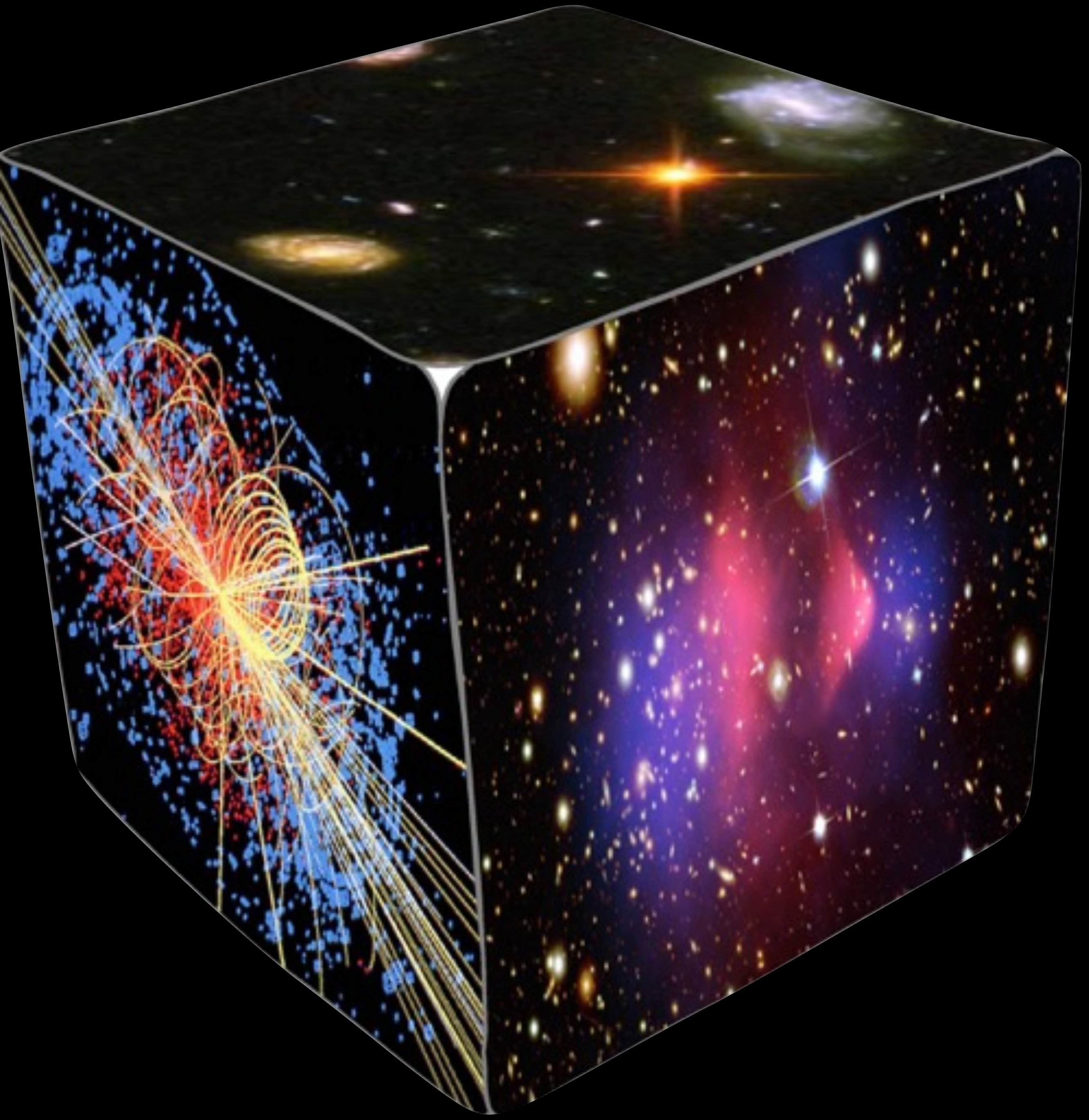
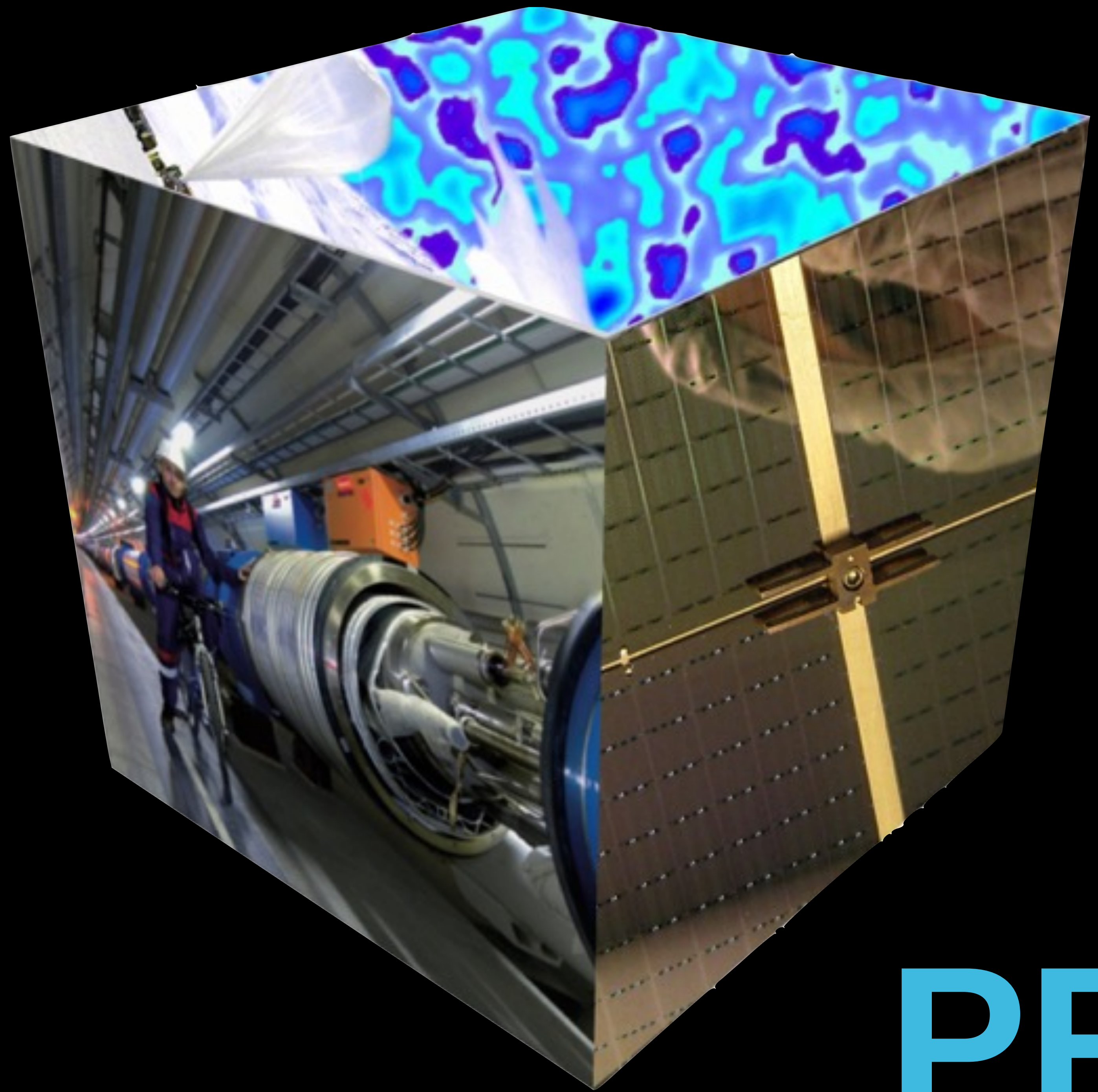
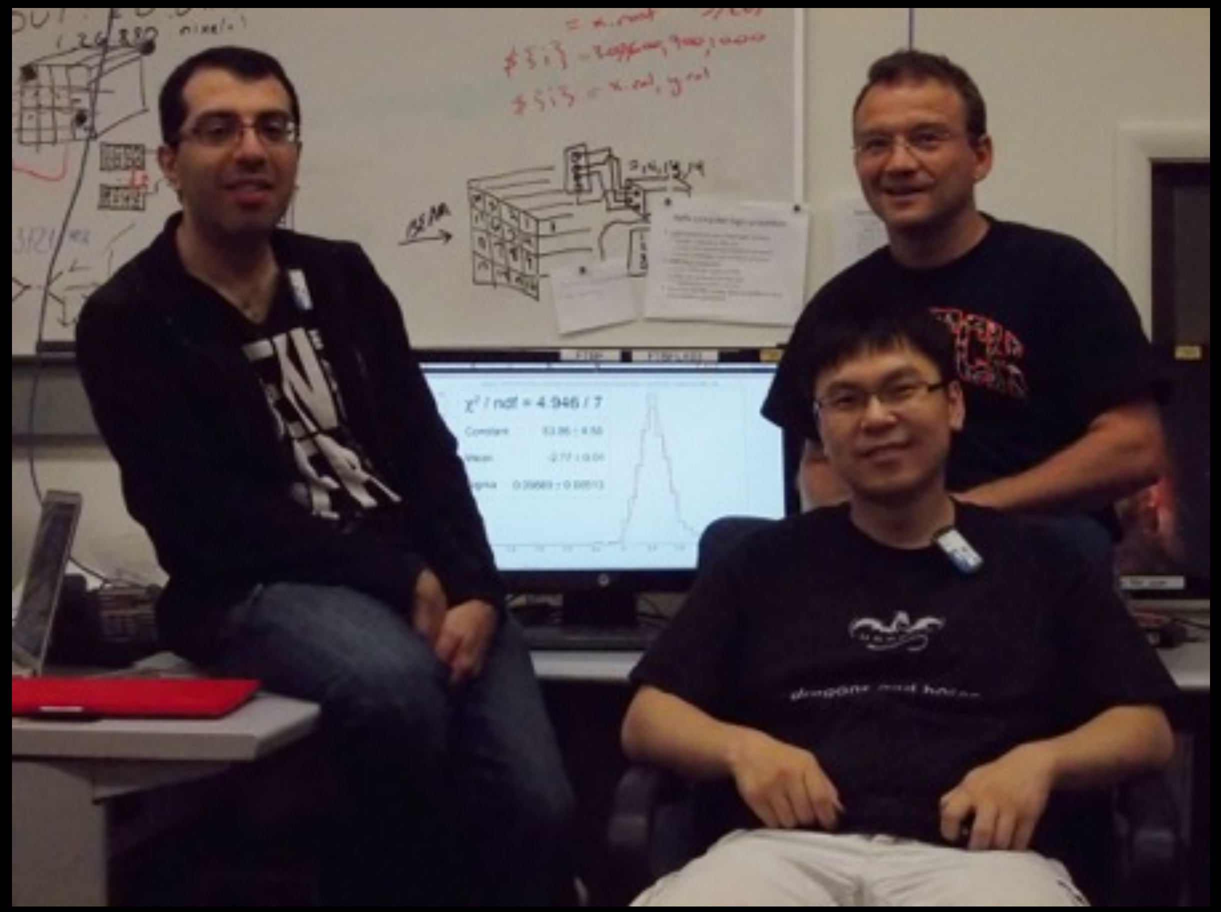




PRECISION TIMING CALORIMETRY

CPAD, DBF INSTRUMENTATION FRONTIER MEETING

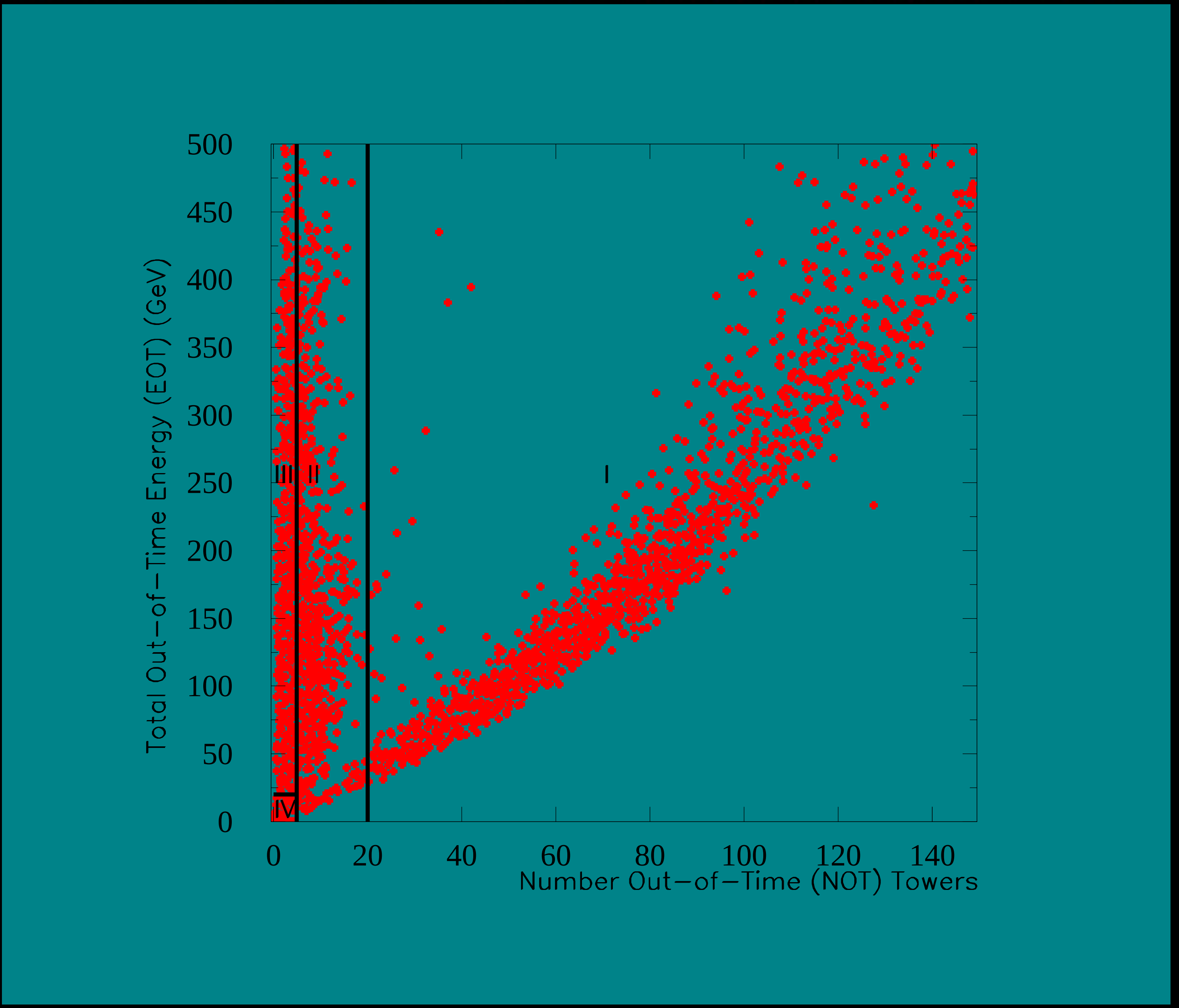
October 5 - 7, 2015 - University of Texas at Arlington

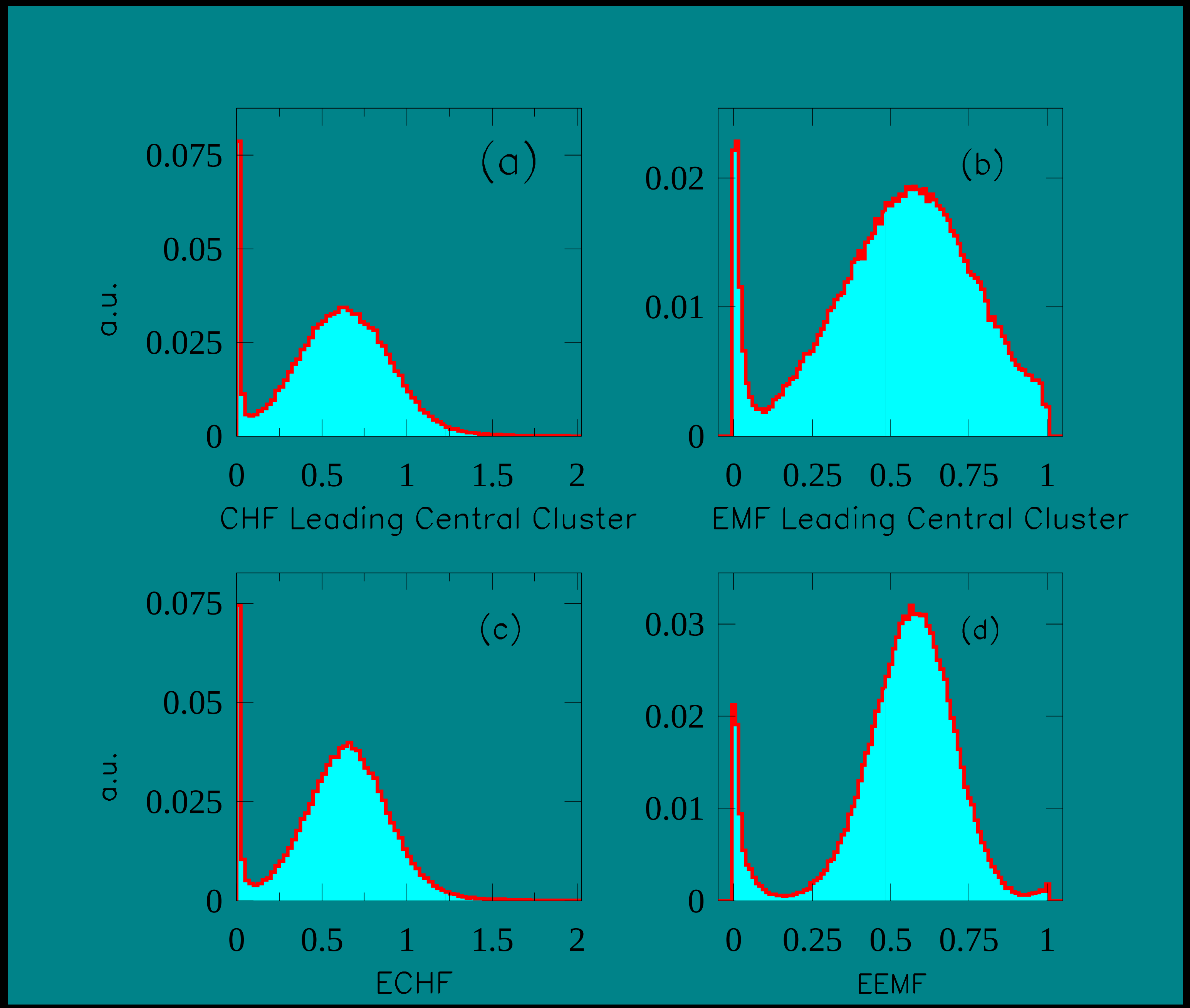


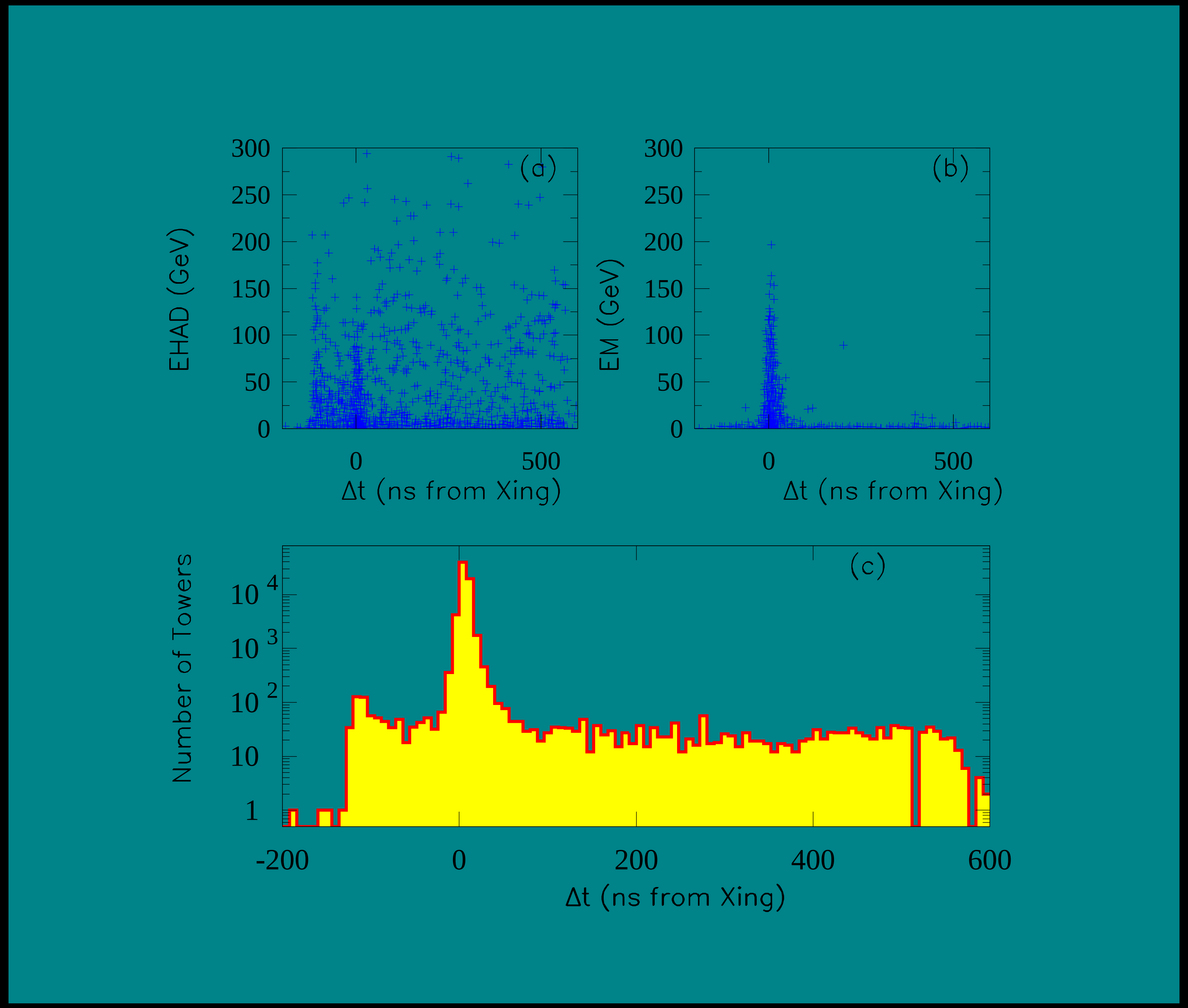
have been working on timing R&D in the past 3 years w/ Anatoly Ronzhin, Erik Ramberg Adi Bornheim, Artur Apresyan Si Xie, Javier Duarte, Cristian Peña, 9 undergrads, + UofC colleagues — profit from Caltech HEP Calorimetry experts (Newman, Hitlin, Zhu)

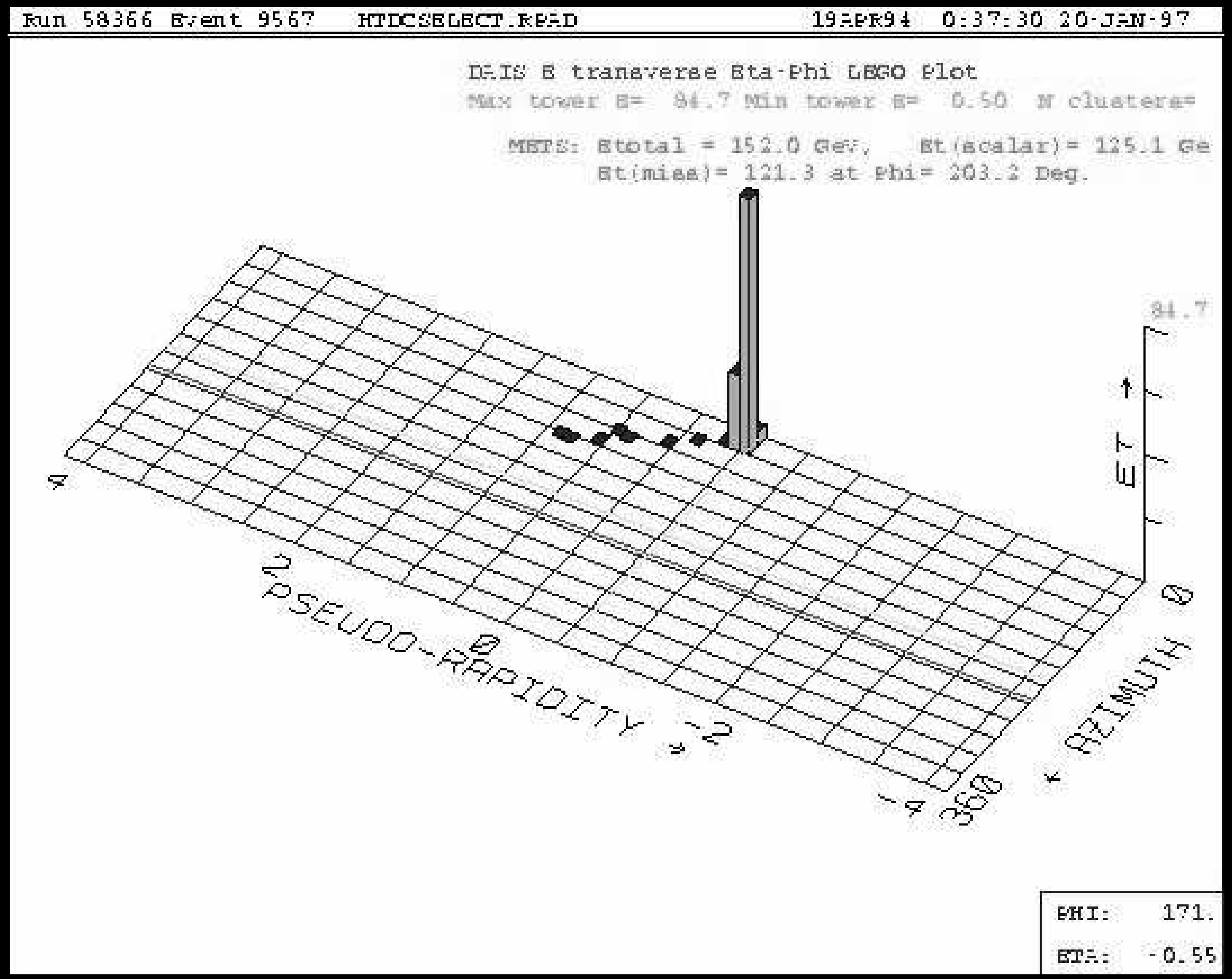
Test Beams at FNAL and CERN priceless!

