Precision Spectrometry

David J.Miller, U.C.L.

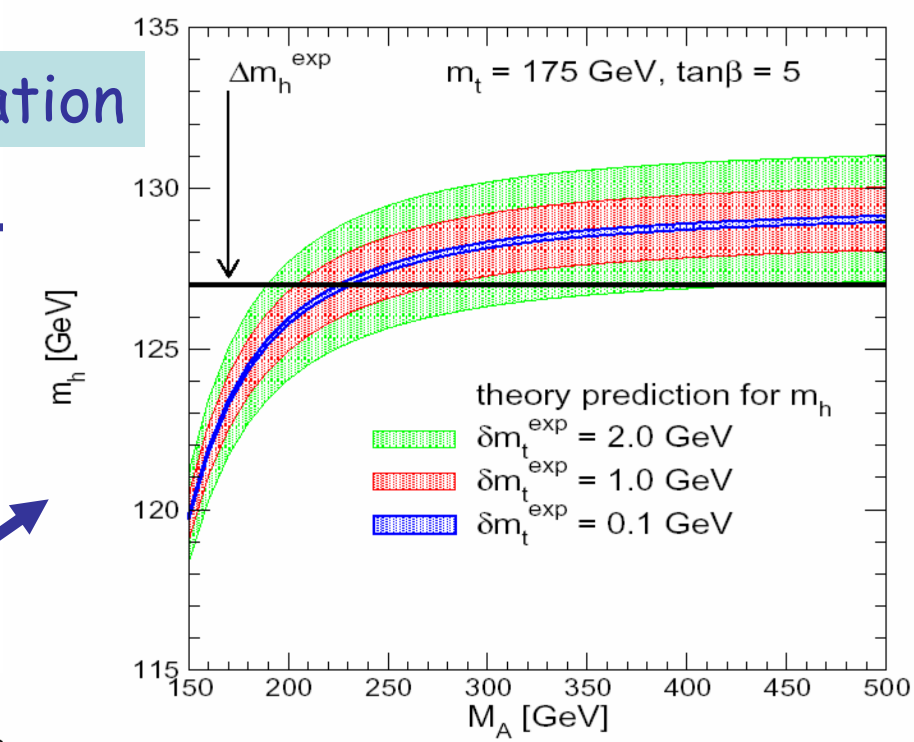
1. Physics motivation and requirements.
2. Range of inputs needed, including detector-based.
3. Pathologies to be measured.
4. BPM technologies.
5. Test beam plans.
6. Summary of where we are.

UCL's Motivation

<u>Precise measurement of m_{top}</u>

- a mandatory task for the LC.

QCD systematics→δm_t^{theory} ~50 MeV.
Experiment **must** match, **or** δm_t would dominate EW precision measurements.
[Heinemeyer *et al* (hep-ph/0306181)].
Also essential for fixing SUSY; e.g.

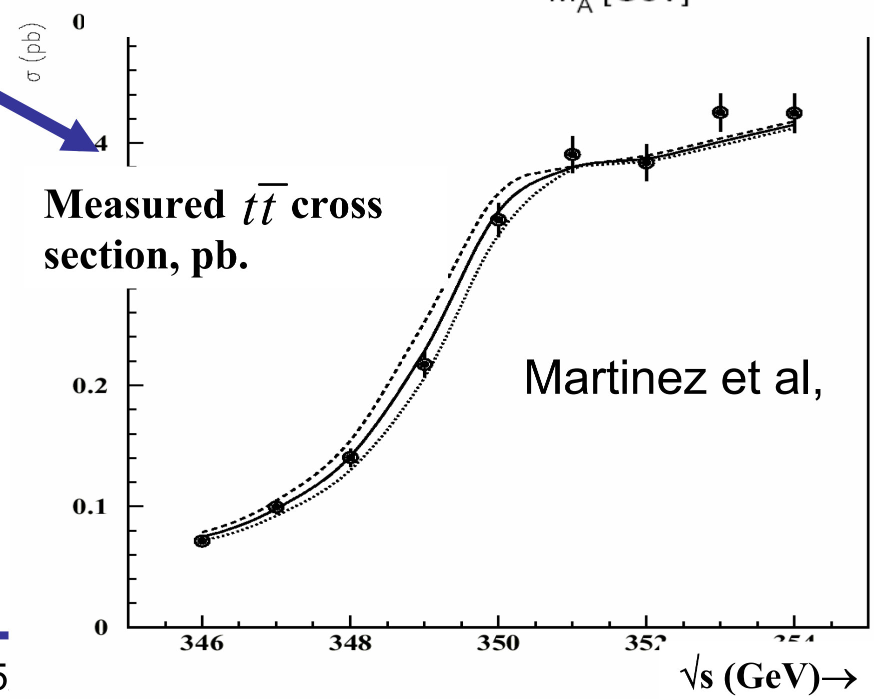


<u>Scanning across the top threshold can achieve</u> $\delta m_t^{exp} < 100$ MeV -

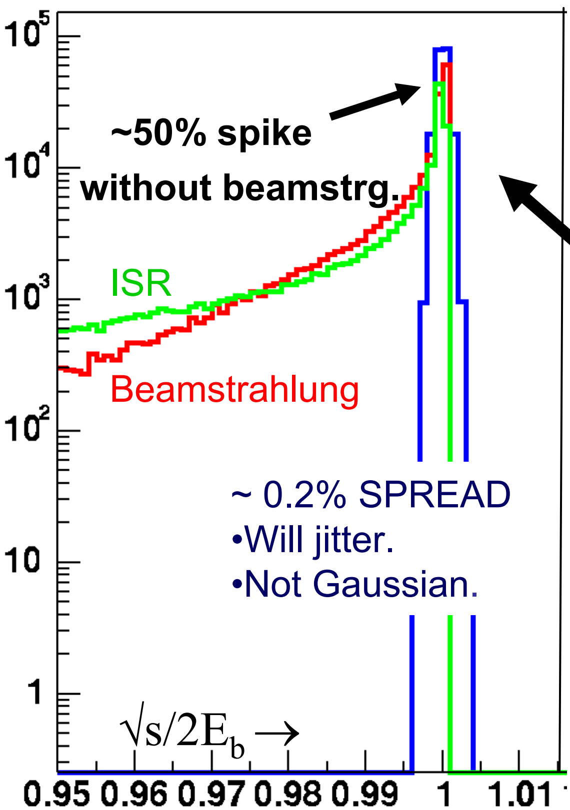
iff 4 new things
can be measured to <5x10^{-4}:

1. Endcap Bhabha acollinearity angles
→ E_b^+-E_b^- distribution, Lumi. weighted.
2. Beam energy jitter
3. Absolute beam energies
4. Shape of beam spectrum

→ E_b^++E_b^- (items 2–4)



UCL's GOAL: learn how to combine Bhabha acollinearity and **spectrometry** to get Lumi Spectrum.



