TOF and Hadron physics from PHENIX

-How does it (TOF) look like ?

-What is it (TOF) designed for ?

-What concerns did we have in the design ?

-How do we get the high resolution in TOF ?

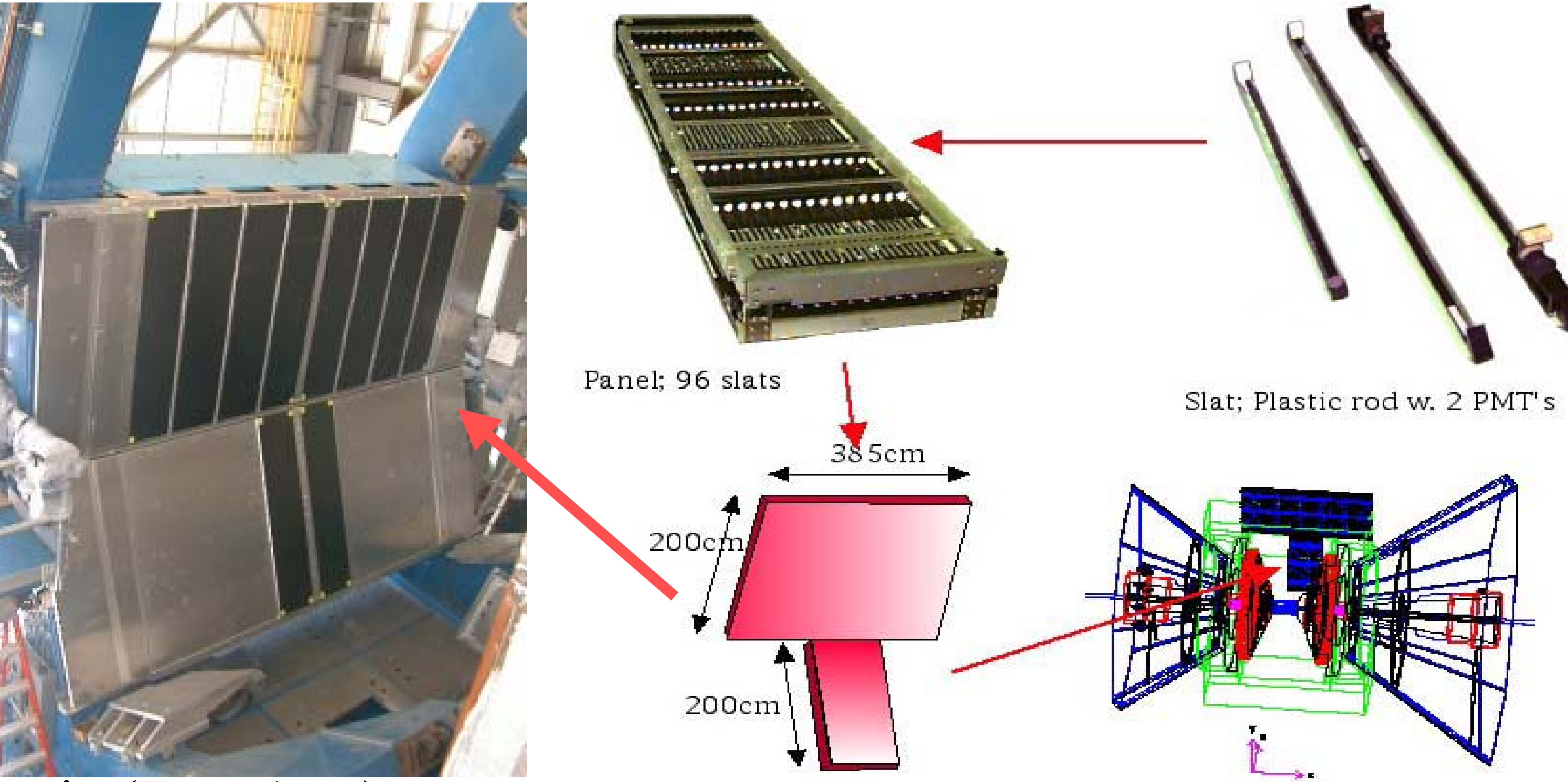
-What does it (TOF) give now for hadron physics

-Summary

Susumu SATO (JSPS at BNL)

For PHENIX collaboration and the TOF group

How does it (TOF) look like ?

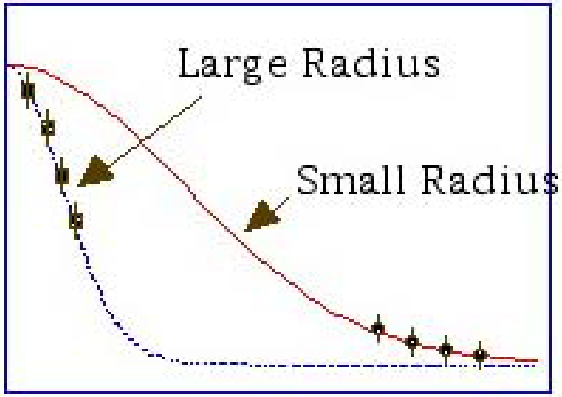


enix (East-Arm)

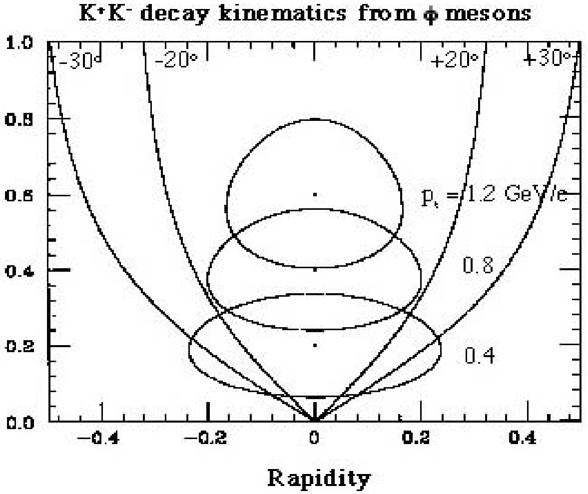
- 960 plastic scintillators with 1920 PMT’s
- locates at 5 meter from the vertex
- Rapidity (-0.35~0.35), 45 degree in phi, Ω~1/3Sr

What is it (TOF) designed for ?

- Single particle Inclusive Measurement
  - From low to high pt with PID,
    slope shape (freeze-out temperature, corrective motion, chemical composition, etc) needs to be measurement.
- Hanbury-Brown-Twiss Correlation
  - For large radius,
    - Momentum resolution
    - Two track separation
  - For small radius
    - Opening angle → Acceptance
      - $\Omega \sim 1/3$ sr
- Detection of ϕ meson in K^+K^- decay
  - For low pt ϕ →Acceptance
  - For high pt ϕ →PID



Relative Momentum



What concerns did we have in the design ?

Acceptance is driven by HBT and ϕ meson

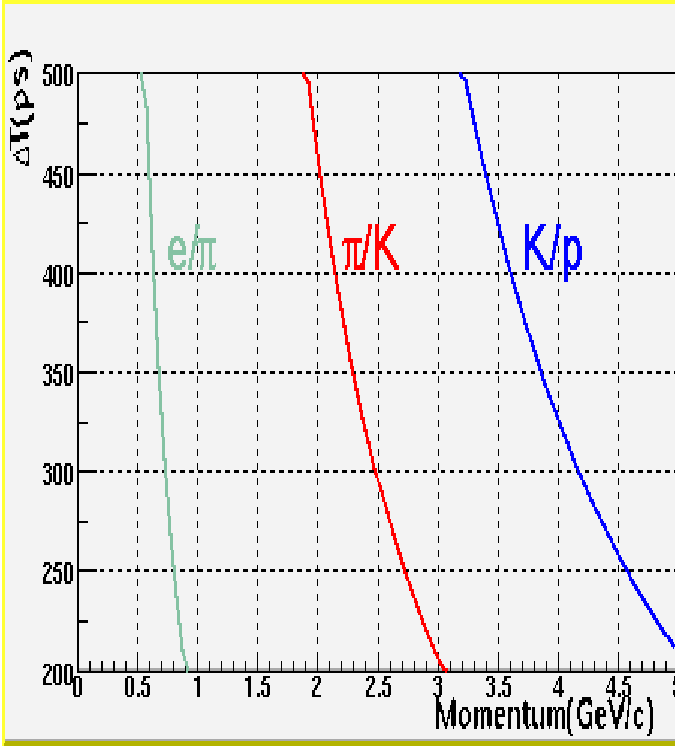
– $\Delta\theta$ = 40 deg ($\Delta\eta$=0.7), $\Delta\phi$ = 30 deg

Timing resolution: for pt distribution and ϕ meson [especially in high pt PID]

– Δt~120ps

– Assuming 3 sigma separation

- Pions, Kaons up to 2-2.5 GeV
- Proton and antiproton up to 4 GeV



Segmentation:

– keep the occupancy <10 %

– $\Delta n_c/dy$~ 1500 → ~1000 segments($\Delta\eta$ =0.7, $\Delta\phi$ = 30 deg)

(=1000 [FRIFIOF at the "CDR" days] + 50% safety factor)

→ ~100cm^2/segment at 5 m from vertex

How do we get the high resolution in TOF ? (1)

Explain each item in the following slides.

) PMT: Δt behaves statistical behavior ($\sigma \propto 1/\sqrt{n_{p.e.}}$)

) Scintillator:

(2-1) light yield & timing resolution behave in exponential with distance, and are consistently described with statistical picture ($\lambda_{timing} \sim 2\lambda_{yield}$)

(2-2) λ_{yield} proportional to cross sectional size ($\lambda \propto d$)

(2-3) TOF timing resolution (consistent with exponential behavior)

(2-4) Aging effect (T_{DG}~200month, consistent with statistical picture)

) Effect of Cherenkov light (PMT & LG):

- self-detectable←association is outside of scintillator)

(3-1)Cher.&Scint. light from LG is separate-able because of their small pulse height

(3-2) Cher. light from PMT is localized at its cathode (only 2mm), and it gives earlier timing.

How do we get the high resolution in TOF ? (2)

Explain each item in the following slides.

