Physikalisches Institut

Study of Tau Decays with s-Quark Final States/ Preshower Studies at BaBar

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- Tau-Physics at BaBar
- Measurement of $|V_{us}|$
- $\tau^- \rightarrow \eta K^- \nu_\tau$ Analysis
- Identification of Preshowers
- Application of Preshowers

BaBar Experiment: PEP-II Collider

PEP-II at SLAC in Kalifornia

Electron-Positron-Collisions:

e^- : 9.0 GeV e^+ : 3.1 Gev

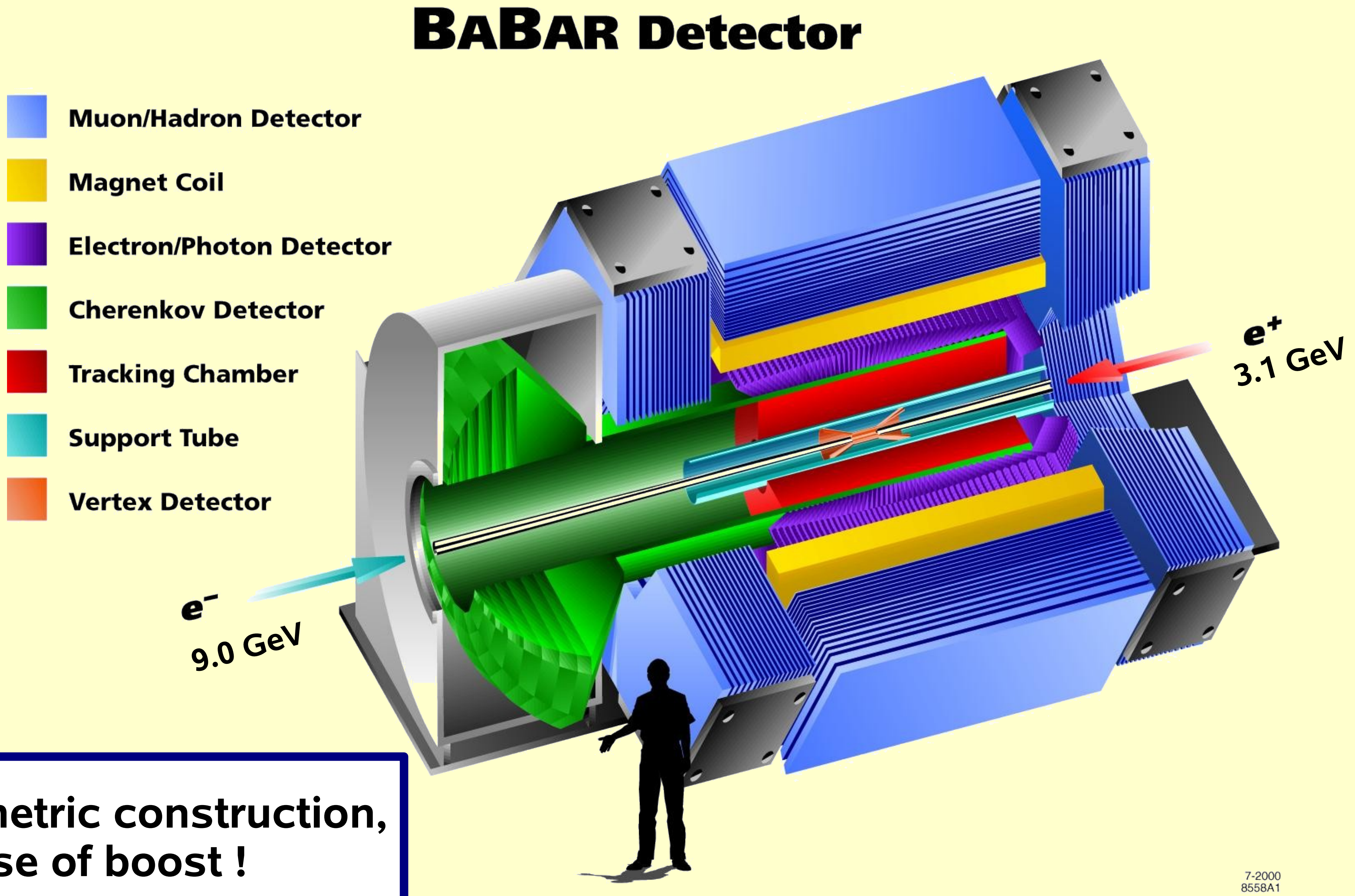
→ two storage rings

→ Boost

→ center of mass energy: 10.58 GeV
- corresponds to $\Upsilon(4S)$ resonance

B-Factory	$e^+ e^- \rightarrow B\bar{B}:$	$\sigma = 1.05\,nb$
... but also Tau-Factory	$e^+ e^- \rightarrow \tau\tau:$	$\sigma = 0.89\,nb$

BaBar Experiment: Detector



Asymmetric construction, because of boost !

CKM-Matrix

Standard Model:
- Quark mass eigenstates not equal to weak interaction eigenstates
- CKM-Matrix describes the mixing

CKM-Matrix:

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} * \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

Unitary by definition

First row unitarity condition: $|V_{ud}{}^2| + |V_{us}{}^2| + |V_{ub}{}^2| = 1$

Status: $|V_{us}|$ from Kaon Decays

PDG2006 world average:

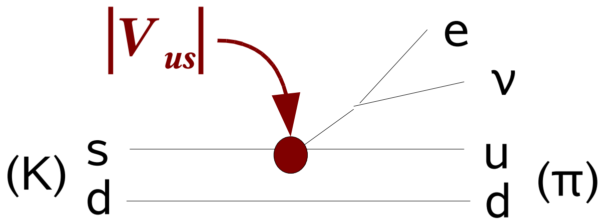
$$|V_{ud}| = 0.97377 \pm 0.00027 \, (\Rightarrow 0.028\,\%)$$

$$|V_{us}| = 0.2257 \pm 0.0021 \, (\Rightarrow 0.93\,\%)$$

$$|V_{ub}| = (4.31 \pm 0.30) * 10^{-3}$$

Measurements of $|V_{us}|$

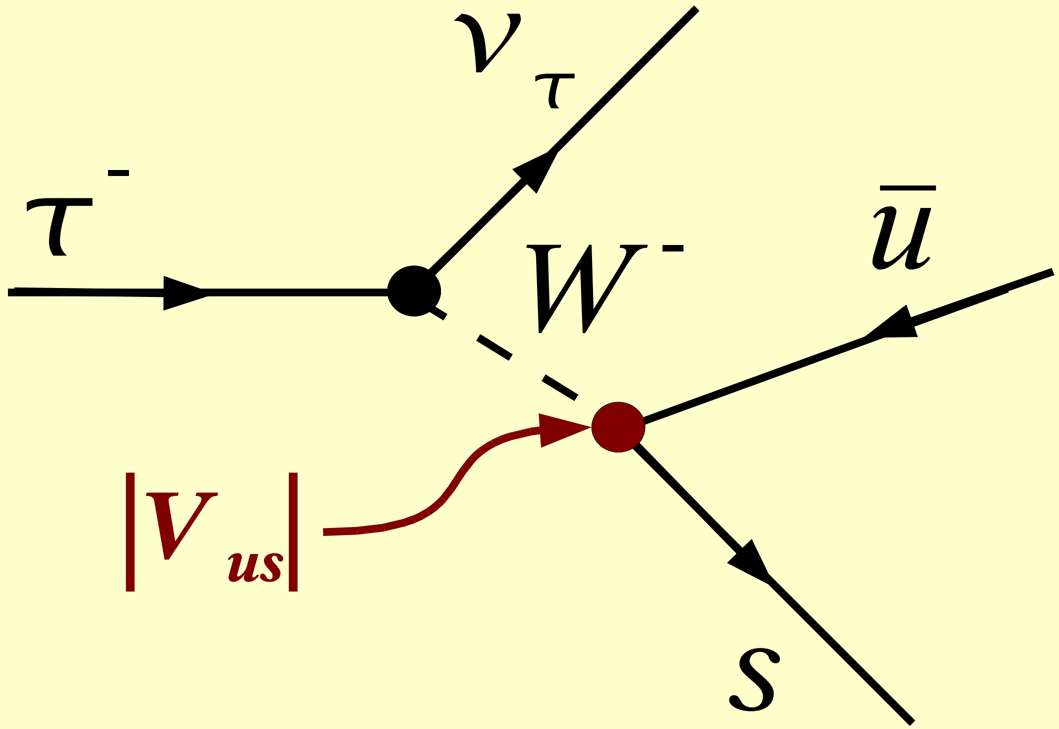
- **use kaon decays** $(e.g.\ \ K^0 \rightarrow e^+ \pi^- \nu_e)$
- **dominated by uncertainty of the theoretical determination of kaon form factor**



Goal: Systematically independent approach to $|V_{us}|$:
alternative measurement in tau lepton decays

Motivation

Goal : Measurement of CKM-matrix-element $|V_{us}|$ in tau-lepton decays with "net-strangeness"



