A Beam Condition Monitoring System for the CDF Experiment using CVD Diamond

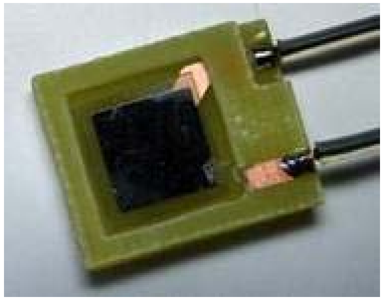
CDF Diamond Group

, Peter Dong, Charles Schrupp, Rainer Wallny
University of California, Los Angeles

Ricardo Eusebi,
Rick Tesarek, FNAL

Anna Sfyrla, University of Geneva

William Trischuk,
University of Toronto



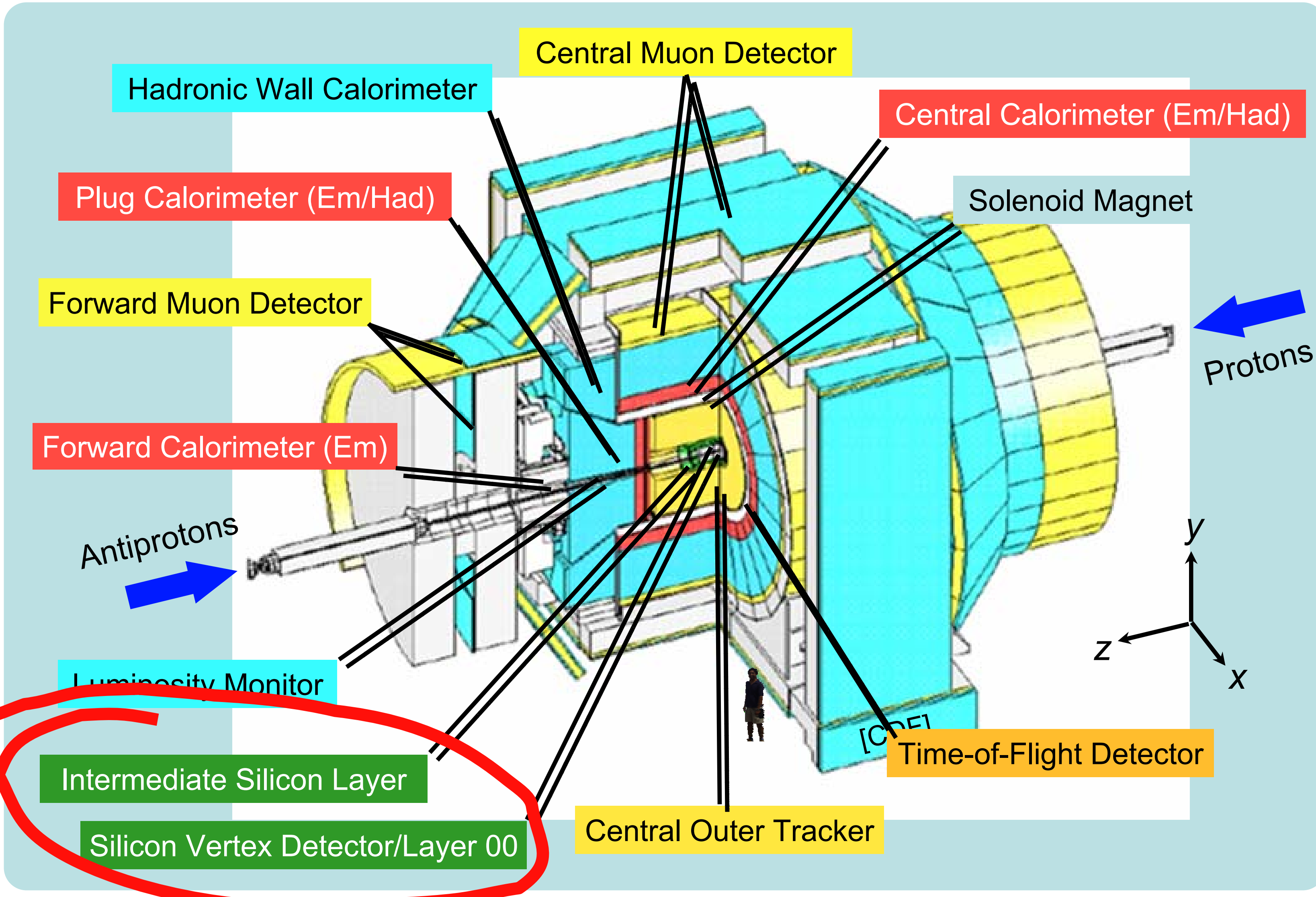
Many thanks to:
Tevatron BLM Electronics Upgrade Project (AD and PPD EE groups)
+
CERN RD42 Collaboration

Outline

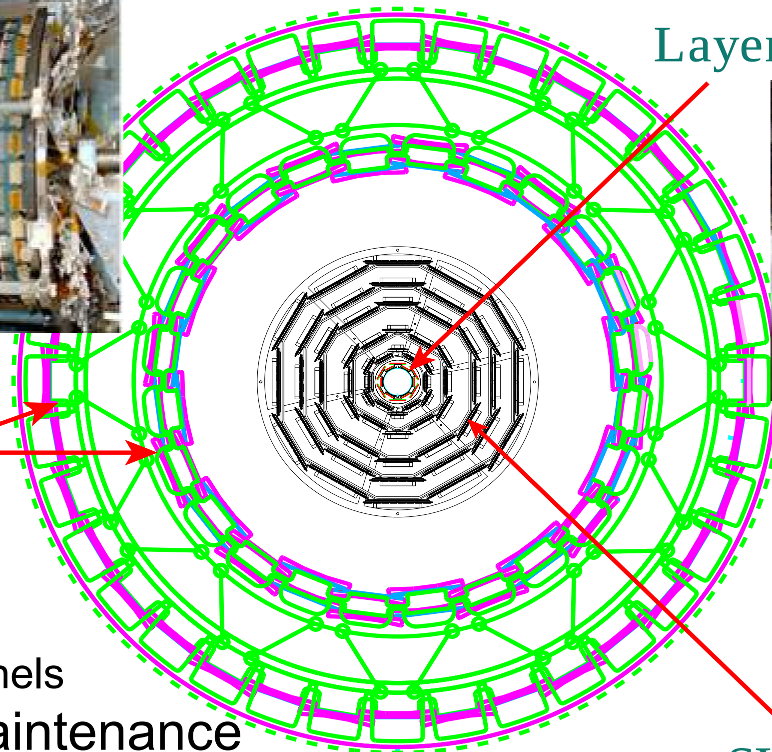
I. Motivation of a Beam Condition Monitoring System (BCM) operated inside a Collider Detector
II. Overview of CVD Diamond
III. The CDF Diamond BCM System
IV. Other Applications
V. Summary and Conclusions

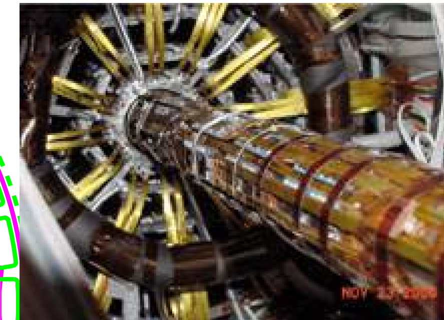
I. Motivation

The CDF Run II Detector



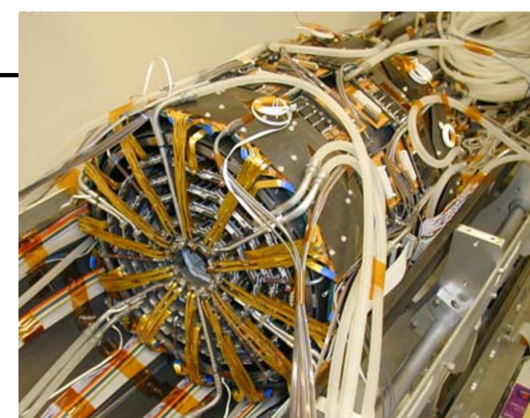
CDF II Silicon Detector





- One of the biggest silicon detectors currently online!
  - 6.2m^2 silicon with 722k channels
- Cannot be accessed for maintenance
  - ‘space probe’ engineering and operation
  - Needs to ‘live’ longer than designed for
- 1.5cm away from the beam
  - improved performance
  - a dangerous place to be

The key to many CDF Flagship Physics Analyses!



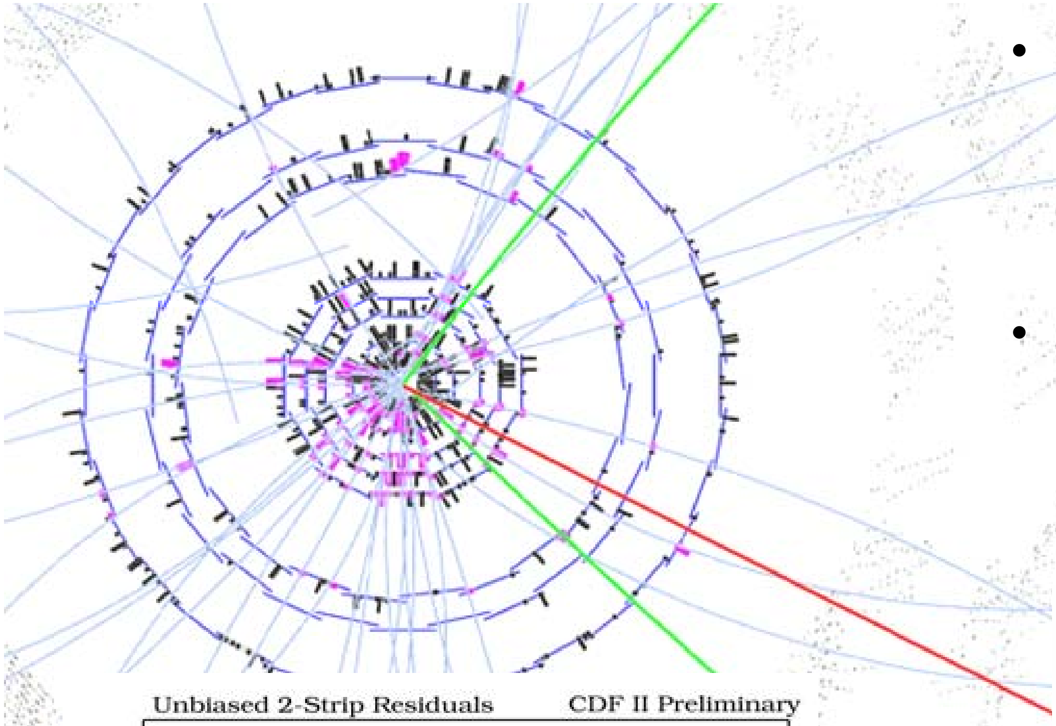
Silicon Commissioning and Operations

- **Silicon cabling took ~7 weeks, 24h/day, 4 people at the time**
  - **Electrical, optical and cooling connections for 722’000 channels**

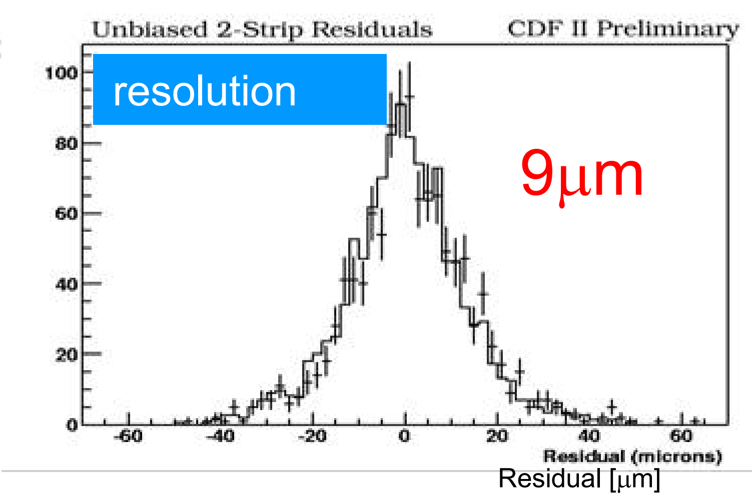
- **A number of unforeseen operational problems:**
  - **Epoxy-blocked cooling lines**
  - **Analog noise pickup in innermost silicon layer**
  - **Wire bond failures due to Lorentz force induced resonances**

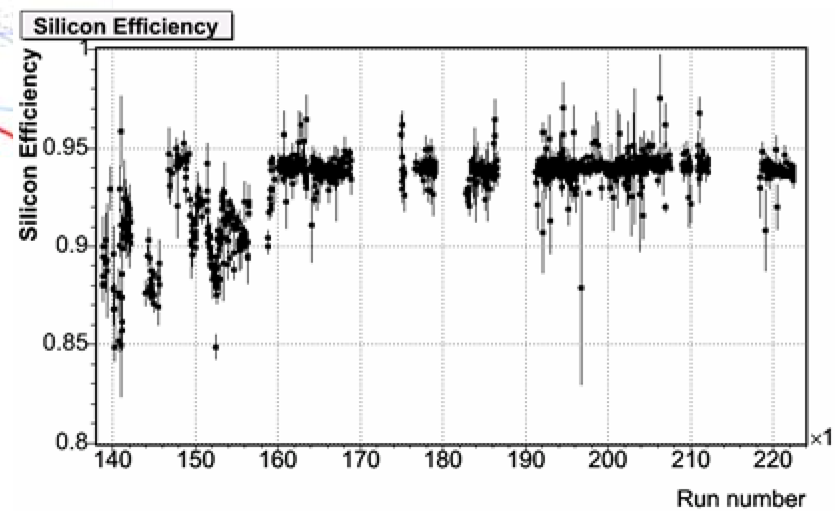
- **It still takes about ~11 people to keep the CDF silicon detector running**
  - **Ladder Maintenance**
  - **Monitoring**
  - **Calibration**

Silicon Detector Performance



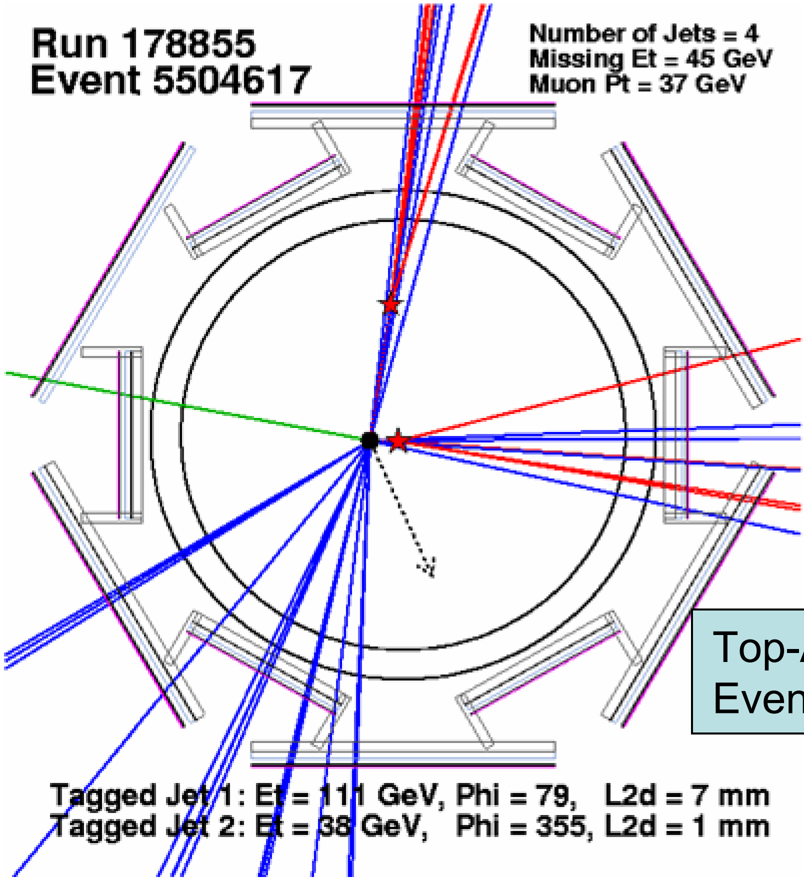
- **S/N as designed**
  - **10 for L00**
  - **14/12 for SVXII ϕ/z**
  - **12 for ISL**
- **Silicon hits-on-track efficiency >93% if requiring 3 r-ϕ layer hits**



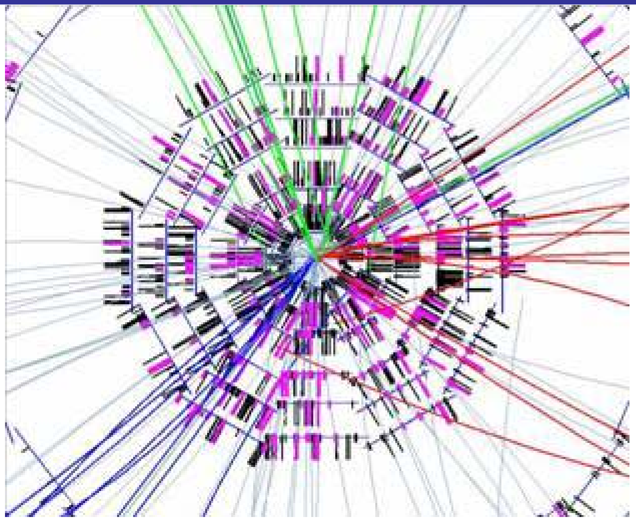


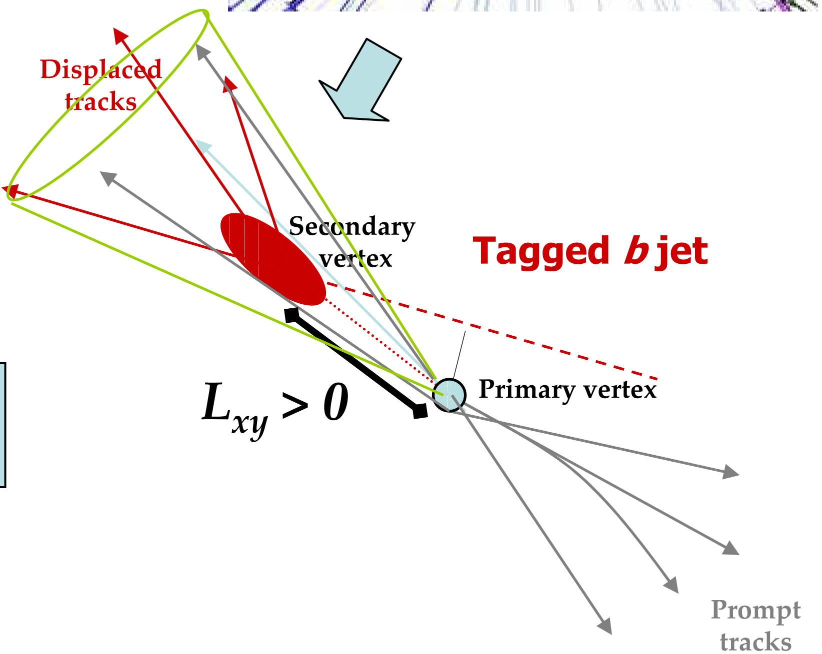
B-Tagging is a Key Experimental Tool

Many interesting physics processes contain b-quarks which give rise to hadrons with a "long" Lifetime **($c\tau$~460 μm)**



Top-Anti-Top Event in L00

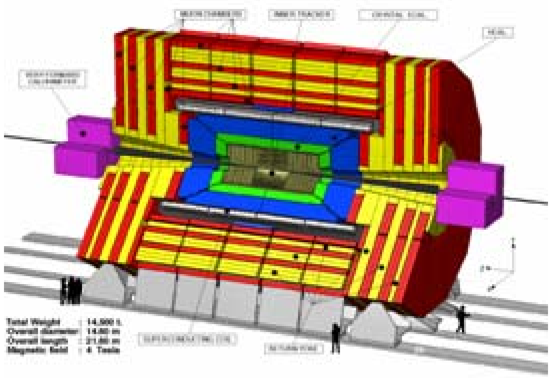




B-tagging is a discovery tool!

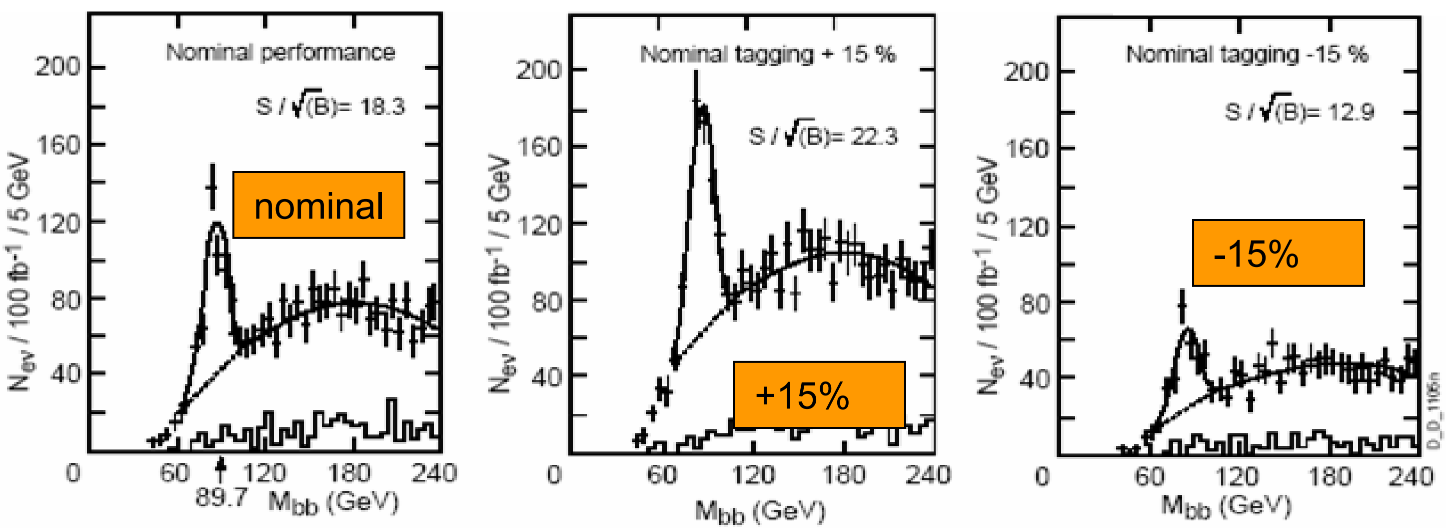
- Final states containing b quarks:

SM Higgs (low mass region)	**Htt $\rightarrow$**	**bbbbWW**
SUSY Charged Higgs (H+):	**tt $\rightarrow$ bh$^+$ bW $\rightarrow$**	**bbW$\tau\nu$,**
	tH$^+$ $\rightarrow$ btt $\rightarrow$	**bbbWW,**
	tbH$^+$ $\rightarrow$ bbtt $\rightarrow$	**bbbbWW**
SUSY Heavy Neutral Higgs:	**bbH/A $\rightarrow$**	**bb$\tau\tau$**
SUSY h^0	**g~g~$\rightarrow$ h$^0\chi^0$....**	**$\rightarrow$ bb χ^0**
SUSY stop:	**t~t~ $\rightarrow$ b~b~ $\chi^\pm$ $\chi^\pm$ $\rightarrow$**	**bbWWχ^0 χ^0**
	t~t~ $\rightarrow$ tt χ^0 χ^0	**$\rightarrow$ bbWWχ^0 χ^0**
SUSY sbottom:	**g~g~ $\rightarrow$ b~b~ bb**	**$\rightarrow$ bbbb χ^0 χ^0**

