The P326 GigaTracker

Alias tracking in 1GHz beam

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on behalf of the P326 collaboration:

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- P326 quick view
- Requirements on GT
- Resolution and material budget
- Rate and radiation
- Front End
- Conclusions

Time05 3rd - 7th October – Zurich

P326

Measure the Rare Decay $K^+ \to \pi^+ \nu \bar{\nu}$ (SM BR $(8.0\pm1.1)\times10^{-11}$)

at the CERN SPS

Collect ~ 5×10^{12} Kaon decays/year

from a secondary SPS hadron beam

☺ high energy kaons:

- high acceptance
- good resolution
- good photon detection efficiency
- redundancy

☹ pions and protons cannot be separated:

- large rate in the beam tracker

SPS 400GeV protons → target → hadron beam: π, p, e, K

highest energy @ max SPS duty cycle

(4.8s spill /16.8s)

K^+/K^- per proton ~ 2.1

75GeV K^+: max acceptance $K^+ \to \pi\nu\nu$bar/total flux

(production rate, flux, decays,

decay products acceptance..)

3×10^{12} protons/spill → 0.8GHz beam particles rate:

(already available)

(2.5×10^{9}ppp/3s effective spill)

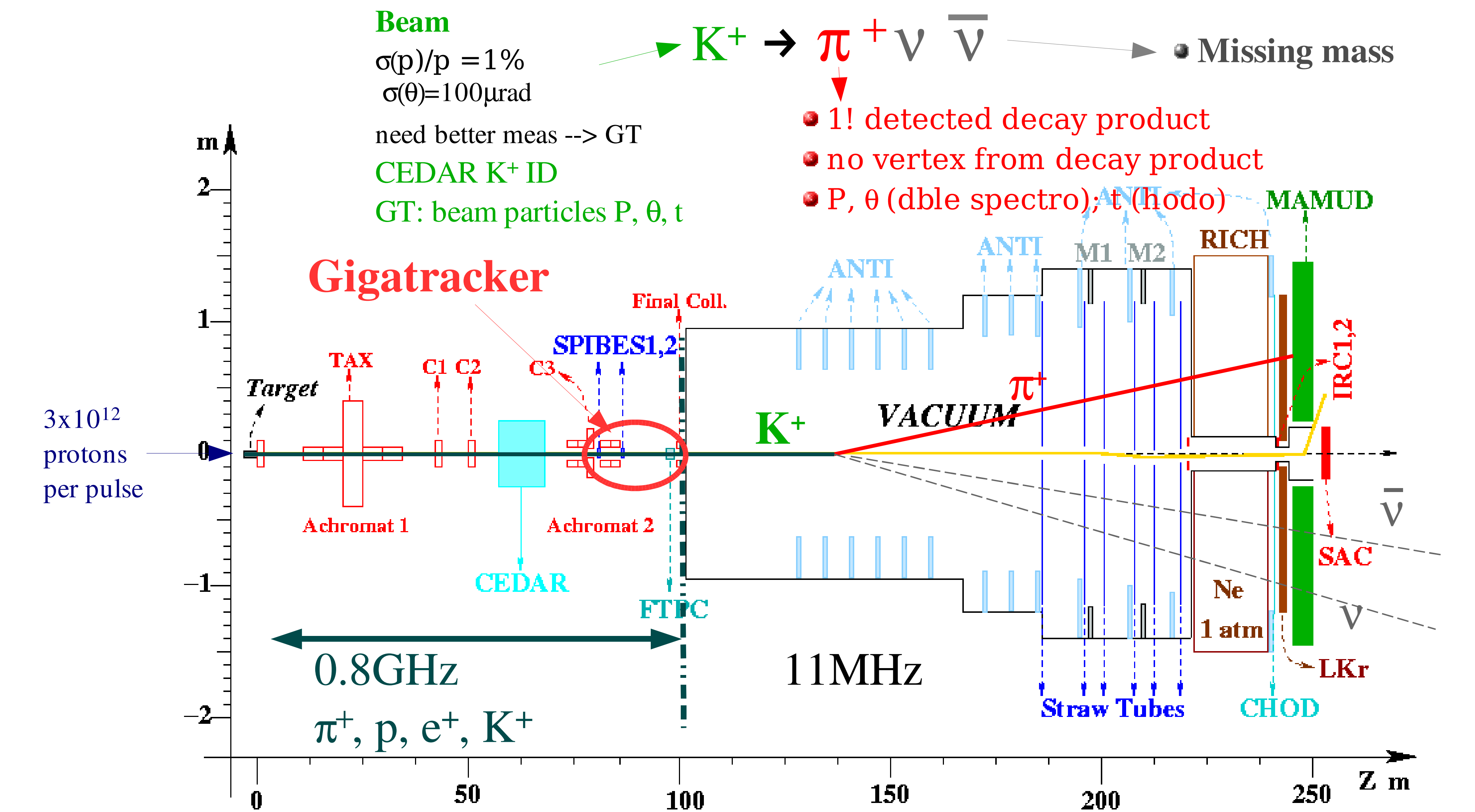
