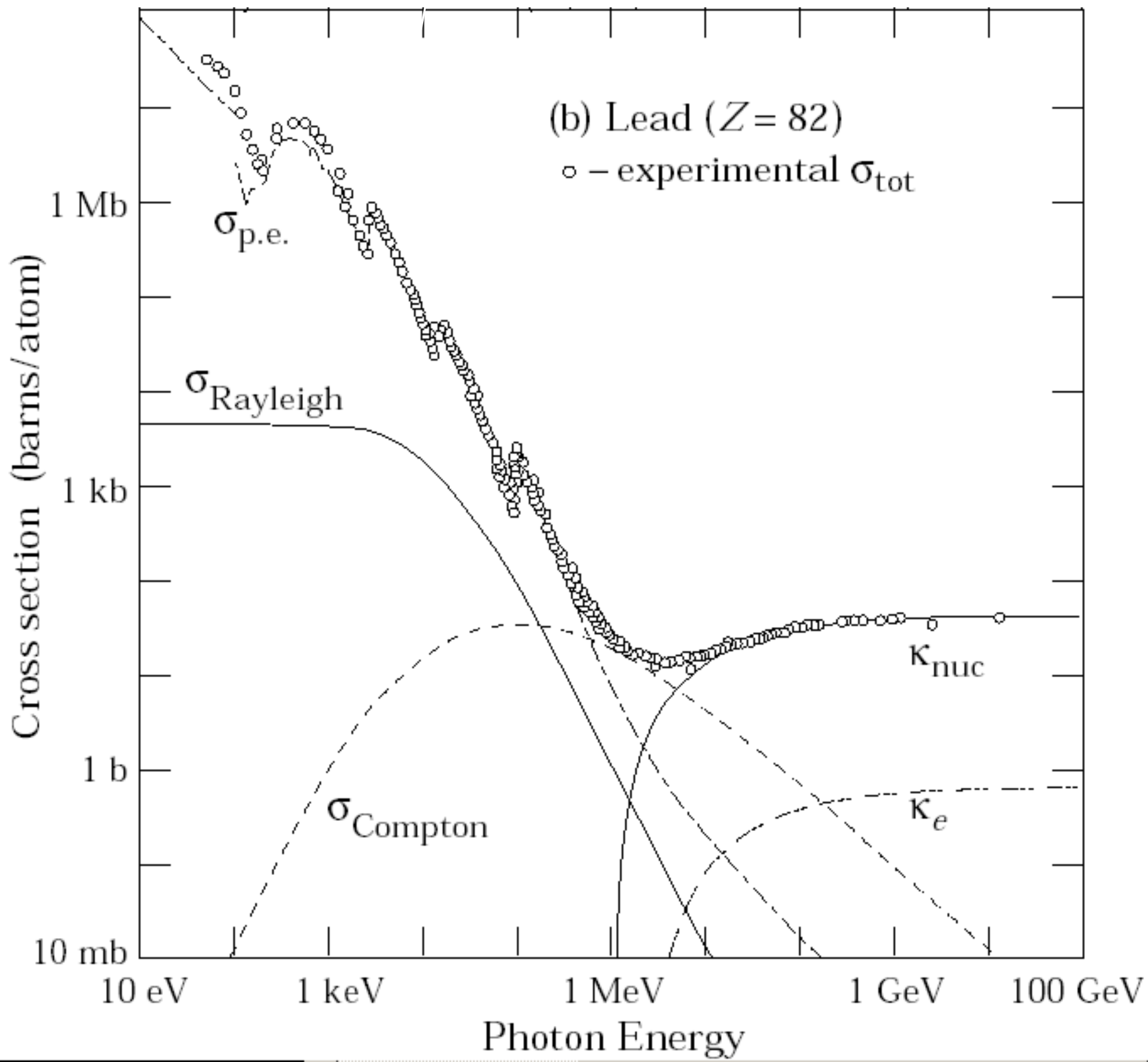
Astrofisica Nucleare e Subnucleare

GeV Astrophysics

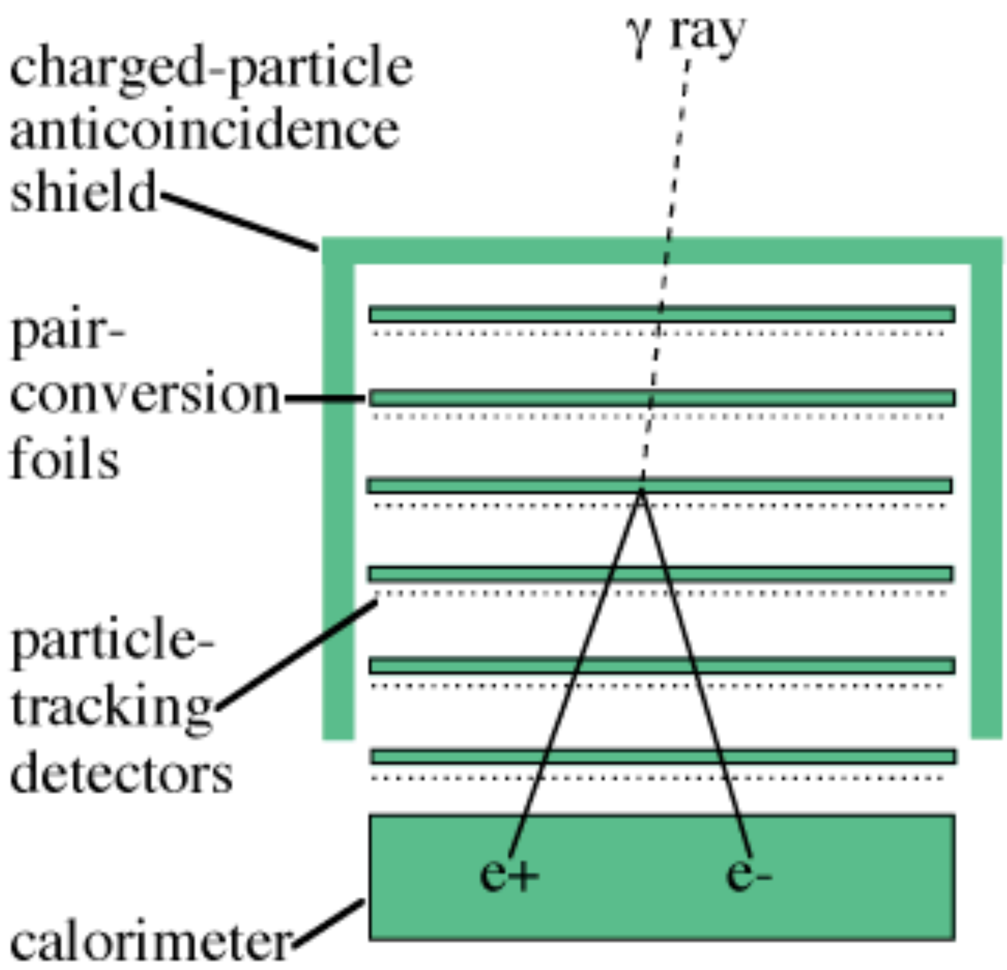
Exercise #4

- Find the web sites of AGILE and Fermi/LAT
- Check the status of future gamma-ray detectors (CALET, DAMPE, Gamma-400(?), HERD)

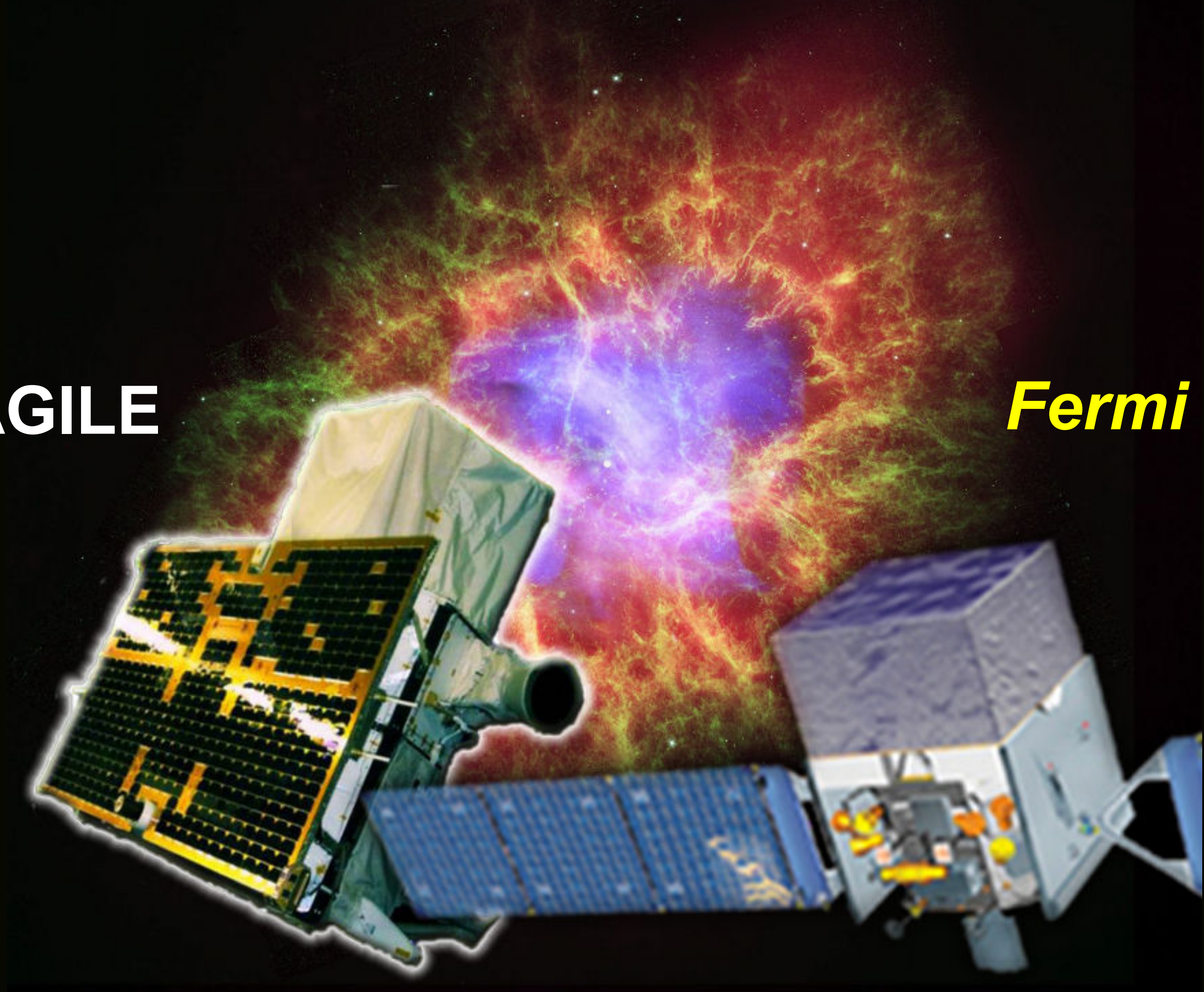
Photon Interactions



Detector Project



Gamma-ray astrophysics above 100 MeV



Picture of the day, Feb. 28, 2011, NASA-HEASARC

Astrofisica Nucleare e Subnucleare

Electromagnetic Showers

ELECTROMAGNETIC SHOWERS

SCIAMI ELETTROMAGNETICI

$$-\frac{dE}{dX} \simeq \frac{E}{X_0}$$

SIA $e^{\pm}$ CHE γ

$E = E_i e^{-\frac{X}{X_0}}$

ΔX DOPO UNA LUNGHEZZA DI RADIAZIONE $= X_0$
(AFTER ONE RADIATION LENGTH)

$$-dE = \frac{E\,dX}{X_0} \qquad \Delta E \simeq E\frac{\Delta X}{X_0} \simeq E$$

RADIAZIONE (RADIATION) $e^{\pm} \rightarrow e^{\pm}\gamma$ BREMSSTRAHLUNG

CONVERSIONE (CONVERSION) $\gamma \rightarrow e^{+}e^{-}$ CREAZIONE COPPIE (PAIR CREATION)

$$1 \rightarrow 2$$

$$E_i \rightarrow 2\left(\frac{E_i}{2}\right)$$

DOPO TANTE LUNGHEZZE DI RADIAZIONE
(AFTER MANY RADIATION LENGTHS)

$$X = t\,X_0 \qquad t = \frac{X}{X_0}$$

$$1 \rightarrow 2^{t} \equiv N$$

$$E_i \rightarrow 2^{t}\left(\frac{E_i}{2^{t}}\right) = N\left(\frac{E_i}{N}\right) = N\,E(t)$$

$$E(t) = \frac{E_i}{N} = \frac{E_i}{2^{t}}$$

QUANDO $E(t)$ ARRIVA A E_c
(WHEN) (REACHES)

DIVENTANO DOMINANTI : $\left(E = \frac{E_i}{N} = E_c\right)$
(BECOME DOMINANT)

PER $e^\pm$: IONIZZAZIONE

PER γ : COMPTON E FOTOELETTRICO

N SMETTE LA CRESCITA ESPONENZIALE

N RAGGIUNGE IL MASSIMO

$$N_{MAX} = \frac{E_i}{E_c}$$

$$N_{MAX} = 2^{t_{MAX}} = \frac{E_i}{E_c}$$

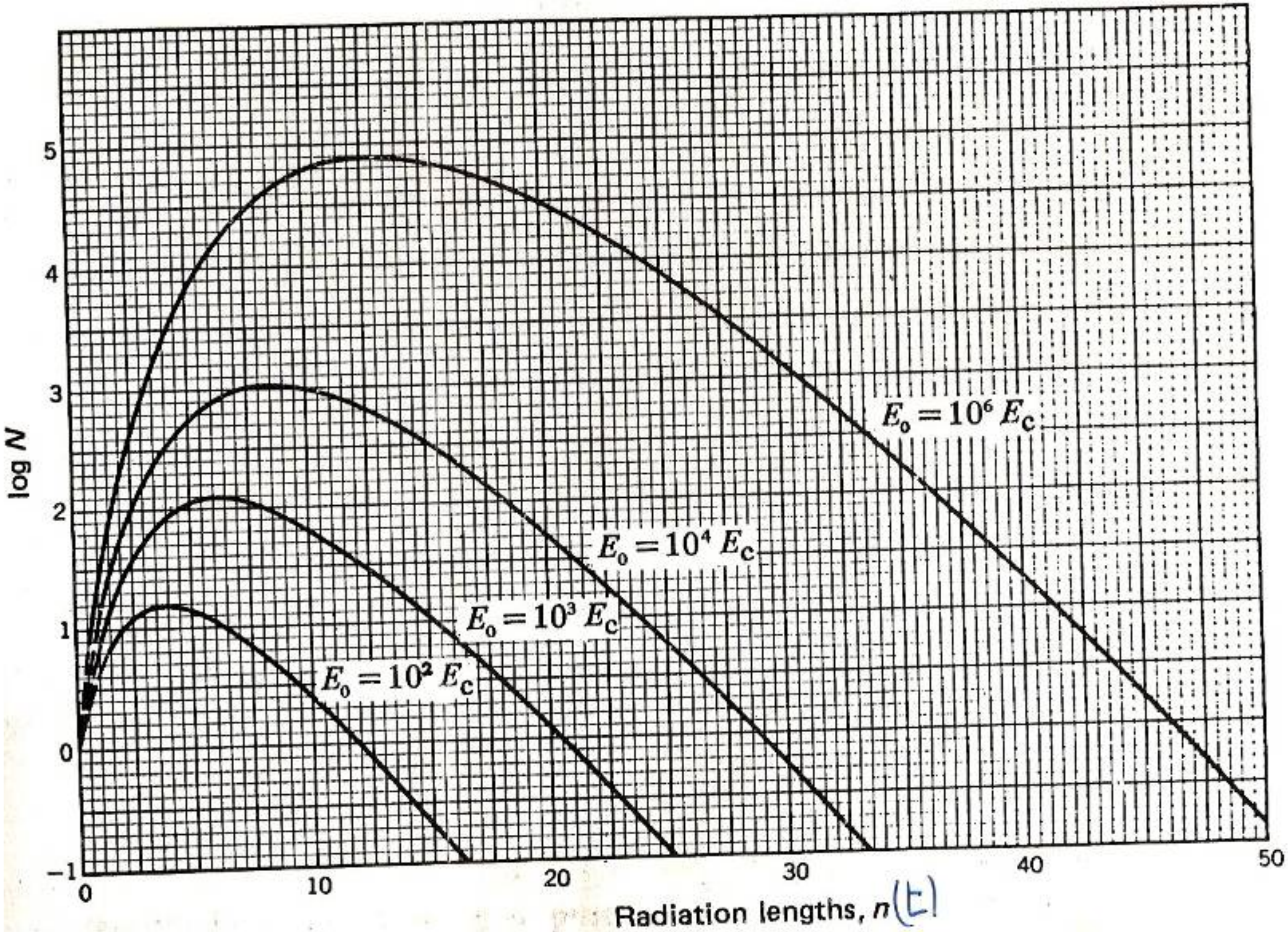
$$t_{MAX} = \ln \frac{E_i}{E_c} \cdot \frac{1}{\ln 2}$$

N POI DECRESCE PER

PROGRESSIVA PERDITA DELLE

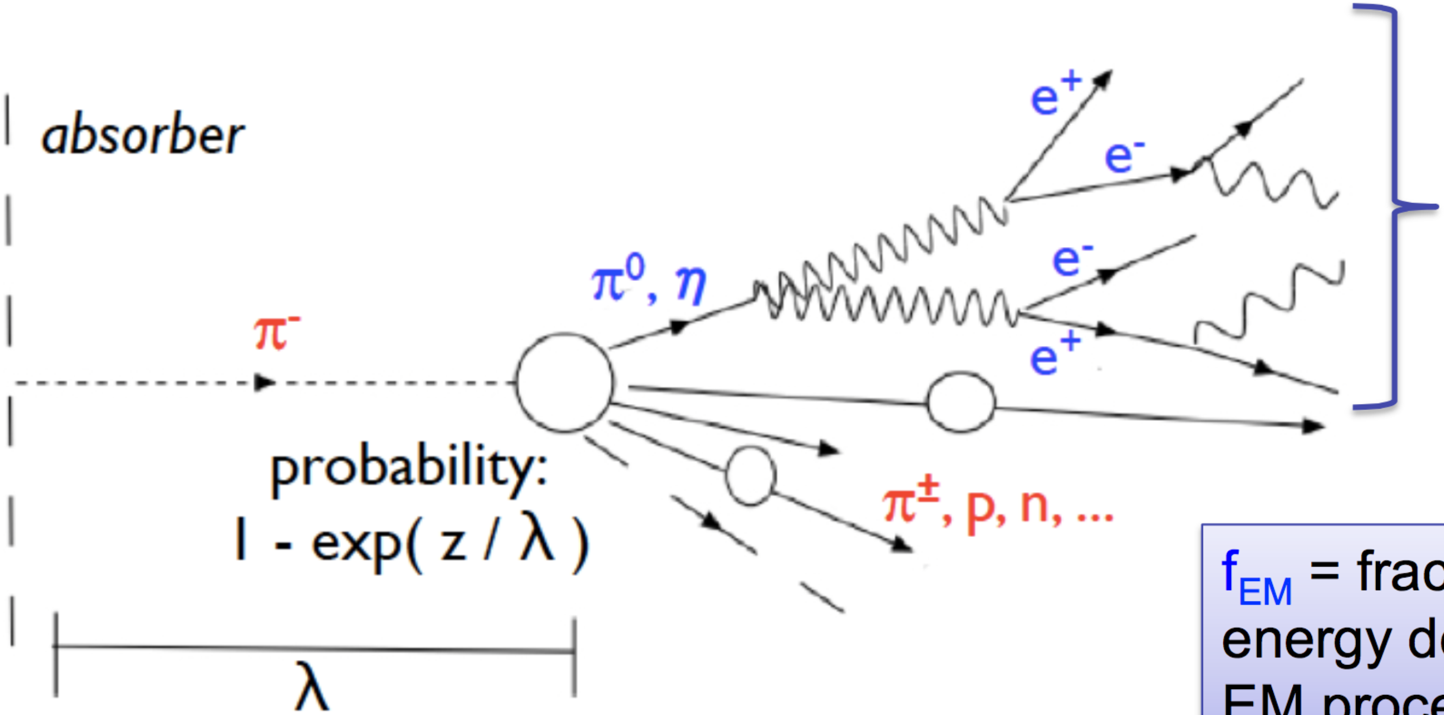
ENERGIE RESIDUE

Fig. 4.6. The total number of particles N in a shower initiated by an electron of energy E_0, as a function of depth n, measured in radiation lengths; E_c is the critical energy of the material. (From Leighton, 1959, p. 693, after Rossi & Greisen, 1941.)



Astrofisica Nucleare e Subnucleare
Hadronic showers

Hadronic showers



π_0 production is a one way street: all energy deposited via EM processes

f_{EM} = fraction of hadron energy deposited via EM processes

Electromagnetic → ionization, excitation (e±)
→ photo effect, scattering (γ)

Hadronic → ionization (π±, p)
→ invisible energy (binding, recoil)

Hadronic shower

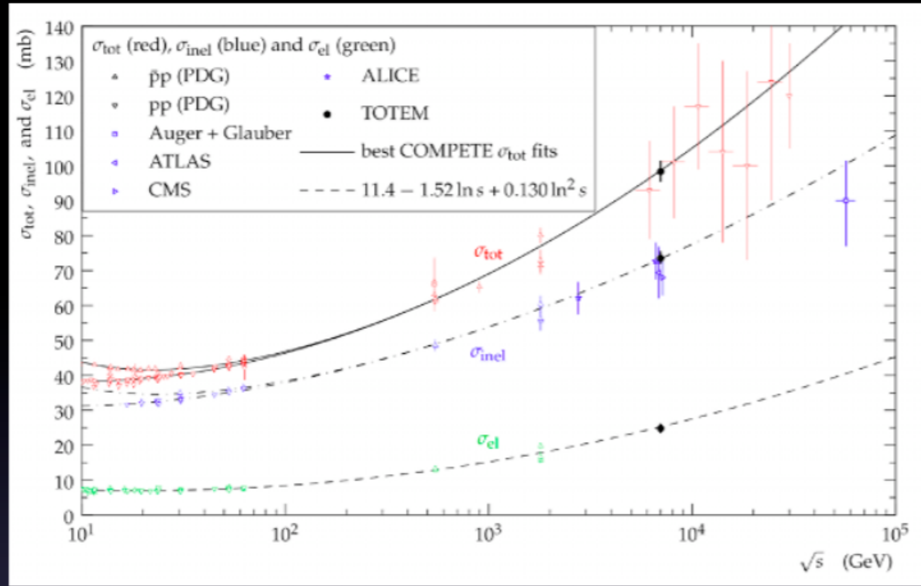
- Hadronic interaction Cross section

$$\sigma_{Tot} = \sigma_{el} + \sigma_{inel}$$

$$\sigma_{el} \approx 10mb \qquad \sigma_{inel} \approx A^{2/3}$$

$$\sigma_{Tot} = \sigma_{tot}(pp)A^{2/3}$$

where: $\sigma_{tot}(pp)$ increases with $\sqrt{s}$



- Hadronic interaction length

$$\lambda_{\text{int}} = \frac{1}{\sigma_{tot} \cdot n} = \frac{A\rho}{\sigma_{pp} A^{2/3} N_A} \approx \left(35g/cm^2\right) A^{1/3}$$

$$N(x) = N(0)e^{-x/\lambda_{\text{int}}}$$

- λ_{int} characterizes both longitudinal and transverse shower profile

Rule of thumb argument: the geometric cross section goes as the square of the size of the nucleus, a_N^2, and since the nuclear radius scales as $a_N \sim A^{1/3}$, the nuclear mean free path in gm/cm^2 units scales as $A^{1/3}$.

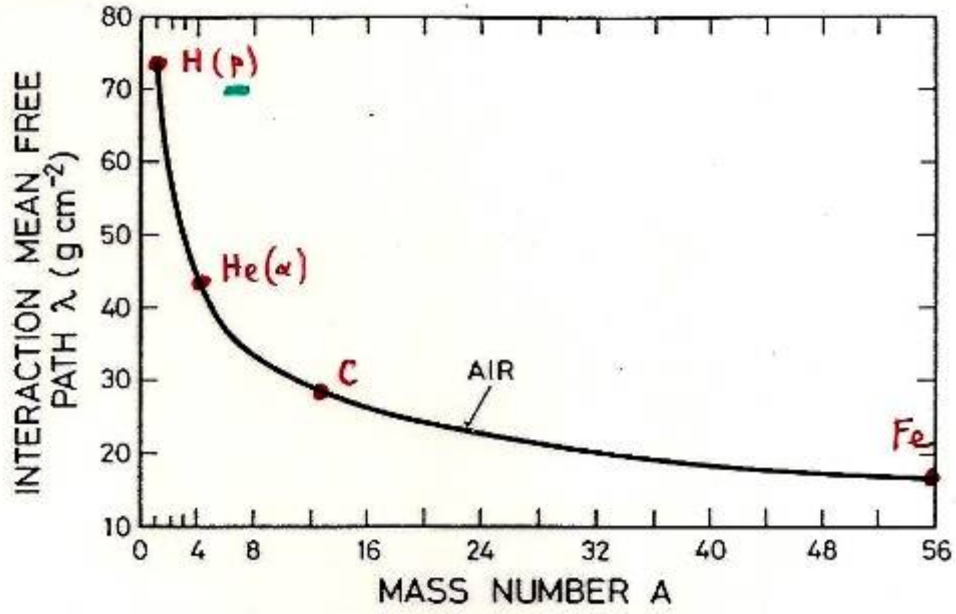


Fig. 1.1.1: Interaction mean free path for high energy nuclear interactions in air versus projectile mass.

