Fermi
Gamma-ray
Space Telescope

asdc
ASI Science Data Center

Dario Gasparrini, Marco Ajello, Roger Romani, Micheal Shaw et al. on behalf of the Fermi-LAT collaboration

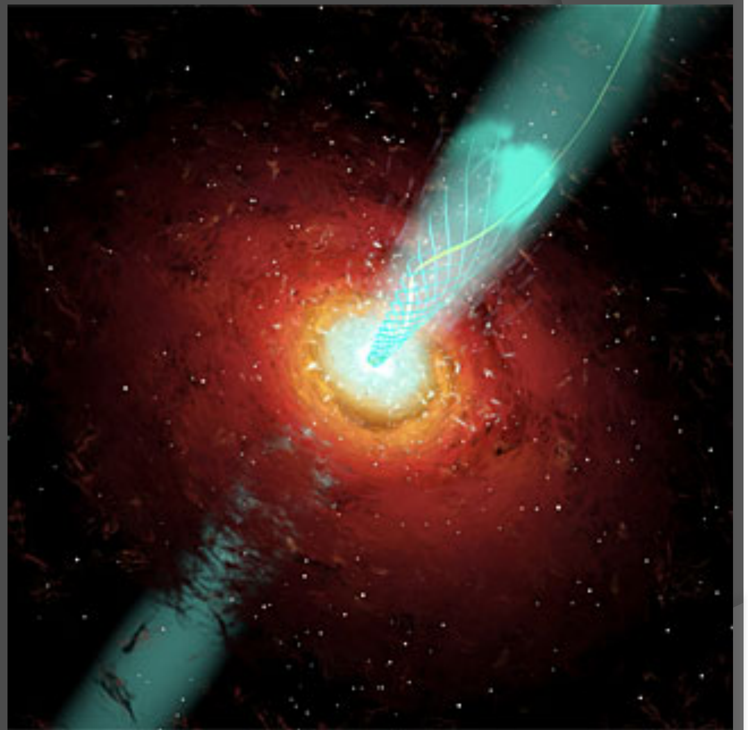
THE COSMIC EVOLUTION OF BL LACERTAE OBJECTS

LUMINOSITY FUNCTION

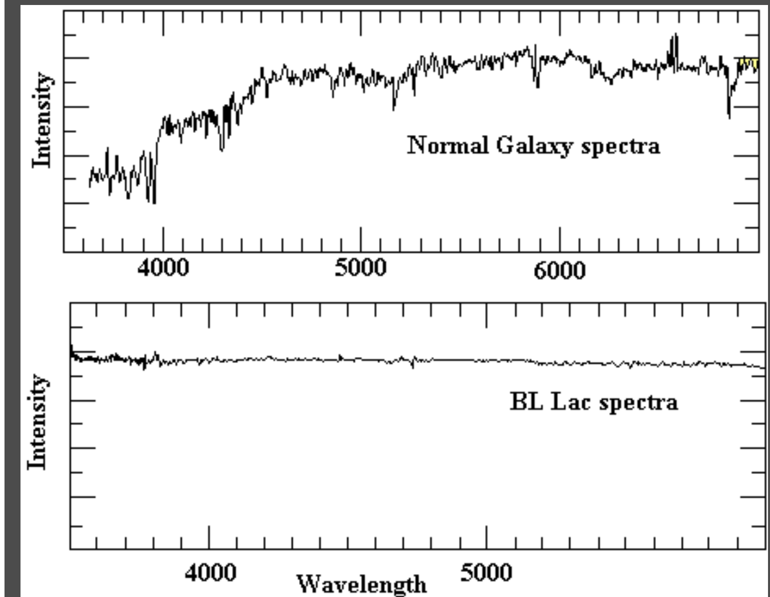
- Number of sources per bin of luminosity per comoving volume unit (Mpc^3)
- It tells us:
  - How the source population formed, evolved, grew
  - Contribution to the gamma-ray background
- A reliable luminosity function of BL Lacs is not derived yet

BL LACERTAE OBJECTS

- Active Galactic Nuclei:
  - Optical Spectrum dominated by the continuum (jet) emission
  - Jet pointing to us
  - Weak disk related emission
  - No emission lines visible
    - no redshift



REDSHIFT ISSUE



- BL Lac samples suffered from redshift completeness problem
- Literature BL Lac Luminosity Functions
  - usually have < 50 objects
  - >30% redshift incompleteness

- How to deal with this problem?

