SUSY 09

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North-Eastern University
Boston
5th - 10th June 2009

- SUSY Higgs
- Jet Algorithms
- Pamela

Conference Overview

- 400 people
- 4 days plenary
  - ~40 plenary talks
- 2 days parallel
  - ~160 parallel talks
  - I could go to 20.
- My impressions:
  - Too many string theorists
  - Not enough SUSY data
  - But quite a good review of particle physics for all that
  - And good to listen to serious SUSY phenomenologists

Keith Dienes put it well:

Despite initial appearances...

...analyzing the vacuum structure of a given model is relatively easy.

Keith Dienes put it well:

Consider the scalar potential

$$V = \frac{1}{2}\sum_a g_a^2 D_a^2 + \sum_i |F_i|^2$$

where

$$D_a = \xi_a + \sum_i q_i^{(a)} |\phi_i|^2 , \qquad F_i = -\frac{\partial W^*}{\partial \phi_i^*}$$

Extrema are located at locations in field space where

$$\frac{\partial V}{\partial \phi_i} = 0$$

U(1)'s are broken if charged fields get a vev.

To understand *stability* properties of extrema, calculate (mass)^2 matrix

$$\mathcal{M}^2 \equiv \begin{pmatrix} \frac{\partial^2 V}{\partial \phi_i^* \partial \phi_j} & \frac{\partial^2 V}{\partial \phi_i^* \partial \phi_j^*} \\ \frac{\partial^2 V}{\partial \phi_i \partial \phi_j} & \frac{\partial^2 V}{\partial \phi_i \partial \phi_j^*} \end{pmatrix}$$

Diagonalize. At extremum, will have one zero eigenvalue (Nambu-Goldstone boson) for each broken U(1). Remaining eigenvalues describe extremum...

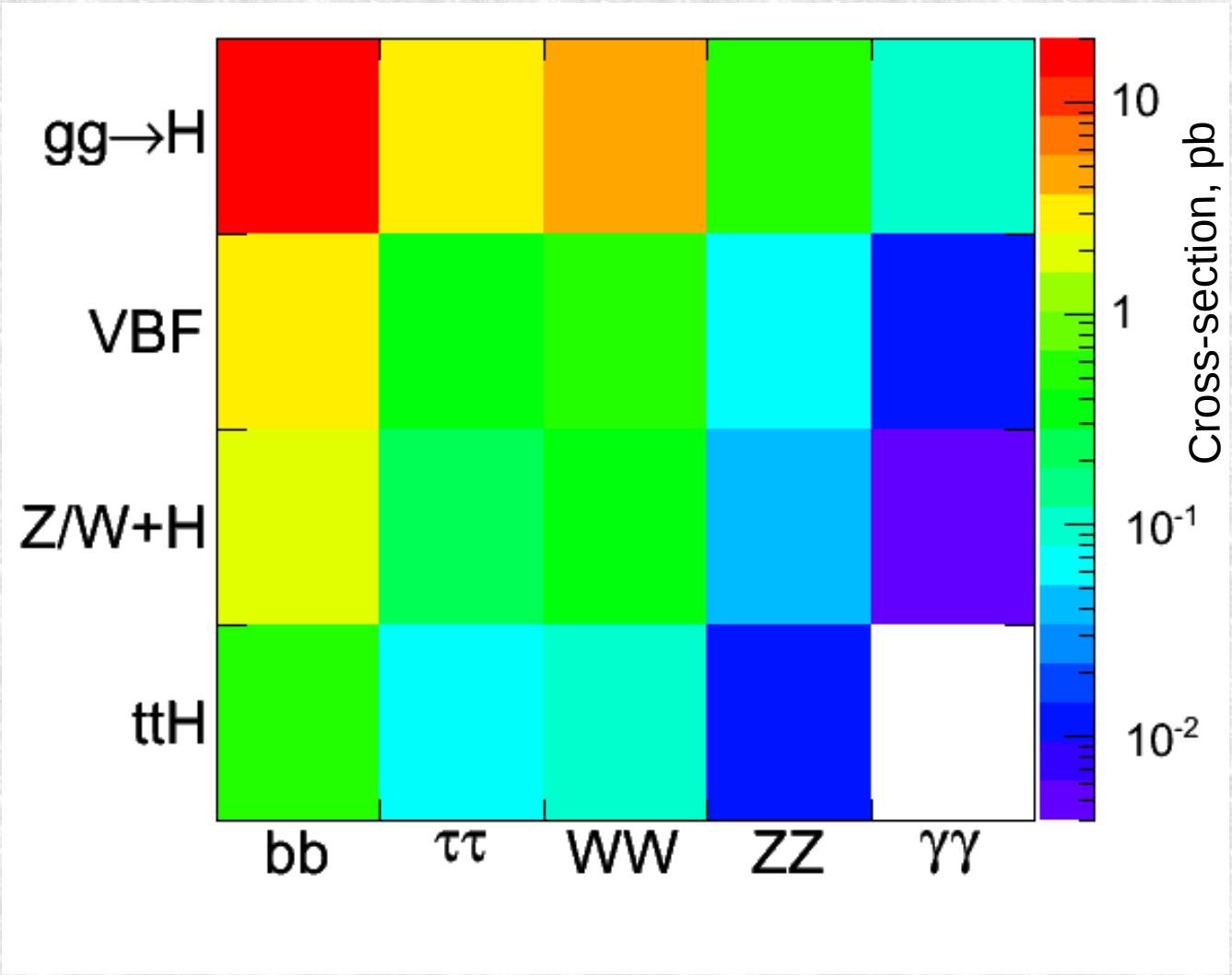
- **Stable vacuum** if all other $m^2 > 0$
- **Unstable** if at least one $m^2 < 0$
- **Flat direction** if at least one additional $m^2 = 0$.

Metastability occurs if two or more stable vacua emerge; true ground state has minimum V.

The Higgs

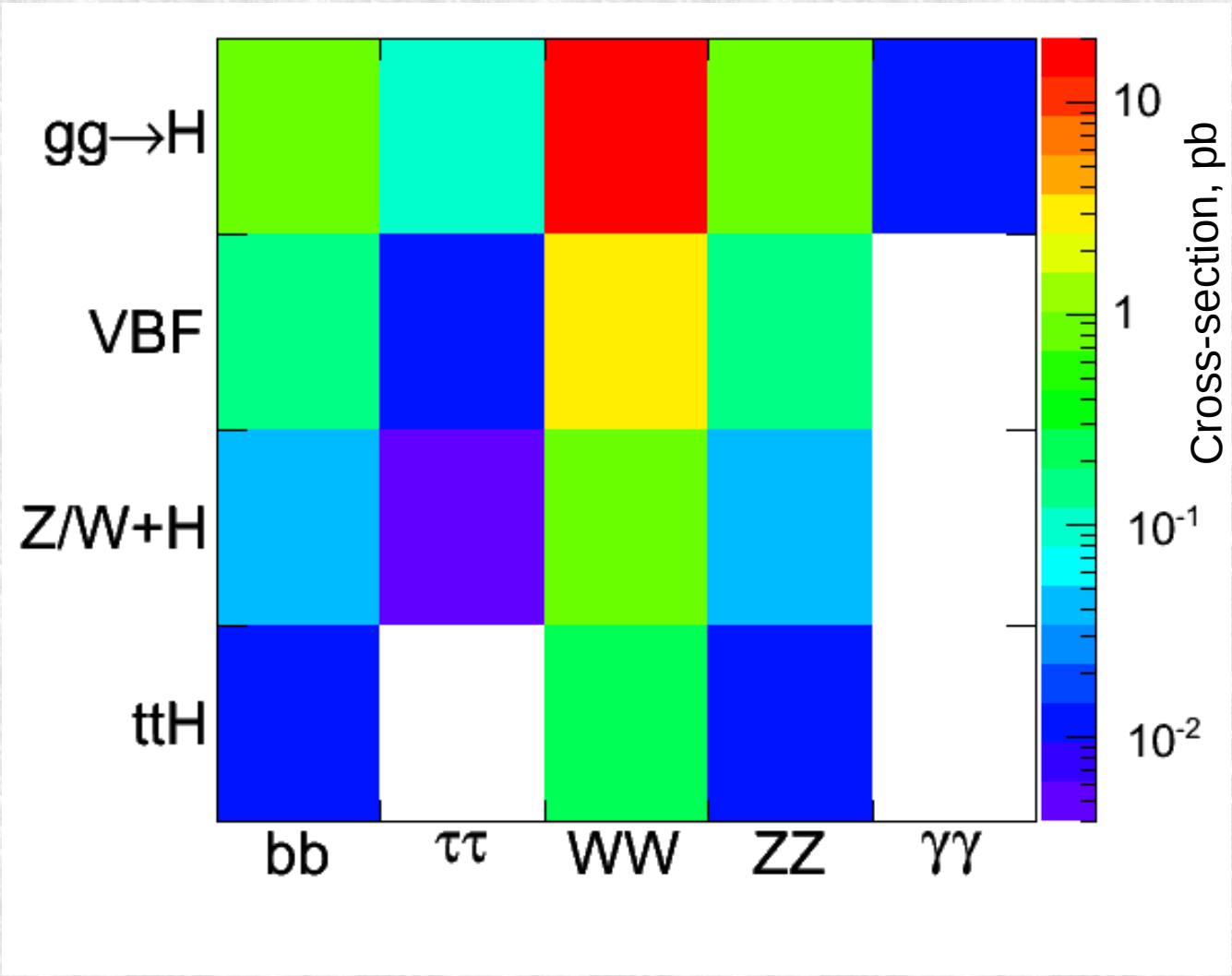
- A SUSY conference is a good place to find the Higgs
  - SUSY theorists will get very nervous if a Higgs below 130GeV is wiped out.
- Covered:
  - LHC expectations
  - TeVatron limits – Volker Buscher nice overview
  - Theoretical developments
- There was a review of the first two, here, a few months back

LHC: Higgs rates: m_H=120GeV



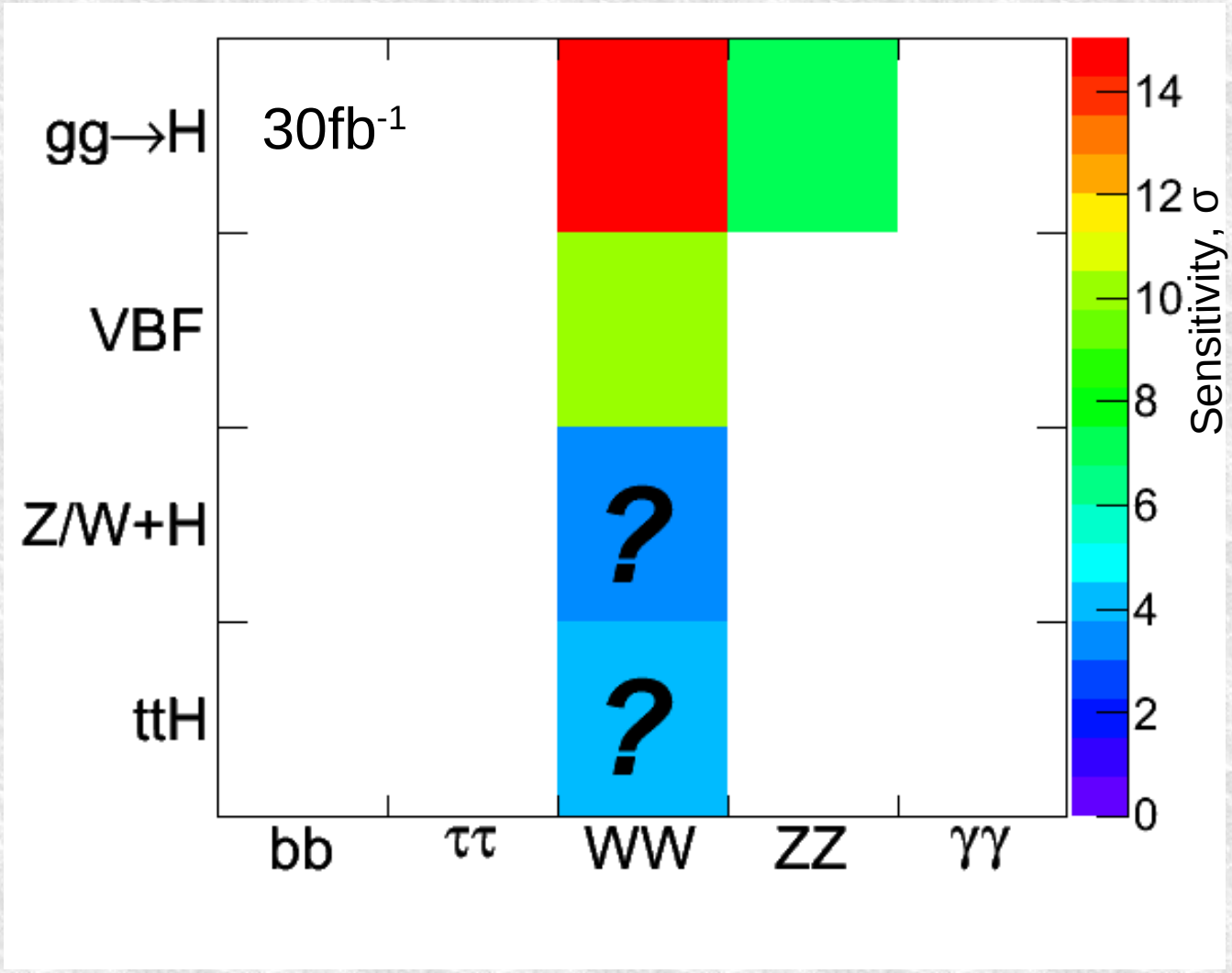
- Cross-section times branching ratio in channels examined

LHC: Higgs rates: m_H=160GeV

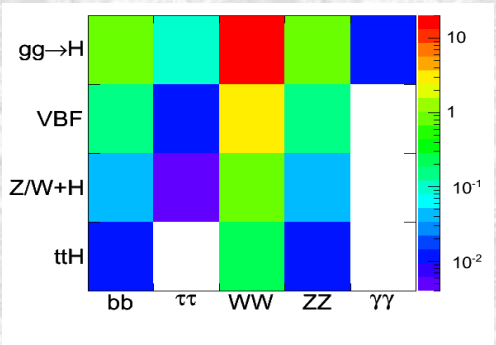


- Cross-section times branching ratio in channels examined
  - WW dominates
  - ZZ similar
  - Others fall

ATLAS: Sensitivity: m_H=160GeV

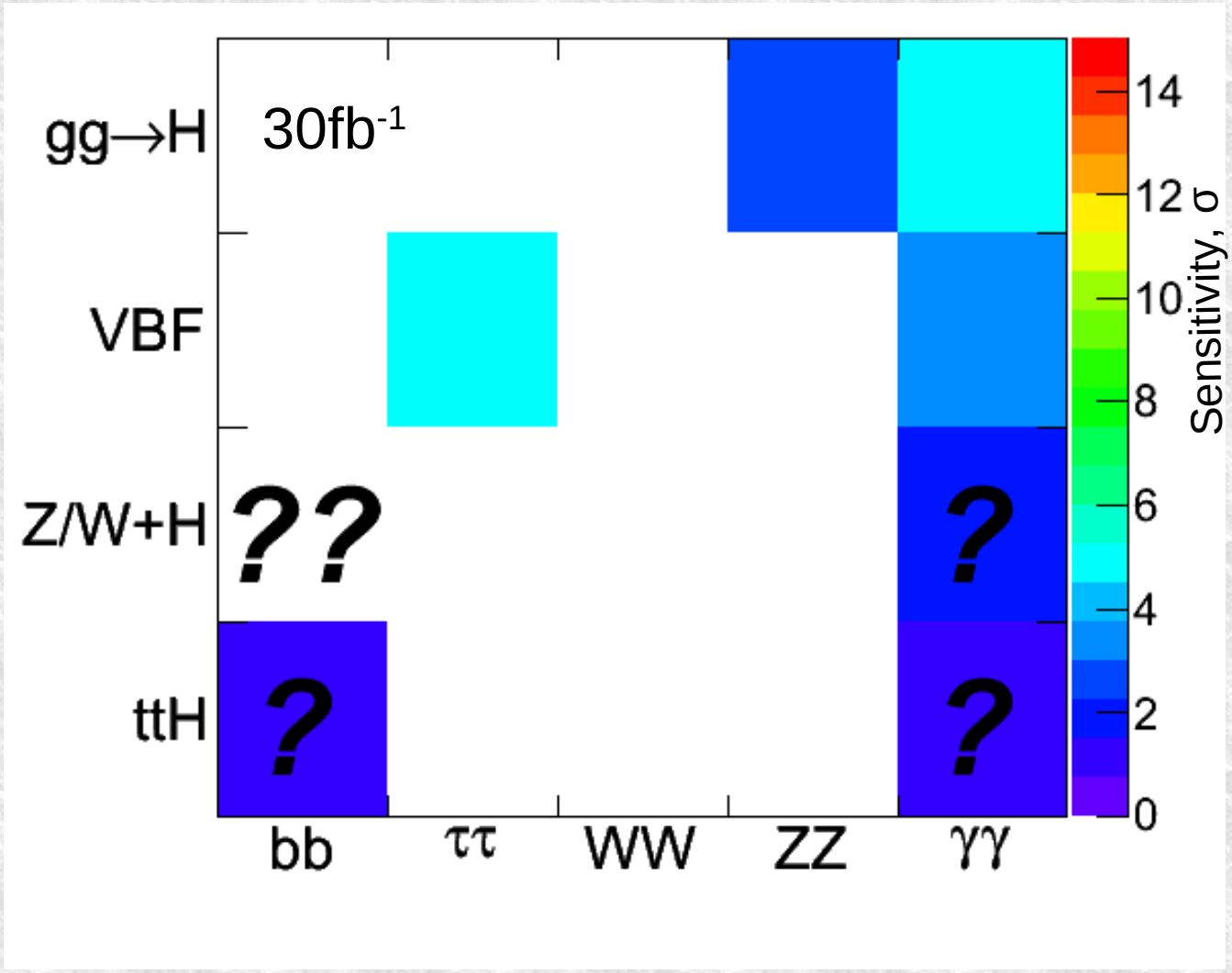


- '?': my estimate.
- ZZ VBF surely possible too
- Cross-sections mimic sensitivity