$X_{INT.\ NUCL.} \longrightarrow \lambda_I$

Table 5. *Radiation length X_0, critical energy E_c and hadronic absorption length λ_{had}^{int} for some materials*

Material	X_0 (g/cm²)	Kg/m²	E_c (MeV)	λ_{had} (g/cm²)
H_2	63	630	340	52.4
Al	24	240	47	106.4
Ar	20	200	35	119.7
Fe	13.8	138	24	131.9
Pb	6.3	63	6.9	193.7
Lead glass SF 5	9.6	96	~ 11.8	
Plexiglas	40.5	405	80	83.6
H_2O	36	360	93	84.9
NaI(Tl)	9.5	95	12.5	152.0
$Bi_4Ge_3O_{12}$	8.0	80	10.5	164

Hadronic shower

Hadronic interaction:

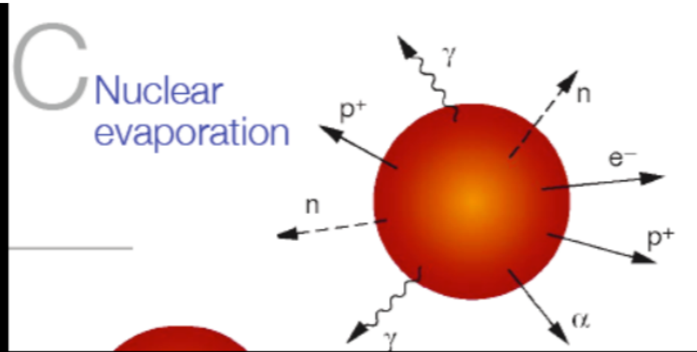
Elastic:

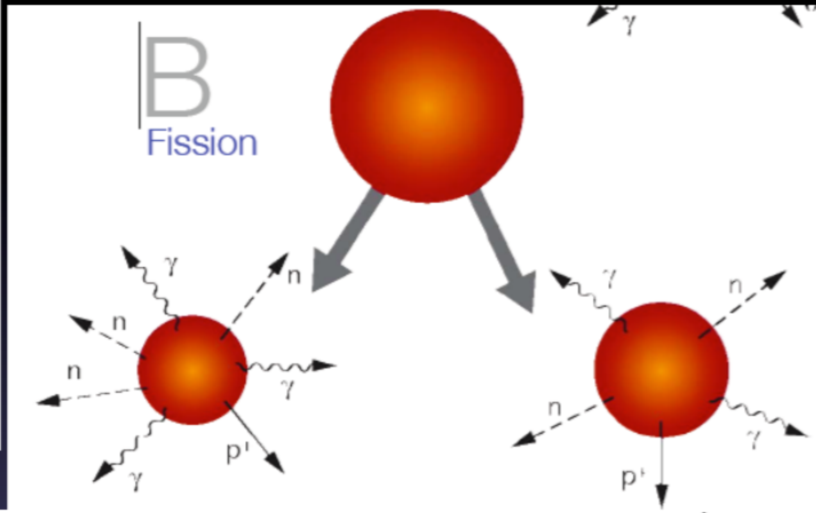
$$p + \text{Nucleus} \rightarrow p + \text{Nucleus}$$

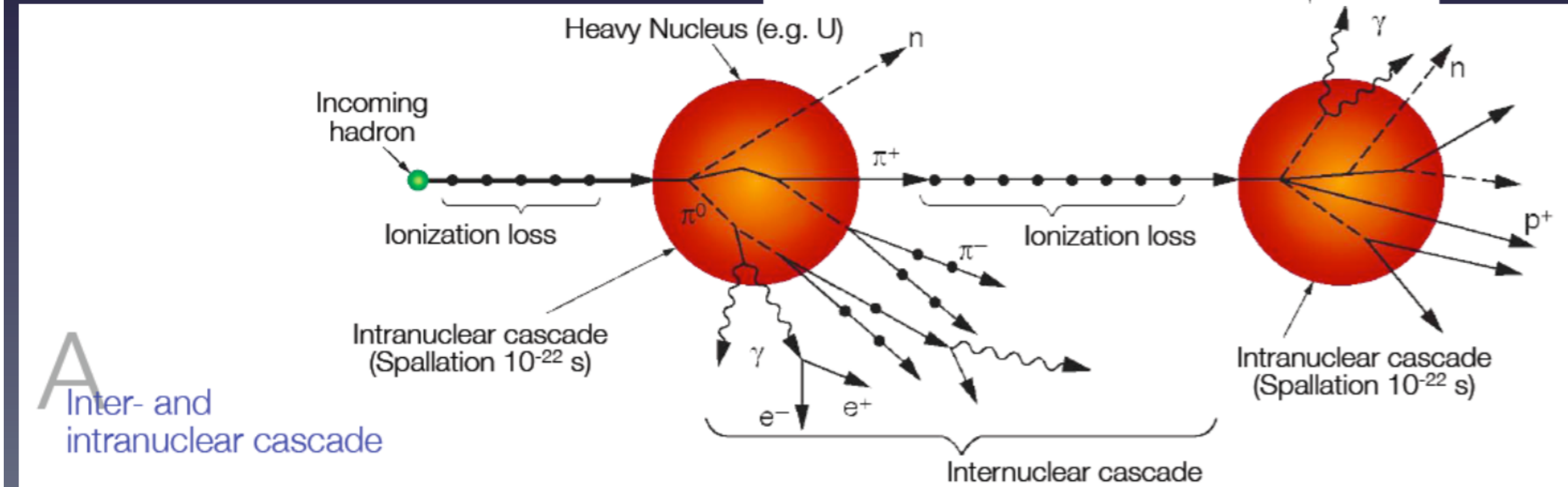
Inelastic:

$$p + \text{Nucleus} \rightarrow$$
$$\pi^+ + \pi^- + \pi^0 + \ldots + \text{Nucleus}^*$$

$$\left[\begin{array}{l} \text{Nucleus}^* \rightarrow \text{Nucleus A} + n, p, \alpha, \ldots \\ \qquad\quad\ \ \rightarrow \text{Nucleus B} + 5p, n, \pi, \ldots \\ \qquad\quad\ \ \rightarrow \text{Nuclear fission} \end{array}\right]$$

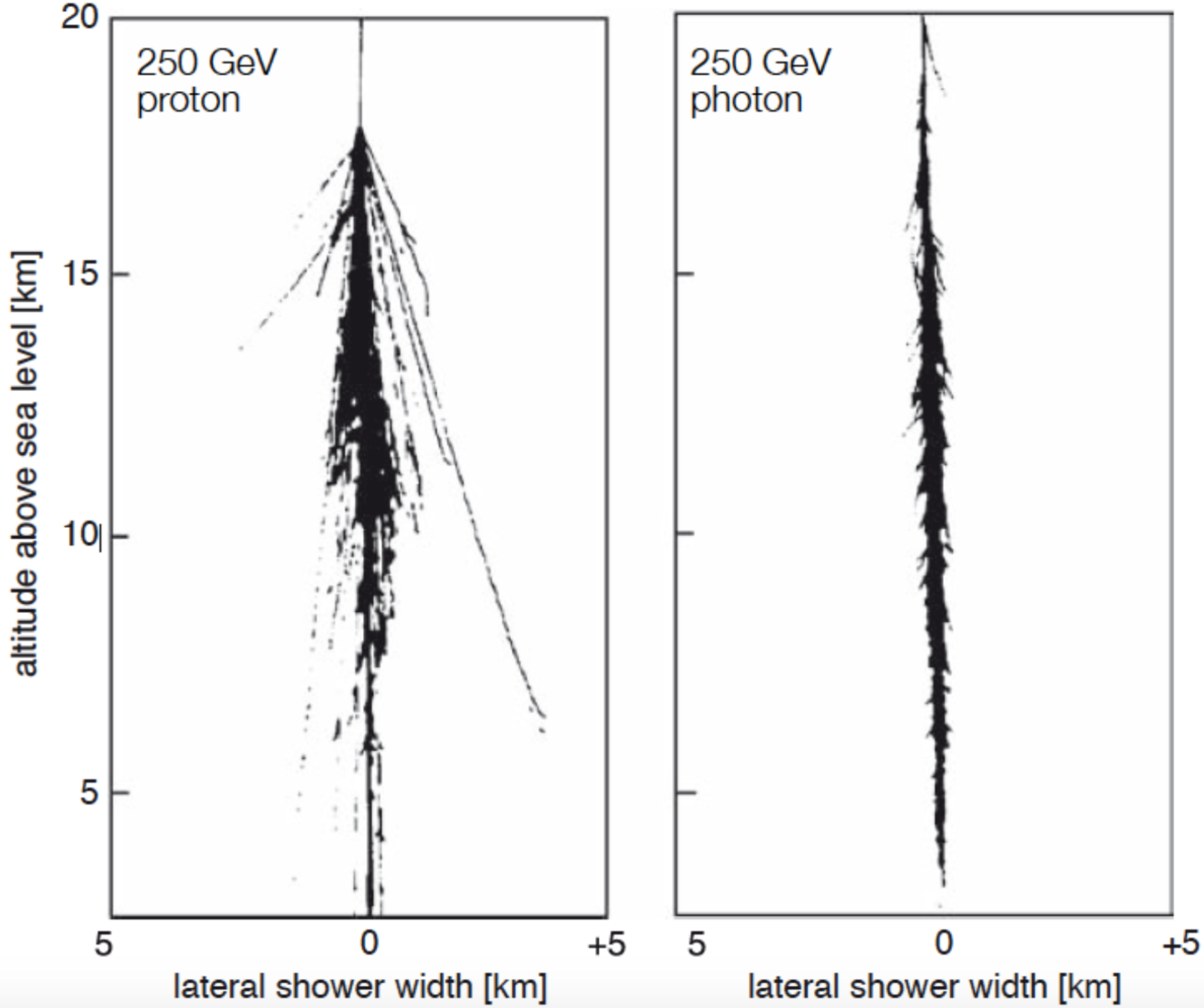






Courtesy of H. C. Schoultz Coulon

Comparison hadronic vs EM showers

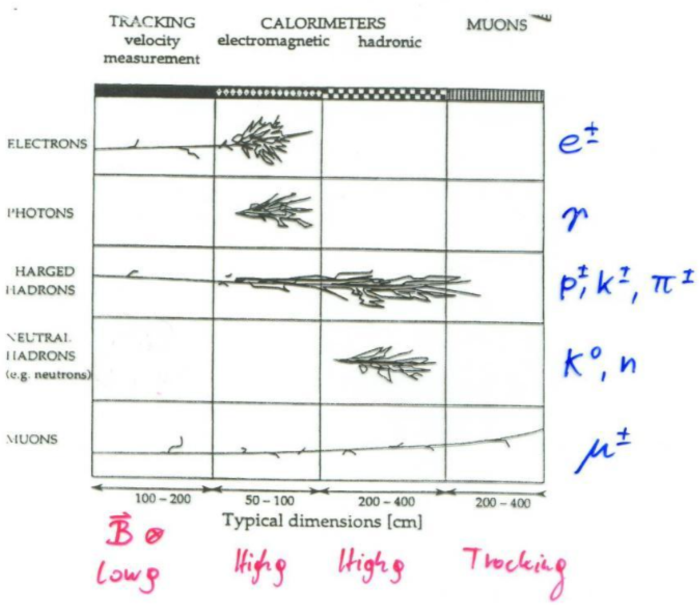


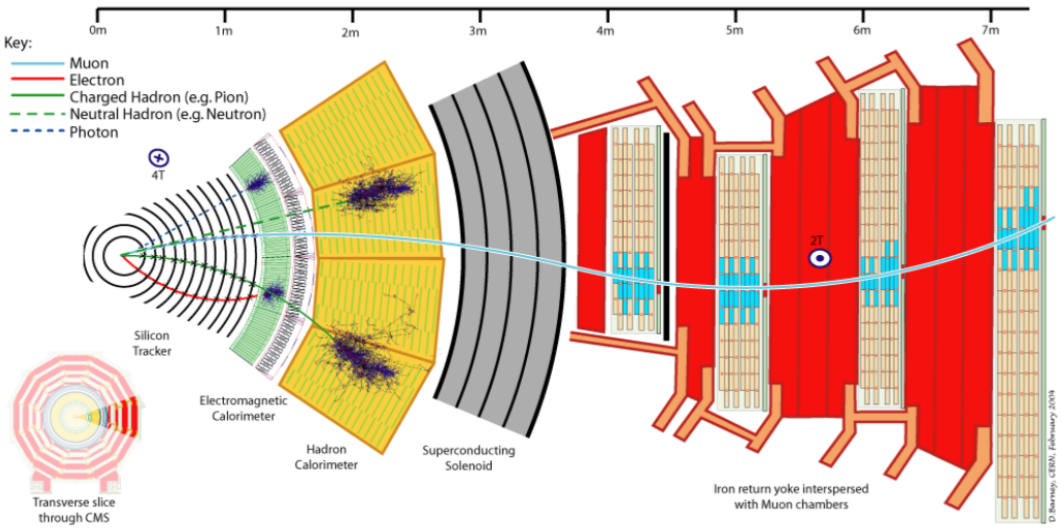
Simulated air showers

Astrofisica Nucleare e Subnucleare

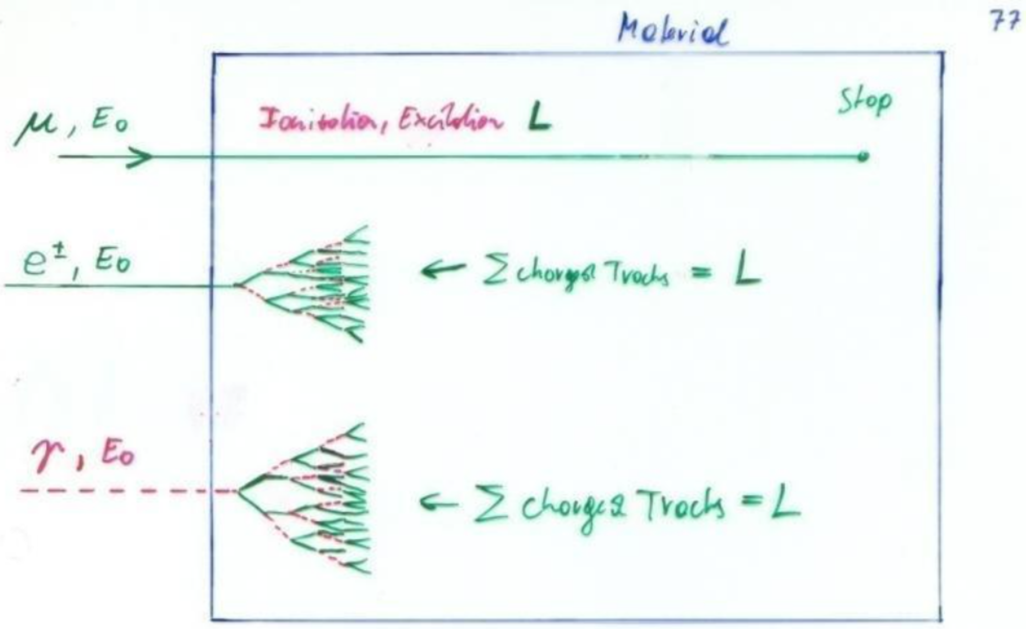
Calorimeters

Calorimetry





Calorimetry: Energy Measurement by total Absorption of Particles



The $e^{\pm}$ in the Calorimeter ionize and excite the Material

Ionization: e^-, I^+ pairs in the Material

Excitation: Photons in the Material

Measuring the total Number of e^-, I^+ pairs or the total Number of Photons gives the particle Energy.

If N is the total Number of e^+, I^+ pairs or photons, $N = c_1 E_0$:

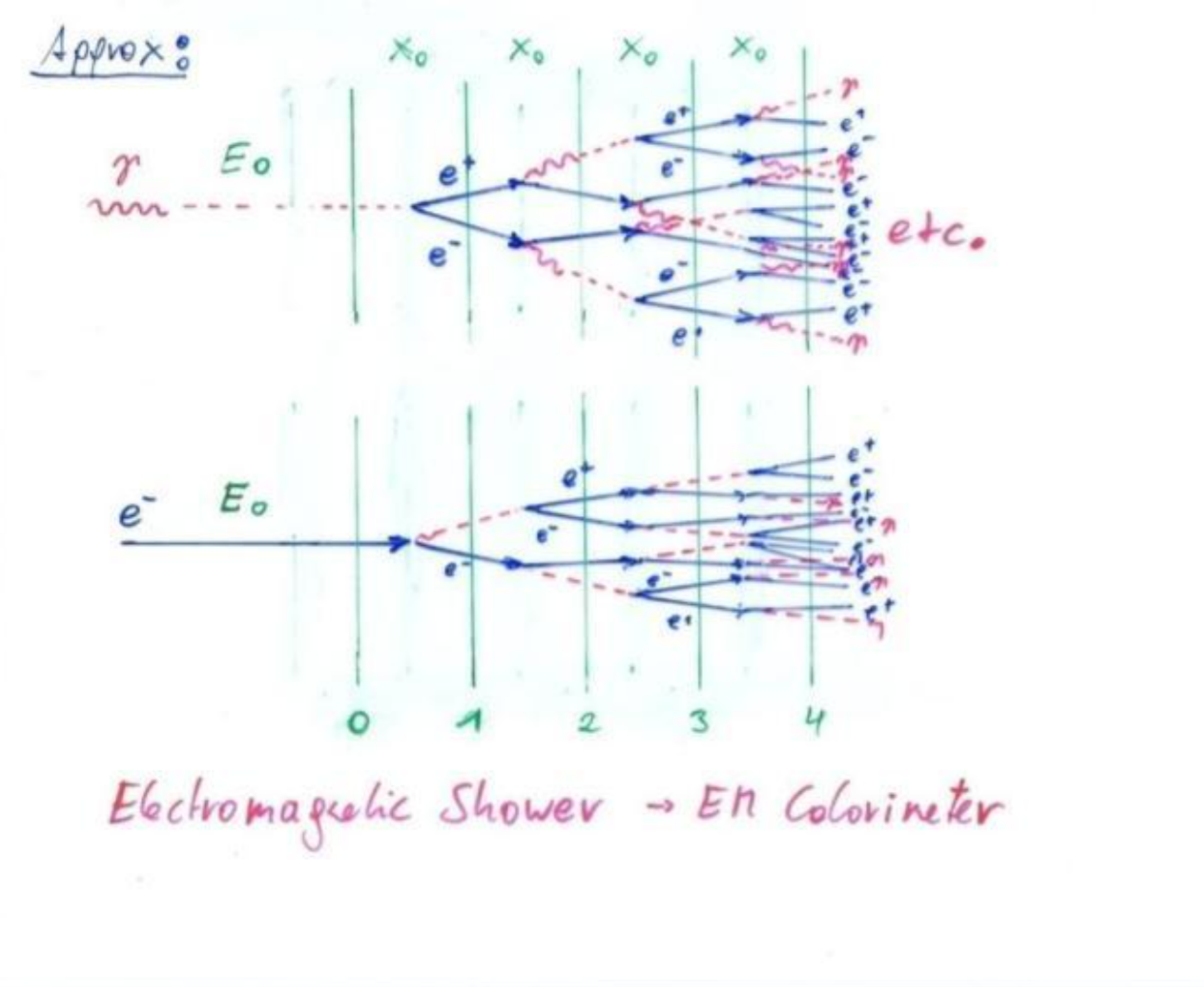
$\Delta N = \sqrt{N}$ (Poisson Statistics)

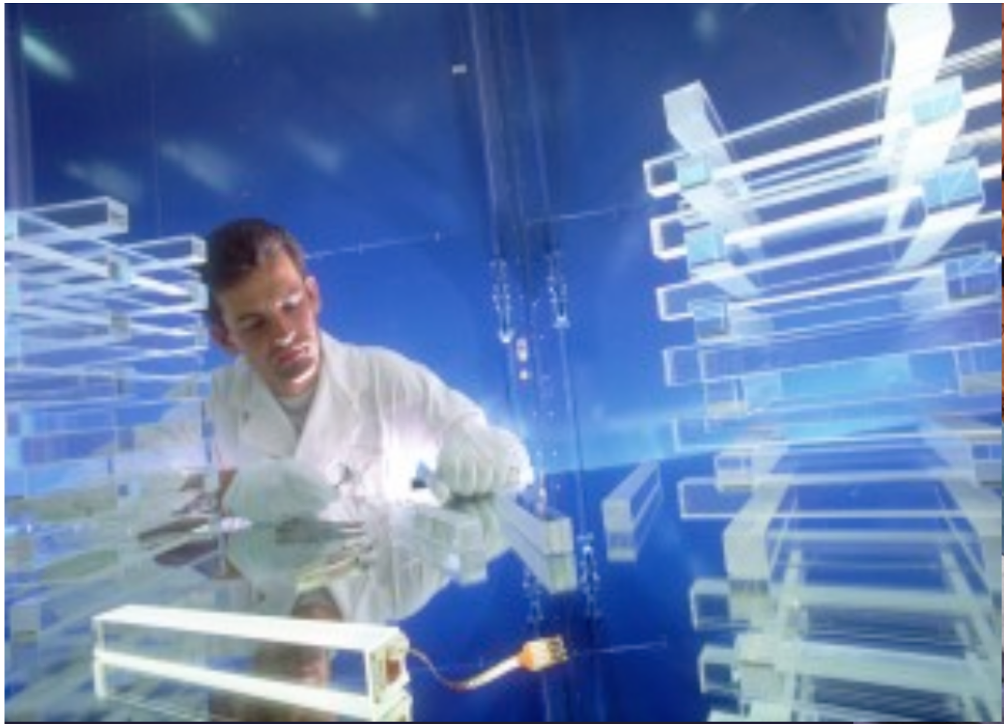
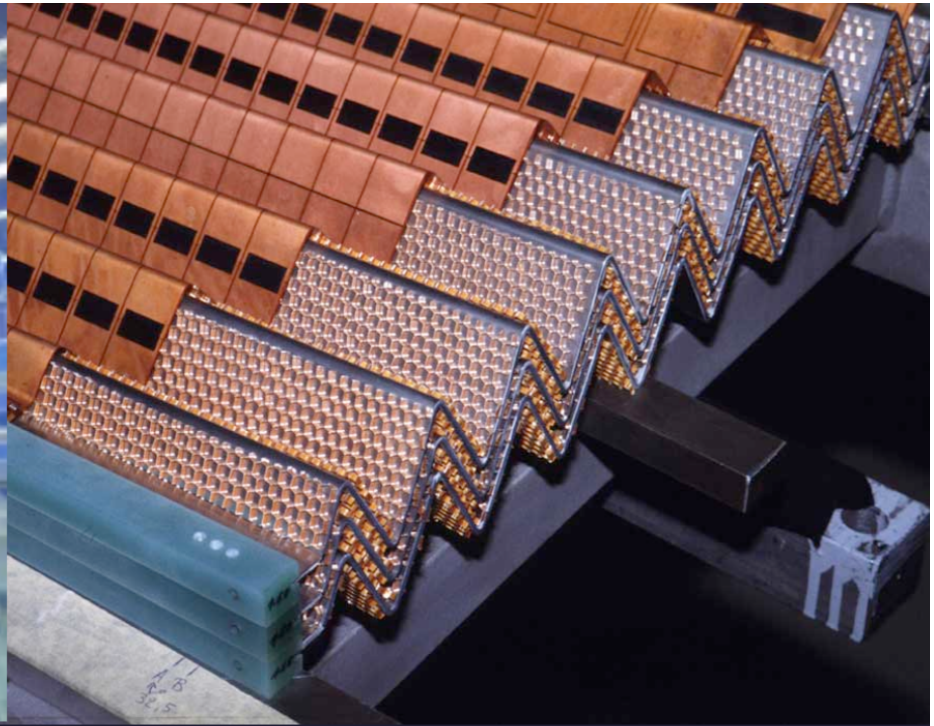
$$\frac{\Delta E}{E} = \frac{\Delta N}{N} = \frac{1}{\sqrt{N}} = \frac{a}{\sqrt{E}} \rightarrow \text{Resolution}$$

Only Electrons and High Energy Photons show EM cascades at current GeV-TeV level Energies.

Strongly interacting particles like Pions, Kaons, produce hadonic showers in a similar fashion to the EM cascade →Hadronic calorimetry

Bremsstrahlung + Pair Production → EM Shower



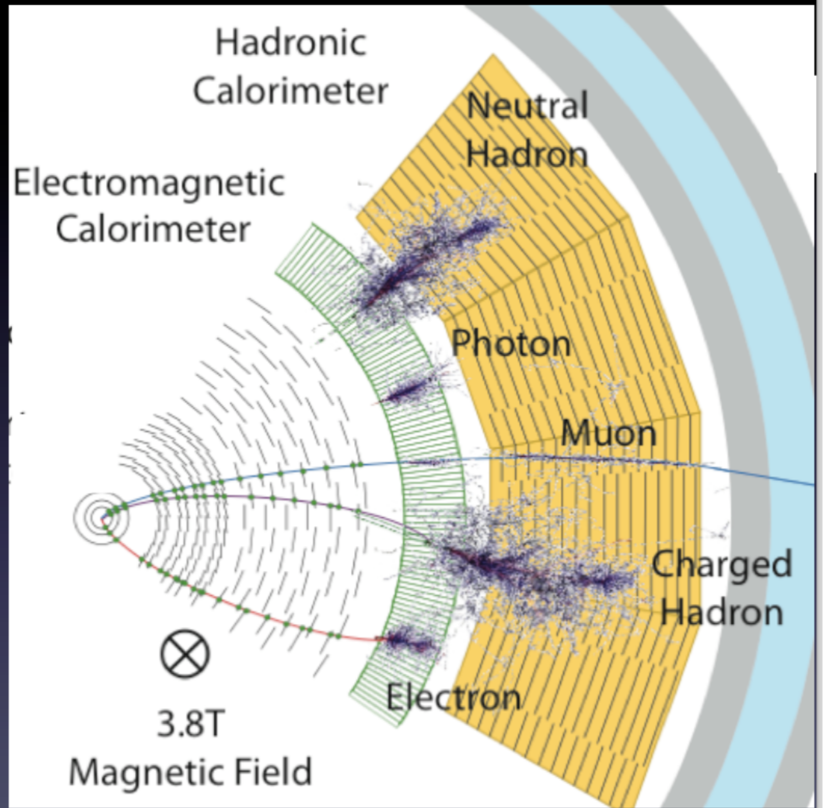
Detectors for Particle Physics

Calorimetry

D. Bortoletto

What is a calorimeter ?