$|V_{us}|$ in Tau Decays

Hadronic Tau-Lepton decay rate

S: Strange
NS: Non-Strange

$$R_{had} = R_{NS} + R_S \qquad R_{S(NS)} = \frac{\Gamma\left[\tau \to h_{S(NS)} \nu\right]}{\Gamma\left[\tau \to e \bar{\nu}_e \nu\right]}$$

$$|V_{us}|^2 = \frac{R_S}{\frac{R_{NS}}{|V_{ud}|^2} - \delta R(m_s)}$$

- where δR_S can be calculated in Operator Product Expansion
- R_{NS} and $|V_{us}|$ other measurements

→ measure R_S

Previous measurements (OPAL):

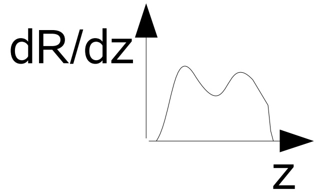
* E. Gamiz et al. , JHEP **01** (2003) 060, hep-ph/0212230, Phys. Rev. Lett. **94** (2005) 011803, hep-ph/0408044

→ $|V_{us}| = 0.2208 \pm 0.0033_{\exp} \pm 0.0009_{theo}$ (*)

→ dominated by experimental uncertainty of R_S:
Precision limited by statistics

Strange Spectral Function

Additional information from moments:

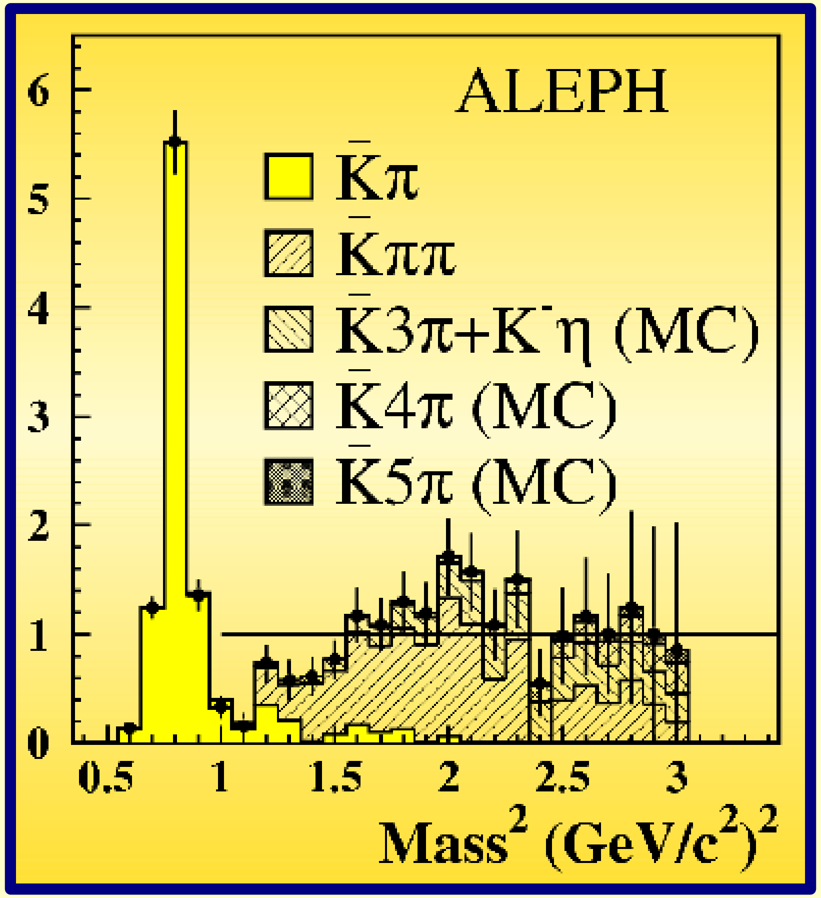


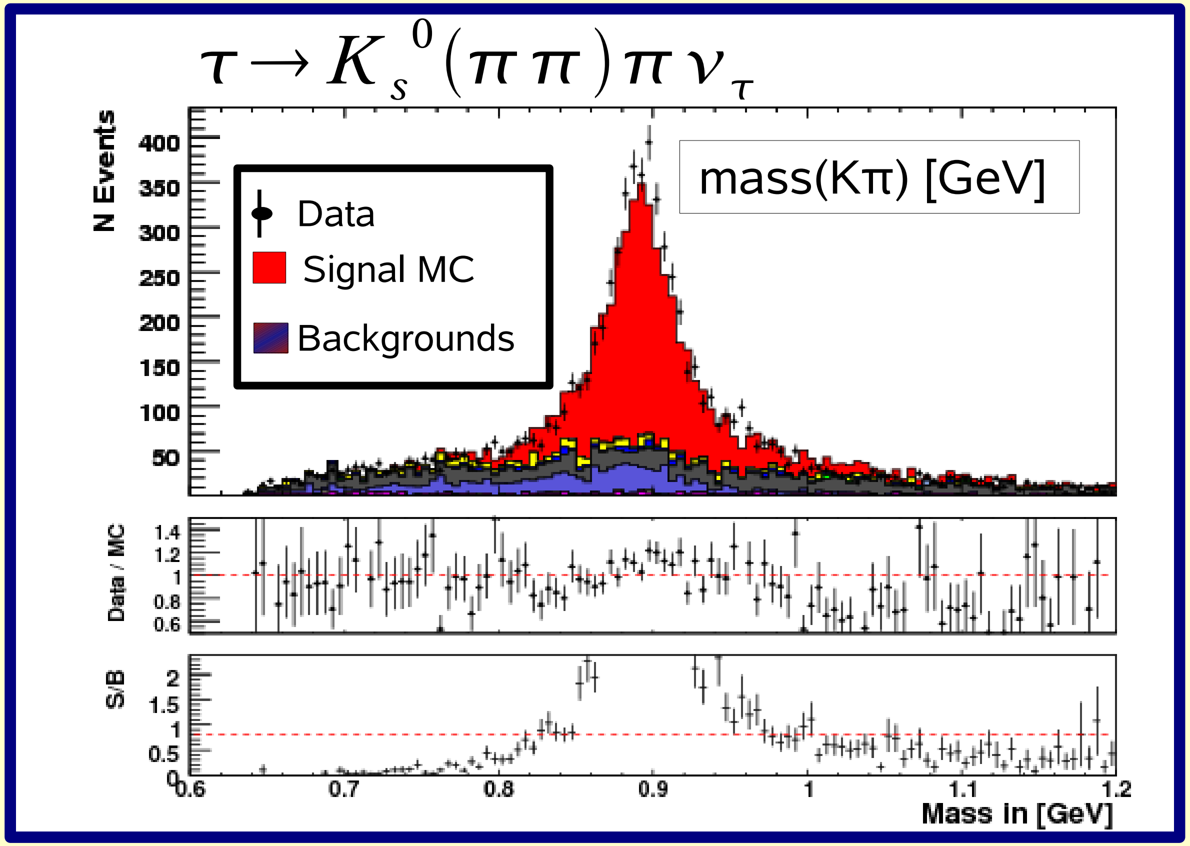
$$R^l = \int_0^1 dz\,(1-z)^l \frac{dR}{dz} \qquad \text{with } z = \frac{m_{had}^2}{M_\tau^2}$$

- **Need to determine the strange spectral function:**
- **Measure the invariant mass spectrum**

→ **Consistent treatment of tau-decay channels with net-strangeness necessary**

Invariant Mass Spectrum





Diploma Thesis: Daniil Nekrassov

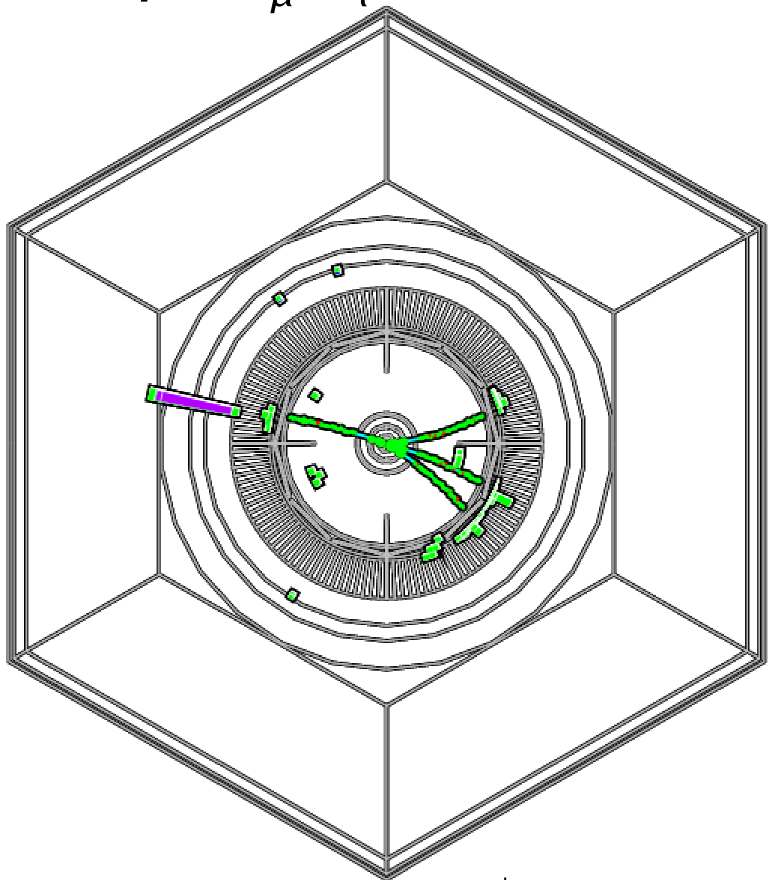
Characteristics of Tau Decays

Tau lifetime: 291 fs
- **Tau decays in beam pipe**
- **Reconstruction via decay products**

