Report from

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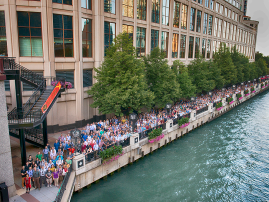
High Energy Physics Seminar

October 14, 2016

ICHEP 2016 has been like a wave

1,430 participants from 51 countries
~600 parallel talks
~500 poster presentations
40 1' elevator speeches
64 parallel session conveners from all continents (50% female)



16 Parallel Sessions

- Higgs Physics
- Neutrino Physics
- Beyond the Standard Model
- Top Quark and Electroweak Physics
- Quark and Lepton Flavor Physics
- Strong Interactions and Hadron Physics
- Heavy Ions
- Astro-particle Physics and Cosmology
- Dark Matter Detection
- Formal Theory Developments
- Accelerator: Physics, Performance, R&D and Future Accelerator Facilities
- Detector: R&D and Performance
- Computing and Data Handling
- Education and Outreach
- Technology Applications and Industrial Opportunities
- Diversity and Inclusion

with up to 9 sessions running in parallel

This report is based on personal (biased) selection of subjects...

16 Parallel Sessions

Not covered:
¤ Neutrino Physics
¤ LHC results
»» dedicated seminars

Higgs Physics
Neutrino Physics
Beyond the Standard Model
Top Quark and Electroweak Physics
Quark and Lepton Flavor Physics
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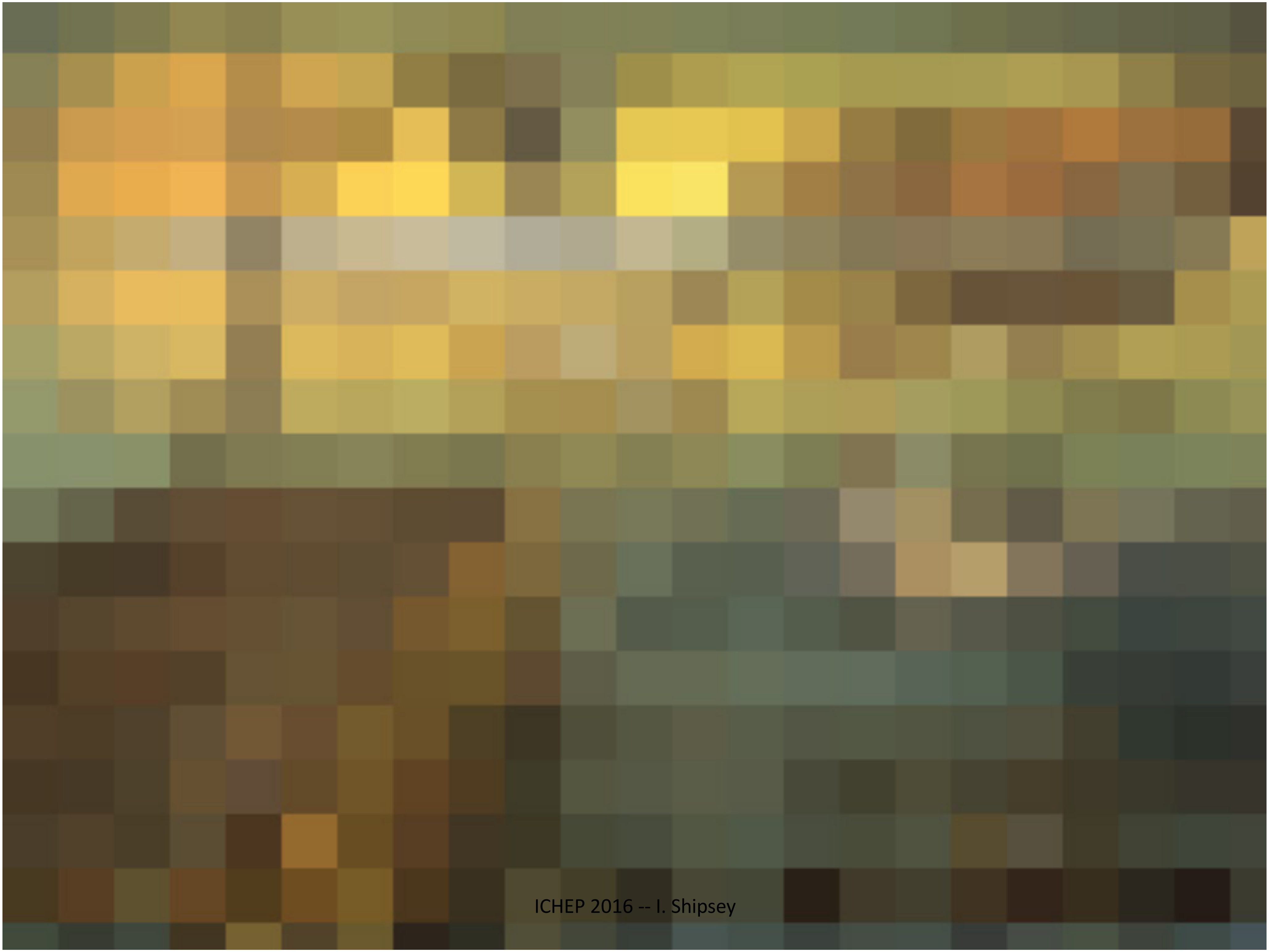
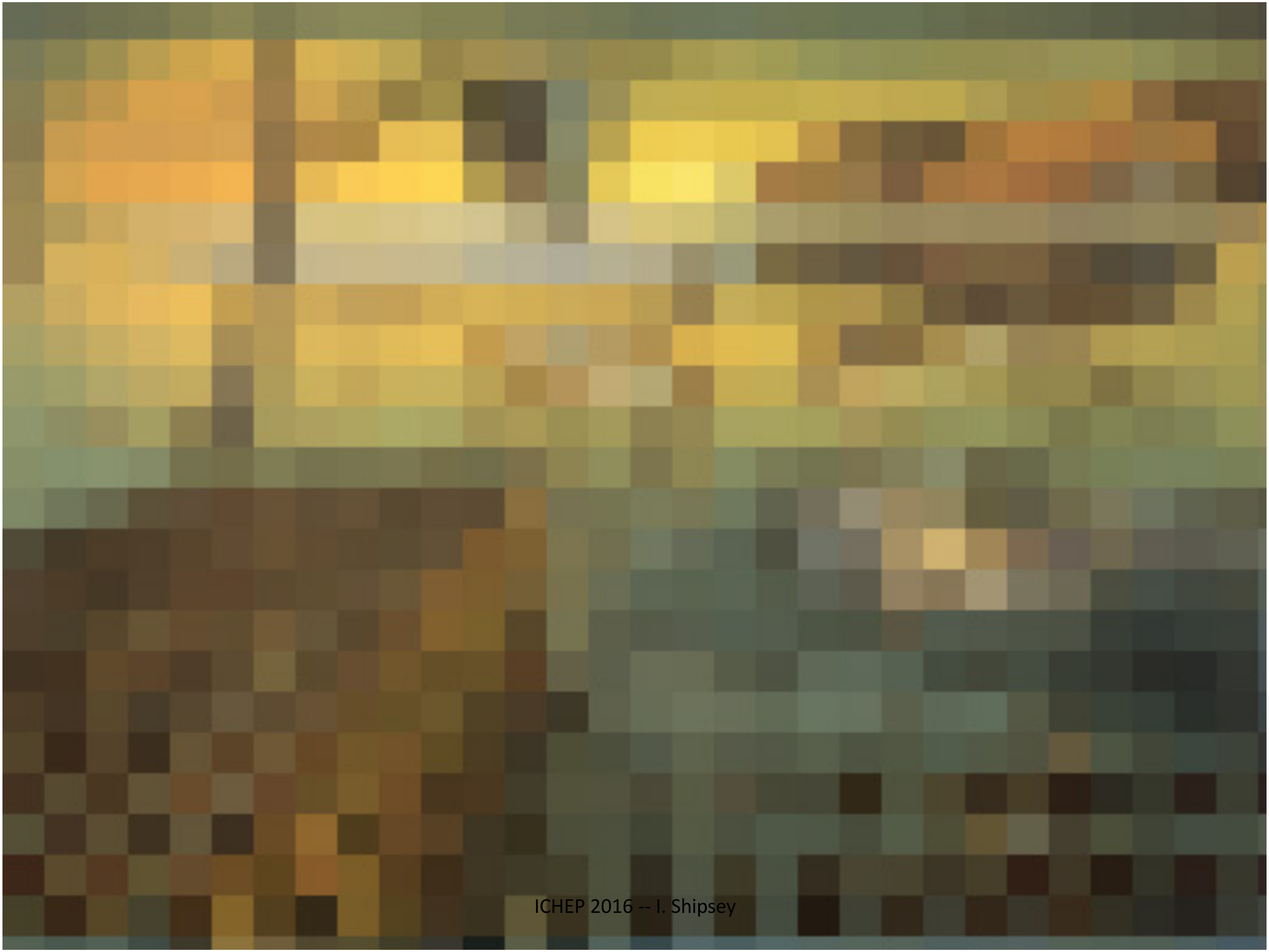
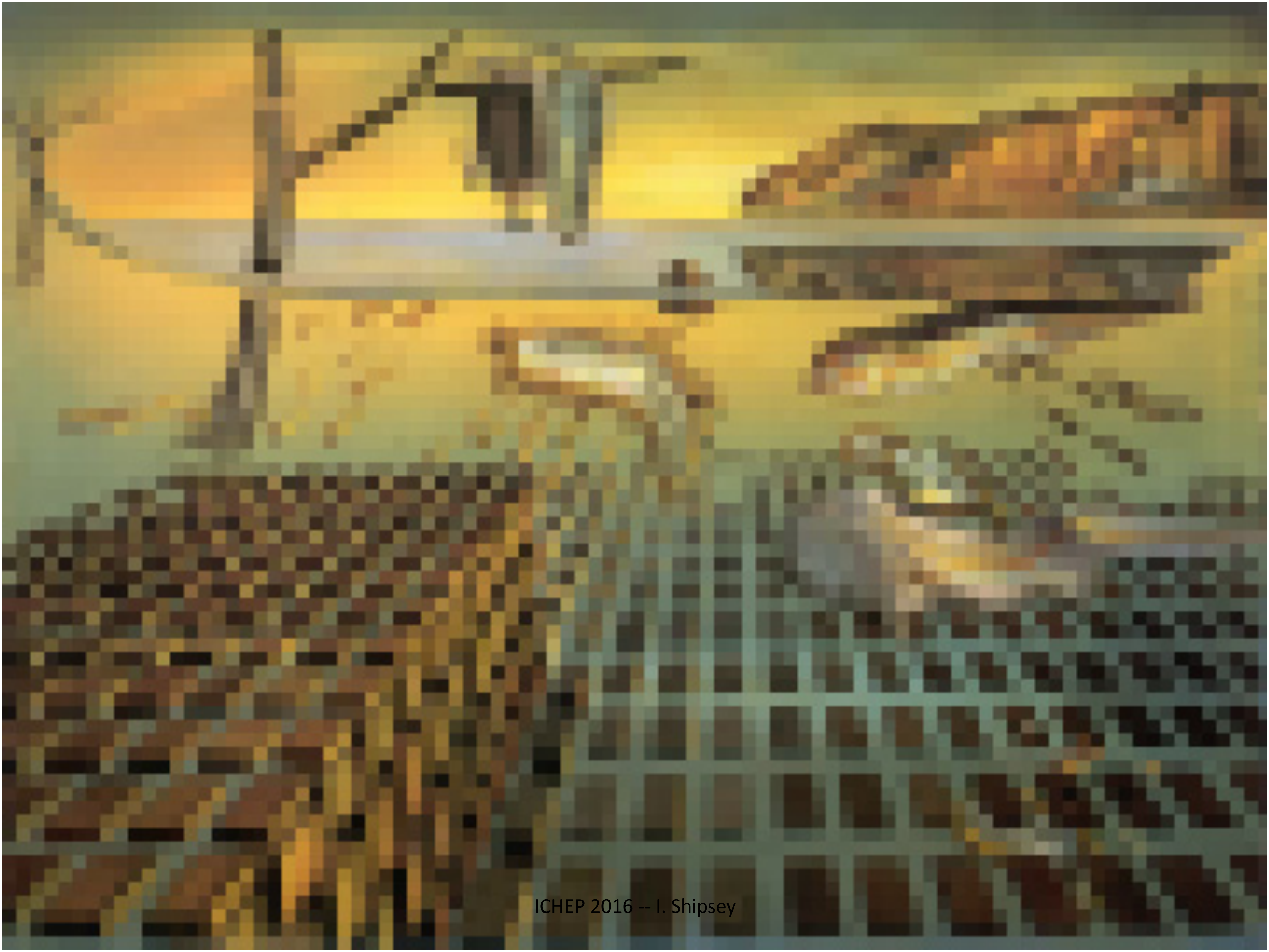
Before 2012…

we knew what we were looking for...

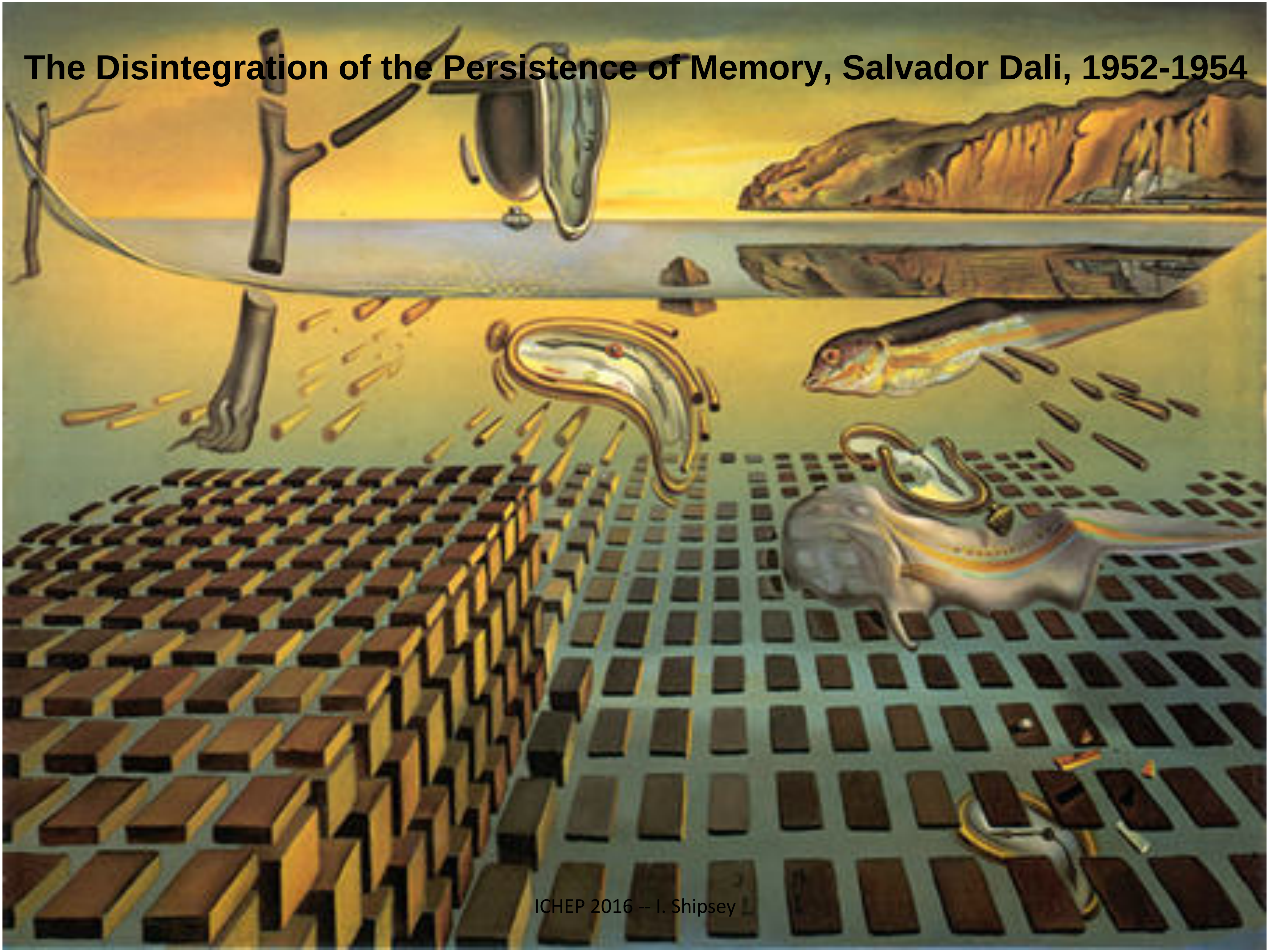
After 2012...



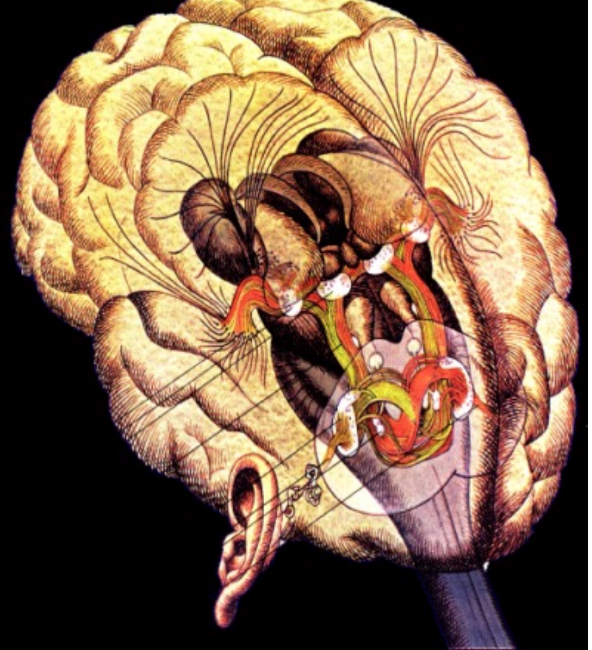




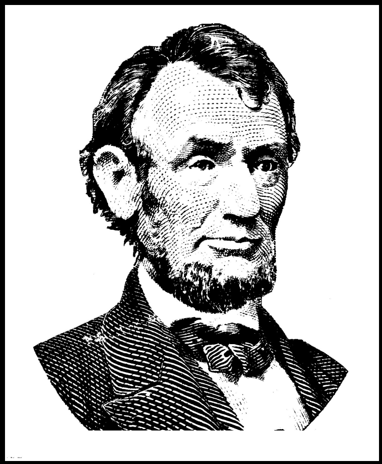
The Disintegration of the Persistence of Memory, Salvador Dali, 1952-1954



Perception & understanding

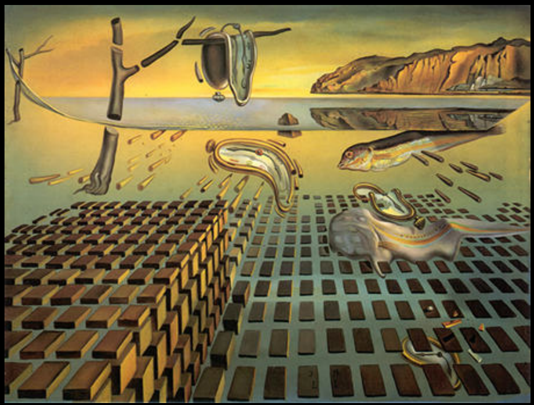


With a roadmap (theory)



(W,t,H) a little
data goes a long way
(top-down dominates)

w/o a roadmap (data driven)

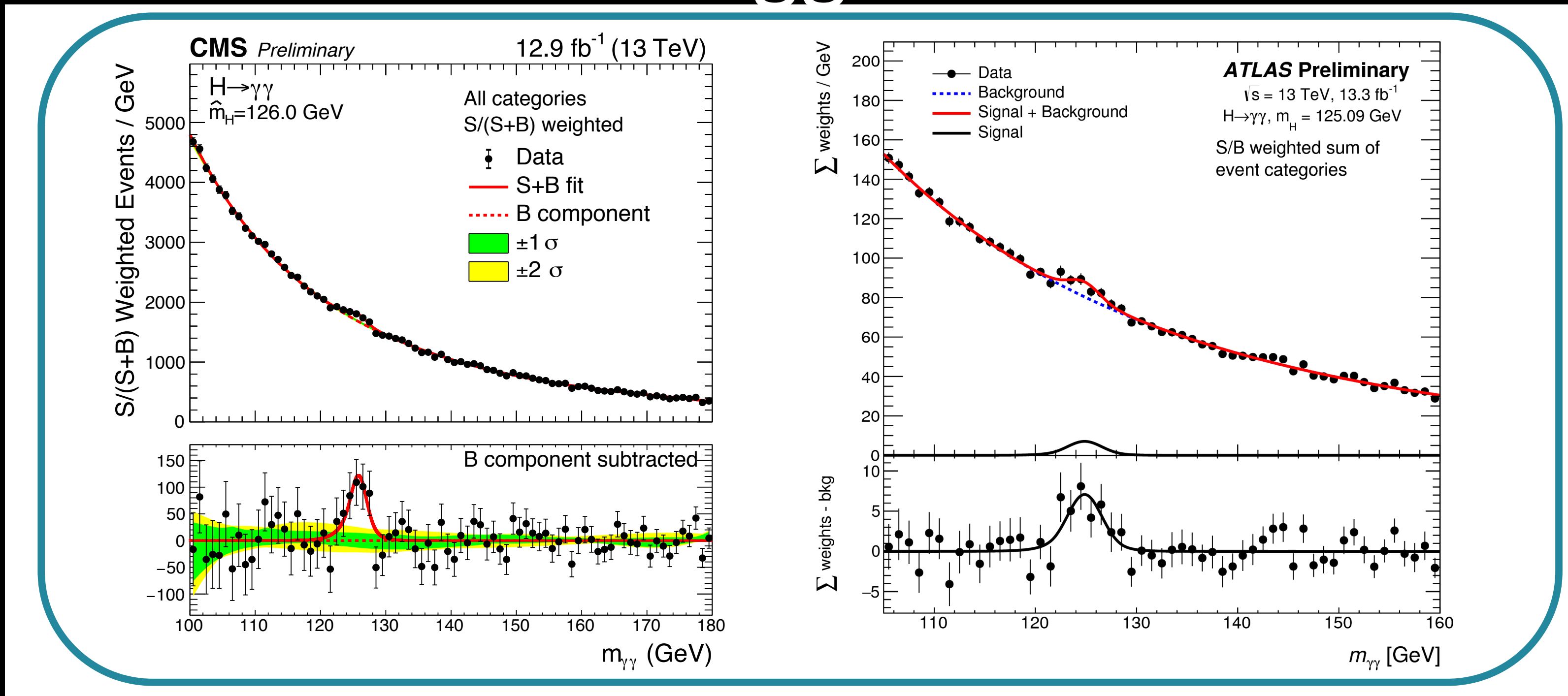


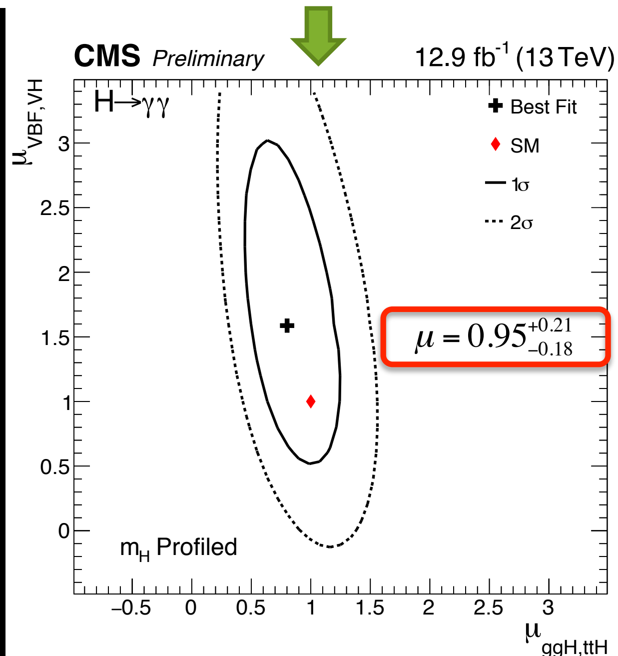
New physics need lots
of data
(bottom up dominates)

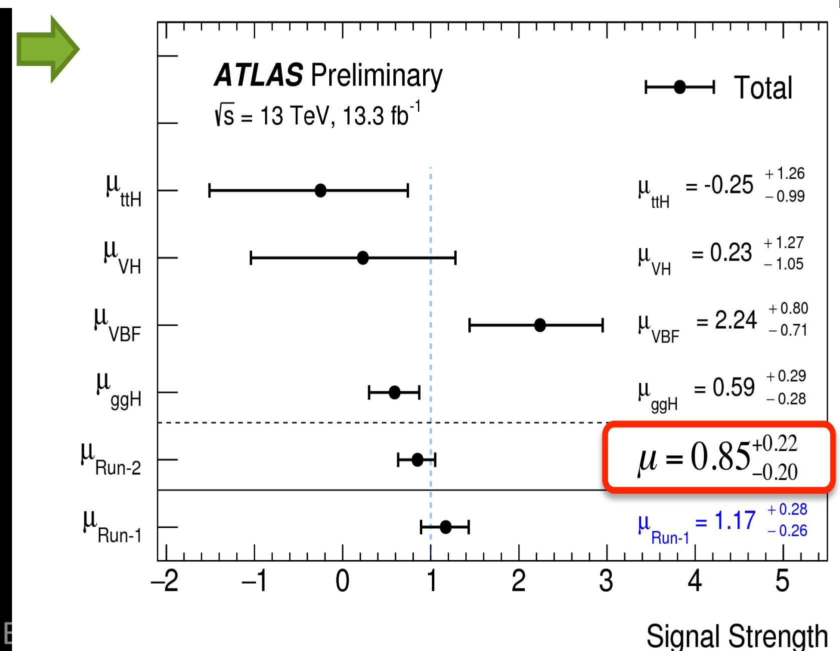
We have a long list of possible BSM physics, but we don't know **where they are.**

After the discovery of the Higgs boson, we don't have anymore a convincing argument to pinpoint the next scale.

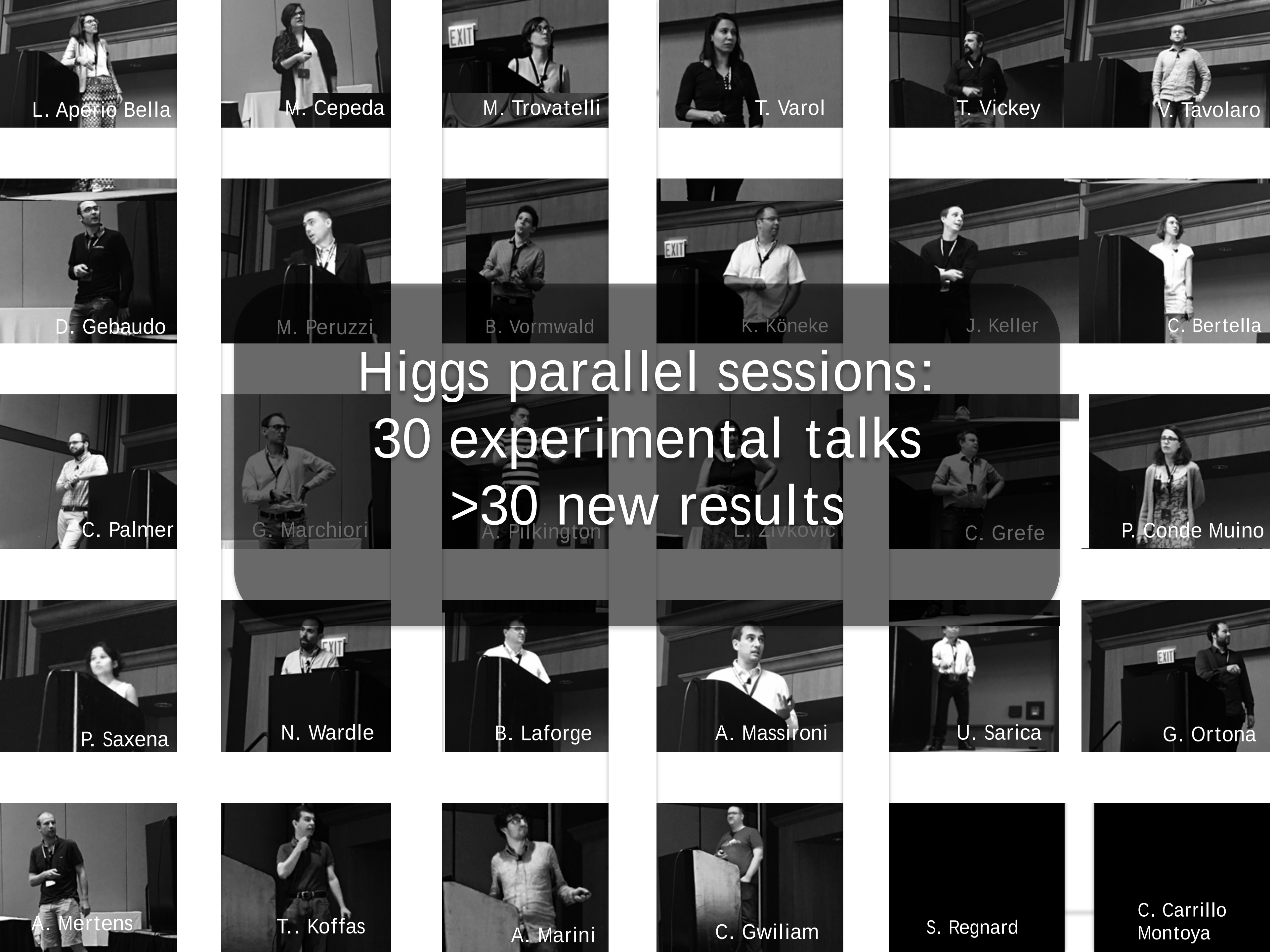
Higgs Run 2



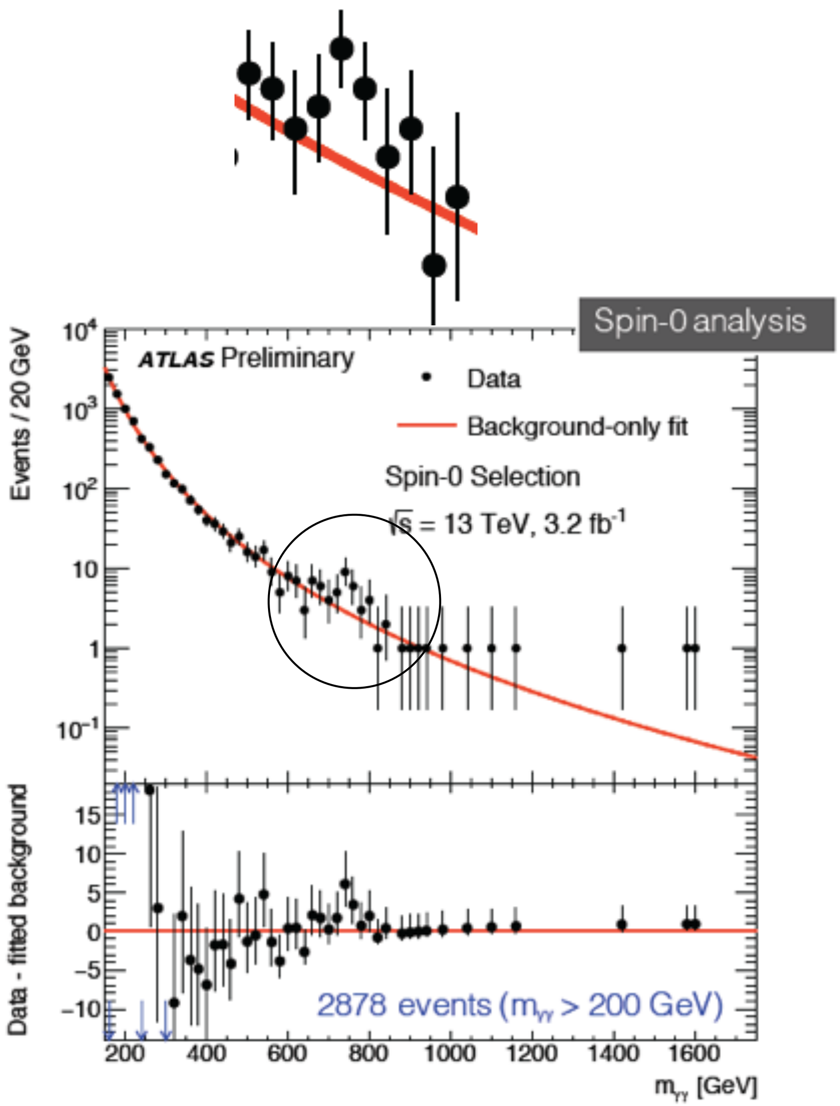


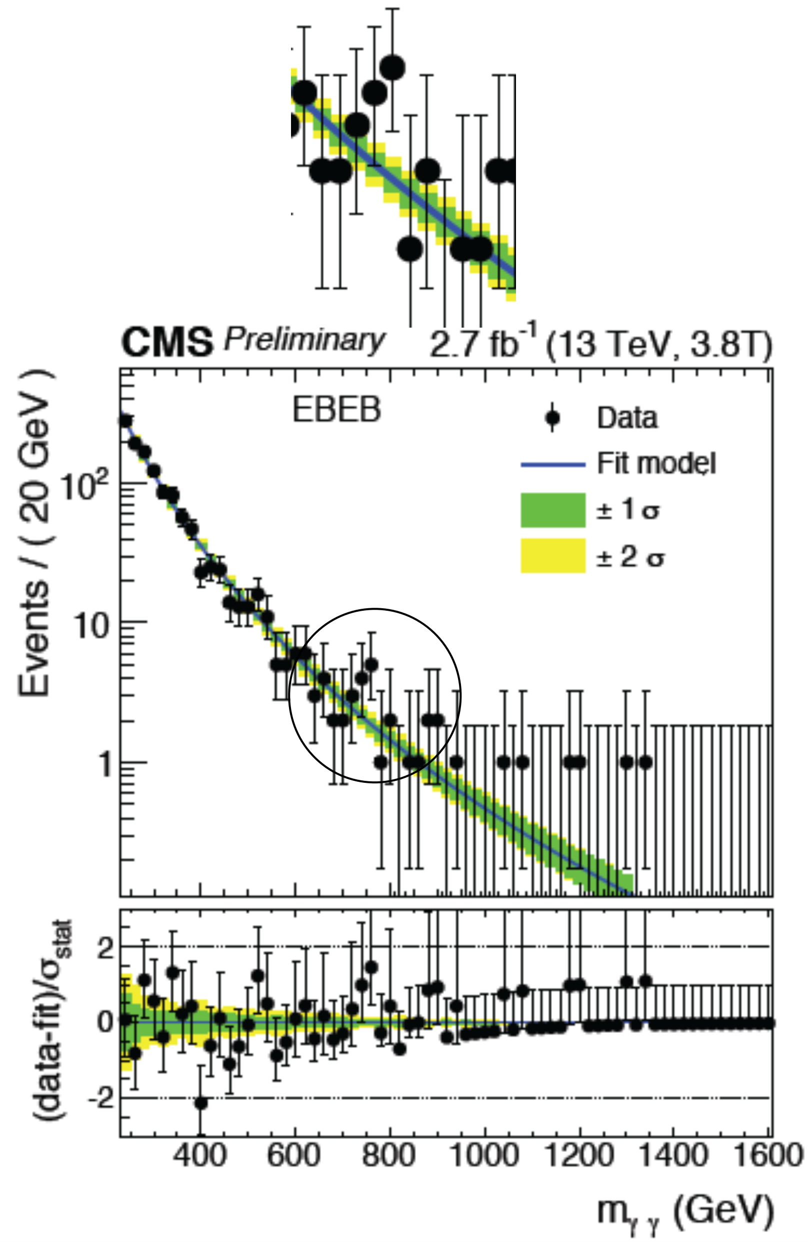


ICHE


Higgs parallel sessions:
30 experimental talks
>30 new results
L. Aperio Bella
M. Cepeda
M. Trovatelli
T. Varol
T. Vickey
V. Tavolaro
D. Gebaudo
M. Peruzzi
B. Vormwald
K. Köneke
J. Keller
C. Bertella
C. Palmer
G. Marchiori
A. Pilkington
L. Zivkovic
C. Grefe
P. Conde Muino
P. Saxena
N. Wardle
B. Laforge
A. Massironi
U. Sarica
G. Ortona
A. Mertens
T.. Koffas
A. Marini
C. Gwiliam
S. Regnard
C. Carrillo Montoya

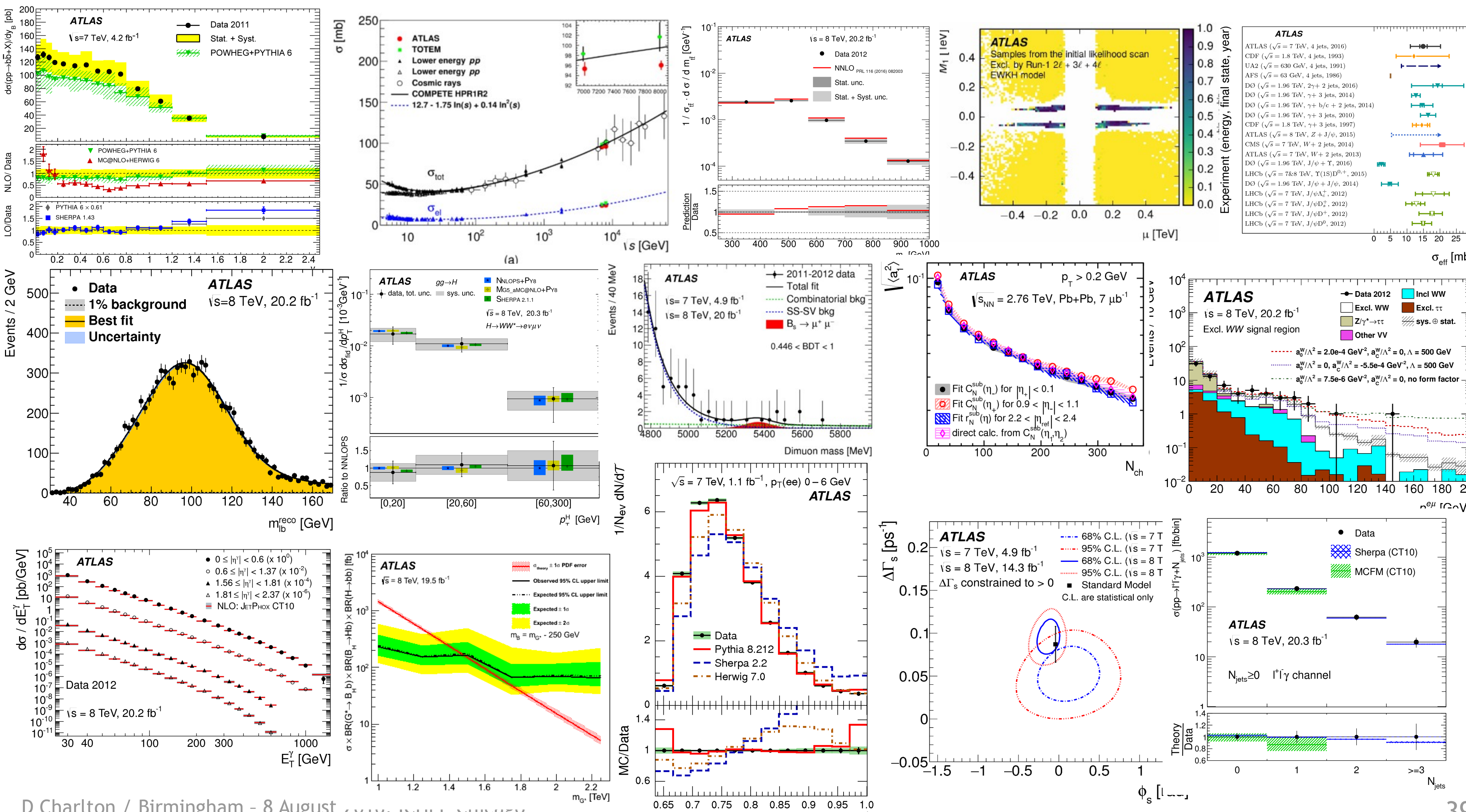
ATLAS and CMS searches for di-photon resonances





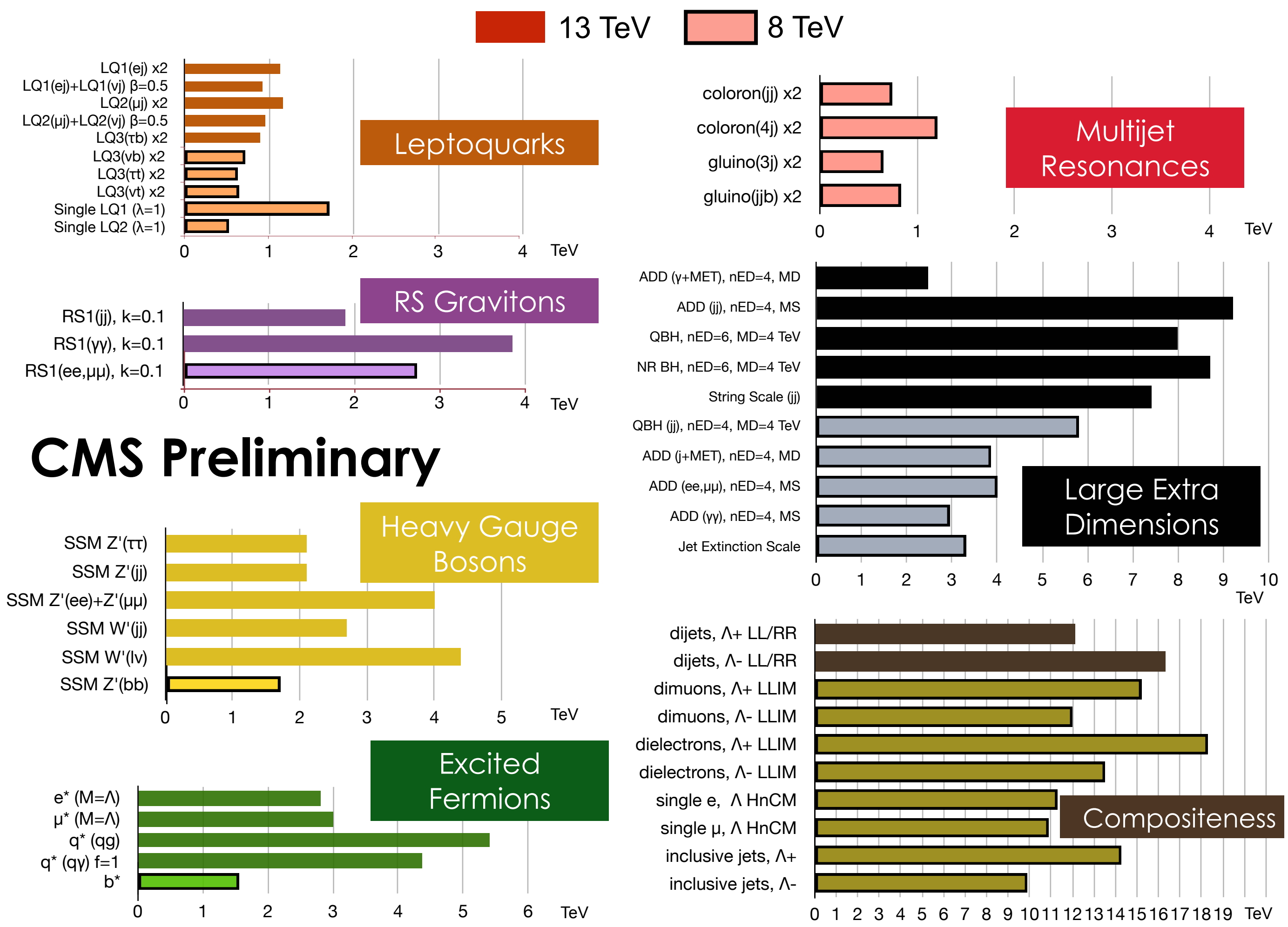
A Small Selection

In total **64** new results prepared for ICHEP, **56** using 13 TeV data and **45** with 2015+2016
ATLAS has now submitted **40** papers with Run-2 data (**576** total with collision data)
The flood-tide of Run-1 results has not yet ebbed



Summary of Exotica limits

Excluding Dark Matter and Long Lived particles searches



Summary

- LHC experiments conducting BSM searches in broad and complementary signatures
- Known excesses (Diboson in Run1 and Diphoton in 2015) **not** confirmed using 2016 data
- No new significant excesses observed. Set new frontier scale:
  - Contact Interaction **energy**: 25.2 TeV
  - ADD BH **mass**: 9.55 TeV
  - W' **mass**: 4.74 TeV
  - Dark photon **lifetime**: 2.5~100 mm (dark photon 400 MeV)
  - **Magnetic charge**: $|g|>1.5g_D$ (up to 4 g_D)
- More data to come - Stay tuned!