((4) Mechanical structure)

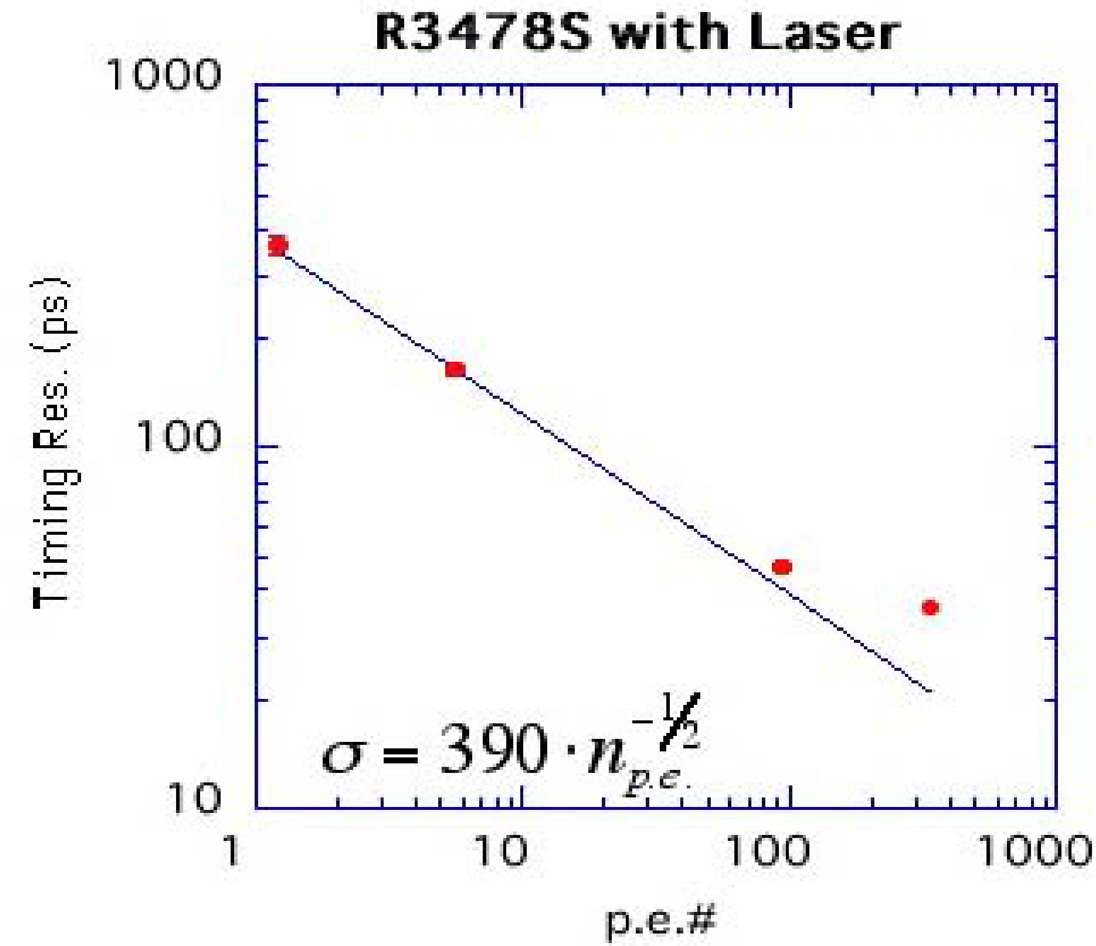
(4-1) Panel structure (honey comb)

(4-2) modulized PMT holder

(5) Design of FEE

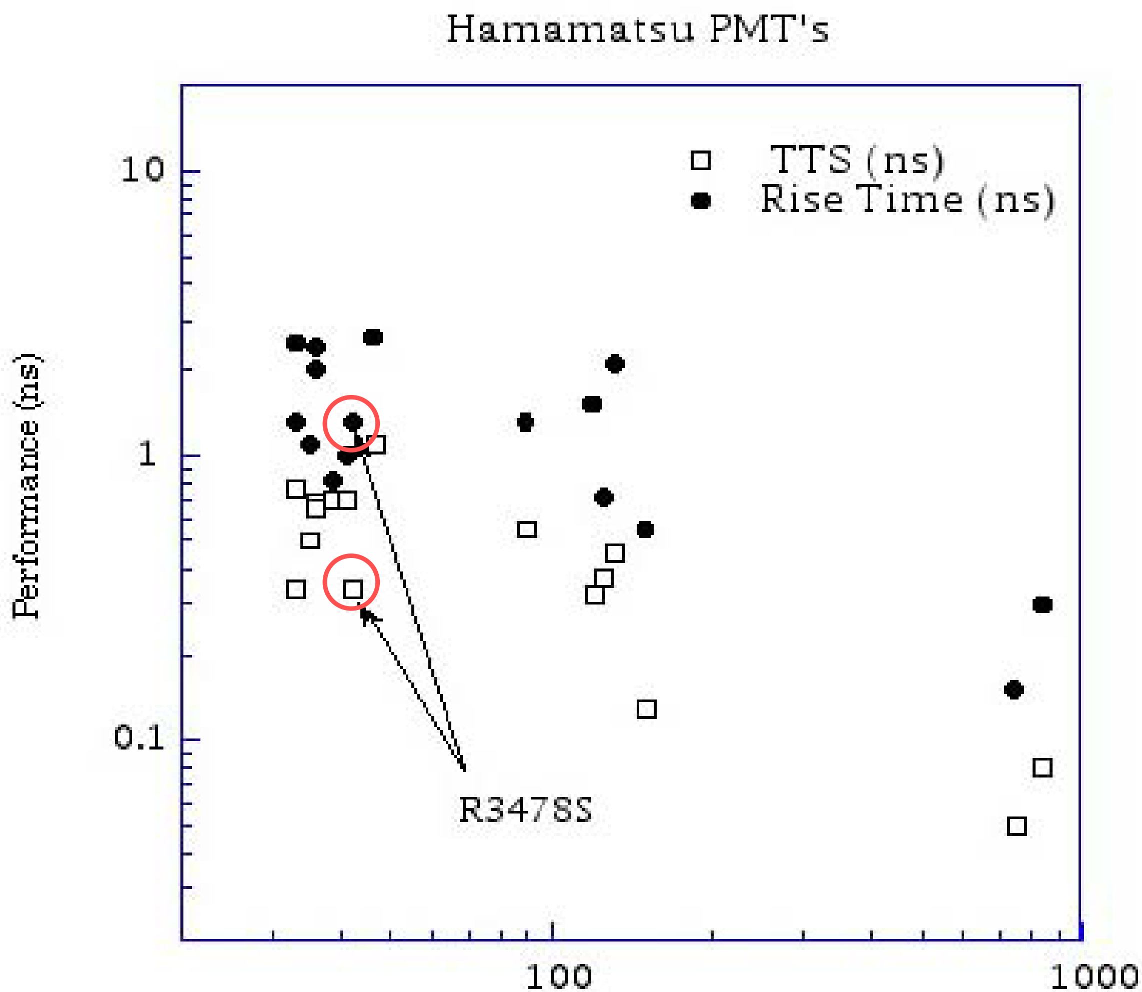
- leading edge discriminator
- programmable 4.2micro-sec AMU(both for TVC and QVC)
- 12 bit ADC
- Cross talk problem in timing,
  and solution (=differential output) with two channels /ch.
- Clock sharing between the start timing detector and
  the stop timing detector is important (use differential-ECL).

PMT intrinsic resolution



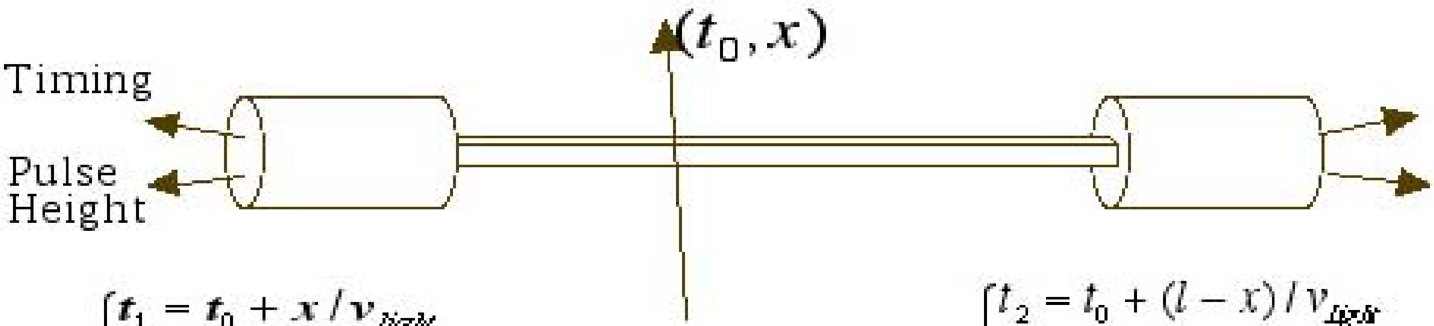
- **Timing resolution decreases with larger p.e.#.** **Resolution** < 100ps, for >10 p.e.
  - Statistical behavior: $\delta t \propto 1/\sqrt{n_{p.e.}}$
  - At larger p.e.#, other mechanism.

PMT selection



- **Timing property of PMT**
  - **TTS(transit time spread) for 1 p.e.**
  - **Rise time**
- **Correlation between cost & performance**

Basics of measurements



$$\begin{cases} t_1 = t_0 + x / v_{light} \\ a_1 = a_0 \exp(-\frac{x}{\lambda}) \end{cases}$$

$$\begin{cases} t_2 = t_0 + (l - x) / v_{light} \\ a_2 = a_0 \exp(-\frac{l-x}{\lambda}) \end{cases}$$

$$\begin{cases} t_0 = \frac{t_1 + t_2}{2} - l / v_{light} \\ x_0 = \frac{t_1 - t_2}{2} - v_{light} \end{cases}$$

$$\delta t_0 = \sqrt{\left(\frac{\delta t_1}{2}\right)^2 + \left(\frac{\delta t_2}{2}\right)^2} \cong \frac{\delta t_1}{\sqrt{2}} \longrightarrow$$ 100ps

$$\delta x = v_{light} \cdot \sqrt{\left(\frac{\delta t_1}{2}\right)^2 + \left(\frac{\delta t_2}{2}\right)^2} \cong v_{light} \cdot \frac{\delta t_1}{\sqrt{2}} \longrightarrow$$ then 1.6cm

Precise TOF and Hit position

Double hit

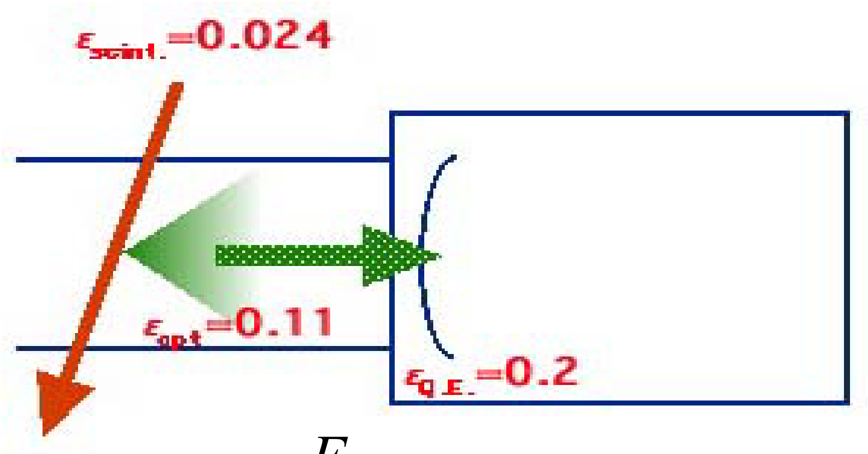
- **Lose timing information →must occupancy level low**
- **Consistency between ratio of ADC and TDC diff.**

$$x = \frac{l}{2} - \log\sqrt{\frac{a_1}{a_2}}$$

$$x = \frac{t_1 - t_2}{2} \cdot v_{light}$$

Plastic scintillator

Intrinsic resolution



$$n_{p.e.}^{timing} = \frac{E_{loss}}{h\nu} \times \varepsilon_{scint.} \times \varepsilon_{optical} \times \varepsilon_{Q.E.} \times \varepsilon_{rise}$$

$$\cong \frac{2_{[MeV/cm]} \times 1.5_{[cm]}}{2_{[eV]}} \times 0.02 \times 0.11 \times 0.2 \times 0.1$$

$$\cong 50$$

$$\sigma = 390 / \sqrt{n_{p.e.}} \rightarrow \sigma_{scint} \approx 55\ ps$$

Concerns

1) Light attenuation & Timing degradatio with respect to distanc from PMT.