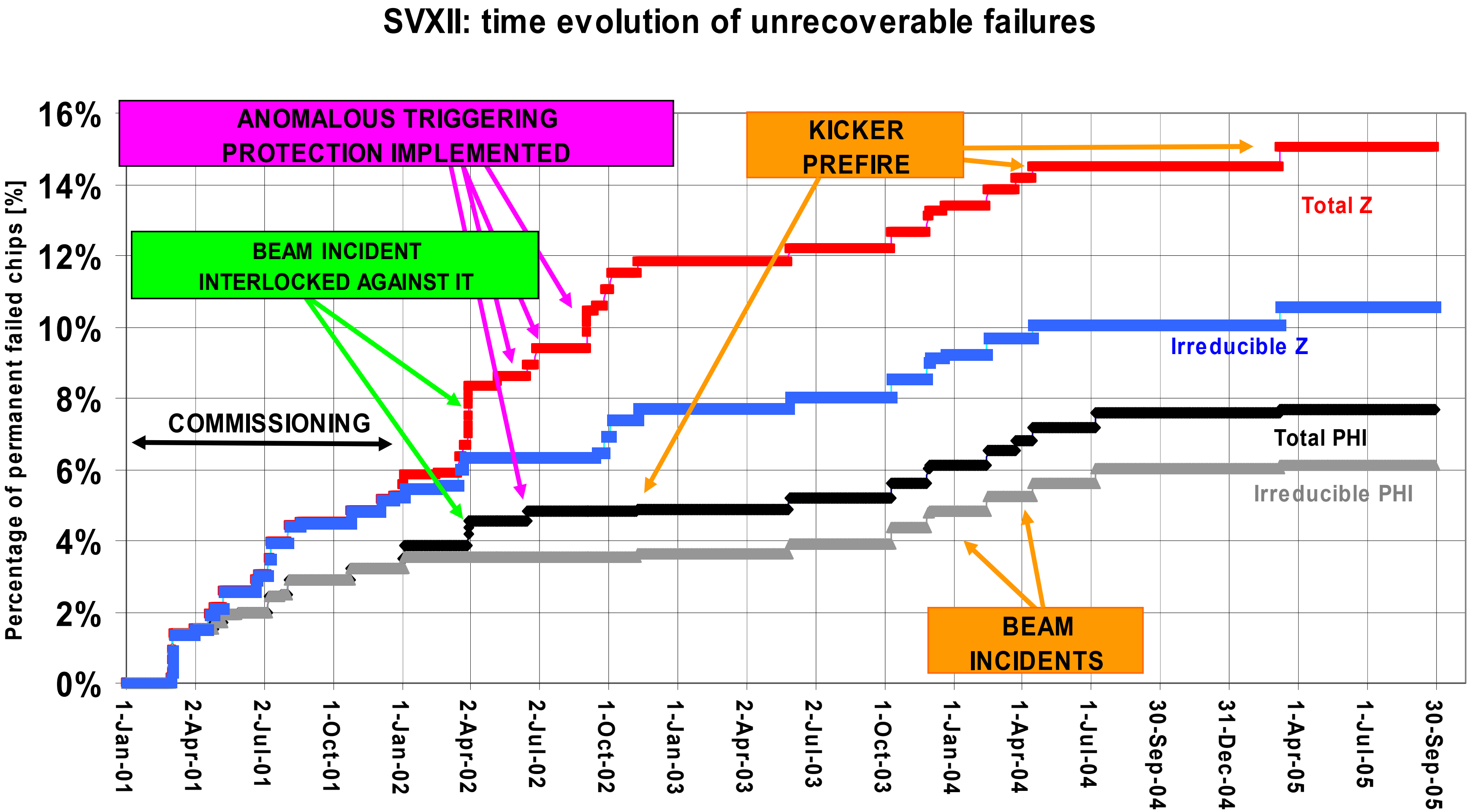


- Requiring b-quarks helps to suppress background processes efficiently
  - Figure of Merit: b-tagging efficiency (~50%)

MSSM h^0 $\rightarrow$ bb



Time Evolution of SVXII Chip Losses



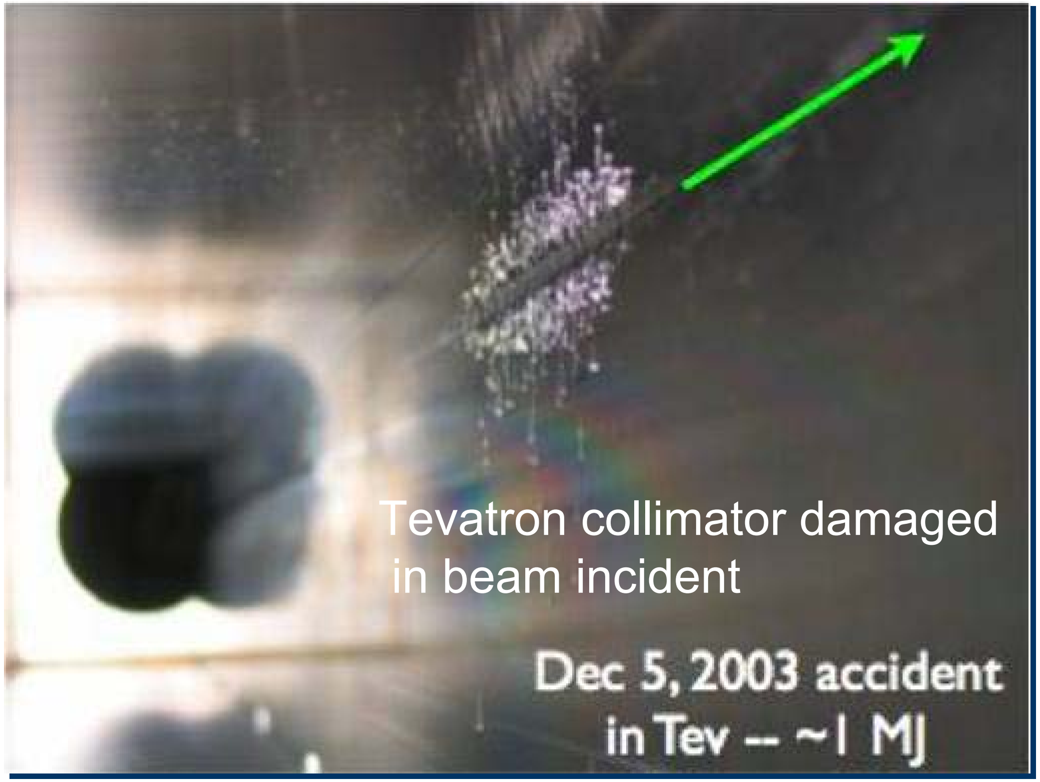
- From 07/01/03 – 07/01/04 have lost 2.5% of z and of ϕ side chips in SVXII as a result of beam incidents and thermo cycles

- Current Status: 92% of all ladders powered, 85% give good data (<1% error rate)

Beam Incidents

- Tevatron
  - 1 MJ/beam = kinetic energy equivalent to a race car at 200 km/h
- Beam incidents:
  - Major concern for longevity of silicon detectors (other than continuous radiation damage)
  - CDF lost 2.5% silicon channels in July 2003 to July 2004 due to beam incidents
- LHC
  - 350 MJ/beam = "80 kg of TNT or 70 kg of Swiss Chocolate" *(S.Peggs)*

=> Beam condition monitoring and fast beam abort system essential to protect sensitive detectors.



"16 House" Quench Dec 5th, 2003:

- Beam aborted after 16ms
- Decision to overhaul the Tevatron BLM system to enable TeV BLM abort capability

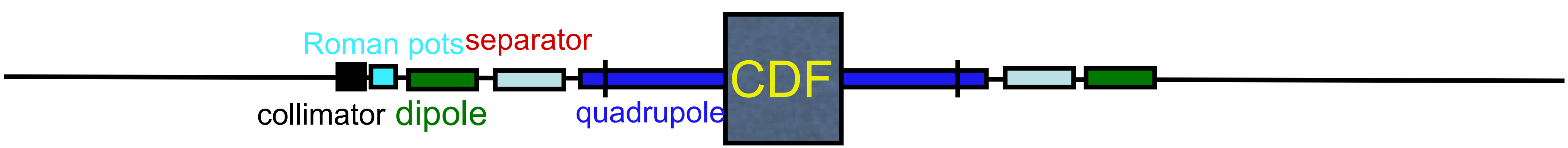
Beam Condition Monitoring

- **Beam Condition Monitoring**
  - Monitor Beam Halo Losses.
    - Detector.
    - Accelerator Magnets (few E9 particles quench them)
  - Monitor Abort Gap.
    - Cannot safely abort if few E9 in abort gap.
  - Monitor Beam Position.
    - Non-uniform irradiation
    - All sorts of trouble with detector performance.
  - Radiation Dose Accounting
    - When will the detector die ?

- **Beam Abort**
  - Abort the beam if conditions unsafe
  - Post Mortem Diagnosis
    - What went wrong?
    - Is it safe to turn back on ?

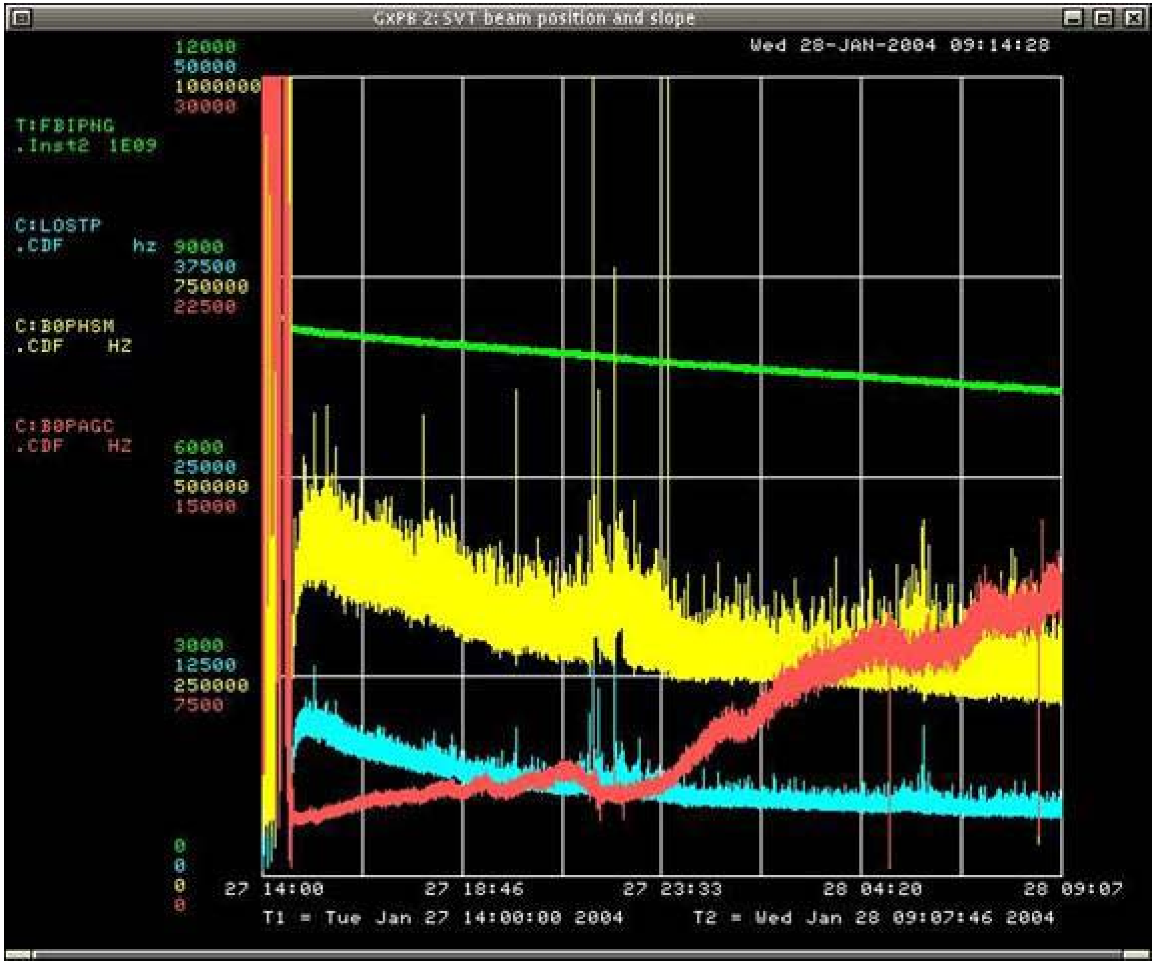
CDF Beam Halo Counters

Rick Tesarek, FNAL



Monitor Experience

“Typical good store”



proton beam current

proton abort gap

proton halo

proton losses

Transmitted via Accelerator NETwork (ACNET)

R. Tesarek

TevMon – Automated Beam Quality Monitoring

CDF TevMon Summary

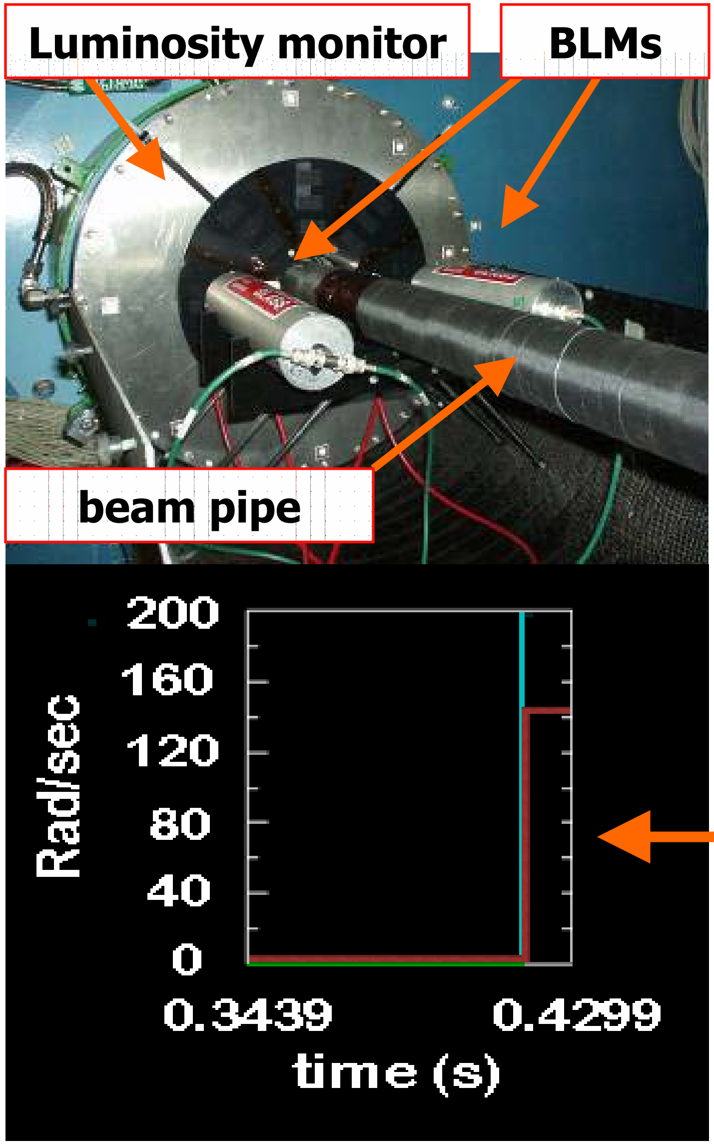
Store	5242
StoreStart	2007.02.23 00:44:36
TimeNow	2007.02.23 17:32:08

Silicon is SAFE

Device	Description	Units	Status	Require	Value	36 second average	3 minut
C:LOSTP	B0 Fast Proton Losses	Hz	OK	√	-370.310	-382.810 ± 15.023	-387.25
C:LOSTPB	B0 Fast Antiproton Losses	Hz	OK	√	-20.313	-13.368 ± 13.958	-7.535
C:B0PAGC	Proton abort gap halo	Hz	OK	√	1890.335	1918.173 ± 89.929	2005.91
C:B0AAGC	Anti-proton abort gap halo	Hz	OK	√	527.658	780.785 ± 413.491	654.877
T:RFSUM	Tev RF Sum	MV/T	OK	√	1.132	1.132 ± 0.000	1.132
T:RFSUMA	Tev RF Sum A	MV/T	OK	√	1.159	1.159 ± 0.000	1.159
T:L2COLI	Tevatron Electron Lens 2	mA	OK	√	11.292	11.207 ± 0.198	11.25
T:AGIGI2	TAGI Gap Intensity 24-25	E09	OK	√	0.235	0.235 ± 0.001	0.237
C:B0ILUM	B0 Luminosity	E30	OK	√	49.851	49.832 ± 0.045	49.90
V:TSCRAP	Tev Scraping State	fsmS	OK	√	3.000		
C:PAK	Proton Abort Kickers	kV	OK	√			
C:AAK	AntiProton Abort Kickers	kV	OK	√			
					– ♦ –		
E:SVXALM	CDF Alarm	flag	OK		0x00020000	*history*	
E:SVXWRN	CDF Warning	flag	OK		0x00020000	*history*	
E:SVXPMT	CDF Permit / Inhibit	flag	OK		0x00000000		
G:TVMNHB	CDF TevMon Heartbeat	cnts	OK		30094.000		

Used by CDF shift crew to make switch on decision – now effectively used as an 'autopilot' for shift crew, but silicon experts still present for almost every shot setup.

Current CDF Beam Abort Hardware

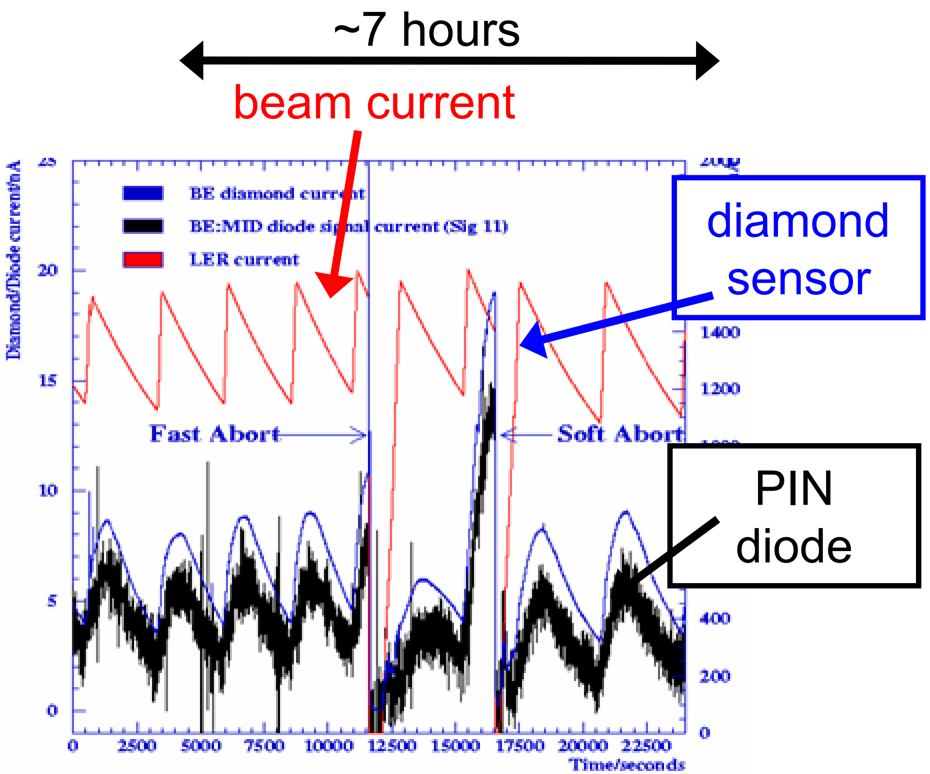


- Based on Beam Loss Monitors:
  Argon filled ionization chambers
- Output signal prop. to dose rate
  ~70nA/(1 Rad/s)
- Amplified/digitized in CAMAC in control room
- FIFO electronics with 2048 210µs bin width (10 revolutions of beam)
- Location dictated by BLM size
  |Z| = 4.3m outside Tracking
- 210 µs is too long
  most "dirty" aborts look like this.

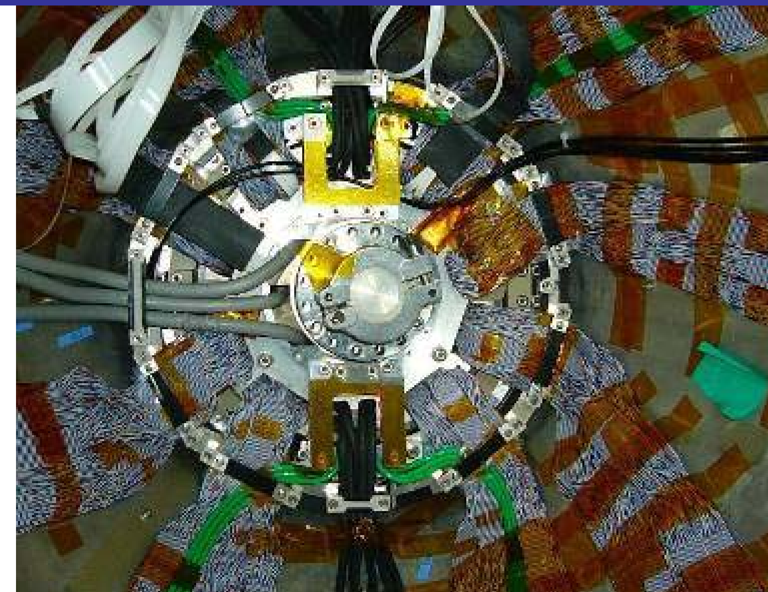
Can we anticipate beam instabilities faster?

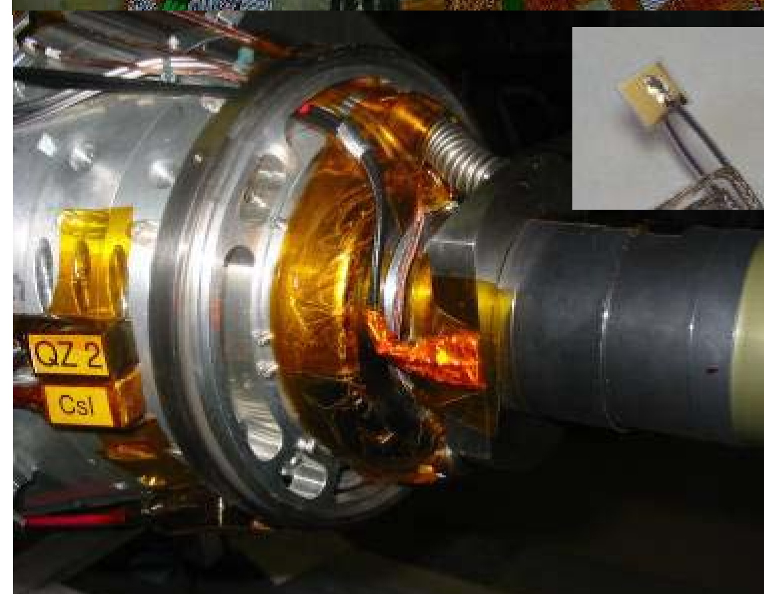
Can we get closer to the Silicon detector ?

BaBar/Belle: Radiation Monitoring with CVD Diamond



M. Bruinsma, Vertex 2004





- Small detector packages within tracking volume
- High radiation field requires high radiation hardness
- simple unamplified DC coupled sensors read out over ~40m of cable

CVD DIAMOND

II. CVD Diamond

Properties of Diamond

	Si	diamond	
Band gap [eV]	1.12	5.45	→ *Low $I_{leakage}$, shot noise*
Electron mobility [cm²/Vs]	1450	2200	→
Hole mobility [cm²/Vs]	500	1600	→ *Fast signal collection*
Saturation velocity [cm/s]	0.8×10^{7}	2×10^{7}	→
Breakdown field [V/m]	3×10^{5}	2.2×10^{7}	
Resistivity [Ω cm]	2×10^{5}	$>10^{13}$	
Dielectric constant	11.9	5.7	→ *Low capacitance, noise*
Displacement energy [eV]	13-20	43	→ *High radiation hardness*
e-h creation energy [eV]	3.6	13	→
Ave e-h pairs per MIP per μm	89	36	→ *Smaller signals*
Charge coll. dist. [μm]	full	~250	→

+ high thermal conductivity:

Room temperature operation

CERN RD42 Collaboration:
- Development of detector grade diamond
- Industrial partner: Element Six, Ltd.