Tau mass: 1.78 GeV
- **Tau events are jet-like**
- **Separation from BB events**

Neutrinos
- **Missing Momentum**

$\tau^{+} \rightarrow \mu^{+} \nu_{\mu} \bar{\nu}_{\tau}$



$\tau^{-} \rightarrow \pi^{+} \pi^{-} \pi^{-} \nu_{\tau}$

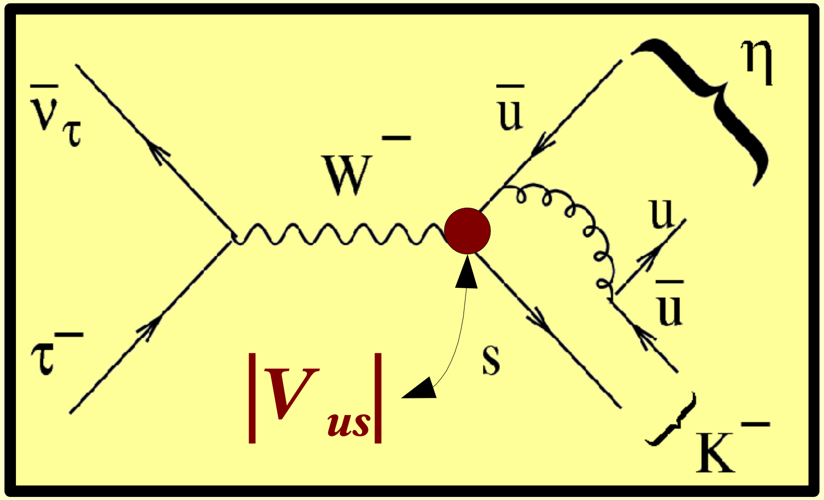
Decay Channels with Strange-Quarks in the Final State

Channels under study in Heidelberg-Babar-Group
are colored :

Zerfallskanal	BF [%] PDG 06
$\tau^- \to K^0\pi^-\nu_\tau$	0,90±0,04
$\tau^- \to K^-\nu_\tau$	0,691±0,023
$\tau^- \to K^-\pi^0\nu_\tau$	0,452±0,027
$\tau^- \to K^-\pi^+\pi^-\nu_\tau$	0,390±0,040
$\tau^- \to \bar{K}^0\pi^-\pi^0\nu_\tau$	0,380±0,040
$\tau^- \to K^-\pi^+\pi^-\pi^0\nu_\tau$	0,079±0,012
$\tau^- \to K^-\pi^0\pi^0\nu_\tau$	0,058±0,023
$\tau^- \to K^-\pi^0\pi^0\pi^0\nu_\tau$	0,042±0,021
$\tau^- \to K^-\eta\nu_\tau$	0,027±0,006
$\tau^- \to \bar{K}^0\pi^-\pi^0\pi^0\nu_\tau$	0,026±0,024

Goal:
Measure branching fraction of

$$\tau^- \to \eta K^- \nu_\tau$$



Identification of Tau Pairs

Selection criteria:

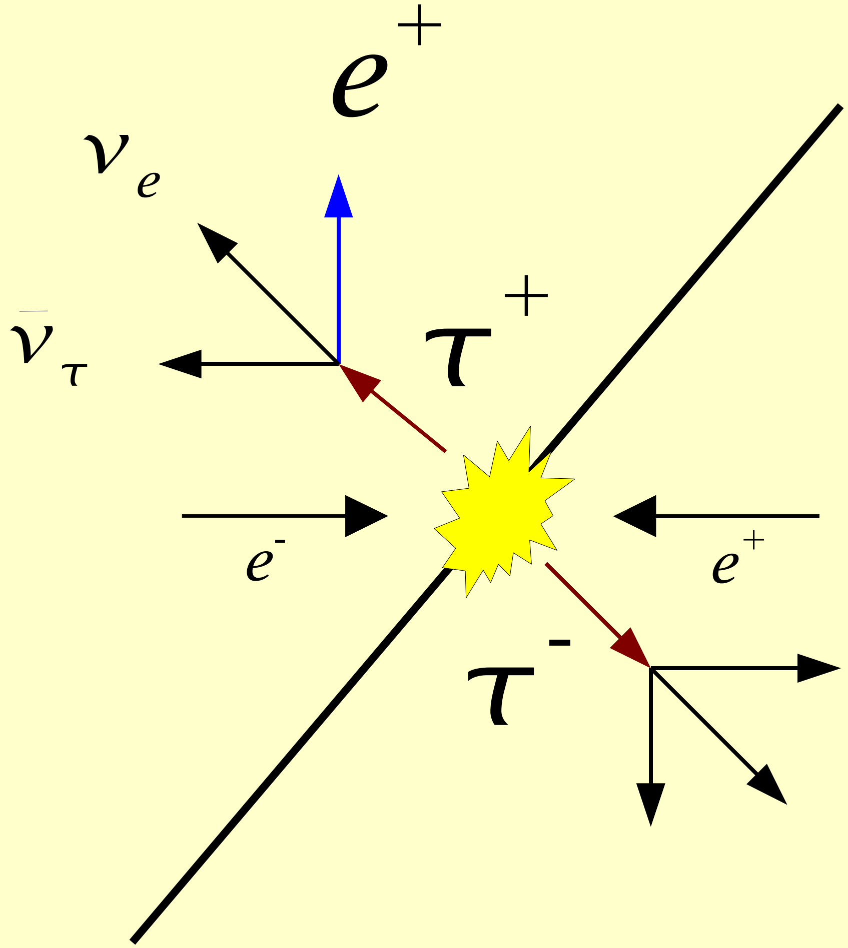
- jet-like events
- divide event in two hemispheres:

lepton-tag on 1-prong side:
require electron or muon

→ all other particles are daughters of "signal-side" tau

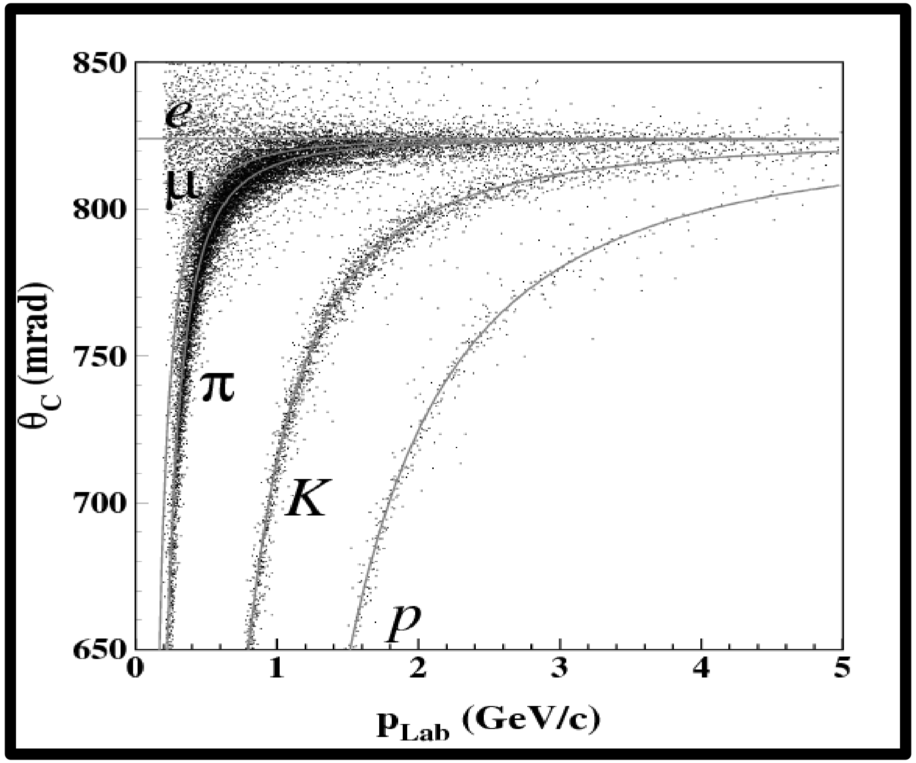
signal side: selection of hadrons

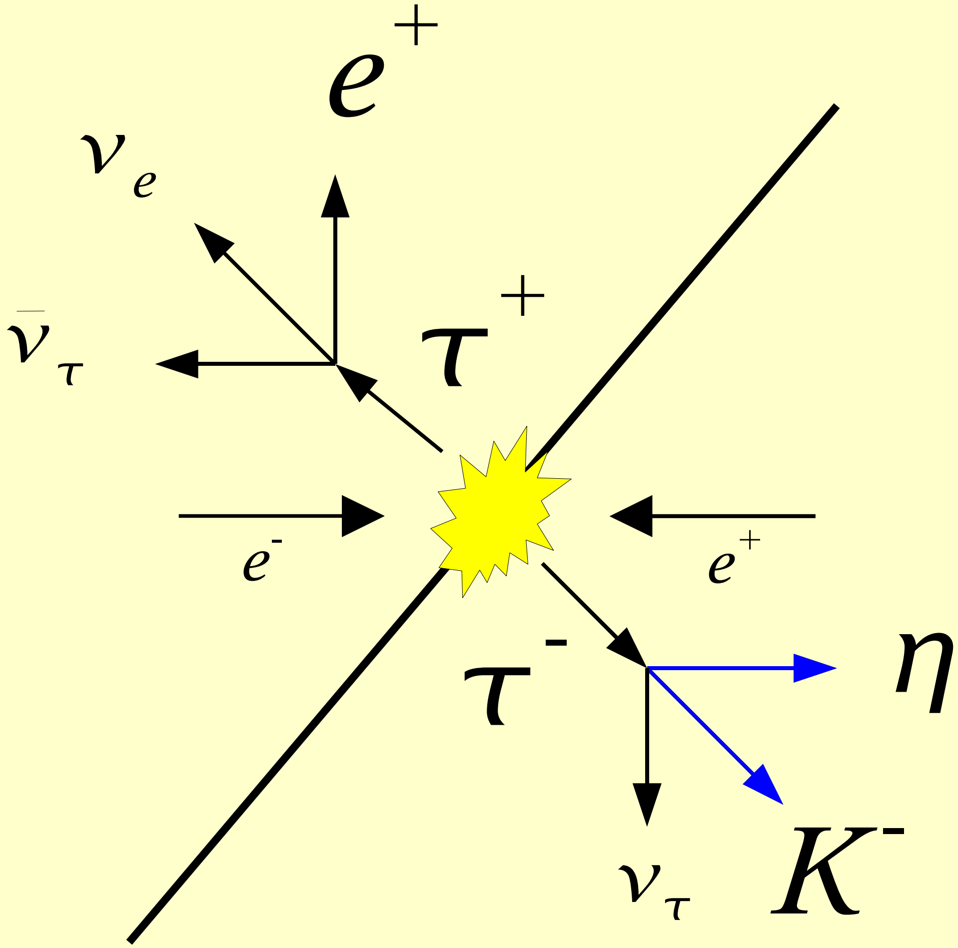
→ strong suppression of non-tau backgrounds



$\tau^- \rightarrow \eta K^- \nu_\tau$

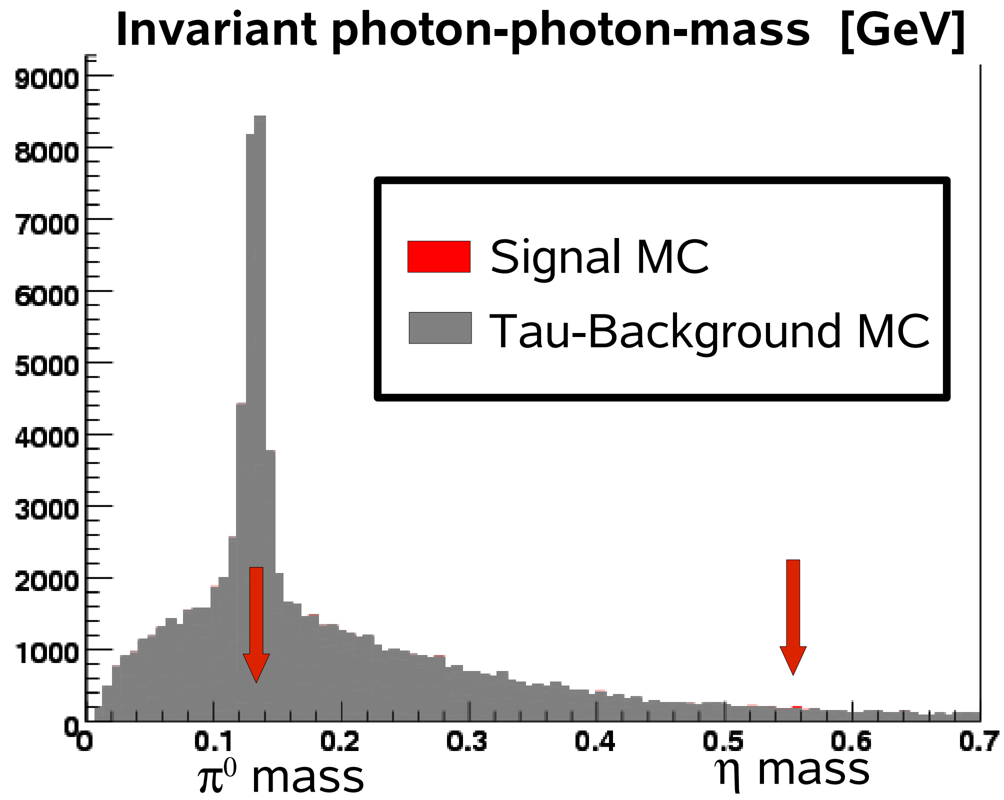
- **Kaon Identification:**
  → **separation from pions with Cherenkov-detector**





$\eta \rightarrow \gamma\gamma$

- **first step :**
  $\eta \rightarrow \gamma\gamma$ $\quad BF:(39.38 \pm 0.26)\%$
- **next step**
  $\eta \rightarrow \pi^+\pi^-\pi^0$ $\quad BF:(22.7 \pm 0.4)\%$

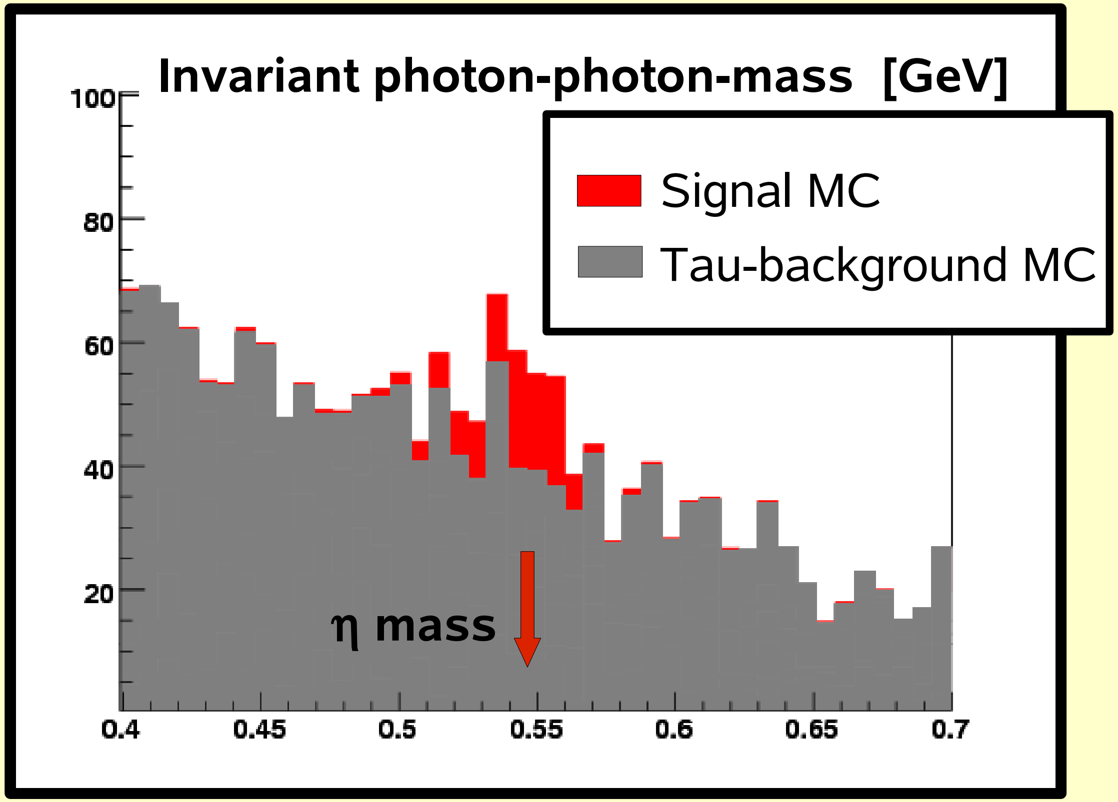


- **Select photons**
- **Combine photons to their mother particle candidates**

Large combinatorial background of decays with neutral pions :
e.g. $\tau^- \rightarrow \pi^0 K^- \nu_\tau$ **(BF is about 15 times larger than BF of η channel)**