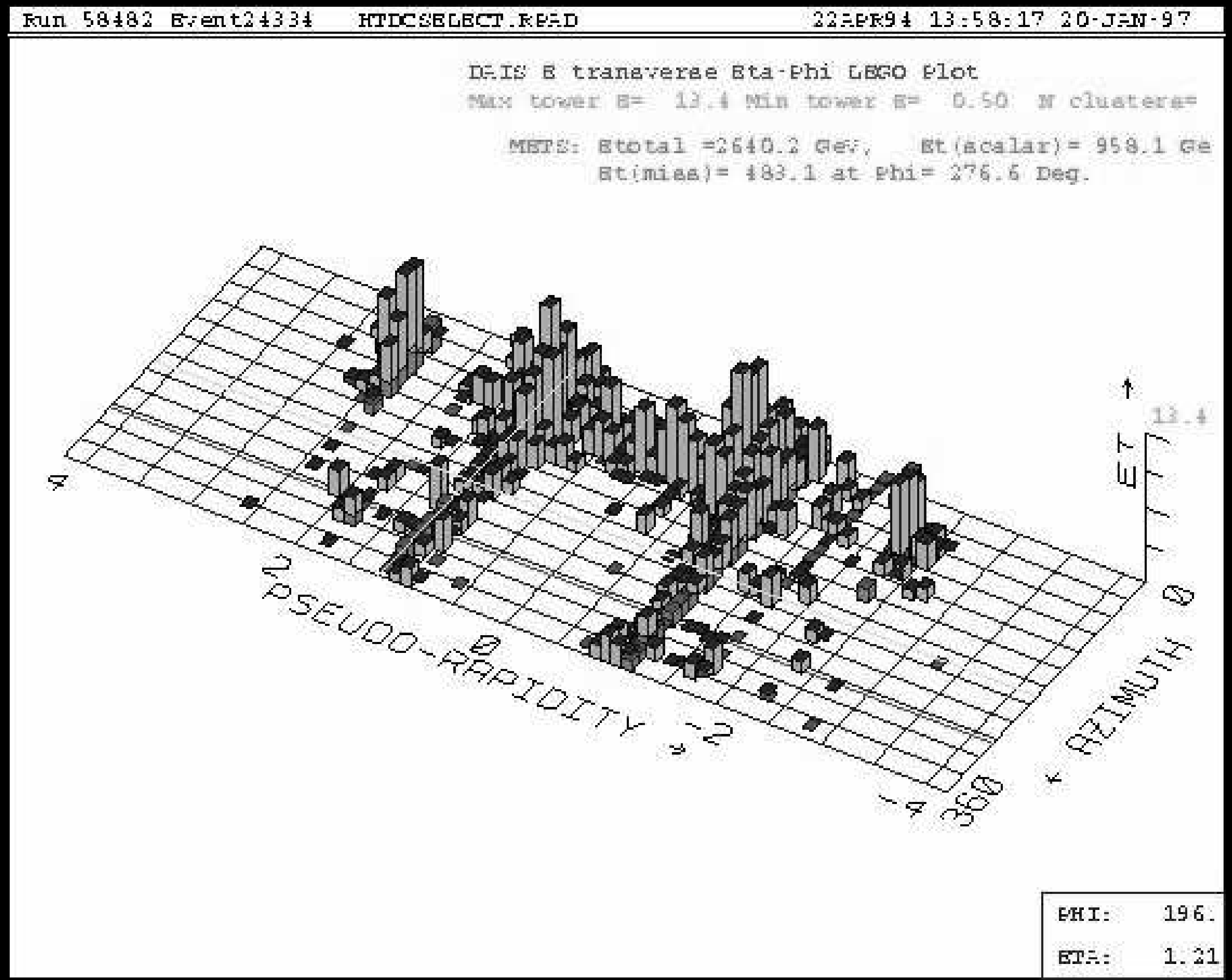
CALORIMETER TIMING MEMOIR (CIRCA 1998)

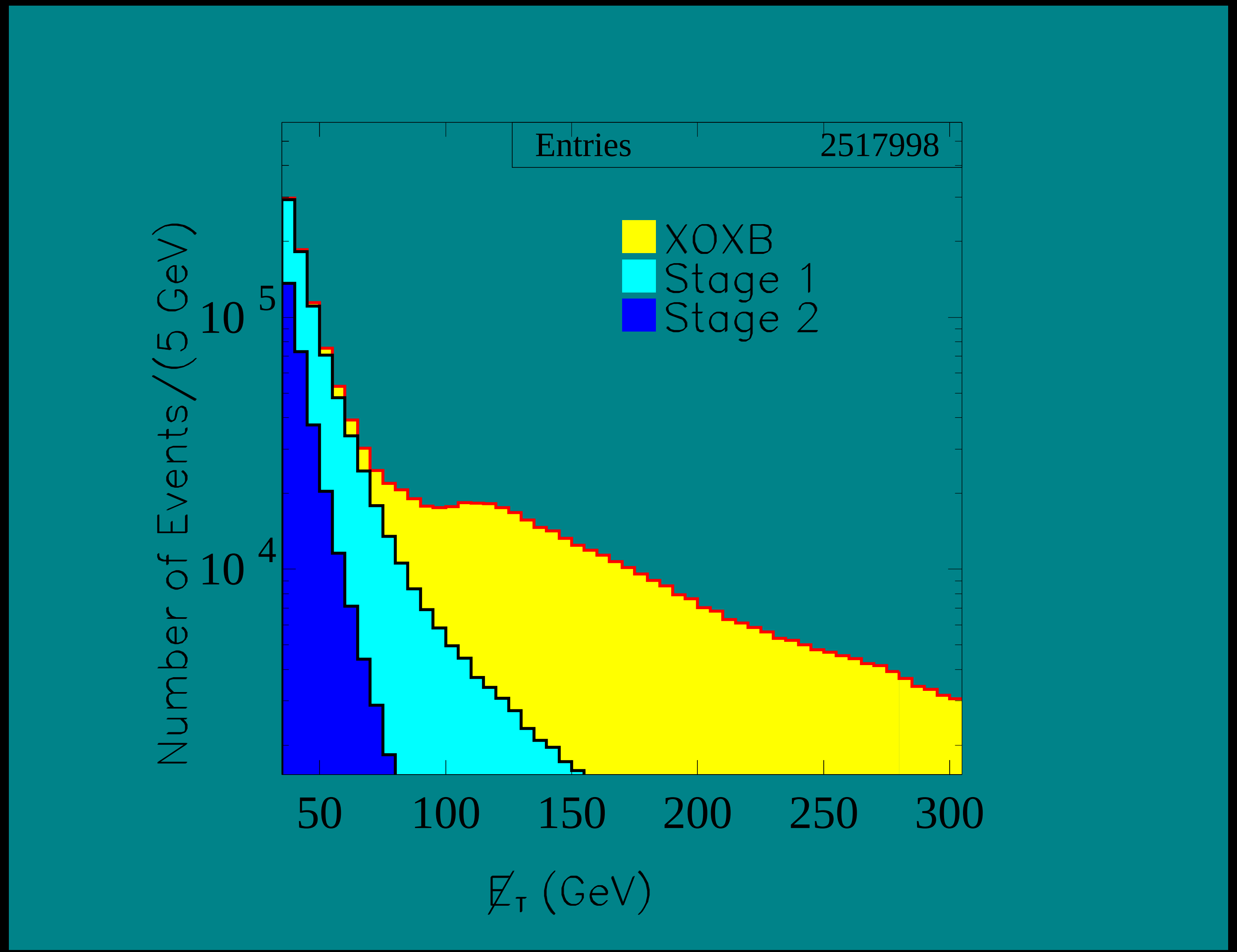






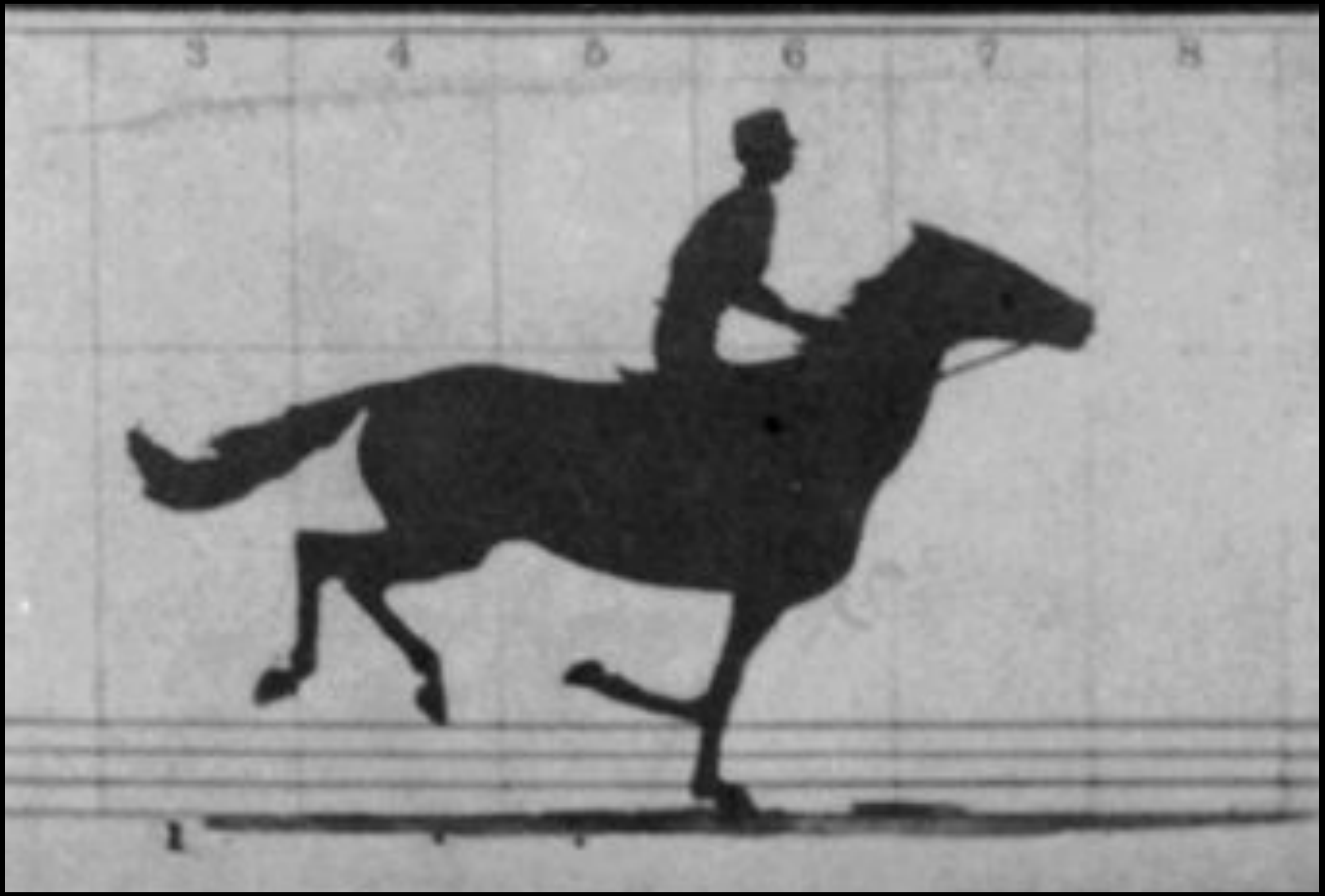


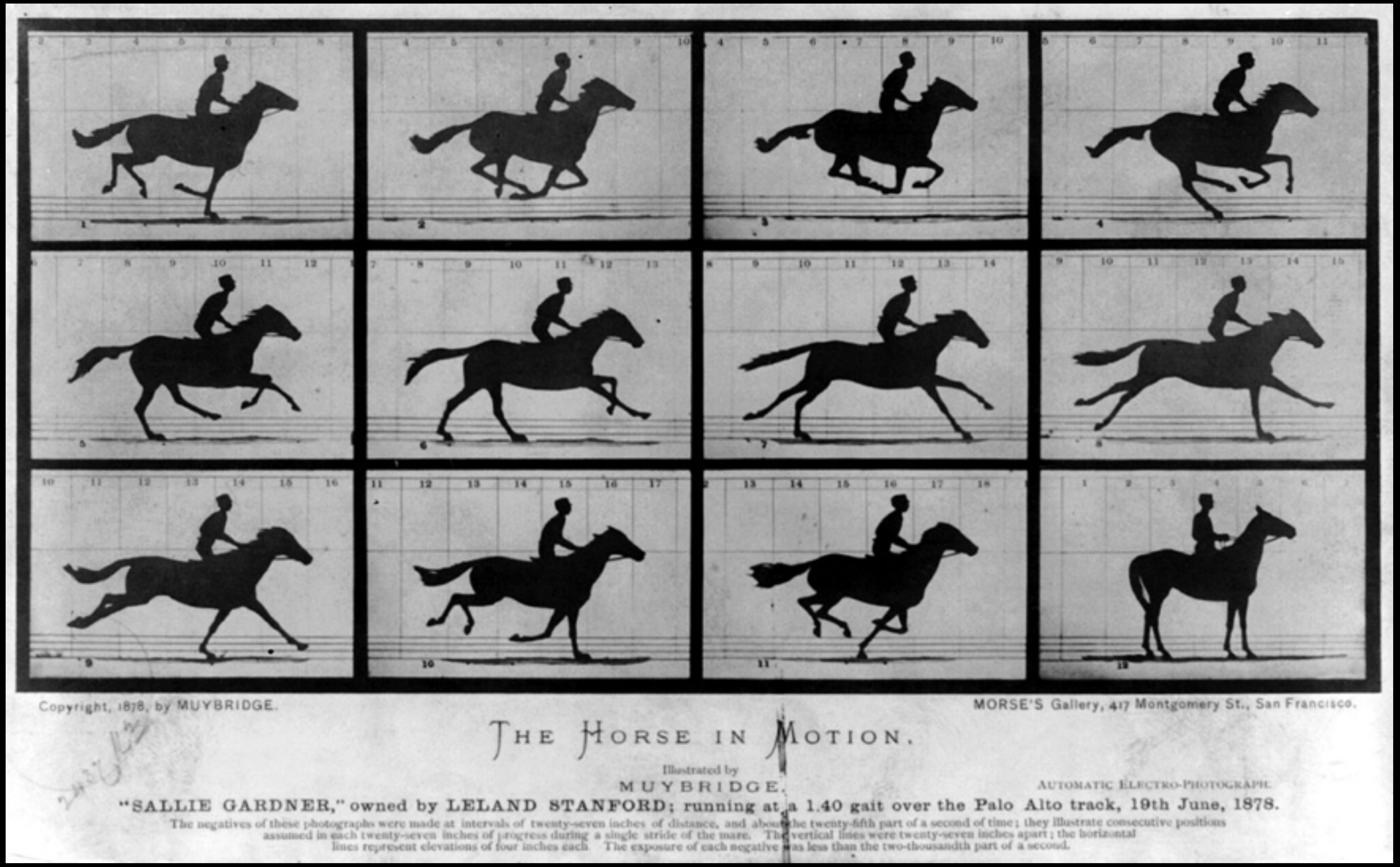




http://inspirehep.net/record/535352

SALLIE GARDNER



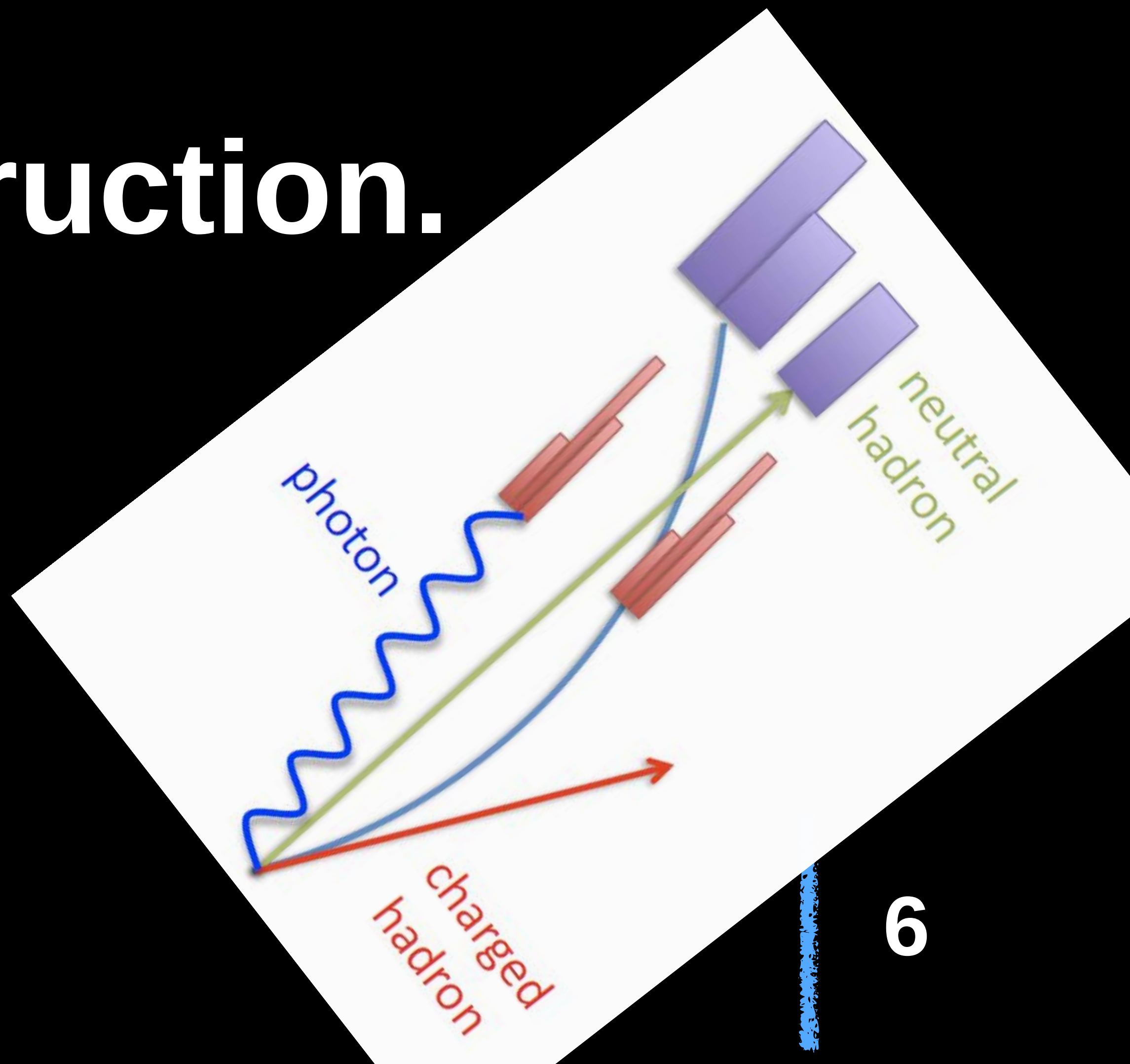


"Muybridge race horse animated" by Photos made by Eadweard MuybridgeAnimation by User Waugsberg - The sequence is set to motion using these frames, originally taken from Eadweard Muybridge's Human and Animal Locomotion series, (plate 626, thoroughbred bay mare "Annie G." galloping) published 1887 by the University of Pennsylvania. Licensed under Public Domain via Commons - https://commons.wikimedia.org/wiki/File:Muybridge_race_horse_animated.gif#/media/File:Muybridge_race_horse_animated.gif

EVOLUTION & MOTIVATION

PUSHING THE ENVELOPE

- High luminosity → more PU, shorter bunch spacing, complex 4D luminous regions
- Higher energy → larger phase space for more complex topologies (jet multiplicity, boosted objects), require larger dynamic range of detectors & granularity & push PFA to limit (substructure, ML tech etc).
- Precision timing allows to extend calorimetric measurements into the high density environment
  - Associate energy to the proper vertex by 4D reconstruction.
  - Exploit 4D information in clustering



COMPLEXITY, SCALE, INTELLIGENCE OF INTEGRATED SYSTEMS

— Scale & complexity of collisions

— Scale & complexity of detectors

— Scale & complexity of DAQ

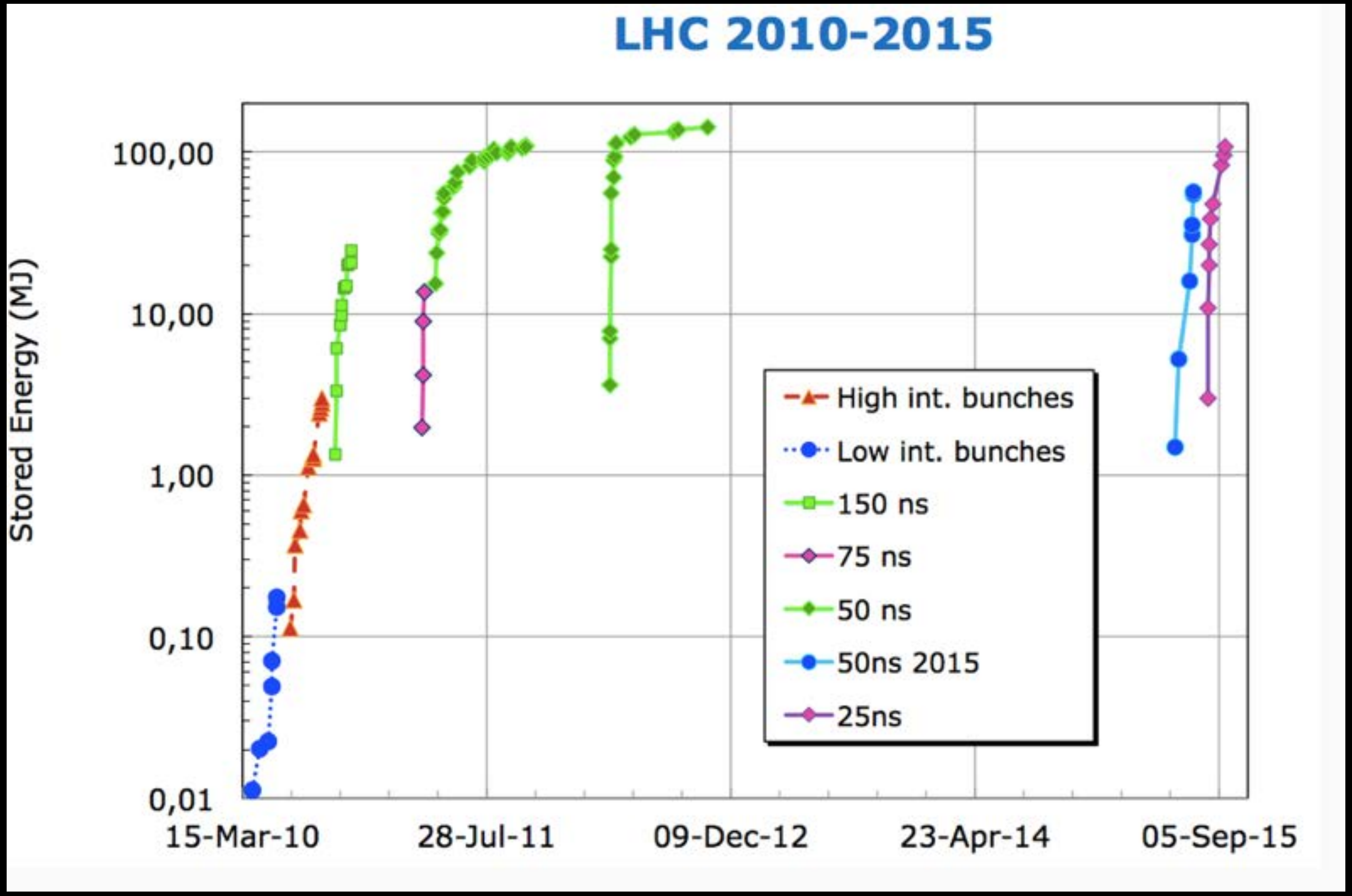
— Scale & complexity of trigger

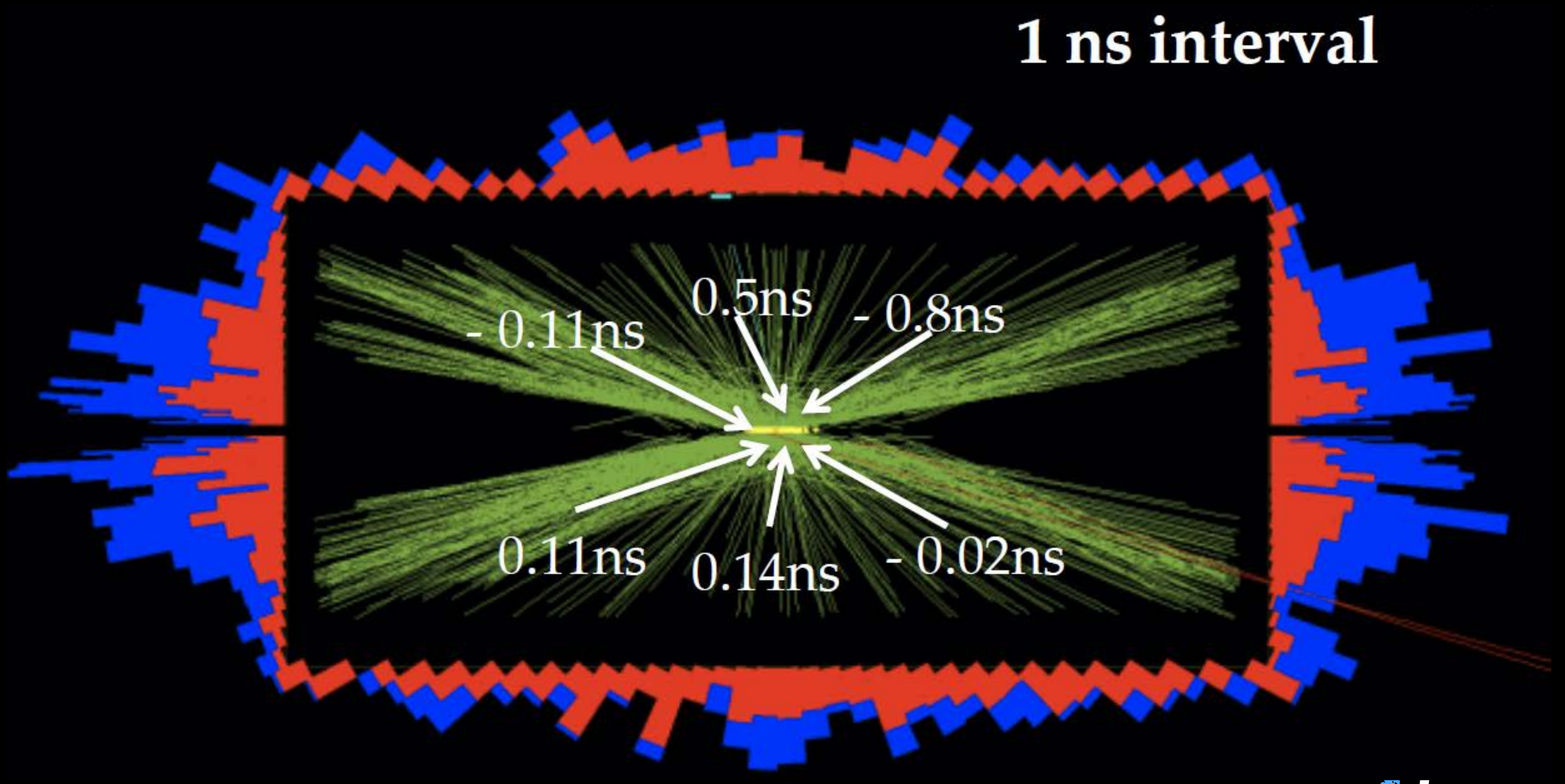
— Complexity of reconstruction

— Complexity of algorithms

— Complexity of data distribution & transfers

— Complexity and tractabilty of detector simulation



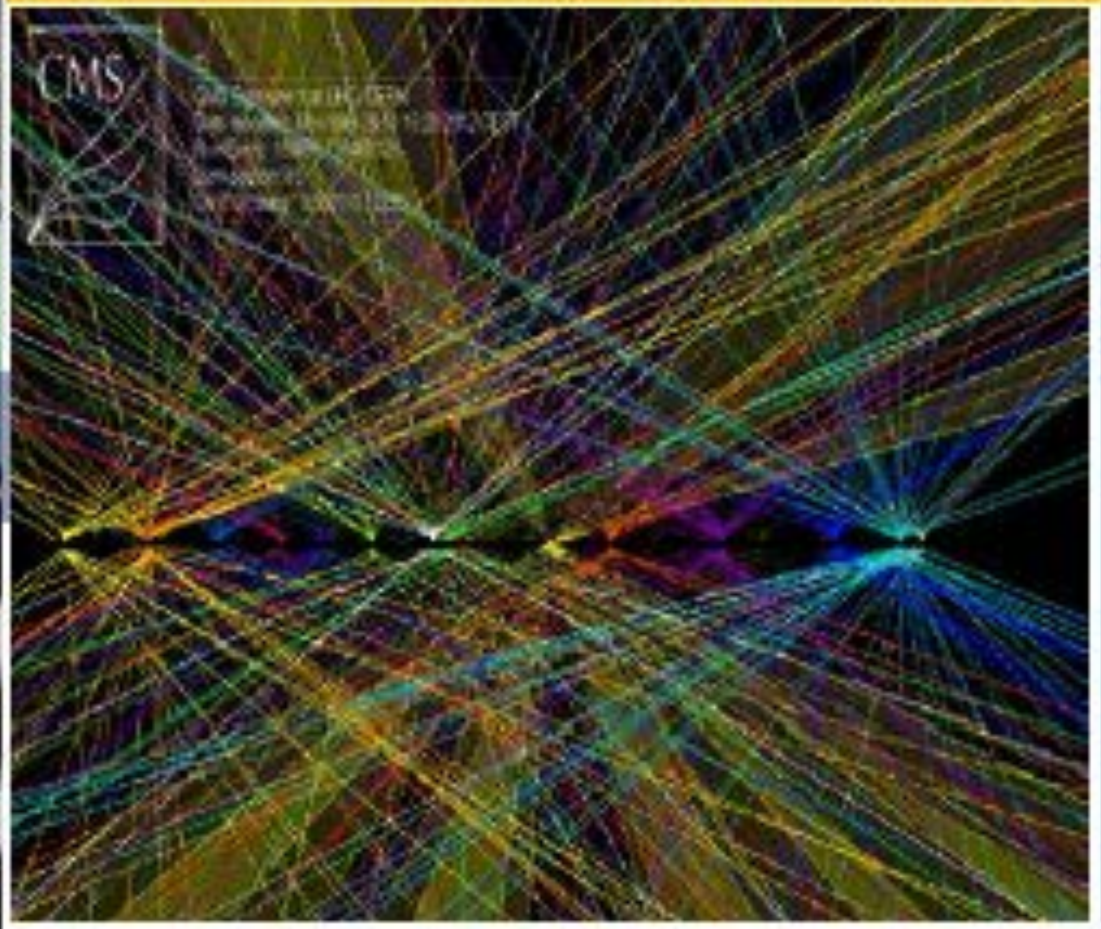


— towards holistic, hybrid integrated intelligent, agile, adaptable, detection systems