60% π^+, 20% p^+ ,14% e^+, **6% K^+**

$\sigma(p)/p = 1\%$

$\sigma_x \sim 8$mm, $\sigma_y \sim 11$mm

angular spread $\sigma(\theta)=100\mu$rad

P326 layout



Beam
σ(p)/p =1%
σ(θ)=100μrad
need better meas --> GT
CEDAR K+ ID
GT: beam particles P, θ, t
K+ → π+ ν ν̄
Missing mass
1! detected decay product
no vertex from decay product
P, θ (dble spectro); t (hodo)
Gigatracker
m
2
1
0
−1
−2
3x10^12 protons per pulse
Target
TAX
C1 C2
C3
SPIBES1,2
Final Coll.
Achromat 1
Achromat 2
CEDAR
FTPC
K+
VACUUM
π+
ANTI
ANTI
ANTI
M1
M2
RICH
MAMUD
IRC1,2
SAC
Ne
1 atm
LKr
CHOD
Straw Tubes
ν̄
ν
0.8GHz
π+, p, e+, K+
11MHz
0
50
100
150
200
250
Z m

P326 strategy

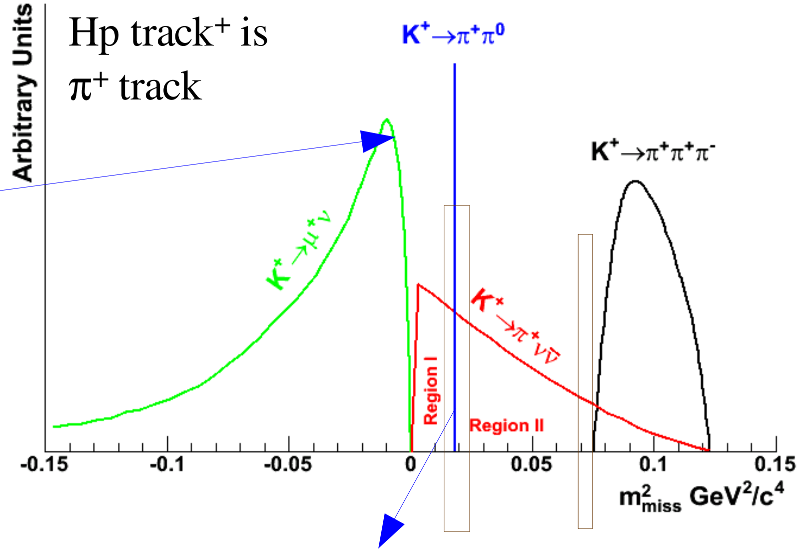
- **Goal of P326: <u>S/B ~ 10</u> ⟷ <u>~10^{12} rejection</u>**
- **2-steps background rejection:**

1) Kinematical rejection

$$m^2_{miss} \approx m^2_K\left(1-\frac{|P_\pi|}{|P_K|}\right)+m^2_\pi\left(1-\frac{|P_K|}{|P_\pi|}\right)-|P_K||P_\pi|\vartheta^2_{\pi K}$$

92% of bkg is kinematically constrained

K^+ decay	BR
$\mu^+\nu$ ($K_{\mu 2}$)	0.634
$\pi^+\pi^0$	0.211
$\pi^+\pi^+\pi^-$	0.070
$\pi^+\pi^0\pi^0$	



