Summary of Detector Development and Performance

Vivian O'Dell, Fermilab

International Conference in High Energy Physics

August 8, 2016

Exciting Sessions!

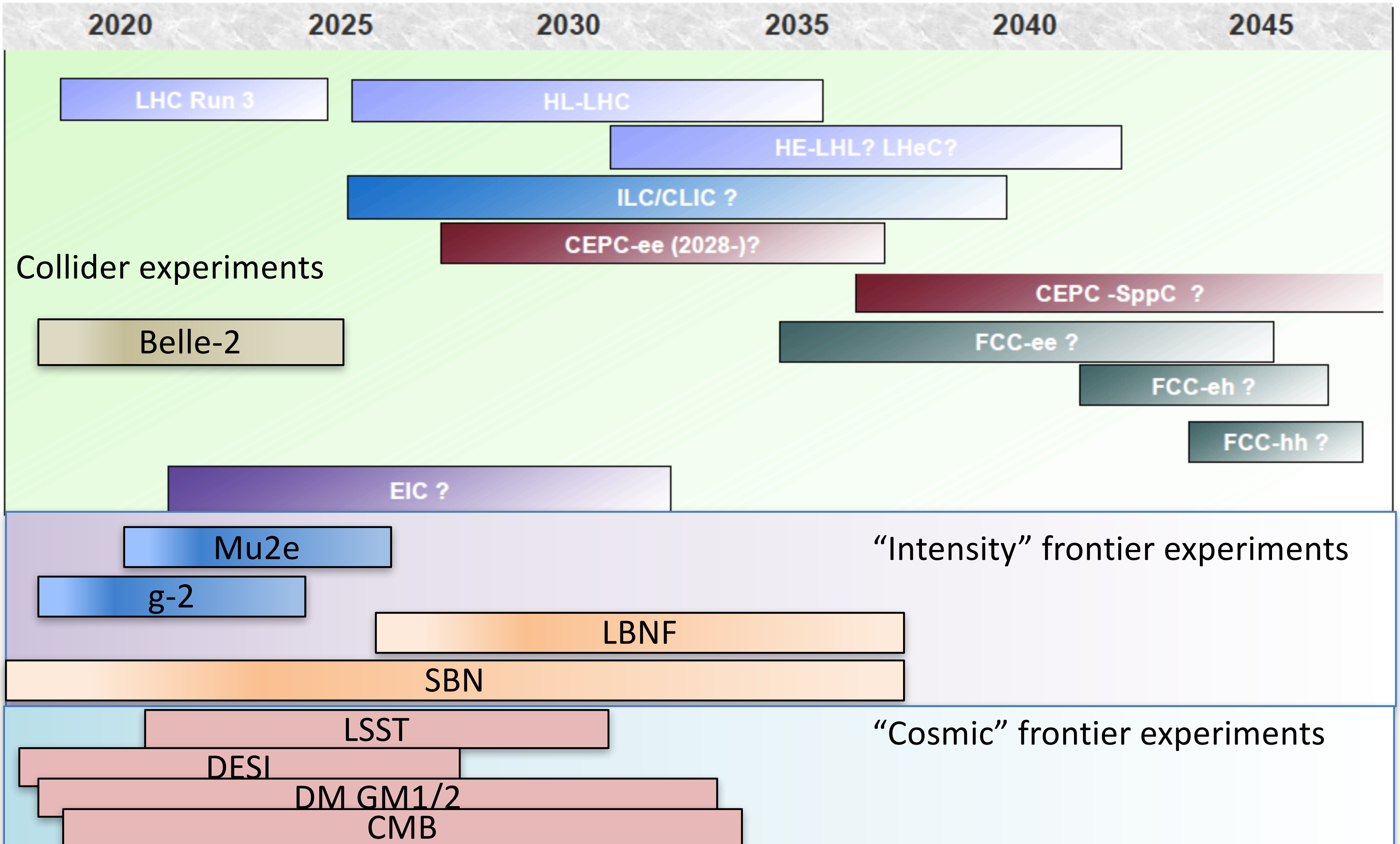
- Apologies in advance – this is not a summary
  - ~ 90 talks covering a wide range of detector developments
  - Much too much to summarize
  - Nice mix between established experts and young experts-in-training

- Since I couldn't possibly summarize all the sessions, this is more a "personal" takeaway from what I learned

“Building [Particle Detectors] for Discovery”

+ host of smaller experiments either building up to major thrusts (e.g. CONNIE, LaRIAT, DAMIC, etc) or ruling out interesting areas of phase space (i.e. LZ, etc.)

Timelines for major experiments



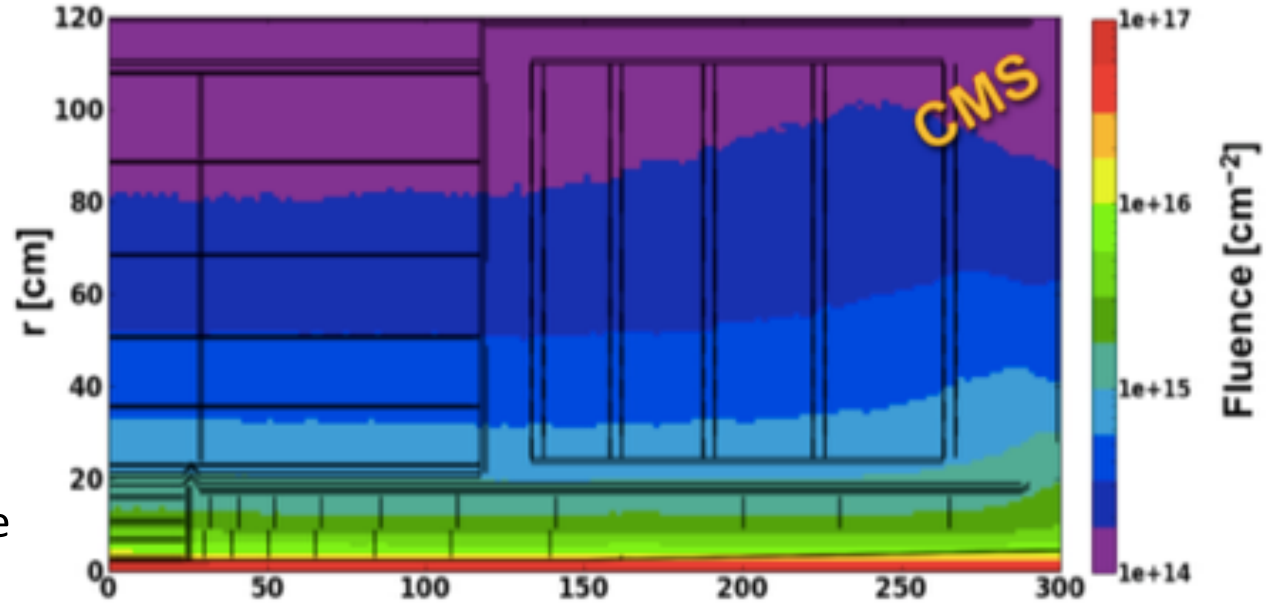
New Detector Requirements

- For collider experiments
  - Radiation hard
  - Excellent particle measurements / resolutions ($e/\gamma/\mu/\tau/ME_T$,b/t-tagging etc.)
    - Even in the presence of ~ 200 overlaid minimum bias events (i.e. pileup)
  - Detectors need good resolution especially at high energy (i.e. small constant terms, minimize contributions from multiple scattering)
  - High rate radiation hard readout with deep buffering to support large dynamic range/occupancy and complex triggers
- For neutrino / DM experiments
  - Pure detector / noble gasses
  - Electronics ”cryogenically” hard and very robust (or the ability to extract and repair them)
  - Ability to resolve and reconstruct very small energies (e.g. on the order of a few keV)
- For all experiments
  - Excellent timing resolution
    - Needs and requirements slightly different across experiments, but roughly in the O(10-100ps) range
    - Important at LHC for mitigating pileup, Heavy Flavor / neutrino experiments for particle id, rejecting cosmics
- Trigger/Data Acquisition systems also have challenging demands
  - Excellent timing synchronization over long baselines for the neutrino program
  - Fast hardware trigger / fast trigger event reconstruction in events with large occupancy for the collider program
- Above all: detectors (and their electronics) must be buildable, low(ish) cost, and maintainable!

