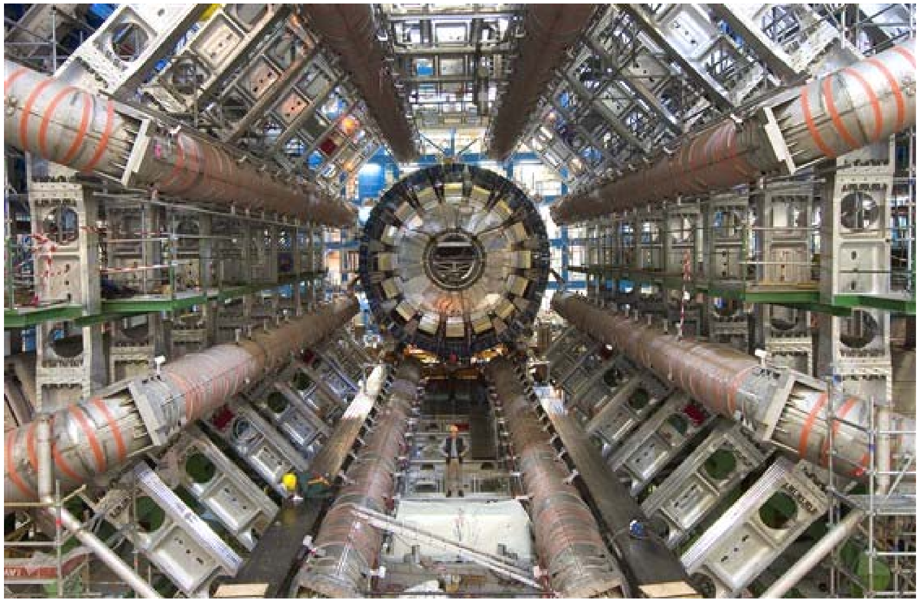
Lepton-pairs from hadrons

- then and now

James E Pilcher

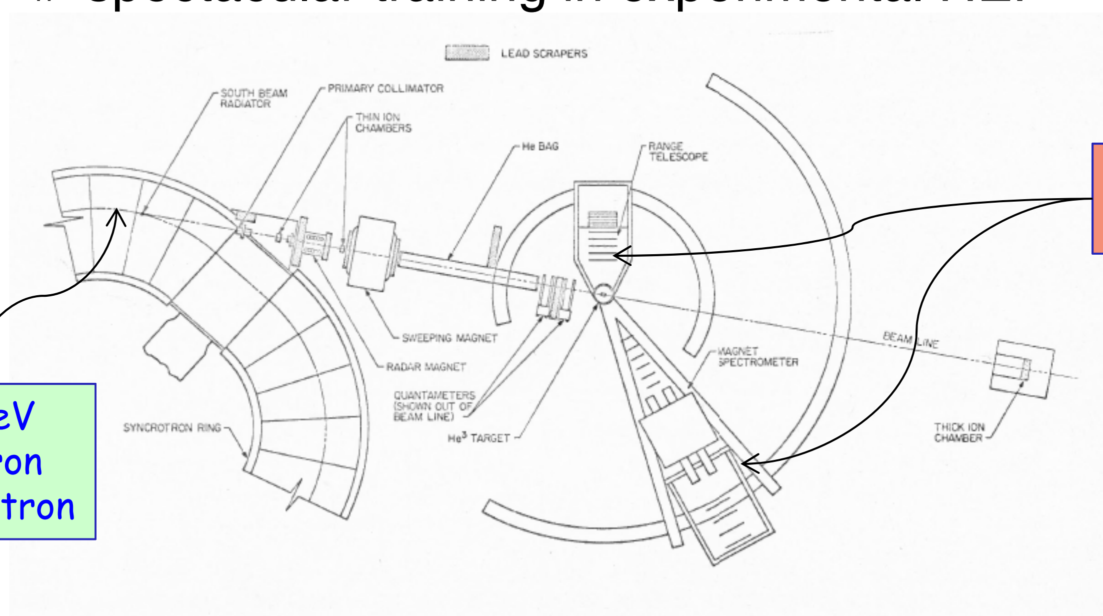


June 17, 2016

The early years

- We worked together on a series of Fermilab experiments on hadronically produced mu-pairs from ~1974 to ~1990
- Kirk came to Chicago as Fermi Postdoctoral Fellow in 1974
  - with an outstanding background
- Thesis with the Heusch group at on the Caltech synchrotron, 1972
  - preceeded by Charlie Prescot, Elliott Bloom, Bruce Winstein
  - spectacular training in experimental HEP

Thesis on $\gamma + He^3 \rightarrow p + d$
as part of a test of T invariance.



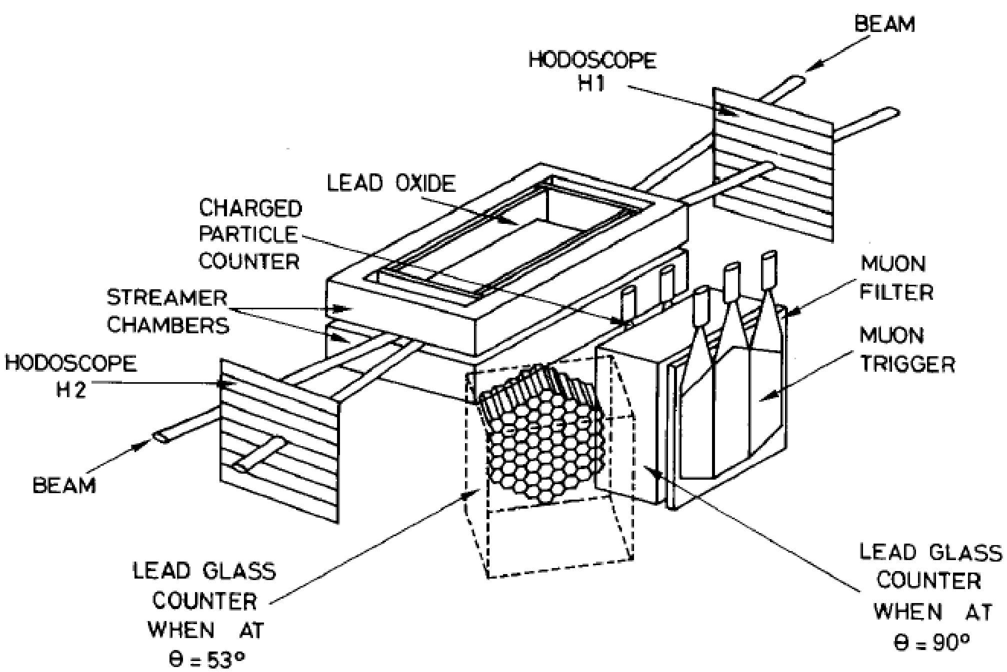
Two arm spectrometer
for p and d detection

