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Studies of Bkg. for FP420

PLAN:

- studies w/ pocket design-I
- halo protons background
- dead material & pocket design-IV
- **MI** & **MSC** with 4 Stations
- towards digitization
- conclusion

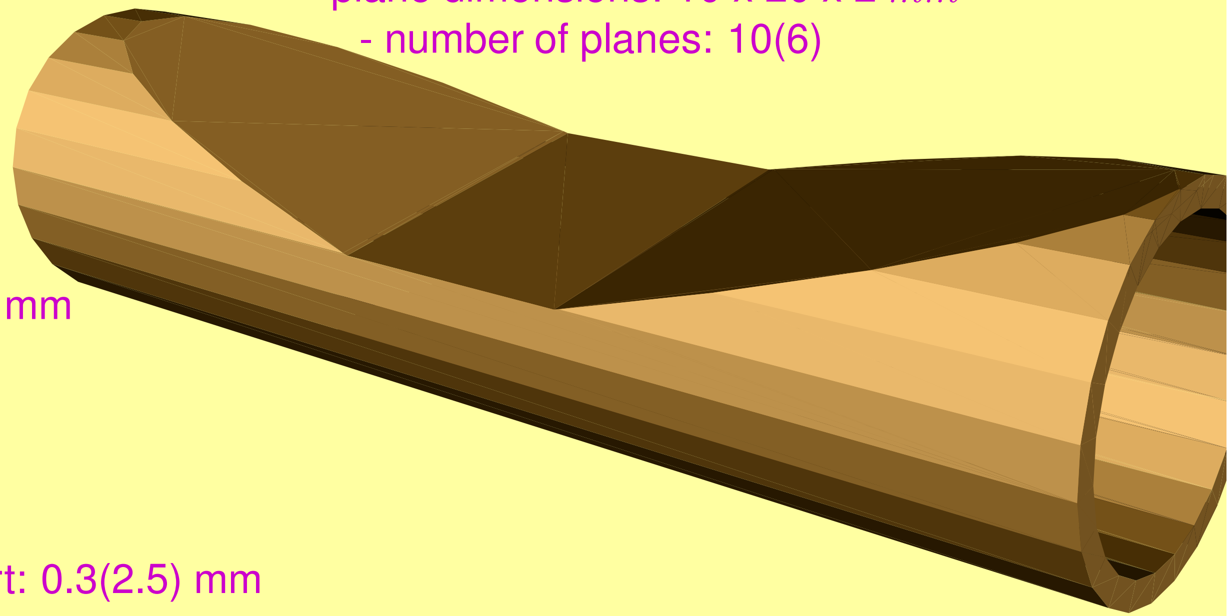
Geometry description for pocket design I

- subtraction Solid combines Tubs and Trapezoid w/ rotation(FP420Rot.xml)

- materials: Stainless Steel, Copper, Vacuum, Air, Silicon, Boron Polyethylene., Ceramic

- general parameters:
  - beam pipe (bp) radius: 40 mm
  - bp unit length (bpul): 2.8(4.0) m
  - z-size of flat pocket part(zfpp): 30 mm
  - window slope: 15^0
- copper coating:
  - bp wall thickness: 0.1 mm
  - y-thickness of flat pocket part: 0.1(0.5) mm
  - window thickness (cowt) : 0.1 mm
- stainless steel material:
  - bp wall thickness: 5 mm
  - y-thickness of flat horizontal pocket part: 0.3(2.5) mm
  - window thickness(sswt) : 0.25 mm

- some detector station parameters:
  - station dimensions: 10 x 20 x 25 mm^3
  - distance between centers of planes: 2.4 mm
    - plane dimensions: 10 x 20 x 2 mm^3
      - number of planes: 10(6)



- plane geometry parameters:
  - 1-st layer Si thickness: 0.200 mm
  - glue thickness: 0.020 mm
  - 2-nd layer Si thickness: 0.300 mm
  - ceramic thickness : 1.00 mm

Geometry XML files verified through visualization

have a look on **MI** & **MSC** for updated set up

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Update of results for MI & MSC with 3 Stations

($\star$- point of origin)

- eta: (9.67 ÷ 10.46) $\simeq$ ($\tan(\theta)$: 52./420000. ÷ 24./420000.); phi: 0 ÷ 2 π
- Vertex: (0., +20., 0.) mm; P_p = 7000 GeV; sswt = 0.25mm, cowt = 0.1mm

MI portion, %

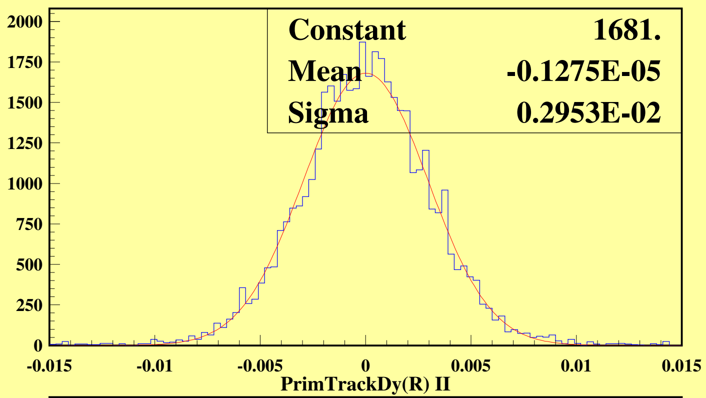
set up	6 Planes	10 Planes
St.steel only	16.9±0.4	23.9±0.6
& Copper	17.2±0.4	24.4±0.6

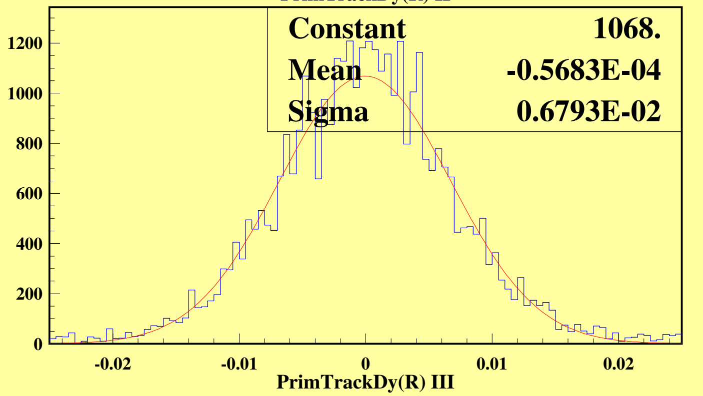
MSC: $\sigma^{X(Y)}_{deviation}$**,** μm

deviation of track from primary direction at z of Si plates $\Longrightarrow$

set up	6 Planes		10 Planes	
St.steel only:	II	III	II	III
2·(bpul)=5.6m	2.6	5.8	3.0	6.8
2·(bpul)=8.0m	3.6	8.1	4.9	9.4
& Copper:	II	III	II	III
2·(bpul)=5.6m	2.8	6.4	3.1	7.2

$$(\Delta P/P)_{msc} \sim tg\theta_{msc} \sim 10^{-6}$$





Code development

Numbering scheme:

FP420NumberingScheme::getUnitID(const G4Step* aStep)

- obtains any volume name & copy number information
- determines station, plane, X-Y plate
- call packFP420Index function

Added packFP420Index and unpackFP420Index functions

Indexing scheme:

bit 20: subdet → 1 $(max : 2^1 = 2)$
bits 7-8 X or Y plate → 1, 2 $(max : 2^2 = 4)$
bits 4-6 stations → 1 $\div$ 4 $(max : 2^3 = 8)$
bits 0-3: planes → 1 $\div$ 10 $(max : 2^4 = 16)$

Sensitive detector (assign SD's via fp420sens.xml):

FP420SensitiveDetectorBuilder:

- create new hit collection : "FP420SI"

FP420SD

- if step occurs inside Si plates the hit collection is created

FP420G4Hit

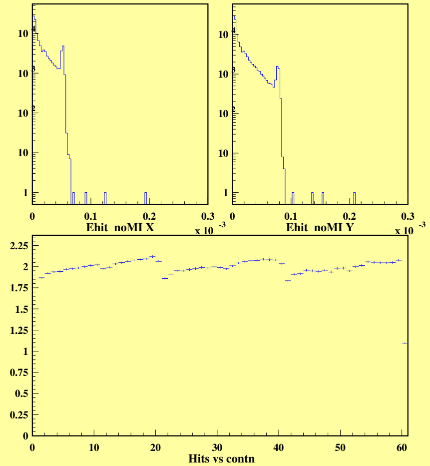
some methods are defined to Set or Get for every hit:

coordinates of entry and exit points, direction of momentum, track ID, PDG code, parent track ID, energy losses, incident(kinetic) energy of track, tof and others

