Muon detectors and particle I.D.

- Generalities on muon detection and identification
- The Tesla design
- Hadron identification
- What could be available (almost for free)
- An attempt to determine what hadrons-id could buy.
- Conclusions

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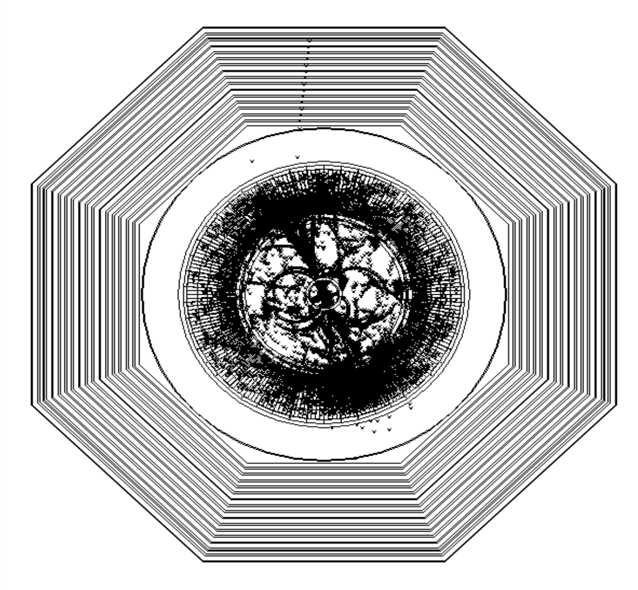
Muon detector…why…how

- The need of a muon identifier in a general purpose e^+e^- detector is sort of obvious.
- There are points however that one need to stress:
  - Muons are good tags to flavor identify jets.
  - Muons are good tags to charge identify gauge bosons.
  - Tagging muon helps improving overall performances of a detector as muonic events are associated with jets containing neutrinos.
    - In applications requiring the very best calorimetric performances one should reject events/jets containing leptons as the ones which in principle part of the energy is not detectable.

Identifying muons at an electron machine

- The cleanliness of an electron machine allows a relatively simple design for a muon detector.
- Muon systems at High Energy Hadronic Colliders usually operate on a stand-alone basis.
- The muon detector for an electron collider can profit of the momentum measurements coming from the inner detectors as associating inner tracks to muon stubs is easily doable in this environment.

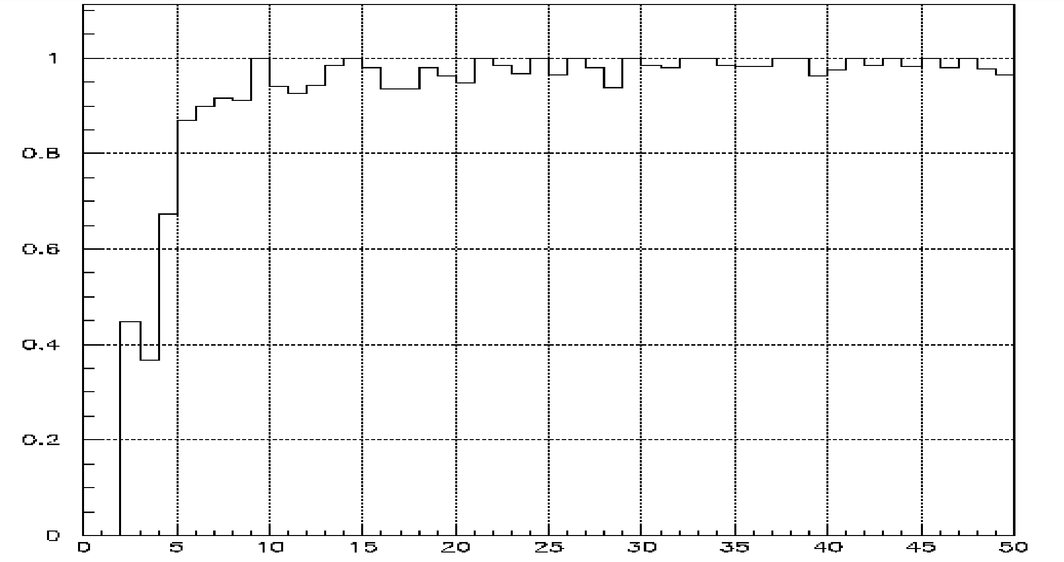


Generalities

- Given the location of the μ detectors one needs devices that offer
  - Absolute reliability
    - Detectors are not serviceable
  - Low cost/m^2
    - Spatial dimensions and areas to cover are big.
    - By the same token good size pulses would be a plus..
  - Industrial production process.

(Other) Detector components constraints

- Muon identification occupies the outermost real estate of a general purpose detector:
  - Momentum cut-off due to:
    - B-field
    - Calorimetry
- Tesla design results in a ~5 GeV/c threshold



Event choice for optimization

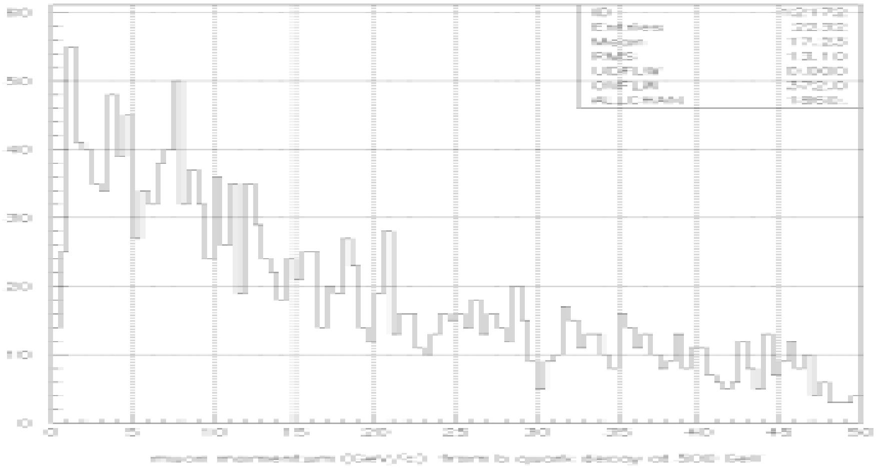
- The hardest task for any muon detector would be to pick-up low energy muons in the middle of a dense jet.
- Simulations were all run on final states with two quarks and in particular *bb* states were the ones with most statistics
- Typical results come from 10,000 fully (GEANT) simulated events.

Irreducible Spatial errors

- Picking up a low energy μ inside a jet, depends on the M.S. amount the calorimetry forces upon us.
- I tried to evaluate the spatial spread our reference detector introduces on particles reaching the magnet iron front face.
- Single particle at given momenta were passed through the apparatus to evaluate the spatial r.m.s at the μ-identifier.

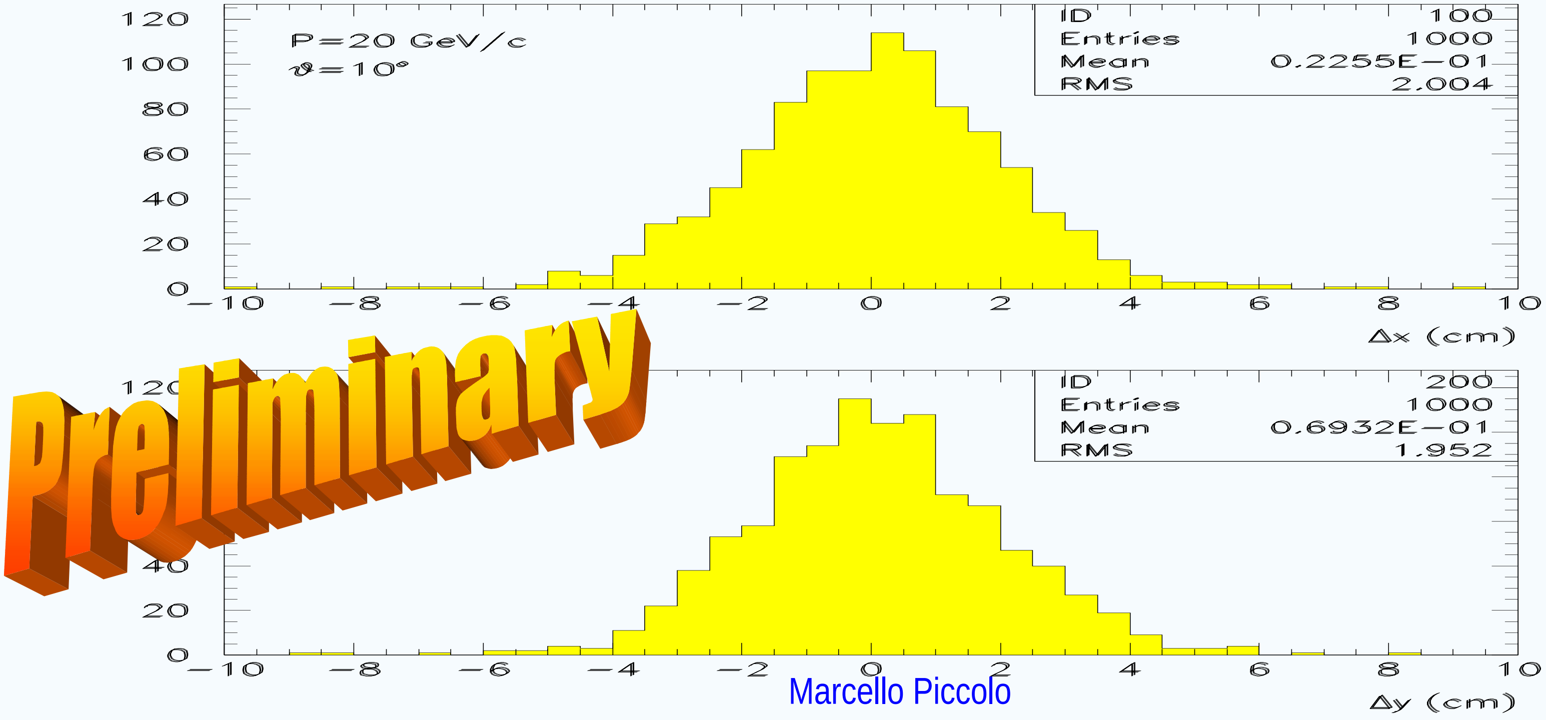
“Soft” muons momentum spectrum

- The momentum spectrum for *bb* μ’s:



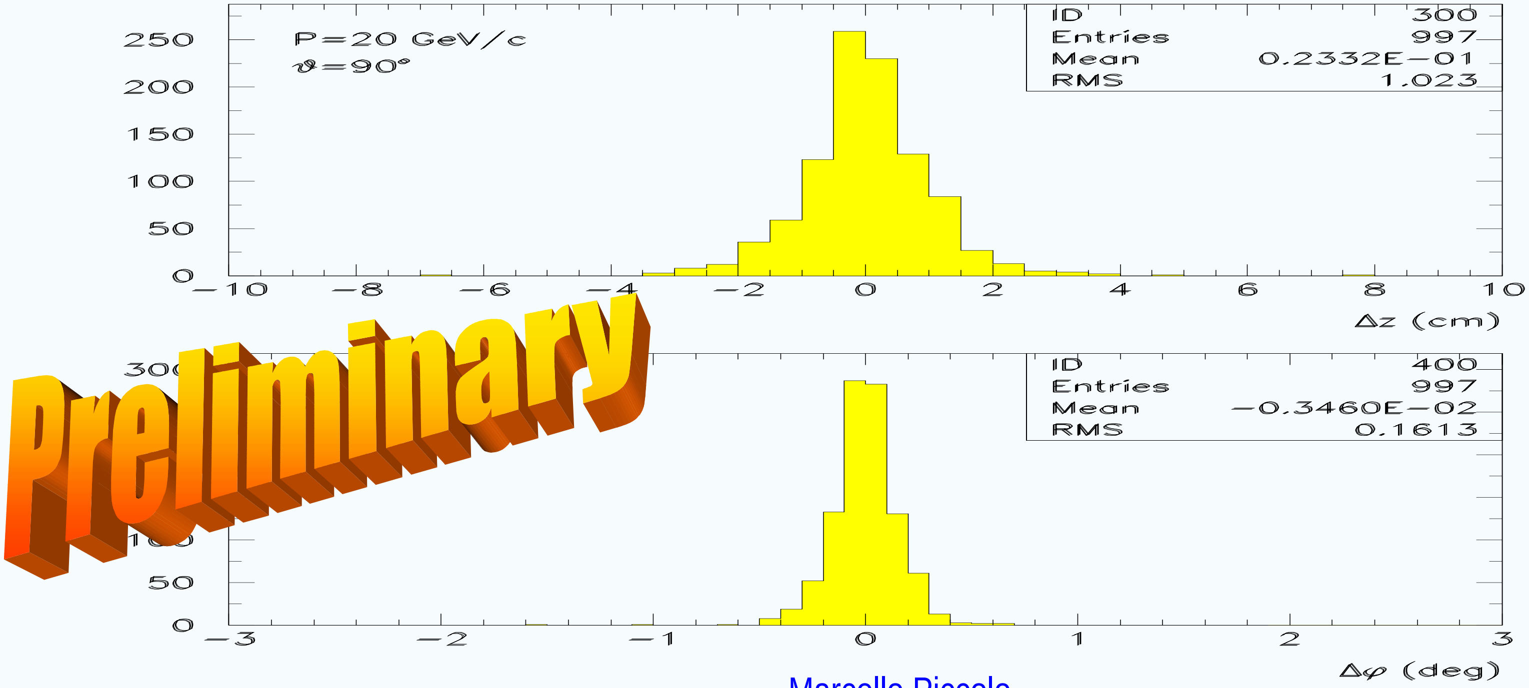
20 GeV/c μ

- The distribution of Δy and Δy from the extrapolated tracks at the entrance of μ identifier for 20 GeV/c muons.

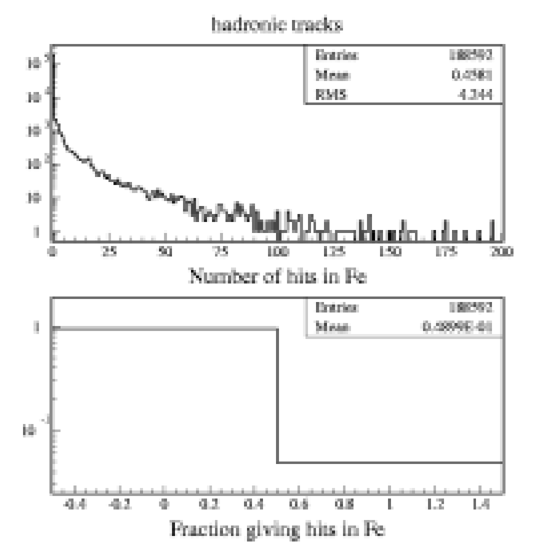


20 GeV/c μ

- The distribution of Δz and Δϕ from the extrapolated tracks at the entrance of μ identifier for 20 GeV/c muons.

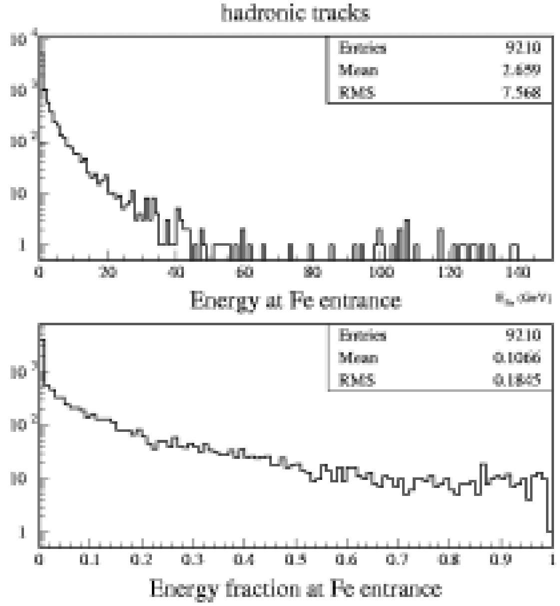


Do we need calorimetric capabilities ?



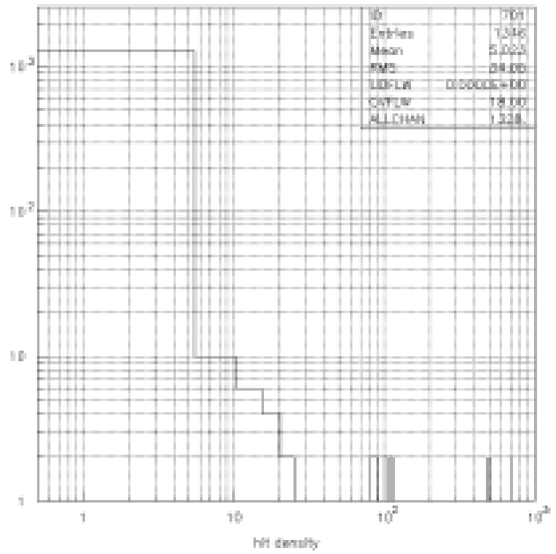
- In a *bb* sub-sample, (5000 evts) 4.9% of the tracks left energy in the muon filter,
- The analyzed sample contains roughly 200,000 tracks.

Do we need calorimetry ?



