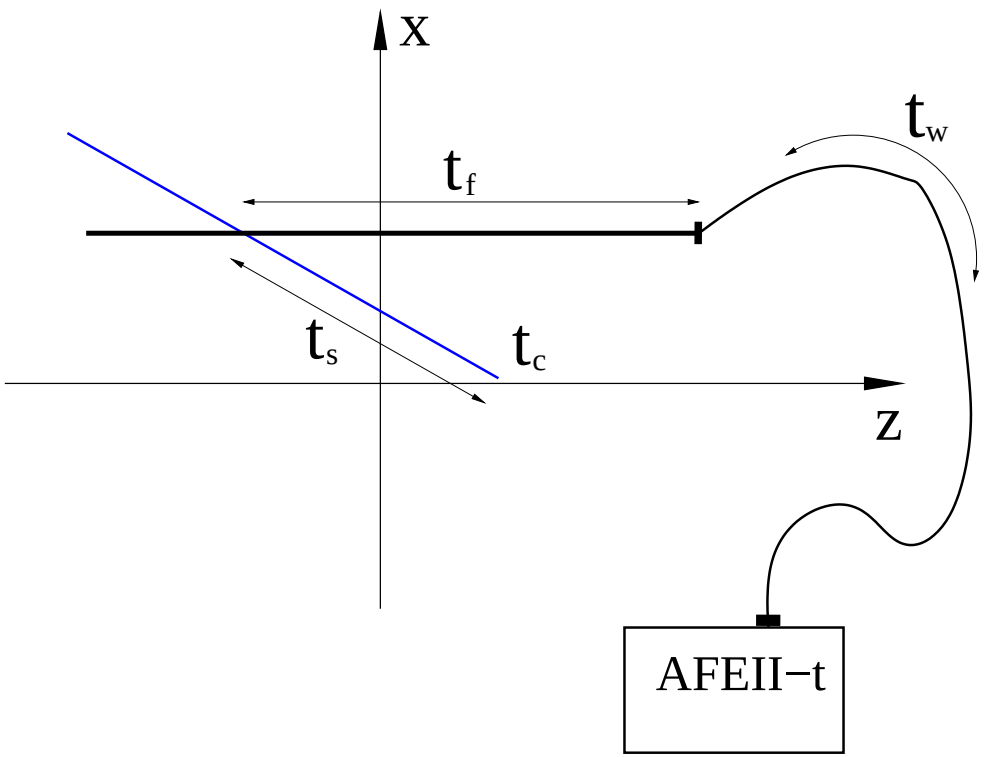


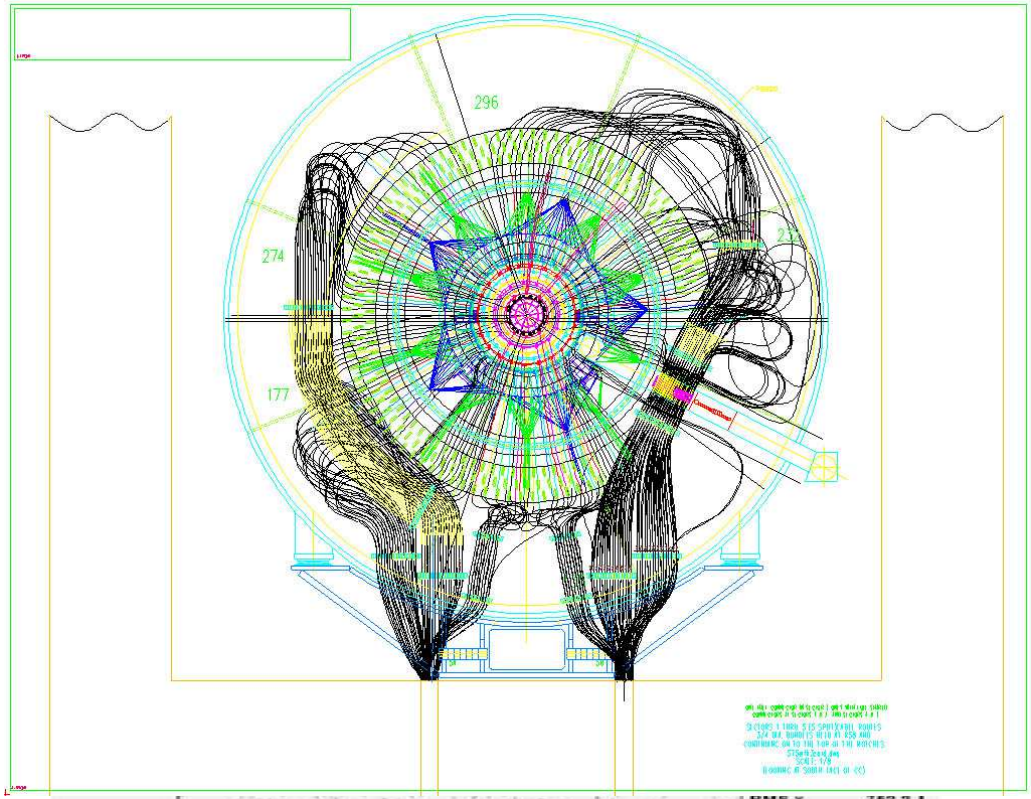
- Unbiased test: Run special event reconstruction with one layer skipped at a time
- Hit efficiency is determined by a cluster within a certain window around the track
- Random background contribution estimated from the tail