Detector based input

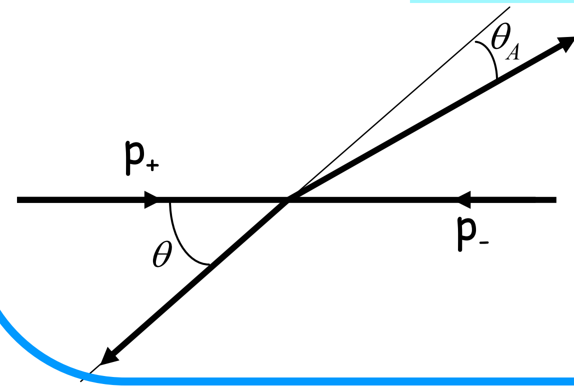
Endcap Bhabha acollinearity; rate >100 times physics channels.

$$\theta_A \simeq \frac{\Delta p \sin\theta}{p_b} \quad \text{, small } \theta_A$$

BUT $\underbrace{\Delta p = p_+ - p_-}_{\text{Acollinearity to <}10^{-4}}$ **while** $\underbrace{\sqrt{s} \simeq p_+ + p_-}_{\text{Calorimetry to >1\%, Not good enough!}}$

Acollinearity to <10 $^{-4}$

Calorimetry to >1%, Not good enough!



Study started; results reported at LCWS 2004. Small correlations manageable.

Required Energy Precision

(Mike Hildreth's version, LCWS 2004)

- Overall measurement precision is set by the expected statistical and systematic errors of "benchmark" measurements of m_{top}, m_{higgs}:
  - require $\delta E_{beam}/E_{beam}$ ~ 100-200 ppm
  - (LEP2 achieved ~170 ppm with a combination of techniques)

- We note that there may be a desire to
  - re-scan the Z lineshape
    - requires $\delta E_{beam}/E_{beam}$ ~ 1 ppm
  - scan the WW threshold
    - requires $\delta E_{beam}/E_{beam}$ ~ 30 ppm
  - Both of these would require significantly different accelerator operation, re-optimization of energy-measurement strategies
  - **ignore for now!**

Energy Jitter and Energy Walk

Expect ~ 0.3% over a train at warm machine.
Nowhere near so serious at TESLA.

Hope that some of it will be reproducible from train to train. Then sample it and apply a correction to individual physics events.

Becomes an important problem if warm technology chosen.

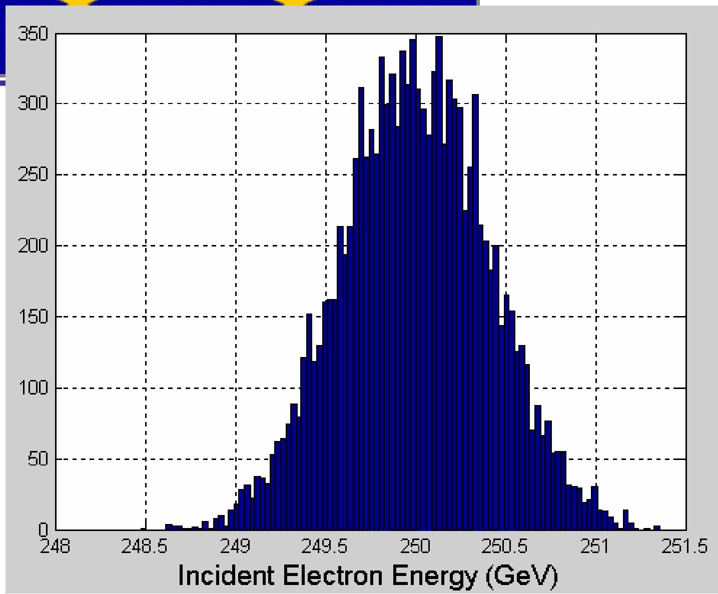
Planned testbeam campaign could address this (see below).