CERN RD42 Collaboration

The RD42 Collaboration

M. Barbero[1], V. Bellini[2], V. Belyaev[15], E. Berdermann[8], P. Bergonzo[14], H. Bol[13], M. Bruzzi[5], V. Cindro[12], W. de Boer[13], I. Dolenc[12], P. Dong[21], W. Dulinski[10], V. Ermin[9], R. Eusebi[7], F. Fizzotti[19], H. Frais-Kölbl[4], A. Furgeri[13], K.K. Gan[17], A. Golubev[11], A. Gorisek[3], E. Griesmayer[4], E. Grigoriev[11], F. Hartjes[16], H. Kagan[17,◇], R. Kass[17], G. Kramberger[12], S. Kuleshov[11], S. Lagomkarsino[6], A. Lo Giudice[19], I. Mandic[12], C. Manfredotti[19], A. Martemyanov[11], M. Mathes[1], D. Menichelli[5], S. Miglio[5], M. Mikuz[12], M. Mishina[7], S. Mueller[13], H. Pernegger[3], M. Pomorski[8], R. Potenza[2], S. Roe[3], C. Schmidt[8], S. Schnetzer[18], T. Schreiner[4], C. Schrupp[21], S. Sciortino[6], S. Smith[17], R. Stone[18], C. Sutera[2], M. Traeger[8], W. Trischuk[20], C. Tuve[2], J. Velthuis[1], E. Vittone[19], R. Wallny[21], P. Weilhammer[3,◇], N. Wermes[1]

◇ Spokespersons

1 Universität Bonn, Bonn, Germany
2 INFN/University of Catania, Italy
3 CERN, Geneva, Switzerland
4 Fachhochschule für Wirtschaft und Technik, Wiener Neustadt, Austria
5 INFN/University of Florence, Florence, Italy
6 Department of Energetics/INFN Florence, Florence, Italy
7 FNAL, Batavia, U.S.A.
8 GSI, Darmstadt, Germany
9 Ioffe Institute, St. Petersburg, Russia
10 IPHC, Strasbourg, France
11 ITEP, Moscow, Russia
12 Josef Stephan Institute, Ljubljana, Slovenia
13 Universität Karlsruhe, Karlsruhe, Germany
14 LETI (CEA-Technologies Avancees) DEIN/SPE - CEA Saclay, Gif-Sur-Yvette, France
15 MEPHI Institute, Moscow, Russia
16 NIKHEF, Amsterdam, Netherlands
17 The Ohio State University, Columbus, OH, U.S.A.
18 Rutgers University, Piscataway, NJ, U.S.A.
19 Univerity of Torino, Italy
20 University of Toronto, Toronto, ON, Canada
21 UCLA, Los Angeles, CA, USA

58 Participants

21 Institutes

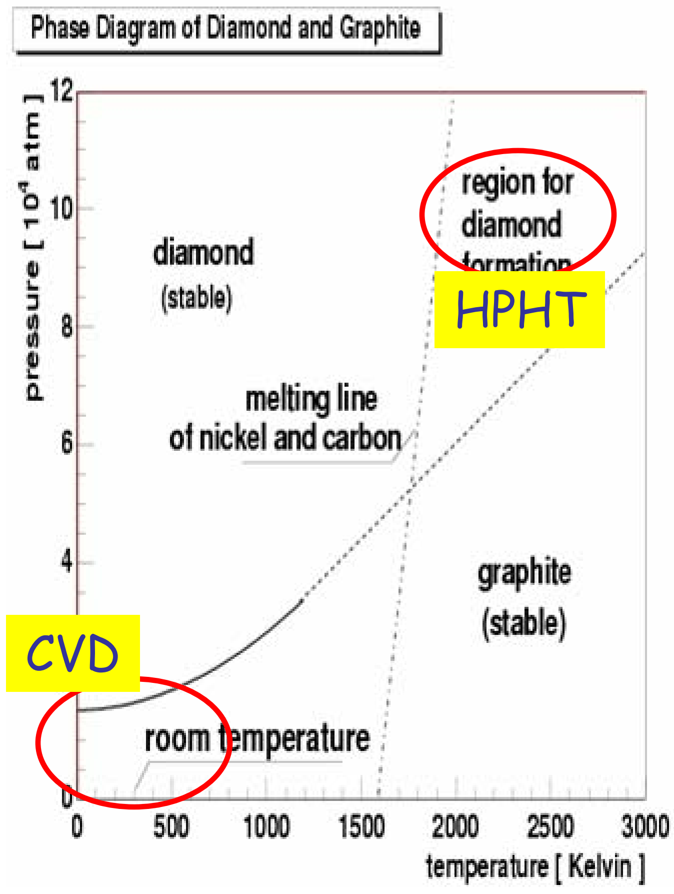
Spokespeople: Harris Kagan (Ohio State University)
Peter Weilhammer (CERN)

FNAL Participants: Ricardo Eusebi, Masa Mishina

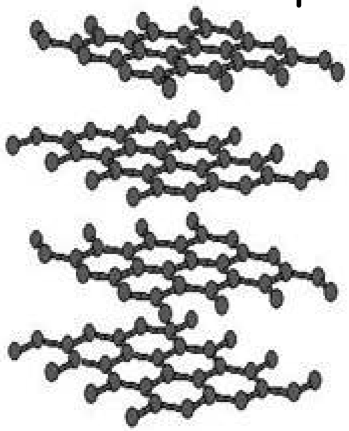
Diamond Detector R&D over ~15 years

CVD: Chemical Vapor Deposition

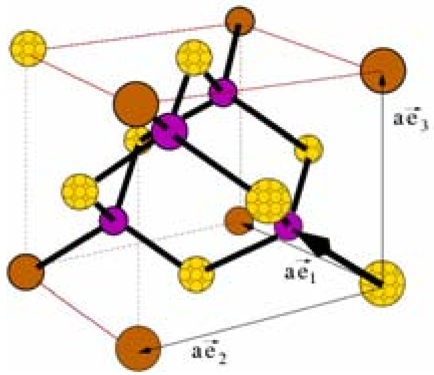
High Pressure High Temperature (HPHT) Process causes high impurity concentration



$C=1s^2 2s^2 2p^2$



$C=1s^2 2s^1 2p^3$



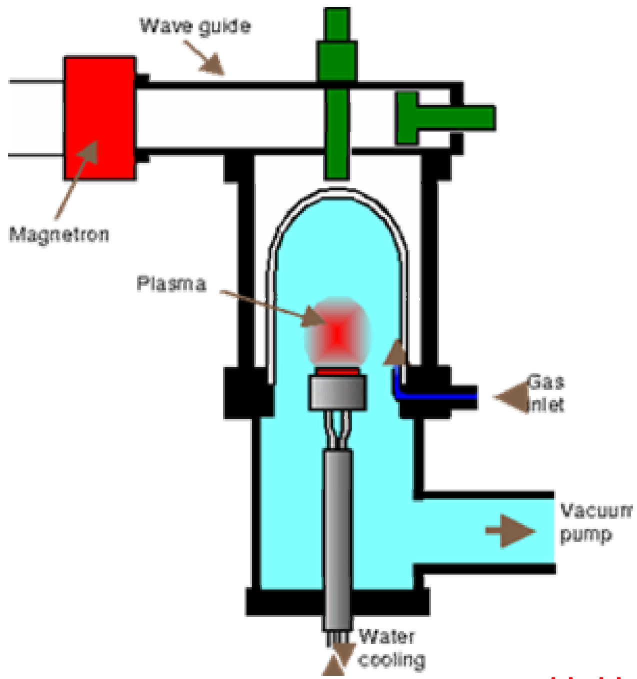
•At 298 K and 1 atm pressure graphite configuration is stable and diamond configuration is meta-stable:

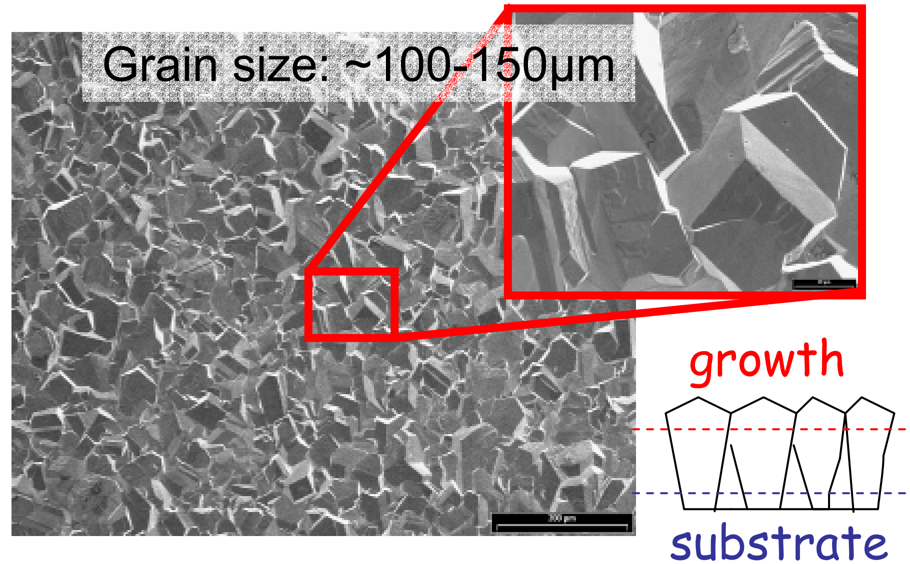
need 0.03 eV/atom but large activation energy barrier

- CVD: C-H bond less tight than H-H bond. atomic hydrogen and radicals edge away C-H layer on surface: exothermic process.
- sp^3-bonds are more energetically favorable than sp^2-bonds.

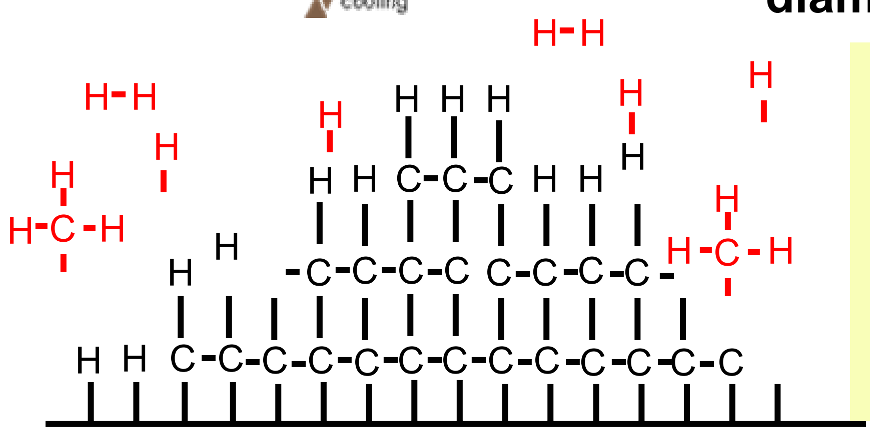
=> Vacant surface site will prefer diamond lattice over graphite lattice

CVD Diamond Production





columnar structure of **polycrystalline CVD diamond** (SEM picture M.Bruzzi)



- Columnar growth of diamond crystal
- Si or diamond substrate
- Growth speed ~ 1 μm/hour
- Grains grow wider from substrate side

-recently: **single crystal diamond**

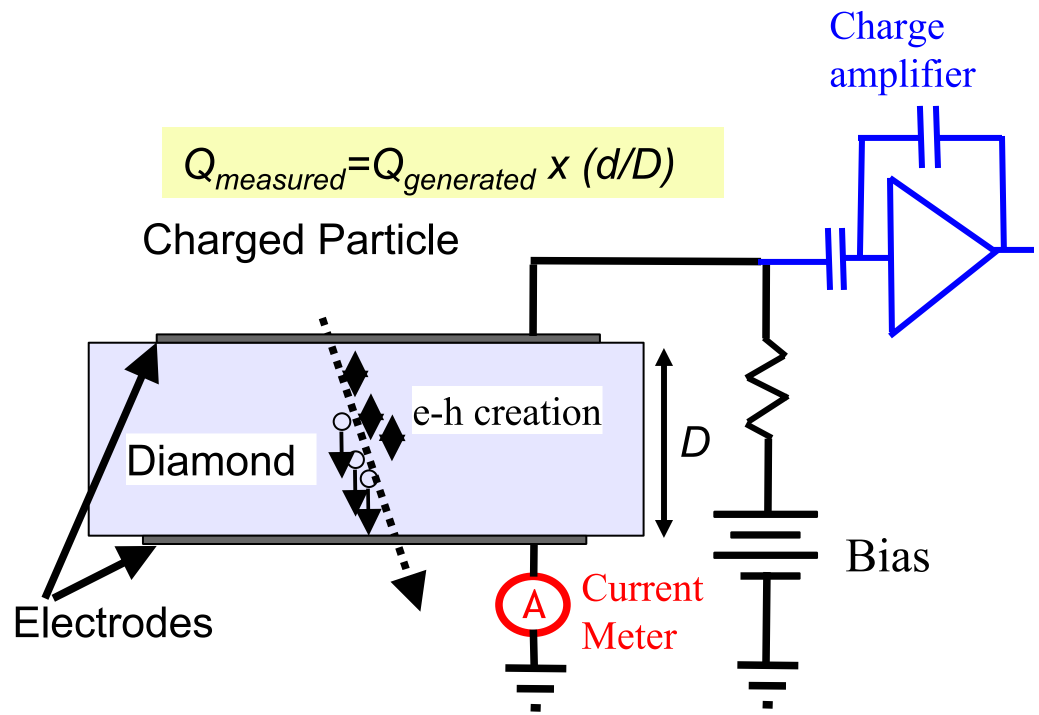
Diamond Particle Detectors

Operation of diamond detector:

- Bias voltage applied across diamond
  - ~500V for 500µm thick detector (1 V/µm)
  - both polarities possible
- Particle generate e-h pairs
- e-h pairs drift apart in E-field to electrodes
- AC-coupled particle detector:
  - detect charge pulses
  - fast, low noise detection
- DC-coupled radiation sensor:
  - measure induced current
  - ~pA leakage current

=> Solid State Ionization Chamber

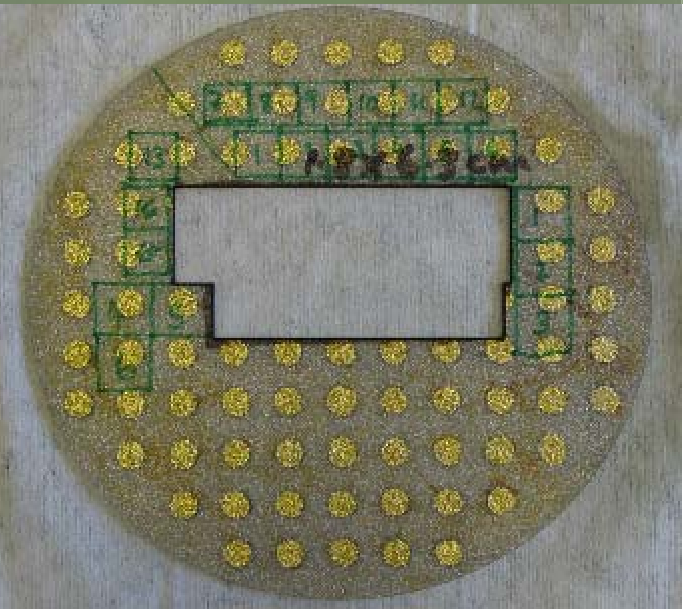
$Q_{measured}=Q_{generated}$ x (d/D)



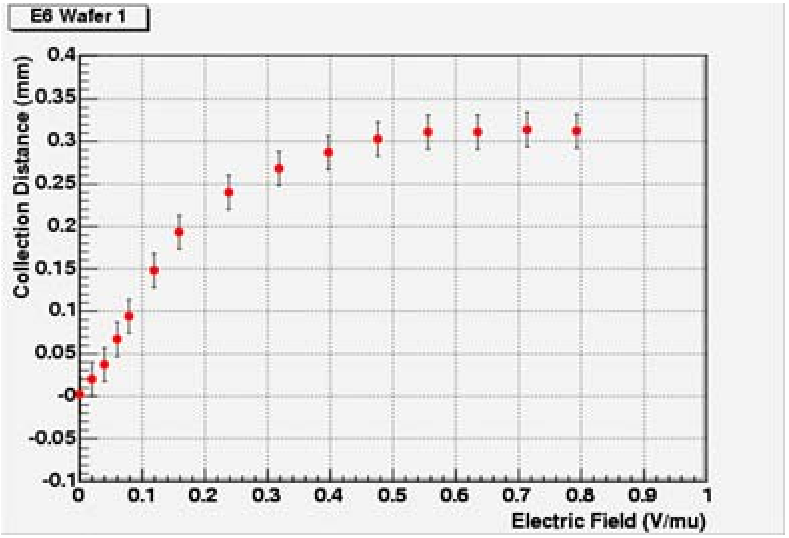
Charge collection in diamond:

- Signal is limited by impurities and grain boundaries
- Increases with electric field up to ~1 V/µm (pCVD diamonds)
- Current pCVD diamonds have charge collection distance d ~200-250 µm

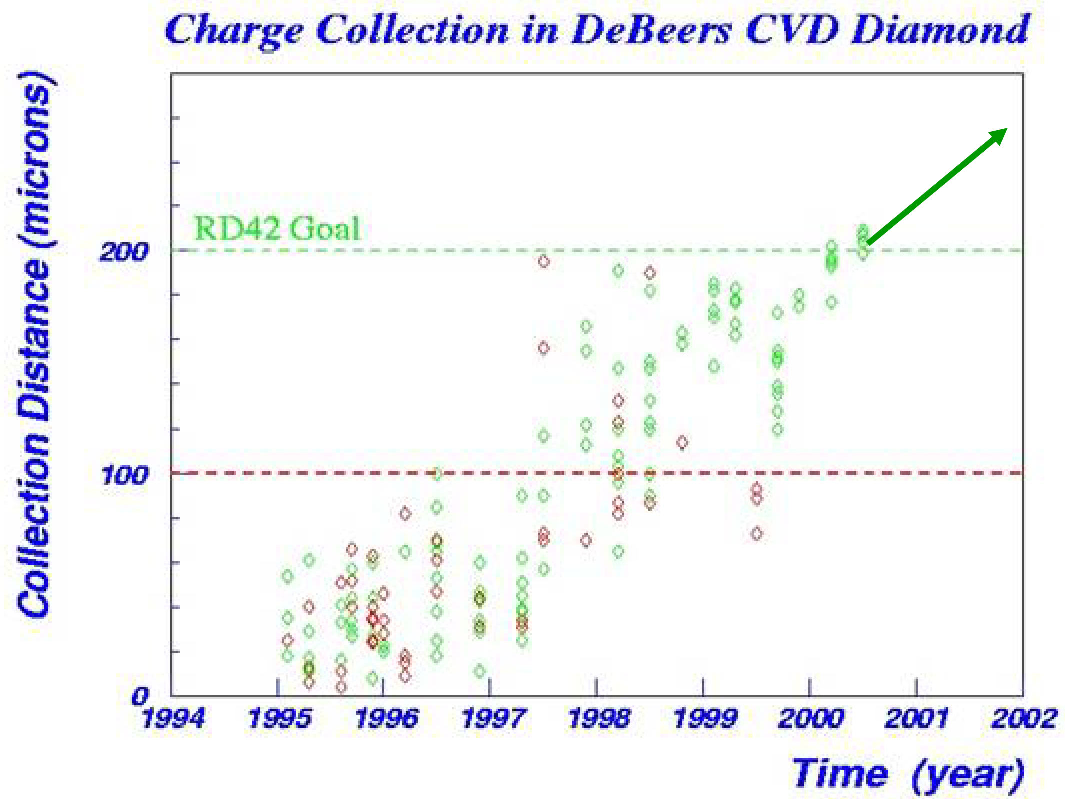
Polycrystalline CVD diamond



- detector grade pCVD wafers now routinely grown >12cm diameter and ~2mm thickness
- finite charge collection distance (CCD)
  - charge trapping (grain boundaries, impurities …)
  - measure CCD = thickness * $Q_{measured}/Q_{induced}$
- typical CCD 250μm (edge) to 310μm (center)
  - RD42 goal was 200 μm
- CCD saturates at around 1 V/μm
  - Typically 9800 e-h pairs in 500 μm sensor



Charge Collection Distance



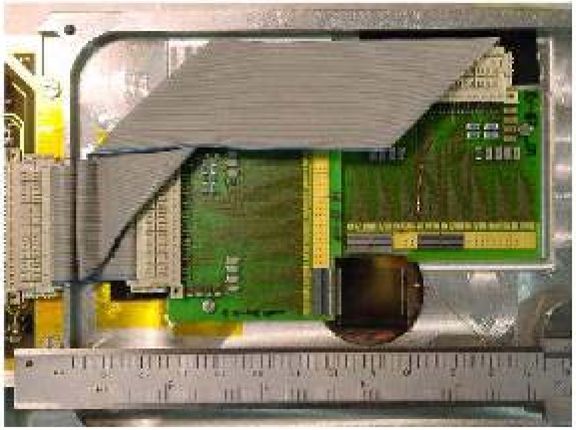
Considerable improvements in pcCVD fabrication:

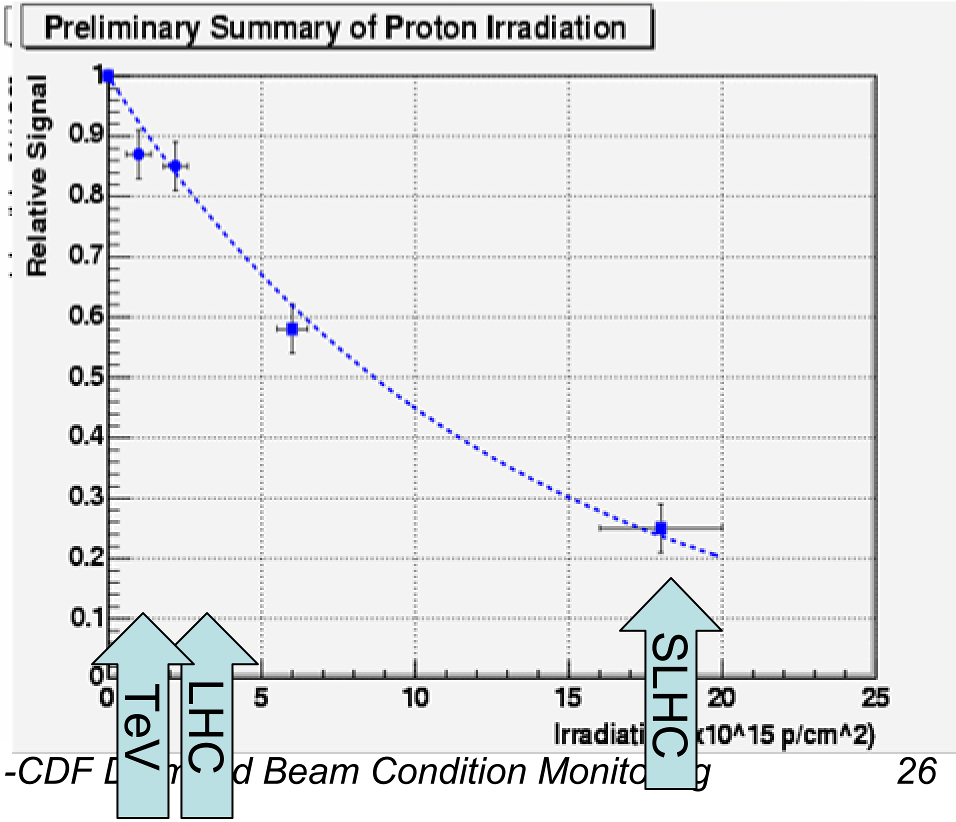
Present samples reaching charge collection distances of 350 μm

Charge collection distance of ~400μm possible in the near future

Radiation Hardness of pCVD diamond

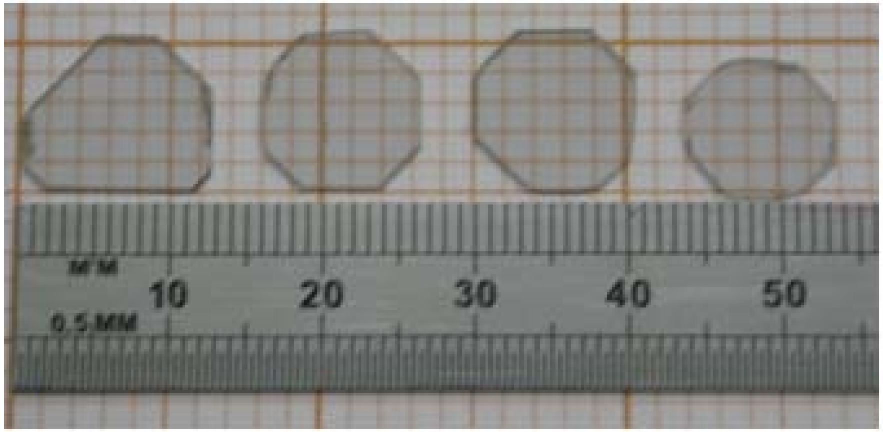
- pCVD detectors have been built as pixel, pad, strip detectors
  - Use strip detectors for irradiation tests
    - Charge and position
- Proton irradiation:
  - Observed 15% loss of S/N at $2.2 \times 10^{15}/cm^2$
- Leakage current (~ pA) decreases with fluence
- Resolution is found to improve 35% at $2.2 \times 10^{15}/cm^2$
  - Irradiated material appears to be more 'uniform'
- Recent proton irradiations:
  - Still 25% of the signal (~2500 e-h) after $1.8 \times 10^{16}/cm^2$ (500 Mrad)
    CDF: 4 MRad/9 fb^{-1} @ 3 cm (R.Tesarek)
  - Low noise performance still affords S/N >10

