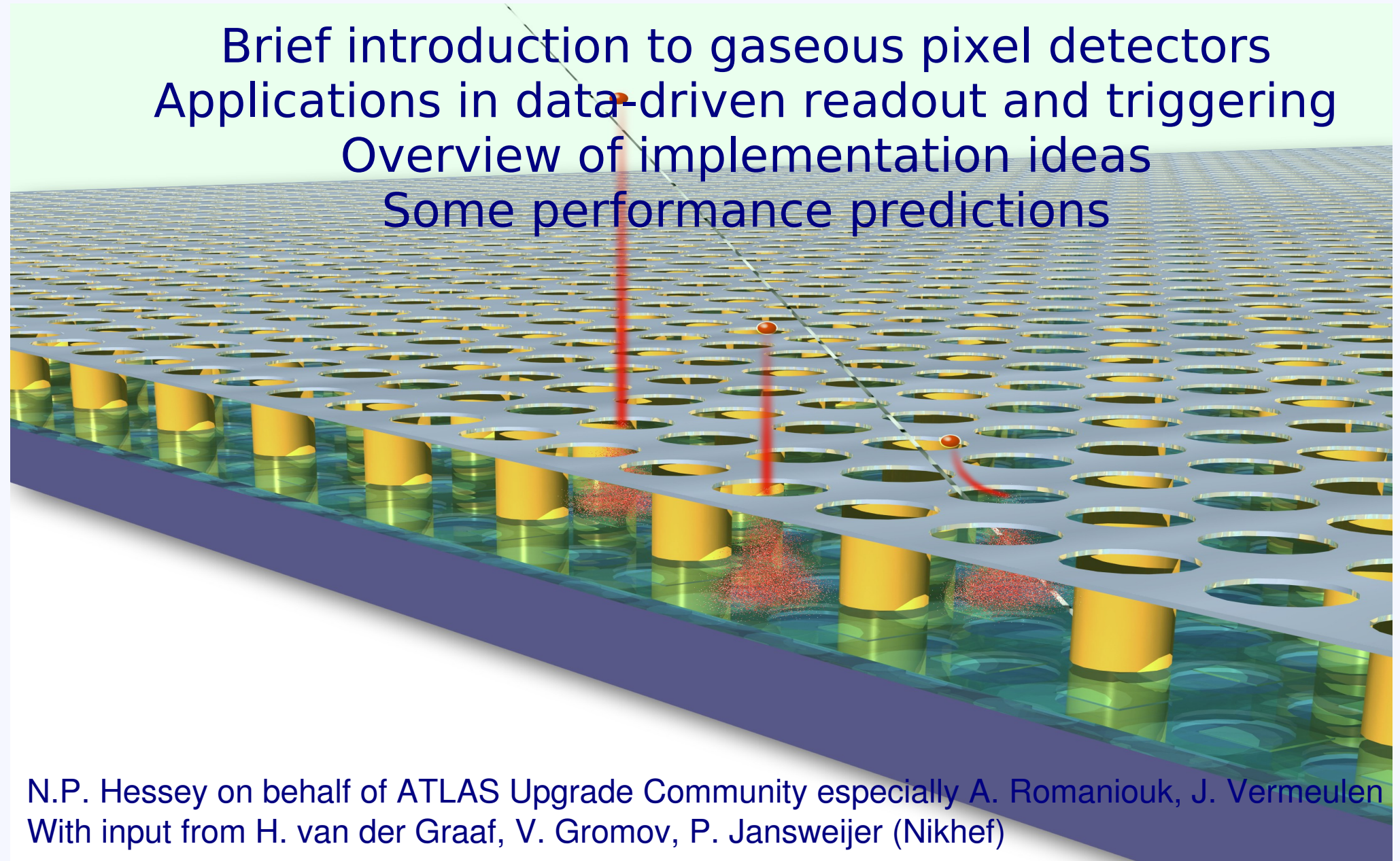




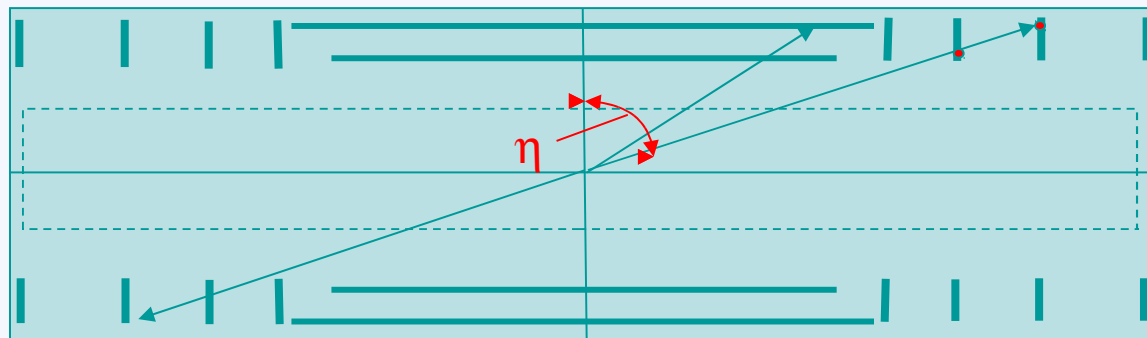
Brief introduction to gaseous pixel detectors
 Applications in data-driven readout and triggering
 Overview of implementation ideas
 Some performance predictions



N.P. Hessey on behalf of ATLAS Upgrade Community especially A. Romaniouk, J. Vermeulen
 With input from H. van der Graaf, V. Gromov, P. Jansweijer (Nikhef)



- Traditionally drift chambers rely on external detectors to trigger their readout and to determine the "t0" - the time-of-passage of a track
- The ability of a drift chamber to recognise internally when a track has passed could be a very generally useful addition
 - Triggerless/data-driven readout
 - Data reduction for reduced bandwidth in data links
 - E.g. medical applications for proton beam monitoring
- As a further step, determining the track angle can be used especially at the HL-LHC for track-triggers
 - Track triggers at HL-LHC for ATLAS and CMS are needed
 - Most work based on silicon detectors, but a gaseous pixel detector has some advantages, which is the main point of this talk



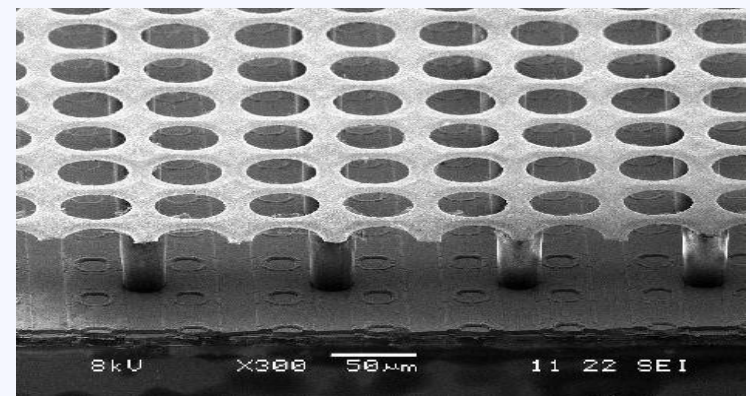
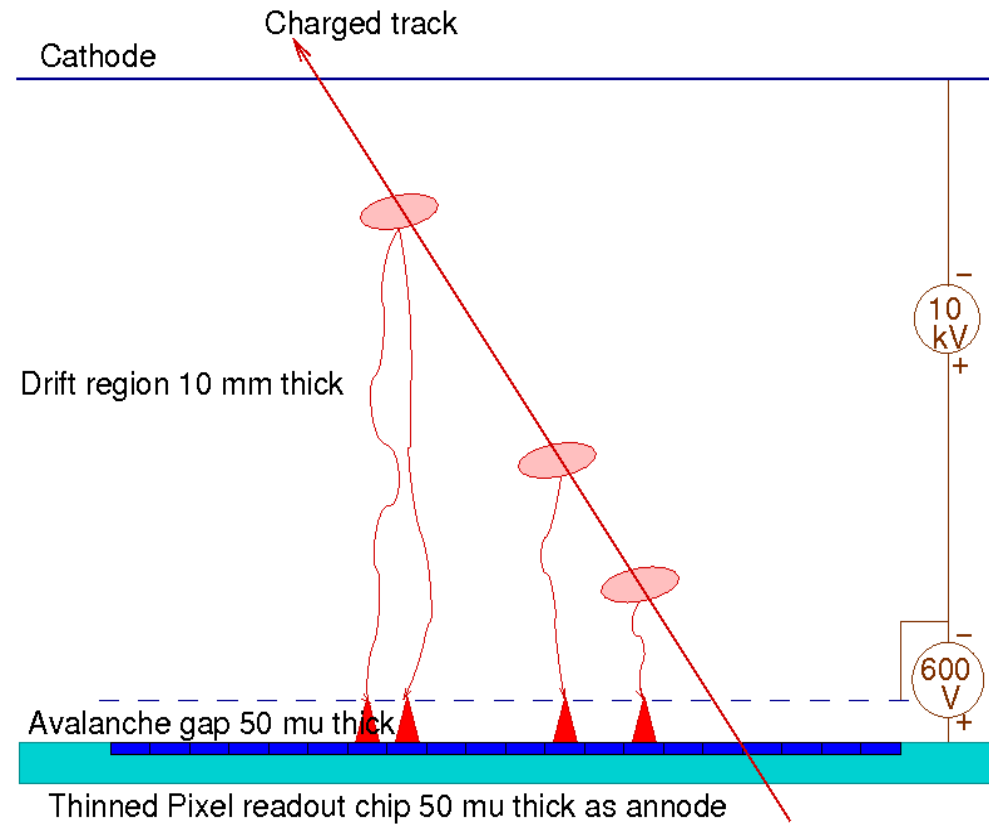
Two layers of GasPix detectors in a solenoid field for triggering on high pT (transverse momentum) tracks

