Statistical Inference Problems in High Energy Physics and Astronomy

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BIRS Workshop
Banff
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- Programme for Workshop
  - Topics
  - Aims
  - Timetable
- What is Particle Physics?

Workshop topics

Topic A1: Confidence limits

- Nuisance parameters
- Criteria for good intervals (e.g. no very small intervals?)
- Unphysical values / empty ranges
- Coverage?

Topic A2: Estimating signal significance

- S/ √ B ?
- Nuisance parameters
- Why 5σ? (Past experience, 'Look elsewhere' effect, Bayesian priors!)
- Goodness of fit: Sparse multi-dimensional data

Multivariate analysis (Signal-background separation)

- Cuts, Fisher, PCA, NN, Bayesian nets, SVM, Boosted Trees, Bagging……

Workshop aims

- Learn from statisticians about possible approaches
- Compare available methods
- Produce written summary of ‘Where we are’

Timetable

- Sunday

  a.m and p.m. Introductory Talks (plenary)
- Monday

  a.m. and p.m. Working groups
- Tuesday

  a.m. Intermediate reports (plenary)

  p.m. Free for hike
- Wednesday

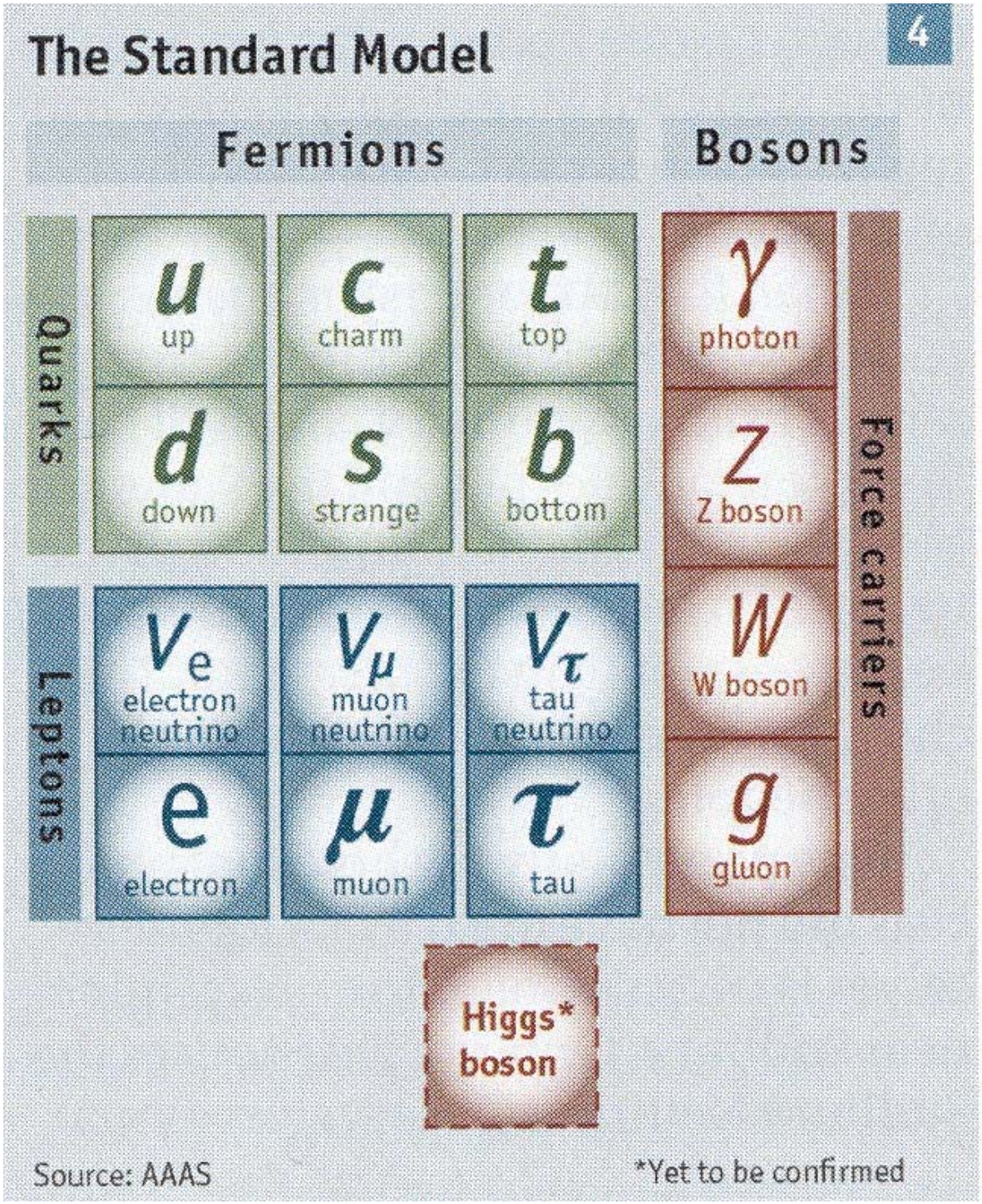
  a.m. and p.m. Working groups
- Thursday