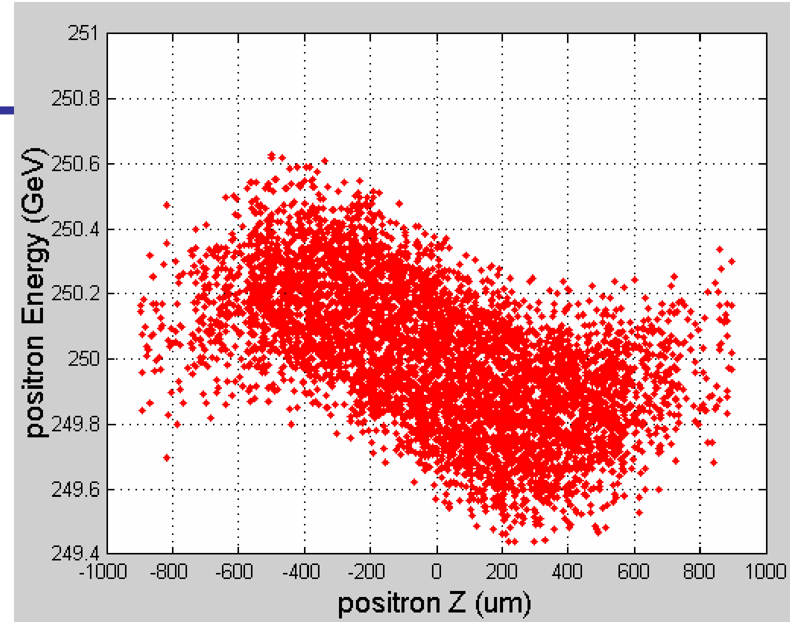
Beam Energy Spread

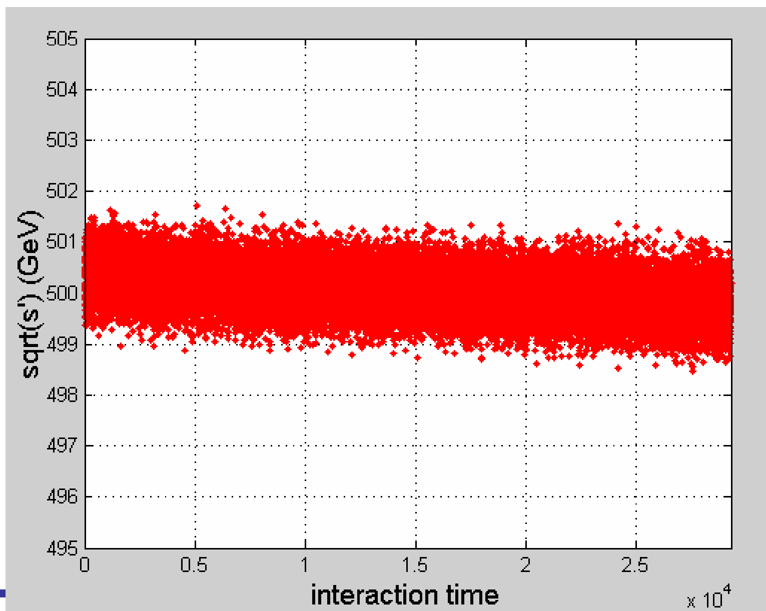
TESLA ~0.1%, Gaussian(?), better for e^+ than e^- because of e^+ source.

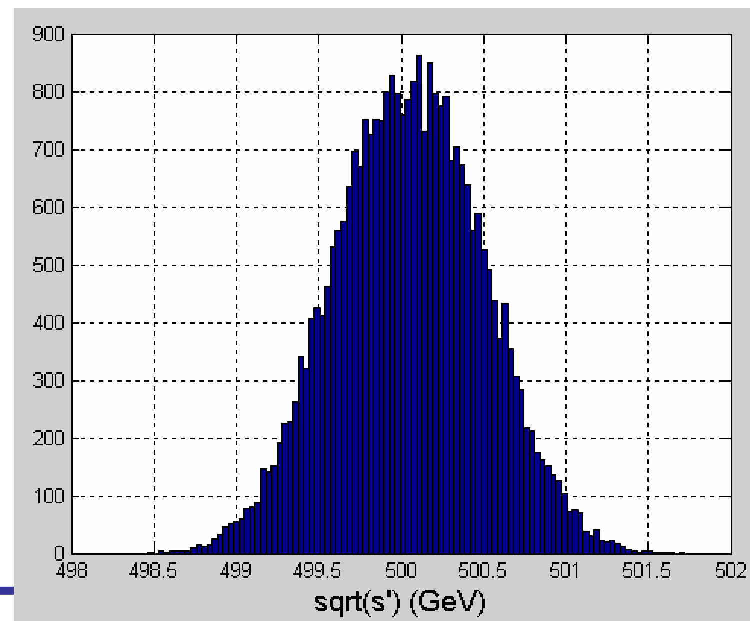
Warm machine ~0.3%, nongaussian, with front to back correlation in each bunch.

TESLA-500 Results (Mike Woods, SLAC)