- In nuclear and particle physics calorimetry refers to the detection of particles through total absorption in a block of matter
  - The measurement process is destructive for almost all particle
  - The exception are muons (and neutrinos) → identify muons easily since they penetrate a substantial amount of matter
- In the absorption, almost all particle's energy is eventually converted to heat → calorimeter
- Calorimeters are essential to measure neutral particles



Electromagnetic shower

- Dominant processes at high energies (E > few MeV) :

- Photons: Pair production

$$\sigma_{pair} \approx \frac{7}{9}\left(4\alpha r_e^2 Z^2 \ln\frac{183}{Z^{1/3}}\right) = \frac{7}{9}\frac{A}{N_A X_0}$$

$$I(x) = I_0 e^{-\mu x} \qquad \mu = \frac{7}{9}\frac{\rho}{X_0}$$

μ= attenuation coefficient
X_0 = radiation length in [cm] or [g/cm^2]

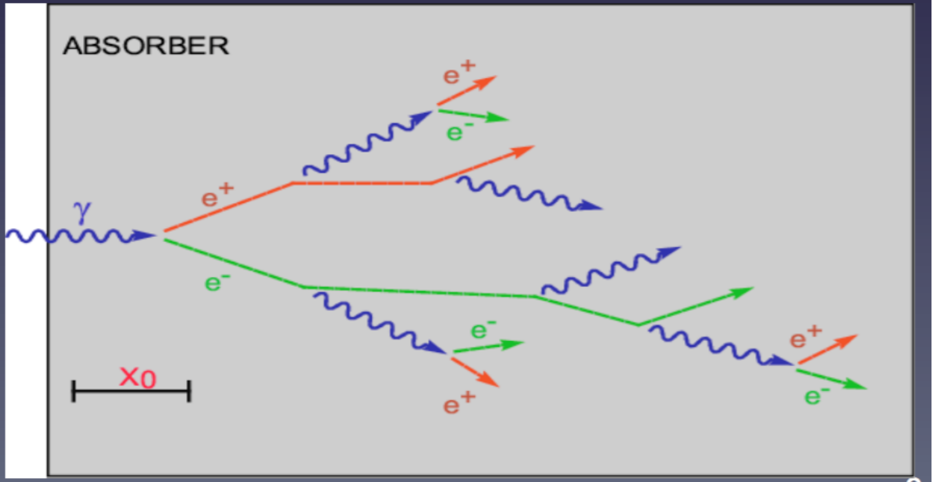
$$X_0 = \frac{A}{4\pi N_A Z^2 r_e^2 \ln\frac{183}{Z^{1/3}}}$$

- Electrons: Bremsstrahlung

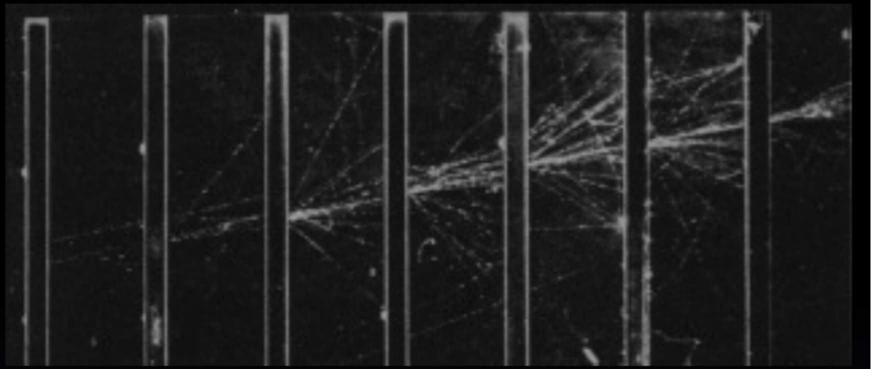
$$\frac{dE}{dx} = 4\alpha N_A \frac{Z^2}{A} r_e^2 E \ln\frac{183}{Z^{1/3}} = \frac{E}{X_0}$$

$$E = E_0 e^{-x/X_0}$$

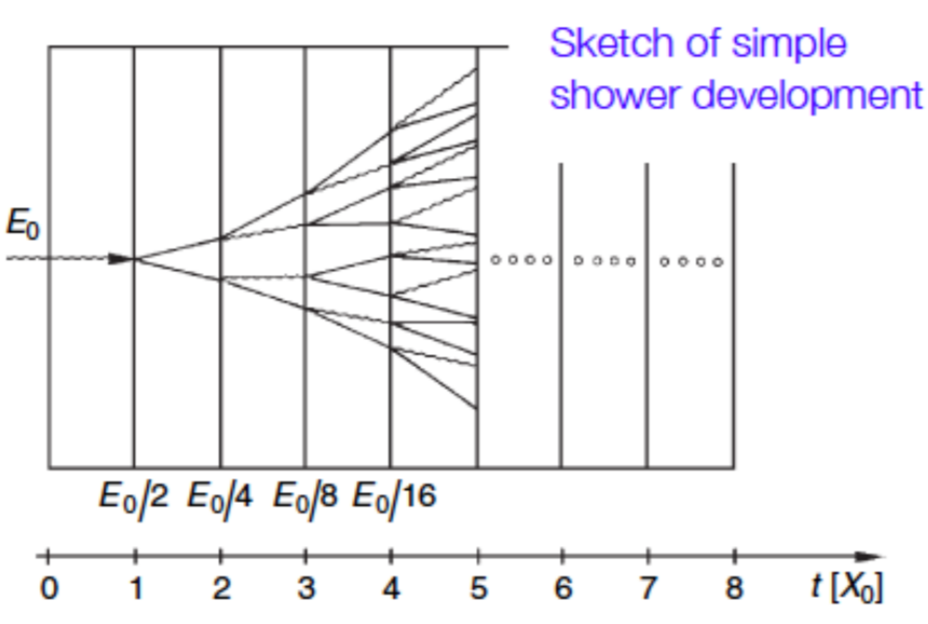
After traversing $x=X_0$ the electron has only 1/e=37% of its initial energy



Analytic shower Model



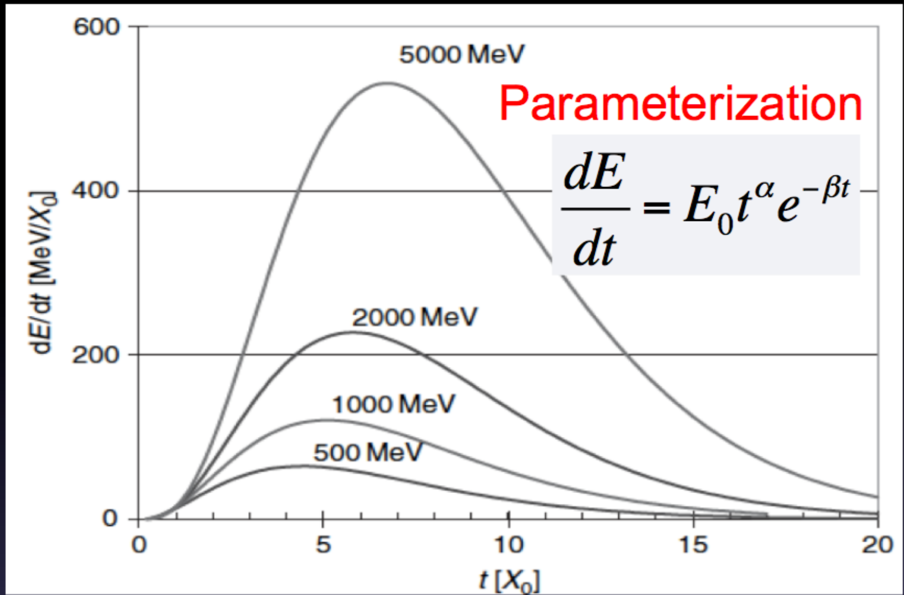
- Simplified model [Heitler]: shower development governed by X_0
  - e^- loses [1 - 1/e] = 63% of energy in 1 X_0 (Brems.)
  - the mean free path of a γ is 9/7 X_0 (pair prod.)
- Assume:
  - E > E_c : no energy loss by ionization/excitation
- Simple shower model:
  - $N(t)=2^t$ particles after $t = x/X_0$ each with energy $E(t)=E_0/2^t$
  - Stops if E (t) < $\mathbf{E_c=E_0 2^{tmax}}$
  - Location of shower maximum at

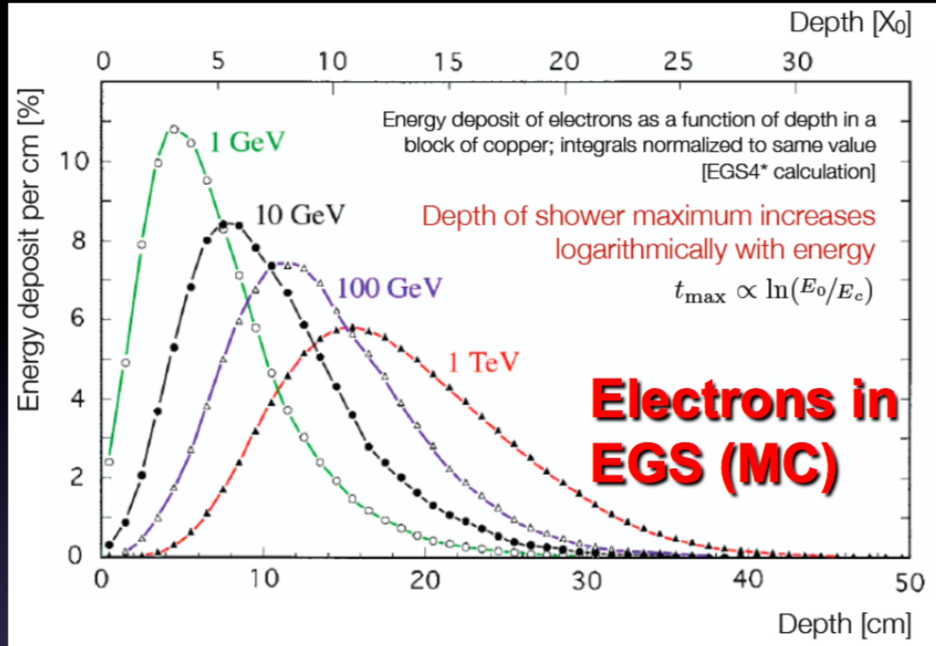


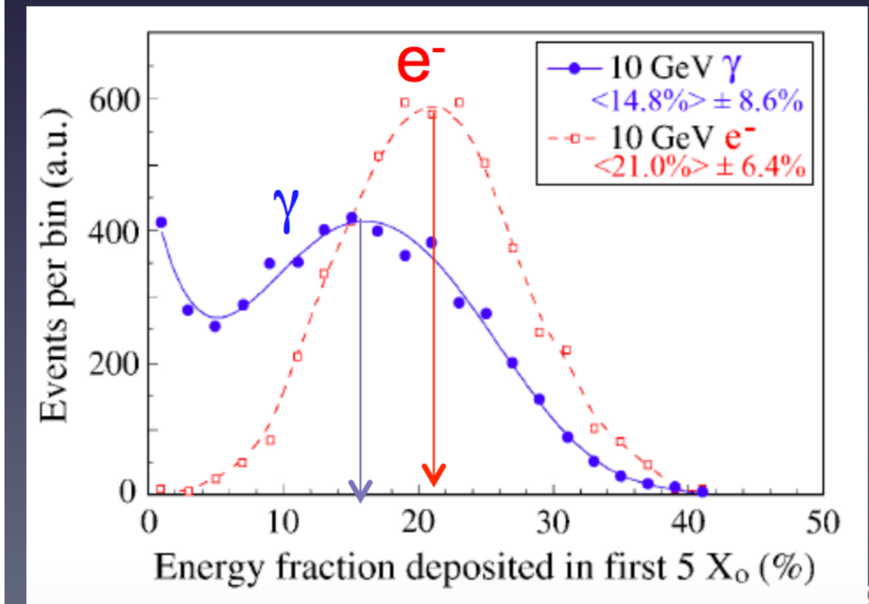
$$t_{\max} = \frac{\ln(E/Ec)}{\ln 2} \propto \ln\left(\frac{E}{E_c}\right)$$

$$N_{\max} = 2^{t_{\max}} = \frac{E_0}{E_C}$$

Longitudinal shower distribution







- Differences between electrons and photons generated showers
- Some photons penetrating (almost) the entire slab without interacting (peak at 0)

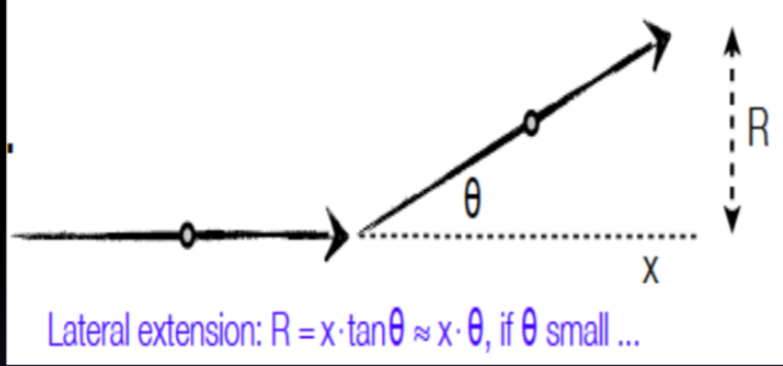
$$t_{max} = \ln\left(\frac{E_0}{E_c}\right) + C_{e\gamma}$$

$C_{e\gamma}$=-0.5 for photons
$C_{e\gamma}$=-1 for electrons

Lateral development of EM shower

- Opening angle:
  - bremsstrahlung and pair production

$$\langle \theta^2 \rangle \approx \left(\frac{m_e c^2}{E_e} \right)^2 = \frac{1}{\gamma^2}$$



  - multiple coulomb scattering [**Molière** theory]

$$\langle \theta \rangle = \frac{E_s}{E_e} \sqrt{\frac{x}{X_0}} \quad \text{where} \quad E_s = \sqrt{\frac{4\pi}{\alpha}} \left(m_e c^2 \right) = 21.2 MeV$$

- Main contribution from low energy e^- as $<\theta> \sim 1/E_e$, i.e. for e^- with $E < E_c$

- **Molière** Radius

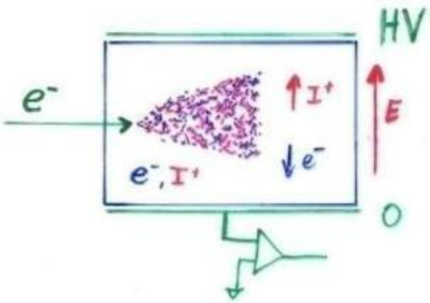
$$R_M = \frac{E_s}{E_c} X_0 \approx \frac{21.2 MeV}{E_c} X_0$$

- Assuming the approximate range of electrons to be X_0 yields $<\theta> \approx 21.2$ MeV/E_e ➛ lateral extension: $R = <\theta> X_0$

Calorimetry: Energy Measurement by total Absorption of Particles

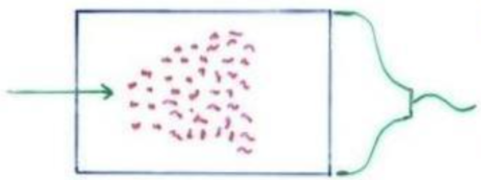
The measurement is destructive. The particle can not be subject to further study.

Energy Measurement by



Collecting the produced Charge

Liquid Nobel Gases (Nobel Liquids)



Measuring the Photons produced by the collision of the $e^\pm$ with Atom Electrons of the material.

Scintillating Crystals, Plastic Scintillators

Total Amount of e^-, I^+ pairs or Photons is proportional to the total track length is proportional to the particle Energy.

Calorimetry

Calorimeters can be classified into:

Electromagnetic Calorimeters,
to measure electrons and photons through their EM interactions.

Hadron Calorimeters,
Used to measure hadrons through their strong and EM interactions.

The construction can be classified into:

Homogeneous Calorimeters,
that are built of only one type of material that performs both tasks, energy degradation and signal generation.

Sampling Calorimeters,
that consist of alternating layers of an absorber, a dense material used to degrade the energy of the incident particle, and an active medium that provides the detectable signal.

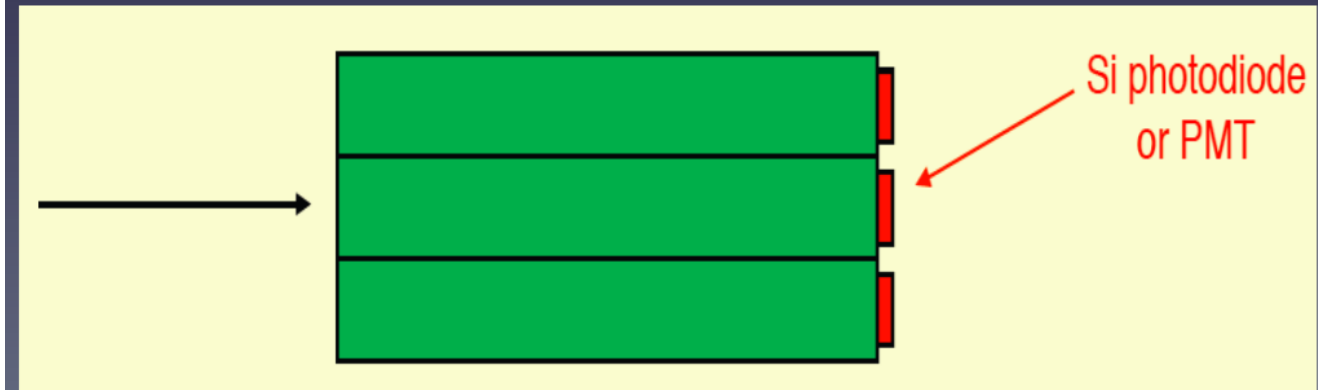
C.W. Fabjan and F. Gianotti, Rev. Mod. Phys., Vol. 75, N0. 4, October 2003

EM Calorimeter configurations

- Total absorption
  - Electrons and photons stop in calorimeter
  - Scintillation proportional to energy of electron
  - Usually non-organic scintillator (BGO, $PbWO_{4,...}$) or liquid Xe
  - Advantage: Excellent energy resolution
    - see all charged particles in the shower (but for shower leakage) ➔best statistical precision
    - Uniform response ➔good linearity
  - Disadvantages:
    - cost and limited segmentation

If W is the mean energy required to produce a signal (eg an e^--ion pair in a noble liquid or a 'visible' photon in a crystal)

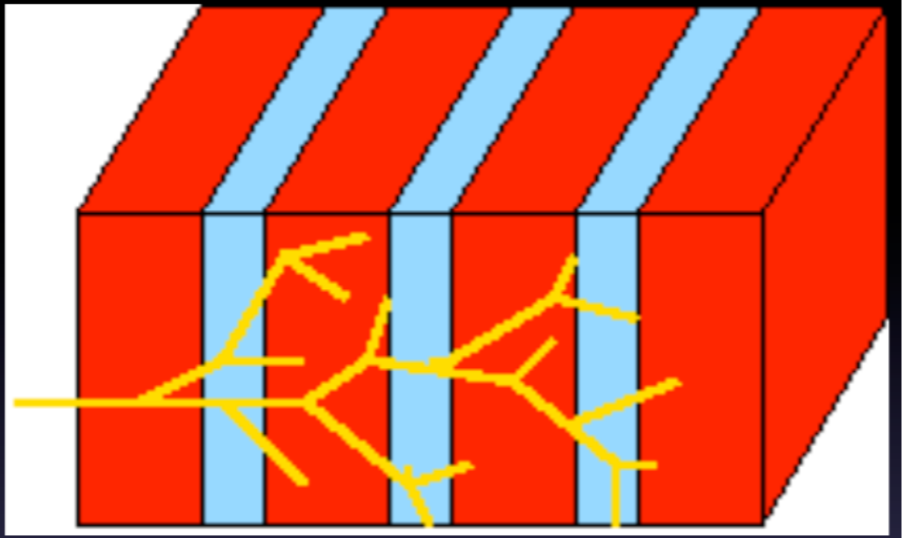
$$\frac{\sigma_E}{E} = \frac{1}{\sqrt{n}} = \frac{1}{\sqrt{E/W}}$$



- Examples:
  - B factories: small photon energies
  - CMS ECAL which was optimized for $H \to \gamma\gamma$

EM Calorimeter configurations

- Sampling Calorimeter
  - One material to induce showering (high Z)
  - Another to detect particles (typically by counting number of charged tracks)
  - Many layers sandwiched together
  - Resolution $\propto E^{-1/2}$
- Advantages
  - Depth segmentation
  - Spatial segmentation
- Disadvantages:
  - Only part of shower seen, less precise
- Examples
  - ATLAS ECAL
  - Most HCALs



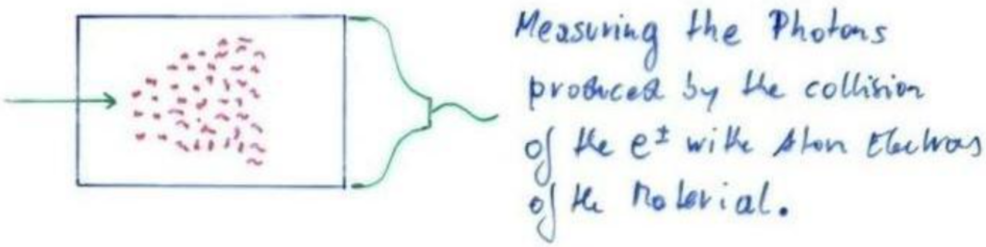
- Sampling fraction

$$f_{sampling} = \frac{E_{visible}}{E_{deposited}}$$

Crystals for Homogeneous EM Calorimetry

In crystals the light emission is related to the crystal structure of the material. Incident charged particles create electron-hole pairs and photons are emitted when electrons return to the valence band.

The incident electron or photon is completely absorbed and the produced amount of light, which is reflected through the transparent crystal, is measured by photomultipliers or solid state photon detectors.



Crystals for Homogeneous EM Calorimetry

	NaI(Tl)	CsI(Tl)	CsI	BGO	$PbWO_4$
Density (g/cm^3)	3.67	4.53	4.53	7.13	8.28
X_0 (cm)	2.59	1.85	1.85	1.12	0.89
R_M (cm)	4.5	3.8	3.8	2.4	2.2
Decay time (ns)	250	1000	10	300	5
slow component			36		15
Emission peak (nm)	410	565	305	410	440
slow component			480		
Light yield γ/MeV	4×10^4	5×10^4	4×10^4	8×10^3	1.5×10^2
Photoelectron yield (relative to NaI)	1	0.4	0.1	0.15	0.01
Rad. hardness (Gy)	1	10	10^3	1	10^5

Barbar@PEPII, 10ms interaction rate, good light yield, good S/N

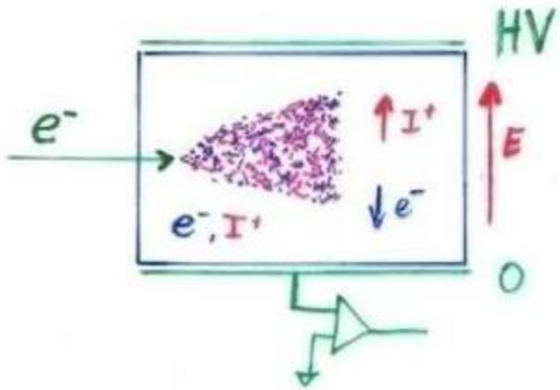
KTeV@Tevatron, High rate, Good resolution

L3@LEP, 25us bunch crossing, Low radiation dose

CMS@LHC, 25ns bunch crossing, high radiation dose

Noble Liquids for Homogeneous EM Calorimetry

	Ar	Kr	Xe
Z	18	36	58
A	40	84	131
X_0 (cm)	14	4.7	2.8
R_M (cm)	7.2	4.7	4.2
Density (g/cm^3)	1.4	2.5	3.0
Ionization energy (eV/pair)	23.3	20.5	15.6
Critical energy ϵ (MeV)	41.7	21.5	14.5
Drift velocity at saturation (mm/μs)	10	5	3

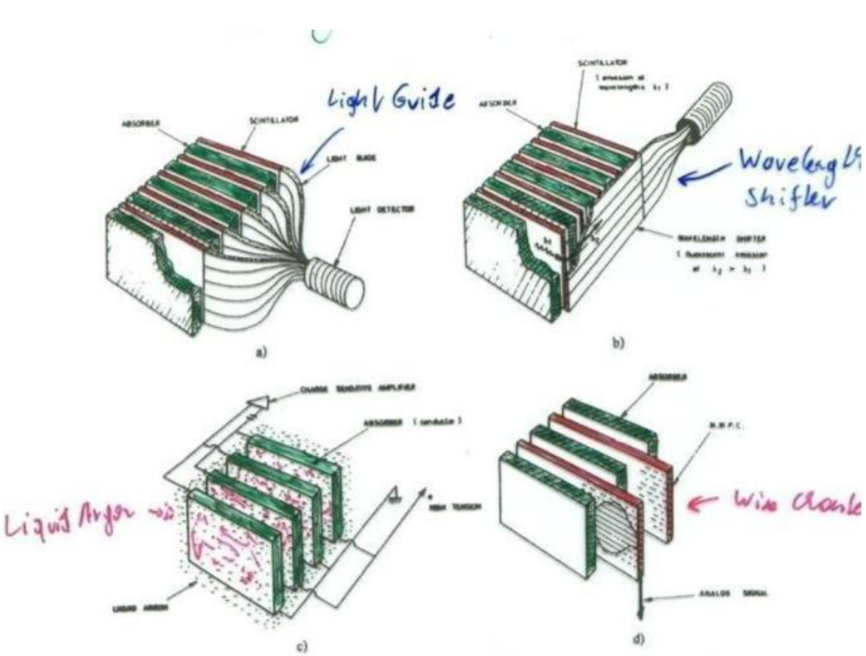


When a charge particle traverses these materials, about half the lost energy is converted into ionization and half into scintillation.

The best energy resolution would obviously be obtained by collecting both the charge and light signal. This is however rarely done because of the technical difficulties to extract light and charge in the same instrument.

Krypton is preferred in homogeneous detectors due to small radiation length and therefore compact detectors. Liquid Argon is frequently used due to low cost and high purity in sampling calorimeters (see later).

Sampling Calorimeters



Alternation of "passive" absorber plates and "active" readout sections

Advantage:
- optimum choice of Absorber Material
- optimum choice of Signal Readout
- Compact and cheap Construction

"passive": Pb, Fe ....

"active": Scintillator (Signal → Photons)

Noble Liquid, e.g. Ar (Signal → e^-, I^+)

Wire Chambers (Signal → e^-, I^+)

Energy resolution of sampling calorimeters is in general worse than that of homogeneous calorimeters, owing to the sampling fluctuations – the fluctuation of ratio of energy deposited in the active and passive material.