Splits signal region in

RegionI: $0 < m^2_{miss} < m^2_{\pi\pi} - \Delta$

RegionII: $m^2_{\pi\pi} + \Delta < m^2_{miss} < \min(m^2_{3\pi}) - \Delta$

$\Delta \div \sigma(m^2_{miss})$ ⇒ worse $\sigma(m^2_{miss})$ ⇨ lower S/B

2) Veto and Particle ID

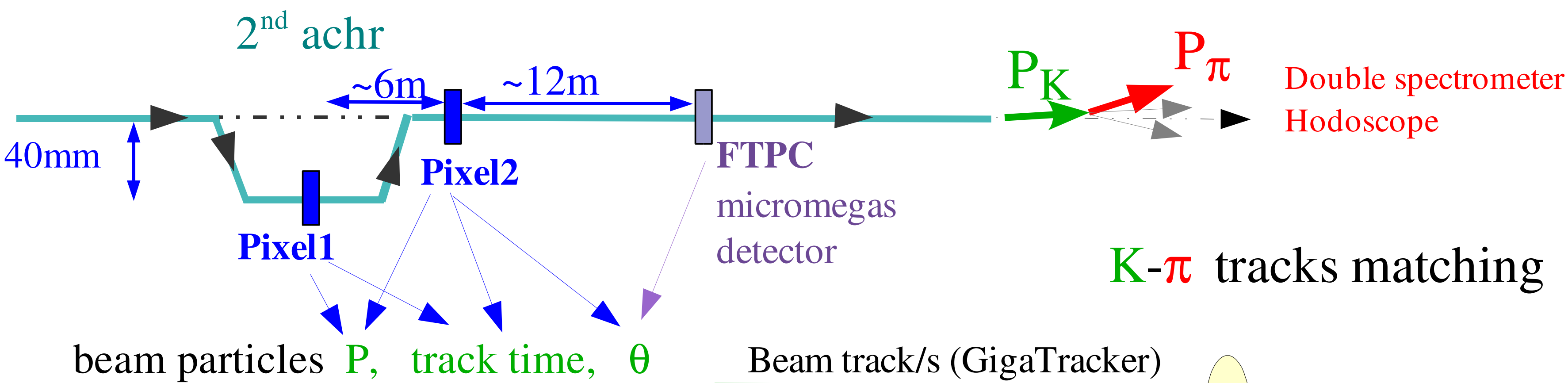
- γ, μ, charged particles
- μ–π-e separation

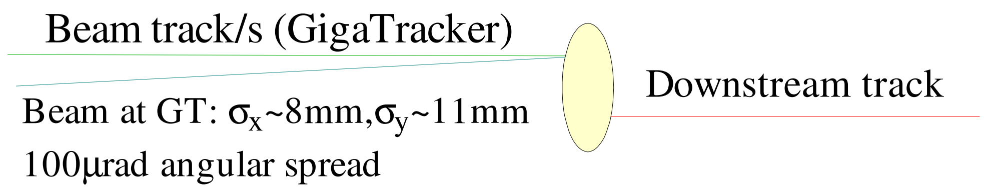
8% bkg not kin constrained: rely on particle ID and veto

K^+ decay	BR
$\pi^0 e\nu$ (K_{e3})	0.049
$K_{\mu 3}$	0.033
$K_{\mu 2}\gamma$	5.5×10^{-3}
$\pi^+\pi^0\gamma$	1.5×10^{-3}
K_{e4}	4×10^{-5}
$K_{\mu 4}$	1×10^{-5}

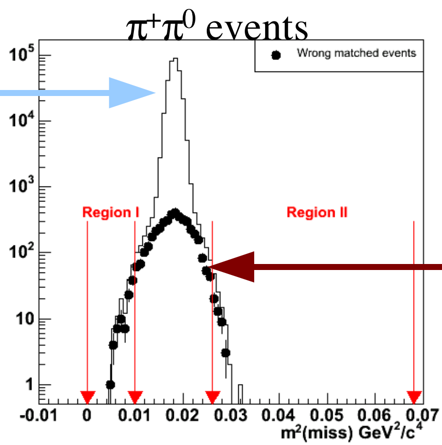
Requirements on GT

- Not spoil beam and downstream measurements
- Sustain high not uniform rate
- Provide precise measurements on all beam tracks (out of which ~6% are K^+)





