# Problems due to HIPs & Pinholes

Review of work done by Hall, Raymond, Bainbridge (IC)
and by Chierici, Huhtinen, Krammer & Hammarstrom

- Introduction
  - What are HIPs and pinholes ???
  - Internal workings of the APV ...
  - History lesson: APV instability and how it was fixed.
  - How HIPS & pinholes affect the APV.
- The HIP effect and how to solve it.
- The pinhole effect and how to solve it.

# Introduction
# What are HIPs and Pinholes ???

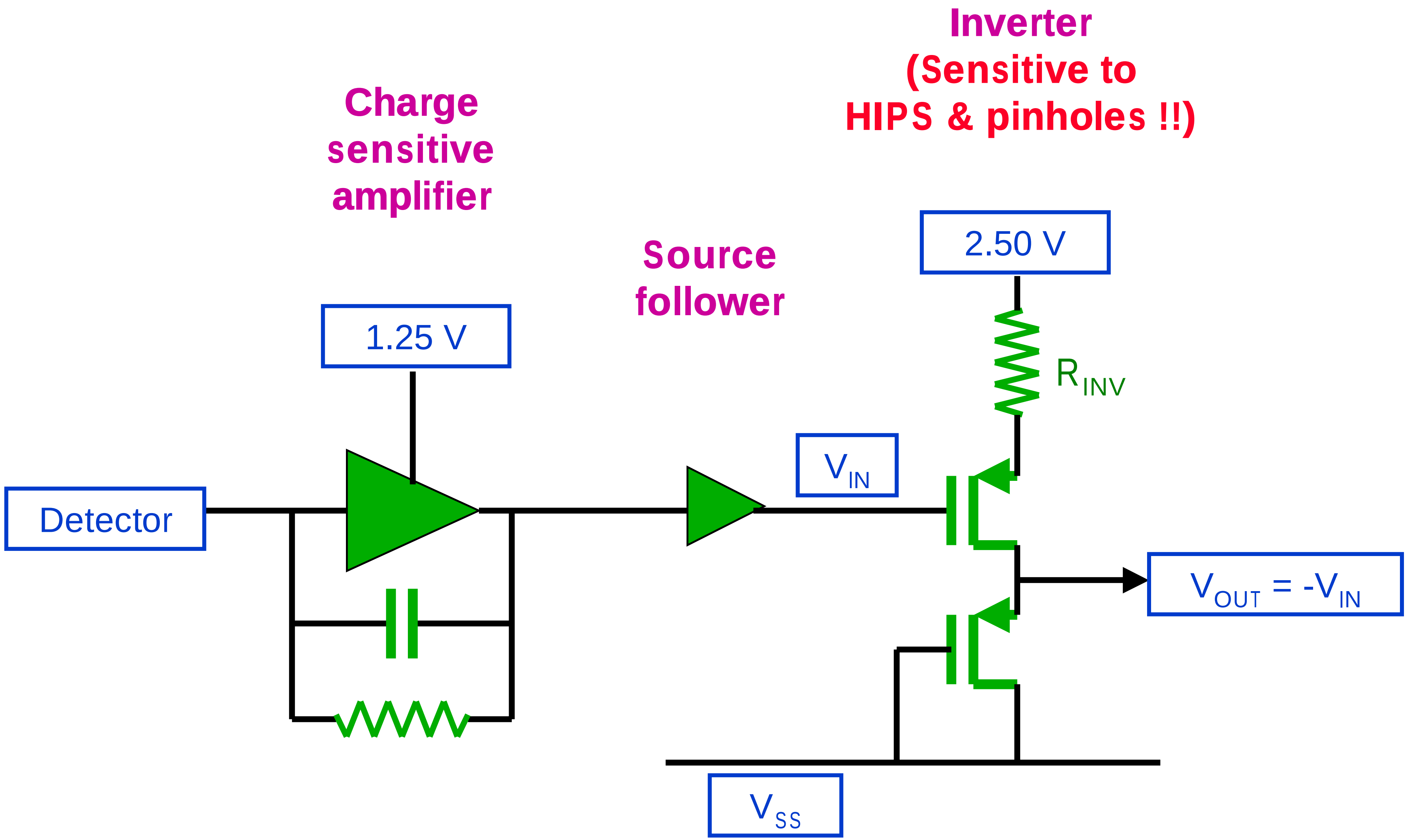
## HIPs

- Highly Ionizing Particle produced in nuclear interaction of particle crossing the silicon (a rare phenomenon).
- HIP gives big signal on a few strips.
  - This can saturate (disable) entire APV (128 channels) for ~200 ns.

## Pinholes

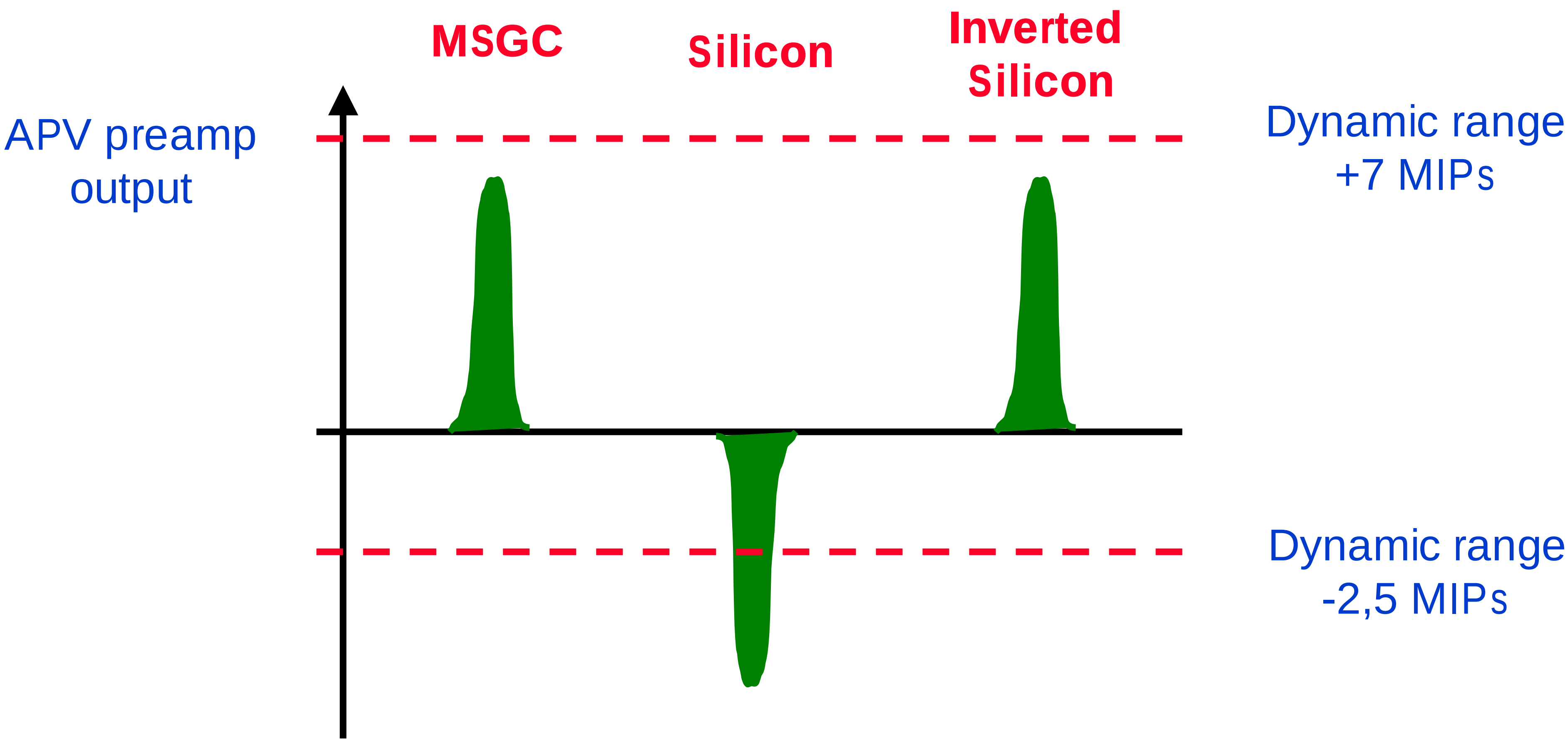
- Detector strips are capacitively coupled to APV.
- The capacitors can occasionally have a short circuit (pinhole).
  - Can give continual (DC) current into APV, which can permanently disable APV.
  - (Problem only arises if $I_{leak}$ is big and several pinholes are present.)

