The NA48/3 GigaTracker

Alias
Tracking in the beam
at 1GHz rate

- GigaTracker: Decay ID & bkg rejection
- Requirements
- In the beam
- Resolution & material budget
- Rate & dose
- Time resolution

K Rare decays meeting, Frascati 26-27.05.2005

M. Scarpa INFN and University of Ferrara

Decay ID

0.8-1GHz beam (2.5x10^9ppp/3s spill +20% error)
60% π^+
20% p^+
14% e^+
6% K^+

Beam
CEDAR,**GT**

Decay products
NA48/3 detector

$K^+ \rightarrow \pi^+ \nu \bar{\nu}$

- Missing mass

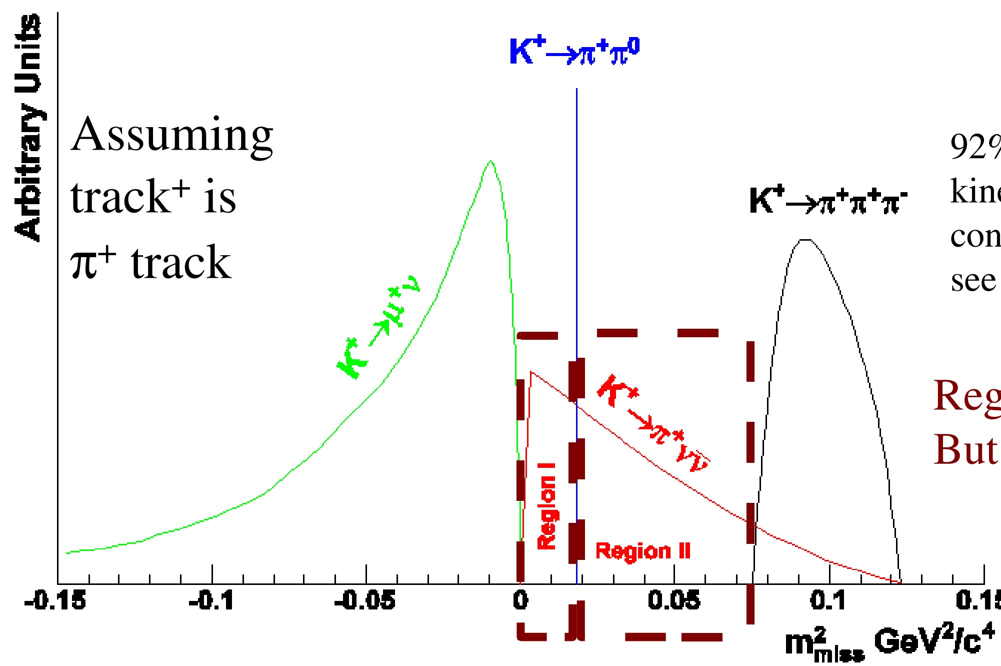
75GeV/c $\sigma(p)/p$ =1%σ_x~8mm,σ_y~1.1mm
angular spread $\sigma(\theta)$=100μrad
⇨ need more precise momentum and direction measurements ⇨ **GigaTracker**

- 1! detected decay product
- no vertex from decay product

$$m^2_{miss} = m^2_\pi(1-P_K/P_\pi)+m^2_K(1-P_\pi/P_K)-P_K P_\pi \theta^2_{K\pi}$$

Decay ID:
K,π ID
K-π tracks matching vtx
P_K, P_π
θ_K,θ_π -> $\theta_{K\pi}$
VETOes ....

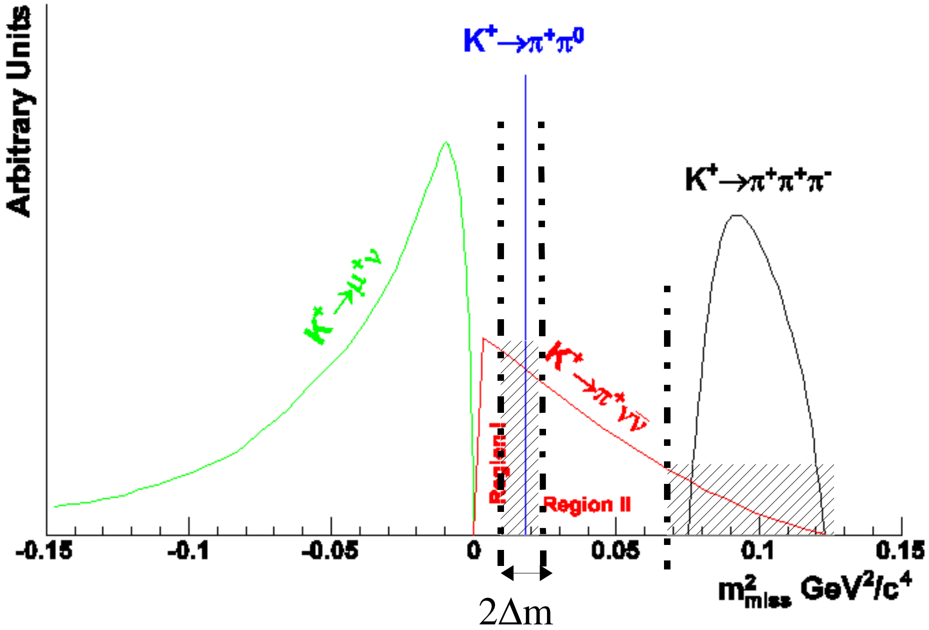
Assuming track$^+$ is π^+ track



92% of total bkg kinematically constrained
see Ruggiero's talk

Region I,II
But... resolution

Kinematical bkg rejection



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

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

$\Delta m \div \sigma(m^2_{miss})$

Worse $\sigma(m^2_{miss})$ ⇨ lower S/B

K-π tracks maching e.g by best CDA

Beam at GT:
σ_x~8mm,σ_y~1.1mm
100μrad angular spread
~70μrad(x), 85μrad(y)

