Lepton τ polarisation at Z peak

- LEP results
- Sensitivities comparison
- Expected precision at FCCee/CEPC at Z peak
- Systematics sources

The $\boldsymbol{\tau}$ polarisation is the statistical value of the cross section asymmetry as a function of the longitudinal helicity

$$P_\tau = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$$

It depends of the polar angle θ (versus the electron beam line)

$$P\tau(cos\theta) = -\frac{A_\tau(1+cos^2\ \theta)+Ae\ (2\ cos\theta)}{(1+cos^2\ \theta)+\frac{4}{3}A_{\rm fb}(2\ cos\theta)}$$

And the parameter A_ℓ is related to vector and axial couplings

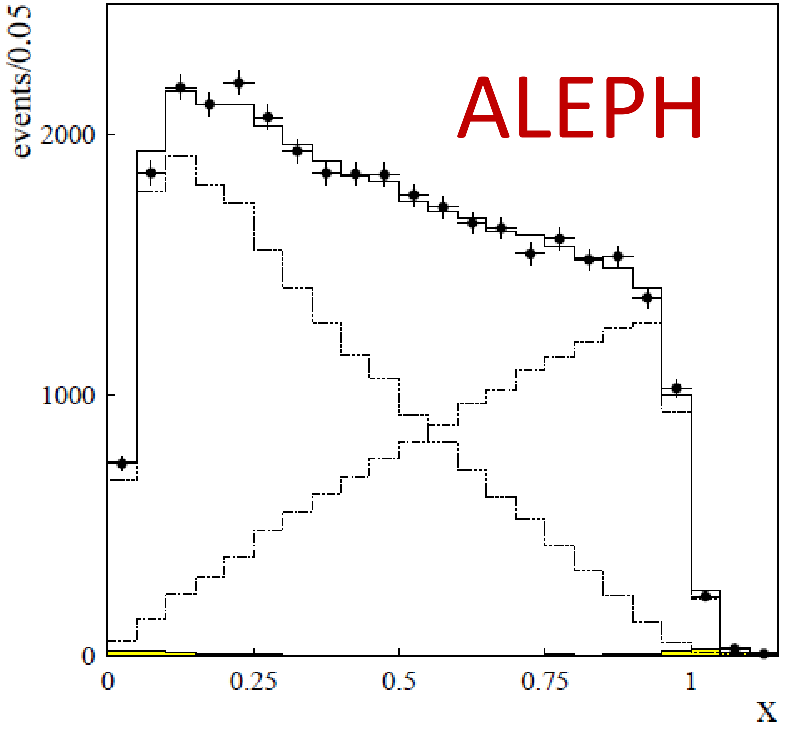
$$A_\ell = 2g_V^\ell\, g_A^\ell /[\, (g_V^\ell)^2 + (g_A^\ell)^2]$$

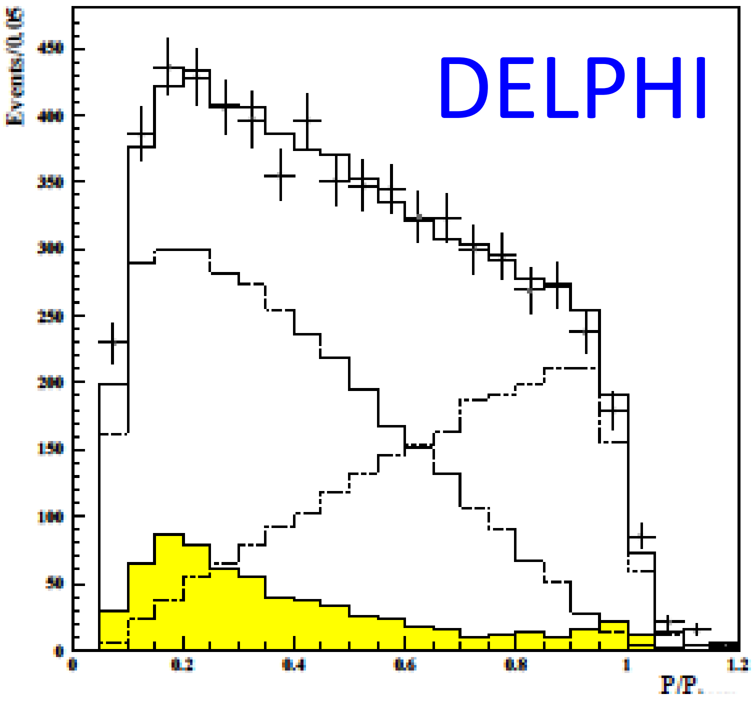
Related to the Weinberg angle $\quad g_V^\ell / g_A^\ell = 1 - 4 \sin^2 \theta_W$