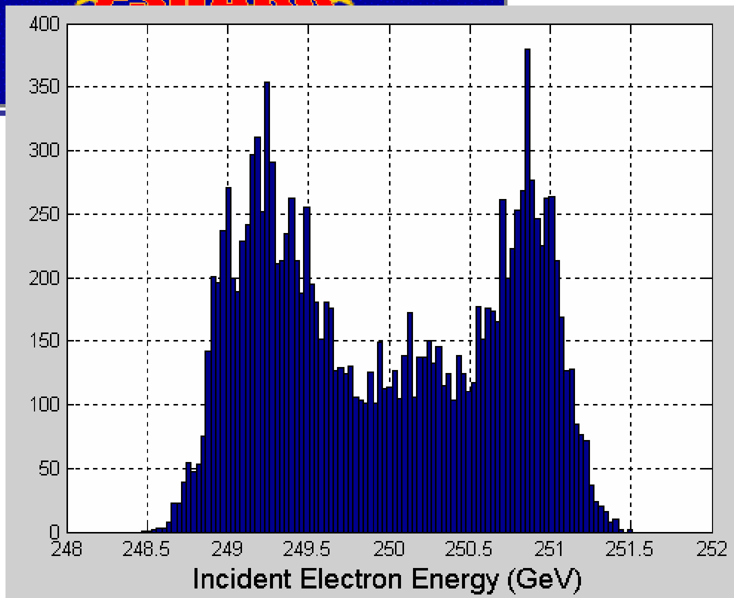


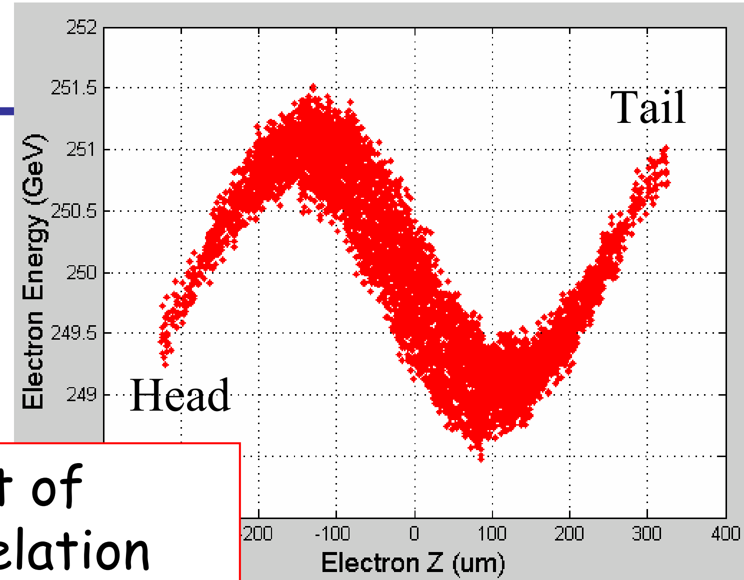


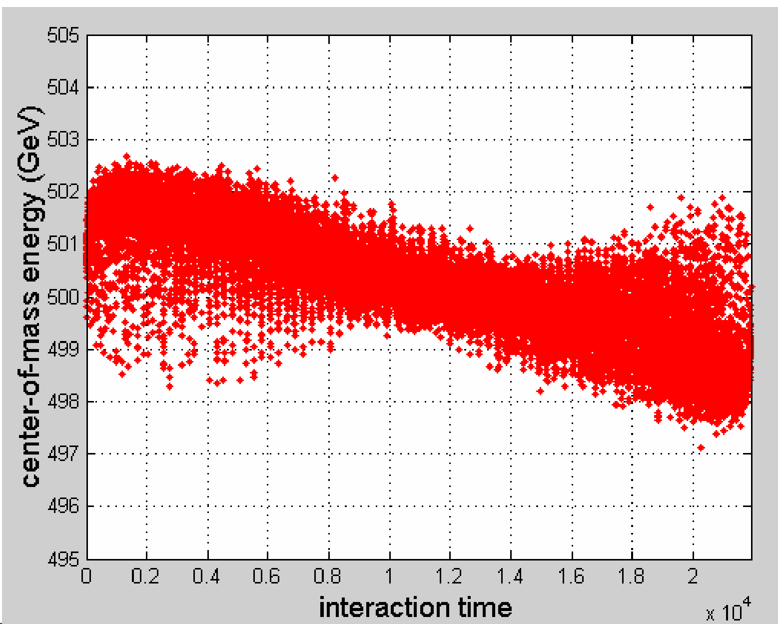


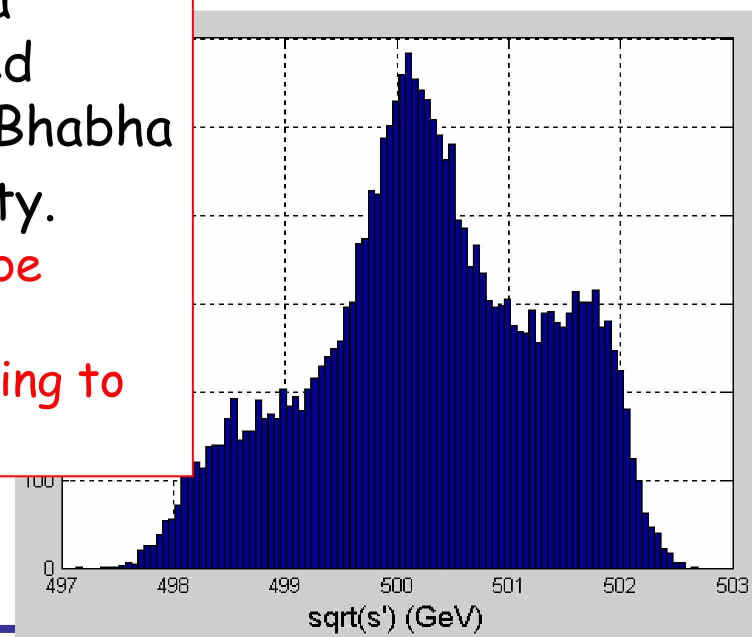


NLC-500 Results (Mike Woods, SLAC)









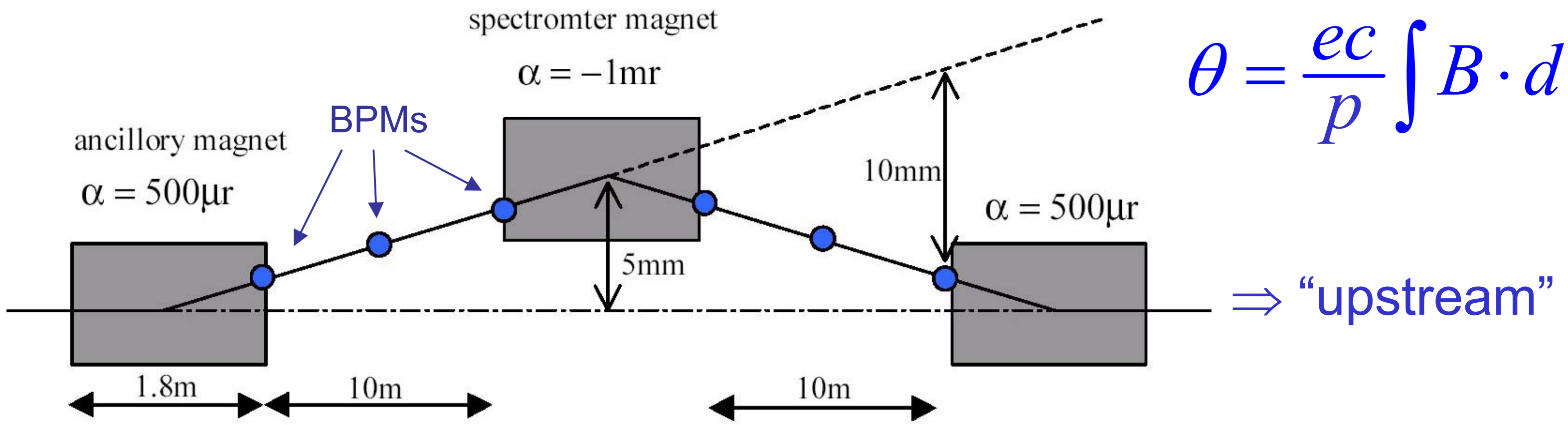
This sort of big correlation Will have a complicated effect on Bhabha acollinearity.