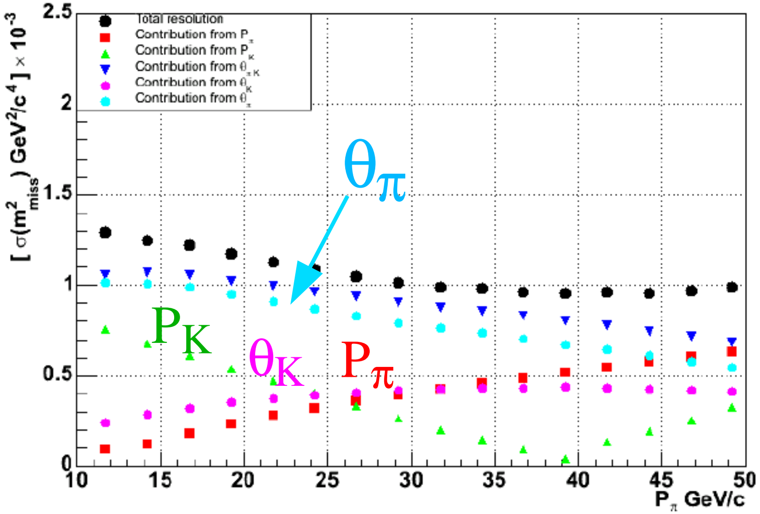
1! track matching in GT
$\sigma\ (m^2_{miss})$ small ⇨ S/B~100



IF >1 track in GT matching
$\sigma\ (m^2_{miss})$ ~3.5 times bigger ⇨ S/B degradation
Keep the events & **add time constraints**

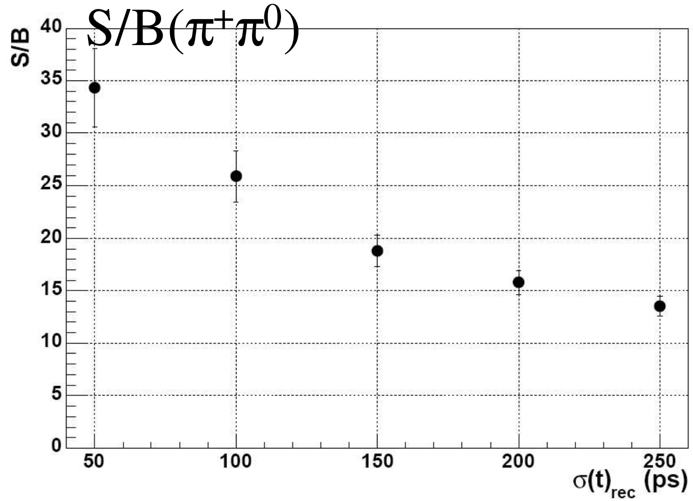
Requirements on GT

- $X/X_0 << 1\%$ per station
- $\sigma(p)/p \sim 0.4\%$
- $\sigma(\theta)$ ~17μrad
- $\sigma(t)_{GT}$ ~120ps on the track



Simulation with
3 pixel stations

- pixel size: $300 \times 300 \mu m^2$
- $0.4\% X_0$/station



Beam track time resolution (ps)

- **Momentum and angular resolution: 300μm(H,V) pixel size and ~80μm FTPC spatial resolution**
- **Material budget: reduce pixel detector material along beam direction preserving the signal**
- **Time resolution pixel station: challenging high complexity readout chip bump bonded on sensor**

Resolution and material budget

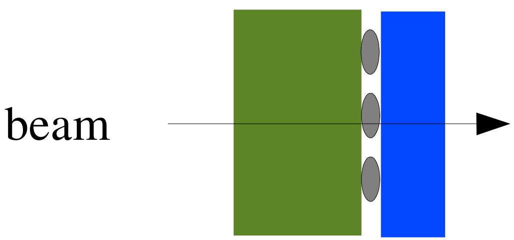
Station 1 and 2: hybrid Silicon pixels

- Pixel size 300x300μm^2
- Minimize material on beam
- produce fast signals
- P326 requirements and timescale (run in 2009)