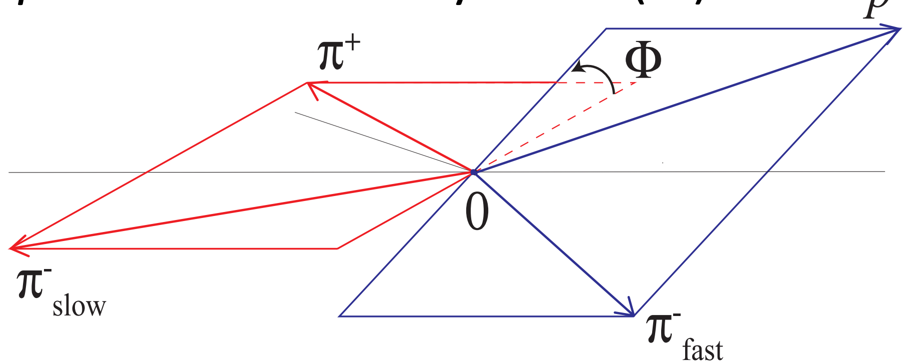
Concluding remarks

- The SM is a stubborn animal, indeed!
- In the current unclear state with perspectives in fundamental physics, it is necessary to have a programme as diversified as possible

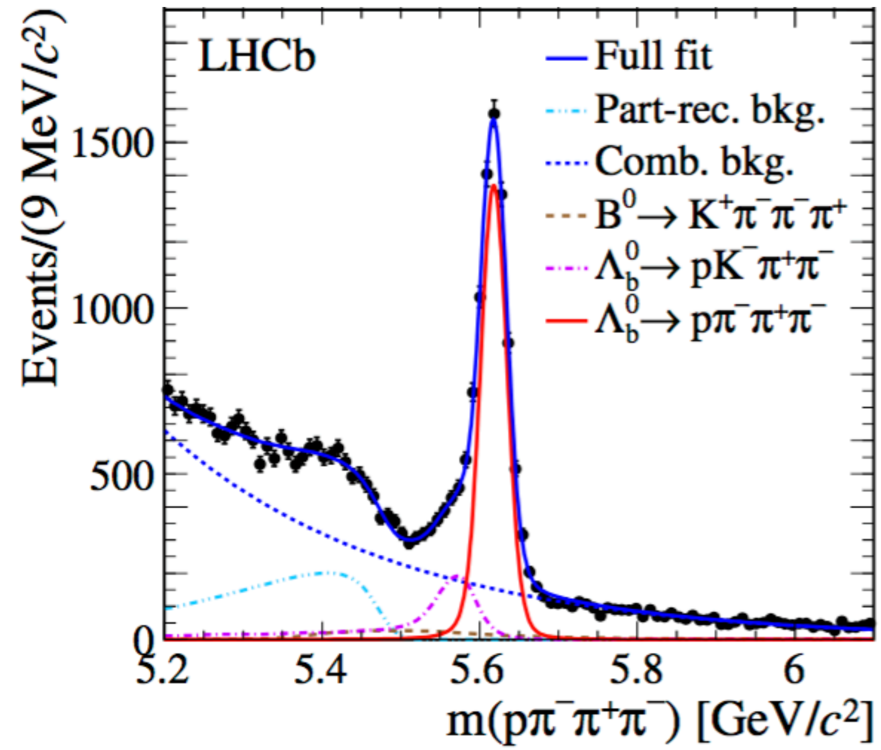
- In the unfortunate event that no direct evidence of NP pops out of the LHC, flavour physics can play a key role to indicate the way for future developments of elementary particle physics
- If instead, as we all hope, new particles will be detected in direct searches, flavour physics will be a crucial ingredient to understand the structure of what lies beyond the SM

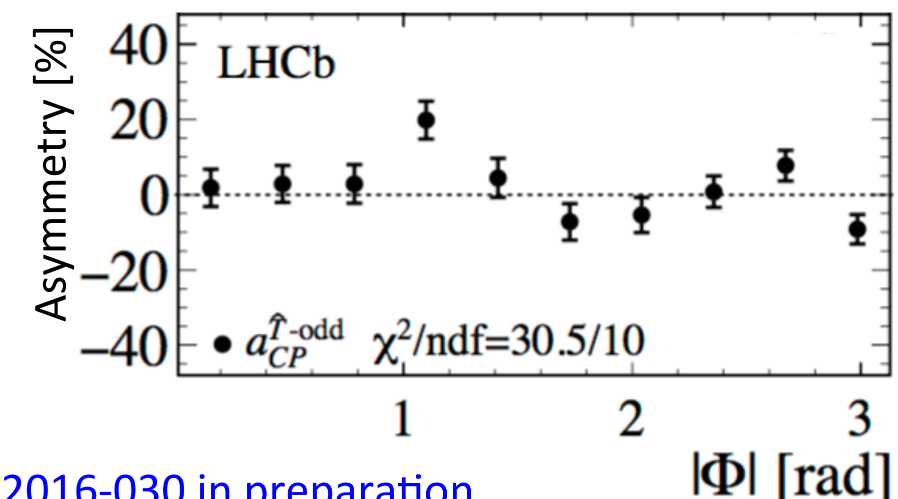
First evidence for *CP* violation in $\Lambda_b \to p\pi^-\pi^+\pi^-$ decays from LHCb

- *CP* violation has never been observed in the decays of any baryonic particle
- $\Lambda_b \to p\pi^-\pi^+\pi^-$ decays used to search for *CP*-violating asymmetries in triple products of final-state particle momenta
  - Local *CP*-violating effects studied as a function of the the relative orientation between the decay planes formed by the $p\pi^-$ and the $\pi^+\pi^-$ systems (Φ)



- An evidence for *CP* violation at the 3.3σ level is found
- This represents the first evidence of *CP* violation in the baryon sector





LHCb-PAPER-2016-030 in preparation

N. Dash

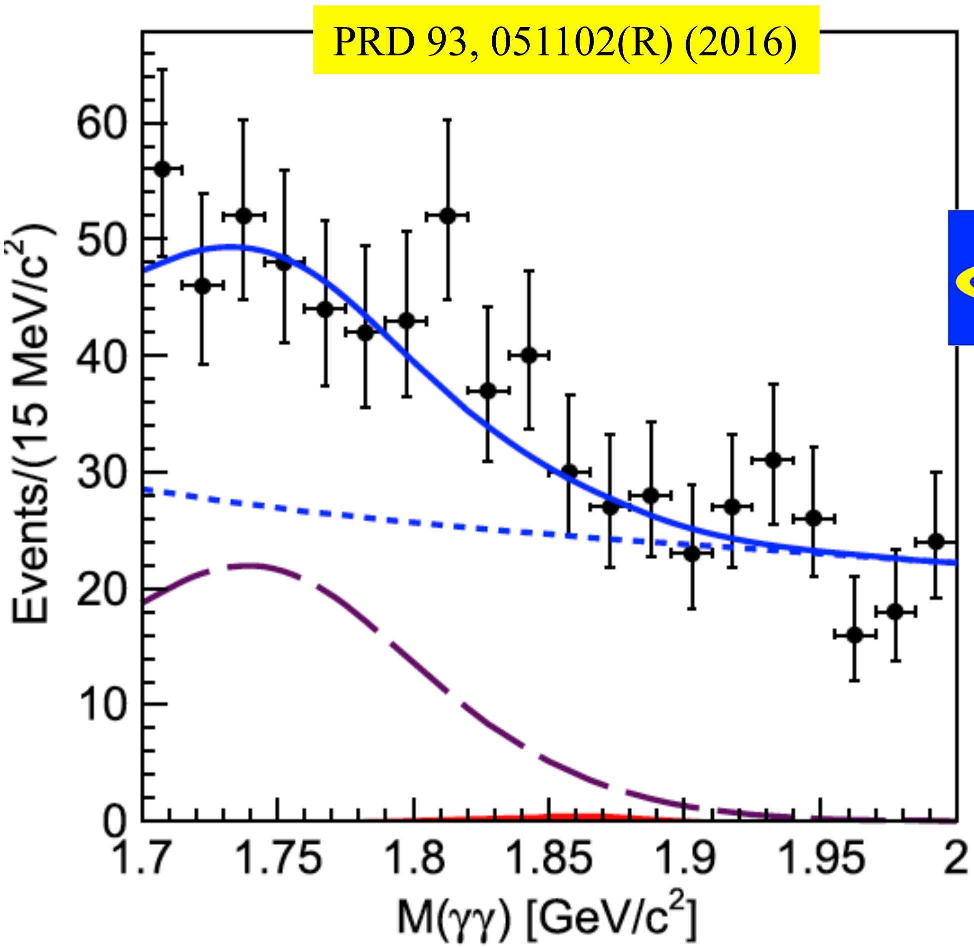
A poster-child search

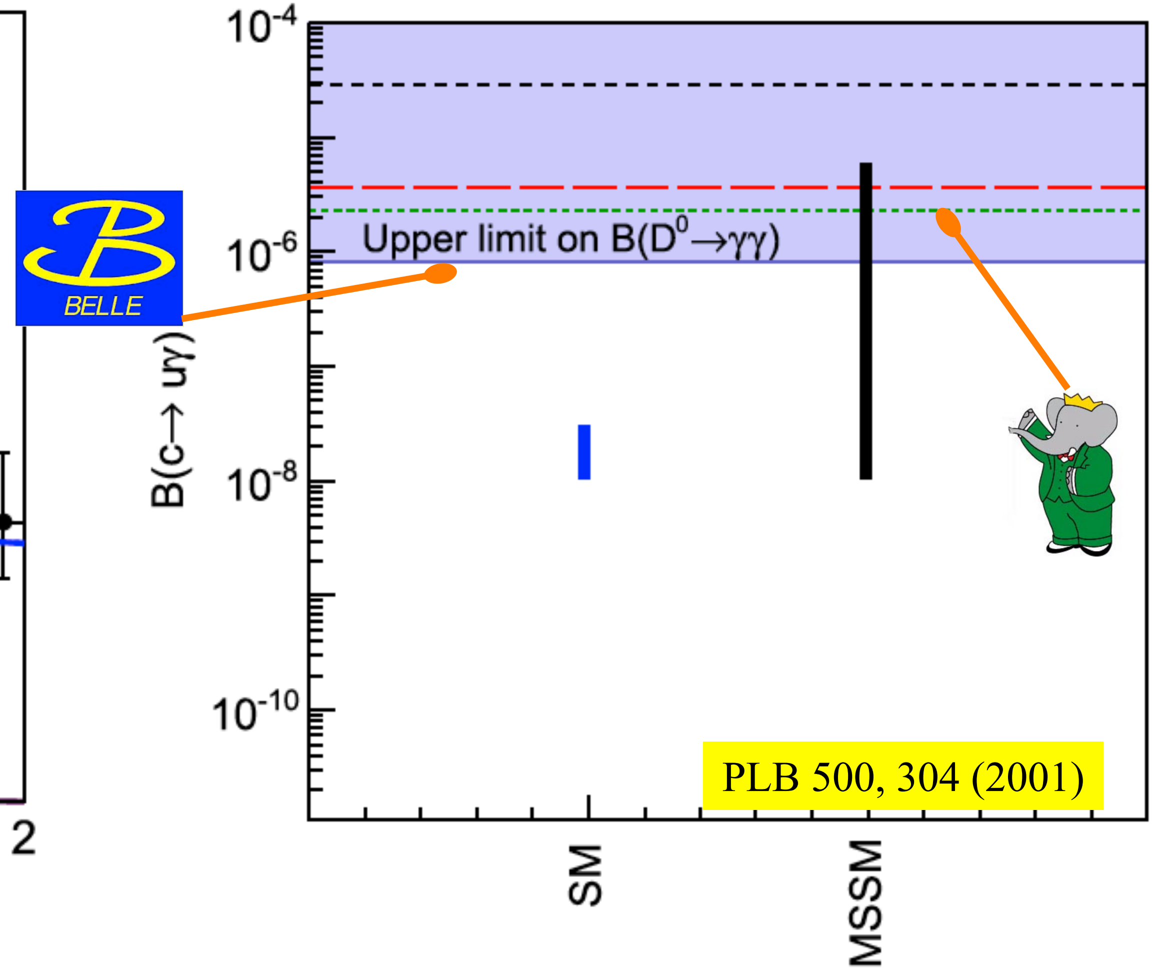
$D^0 \to \gamma\gamma$

- Mediated by FCNC transition with small short-distance contribution
- Sizable long-distance contribution within the SM

PRD 64, 074008 (2001)

PRD 66, 014009 (2002)





- Set world's best limit at 8.5×10^{-7} in absence of a signal
- Helps restrict new physics, viz. MSSM parameter space

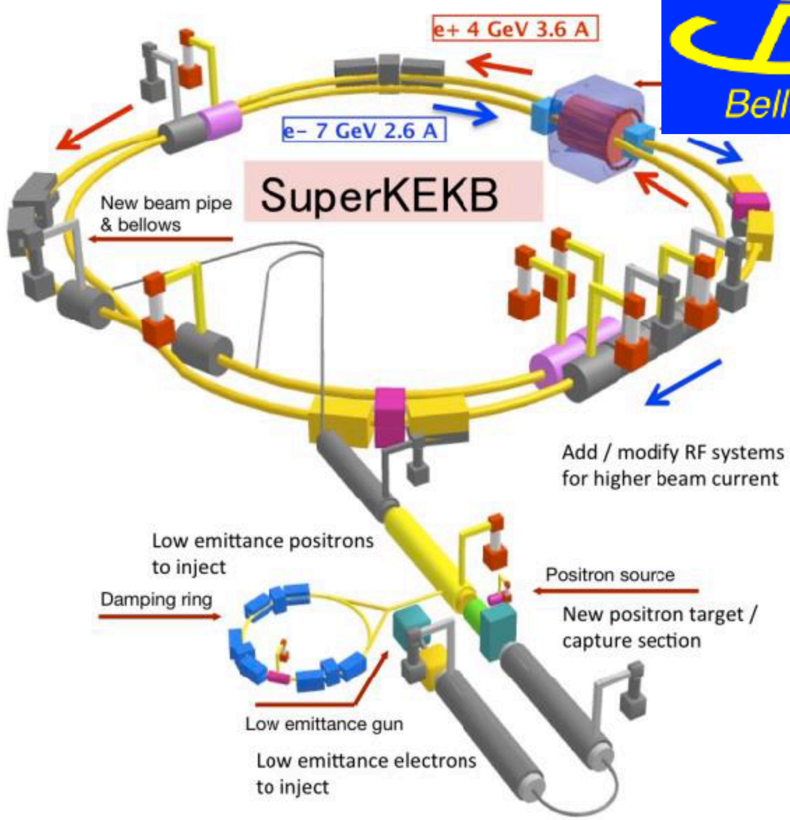
Epilogue

A. Contu

- Doing exceedingly well and prospect looks even brighter

Mode	CP asymmetry Run II	Upgrade
$D^+ \to \pi^+\mu^+\mu^-$	0.6%(30K events)	0.2%(300K events)
$D^0 \to \pi^+\pi^-\mu^+\mu^-$	3%(1500 events)	1%(15K events)
$D^0 \to K^-\pi^+\mu^+\mu^-$	1%(10K events)	0.3%(100K events)
$D^0 \to K^+\pi^-\mu^+\mu^-$	40%(30 events)	12%(300 events)
$D^0 \to K^+K^-\mu^+\mu^-$	11%(150 events)	4%(1500 events)

B. Fulsom



- Will be soon in running and produce lots of interesting results in the charm sector, especially the decays involving neutral and neutrino

- BESIII plans to run for 8-10 years and will continue to be productive

- Looking at distant future, possible super tau-charm factories at BINP, Russia and China (HIEPA) are exciting prospects

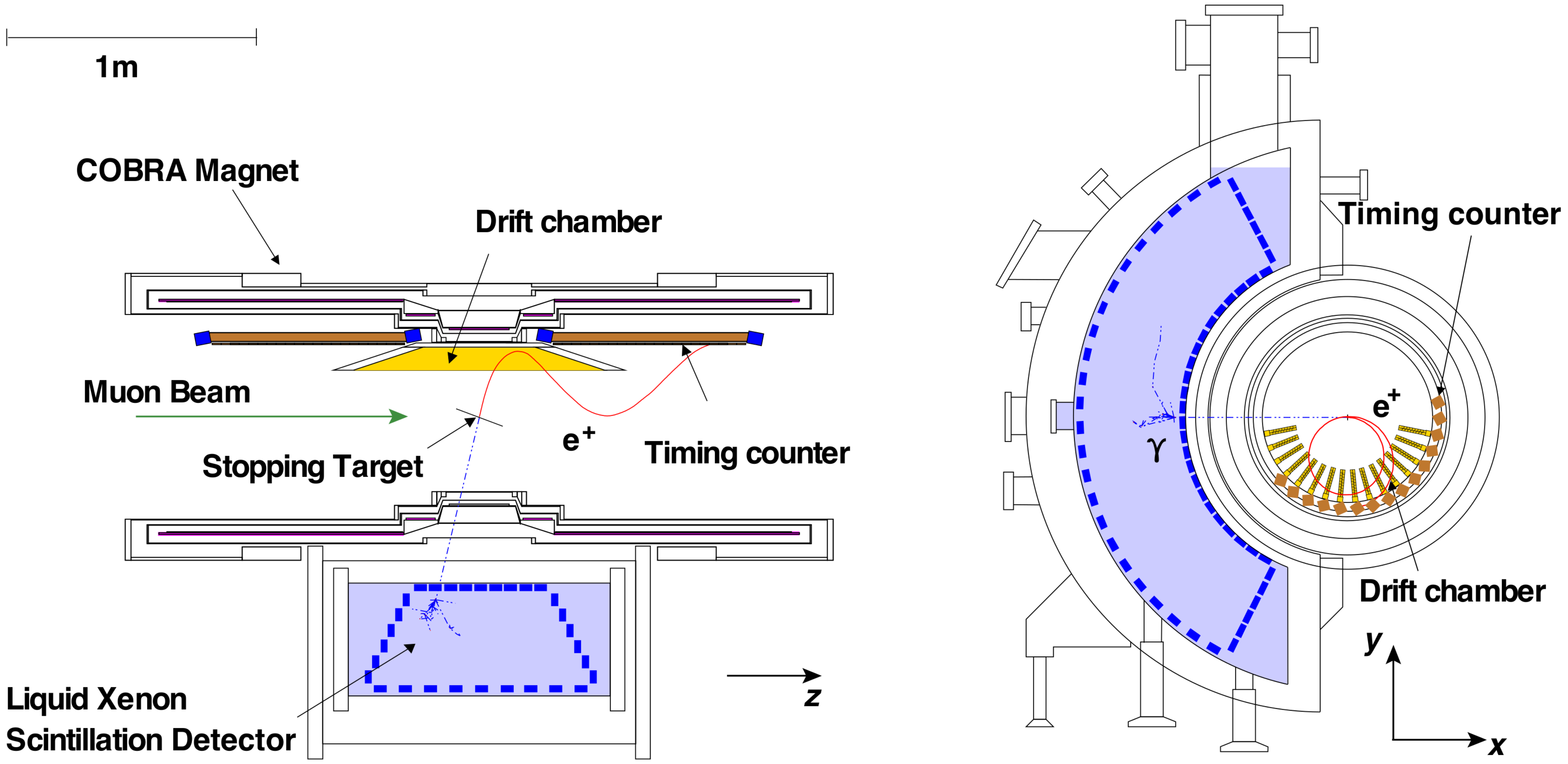
- On the strange sector, NA62 and KOTO will be the two major players

$\mu \to e\gamma$: MEG

- Searching for cLFV decay $\mu^+ \to e^+\gamma$
- Most intense DC μ^+ beam, 3×10^7 μ/sec @ PSI, Switzerland
- Detector
  - Photon : Largest LXe photon detector
  - Positron : gradient B-field, Ultra light drift chamber, high resolution e^+ timing counter
- Data taking in 2008-2013
- Previous result with 2009-2011 dataset
  - Br UL : 5.7×10^{-13} (90%CL)

PRL, 110 201801 (2013)

- Analysis of full data completed



Final result of MEG

No excess was found and the new UL was set

$$\mathcal{B}(\mu^+ \to e^+\gamma) < 4.2 \times 10^{-13} \text{ @ 90\% C.L.}$$

arXiv:1605.05081
ready for publication from EPJC

×30 more stringent than the previous experiment

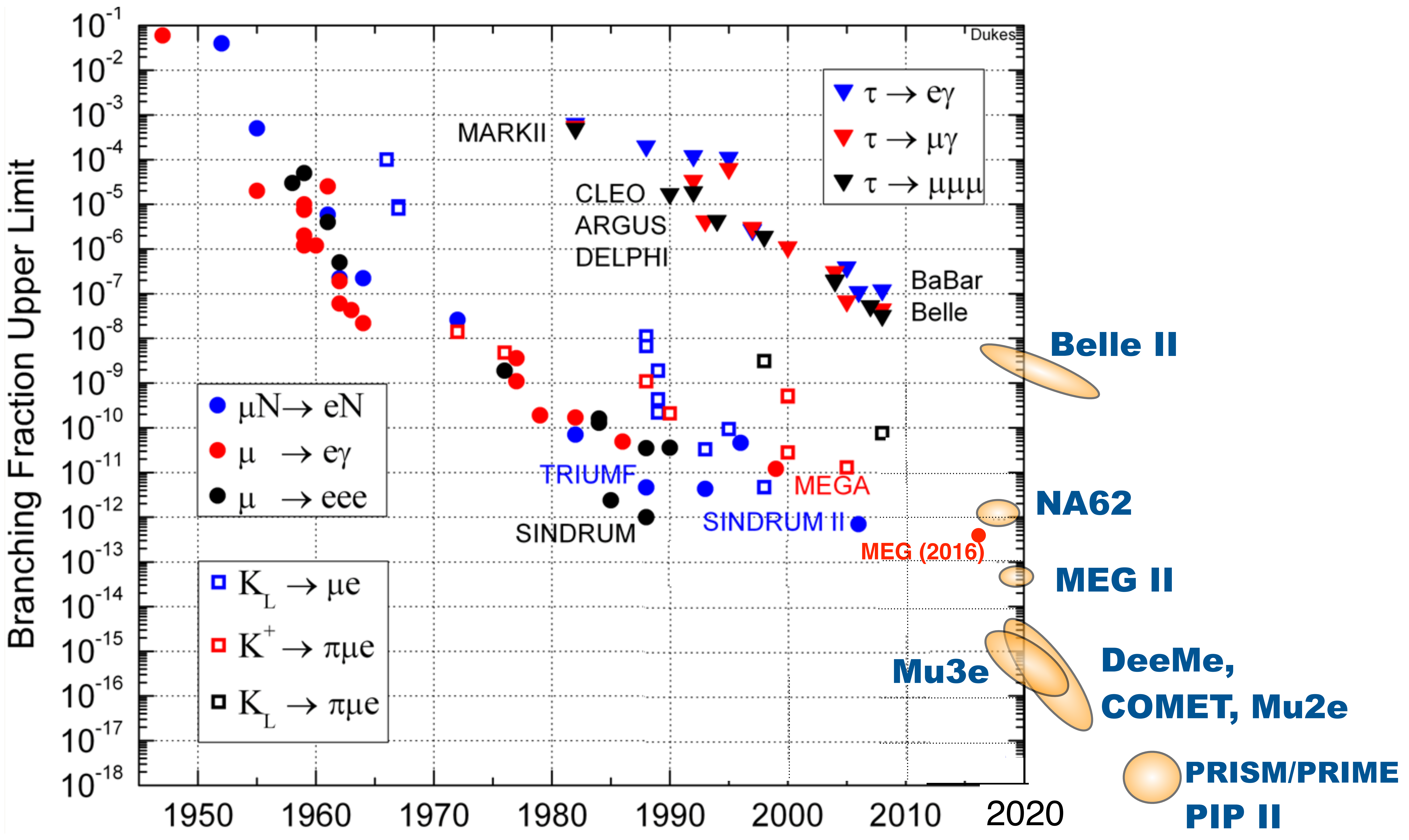
($\times 10^{-13}$)	2009-2011 data	2012-2013 data	All combined
Best Fit	-1.3	-5.5	-2.2
90% CL Upper limit	6.1	7.9	**4.2**
Sensitivity	8.0	8.2	**5.3**

Previous limit with 2009-2011 dataset : 5.7×10^{-13}

UL : Feldman-cousins with profile-likelihood ratio ordering

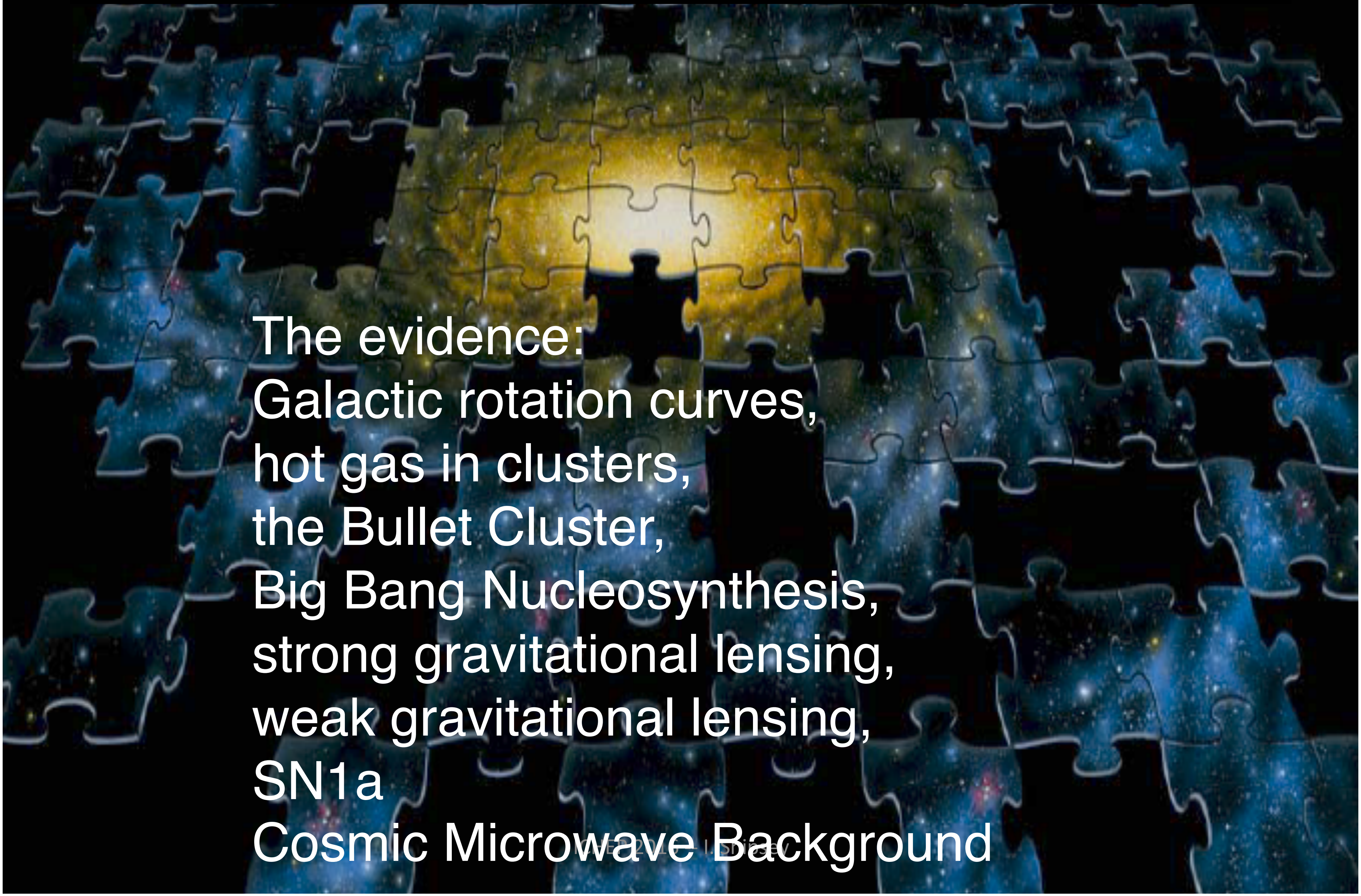
Systematic uncertainties
UL increase by
- 5% by target position/shape uncertainties
- <1% by other systematic uncertainties

Prospects



Branching Fraction Upper Limit
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
10^-10
10^-11
10^-12
10^-13
10^-14
10^-15
10^-16
10^-17
10^-18
1950
1960
1970
1980
1990
2000
2010
2020
Dukes
τ → eγ
τ → μγ
τ → μμμ
MARKII
CLEO
ARGUS
DELPHI
BaBar
Belle
μN→ eN
μ → eγ
μ → eee
K_L → μe
K^+ → πμe
K_L → πμe
TRIUMF
MEGA
SINDRUM
SINDRUM II
MEG (2016)
Belle II
NA62
MEG II
Mu3e
DeeMe,
COMET, Mu2e
PRISM/PRIME
PIP II

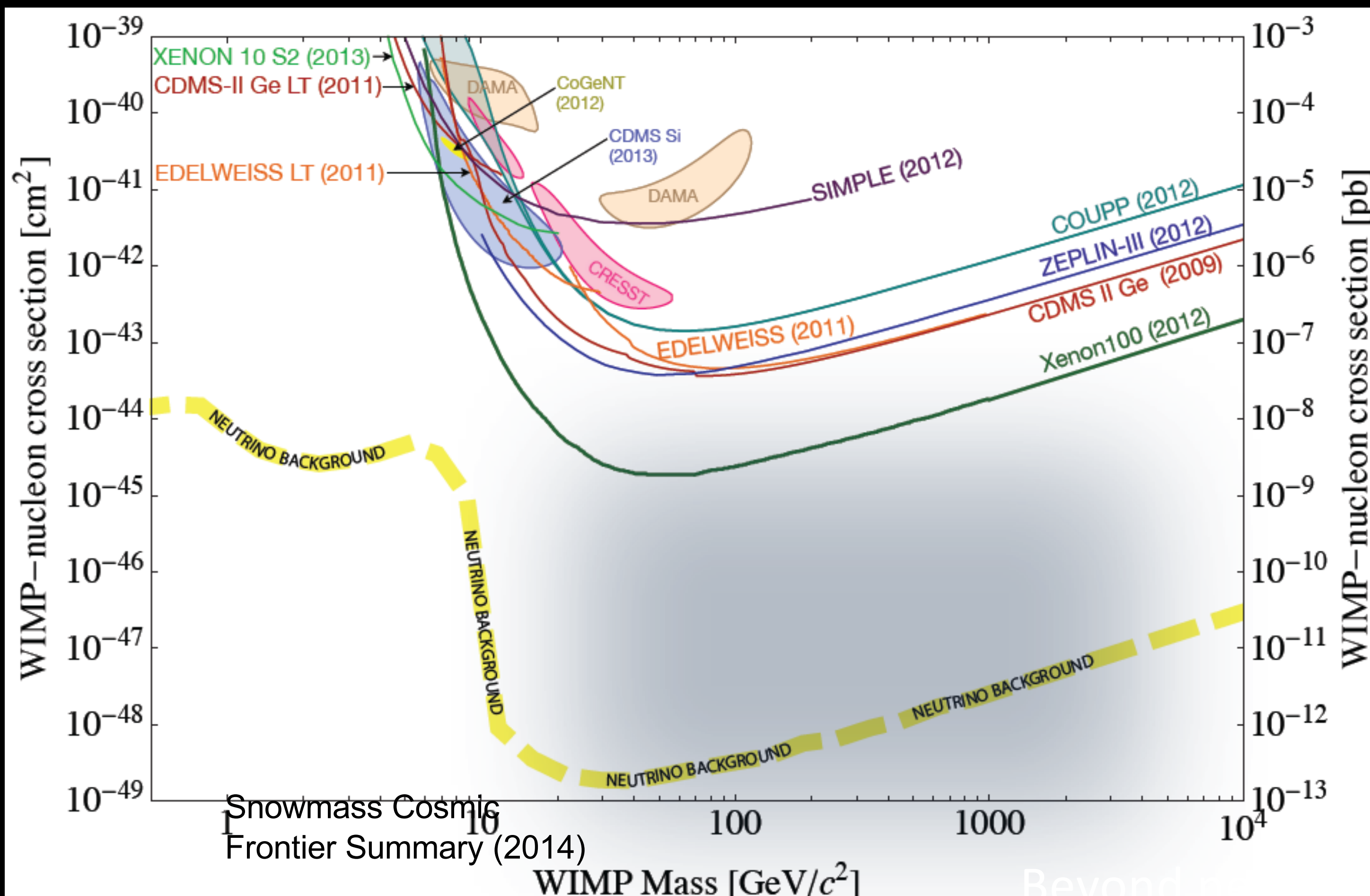
Mystery: Dark Matter



The evidence:
Galactic rotation curves,
hot gas in clusters,
the Bullet Cluster,
Big Bang Nucleosynthesis,
strong gravitational lensing,
weak gravitational lensing,
SN1a
Cosmic Microwave Background

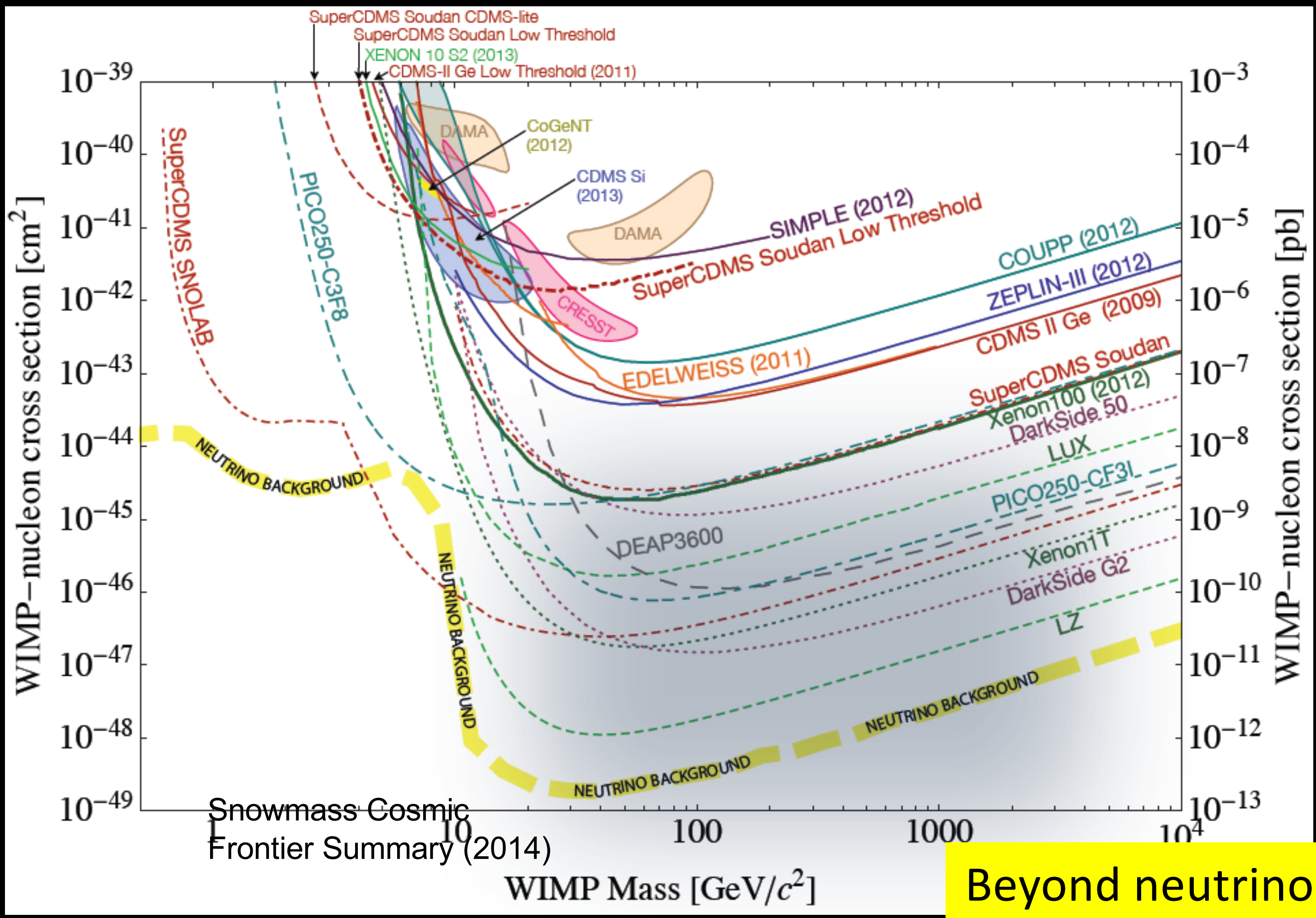
DIRECT DETECTION: STATUS AND PROSPECTS

- Since 2010, sensitivity improved by ~100 (for m ~ 100 GeV)



DIRECT DETECTION: STATUS AND PROSPECTS

- Since 2010, sensitivity improved by ~100 (for m ~ 100 GeV)
- Further improvements by 2-3 orders of magnitude expected by a suite of experiments world-wide

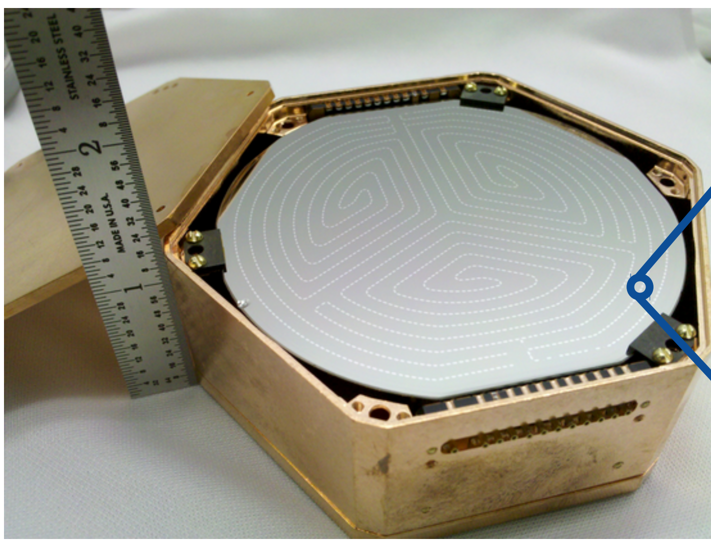


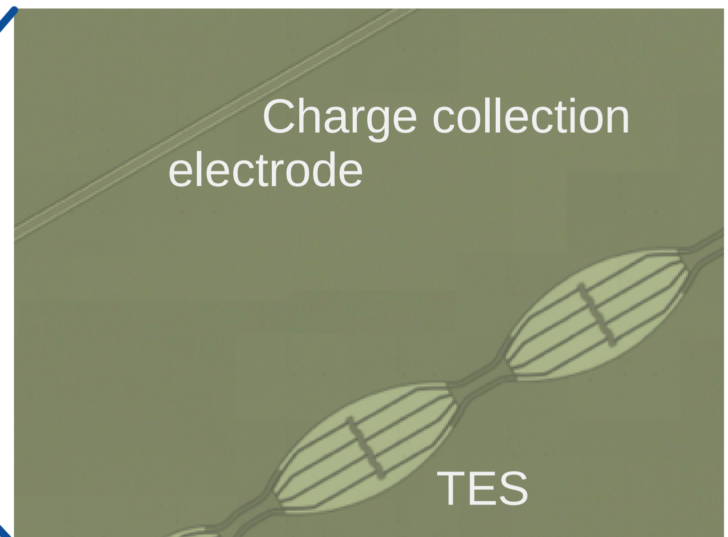
Beyond neutrino floor directional detection needed

SuperCDMS Soudan Detectors

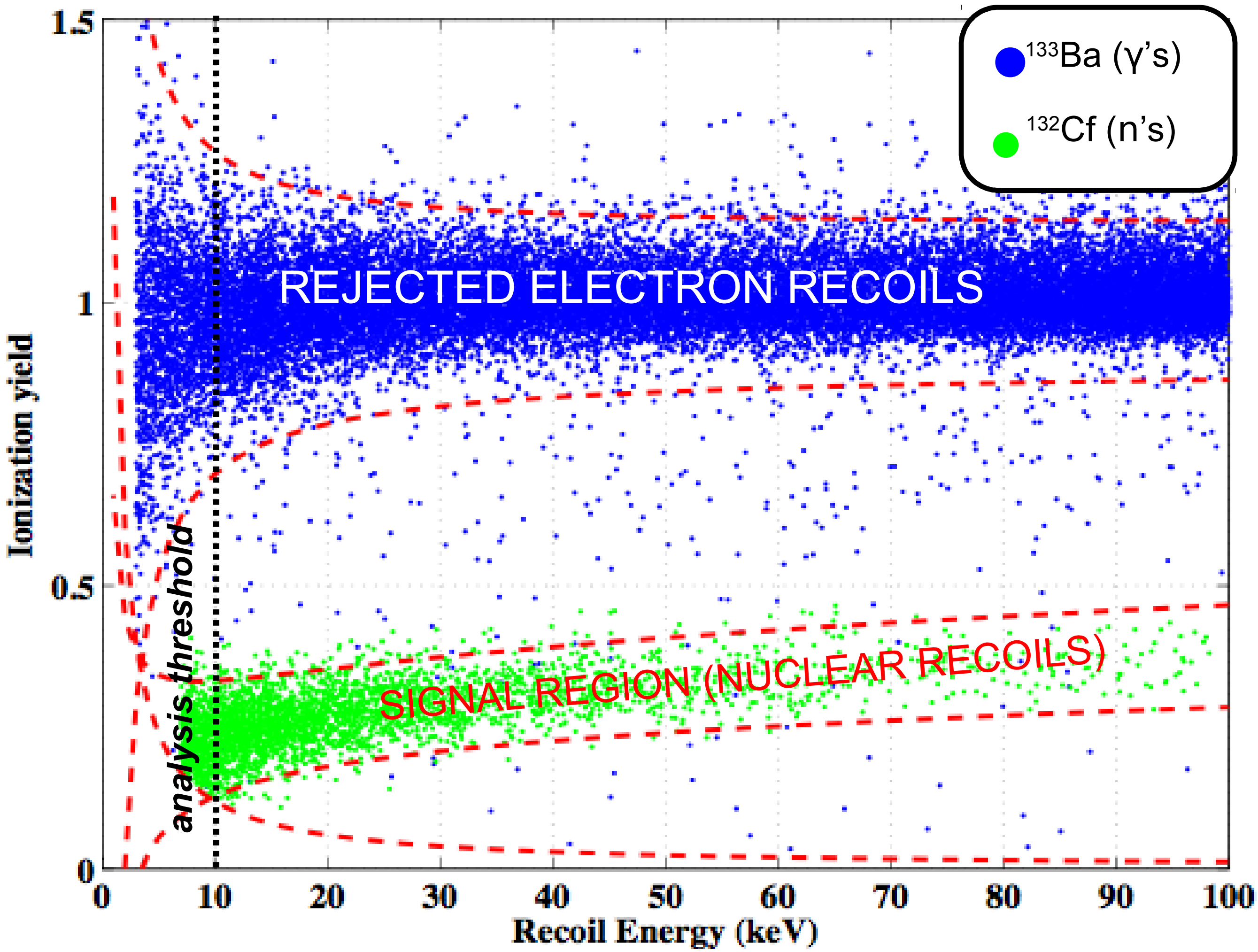
Ge iZIP (interleaved Z-sensitive Ionization and Phonon sensors)

- Measure heat and ionization
  - Athermal phonons measured with Transition Edge Sensors (TES)
  - e^-/h^+ pairs drifted across ±2 V bias.
  - 15 detectors, 0.6 kg each at ~50 mK





Background Rejection

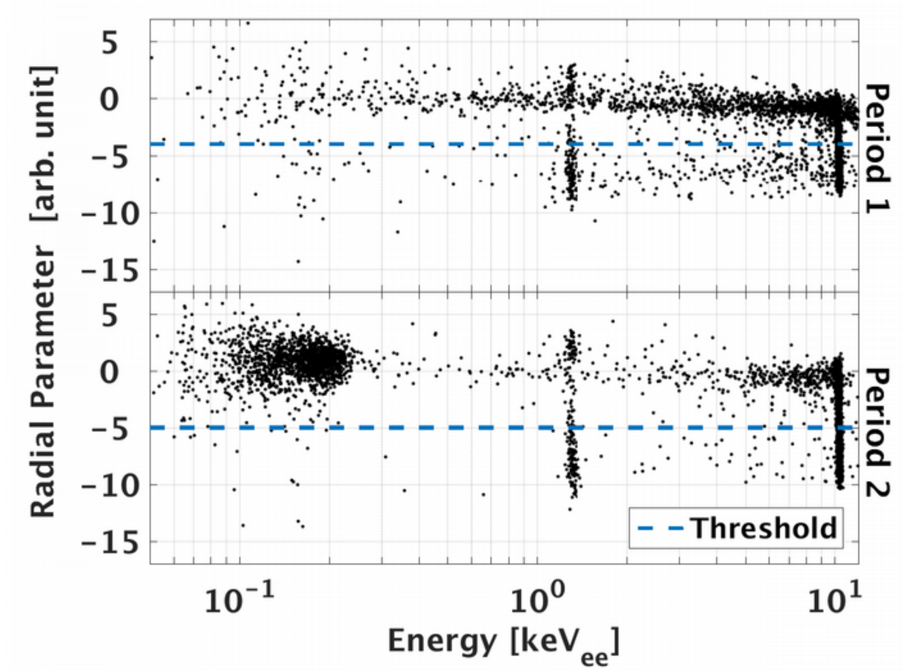


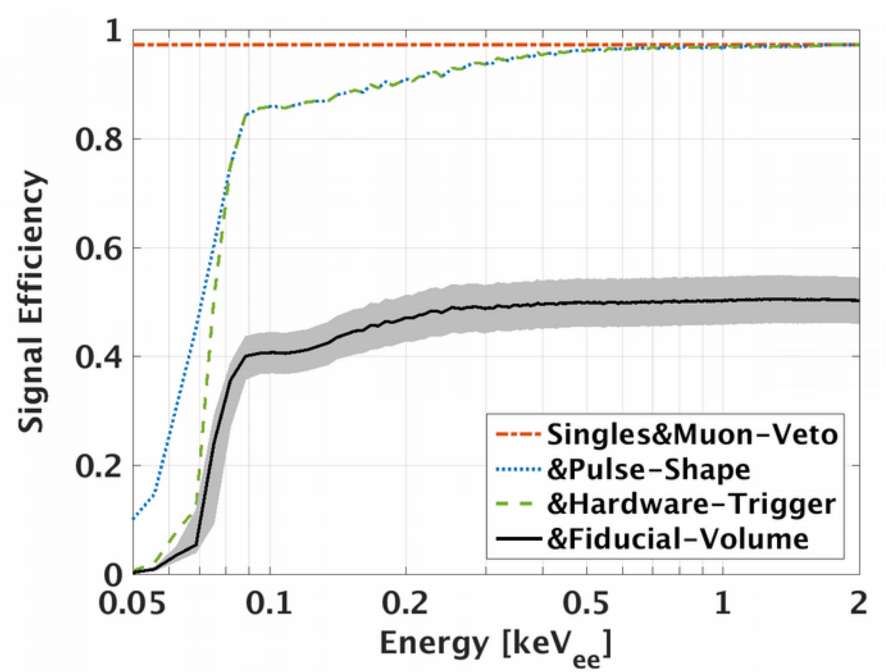
Fermilab

CDMSlite

PRL **116** 071301 (2016)

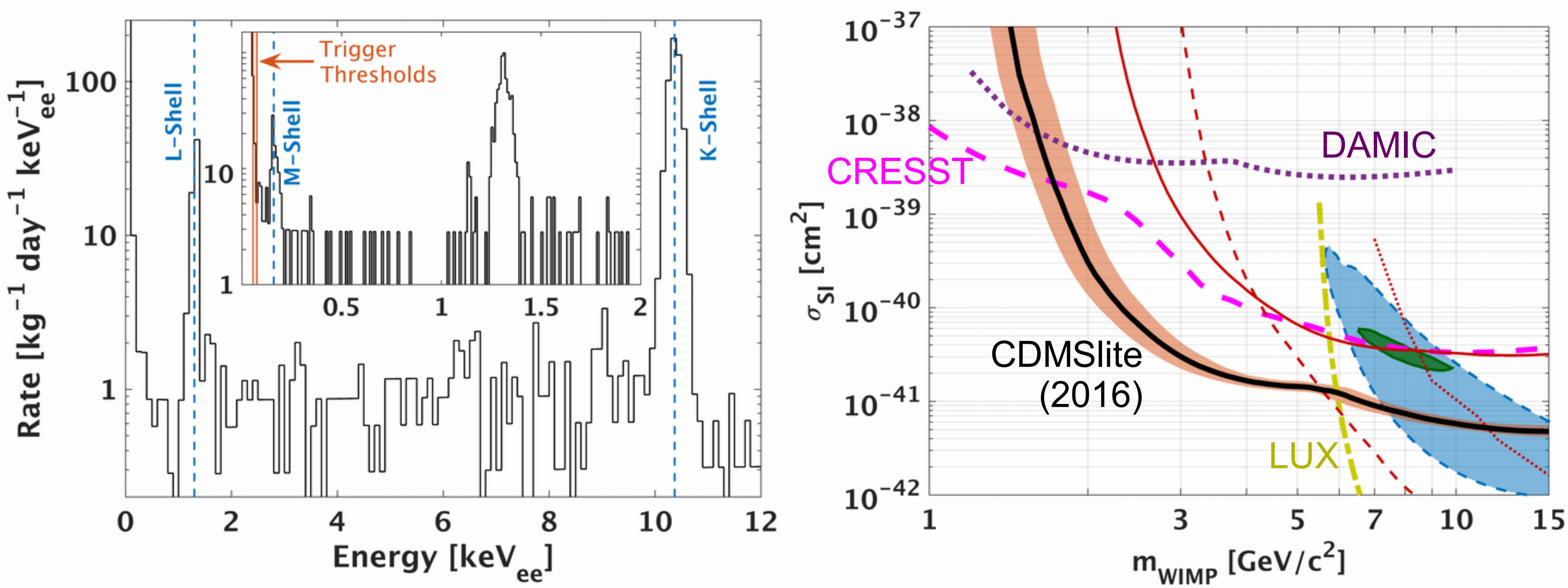
- Thresholds at 75 eV_{ee} (period 1) and 56 eV_{ee} (period 2) limited by low-frequency vibrations.
- Fiducial cut using phonon pulse shape and radial cuts.



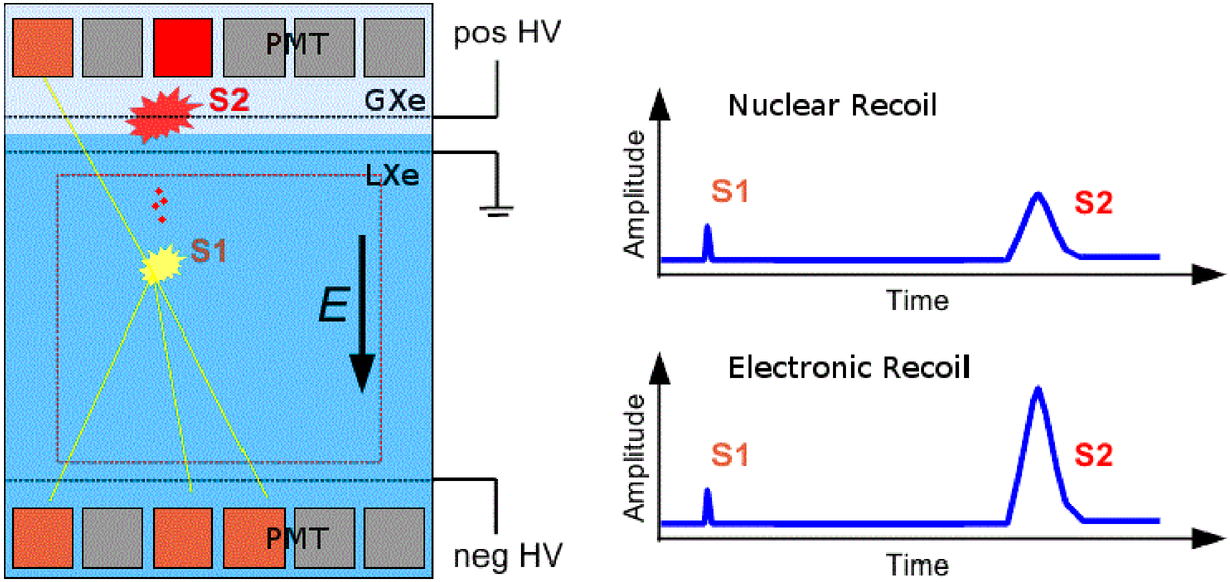


CDMSlite

- New results – PRL **116** 071301 (2016)
  - World leading low-mass WIMP limits.
- Final data set with lower hardware threshold under analysis.