— emerging innovation (e.g. Askaryan/Gorham @slam)

Data Complexity: The Challenge of Pileup

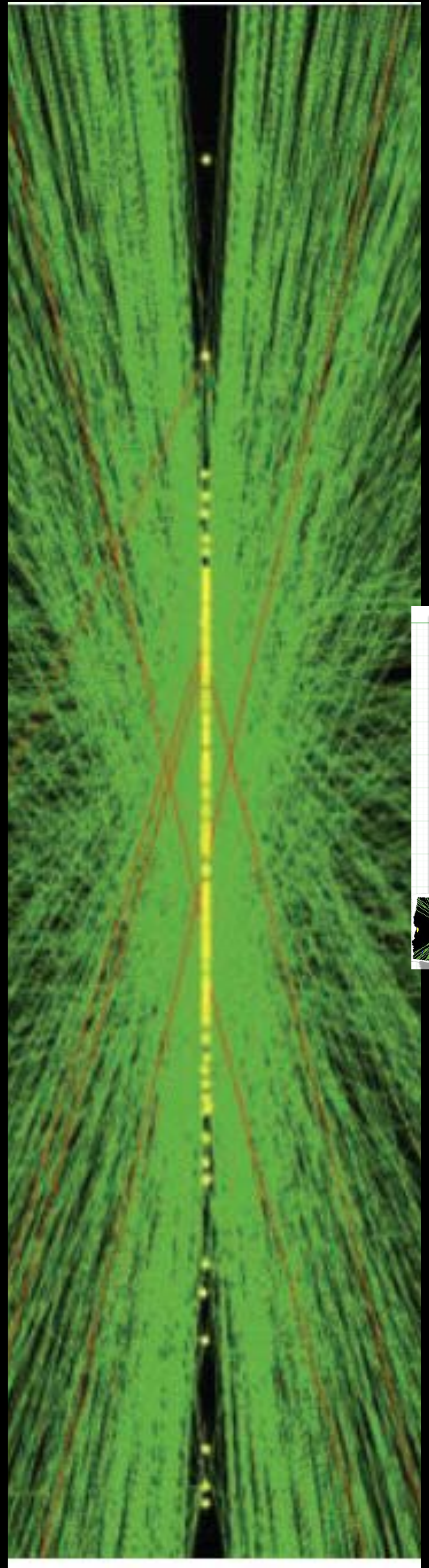
~3.5 X 10^{15} pp Collisions
1M Higgs Bosons created in Run 1

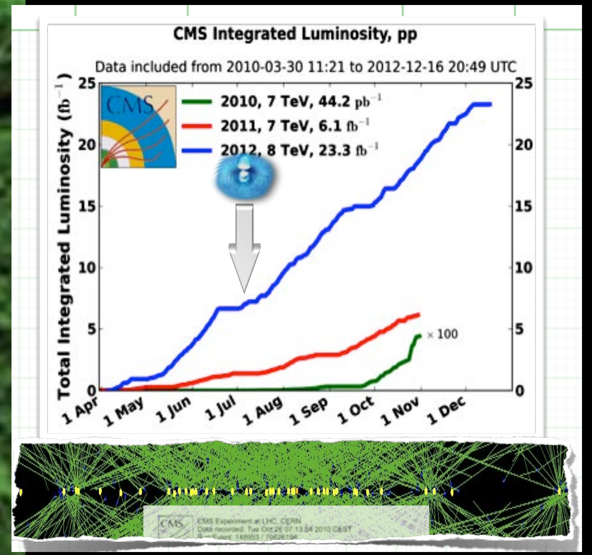


~50 Vertices, 14 Jets, 2 TeV

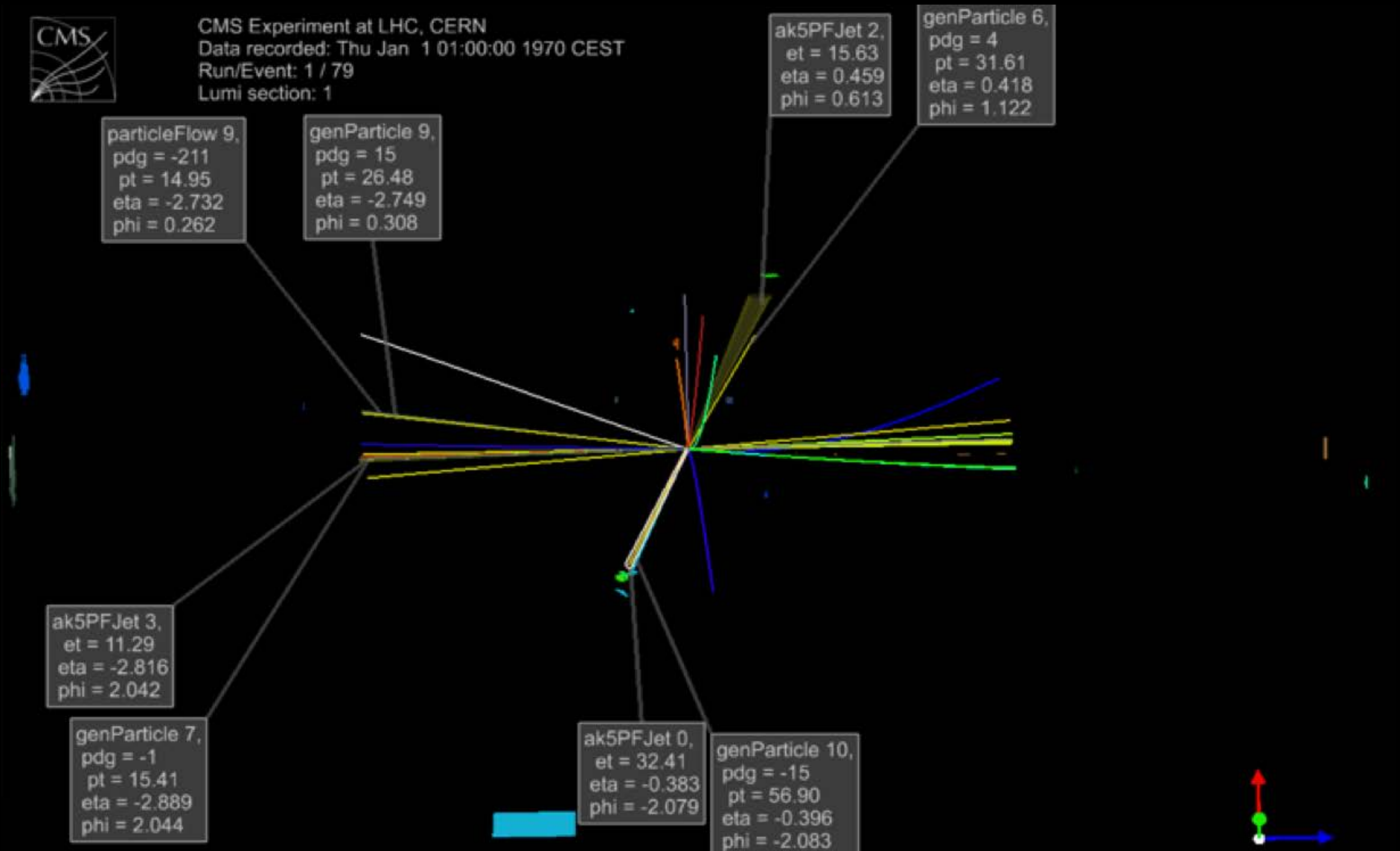
Average Pileup
- Run 1 21
- Run 2 42
- Run 3 53
- HL LHC 140-200

Run2 and Beyond will bring:
- Higher energy and intensity
- Greater science opportunity
- Greater data volume & complexity
- A new Realm of Challenges

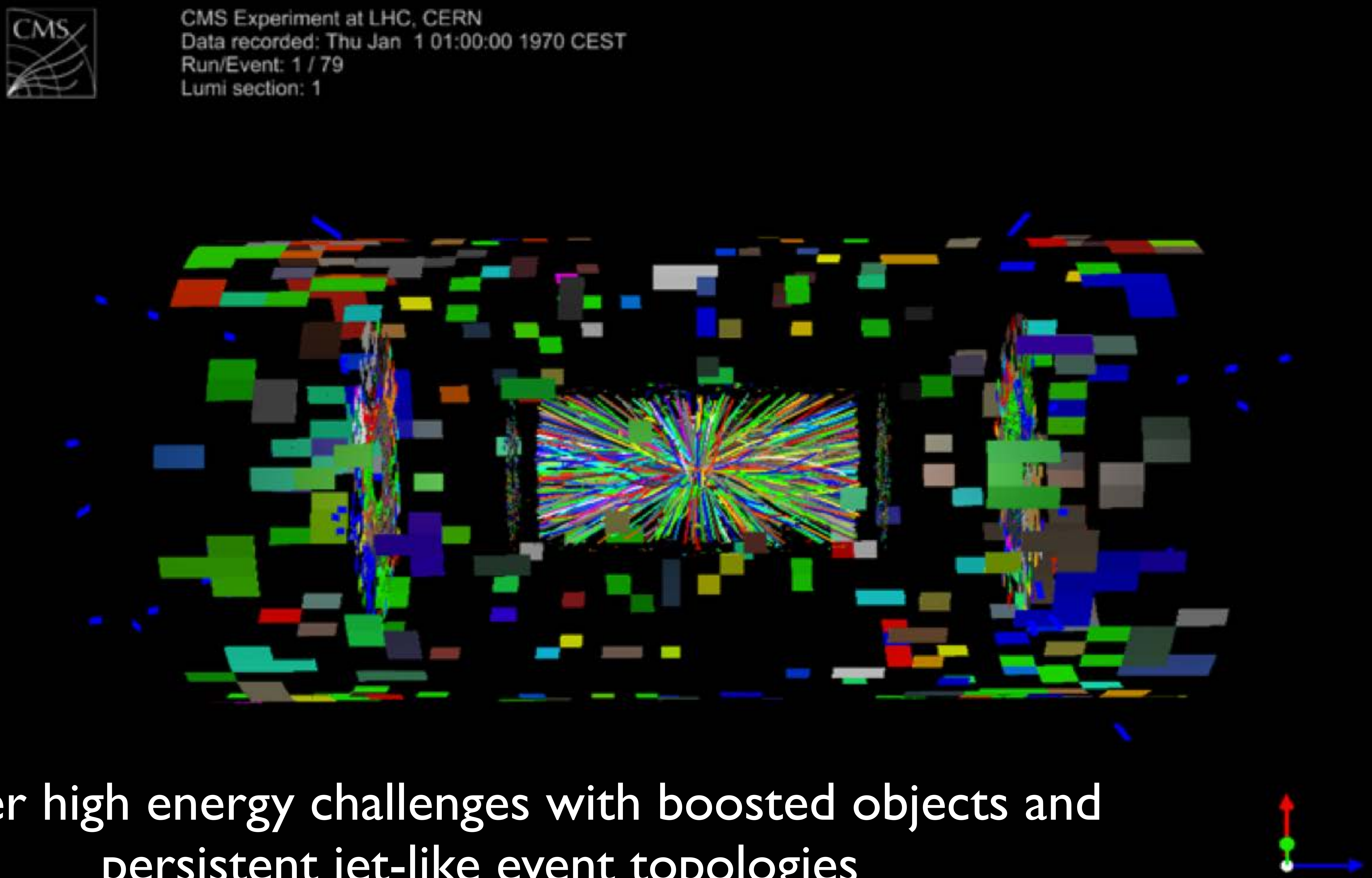




EXAMPLE: 0 PU H (ττ)



EXAMPLE: 140 PU H(ττ)



+ super high energy challenges with boosted objects and persistent jet-like event topologies

TIMING AND 5D CALO-RECONSTRUCTION

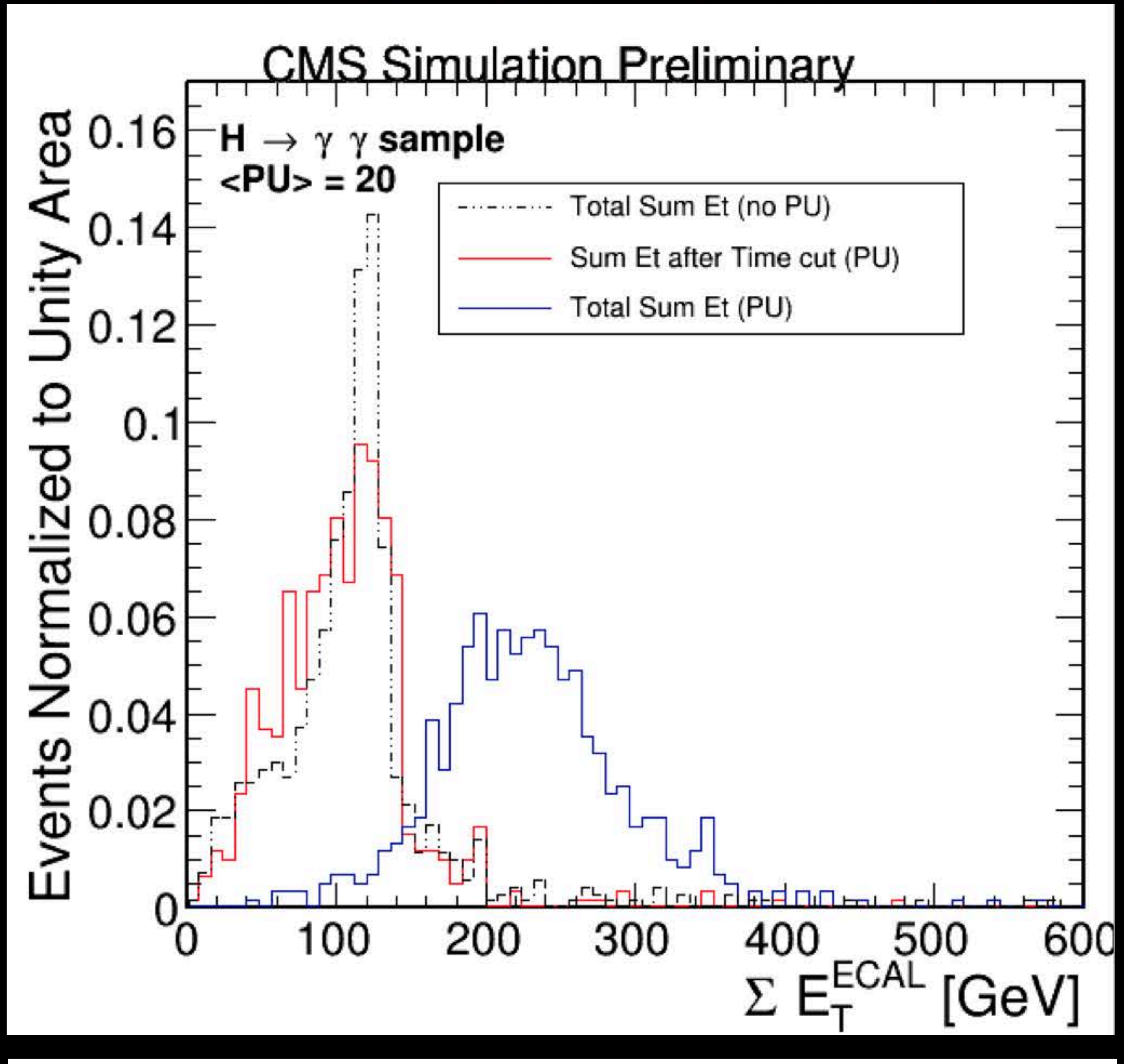
— **PU effects**

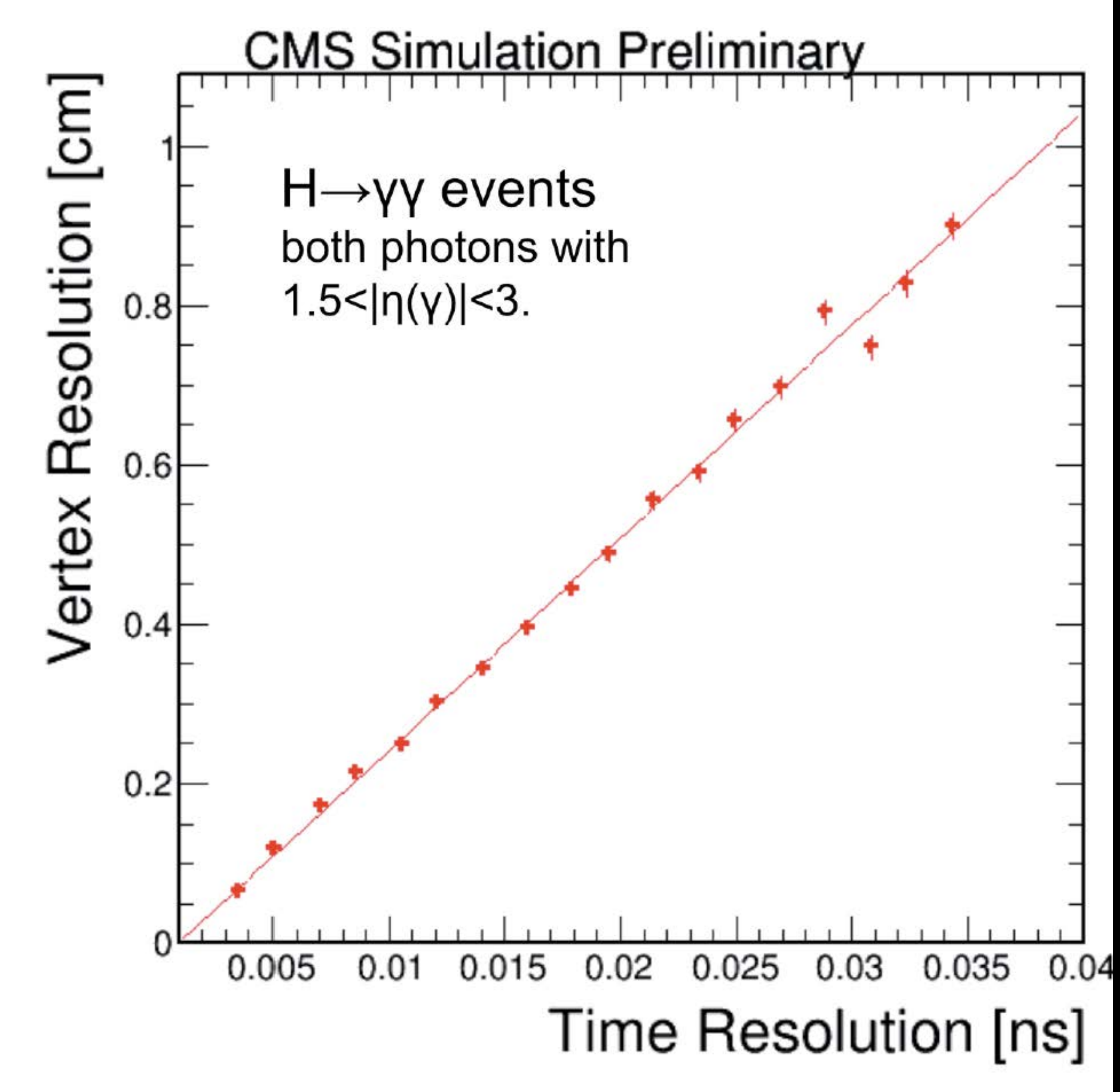
  - quantify this in terms of effective PU

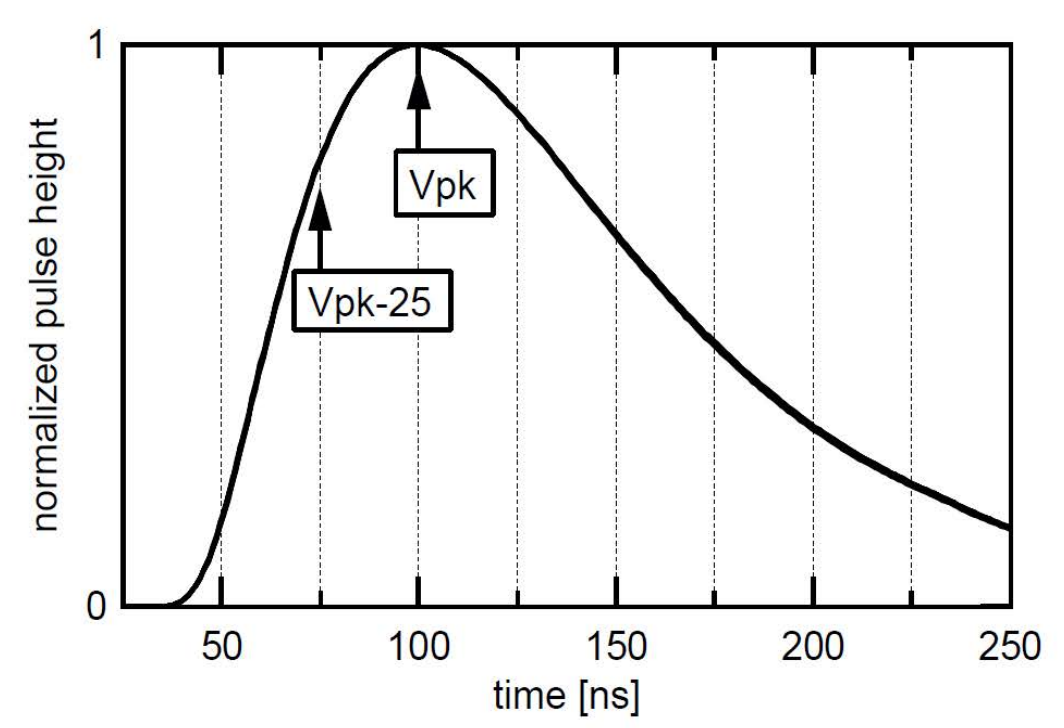
— **PID/PFA**

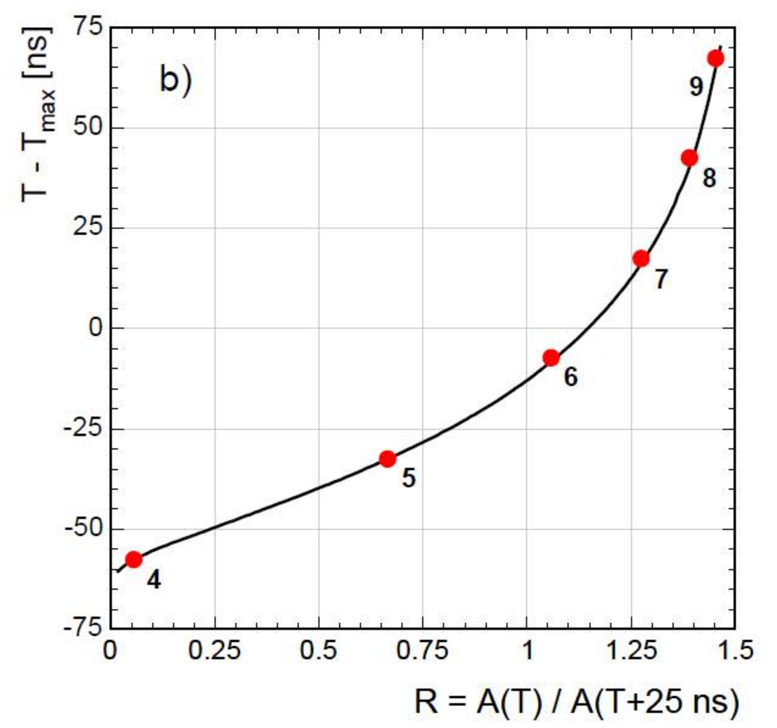
— **CALO-Timing: simultaneous x,y,z,t,E 5D reconstruction**

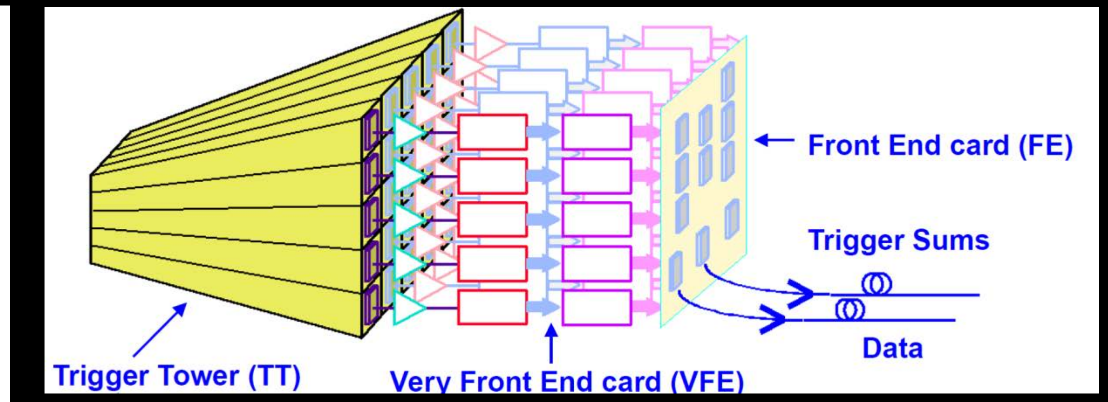
— **time resolution vs energy resolution vs granularity vs eta (to be optimized)**