Beam track/s (GT)

Downstream track (double spectrometer)

best CDA
closest distance
of approach σ_{CDA} ~1.4mm (*)

IF 1 track matching in GT
σ (m^2_{miss}) tiny ⇨ S/B~100

IF >1 track in GT matching (8.6% events *)
σ (m^2_{miss}) ~3.5(*) times bigger ⇨ S/B degradation
Keep the events & **add time constraints**

(* MC detail see next slide)

Requirements on GT from

The experiment:

- Acceptance 10% (50% data taking efficiency included)
- S/B $\geqslant$10

The beam:

- Beam K^+ 75GeV/c **momentum bite 1%**
- @GT σ_x~8mm,σ_y~1.1mm
- minimum amount of material on beam X/X0<<1%
- Tracking in a not uniform (converging beam) rate distribution
- total rate of ~1GHz out of which only ~6% are K^+
- High radiation level

The MC study on $\pi^+\pi^0$ assuming

- photon rejection inefficiency 2x10^{-8}
- (15< P_π < 35)GeV/c
- Hodoscope event time σ(t) ~50ps
- Double spectrometer: straws ~0.5%X0 per chamber,
  spatial resolution 120µm per view
  100% reconstruction efficiency,

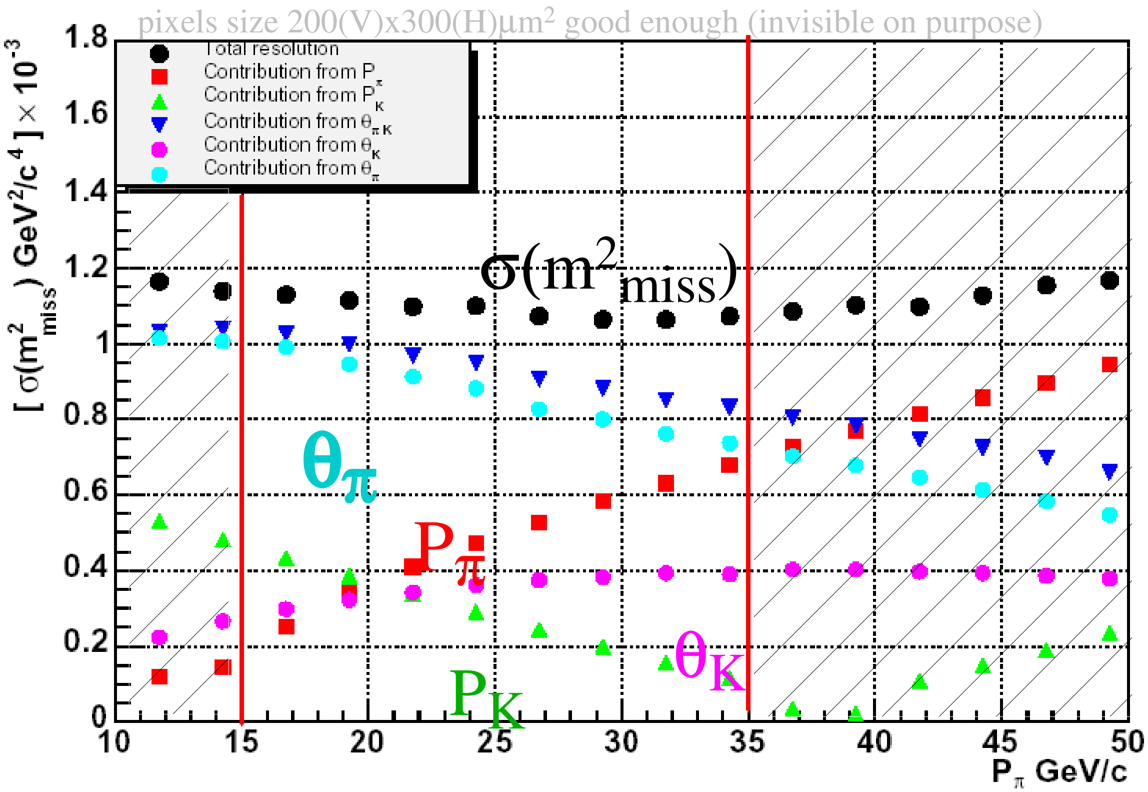
⇨ **Double spectrometer** σ(p)/p = 0.33% ⊕ 0.0077%p , **σ(θ)** in X and Y projections ~30µrad
not spoil the spectrometer angular measurements: minimize MS in the last part of GT

