# Thoughts on
# Test Beams for the ILC Detector(s)

Adam Para, Fermilab

# Why? What Test Beams? Role of Test Beams in the Design and Construction of a HEP Experiment

- Lifecycle of the Experiment:
  - Conception
  - Conceptual design, choice of detectors/technologies
  - Technical design, prototypes construction and testing
  - Detector construction
  - Calibrations
  - Commissioning
  - Data taking
  - Analysis, systematics studies

Test Beams

Test Beams

Test Beams

Test Beams

# LHC Experiments: a Model for the ILC Experiments

- Is it a relevant model ?
- Is it the good/only model ?
  - Similar scale (people/cost/size)
  - Similar requirements (more emphasis on precision?)
  - Similar distributed cast of characters
- … but let's examine it anyway
- CMS/ATLAS will start taking data in 2008
- We would like to hope that the ILC experiment(s) will start operation in 2020 (feel free to adjust the last digit, or two). Thus the ILC is ~12 years 'behind' the LHC. Hence it is interesting to examine the detector R&D, design, test beam efforts in ~ 1995.

# Early History of LHC Experiments

- 1990 – LHC announced as a new CERN project (expected commissioning in 1998)
- July 1990 Detector Research and Development Committee established to initiate and manage the necessary R&D and test beam studies program.
- 50 Projects approved and funded
- Recognition of a need for 'generic' detector R&D to establish the possible solutions/technologies enabling a successful detector concept:
  - Timely
  - Adequately funded
  - Adequate test beam infrastructure
  - Well managed (selection of projects, reporting of results)
  - Profit from intensive detector R&D in the US directed towards the SSC detectors

# Sample of Approved 'Generic' R&D Projects

- RD-1 ( P1 )
  - Scintillating fibre calorimetry at the LHC.
- RD-3 ( P5 )
  - Liquid argon calorimetry with LHC-performance specifications.
- RD-16 ( P19 )
  - A digital front-end and readout microsystem for calorimetry at LHC.
- RD-33 ( P45 )
  - Study of a novel concept for a liquid argon calorimeter.
- RD-34 ( P46 )
  - Developments for a scintillator tile sampling hadron calorimeter with "longitudinal" tile configuration.
- RD-40 ( P54 )
  - Development of quartz fiber calorimetry.
- RD-44 ( P58 )
  - GEANT 4: an Object-Oriented toolkit for simulation in HEP.
- RD-50 ( LHCC P6 )
  - Development of Radiation Hard Semiconductor Devices for Very High Luminosity Colliders

# LHC Experiments/Collaborations

- March 1992 (Evian): 4 proto-collaborations (CMS, ASCOT, EAGLE, L3+1). LHCC established.
- Under enormous pressure from CERN management:
  - One merge: ASCOT + EAGLE = ATLAS
  - One shootout CMS + L3+1 = CMS
- June 1993: LHCC recommends that ATLAS and CMS proceed with Technical Proposals. Vast majority of the detector concepts/technologies resulting from the generic R&D and progress in technology
- November 1995: LHCC approves ATLAS and CMS projects
- January 1995: DRDC committee terminated. End of generic R&D era and start of the effort focused on specific experiments, under the guidance of the LHCC.

# Post-Generic 'Test Beams' Studies

- 1995 – 2000: preparation of Technical Design Reports (Magnet, Electromagnetic Calorimeter, Hadron Calorimeter, Tracking, Muon systems, Trigger, DAQ [typically ~ 500 pages each] )
- Test beam validation/evaluation of specific pre-production prototypes
- 2000-2007: Calibration, understanding, mapping, commissioning of the 'final' detectors. Enormous effort.. (CMS request: 64-66 weeks of test beams/year, 5 different beam lines)
- ~ 10 test beams at CERN, more then 50% dedicated to LHC experiments (including LHCb, ALICE, TOTEM)
- Dedicated areas/floor space (large, not moveable infrastructure)
- 1995: recognition of a need for 40 MHz time structure. Possible, but requiring significant modifications to the accelerator complex. 80 MHz RF cavities built in collaboration with TRIMF, test beam operational in May 2000.