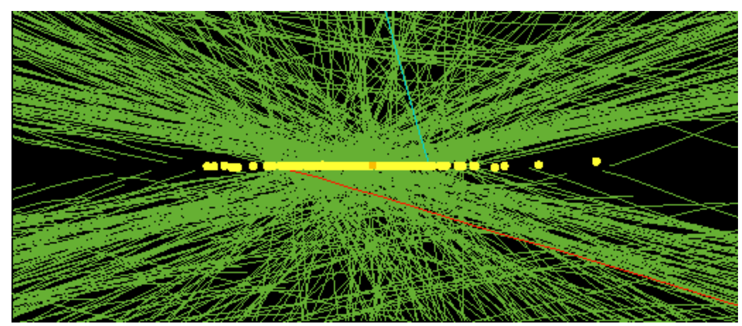
Collider Detectors: The challenges

- Requirements:
  - Tracker sensors that can withstand an extremely high radiation environment
  - Good track resolution in a busy environment: 150-200 events per 25 nsec crossing
  - Innovative triggering at level 1 to keep up with the flood of data
  - New calorimeter designs with high degree of pixelation and potentially fast timing.

  - Challenge in photo-detection
  - Challenge in silicon
  - Challenge in data collection / trigger



Expected Fluences in CMS at 3 ab^{-1}



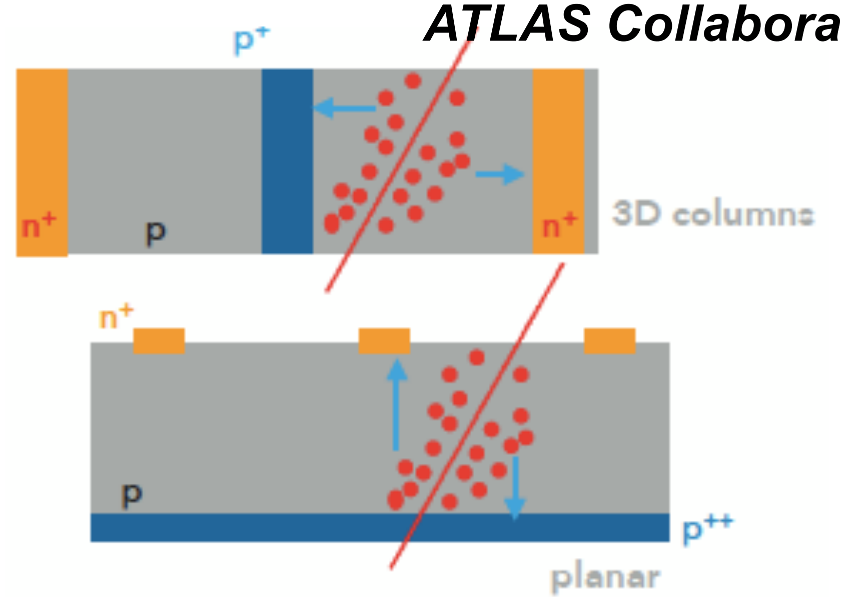
What an event with 140 vertices looks like in the CMS tracker

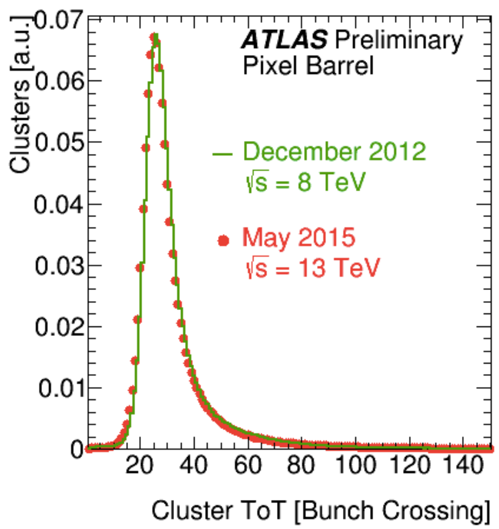
Silicon Tracking Detectors

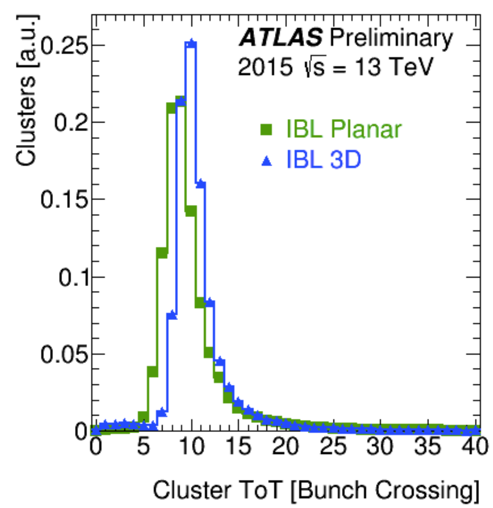
HL-LHC silicon tracking detectors

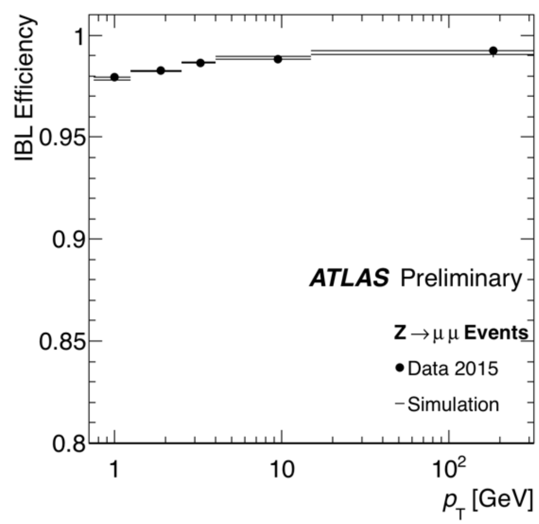
From: M. Giordani
ATLAS Collaboration

- Pixel detectors: Joint radiation hard sensor R&D with CMS and ATLAS (RD50)
  - Many investigations comparing different manufacturing techniques, thinness of sensors and type of silicon junctions
  - Baseline for both CMS and ATLAS are thin n-in-p planar sensors
  - However, for the innermost region, studies of 3d pixel sensors are ongoing