The resolution is typically in the range 5-20%/Sqrt[E(GeV)] for EM calorimeters. On the other hand they are relatively easy to segment longitudinally and laterally and therefore they usually offer better space resolution and particle identification than homogeneous calorimeters.

The active medium can be scintillators (organic), solid state detectors, gas detectors or liquids.

Sampling Fraction = Energy deposited in Active/Energy deposited in passive material.

Hadron Calorimeters are Large because λ is large

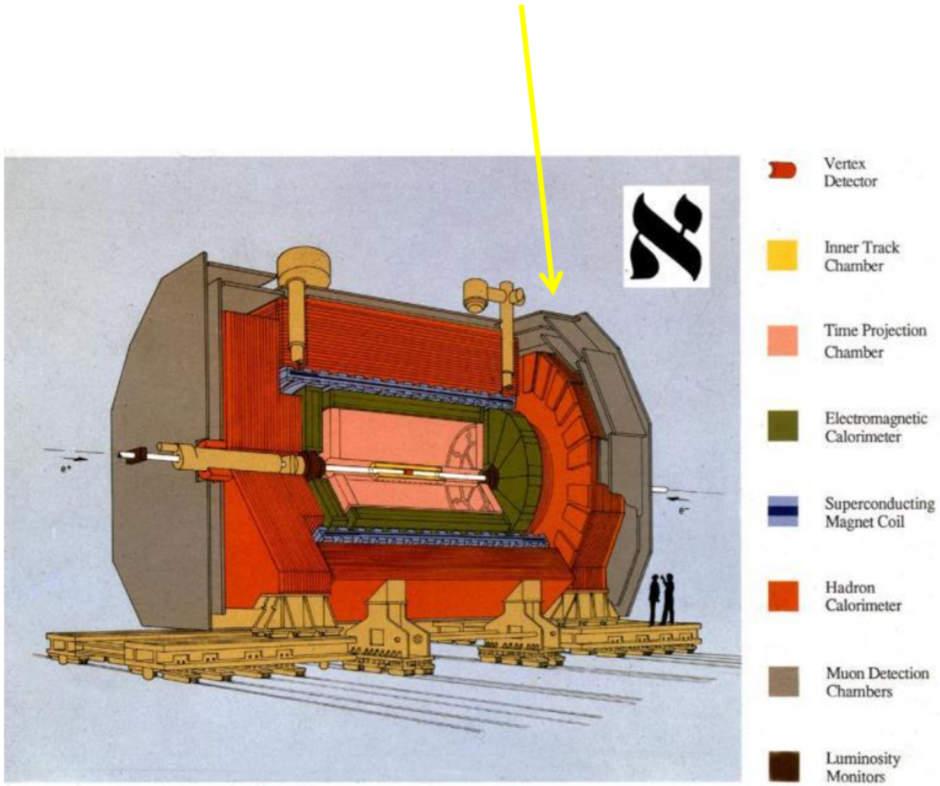
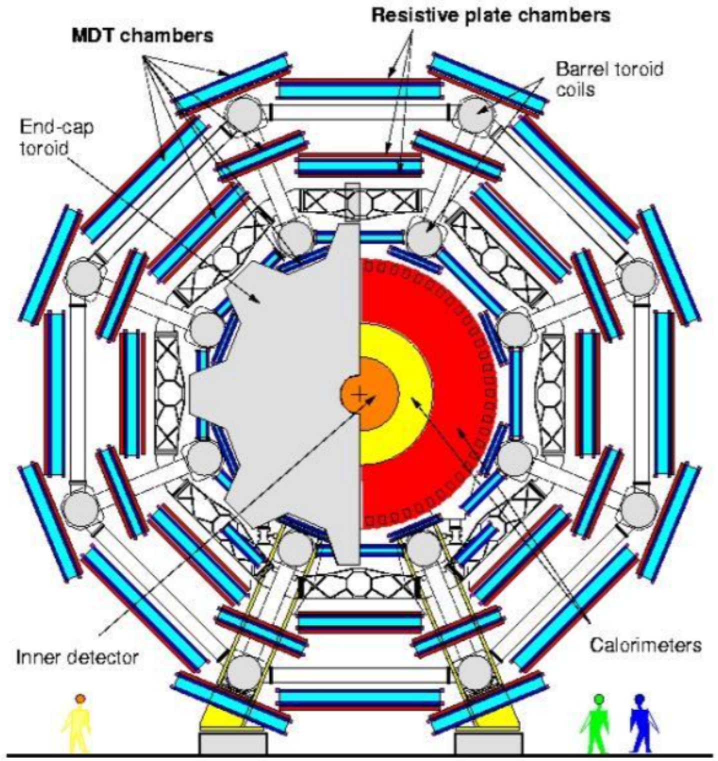


Fig. 1 - The ALEPH Detector

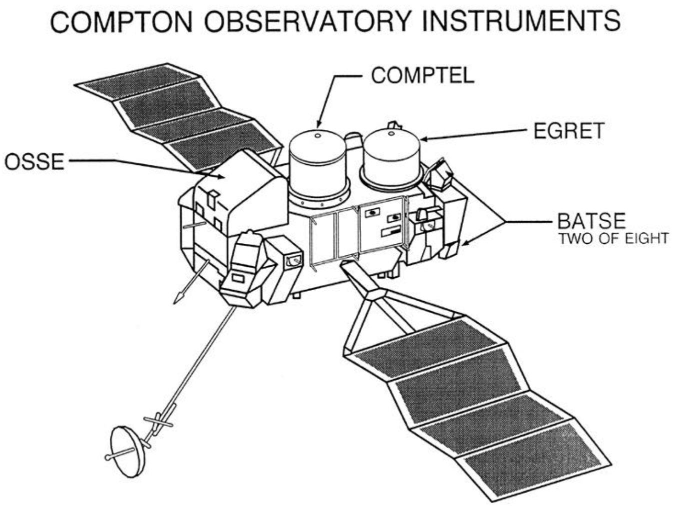
Hadron Calorimeters are large and heavy because the hadronic interaction length λ, the 'strong interaction equivalent' to the EM radiation length X_0, is large (5-10 times larger than X_0)

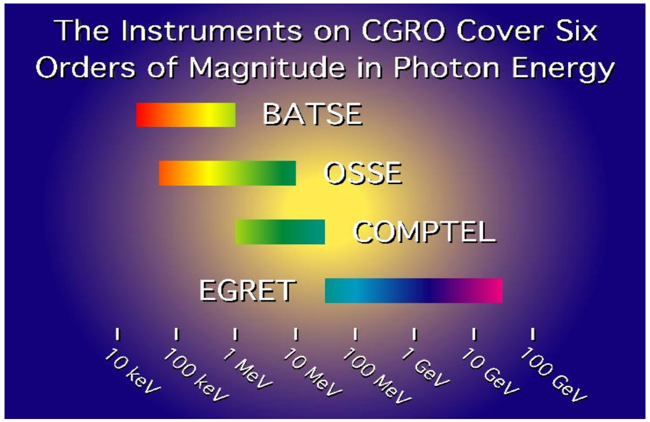


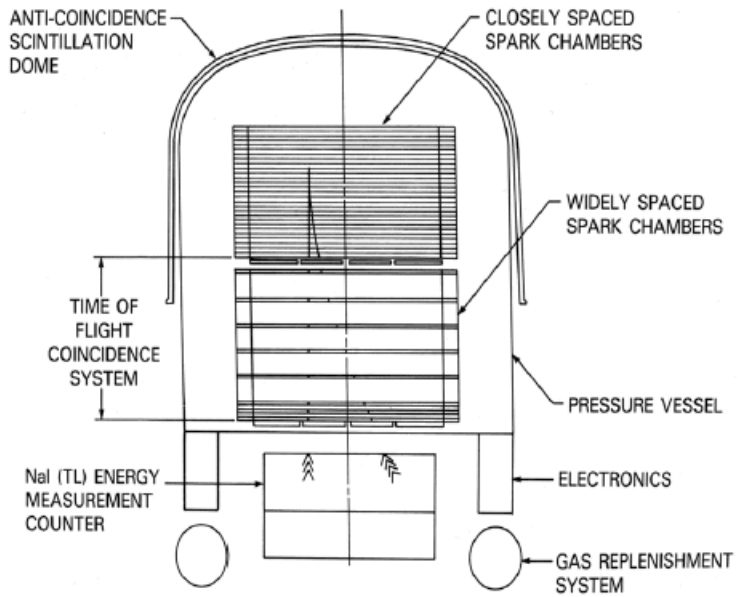
Because part of the energy is 'invisible' (nuclear excitation, slow nucleons), the resolution of hadron calorimeters is typically worse than in EM calorimeters 20-100%/Sqrt[E(GeV)] .

HE Gamma-ray Astrophysics
The EGRET legacy

EGRET



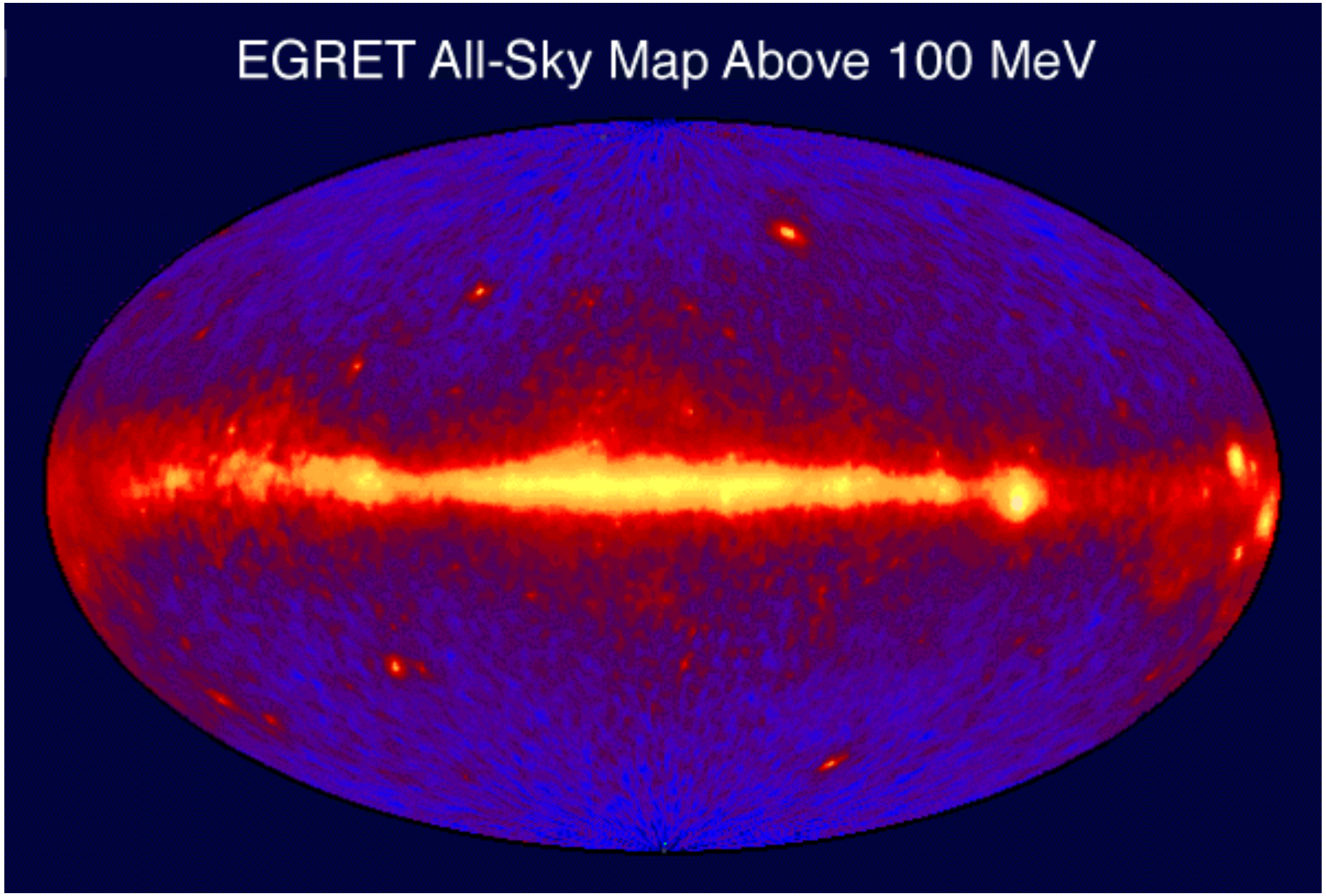




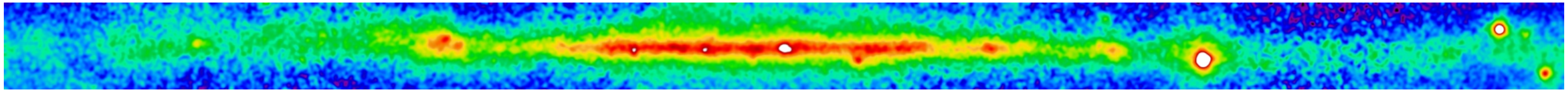
EGRET

- 1991-2000
- 30 MeV - 30 GeV
- AGN, GRB, Unidentified Sources, Diffuse Bkg

The HE sky from EGRET



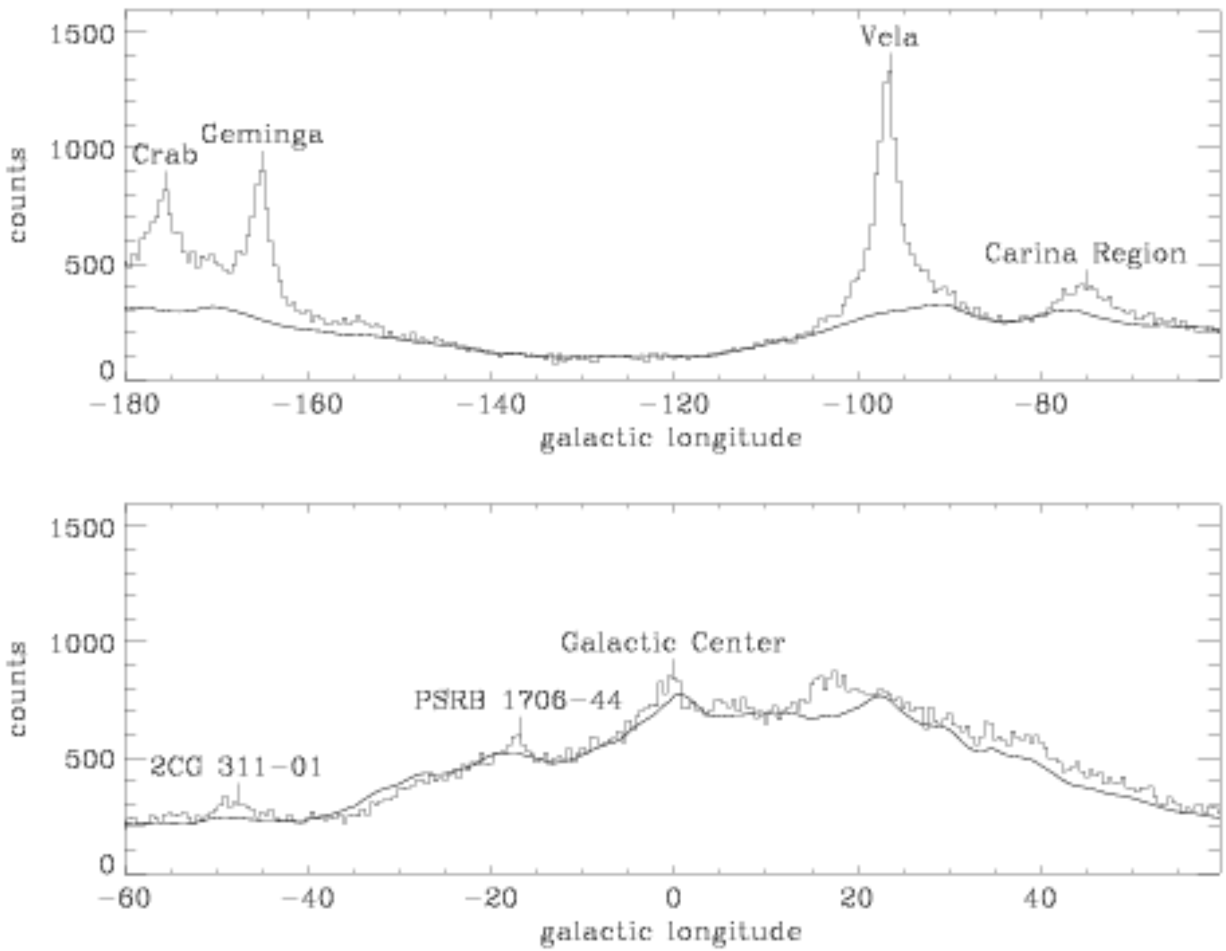
Analysis Topics



EGRET >300 MeV

- First a word about interstellar gamma-ray emission:
- Brightest at low latitudes, but detectable over the whole sky
- >60% of EGRET celestial gamma rays
- It fundamentally affects the approach to the analysis

Data Analysis



Analysis Topics: Source detection

- Source detection means at least 2 things:
  - Recognizing that you've detected a point source that you didn't know about (and defining its statistical significance and location on the sky)
  - Determining the significance of the detection of (or measuring an upper limit for) an already-known source

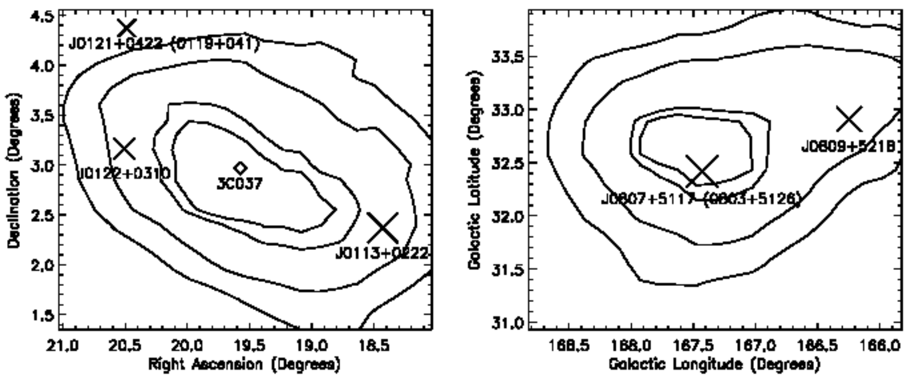


FIG. 3.—TS maps of possible composite 3EG sources. *Left*: 3EG J0118+0248. The 3EG identification 0119+041, the steep spectrum Mattox et al. (2001) counterpart 3C 037 (*diamond*), and our two new blazar counterparts (along the uncertainty region major axis) are shown. *Right*: 3EG J0808+5114. Again, two high-confidence identifications lie along the major axis.

Source location contours for two 3EG sources (Hartman et al. 1999). Potential (additional) counterparts, unresolved by EGRET, are indicated

Sowards-Emmerd, Romani, & Michelson (2003, ApJ, 590, 109)

Analysis Topics: Spectral analysis

- Well, this means measuring spectra
  - Mostly power laws resulting from shock acceleration, which is scale free
  - Spectral breaks occur for physics reasons and measuring them is diagnostic of the sources.
- For EGRET, the analysis of source spectra was a 2-step process
  - Fluxes were derived for fairly broad ranges of energy independently
  - Then a spectral model was fit
- The complication was that the exposure for a broad energy range depends on the source spectrum, so the fitting process was iterative.

$$F_{\gamma} = (2.01 \pm 0.12) \times 10^{-6}(E/0.214\ \mathrm{GeV})^{-2.18 \pm 0.08}\ \mathrm{photon\ (cm^2\ s\ GeV)^{-1}}\ .$$

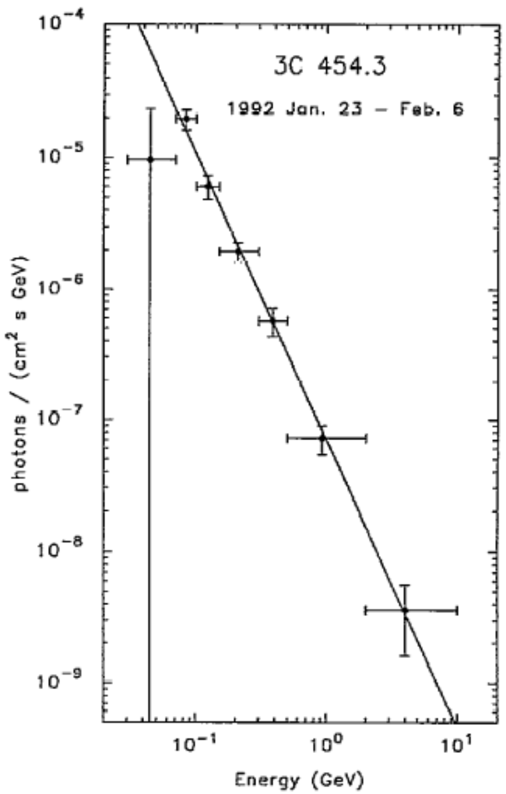
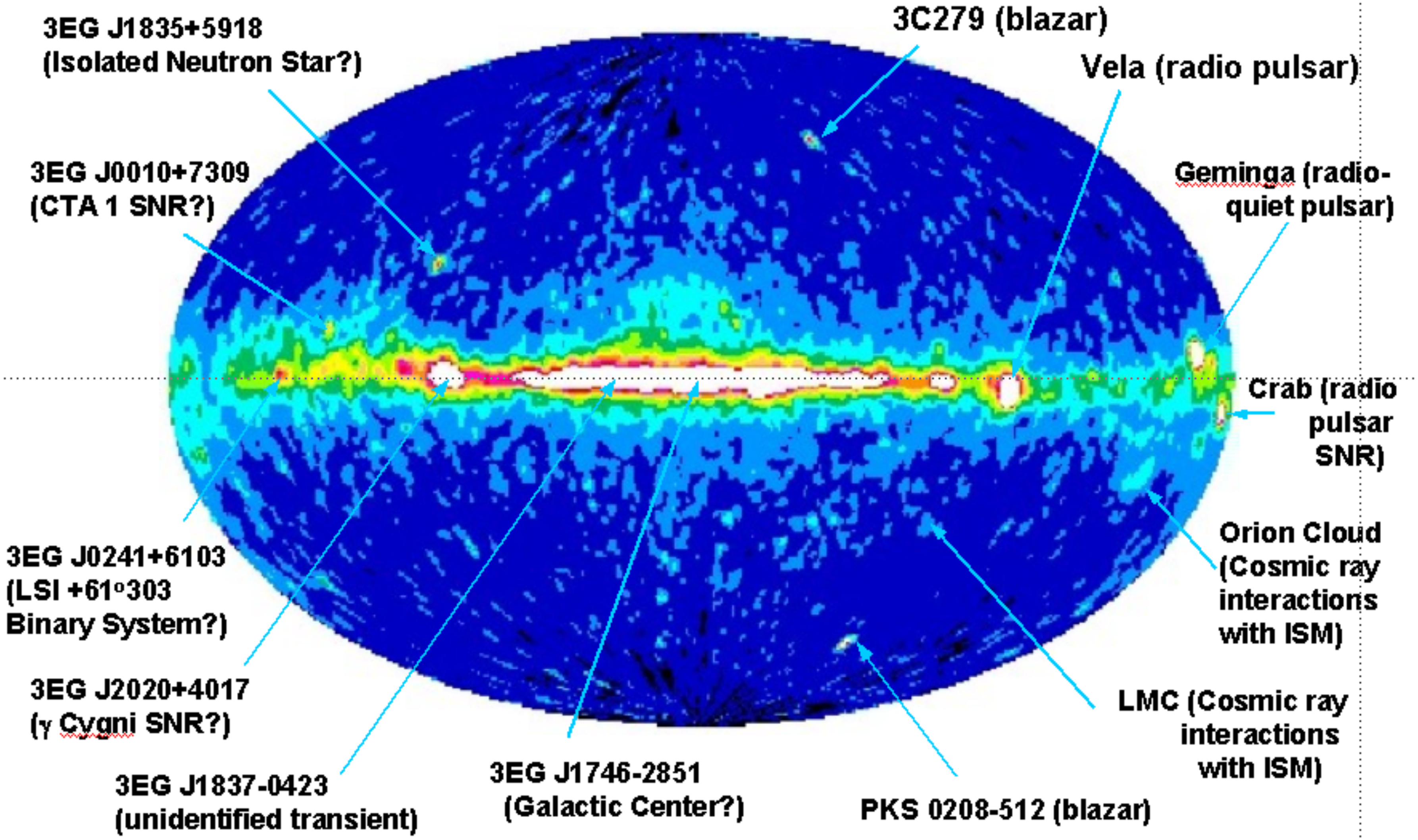


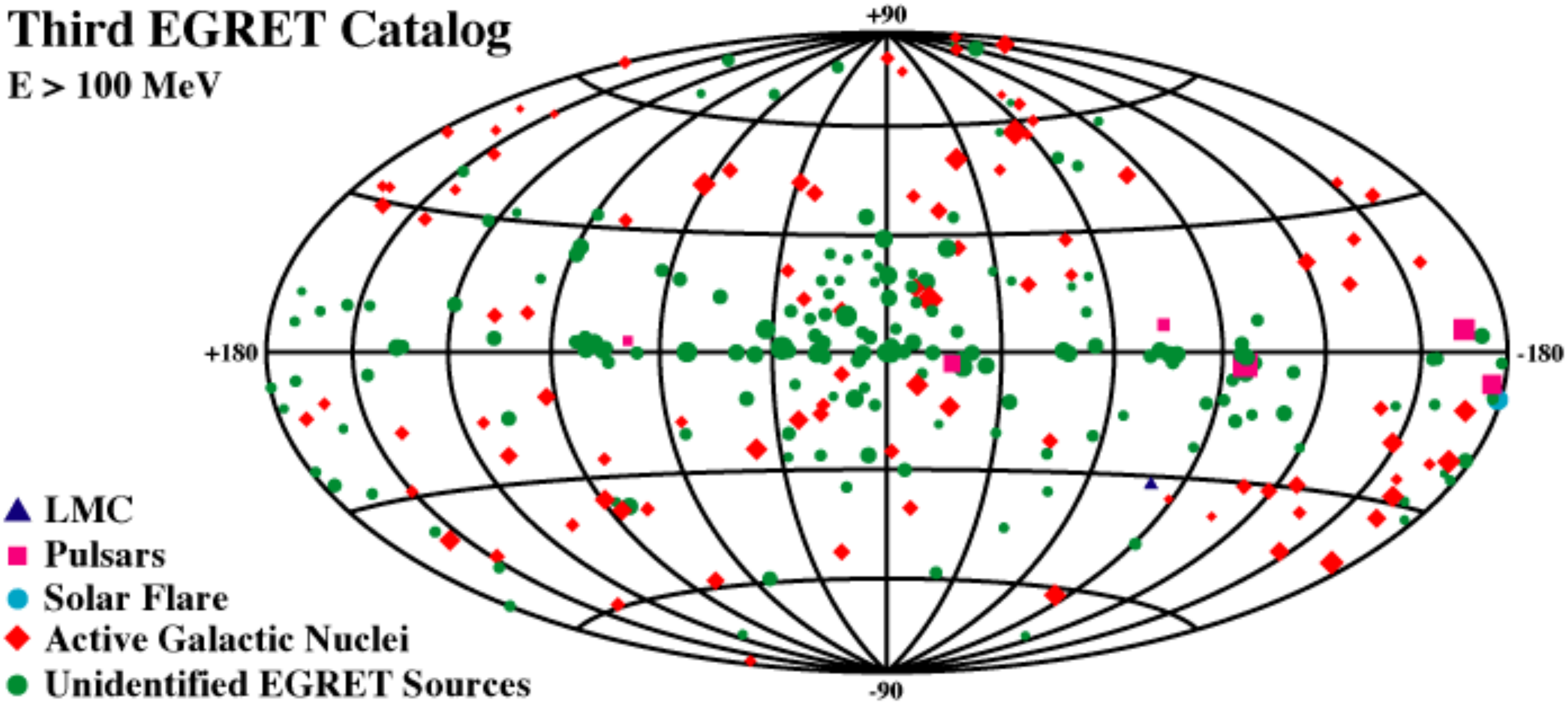
FIG. 3.—High-energy gamma ray spectrum of 3C 454.3 during the time interval 1992 January 23 to February 6. See text for comments on the 30–70 MeV point.