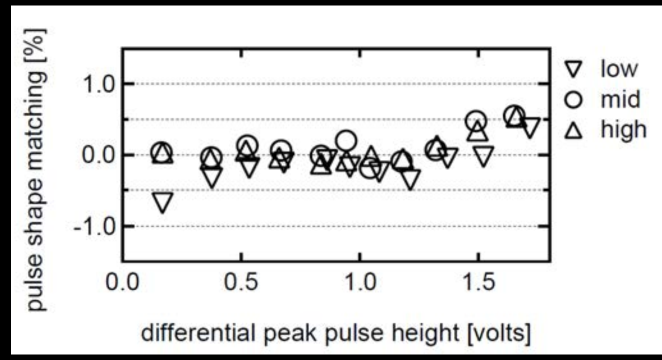


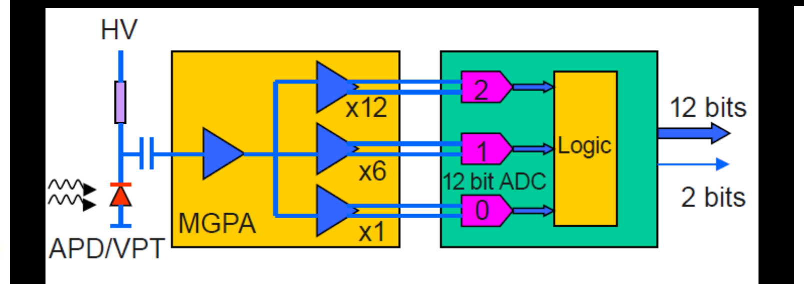




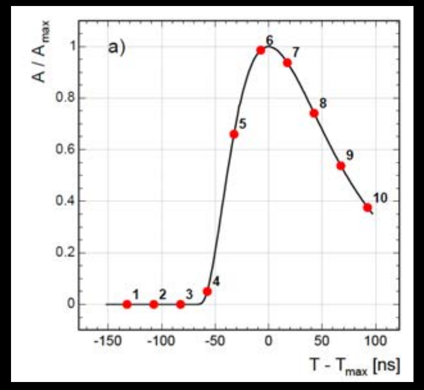








VFE architecture for single channel
0.25 μm IBM CMOS process



RELATED

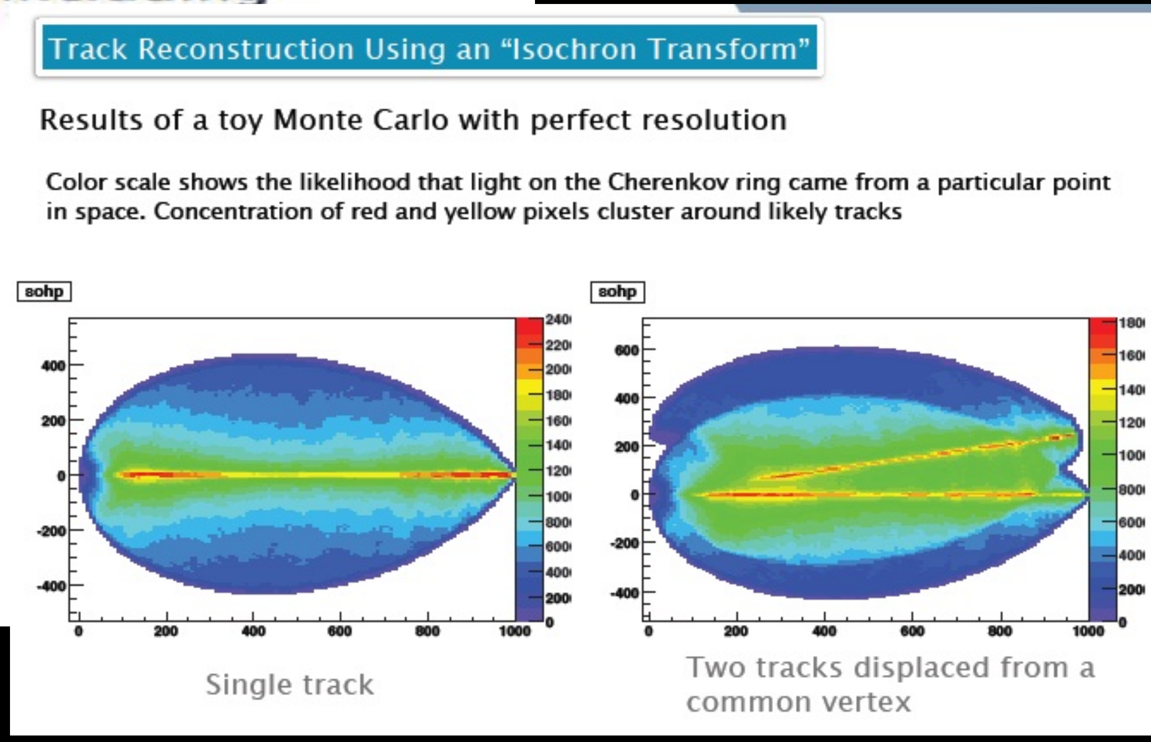
Sensor Compendium

M. Artuso, M. Battaglia, G. Bolla, D. Bortoletto, B. Cabrera, J.E. Carlstrom, C.L. Chang, W. Cooper, C. Da Via, M. Demarteau, J. Fast, H. Frisch, M. Garcia-Sciveres, S. Golwala, C. Haber, J. Hall, E. Hoppe, K.D. Irwin, H. Kagan, C. Kenney, A.T. Lee, D. Lynn, J. Orrell, M. Pyle, R. Rusack, H. Sadrozinski, M.C. Sanchez, A. Seiden, W. Trischuk, J. Vavra, M. Wetstein, R-Y. Zhu

(Submitted on 18 Oct 2013 (v1), last revised 25 Oct 2013 (this version, v2))

Sensors play a key role in detecting both charged particles and photons for all three frontiers in Particle Physics. The signals from an individual sensor that can be used include ionization deposited, phonons created, or light emitted from excitations of the material. The individual sensors are then typically arrayed for detection of individual particles or groups of particles. Mounting of new, ever higher performance experiments, often depend on advances in sensors in a range of performance characteristics. These performance metrics can include position resolution for passing particles, time resolution on particles impacting the sensor, and overall rate capabilities. In addition the feasible detector area and cost frequently provides a limit to what can be built and therefore is often another area where improvements are important. Finally, radiation tolerance is becoming a requirement in a broad array of devices. We present a status report on a broad category of sensors, including challenges for the future and work in progress to solve those challenges

Comments:	66 pages, Prepared for the Snowmass 2013 Community Summer Study
Subjects:	**Instrumentation and Detectors (physics.ins-det)**; High Energy Physics - Experiment (hep-ex)
Report number:	Fermilab--?FN--?0971--?PPD, ANL--?HEP--?TR--?13--?51
Cite as:	arXiv:1310.5158 [physics.ins-det]
	(or arXiv:1310.5158v2 [physics.ins-det] for this version)



—i will focus on fast timing applications for HCs mostly (the report includes TOF systems for intensity and cosmic frontier detectors)

SOME RELATED TALKS HERE

— **Tracking and Vertex Detectors session:**

- **Non-silicon fast timing : Anatoly Ronzhin (Fermilab)**
- **Silicon Fast Timing : Hartmut Sadrozinski (University of California, Santa Cruz)**

— **Photodetectors :**

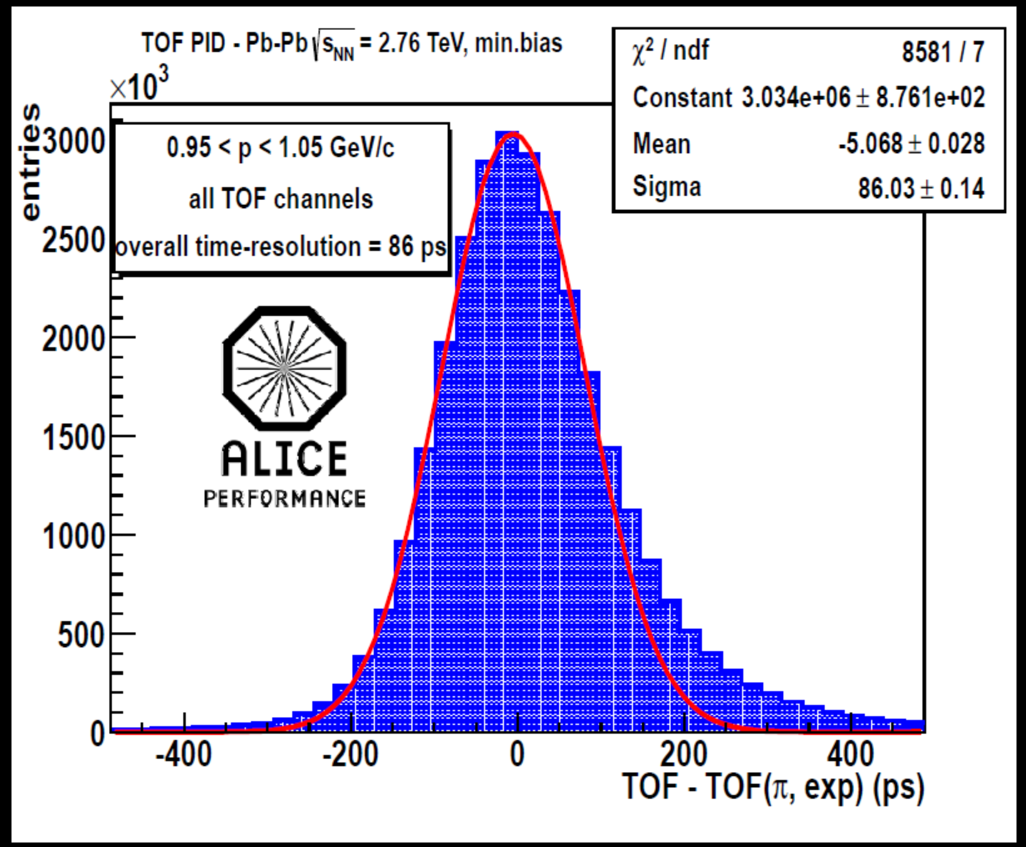
- **New Large Area MCP's, Andrey Elagin (University of Chicago)**
- **A Large Area APD for the Readout of the Fast Scintillation Component of Barium Fluoride, David Hitlin (Caltech)**

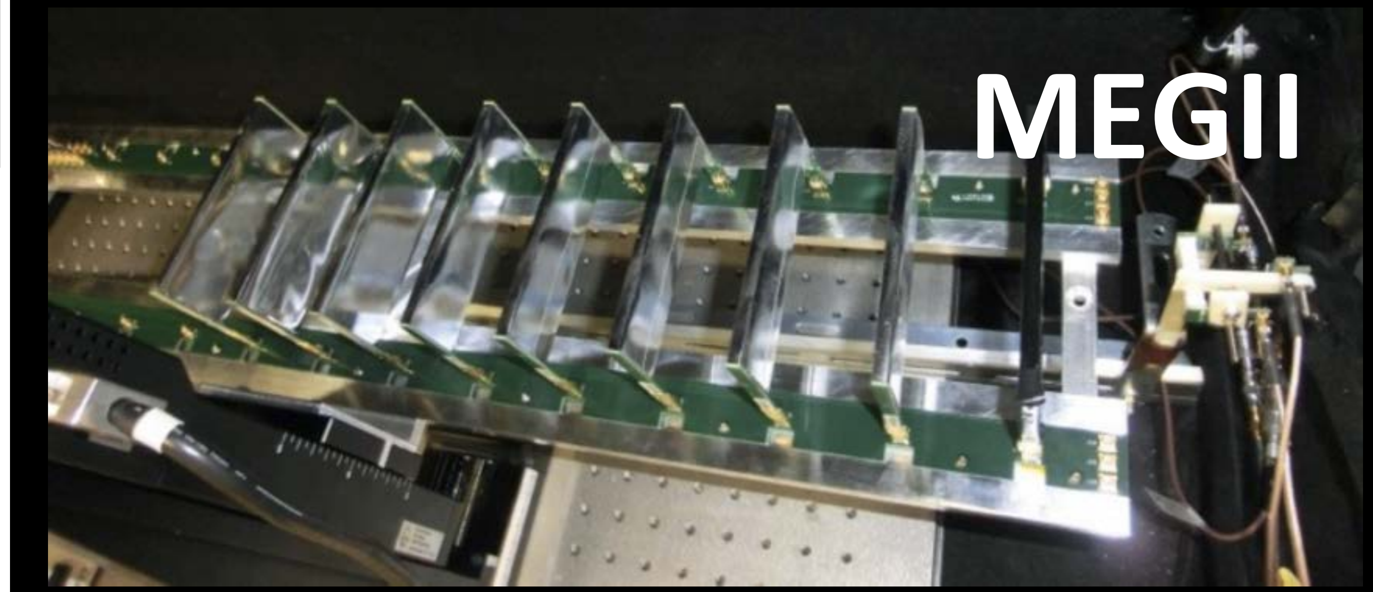
— **Calorimetry :**

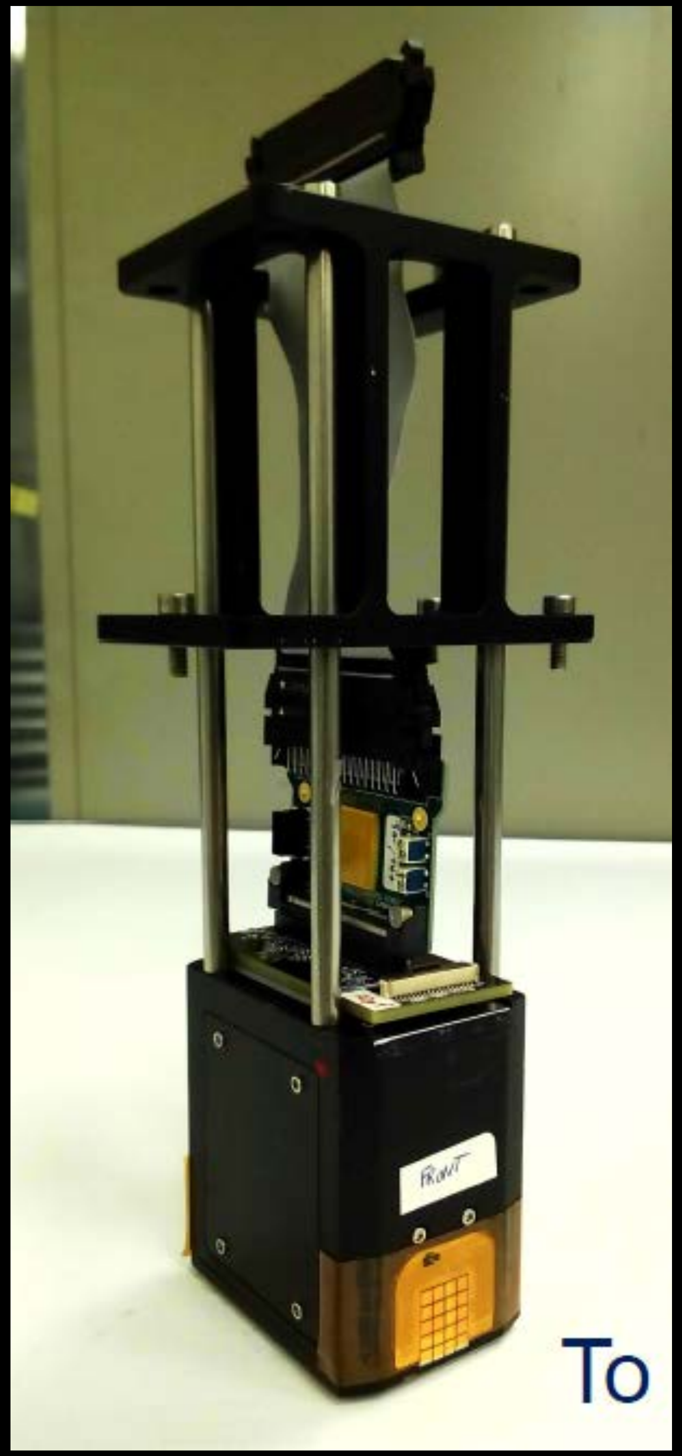
- **Secondary Emission calorimetry, Si Xie (Caltech)**
- **CALICE Calorimeter Jose Repond(ANL)**
- **HGC Calorimeter Roger Rusack (Minnesota)**

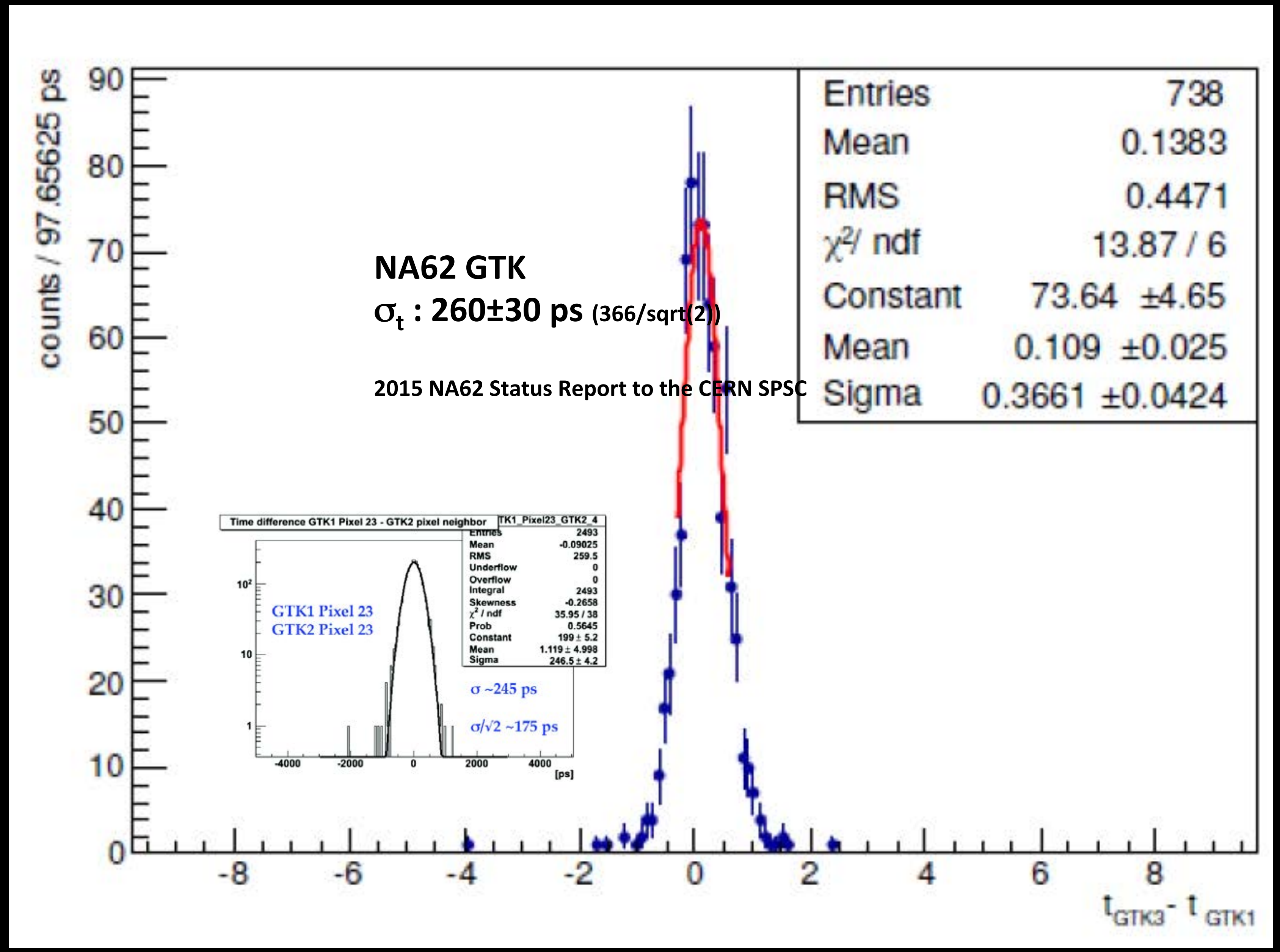
https://indico.hep.anl.gov/indico/conferenceOtherViews.py?view=standard&confId=625

CHARGED PARTICLE TIMING EXAMPLES









- MEG2 (Scintillator, SiPM, ~35 ps from 8 tiles– multiple measurements (talk by S. Ritt)
- Alice TOF (MRPC, ~86 ps) textbook example
- NA62 GTK (Si, ~260 ps)
- Totem Roman pots Quartz Cherenkov, SiPM, ~30 ps (2015 TB)/ Diamond, ~100 ps

— **N.B.** TB result always better than in-situ (integrated prototype systems needed)

CALO-TOF

CALO-TIME (I)

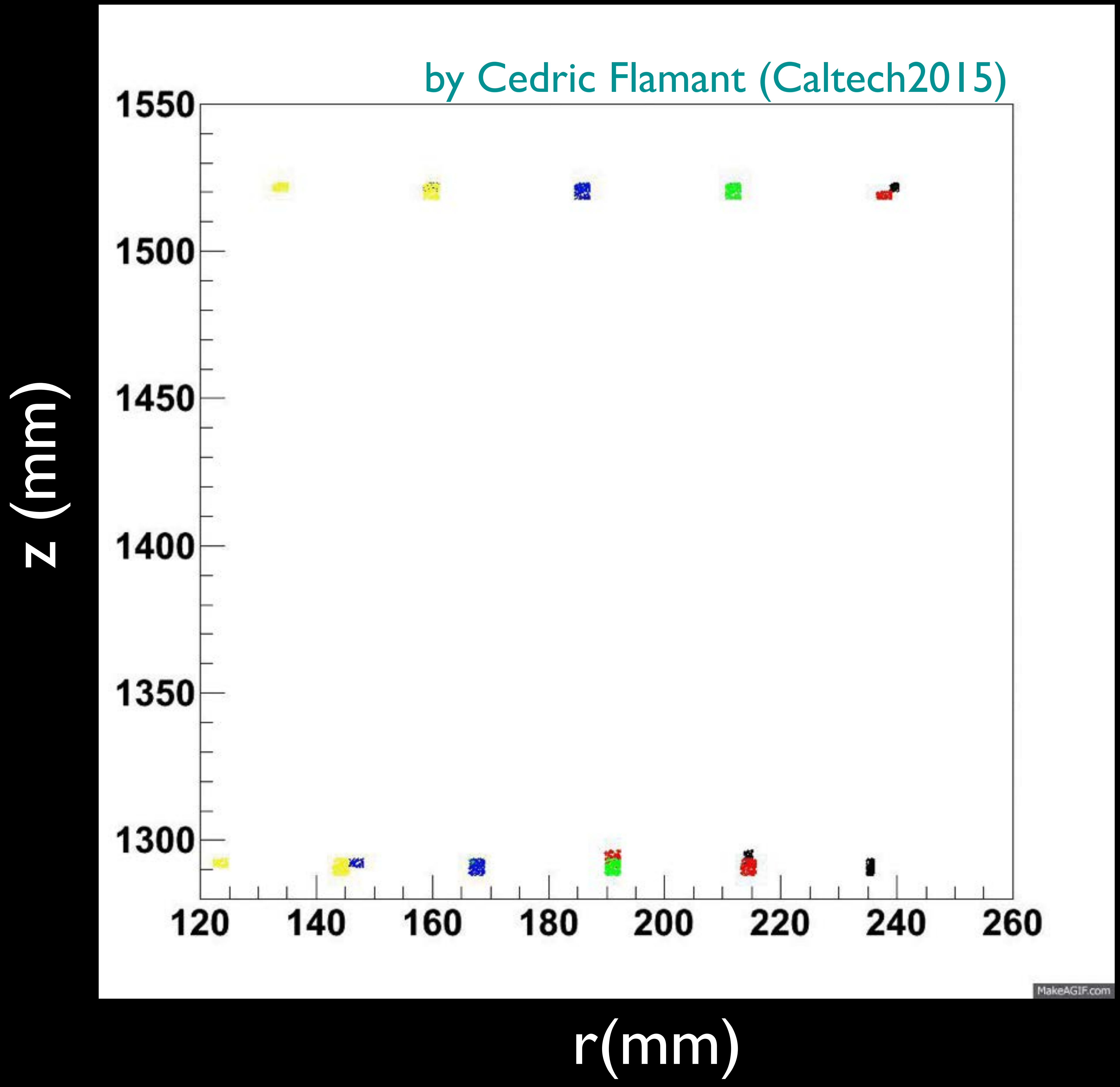
- Calorimeters inherently create huge raw primary signals since they convert entire particle energy.
- Calorimeters detect charged and neutral particles.
- EM showers exhibit a very coherent and reproducible 4D evolution
  - Perform multiple measurements, gaining in precision with sqrt(n).
  - Integrate raw signal from larger detector volume.
- HAD showers inherently are less coherent and unfold in a significantly larger volume. May exploit EM components of HAD showers (Synergies with imaging calorimeter).

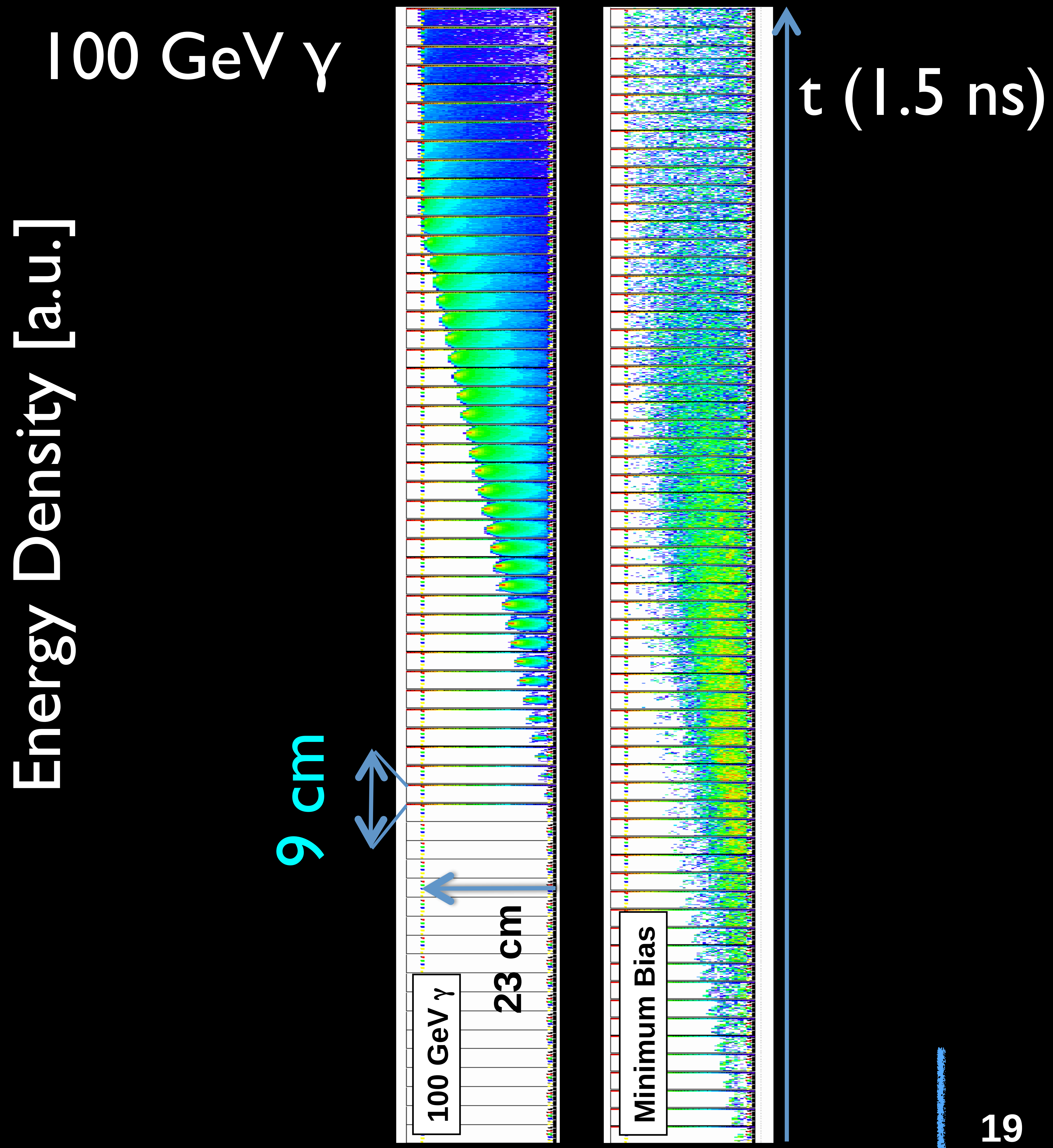
CALO-TIME (II)

- Calorimeters typically equipped with a very precise, large dynamic range readout.
- Enhancing this to be capable of ps precision timing is a relatively minor operation.
- Additional readout bandwidth and power budget can be more easily accommodated than inside the tracking volume.
- BONUS: Simultaneous measurement of energy, position and time – 5D measurement.

