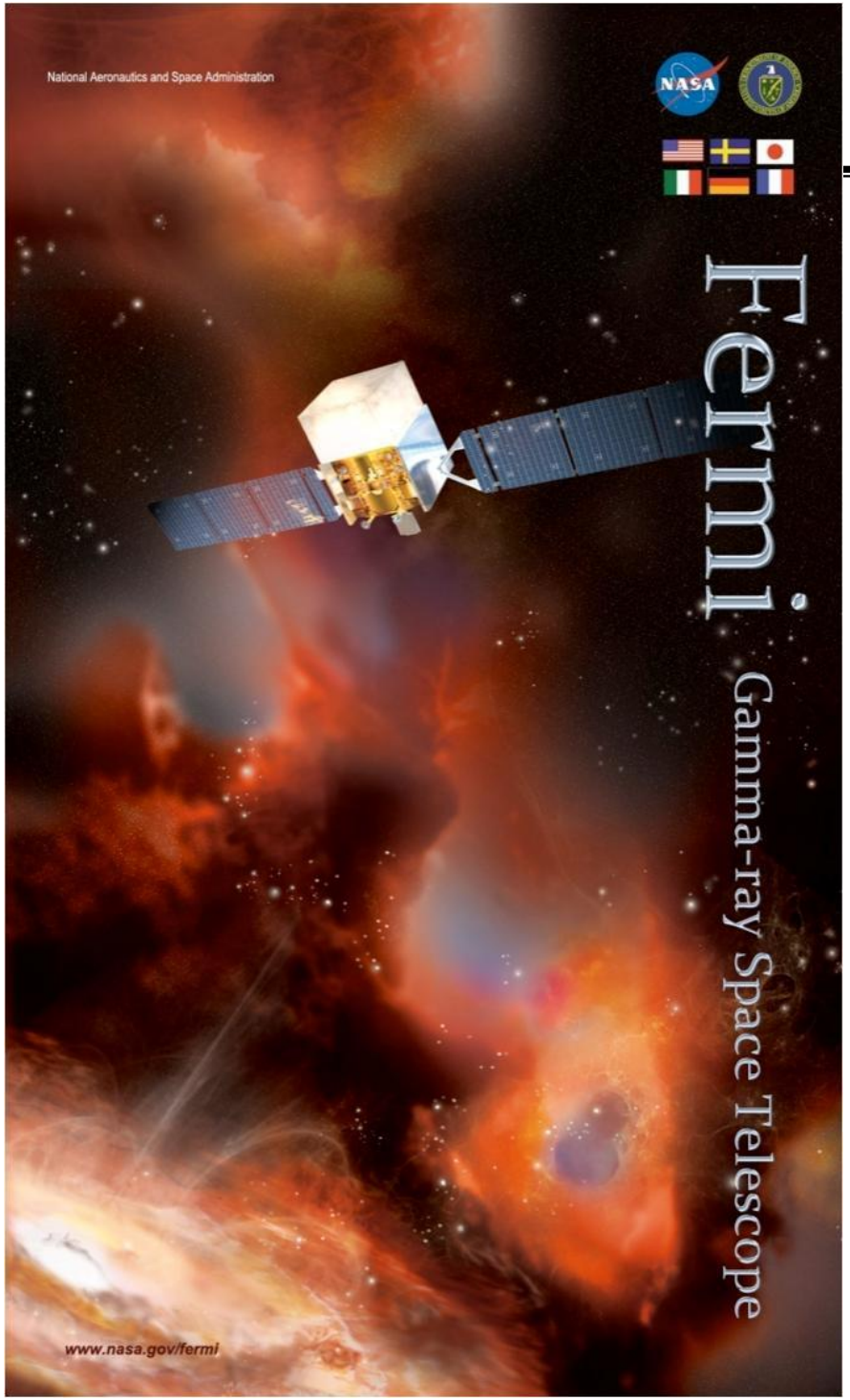


Fermi-LAT likelihood analysis (2)