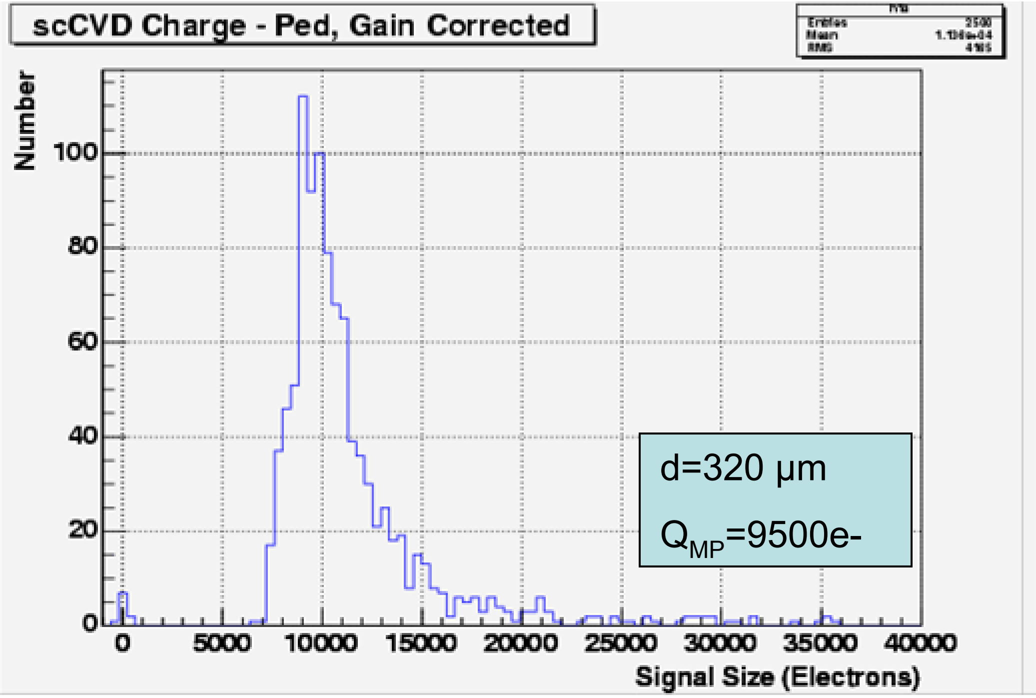




Single Crystal CVD Diamond

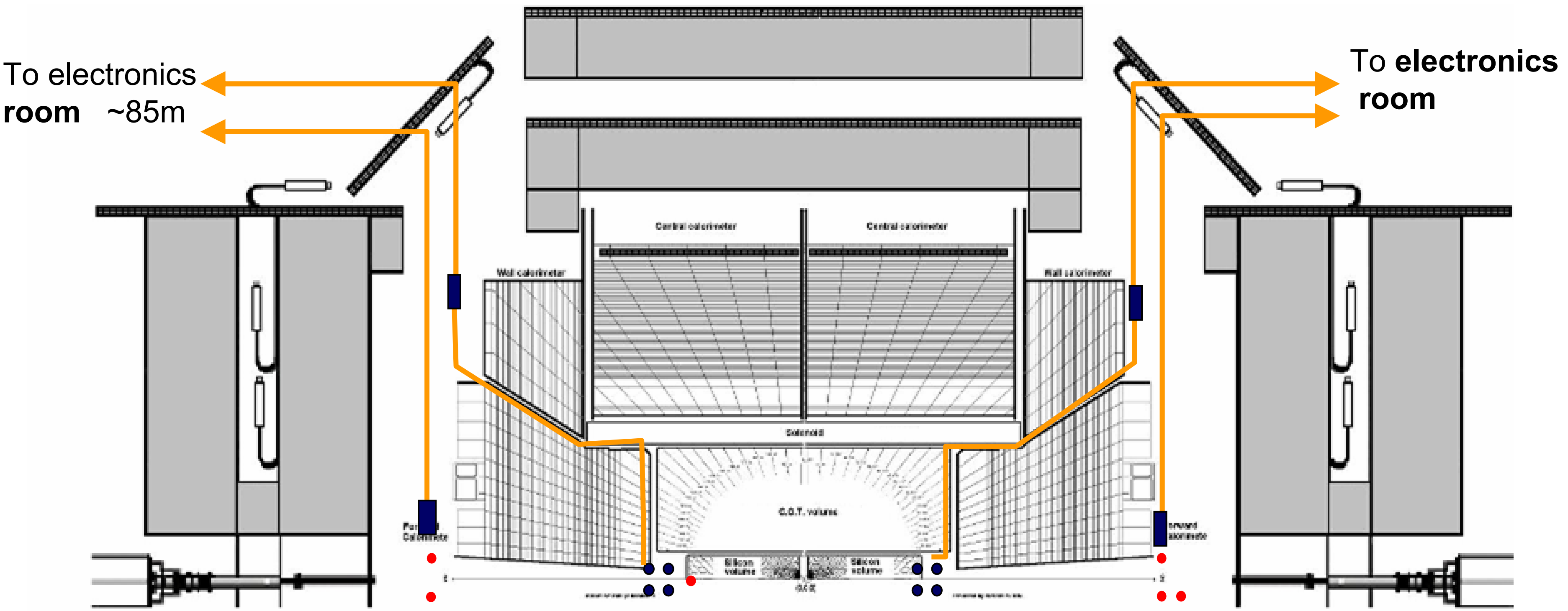
- Development of this material in collaboration with Element Six, Ltd
- scCVD diamond has been grown to 10mm x 10 mm with >1mm thickness
- Largest grown scCVD diamond is 14 mm x 14 mm
- scCVD diamond collects full charge
  - Tested up to ~ 1mm thickness
- Full charge collection at E=0.2V/µm!
- Signal and Noise well separated
  - FWHM/MP ~ 0.3-0.5 - 1/3 of pCVD, 1/2 of silicon
  - Lower cutoff at 75% of MP signal
- Radiation hardness still to be fully understood





II. Diamonds at CDF

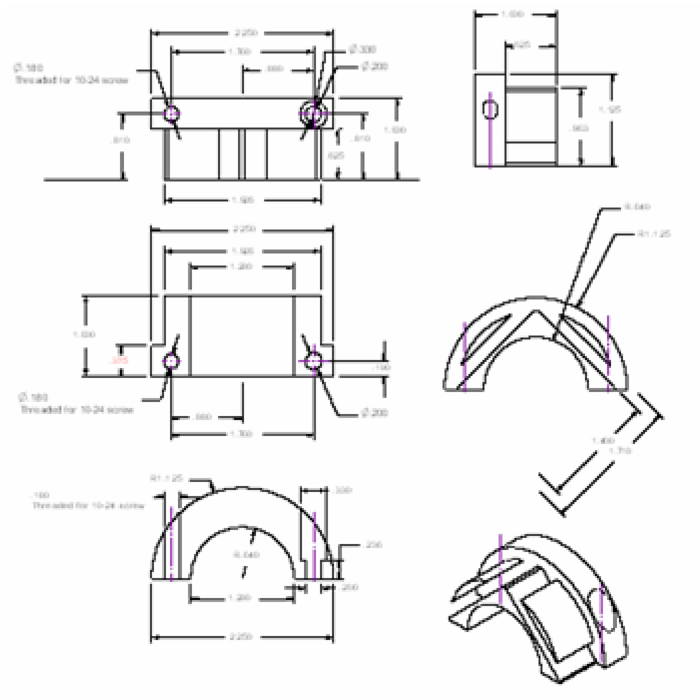
Diamonds in CDF

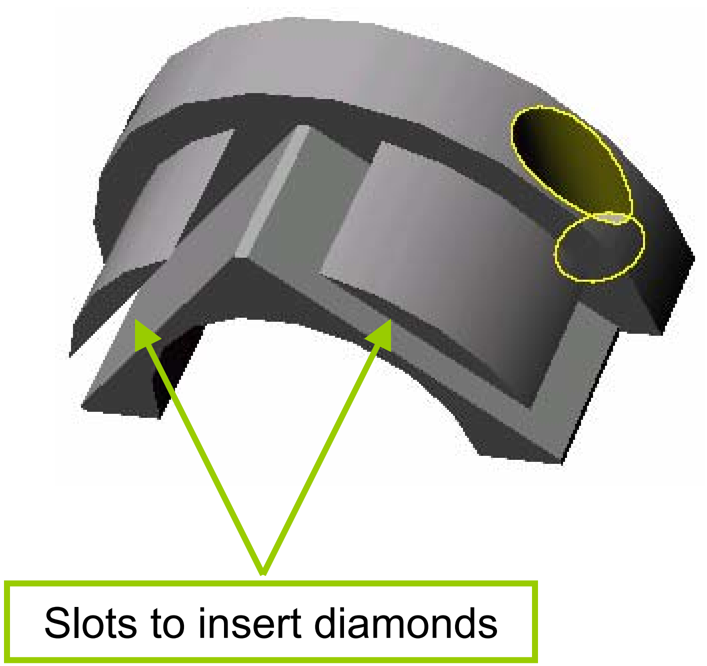


Since Fall 2004:	➢ prototype pCVD diamond
Since Spring 2006:	➢ 8 pCVD diamonds in E and W Inside Tracking Stations (Mag. Field 1.4T) r = 2cm from beamline, at |z| = 1.8m ➢ 5 diamonds (2 CDF pCVD, 1 CMS pCVD, 2 CMS scCVD) outside tracking. Calibration region near BLMs r = 10.7cm, z = 4.3m ➢ Plan to install 4 more close to limiting beamline apertures

Diamond Detector Support Structure

- The support structure holds the diamonds in place around the beam pipe.
- Designed to be **very light**
  - Used results of 1999 Finite Element Analysis of strain on beampipe
- Made in High Density Polyethlene, two halves needed in each side.
- The prototype fully populated with cables and diamonds weights **80 grams**.
- Mock-Up ‘Training’ in B0
- Accelerator Division and CDF Operations Review on March 14th, 2006





Getting close is not easy ….

Outer ring

Film of Polyethylene, aka "Silicon baggy"

Protection of the beam-pipe added during work at bore.

Plastic flange

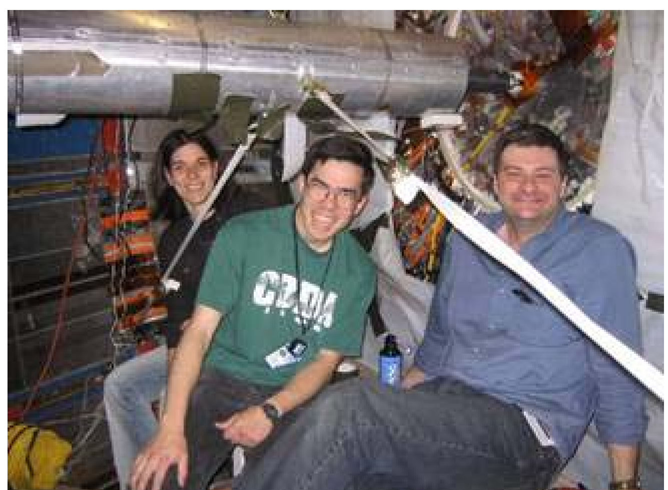
Since the silicon is not to be warmed, the plastic baggie is not to be opened. There are ways to open the baggie, but are complicated and risky.

Diamond Installation

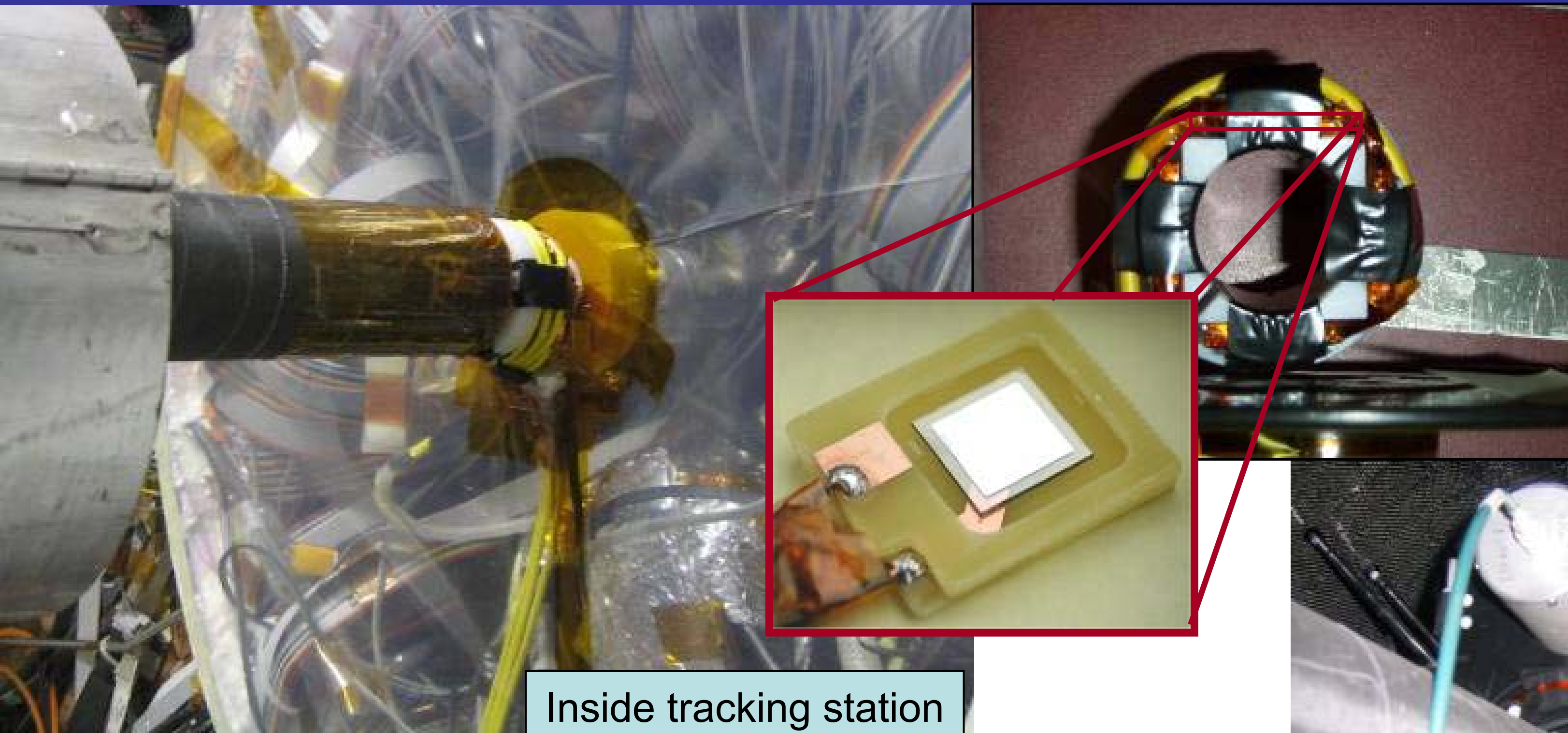
West side

East side

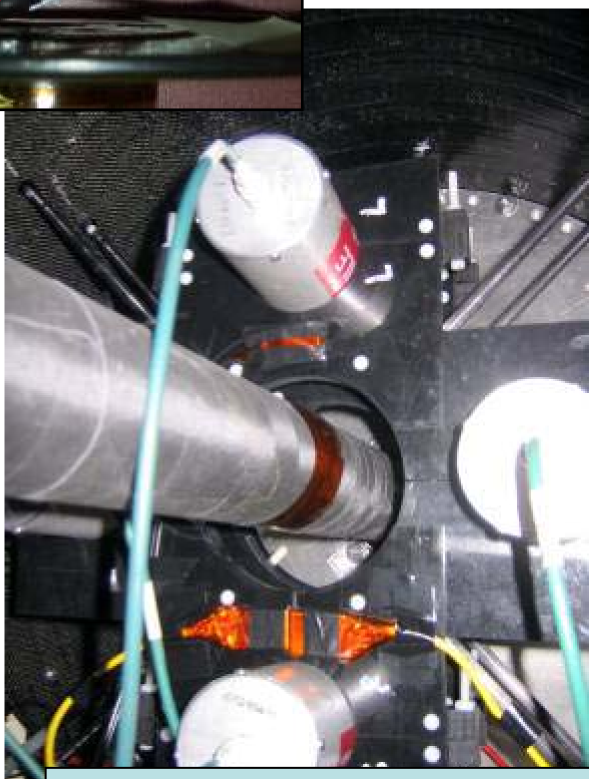
The installation crew



Diamond Installation in CDF

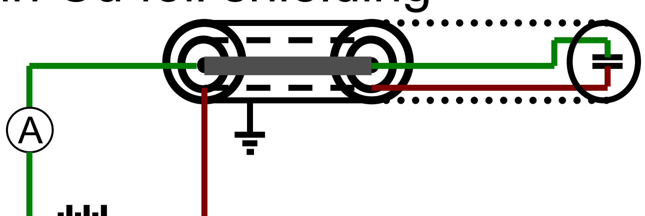


Inside tracking station



Outside calibration stations

- ATLAS style sensor 1cm x 1cm, Al based metalization (from RD42/Ohio State University)
- G10 package, wrapped in Cu foil shielding
- Triax cable DC readout (85m to counting room)

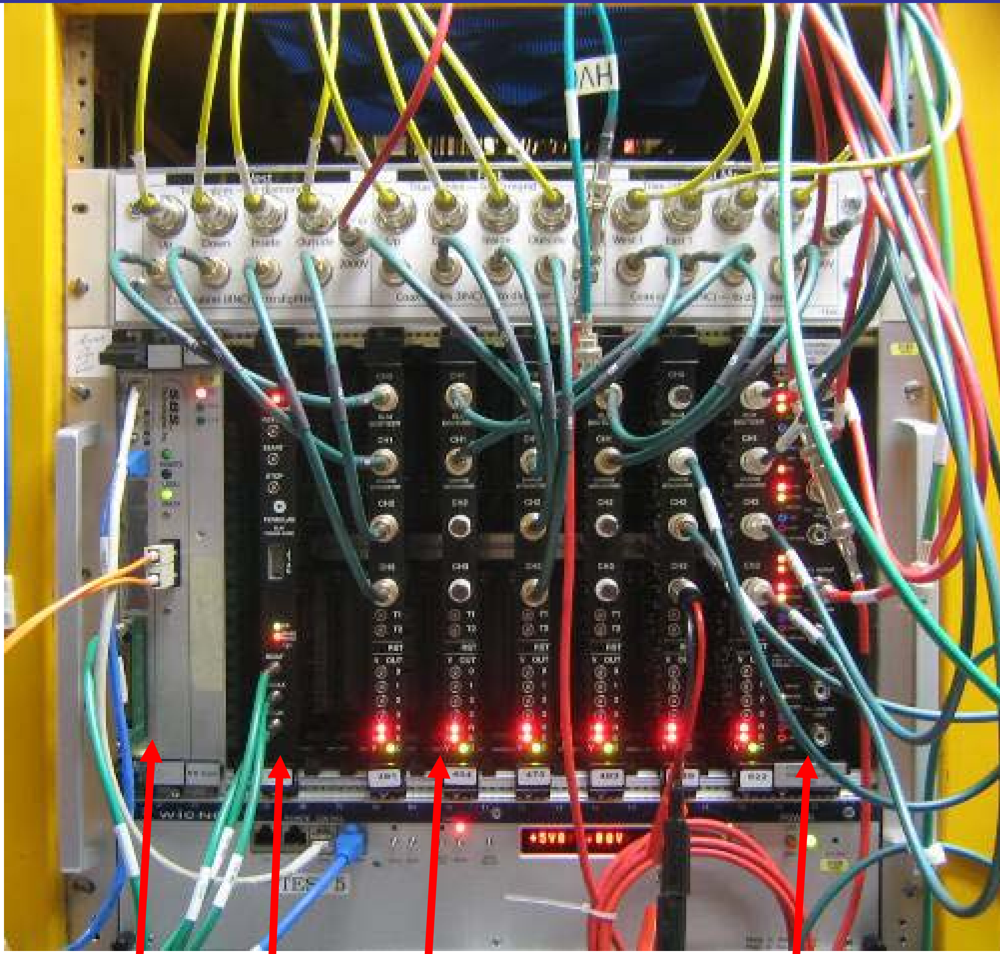


Readout Electronics

- Data acquisition system based on Tevatron BLM upgrade electronics

- Dual ping pong current integrator
  12μs – 1.4s time granularity
  -16 bits digitization
  - 4 32-bit sliding sums in parallel
  - 4 thresholds selectable over (~20 μs … few s) sums

- Memory:
  - 1.4 seconds of 20μs data (64K)
  - 16 seconds of 1ms data (16K)
  - 200 seconds of 50ms data (4K)



FE CPU

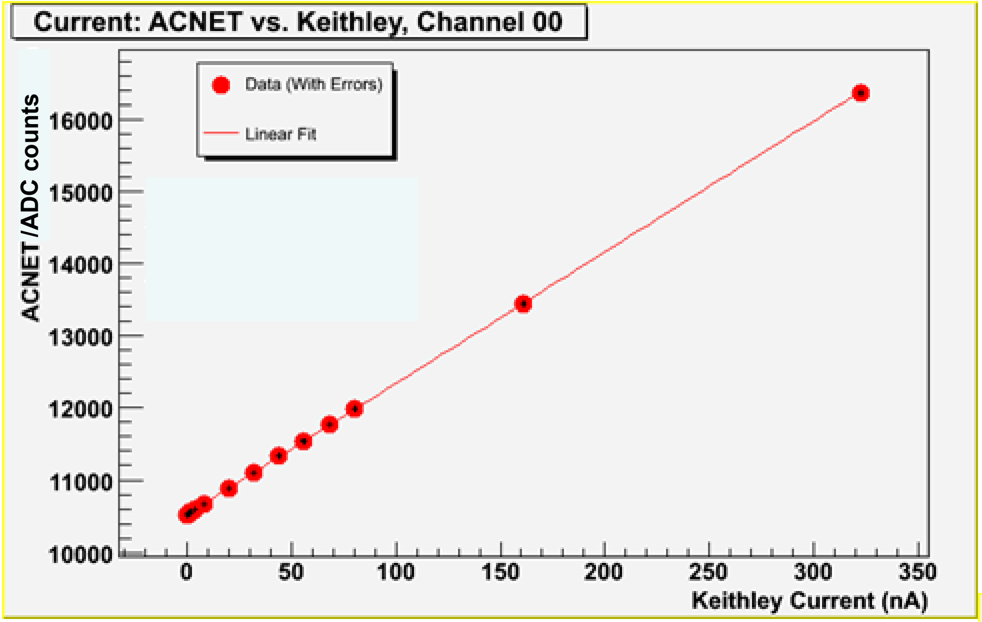
Timing Card

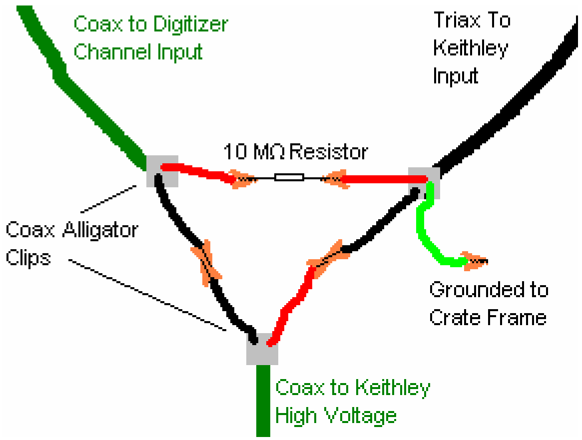
Digitizer cards

HV card (4 ch)

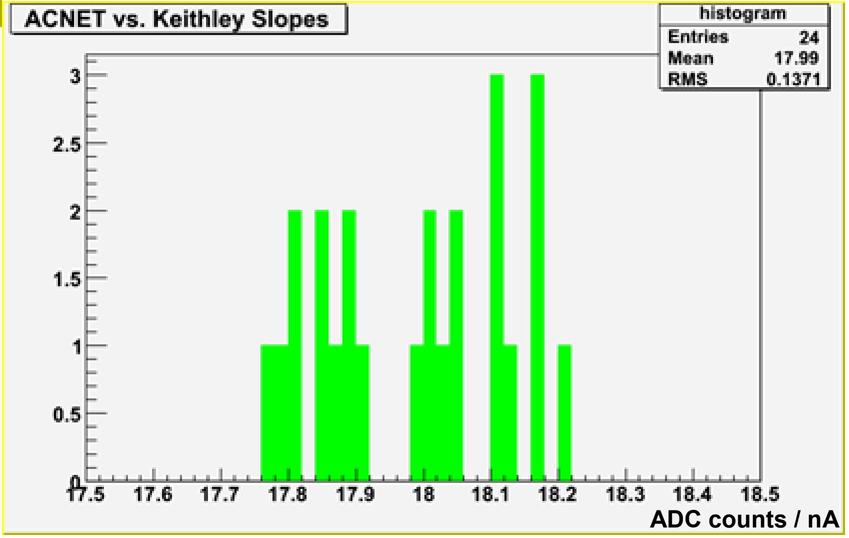
FNAL PPD Electrical Engineering Dept.