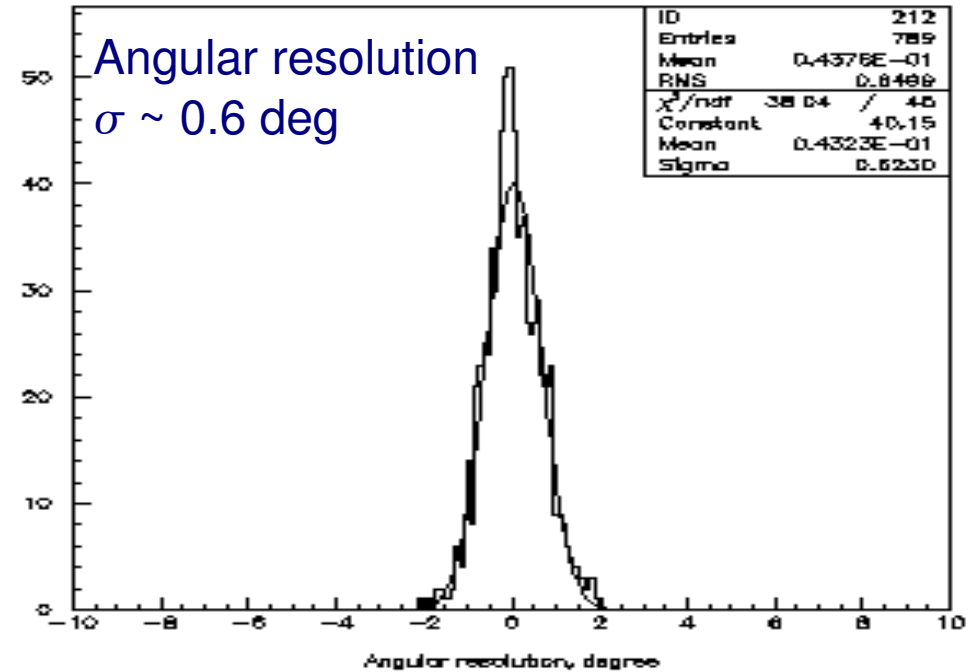
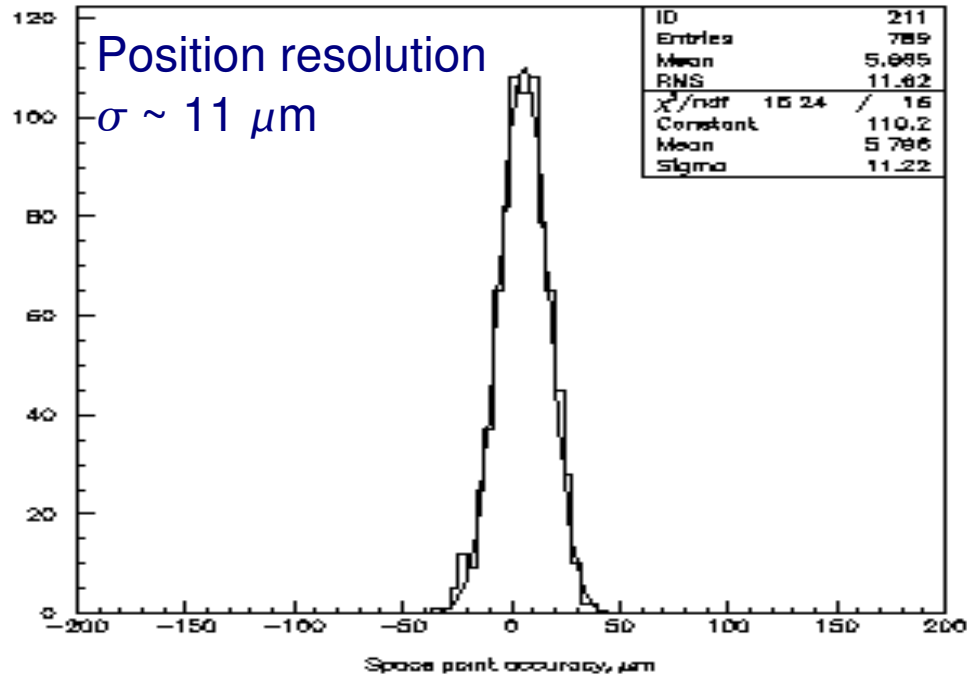


Primary ionisation electrons drifted to a grid
 - max. drift time ~ 250 ns for 10 mm
 After the grid, high field gives gas multiplication
 Pixel readout chip detects the signal
 Drift gap chosen to suit application:
 : ~ 1 mm (Gossip, B-layer region)
 ~ 10 mm outer layers e.g. track triggers
 ~ 1 m (TPC at ILC)

3D detection: x, y from pixel; z from drift time.
 ~ 20 μm each e-, each direction
 Correct time-slewing with ToT
 Gives a **track vector** (5D: x, y, z, θ , ϕ) cf 2D (strip) 3D (stereo strips and pixels).

InGrid built with MEMS techniques on readout chip
 Spark protection layer for electronics (Si-rich N)
 Support pillars between readout pads
 - no dead areas





Each primary e- detected --> much higher precision than previous gaseous detectors

Achievable Offline Performance:

Position ~ 10 micron

Angles ~ 10 mrad

Small ion-drift region (50 μm)
- high rate capability

Current results based on Timepix chip
Far from ideal - slow front end (150 ns time slewing),
10 ns tdc, and no ToT with hit arrival time

2009 Testbeam result plots from Anatoli Romaniouk, 4th
Workshop on Advanced Transition Radiation Detectors for
Accelerator and Space Applications

Currently prototyping efforts going beyond proof of
principle to reliable production and robustness



- Some main advantages:
 - Track angles in addition to position (3D hit measurement)
 - No silicon detector and bump-bonding
 - Potential for lower radiation length and cost compared to silicon pixel detectors
 - Continuously-replaced detection medium
 - Possibility for rad-hardness
 - Possibility of pT trigger in inner trackers with all data collected on one chip
 - Higher pT resolution
 - Both angles well measured of double strip layers
- Some challenges relevant to intelligence in front-end:
 - Measurement of all electrons --> much higher data rate (~50 hits for 10 mm gap)
 - Reduction of amount of data read out is desirable
 - Usually drift chambers need external reference/trigger to start readout and give track passage time
 - Stand-alone trigger for "data-driven" readout desirable