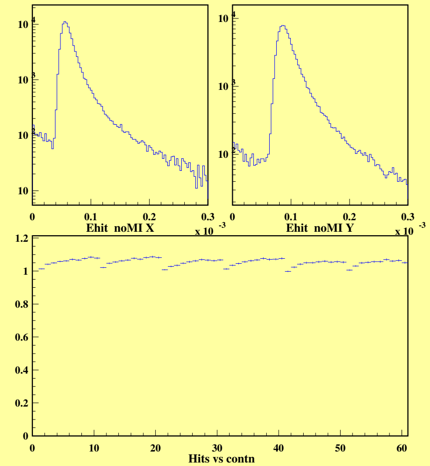
⋘ functions fully debugged ⋙

Optimization of production cuts

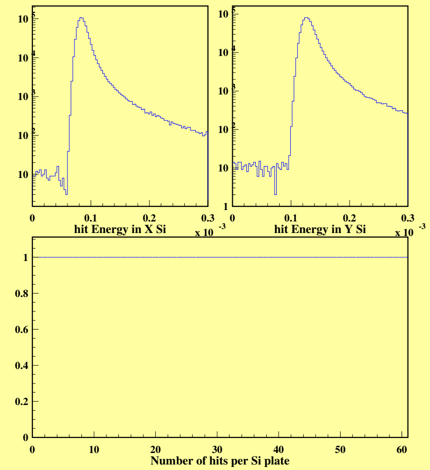
Aim: 1 hit per each Si plate



- why are production cuts needed ?
  - EM processes with infrared divergence (e.g. ionization process) generates huge number of smaller and smaller energy photons/electrons (Bremsstrahlung,δ-rays)
  - production cuts limit this production to secondaries above the threshold, allow a particle to be born or not. (in some cases $\rightarrow$ violations of production threshold typically for decays, e^+ production in annihilation, hadronic processes)
  - production of secondary particle is relevant if it can generate visible effects in the detector (otherwise $\rightarrow$ “local energy deposit”)
  - range cut allow to easily define such visibility (and reduce CPU time significantly)



- for one track in the detector one need to have one hit for every Si plate, no need to have shower development as for calorimeter.
  So, the cuts(FP420ProdCuts.xml) for e^+, e^-, γ to be large: $\sim$ 1000 mm for all materials
  (in Geant4, cuts are defined in length and are converted into energy cuts).



- few iterations with some set of cuts: energy in X,Y plates and average hit number per plate are shown on the plots

halo protons going through the flat horizontal part of pocket

(in the same event, the proton we are interested in can be accompanied by proton from halo)

- Y-thickness of flat horizontal pocket part:
  0.4 mm:
  [0.3mm (st.st.) + 0.1mm (copper)]
- Vertex:
  z - right in front of flat pocket part
  XY: over all cross-section ⟹
  (-5. ÷ +5., +9.6 ÷ +10., 1100.) mm
- P_p = 7000 GeV;
  protons go through 9 cm of Steel/Copper:
  (3 station) x (3cm)

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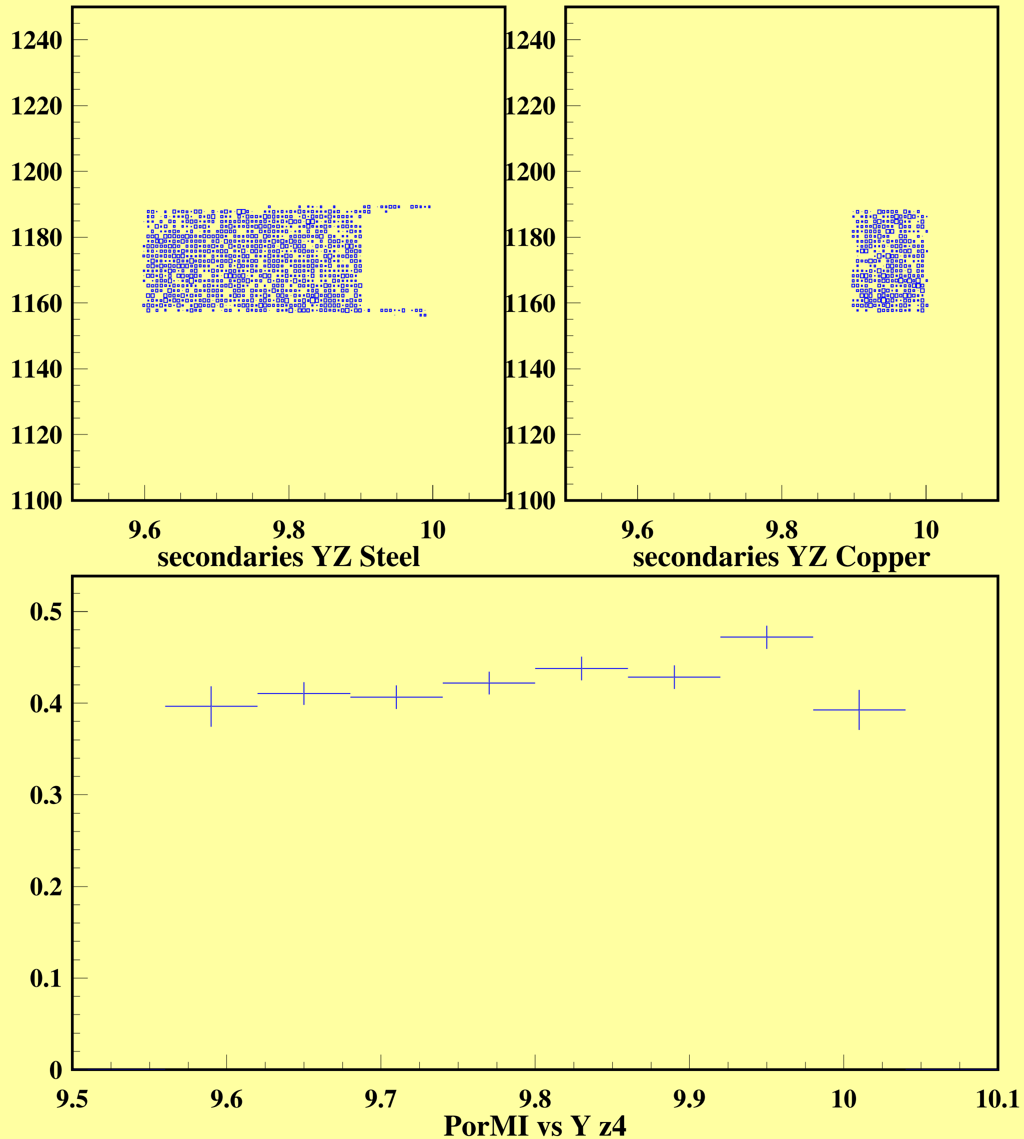
MI portions ∼ 40 %

How many secondaries going into detector?

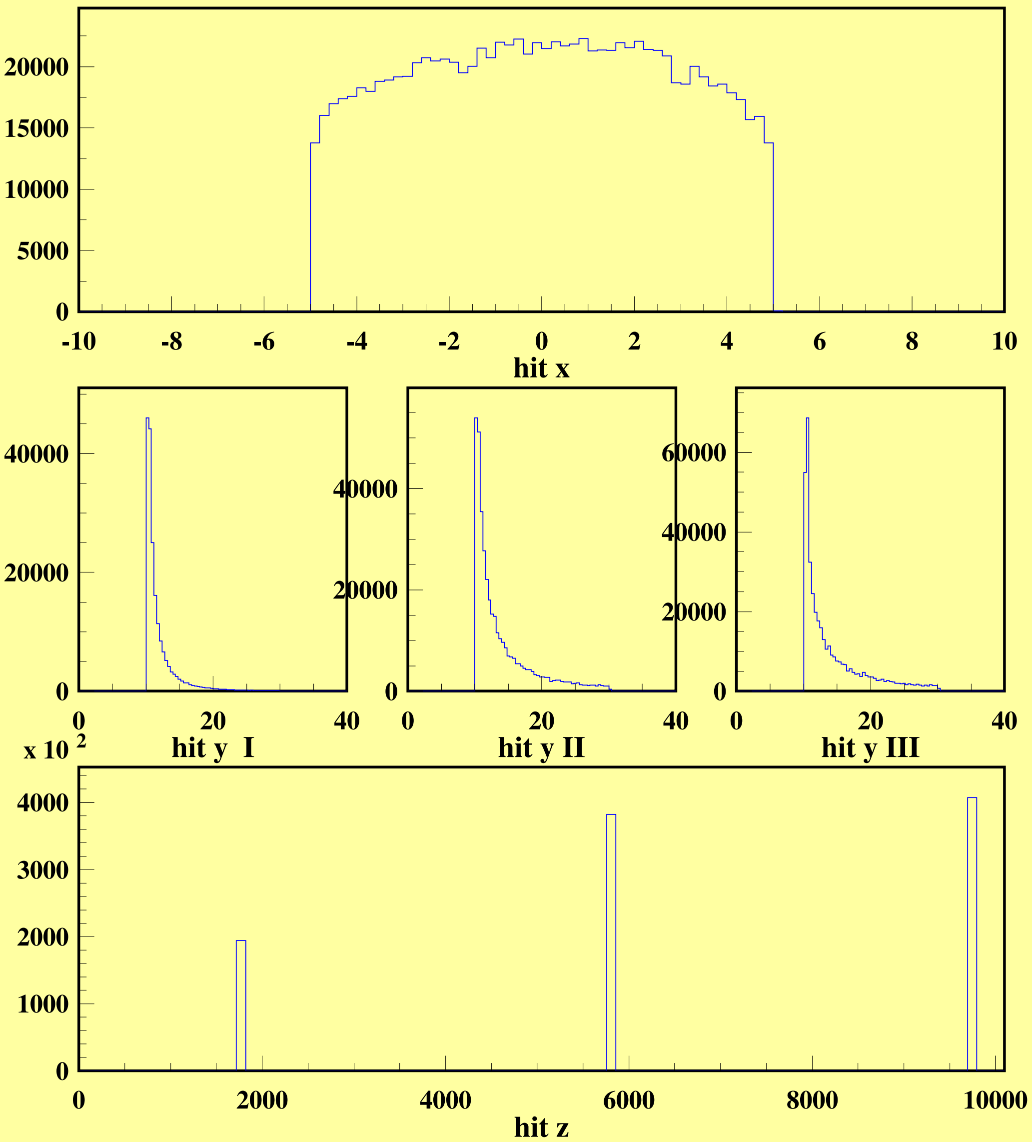


Distribution of hits in the detector

- distribution goes down to edges
  (detector acceptance in X: -5 $\div$ 5 mm)
  $\rightarrow$ scraps of secondaries