# CERN-centric Nature of the LHC Test Beams Efforts

- Existing infrastructure (but evolving if necessary, e.g. 40 MHz): several areas, 10 beams, instrumentation
- Central management (DRDC, LHC) enforcing smooth transition between different phases of the test beam work. Test beam program not a goal by itself but rather a means of achieving experiments-dictated goals.
- Technical and financial support (including contributions from external sources)

# Challenges of the Test Beam Program ILC Detector(s)

- Known unknowns and unknown unknowns
- When start data taking?
  - 2020? We are behind already? Or can we gain significantly in comparison with ATLS/CMS schedules? How?
  - 2025? Tough, but perhaps we can make it
  - 2030? Let's think and tinker..
  - Focus and direction of the test beam effort, needs and requirements in the near future depend very much on the model assumed.
- How many detectors? 1? 2? One phase one, one phase two?
- Who and how will organize/manage/decide/support? (EDUDET is a great initiative here, but it is limited to infrastructure only and is of limited duration)
- These questions (and similar) are fun to discuss and collect/compare opinions, but they need to be addressed at much higher level.

# Challenges of the ILC Detector R&D

- FAQ: Are there any? This is a good question and it deserves a better answer than usually given. 10 years old 'blue-and-black' plot doesn't cut it. Major progress here would help a lot. Test beam program should serve as a tool to address these challenges.
- Precision measurements, little room for imperfections and/or inefficiencies. Trade-offs between the detector performance and (costly) machine operation.
- Principal differences between the (desired) ILC experiments and the LHC (LEP) experiments:
  - High resolution jet energy measurement (W/Z separation a benchmark)
  - High precision ('massless') vertex detector (efficient b/c tagging)
  - Machine-detector interface (forward calorimetry, luminosity, backgrounds)

# Comments on Current Detector R&D

- Limited by funding rather by the availability of test beams
- Strongly influenced by the existing detector concepts (in the absence of more organized funding and/or management)
- Present activities are a mix of some generic R&D and the concept-specific ones. Very little, if any, activities not directly associated with any of the concepts (lack of available resources a significant factor here). Examples of neglected areas/directions:
  - Picoseconds range time-of-flight (particle ID)
  - High resolution calorimetry
  - Optimal detector geometry
  - Magnetic field configurations
  - High resolution electromagnetic calorimeters

# Calorimetry for the ILC: a 1000 tonnes Gorilla

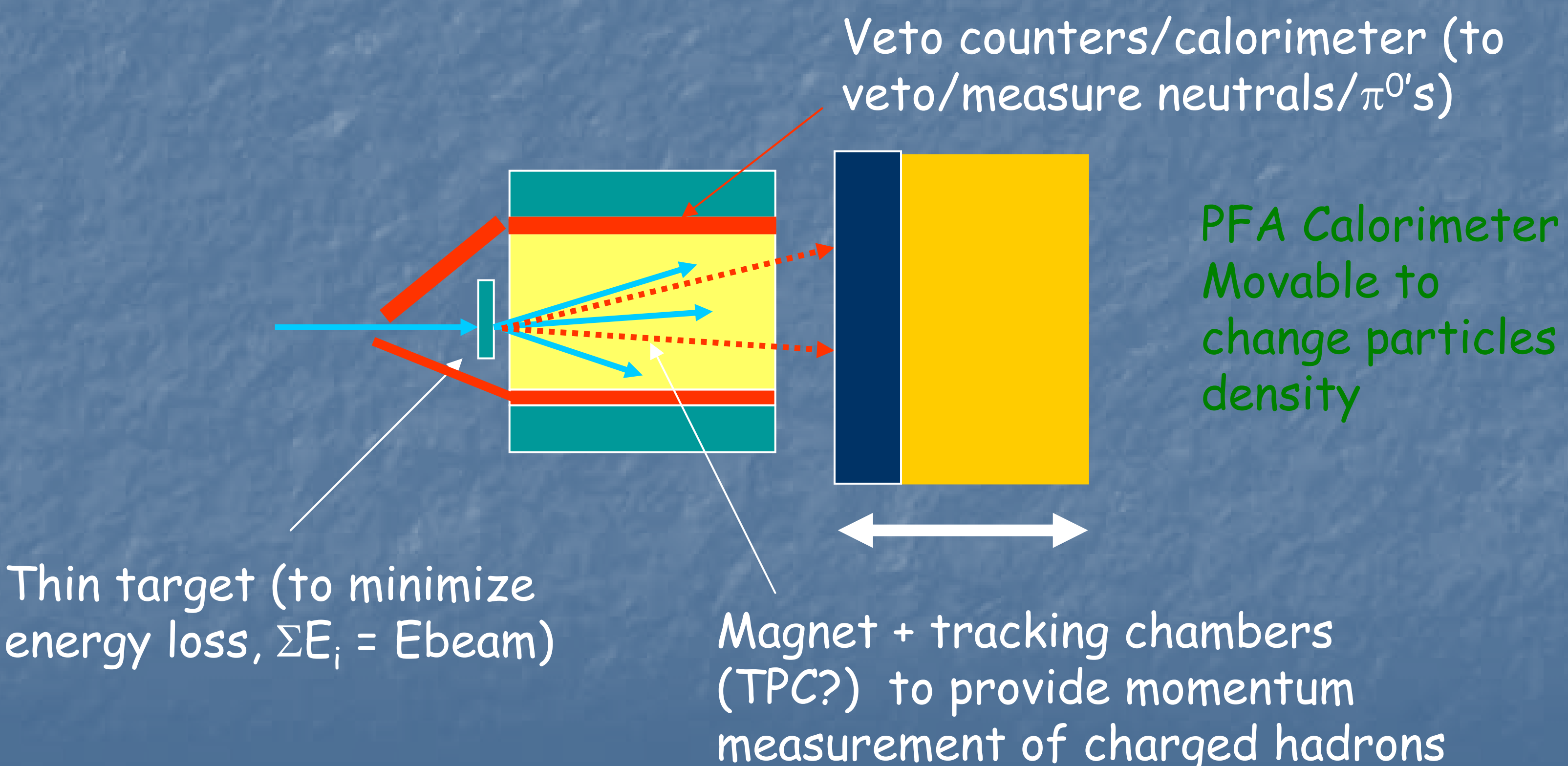
- PFA or not PFA. (When does the absence of a proof become the proof of absence?)
- PFA: a brilliant idea used as a baseline in three main detector concepts. Novelty: reduce the role of the hadron calorimeter to measurement of neutral long-lived hadron only. Can it be done? What kind of calorimeter is necessary:
  - Electromagnetic calorimeter/granularity
  - Sampling of the hadron calorimeter
  - Active medium: gas/scintillator
  - Transverse segmentation
  - Digital or analog readout
- Specific answers to the above listed questions have major implications for the detector design and cost