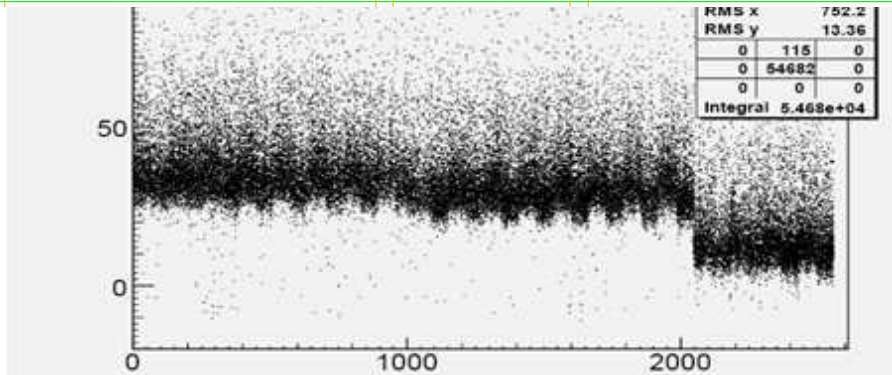


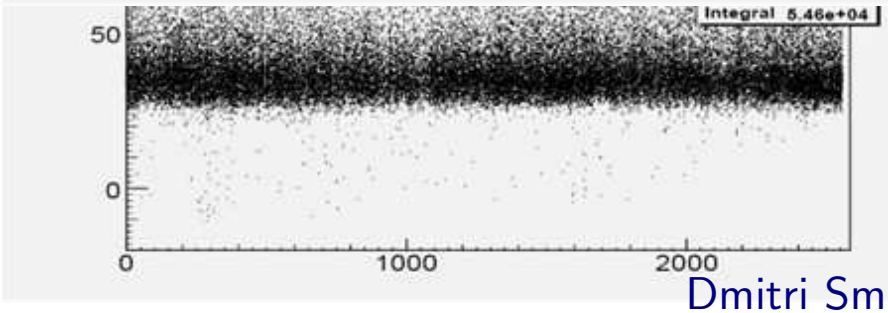


Successful Calibration of New Detector Features



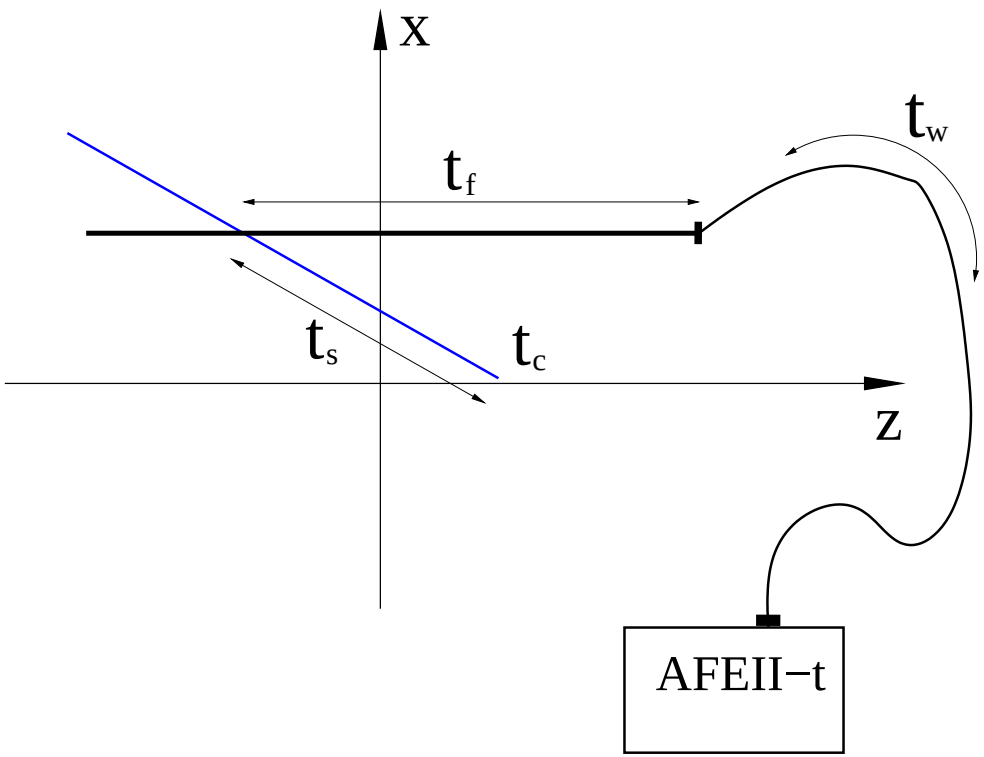


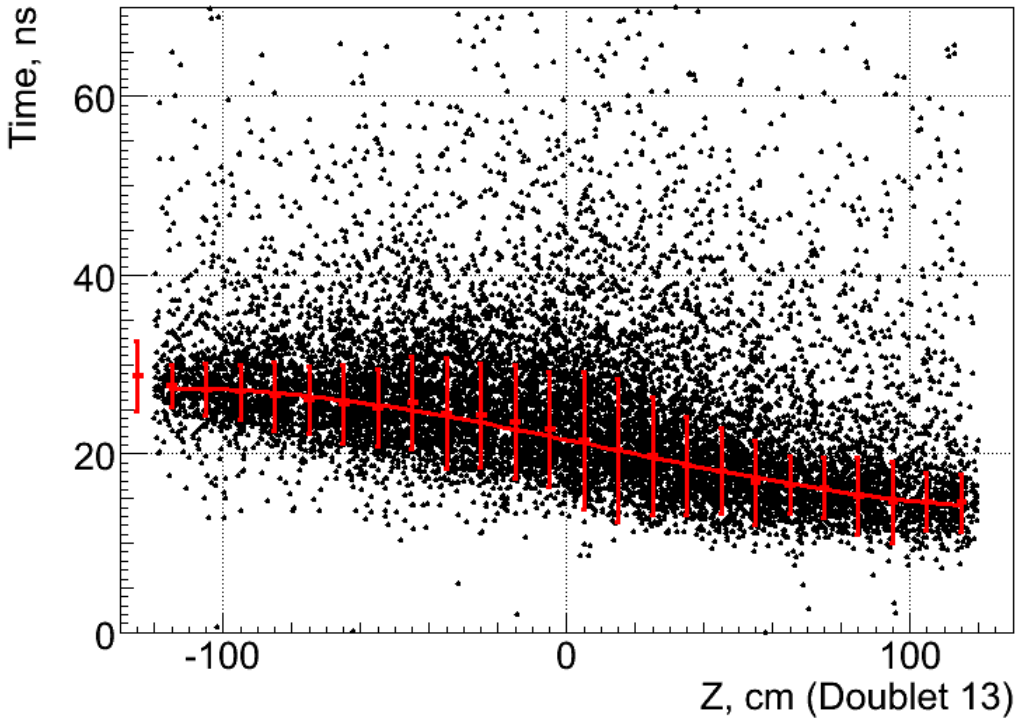


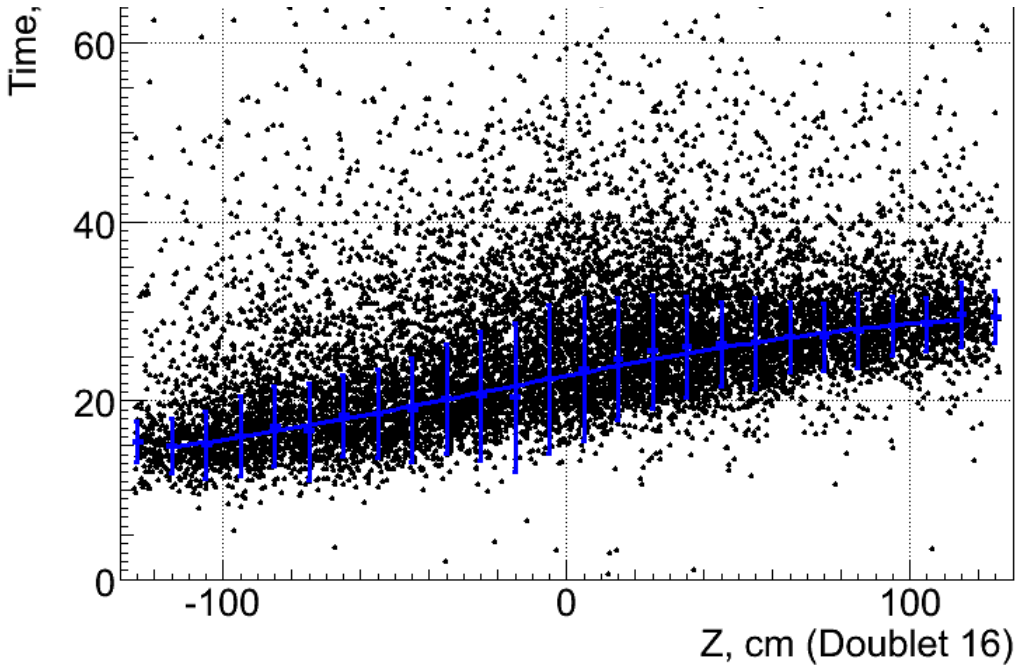


- The time of signal arrival depends on the hit position and waveguide length
- Calibrated for variation (≈ 3m) in waveguide length

