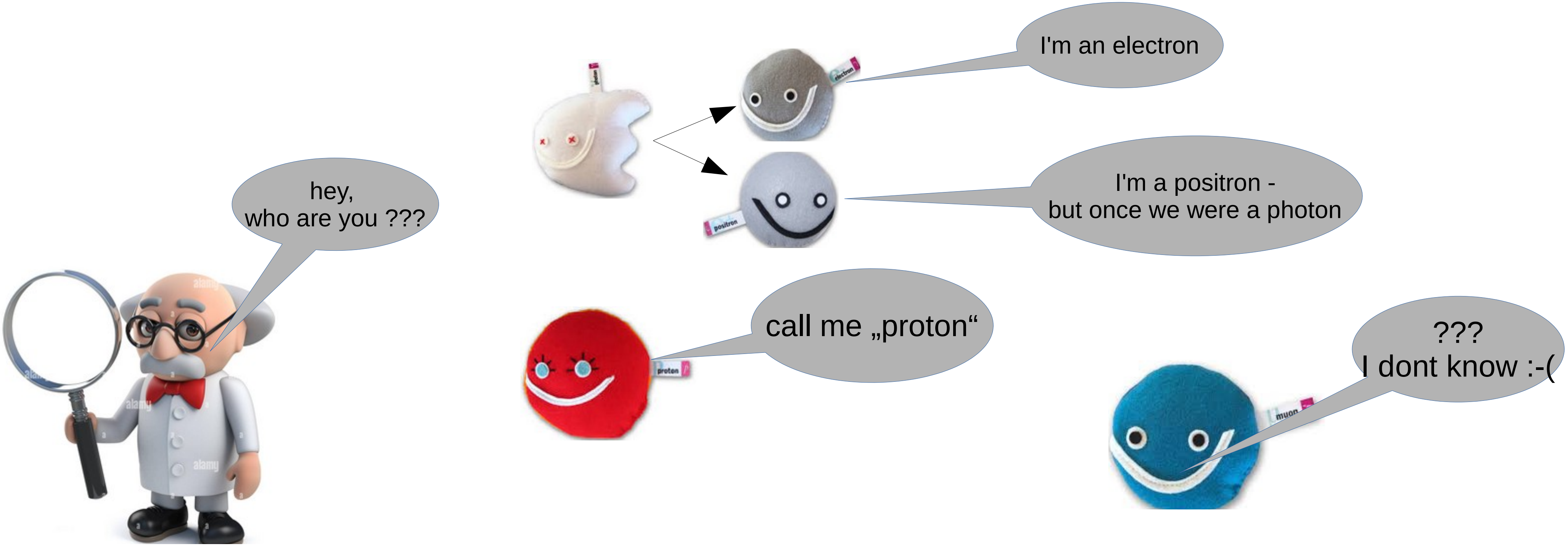
~~The art of particle ID~~
Basic topics on particle ID

Christian Pauly, BU Wuppertal



overview

- Particle-ID in general
- Particle-ID based on energy loss
- Particle-ID based on Time-of-Flight
- Particle-ID using kinematics : Invariant- and Missing mass
  - Dalitz plot
- Particle-ID using TRD
- Particle-ID using RICH

What is particle ID ?

- In general, if we deal with a new particle:
  “the **determination of all quantities** that allow us to infer the identy of the particle“
  - particle **mass m_0**
  - particle **lifetime τ**
  - **quantum numbers** : charge, spin, Isospin, parity…

$$rho(728) \quad I^G(J^{PC}) = 0^-(1^{--})$$

- In CBM data analysis, **we usually know with which particles we deal**

  => particle ID: **Determine particle mass m_0 and charge q**
  from the signals of one or several detector components

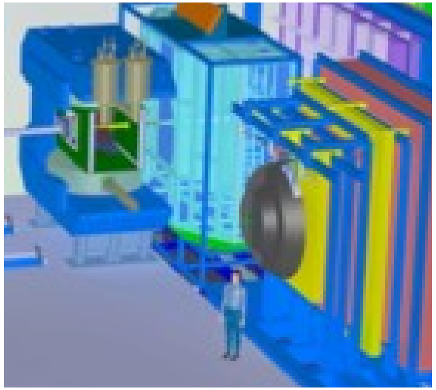
- Short-lived particles (e.g. like rho meson) => identify decay products to infer the decaying particle

Methods of particle ID

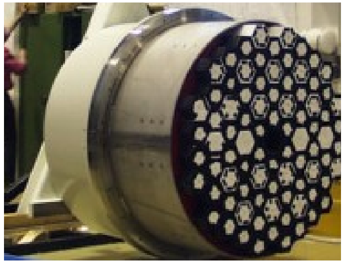
$$m = \frac{p}{\gamma\beta}$$

- **Charged particles:** → Measure momentum p and velocity β:
  - momentum, charge → **magnetic field, tracking**
  - for β, ɣ, or βɣ : 4 basic techniques:
    - Time-of-Flight
    - specific energy loss by ionisation: dE/dx
    - Cherenkov radiation
    - Transition Radiation
- **Decaying particles:** (e.g. π^0 , η, ρ, ϕ, J/Ψ , ...)
  - via their decay products: **invariant- or missing mass**
  - 3-body decays : **Dalitz plot**… (also to obtain quantum numbers)
- **Electrons or Photons:**
  - electromagnetic shower in ECAL calorimeter, measurement of total energy E
  - E ~= p, → if electron, measured momentum p (tracking) must match energy E (ECAL)
  - photons : leave no trace in tracking station
  - ECAL response identical for photons and electrons !

Methods of particle ID



- **Muons:**
  - capability to **penetrate thick absorber layers**
  - our CBM MUCH Detector: 4 absorber layers of thick carbon and iron
- **Neutrons:**
  - neutral, so no ionizining track… but:
  - can undergo nuclear interactions, e.g. **scatter and transfer energy to a proton**
    → proton gets „kicked“, preferably in forward direction (Lorentz boost)
    → **proton leaves ionizing track behind**
  - sufficiently „long“ scintillators, special doping to enrich neutron cross section



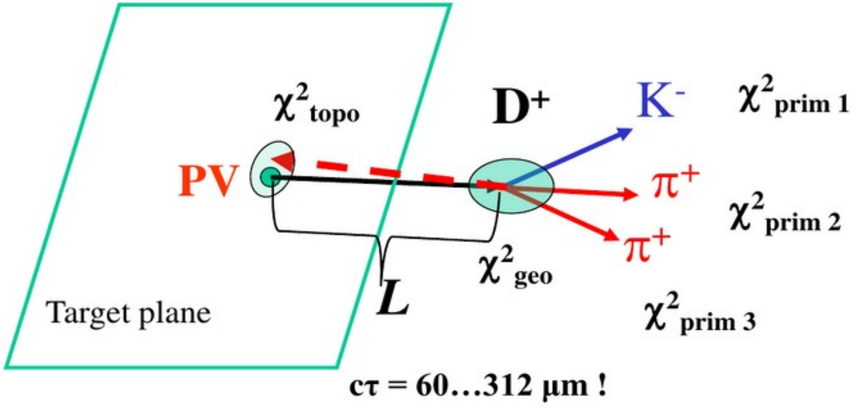
TOF endcap calorimeter

TOF nCAL

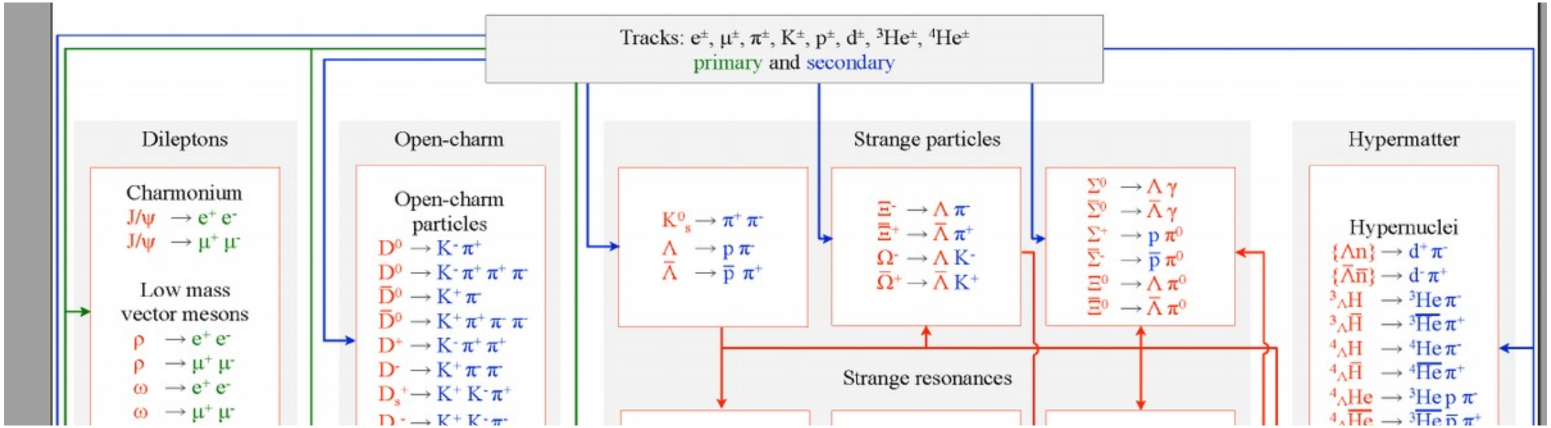
veto scintillator in front of nCAL

Methods of particle ID

- **Short-lived particles:**
  → secondary vertex reconstruction
  - **e.g. open charm : D-mesons**
  - **decay still inside target region**
  - primary vertex very well known
    from track fit of many tracks
  - need for very good secondary vertex reco → **MVD**



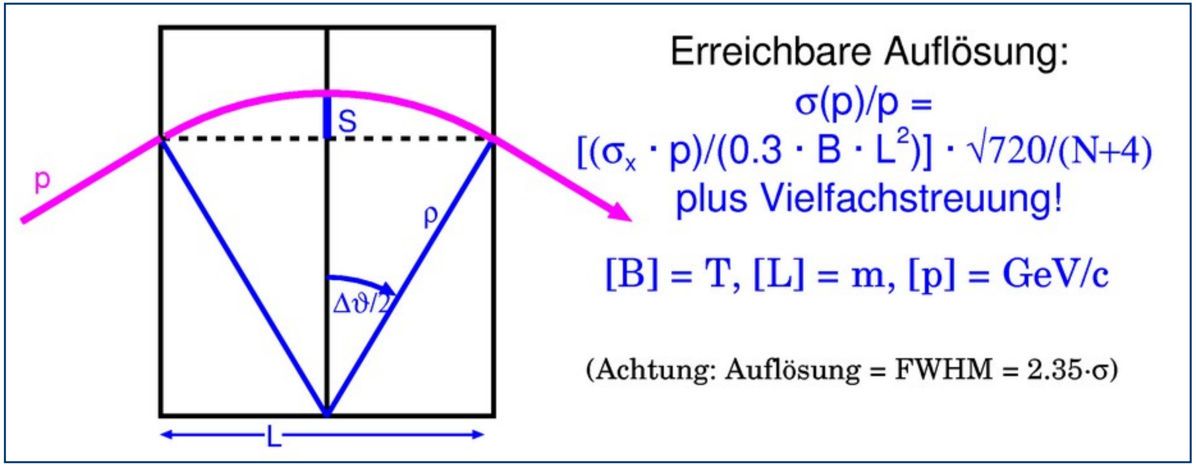
- **tool : „CBM KF Particle Finder“**



Momentum from magnetic field

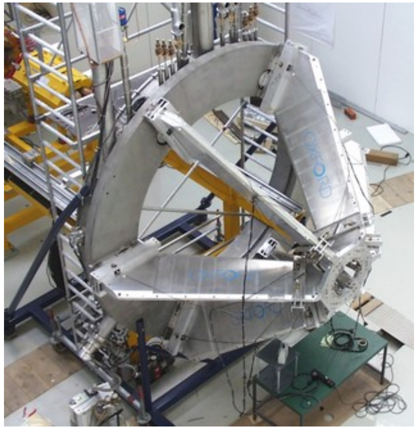
$$2\sin\frac{\theta}{2} = \frac{L}{R} = -q\frac{B_y L}{p}$$