- The average energy a track dumps in the muon filter is small.
- On the average a couple of GeV.
- It would be nice, however to design a device that would allow measuring it

An other ingredient: hit density



- Important to choose active detectors
- …or operational properties

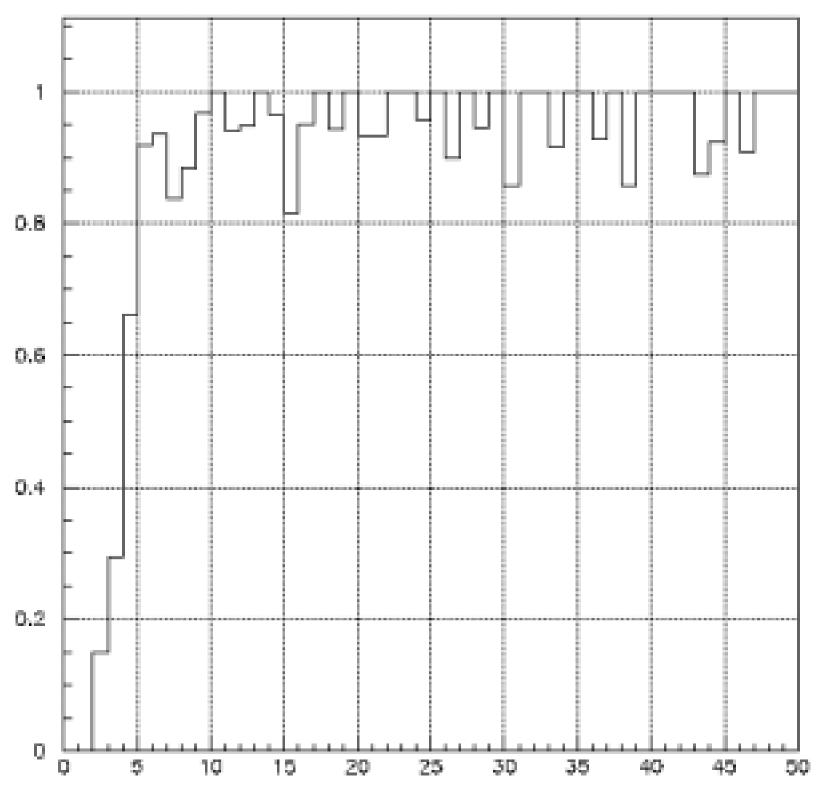
Technology Choice

- Given the reasonably small occupancy expected and the big dimension one has to cover two alternatives have been considered:
  - Plastic streamer tubes
  - Resistive plate Chambers
- Weighting the relative merit of these two technologies my inclination would be toward RPC's

A reference detector

- I tried to evaluate performances in the scenario of maximal # of active planes.
- Given the total amount of iron needed to close the B-field flux (150 cm.),I simulated a device with active planes every 10 cm of Fe.
- Performance optimization can be achieved turning off at the analysis level one or more active planes....

Performances



- Here is the efficiency vs. p of a configuration that uses 150 cm Fe.

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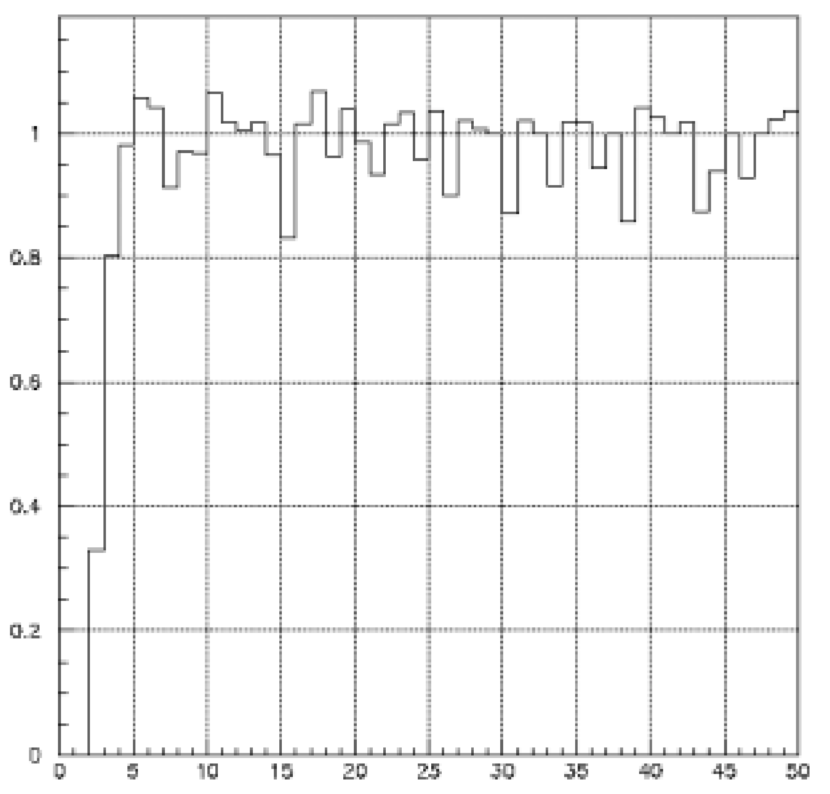
- In high energy μ's identification , efficiency of last planes is at a premium.

Performances (cont.)

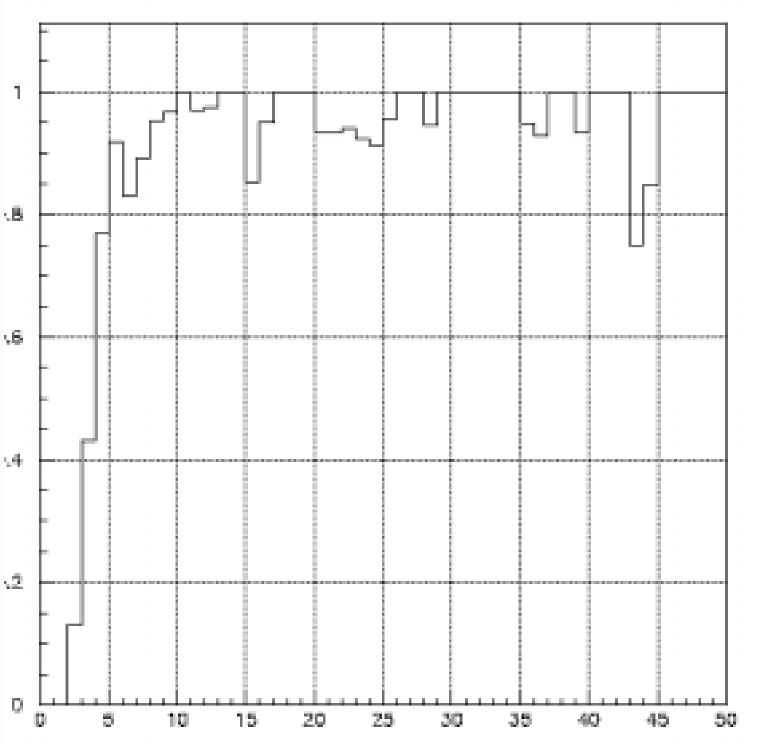


- Here we have the ratio of single μ to *bb* μ efficiency.
- Within the statistic of the simulation no relevant loss of efficiency can be seen in jetty events.

Radiator thickness and segmentation

- As stressed before the amount of iron needed to close the magnetic flux is 1.5 m .
- The segmentation buys rejection power, at a cost of increasing the active detector area.
- A preliminary design has been carried out segmenting at 10 cm of iron ten times and then adding the remaining 50 cm all together.
- This corresponds to 12/11 planes of detector. (barrel/end-caps)
- The length of the barrel elements would be 14.5 m (long barrel option).
- The design,carried out in this way, turns out to require an amount of active detectors in between the already built systems and what’s planned for the LHC apparata.

Performances

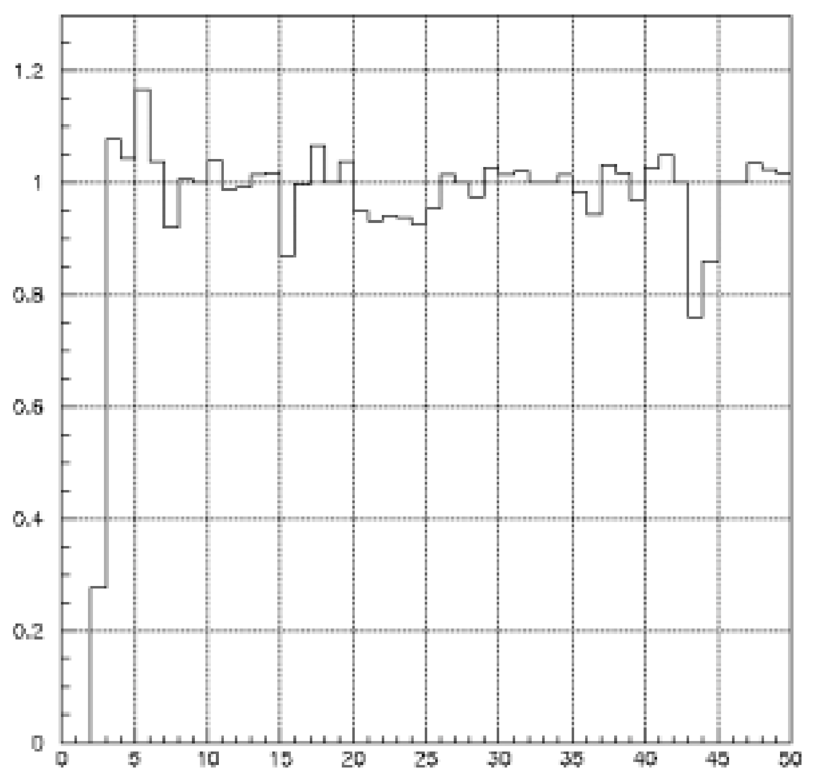


- Here is the efficiency vs. p of an *optimized* configuration that uses 150 cm Fe

.