Benoît Lott
CEN Bordeaux-Gradignan
lott@cenbg.in2p3.fr

on behalf of the *Fermi*-LAT collaboration

Credits for the likelihood talks:
J. Chiang, S. Digel, F. Longo

gtfindsrc

Optimizes a point source location using the likelihood test-statistic

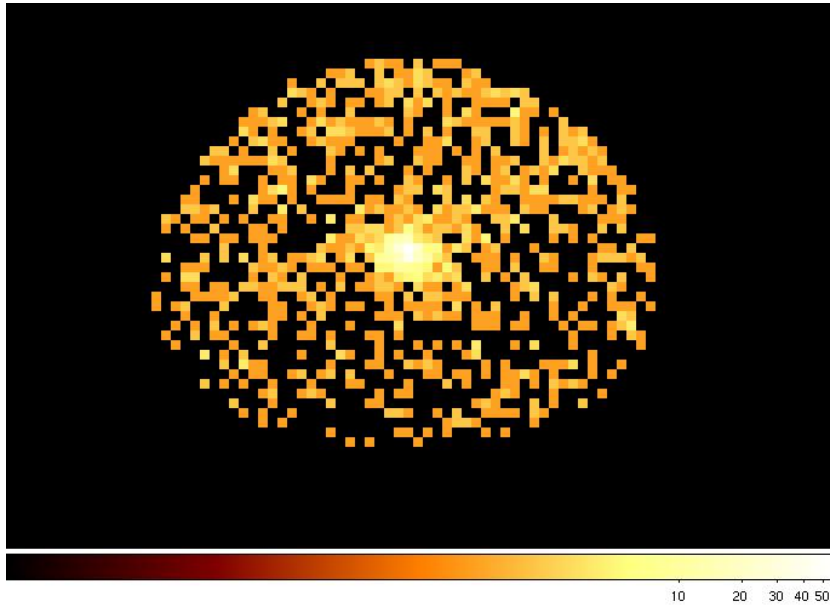
/COSPAR < 66 >**gtfindsrc**
Event file[3c454_100_300000_evt02.fits]
Spacecraft file[L090923112502E0D2F37E71_SC00.fits]
Output file for trial points[out_findsrc]
Response functions to use[P6_V3_DIFFUSE]
Livetime cube file[3c454_expcube.fits]
Unbinned exposure map[3c454_expmap.fits]
Source model file[3c454_srcmdl.xml]
Building source model from 3c454_srcmdl.xml
-log-likelihood of input source model: 326013
Target source name[3c454] _3c454
Optimizer (DRMNFB|NEWMINUIT|MINUIT|DRMNGB|LBFGS) [MINUIT]
Tolerance for -log(Likelihood) at each trial point[0.01]
Covergence tolerance for positional fit[0.01]
Best fit position: 343.517, 16.1597
Error circle radius: 0.0175704

gtobssim

Generate photon events from astrophysical sources and process those photons according to the specified instrument response functions

/obs < 161 >gtobssim

File of flux-style source definitions[obsSim_source_library.xml]
File containing list of source names[source_names.dat]
Pointing history file[../L090923112502E0D2F37E71_SC00.fits]
Prefix for output files[sim]
Simulation time (seconds)[86400]
Simulation start date[2009-07-02 00:00:00]
Apply acceptance cone?[yes]
RA of cone center (degrees) (-360:360) [343.5]
Dec of cone center (degrees) (-90:90) [16.15]
Acceptance cone radius (degrees) (0:180) [20]
Response functions[P6_V3_DIFFUSE]
Random number seed[293049]



added source "Extragalactic_diffuse"
added source "Galactic_diffuse"
added source "_3c454"
Generating events for a simulation time of 86400 seconds....
Warning: 268188711 seems to be in an invalid interval: it is 67.1292 seconds beyond the start of the current FT2 entry
----
Warning: 268188711 seems to be in an invalid interval: it is 67.36 seconds beyond the start of the current FT2 entry
Done.
132.096u 5.238s 2:29.17 92.0% 0+0k 0+0io 0pf+0w
/obs < 162 >

Photon file is sim_events_0000.fits

gtobssim (2)

/obs < 82 >more obsSim_source_library.xml

```
<!-- $Header -->
<source_library title="Source Library">
<source name="Galactic_diffuse">
      <spectrum escale="MeV">
         <SpectrumClass name="MapCube" params="25,../gll_iem_v02.fit"/>
         <use_spectrum frame="galaxy"/>
      </spectrum>
   </source>
<source name="Extragalactic_diffuse">
      <spectrum escale="MeV">
        <SpectrumClass name="Isotropic"
                  params="flux=10.7,gamma=2.1,emin=20.,emax=2e5,ra=0,dec=0,radius=180"/>
        <use_spectrum frame="galaxy"/>
      </spectrum>
    </source>
<source name="_3c454" flux="0.0980184334659">
     <spectrum escale="MeV">
       <particle name="gamma">
         <power_law emin="100.0" emax="1000000.0" gamma="2.46"/>
       </particle>
       <celestial_dir ra="343.5" dec="16.5"/>
     </spectrum>
</source>
</source_library>
```

/obs < 83 >more source_names.dat

```
Extragalactic_diffuse
Galactic_diffuse
_3c454
```