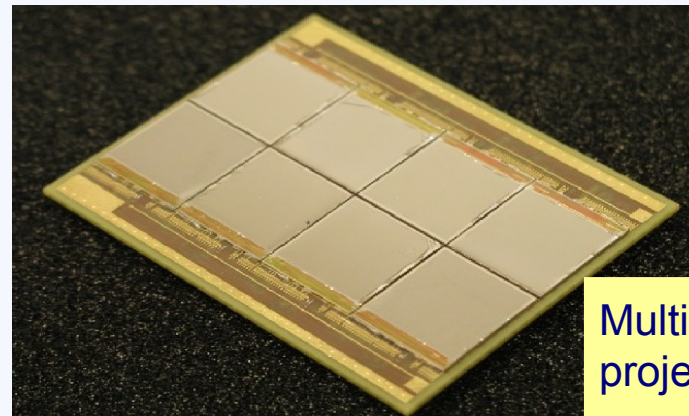


- Fast recognition of passage of a track and identify track arrival time without external input
 - Use for data-driven readout
- Fast determination of track angle
 - Correlated to particle momentum when used in a solenoidal magnetic field
 - L1Track trigger at LHC experiments
 - Advantages over silicon pixel or strip correlated pairs...
 - No 40 MHz correlator-chip and high speed local bus
 - No large CAM off-detector pattern recognition
- Dream even further: Local determination of track parameters
 - Can we switch from hits readout (pixel x and y, hit arrival time, ToT) for every hit to track readout: track x, y, theta and phi and track arrival time?
 - Much reduced data rate; higher precision and better information for L1Track Trigger



B-field	2 T	CMS is 4 T giving better resolution at equal radius
Radius	1 m	CMS may need less to reduce photon conversions
Chip size	14 x 14 mm	Like Timepix3; prefer bigger, e.g. FE-I4 ~graticule limited
Pixel size	110 x 220 μm^2	8 times bigger than Timepix: 110 μm is in phi/pT direction Electron diffusion limits advantages of going smaller than 110 μm . Other direction is less important.
Drift gap	10 mm	Larger gives longer max. drift time and needs higher voltage, but gives better pT resolution
TDC per pixel	25/16 ns bins	"tic" on plots
Peaking time	25 ns	
Gas	CO ₂ -DME 50-50	Very low diffusion but needs a high field for fast drift

Read-out chip would be combination of
TimePix-3 pixels
FE-I4 LHC-type readout
+ additional triggering circuitry



Multi-chip modules ("Octopuce" project) ~ 8cm x 4 cm or bigger



Garfield to get basic parameters -

Full simulation for:

- Ionisation features: clusters/mm, cluster-size distribution
- Drift parameters: velocity, diffusion

Fast (smearing) MC using Garfield parameters as input:

- Primary ionisation (including cluster size distribution)
- Drift (including diffusion)
- Avalanche (Polya distribution controlled by Byrne parameter)
- Signal development
 - e⁻ and ion induced signals
 - parallel plate capacitor geometry for now
- Electronics signal processing:
 - Noise, shaping (25 ns peaking time)

Process fast MC output

Simulate digital signal processing (Stage 1, 2, 3)
Get efficiencies, resolutions, histograms



- Drift detectors usually employ other detectors to determine the passage time of a track
 - Hit arrival time minus track passage time --> drift-time
 - Drift-time times drift-velocity gives 3rd coordinate
- For GasPix detectors, there is the possibility to determine the track passage time internally (with useful time resolution, ~ 8 ns)
 - In many cases, one can use external information to convert this low resolution to a high precision T0
 - e.g. at LHC, once the BC is identified the 40 MHz clock determines the track passage time very precisely
- Generally useful in many scenarios, not just LHC

See Vladimir Gromov's talk on Friday for details of how this can be implemented
Including power, space and latency estimates
Here I give a slightly different schematic, looking ahead to the pT measurement



Conceptually:

Look at a projection of hits onto drift direction
 When hits stretch from chip to cathode, a track passed in the corresponding BC

Realisation:

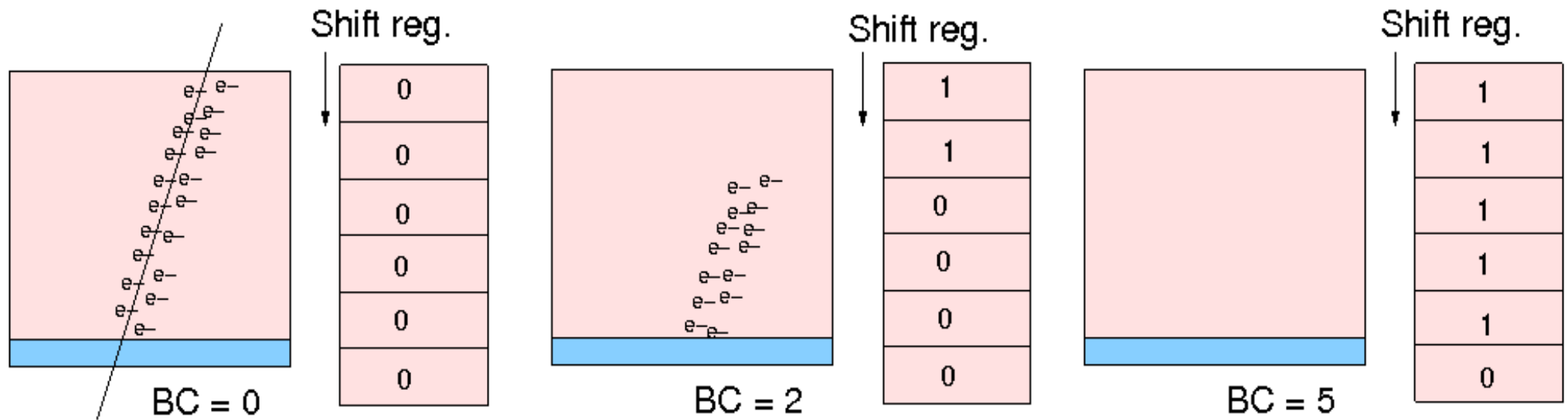
Feed hits into a shift register (SR) clocked at 40 MHz

Typically 5 e- per mm = 25 ns

- SR gets filled with continuous row of hits

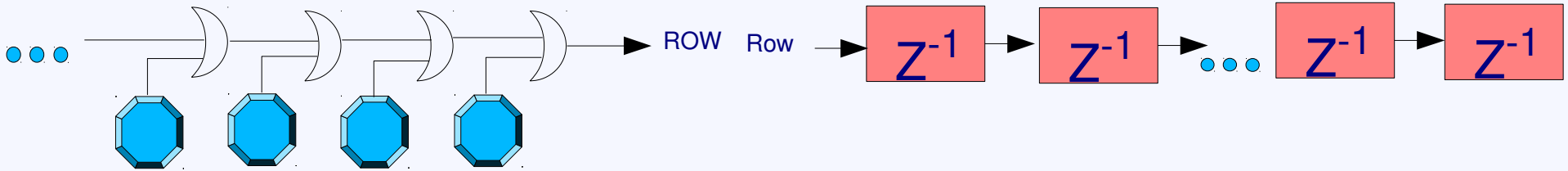
Picture below assumes max drift time = 5 BC

0 - 1 transition plus 5 registers with hits determines track arrival time





OR all pixels in a row together
 Feed each row-output into a shift register (SR) clocked with the LHC 40 MHz clock
 1-bit per row; (max. drift time + 1) cells long
 Keeps a history of an entire row for duration of max. drift time