$\eta \rightarrow \gamma\gamma$

First look at signal region:



Selection of neutral pions : don't use their daughter photons for η candidates

Next steps:

- **Improvement of event selection**
- **Study of backgrounds**
- **Expand analysis with channel** $\eta \rightarrow \pi^{+}\pi^{-}\pi^{0}$
- **Measure branching fracton**
- **Determine invariant mass** $m(K\eta)$

Summary and Outlook

- BaBar is also a Tau-Factory
- The large tau dataset offers the possibility for an alternative measurement of V_{us}
- Many tau-decay with net-strangeness channels are already under study in Heidelberg
- Study of decay channel $\tau^- \rightarrow \eta K^- \nu_\tau$ started

Future steps:

- Study of remaining tau decays with net-strangeness
- Consistent treatment of all tau decays in a combined measurement

Preshower Study: Motivation

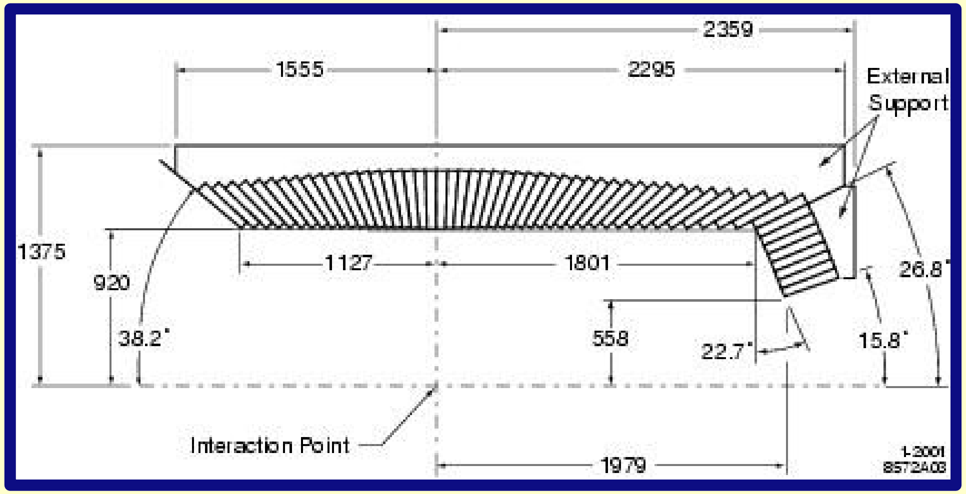
Electromagnetic Calorimeter (EMC)

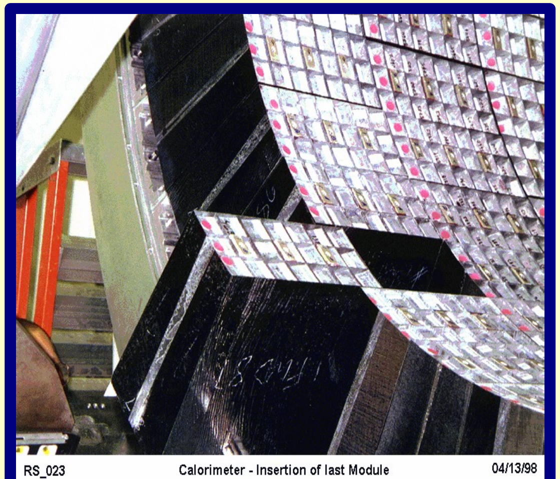
CsI(Tl) Crystals: 5760 in "barrel"
820 in "endcap"

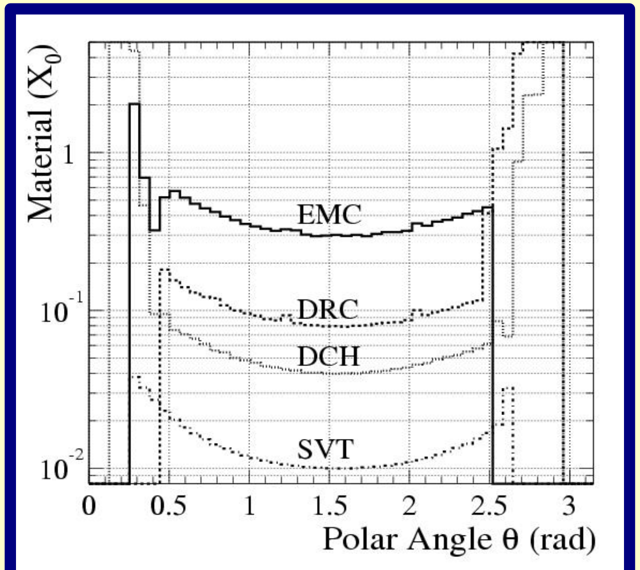
Material in front of the calorimeter:
about 0.4 X_0.
mainly: DIRC (0.3 X_0)

Interaction of photons with this material leads to "Preshowers"

Preshower:
Photon which started to shower already in front of the EMC







Preshower Study: Motivation

13 % of all photons are preshowers:

- **Preshowers “lose” energy in front of the calorimeter**

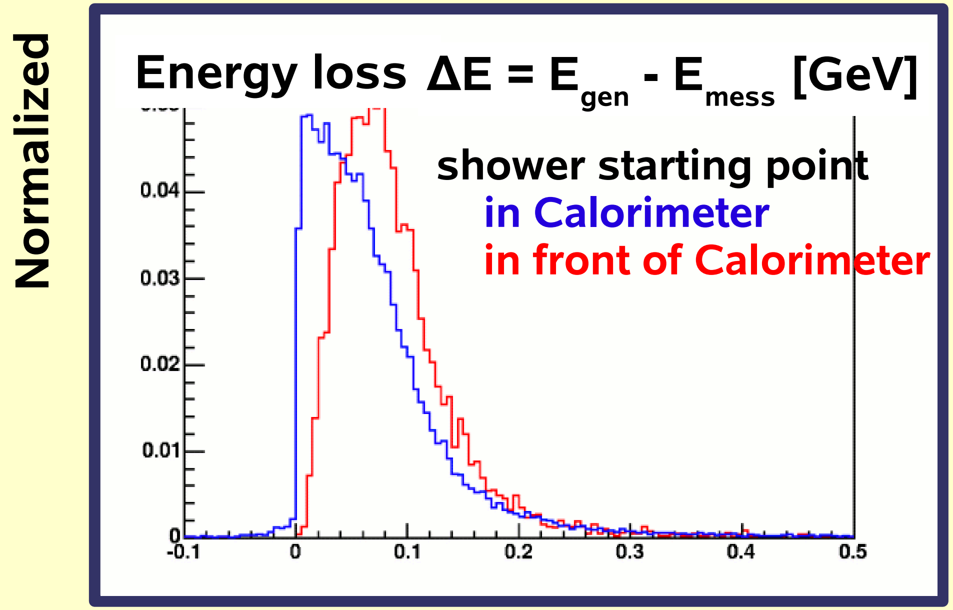
Questions:

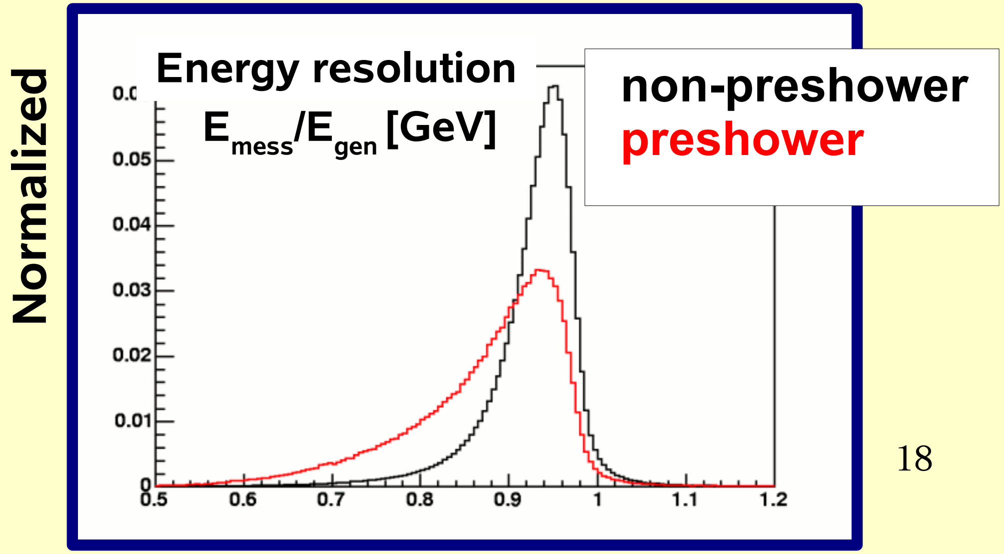
- **What happens to energy resolution?**
- **How is the (Pre)Shower shape ?**
- **How does MC describe Preshowers?**

Diploma theses topic:
Is it possible to identify preshowers ?

