Detection Methods and Detectors

Energy Loss

TOF detectors

Gas Detectors

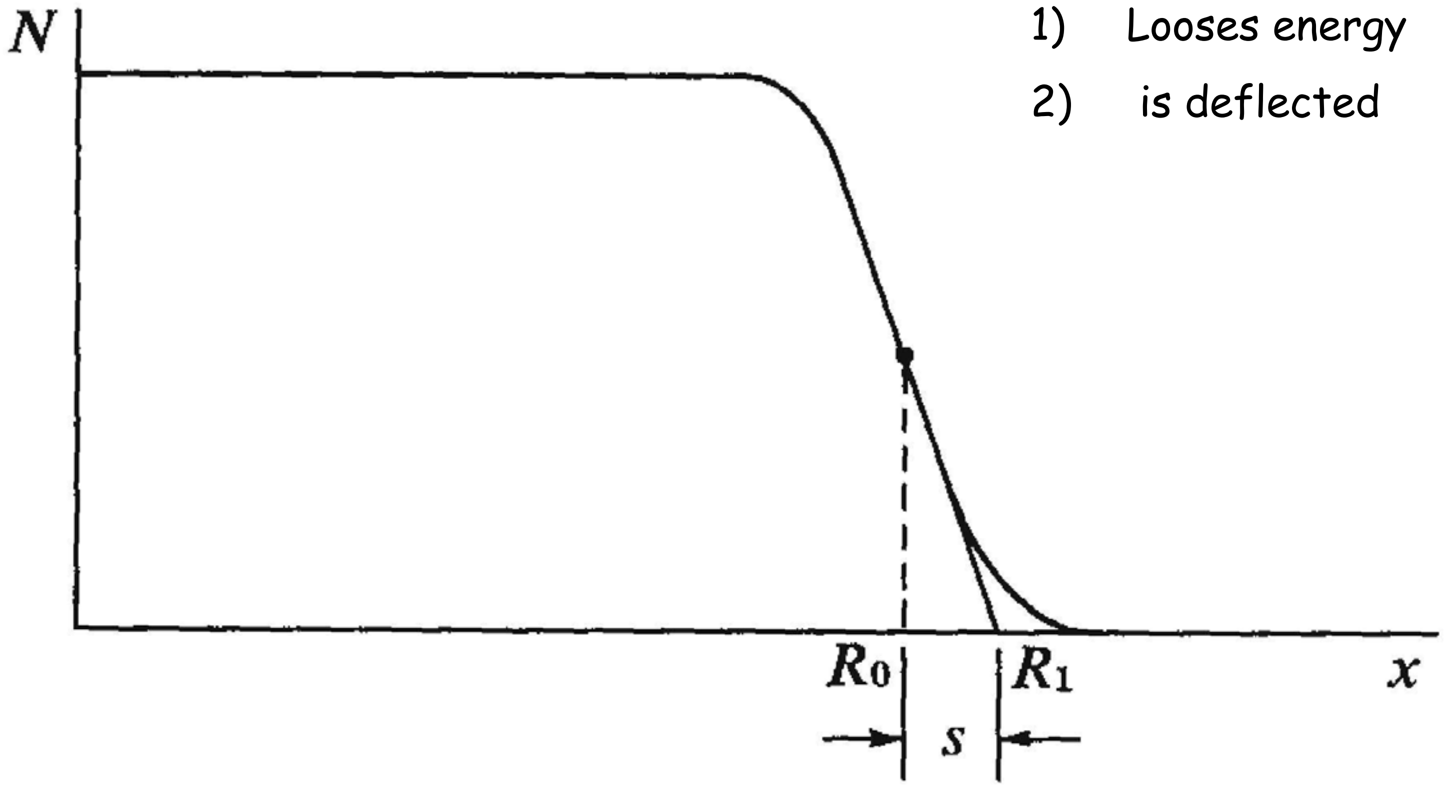
Cherenkov Detectors

Tracking

Dilepton Reconstruction

Range of charged particles

(E. Segrè, Nuclei and particles)



Particle through the medium:

1) Looses energy
2) is deflected

Alpha-particles in air (discovery of the proton)

(E. Segrè, Die großen Physiker...)

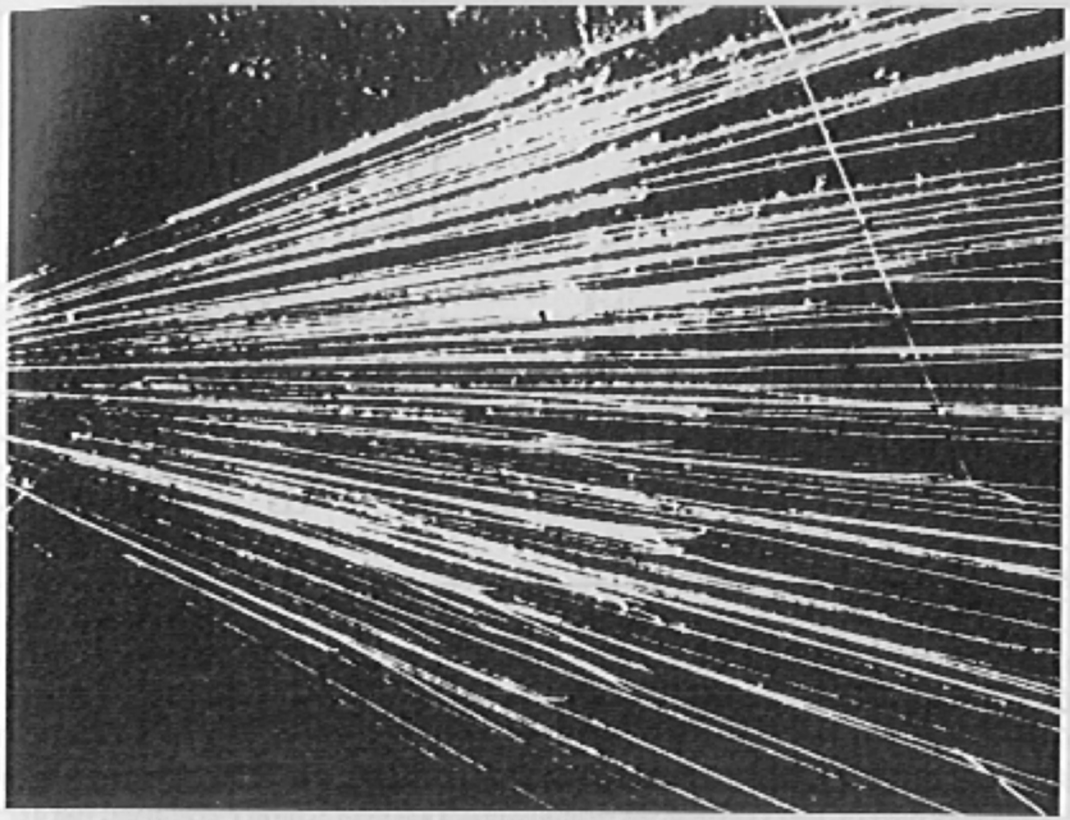
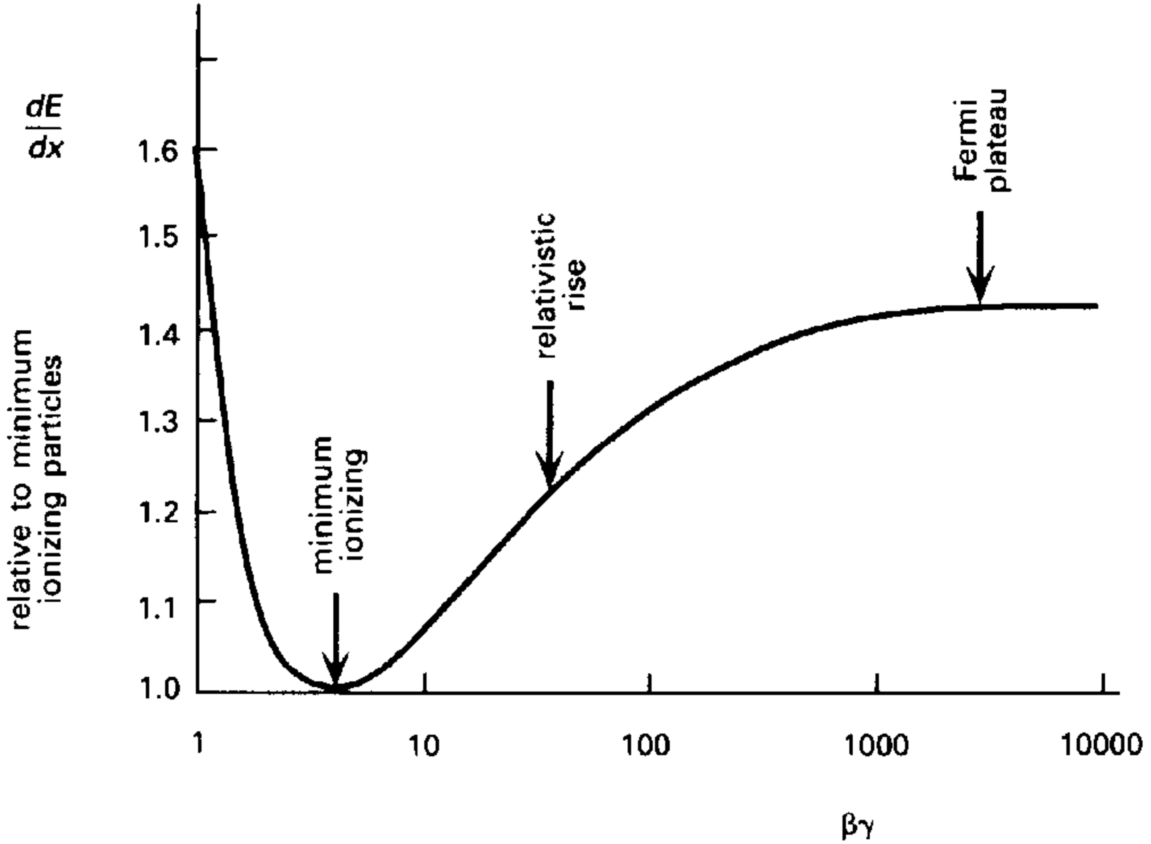


Abb. 6.5 **Von Blackett beobachtete Zertrümmerung eines Stickstoffkerns in einer Nebelkammer. Die Quelle enthält $Pb^{212} + Bi^{212} + Po^{212}$ im radioaktiven Gleichgewicht und emittiert α-Teilchen mit zwei verschiedenen Reichweiten: 8,6 und 4,8 cm. Ein Teilchen mit der längeren Reichweite trifft auf einen Stickstoffkern und bricht ihn entsprechend der Reaktion $_7N^{14} + {}_2He^4 = {}_8O^{17} + {}_1H^1$ auf. Die längere quer verlaufende Spur stammt vom Proton, die andere ist die von $_8O^{17}$. (P. M. S. Blackett und D. Lea in *Proceedings of the Royal Society, London* 136, 325 [1932])**

Figure 2-4 Cloud-chamber tracks of alpha rays showing delta rays. The first picture is in air, the last three in helium; the gas pressure in the chamber is such that the tracks cross about 10^{-5} g cm^{-2} of air equivalent. Note nuclear collisions in the section on the right. [T. Alper, *Z. Physik*, **67**, 172 (1932).]

Energy loss of charged particles due to ionisation



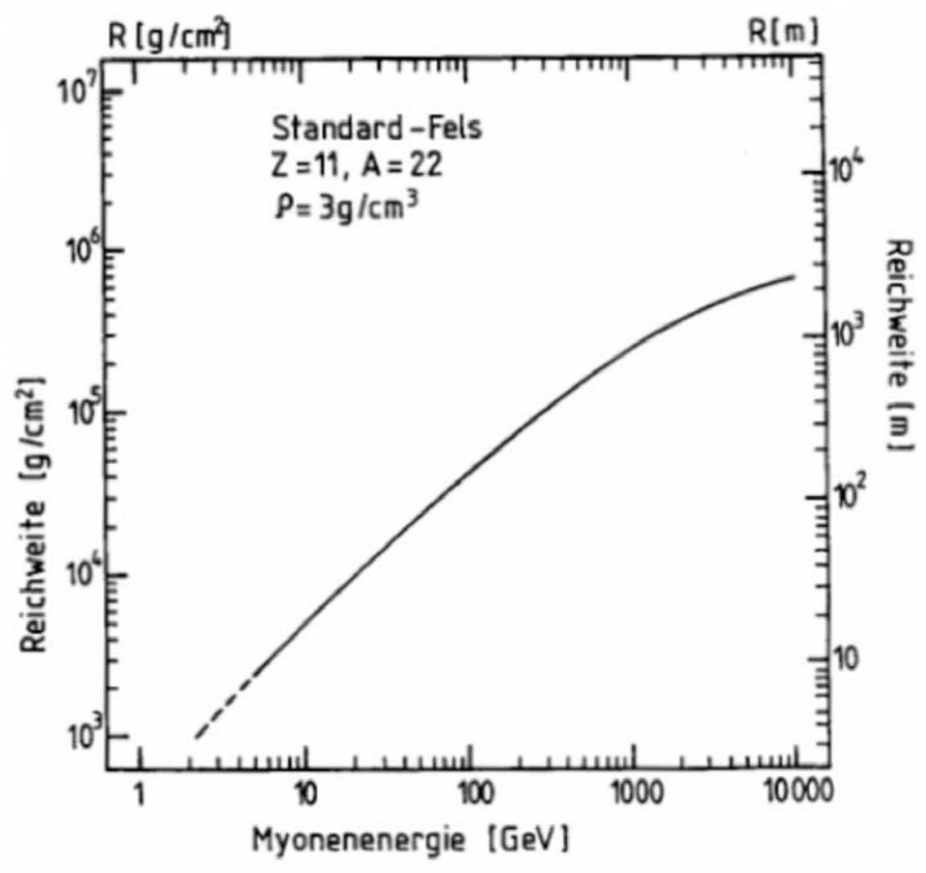
Bethe – Bloch formula:

$$-\frac{dE}{dx} = \frac{z^2 e^4 n_e}{4\pi\varepsilon_0 m_e v^2}\left(\ln\frac{2m_e v^2}{I\left(1-\beta^2\right)} - \beta^2 - \frac{\delta}{2}\right)$$

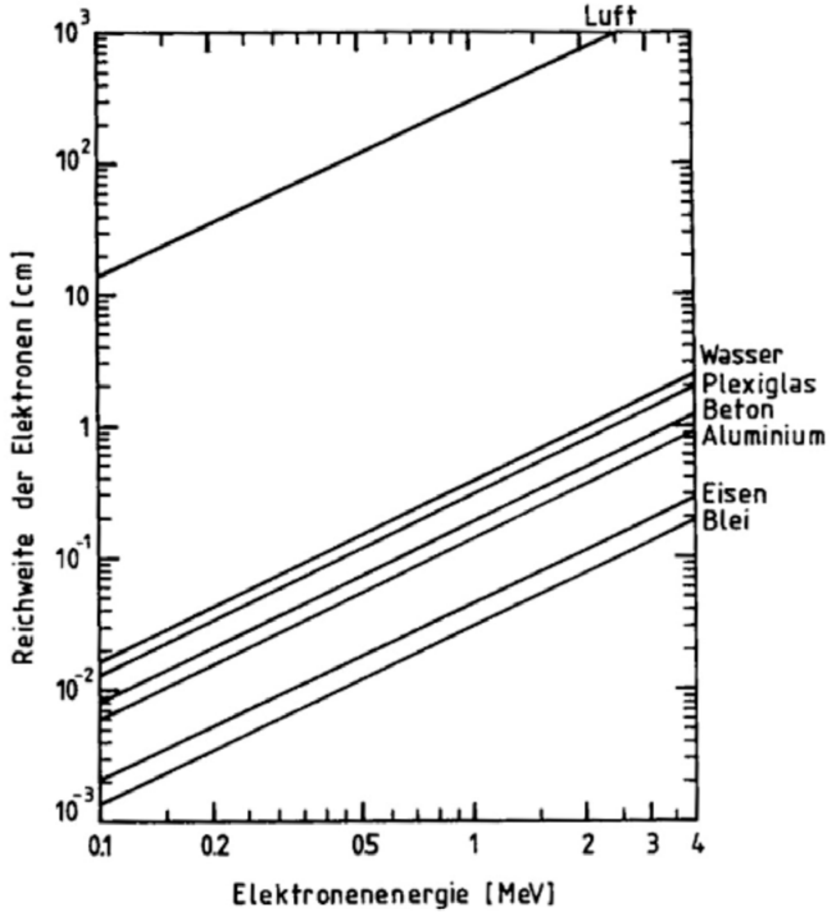
Range of charged particles

(aus: C. Grupen, Teilchendetektoren)

Muons in rock:

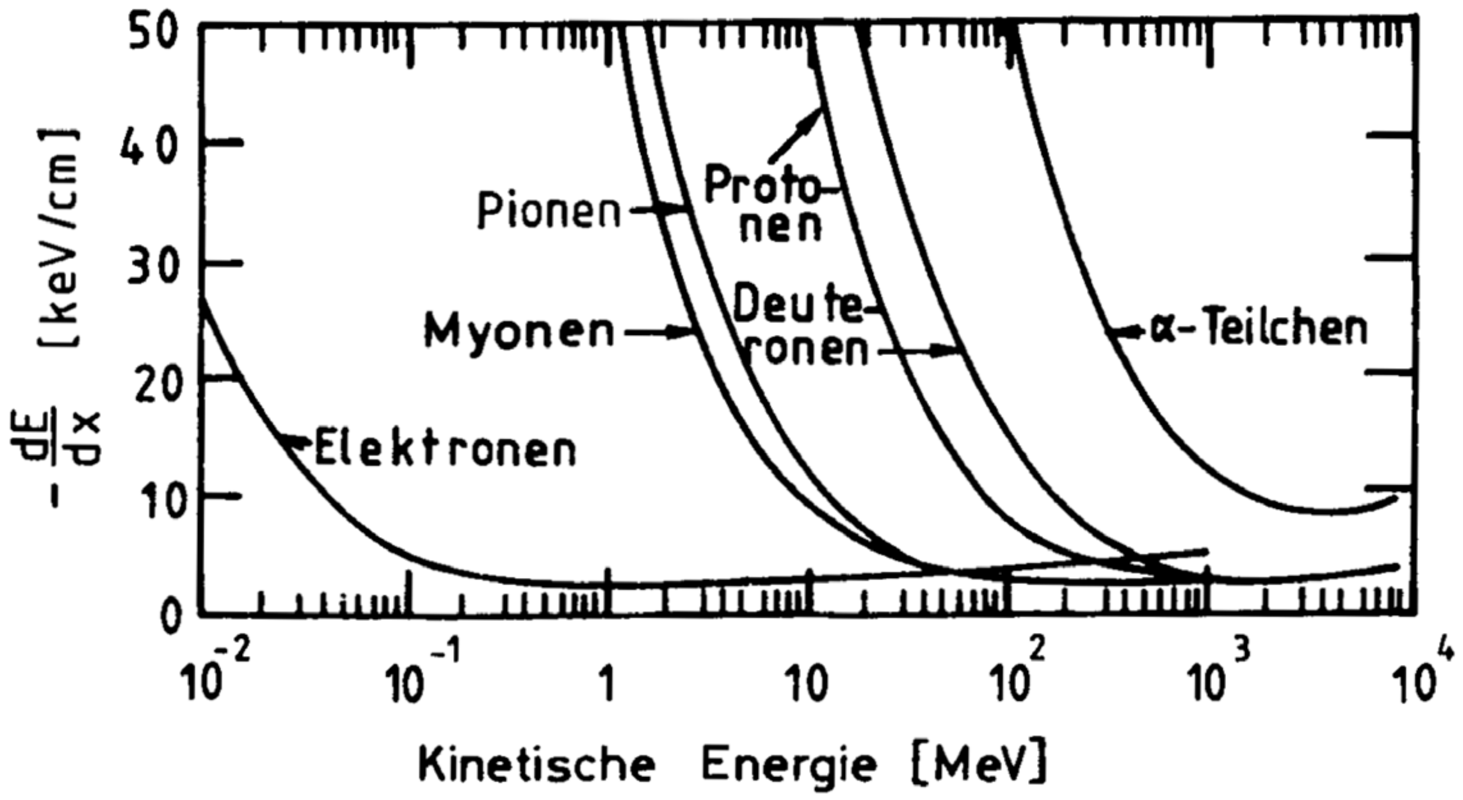


Electrons in various materials:



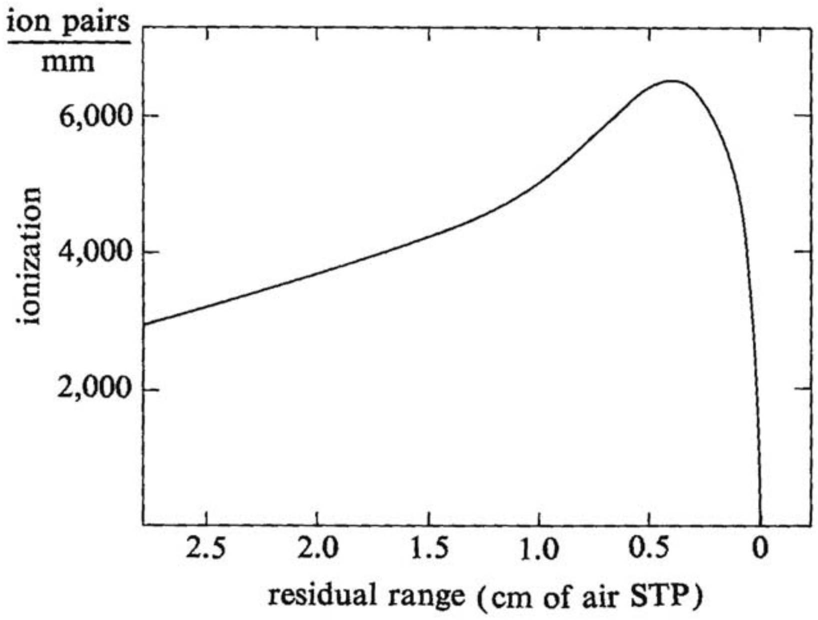
Energy loss of various charged particles in air

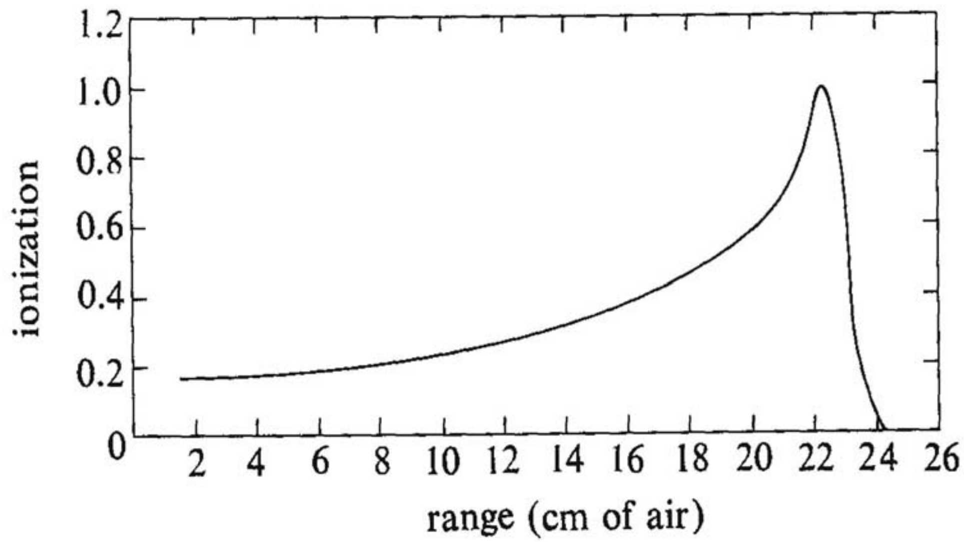
(C. Grupen, Teilchendetektoren)



Bragg curves

(E. Segrè, Nuclei and particles)

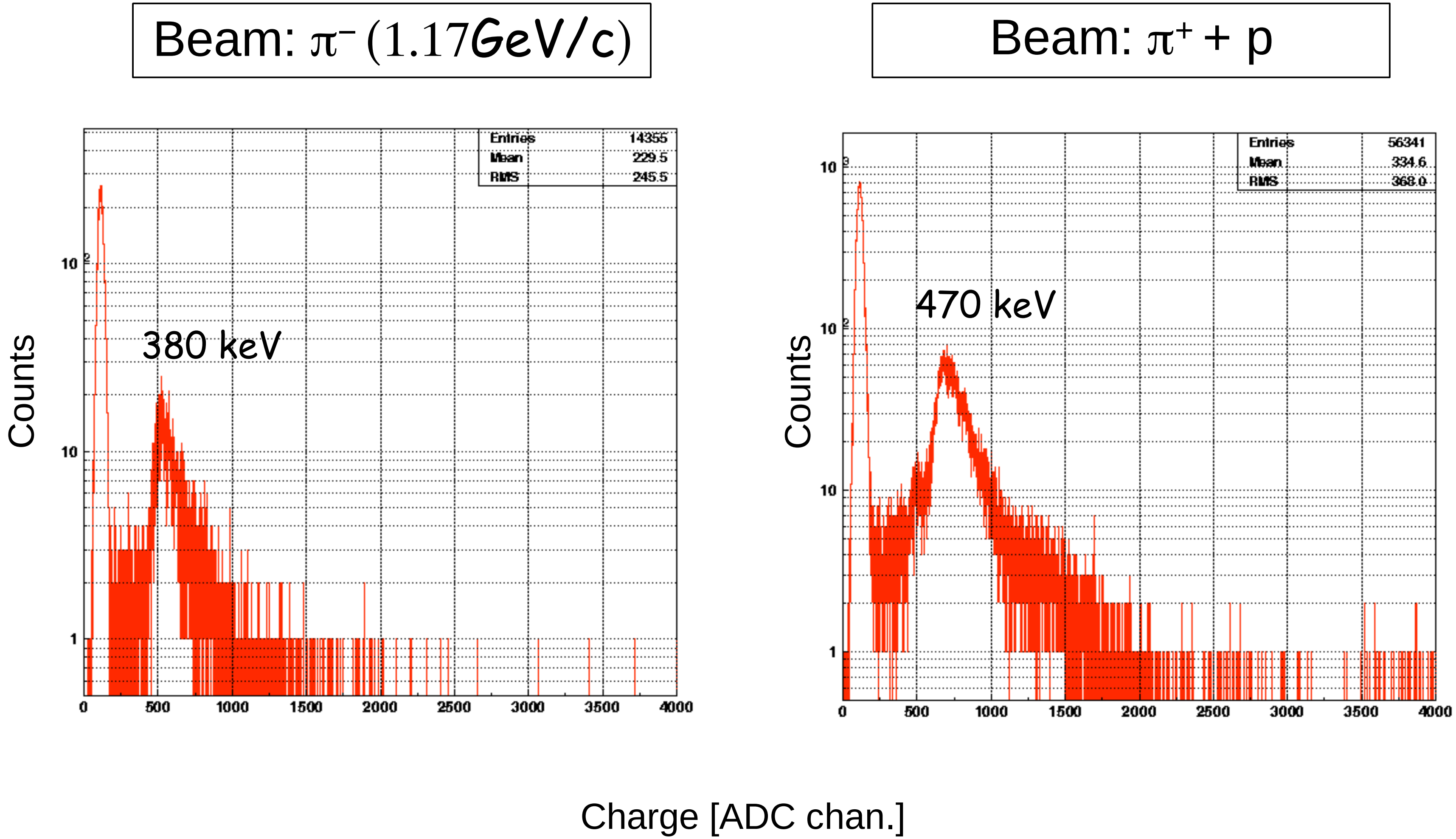




Energy loss of minimum ionising particles

Absorber	$\left.\frac{dE}{dx}\right\|_{min}$ $\left[\mathrm{MeV cm^{-1}}\right]$	$\left.\frac{dE}{d(\rho x)}\right\|_{min}$ $\left[\mathrm{MeV g^{-1} cm^{2}}\right]$
Water	2.03	2.03
Xenon (gaseous)	7.3×10^{-3}	1.24
Iron	11.7	1.48
Lead	12.8	1.13
Hydrogen (gaseous)	3.7×10^{-4}	4.12

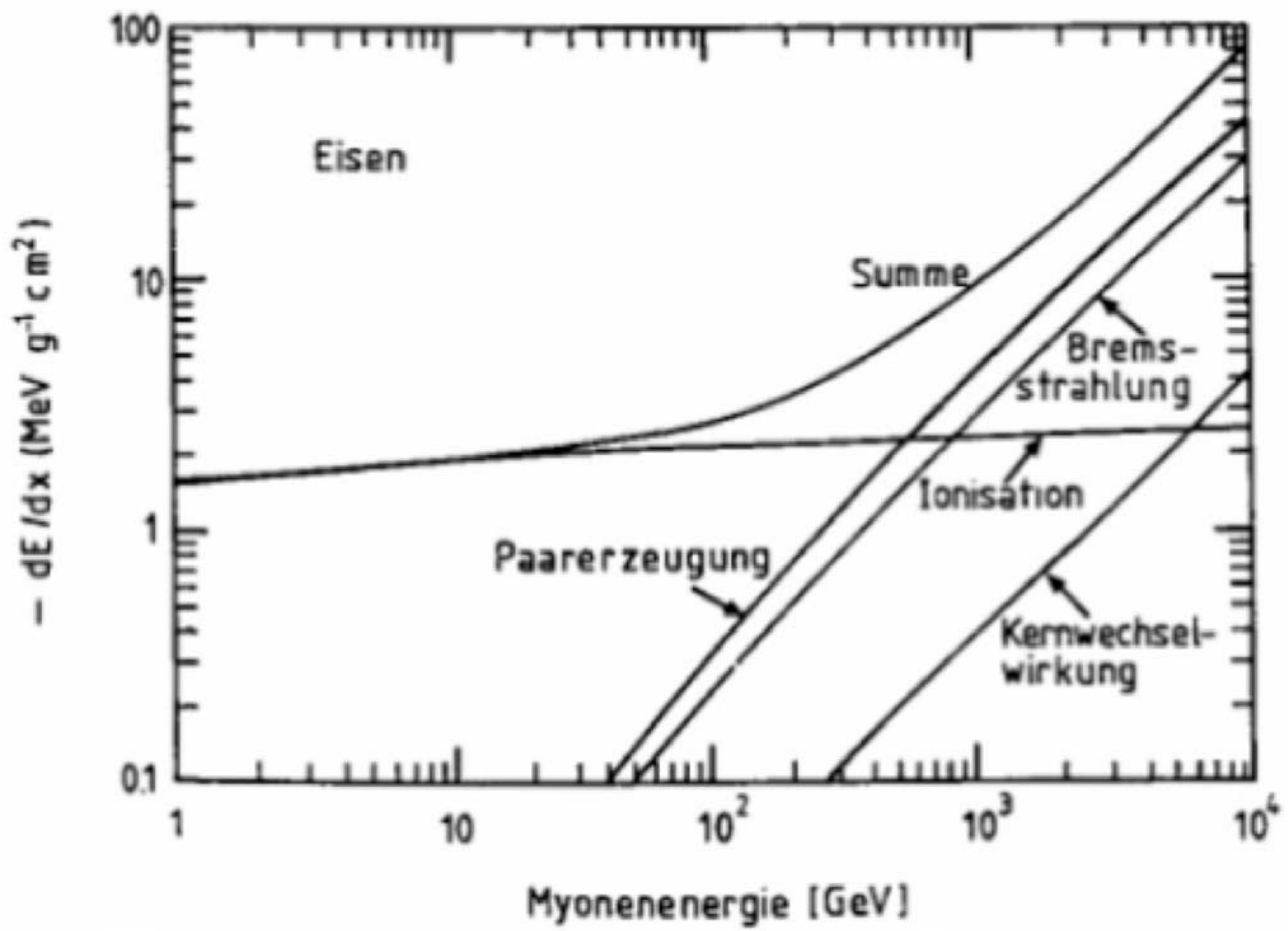
RAW Data



Beam: π^- (1.17GeV/c)
Beam: π^+ + p
Counts
380 keV
470 keV
Entries 14355
Mean 229.5
RMS 245.5
Entries 56341
Mean 334.6
RMS 368.0
0
500
1000
1500
2000
2500
3000
3500
4000
1
10
10^2
10^3
Charge [ADC chan.]

Contributions to the energy loss of muons in iron

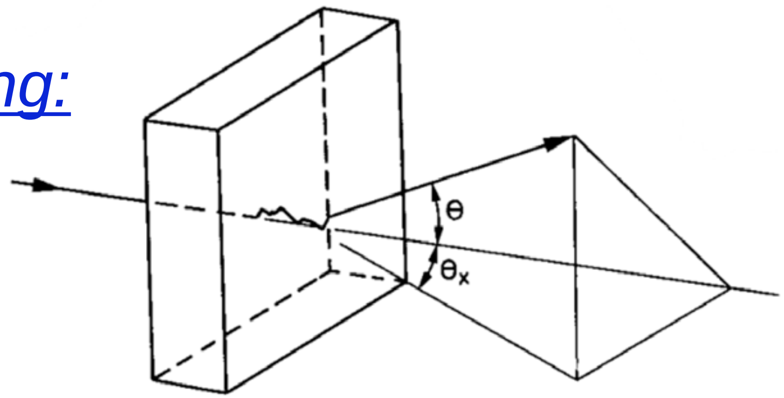
(C. Grupen, Teilchendetektoren)



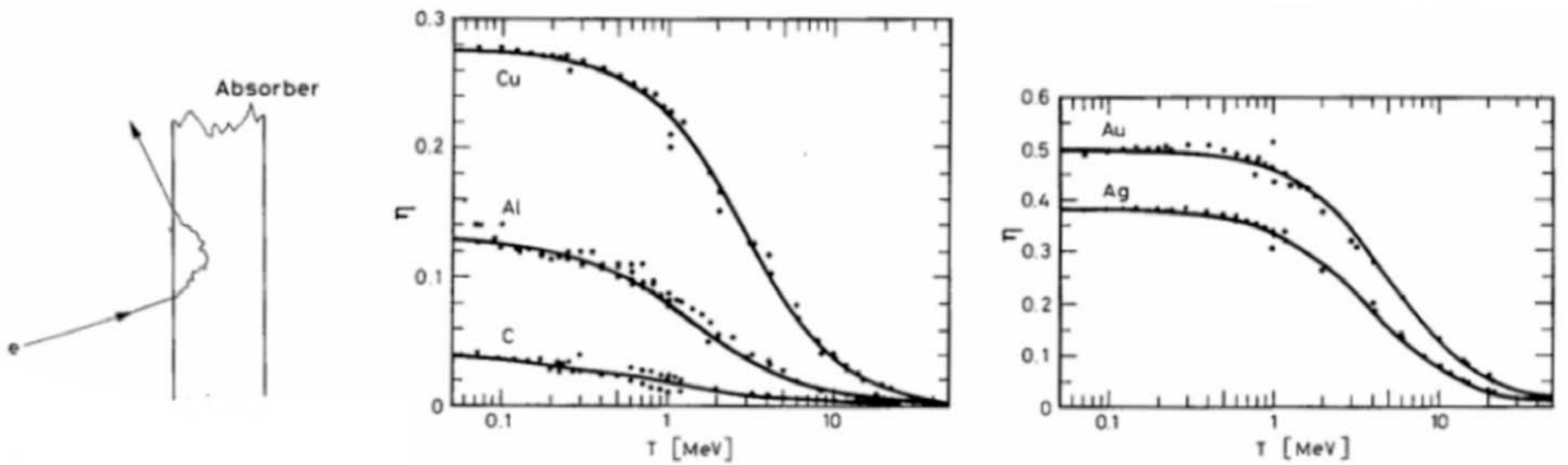
Multiple scattering of electrons

(W.R. Leo, Techniques...)

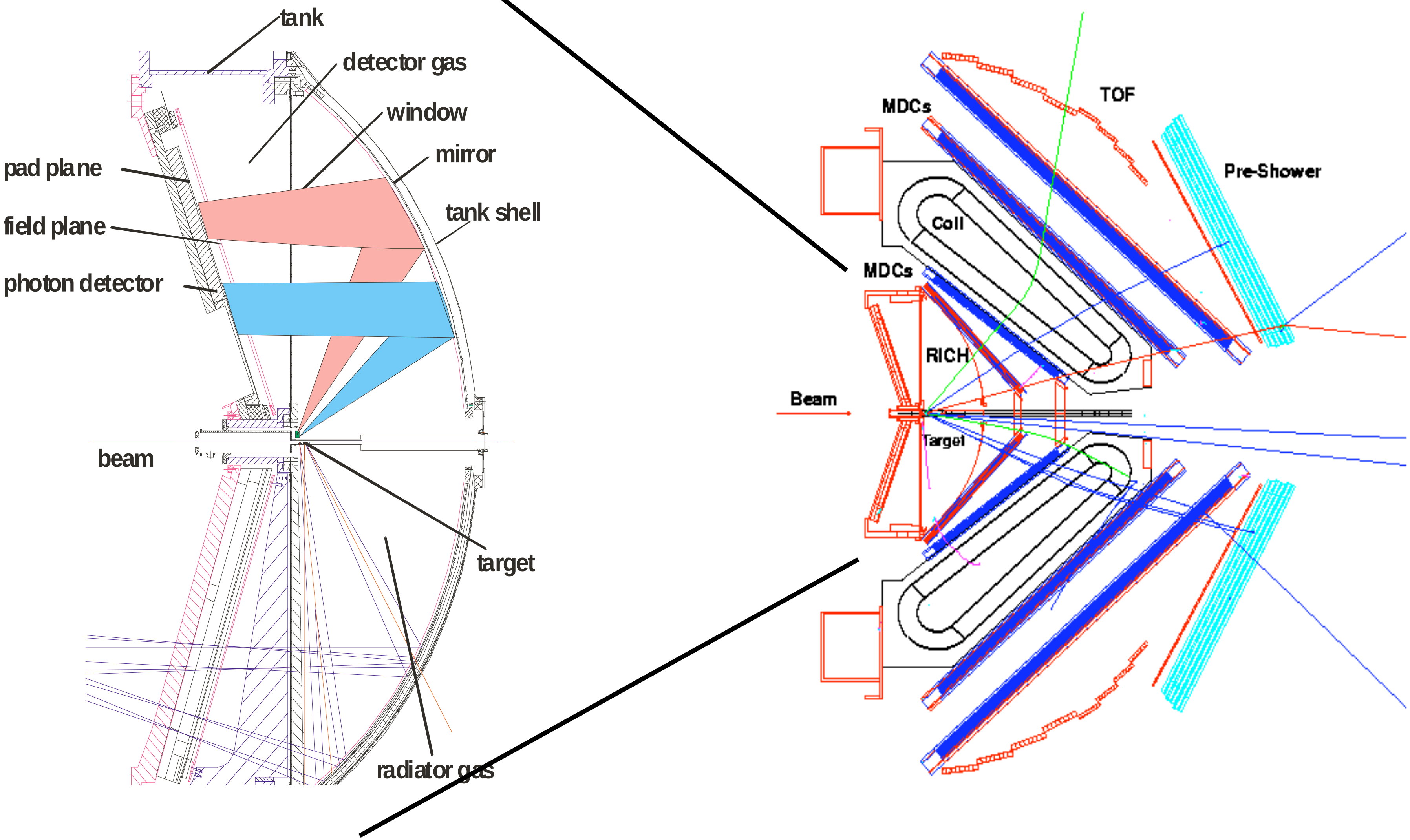
Beam broadening:

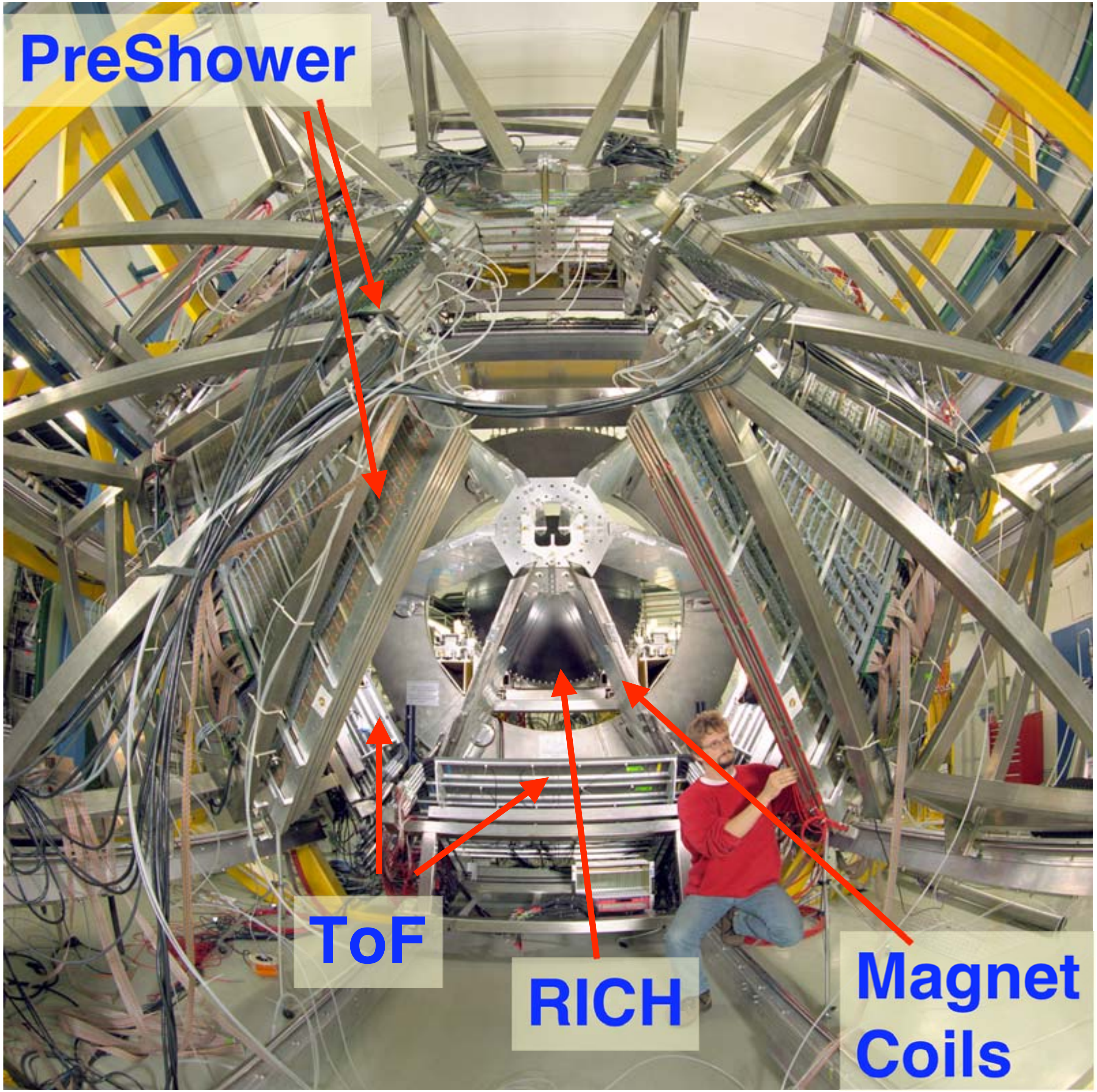


Backscattering:



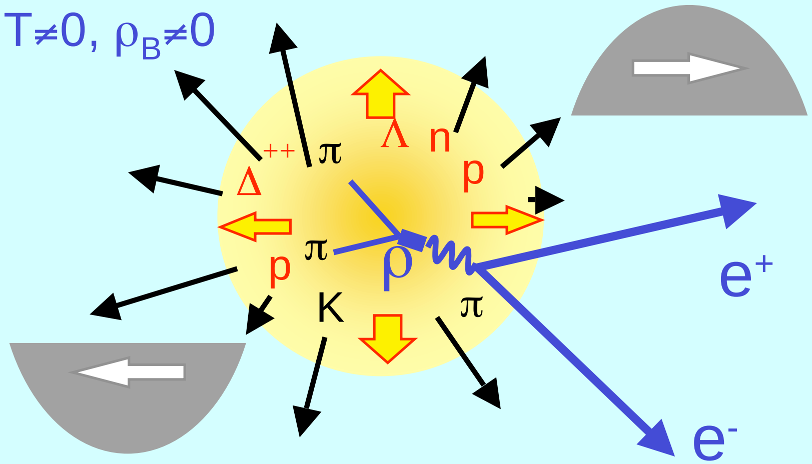
RICH in detail





HADES

Physics Motivations



Heavy-ion collisions at relativistic energies (1÷2 AGeV)

Hadron properties inside the nuclear matter

M, Γ

Light vector mesons

Probes for nuclear matter

Mesons	Mass [MeV/c^2]	Mean life [fm/c]	Main decay	Branching ratio e^+e^-
ρ	769	1.3	$\pi\ \pi$	$4.5\cdot10^{-5}$
ω	783	23	$\pi^+\pi^-\pi^0$	$7.1\cdot10^{-5}$
ϕ	1019	44	K^+K^-	$2.9\cdot10^{-4}$

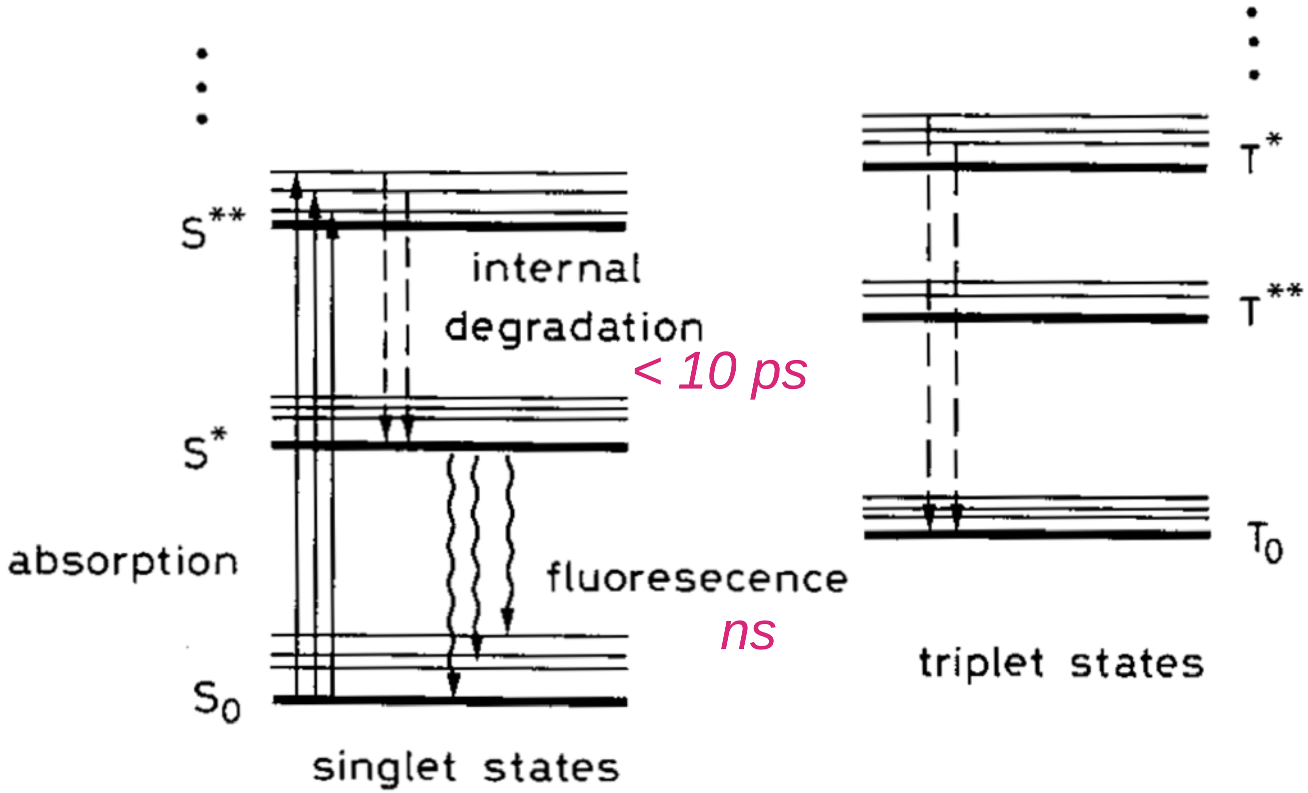
LEPTONS

NO strong final interaction

Very low probability

Organic Scintillator

(Leo, Techniques...)

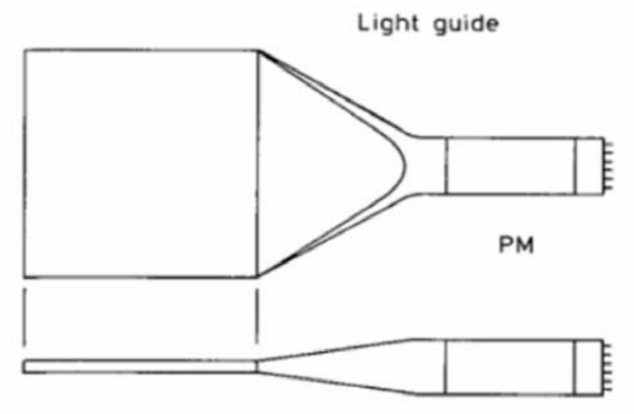


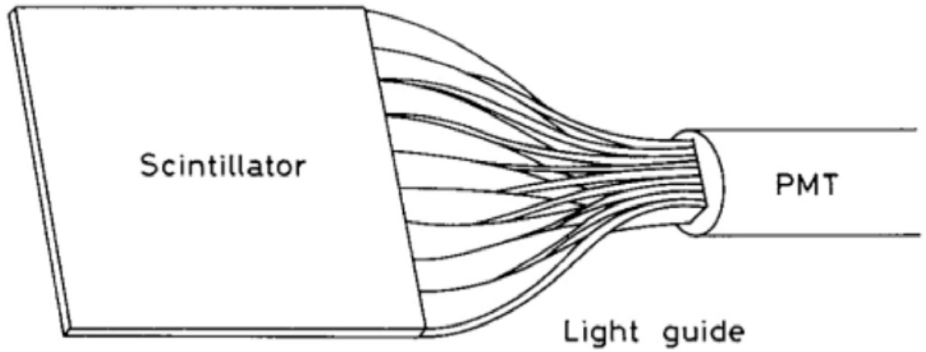
Very rapid fluorescence signal (a few ns) → timing

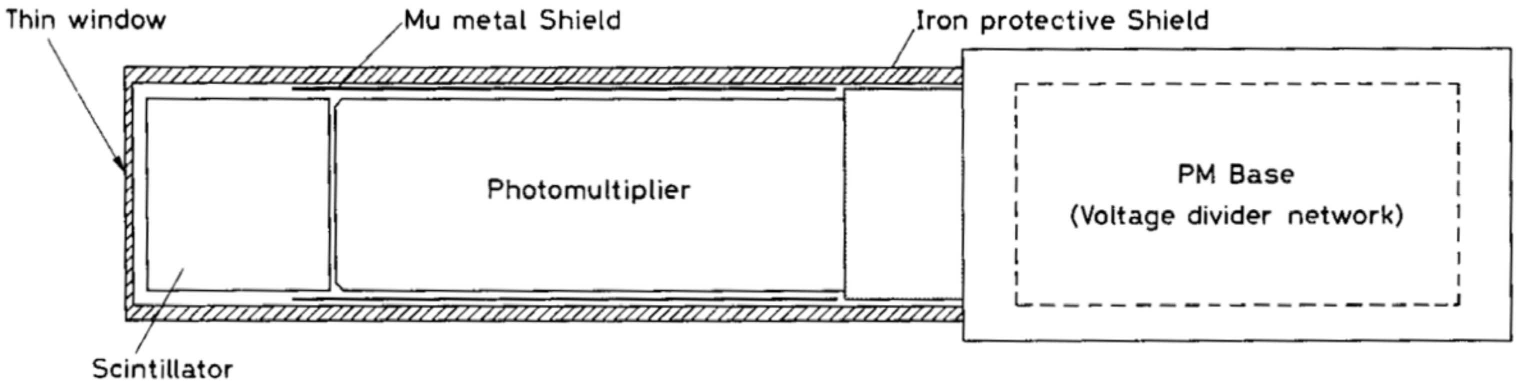
Production of light requires 100 eV per photon (NaI: 25 eV)

Scintillator – light guide – photomultiplier

(Leo, Techniques...)



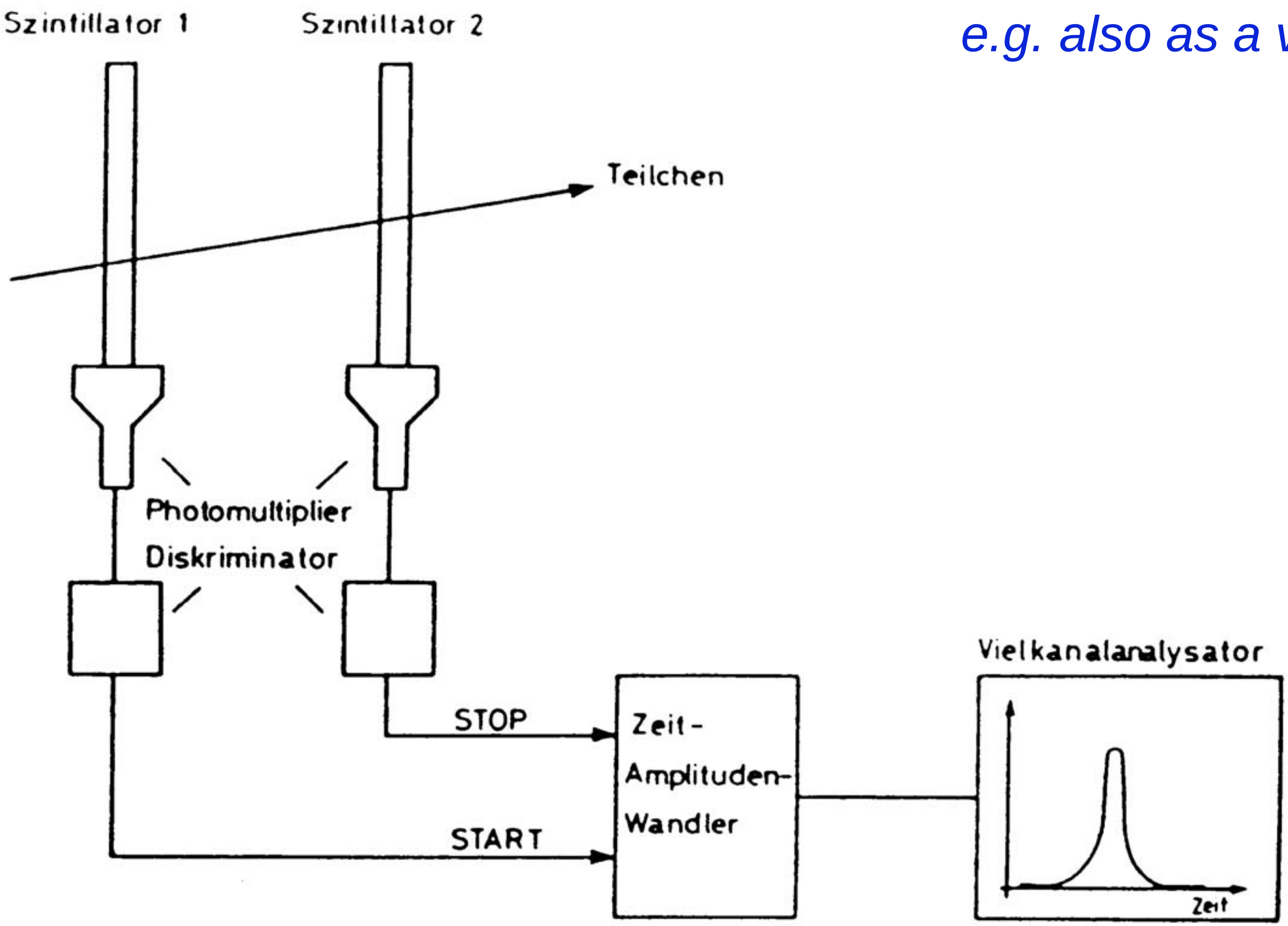




Measurement of time-of-flight

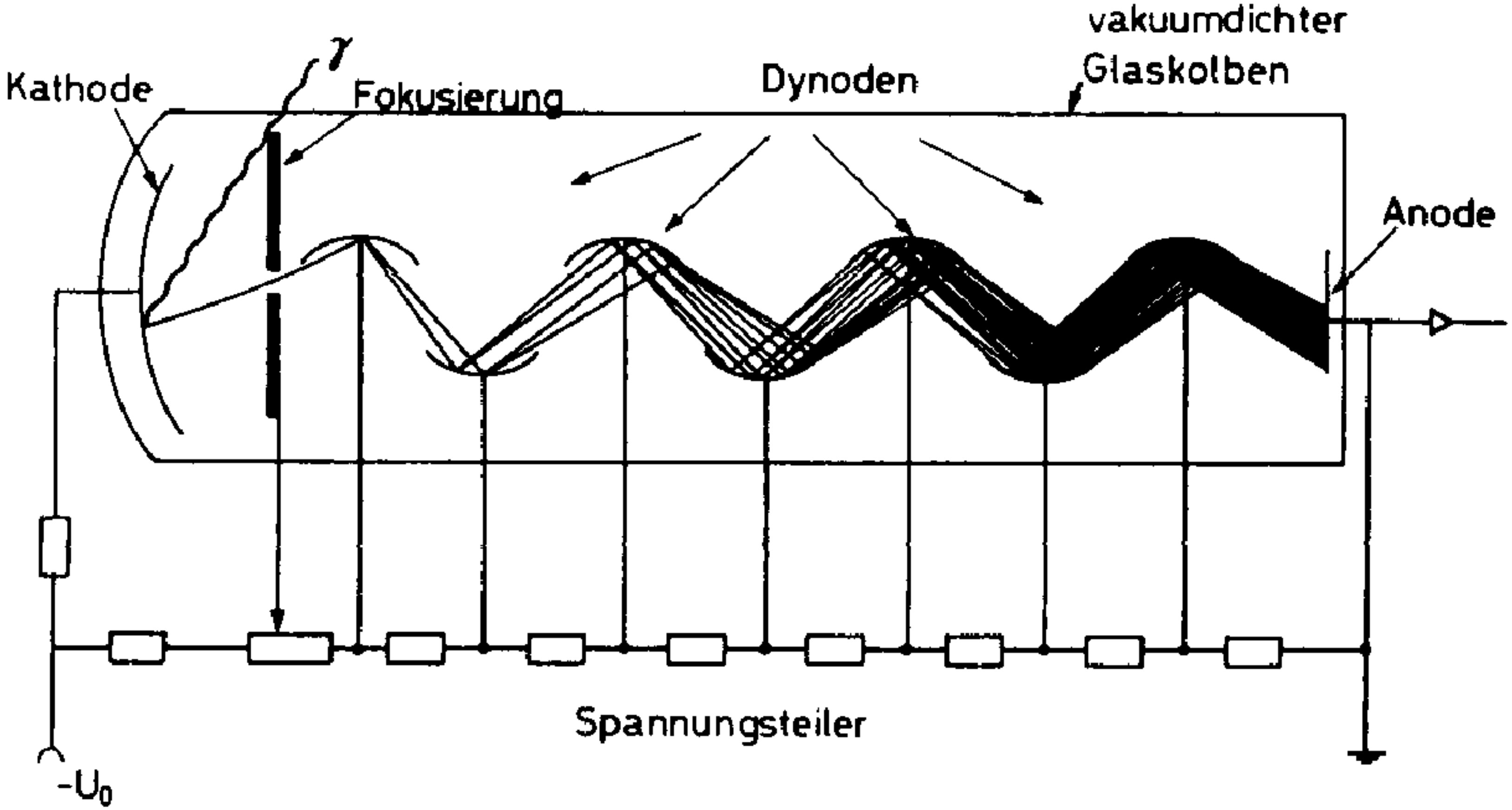
(Grupen, Teilchendetektoren)

e.g. also as a veto detector



Photomultiplier tube

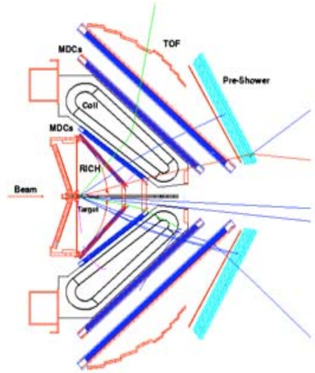
(Grupen, Teilchendetektoren)

