A Beam Condition Monitor for CMS

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<u>BCM Group</u>

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Beam Condition Monitor for CMS

Idea:

- CMS and Atlas investigate diamond sensors for use in beam monitoring beam conditions.
- Try to develop a common system so to simplify interfacing to the LHC

Purpose

- The Beam Condition Monitor (BCM) has to provide online radiation monitoring within CMS
- BCM is to form a central part of the radiation monitoring system for equipment safety and radiation level/beam monitoring
- The BCM should be in addition to the LHC machine protection system and Beam Loss Monitors

BCM Issues

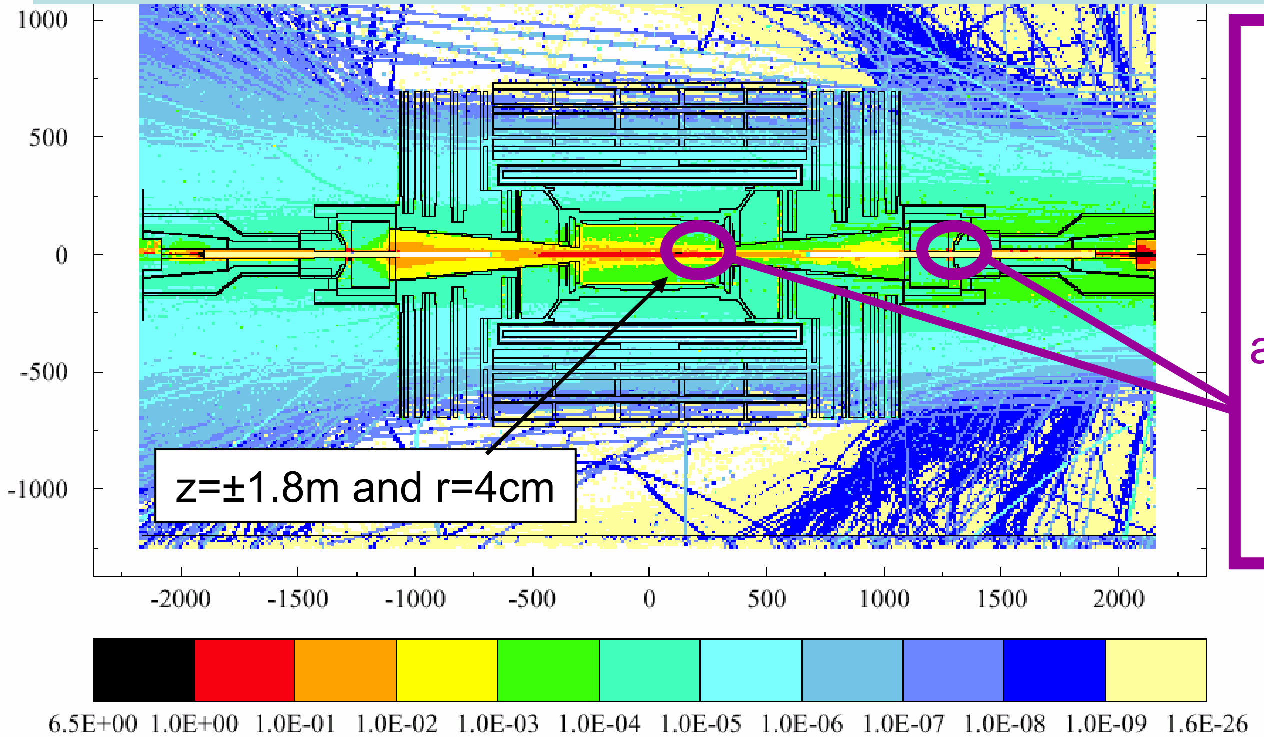
- Allow to protect equipment during instabilities/accidients
- Provide fast feedback to the machine for optimization of beam conditions
- Provide fast feedback to the machine for detection of adverse beam conditions
- Monitor the instantaneous dose during operation
- Provide input into LHC beam abort system (1 input/ experiment)
- Could monitor bunch by bunch and also the inter-bunch spacing

Advantages of diamond for this application

- Radiation hard, low leakage currents, fast signal response (~1ns)
- Minimal Services required
- Benefit from fast signal: Use fast electronics
  - Read out ionization signal (no integration) using a ~2GHz bandwidth amplifier
- Choice of Amplifiers very similar to ones under investigation by machine group

Accident Scenarios

Unsynchronised beam abort: ~10^{12} protons lost in IP 5 in 260ns



Beam condition monitors

Looking for increase over normal rate

Monitors to be within CMS and feed to machine interlock

Sensors to be placed in the Pixel volume and after the Forward calorimeter

- Sensors under investigation: Polycrystalline Diamond
  - Fast signal response due to high mobility
  - Short charge life time of polycrystaline CVD diamond
  - Radiation hardness
  - Minimal services required ie cooling not necessary

Evaluated using a fast extraction beam from the CERN PS at the T7 beamline (November 2003)

Generic Accidents

Dose in innermost Si-strip layer of CMS Tracker (R=22 cm)

Loss Type	**Dose per event**	**Flux factor**	Ratio
Unsynchronised abort	**10mGy**	**1**	1
One 7 TeV proton on TAS	**15 pGy**	10^{12}	1500*
One 450GeV proton on TAS	**1pGy**	10^{12}	10*

Unsynchronised beam abort: ~10^{12} protons lost in IP 5 in 260ns

* Dose rates up to 1000 times higher if consecutive full bunches lost on TAS

⇒ Losses directly on the TAS worse than unsynchronised abort

For an unsynchronised abort: Little warning - CMS just has to survive it

Generic accident (eg losses on TAS): May be able to detect beam deterioration.