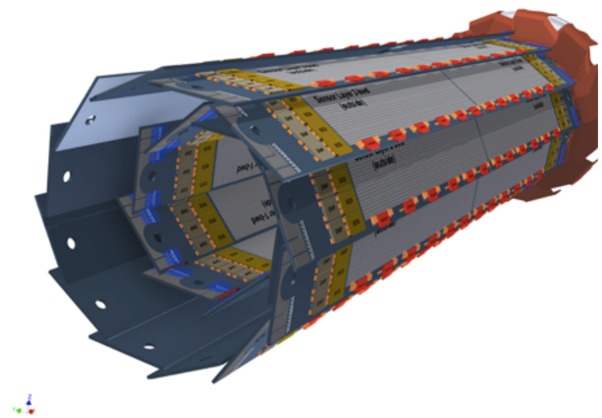


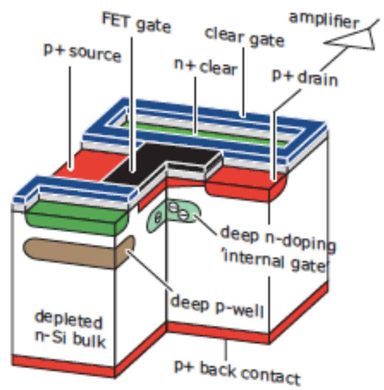


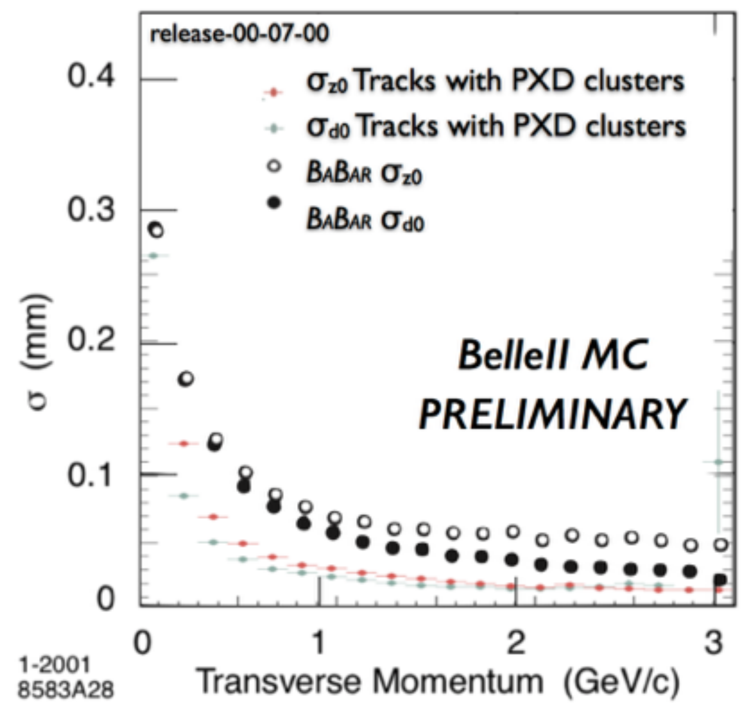
Results from planar vs. 3-D sensors in the ATLAS IBL

ILD/Belle silicon tracking detectors

From: A. Palladino
BELLE Collaboration





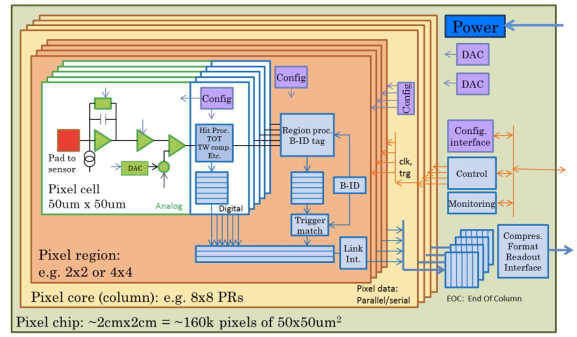


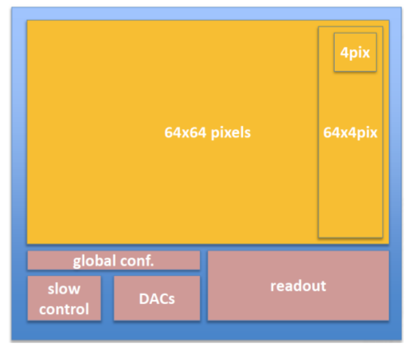
- Two layers of DEPFET pixels
- Thickness: 75 μm
- Pixel size: 50x55 μm^2
- Low noise
- Low power consumption

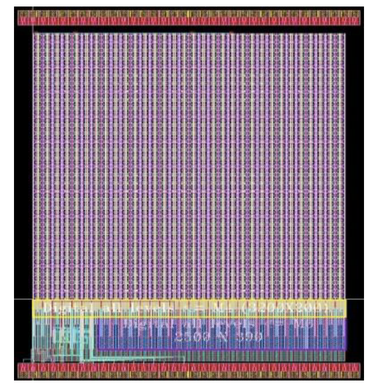
Modest data rate => can go to much thinner sensors, lower power consumption
By using Depleted p-channel Field Effet Transister achieve:
good signal-to-noise ratio, thin detectors, low power consumption

HL-LHC silicon tracking detectors: Readout Chips

- Sensors will be bump bonded to a Readout Chip that must also be radiation hard
- These chips must be capable of high rates, radiation hard
  - Being developed in the context of another joint R&D project – RD53
  - Developing ROC in 65nm CMOS technology
  - 50x50 μm unit cell size
  - Rad-hard Ips, low power, low noise analog circuit
  - Full scale demonstrator in 2017







RD53A chip – submission in March

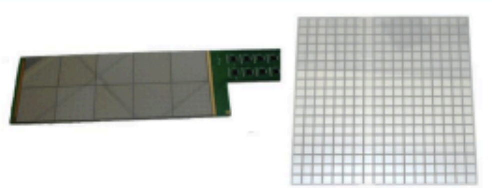
Calorimetry

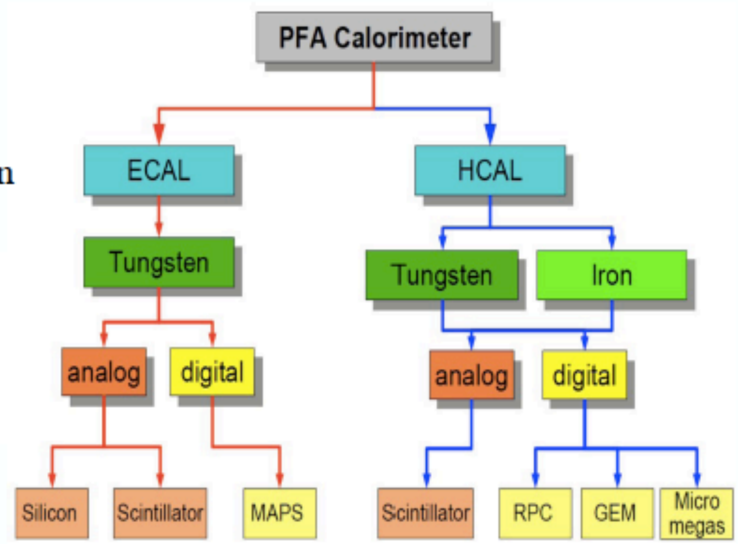
High Granularity Calorimeters

From: H.L. Tran
CALICE Collaboration

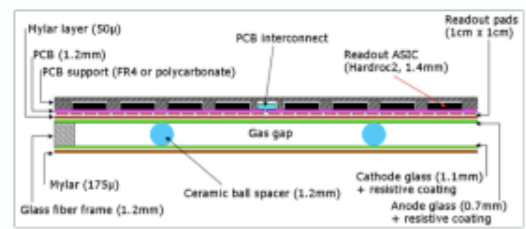
The CALICE collaboration

- **Goal**: Research and development of highly granular calorimeters for future lepton colliders
- **Technologies**:
  - *Silicon*:
    - Compact, stable calibration
    - 0.5-1.0 cm^2 cells