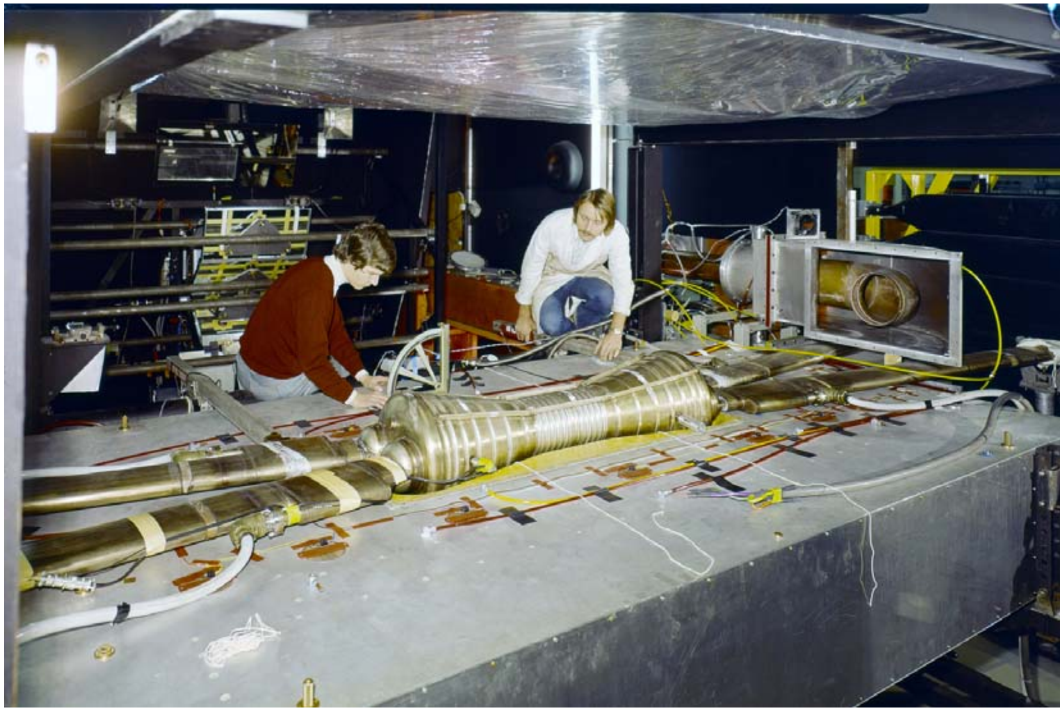
1.5 GeV
electron
synchrotron

The early years

- After Caltech, CERN ~1972-74
  - early operation of the Intersecting Storage Rings
  - first evidence for hard parton-parton scattering
- Streamer chamber experiment triggering on high p_T π^0s
  - with Aachen, CERN, Heidelberg, Munich group, R701

    including Pierre Darriulat

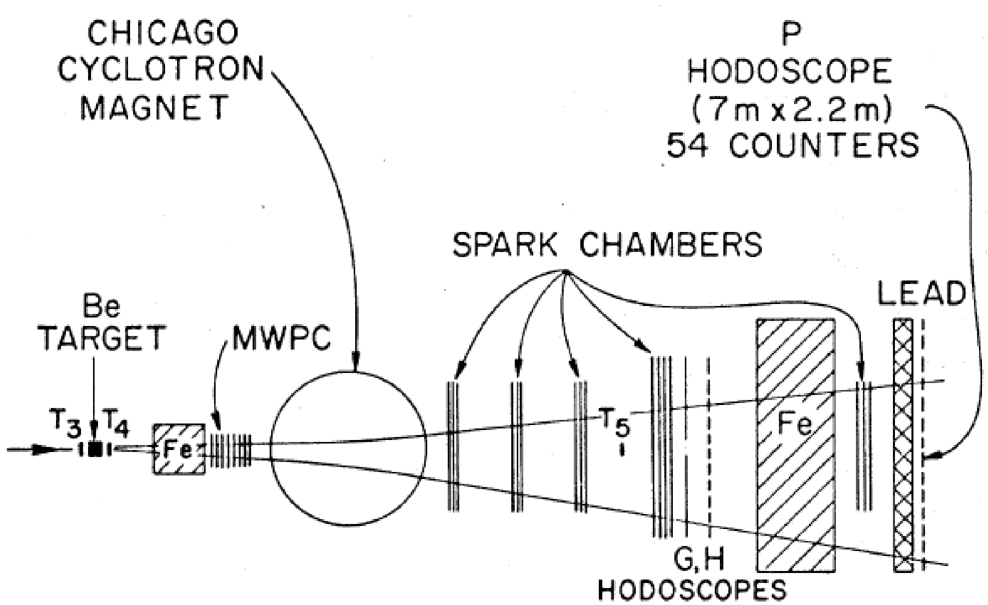




At Chicago

- Kirk joined us at Chicago in 1974
  - Enrico Fermi Fellow
- Experiment 331 proposed at Fermilab in August 1974
  - study lepton pair production with a large acceptance spectrometer
  - PAC suggested we use the Chicago Cyclotron Spectrometer assembled for deep inelastic muon scattering

    with modest changes for triggering, beam definition, hadron filtering, etc.
  - approved Nov. 25, 1974, just after the "November revolution"



Group of 9 people made it all work
- with Kirk a key player

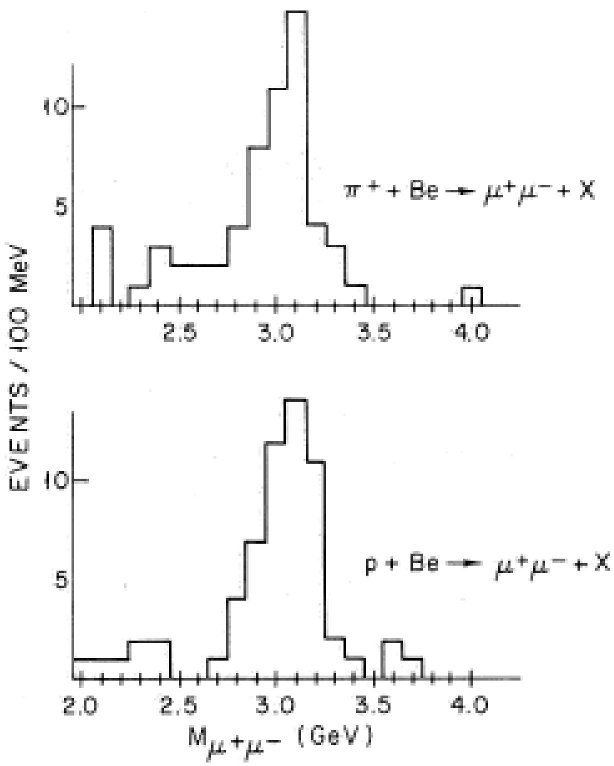
Fermilab E-331

Production of Muon Pairs by 150-GeV/c π^+ and Protons*

K. J. Anderson, G. G. Henry, K. T. McDonald,† J. E. Pilcher, and E. I. Rosenberg
Enrico Fermi Institute, University of Chicago, Chicago, Illinois 60637

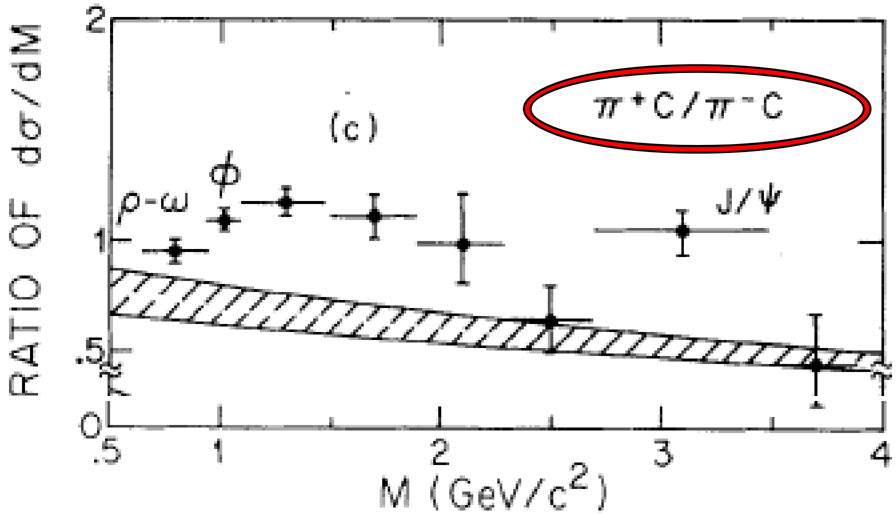
and

J. G. Branson, G. H. Sanders, A. J. S. Smith, and J. J. Thaler
Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08540
(Received 30 October 1975)



Our first publication
Clear sighting of J/ψ production by pions
- ratty early data
- much more to come

