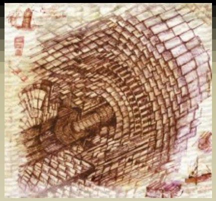


Two-in-one strip triggering module: construction and studies

J.Bernardini[(2)], F.Bosi[(1)], G.Broccolo[(2)], R.Dell'Orso[(1)], F.Fiori[(3)], A.Messineo[(3)], F.Palla[(1)], G.Parrini[(4)], A.Profeti[(1)] & P.G.Verdini[(1)]

(INFN [(1)], Scuola Normale Superiore-Pisa [(2)], University-Pisa [(3)] & University-Florence [(4)])

Work done within the CMS Tracker upgrade framework, in coordination with parallel upgrade activities see ACES contribution talks: D.Abbaneo, H.Chanal, M.Mannelli, S.Mersi.

Outline

1. Introduction: ***ideas and model***

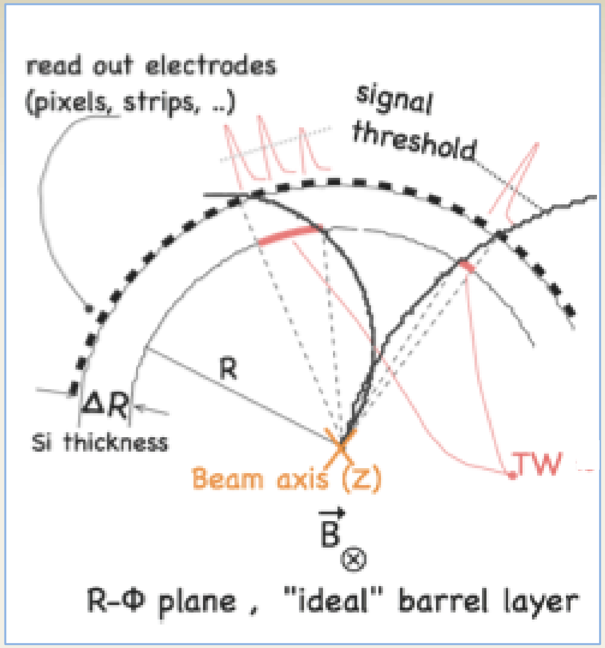
2. Method validation: ***study with LHC p-p collisions***

3. Simulation: ***performance in LHC high luminosity scenario***

4. Prototypes: ***two-in-one modules assembly and test***

1. Conclusions

Basic Idea



Model by F. Palla & G. Parrini

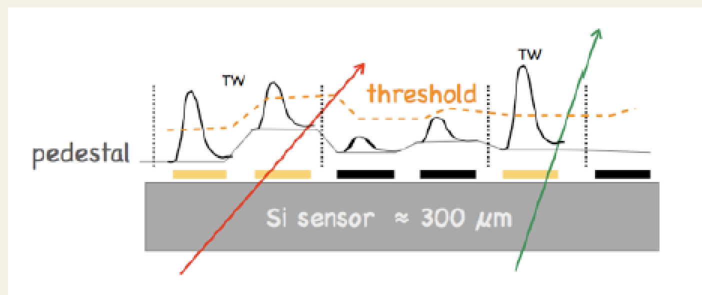
In a B field ➔ $P_T \approx 0.15 \cdot B \cdot \Delta R \dfrac{R}{TW}$ (Ideal case)

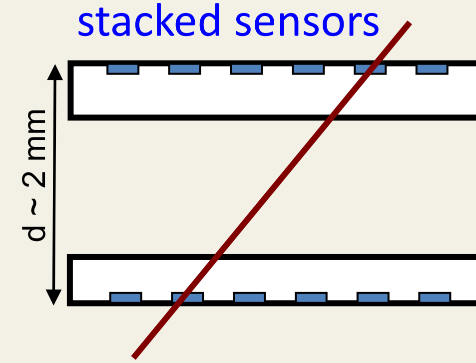
TW is measured by the reconstructed Cluster Width (CW)

ΔR can be:

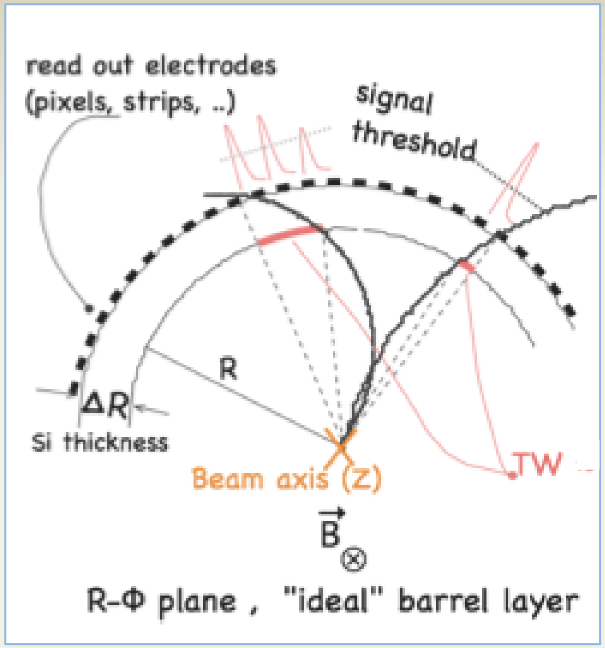
1) Si thickness for single sensor

2) Distance between 2 stacked sensors





Basic Idea



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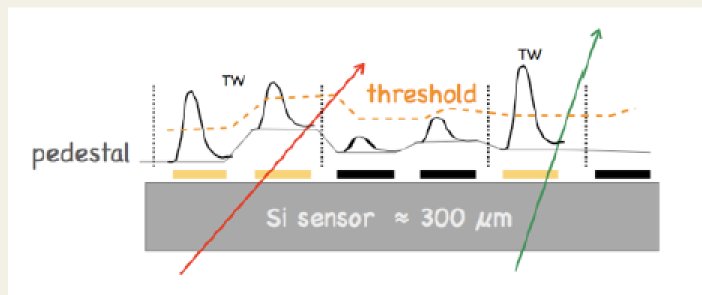
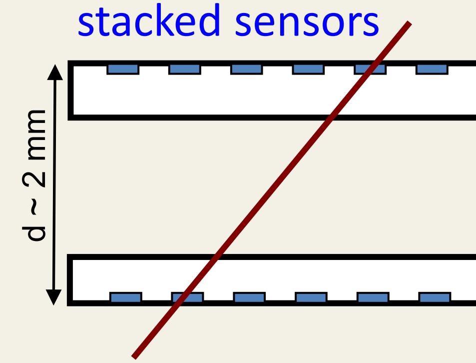




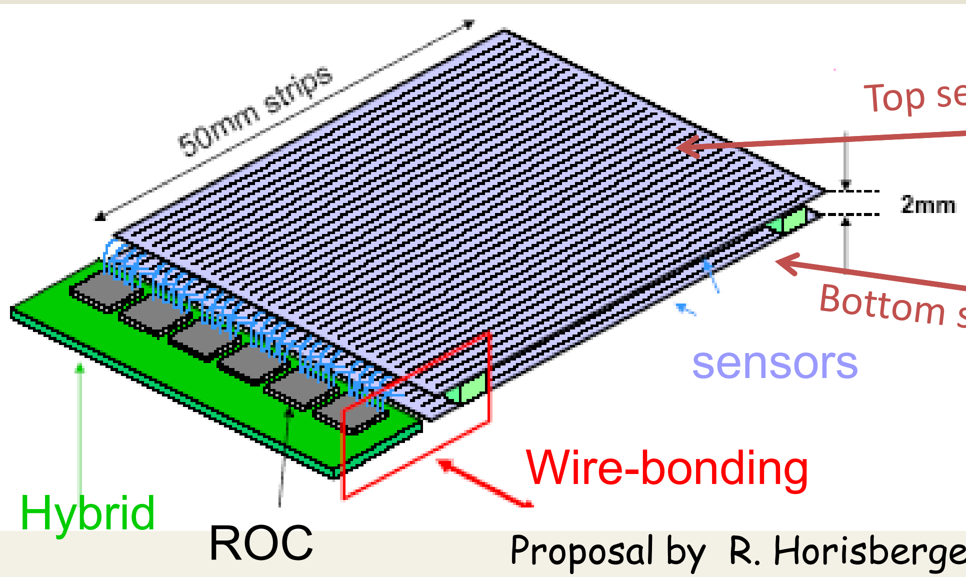
Two stacked sensors represents a two-in-one module, that can :

1) Achieve good angular resolution (strip pitch (≅100 μm) over 2mm lever arm)
2) Measure 2 independent points for tracking
3) Select a direction for triggering

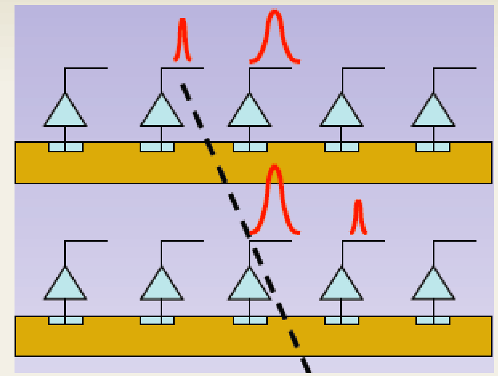
➔ Open the possibility to cut on P_T for a track trigger

Implementation of two-in-one module

Two micro-strip stacked sensors assembled in a single readout unit



Proposal by R. Horisberger

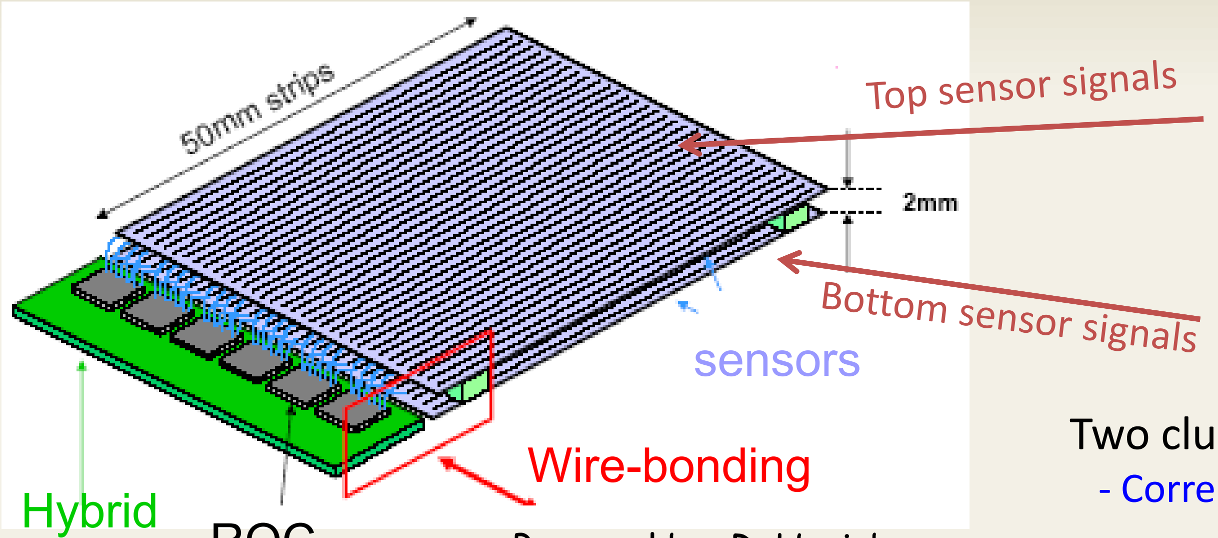


Two clusters produced per charged track:

- Correlation between sensitive planes

Implementation of two-in-one module

Two micro-strip stacked sensors assembled in a single readout unit



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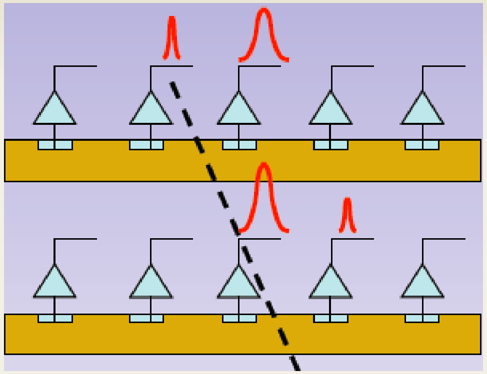


Two clusters produced per charged track:
- Correlation between sensitive planes

Two-in-one module design optimizes the common use of:

1) Assembly infrastructures: mechanical, material, ROC, cooling, cabling, ….
2) Read out electronics: simple logic to correlate hits, no need of high speed links or external correlation circuits, saving power,….

➔ **Maximize Benefit/Cost**

Method Validation with CMS Tracker

Performance of two-in-one modules measured in real data

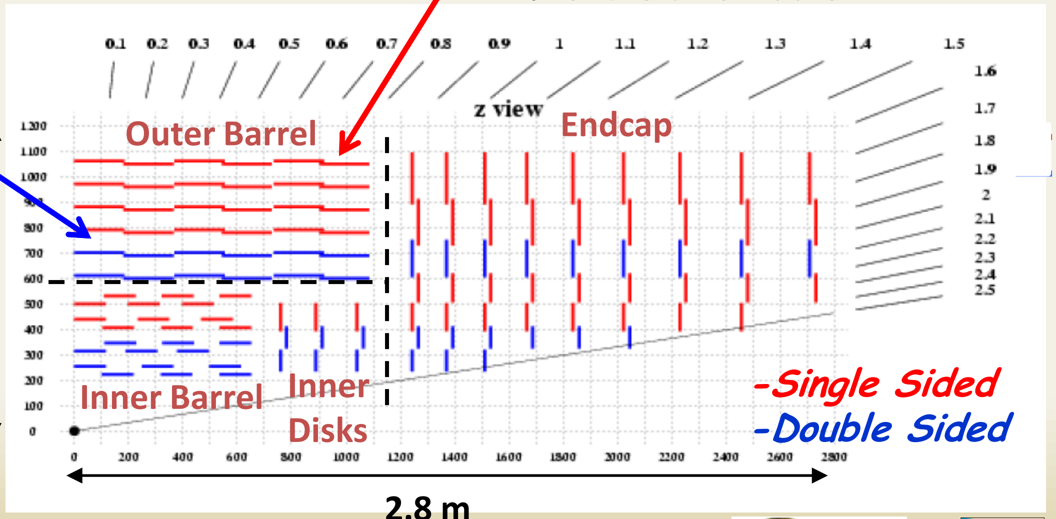
– 7 TeV p-p collisions data: good quality tracks, π & μ tracks

- Double Sided (DS) modules to mimic the two-in-one stacked modules
  - **TOB Layer 2**, R=70 cm, pitch=183 μm, thickness=500 μm, ΔR =2000 μm
- Single Sided (SS) modules for Cluster Width selection
  - **TOB Layer 6**, R=108 cm, pitch=120 μm, thickness=ΔR=500 μm

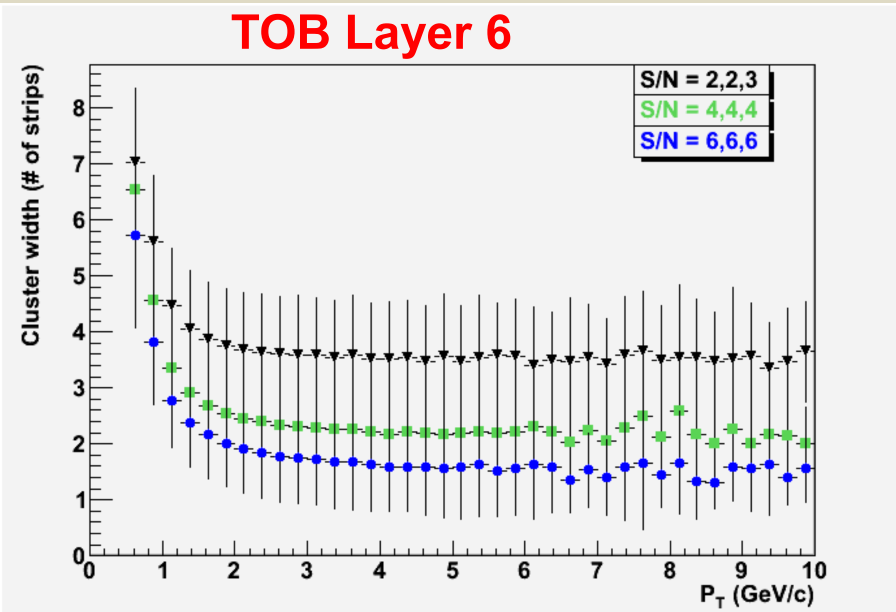
-Single Sided

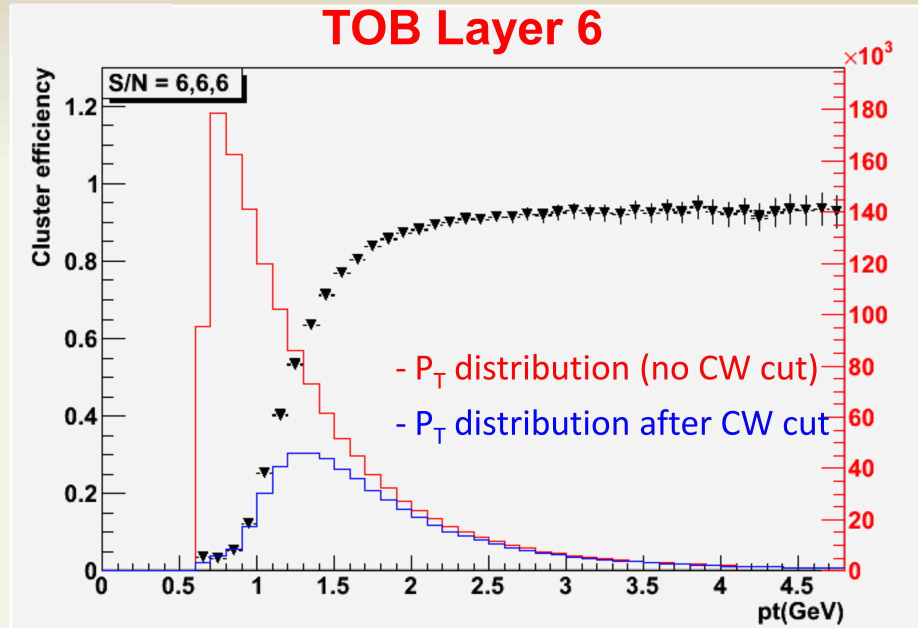
-Double Sided

¼ of the CMS Tracker



SS: sensitivity to CW

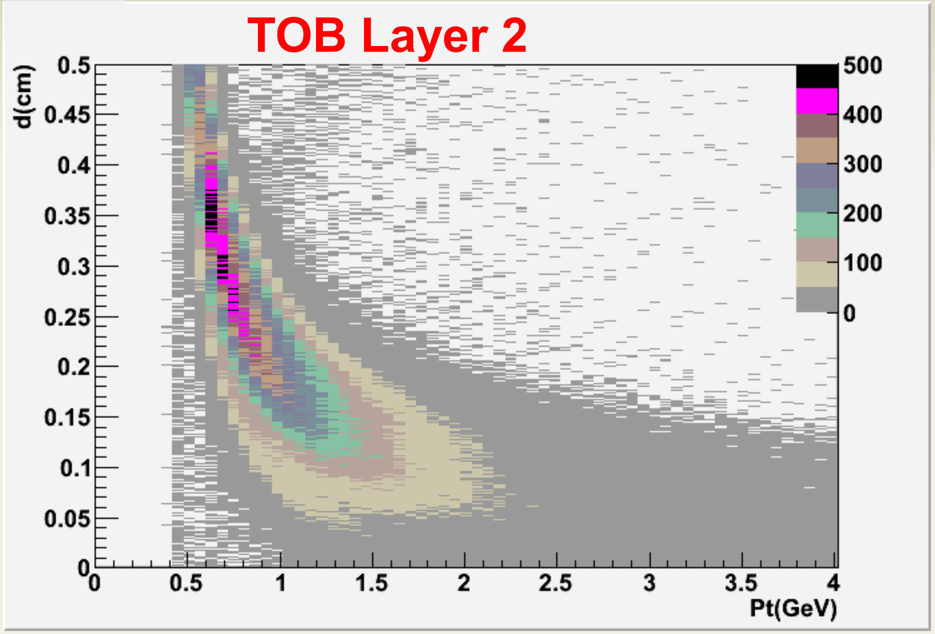


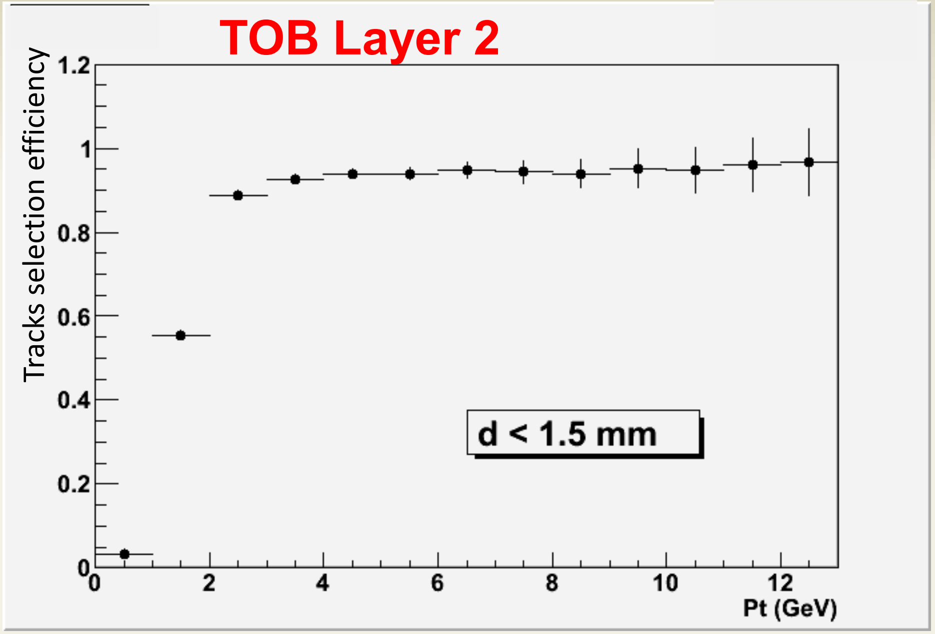


- Tracks Cluster Width correlated with the P_T
  - ✓ Good P_T sensitivity with cluster reconstruction threshold S/N =6

