LAGUNA-LBNO: what, where, when ?

André Rubbia (ETH Zurich)

on behalf of the LAGUNA-LBNO consortium

See also the talks of:
Alain Blondel, "Directions for Neutrino Physics in Europe"
Tobias Lachenmaier, "Large Liquid Scintillator Detectors"

FUNDAMENTAL PHYSICS AT THE INTENSITY FRONTIER
November 30 - December 2, 2011
Rockville, MD

The LAGUNA design study (2008-2011)

- **Large Apparatus for Grand Unification and Neutrino Astrophysics**
  - ➡ Proposal discussed for the first time at ASPERA "Town meeting" in 2005 to "*combine efforts*" and "*regroup all European physicists interested in this kind of physics*" → combined submission to FP7 programme
  - ➡ FP7 funded LAGUNA "Design Study" (2008-2011)
  - ➡ Detailed investigation of the feasibility of a deep underground "megaton-scale" detector, considering three detector technologies (WC, LAr, LS) and seven potential European sites
  - ➡ Focused on European options, but following closely developments of other options worldwide (Americas, Asia)
  - ➡ Outcome of studies summarized in 16 deliverables: fundamental material for site prioritization

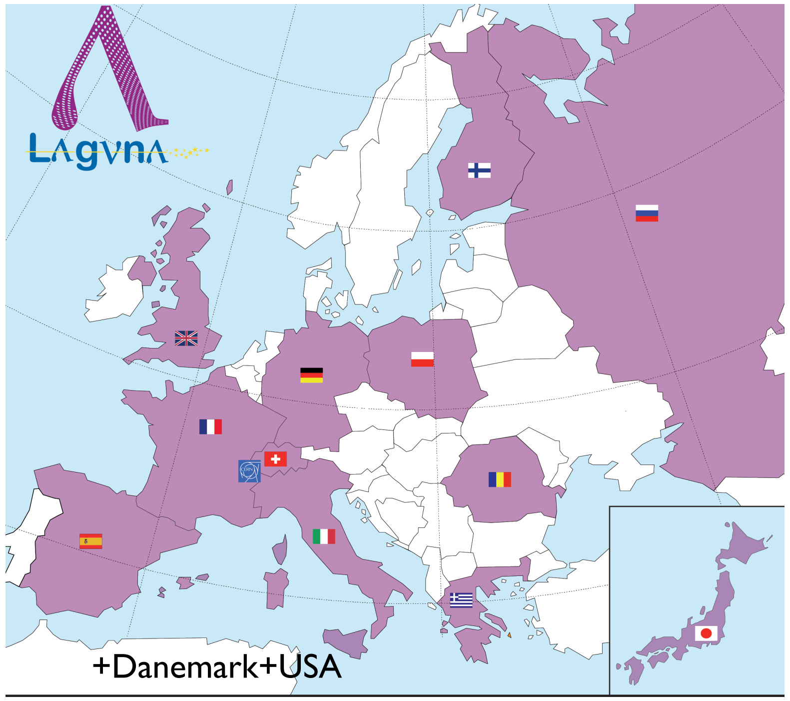
- **Recommendation to consider potential beam options**
  - ➡ In 2008, LAGUNA evaluation expert panel (ESR) strongly suggested to take into account potential neutrino beams (from CERN)

The LAGUNA design study (2011-2014)

- **Large Apparatus for Grand Unification and Neutrino Astrophysics and Long Baseline Neutrino Oscillations**
  - ➡ FP7 funded LAGUNA-LBNO "Design Study" (2011-2014)
  - ➡ Wider scope (LBNO) & more focus (sites, technologies): continue with the same "successful format" but to address new questions (→detector construction+operation and CERN long baseline beam)
  - ➡ Enlarged, stronger collaboration, and larger budget: includes all LAGUNA beneficiaries and new industrial and academic beneficiaries (in total 39) among them CERN, KEK(Japan) and Russian institutes and additional associated institutes (Denmark, USA)
  - ➡ Investigations must lead to a "preparatory phase"

- **Exploit new opportunities**
  - ➡ T2K, MINOS, Double Chooz point to $\sin^2 2\theta_{13} > 0.01$
  - ➡ CERN European Particle Physics Strategy Review in 2012-2013
  - ➡ Real-time reaction to explore options towards a "realistic plan" for a European LBL programme with great discovery potential

LAGUNA-LBNO consortium



14 countries, 47 institutions, ~300 members (open)

France
CEA
CNRS-IN2P3
Sofregaz*

Spain
LSC
UA Madrid
CSIC/IFIC
ACCIONA*

Romania
IFIN-HH
University Bucharest

Denmark
Aahrus

Germany
TU Munich
University Hamburg
Max-Planck-Gesellschaft
Aachen
University Tübingen

Switzerland
University Bern
University Geneva
ETH Zürich (*coordinator*)
Lombardi Engineering*

Finland
University Jyväskylä
University Helsinki
University Oulu
Rockplan Oy Ltd*

CERN

Poland
IFJ PAN
IPJ
University Silesia
Wroklaw UT
KGHM CUPRUM*

Greece
Demokritos

United Kingdom
Imperial College London
Durham
Oxford
QMUL
Liverpool
Sheffield
Sussex
RAL
Warwick
Technodyne Ltd*
Alan Auld Ltd*
Ryhal Engineering*

Italy
AGT*

Russia
INR
PNPI

Japan
KEK

USA
Virginia Tech

(=industrial partners)*

The EU design study “menu”

LAGUNA

- -far detector “RI” for astroparticle and beam physics
- -three detector options
- -seven potential sites
- -excavation costs
- -industrial links

2008

time

2011

EuroNu

- -international consortium
- -low energy MW-superbeam (HP-SPL)
- -beta beam
- -neutrino factory
- -costs
- -comparison of facilities

LAGUNA-LBNO

- -international consortium including EU, Japan and Russia
- -two+one main far sites
- -new conventional beam from SPS
- -high energy MW-superbeam (HP-PS)
- -near detector infrastructure
- -detector magnetization
- -detector construction and costs

2014

“preparatory phase”

The EU design study "menu"

2008

time

2011

2014

LAGUNA

- -far detector "RI" for astroparticle and beam physics
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EuroNu

- -international consortium
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- -neutrino factory
- -costs
- -comparison of facilities

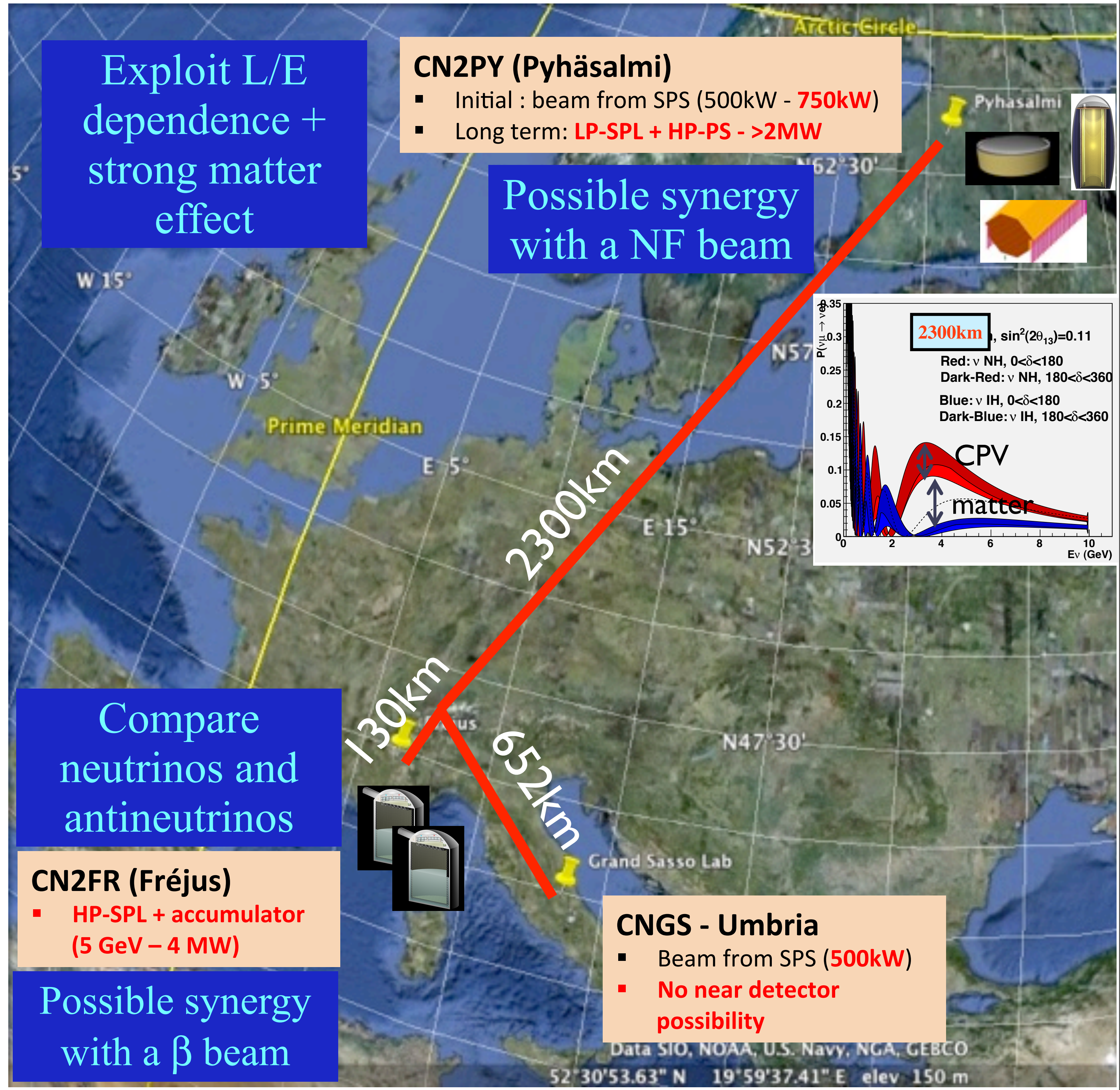
-Update European Strategy for Particle Physics (CERN)

"preparatory phase"

Preparing the LAGUNA-LBNO input to the European Strategy: global view

arXiv:1003.1921 [hep-ph]

- Seven different sites were studied in details to assess their ability to host large underground detector (LAGUNA, 2008-2011)
- This design study phase has converged in a prioritization towards **three far sites** which could also be offer very unique opportunities for long baseline physics (LAGUNA-LBNO, 2011-2014)
- **CERN-Fréjus** is a short baseline coupled to the **WCD detector**. It offers good synergy for enhanced physics reach with β-beam at γ=100
- **CERN-Pyhäsalmi** is the longest baseline and is coupled to a **LArTPC, possibly coupled to a magnetized muon ranger**. It offers good synergy for enhanced physics reach with a neutrino factory (NF). In addition, Pyhäsalmi is an adequate site for a large **LSc** with lowest reactor neutrinos background in Europe.
- [**CERN-Umbria** has an existing beam but is considered at lower priority (missing near detector, limited power upgrade scenarios)]
- Other LAGUNA sites could serve as alternative options.



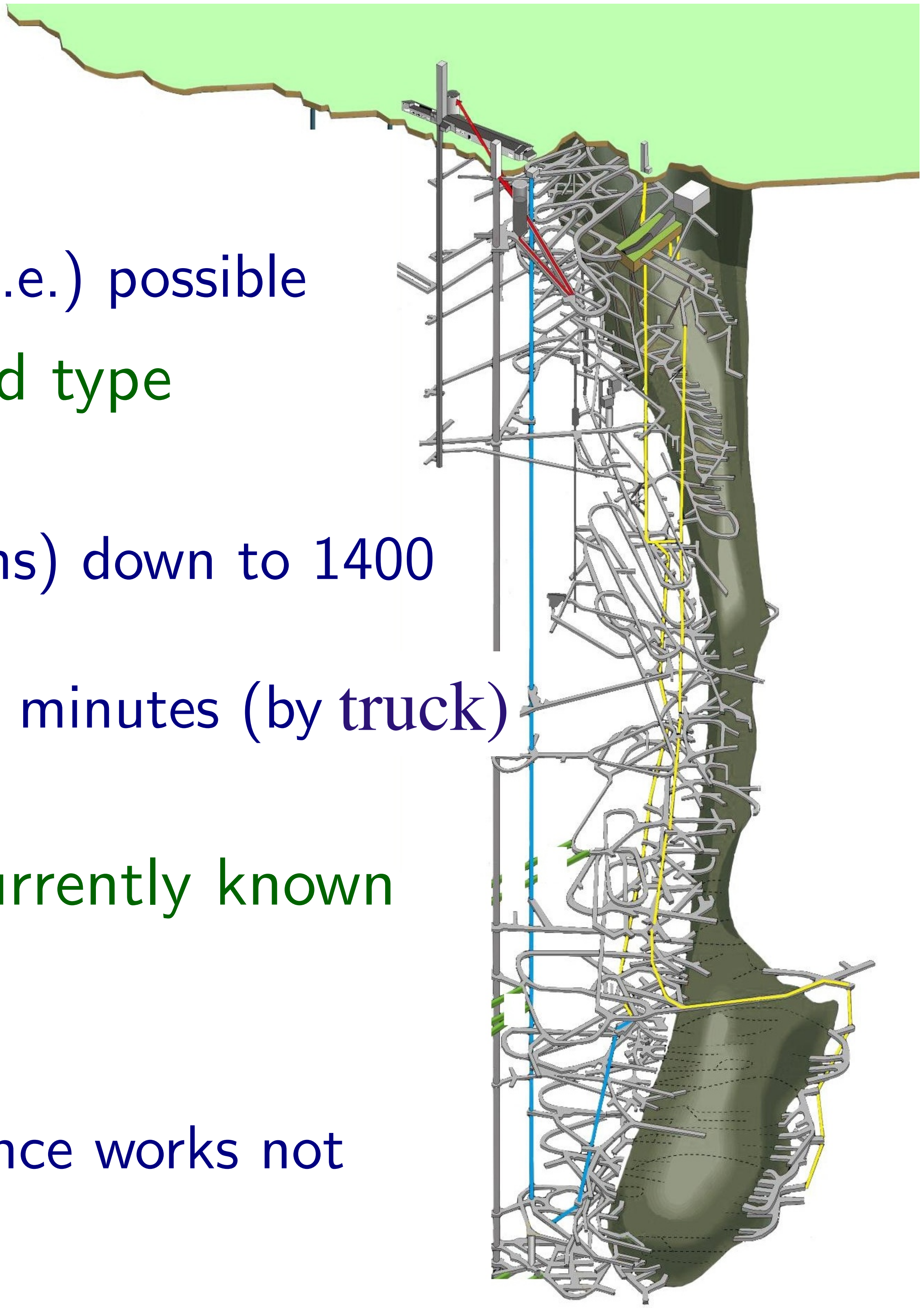
From now on, we focus on the CERN-Pyhäsalmi option

Pyhäsalmi site (Finland)

- CUPP : Centre for Underground Physics in Pyhäsalmi (www.cupp.fi)
- Location: 63^o 39' 31''N – 26^o 02' 48''E
- Distances (by roads)
  - Oulu – 165 km
  - Jyväskylä – 180 km
  - Helsinki – 450 km
- Distance to CERN 2300 km
- Good traffic connections
  - the main highway: Helsinki – Jyväskylä – Oulu – ...
  - the second busiest airport in Oulu
  - rail yard at the mine
- Inhabitants: $\sim$6000

Present state of location

Present: The Pyhäsalmi mine (Inmet Mining Ltd., Canada)

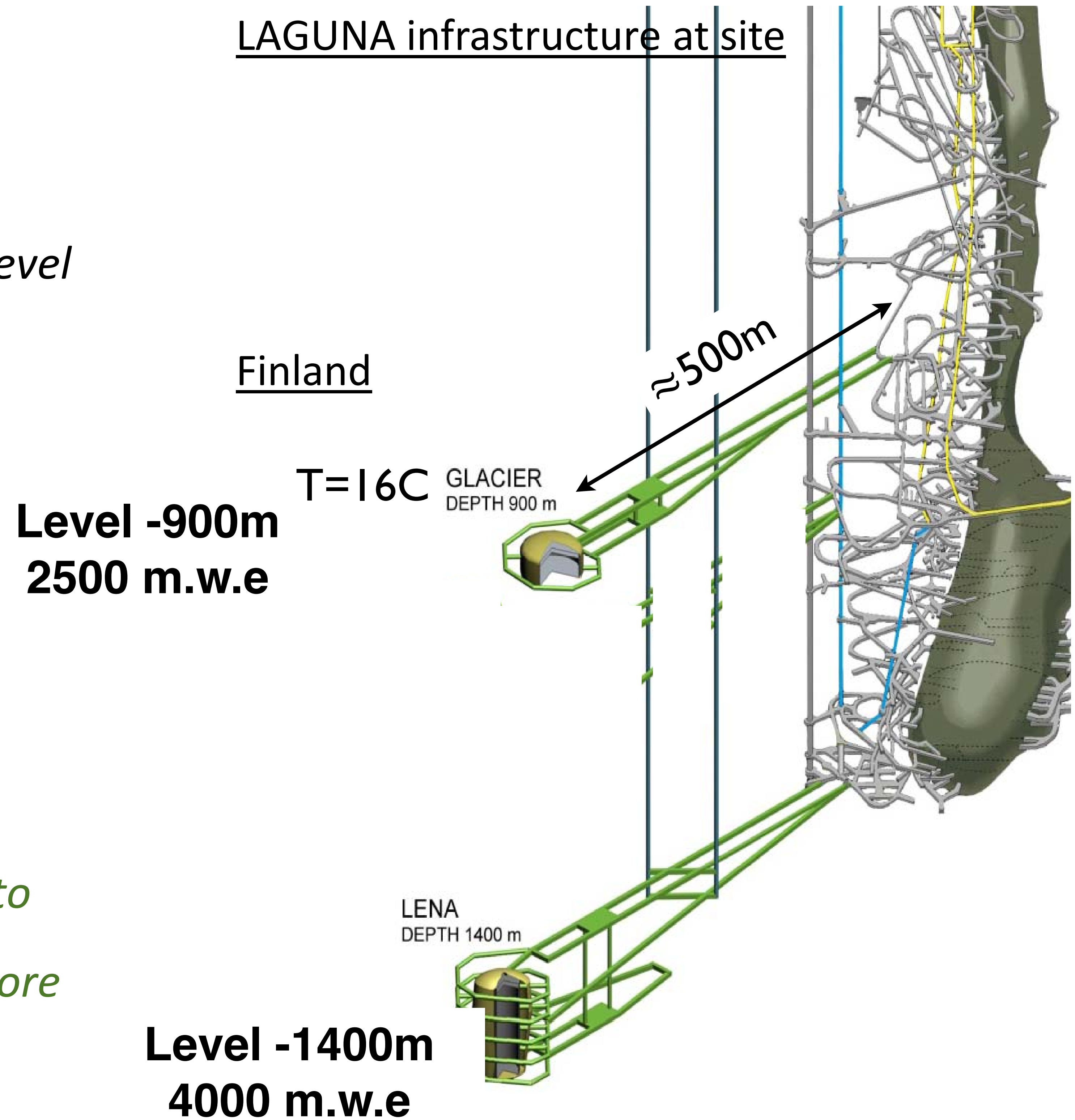


- Produces Cu, Zn, and FeS_2
- The deepest mine in Europe
  - Depths down to 1400 m (4000 m.w.e.) possible
- The most efficient mine of its size and type
- Very modern infrastructure
  - lift (of 21.5 tons of ore or 20 persons) down to 1400 metres takes ∼3 minutes
  - via 11-km long decline it takes ∼40 minutes (by truck)
  - good communication systems
- Operation time still 7–8 years with currently known ore reserves
- Compact mine, small 'foot print'
  - water pumping and other maintenance works not major issues