Fermilab E-331

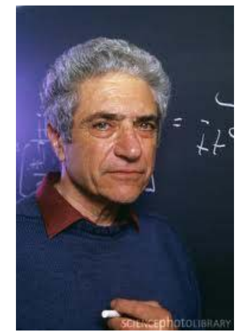


- π^+ and π^- are equally effective at producing J/ψ
- Continuum cross section at higher masses is larger for π^-
- Need more sensitive data ⇒ E-444

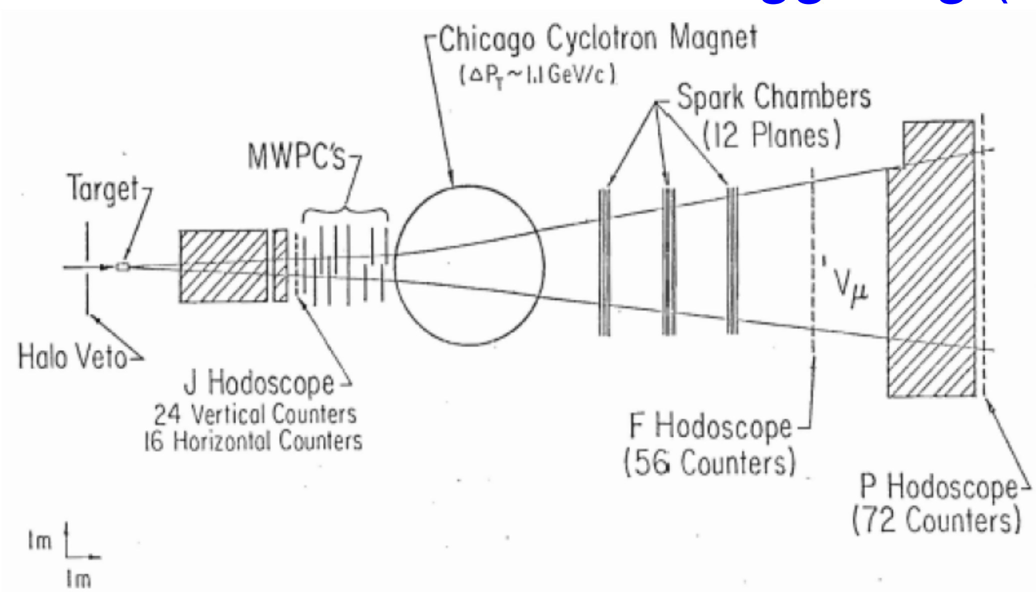
E-331 gave us 7 PRL articles appearing in 1976-7
- 4 with over 100 citations ("very well known papers" in SPIRES)
- 1 with over 250 citations ("famous papers" in SPIRES)

Fermilab E-444

- Proposed as a higher sensitivity follow-on to E-331 in Sept. 1975
  - Approved Nov. 1975
  - First data taking June 1977
- Larger MWPC array upstream of magnet to increase acceptance at low x
  - Kirk borrowed the Steinberger chambers from CERN



- Second large triggering hodoscope downstream of magnet
  - F (Fermi) hodoscope
- Electronic “mass-box” for triggering (note 3 hodoscopes after filter)



Improved cross section sensitivity by over two orders of magnitude.

- Kirk cleaned up the neutron background in the J hodoscope

Fermilab E-444

The team

Stew at the control desk

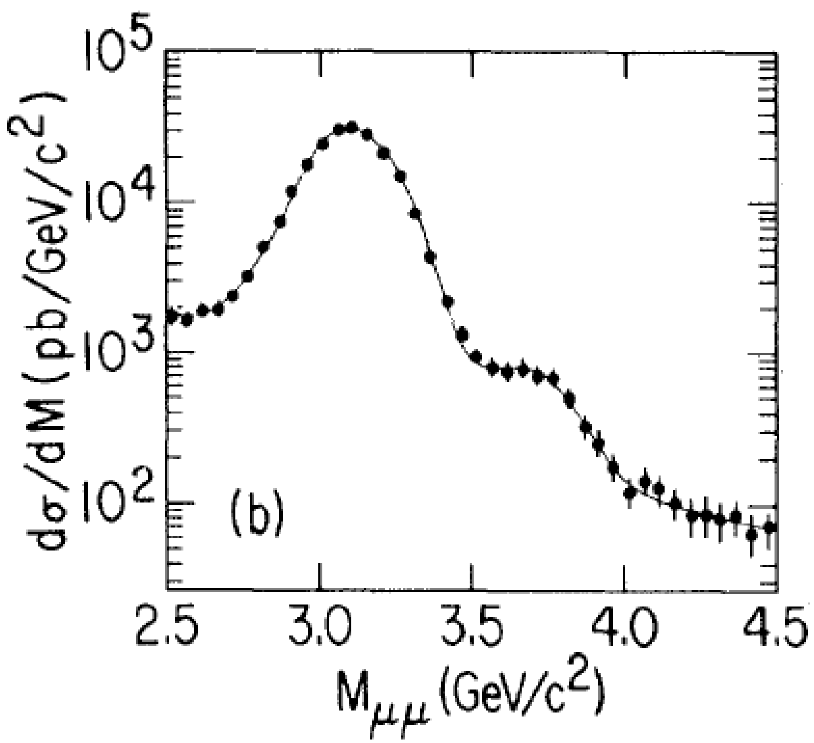
Fermilab E-444

Production of Muon Pairs by 225-GeV/c $\pi^{\pm}$, K^{+}, $p^{\pm}$ Beams on Nuclear Targets

K. J. Anderson, R. N. Coleman,[a] G. E. Hogan, K. P. Karhi, K. T. McDonald, C. B. Newman, J. E. Pilcher, E. I. Rosenberg, G. H. Sanders,[b] A. J. S. Smith, and J. J. Thaler

Enrico Fermi Institute, University of Chicago, Chicago, Illinois 60637, and University of Illinois, Urbana, Illinois 61801, and Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08540

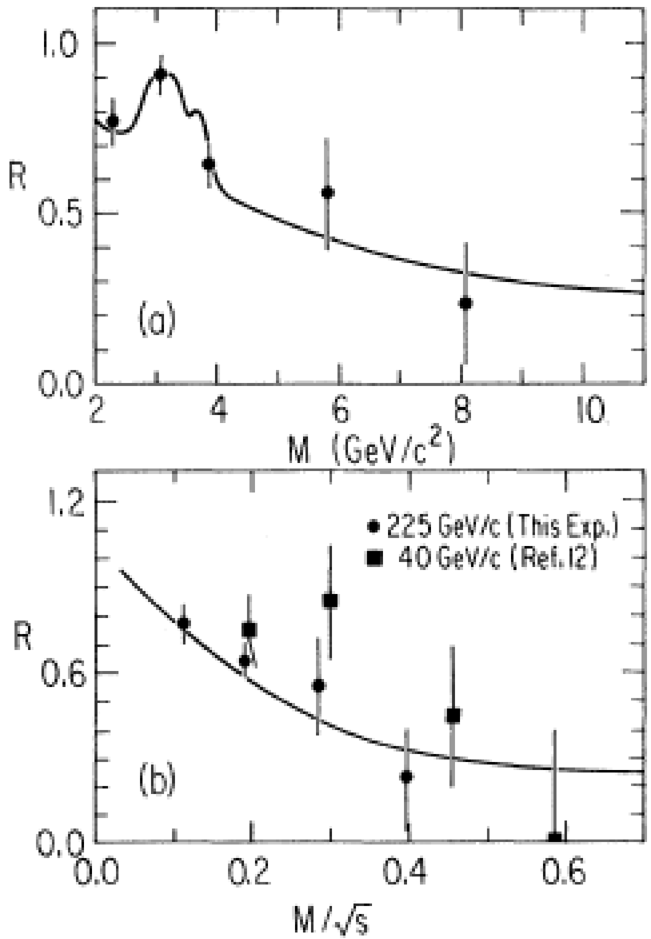
- similar cast of characters with rotation of the two students