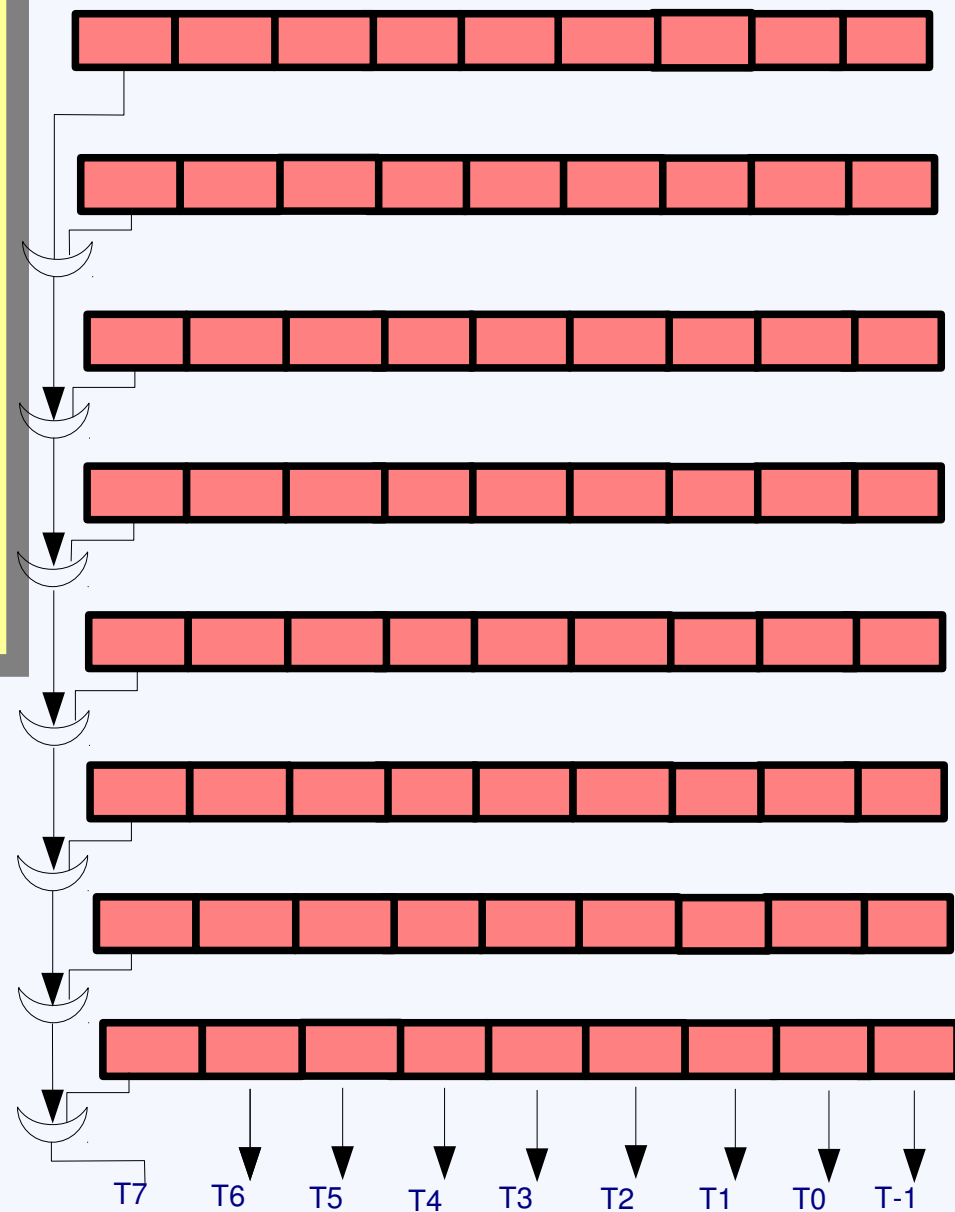




Split chip into several phi-regions: here 8 rows wide
 Number of rows depends on the track angles you are interested in; 16 might be more interesting at LHC

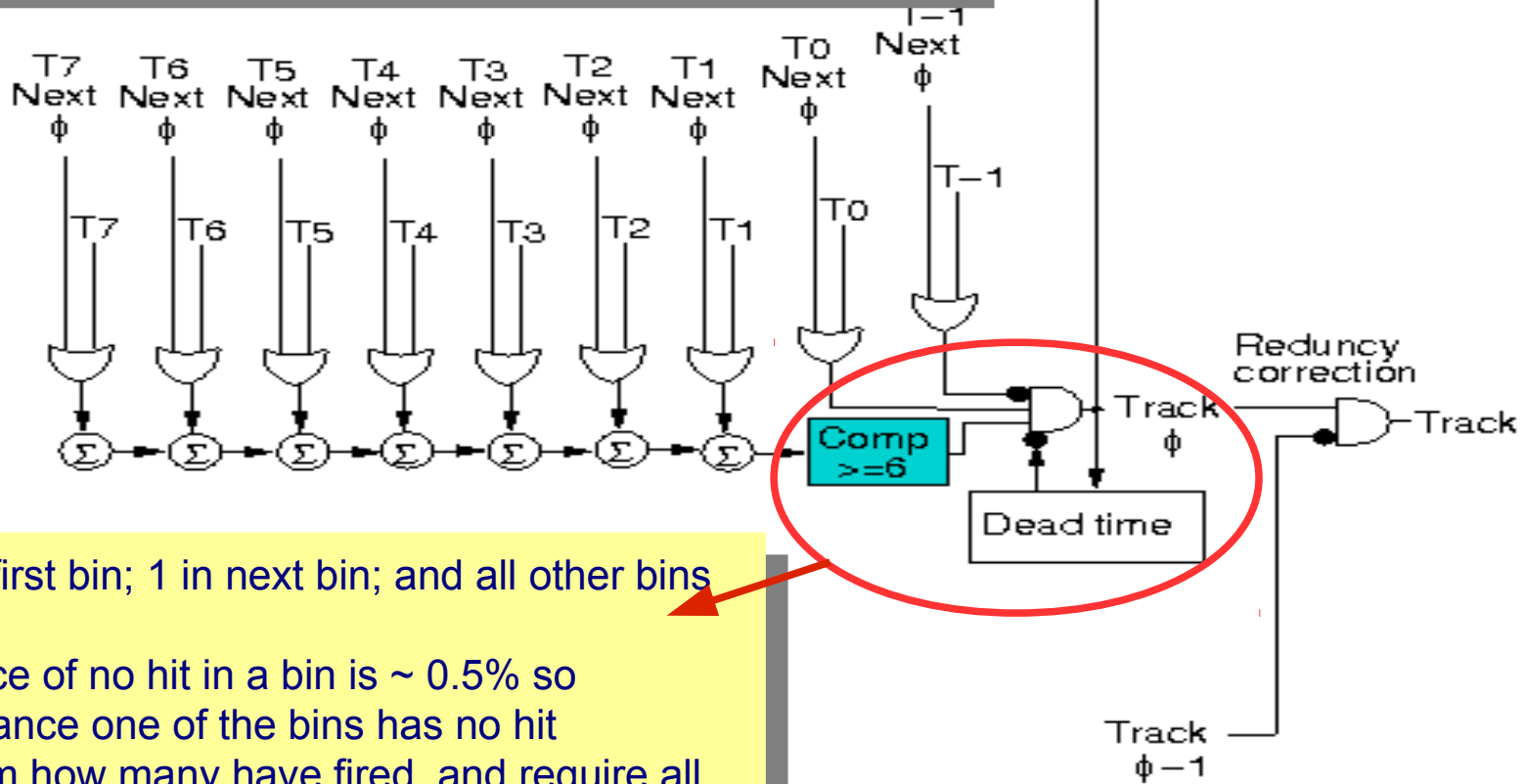
Within each region, OR the SR-cells in all rows (vertically)

T-1 is the time bin before the track passed
 T7 is the time bin in which the last electrons should arrive at the pixel readout chip





Must allow for tracks which cross from one phi region to the neighbour:
 OR T-signals with corresponding T-signal from next region