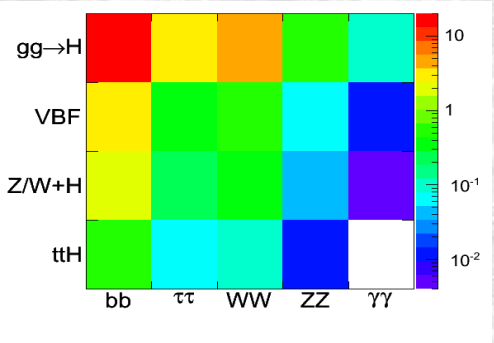
From CERN-OPEN-2008-020

Higgs sensitivity: m_H=120GeV



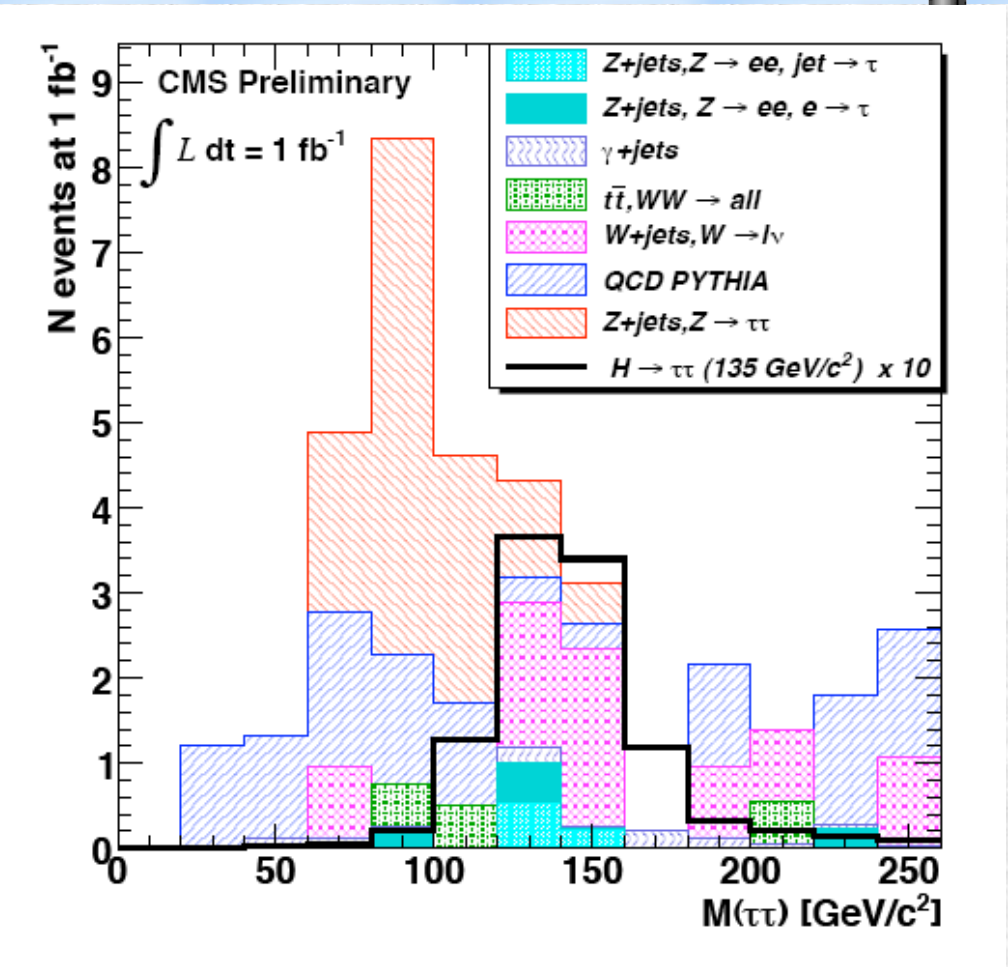
From CERN-OPEN-2008-020

- '?': my estimate.
- '??' for VBF H→bb, currently under study.
- ττ VBF isolated
- Several weak



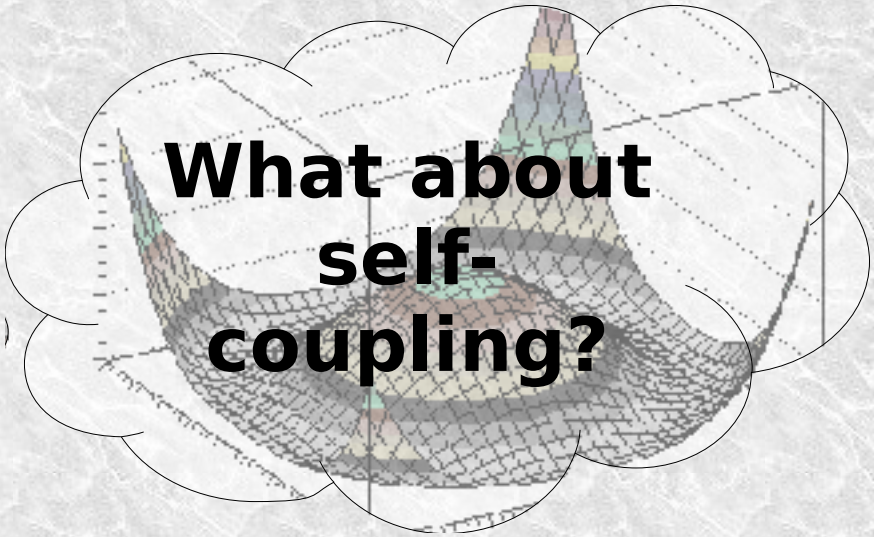
CMS (Marinelli): $\tau^+\tau^-$ in VBF

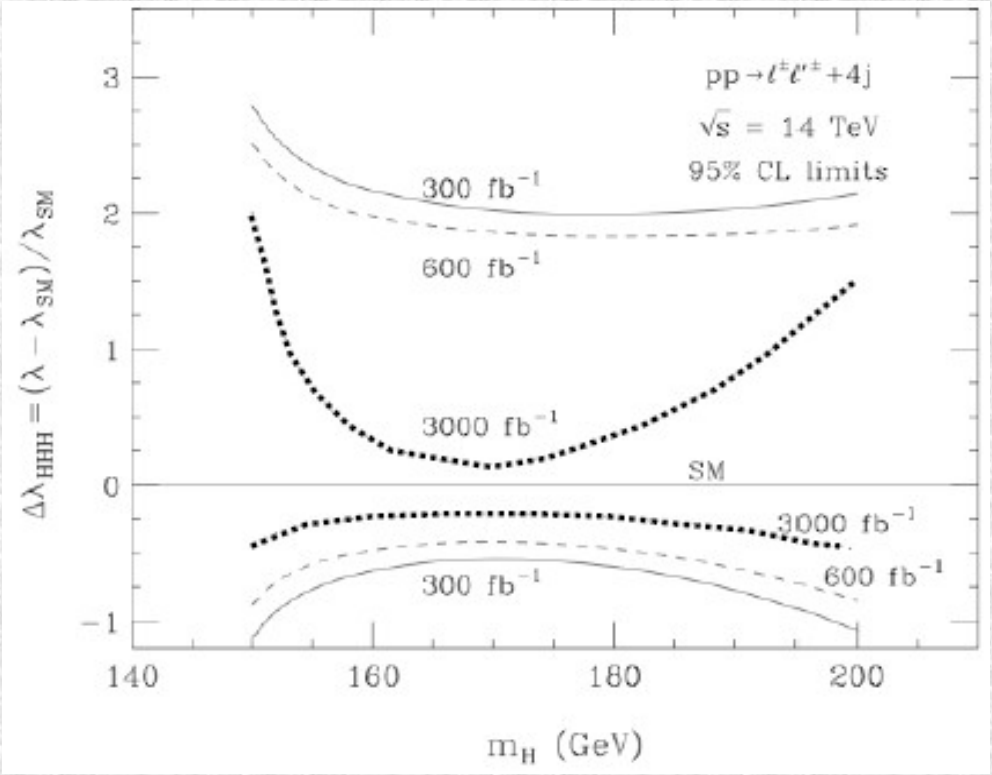
- 1fb^{-1} "early data"
- CMS H →ττ has tuned the selection to allow in maximum rate
  - and background
- This is based upon trying to make a limit -
  - Which will be 10 times SM anyway
- Why are we not preparing for discoveries?



Higgs self-coupling

- Very desirable test of the theory
  - Quartic self-coupling drives VeV

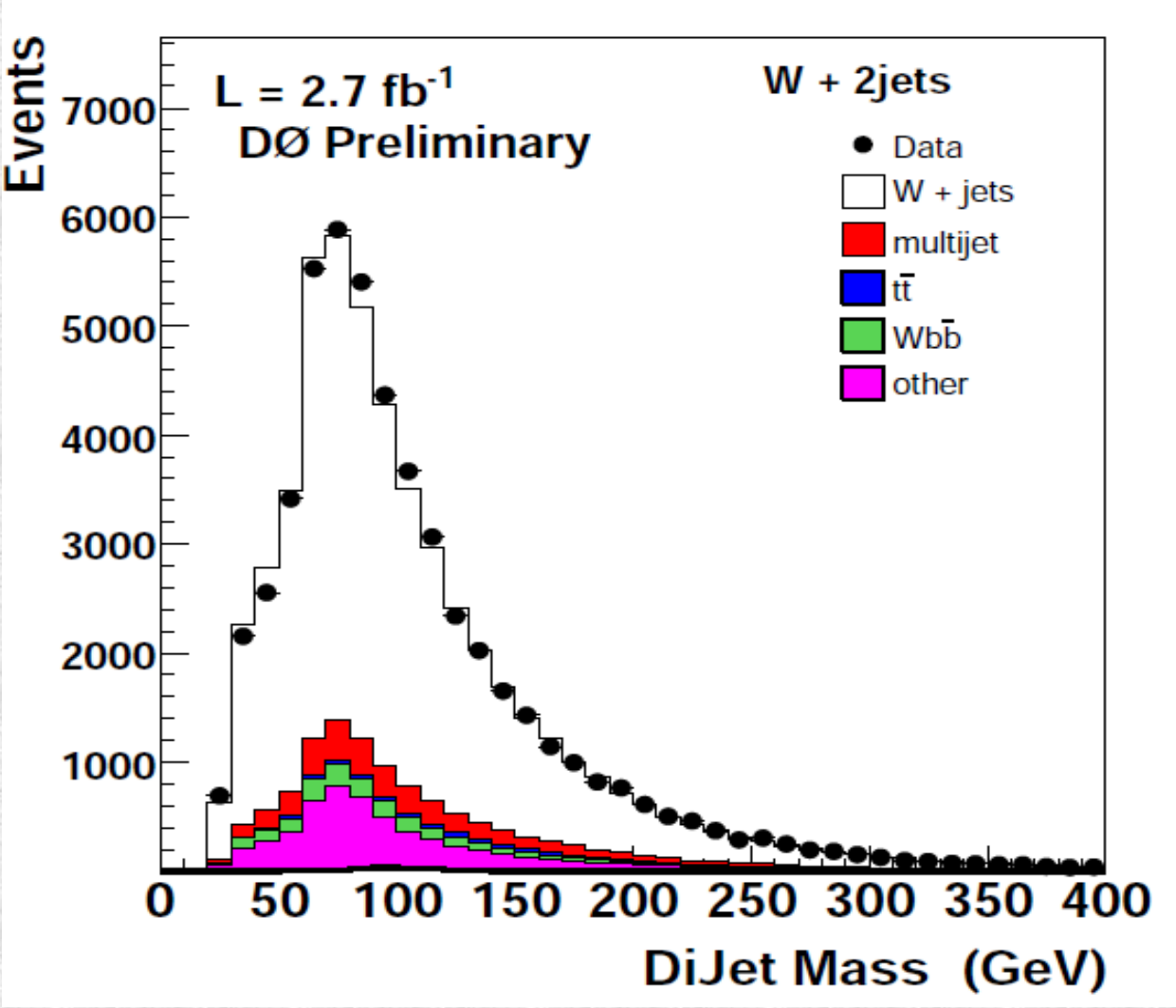




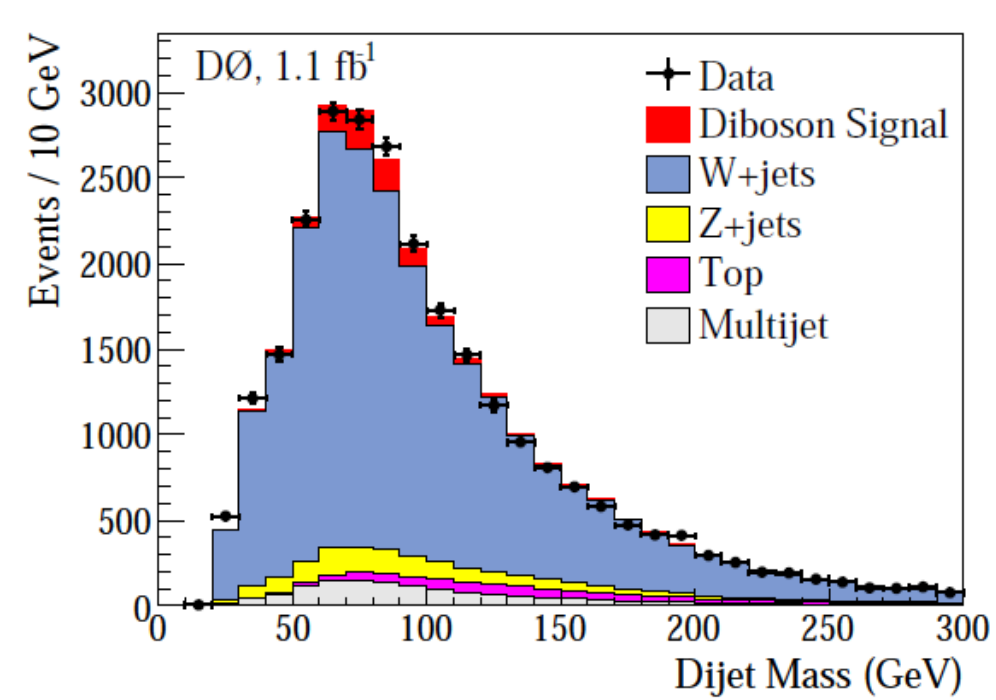
- Extremely challenging
  - SLHC required, plus luck
- hep-ph/0304015 finds 160-180GeV plausible
  - No pileup, fast-sim, backgrounds look low
  - Now ~ excluded!

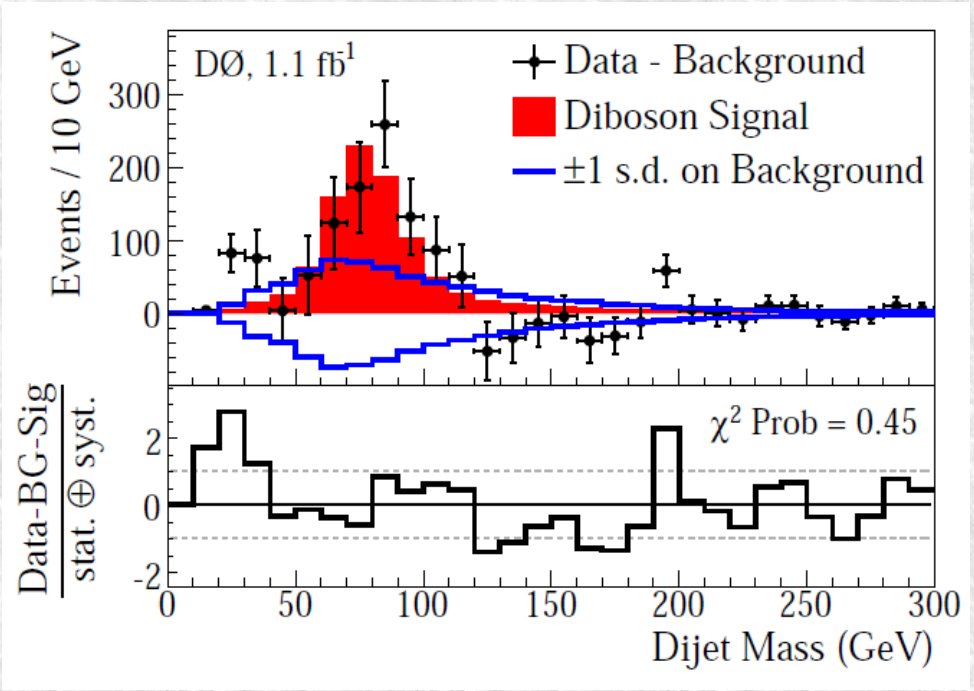
TeVatron Higgs

- D0 $W\bar{j}j$ spectrum
- First step toward $W\bar{b}b$ to look for a light $H\rightarrow b\bar{b}$