- Track selected with Cluster Width < 3
  - ✓ High P_T tracks are selected efficiently

DS: sensitivity to P_T



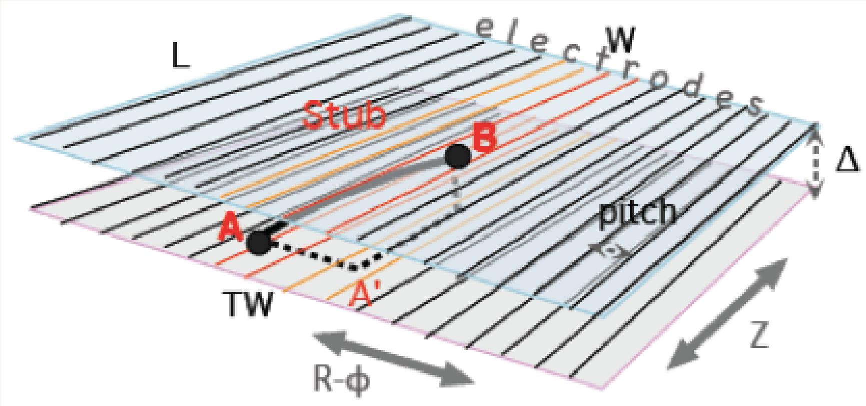


- Track P_T as measured by the hits distance on the 2 planes
  - Clusters are correlated off-line after a rotation for the stereo angle
    - High P_T tracks have clusters almost overlapping
    - Clusters for Low P_T ones are far each other

- Tracks selected with cluster separation d< 1.5 mm
  - ✓ Efficient selection of high P_T tracks

Simulation of two-in-one module

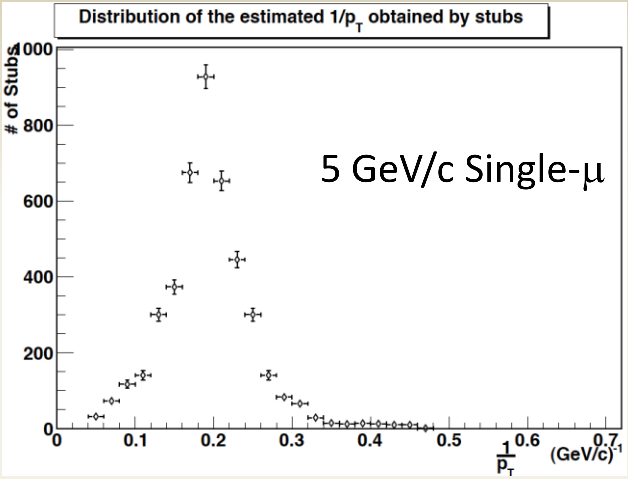
- LHC Scenario: Phase II
  - 200 events per Bunch-X
  - Full Simulation of CMS
    - Minimum Bias
    - Single muon
- Sensors
  - **Thickness:** 300 μm
  - **Strip pitch:** 90 μm
  - **Strip length :** 4.6 cm
  - **Strip #** : 1024/module
  - **Sensor planes separation:** Δ = 2mm

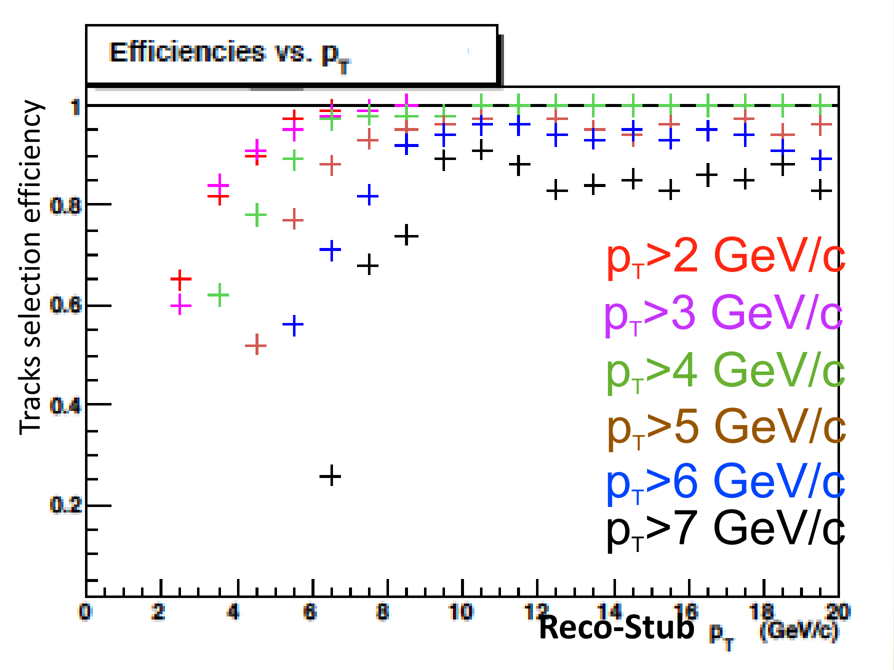


- Front End
  - Single threshold digital micro-strip read-out
- Definition of a Stub
  - Stub = 3 vector (global pos.) + 2 vector (flight dir.) + scalar (P_T)

P_T measurement

- Single-μ events P_T : 2-20 GeV/c
- Evaluation of reconstructed momentum from the Stub $$\frac{\sigma(P_T)}{P_T{}^{2}{}_{measured}} \square\, 5\%$$





Layer at R=102 cm equipped with two-in-one modules. P_T selection strongly depends from P_T Stub resolution $\sigma(p_T)$ that :

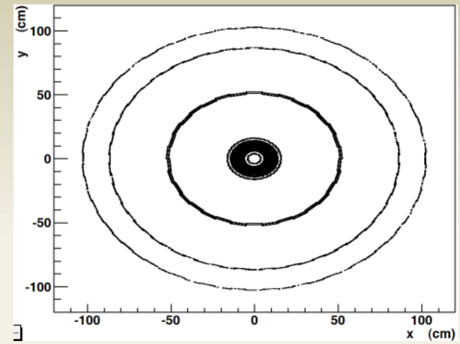
(1) increases as measured $P_T{}^2$

(2) is not gaussian and skewed toward larger P_T

Inefficiency appears for P_T larger than 5 GeV/c because of (1) and rejection is milder at high P_T because of (2)

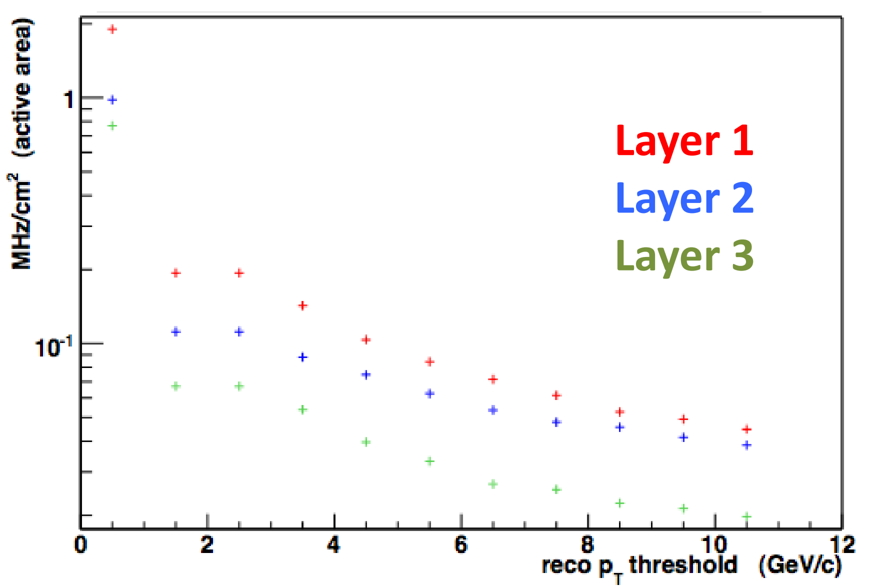
Trigger Rate

- Study of Stub trigger rate for
  - 200 Minimum Bias overlapping events
  - X-ing rate: 40 MHz
- Simulation of a simple layout
  - Full and detailed material description(inner detector 4 pixel layers & services)



layer	L1	L2	L3
Radius (cm)	51	86	102
Strip Occupancy (%)	1.5	1.1	0.9

Stub production rate per cm^2

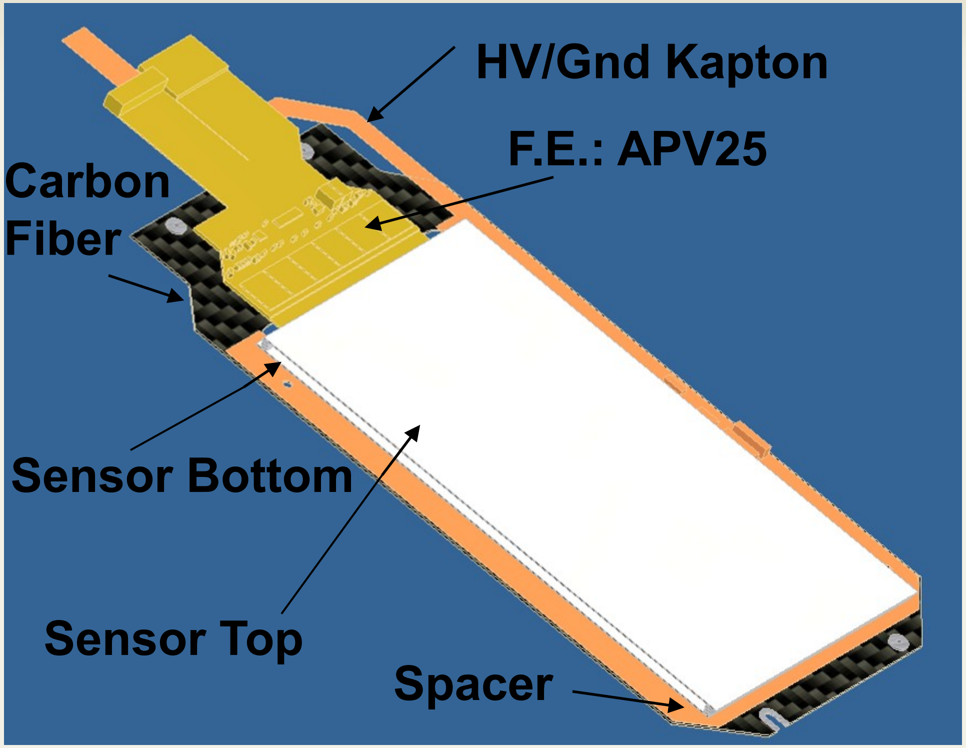


Cut on Stub reconstructed P_T, also at 1-2 GeV/c, is effective to reduce the rate at fraction of MHz/cm^2