Mine features and LAGUNA layout

Main advantages for LAGUNA:

- *existing working mine with very high standards*
- *existing decline tunnel access to deepest level*
- *very little environmental water*
- *efficient rock disposal*
- *sufficient ventilation*
- *supply routes for construction*
- *existing pipe lines for liquids*
- *existing underground repair shops*
- *mine closure foreseen around 2018; plan to hand over from mine owner to LAGUNA (more after January 2012)*



Mine infrastructures – Restaurant at 1410 level

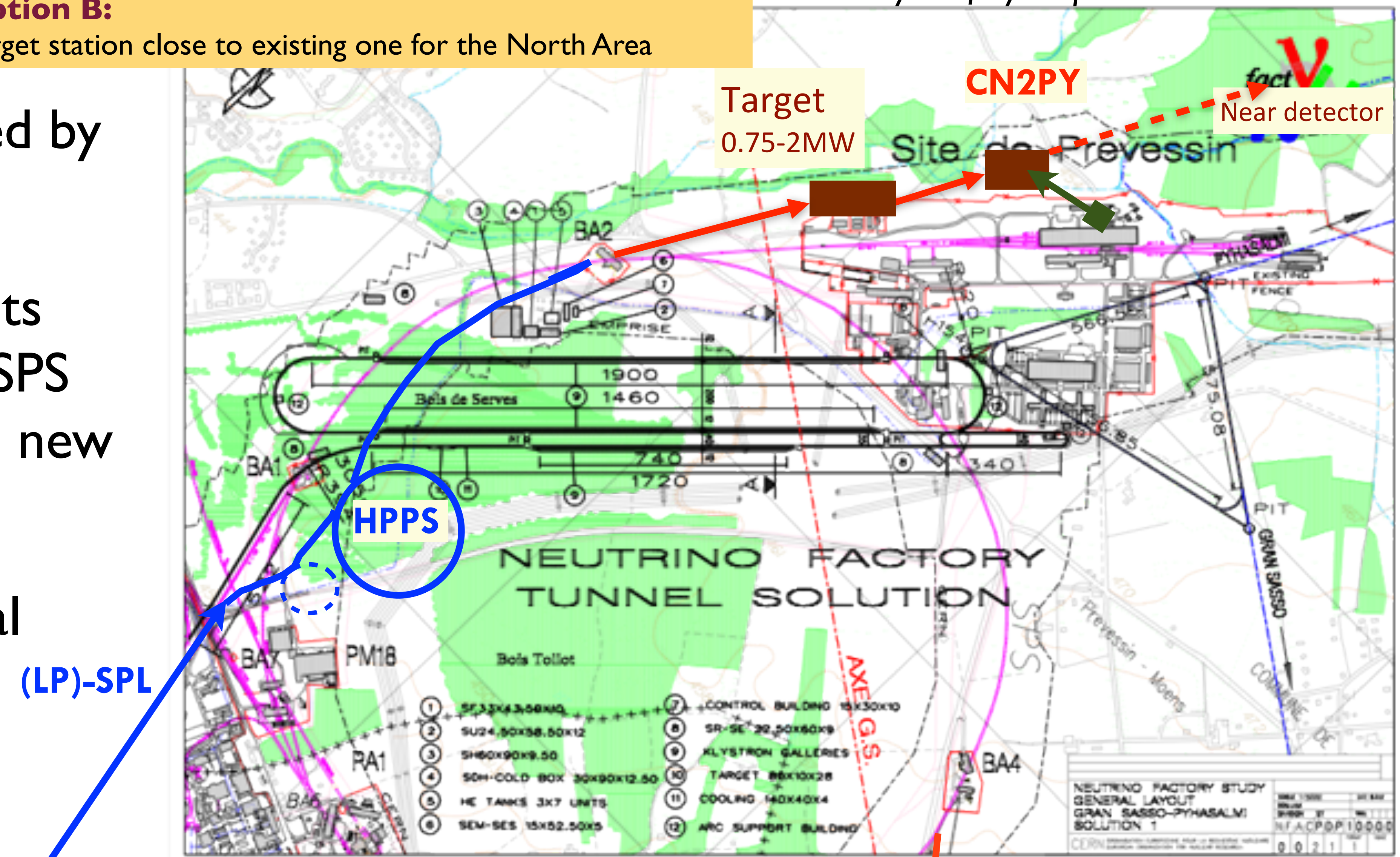
Mine infrastructures – Maintenance hall at 1410 level

Study of the CERN-Pyhäsalmi beam

Courtesy: I. Efthymiopoulos

Option B:
Target station close to existing one for the North Area

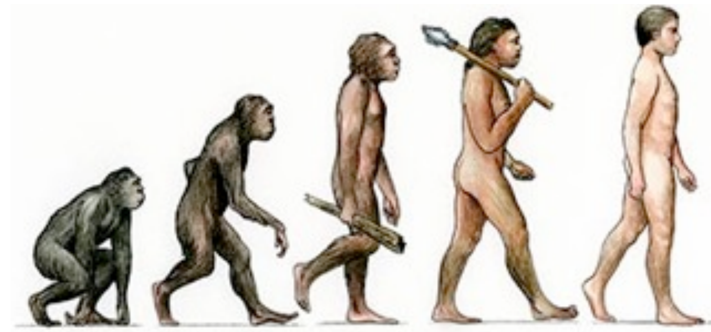
- Feasibility study approved by CERN management
- New beam facility accepts protons from 400 GeV SPS (0.75 MW) and eventual new 50 GeV HP-PS (>2MW)
- Will produce conceptual design reports within 2014



LAGUNA-LBNO:

- **Task 4.1** Study of impact of CERN SPS accelerator intensity upgrade to neutrino beams
- **Task 4.2** Feasibility of intensity upgrade of CNGS facility
- **Task 4.3** Conceptual design of the CN2PY neutrino beam
- **Task 4.4** Feasibility study of a 30-50 GeV high power PS (HP-PS)
- **Task 4.5** Definition of the accelerators and beamlines layout at CERN
- **Task 4.6** Study of the Magnetic Configuration for the LAGUNA detector
- **Task 4.7** Definition of near detector requirements and development of conceptual design

Incremental far detector




- **It is very likely that the far detector will be realized *incrementally*:**
    - Phase 0 : excavation (caverns @900m+1400m) and preparation of underground space
    - Phase 1: LAr 20kt @ 900m + LSc 25kt @ 1400m + Fe detector
    - Phase 2: add LAr 50kt @ 900m + add 2nd LSc 25kt + add Fe
    - Phase 3: replace LAr 20kt by LAr 50kt + add Fe

- **Advantages of an incremental approach:**

Produce significant physics results at each phase
Reduce overall risks
Alleviate some funding challenges w/ acceptable total cost
Leave possibility to alter the direction after each phase

Incremental exposure

We define **exposure** ≈ Npot@50GeV * mass(kt)

	SPS now	SPS+LIU	SPS++	LP-SPL+HP-PS
Proton energy (GeV)	400	400	400	50
ppp	4.00E+13	6.00E+13	7.00E+13	2.50E+14
Tc (s)	6	6	6	1.2
Beam power (MW)	0.43	0.64	0.75	1.67
Global eff	0.85	0.85	0.85	0.85
Beam sharing	0.85	0.85	0.85	1
Running (d/year)	200	200	200	200
Npot/year	8.32E+19	1.25E+20	1.46E+20	3.00E+21
Npot equiv at 50 GeV	7.00E+20	1.00E+21	1.20E+21	3.00E+21

}4xPS2

Phase 1 + SPS+LIU: 5+5 years running : 200e21 pot*kt

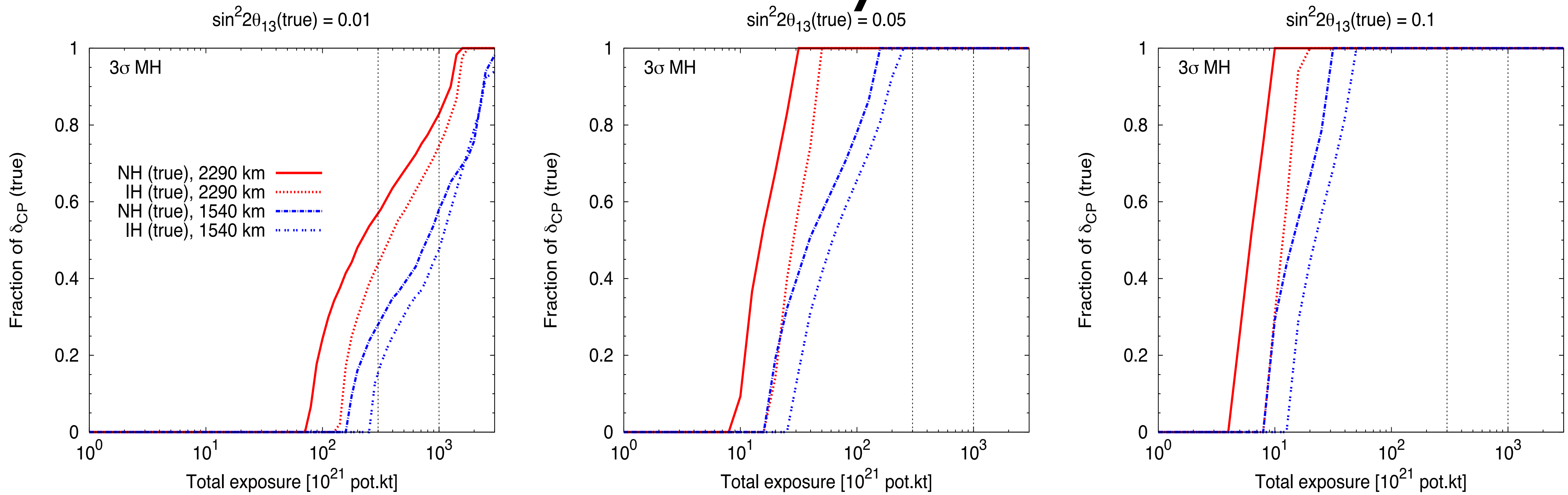
Phase 2 + SPS++: 5+5 years running : 840e21 pot*kt