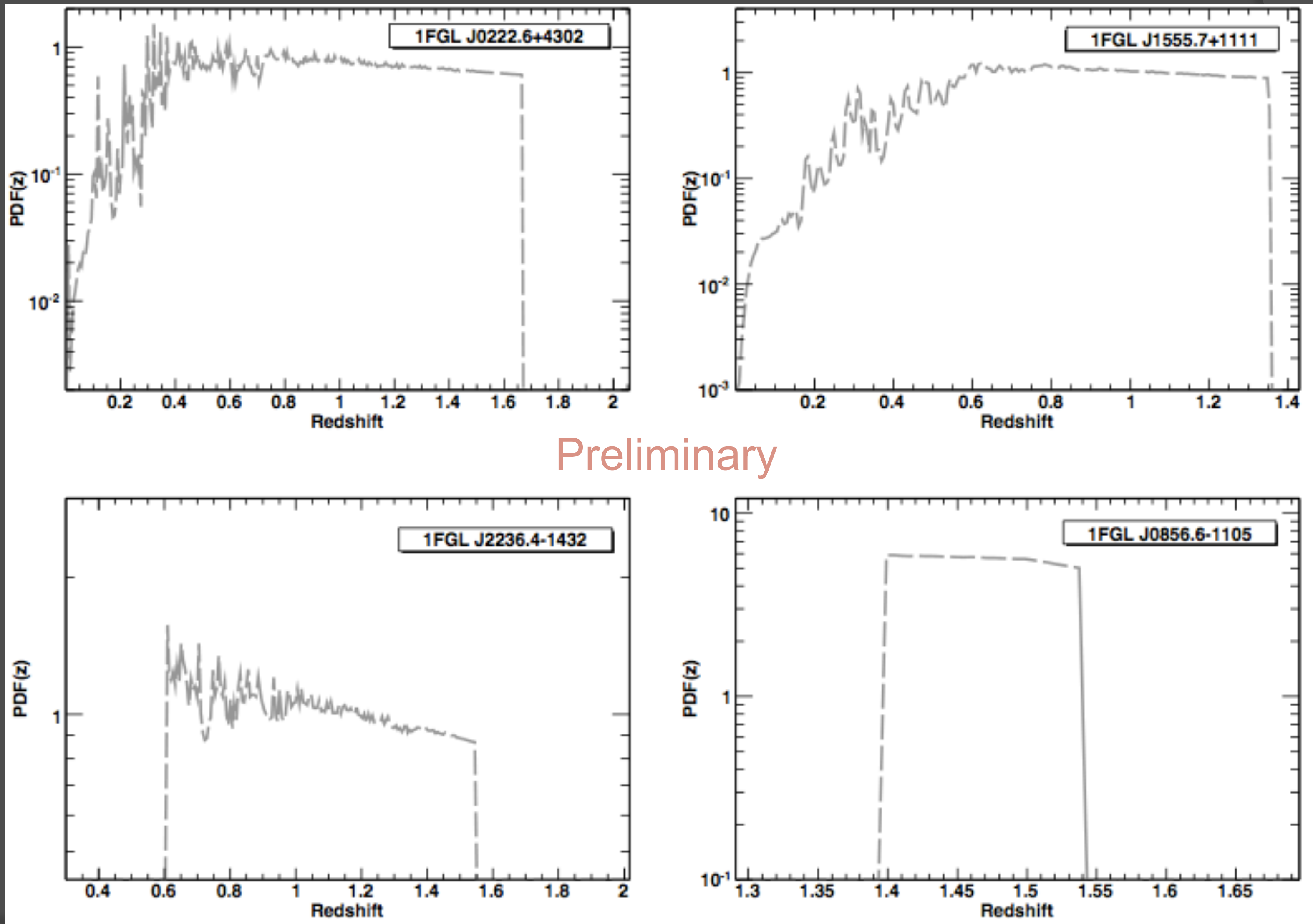
OUR BL LACS SAMPLE

- 211 objects from 1° Fermi AGN catalog (Abdo et al. 2009)
  - ~ 100 with spectroscopic redshift
  - ~ 100 with redshift constrains:
    - Photometric Z (Rau et al. 2012)
    - Photometric Upper Limit (Rau et al. 2012)
    - Spectroscopic Upper Limit (Shaw et al. 2013)
    - Spectroscopic Lower Limit for Intervening system (Shaw et al. 2013)
    - Host galaxy Fitting (Shaw et al. 2013)
  - 206/211 have redshift info
- Largest and most complete BL Lac sample ever !

HOW TO USE THE CONSTRAINS

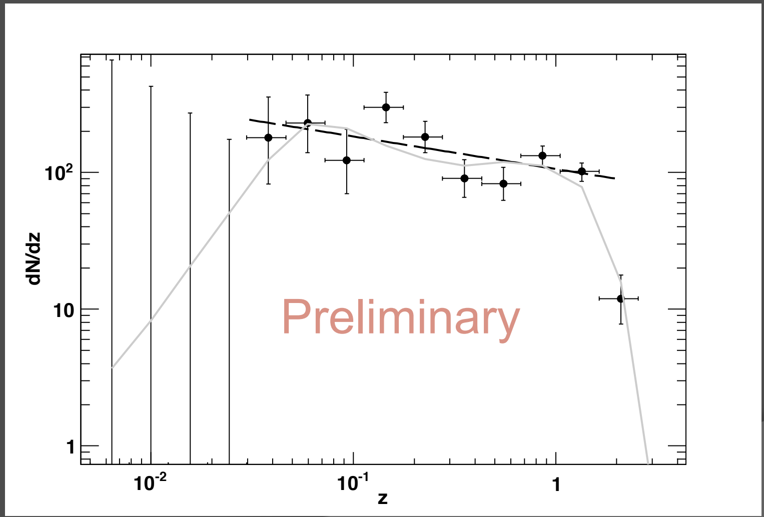
- For each object , derive a probability density function (PDF) of the source redshift combining by:
  - All the constrains
  - A *priori* function
- The prior would be true distribution dN/dz for all the Fermi BL Lacs if there were no selection effects
  - Since we don't know it we use the luminosity function and then iterate
  - Let's start from a flat a priori distribution