The 300 J/ψ from E-331 ⇒ 66,000 in E-444
• 220 times gain in sensitivity for π^- beam

- similar gains for continuum cross sections

$$\frac{\sigma(\pi^+ C)}{\sigma(\pi^- C)}$$

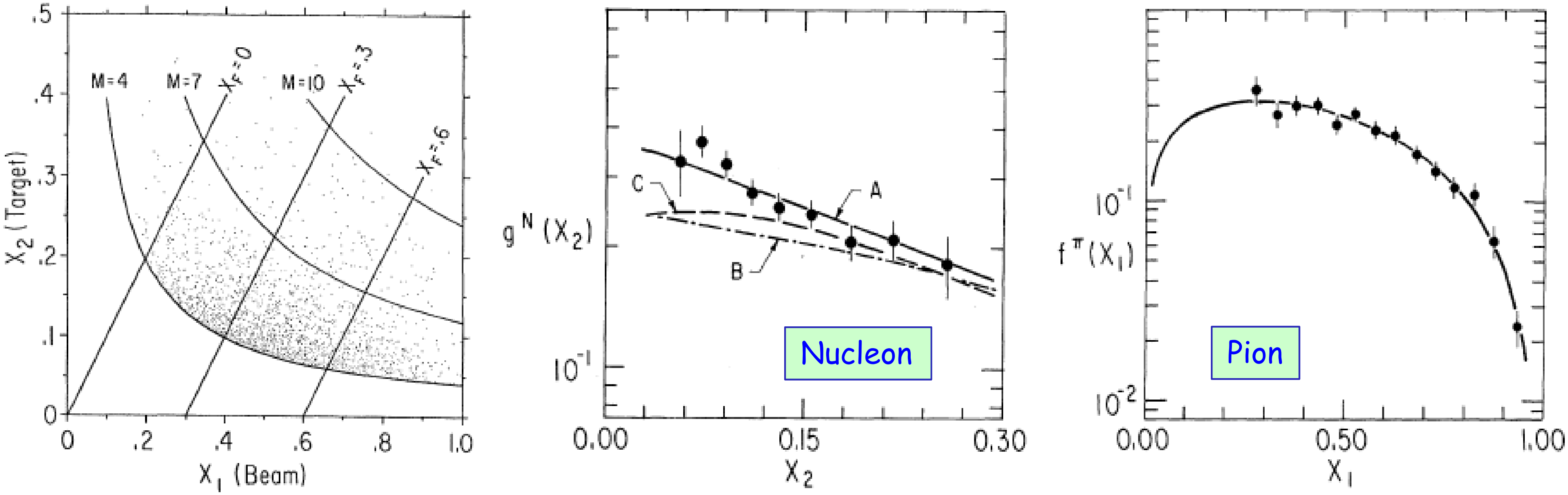


Ratio → 1/4 for quark-antiquark annihilation at high x when the contribution from sea quarks becomes small.

- nice confirmation of Drell-Yan mechanism

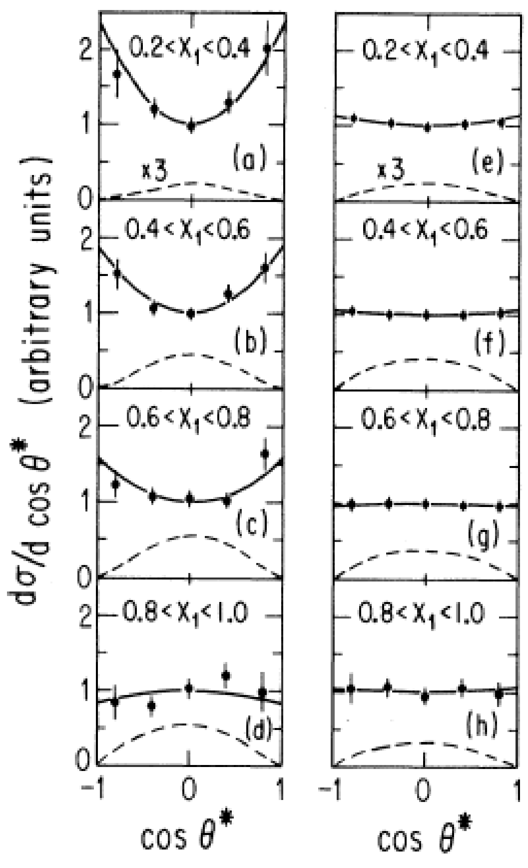
Fermilab E-444

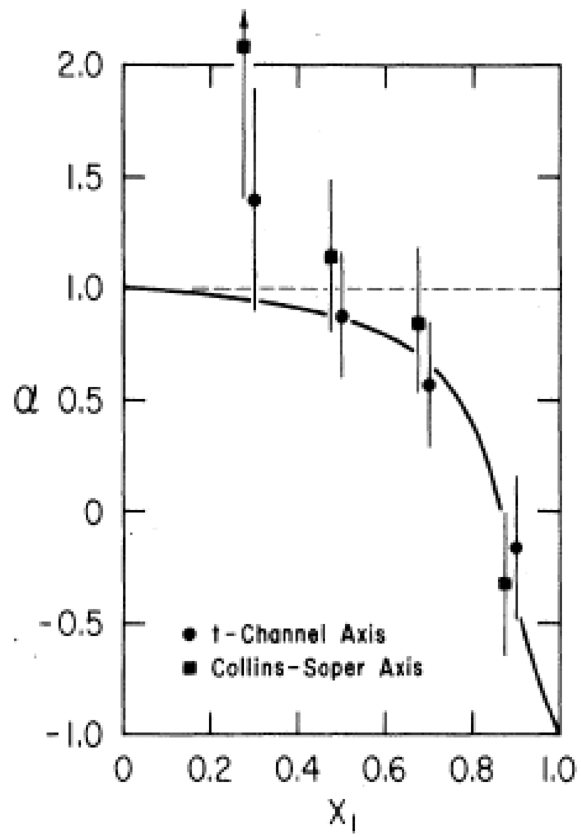
- Measure pion structure function

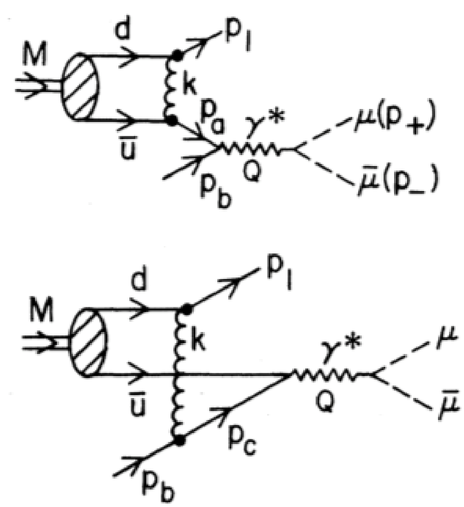


E-444 gave us 6 PRL articles appearing in 1979-80
- 2 with over 100 citations ("very well known papers" in SPIRES)

- A bonus
  - Unexpected effect observed in E-444 at high X_1
  - evidence for longitudinal photon polarization characteristic a modified production mechanism (higher twist effect?)