Phase 3 + HP-PS: 5+5 years running : 3000e21 pot*kt

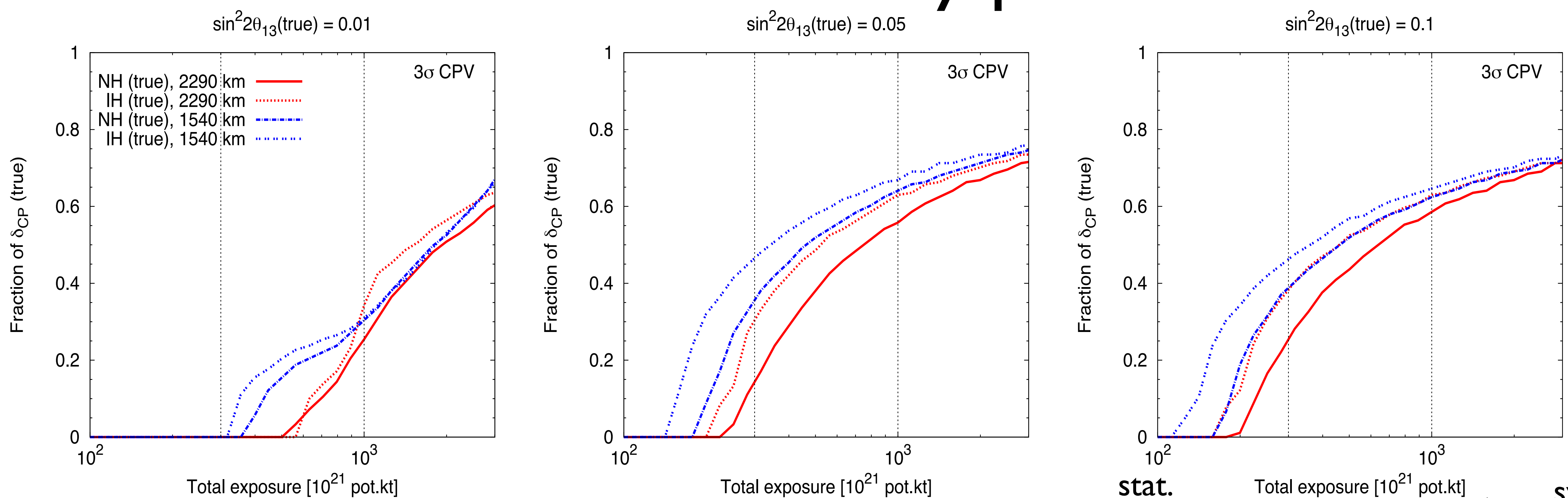
Incremental discovery reach

Phase 1
Phase 2
Phase 3

3σ mass hierarchy determination



3σ CPV discovery potential

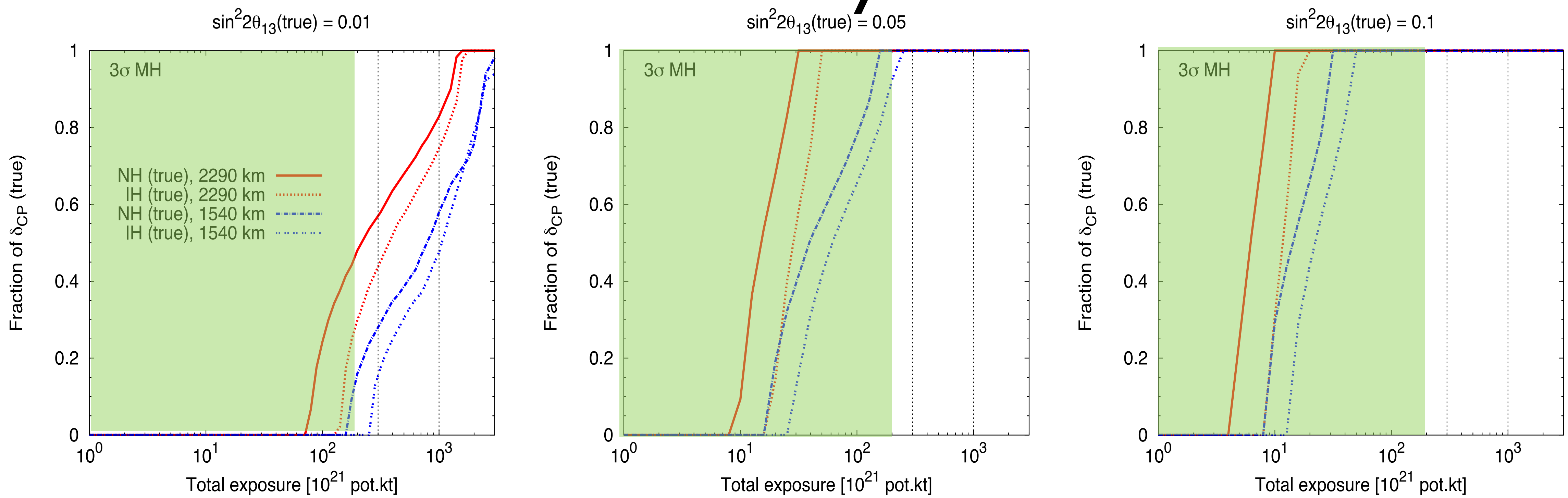


stat. dominated → syst. dominated

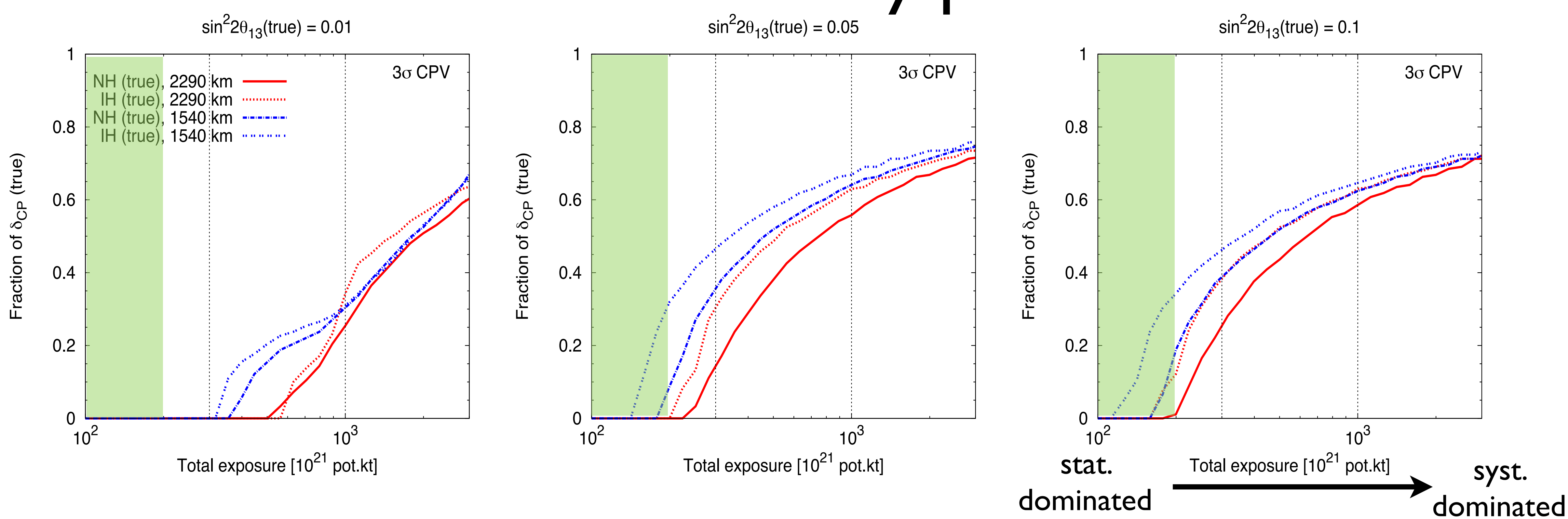
Incremental discovery reach

3σ mass hierarchy determination

Phase 1
Phase 2
Phase 3

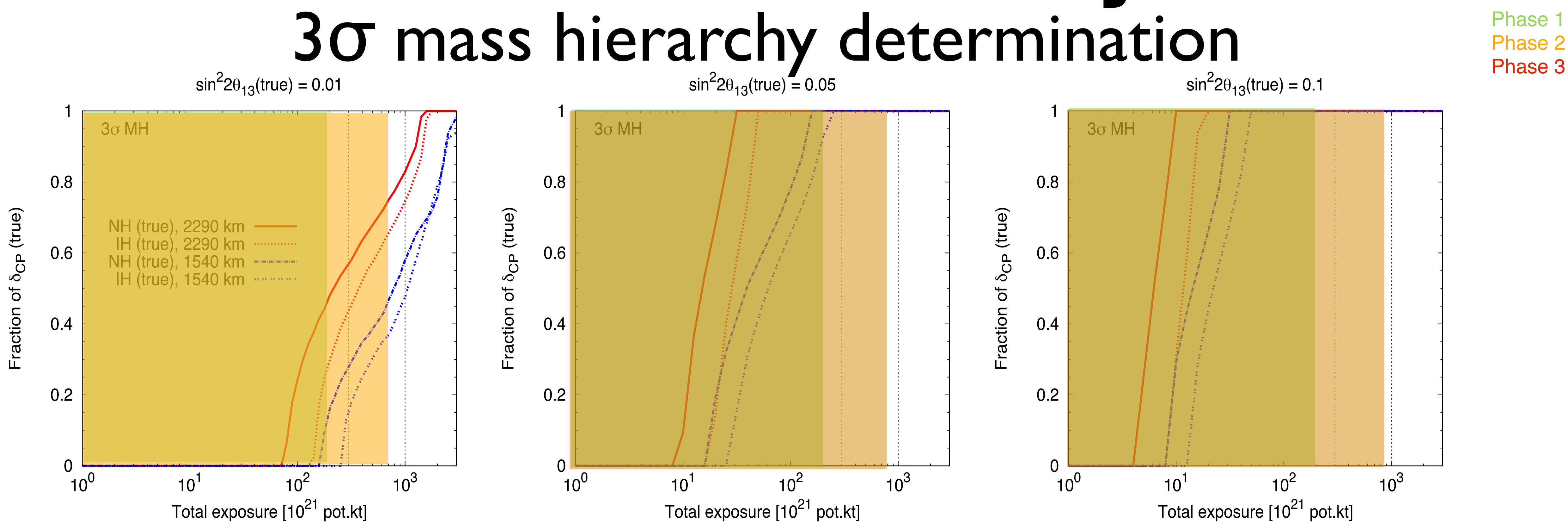


3σ CPV discovery potential

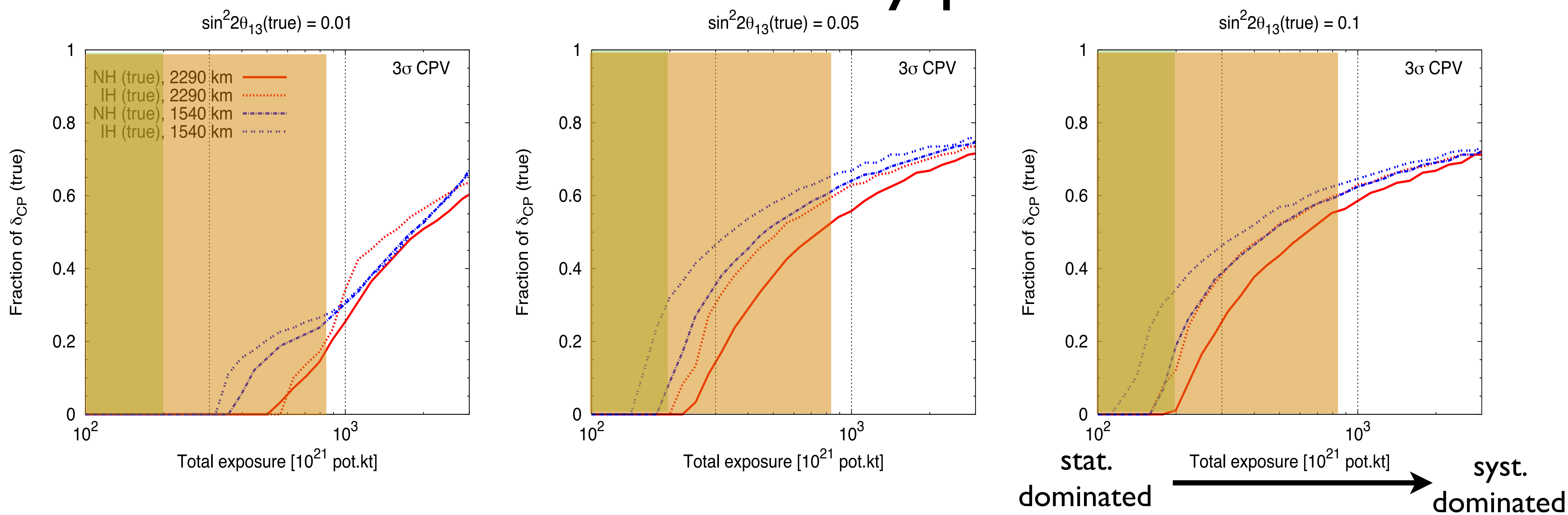


Incremental discovery reach

3σ mass hierarchy determination



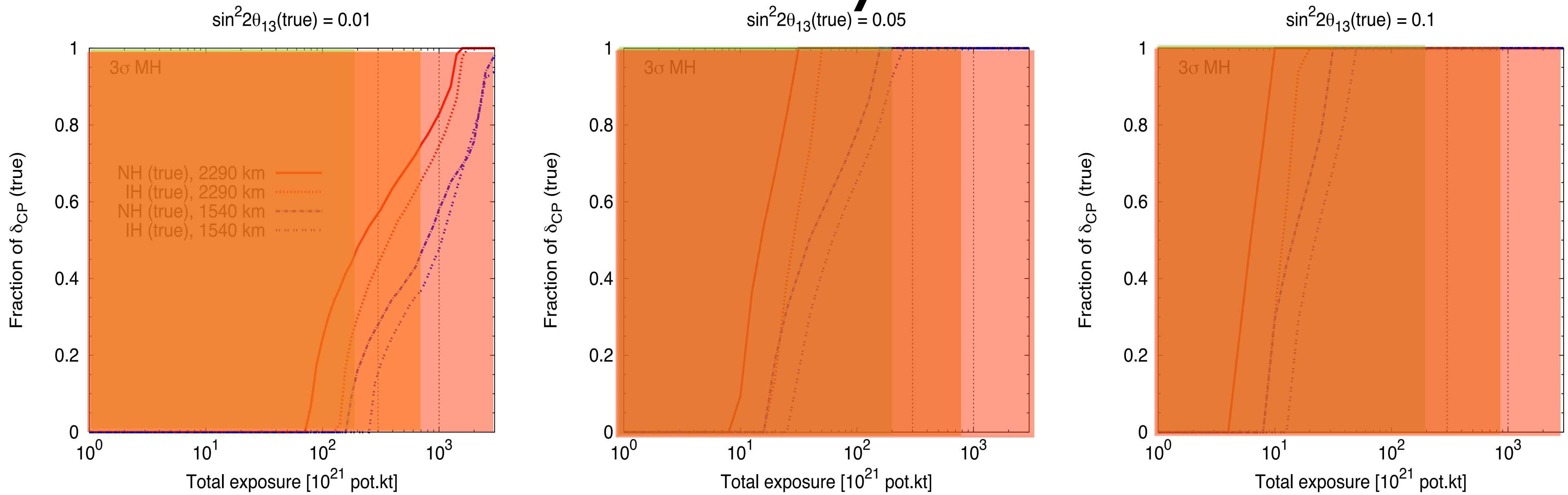
3σ CPV discovery potential



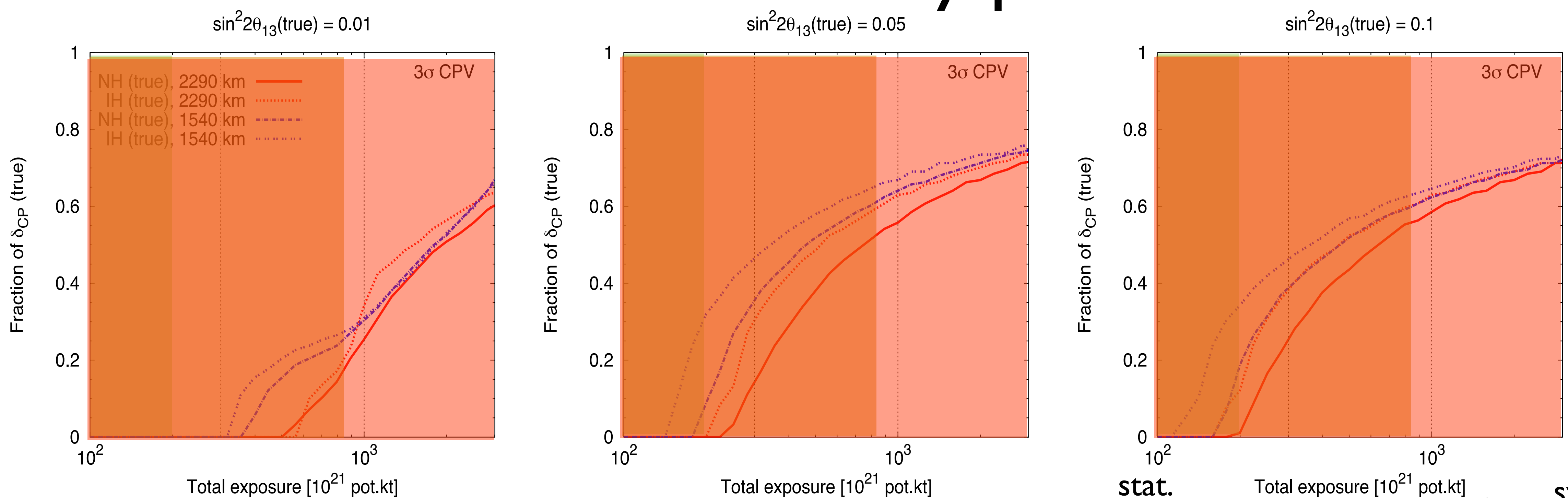
Incremental discovery reach

Phase 1
Phase 2
Phase 3

3σ mass hierarchy determination



3σ CPV discovery potential

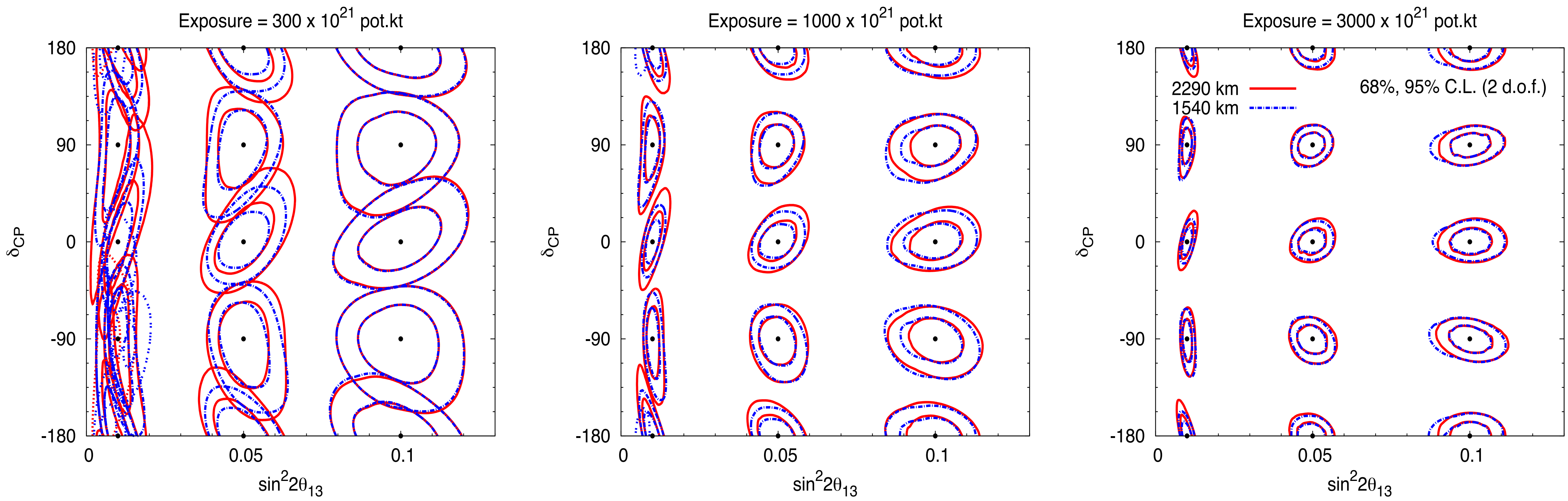


stat. dominated → syst. dominated

Incremental CP-phase measurement

300e21 pot*kt — 1000e21 pot*kt — 3000e21 pot*kt

stat. dominated → syst. dominated



(red) CERN-Pyhäsalmi 2300 km
(blue) CERN-Slanic 1540 km
(similar to FNAL-LBNE)

1540 & 2300 km are both optimal for CP measurement

Liquid Scintillator (LScint)

Very high purity liquid scintillator with high light yield, optimized for lowest energy range (large size: KamLAND, Borexino, SNO+, etc.)

ideally matched to study low energy neutrinos (MeV) with high statistics

LENA (LAGUNA LScint option)
4200 mwe

Liquid scintillator

50 kt LAB/PPO+ bisMSB

Inner vessel (nylon)

Radius r = 13m

Buffer

15kt LAB, Δr =2m

Cylindrical steel tank, e.g. 55000 PMTs (8") with Winston Cones (2x area)

r = 15m, height = 100m,

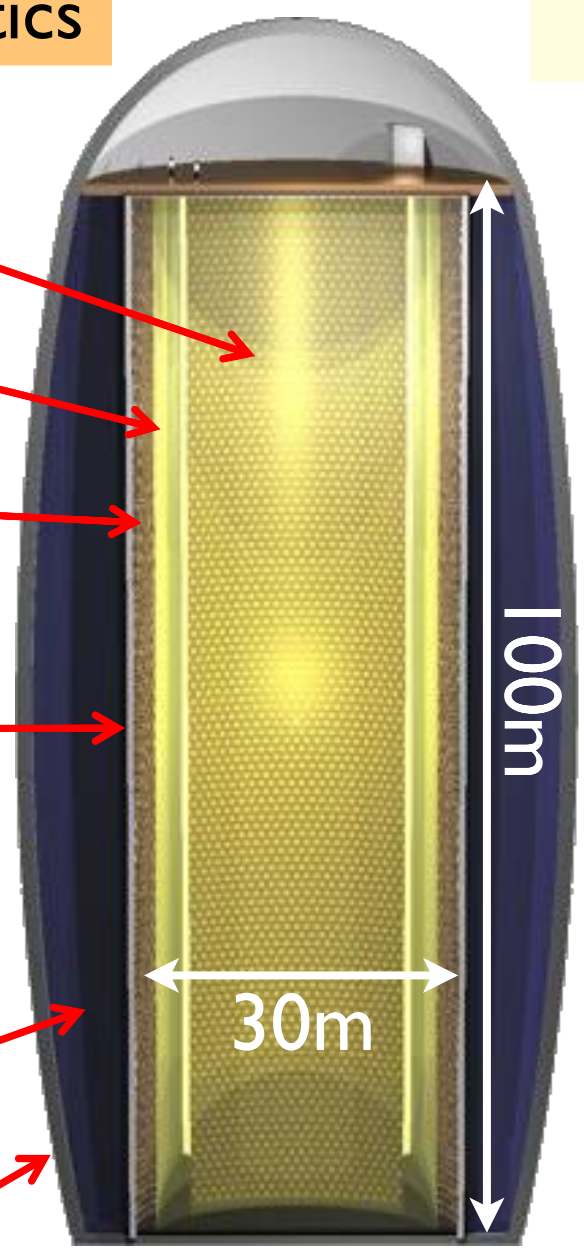
optical coverage: 30%

Water cherenkov muon veto

5,000 PMTs, Δr > 2m to shield fast neutrons

Cavern egg-shaped for increased stability

Rock overburden: 4000 mwe



Pyhäsalmi design

Desired **energy resolution**
→ 30% optical coverage
→ 3000m² effective photo-sensitive area

Light yield ≥ 200 pe/MeV

The **tracking option** adds to the requirements of the PMT array and electronics:
→ more, but smaller, faster PMTs
→ full waveform digitizing

response to high energy neutrino beam under study

Liquid Argon Detectors (LArTPC)

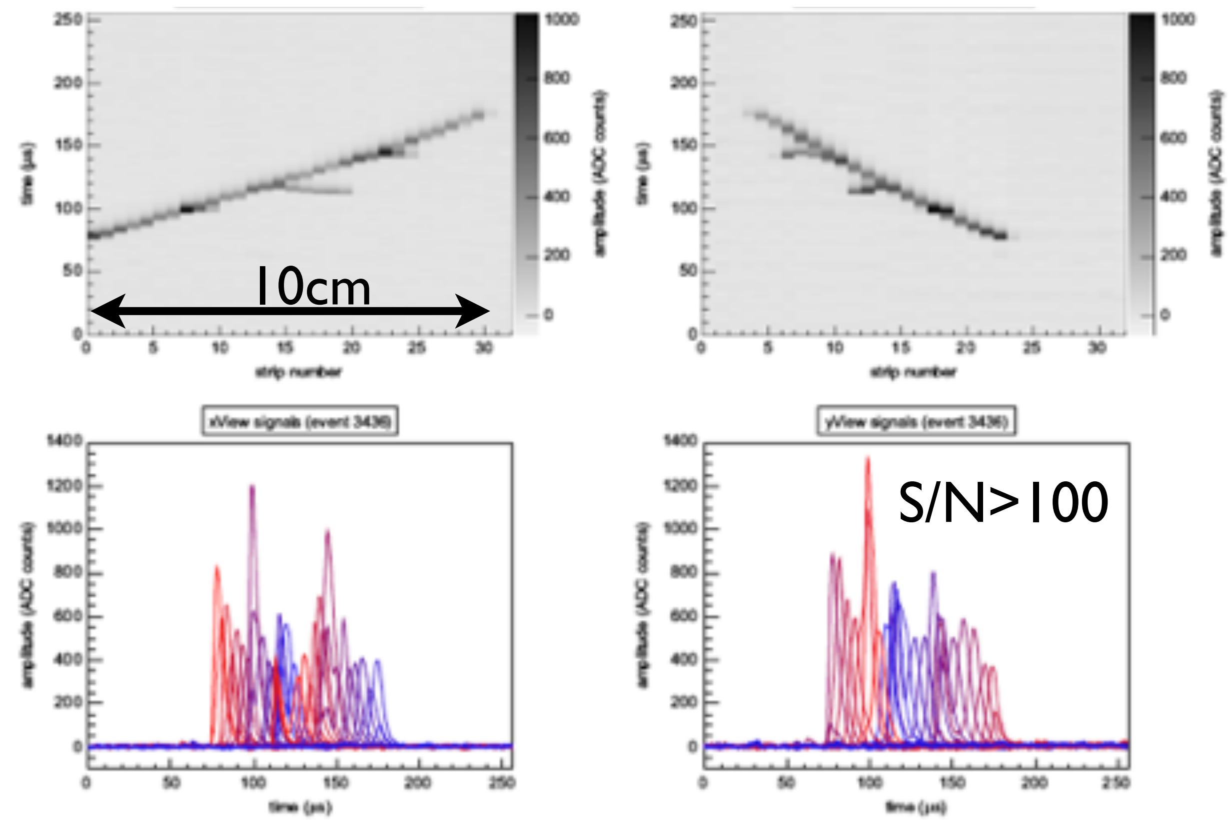
Challenging technology but long term likely to provide best beam physics performance