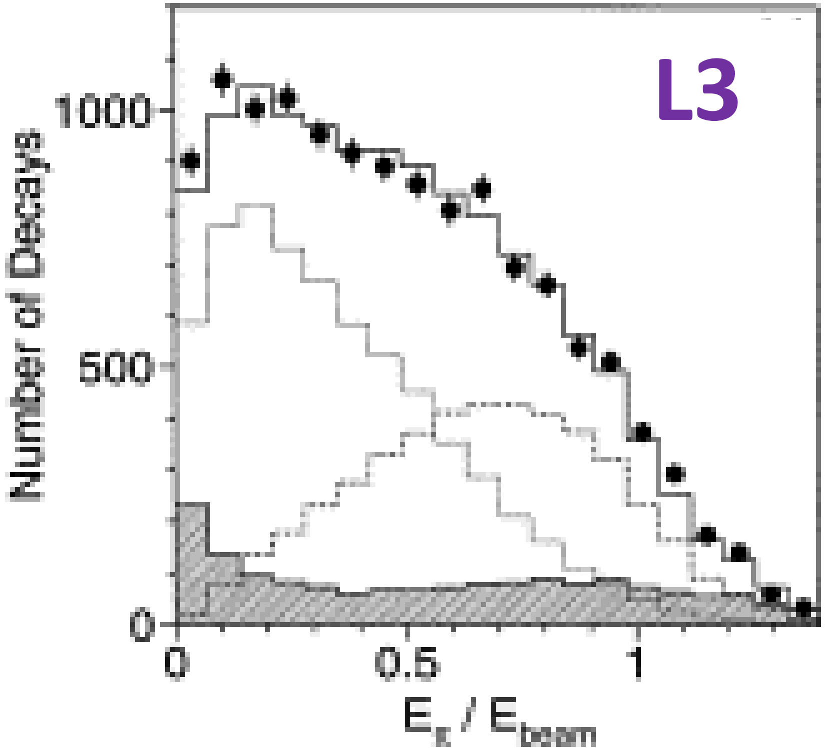
How to measure the polarisation ?

$\tau \to \pi(k)\ \nu$ Helicity directly related to the pion momentum

- S/N at low and high momentum (2-photons bkg and rho nu)
- Efficiency to reconstruct low Pt track
- Rejection of ee and mumu at P≈ Ebeam





