Timing measurements with CVD diamonds

A new start detector for FOPI

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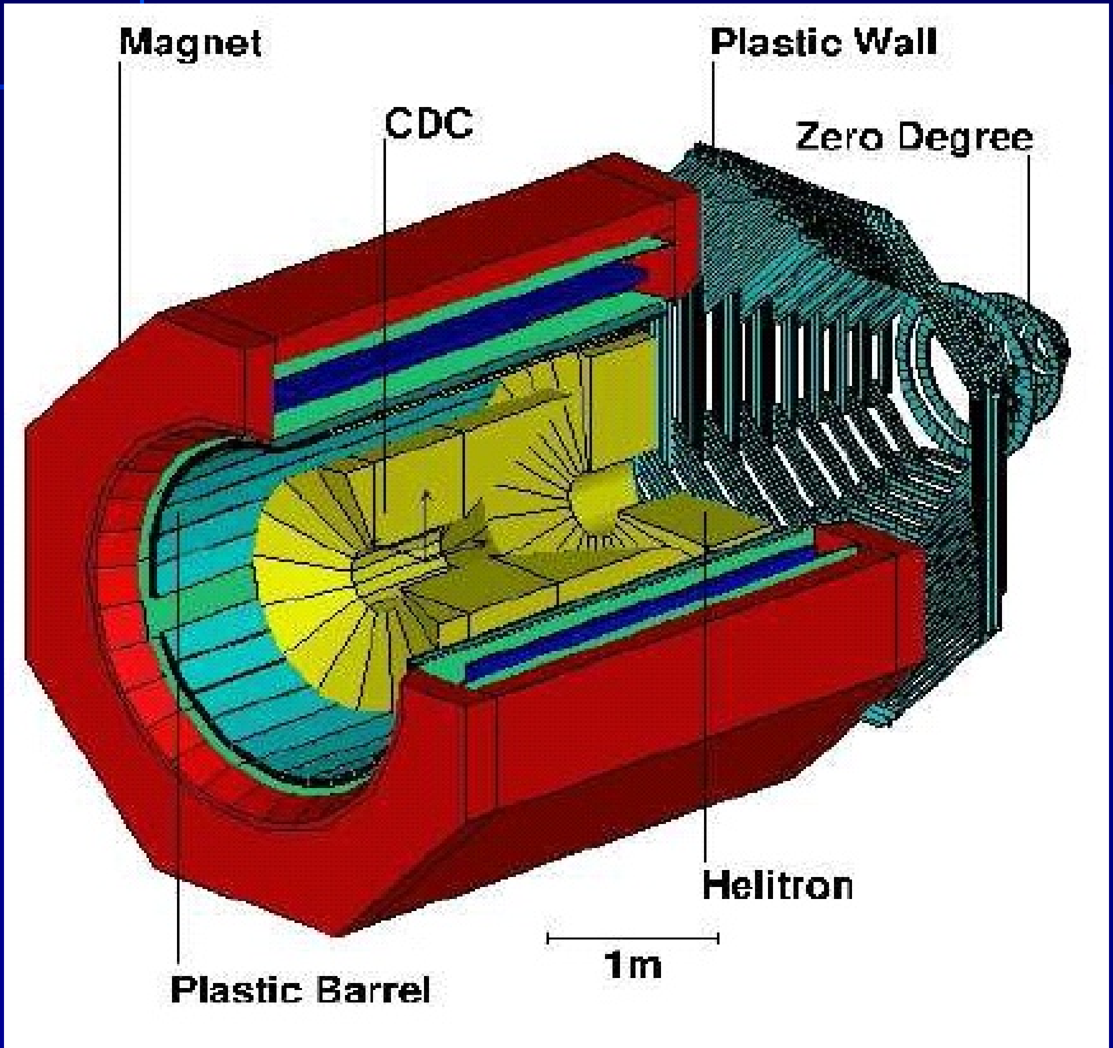
for FOPI collaboration

Outline

- Introduction & motivation
- Front end electronics
- β-source test results
- Beam test results
- Conclusion
- Outlook

FOPI detector

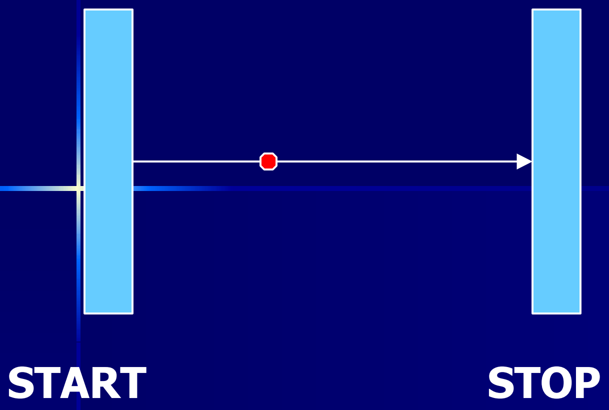


- 4π solid angle coverage charged particle detector

- beam with energies 0.1-2AGeV available from the SIS synchrotron

- heavy ion beam & target

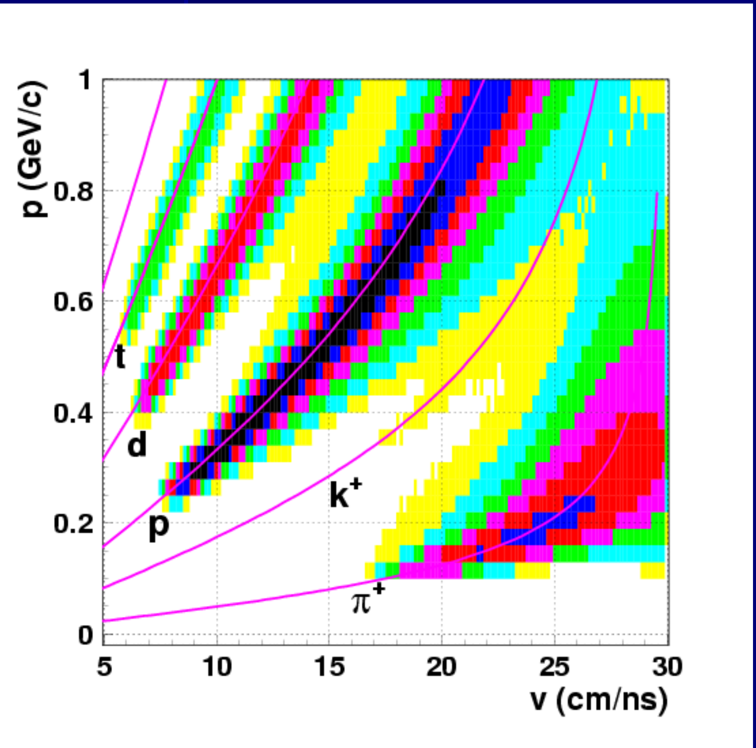
Time of flight method & resolution



$$p = mv\gamma$$

$$m = \frac{p}{c}\sqrt{\frac{c^2 t^2}{l^2} - 1}$$

$$\delta t = L\left(\frac{1}{v_1} - \frac{1}{v_2}\right) \approx \frac{Lc}{2p^2}(m_1^2 - m_2^2)$$



σ_{ToF} – total ToF time resolution
σ_{START} – start detector time resolution
σ_{STOP} - stop detector time resolution

(relativistic case)

$$\sigma_{ToF} = \sqrt{\sigma^2_{START} + \sigma^2_{STOP}}$$

- **current FOPI ToF system:**

  - START: scintillator foil, σ~50-70ps (for heavy ions)
  - STOP: ~1000 scintillators, σ~120-350ps

