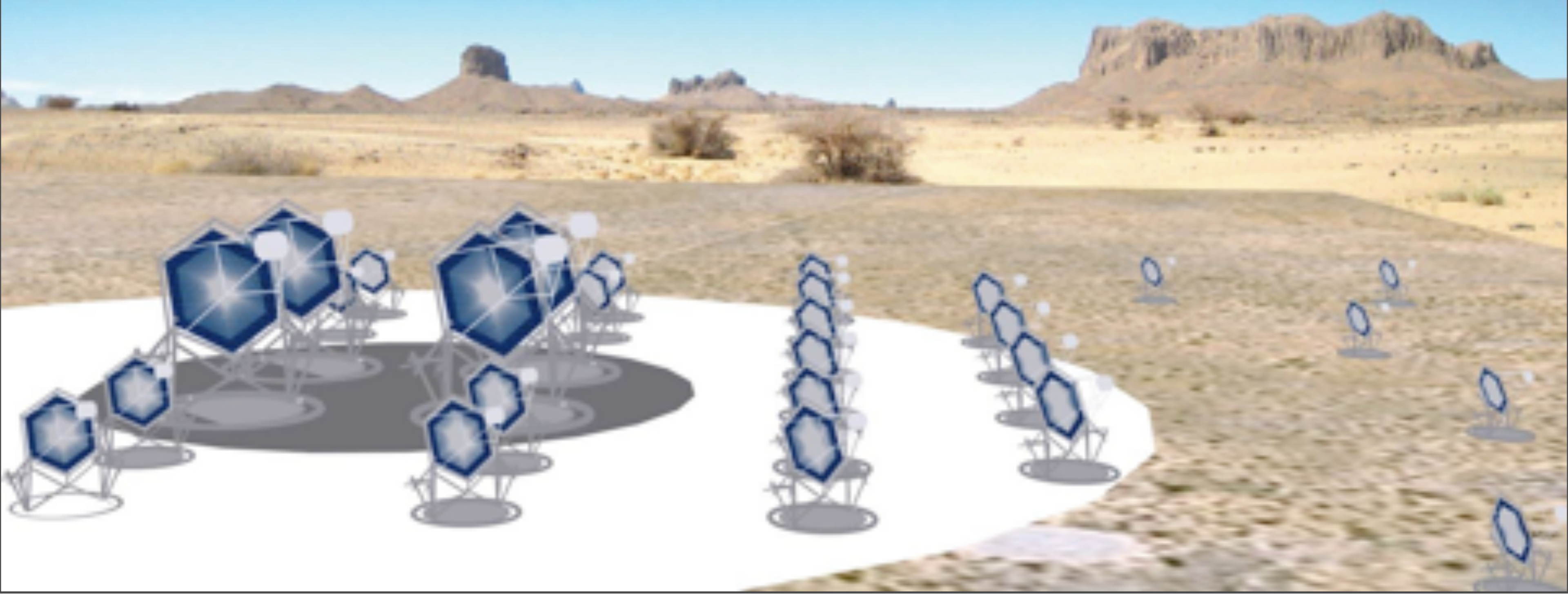
Cherenkov Telescope Array (CTA) Project

An advanced facility for ground-based gamma-ray astronomy

Thomas Schweizer
Max-Planck-Institut Munich



Toward CTA

Next generation VHE gamma ray facility

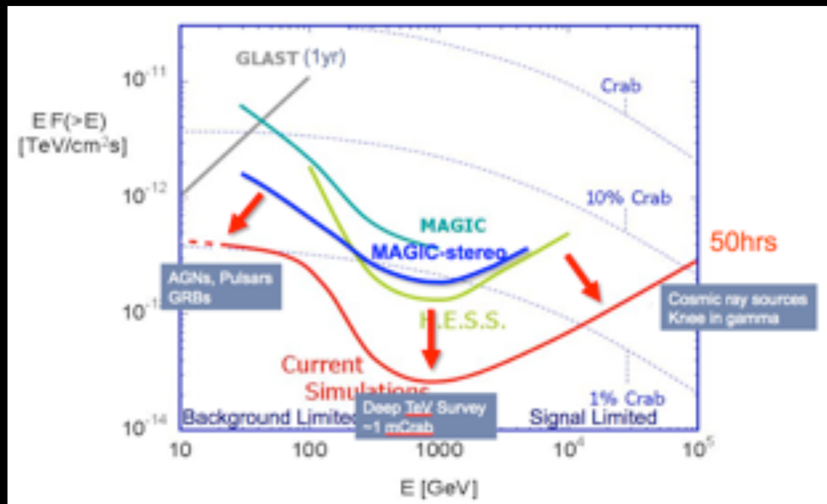
MAGIC Phase II (MAGIC-I + MAGIC-II)

HESS Phase II (HESS + 28m Telescope) in 2011

Astronomers in EU

JAPAN, US

~900 scientists / 100 institutions



Rich Physics is waiting for CTA !

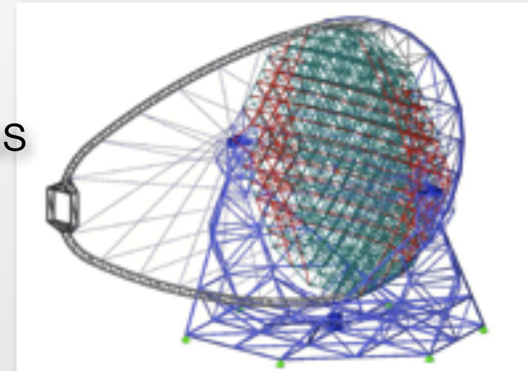
--> 1000 sources

Large Size Telescope (LST) in CTA
Project leadership: MPI Munich

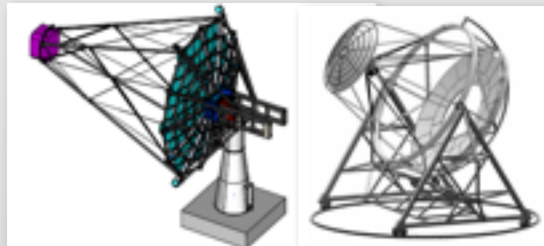
Two stations for all sky observatory

North: Canaries / Mexico / US

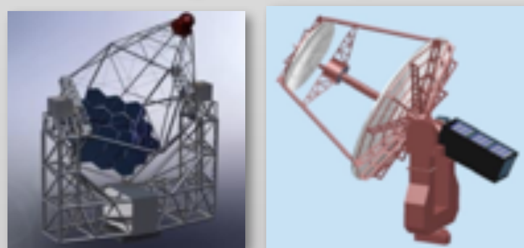
South: Namibia / Argentina



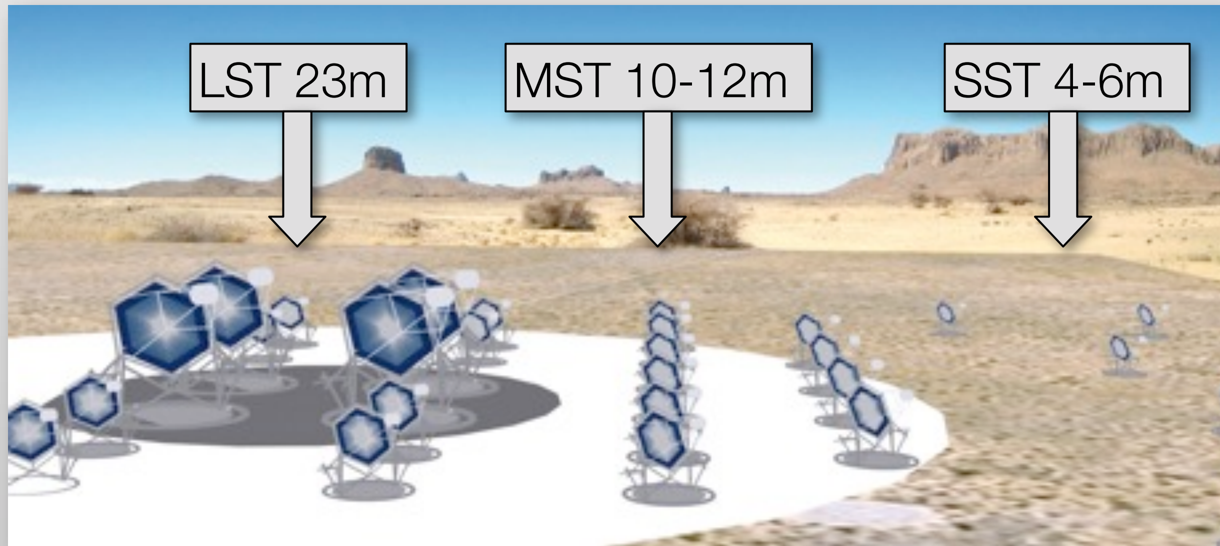
LST 23m



MST 10-12m



SST 4-6m



Large Size Telescope (LST) in CTA
Project leadership: MPI Munich

Two stations for all sky observatory

North: Canaries / Mexico / US

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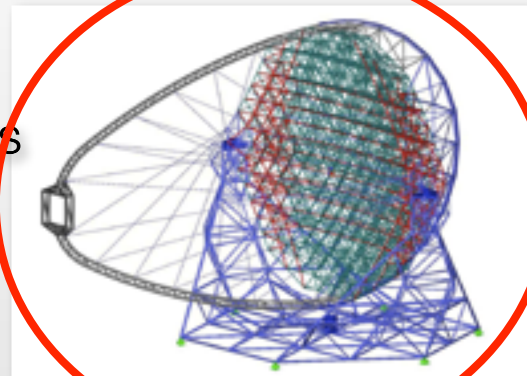
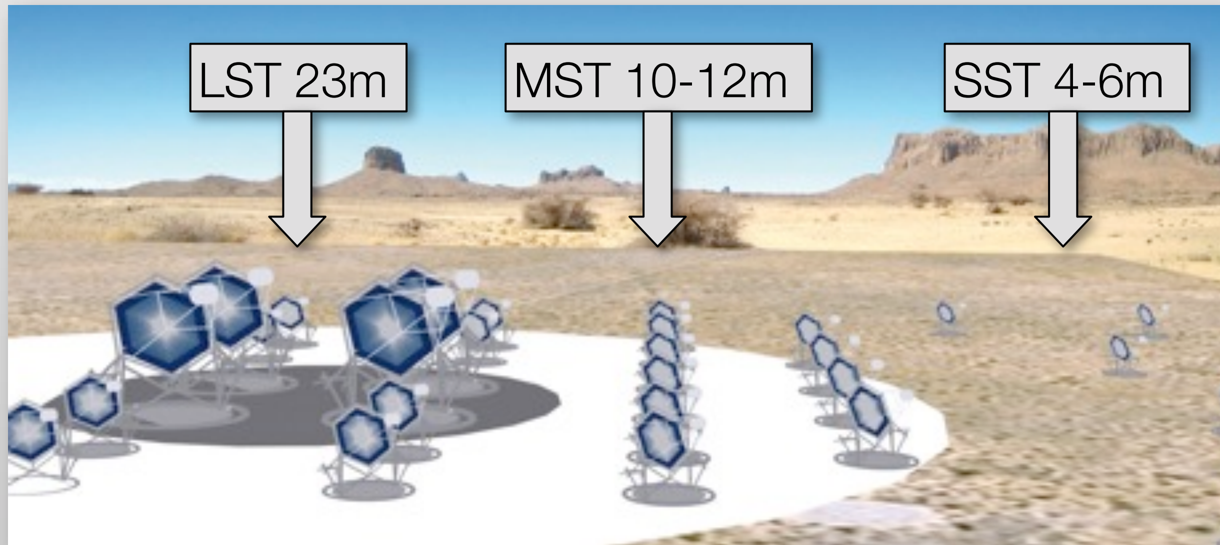
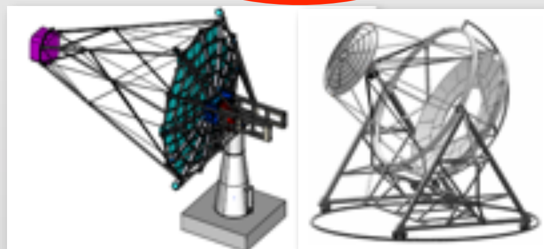
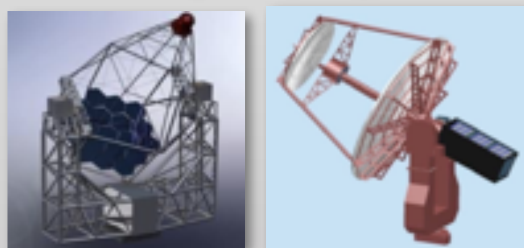


LST 23m



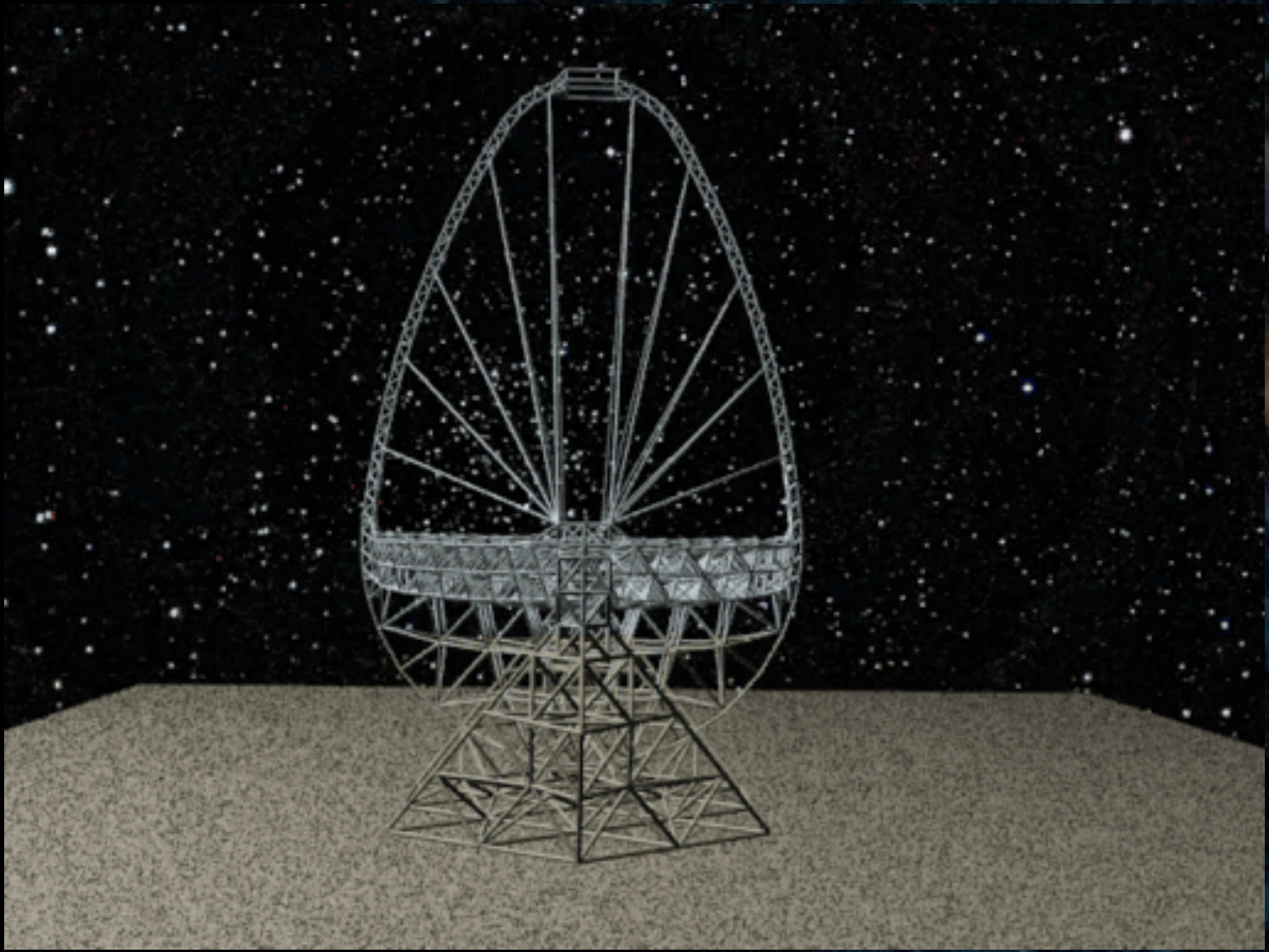


MST 10-12m



SST 4-6m

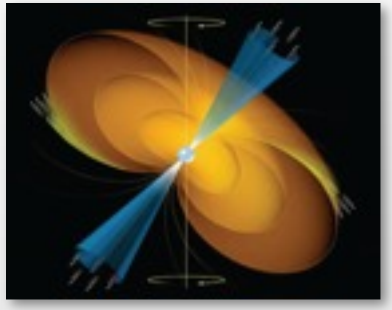
MPI
The Large Size Telescope



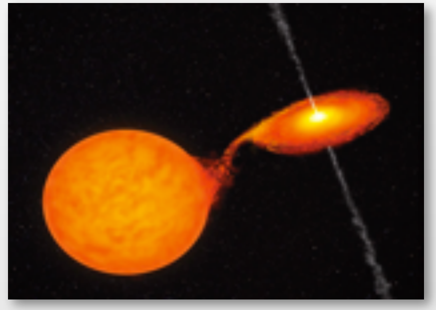
Science case of LST

High redshift AGNs (z<3)

GRBs (z<10)



Pulsars



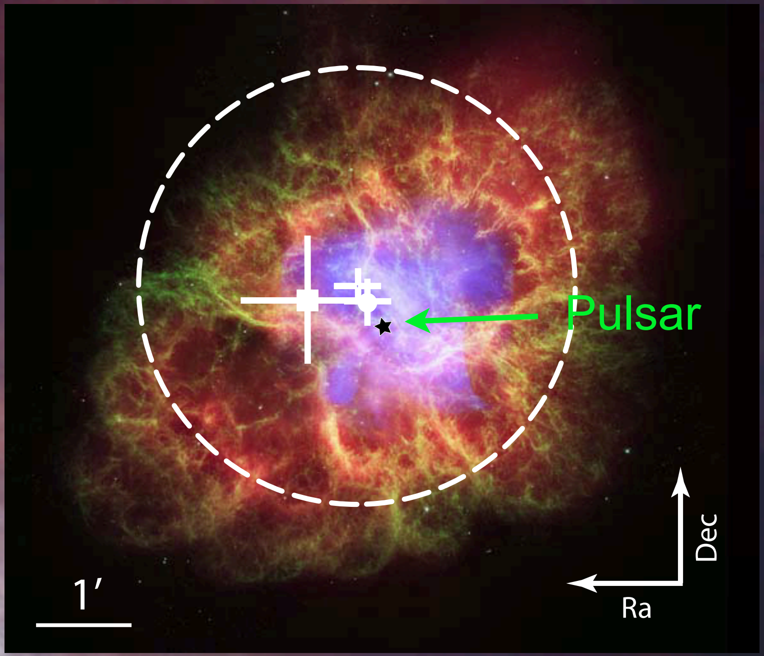
Binaries and transients

- LST is optimized in the energy range between 20 - 200 GeV
- Low energy threshold
  - Trigger threshold: 15-20 GeV
  - Analysis threshold: 20-30 GeV

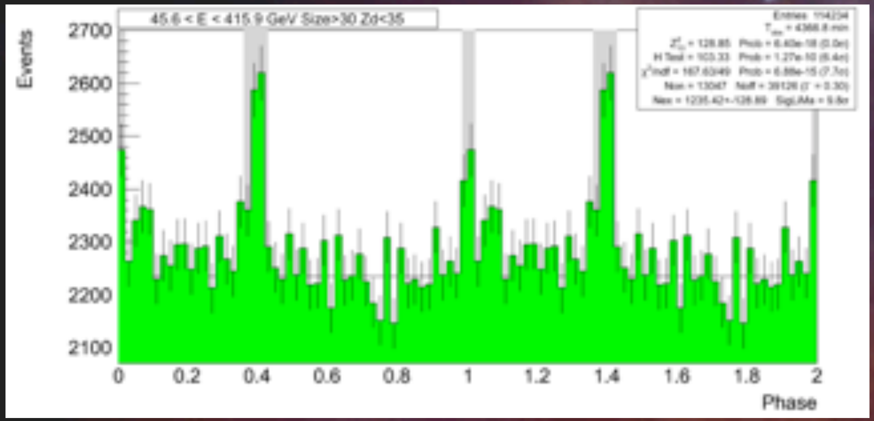
- Key physics cases:
  - High-redshift AGNs and GRBs
  - Binaries, Pulsars and other type of transients at low energy

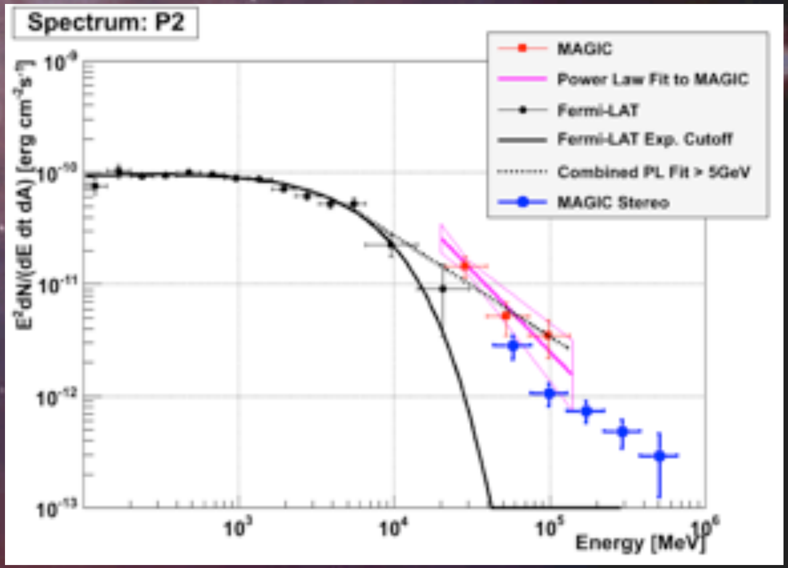
Pulsar physics

- Pulsars seem to have high energy tails (not explained by theory)
- CTA will see several pulsars
- Connection between pulsar and pulsar wind nebula ?



Crab (MAGIC)

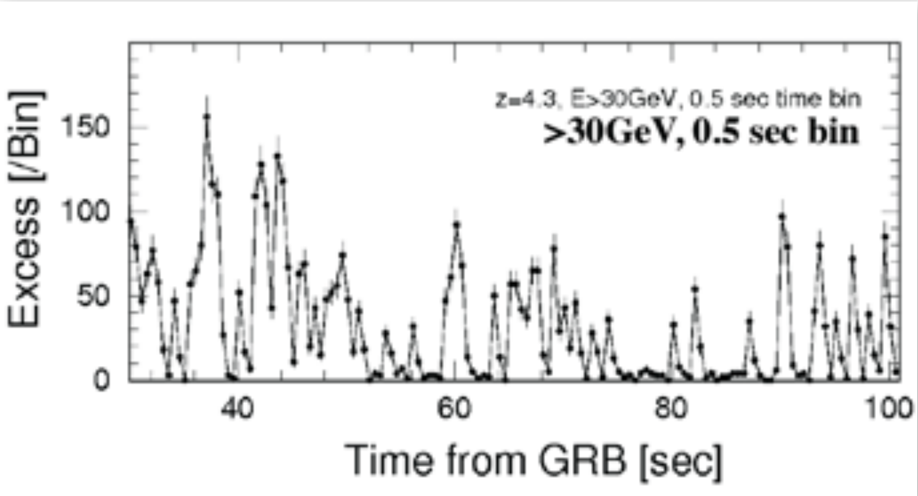


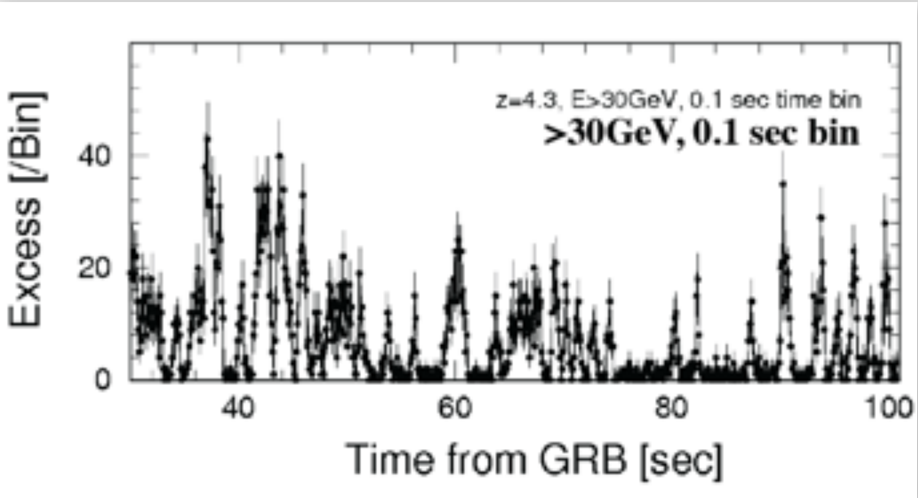


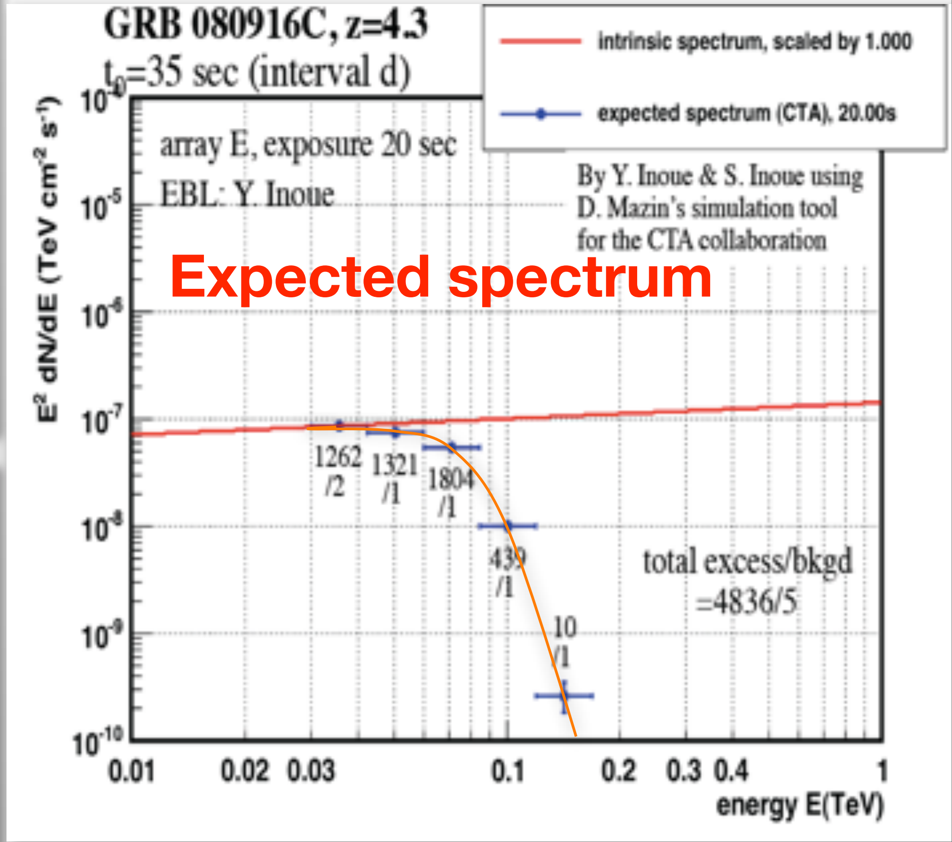
Gamma ray bursts

CTA Monte Carlo:
Expected Light curve + Spectrum for GRB at z=4.3

CTA performance study by S.Inoue, Y.Inoue, T.Yamamoto, et al







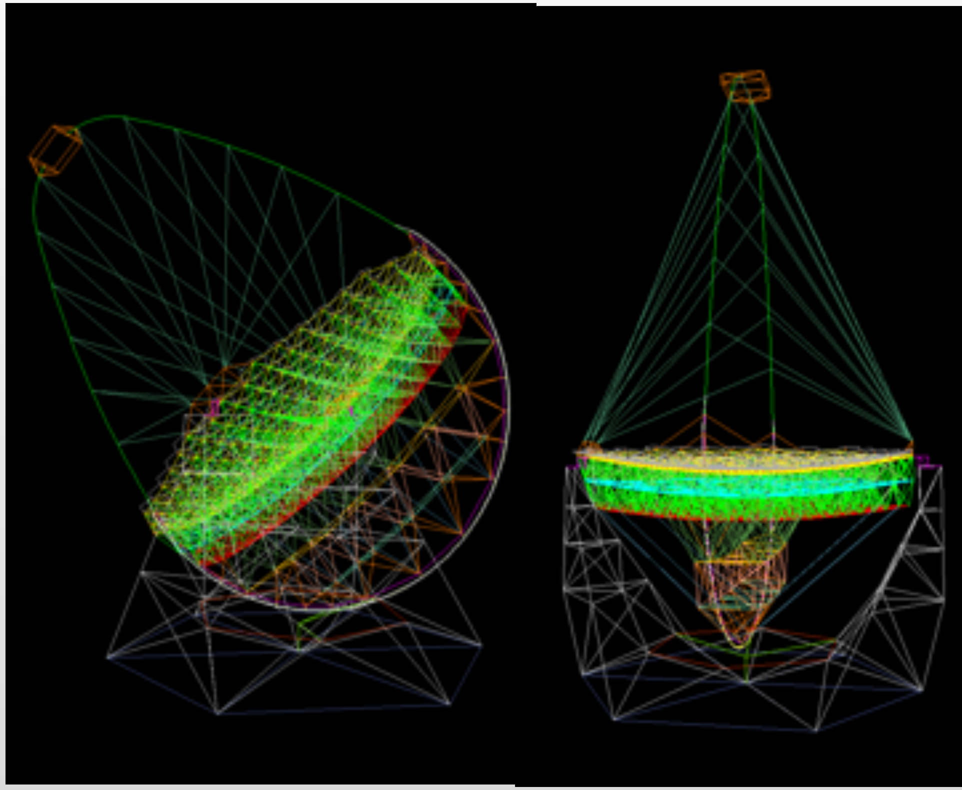
Specifications/Requirements of LST
Designed by MPI Munich

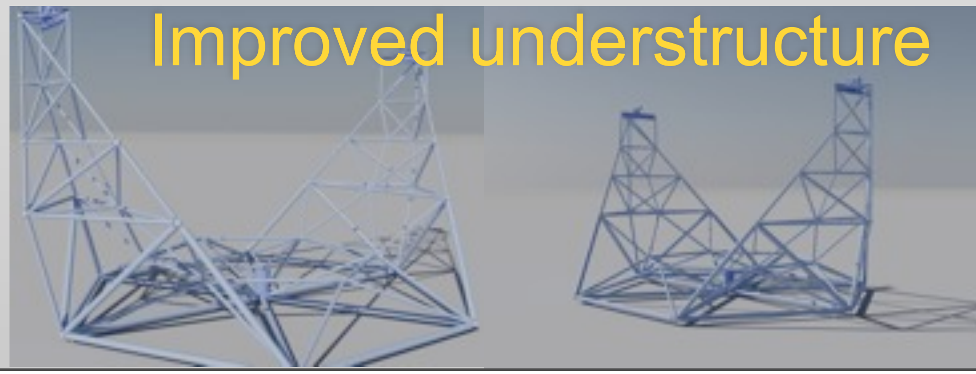
- Diameter: 23m
- Dish area: 400 m^2
- F/D = 1.2, F=28m

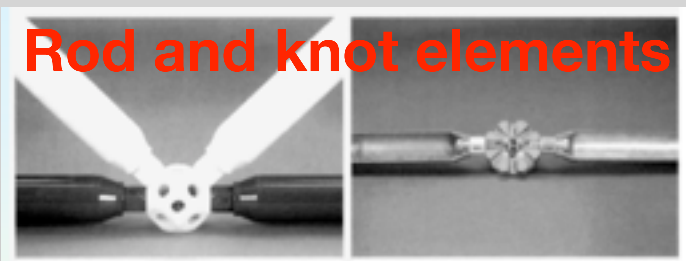
- FOV = 4.5 degrees,
  Pixel size = 0.1 degrees
  (1800~2300ch camera)

- Fast rotation: <180 deg/20 sec

- Dish profile: parabolic ➔ isochronicity:
  <0.6 ns peak to peak
- Camera sagging & oscillation:
  < 1 pixels
  ➔ Active oscillation damping by LAPP IN2P3



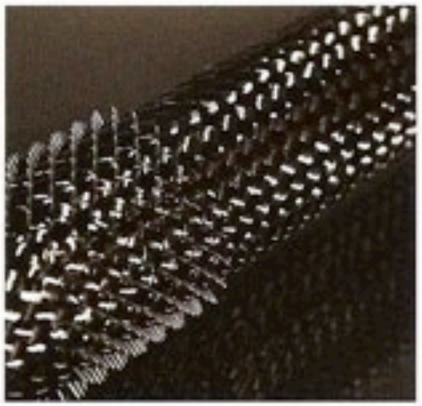




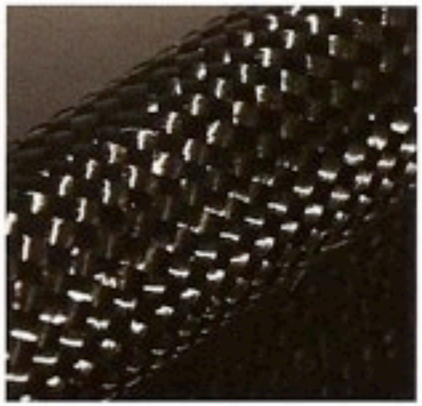
Solutions for thick CF tubes in understructure

T-Igel-Solution

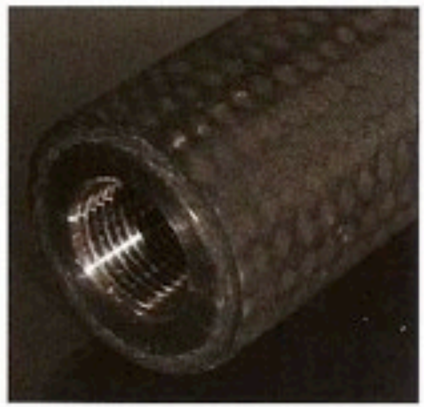
T-IGEL® Verbindung



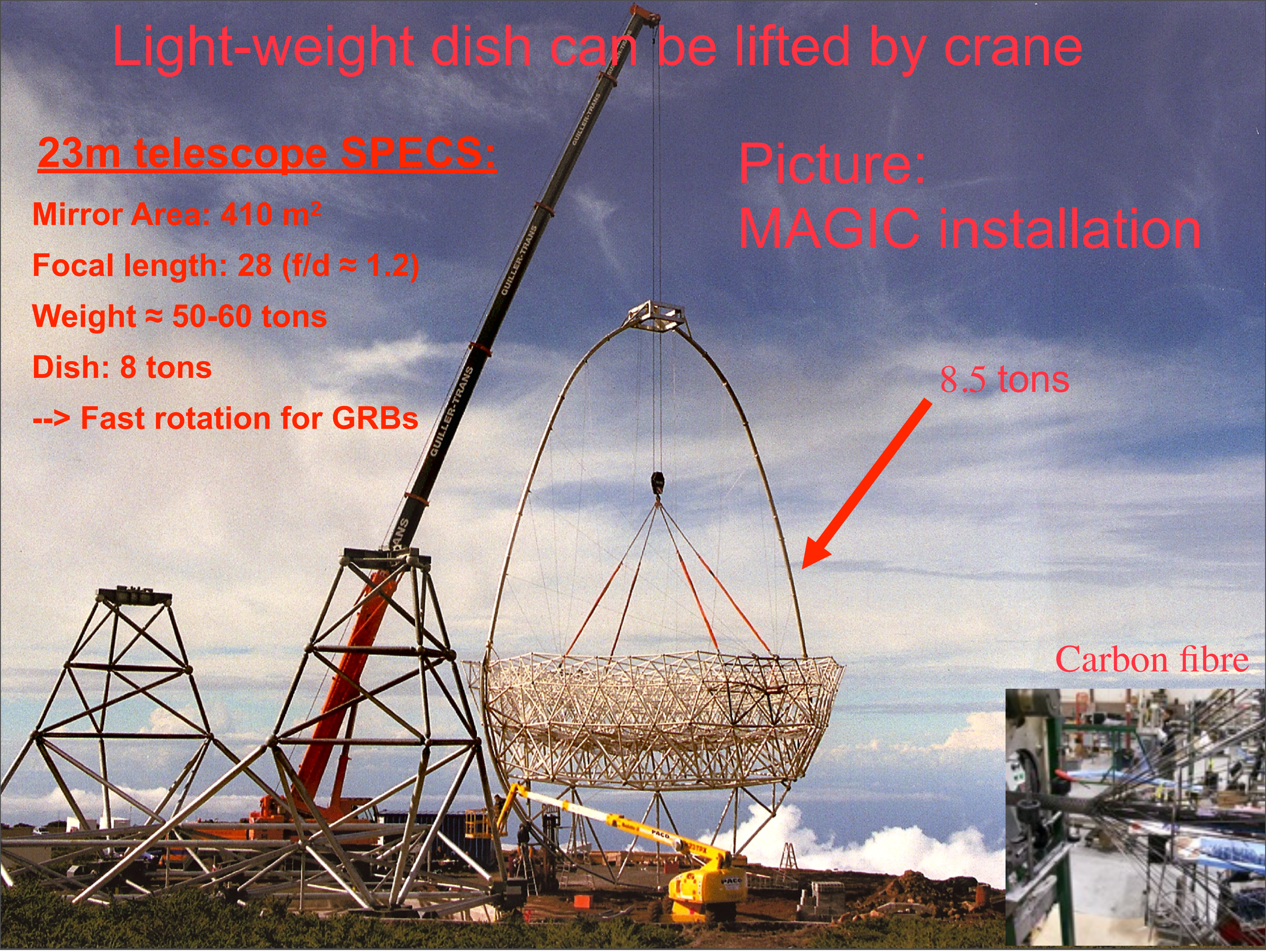
T-IGEL® teilweise eingeflochten



T-IGEL® vollständig eingeflochten



Ausgehärtete CFK-Welle


Light-weight dish can be lifted by crane
23m telescope SPECS:
Mirror Area: 410 m²
Focal length: 28 (f/d ≈ 1.2)
Weight ≈ 50-60 tons
Dish: 8 tons
--> Fast rotation for GRBs
Picture:
MAGIC installation
8.5 tons
Carbon fibre

Extremely robust structure

Withstand storm (200 km/h)

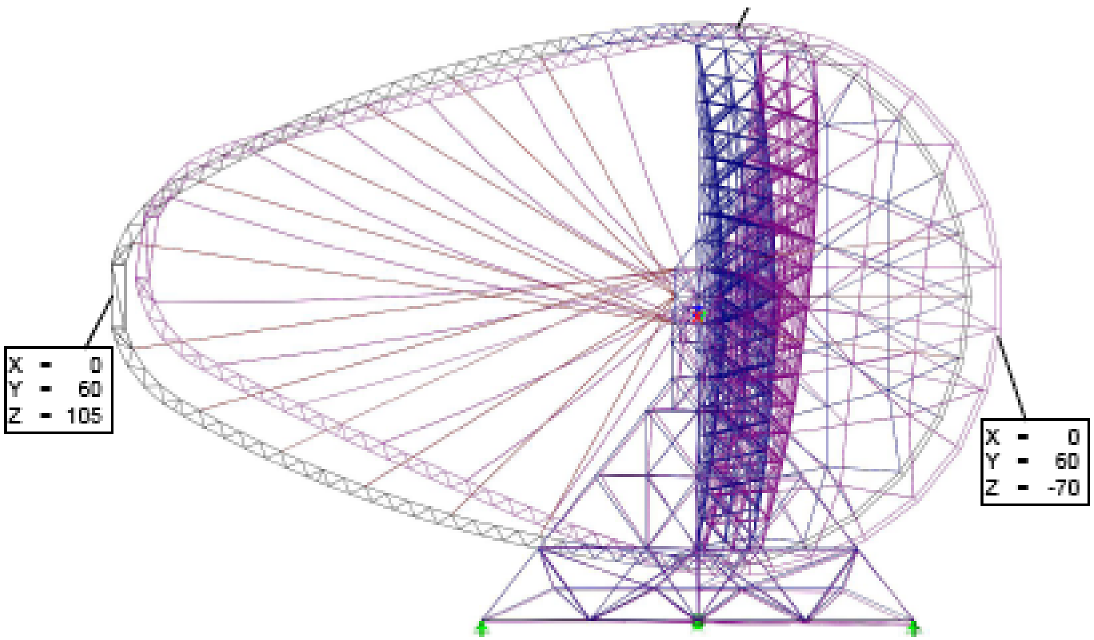
- Wind load at the order of 60-70 t on dish

and from the side on the space frame

--> Pressure on boggies

(up to 75t and about 25t uplift) !