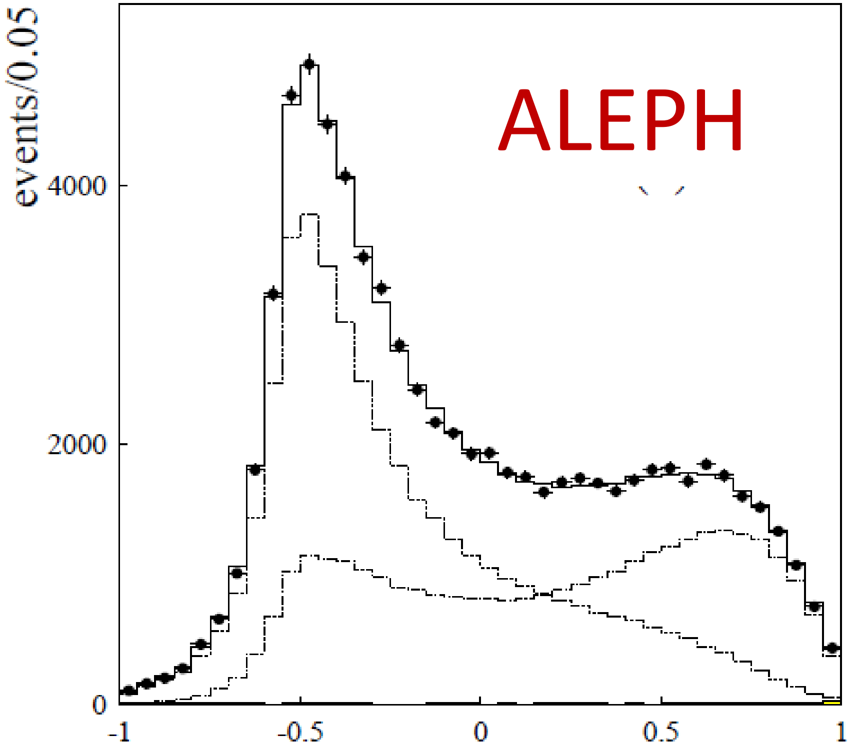


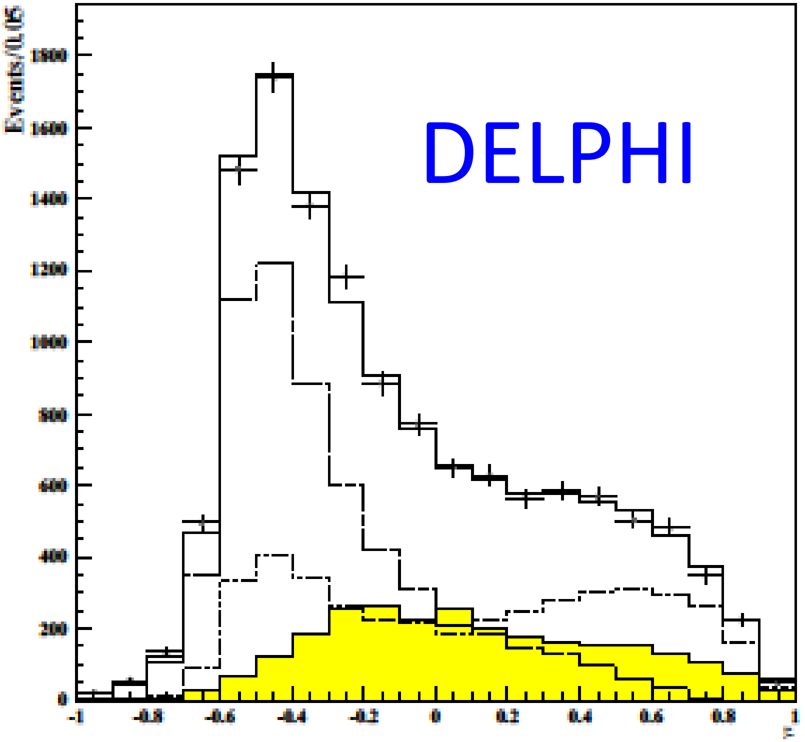
How to measure the polarisation ?

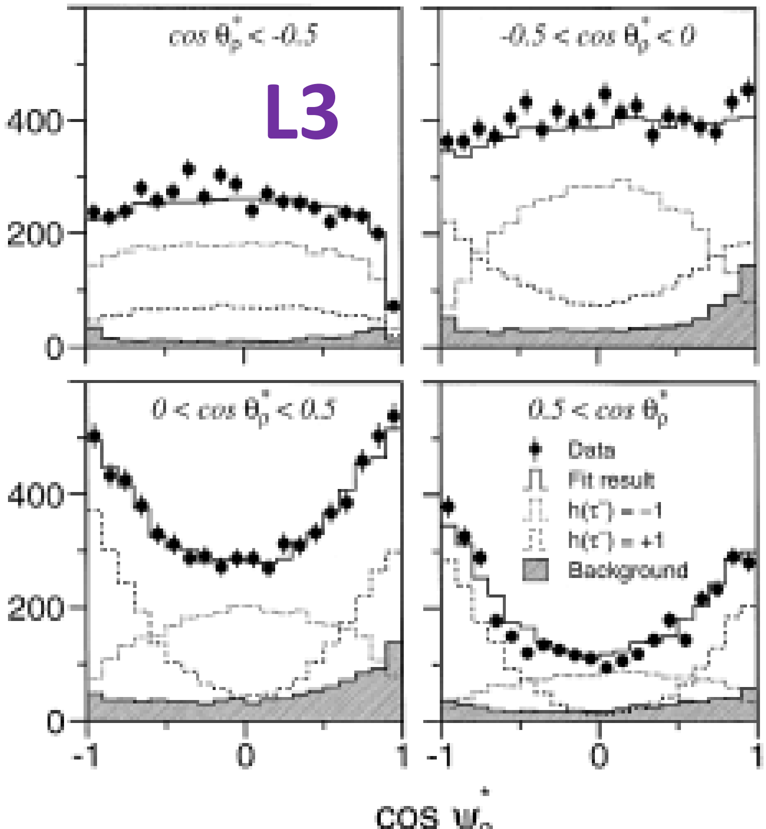
$\tau \rightarrow \rho(k^*)\ \nu$

Polarisation related essentially to the (charged – neutral) pion energy asymmetry

- S/N at low and high charged –neutral pion energy
- ESSENTIAL low energy photon !!!
- Cross contamination of others τ decays , namely a_1 and π bkg







$$\cos\psi = \frac{m_\rho}{\sqrt{m^2_\rho - 4m^2_\pi}} \; \frac{E_\pi - E_{\pi^\circ}}{(P_\pi + P_{\pi^\circ})}$$

$$\cos\phi = \frac{4m^2_\tau}{m^2_\tau - m^2_\rho} \; \frac{E_\pi + E_{\pi^\circ}}{\sqrt{s}} - \frac{m^2_\tau + m^2_\rho}{m^2_\tau - m^2_\rho}$$

E_π and P_π are the energy and momentum of the charged pion

E_{π° and P_{π° are the energy and momentum of the neutral pion

Most sensitivity are in cos ψ

- Low energy neutral with high momentum of the charged pion
- Low momentum charged pion and high π° energy

LEP results

experiments	$\mathcal{A}\tau$ (x100)
ALEPH	14.51 ± 0.52 ± 0.29
DELPHI	13.59 ± 0.79 ± 0.55
L3	14.76 ± 0.88 ± 0.62
OPAL	14.56 ± 0.76 ± 0.57
Combined	**14. 39 ± 0.35 ± 0.26**

experiments	$\mathcal{A}e$ (x100)
ALEPH	15.04 ± 0.68 ± 0.08
DELPHI	13.82 ± 1.16 ± 0.05
L3	16.78 ± 1.27 ± 0.30
OPAL	14.54 ± 1.08 ± 0.36
Combined	**14. 98 ± 0.48 ± 0.09**

Combination paper 2001

"Although the sizes of the event samples used by the four experiments are roughly equal, smaller errors are quoted by ALEPH. This is largely associated with the higher angular granularity of the ALEPH electromagnetic calorimeter."