- **future FOPI ToF system:**

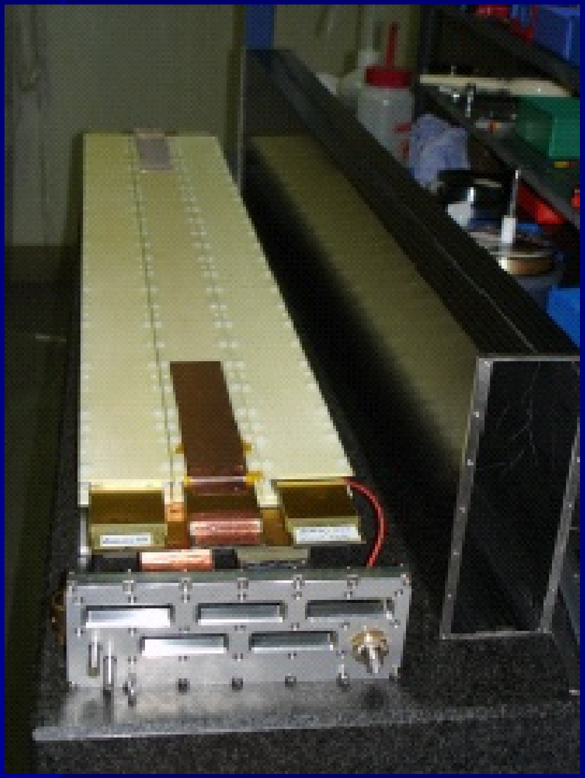
  - diamond start detector + MMRPCs

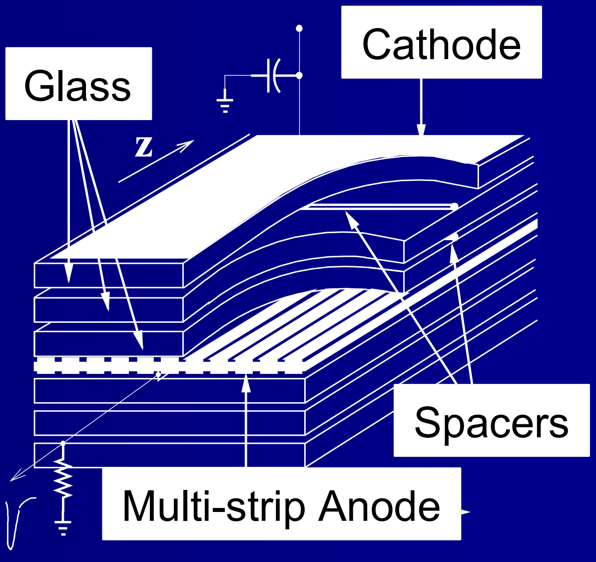
- **future timing requirements:**

  - total resolution better than 100 ps
  - high efficiency (>98%)
  - rate 1 MHz(start detector)

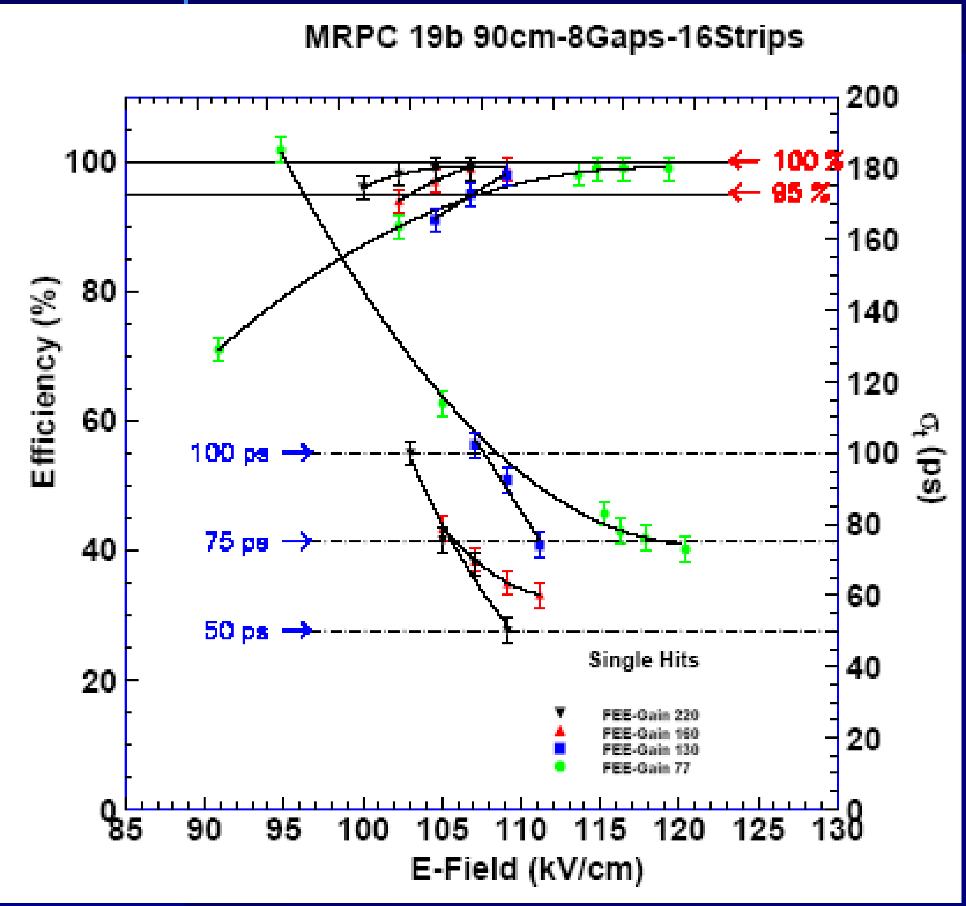
MMRPCs

- 5 MMRPCs in a supermodule
- 30 SM total
- 90x4.6 cm active area
- 10 glass plates
- 8 gaps of 220 µm,
- ~10 kV applied voltage
- 16 strips(1.94mm wide, 1mm gap)
- gas: C2F4H2/isobutane/SF6 (85/5/10)





MMRPC performance



by A.Schüttauf

- system electronics resolution σ ~ 25 ps
- optimal gain range: 150-170
- rate: up to 1kHz/cm^2
- single hit total resolution: σ<75 ps
  - efficiency >99%
- double hit total resolution: σ<100 ps
  - efficiency >85%

- total ToF resolution 100ps
- MMRPC resolution <75ps

→ corresponds to <40 ps START resolution → diamonds

- high resistivity → el. fields ~ 1-2 V/μm
- low capacitance(~1.5 pF) & high carrier mobilities → sharp signals
- radiation hardness

CVD diamonds used

POLYCRYSTAL

- high recombination e/h rate
- good results with heavy ions

SINGLE CRYSTAL

high signal & collected charge → suitable for MIPs(protons)

Minimum ionizing particles

- Bethe – Bloch :

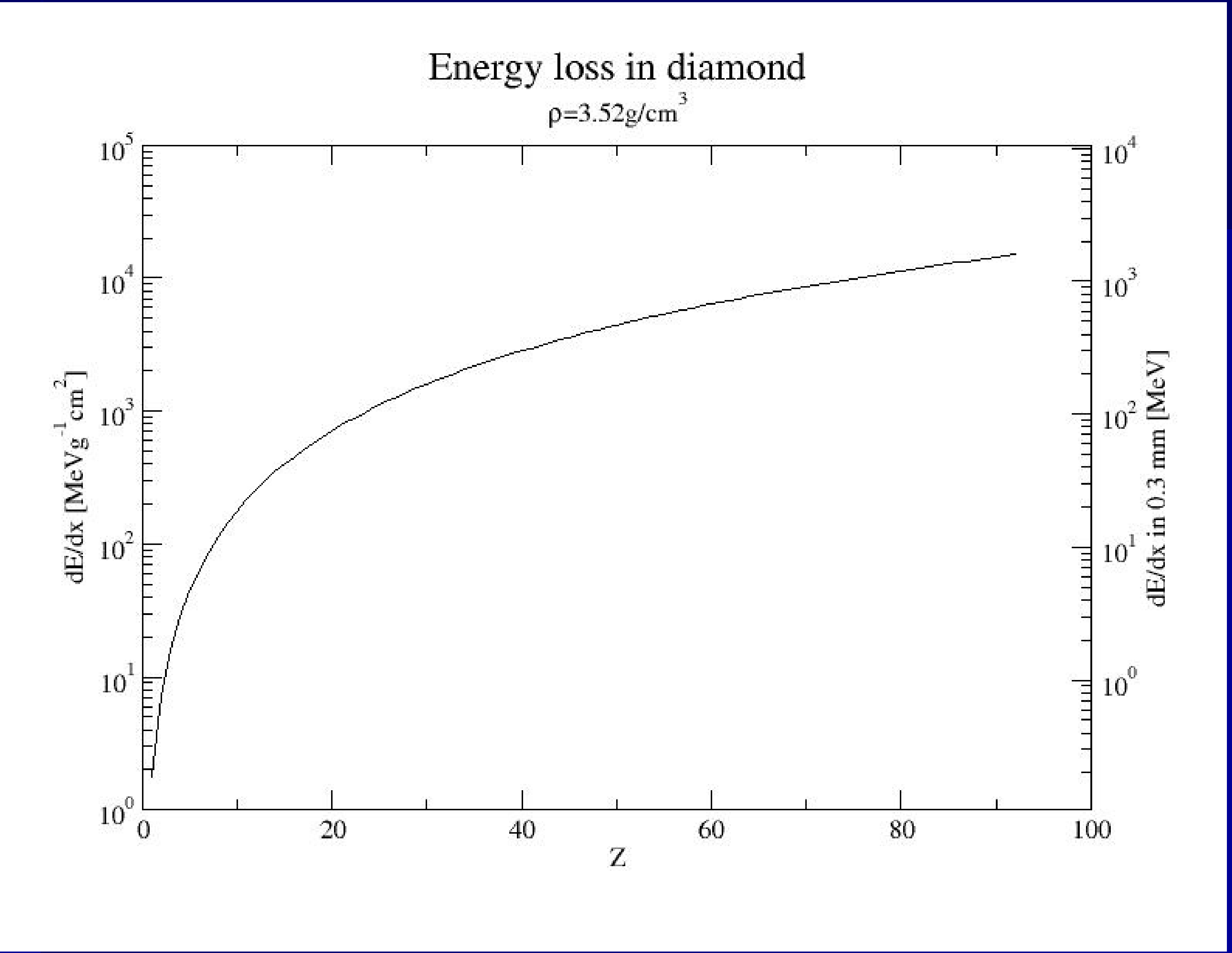
$$-\frac{dE}{dx} = \frac{4\pi}{m_e c^2} \cdot \frac{nz^2}{\beta^2} \cdot \left(\frac{e^2}{4\pi\epsilon_0}\right)^2 \cdot \left[\ln\left(\frac{2m_e c^2\beta^2}{I\cdot(1-\beta^2)}\right) - \beta^2\right]$$