Idea : Try to do it with the DIRC

Single Photon MC

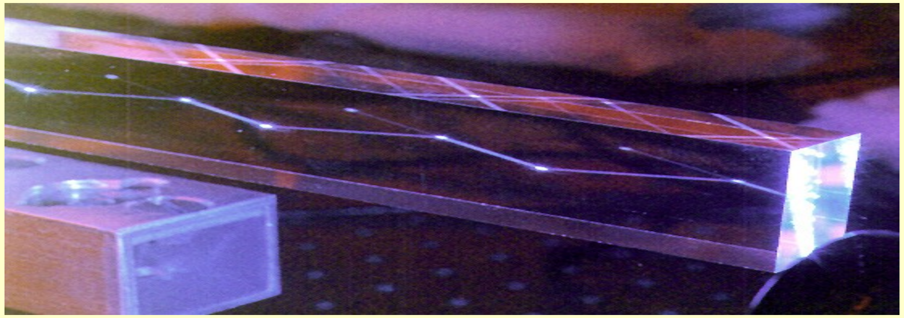


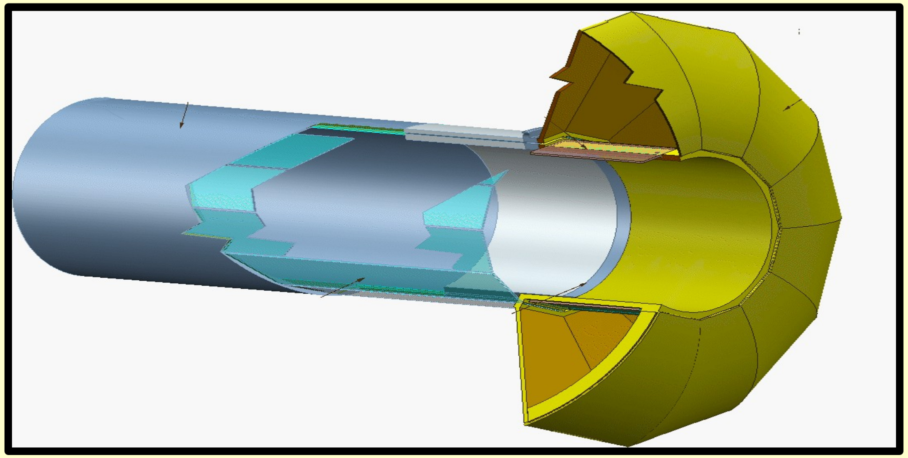


DIRC

Detector of Internally Reflected Cherenkov Light

- 144 quartz bars in 12 sectors
- 6 m^3 water tank
- about 11000 photo multipliers





- Charged particle with velocity β emits Cherenkov-Photons in DIRC-bars with angle Θ_c :

$$\cos(\Theta_C) = \frac{1}{(n\beta)}$$

- Photons travel through the bars via internal reflection to the photo multiplier tubes
- Determined Θ_c is compared to particle momentum measured in tracking system

DIRC

Observable:

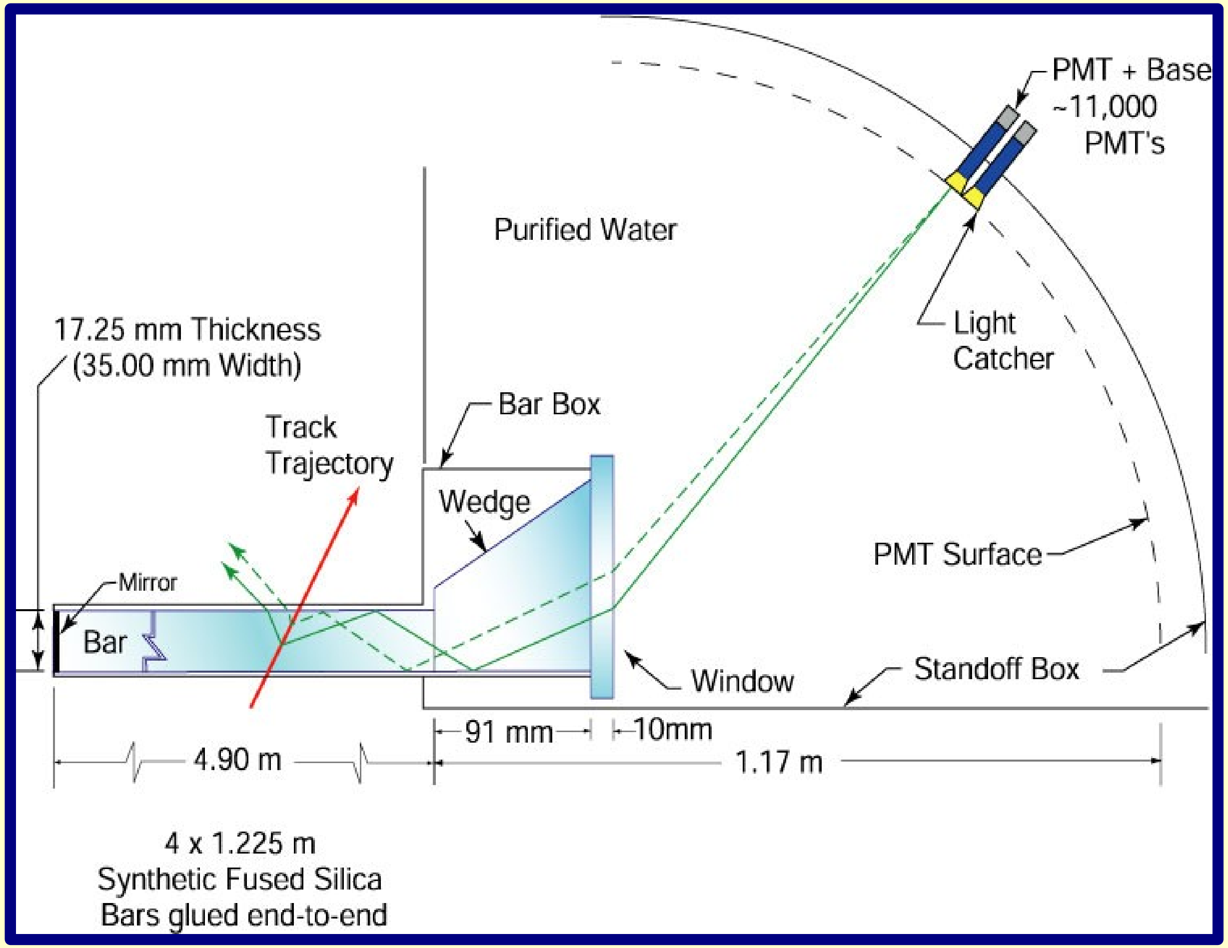
- **Track trajectory coordinates and angle at DIRC**
- **Photo Tube coordinates**

➡ **geometric reconstruction of Cherenkov angle for each photo tube hit**

➡ **up to 16 ambiguities: multiple paths are possible**

- **Time of photon detection T_{mess} relative to bunch crossing**

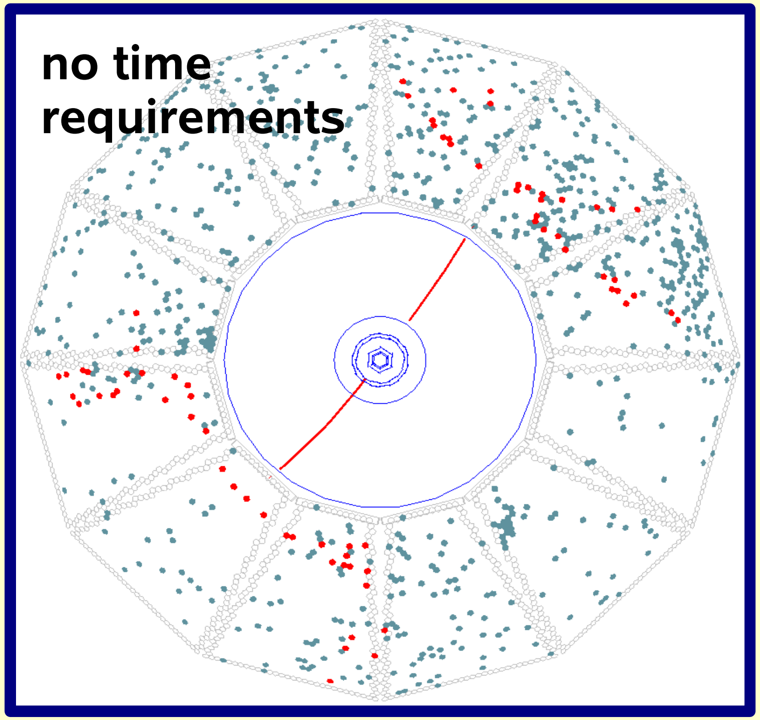
➡ **can be compared with expected calculated time T_{ex}**