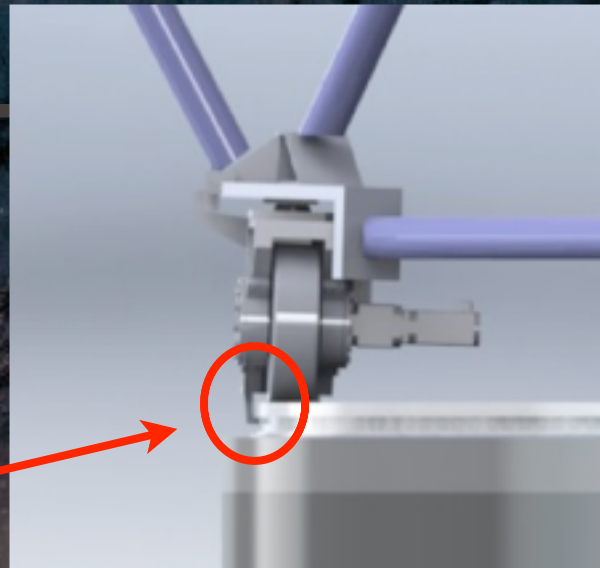
--> Windshield

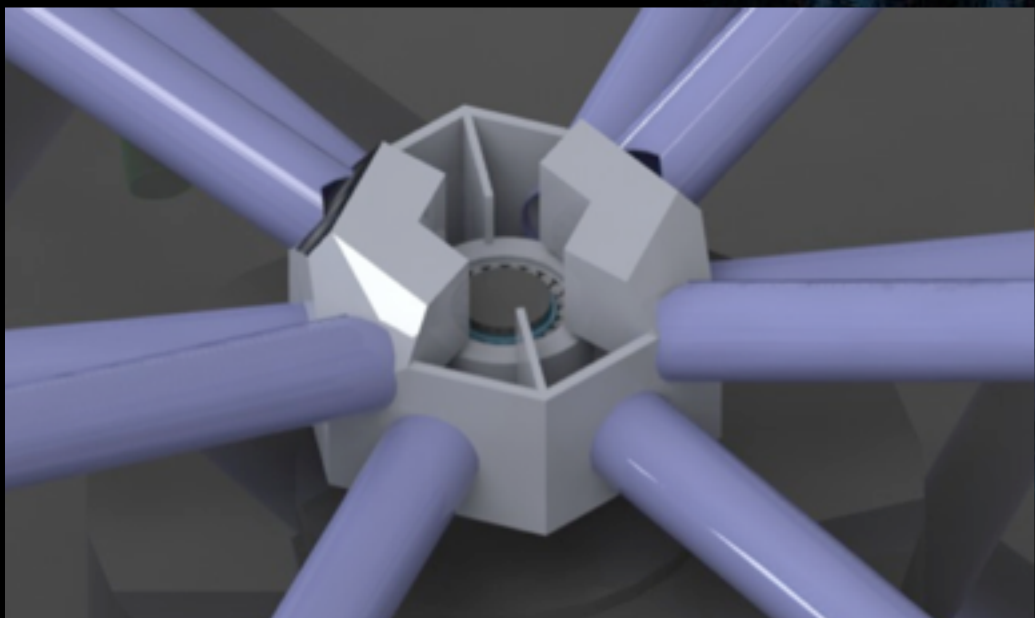


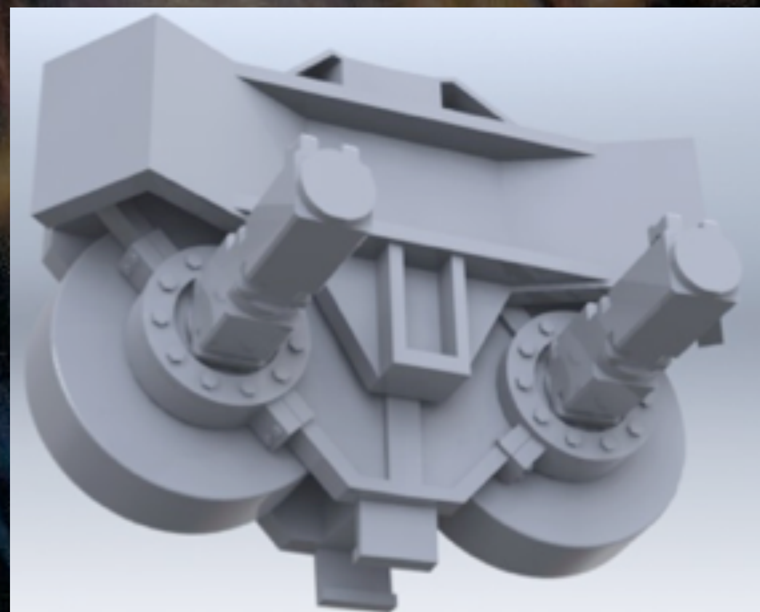
Windshield

Boggies, rails, central axis, IFAE Barcelona

- 6 Boggies/rail system
- Up to 60-75t load under tower
- 40t load for the other boggies
- > 0.1 rad/sec^2 acceleration without sliding
- Clamping and protection against uplift





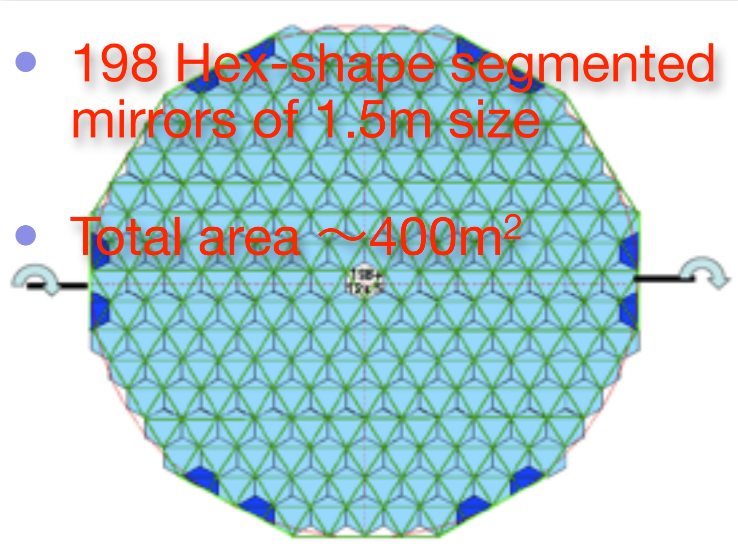


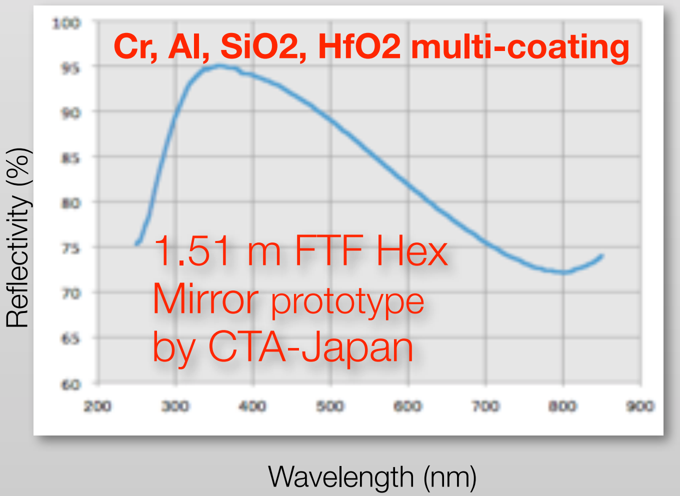
Thomas Schweizer, MPI Project review, December 2011

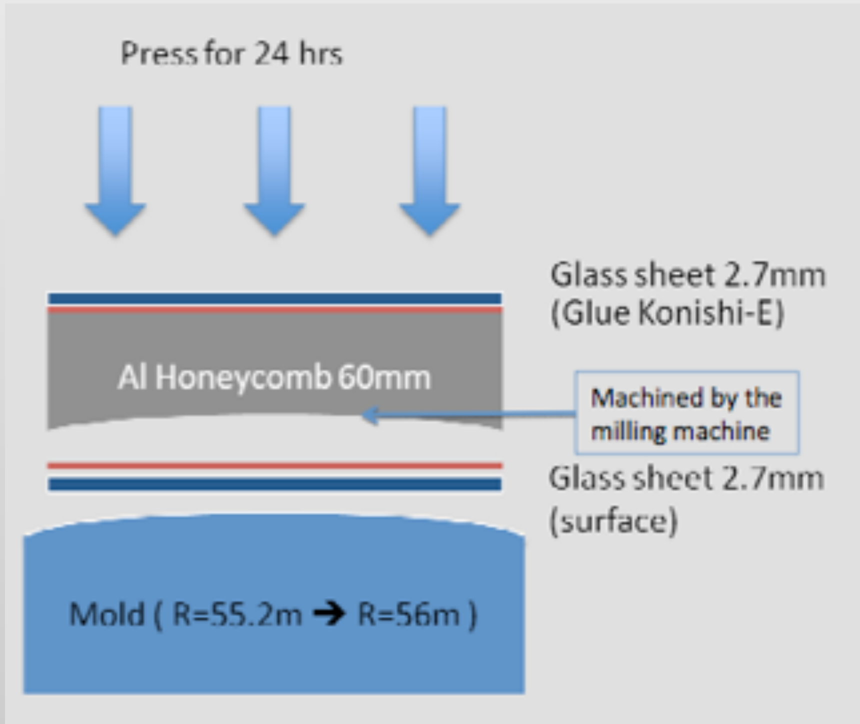
LST 23m size mirror reflector: Masahiro Teshima

cta cherenkov telescope array

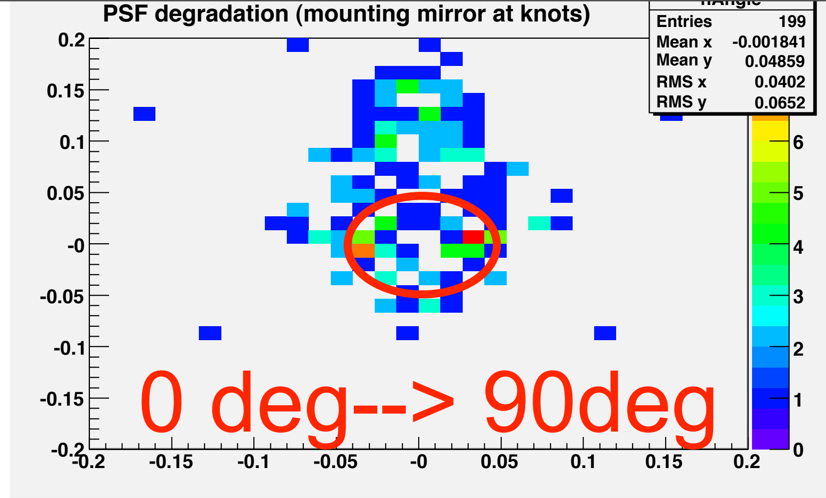
- 198 Hex-shape segmented mirrors of 1.5m size
- Total area ~400m^2

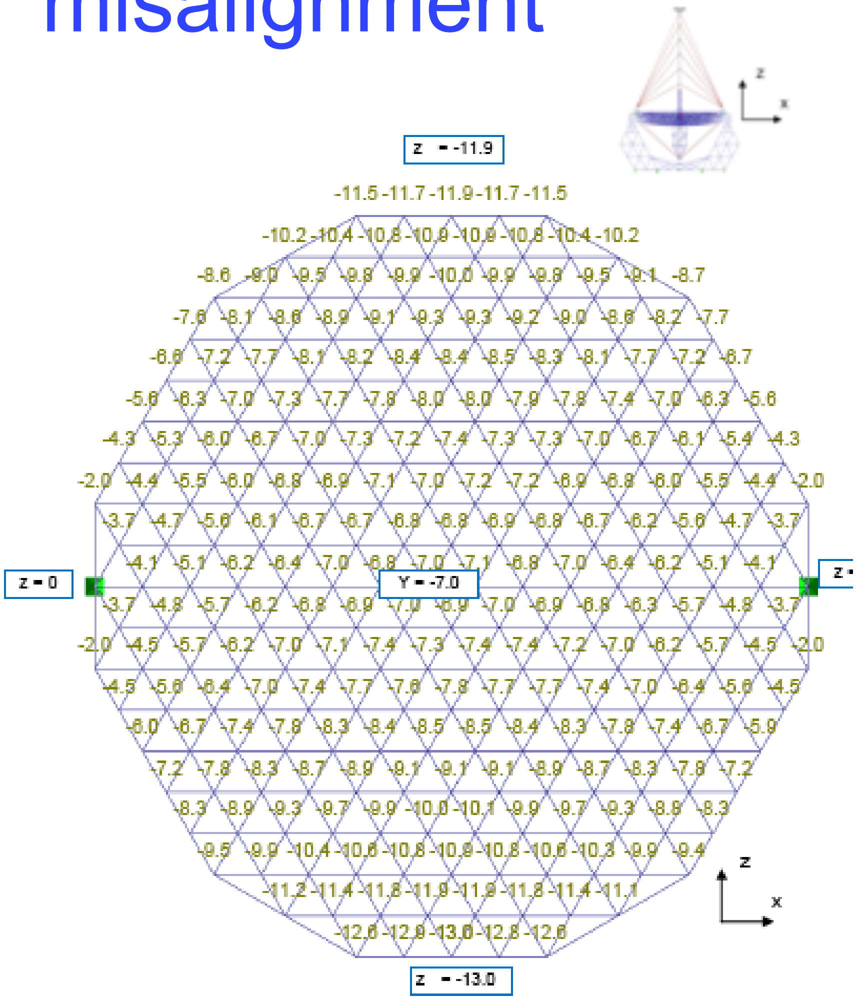


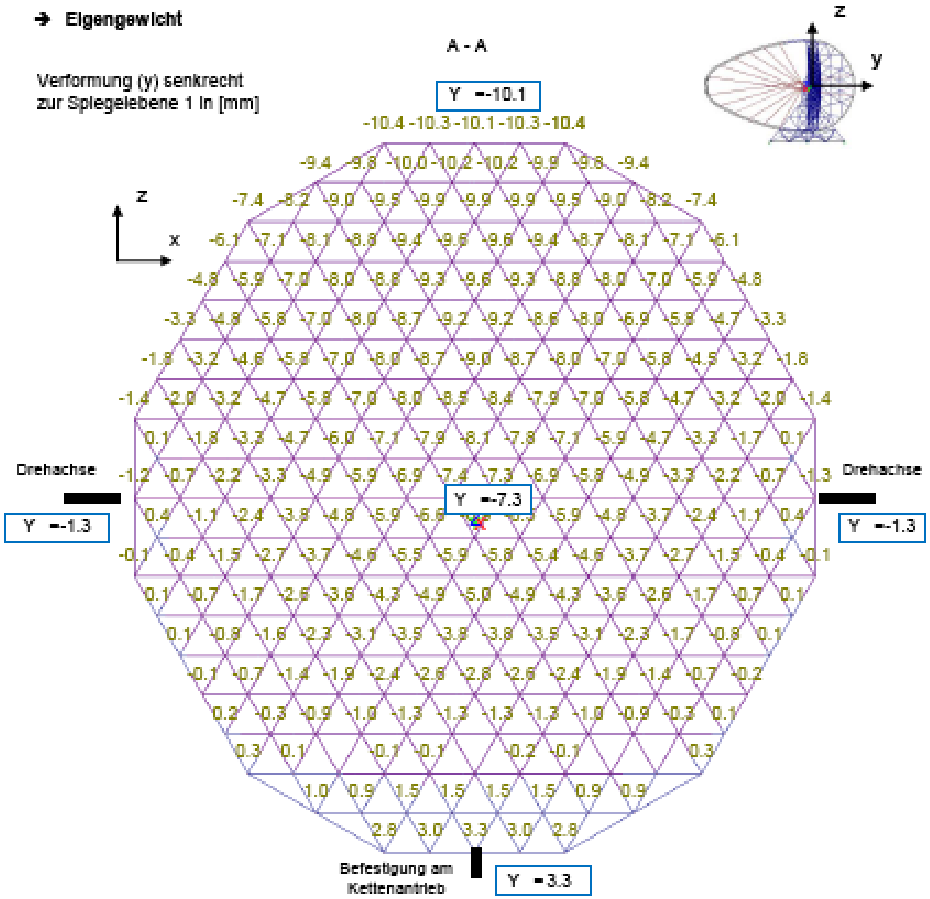




Self weight dish deformation and mirror misalignment

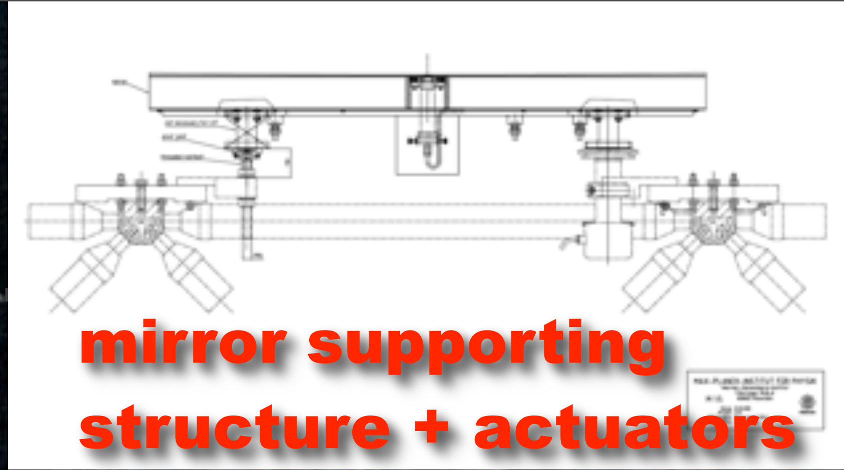


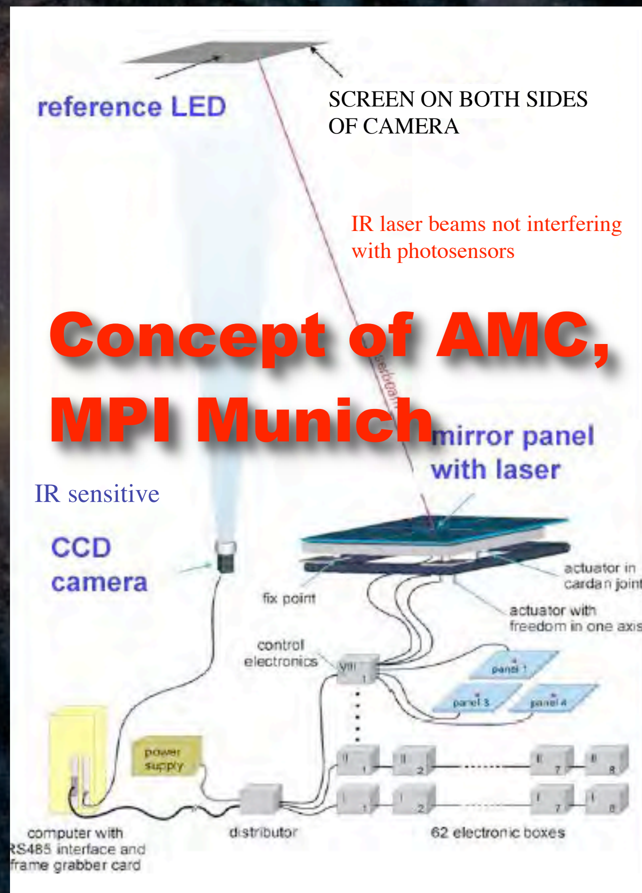




Active mirror control: MPI

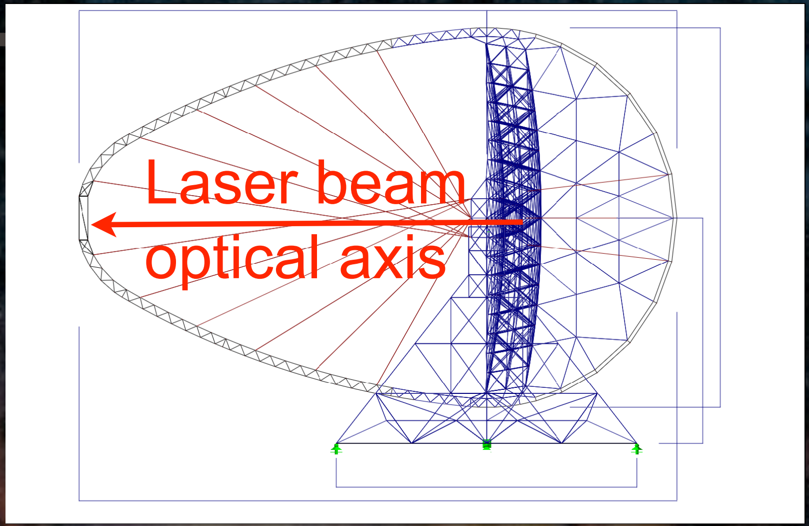
- Need to adjust mirrors for changing zenith angle
- Need to adjust thermal expansion
- Adjust minute deformations due to wind
- Fast response (5-10 minutes)

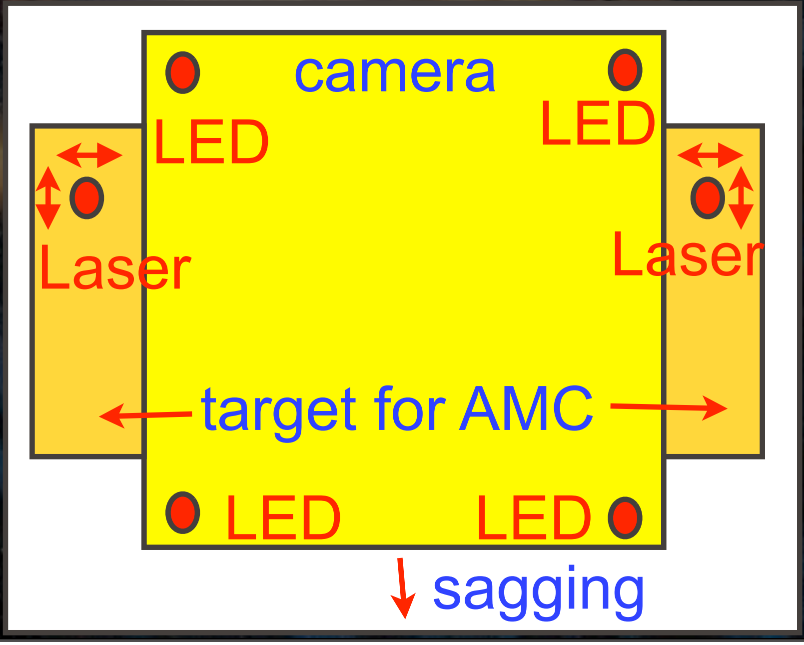




Optical axis reference beam and AMC adjustment: MPI

- Use infrared lasers for AMC on target next to camera
- AMC: Focus mirrors with respect to lasers (optical axis)
continuously every 5-10 minutes,
no usage of lookup tables (only as backup)
- Measure the focal length with a precision of better than 0.5 cm (readjust AMC with new focal length to keep the spot sharp)
- Measure x,y camera position with LED (in comparison with laser spot) to record camera sagging and sidewards movements due to wind gusts

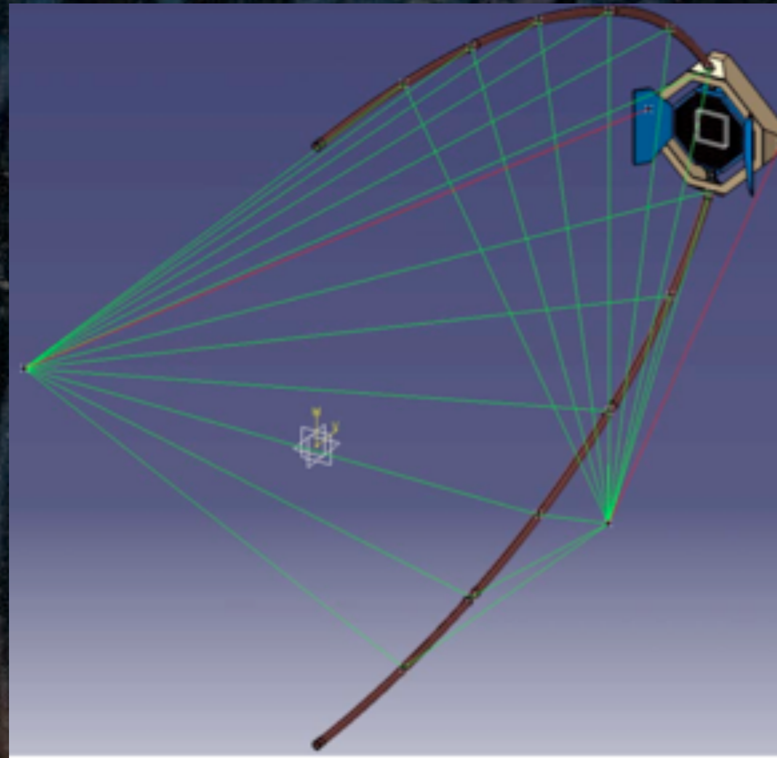


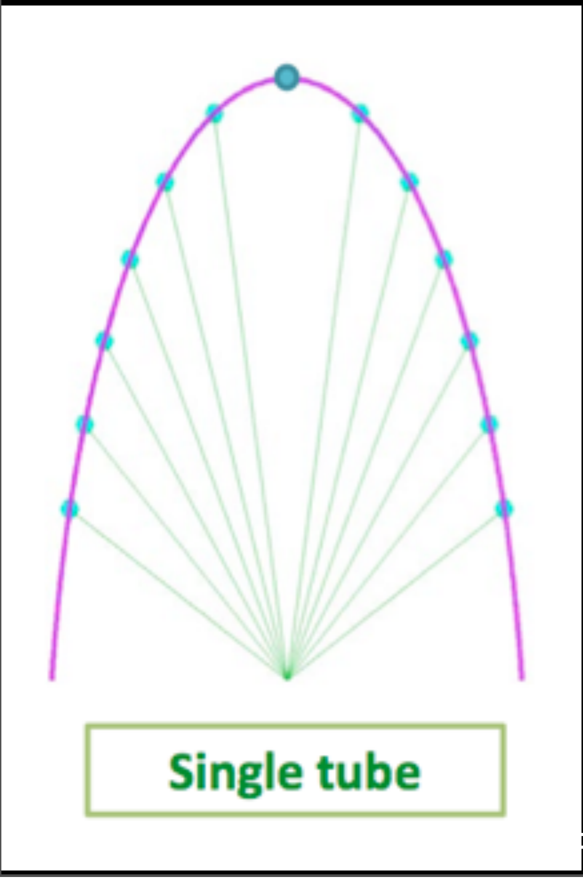


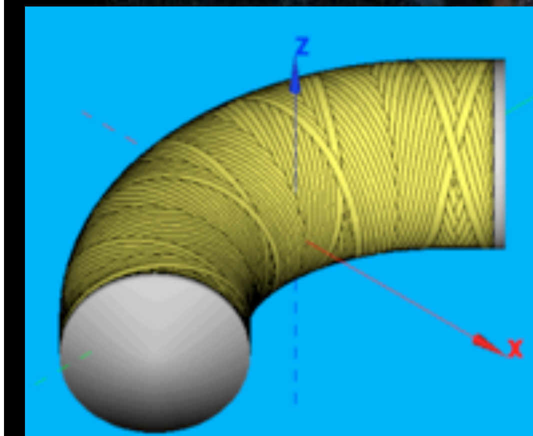
Thomas Schweizer, MPI Project review, December 2011

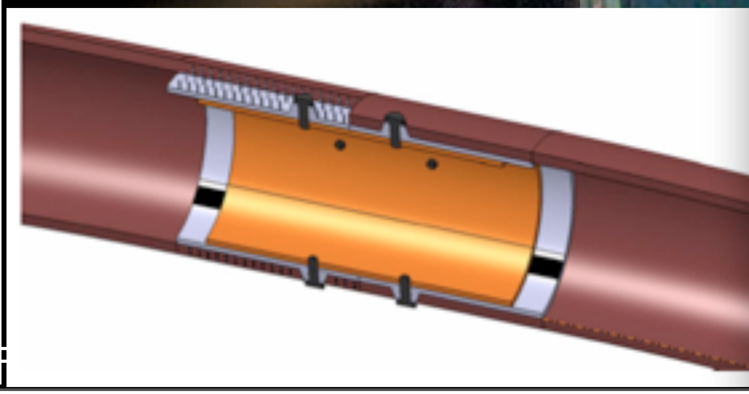
Arc design (LAPP) (+ camera frame)

- Single curves CF tubes
  3-4 sections each side
- Stiff light weight CF cables

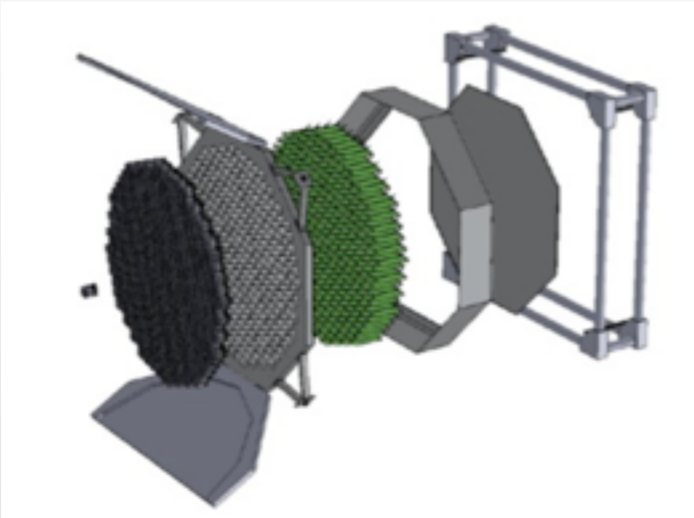








Camera design, camera body and Cooling:
Project lead: IFAE Barcelona, several institutes in Spain



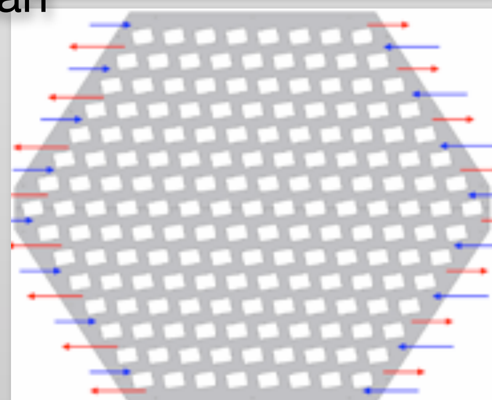
Sealed Camera
(MAGIC-II camera)

CTA Camera
Size: 2.5 m
Weight: 2 tons
# of Ch: 1855 ch
Heat: ~ 5kWatt

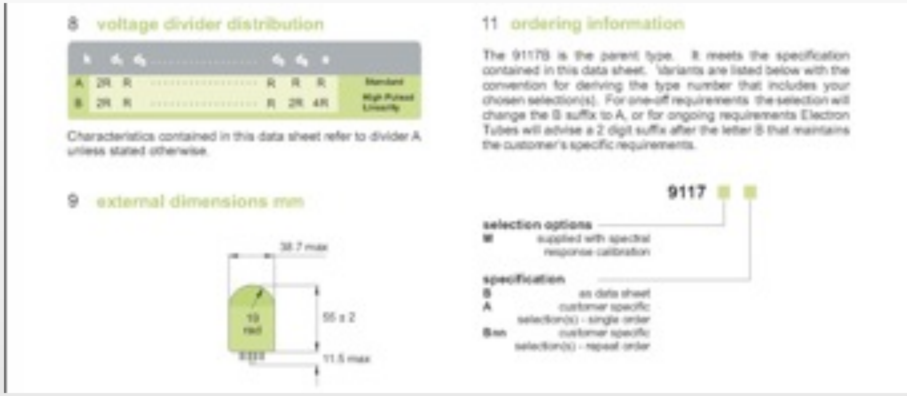
Water cooling System
MPI Munich

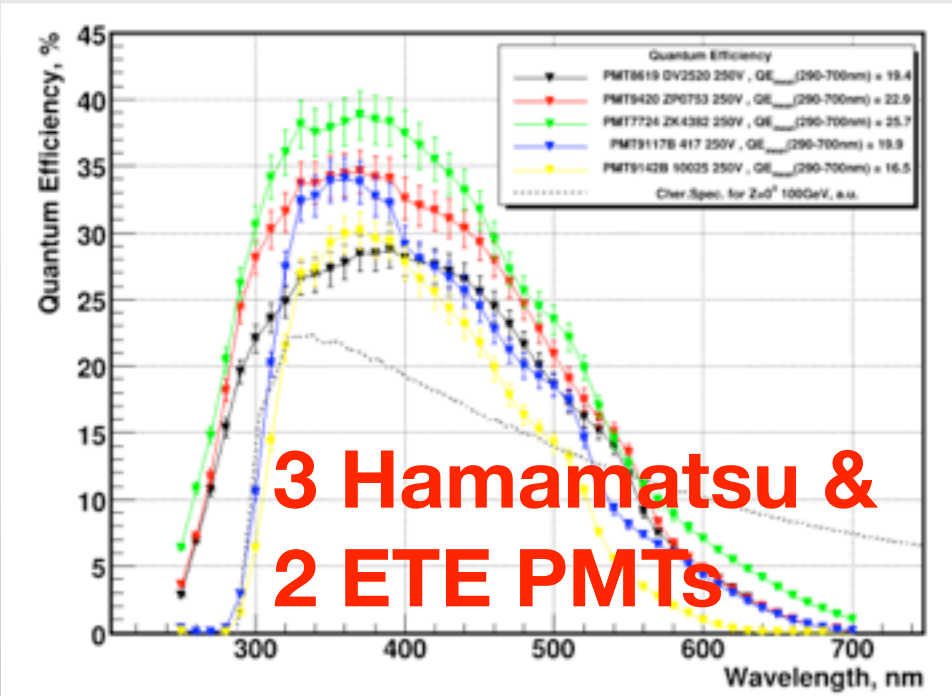
Cluster Prototype by CTA-Japan
(R.Orito: #1091)