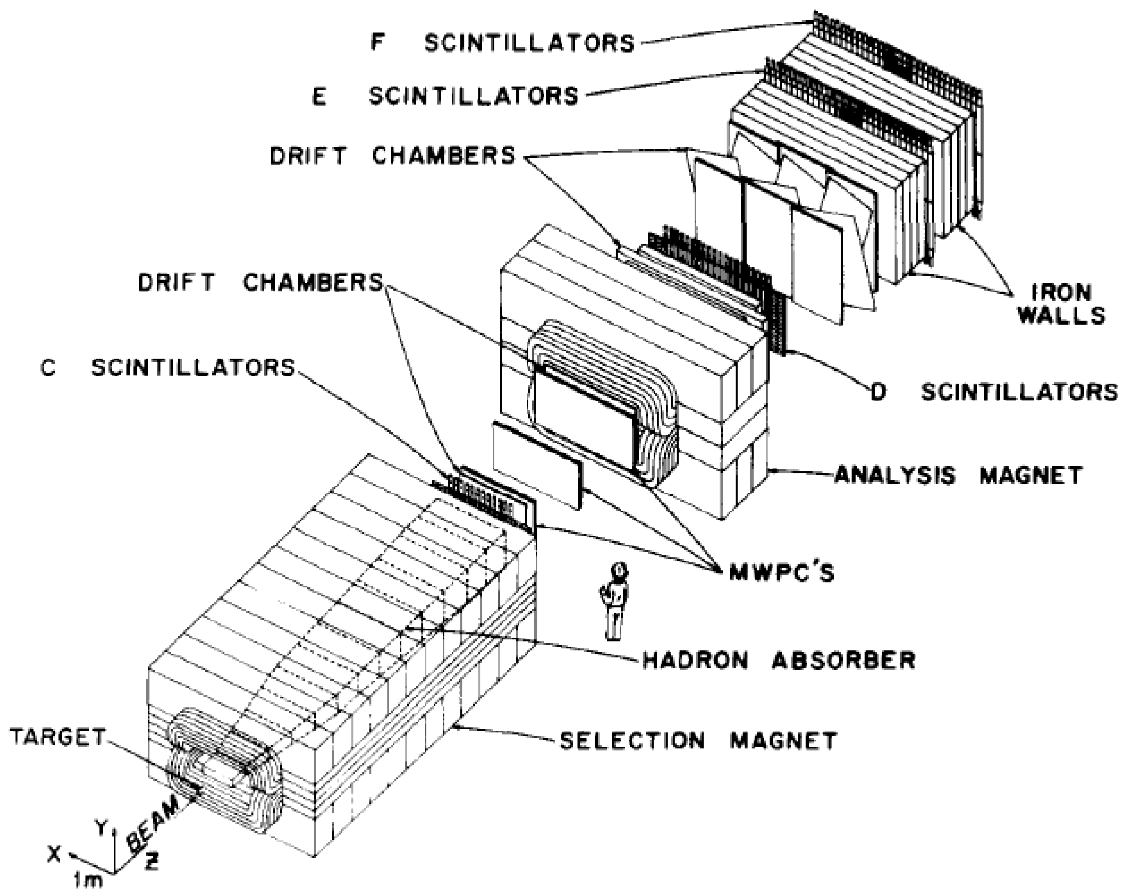




Annihilating quark predicted to be off-shell (massive) in this kinematic region.
- modifies angular distribution

Fermilab E-615

- proposed to follow up on this observation
  - go to the ultimate sensitivity possible at Fermilab
    - beam of 3 x 10^8 pions/s in Proton West area
  - new dedicated detector set-up



Fermilab E-615

- Experiment proposed in May 1979
  - approved July 1979
  - Kirk spokesperson
- First engineering run in 1983 with main operation in 1983-4
  - huge data sample collected
  - ~60K events with masses above 4 GeV

Longitudinal photon polarization in muon pair production at high x_F

J. P. Alexander, C. E. Adolphsen, K. J. Anderson, J. S. Conway,
J. G. Heinrich, K. W. Merritt, and J. E. Pilcher
Enrico Fermi Institute and Department of Physics, University of Chicago, Chicago, Illinois 60637

E. I. Rosenberg and D. T. Simpson
Ames Laboratory and Department of Physics, Iowa State University, Ames, Iowa 50011

C. Biino, J. F. Greenhalgh, W. C. Louis, K. T. McDonald,
S. Palestini, F. C. Shoemaker, and A. J. S. Smith
Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08544

(Received 3 April 1986)

Muon pair production by pions has been studied in an apparatus optimized for detection at large x_F. Results, based on a small fraction of the data, are reported here for the virtual-photon polarization and the pion structure function. These results confirm our previous work and are consistent with a QCD model involving higher-twist effects at large x_F.

Fermilab E-615

- Able to characterize clear departures from leading order $q\bar{q}$ annihilation

> E-615 gave us 8 journal articles appearing between 1986 and 1991
> - 2 with over 100 citations ("very well known papers" in SPIRES)
> - 1 with 336 citations (where > 250 is a "famous paper")
>   - this was the most cited of all our mu-pair papers
>   - John Conway's PRD thesis paper

- By 1990 most of us had gone our separate ways

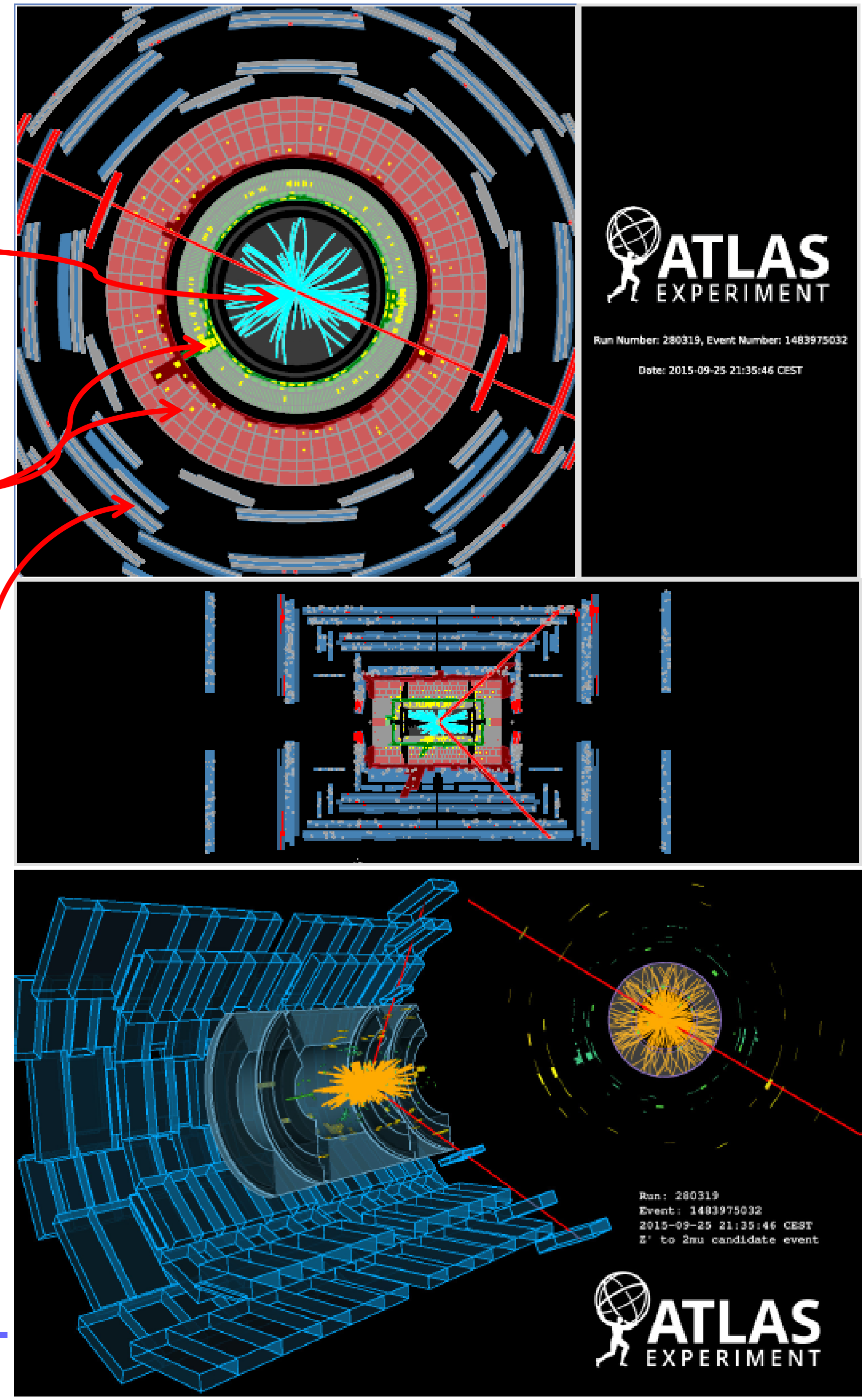
And now?