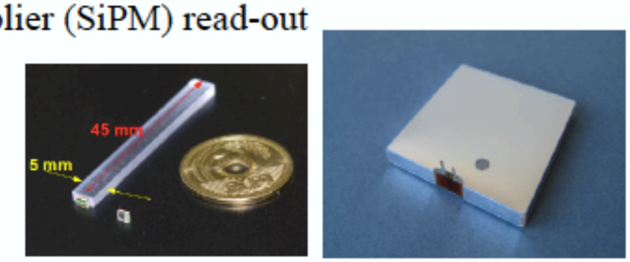




  - *Gaseous*:
    - Easily segmented 1x1 cm^2
    - Glass RPCs (GRPC): good and well-known technology



  - *Scintillator*:
    - Robust and reliable
    - Easy to machine, various cell sizes
    - Silicon Photomultiplier (SiPM) read-out



  - *Other technologies*:
    - Micro Pattern Gaseous Detectors (MPGD): GEMs, Micromegas

High Granularity Calorimeters

From: H.L. Tran
CALICE Collaboration

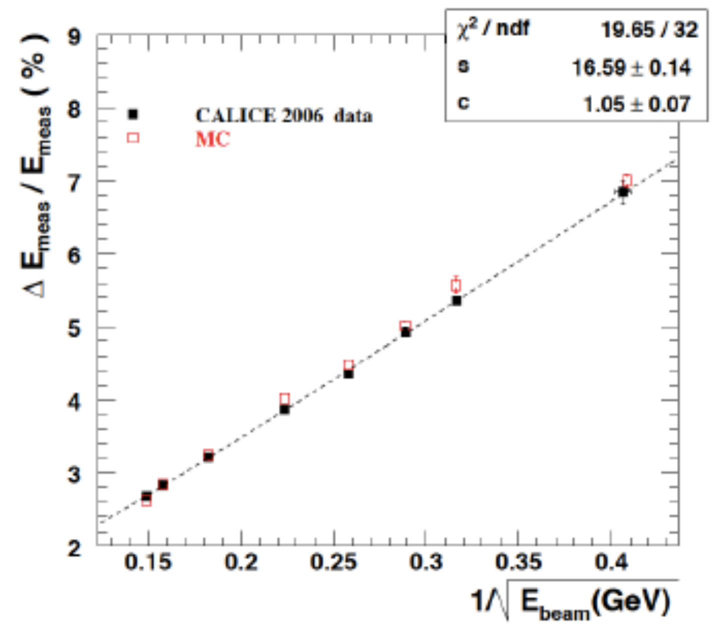
Silicon-Tungsten ECAL

- Si-W ECAL in various beam tests with nice results
  - Energy resolution measured on electron and positron beams
    - Stochastic term: $(16.6 \pm 0.1)\%/\sqrt{E(\mathrm{GeV})}$
    - Constant term: $(1.1 \pm 0.1)\%$

ECAL

Si-W ECAL: 30 layers, 1x1 *cm² cells*

Si-W relative energy resolution as a function of beam energy (data collected at CERN 2006)



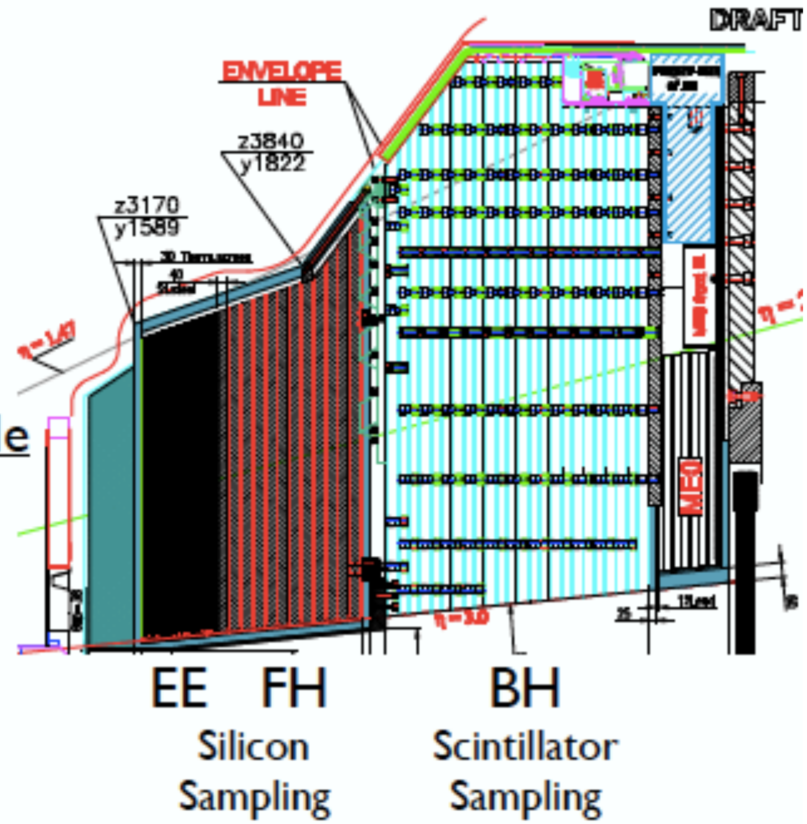
[NIM A608 (2009) 372]