$$p = q B_y R$$



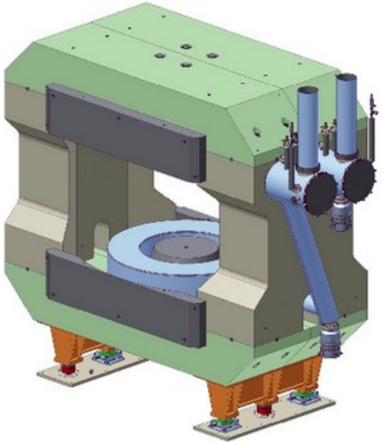
HADES:
Toroidal field
- closed field lines
- acceptance down to 0°
- **phi symmetric**
- deflection in / out

$$\int B\,dl < 0.5\,Tm$$



CBM:
Dipol field
- larger field integral
- large horizontal acceptance
- no phi symmetry
- deflection left / right

$$\int B\,dl \sim 1\,Tm$$

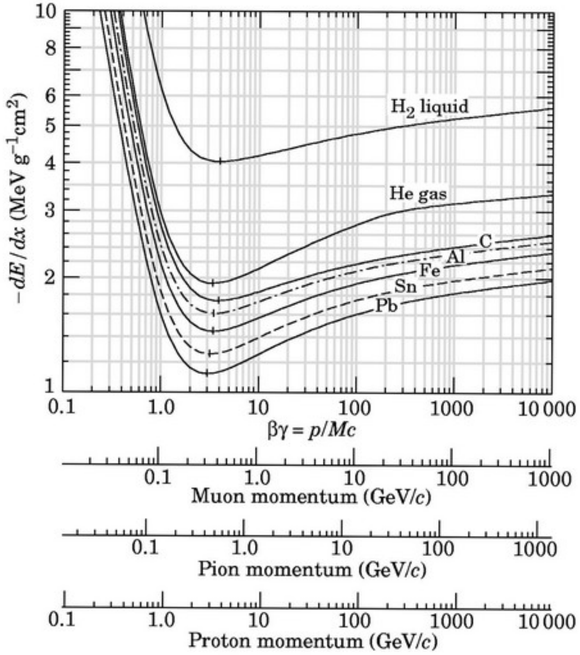


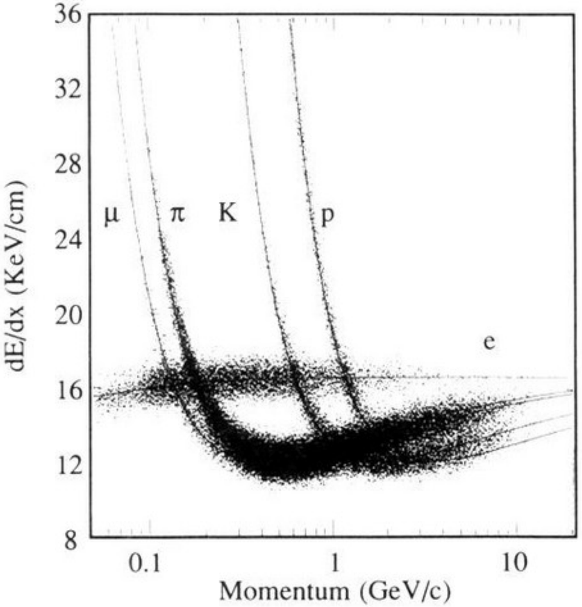
dE/dx energy loss technique

energy loss of ionizing particle according to Bethe-Bloch

$$-\frac{dE}{dx} = 4\pi\alpha^2 \frac{(\hbar c)^2}{mc^2} n_0 \frac{z^2}{\beta^2}\left[\ln\left(\frac{2mc^2\beta^2}{(1-\beta^2)I}\right) - \beta^2\right]$$

α : Feinstructure constant
I : average ionisation potential



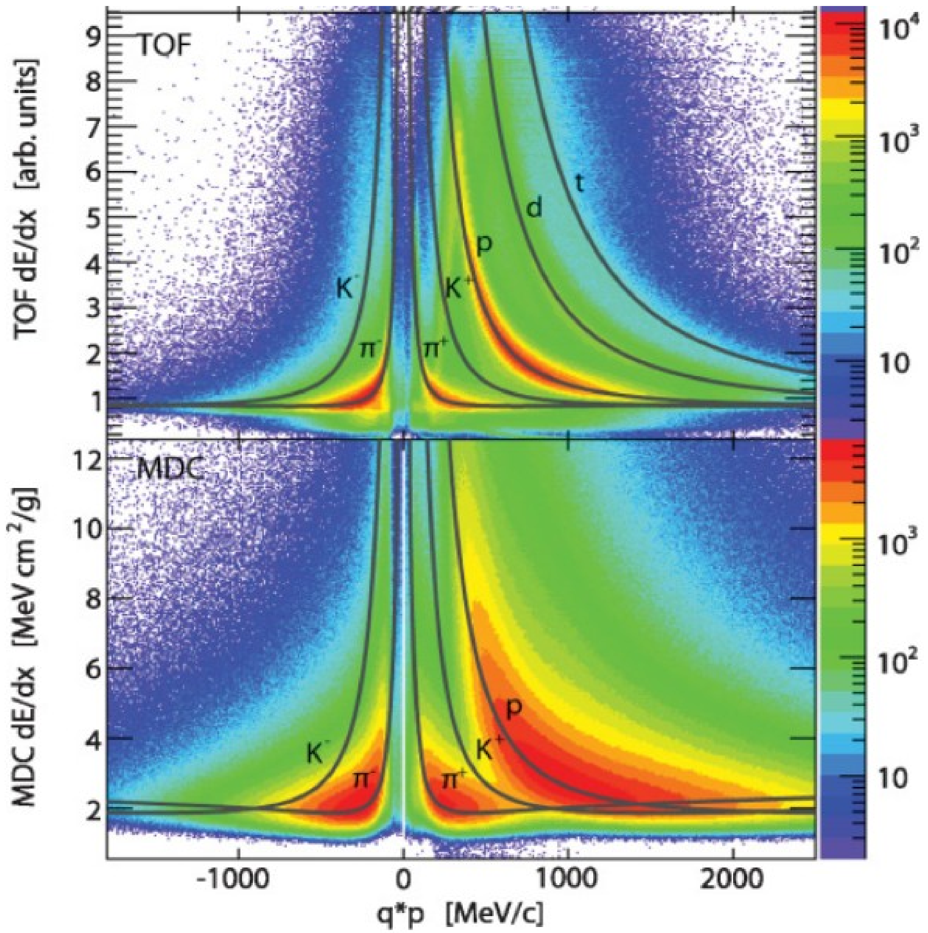


- energy loss in material is function of βɣ

$$\beta\gamma = \frac{p}{mc}$$

- for particle with given p, dE/dX depending on mass
- dE/dx from scintillator - or drift chamber, TRD, TOF, … - often measured as „by-product“
- minimum ionizing particle in plastic scintillator:
  dE/dX ~ 2 MeV / (g / cm^2)
  ~ 2 MeV /cm

example : HADES dE/dX from MDC / TOF



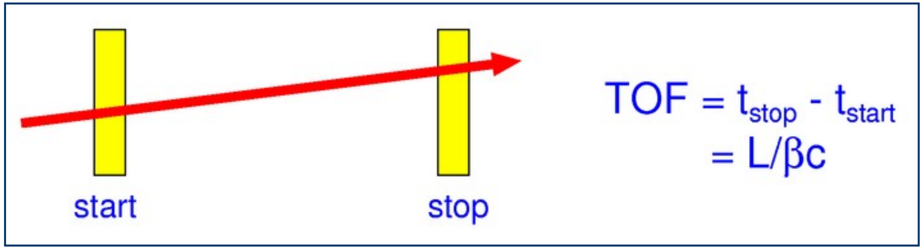
HADES TOF

HADES MDC

Time-of-Flight

- Time-of-Flight measures velocity β of a particle:

$$\beta c = \frac{L}{\mathrm{ToF}}$$



- by combining with measured momentum (p = ɣβm)

$$m^2 = p^2 [(\frac{ToF\ \ c}{L})^2 - 1]$$

=> measuring momentum p and Time-of-Flight together yields mass of the particle !
(m² to prevent problems in case of negative masses due to measurement uncertainty)

- actually : tracking system measures p/q, not p:

$$(\frac{m}{q})^2 = (\frac{p}{q})^2 \ [(\frac{ToF\ \ c}{L})^2 - 1]$$

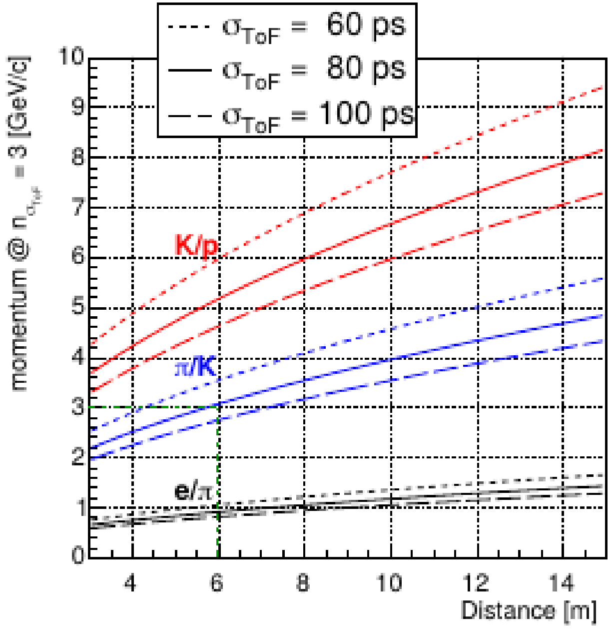
=> **ToF alone can not distinguish particles with same m/q** : eg deuteron <> ^{4}He