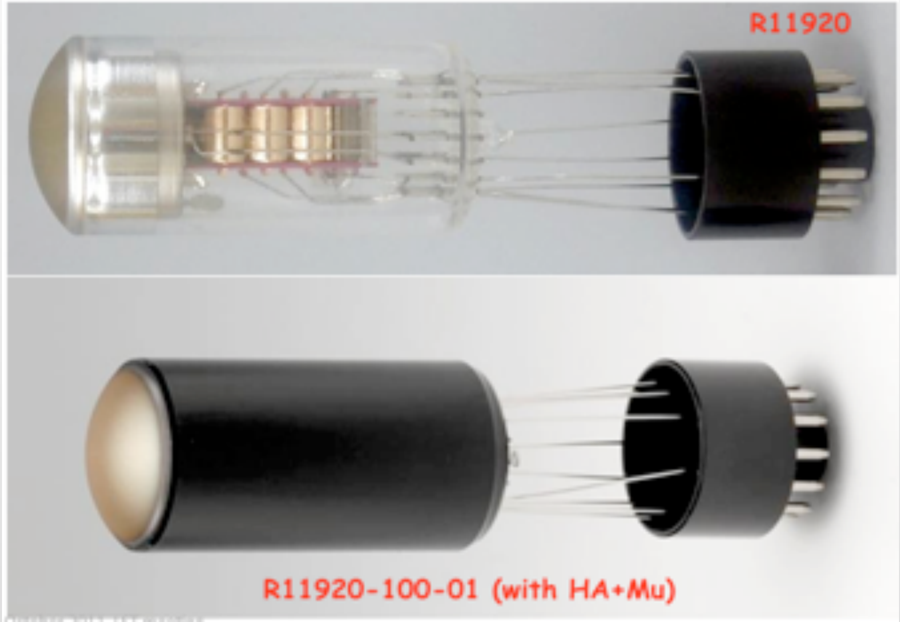
7PMTs
CW HV system
Pre-Amplifier
DRS-4 readout system (4μsec)
G-bit ethernet

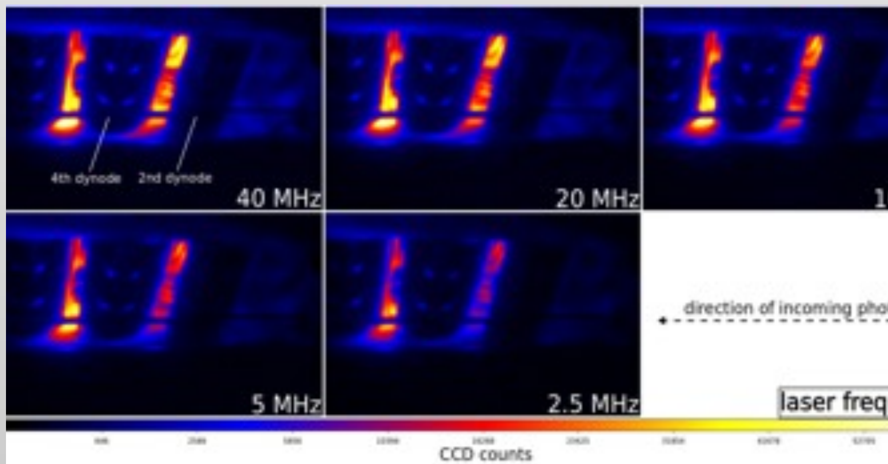


PMT Development: Hamamatsu & ETE
Razmik Mirzoyan, MPI



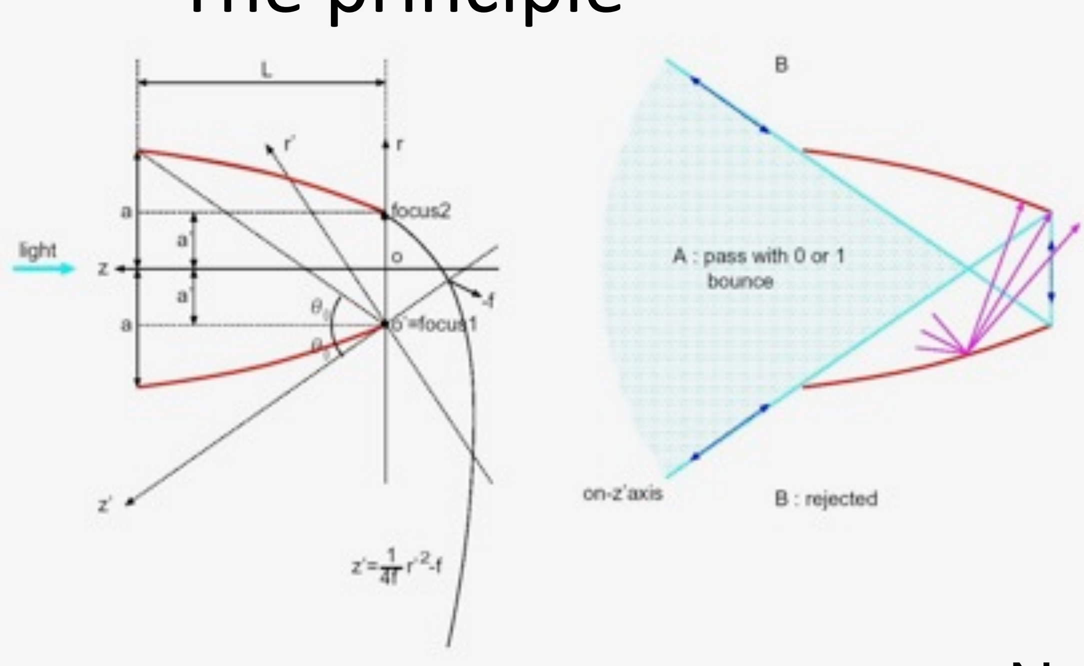




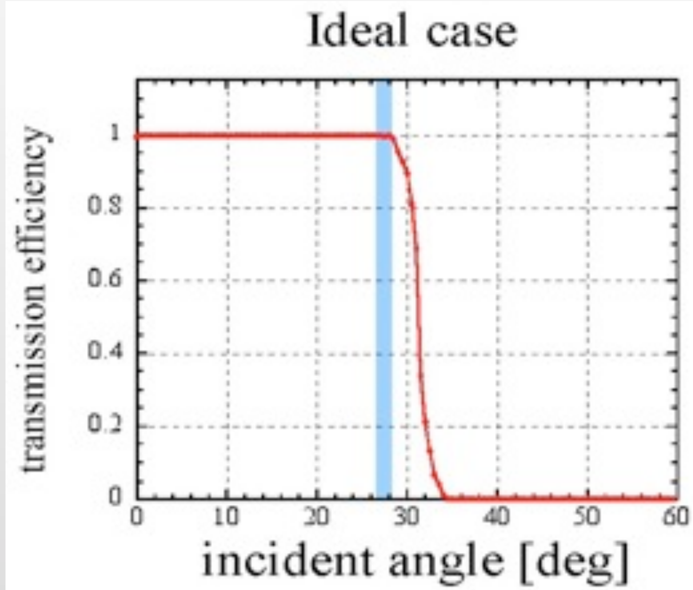


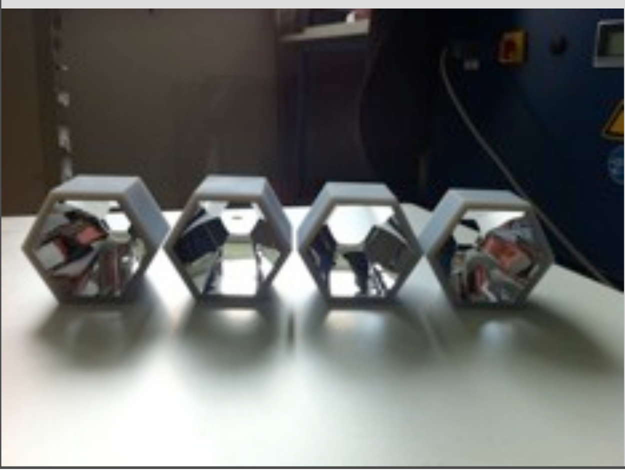
Development of Light guides: Razmik Mirzoyan, MPI

- The principle

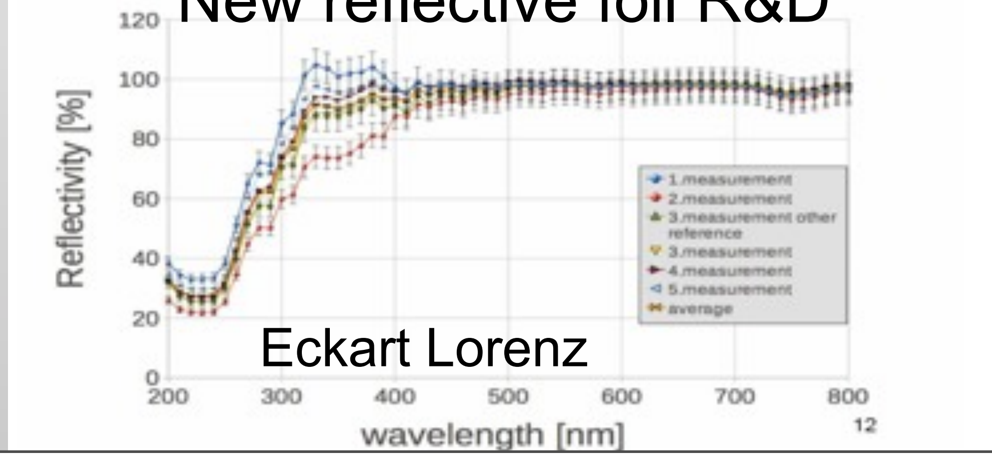


Cutoff angle





New reflective foil R&D



Eckart Lorenz

Outline of schedule of LST design and construction

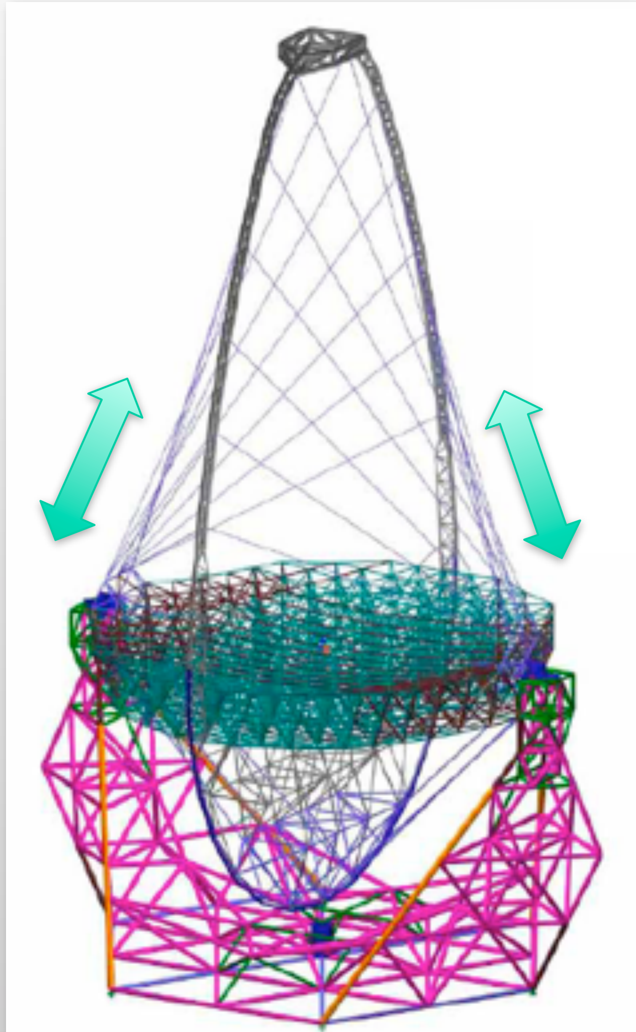
- Baseline design report: November 2011
- Prototyping of important elements until October 2012, finalizing design
- Prototype report: November 2012
- **Start of production of LST elements : November 2012 !! (Dish, understructure, arc, boggies, etc.)**
- **Final design document: August/September 2013**
- Factory tests until June 2014
- Shipping: June/July 2014
- **Start of construction of prototype LST on-site: August 2014**
- **Commissioning March 2015**

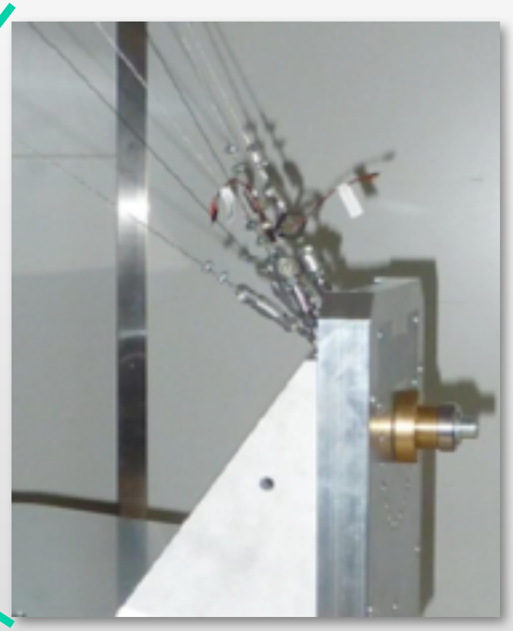
Conclusions

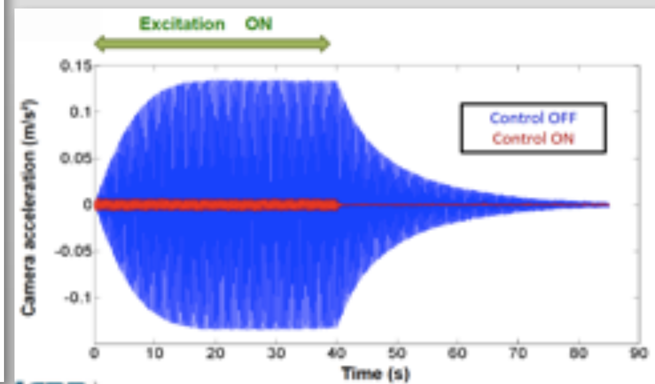
- MPI is the leading institute for the development and construction of the large 23m telescope
- Collaboration with institutes in Spain and France
- Energy threshold 15-20 GeV
- Telescope shall be optimized for the lowest possible energies
- Start of construction August 2014

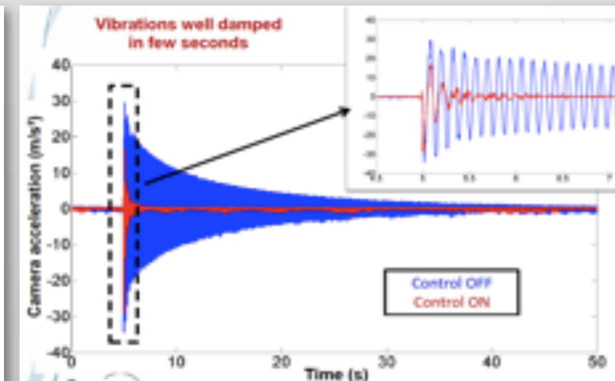

The end

Demonstration of Active Oscillation Damping System for the LST Arch by LAPP IN2P3



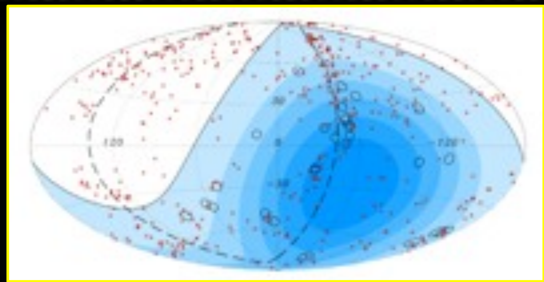




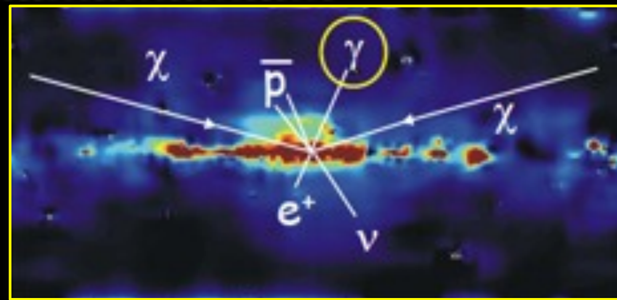


Rich physics in low energy range (>10-20 GeV): Unexplored physics !!

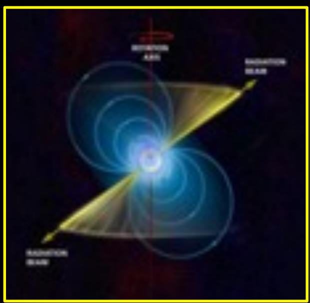
GRBs



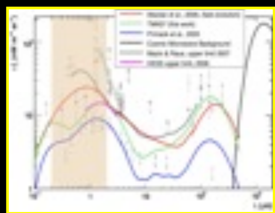
AGN & UHECR Sources



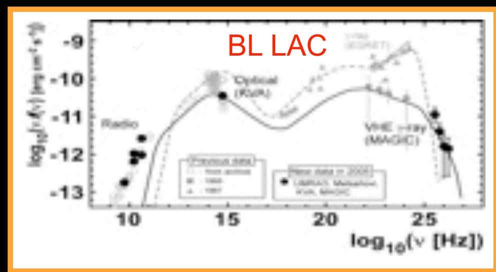
Dark Matter Annihilation



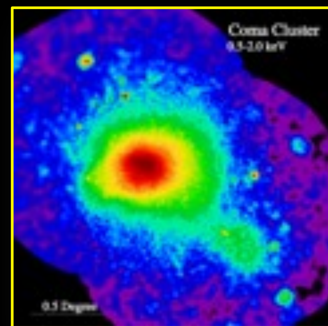
Pulsars



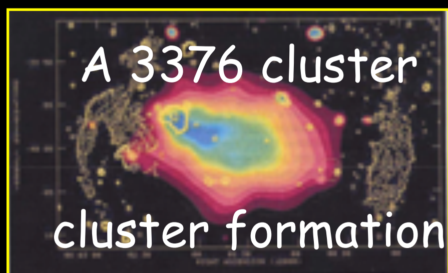
high redshift BL BLAC & EBL



LBLs

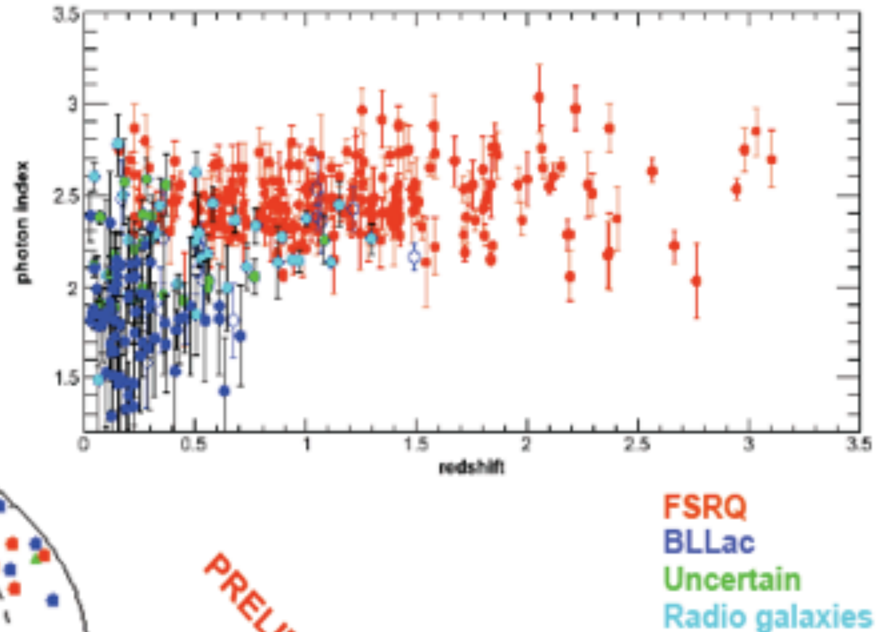


Clusters of galaxies

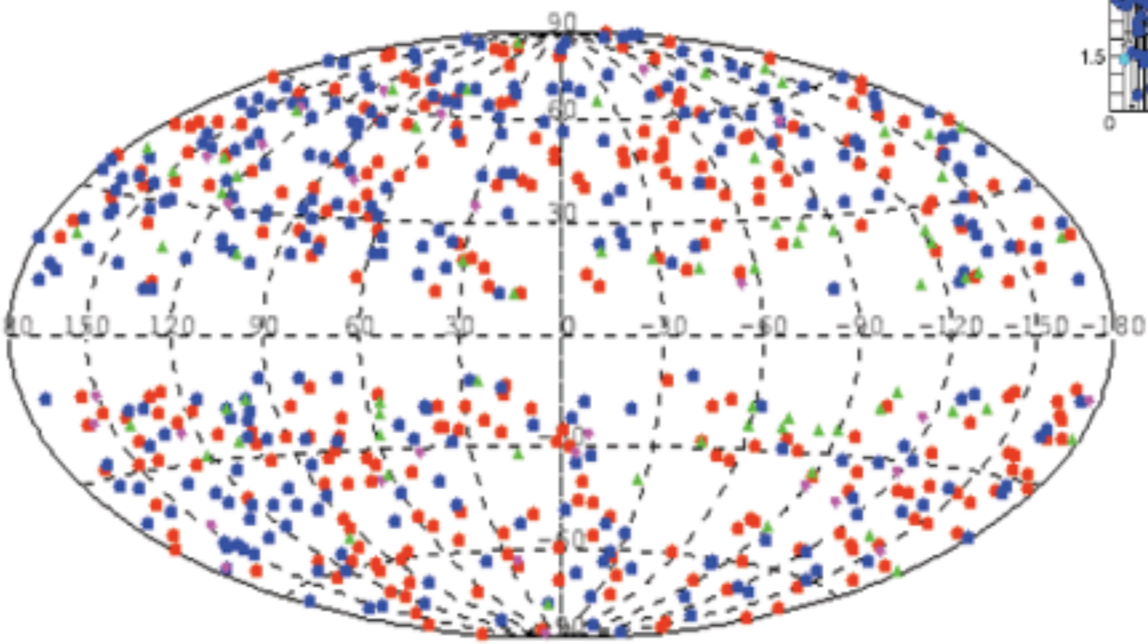


The First LAT AGN Catalog (1LAC)

- 1079 TS>25 (~5σ), |b|>10° sources based on 11 month data set
- 668 high-confidence (P>80%) associations with AGNs
  - +186 lower-confidence (40%<P<80%) associations
  - 286 FSRQ
  - 285 BL Lac (141 with measured z)
  - 69 unknown class
  - ~10 Radio galaxies



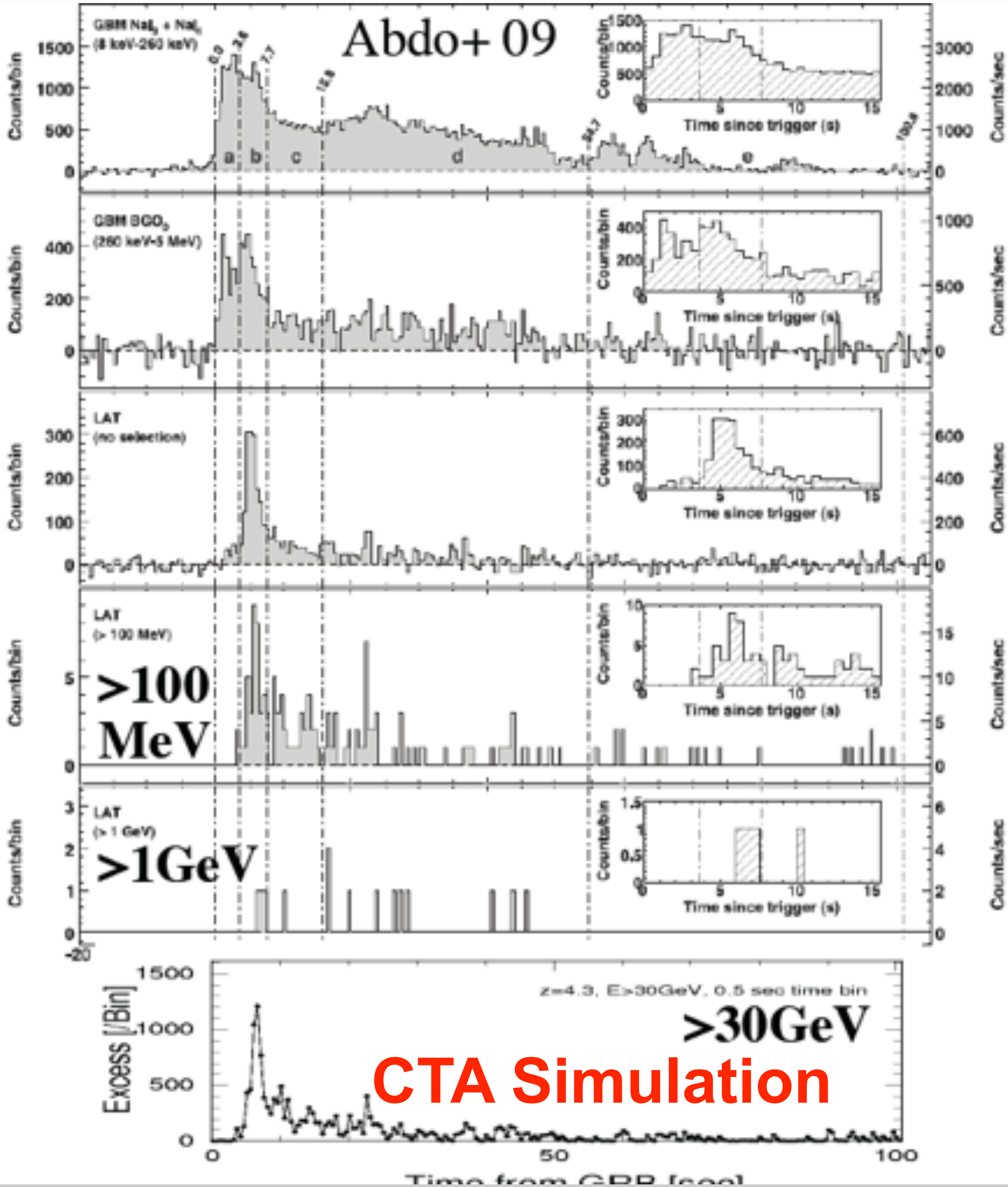
PRELIMINARY



GRB 080916C Fermi results +CTA simulation

- normalize to GBM light curve
- extrapolate GBM+LAT spectra with Y. Inoue EBL
- simulate with D. Mazin's tool

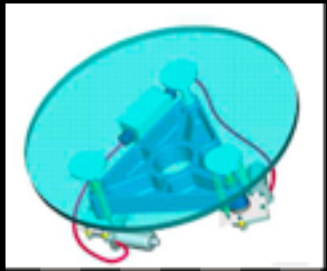
T. Yamamoto, Y. Inoue & R. Yamazaki



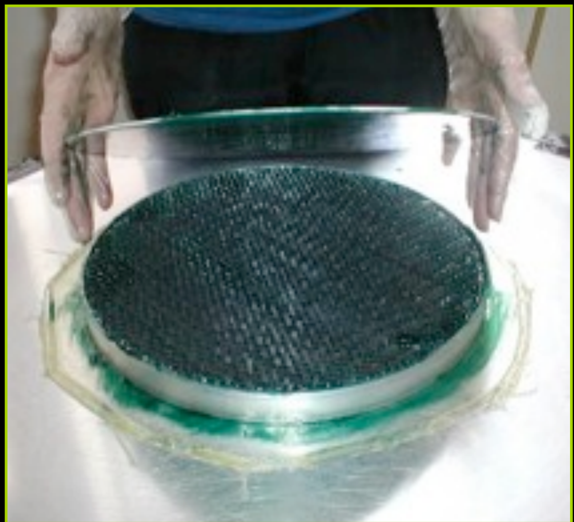
Fermi: 1 gamma > 30 GeV

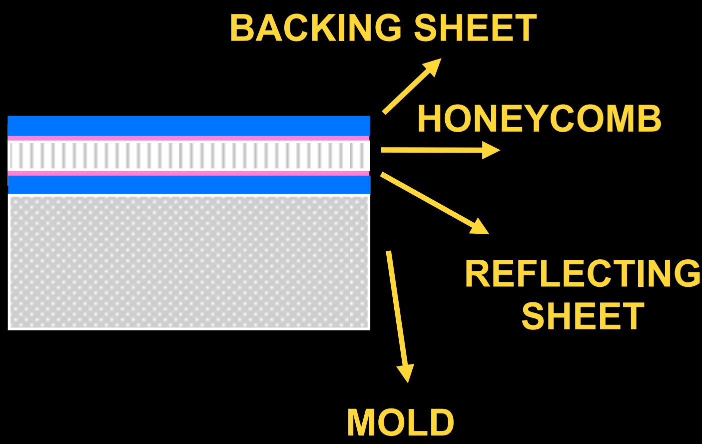
Cost estimates for baseline LST structure without camera --> still first guess

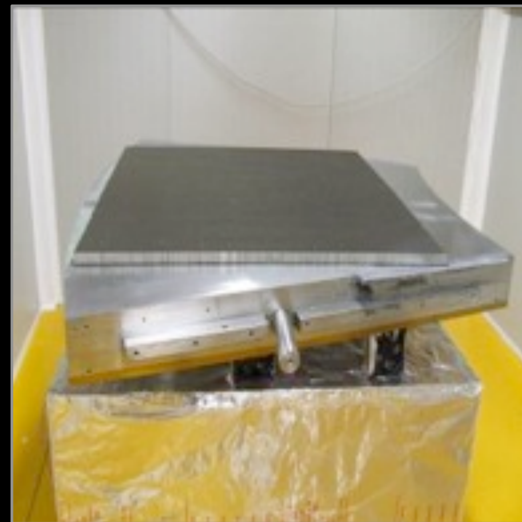
- CF Tubes for dish and undercarriage + MERO work:1.4 - 1.6 Mio
- Mast + damping system: 150k - 200k
- Drive (Bogeys, Rails, Barings, Chains, Motors, Electronics, etc.): 350-500k
- Foundation: 380-450k
- Transport + Installation + Access Tower: 200k - 380k
- Mirrors + Installation: 920k - 1410k
- AMC + Installation: 260k - 350k
- Site preparation + Power grid to telescopes: 200k
- AOB + Safety Equipment + Emergency park system: 200 - 300k
- Total: 4.1 - 5.4 Mio (Average 4.7 Mio)
- + 20% Contingency: 5.0 - 6.5 Mio (About 6.0 Mio)



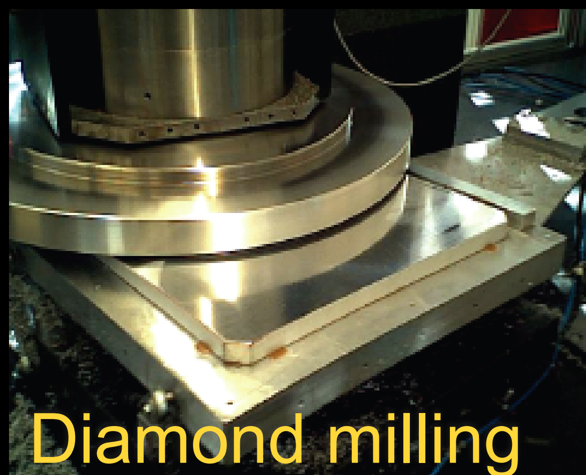
Mirrors must be cheap and good quality/ high reflectivity

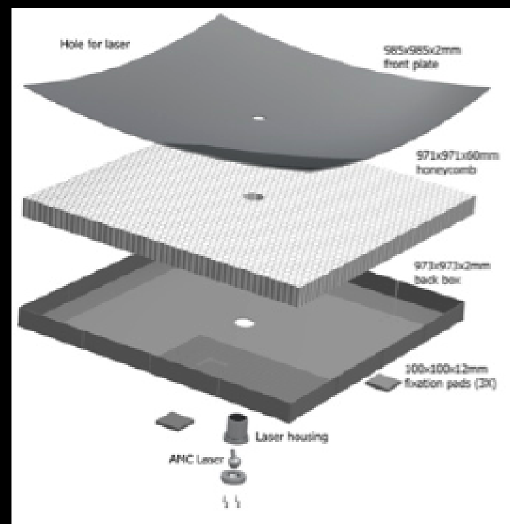




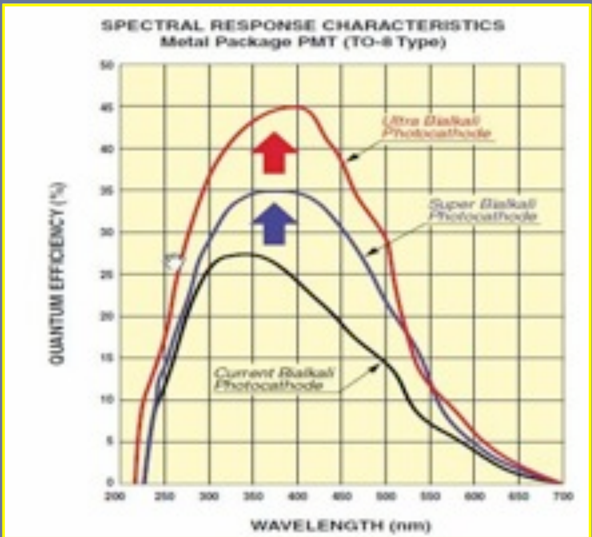


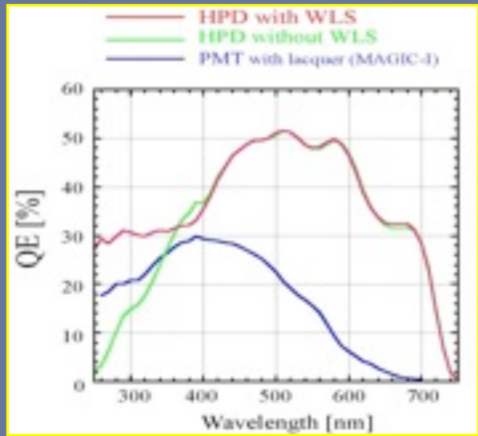
Replica techniques (thin glas sheet on honeycomb structure with aluminized surface), are a cheap possibility, while diamond milled surfaces have a longer life time



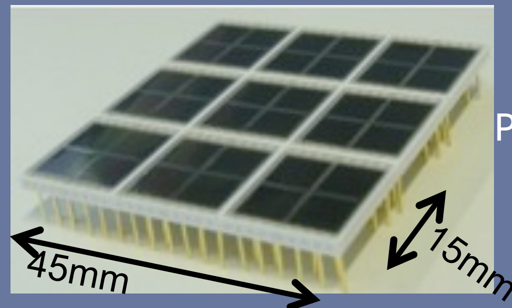


High QE photosensors we need 200K PMs

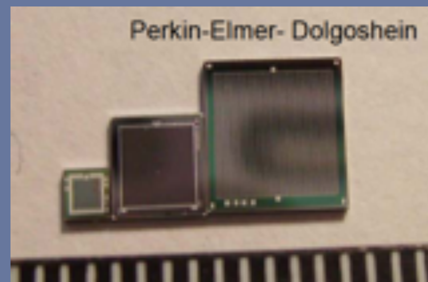




Hamamatsu &MPI MPPC Array



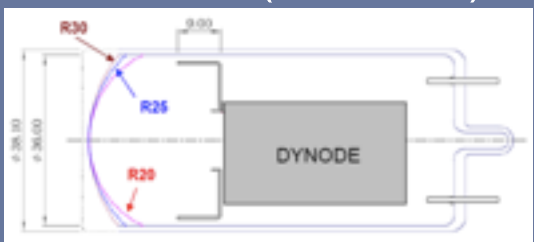
PDE~30-40%



Size 5x5 mm^2

PDE~50-60%

R9420 (QE=34%)



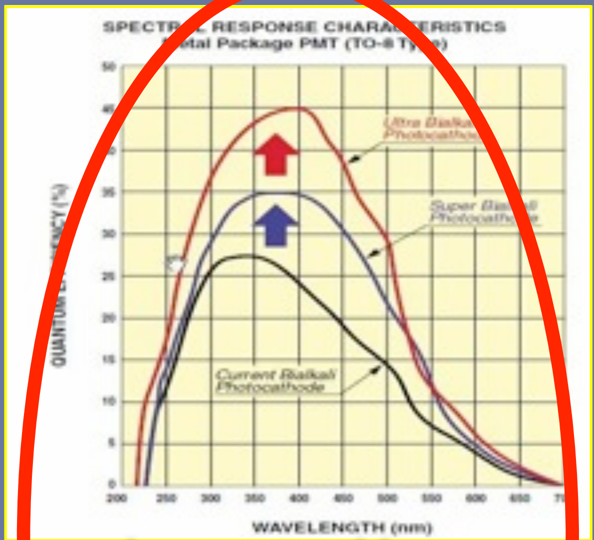
MPI-HLL SiMPL
PDE~60%(target)