How can it be measured?

Just beginning to find out.

Energy Spectrometers 1
(after Hildreth)

- **"LEP-Type"**: BPM based, bend angle measurement



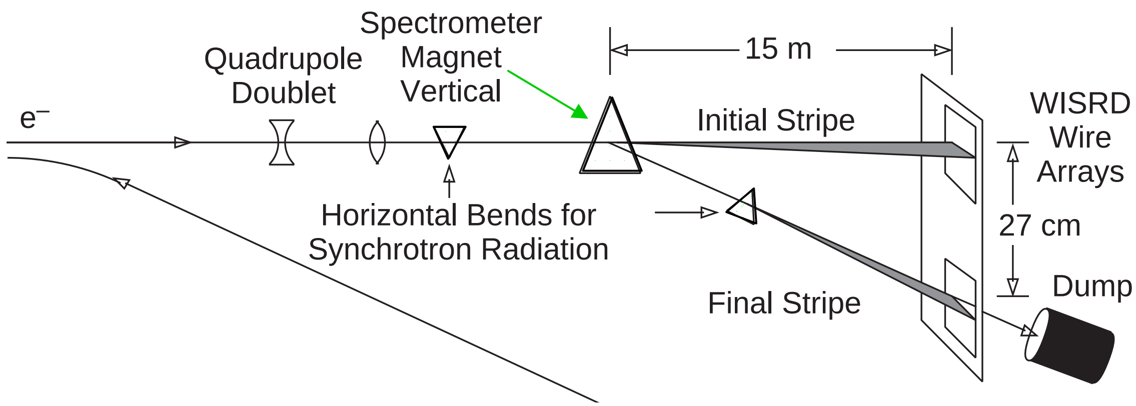
$$\theta = \frac{ec}{p} \int B \cdot d\ell$$

- Good for absolute energy; possibly also jitter and timewalk.

- LEP spectrometer was not stable over time. Background or noise effects?

Energy Spectrometers 2

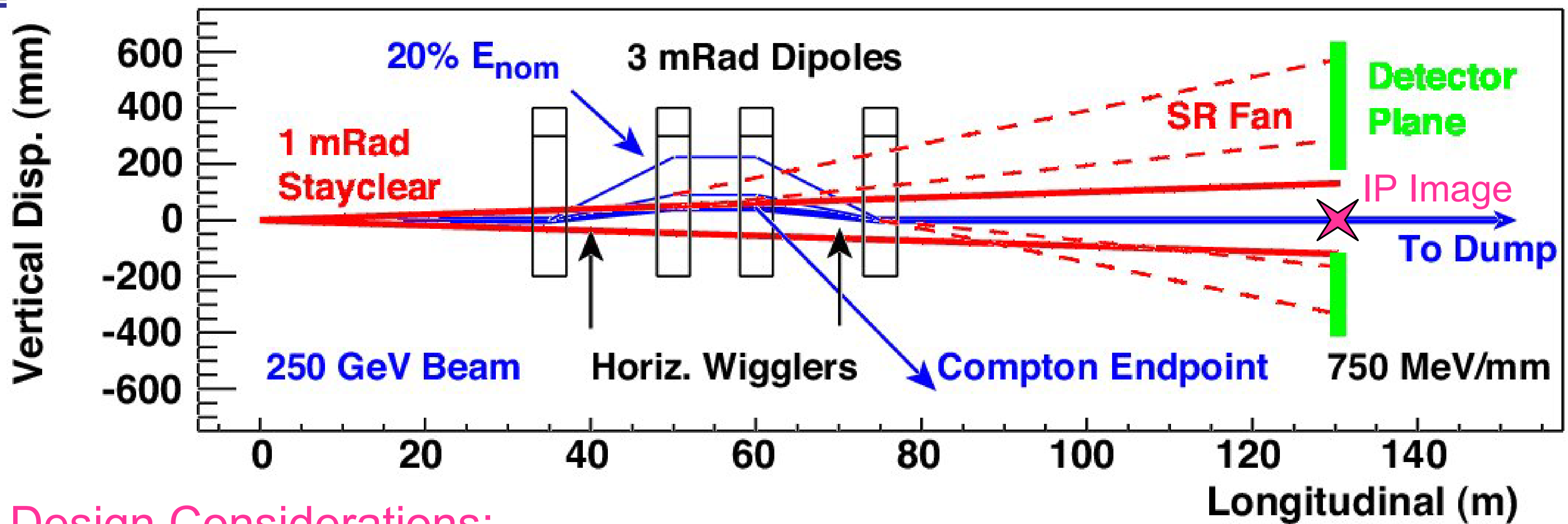
- "SLC-Type": SR stripe based, bend angle measurement



⇒ "downstream"

- Could give spectral shapes. Would need empty bunches in opposing beams to sample undisrupted spectra.
- (Alternative spectrum measurement might use laserwire at high dispersion point. Maybe upstream)

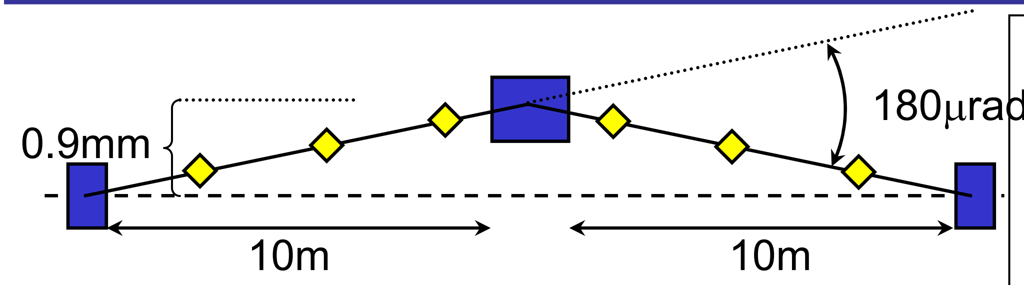
Extraction Line Spectrometer for FLC
(Hildreth LCWS 2004)