- for MIP: $$\frac{\Delta Q}{\Delta x} = 36e/\mu m$$

$$Q\Big|_{MIP}^{300\mu m} \approx 11000e = 1.75\,fC$$

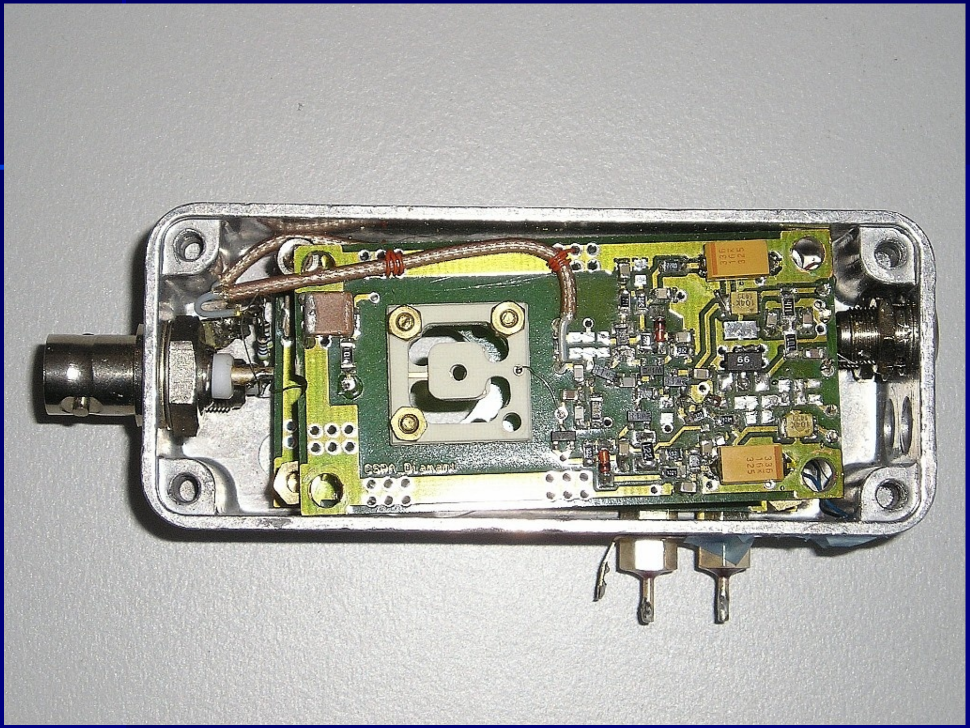
→ SC diamonds needed for MIPs

- PC diamond suitable for heavy ions

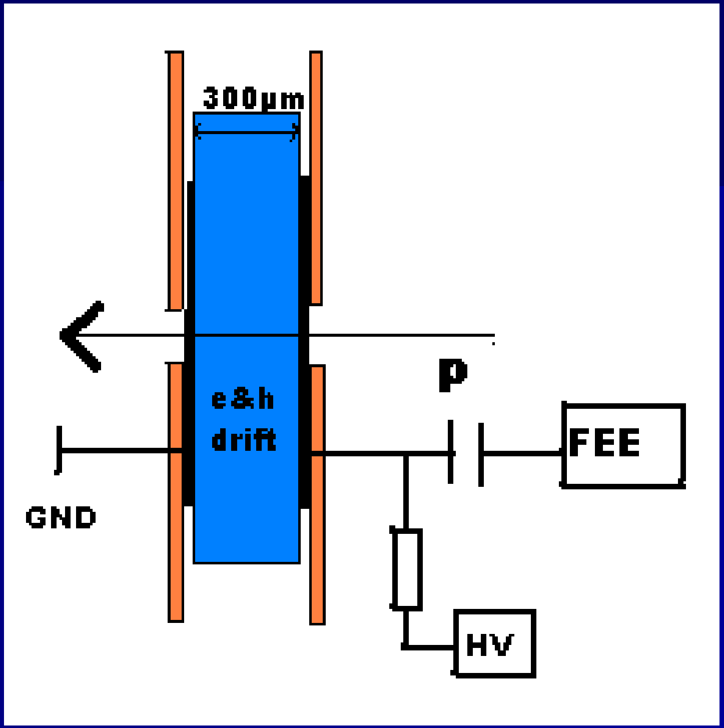


Energy loss in diamond
ρ=3.52g/cm3
dE/dx [MeVg-1cm2]
dE/dx in 0.3 mm [MeV]
Z
10^0
10^1
10^2
10^3
10^4
10^5
0
20
40
60
80
100

Diamond



Diamond & preamplifier



Schematic view

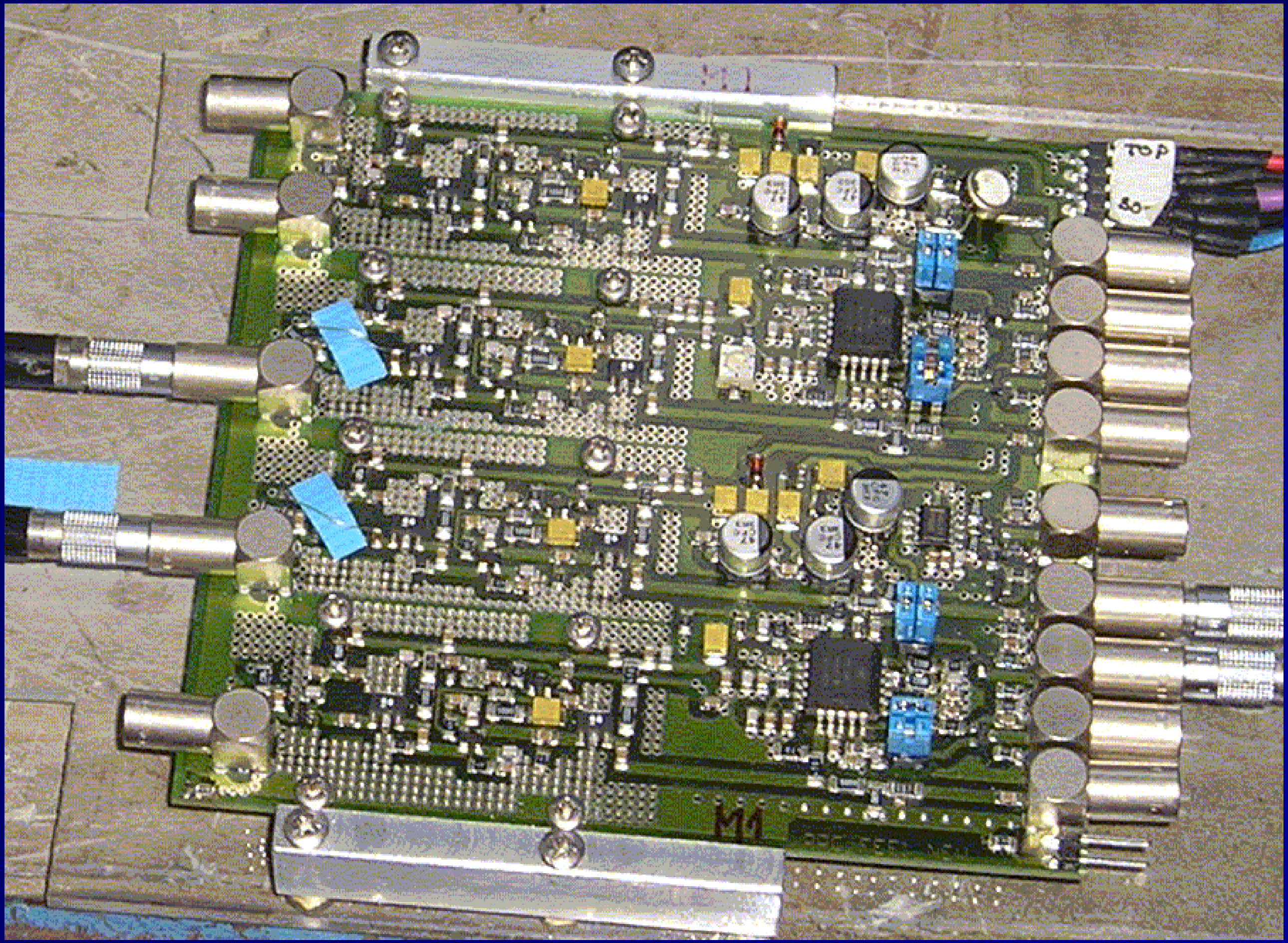
- two diamonds
- resolution was calculated from time difference spectra:

$$resolution = \sigma(D2 - D1)/\sqrt{2}$$

Our CVD detector parameters

- single crystal, 5x5mm^2 surface
- 300 μm thickness
- two diamonds, stacked
- 250 V bias (experienced breakdown at 300 V)
- active area: 3mm diameter, limited by surface leakage current