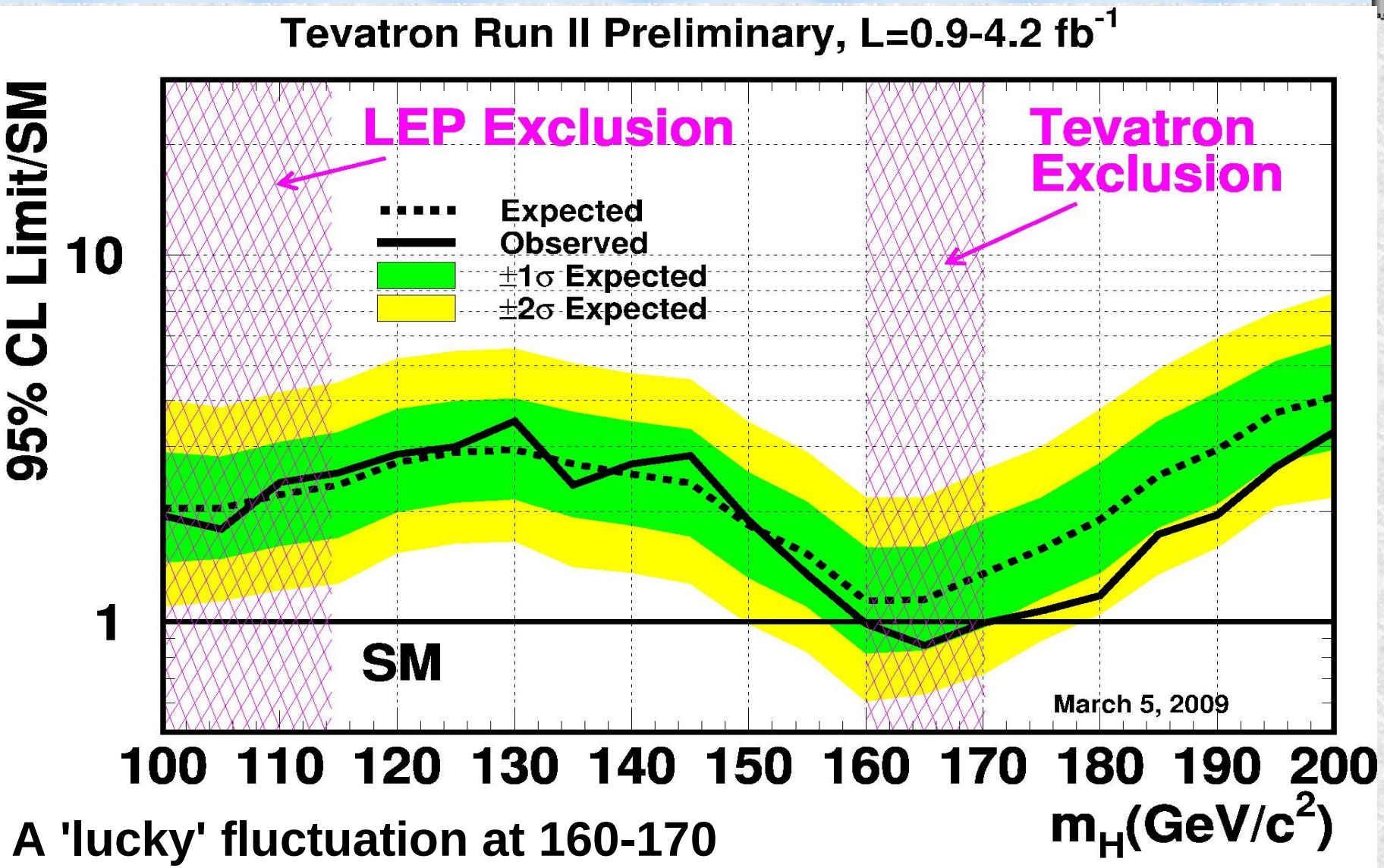
D0 WZ signal





- Wjj includes WZ.
- Diboson peak 4.4σ
  - Is rising edge under control?

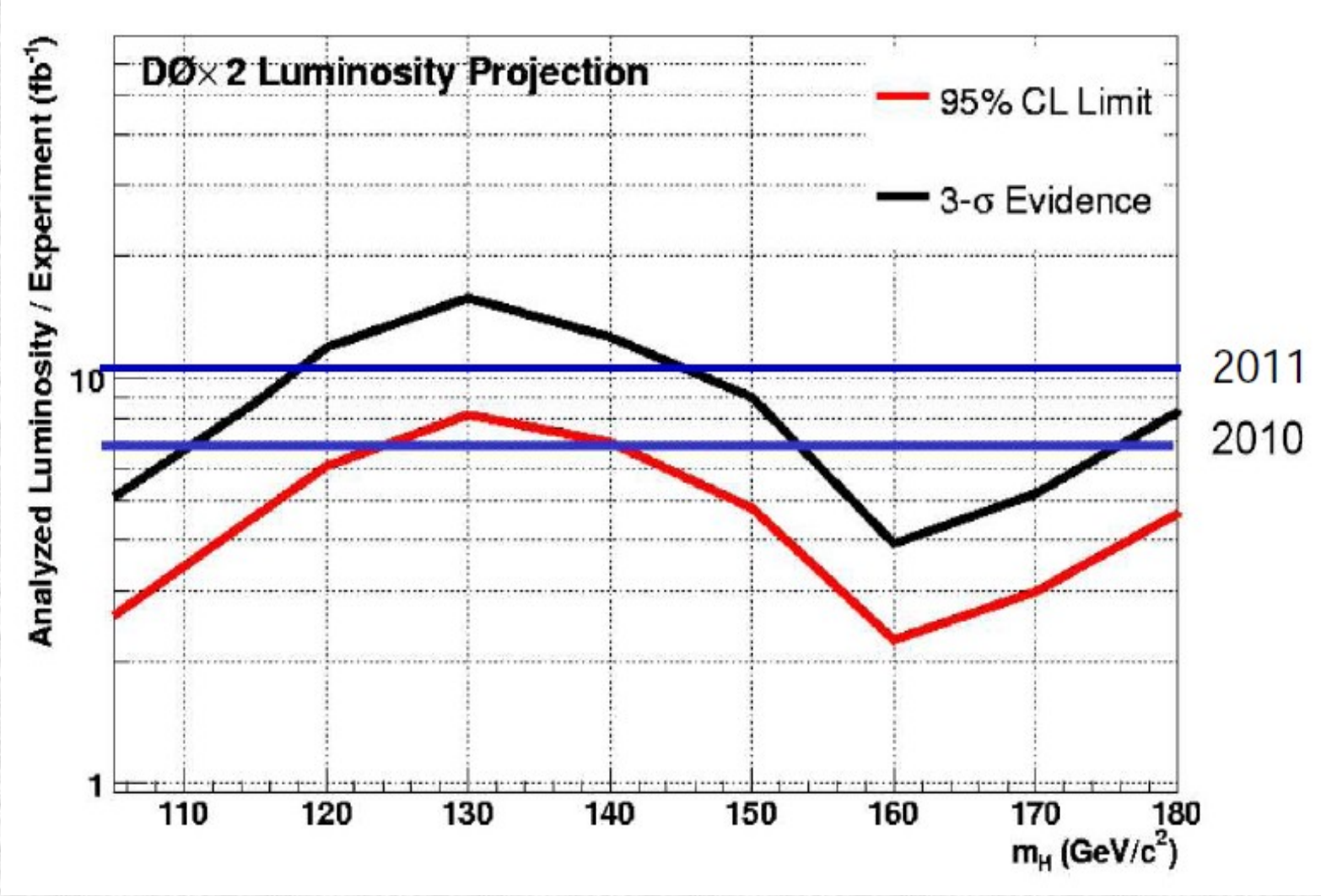
Tevatron Higgs Combination



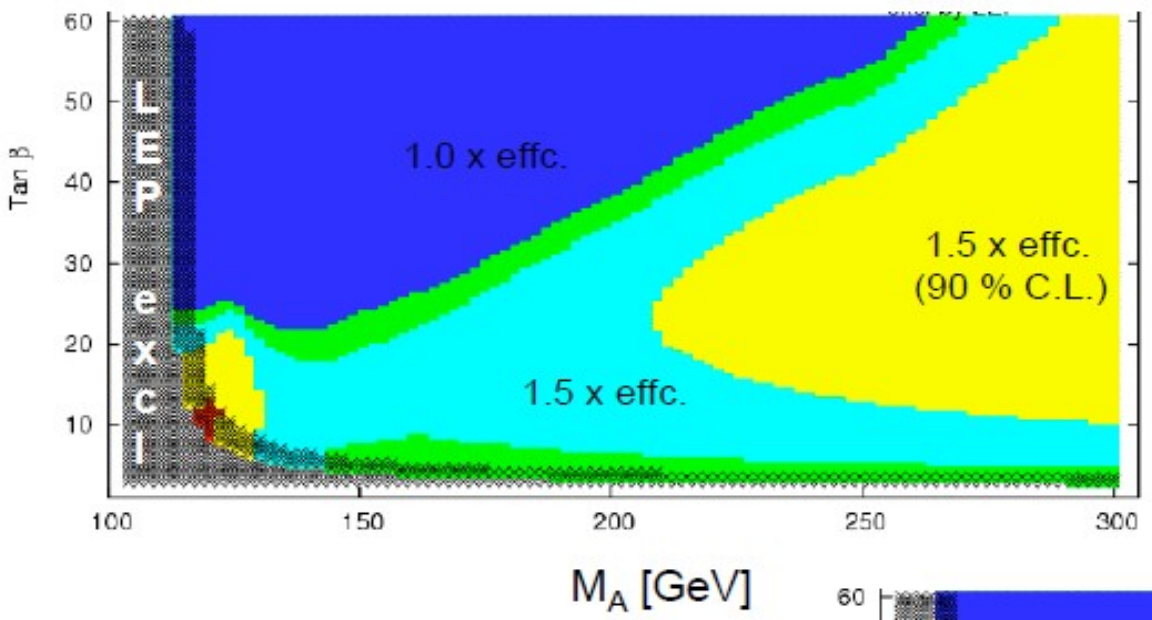
A 'lucky' fluctuation at 160-170

Projection

- Factor ~2 sensitivity assumed
- No chance of discovery
- But exclusion of SM Higgs
  - And SUSY?

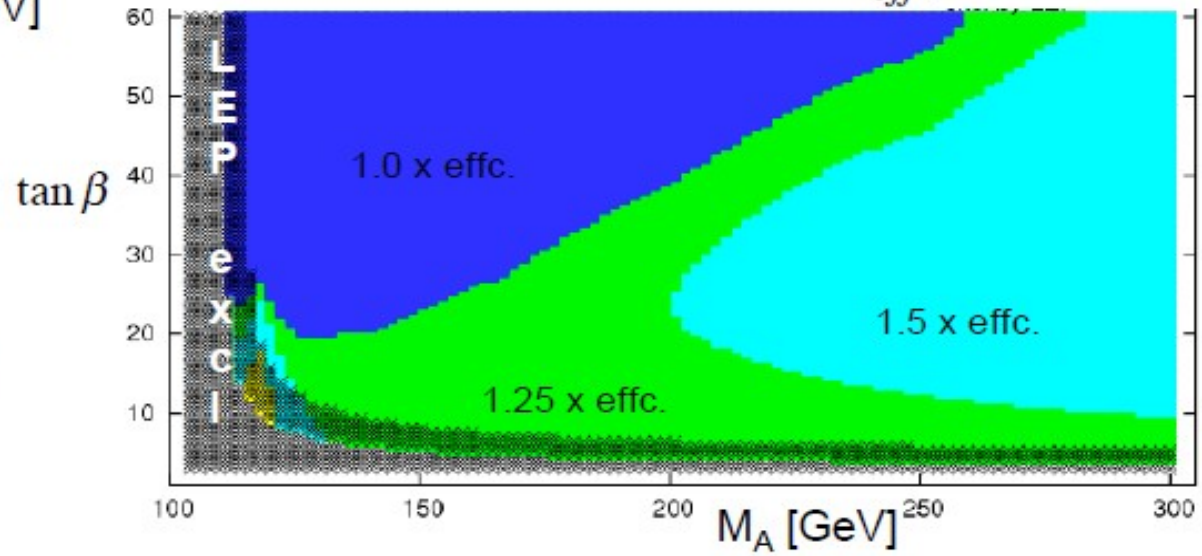


SUSY Higgs: Marcela Carena



M_h^{max}. Scenario

Small $\sin\alpha_{eff.}$ scenario



All channels combined
both exp. and for 10 fb^{-1}

MSSM Higgs

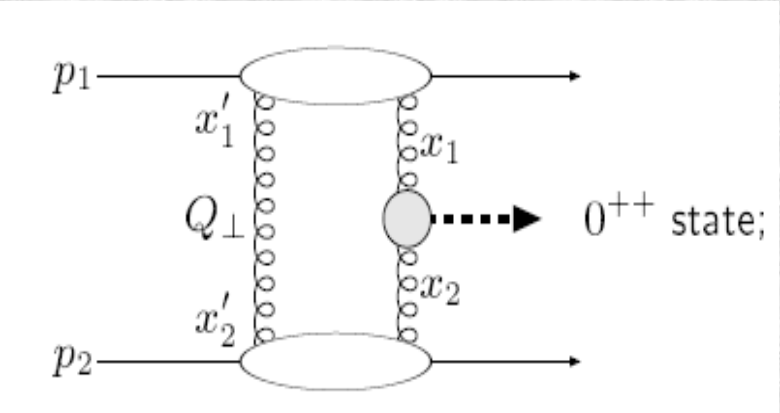
- LEP benchmarks cannot all be excluded
- But some of them will be
  - If the analyses still improve
  - And there are no nasty bumps in the data
- These are essentially from the lightest Higgs

CPX

- Nice talk on calculations of x0 in this
- Challenge: 40GeV h1 decaying bb.
- Decay chain of gluino with χ0 and h to bb, and jets.
- Caleb's q's:
  - Vary mu in the tan-beta mA exclusion plane
  - Why does mA limit go 200GeV higher in CMS at tan-beta=50 (800 c/f 600)

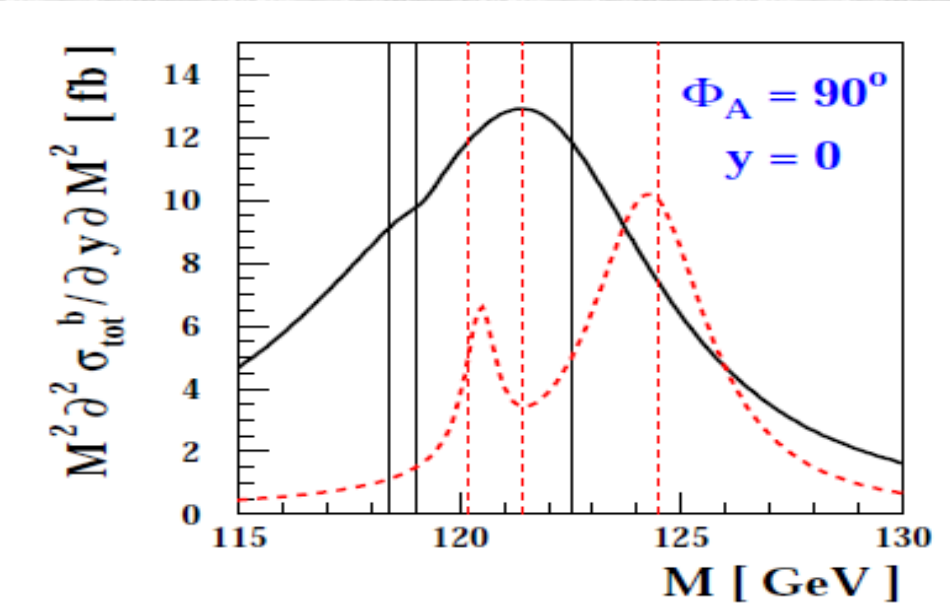
CP violation in SUSY Higgs

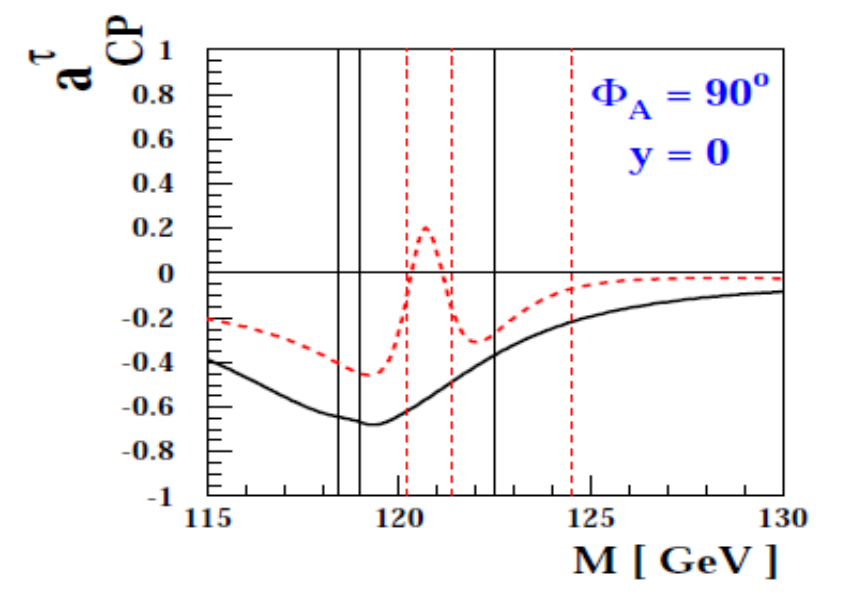
- Apolstalos Pilaftsis
- 3 Higgs h, H, A → H_1, H_2, H_3
  - Introduce via loop corrections
  - LEP holes should be reduced by D0 analysis
- Diffractive Higgs production might allow separation of H_2, H_3 and analysis of CP asymmetries



Tag outgoing intact protons
Reconstruct centre-of-mass energy
FP420 and friends
(Up for review in ATLAS next week)

CP Higgs diffractivly





- Vertical lines are pole masses
  - a^{τ} is σ_{rr} - σ_{ll}
  - Red/black different phases
- This used to be muon collider territory!
- J. Ellis, J.S. Lee, A. Pilaftsis PRD71(2005) 075007.