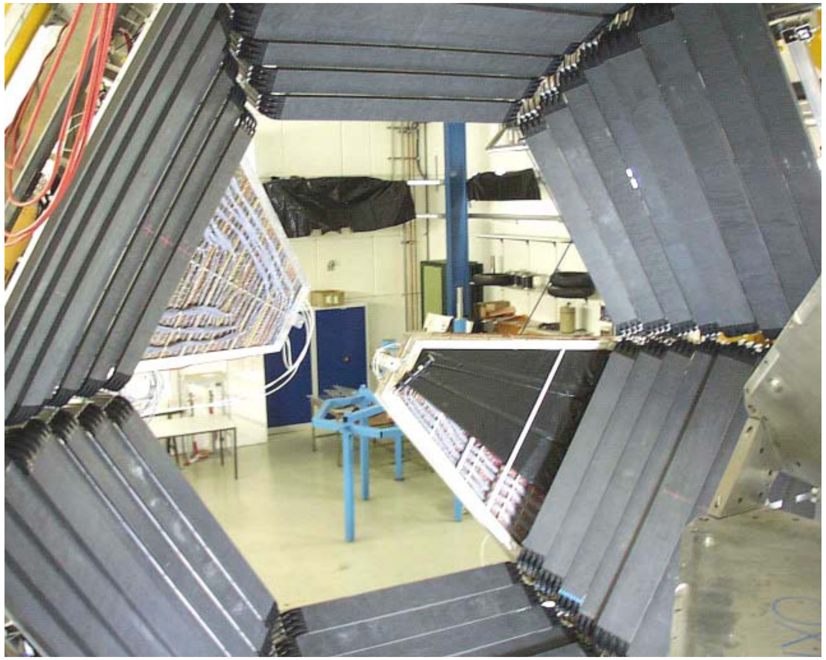


Quantum efficiency of the photocathode: 10 – 30 %

Amplification: up to 10^7

The TOF Detector



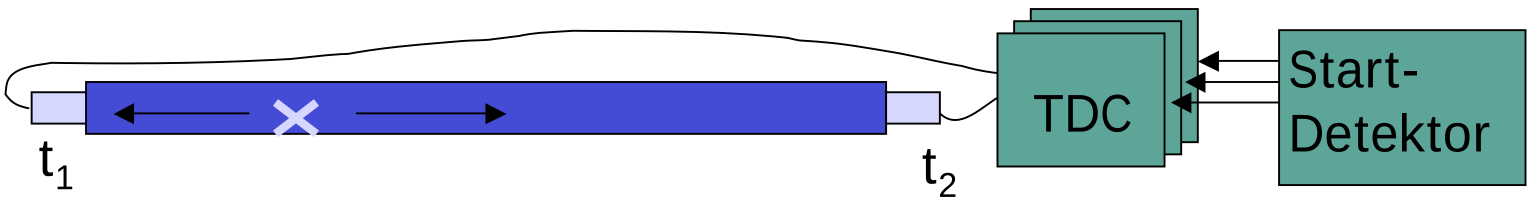


Catania (INFN - LNS)
Milano (INFN, Univ.)
Rez (CAS, NPI)
Bratislava (SAS, PI)

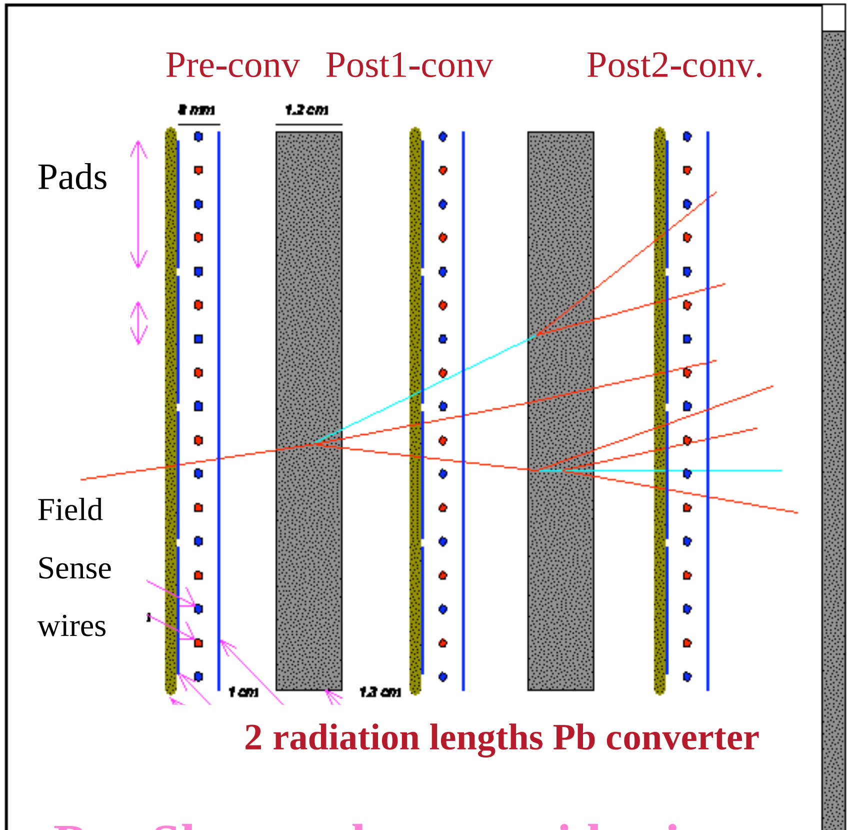
- 6 x 64 Scintillators

  σ_{tof} : 90-140 ps
- In beam start detector

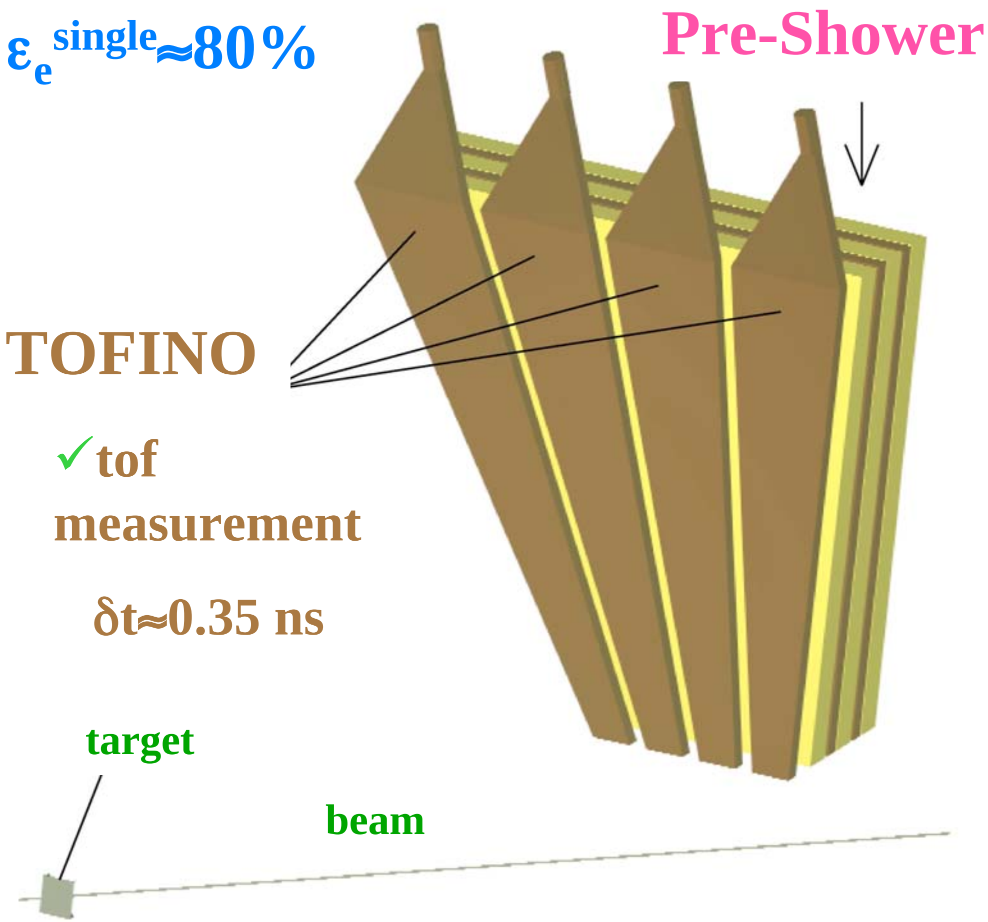
Diamond, d = 120μm, σ_t = 66ps



Pre-Shower/TOF system $\Theta < 45^0$



Pre-Shower detector side view

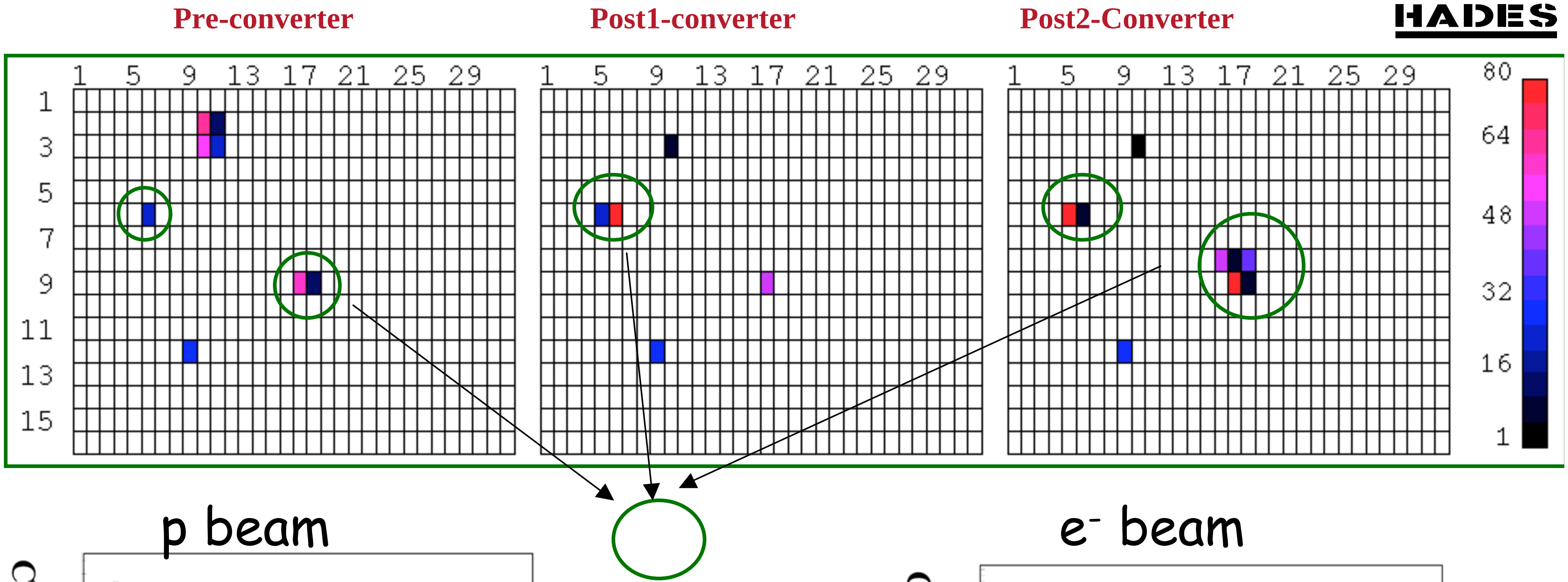


- ✓3 pad chambers (20000 pads)
- ✓em. showers in Pb converters

One event: detector response

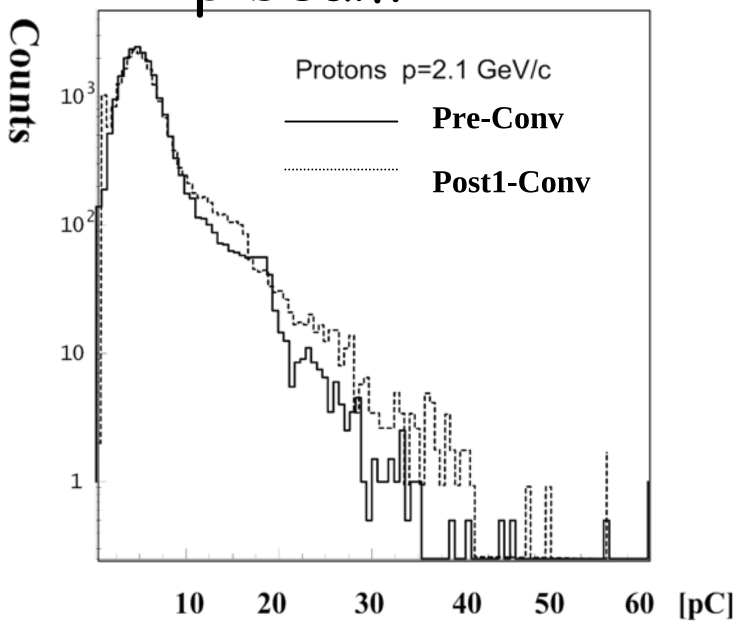
C+C 1.5 AGeV

HADES

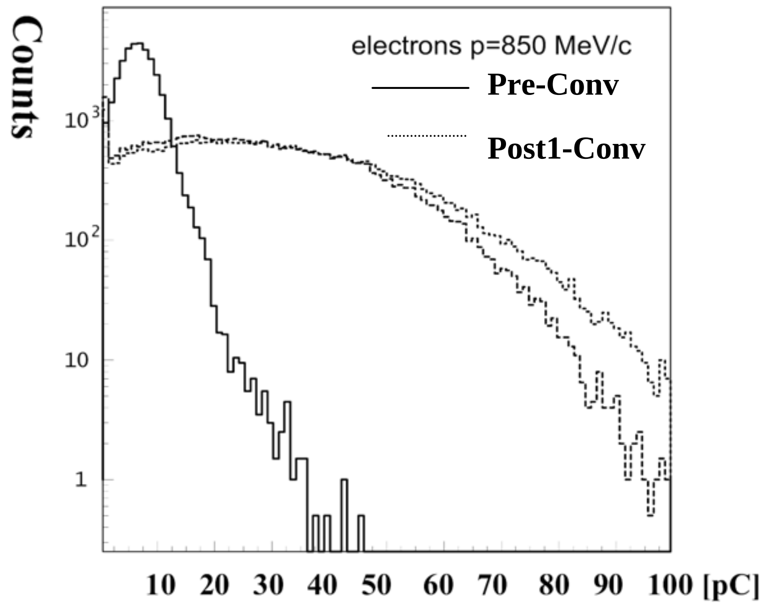


Shower candidate

p beam

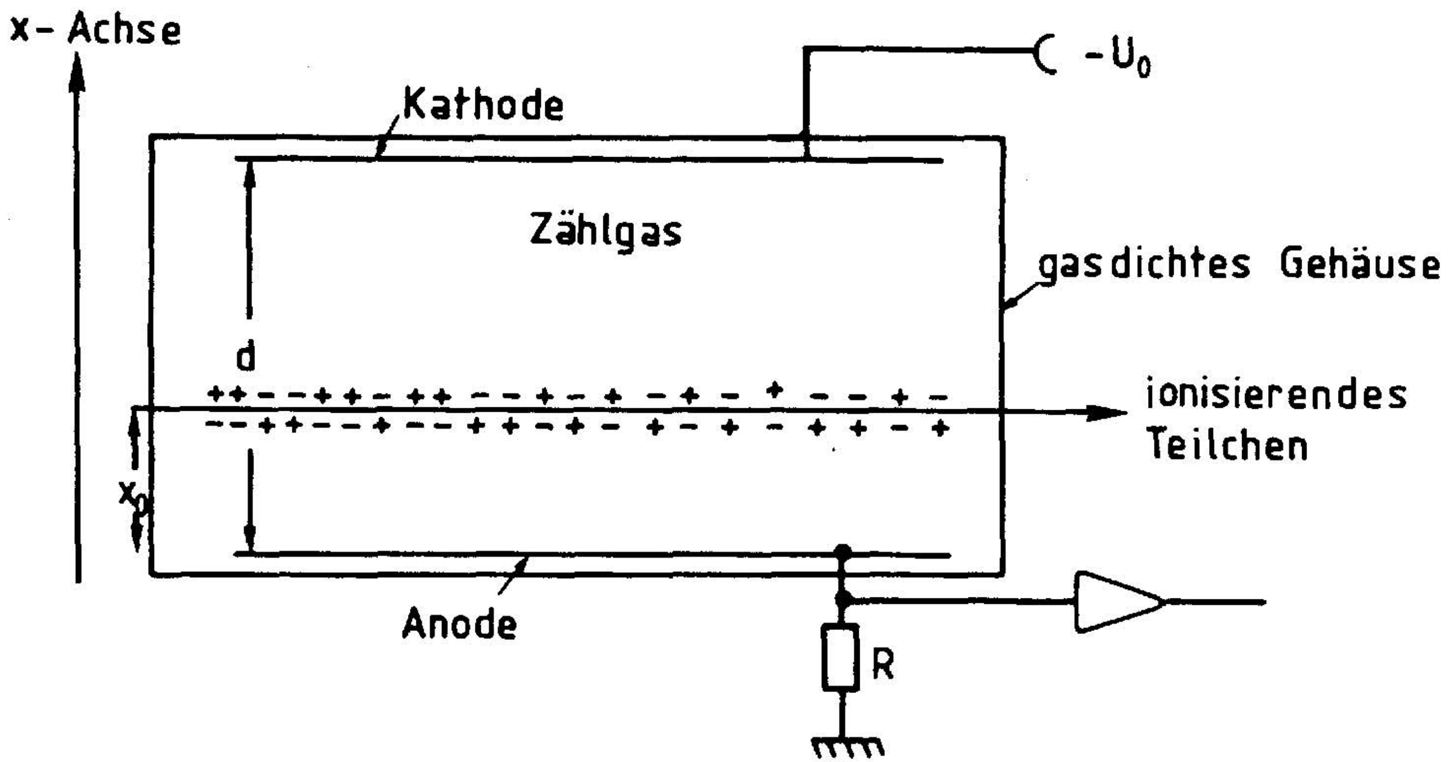


e⁻ beam



Ionisation chamber

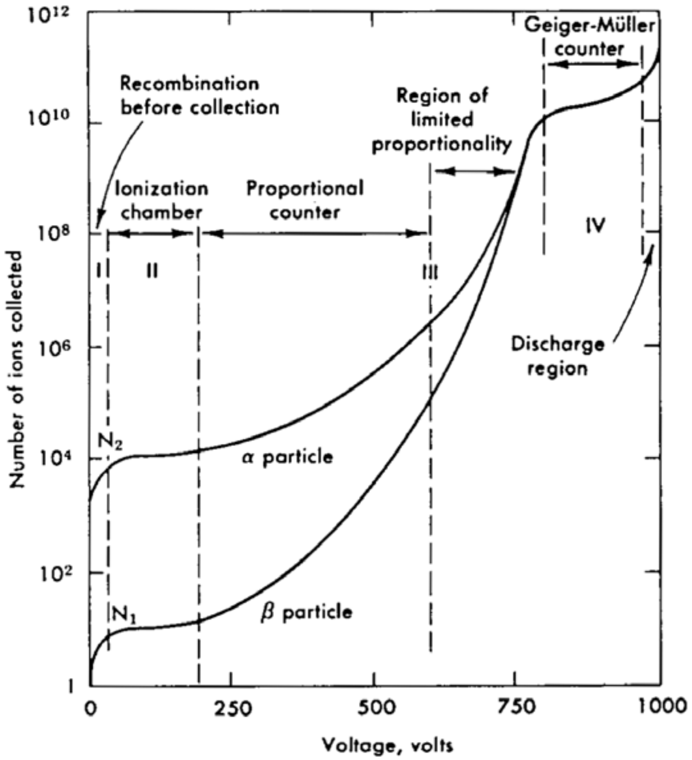
(Grupen, Teilchendetektoren)

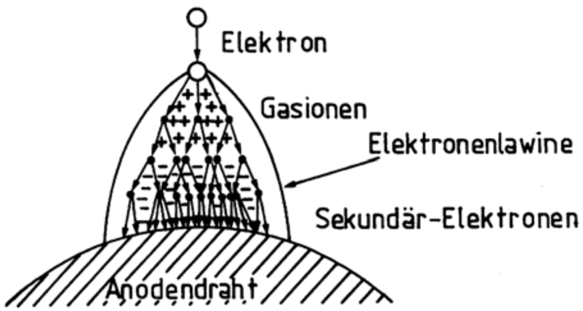


1 electron – ion pair per w ≈ 30eV

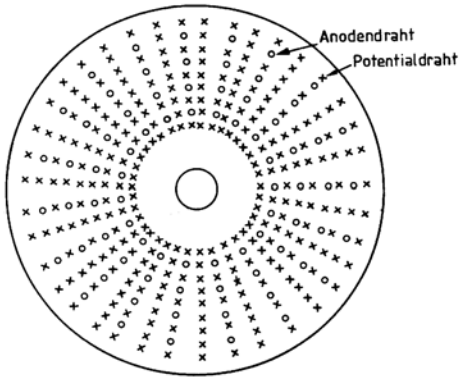
$$\text{Energy resolution: } R = 2.35\sqrt{\frac{Fw}{E}}\,, \quad F < 0.2$$

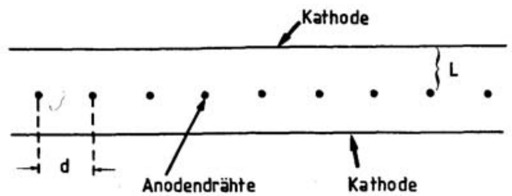
Yield of ions in a gas detector
(Leo, Techniques...)