RPC FEE1



- total gain: 250
  - charge and timing signal output

RPC FEE1 characteristics

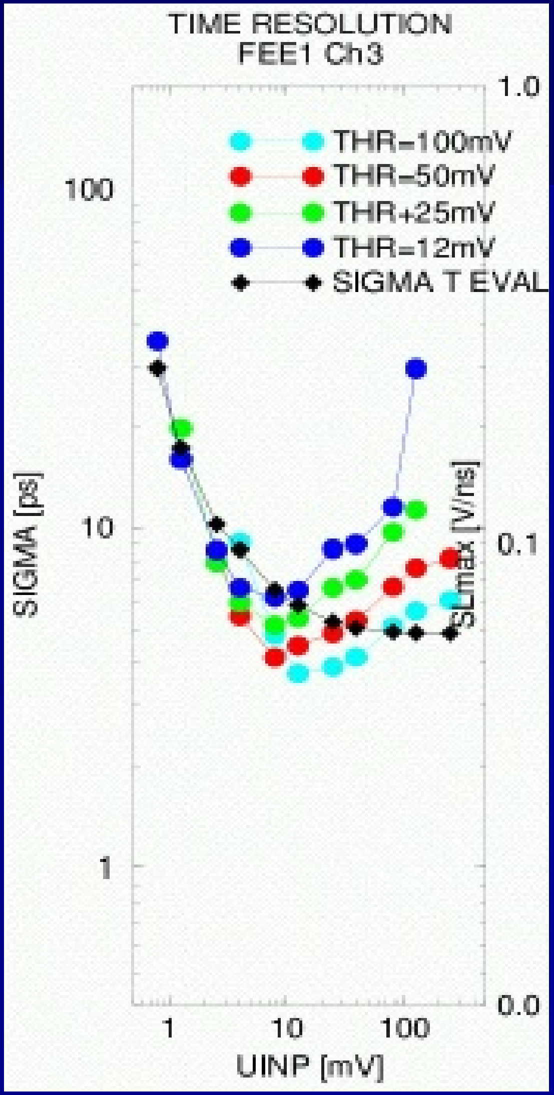
- 4 channels
- manual gain & treshold adjustment
- gain: 0-100(two stages)
- bandwidth: 1GHz
- digital & analog output
- A:

  - noise: 20 µV

  - rise time: 350 ps
- D:

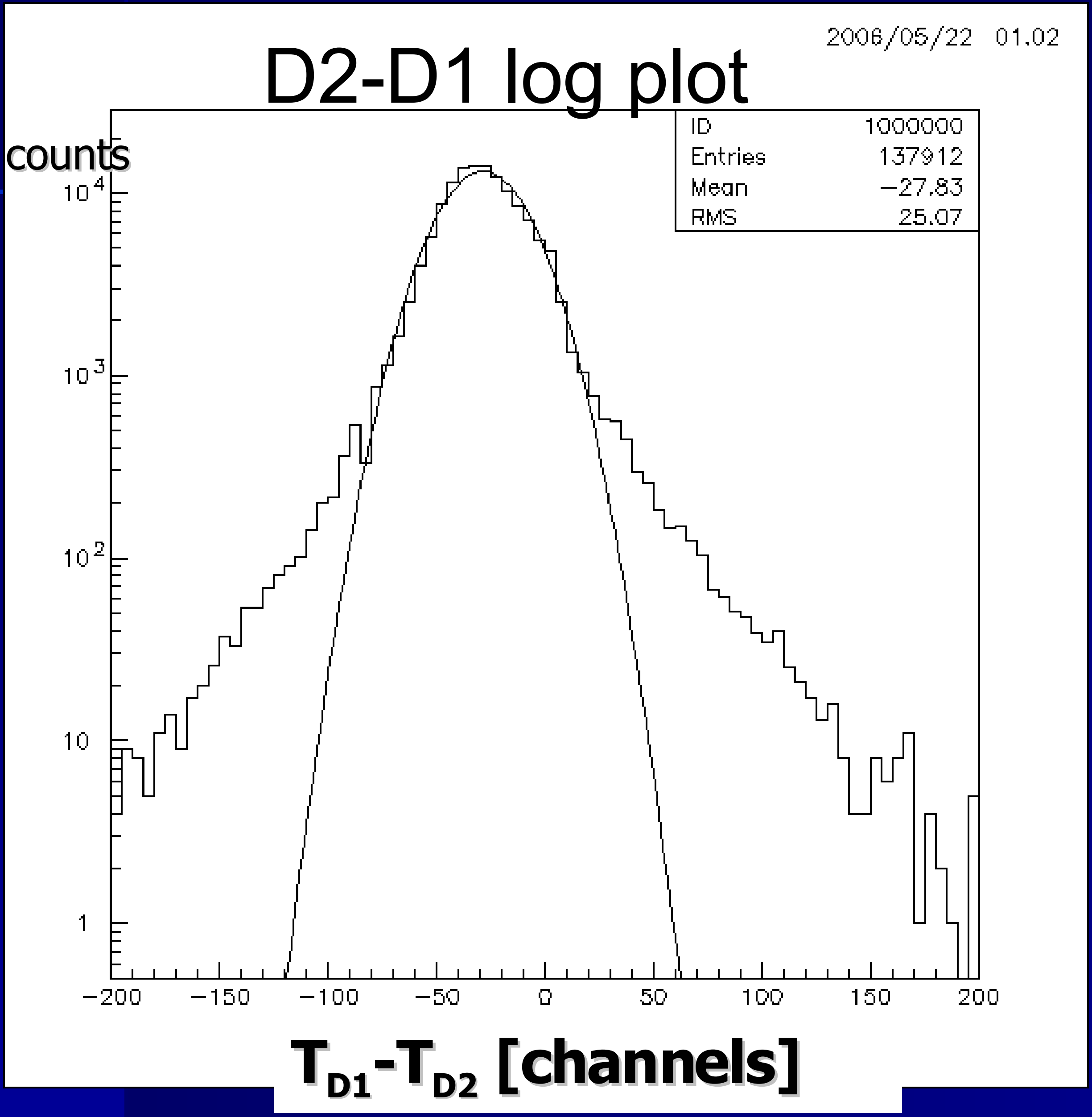
  - noise: 20 µV

  - rise time: 500 ps



by M. Ciobanu

New results - β-source test



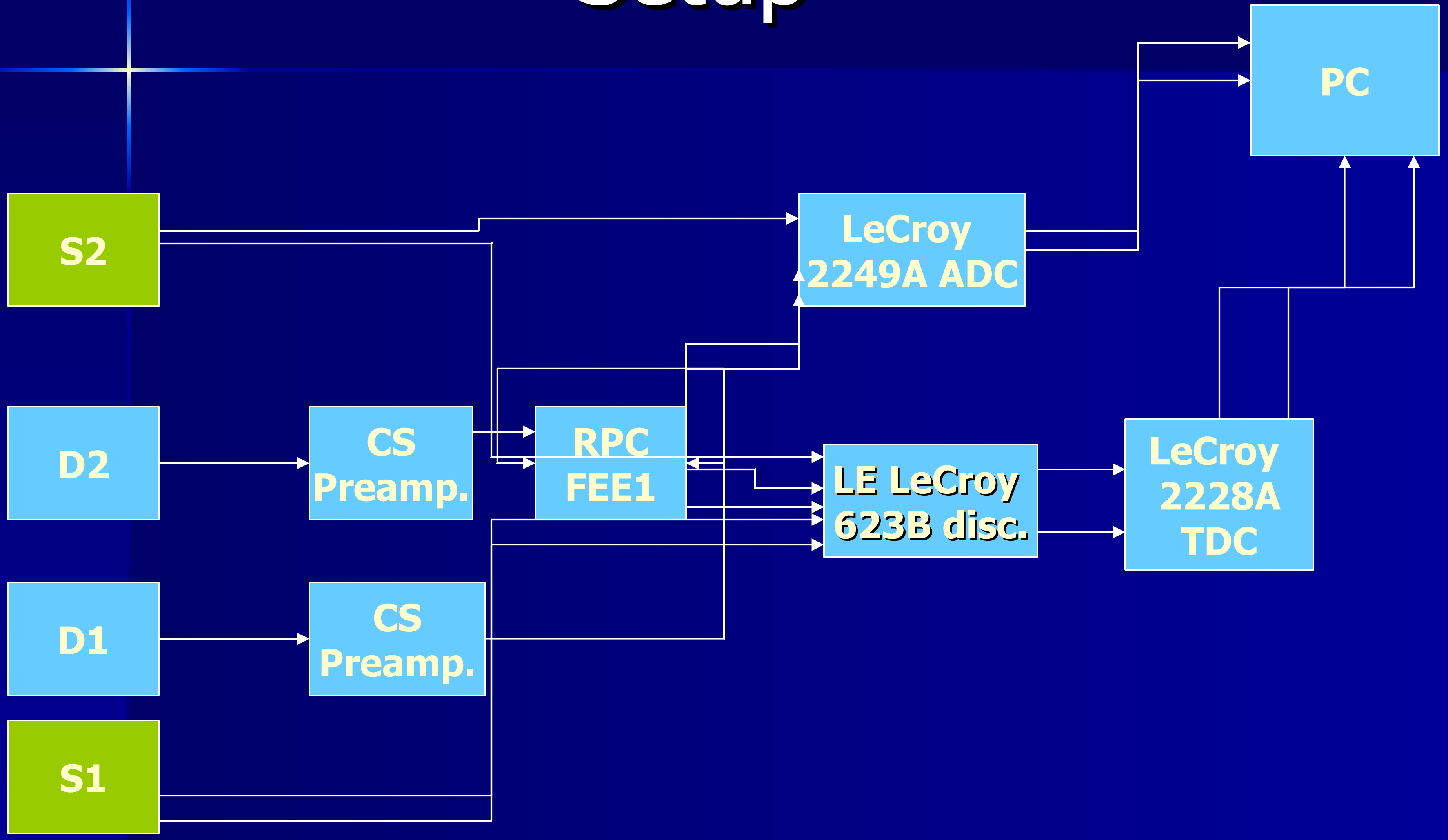
Sr 90 source

2.28 MeV

σ < 600ps

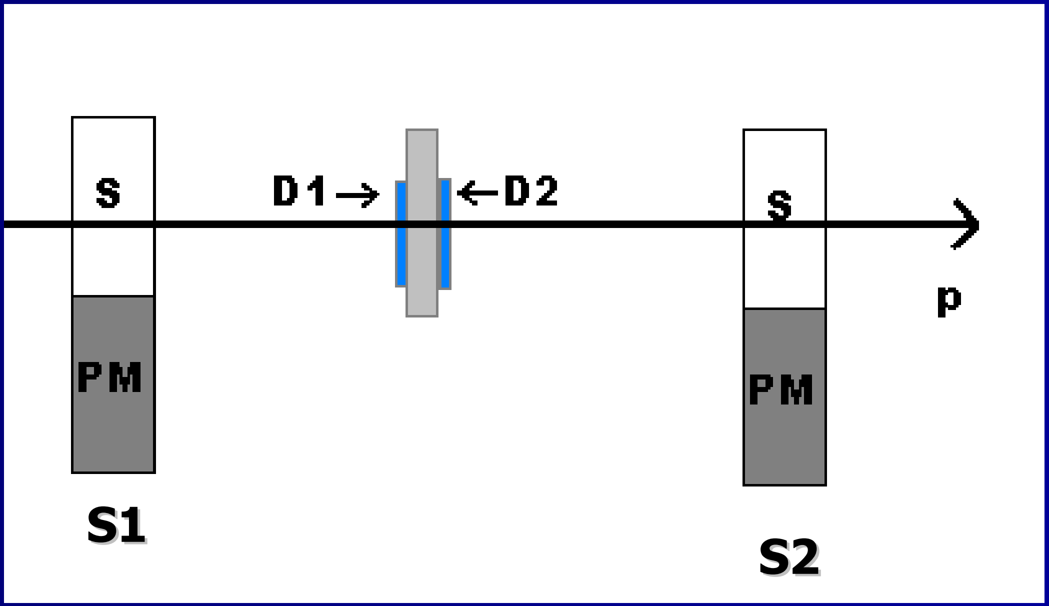
- two diamonds in coincidence
- no cuts were used

Setup

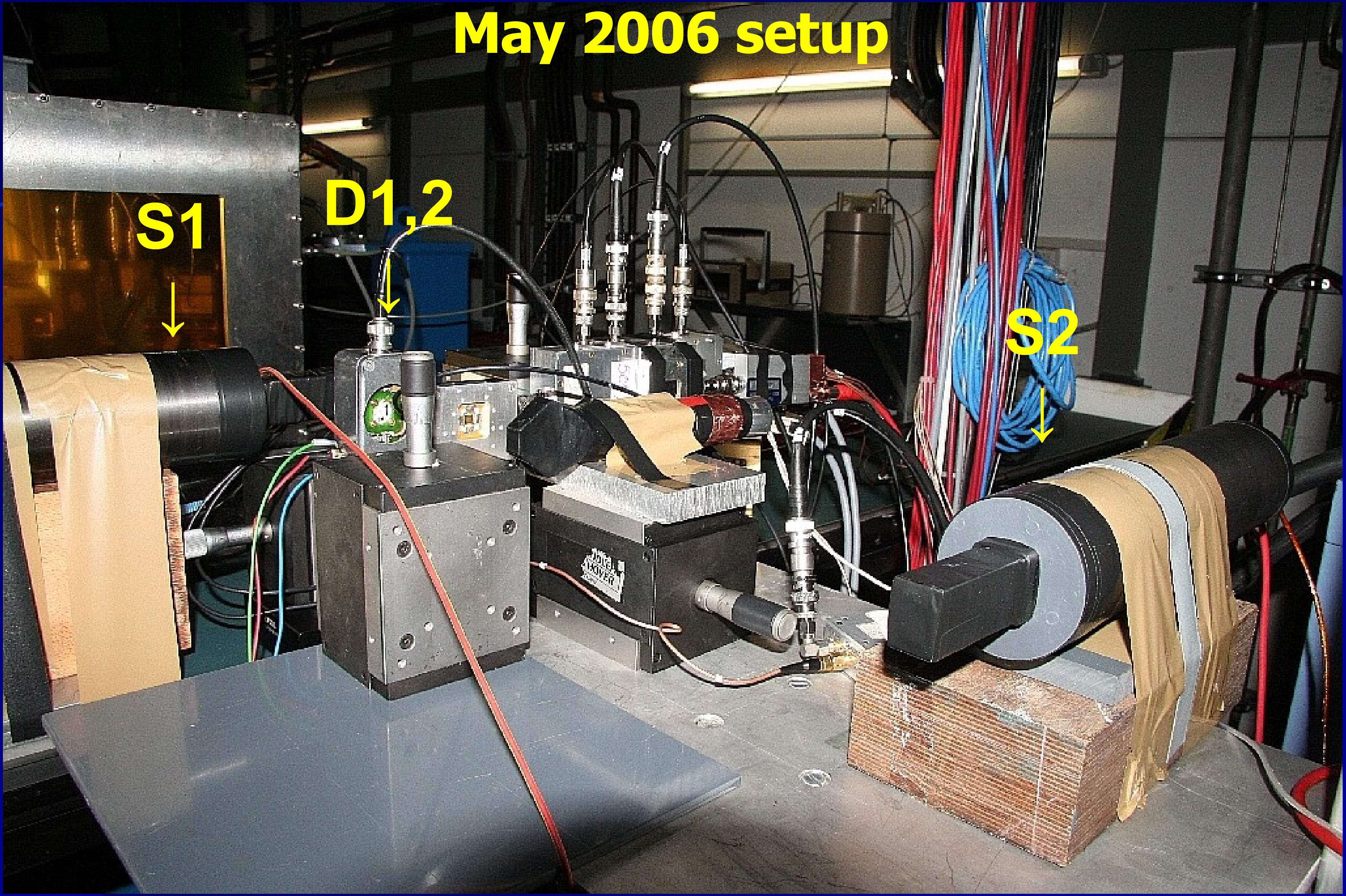

PC
S2
LeCroy
2249A ADC
D2
CS
Preamp.
RPC
FEE1
LE LeCroy
623B disc.
LeCroy
2228A
TDC
D1
CS
Preamp.
S1

Beam test

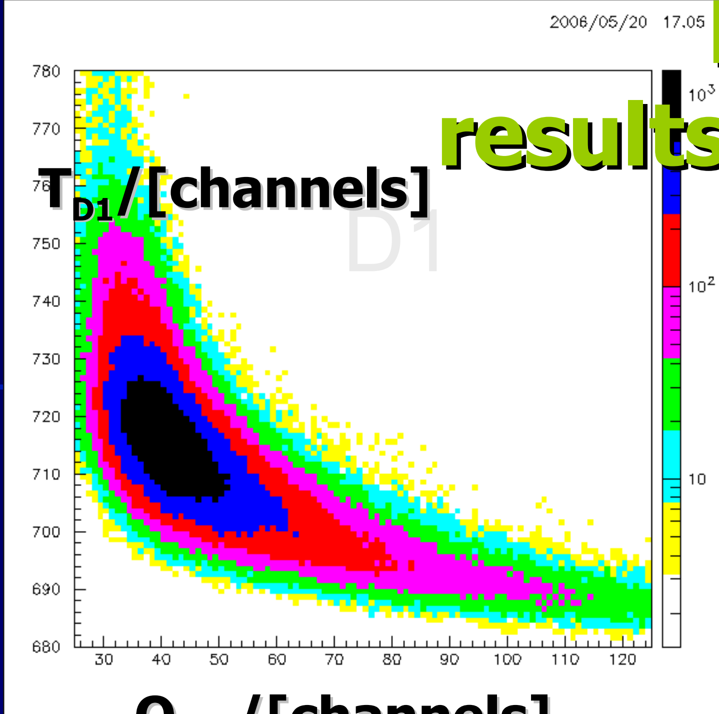
- beam rate ~ 60 kHz
- beam energy: 1.25 GeV
- trigger – all four detectors
- start – first scintillator
- relative time spectrum (D2-D1) used for resolution