10⁹ intactions per second
~30 "simultaneously"
100 x 10⁶ tiny detection elements

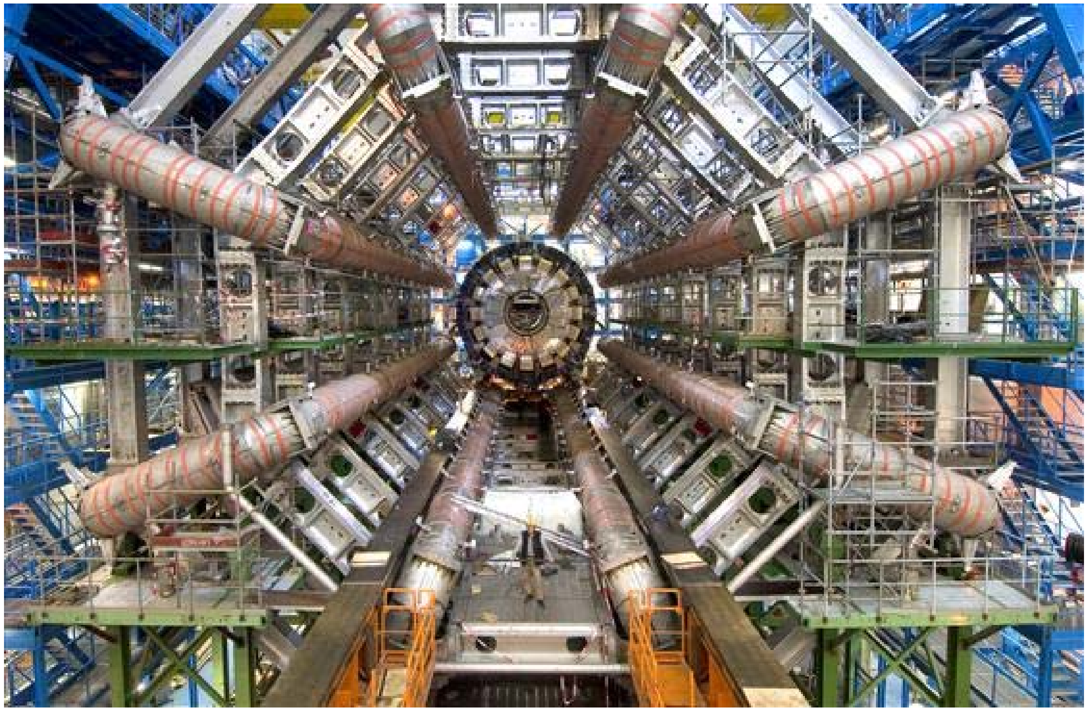
Heavy material to absorb strongly interacting particles
- but segmented and instrumented to measure energy and position

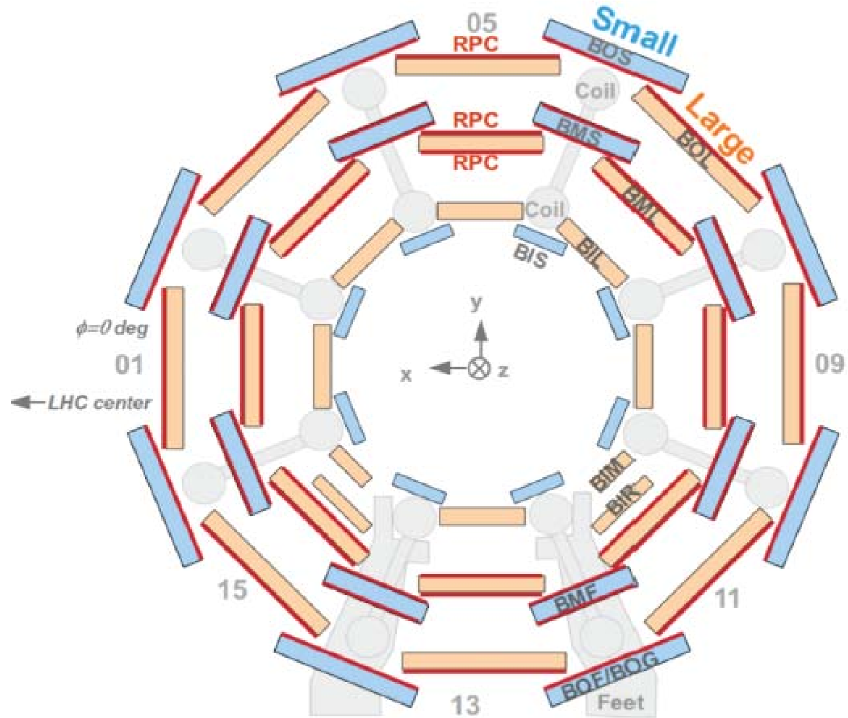
Muons bent in a magnetic field
Trajectory measured