⇩

- Hybrid Silicon (X_0=9.36cm) pixel detectors:

  Silicon chip bump bonded to Silicon sensor



- CFibre: cooling & support
- in vacuum: save 100µm mylar windows front and back: 0.07%X_0 ⇒ cooling by conduction

Station 3: FlashTPC

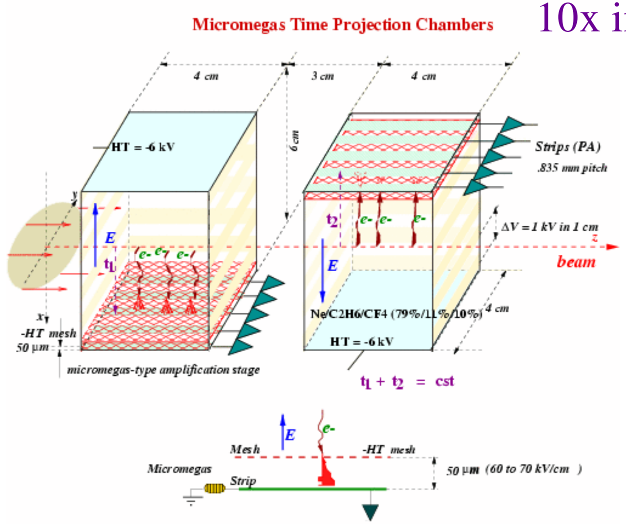
Minimize MS effect on downstream detector measurements (especially angle)

TPC with micromegas amplification

Upgraded version of Kabes-NA48/2 where:

- position resolution ~70µm
- σ_t ~ 600ps
- X/X_0=0.13%
- central strips rate NA48/2 run ~2MHz

  10x in P326



P326: reduce amplification gap, new electronics, ...

Pixel station material budget

%X_0 per station:

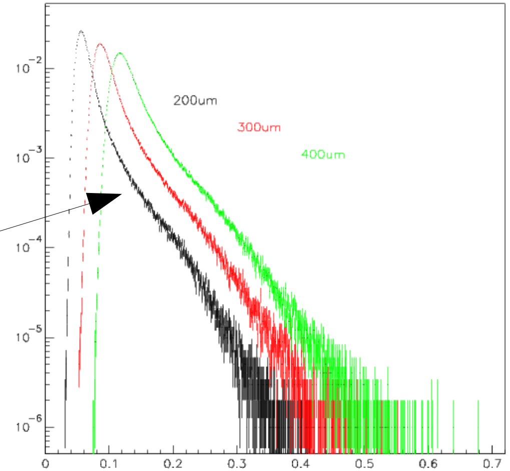
	µm	X_0 (cm)	%X_0	
Si sensor+chip	**200+100**	**9.36**	**0.32**	
CFibre	125	22.4	0.06	**~ 0.4%**
bb(SnPb)			0.01	

Silicon on chip side is mostly a support
⇩
reduce it to 100µm
not easy (fragility)
but feasible

Sensor = signal production

200µm thick

peak @ 55KeV ~ 15Ke-/holes
mean 68KeV ~ 19Ke-/holes
min signal ~11000e-/holes
(but 0.5% low energy tail)



Energy deposit (MeV)

Geant4 v6.2, 10^6 75GeV K+
all secondary processes on, 5µm cuts

Sensor with thickness down to 200µm already produced and bump bonded (e.g. Alice SPD)