Hamamatsu
SBA 34% QE
==> 30% PDE

GaAsP HPD
(MPI &
Hamamatsu):
50% PDE

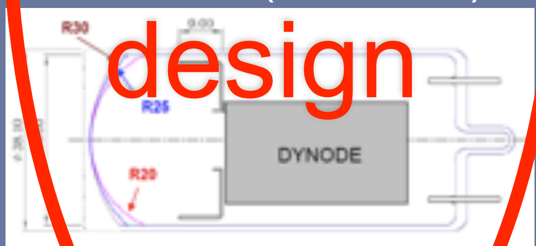
SiPM
About 60% effective PDE will be realistic

High QE photosensors
we need 200K PMs

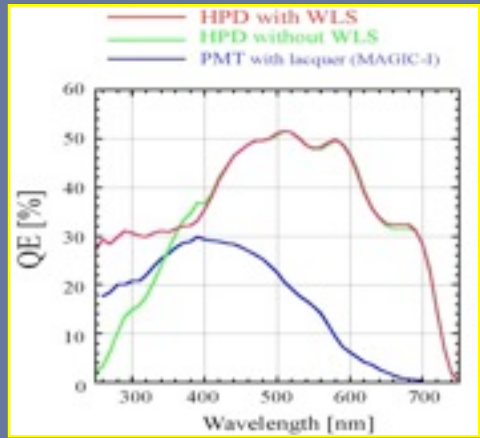


baseline design

R9420 (QE=34%)

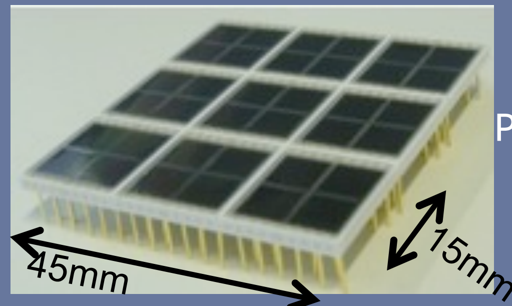


Hamamatsu
SBA 34% QE
==> 30% PDE

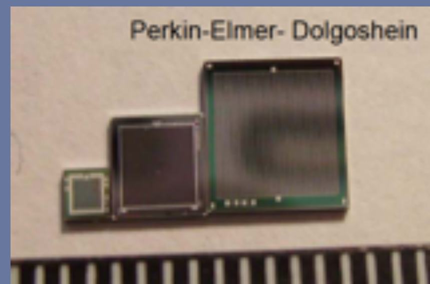


GaAsP HPD
(MPI &
Hamamatsu):
50% PDE

Hamamatsu &MPI MPPC Array



PDE~30-40%



Size 5x5 mm^2
PDE~50-60%

MPI-HLL SiMPL
PDE~60%(target)

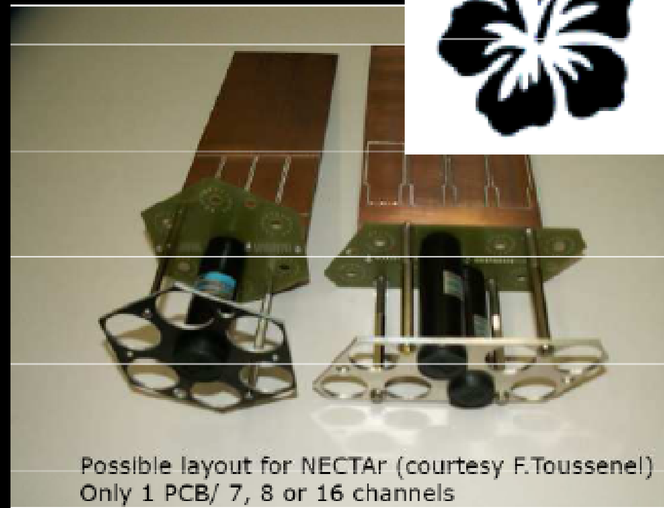
SiPM
About 60% effective PDE will be realistic

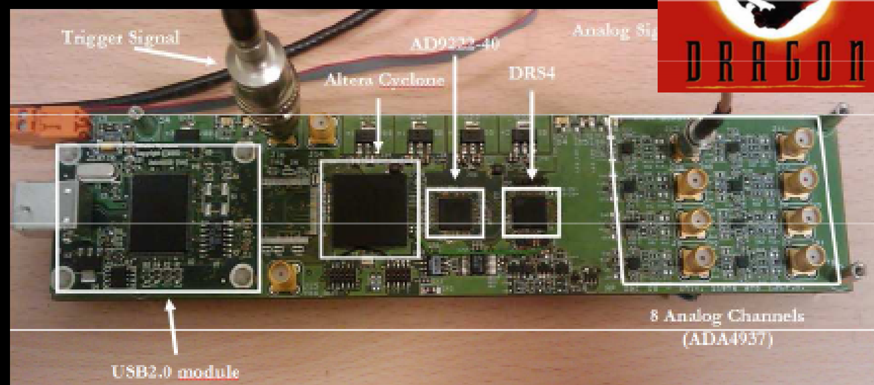
CTA readout Electronics

- NECTAr project (SAMOSO chip) (development of new analog capacitor array)

- Dragon project (Domino Ringsampler 4 700 Mhz bandwidth, Ethernet output

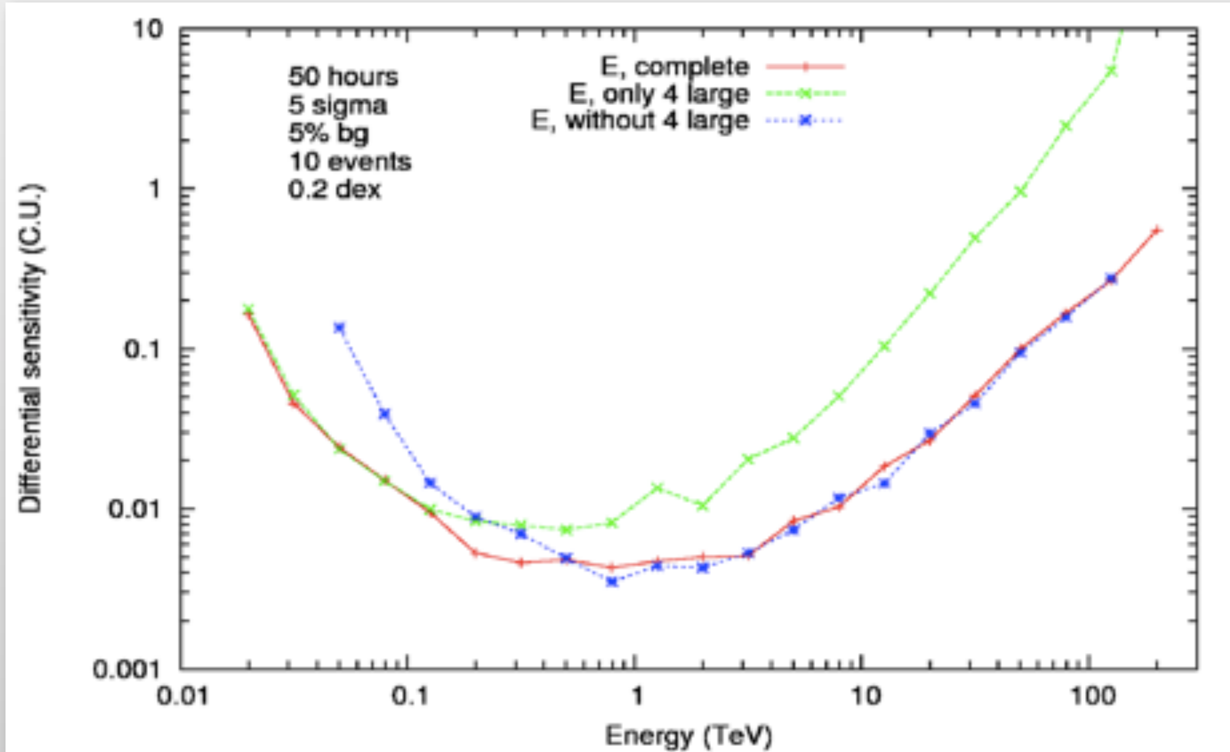
- Fully digital camera (sampling the signal with commercial 60-200 Mhz FADC and processing with FPGAs, including the trigger)



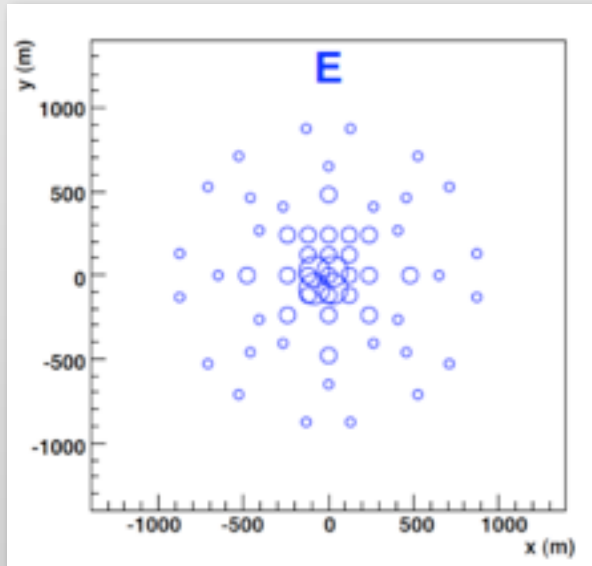


Differential Sensitivity of 4 x LSTs

Below 200GeV LSTs will have a good sensitivity

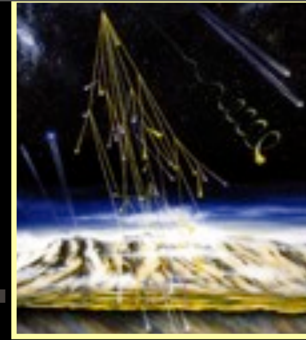


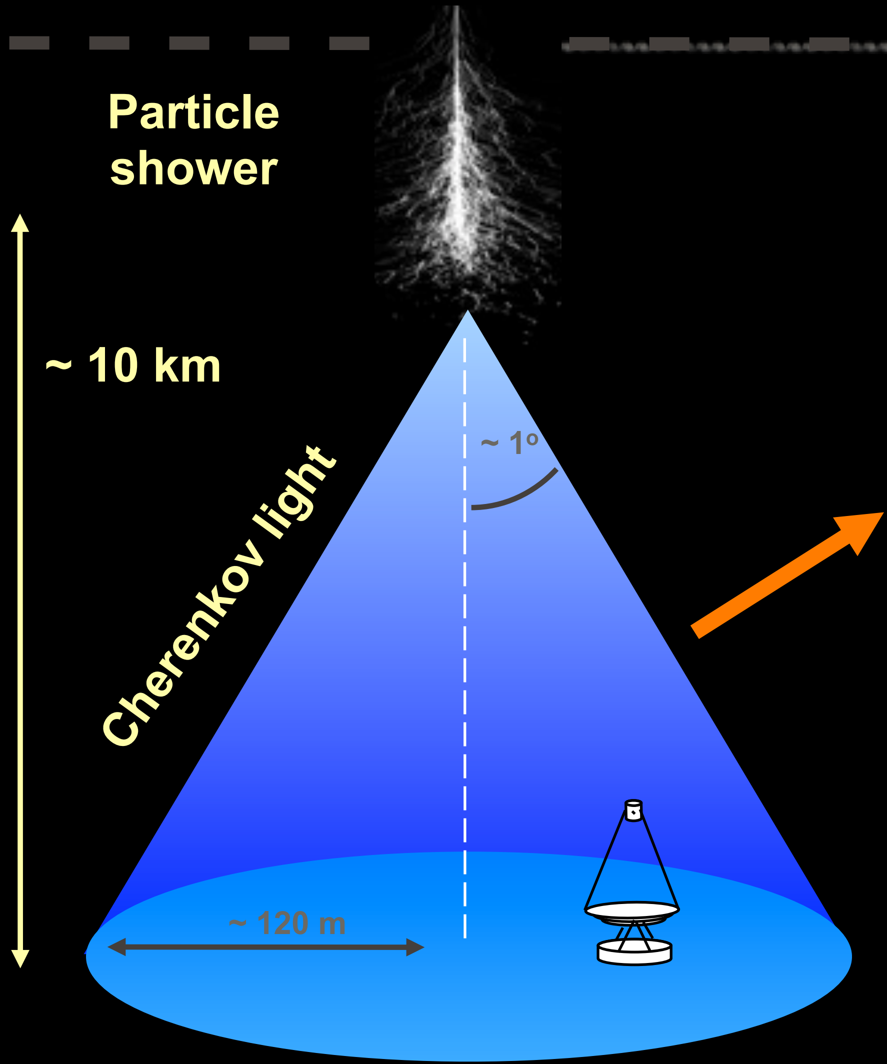
Configuration E
LST x 4, MST x 23, SST 32



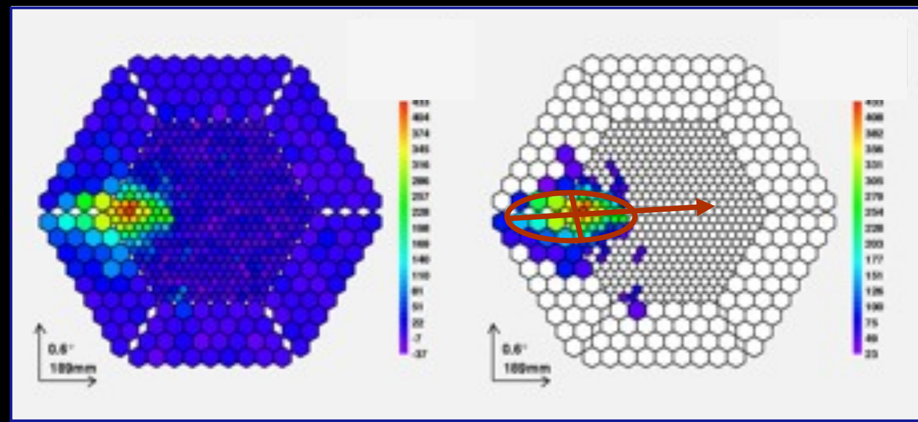
Observation technique

The Imaging Cherenkov

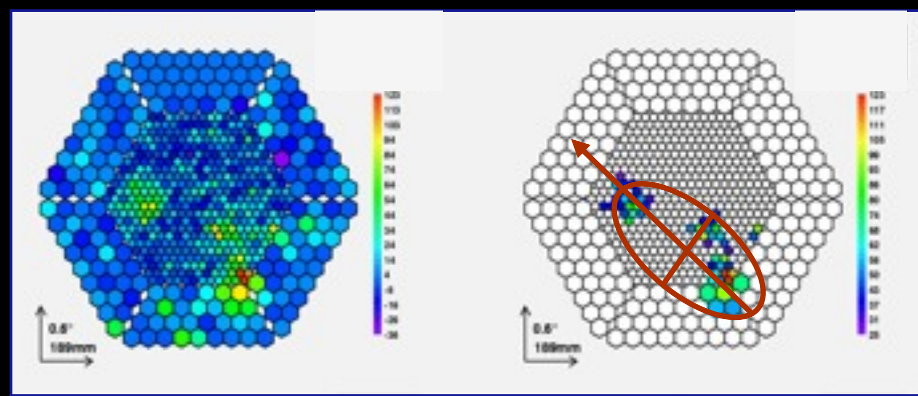




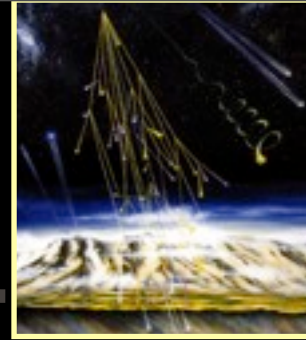
Gamma event: Signal

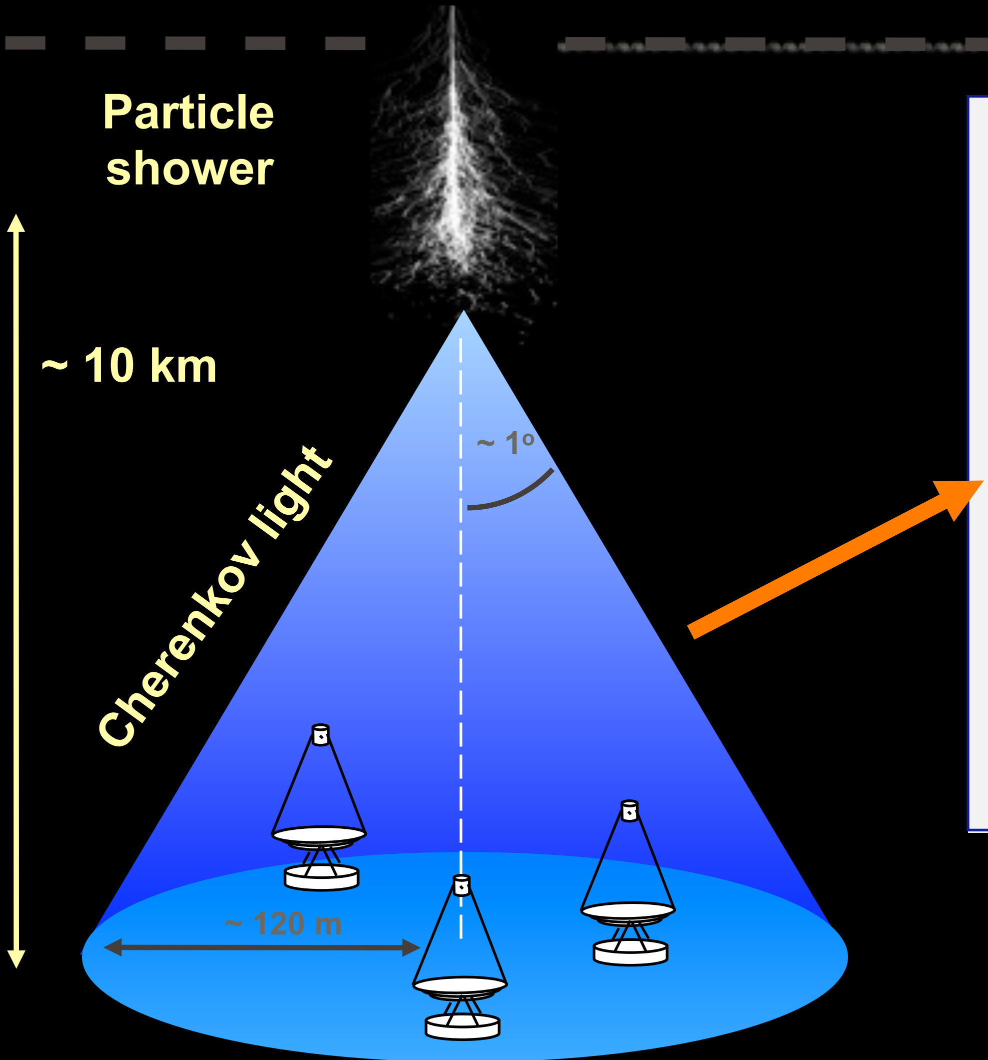


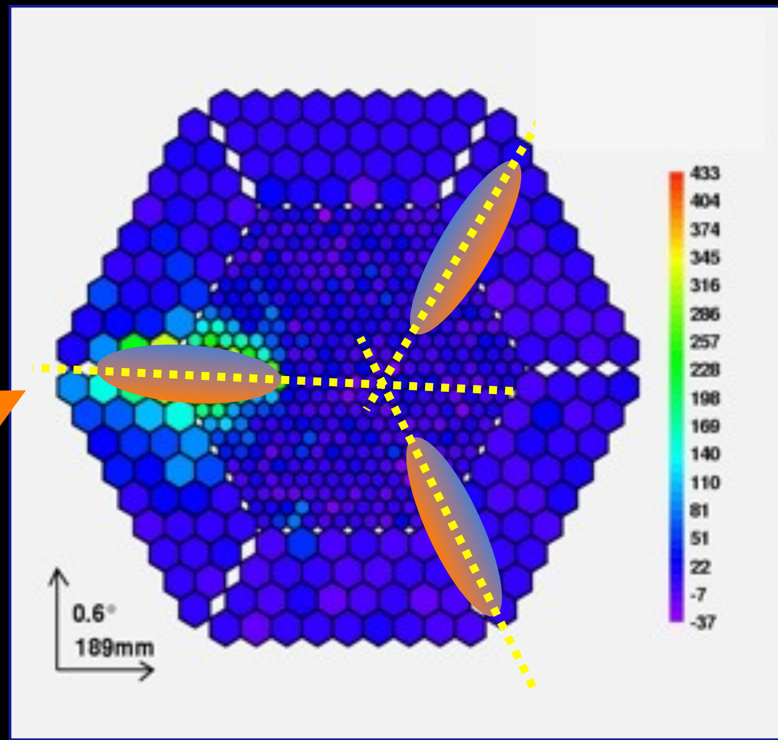
Hadronic event: Background



The Imaging Cherenkov

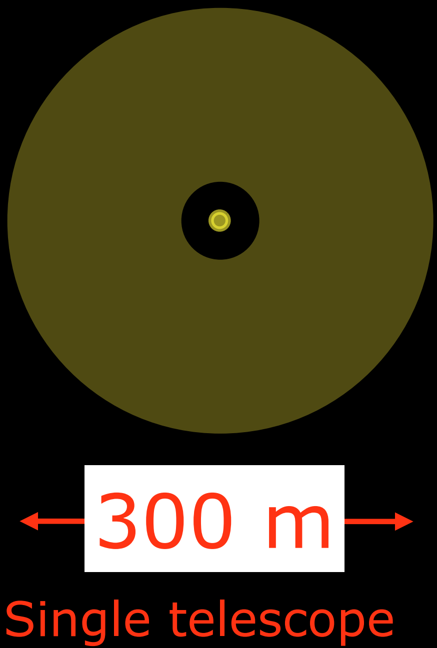




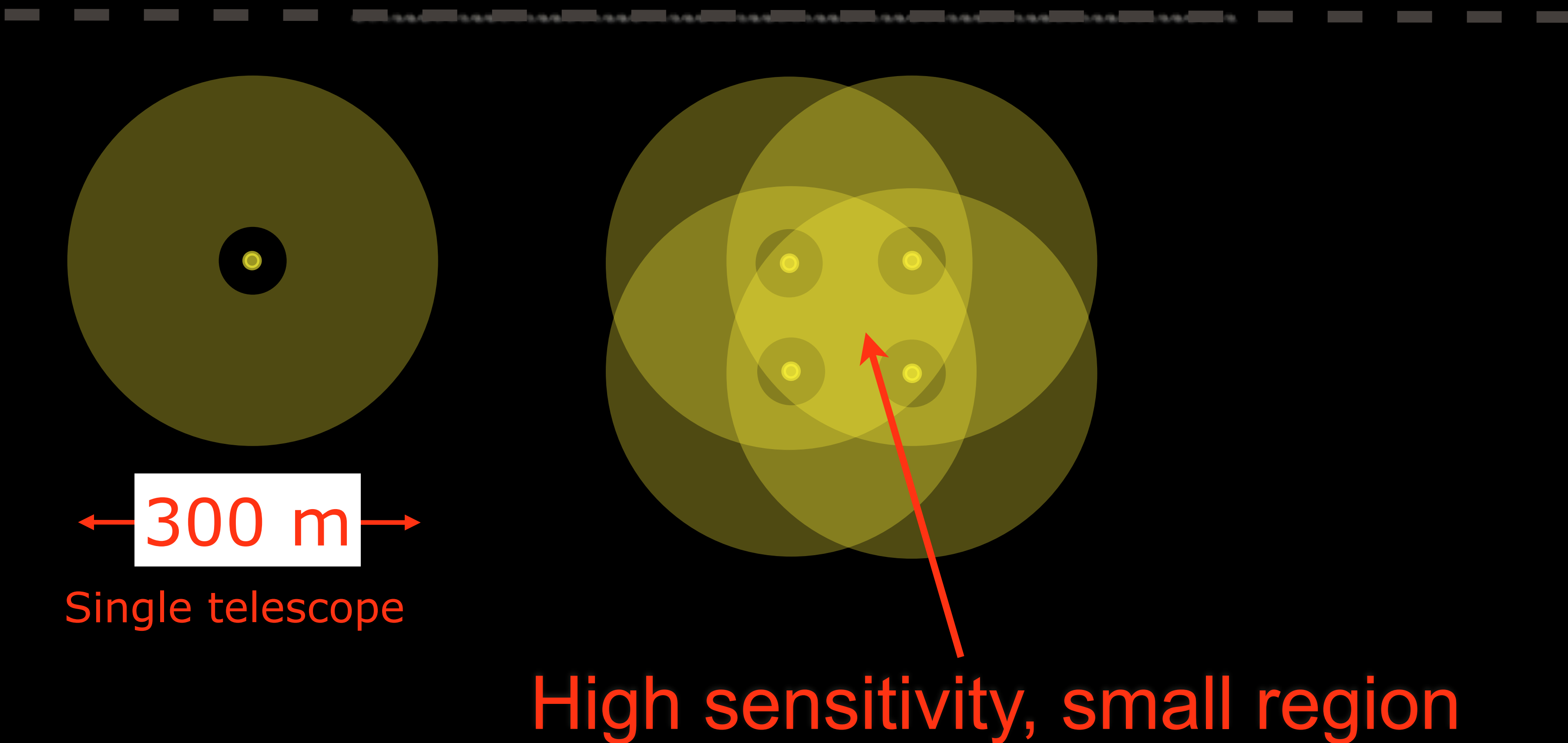


Better background reduction
Better angular resolution
Better energy resolution

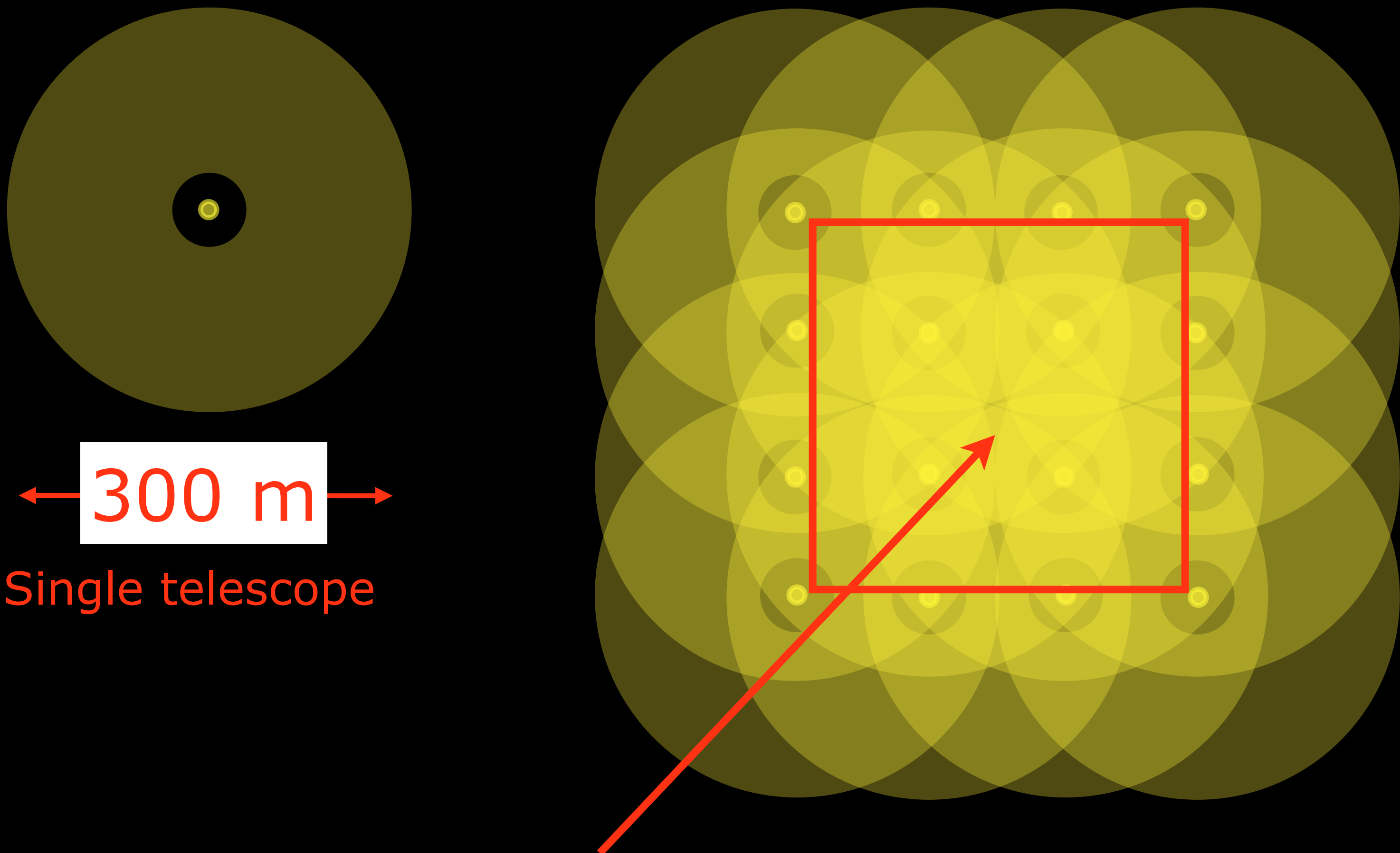
Design and layout: Telescope Array



Design and layout: Telescope Array

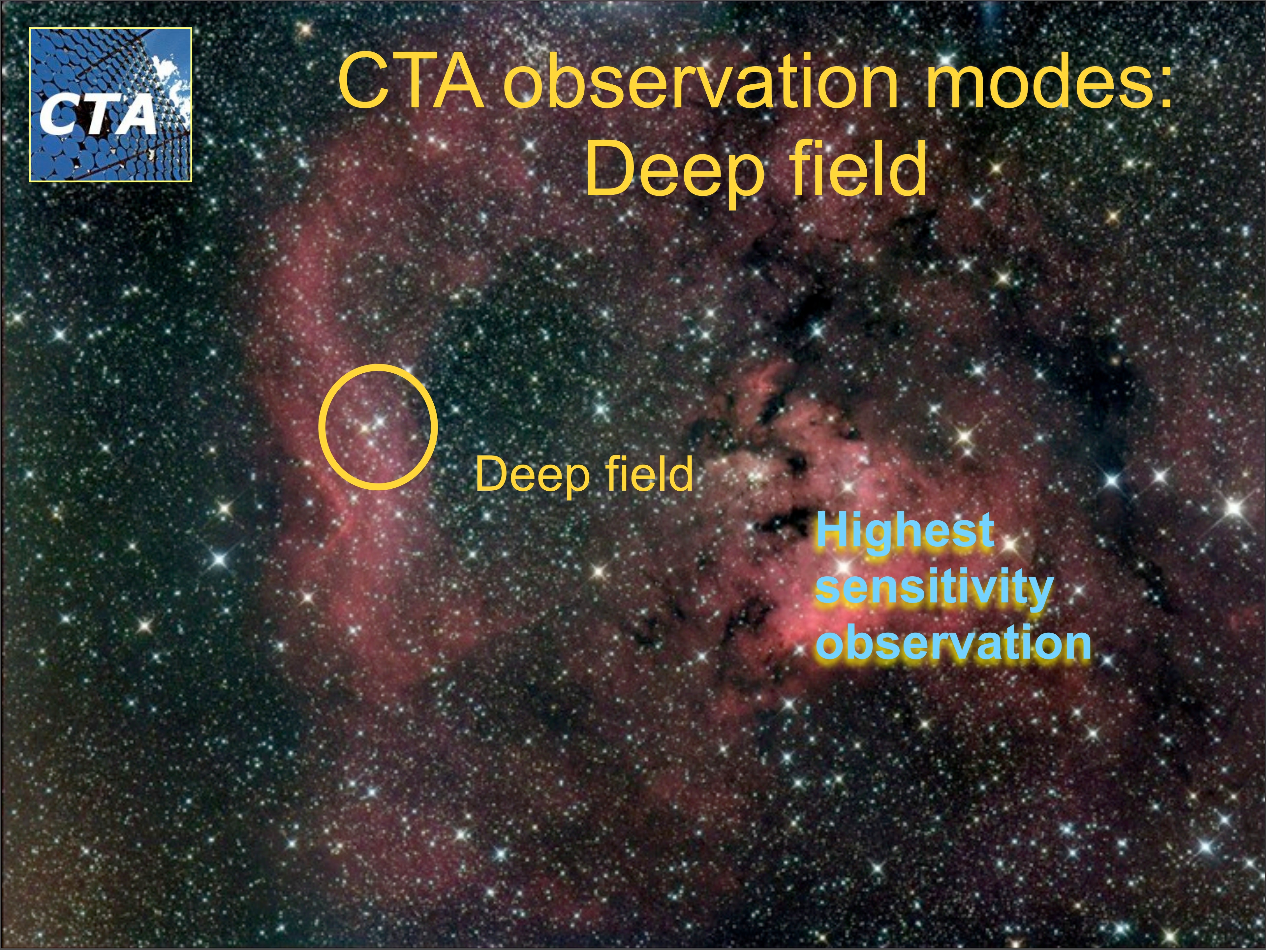


Design and layout: Telescope Array



High sensitivity, larger region per telescope

CTA observation modes:
Deep field



CTA observation modes: high flexibility

1/3 array
Deep field

1/3 array
Deep field

Permanent monitoring of some AGN

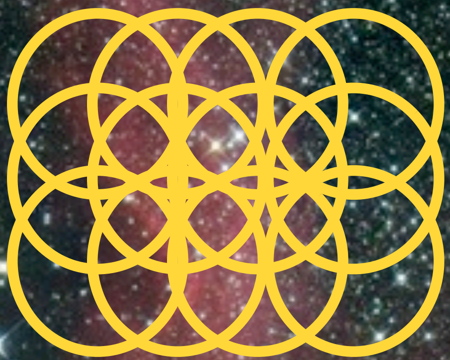
1 telescope
Monitor

4 telescopes
Monitor

--> ToO-triggers on huge flares

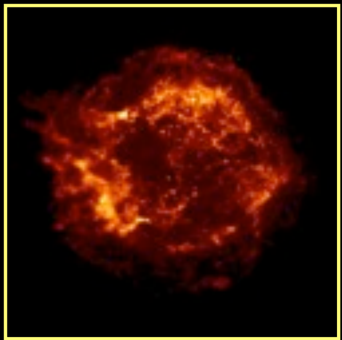
CTA observation modes: survey mode

Wide FOV Scan



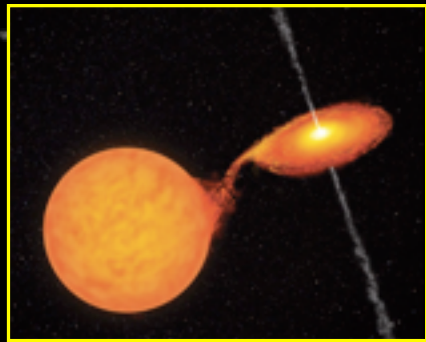
Systematic scan of some good part of the sky

200 GeV - 10 TeV energy range: High sensitivity and better angular resolution: Galactic sources



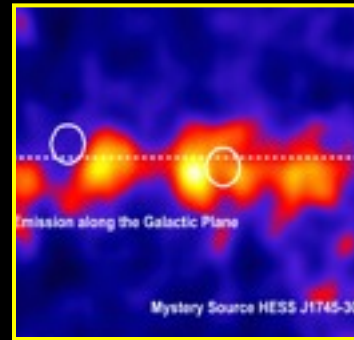
SNRs

PWNe

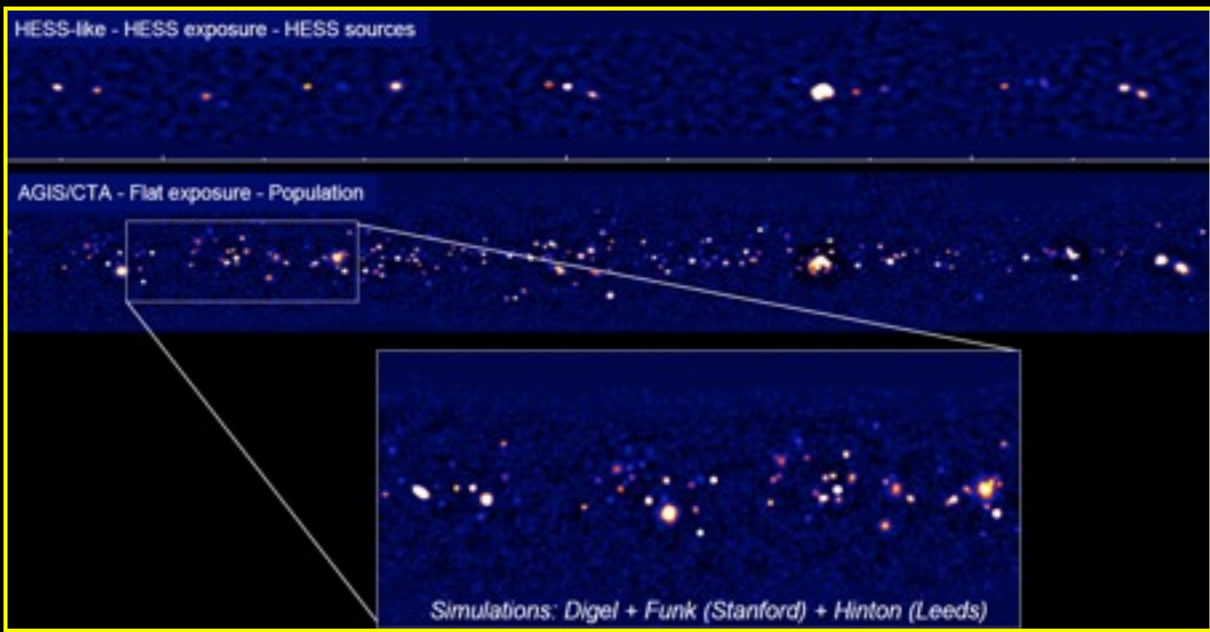


Micro quasars
X-ray binaries

Un-ID sources
Dark Sources



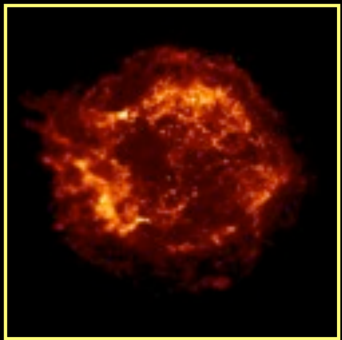
Diffuse gamma radiation



Galactic sources
200~400 sources with CTA

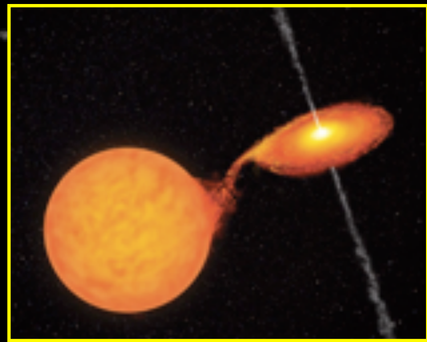
- CTA sensitivity
  (1 mCrab)
- CTA angular resolution
  -> needed for
  morphology
  and separation