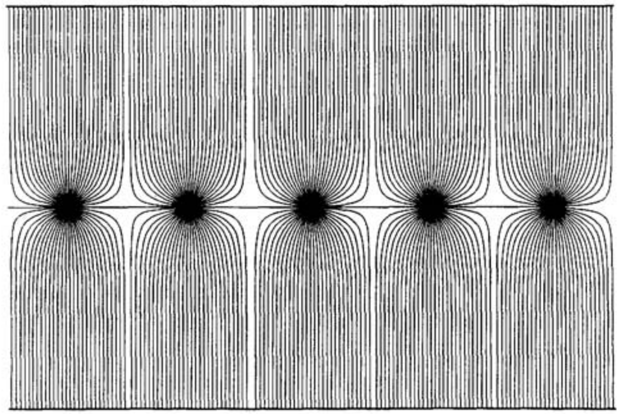




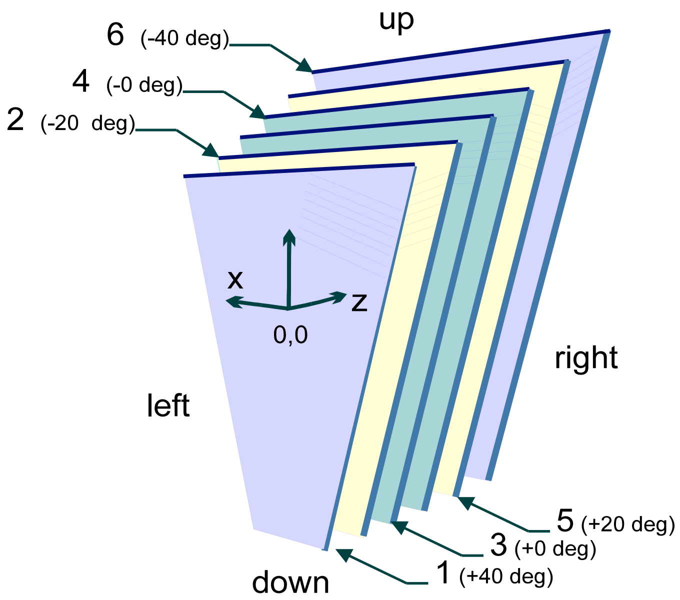
Multiwire chamber (Charpak)
→ position sensitivity

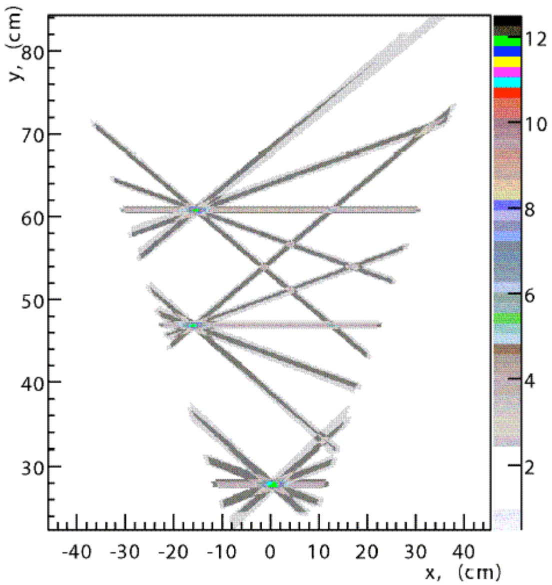






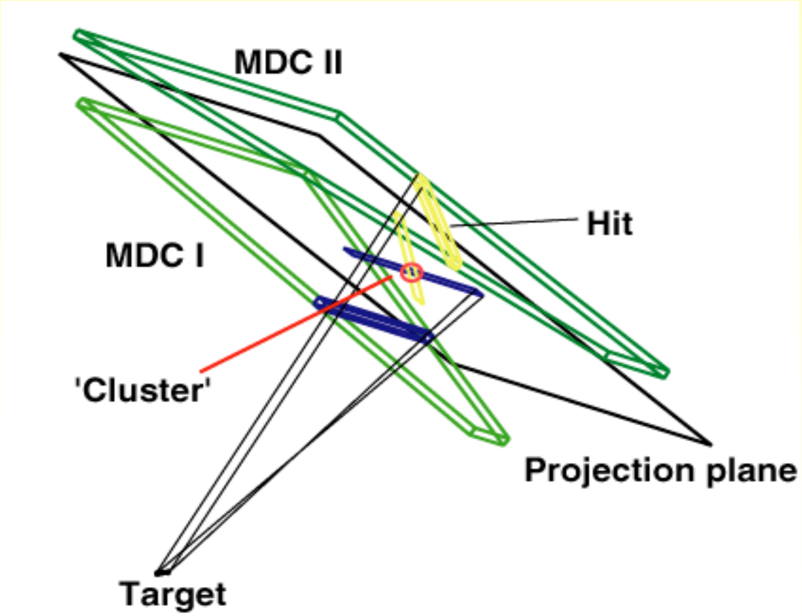
Track Reconstruction in the Drift Chamber



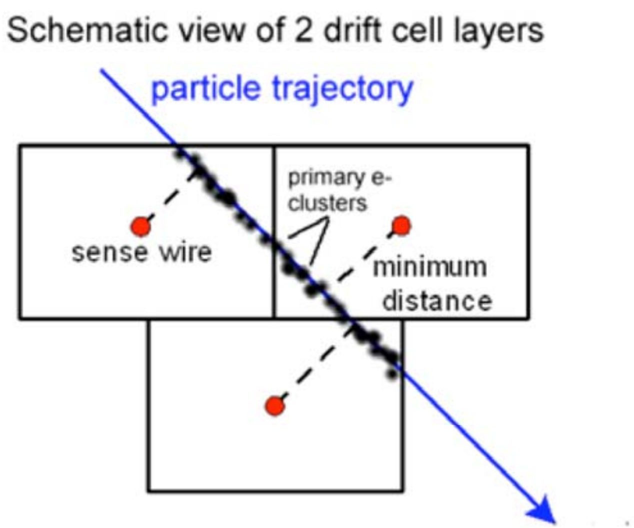


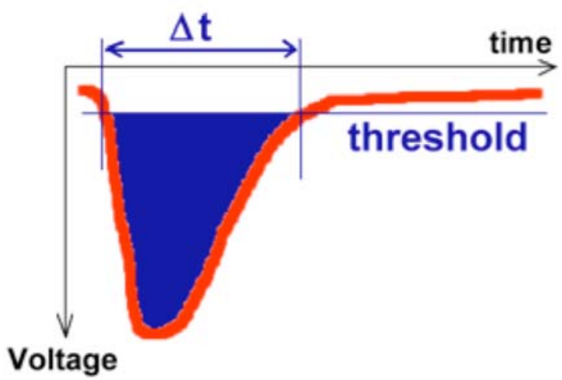
Track Reconstruction:

1. Search for Wire Hit
2. Targetprojection
3. Straight-line-fit



Particle ID with the tracking chambers





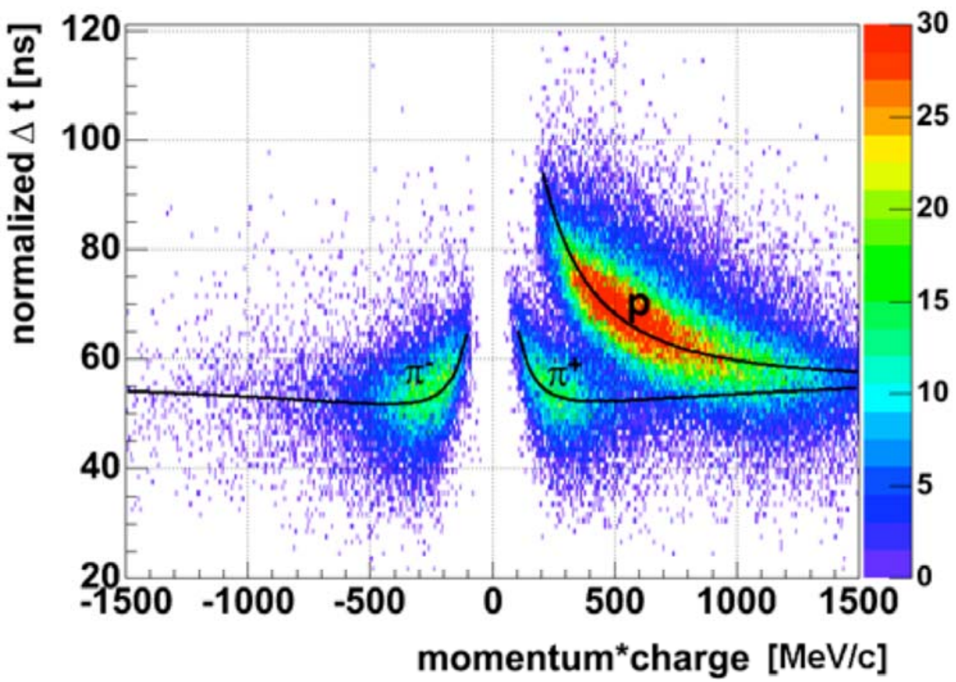
$\Delta t^2 \sim dE/dx * \text{Corr.}$

Correct time-above-threshold for track topology.

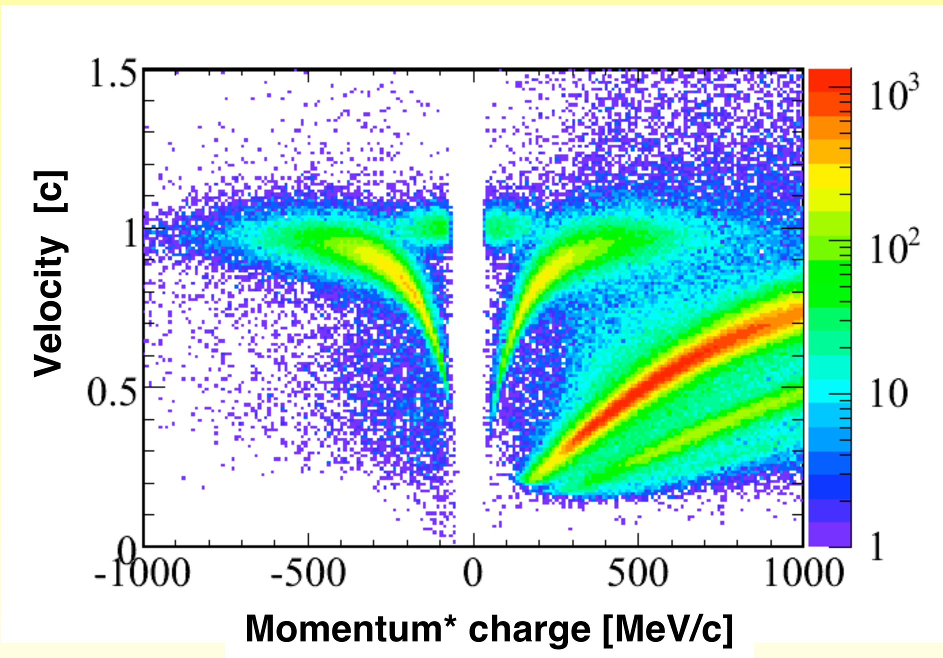
- Simulation (Garfield)
- Use tracking information

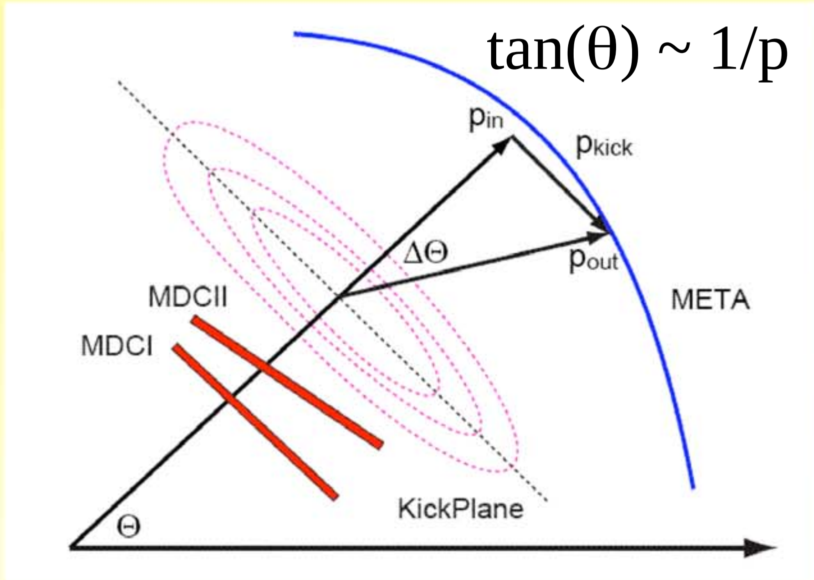
Will be exploited for:

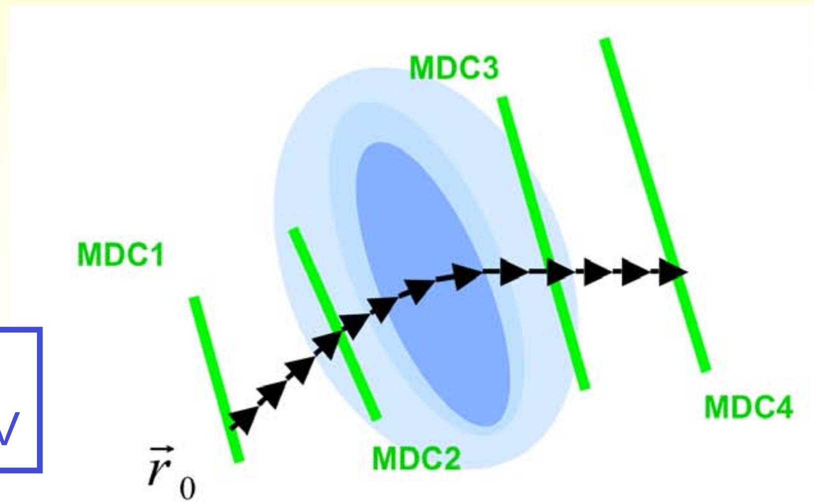
- Track matching
- Close pair rejection



Momentum Reconstruction

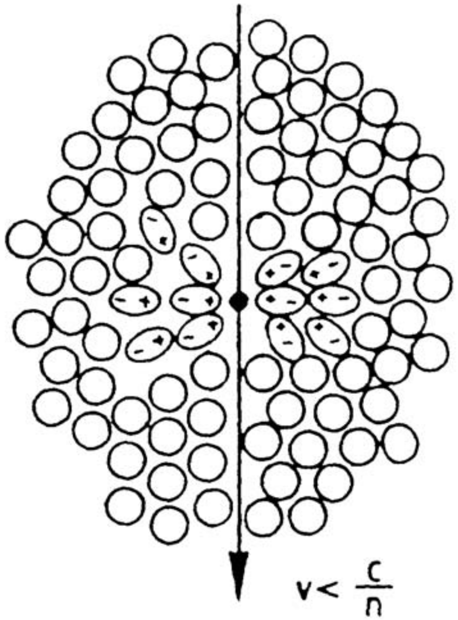


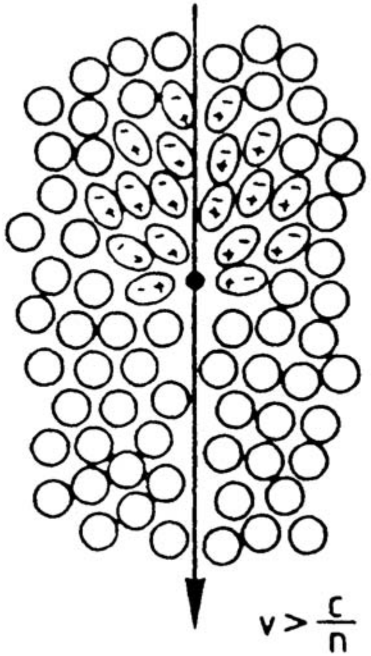


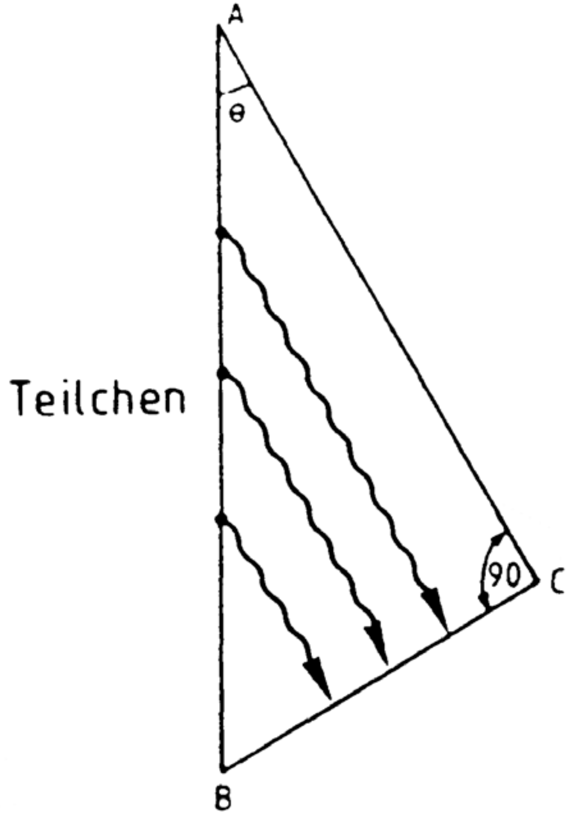


Relative Momentum Resolution with
All tracking Chambers: ~ 3% for p < 800 MeV

Cherenkov - Effect







$$\beta > \beta_{thr} = \frac{1}{n} = \sqrt{1 - \frac{1}{\gamma_{thr}^2}}$$

$$\cos\vartheta_C = \frac{1}{\beta n} \xrightarrow{\beta \to 1} \frac{1}{n}$$

$$p = m_0 \gamma v = m_0 c \gamma \beta \xrightarrow{\beta \to 1} m_0 c \gamma$$

$$\gamma_{thr} = 18$$

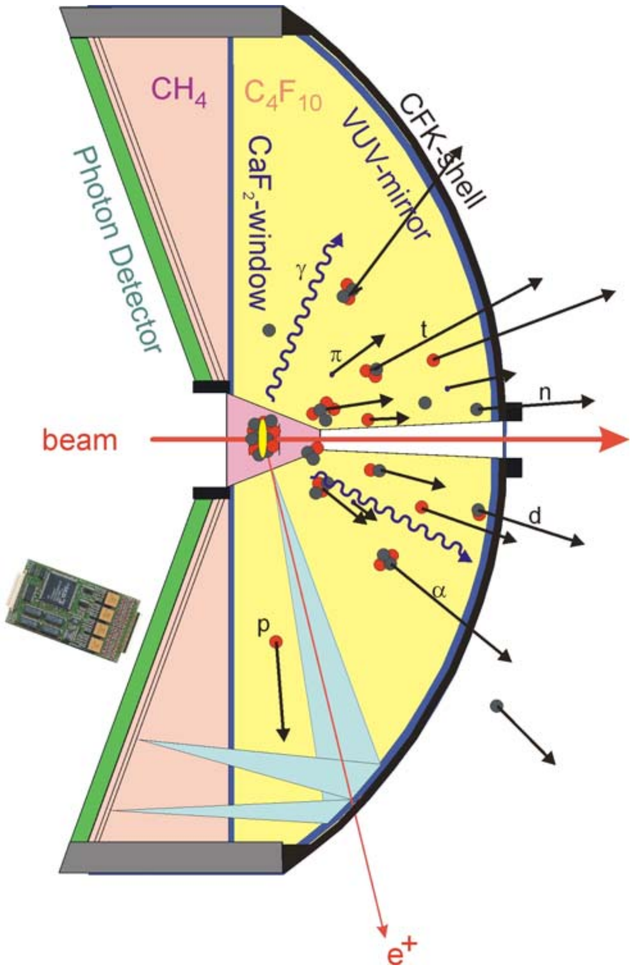
$$for\ e^- : p_{thr} = 0.511\, MeV/c \cdot 18 = 9\, MeV/c$$