Manageable level for Triggering purposes

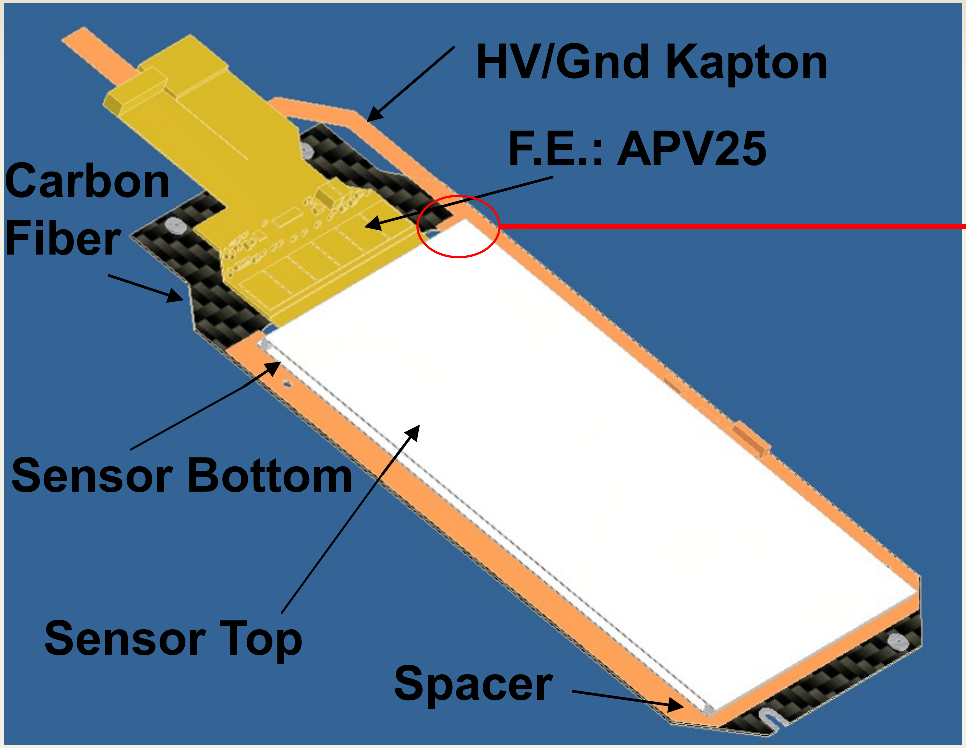
Two-in-one Prototypes

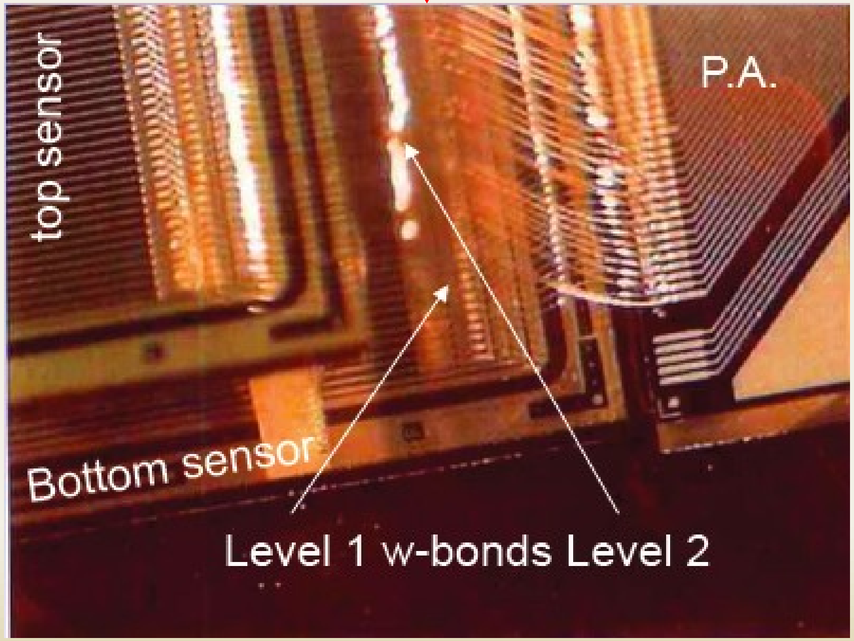
- Detector assembled with production components of the present CMS tracker

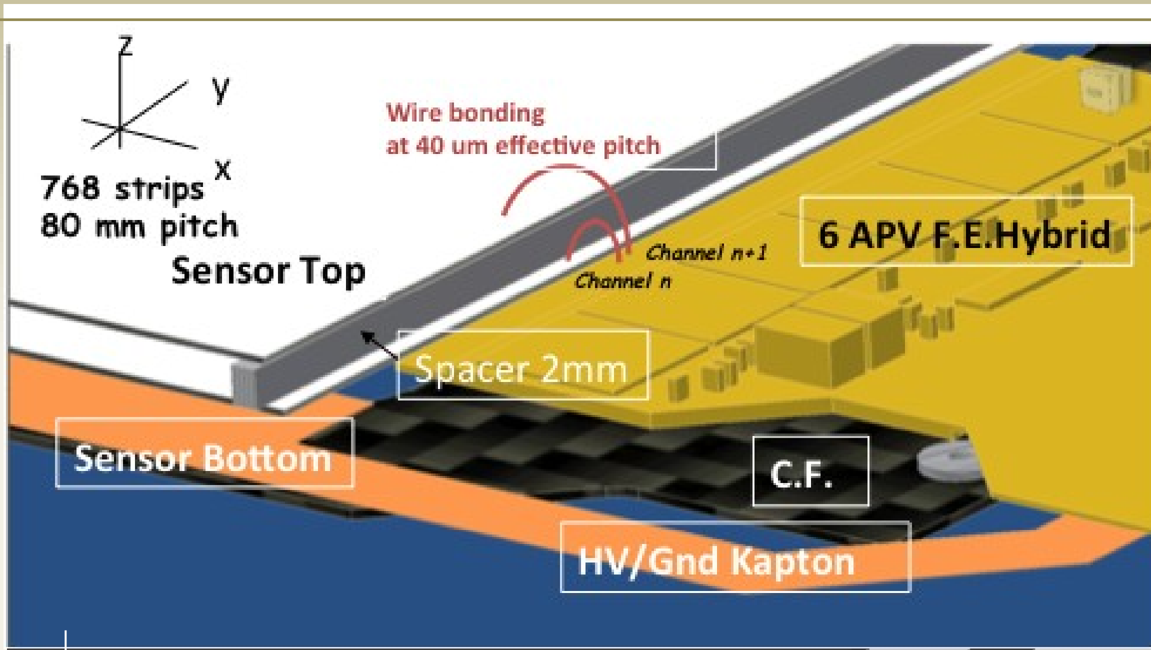


Prototypes

- Detector assembled with production modules of present CMS tracker



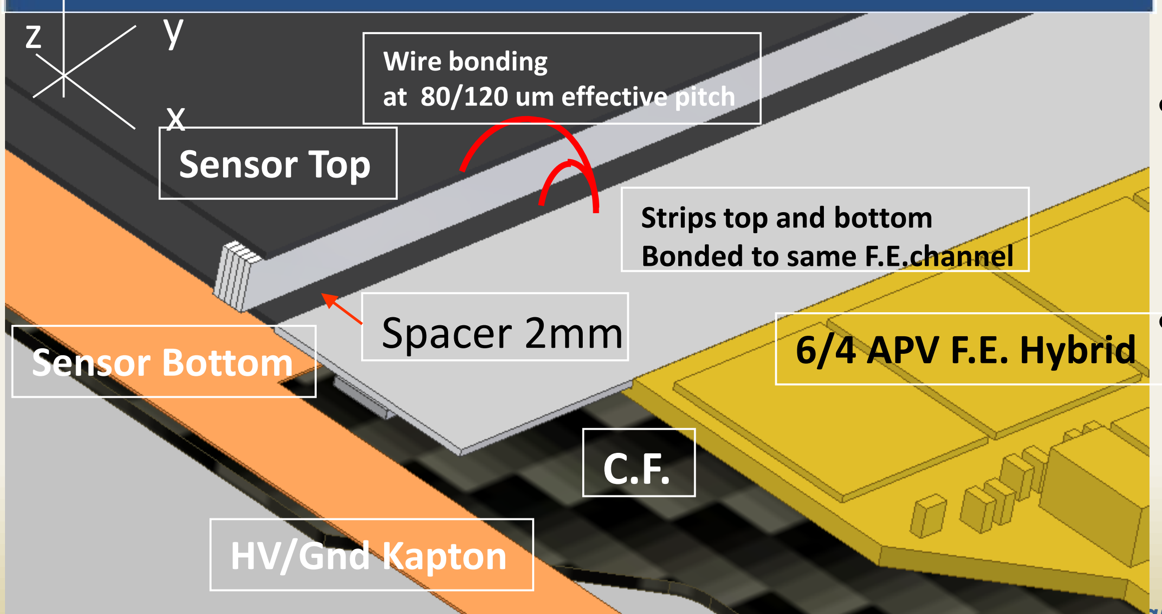




Module A

- Pair of corresponding strips wire-bonded to a pair of neighboring readout channels
- Sensors pair with:

  80 μm pitch and 768 strips



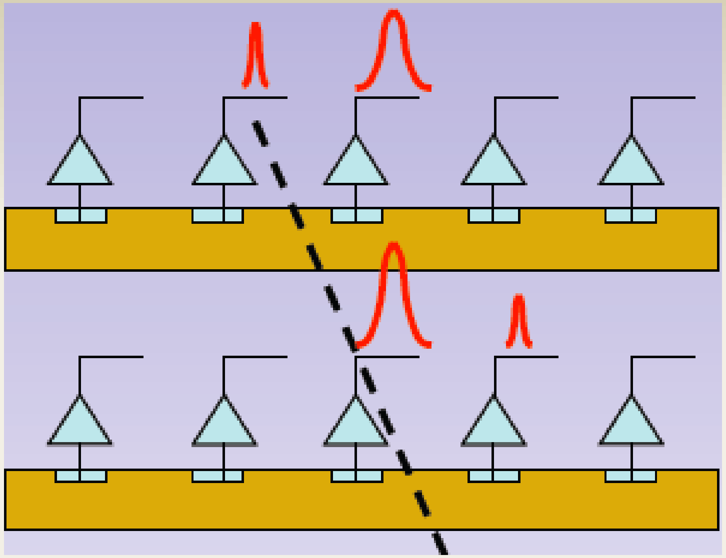
Module B

- Pair of corresponding strips wire-bonded to the same read-out channel
- Sensors pair with:

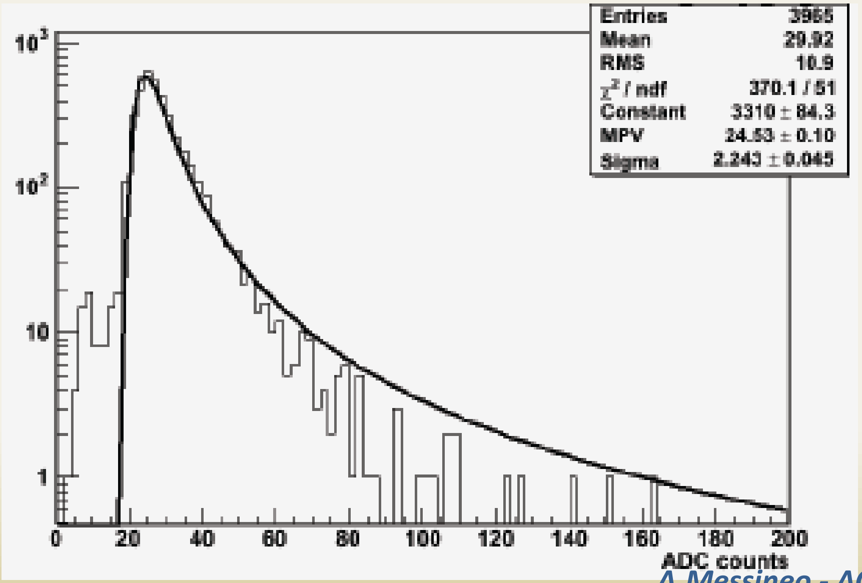
  120 μm pitch and 512 strips

  80 μm pitch and 768 strips

Module A: Working Principle

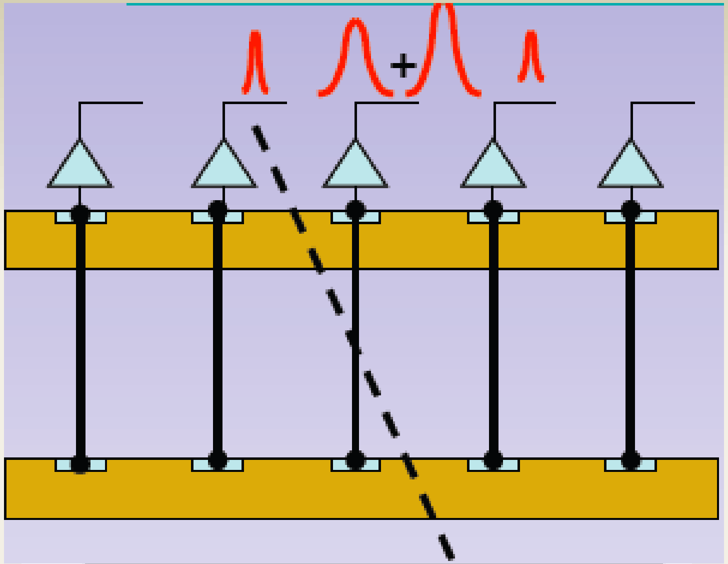


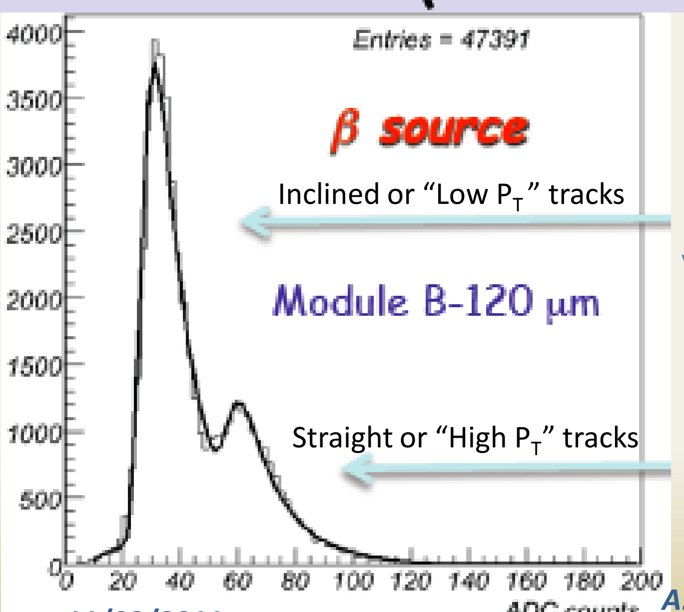
- Tracks generate signals on both sensors
  - Strip signals collected independently
  - Top and Bottom Cluster position & width reconstructed independently
  - Correlation between top & bottom sensors needed



- Off Detector Cluster analysis
  - Select events with 2 clusters only
  - No X-talk or Common Mode affect performance
    - Fit on S/N distribution: Landau with MPV=24.5±0.1

Module B: Working Principle





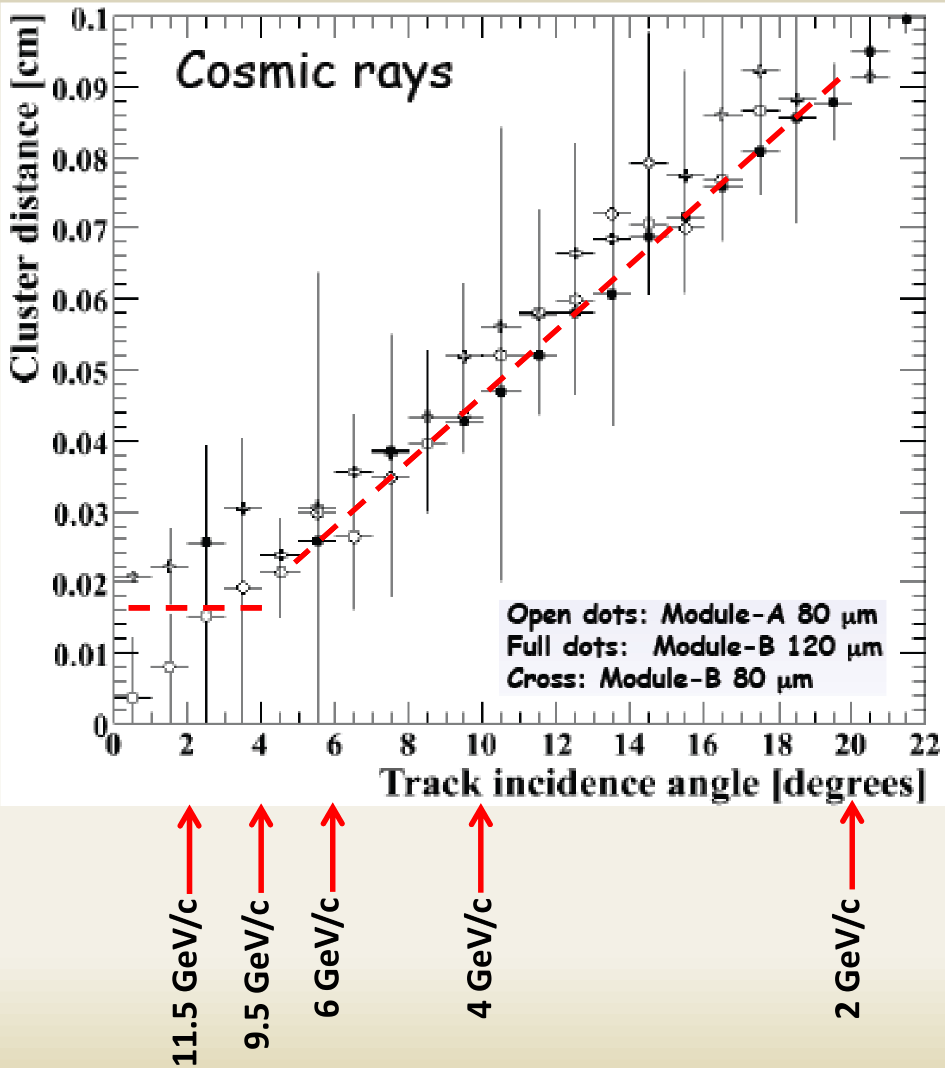
- Tracks generate signals on both sensors
  - Strip signals are summated by wire bonding
  - Clusters position & width reconstructed as for a single sensor
  - Only one cluster reconstructed per track if clusters overlap in space

- Off Detector Clusters analysis
  - Clustering performed for track with 1 cluster or 2 clusters

Fit on S/N distribution:

2 clusters	MPV=20.8±0.2
1 cluster	MPV=39.2±0.5

Track Direction of Flight measurement



Cluster Distance separation:

- Module A linear in the full range of incidence angles
- Module B non-linear for small incidence angle (clusters overlap)
- P_T discrimination in 4 Tesla B field at R=108 cm

Conclusions

- Two-in-one module design is a viable solution for Tracker Trigger. Proven to work with:
  - Real LHC collision data
  - Prototypes
  - Full Tracker simulation

- Main features:
  - Low mass and HW optimized
  - Capable to decrease P_T trigger data rate down to ~ 100 KHz /cm^2
  - Local trigger & P_T evaluation

Conclusions

- Work in progress:
  - Some R&D remain to be done, this activity will continue since is needed for the Phase II
    - Implement detector optimized design (sensor/layout)
    - Trigger performance simulation study on benchmark channels
    - Particle beam prototypes study
    - INTRA sensors in module connectivity optimization & packaging
    - INTER layer/Rod module studies (HW, SW as A.M., ..)