=> enable possibility of preventative/protective action

=> develop a Beam Condition Monitor (BCM)

Beam Accidents

What are the timescales

List of machine-identified equipment failures

Name	Operation Mode	Loss Type	Loss Location	ΔT
D1 warm	collision	local	triplet / collimator	5 turns
damper	injection	local	arc / triplet	6 turns
warm quadrupoles	any	distributed	collimator	18 turns
dump septum	any	local	diluter kicker / septum	35 turns
warm orbit corrector	collision	local	triplet / collimator	55 urns
RF ?	any	local	arc / triplet / septum	55 turns
D1 warm	injection	local	arc / triplet / collimators	120 turns
D1 cold	collision	local	triplet / collimator	220 turns
warm orbit corrector	injection	local	arc / triplet / collimator	250 turns
MB quench	collision	local	triplet / collimator	280 turns

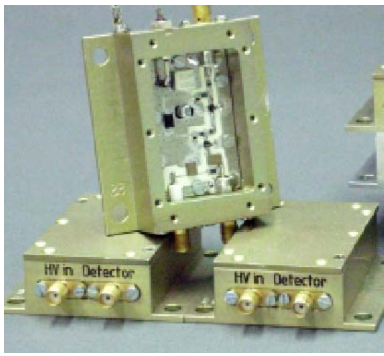
Fastest generic beam loss scenarios: ~ 5 orbits ie ~ 500μs
This defines the response timescale

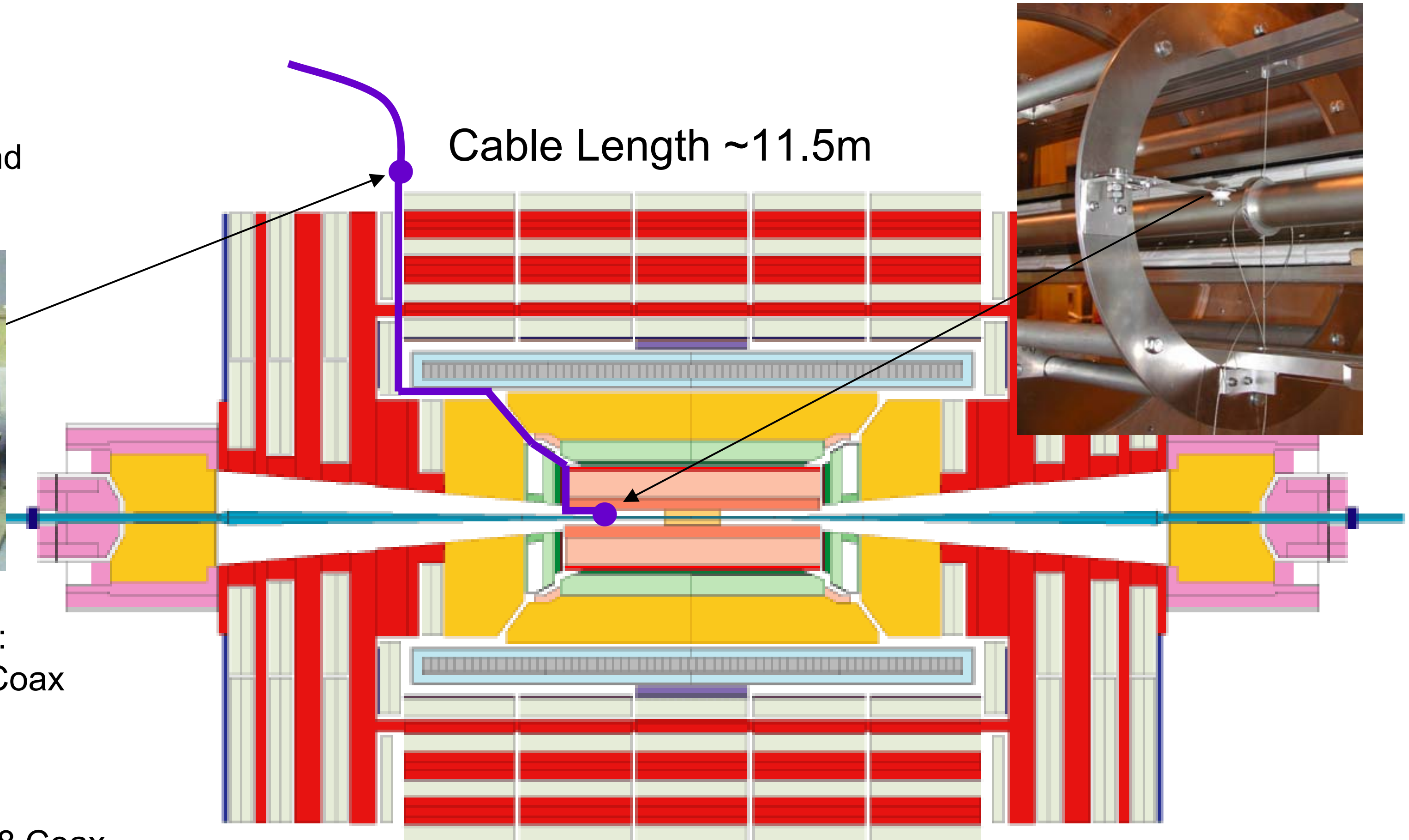
BCM should look bunch by bunch, but form decisions on a few 100ns time scale

Conceptual BCM layout

BCM sensors close to beampipe

Fast Amplifiers
Placed outside CMS
Drives a 50Ω load
Designed for Diamond
Available