Elusive light CP-violating Higgs bosons at LEP2

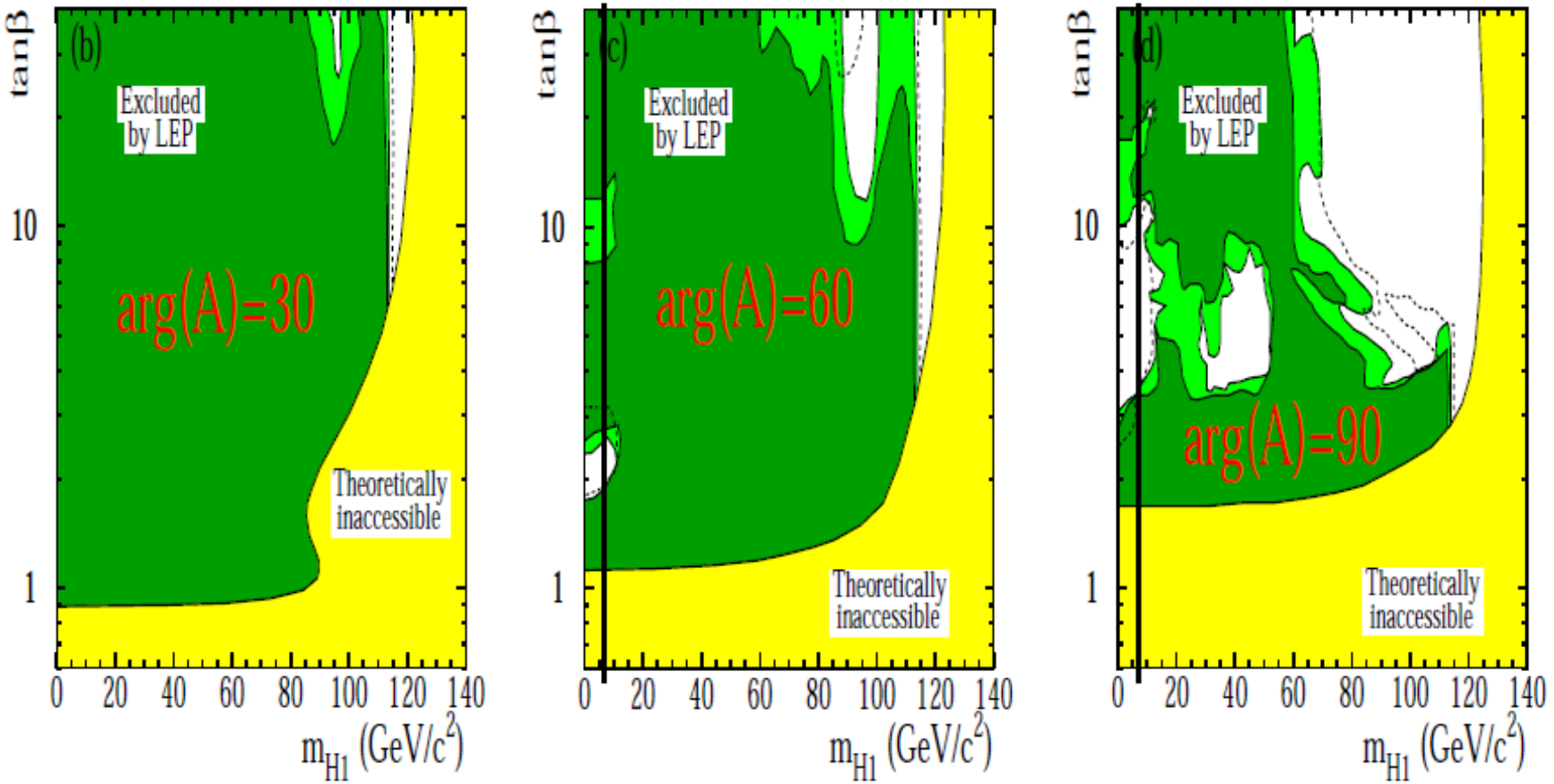
CPX scenario: $\mu = 4\, M_{\rm SUSY}\,, \quad A_{t,b} = 2\, M_{\rm SUSY}$

[M. Carena, J. Ellis, A.P., C.E.M. Wagner, PLB495 (2000) 155.]

$m_t = 174.3$ GeV

D0

D0: arXiv:0905.3381 [hep-ex]

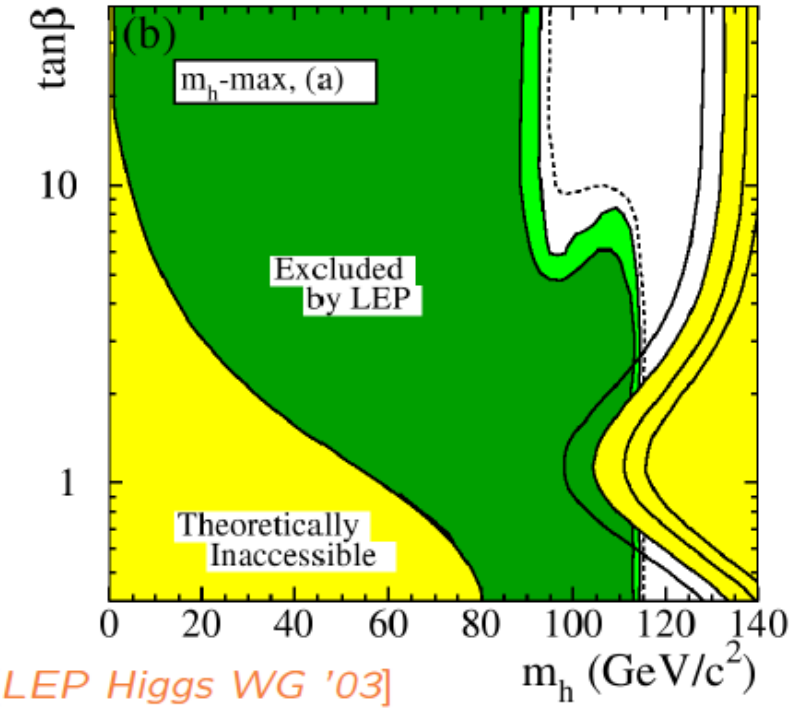


[Combined analysis from LEP collaborations, Eur. Phys. J. C **47** (2006) 547, uses CPsuperH + FeynHiggs]

Sven Heinemeyer: HiggsBounds

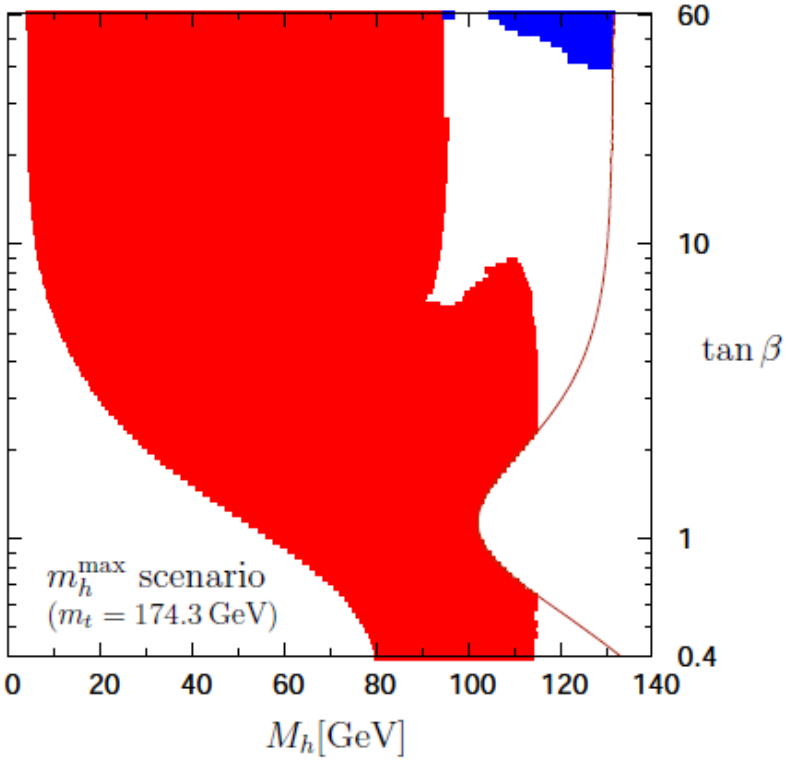
- http://www.ipp.dur.ac.uk/HiggsBounds
- Answers the question: Is my boson excluded?
  - Can feed in new theory or new data

LEP bound (m_h^{max})



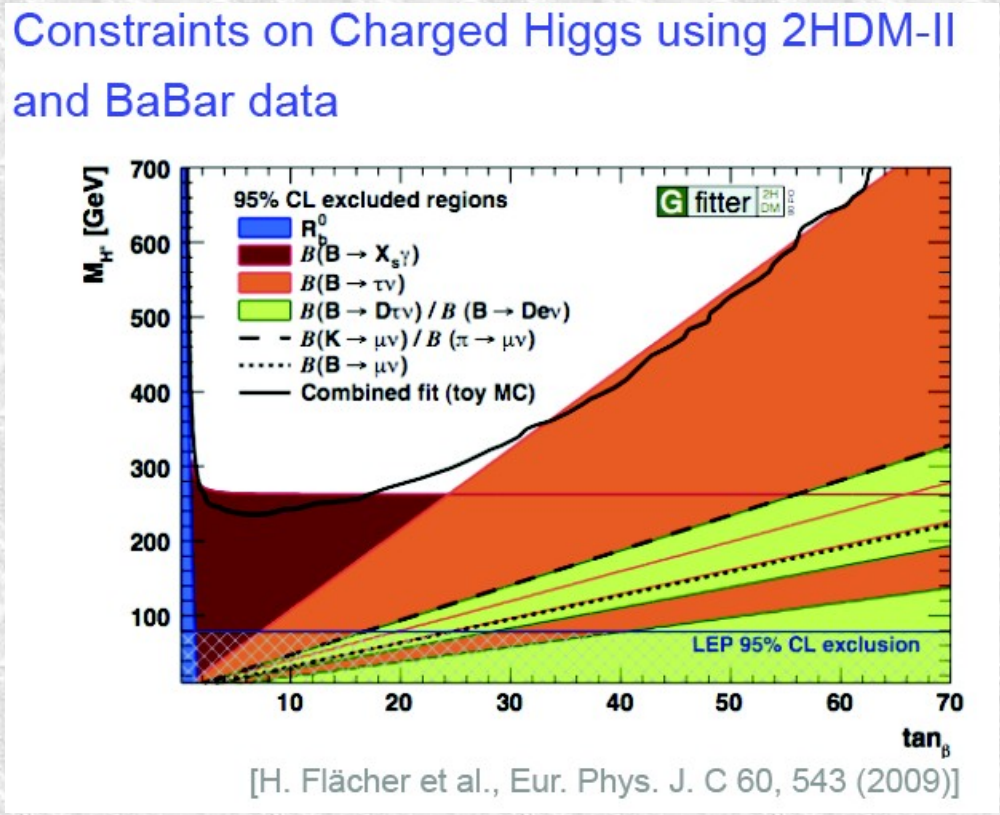
[LEP Higgs WG '03]

HiggsBounds result



B decays and SUSY

- De Sangro review
- B to τυ
  - New results from Moriond,
- B to eυ/μυ
- B to sγ
- Combined H^+ limit
  - 280GeV
  - More for large tan β

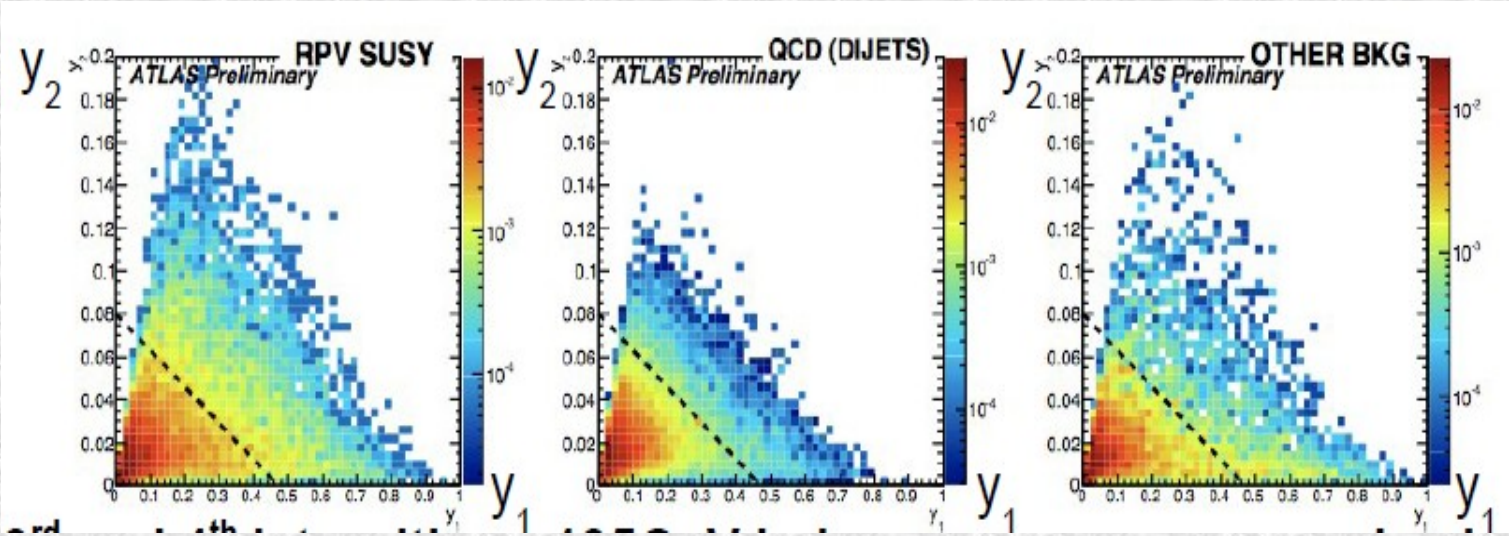


Jet Analysis

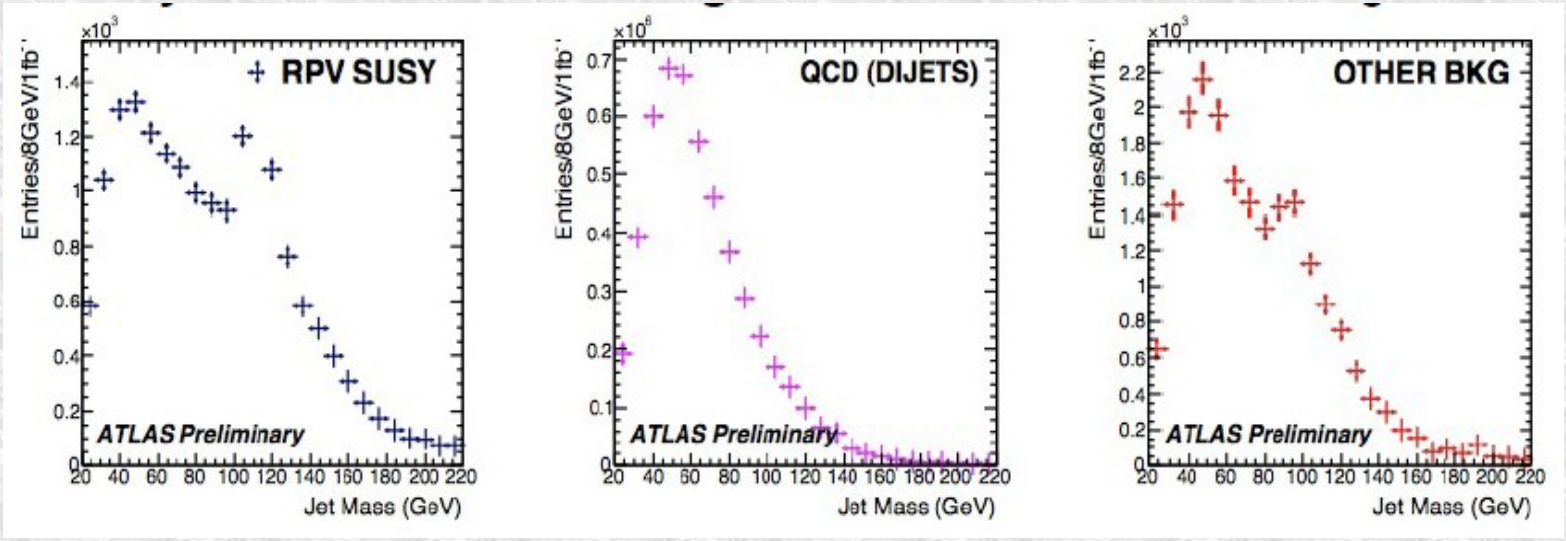
Jet Substructure – Sky French
Variable R jets – David Krohn