- for 2nd & 3rd stations - more broad hit distribution in radius

- number of hits increase in z



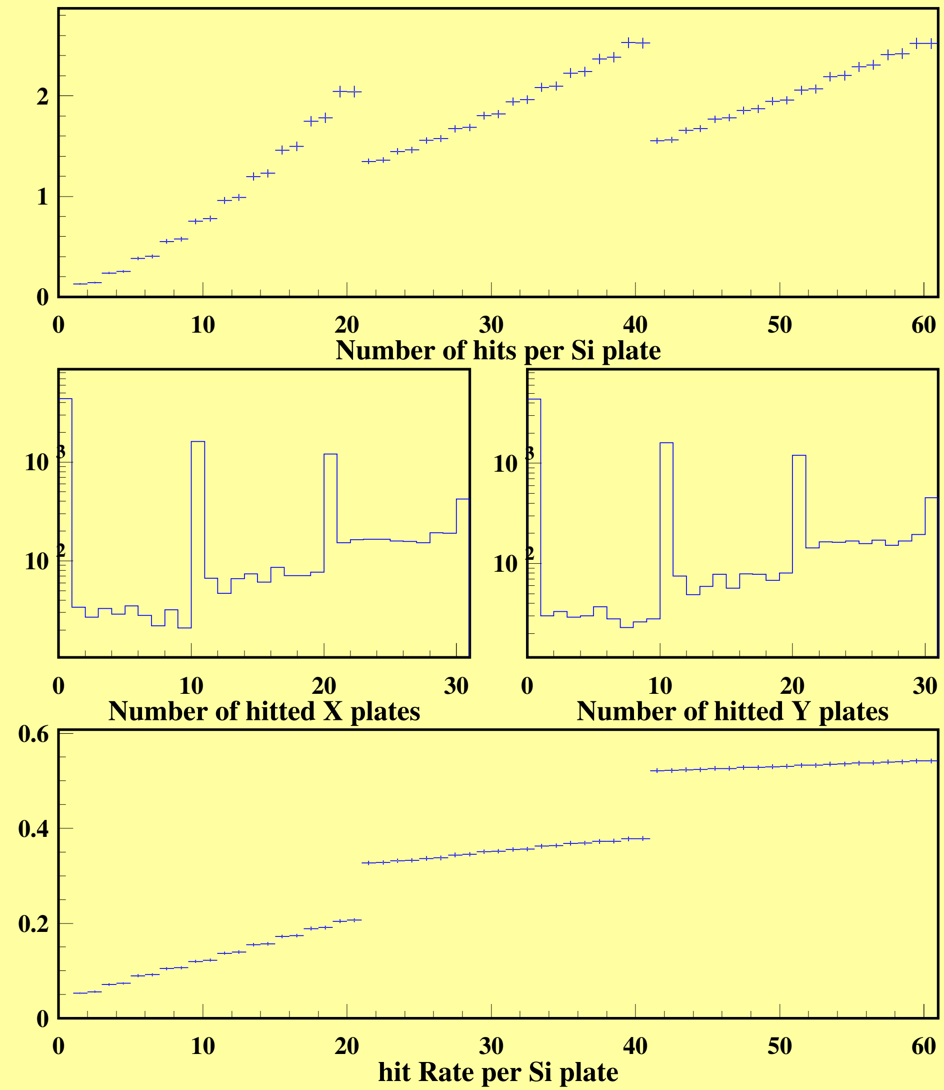
how many hits are in planes ?

Hits in planes

- average number of hits per plate in 1st station ~ 1 , in 2nd&3rd ~ 2 (production cuts were tuned to have one hit per plate from one track
  ∴
  this distribution can say how many secondary tracks irradiate the detector)

- total number of X&Y plates were hit ⟹
  → large portion of events with small number or no hits (!)

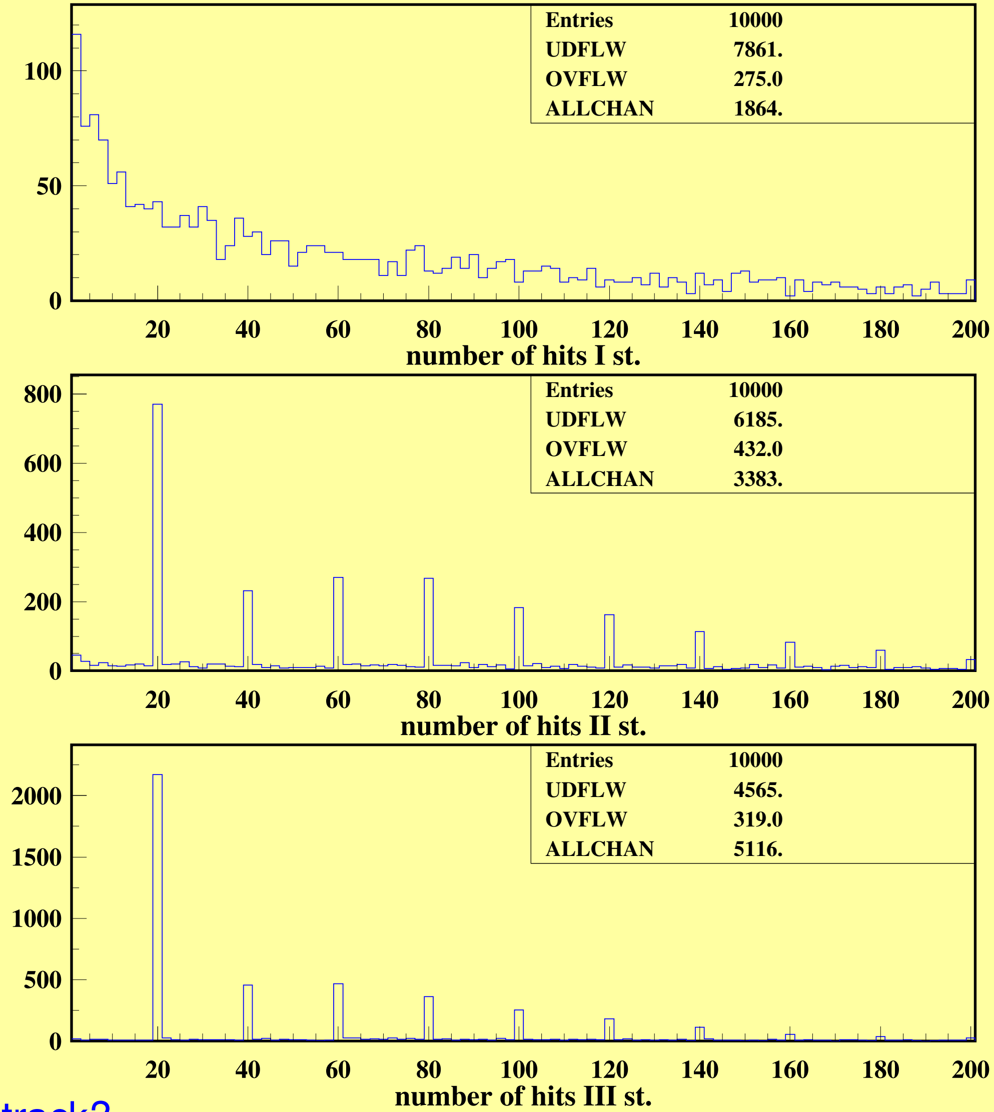
- hit rate per plate grows steeply and becomes ~ 35 % for 2nd station and ~ 55 % for 3rd station (clarifying: for hit rate calculation take into account all events, but for 1st plot - the events only which produce hits)



What is about a hit plate rate per stations ?