with **GT: σ(p)/p = 0.3% , σ(θ) in X and Y projections ~15µrad**

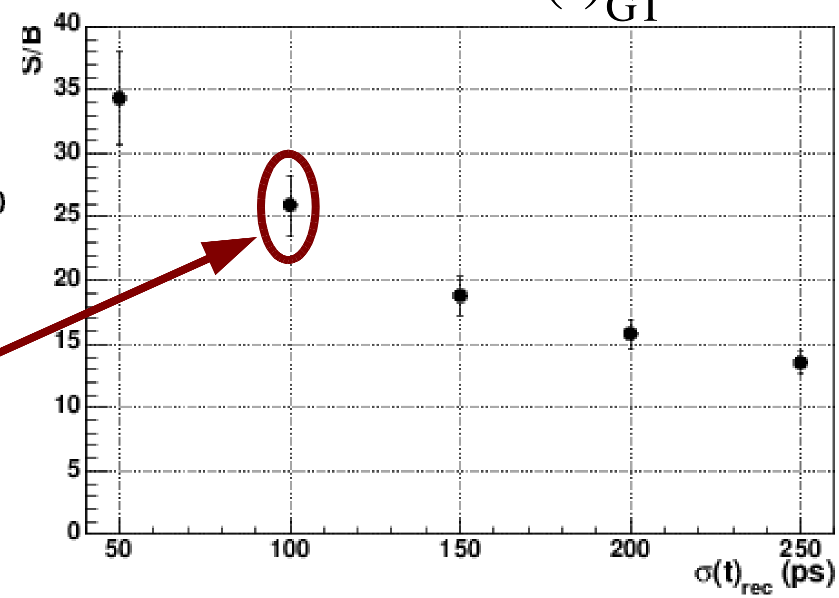
⇨ ~8.6% events have >1 track matching in GT with bestCDA(*) approach, reducible to ~3% by time coincidence in ±2$\sigma(t)_{GT}$ **IF $\sigma(t)_{GT}$=100ps** ⇨ S/B ~25

(*) might be improved by other matching methods e.g. 2D impact parameter

MC Requirements on GT



S/B vs $\sigma(t)_{GT}$



P_π

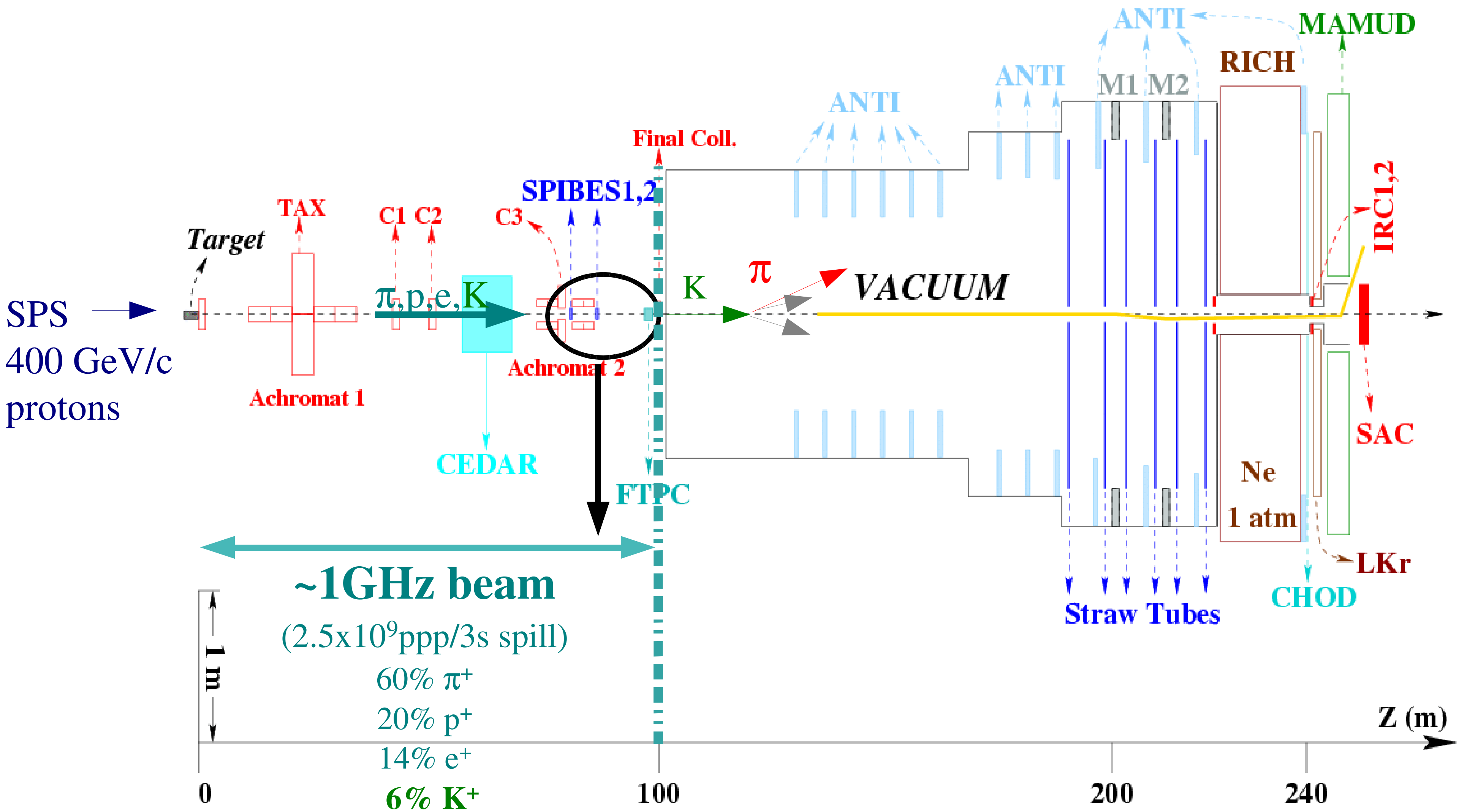
GT:

$\sigma(p)/p$ = 0.3% (<0.5%)

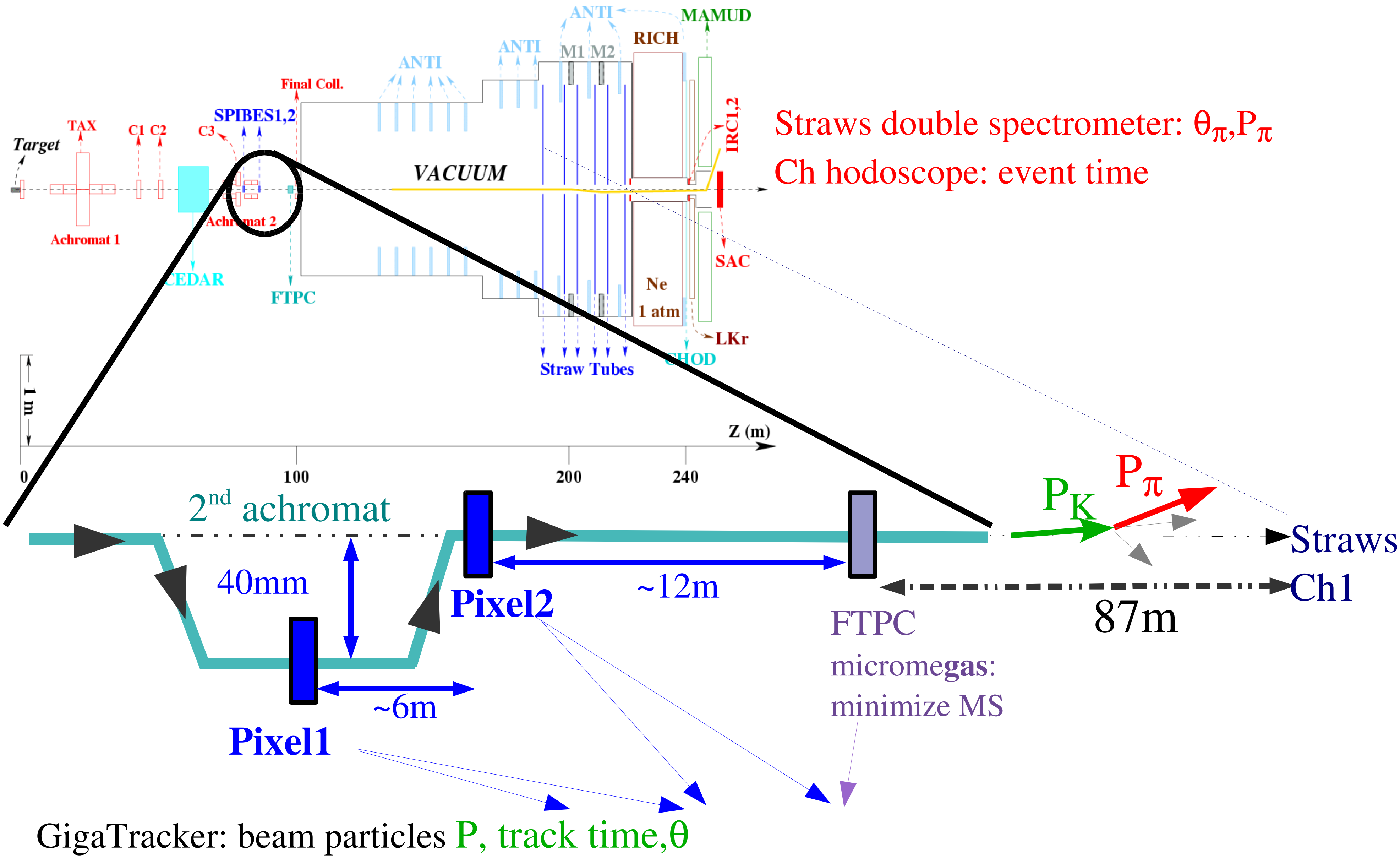
$\sigma(\theta_{x,y})$ ~15μrad

$\sigma(t)_{GT}$=100ps on the track

In the beam....


SPS
400 GeV/c
protons
Target
TAX
Achromat 1
C1 C2
C3
π,p,e,K
CEDAR
SPIBES1,2
Achromat 2
Final Coll.
FTPC
K
π
VACUUM
ANTI
ANTI
ANTI
M1 M2
RICH
MAMUD
IRC1,2
SAC
Ne
1 atm
LKr
CHOD
Straw Tubes
~1GHz beam
(2.5x10^9ppp/3s spill)
60% π+
20% p+
14% e+
6% K+
1 m
Z (m)
0
100
200
240

In the beam with GT



Resolution and material budget

Station 1 and 2: hybrid Silicon pixels

- Minimize material on beam
- produce signals, fast signals
- electronics
- cooling
- support
- respecting the NA48/3 requirements and timescale