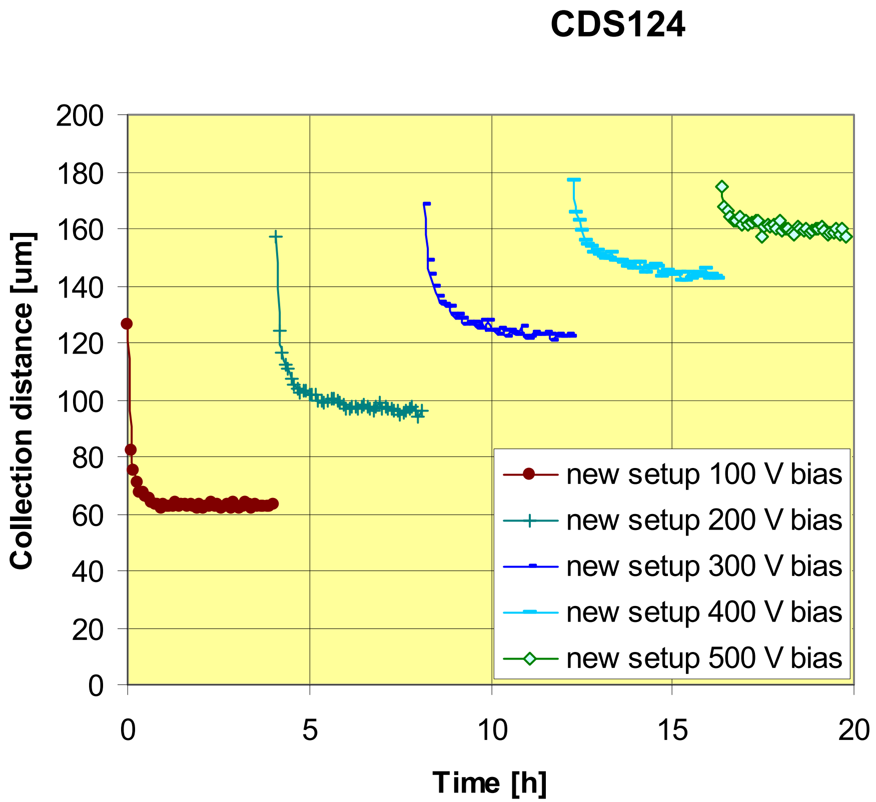
Cables requirements:
- 1 very good 50Ω Coax Cable per detector

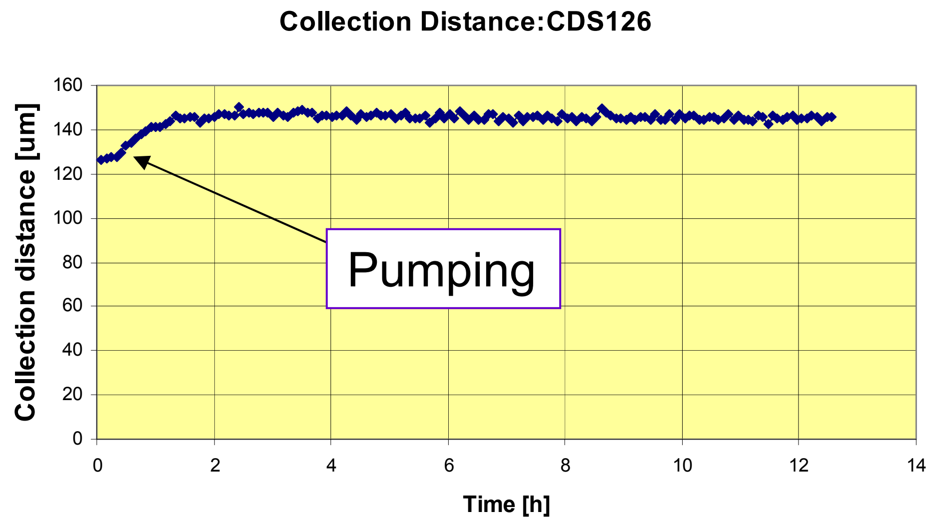
Testbeam Cables
- Used 16m of RG58 Coax

The BCM must be installed for the pilot run ie independent of the final pixel system

Sensors: CVD Polycrystalline Diamond

- Sensors are 1x1 cm polycrystalline diamond. Typically 300um thick
- Measurements taken with the samples fully pumped (ie charge traps filled up)
- Collection distance is stable with time