# Introduction
# Internal Workings of the APV



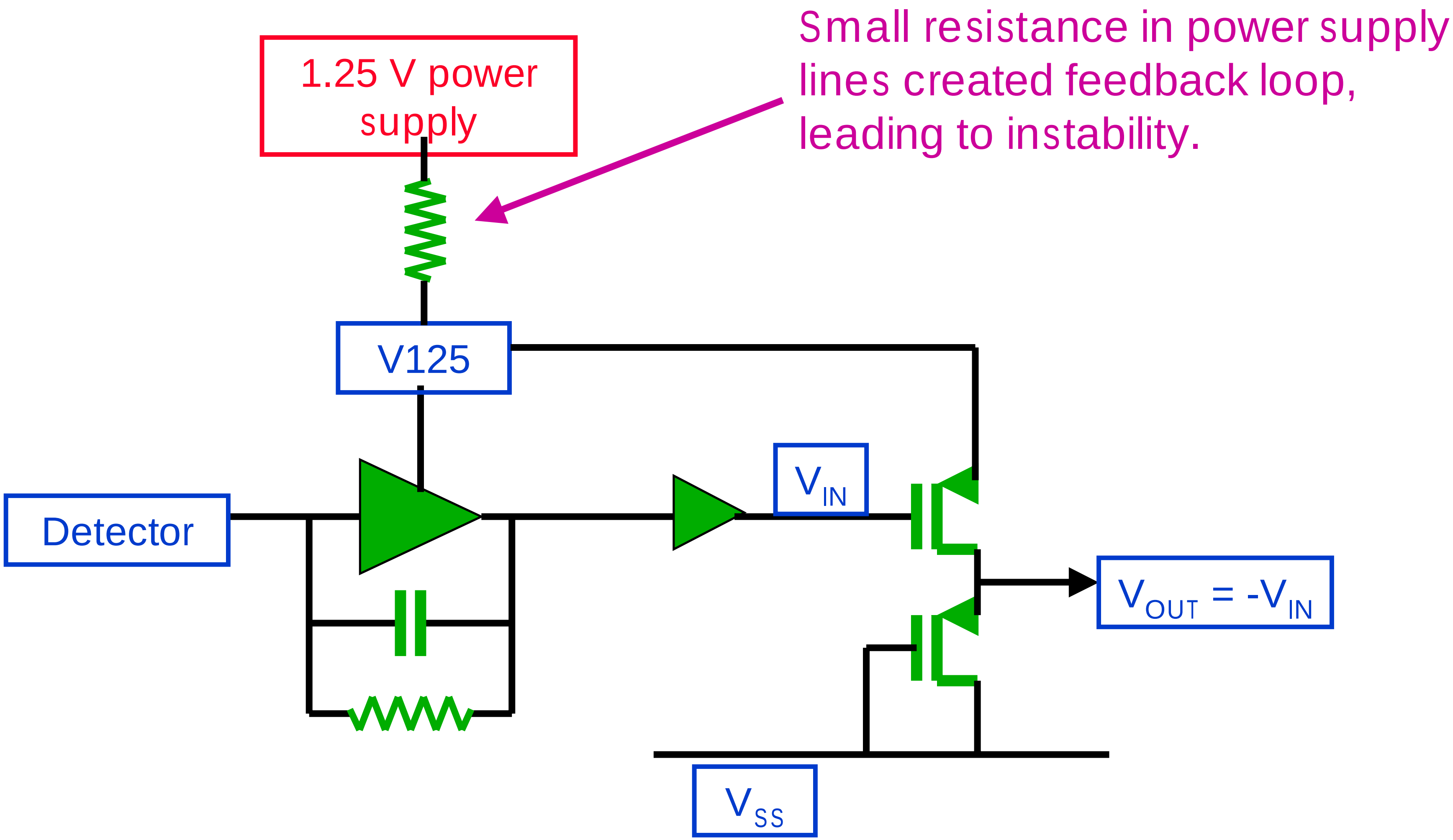
# Introduction
# Internal Workings of the APV

Why is the inverter there ?
– It increases APV dynamic range for silicon strip detector.



# A History Lesson: APV Instability and how it was fixed.

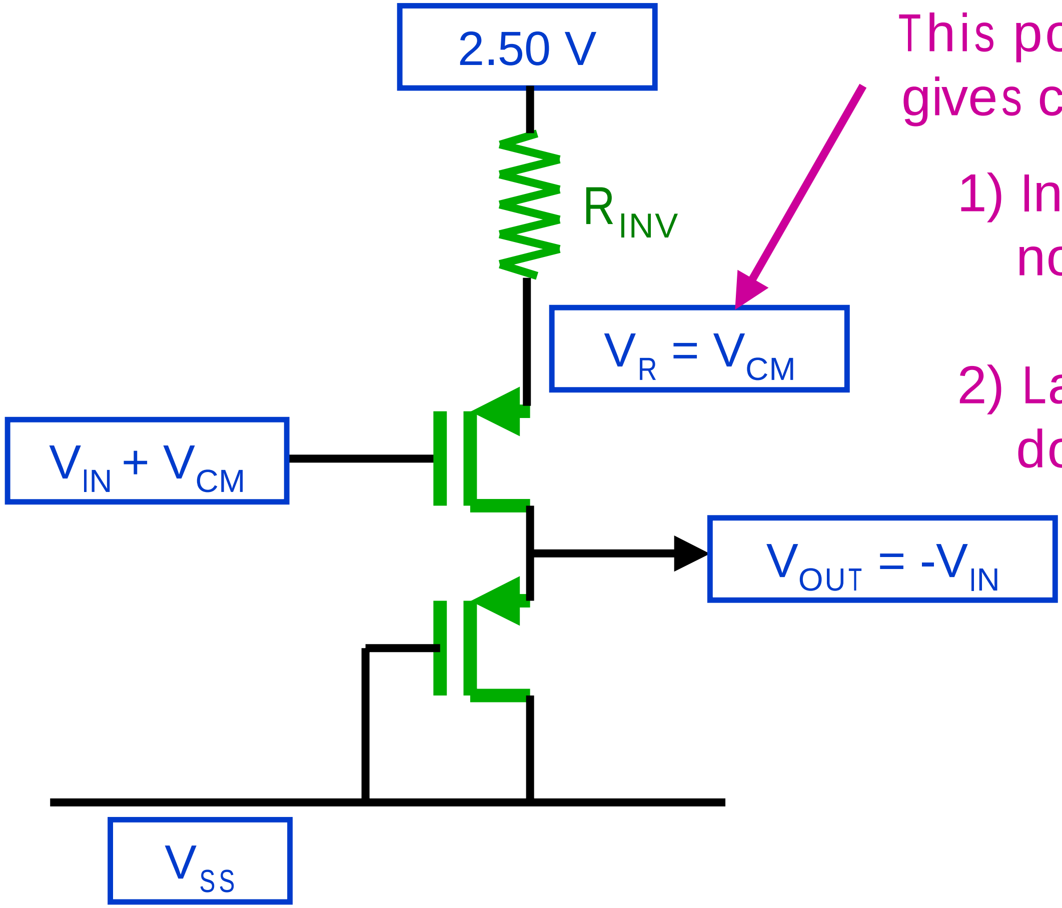
## Once upon a time ...