TOF requirements

- Time-of-Flight measurement requries
  - very **precise start+stop time measurement σ (t_{stop} – t_{start})** (CBM-TOF: σ_{stop} ~ 50-100 ps)
  - sufficient measurement length L (CBM TOF: L~6m !)
- Usually, mass resolution is limited by the timing precision:

$$\sigma_m^2 = \frac{2p^2}{\beta^2}\frac{\sigma_t}{t}$$

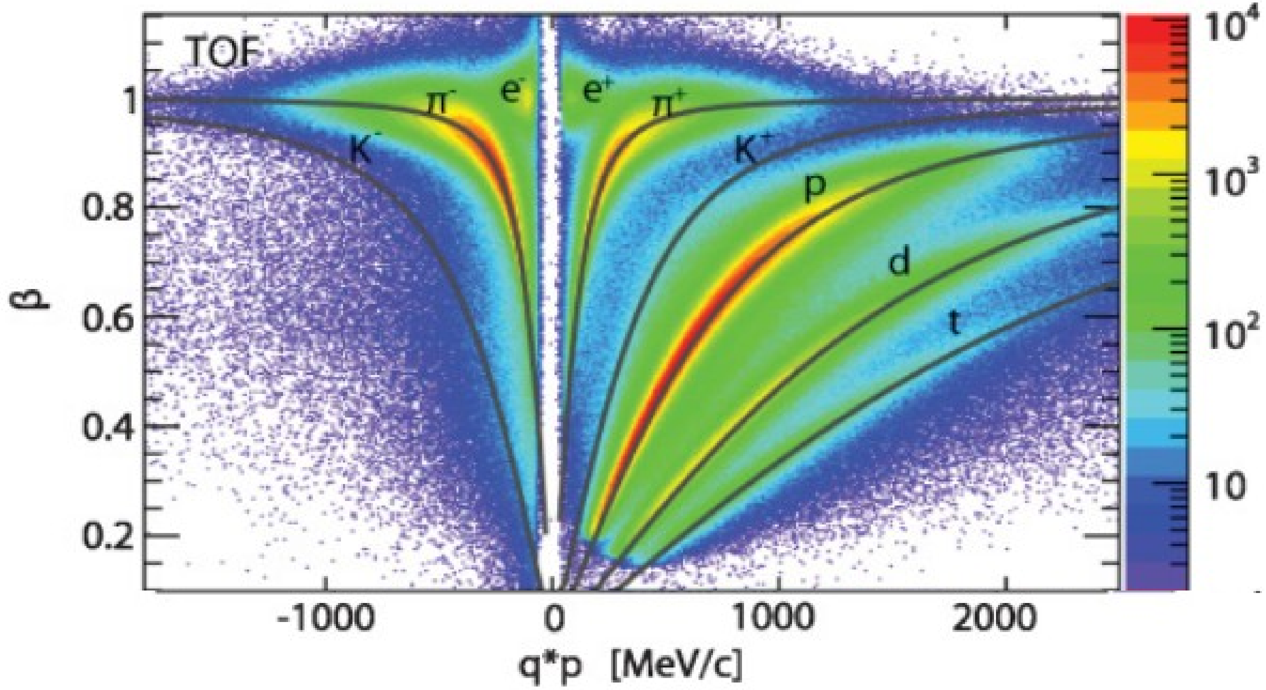
  - **$\sigma_m{}^2$ proportional p^2 !**
  - only applicable for momenta up to few GeV/c



from CBM TOF TDR

Figure 2.4: Dependence of separation power of TOF system as function of momentum, time resolution and flight path length.

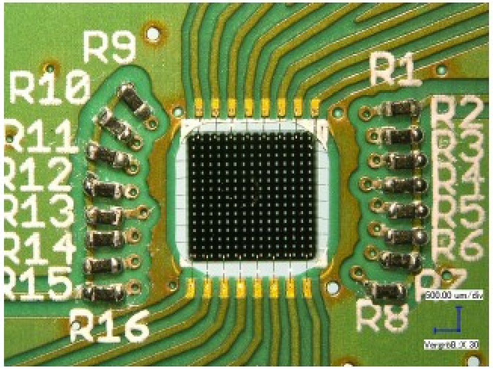
ToF in HADES



dedicated start detector:
- either diamond detector
- or LGAD Si detector

outer TOF: scintillators, PMTs
$\sigma_{TOF,Sci}$ ~ 150 ps

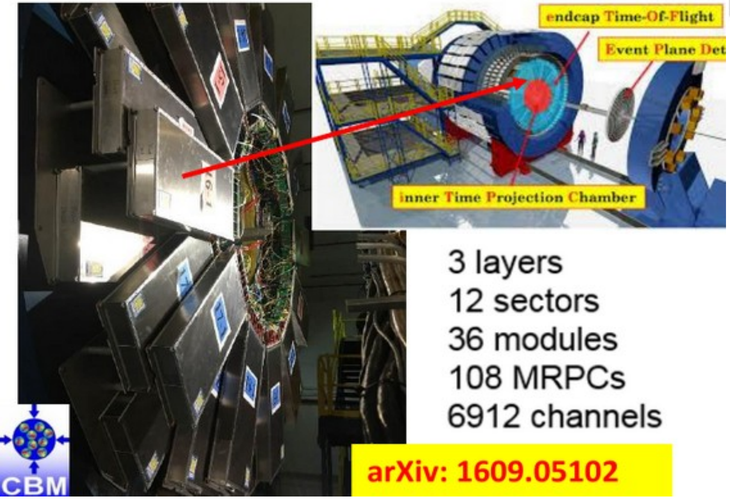
inner TOF: RPCs
$\sigma_{TOF,RPC}$ ~ 75 ps



HADES CVD diamond start detector
“**C**hemical **V**apour **D**eposit“

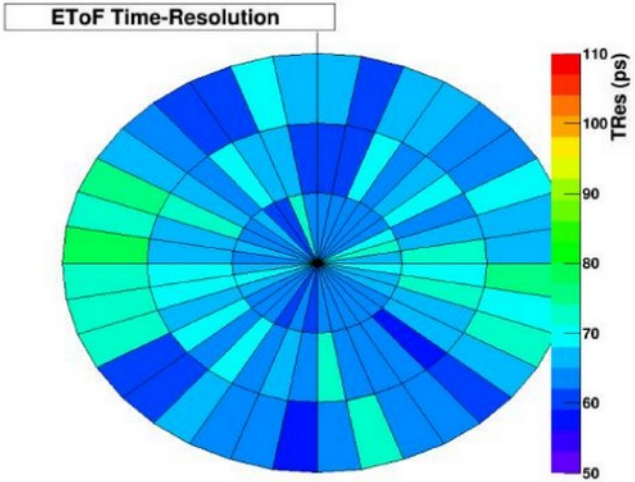
- very good electron / pion separation at low momenta
- above ~300 MeV/c we need the RICH

CBM eTOF@STAR/BNL

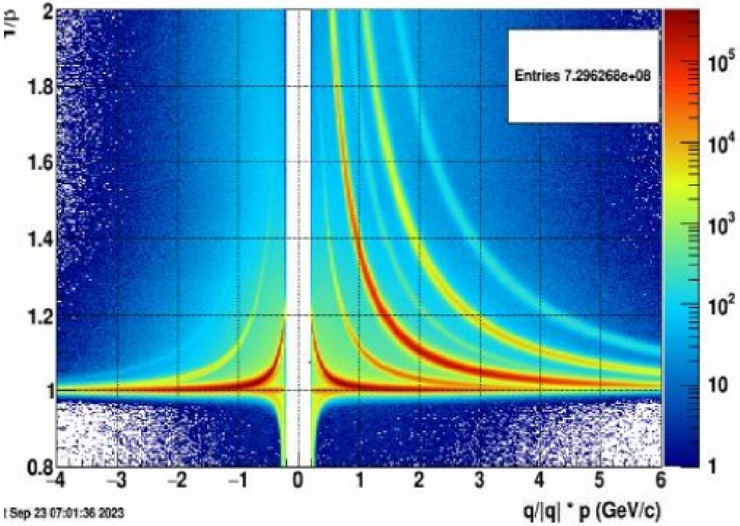


3 layers
12 sectors
36 modules
108 MRPCs
6912 channels

arXiv: 1609.05102



EToF-Time-Resolution at 3.5 GeV FXT 2020



$1/\beta$ vs. momentum

from I. Deppner

Options for START

- ToT not only needs a precise STOP-detector („ToF-detector),
  it also needs precise **START time**

- different options:

  - **dedicated start detector** upstream of target
    usually CVD diamond detectors (the primary beam goes through the detector !)
    or Low-gain Avalanche („LGAD“) Si detectors

    in HADES, the start detector has to be moved regularly to mitigate beam damage

  - in a (central) heavy ion collision, START time can be deduced from event itself
    assuming that always a few fastest particles have v=c, $\beta=1$
    the more particles, the better...

kinematic particle ID

Missing – and Invariant Mass Technique

Invariant Mass

- Based on the **relativistic energy – momentum correlation**:

  $$E^2 = p^2 c^2 + m^2 c^4$$ or, if we put c := 1 $$E^2 = p^2 + m^2$$

  E: total energy of the system, $E=m_0 c^2 + E_{kin}$
  p: total momentum, of the system
  m: “total mass“ of the system

- for a **single particle,** in a system where this particle is at rest,
  this relation correlates energy, momentum, and mass of this given particle.
  → for a photon: m=0 → $E^2 == p^2$

- In a system with more than one particle: $$\left(\sum_i E_i\right)^2 = \left(\sum_i \vec{p}_i\right)^2 + m_{inv}^2$$

- m_{inv} is called **„invariant mass“**,
  because it is Lorentz invariant quantity !

Invariant Mass

- m_{inv} is called **„invariant mass“**, because it is Lorentz invariant quantity !
- For a particle decay, this has an interesting consequence: Lets assume $\eta \rightarrow \pi^{+} \pi^{-} \pi^{0}$
- First, we transform into the rest frame of the η-meson :
  - here, p==0, E_{kin}=0 -> E=m : m_{inv} , the Eigenmass of the η Meson , m_{inv} = 547 MeV
- Now we transform into the lab system, measure E_{lab} and $\mathbf{p}_{lab}$ of each pion, and calculate m_{inv}:

$$\left(\sum_i E_i\right)^2 - \left(\sum_i \vec{p}_i\right)^2 = m_{inv}^2$$

- since m_{inv} is **invariant under Lorentz Transformation**, we still get m_{inv}=547 MeV == m_η
  - even including relativistics → fast particles v close to c !

Invariant Mass

- The **invariant mass of a system of particles** in their common CMS reference frame is the **sum of Eigenmasses** of the particles **plus** the mass equivalent of the kinetic energy of their relative motion

- If all particles stem from the decay of a single, common particle then we can transform into the restframe of this single particle, where kinetic energy is 0, and $m_{inv} = m_0$

- In this case, **$m_{inv} = m_0$** , i.e. the **mass of the decaying particle**, also in every other reference system !

- Using 4-vectors:

$$\boldsymbol{P_i} = \begin{pmatrix} E_i \\ -\boldsymbol{p}_{i,x} \\ -\boldsymbol{p}_{i,y} \\ -\boldsymbol{p}_{i,z} \end{pmatrix} \qquad m_{inv}^2 = \left(\sum_i \boldsymbol{P_i}\right)^2$$

→ easy to use in ROOT / PyROOT

Missing Mass

- closely related to invariant mass m_{inv} is the **missing mass: m_{miss}**
- Lets assume meson production in proton-proton scattering: p+p → $p_1 + p_2 + \pi^0$
  and we only measure the two protons:

$$E_{beam} + E_{target} \rightarrow E_1 + E_2 + E_x$$
$$\vec{p}_{beam} + \vec{p}_{target} \rightarrow \vec{p}_1 + \vec{p}_2 + \vec{p}_x$$

- Usually, both beam – and target momentum are well known (in proton – proton scattering).
  → from energy- and momentum conservation:

$$E_{missing} = (E_{beam} + E_{target} - E_1 - E_2) = E_x$$
$$\vec{p}_{missing} = \vec{p}_{beam} + \vec{p}_{target} - \vec{p}_1 - \vec{p}_2 = \vec{p}_x$$

Missing Mass

- According to $E^2 = p^2 + m^2$: relativistic energy momentum correlation
  we can also assign a mass to E_{miss} and p_{miss}:

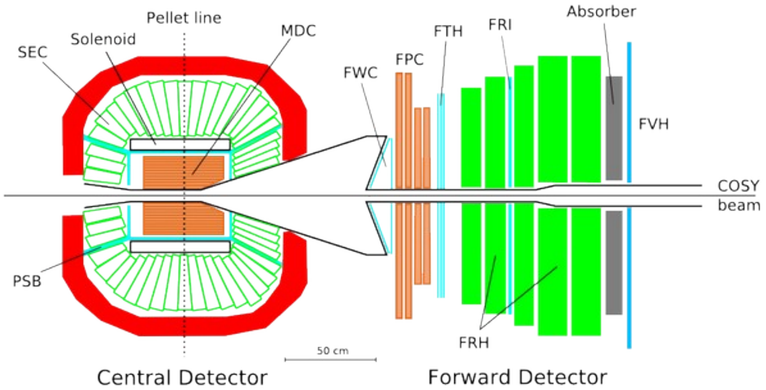
$$m_{miss}^2 = E_{miss}^2 - \vec{p}_{miss}^{\,2} = E_X^2 - \vec{p}_X^{\,2} = m_X^2$$

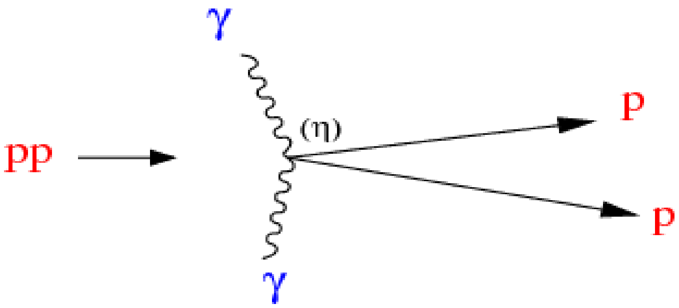
- m_{miss} is the „Missing Mass“ based on measurement of the two measured protons.