Hartman et al. 1993 (ApJ, 407,L41),

EGRET All Sky Map

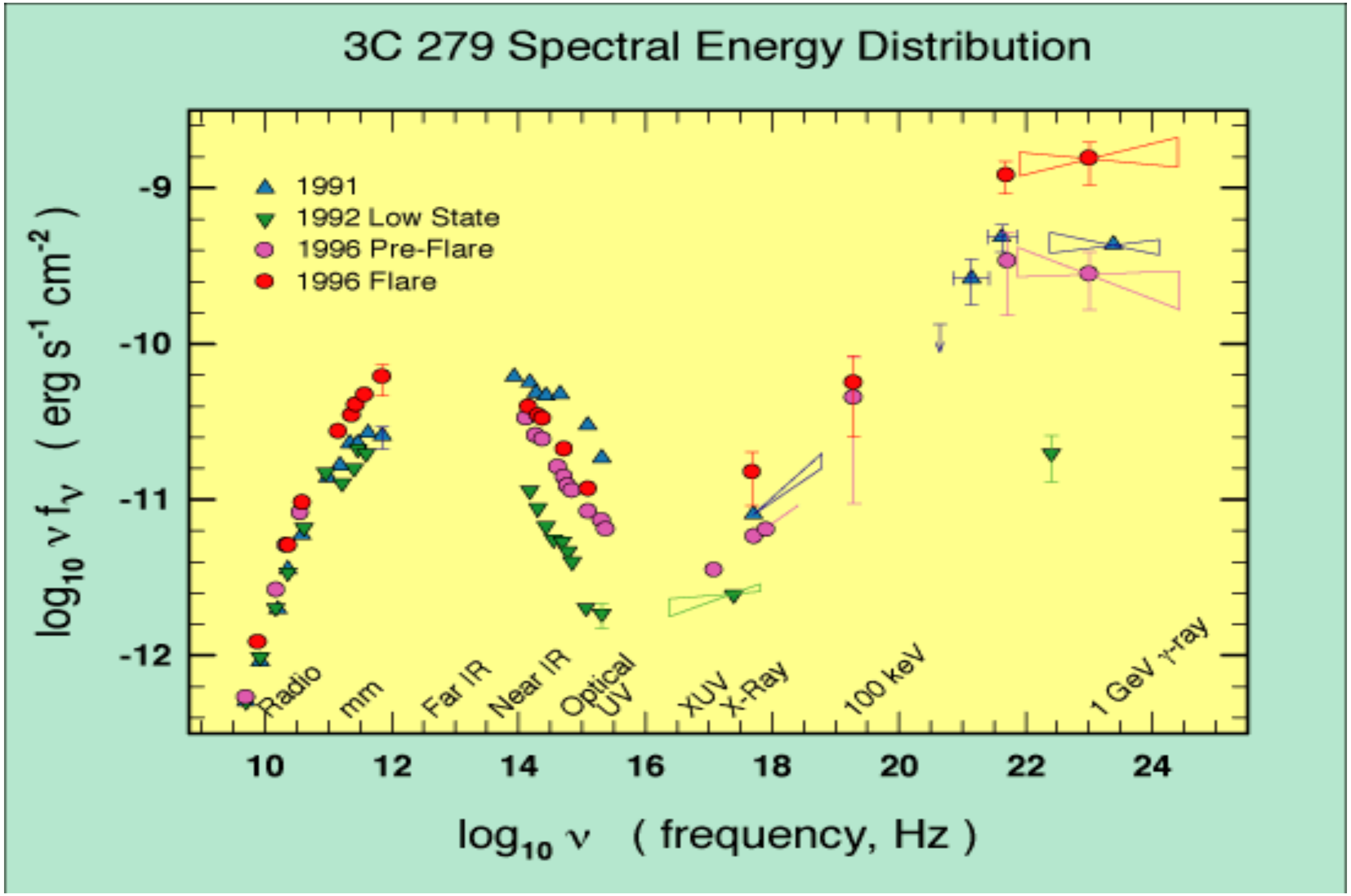


EGRET Gamma-ray Sources

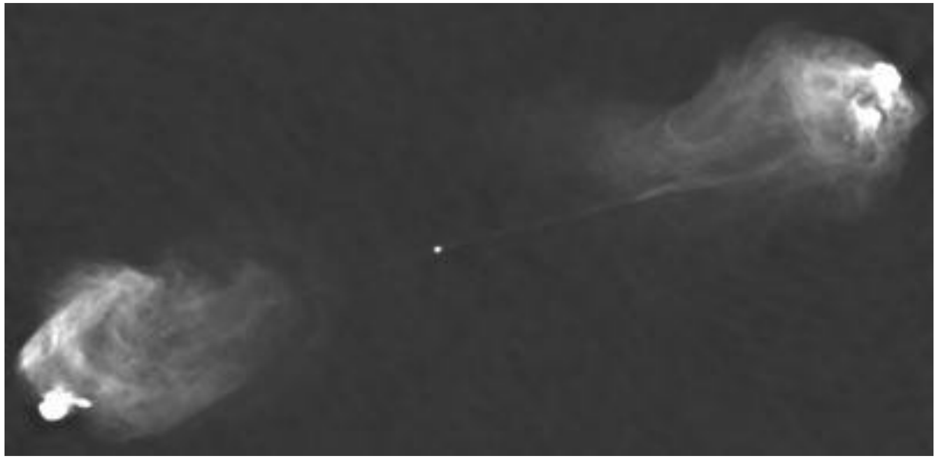


Challenge # 1

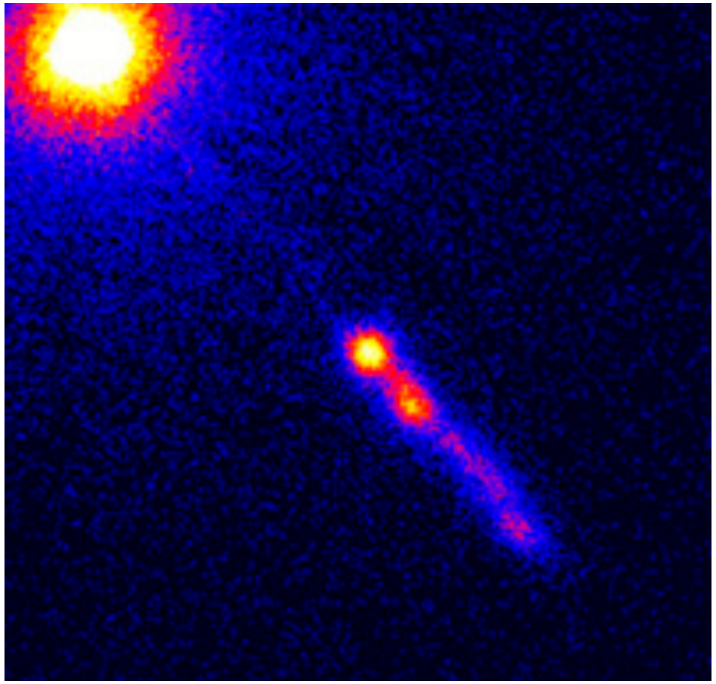
- Need simultaneous multiwavelength data to study variability and emission processes



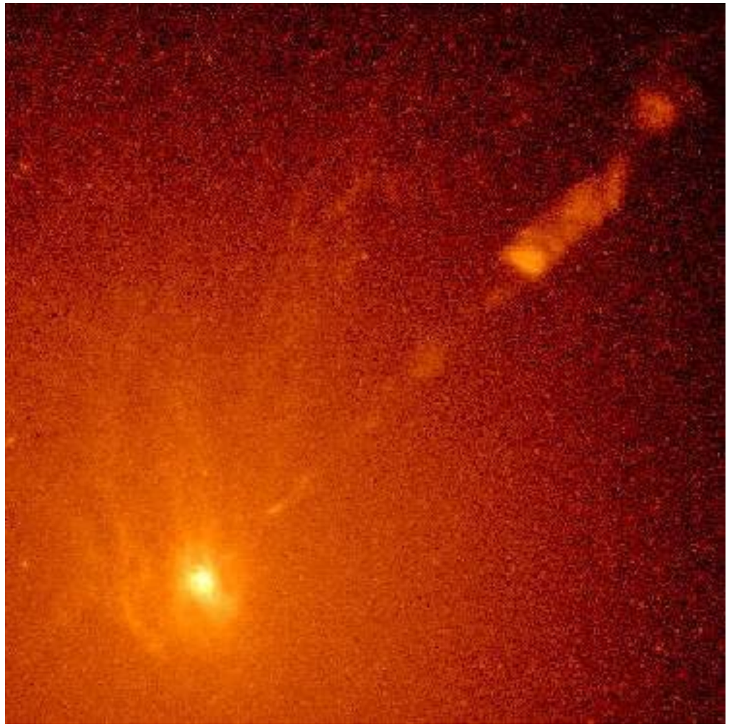
Active Galactic Nuclei



Radio

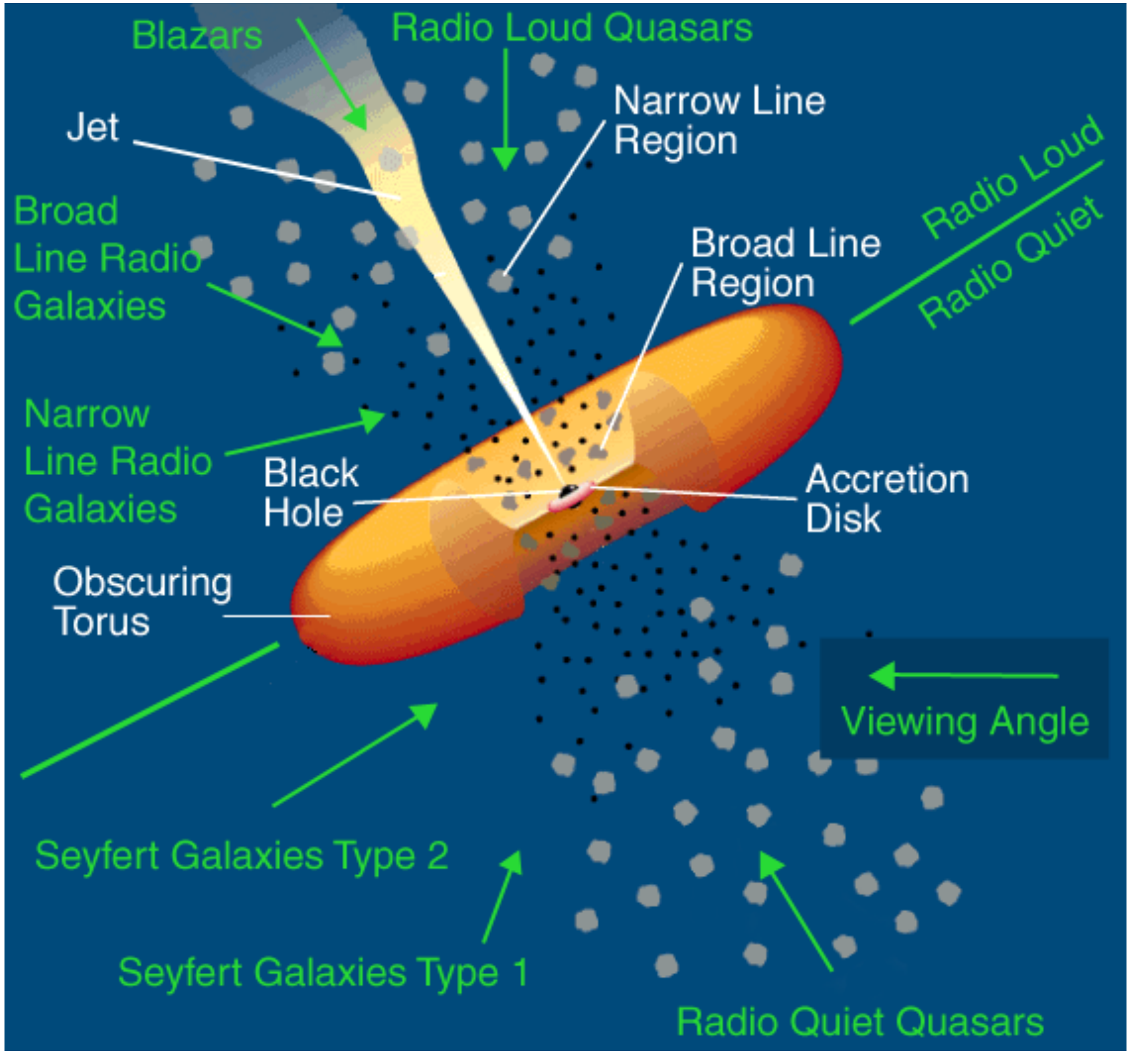


X-ray

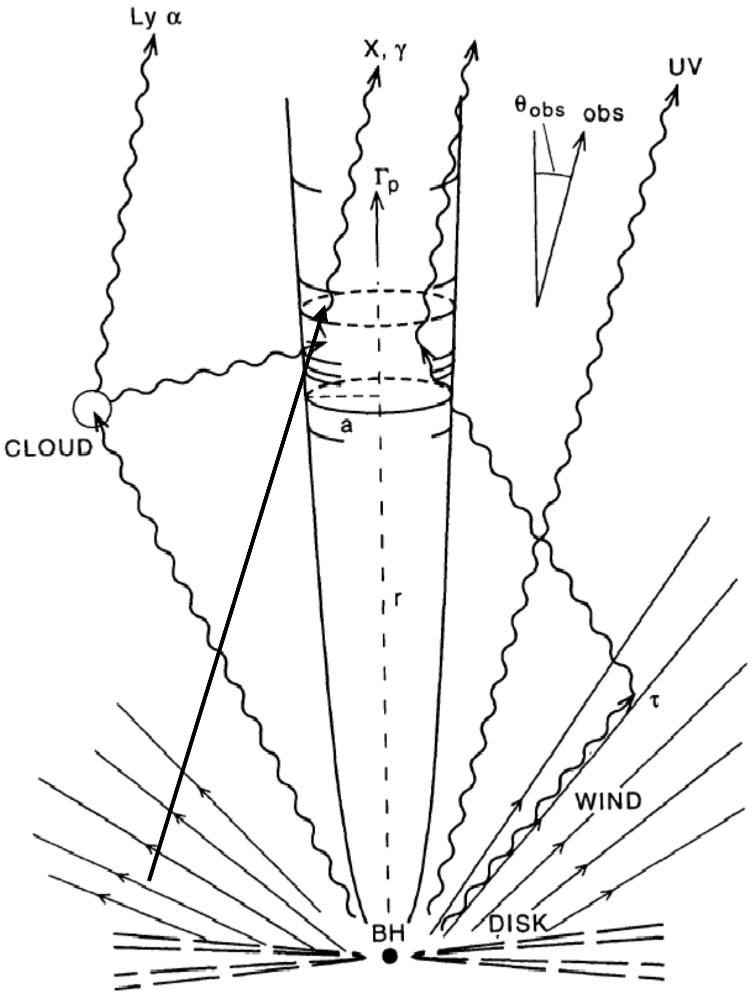


Optical

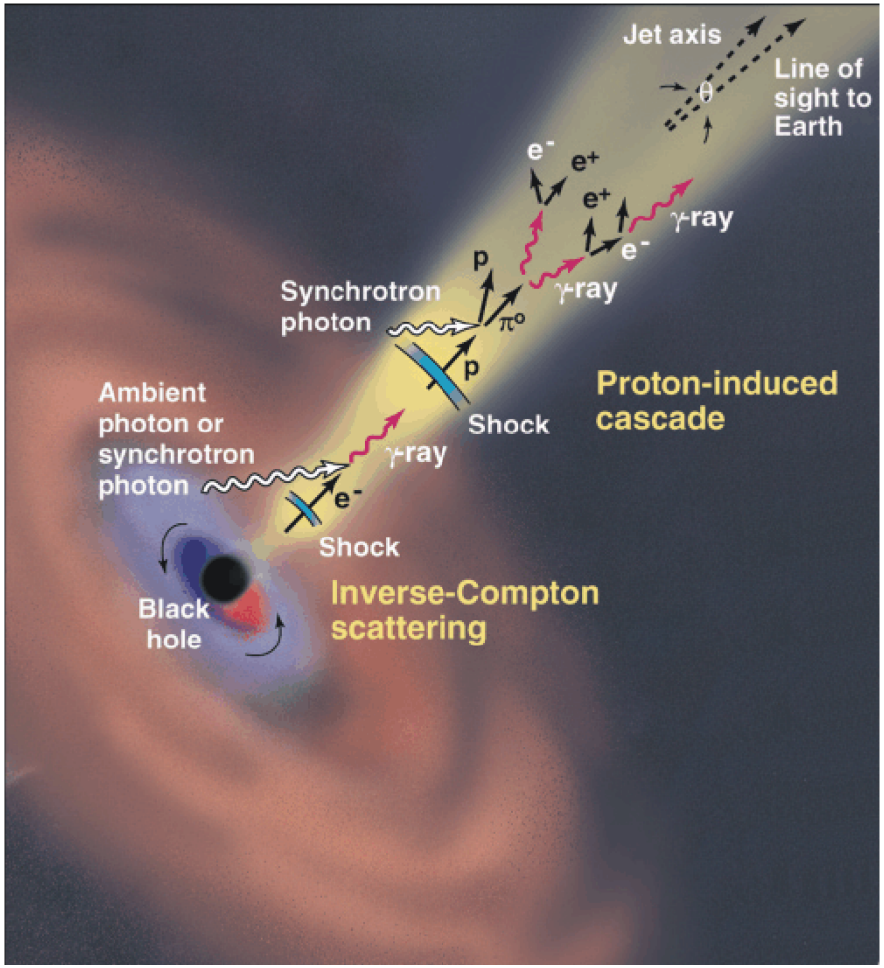
Active Galactic Nuclei



Models of AGN Gamma-ray Production

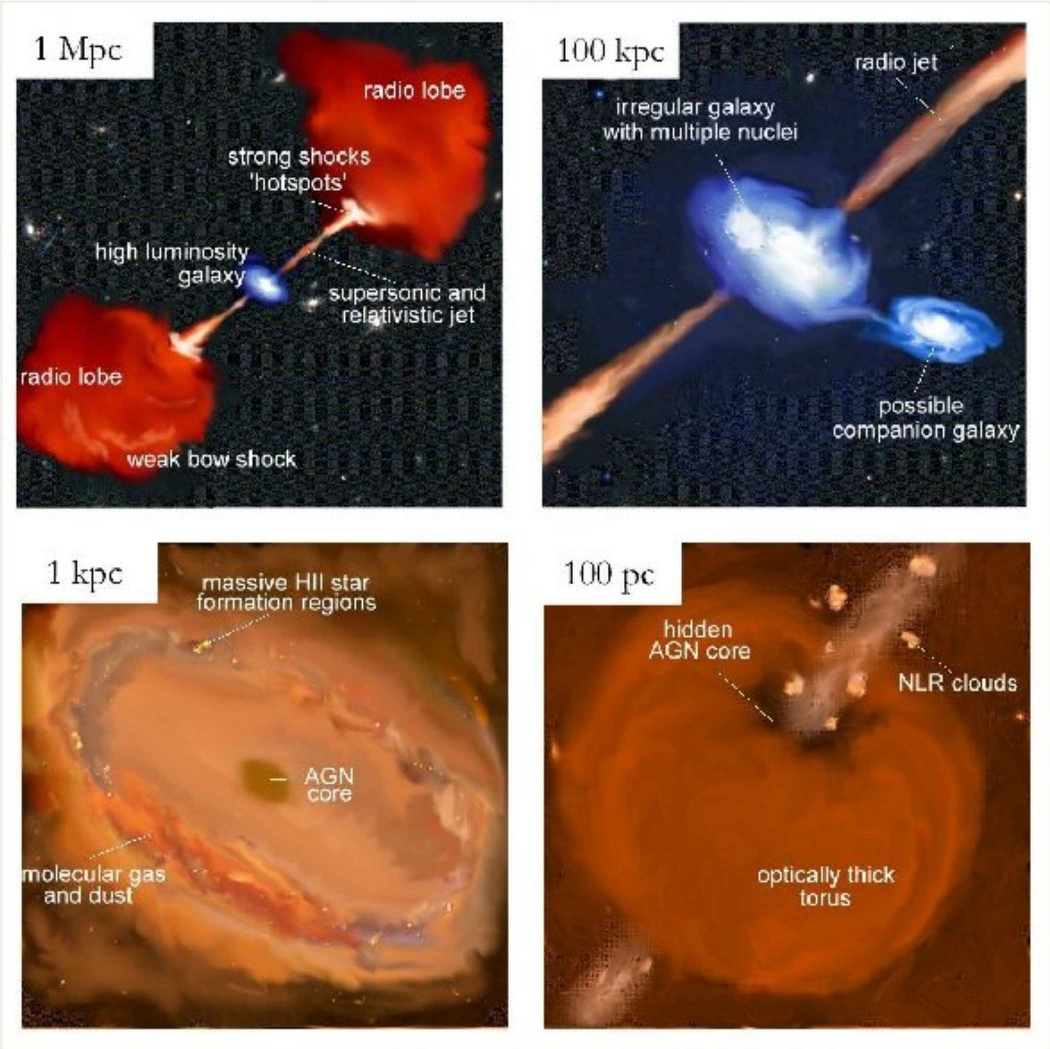


(from Sikora, Begelman, and Rees (1994))



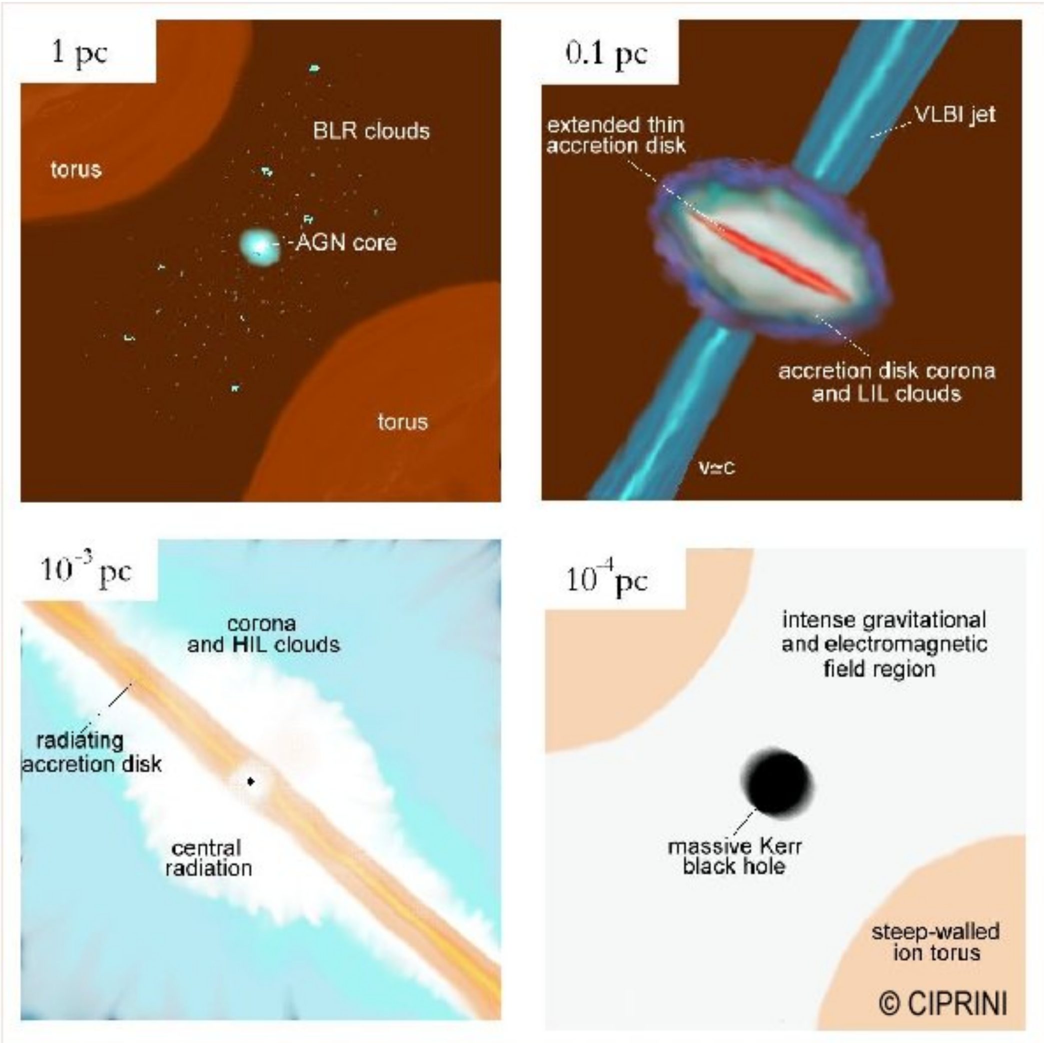
(credit:J. Buckley)