  a.m. Final Reports (plenary)

  Conclude with lunch

Sunday Talks

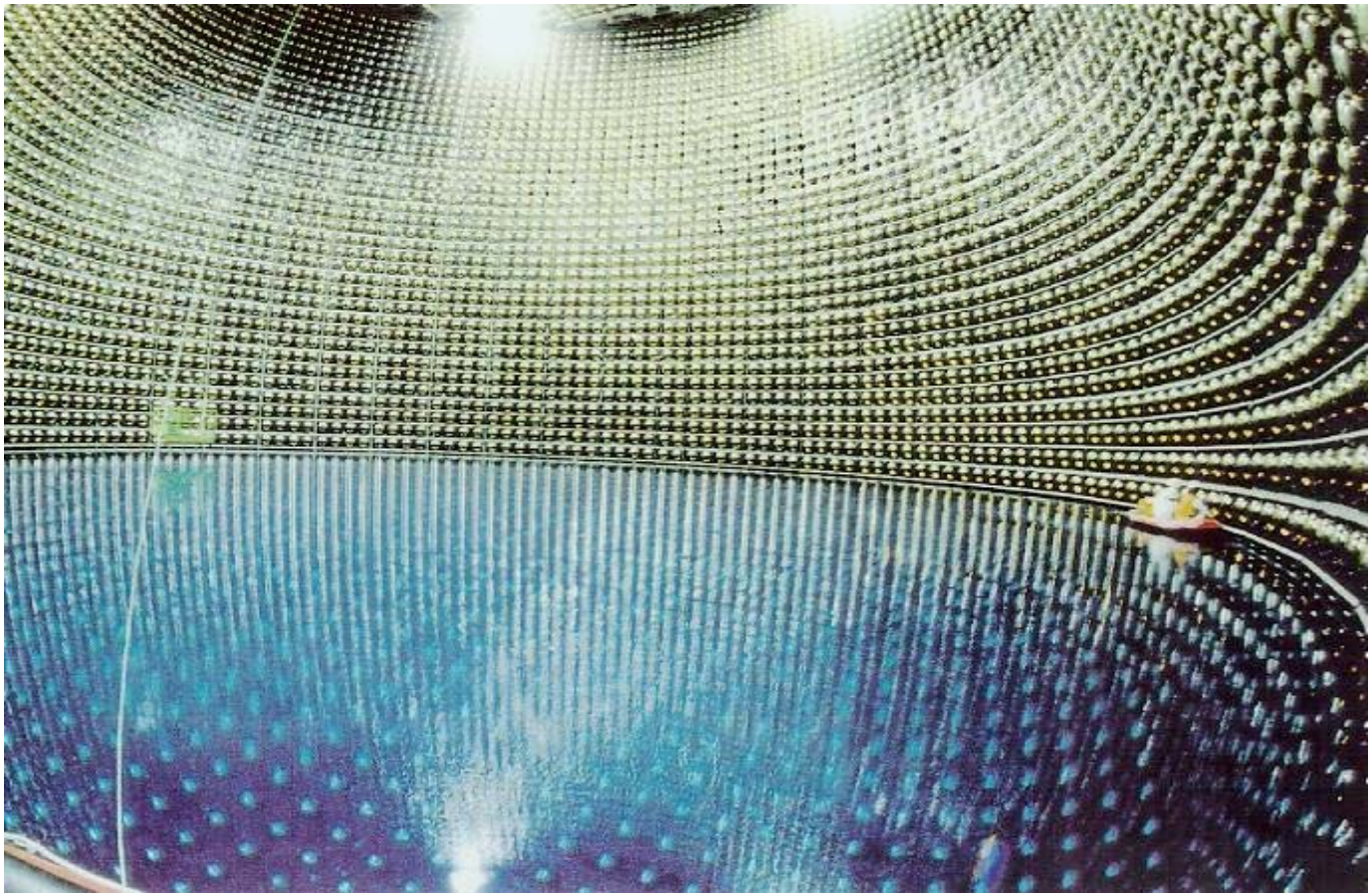
- Joel Heinrich
- Luc Demortier
- David van Dyk
- Byron Roe
- Radford Neal
- Xiao-Li Meng