- **The missing mass of all measured particles is equal to the invariant mass of all not-measured particles.**
  - If only a **single particle was not measured** (e.g. a decaying meson), then the **missing mass is aequivalent to the Eigenmass of the unmeasured (e.g. decaying) particle**

- **This can be used for „tagging“**

example : WASA experiment





pp → pp η   or   pd → ^{3}He η

η tagging via missing mass (from FD)

Forward Detector FD
angular and energy reconstruction for protons and pions
EdE particle Identification
fast signals for trigger

Central Detector CD
reconstruction of all charged/neutral decay products
magnetic field: momentum rec.
CsI (Na) calorimeter with Photo Multiplier readout

Pellet Target
high target density
good vertex definition

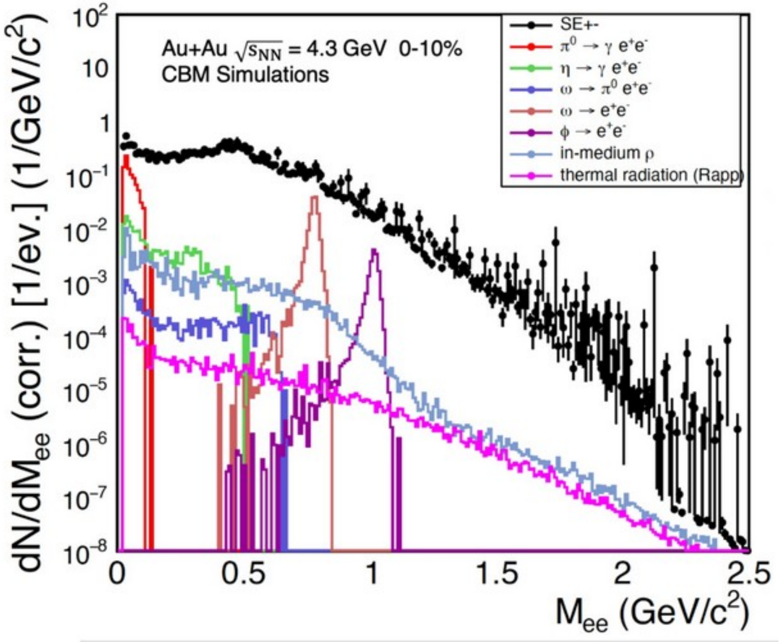
what about heavy-ion collisions ?

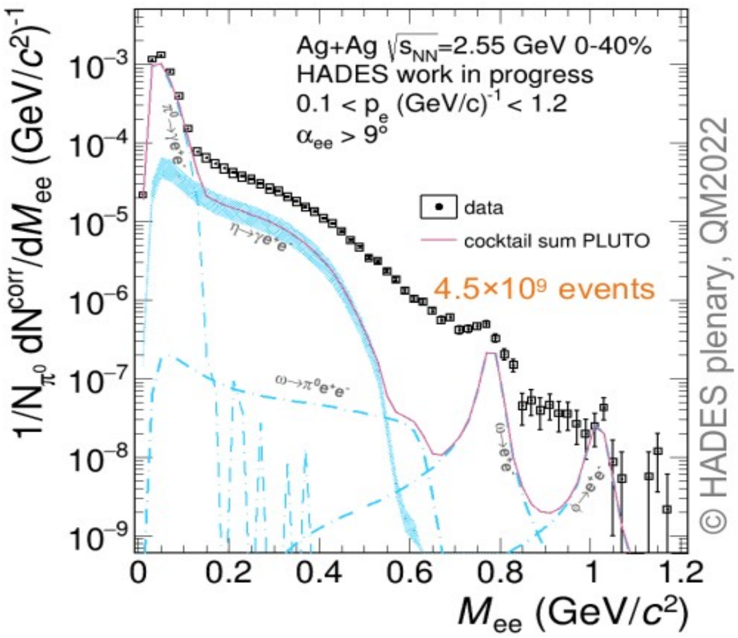
- in a heavy ion collision, missing mass technique is of limited use :
  - heavy-ion collision can basically be seen as many individual nucleon-nucleon collisions of both colliding nuclei
  - Inside each nucleus, the nucleons are confined → **have Fermi motion**

    → individual nucleon momenta are not precisely knows

- **Invariant mass can still be useful !**
  - invariant mass of decay products of a decaying particle (e.g. rho Meson), measured – for example – in the lab system, still carry invariant mass of the mother particle !
  - best example : Dilepton spectrum $\rho \rightarrow e^{+} e^{-}$

Example: Dilepton spectrum





Di-leptons measured in the lab system, still carry their origin from decaying rho meson
Measuring not even the rho vacuum mass,
but the **effective mass (or spectral function) of the decaying rho inside dense medium** !

The Dalitz plot

- very usefull tool for describing 3-body decay dynamics (R. H. Dalitz, 1953)
- 3-body phase space is characterized by only two independant variables:
- different variables can be chosen,
  usual choice: **Mandelstam variables:**

$$s_i = (P_0 - P_i)^2$$

P_0 : 4-vector of decaying particle
P_i : 4-vector of decay products

3x 4-vectors	12
4-momentum conservation	-4
3 invariant masses	-3
rotational symmetry	-3
Σ	2

- then: s_1 = invariant mass $m_{2,3}$, analogue s_2 and s_3
- any pair of two s_i^2, s_j^2 spans a 2-dimensional Dalitz plot
  - the Dalitz plot represents kinematically allowed phase space
  - pure phase space kinematics → constant matrix element
    → homogenous Dalitz plot, $|A(s_i,s_j)|^2 = \text{const}$

"invariant mass" from relativistic energy-momentum correlation

$$E^2 = p^2 c^2 + m^2 c^4$$

$$m_{inv}{}^2 = E^2 - p^2$$

Lorentz invariant !

example for a Dalitz plot analysis

$D^+ \rightarrow K^+ K^- \pi^+$

border of Dalitz plot defined by
energy and momentum conservation

$$T_a + T_b + T_c = E_{ges} - m_a c^2 - m_b c^2 - m_{c^2} c^2 = Q$$

Q: excess energy

phase space inhomogeneity:

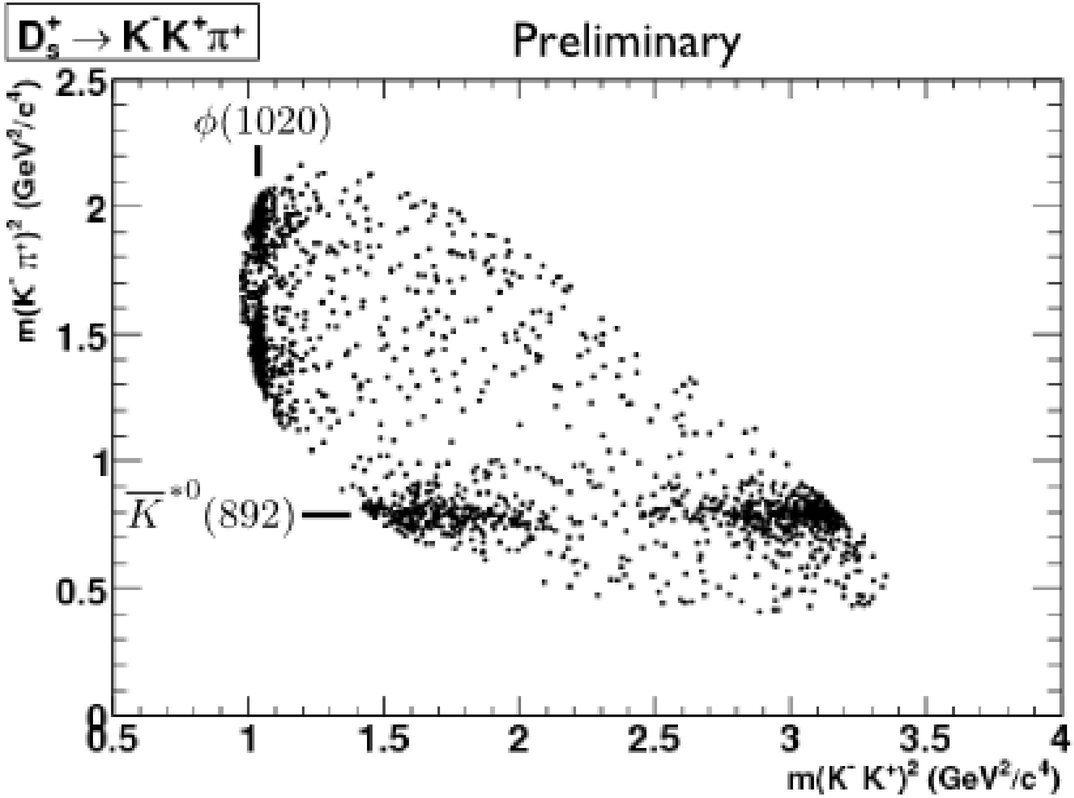
-> obviously, there are resonant sub-systems

$D^+ \rightarrow (\Phi \rightarrow K^+ K^-) \pi^+$

$D^+ \rightarrow (\bar{K}^{*0} \rightarrow \pi^+ K^-) K^+$

population along the bands allows conclusions on

- angular distributions
- quantum numbers for angular momentum
- ...