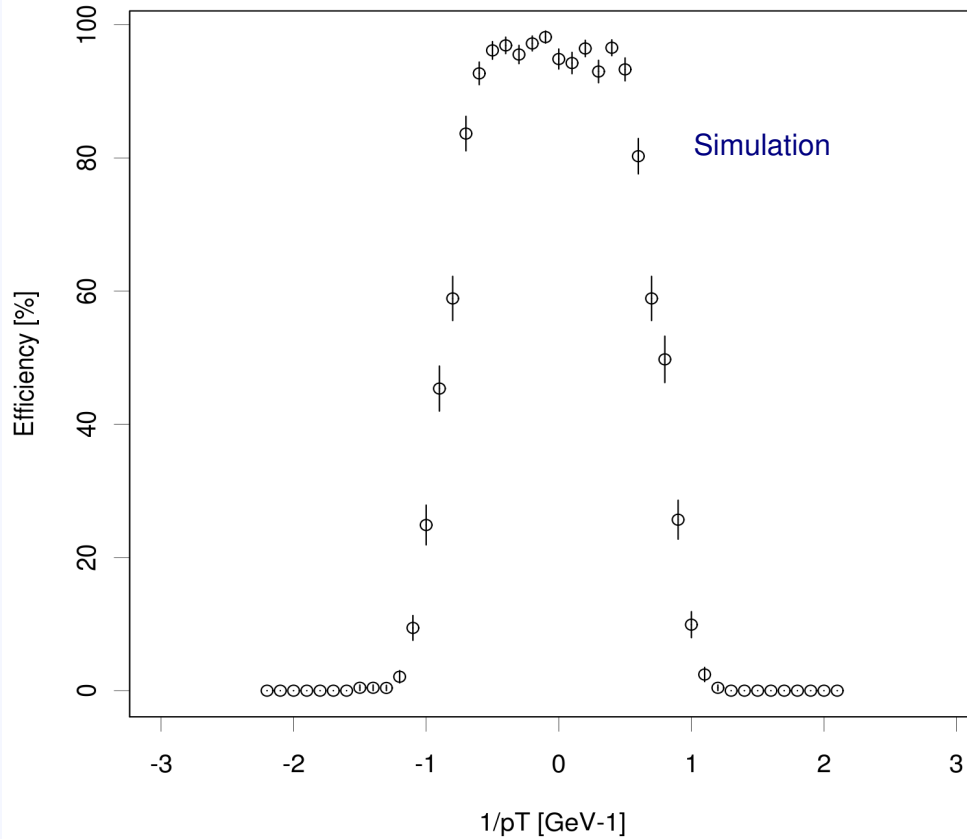
Look for 0 in first bin; 1 in next bin; and all other bins to fire.

In fact, chance of no hit in a bin is ~ 0.5% so significant chance one of the bins has no hit
 Therefore sum how many have fired, and require all or all but one to have fired.

Reduncy correction:
 Veto triggers in neighbour phi-region to avoid 2 triggers from the same track

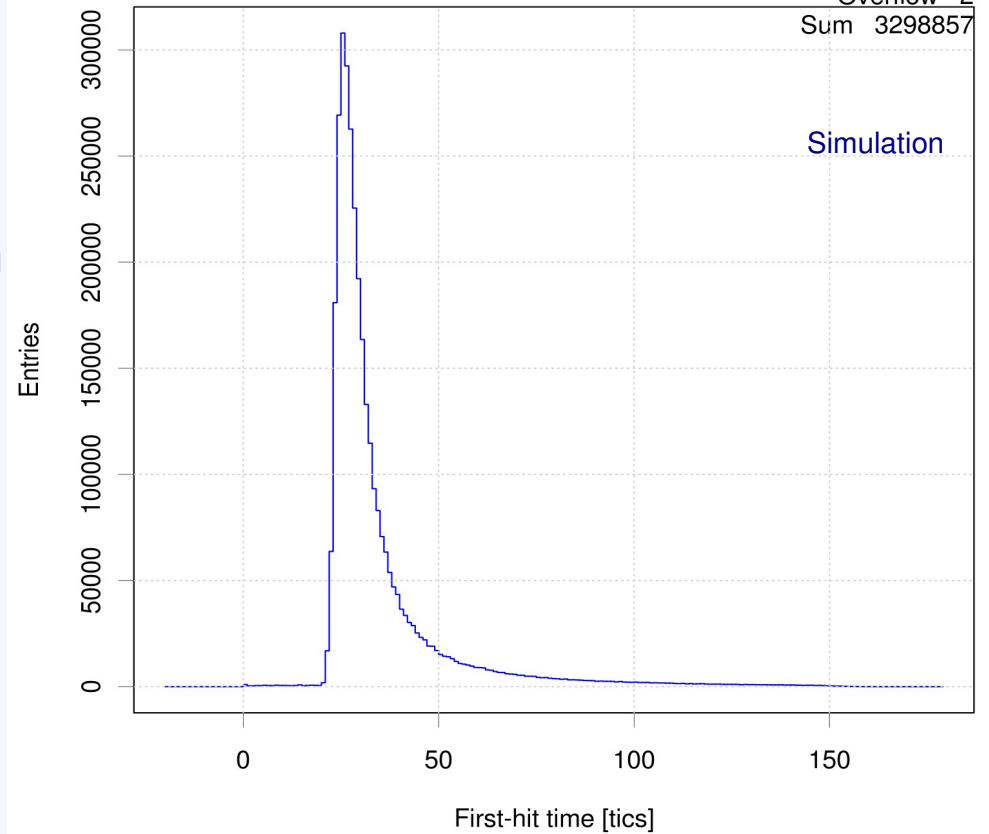


Efficiency to find track at correct T0 BC



Approx. 96 % efficient at identifying track in correct BC for $p_T > 2$ GeV/c
Use two layers for high efficiency

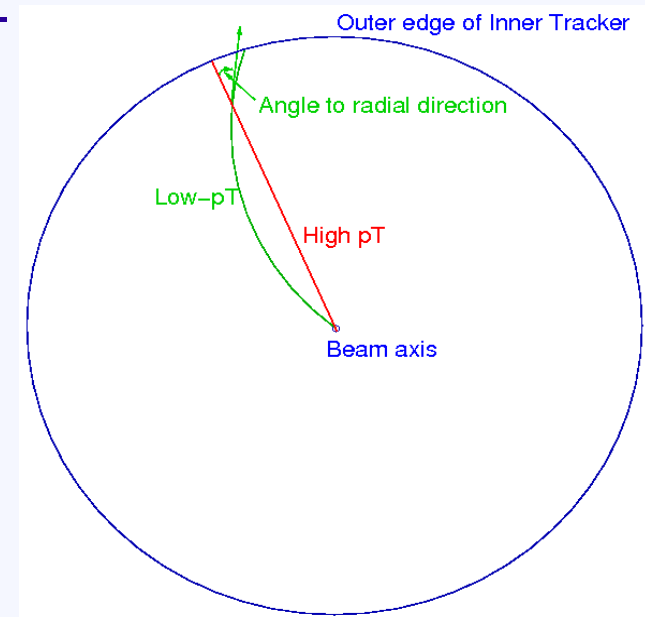
First-hit time [tics]



Time resolution:
FWHM = 8 bins \times 25/16 = 13 ns
 $\sigma \sim 5$ ns (ignoring tail)
(or: $25/\sqrt{12} \sim 8$ ns)

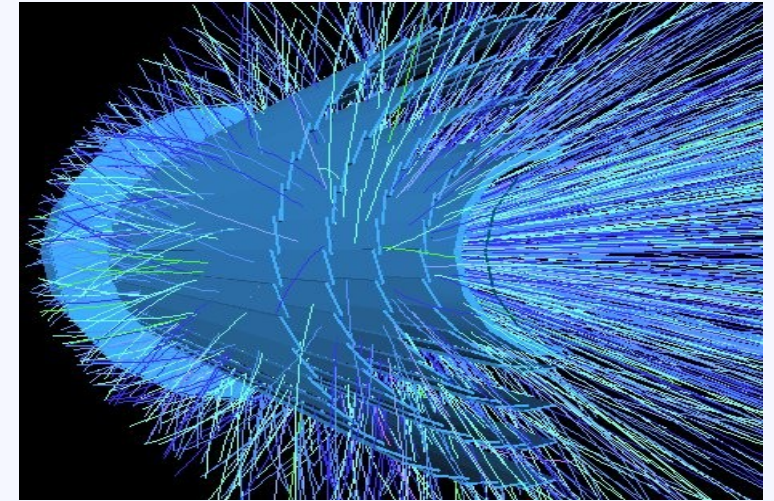


- Bring inner trackers into the L1 trigger with high-momentum track selection
- L1GasPix sends out BC, track position, and p_T information for off-detector trigger processors to analyse and make L1 trigger decision
- Similar to proposals with silicon detectors, but:
 - In place of correlator-chips and data-buses transferring hit information from one silicon detector to another, use drift of electrons to transfer the information
 - Large drift gap gives good resolution up to higher p_T
 - If silicon strip detectors are used for the trigger, the strips must be parallel and you lose 2nd coordinate precision - no track angle to magnetic field axis
 - Gas pixel detector can give good angular and second coordinate precision
 - Angle to magnetic field can be used to select tracks from primary vertex
 - No need for large off-detector array of contents-addressable memory for track pattern recognition from all silicon layers