Active Galactic Nuclei



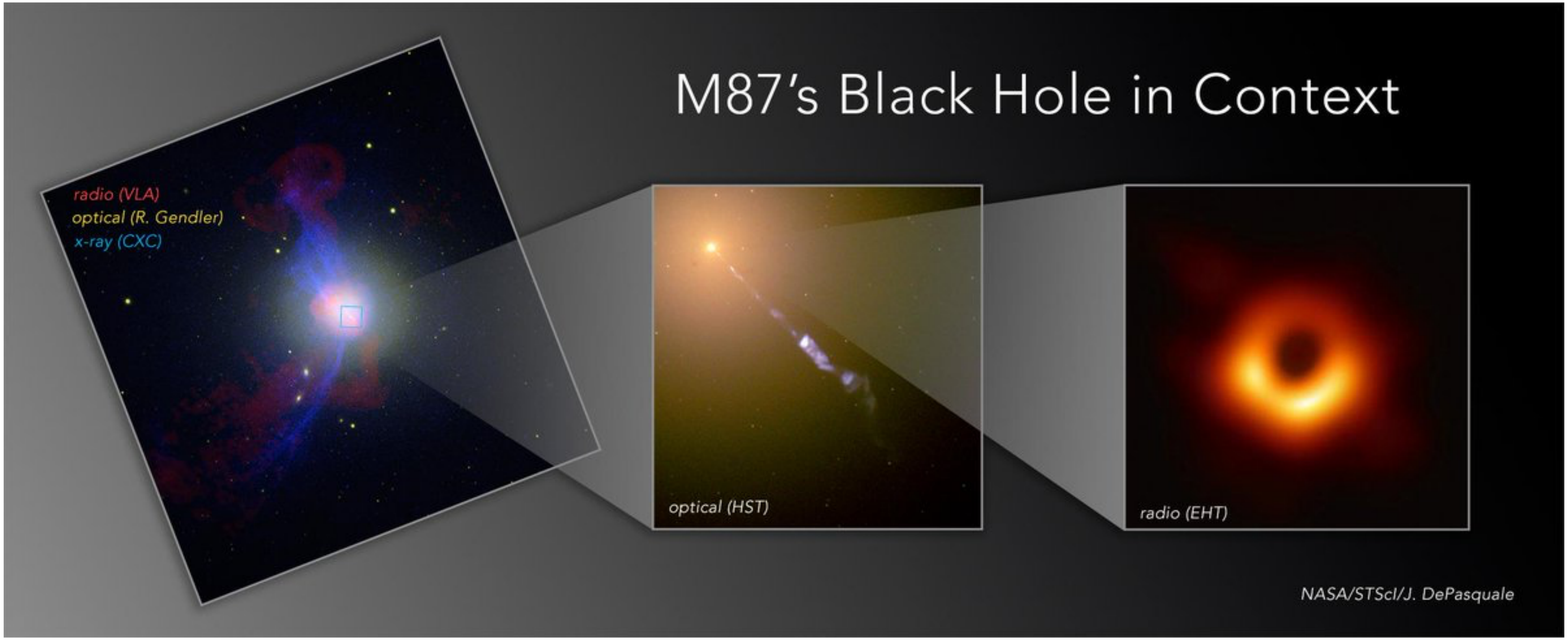
Artistic picture by S.Ciprini

Active Galactic Nuclei



Artistic picture by S.Ciprini

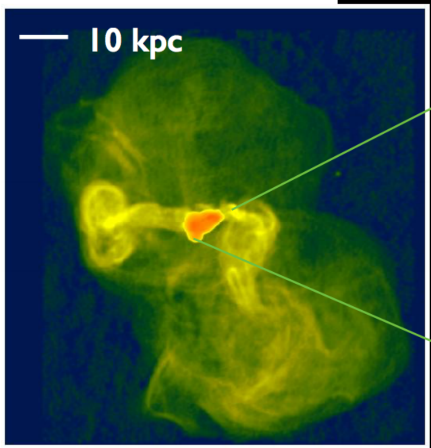
M87 scales…

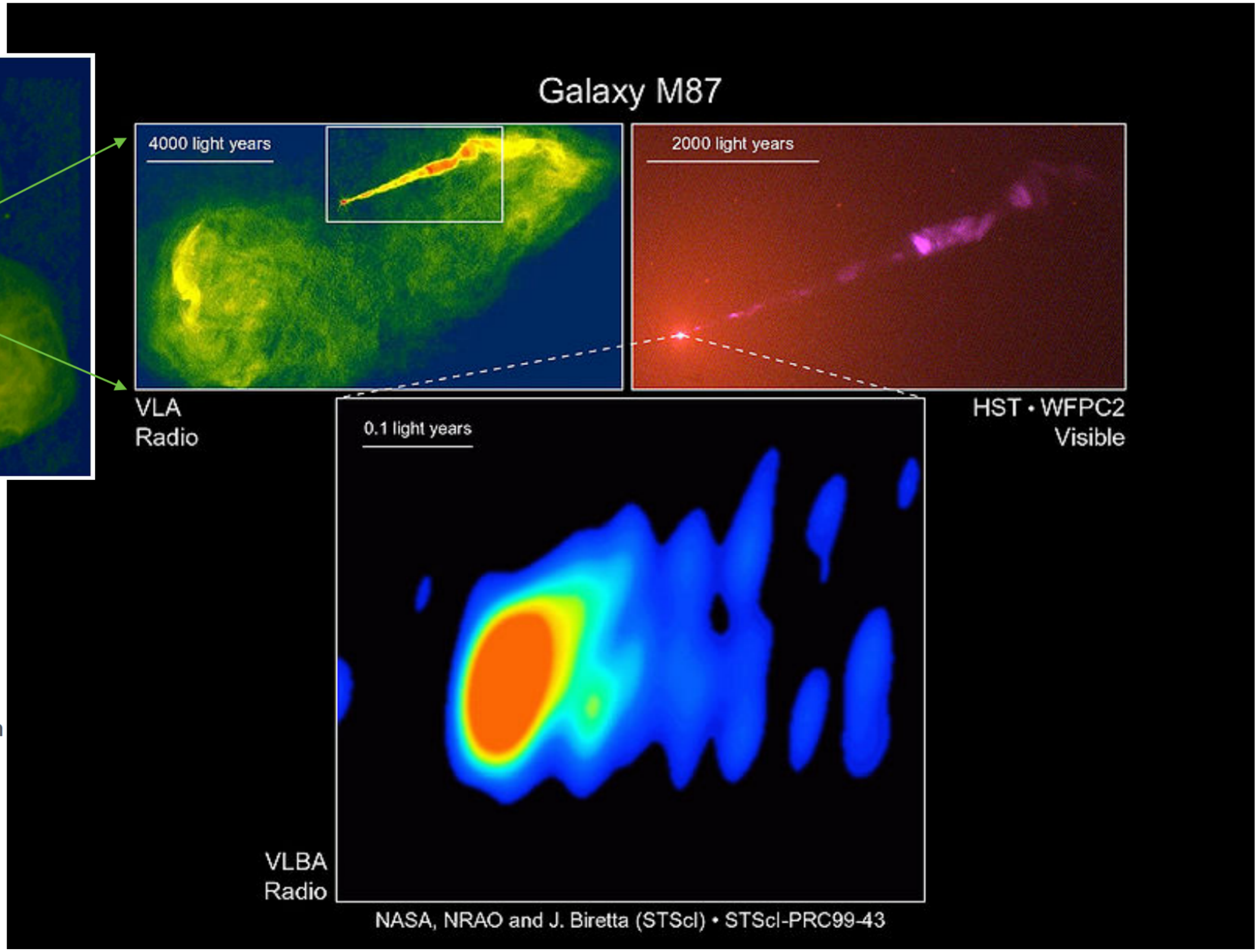


M87's Black Hole in Context
radio (VLA)
optical (R. Gendler)
x-ray (CXC)
optical (HST)
radio (EHT)
NASA/STScI/J. DePasquale

M87 scales…

radio “bubbles”





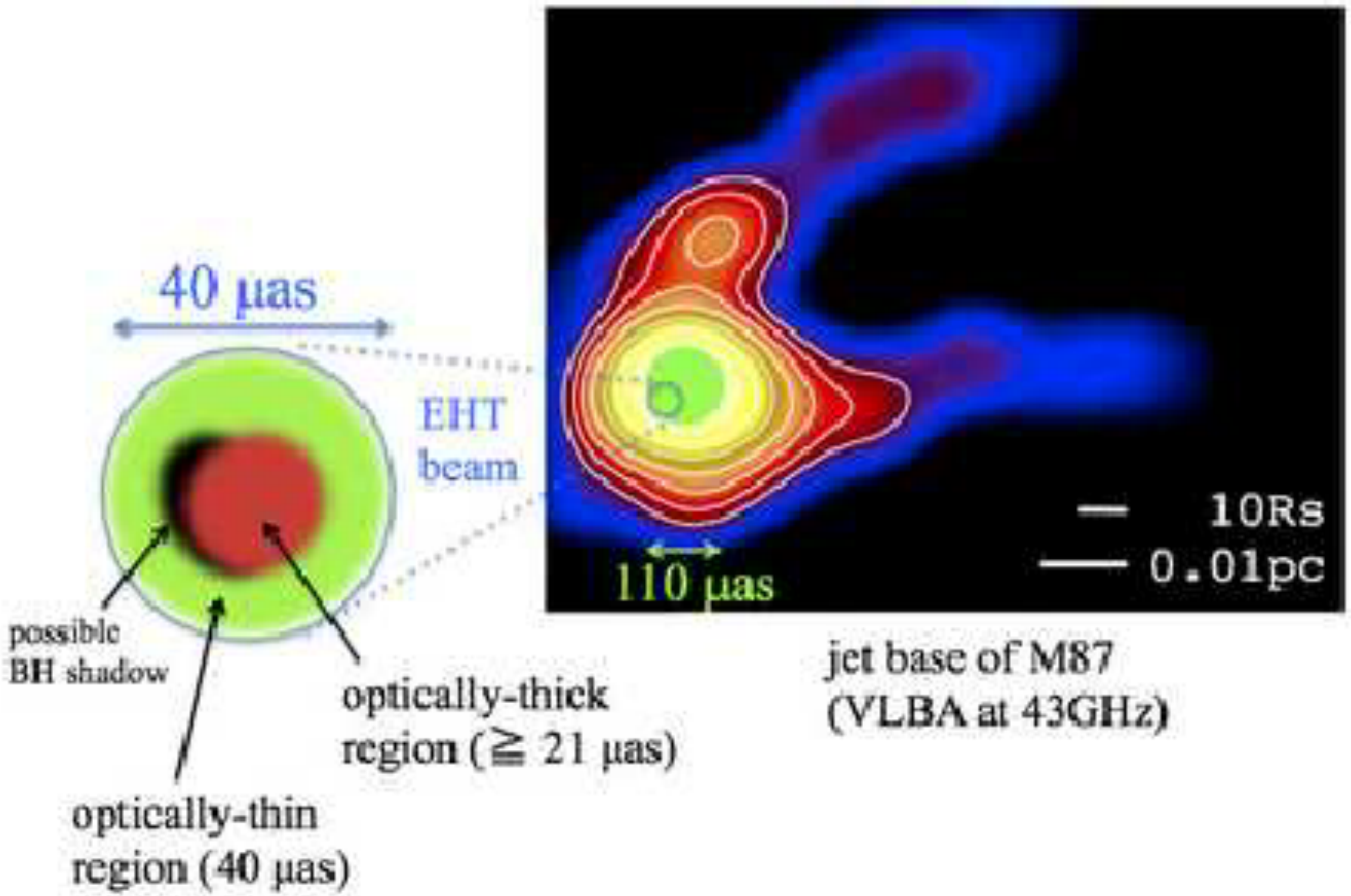
M87:

FR I radio galaxy

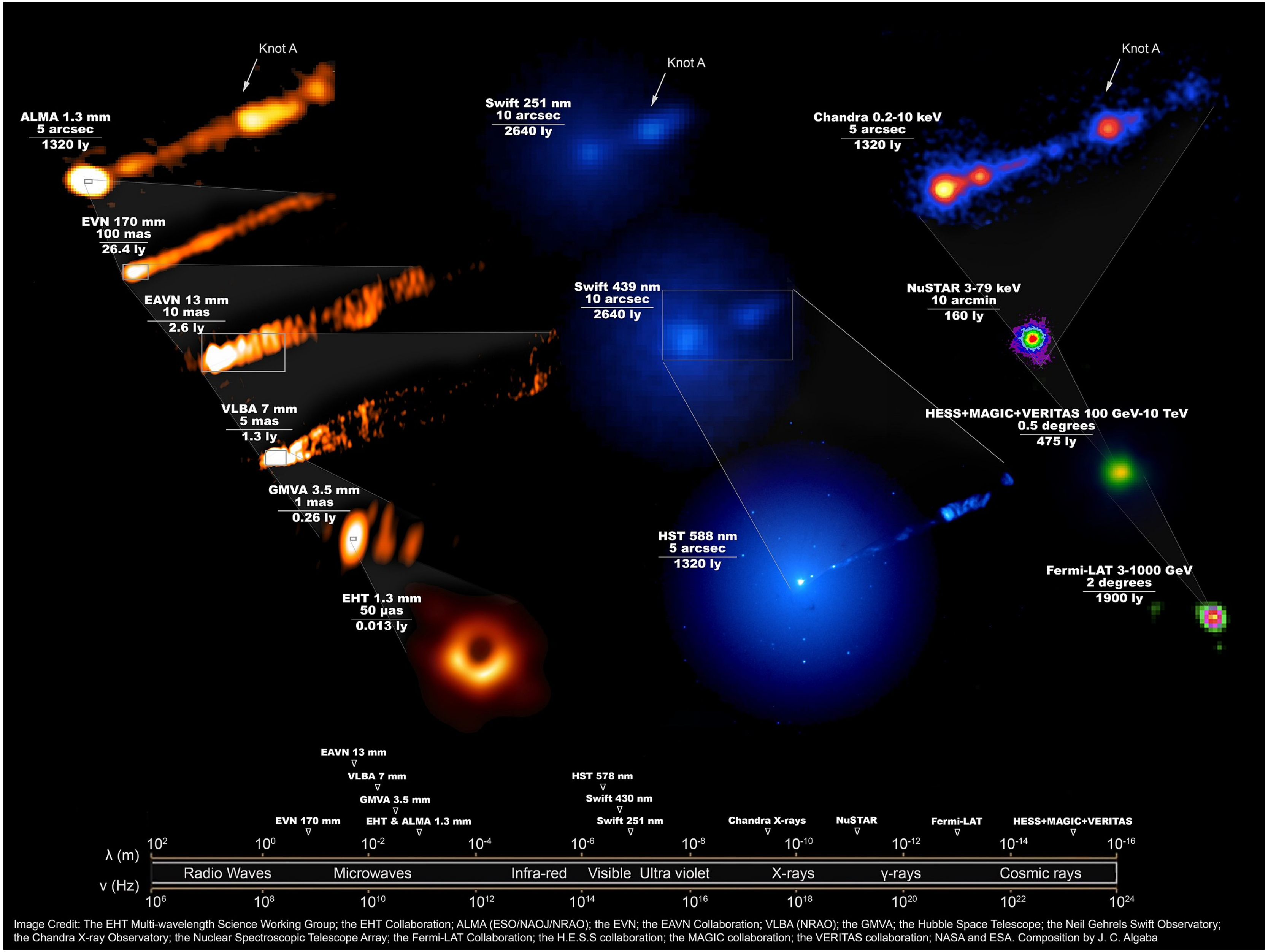
d~16 Mpc

M_{BH}=(3-6)x10^9 M_{sun}

M87 scales…

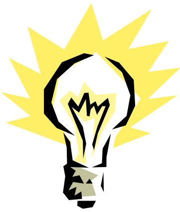

40 µas
EHT
beam
possible
BH shadow
optically-thick
region (≧ 21 µas)
optically-thin
region (40 µas)
10Rs
0.01pc
110 µas
jet base of M87
(VLBA at 43GHz)

M87 scales…



Knot A
ALMA 1.3 mm
5 arcsec
1320 ly
EVN 170 mm
100 mas
26.4 ly
EAVN 13 mm
10 mas
2.6 ly
VLBA 7 mm
5 mas
1.3 ly
GMVA 3.5 mm
1 mas
0.26 ly
EHT 1.3 mm
50 μas
0.013 ly
Knot A
Swift 251 nm
10 arcsec
2640 ly
Swift 439 nm
10 arcsec
2640 ly
HST 588 nm
5 arcsec
1320 ly
Knot A
Chandra 0.2-10 keV
5 arcsec
1320 ly
NuSTAR 3-79 keV
10 arcmin
160 ly
HESS+MAGIC+VERITAS 100 GeV-10 TeV
0.5 degrees
475 ly
Fermi-LAT 3-1000 GeV
2 degrees
1900 ly
EAVN 13 mm
VLBA 7 mm
GMVA 3.5 mm
EVN 170 mm
EHT & ALMA 1.3 mm
HST 578 nm
Swift 430 nm
Swift 251 nm
Chandra X-rays
NuSTAR
Fermi-LAT
HESS+MAGIC+VERITAS
λ (m)
10^2 10^0 10^-2 10^-4 10^-6 10^-8 10^-10 10^-12 10^-14 10^-16
Radio Waves Microwaves Infra-red Visible Ultra violet X-rays γ-rays Cosmic rays
ν (Hz)
10^6 10^8 10^10 10^12 10^14 10^16 10^18 10^20 10^22 10^24
Image Credit: The EHT Multi-wavelength Science Working Group; the EHT Collaboration; ALMA (ESO/NAOJ/NRAO); the EVN; the EAVN Collaboration; VLBA (NRAO); the GMVA; the Hubble Space Telescope; the Neil Gehrels Swift Observatory; the Chandra X-ray Observatory; the Nuclear Spectroscopic Telescope Array; the Fermi-LAT Collaboration; the H.E.S.S collaboration; the MAGIC collaboration; the VERITAS collaboration; NASA and ESA. Composition by J. C. Algaba

AGN and the Extragalactic Background Light (EBL)



Look for roll-offs in blazar spectra due to attenuation:

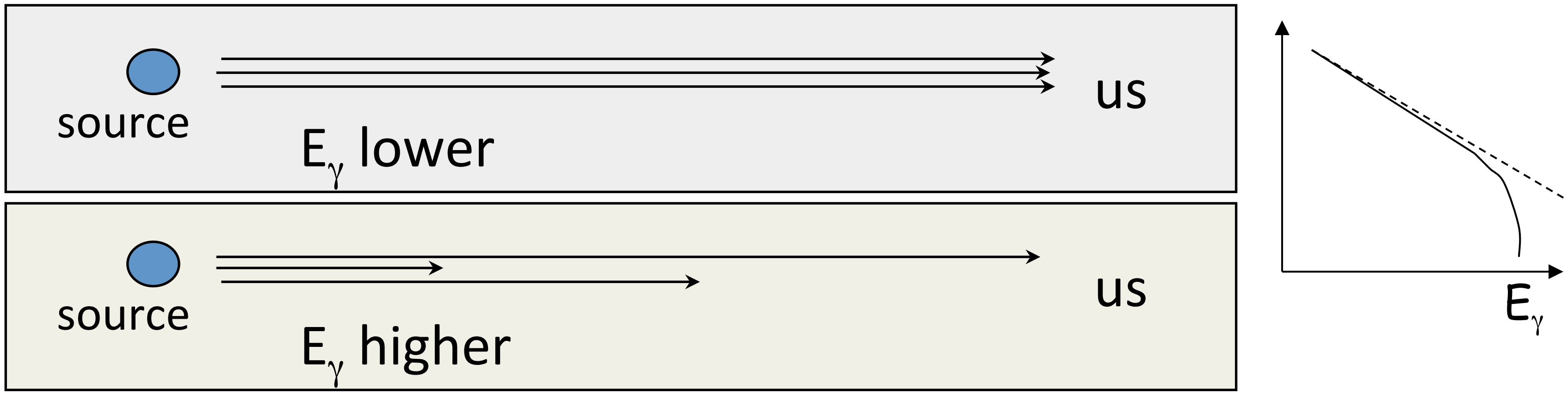
(Stecker, De Jager & Salamon; Madau & Phinney; Macminn & Primack)

the start: A.I. Nikishov, Sov. Phys. JETP 14 (1962) 393.

If γγ c.m. energy > $2m_e$, pair creation will attenuate flux. For a flux of γ -rays with energy, E, this cross-section is maximized when the partner, ε, is

$$\epsilon \sim \frac{1}{3}(\frac{1TeV}{E})eV$$

For 10 GeV- 100 GeV γ - rays, this corresponds to a partner photon energy in the <u>optical - UV range</u>. Density is sensitive to time of galaxy formation.



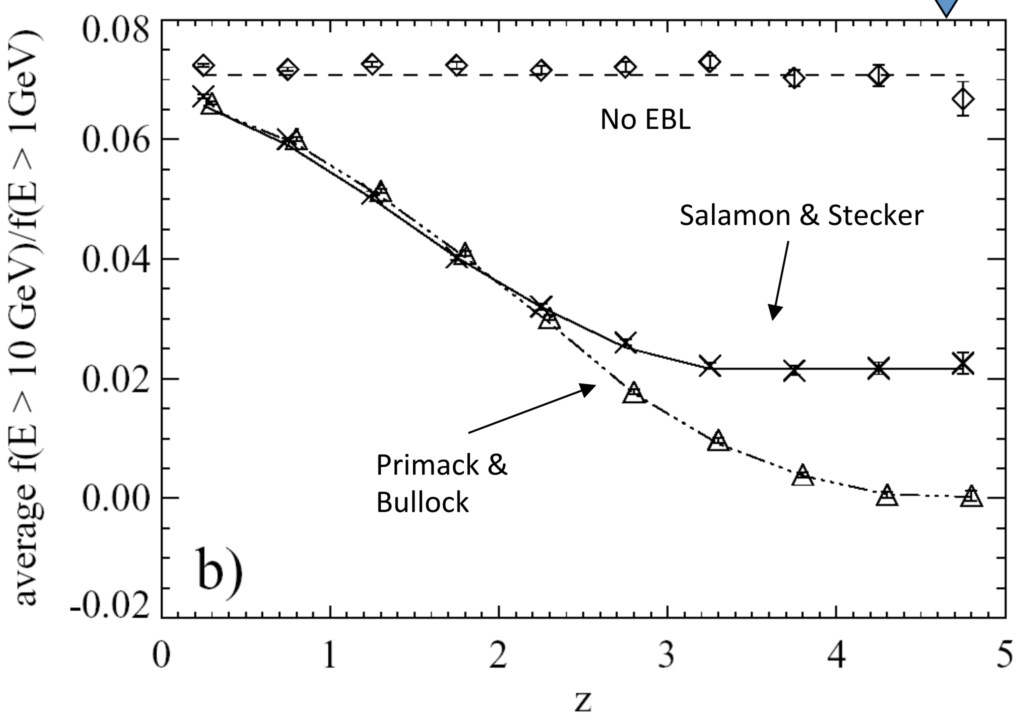
AGN and EBL

- **Important advances offered by Fermi:**

  (1) thousands of blazars - instead of peculiarities of individual sources, look for systematic effects vs redshift.

  (2) key energy range for cosmological distances (TeV-IR attenuation more local due to opacity).