This interaction has a pair of muons with an effective mass of 1390 GeV



The ATLAS muon spectrometer



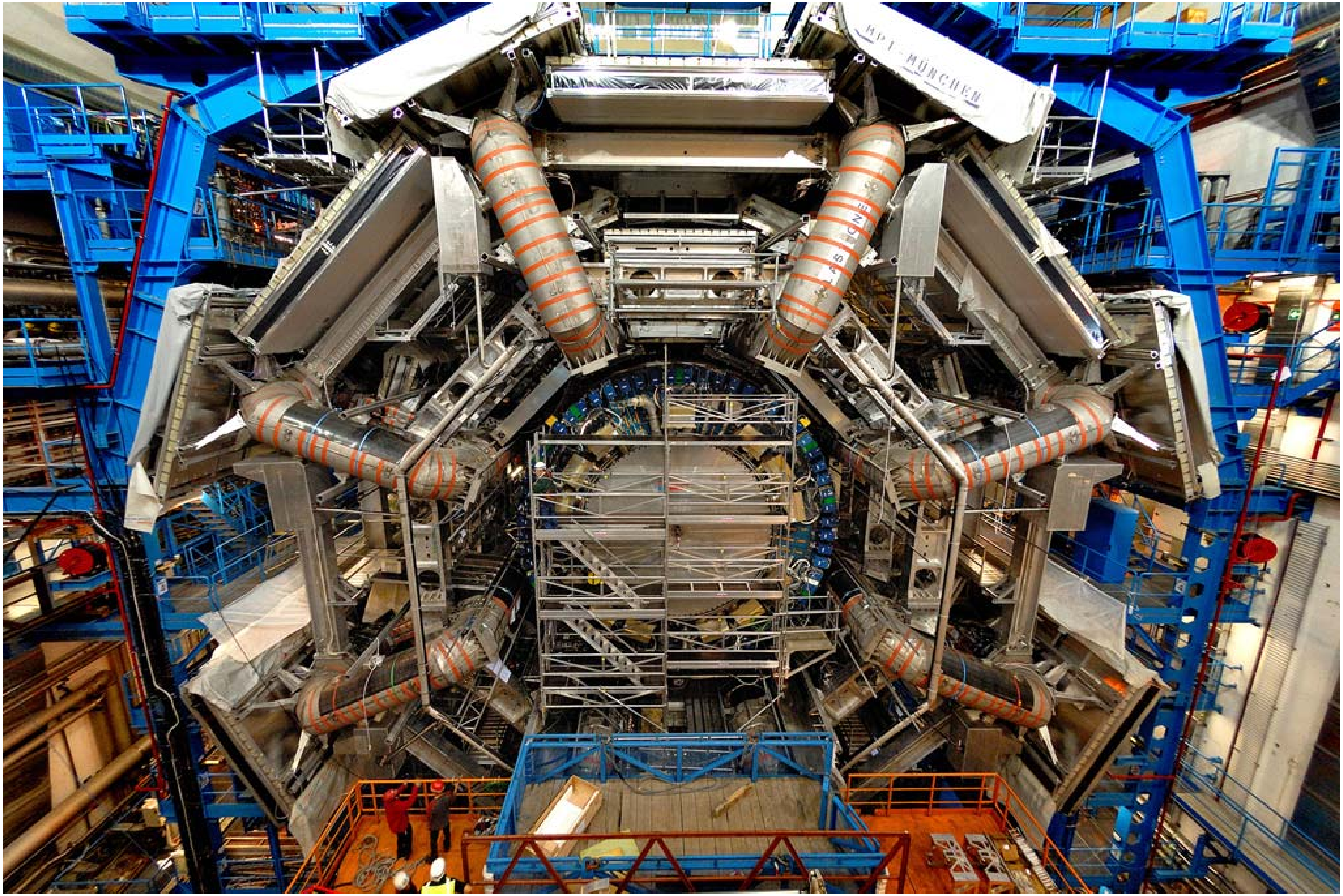


8 superconducting coils carrying 25,000 A
- 25 m long
- outer diameter 20.1 m
- inner diameter 9.4 m

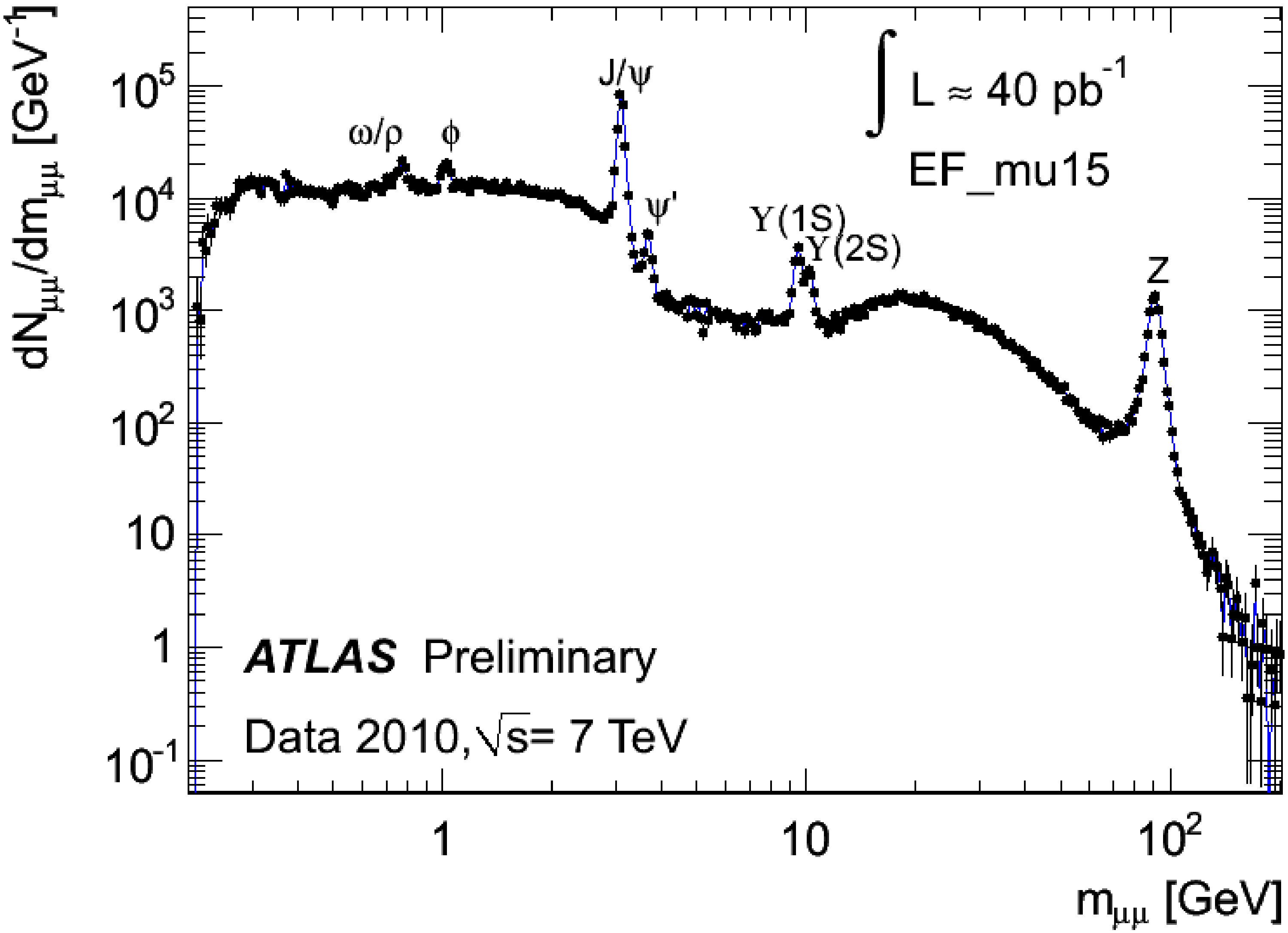
Trajectories measured with groups of 3-cm dia. drift tubes
resolution for each station (multi-layer) ~35 um

Momentum resolution ~10% for 1 TeV muons
Performance for lower momentum aided by inner detector