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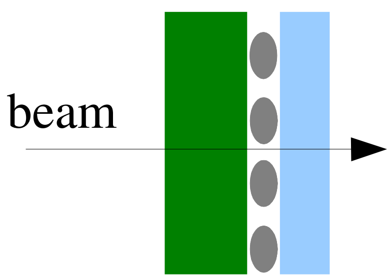
- ➢ Hybrid Silicon (X_0=9.36cm) pixel detectors: Silicon sensor bump bonded (~0.01%X_0) to Silicon chip



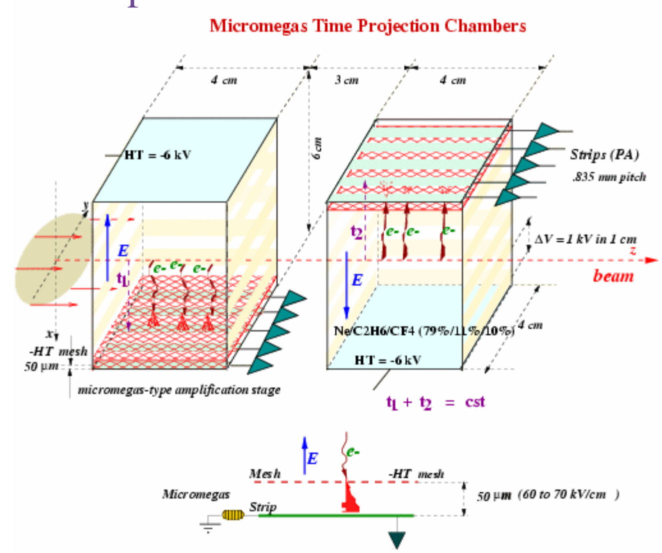
- ➢ cooling & support with the same CFiber
- ➢ In vacuum (save 100µm mylar windows front and back: 0.7%X_0) -> cooling by conduction

Station 3: FlashTPC

Minimize MS effect on downstream detector measurements (especially angle)

TPC with micromegas amplification
Upgraded version of Kabes-NA48/2:

- **position resolution 80µm**
- σ_t =0.7ns
- max strip rate ~2MHz



Reduce the amplification gap, sampling each strip with 1GHz FADC, sustain 10x higher rate per unit area

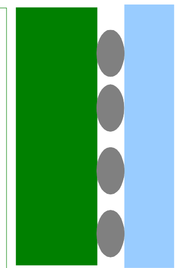
Pixel stations material budget

$\%X_0$ per station mainly due to Silicon:

	µm	X_0 (cm)	$\%X_0$
Si det+chip	**200+100**	**9.36**	**0.32**
CFiber	125	22.4	0.06
bb(SnPb)			0.01
(Mylar windows			0.07)
no if in vacuum			---------
			~0.4

Coulomb MS θrms~13mrad

Silicon sensor produces the signal!



Silicon on chip side is mostly a support

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try to reduce it to 100µm (fragility!)

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

200µm thick Si signal:

peak @ 55KeV ~ 15Ke-/holes

mean 68KeV ~ 19Ke-/holes

min ~11Ke-/holes

(but 0.5% low energy tail)

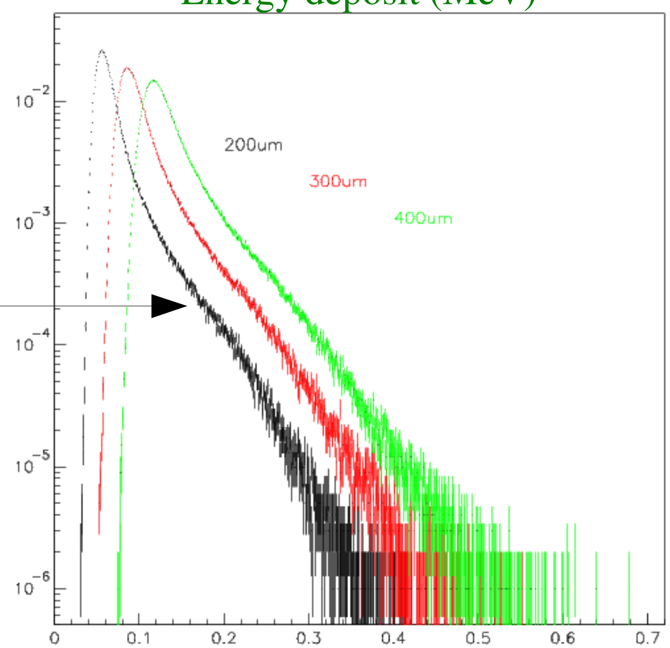
Geant4 v6.2

10^6 75GeV K+

all secondary processes on

5µm cuts

Energy deposit (MeV)