Dual phase TPC for DM



Scintillation light (S1) and ionization charge from primary event, which is converted to proportional scintillation (S2) in gas phase. Time between S1/S2 and top PMT pattern used to localize event. S2/S1 provides recoil discrimination.

relatively “new” application in DM, about 10 years

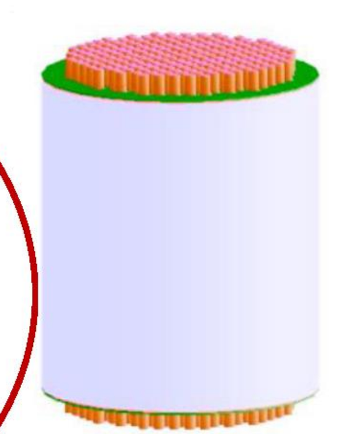
PandaX experiment

PandaX = Particle and Astrophysical Xenon Experiments

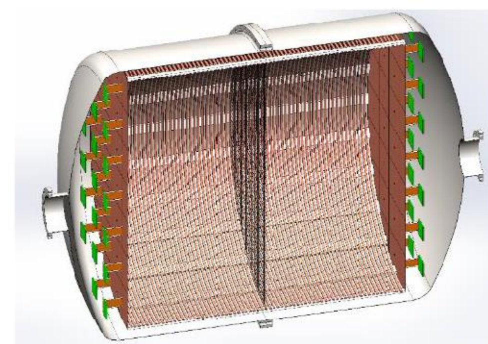
PANDA X

Phase I:
120 kg DM
2009-2014

Phase II:
500 kg DM
2014-2017



PandaX-xT:
multi-ton DM
future



PandaX-III:
200 kg to 1 ton
^{136}Xe 0vDBD
future

Run history

Series of Engineering runs

Distillation and re-started (Run9, 80 days)

Detector installation at CJPL

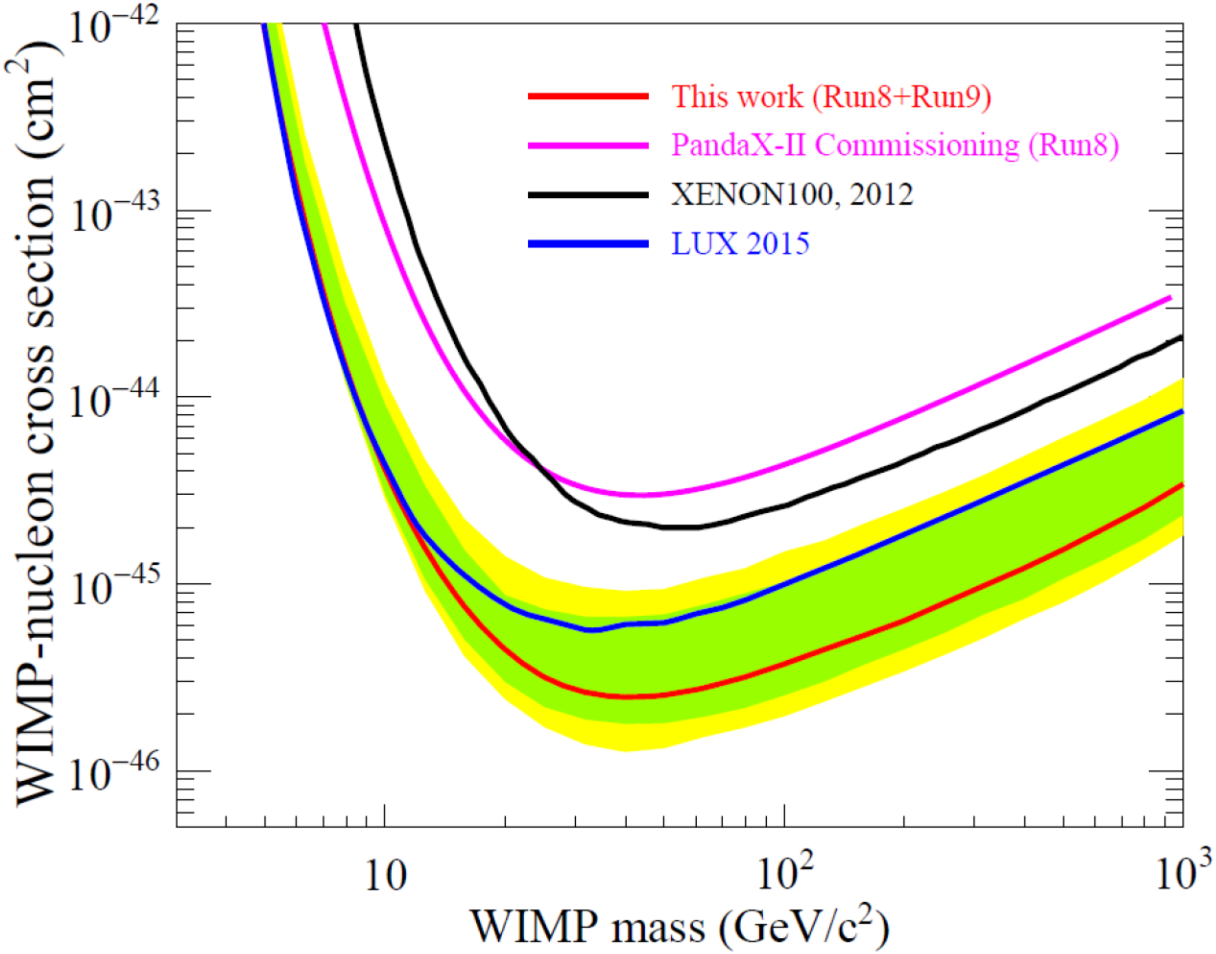
Nov 22 – Dec 14, Physics commission (Run8, 19 days, stopped due to high Krypton background)

Phys. Rev. D. 39, 122009 (2016)

Run8+Run9=98.7 days
Exposure:3.3x10^4 kg-day

Combined results

arXiv:1607.07400 Submitted to PRL

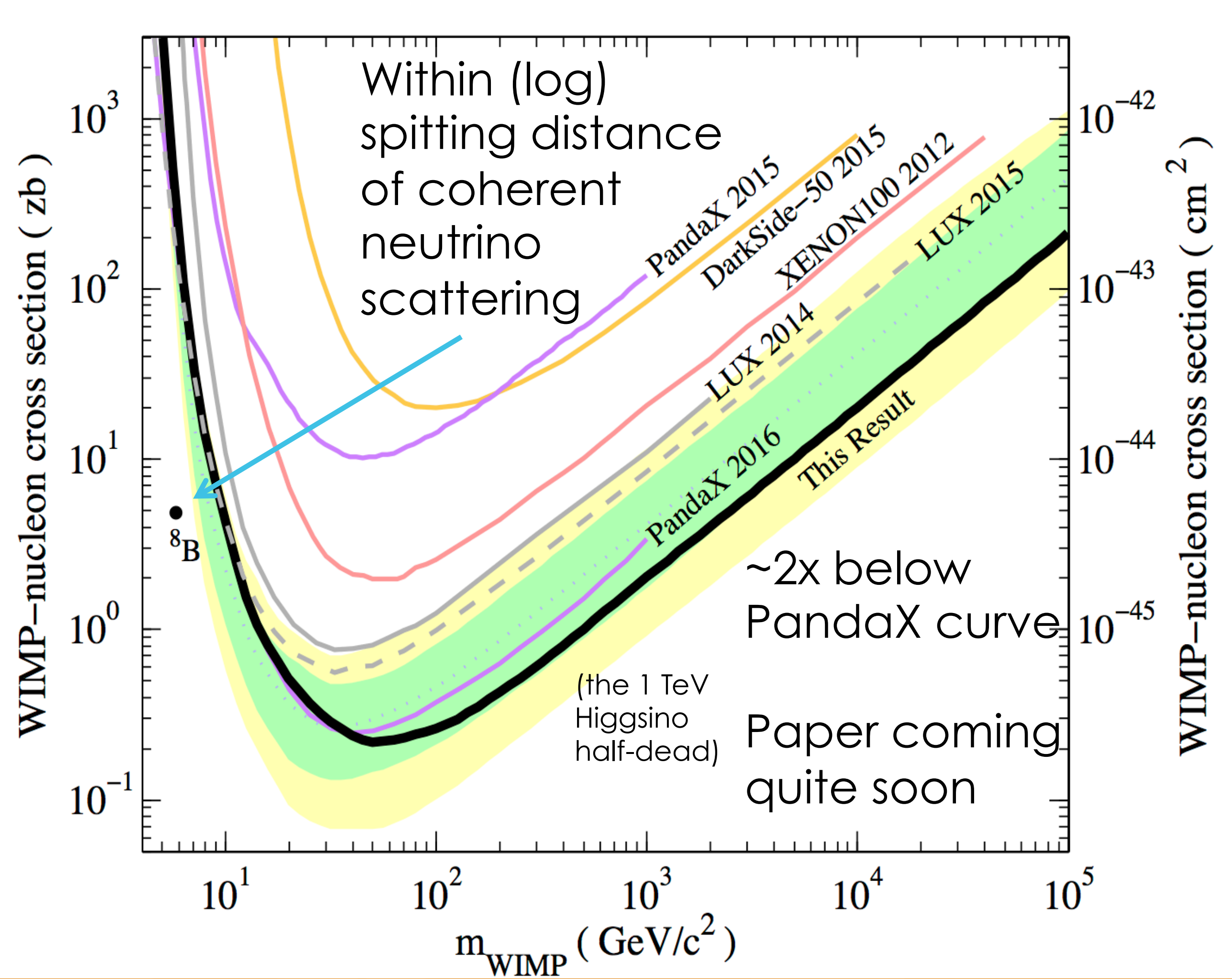


- Minimum upper limit for isoscalar SI elastic cross section reaches 2.5x10^{-46} cm^2 at 40 GeV.
- More than a factor of 2 improvement for high-mass DM compared to the LUX 2015 results

WIMP-nucleon SI Exclusion

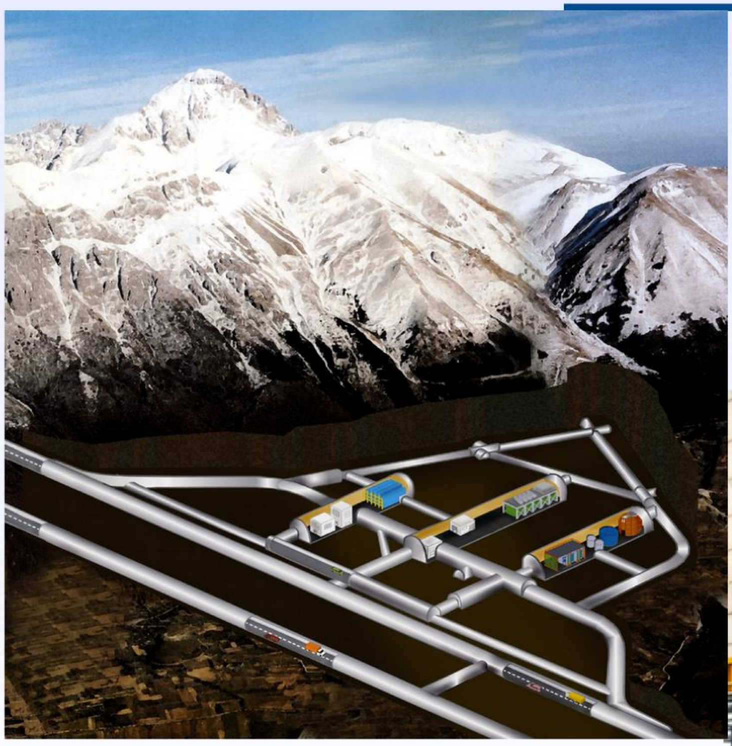
- Our best, lowest exclusion is at 50 GeV: 2.2×10^{-46} cm^2 (That's 0.22 zeptobarns in σ!)
  - 1 order of magnitude off XENON1T
  - Within < 2 orders of LZ projection
- Comparable to LUX 2015 re-analysis of 3 months' worth of data at low mass but FOUR TIMES better at high mass. (Final G1?)

(NOT preliminary. Analysis/limit is final. Text under internal review.)



XENON1T

- Reduce background 100X from XENON100
  - Goal: 2 t-yr exposure
- Increase sensitivity by factor 100 compared to XENON100
  - 1.6 X 10^{-47} cm^2 @ 50 GeV WIMP

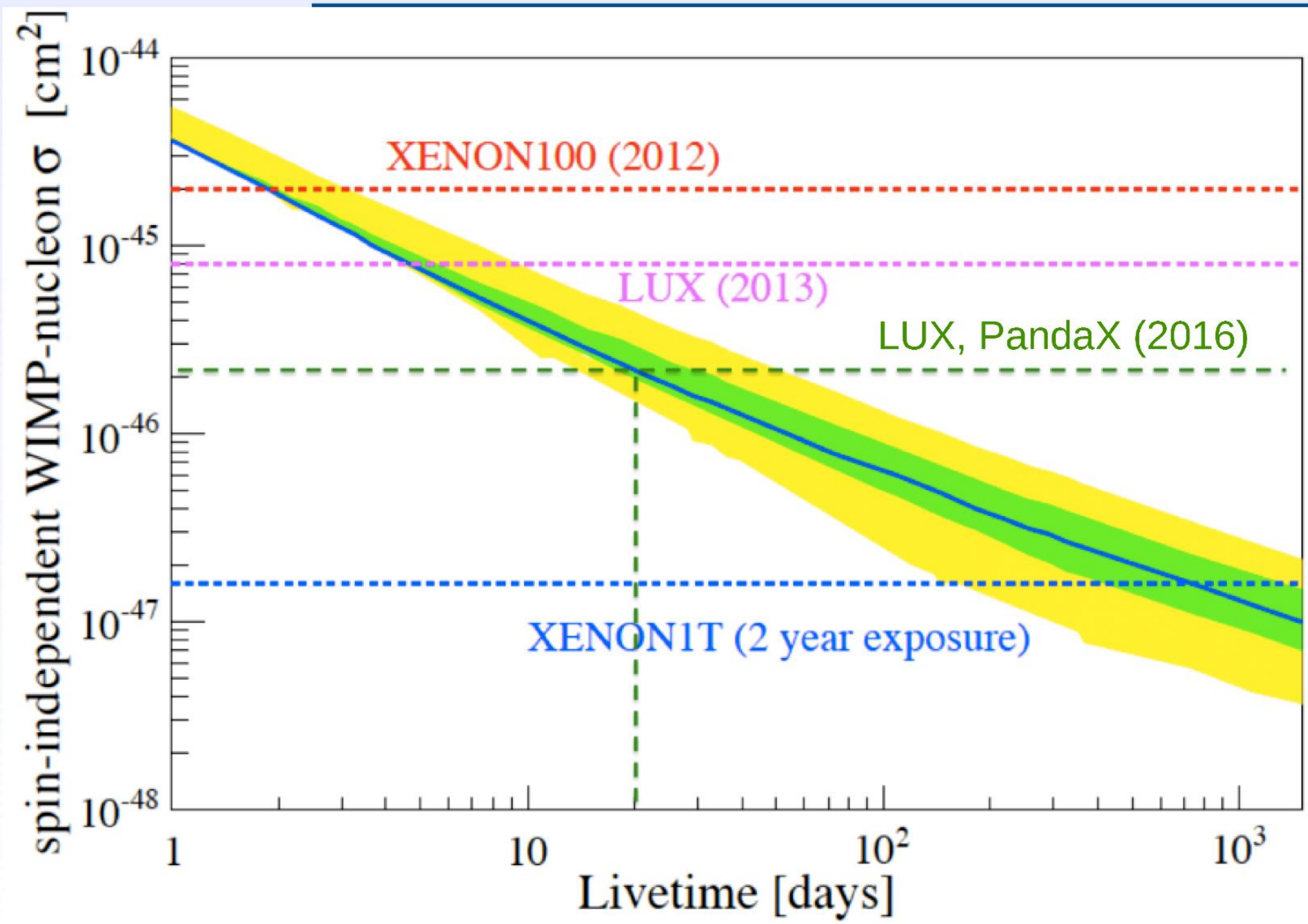


- Located in LNGS
- Many systems upgraded from successful operation of XENON100
- 3.2 tons Xe (2.0 t active volume)
- Water Cherenkov muon veto
- Cyrogenics plant for high purity xenon (~10t)

Rensselaer

Projected Sensitivity

XENON Dark Matter Project



- Only need 20 days to reach LUX/PandaX sensitivity!
- Commissioning nearly complete
- Operations of TPC and other systems already underway

- 2.0×10^{-47} cm²
- @ 50 GeV WIMP
- 2 t-yr data

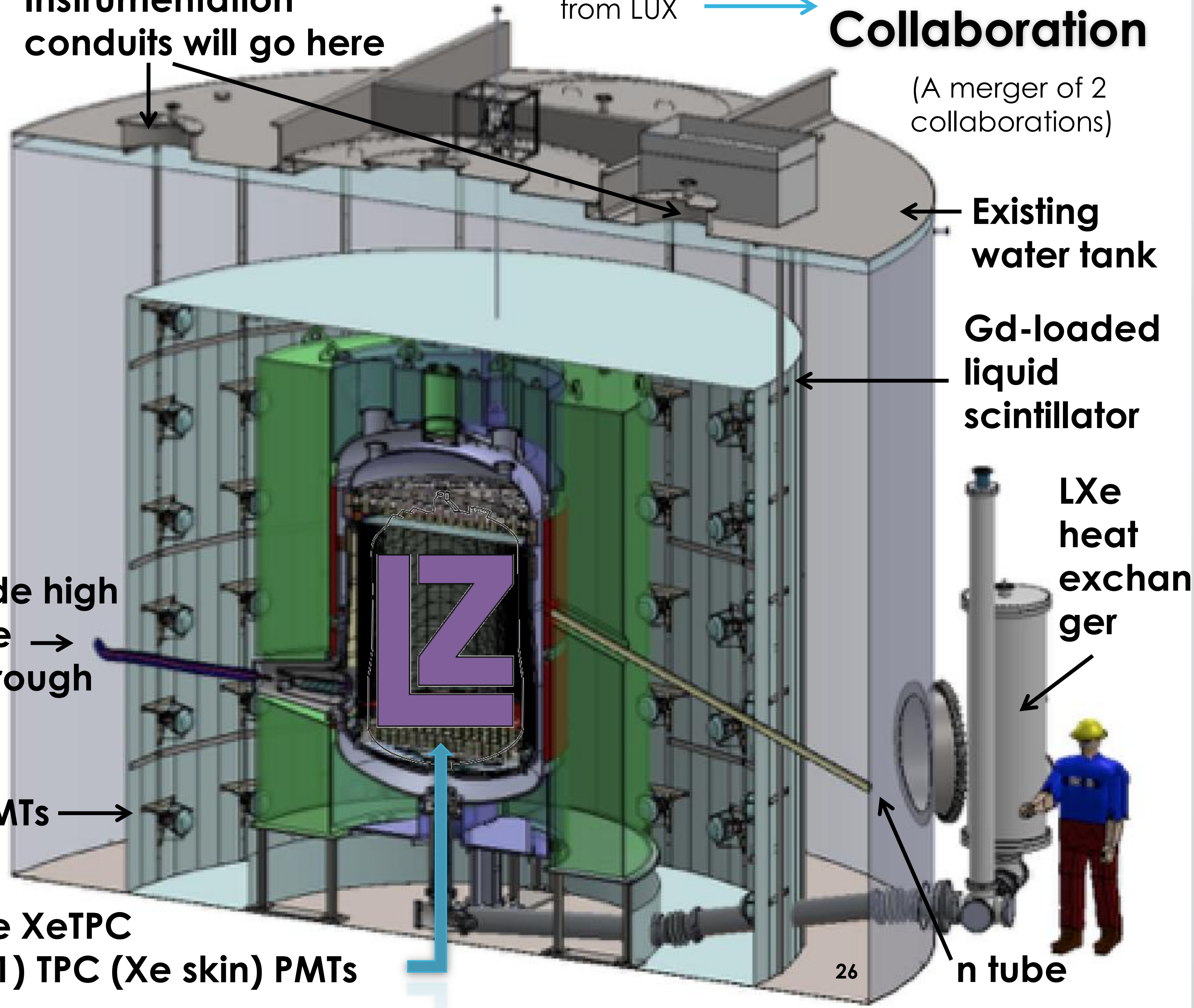
LUX-ZEPLIN Collaboration

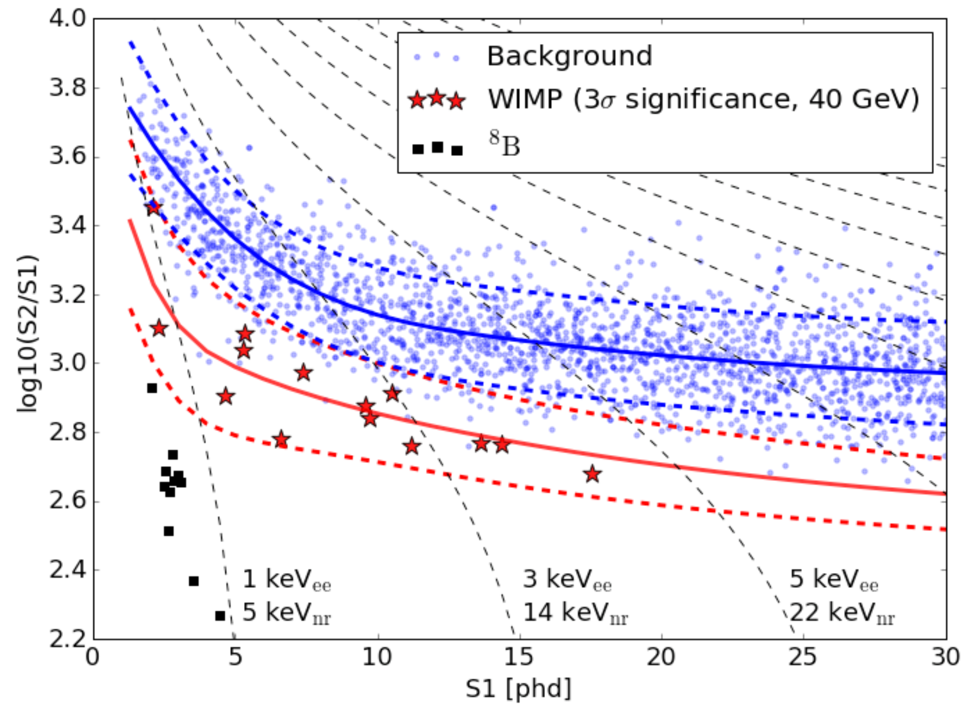
Separate project from LUX

(A merger of 2 collaborations)

A bigger and *better* version of LUX. Selected!

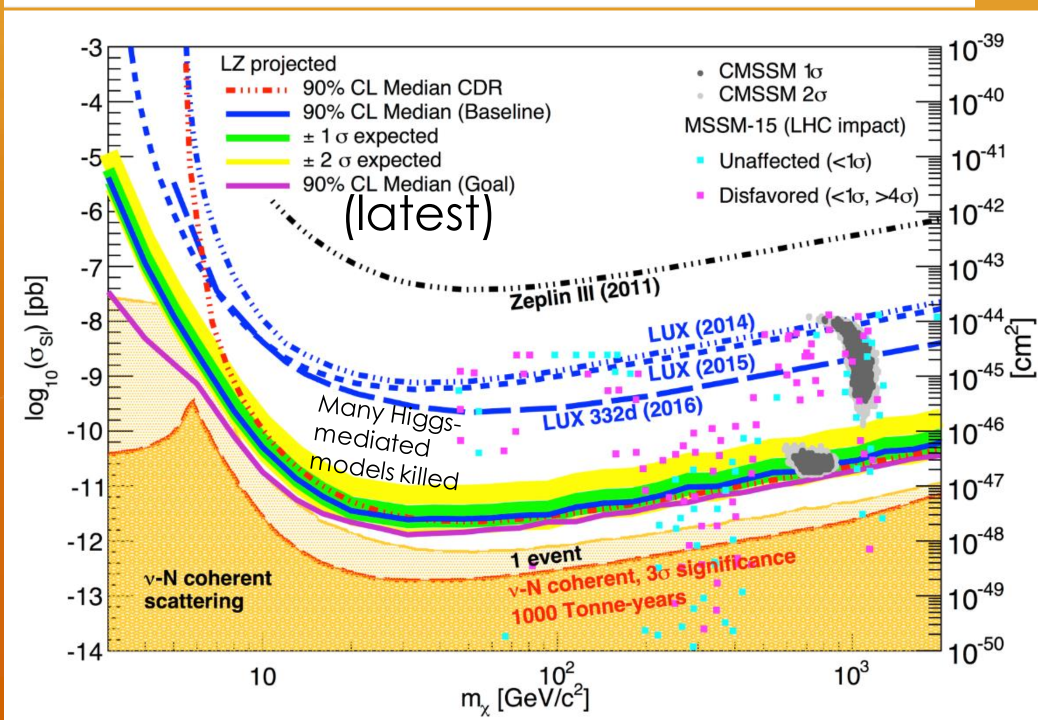
LZ is now in the midst of its DOE CD-2/3 review. It is already past CD-1 as of last year.





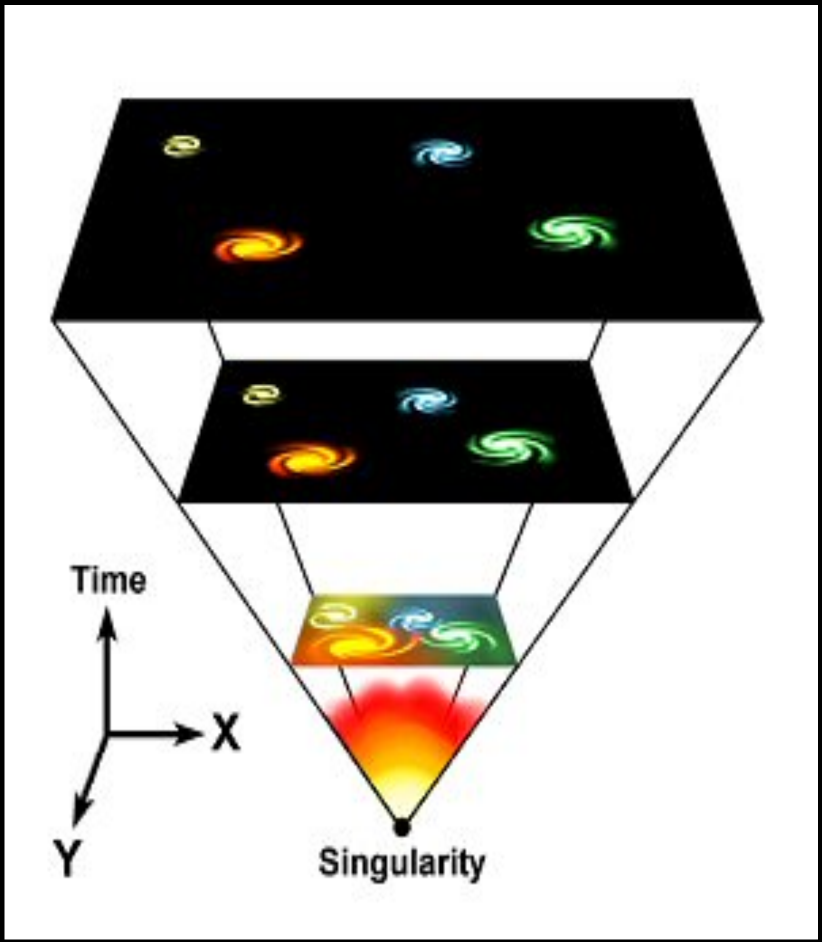
LZ's Reach

- Turning on by 2020 with 1,000 initial live-days plan
- 10 tons total, 7 tons active, ~5.6 ton fiducial mass
  - Due to unique triple veto
- GOALS: < 3 x 10^{-48} cm^2, at 40 GeV. Clip ν shoulder



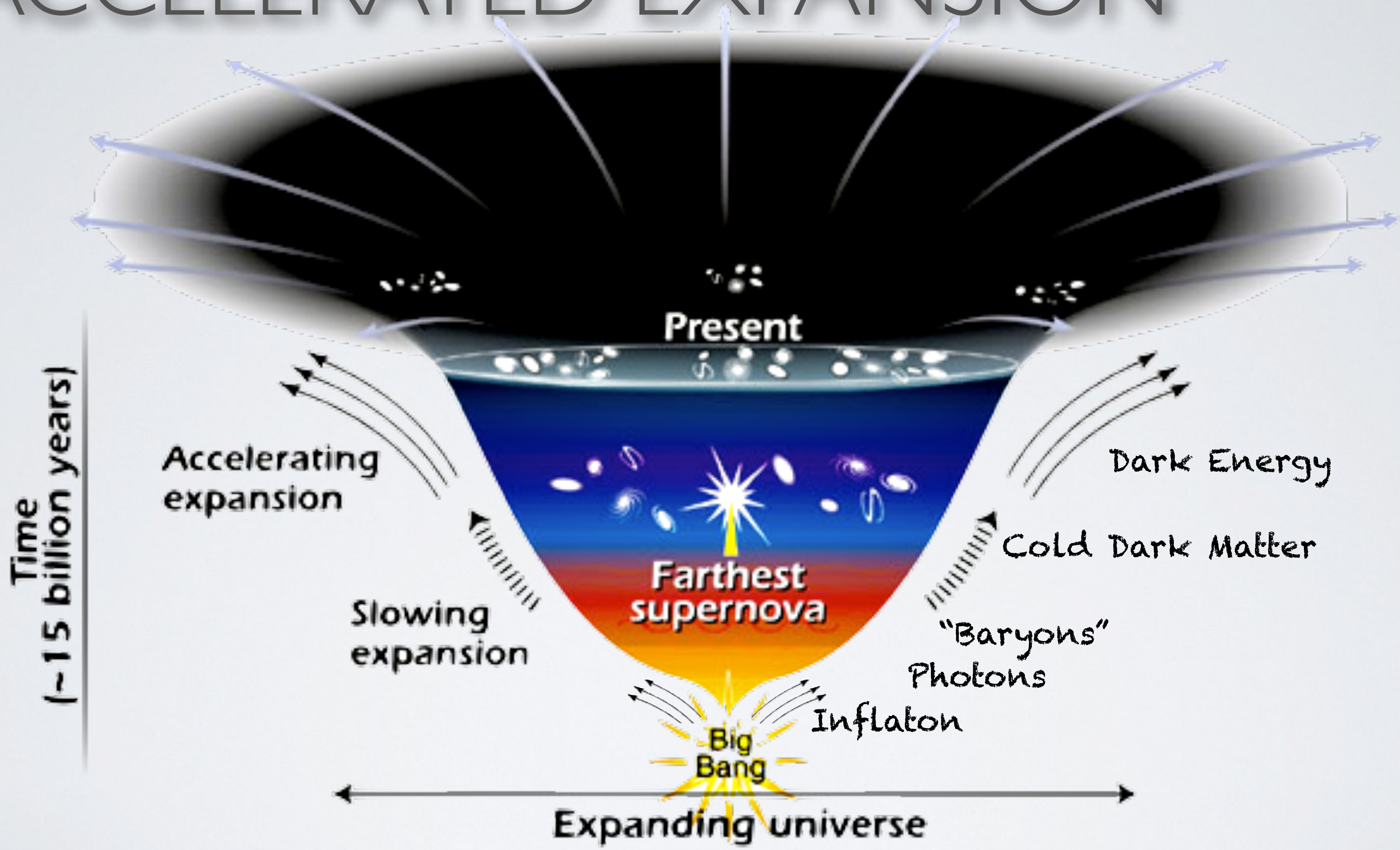
*plot and models from LZ's Conceptual Design Report, arXiv:**1509.02910**

Mystery: Dark Energy



The evidence
SN1a
BAO in the galaxy distribution
Cosmic Microwave Background

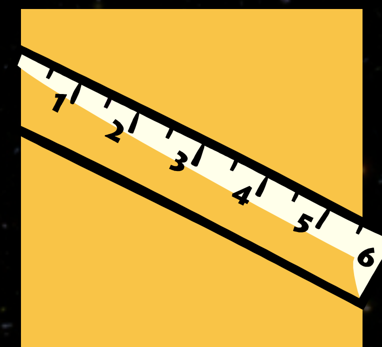
DARK ENERGY & ACCELERATED EXPANSION



Probing Dark Energy

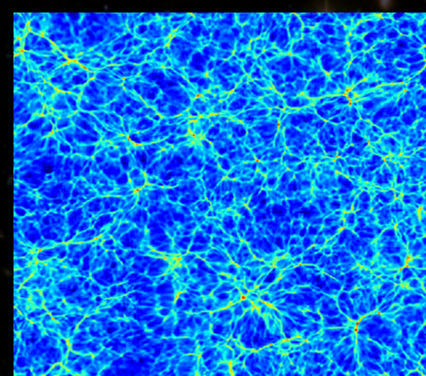
luminosity distances of standard candles (Type 1a SNe)

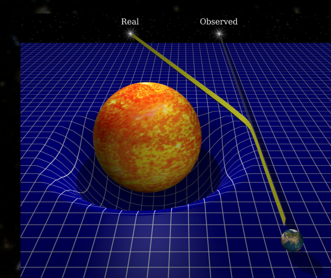
angular diameter distances of standard rulers baryon acoustic oscillations (BAO)



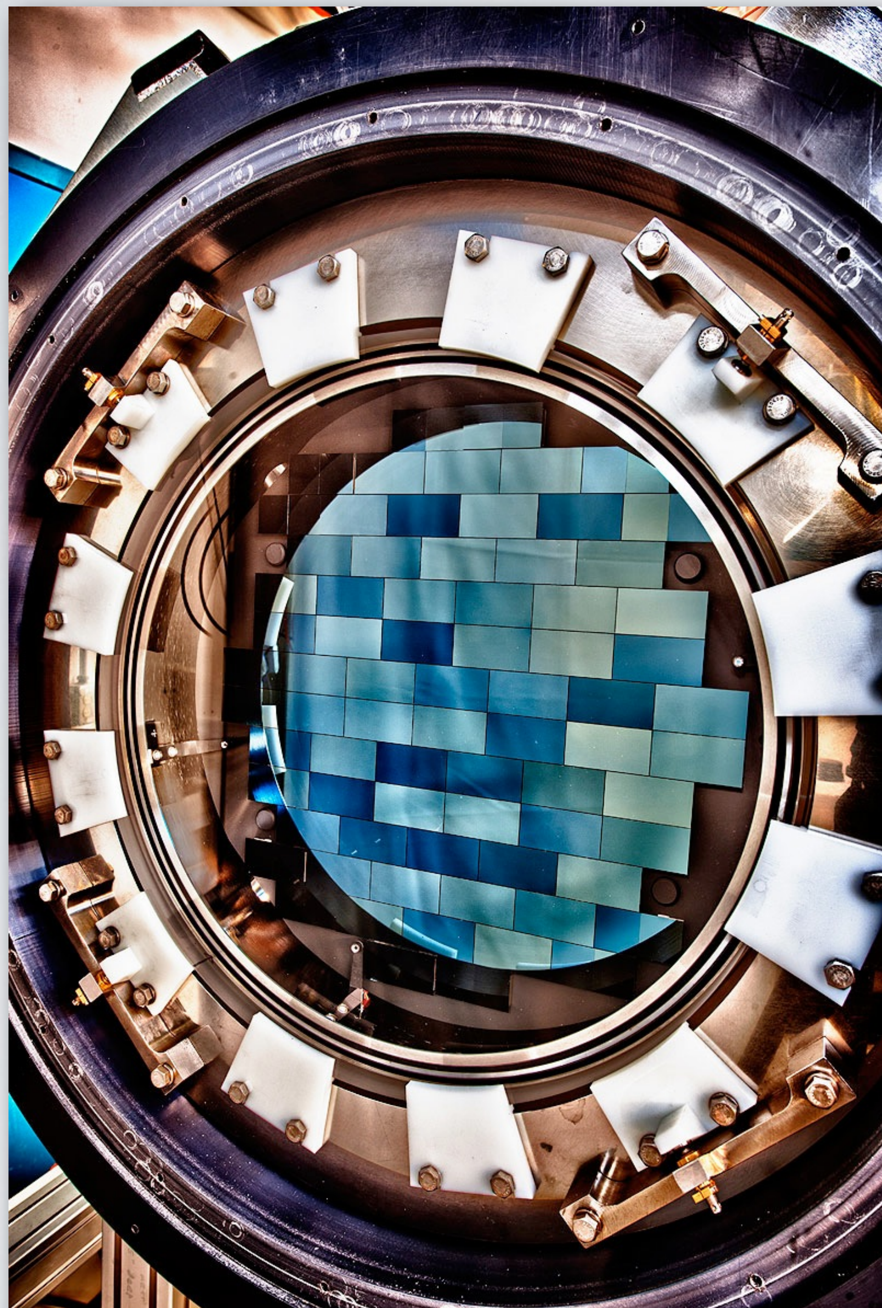
•measure growth of structure as function of redshift

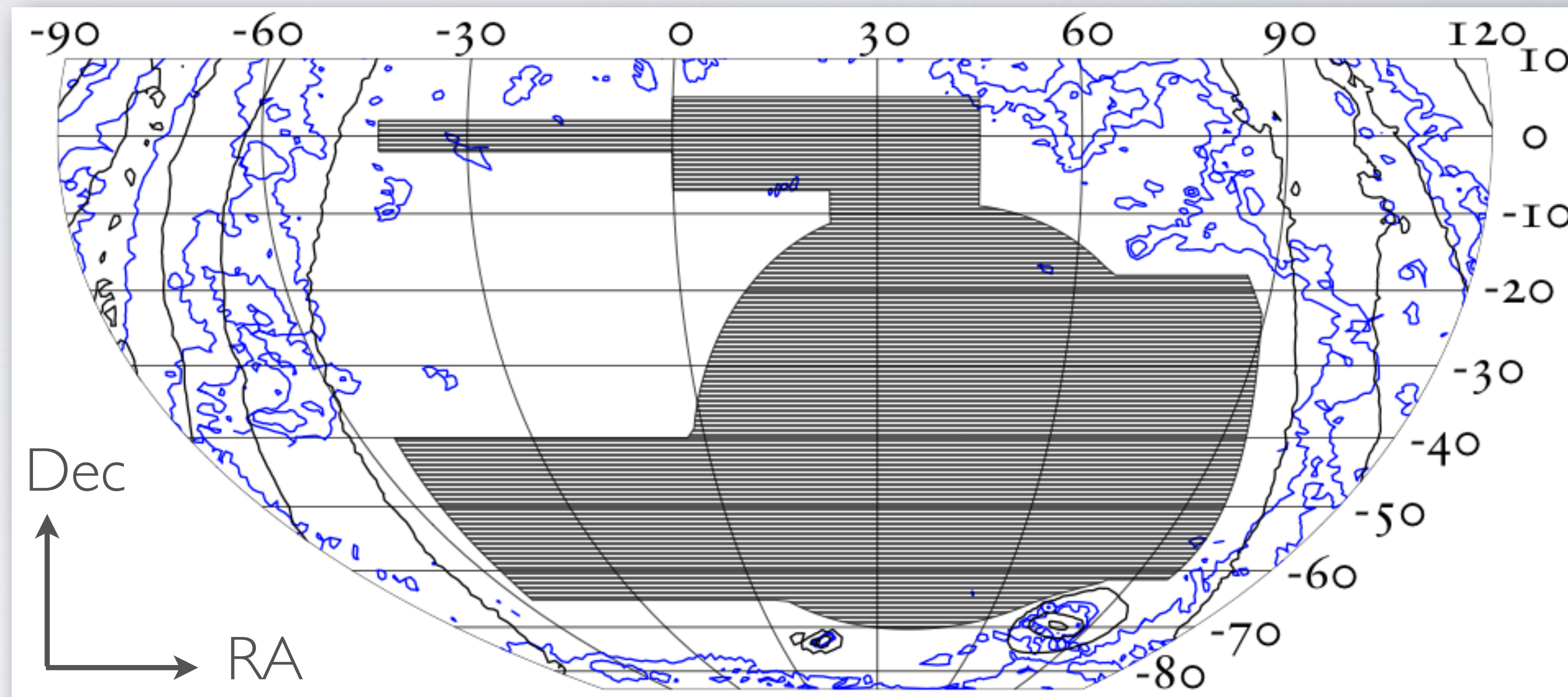
•Galaxy Cluster surveys & Weak Lensing (WL) Surveys





DARK ENERGY SURVEY





DEcam

3 sq deg FOV, **570 Mpix** optical CCD camera

Facility instrument at **CTIO Blanco 4-m telescope in Chile**

First light: Sep 2012

Survey

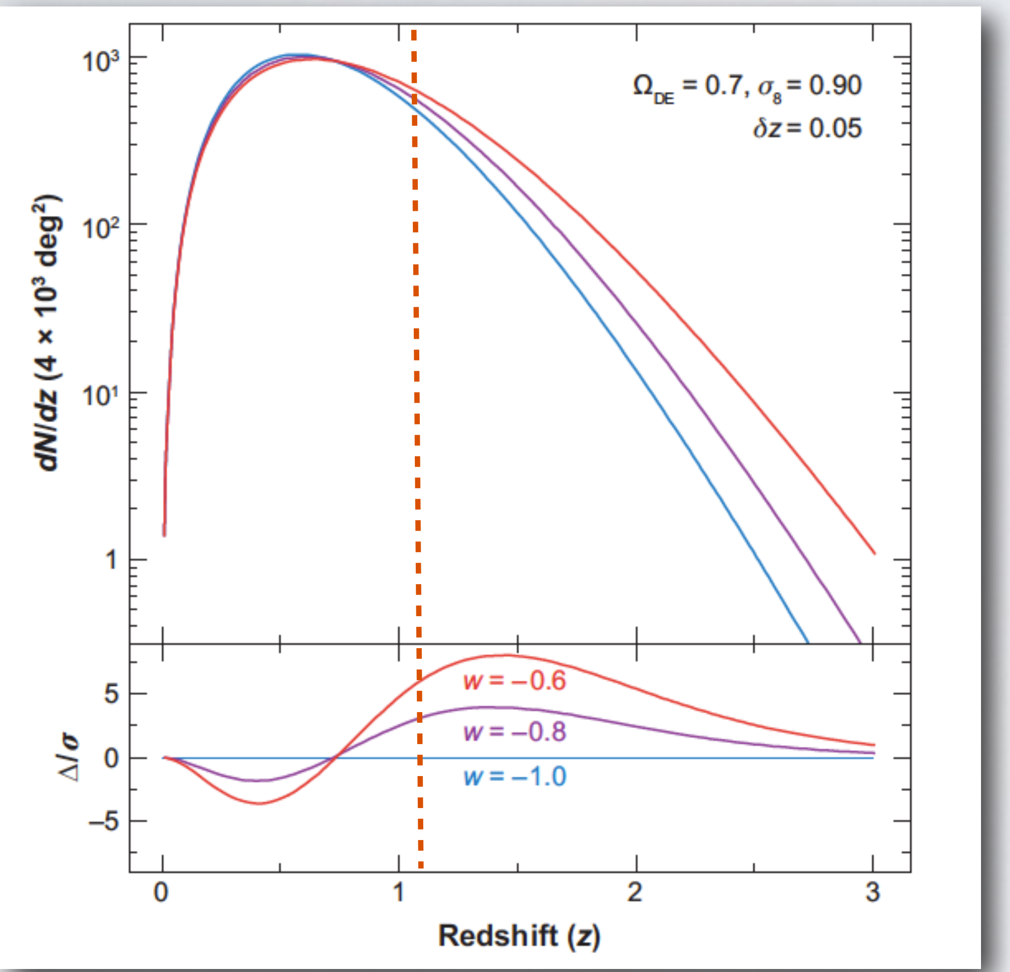
5000 sq deg grizY to **24th mag** overlaping with SPT and VISTA

30 sq deg SNe survey
0.9 arcseconds seeing

525 nights: 2013-2018

CLUSTERS AS DE PROBES

DES sample: up to z ~ 1



Number of clusters above $10^{14.5}$ solar masses as a function of z, for a 4000 sq-deg survey in 3 different cosmologies.

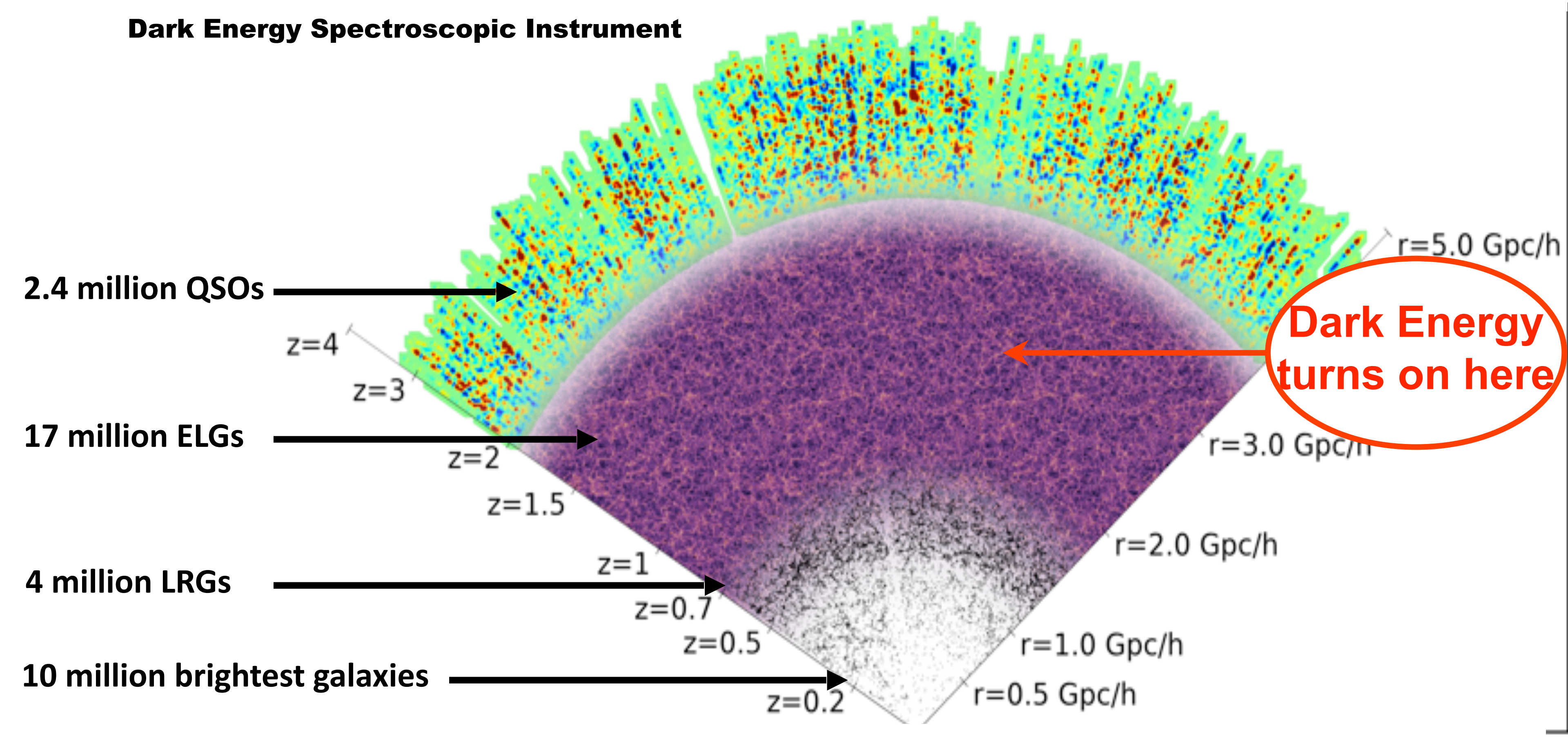
The number of clusters as a function of **mass** and **redshift** is a **dark energy** probe.

Reliable **detection** of clusters, and accurate mass **calibration** are required.

Systematics can be controlled by understanding the **astrophysics** of clusters.