The CMS High Granularity Calorimeter

Integrated sampling Silicon ECAL+HCAL and Backing Calorimeters

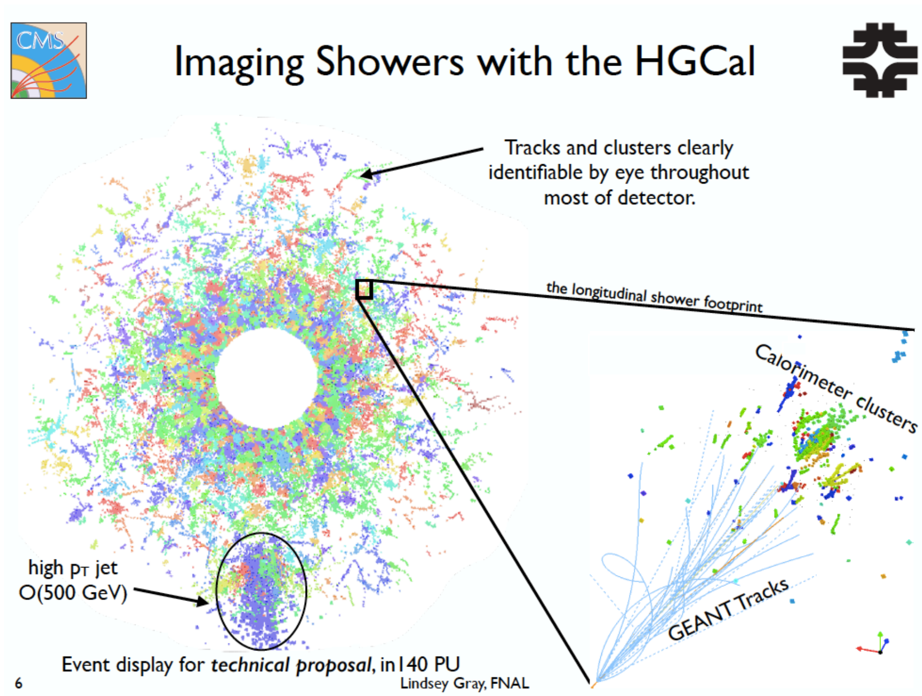
From: L. Gray
CMS Collaboration

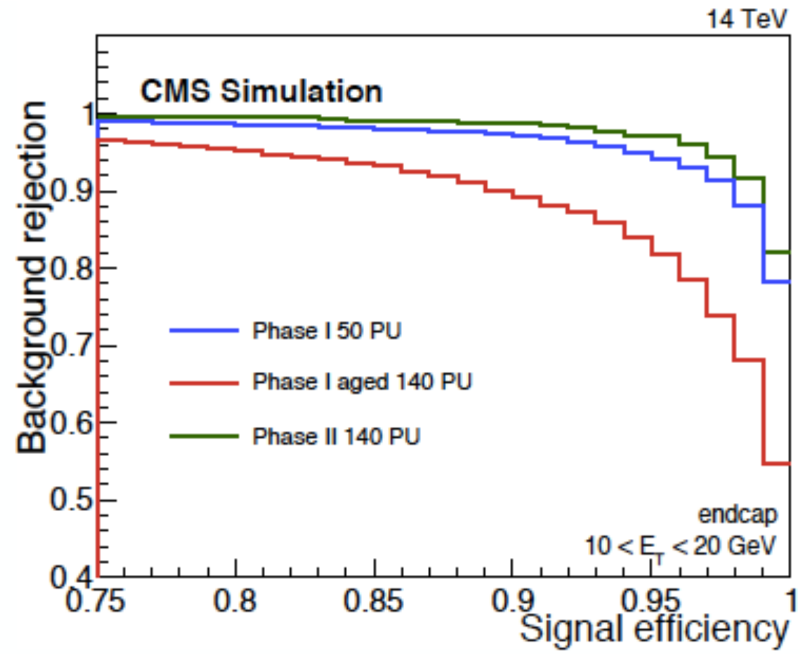
- Profit from the Linear Collider research into 'imaging' calorimeters
  - Sampling calorimeters with fine longitudinal and transverse segmentation
  - ~$26X_0$ in 28 layers W/Cu ECAL, 10.5 λ_0 over 52 layers
- Fine granularity calorimetry enables precise particle flow techniques and ideas applied to calorimetry
  - Now must follow particles through the calorimeter layers
  - Fine sampling brings robustness against pileup

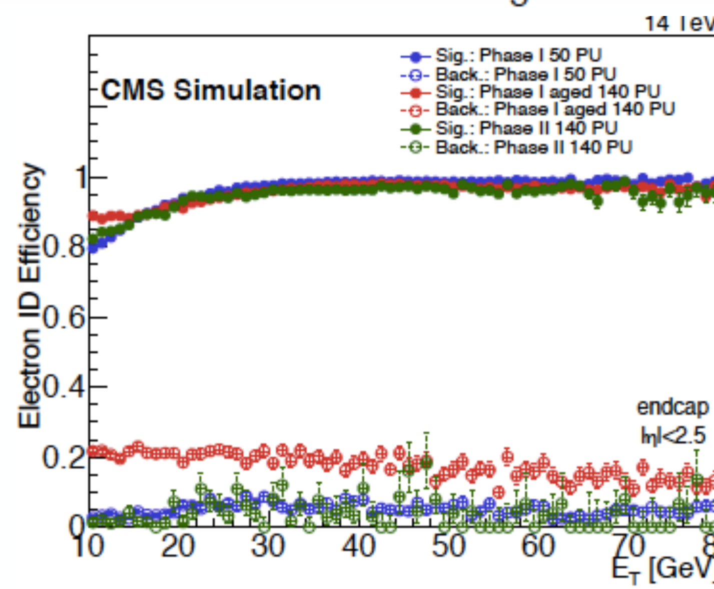


HGCal

From: L. Gray
CMS Collaboration





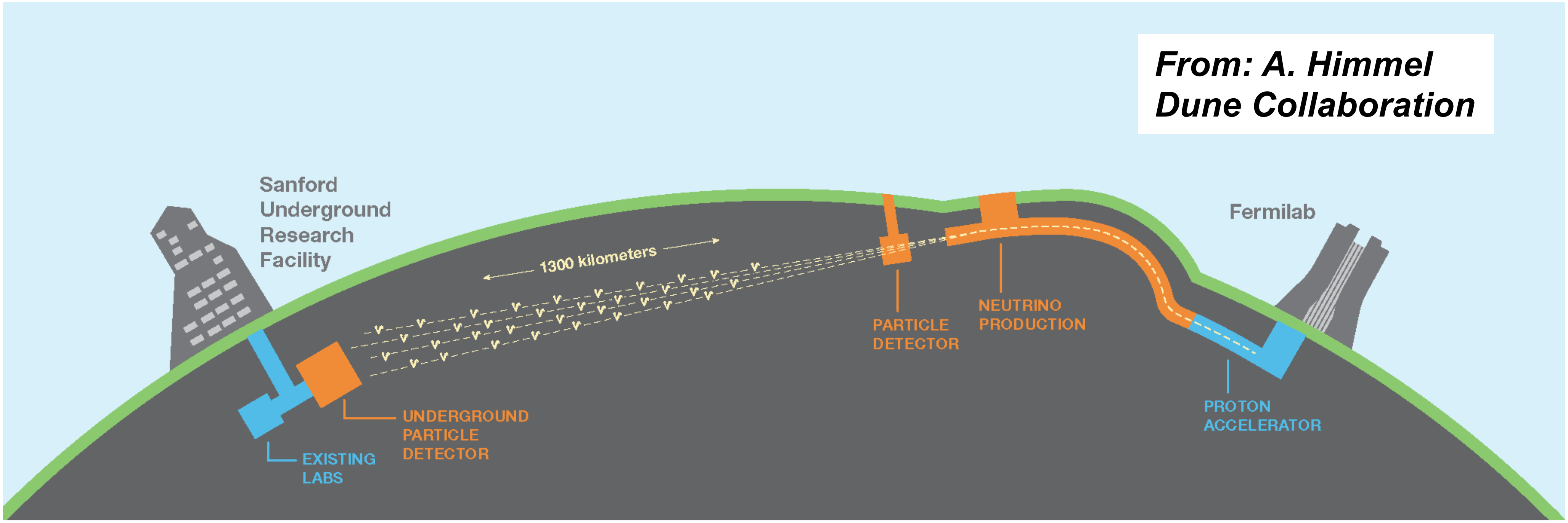


Using a per-cell Δt = 50 ps,
20ps resolution possible from E = 10 GeV
See poster by R. M. Chatterjee

- ATLAS planning to use similar technology for a "High Granularity Timing Device" for $2.5 < |\eta| < 4.3(5.0)$

Neutrino Detectors

Neutrino Detectors



The Deep Underground Neutrino Experiment (DUNE) will be:

- a ***40 kton fiducial liquid argon*** neutrino detector, located 1.5 km underground, 1300 km from Fermilab, which will host a 1.2 MW at 120 GeV neutrino beam, and a highly-capable near detector.