The Standard Model
4
Fermions
Bosons
Quarks
u up
c charm
t top
d down
s strange
b bottom
Leptons
ν_e electron neutrino
ν_μ muon neutrino
ν_τ tau neutrino
e electron
μ muon
τ tau
Force carriers
γ photon
Z Z boson
W W boson
g gluon
Higgs* boson
Source: AAAS
*Yet to be confirmed

Typical Experiments

Experiment	Energy	Beams	# events	Result
LEP	200 GeV	e+ e-	10^7 Z	N = 2.987± 0.008
BaBar/Belle	10 GeV	e+ e-	10^8 B anti-B	CP-violation
Tevatron	2000 GeV	p anti-p	"10^{14}"	SUSY?
LHC	14000 GeV	p p	(2007…)	Higgs?
K2K	~3 GeV	Neutrinos	100	ν oscillations

Aerial View of CERN



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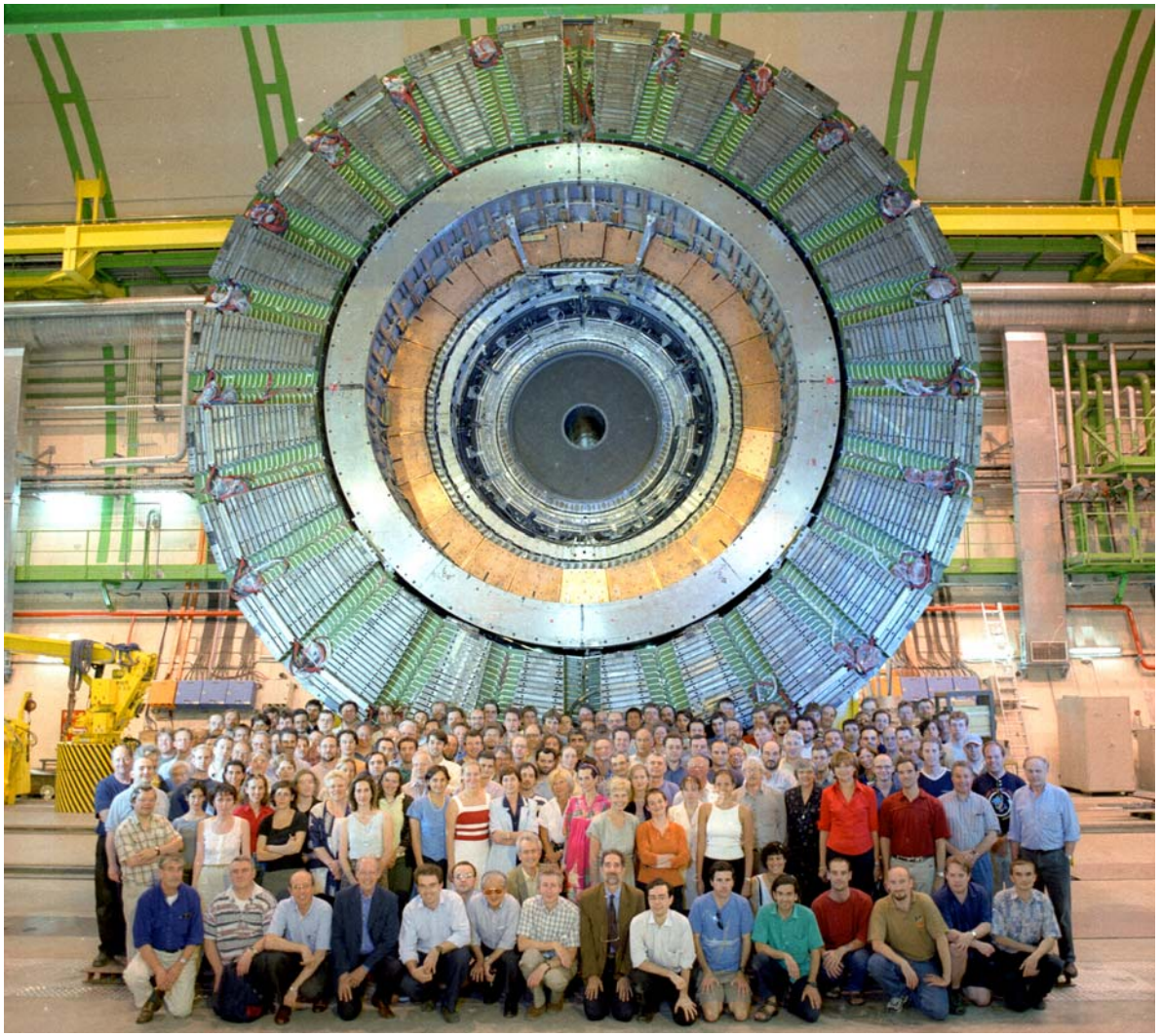
CDF at Fermilab