Successful Calibration of New Detector Features

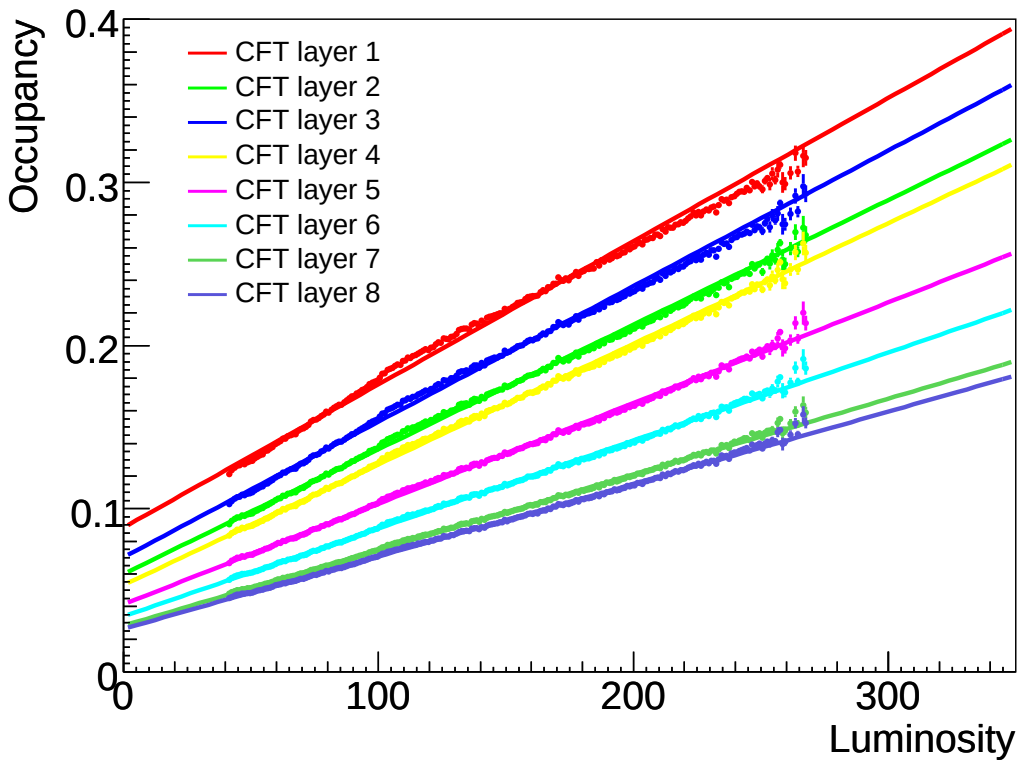






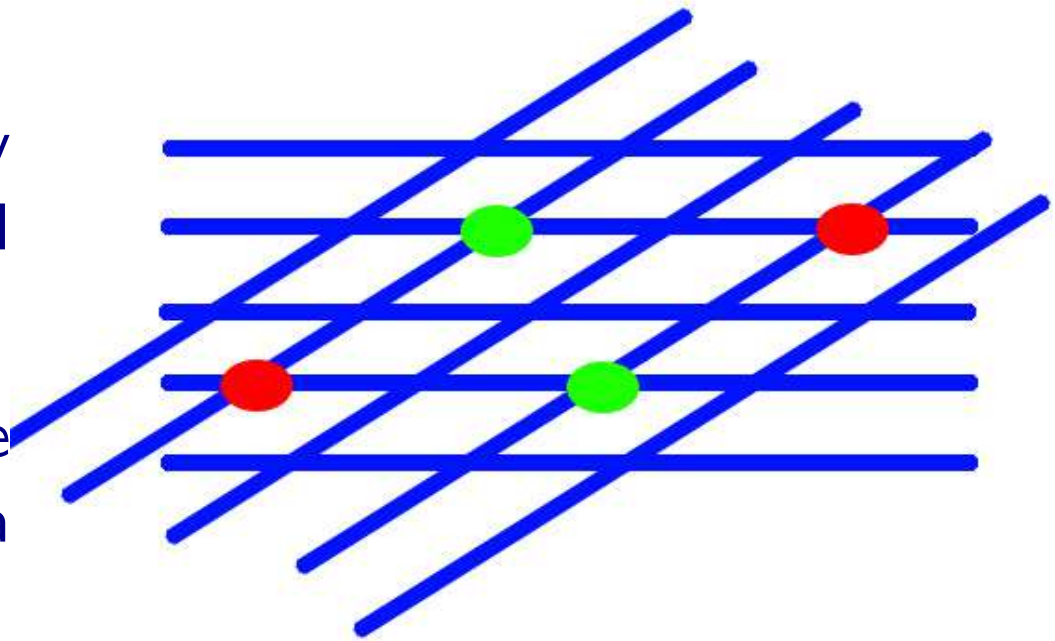
- The time of signal arrival depends on the hit position and waveguide length
- Found average slope to be consistent with the nominal speed of light in the fiber (≈ 18 cm/ns)
- Estimated time resolution at ≈ 4 ns or ~ 60 cm

Reconstruction Challenge at High Luminosity

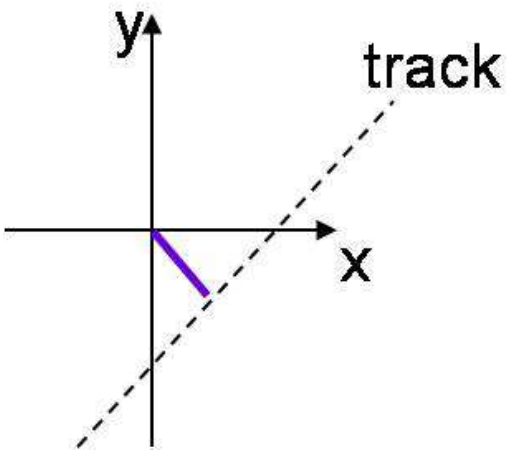


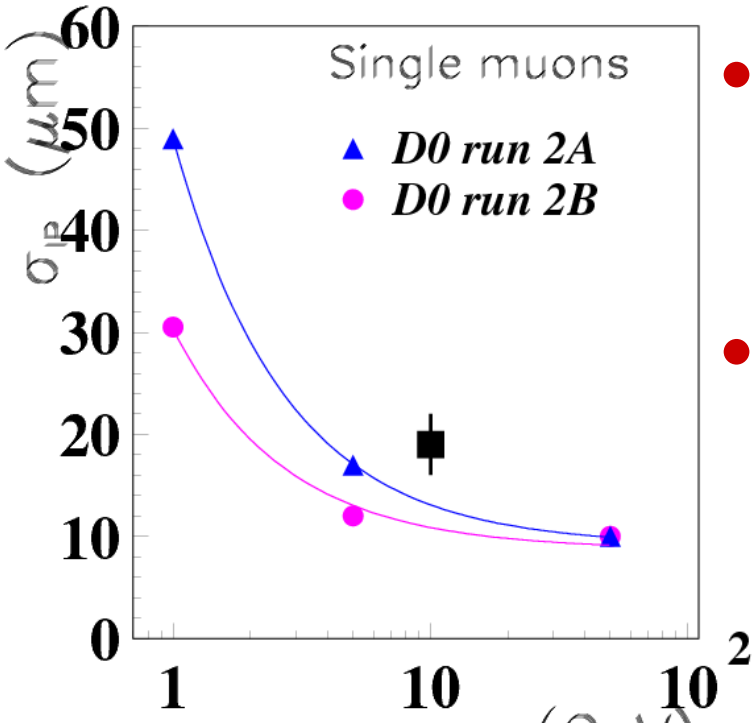
- At high instantaneous luminosities occupancy of the inner layers could be 30% and higher
- Fake tracks can be reconstructed by chance from a large number of fake clusters

- The effect has been mitigated by assigning a weight to the cluster based on the z and t correlation
- Overall fake track rejection was done by combining track parameters into a single weight factor