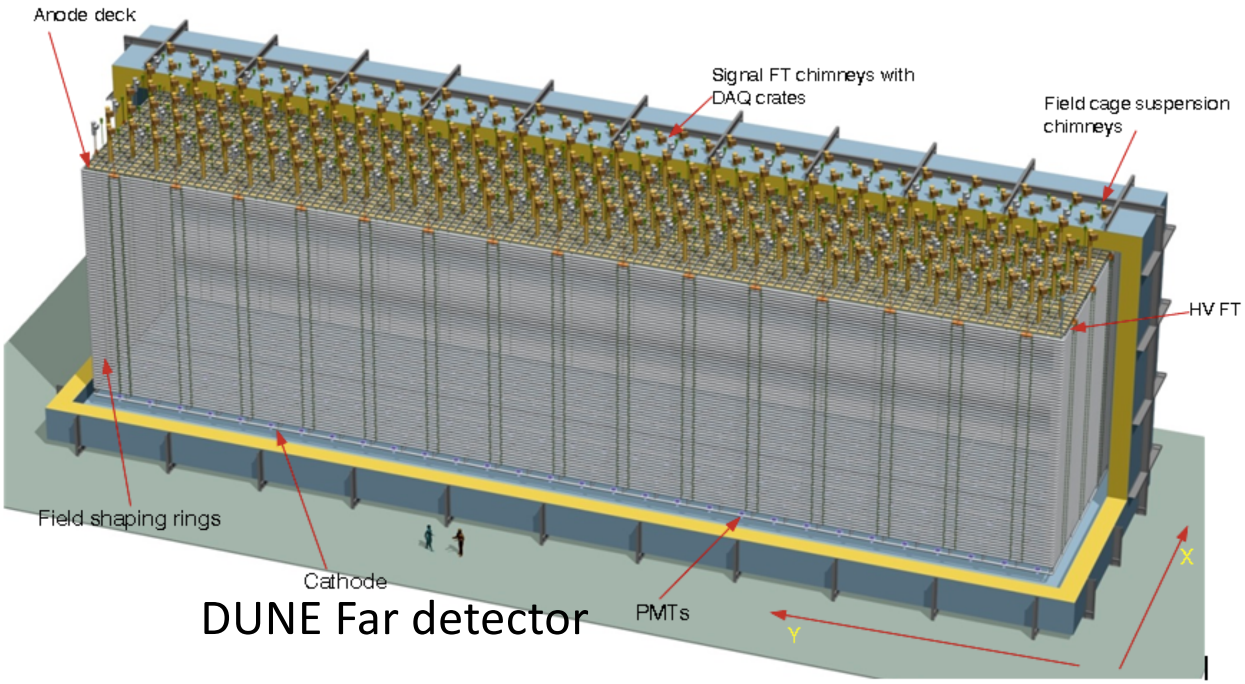
Detector Requirements:

Large detector mass, long baseline, good energy resolution at several GeV, efficient electron neutrino identification (hence LiAr)

Low cosmic ray background (hence underground)

timing for non-beam events (hence photon detection) and several MeV energy threshold (good signal/noise)

Neutrino Detectors

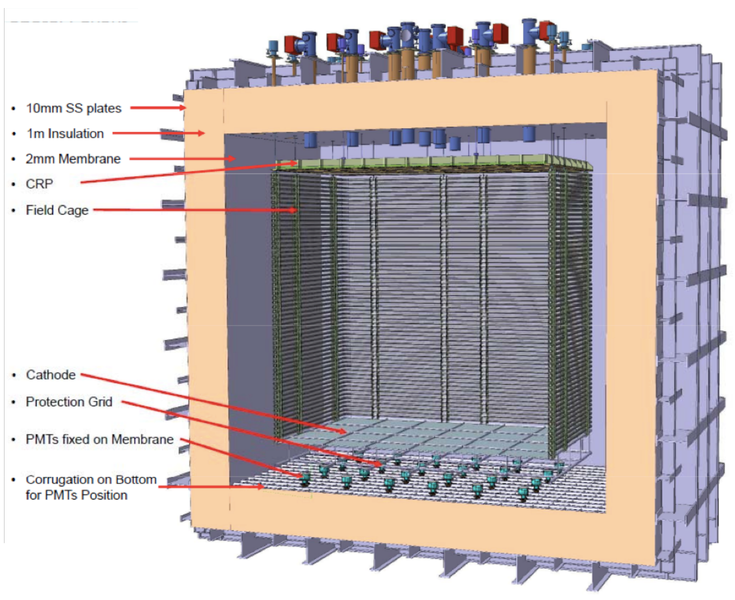


DUNE Far detector

From: A. Himmel
Dune Collaboration

Detector could be single or dual phase

- Single phase is more complicated, electronics held cold (low noise!) but difficult to maintain
- Dual phase, services easier to route, electronics partially cold, but accessible for maintenance

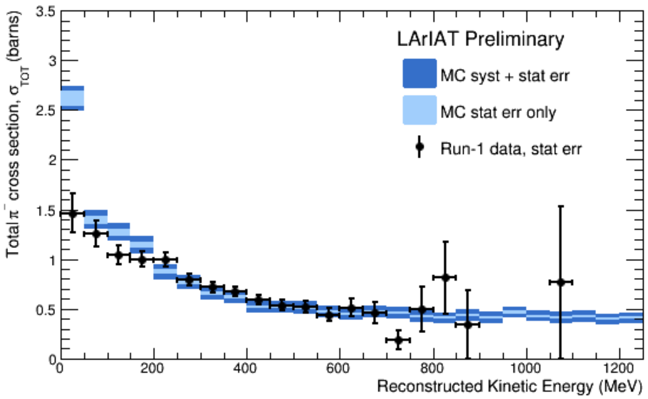


protoDUNE (CERN neutrino platform)
Full scale engineering prototypes for both single and dual phase detectors.

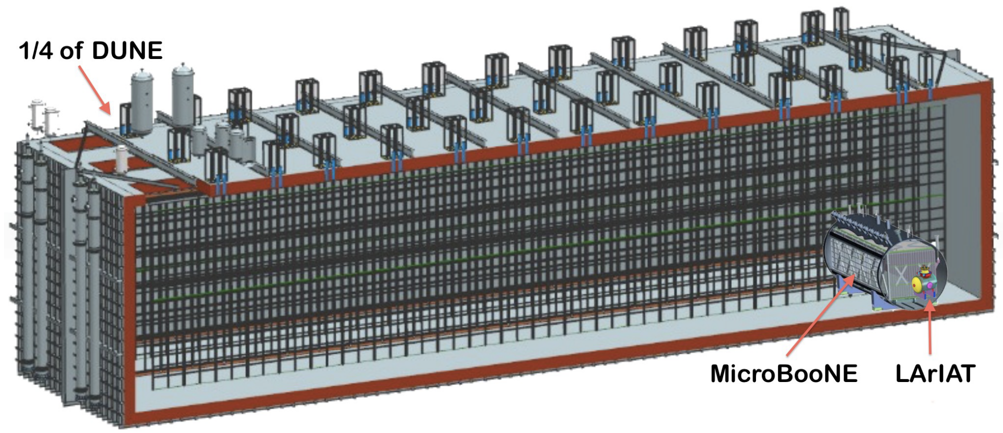
- protoDUNE detectors will be operational in 2018

Neutrino Detectors

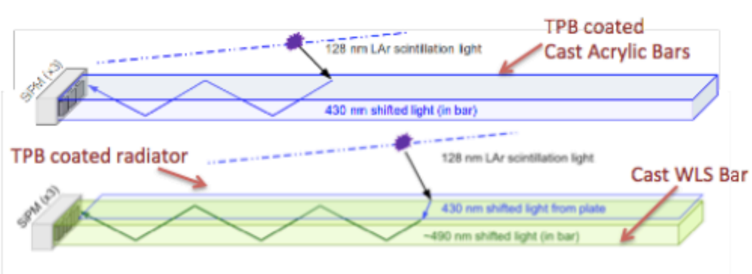
Meanwhile, getting some interesting results and experience in LiAR using LARiaT (Liquid Argon in a Test Beam)



From: A. Chatterjee
Lariat Collaboration



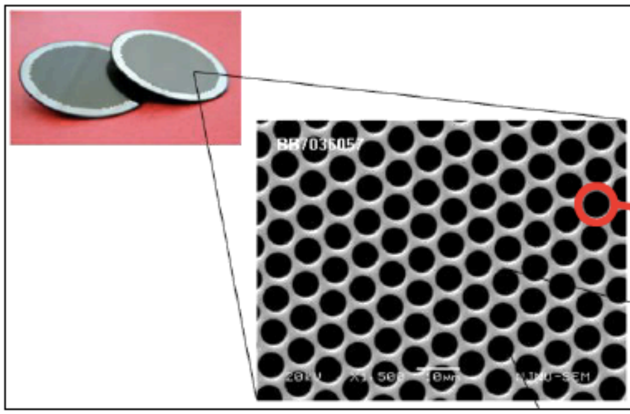
- Single-phase:
  - Light guides with SiPMs embedded in the APAs.
  - Multiple designs under consideration.
- Dual-phase:
  - PMTs coated in wavelength shifter sit below the cathode (floor).