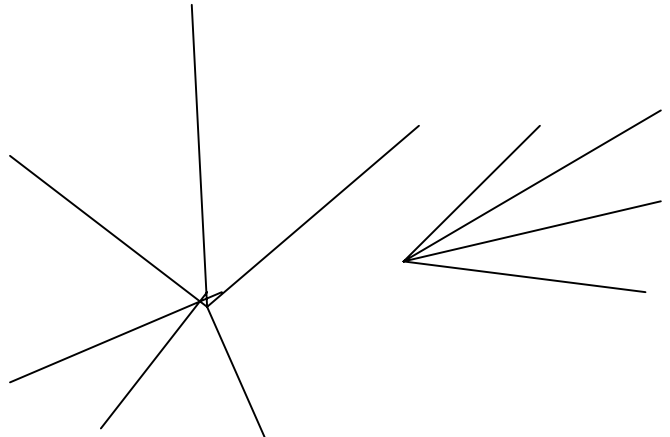


Typical Analysis, 1

- Parameter determination: $dn/dt = 1/\tau * \exp(-t/\tau)$

Worry about backgrounds, t resolution, t-dependent efficiency

- 1) Reconstruct tracks
- 2) Select real events
- 3) Select wanted events (cuts)
- 4) Extract t from L and v
- 5) Model signal and background
- 6) Likelihood fit for lifetime and statistical error
- 7) Estimate systematic error $\tau \pm \sigma_\tau\,(\text{stat}) \pm \sigma_\tau\,(\text{syst})$
- 8) Does data agree with expected dn/dt?



Typical Analysis, 2

Group A: Looking for interesting signal

Simplest example:

Define set of cuts to select possible signal

Expect b ($\pm\sigma_b$) from uninteresting sources. Assume Poisson.