DESI Survey: ~ 34M Galaxies, 14K deg^2

- 10 million Bright Galaxies 0.0<z<0.4
- 4 million Luminous Red Galaxies (LRGs) 0.4<z<1
- 17.1 million Emission Line Galaxies (ELGs) 0.6<z<1.6
- 1.7 million Tracer Quasars (QSOs) 1<z<2.1
- 0.7 million High redshift Quasars probe IGM (Lyman-alpha forest) (z>2.1)

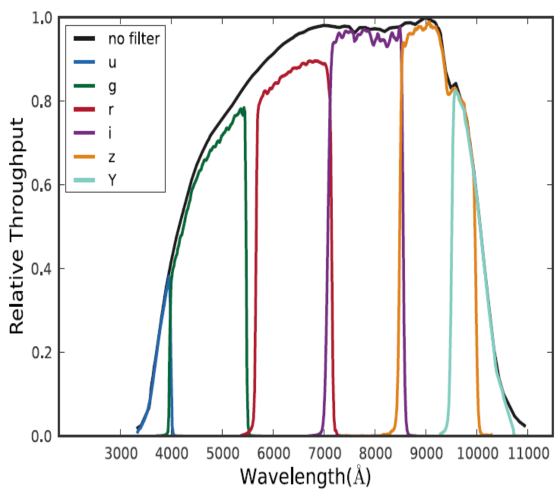


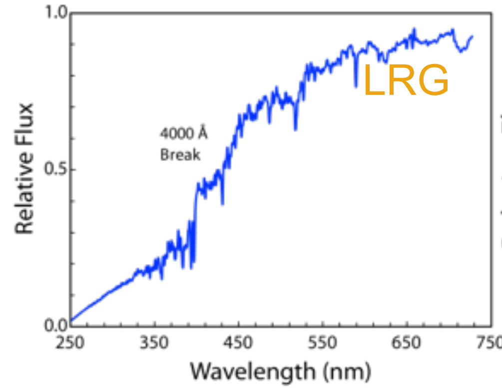
DESI Science requirements

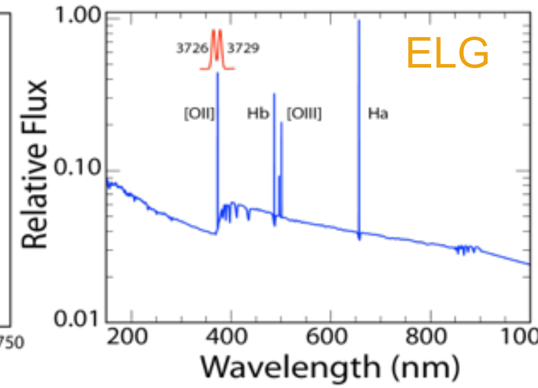
- Identify spectral features for each type of target
  - *Bandpass* from 360 – 980 nm, Δz/(1+z) ~0.0005, λ/Δλ resolution ~ 2000-4000

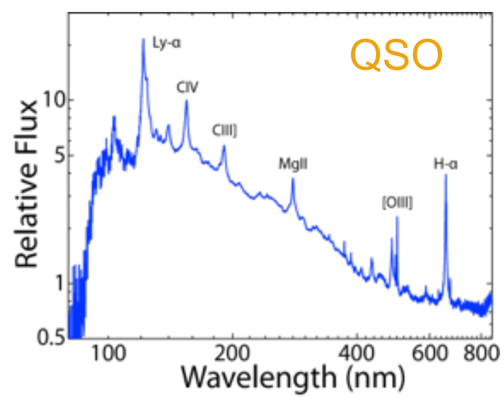
For comparison: DES measures "photometric" redshifts using 5 filters

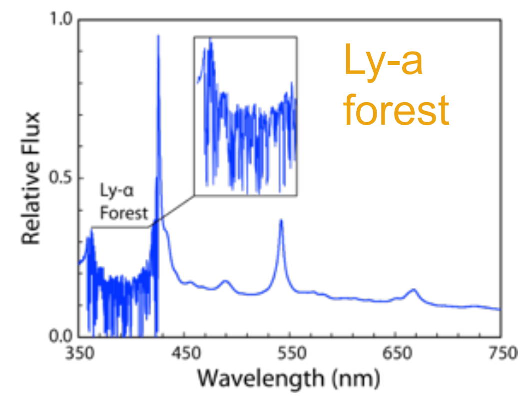
Δz ~ 0.01-.02 for clusters,
0.1 individual galaxies









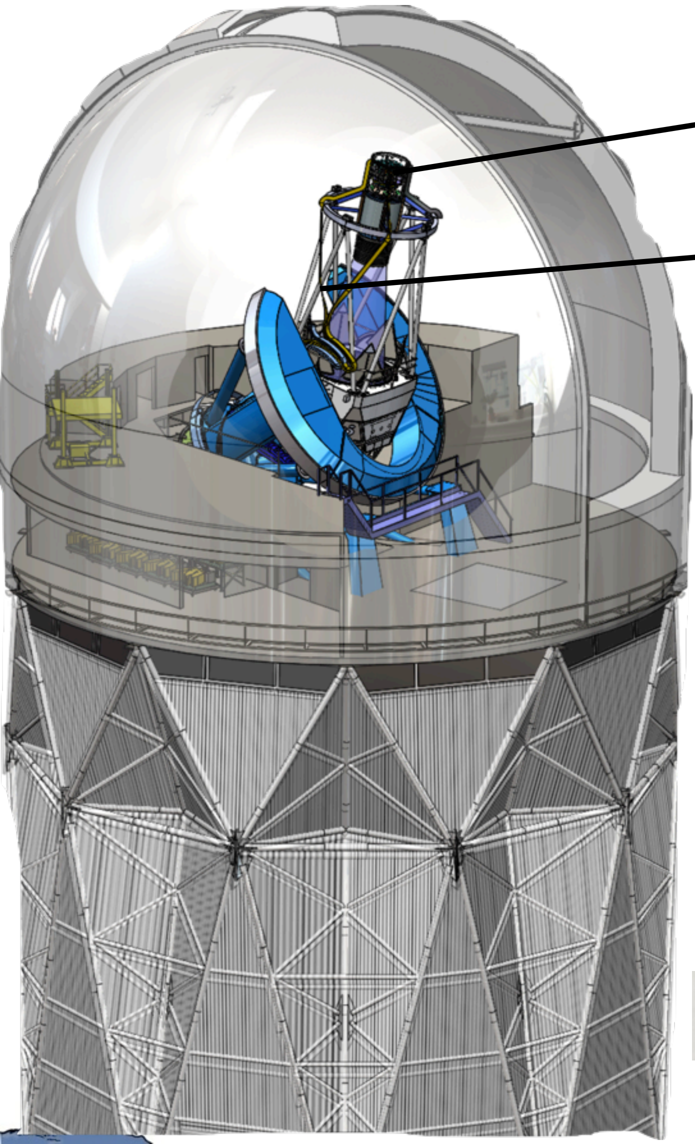


DES is a ~2.5D Survey

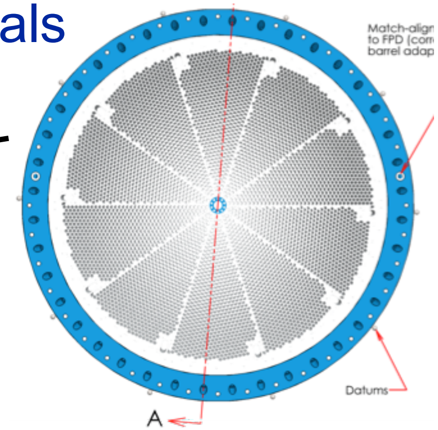
DESI is a 3D Survey

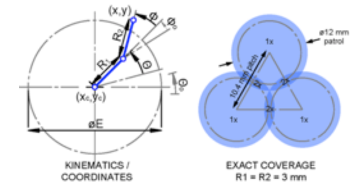
DESI Instrumentation: Focal Plane

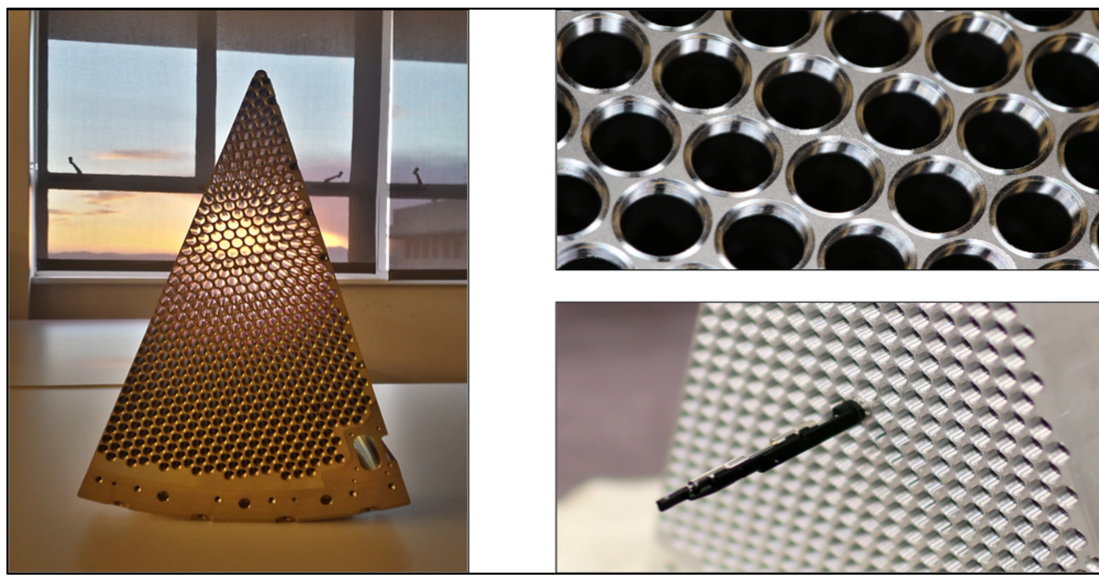
Focal Plane 5000 Fiber robots in 10 petals



5000
Fibers



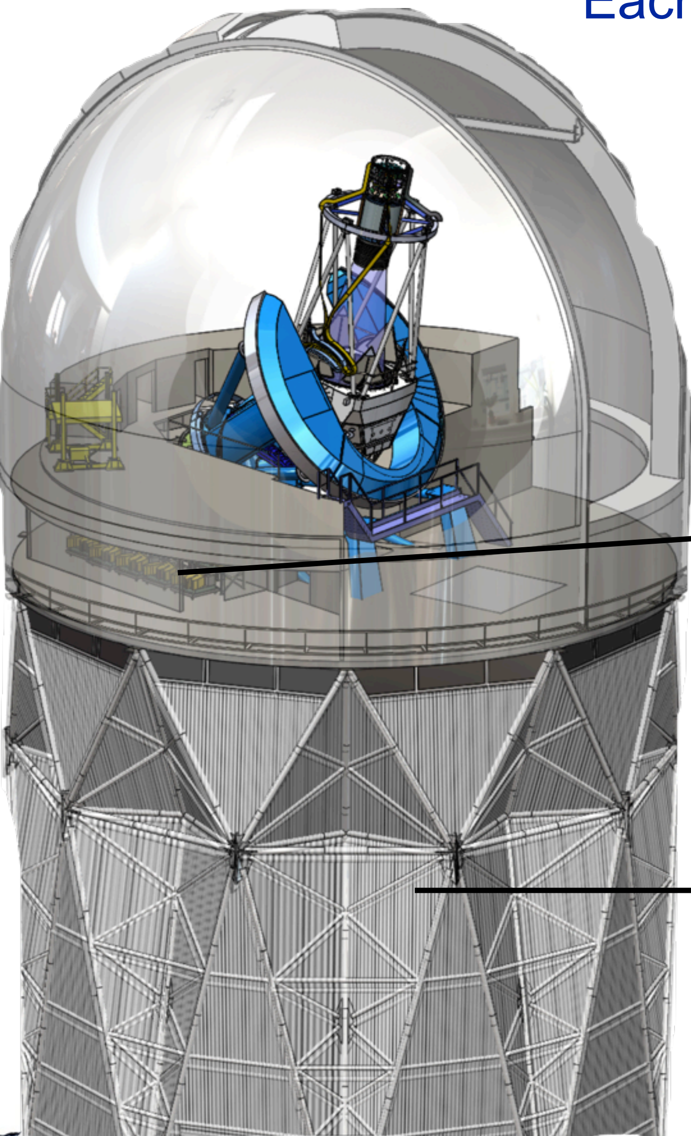


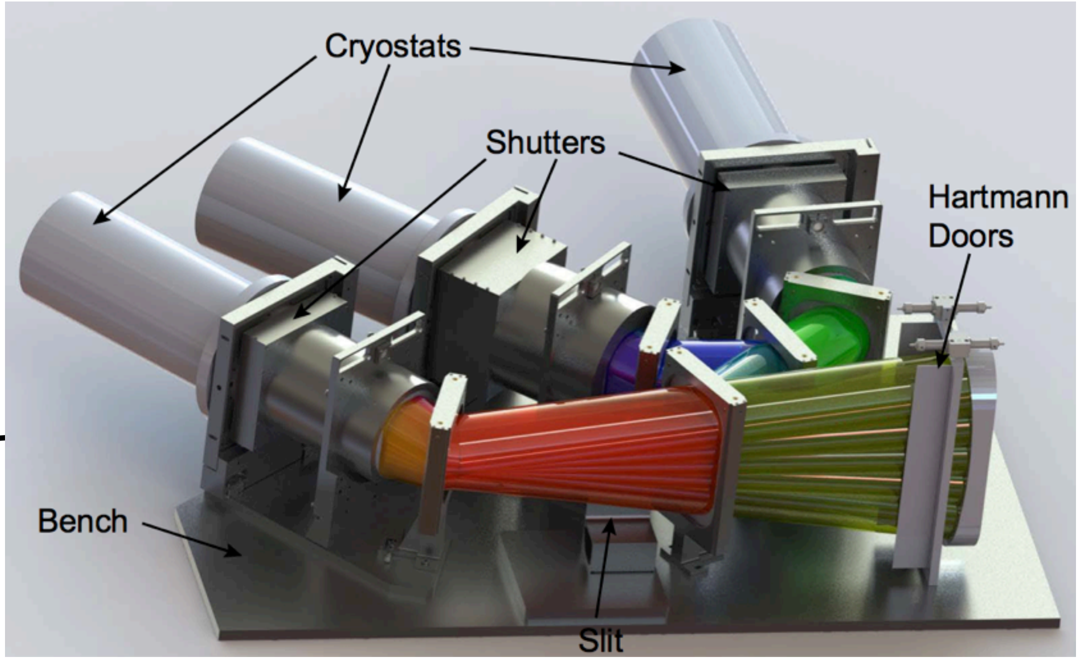


DESI Instrumentation: Spectrographs

10 spectrographs, 5000 simultaneous spectra

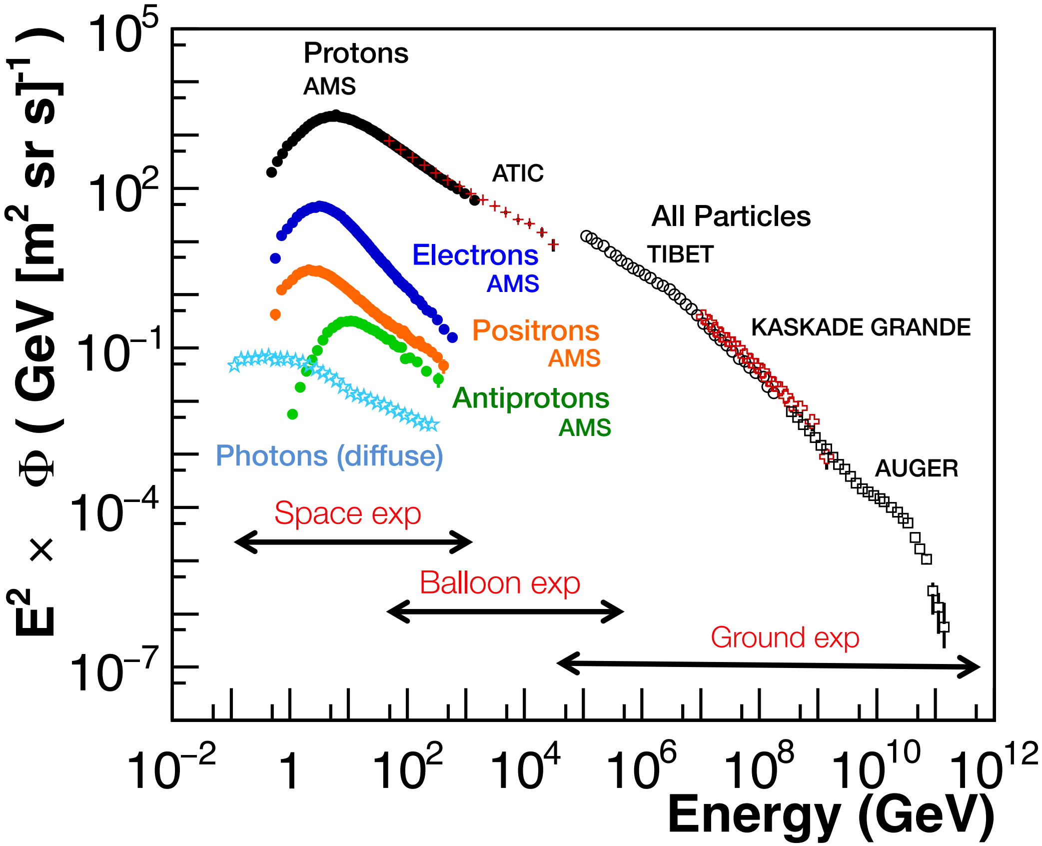
Each spectrograph: 500 fibers, 3 arms, 4kx4k CCDs



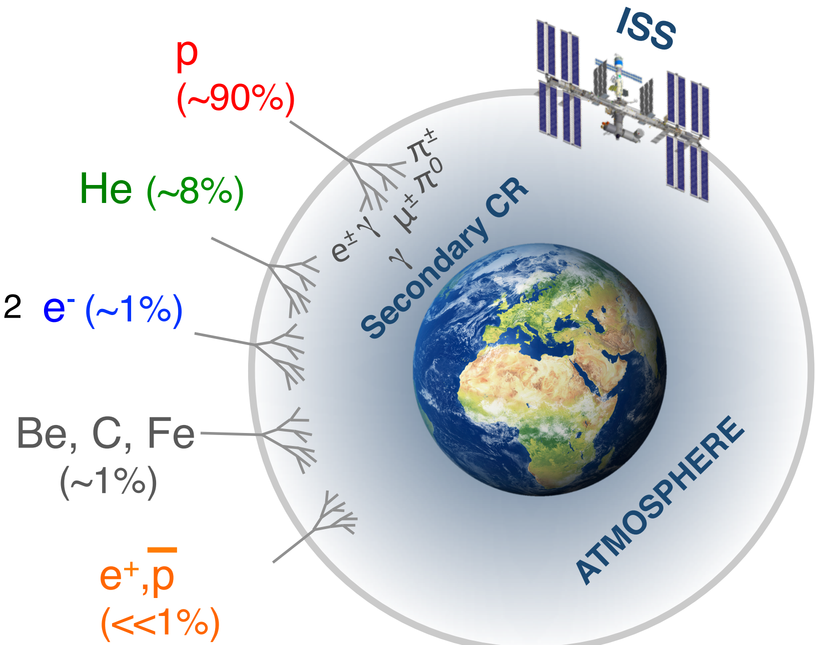


Readout
& Control

Cosmic Rays



- Cosmic rays cover an energy range up to 10^{20} eV
- Most of cosmic rays are protons and nuclei produced by standard astrophysical mechanisms
- New physics can be hidden in rare components spectra ($e^{+/-}$, $\overline{p}$, $\overline{D}$, γ, ….)

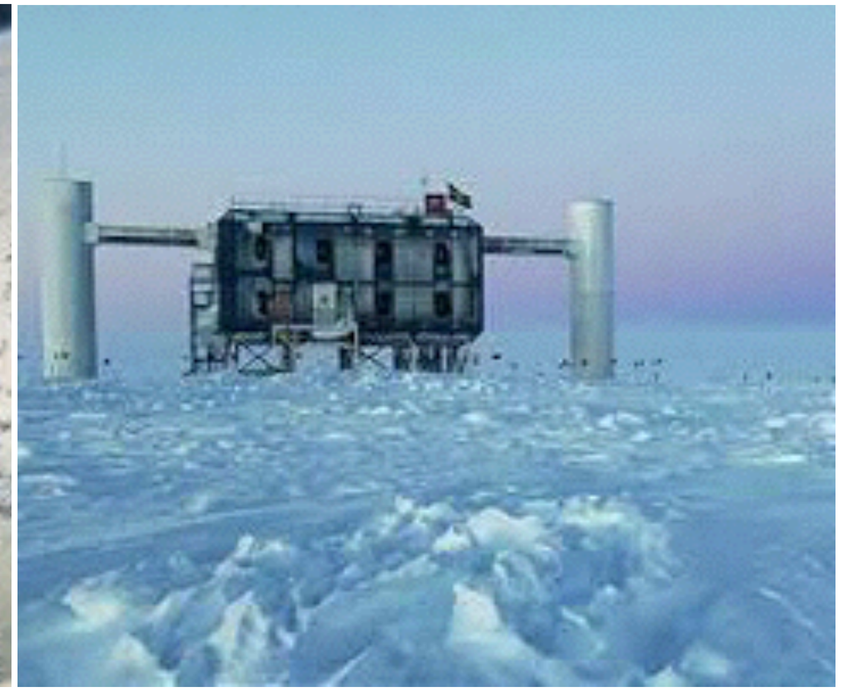


The nature of the incoming cosmic rays can be precisely identified only outside the atmosphere

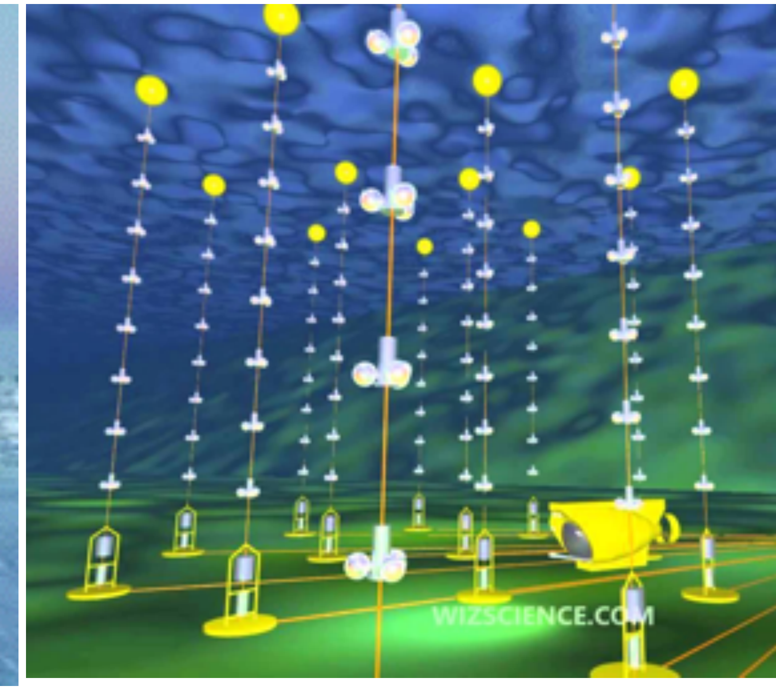
An exciting field and a lot of ambitions

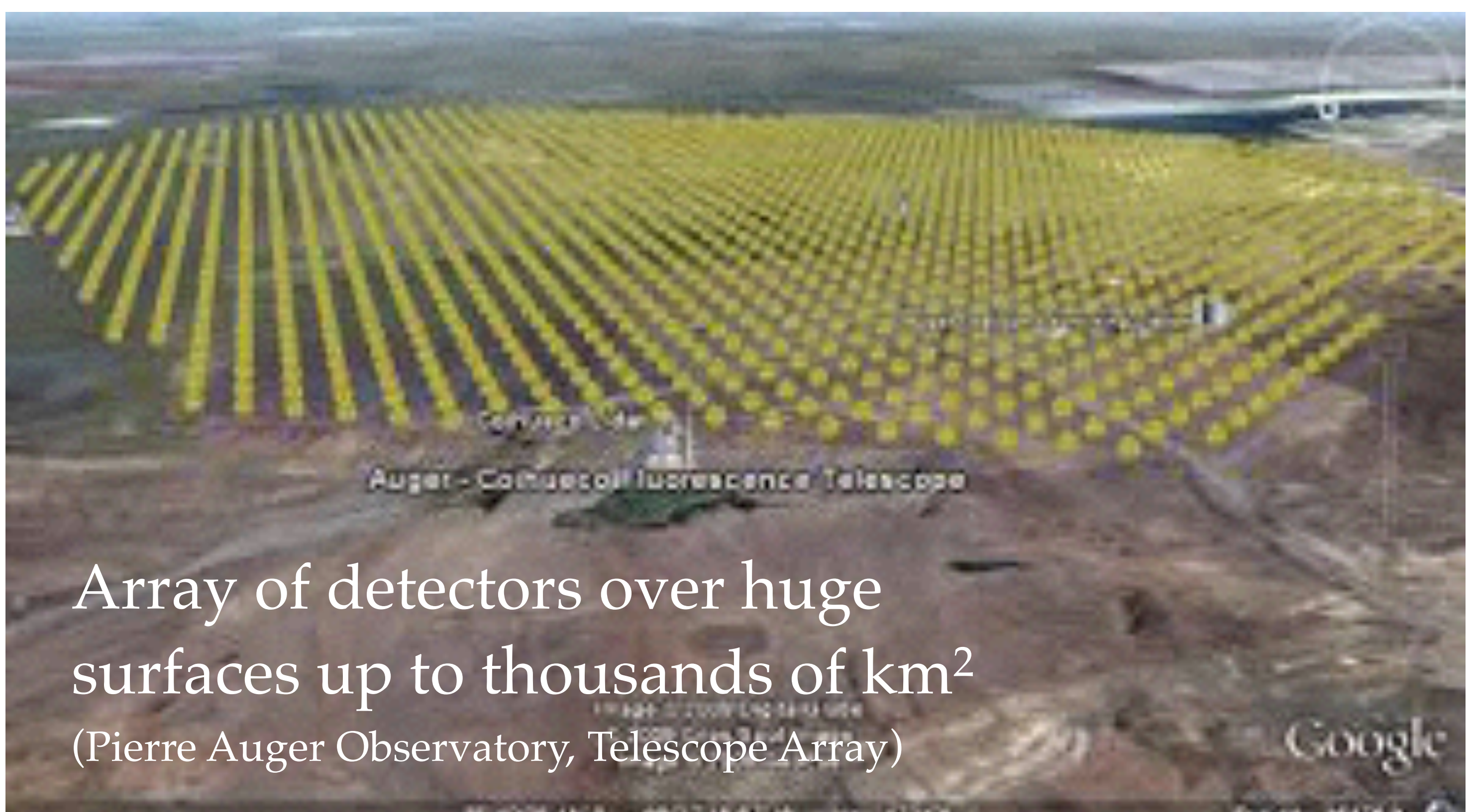
In space (satellites, ISS,…)

At the South Pole



Under water

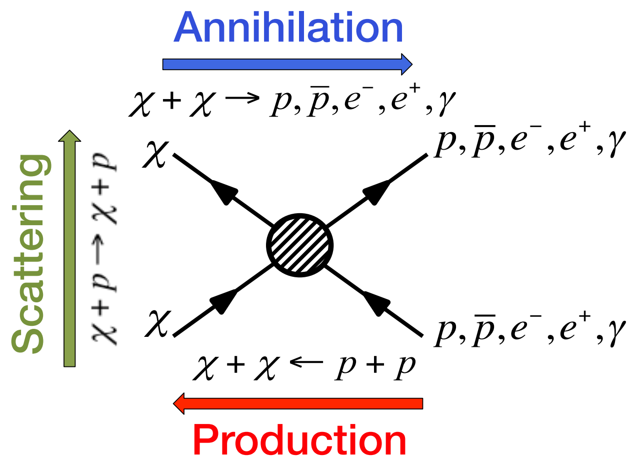


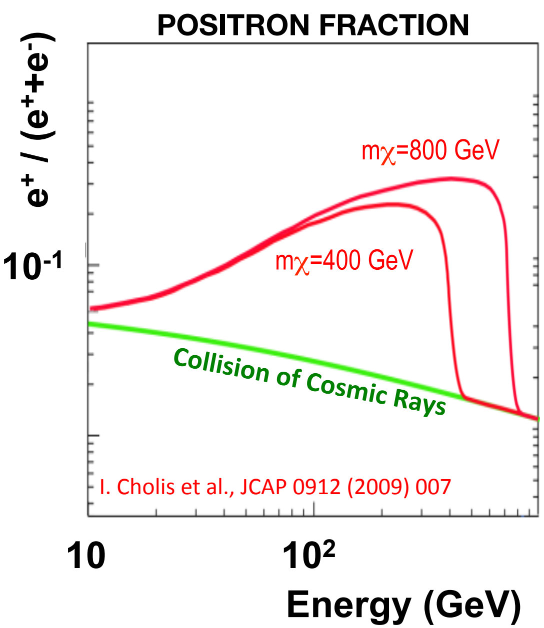


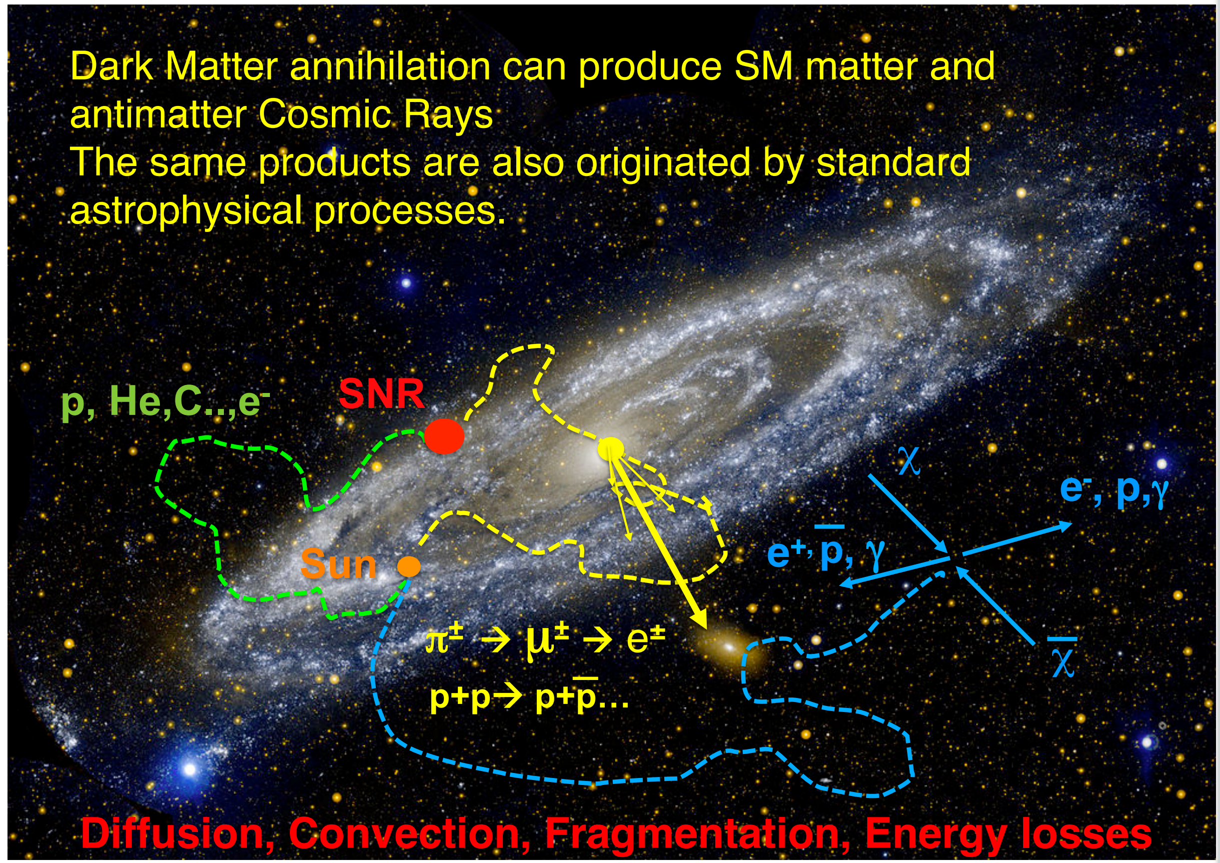
Array of detectors over huge surfaces up to thousands of km^2
(Pierre Auger Observatory, Telescope Array)

Cherenkov Telescopes in Africa, Arizona, Canarie

The quest for Dark Matter





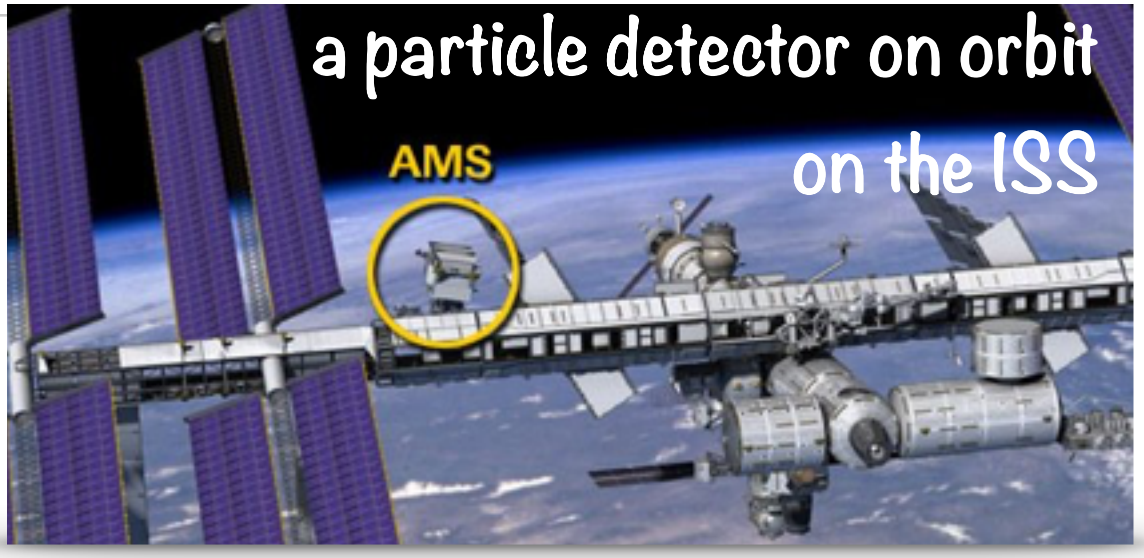


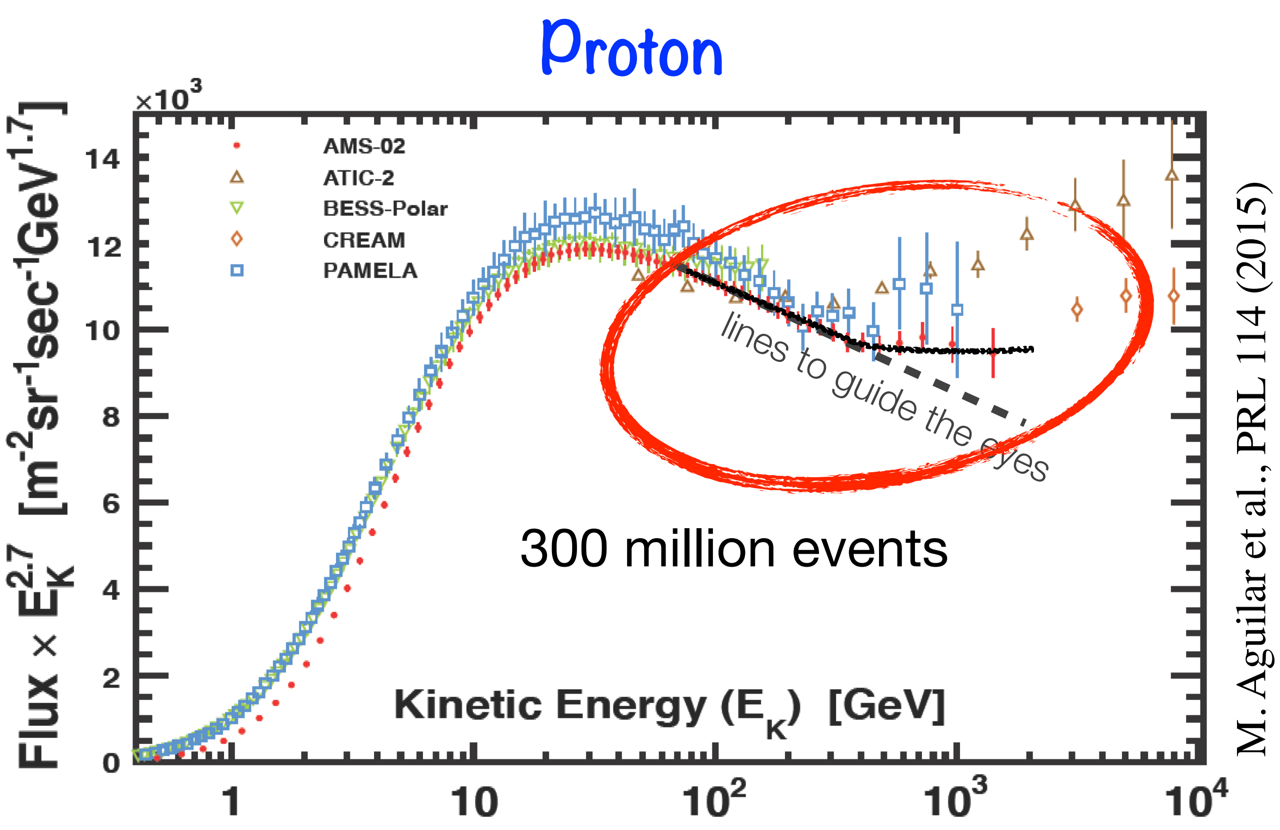
A comprehensive *standard model* of CR **origin**, **acceleration** and **propagation** is mandatory to search for antimatter excesses in CRs.

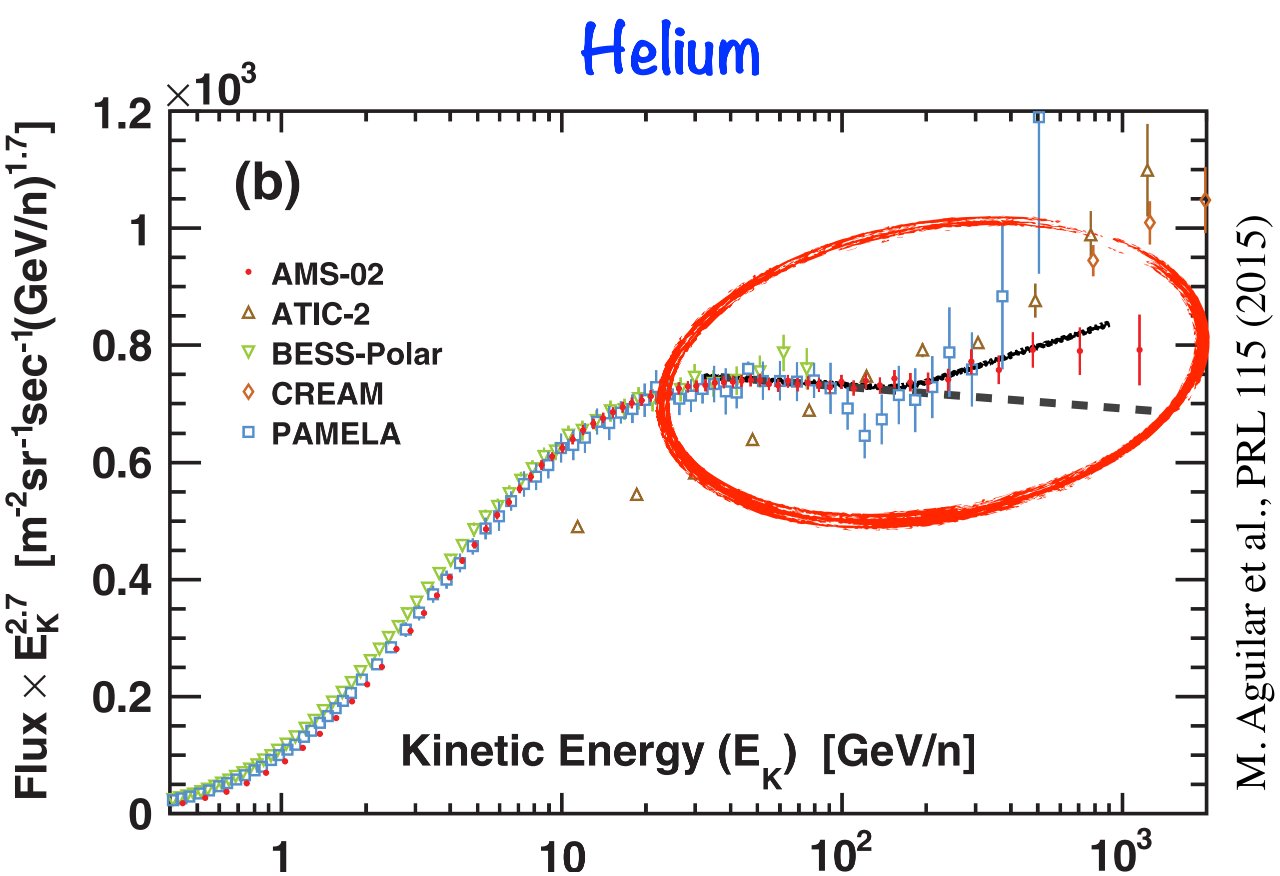
Proton and helium spectra

With 30 months of AMS-02 data

the hardening of the proton and helium spectra is confirmed





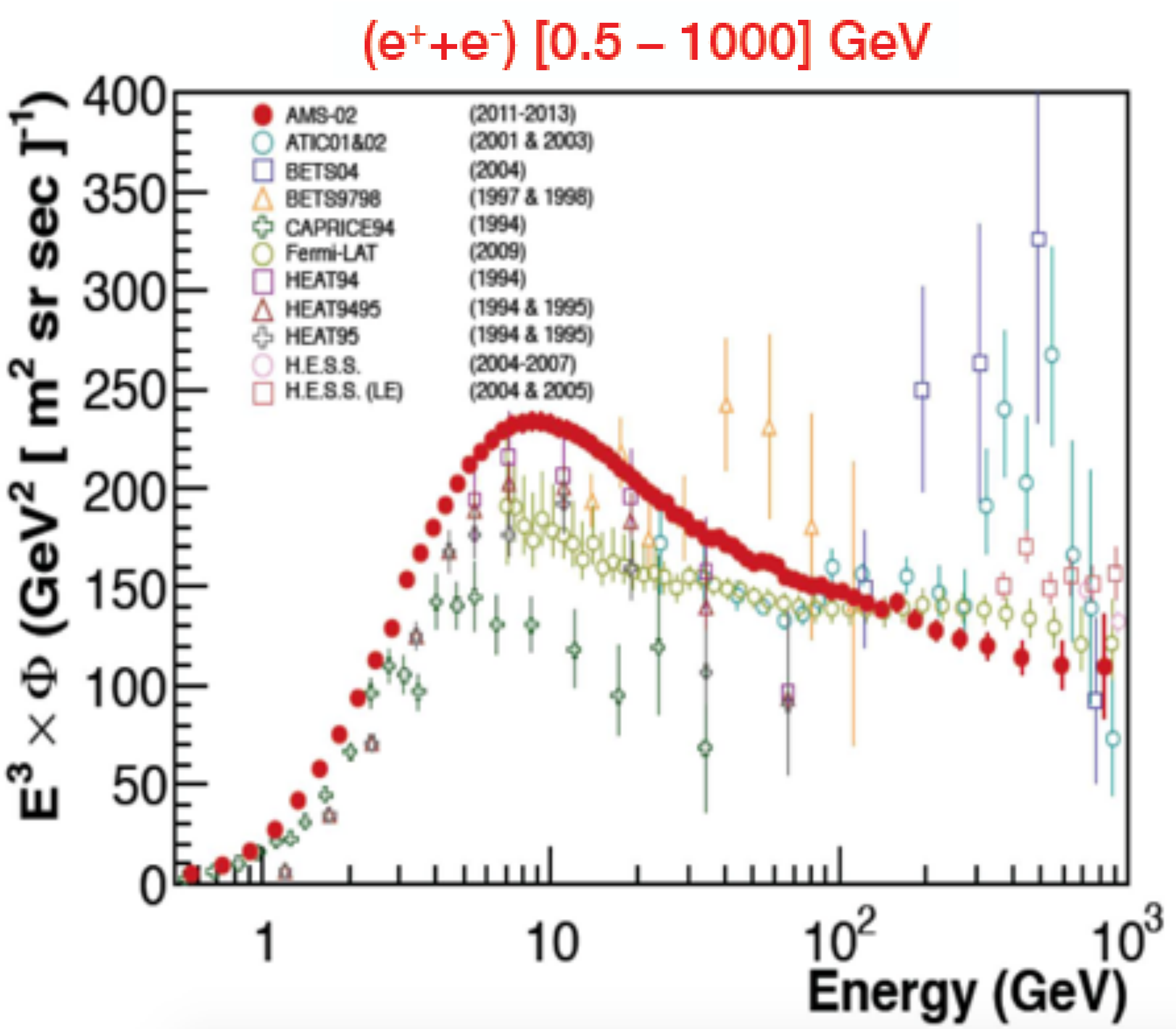


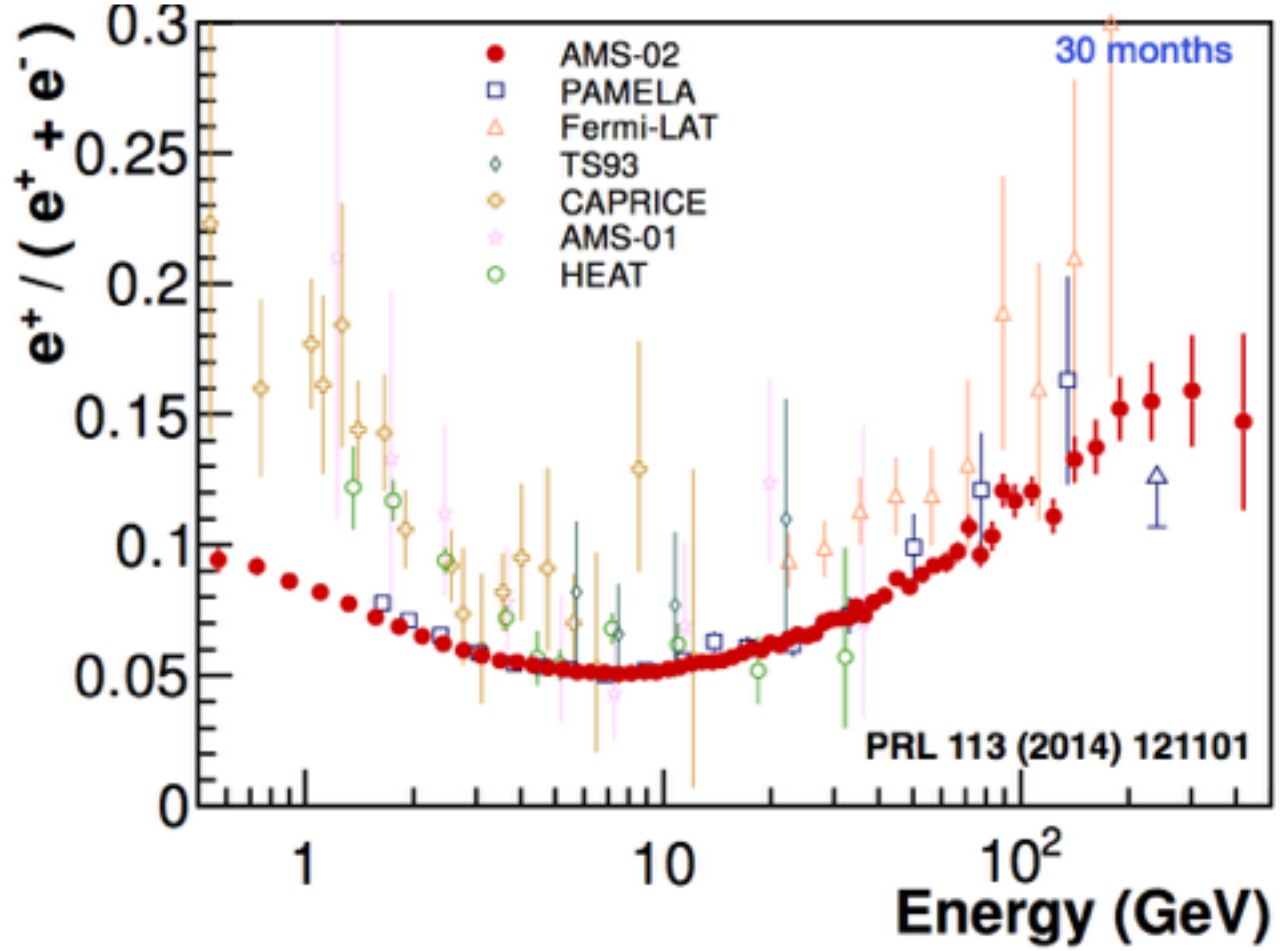
Propagation, re-acceleration, new sources?

The electron/positron fluxes

Study of cosmic ray propagation (see also B/C ratio)

Rise in the e^+/e^- ratio observed by Pamela and AMS





V. Vagelli, parallel session

Hints for Dark Matter or not-well modeled astrophysical origin?