— **challenge** : achieve MEG2-like performance with CMS2 (i.e. go to detector area of several 10s of meters, traverse granularity of O(cm), super high rates, radiation >10 Mrads, with bunch spacing <25 ns)

5D EVOLUTION OF THE SHOWER (CMS ECAL)

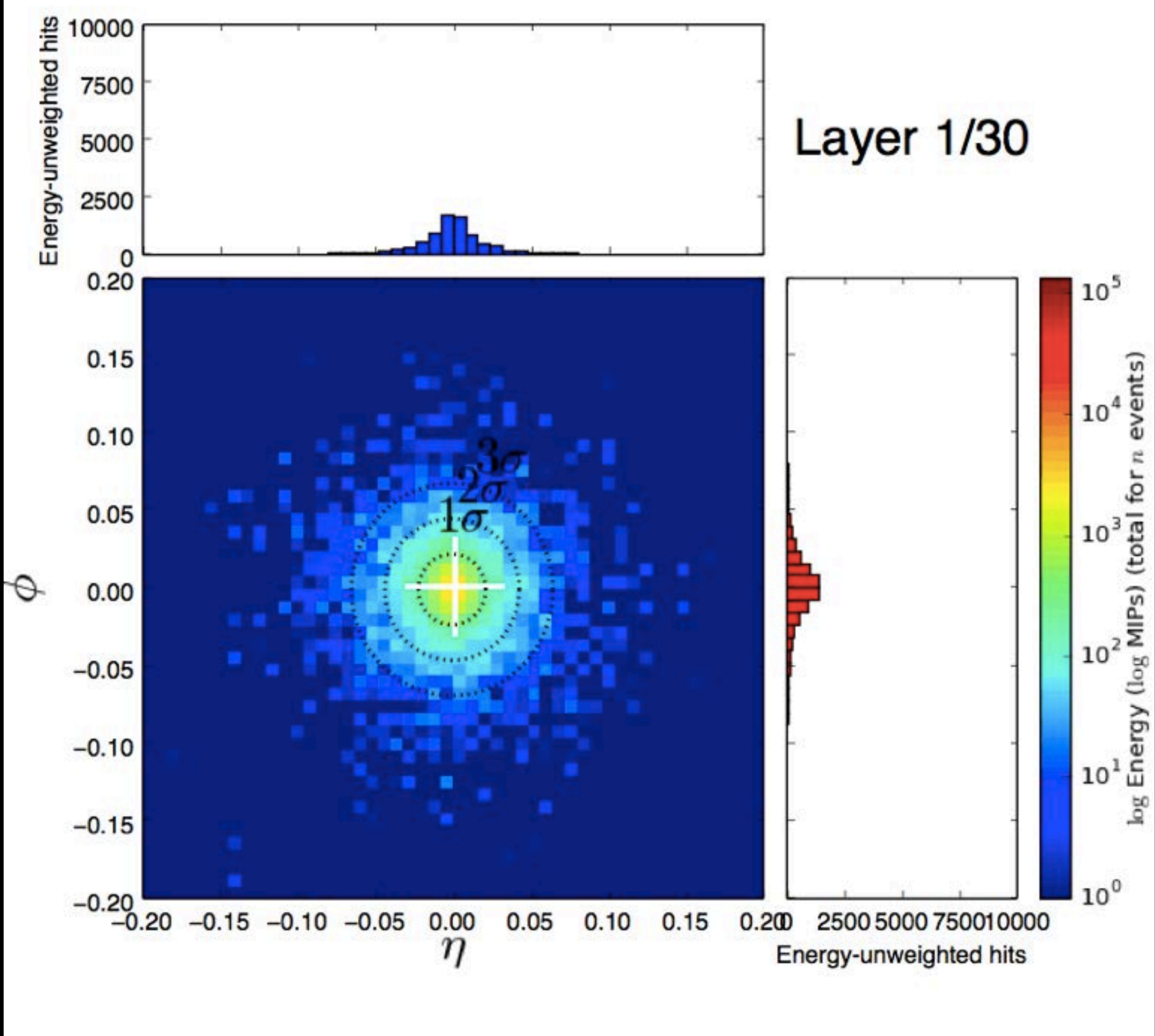


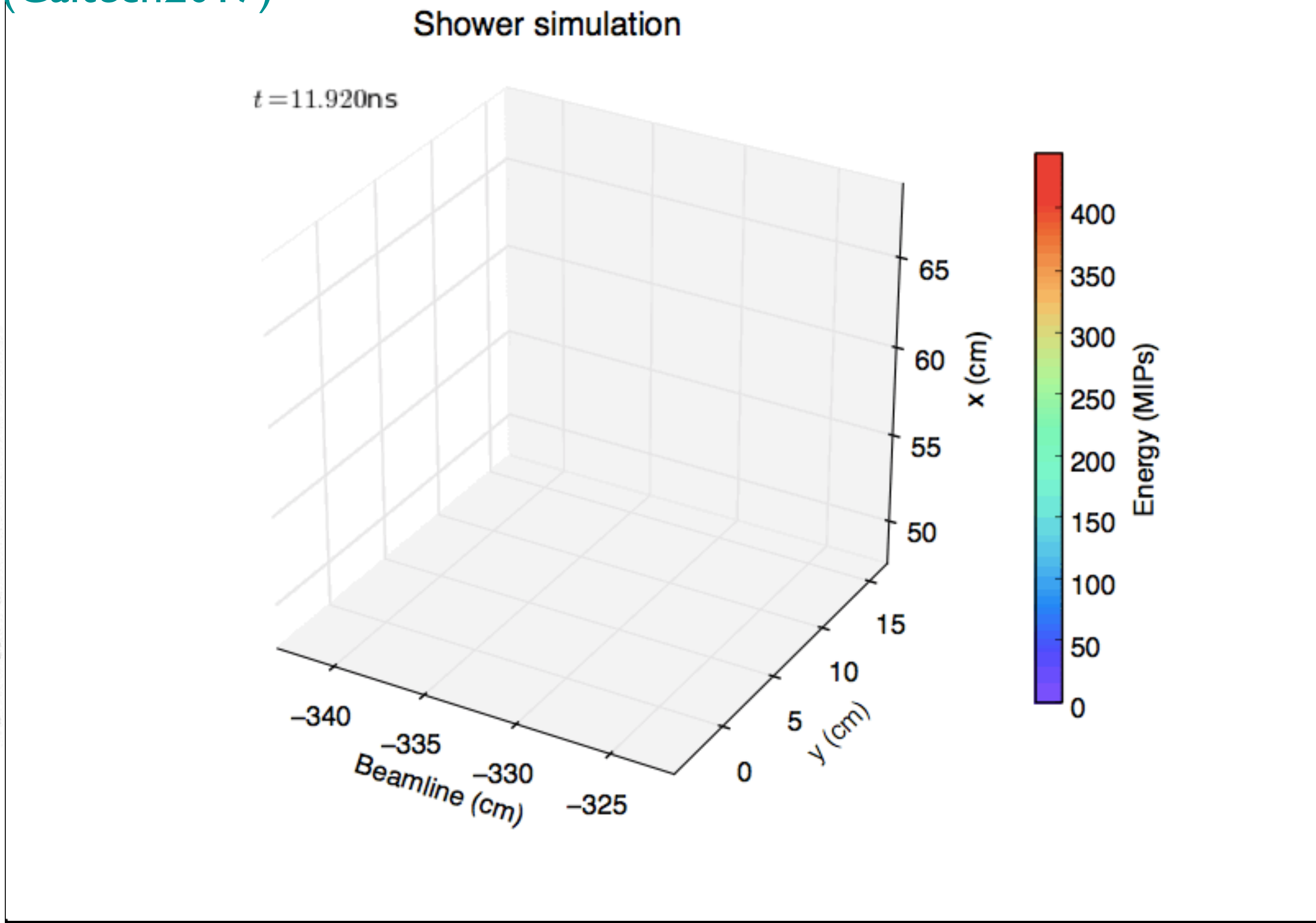


5D EVOLUTION OF THE SHOWER (CMS2 HGC)

500 GeV γ

by Ben Barlett (Caltech2017)





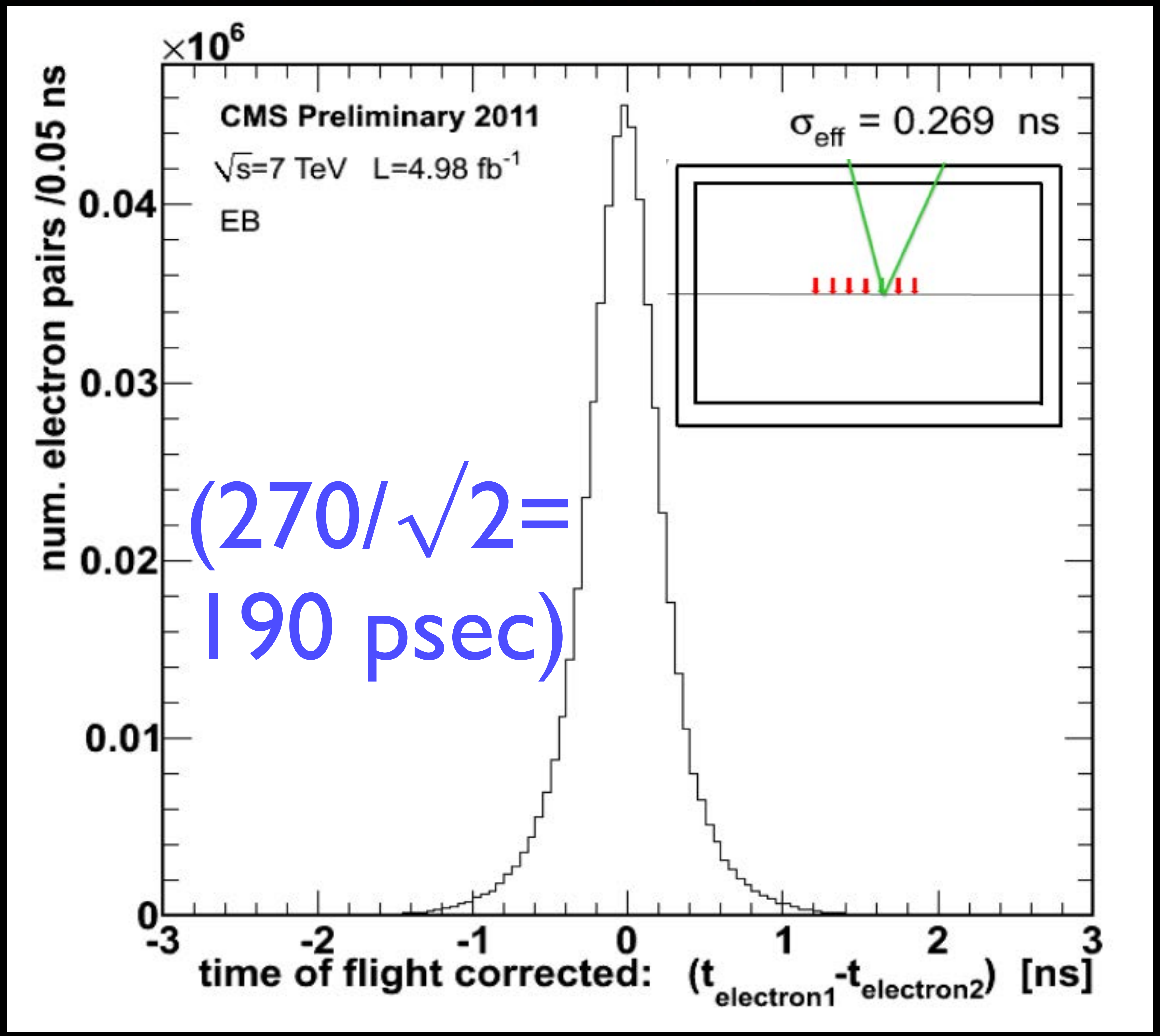
CALO-TIME RESOLUTION

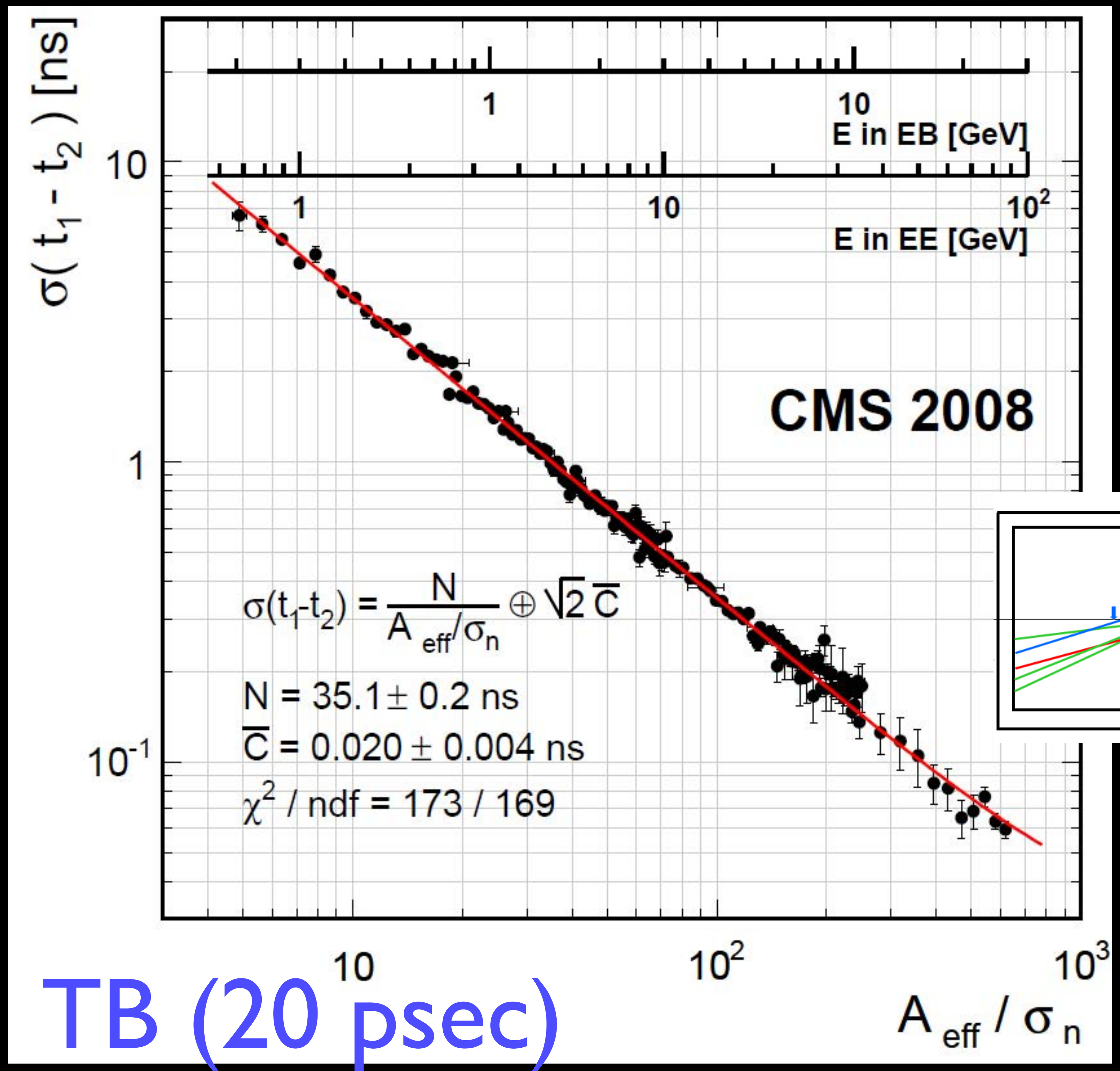
Technology (Experiment)	Depth	Energy resolution	Date	
NaI(Tl) (Crystal Ball)	$20X_0$	$2.7\%/E^{1/4}$	1983	Homogeneous
$Bi_4Ge_3O_{12}$ (BGO) (L3)	$22X_0$	$2\%/\sqrt{E} \oplus 0.7\%$	1993	
CsI (KTeV)	$27X_0$	$2\%/\sqrt{E} \oplus 0.45\%$	1996	
CsI(Tl) (BaBar)	$16–18X_0$	$2.3\%/E^{1/4} \oplus 1.4\%$	1999	
CsI(Tl) (BELLE)	$16X_0$	1.7% for $E_\gamma > 3.5$ GeV	1998	
$PbWO_4$ (PWO) (CMS)	$25X_0$	$3\%/\sqrt{E} \oplus 0.5\% \oplus 0.2/E$	1997	
Lead glass (OPAL)	$20.5X_0$	$5\%/\sqrt{E}$	1990	
Liquid Kr (NA48)	$27X_0$	$3.2\%/\sqrt{E} \oplus 0.42\% \oplus 0.09/E$	1998	
Scintillator/depleted U (ZEUS)	$20–30X_0$	$18\%/\sqrt{E}$	1988	Sampling
Scintillator/Pb (CDF)	$18X_0$	$13.5\%/\sqrt{E}$	1988	
Scintillator fiber/Pb spaghetti (KLOE)	$15X_0$	$5.7\%/\sqrt{E} \oplus 0.6\%$	1995	
Liquid Ar/Pb (NA31)	$27X_0$	$7.5\%/\sqrt{E} \oplus 0.5\% \oplus 0.1/E$	1988	
Liquid Ar/Pb (SLD)	$21X_0$	$8\%/\sqrt{E}$	1993	
Liquid Ar/Pb (H1)	$20–30X_0$	$12\%/\sqrt{E} \oplus 1\%$	1998	
Liquid Ar/depl. U (DØ)	$20.5X_0$	$16\%/\sqrt{E} \oplus 0.3\% \oplus 0.3/E$	1993	
Liquid Ar/Pb accordion (ATLAS)	$25X_0$	$10\%/\sqrt{E} \oplus 0.4\% \oplus 0.3/E$	1996	

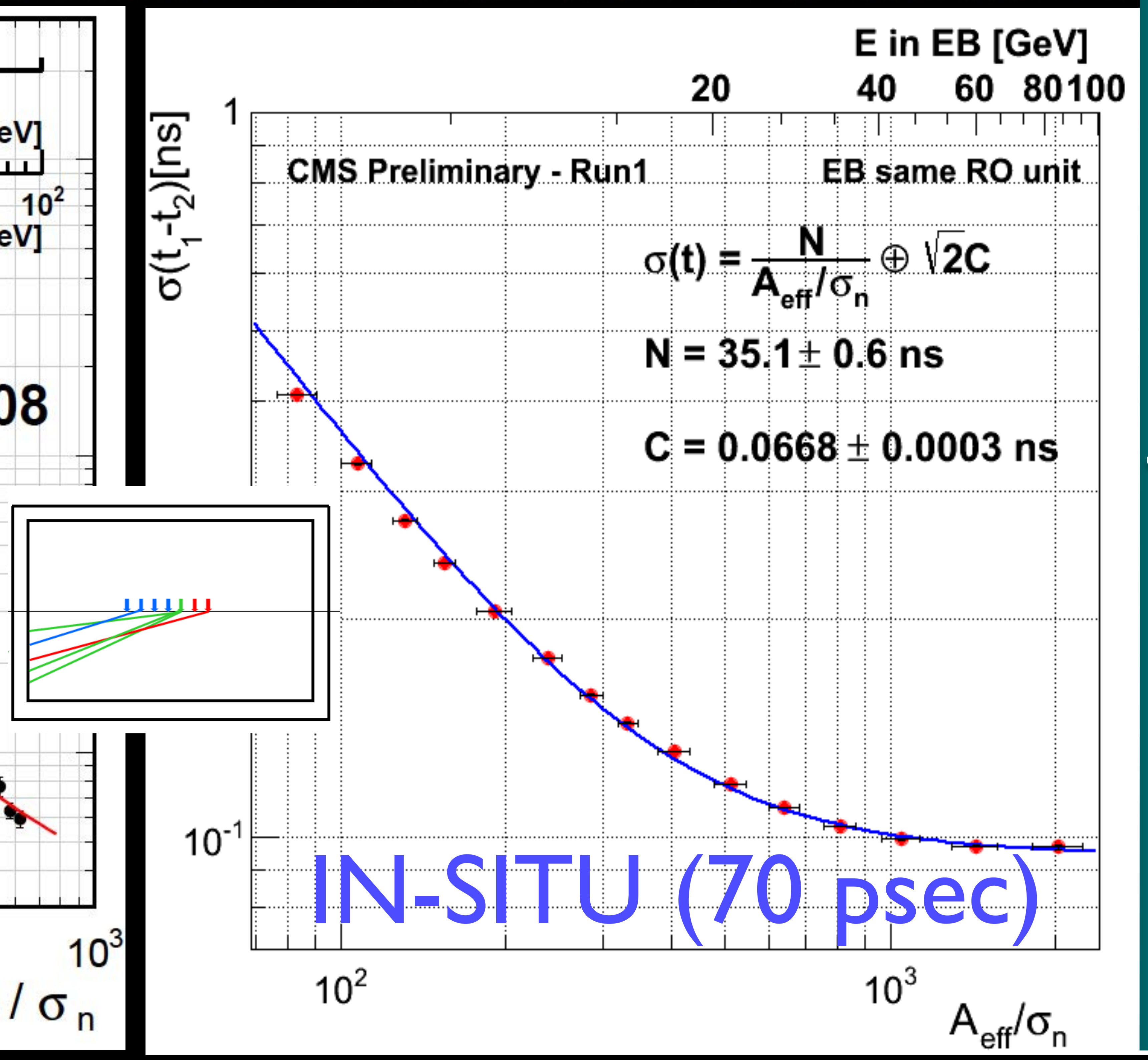
add granularity, time resolution, (vs eta coverage).

Add Imaging and other modern PF devices of hybrid detectors /other “magic” materials (see MGS @slam)

CALO-TIME RESOLUTION CMS ECAL







— TB result always better than in-situ

Time Reconstruction and Performance of the CMS Electromagnetic Calorimeter

- — Clock distribution most severe limitation— as high precision timing was not a design feature; can easily be improved.
- — Poor exploitation of raw signal (scintillation light) : less than 10% of rear face covered with sensor. CMS APD state of the art >10 years ago, advances in photo detection.
- — Slow pulse shaping time : 40 ns, partly due to the small raw signal

CALCULATE

σ_t timing resolution as a function of the scintillator decay time, τ, the light yield LY (phe/MeV), the energy deposit, E (MeV) and the threshold, TH (in MeV):

$$\sigma_t = \tau \ \mathrm{ln}[1/2\mathrm{LY}(\mathrm{TH} - \mathrm{E} + \sqrt{(\mathrm{TH} - \mathrm{E})^2 + 4\mathrm{E}/\mathrm{LY}}] \quad (1)$$

CMS ECAL barrel calorimeter PWO crystals read out by APDs produce ~5 phe/MeV. A 10 GeV energy deposit in a crystal will generate 50,000 phe. If the threshold is set at 100 MeV the corresponding time resolution will be σ_t= 200 ps.

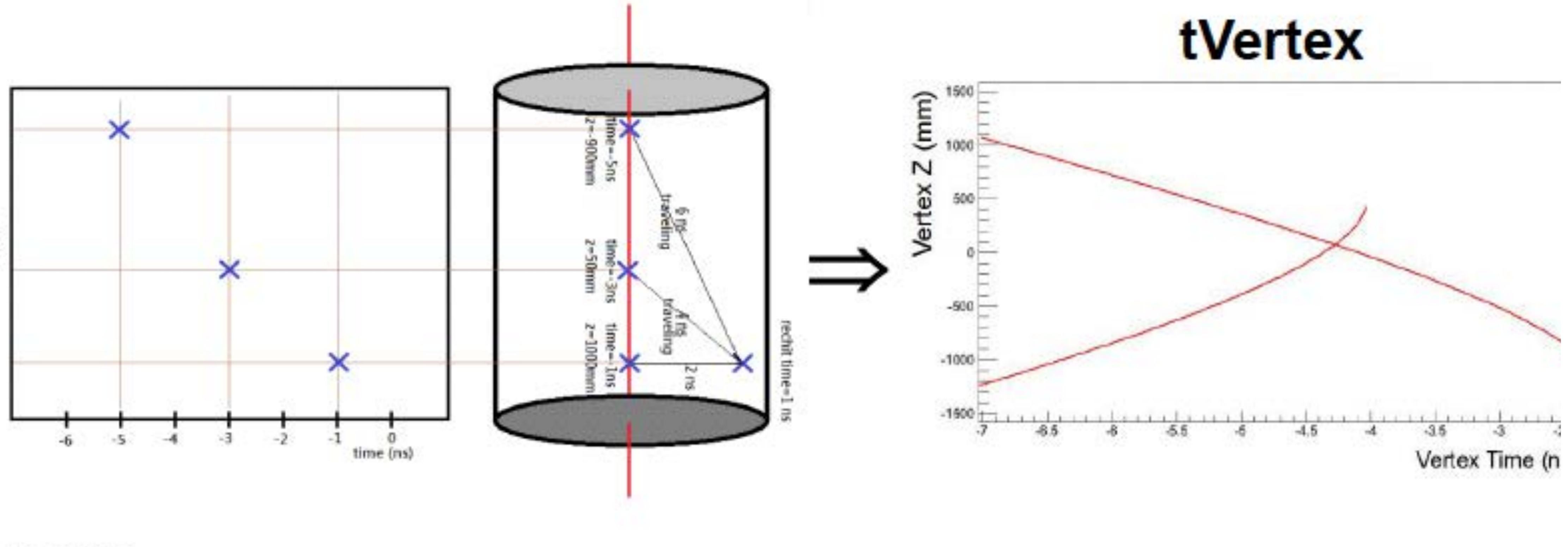
P. Lecoq, "New approaches to improve timing resolution in scintillators", Proc. SCINT2011,
Giessen, Germany, Sept. 2011, IEEE Trans. Nucl. Sci.

CALO-TIME JET VERTEXING

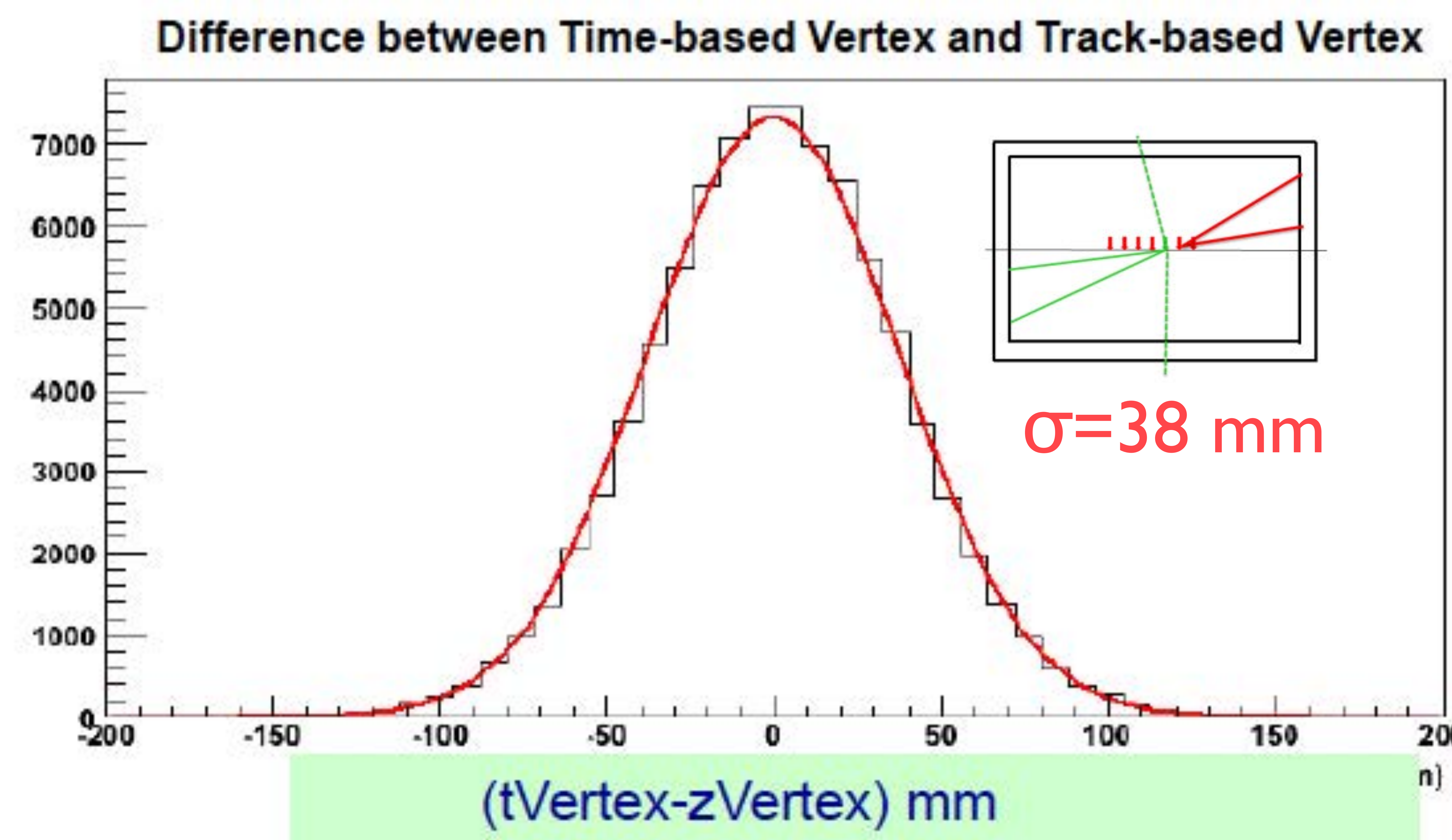
Time-Based Vertex

- Extrapolate z vertex position of a particle as a function of time.
- We refer to this diagram as the `Time Vertex Diagram` (tVertex).
- Do so for two or more particles and determine the z position where the lines of the tVertices cross.

⇒ Time-based vertex is z position for which particles have same TOF.