# A History Lesson: APV Instability and how it was fixed.

## Solution ...

Power inverter from 2.50 V instead (via 100Ω resistor).

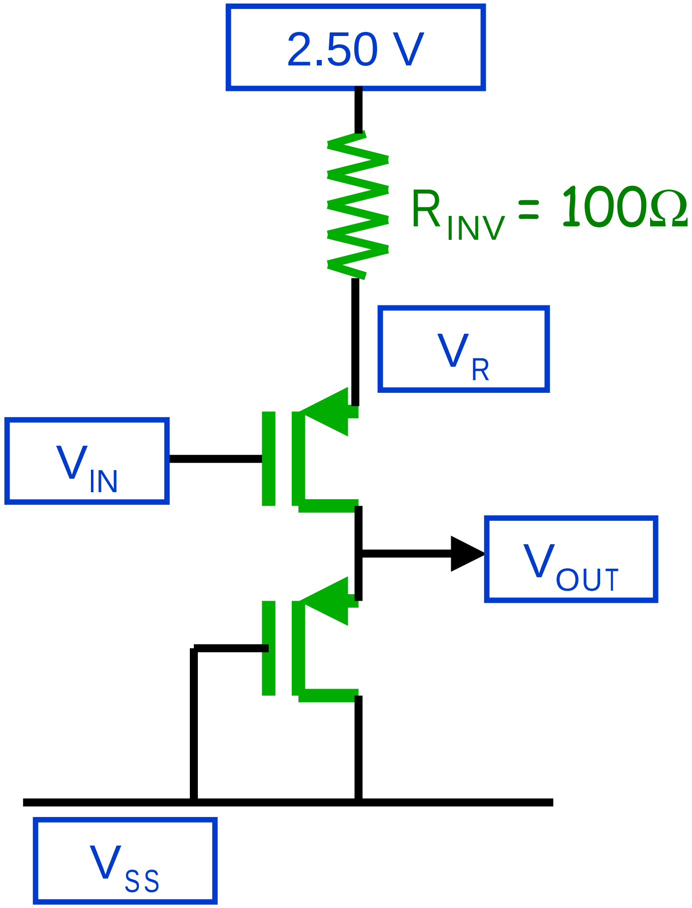



This point common to all 128 inverters -- gives cross-talk effects:

1) Insensitivity to common-mode noise.

2) Large signal on one channel drives down output on other 127 channels.

# Introduction
# How HIPs & Pinholes affect the APV




- **Big signal from silicon (holes) gives -ve pulse at $V_{IN}$ :**
  - Inverter FET switches hard on, which steals current from 127 other inverters. (APV disabled until capacitor discharges.)
  - N.B. If $R_{INV}$ were reduced, total current available to inverters would increase.

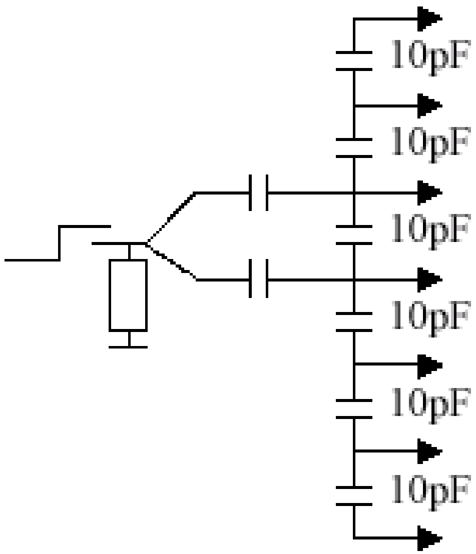
- **Leakage current via pinhole into APV :**
  - Same again, but permanent.

- **Leakage current via pinhole out of APV :**
  - Inverter FET switches hard off. Takes no current, so other 127 channels still work.

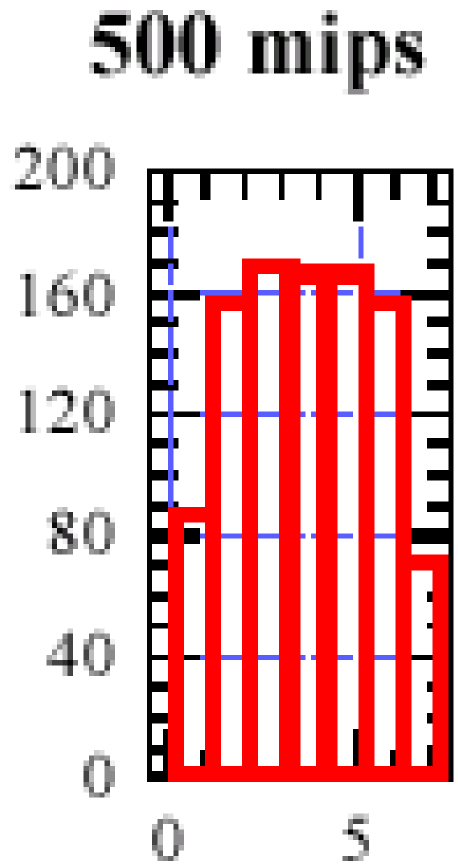
## APV Dead-Time Measurement by Charge Injection

Expect a HIP to deposit charge on one or two strips (based on FLUKA simulation). However, this charge will be spread over several APV input channels because of inter-strip capacitive couplings. So …

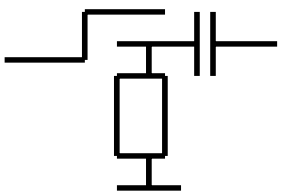
Inject up to 1000 MIPs on one or two channels




Spread it to several channels with 'inter-strip capacitors'



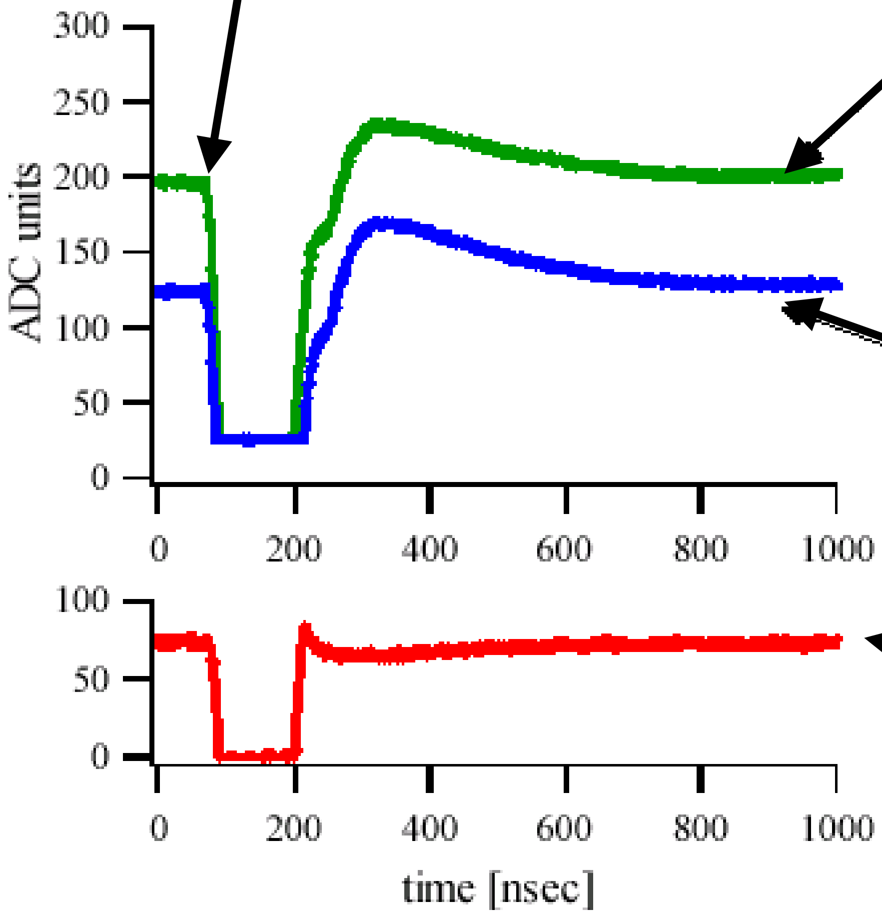

Inject 1 MIP on one other channel



## Dead-time Measurement Technique

Inject HIP here

Inject 1 MIP several hundred nanoseconds after HIP, and this is the resulting signal.