At FCCee, CEPC, at Z peak, , with 10^5 more Z than at LEP,
it is expected that the systematics uncertainties will dominated

For the same number of Z produced, stat. error 2X bigger in DELPHI and the systematics X2 smaller ??

ALEPH exclusive

Channel	$\mathcal{A}\tau$ (%)	$\mathcal{A}_e$ (%)
$\tau \to \pi(k)\ \nu$	0.152 ± 0.01 ± 0.005	15.28 ± 1.30 ± 0.12
rho	13.79 ± 0.84 ± 0.38	14.66 ± 1.12 ± 0.09
a1(3h)	14.77 ± 1.60 ± 1.00	13.58 ± 2.11 ± 0.40
a1(h2π^0)	16.34 ± 2.06 ± 1.52	15.62 ± 2.72 ± 0.47
electron	13.64 ± 2.33 ± 0.96	14.09 ± 3.17 ± 0.91
muon	13.64 ± 2.09 ± 0.93	11.77 ± 2.77 ± 0.25
pion inclusive	14.93 ± 0.83 ± 0.87	14.91 ± 1.11 ± 0.17
Combined	14.44 ± 0.55 ± 0.27	14.58 ± 0.73 ± 0.10

DELPHI exclusive

Channel	$\mathcal{A}\tau$	$\mathcal{A}_e$
$\tau \to e\nu\bar{\nu}$	0 $\mathcal{A}\tau$ ± 0.038 ± 0.0 $\mathcal{A}e$	0.182 ± 0.058
$\tau \to \mu\nu\bar{\nu}$	0.149 ± 0.029 ± 0.020	0.106 ± 0.039
$\tau \to \pi(k)\ \nu$	0.187 ± 0.020 ± 0.022	.127 ± 0.031
$\tau \to \rho\nu$	0.116 ± 0.019 ± 0.016	0.143 ± 0.028
$\tau \to a_1\nu$	0.133 ± 0.034 ± 0.032	0.162 ± 0.050
Inclusive	0.1268 ± 0.0091 ± 0.0070	0.1400 ± 0.0131

L3 exclusive

method	channel	$\mathcal{A}\tau$	$\mathcal{A}_e$
Exclusive	$\tau^- \to e^-\bar{\nu}_e\nu_\tau$	0.121 ± 0.031	0.257 ± 0.046
	$\tau^- \to \mu^-\bar{\nu}_\mu\nu_\tau$	0.144 ± 0.033	0.206 ± 0.047
	$\tau \to \pi(k)\ \nu$	0.142 ± 0.015	0.146 ± 0.023
	$\tau \to \rho\ \nu_\tau$	0.155 ± 0.012	0.147 ± 0.019
	$\tau^- \to a_1^-\nu_\tau$	0.191 ± 0.056	0.214 ± 0.084

For the same number of Z produced, stat. error 2X bigger in DELPHI and the systematics X2 smaller ??

ALEPH exclusive

Channel	$\mathcal{A}_\tau$ (%)	$\mathcal{A}_e$ (%)
hadron	$15.21 \pm 0.98 \pm 0.49$	$15.28 \pm 1.30 \pm 0.12$
$\tau \to \rho\nu$	$13.8 \pm 0.8 \pm 0.4$	$14.66 \pm 1.12 \pm 0.09$
a1(3h)	$14.77 \pm 1.60 \pm 1.00$	$13.58 \pm 2.11 \pm 0.40$
a1(h2π^0)	$16.34 \pm 2.06 \pm 1.52$	$15.62 \pm 2.72 \pm 0.47$
electron	$13.64 \pm 2.33 \pm 0.96$	$14.09 \pm 3.17 \pm 0.91$
muon	$13.64 \pm 2.09 \pm 0.93$	$11.77 \pm 2.77 \pm 0.25$
pion inclusive	$14.93 \pm 0.83 \pm 0.87$	$14.91 \pm 1.11 \pm 0.17$
Combined	$14.44 \pm 0.55 \pm 0.27$	$14.58 \pm 0.73 \pm 0.10$

DELPHI exclusive

Channel	$\mathcal{A}\tau$	$\mathcal{A}e$
$\tau \to e\nu\bar{\nu}$	$0.166 \pm 0.038 \pm 0.042$	0.182 ± 0.058
$\tau \to \mu\nu\bar{\nu}$	$0.149 \pm 0.029 \pm 0.020$	0.106 ± 0.039
$\tau \to \pi(K)\nu$	$0.187 \pm 0.020 \pm 0.022$	0.127 ± 0.031
$\tau \to \rho\nu$	$11.6 \pm 1.9 \pm 1.6$	0.143 ± 0.028
$\tau \to a_1\nu$	$0.133 \pm 0.034 \pm 0.032$	0.162 ± 0.050
Inclusive	$0.1268 \pm 0.0091 \pm 0.0070$	0.1400 ± 0.0131
Neural net	$0.1348 \pm 0.0123 \pm 0.0061$	0.1369 ± 0.0183