Two observatories for UHECRs

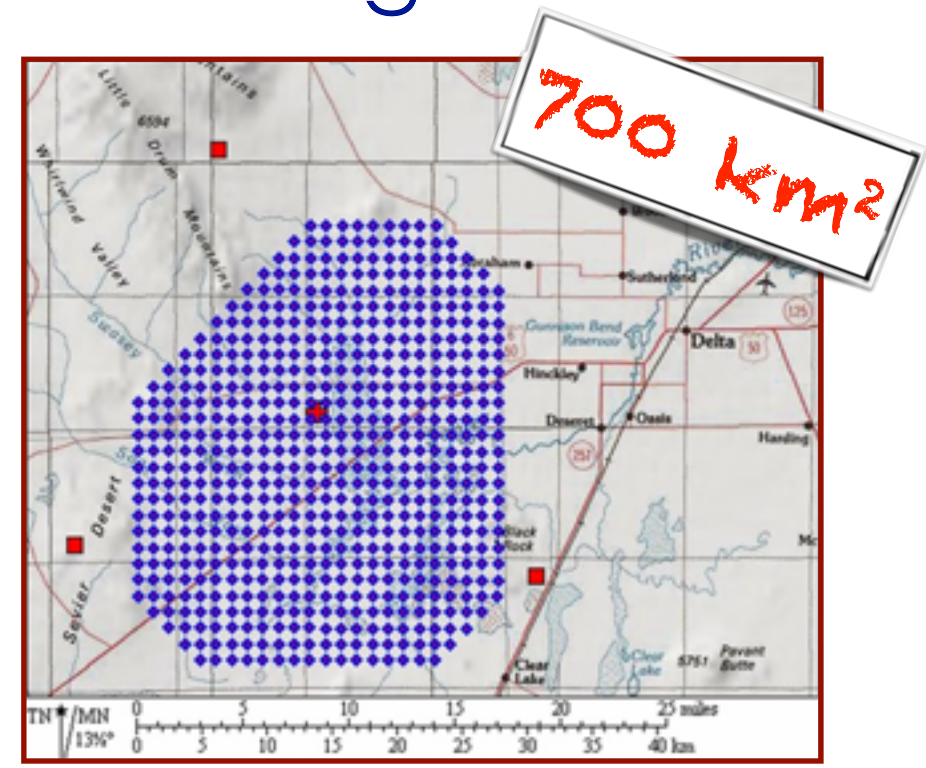
hybrid design and full sky coverage

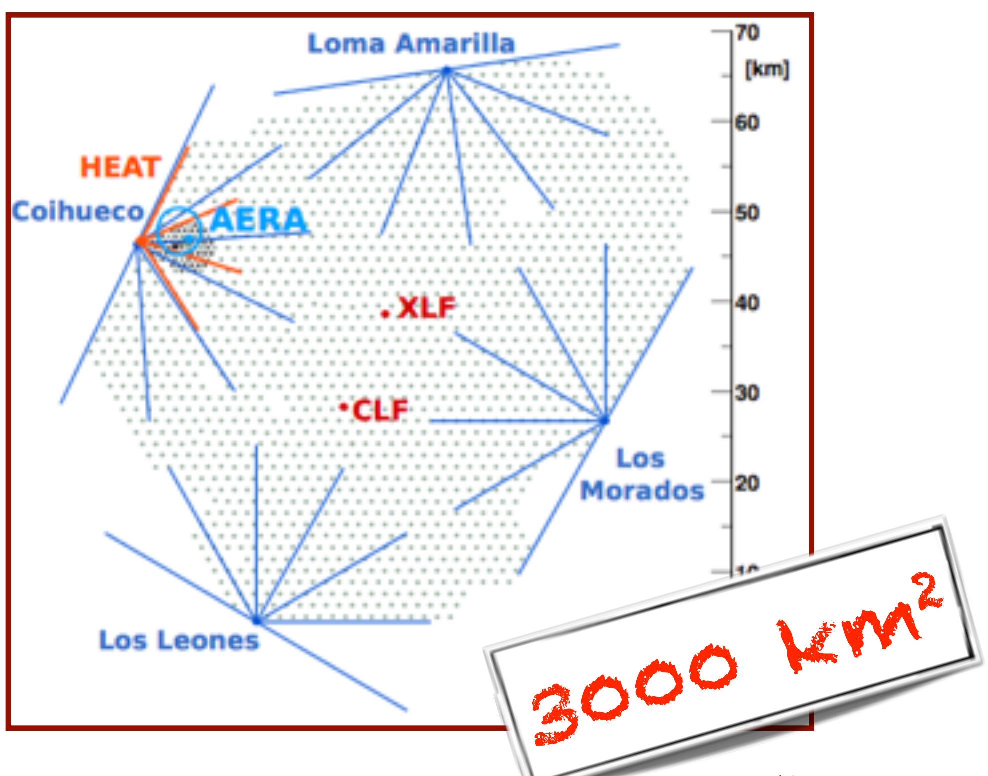
Telescope Array

Millard County, Utah, USA, 1400 m a.s.l.

507 Scintillators
($3\ m^2$ surface)

38 Fluorescence Telescopes



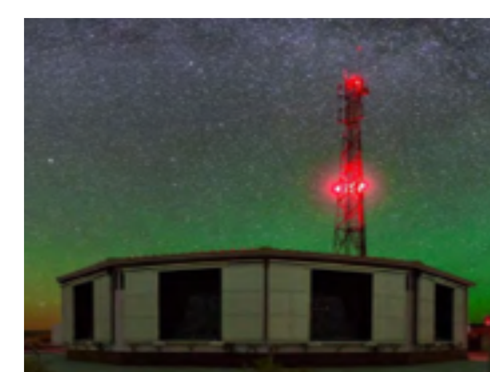


Pierre Auger Observatory

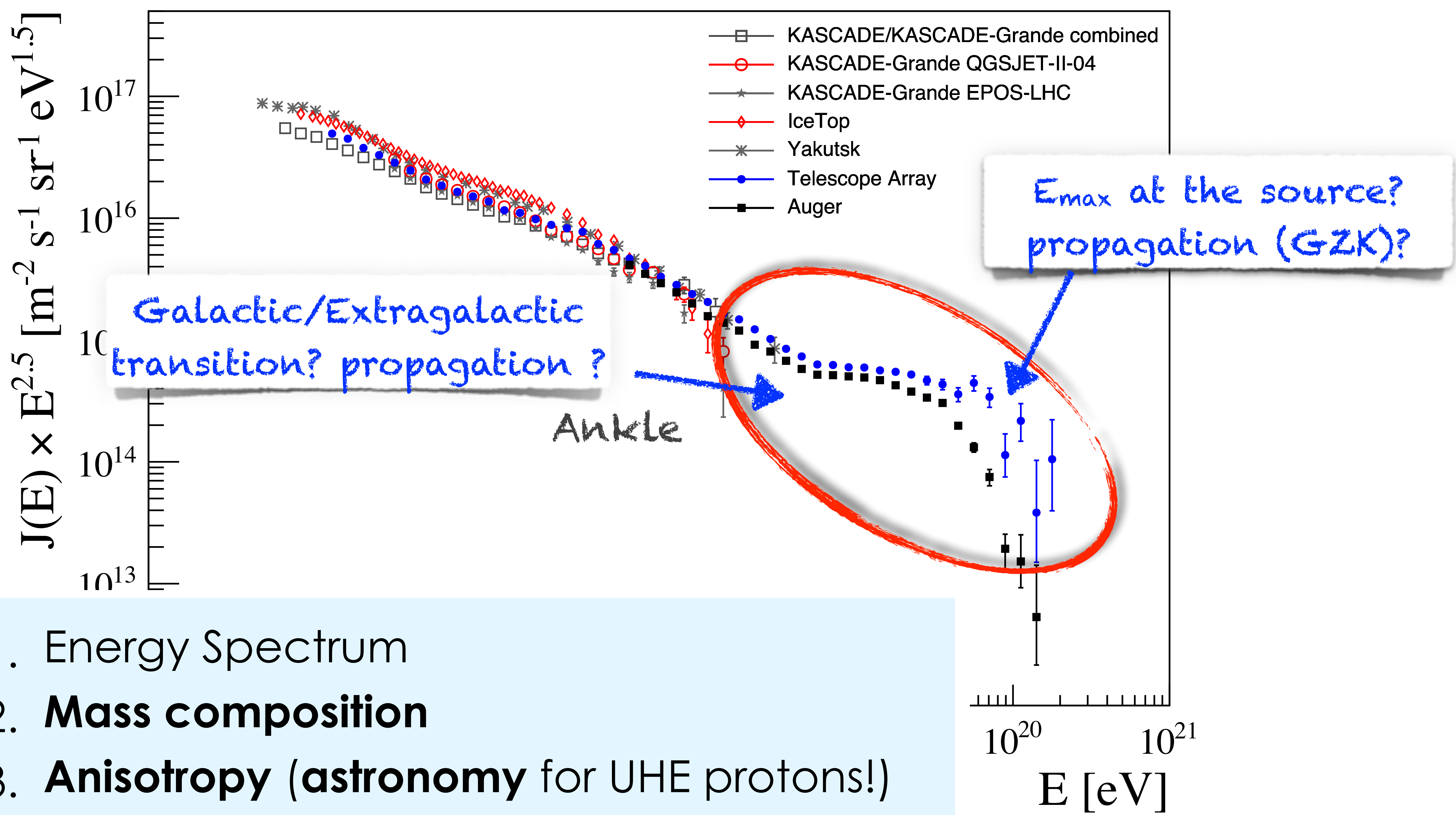
Malargue, Argentina, 1400 m a.s.l.

1660 Water Cherenkov Detectors

27 Fluorescence Telescopes

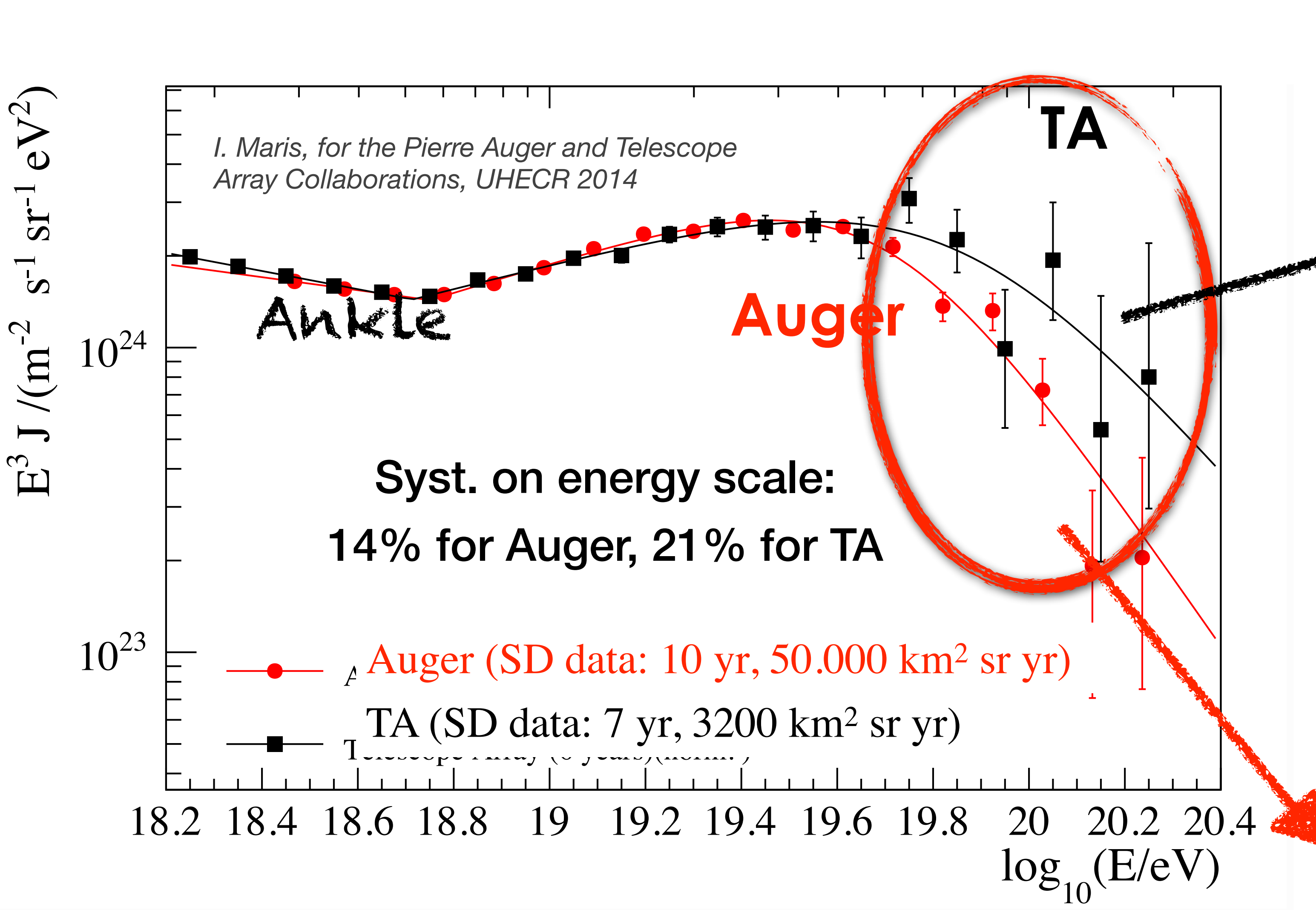


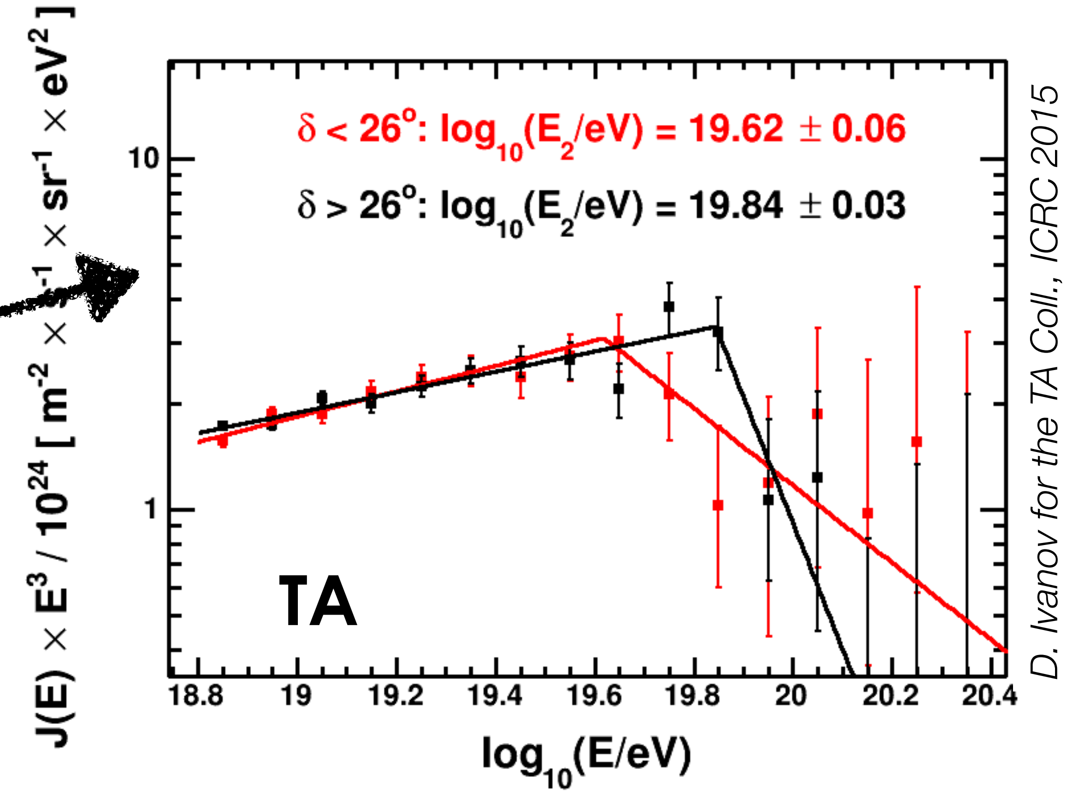
The end of the spectrum?

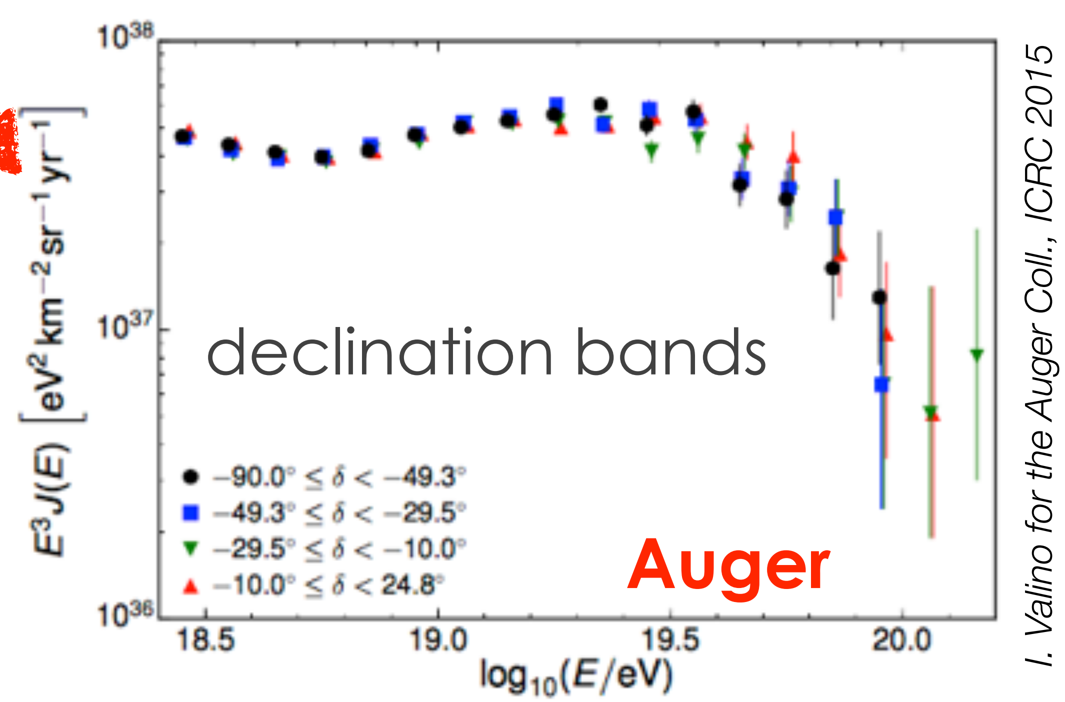


1. Energy Spectrum
2. **Mass composition**
3. **Anisotropy** (**astronomy** for UHE protons!)
4. Cosmogenic **photons and neutrinos**

Are Northern and Southern skies different?



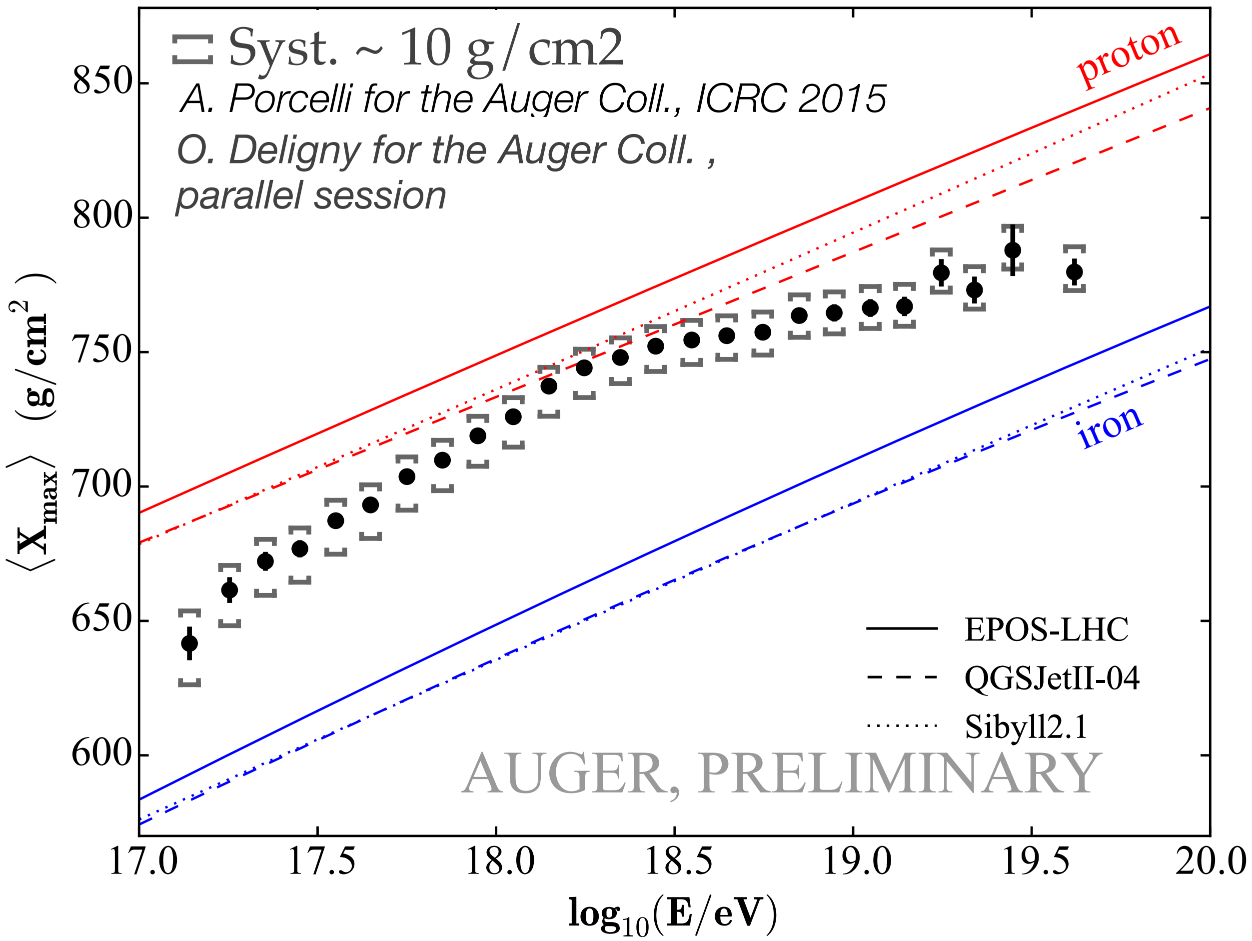




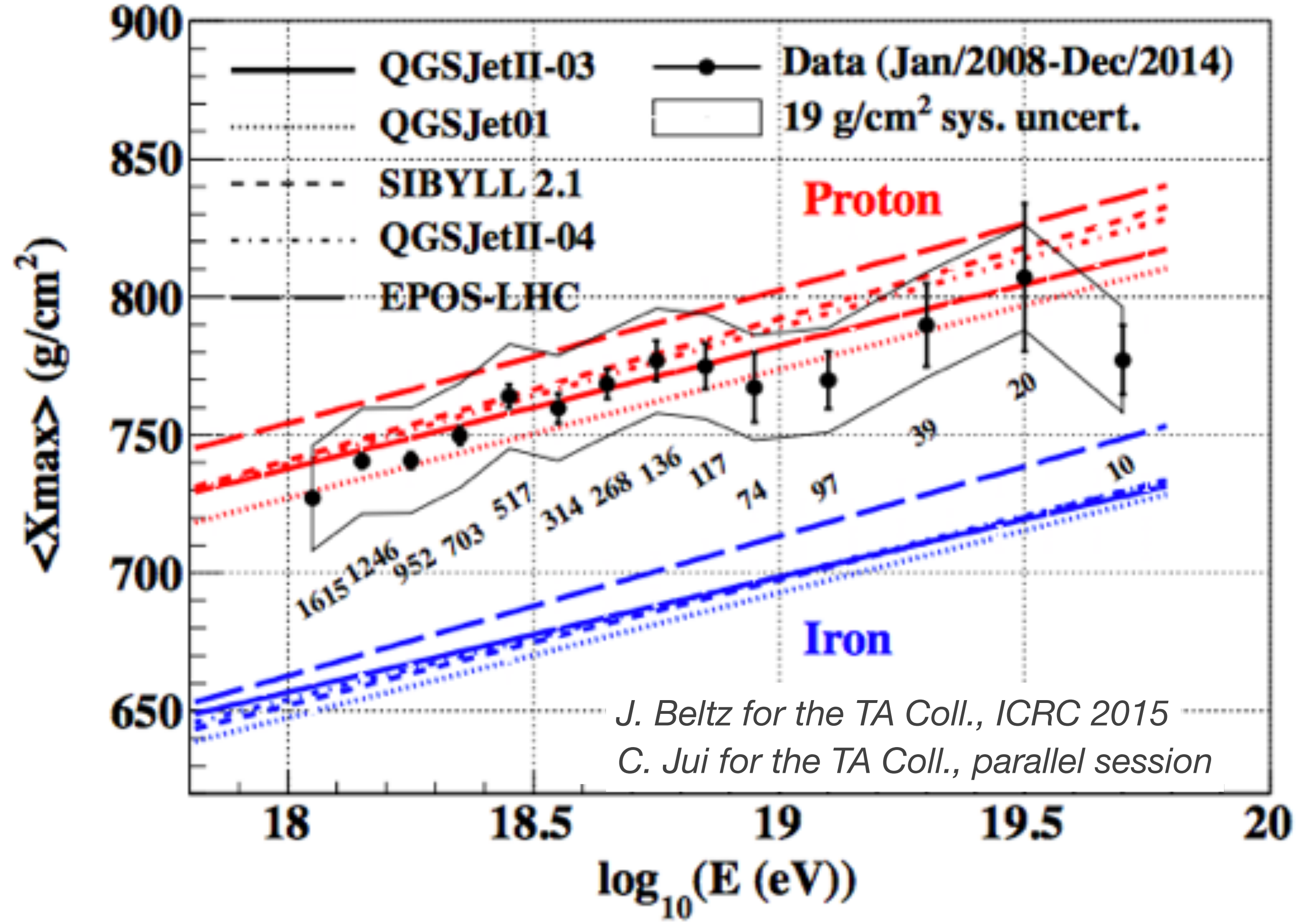
- **Ankle** position in good agreement
- **Flux suppression** at different energies **(different skies?)**

2. Mass composition:

Pierre Auger Observatory



Telescope Array



Change in composition and break point at E ~$10^{18.3}$ eV

Proton dominant composition

Auger&TA joint work: TA uncertainties too large to distinguish between the Auger-mix and a light composition

3. Anisotropy at UHE (E ≳ 55 EeV)

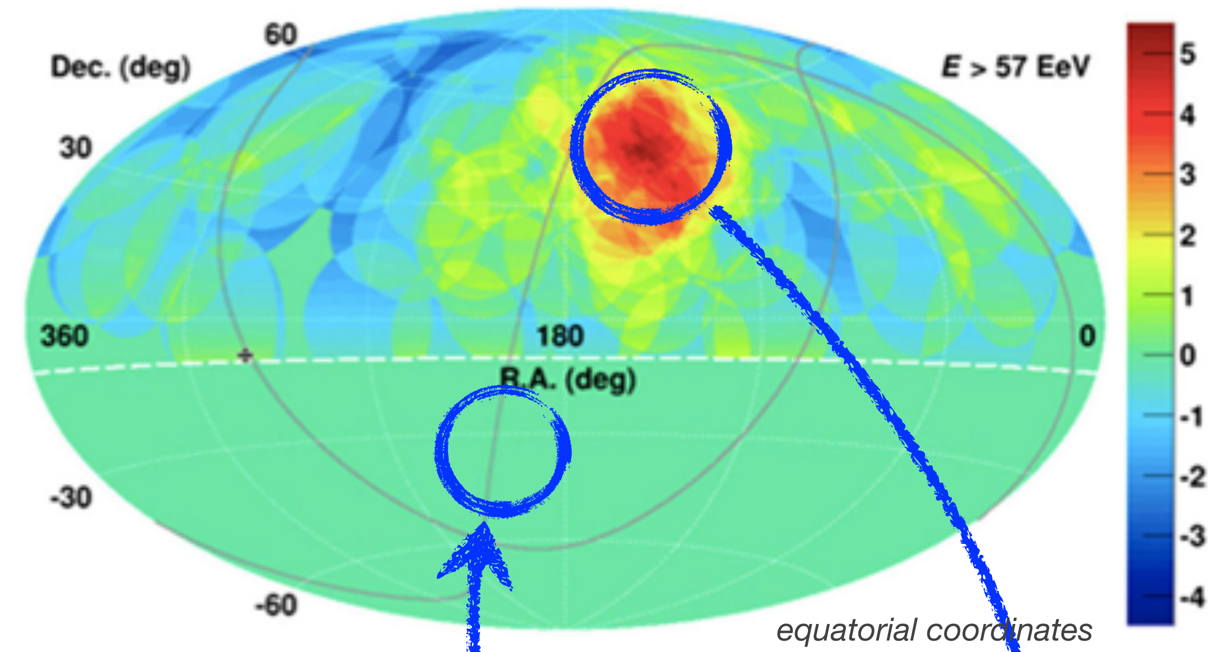
No significant deviation from isotropy at small angular scale.
Maximum significance at intermediate angular scales.

Telescope Array

Max significance: 5.1σ (pre-trial)
post-trial: 3.4 σ
E_{thr} > 57 EeV, ψ = 20°

(N_{obs} = 24, N_{bg}=6.88)

K.Kawata for the Telescope Array Collab., ICRC 2015

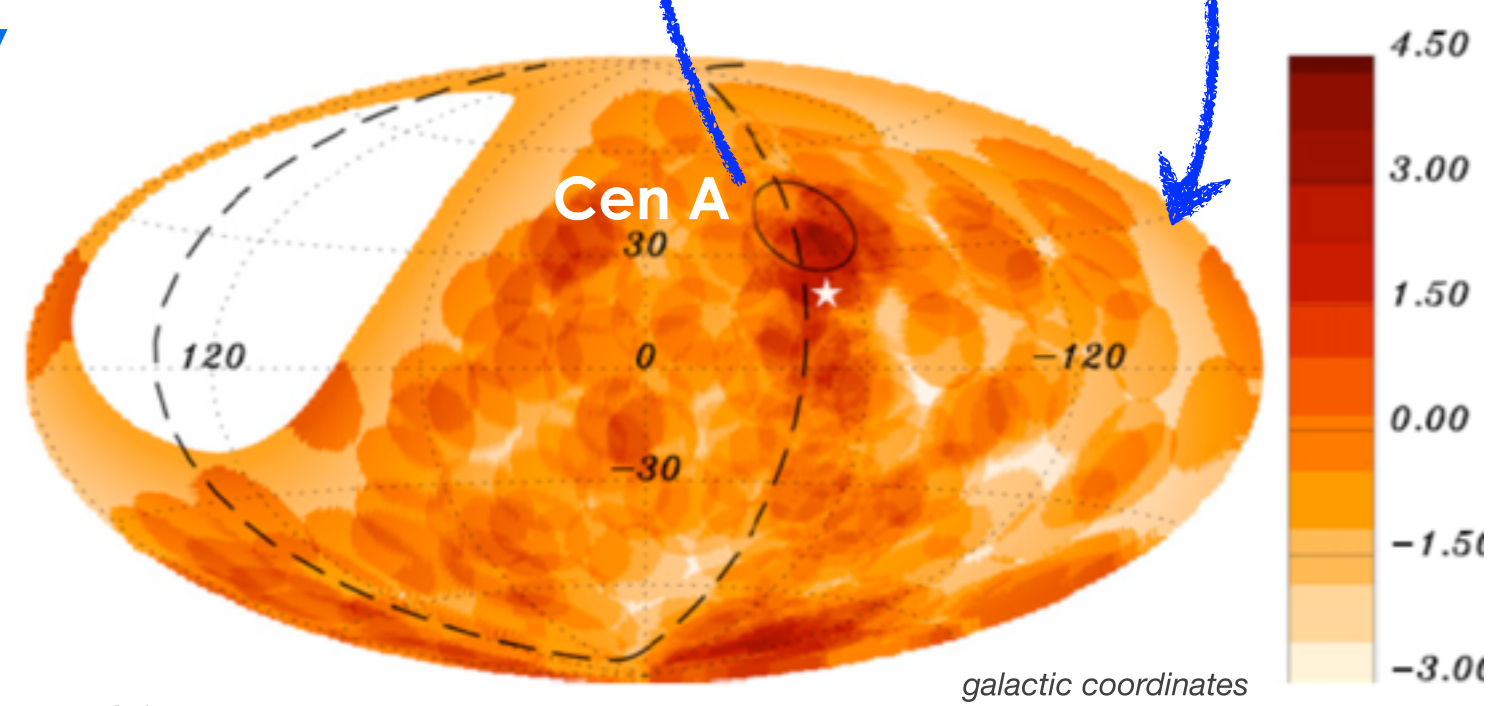


Pierre Auger Observatory

Largest excess: pre-trial 4.3 σ,
69% post-trial probability)

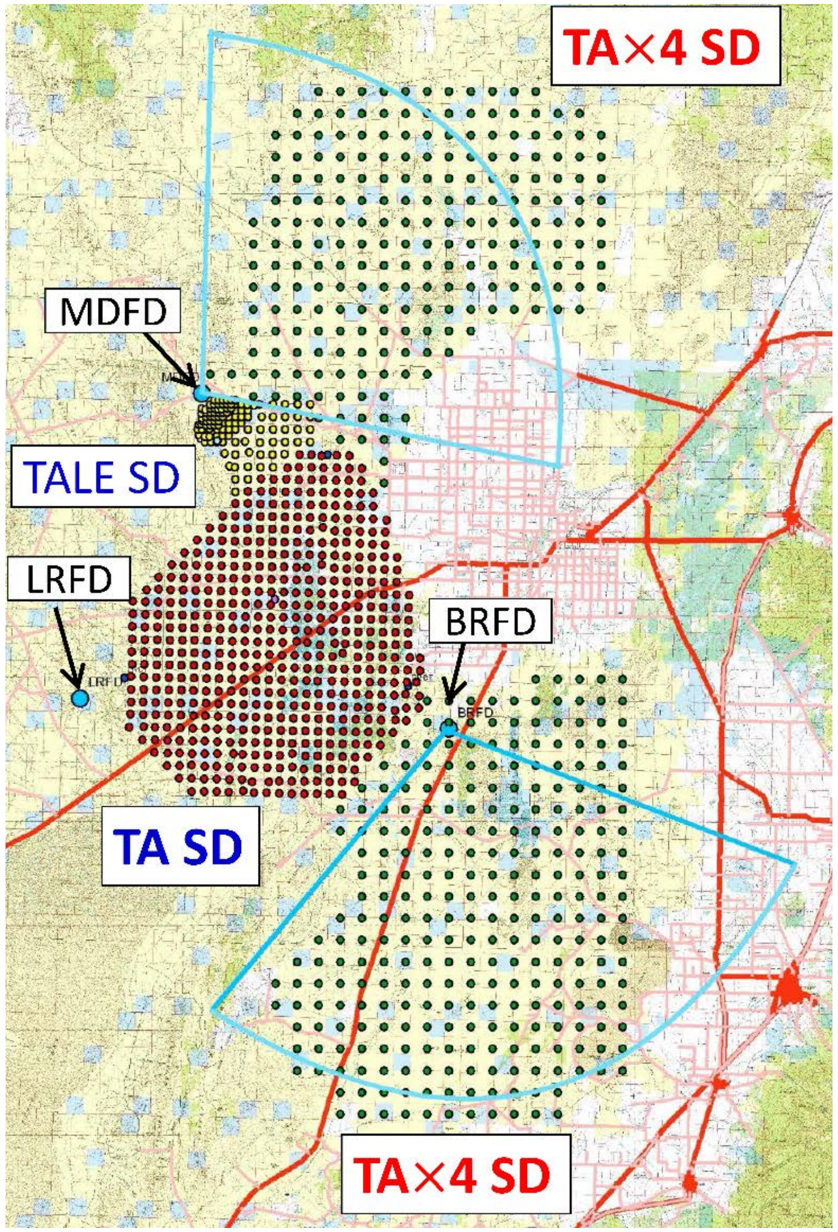
E_{thr} > 54 EeV, ψ = 12°,
N_{obs} = 14 / N_{bg} = 3.23

The Pierre Auger Collaboration, ApJ, 804 , 15, (2015)
J. Aublin for the Auger Coll., ICRC 2015



Whats's next?

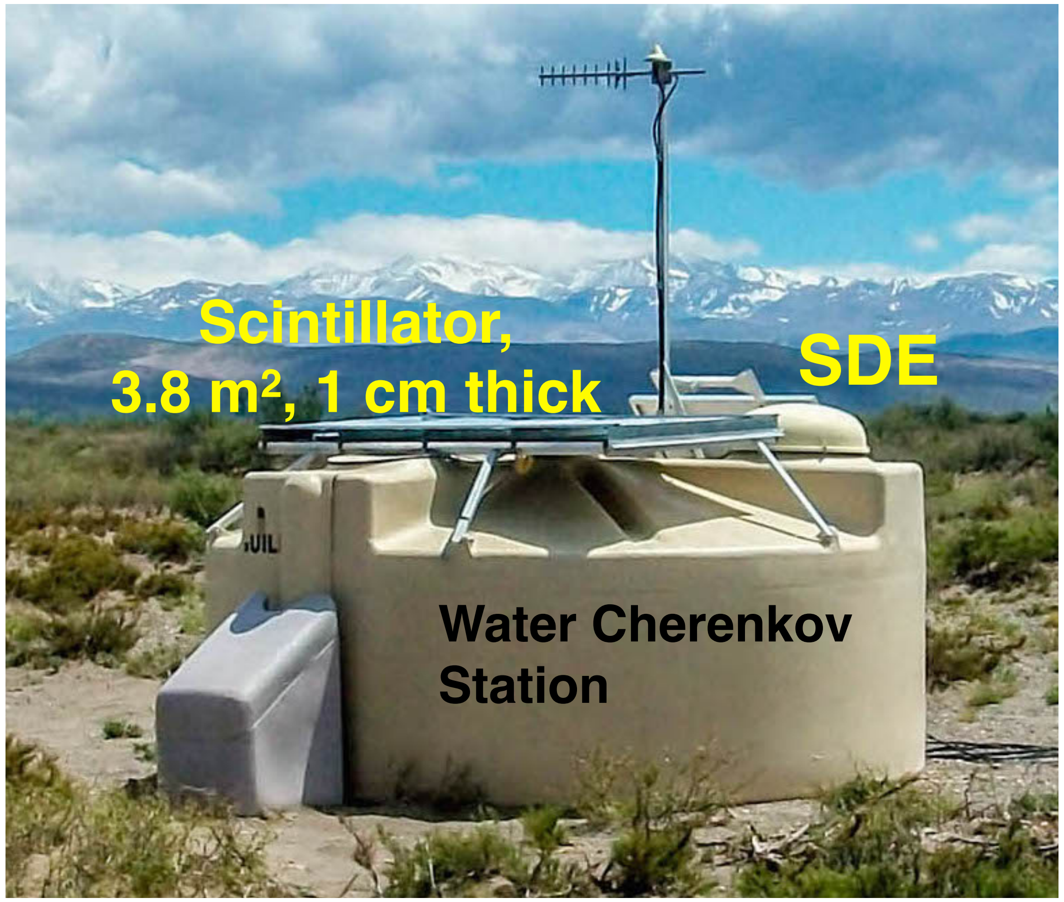
TA extension to ~ 3000 km^2



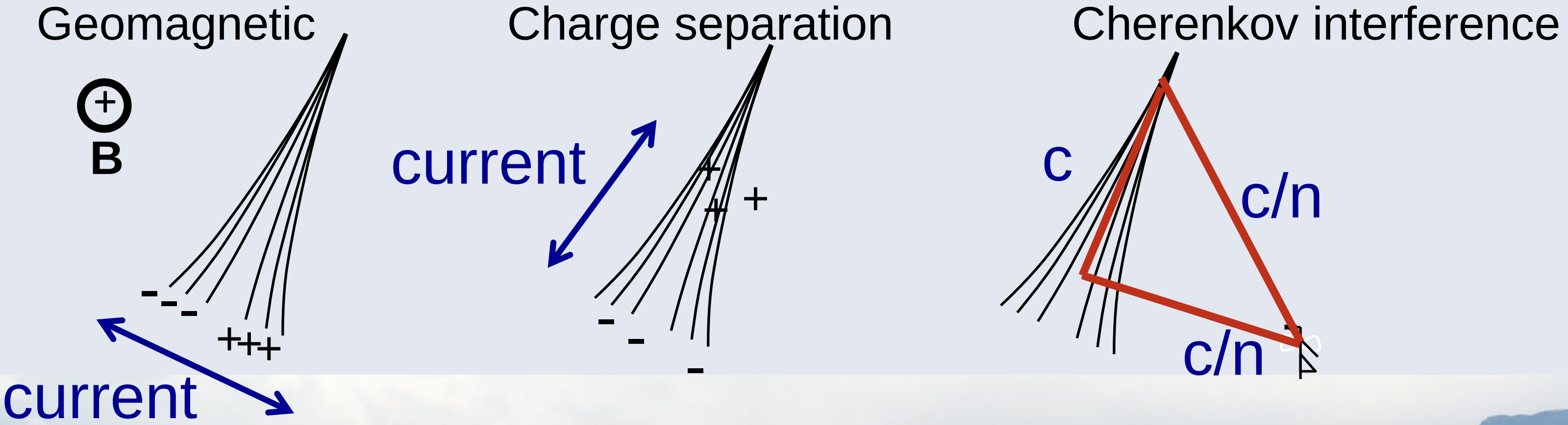
- **Hot-spot** at > 5 σ
- Statistics for **mass composition** and **energy spectrum** at highest energies

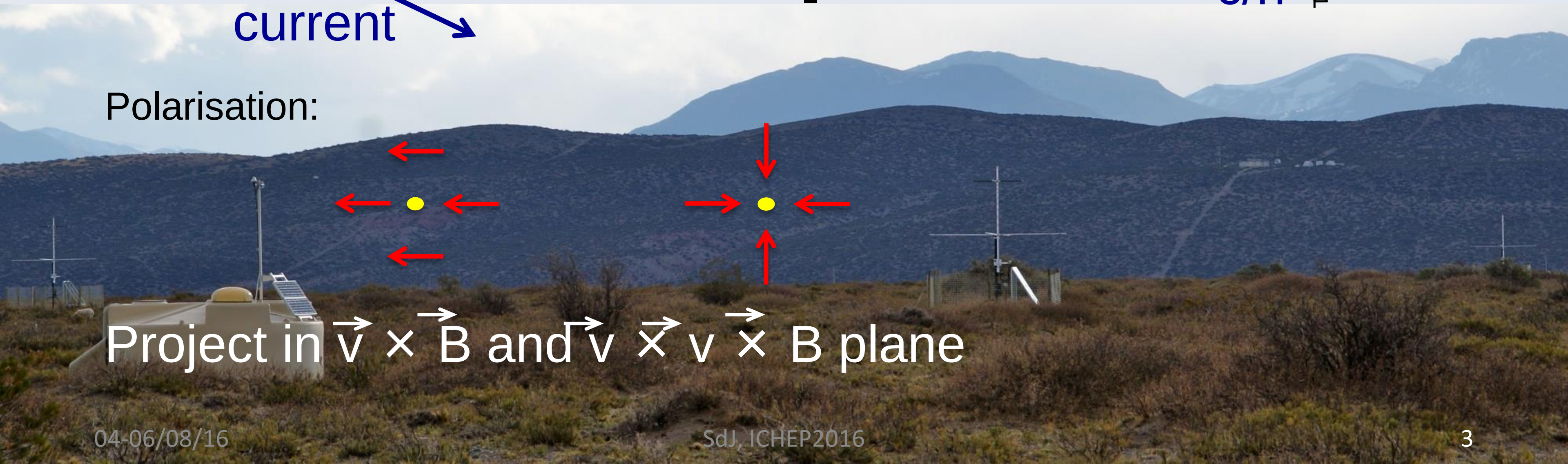
AugerPrime

- **Muon content and mass composition**
- Origin of the **flux suppression**
- Search **proton flux** (test **astronomy** for future detectors)
- **Hadronic models** and EAS physics



Radio Detection of (Ultra-)High-Energy Cosmic Rays





Polarisation:

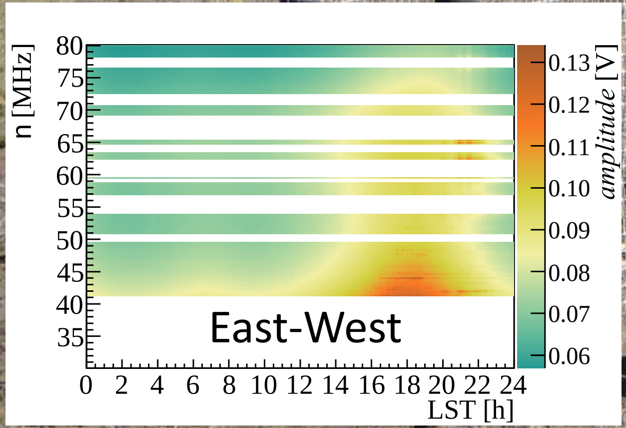
Project in $\vec{v} \times \vec{B}$ and $\vec{v} \times \vec{v} \times \vec{B}$ plane

The Auger Engineering Radio Array (AERA)

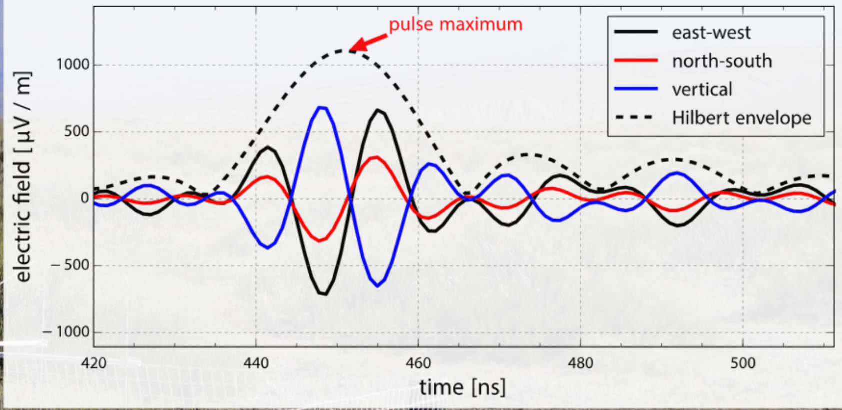
Calibration:

$$U_{\substack{\text{North-South}\\\text{East-West}}} = \vec{\vec{H}}_{\substack{\text{North-South}\\\text{East-West}}} \vec{E}$$

- Calculation/simulation
- Octocopter calibration
- Galactic center calibration



Signal treatment



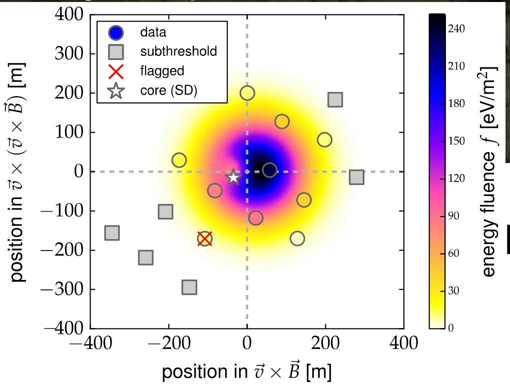
(Absolute) 30-80 MHz radio energy density:

$$\varepsilon = \varepsilon_0 c \left[\underbrace{\sum_{t_i=t_1}^{t_2} \left|\vec{E}(t_i)\right|^2 \Delta t}_{\text{signal region}} - \frac{t_4 - t_3}{t_2 - t_1} \underbrace{\sum_{t_i=t_3}^{t_4} \left|\vec{E}(t_i)\right|^2 \Delta t}_{\text{background region}} \right] \ \mathrm{eV/m^2}$$

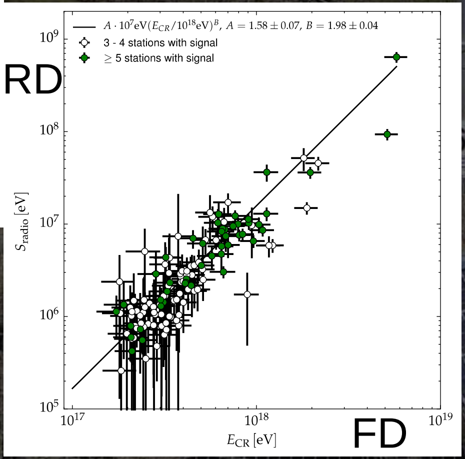
Radio detection results: Energy measurements

$$\varepsilon(\vec{r}) = A\left[e^{-\left(\vec{r}+C_1\vec{e}_{\vec{v}\times\vec{B}}-\vec{r}_{core}\right)^2/\sigma^2} - C_0\, e^{-\left(\vec{r}+C_2\vec{e}_{\vec{v}\times\vec{B}}-\vec{r}_{core}\right)^2/\left(C_3 e^{C_4\sigma}\right)^2} \right] \ \mathrm{eV/m^2}$$

$C_0 \ldots C_4$ zenith angle dependent determined from CoREAS MC; fit: A, r_{core}, σ;



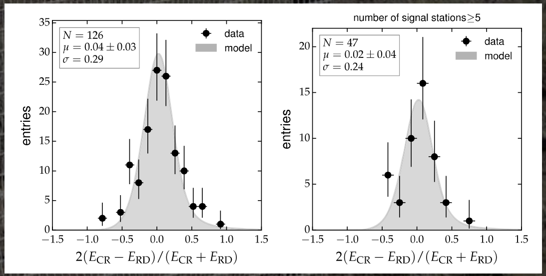
Energy estimator: $S_{radio} = \frac{1}{\sin^2\alpha}\int \varepsilon(\vec{r})\,d\vec{r} = \frac{A\pi}{\sin^2\alpha}\left[\sigma^2 - C_0 C_3^2 e^{2C_4\sigma}\right]$ eV



Energy in 30-80MHz radio emission:

$$E_{30\text{-}80\mathrm{MHz}} = (15.8 \pm 0.7 \pm 6.7)\ \mathrm{MeV}\left(\sin\alpha \frac{E_{\mathrm{Cosmic\ Ray}}}{10^{18}\ \mathrm{eV}} \frac{B_{\mathrm{Earth}}}{0.24\ \mathrm{G}}\right)^2$$

Resolution:



σ/E= 29% 24% (FD≈20%)

Compare to Fluorescence det:

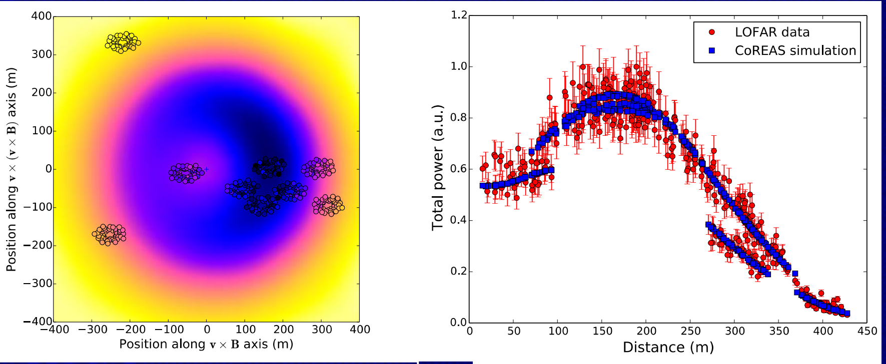
PRL 116 (2016) 241101
PRD 93, (2016) 122005