Hit distribution in stations

- number of hits in distributions starts from 1 (!) $\rightarrow$ from UNDFL one can obtain number of events w/o hits in plates of every station:
  Ist - 78.6 %; IInd - 61.9 %; IIIrd - 45.7 %
  (rates for lost events or “bad cases” for us:
  Ist - 21.4 %; IInd - 38.1 %; IIIrd - 54.3 %)



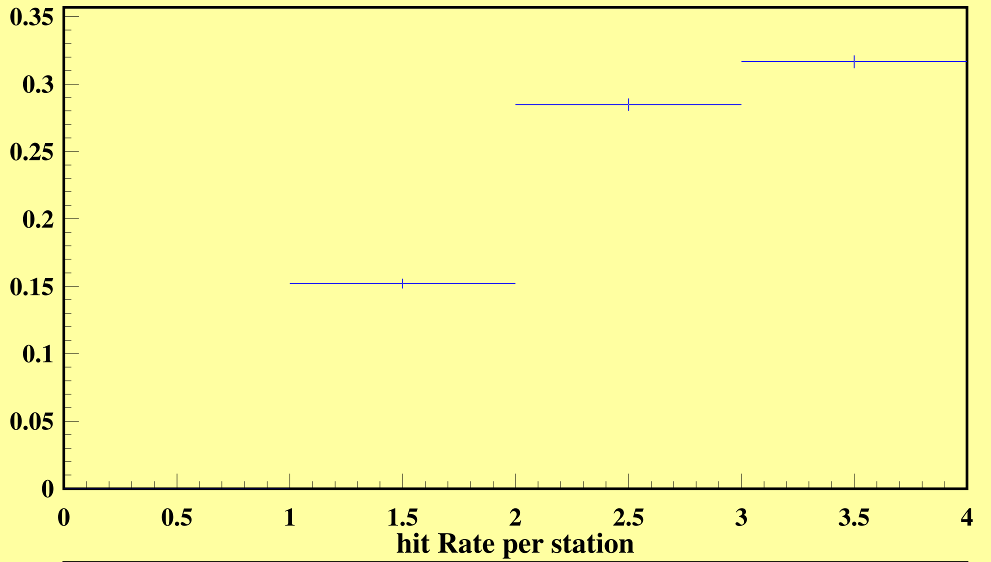
- Let us try to reduce number of “bad cases” as possible. One can ratiocinate like that:
  one secondary cross the plates of one station under large theta $\therefore$
  for event with only one additional secondary there is a hope to distinguish 2 tracks:
  track from IP and track of secondary
  (consider that still as a “good case”) $\therefore$

What is the rate of events per station with $>$ 1 secondary track?
(one can name it as “loose bad cases”):

$\rightarrow$ apply cut: number of hits $>$ 20 (assume that one secondary produce $\leq$ 20 hits per station)

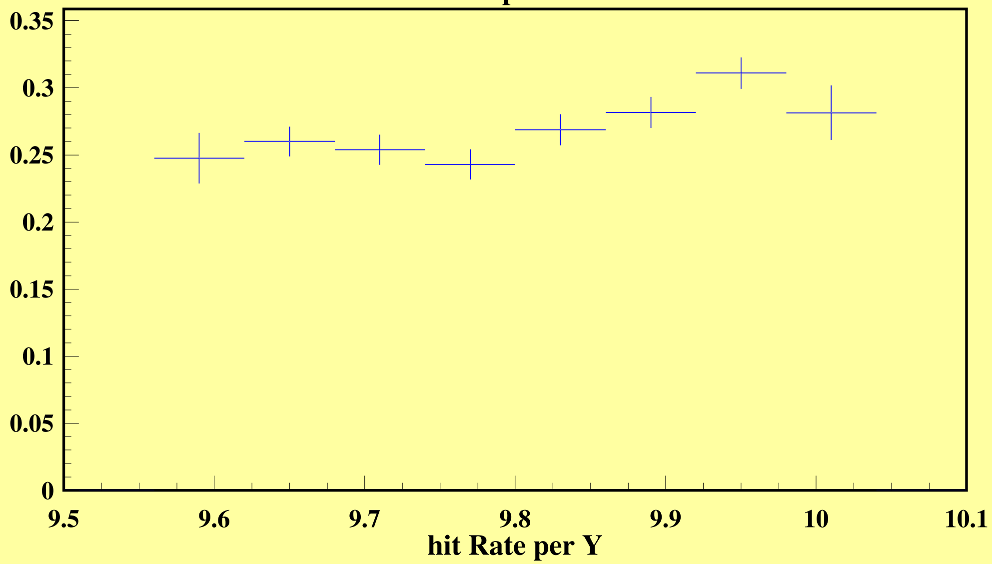
Rate of events to be lost due to contamination of beam-halo protons

- rates for loose "bad cases":
  Ist $\sim$ 15.5 %; IInd $\sim$ 29.5 %; IIIrd $\sim$ 32.5 %



- assume that one can reconstruct track using at least 2(not all 3) stations
  ("good case" for any 2 stations)

  With this assumption the rate of events to be lost is plotted as function of Y $\rightarrow$

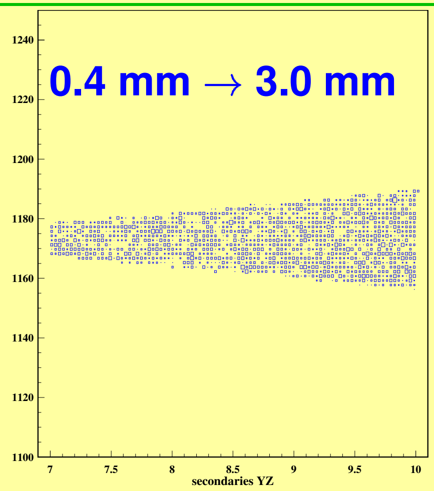


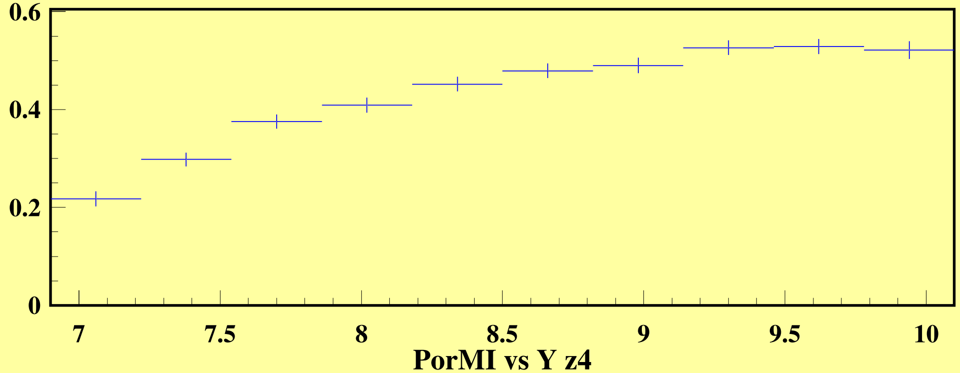
losses ($\equiv p^{bkg}$) $\sim$ 25 %

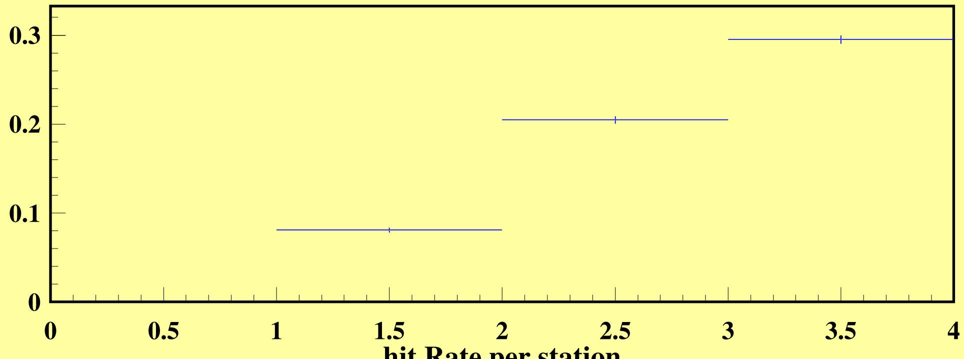
40% of events produce MI , but only 25% is lost forever ($r^{save} = 25/40 \approx 0.63$);

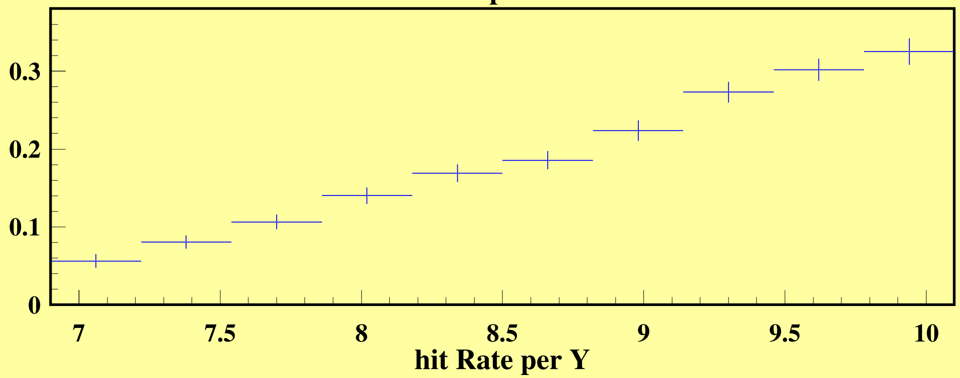
let's assume for 4 stations: $r^{save} = 20/40 \approx 0.50$