The ATLAS muon spectrometer

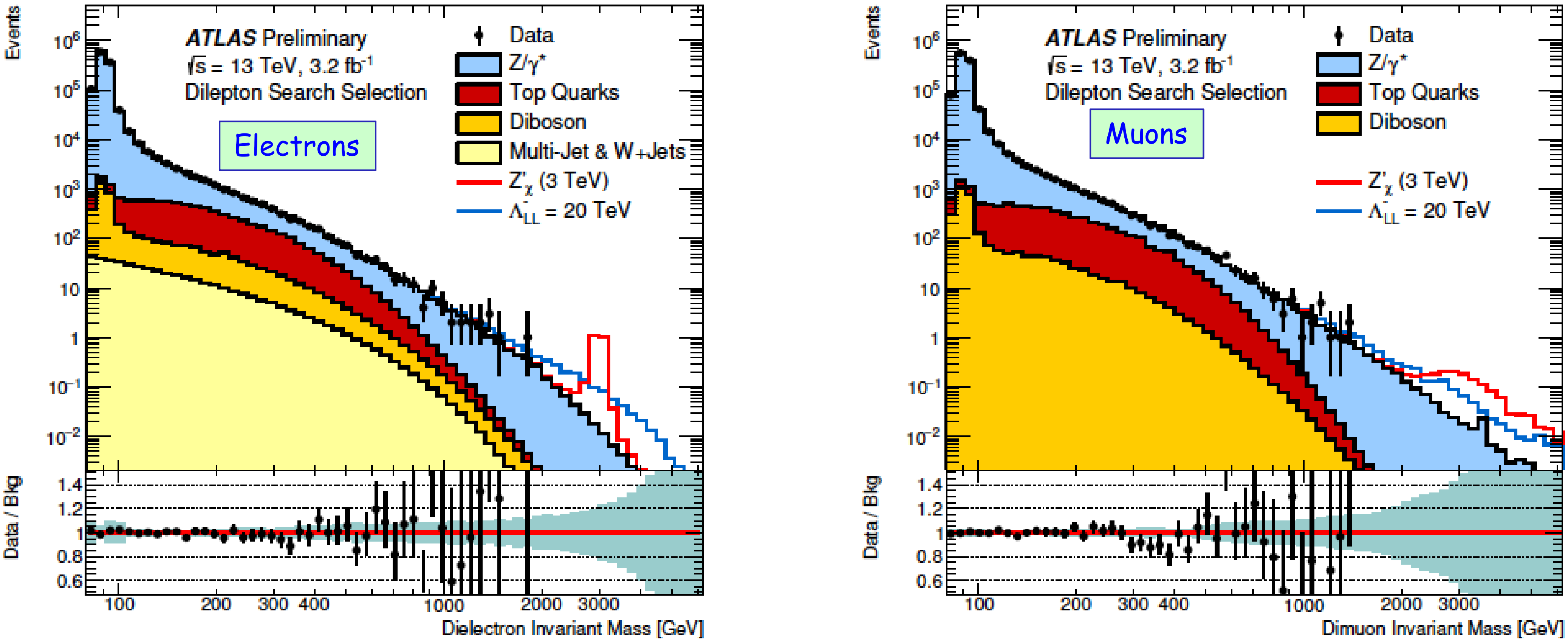


ATLAS μ-pair signal



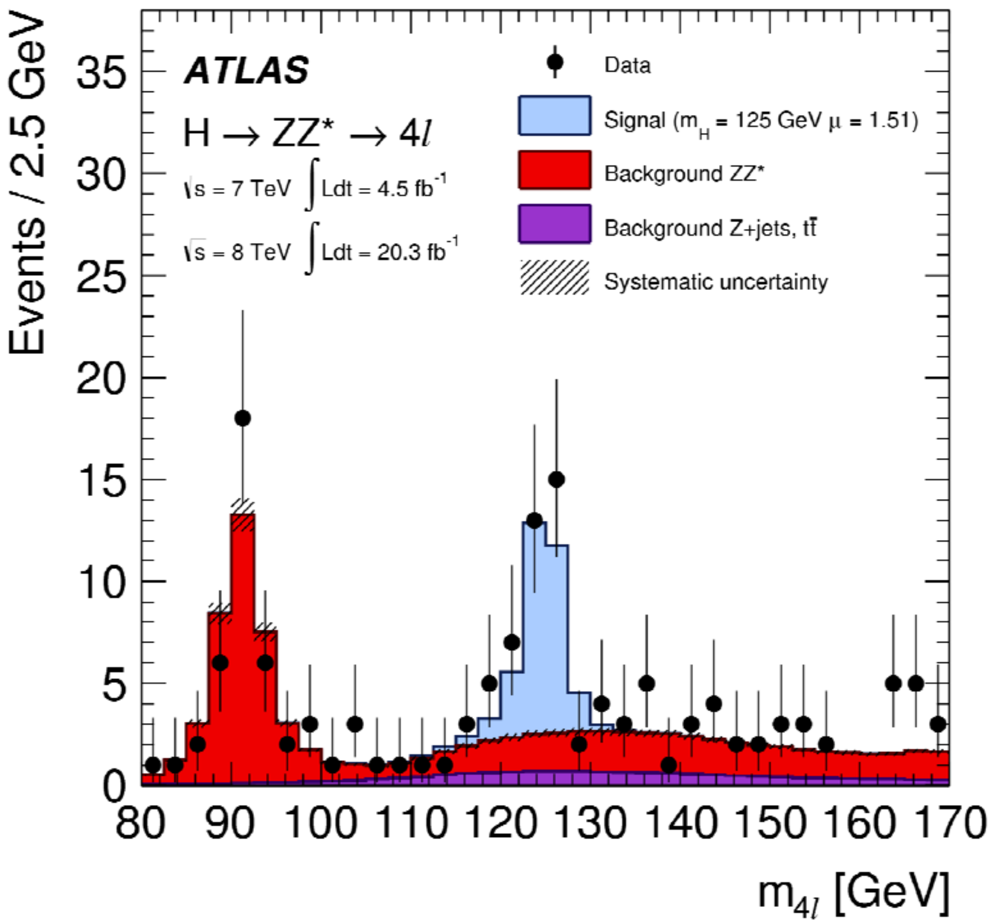
- uncorrected mass spectrum (distorted by trigger)
- data from ~2 hrs of operation at current luminosities

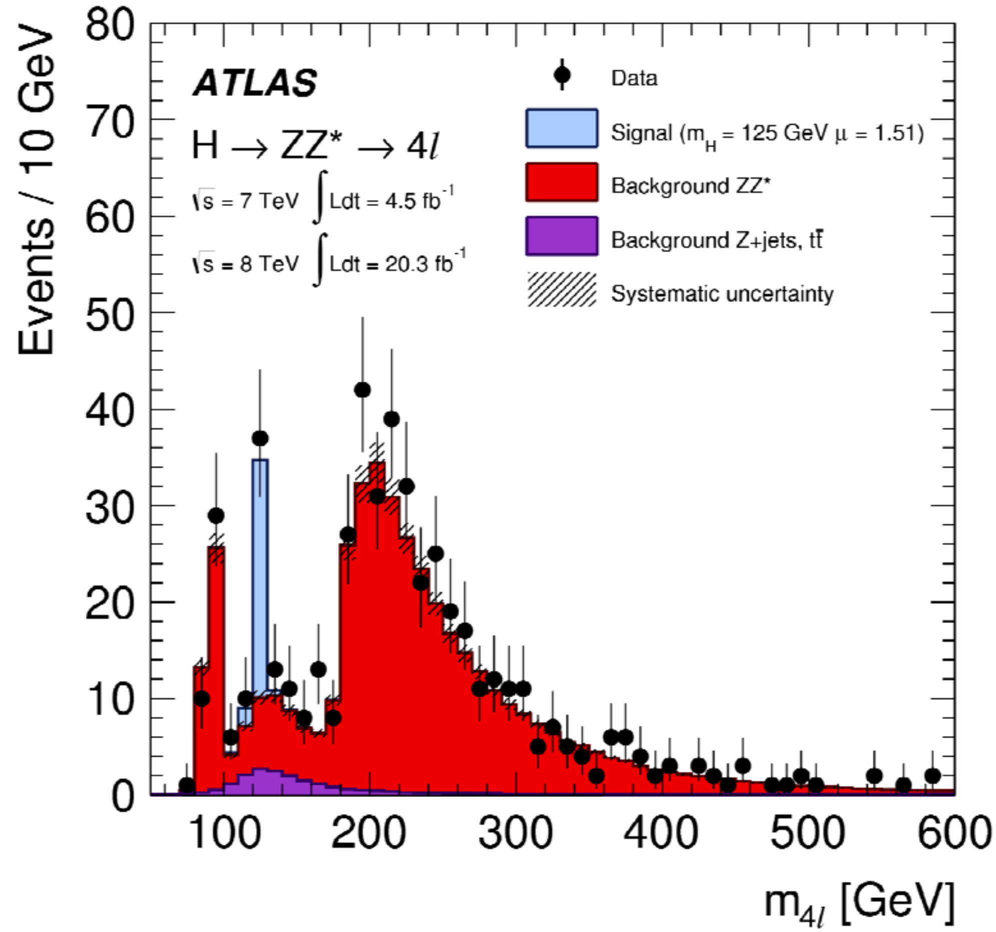
ATLAS Drell-Yan mass spectrum



- spectral shapes very well understood
- no new mass enhancements seen
  - $M_{Z'} > 3.4$ TeV (with SM couplings)
- mass scale of any "contact" interactions distorting the spectrum
  - M > 16 TeV

An ATLAS signal instead of a limit





- the Higgs decay mode with the lowest background
  - signal is also small because of the Z branching ratios to leptons
  - ~26 events on a background of 10 events from Run 1 data
- excellent information on the Higgs mass
  - unlike $H \to W^+W^-$

Conclusions

- mu-pair physics is still alive and well
- the environment has evolved
  - 15 years to plan and build the detector
  - ~$1B to be assembled
  - ~3000 people involved
- the style has evolved
  - no stone is left unturned
- the performance of the detector and analysis environment is outstanding
  - very powerful simulation tools
    - accurate physics generators for most processes
    - full simulation of particle interactions in the detector material
    - massive computing environment
- now embarked on Run 2 at 13 TeV
  - physics beyond the lightest Higgs boson?