Electronics Calibration

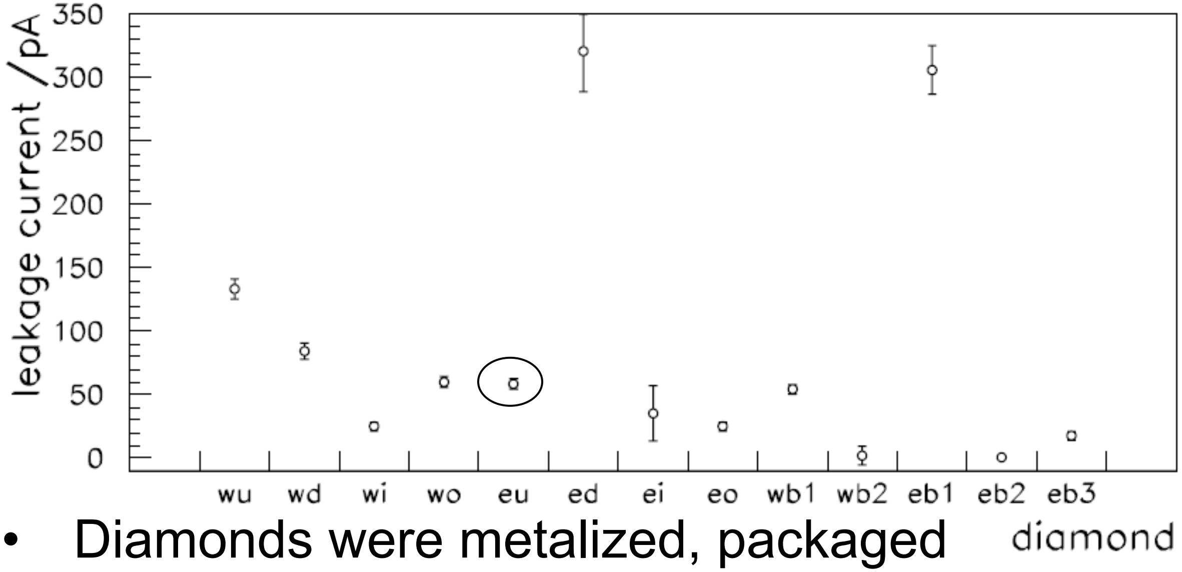


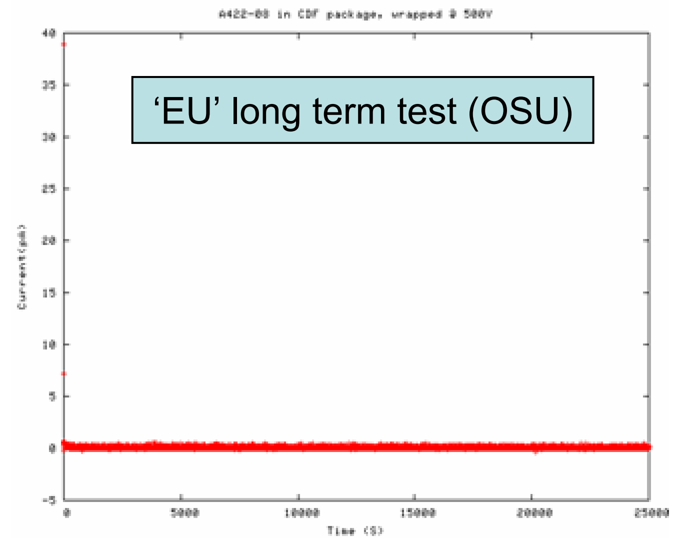


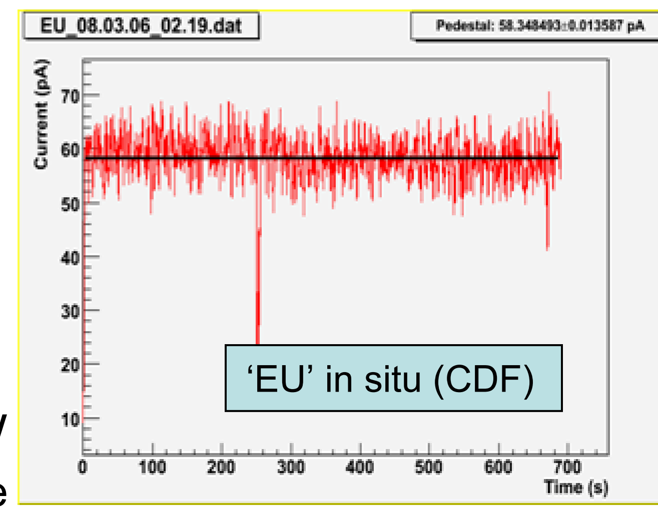
- We calibrated electronics using a precision current source and electrometer (Keithley 6517A)
- Determined electronic pedestals and gain to map ADC counts in nA
- Electronics gain is the same as for the BLMs
  - Direct comparisons possible



Diamond Leakage Currents

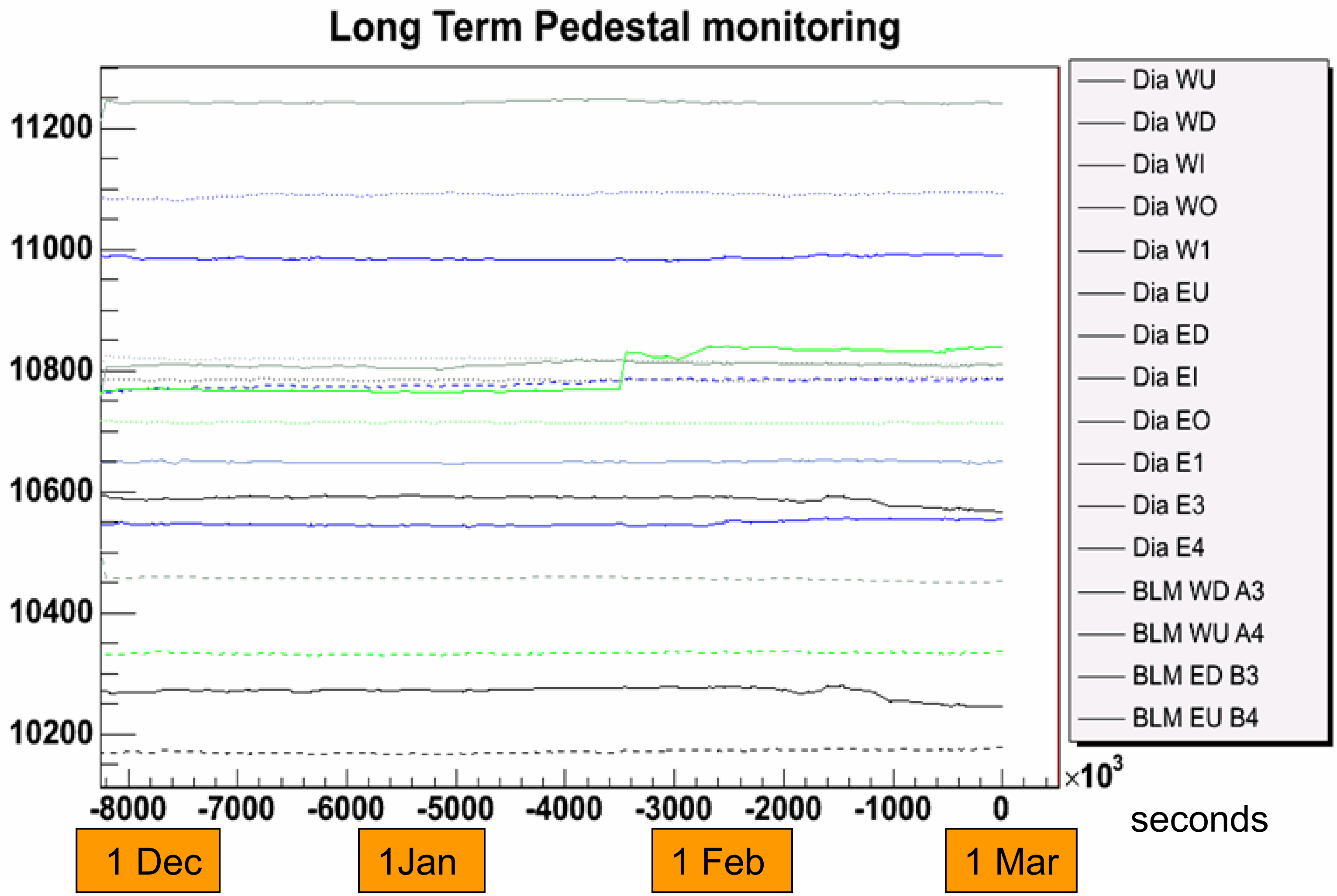






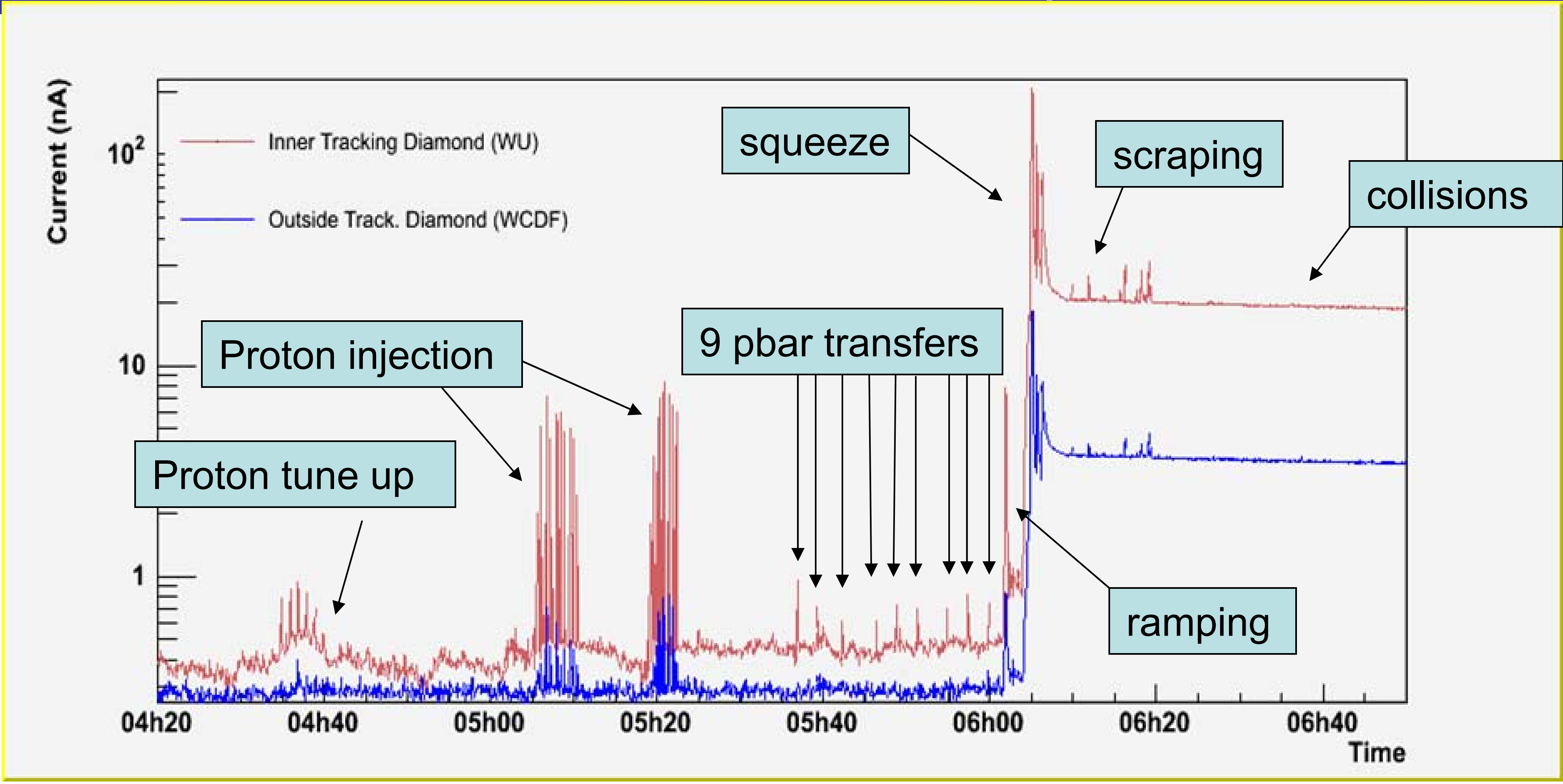
- Diamonds were metalized, packaged and tested at OSU
  - piggy-backed on ATLAS BCM production
  - CCD > 230μm, 250 μm typical
  - Leakage current measurements >10 hrs
  - All detectors < 10 pA
- After installation and first irradiation, all detectors work, leakage currents are stable and noise is low
  - Leakage current 10-150 pA, two ~ 300 pA over 50m cable
  - RMS fluctuation a few pA in most cases!
  - Innermost diamonds have seen >700 kRad up to now

Long Term Pedestal Stability



Determined from regular 'end of store' buffer readings

Diamond Beam Condition Monitoring: A Tevatron Shot Setup



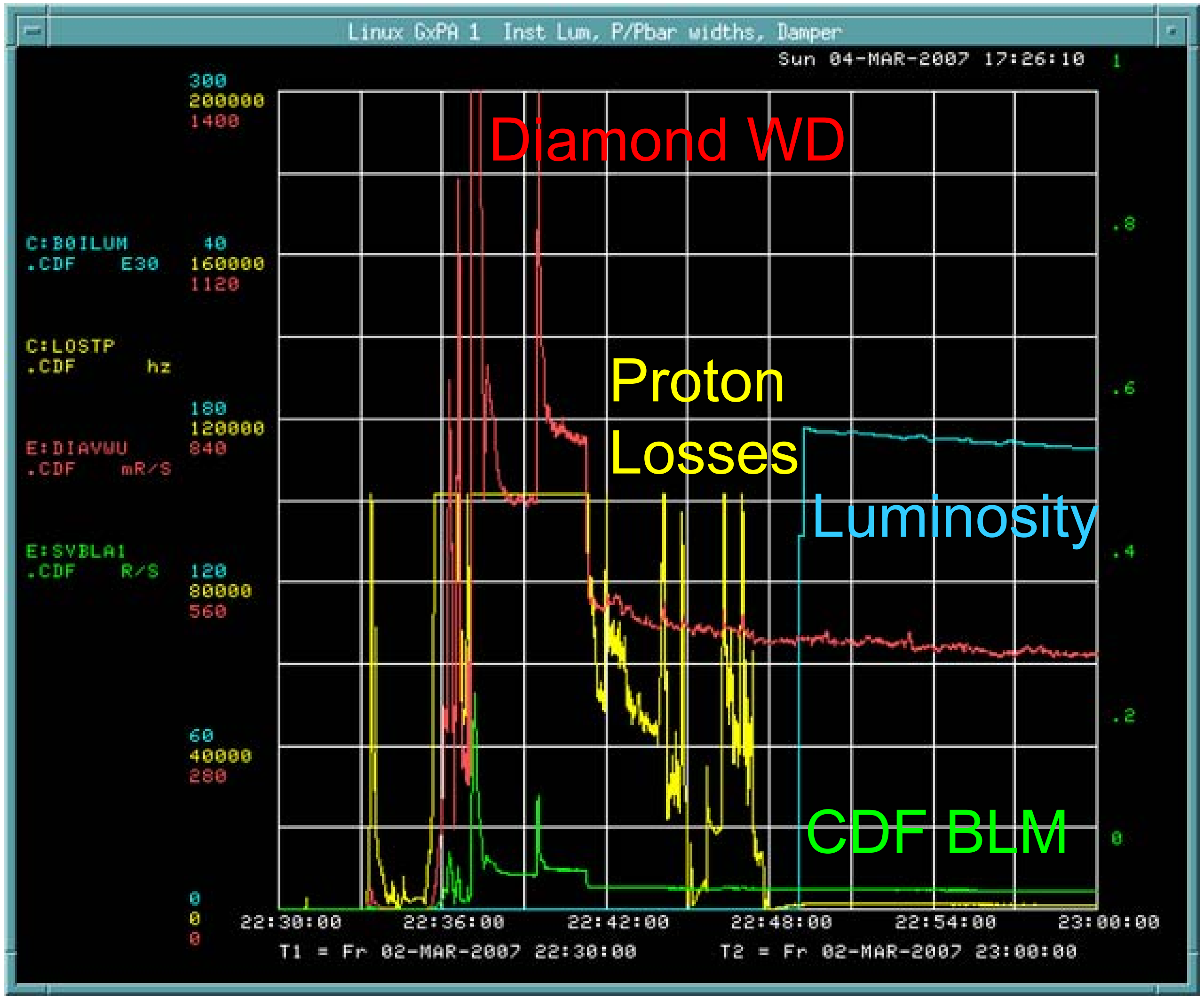
Comparison of inside and outside tracking diamonds during shot setup

- using final Tevatron BLM electronics (averaged 20µs buffer, non-ACNET readout)

Online ACNET Display

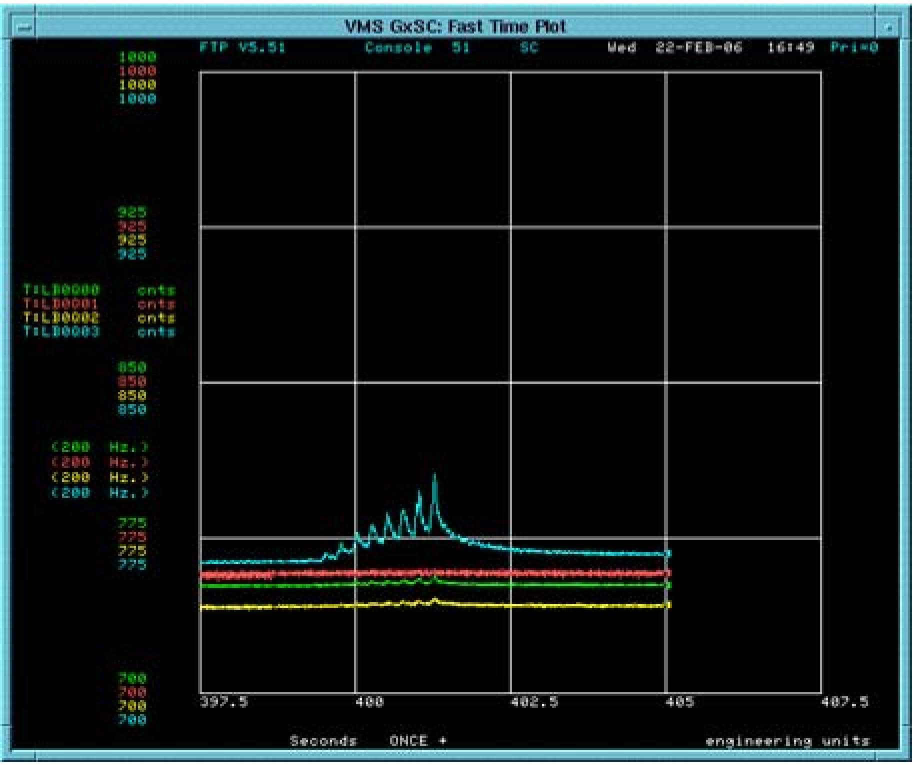
Store #5259

- Datalogger (E44) limited to 1 Hz
- Fast Time Plots (E11) with a few Hz

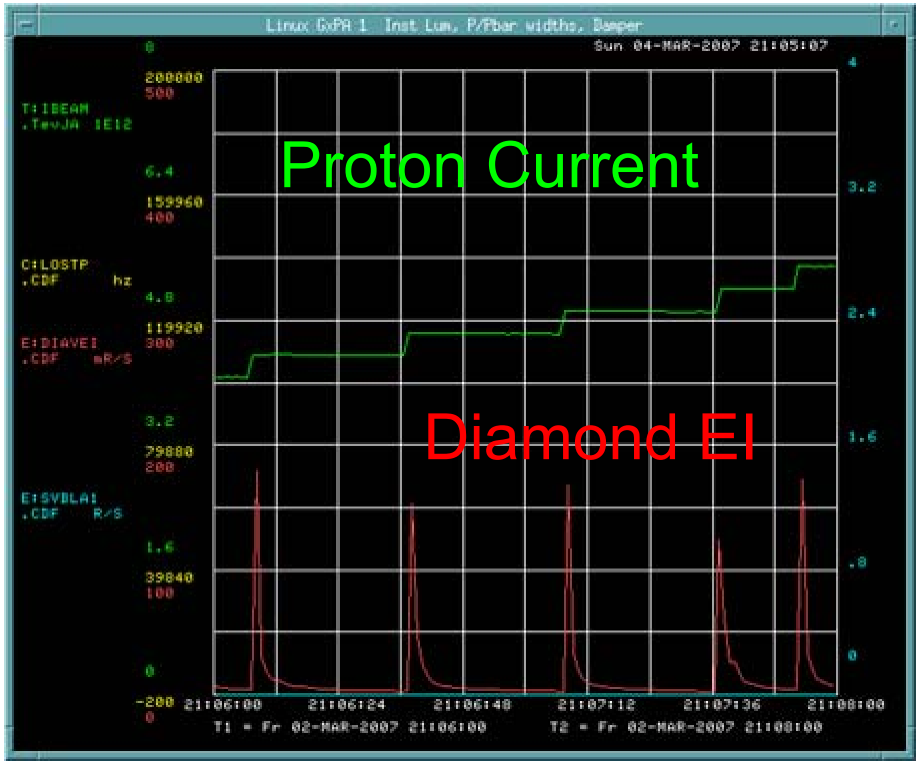


Online ACNET Display (con't)

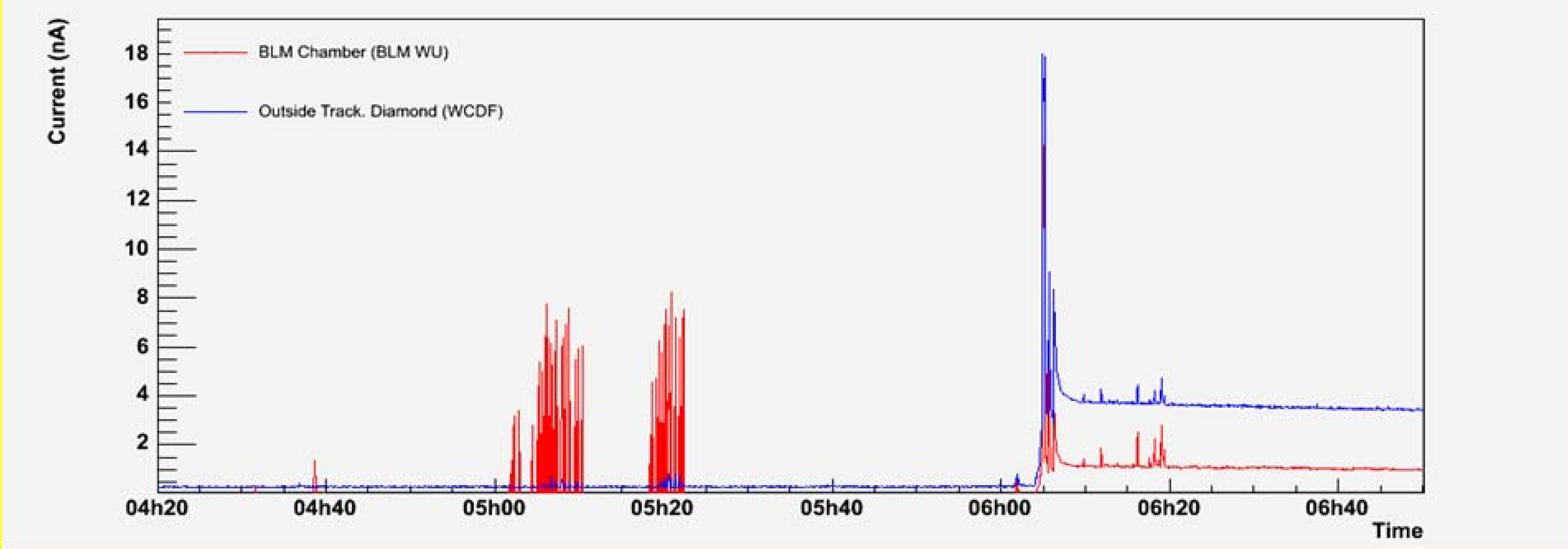
Online display of diamond currents during collimator movements



Data Logger Picture of Proton Injection

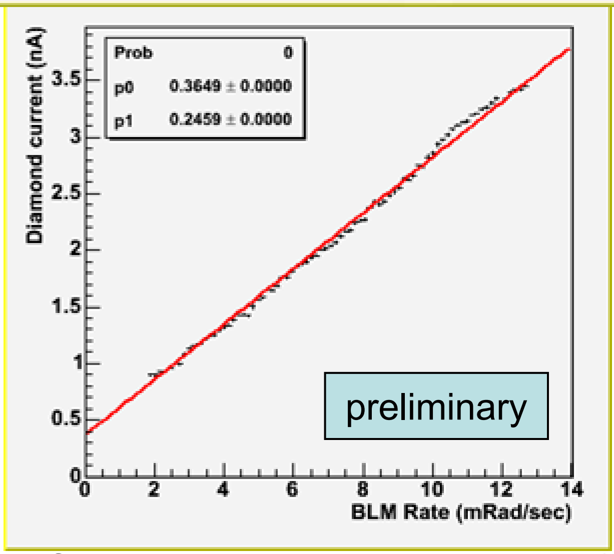


Comparison/Calibration Diamonds vs. BLM



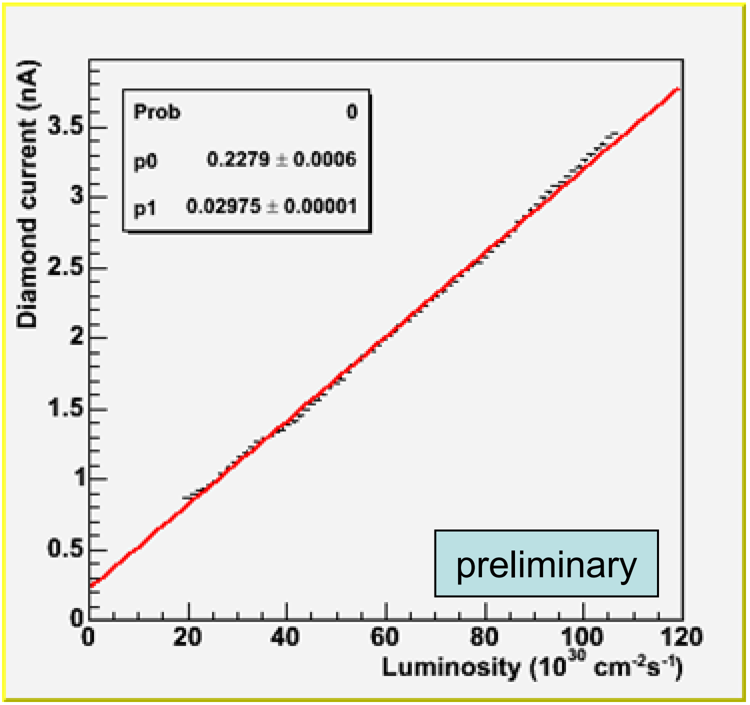
Calibration Diamonds and BLMs nicely correlated:

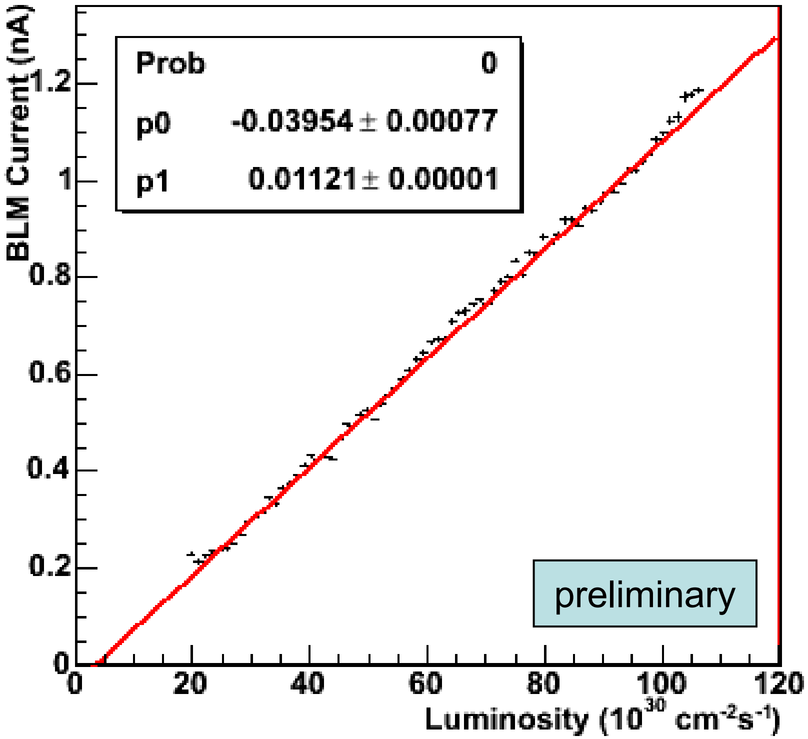
- approx 0.25 nA/mRad/s



Correlation with Luminosity

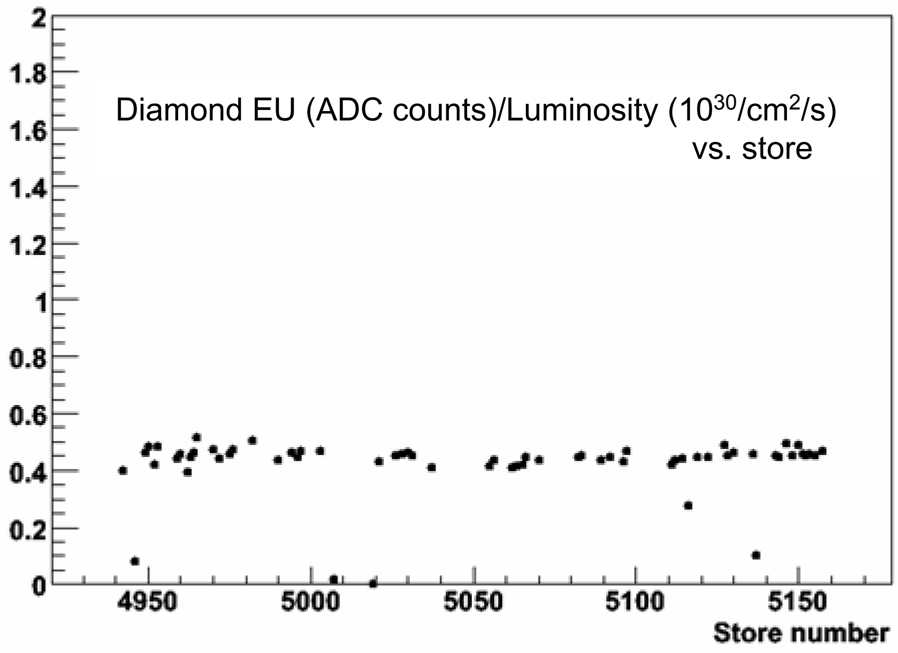
- Calibration diamonds and BLMs are in collision rate dominated locations
  - Currents should be correlated with online luminosity

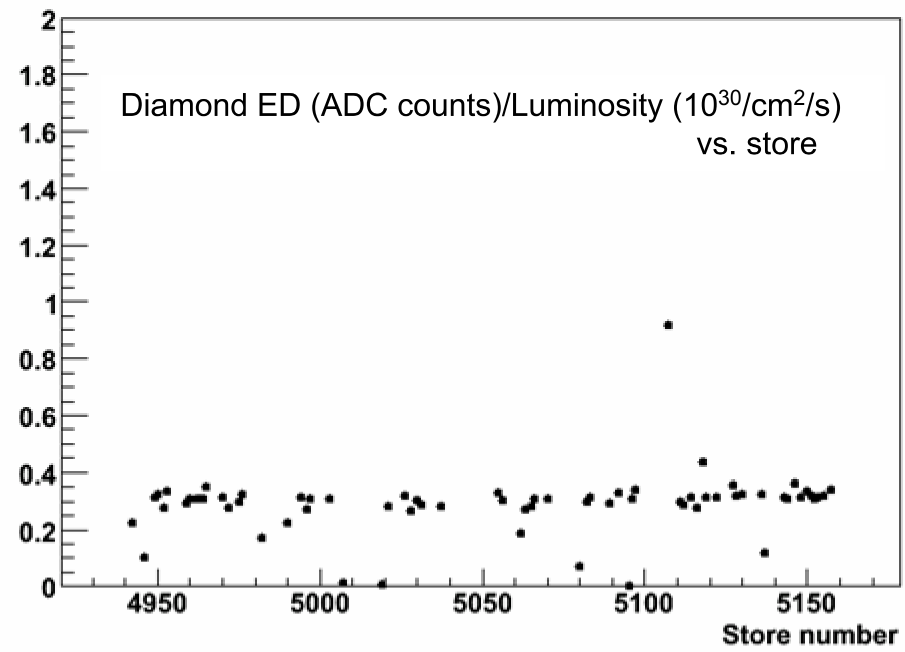




  - Observe higher signal in diamonds than BLMs for given luminosity

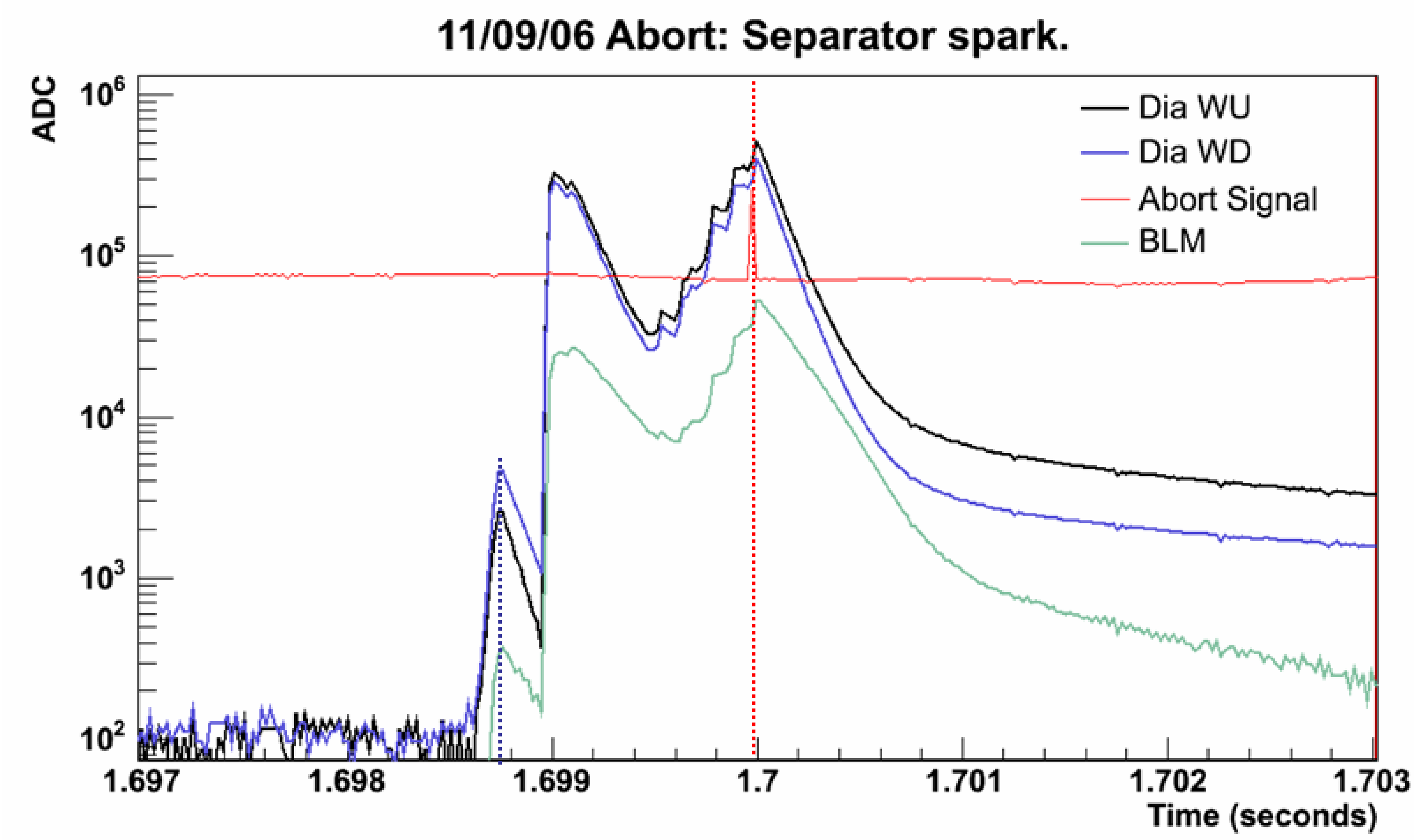
Long-Term Stability





System running with little interference since ~ mid-September
Test abort thresholds implemented since end of January

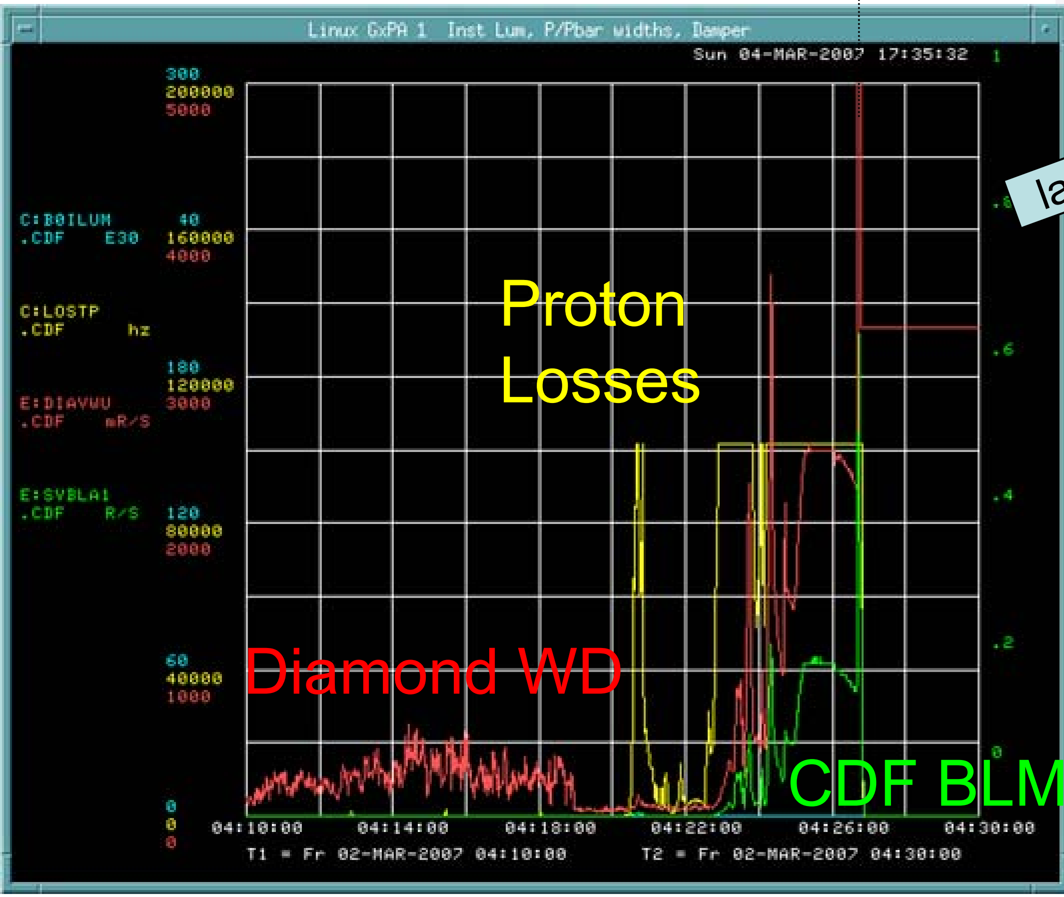
Separator Spark 11/09/06

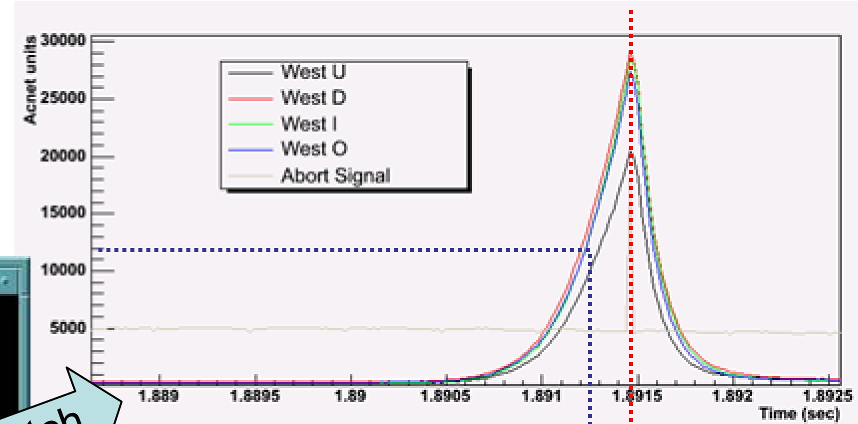


Resolving time structure of the spark(s).

Recent Stores

Store #5257





=> Δt ~500 μs

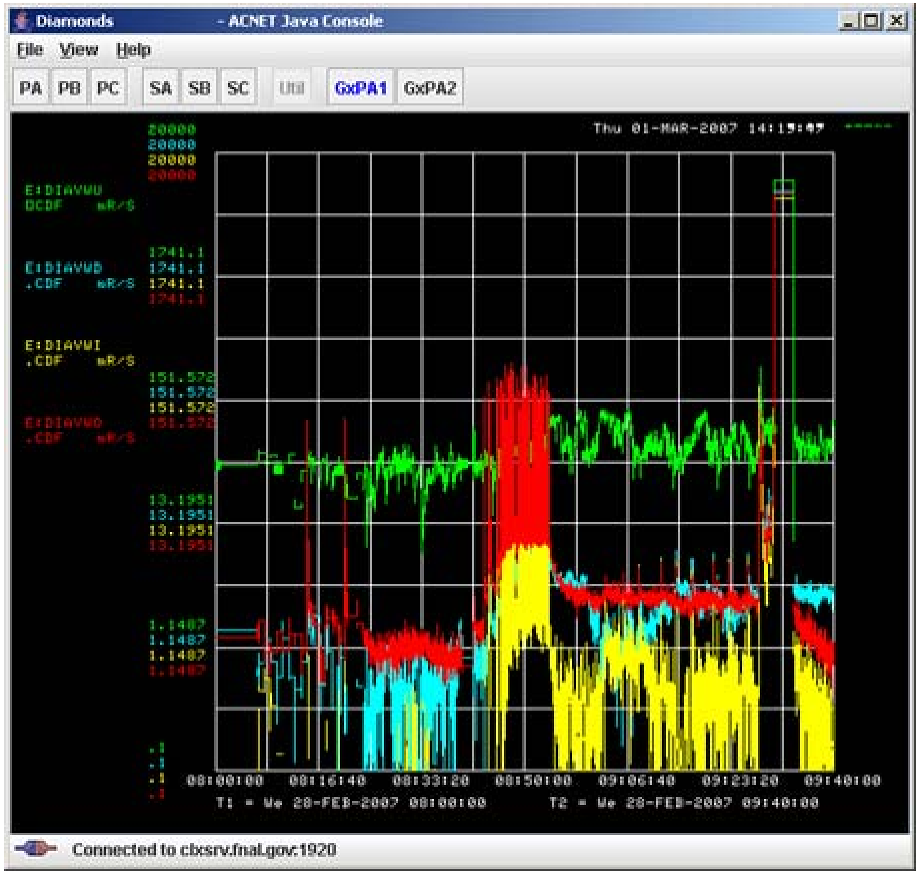
Integrated Dose Radiation Alarm on beginning of store 5257 during scrape with subsequent quench of B0 low beta

AD Run Coordinator –Elog:

"The tunes for failed Store 5257 appear to have landed in a bad place, resulting in quenches at BA, BB, and B26L."

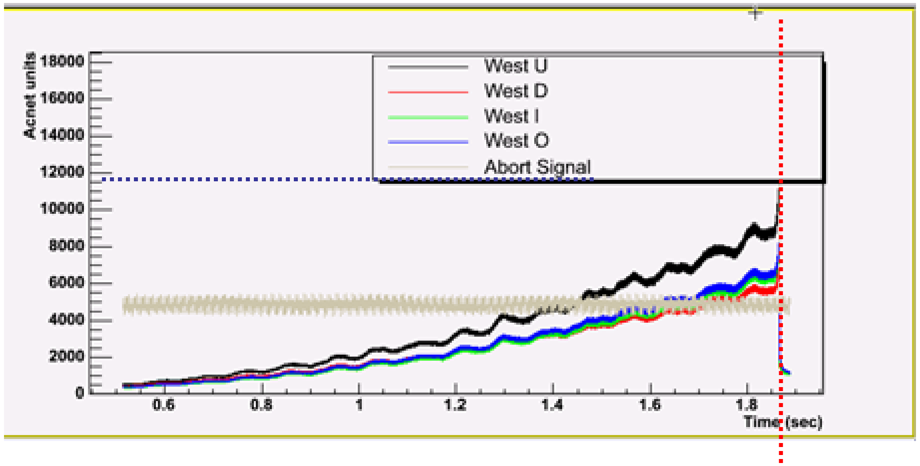
Recent Stores (con't)

Store #5247



AD Run Coordinator –Elog:

"During the 9am meeting, we were in shot setup from a record ~450e10 stash. We quenched the Tevatron during step 9 of the squeeze, when QDD1 did not follow its reference. Experts speculate that the 467 card that was replaced on the owl shift was bad. Upon closer inspection, I see that the supply also did not follow its reference during our squeeze before the shot. The alarm posted briefly during the squeeze, but since our C23 compare does not look at every slot of the squeeze, the difference was missed. "



TeV Abort Signal

The Plan: Four Steps

1. Perform several studies:
   A. Determine the optimal thresholds for all Tevatron machine states.
   B. Show that these thresholds do not produce spurious aborts.
   C. Determine what to do with solenoid trips and other accidents
      - Veto on solenoid trips ?
      - Lowering of the bias ?
   D. Study the long term behavior and stability of the sensors and electronics

2. Once this is defined ask for a review and permission by AD Division and CDF Operations

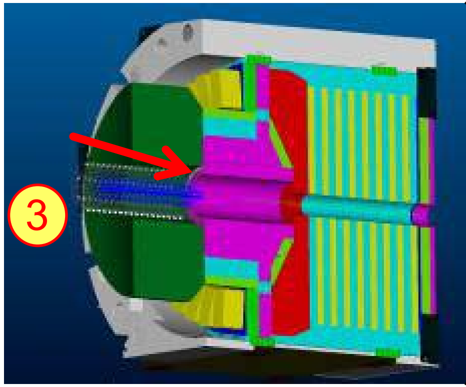
3. Move the electronics to CDF Control Room.
   A. Must be placed in Tev racks and should run on Tev power.
   B. Implement thresholds and monitor for a little while.
   C. Perform cross checks.

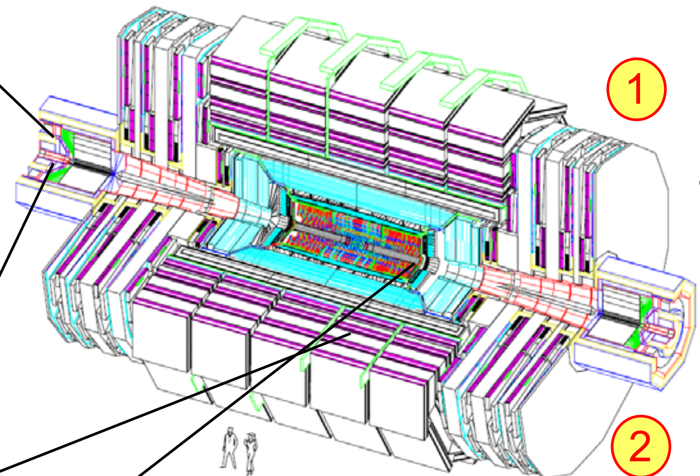
4. Go online.

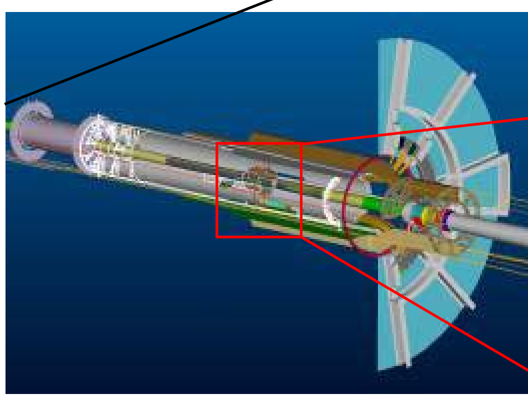
III. Further Diamond Applications

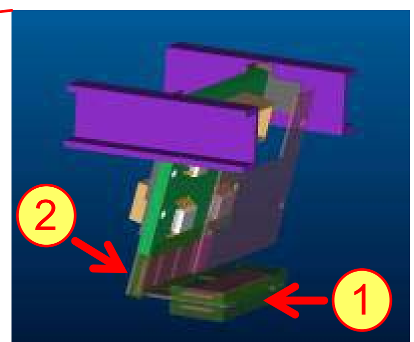
CMS Beam Condition Monitor

Auckland, Canterbury/NZ,CERN, Karlsruhe, Princeton, Rutgers, Tennessee, UCLA









CMS BCM Units

1 **BCM1L: Leakage current monitor**

Location: z=±1.9m, r=4.5cm

4 stations in φ

Sensor: 1cm^2 pCVD Diamond

Readout: 100kHz

CDF/Tevatron-style electronics

2 **BCM1F: Fast BCM unit**

Location: z=±1.9m, r=4.3cm

4 stations in φ

Sensor: scCVD Diamond

Electronics: Analog+ optical

Readout: bunch by bunch

3 **BCM2: Leakage current monitor**

Location: z=± 14.4m, r=29cm

8 stations in φ

Sensor: 1cm^2 pCVD Diamond

Readout: ~20kHz

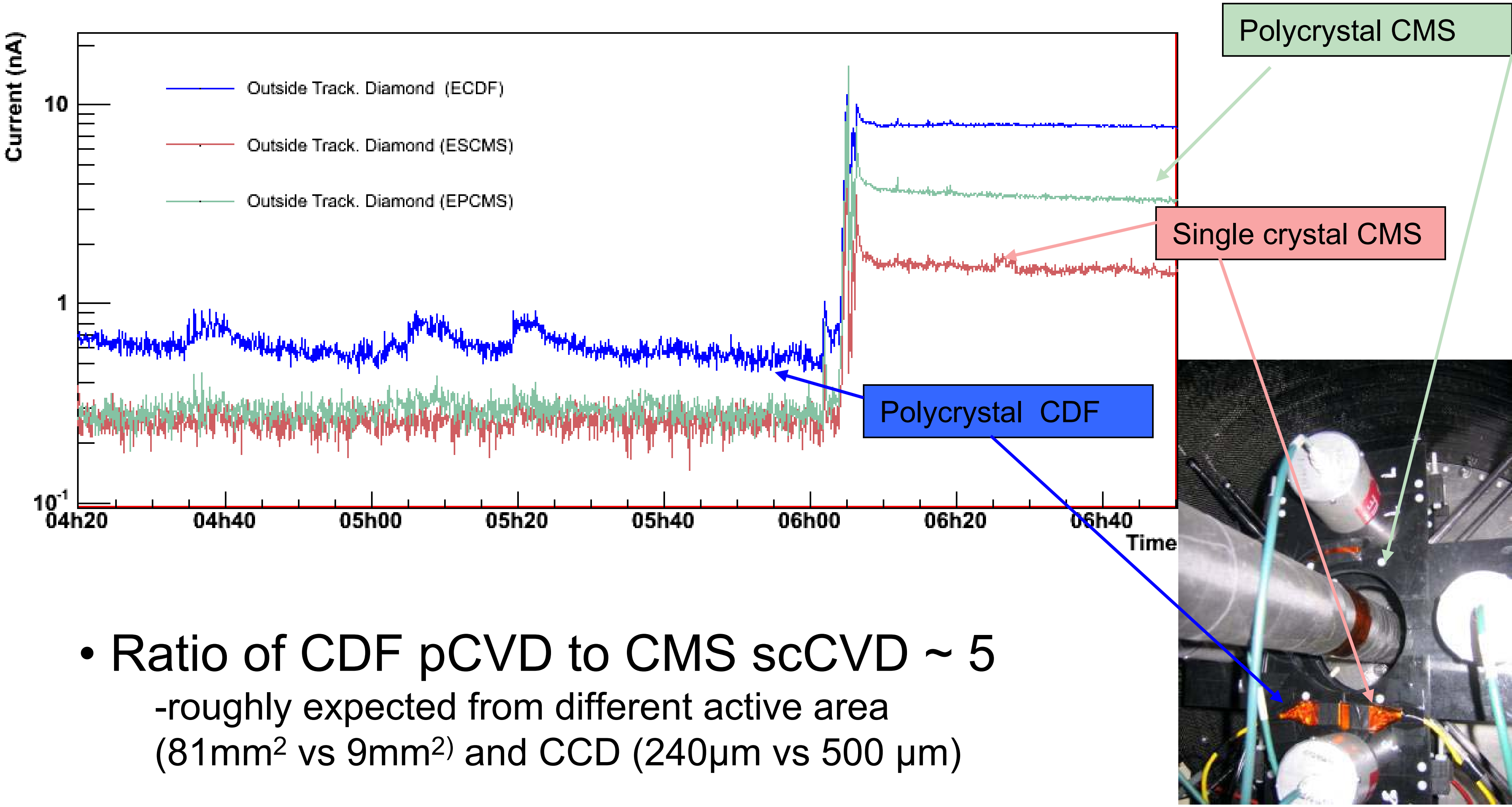
Sensors shielded from IP

uses LHC BLM electronics

2 Sensor Locations, 3 Monitoring Timescales

- staging/upgrading possible

CMS Prototype Diamonds



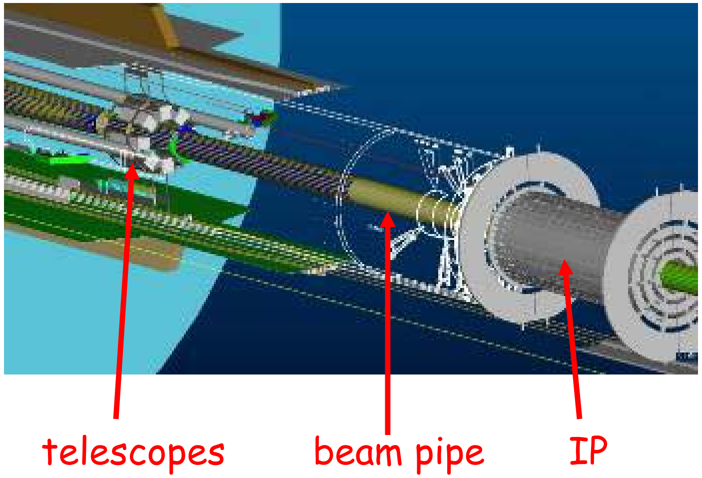
- Ratio of CDF pCVD to CMS scCVD ~ 5
  - -roughly expected from different active area ($81mm^2$ vs $9mm^2$) and CCD (240μm vs 500 μm)