# Comments on PFA calorimetry

- This is probably the biggest departure from the present day detector technology. In particular, it involves several detector subsystems in a common measurement. It probably requires unusually expensive hadron calorimeter, which is likely not to perform very well on its own, hence..
- It will be mandatory to demonstrate the performance of the putative PFA calorimeter beyond a reasonable doubt wit a combination of test beam studies and simulations
- CALICE 1m$^3$ test calorimeter is a major, non-trivial step in the right direction, but it is unlikely to provide the enough of the proof

# Experimental Demonstration of PFA ?

- Demonstrate that a given a collection of particles (a.k.a. jet) and given the momenta of charged particles  one can measure the total jet energy with the claimed resolution

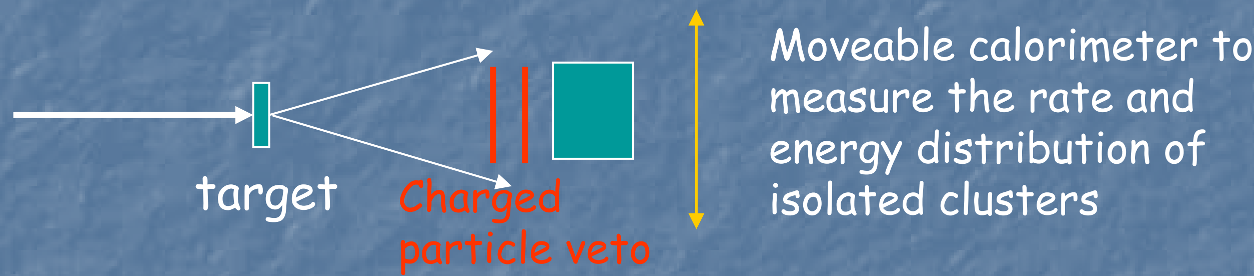


# PFA (Jet) Test Beam?

- Primary beam (protons) $\Delta p/p < 0.2/\sqrt{p}$. High energy beam 200? 300? GeV essential to demonstrate the robustness of the technique at high particles density. Perhaps can be traded for close proximity of the calorimeter to the target, provided the momentum resolution is maintained (silicon tracker?)
- Analysis magnet (not necessarily 5T)
- A tracking system (not necessarily the same design as the real experiment) with adequate $\Delta p/p$ resolution
- EM and hadron calorimeters with sufficient transverse extent (~ 3 x 3 $m^3$) to measure the energy of an ensemble of particles scattered over ~ a cone of 1-2 m opening and ensure the full coverage at all distances (narrow/wide jets)
- Add muon system/tail catcher if deemed necessary for the PFA
- A post-PFA application: a prototype for a vertical slice test of the entire detector ?
- Make no mistake: this is not a simple 'test beam'. It is a complicated and resource consuming experiment. It would be wonderful to be able to prove the performance of PFA calorimeter in a simpler (and faster!) way..