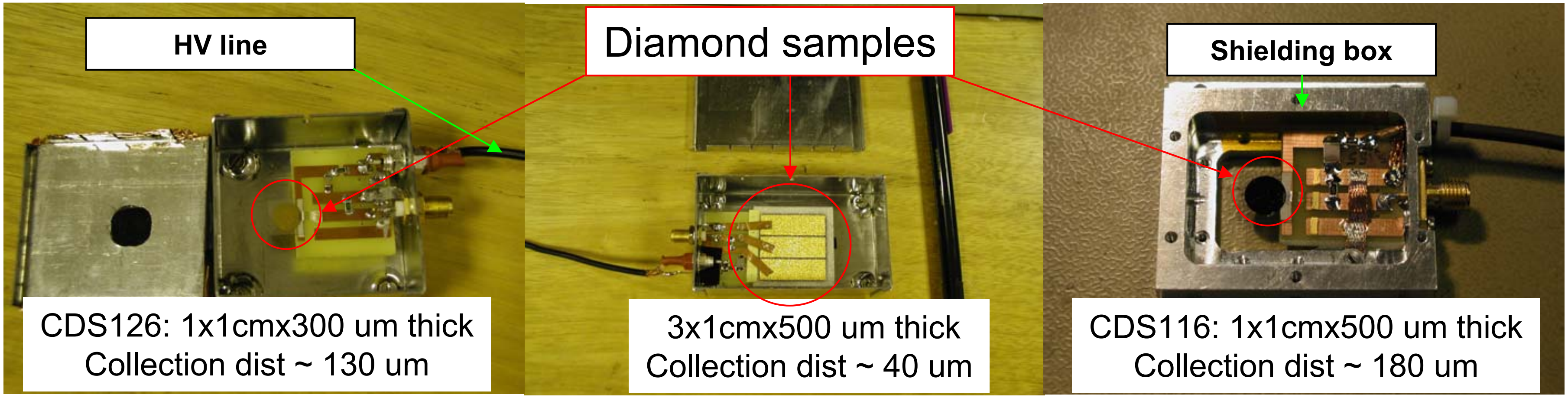


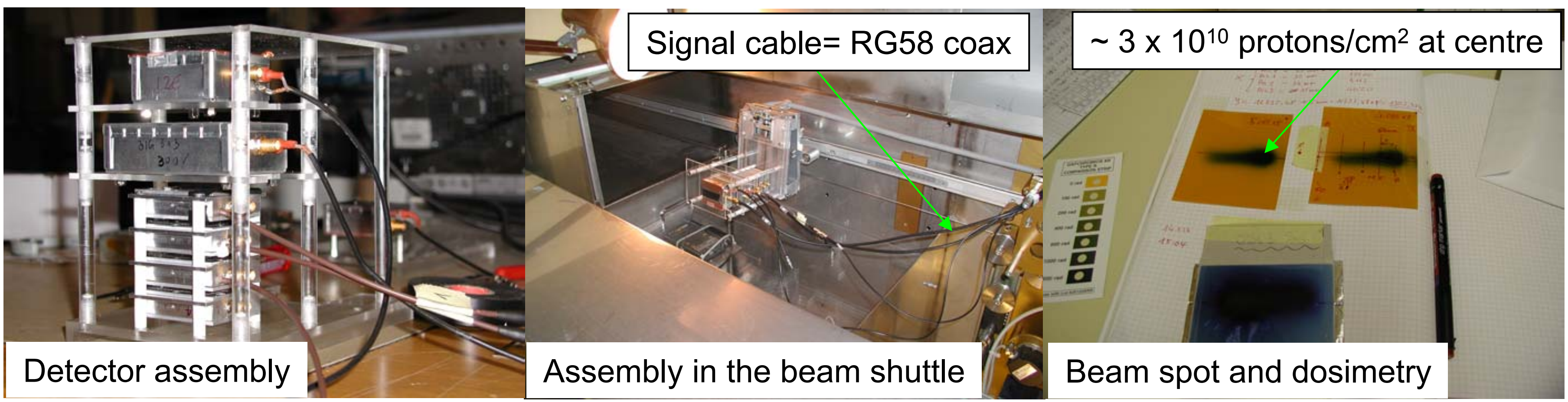


Collection distance:

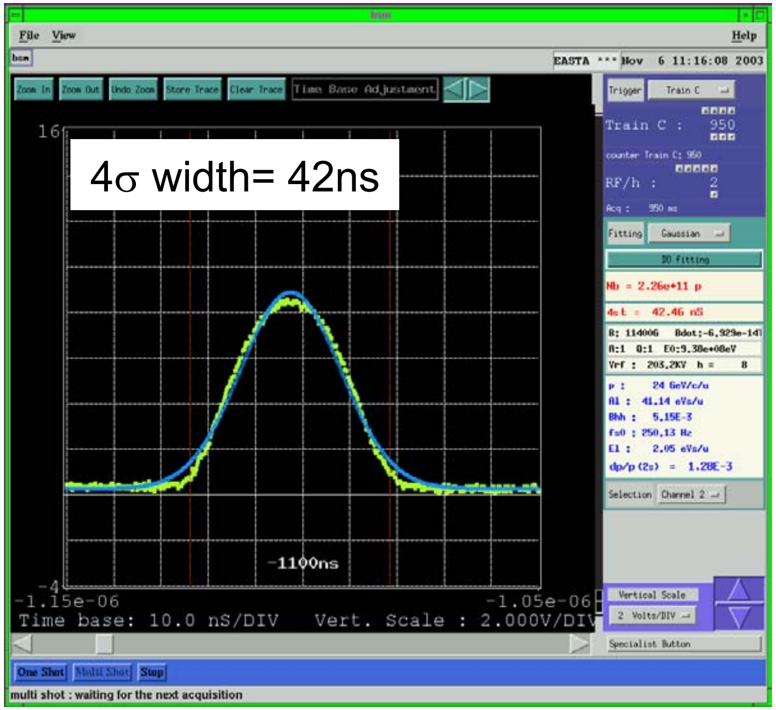
- Larger collection distance => larger signal
- Transient collection dist = internal polarisation due to changing bias
- At 1 V/um, on this diamond we get ~6000 e^-/MIP

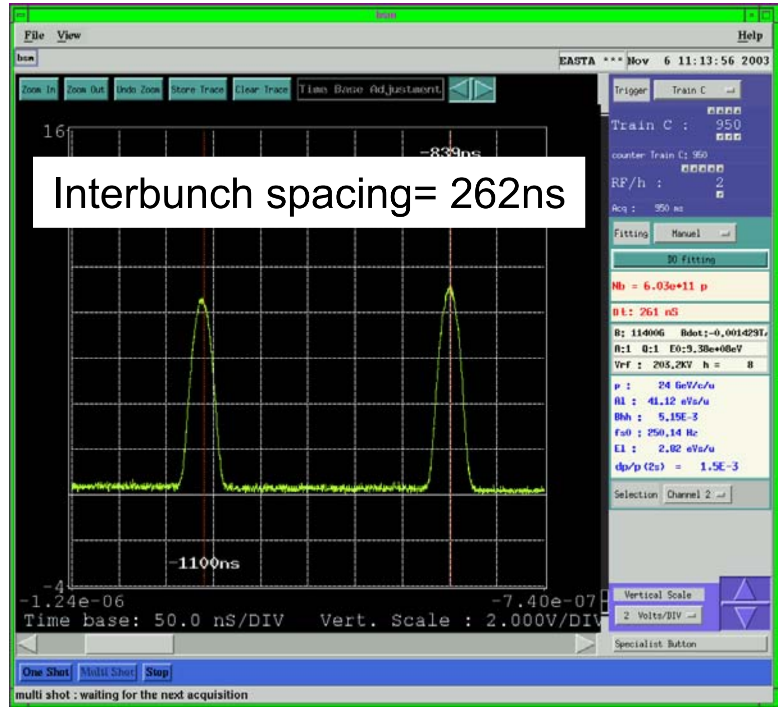
T7 Testbeam Hardware





November T7 Test beam:
Fast extraction beam from the PS





Beam intensity: $8x10^{11}$protons per spill

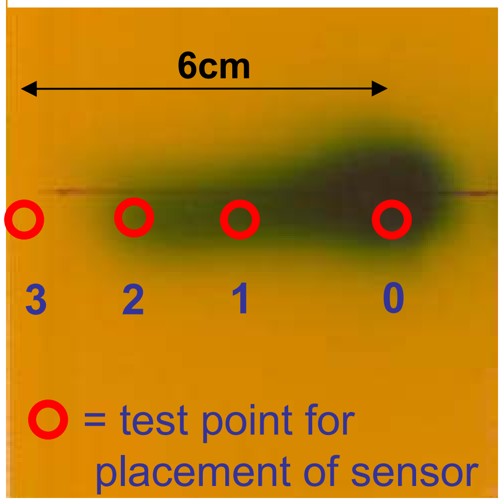
Fluence: ~$3x10^{10}$ protons/cm^2/spill at the centre of the beam spot