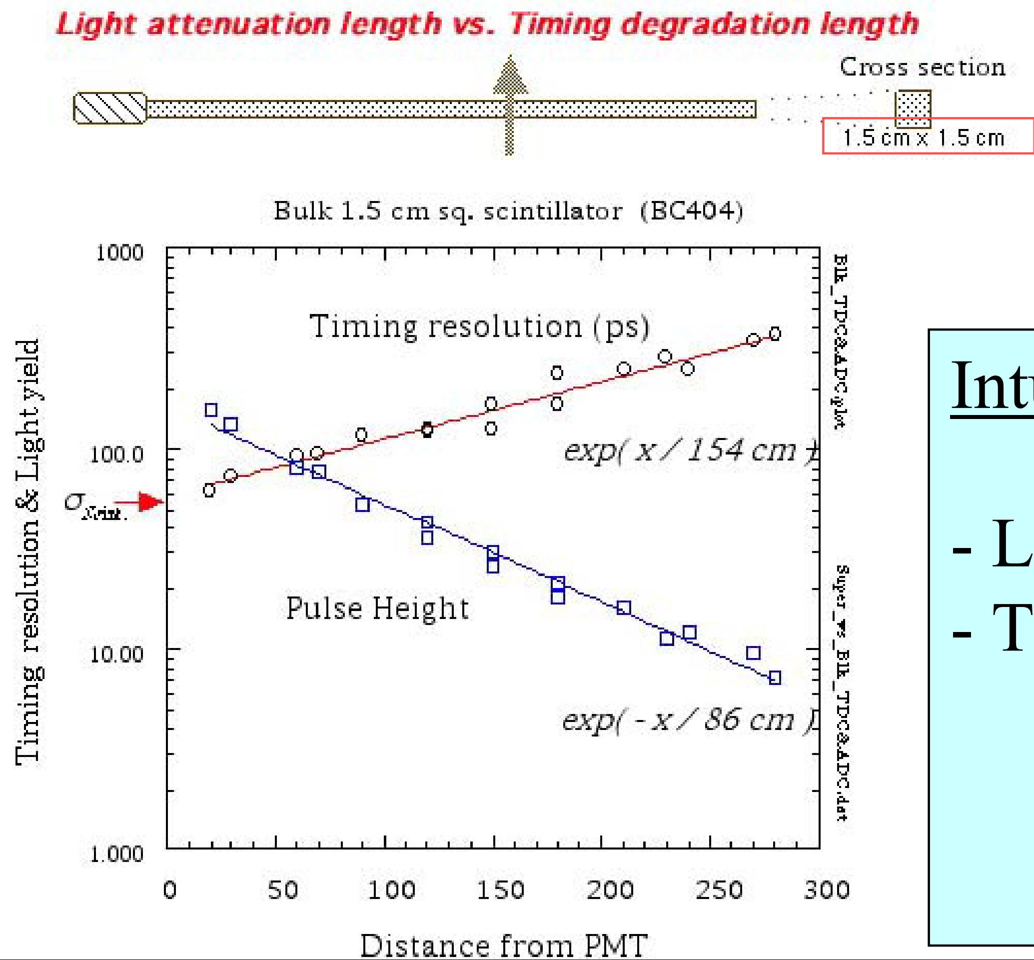
2) Rod with smaller Cross sectional size

3) TOF resolution

4) Aging effect

See next slides for details

(1) Light attenuation vs. Timing degradation



Intuitive explanation

- Light yield $(\propto n_{p.e.}) = e^{-x/\lambda}$
- Timing resolution $\propto n_{p.e.}^{-1/2} = e^{x}$

↓

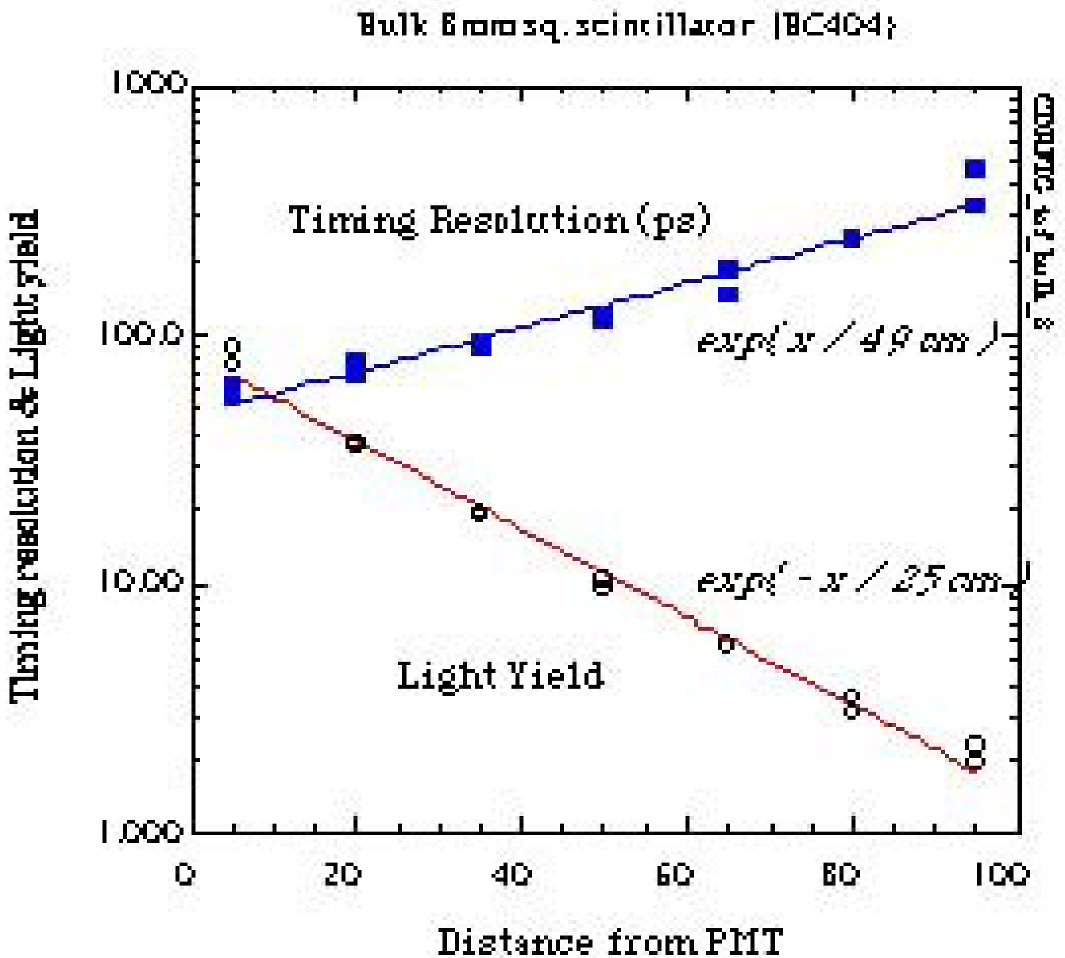
$$\lambda_{timing} = 2 \cdot \lambda_{yield}$$

Light yield decreases exponentially

Timing resolution degrades exponentially, too.

$$\lambda_{timing} = 2 \cdot \lambda_{yield}$$

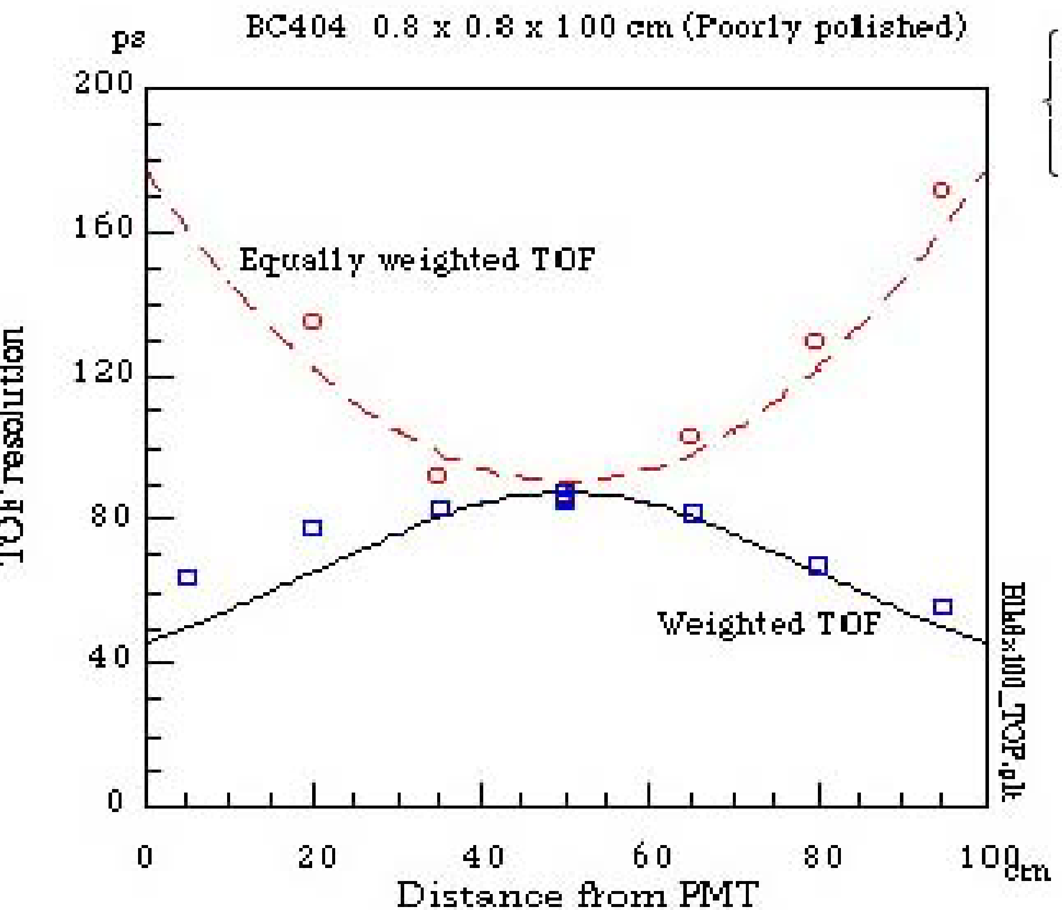
(2) Small cross sectional size

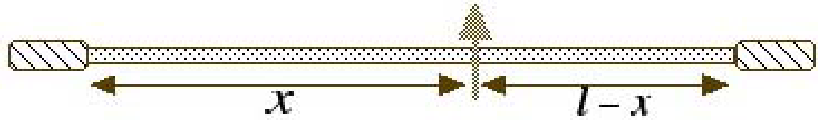


Cross section
0.8 cm x 0.8 cm

Same exponential behavior, but shorter attenuation length,
and $\lambda_{yield} \propto d$ for smaller cross sectional size (d) .