RPV via jet substructure

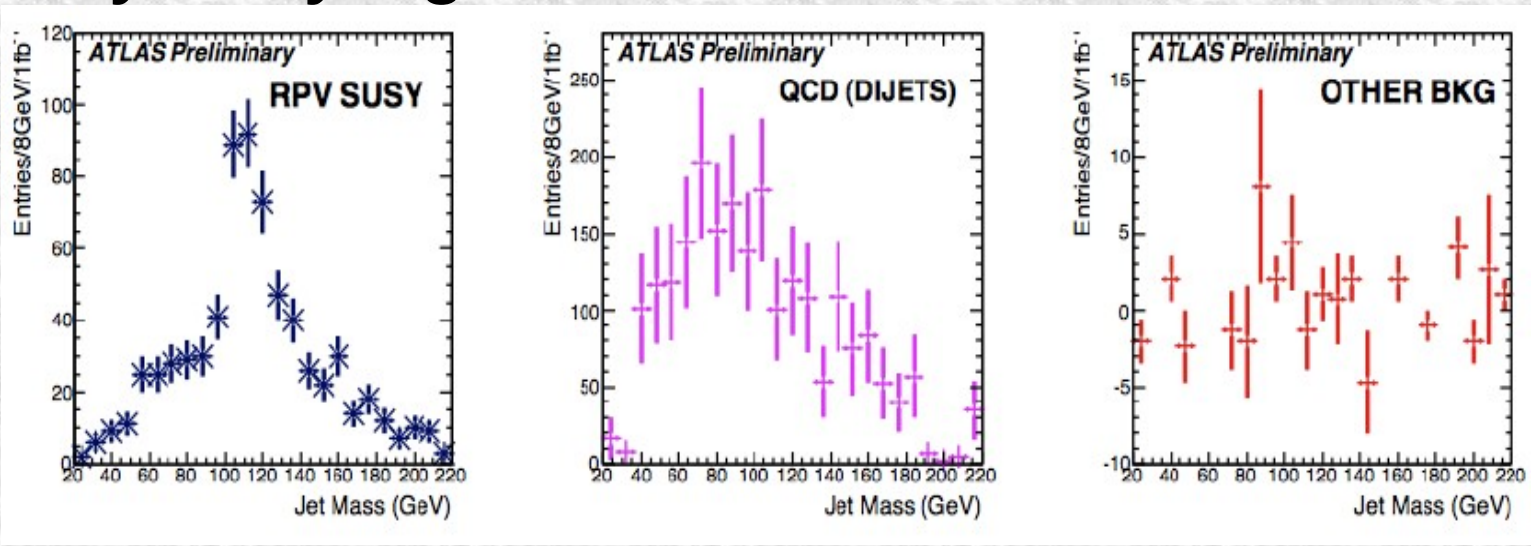
- Sky French – LSP decays to 3 jets
- Look for boosted LSP, all 3 jets merged
- Plot jet mass
- Now look at substructure:
  - k_T algorithm uses: $y=d_{kl}/m^2$
  - Find y1, y2, from last two splitting
  - Cut on these to select signal



RPV via substructure



- Cut on y1 & y2 gives:

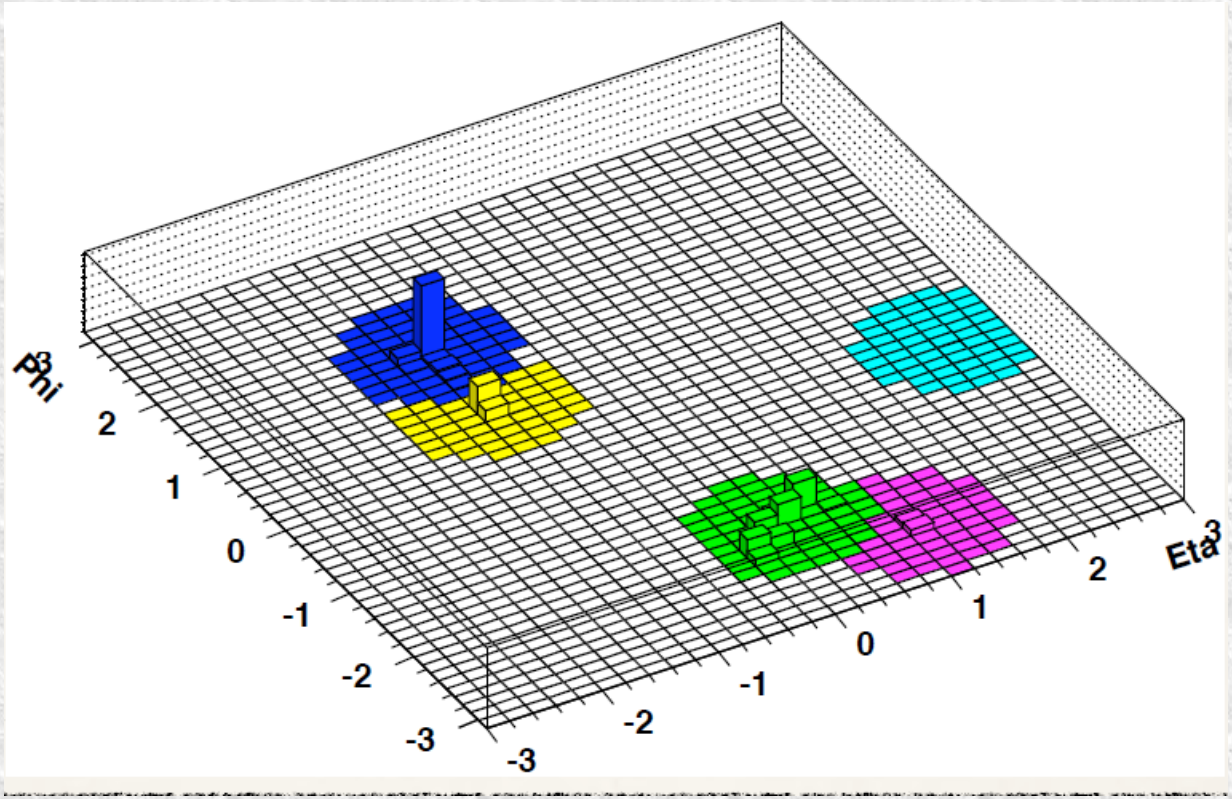


Variable R jets

- Jet algorithms much in discussion
  - Cone algorithm used by ATLAS >10 years
  - Not IR safe
    - A soft emission can change jet results
    - Theoretical predictions not well defined
    - A Problem for TeVatron analyses?
- Many solutions:
  - k_T
  - Fast-k_T
  - Midpoint cone
  - Siscone
  - Anti k_T
    - ATLAS just adopted this as least-bad
- All have a fixed radius

Variable R jets

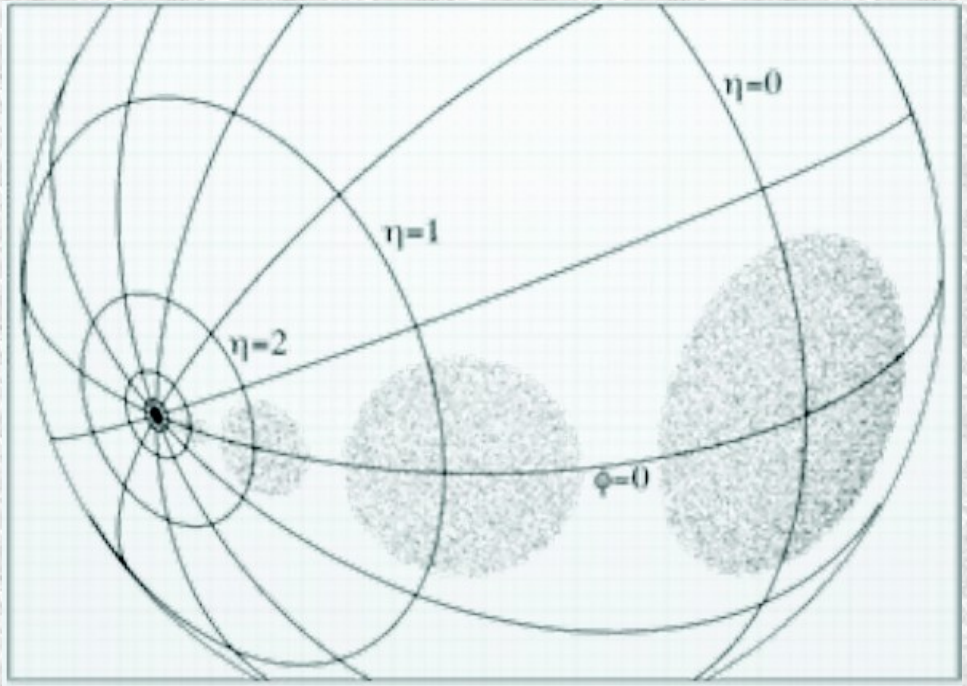
- Jet diagram in η-φ space



- This example is anti-k_T
- Existing pp($\bar{p}$) algorithms are all fixed radius

The problem with fixed R

- Fixed R is extremely variable in θ-φ space
- W →jet $\overline{\text{jet}}$ does not depend upon orientation
- But fixed R algorithms do.



By the way, I am really happy that OpenOffice 3.1 allows jet $\overline{\text{jet}}$ over-lining with one button

Proposed solution

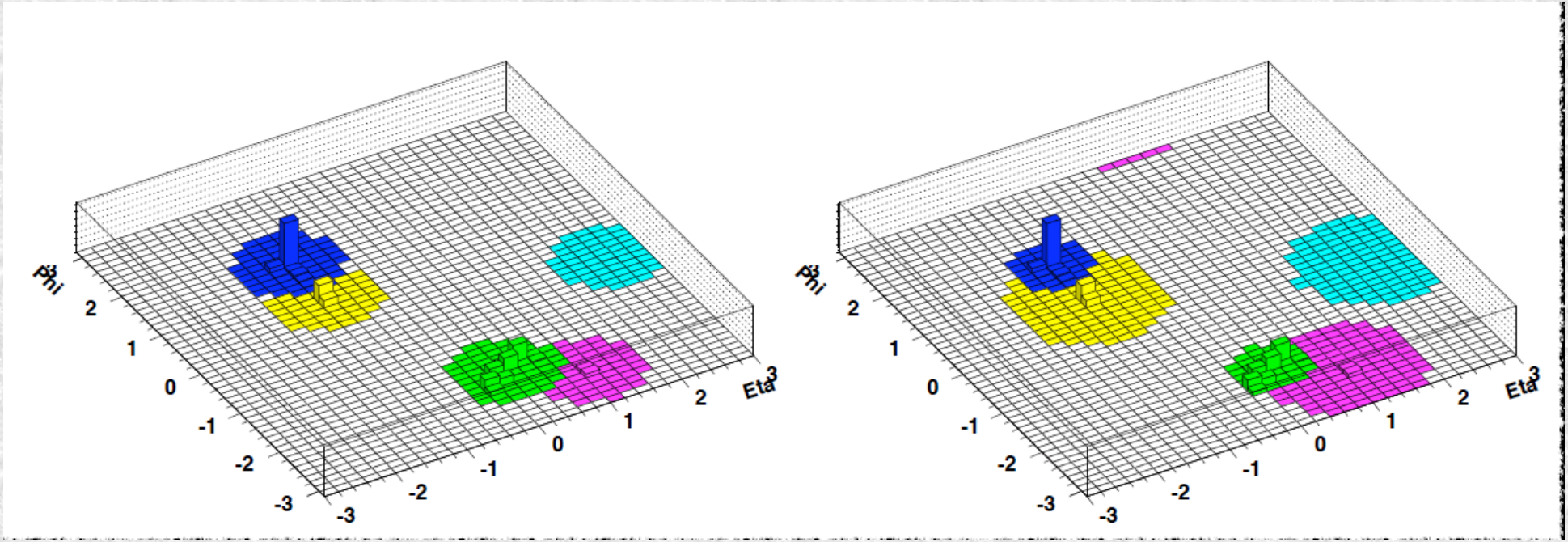
- A jet of given E and angular width, W, if rotated, will have variable p_T and R.

$$W/E \sim R/p_T$$

- So scale R with p_T
- If 'adjust' anti-kT, result is
  - boost invariant
  - IR safe
- See http://jthaler.net/VR
- arXiv:0903.0392

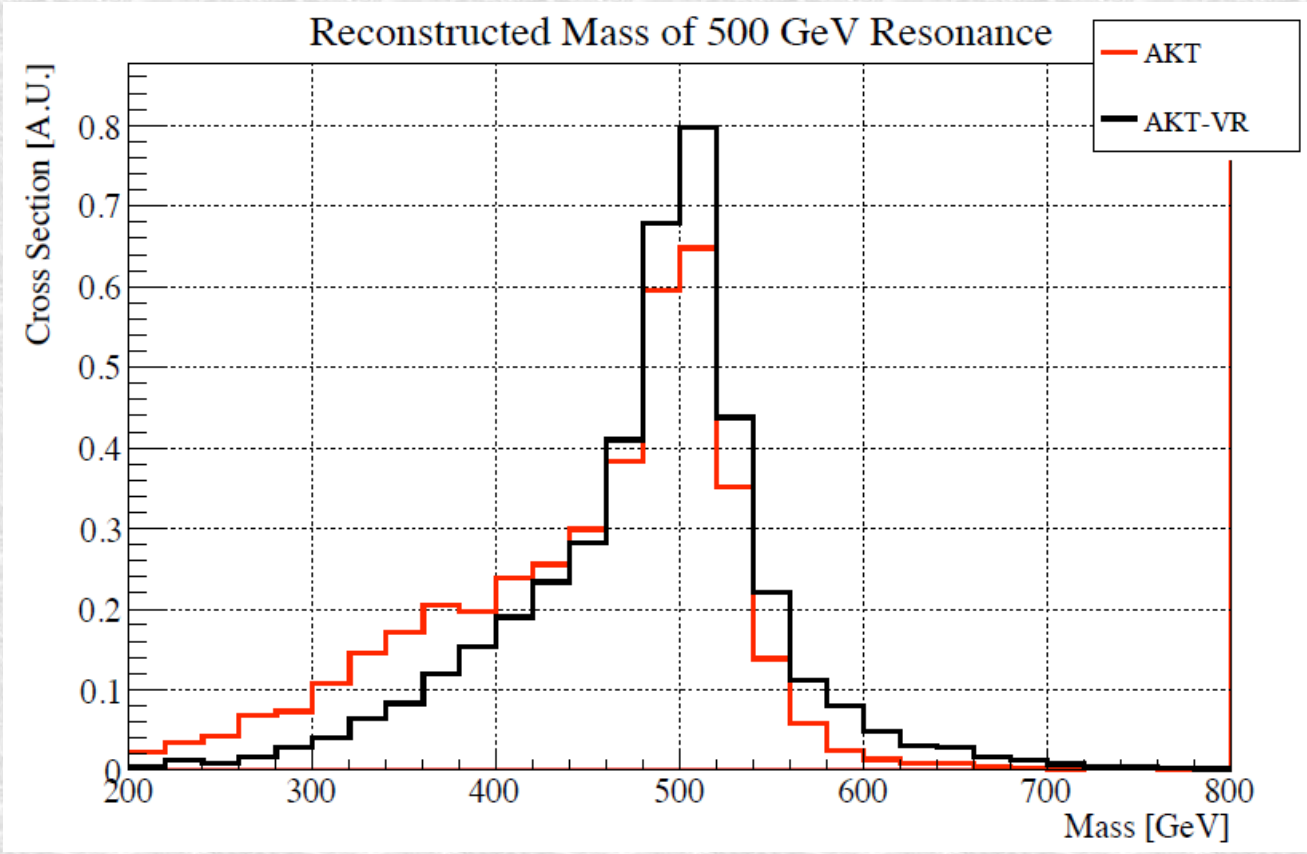
Comparison for one jet

- Left is anti-k_T, right VR anti-k_T



- Counter-intuitive?
  - High-energy jets are smaller
  - But this separates $W \to j\bar{j}$ a bit like jet substructure

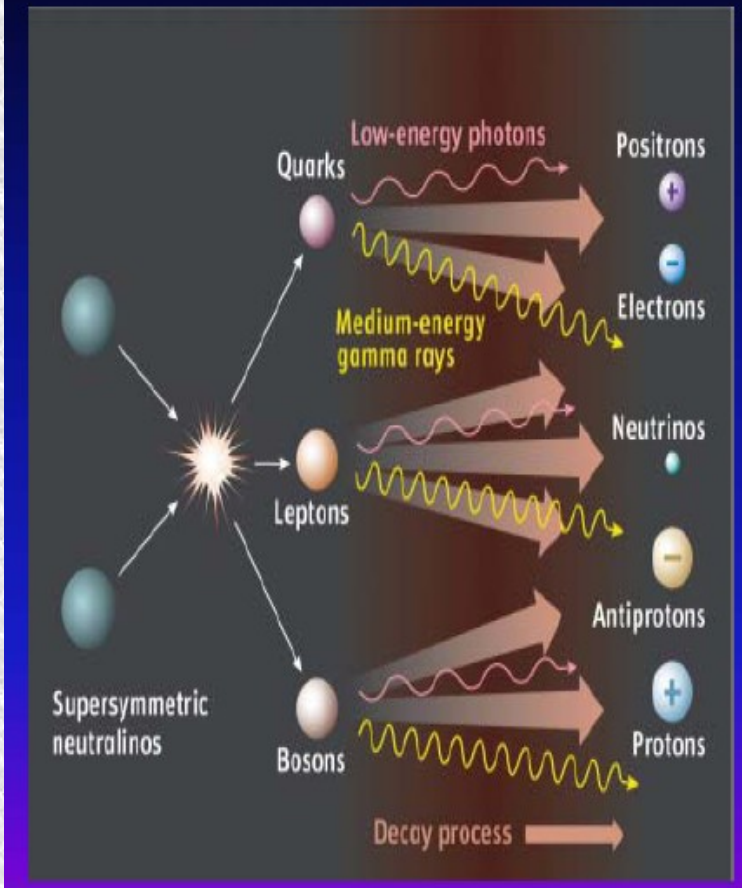
Performance on X→jj̄



- 20% more signal in peak!
  - VR was optimised for this
  - Not sure that k_T was...