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

Presentation at BOND'03 workshop, CERN, June 2003

Pixel size and resolutions

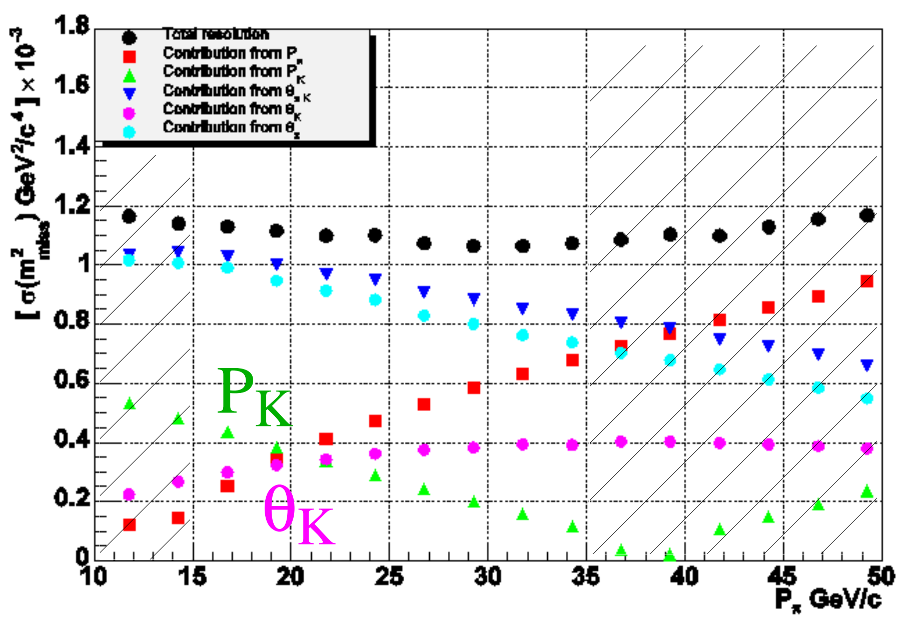
$P_K = f(\text{Pix1}, \text{Pix2})$ $\theta_K = f(\text{Pix2}, \text{FTPC})$

6m

40mm

12m

x,y dim (μm)	$\sigma_{x,y}$ (μm)	$\sigma(P)/P$ %	σ_θ (μrad)	
		$(\sigma_y\sqrt{2} \oplus \sigma_{MS})$/40mm	$(\sigma_X \oplus \sigma_{FTPC})$ /12m $\oplus \sigma_{MSP}$	
100	29	0.22	14.7	, if Pixel3 13.4
200	58	0.29	15.3	14.6
300	87	0.37	16.4	16.4