R/o chip wafers thinned down to 150µm already exist: Alice SPD

Presentation at BOND'03 workshop, CERN, June 2003

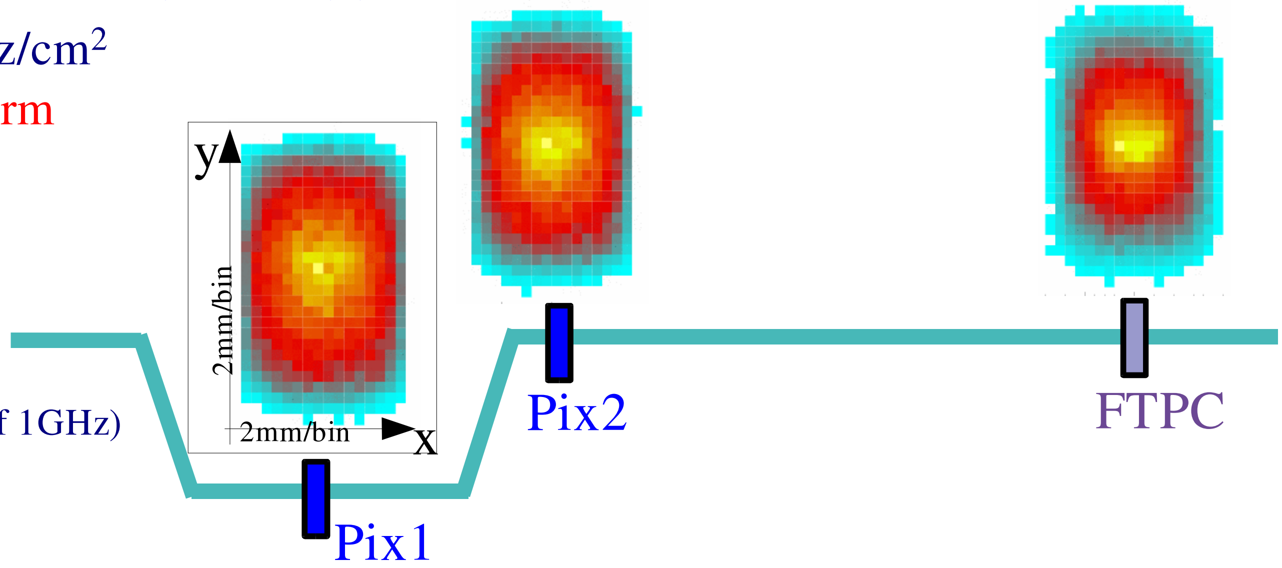
Rate at GigaTracker

~1GHz beam particles rate

GT area per pixel station (beam tails<10^{-4}): 36mm(X) x 48mm(Y)

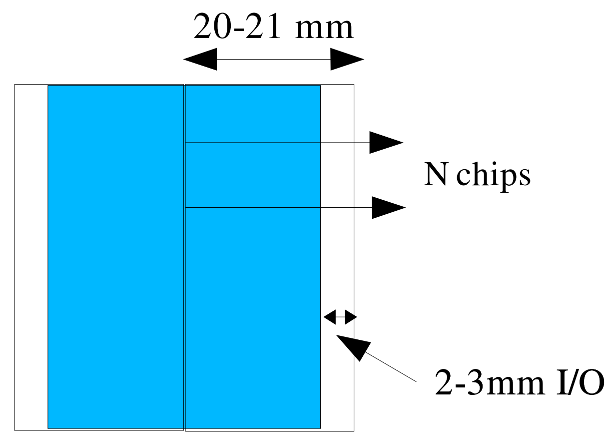
Average rate per station ~60MHz/cm^2

Converging beam: rate not uniform



Maximum rate in the hottest mm^2:
(occupancy normalized to total rate of 1GHz)
~1.5MHz/mm^2 in station1,
~1.6MHz/mm^2 in station2,
~1.9MHz/mm^2 in station3

r/o chip max 20-21mm wide
(power and clock distribution)
⇨ 2 half detectors to cover the area



Radiation at GigaTracker

average particle flux/cm^2 per day per station:

1GHz*3.125s(eff spill)*5000(spills/day)/area ~ 9×10^{12} particles/cm^{2}day

- Approx π only beam (60%)
- conversion factor 0.37 ratio of displacement damage cross sections for high energy (>GeV) π (35MeV mb) and 1MeV neutron (95MeV mb) (Huhtinen private communication, NIMA491)
- safety factor 2

⇨ Φ_{eq}(1MeV n)/cm^2

~ 7×10^{11} day

7×10^{13} **100 days (P326 'year')**

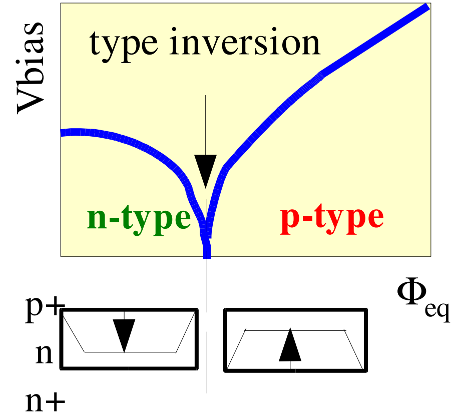
x3 in the hottest mm^2

1MeV equiv n/cm^2: norm fluence unit used to compare real beam with 1MeV n beam producing the same displacement damage