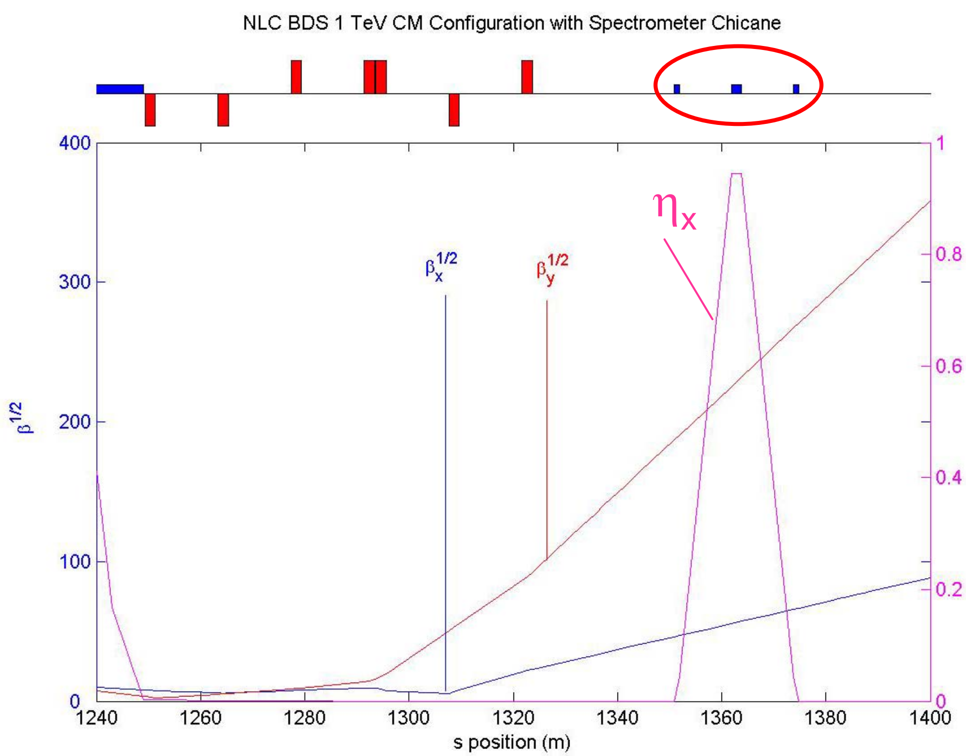


Design Considerations:

- Secondary IP image needs to be at detector plane for optics to work
- Wide-aperture 3mrad bends needed to extract SR fans and Compton Endpoint from Stayclear
- Geometry less severe if beam can be collimated to 50% of E_{nom}
- Wigglers + 4 SR detectors can be used to remove prominent WISRD systematic errors from tilts
- Only need upper/lower detector for relative dE/E, E spectrum measmt.
- "off-the-shelf" detector specs

Upstream BPM-based Spectrometer
(Mike Hildreth + Peter Tenenbaum's optics)





Design Considerations:

- limit SR emittance growth
  - 360mrad total bend $\Rightarrow$ 0.5%
- available space in lattice
  - no modifications necessary, yet
- 10m drift space maximum one can consider for mechanical stabilization, alignment
- 37m total empty space allows for BPMs outside of chicane to constrain external trajectories
- *Tiny* energy loss before IP $\begin{pmatrix} 1.2\text{MeV}@250 \\ 11.9\text{MeV}@500 \end{pmatrix}$
- non-ideal b-variation?

$\Rightarrow$ Constraints lead to a required BPM resolution of ~100nm (Resolution $\oplus$ Stability)

Plan to get our BPM technology From EITHER:-

NanoBPM Collaboration

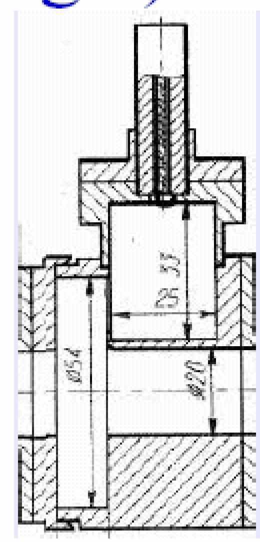
(Y.Kolomensky, UCB)

- Collaboration between SLAC, KEK, LLNL, UCB
- Ambitious goals
  - Position resolution for a single pulse at ~ nm scale
  - Similar accuracy and position stability of the BPM structure
  - Demonstrate beam tilt measurement with tens of mrad resolution
- Operational experience with precision devices
  - Nanometer resolution: push technology to the limit
  - Mechanical stability: Final focus, beam energy spectrometer
  - Tilt measurement: find (and correct for) sources of emittance growth in the linac → luminosity optimization.

The BPMs

(Y.Kolomensky, UCB)

- C-band cavities constructed at BINP (V.Vogel)
  - Resonant at 6426 MHz
  - Q ~ 5100 internal, 3300 external
  - Monopole mode suppression
  - Coupling $1.4 \cdot 10^{10}$ J/C^2/mm^2
  - Idealized resolution of ~0.5 nm for ~1 nC