PDF EXAMPLES



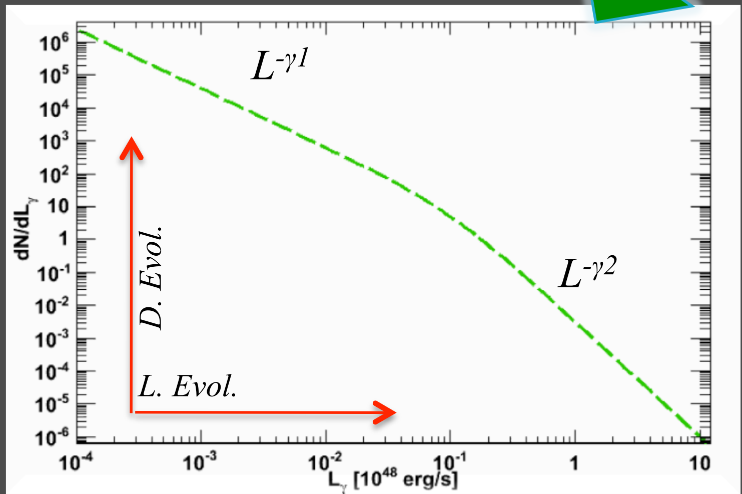
RECIPE FOR A LUMINOSITY FUNCTION

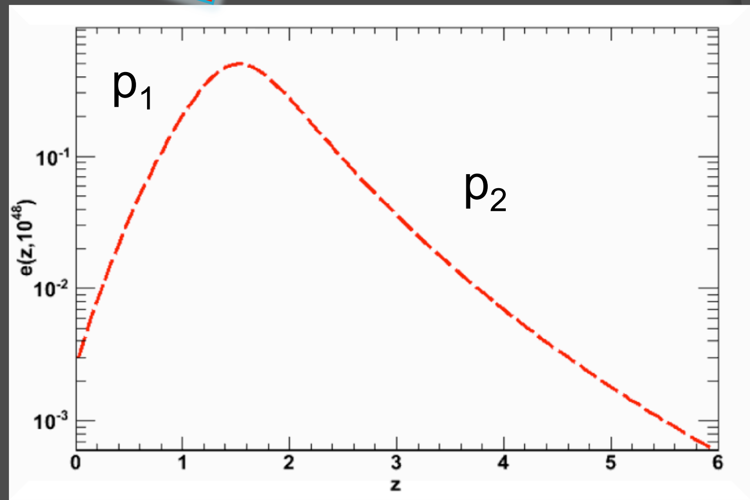
1. Produce N(~1000) samples of 206 BLLs
2. For each source draw a random redshift from the source PDF
3. Derive a LF for each sample
4. Average out all the LFs to obtain the final one
5. Use the LF to predict the dN/dz (~*priori*)
6. If "predicted dN/dz" is different than *priori* (instep 2), update *priori* and iterate 1-to-6 till convergence



$$\frac{d^3N}{dL_\gamma dz d\Gamma} = \frac{d^2N}{dL_\gamma dV} \times \frac{dN}{d\Gamma} \times \frac{dV}{dz} = \Phi(L_\gamma, V(z)) \times \frac{dN}{d\Gamma} \times \frac{dV}{dz}$$

$$\Phi(L_\gamma, V(z)) = \Phi(L_\gamma, 0) \times e(z, L_\gamma)$$





$$\Phi(L_\gamma) \propto \left[\left(\frac{L_\gamma}{L_*}\right)^{\gamma_1} + \left(\frac{L_\gamma}{L_*}\right)^{\gamma_2}\right]^{-1}$$

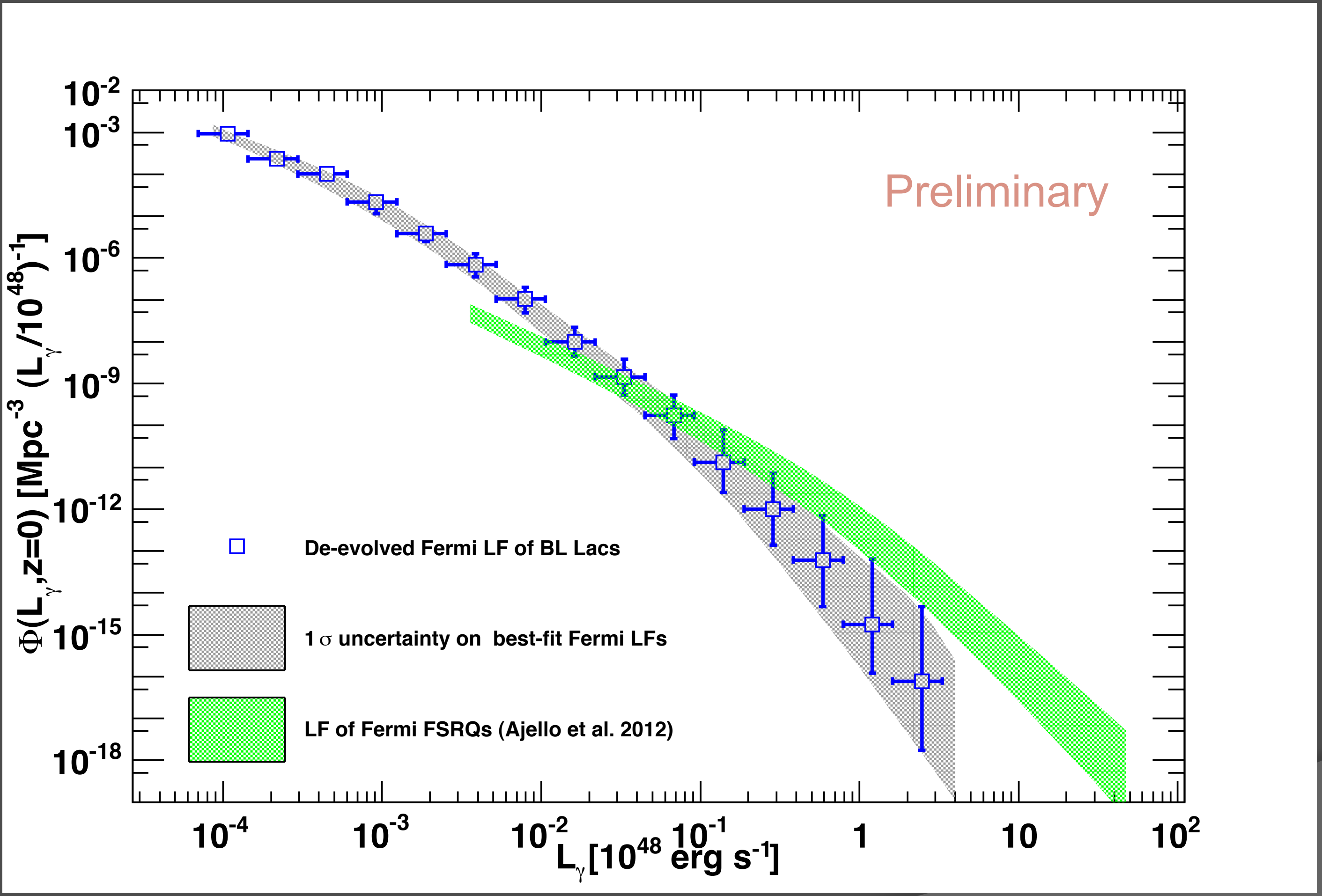
$$e(z, L_\gamma) = \left[\left(\frac{1+z}{1+z_c(L_\gamma)}\right)^{p1(L_\gamma)} + \left(\frac{1+z}{1+z_c(L_\gamma)}\right)^{p2}\right]^{-1}$$