Observe n events

A1: For n smaller or not much greater than b, establish upper limit on possible excess from interesting new source

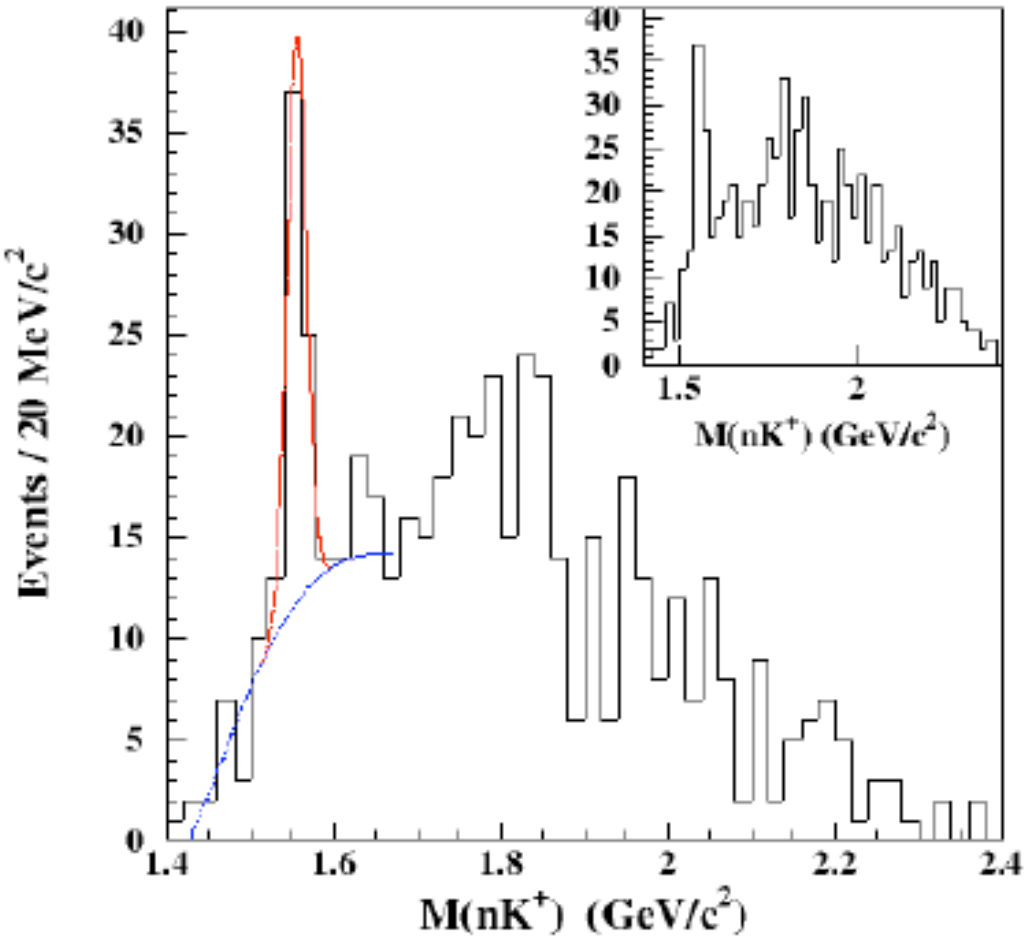
A2: For n rather larger than b, quantify significance of deviation.

Realistic examples have multivariate data, rather than just one integer, or a single histogram

e.g. Is apparent peak on top of smoothish bgd a statistical fluctuation, or an interesting signal?

Typical Analysis, 2

Hypothesis testing: Peak or statistical fluctuation?



Typical analysis, 3 (Group C)

Try to determine properties of events containing top-quarks (relatively rare)

Observe events, characterised by many variables

Use training data (M.C?) for signal and for backgrounds in multivariate classification schemes, to separate top from backgrounds

Assess efficiency and purity for selection procedure, including possible systematics.

Issues: Which variables, adequacy of training sets, what method, what optimisation, …….. ?

Where we would like help

- Access to understood programs
- Confidence limits
  - Nuisance parameters
  - Unphysical values
  - Coverage?
  - Very small intervals
- Estimating signal significance
  - S/ √ B
  - Nuisance parameters
  - Look elsewhere effect
- Multivariate analysis
  - Cuts, Fisher, PCA, NN, Bayesian Nets, SVM, Boosted Trees…….
- Goodness of fit
  - Sparse multi-dimensional data
- Combining results
  - Asymmetric errors
  - Overlapping data samples
  - Correlated systematics