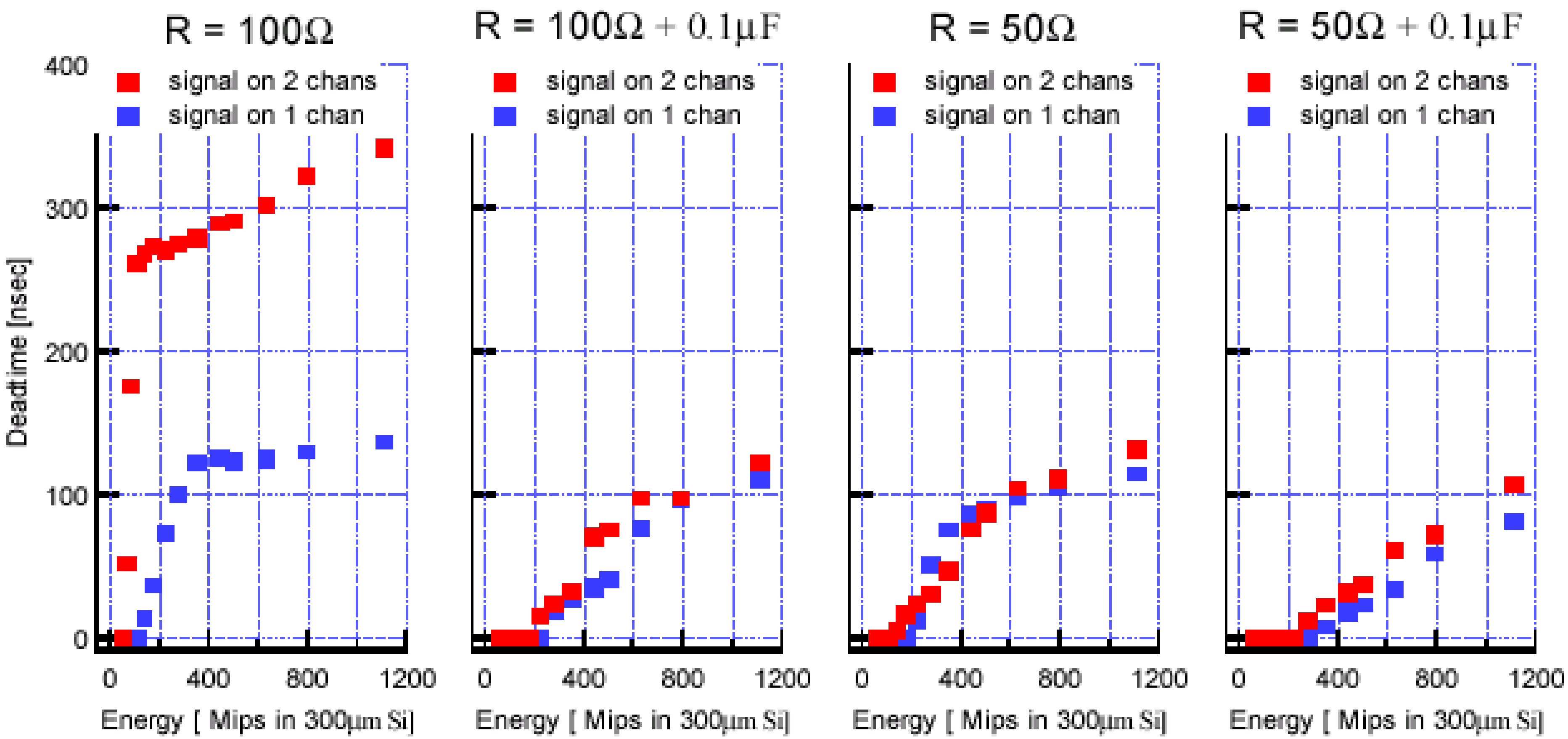



Baseline measured at same time as 1 MIP signal

Signal minus baseline (If zero, APV was dead)

# The HIP Effect and how to solve it

## Dead-time vs. HIP energy for HIP injected on 1 or 2 channels.

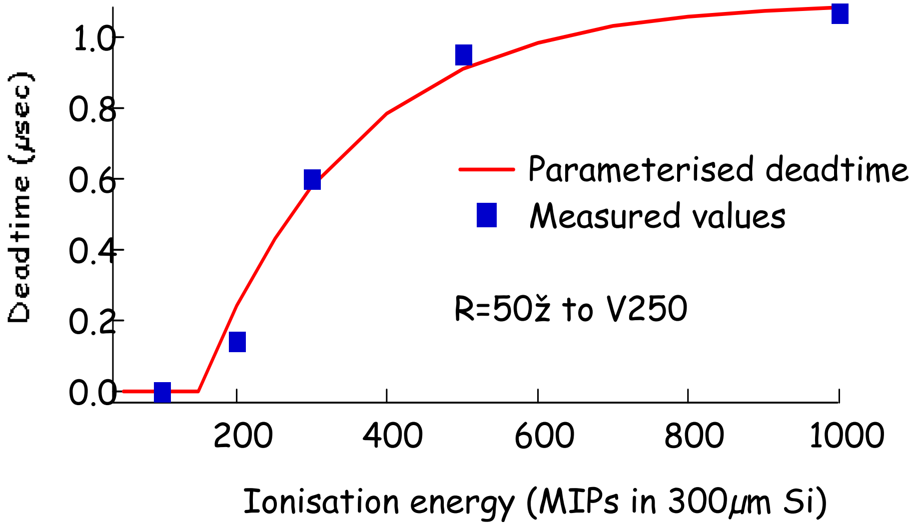



N.B. Dead-time decreases if $R_{INV}$ reduced to 50Ω or if $R_{INV}$ bypassed by capacitor (Expected from SPICE simulation).