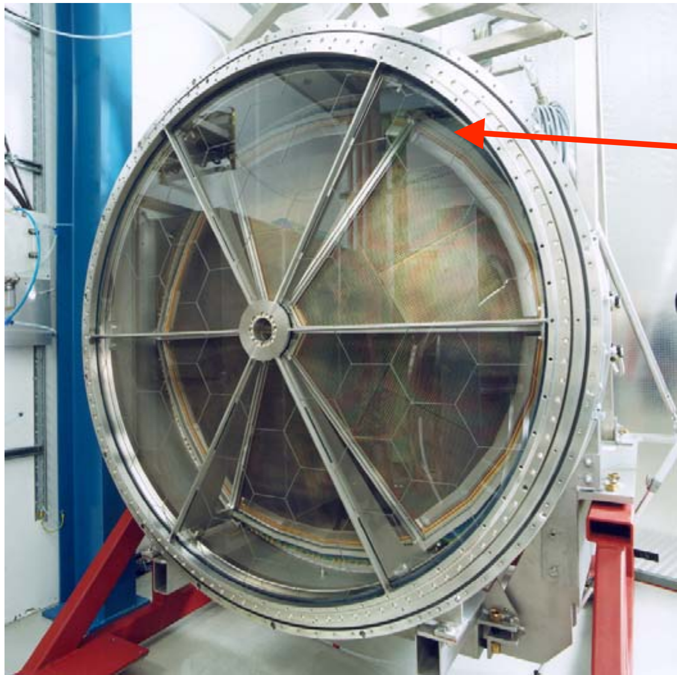
$$for\ pions : p_{thr} = 135\, MeV/c \cdot 18 = 2.43\, GeV/c$$

Cherenkov-radiators

Material	$n-1$	β-min	γ-min
solid Sodium	3.22	0.24	1.029
Diamond	2.91	0.26	1.034
Flintglas	0.92	0.52	1.17
Water	0.33	0.75	1.52
Aerogel	0.025 - 0.075	0.93 - 0.976	4.5 - 2.7
Pentane	1.7×10^{-3}	0.9983	17.2
Air	2.93×10^{-4}	0.9997	41.1
Helium	3.3×10^{-5}	0.99997	123

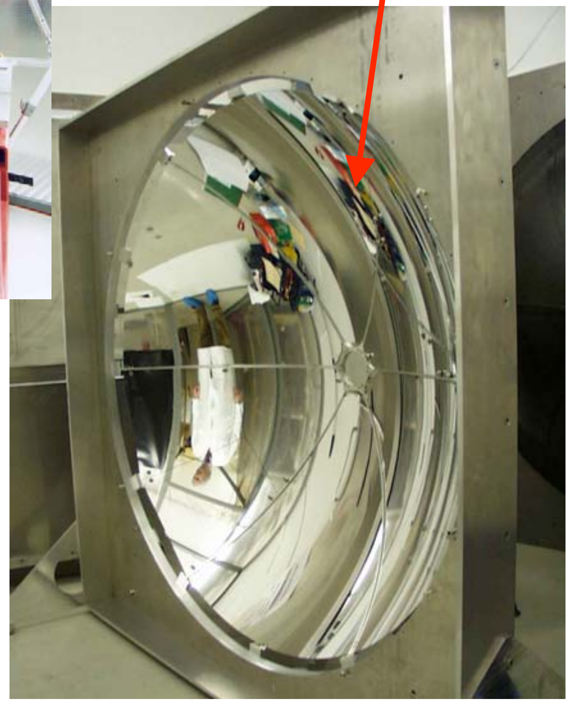
The HADES RICH Detector





CaF_2 window

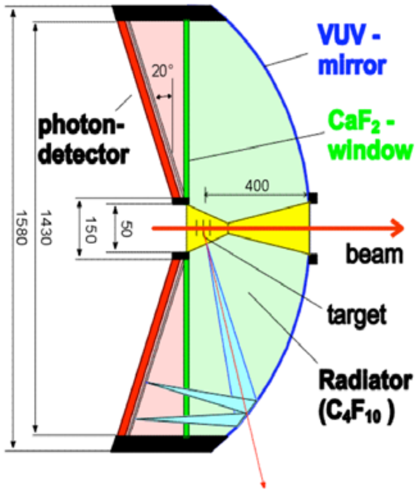
VUV mirror



Photon Detector :

- CH_4 MWPC
- CsI cathode
- 28.600 pads
- 10 μs readout

The RICH Detector



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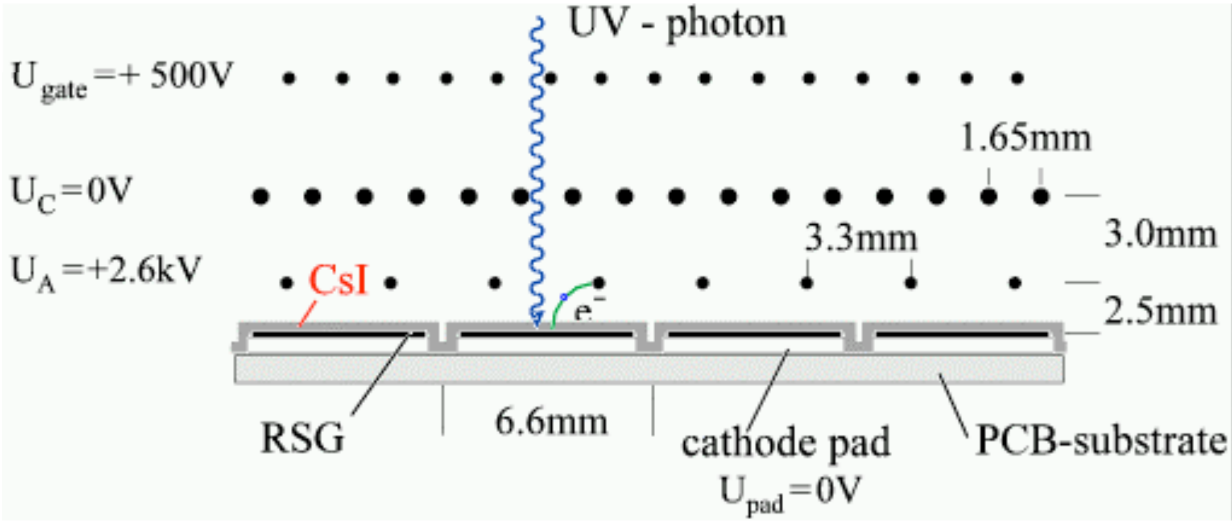
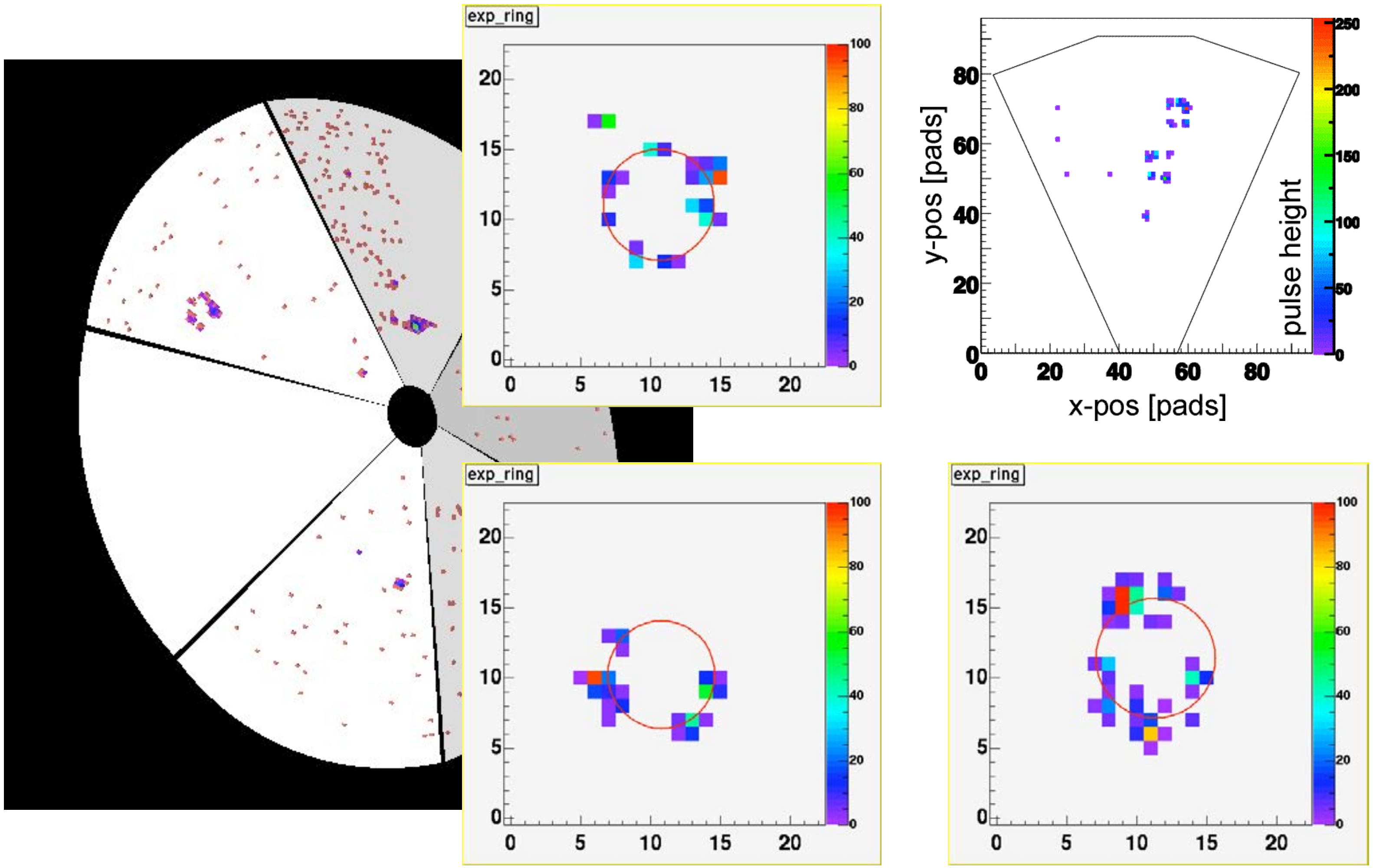
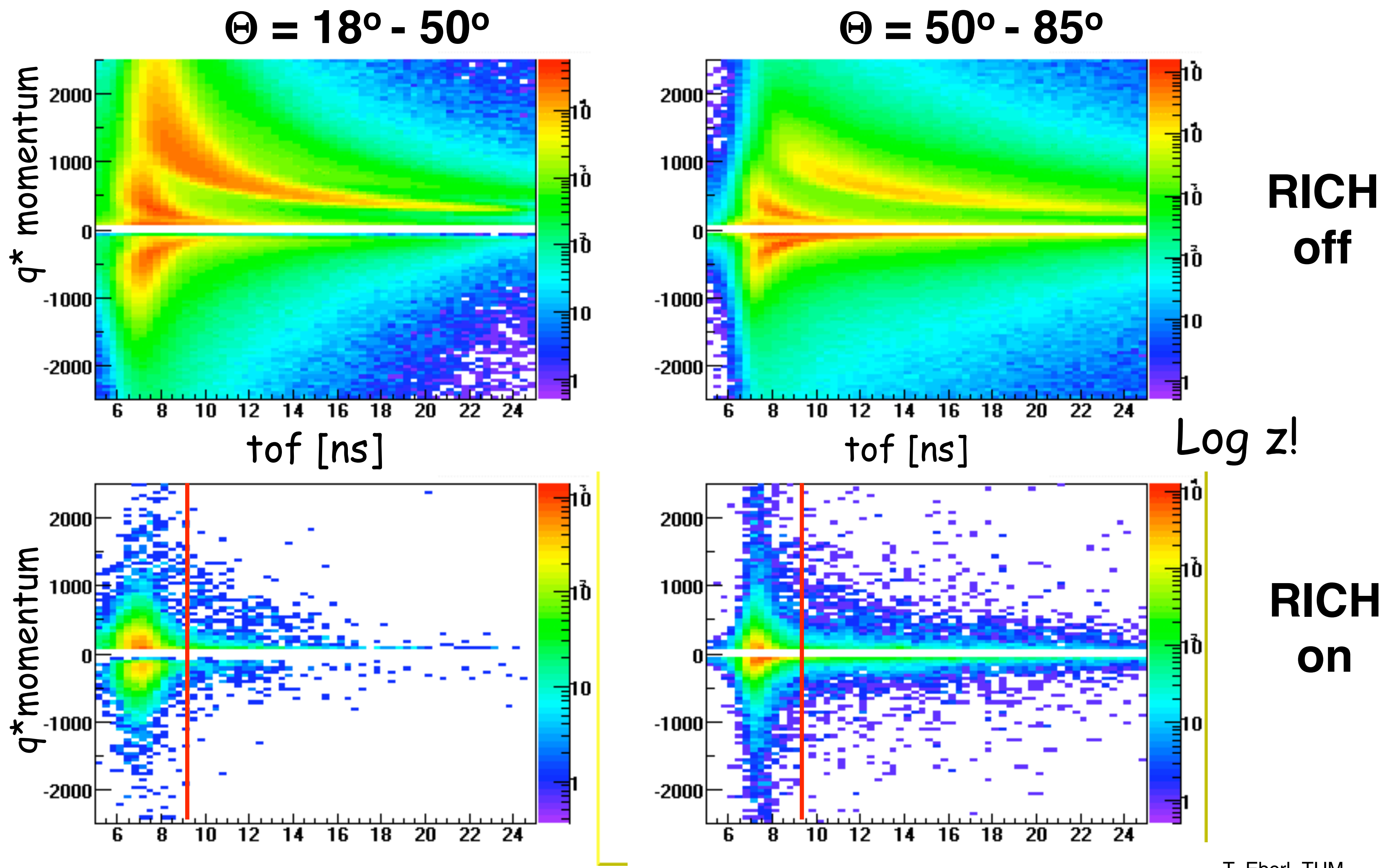
Photon Detector



Single events in the RICH

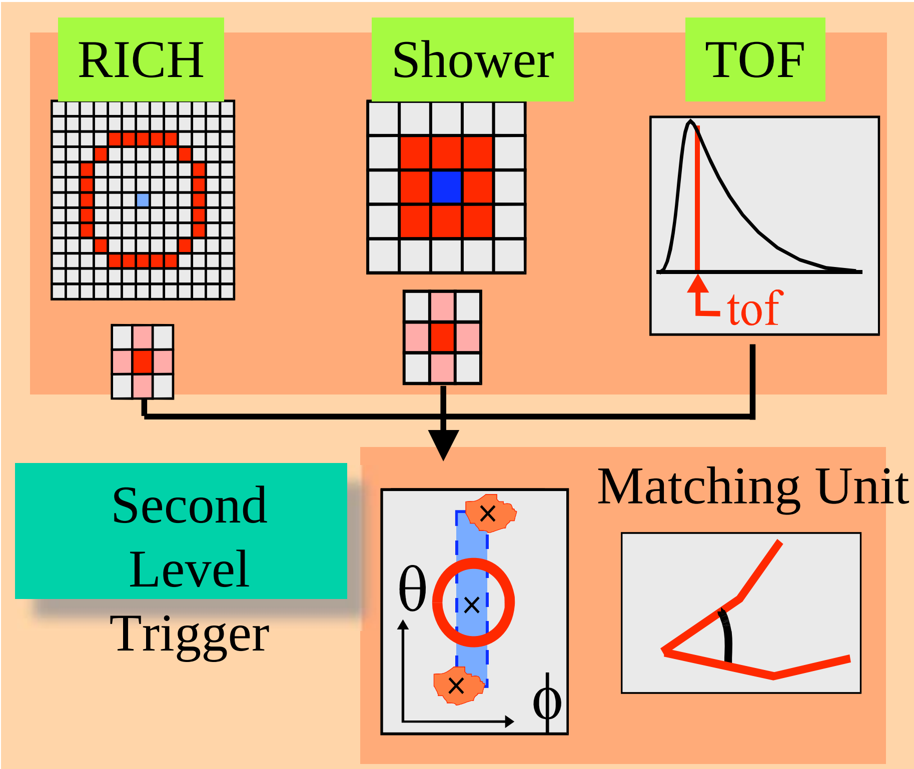


Lepton identification: C+C @ 2 AGeV

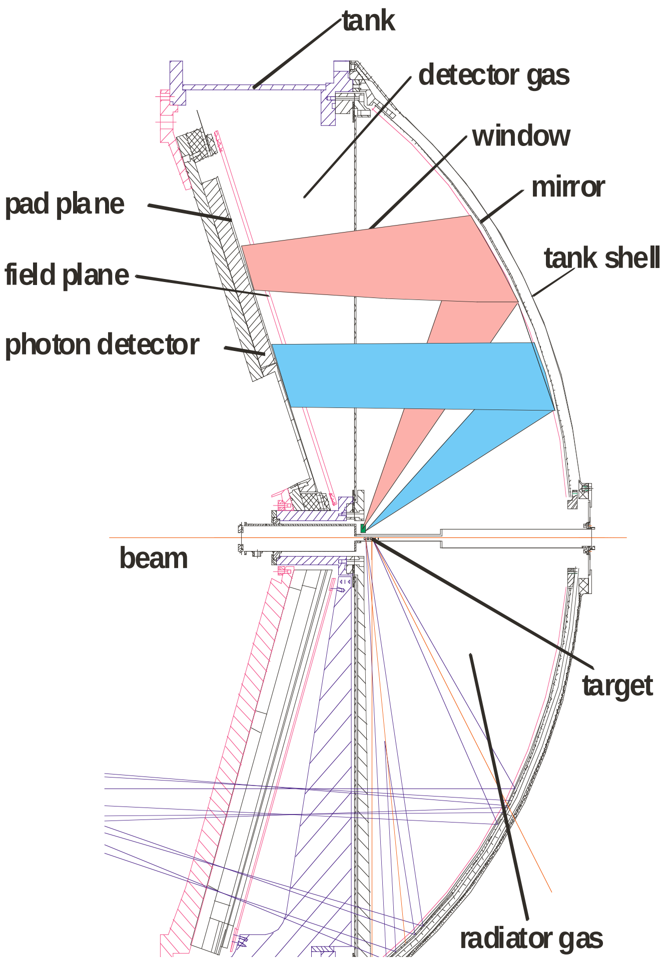


Online Lepton ID

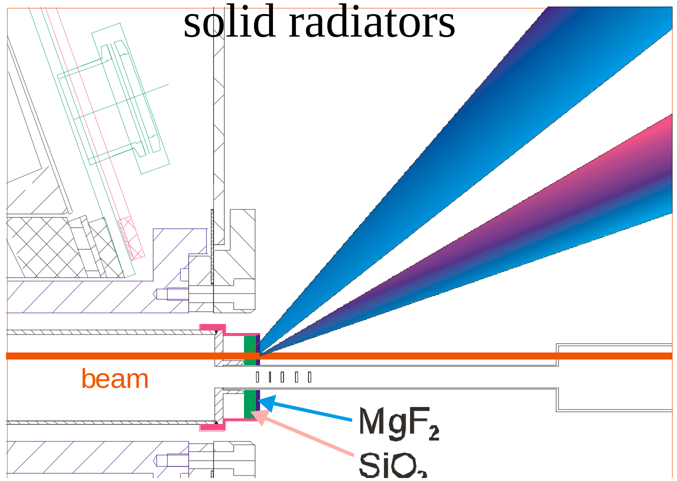
- Fast readout of all PID - detectors (10μs)
- Real time processing with
  - Calibration
  - Pattern recognition
  - Position calculation
- Transfer to Matching Unit
- Decision and second level trigger distribution

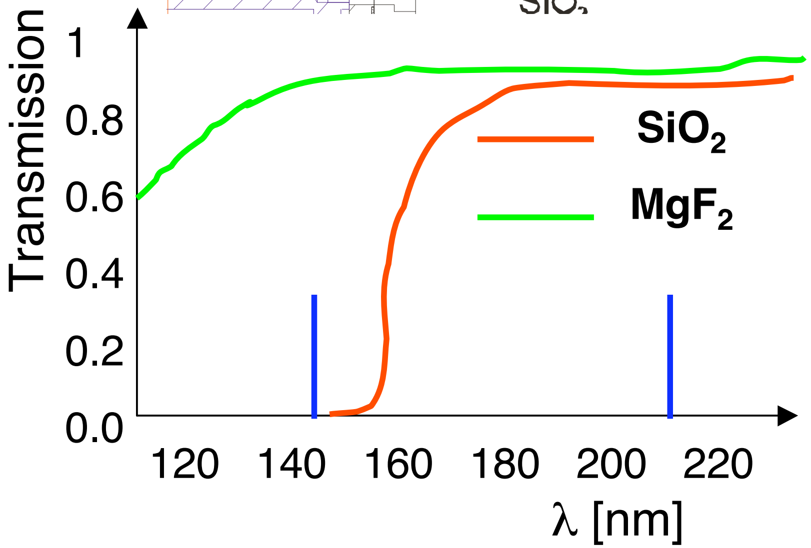


Efficiency calibration (OEM)