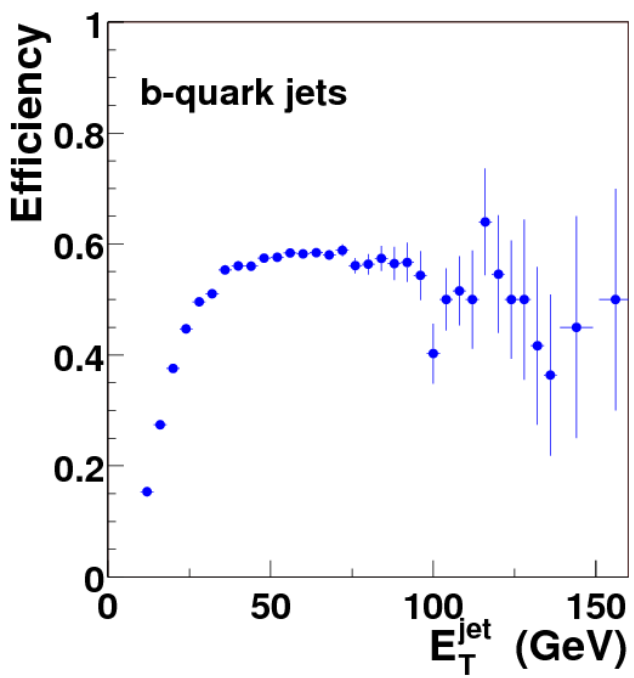
Tracking Performance from Physics Point of View

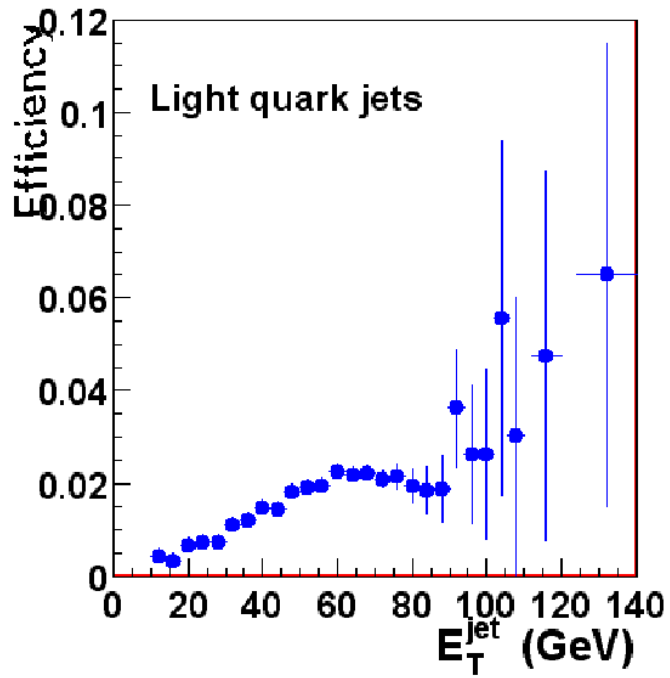




- **Many D0 analyses benefited from improved tracking**
- Single track DCA resolution is $\sim 20\ \mu m$ for tracks $p_T > 10$ GeV

- Secondary vertex b-tagging improved by $\sim 5 - 8\%$ for high p_T jets



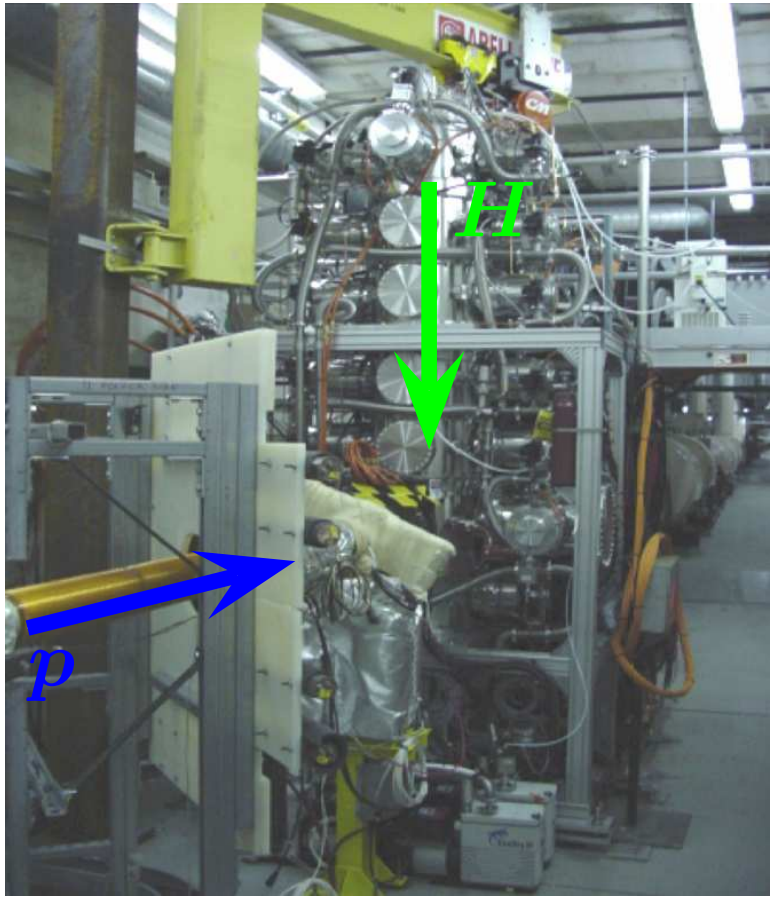


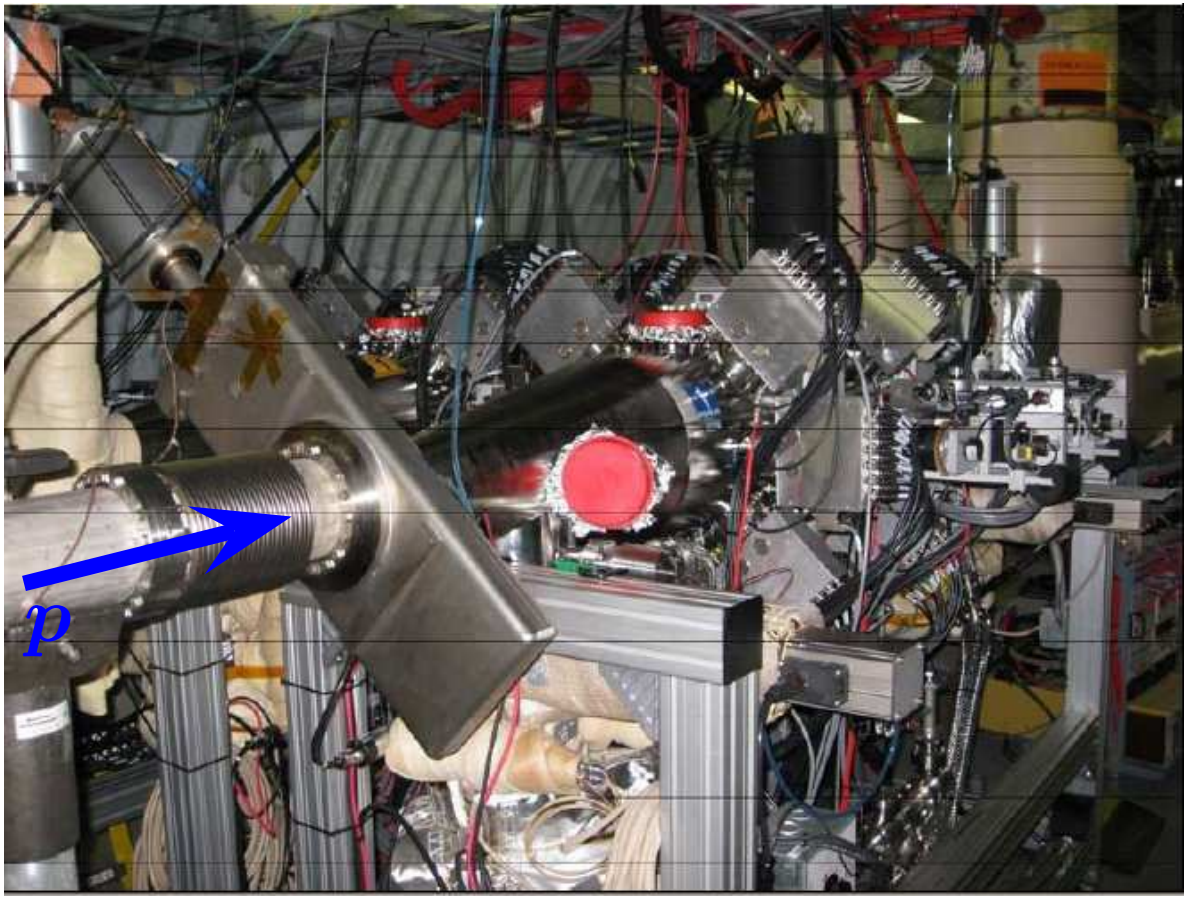
"Other Software Development"

a.k.a.