LUMINOSITY-DEPENDENT DENSITY EVOLUTION

- Density of BLLac evolves as $(1+z)^{p1}$
- $p1=p1^{*} + \tau\, ^{*}(\mathrm{Log}L-46)$

L_γ(erg s^{-1})	p_1 Evolution
10^{44}	<0
10^{46}	2.1
10^{47}	~7

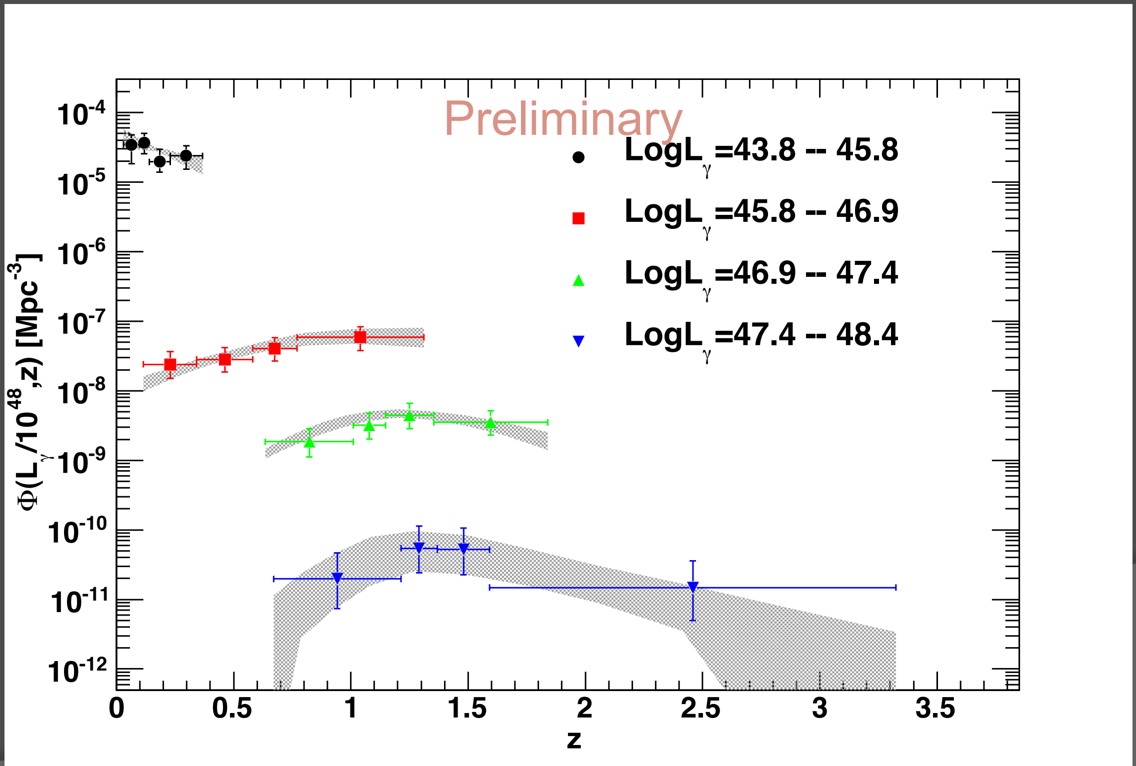
LOCAL LF (Z~0)



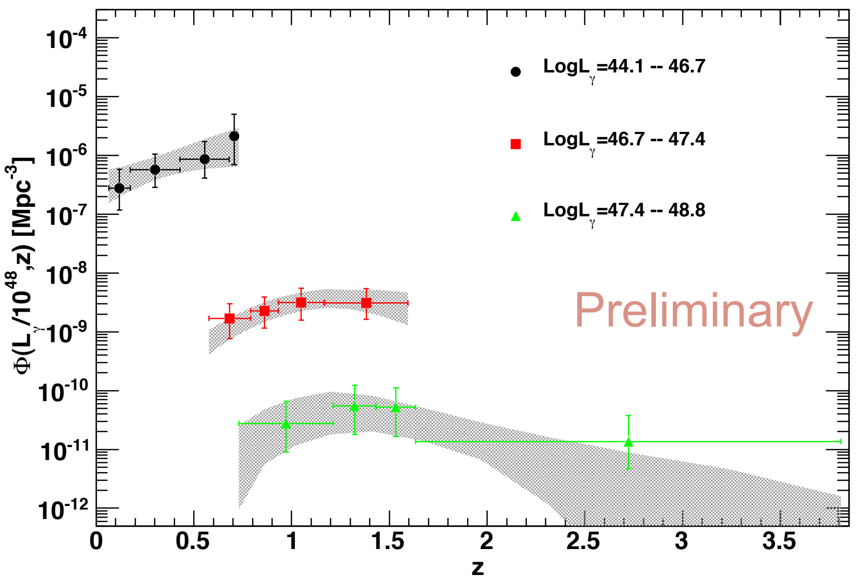
Preliminary
De-evolved Fermi LF of BL Lacs
1 σ uncertainty on best-fit Fermi LFs
LF of Fermi FSRQs (Ajello et al. 2012)
$\Phi(L_\gamma, z=0)$ [Mpc^{-3} $(L_\gamma/10^{48})^{-1}$]
L_γ [10^{48} erg s^{-1}]
10^{-2}
10^{-3}
10^{-6}
10^{-9}
10^{-12}
10^{-15}
10^{-18}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
10^{2}

REPRESENTATION

- Evolution is positive for high luminosity sources
- Evolution is negative for low luminosity sources
- Evolution is similar to FSRQ for L >10^{46}