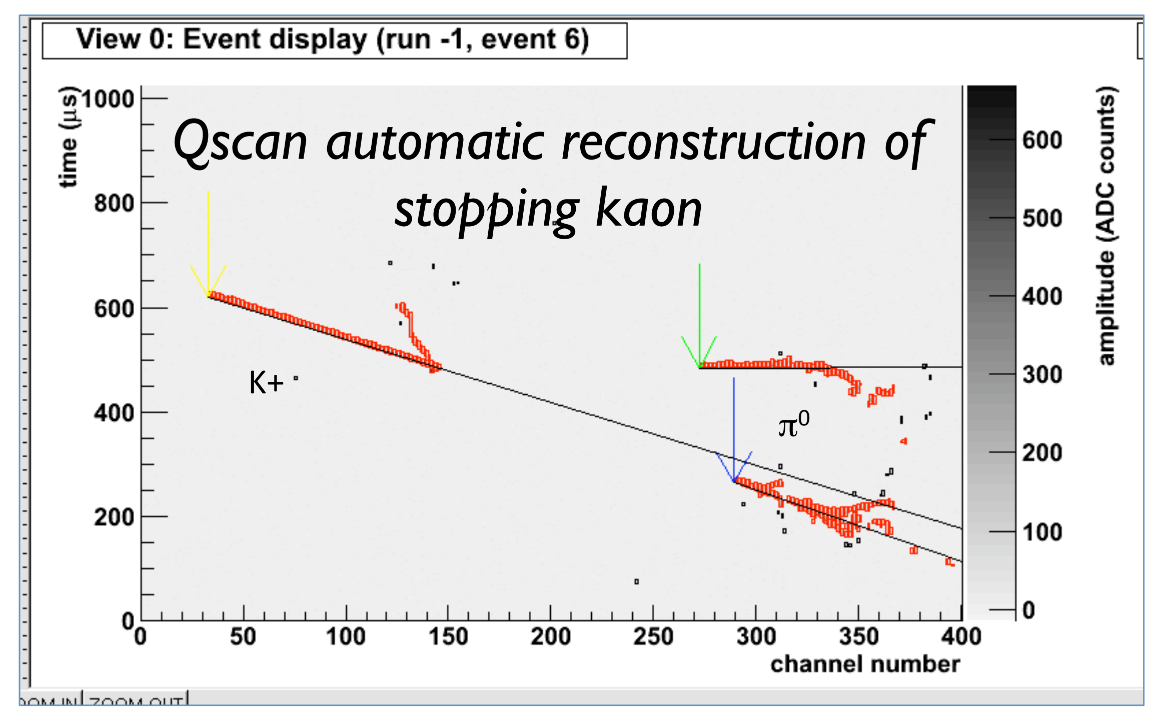
- **Homogeneous 4π full sampling tracking-calorimeter**
  - ➡ 3D tracking of ionizing particles with millimeter space precision
  - ➡ Low detection threshold (<100 keV with charge amplification)
  - ➡ Excellent energy resolution
  - ➡ Measurement of local energy deposition
  - ➡ dE/dx measurement, ≈2% X_0 sampling
  - ➡ Excellent particle identification (e/π0,μ/π/K, ...)
  - ➡ Exclusive final state event topologies reconstruction
  - ➡ Timing information with light readout
- **Technology applicable to a very wide range of energies**
  - ➡ from 10's keV to 10's GeV
- **Technology scalable to large masses (ICARUS T600)**

Nucl.Instrum.Meth. A527 (2004) 329-410

Cosmic track in double phase LAr-LEM TPC with adjustable gain (e.g. below G≈30) and symmetrical readout views

Nucl.Instrum.Meth. A641 (2011) 48-57



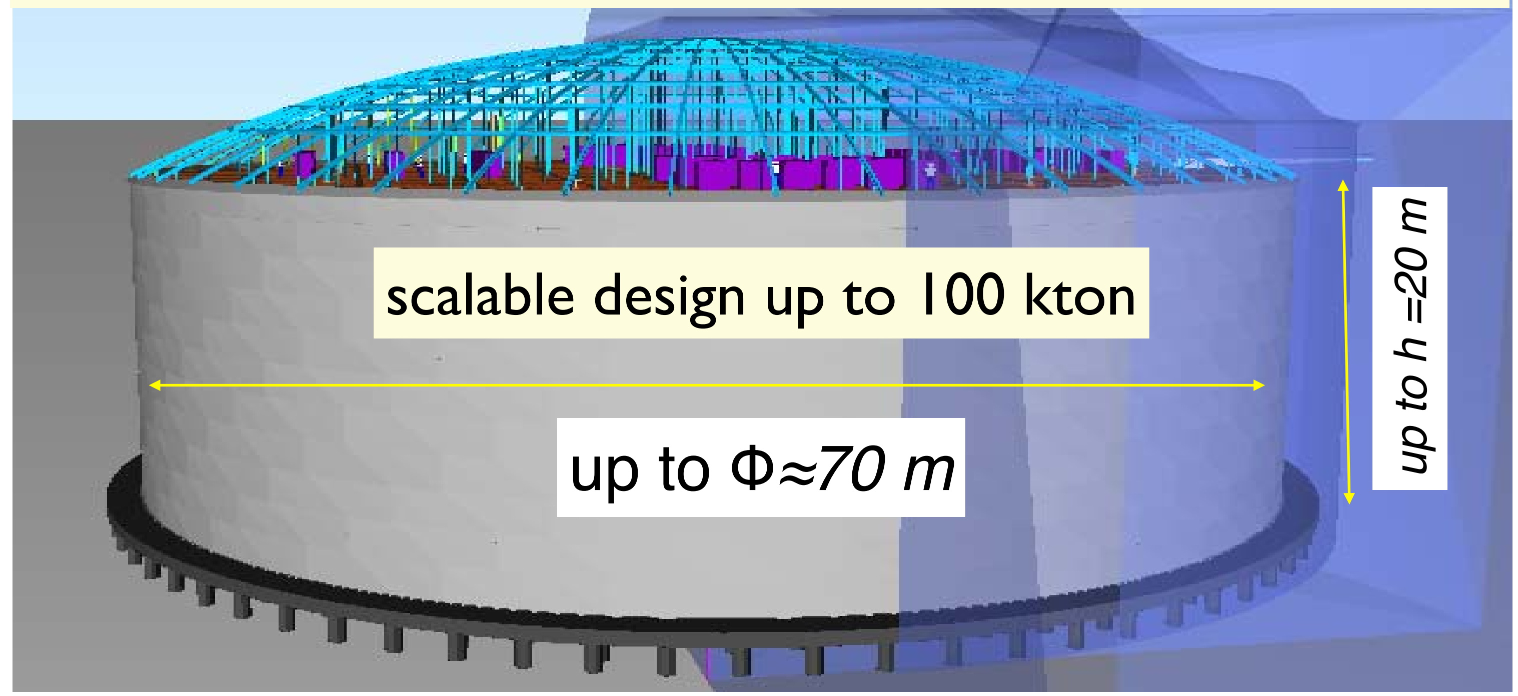


GLACIER detector concept

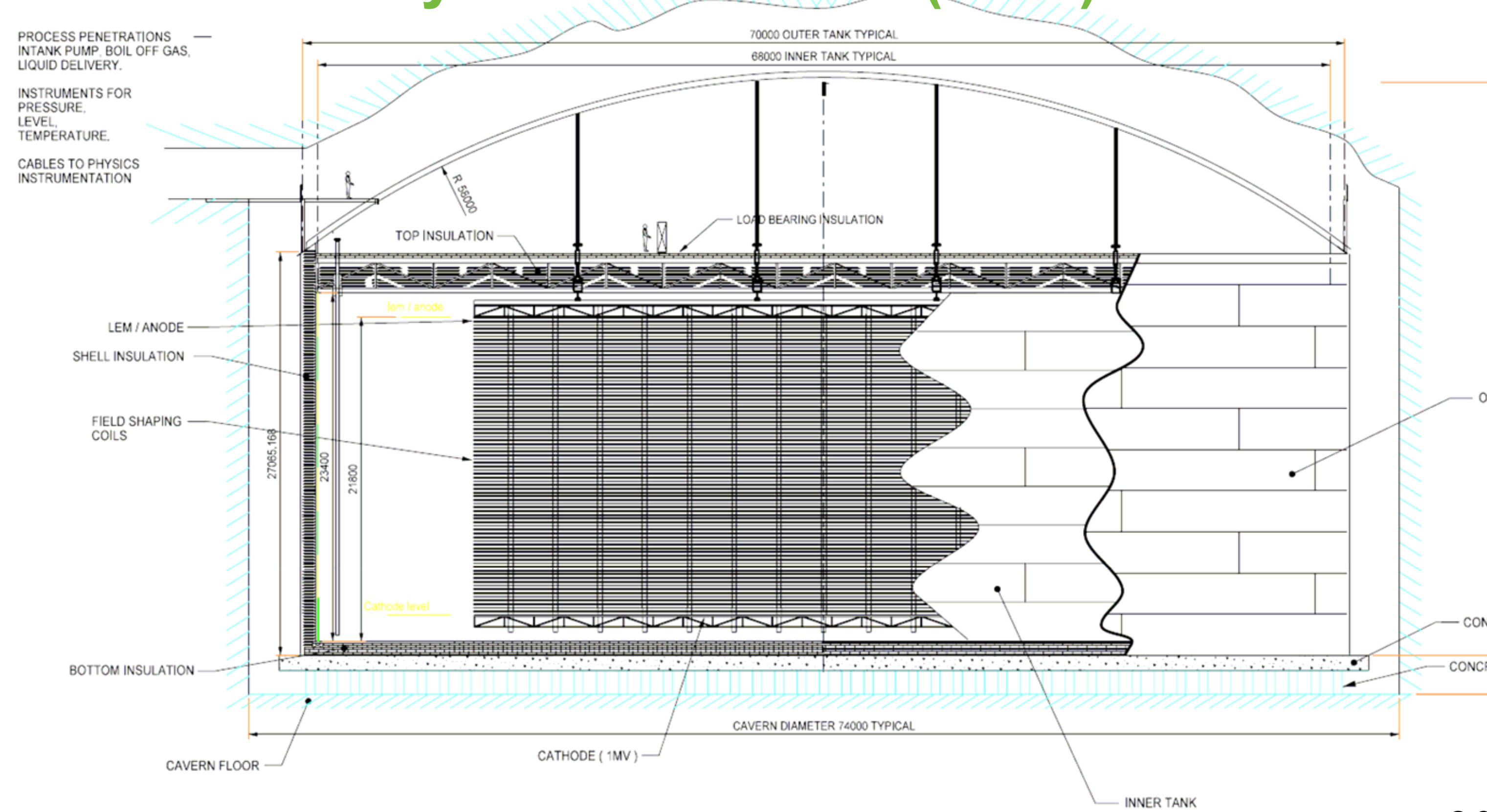
EU+Japan effort

- **Concept unchanged since 2003 (hep-ph/0402110)**
- **Simple, scalable detector design, from one up to 100 kton**
- **Single module non-evacuable cryo-tank based on industrial LNG technology**
- **Cylindrical shape with excellent surface / volume ratio**
- **LAr recirculation (purification) and recondensation of boiloff**
    - ➡ Purity goal <10 ppt O_2 equiv.
- **Engineering study performed in collaboration with Technodyne Ltd**
    - ➡ Cavern and tank decoupled
    - ➡ Tank based on existing design and operating experience
    - ➡ Tank design variations have several known solutions
    - ➡ Excellent safety record (on surface)
    - ➡ Cost for above ground installation, multiplier for below ground (dominant uncertainty → deliverable LAGUNA-LBNO)
- **Reasonable excavation requirements (<250‘000 m3)**

GLACIER (LAGUNA LAr option 2700mwe and Japan 600mwe)