Radio detection results: X_{max} measurement

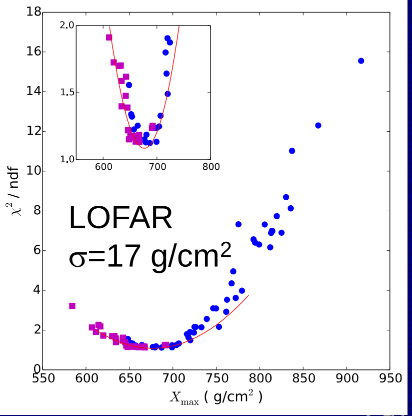
- Simulated LDF method:

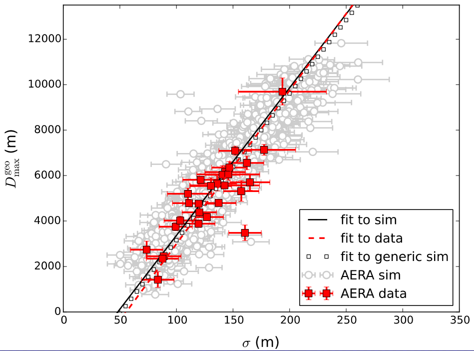
CoREAS to simulate same shower

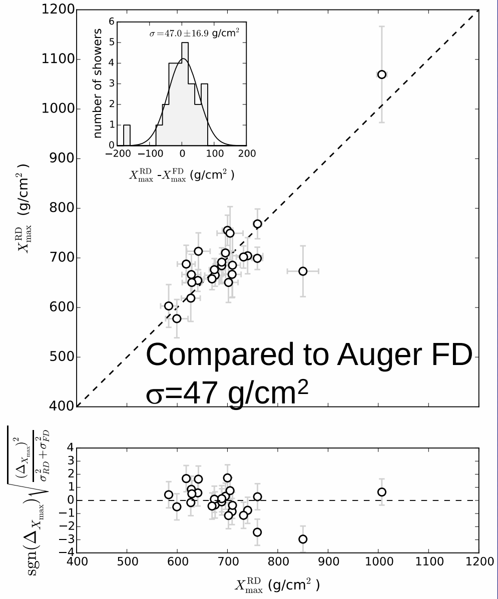
LDF fit parameter σ most sensitive to X_{max}



LOFAR: PRD 90 (2014) 082003







AERA:
PhD thesis Johannes Schulz, 2015,
Radboud University Nijmegen

UHE Neutrino detection via the Askaryan effect

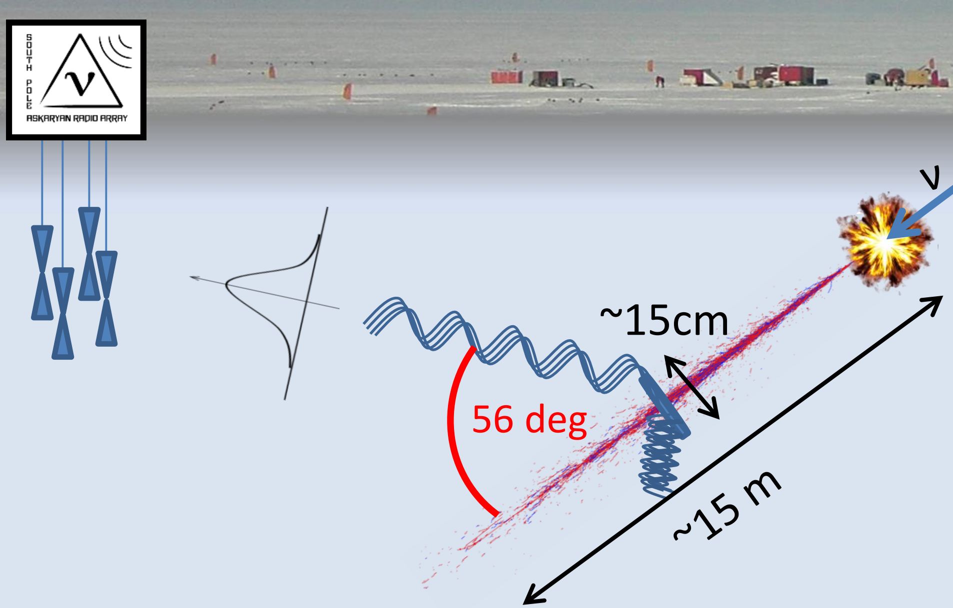
The Askaryan effect:

An excess negative charge (~20%) built up in neutrino induced cascades through:

- **Compton scattering**
- **Other ionizing effects**

→ Moving current, emits electromagnetic radiation

→ Coherent for radio wavelength



The advantages of radio waves:

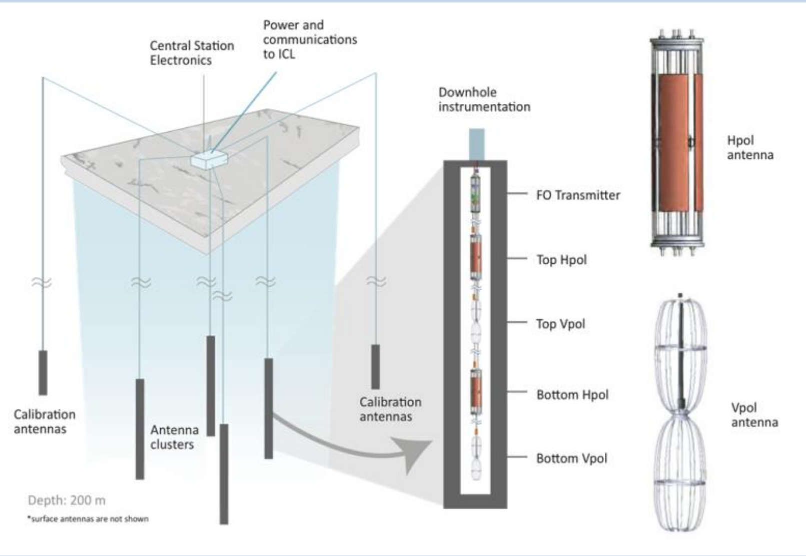
- visible within ~1 km in ice

→ Observe big detector volume with few sensors

→ **Very cost efficient**

→ **Effect has been verified in beam tests:** arXiv:hep-ex/0611008

The Askaryan Radio Array (ARA)

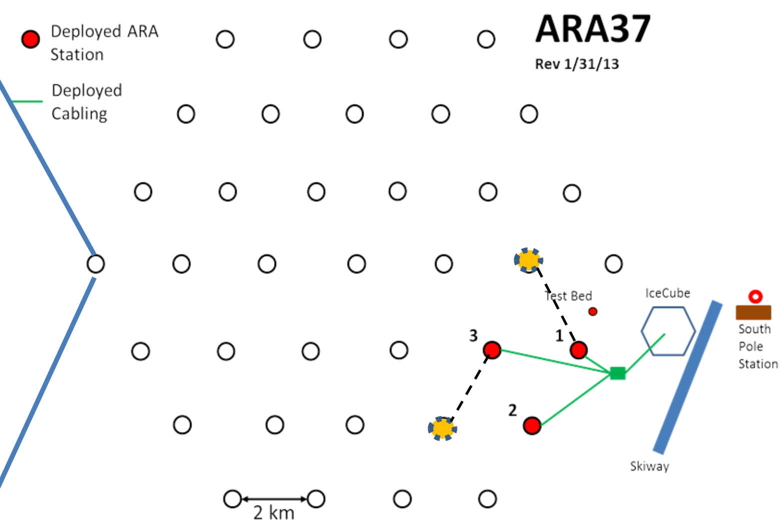


One station:

- **Measurement system:**
  - 4 holes, 20 m spacing
  - Deployed at depth of 180 m
  - 16 antennas, 150 MHz – 850 MHz (8 horizontally polarized., 8 vertically pol.)
- **Calibration system:** 4 pulsing antennas

Each station is an autonomous detector!

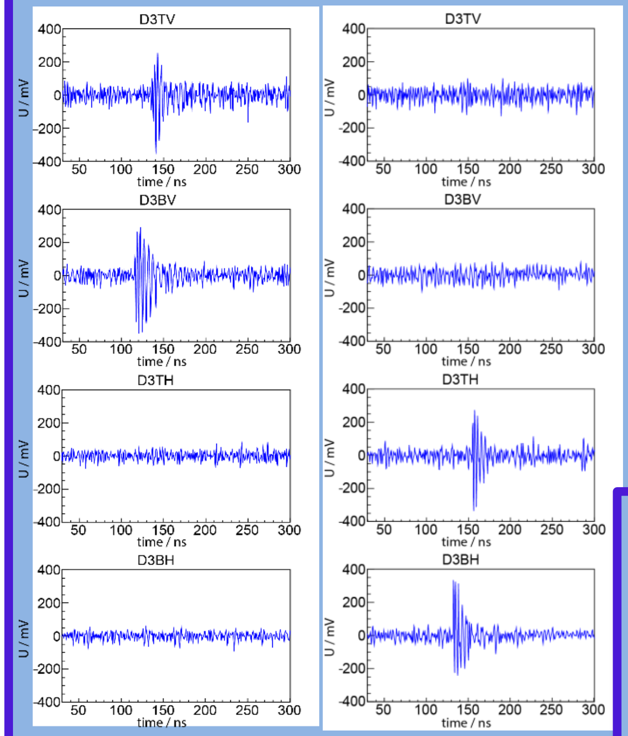
- 37 antenna stations planned (7-8M$)
- spaced by 2 km
  → **Maximizing effective volume by avoiding overlap**
- 180m Depth to avoid **ray bending effects**



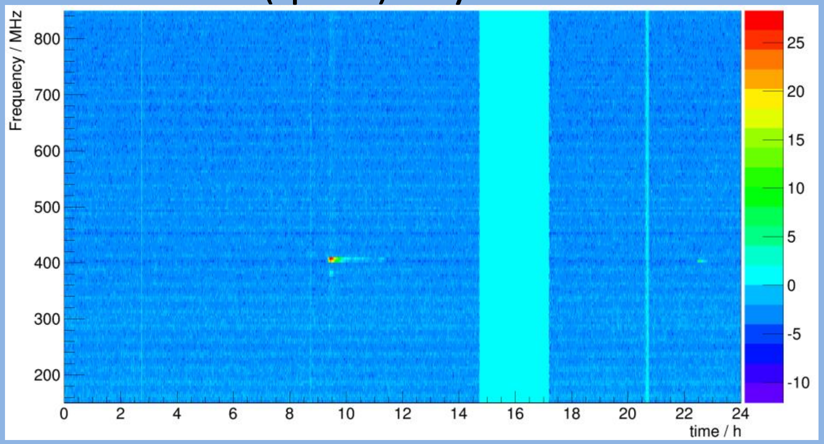
- Prototype station: Testbed, first results: [arXiv:1404.5285]
- 3 deep stations deployed and operating at the current date
- 2 additional stations funded for 17/18 deployment

The detector performance

A calibration signal on ARA03

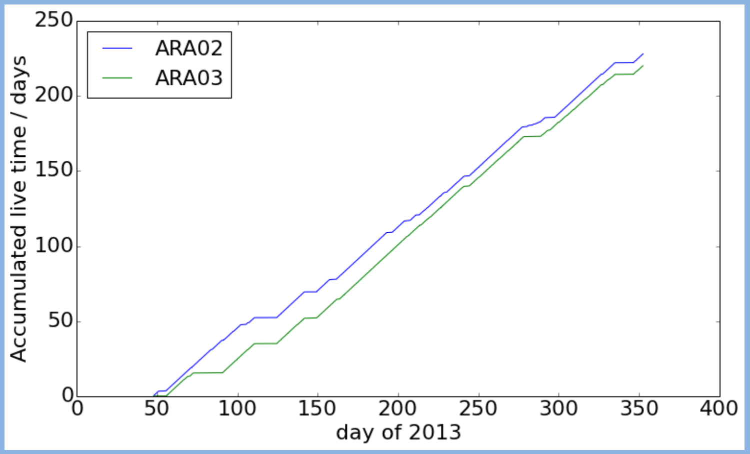


Winter (quiet) day in ARA03

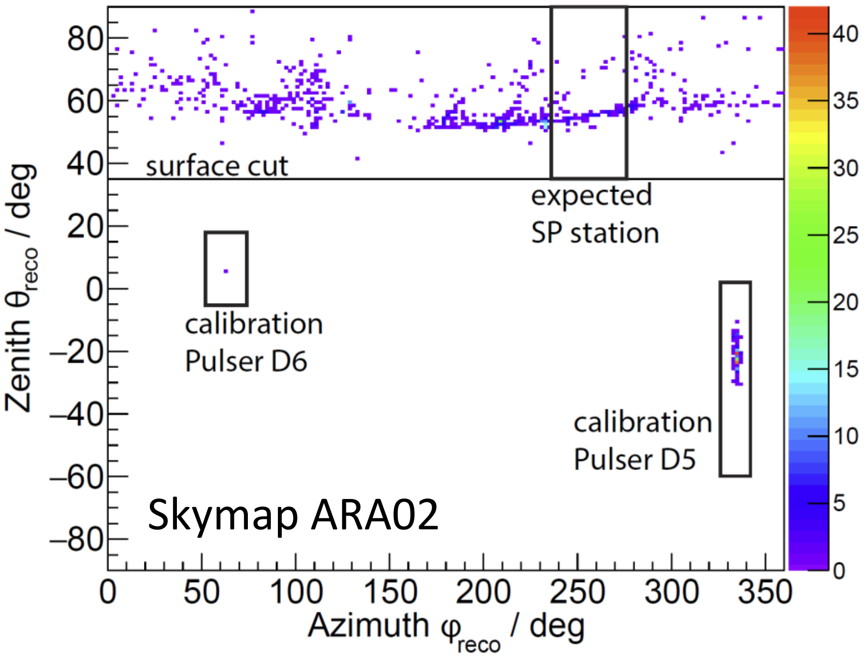


Accumulated ~224 days of live time in 10 months

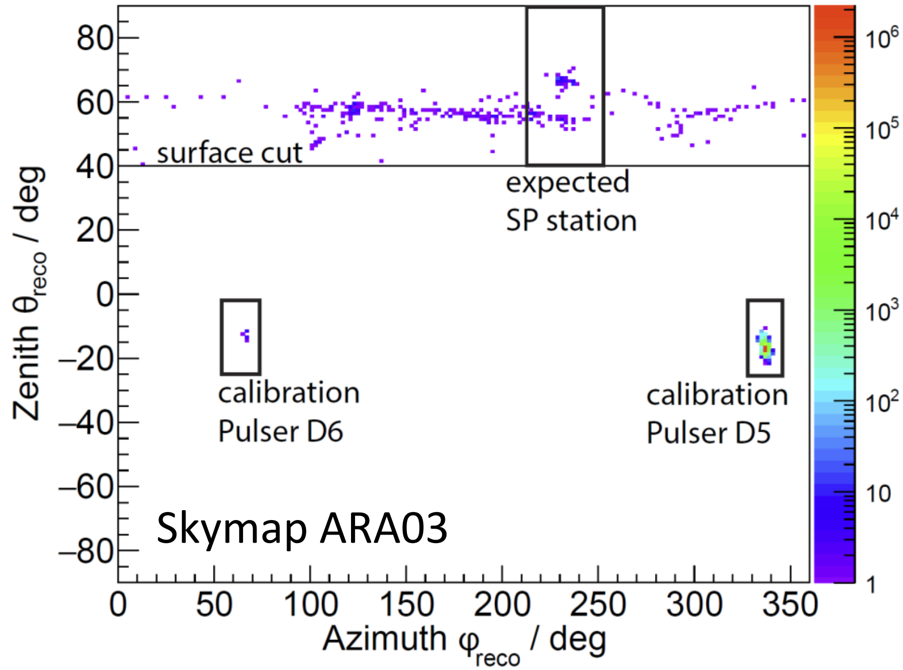
31 of 32 channels performing well

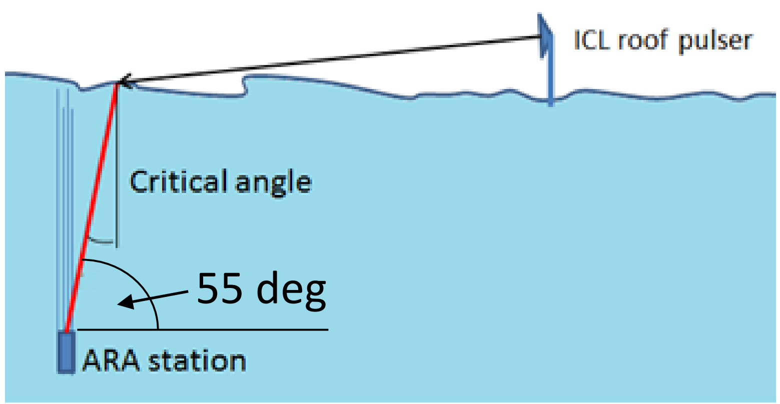


Results

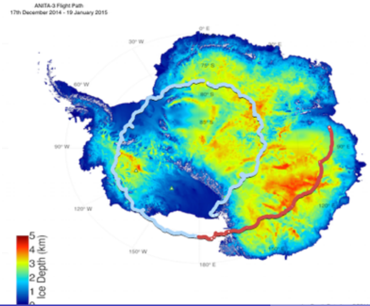


No event in signal region!





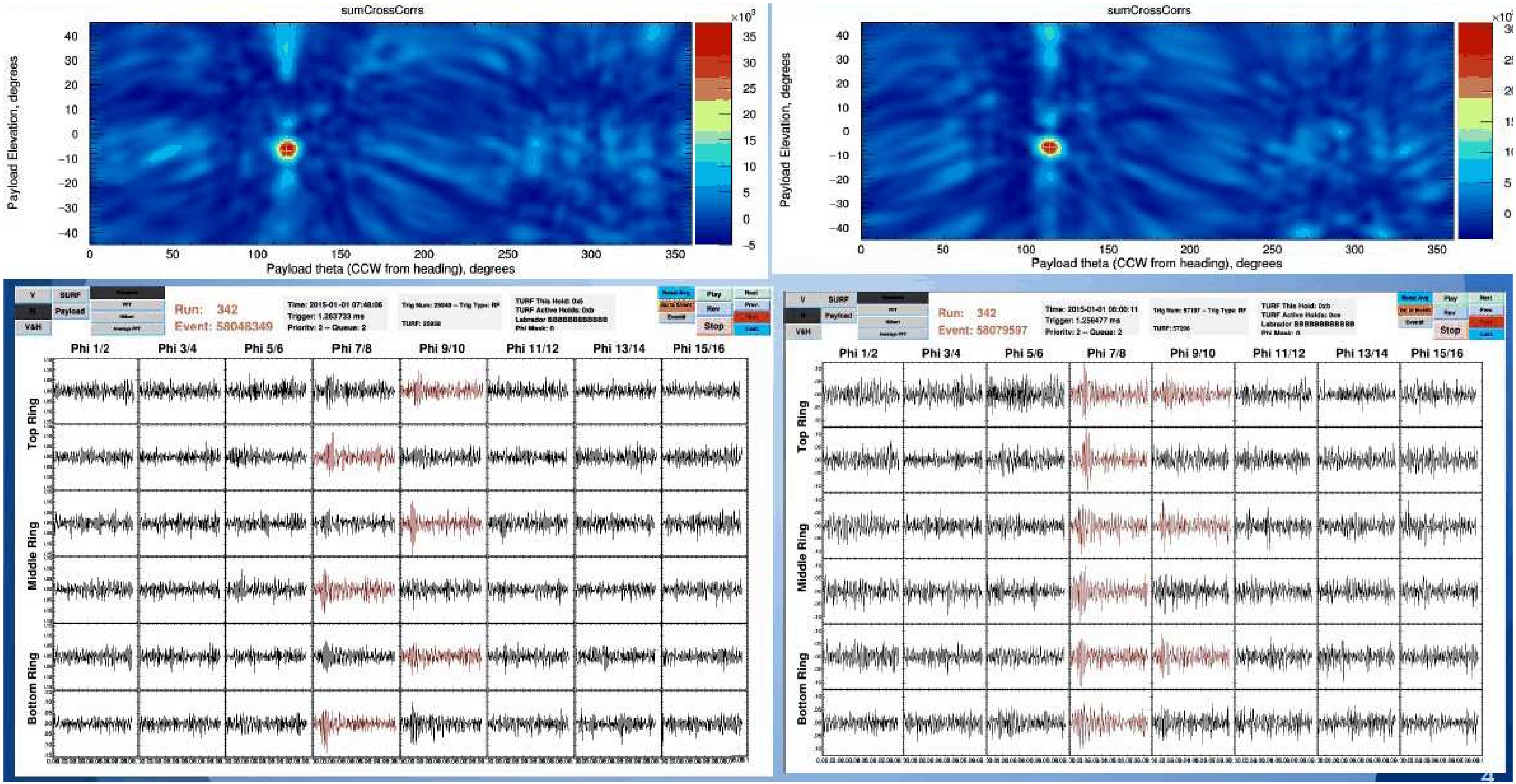
ANITA-3 (2014-2015)



- 22 days in-air
- More antennas
- Got rid of banded trigger (to maximize SNR). Independently trigger on HPol and VPol. Better sensitivity to low SNR, but more susceptible to CW (e.g. satellites) which led to high deadtime.
- GPU prioritizer for telemetry allowed higher event rate
- ∼78 million events recorded
- Data analysis still under way

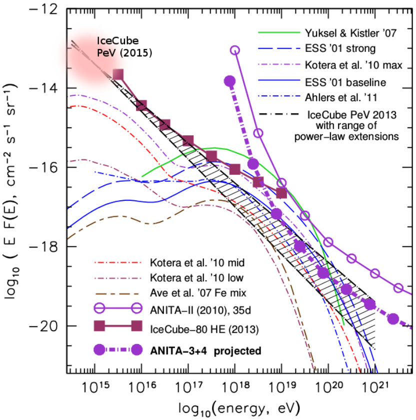
ANITA-III

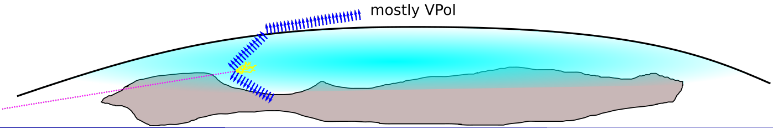
sample events



Askaryan Neutrino Search

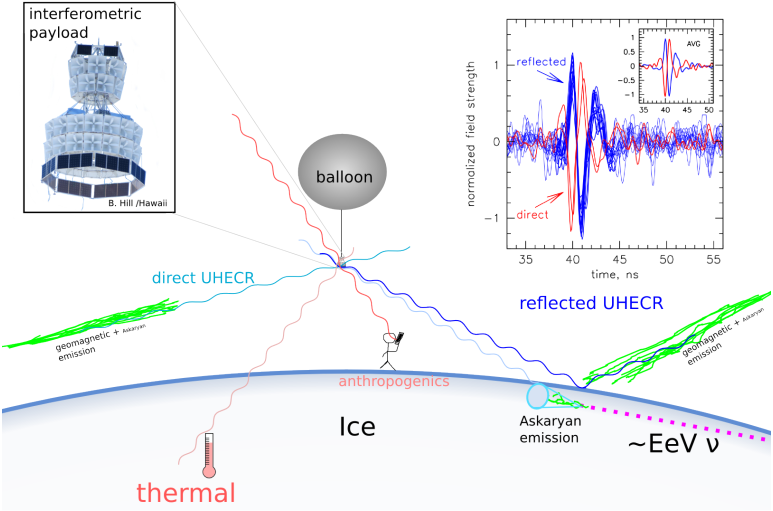
- Look for isolated, impulsive, predominantly VPol events
- VPol due to geometry of emission cone for ice-skimming neutrinos
- For e.g. ANITA-2, expected ~ 1 remaining background, based on number of doubles and triples.
- ANITA-1 saw zero candidates, ANITA-2 saw one.
- Papers:
  10.1103/PhysRevD.85.049901
  10.1103/PhysRevD.82.022004
  10.1103/PhysRevLett.103.051103



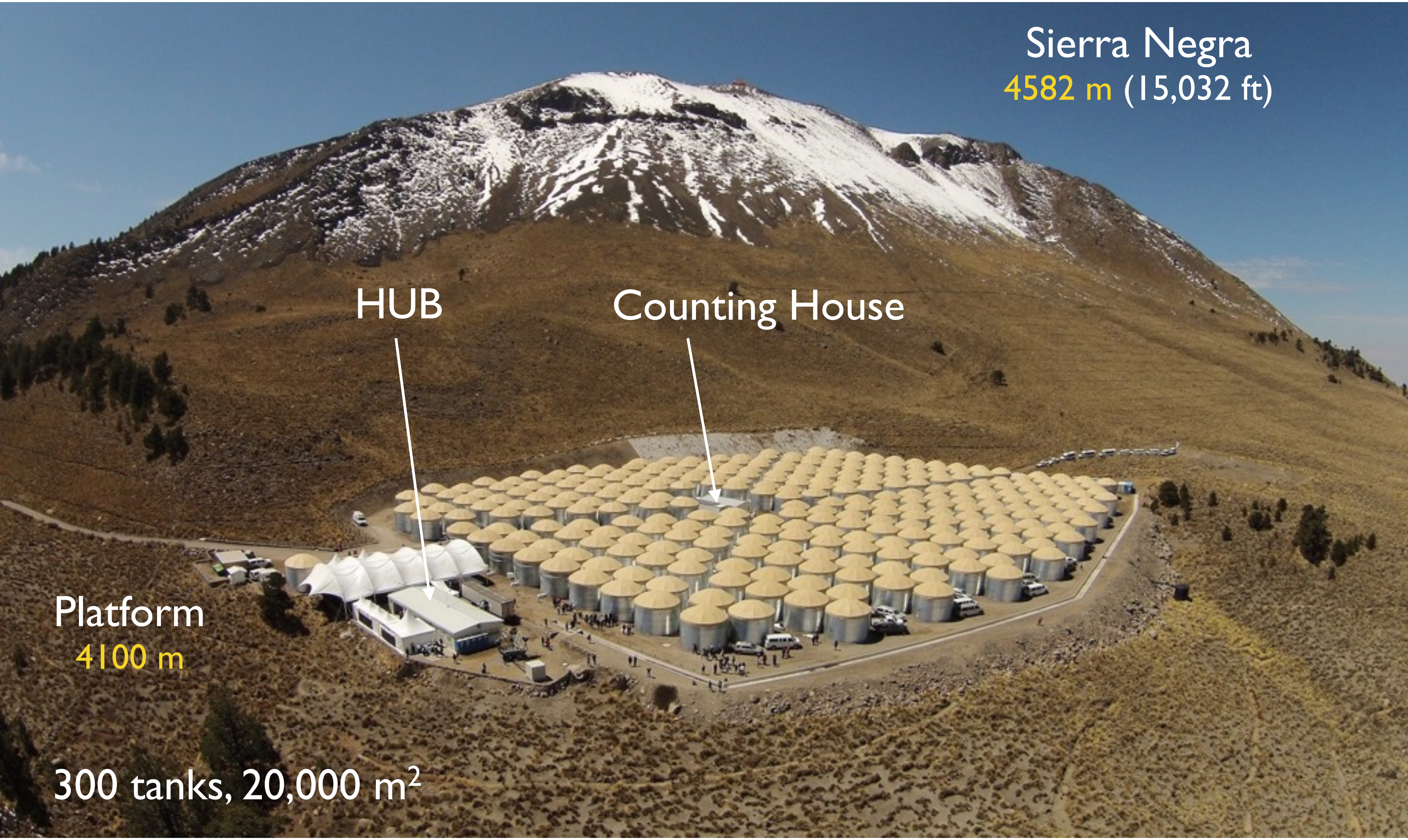


UHE Cosmic Ray Search

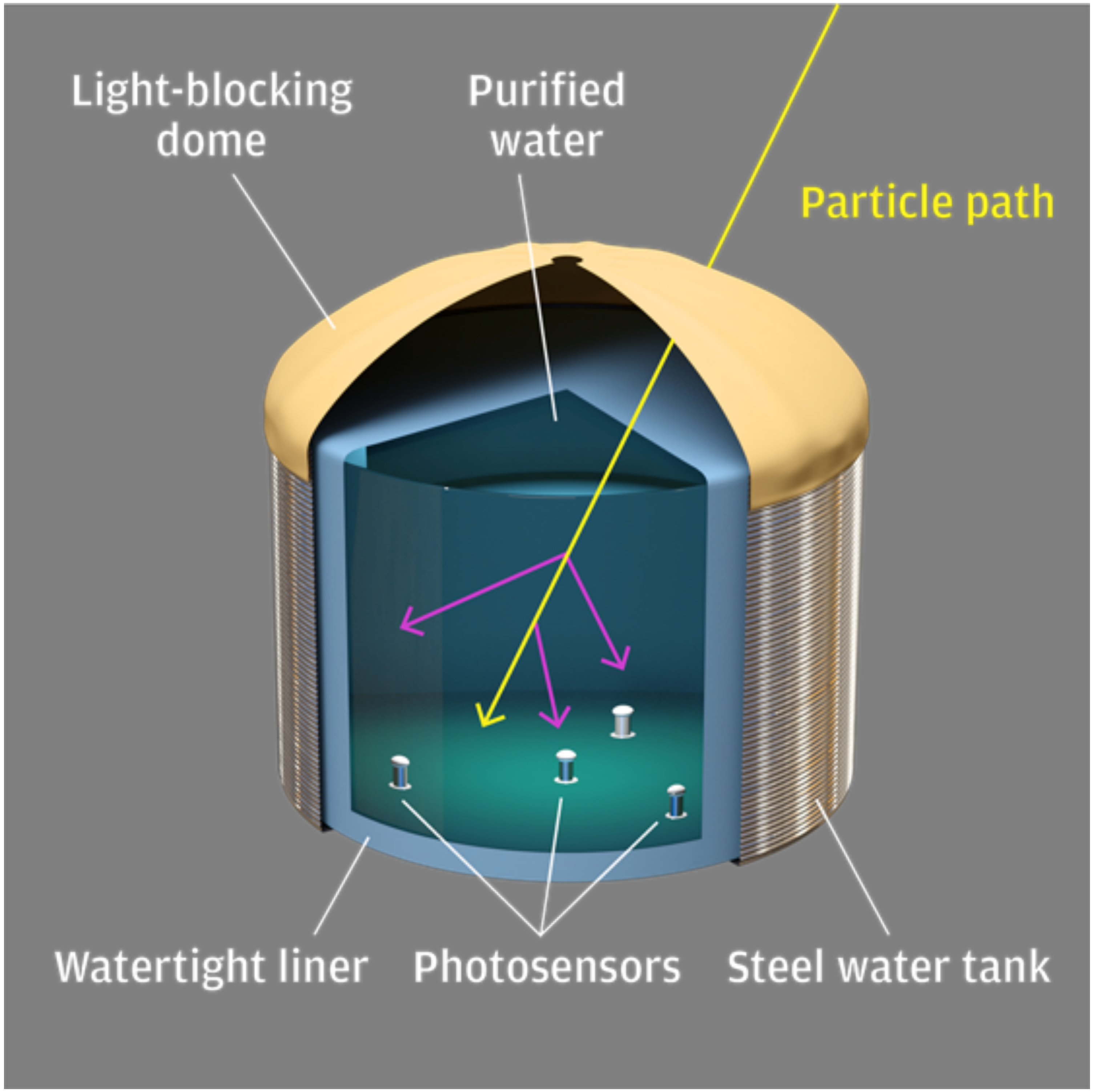
- ANITA-1 saw 16 isolated events in HPol, identified as cosmic rays
  - Reflected cosmic rays: point to ground, Fresnel modifies polarization
  - Direct cosmic rays: miss the ground. **Inverted polarity from reflected**



High Altitude Water Cherenkov Observatory



Water Cherenkov Detectors



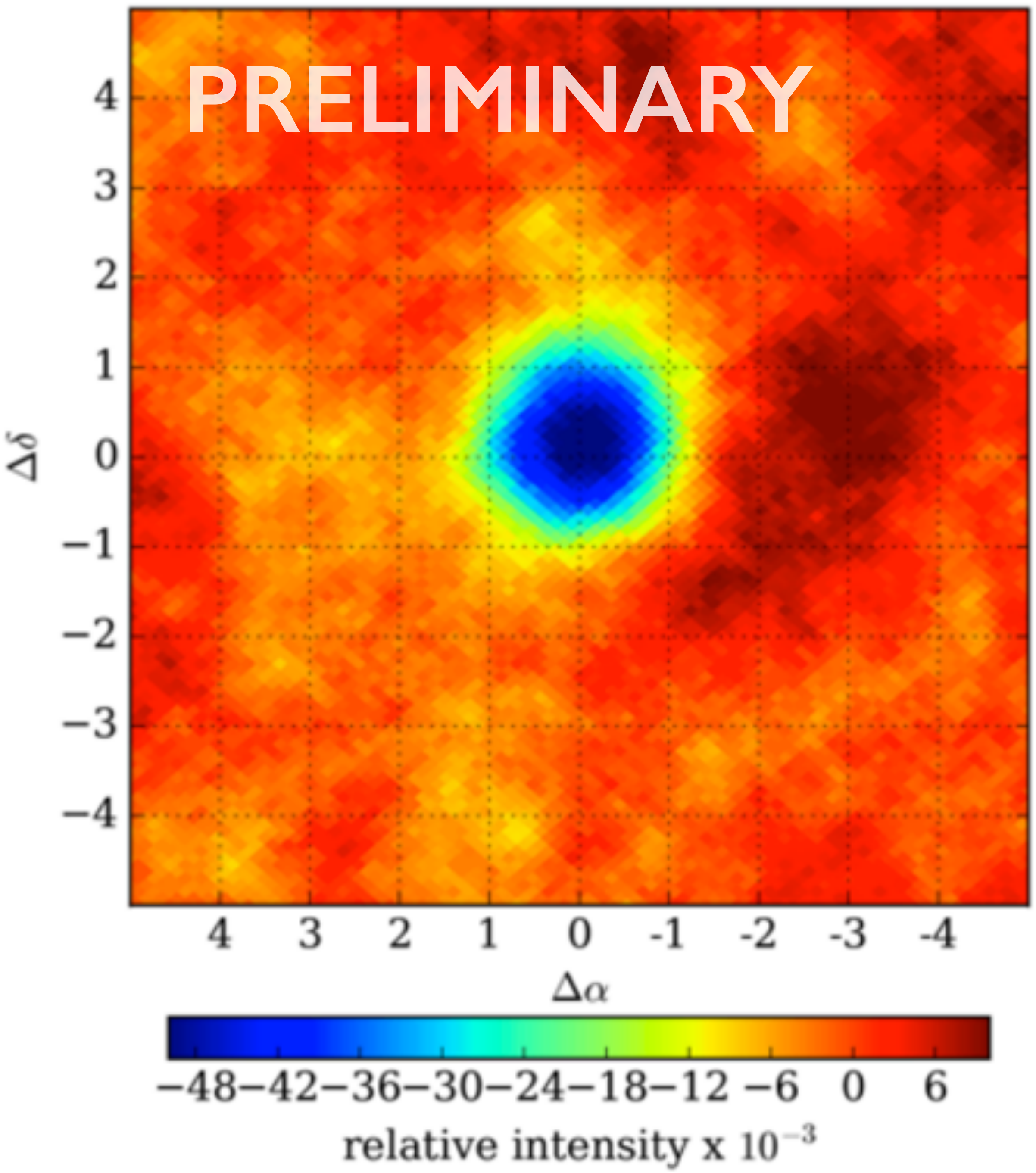
Multi-messenger Physics

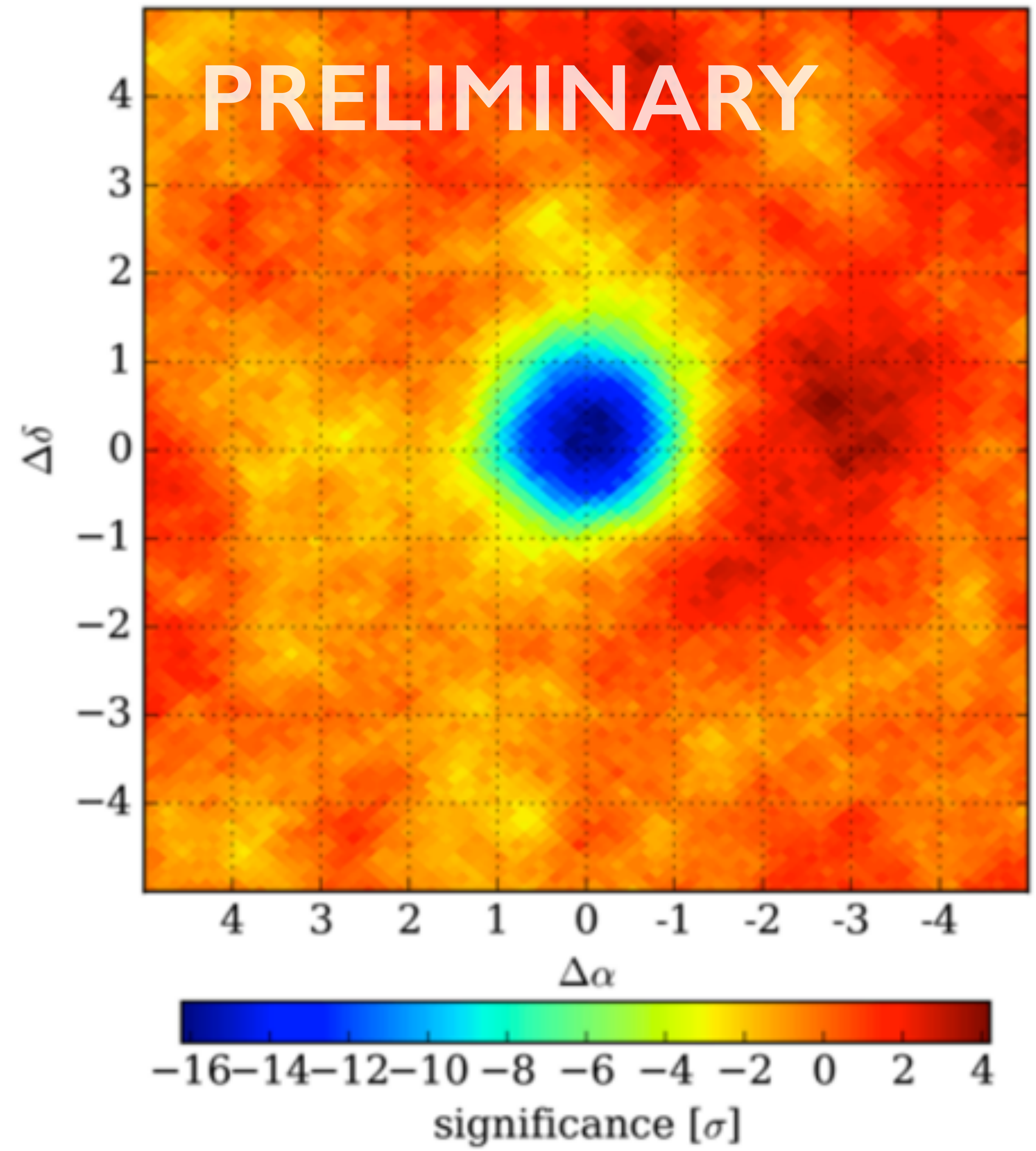
- **Primary cosmic rays: ~100 GeV to 100 TeV**
  - Cosmic-ray spectrum and anisotropy (10^{-3} level): nearby accelerators
  - Lunar shadow: antiparticles (antiprotons, e+)
  - Solar shadow: heliospheric/coronal magnetic field
- **Galactic and extragalactic γ rays: ~1 TeV to 100 TeV**
  - Unbiased wide-FOV survey of Northern Hemisphere
  - Continuous observations (>90% total uptime): transient sources
  - High energies: distinguish IC from π^0 emission as Klein-Nishina effects become important
  - Galactic and extragalactic diffuse emission: neutrino origins
  - Distinguish "astrophysical" γ rays from Dark Matter (**K. Tollefson**)

Lunar Shadow

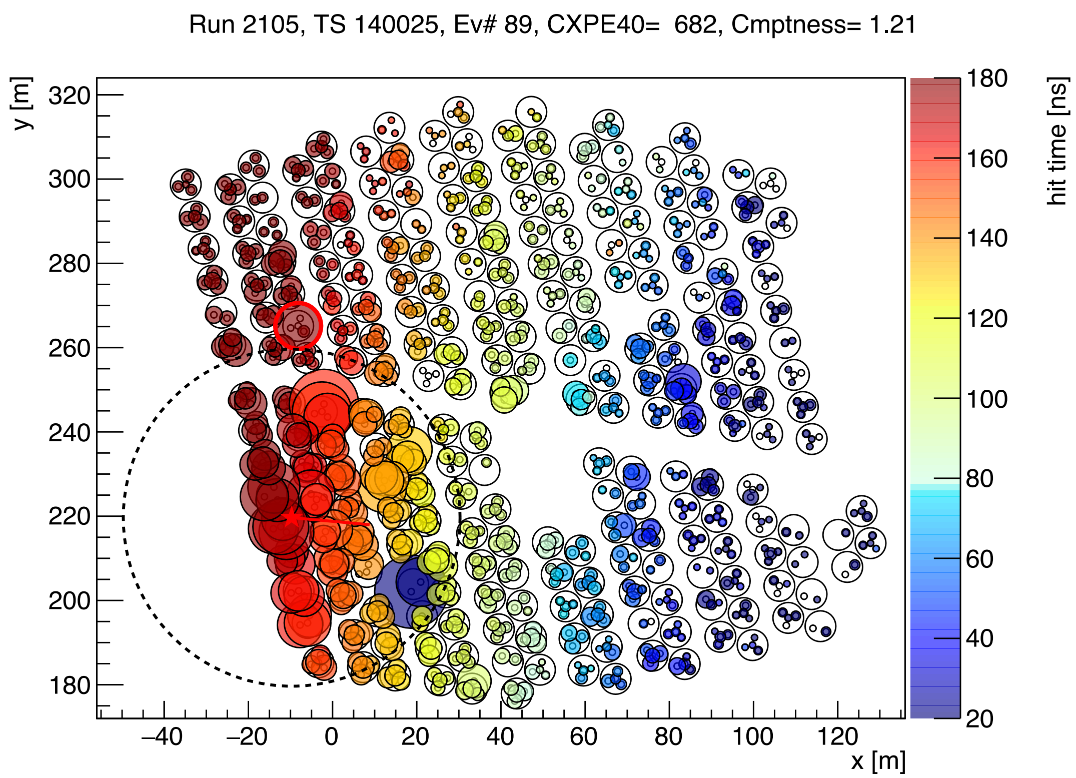
Median Energy: 51.0 TeV

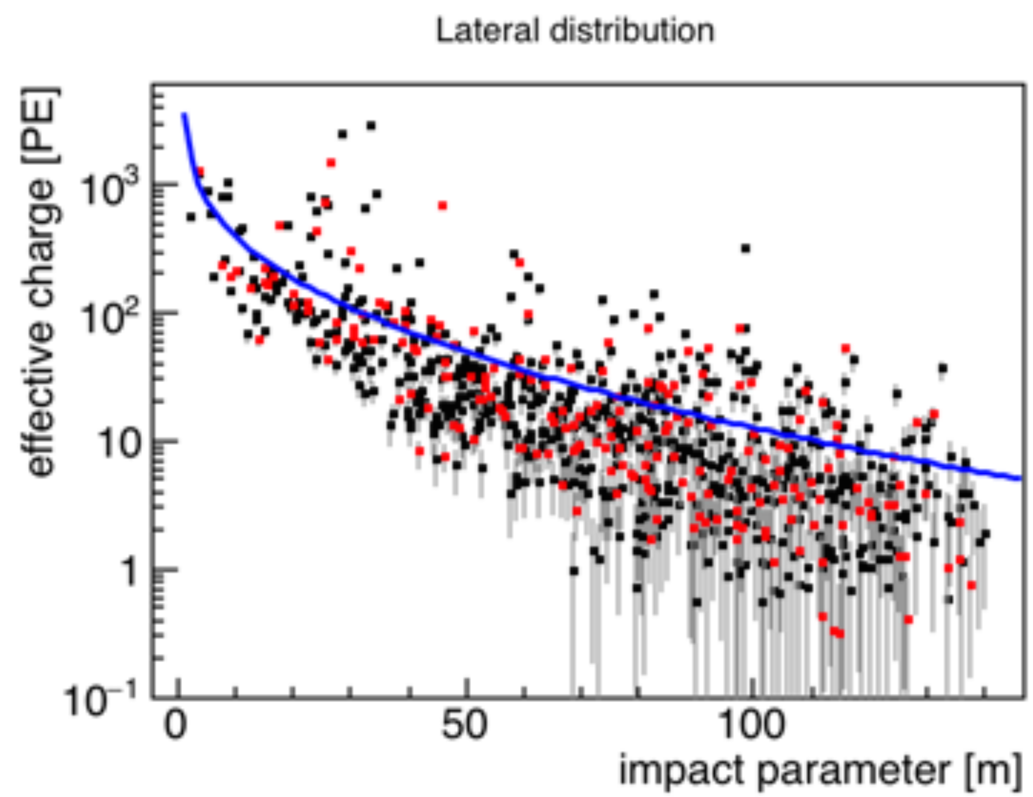
Z. Hampel-Arias
UW-Madison





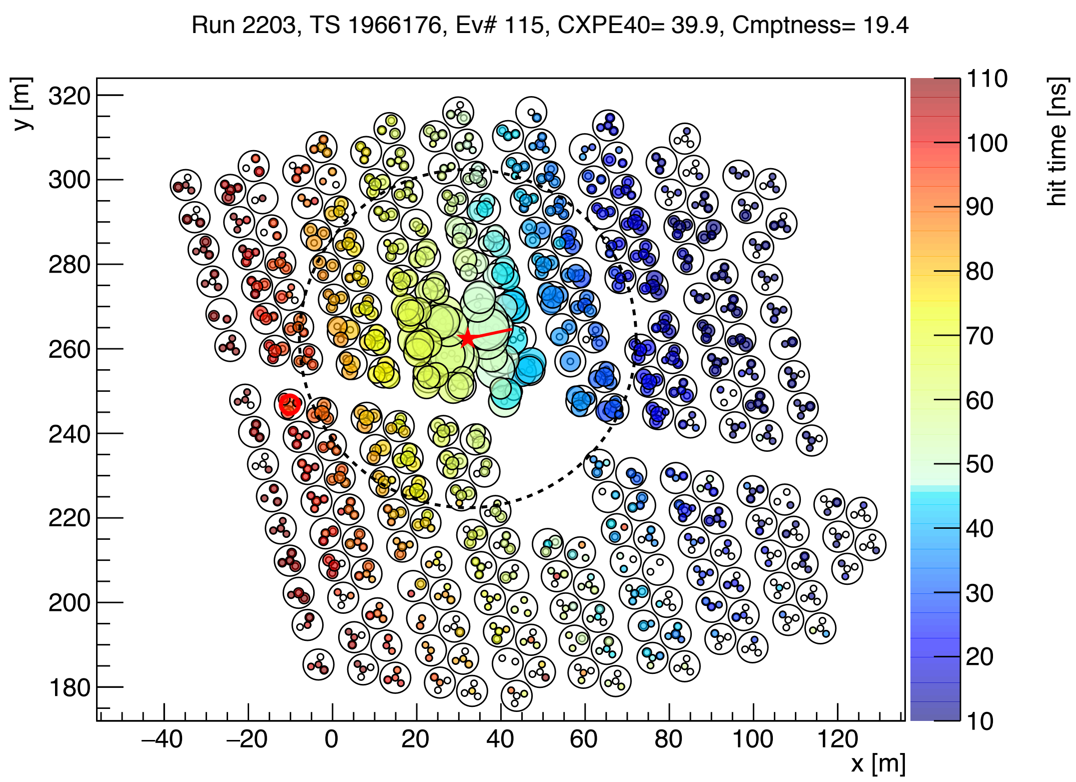
Background Suppression

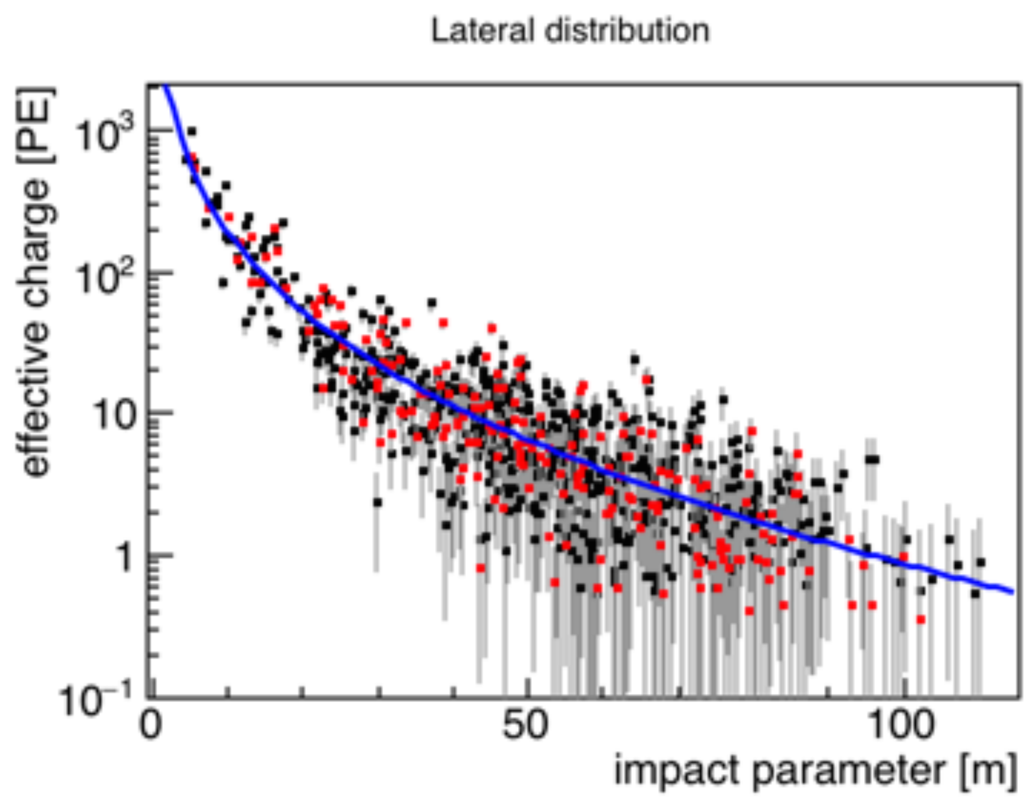




- Cosmic ray background: 25 kHz at trigger level
- Cosmic ray showers produce "clumpy" deposits of charge at large distances from the shower core
- Showers characterized by large variance in charge as a function of distance from shower core