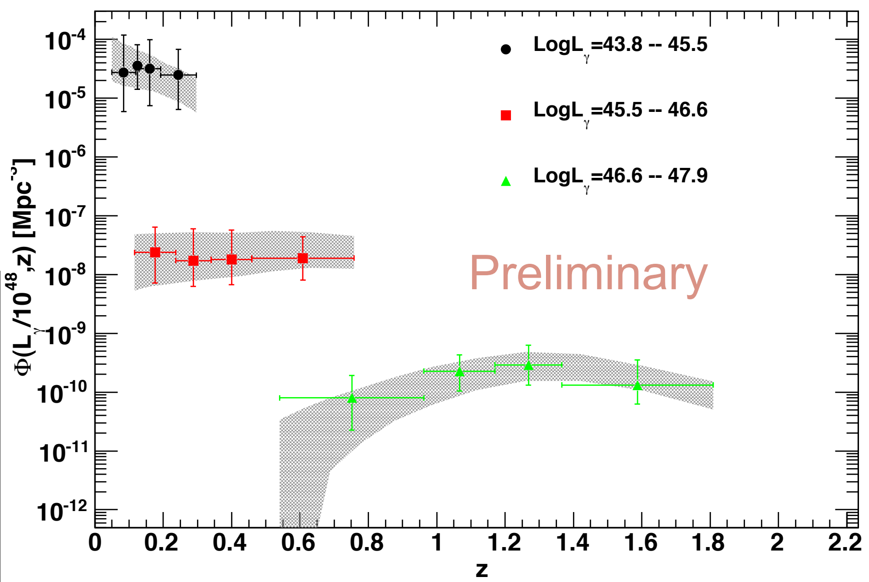


COMPARISON ON DIFFERENT BL LAC CLASSES



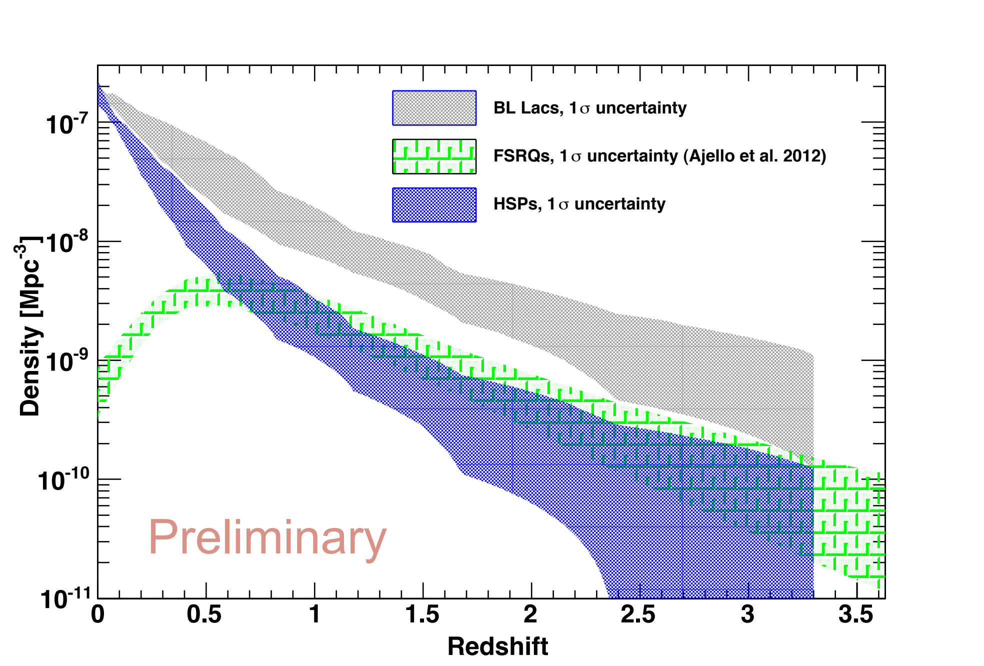
LSP+ISP

HSP



SPACE DENSITY

- The increase in the space density of BL Lacs at low z is produced by the negative evolution of HSPs
- The rise in number of HSPs coincides with the decline in number of FSRQs



- Possible explanation: HSPs might be end-of-state/starved/recycled FSRQs

genetic link *à la* Cavaliere & D'Elia 02, Böttcher&Dermer 02

FINAL REMARKS

- Largest and most complete sample
- BL Lac class evolution is complex
  - Most luminous evolve strongly
  - Less luminous have negative evolution (mostly HSP)
- The nearby universe (z~0) is populated by massive black holes which are starving for gas
- Many outcomes foreseen:
  - BL Lacs might produce a substantial fraction of the Isotropic Gamma-Ray Background (10-15%)
  - CTA will help finding hundreds of sources

THANK YOU!