References

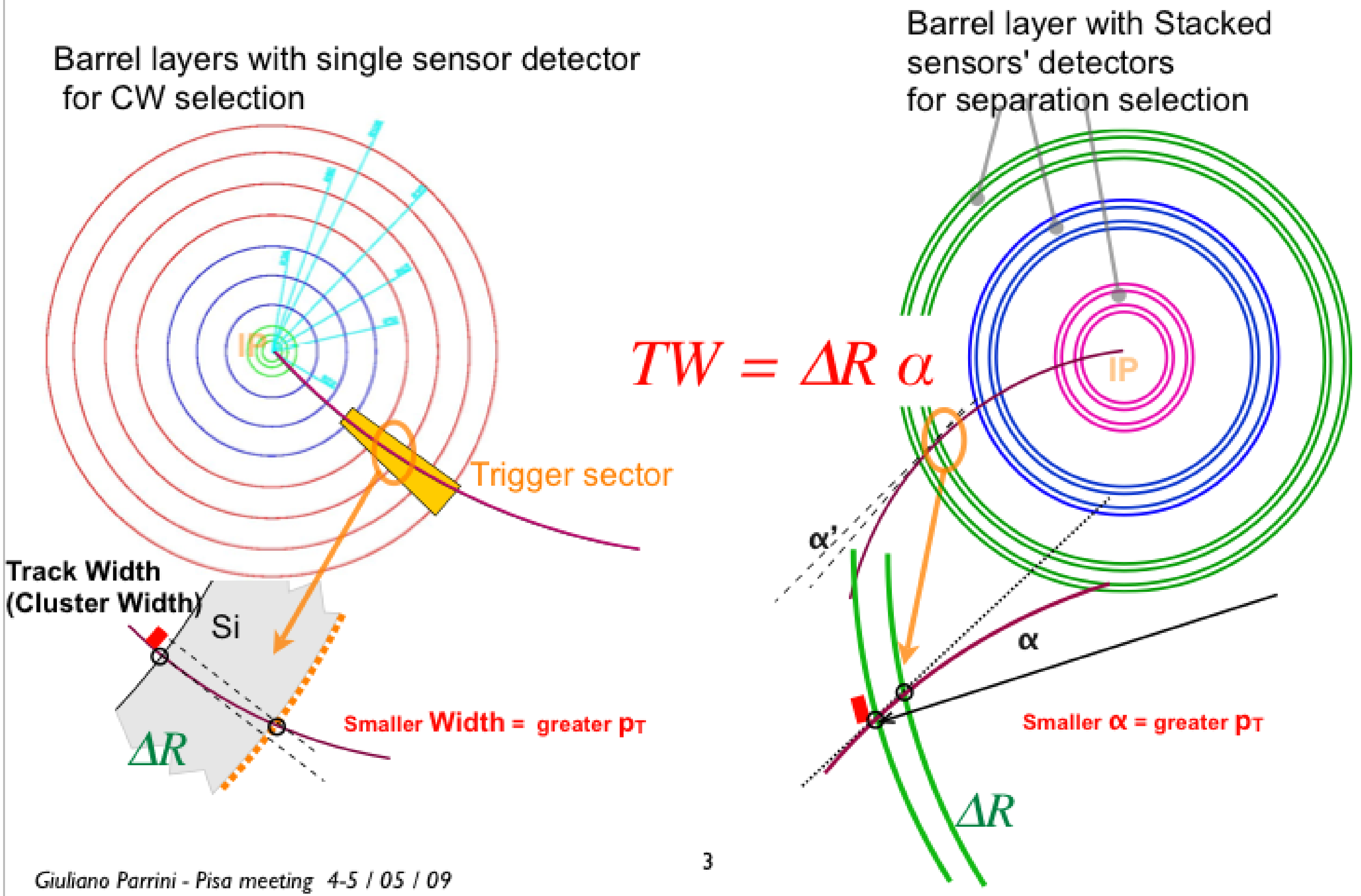
- *Concepts for a tracker trigger based on a multi-layer layout and on-detector data reduction using a cluster size approach.* **JINST 5:C08002,2010**
- *Track momentum discrimination using cluster width in silicon strip sensors for SLHC.* **Published in *Prague 2007, Electronics for particle physics* 80**
- *Tracking in the trigger: From the CDF experience to CMS upgrade.* **PoS VERTEX2007:034,2007**
- *Design and development of micro-strip stacked module prototypes for tracking at S-LHC.* **JINST 5:C11018,2010**
- *Design and development of micro-strip stacked module prototypes to measure flying particle directions.* **JINST 5:C07014,2010.**

Talks

- http://indico.cern.ch/contributionDisplay.py?sessionId=0&contribId=16&confId=68677
- G. Parrini , Talk at Joint SLHC Trigger-Tracker meeting 2007, CERN and TWEPP 2007
- http://indico.cern.ch/getFile.py/accesscontribId=80&sessionId=29&resId=0&materialId=paper&confId=11994

Extra

The two approaches for a quick "measure" of pT



Simplified formulas

Using **acceptances W/ R < 0.2** the stub width formula can be simplified

$$TW_r \approx F + \left(1 + F^2\right)(x/R)$$

$$F = \pm \frac{1}{\sqrt{\left(\frac{pT}{pT_{\min}}\right)^2 - 1}} \approx \pm \left(\frac{pT_{\min}}{pT}\right) \times \left[1 + \frac{1}{2}\left(\frac{pT_{\min}}{pT}\right)^2 + \ldots..\right]$$

If pT* >> 1

$$TW \approx \pm \left(\frac{pT_{\min}}{pT}\right) + x/R = \pm 1/pT^{*} + x/R$$

“Linear”
cylindrical layer (pT* any)
+
flat layer (pT* =!)

pT selection : from TW to pT

$$\frac{TW}{pitch} = TW_r \frac{''}{pitch} \# \left(\begin{matrix} \% \; \% \\ ', \pm ', \\ \& \; \& \end{matrix} \frac{1}{pT} * \right) + \frac{X}{R+} + \tan, \quad + \left(2\, D/'' \right) \tan\theta_L \left(\frac{''}{pitch} \right.$$

$TW_{measured}$

cylindrical layer

flat layer

rotation

Lorentz spread

ToP

After the digitization the inverse transformation gives not unique results:

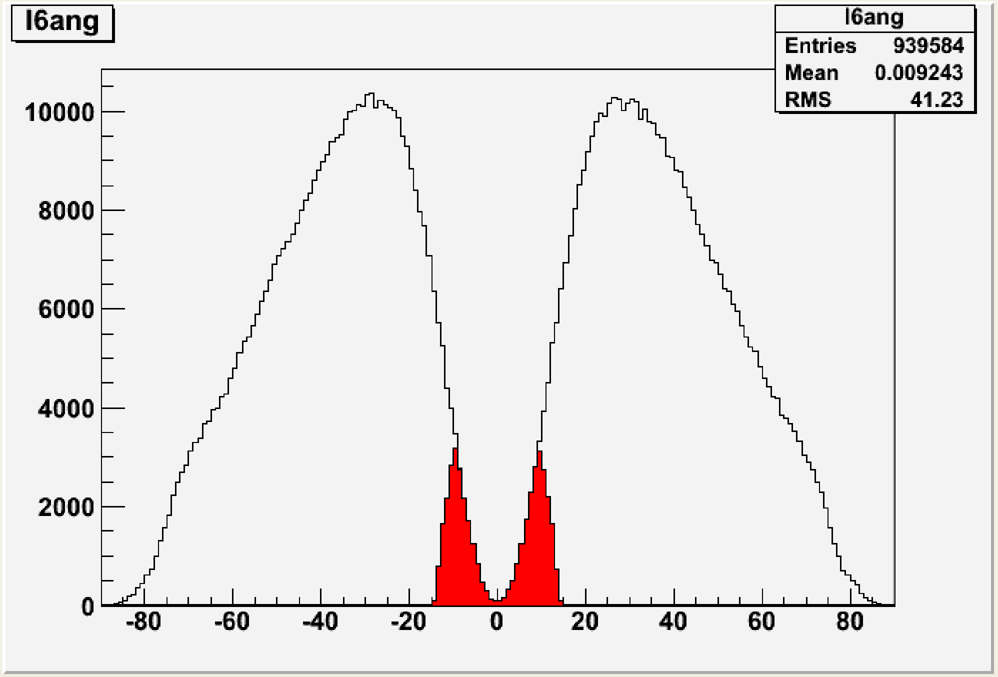
if **$TW_{measured}$** = **N**x**pitch** we have **N-2 %TW < N**

This observation is the starting point to calculate the threshold of the selection

TOB Layer 6

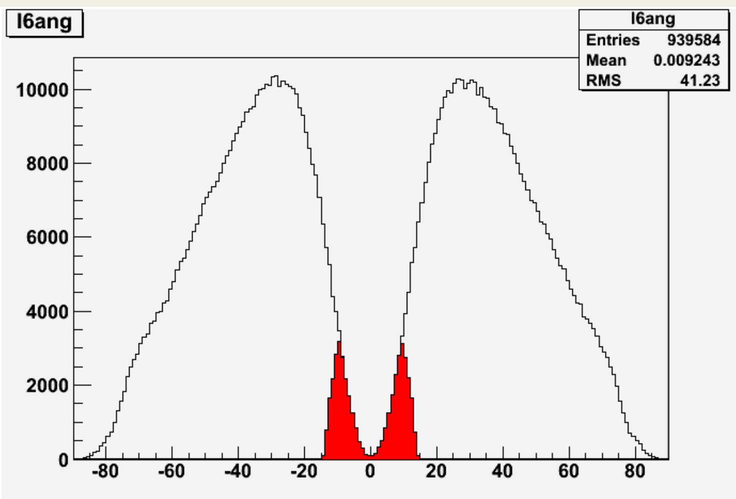
- Layer 6:
  - R = 108 cm
  - Strip pitch = 120 μm
- Good tracks only:
  - Chi2 < 2
  - Nhits > 11
  - Npixel > 1
  - Z0 < 10 cm
  - D0 < 5 cm (0.1 cm)