Background Suppression



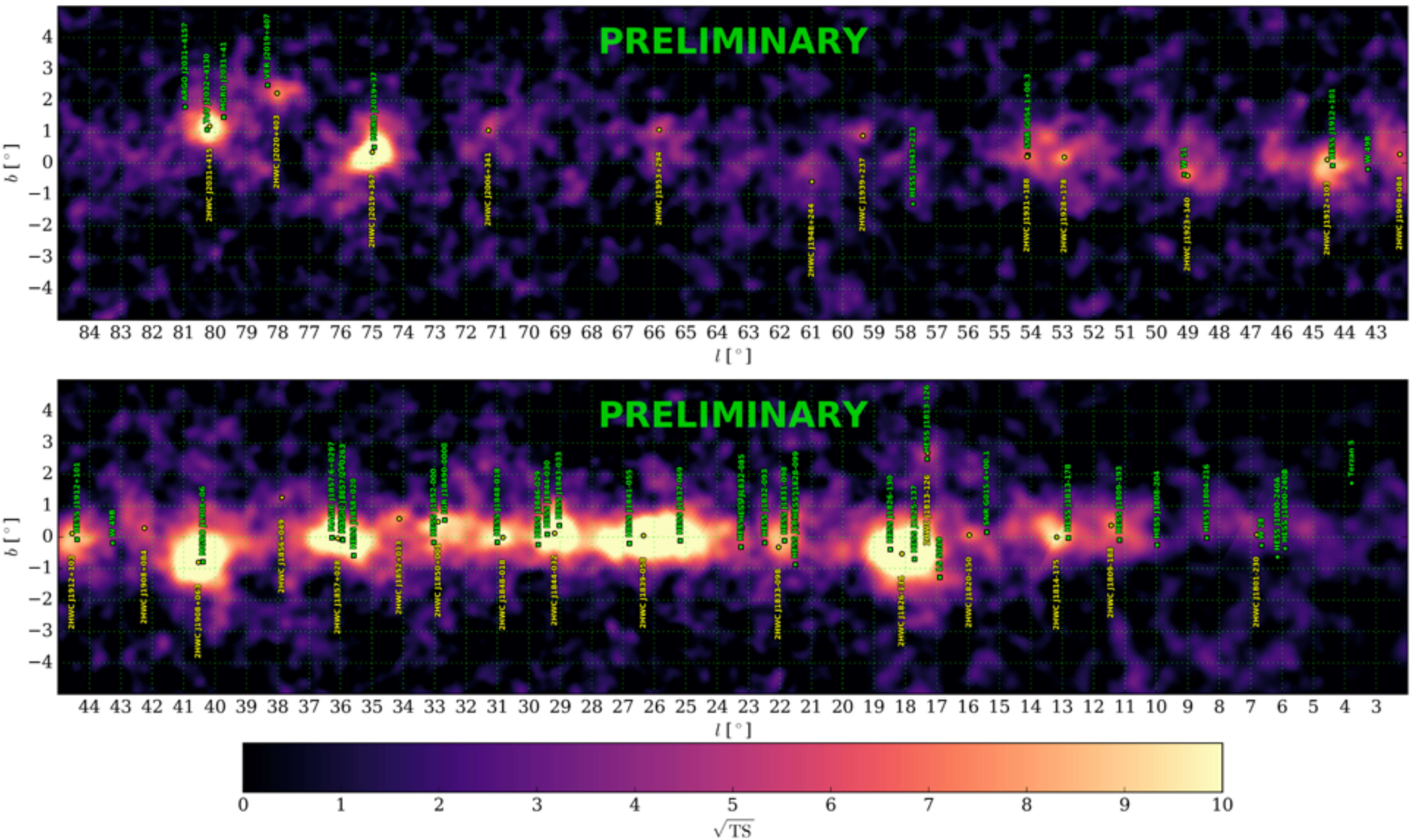


- Gamma ray signal: ~5 mHz from Crab Nebula
- Showers characterized by small variance in deposited charge vs distance from shower core
- 99.9% background suppression at 10 TeV

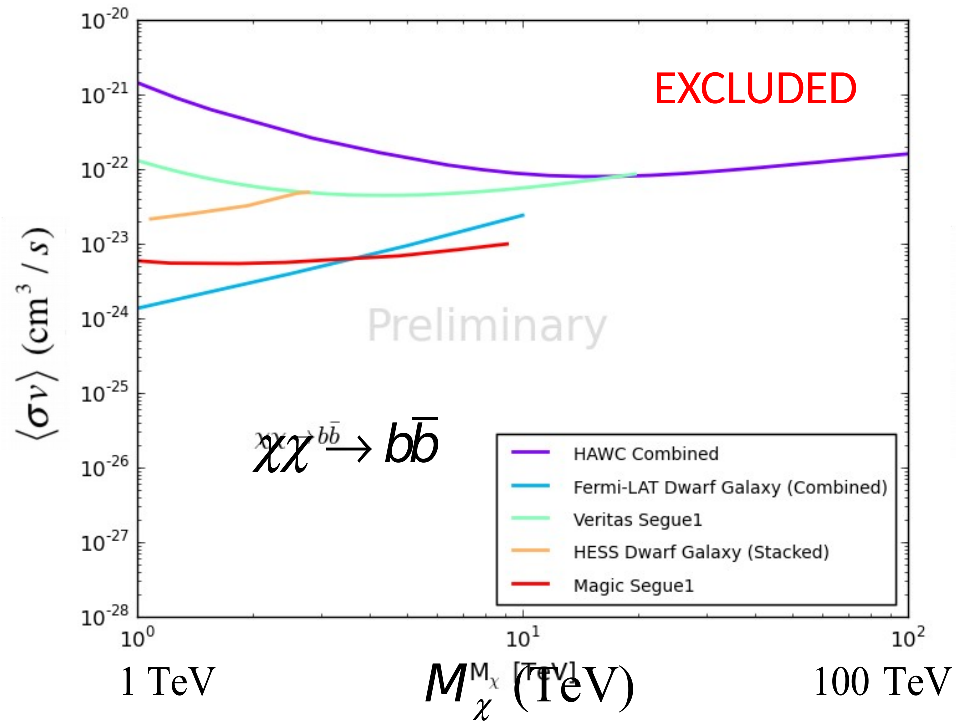
Galactic Plane

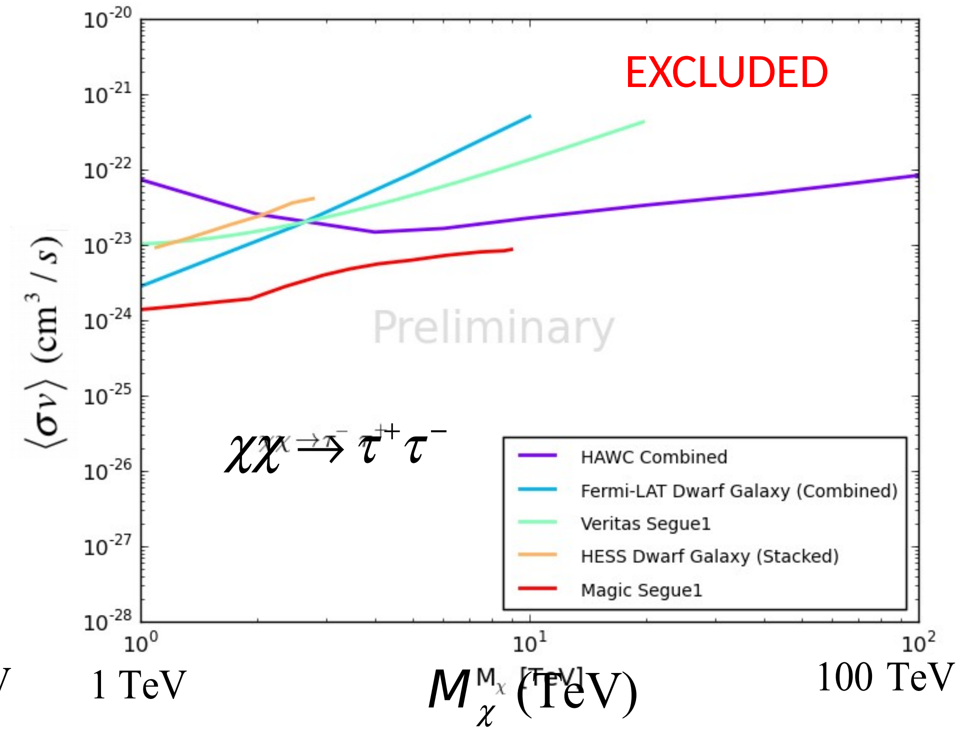
TeVCat Sources
HAWC Sources

C. Rivière, UMD



DM Annihilation Cross-Section Limits from 14 Dwarf Galaxies

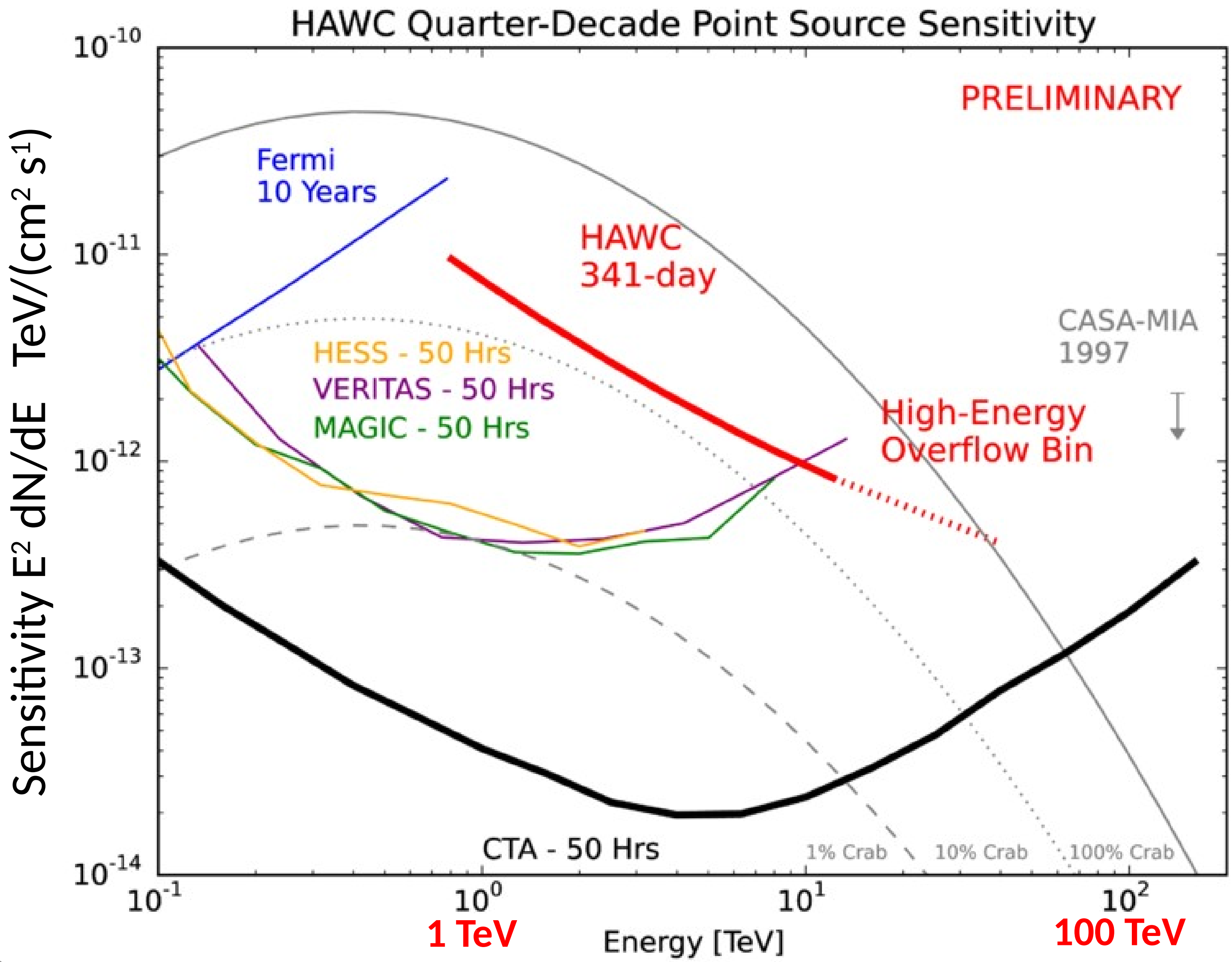




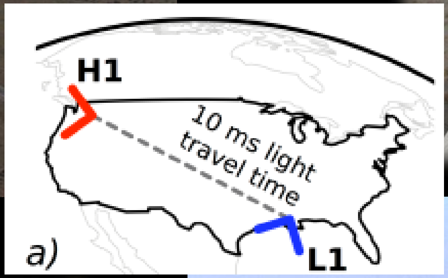
HAWC's combined limit assuming WIMP decays to bbbar (left plot) or taus (right plot) 100% of the time compared to results from other gamma-ray experiments:

- Fermi-LAT from Ackermann et al. (Fermi-LAT Collaboration), Phys. Rev. D 89, 042001 (2014)
- VERITAS from Aliu et al. (VERITAS Collaboration), Phys. Rev. D 85, 062001 (2012)
- HESS from Abramowski et al. (HESS Collaboration), Phys. Rev. D 90 (2014) 11
- MAGIC from Aleksic et al. (MAGIC Collaboration), JCAP 02 (2014) 008

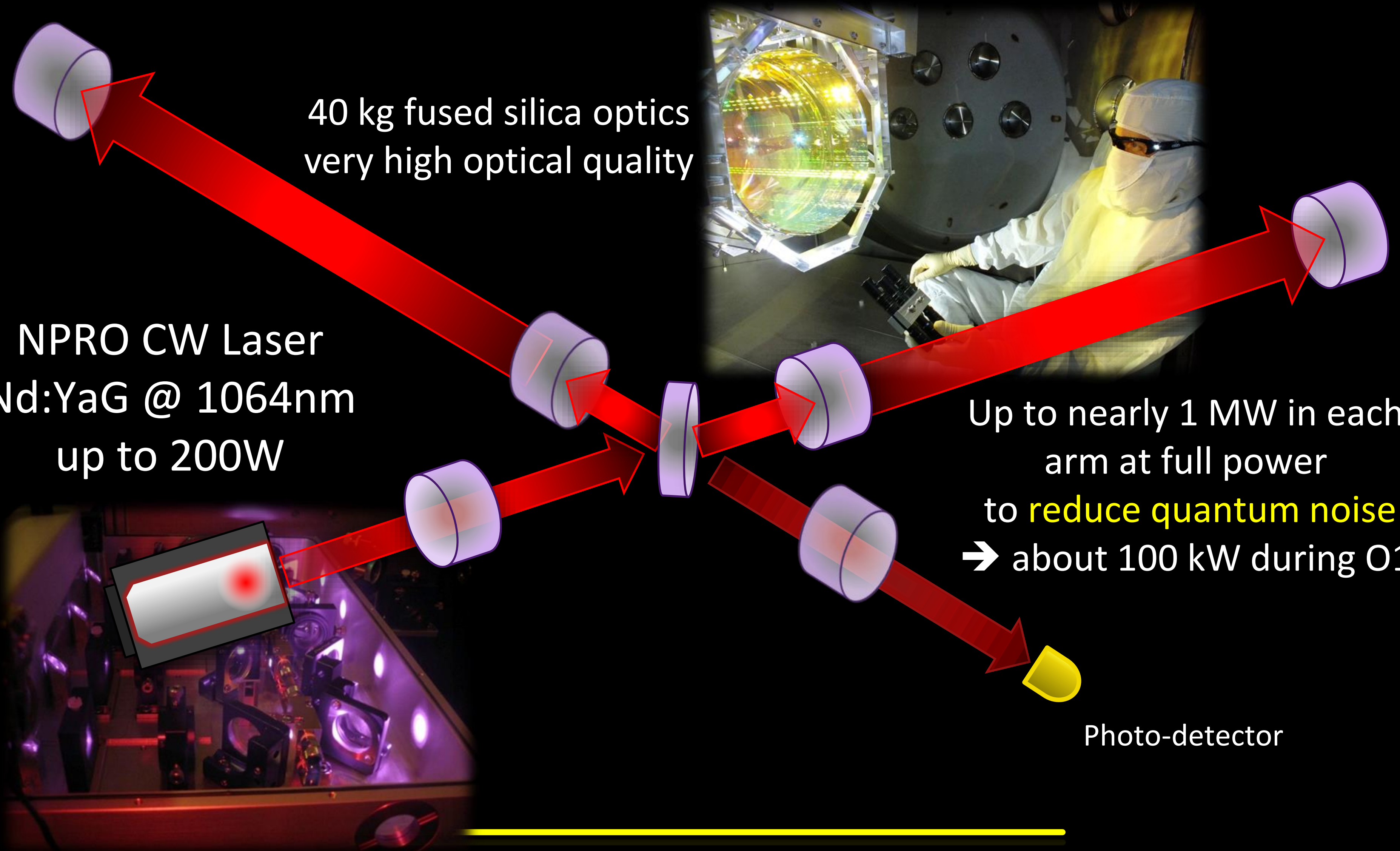
Differential Sensitivity



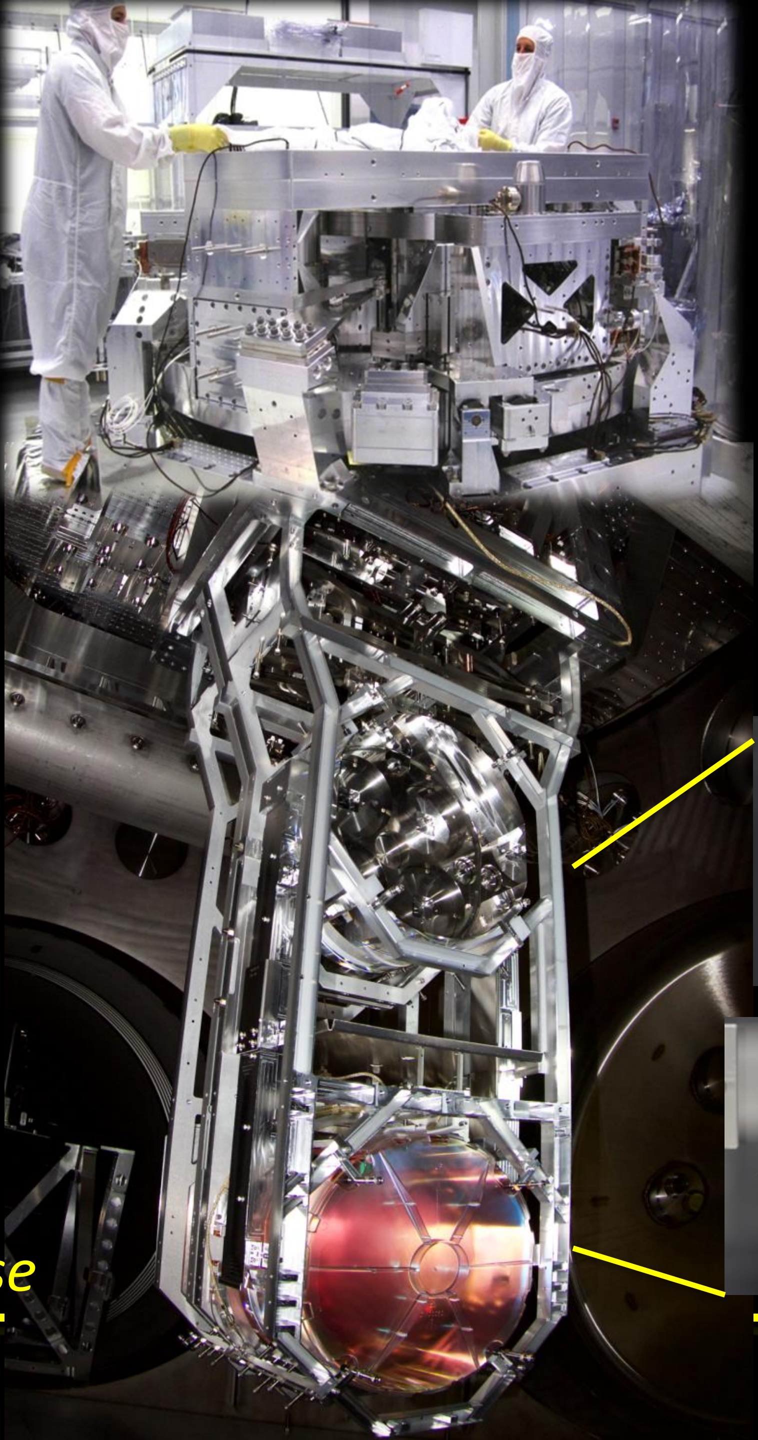
Advanced LIGO: 2 twins 4 km laser interferometers



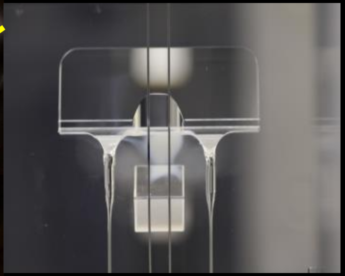
The Advanced LIGO detectors

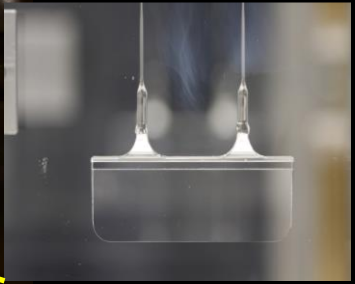


Test mass suspended by a quadruple pendulum, attached to two stages of active isolation to ***reduce seismic noise***



Final stage of test mass suspension all fused silica, very high quality factor, designed to ***reduce thermal noise***

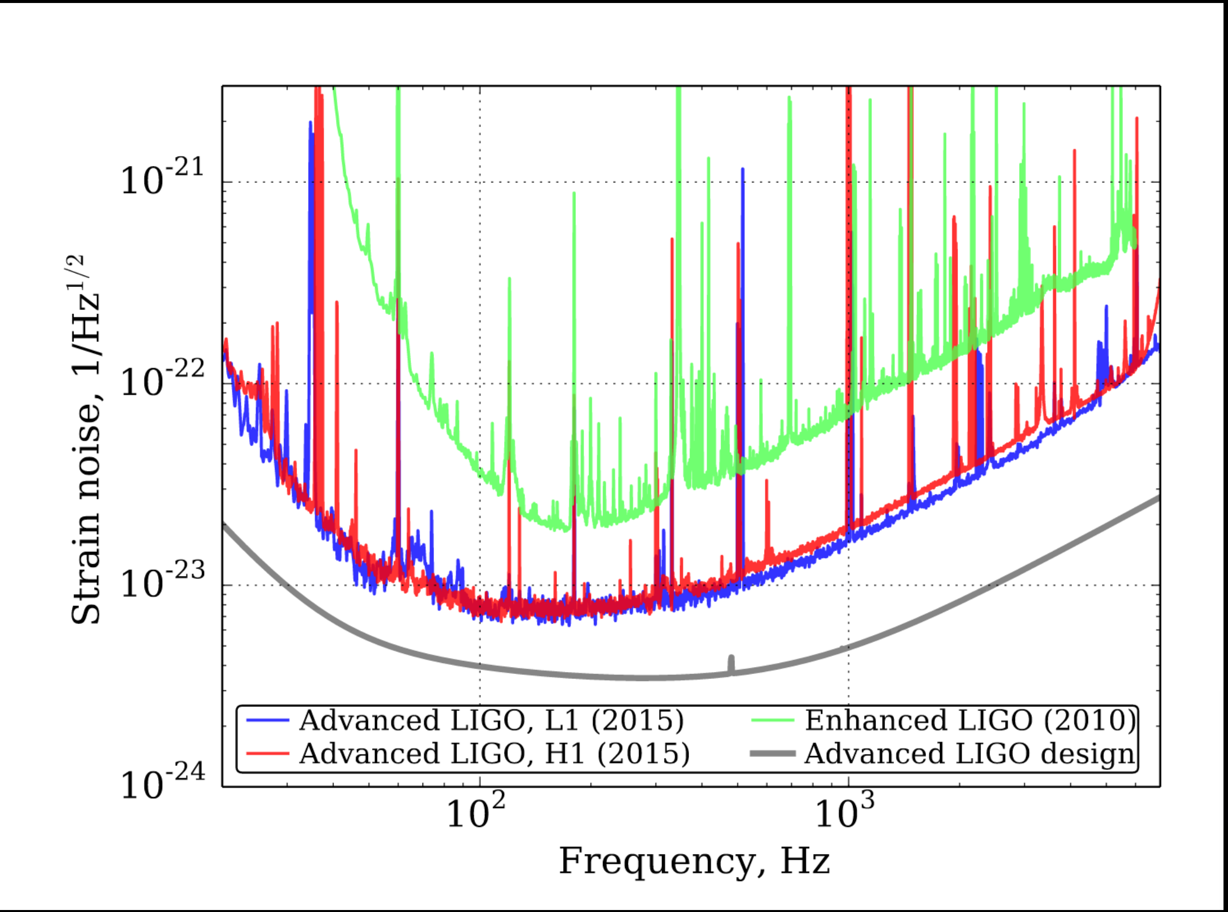




Test masses have dielectric coating material with low mechanical loss to ***reduce thermal noise***

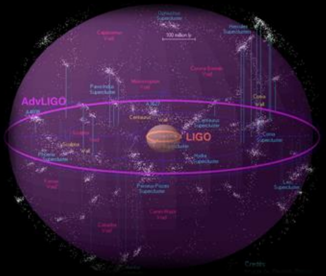
Strain noise during O1:
better than ever, not at design sensitivity yet

“Strain Noise”
=
Detector noise expressed as equivalent GW strain



Initial LIGO (2010)

Advanced LIGO Design

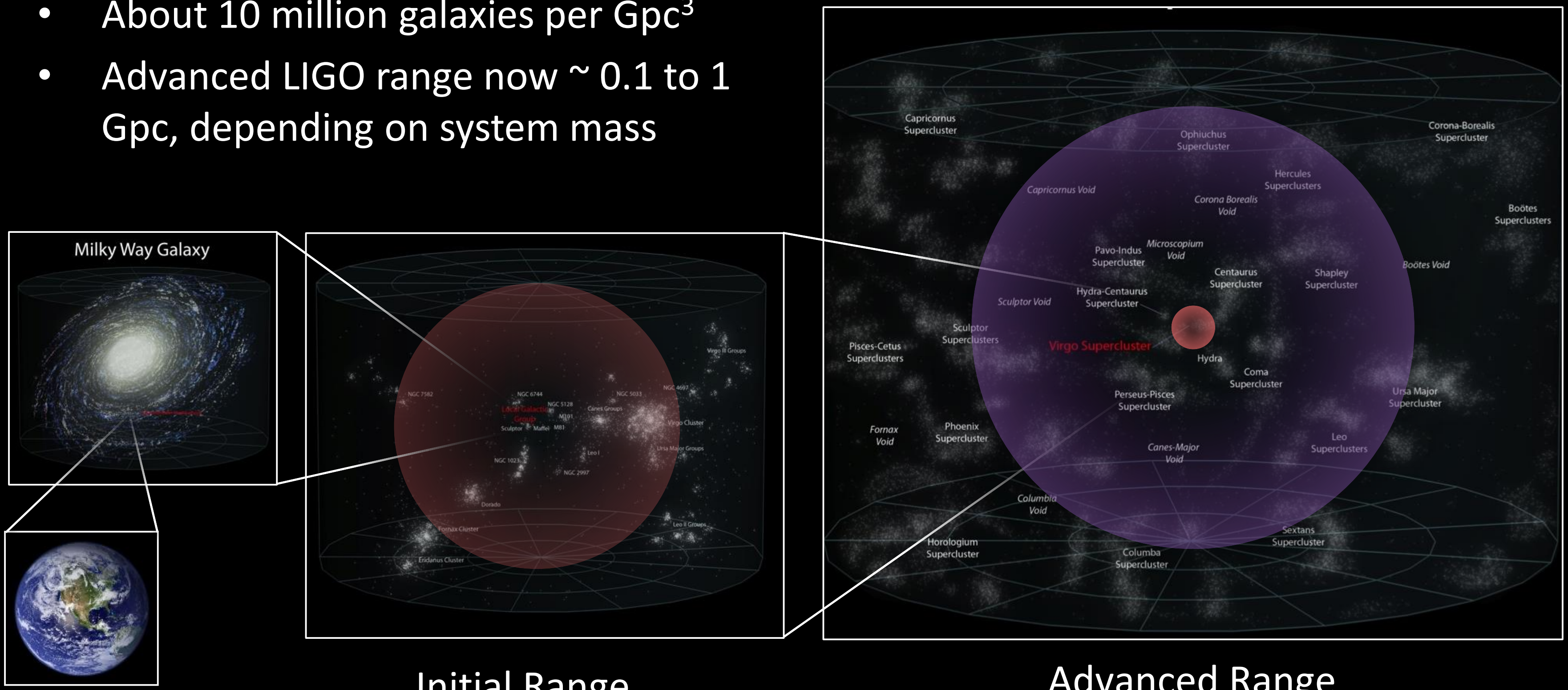


Sensitivity of the Advanced LIGO detectors at the beginning of gravitational wave astronomy D. V. Martynov et al. Phys. Rev. D 93, 112004

Advanced LIGO Sensitive Volume

- Rate roughly 50 BBH mergers each year in a volume of 1 Gpc^3
- About 10 million galaxies per Gpc^3
- Advanced LIGO range now ~ 0.1 to 1 Gpc, depending on system mass

We can expect 5 or more BBH events in the next observing run



Initial Range

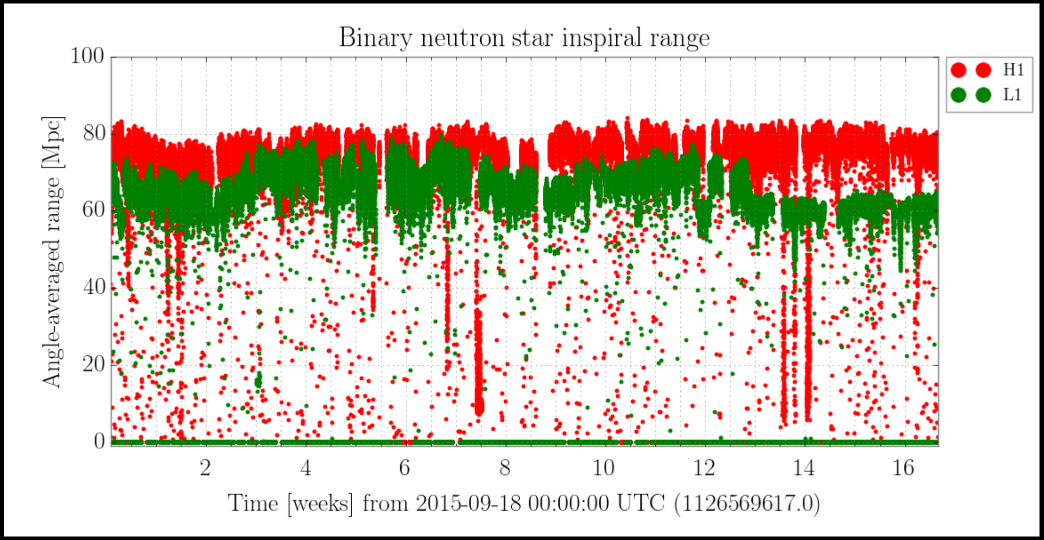
Advanced Range

Observing Run O1

(from mid-September 2015 to mid-January 2016)

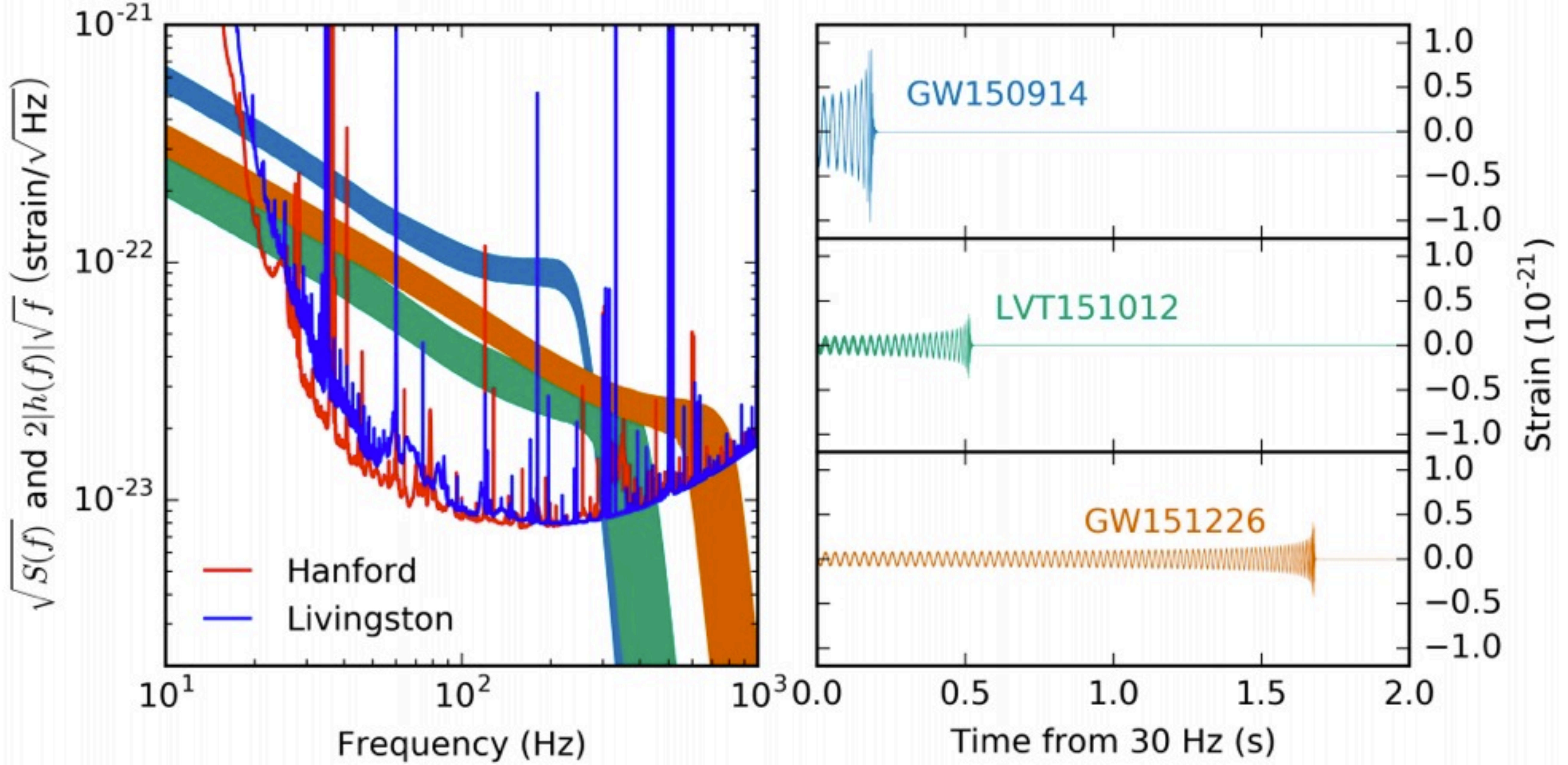
- ✓ During O1: H1 and L1 operational for ~4 calendar months
- ✓ Duty cycle: H1 = 62%, L1 = 55% ➔ H1&L1 = 43%
- ✓ 51.5 days of coincident time, 48.6 days after data quality process

The product of <u>observable volume</u> and <u>measurement time</u> exceeded that of all previous runs within the first 16 days of coincident observation



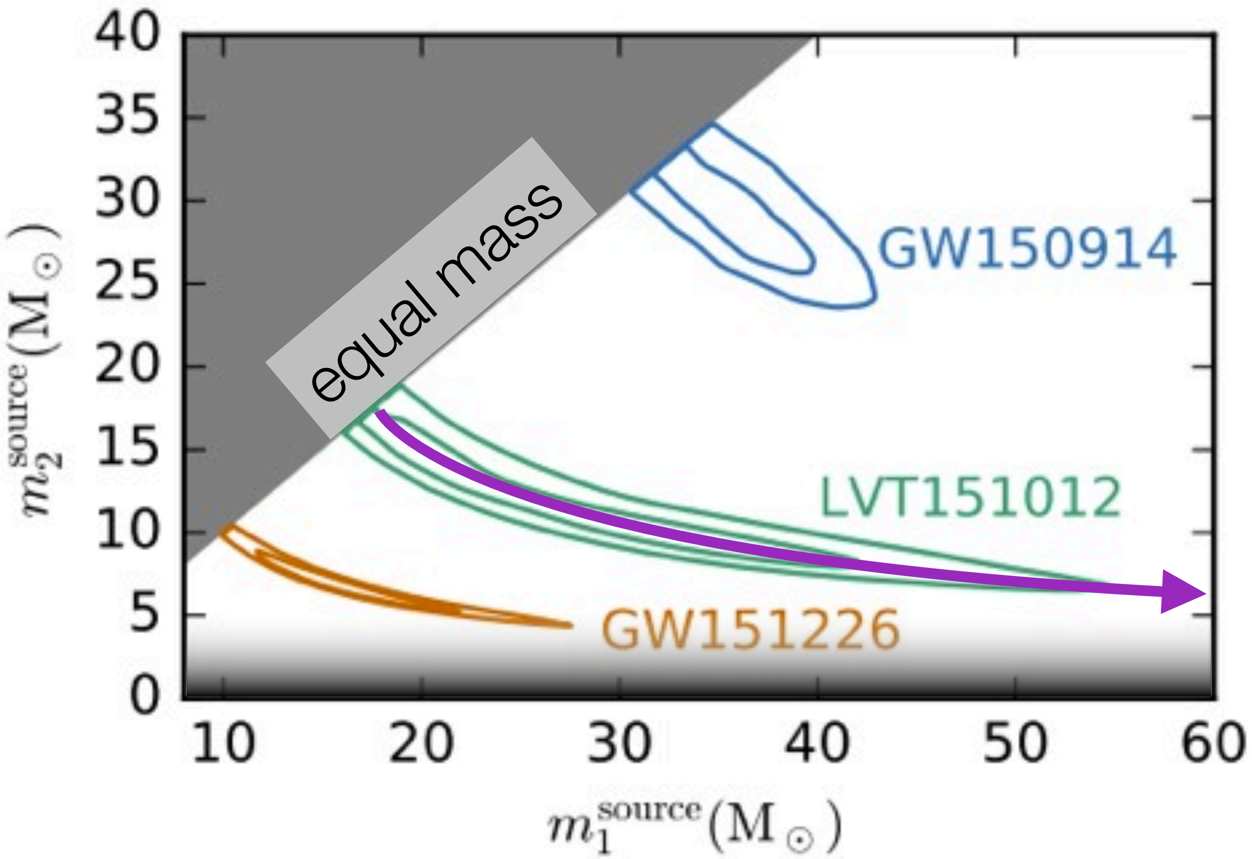
O1 BBH Events

arxiv:1606.04856

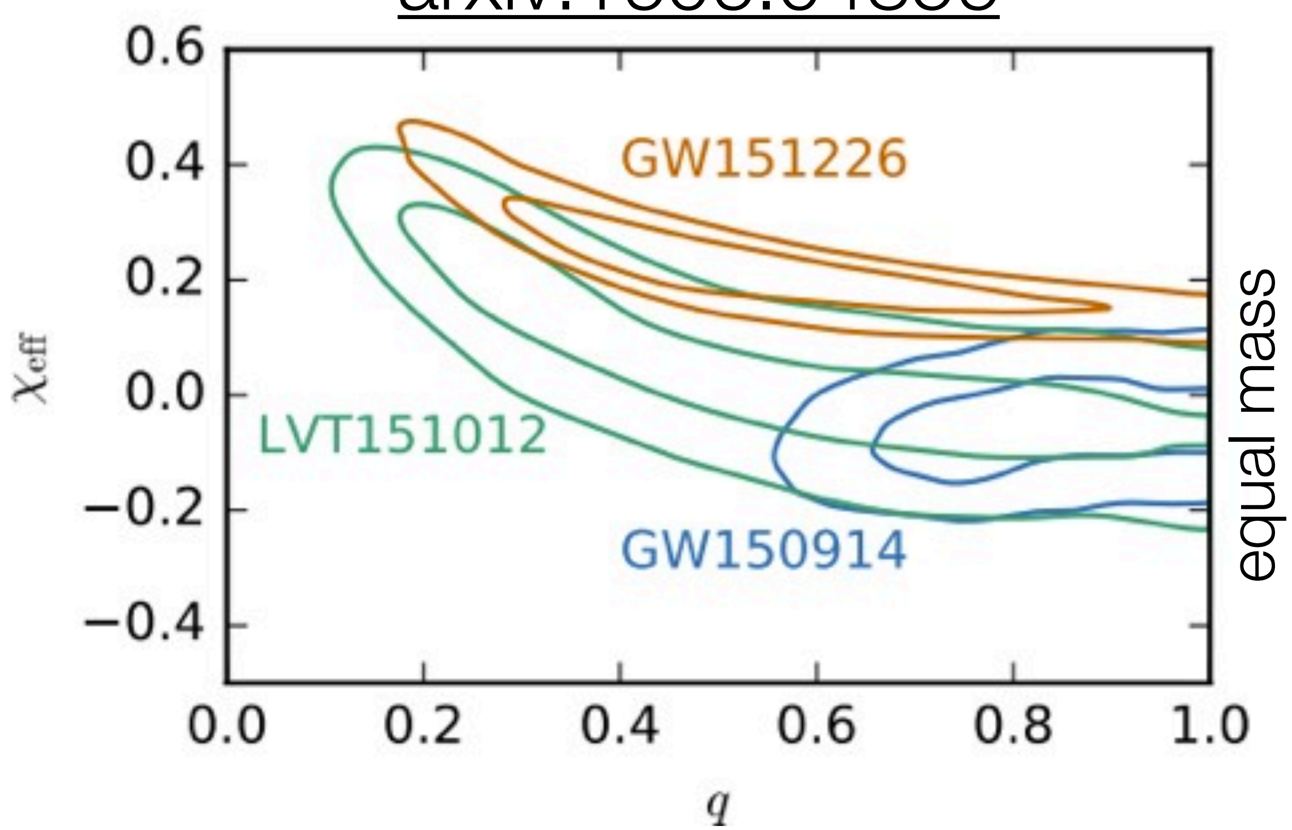


"Chirps" in the time domain (monotonically increasing in frequency vs time)
Lower mass → Higher frequency content / longer "in band"

BBH Masses and Spins



arxiv:1606.04856



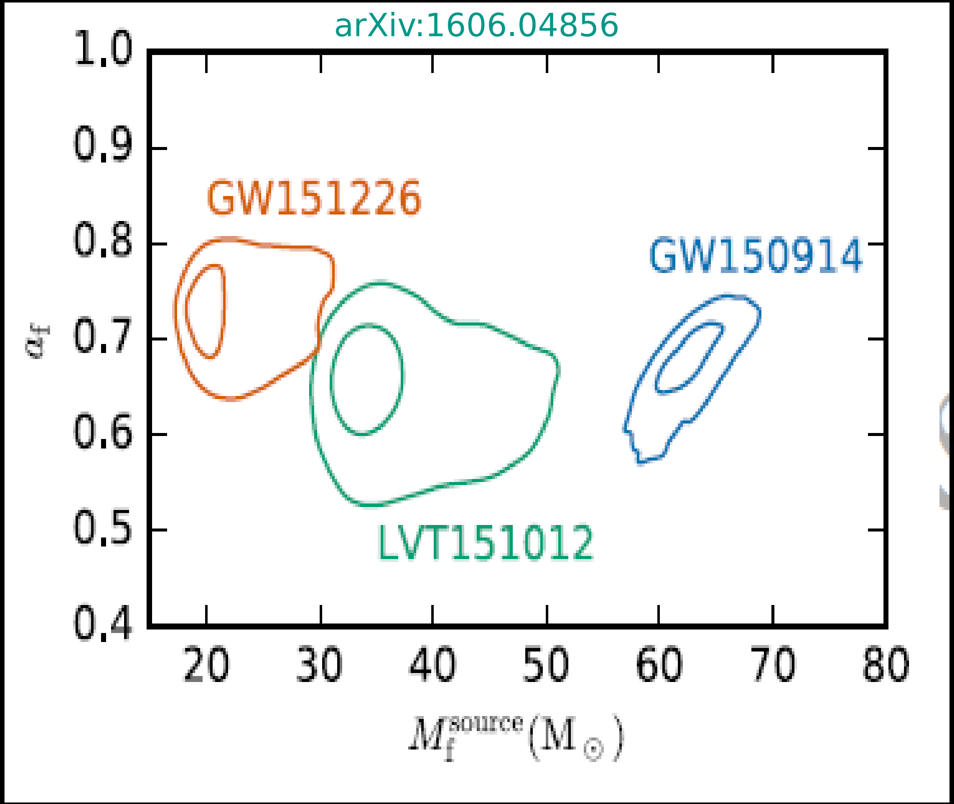
Parameter Degeneracies: Primarily sensitive to the *chirp mass* — leaves **large degeneracies** along contours of chirp mass (**GW151226** approaching $m_2 < 3$ region)

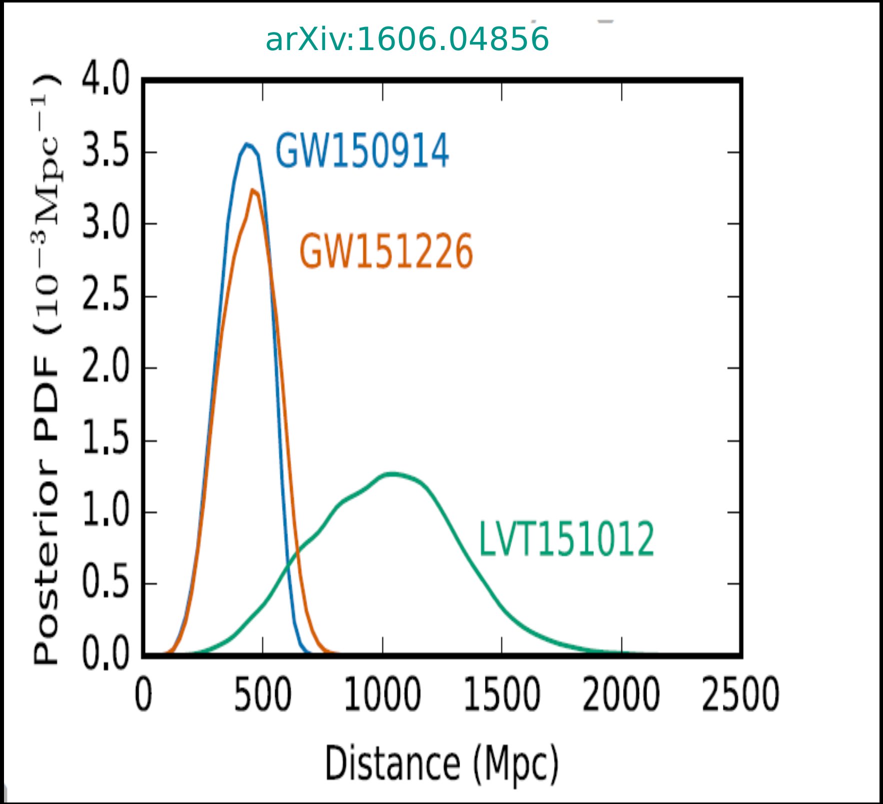
$$\mathcal{M}_c = \frac{(m_1 m_2)^{3/5}}{(m_1 + m_2)^{1/5}}$$

$$\chi_{\rm eff} = \frac{m_1 s_{1,z} + m_2 s_{2,z}}{m_1 + m_2}$$

Frequency content (and thus "length in band" affected by both *effective spin* and *mass ratio* at same order in expansion of radiation amplitude/phase