200 GeV - 10 TeV energy range: High sensitivity and better angular resolution: Galactic sources



SNRs

PWNe



Micro quasars
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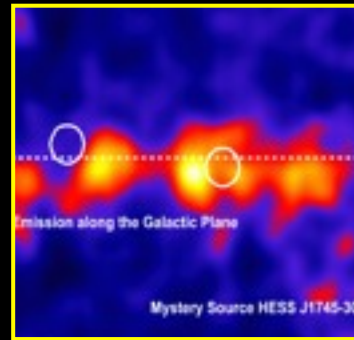
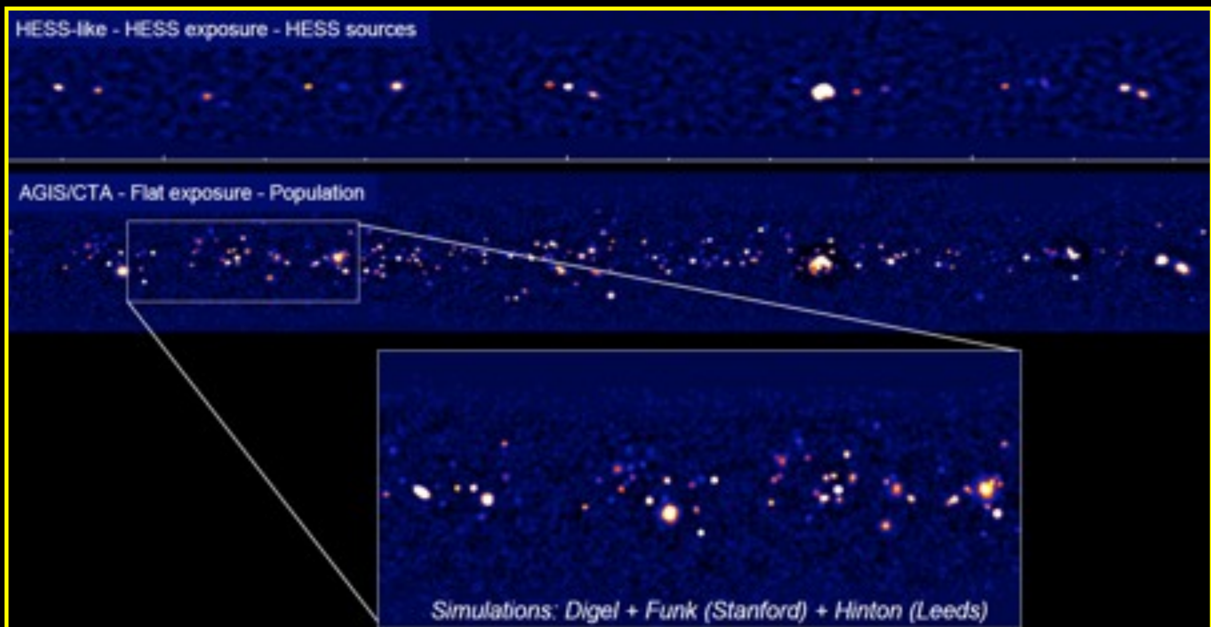


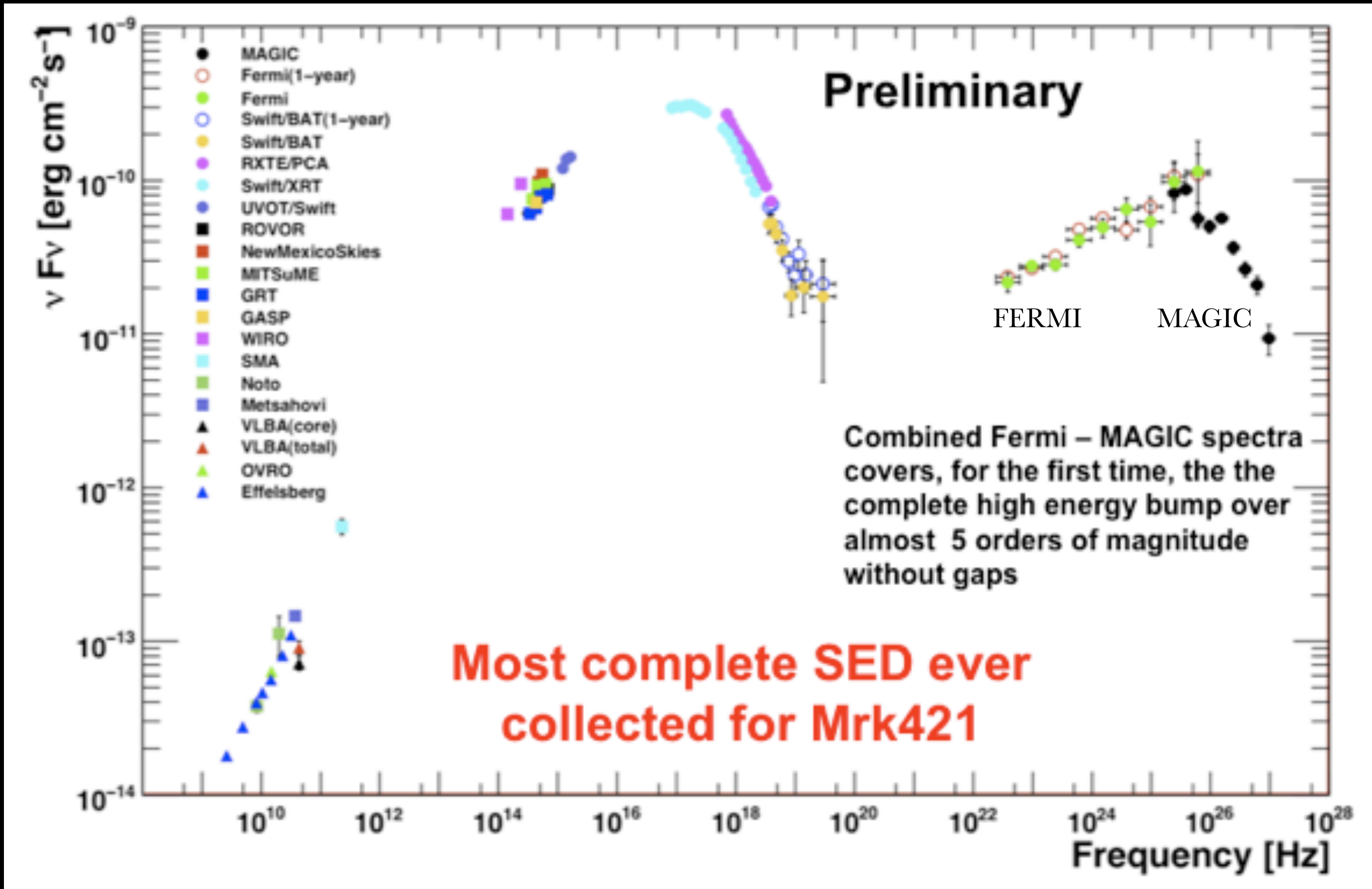
Diffuse gamma radiation



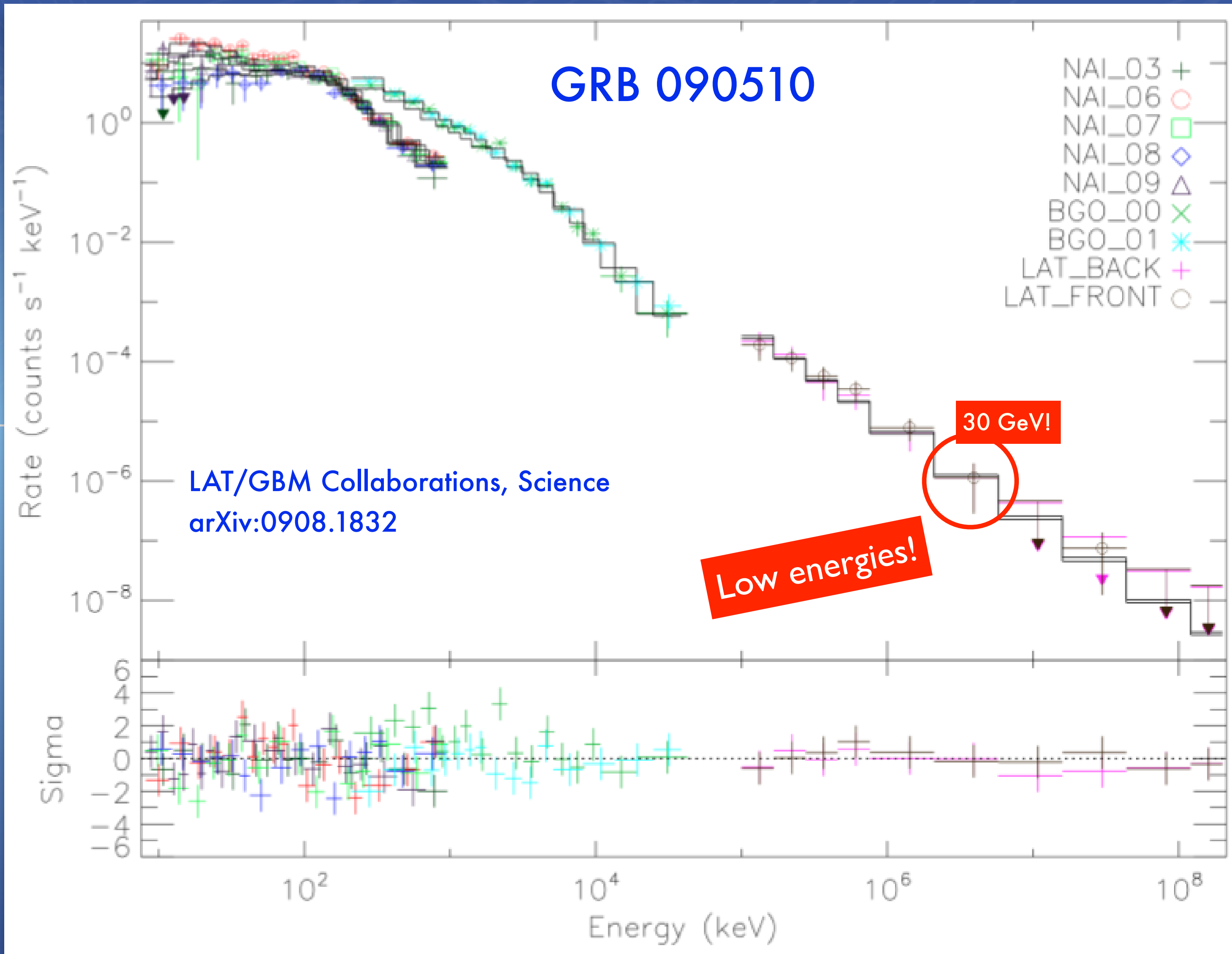
Galactic sources
200~400 sources with CTA

- CTA sensitivity (1 mCrab)
- CTA angular resolution -> needed for morphology and separation

Future: Multiwavelength astronomy: Mrk421 SED

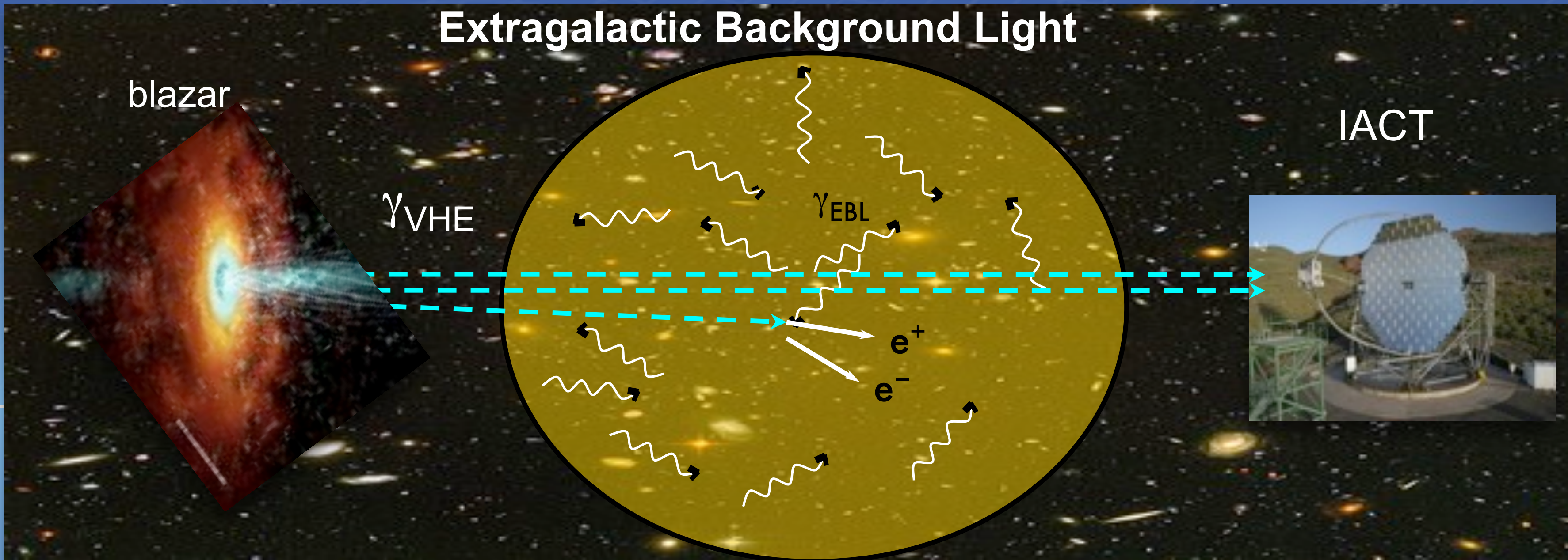


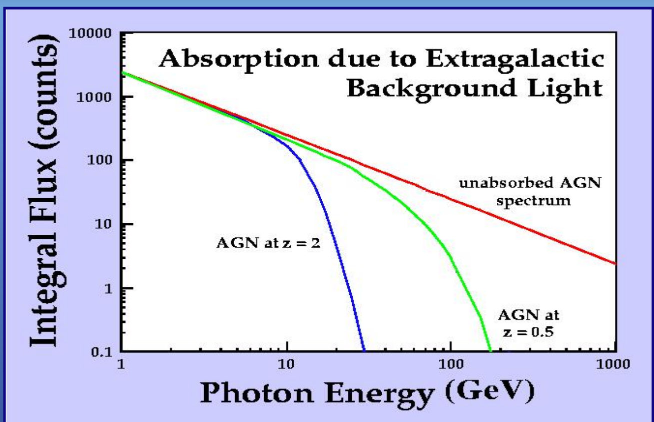
2 Fermi GRB Gammas: up to 30 GeV

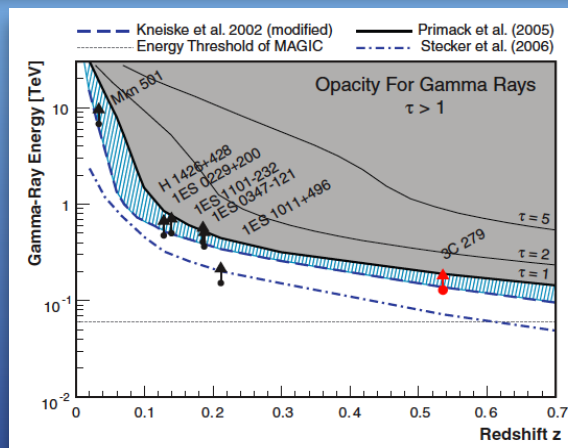


Sunday, December 18, 2011

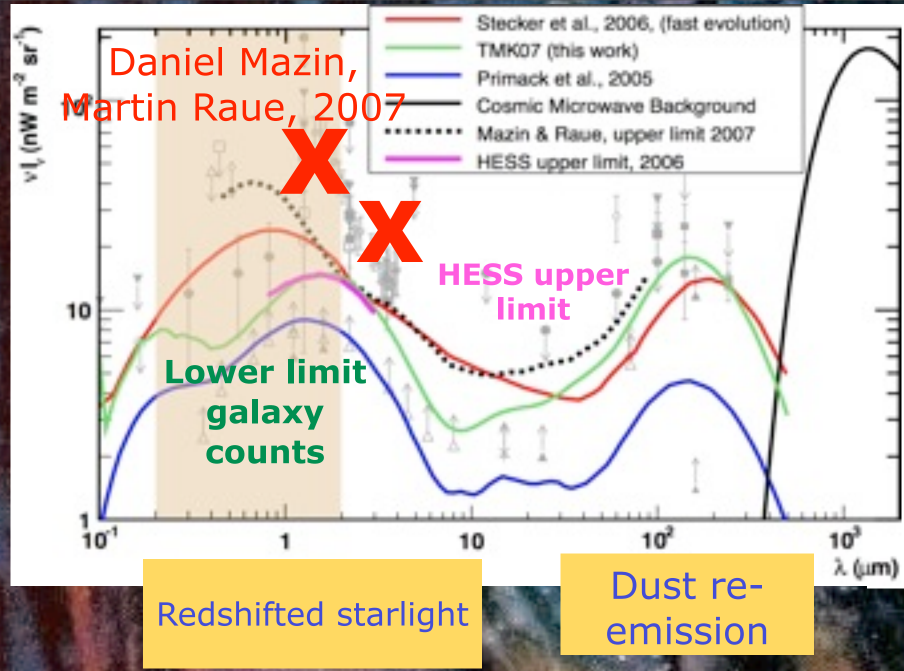
Why Low Energy Threshold? Distant AGN, GRB

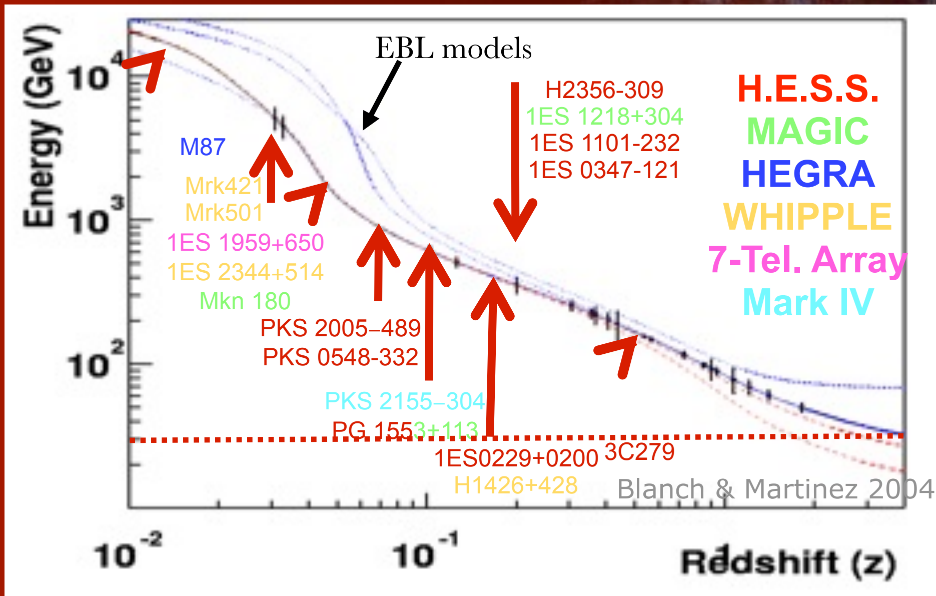




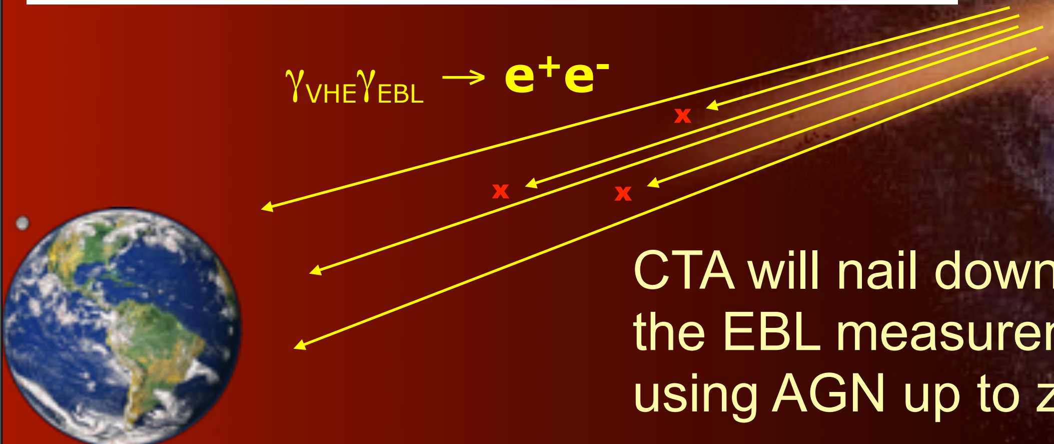


Nail down gamma ray horizon up to z=2





$\gamma_{VHE}\gamma_{EBL} \rightarrow e^{+}e^{-}$

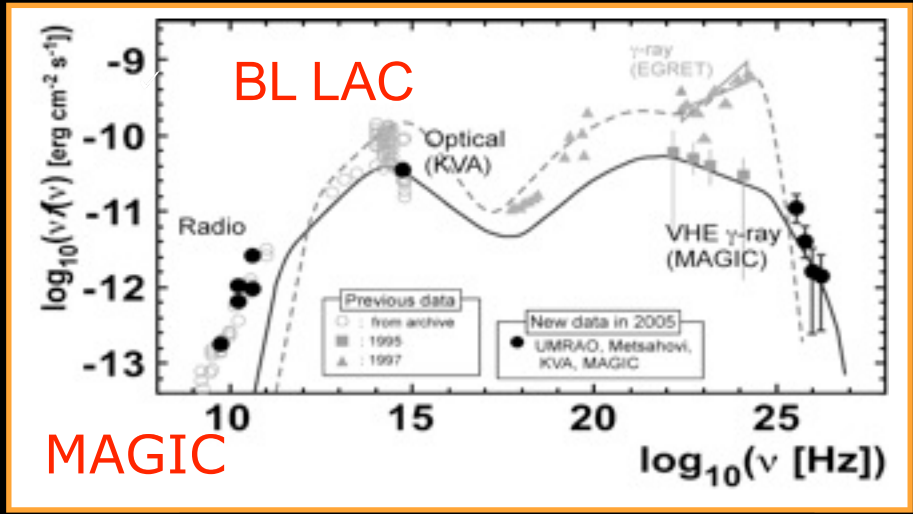


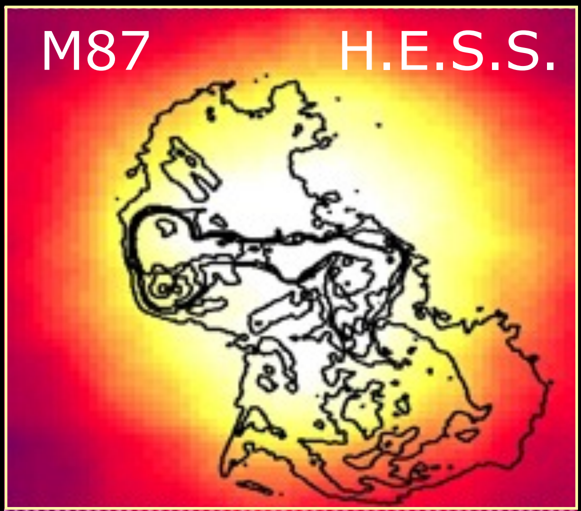
Constrain the model for the star formation in the universe

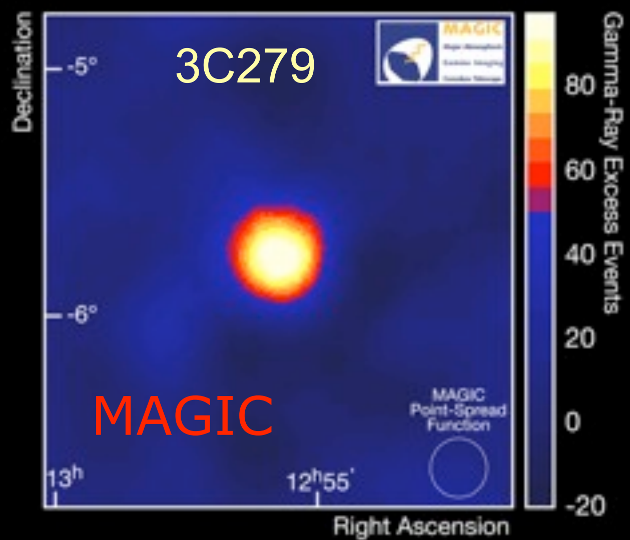
CTA will nail down the EBL measurement using AGN up to z=2.0 !!

Steep spectra AGN:
LBL, FSRQ & high redshift (z<2.0) AGN

- The extension of CTA to low energies will uncover many soft and steep spectrum AGN
- ~200 AGN (z<2.0) with CTA Threshold energy some 10 GeV to be free from EBL absorption

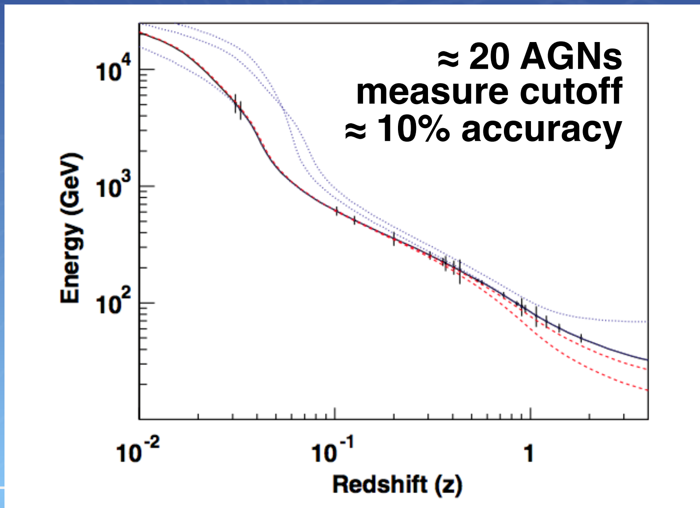


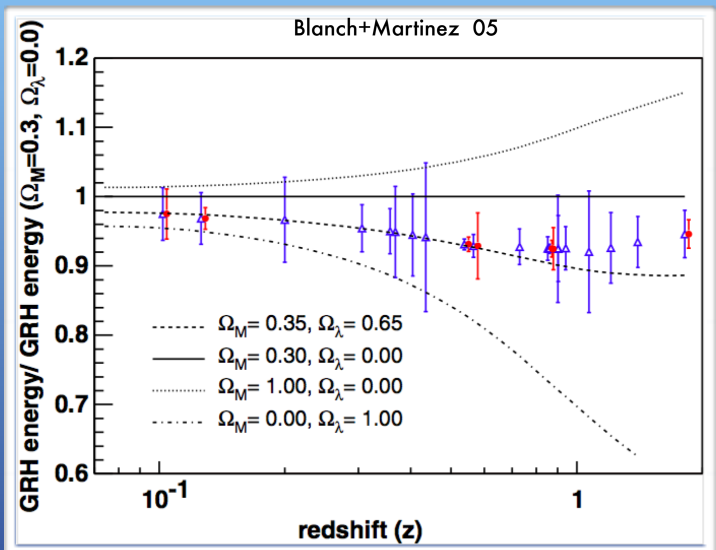


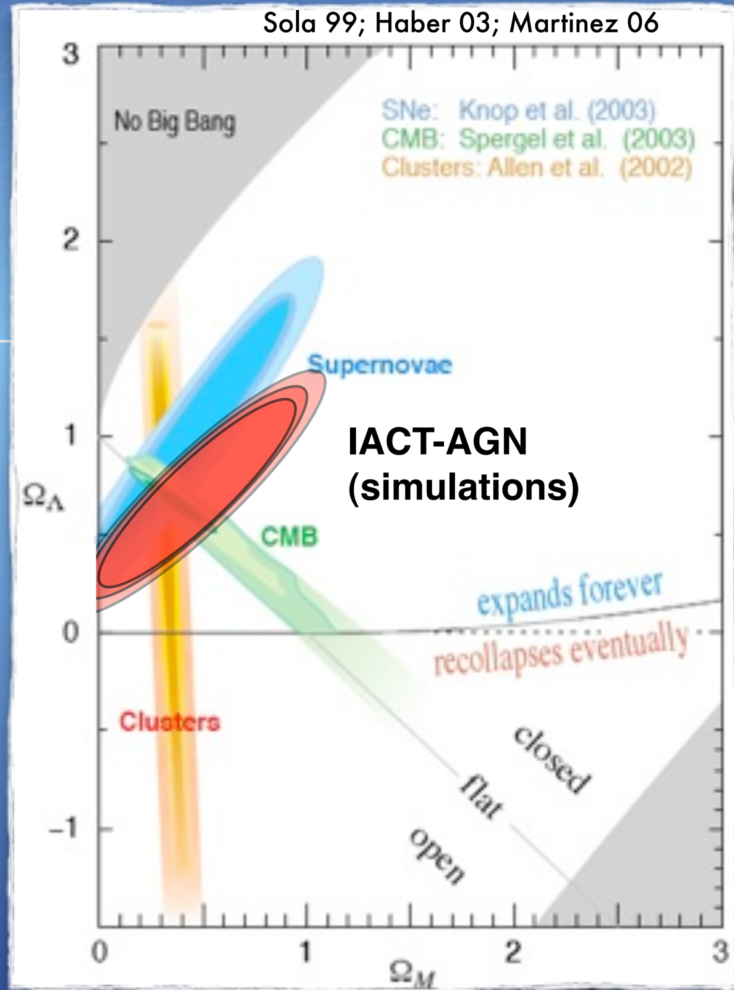


EBL carries cosmological information

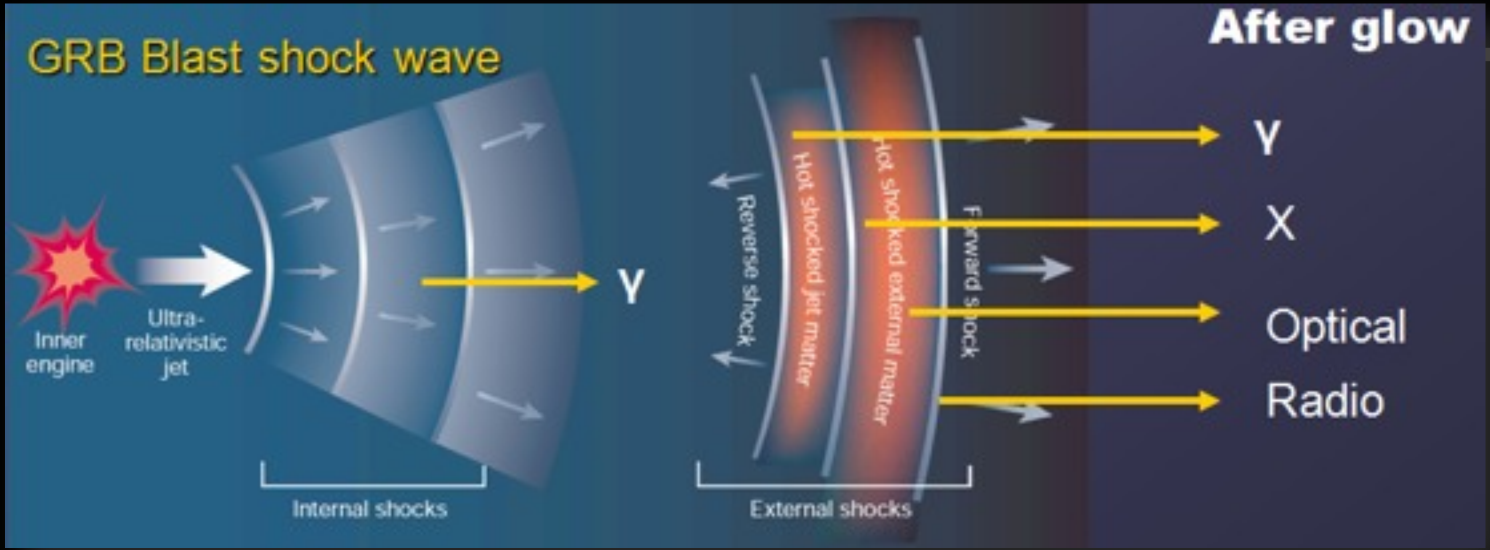
$$\frac{\mathrm{d}l}{\mathrm{d}z} = c\frac{1/(1+z)}{H_0\sqrt{\Omega_M(1+z)^3+\Omega_K(1+z)^2+\Omega_\Lambda}}$$

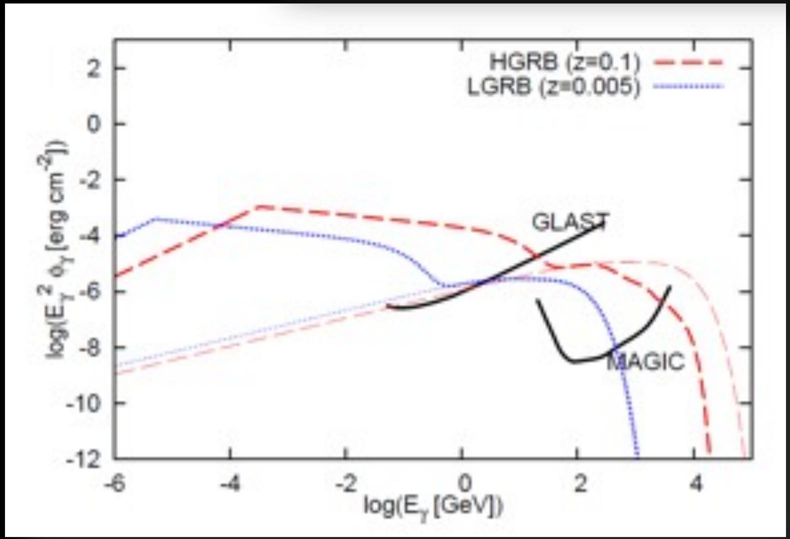




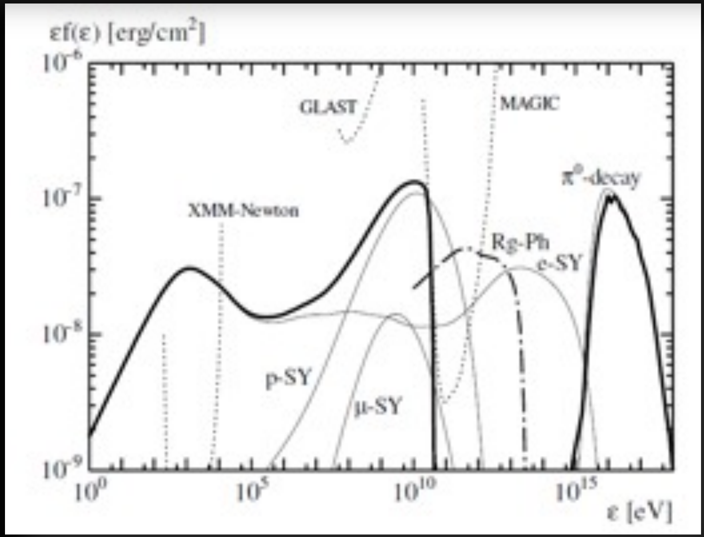


Gammas from GRBs





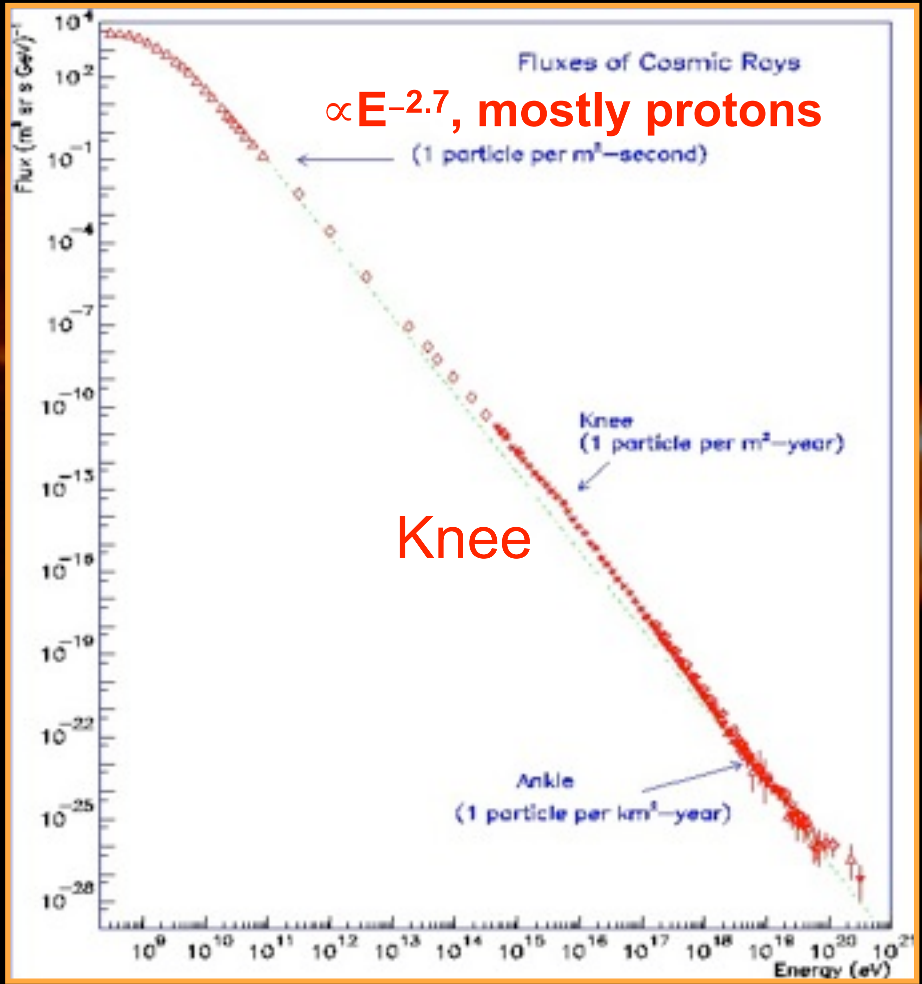
Murase et al. 2008



Asano and Mezaros 2008

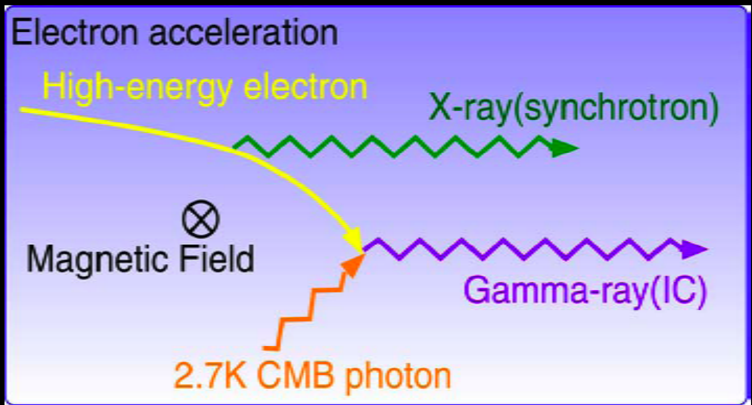
Which are the sources of the cosmic rays ?