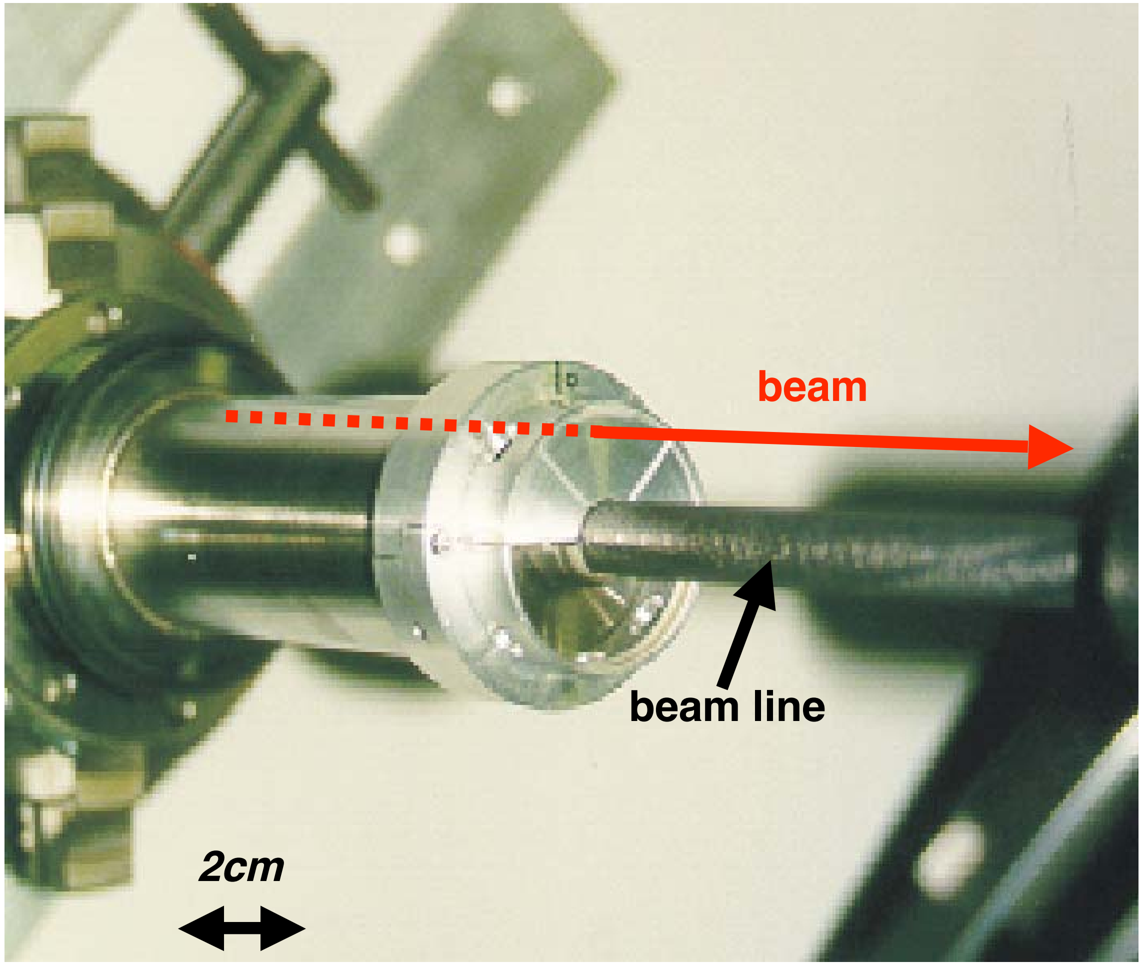


Photons produced by 600 AMeV 12C beam particles passing two different solid radiators





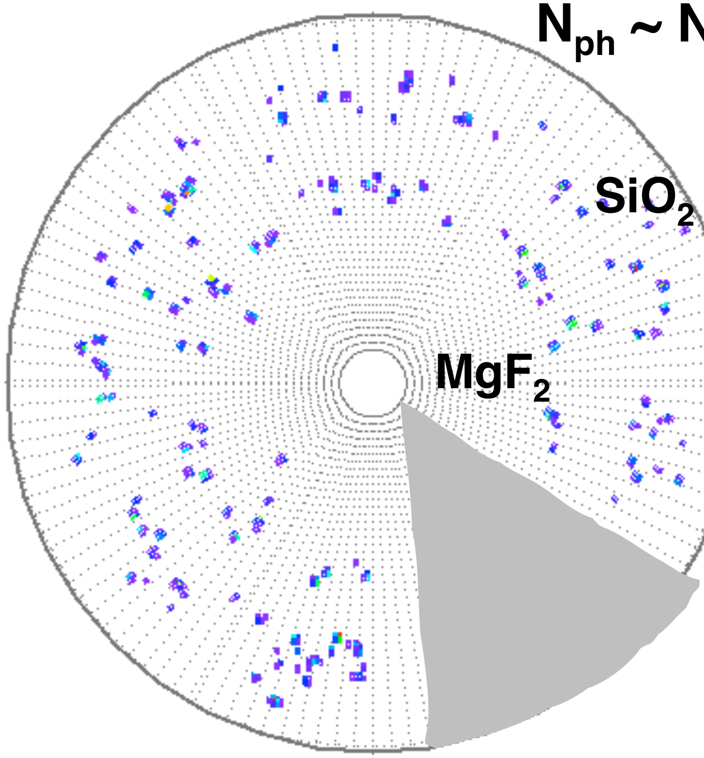
OEM Radiator



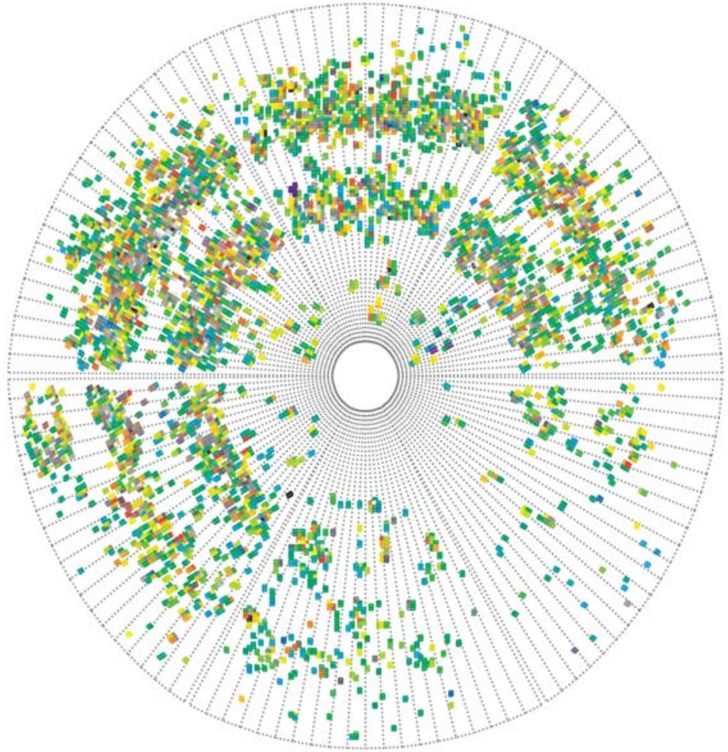
Detector Response to VUV Photons

C^{12} ions, E = 600 AMeV

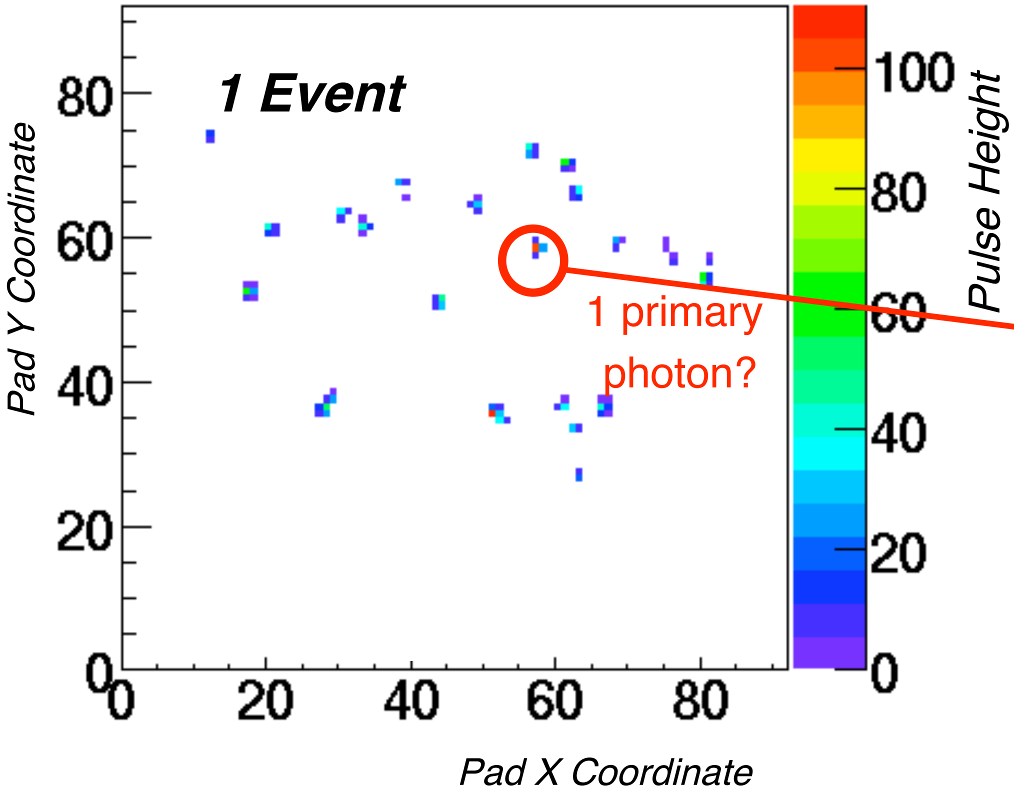
1 evt

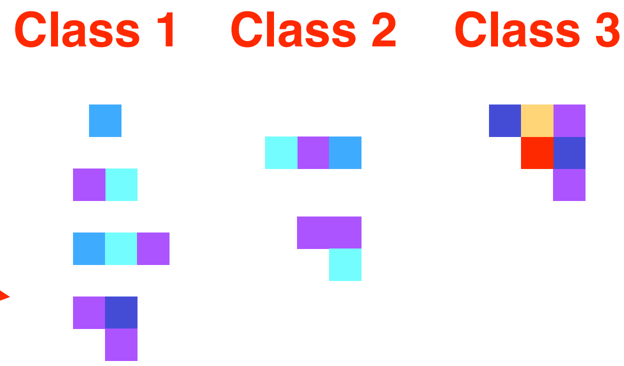


500 evt accumulated

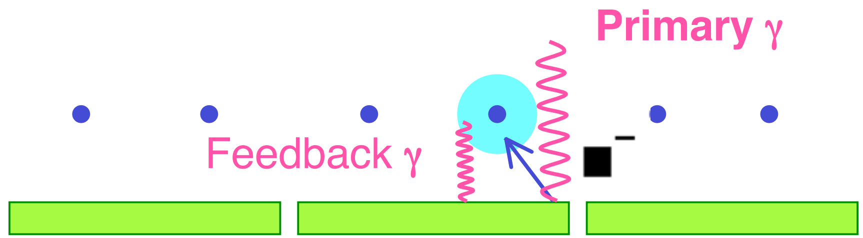


Pulse Height Analysis

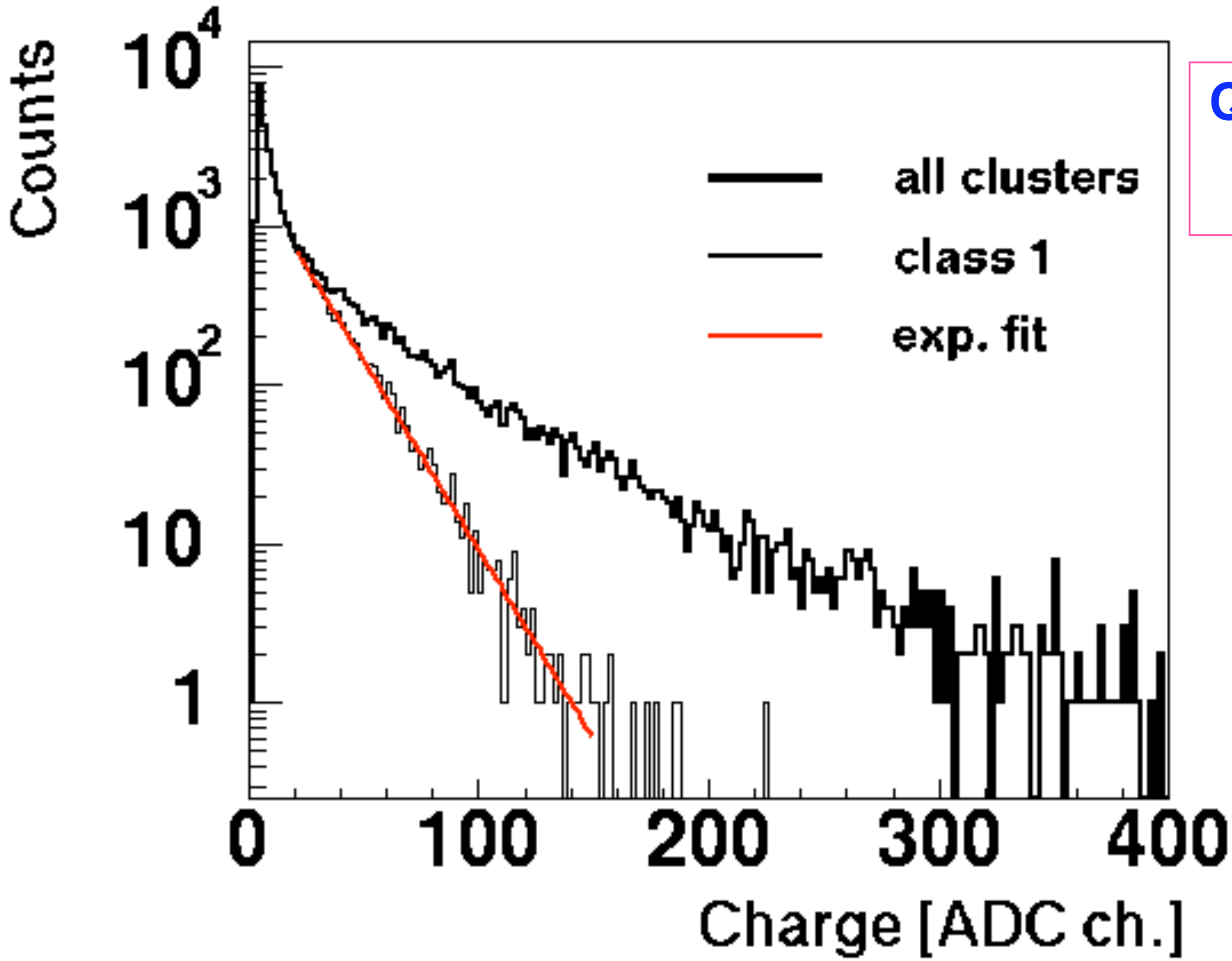




Primary and feedback photons



Pulse Height Distribution



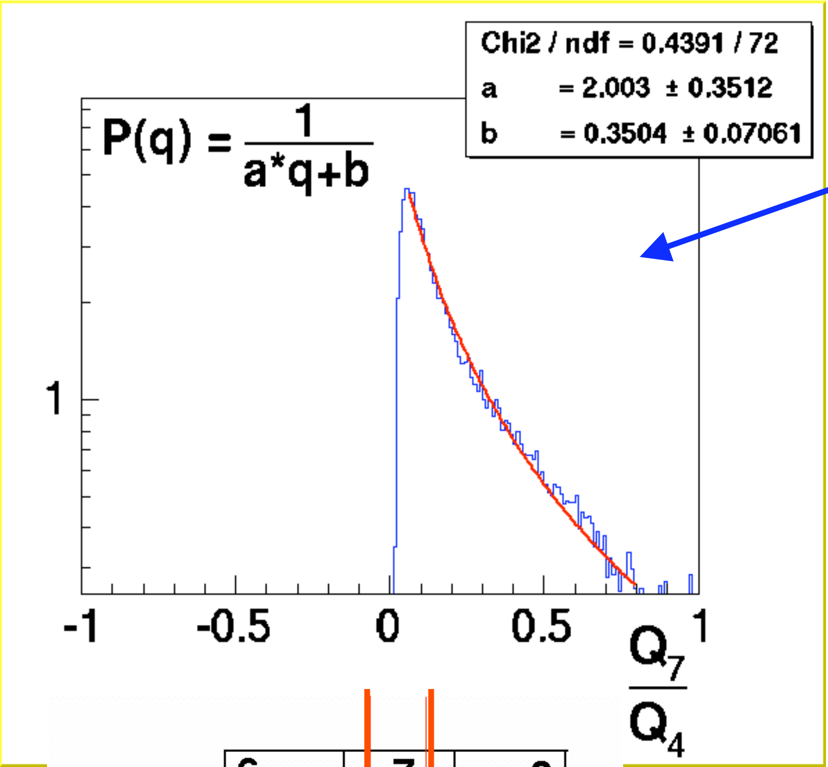
$Q_{Mean} = 5 * 10^4 e^-$

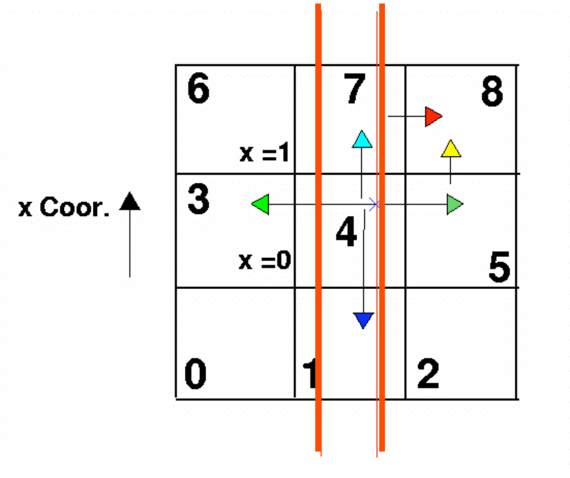
$\varepsilon_{SE} \sim 90\%$

Anode Voltage = 2450 V

CH_4 atmos. press.

Coupling to Neighbouring Pads



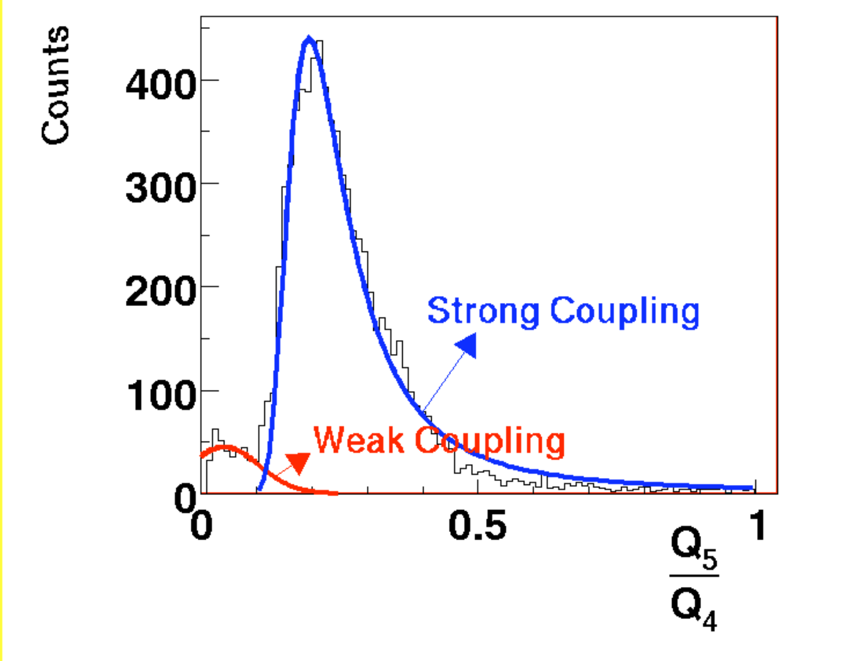


Only Class 1 clusters are used!!