L3 rho channel, $\mathcal{A}\tau$ = 15.5 ± 1.2

At FCCee/CEPC , it is expected that the systematics errors dominate

ALEPH

Table : Results for $\mathcal{A}_e$ *and* $\mathcal{A}_\tau$ in the analysis. The first error is statistical, the second systematic

Tau decays channels	$\mathcal{A}_\tau$ %	$\mathcal{A}_e$ %
$h^\pm\ \nu$	$15.21 \pm 0.98 \pm 0.49$	$15.28 \pm 1.30 \pm 0.12$
$\rho^\pm\ \nu$	$13.79 \pm 0.84 \pm 0.38$	$14.66 \pm 1.12 \pm 0.09$
a1 ($3h^\pm$)	$14.77 \pm 1.60 \pm 1.00$	$13.58 \pm 2.11 \pm 0.40$
a1 ($h^\pm\ 2\pi°$)	$16.34 \pm 2.06 \pm 1.52$	$15.62 \pm 2.72 \pm 0.47$
electron	$13.64 \pm 2.33 \pm 0.96$	$14.09 \pm 3.17 \pm 0.91$
muon	$13.64 \pm 2.09 \pm 0.93$	$11.77 \pm 2.77 \pm 0.25$
$h^\pm$ inclusive	$14.93 \pm 0.83 \pm 0.87$	$14.91 \pm 1.11 \pm 0.17$
Combined	$14.44 \pm 0.55 \pm 0.27$	$14.58 \pm 0.73 \pm 0.10$

Table : Summary of the systematics uncertainties (%) $\mathcal{A}_\tau$ in the analysis

ALEPH

sources	h	ρ	3h	h 2π°	e	μ	Incl. h
selection		0.01			0.14	0.02	0.08
tracking	0.06		0.22			0.10	
ECAL En. Scale	0.15	0.11	0.21	1.10	0.47		
PID	0.15	0.06	0.04	0.01	0.07	0.07	0.18
misid	0.05				0.08	0.03	0.05
photon	**0.22**	**0.24**	**0.37**	**0.22**			
Non-τ Bkg	**0.19**	0.08	0.05	**0.18**	0.54	0.67	0.15
τ BR	0.09	0.04	0.10	0.26	0.03	0.03	0.78
modeling			0.70	0.70			0.09
MC stat	**0.30**	**0.26**	**0.49**	**0.63**	**0.61**	**0.63**	**0.26**
Total	**0.49**	**0.38**	**1.00**	**1.52**	**0.96**	**0.93**	**0.87**

In red, errors which do not scale with luminosity

Table : Summary of the systematics uncertainties (%) on $\mathcal{A}_e$ in the analysis

ALEPH

sources	h	ρ	3h	h 2π°	e	μ	Incl. h
tracking	**0.04**					**0.05**	
Non-τ Bkg	**0.11**	**0.09**	**0.04**	**0.22**	**0.91**	**0.24**	**0.17**
modeling			**0.40**	**0.40**			
Total	0.12	0.09	0.40	0.47	0.91	0.25	0.17

How to control the level of non-tau background ?

- Bhabha
- 2-Photons

DELPHI

Systematics errors estimation as a function of the source of the uncertainties

	$\tau \to e\nu\bar{\nu}$	$\tau \to \mu\nu\bar{\nu}$ (br.)	$\tau \to \mu\nu\bar{\nu}$ (fw.)	$\tau \to \pi(K)\nu$	$\tau \to \rho\nu$	$\tau \to 3\pi^{\pm}\nu_\tau$
e id./rej.	0.025	–	–	0.007	–	–
μ id./rej.	–	0.005	0.020	0.017	–	–
γ and π^0 id./rej.	–	–	–	0.010	0.009	0.024
external back.	0.025	0.008	0.020	0.002	–	–
energy scale/resol.	0.030	0.009	0.009	–	0.011	0.013
simulation stat.	0.013	0.009	0.016	0.007	0.006	0.012
others	–	–	–	0.001	0.008	0.016
total	0.048	0.018	0.033	0.022	0.017	0.033