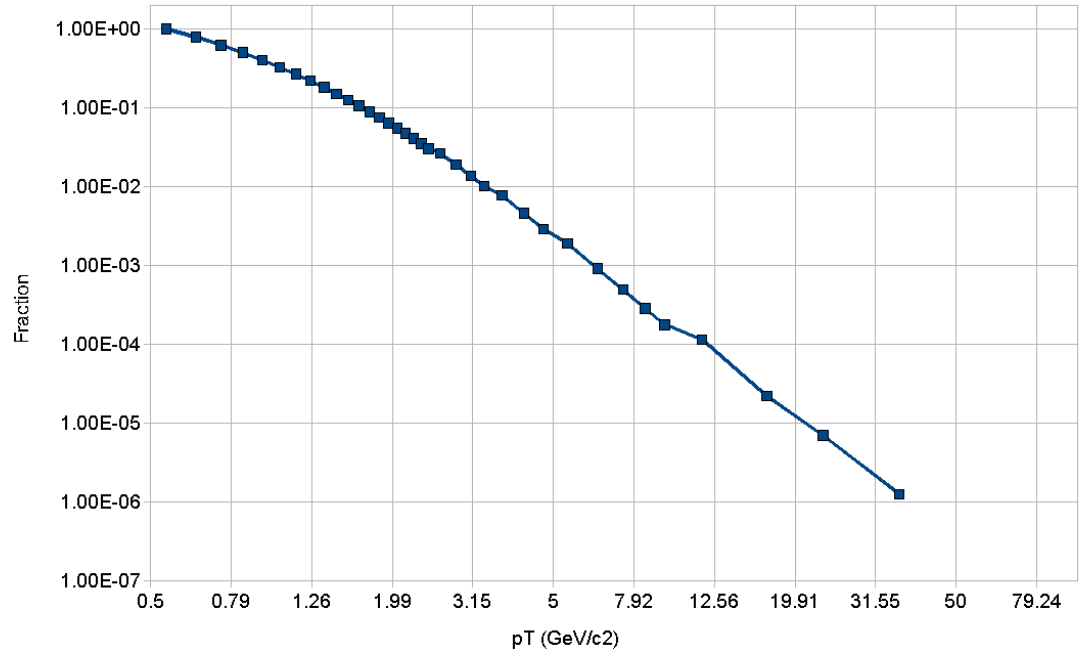




Track rates at outer radius are not so high even at HL-LHC:
 $\sim 0.25 \text{ MHz/cm}^2$ (200 pile-up)
 Drops very rapidly with p_T
 Factor 100 at 3 GeV/c: 2.5 kHz/cm²
 Factor 10^5 at 20 GeV/c \rightarrow 1 MHz total tracker rate
 Jets: Several cm between tracks
 $p_T < 300 \text{ MeV/c}$ curl up and don't reach the outer layers



Fraction of charged particles above a given p_T
 (ATLAS 7 TeV data)

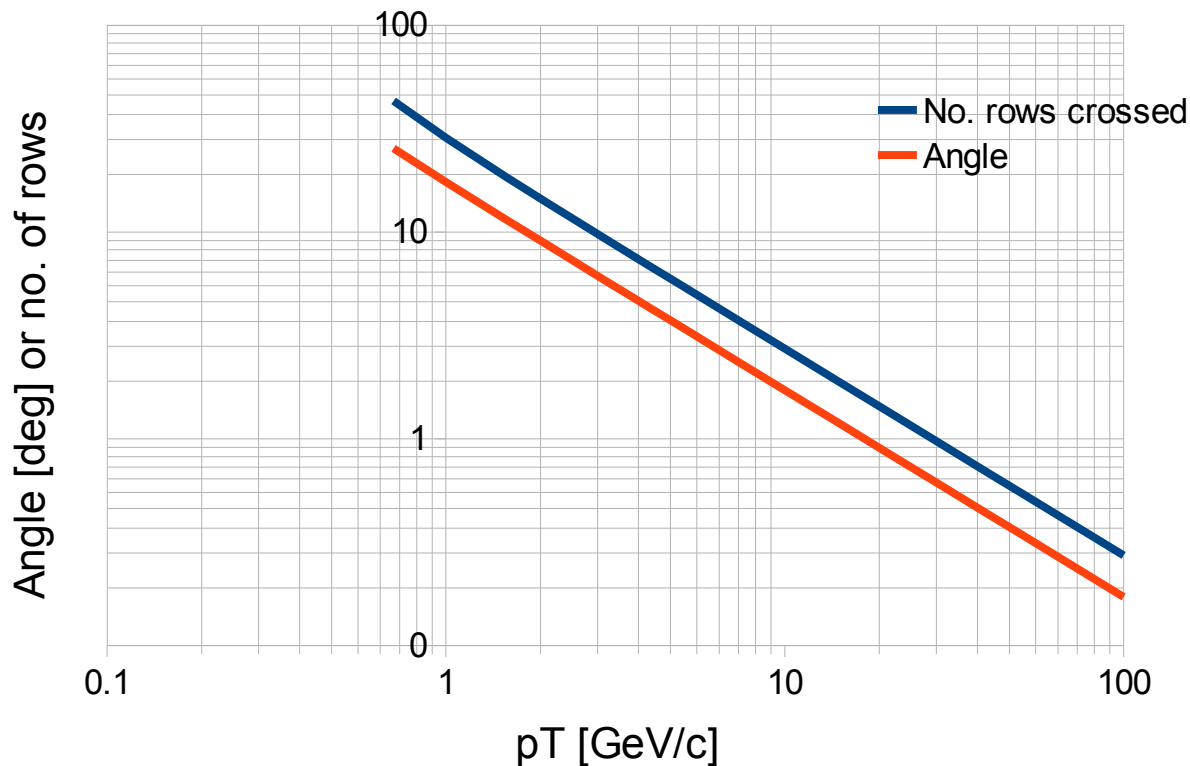




Conceptually:

Project hits onto momentum-analysing direction (rows)
 Gives a cluster of hits with width correlated with $1/p_T$

Angle and no. rows crossed vs p_T



Expect some discrimination up to
 ~ 10 GeV/c using cluster width
 Higher using full track-angle information
 Can be increased with larger drift gap