Wim de Boer's Indirect talk

Indirect Dark Matter Searches in the light of ATIC, HESS, EGRET, FERMI and PAMELA



Annihilation products from dark matter annihilation:

Gamma rays (EGRET, FERMI)

Positrons (PAMELA)

Antiprotons (PAMELA)

e+ + e- (ATIC, FERMI, HESS, PAMELA)

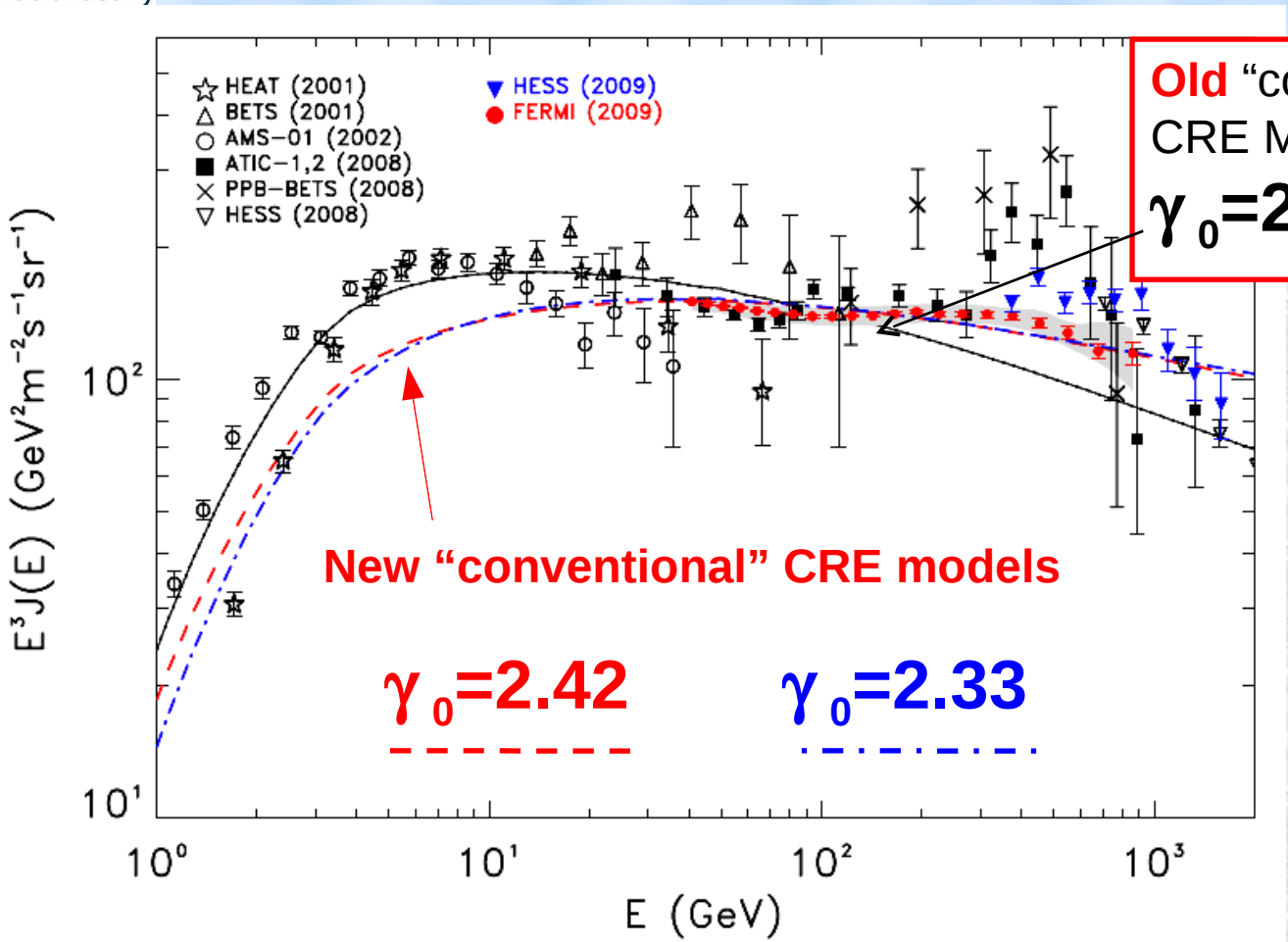
Neutrinos (Icecube, no results yet)

e-, p drown in cosmic rays?

FERMI measures GeV gamma rays + electrons

Gamma-ray Space Telescope

e^+e^- spectrum (Profumo)



Old "conventional" CRE Model

γ_0=2.54

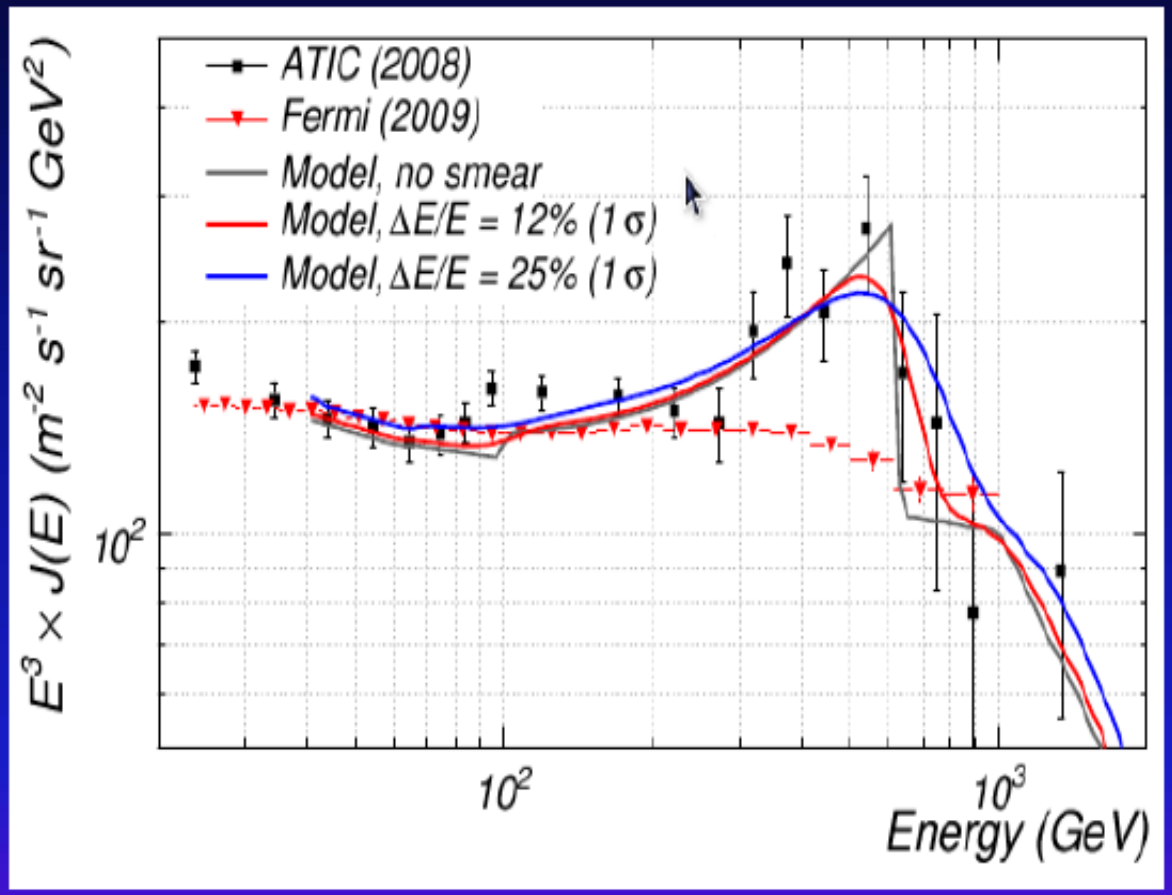
Spectrum well reproduced by **Diffuse Galactic Cosmic-Ray** Model, with **harder** injection spectral index γ_0 than in previous CR models

[*electrons accelerated by continuously distributed astrophysical sources, e.g. Supernova Remnants*]

$$\gamma_{local} \sim g_0 + \frac{d+1}{2}$$

FERMI electron spectrum: NO BUMP at 600 GeV

Simulating the LAT response to a spectrum with an "ATIC-like" feature:



Alexander Moiseev
Pamela workshop
May 11, 2009

This demonstrates that the Fermi LAT would have been able to reveal "ATIC-like" spectral feature with high confidence if it were there.
Energy resolution is not an issue with such a wide feature

The PAMELA Satellite Experiment (launched July 2006)

Transition Radiation Detector

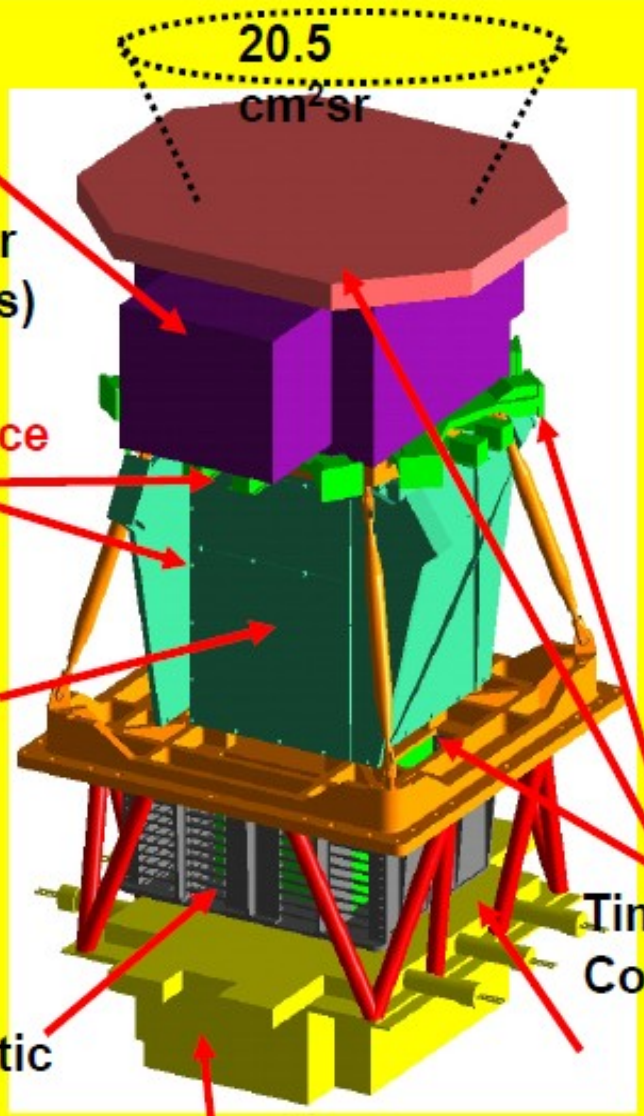
(removed for tech.reasons)

Anticoincidence Shield

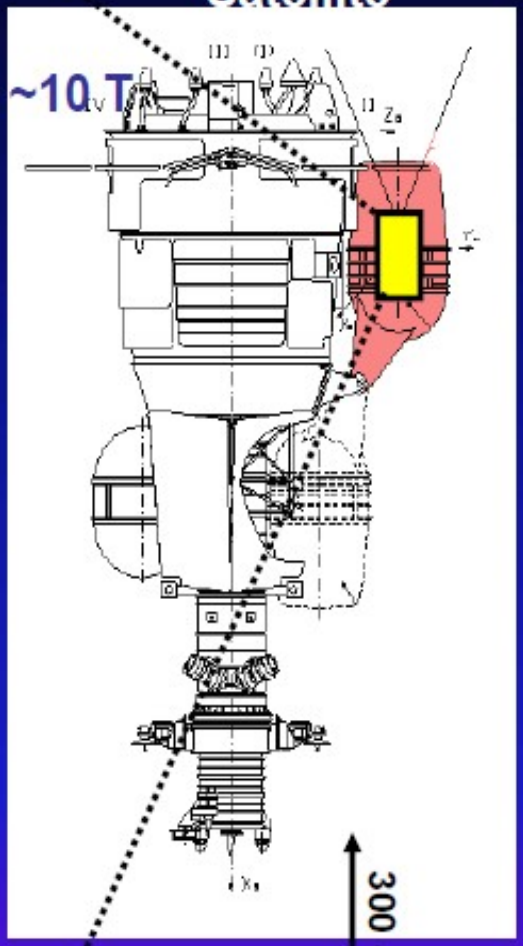
Silicon Tracker and Permanent Magnet

Si-W Electromagnetic Calorimeter

~450 kg



Resurs Dk1 Satellite



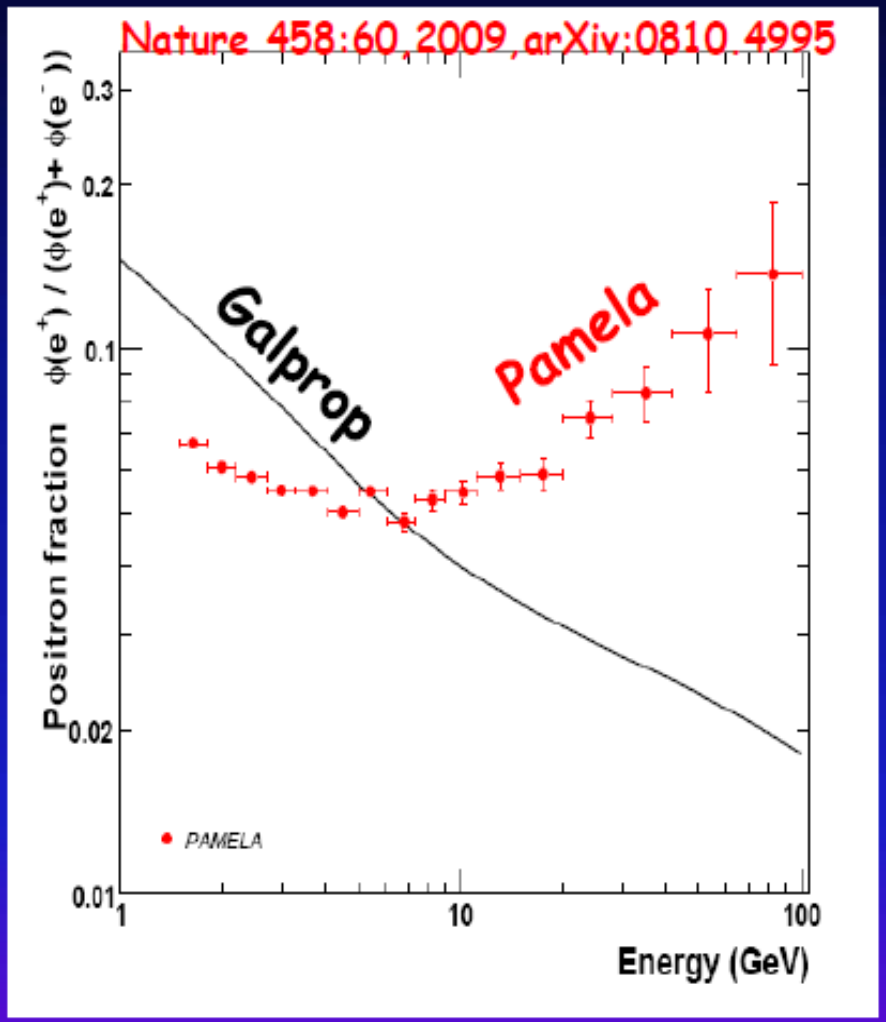
Pamela – the Belle of the ball

- But does anyone want to ask her to dance?

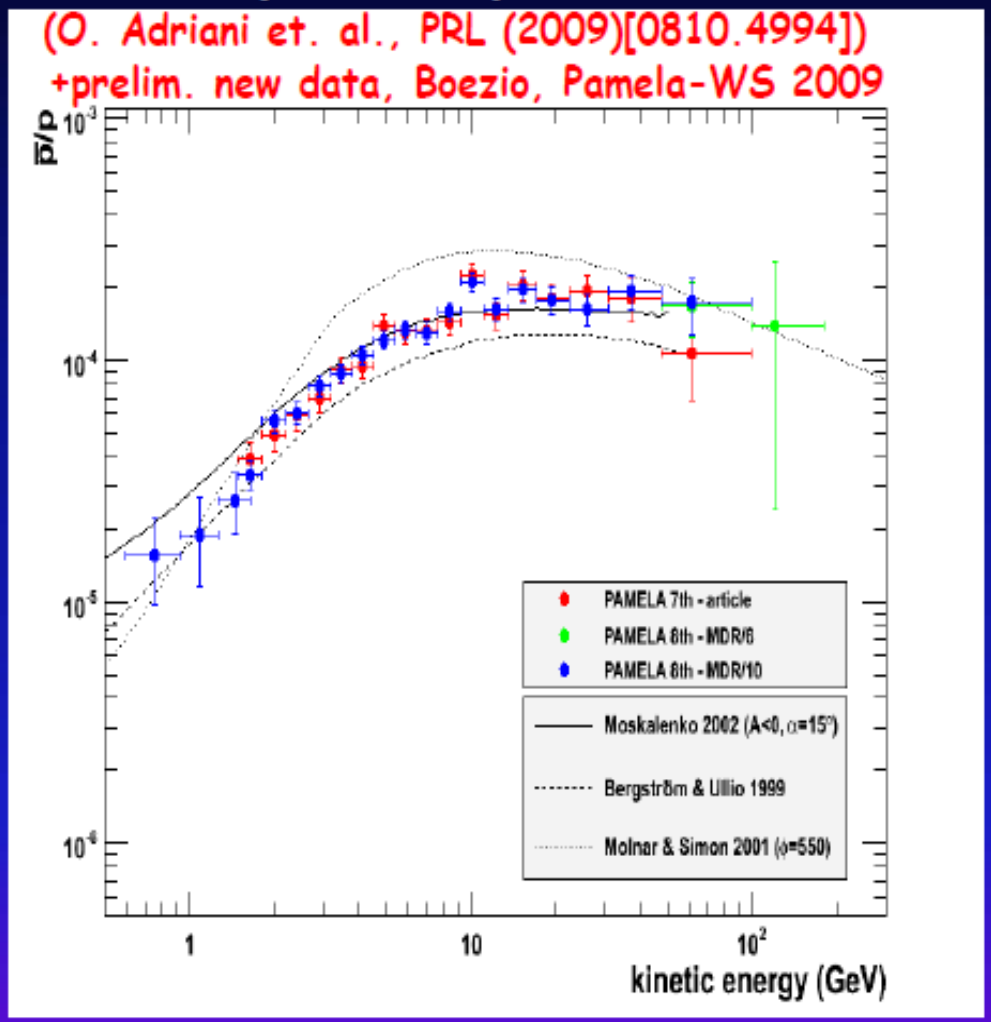
- In a nutshell:
  - Pamela see excess of high energy positrons
  - They do NOT see excessive antiprotons
  - Wimp annihilation to jets would produce both.