Exercise with thickness of the flat horizontal part of pocket









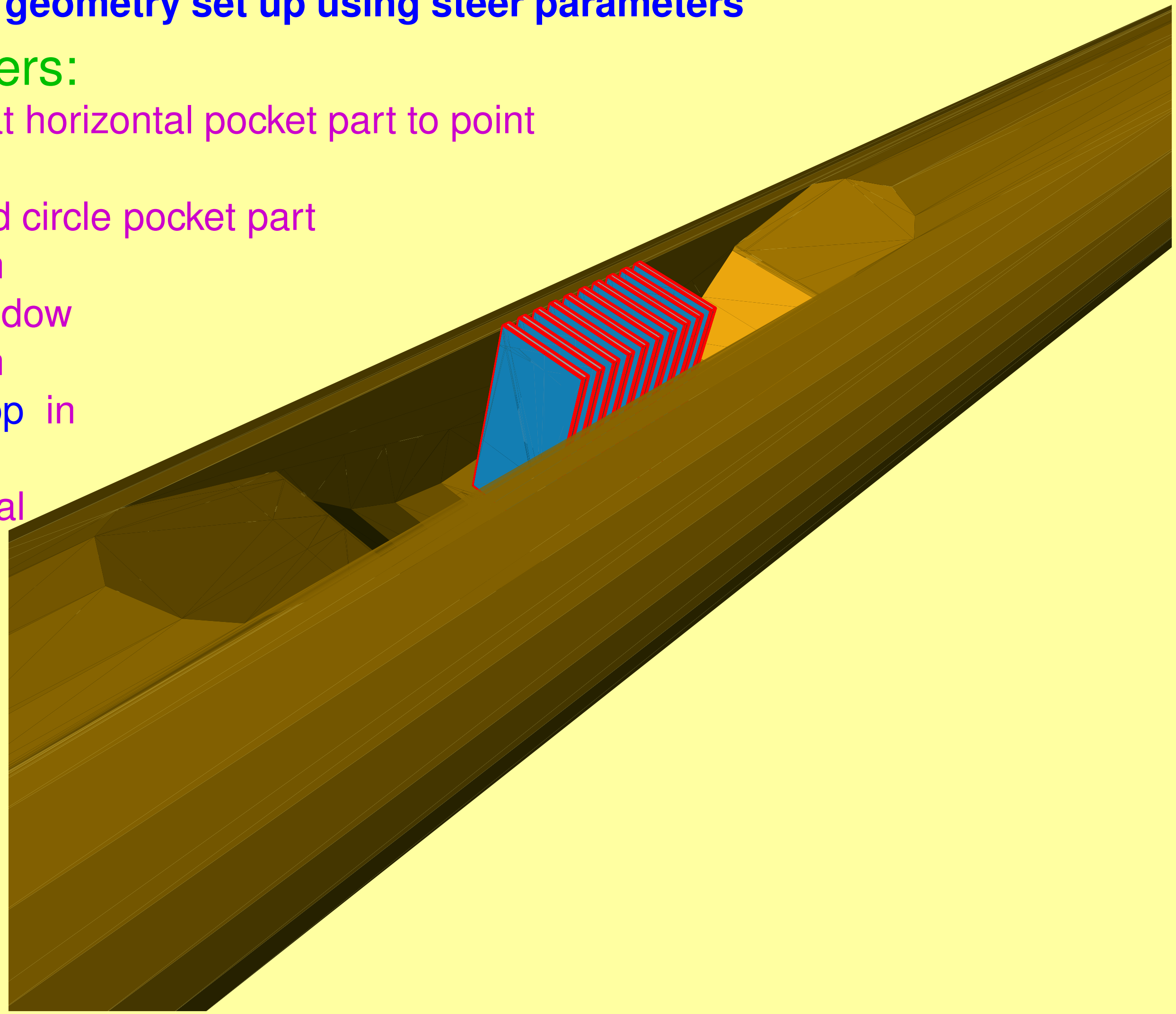
- in increase of thickness of flat pocket part from 0.4 mm to 3.0 mm the z-size of its bottom is order of 1 cm (top - 3 cm)
  $\Longrightarrow$ portions of MI for protons going through bottom $\sim$ 20 % and increase to $\sim$ 50 % at top
- rates for loose "bad cases":
  Ist $\sim$ 9.0 %; IInd $\sim$ 21.0 %; IIIrd $\sim$ 30.0 %
- rate of events to be lost due to beam-halo contamination increase from 6 % to 32 %

the halo proton close to station
the more probability to reject event

Geometry description for pocket design IV

- subtraction Solid combines Tubs, Box and Trapezoid
- one can change geometry set up using steer parameters

- update and new parameters:
  - distance(in Y) from bottom of flat horizontal pocket part to point of window slope begin: 25.5 mm
  - bp thickness in range of flat and circle pocket part (Copper-St.Steel): 0.1mm/0.4mm
  - bp thickness of 15^0 inclined window (Copper-St.Steel): 0.1mm/0.9mm
  - (Copper-St.Steel) thickness of bp in pocket region: 0.1mm/1.75mm
  - gap between top of flat horizontal part of pocket and detector bottom: 0.2 mm
  - (Copper-St.Steel) x-thickness of pocket walls: 0.1mm/0.4mm
  - x-dimension of pocket: 30 mm
  - y-distance to center: 2.5 mm
  - zfpp: 50 mm
  - bp radius: 33.35 mm
  - bpul: 2.5
  - 4 stations
  - radius of window: 50 mm



Dead material description

- (around pocket)

- flanges implemented
- bellows implemented
- in xml file there are:

  - 26 parameters to describe pocket, dead material
  - 14 parameters to describe stations (detector)
  - 6 internal parameters calculated via expressions

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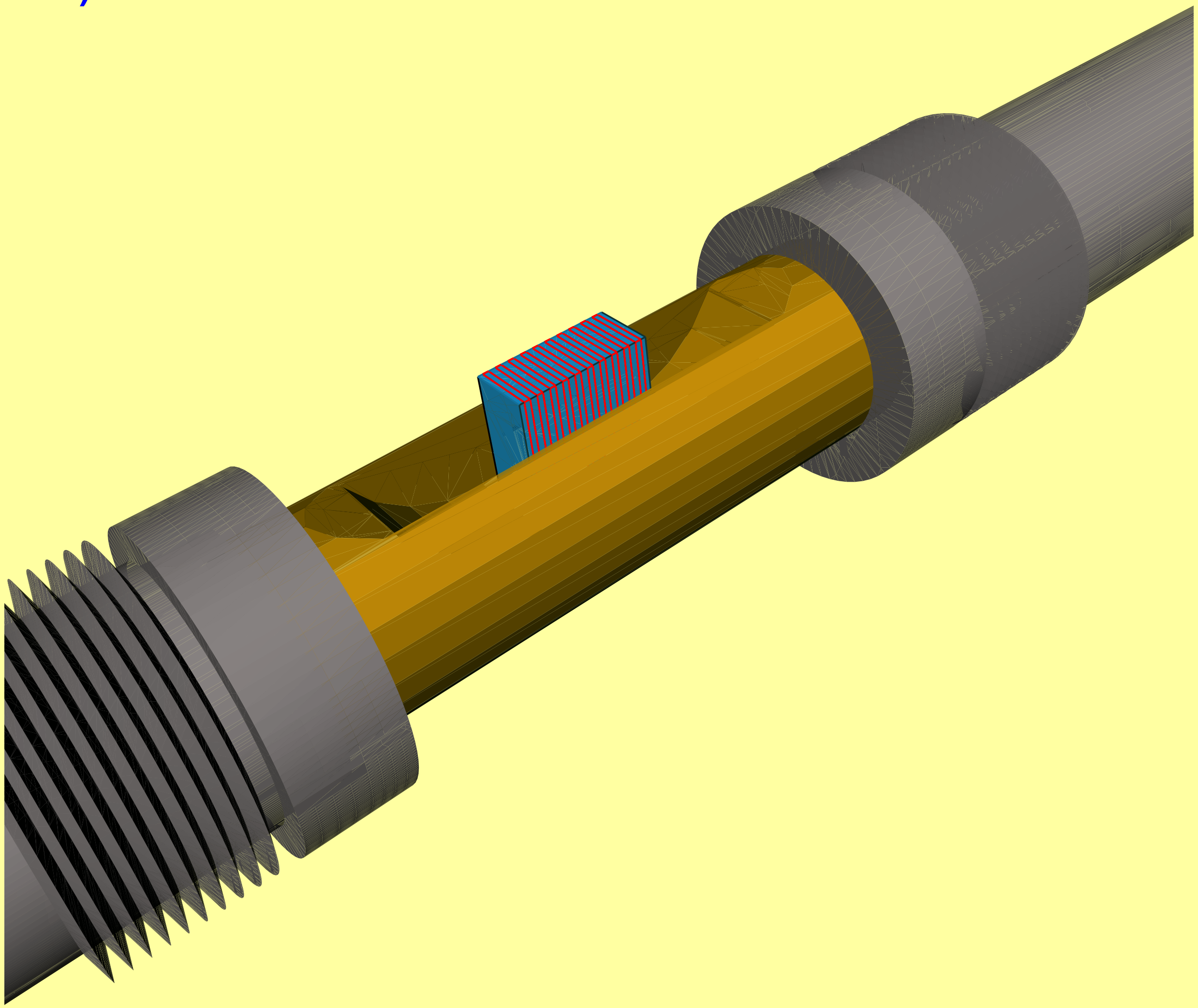
  (see Appendix 1 at the end of the talk for references)



Validation of geometry structure implementation

- scan with proton Gun over geometry

- it seems, the visualization with IGUANA do not correctly shows Subtraction Solid obtained as a result of few(=4) subtraction iterations ⇒ one need to have x-check of geometry implementation