MC simulation: 3 stations

0.4% X_0 per station

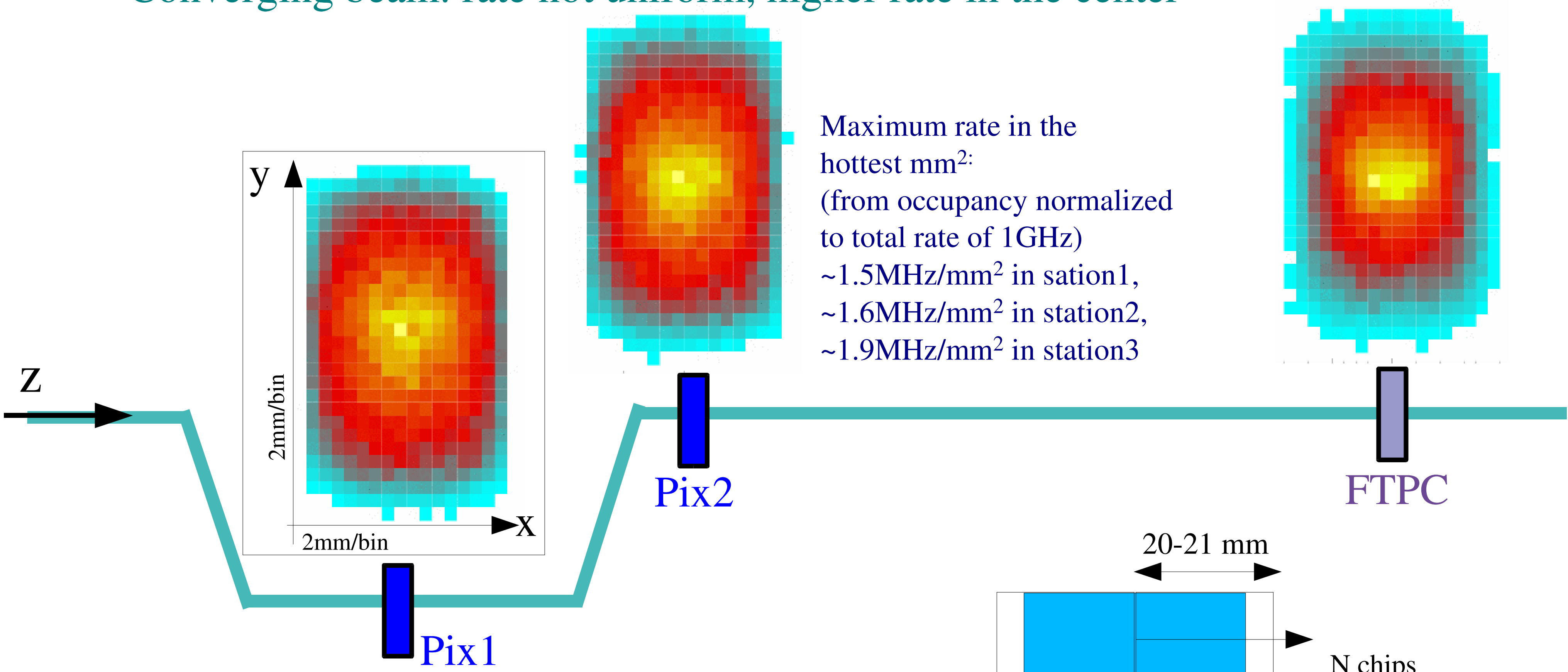
pixel 200(V)x300(H) μm^2

good enough

Rate and radiation at GigaTracker I

Average rate per station ~60MHz/cm^2

Converging beam: rate not uniform, higher rate in the center



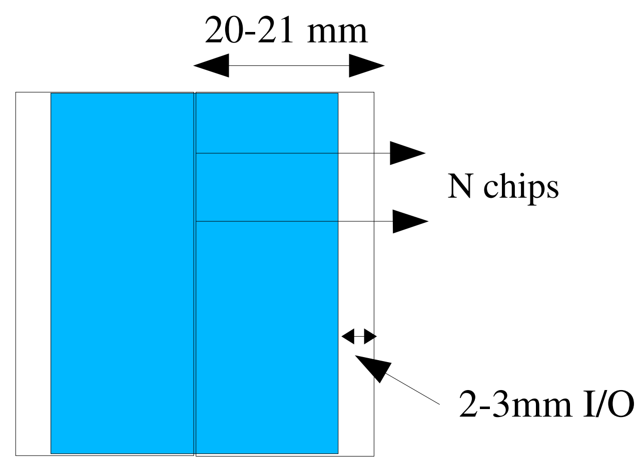
Maximum rate in the hottest mm^2:
(from occupancy normalized to total rate of 1GHz)
~1.5MHz/mm^2 in sation1,
~1.6MHz/mm^2 in station2,
~1.9MHz/mm^2 in station3

GT area per pixel station (beam tails<10^{-4}):

36mm(X) x 48mm(Y) but Photolithographic process

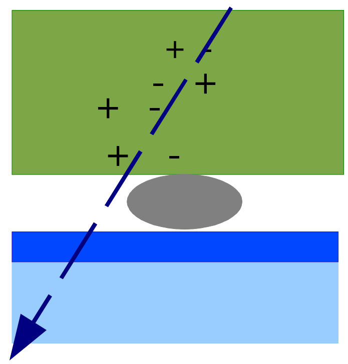
for r/o chip max 20-21mm wide

⇨ 2 half detectors to cover the area



Rate and radiation at GigaTracker II

Radiation damage on pixels detector



Sensor: full bulk sensitive to damage

Bulk damage

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change electrical characteristics, evolves with time and doesn't stop when stopping irradiation

- **Increase I_{leak}** ÷ exp(-Egap/2KT) due to generation/recombination levels

  ➲ cooling, thinner sensor, sensor technology and design

- **Change in V_d** (depletion voltage): **type 'inversion': n-type bulk behave like p-type**, depletion from backside and V_d increase with fluence, risk to operate with under-depleted sensor: charge loss and spread. Too high voltages --> current break down

- Annealing effect (beneficial and reverse) long term exposition , temperature dependent

CMOS readout chip: sensitive components close to the surface

- Total Ionizing Dose (TID)

  ionization in SiO_2 layer and defects creation SiO_2-Si interface

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  - 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 best)

- Single Event Upset (SEU) (reversible) affecting bit

  ➲ redundancy e.g. cells x3 & major voting or special coding schemes

Rate and radiation at GigaTracker III

Per GT station in NA48/3 beam the expected
average particle flux/cm^2 per day is:

1GHz*3.125s(eff spill)*5000(spills/day)/area ~ $9x10^{12}$ particles/cm^2day

- 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

~$7x10^{11}$ day
$7x10^{13}$ **100 days**
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

$3x10^{14}$ **CMS** innermost pixels in **1 year**
$3x10^{12}$ **ALICE** pixels in **10 years**

1-fewx10^{12} expected n-type-inversion point

➡ **Replace the pixel stations** every 2 weeks (profiting of SPS MD)
⇨ easy replacement and alignment

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

R/O chip: up to TID=30Mrad with radiation tolerant layout (vast majority LHC experiment):
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)

Time resolution requirement I

- Requirement on spatial resolutions: easy with Si pixels + FTPC
- Requirement on material budget: easy FTPC, pixels less easy but feasible
  - investigation on chip silicon thickness
  - investigation on CF support and cooling (depends on chip consumption)

- **Requirements on time resolution: 100ps on the track**

⇨ **~150ps per pixel station(TDC)**

high complexity R/O CHIP bump bonded on sensor

- on beam (radiation hardness technology --> space)
- analogue AND digital high frequency part together:

  influence of the noisy digital part on the analogue part

  Switching noise originated from the digital circuits can be coupled in the analog part through power and ground lines, parasitic capacitances between interconnection lines and, the most difficult to eliminate,common substrate noise

Building blocks: fast preamplifier and shaper,
low time walk discriminator,
high resolution TDC,
peripheral circuitry

- power dissipation
- technology CMOS process: 250nm might be insufficient ⇨ 130nm