1 - Importance of the cross contamination (tau background) on sensitivity

2 - Systematics which do not scaled with the luminosity

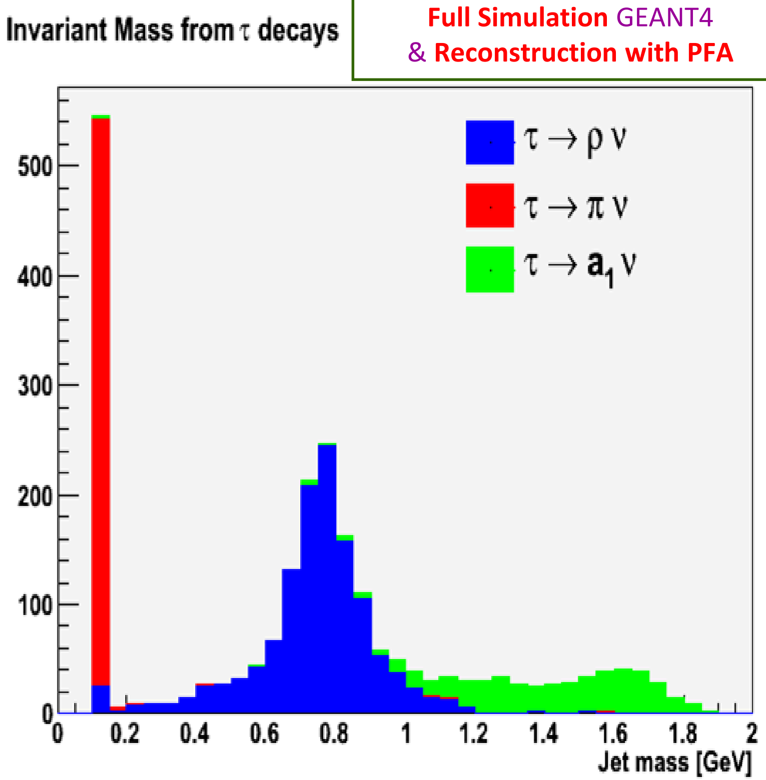
- good ratio genuine/fake at low photon energy (below 0.5 GeV)
- good π° reconstruction at high energy (20-45 GeV)
- control of the bias on charged pion momentum creation of fake photon (Simul. vs real data)

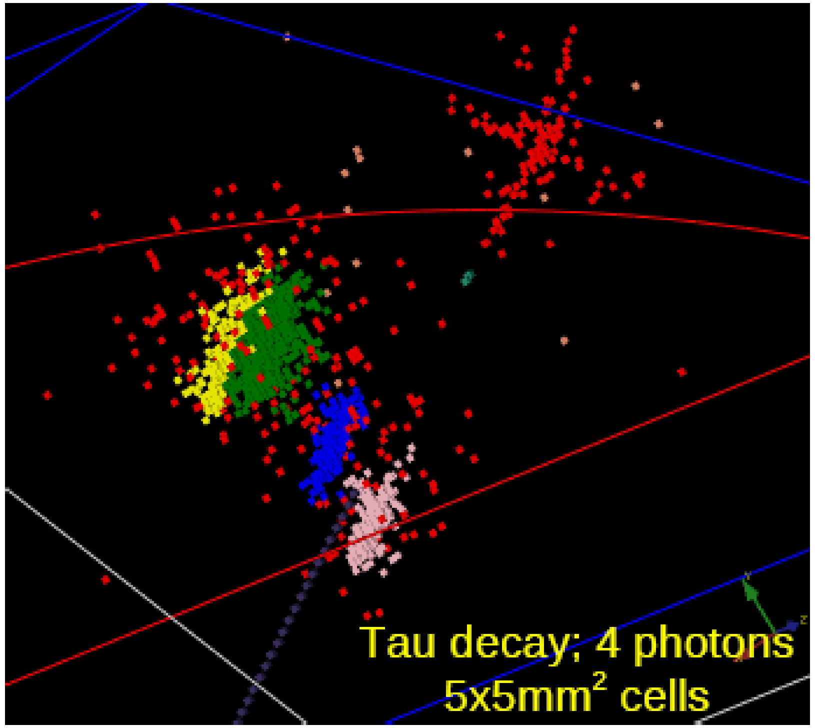
- Charged track PID efficiency and purity as a function of momentum (Simul. vs real data)
- Non-tau bkg as low as possible and method to control it

What can be done with High Granularity Calorimeter !!!

→ Need to reconstruct photon(s) in dense environment…. **Even at 250 GeV**

Full Simulation GEANT4
& Reconstruction with PFA





	Jet mass < 0.2	Jet mass in 0.2-1.1	Jet mass >1.1
$\tau \rightarrow \pi\nu$	90.2 %	1.7 %	8.1 %
$\tau \rightarrow \rho\nu$	1.7 %	87.3 %	7.4%
$\tau \rightarrow a_1\nu$	0.6 %	7.4 %	92.0 %

Performances depends strongly on ECAL granularity

What can be done with High Granularity Calorimeter !!!

PID tagging efficiency

3cmx3cm	e	μ	h
e id	100	0	0
μ id	0	99.6	4
h id	18	11	97.1

Need a method to check
Simulation vs real data !!
With very high precision

From M.Ruan (IHEP-Beijing) based on simulation of ultragranular calorimeter and ARBOR PFA reconstruction software (using fractal dimension method)

- With such values, the non-τ background at high energy would be very small
- Low angle electron/positron tagging could help to reduce 2-Photons background

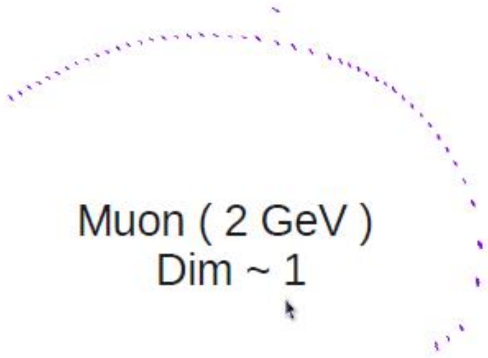
Conclusion

1. Fantastic precisions expected
2. Totally dominated by systematics
3. Capability on photon(s) at low energy and on π^o at high energy is the key
   (and bias on momentum of the charged pion due to rejection of hemisphere with γ(s))
4. PID is also part of the game of the systematicsn specially for Ae

For points 3 and 4 , how to control the efficiencies on simulation with real data ?