~$1x10^{8}$ protons/cm^2/spill in the halo

=> Models an unsynchronised beam abort

Beam profile

Film exposure of the beam after 40 bunches



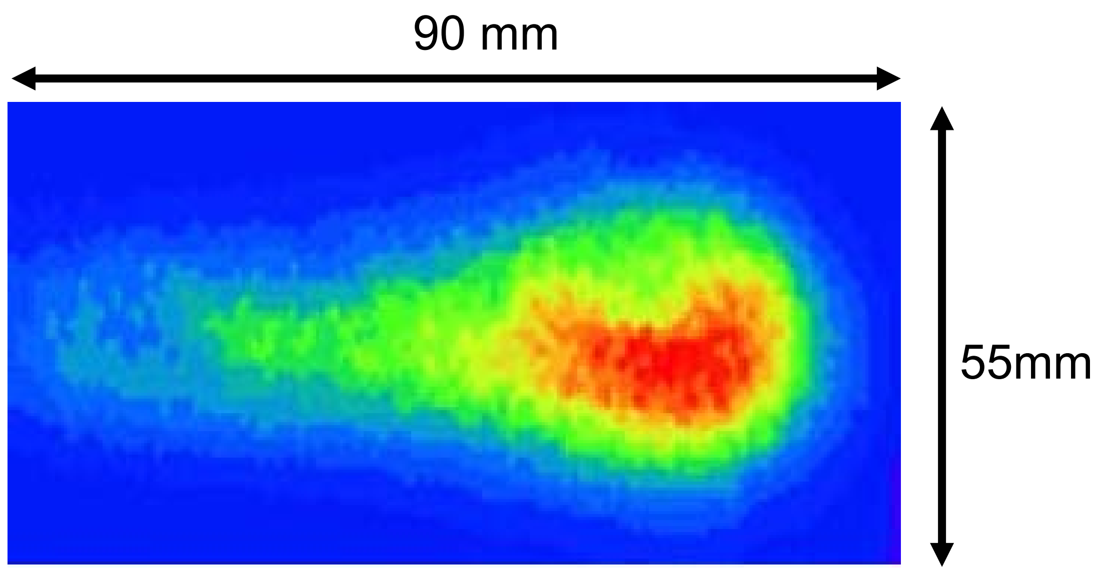
Relative fluence levels

Position 0 = 1.0

Position 1 ~ 0.4

Position 2 ~ 0.2

Position 3 ~ 0.01



Beam Profile as measures by OSL film

OSL =Optically Stimulated Luminesence

mm	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90
0	0.2	0.2	0.2	0.2	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.0
5	0.2	0.2	0.2	0.3	0.3	0.3	0.1	0.3	0.4	0.8	0.7	1.0	1.0	1.4	1.3	1.2	1.0	0.1	0.1
10	0.6	0.6	0.6	0.8	0.9	0.9	0.8	0.8	1.0	1.0	1.1	1.3	1.5	2.1	2.0	2.0	1.6	0.2	0.1
15	0.6	0.6	0.6	0.8	1.1	1.1	1.3	1.1	1.4	1.6	1.8	2.3	2.6	3.5	3.0	2.9	2.7	0.2	0.1
20	0.7	0.7	0.7	1.1	1.4	1.7	1.9	2.1	2.8	3.2	4.9	5.0	7.7	9.8	12.7	10.6	6.2	0.5	0.1
25	0.7	0.9	0.9	1.0	1.5	3.1	7.4	10.3	13.1	15.6	17.6	21.5	26.7	38.9	56.7	45.0	17.7	1.2	0.1
30	0.7	0.9	0.8	1.1	2.2	7.4	18.6	28.4	28.9	39.3	45.6	48.9	70.8	82.1	100	87.8	36.5	4.3	0.2
35	0.7	0.8	0.9	1.1	2.7	6.1	17.4	25.1	28.5	34.4	27.7	42.4	42.2	61.1	58.1	69.2	28.1	6.1	0.2
40	0.6	0.7	0.8	1.1	2.2	4.1	6.6	8.1	8.5	8.6	10.3	13.5	18.7	26.7	36.0	28.3	10.5	3.4	0.2
45	0.6	0.7	0.7	0.8	1.1	1.9	2.2	1.7	1.7	2.7	3.1	4.3	5.8	7.6	8.1	5.7	4.0	2.4	0.2
50	0.7	0.6	0.7	0.9	0.8	1.0	1.2	1.1	1.3	1.5	1.6	2.2	2.2	2.6	3.1	2.6	2.3	1.8	0.1
55	0.4	0.5	0.6	0.7	0.8	0.8	0.8	0.7	0.8	1.1	1.0	1.1	0.7	0.6	0.4	0.4	0.3	0.2	0.1