BACKUP SLIDES

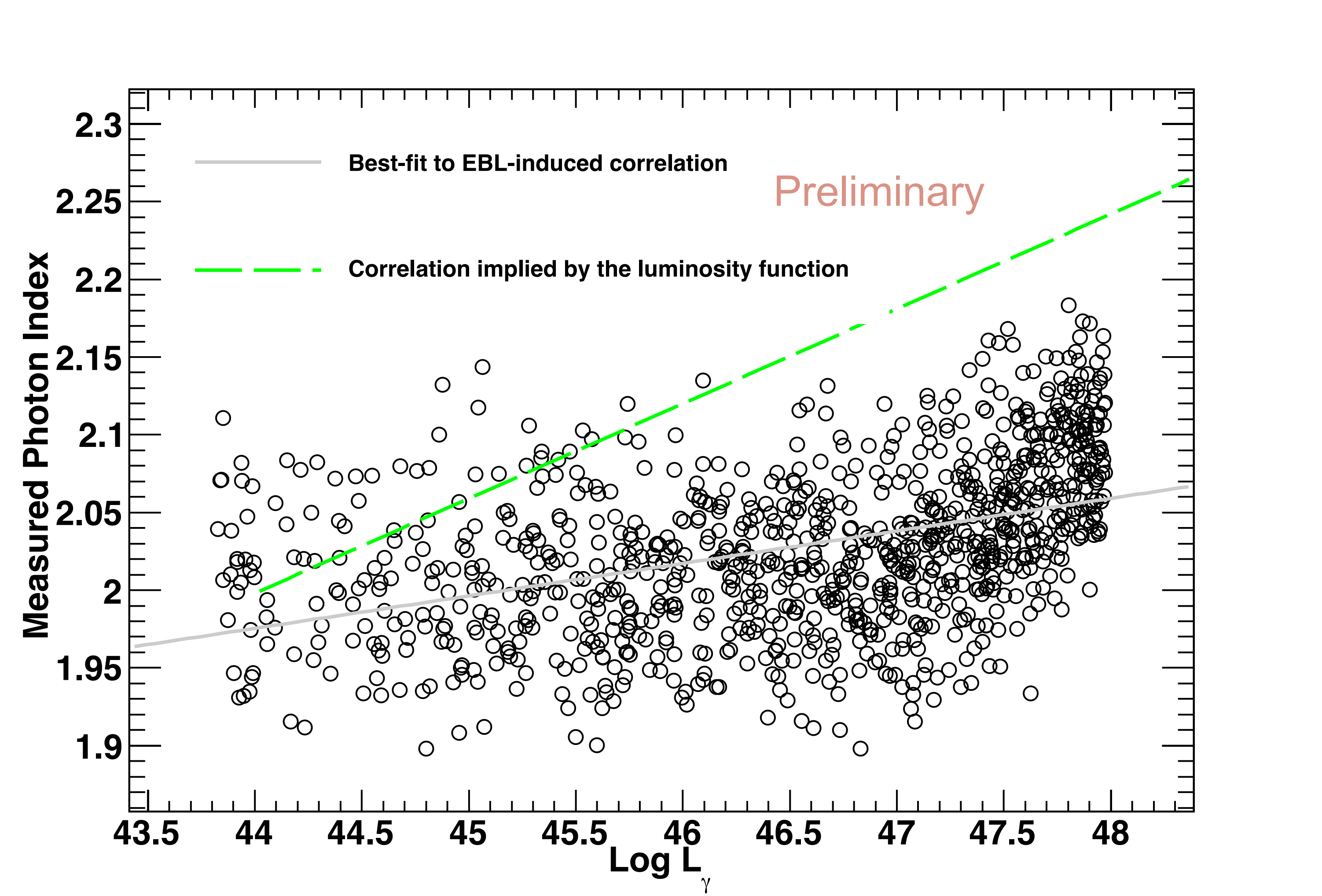
ANALYTIC STUFF

$$\frac{dN}{d\Gamma} = e^{-\frac{(\Gamma - \mu)^2}{2\sigma^2}}$$

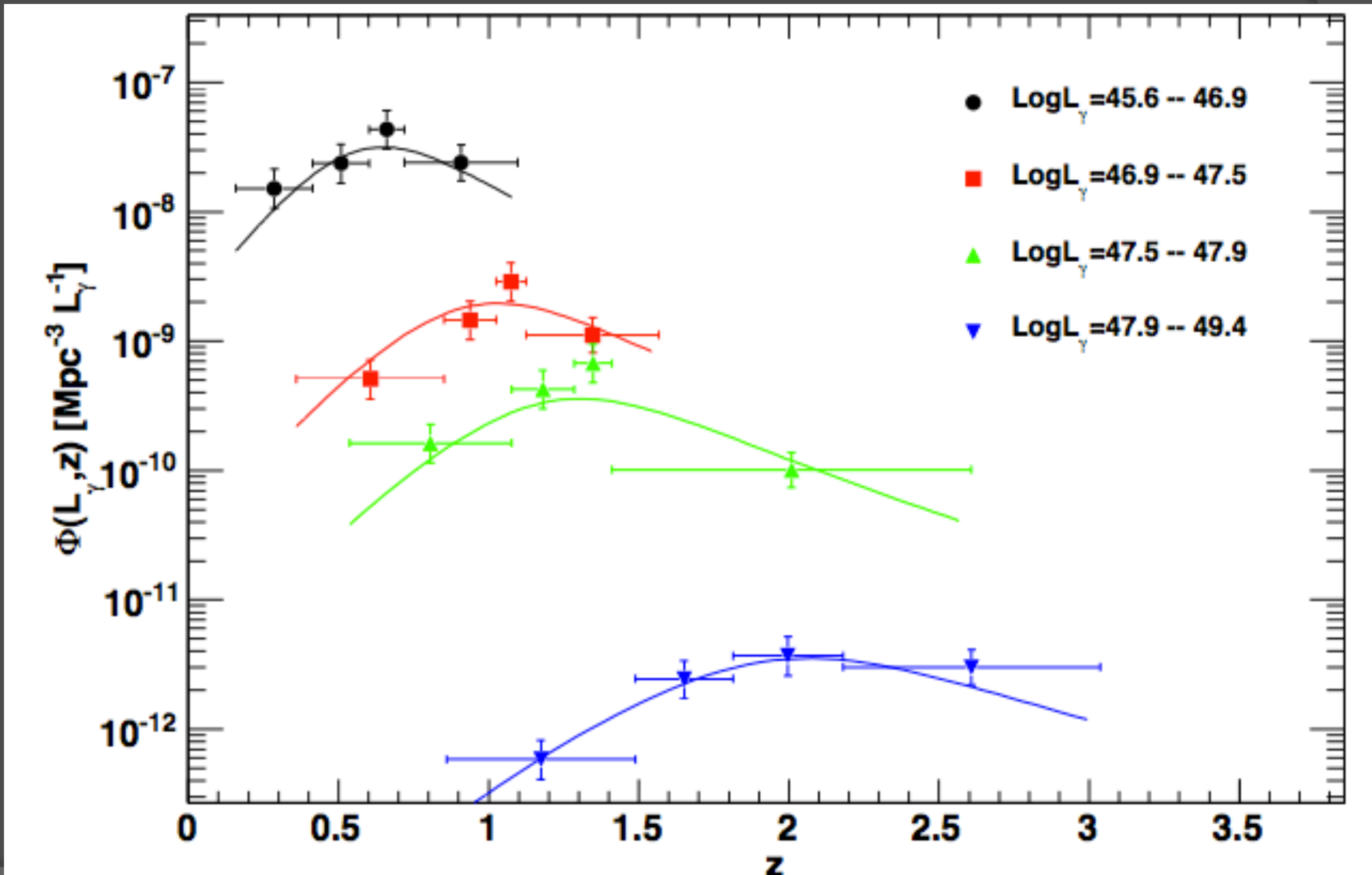
$$z_c(L_\gamma) = z_c^* \cdot (L_\gamma / 10^{48})^{\alpha}$$