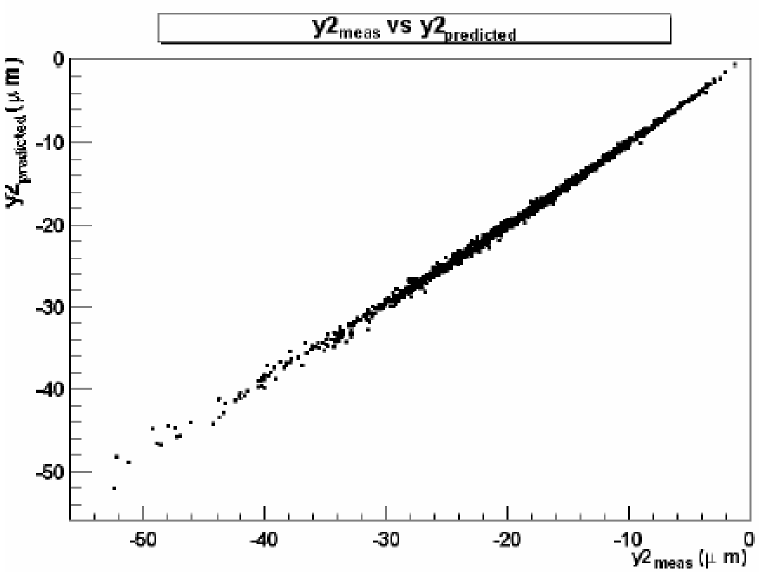


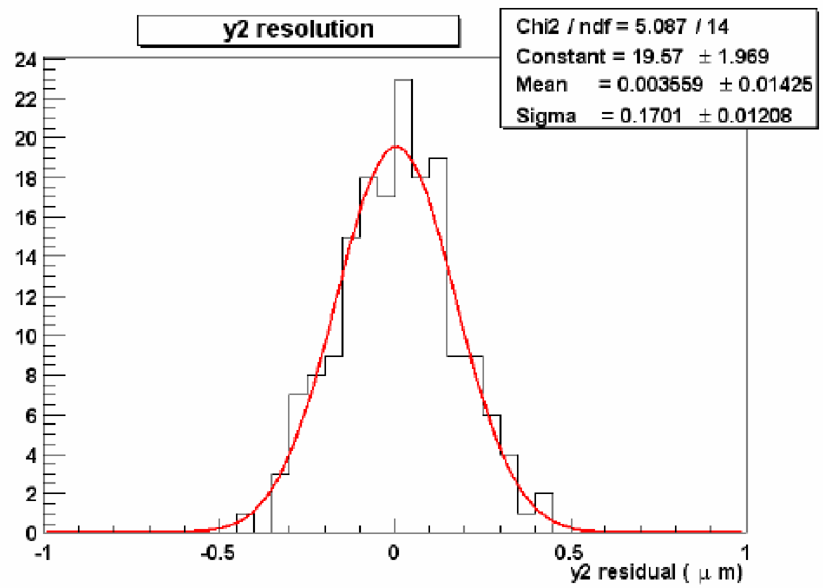
- Digital IF readout
  - Mix signal down to 15 MHz, digitize using a 14 bit 100 MHz sampling ADC

Resolution (quick first try using new ATF results)

(Y.Kolomensky, UCB)

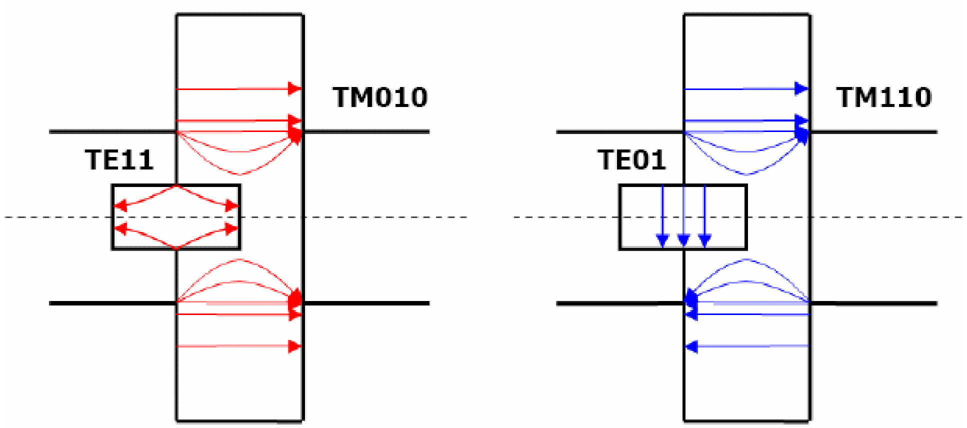
- Use cavities 1 and 3 to predict position of beam in 2, then compare
- Good linearity over large dynamic range (even past digitizer saturation)
- Resolution of 170 nm near cavity center
  - SLAC analysis sees better results, different dataset
  - Still significantly above thermal noise limit

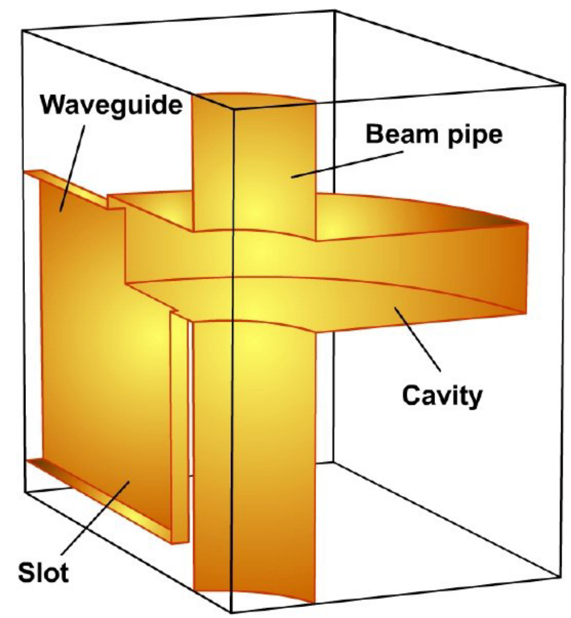




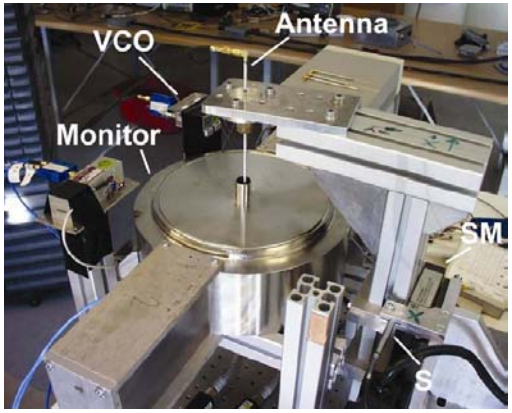
OR may get technology from DESY BPM R&D
(also derived from Russian ideas)
[Hope to incorporate through EUROTeV]

RF Cavity BPMs:





- Cavity BPMs designed so that only dipole mode of main cavity couples strongly to output waveguide.
- 1.5 GHz and 5.5 GHz prototypes constructed for bench tests
- achieved 150nm resolution on 1.5GHz prototype



H-J Schreiber et al

End Station A beam (E-158) is more like the real LC world than is KEK ATF beam.