03.10.2012



- Jets consist of a number of particles (predominantly pions, ~1/3 of them π^0) and jet reconstruction extends over a large area (dR = 0.5 2500 crystals)
- Precision of time-based vertexing improves by using many independent time measurements.
- Some local systematic effects on the time measurement expected to cancel out in extended objects, i.e. Jets.
- One can choose granularity to make optimal number of time measurements per physics object

TAXONOMY OF PRIMARY SIGNAL GENERATION

- **Crystal Scintillators**
  - **46.6 MeV deposited in 43.5 mm LYSO. Very high light yield, very radiation hard, signal rise time very fast, few 10 ps, ~32000 phe per mm, needs photo detector which may have gain or not**
- **Silicon detectors**
  - **32000 e-h pairs per 300μm, signal rise time typically ~1 ns (theoretical limit before charge collection efficiency ~10%)**
- **Micropattern, eg. MCP**
  - **MCP : bare detector may yield few phe or one secondary electron emissions, gain large (eg. 10^5)**
  - **Charge and photon collection can vary greatly depending of detector layout**

Ongoing R&D on ultimate precision timing and limiting factors with large solid crystals, crystals based sampling calorimeters, MCP based sampling calorimeters, silicon based sampling calorimeters (single and dual readout) ++

twiki.hep.caltech.edu

cms.cern.ch...newexception | Any.do | Q: Why does "... a Physicist | Information ...Google Books | D&G High Wai...e Shipping! | oneworld planner | Review of SUS-10-009 | Diphotons-Lyon

CPAD Instrumentation Frontier Meeting (05-7 October 2015) | https://indico.hep.anl.gov/indico/getFile.py/access?contribl... | TimingConferenceTalks < Main < TWiki

- Talks on fast timing :
- Papers on fast timing :

Talks on fast timing :

1. Calor2014, "Calorimeters for precision timing measurements in high energy physics", Adi Bornheim : http://indico.uni-giessen.de/indico/contributionDisplay.py?contribId=67&confId=164 , Proceedings : http://iopscience.iop.org/1742-6596/587/1/012057/pdf/1742-6596_587_1_012057.pdf, doi:10.1088/1742-6596/587/1/012057

2. TIPP2014, 02.06.2014, "Timing performance of the CMS electromagnetic calorimeter and prospects for the future", Adi Bornheim : https://indico.cern.ch/event/192695/session/4/contribution/201 , https://indico.cern.ch/event/192695/session/4/contribution/201/material/slides/0.pdf, Proceedings : pos.sissa.it/archive/conferences/213/021/TIPP2014_021.pdf

3. TIPP2014, 05.06.2014, "Calorimeters for precision timing measurements in high energy physics", Artur Apresyan : https://indico.cern.ch/event/192695/session/7/contribution/236 , https://indico.cern.ch/event/192695/session/7/contribution/236/material/slides/0.pdf

4. NDIP2014, 03.07.2014, "Precision timing measurements for high energy photons", Dustin Anderson : https://twiki.hep.caltech.edu/twiki/pub/Main/TimingConferenceTalks/ndip14timingposterSmall.pdf , Proceedings : http://www.sciencedirect.com/science/article/pii/S0168900214013291

5. IEEE2014, Seatle, Cristian Pena

6. FRONTIER DETECTORS FOR FRONTIER PHYSICS - 13th Pisa Meeting on Advanced Detectors, 29.05.2015, "Precision Timing Calorimetry for High Energy Physics", Adi Bornheim, https://agenda.infn.it/getFile.py/access?contribId=194&sessionId=10&resId=0&materialId=slides&confId=8397, http://server11.infn.it/video/multimedia/2015-05-24-Pisa-Meeting-2015/video097.html, Proceedings:

7. SCINT2015, San Francisco, "Precision Timing Calorimeter for High Energy Physics", Cristian Pena, Proceedings :

8. IEEE2015, San Diego, "Studies Towards a Precision Timing Calorimeter for High Energy Physics Collider Experiments", Cristian Pena,

Papers on fast timing :

1. "On timing properties of LYSO-based calorimeters", NIM-A, Volume 794, 11 September 2015, Pages 7–14 , doi:10.1016/j.nima.2015.04.013 : http://www.sciencedirect.com/science/article/pii/S0168900215004829

2. "Development of a new fast shower maximum detector based on microchannel plates photomultipliers (MCP-PMT) as an active element", NIM-A, Volume 759, 21 September 2014, Pages 65–73, doi:10.1016/j.nima.2014.05.039, http://www.sciencedirect.com/science/article/pii/S016890021400566

3. "Study of the timing performance of micro-channel plate photomultiplier for use as an active layer in a shower maximum detector", NIM-A, doi:10.1016/j.nima.2015.06.006

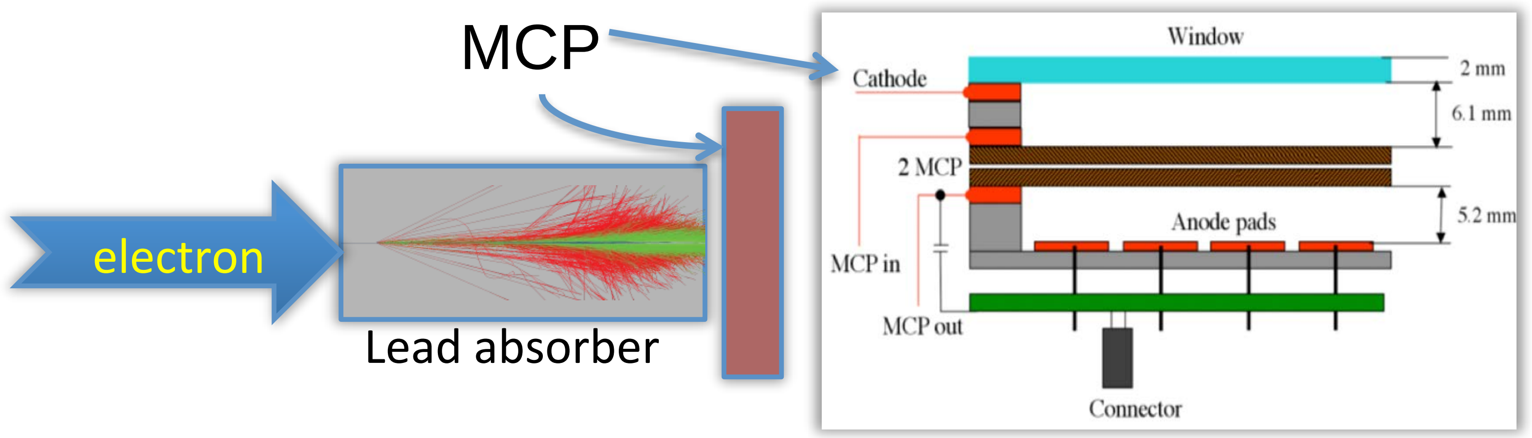
4. "Direct tests of micro channel plates as the active element of a new shower maximum detector", NIM-A, doi:10.1016/j.nima.2015.05.029

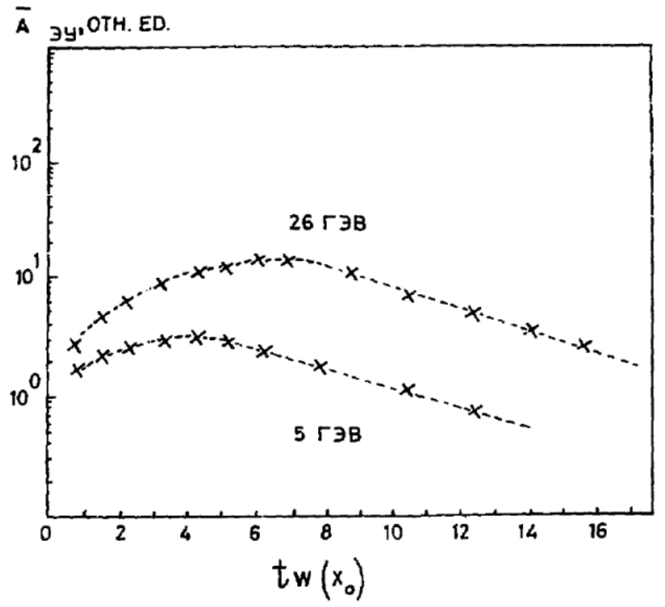
Follows some FNAL/ Caltech results from TBs the past 2 years (several NIM papers) at FNAL and CERN. There is much work going on (@Princeton, INFN, CERN, ++)

ONGOING R&D

Fast timing with Microchannel Plates

- Starting point in exploring precision timing in calorimeters
  - Secondary emitter material as active element in a sandwich type calorimeter
  - First proposed: "*On possibility to make a new type of calorimeter: radiation resistant and fast*", A. I. Ronzhin et. al, preprint IFVE 90-99, 1990.



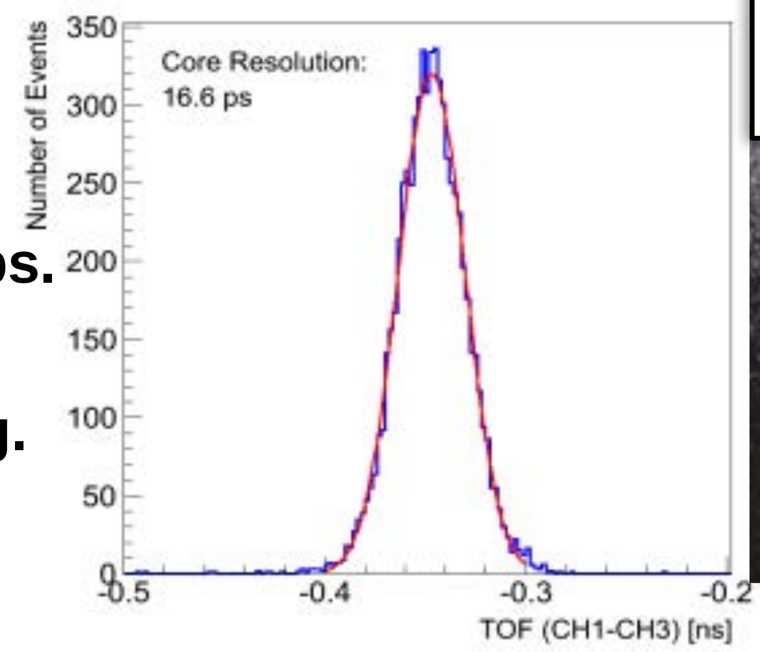


- Secondary particles from EM shower are detected by MCP
  - Signal is proportional to the number of secondaries → energy of parent
  - Most of secondary particles are low energy → MCP very efficient
  - MCP are intrinsically very fast → calorimeter with very fast timing

29.05.2015 Adi Bornheim, Elba 2015, Precision Timing Calorimeter 10

Photek 240 and Photonis MCP-PMT

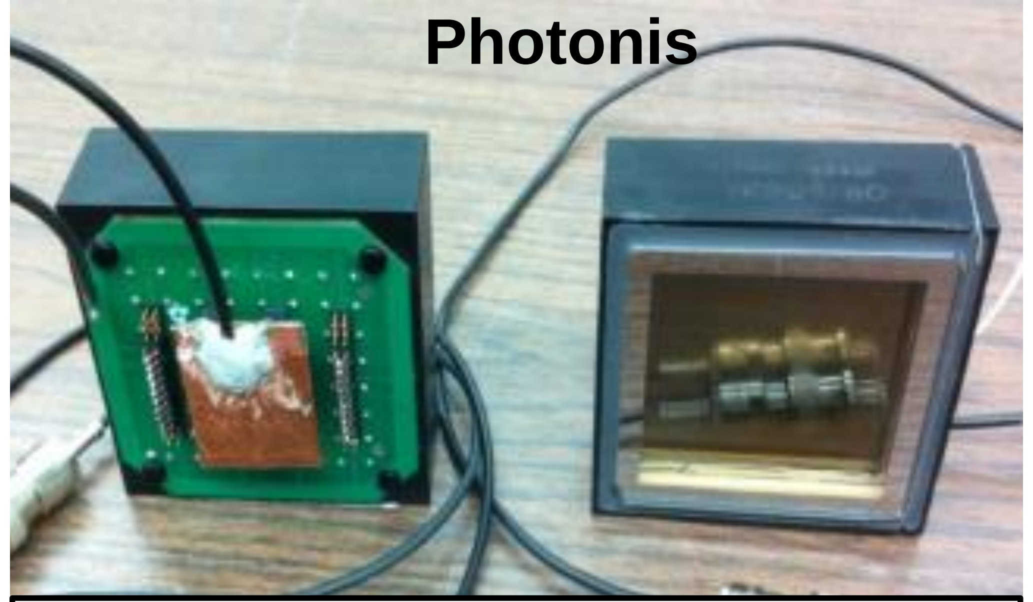
- TOF time resolution for protons between two MCPs (Photonis vs Photek) found to be ~17 ps.
- MCPs in SEC mode better than 40 ps.
- Includes 5 ps from readout (DRS4).
- MCPs serve as our reference timing.



DRS4 boards
5 GSPS, 700 MHz

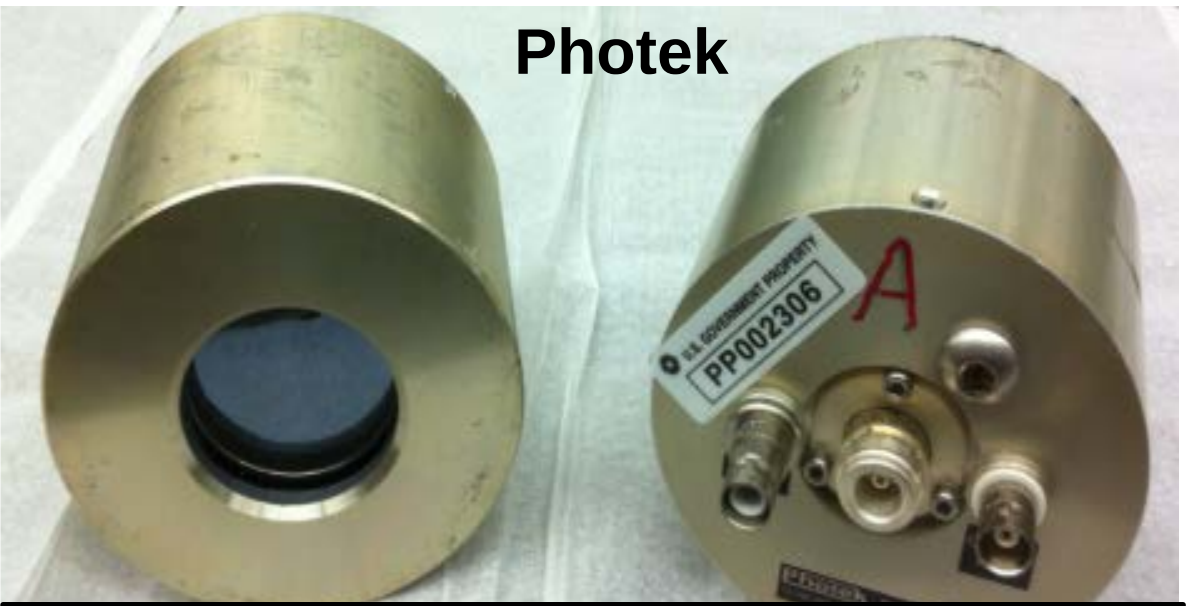
A. Ronzhin et. al. NIM A, Vol 749 p 65-73

Photonis



25 µm pore size, 60x60mm^2 sensitive area, rise time~300 ps, SPTR~120 ps,

Photek



10 µm pore size, 41mm aperture, PC-MCP distance ~5mm, rise time~60 ps, SPTR~40 ps

11

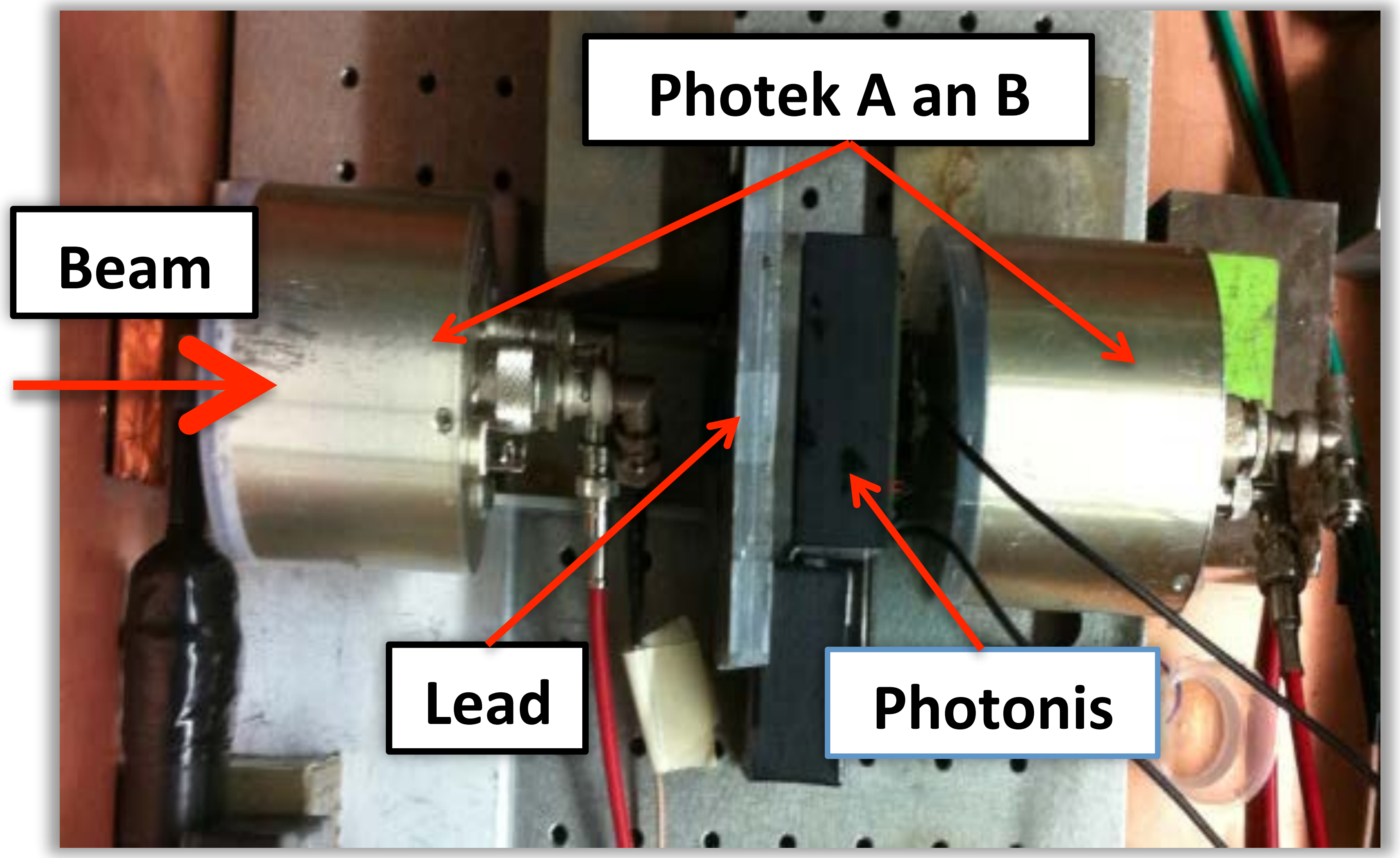
From single MIP to full showers with MCPs

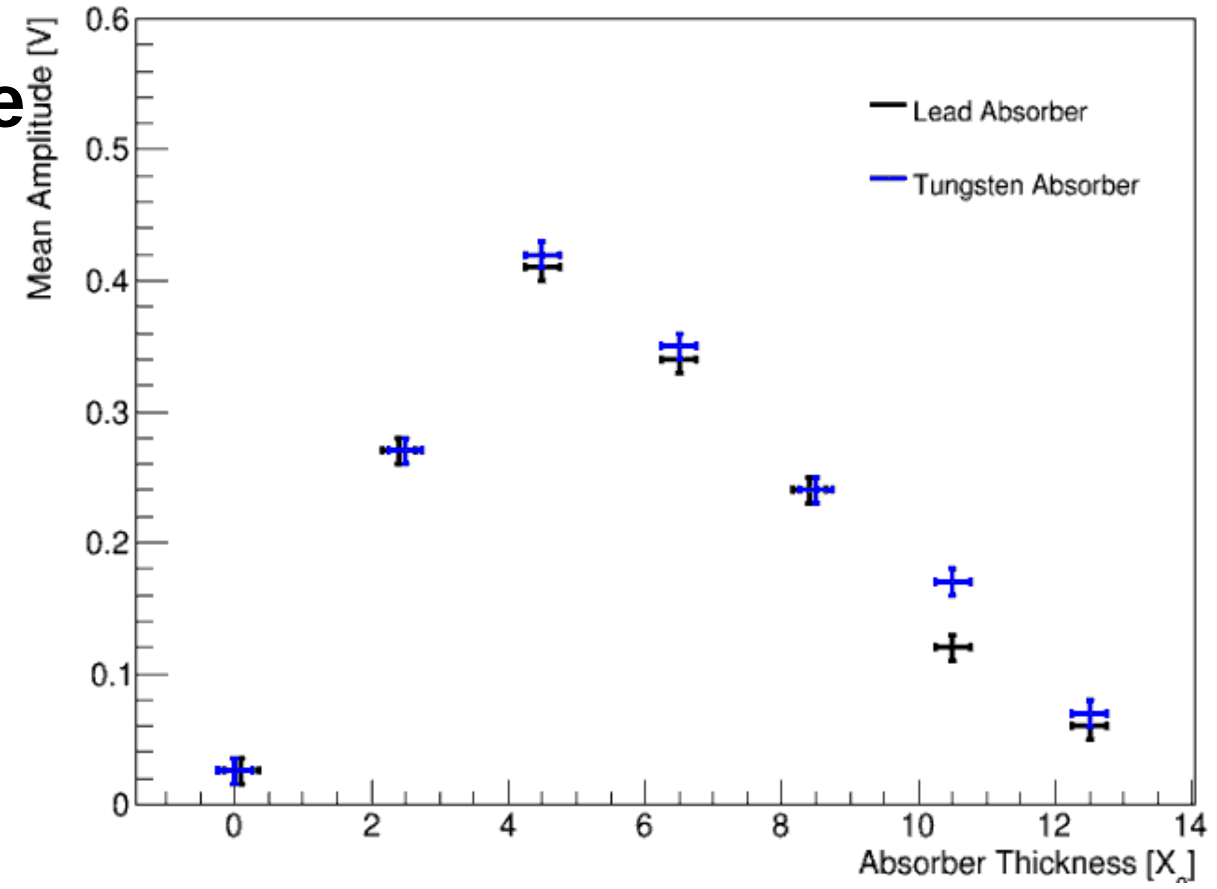
See poster presentation :

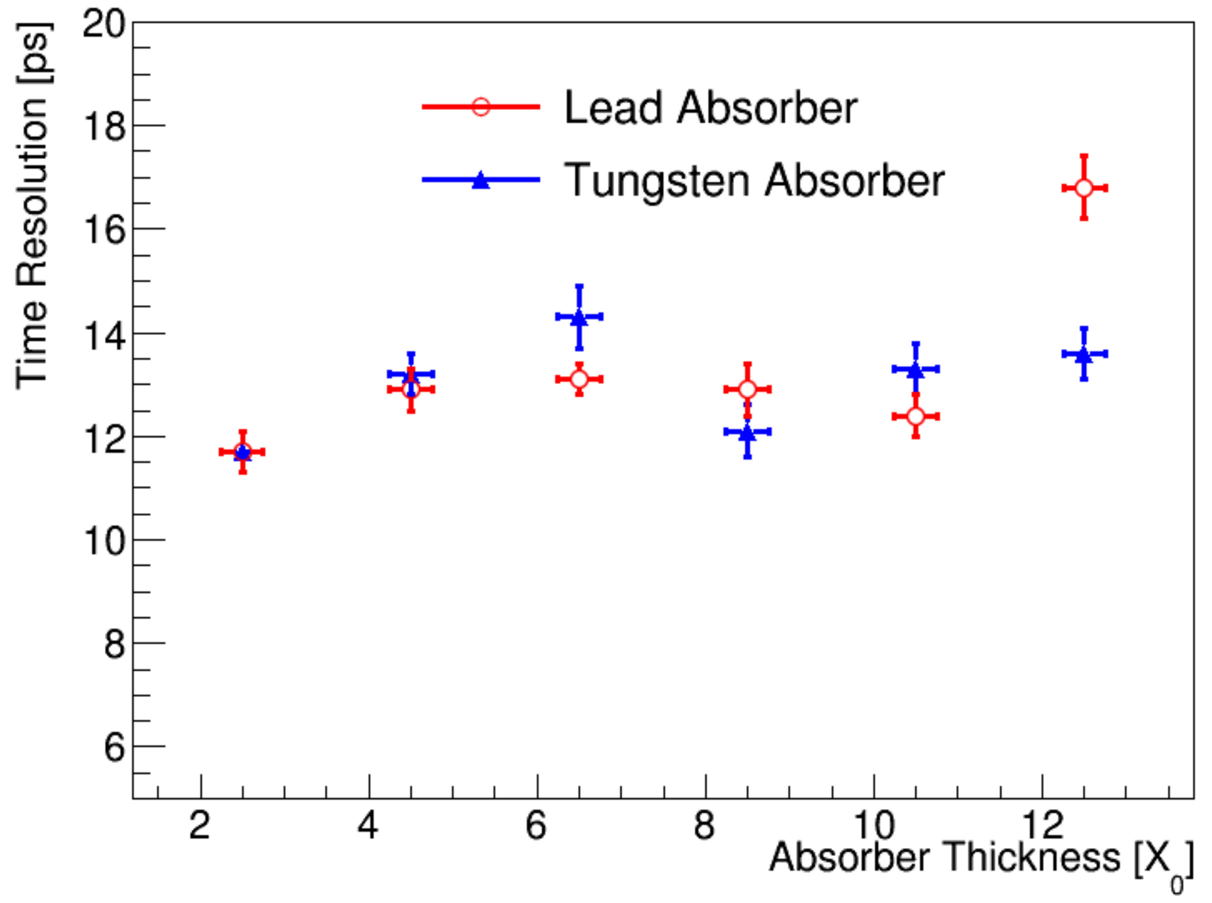
Fermilab: Sergey Los, Erik Ramberg, Erik Ramberg, CalTech: Artur Apresyan, Si Xie, Maria Spiropulu, U. Of Chicago: Heejong Kim

And forthcoming NIM paper (submitted) from the same authors.

- Measurements of shower profile with MCPs as active layer.
- Time resolution as a function of the shower depth : ~13 ps with Photek, <40 ps with Photonis.
- Time resolution among different transverse regions inside a shower : ~30 ps with Photonis
- To appear in NIM.