CMS Pixel Luminosity Telescopes (PLT)

CERN, Davis, Rutgers, Princeton University

Proposed luminosity monitor for CMS

- Arrays of small angle telescopes
  - eight per detector side
- Three planes per telescope
  - 5 mm x 5 mm single crystal diamond pixel sensors
  - sensors bump bonded to CMS pixel readout chips
- Count number of particle detected per bunch crossing
  - fast out signals from chip (40MHz rate)
  - form 3-fold bunch-by-bunch coincidences
- Full pixel information (~ 1 kHz rate)
  - pixel row & column addresses
  - pixel pulse heights
  - allows track extrapolation



Schedule

- Approval Dec. ‘06
- Preproduction Spring ‘07
  - 12 planes
- Production last half ‘07
  - 16 telescopes
- Installation in CMS Spring ‘08
  - first physics run

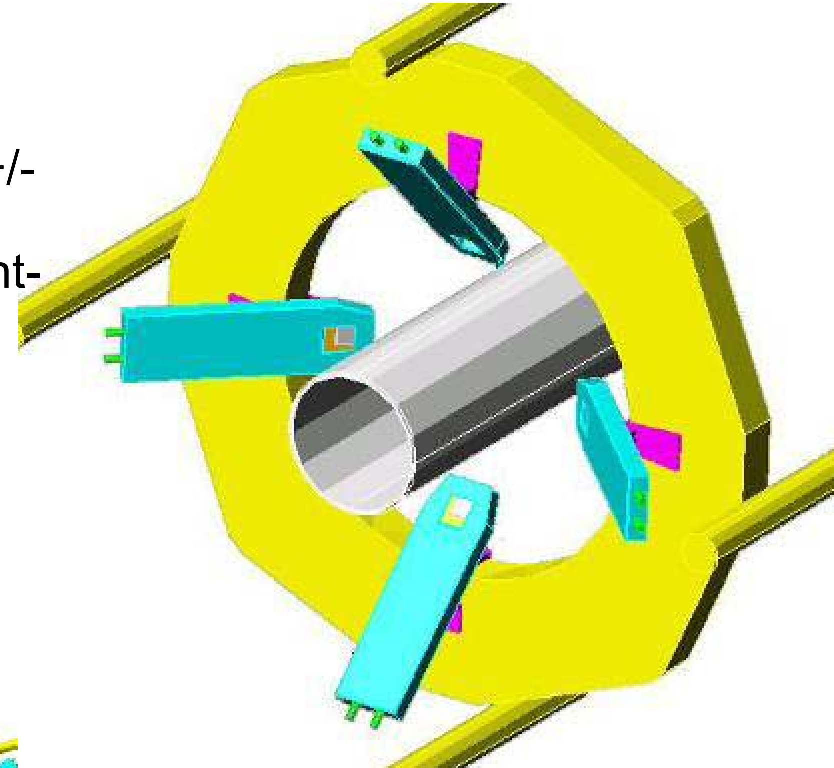
Performance

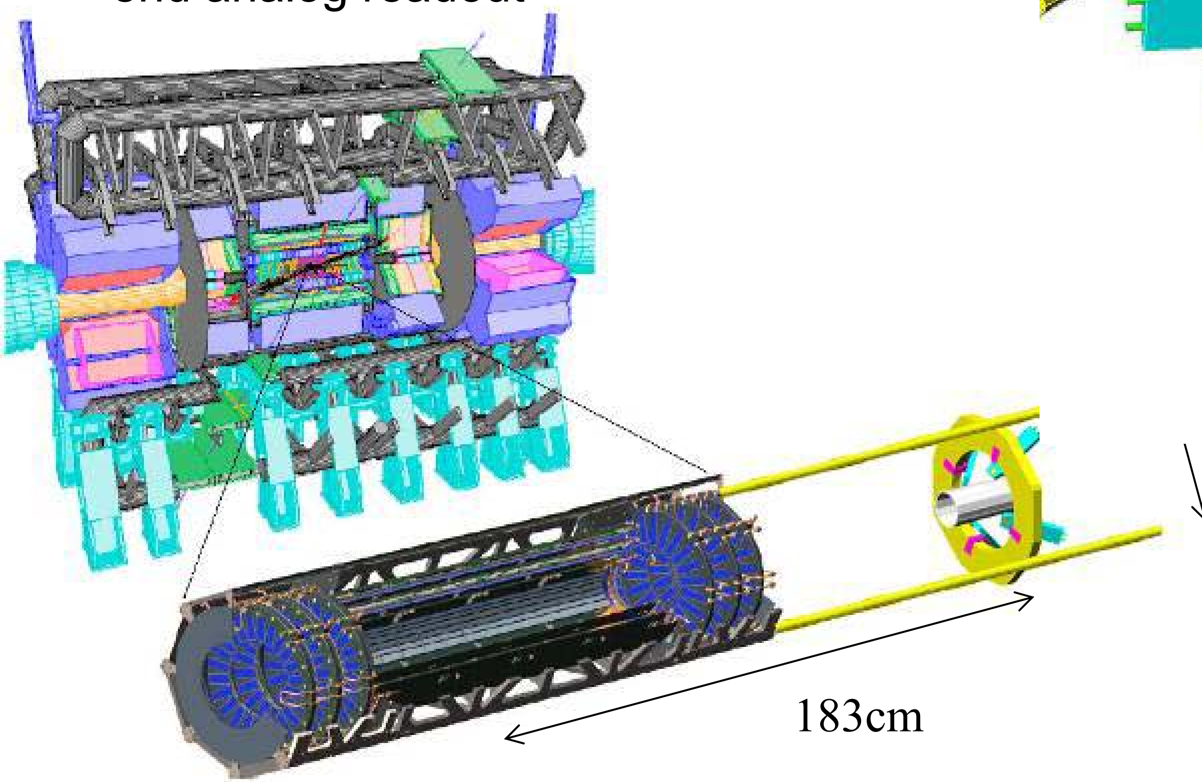
- Bunch-by-bunch relative luminosity
  - 1% precision in real time
- Location of IP centroid
  - order of 30 μm precision in real time
- Identification of tracks sources
  - beam halo
  - beam “hot spots”
- Beam monitoring
  - fluctuations in luminosity & IP spot
  - identify beam in orbit gap

ATLAS Beam Condition Monitor

Univ. Ljubljana / Jožef Stefan Institute, CERN, University of Toronto, Fotec Wiener Neustadt, Ohio State University

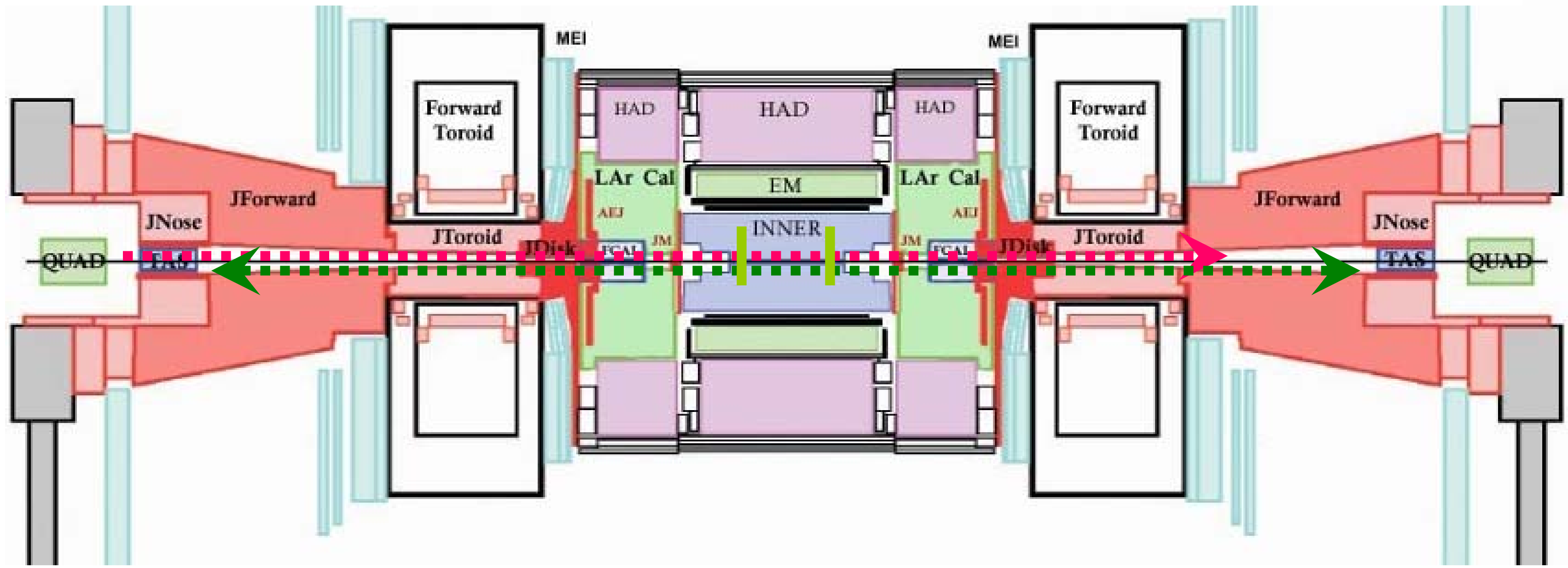
- 4 BCM stations on each side of the Pixel detector
  - Mounted on Pixel support structure at z = +/- 183.8 cm and r = 5.5 cm (sensor center)
  - Each station: 1cm^2 detector element + Front-end analog readout



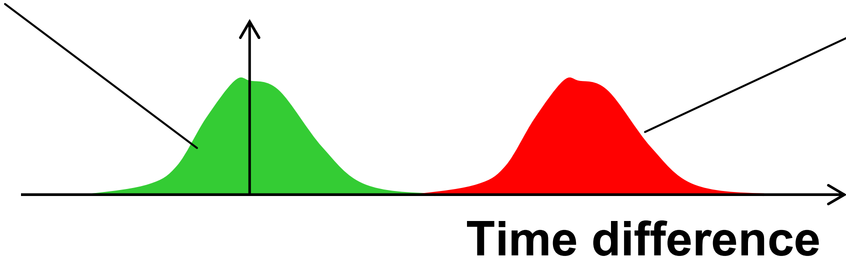


Distinction of Collisions from Beam Losses

- Distinguish collisions from background through time-of-flight measurement
- Measure number of charged particle/cm^2 using analog pulse height

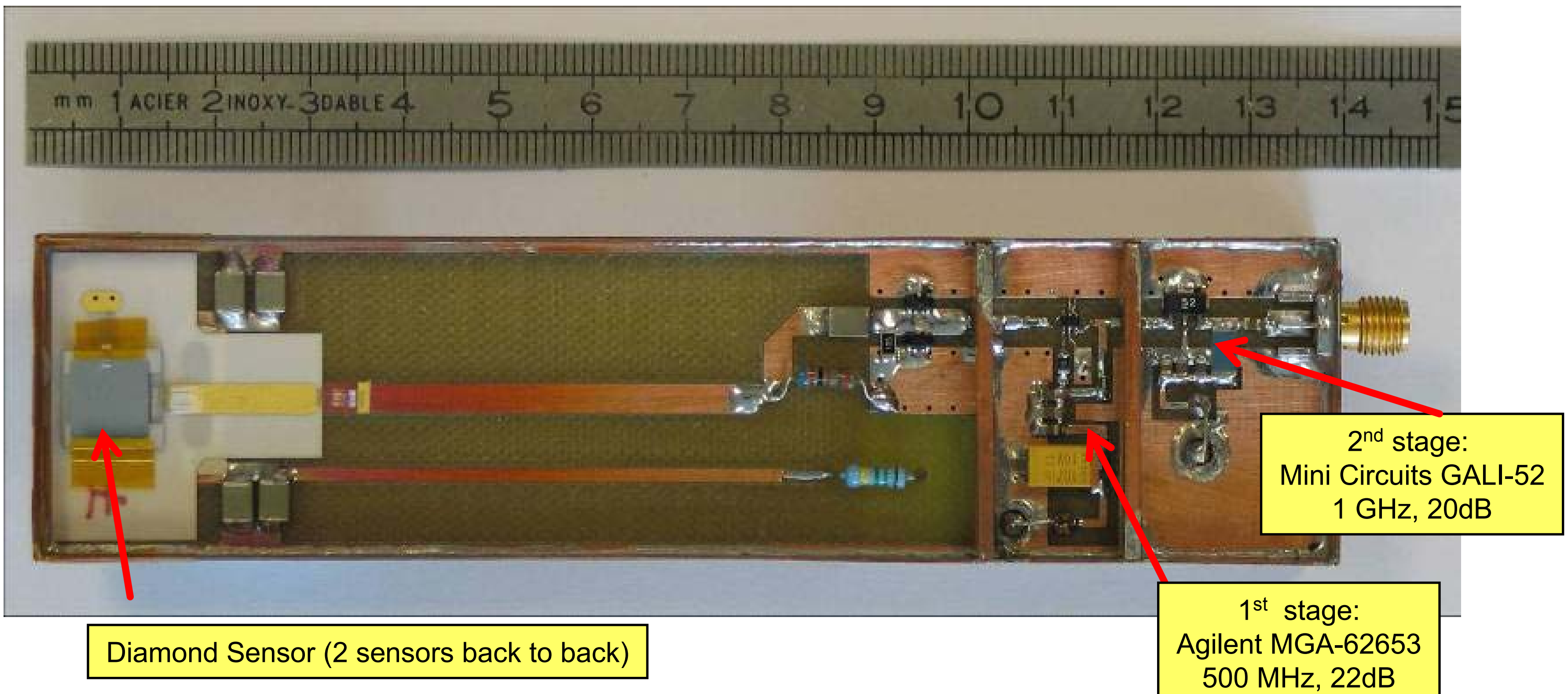


Interactions: Δt = 0, 25, … ns Upstream background: Δt = 2z/c = 12ns

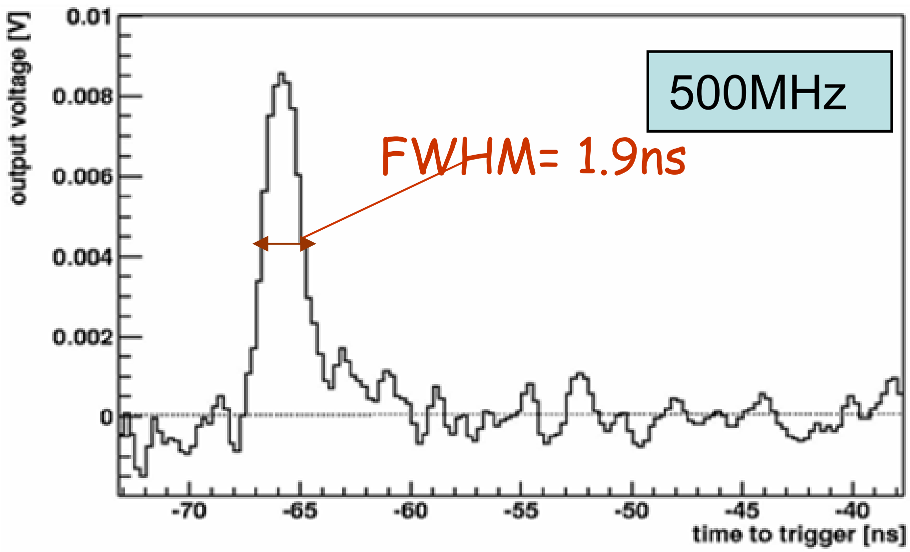


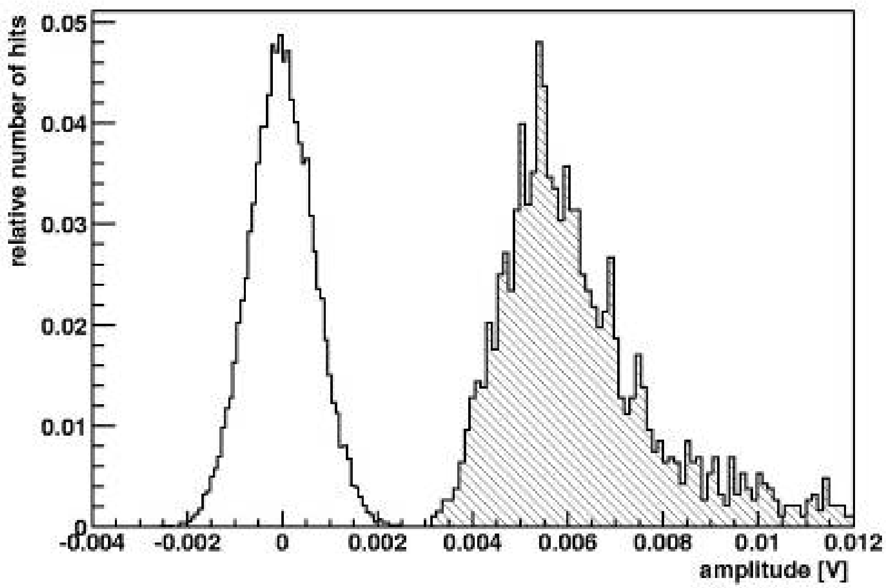
BCM Module

- All modules assembled and ready for deployment
  - Size 10 mm x10 mm, active 8 mm x 8 mm (metallization)
  - Thickness ~500 µm
  - Charge collection distance ~220 µm
  - Holds ~ 2 V/ µm, operating voltage 1000 V, current ~ nA



Beam Test Results





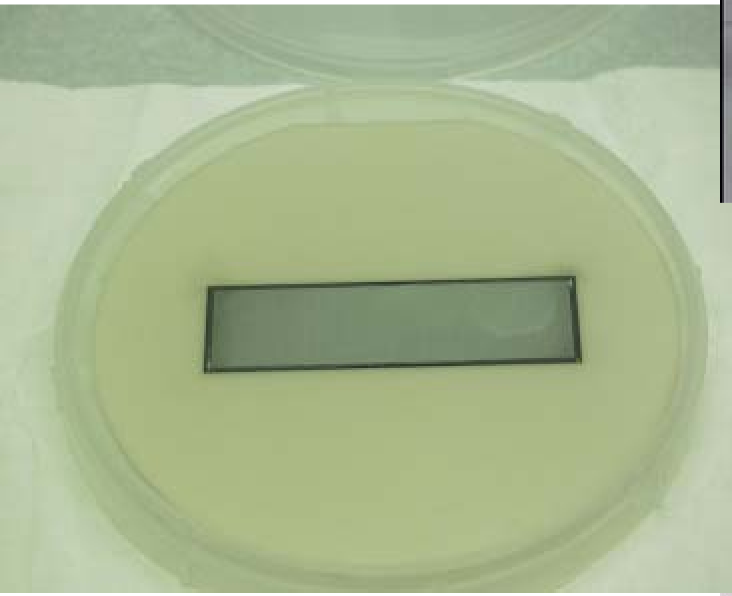
- Single MIP time response:
  - After 16m coax cable
- Average Rise-time: ~1.5 ns
- Average Pulse width : ~ 3 ns

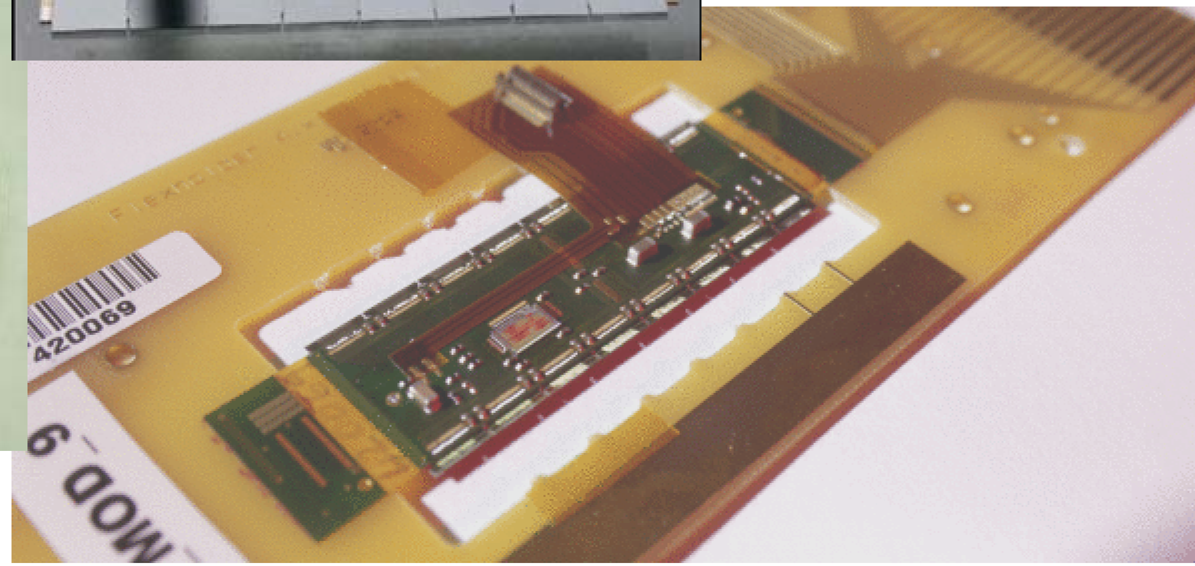
MIP signal distribution:
S/N_{mp} ~ 8:1

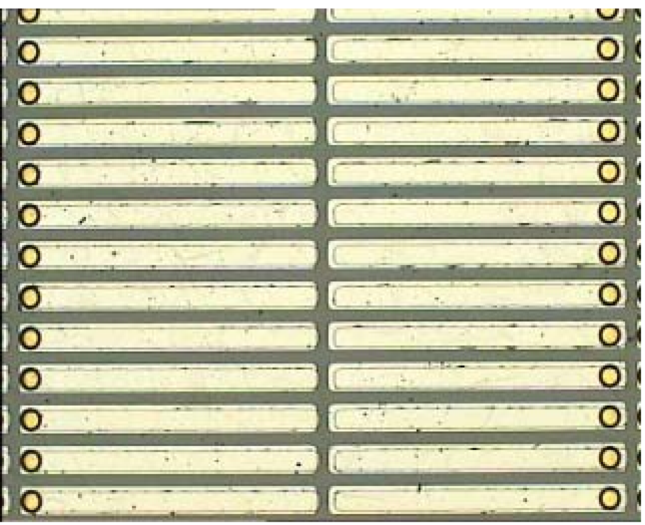
- Affords single particle counting
- Can monitor on bunch-by-bunch basis
- Can provide Luminosity measurement via hit counting and dedicated L1 trigger

ATLAS Diamond Pixel Module

(M.Mathes,F.Huegging, H.Kagan,W.Trischuk, J.Velthuis, N.Wermes)