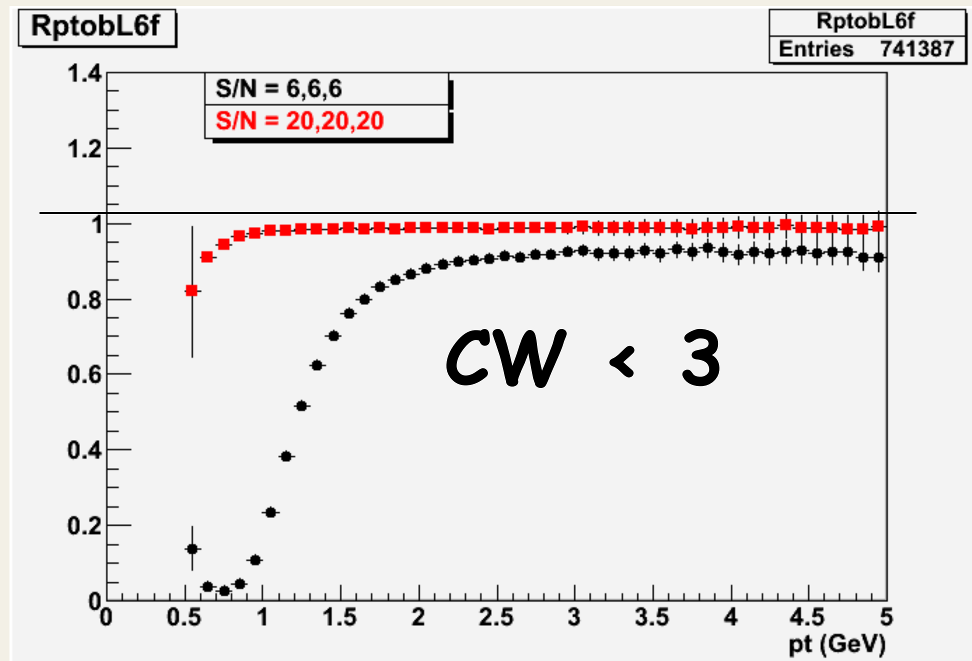
- **Incident angle (degrees)**
  - **In red pt > 3 GeV**



Study of CW sensitivity

- Good pt selection with clusterizer σ = 6

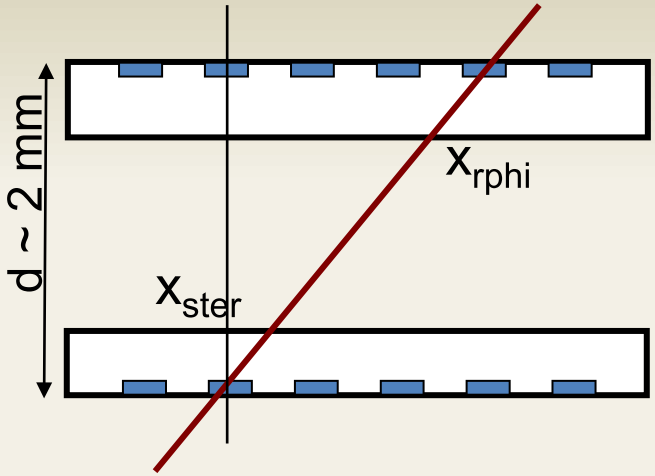




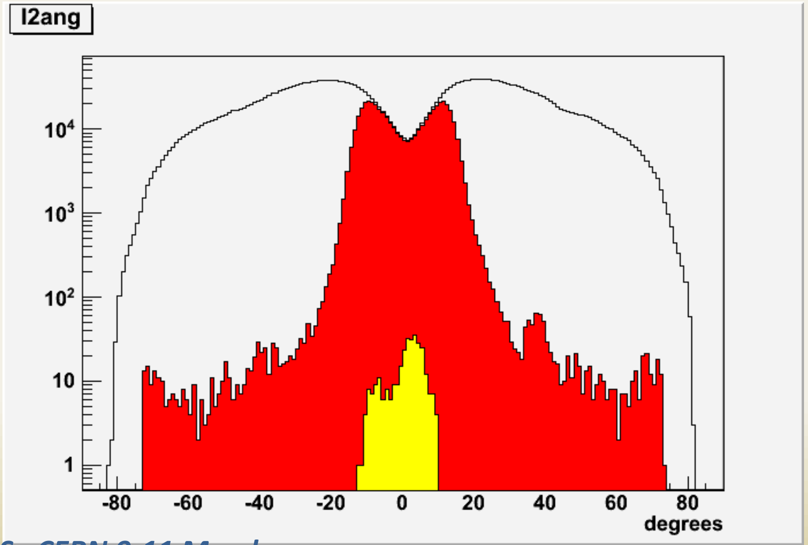
- **Pt distribution before and after cut**

TOB Layer 2

- Layer 2:
  - DS module used to mimic stacked modules with 2 mm separation
  - R = 70 cm
  - Strip pitch = 183 μm
- Good tracks only:
  - Chi2 < 2
  - Nhits > 11
  - Npixel > 1
  - Z0 < 10 cm
  - D0 < 5 cm (0.1 cm)

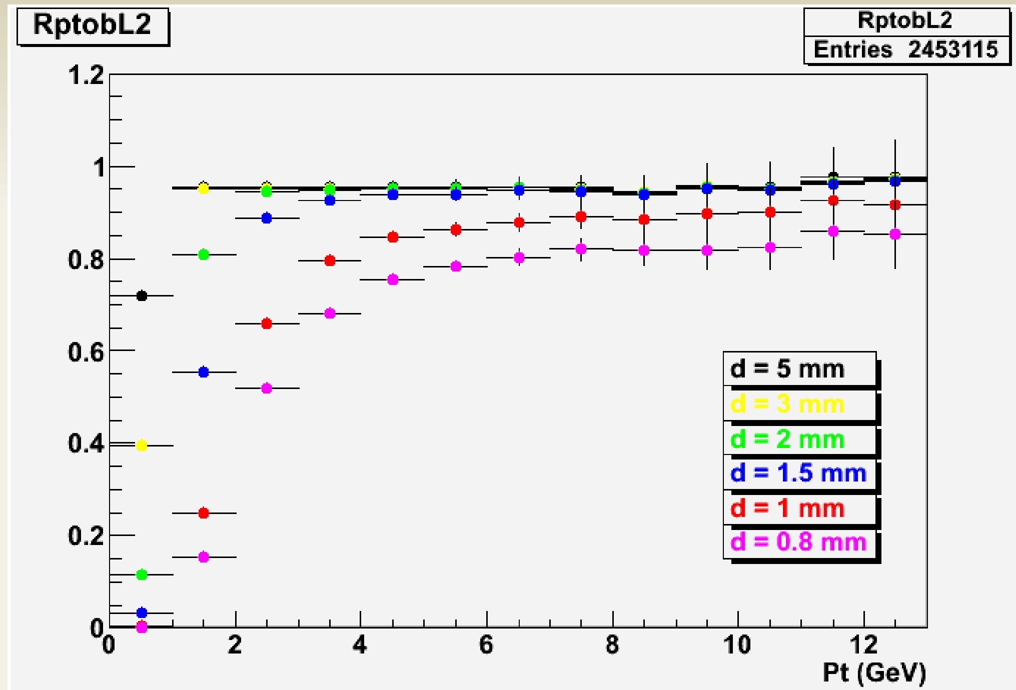


- **Incident angle distribution**
- **In red pt > 3 GeV**
- **In yellow pt > 20 GeV**

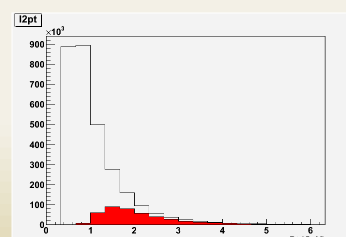


Study of PT module sensitivity

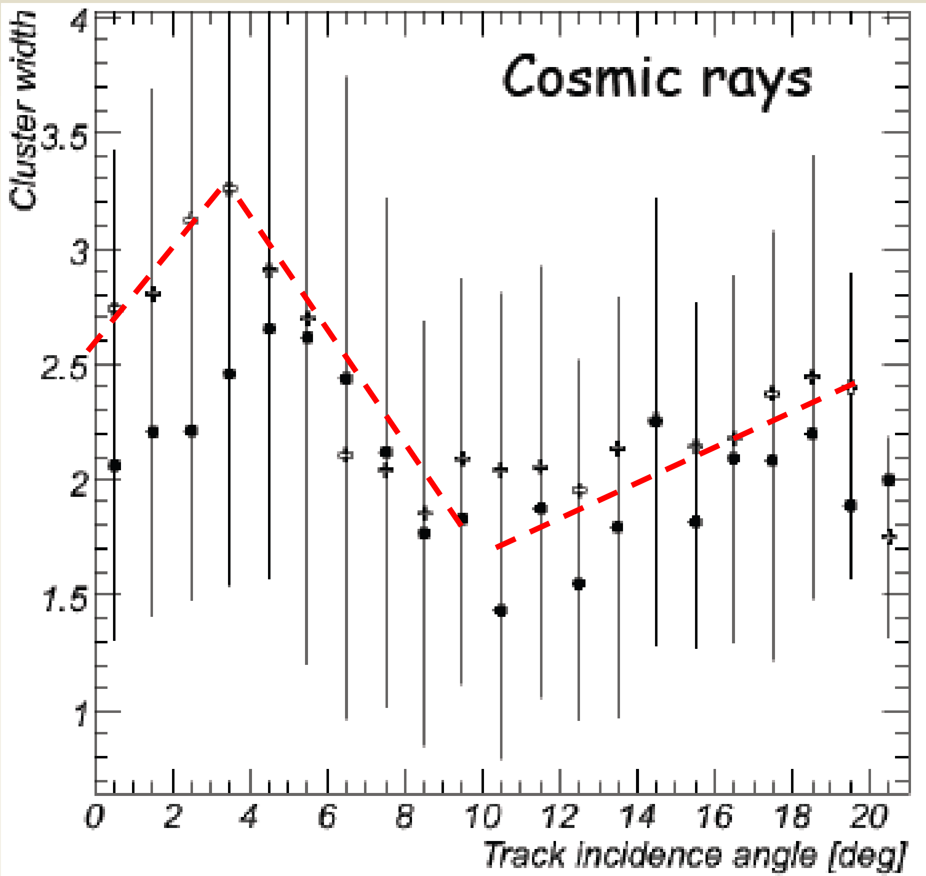
- Correlation of track flight path measurement with P_T
  - Tracks selected if clusters separation smaller than 1 mm
    - selection of high P_T tracks