Comparison of E-158 and NLC Beam Parameters

Parameter	E-158	NLC-500
Charge/Train	6×10^{11}	14.4×10^{11}
Repetition Rate	120 Hz	120 Hz
Energy	45 GeV	250 GeV
e^- Polarization	85%	85%
Train Length	270ns	267ns
Microbunch spacing	0.3ns	1.4ns
Beam Loading	13%	22%
Energy Spread	0.15%	0.16%
Intensity Jitter	0.5% rms	0.5% rms
Energy Jitter	0.03% rms	0.3% rms
Transverse Jitter	5% of spotsize (x or y)	22% of x spotsize, 50% of y spotsize

Can knock out bunches

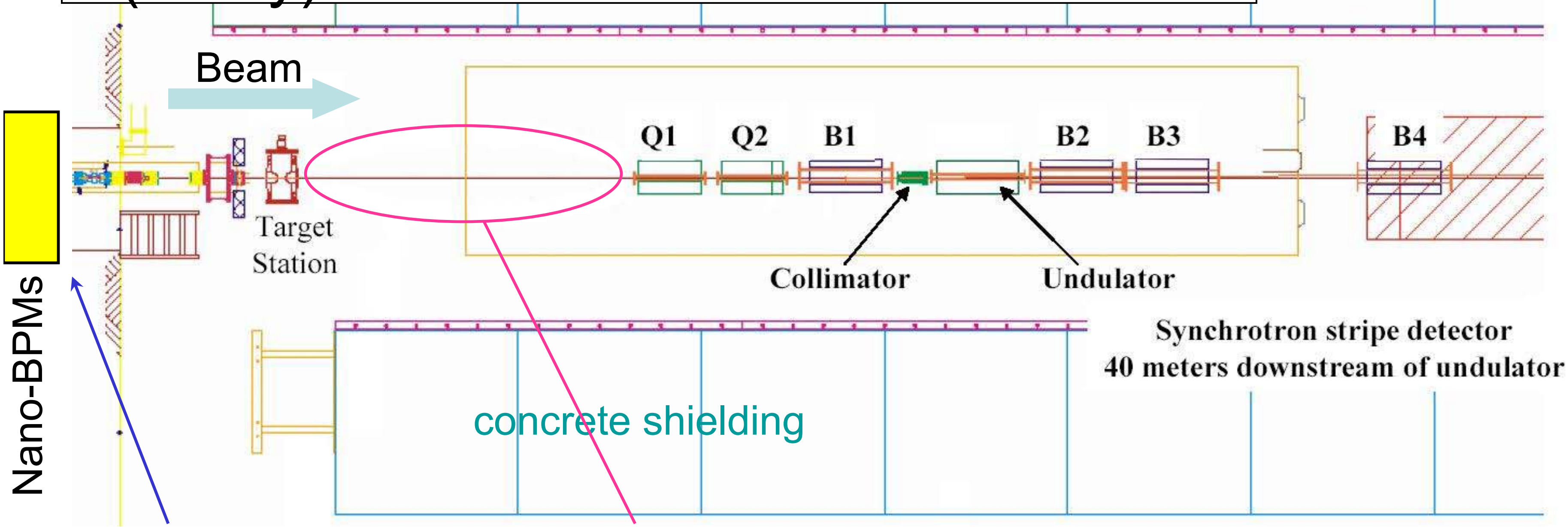
Can induce bigger values

Other: At the end of the SLAC Linac, the invariant emittance has been measured to be $\gamma\varepsilon_x = \gamma\varepsilon_y = 13.2 \times 10^{-5}$ m-rad, giving $\varepsilon_x = \varepsilon_y = 1.5 \times 10^{-9}$ m-rad at E=45.48 GeV.
Synchrotron radiation in the 24.5^0 bend in the A-line increases the horizontal emittance by a factor 25 at this energy.
Emittance increase at 28 GeV beam energy is negligible. 180-degree spin precession every 3.237 GeV.

M. Woods (SLAC)

SLAC End Station A Test Program being worked out now

- BDI equipment tests in “realistic” (=dirty) environment



Existing RF BPMs can be used for stability, resolution tests

5 meter region for test equipment. Put our BPM girder here? Or radiators to simulate IP..

Beamline components scavenged from SPEAR, other SLAC surplus

BPM Spectrometer test programme in ESA

UCL, Cambridge, Notre Dame, SLAC, UCB, DESY(?)

2005/06. Scan one bpm with 2 or 3 neighbours fixed.
Attempt to regain ATF performance in presence of synchrotron background and beam jitter.

Longer term. Prototype spectrometry chicane with all bpms on movers.
Track deflection of beam as magnets turned on and off from null to full bend.
Survey and controls crucial.

If warm technology chosen. Develop fast readout for bpms to measure energy jitter and timewalk with resolution ~10s of nanoseconds.

Spectral Shape measurements (downstream)

Main effort now coming from US (Torrence, Oregon; Herzbach, U.Mass., et al)

Also planning campaign in End Station A, developing new detectors for SR stripes.

Plan to simulate disruption with lead foils, and mock-up other features.

Summary

1. Demand is clear. But techniques not yet established, either for spectrometry or integration with experimental analysis.

2. Lots of ideas; not enough effort, so far.

3. Support now appearing for beam testing. Worldwide collaboration needed to use existing expertise and test beams.

4. Dialogue starting between optics designers, instrumentation developers and physics analysis groups.

5. EUROTeV will strengthen existing UK plans and bring in other European groups.

6. Modest initial goals must be followed up with full prototype tests and complete simulations of experimental analyses with all pathologies. Will need more people; hence more money!