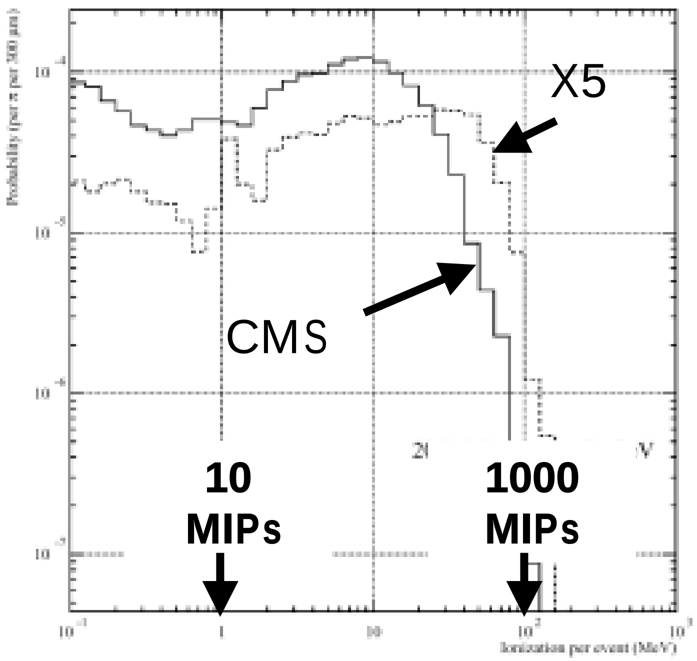
# The HIP Effect and how to solve it

## Estimate APV inefficiency at CMS.

Measured dead-time versus HIP energy




FLUKA estimates of
Prob. (HIP energy)




Inefficiency = $\Sigma$ Prob(E) $\times$ [deadtime(E)/25ns] $\times$128 $\times$ occupancy

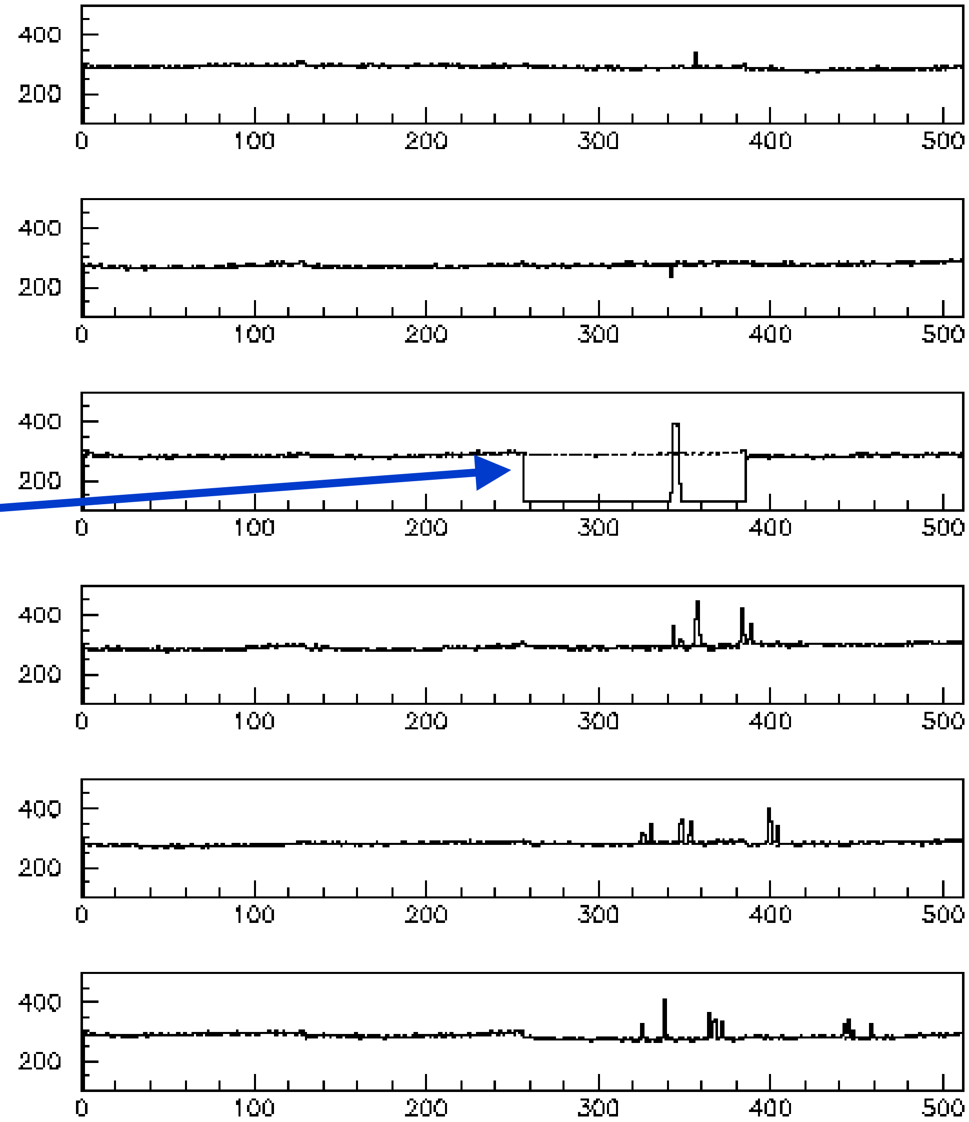
If HIP injected on two channels:

Inefficiency = 0.65% per percent occupancy if $R_{INV}$ = 100Ω

but only 0.05% per percent occupancy if $R_{INV}$ = 50Ω !!!

# The HIP Effect and how to solve it

## Observations in X5 Test-Beam



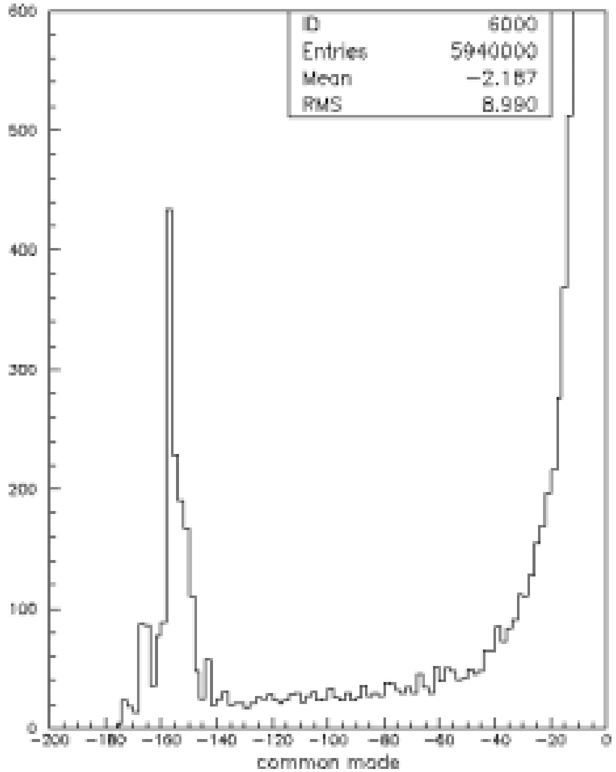

**Typical Hip event:**

- Saturated baseline, with large, wide cluster.

