Detectors

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- Human Sense and Detector
- Particle Identification

Human Sense and Detector

Eyes → Neurons → Brain

Sense — Signal — Cognition

Detectors → Cables, Circuits → Computer

Can you trust human sense ?

Importance of Detector

Detector innovation can arise new physics

Telescope (1590) → Newton Mechanics (17C)

Velocity of Light (1873) → Special Relativity (1905)

Spectroscopy of Hydrogen → Quantum Mechanics

Human Sense and Detector 2

Eyes	Detector
Shapes	Position
Colors	Energy
Of course, Light	Particle Identification

Particle Identification

Mass Identification

$P = m\gamma\beta$: momentum

$E = m(\gamma-1)$: kinematic energy

β : velocity

We need
2 of 3. & Z.

Special Detectors

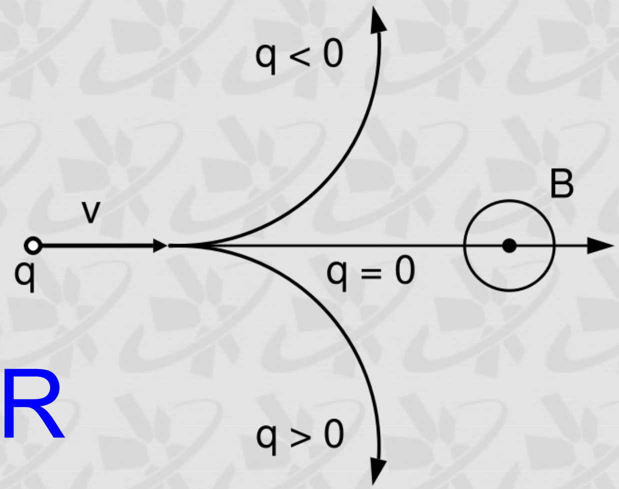
Neutron counter, Cherenkov counter,
Shower counter, Muon counter … etc.

Momentum Measurement

Charge : q

Magnetic field : B

Curvature radius : R



$$P / q = 0.3 \times B \cdot R$$

[MeV/c]	[kgauss]	[cm]
[GeV/c]	[T]	[m]
[TeV/c]	[T]	[km]

Requirement for Momentum Measurement

Position Resolution

Thin Material

Table 28.1: Typical resolutions and deadtimes of common detectors. Revised September 2003 by R. Kadel (LBNL).

Detector Type	Accuracy (rms)	Resolution Time	Dead Time
Bubble chamber	10–150 μm	1 ms	50 ms[a]
Streamer chamber	300 μm	2 μs	100 ms
Proportional chamber	50–300 μm[b,c,d]	2 ns	200 ns
Drift chamber	50–300 μm	2 ns[e]	100 ns
Scintillator	—	100 ps/n[f]	10 ns
Emulsion	1 μm	—	—
Liquid Argon Drift [7]	~175–450 μm	~ 200 ns	~ 2 μs
Gas Micro Strip [8]	30–40 μm	$<$ 10 ns	—
Resistive Plate chamber [9]	$\lesssim$ 10 μm	1–2 ns	—
Silicon strip	pitch/(3 to 7)[g]	h	h
Silicon pixel	2 μm[i]	h	h

Multiple Scattering

$$\theta_0 = \frac{13.6\ \text{MeV}}{\beta c p}\, z\, \sqrt{x/X_0}\Big[1 + 0.038 \ln(x/X_0)\Big]$$