PAMELA, positron and antiproton measurements

Positron fraction



Antiproton/proton ratio



Positrons: excess

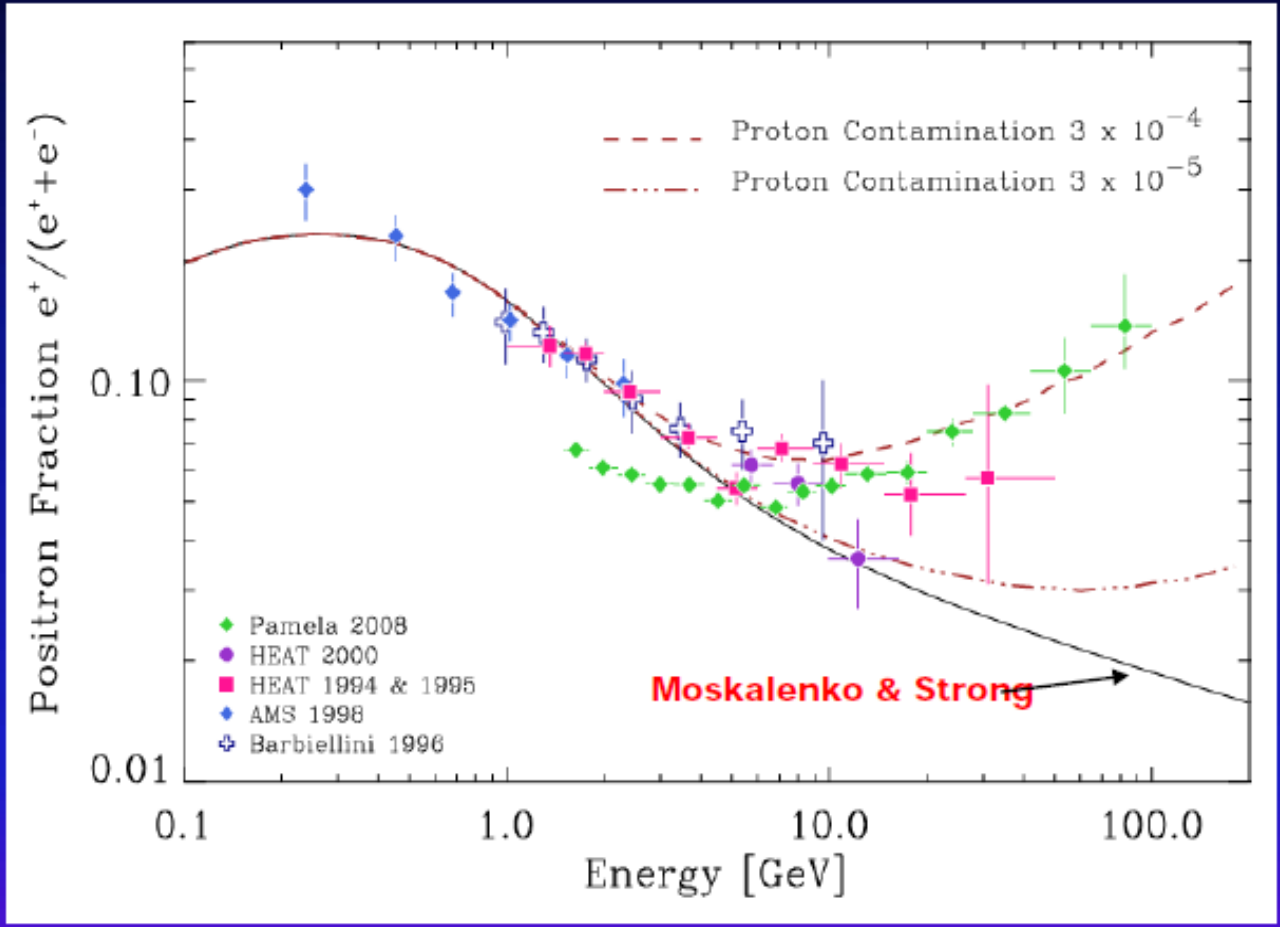
Antiprotons: NO excess

MisID Pamela interpretation

- $Ap \rightarrow Ap\pi^0$; confuse p for e^+.
- Mising TRD in Pamela may be the problem

What a *little* dash of protons can do!

Gregory Tarle at PPC09, 20.5.09

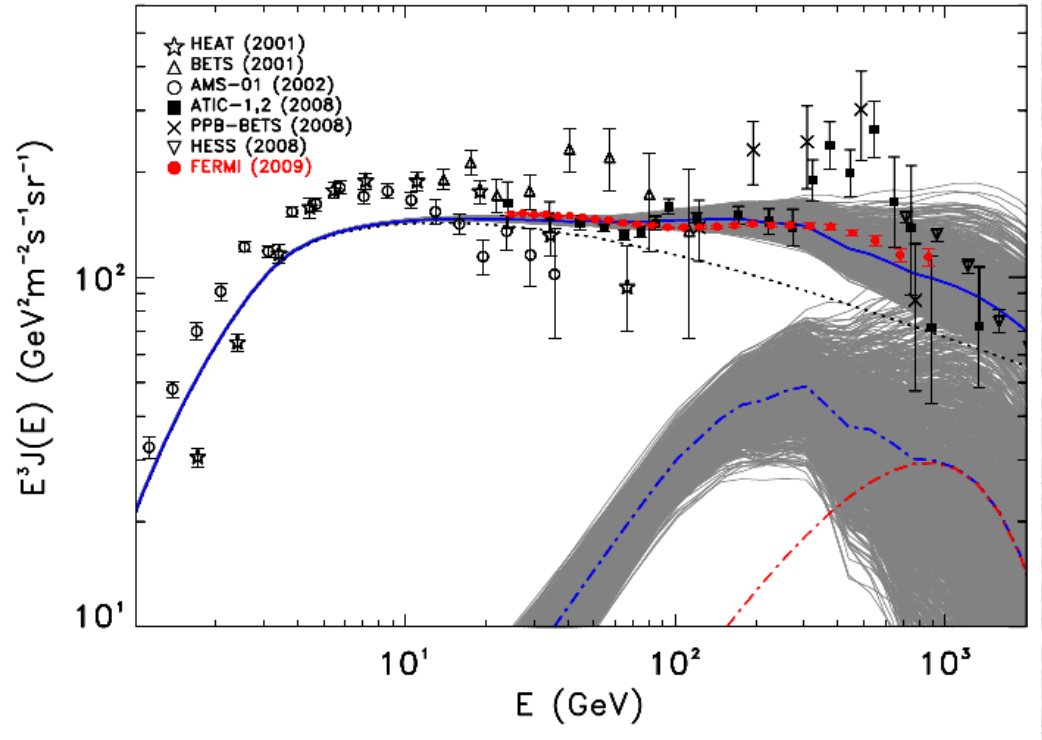


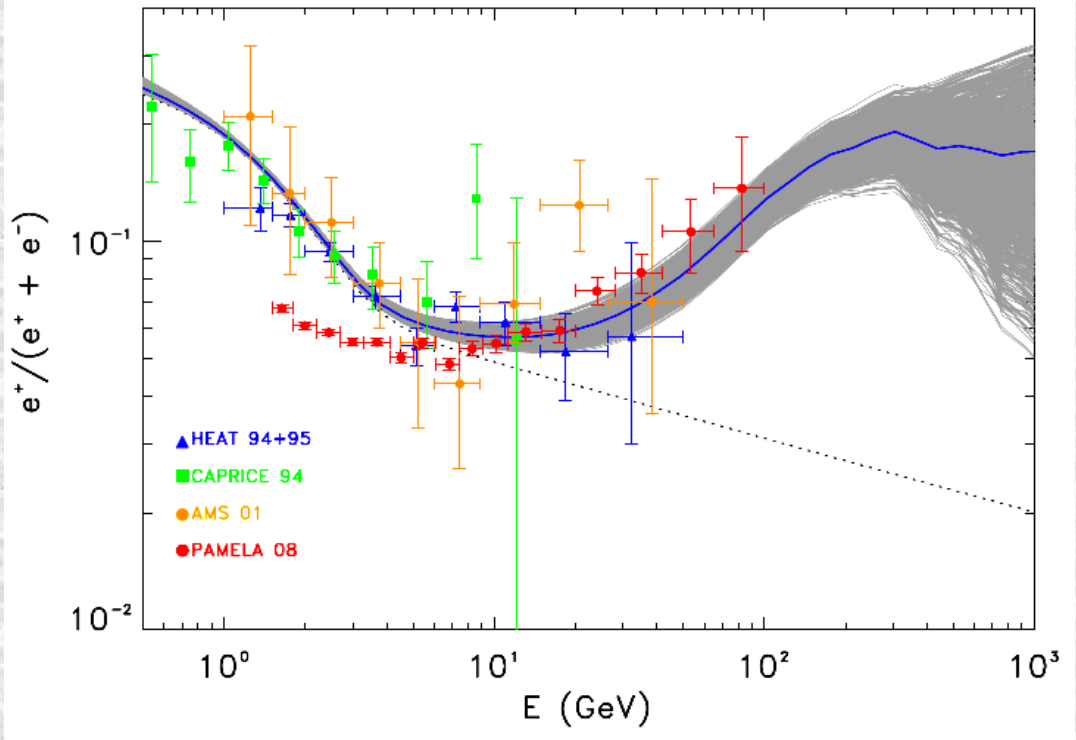
PAMELA claims p rejection of 10^{-5}. CAUTION! This is not verified using independent technique in flight.

Astrophysical Pamela

- Super Nova Remnants
  - Produce photons
  - Split to e+e-
  - Accelerate
- Pulsars
  - Similar explanation
  - But how do they escape B field?

Pulsar e^+e^- emission





Under reasonable assumptions, electron/positron **emission** from **pulsars** offers a **viable interpretation** of **Fermi** CRE data which is also **consistent** with the **HESS** and **Pamela** results

Grasso, Profumo, Strong et al., 0905.0636

SUSY Pamela interpretation

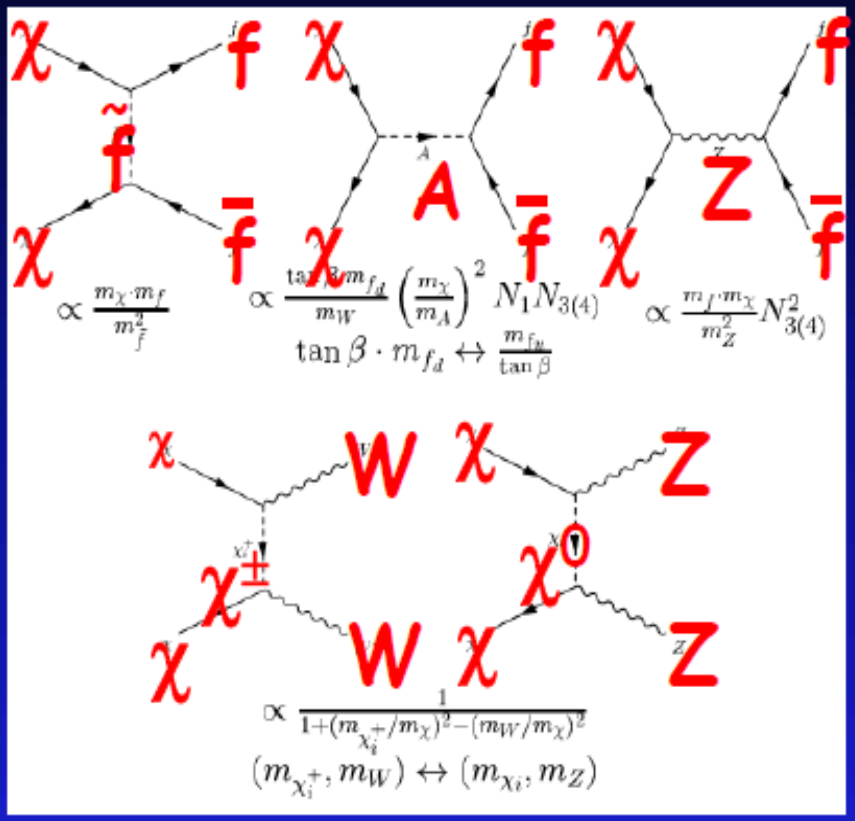
- TeV scale WIMP -> light X -> leptons
  - TeV scale WIMPs form bound states
  - Boosts annihilation rate
  - ArXiv:0810.0717
  - ArXiv:0810.5397
  - ArXiv:0905.0333
- Non-thermal Wimp history, anti-protons were overlooked
  - Kane, see following

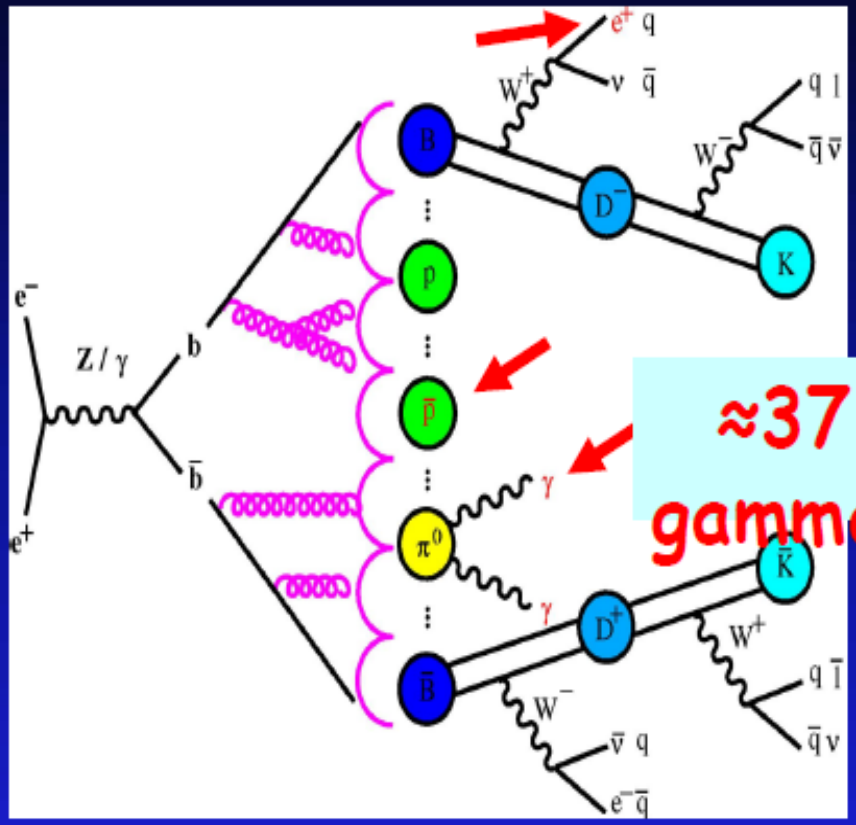
Kane's take on Pamela

- ArXiv:0812.4555
- Agrees that Wino in thermal abundance cosmology cannot produce enough e^+
- Assume non-thermal history, 'invent' density.
- Antiprotons are in Pamela data, but soft and were mistaken for background

- 180-200GeV Wino plus an extra 'background' from SNR/pulsars his best fit

Example of DM annihilation (SUSY)

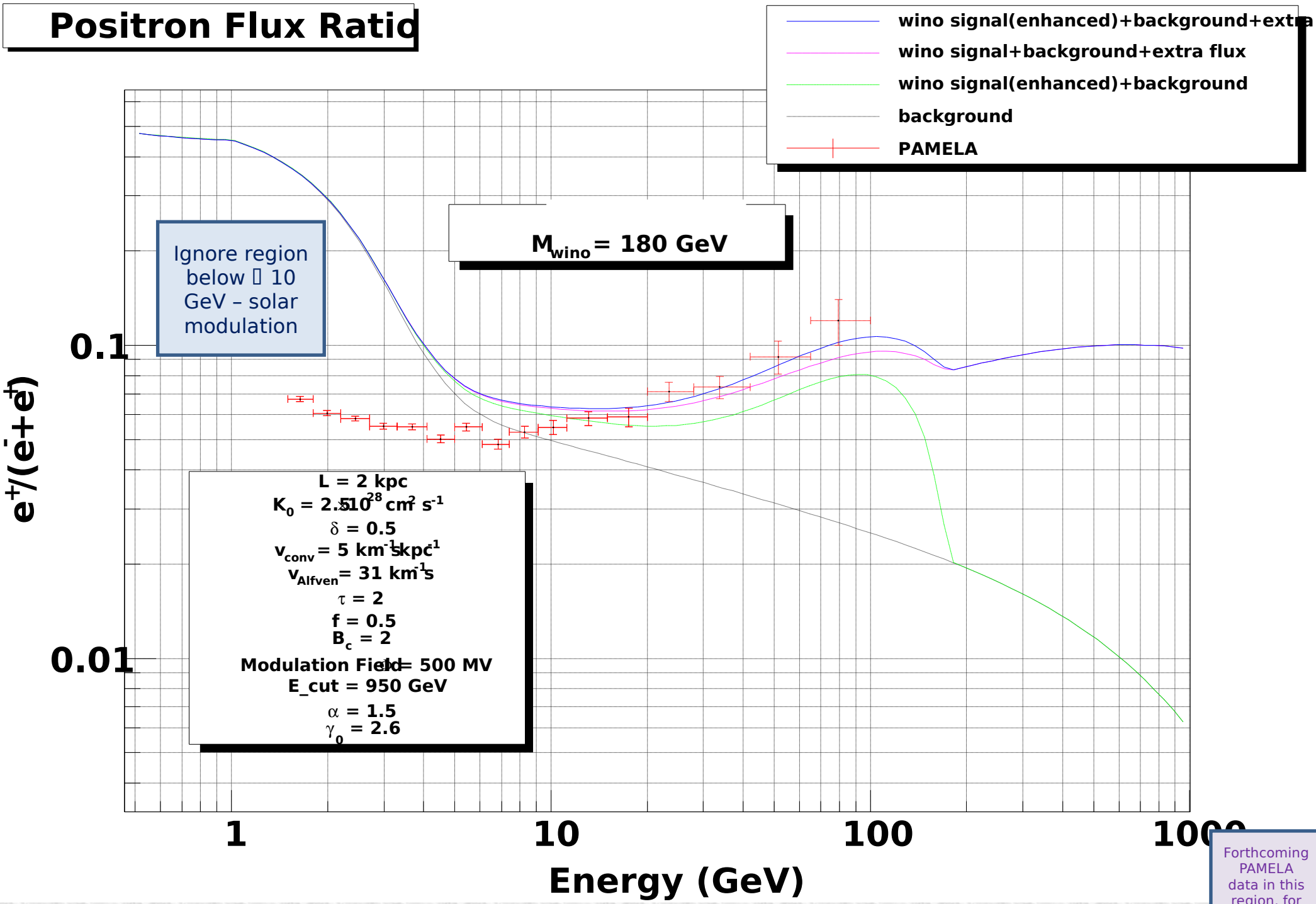




Dominant
$\chi + \chi \Rightarrow A \Rightarrow$ b bbar quark pair
Sum of diagrams should yield
$\langle\sigma v\rangle = 2.10^{-26}$ cm^3/s to get correct relic density