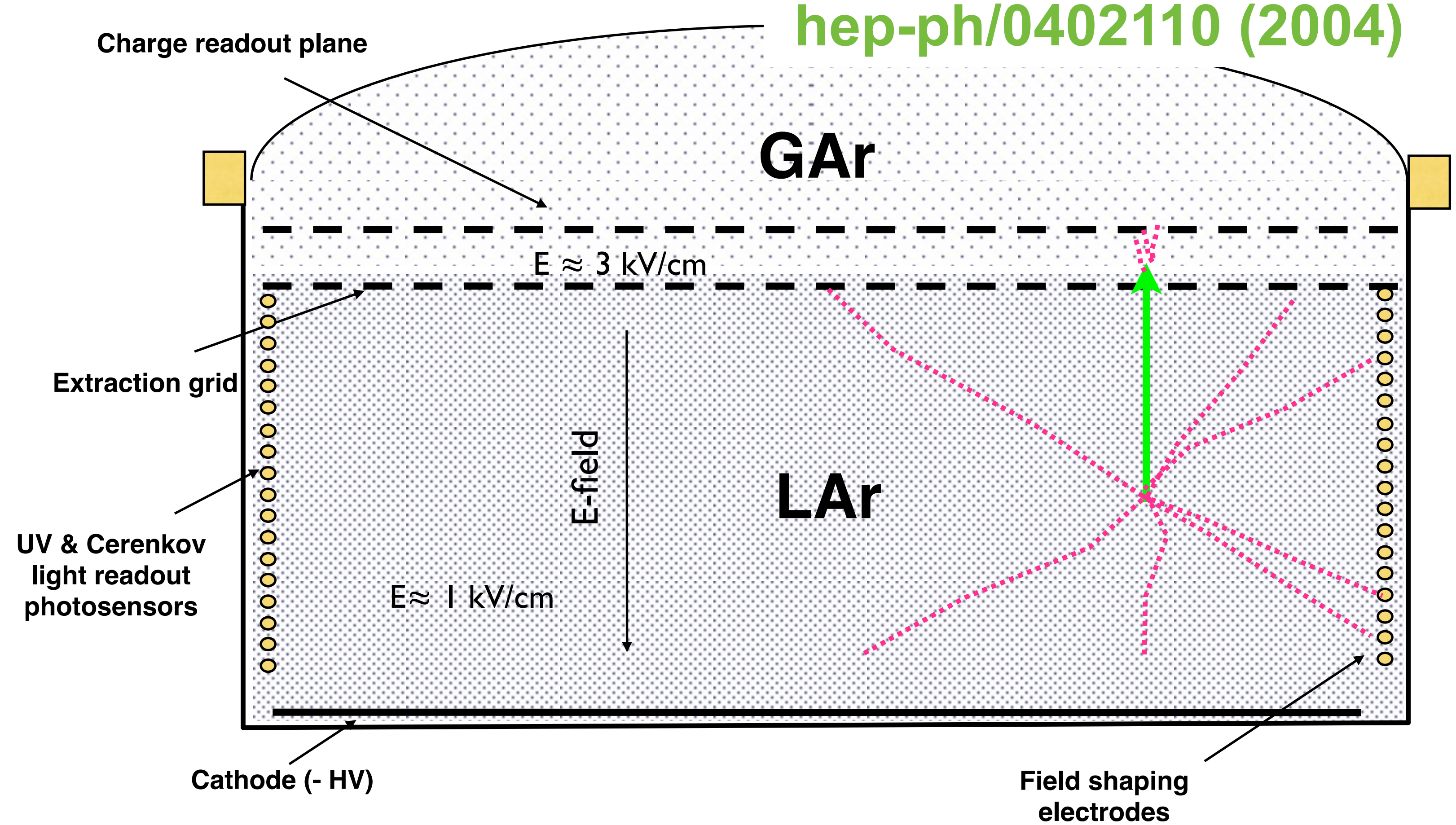
J.Phys.Conf.Ser. 308 (2011) 012030

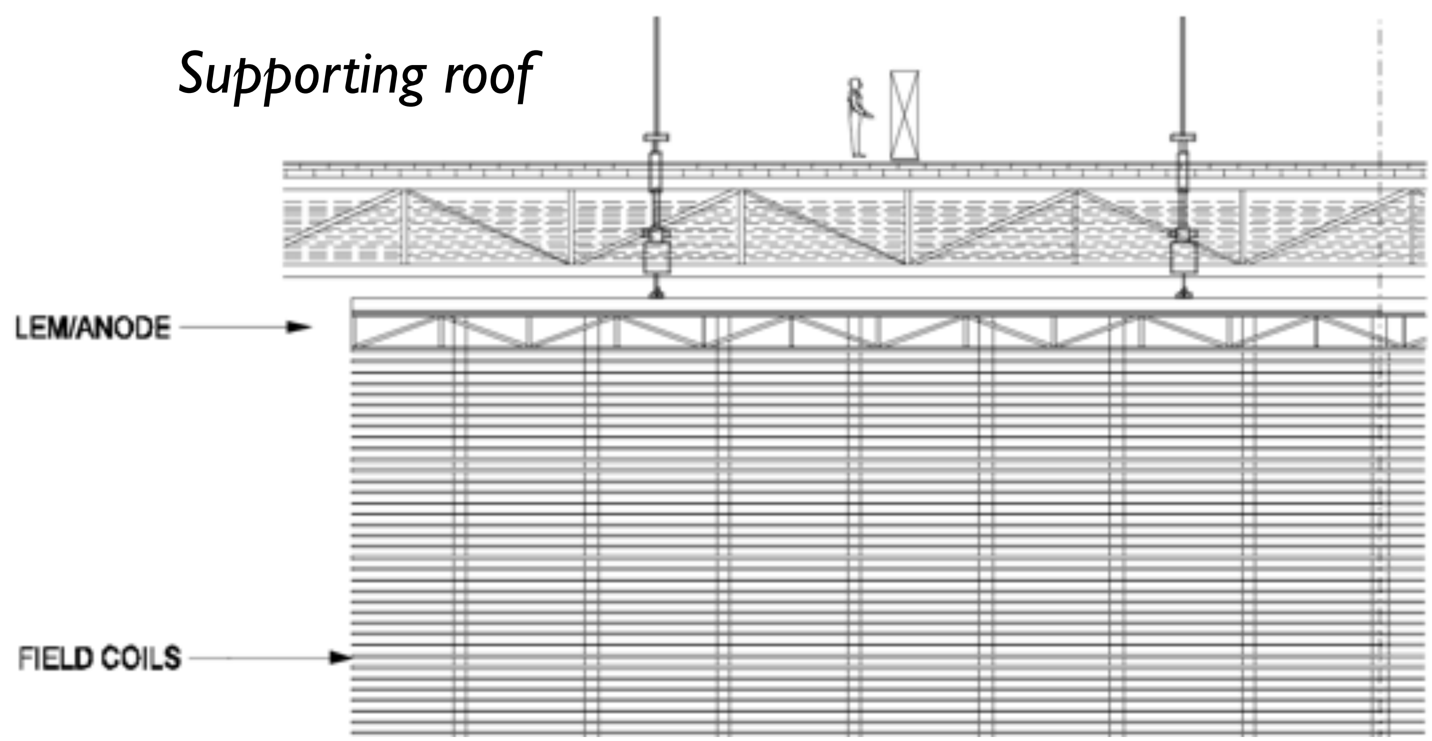


Detector concept : readout scheme

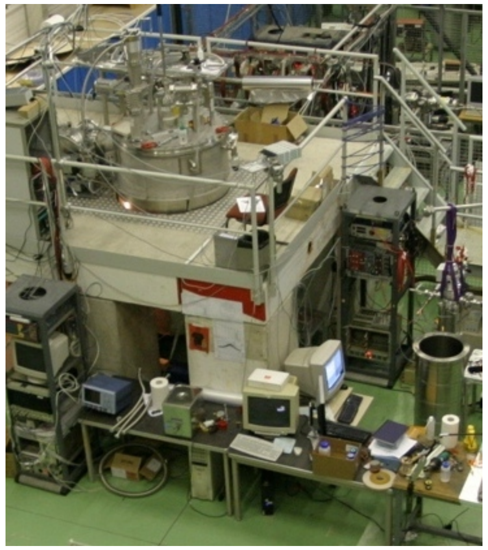
- **A very large area with single long vertical drift paths with full active mass**
- **Double phase readout with adjustable gain at top**
  - ➡ Full extraction from LAr to GAr with ≈3 kV/cm (local)
  - ➡ MPGD, technologies under test LEM, THGEM, Micromegas
  - ➡ Independent readout units
  - ➡ O(10^6) readout channels
- **Immersed high voltage multiplier for drift field**
  - ➡ 0.5÷1 kV/cm
- **Immersed light readout system**
  - ➡ WLS-coated 1000x 8" PMT and reflectors for DUV light detection
  - ➡ Cerenkov imaging with 27000x 8" uncoated PMT
- **Possibly embedded in magnetic field ?**
  - ➡ 0.1÷1 T depending on goal

hep-ph/0402110 (2004)





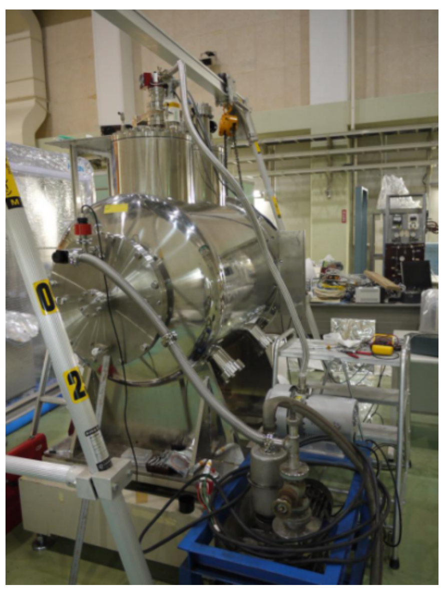
Overview of our LAr activities



(1) ArDM-1t @ CERN

J.Phys.Conf.Ser. 39 (2006) 129-132

1 ton LAr, large area readout, 1m drift with Cockroft-Walton, LAr recirculation and purification, electronics, safety, optimized for dark matter searches, underground operation



(2) J-PARC P32

J.Phys.Conf.Ser. 308 (2011) 012008

0.4 ton LAr, vacuum, cryogenic system, gas purging, argon liquefaction, optimized for test beam pion / kaon response, software development

(3) ArgonTube @ Bern

Nucl.Phys.Proc.Suppl. 139 (2005) 301-310

R&D towards direct very long drift demonstration, HV, liquid purification

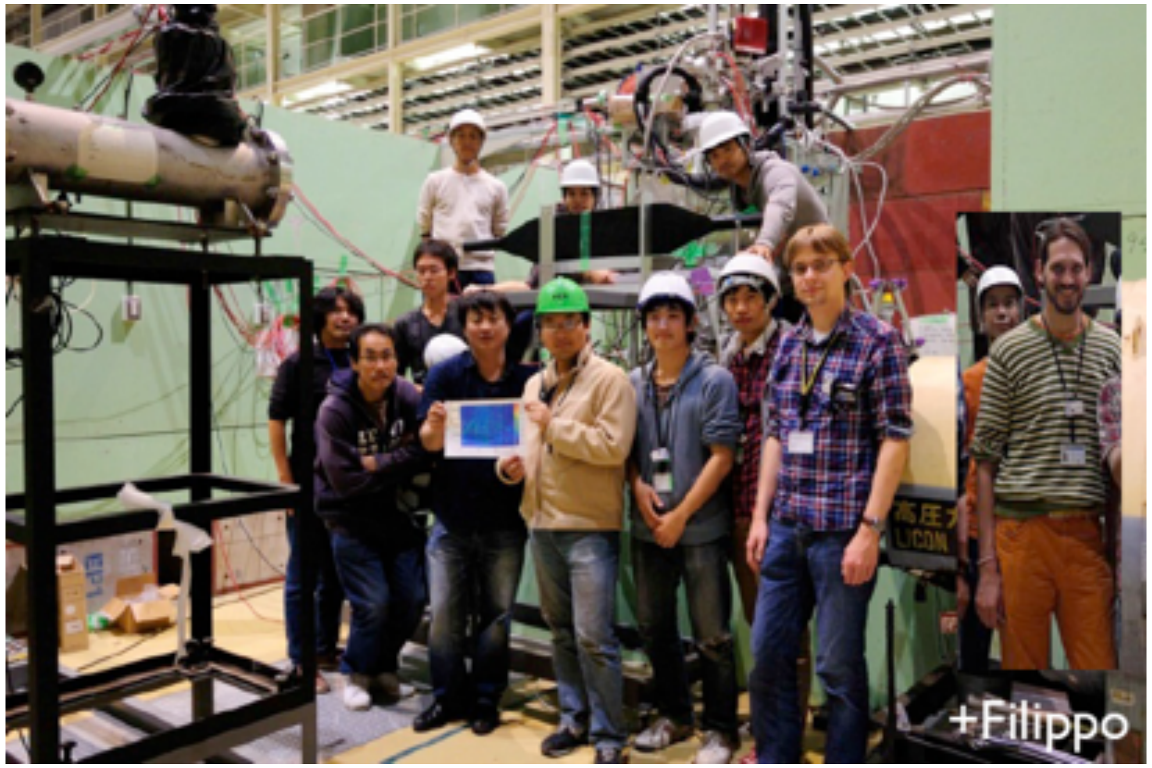
(4) 10T @ CERN

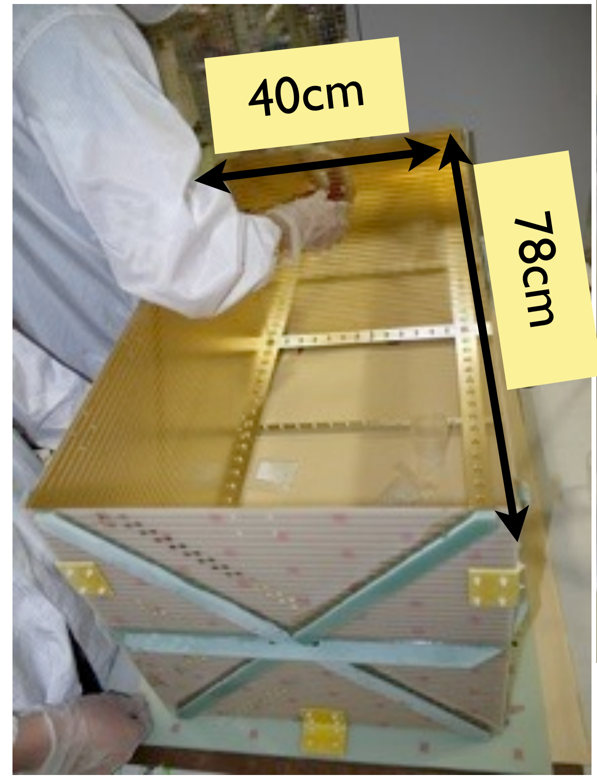
R&D towards non evacuated vessels, warm Ar purging starting from air, high capacity closed gas recirculation

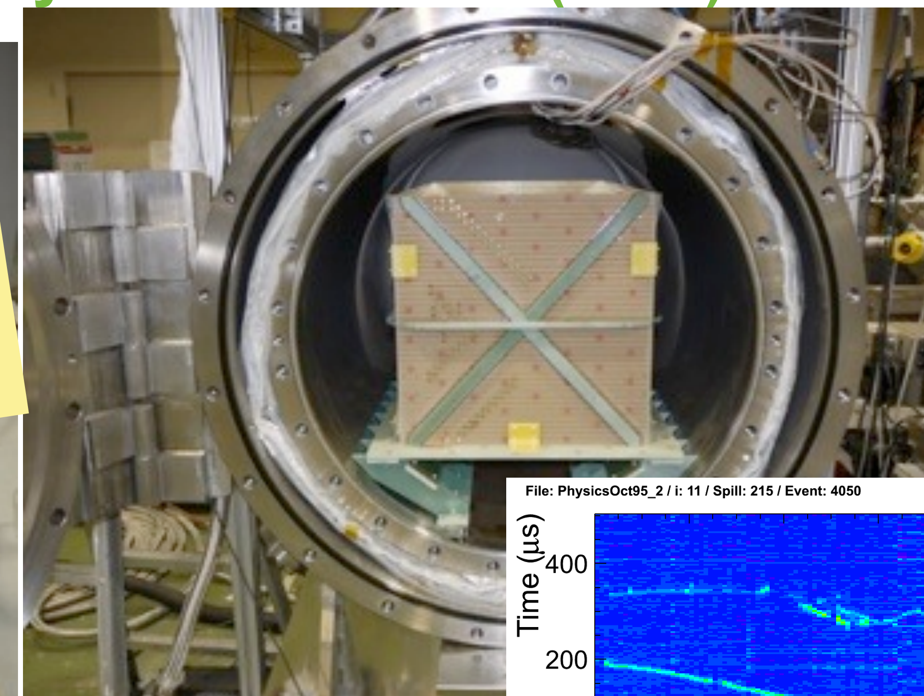
First results from the P32 beam test at JPARC

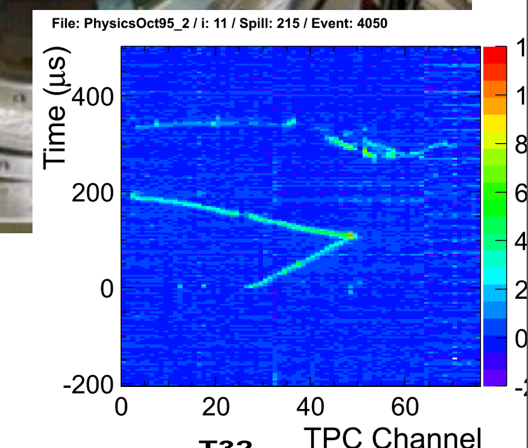
O. Araoka, J.Phys.Conf.Ser. 308 (2011) 012008

First beam event (Oct 2010)

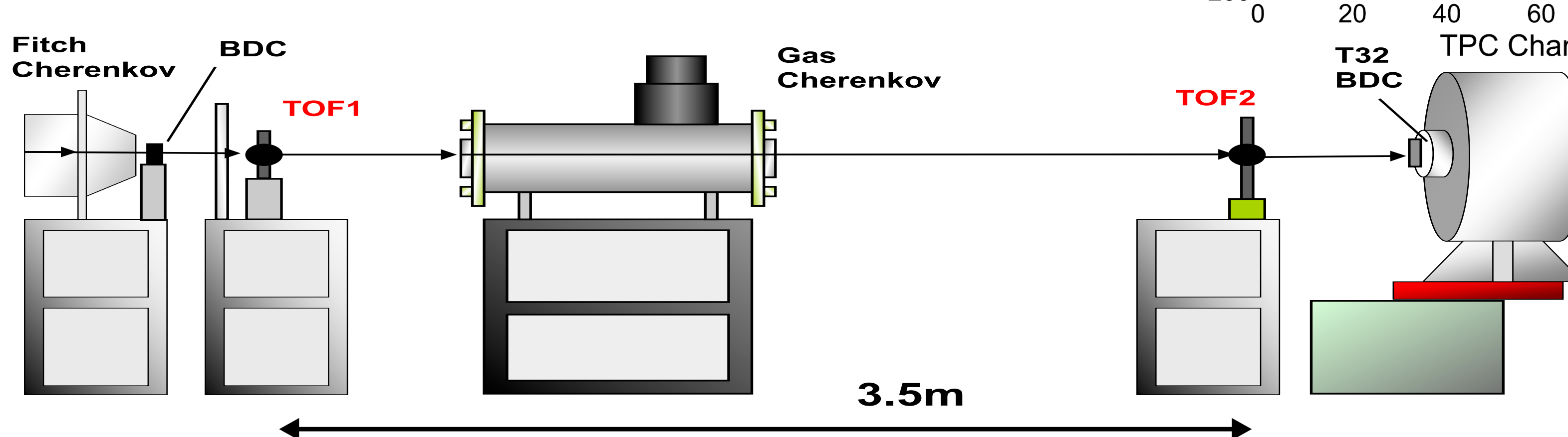




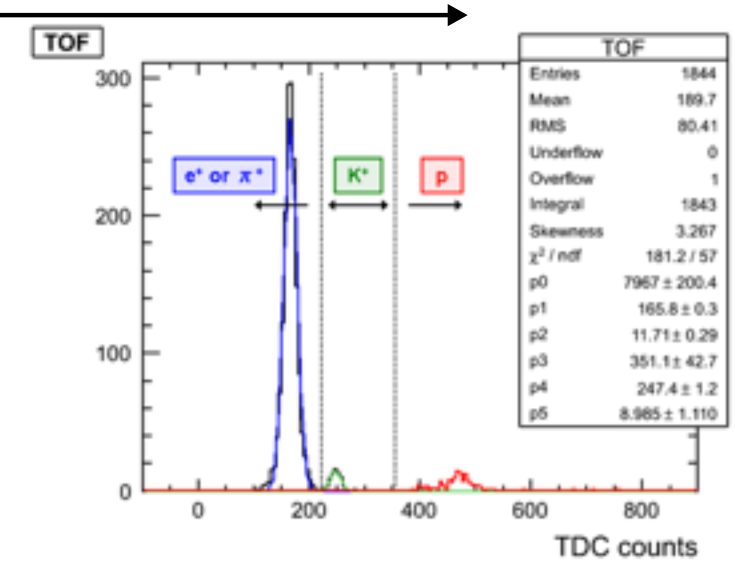




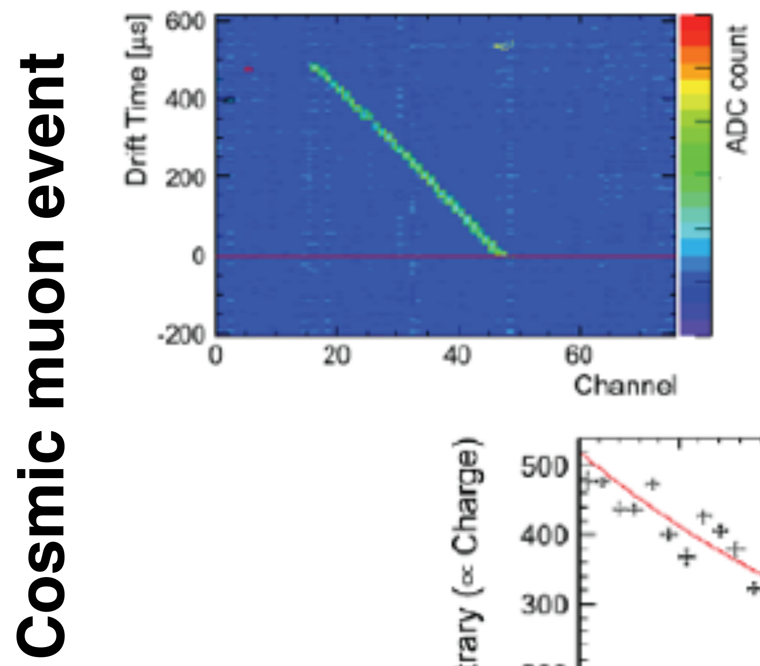
- for the first time ever a LAr-TPC was operated in a tagged charged particle beam
- momentum scale relevant for proton decay studies
- more than 200'000 K^+,π^+,e^+ and proton events acquired
  ➡ **largest amount of K+ events detected with a LAr TPC**