Z: particle charge

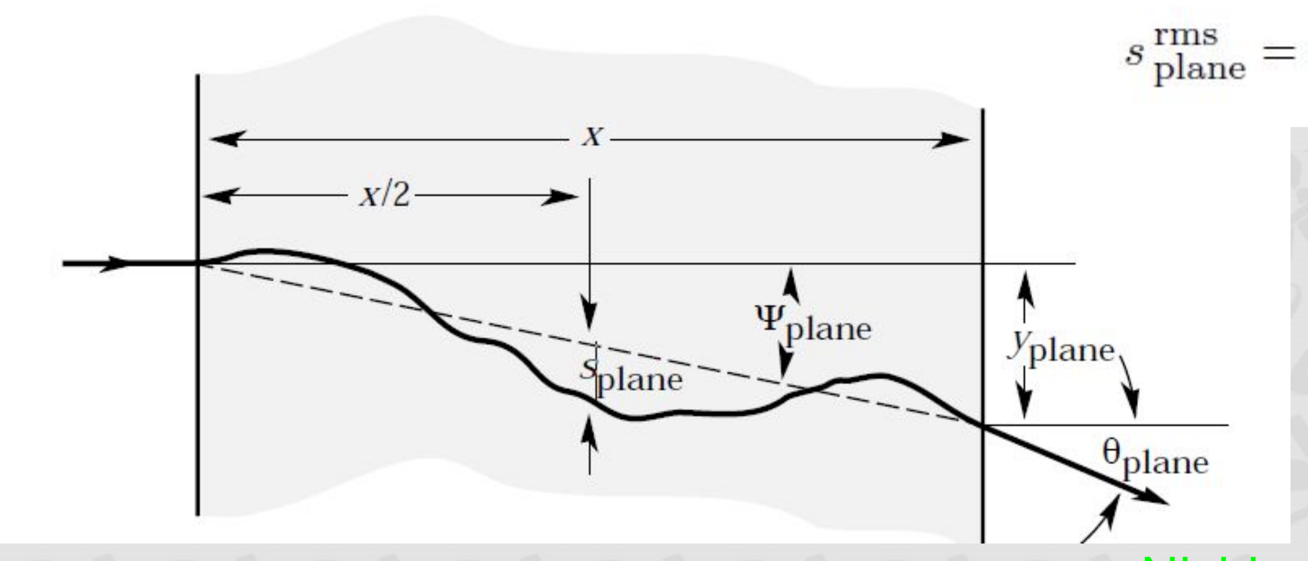
x: material thickness

X_0: radiation length

$$\psi^{\text{rms}}_{\text{plane}} = \frac{1}{\sqrt{3}}\, \theta^{\text{rms}}_{\text{plane}} = \frac{1}{\sqrt{3}}\, \theta_0 \,,$$

$$y^{\text{rms}}_{\text{plane}} = \frac{1}{\sqrt{3}}\, x\, \theta^{\text{rms}}_{\text{plane}} = \frac{1}{\sqrt{3}}\, x\, \theta_0 \,,$$

$$s^{\text{rms}}_{\text{plane}} = \frac{1}{4\sqrt{3}}\, x\, \theta^{\text{rms}}_{\text{plane}} = \frac{1}{4\sqrt{3}}\, x\, \theta_0$$