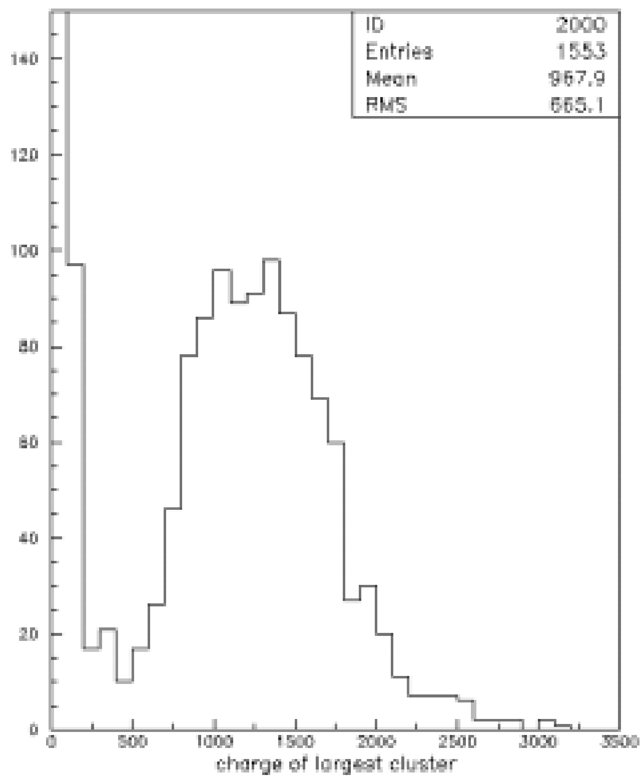
# The HIP Effect and how to solve it

## Observations in X5 Test-Beam

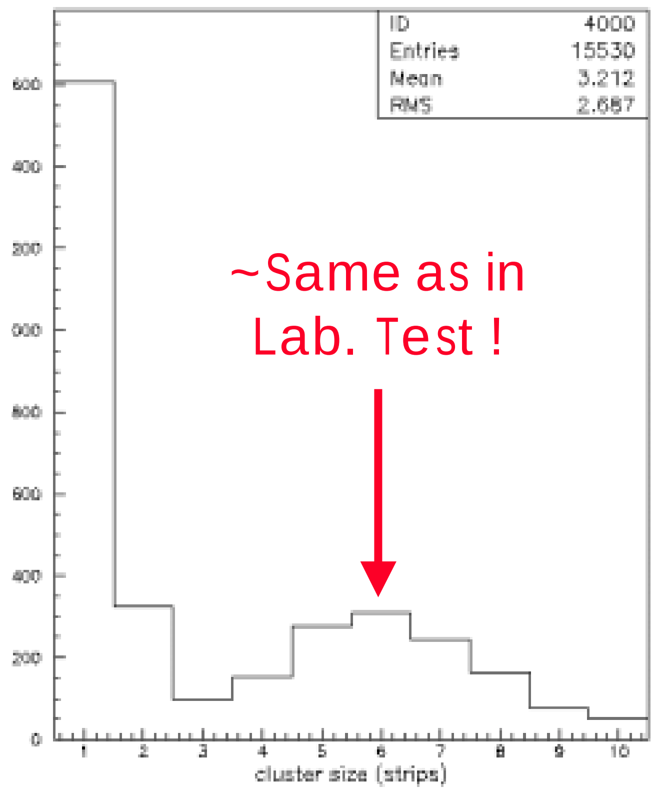
Common mode
[ADC channels]




Total charge of
largest cluster
[ADC channels]




Cluster width
[strips]



## Observed HIP rate in X5 Test-Beam

- Observed HIP (= saturated baseline plus HIP signal) rate:
  - $4\times10^{-4}$ per detector per incident pion.
  - $3\times10^{-6}$ per detector per incident muon (no nuclear interactions !)

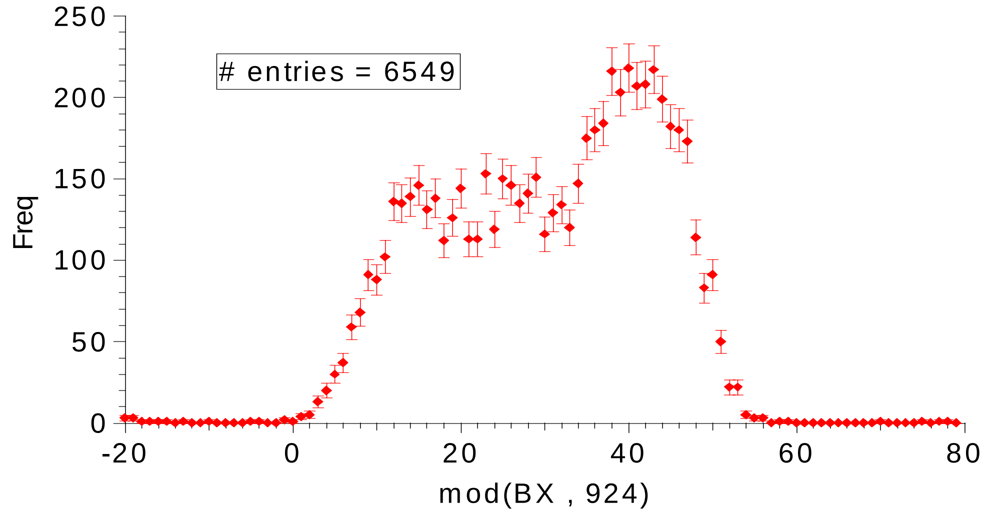
- Estimated HIP energy needed to saturate baseline
  8 – 18 MeV (based on Lab. Measurements)
  or 50 MeV (from theory if APV assumed to be linear).

- FLUKA estimates prob. that pion gives HIP energy of more than this is (1 -- 5) $\times10^{-4}$. **It agrees with test-beam measurement !**

## Observed APV dead-time in X5 Test-Beam

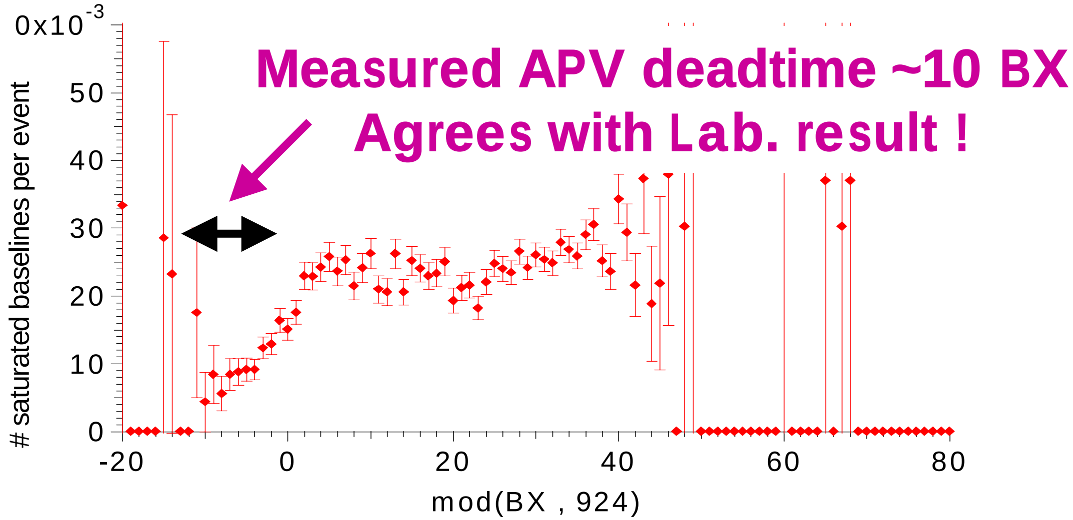
X5 beam consisted of trains about 48 BX long.

Triggers occur throughout train




Probability of saturated baseline small at start of train as can't be HIP in preceeding bunch crossings.