3×10^{14} **CMS** innermost pixels in **1 year**

3×10^{12} **ALICE** pixels in **10 years**

few$\times10^{12}$ expected n-type-inversion point



Vfd << Vbias < Vbreakdown

If conventional p+ on n sensor

⇒ **replace the 2 pixel stations** every XXX weeks (during SPS MD)

⇨ easy replacement and alignment

and an **average TID (rad) ~2Mrad in 100 days**

R/O chip: TID up to 30Mrad with radiation tolerant layout: 0.25µm CMOS + enclosed + guard rings (IEEE Vol.46 No.6 1999, G.Anelli Ph.D Thesis http://rd49.web.cern.ch/RD49/RD49Docs/anelli/these.html)

Front End

High complexity R/O CHIP bump bonded on sensor

- preamplifier
- comparator
- high resolution TDC

➢ **in beam: radiation hardness technology ⇒ size**

- Total Ionizing Dose (TID)
  ionization in SiO_2 layer and
  defects creation SiO_2-Si interface
  ⇩
  - transistor level leakage (mainly digital)
    ➲ **enclosed transistors**
  - threshold voltage shift (analogue)
    ➲ sub-micron tech e.g. 0.25μm or 0.13μm
    (the thinner the oxide the better)

- Single Event Upset (SEU)
  (reversible) affecting bit
  ➲ redundancy e.g. **cells x3** & major voting
  or special coding schemes

➢ **analogue AND digital high frequency together:** influence of the noisy digital part on the analogue (common substrate noise – the most difficult to eliminate -, switching noise from the digital circuits)

➢ **power dissipation**

➢ **technology CMOS process:** 250nm might be insufficient ⇒130nm
dimensions/consumption of building blocks, components density,noise

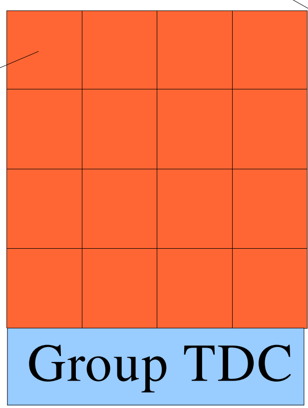
Front End

Architectures under study:

- preamplifier
- comparator → Multiple thresholds; Constant Fraction Discriminator
- high resolution TDC
- logic → Trigger matching on chip; Trigger matching off chip
- peripheral circuitry

1 TDC/group of pixels

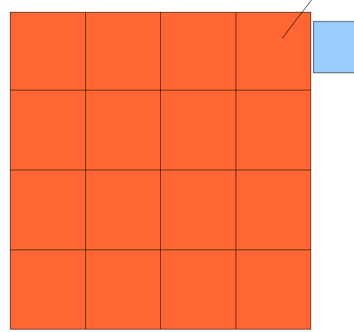
Preamp
Comparator
Logic



How to group pixel
e.g. merge pixel
from high and low
rate zones

PLL & delay lines
based TDC.