Measuring Proton Beam Polarization at RHIC

RHIC Polarimeters: Area of Responsibility





- **Hydrogen Jet Polarimeter**
  - **Jet is polarized!**
  - Continuous operation throughout the fill ($\sim 8 - 10$ hours)
  - Provides **absolute average** polarization over the fill
  - Lower statistical power

- **p-Carbon Polarimeters (two in each ring)**
  - About four 2-minute measurements per fill
  - Polarization decay in fill
  - Beam polarization profiles
  - Higher statistical power

Project Goals and Resolutions

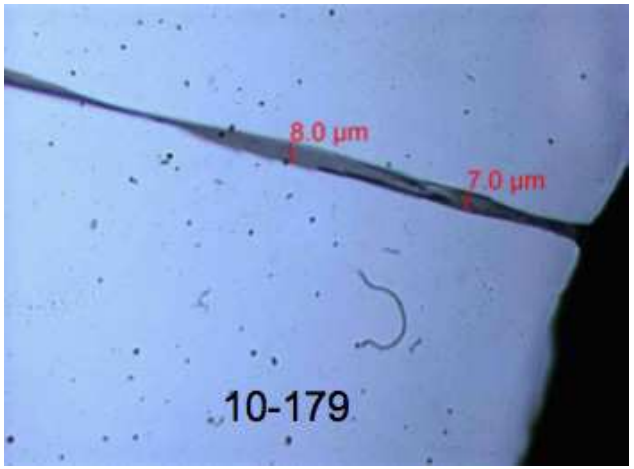
- **Precise knowledge of polarization $P \pm \Delta P$ is essential for all spin analyses at RHIC**

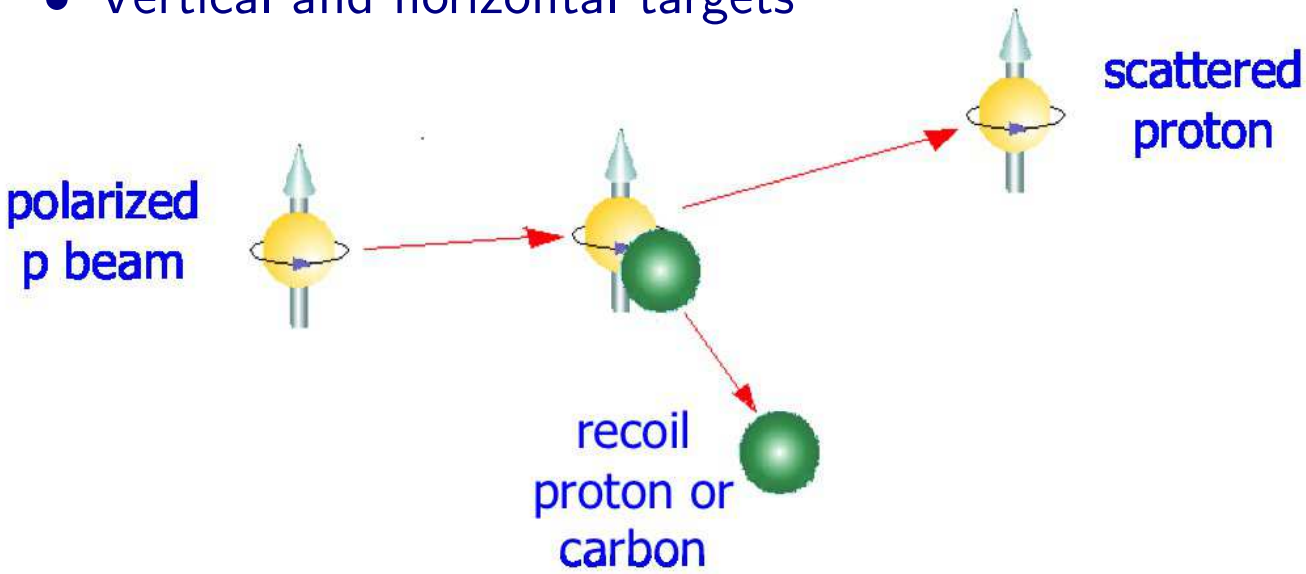
- **Provide reliable results from regular polarization measurements**
  - Consolidated the existing previous efforts into a single framework (lots of clean up!)
  - Converged to single package with clear hierarchy of C++ classes
  - Resolved the systematic difference between the "online" and "offline" measurements

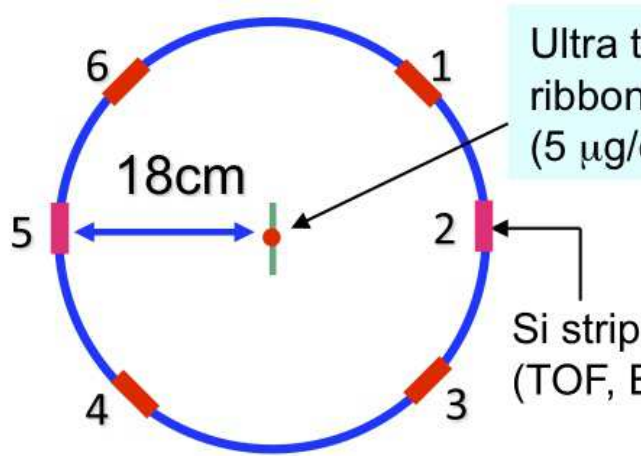
- **Understand systematic year-to-year differences**
  - Used the same framework to analyse past and current data
  - Implemented lots of intermediate cross checks

Principles of RHIC Polarimetry

- Fixed targets are used to measure proton beam polarization
  - **H-jet polarimeter**
    - Vertical hydrogen jet target $\sim 6 - 7$ mm in diameter
  - **p-Carbon polarimeters**
    - Ultra thin carbon ribbon 2.5 cm $\times$ 10 μm $\times$ 25 nm
    - Vertical and horizontal targets





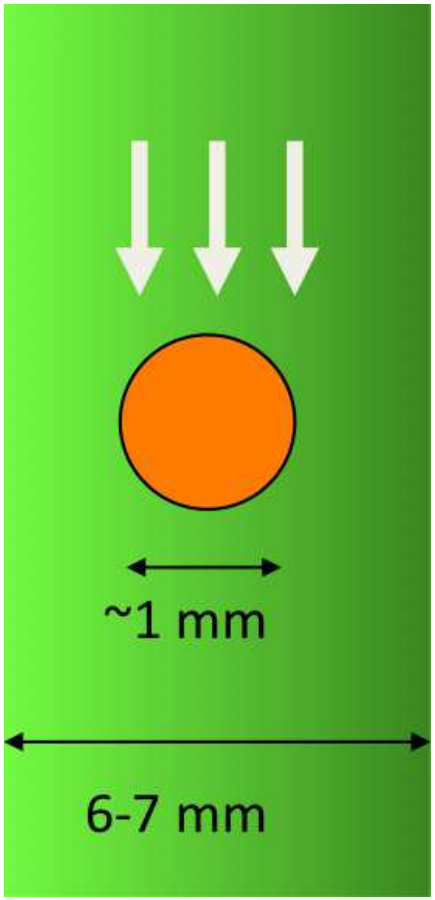


- **Measured polarization is:** $\boxed{P = \frac{1}{A_N} \times \frac{N_L - N_R}{N_L + N_R}}$, where A_N is $\sim 3\%$