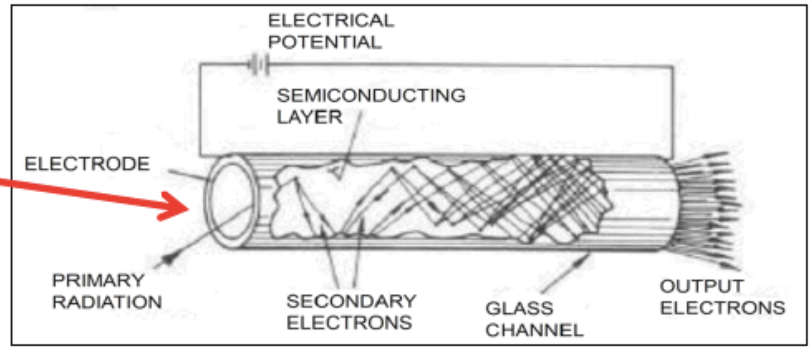


And a place to test / study light collection / detection alternatives for DUNE

Micro Channel Plate detectors

Microchannel Plates (MCPs) *From: A. Mane, J. Elam and LAPPD Collaboration*





Conventional Fabrication Method:

- Draw lead glass fiber bundle
- Slice and polish
- Chemical etch
- Hydrogen firing

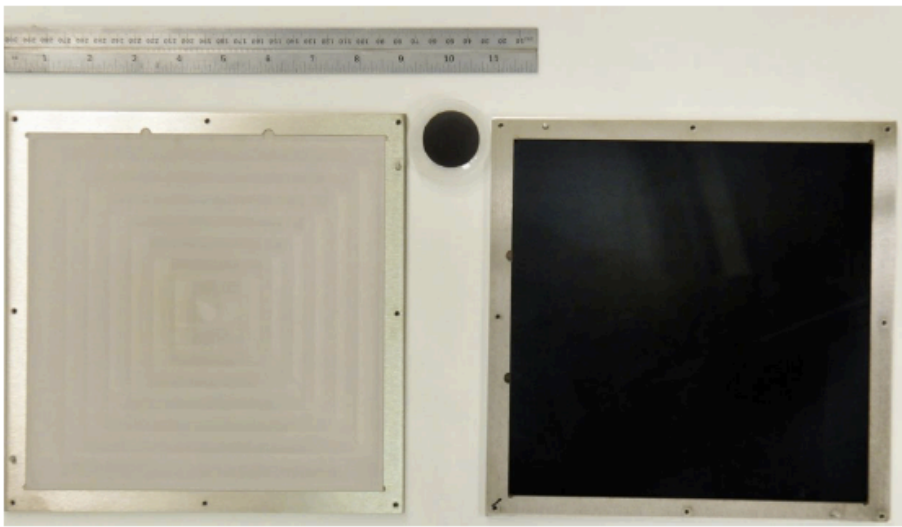
Issues:

- Expensive and need to import
- Resistance and secondary emission properties are linked
- Very long conditioning timing
- Contains lead
- Available in small form factor

Micro Channel Plate detectors

From: A. Mane, J. Elam and LAPPD Collaboration

Large Area ALD MCPs

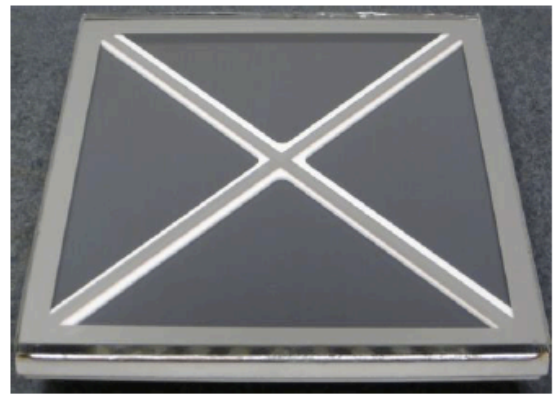


Bare MCA   ALD MCP

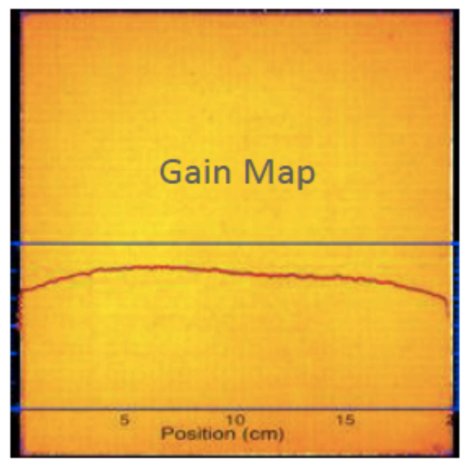
- **High Gain ($>10^5$)/mcp**
- **Very Low Background**
- **10x *psec* time resolution**
- **100µm spatial resolution**
- **Excellent Stability**
- **Short (2-3days) scrubbing time**

>200 publications using ALD MCPs, from LAPPD collaboration (http://psec.uchicago.edu/)