$$p1(L_\gamma) = p1^* + \tau \times (Log_{10}(L_\gamma) - 46)$$

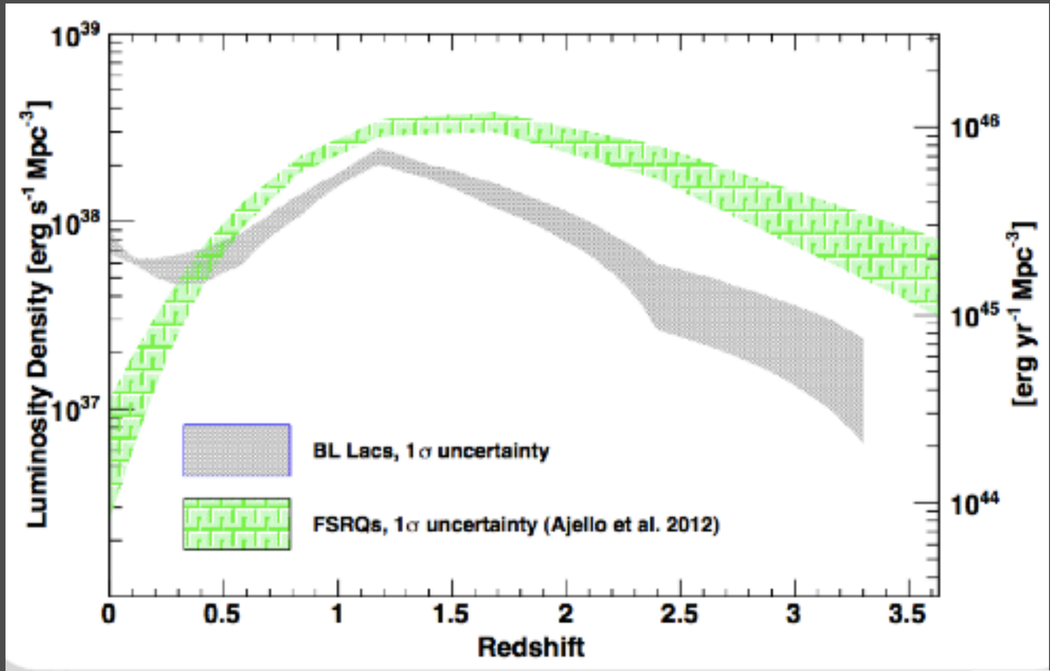
EFFECT OF EBL



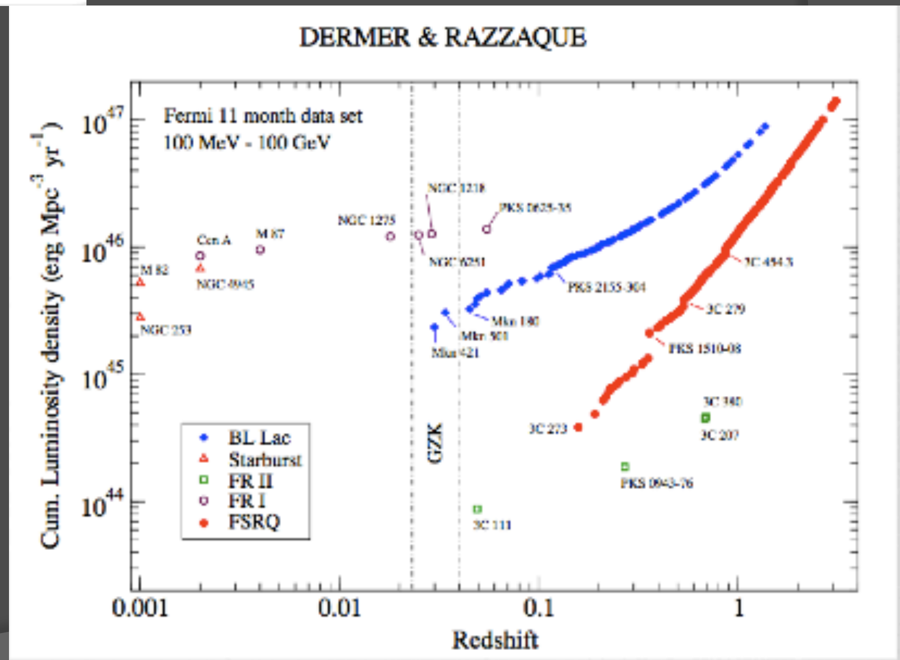
FSRQ LF



LogL$_\gamma$ =45.6 -- 46.9
LogL$_\gamma$ =46.9 -- 47.5
LogL$_\gamma$ =47.5 -- 47.9
LogL$_\gamma$ =47.9 -- 49.4
$\Phi(L_\gamma,z)$ [Mpc^{-3} L$_\gamma^{-1}$]
z



BL Lacs, 1σ uncertainty
FSRQs, 1σ uncertainty (Ajello et al. 2012)
Luminosity Density [erg s-1 Mpc-3]
[erg yr-1 Mpc-3]
Redshift