Beam Polarization Profile

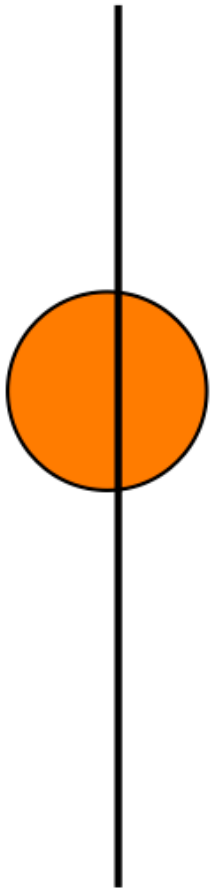
- Polarization varies across the beam
- Polarization seen by polarimeters and experiments is different

H-Jet



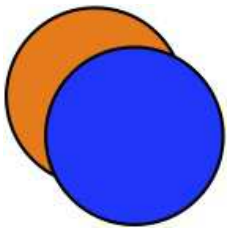
$$P = \frac{\int P(x,y)I(x,y)dxdy}{\int I(x,y)dxdy}$$

p-Carbon



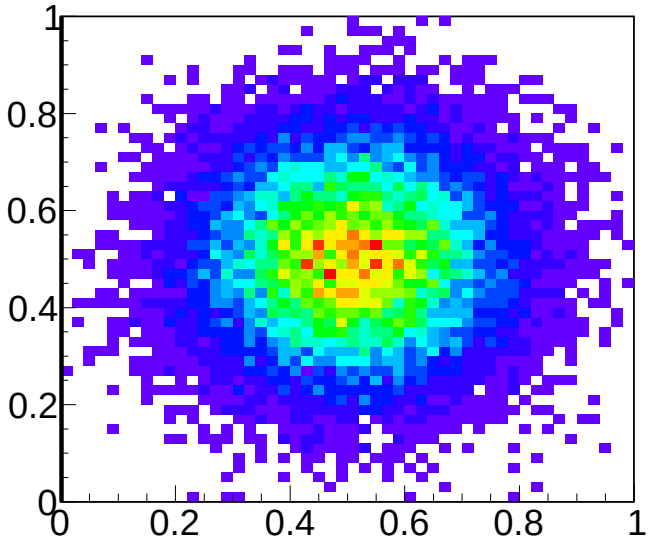
$$P_{\text{sweep}} = P$$

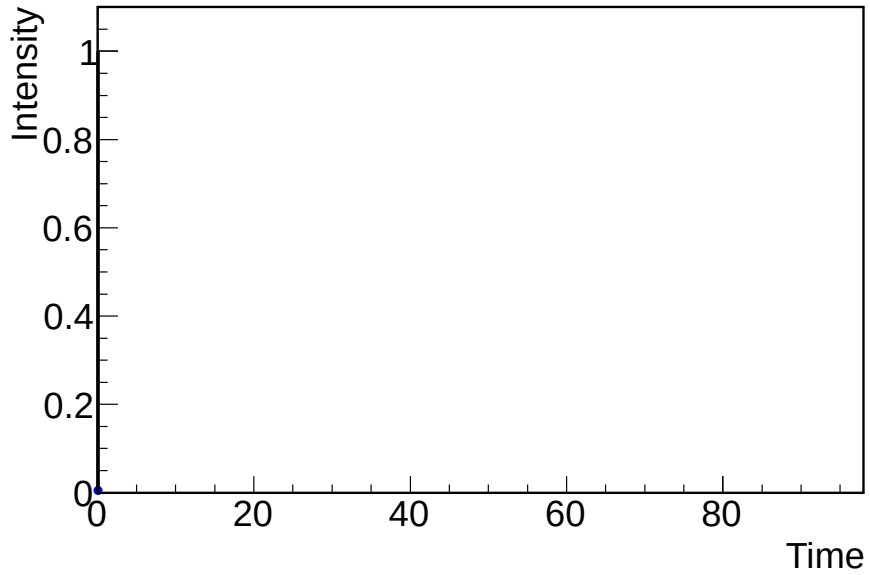
Beam collisions



$$P_{\text{coll}} = \frac{\int P(x,y)I_1(x,y)I_2(x,y)dxdy}{\int I_1(x,y)I_2(x,y)dxdy}$$

Measuring Beam Polarization Profile

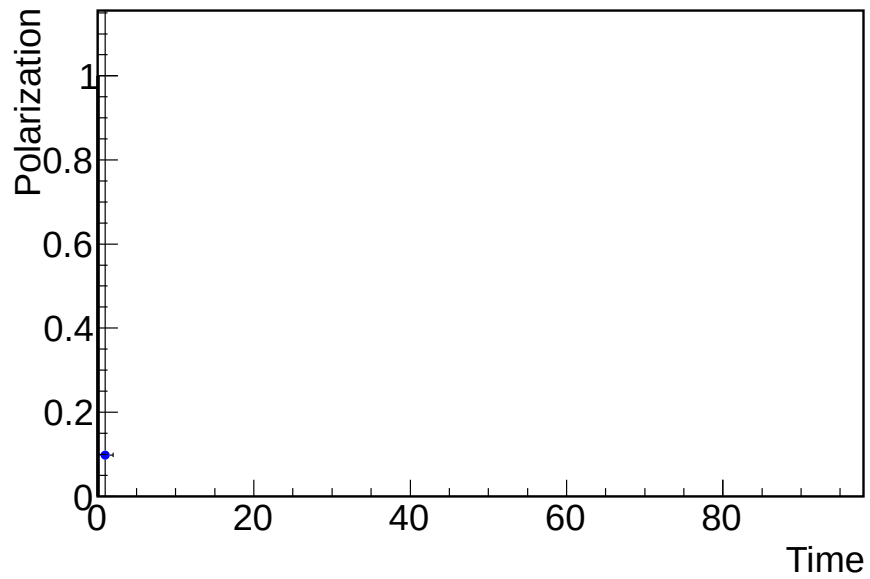




- Polarization and intensity profile can be described with gaussian distributions:

$$P = P_{\text{max}} e^{-\frac{\vec{x}^2}{\sigma_P^2}}, \qquad I = I_{\text{max}} e^{-\frac{\vec{x}^2}{\sigma_I^2}}$$

- Profile parameter $\boxed{R = \frac{\sigma_I^2}{\sigma_P^2}}$



Carbon Target Crossing Beam

- Direct observation helps to identify broken targets which can produce normal profiles
- A python script creates short movies from a continuous surveillance system based on the actual measurement time

Polarization Measurements Database

RHIC Polarimetry Results: p-Carbon Measurement Database

Presentations – R... | vbasym: Class List | RHIC Polarimetry ... | eic – Revision 22... | root.cern.ch Git | Issue Navigator –... | Account Manage... | TH2

www.phy.bnl.gov/cnipol/rundb/?rp=13&rn=&himg=&pi=&mt=2&be=&to=&ti=&sb=Select

latex dvi resolution

Contact CNIPol, Dmitri Smirnov

Home | pC Measurements | Fill Results | Summary Plots | Target History

p-Carbon Measurements

Individual measurements are clickable. More information for QA!