Dosimetry measurements

Beamspot Dosimetry

Used ^{24}Na for dosimetry on aluminum placed in the beam

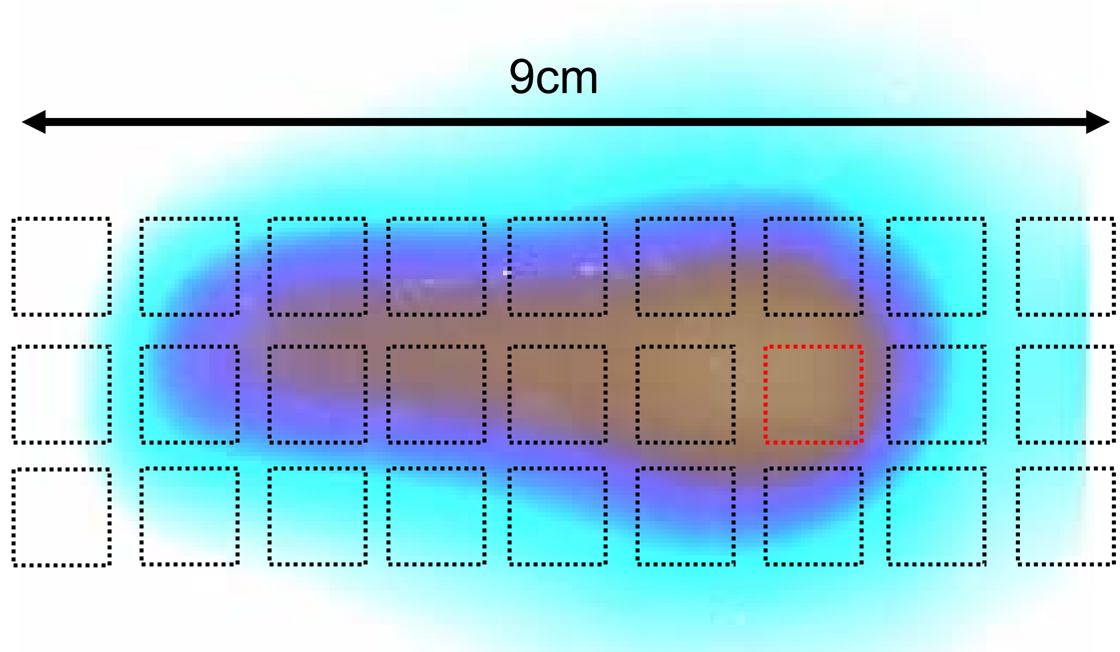
Dosimetry done with Maurice Glaser and Federico Ravotti

Result

Fluence at beam "centre" = **2.8×10^{10} protons/cm^2 ± 10%**

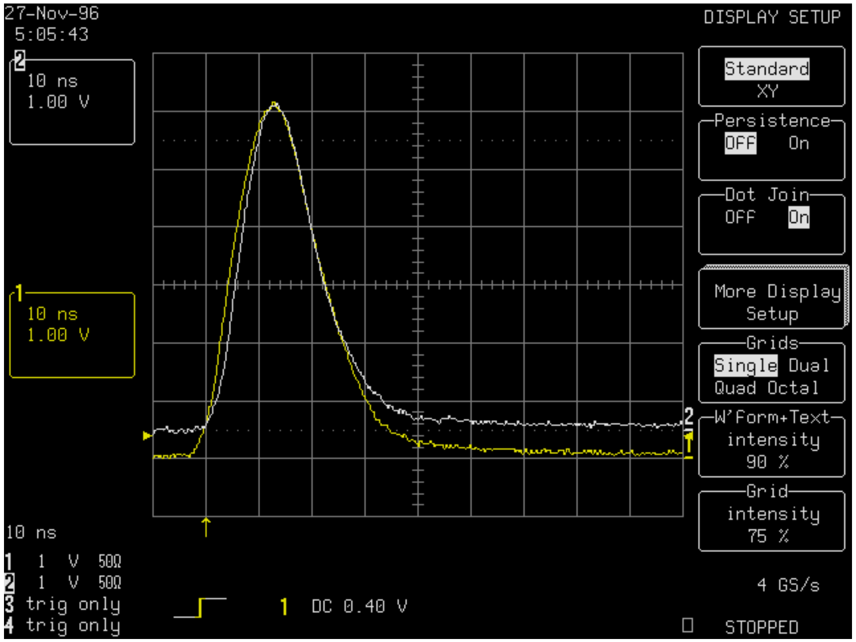
Mapping of beam spot

Consistency between the different films, the OSL, and the aluminum



Dosimetry Results from Grid of Aluminum samples: Relative variation %								
0.0	3.3	10.2	13.8	16.5	27.7	33.1	0.0	0.0
1.3	5.3	11.9	19.1	31.8	74.2	100.0	63.0	0.0
0.0	0.0	0.0	0.0	3.4	8.0	6.2	0.0	0.0