Plotting results

Assuming a power law model: $F(E) = dN/dE = F_0(E/E_0)^{-\Gamma}$

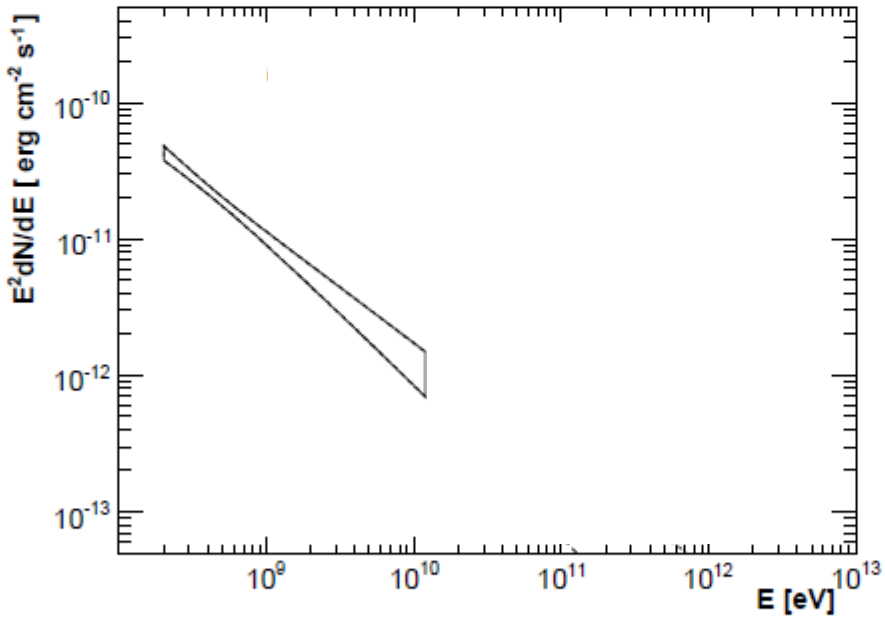
The uncertainty on F at a given energy E is:

$$\frac{\Delta F^2}{F^2} = \frac{\Delta F_0^2}{F_0^2} - \frac{2\,\mathrm{cov}(F_0,\Gamma)}{F_0}\log\left(\frac{E}{E_0}\right) + \Delta\Gamma^2\log^2\left(\frac{E}{E_0}\right)$$

which is minimum at: $E_d = E_0\exp[\mathrm{cov}(F_0,\Gamma)/F_0\,\Delta\Gamma^2]$

The cross term of the covariance matrix must be obtained using python….

Beware of the maximum energy:
the maximum energy of photons potentially coming from the source (small ROI) is an option.



covariance matrix

gtlike display output

Final values:
Normalizat = 0.615683
Integral = 1.57847
Index = 2.32047
Integral = 0.434516
Index = 2.21215
Integral = 1.57868
Index = 3.15148
Prefactor = 1.29008
Prefactor = 0.0235878
Index = 2.5075

parameters for source of interest

Minuit fit quality: 3 estimated distance: 0.0001474
Minuit parameter uncertainties:
1 0.0453642
2 0.154493
3 0.0684055
4 0.122061
5 0.151336
6 0.20743
7 0.148624
8 0.0425466
9 0.000754517
10 0.0205287

ΔF_0
$\Delta \Gamma$

EXTERNAL ERROR MATRIX. NDIM= 10 NPAR= 10 ERR DEF= .500
.206E-02 -.478E-03 -.219E-03 -.526E-03 -.586E-03 -.205E-02 -.737E-03 -.184E-02 -.444E-05 -.100E-03
-.478E-03 .239E-01 .737E-02 .253E-03 .215E-03 .988E-03 .194E-03 .140E-03 .158E-05 .172E-04
-.219E-03 .737E-02 .468E-02 .672E-04 .590E-04 .338E-03 .835E-04 .128E-03 .465E-06 .637E-05
-.526E-03 .253E-03 .672E-04 .149E-01 .151E-01 .907E-03 .224E-03 .281E-03 -.876E-05 -.150E-03
-.586E-03 .215E-03 .590E-04 .151E-01 .229E-01 .927E-03 .244E-03 .358E-03 -.948E-05 -.166E-03
-.205E-02 .988E-03 .338E-03 .907E-03 .927E-03 .430E-01 .176E-01 .152E-02 .213E-05 .346E-04
-.737E-03 .194E-03 .835E-04 .224E-03 .244E-03 .176E-01 .221E-01 .643E-03 -.239E-06 -.354E-05
-.184E-02 .140E-03 .128E-03 .281E-03 .358E-03 .152E-02 .643E-03 .181E-02 .297E-05 .797E-04
-.444E-05 .158E-05 .465E-06 -.876E-05 -.948E-05 .213E-05 -.239E-06 .297E-05 .569E-06 .129E-04
-.100E-03 .172E-04 .637E-05 -.150E-03 -.166E-03 .346E-04 -.354E-05 .797E-04 .129E-04 .421E-03

Upper limits

Some analysis results may be not statistically significant, $TS<TS_{thresh}$. Typically, $TS_{thresh}=25$ but it can be lower for some purposes.

The resulting flux should then not be considered as the real source flux.