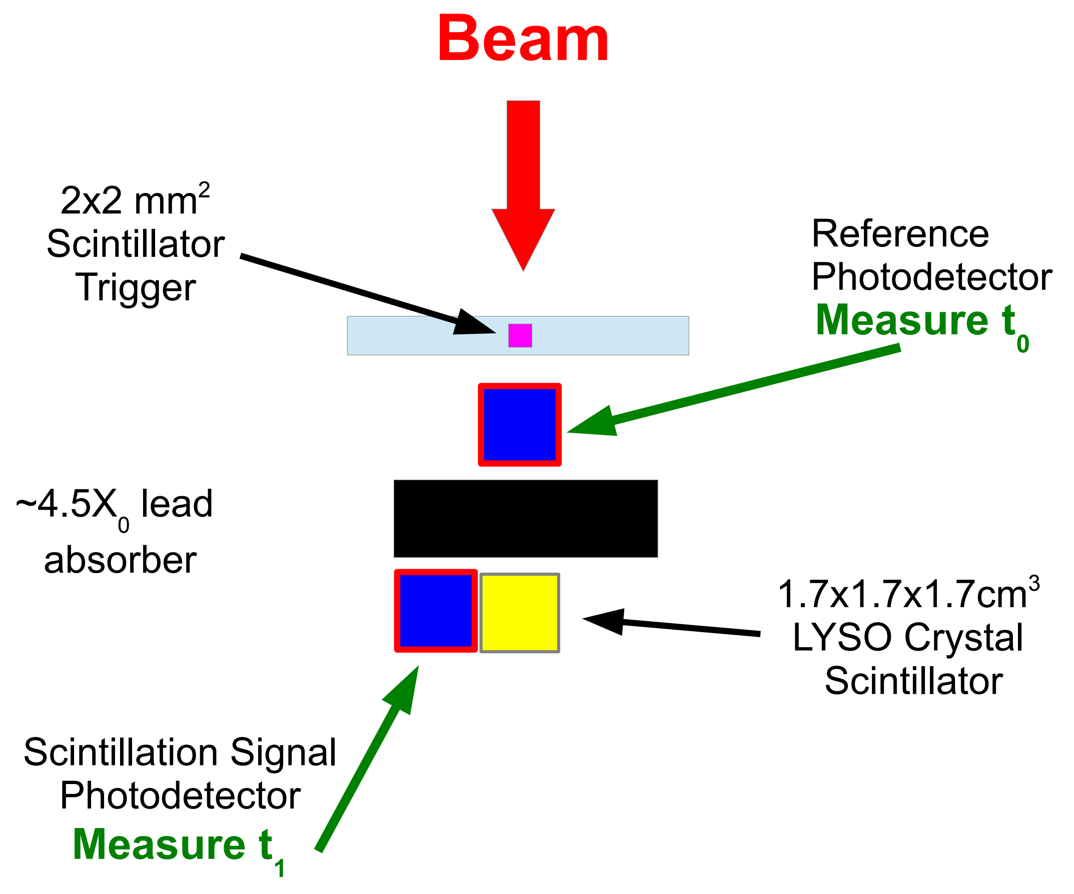


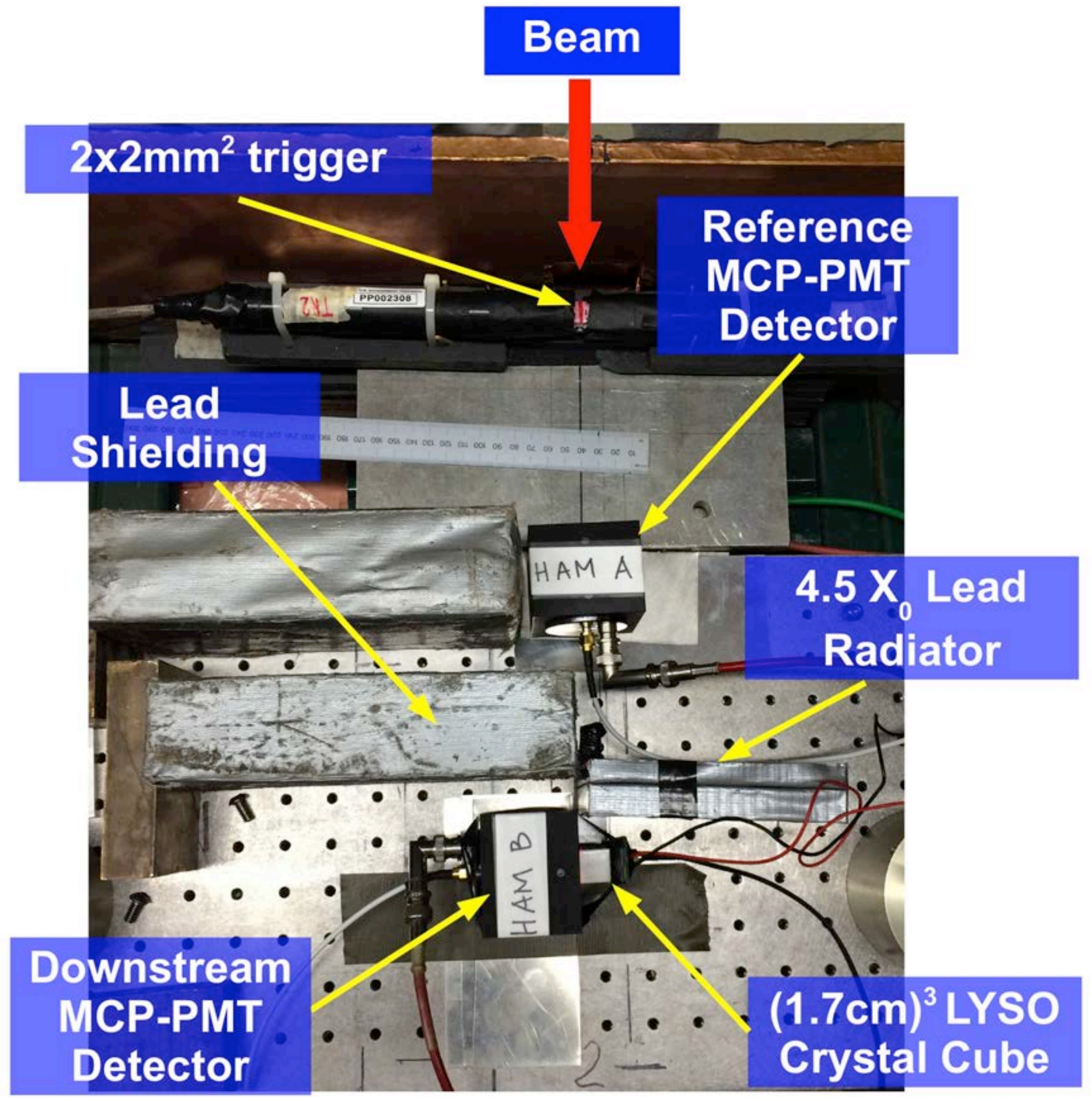


Si Xie's talk later totally for recent progress

ONGOING R&D

Experimental setup LYSO timing

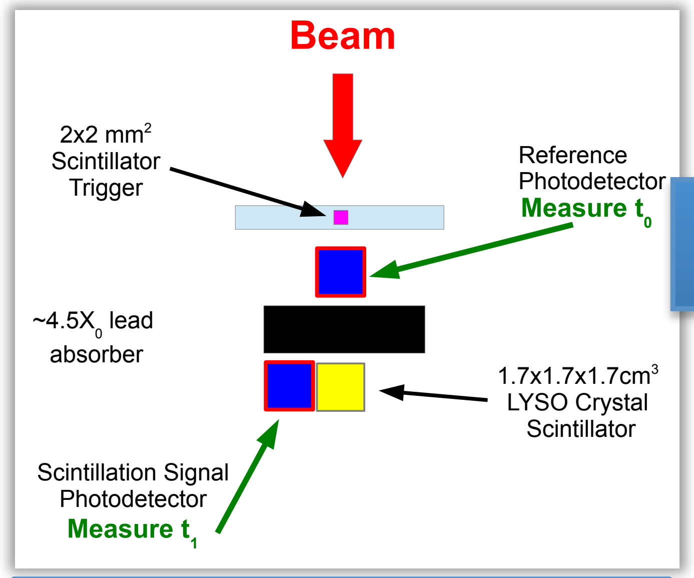




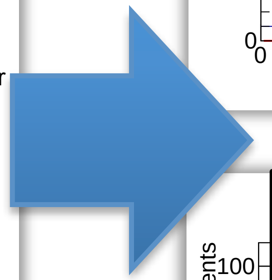
- **Study the effect of scintillation (of LYSO) on time resolution**
  - **Minimize the effect of optical transit by using a relatively small LYSO crystal (1.7cm x 1.7cm x 1.7cm cube)**

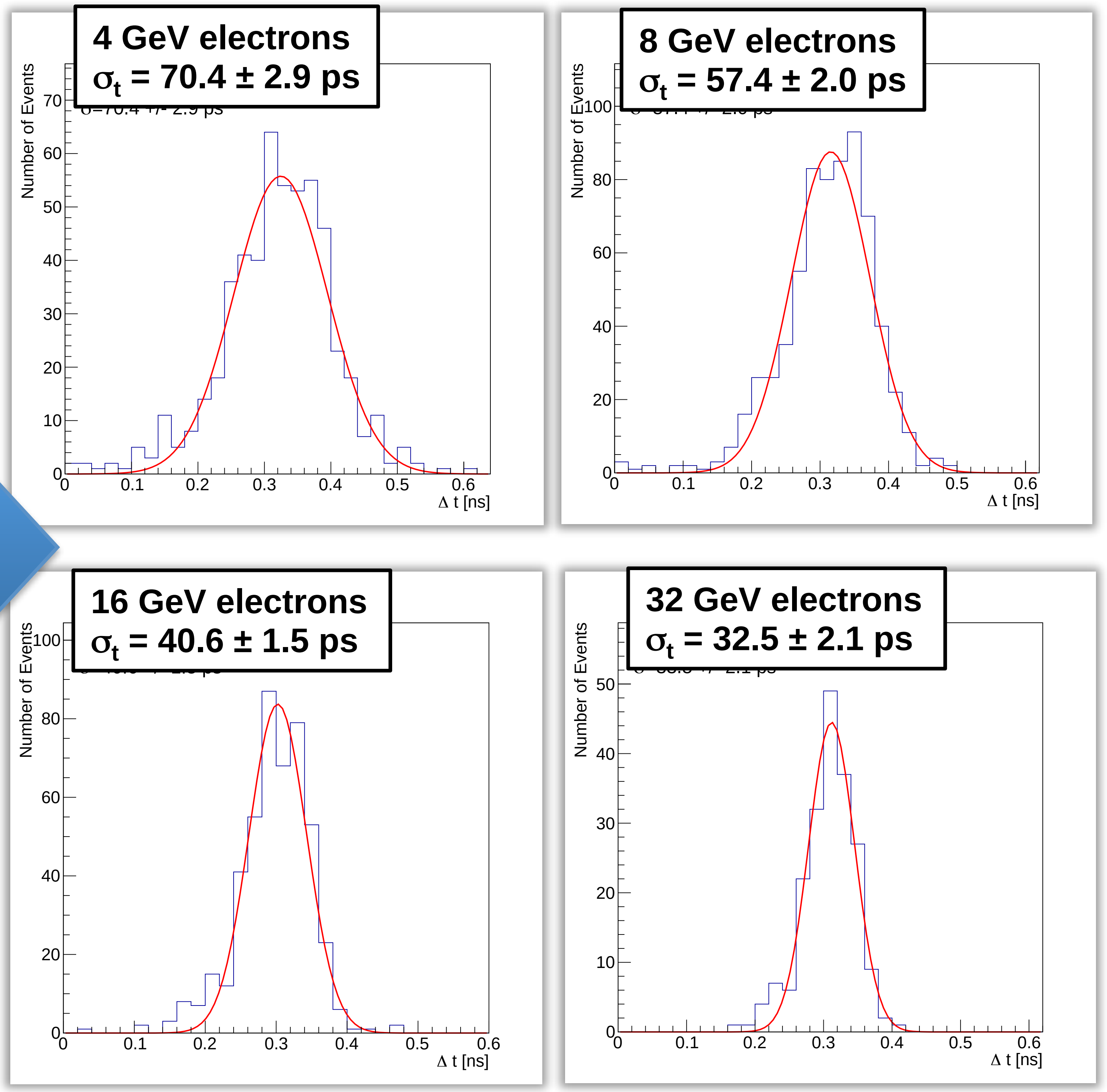
29.05.2015 Adi Bornheim, Elba 2015, Precision Timing Calorimeter 13

TOF Measurements (1.7 cm^3 LYSO)



measure t_1-t_0



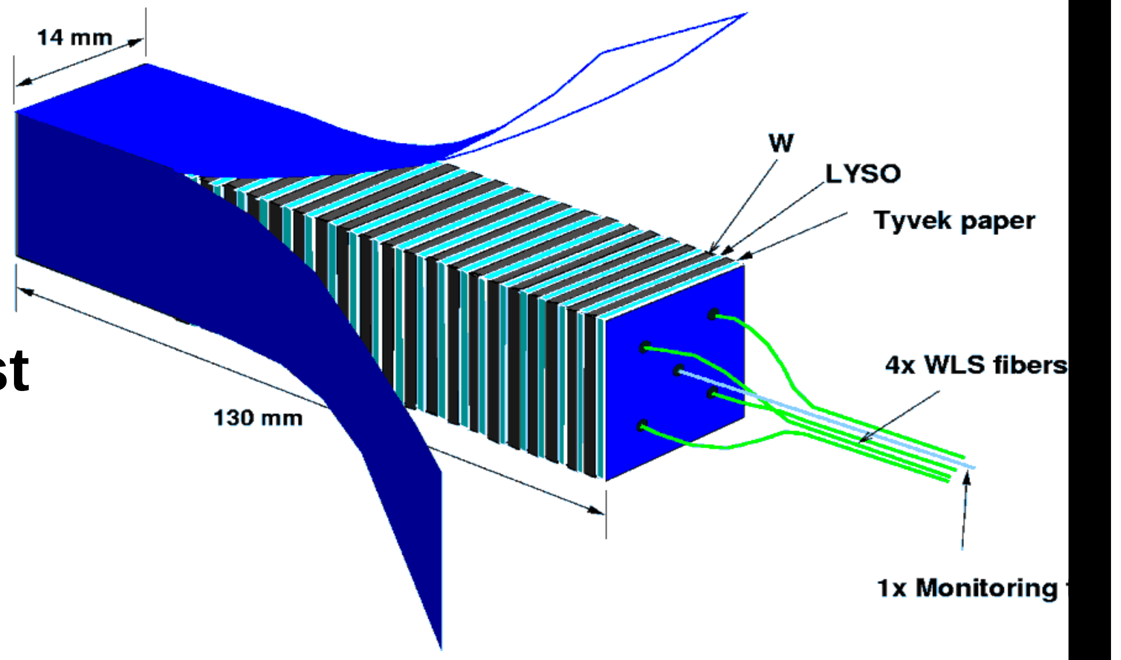


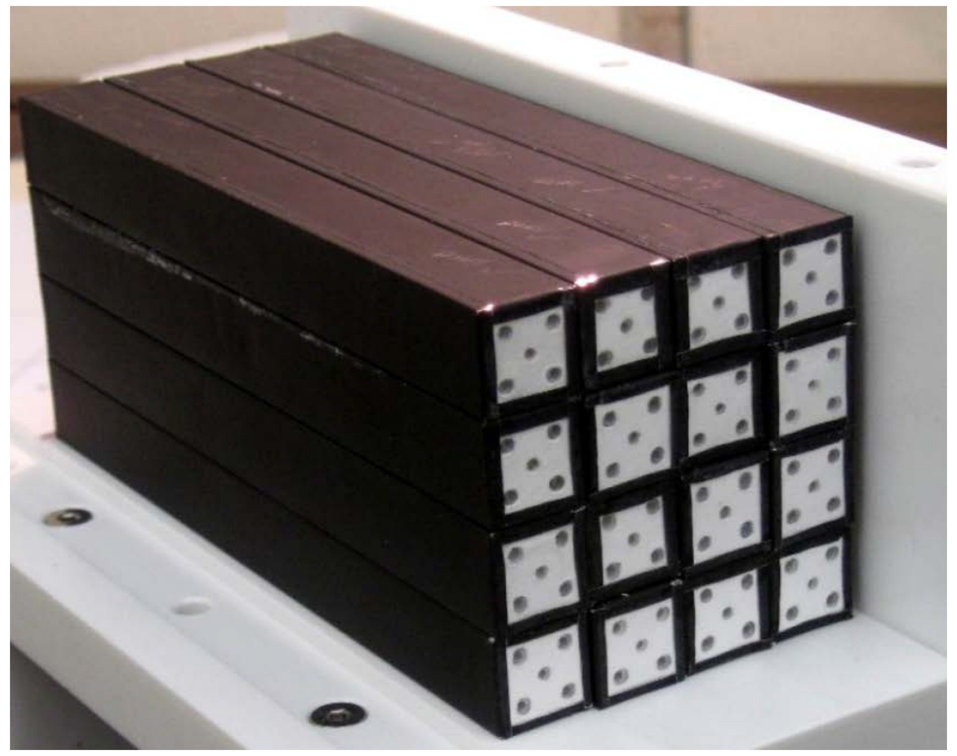
29.05.2015 Adi Bornheim, Elba 2015, Precision Timing Calorimeter 14

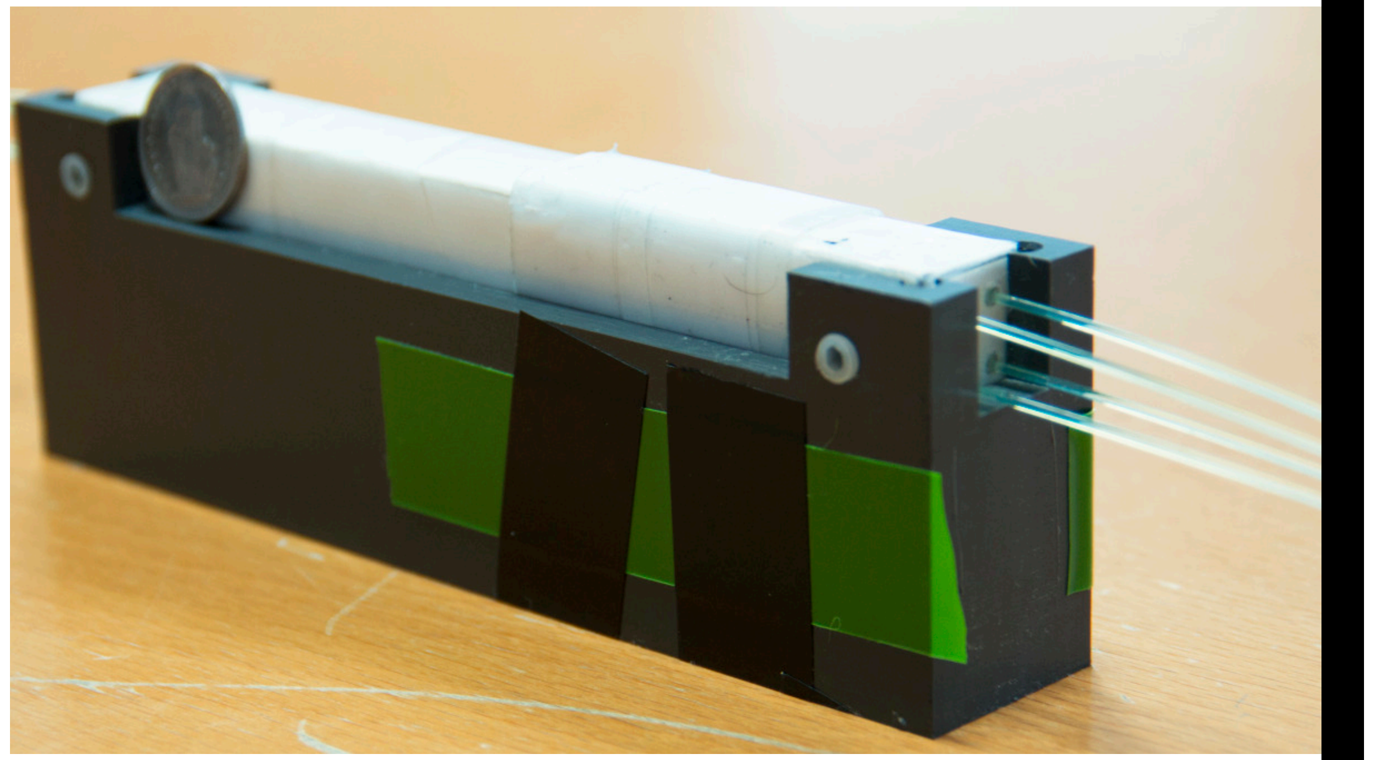
ONGOING R&D

Increased Light Path Complexity

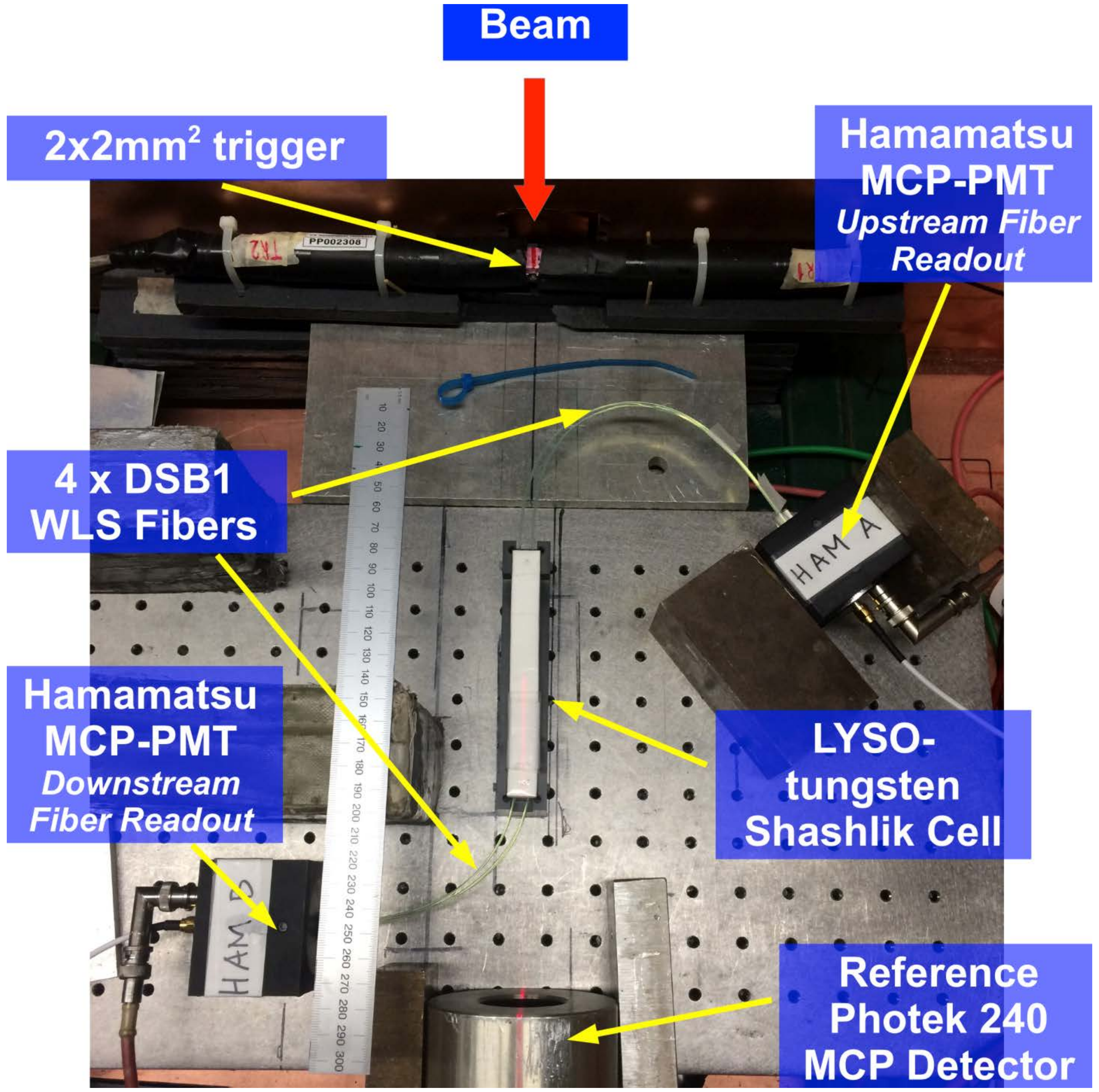
- R&D for HL-LHC on LYSO/W Shashlik calorimeter.
- Radiation hard in HL-LHC environment up to 3 ab^{-1},energy resolution of 10%/sqrt(E)⊕1%.
- Resolution performance demonstrated in test beam on a 4x4 matrix.
- Use single Shashlik cell to test timing performance with very complex light path.





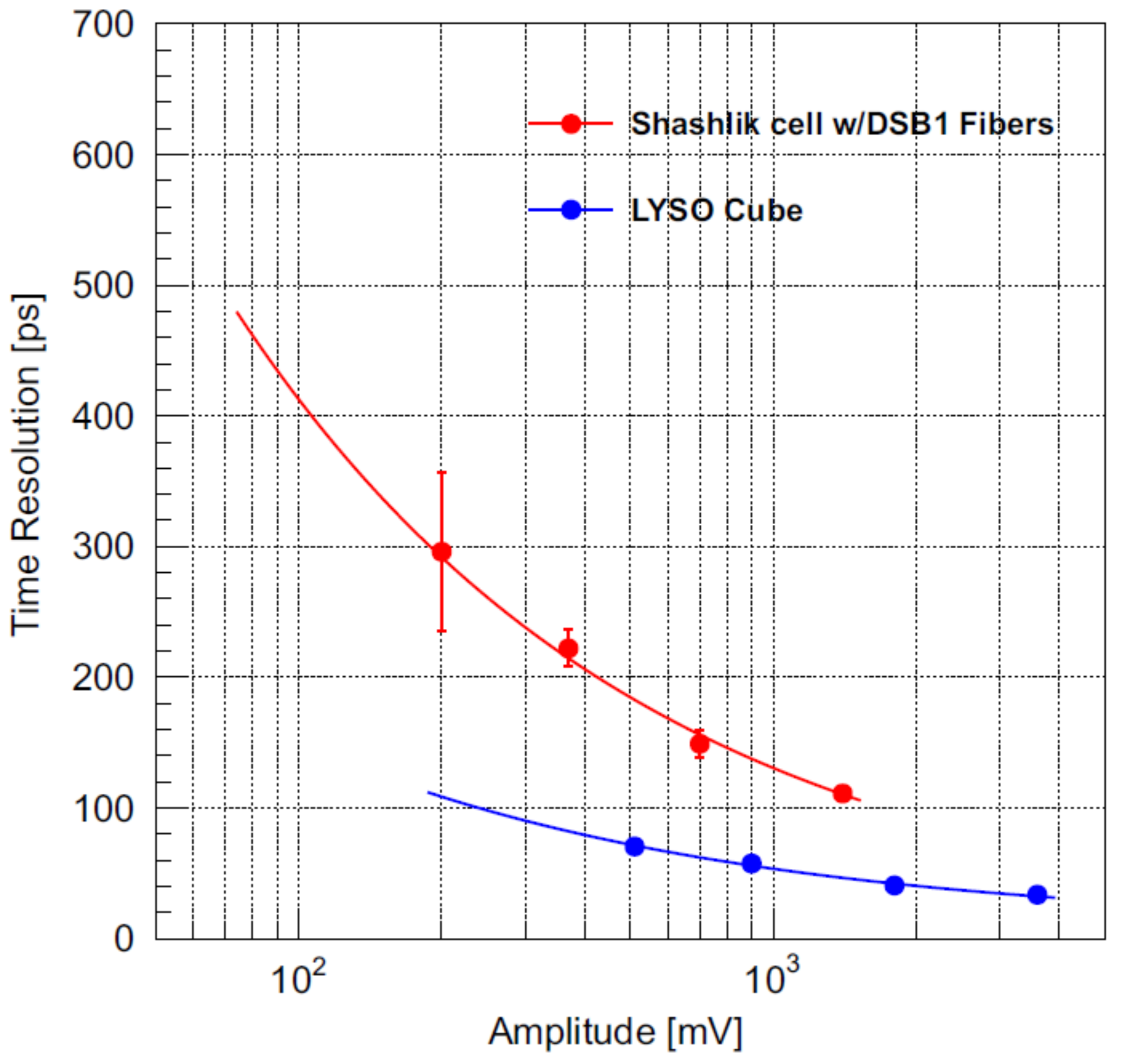


Beam Test Setup Shashlik Cell



ONGOING R&D

Shashlik Timing Performance

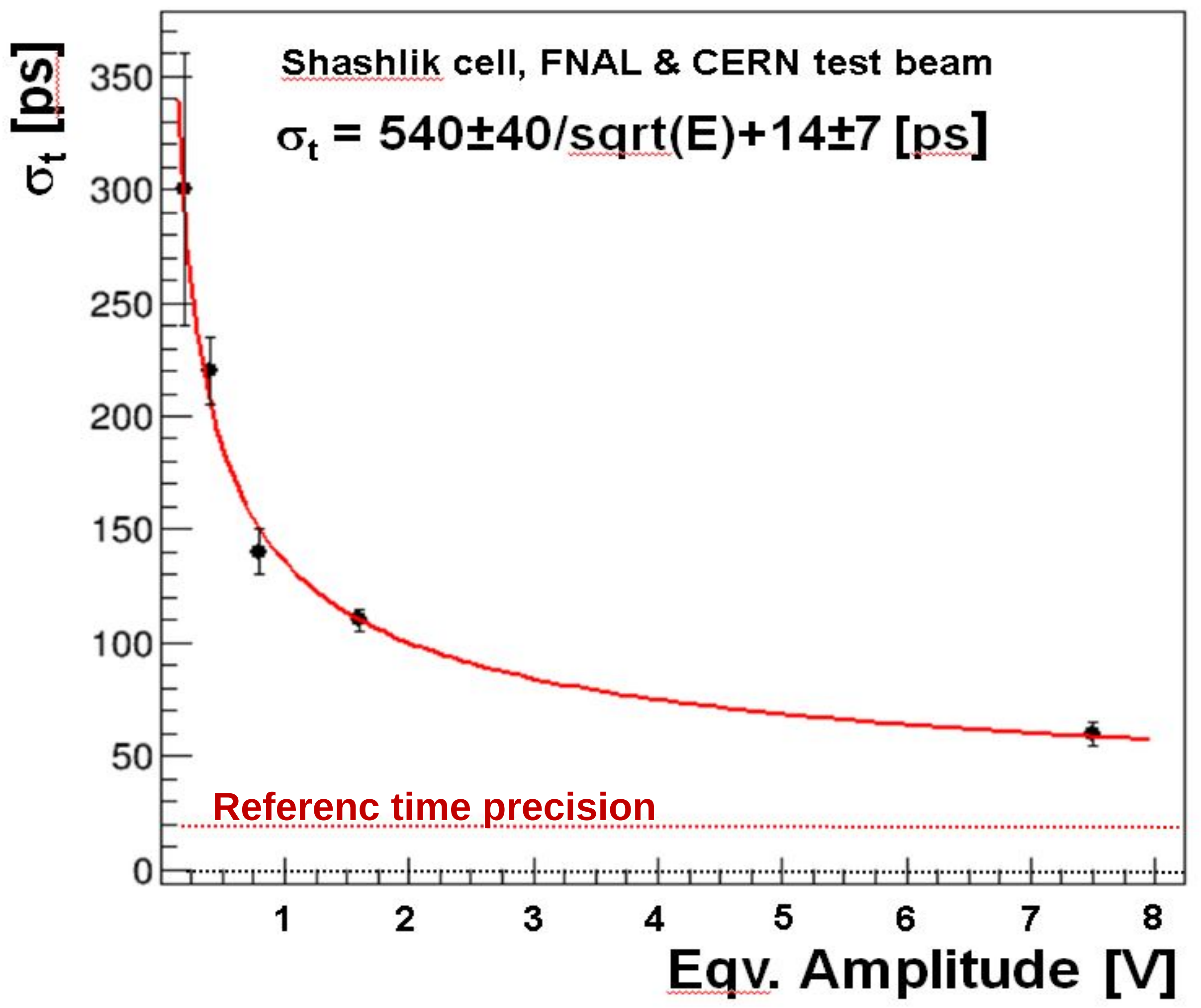


- **Performance of solid LYSO cube and LYSO/W scales with the rise time difference due to the WLS.**
- **Few 10 ps resolution achievable with LYSO based calorimeter, reaching ~32 ps at 32 GeV equivalent signal.**