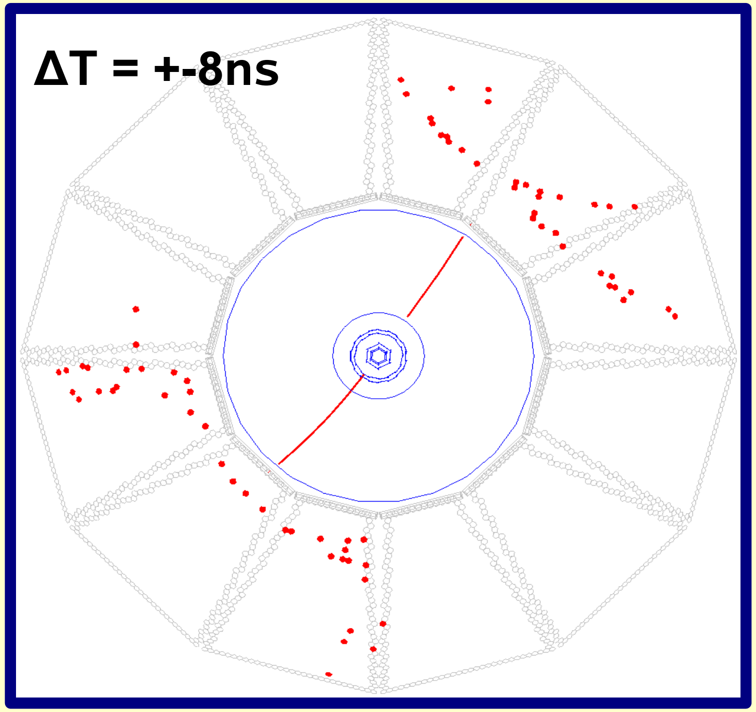


DIRC Time Information

Time information $\Delta T = T_{mess} - T_{expected}$ used to:

1) suppress background (Factor 40)
2) resolve geometric ambiguities
   (large ΔT more unlikely than small ΔT)

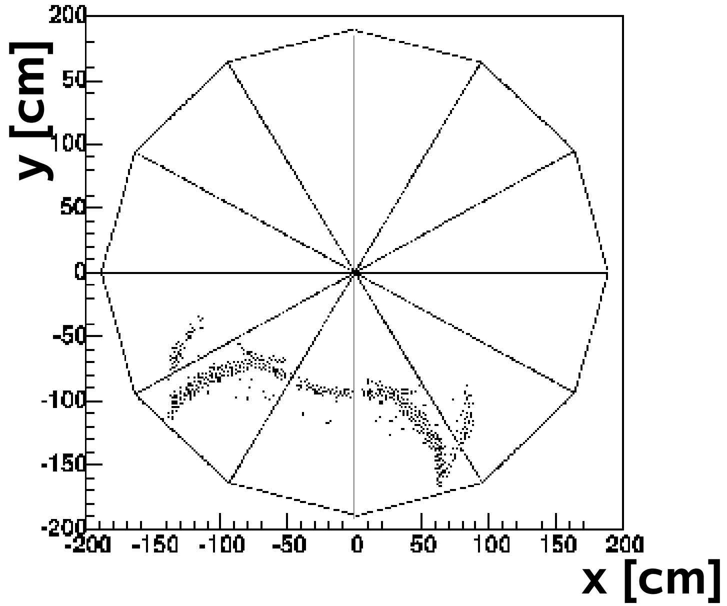




Preshower from MC photons

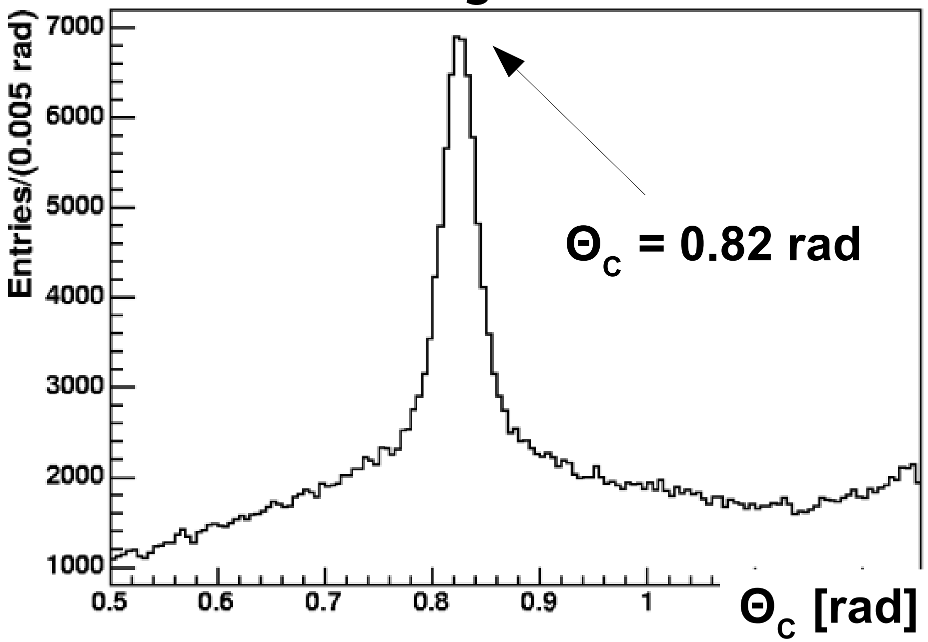
Single Photon Monte Carlo

➔ **All photo multiplier hits originate from shower-electrons**



2000 Photons (500 MeV) in equal direction

Cherenkov angle



➔ **Θ_C distributed at expected value for relativistic electrons**

Preshower photons “emit” Cherenkov-photons !

DIRC-Hit to EMC-Photon Association

In generic Events:

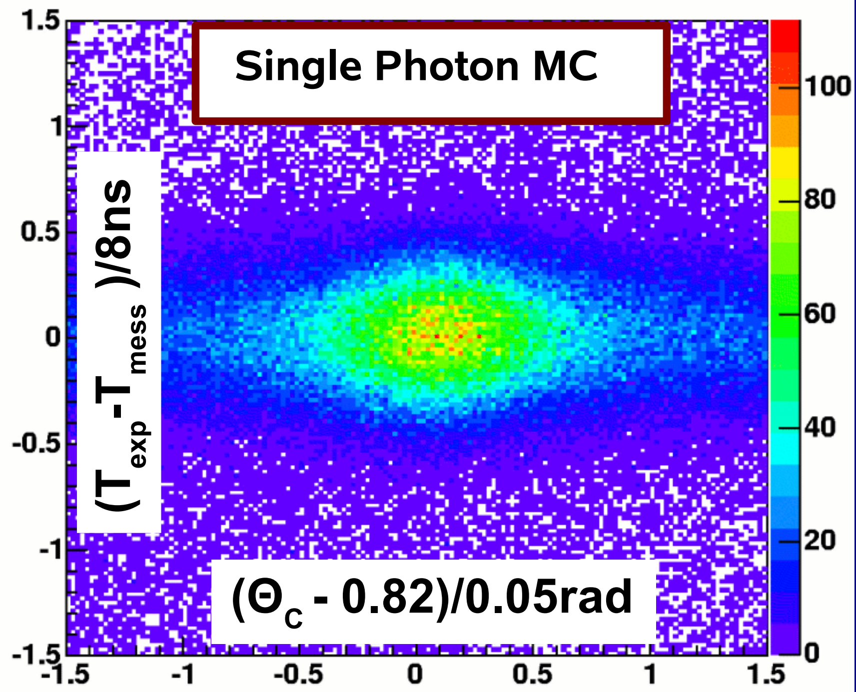
- A lot of wrong accociations need to be resolved
- Don't use DIRC-tube-hits already associated to charged particles
- Define for each geometrical possibility to associate one DIRC-hit with one EMC-photon :

$$A = \frac{(T_{erwart} - T_{mess})^2}{(8\text{ns})^2} + \frac{(\Theta_C - 0.82)^2}{(0.05\text{rad})^2}$$

Uses

- Time information
- Expected Cherenkov angle for electrons

Choose unique association with minimal A



Definition of Preshowers

Data samples for different studies can be defined:

- Low preshower content: Higher photon energy resolution
- High preshower content: Studies of preshower photon behavior

For high preshower content:

A preshower photon is an EMC-cluster with:

- a DIRC-tube-hit to EMC-cluster association with A<0.2
- a number of this associations > 10