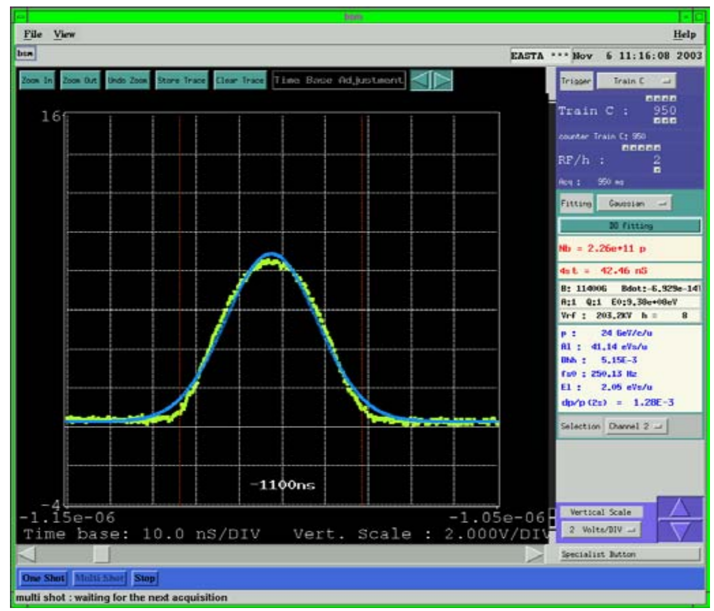
Single shots



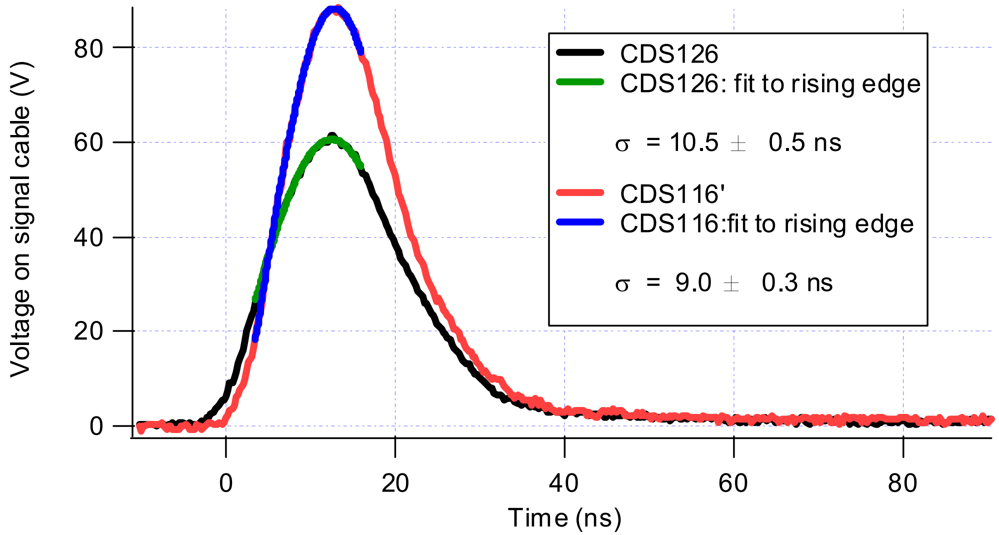
Almost identical to PS beam profile

<u>Single pulses from diamond</u>

- Bias on Diamond = +1 V/um
- Readout of signal:
    - 16m of cable
    - no electronics
    - 20dB attenuation on signal cable (factor 10)



Single shots: Details



Diamond Collection Distance

Diamond signal ~ collection distance

Collection distance (CDS116) ~180 μm

Collection distance (CDS126) ~130 μm

For std bias voltage of 1 V/μm

Area of pulse

- Proportional to current from a bunch.
- Use area to estimate bunch fluence.

  Pulse area(CDS116@Pt 3) = $8.2x10^7 p/cm^2$

  Pulse area(CDS126@Pt 3) = $7.0x10^7 p/cm^2$
- Fair agreement with dosimetry results

  Dosimetry(Al, @ Pt 3) = $2.2x10^8 p/cm^2$

Output Signal

Signals from sensors are very large

- V_max (CDS116) = 88 volts => 1.76 Amps into a 50 Ohm load
- V_max (CDS126) = 61 volts => 1.22 Amps into a 50 Ohm load

Time response

Fit Gaussian to leading edge of pulses

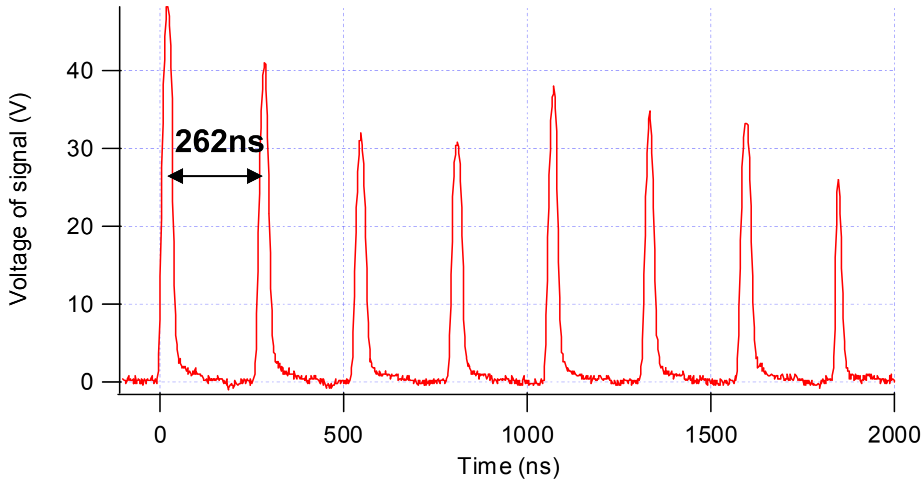
σ (CDS126) =10.5 ± 0.5 ns

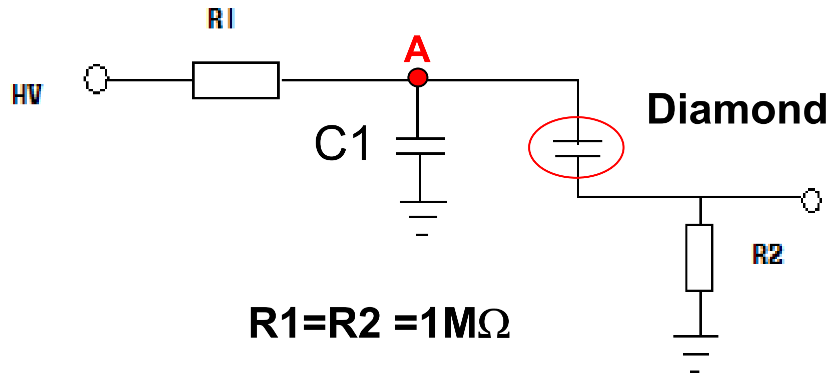
σ (CDS116) = 9.0 ± 0.3 ns

Comparable to σ(PS)=10.5 ns with ~6% distortion from the signal cable

=> No problem with extracting timing structure from sensors on 16 m coax cable

Multiple Bunches





C1 acts as a reservoir capacitor

=>The larger the value the longer the bias field on the can be maintained.