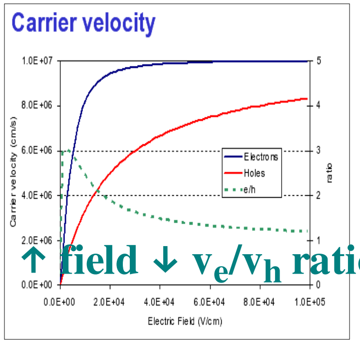
1 TDC/pixel



Preamp
Comparator
TDC (analog to digital converter)
Logic

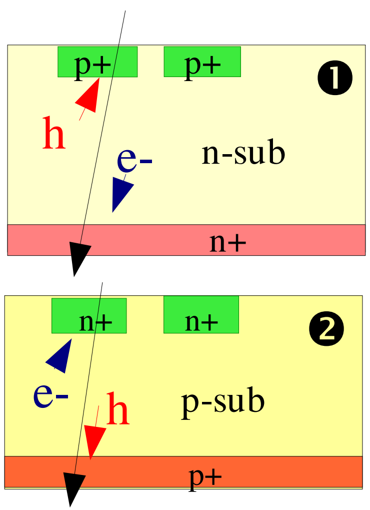
FE: signal collection time

- Time resolution required per station: $\sigma_{GT\_TRACK} * \sqrt{N_{pixel\_stations}}$
- Charge collection time in few ns achievable from silicon sensor 200µm thick, both p and n type substrate: TCAD simulation – Claudio Piemonte ITC-IRST



- e/h drift velocity difference decrease increasing voltage
- both holes and e- induce current contributing to the signal
- the bigger the pixel the wider the induction zone

n+pixels on p_substrate signal faster only in case of small pixel size wrt thickness: e.g. Alice case **50**(V)x425(H)µm^2 , **200**µm thick:

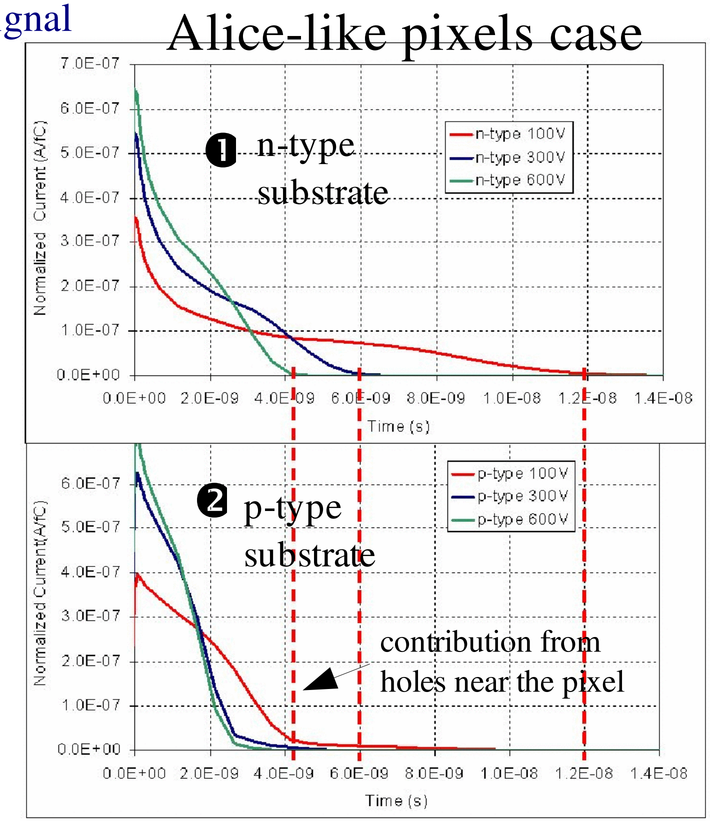


❶ p+ pixel on n_substrate: signal determined by holes (mainly) + fast 'tail' signal due to electrons close to the pixel

❷ n+ pixel on p_substrate: signal determined by electrons (mainly) + slow tail due to holes close to the pixel

But bigger the size (GT case) bigger the electrons (❶) and holes (❷) contributions + high voltage applied --->

❶ and❷ ~ same collection time



Conclusions

GigaTracker: 2 pixels stations + 1FTPC
tracking @1GHz rate IN THE BEAM

station spatial resolution σ~90μm --> pixel(300μm size V,H), FTPC
time resolution ~120ps on the beam track

FTPC: improved Kabes

New Pixel stations

- sensor
  few ns collection time achievable with both p and n substrates
- readout chip (challenging)
- cooling (chip power dissipation)
- support & alignment (in case of frequent replacement)

Data taking 2009 and 2010

Assuming 4.8×10^{12} K^+ decays per year(100days)
(5×10^5 spills/year, 60% working time SPS*detector)
MC signal acceptance ~10% (20% reconstruction & dead time losses) , S/B ~10
⇒ **40events/year** @ BR~10^{-10} , CERN-SPSC-2005-013 SPSC-P-326