An upper limit associated with a given confidence level (90% in the following) has then to be reported.

Ex: Catalog, light curves…

Profile Likelihood Intervals

meas n, meas. b

ML of b given s

$$\lambda(s) = \frac{\mathcal{L}(n, b_m | s, \hat{b}(s))}{\mathcal{L}(n, b_m | \hat{s}, \hat{b})}$$

ML of b and s given observations

$$-2\ln\mathcal{L}(n|s)$$

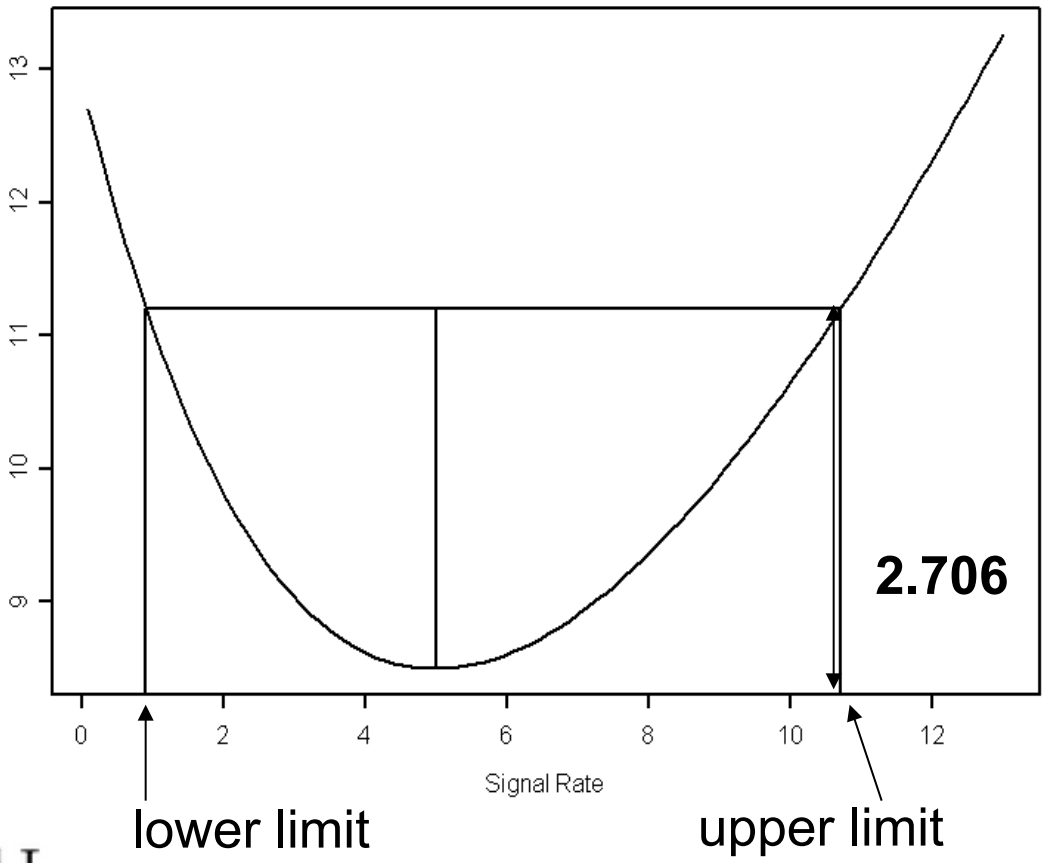
$\hat{s}, \hat{b}$ **fitted signal and background levels respectively**

To extract limits:

$$-2\ln\lambda \approx \chi^2$$

$$\chi^2 - \chi^2_{min} = 2.706 \quad \equiv 90\%\ \text{C.I.}$$

from Jan Conrad



www.particle.kth.se/~conrad/NuFACT_25082006_Conrad.ppt

Computing the upper limit with python

```
from UnbinnedAnalysis import *
from UpperLimits import *
run the analysis as described earlier
Final values:
  Normalizat = 0.611601
  Integral   = 1.57993
  Index      = 2.32102
  Integral   = 0.43457
  Index      = 2.21217
  Integral   = 1.58454
  Index      = 3.15335
  Prefactor  = 1.29348
  Integral   = 15.6587
  Index      = 2.50804
ul=UpperLimits(analysis)
ul['_3c454'].compute()
>>> v1,v2=ul['_3c454'].compute()
0 15.6587330996 0.000156784255523 1.57338580306e-06
1 15.7965473761 0.0848209382384 1.58725912491e-06
2 15.9343616525 0.326505145233 1.60113212085e-06
3 16.0721759289 0.722714903357 1.61500547877e-06
4 16.2099902053 1.27068113437 1.6288792121e-06
5 16.3478044817 1.9678234919 1.64275331967e-06
>>> print v1
1.63055727541e-06
```