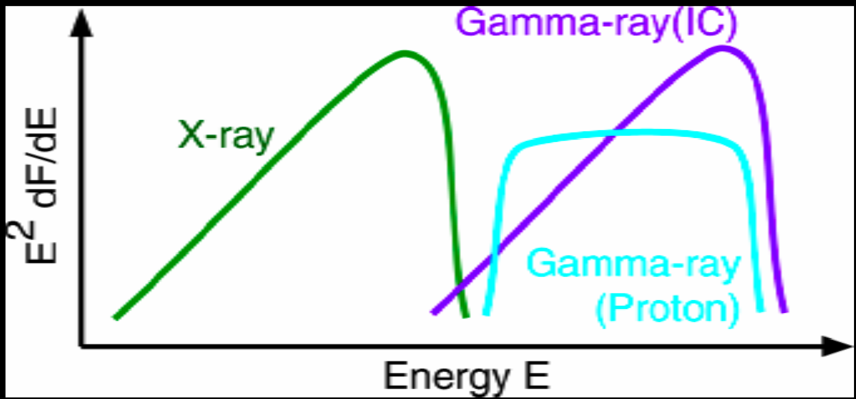
Victor HESS 1912

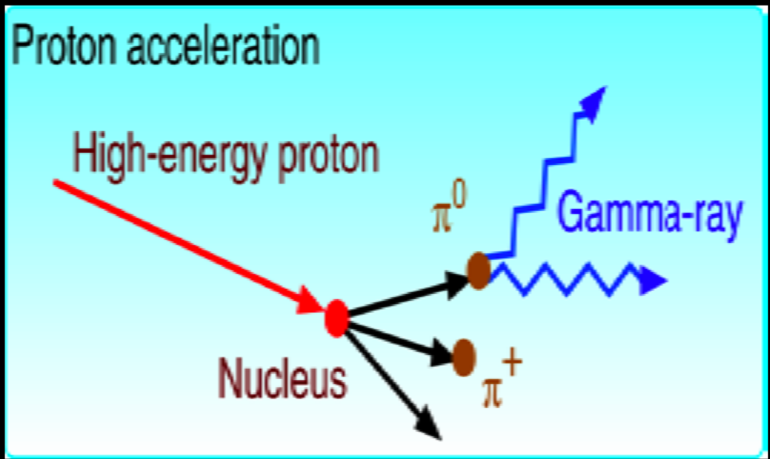


Wide energy range of CTA: determination of sources of hadronic cosmic rays ?

Question: In which objects do we have hadronic acceleration and in which objects leptonic acceleration ?

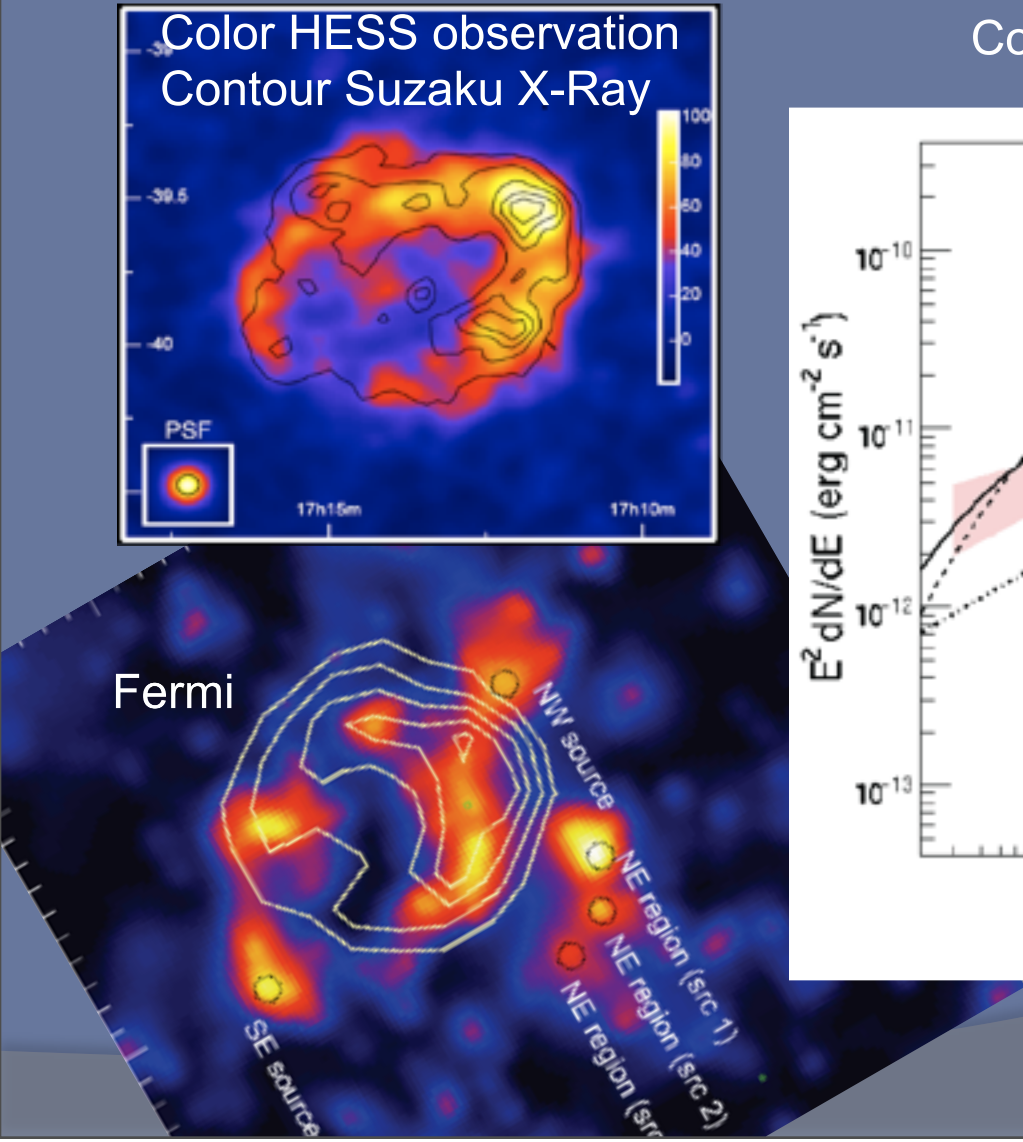




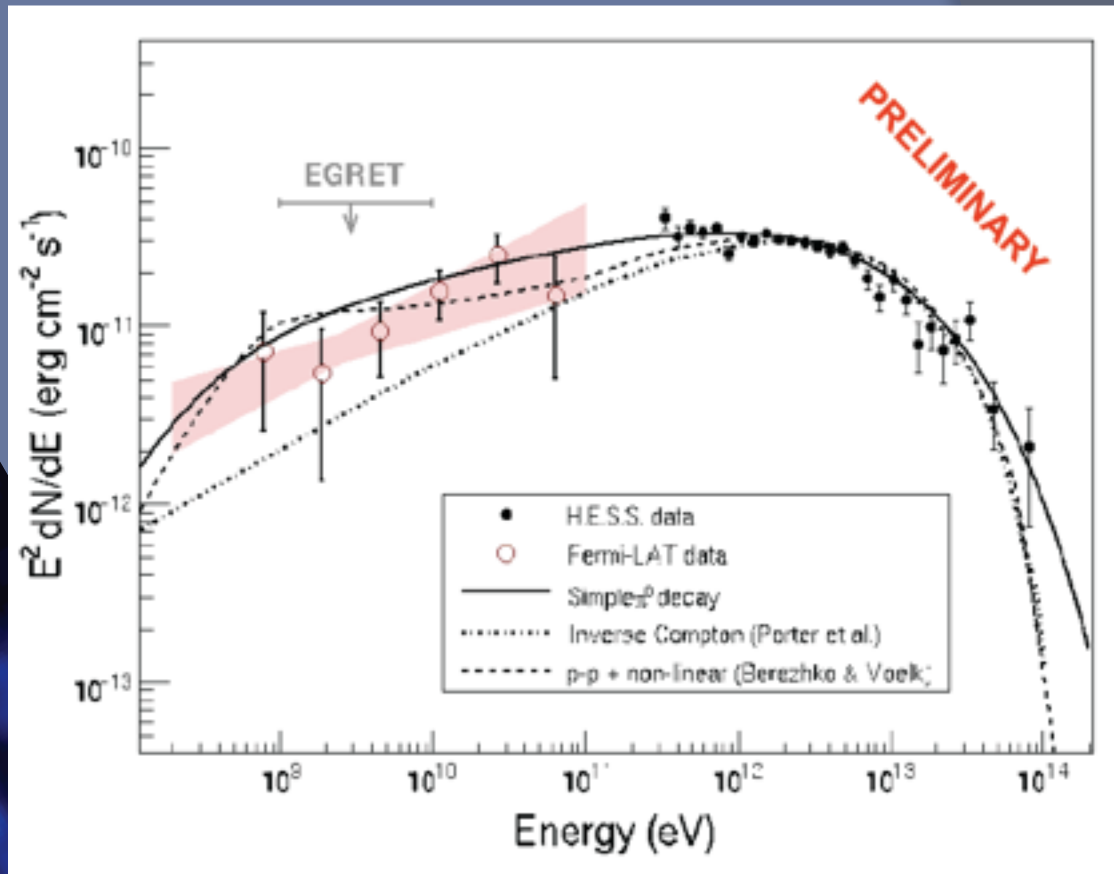


- SSC model: leptonic acceleration
  - High energy gamma rays
  - Strong synchrotron emission
- π^0-decay: hadronic acceleration
  - High energy gamma rays
  - High energy hadrons --> CR
  - 10 TeV proton -> 1 TeV gamma

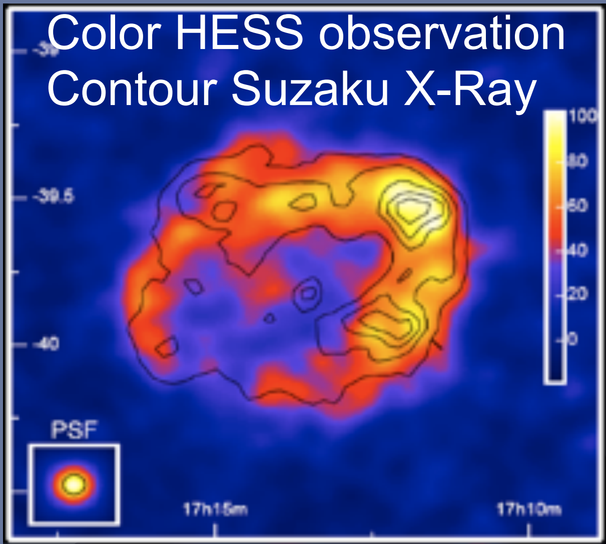
Low energies in SNR Study
RX J1713 HESS + Fermi

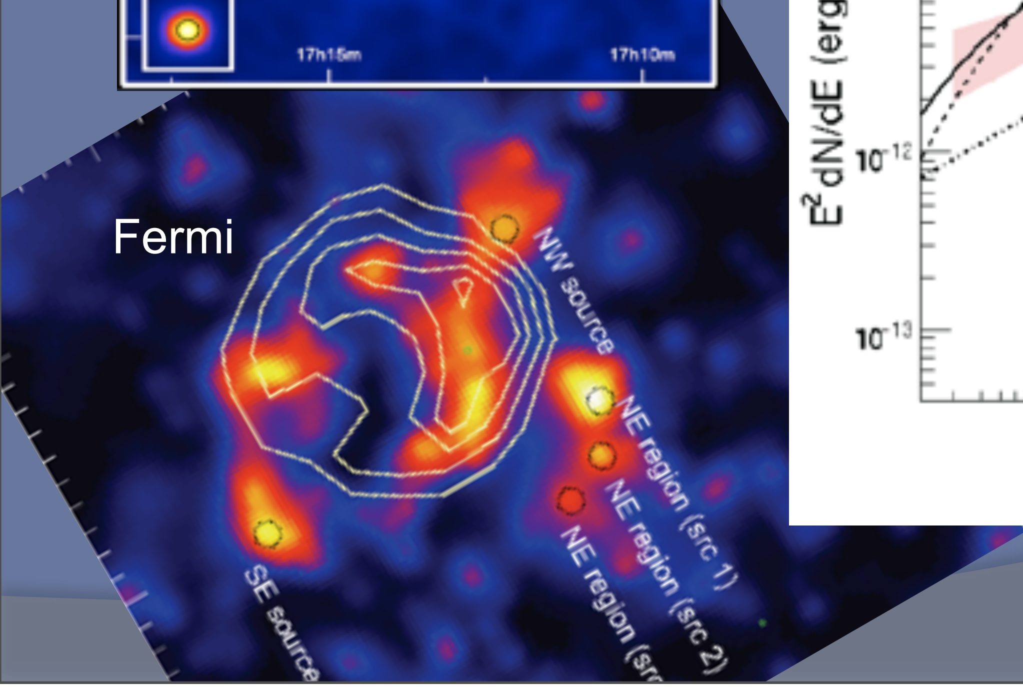


Concaved spectrum (non-linear effect)??

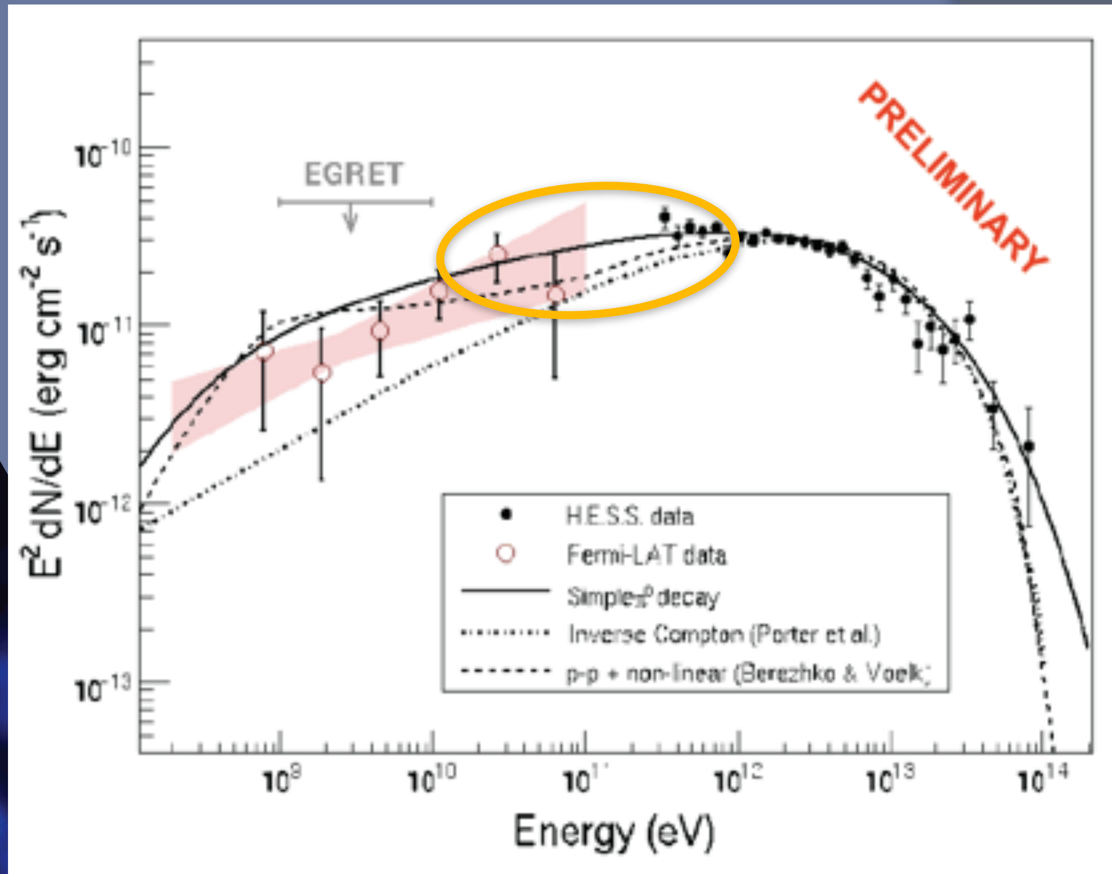


Low energies in SNR Study
RX J1713 HESS + Fermi



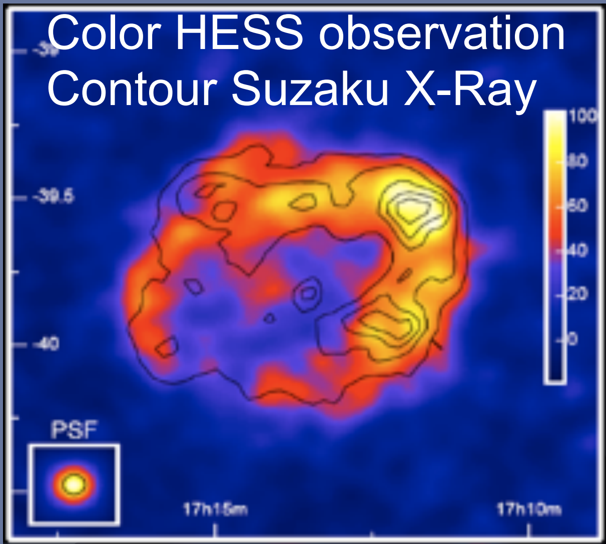


Concaved spectrum (non-linear effect)??

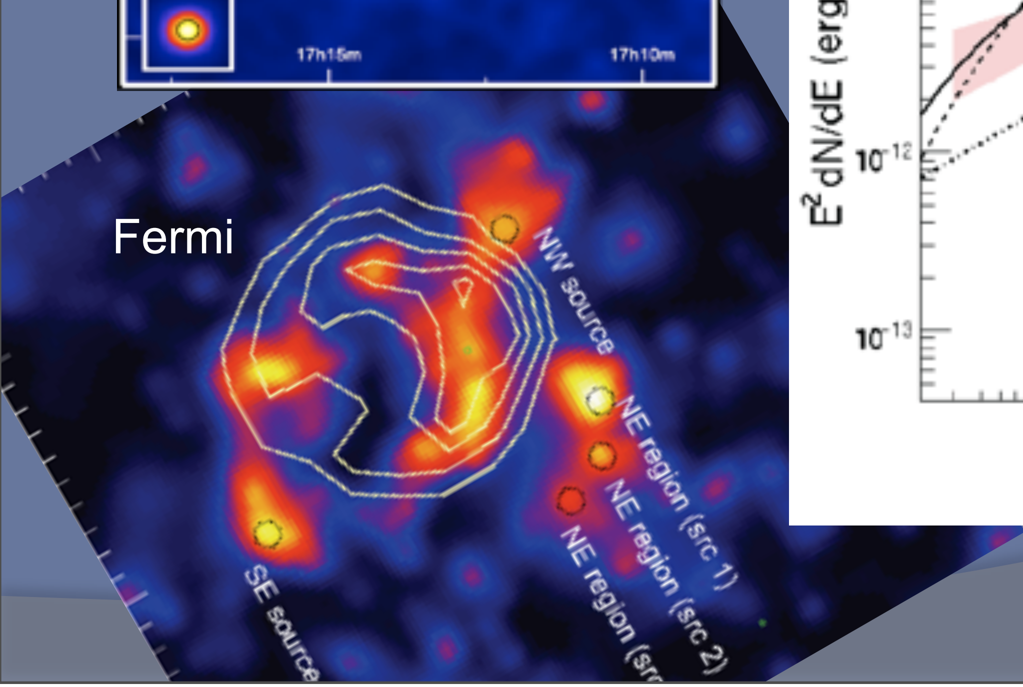


Low energies in SNR Study
RX J1713 HESS + Fermi

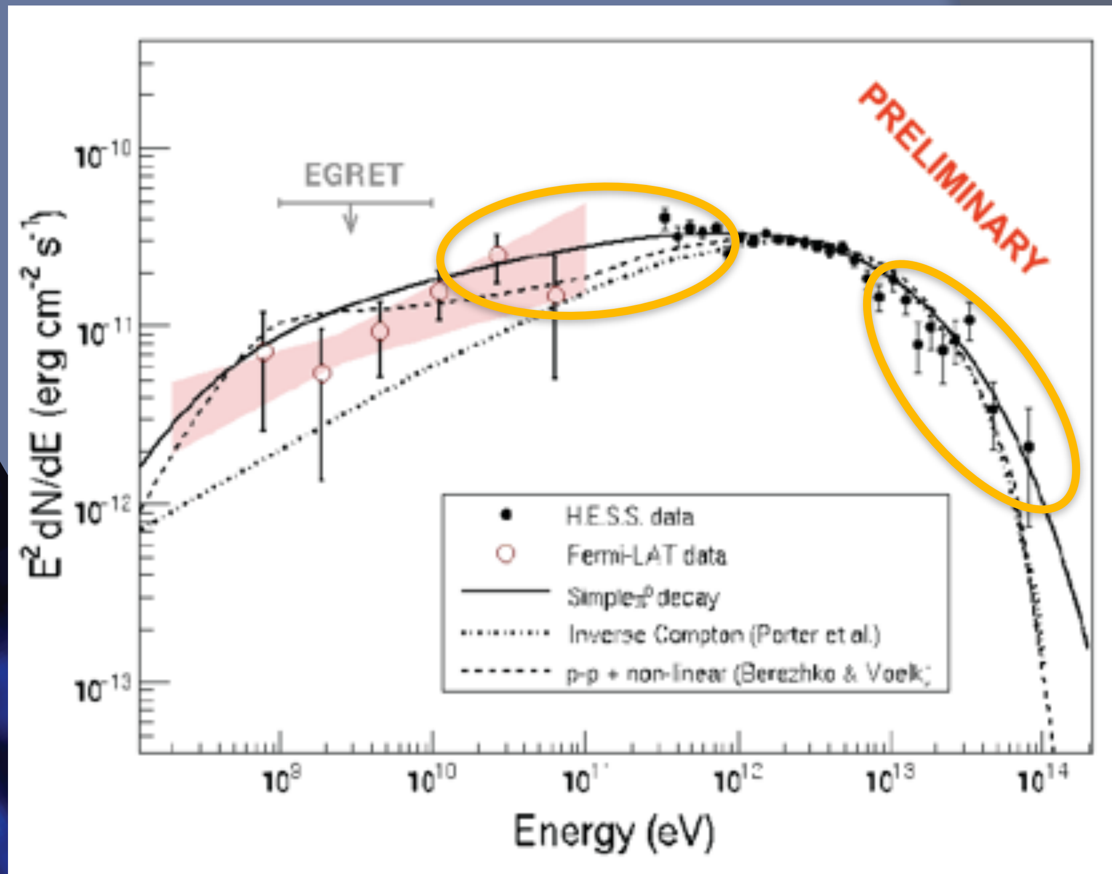
Color HESS observation
Contour Suzaku X-Ray



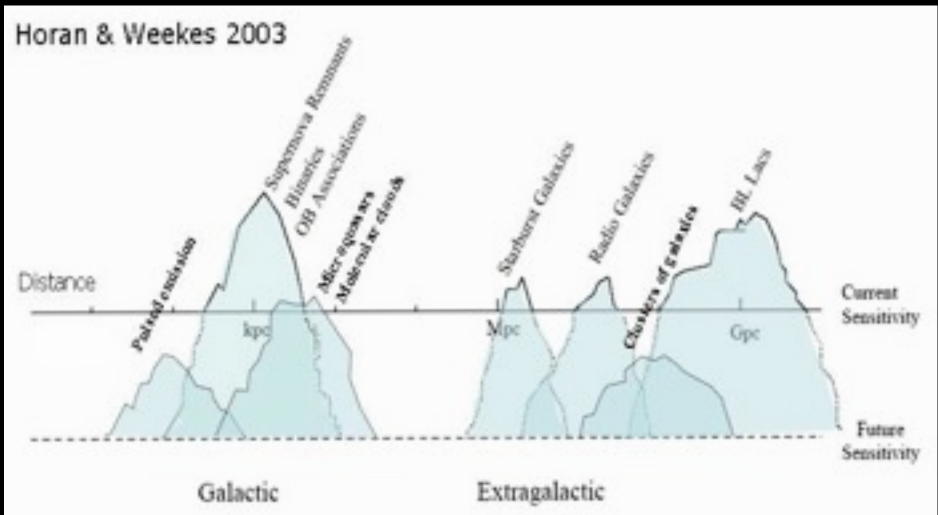
Fermi

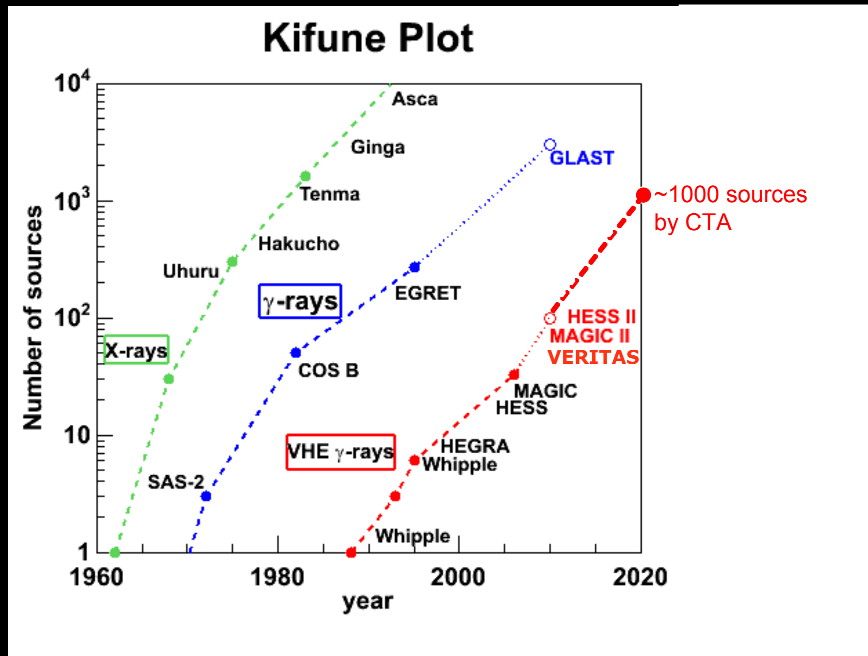


Concaved spectrum (non-linear effect)??



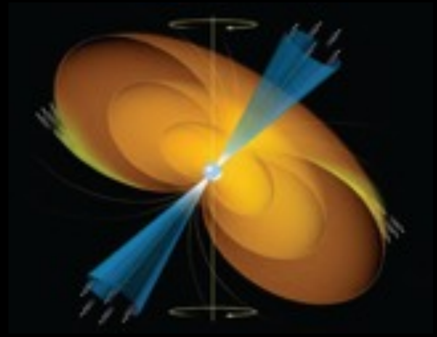
High discovery potential of CTA





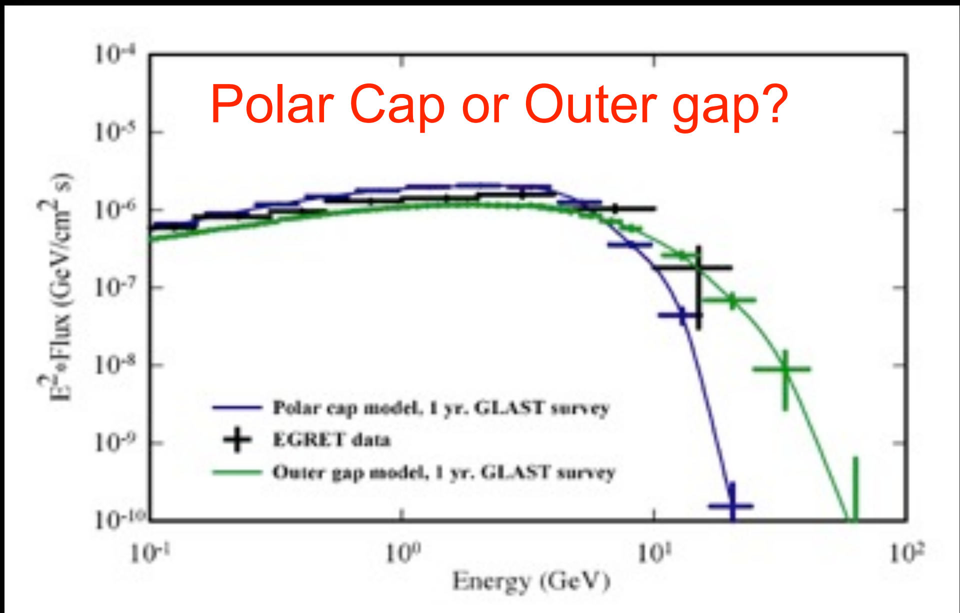
- ✓ At the moment we see only the tip of the iceberg
  -> we expect many new sources and source classes

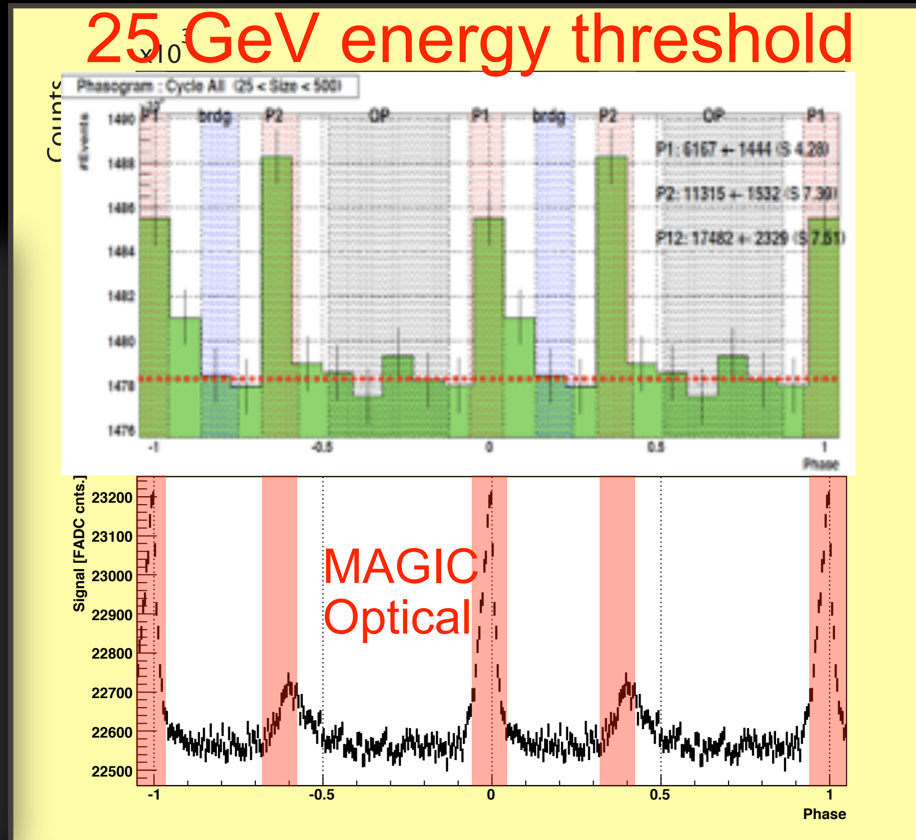
New source class: Pulsars with CTA



- FERMI has seen 36 pulsars !
- Most interesting physics is in the high-end of the spectrum
- Emission at high energy excludes polar cap model
- Need lowest energy threshold !!