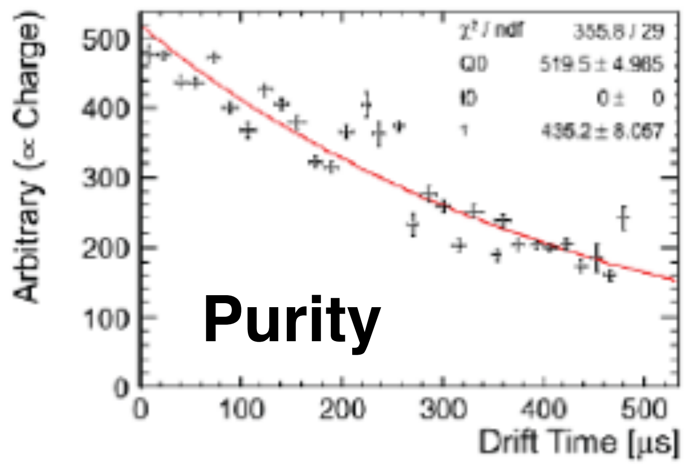


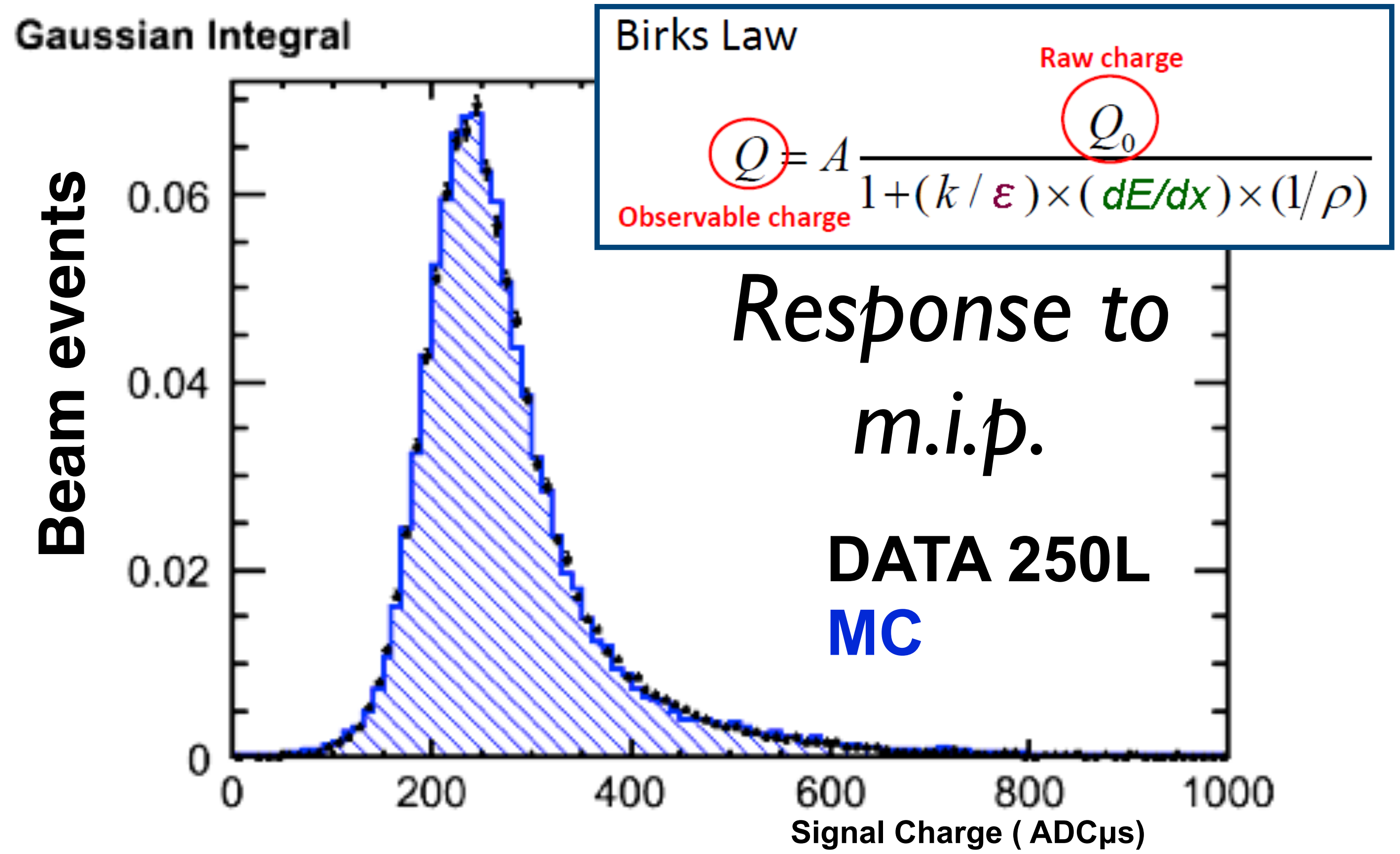
- **External PID power from TOF + Cerenkov equipment is providing ~100% pure K before the degrader(s).**

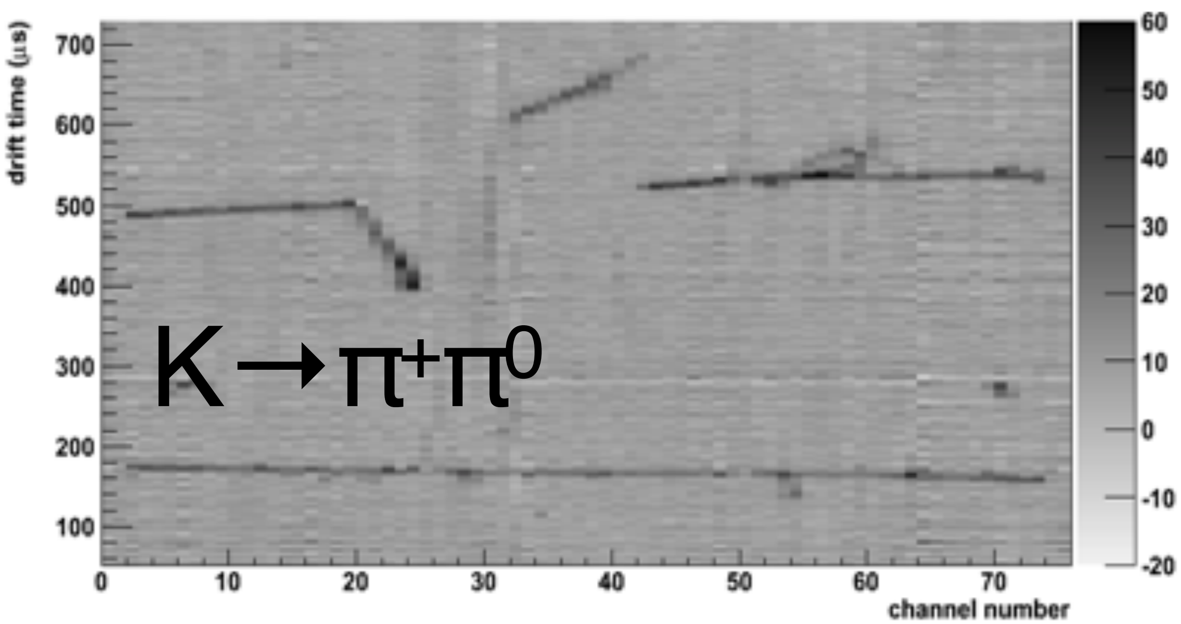


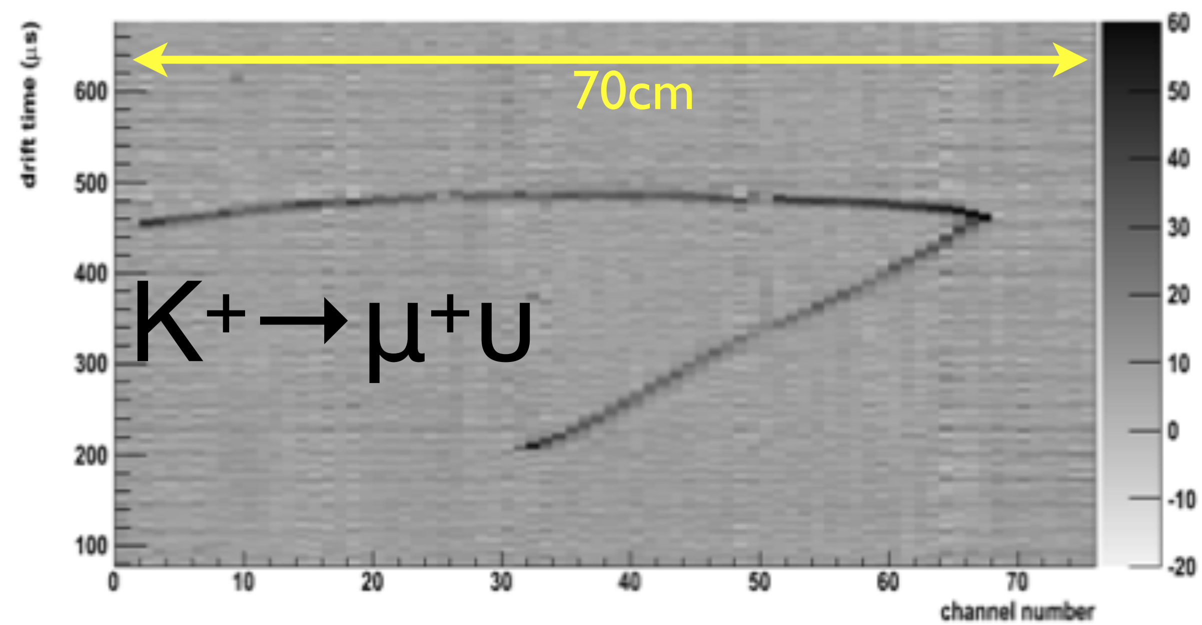
Gallery of events from P32 @ J-PARC











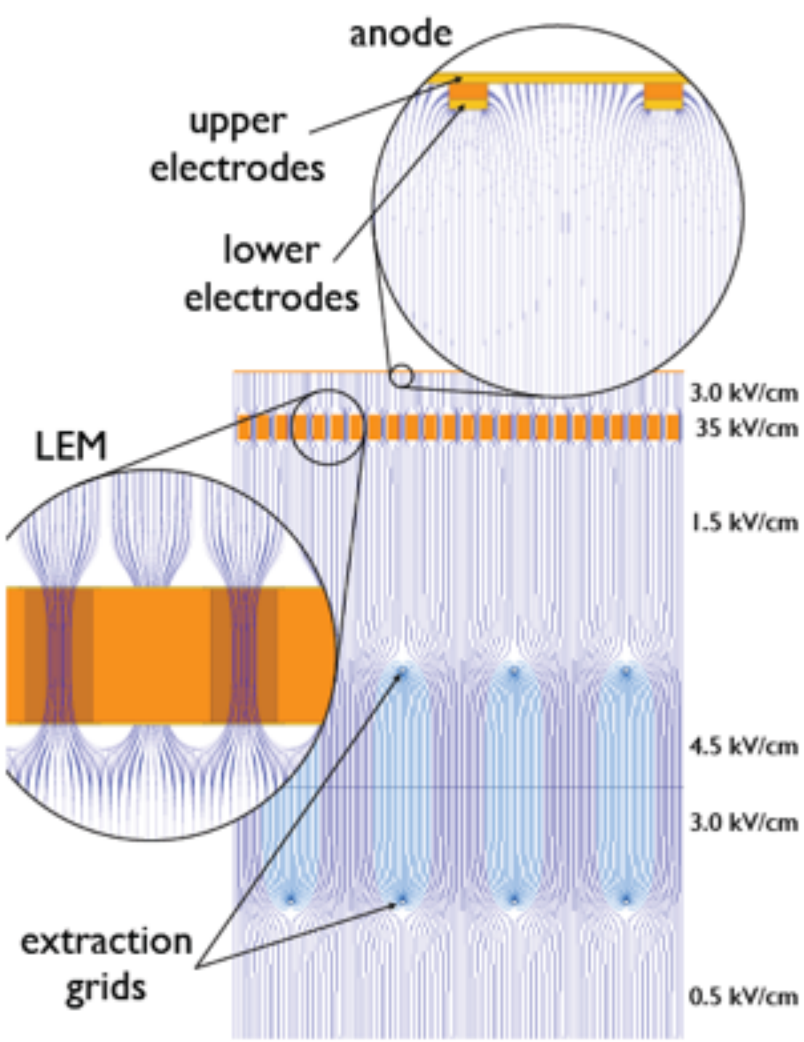
- strength of the LAr-TPC in PID obvious
- excellent agreement between data and tuned MC for π, p and K (in preparation)

Double phase charge readout principle: LEM and projective 2D anode

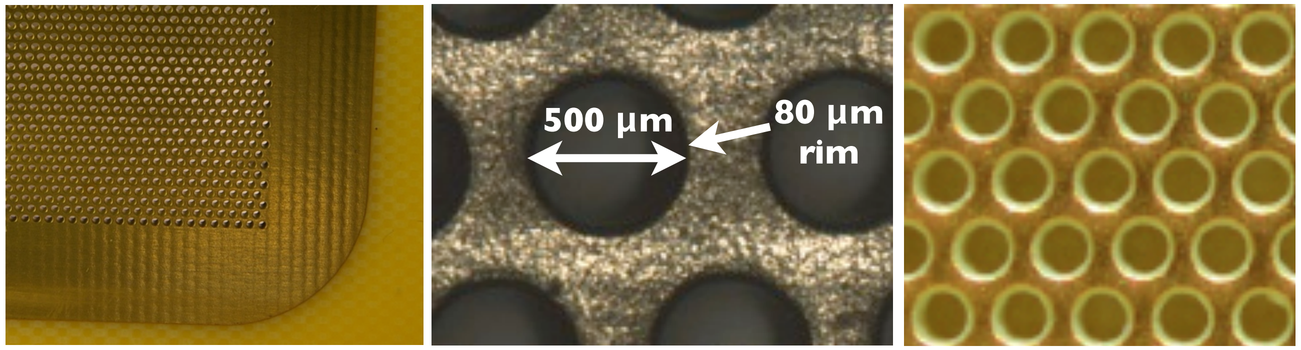
A. Badertscher, et al., NIM A 641 (2011) 48-57

Readout principle
1. ionization electrons are **drifted** to the liquid-gas interphase
2. if the E-field is high enough (≈ 3 kV/cm) they can efficiently be **extracted** to the gas phase
3. in the holes of the LEM the E-field is high enough to trigger an electron avalanche
4. the **multiplied** charge is collected on a 2D readout

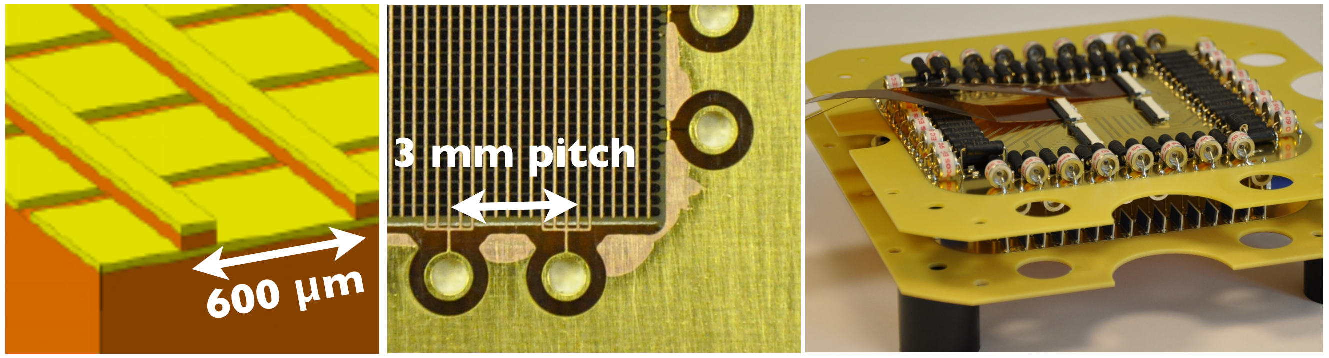
Electric fields



LEM (THGEM): Large electron multiplier
- Macroscopic Gas hole multiplier
- more robust than GEMS (cryogenics, discharges)
- manufactured with std. PCB techniques
- Large area coverable (1 m^2 size modules)



Projective 2D anode readout
- Charge is equally collected on two sets of strips (views)
- induced signals have the same shape for both views
- readout independent of multiplication



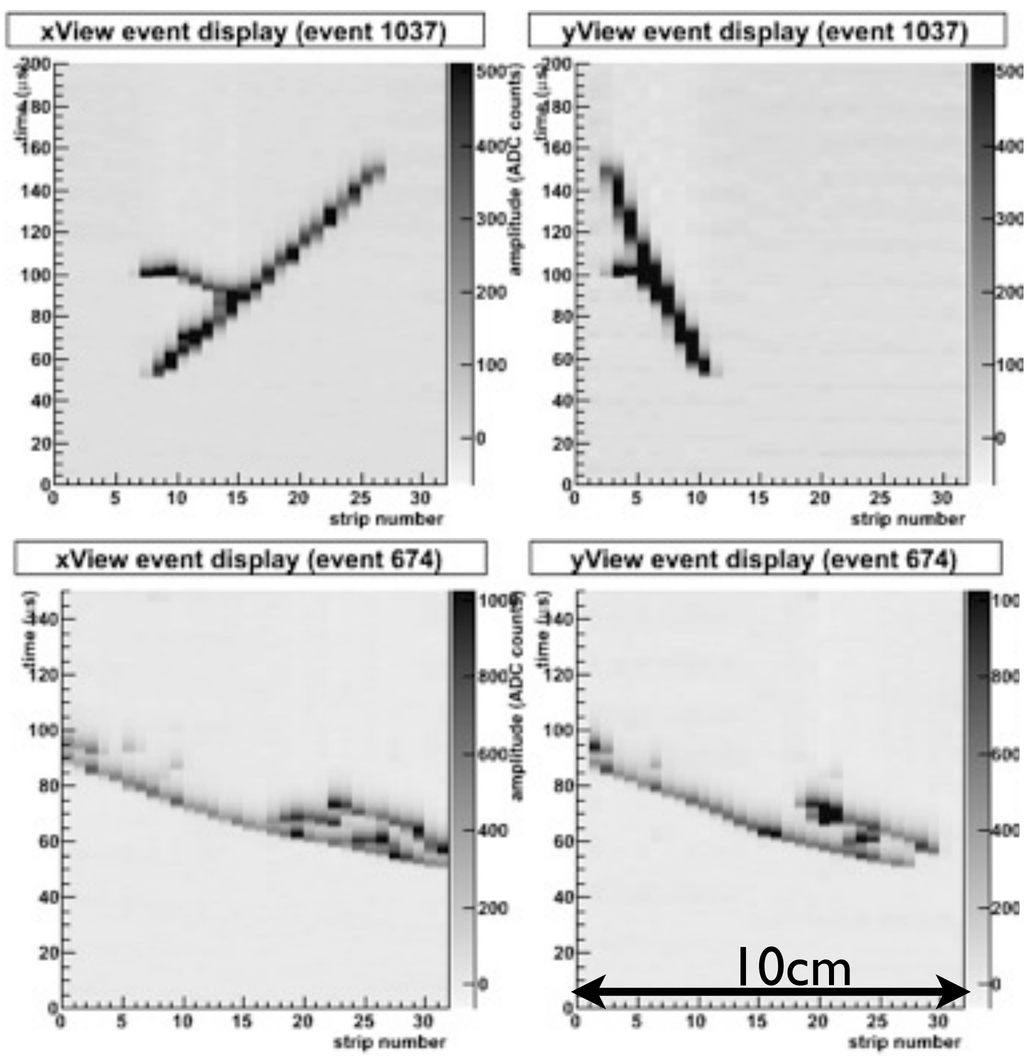
LEM and 2D anode produced by CERN TS/DEM group