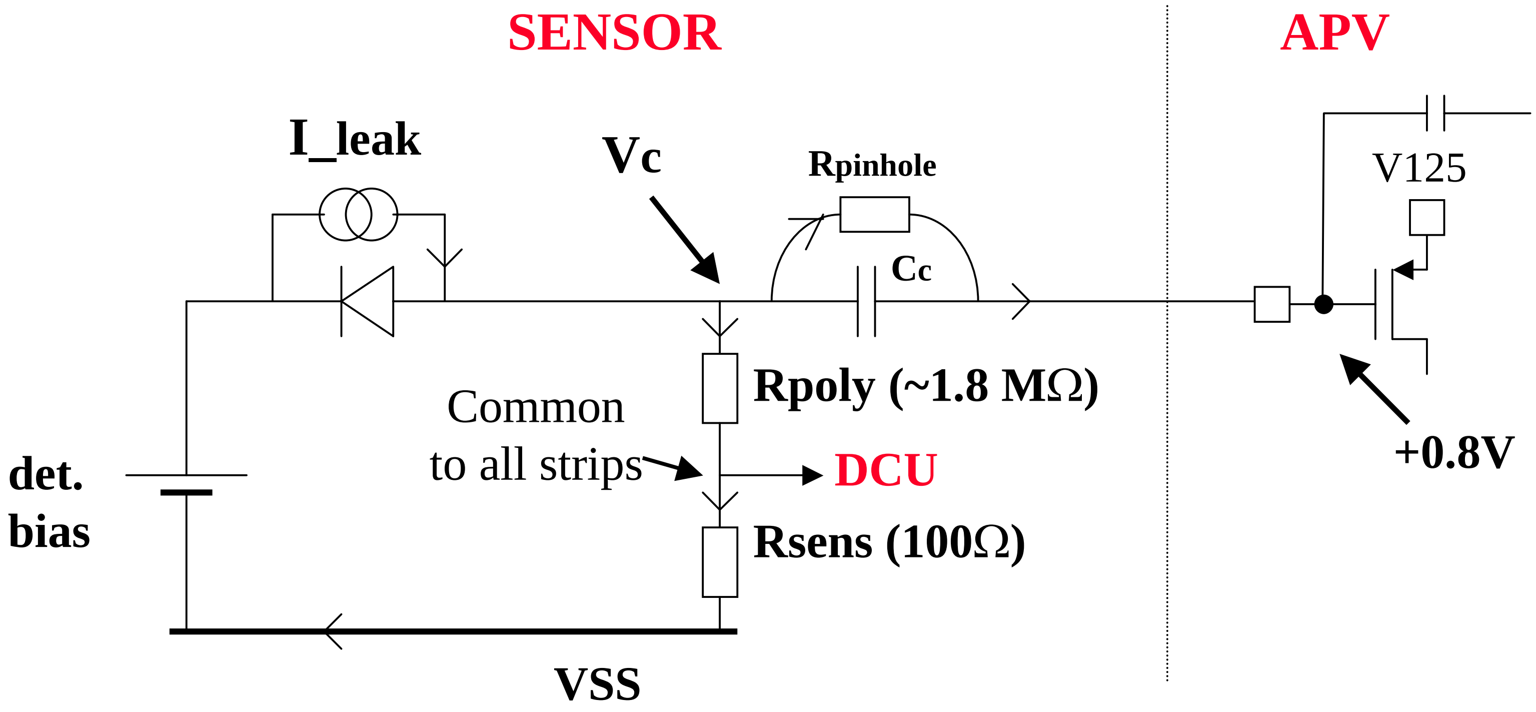
Probability saturates later in train.



## HIP Conclusion

- If $R_{INV}$ reduced to 50Ω , HIP effect gives only 0.05% APV inefficiency per percent tracker occupancy.
  - Negligible, so problem seems solved !
- Lab tests, FLUKA HIP simulation, SPICE electronics simulation and test-beam are mutually consistent.
- Results worsen if HIP charge injected on more channels, so check if Lab. Test assumptions are realistic.

# The Pinhole Effect and how to solve it



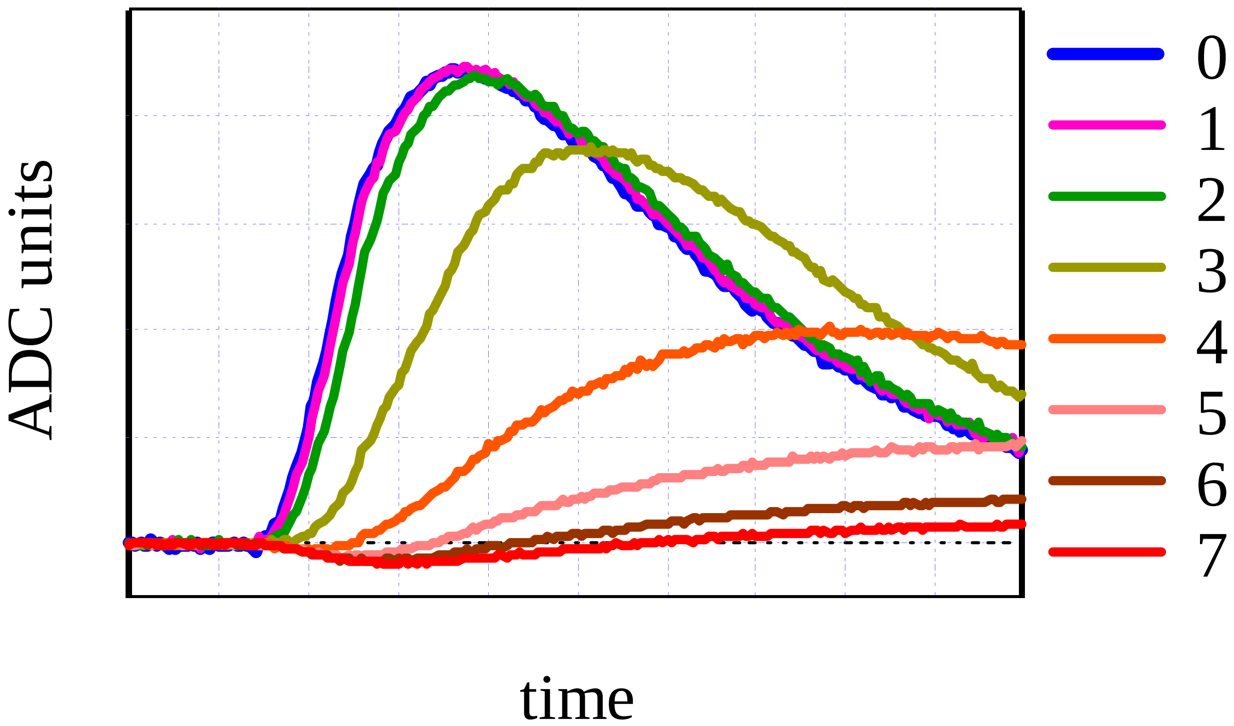

If Vc > 0.8 Volts, current flows into APV via pinhole (BAD).
If Vc < 0.8 Volts, current flows out of APV via pinhole (OK).

Vc will exceed 0.8 Volts in old detector with large leakage current.

Possible solution: If Rpoly and Rsens could be reduced,
Vc would good down !

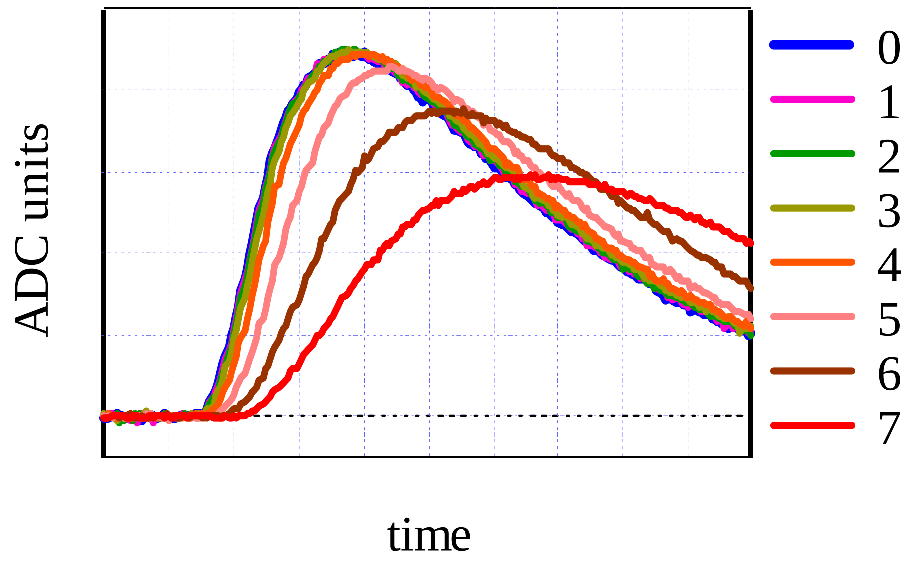
## Laboratory Measurements of Pinhole Effect