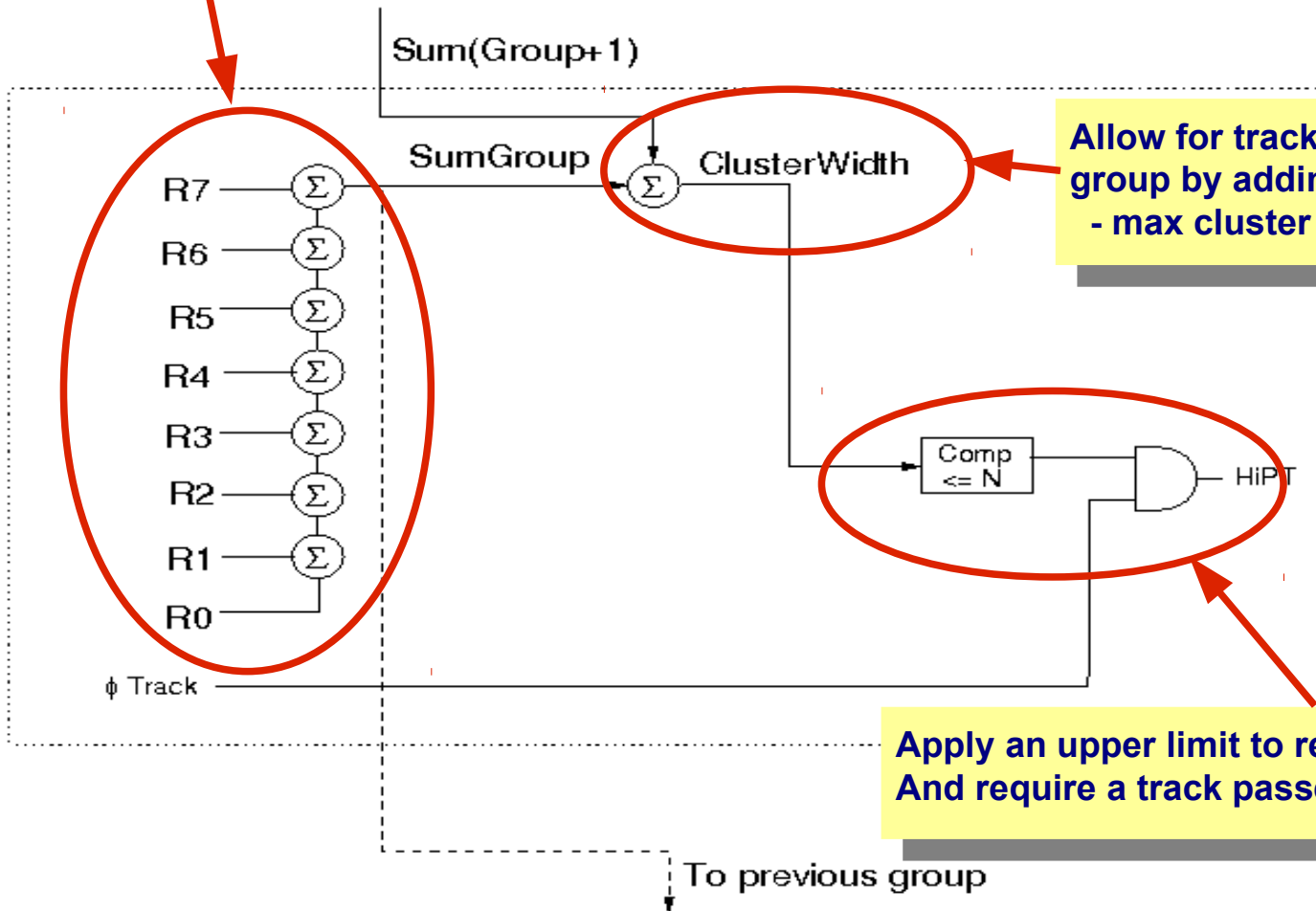
Use same SR as for T0, but now OR all times together within a row
 Produce Rn signals indicating which rows had a hit during the last maximum drift time period





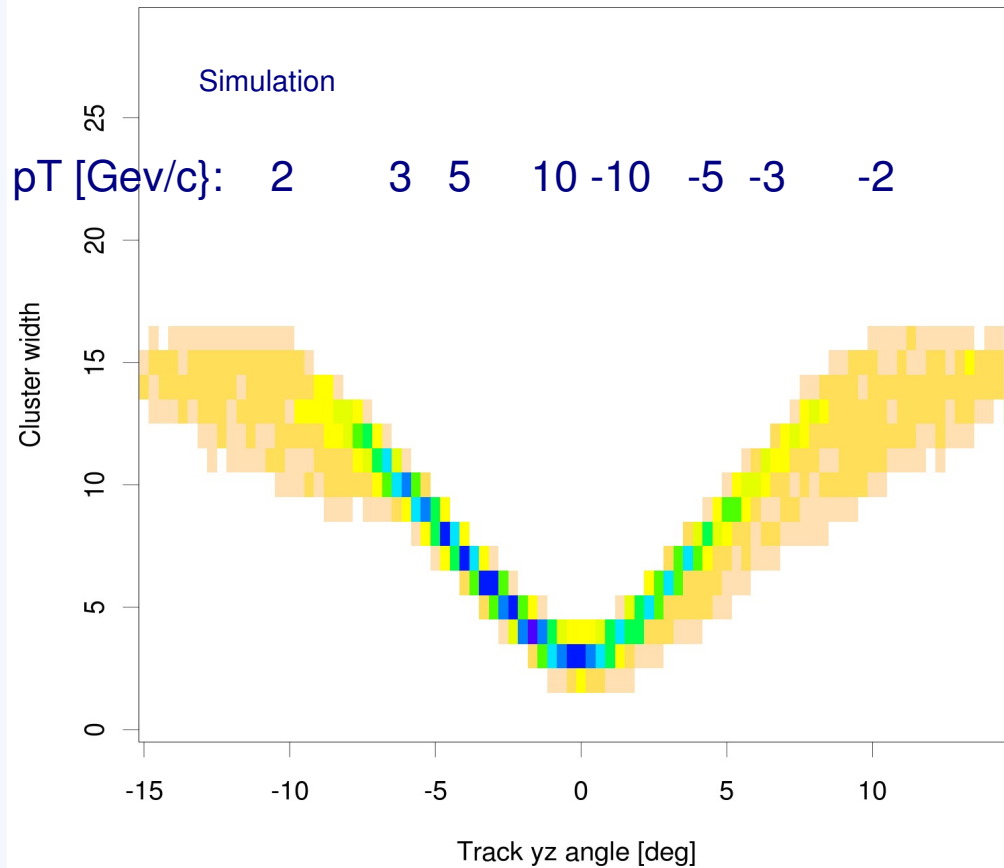
Count number of rows within a group with a hit in relevant time range

PT Selector via row cluster-width



Allow for tracks crossing to neighbour group by adding rows in neighbour group - max cluster width 16

Apply an upper limit to require high-pT tracks And require a track passed in this BC



Max measured is 16, i.e. twice the group width
Increasing the groupwidth to say 16 would
halve the pT-threshold for track recognition

A higher threshold can then be recovered with
a cluster width cut

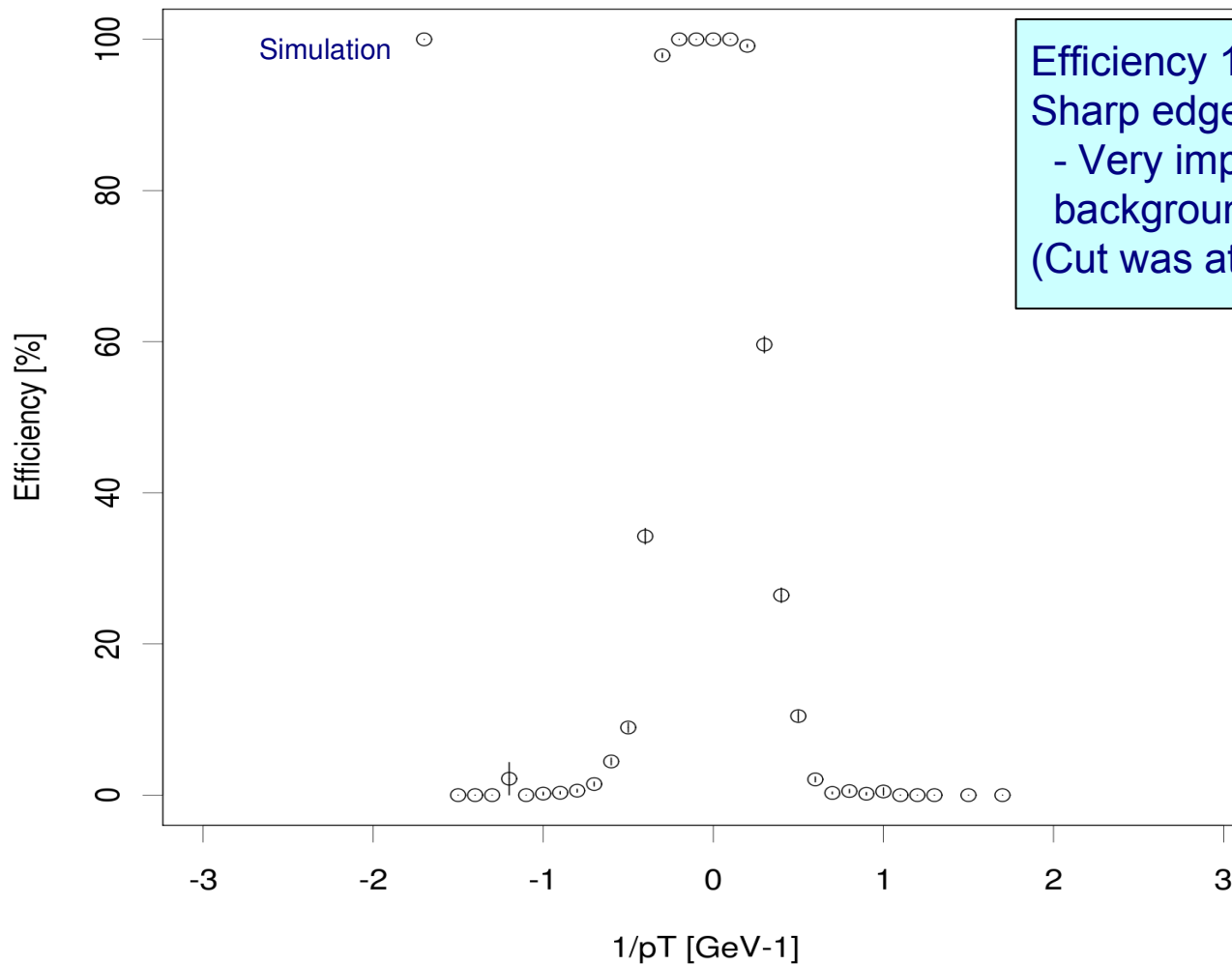
This is more easily programmable on the chip
than trying to alter the group width