SETUP

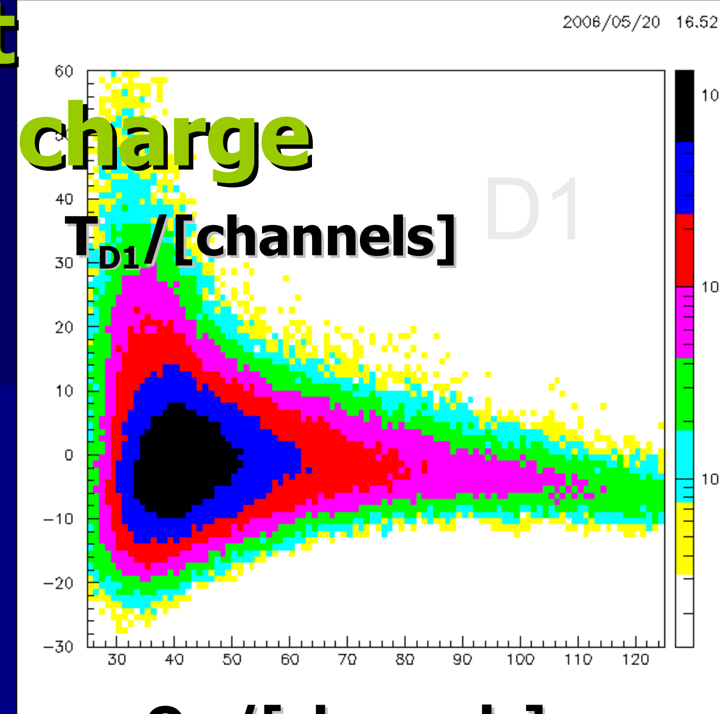

May 2006 setup
S1
D1,2
S2

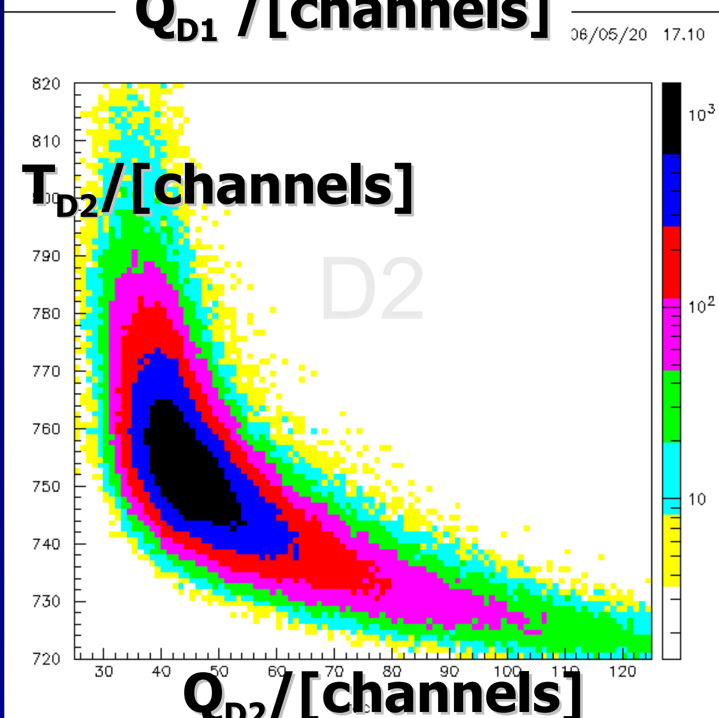
Beam test results, time vs. charge



← no walk correction

walk corrected →





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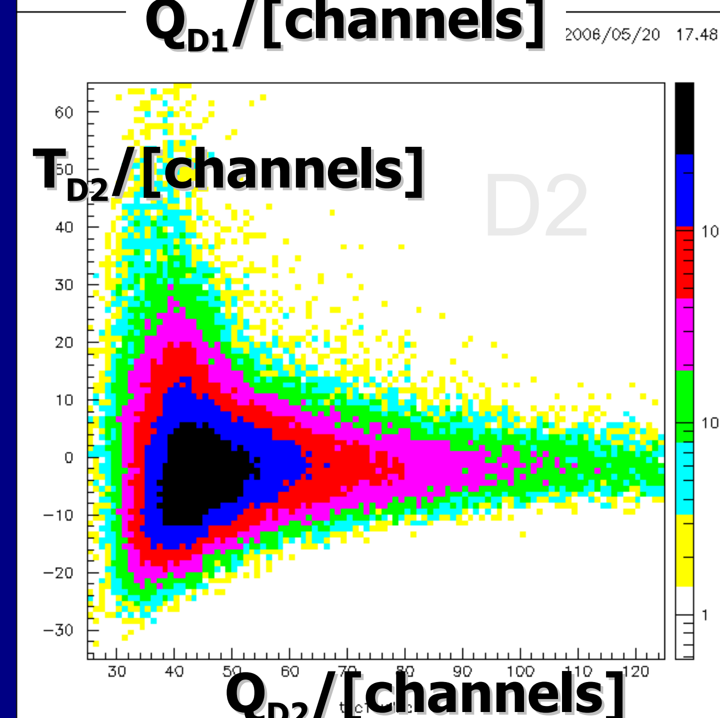
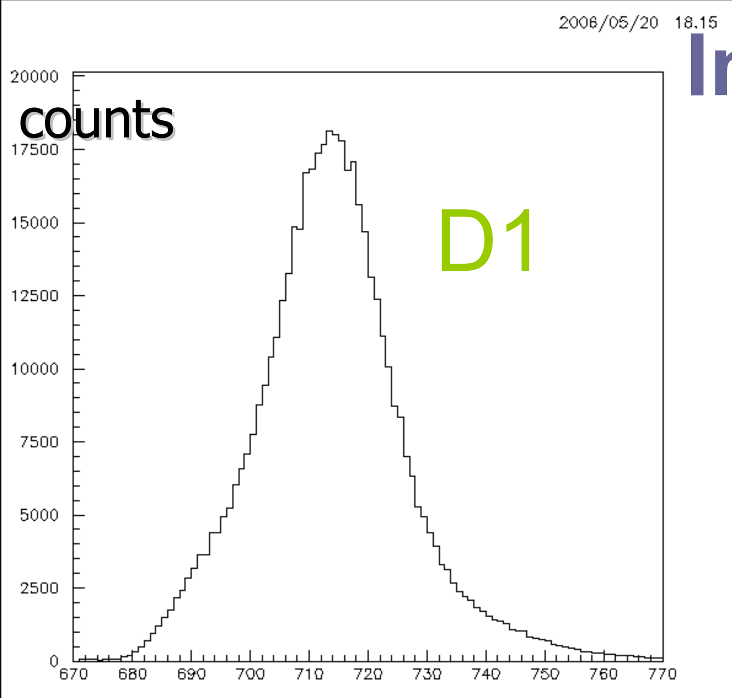
walk corrected →