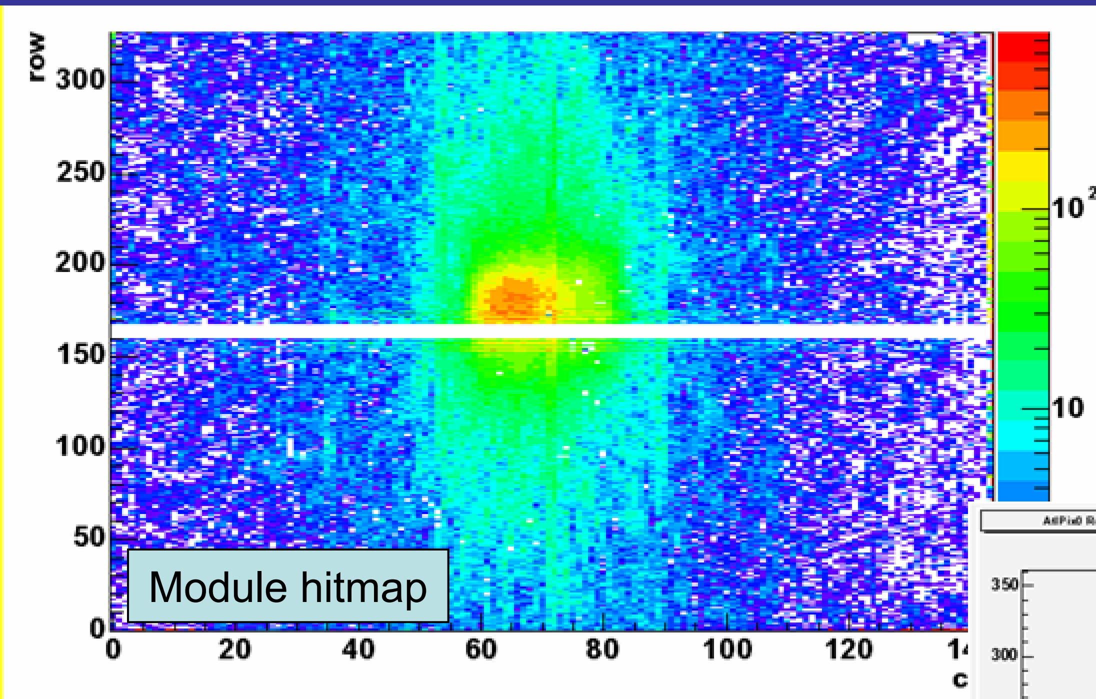


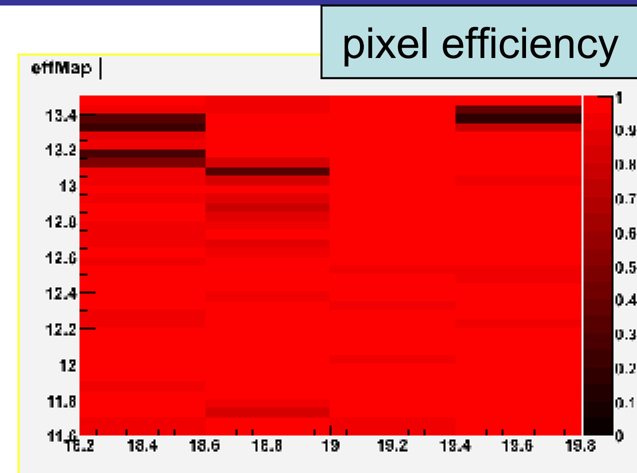


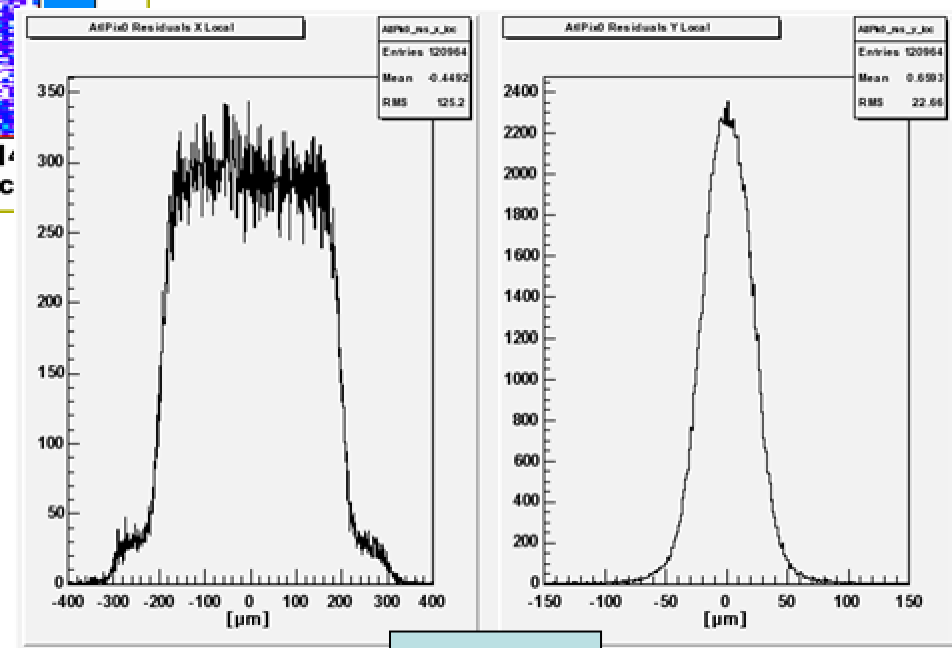


- Previous tests used 1-chip (CMS and ATLAS) diamond detectors
- Recently, a full 16 chip pCVD diamond ATLAS module was built
  - Element Six Ltd (crystal growth), OSU (metalization), IZM (bump-bonding), U Bonn (electronics, testing)
- Test beams at CERN (cut short) and DESY (lower energy electrons)
- Work ongoing

ATLAS Diamond Module: Test Beam Results







- Preliminary test beam results:
  - r-φ Resolution ~23µm
    - Multiple scattering not unfolded
  - Module Hit Efficiency > 97.5%
    - No correction for multiple scattering and tracking errors
    - Still need better fiducial region

Summary

- CDF has deployed the largest pCVD diamond BCM system so far
  - Low noise demonstrated
  - Complementary measurement of beam conditions
  - Capable to resolve 20 μs time structures using unamplified DC coupled sensors
  - Beam abort capability envisaged after system is fully commissioned and understood
- All LHC Experiments have built or planned similar systems
  - Differences in time resolution, sensor technology, readout scheme
  - CMS baseline system is essentially a re-implementation of the CDF/TeV-BLM system
- Diamond as detector material now well established with BCM as first large scale (HEP) application
  - Detector application (pixel, strip, pad) demonstrated

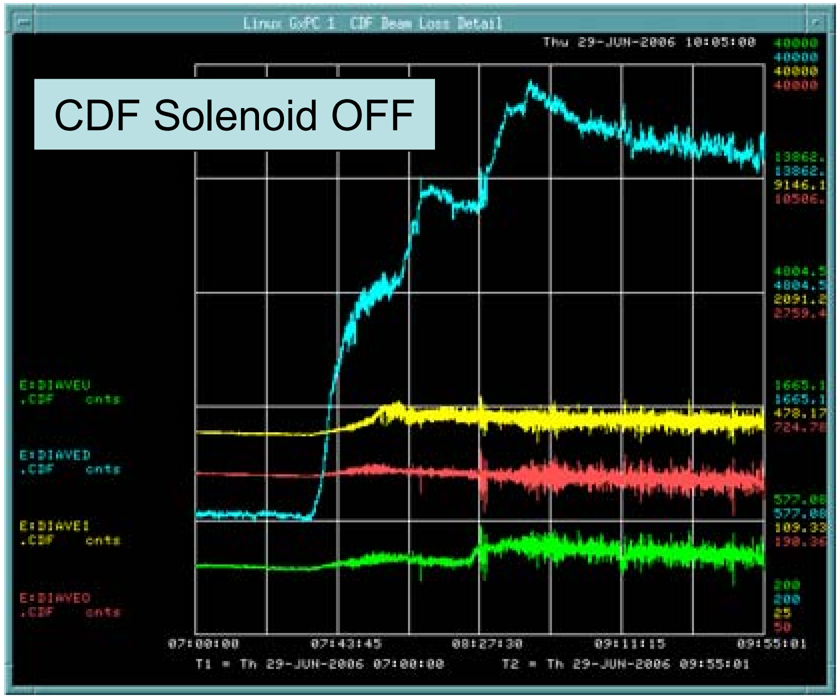
THANKS!

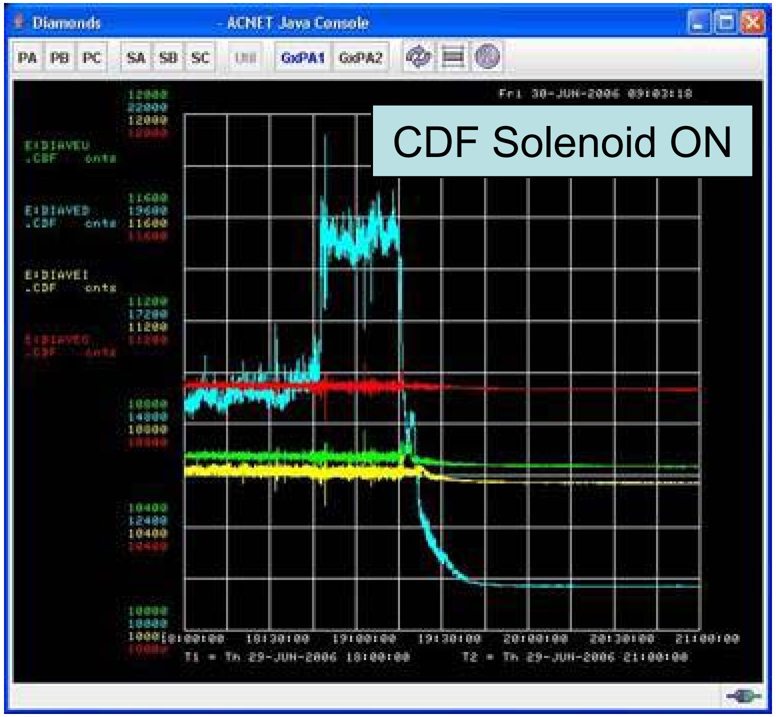
- **Many Thanks to everybody who helped and are helping:**
  - **CDF : M. Lindgren, R. Roser, W. Sakumoto, Ken Schultz, P. Wilson, B. Wagner, A. Mukherjee, …**
  - **BLM Upgrade: A. Bambaugh, C. Briegel, K. Knicker-bocker, Randy Thurman-Keup, J. Lewis, D. Still, Ray Yarema, ….**
  - **RD42: H. Kagan**

- **And Apologies to the ones I forgot – your help is much appreciated!**

‘Erratic’ Dark Currents

- Discovered by BaBar in pCVD diamond
- CDF observation:



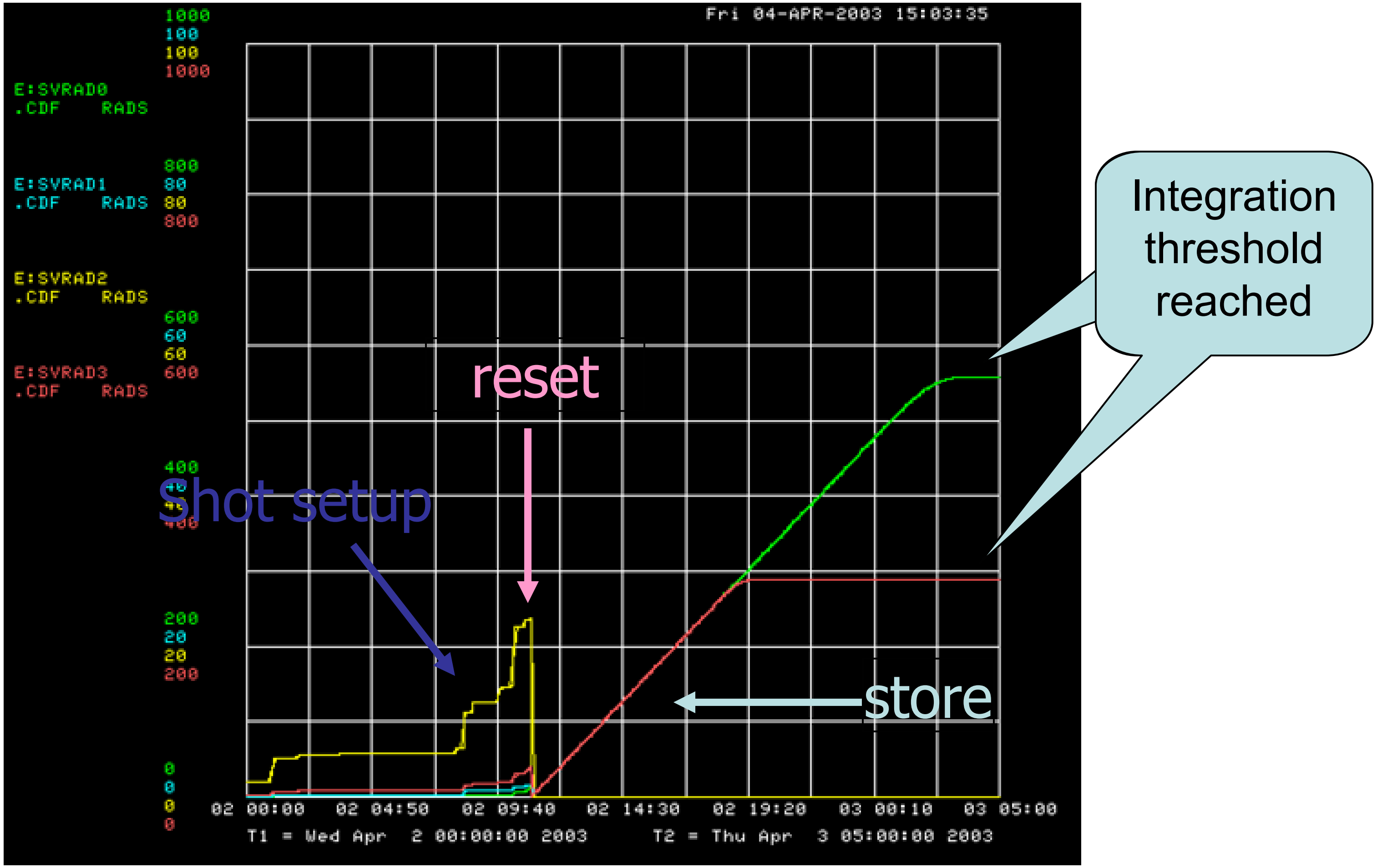


BaBar experience:

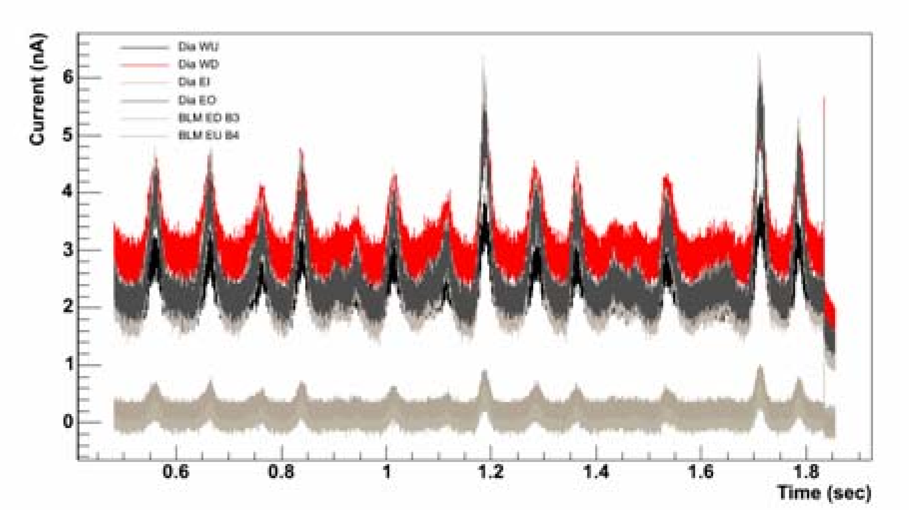
- ~ 0.5 T B field ⊥ to E field stabilizes diamond
- Lowering bias stabilizes diamond
- Effect confirmed by bench studies

M. Bruinsma, Vertex 2004

Typical CDF BLM Dose Behavior




Diamonds - ACNET Java Console
File View Help
PA PB PC SA SB SC Util GxPA1 GxPA2
E:DIAVWU .CDF mR/S
E:DIAVWD .CDF mR/S
E:DIAVWI .CDF mR/S
E:DIAVWO .CDF mR/S
22:00:00 22:02:39 22:05:19 22:07:59 22:10:38 22:13:18 22:15:58
T1 = We 28-FEB-2007 22:00:00 T2 = We 28-FEB-2007 22:15:58
Connected to clxsrv.fnal.gov:1920

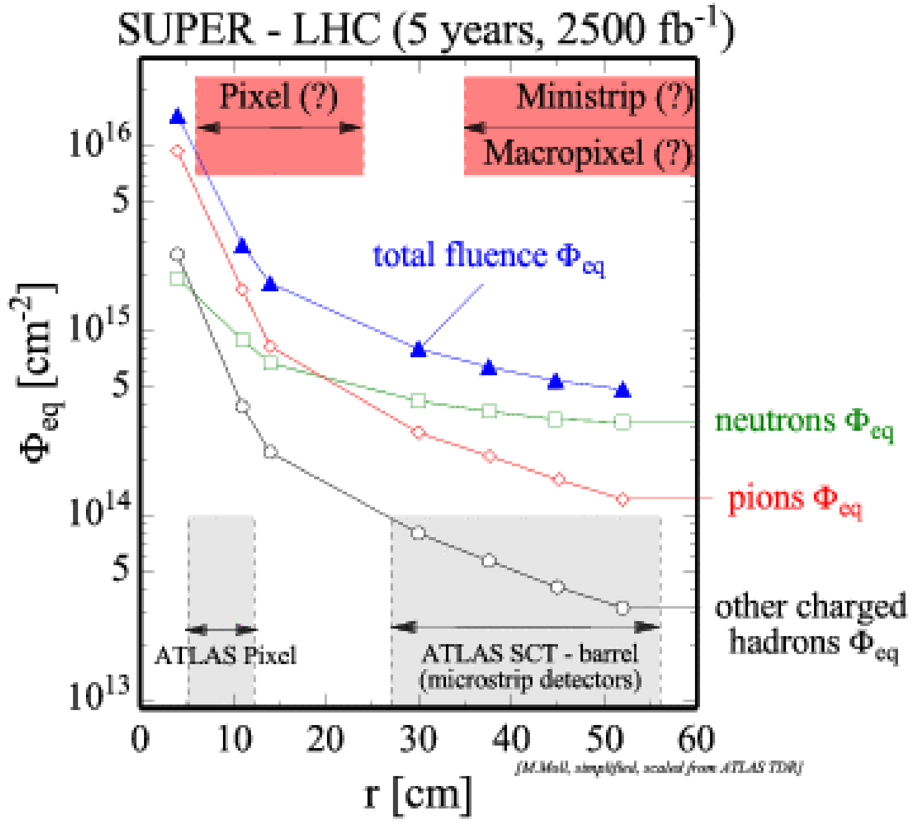

Dia WU
Dia WD
Dia EI
Dia EO
BLM ED B3
BLM EU B4
Current (nA)
Time (sec)

ACNET Device Names

Name	Position	Location	Digitizer Channel	ACNET Variable	Digitizer Card #
A230-1	Up	West Tracking Volume	00	E:DIAXWU	391
A422-01	Down		01	E:DIAXWD	
A377-05	Inside		02	E:DIAXWI	
A230-12	Outside		03	E:DIAXWO	
46T0-6	Up Outer	West BLM	04	E:DIAXW1	404
CMS-S4	Up Inner		05	E:DIAXW2	
Unused			06	E:DIAXW3	
			07	E:DIAXW4	
A422-08	Up	East Tracking Volume	08	E:DIAXEU	470
CD159	Down		09	E:DIAXED	
CD162	Inside		10	E:DIAXEI	
E1	Outside		11	E:DIAXEO	
A422-10 (old) A230-03 (new)	Down Outer	East BLM	12	E:DIAXE1	483
CMS-S5	Down Inner		13	E:DIAXE2	
Unused			14	E:DIAXE3	
			15	E:DIAXE4	
Crate Abort Signal			16	E:DIAXWM	499
CMS-P1	Up	East BLM	17	E:DIAXEM	

X=Q(uick),
S(low),
V(ery Slow)

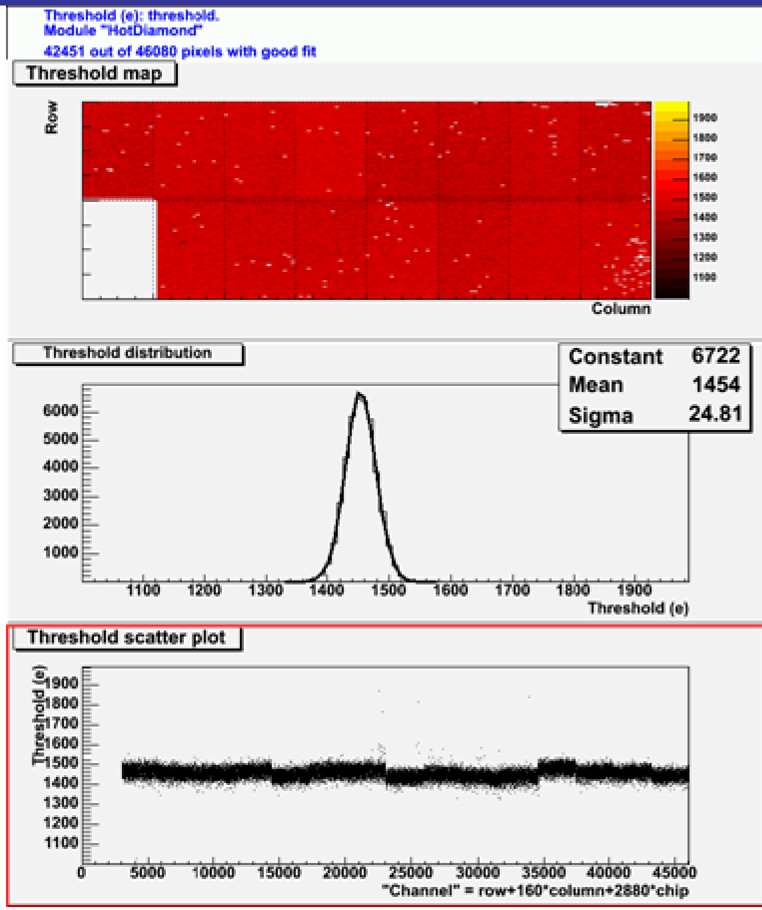
The Challenge

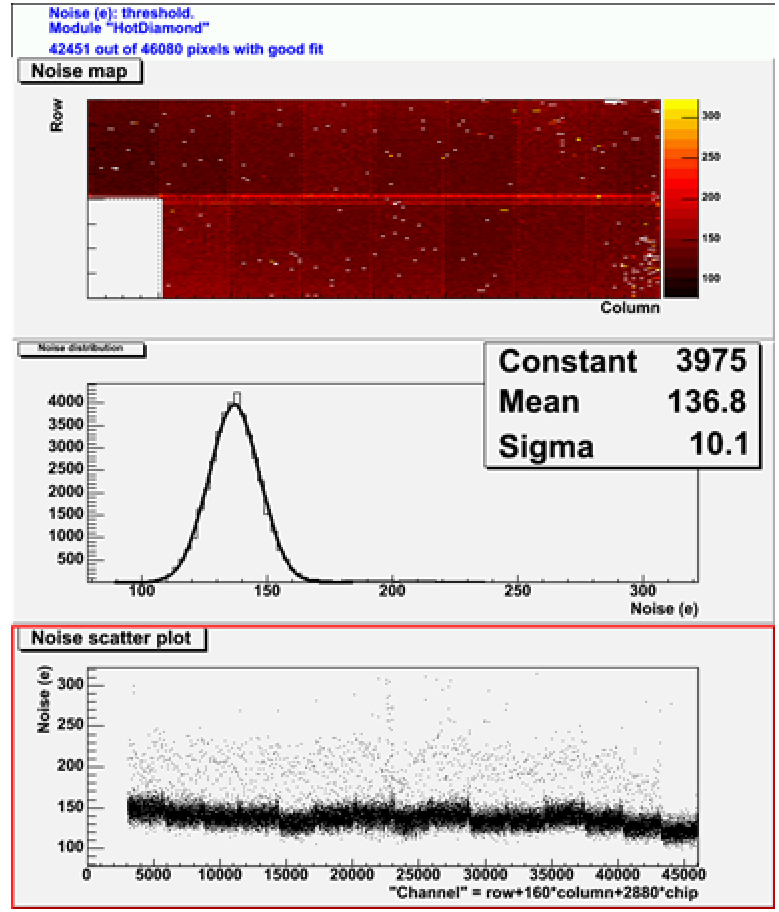


Motivation: Tracking close to interaction region

- At SLHC (~10^{35}/cm^2/s) inner tracking layers receive fluence in excess of Φ_{eq}~10^{16}/cm^2 (5 years)
- Silicon based tracker maybe good to ~10^{15}/cm^2 (charge trapping)
- Frequent replacement of layers ?

ATLAS Diamond Module: Bench characterization





- Mean threshold 1454e-, Noise ~137e-, threshold spread 25e-
- Compare to silicon: (From Markus' Talk on Monday)

  Mean threshold 4170e-, Noise ~185e-, threshold spread 62e-