Radiation Length

Material	Z	A	$\langle Z/A \rangle$	Nucl.coll. length λ_T {g cm^{-2}}	Nucl.inter. length λ_I {g cm^{-2}}	Rad.len. X_0 {g cm^{-2}}	$dE/dx\|_{min}$ { MeV g^{-1}cm^2}	Density {g cm^{-3}} ({gℓ^{-1}})	Melting point (K)	Boiling point (K)	Refract. index (@ Na D)
H_2	1	1.00794(7)	0.99212	42.8	52.0	63.04	(4.103)	0.071(0.084)	13.81	20.28	1.11[132.]
D_2	1	2.01410177803(8)	0.49650	51.3	71.8	125.97	(2.053)	0.169(0.168)	18.7	23.65	1.11[138.]
He	2	4.002602(2)	0.49967	51.8	71.0	94.32	(1.937)	0.125(0.166)		4.220	1.02[35.0]
Li	3	6.941(2)	0.43221	52.2	71.3	82.78	1.639	0.534	453.6	1615.	
Be	4	9.012182(3)	0.44384	55.3	77.8	65.19	1.595	1.848	1560.	2744.	
C diamond	6	12.0107(8)	0.49955	59.2	85.8	42.70	1.725	3.520			2.42
C graphite	6	12.0107(8)	0.49955	59.2	85.8	42.70	1.742	2.210			
N_2	7	14.0067(2)	0.49976	61.1	89.7	37.99	(1.825)	0.807(1.165)	63.15	77.29	1.20[298.]
O_2	8	15.9994(3)	0.50002	61.3	90.2	34.24	(1.801)	1.141(1.332)	54.36	90.20	1.22[271.]
F_2	9	18.9984032(5)	0.47372	65.0	97.4	32.93	(1.676)	1.507(1.580)	53.53	85.03	[195.]
Ne	10	20.1797(6)	0.49555	65.7	99.0	28.93	(1.724)	1.204(0.839)	24.56	27.07	1.09[67.1]
Al	13	26.9815386(8)	0.48181	69.7	107.2	24.01	1.615	2.699	933.5	2792.	
Si	14	28.0855(3)	0.49848	70.2	108.4	21.82	1.664	2.329	1687.	3538.	3.95
Cl_2	17	35.453(2)	0.47951	73.8	115.7	19.28	(1.630)	1.574(2.980)	171.6	239.1	[773.]
Ar	18	39.948(1)	0.45059	75.7	119.7	19.55	(1.519)	1.396(1.662)	83.81	87.26	1.23[281.]
Ti	22	47.867(1)	0.45961	78.8	126.2	16.16	1.477	4.540	1941.	3560.	
Fe	26	55.845(2)	0.46557	81.7	132.1	13.84	1.451	7.874	1811.	3134.	
Cu	29	63.546(3)	0.45636	84.2	137.3	12.86	1.403	8.960	1358.	2835.	
Ge	32	72.64(1)	0.44053	86.9	143.0	12.25	1.370	5.323	1211.	3106.	
Sn	50	118.710(7)	0.42119	98.2	166.7	8.82	1.263	7.310	505.1	2875.	
Xe	54	131.293(6)	0.41129	100.8	172.1	8.48	(1.255)	2.953(5.483)	161.4	165.1	1.39[701.]
W	74	183.84(1)	0.40252	110.4	191.9	6.76	1.145	19.300	3695.	5828.	
Pt	78	195.084(9)	0.39983	112.2	195.7	6.54	1.128	21.450	2042.	4098.	
Au	79	196.966569(4)	0.40108	112.5	196.3	6.46	1.134	19.320	1337.	3129.	
Pb	82	207.2(1)	0.39575	114.1	199.6	6.37	1.122	11.350	600.6	2022.	
U	92	[238.02891(3)]	0.38651	118.6	209.0	6.00	1.081	18.950	1408.	4404.	
Air (dry, 1 atm)			0.49919	61.3	90.1	36.62	(1.815)	(1.205)		78.80	
Shielding concrete			0.50274	65.1	97.5	26.57	1.711	2.300			
Borosilicate glass (Pyrex)			0.49707	64.6	96.5	28.17	1.696	2.230			
Lead glass			0.42101	95.9	158.0	7.87	1.255	6.220			
Standard rock			0.50000	66.8	101.3	26.54	1.688	2.650			