Asymmetry for +ve and -ve charged tracks is
due to ordering of groups
- needs further study

Some discrimination up to 3 deg = 7 GeV/c



Efficiency after cluster-width cut



Efficiency 100 % in central region
 Sharp edges ~ sharp threshold
 - Very important for avoiding low-pT backgrounds leaking through
 (Cut was at 10 rows hit)



- Having reduced the trigger rate very substantially, you can now read out all hits in the relevant row and time region
- Can imagine a local FPGA serving several pixel chips processing these hits
- Fit straight line using integer arithmetic
- Calculate track x , y , θ , ϕ and quality of fit ("chi-sq")
- Send this data off-detector for high precision trigger data
 - For some applications e.g. beam monitoring this may be precise enough
 - For LHC triggers, combine this much-reduced data with other detector elements to form an L1 trigger
 - Then read-out all hits from tracks in this BC, for maximum off-line performance



When a high-pT track has been found with its T0, read-out all hit tdc's in the relevant phi-region

Do an unweighted linear regression in η and ϕ separately

- all integer arithmetic
- make various sums of tdc's, their row numbers, and columns
- combine these to get chi-sq and the coefficients in:

$$x = a_x + b_x z \quad (\eta \text{ direction; } z\text{-vertex pointing})$$

$$y = a_y + b_y z \quad (\phi \text{ direction; momentum analysing})$$

Choose units to avoid scaling:

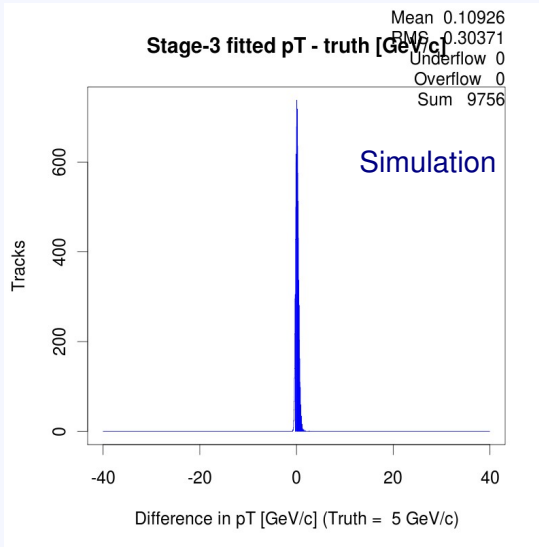
Length units: pixel sizes

z-coordinate: in units of drift velocity

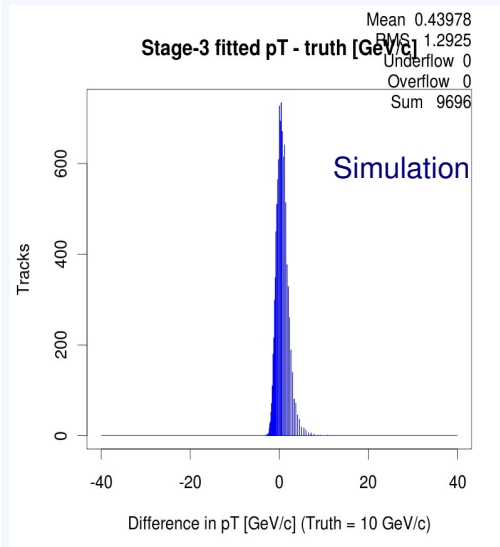
Apply cuts on chi-sq, b_y (for p_T), b_x (vertex region in z)

==> Well-measured high-pT track

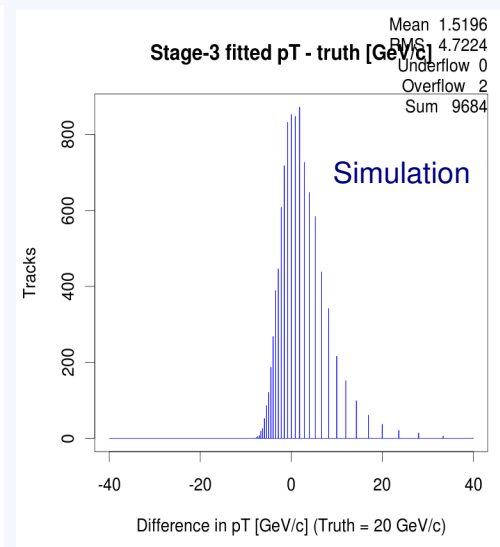
Send track position (a_x , a_y), track direction (b_x , b_y), and chi-sq values off-detector.



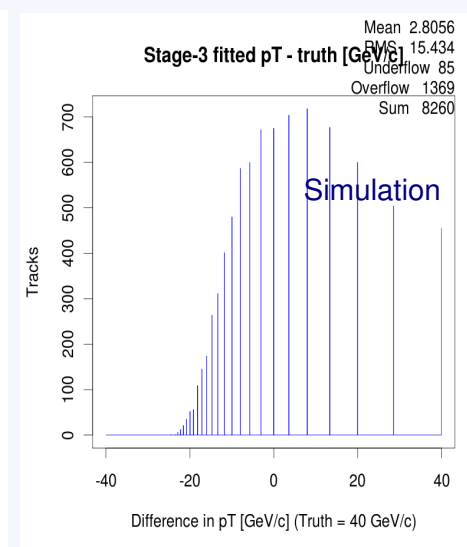
5 GeV/c
rms resolution 6 %



10 GeV/c
rms resolution 13 %



20 GeV/c
rms resolution 23 %



40 GeV/c
rms resolution 40 %

Resolution evolution with pT:
For 10 mm drift gap at 1 m
For 40 GeV, you need thicker drift gap or
combine two layers off-detector

These results are from
earlier studies with slightly
different arrangement and
geometry; however, do not
expect much change

Angular resolution in eta direction depends on
pixel size, but extrapolation could give ~1 mm
precision on z-vertex
Could be important in a high-pile-up environment



- Intelligence in the front-end of a gaseous pixel detector can have major benefits:
 - Data-driven readout
 - Data reduction
 - Data-driven L1 Track Triggers at LHC
- Simulation shows FE chip can recognise particle passage with 8 ns precision without external input
- Simulation shows a FE chip can very quickly (\sim max. drift time of 200 ns) apply a momentum threshold and have an approximate momentum estimate ready for readout
- A further stage can be imagined with trigger selection up to 20 GeV/c in an ATLAS-like inner tracker using track fits