(3) TOF resolution





$$\begin{cases} \delta t_1 = c_0 \exp(\frac{x}{\lambda_t}) \\ \delta t_2 = c_0 \exp(\frac{l-x}{\lambda_t}) \end{cases}$$

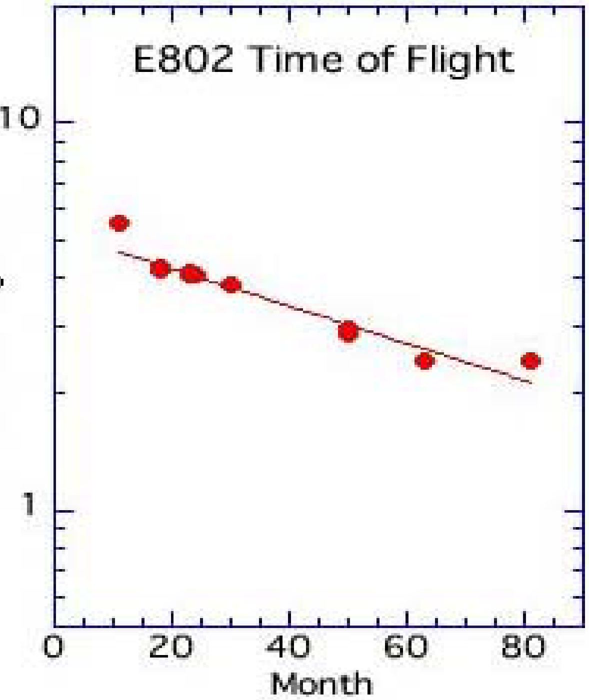
$$\therefore \delta(\frac{t_1+t_2}{2}) = \frac{c_0}{2}\sqrt{\exp(2\frac{x}{\lambda_t}) + \exp(2\frac{l-}{\lambda_t}}$$

Weighted TOF
see → NIM A349(1994)447-45

Consistent with exponential behavior

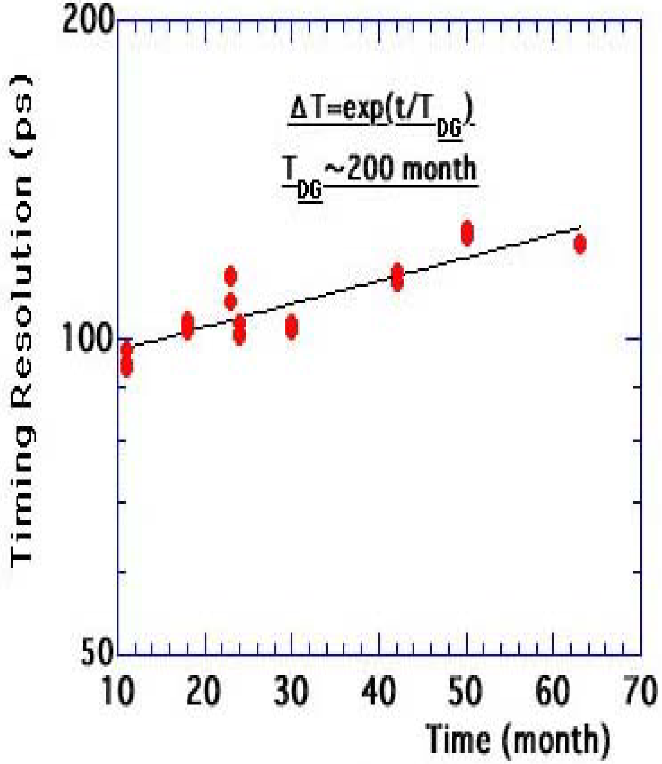
(4) Aging effect

Pulse height



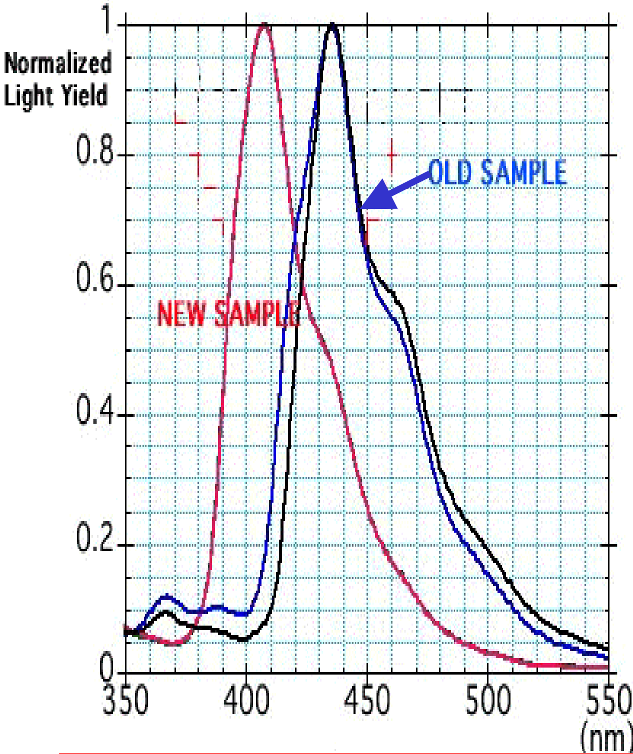
- **Exponential decrease**
- **Life time of <u>8 years</u>**

Timing resolution



- **Exponential degradation**
- **Lifetime of <u>~17 years</u>**

Optical property

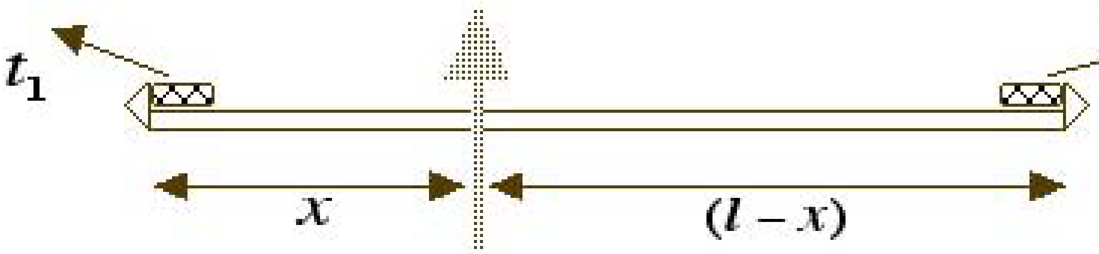


- **Change in emission spectru**
- **More damage in the region closer to the surface**

→ Oxidization ?

Consistent with statistical picture.

Expected effects of Cherenkov



$$\begin{cases} t_1 = t_0 + x / v_{light} \\ t_2 = t_0 + (l - x) / v_{light} \end{cases} \qquad \frac{t_1 - t_2}{2} = \frac{x - l/2}{v_{light}}$$

$$\therefore -\frac{l}{2v_{light}} \le \frac{t_1 - t_2}{2} \le \frac{l}{2v_{light}}$$

; Length of the scintillator
(Condition on the fiducial)

At x~0, the effect of Cherenkov emission is on t_1, while no effect on t_2.

500ps~1000ps

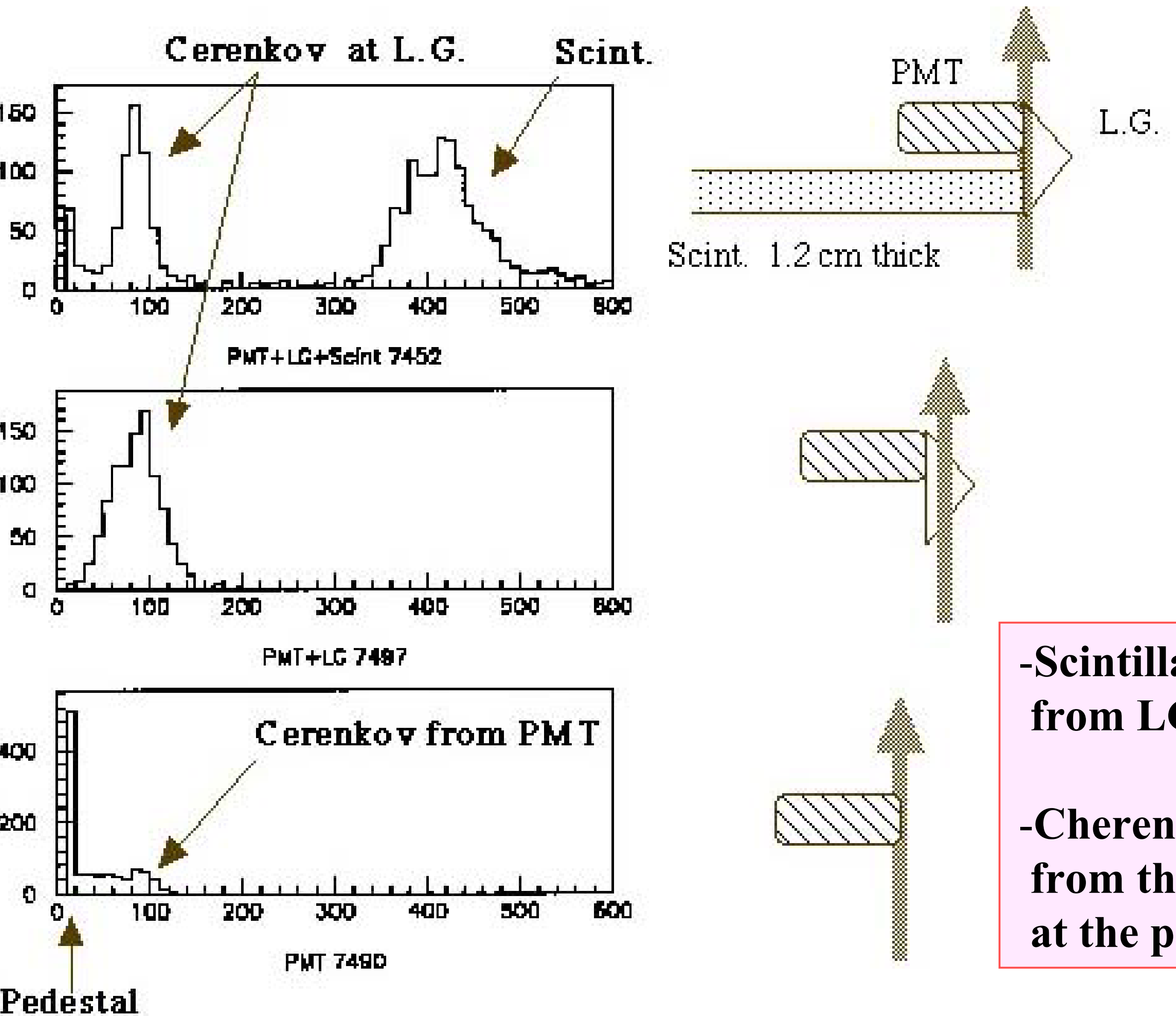
$$t_1' = t_1 - \Delta \longrightarrow \frac{t_1' - t_2}{2} = -\frac{l}{2 \cdot v_{light}} - \frac{\Delta}{2}$$

Similarly, at x~l,

$$t_2' = t_2 - \Delta \longrightarrow \frac{t_1 - t_2'}{2} = \frac{l}{2 \cdot v_{light}} + \frac{\Delta}{2}$$