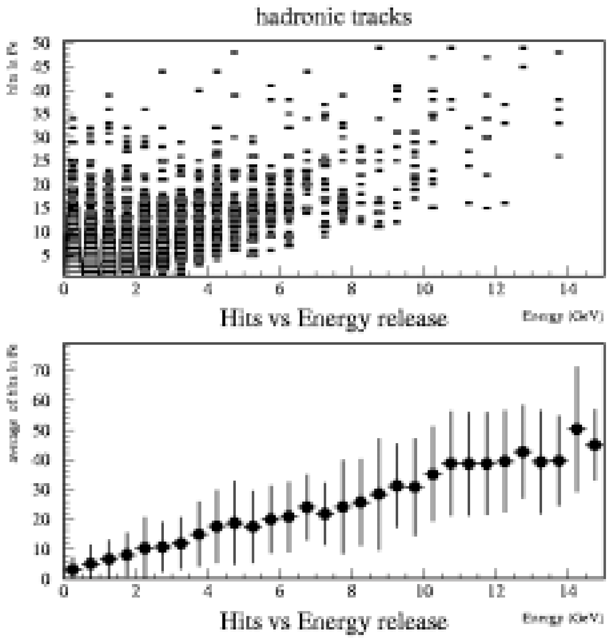
- Here the efficiency for detecting μ’s s shown for the 12/11 active planes configuration.

Performances (cont.)



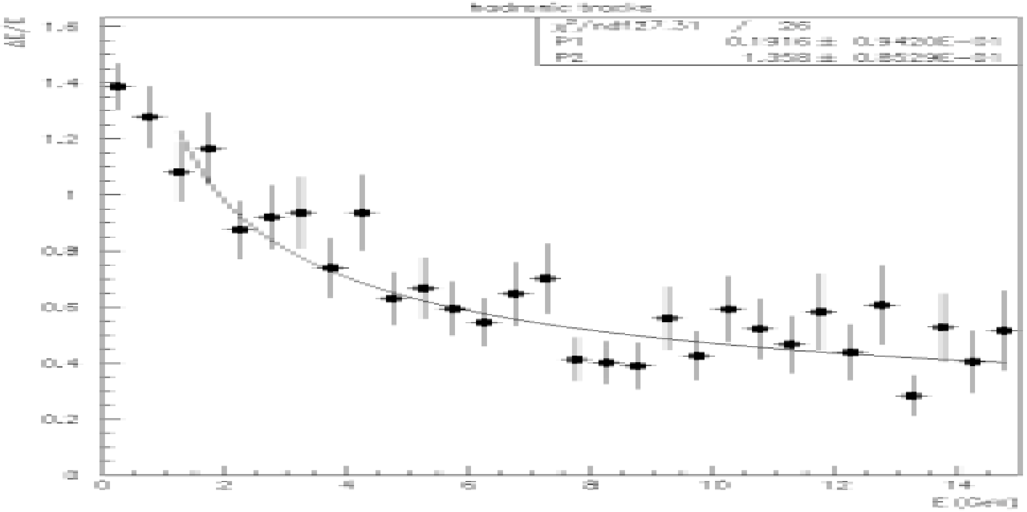
- Here we have the ratio of single μ to *bb* μ efficiency.
- Again this is the 12/11 planes configuration.
- No derating in performances can be seen with respect to the 15 active planes case.

Measuring energy



- Here is the correlation between the energy at the entrance of the muon system and the # of hits generated in the system itself.
- The correlation is reasonably straight and leads to an overall resolution of …

Energy resolution



Few figures concerning iron

- The iron would be shaped in octagonal form.
- Practicality in construction and assembly suggests to use the long barrel configuration.
- Barrel length will be 14.4 m., broken out in three pieces: 3.7 7.0 and 3.7 m. respectively.
- Joining of the barrel pieces done in a slanted way, pointing away from the I.P.
- End-caps would as usual be pie shaped with an outside radius of 3.8 m and an inside radius of .4 m.

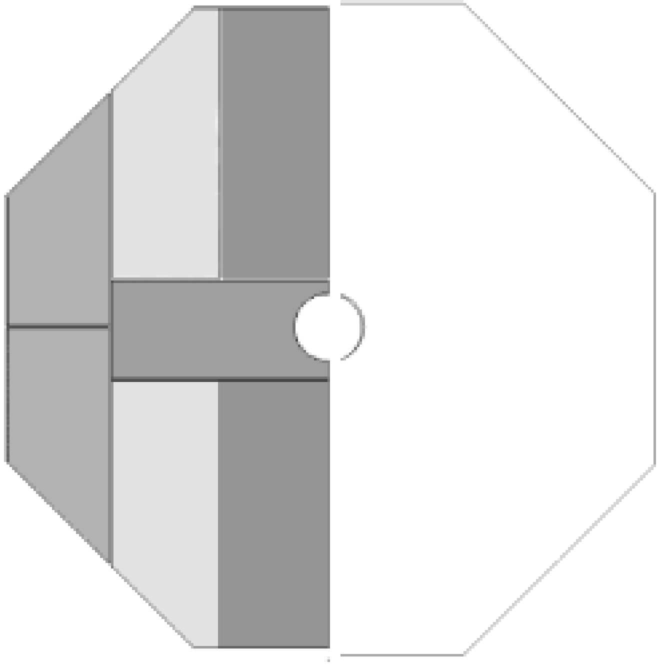
Barrel chambers

- One way to fill the gaps with EXISTING TECHNOLOGY for what RPC's are concerned:
  - Max ch's dimension 1.3x3.2 m^2

⇓

  - Use 12 ch's for the long barrel slots: 1.15x1.57…2.38
  - Use 2x6 ch's for the short barrel slots: 1.22x1.57…2.38
- Total area roughly 5000 m^2.

End-caps chambers



- Here is a possible chamber layout for the end-caps.
- The criterion used here was to maximize the # of ch's with one max. dimension.
- One layer filled with 14 modules; 4 different shapes would be needed.
- Relatively small area 23.5 m^2/layer.

Wrap-up figures

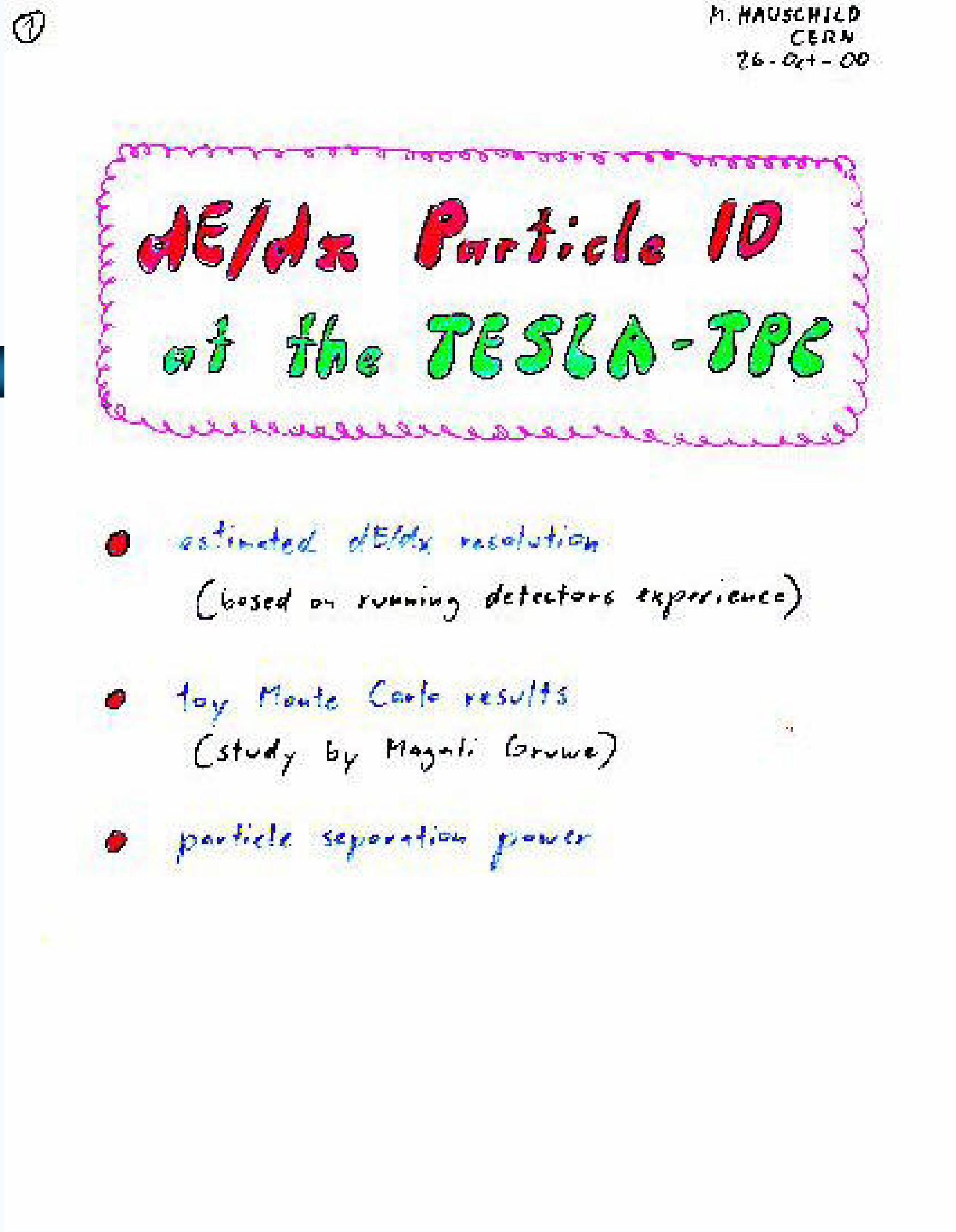
- The μ-identifier in the design sketched above will consist of :
  - 12 planes of (RPC) detector: area ~ 5000 m^2 (barrel)
  - 11 planes of (RPC) detector: area ~ 500 m^2 (end-caps)
- Assuming strips ~ 3 cm wide, alternating read-out directions in the various planes, a total of 70,000 (one bit) discriminators channels should be implemented.
- Should one decide to implement calorimetry and read out with projective towers 25x25 cm^2 , 2500 ADC channels would be needed.
- TDC 's with a granularity 16 (32) times coarser than the overall electrodes granularity would imply 5.0 (2.5) KTDC ch's.
- Electronics performances required might vary according to the regime one would use, costs must be assessed accordingly.