NIM A, Vol 794 (2015) p 7-14

Current Systematic Limits

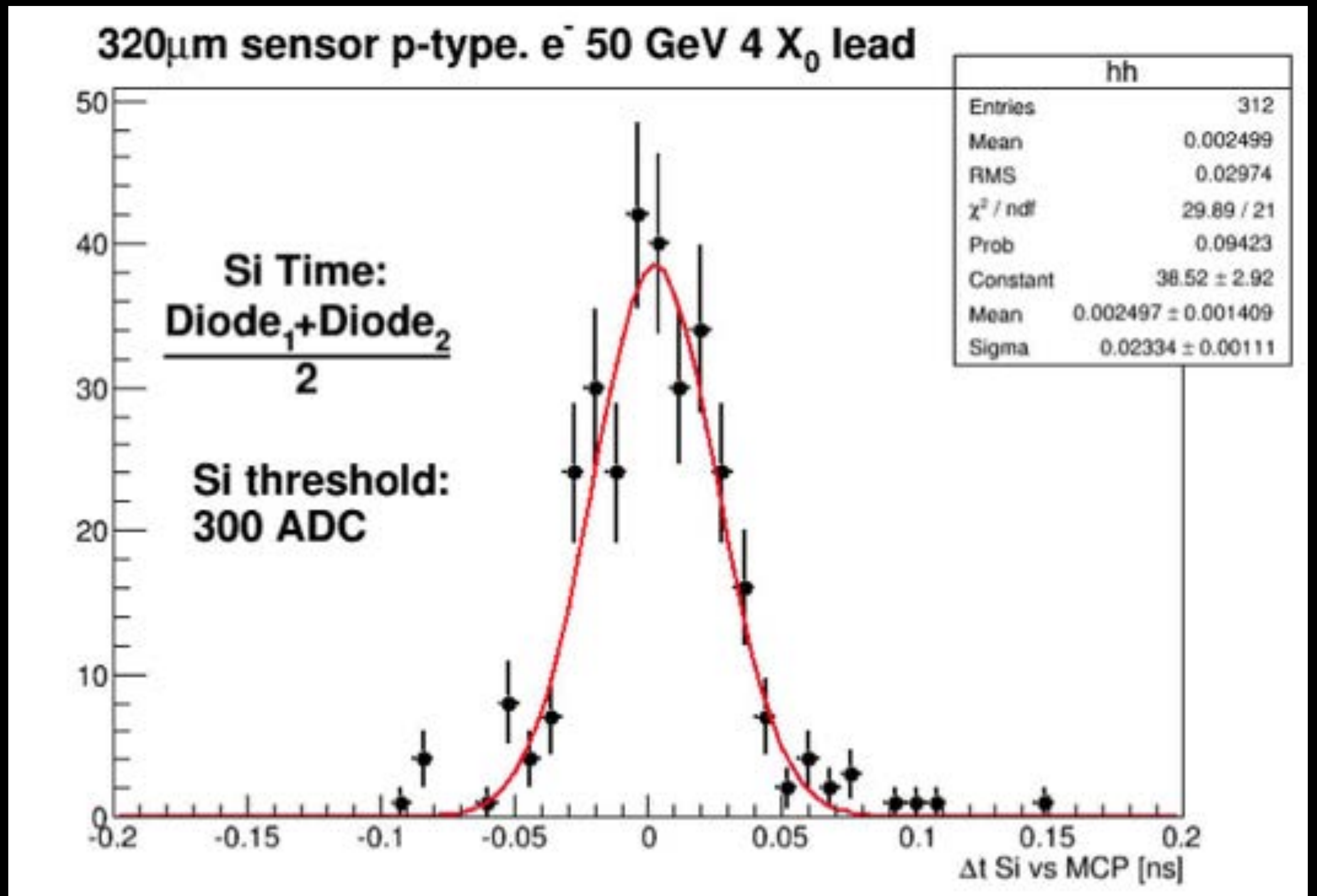
- **Extended measurement up to 150 GeV suggest that the systematic limit is small.**
- **Fit yields constant term compatible with the reference time resolution of around 15 ps.**



Order few 10 ps resolution for EM showers can be achieved with crystals independent of the level of complexity of the light propagation. Similar conclusions for HGC with Si sensors and MCPs

SOME NEAR FUTURE WORK & OBJECTIVES

— Test PbWO ultimate timing with double readout.



— Test Shashlik cell timing with multiple SiPMs.

— Test HGCAL Si sensors.

— Cross benchmark the above.

— Scale to multichannel systems and optimize fine grain detection vs technical constraints.

— Optimize jet reconstruction algorithm to use the timing information and derive set of requirements for the spatial granularity and timing resolution for an optimized jet calorimeter for high lumi and higher energy HC (18 TeV, 30 TeV, …)

FUTURE WORK & OBJECTIVES

— Optimize high resolution TOF calorimetry by improving the light extraction efficiency (e.g. compress photons in the fastest propagation modes by means of photonic crystals and plasmonic resonances as in 4D TICAL ERC proje (2013-2018, Lecoq et al).

— Optimize read-out electronics (next generation fastest SiPMs/TDCs/discriminators/amplifiers etc)

— Use graphene quantum dots as WLS

— Augment classical scintillators with quantum dots (e.g. nano-crystaline scintillators)

— Ose modern (IOT-like) network tech to extract the data

— Other apps (homeland, medical, etc)

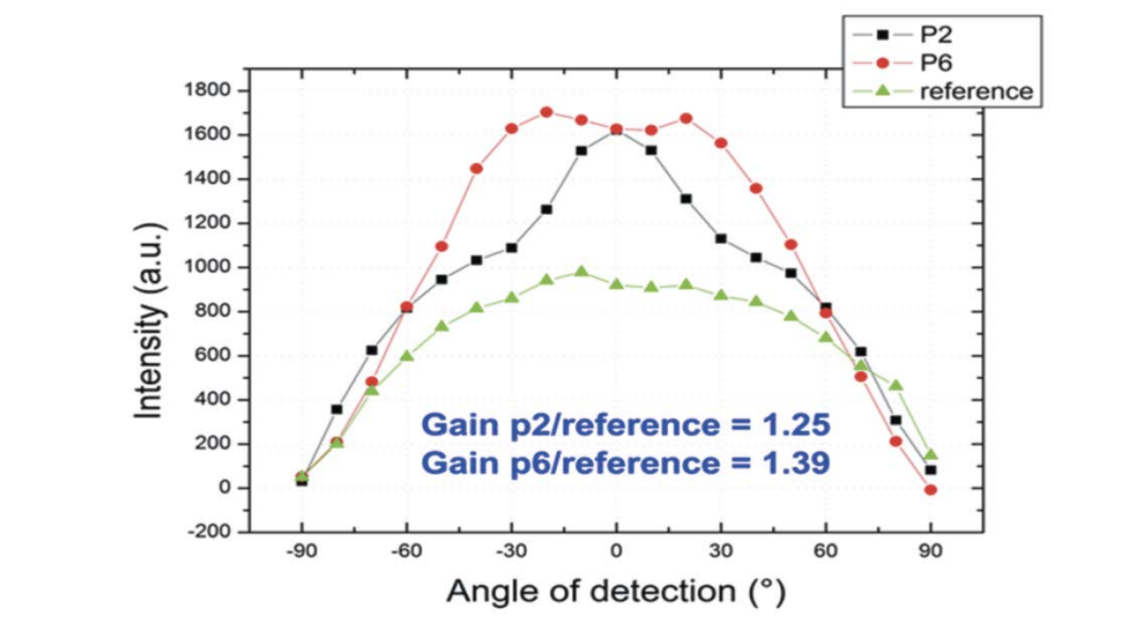


Fig. 2. Angular distribution of extracted photons from two PhCs deposited on a LSO crystal (P2 and P6) as compared to the flat LSO reference. On top of the improved light extraction efficiency P2 shows a strong collimation effect in the forward direction.

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Vol. 29, No. 30 (2014) 1430070 (31 pages)
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DOI: 10.1142/S0217751X14300701

A. Knapitsch & P. Lecoq

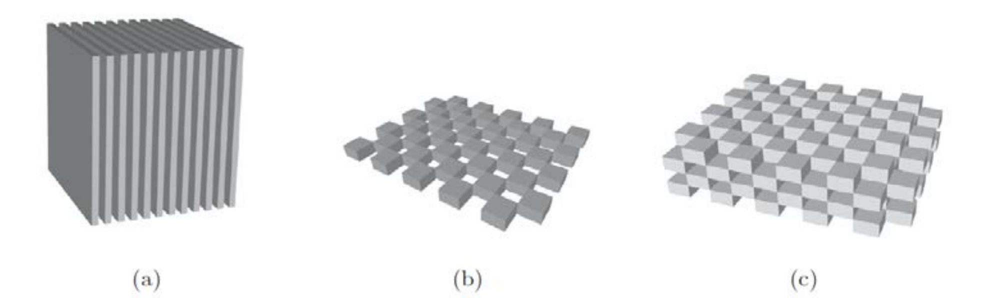
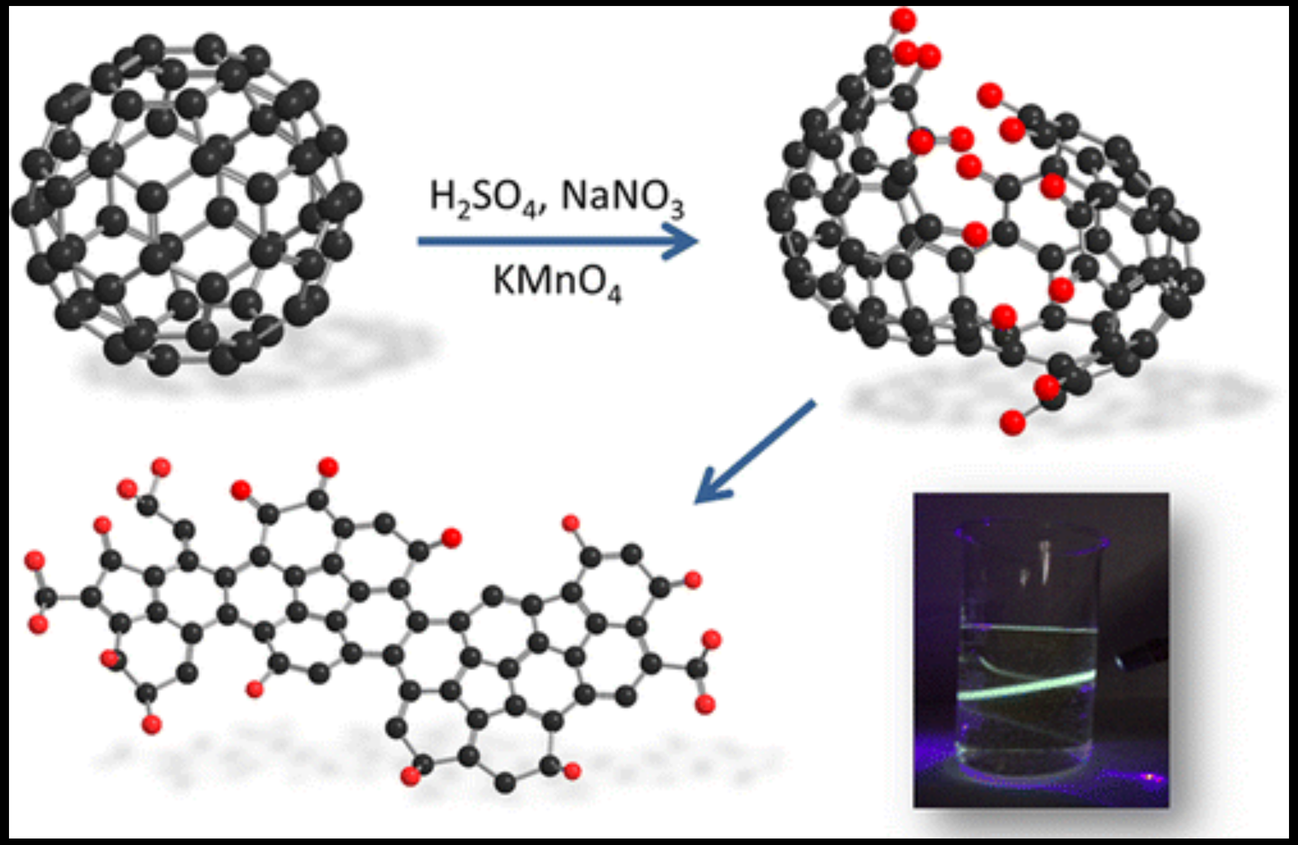
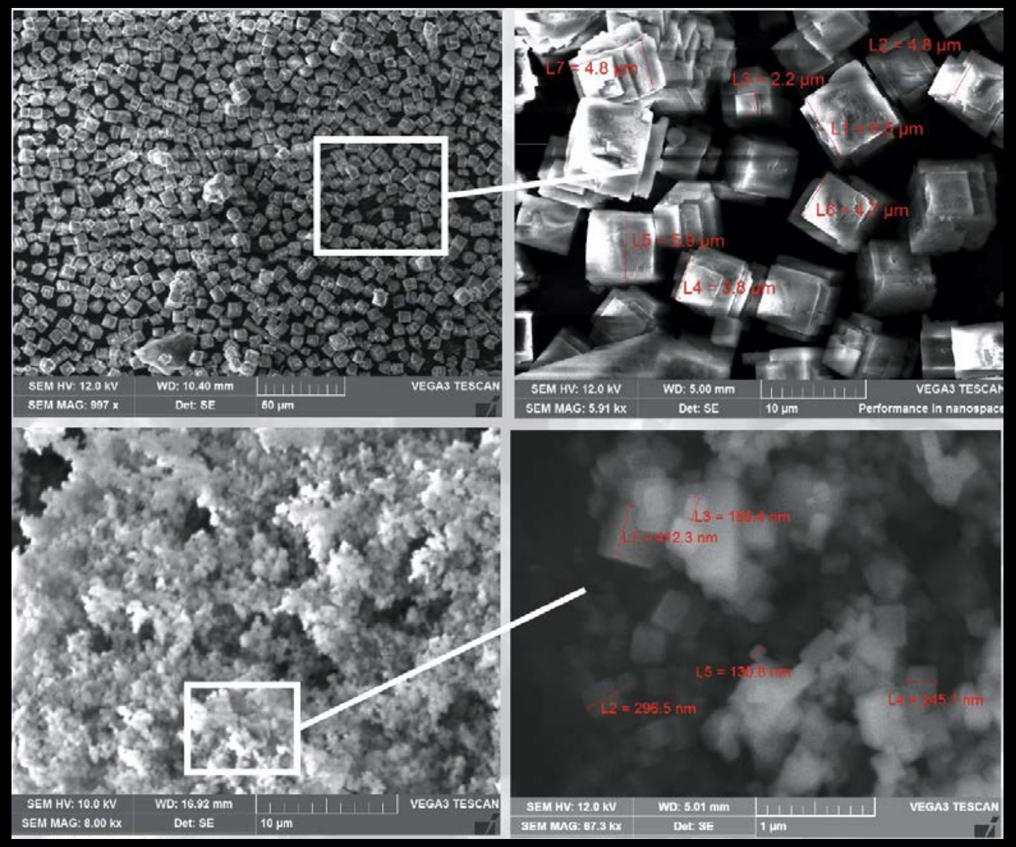
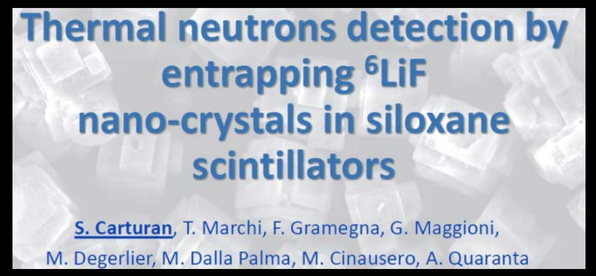


Fig. 3. The different dimensional arrangements of PhCs. Photonic crystals are composed of a periodic dielectric or metallo-dielectric that affects the propagation of electromagnetic waves in one, two or three dimensions.

Synthesis of Strongly Fluorescent Graphene Quantum Dots by Cage-Opening Buckminsterfullerene"
Chun Kiang Chua, Zdeněk Sofer, Petr Šimek, Ondřej Jankovský, Kateřina Klímová, Snejana Bakardjieva,
Štěpánka Hrdličková Kučková, and Martin Pumera
ACS Nano, 2015, 9 (3), pp 2548–2555
DOI: 10.1021/nn505639q







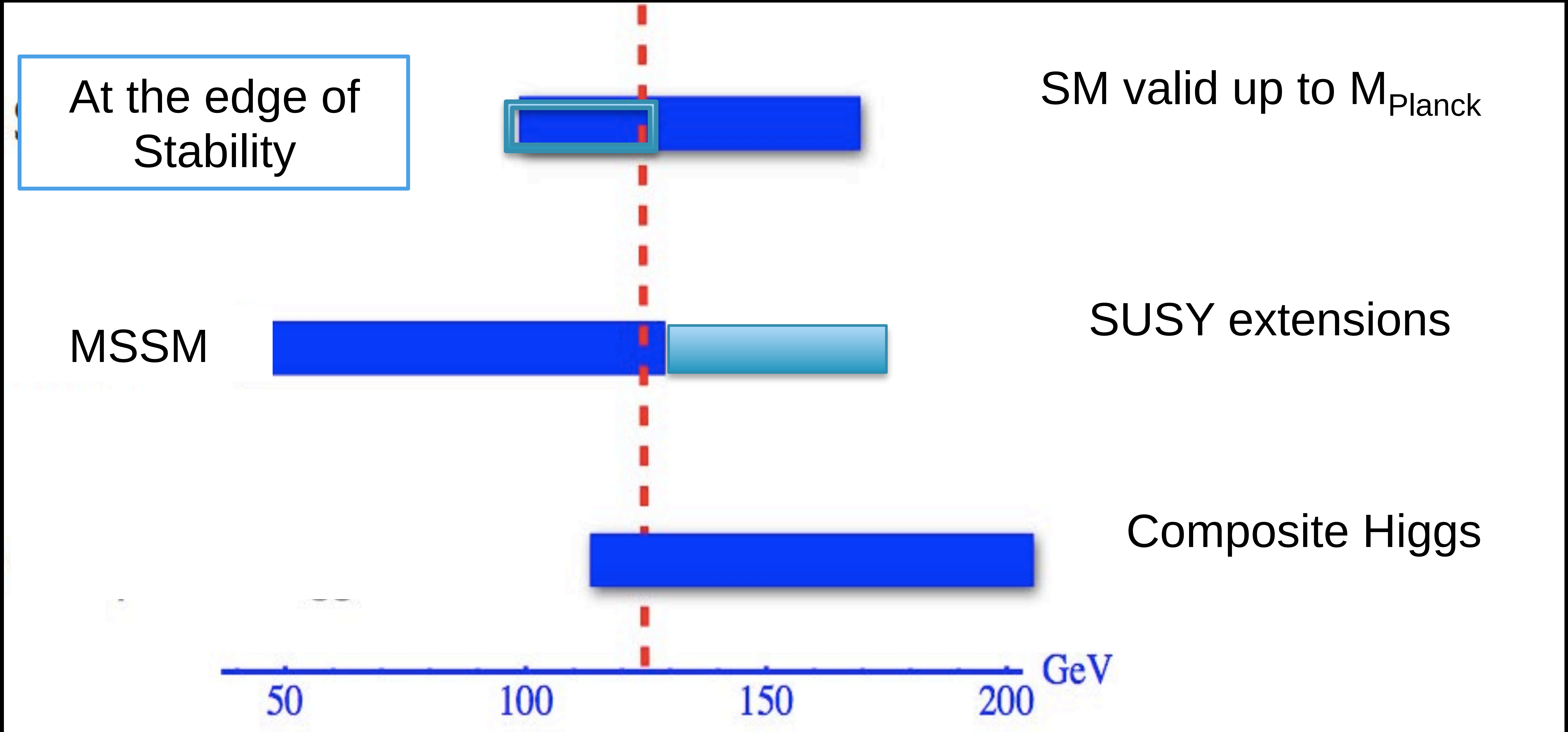
ANSRI Workshop, Dublin, 12-14th January, 2015

CLOSING REMARKS

- Fast timing in 4π hadron collider detectors of the future is rather inevitable.
- Building end-to-end fully integrated prototype systems slices is important to have validation and verification and confidence in performance
- The new era of materials (nanophotonics, plasmonics, quantum dots, hybrid sensitive volumes and readout technologies) is here for HEP
- The new era of computation, algorithms including networking technologies is here and part of the solution to the daunting amounts of data and complexity of the current and future hadron colliders detectors
- Investing in calo-TOF R&D is likely to produce major breakthroughs (in HEP and other fields)

PHYSICS MATTERS

126 BORDERLINE DISORDER



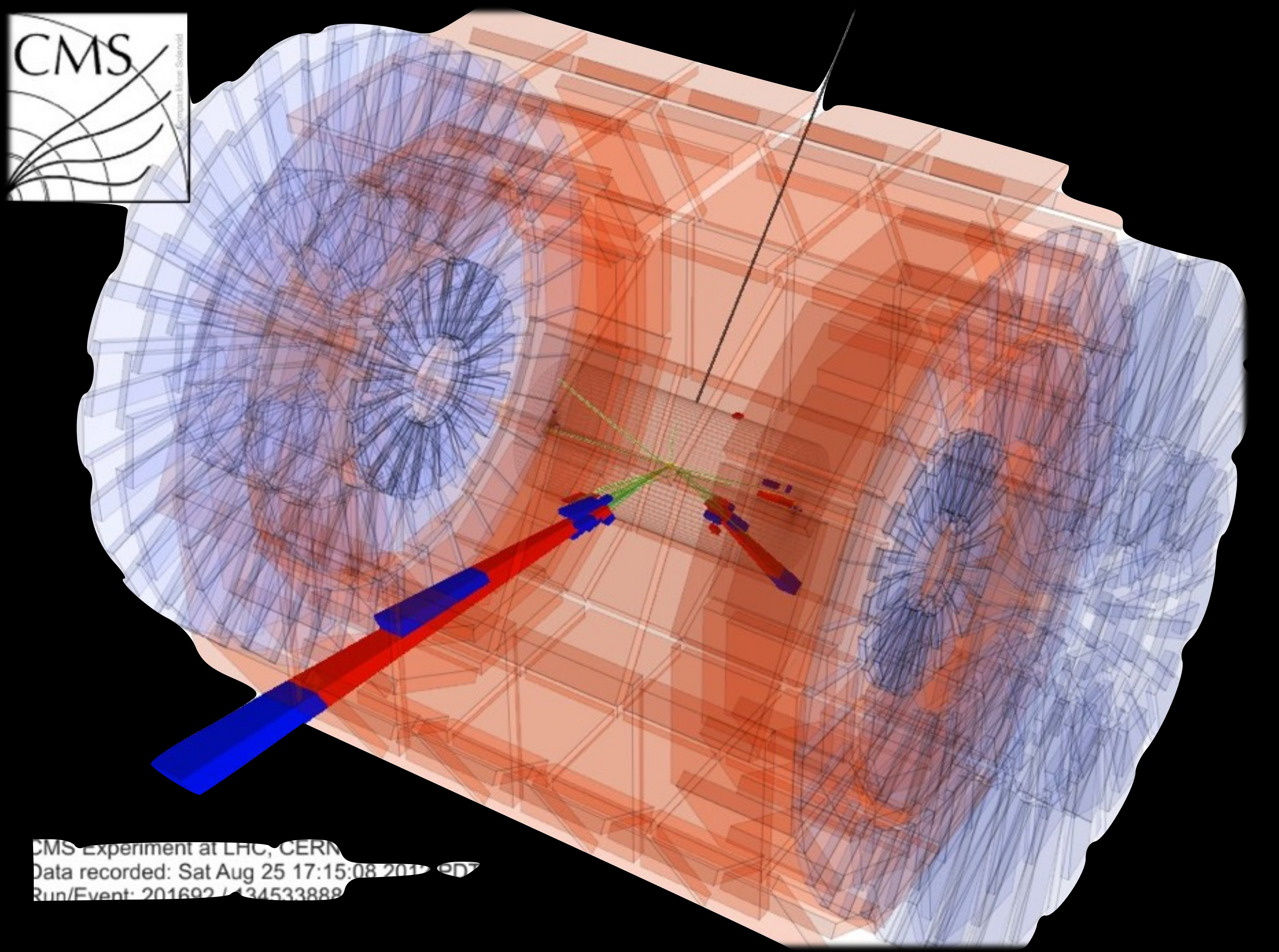
126 GeV is suspiciously light for a composite Higgs boson
and it is suspiciously heavy for minimal SUSY
(you need to work SUSY extensions with **enlarged Higgs sectors**)

THE COMING DISCOVERIES

- No evidence for supersymmetry so far at the LHC
- Without supersymmetry, we don't understand how the Higgs boson can exist without violating basic mechanisms of quantum physics
- The apparent instability of the Higgs vacuum adds to the mystery
- More data from many sources (particle, astro, cosmo) and will guide us

Either the new run of the LHC should discover superpartners or some such, or radical new ideas are needed

SUSY IN THE DETECTORS



HIGGS CONNECTIONS TO "THE BEYOND"

- Is there a Higgs portal to dark matter
- Electroweak baryogenesis
- What principle creates and stabilizes the electroweak scale
- How does the Higgs talk to neutrinos
- What are the dynamical origins of fermion masses, mixings and CP violation
- Extra credit: is the Higgs related to inflation or dark energy

Needs a multi-decade global experimental effort on many fronts, with new ideas and new technologies

OPPORTUNITY AND IMPOSSIBILITIES

People who say it cannot be done should not interrupt those who are doing it.
GB Shaw

Opportunity is missed by most people because it is dressed in overalls and looks like work.
Thomas A. Edison