Double phase charge readout: LEM and projective 2D anode

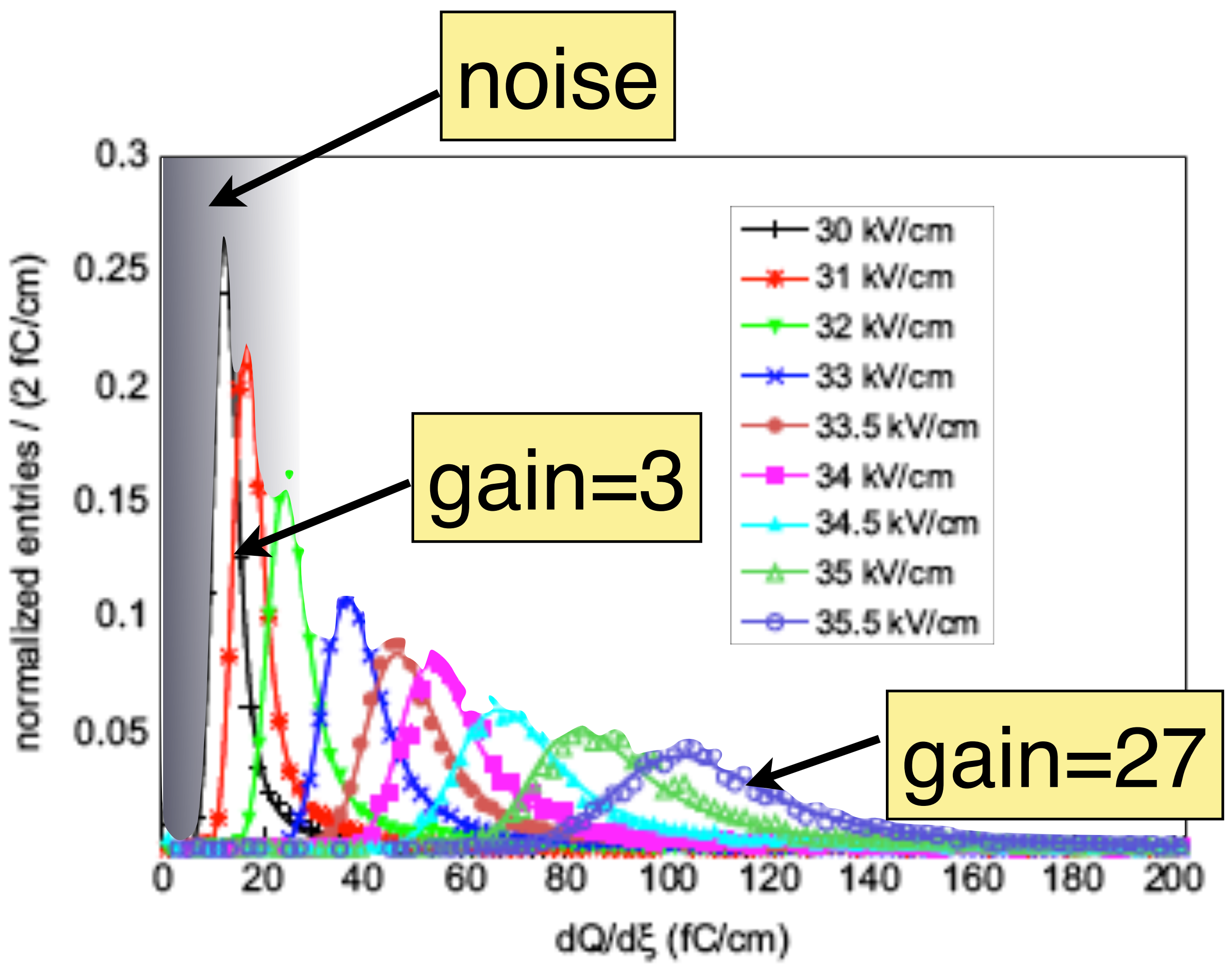
A. Badertscher, et al., NIM A 641 (2011) 48-57

- Multiplication in gas phase leads to a signal gain of >30 @ 35.5kV/cm (single stage)
- With a projective anode, both views see the same (collection) signal waveform
- System provides excellent S/N ratio >100 allows precise reconstruction of:
  - 3D track topology
  - energy loss (landau fluctuations)

cosmic triggers



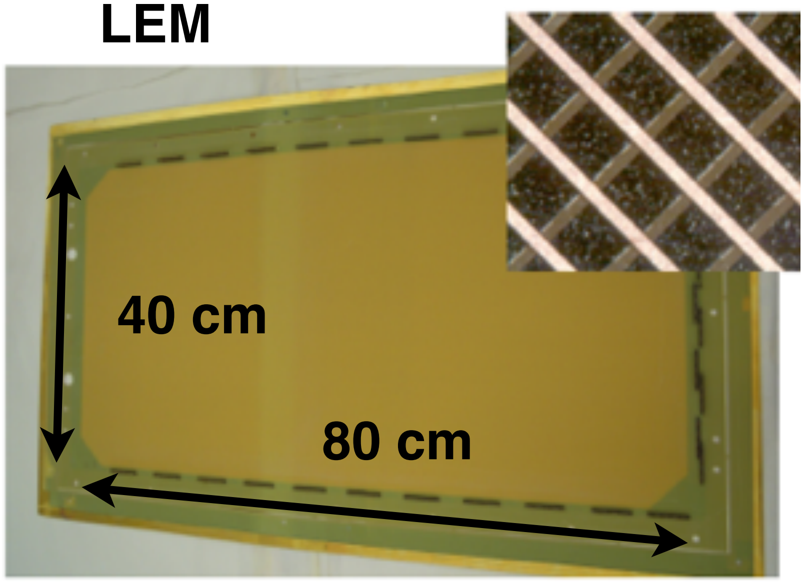
Landau distribution fitted to dE/dx distributions of muons



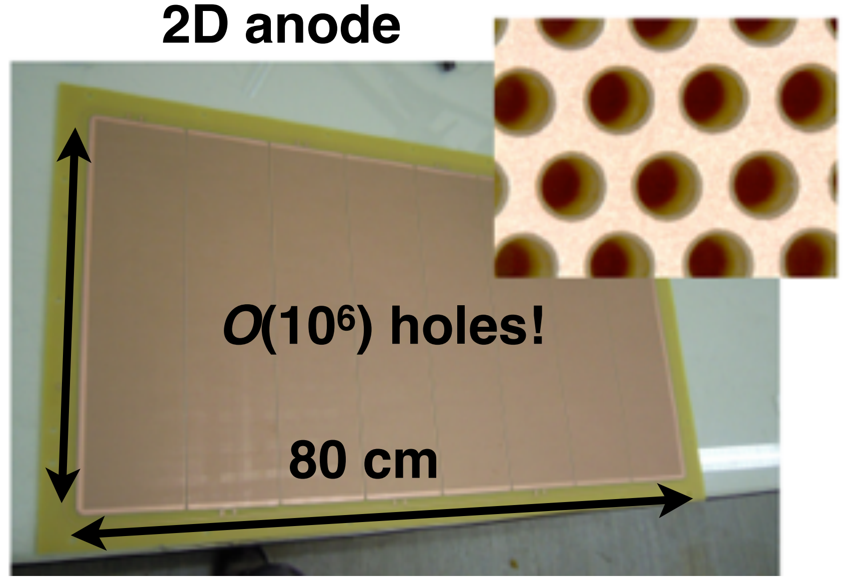
Large LAr-LEM TPC@CERN: Production of a 40x80 cm^2 charge readout sandwich

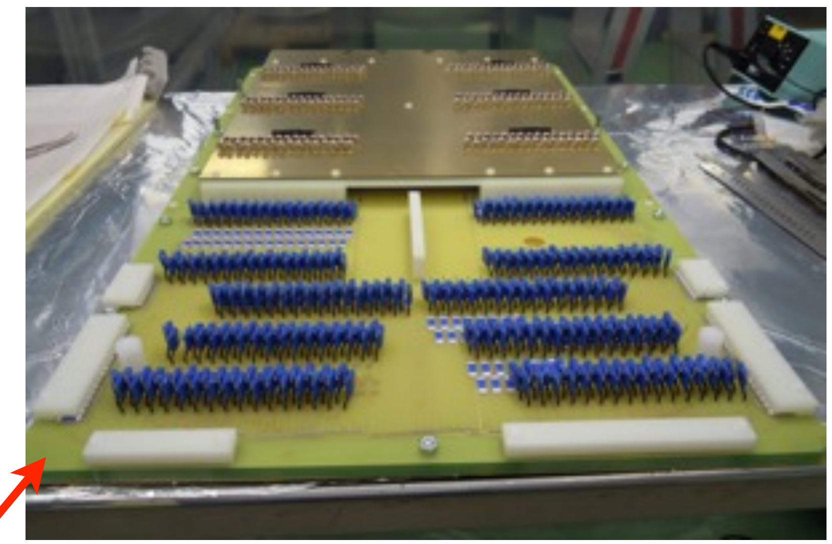
- After successful test of LEM and 2D anode in the 3L setup we designed and produced a 40x80 cm^2 charge readout for a new 250L LAr LEM-TPC (production and assembling finished by summer 2011)
- The ArDM cryostat @CERN is currently being used for a first test of the new charge readout system

LEM



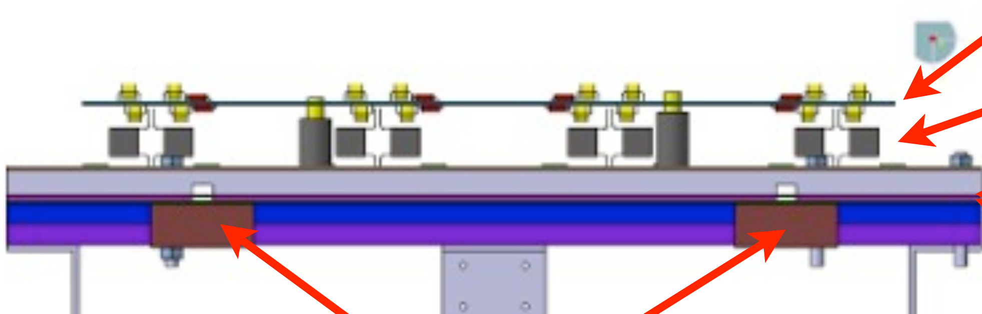
2D anode

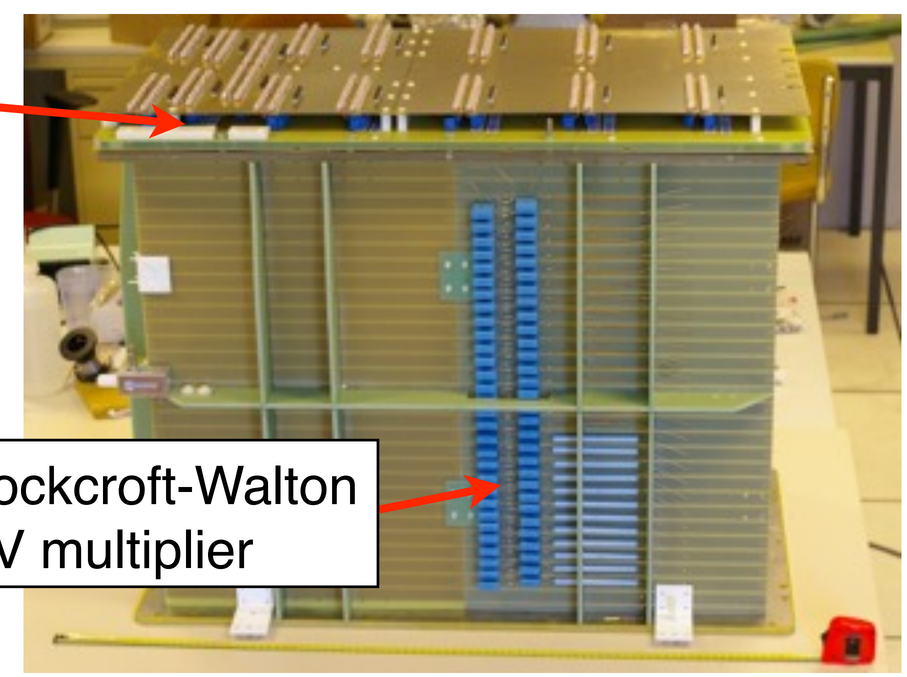




- Manufacturer: CERN TS/DEM group and ELTOS company (Italy)
- Largest LEM/THGEM and 2D readout ever produced!!!

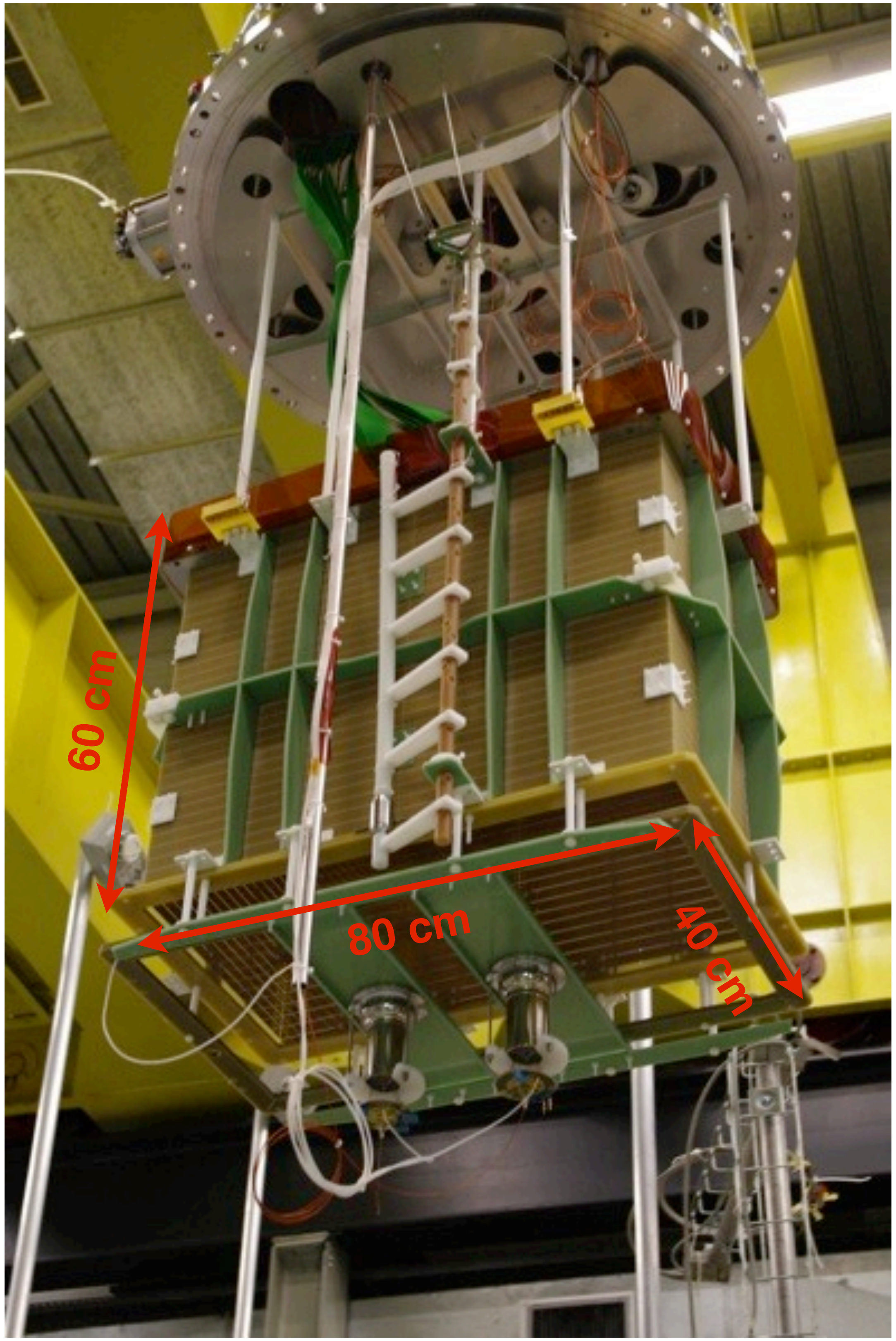
Design of a compact, robust and scalable readout cassette (“sandwich”)