Sample contains about 60% of preshowers :
Enrichment by almost a factor of 5

Preshower Identification in Real Data

$\pi^0 \rightarrow \gamma\gamma$

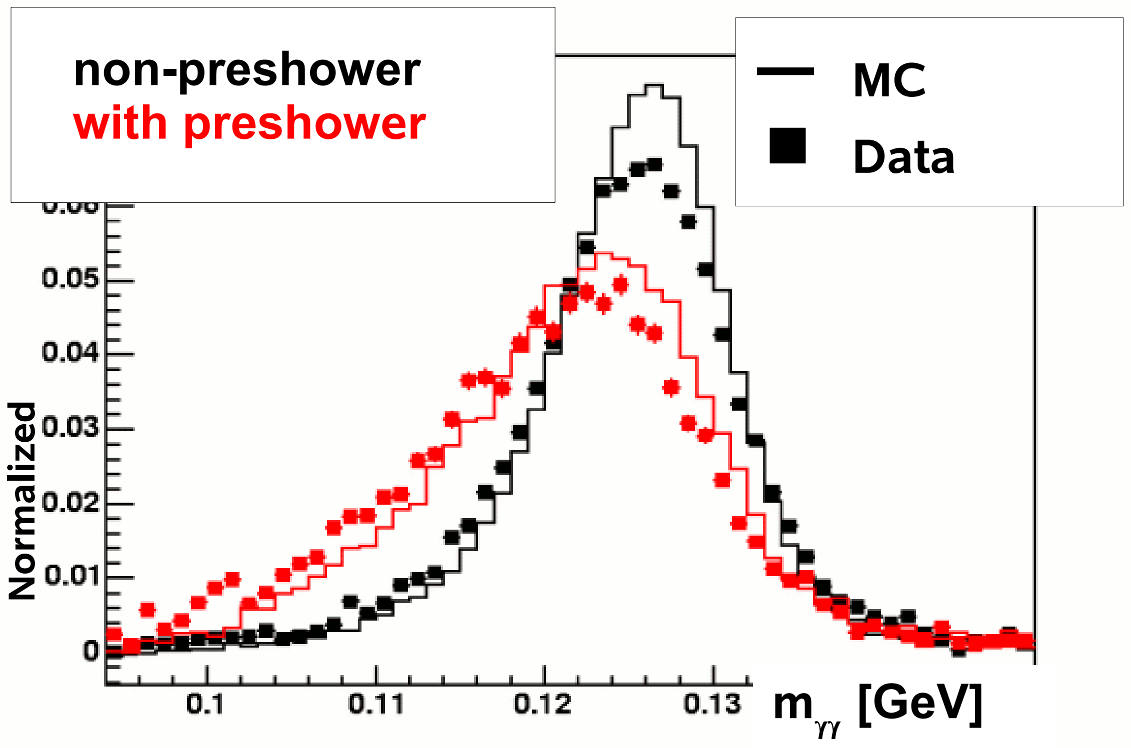
π^0 non-preshower:

➔ both daughter-photons are non-preshower.

π^0 with preshower:

➔ at least one photon is preshower.

Reconstructed π^0-mass
(combinatorial background subtracted)



➔ **Preshowers can also be identified in data**

Application of Preshowers

BaBar-Service-Task: Study preshower cluster shapes in the EMC
Compare data and Monte Carlo

Lateral Moment:
describes shower shape

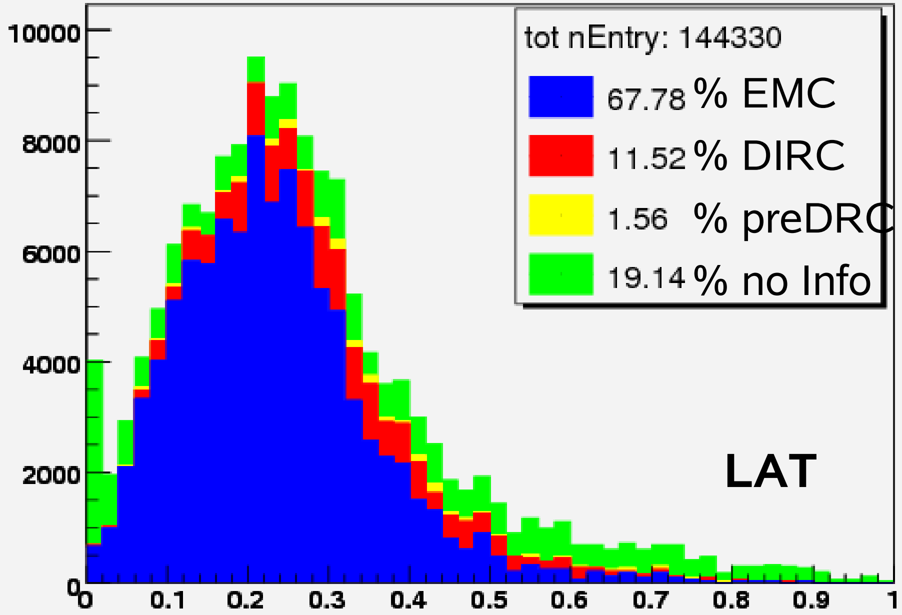
$$LAT = \frac{\sum_{i=3}^{N} E_i r_i^2}{\sum_{i=3}^{N} E_i r_i^2 + E_1 r_0^2 + E_2 r_0^2}$$

$E_1 > E_2 > \ldots > E_N$

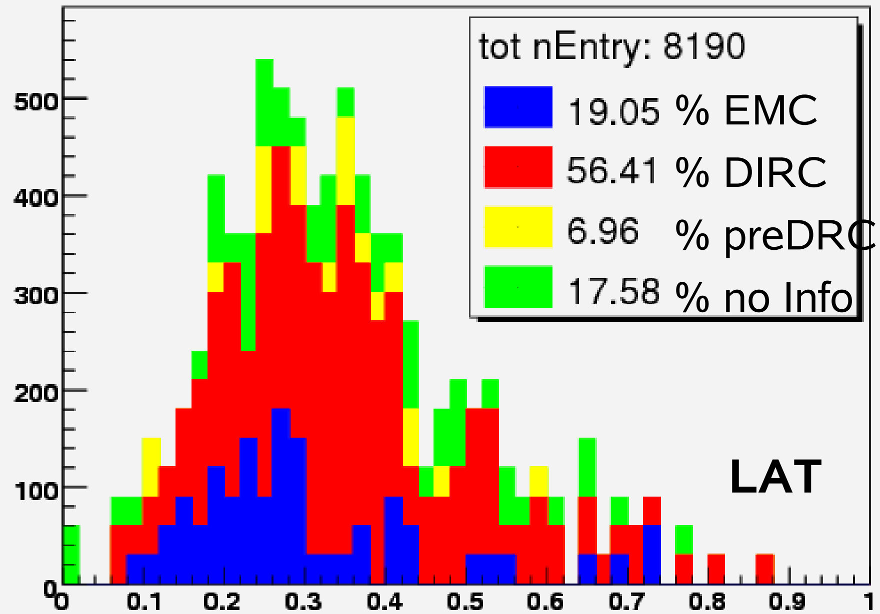
$r_i = distance(Crystal_i, Crystal_{clusterCenter})$

$r_0 = distance\ between\ 2\ crystals$

Total MC sample



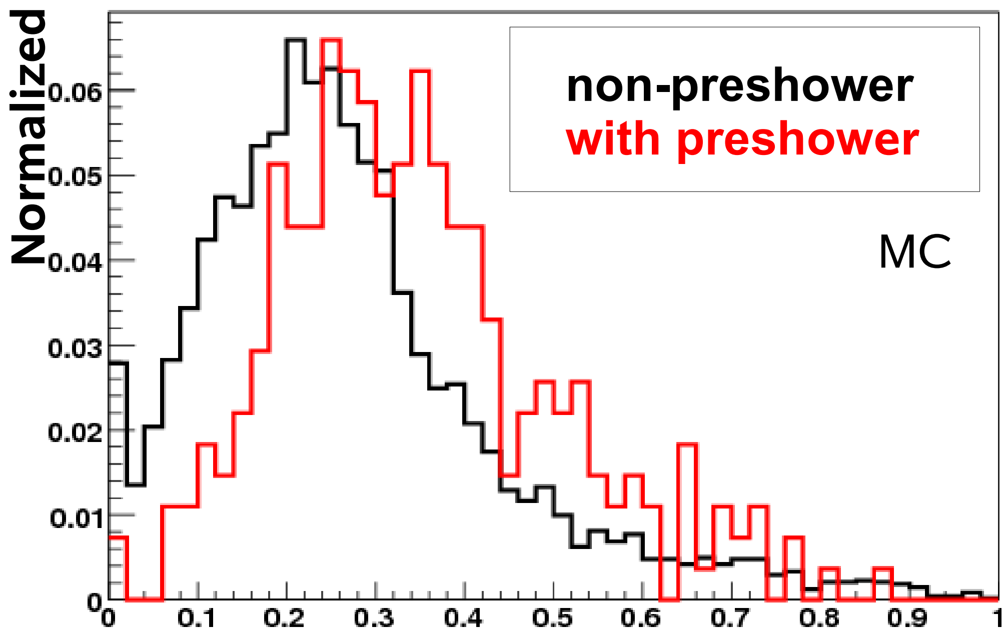
Preshower enriched MC sample



Summary and Outlook

First Look at Lateral Moment:

- shape shifted as expected
- how do real data look like?



- Showed in diploma thesis: Identification of preshowers with the Cherenkov detector is possible

- Started to use this tool to study calorimeter characteristics