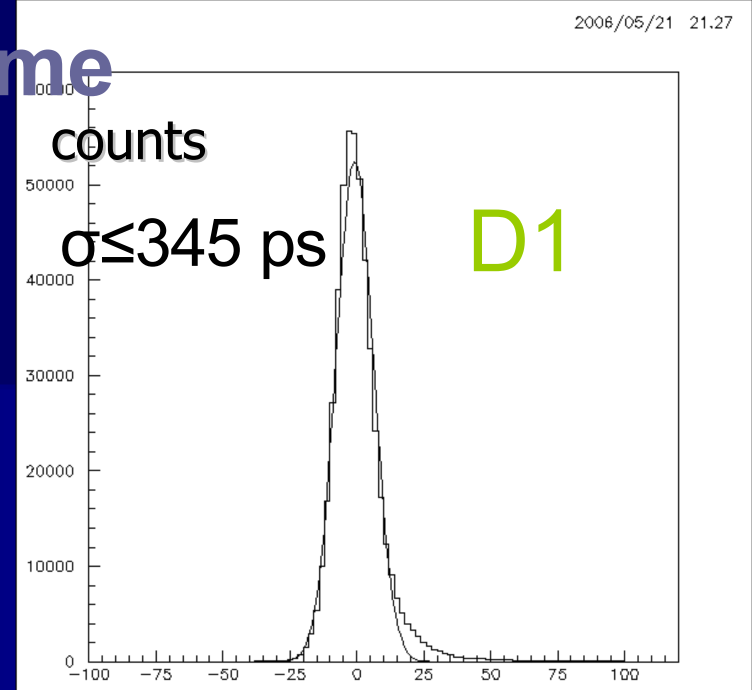


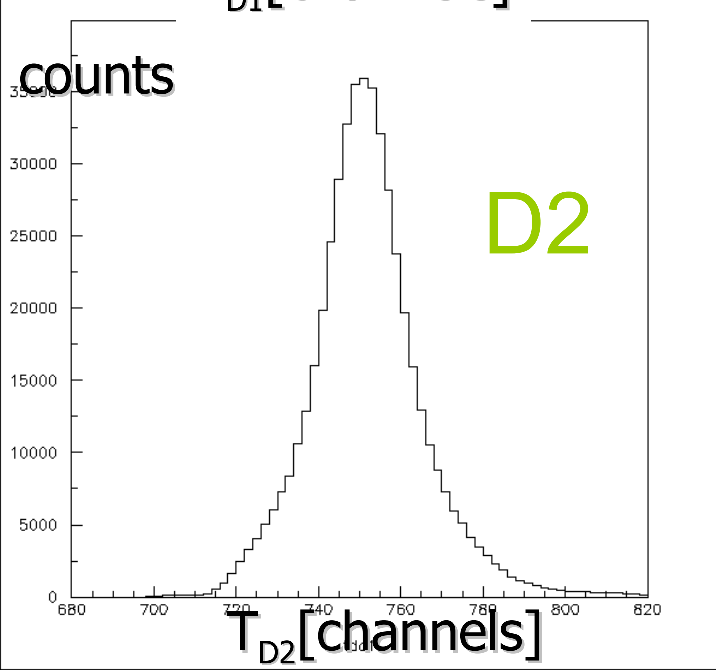
Individual time spectra



← no walk correction

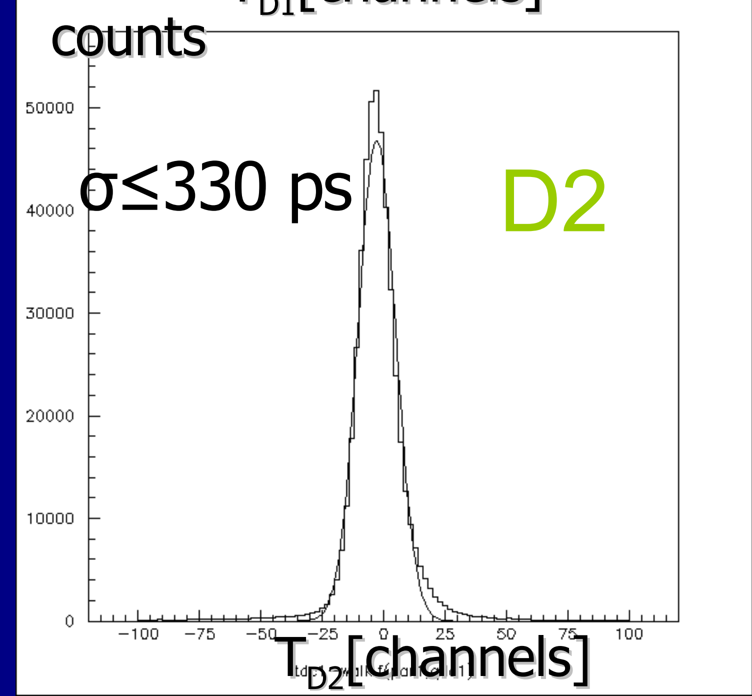
walk corrected →



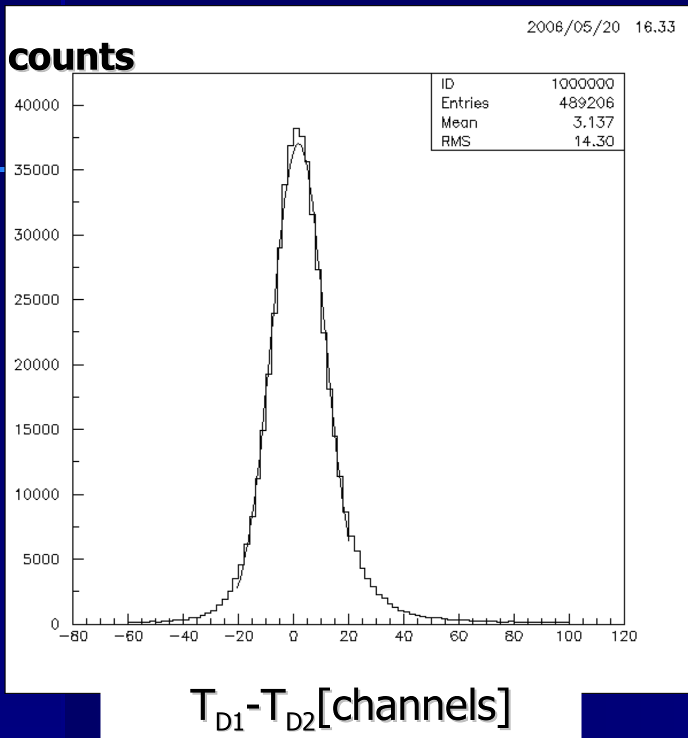


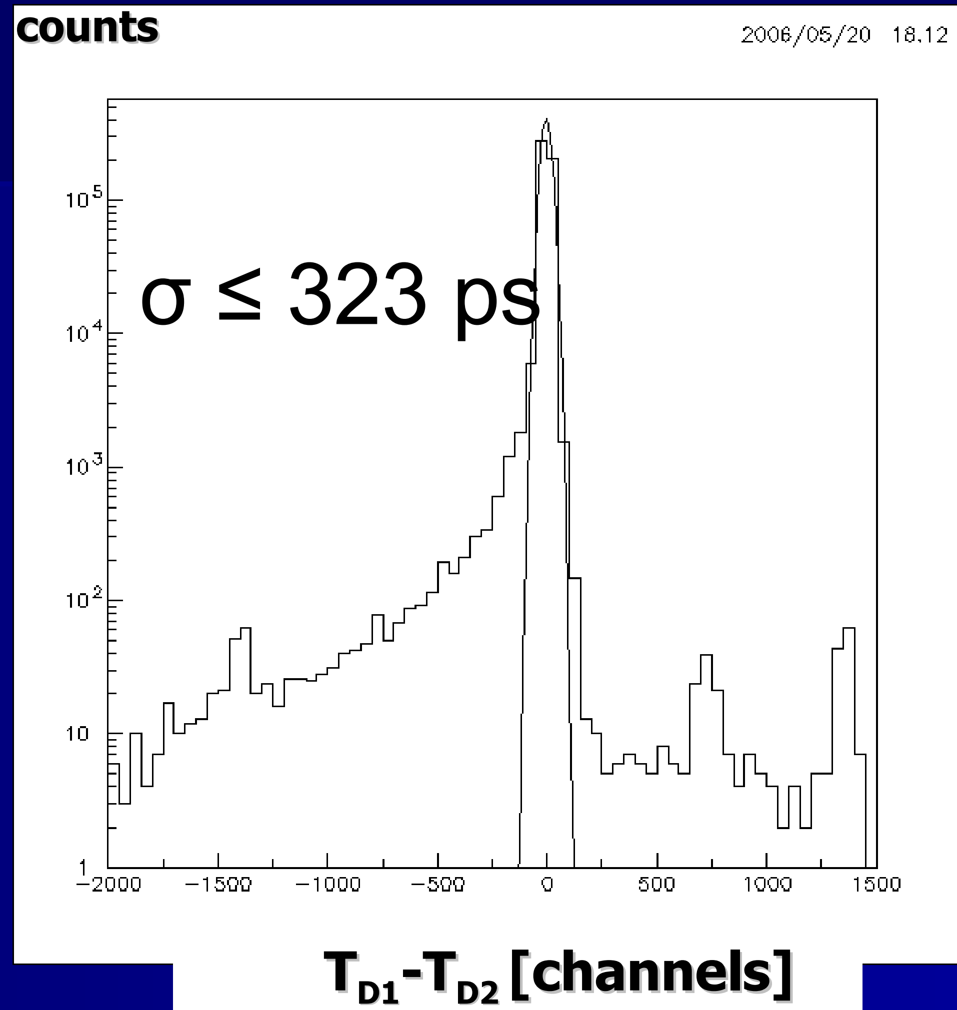
← no walk correction

walk corrected →



Time difference spectra





- relative efficiency:

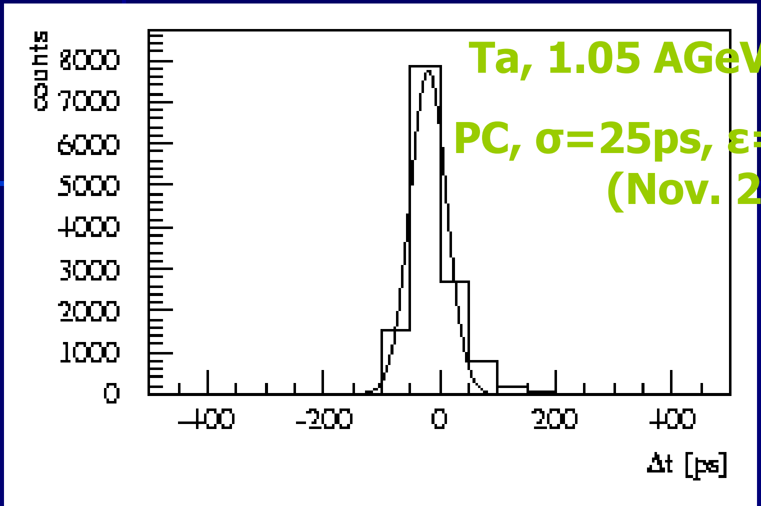
$$\varepsilon_1 = \frac{\$D_1 \& \$D_2}{\$D_1} = 97.8\%$$

log plot, walk corrected

Summary of proton beam results

- we tested the diamonds with a source and the proton beam
- time resolution obtained for protons: <323ps
- time resolution obtained for β-source: <600ps
- probable reason for the high time resolution: large time constant of the charge sensitive preamplifier

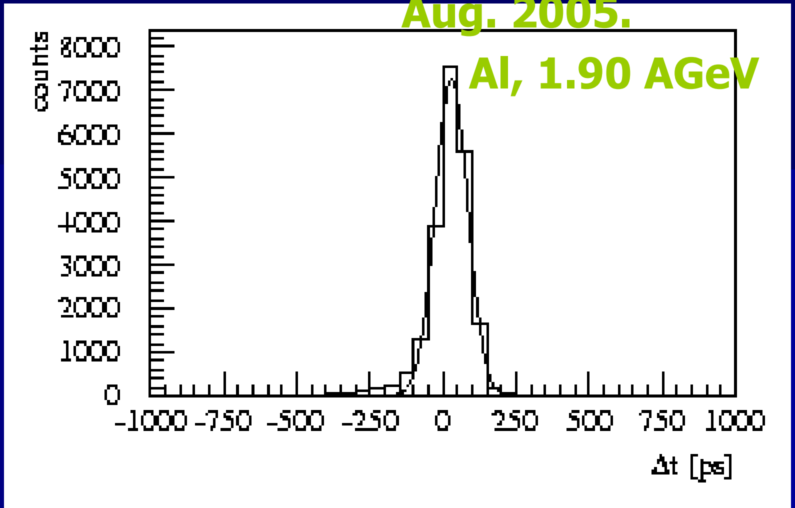
Previous experiments with PC & SC diamonds



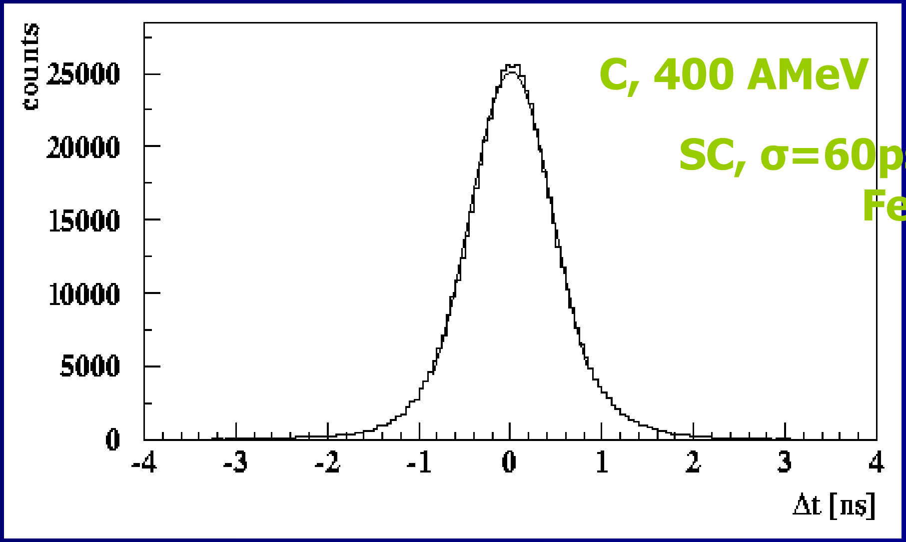
Ta, 1.05 AGeV

PC, σ=25ps, ε=94% (Nov. 2004.)

SC, σ=40ps, ε=92% Aug. 2005.



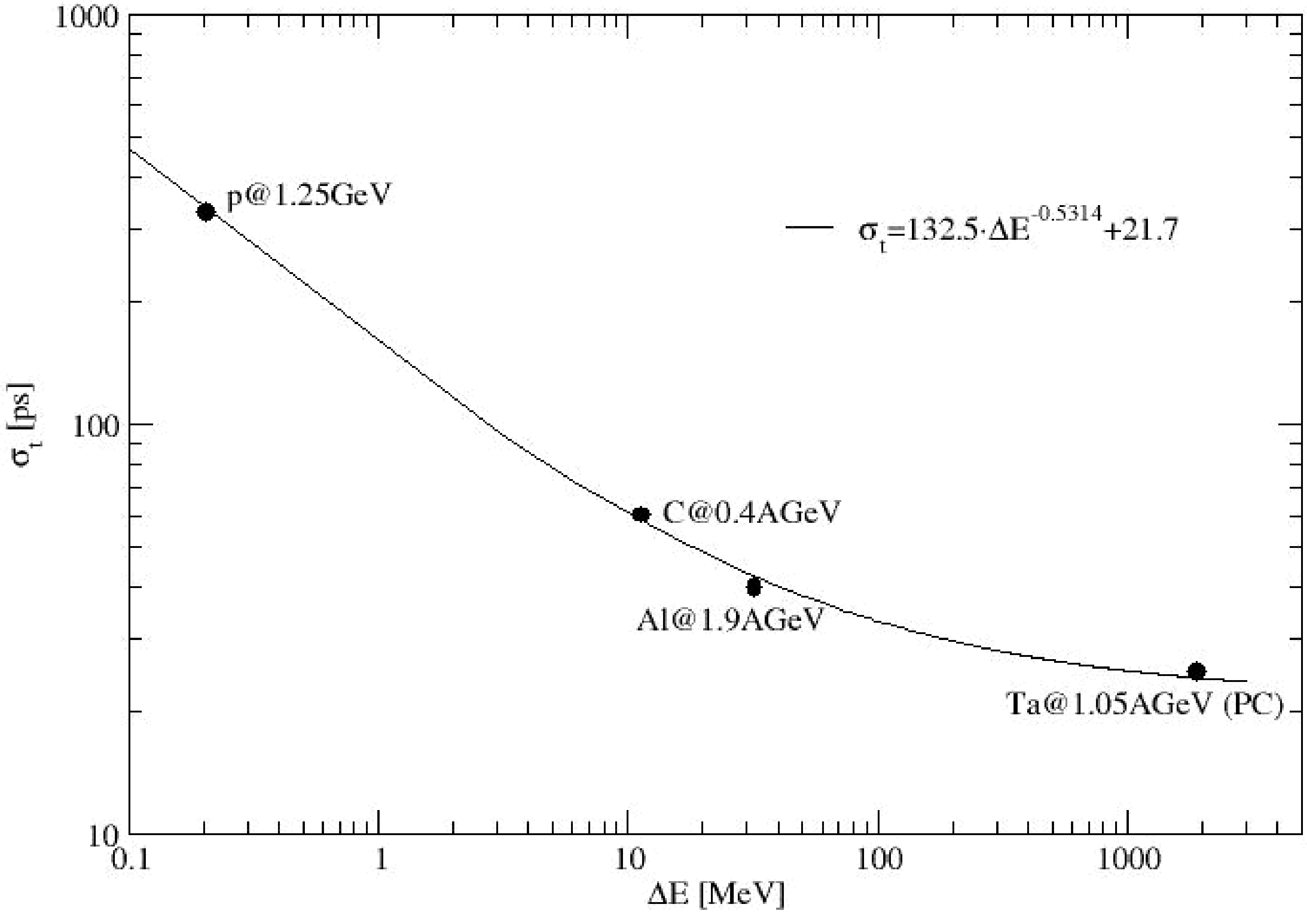
Al, 1.90 AGeV



C, 400 AMeV

SC, σ=60ps, ε=96% Feb. 2006

Timing measurements with CVD diamonds at FOPI



Outlook

- construction of polycrystalline detector for heavy ions

- proposed solutions for SC CVD

- cooled preamplifier FET
- differential readout – both sides of the diamond(electrons&holes)