- Pt distribution (lin & log scales)
  - In red clusters distance < 1 mm



Cluster Width measurement performances: Module B

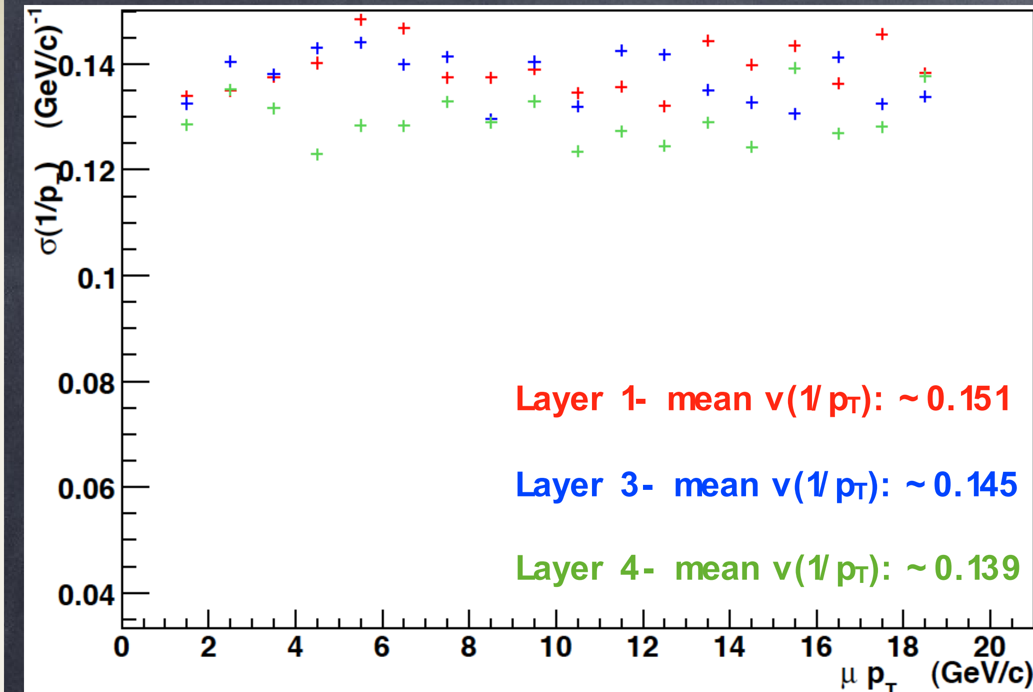


- Full dots: Module-B 120 μm
Cross: Module-B 80 μm

- Cluster Width (# of strips):
  - Increases until top & bottom sensors produce events with 1 cluster
    - 80 μm pitch module has larger CW
  - Drops at 2 clusters splitting angle
    - Smaller for 80 μm pitch module
  - Follows a standard behavior at larger angles (where 2 cluster events are collected)
    - Slope compatible with standard tracker modules

Single-n events study

>> resolution of (reco from stub) $1/p_T$ as a function of (MC truth) n p_T:



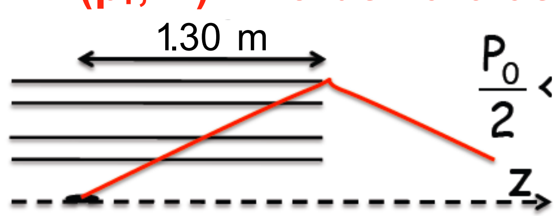
Single n 2-20 GeV

(ADC threshold: 30)

- >> Obtained fitting $1/p_T$ distribution (see slide 7) for each n p_T bin.
- >> As expected from v(p_T) relation in slide 5, v($1/p_T$) is ~constant.
- >> v($1/p_T$) decreases with the radius because p_T is better estimated (see relations in slide 5).

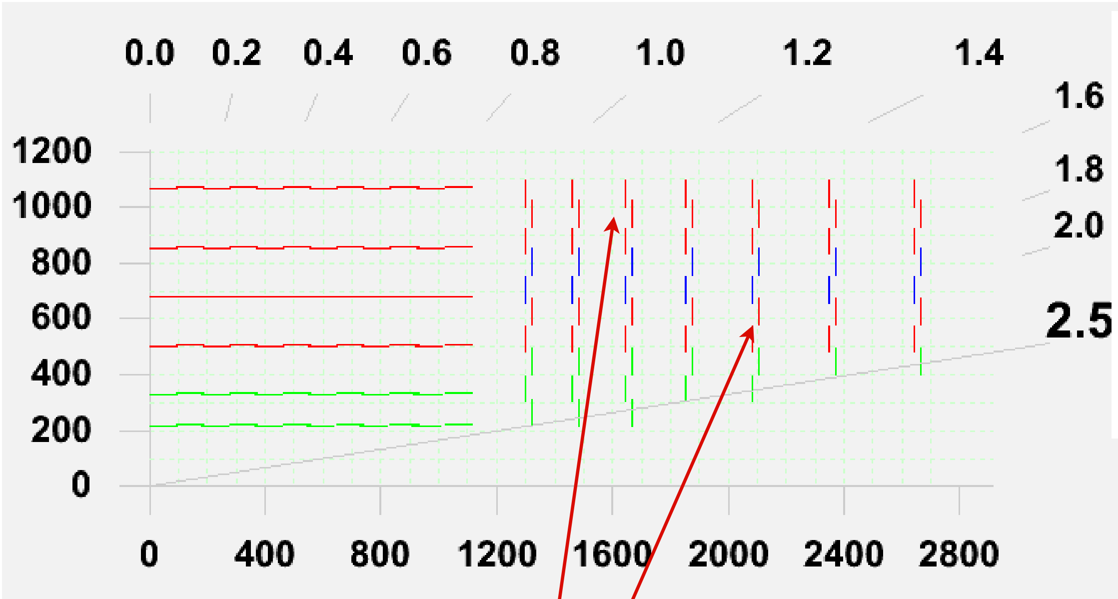
>> Efficiencies estimate: only n passing through ALL layers.

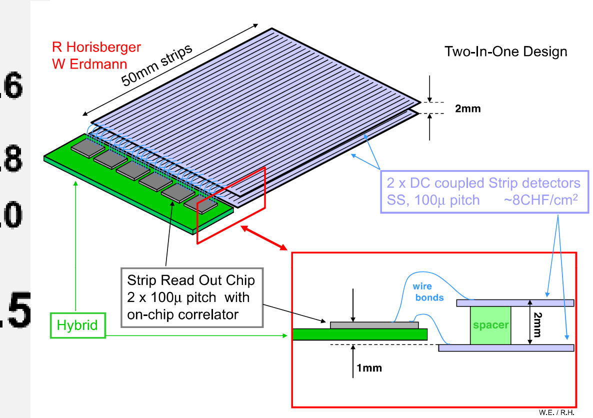
(p_T, h) in order a track passes through the 4 layers

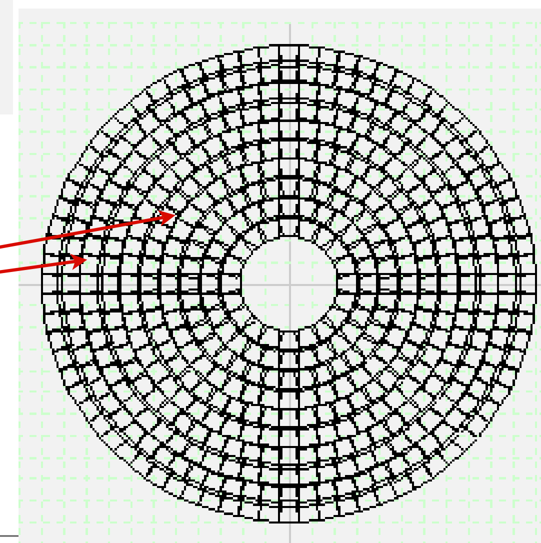


$$\frac{P_0}{2} < 1.30\ m \Rightarrow p_t \cdot \sinh(\eta) < \frac{1.30\ m}{\pi \cdot 0.3B}$$

Endcap Geometry (fast simulation)



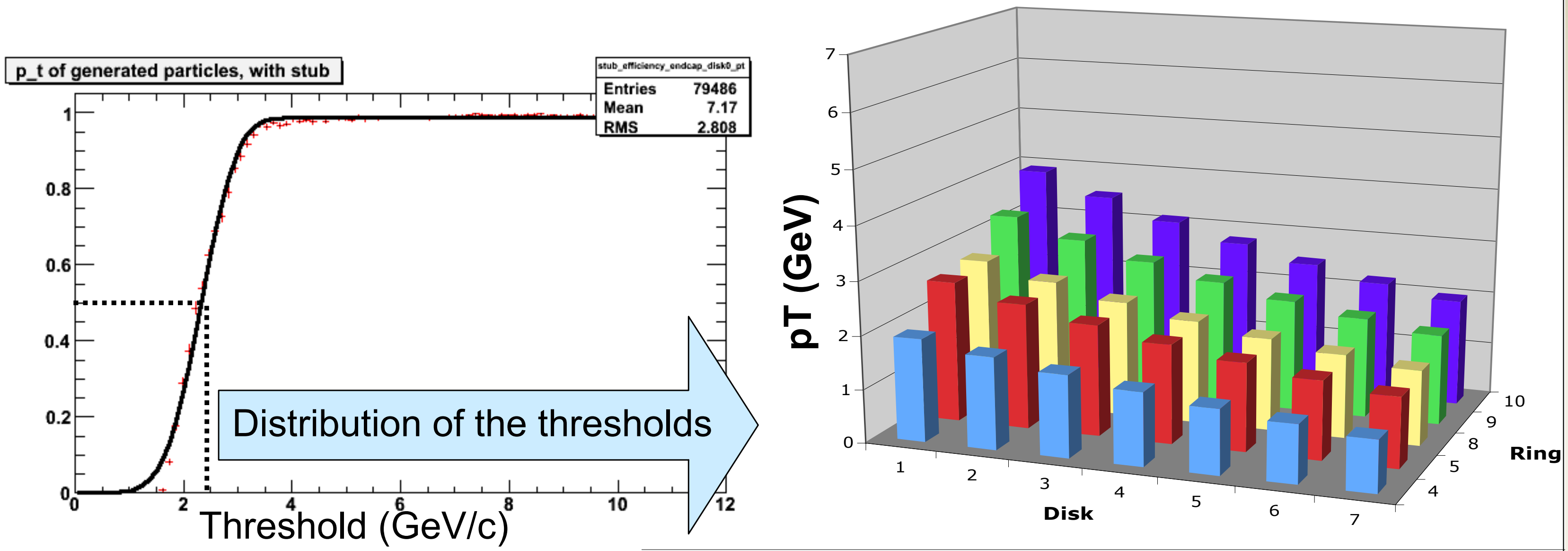




47 µm

Trigger rings

Endcap (preliminary) results



- **Quite promising results for rings>40 cm**
  - **low occupancy**
  - **small number of stubs/module**
  - **relatively small pT threshold**

R. Frazier

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