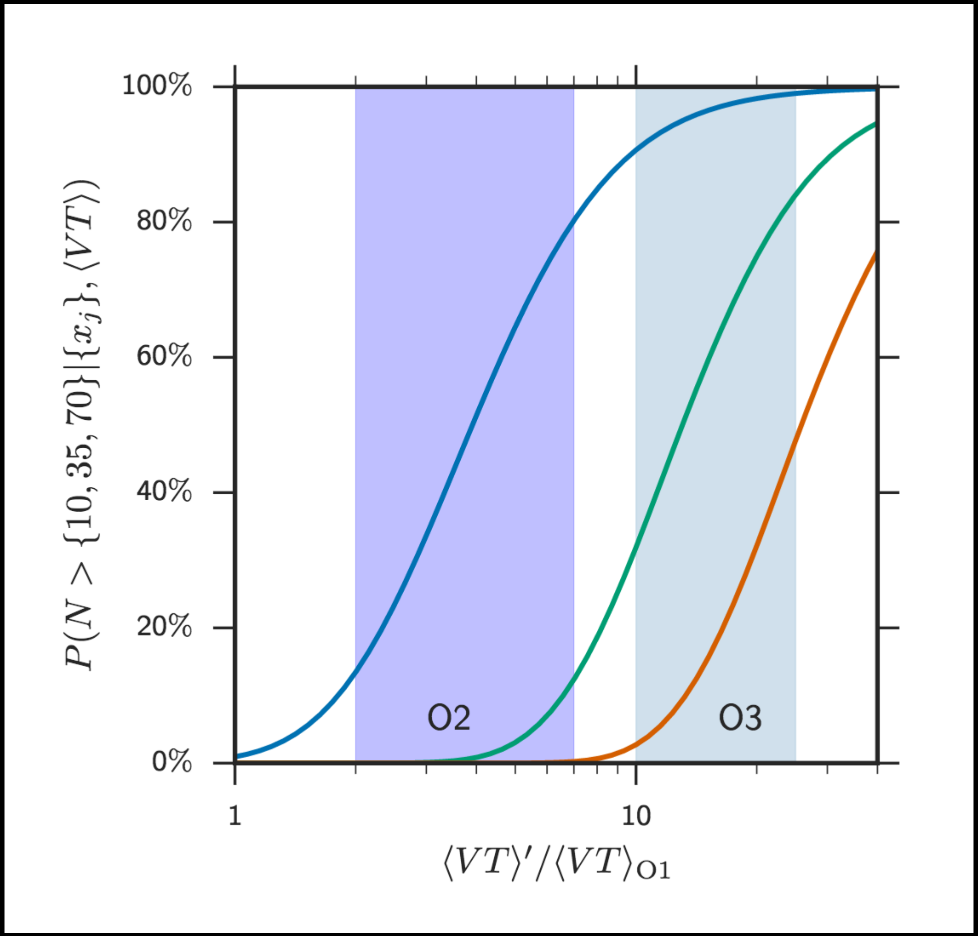
Final Black Hole Masses, Spins and Distance





Binary Black Holes Rates

https://arxiv.org/abs/1606.04856

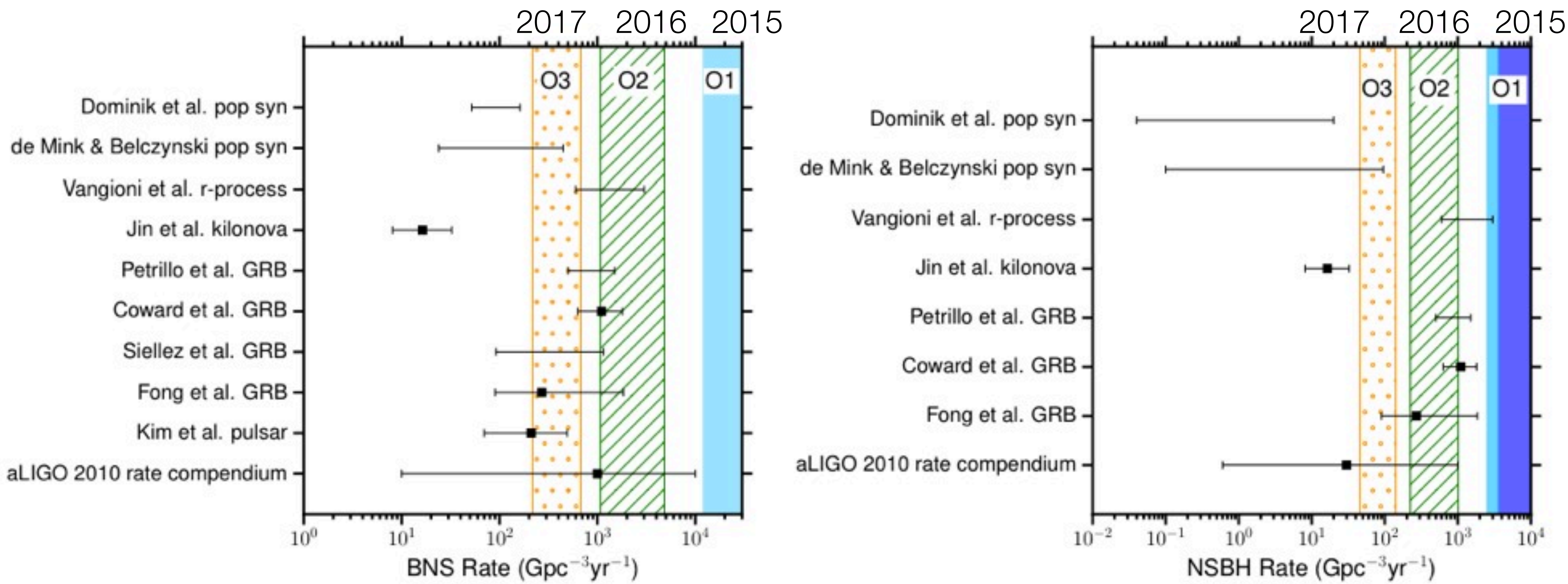


surveyed time-volume (shown as multiple of VT analyzed for O1)

- O2: projected time volume at least 2/2.5 larger wrt O1
- Expect to see (at least) a few significant events by the end of O2
- Ten(s) of events by the end of O3

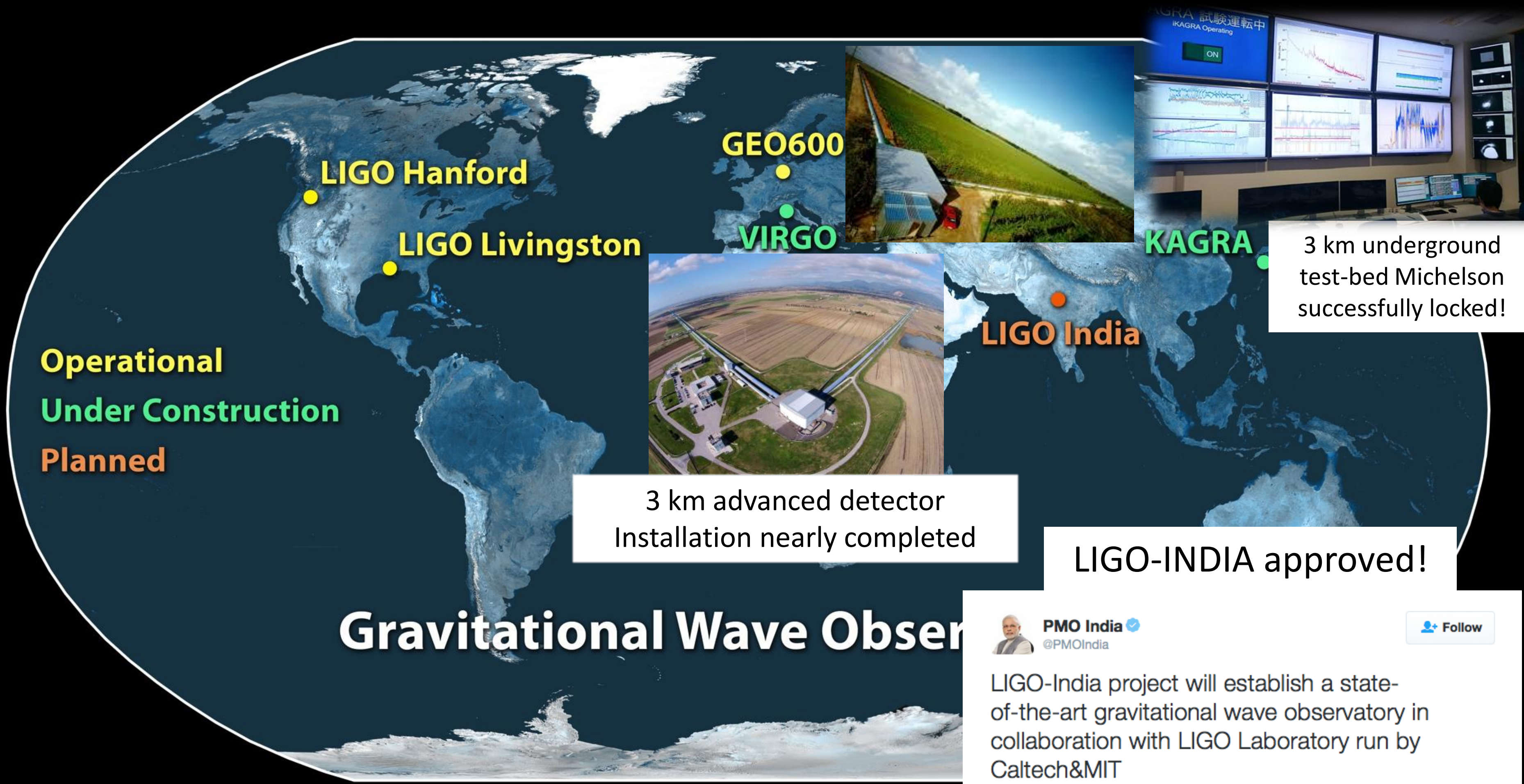
BNS / NSBH Upper Limits

https://arxiv.org/abs/1607.07456

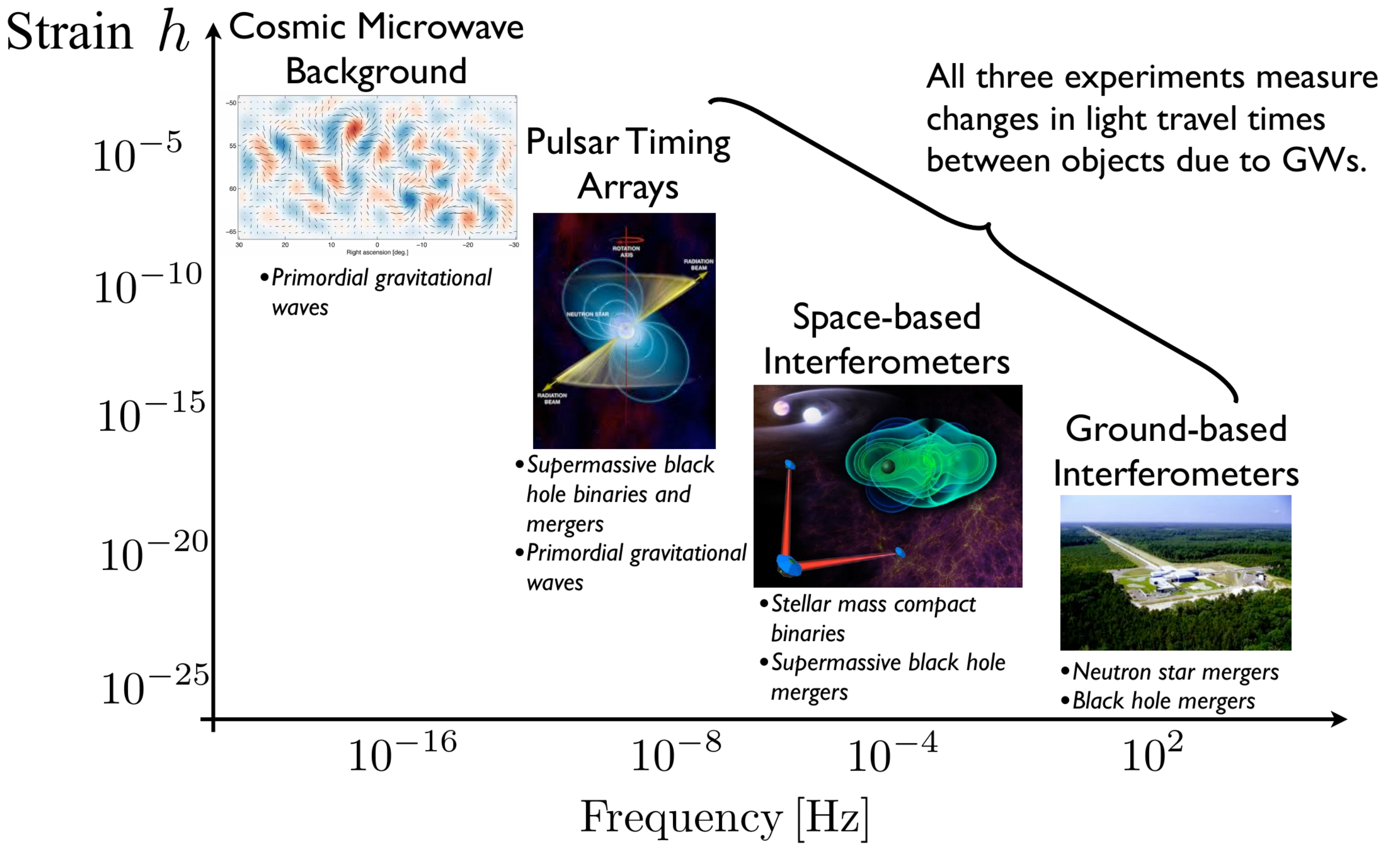


Compact Sources: Only BBH detections so far, NSBH and BNS remain elusive, but expected to constrain models in the next year

The upcoming world-wide network of advanced detectors

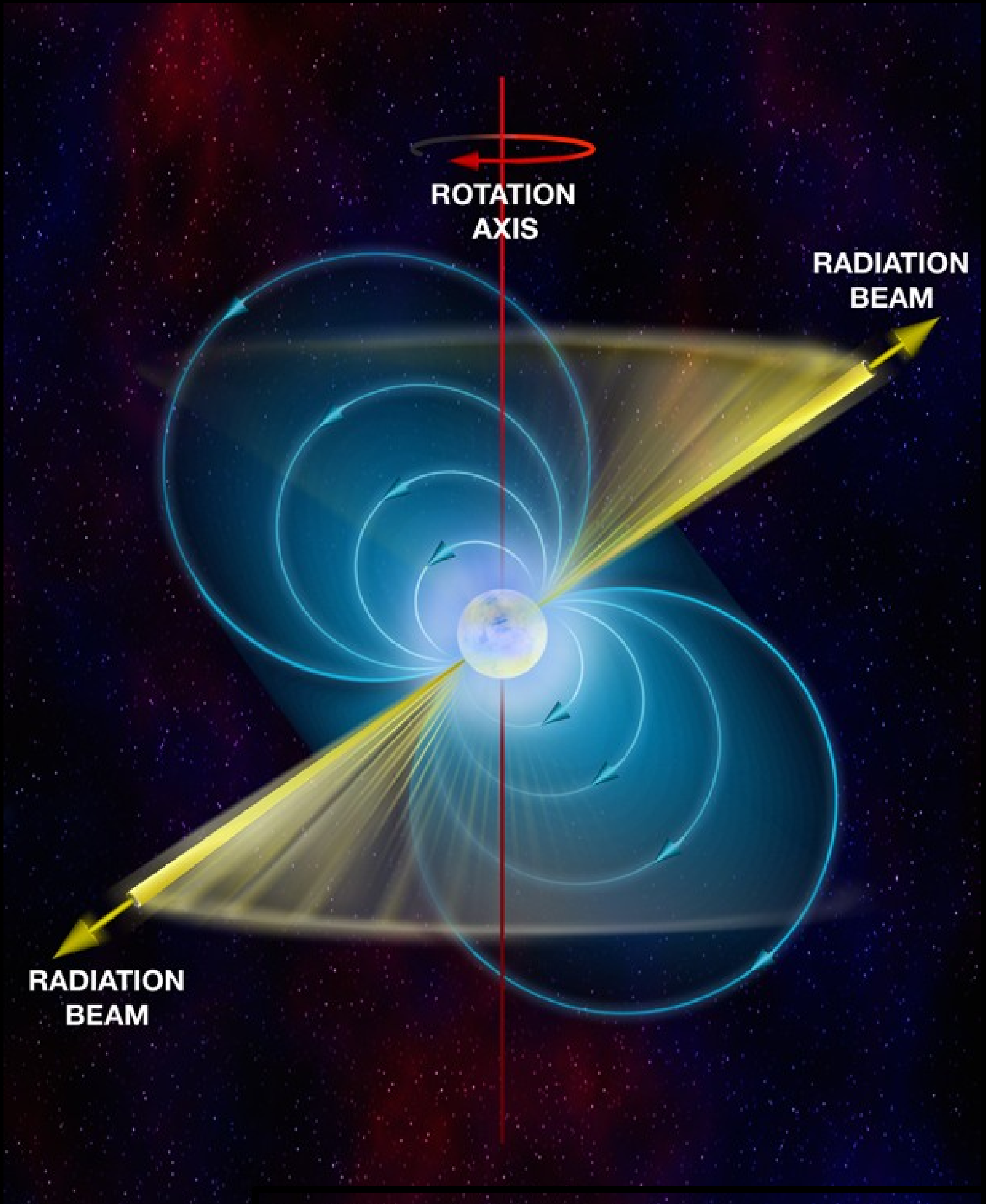


Gravitational wave physics experiments



What's a Millisecond Pulsar ?

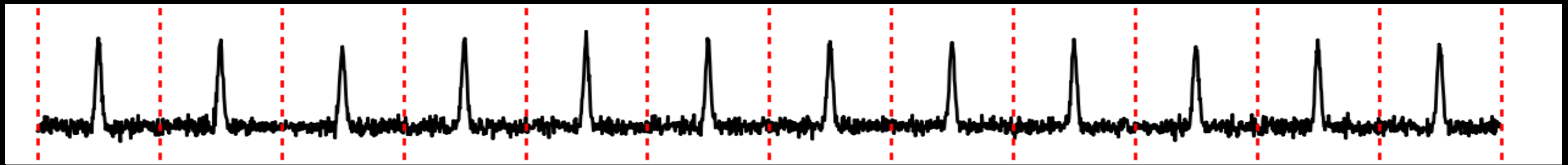
- Rapidly Rotating Neutron Star! (300-700 times/sec!)
- Size of city:
  - R ~ 10-15 km
- Mass greater than Sun:
  - M ~ 1.4-2.0 M_{sun}
- Strong Magnetic Fields:
  - B ~ 10^8-10^9 Gauss
- Pulses are from a "**lighthouse**" type effect
- "Spin-down" power up to 1000s times more than the Sun's total output!



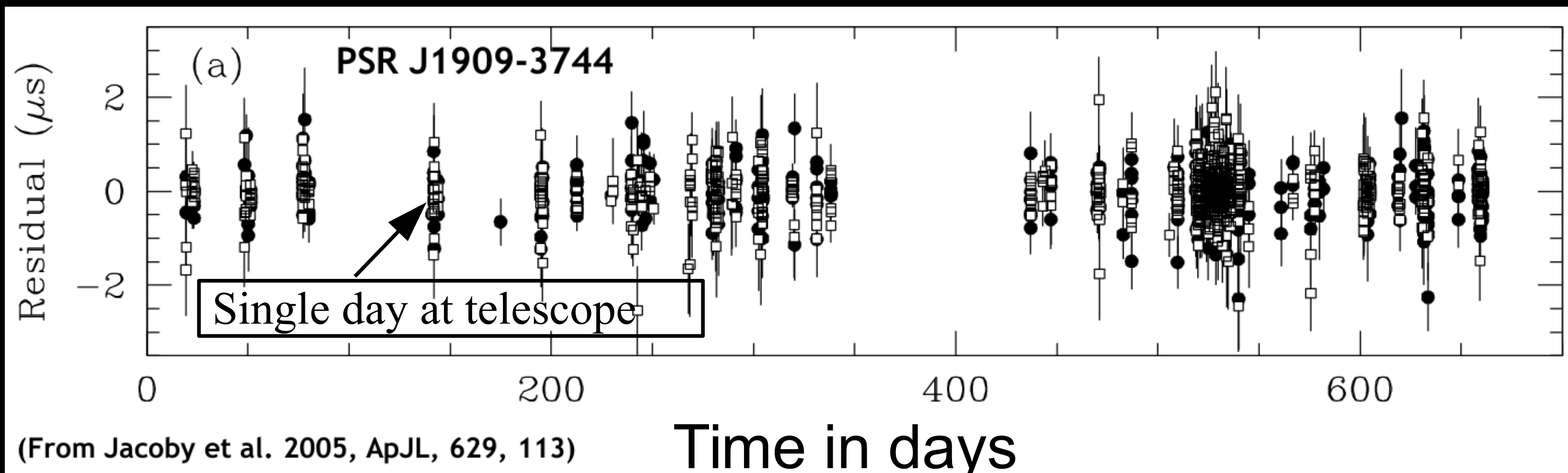
Credit: Bill Saxton, NRAO/AUI/NSF

Pulsar Timing:

Unambiguously account for every rotation of a pulsar over years



Measurement - Model = Timing Residuals

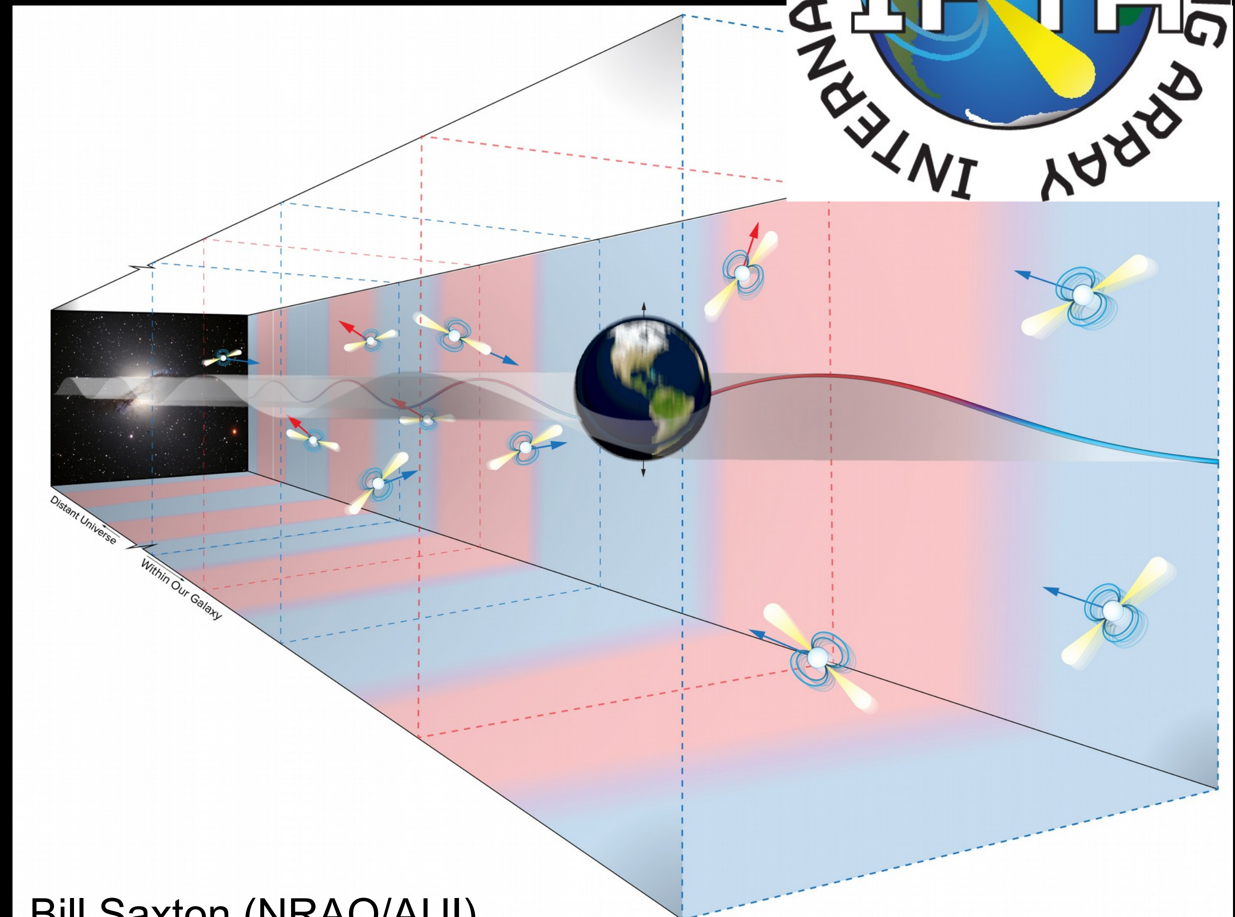


(From Jacoby et al. 2005, ApJL, 629, 113)

Predict each pulse to ~200 ns over 2 yrs!

Direct Gravitational Wave Detection (Pulsar Timing Array)

- Looking for nHz freq gravitational waves from super massive black hole binaries
- Need good MSPs:
  - Significance scales with the number of MSPs being timed
- Must time 20+ pulsars for 10+ years at precision of ~100 nanosec!



Bill Saxton (NRAO/AUI)

INTERNATIONAL PULSAR TIMING ARRAY
IPTA

PPTA
Australia

EPTA
Europe

NANOGrav
North America

For more information, see *nanograv.org*

A Pulsar Timing Array (PTA)

Timing residuals due to a GW have two components:

"Pulsar components" are uncorrelated between MSPs

"Earth components" are **correlated** between MSPs

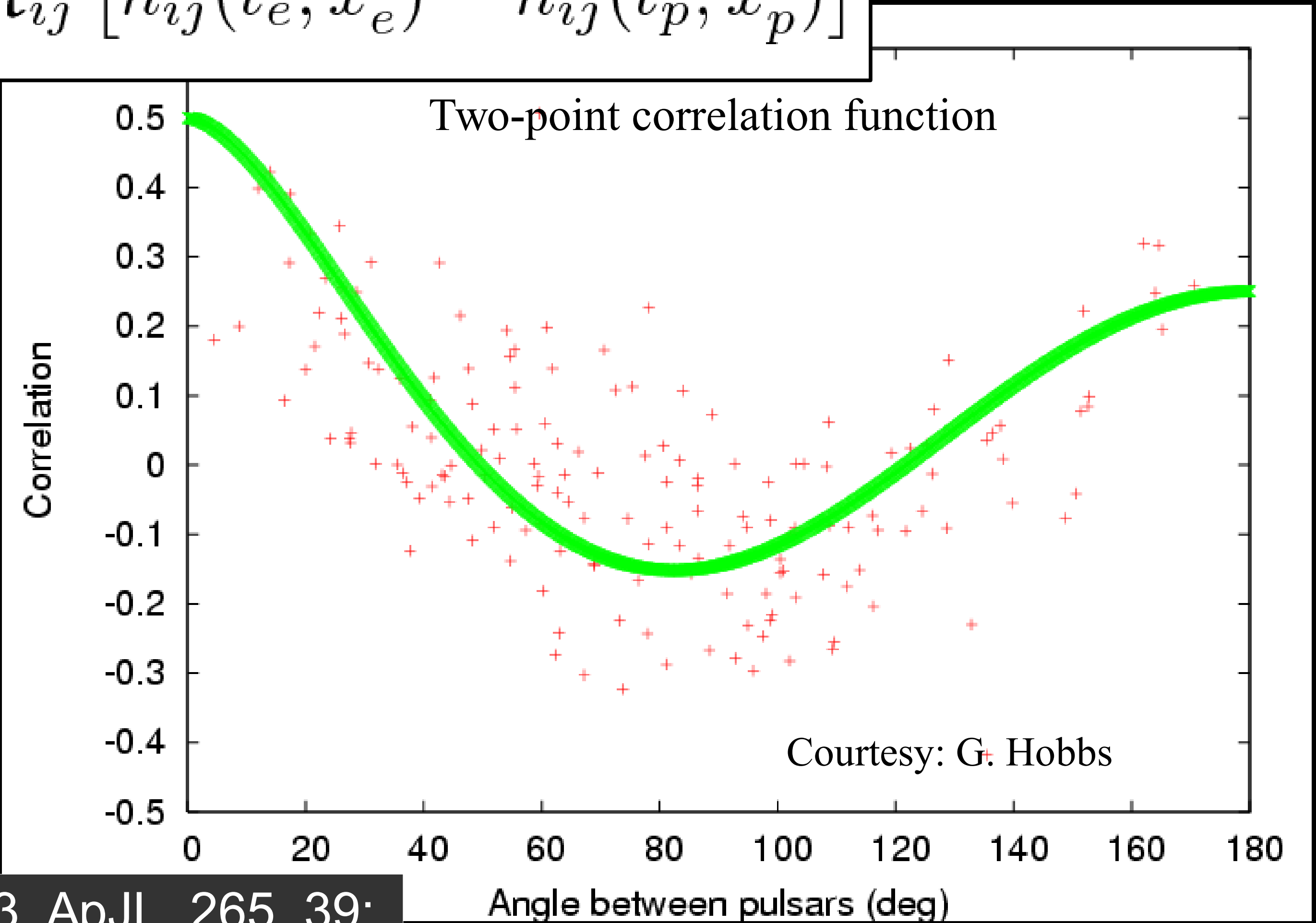
$$\frac{\delta\nu}{\nu} = -\mathcal{H}_{ij}\left[h_{ij}(t_e, x_e^i) - h_{ij}(t_p, x_p^i)\right]$$

Signal in Residuals

Clock errors:
- monopole

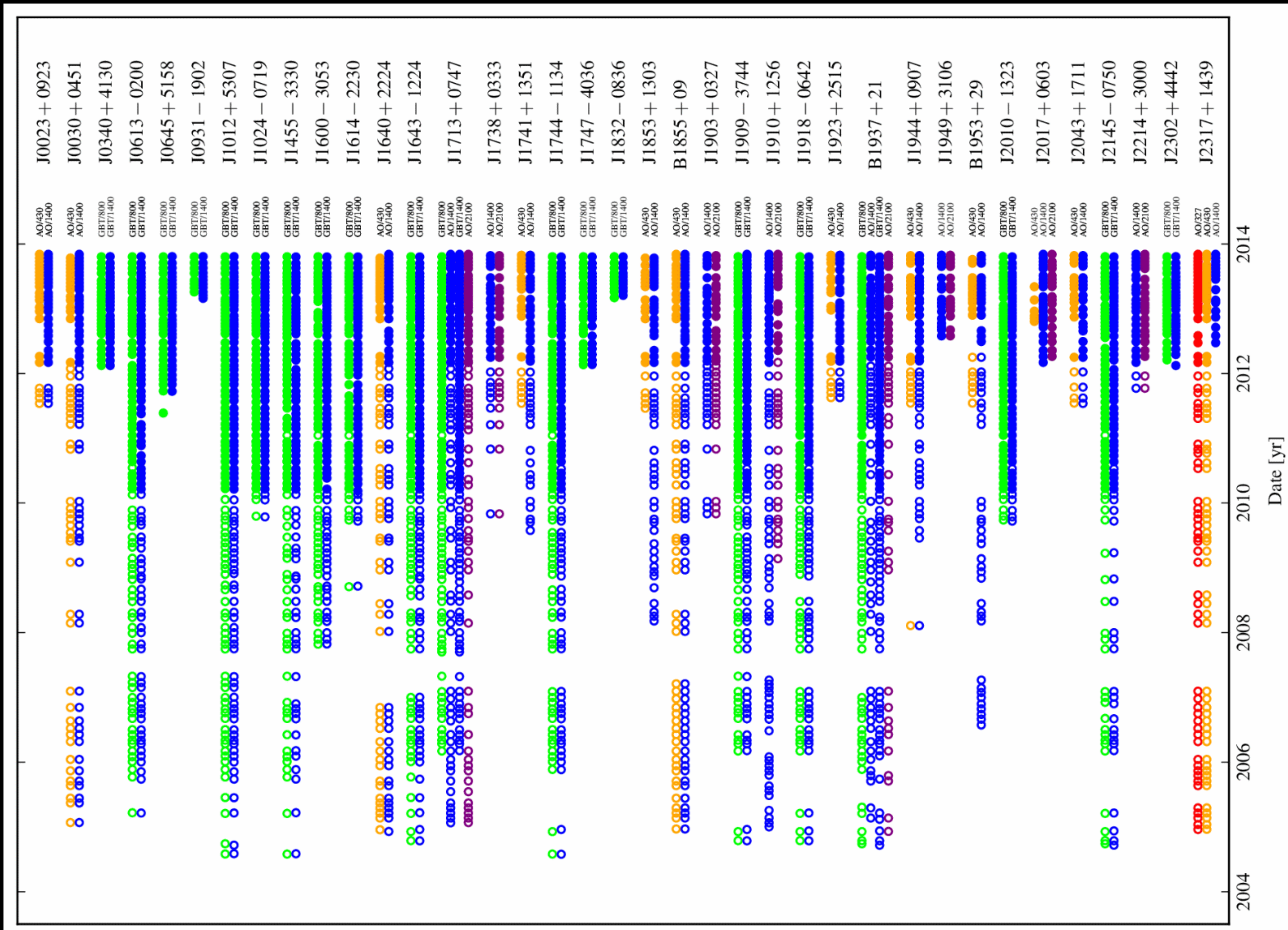
Ephemeris errors:
- dipole

GW signal:
- **quadrupole**

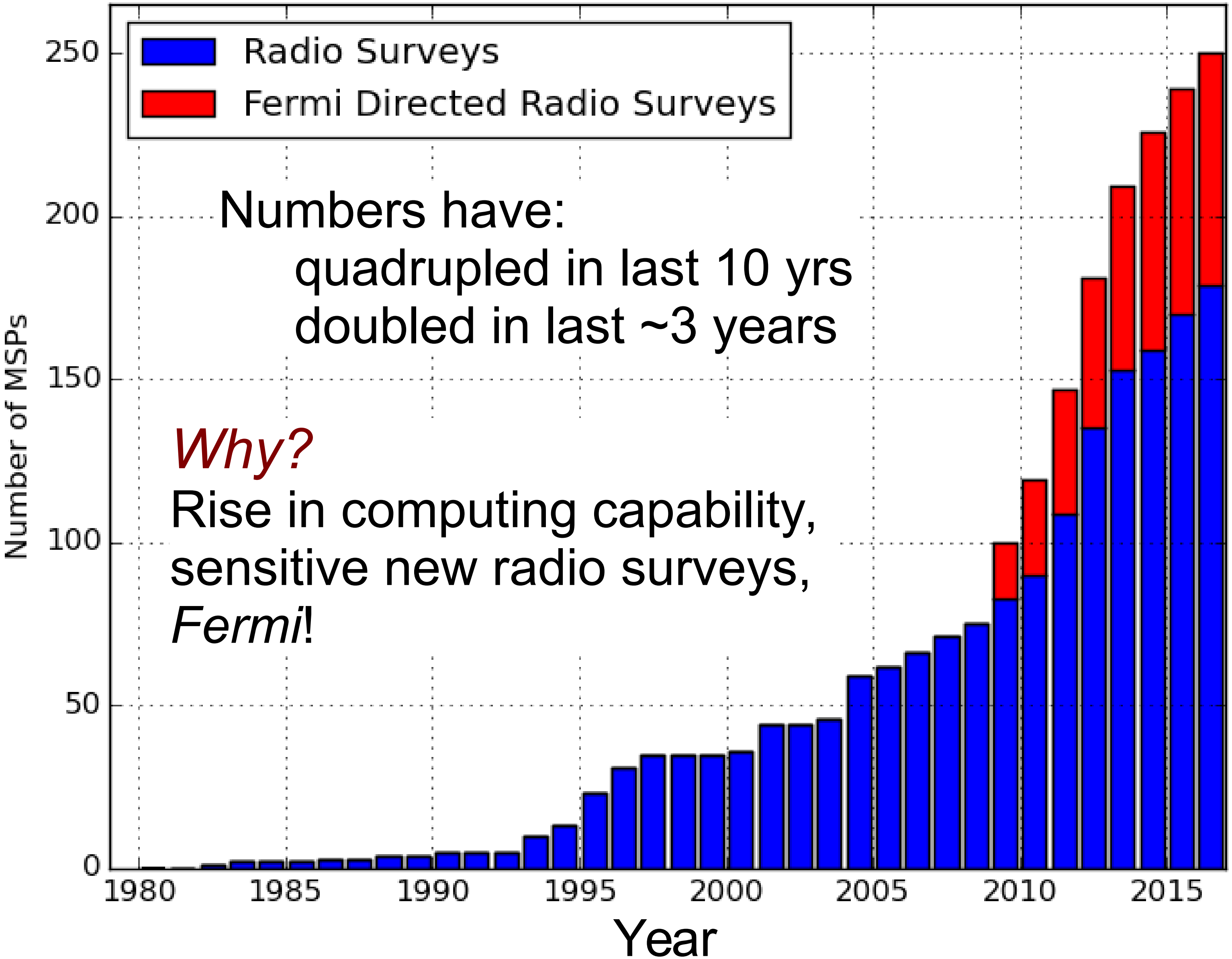


e.g. Hellings & Downs, 1983, ApJL, 265, 39; Jenet et al. 2005, ApJL, 625, 123

NANOGrav 9-yr Data



New Millisecond Pulsars



Numbers have:
quadrupled in last 10 yrs
doubled in last ~3 years

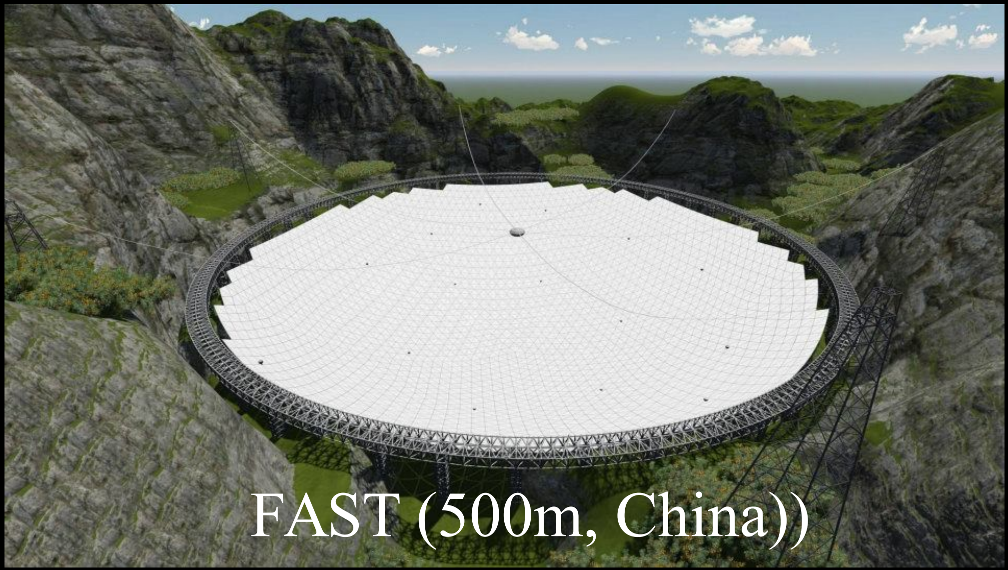
Why?
Rise in computing capability,
sensitive new radio surveys,
Fermi!

What about the future?

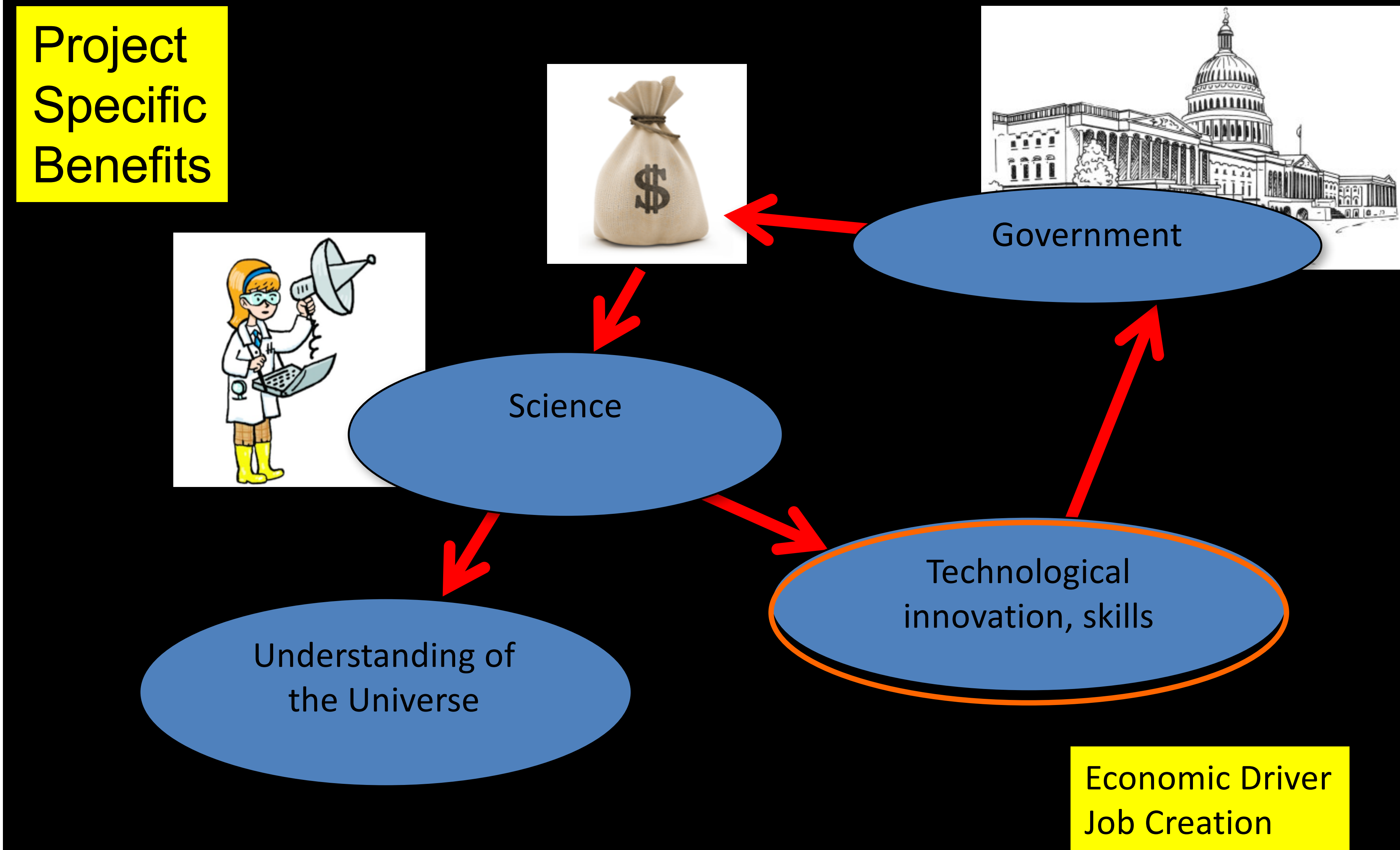
- We only know of about 2,500 out of ~50,000+ pulsars in the Galaxy!
  - Many of them will be "Holy Grails"
    - Sub-MSP, PSR-Black Hole systems, MSP-MSP binary
- Several new huge telescopes...

We need them because we are sensitivity limited!

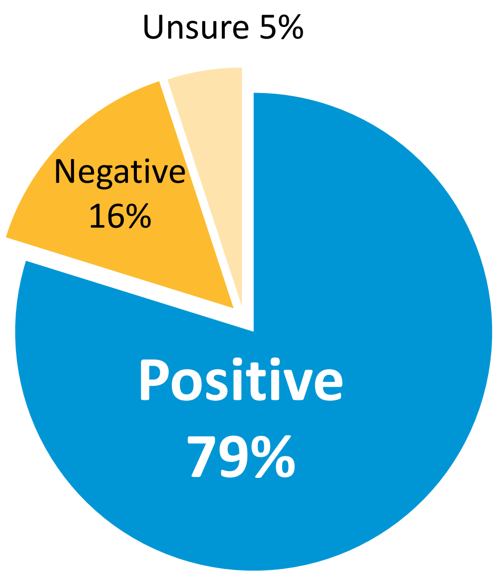

MeerKAT (64 dishes, SA)


FAST (500m, China))

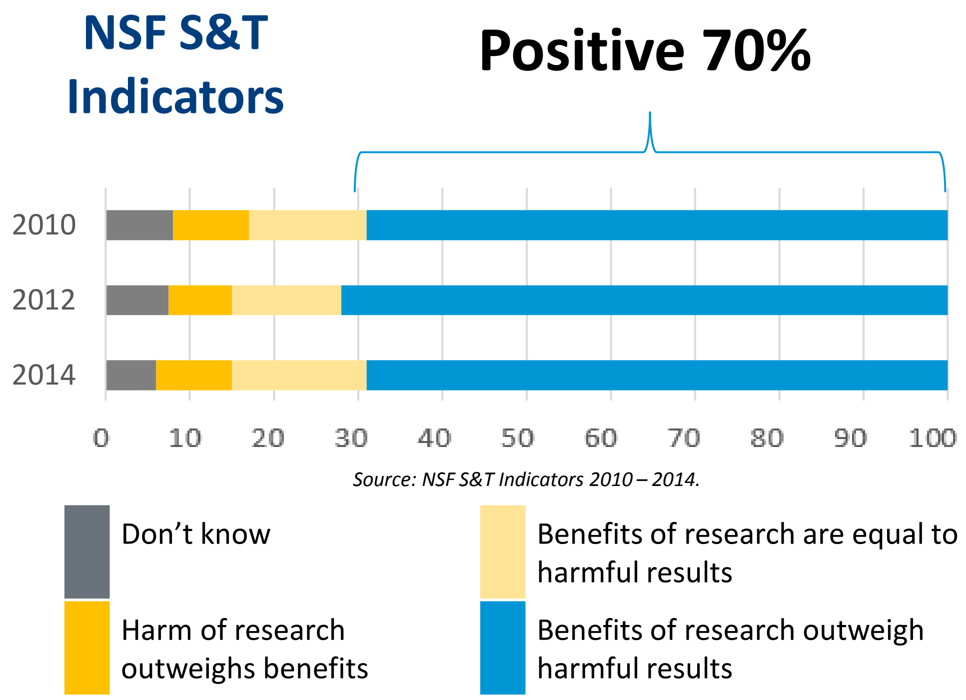
Why do governments support science?



Public's Overall View of Science



PEW/AAAS 2015



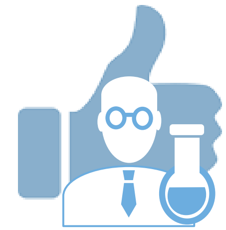
Public's view of science and scientists is overwhelmingly positive

Key Findings: ATTITUDES

1

THE SCIENCE BRAND IS STRONG

70% trust scientists to conduct beneficial research, and **74% trust** scientists to tell the truth.



Public is already on board:
need to get them engaged

2

NO GOV FUNDS, NO BIG DEAL

Only 1 in 4 Americans believe government's role in funding science is **irreplaceable**.

Ignorance is bliss:
must relay gov's essential role

3

PRIVATE & PUBLIC IN HARMONY

Sentiment is **private research is better at solving specific problems,** while **government research is better at serving the greater good.**

Doesn't Translate Directly to Policy

Top Domestic Program Willing to Cut to Reduce Deficit Among All Voters	2015
Scientific Research	25%
Unemployment Benefits	19%
National Defense	14%
Roads, Bridges, and Other Infrastructure	9%
Public Education	8%
Medical Research	7%
Medicare	4%
Social Security	2%
Veterans Benefits	2%
None of these	28%

Source: Public Opinion Strategies/Greenberg Quinlan Rosner – Research Funding – 2015.

Congressional Adage:

"Consult the Experts when Spending; Consult Your Constituents When Cutting."

SCIENCE IS HOPE

Americans view science as a path to a better tomorrow, a means to serve the greater good. Science is a source of optimism, a catalyst for personal and communal aspirations.

For more information or to get involved, please contact Chris Volpe at:
info@sciencecounts.org

www.sciencecounts.org

Benefit of a Campaign

Previous Survey

Top Domestic Program Willing to Cut to Reduce Deficit Among All Voters	2015
Scientific Research	25%
Unemployment Benefits	19%
National Defense	14%
Roads, Bridges, and Other Infrastructure	9%
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Medical Research	7%
Medicare	4%
Social Security	2%
Veterans Benefits	2%
None of these	28%

Source: Public Opinion Strategies/Greenberg Quinlan Rosner – Research Funding – 2015.
Note that some respondents gave more than one answer

This Survey

Top Domestic Program Willing to Cut to Reduce Deficit Among All Voters	2016
National Defense	21%
Unemployment Benefits	19%
Roads, Bridges, and Other Infrastructure	5%
Public Education	5%
Scientific Research	5%
Medical Research	2%
Medicare	2%
Social Security	2%
Veterans Benefits	2%
None of these	39%

Source: Raising Voices for Science – ScienceCounts and Research!America - 2016

Thank you !


38TH INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS
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2016CHICAGO
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