Particle ID using Transition radiation

- TR occurs, if a **particle traverses a medium with varying dielectricity index ε**
- one possible explanation (of many):
  - particle in vacuum generates **image charge in dense medium**
  - **charge + image charge from a dipol**
with **changing field strength** as particle is approaching
  - this **dipole radiates energy → TR photons**

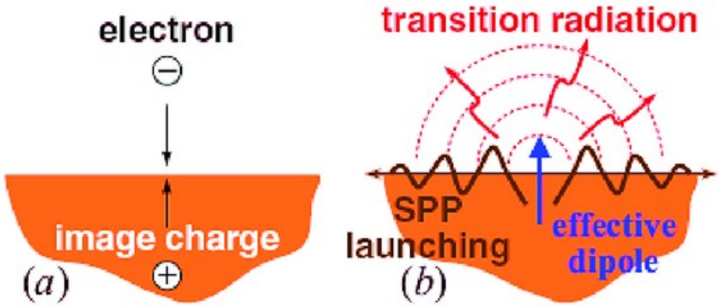
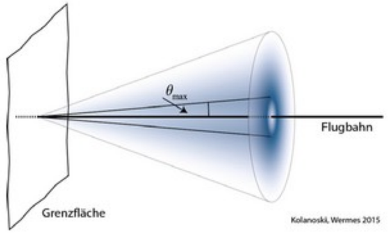


image:
Das, Pabitra. (2014). 10.13140/RG.2.2.23943.3

- **“Ginzburg – Frank formula“:** TR emission for single layer transition

$$\frac{d^2 n}{d\omega\, d\Omega} = \frac{\alpha}{\pi^2 \omega} \Phi^2 4 \sin^2\left[\frac{\omega L}{4c}\left(\frac{\omega_p^2}{\omega^2} + \Phi^2 + \gamma^{-2}\right)\right] \times \left(\frac{1}{\gamma^{-2} + \omega_p^2/\omega^2 + \Phi^2} - \frac{1}{\gamma^{-2} + \Phi^2}\right)^2$$

- **important features:**
  - emission into cone with **opening angle θ** : $\Theta \sim \frac{1}{\gamma}$
  - total emitted TR energy: **proportional ɣ**
  - energy of TR photons : few keV, **X-ray spectral range**

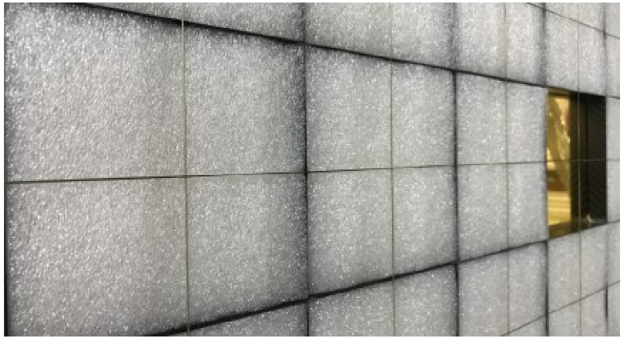


- **Detection of TR photons only possible if: ɣ ≥ ~1000**
→ electrons : p> 0.5 GeV/c pions: p > 140 GeV/c
→ in CBM: only electrons emit TR photons !!!

choice of TR radiator

- TR radiators made of foils, foam or fibres
- two basic concepts:
  - **regular radiator:** regular, equally spaced stack of foils
    → coherent interference → larger TR photon yield per incident electron per layer
  - **irregular radiators :** foams, or fiber stacks
    → less TR photons per boundary, but more boundaries due to more dense spacing
- further requirements:
  - **low absorption for TR photons** → low Z material (lower probability for photo effect)
  - **low material budget (scattering length X_0)**

- CBM TRD choice : irregular radiator
  PolyEthylene (PE) foam stack



CBM TRD radiators from mTDR (picture from TRD-TDR)

TRD detector principal

- **Radiator** in front of **drift chamber**
- Drift chamber gas : **Xenon**
  → high Z (Xenon : Z=54)
  → large probability for photon effect: **proportional** $\mathbf{Z^3}$
- All charged particles cause ionization in the gas !
- but only electrons (in CBM):
  TR photon → photo effect → additional ionization
- **in average:**
  larger energy deposit for elctrons than for pions
- **but:**
  - Ionization energy loss : **Landau distribution, long tail**
  - no absolute separation for single track, only statistical
    → **need for multiple layers of TRD for good efficiency**

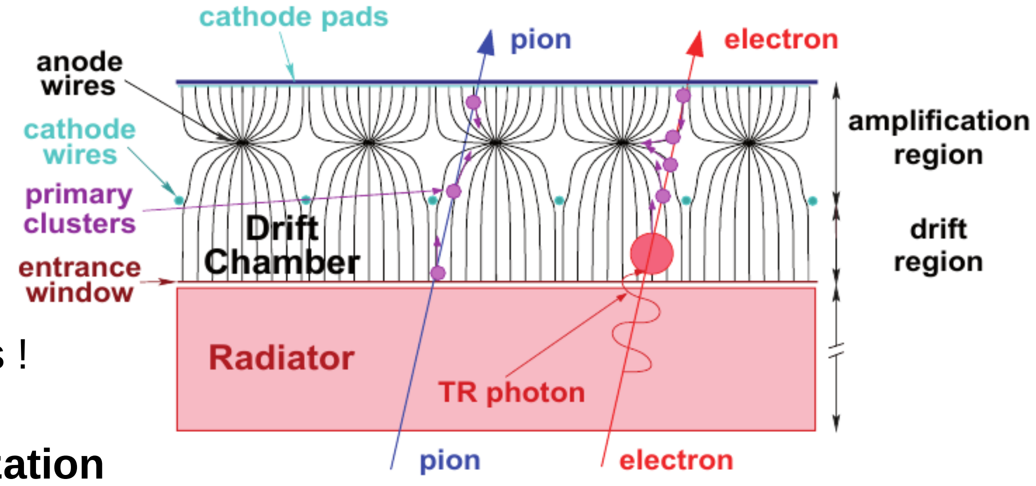
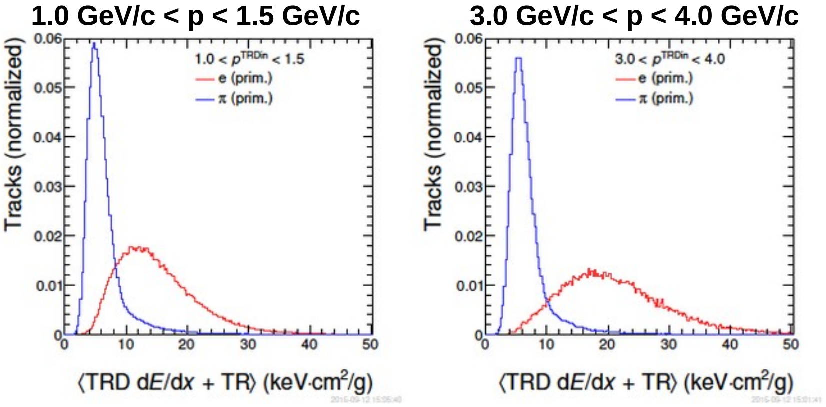


Figure 4.1: A schematic illustration of the working principle of the CBM-TRD.

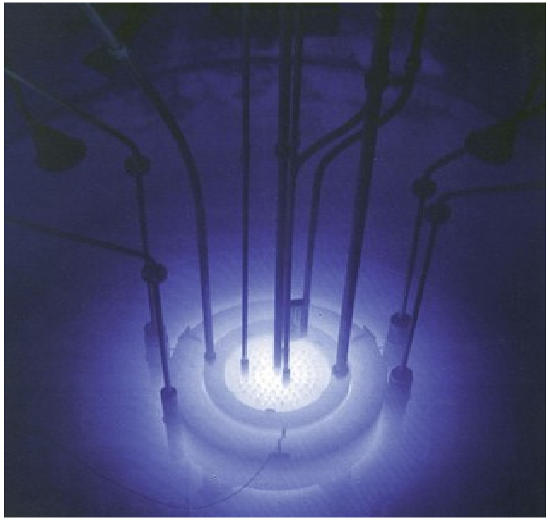


RICH Particle ID

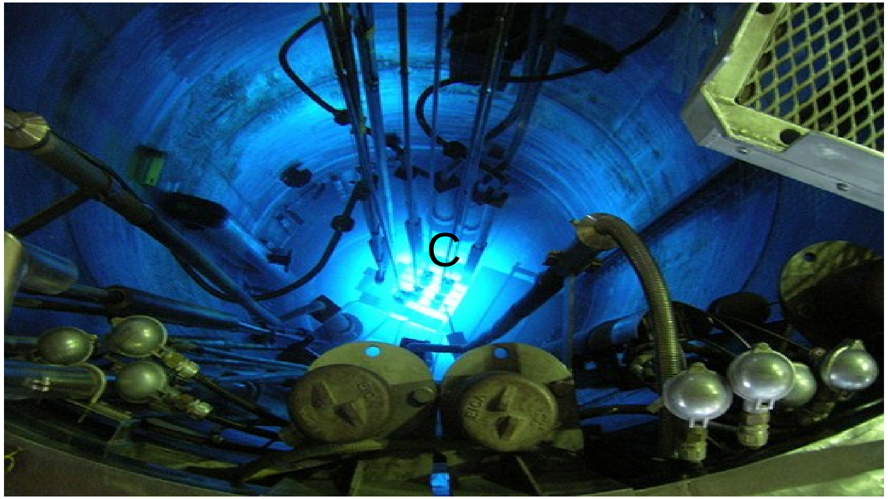
- particle ID with RICH detectors is based on **detection of Cherenkov radiation**,
- **only emitted if particle is traveling faster than speed of light in the radiator medium**
- For given momentum p, a heavy particle is slower than a light particle
  → Cherenkov threshold can be used for particleID separation
  → **Threshold Cherenkov detectors**
- if particle traveling faster than speed of light, Cherenkov emission angle depends on beta
  → Cherenkov emission angle as measure of beta
  → **Imaging Cherenkov detectors**

Cherenkov radiation in nuclear reactors

- Cherenkov radiation produced in core of nuclear reactors by fast electrons
  - β-decays of activated material
  - Compton scattering of photons from γ-decays



Reed Research Reactor, Portland (Oregon)



core of RA-6 reactor, Centro Atomico Bariloche

Cherenkov radiation - basics

- a charged particle in medium polarizes its surrounding
- if speed slower than speed of light:
  - symmetric polarization around particle
  - **no net radiation** due to destructive interference
- if speed larger than speed of light:
  - unsymmetric polarization
  - non-vanishing dipole field
  - **emission of Cherenkov radiation** into cone, angle θ_c

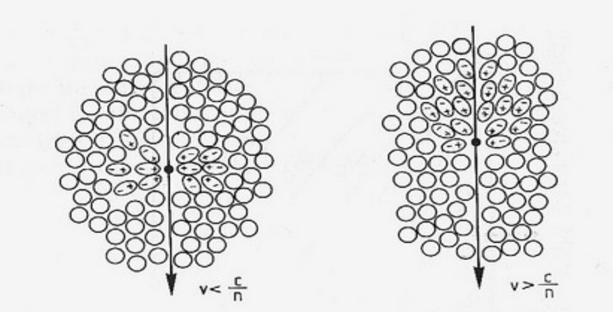
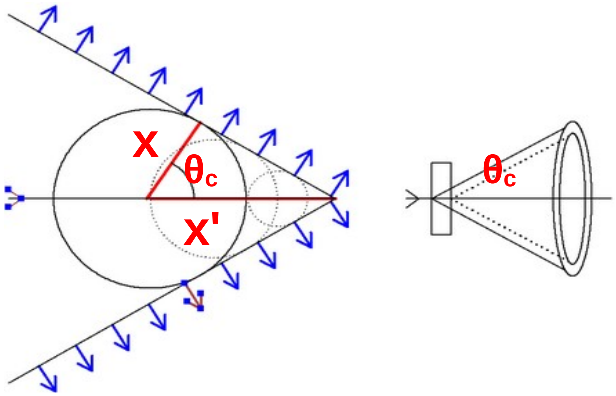


Fig. 6.7. Illustration of the Cherenkov effect [68].