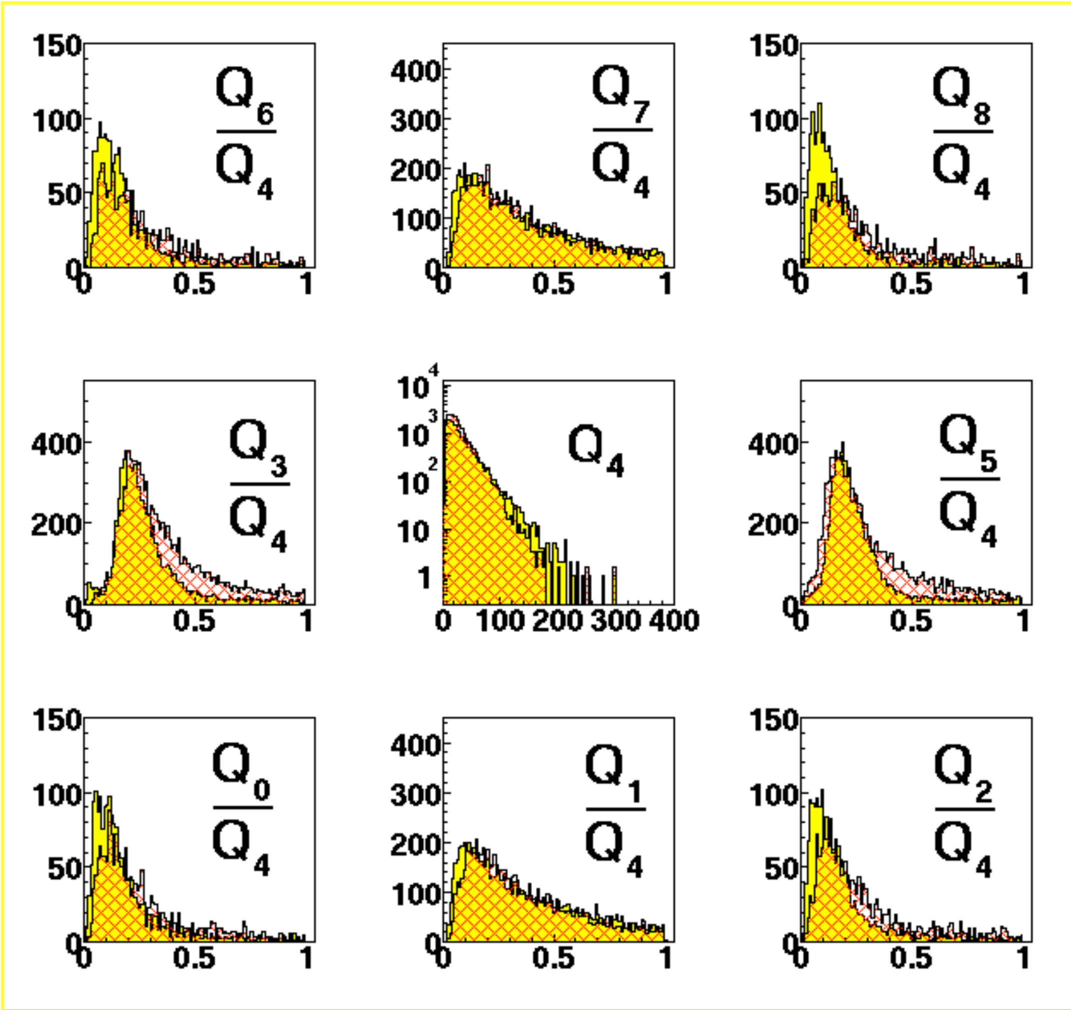
Along the wire

⇒ photon impact resolution ~ 0.5 mm

Perpendicular to wire



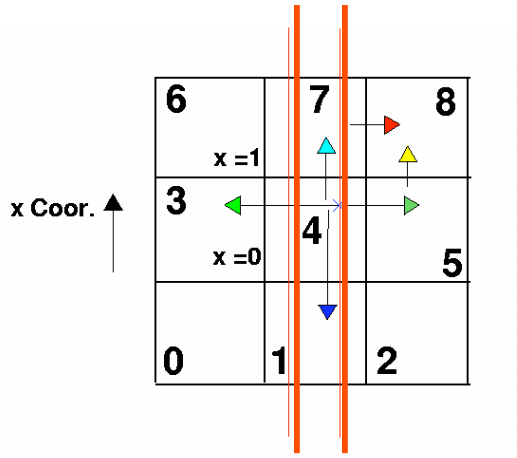
Charge Distribution of Single Photons



Simulation

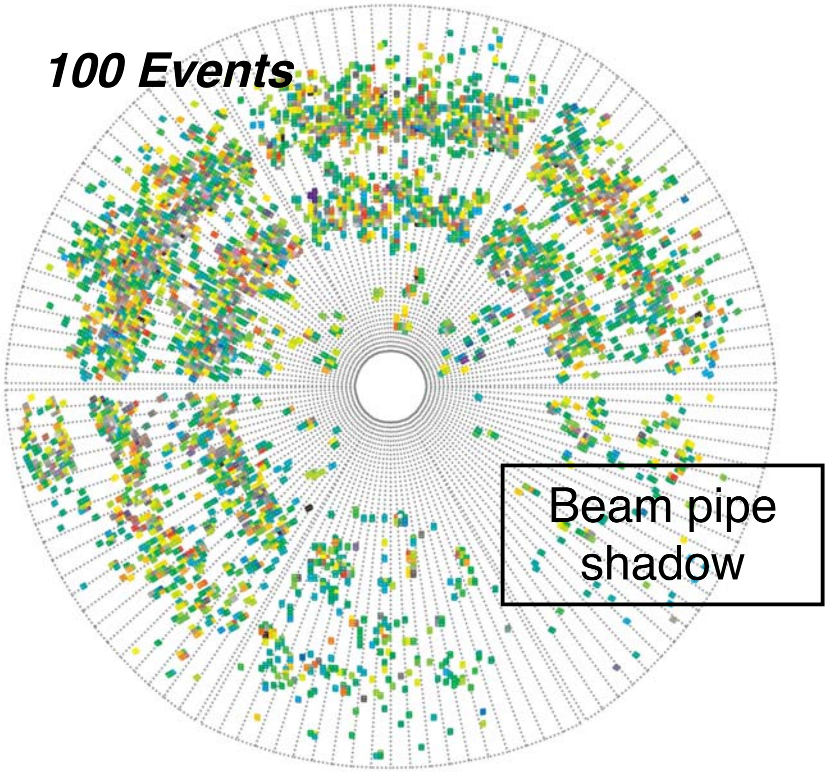
Experiment

single photon response
well understood

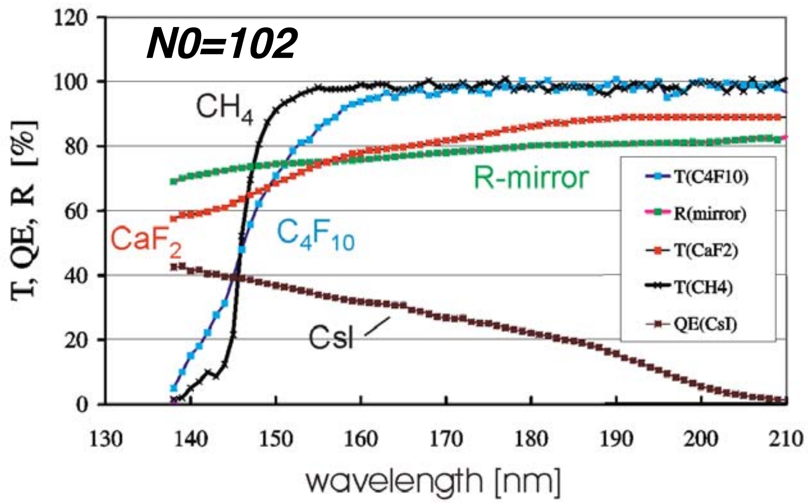


Analysis of Photon Yield

Experimental Data

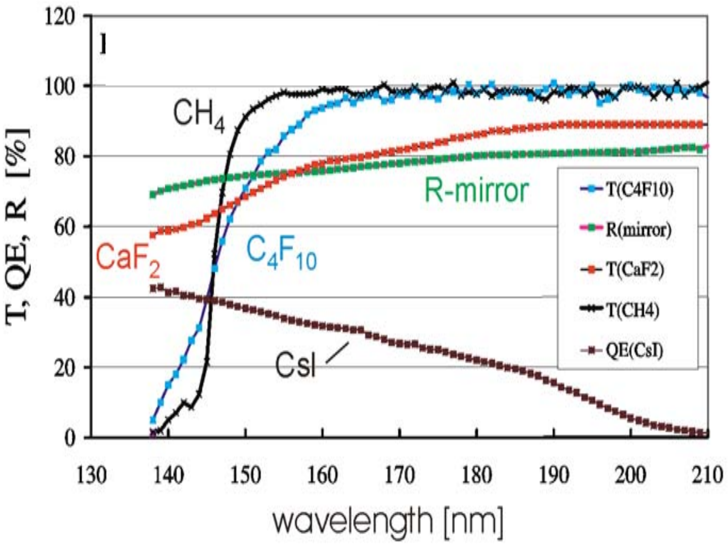


Simulation Input ***(HGeant)***



- ***Optical parameters (all independently measured)***
- ***Simulation of single photon response***
- ***Electronic noise***

N_0 Calculation



$$N_0^{Sim} = const. \int_{\lambda_1}^{\lambda_2} \prod_i \varepsilon_i^{Sim}(\lambda) \frac{\delta\lambda}{\lambda^2}$$

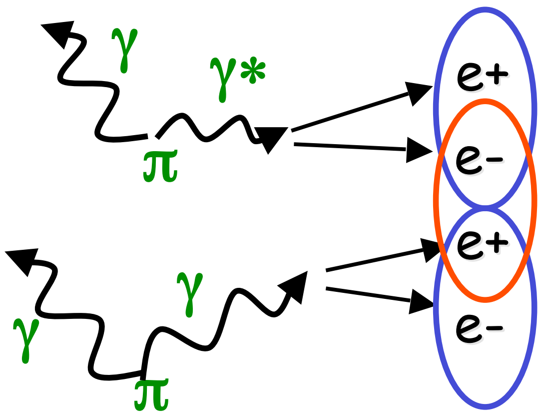
$$N_0^{Sim} = 102$$

$$N_0^{Exp} = const. \int_{\lambda_1}^{\lambda_2} R(\lambda) \cdot \prod_i \varepsilon_i^{Sim}(\lambda) \frac{\delta\lambda}{\lambda^2}$$

	Sector 1		Sector 2		Sector 3		Sector 6	
	MgF_2	SiO_2	MgF_2	SiO_2	MgF_2	SiO_2	MgF_2	SiO_2
N^{Sim}_0	102	102	102	102	102	102	102	102
N^{Exp}_0	78 / 88	80/ 99	92/ 106	78/ 88	94/ 106	88/ 100	96/ 110	98/ 130

Combinatorial Background

e+/e- from different Sources!



Same-event like-sign (LS) CB

$$N_{CB} = 2 * \sqrt{N_{e+e+} * N_{e-e-}}$$

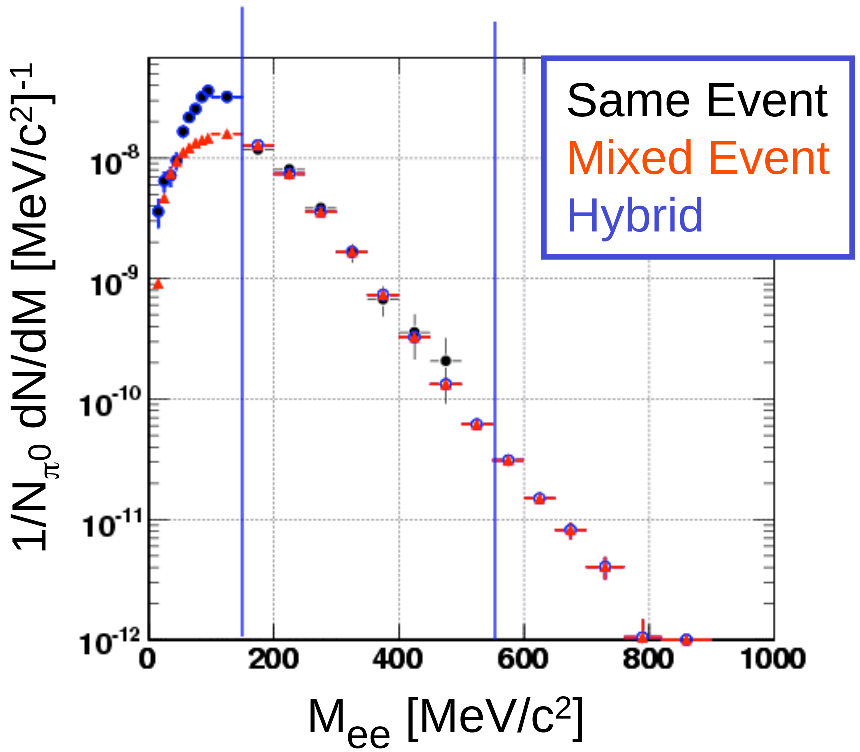
- **Correlations under M_{ee} = 150MeV/c^2**
- **Low Statistic above M_{ee}~ 450 MeV/c^2**

Event-Mixing (EM) CB

- **Good statistics**
- **The correlation is not described**

Hybrid Method

Normalization of the EM-CB on top of the LS-CB [150 MeV/c^2 < M_{ee} < 550 MeV/c^2]

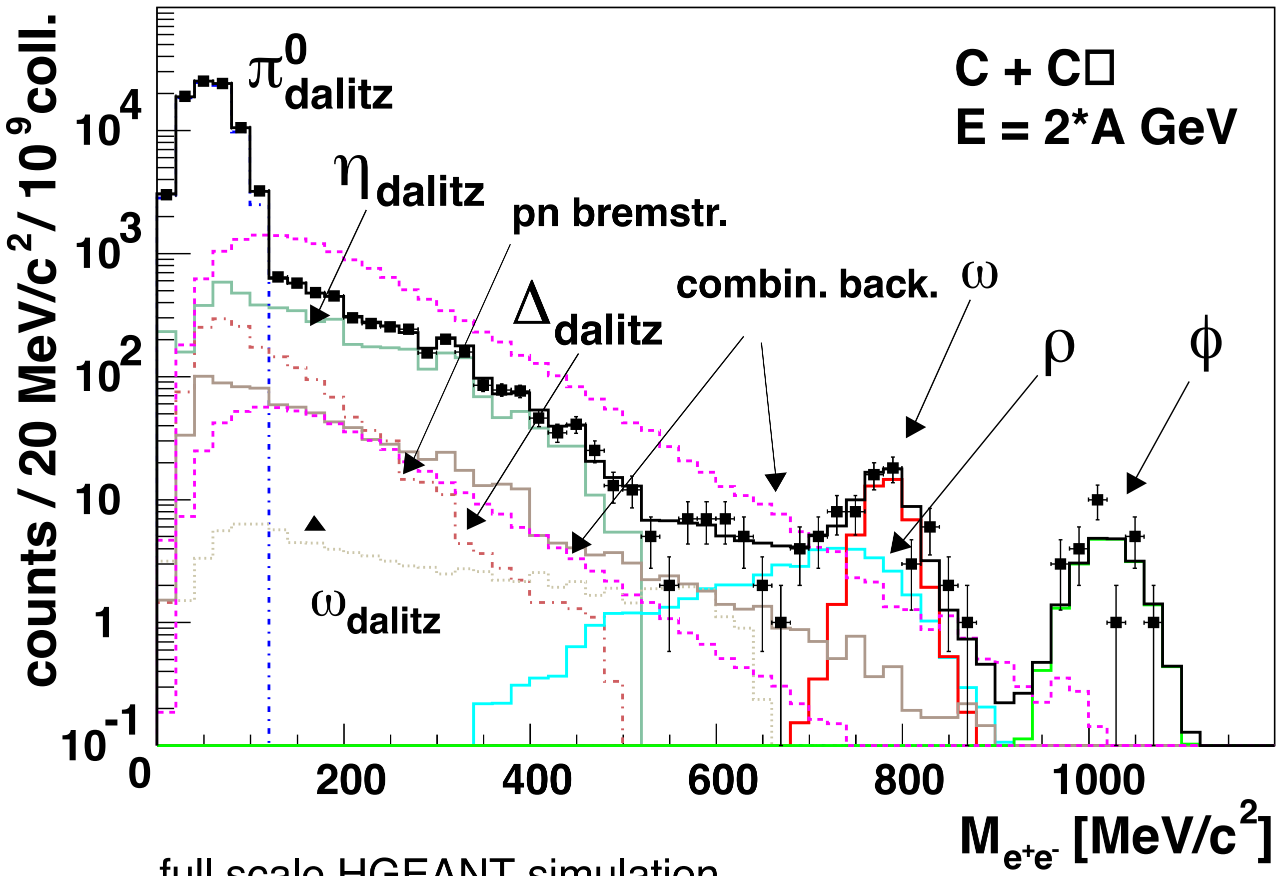


M_{ee} < 150 MeV/c^2 - Like-sign CB
M_{ee} > 150 MeV/c^2 - Event mixing CB

Dilepton Spectroscopy

HADES : Study of in-medium hadron properties via
low mass e^+e^- pairs from π, p, A + A collisions

Example:



full scale HGEANT simulation

Comb. Backgr. Suppression

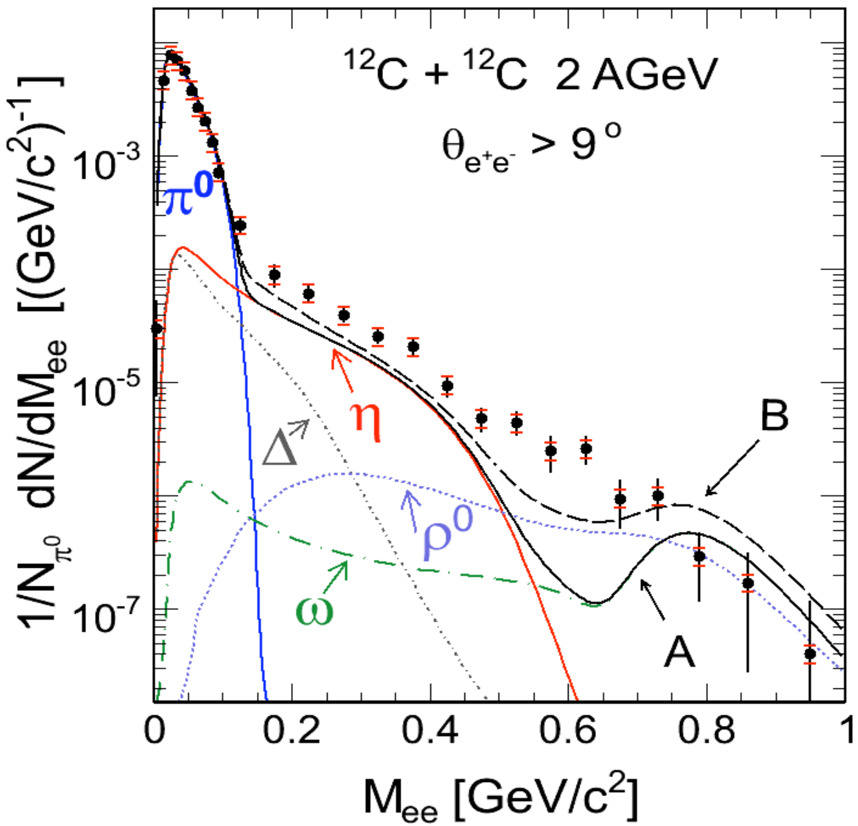
Close pair recognition !!!!
&
rejection

2 close rings in RICH

2 close tracks in MDC

Data vs. PLUTO cocktail: C+C@2AGeV

Efficiency corrected spectra!



Agakishiev et al., Phys. Rev. Lett. 98, 052302 (2007)

- Cocktail A: $\pi^0 + \eta + \omega$
  = "long-lived" components only
- Cocktail B: Cocktail A + Δ + ρ

➔ **Large excess yield!**

Systematic errors:

15% efficiency correction
10% combinatorial background
11% π^0 normalization

21% Total