Pointing outside of the scintillato

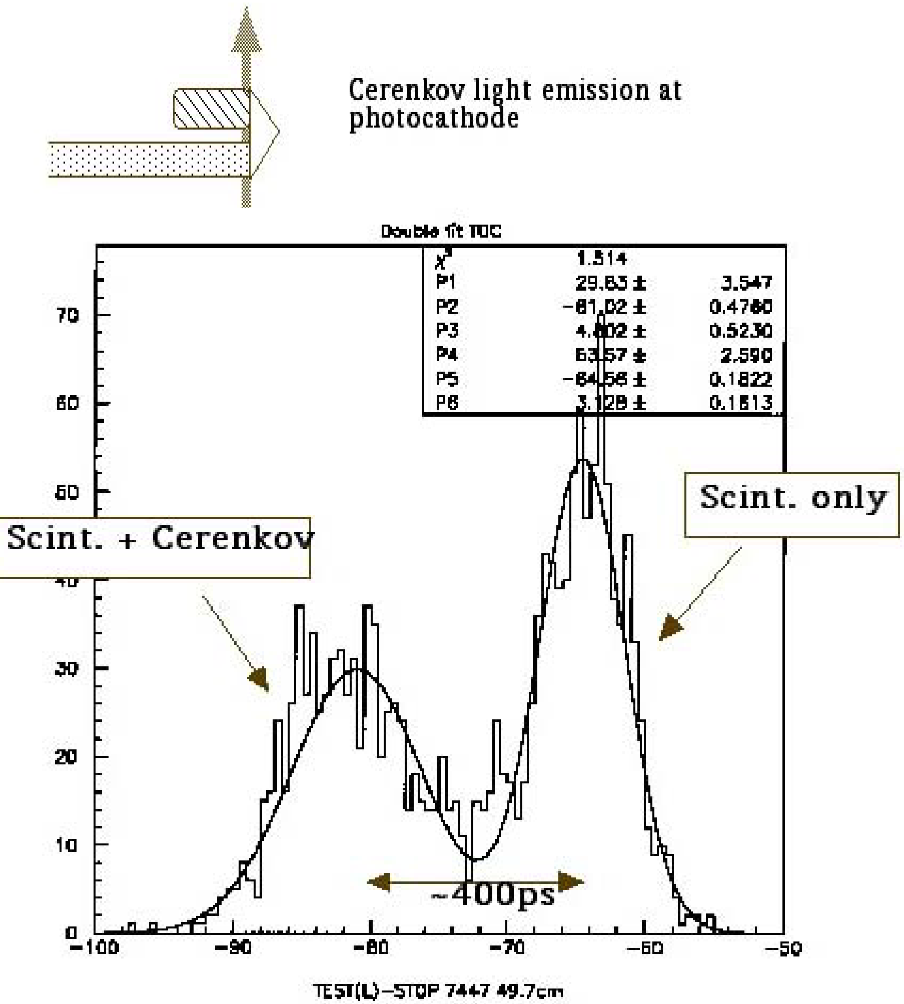
Pulse height of Scintillator & Cherenkov light

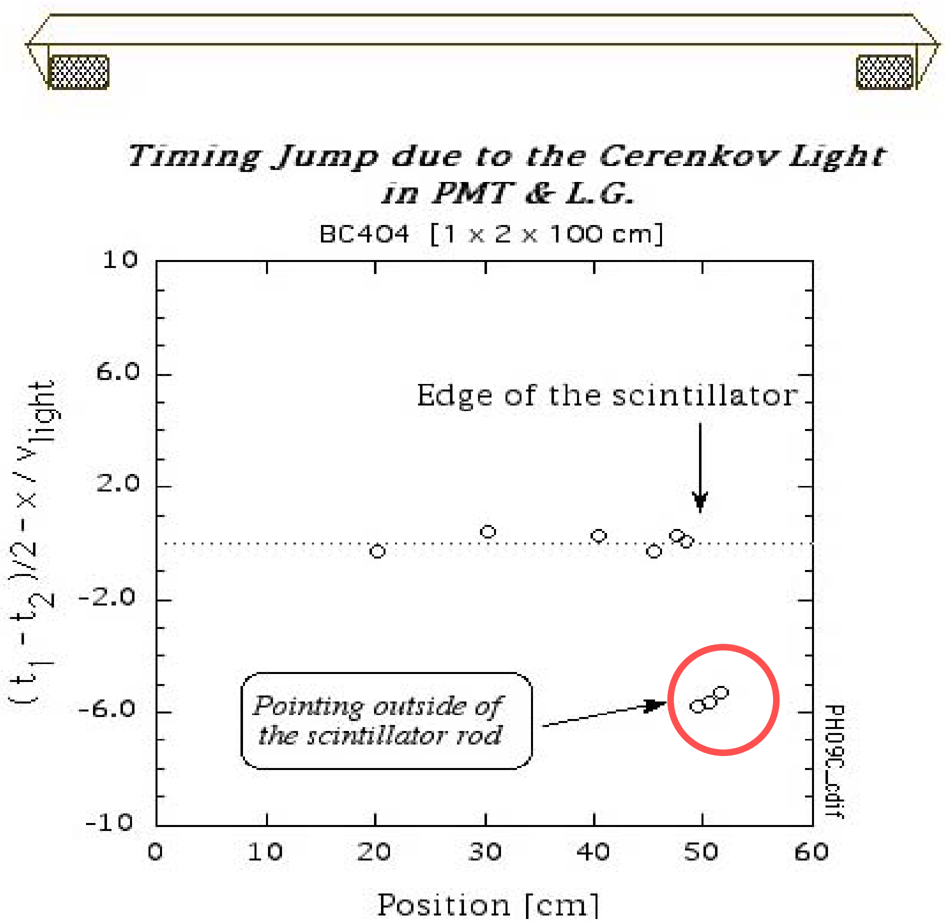


-Scintillation and Cherenkov lig
from LG can be separated clear

-Cherenkov emission
from the PMT is localized
at the photocathode (2mm)

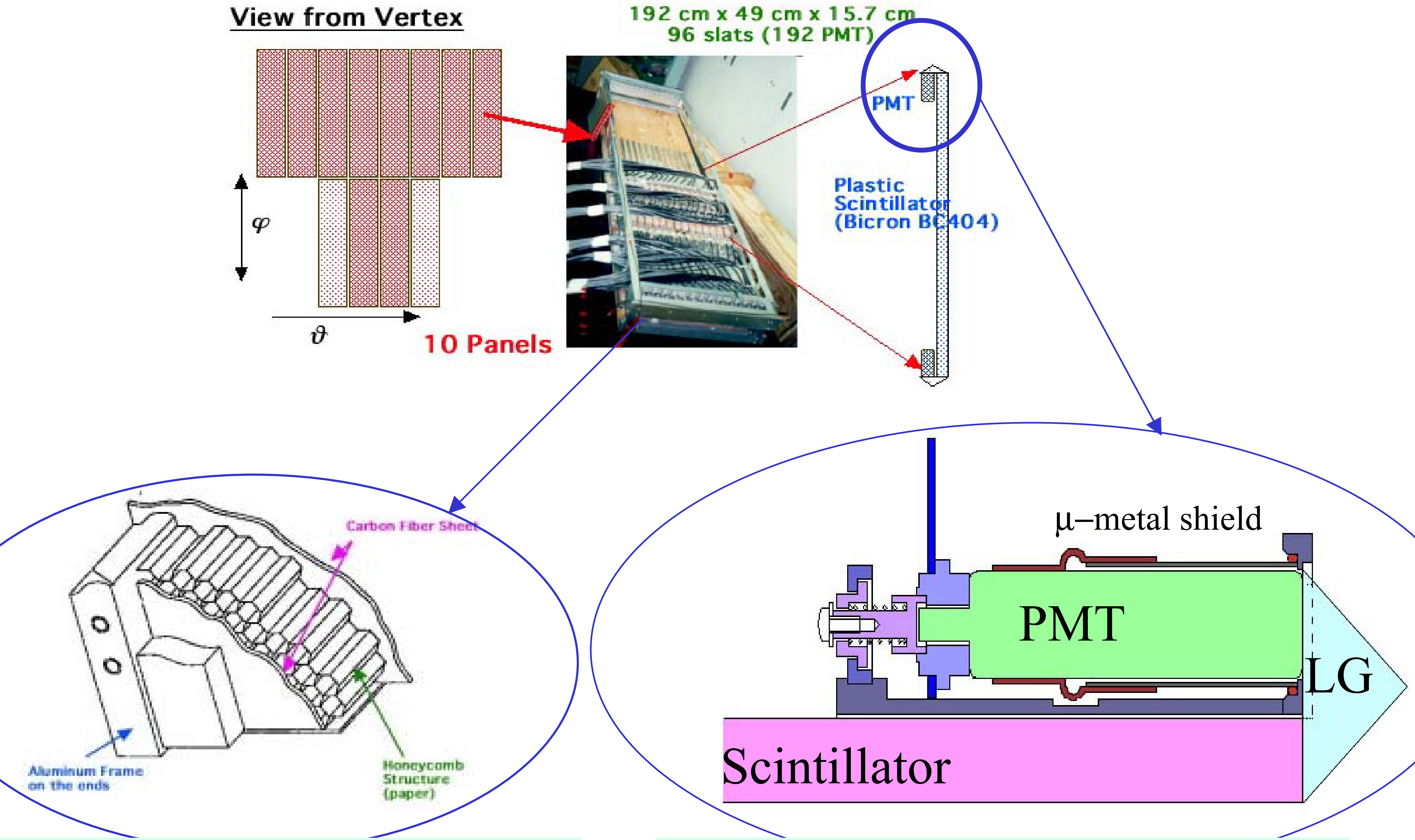
Cherenkov Effect on Timing
→ Fiducial cut with timing difference





Early timing seen at the photocathode region (~2mm) → Pointing outside → **Self detectable !!**

(Mechanical Structure)

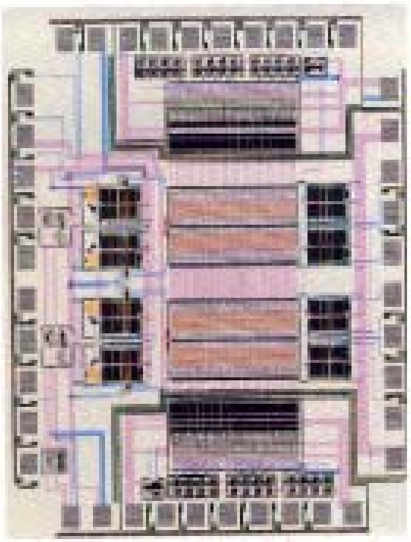


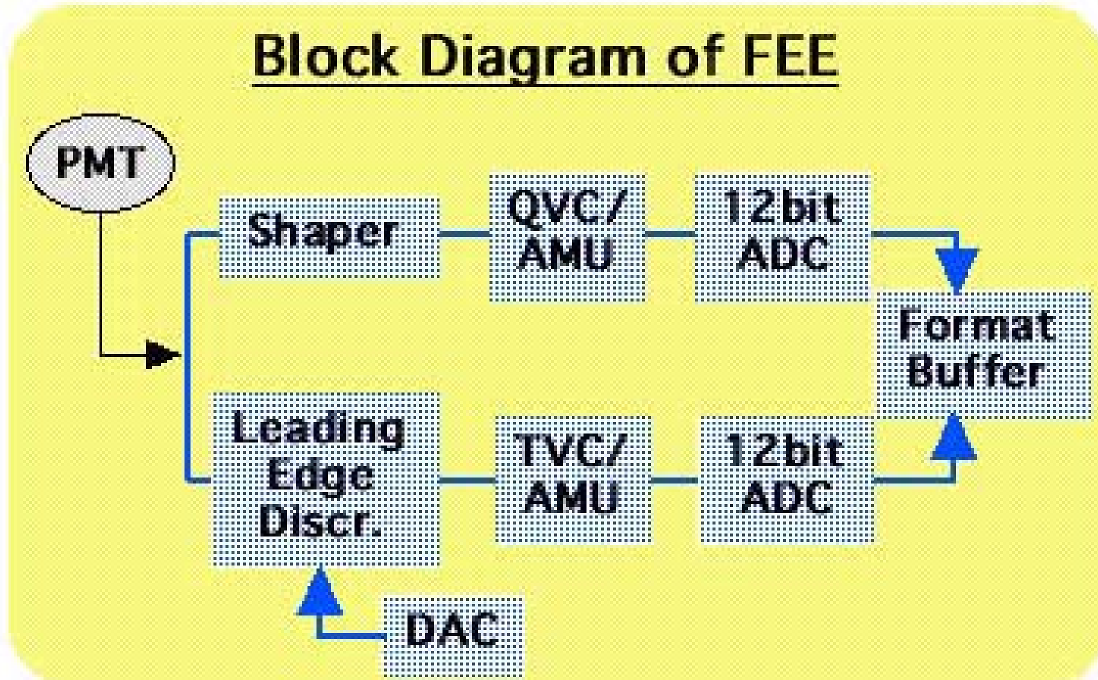
oney comb + Carbon fiber sheet
r supporting structure with “no mass”

Easy maintenance of PMT and bleeder
Easy light shield using rubber tube & O-ring

Features of TOF-FEM

Custom made
TVC/AMU chip





Custom-made chips of TVC+AMU ad QVC+AMU.