- opening angle of cone :



$$x = \Delta t \frac{c_0}{n}$$

$$x' = \Delta t \beta c_0$$

$$\cos\theta_c = \frac{1}{\beta n}$$

$$\theta_c^{max} = \arccos\frac{1}{n}$$

Cherenkov photon yield

- Photon yield given by : **Frank – Tamm – Formula** (by solving Maxwell equations)

$$\frac{d^2 E}{dx\, d\omega} = \frac{Z^2 \alpha \hbar}{c} \omega \left(1 - \frac{c^2}{v^2 n^2(\omega)}\right)$$

$$= \frac{Z^2 \alpha \hbar}{c} \omega \sin^2(\Theta_c)$$

$$with\, E = h\nu = \hbar \omega$$

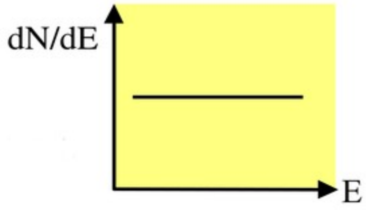
$$\frac{d^2 N}{dx\, d\omega} = \frac{Z^2 \alpha}{c} \sin^2(\Theta_C)$$

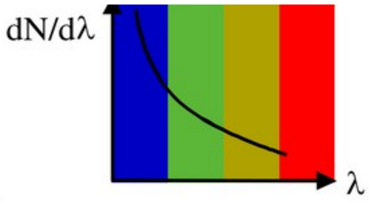
$$with\, \omega = 2\pi \frac{c}{\lambda}, \quad d\omega = -\frac{1}{\lambda^2} 2\pi c\, d\lambda$$

$$\frac{d^2 N}{dx\, d\lambda} = -2\pi Z^2 \alpha \frac{1}{\lambda^2} \sin^2(\Theta_C)$$

Z: charge of particle (units e)
α: fine structure constant
n(ω): refractive index
$\theta_{c:}$ Cherenkov angle

$1 - c^2/v^2 n^2(\omega) = \sin^2(\theta_c)$





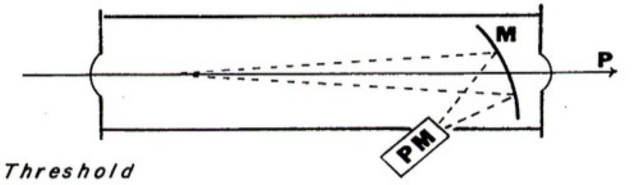
here: assuming constant n (=n(ν) if dispersion)

Threshold Cherenkov Counters

- Threshold Cherenkov Counter is **simplest way to utilize Cherenkov radiation for particle ID** → only binary information: particle above Cherenkov threhsold ? yes / no

$$\beta_{threshold} = \frac{v_{thr}}{c} = \frac{1}{n}$$

$$p_t = \gamma m v_{thr} = \frac{m v_{thr}}{\sqrt{1 - \frac{v_{thr}^2}{c^2}}} = \frac{m c}{\sqrt{n^2 - 1}}$$



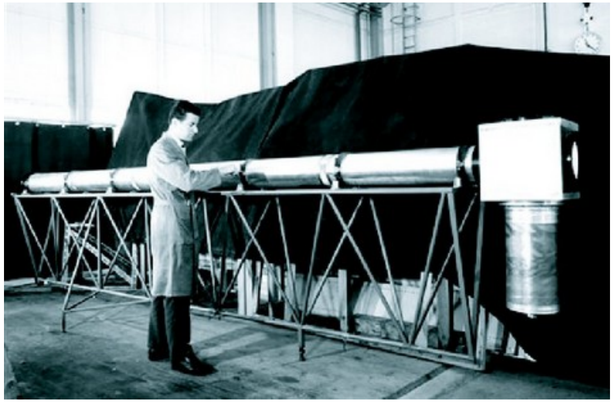
β values for different particles at p=1 GeV/c and p=10 GeV/c

for CO_2 at normal pressure:
n=1.00043 → $\boldsymbol{\beta_{thr,CO2}}$ **= 0.99957**

β = 1/n	**1 GeV/c**	**10 GeV/c**
Electron	0.9999	0.9999
Pion	0.9910	0.9999
Kaon	0.8966	0.9988
Proton	0.7293	0.9956

- n and $\beta_{thr\ t}$hreshold can be adjusted via pressure in the tube:

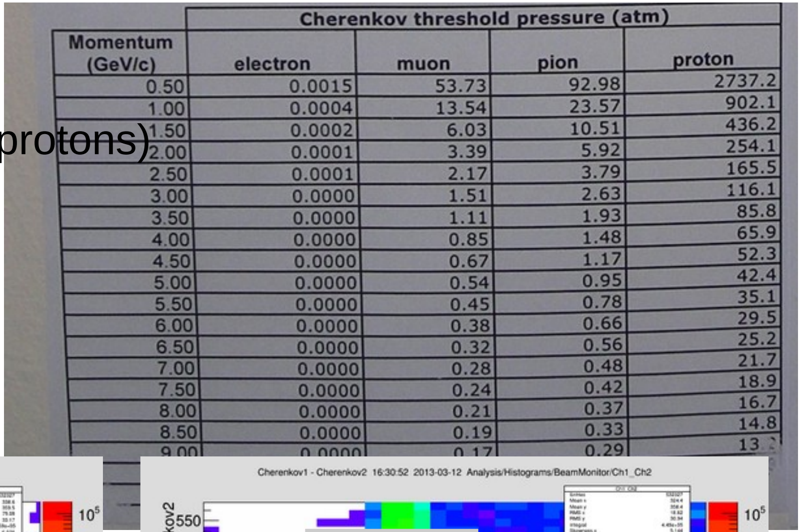
$$n_{gas} - 1 = (n_0 - 1)\ \frac{p}{p_0}$$



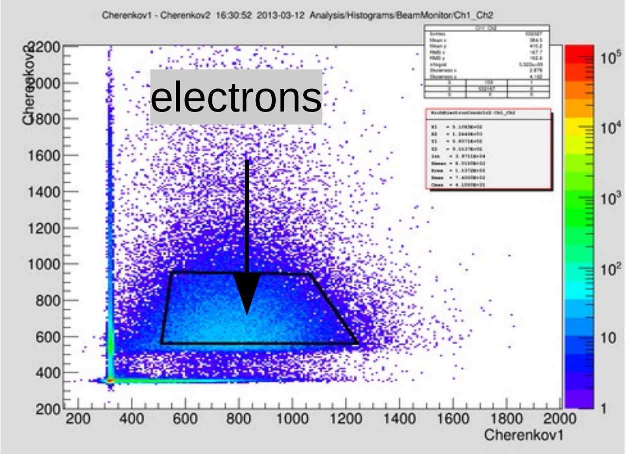
Cherenkov Threshold detector PS T9

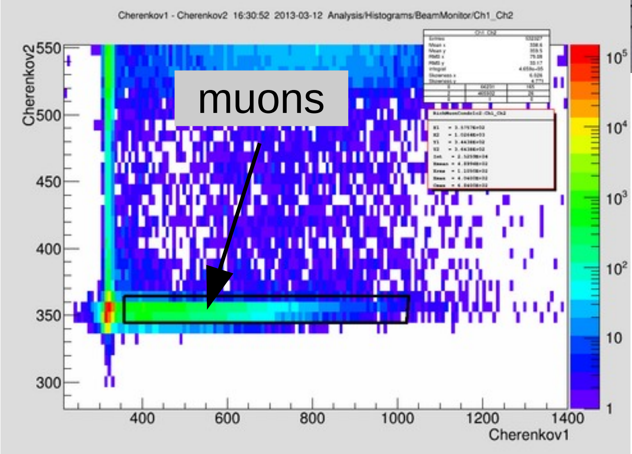
Example : CERN PS T9

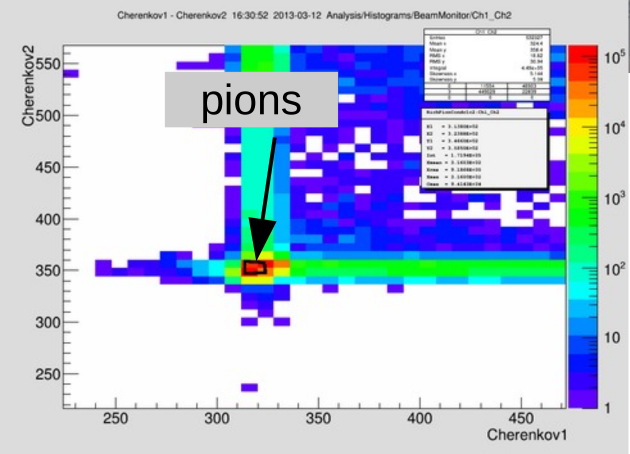
- CERN PS T9 test beamline :
  - Mixed secondary test beam : electrons / pions / muons / (protons)
  - Common momentum selected by beam line magnets
  - Two consecutive threshold counters available
  - CO_2 radiator with individually adjustable pressure



Momentum (GeV/c)	Cherenkov threshold pressure (atm) electron	muon	pion	proton
0.50	0.0015	53.73	92.98	2737.2
1.00	0.0004	13.54	23.57	902.1
1.50	0.0002	6.03	10.51	436.2
2.00	0.0001	3.39	5.92	254.1
2.50	0.0001	2.17	3.79	165.5
3.00	0.0000	1.51	2.63	116.1
3.50	0.0000	1.11	1.93	85.8
4.00	0.0000	0.85	1.48	65.9
4.50	0.0000	0.67	1.17	52.3
5.00	0.0000	0.54	0.95	42.4
5.50	0.0000	0.45	0.78	35.1
6.00	0.0000	0.38	0.66	29.5
6.50	0.0000	0.32	0.56	25.2
7.00	0.0000	0.28	0.48	21.7
7.50	0.0000	0.24	0.42	18.9
8.00	0.0000	0.21	0.37	16.7
8.50	0.0000	0.19	0.33	14.8
9.00	0.0000	0.17	0.29	13.[illegible]







Proximity focussing Cherenkov Counters

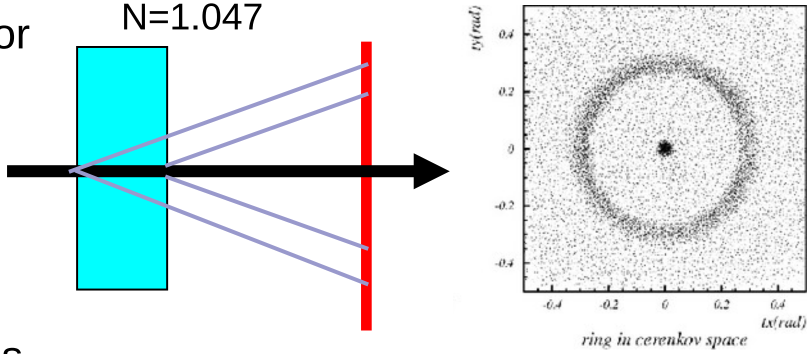
- Simplest way to evaluate Cherenkov angle information :
  → Project Cherenkov cone onto (spatially resolved) detector
  → **„proximity focussing“**

- **Pros:** - no photon losses due to additional mirror
  - compact design
  - very fast

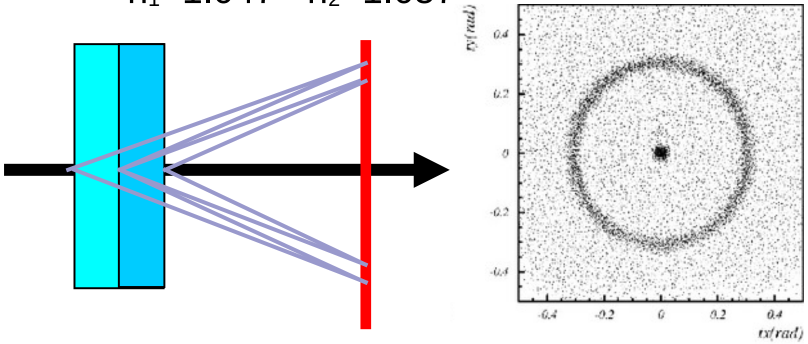
  Cons: - Ring smearing with increasing radiator thickness
  - detection plane inside acceptance
  - Limited radiator choice
  - impossible with gas radiators (l >= 0.5m)

- **State of the art:**
  “A novel type of proximity focussing RICH counter with multiple refractive index aerogel radiator”,
  T. Iijima et al, NIM A 48 (2005) 383
  → **Belle II RICH detector**

Conventional radiator,
4cm aerogel
N=1.047



Multiple radiators,
2+2cm aerogel
n_1=1.047 n_2=1.057



mRICH is a proximity focussing Aerogel RICH detector

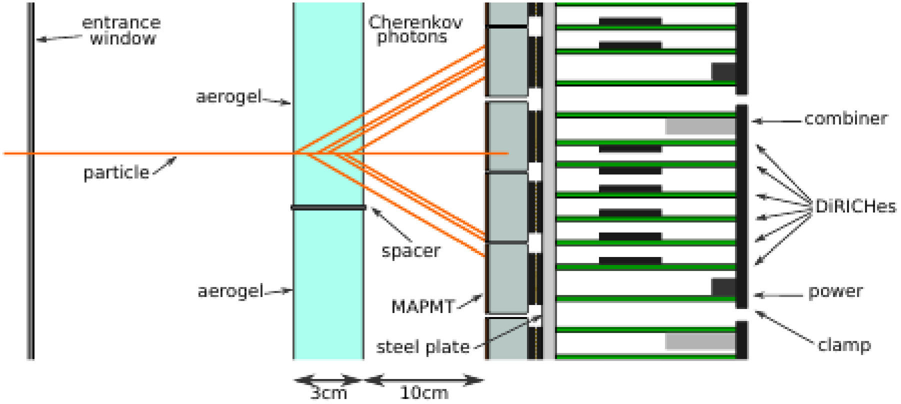


Figure 6.1: Schematic drawing of a side view of the inner mRICH detector. All main parts of the detector as well as the production of Cherenkov photons in the aerogel block are shown.