Now for particle (hadron) identification

- To my understanding, not a lot of effort went into this topic.
- The attitude up to now is ….probably it won't be there ,so I better do without.
  - Not completely correct in my opinion

- I will report on two contributions given at the LCWS2000

  - The first one: what is available (almost) for free from a TPC detector
  - The second: a brave attempt to see whether particle id would buy some B^0 tagging capability in topologically complicated events.



①

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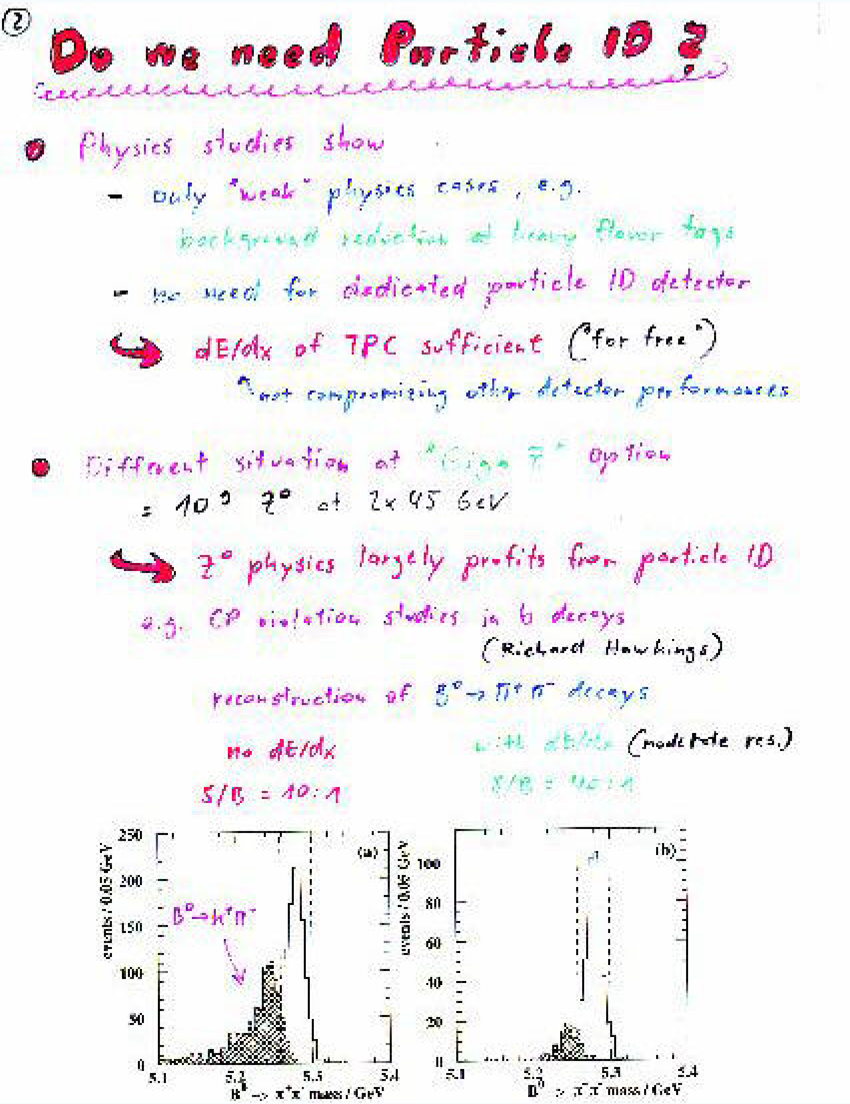
CERN
26-Oct-00

dE/dx Particle ID at the TESLA-TPC

- estimated dE/dx resolution (based on running detectors experience)
- toy Monte Carlo results (study by Magali Gruwe)
- particle separation power



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Do we need Particle ID ?

- Physics studies show
  - only "weak" physics cases, e.g. background reduction at heavy flavor tags
  - no need for dedicated particle ID detector

  ↪ dE/dx of TPC sufficient ("for free*")

  *not compromising other detector performances

- Different situation at "Giga Z" option

  = 10^9 Z^0 at 2x45 GeV

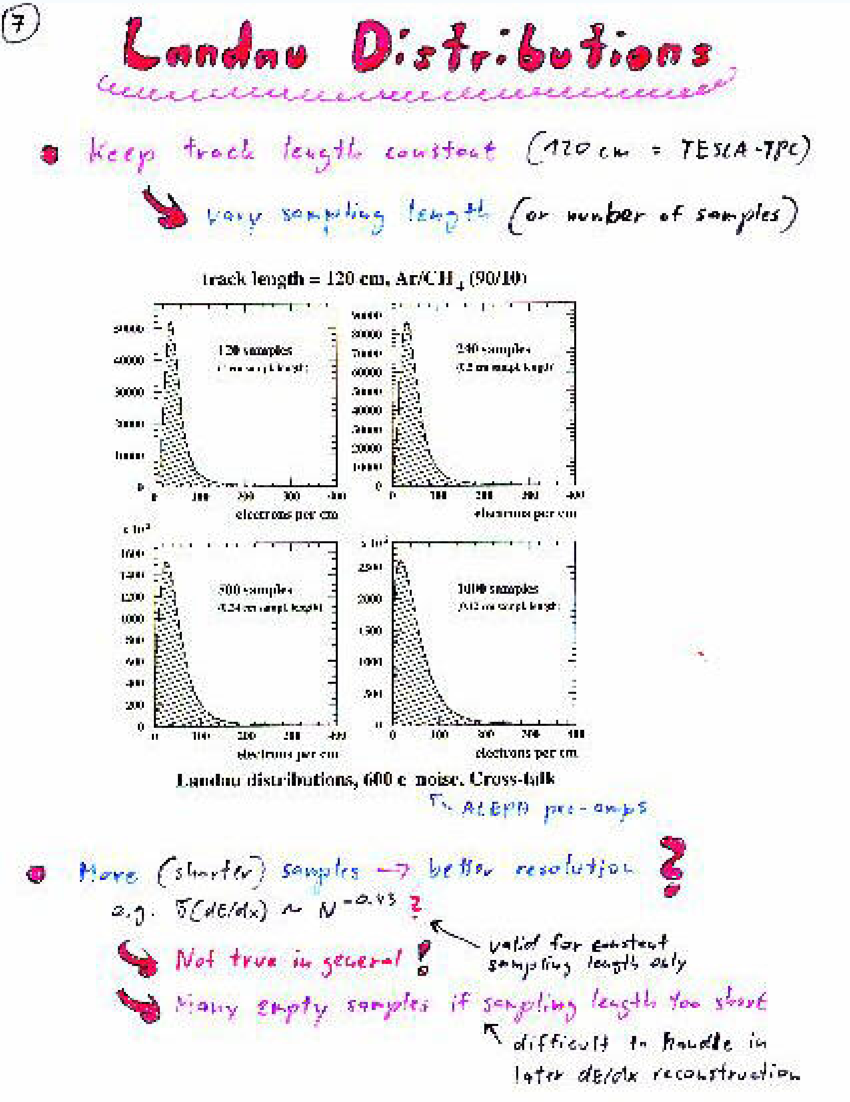
  ↪ Z^0 physics largely profits from particle ID

  e.g. CP violation studies in b decays

  (Richard Hawkings)

  reconstruction of $B^0 \to \pi^+\pi^-$ decays

no dE/dx	with dE/dx (moderate res.)
S/B = 10:1	S/B = 45:1



Landau Distributions

- Keep track length constant (120 cm = TESLA-TPC)