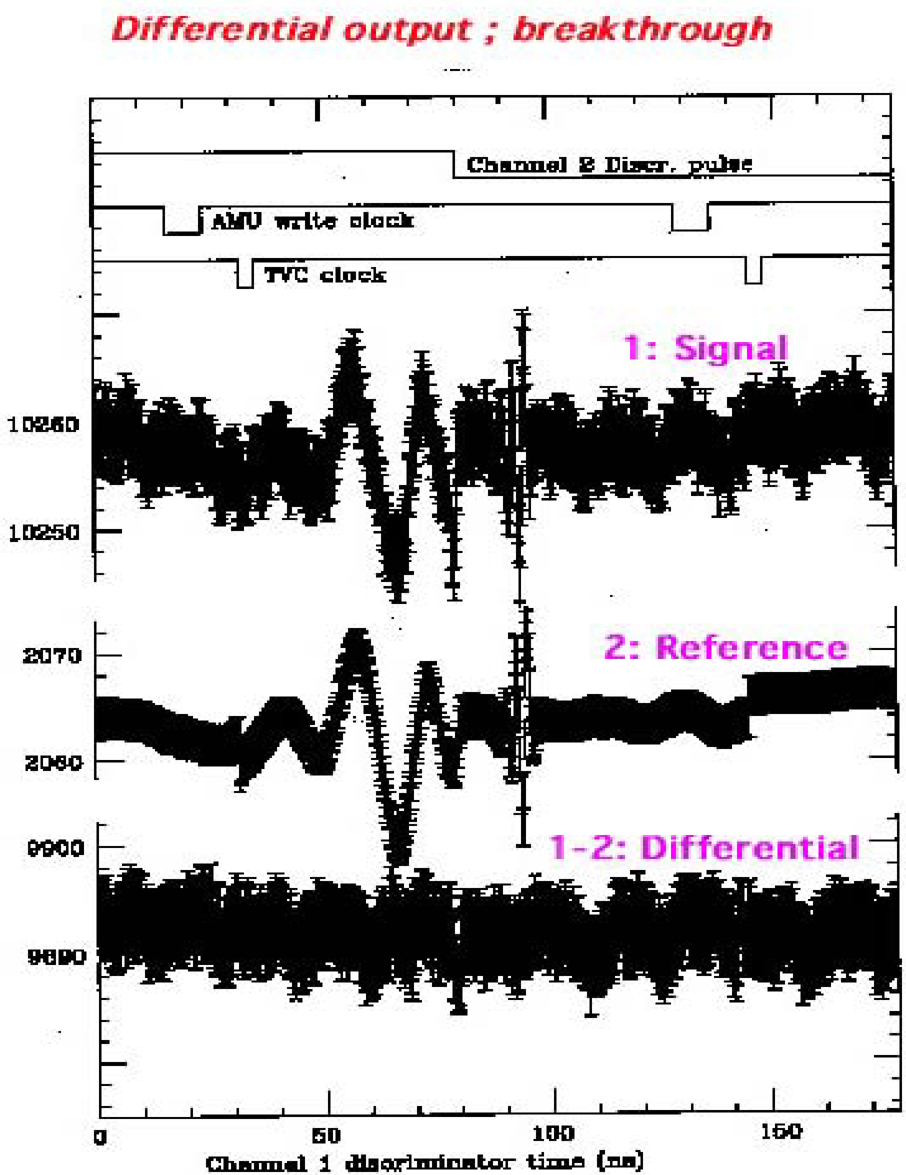
- overall timing resolution of <25 ps
- cross talk problem → see next slide

Programmable Analogue Memory Unit

- programmable up to 4 micro-sec.

Clock is shared with start counter FEM which is transmitted by differential ECL.

Cross talk problem



Each channel consist of 2 independent Ch

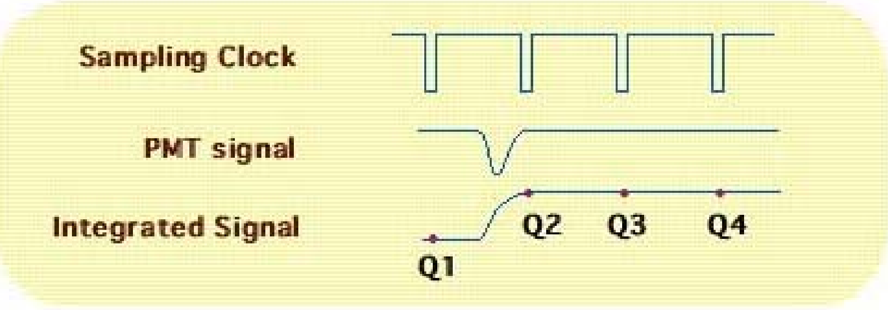
- One connected to PMT

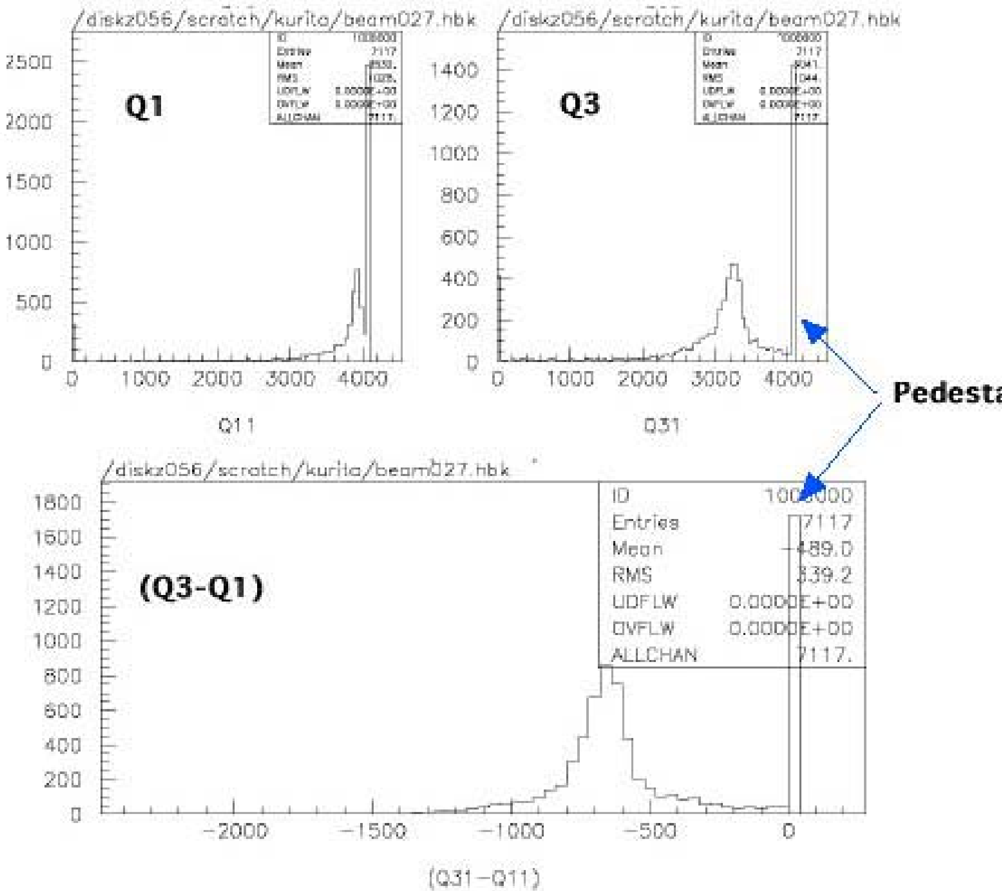
- The other serves as "antenna" for the cross talk.

↓

No cross talk in the differential output

Charge measurement as an example





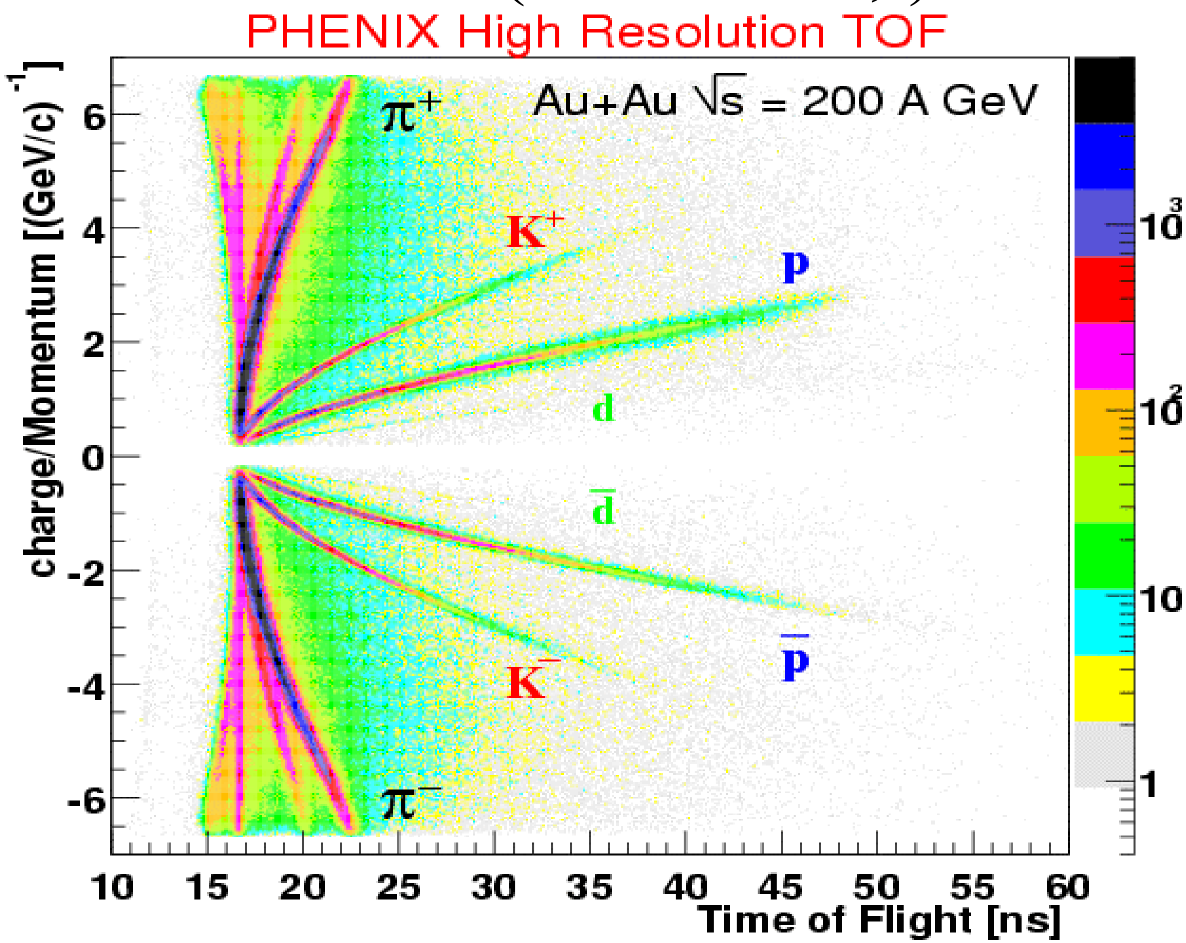
Voltage of integrator are sampled at each clock.