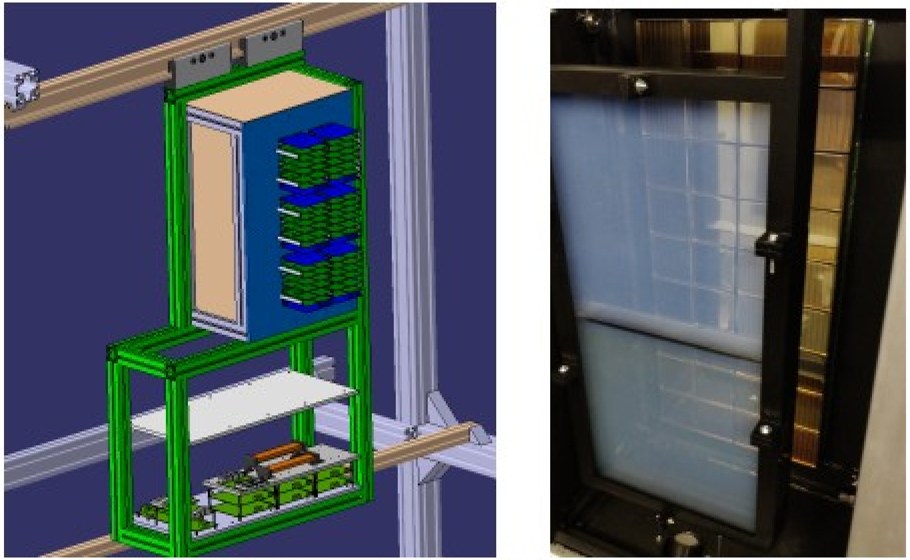
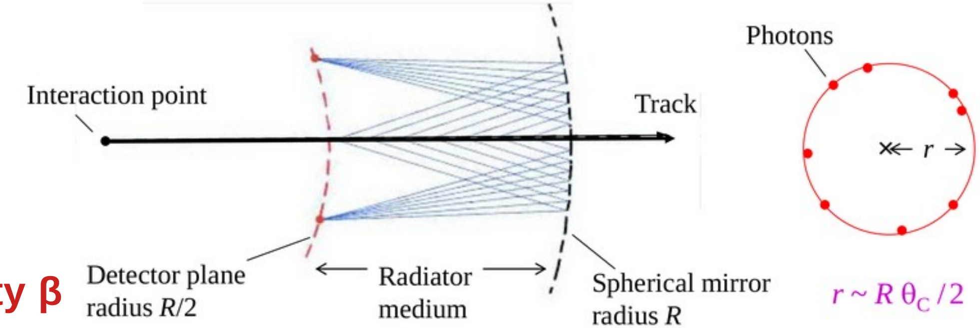


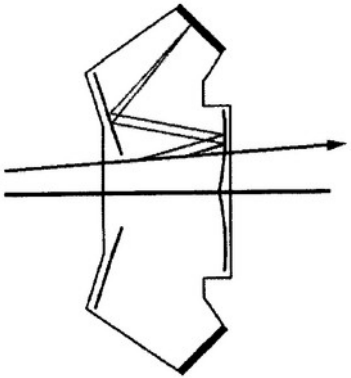
Figure 6.2: **(left)** CAD drawing of the mRICH detector with support structure and connection to the mTOF frame (to the left). **(right)** View into the inside of the mRICH. The two aerogel radiator blocks are mounted with 10 cm distance to the MAPMT detection plane.

Imaging Cherenkov detectors

- A sperical focussing mirror can be used to focus the parallelly emitted light of the Cherenkov cone, emitted along the radiator, into a sharp ring image:
  J. Seguinot and T. Ypsilantis, NIM143 (1977) 377
- **ring radius → Cherenkov angle Θ_c → particle velocity β**
- **Allows to use „thick“ gas radiators**
  → needed for sufficient photon yield
- **Allows for RICH detectors with large acceptance**
- **Size of photon detector scales with R_{mirror}**
  → potentially large photon detectors
  → spatially resolved single-photon position resolution
- Tilting the focussing mirror moves photon detector out of acceptance
  → second, flat mirror can help (as in LHCb RICH 2)



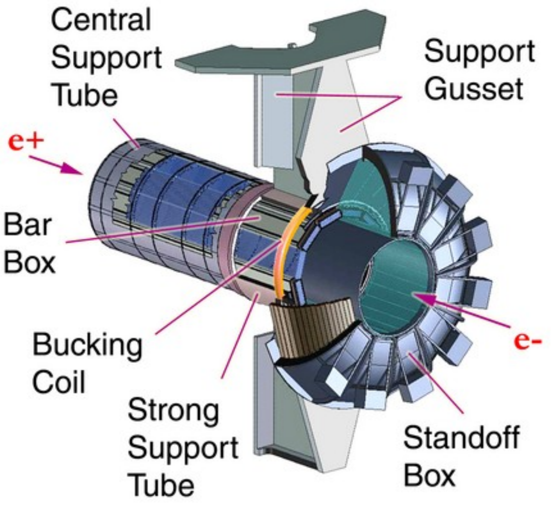
Sketch of a classical focussing RICH
(from “Particle ID lecture”, Roger Forty)



A possible 2nd flat mirror can be used to prolong focal length / move photon det.

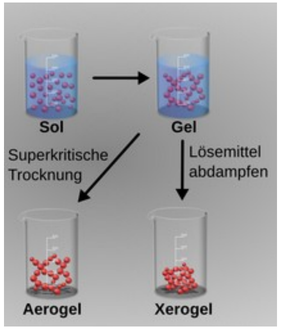
Choice of Cherenkov radiator

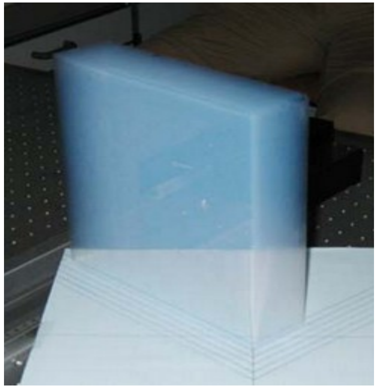
- Choice of radiator determines momentum range and ID capabilities
- **Solid radiators:** Quartz, Plexiglas, water, ice
  - typically large refractive index n>1.3
    (water: N=1.33, ice: n=1.31, plexiglas: n=1.48, fused silica: n=1.45)
  - Limited UV transparency
  - large refraction when light leaving the radiator
  - Large chromatic dispersion !
  - Useage: DIRC detectors, threshold counters,
    ICEcube, Water Cherenkov (AUGER) , KAMIOKANDE,…
  - **hadron ID: Kaon / proton / Deuterium / Triton**



BaBar DIRC detector

- **Aerogel Radiators:**
  - refractive index : ~1.03 – 1.06, (1.07 – 1.20 with pinhole drying)
  - closing gap in refr. index between gases and solids
  - optical transparent
  - **hadron ID at low momenta, pi / K separation**



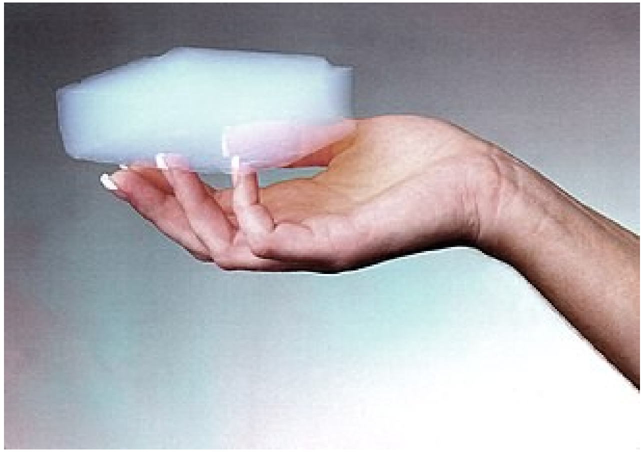


Production of Aerogel

- Highly porous solid,up to 99.98% porous
- Blue shimmer: „frozen smoke“ due to Rayleigh scattering
- Often made of silicat, SiO_2
  using an autoclave (high pressure+high temp)
- **Nowadays : „Sol Gel process“**
  - **Tetramethylortosilicat** with water:

$$(H_3CO)_4Si + 4H_2O \rightarrow H_4SiO_4 + 4CH_3OH$$

$$H_4SiO_4 \rightarrow SiO_2 + 2H_2O$$



  - **H_4 Si O_4 : „Kieselsäure“,** of which the water slowly emerges, leaving a gel of SiO_2 „“silicat“
  - This silicat „gel“ is mixed with alcohol, forming „**Alcogel**“
  - Alcogel dryed in an Autoclave (ca 240°C, 80 bar)
  - **„super crytical drying“** → **no liquid→gas phase transition** of the alcohol, which would destroy the structure during drying
  - Final properties of the aerogel depend on exact parameters while drying

gas radiators

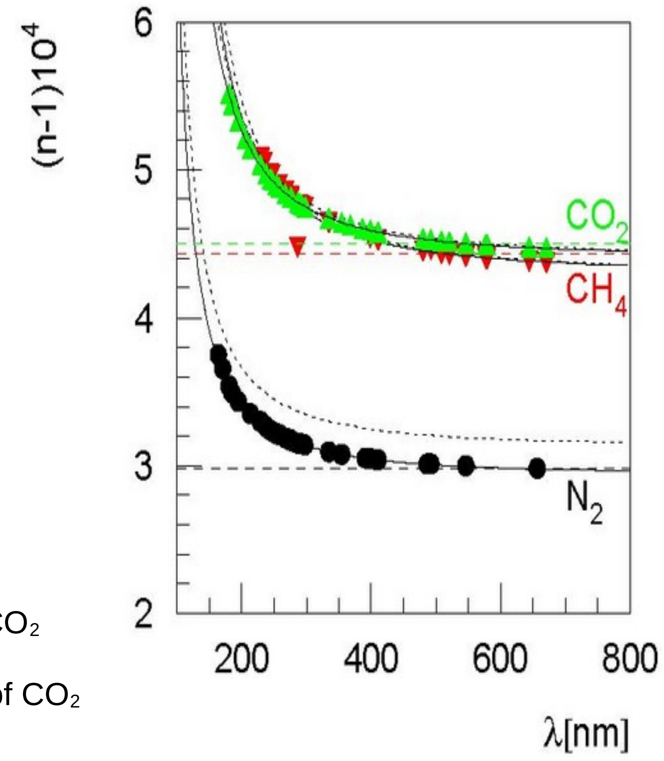
very low refractive index, n~ 1.0001
perfect electron / pion separation in FAIR momentum range
(electrons always above Cherenkov threshold, pion threshold few GeV/c)