Movies!!!

Run 13

Use "%" to match any number of characters, use "_" to match any single character in run id

Type: sweep Beam energy: Target:

Select

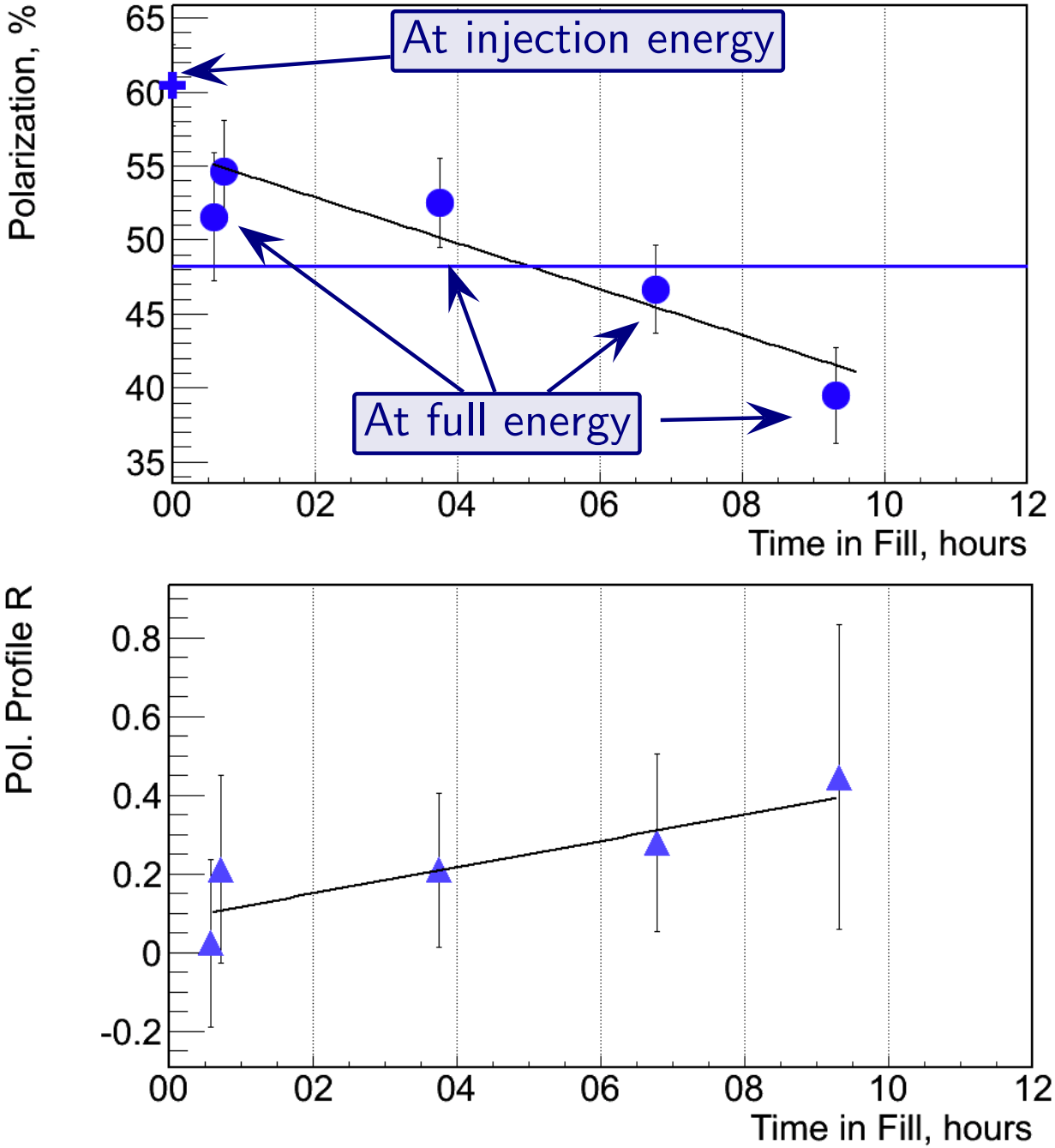
Runs selected: 347

Export to CSV file: download

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

Run	Date & Time	Polarimeter	Polarization, %	Prof. Ratio R	Type	Beam Energy, GeV	Target	Bunches −/0/+	Total Events	Offline analysis			
										R	V	Ver	Date & Time
17601.310	Jun 10, 2013 14:17:32 Mon	Y2U	0.0 ± -100.0	0.00 ± -1.00	sweep	0.94	H6	0/120/0	1,045,241	ϕ	β	2125	Jul 23, 2013 14:29
17601.212	Jun 10, 2013 14:13:47 Mon	B2D	0.0 ± -100.0	0.00 ± -1.00	sweep	0.94	H5	0/120/0	405,189	ϕ	—	2125	Jul 23, 2013 14:29
17601.211	Jun 10, 2013 14:12:12 Mon	B2D	0.0 ± -100.0	0.00 ± -1.00	sweep	0.94	H5	0/120/0	1,688,243	ϕ	β	2125	Jul 23, 2013 14:31
17601.308	Jun 10, 2013 08:06:14 Mon	Y2U	48.8 ± 3.3	0.05 ± 0.17	sweep	254.82	H6	56/9/55	55,144,435	ϕ	β	2125	Jul 23, 2013 14:31
17601.209	Jun 10, 2013 08:04:03 Mon	B2D	51.1 ± 3.1	0.07 ± 0.22	sweep	254.82	H5	55/9/56	54,643,568	ϕ	β	2125	Jul 23, 2013 14:31
17601.006	Jun 10, 2013 08:01:42 Mon	B1U	50.2 ± 2.4	0.15 ± 0.14	sweep	254.82	V2	55/9/56	52,656,841	ϕ	β	2125	Jul 23, 2013 14:32
17601.005	Jun 10, 2013 05:34:47 Mon	B1U	49.5 ± 2.3	0.20 ± 0.14	sweep	254.82	V2	55/9/56	55,852,558	ϕ	β	2125	Jul 23, 2013 14:32
17601.307	Jun 10, 2013 05:32:17 Mon	Y2U	53.4 ± 3.2	0.39 ± 0.24	sweep	254.82	H6	56/9/55	56,349,227	ϕ	—	2125	Jul 23, 2013 14:32
17601.208	Jun 10, 2013 05:29:59 Mon	B2D	51.0 ± 3.0	0.41 ± 0.27	sweep	254.82	H5	55/9/56	57,780,464	ϕ	β	2125	Jul 23, 2013 14:32
17601.004	Jun 10, 2013 02:34:42 Mon	B1U	48.2 ± 2.3	0.20 ± 0.15	sweep	254.82	V2	55/9/56	59,133,219	ϕ	β	2125	Jul 23, 2013 14:32