- XY, XZ, YZ - 2D plots of deposited energy on every step of tracks, vertex of secondaries are shown ⇒

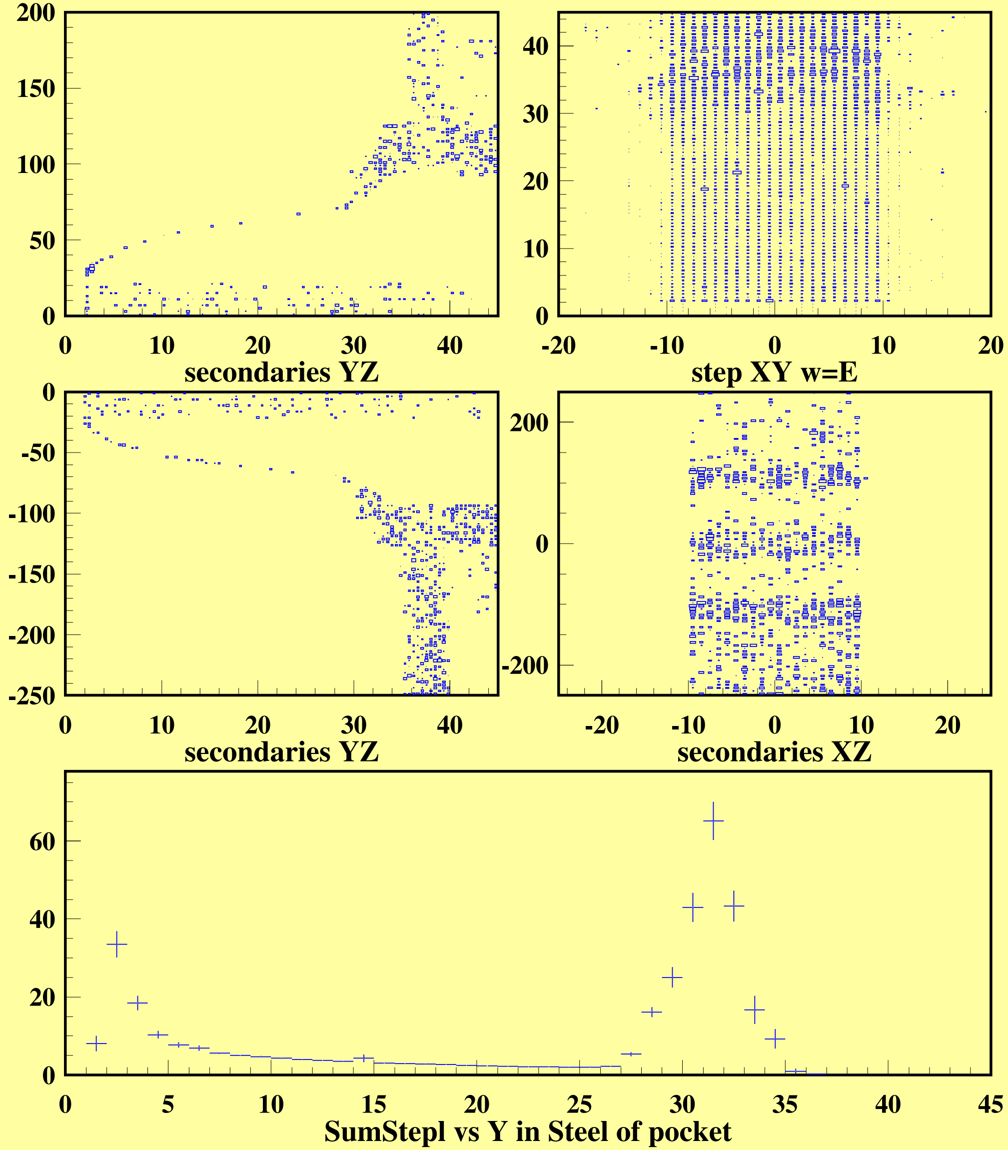
- average track path inside of St.Steel versus Y ⇒

confirm

⇓

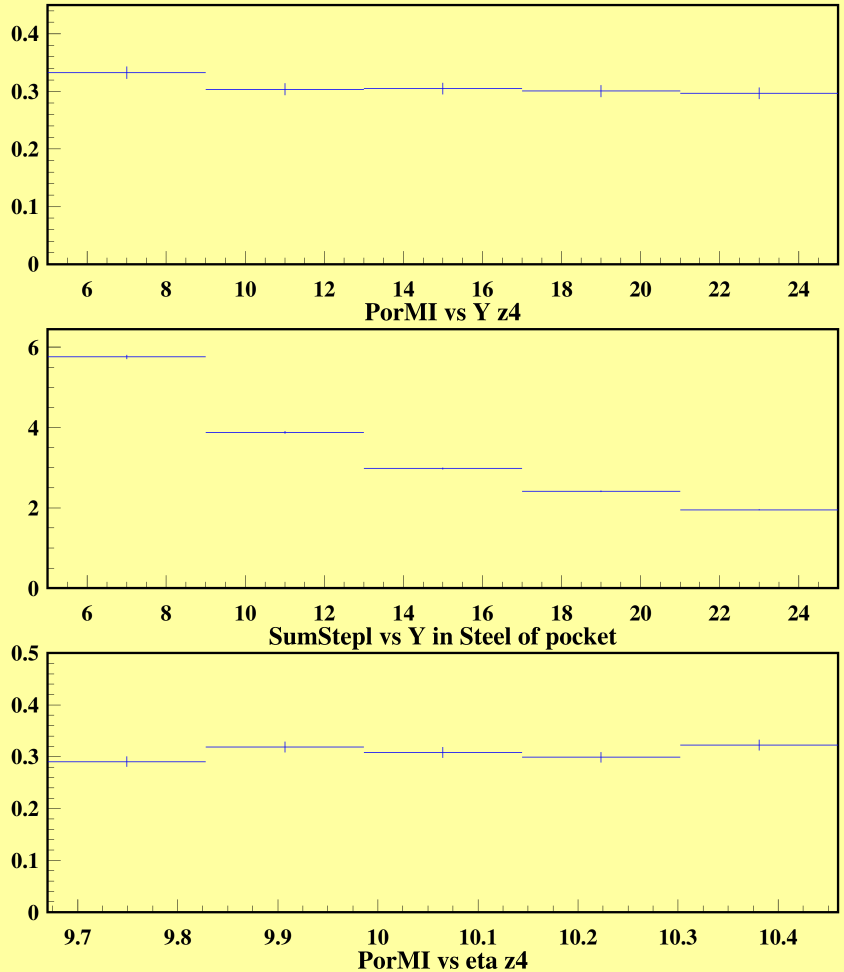
geometry is implemented correctly

(no surprises !)



MI & MSC with 4 Stations

- 10 Planes per Station, 3· pul = 7.5 m



- Y dependence of **MI**: slight slope due to window material influence $\Longrightarrow$
- average track path inside of St.Steel windows: strong Y dependence $\Longrightarrow$ (reminder: contribution of thin St.Steel to MI is small - can see again on next slide)
- no η dependence for **MI** $\Longrightarrow$

$\sim$ 30% of **MI**

MSC: $\sigma^{X(Y)}_{deviation}$, μm

I	II	III	IV
0.02	2.4	5.5	9.3

$(\Delta P/P)_{msc} \sim tg\theta_{msc} \sim 10^{-6}$

$\sigma_X^{IP-vtx} = \sigma_Y^{IP-vtx} = 310\mu m \sim 0.3mm$

Total losses due to **MI** in the detector & halo proton contamination

(10 planes per station)

p^{MI} = N^{MI} / N^{tot} (protons from IP)
p^{bkg} = N^{det} / N^{halo} (protons from halo)
N^{halo} = k · N^{tot} , where
k (= 0 ÷ 1) - portion of events with halo proton contamination:
k = 0 → no contamination at all,
k = 1 → **every(!)** proton from IP is accompanied by second bkg. proton

$$p^{losses} = (N^{MI}+N^{det}) / N^{tot} = p^{MI} + \mathbf{k} \cdot p^{bkg}$$

set up	p^{MI}	p^{bkg}	p^{losses}
15^o pocket - 3 station	24.4%	k · 25.0%	∼ 25% ÷ 50%
circle pocket - 4 station	30.0%	k · 20.0%	∼ 30% ÷ 50%

MI results for last 4 pocket variants

(4 Stations)

MI portion, (p^{MI}), %

set up	7m long indent	4 short pockets	4 long pockets	4 short rectangular pockets
variant	1	2	3	4
6 Planes	20.7±0.4	24.1±0.5	27.3±0.5	20.4±0.4
10 Planes	28.6±0.5	31.7±0.6	35.0±0.6	28.1±0.5
pure st.st.	1.7±0.1	4.8±0.2	8.0±0.3	1.2±0.1
st.st., mm	1.9 (1window)	5.4 (7w)	8.1 (7w)	1.4 (7w)
1 wt, mm	0.5	0.2	0.3	0.2

Bkg. portion, (p^{bkg}), %

$p^{MI}_{flat\ st.st.} \cdot r^{save}$	$100 \cdot 0.5 = 50$	$64 \cdot 0.5 = 32$	$100 \cdot 0.5 = 50$	$65 \cdot 0.5 = 32.5$
st.st. z-size, cm	700.	16.	80.	16.2