# Principal Uncertainties of the PFA?

- Not very well (not at all?) understood
- My guess: Neutral hadrons production modeling
- Very scarce experimental information. Need dedicated experiment?
- $K^0$ – MIPP/son of MIPP? Acceptance?
- Neutron/antineutron production by pion beams 1- 20 GeV:




  - Isolated neutrals only. Enough for validation?
  - Antineutrons?

# PFA Calorimeter: Optimistic Scenario

- Let's assume that the PFA Calorimeter 'works': it can separate correctly the energy deposits of charged particles, photons and neutral hadrons (Function I, topological)
- PFA Calorimeter Function II: measure energy of neutral hadrons. This is quite a new requirement. We have never calibrated hadron calorimeter with neutrals. The final (jet) energy resolution will be dominated by the resolution of the neutrals. Need the resolution as well as the overall response!
- Need a known energy neutral beam:
  - Neutrons (from deuterons, stripped in thin foil, bent protons away)
    - Need an ion(deuterons) source. CERN? Brookhaven?
    - Inject into the normal accelerator chain, accelerate to a desired energy, extract…
- Or..

# Diffractively Produced Tagged Neutral Hadron Beam (R. Raja, hep-ex/0608038)

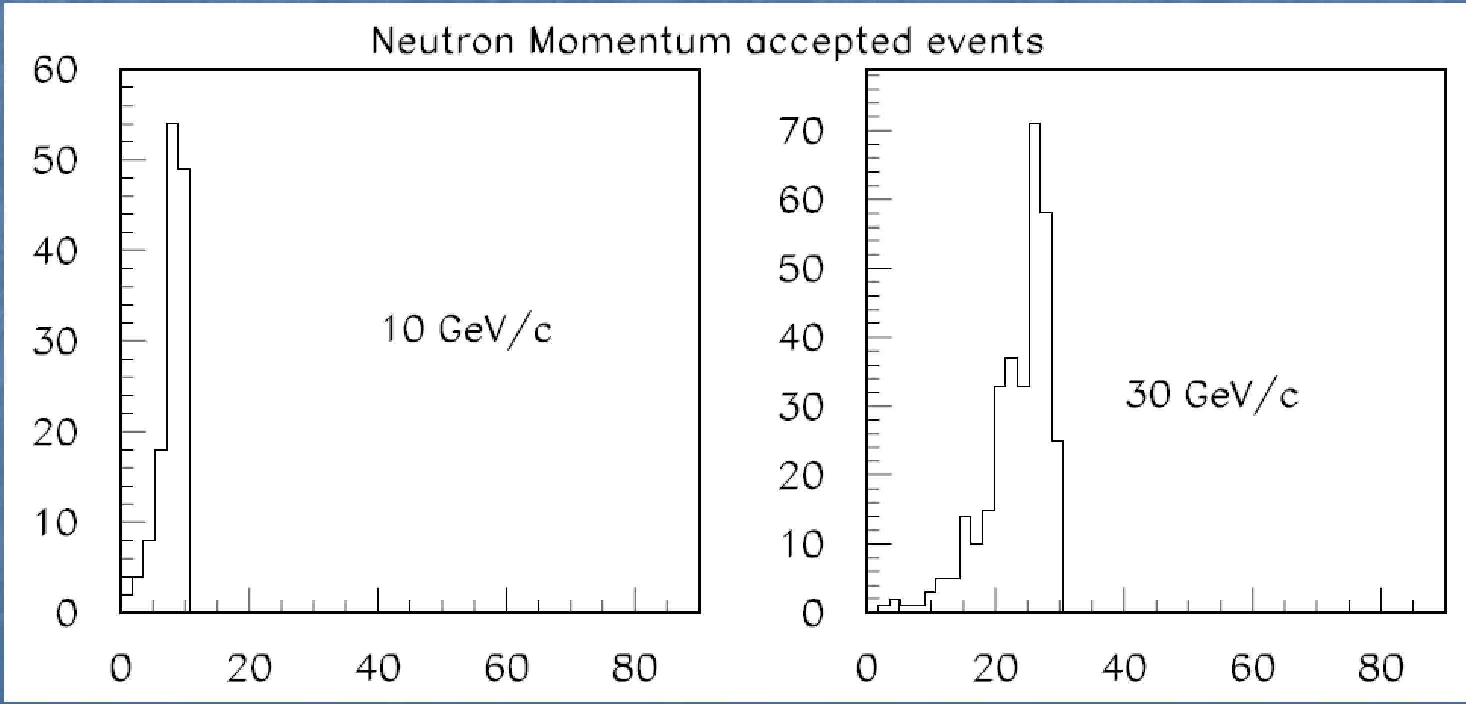
$pp \rightarrow pn\pi^{+}$ $\quad K^{+}p \rightarrow p\overline{K^{o}}\pi^{+}$ $\quad \overline{p}p \rightarrow p\overline{n}\pi^{-}$