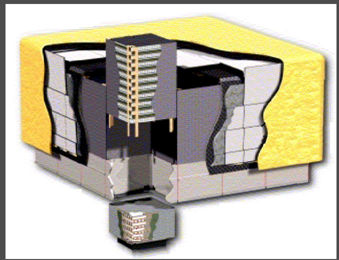
DERMER & RAZZAQUE
Fermi 11 month data set
100 MeV - 100 GeV
Cum. Luminosity density (erg Mpc-3 yr-1)
Redshift
GZK
BL Lac
Starburst
FR II
FR I
FSRQ

THE FERMI OBSERVATORY

- Satellite gamma-ray telescope
  - Large Area Telescope (LAT)
    - 20 MeV – > 300 GeV
  - Gamma Burst Monitor (GBM)
    - 8 KeV – 40 MeV
- Key features
  - Huge field of view (2.4sr)
    - 20% sky any instant
    - All sky for 30' every 3h
  - Huge energy range
    - Including unexplored 10-100 GeV range

LARGE AREA TELESCOPE

Atwood, W. B. et al. 2009, ApJ, 697, 1071

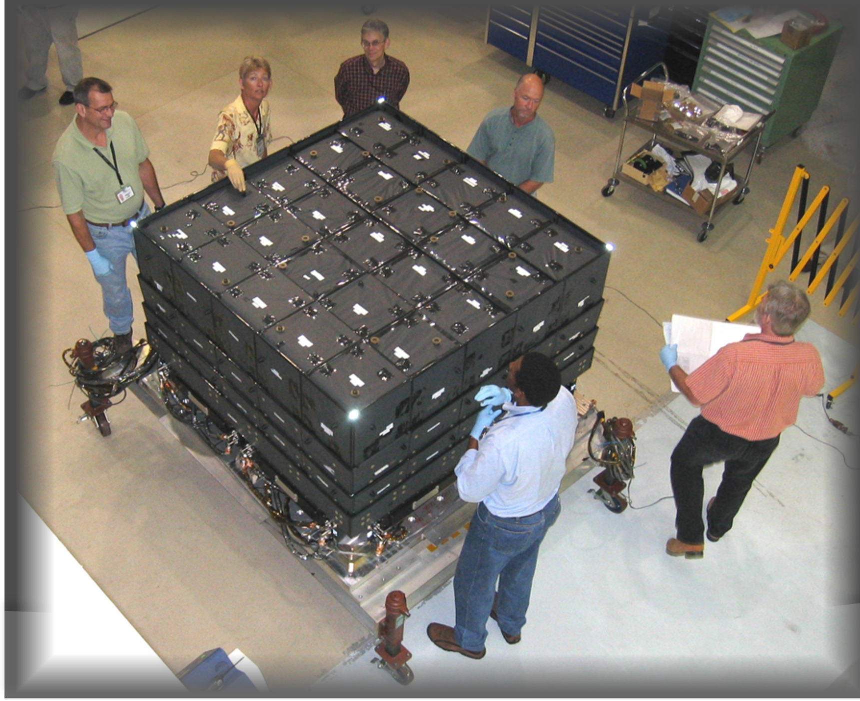


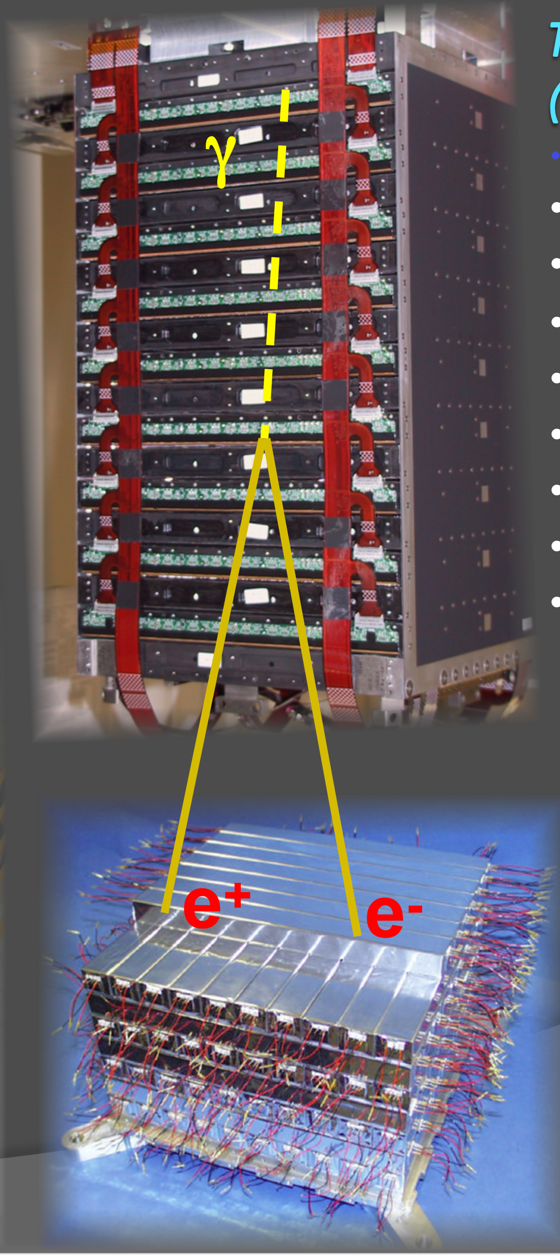
LAT

- modular - 4x4 array
- 3ton – 650watts

ANTI-COINCIDENCE (ACD):

- Segmented (89 tiles + 8 ribbons)
- Self-veto @ high energy limited
- **0.9997 detection efficiency**





TRACKER/CONVERTER (TKR):

- Si-strip detectors
- ~80 m2 of silicon (total)
- W conversion foils
- 1.5 X0 on-axis
- **18XY planes**
- ~106 digital elx chans
- Highly granular
- High precision tracking
- Average plane PHA

CALORIMETER (CAL):

- 1536 CsI(Tl) crystals
- **8.6 X0 on-axis**
- large elx dynamic range (2MeV-60GeV per xtal)
- **Hodoscopic (8x12)**
- Shower profile recon
- leakage correction
- EM vs HAD separation