Total losses, (p^{losses}), %

6 Planes	21÷71	24÷56	27÷77	20÷53
10 Planes	29÷79	32÷64	35÷85	28÷61

variants 1 & 3 do not work due to high contamination of halo protons
variants 2 & 4 can be used but need to reduce st.st. z-size (16→12cm)

Towards Digitization

(experience of H1 and CMS used)

- SimHitsCollection provide input information for signal simulation

  ⇓

- **Digitization(very preliminary):**

  charge collection:

  Input: (SimHitsCollection) entrance and exit points, E_{dep}

  - divide track segment(hit inside 200/300 μm plate) into slices ($\sim$ 20)
  - assign a fraction of energy for each slice: take into account Landau (or Bichsel?) fluctuations in thin material layers
  - drift $\&$ diffusion in electric $\&$ magnetic fields(need to know the B-field),
  - take into account Lorentz angle (for electrons and/or holes?)
  - induce charge on strips

  see Appendix 2 for parameters $\&$ details of algorithm !!!

  pile up signals

  convert the charge into an integer number(ADC digitization)

  noise contribution

  strip zero suppression

  ⇓

  26 classes:

  some of them just copy of standard classes(for instance, related to Landau fluctuations)

  to be independent of any framework as much as possible

  There is also no any inheritance of any CMS detector

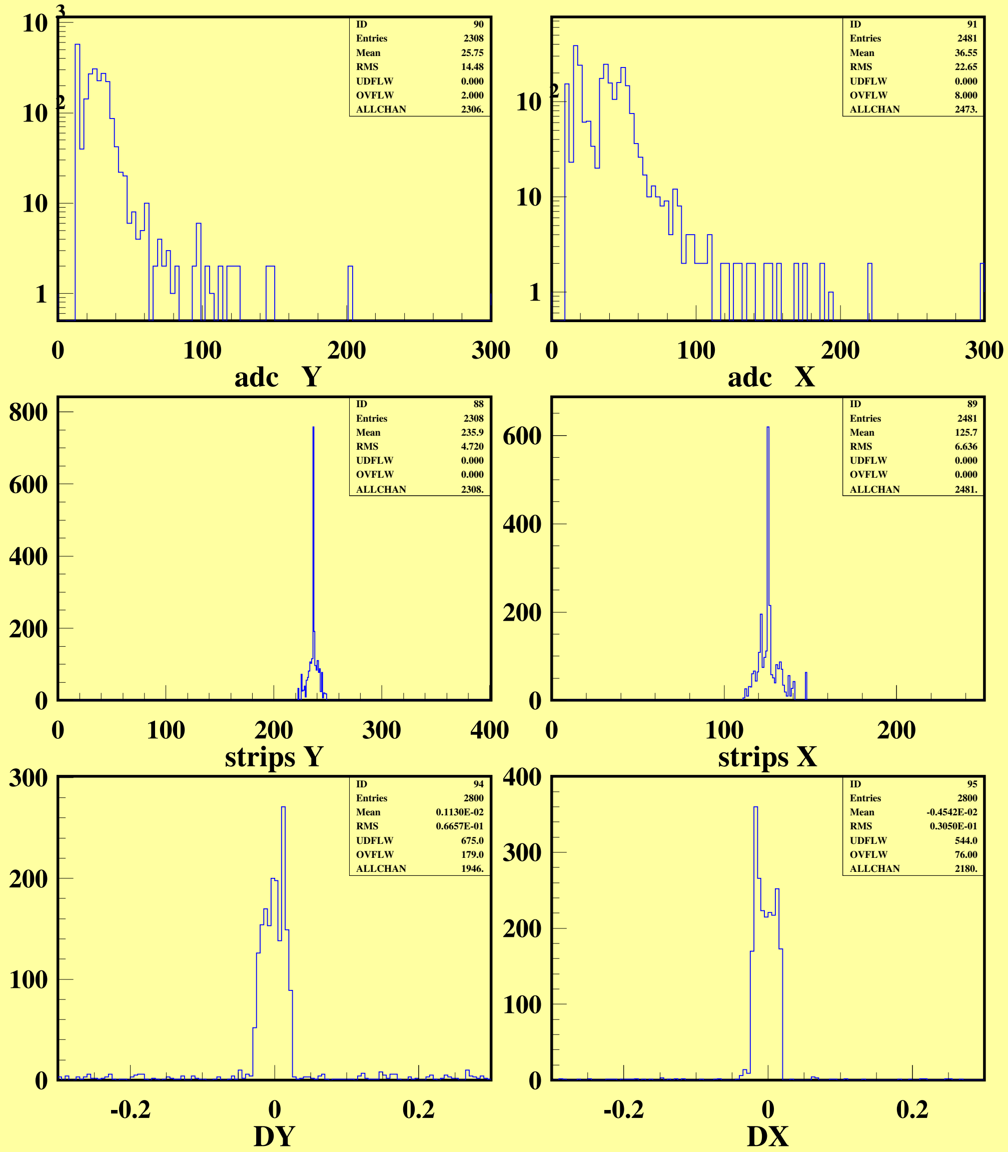
  !!!!! Result of DIGI: collection of strips with amplitudes !!!!!

- **BUT, one need specify algorithm and tune parameters !!!**
- To complete MC: one need to have a track reconstruction

What can we see with DIGI

- shoot conditions: $P_p = 7\ TeV, Vtx = (0., 15., -250.)cm., \eta \sim 10, \phi = 0 \div 2\pi$

no noise



- adc amplitudes of hit strips
- strip distribution from strip collection
  $\rightarrow$ only hit strips there
- difference of simulated hit position and reconstructed position taken as barycenter of charge/amplitude(w/o Lorentz shift correction) over all strips in collection

code “breathe” !

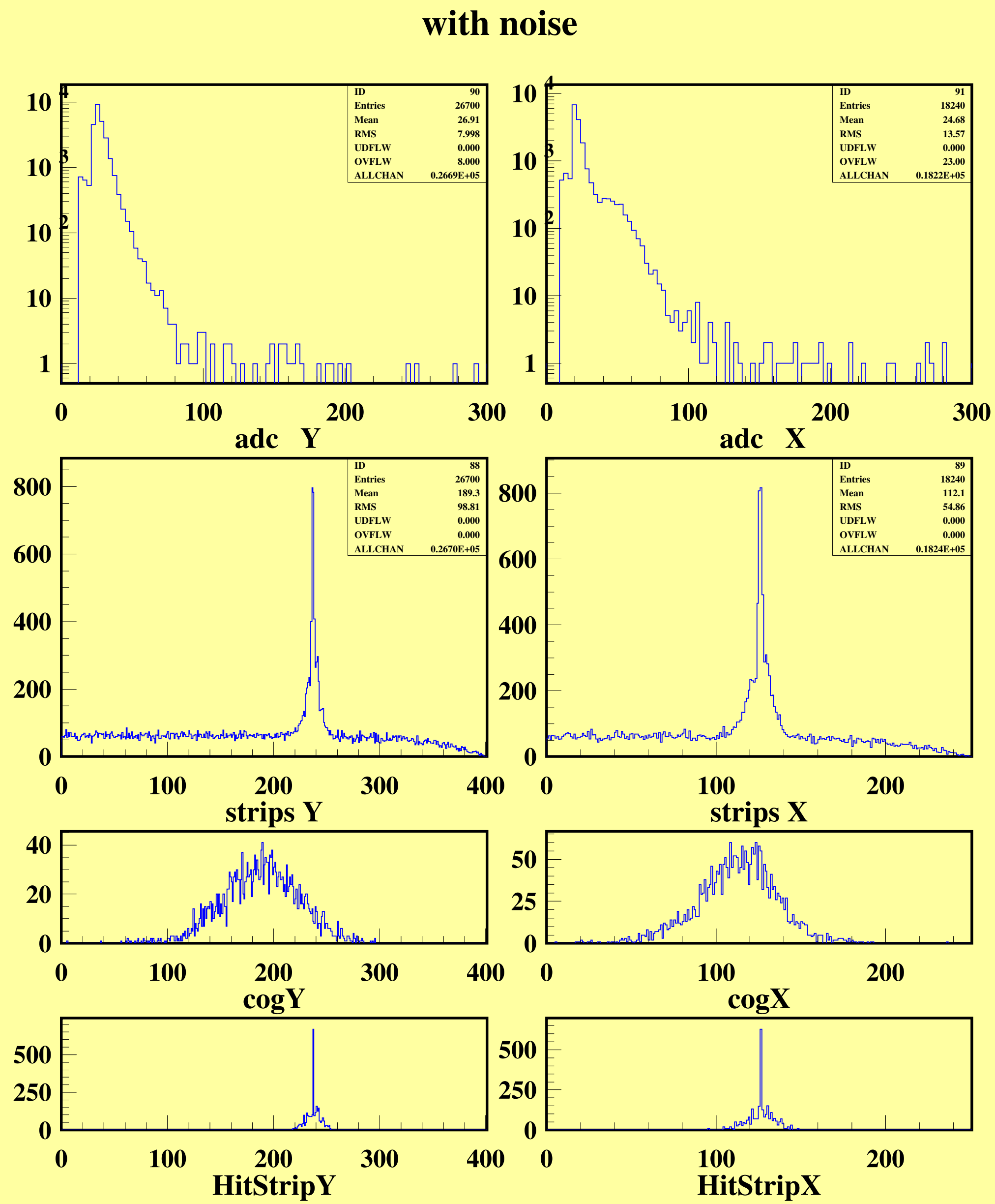
with noise added

- adc amplitude and strip distributions look reasonable

- with noise (or for case of few hits) there is no chance to reconstruct hit position using all strips ∴.