8"x8" MCP-photodetector tile

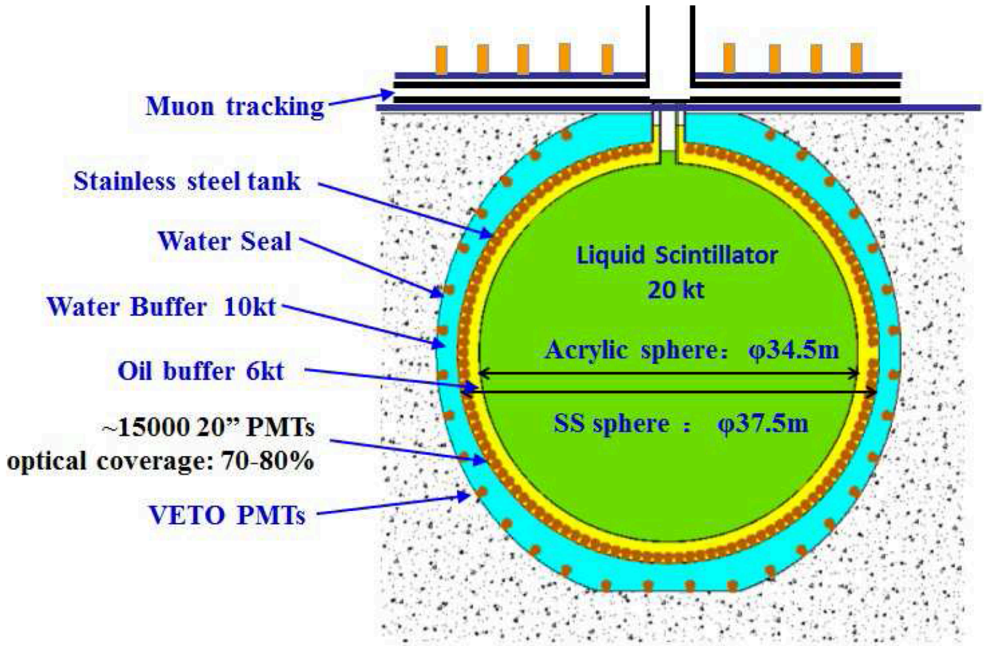


ALD MCPs in Photodetector



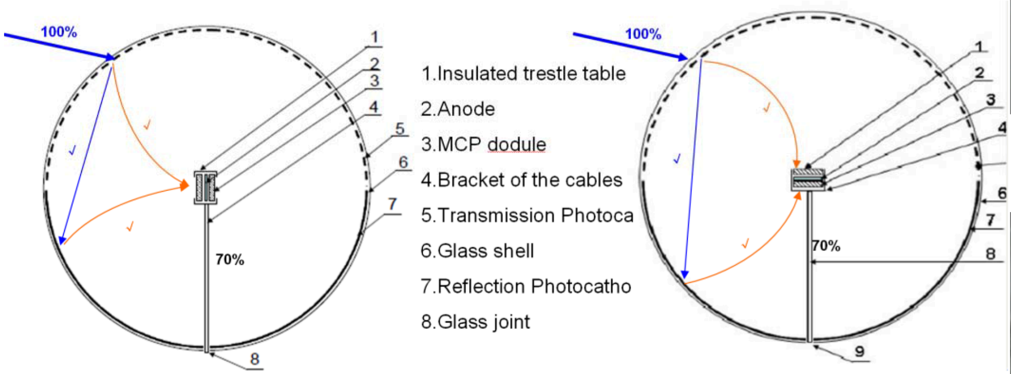
Working 20cm x20cm MCP in large area photodetector

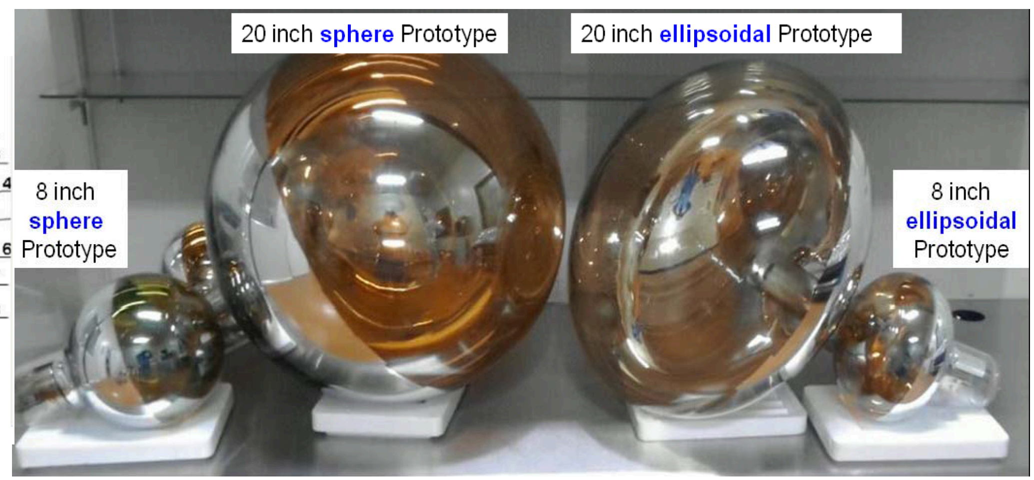
JUNO's MCP based PMT



Goal is to measure mass heirarchy to 3-4σ in 6 years with reactor anti-neutrinos. Need energy resolution of 1200 photons per MeV

Developed extremely elegant 20" phototubes with microchannel plates at center – Qian (IHEP Beijing)





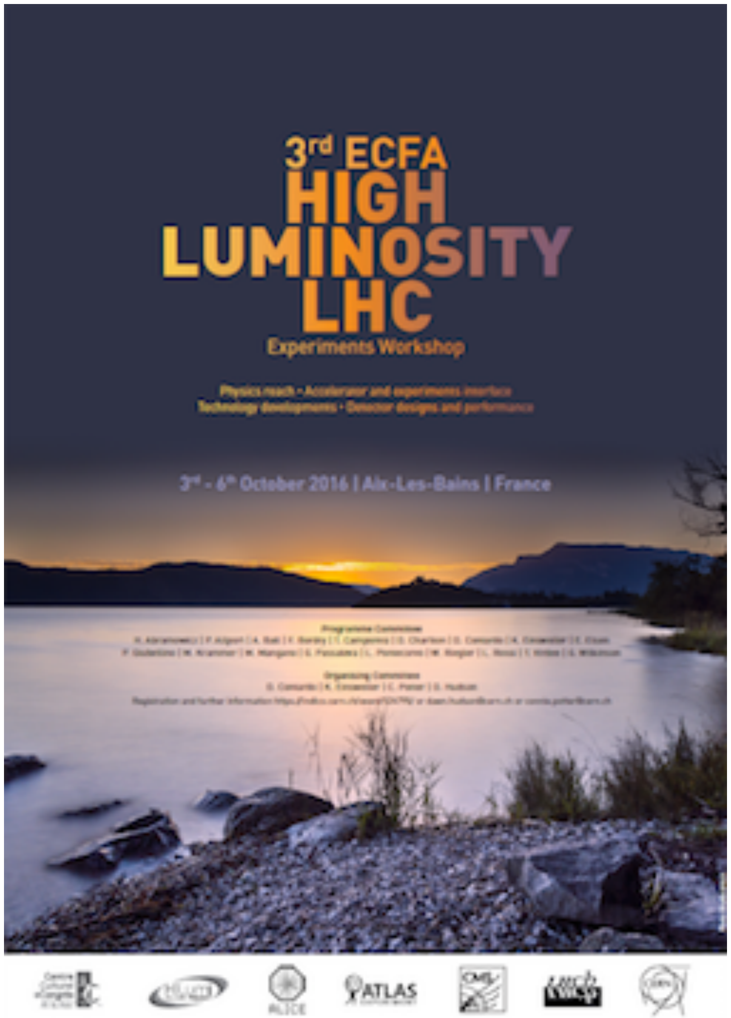
	HV	Gain	QE@410nm	P/V	Rise Time	Fall Time	Dark rate @1E7 (0.25PE)
20"-51#	2000V	~1E7	22%	~3	~1.2ns	~15ns	~50kHz

Conclusions

- Three days of parallel sessions on detector development and performance
  - Can not possibly be summarized in this talk
  - Apologies to all of those great ideas / presentations that I left out
- We continue to focus detector R&D on future challenges, while monitoring the detector performance in today's experiments
- While the full suite of experiments are diverse, there are many synergies within the detectors
  - Such as high radiation, cryogenic, low noise demands
- Our detector R&D collaborations really pay off! (i.e. CALICE, LAPPD, RDxx)

… and Advertisement

ECFA High Luminosity LHC Workshop
October 3-6 Aix-les-Bains



CPAD Instrumentation Frontier Meeting 2016:
New Technologies for Discovery
October 8-10, California Institute of Technology

https://indico.hep.anl.gov/indico/conferenceDisplay.py?confId=1017

Two great conferences to share experiences and ideas!

https://indico.cern.ch/event/524795/

Backup Slides