  ➔ vary sampling length (or number of samples)

track length = 120 cm, Ar/CH$_4$ (90/10)

Landau distributions, 600 e noise, Cross-talk

↖ ALEPH pre-amps

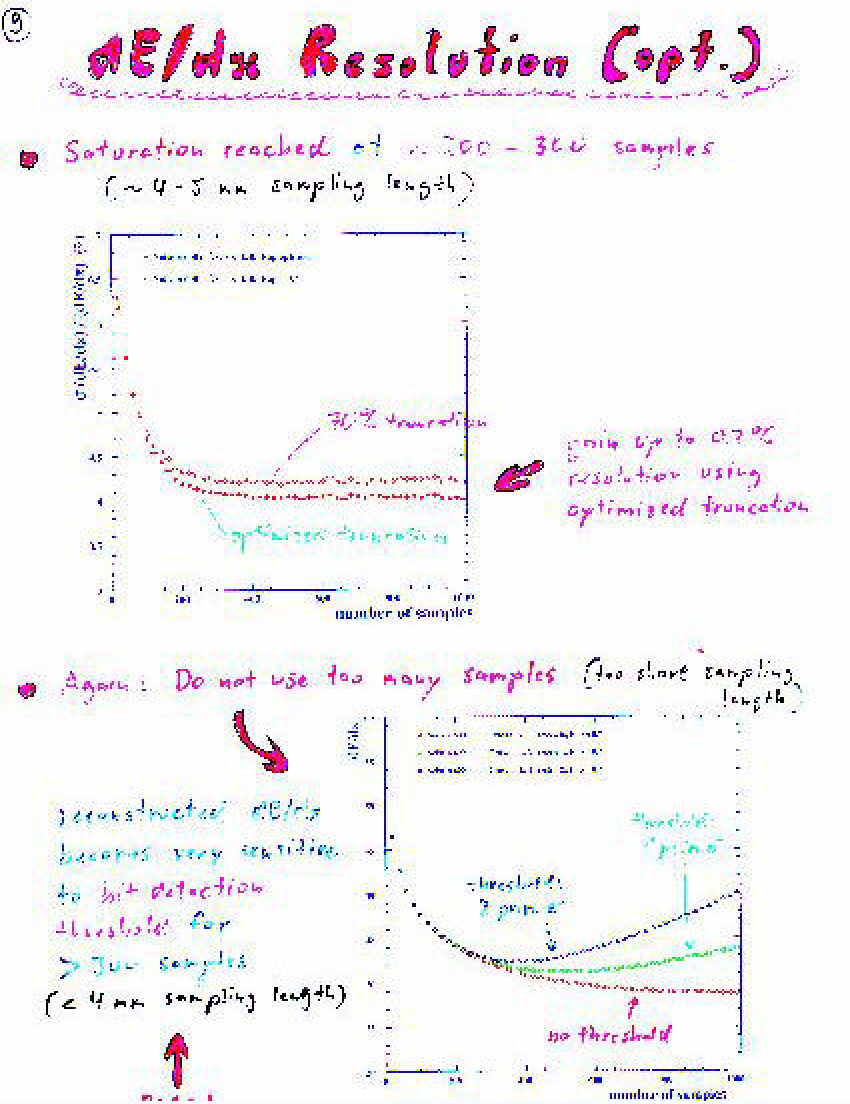
- More (shorter) samples → better resolution ?

  e.g. $\sigma(dE/dx) \sim N^{-0.43}$? ← valid for constant sampling length only

  ➔ Not true in general !

  ➔ Many empty samples if sampling length too short

  ↖ difficult to handle in later dE/dx reconstruction



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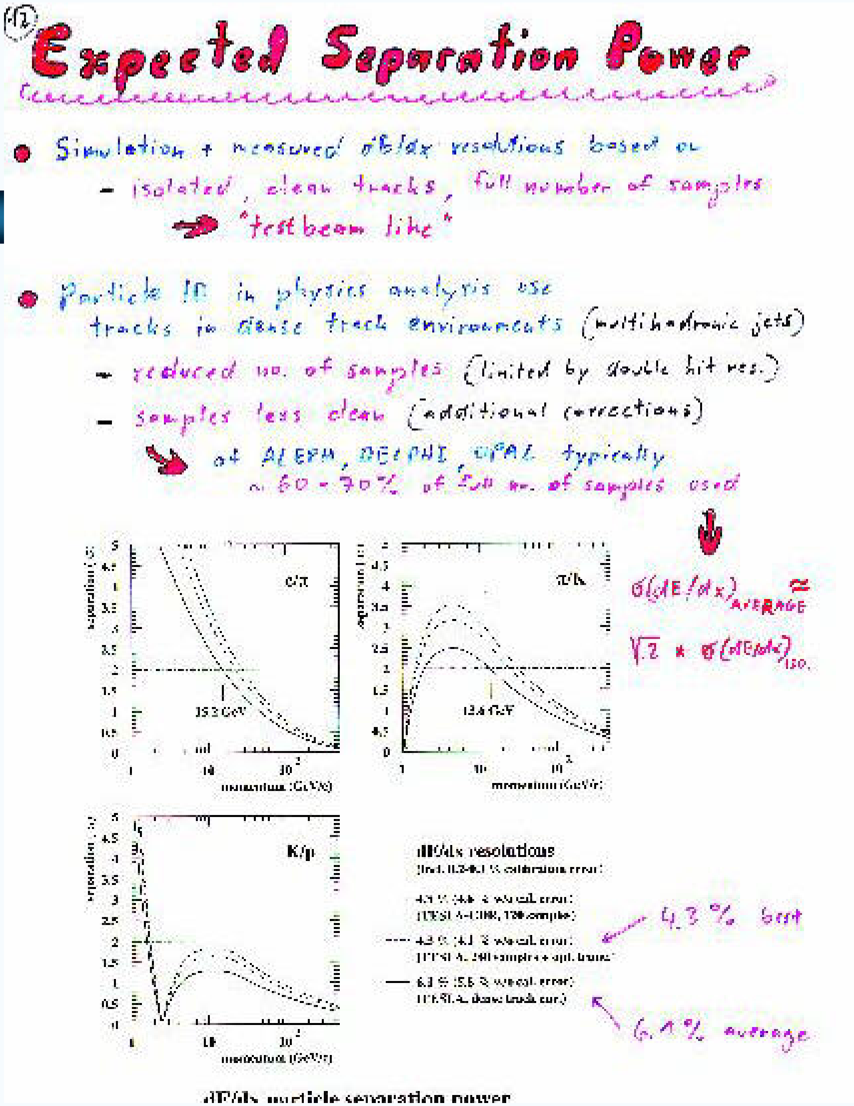
dE/dx Resolution (cont.)

- Saturation reached at ~200 - 300 samples (~4-5 mm sampling length)

gain up to 0.7% resolution using optimized truncation

- Again: Do not use too many samples (too short sampling length)

reconstructed dE/dx becomes very sensitive to hit detection threshold for > 300 samples (< 4 mm sampling length)



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Expected Separation Power

- Simulation + measured dE/dx resolutions based on
  - isolated, clean tracks, full number of samples
    → "test beam like"
- Particle ID in physics analysis use tracks in dense track environments (multihadronic jets)
  - reduced no. of samples (limited by double hit res.)
  - samples less clean (additional corrections)
    → at ALEPH, DELPHI, OPAL typically ~ 60 - 70% of full no. of samples used

$\Downarrow$

$\sigma(dE/dx)_{AVERAGE} \simeq \sqrt{2} * \sigma(dE/dx)_{ISO.}$

dE/dx resolutions
(incl. 0.2-0.3 % calibration error)

4.5 % (4.4 % w/o cal. error)
(TESLA-CDR, 120 samples)

---- 4.3 % (4.1 % w/o cal. error)
(TESLA, 200 samples + opt. frame)

— 6.1 % (5.8 % w/o cal. error)
(TESLA, dense track cor.)