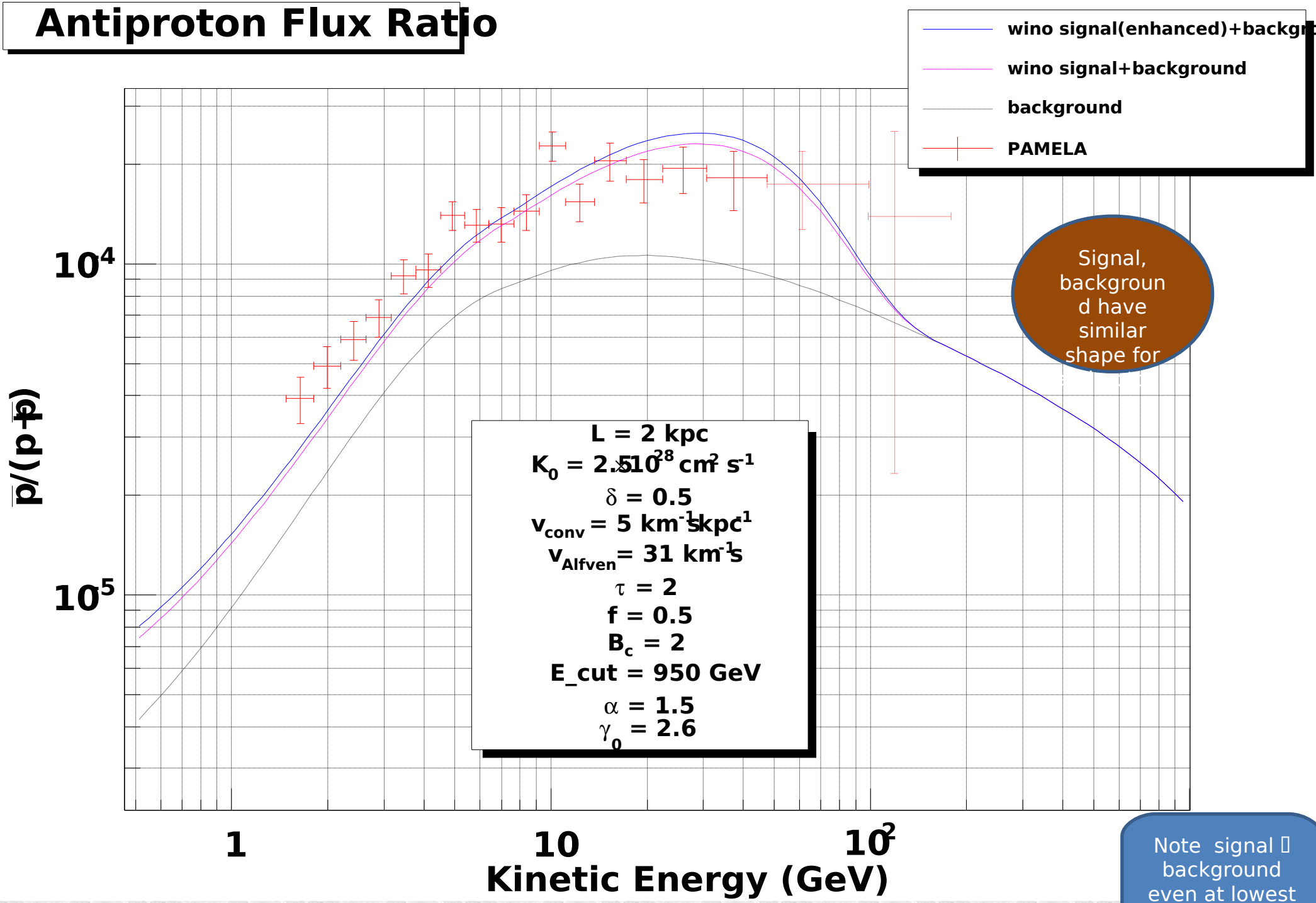
Quark-fragmentation known!
Hence spectra of positrons, gammas and antiprotons known!
Relative amount of γ,p,e+ known as well.

Positron Flux Ratio

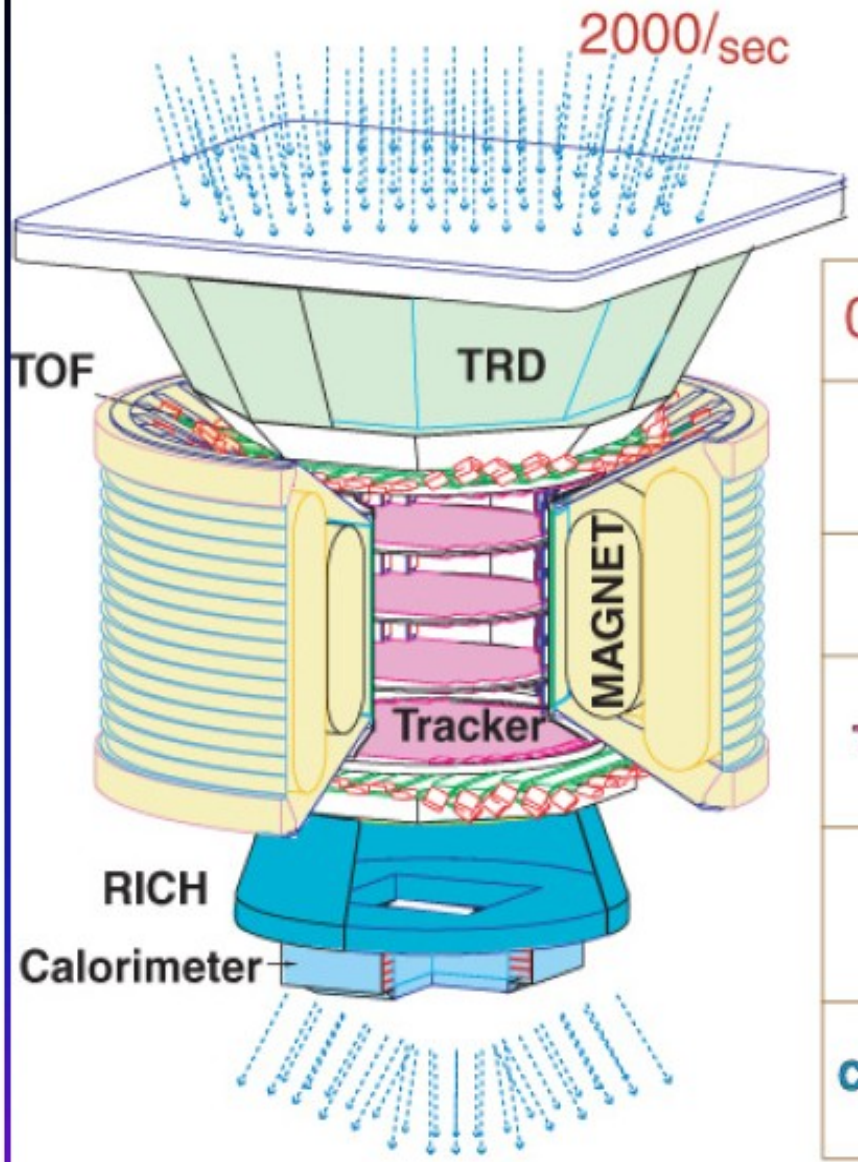


Forthcoming PAMELA data in this region. for e^+ , e^- , e^+ ratio

Antiproton Flux Ratio



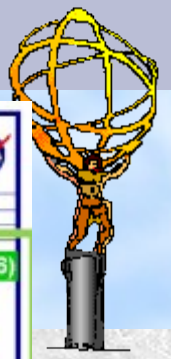
AMS: A TeV Magnetic Spectrometer in Space

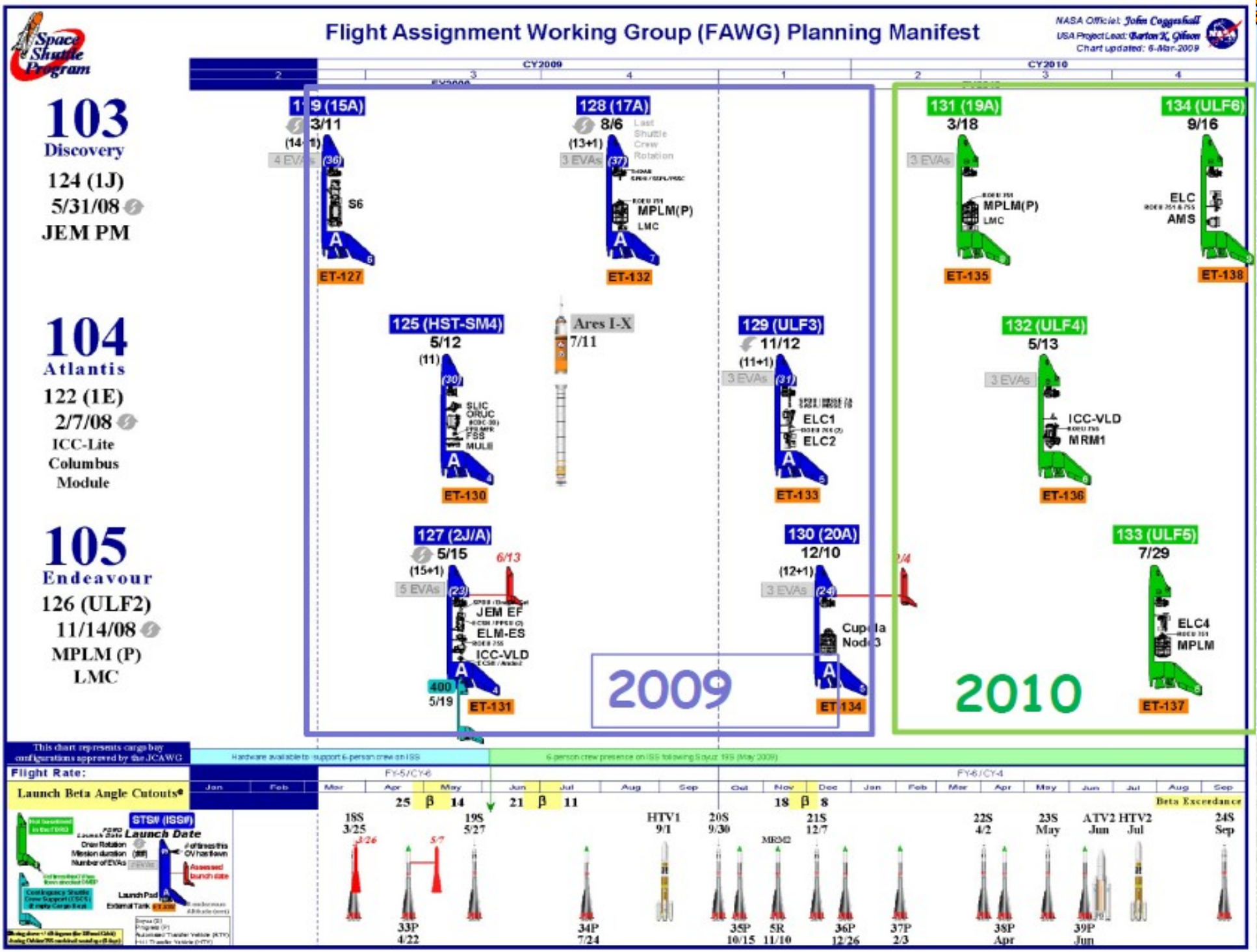


G.F. 5000 cm² sr
Exposure > 3 yrs

0.3 TeV	e⁻	e+	P	$\bar{He}$	γ
TRD					
TOF					
Tracker					
RICH					
Calorimeter					

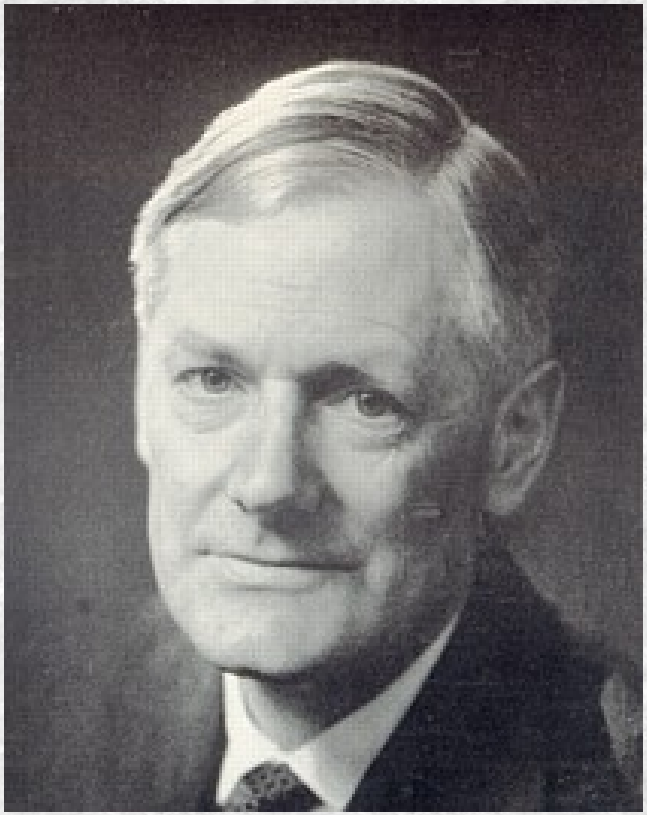
$dP/P^2 \sim 0.004$ → 2.5 TV, p rejection = 10^{-5} (ECAL +TRD); Δx=10μm; Δt=100ps




Space Shuttle Program
Flight Assignment Working Group (FAWG) Planning Manifest
NASA Official: John Coggeshall
USA Project Lead: Barton K. Gibson
Chart updated: 6-Mar-2009
CY2009
CY2010
103
Discovery
124 (1J)
5/31/08
JEM PM
119 (15A)
3/11
(14+1)
4 EVAs
(36)
S6
ET-127
128 (17A)
8/6
(13+1)
Last Shuttle Crew Rotation
3 EVAs
(37)
MPLM(P)
LMC
ET-132
131 (19A)
3/18
3 EVAs
MPLM(P)
LMC
ET-135
134 (ULF6)
9/16
ELC
AMS
ET-138
104
Atlantis
122 (1E)
2/7/08
ICC-Lite
Columbus
Module
125 (HST-SM4)
5/12
(11)
(30)
SLIC
ORUC
FSS
MULE
ET-130
Ares I-X
7/11
129 (ULF3)
11/12
(11+1)
3 EVAs
(31)
ELC1
ELC2
ET-133
132 (ULF4)
5/13
3 EVAs
ICC-VLD
MRM1
ET-136
105
Endeavour
126 (ULF2)
11/14/08
MPLM (P)
LMC
127 (2J/A)
5/15
6/13
(15+1)
5 EVAs
(23)
JEM EF
ELM-ES
ICC-VLD
400
5/19
ET-131
130 (20A)
12/10
(12+1)
3 EVAs
(24)
Cupola
Node 3
ET-134
133 (ULF5)
7/29
ELC4
MPLM
ET-137
2009
2010
This chart represents cargo bay configurations approved by the JCAWG
Hardware available to support 6-person crew on ISS
6-person crew presence on ISS following Soyuz 19S (May 2009)
Flight Rate:
Launch Beta Angle Cutouts*
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep
FY-5/CY-5
FY-6/CY-6
25 β 14
21 β 11
18 β 8
Beta Exceedance
STS# (ISS#)
Launch Date
Crew Rotation
Mission duration
Number of EVAs
# of times this OV has flown
Assessed launch date
Launch Pad
External Tank
Contingency Shuttle Crew Support (CSCS)
18S 3/25
3/26
5/7
19S 5/27
HTV1 9/1
20S 9/30
MRM2
21S 12/7
22S 4/2
23S May
ATV2 Jun
HTV2 Jul
24S Sep
33P 4/22
34P 7/24
35P 10/15
5R 11/10
36P 12/26
37P 2/3
38P Apr
39P Jun

Redman's Theorem

"Any competent theoretician can fit any given theory to any given set of facts" (*)



Roderick O. Redman
(b. 1905, d. 1975)
Professor of Astronomy
at Cambridge University

(*) Quoted in M. Longair's
"High Energy Astrophysics", sec 2.5.1
"The psychology of astronomers
and astrophysicists"