Energy Measurement

Energy Loss

Total Energy

$$-\frac{dE}{dx} \propto \frac{z^2}{\beta^2}$$

All deposited energy

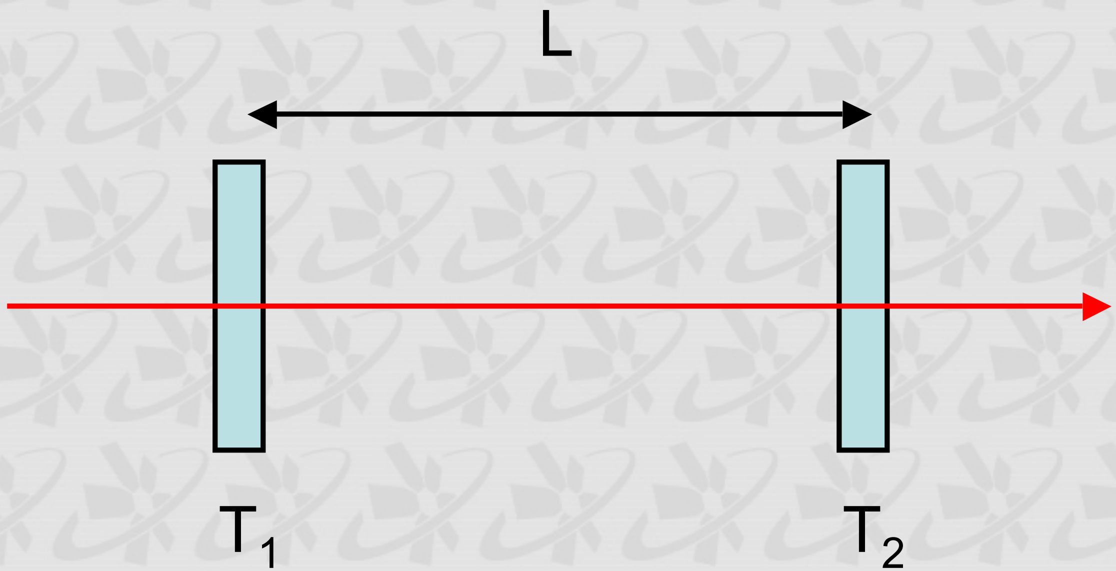
Requirement for Energy Measurement

Energy Resolution

Thick Material

Detector	Ionization energy I (eV)	Energy resolution @ 5MeV
Scintillation	100 ~ 500	1.1 ~ 2.4 %
Gas	30	0.6 %
Semiconductor	3	0.2%

Velocity Measurement



$$\beta = L\,(T_1 - T_2)\,/\,c$$

Requirement for Velocity Measurement

Timing Resolution

Thin Material

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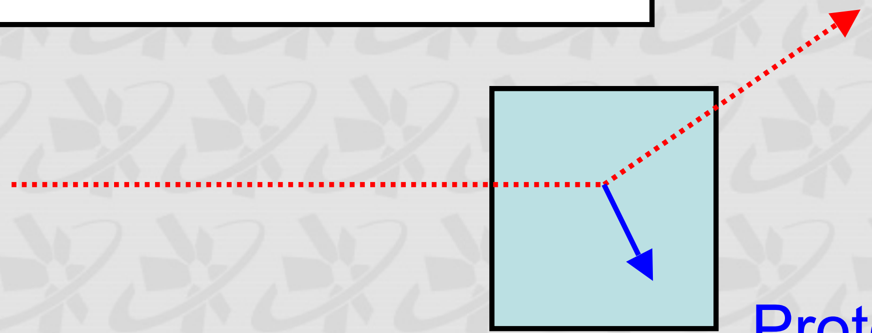
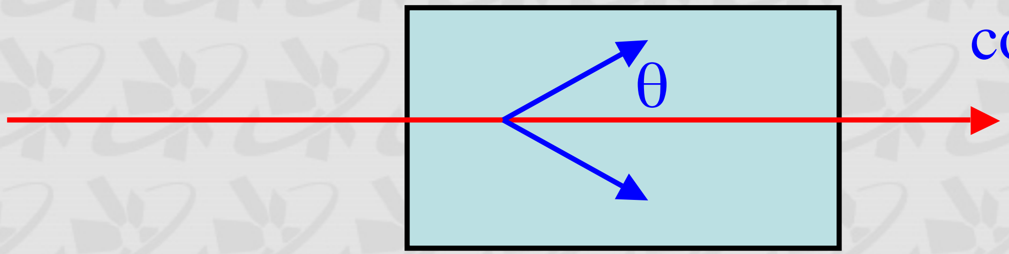
Special Detectors