↓

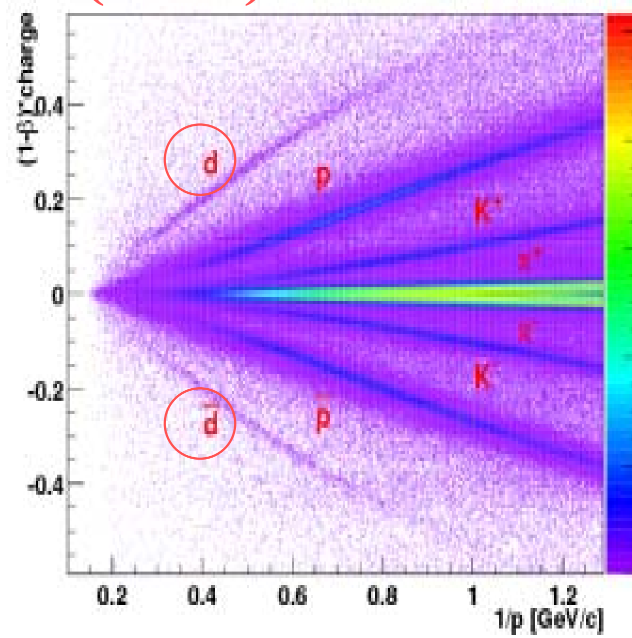
(Q3-Q1) gives
the integrated charge.

What does it give now ?

(First of all,) → Hadron Identification



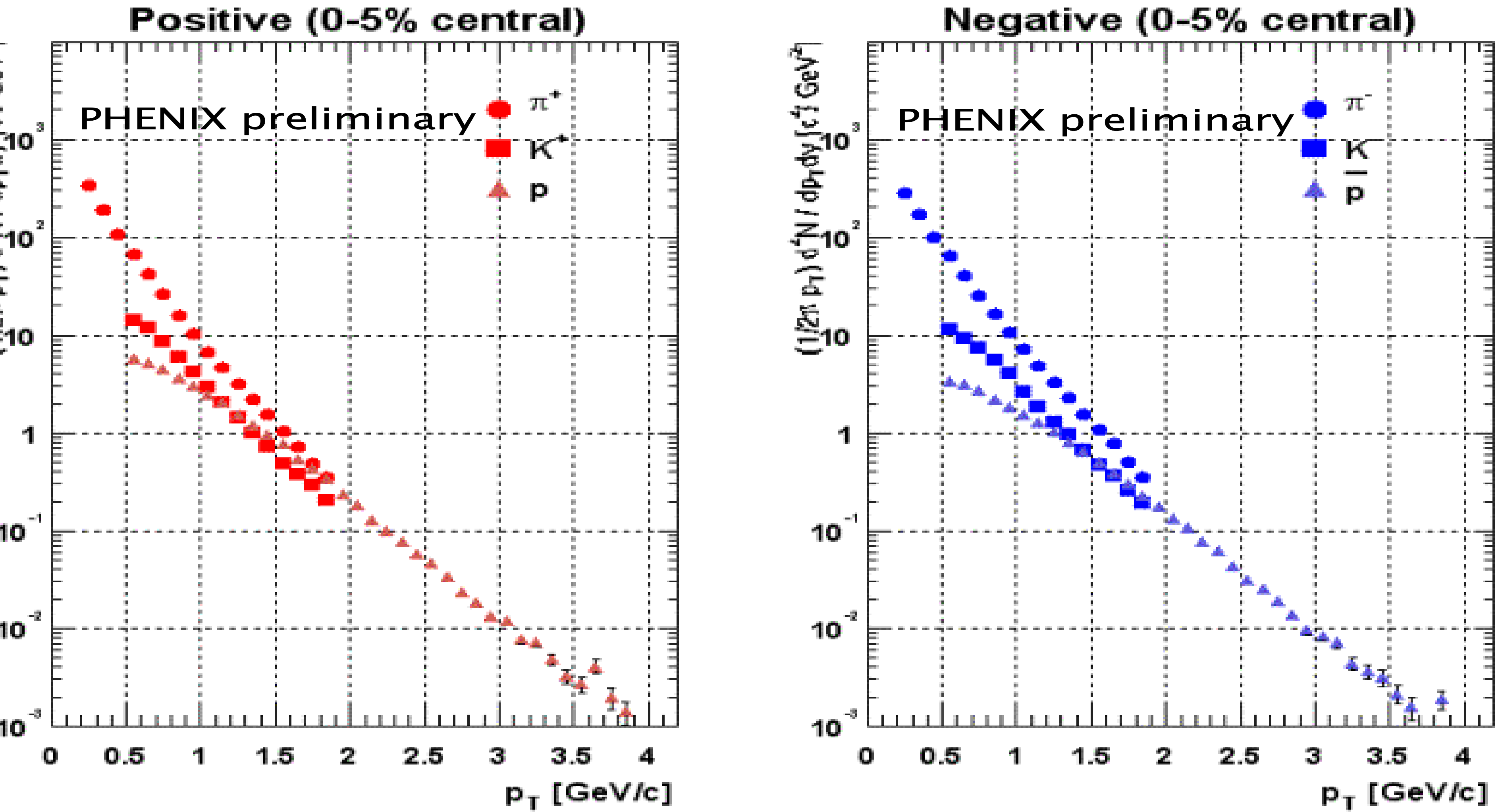
(anti-)deuteron



- Pion, Kaon, proton, and deuteron are clearly identified.
- Overall, ~120ps time resolution is achieved

What does it give now ?

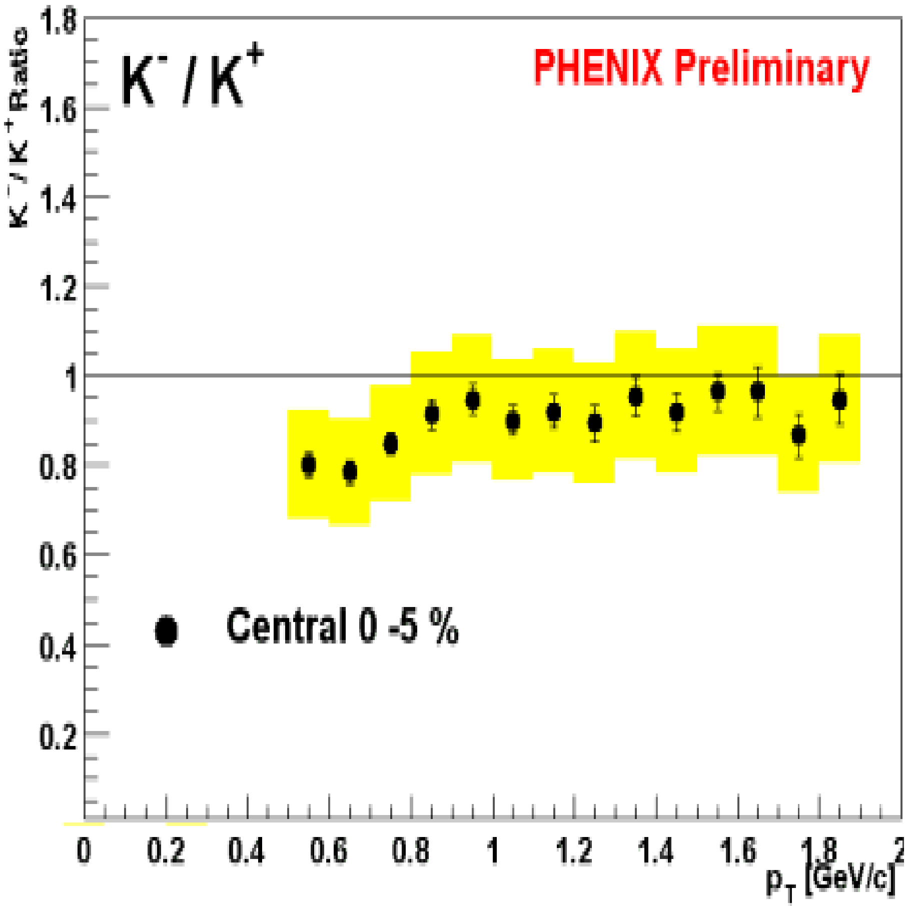
(e.g. #1) → Single particle transverse momentum Spectra / Ratio

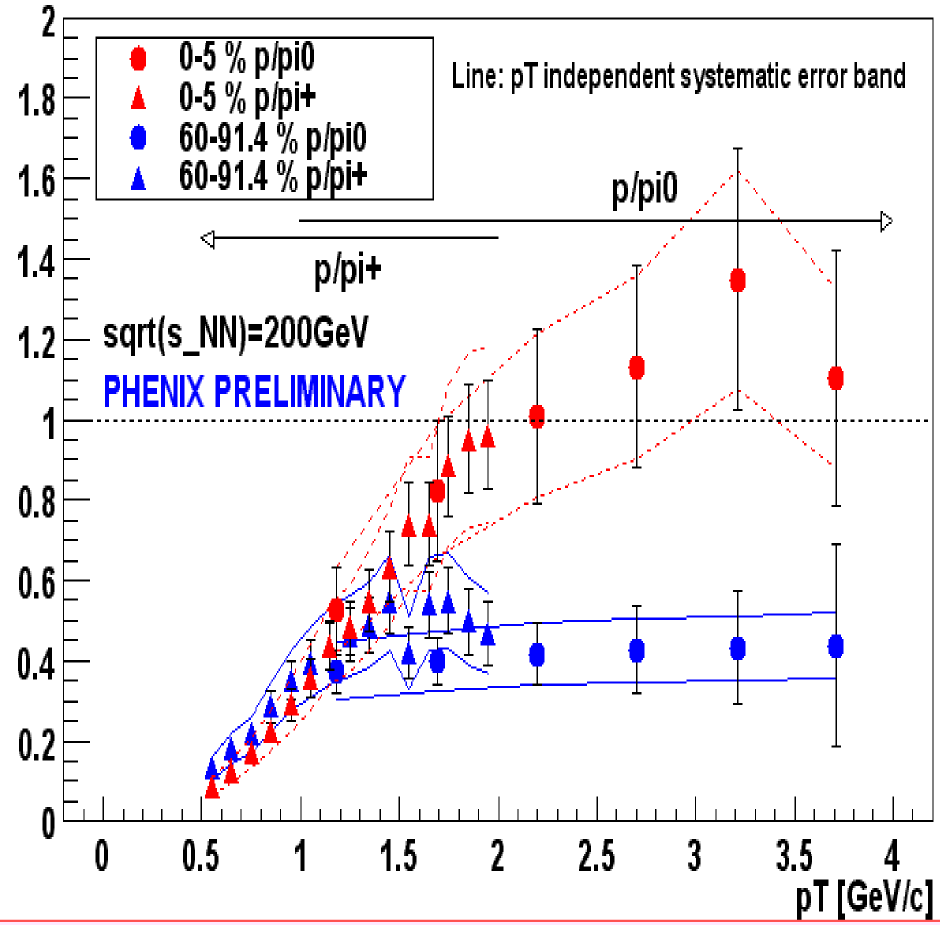


Pion , Kaon up to 2 GeV/c, Proton up to 4 GeV/c.