- **Fluorocarbon:**
  - were widely used in many different RICH detectors (also industry, cooling)
  - **Low chromatic dispersion**
  - **Good optical transparency,** even far UV (<< 200nm)
  - **Potential scintillation light in visible range**
  - **Green house gas,** nowadays difficult to obtain

- **C_4H_{10} : Methane** (used in HADES RICH)
  - **good alternative for C4F10** : similar density, refrative index
  - **no scintillation in visible range**
  - **flammable**

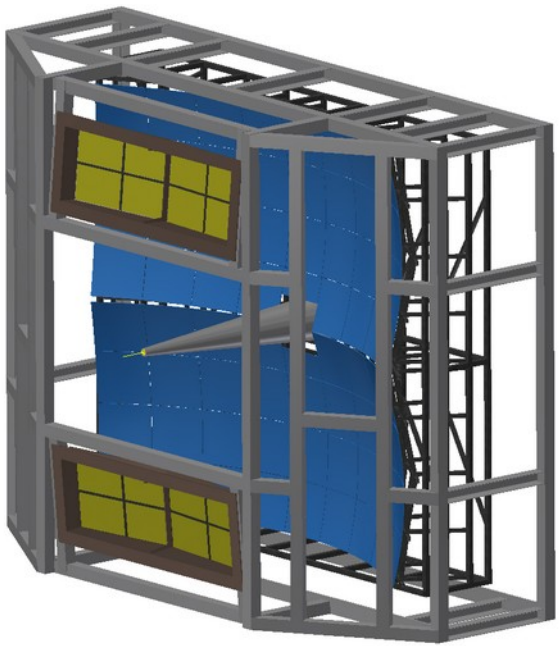
- **CO_2**
  - Simple to handle (danger of suffocation)
  - quencher gas : no scintillation light
  - Transmission cut at 190nm
  - Larger dispersion in UV range

- **N_2**
  - possible alternative to CO_2 lower n than CO_2
  - scintillation, admixture of CO_2



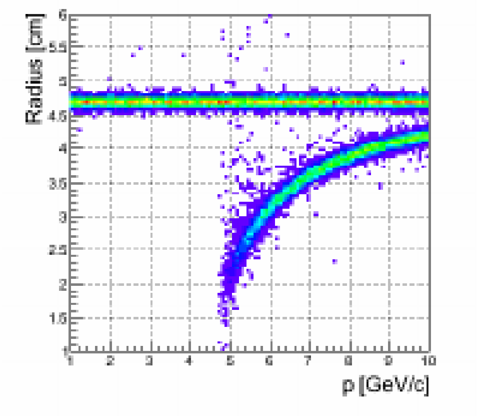
The CBM RICH

- **Radiator:** CO_2 at normal pressure
  - Radiator length : 1.7m
  - Refr. index n=1.00043, θ_c =1.67°, γ_{thr}=33
  - electron radius : 4.8 cm
  - Pion threshold : ~4.8 GeV/c
  - R_π = 90% R_e for p> 11 GeV/c
- **Mirror: segmented spherical glas mirror**
  - spherical glas mirror, two separate halfs, 12° tilt angle
  - $R_{curvature}$ = ~3.0m, focal length : 1.5m
  - ~80 rectangular mirror tiles, 40x40 cm², 6mm glass, Al coating
- **Photon detector:**
  - Multianode PMTs, ~1100 pc, ca 70k pixel
  - DIRICH FPGA-based readout chain

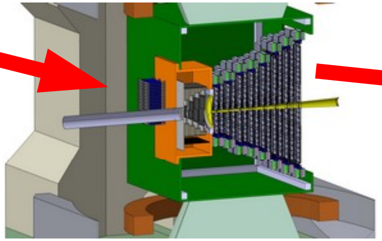


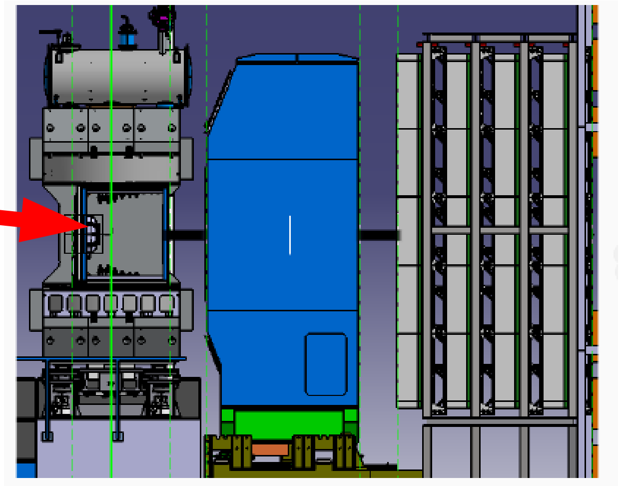
limiting factors for CBM RICH electron ID

- In principal, a gas Cherenkov detector is a perfect tool for el / pi separation
- limiting factor :
  - The RICH is part of a larger, multi-purpose detector system
  - CBM detector is multi-purpose, not focussed on Dileptons only (as HADES is)
    → a lot of material budget in front of CBM RICH



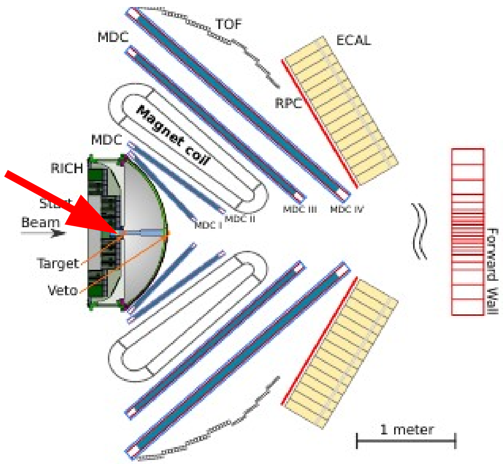
target
MVD
STS
target box
RICH window





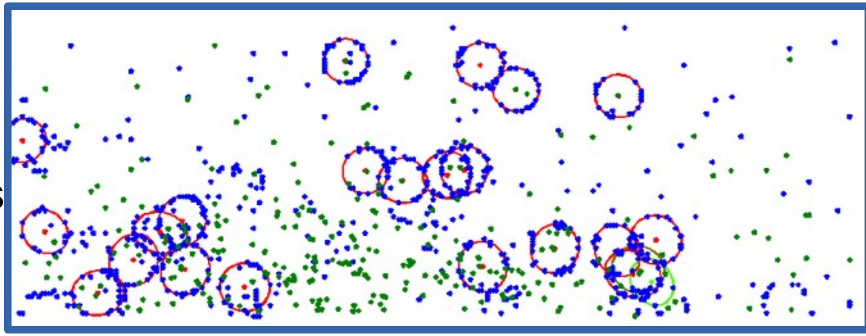
CBM detector stack

target

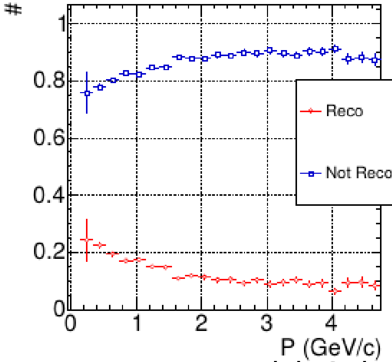


HADES detector stack

limiting factors for CBM RICH electron ID

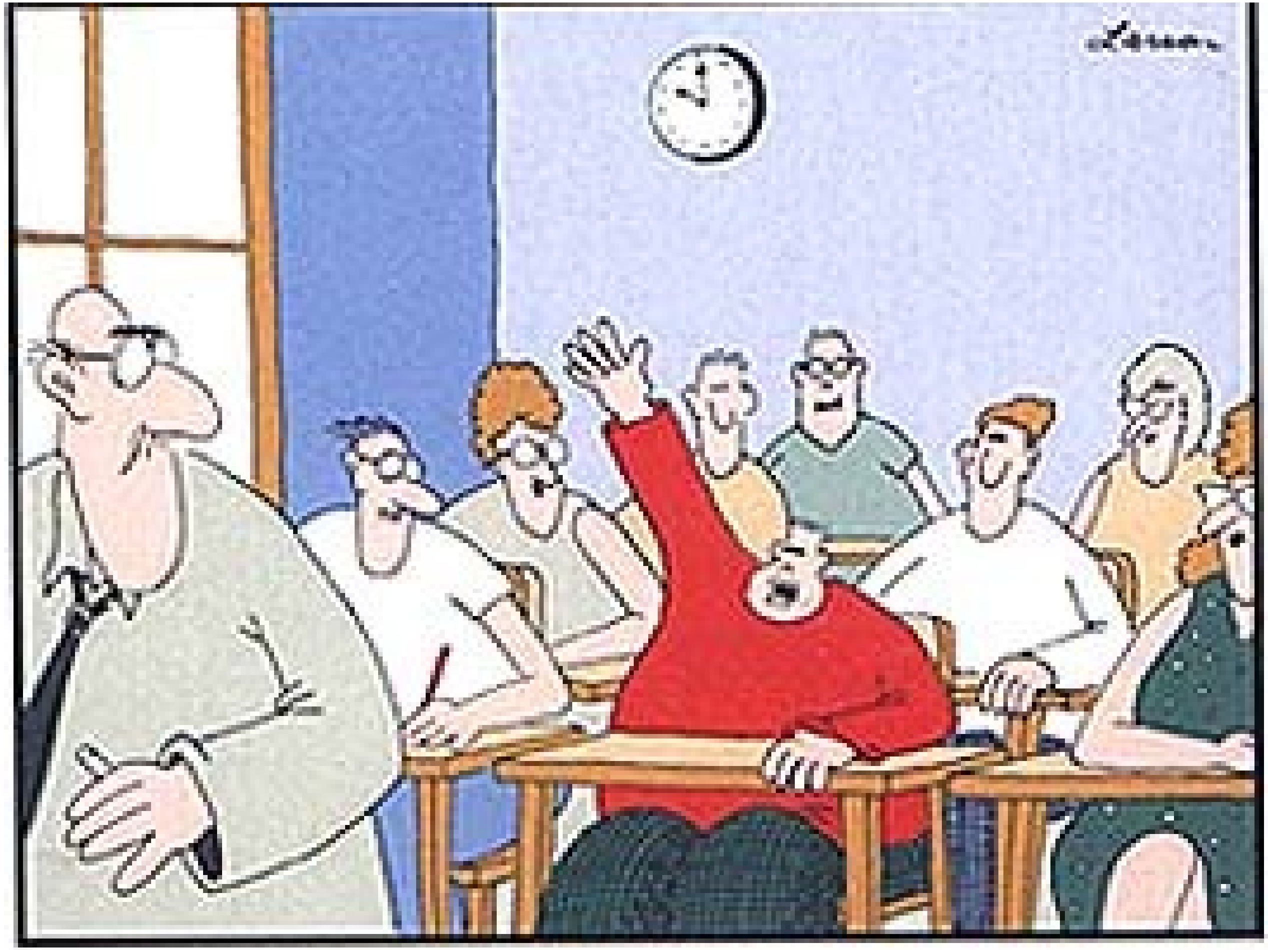


- main limitation:
  Photon conversion in material before RICH
- For each single primary dilepton, up ~50 additional rings from photon conversion in the RICH
  - main source : $\pi^0 \rightarrow \gamma\gamma$, Bremsstrahlung
- Pion tracks close to such rings get miss-identified as electron
- Most of the rings have no corresponding track in STS
- How can we improve ?
  → **remove number of rings before track matching**
  - TRD / TOF backtracking
  - use AI based methods to better select rings
  - use „topological cuts“ to remove conversion legs



Almost 80 percent of the electron tracks which produce rings that are matched to pions **are not reconstructed in the tracker before RICH**.

Pavish Subramani, PHD thesis



"Mr. Osborne, may I be excused?
My brain is full."