- one need to have cluster finding algorithm: define cluster as a set of adjacent strips, create cluster collection

- to complete reconstruction:
  - provide method to define precise hit position for every cluster
  - provide track reconstruction (helix in magnetic field)



Conclusion

- for FP420 configuration set up with 3 stations and 10 plates per each, 0.25+0.10 st.steel/coppe thickness of pocket walls
  including 15^0 inclined windows:
  - the contribution of MI is about 24$\%$
  - the uncertainty of momentum reconstruction
    because of MSC is negligible $\sim 10^{-6}$
  - for events with one accompanied proton from beam halo bkg.
    the losses $\sim$ 25 $\%$
- for FP420 configuration set up with 4 stations and 10 plates per each, 0.40+0.10 st.steel/coppe thickness of circle pocket walls:
  - the contribution of MI is about 30$\%$
  - the uncertainty of IP vertex reconstruction because of MSC

$$\sigma_{X(Y)}^{IP-vtx} \sim 0.3mm$$

- total event losses due to Bkg. are varied:
  $\sim$ 25$\%$ $\div$ 50$\%$ for more reasonable set up configurations
- digitization is implemented but need to be specified and tuned

Appendix 1

Parameter for station:
=======================
x-size of solid to keep all planes together: XSi
x- dimension of one plane: XSiPlane
x-size of Si plate: XSiDet
y-size of solid to keep all planes together: YSi
y- dimension of one plane: YSiPlane
y-size of Si plate: YSiDet
gap between top of flat horizontal part of pocket and detector bottom: dYGap
z-size of solid to keep all planes together: ZSi
distance between plane centers: ZSiStep
z- dimension of one plane: ZSiPlane
z-size of left Si plate: ZSiDetL
z-size of material between plates: ZBoundDet
z-size of right Si plate: ZSiDetR
z-size of ceramic plate in plane: ZCeramDet

z-size of Flange: ZinFlanze
total width of area with other flange and bellows: ZoutWidth
other flange width in area: ZoutFlanze

General Geometry Parameters:
==============================
external radius of beam pipe in pocket area: TubR
external radius of beam pipe out pocket area: OutTubR
radius of window: dRBRST
x-size of pocket: BoxDx
copper x-thickness of pocket: DxThickCop
st.steel x-thickness of pocket: DxThickSte
z-size of flat part of pocket: BoxDz
copper thickn. for bp Radius in pocket range: dRcopper
copper thickn. (in Y) in range of flat pocket part and circle part: dYcopper
copper thickn. of inclined (15 degree) window: dZcopper
StSteel thickn. of beam pipe in pocket region: dRsteel
StSteel thickn. (in Y) in range of flat pocket part and circle part: dYsteel
StSteel thickn. of inclined (15 degree) window: dZsteel
tan(alpha), alpha is slop of window: tga
sin(alpha): sna
y-size from tube center to bottom of flat horizontal pocket part: gap
y-size from bottom of flat pocket part to point of pure window slope: Yleft
area for flange in frame of pocket area: ZinWidth
external Flange radius: RinFlanze

thickn. of tube in area with other flange and bellows: RoutThick
bellows shift from flange: BellowsShift
StSteel thickness of bellows: BellowsT
total unit length in z - distance between centers of any 2 Stations: ZUnit

Internal Parameters(calculated via expressions)

==

z-size from left edge of flat pocket part to point of window slope start:Zleft
y-distance from tube center to top of flat pocket part: BoxYshft
z-size of unit of tube of the same radius with one pocket: TubZ
total width of bellows: BellowsWidth
z-size of tube to complete space between pockets: ZpureTube
variable to change global z-position of pocket: ZsafetyShift

Appendix 2

(parameters to be specified)

parameters for Si

===============

depletion voltage $V_d = 140.$ [V]

applied voltage (bias voltage) $V_b = 150.$

holes mobility (p-side): $\mu_h = 480.[cm^2/V/sec]$

electron mobility (n-side): $\mu_e = 1350.$

temperature $t = 297.^oK$ ($\rightarrow 24.^oC + 273. = 297.$)

diffusion constant for electrons $D_e = 34.6$

diffusion constant for holes $D_h = 12.3$, where

($D = 1.38 \cdot 10^{-23}/1.6 \cdot 10^{-19} \cdot \mu \cdot t[cm^2/sec]$)

constant in t_n expression: $C_{RMS} = 6.5e - 10[sec]$

arbitrary constant vector of $B_{field} = (B_x, B_y, B_z)$

tg of Lorentz angle for e^-: $tg(\theta)^n_{Lorentz} = 0.106$

tg of Lorentz angle for holes: $tg(\theta)^p_{Lorentz} = 0.038$

cluster width $W_{cluster} = 3.$

gev per electron = 3.61e-09

General Geometrical Parameters:

==============================

X-direction: plate size:250*0.040=10mm

numStrips = 250

z-thickness d= 0.2 mm

pitchX= 0.040

Y-direction: plate size:400*0.050=20mm

numStrips = 400

z-thickness d= 0.3mm

pitchY= 0.050

GaussianNoise, DigitalConverter, ZeroSuppression:

==

EquivalentNoiseCharge300um (ENC) = 2160.

normalized to 300micron Silicon - Dist300 = 0.0300

noiseRMS = ENC*pitch/Dist300

ElectronPerAdc = 313., theMaxADC = 1023

noiseInAdc=noiseRMS/ElectronPerADC

FEDlowThresh = (1.) $\cdot$ noiseInAdc

FEDhighThresh = (3.) $\cdot$ noiseInAdc

in Gaussian noise: AdcThreshold = 2.

Essential part of digi algorithm

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1. divide track segment(hit inside 200/300 μm plate) into slices ($N_{slices} \sim 20$) equidistant over hit path with coordinates (seg_X, seg_Y, seg_Z) in local reference frame of Si-plate (if N_{slices} large, precision of simulation improves)

2. assign a fraction of energy for each slice: take into account Landau (or Bichsel?) fluctuations in thin material layers (energyLoss weighted with a Gaussian centered at t0)

The charge from each slice is drifted to (p- ,n-) strips and simultaneously diffused in the perpendicular plane(in X(Y) and Z) $\Downarrow$

3. evaluate the drift time for the charge released in each slice on each n-strip (similar expressions for p-strips):

$$t_n = [-C_n \cdot ln(1. - 2 \cdot V_d * T_f/(V_b + V_d))] + C_{RMS}$$

where:
time normalization - $C_n = pitch^2/(2 \cdot \mu_h \cdot V_d)$,
fraction of path to strip - $T_f = (pitch - seg^{pit.r.f.}_{X(Y)})/pitch$,

4. evaluate the width of the charge distribution due to diffusion during drift time:
(diffusion is assumed to be Gaussian and is proportional to the square-root of the drift length)

$$\sigma_n = \sqrt(2 \cdot D_h \cdot t_n)$$

5. evaluate the position of slice due to drift:

$seg^{new}_{X(Y)} = seg_{X(Y)} + x(y)^{Drift}$ **(E field in Y(X) direction)**
$seg^{new}_{Z} = seg_{Z} + z^{Drift}$,

where drift length depends on Lorentz angle:
$x(y)^{Drift} = (pitch - seg^{pit.r.f.}_X) \cdot tg(\theta)^n_{LorentzX(Y)}$
$z^{Drift} = (pitch - seg^{pit.r.f.}_X) \cdot tg(\theta)^n_{LorentzZ}$,

which depends on the strength of the magnetic field:
$tg(\theta)^n_{LorentzX(Y)} = Drift^{dir}_{x(y)}/Drift^{dir}_{y(x)}$
$tg(\theta)^n_{LorentzZ} = Drift^{dir}_{z}/Drift^{dir}_{y(x)}$,

where drift direction:
$Drift^{dir}_{y(x)} = 1.$,
$Drift^{dir}_{x(y)} = \pm tg(\theta)^n_{Lorentz} \cdot B_z$,
$Drift^{dir}_{z} = \mp tg(\theta)^n_{Lorentz} \cdot B_{x(y)}$

the sign is related to $e^-/holes$,
(if E field is in -Y(-X) direction, then do sign exchange $\pm \leftrightarrow \mp$)

- check after diffusion: is slice inside of fiducial volume of the current plate

- do not take yet into account the change of electric field direction for even and odd pitch(!)

6. induce charge on strips (calculated as Gaussian distribution),
determine the fraction of charge collected by every strip
(integration over strips interval:
$W_{cluster} \cdot \sigma_n / pitch \rightarrow$ cut-off value is defined by $W_{cluster}$),

calculate signal on strips including capacitive coupling

7. all strips have Gaussian noise contribution added

8. signal digitization:
charge is multiplied by gain factor and converted into integer number

9. strip zero suppression is applied with taking into account the threshold of each channel