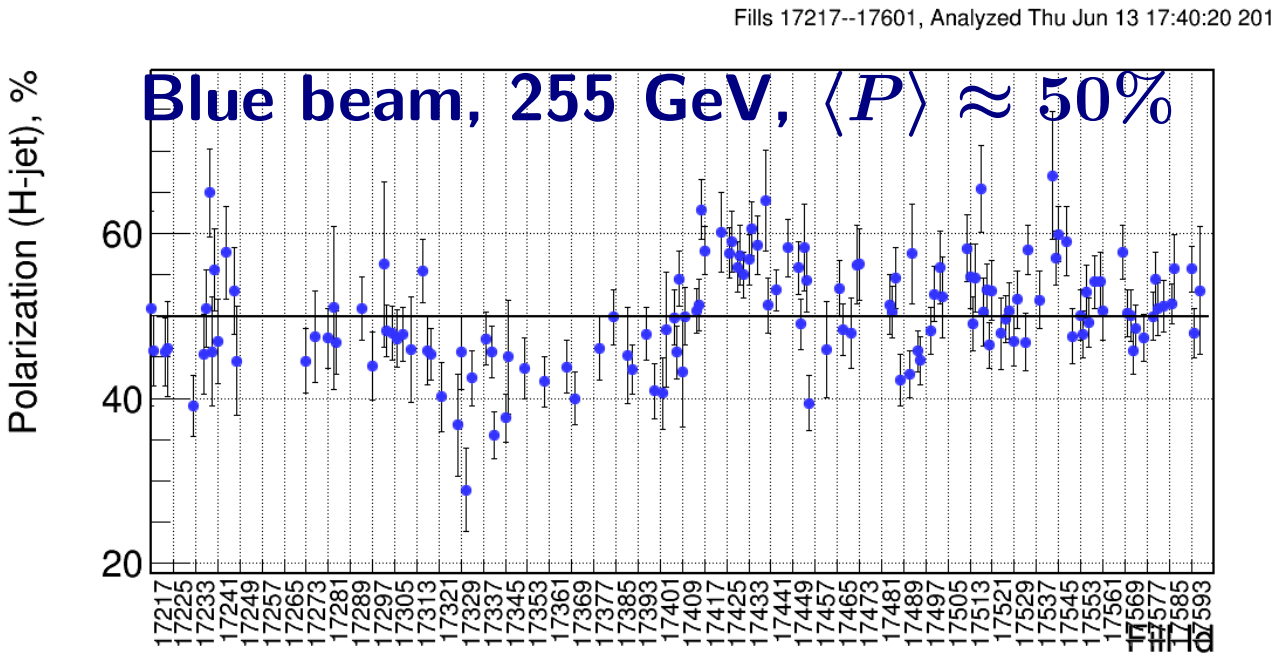
Polarization Losses in a Fill

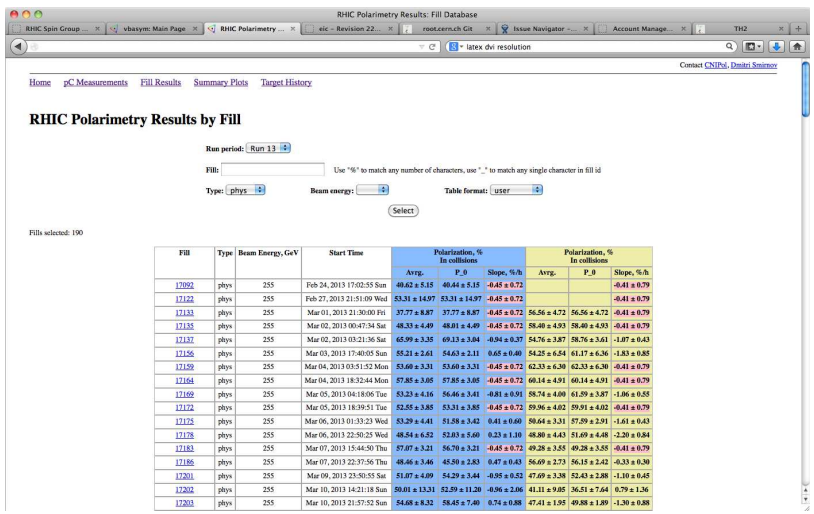


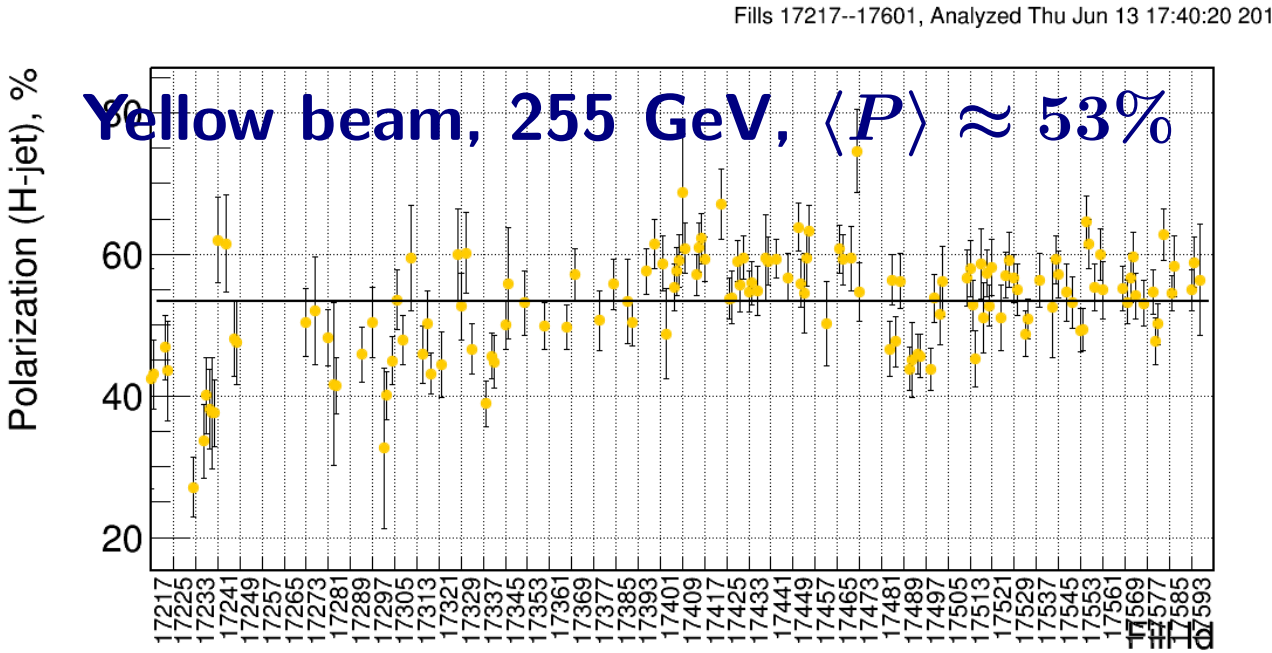
- Confirmed polarization losses during beam acceleration
- Systematically studied the decrease in polarization during a fill
  - Our measurement confirmed de-polarizing mechanism due to widening of polarization profile, i.e. increase of R

Average Polarization in 2013 at $E_{\text{beam}} = 255$ GeV

- 60% polarization achieved during the "golden week"
- Results for all RHIC fills in Runs 9, 11, 12, 13 accessible via web interface







Pre-Summary: Lessons Learned

- Re-use existing code, packages, libraries, modules
  - eSTAR/EIC might be a good example of reusing from other experiments
- Tend towards the latest and most popular versions and tools
- Keep the analysis/results as open as reasonably possible (give back)
  - Browsable repositories: `git`
  - Documentation: `doxygen`
  - Analysis results on the web, wiki, drupal, etc.
- *"A designer knows he has achieved perfection not when there is nothing left to add, but when there is nothing left to take away."* Antoine de Saint-Exupery

Summary: Experience Highlights

- Experience with a significantly detector upgrade in the running experiment
  - Successful integration in existing track reconstruction software
  - Methodology for detector-independent performance monitoring
- Enhanced knowledge of software development principles and tools
  - Some record of software projects development and support
    `https://github.com/plexoos`

- Scientific background is helpful in understanding the design and needs for new detectors
  `http://www.phy.bnl.gov/vbasym/`
- Experience from working with CAD improved understanding on RHIC future (eSTAR, EIC)
  `http://www.phy.bnl.gov/cnipol/`