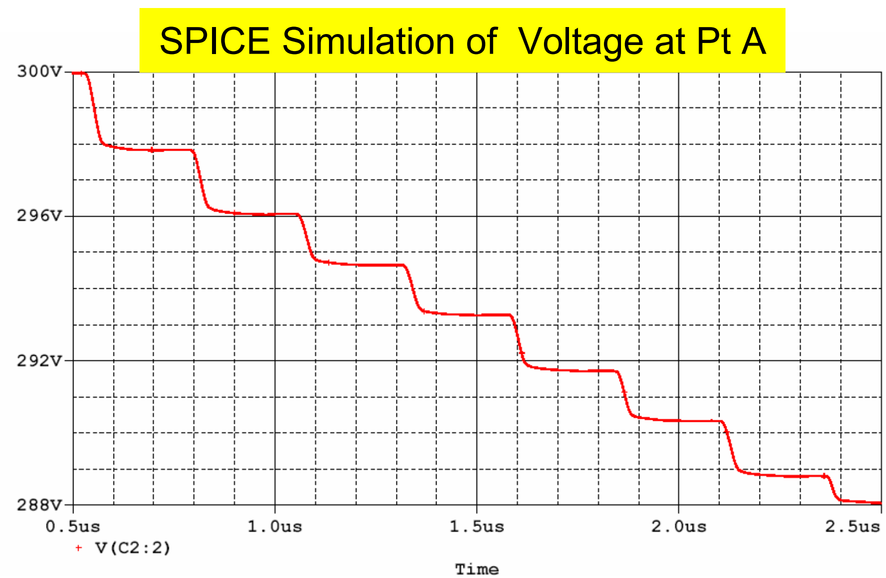
=>Bunch amplitude variation is real

C1(CDS126)=15 nF

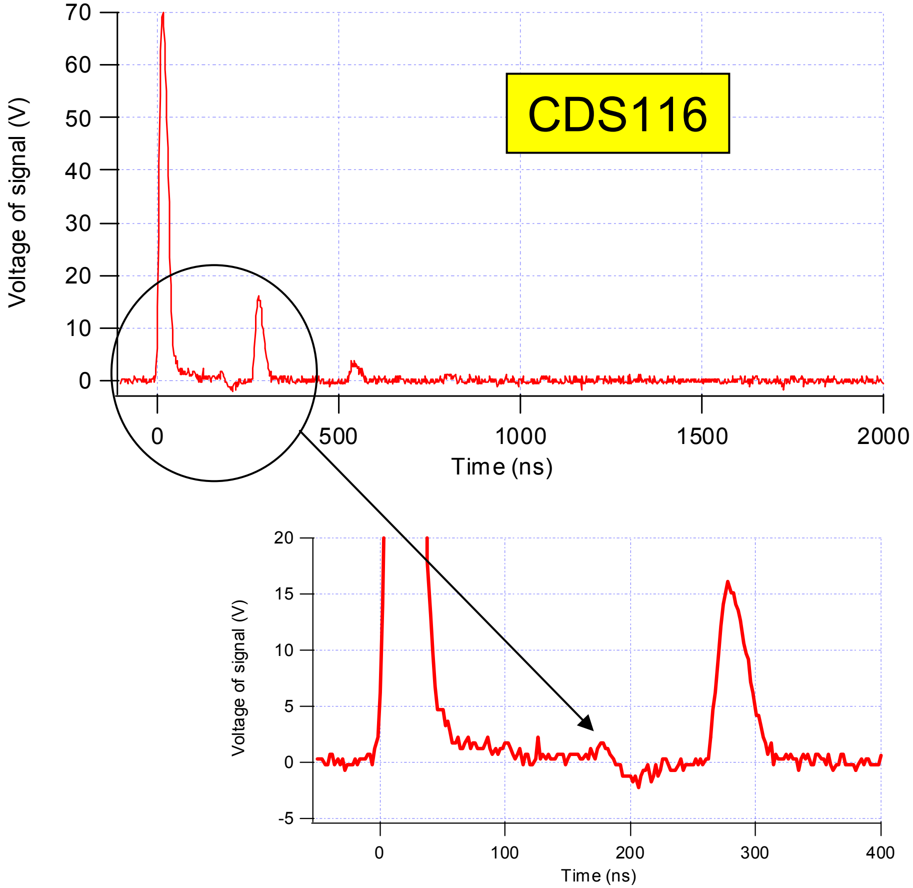
C1 is sufficiently large to maintain bias across the diamond for the 8 bunches.

C1R1 time constant ~15 ms

⇒ recharging of C1 is slow compared to bunch structure



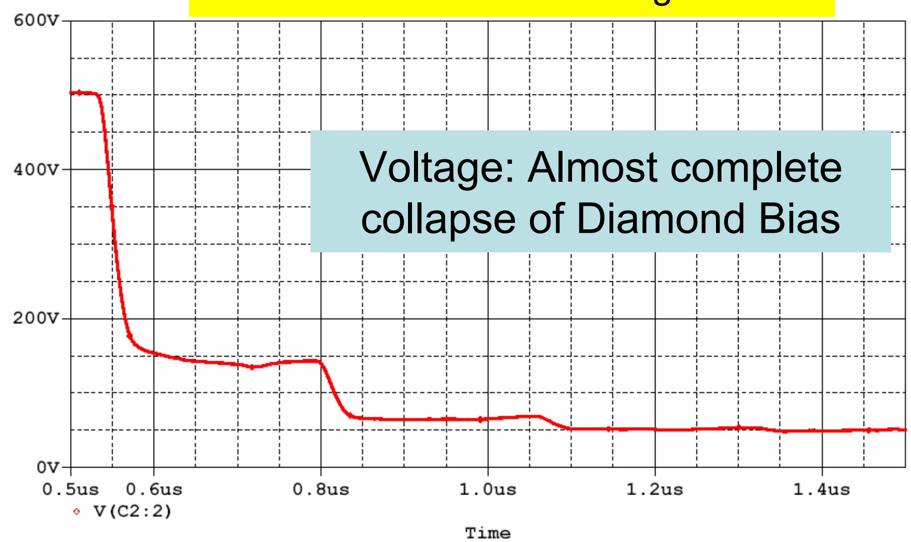
Multiple Bunches
Small Reservoir Capacitors



C1= 100pF
⇒Insufficient charge in C1 to maintain the diamond bias for 8 bunches

The C1R1 time constant = 100 us
⇒ recharging of C1 is slow compared to 8 bunch structure

SPICE Simulation of Voltage at Pt A



Reflections from impedance mismatch
⇒ Readout cables will have to be well matched to electronics

Next Steps

- Finish analyzing the data that we have from the November testbeam:
  - Data taken is for the "worst case" scenario
- Build a prototype BCM (sensors+ electronics + decision logic)
  - Reduce signal to noise so to clearly see MIPs
- April 04: Return to the East Hall for dedicated fast extraction beam
  - Intensity: 10^3 to 10^6 particles/cm^2
  - Test prototype electronics
  - Evaluate BCM threshold-response time parameter space - including Power supply and DSS response times

<u>Example from T11 slow extraction beam</u>

Single particle response (Ionization>1MIP)

- Fast amplifiers connected after 16m of cable
- Use T11 3.5 GeV hadron enriched beam

Yellow = CDS 154 Amplifier gain ~100
Purple = CDS 126. Amplifier gain ~11
Green = beam telescope coincidence