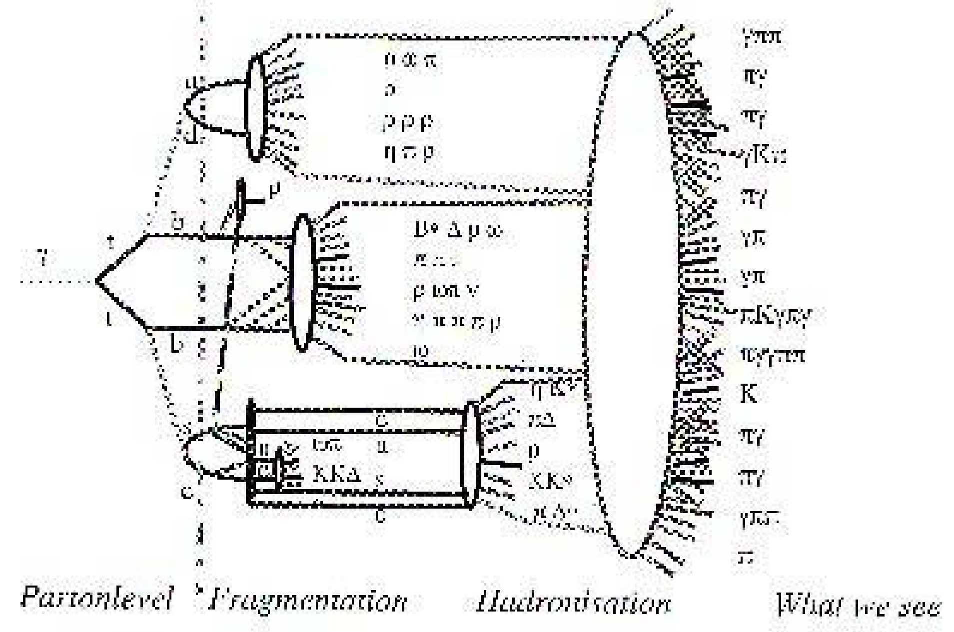
← 4.3 % best

6.1 % average

dE/dx particle separation power

Marcello Piccolo

The Challenge: “typical!” t–tbar decay ...



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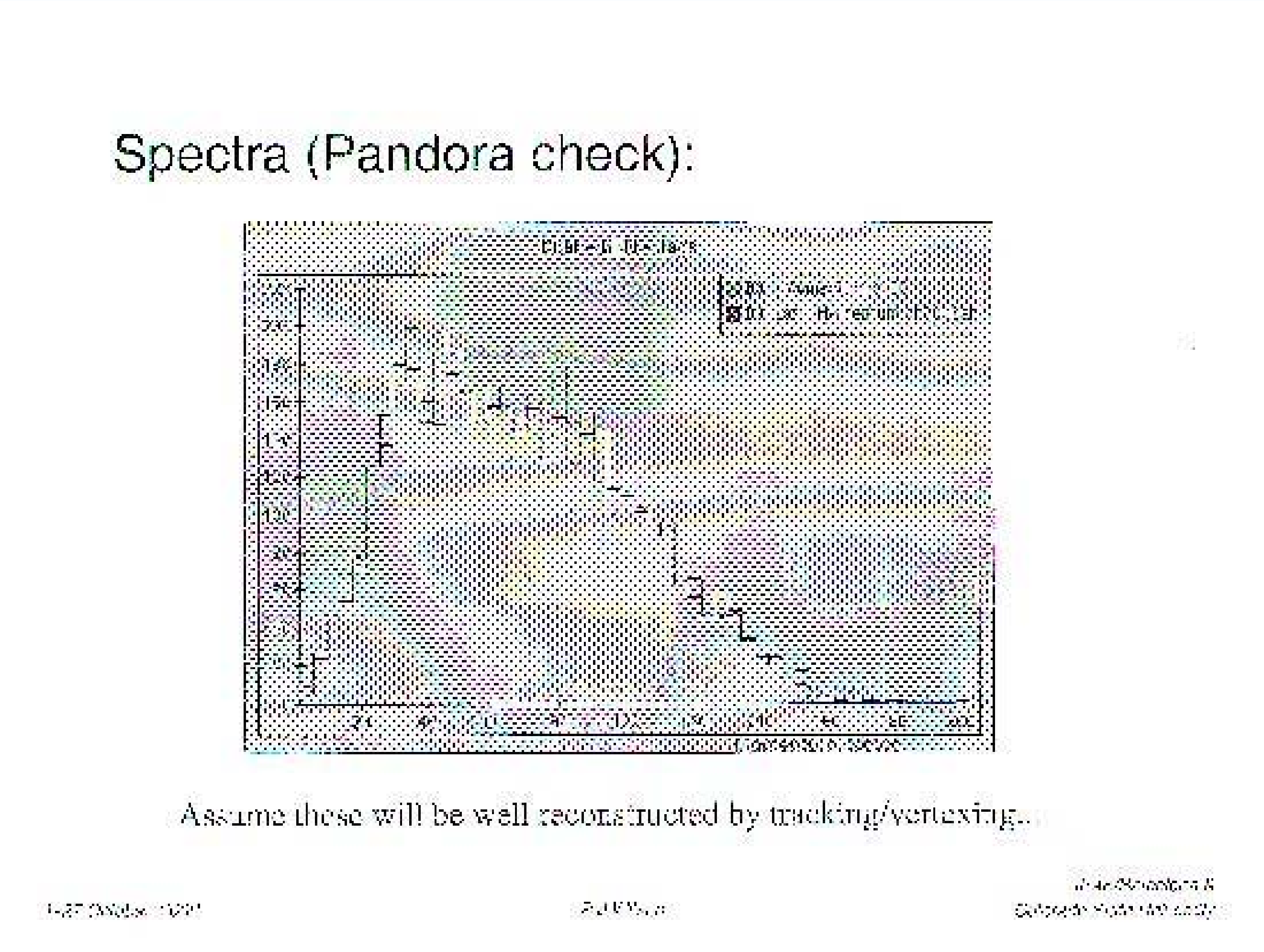
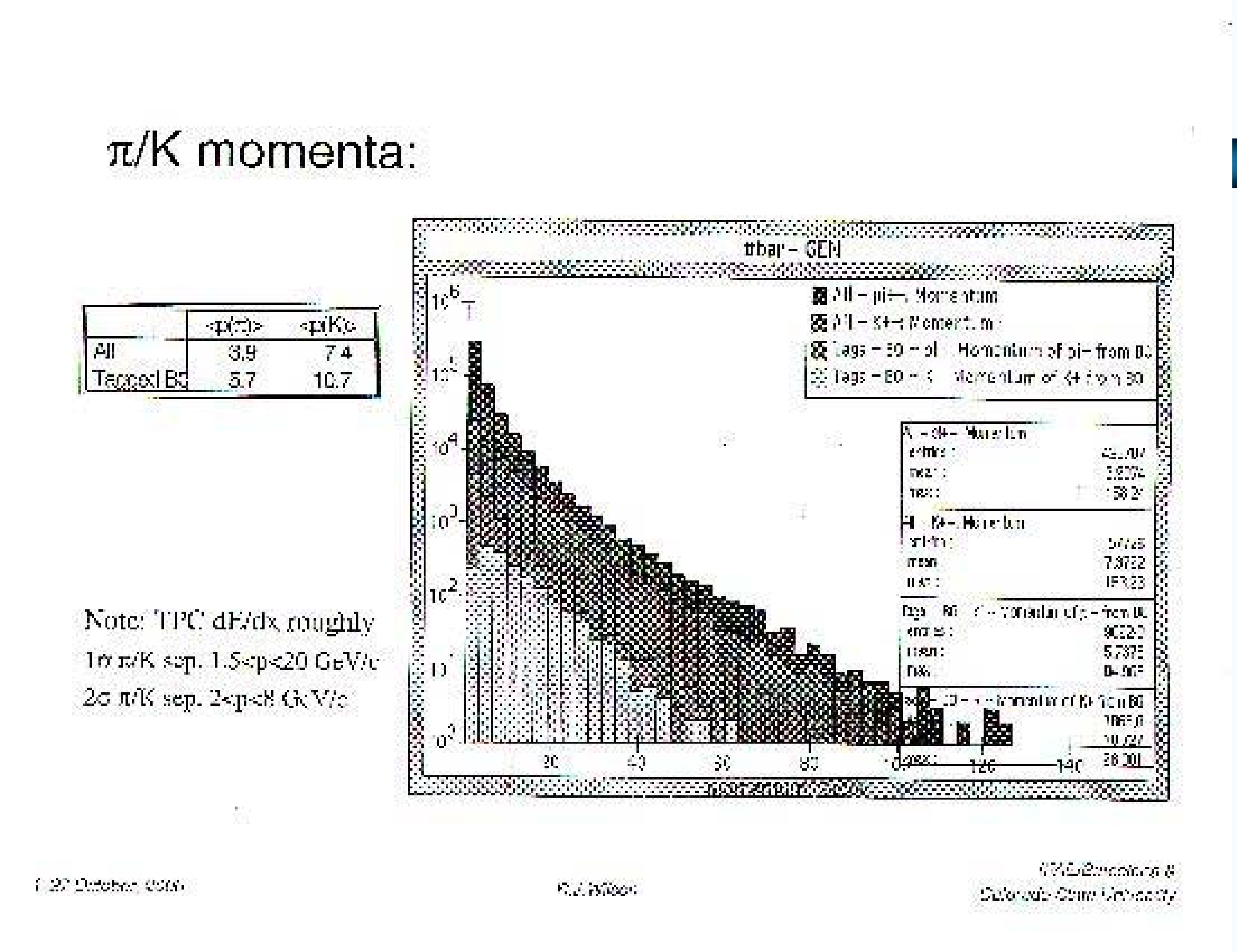


Spectra (Pandora check):

Assume these will be well reconstructed by tracking/vertexing..