Neutron Counter



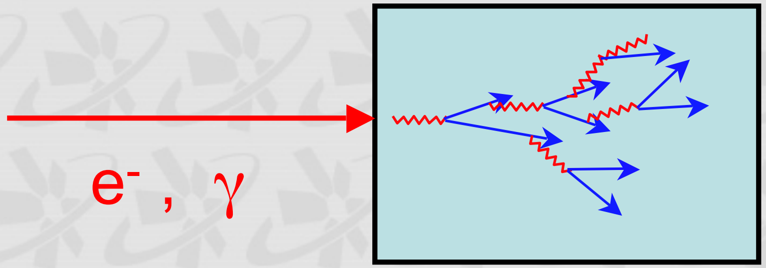
Cherenkov Counter



$$\cos\theta = 1 / n\beta$$

Special Detectors 2

Shower Counter

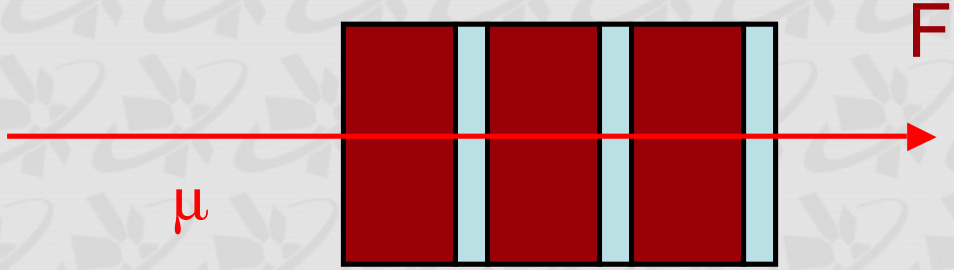


CsI, BGO, GSO

Lead Glass

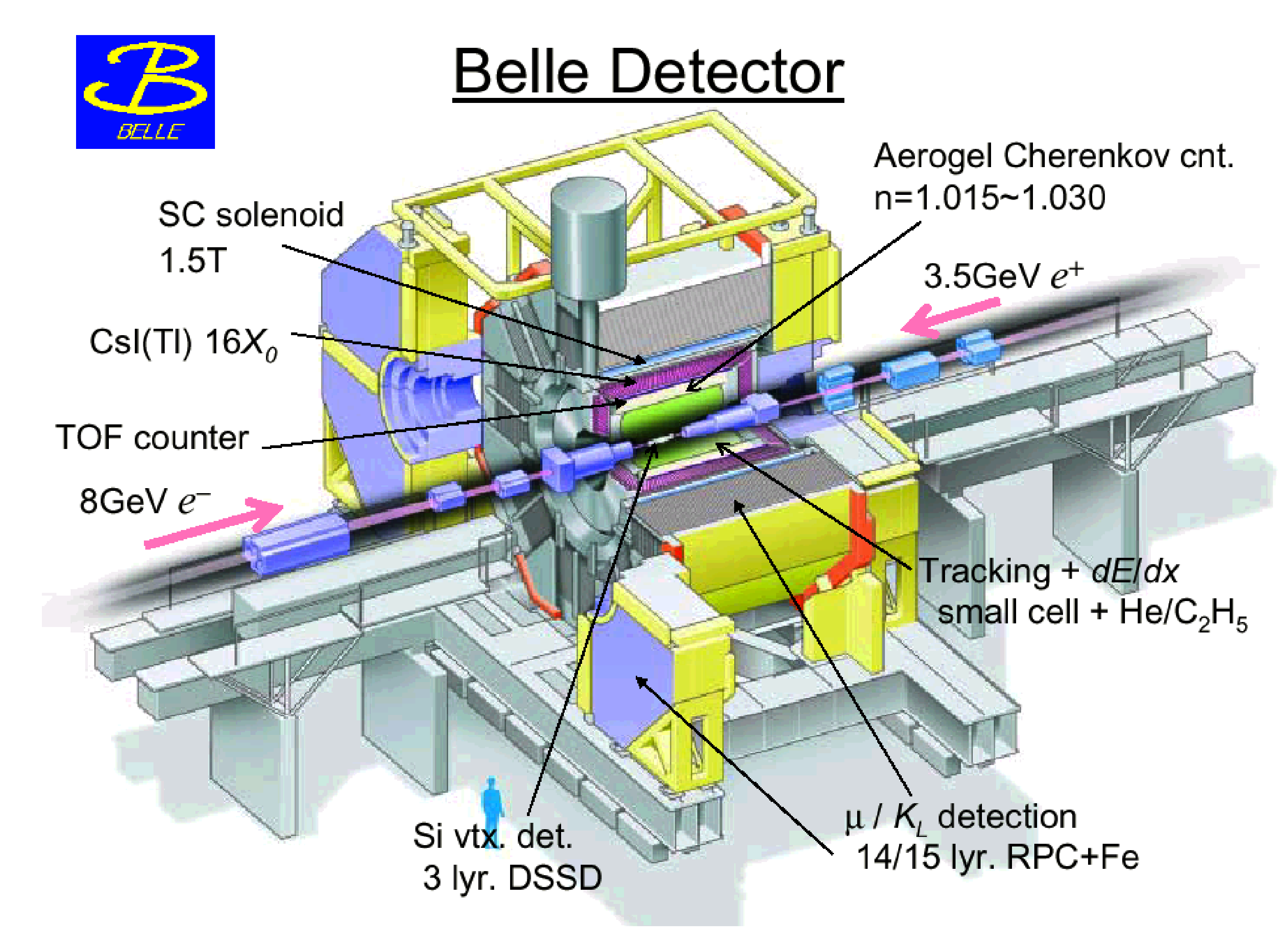
Electromagnetic shower

Muon Counter

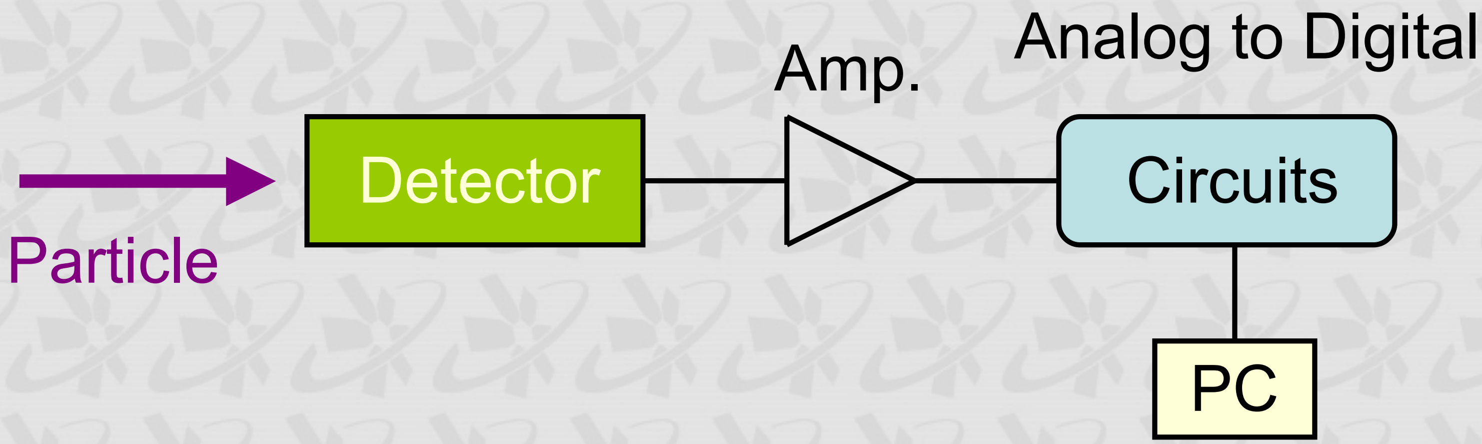


Fe + Counter

Total Detector System (Belle)



Data Taking



1. Generating some signals
2. Amplification
3. Analog to Digital Conversion and Logic
4. Getting into Computer and Analysis

Summary

- You need detectors to investigate nature, because you cannot feel particles and nuclei.

- You have to build and/or be familiar with detectors for your own experiments.

from this afternoon