- Effect is model-dependent (this is good):

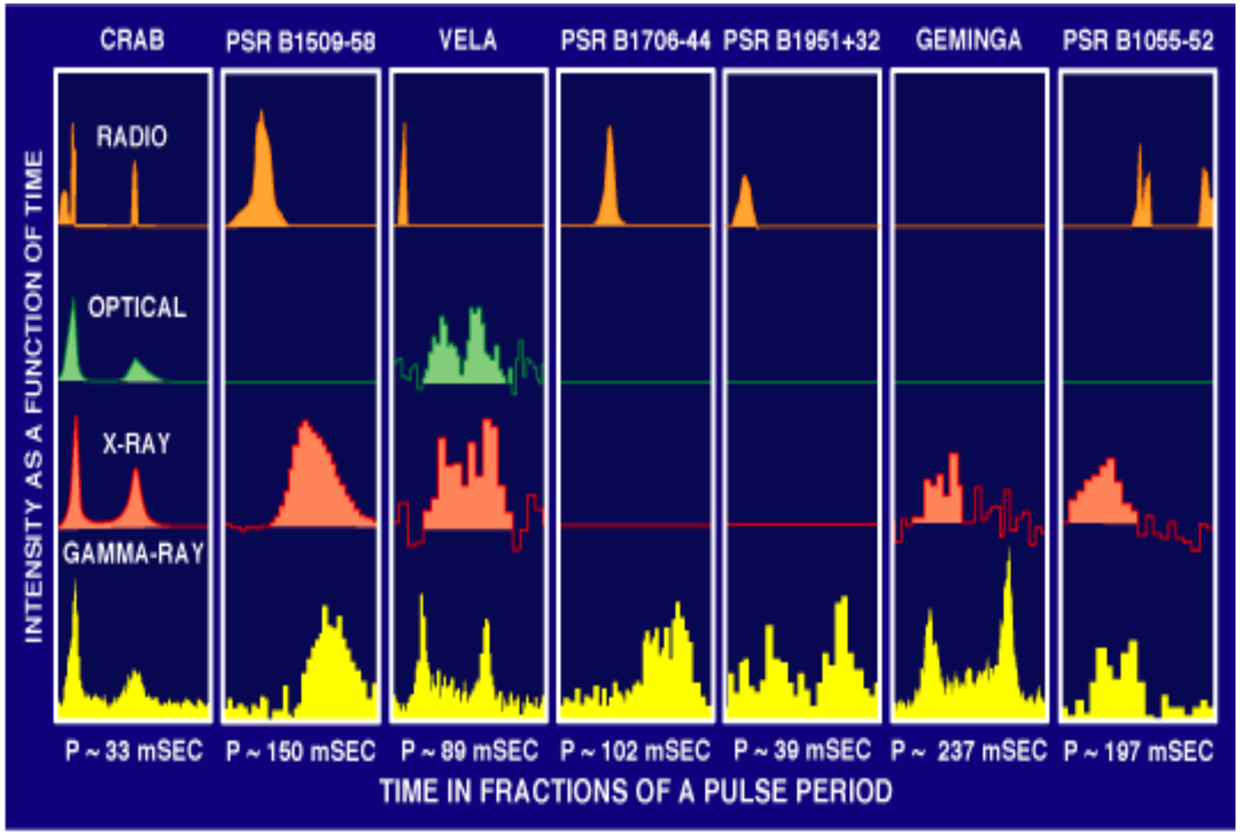


Caveats

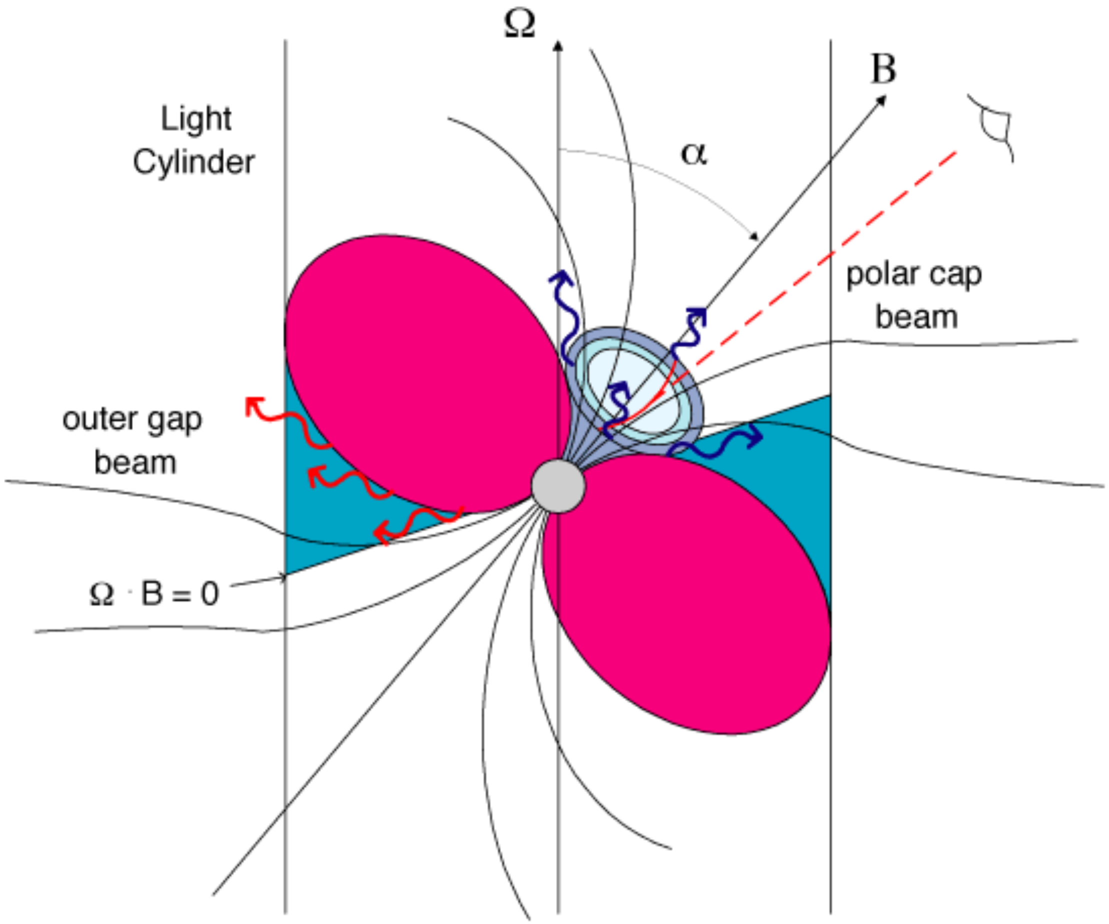
- How many blazars have intrinsic roll-offs in this energy range (10-100 GeV)? (An important question by itself for GLAST!)
- What if there is conspiratorial evolution in the intrinsic roll-of vs redshift? More difficult, however there may also be independent constraints (e.g., direct observation of integrated EBL).
- Must measure the redshifts for a large sample of these blazars!

Challenge # 2

- Need more exposure and optimal timing (and radio monitoring) to discover more gamma-ray PSRs.



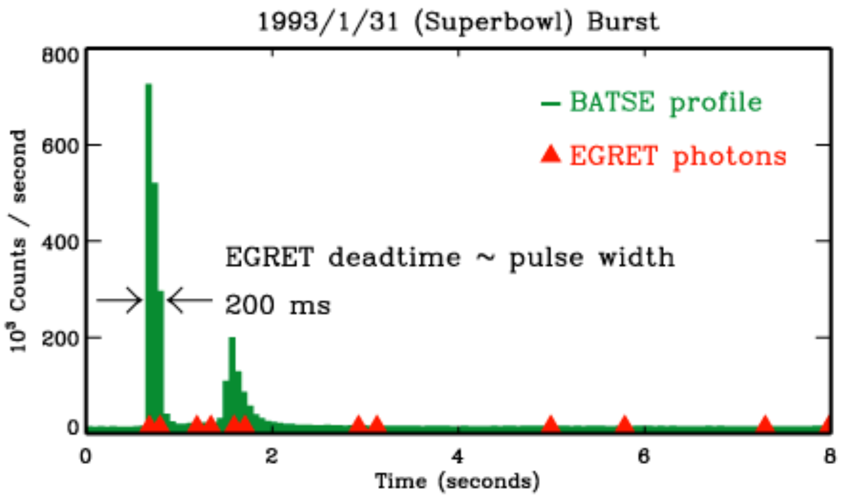
Pulsars



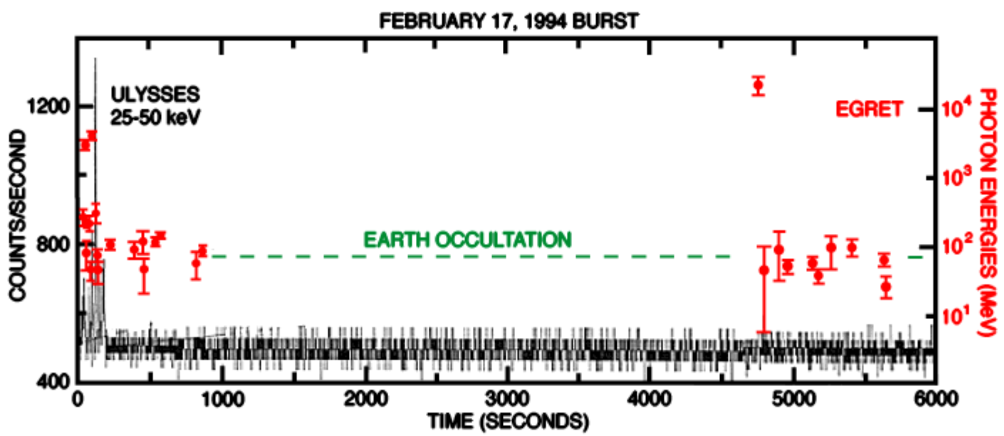
Challenge # 3

- Need fast timing for gamma-ray detection (improving EGRET deadtime, 100 msec → 100 microsec or less).

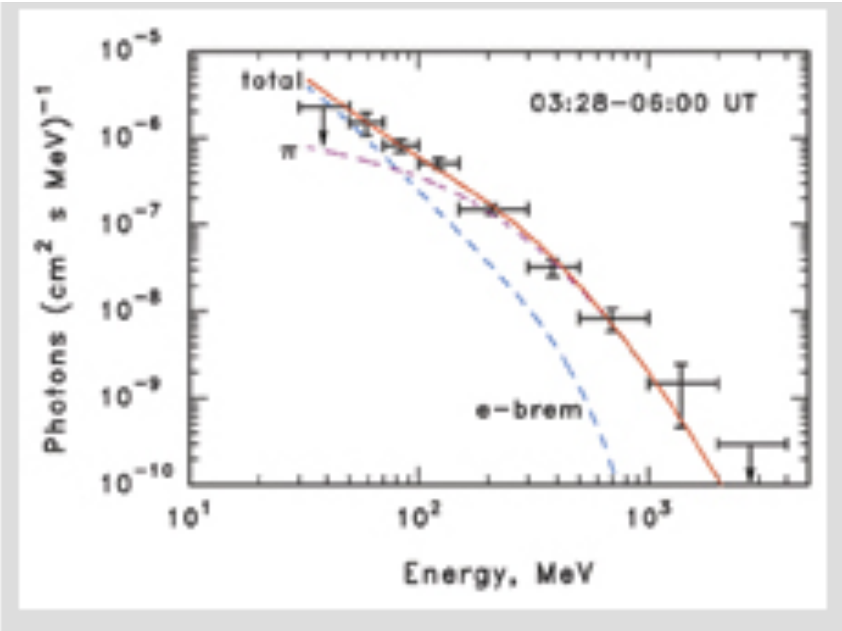
Prompt Emission (GRB 930131)

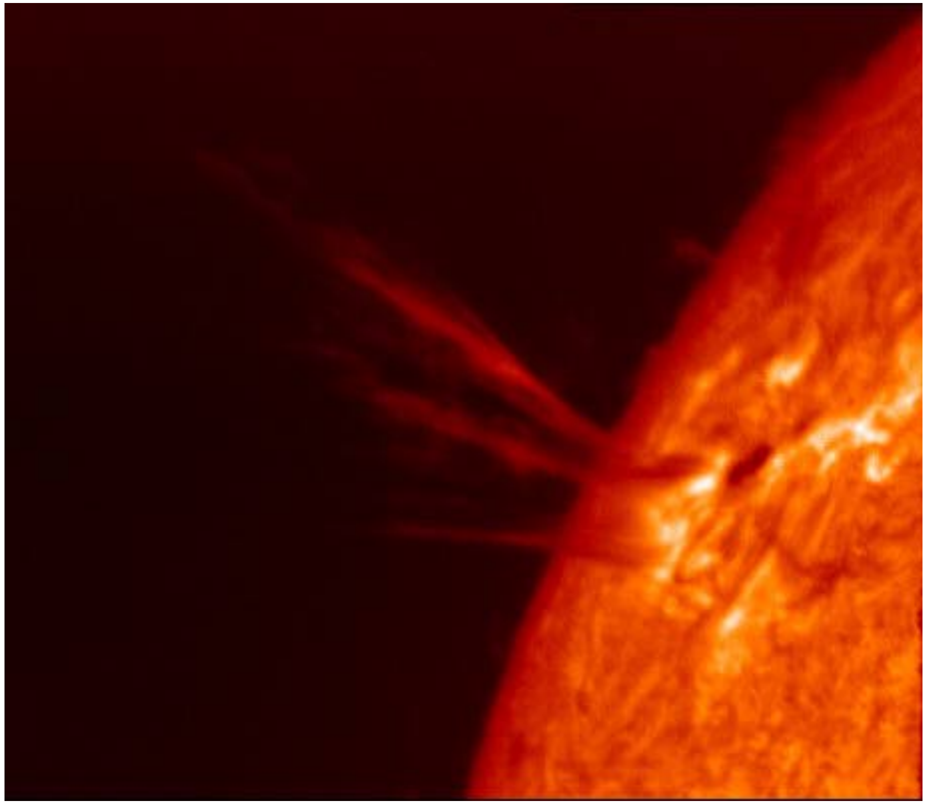


Delayed Emission (GRB 940217)

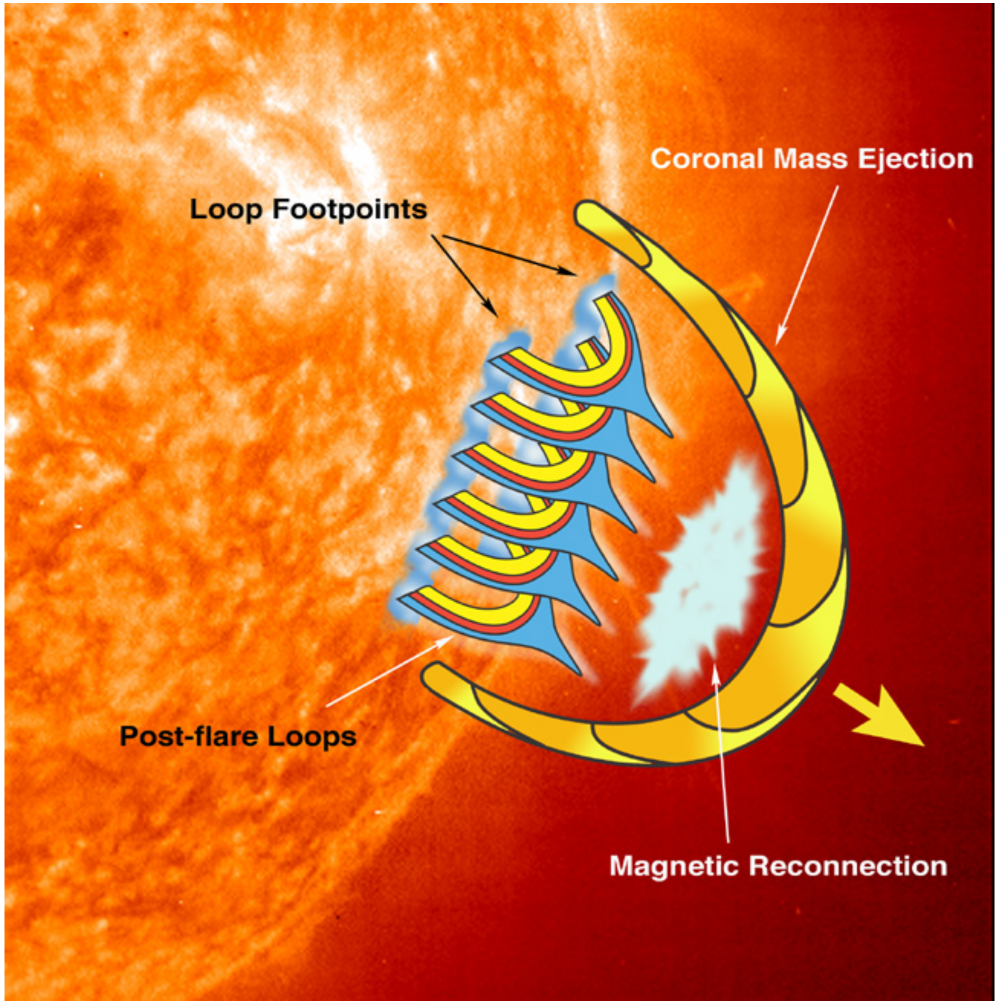


Solar flares



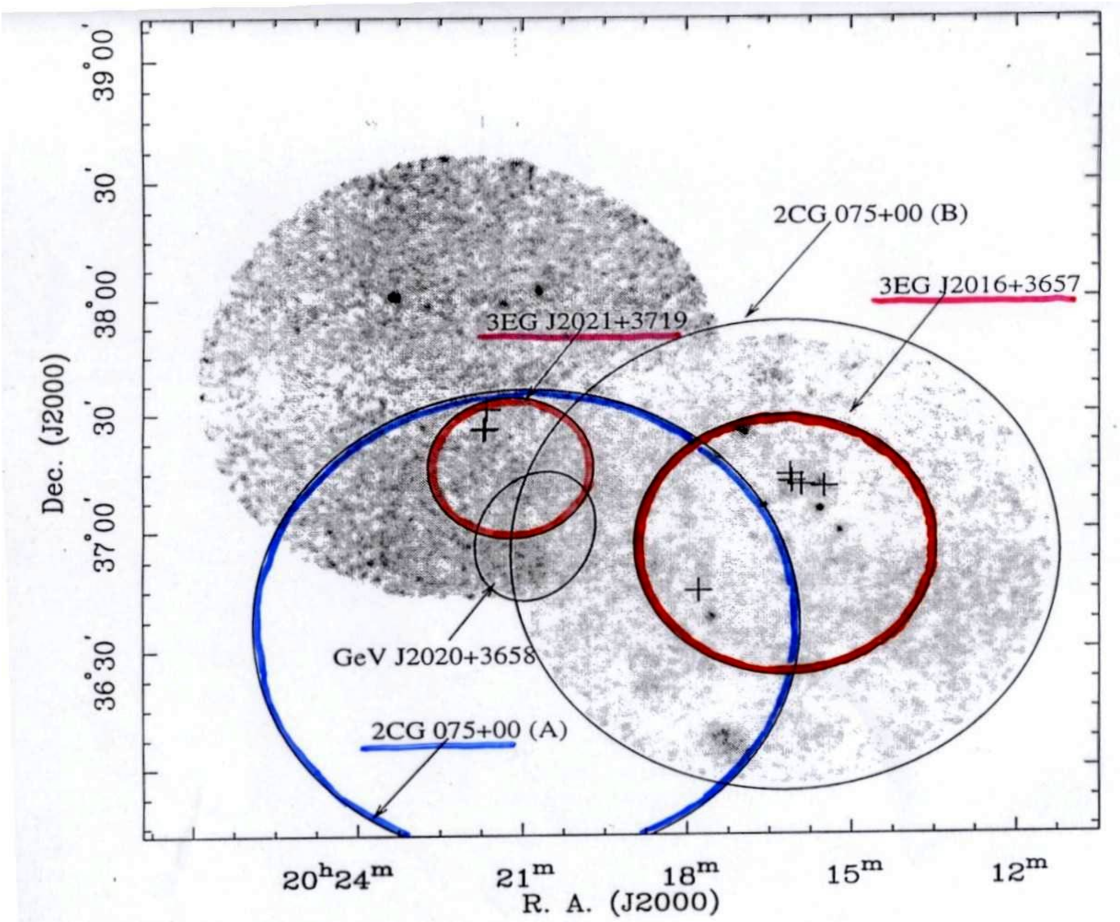


Solar Flares

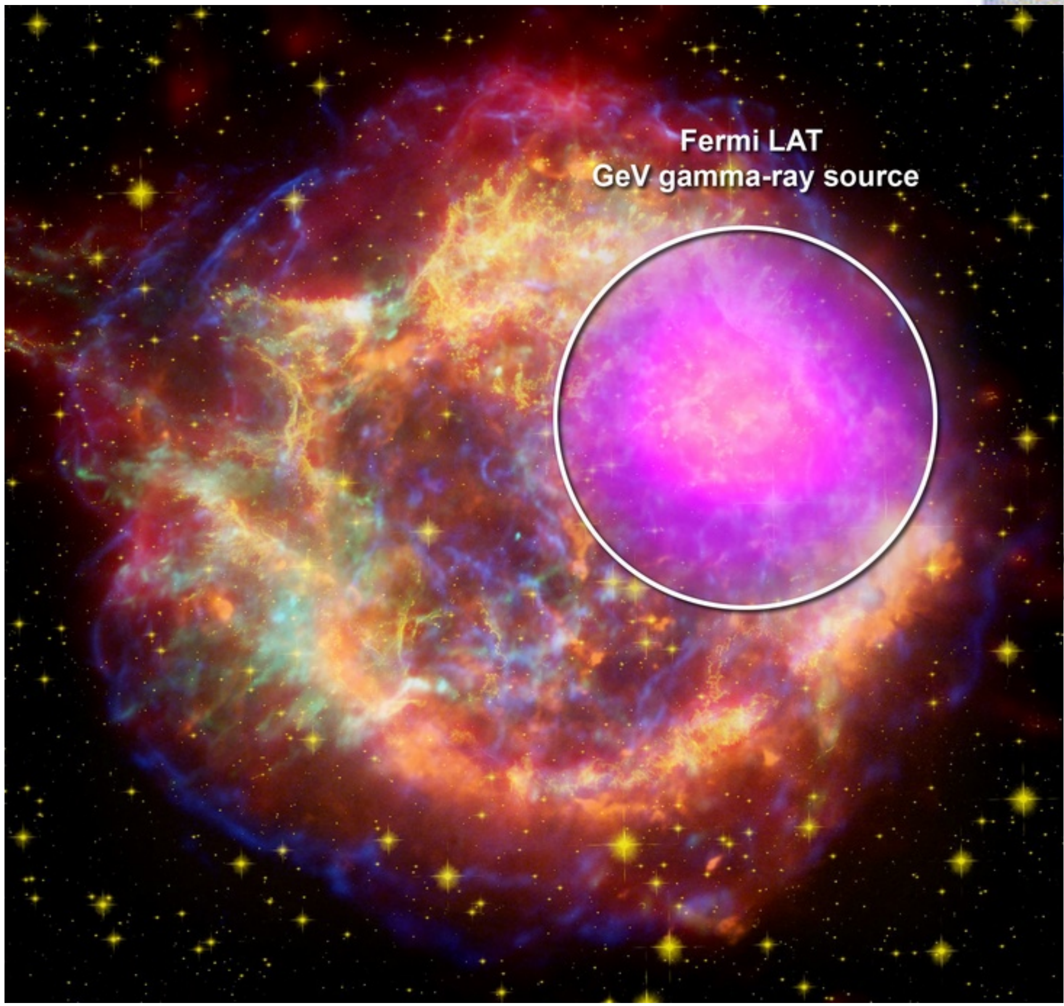


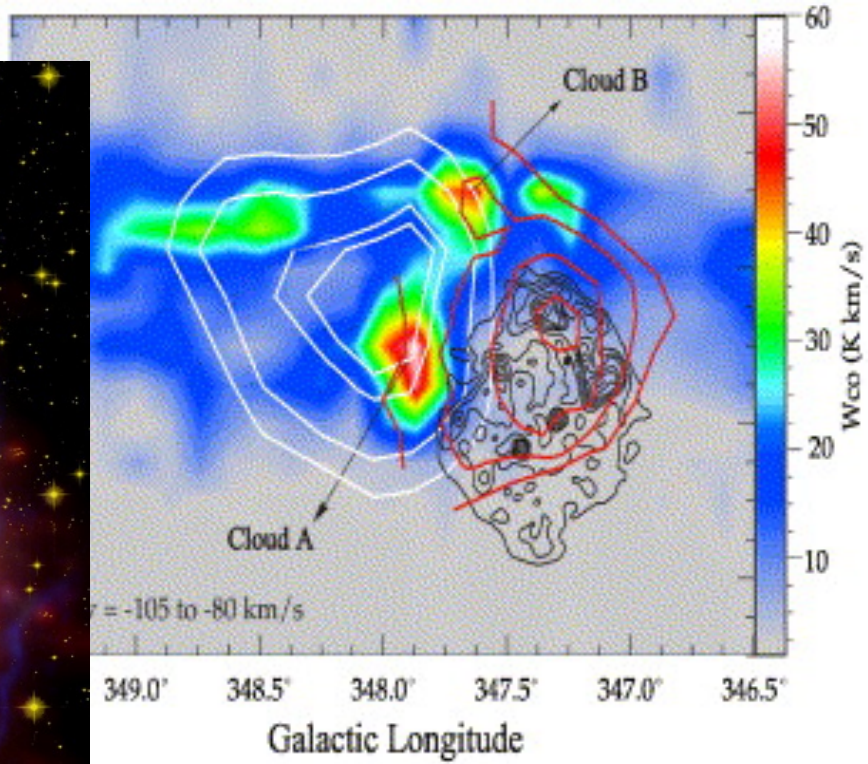
Challenge # 4

- Need arcminute positioning of gamma-ray sources (improving EGRET error box radii by a factor of 2-10).