Time resolution requirement II

Very challenging but good hints from TCAD simulations of 200μm thick sensor:

few ns charge collection time achievable using n or p substrates

Simulation on 'a la' ALICE pixels: $50(V)x425(H)\mu m^2$

Pixels **50**(V)x425(H)μm^2 , **200**μm thick

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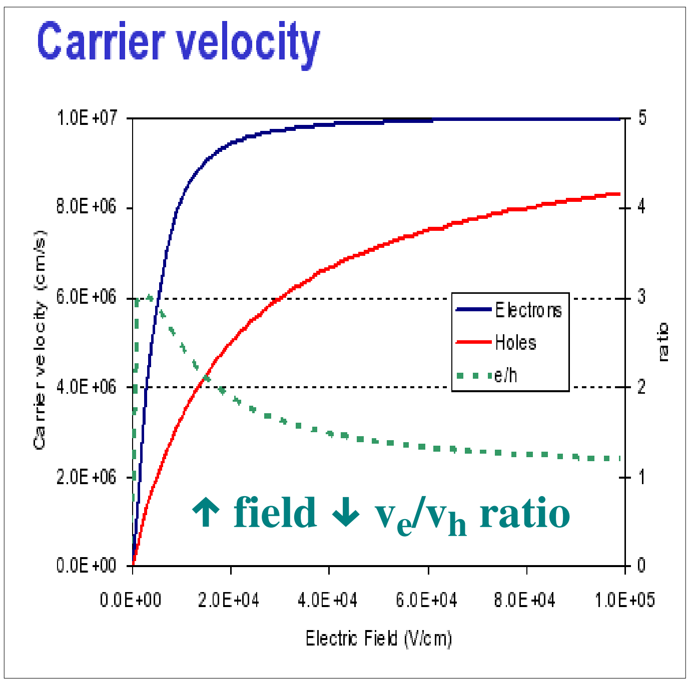
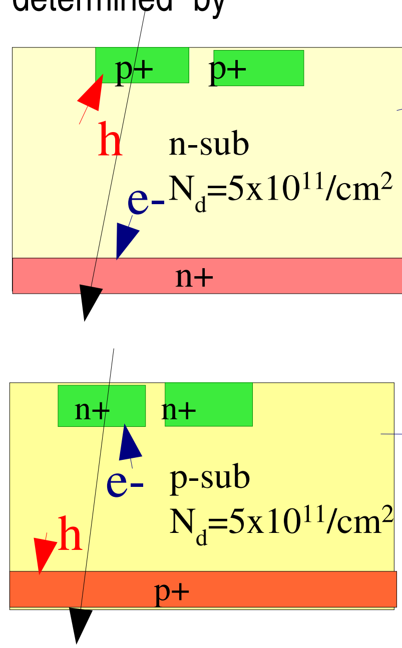
small pixel wrt thickness ⇨ signal mainly determined by

❶ p+ on n-type substrate: holes

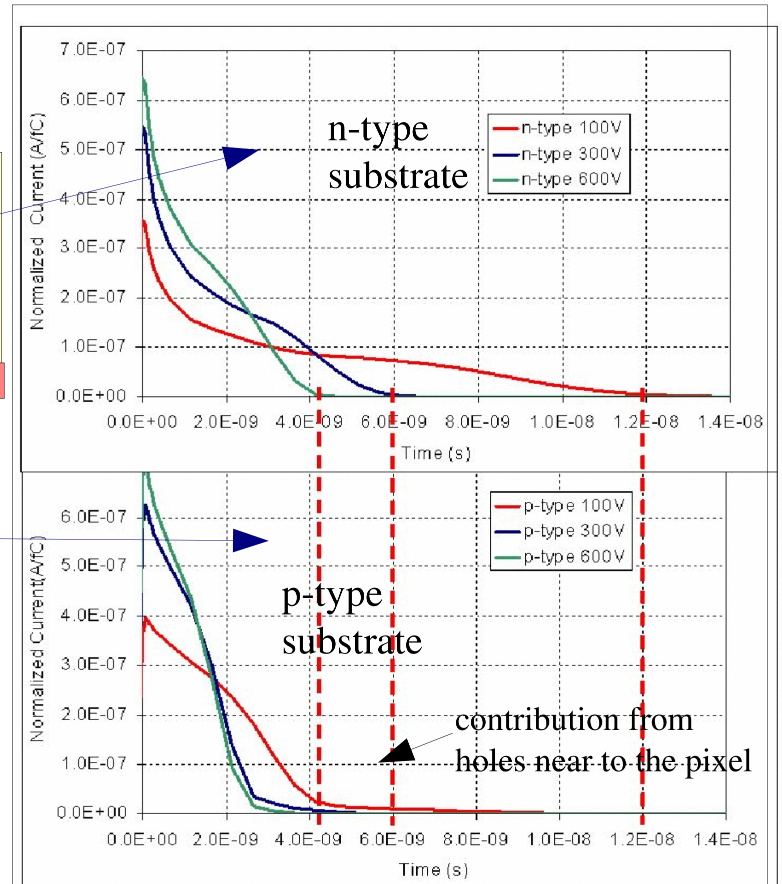
❷ n+ on p-type substrate: e-





↑ pixel size 'a la' GT ↑tails

⇨ n and p substrate ~ same collection time



TCAD simulation

Claudio Piemonte, ITC-IRST

Conclusions

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

spatial (good if 200(V)x300(H) μm^2 pixel and σ= 80μm FTPC)
AND time resolutions (100ps on the track ⇨ 150ps per TDC)

FTPC upgrade

New Pixel stations

- sensor (tests to be done, 'easiest' part wrt r/o chip)
  few ns collection time achievable with both p and n substrates
- readout chip (challenging)
- cooling (chip power dissipation)
- support & alignment (frequent replacement)

Be ready for data taking in 2009