- Liquid hydrogen target
- relatively large cross sections (0.2 – 2 mb)
- Recoil proton and charged pion momentum measurement (TPC) yields 'missing mass'. Position (angle) the neutral cluster measurement gives 3C fit.
- Yields into 1.5 m diameter circle located ~ 25 m from the target (MIPP running conditions: 5 million events/day)

| Beam Momentum GeV/c | Proton Beam n/day | K+ beam K-Long/day | K- beam K-Long/day | Antiproton beam anti-n/day |
|---|---|---|---|---|
| | | | | |
| 10 | 20532 | 4400 | 4425 | 6650 |
| 20 | 52581 | 9000 | 9400 | 11450 |
| 30 | 66511 | 12375 | 14175 | 13500 |
| 60 | 47069 | 15750 | 14125 | 13550 |
| 90 | 37600 | | | |

# Example of Spectra (neutrons)

- Forward (diffractive peak): most of neutrals close to the beam energy
- Event-by-event neutral energy measurement ($\Delta E/E \sim 2\%$)



# What if a Convincing Proof of PFA is not Available in Time for Detector Decision ?

- Case A: two experiments. Take a risk in one of them?
- Case B: one experiment. What are the alternatives (also in case A, for the 'other' detector)?
- Or did we take our gamble already? (see three major detector concepts)
- IMHO: given the slope of progress on PFA and the critical role of calorimetry in the ILC experiment, it is very important to pursue (i.e. to provide adequate resources) other avenues for high precision hadron calorimetry (dual readout? Other methods of compensation?)
- High precision hadron calorimeters tend to be large and heavy. Need dedicated beams? Or at least dedicated floor space?

# Luminosity/Beam Calorimeters

- One easy aspect of the ILC calorimetry: no concerns with radiation damage, except for..
- Very forward calorimetry
- Need irradiation facilities
- Need R&D on RadHard sensors. Synergy with LHC upgrades

# Trackers Need Test Beams Too..

- Ultra-light Vertex detector: the primary challenge at the moment is the development of the suitable sensor technology, including readout electronics and
- Engineering design of low mass, yet robust structures.
- They need to be proven in the test beams
- The similar situation with the gaseous and/or silicon tracker.
- Does one need an integrated tracker test? It may be doable for silicon tracker, but it seems rather difficult for the TPC.
- Tracking test beams probably can co-habit the same areas with calorimeters.
- Vertical slice: ILC detector subsystems are much more interconnected than before (for example: calorimeter-assisted tracking in SiD, tail catcher to improve energy resolution). Can one proceed with such detector concepts without experimental demonstration?

# Challenge of High Magnetic Fields

- Detectors will be immersed in high magnetic fields (up to 5T).
- Large number of pulsed components, wires, connections..
- Sensors: silicon detectors, photodetectors
- Low noise, sensitive electronics
- …
- Need 5T magnet with large enough opening. Need 5T for the test beam studies? There might be 2T solenoid avilable in the next few years..
- Need test beam with ILC-like time structure (need RF structure of the trains?)

# Concluding Remarks

- Whereas opinions about the relative importance of various potential test beam studies may vary, it is quite likely that an intensive detector R&D and test beam studies is necessary to ensure successful design and construction of the ILC detector(s).
- At the moment the pressure on the existing test beam infrastructure is relatively low due to low level of resources available. This will hopefully change once the ILC project gains some traction.
- Specific and detailed needs of the test beam infrastructure for the ILC experiment(s) are not very well known at this moment, but they will emerge very soon, especially once the final collaborations are formed.
- Availability of CERN test beams is a significant unknown. If they are used mostly to support the ongoing LHC experiments and their upgrades then a major test beam infrastructure must be constructed 'somewhere'. This may require significant resources which, perhaps, should be part of the overall cost estimate.