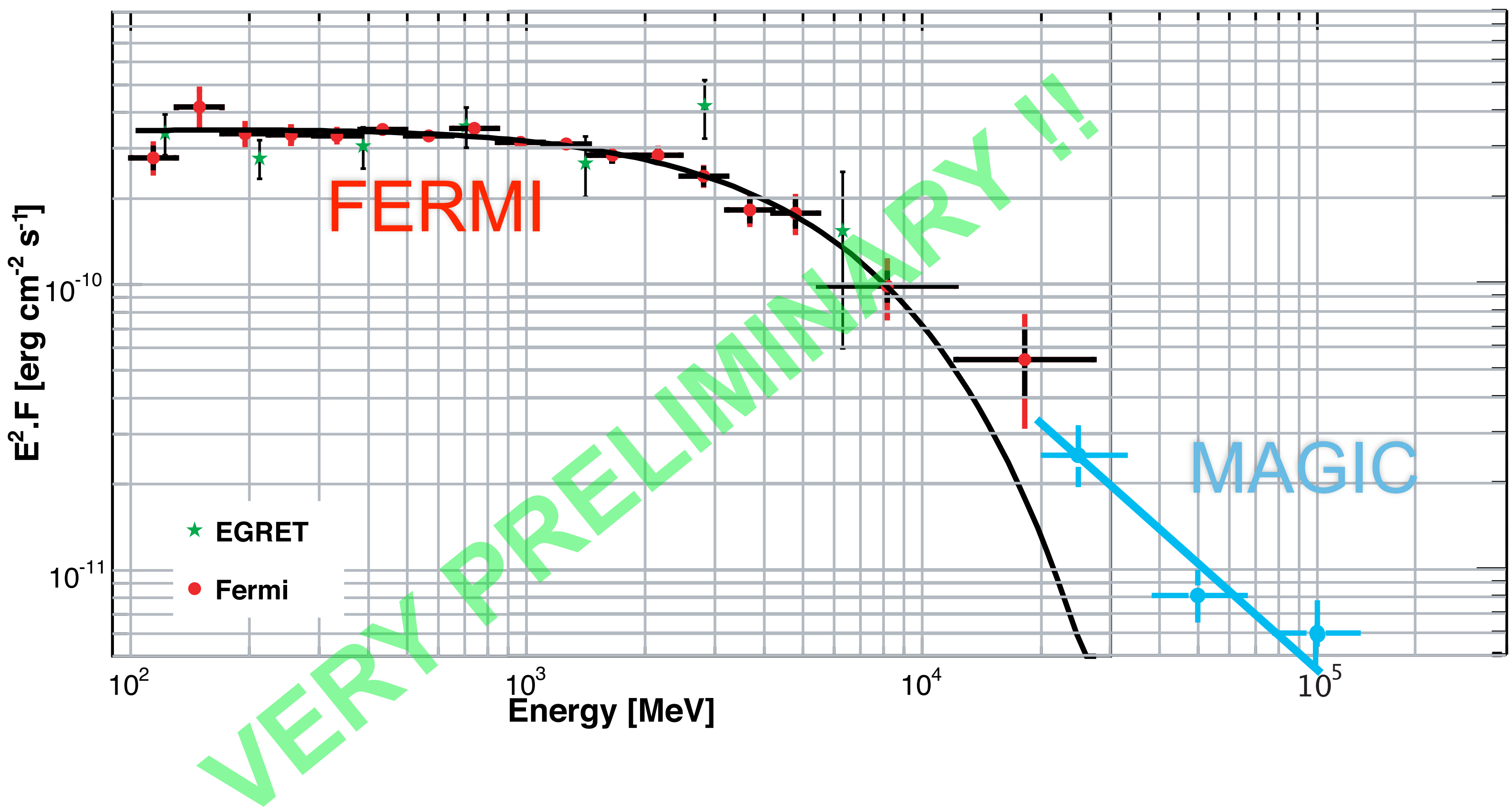
MAGIC detection of Crab pulsar



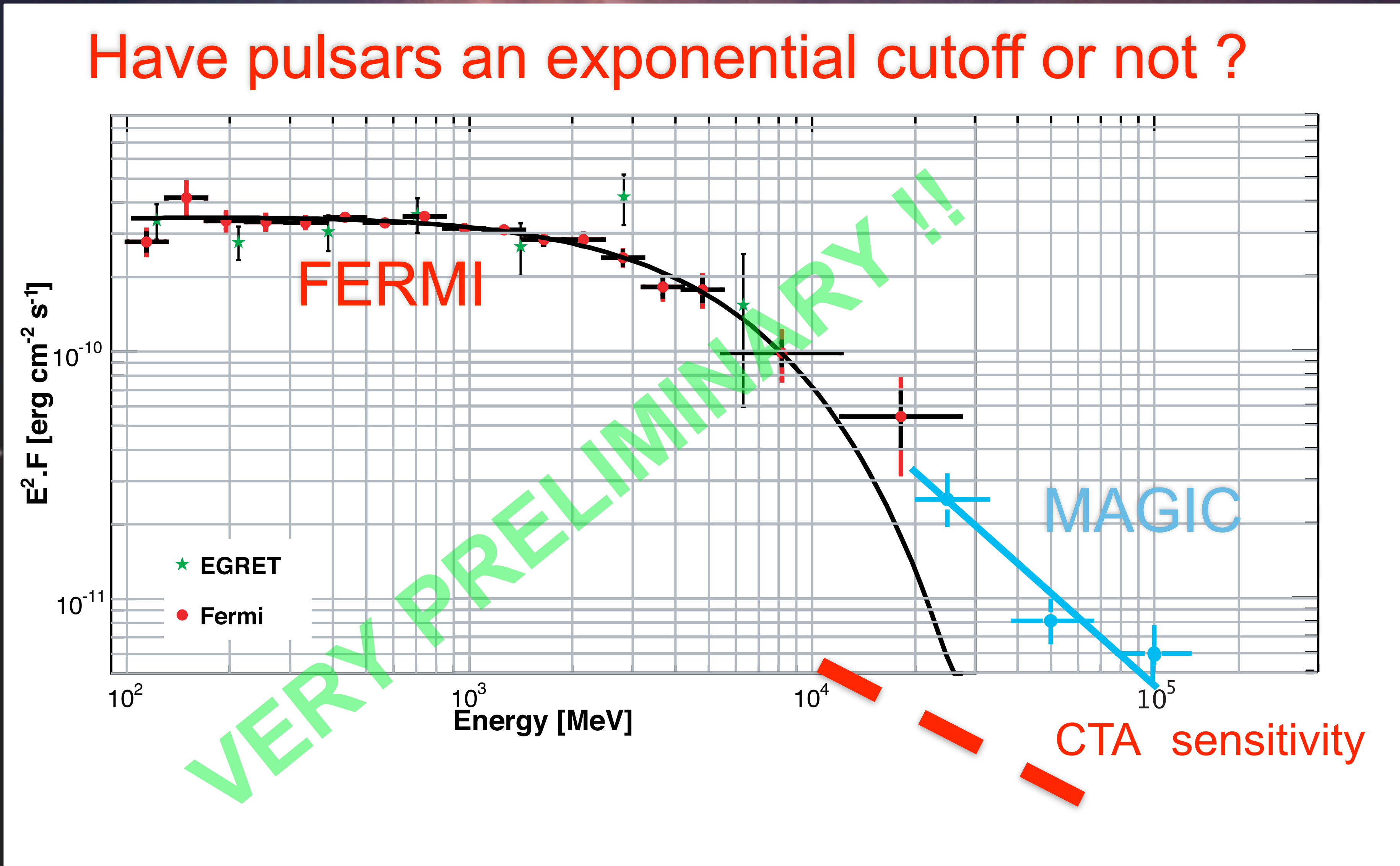


FERMI/MAGIC Crab pulsar spectrum: MAGIC sees high energy extension

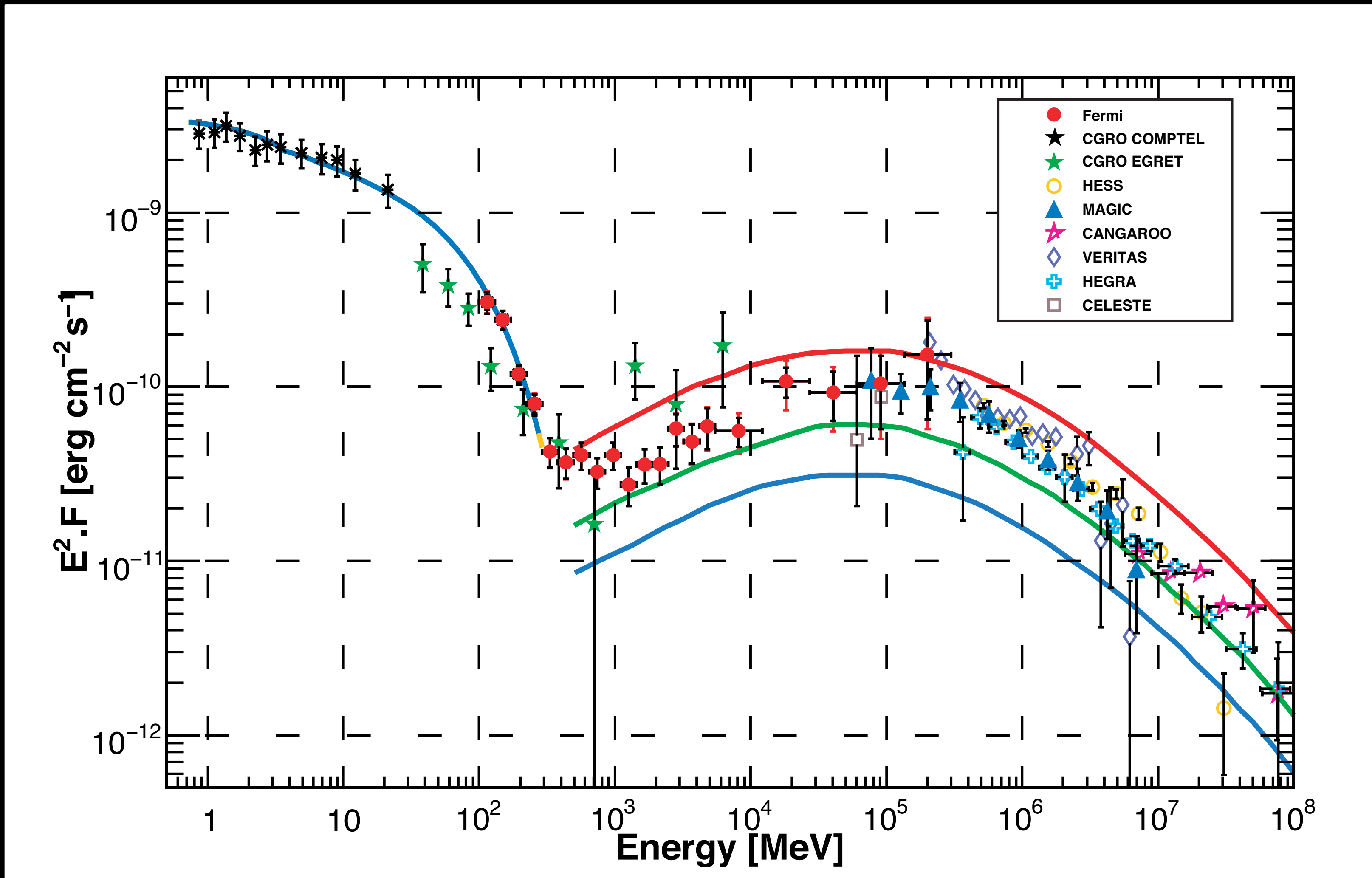
Have pulsars an exponential cutoff or not ?



FERMI/MAGIC Crab pulsar spectrum: MAGIC sees high energy extension

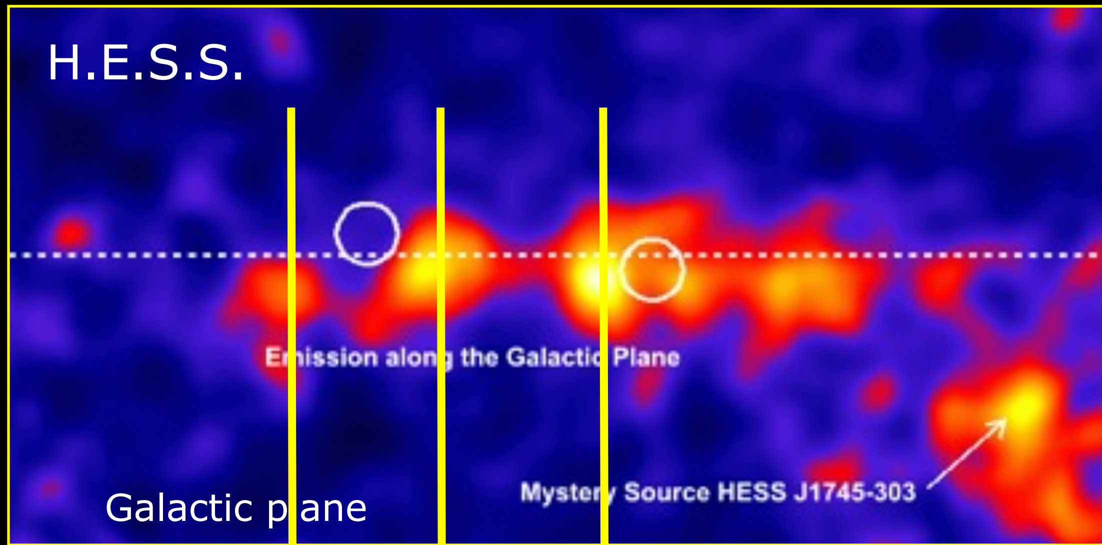


COMPTEL/FERMI/IACT Multiwavelength Crab nebula emission

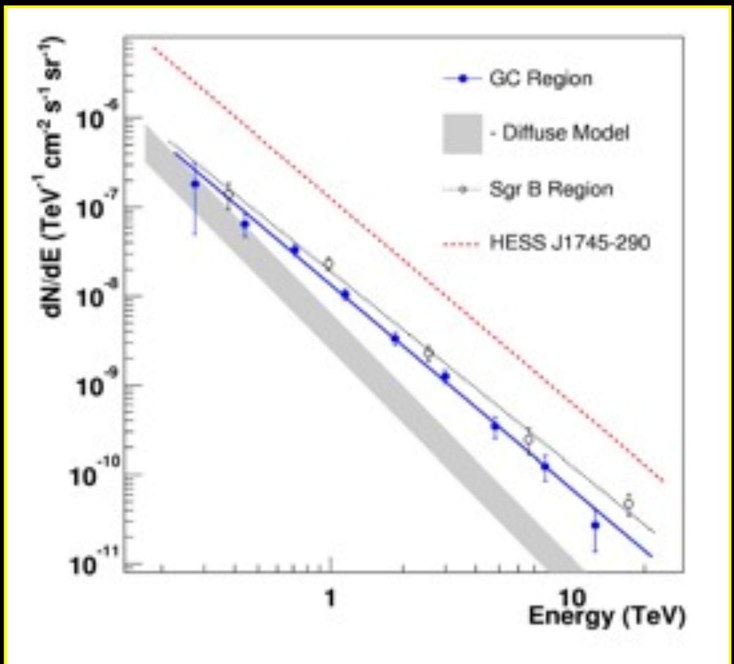


Probing Cosmic rays in the Galaxy using molecular clouds

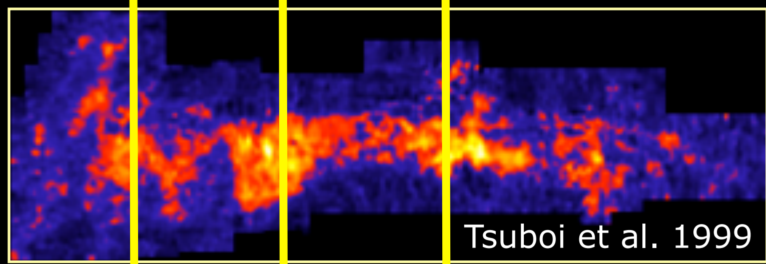
Gamma rays



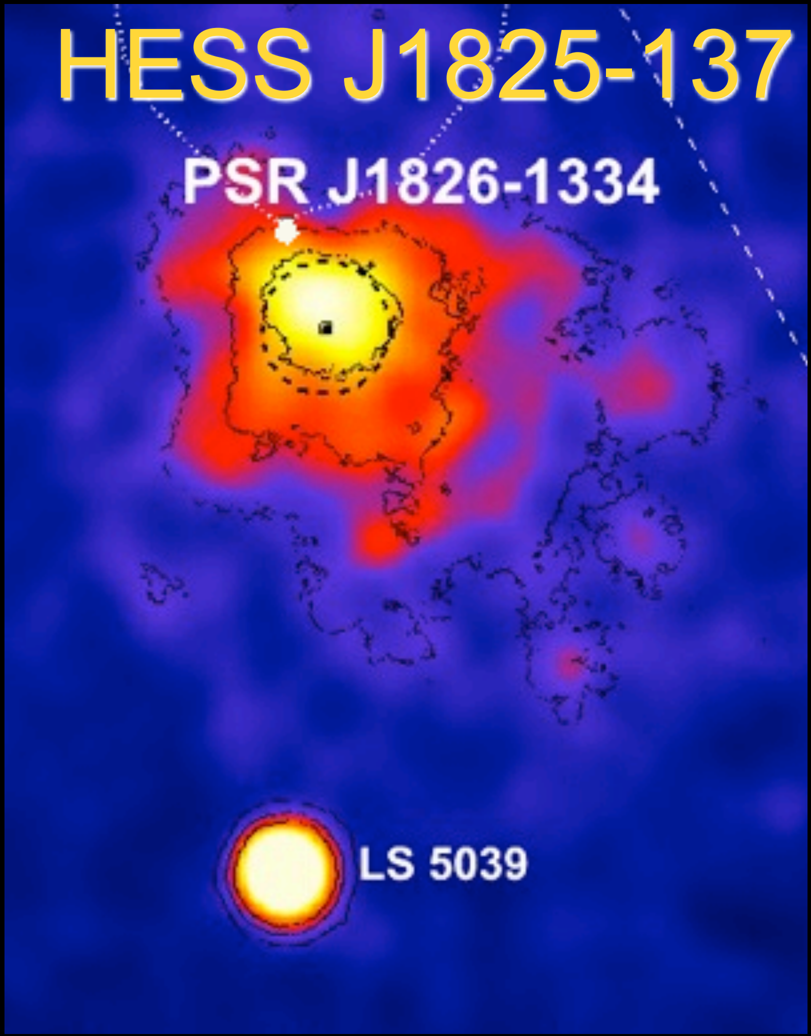
Gamma Spectrum
from diffuse radiation



Molecular clouds

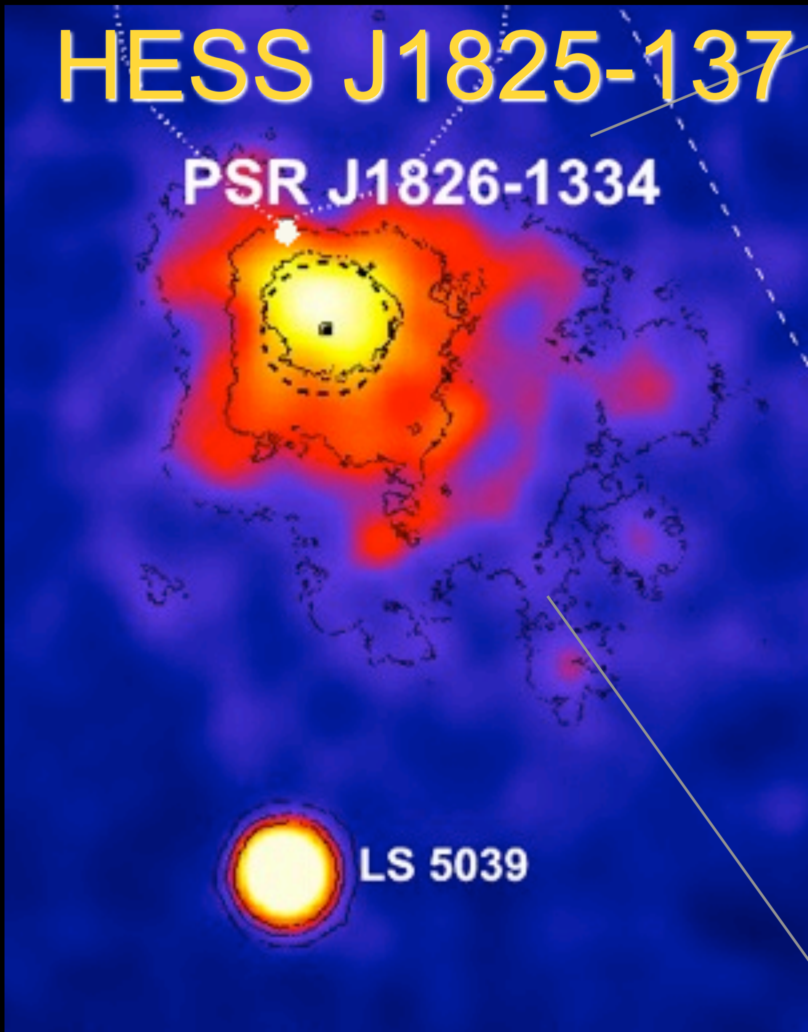


Morphology studies with CTA
High angular resolution

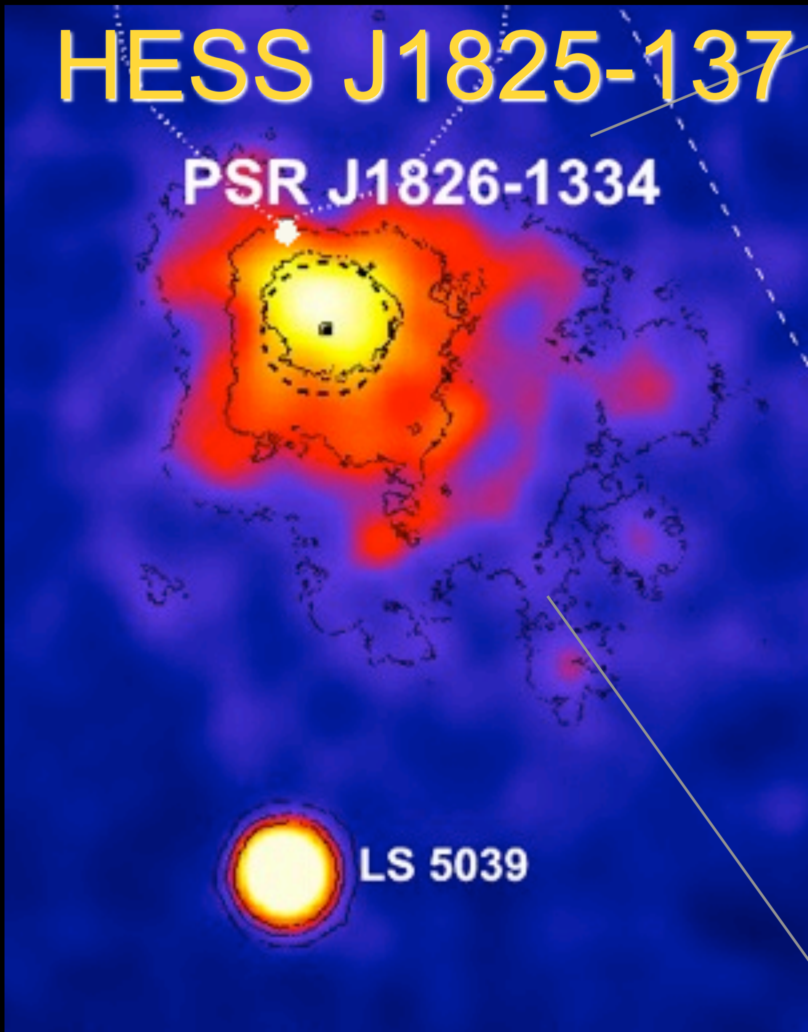


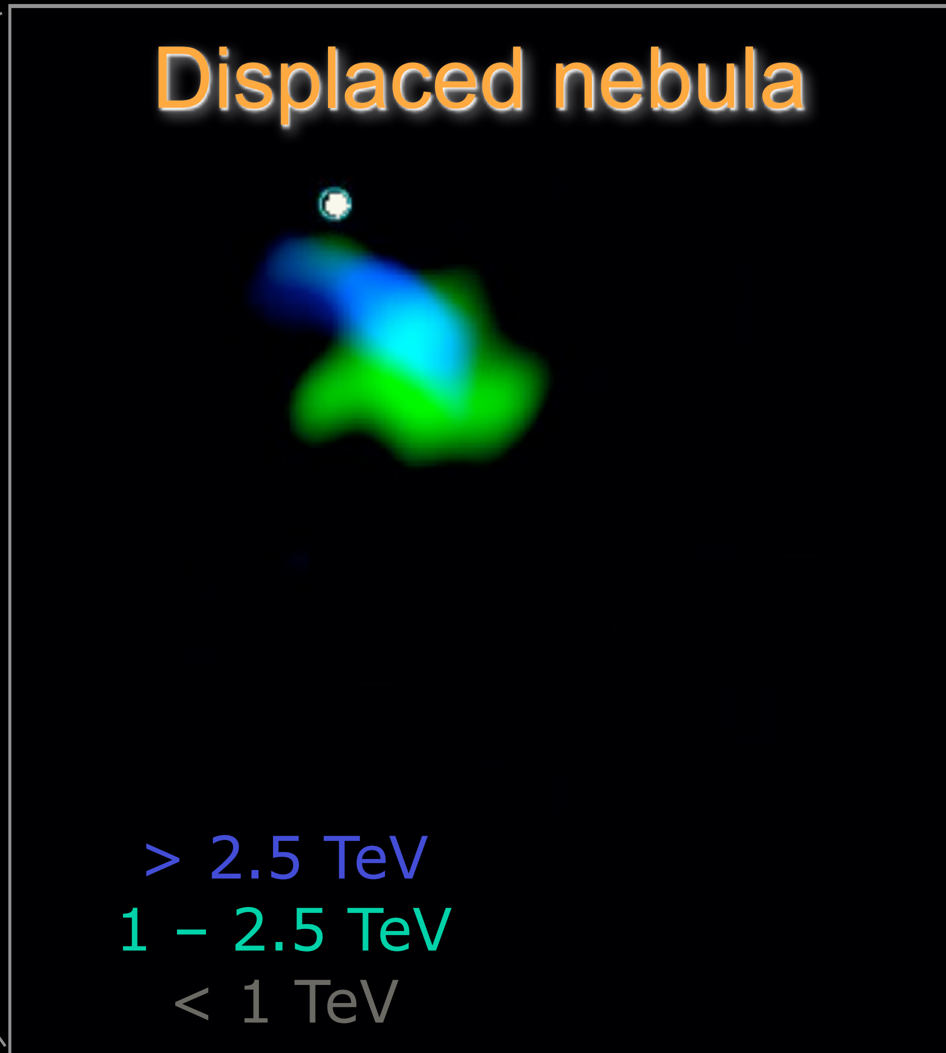
Displaced nebula

Morphology studies with CTA
High angular resolution

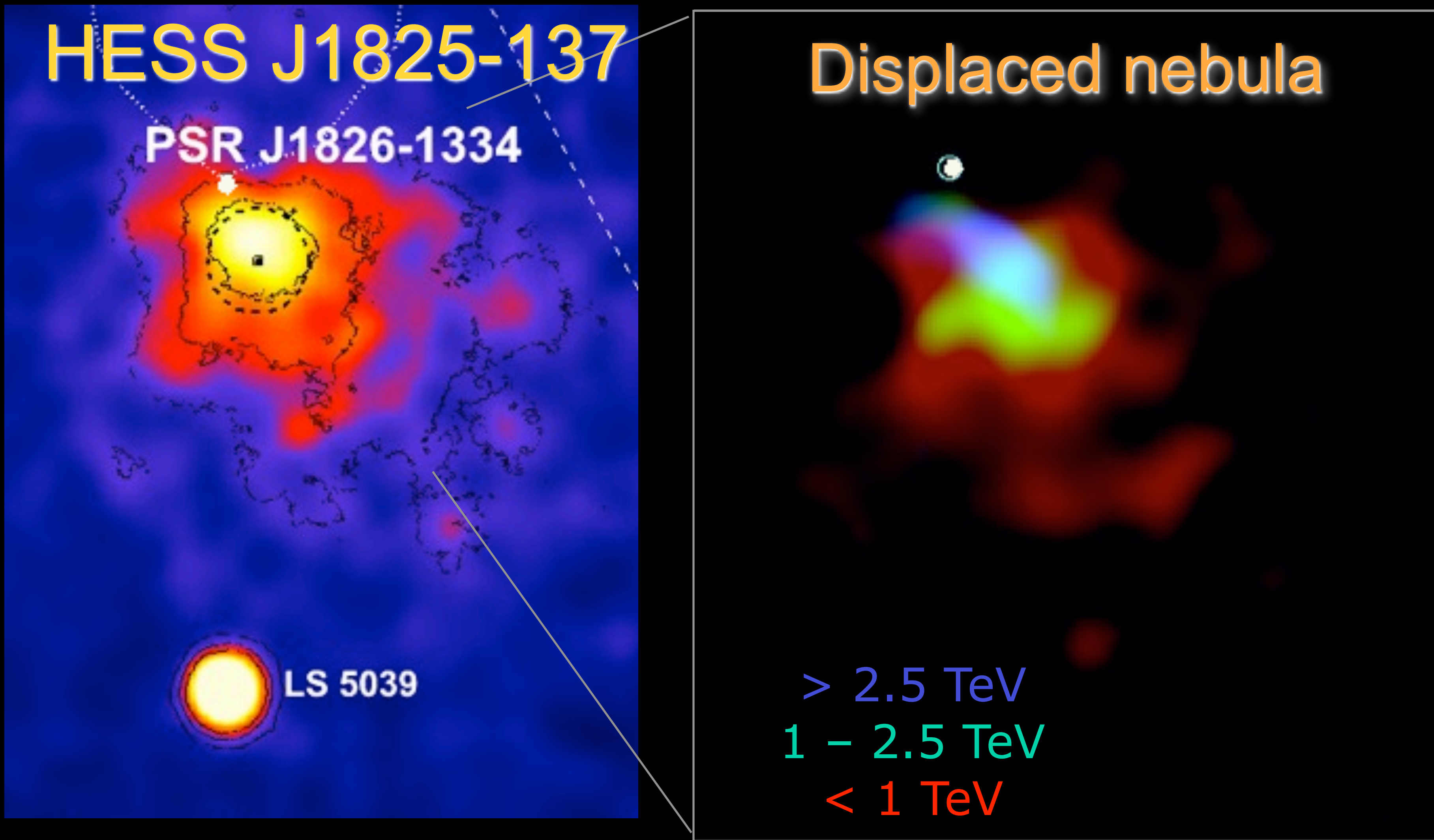


Morphology studies with CTA
High angular resolution



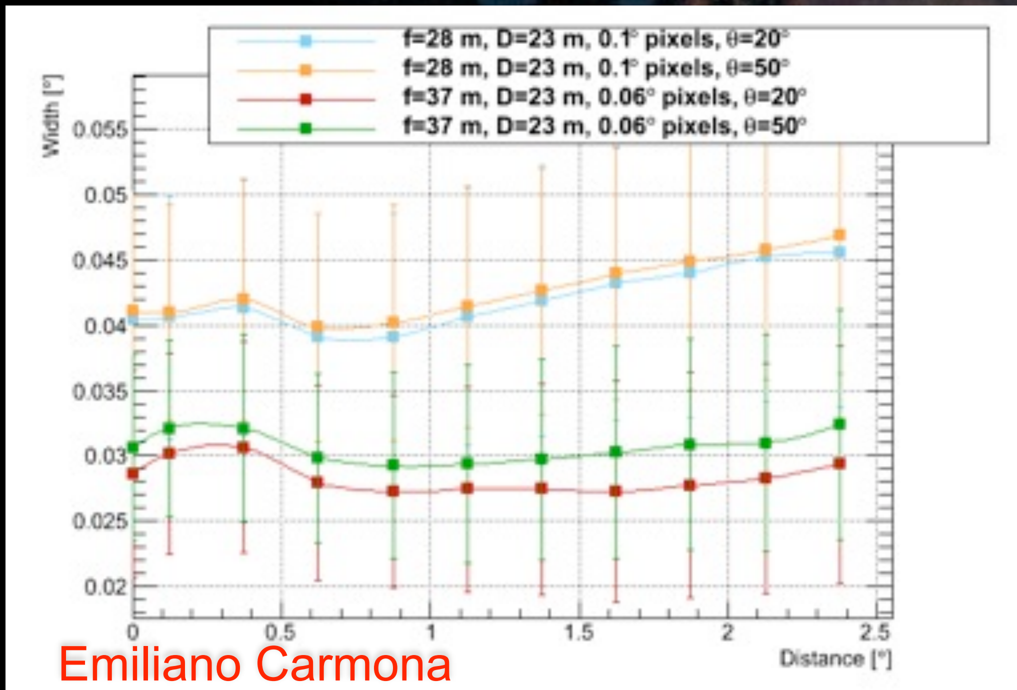


Morphology studies with CTA
High angular resolution



Simulation for F/D=1.2 & 1.6

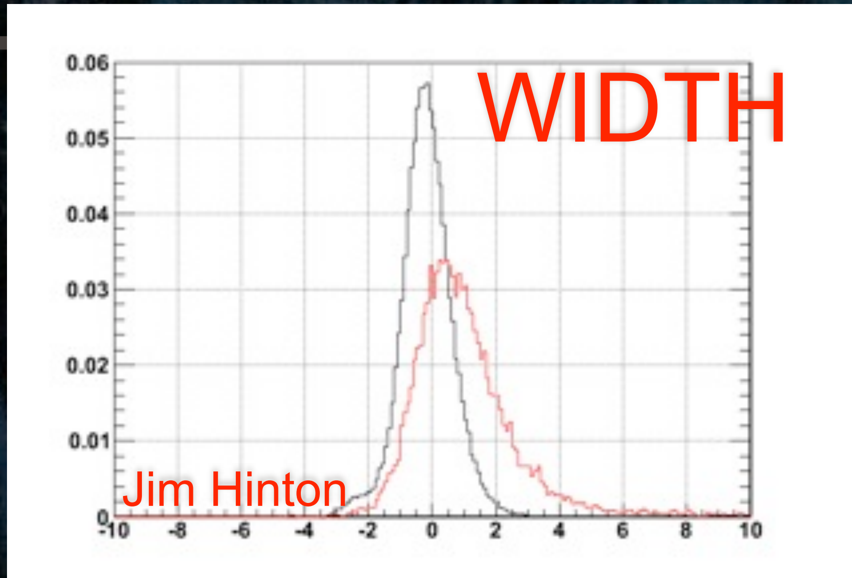
- Comparison of WIDTH parameter for F/D=1.2 (0.06 deg pixels) and F/D=1.6 (0.1 deg pixels)
- F/D=1.2 is good enough for this parameter

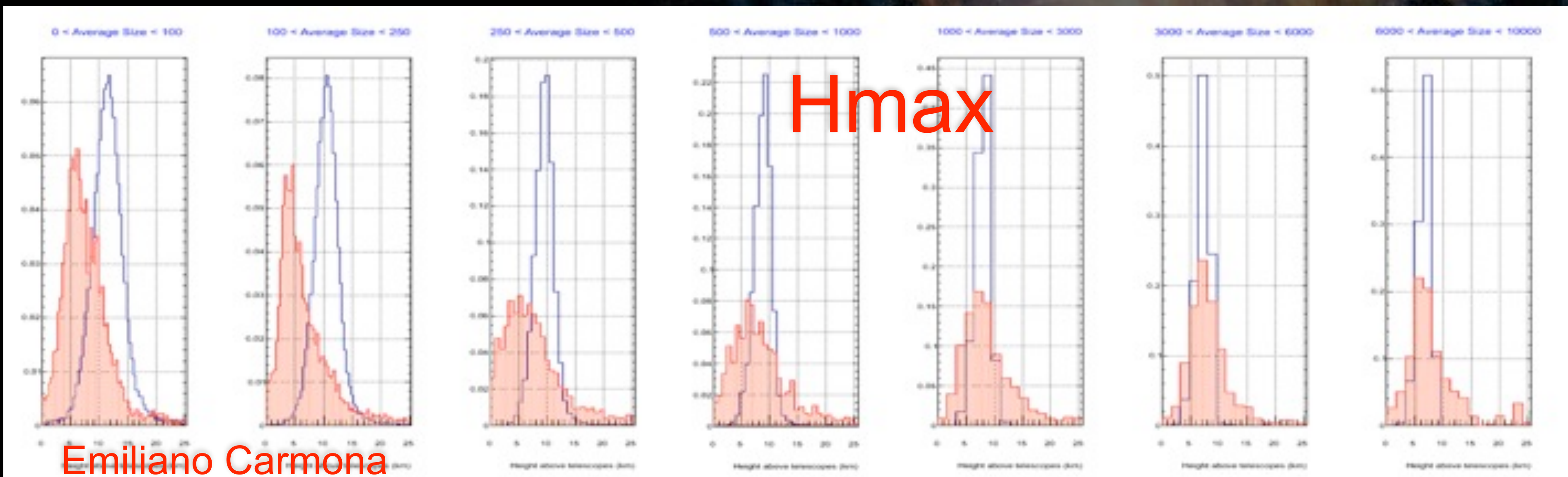


Thomas Schweizer, MPI Project review, December 2011

Importance of WIDTH for low energy analysis

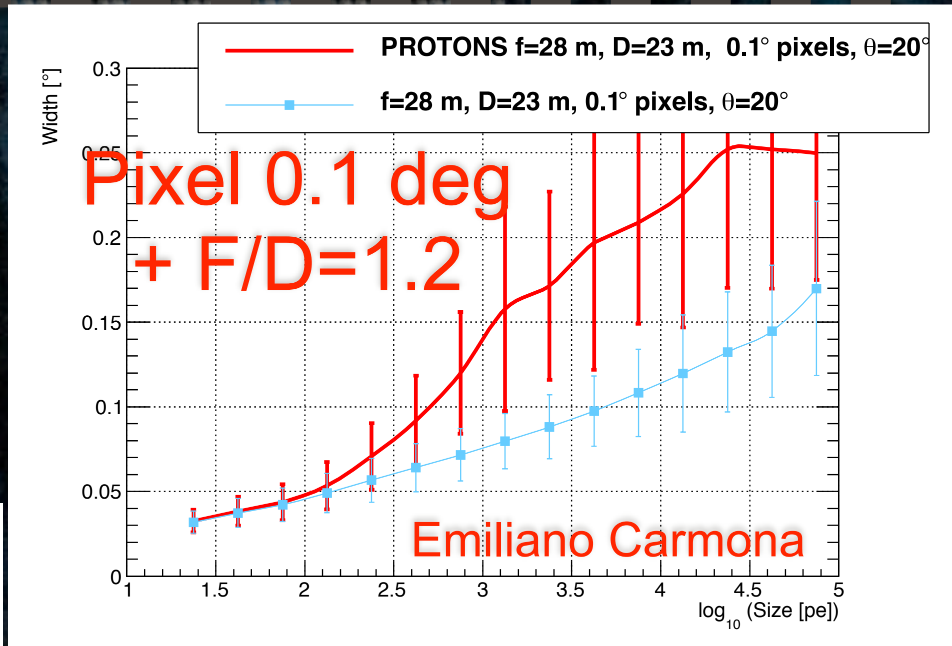
- Needed optical quality related to WIDTH (important separation parameter)
- Still small separation for 30-50 GeV (in stereo)
- Main separation parameter is Hmax

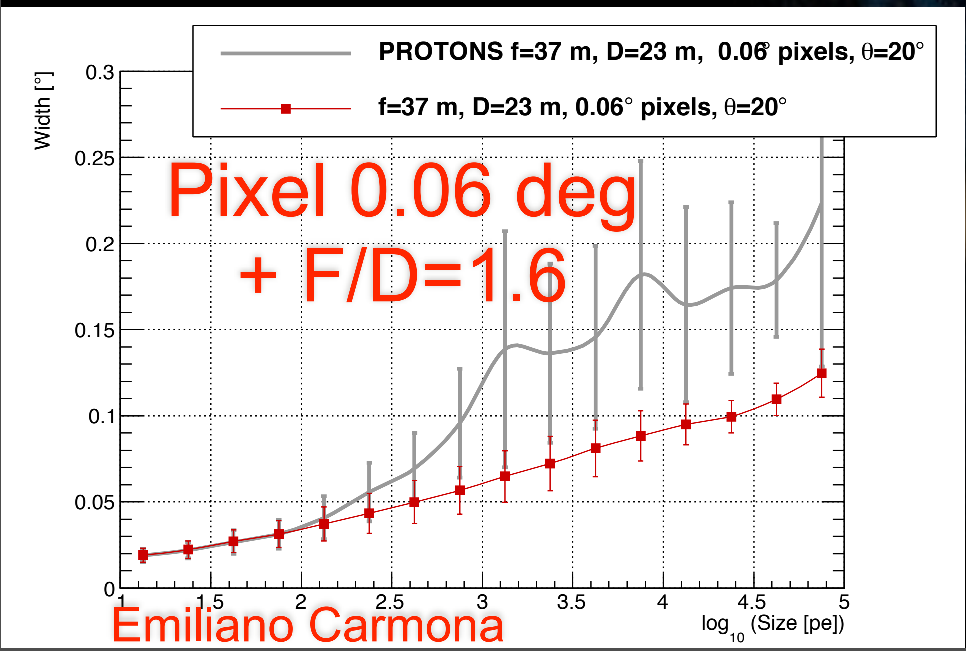




Gamma/Hadron separation (mono) using shower WIDTH for different pixel size

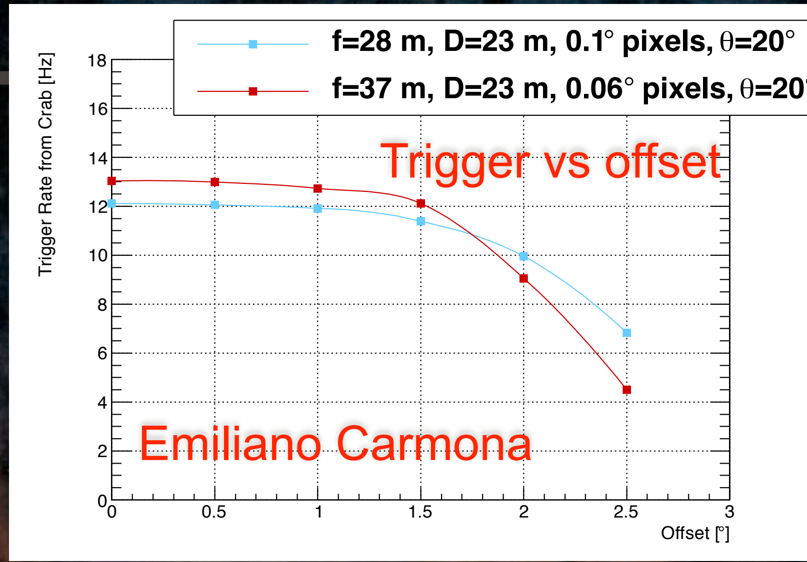
- Pixel size and optical quality are related.
- No improvement in gamma/hadron separation (WIDTH) with smaller pixels and better optics !!