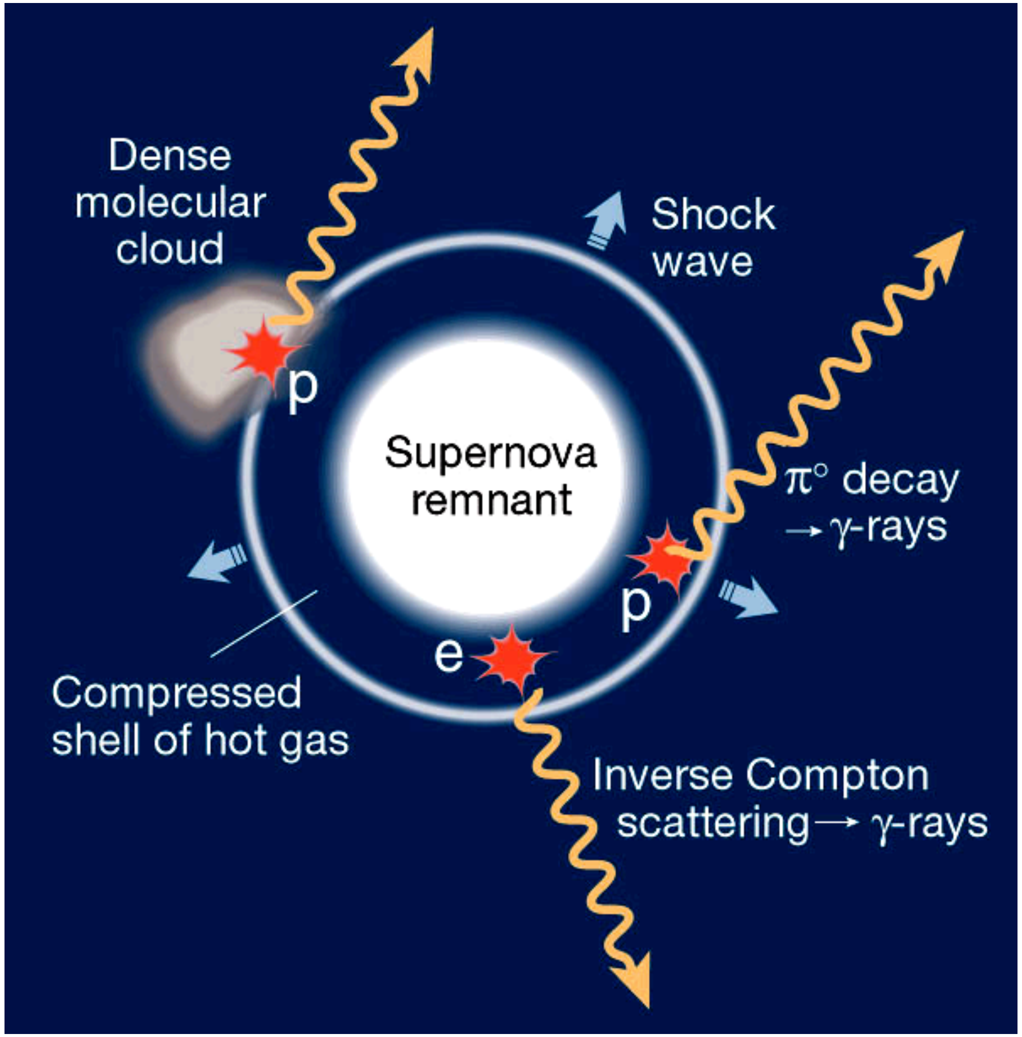


Supernova Remnants





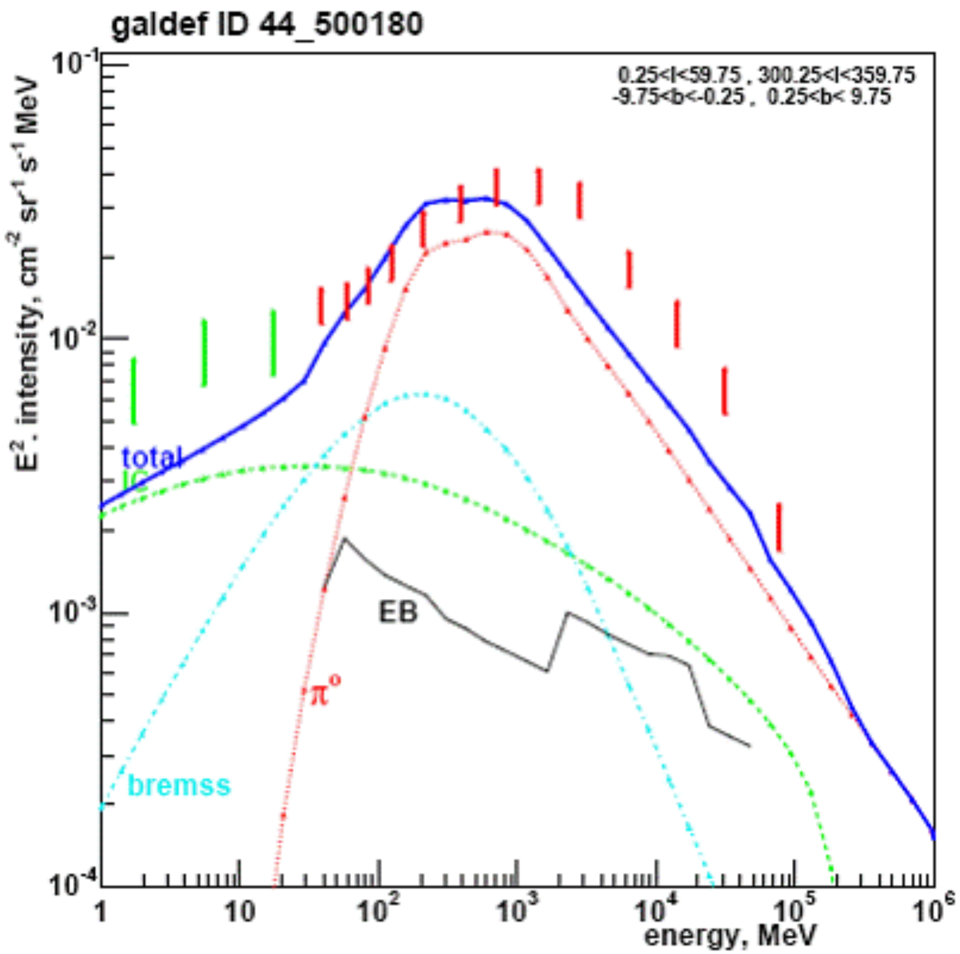
SNR



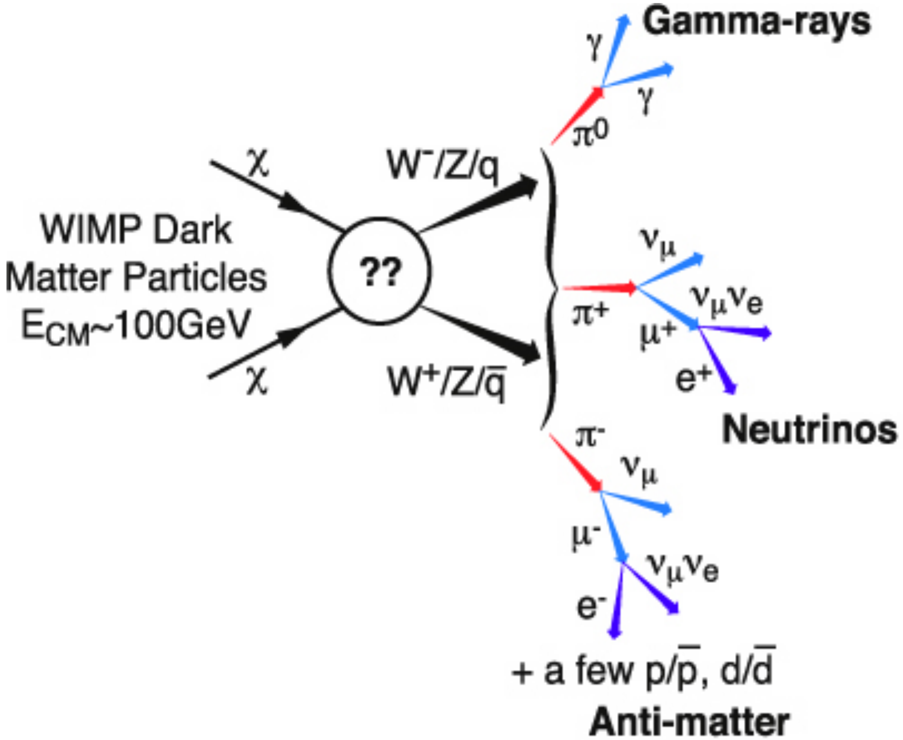
Dense molecular cloud
Shock wave
p
Supernova remnant
π° decay → γ-rays
p
e
Compressed shell of hot gas
Inverse Compton scattering → γ-rays

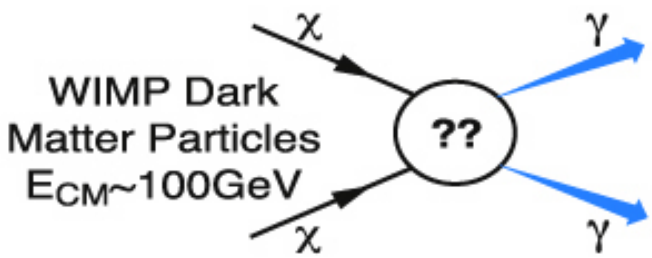
Challenge # 5

- Need improvements in Spectral Resolution fo check for DM signals



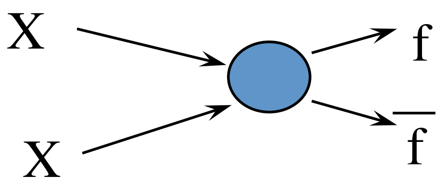
Dark Matter


Gamma-rays
γ
γ
π0
χ
W⁻/Z/q
WIMP Dark
Matter Particles
ECM~100GeV
??
χ
W+/Z/q̄
νμ
π+
νμνe
μ+
e+
Neutrinos
π-
νμ
μ-
νμνe
e-
+ a few p/p̄, d/d̄
Anti-matter


χ
γ
WIMP Dark
Matter Particles
ECM~100GeV
??
χ
γ

Particle Dark Matter

Some important models in particle physics could also solve the dark matter problem in astrophysics. If correct, these new particle interactions could produce an anomalous flux of gamma rays (“indirect detection”).

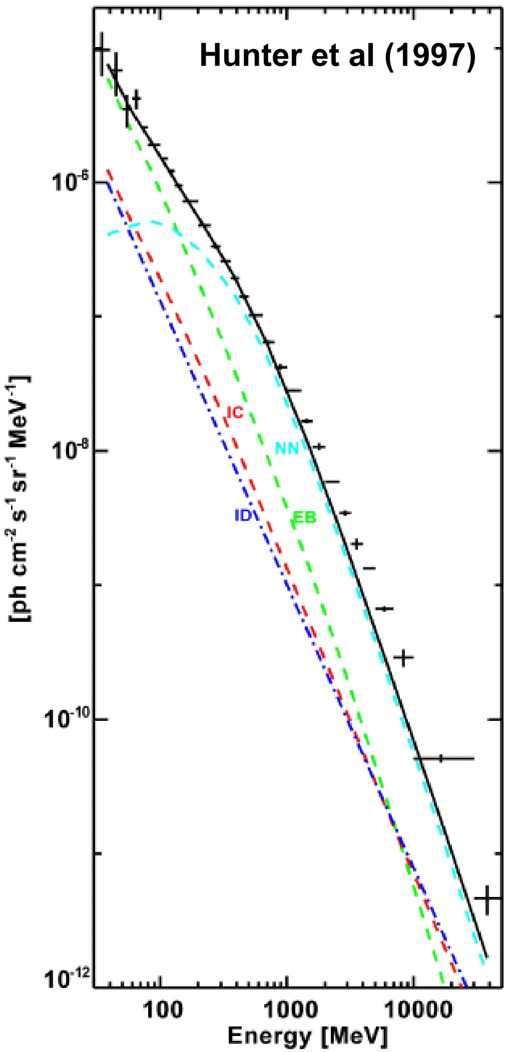


anomalous continuum
or γγ or Zγ “lines”?

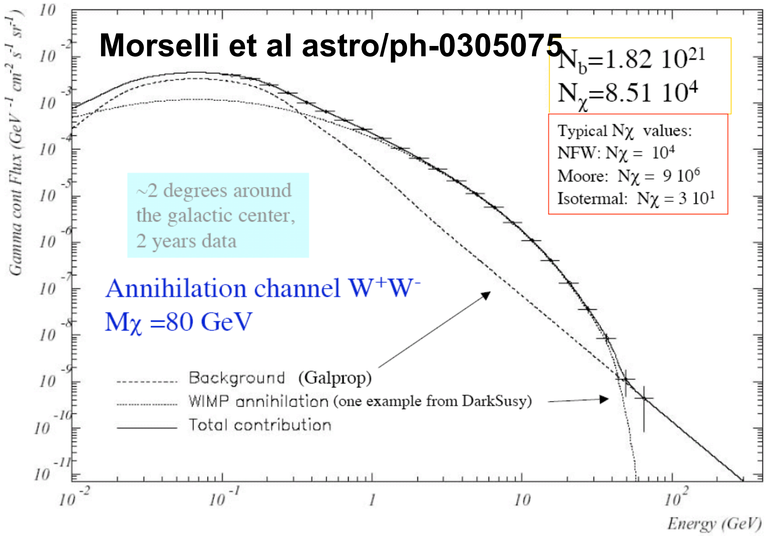
- Key interplay of techniques (see Baltz et al., astro/ph-0602187):
  - colliders (TeVatron, LHC, ILC)
  - direct detection experiments
  - indirect detection (best shot: gamma rays)
    - GLAST full sky coverage look for clumping throughout galactic halo, including off the galactic plane (if found, point the way for ground-based facilities)
    - Intensity highly model-dependent
    - Challenge is to separate signals from astrophysical backgrounds

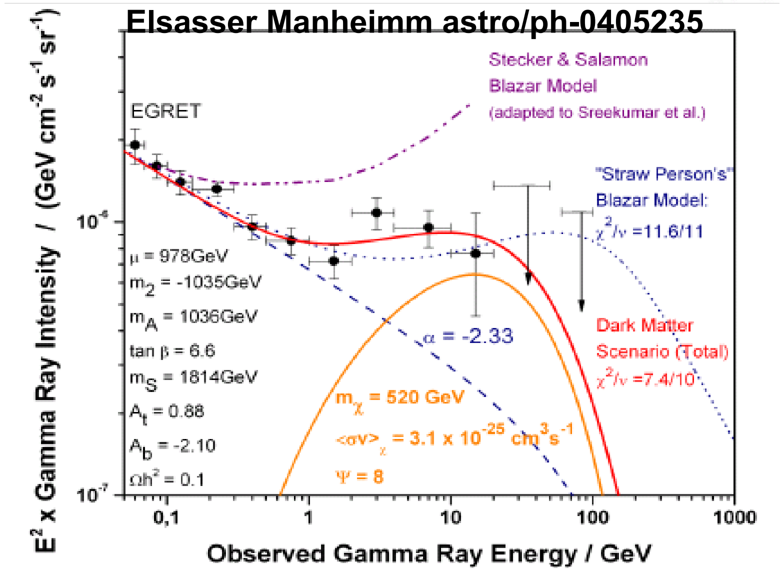
Just an example of what might be waiting for us to find!

Dark Matter Searches



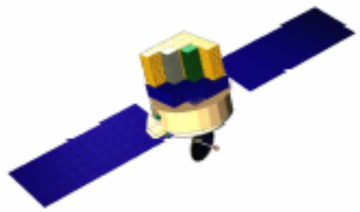
- WIMP annihilation in galactic centre or galactic halos
- Extragalactic WIMP annihilation relic
- SUSY dark matter
- Kaluza Klein dark matter





➢ this science require large sensitivity on a broad energy range, localization power, energy resolution, time resolution for variability search … key elements for the whole GLAST physics program

Detector Project



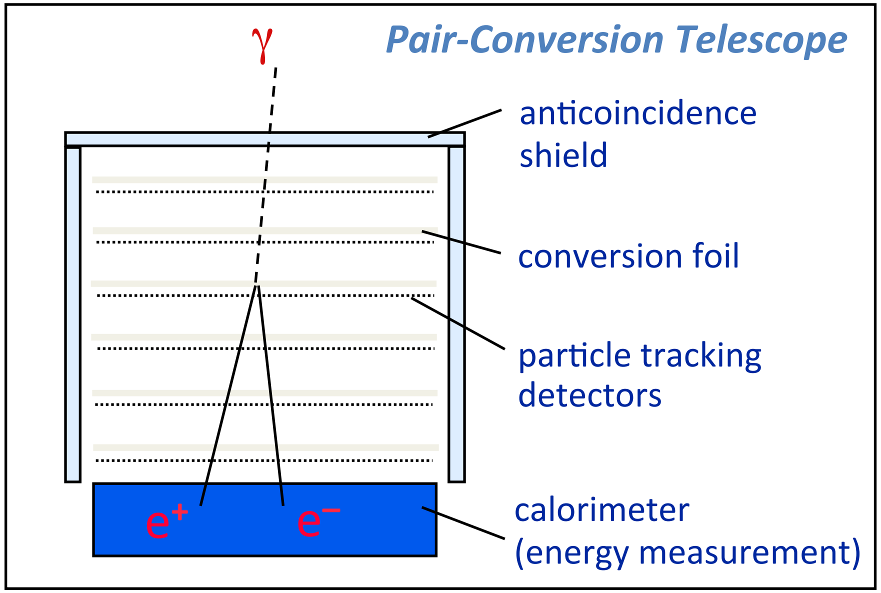
Sources Classes Predicted for GLAST

Source Class	Basis for Prediction
Active Galactic Nuclei (AGN)	EGRET quasars
Diffuse Cosmic Background	EGRET, Theory
Gamma Ray Bursts (GRBs)	EGRET, BATSE, Milagrito
Molecular Clouds, Supernova Remnants Normal Galaxies	COS-B, EGRET, Theory
Galactic Neutrons Stars (NS) & Black Holes (BHs)	COS-B, EGRET
Unidentified Gamma-ray Sources	COS-B, EGRET
Dark Matter	Theory

Detector Project

- Instrument must measure the direction, energy, and arrival time of high energy photons (from approximately 20 MeV to greater than 300 GeV):

- photon interactions with matter in GLAST energy range dominated by pair conversion:
  - determine photon direction
  - clear signature for background rejection
- limitations on angular resolution (PSF)
  - **low E: multiple scattering => many thin layers**
  - **high E: hit precision & lever arm**



Energy loss mechanisms:

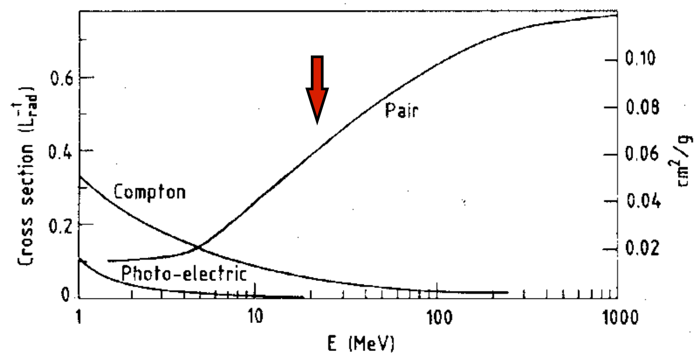


Fig. 2: Photon cross-section σ in lead as a function of photon energy. The intensity of photons can be expressed as $I = I_0 \exp(-\sigma x)$, where x is the path length in radiation lengths. (Review of Particle Properties, April 1980 edition).

- must detect γ-rays with high efficiency and reject the much larger (~10^4:1) flux of background cosmic-rays, etc.;
- energy resolution requires calorimeter of sufficient depth to measure buildup of the EM shower. Segmentation useful for resolution and background rejection.

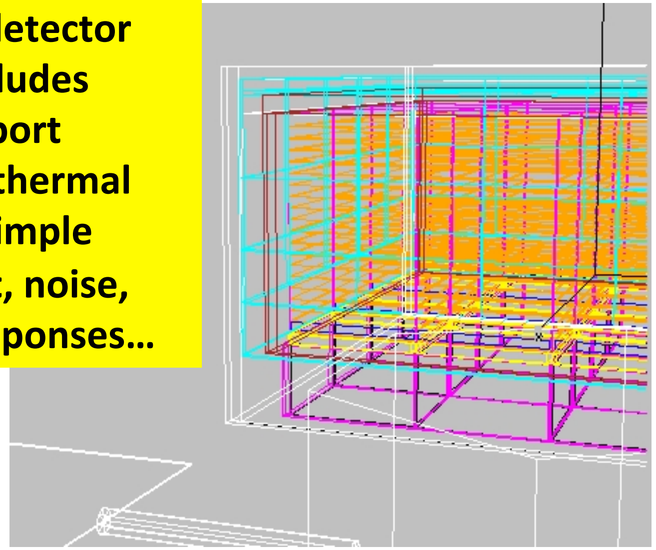
Detector Project

The LAT design is based on detailed Monte Carlo simulations.
Integral part of the project from the start.

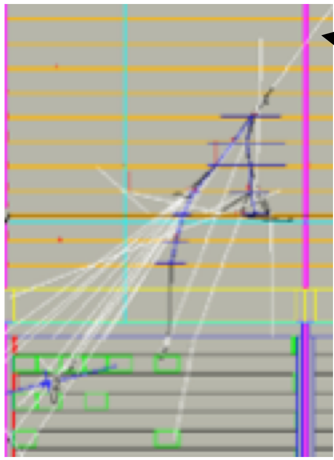
- **Background rejection**
- **Calculate effective area and resolutions (computer models now verified by beam tests). Current reconstruction algorithms are existence proofs -- many further improvements under development.**
- **Trigger design.**
- **Overall design optimization.**

Simulations and analyses are all C++, based on standard HEP packages.

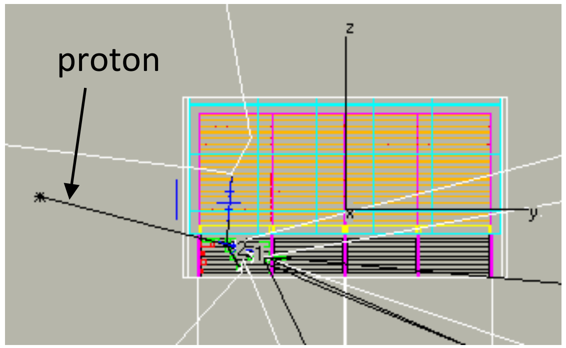
Detailed detector model includes gaps, support material, thermal blanket, simple spacecraft, noise, sensor responses…



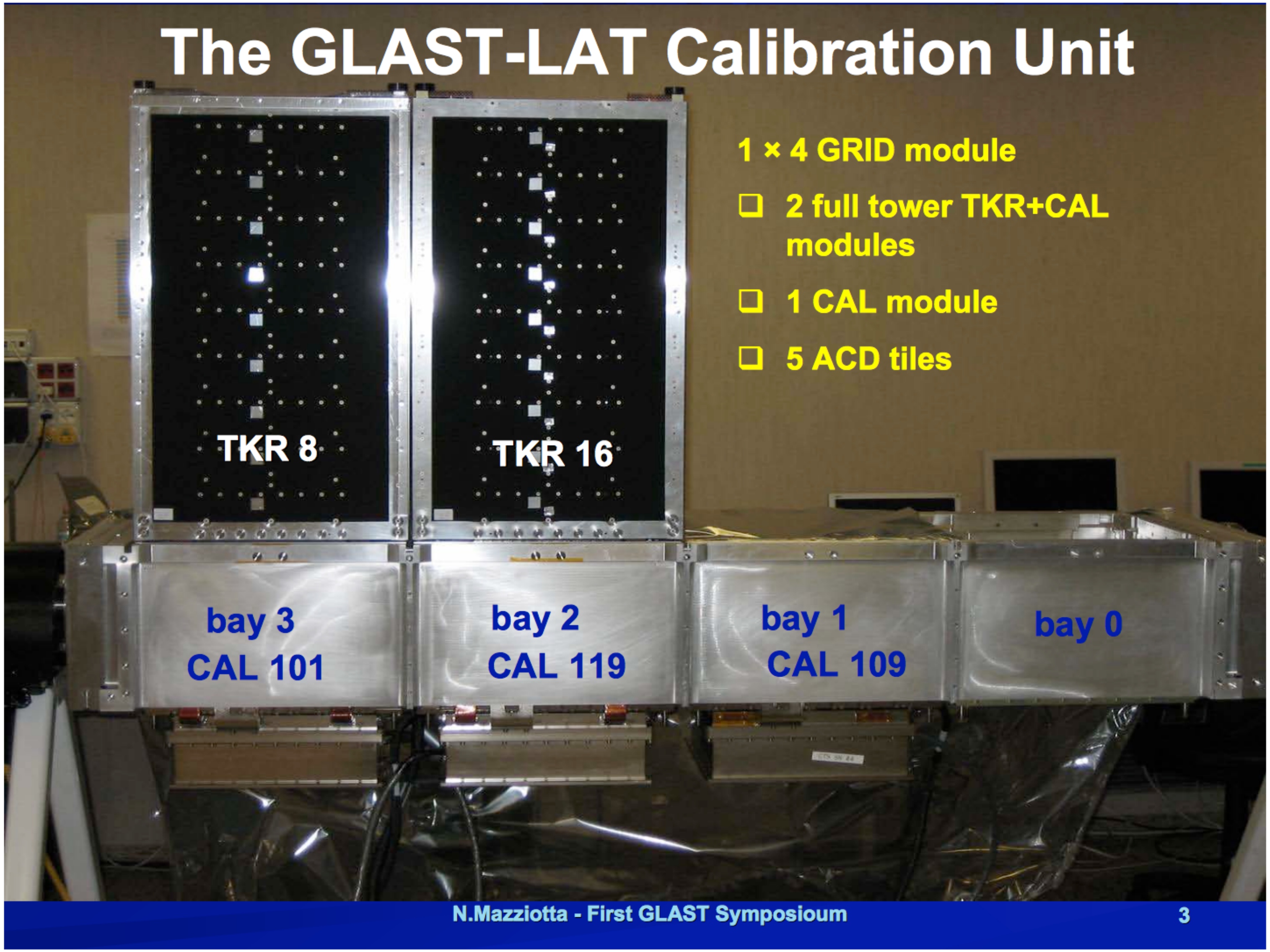
Instrument naturally distinguishes gammas from backgrounds, but details matter.



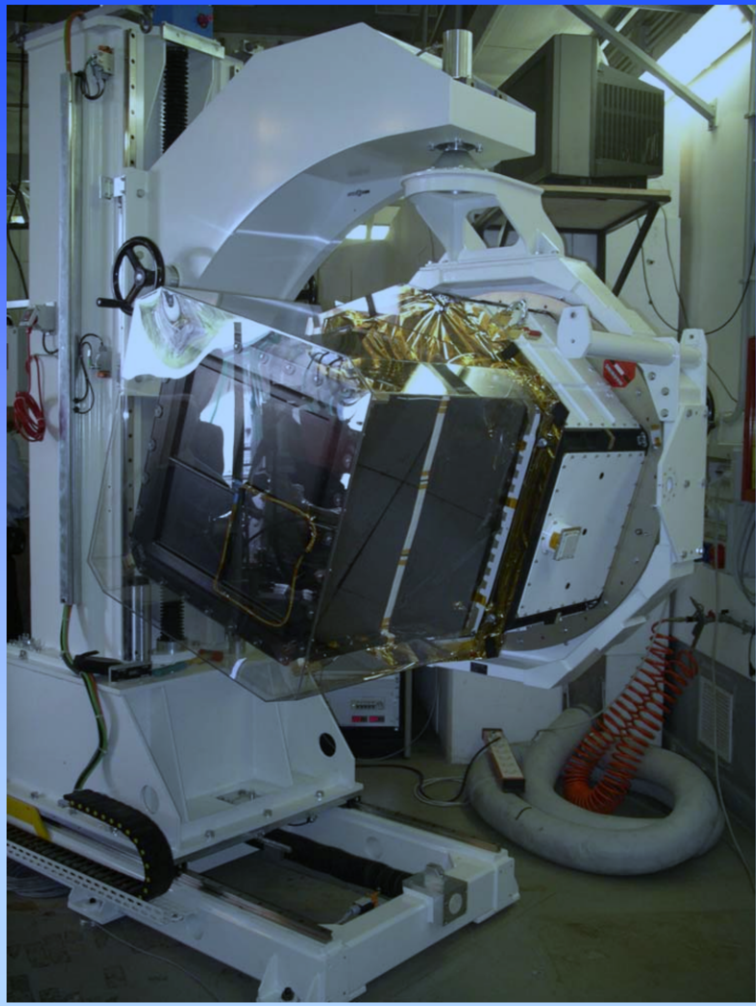
gamma ray



Beam test


The GLAST-LAT Calibration Unit
1 × 4 GRID module
❑ 2 full tower TKR+CAL modules
❑ 1 CAL module
❑ 5 ACD tiles
TKR 8
TKR 16
bay 3
CAL 101
bay 2
CAL 119
bay 1
CAL 109
bay 0
N.Mazziotta - First GLAST Symposioum
3

AGILE calibration



After a long story ...