π/K momenta:

	<p(π)>	<p(K)>
All	3.9	7.4
Tagged B0	5.7	10.7

Note: TPC dE/dx roughly
1σ π/K sep. 1.5<p<20 GeV/c
2σ π/K sep. 2<p<8 GeV/c

27 October 2000

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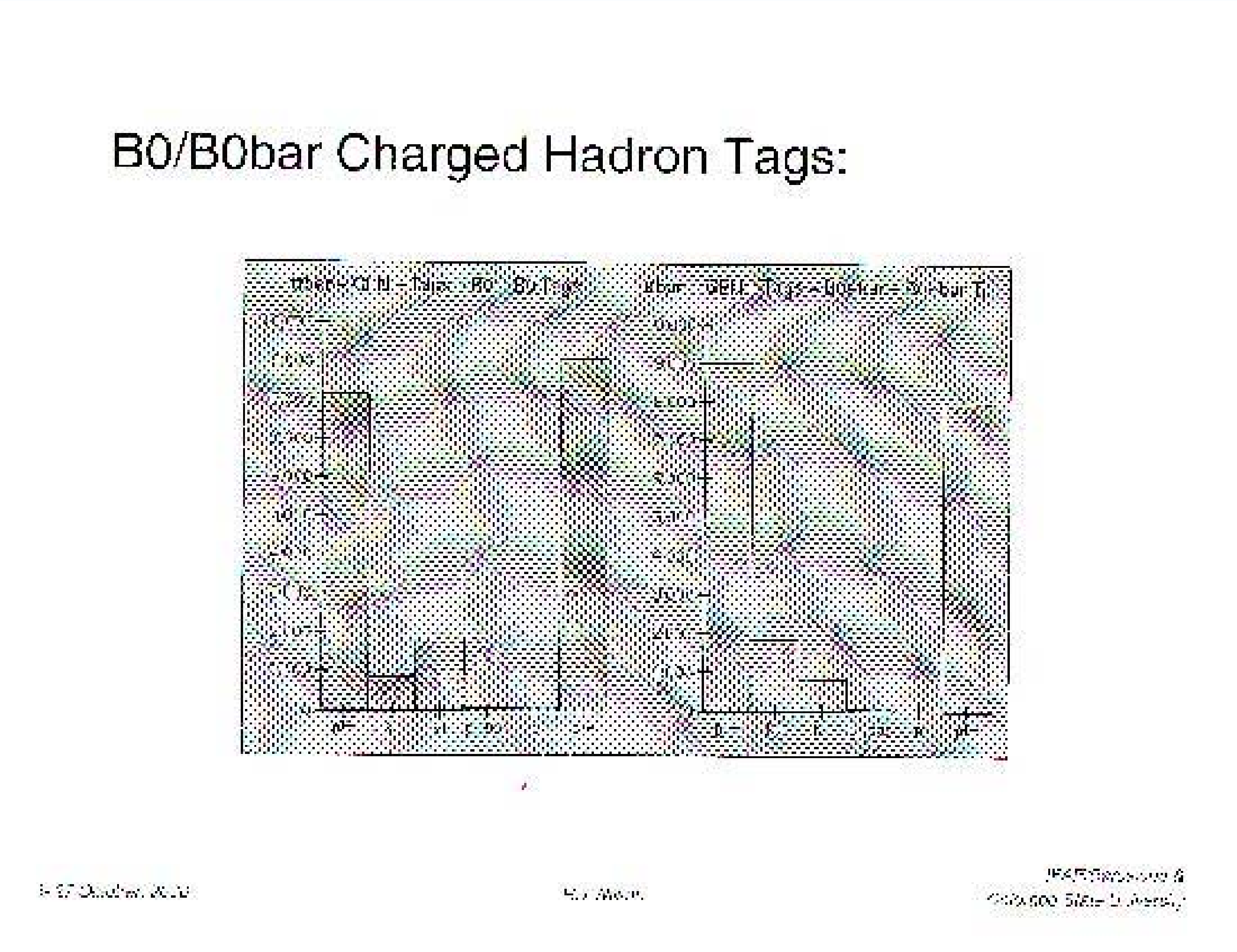
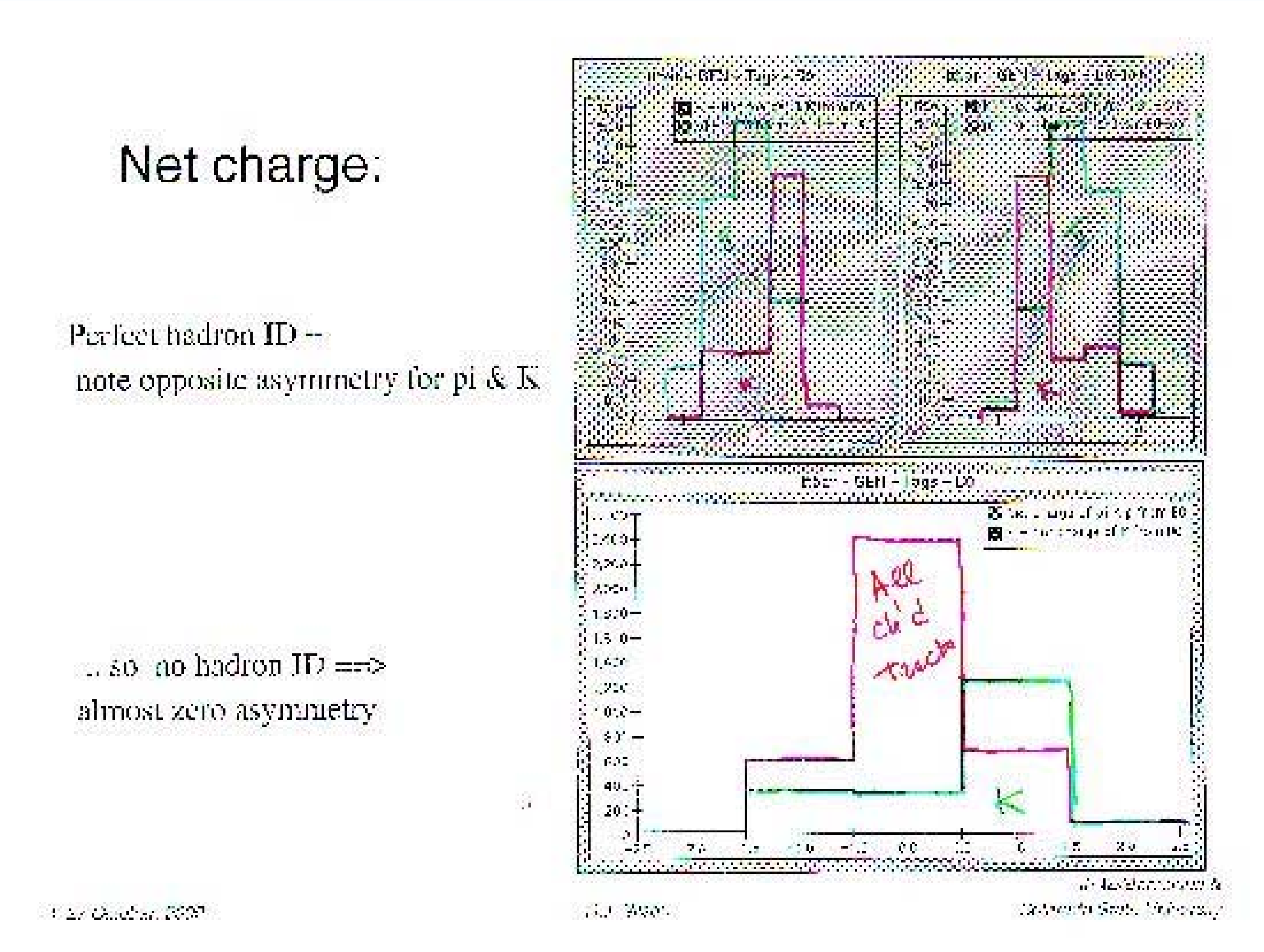


B0/B0bar Charged Hadron Tags:



Net charge:

Perfect hadron ID --
note opposite asymmetry for pi & K

... so no hadron ID ==>
almost zero asymmetry

Bottom line: μ-system

- Muon detectors at a LC would be required to perform tagging; they can be designed with today technology without much R&D .
- There is a reasonable choice of detectors that can be used.
- Tesla design relies on RPC’s, other proposals could be worked out.
- My personal opinion is that gas devices are economically preferable.

Bottom line: Particle id

- A clear case for the H.E. has not been presented jet:a complete attempt to assess benefit and cost is still to come.
- The situation in the low energy regime (Giga Z) is in my opinion a bit clearer: here we have something to gain as exclusive processes are important.
- Apart from the CP asymmetries, (not so) rare B decay would benefit a lot from PID.

Conclusions

- The design and optimization of the μ-identifier for a general purpose LC detector is proceeding: for Tesla the RPC option has been chosen, other groups might explore other possibilities.
- Particle i.d. does require a definite effort in order to state, on solid bases which ratio benefit/cost this subsystem would imply.
- The Giga Z physics program would clearly benefit, in my opinion, from hadron identification capabilities.