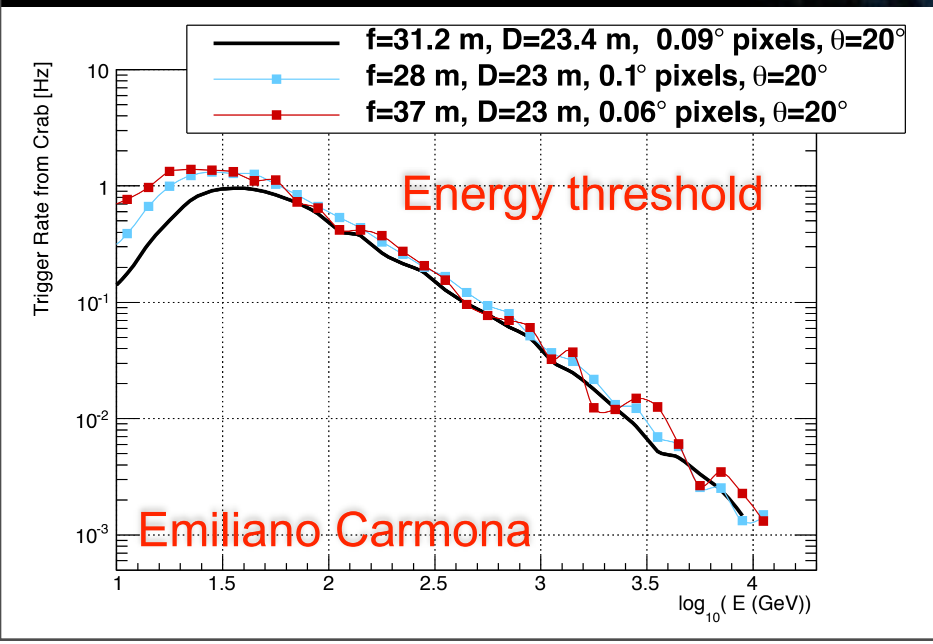


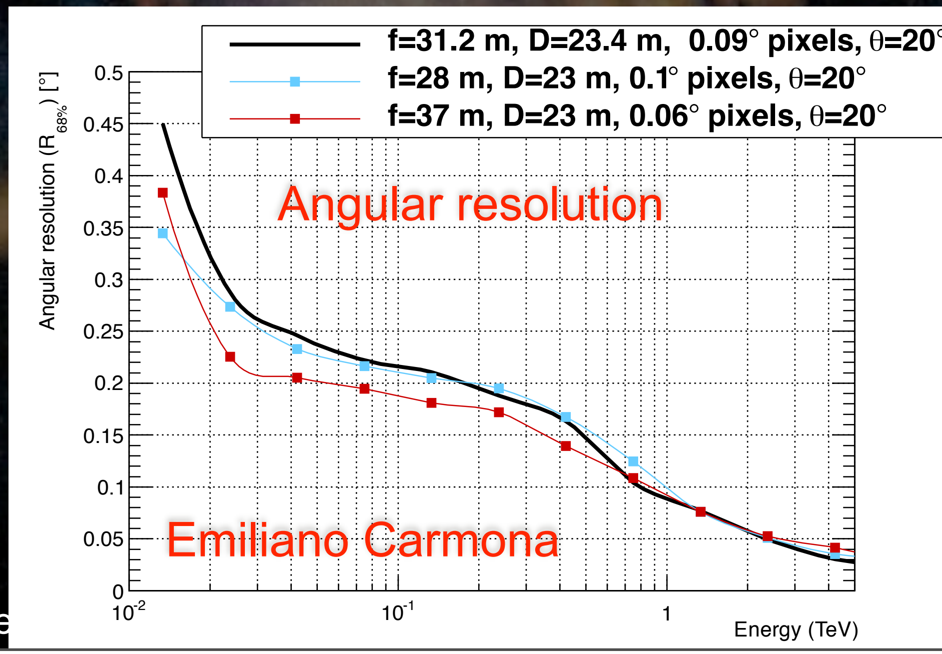


Importance of pixel size

- Two plots for **0.1 degree and 0.06 degree pixels:**
  1) Angular resolution & 2) Trigger rate
- Trigger threshold almost unaffected by pixel size and optical quality
- Angular resolution is slightly affected.

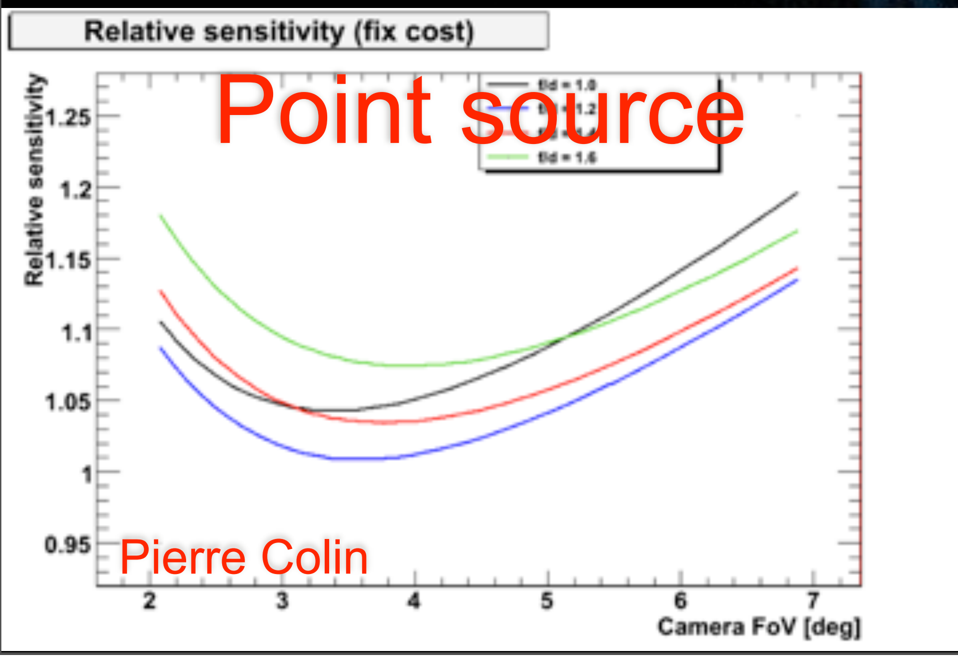


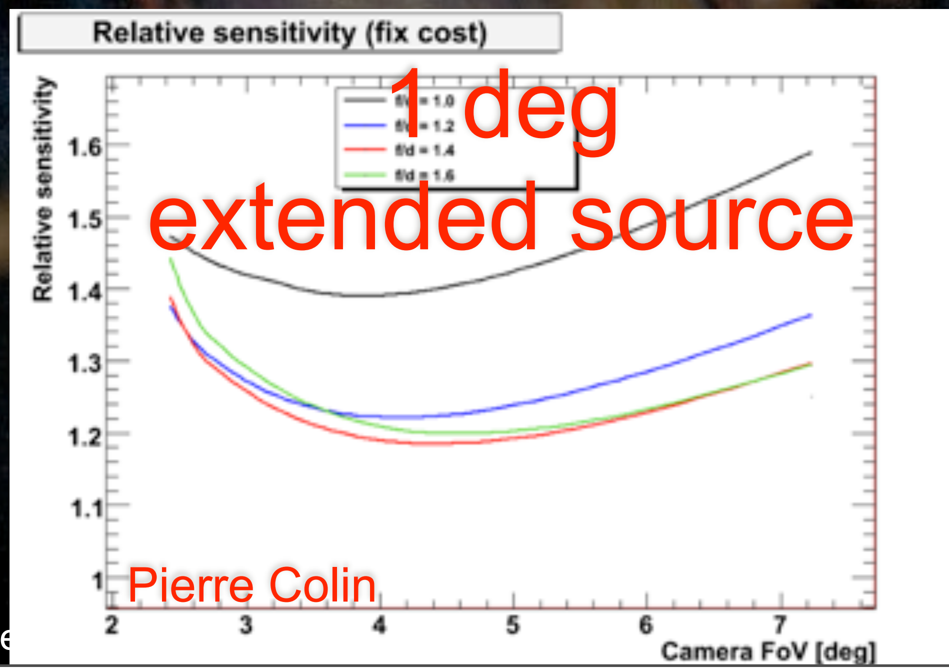




Relative sensitivity in dependence on FoV for fixed cost

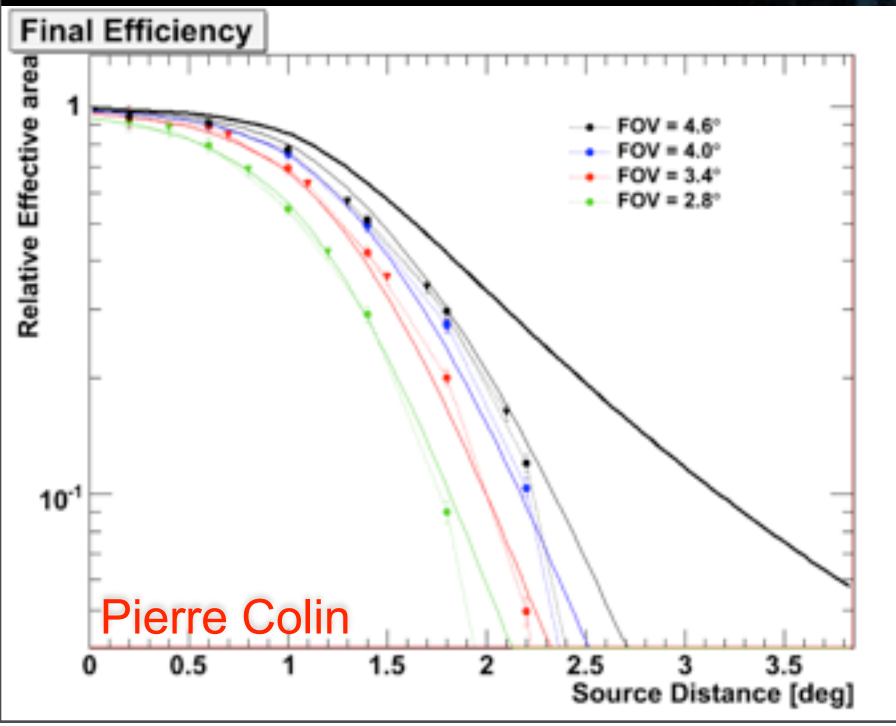
- For point sources the most cost effective F0V is 3.5 degrees and the best F/D=1.2
- For extended sources the best FoV is between 3.8 and 4.5 degrees and the F/D=1.2-1.6 are similar
- All in all, the variation seems small, the distribution is rather flat.

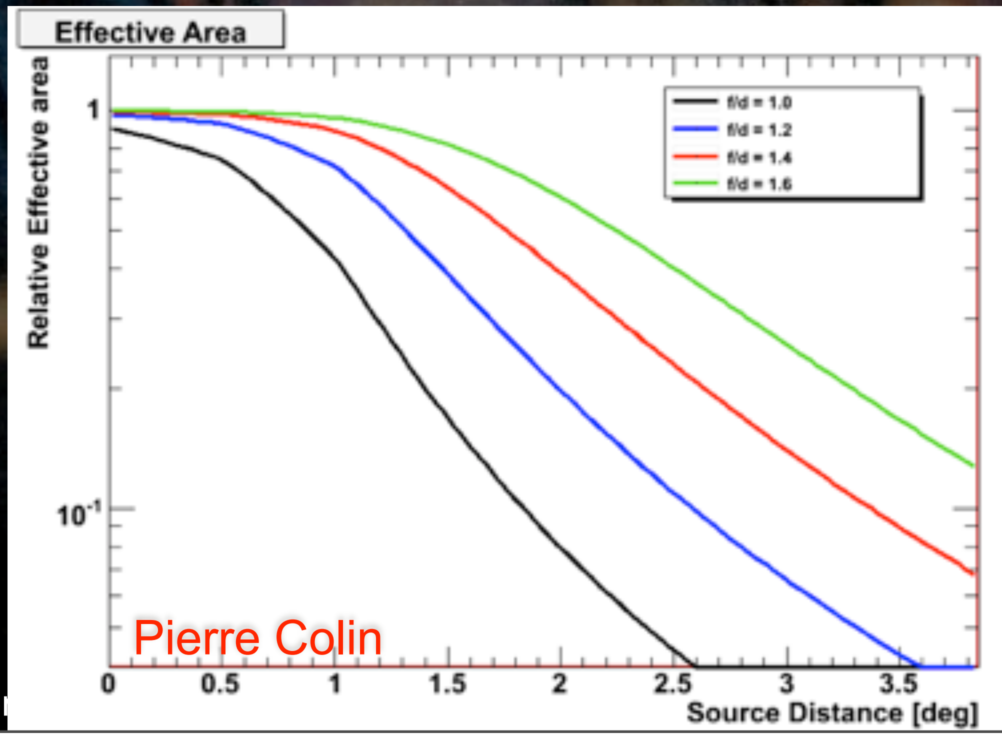




Pierres toy model F/D and FOV

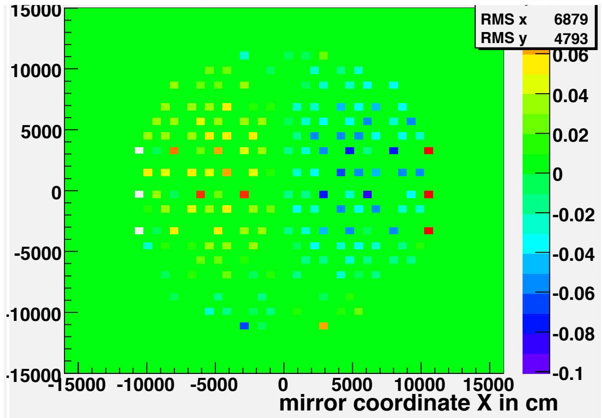
- Trigger efficiency decreases off angle due to the degradation of optical PSF
- It increases with F/D due to improvement in optical PSF



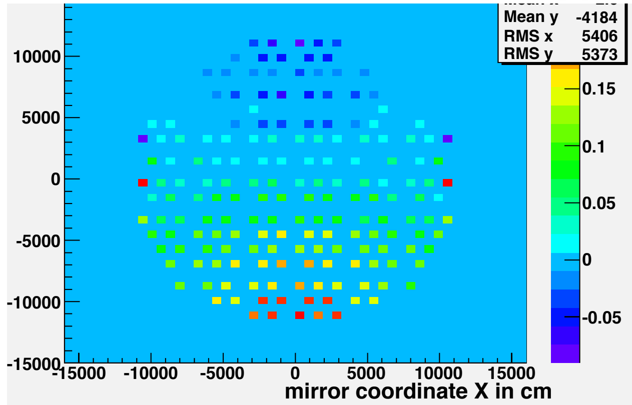


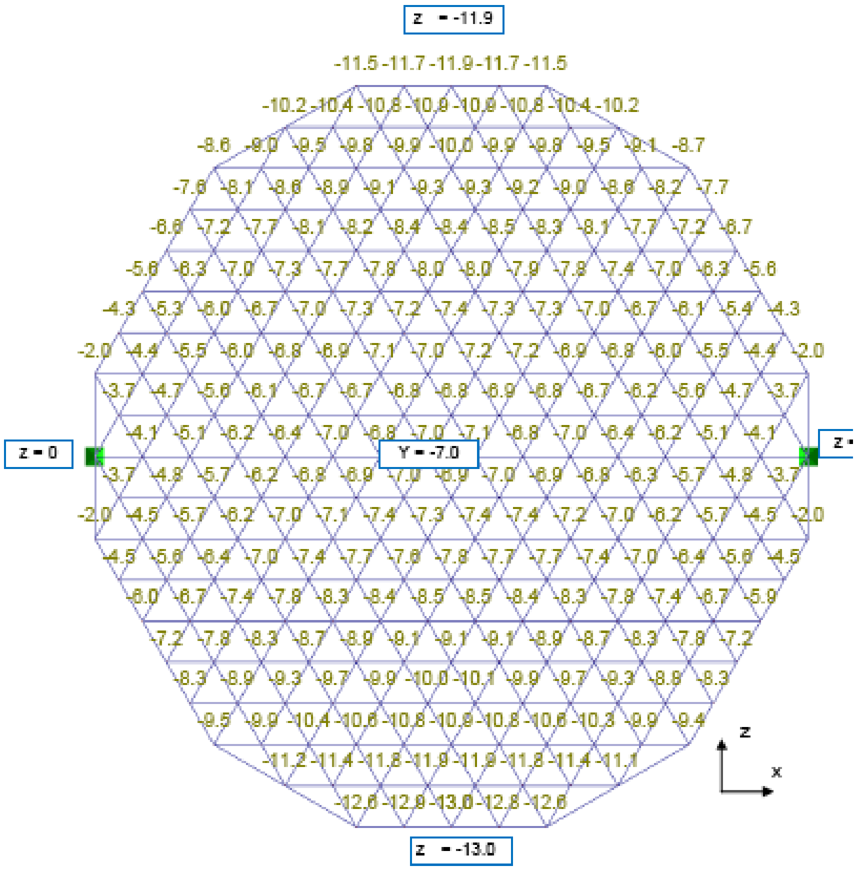
Self weight dish deformation and mirror misalinment

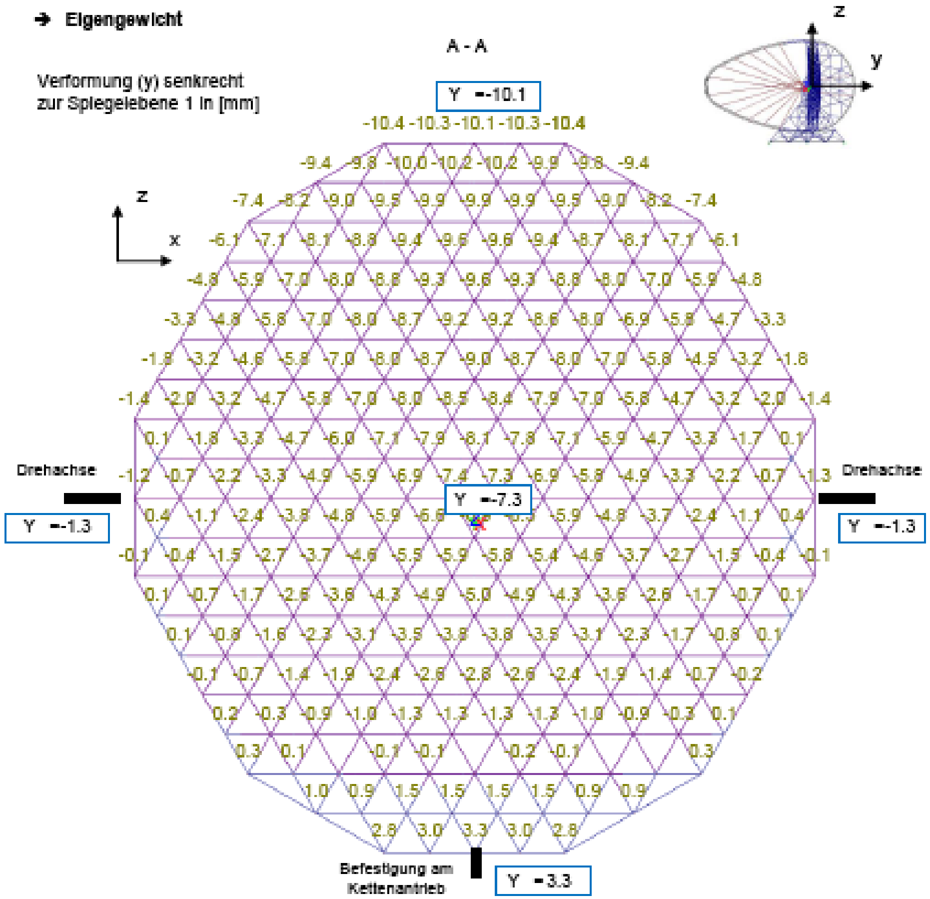
Misalingment in X (deg)



Misalignment in Y (deg)

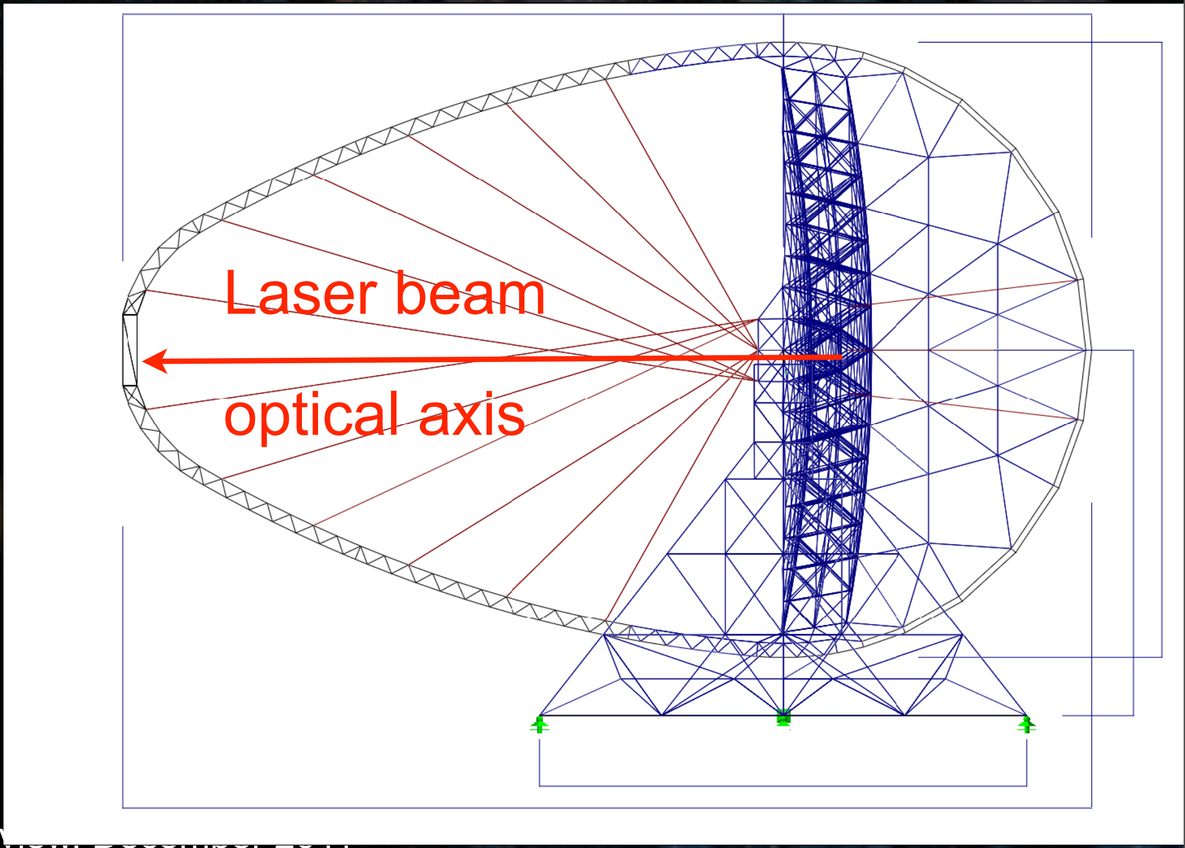


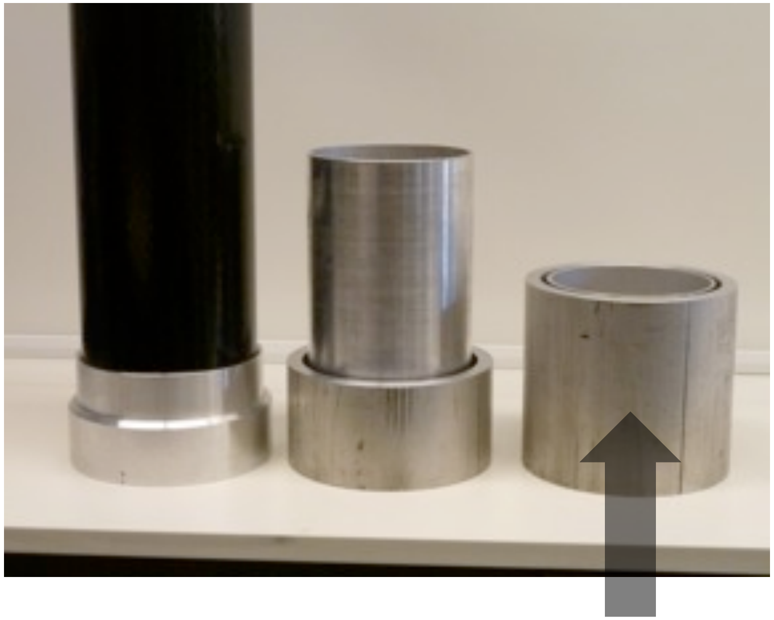


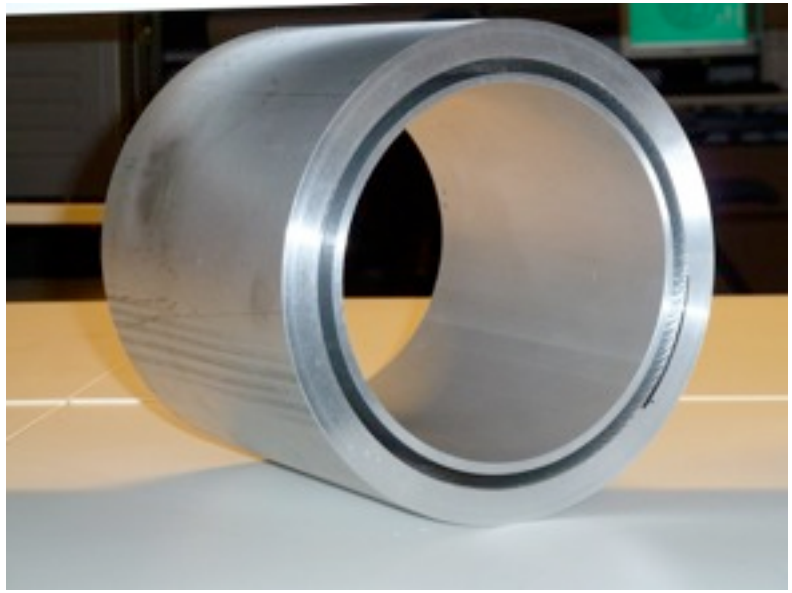


Need to define the optical axis

- Choose one point in the dish (which is rather stable) and mount a IR-laser in that point
- Define laser beam as optical axis
- Use this reference for the AMC adjustment
- suggest 2 lasers for cross check
- mount a precision inclinometer to the laser to measure azimuth angle

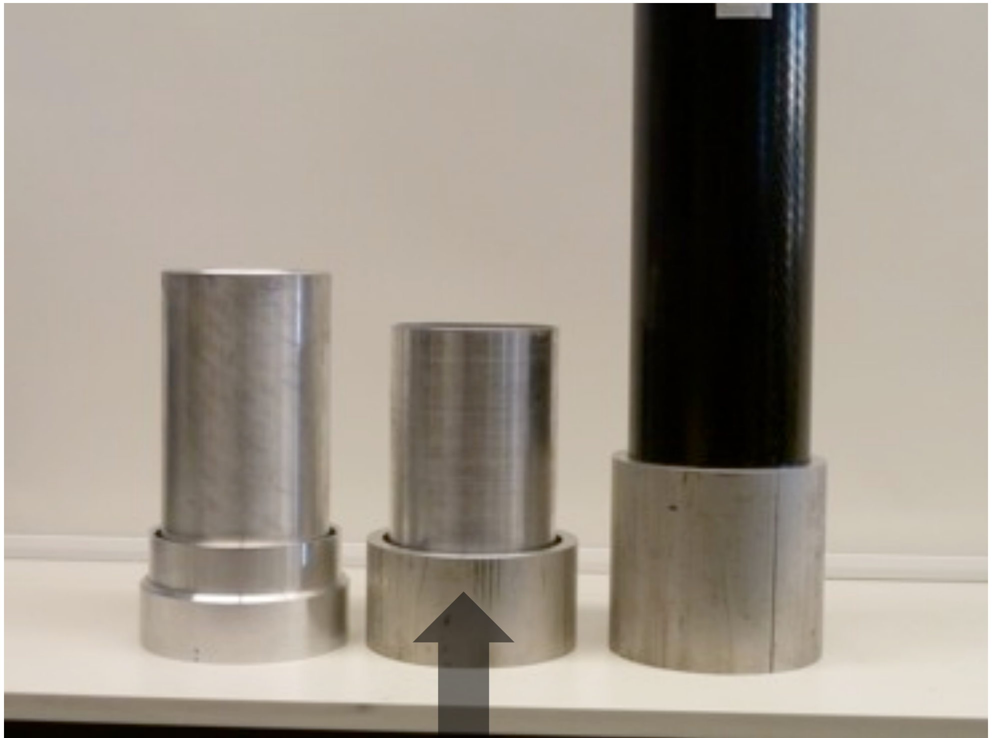


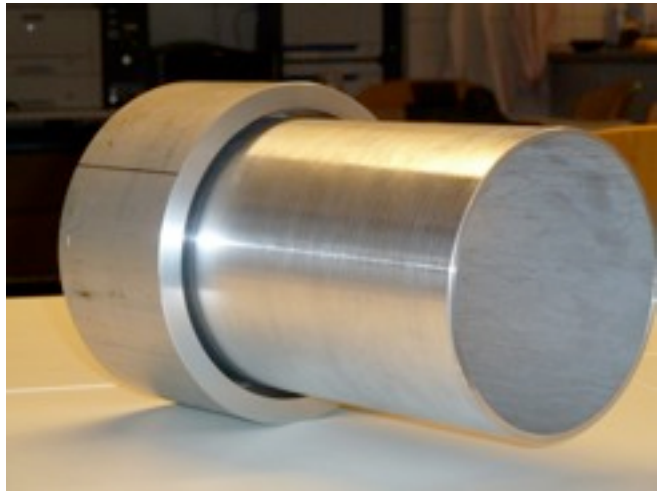


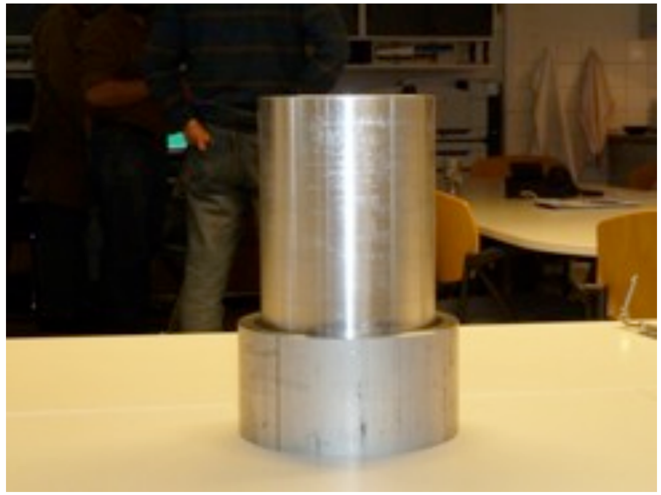


Flange 1

- depth of clearance groove: 100 mm
- special tool necessary (expensive)
- poor precision (depends on stability of tool)

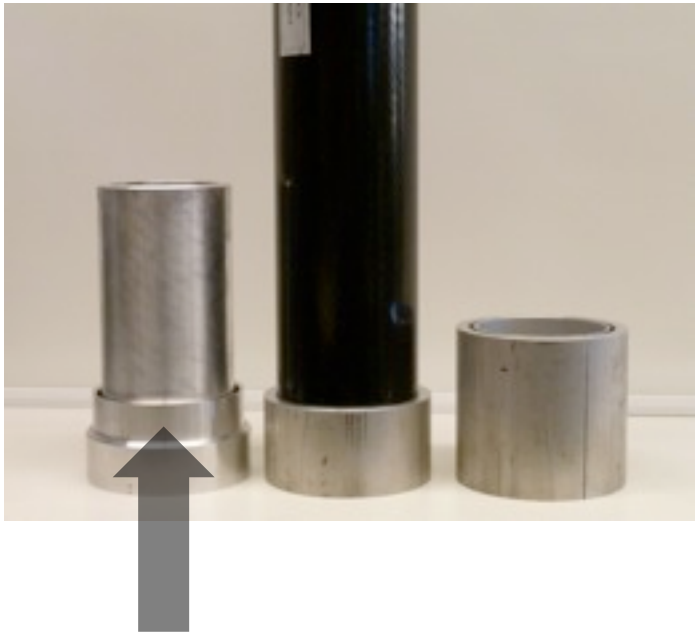


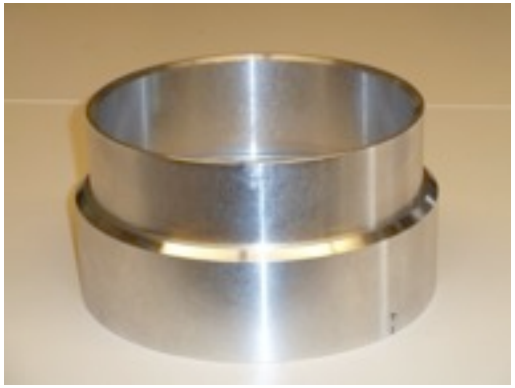




Flange 2

- depth of clearance groove: 50 mm
- difficult to produce
- special tool necessary (similar to flange 1)





Flange 3

- divided into two parts (connected by thread)
- easy and cheap production
- no special tools necessary



Additional test tubes from Epsilon at hand

- diameter/wall thickness ∅241/5.0 and ∅333/6.5
- length 1 m, 4.8 m (∅241/5.0) and 4.5 m (∅333/6.5)