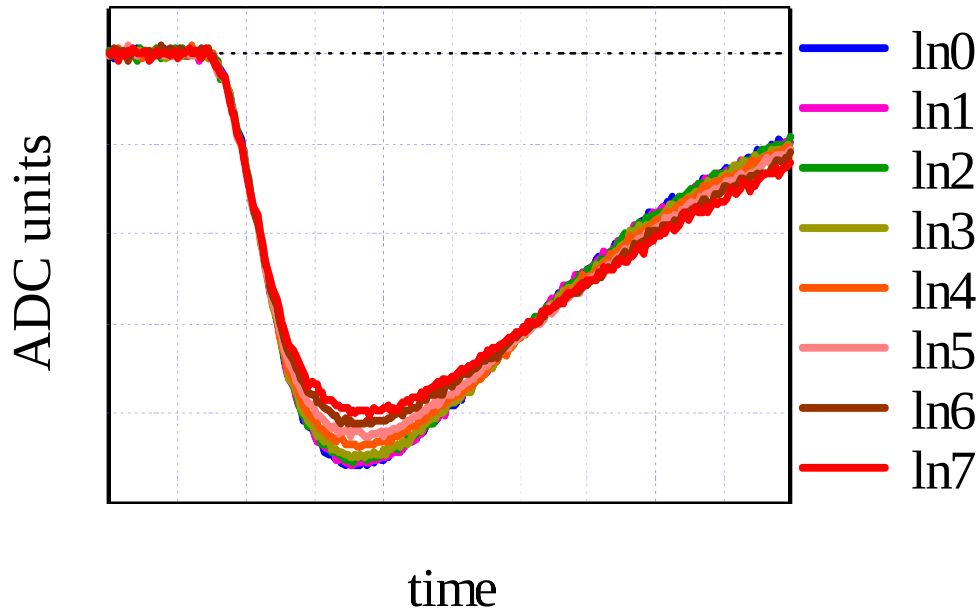
Inject 1 μA of (pinhole leakage) current into 1-7 APV channels.
Then inject a 1 MIP charge into 1 other channel and see what it looks like:




If $R_{INV}$ = 100Ω signal pulse shape suffers if > 2 pinholes !

## Laboratory Measurements of Pinhole Effect




If $R_{INV} = 50\Omega$ ,
signal pulse shape
suffers if > 4 pinholes !

If APV inverter switched off,
signal pulse shape OK for > 7
pinholes !

# Pinhole Conclusions

- If $R_{INV}$ reduced to 50Ω , APV can tolerate up to 4 pinholes (per 128 channels).
  - N.B. Accepted modules will have < 1% (2% ?) pinholes.
  - N.B. CDF observes that very few new pinholes appear during running in their Layer00 (single-sided ST + Hamermatsu detectors).
- *If* some APVs see >4 pinholes during CMS running, then we can switch off their inverters.
  - They will continue to function, with reduced dynamic range.

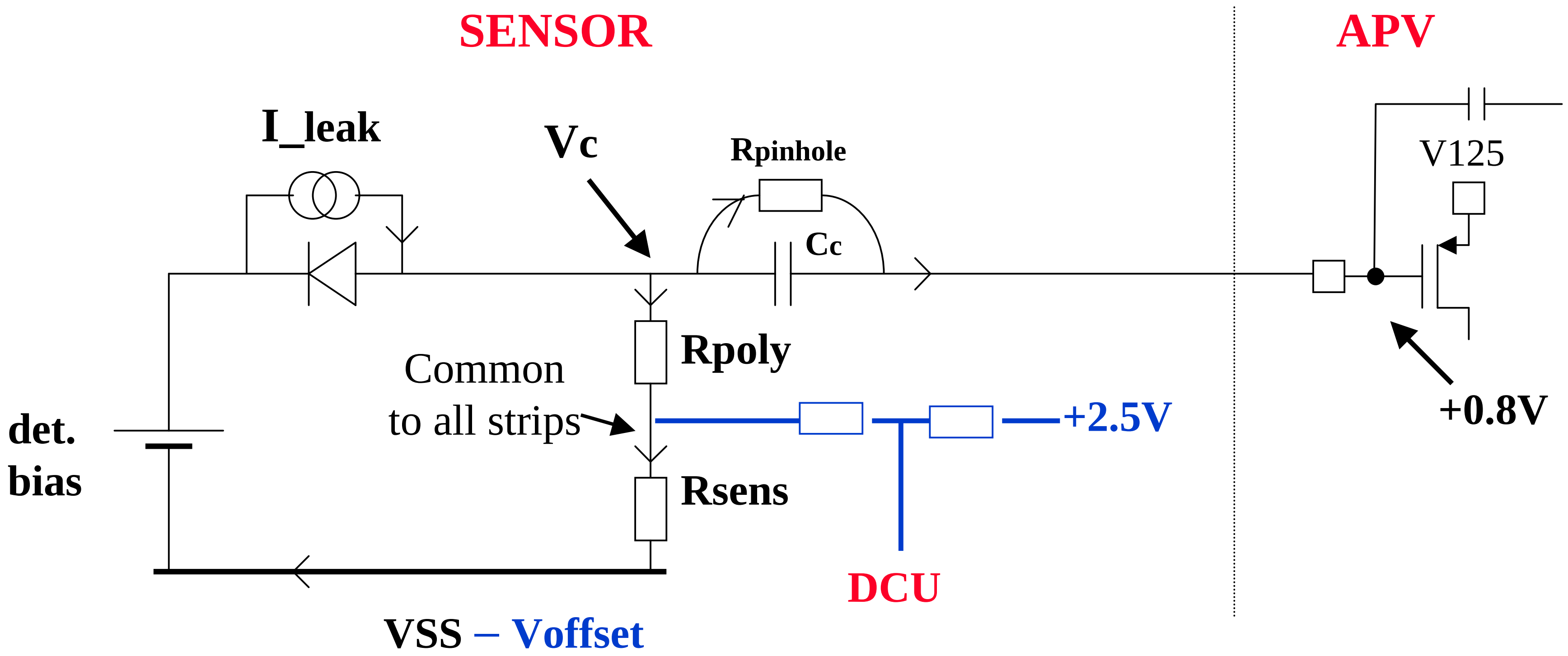
# The Pinhole Effect and how to solve it

## For completeness …

### Other possible solutions:

- Reduce Rpoly (very difficult) and Rsens (easier, but degrades DCU's I_leak measurement).
- Redesign APV (very difficult – delays project by ~1.5 years and costs money).
- Use `Hammarstrom' detector biasing scheme (interesting – worth considering).

## The Hammarstrom Detector Biasing Scheme




- ❖Reducing high voltage reference point by Voffset.
- ❖That reduces Vc too, so it never exceeds 0.8 Volts and APV stays alive.
- ❖However, makes DCU sample point too negative, so need voltage divider to bring it back within DCU input range.

# Final Conclusions

- Advise reducing $R_{INV}$ from 100Ω to 50Ω (easy):
  - Reduces APV inefficiency from HIP effect to 0.05% per percent tracker occupancy (negligible).
  - Allows APV to tolerate up to 4 pin-holes.
- If some APVs suffer > 4 pin-holes during running, propose to switch off their inverter, so they continue working (with reduced dynamic range).
- Hammarstrom biasing scheme eliminates APV pin-hole problem – should be considered.
- Other solutions (Reducing Rpoly or APV redesign)
  VERY PAINFUL and UNNECESSARY.