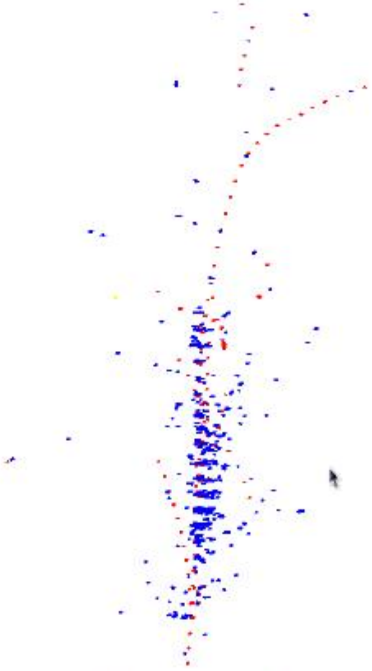
BACK-UP

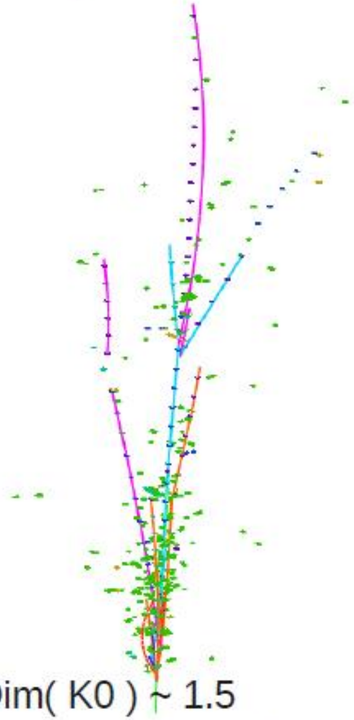
Fractals in Nature



Muon (2 GeV)
Dim ~ 1

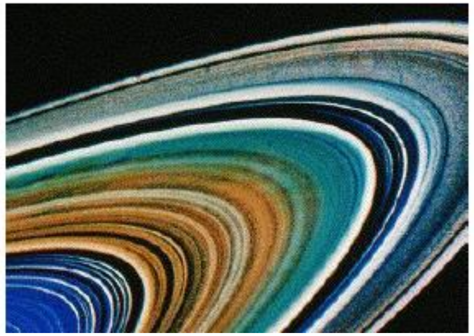
Straight line:
Dim = 1

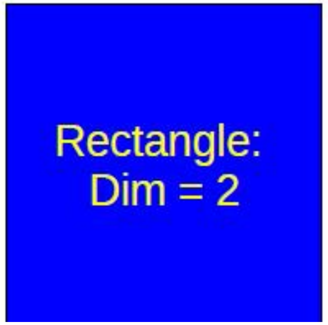




Hadrons: Dim(pi) < Dim(K0) ~ 1.5

Positron (40GeV)
Dim ~ 1.75



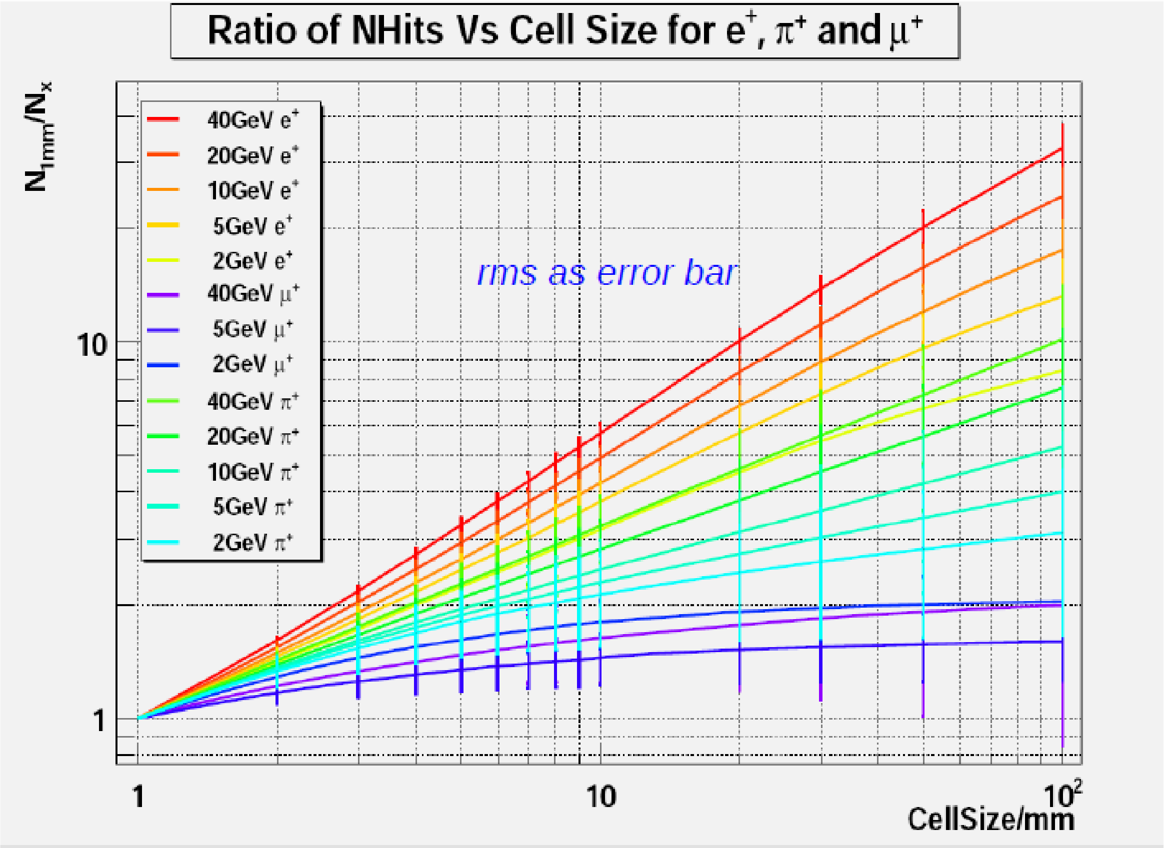


Shower: Self Similar

- Characteristic constant based on energy/PID:

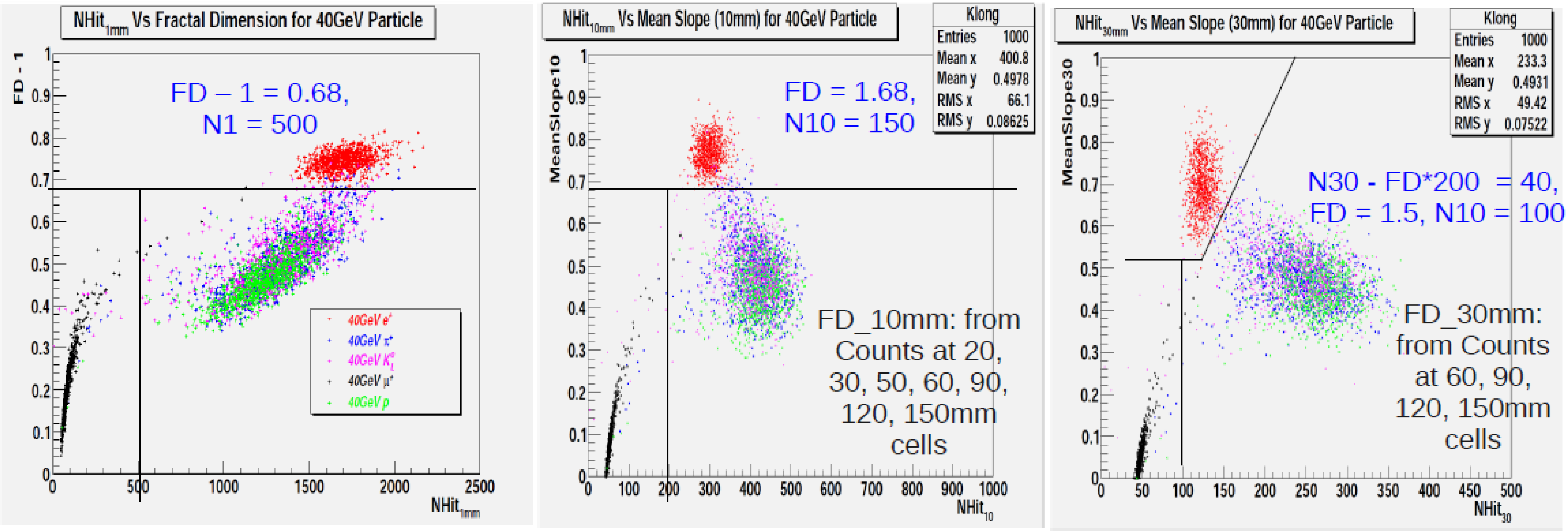
  $D = < \ln RN_a / \ln(a) >$

  - Global parameter based on local density
  - *Cell Sizes: 2 – 10, 20, 30, 50, 60, 90, 120, 150mm.*
  - *Samples: Particles shot directly to GRPC DHCAL with only B Field*



- Be observed within
  - Low scale: minimal interaction energy & sensor layer thickness (1.2mm)
  - High scale: fully containment ~ 1 hits per layer

Potential tool for PID



FD together with other info (Nhits): Clear separation at different scales

Remark: Energy dependent Cuts, easier for charged particles

1mm	e+	u	h
e+	998	0	2
u	1	994	5
h	15	14	971

10mm	e+	u	h
e+	1000	0	0
u	0	995	5
h	17	14	969

30mm	e+	u	h
e+	1000	0	0
u	0	996	4
h	18	11	971