What does it give now ?

(e.g.#2)→ Particle Ratio



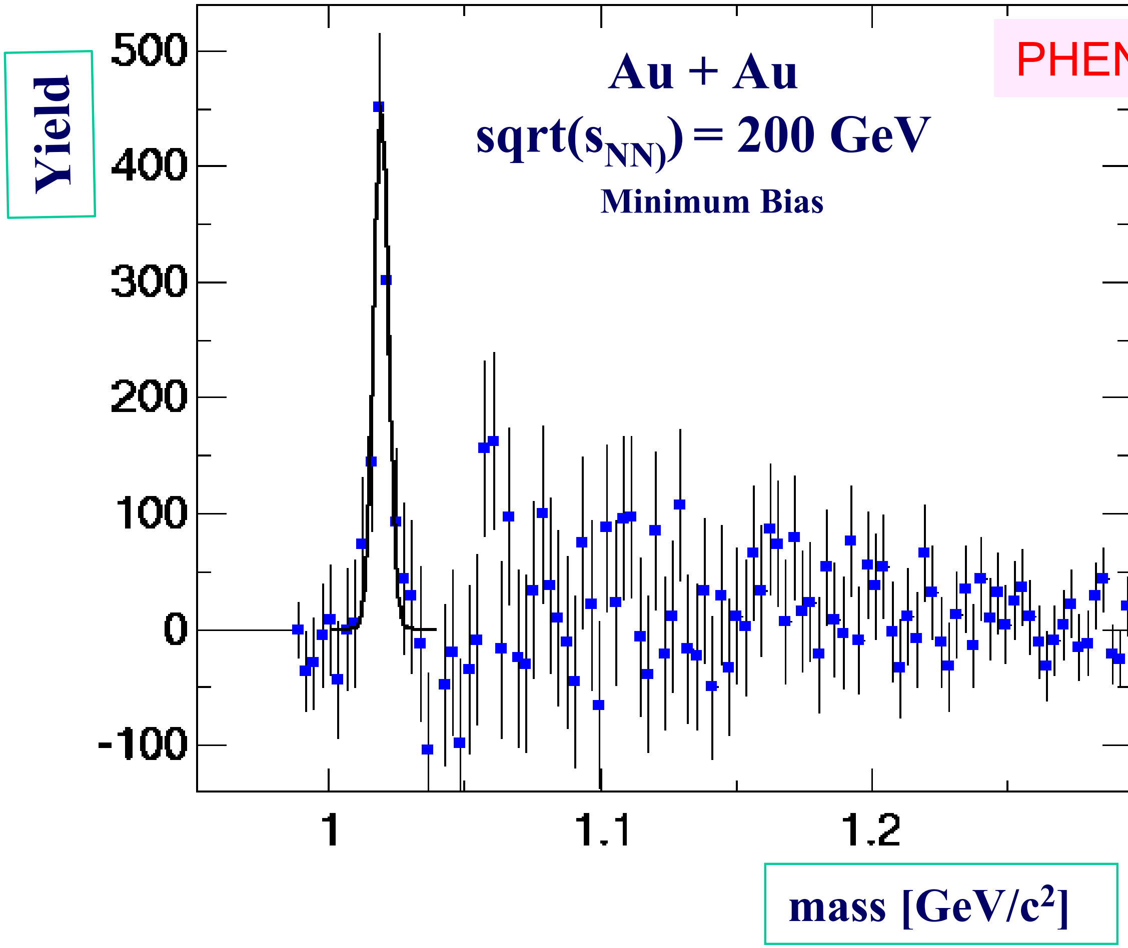


Kaon up to 2 GeV/c, Proton/pion$^{(0)}$ up to 4 GeV/c.

Proton/pion$^{(0)}$ changes from "< 1." to ">1" at ~ 2GeV/c.

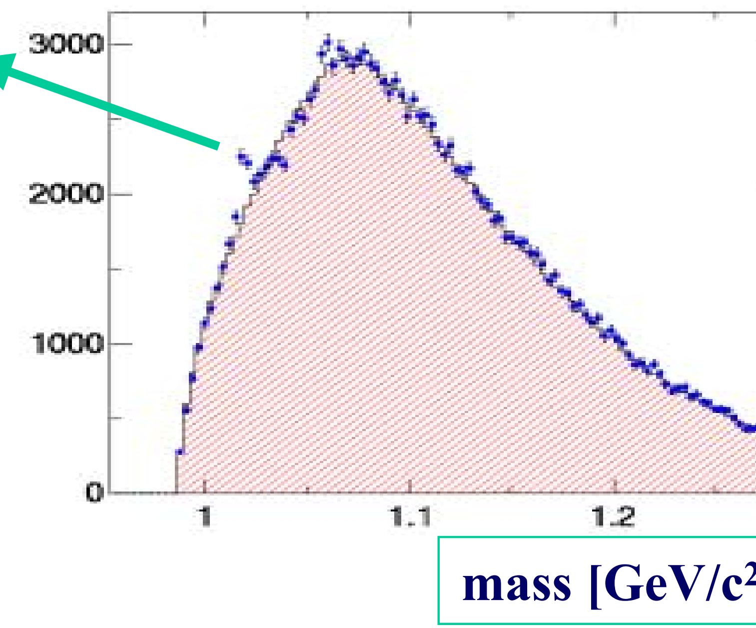
What does it give now ?

(e.g. #3)→ ϕ meson measurement in K^+K^- decay



$$\frac{dN}{dy} = 2.01 \pm 0.22(stat)^{+1.01}_{-0.52}(sys)$$

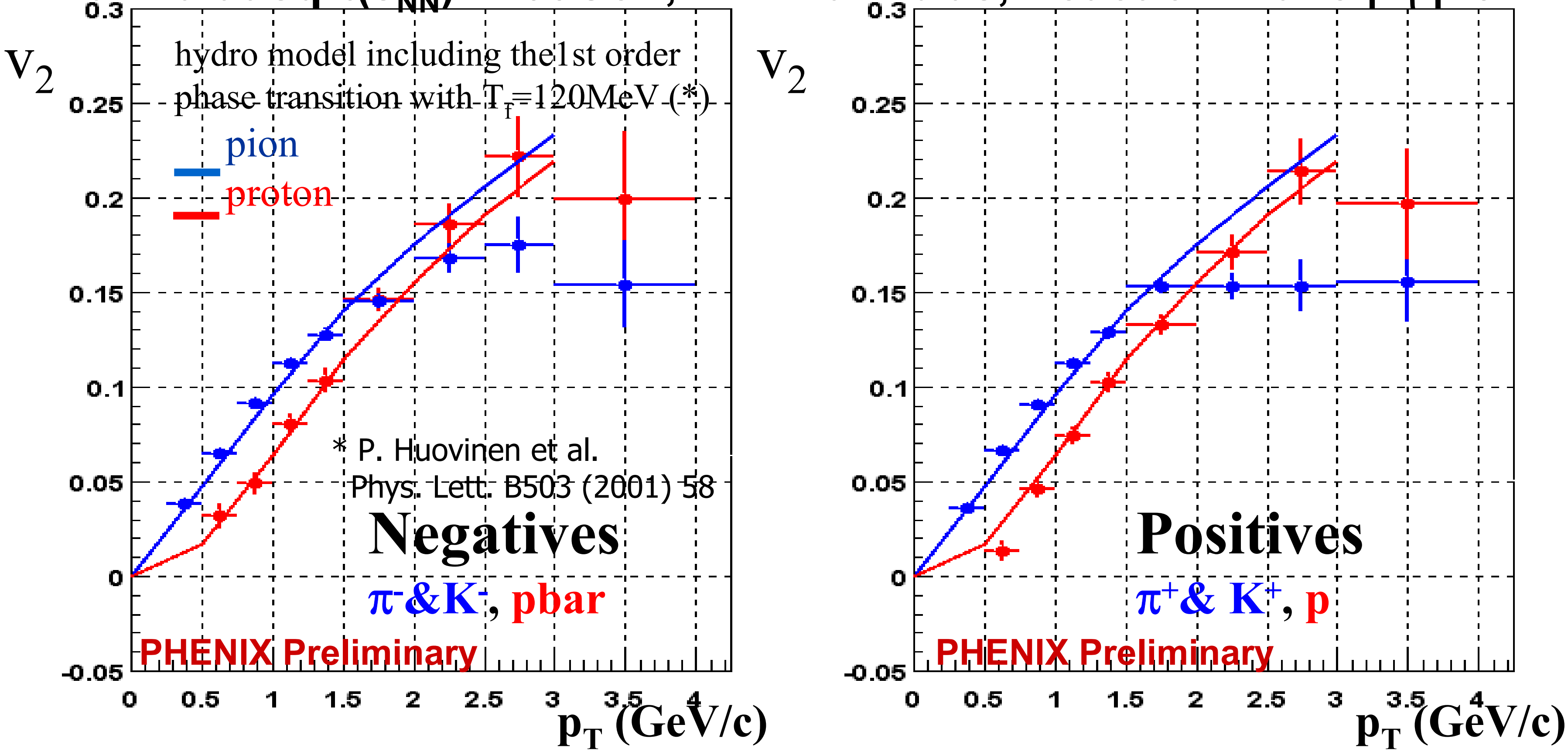
Au + Au minimum bias (0-90% central)
result at E_{cm}=200 GeV



Clear identification of the ϕ meson

What does it give now ?
(e.g. #4)→ Elliptic flow measurement

Au+Au at sqrt(s_{NN}) =200GeV, Minimum bias, Reaction Plane | η |=3~4



- Up to 4 GeV, v2 has been measured.
- Deviation for pions from model at higher p_T?

Summary

(1) The TOF is designed for Singles, HBT, f-meson measurement and successfully operated for the PID (up to ~ 2 GeV for pion and kaon, and up to ~ 4 GeV/c for (anti-)proton).

(2) The skills/ techniques of the detector are described.

- PMT performs with statistical picture ($\sigma \propto 1/\sqrt{n_{p.e.}}$) .
- Light yield and timing resolution are consistently described with statistical picture ($\lambda_{timing} = 2 \cdot \lambda_{yield}$).
- Aging effect (life time of timing resolution ~ 17 years) is intuitively described with statistical picture.
- Readout electronics uses differential technique in FEM, and long-distance clock transmission.

(3) TOF now gives important physics measurements at RHIC energy ex.1-2, single particle spectra, ratio, ex.3, ϕ meson measurement, or, ex.4, elliptic flow at higher pt.

謝謝！