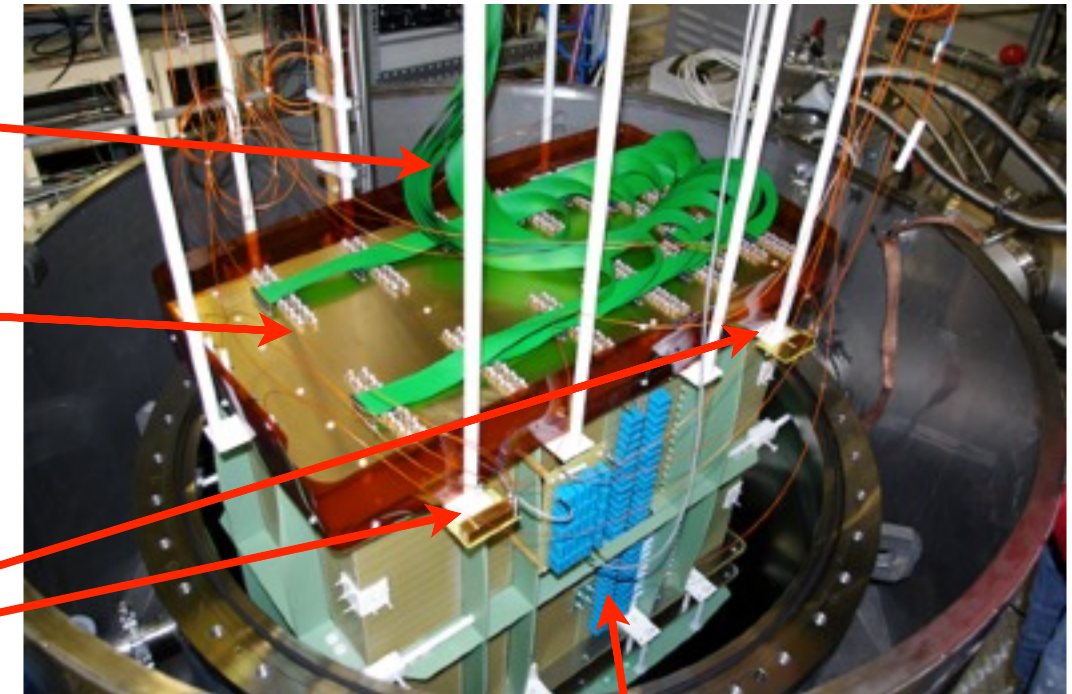


40x80cm² LAr-LEM TPC@CERN: assembly

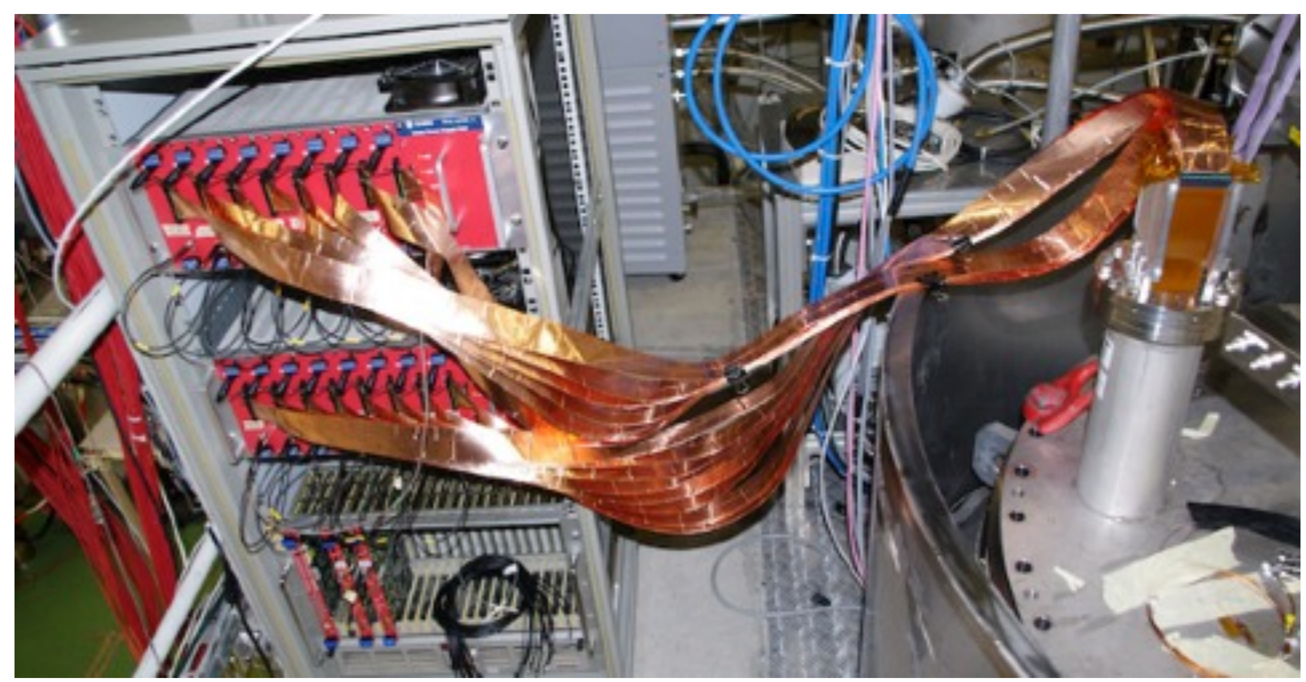
250L detector fully assembled



250L going into the ArDM cryostat



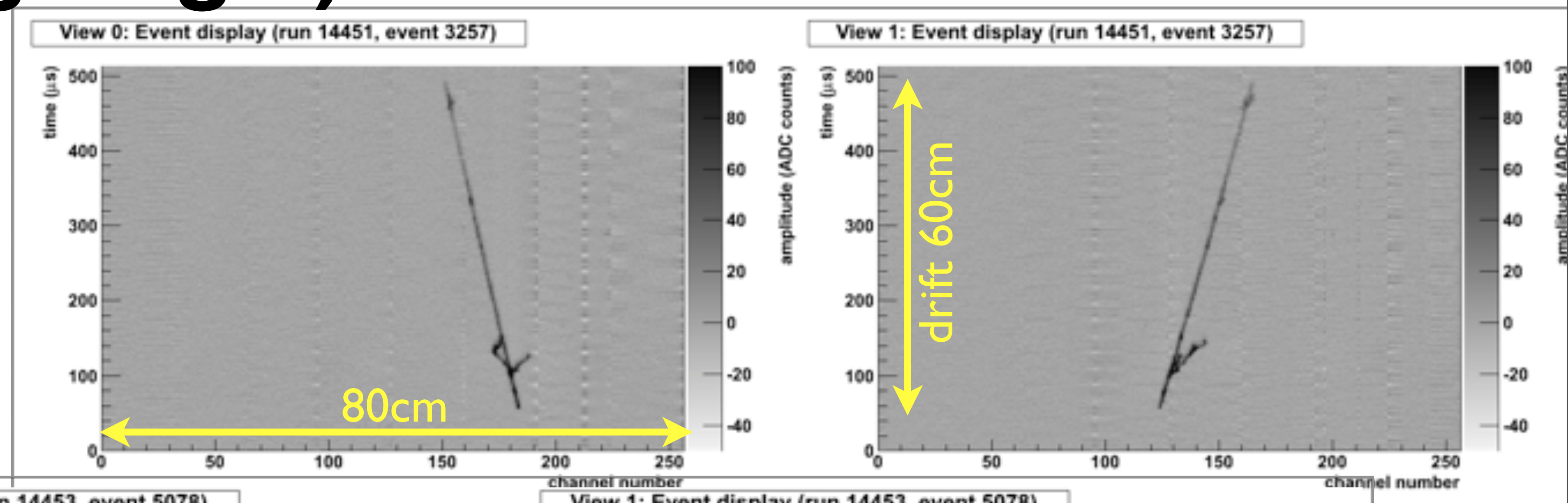
Final connection to the DAQ system

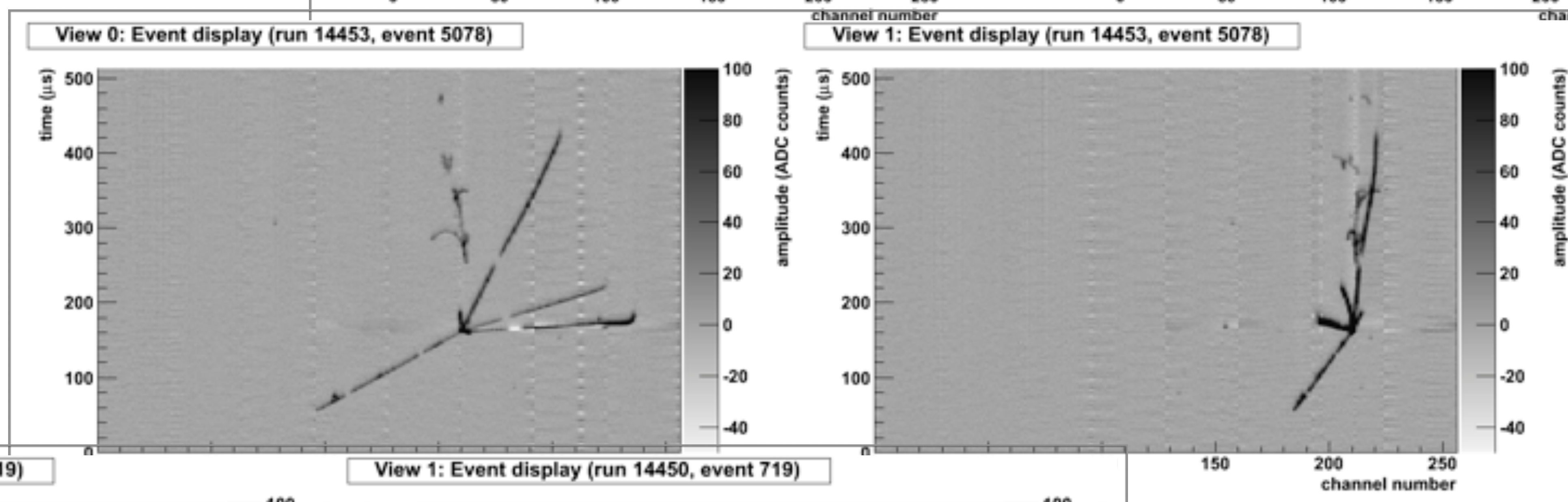


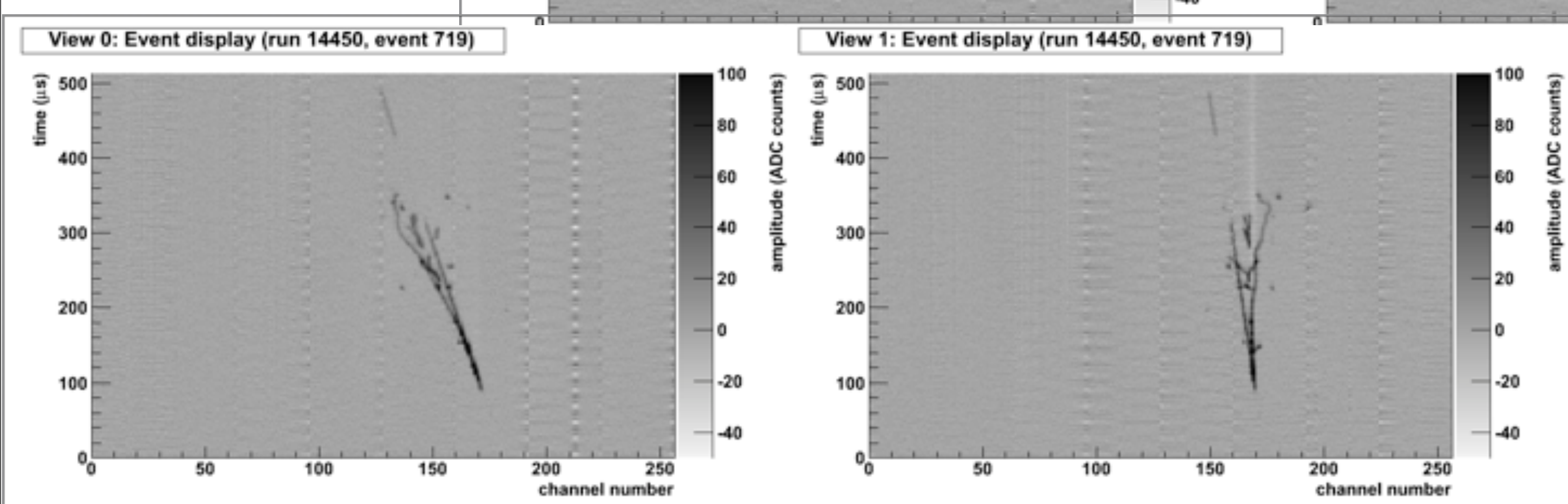
First events from the 40x80cm2 LAr LEM-TPC! (data taking ongoing...)

Electric field configuration

LEM-Anode	2400 V/cm
LEM	35 kV/cm
grid-LEM	800 V/cm
extraction	2500 V/cm
drift	400 V/cm



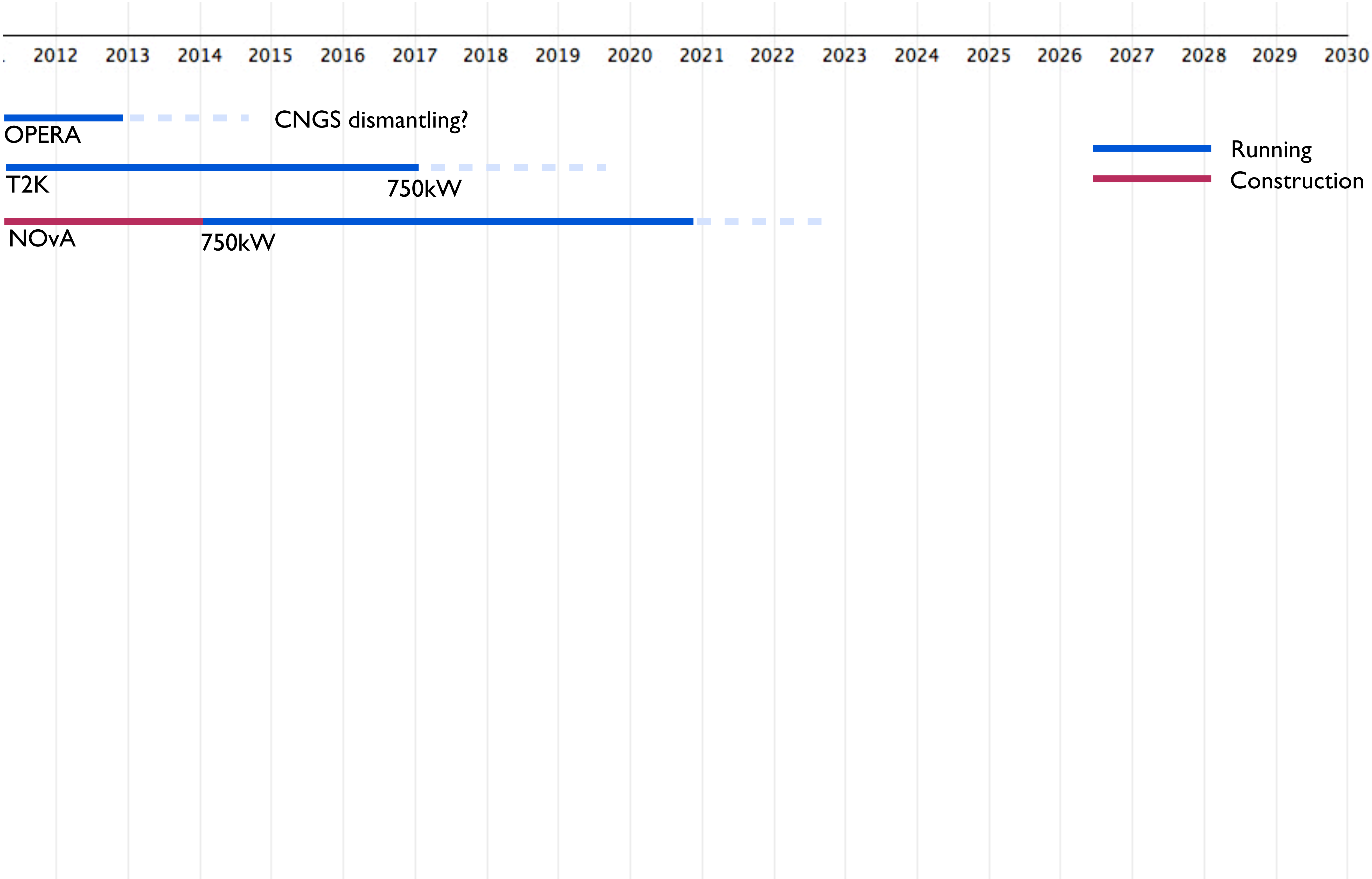




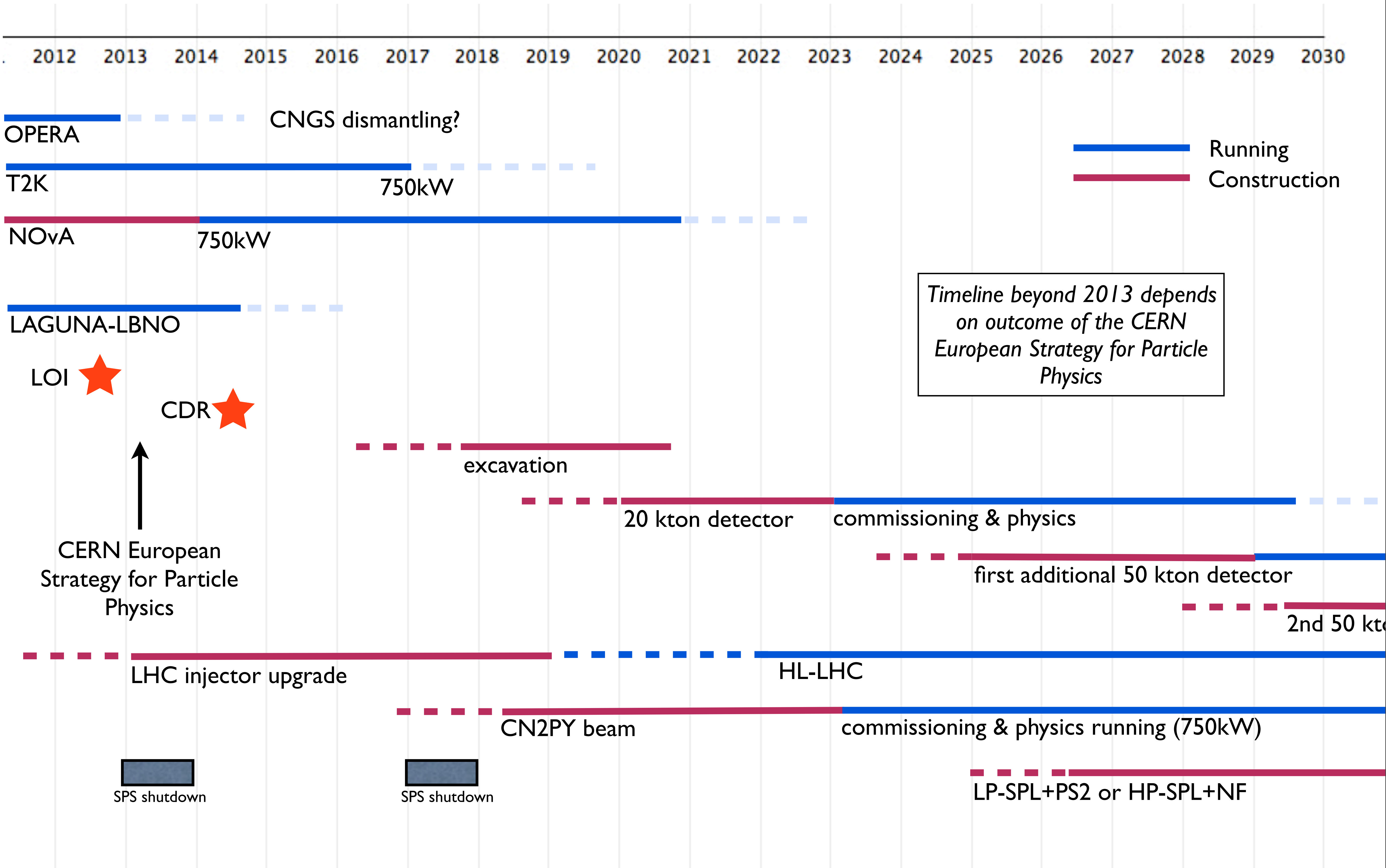
- Noise not fully optimized

- Both views are charge collection !

LAGUNA-LBNO Timeline



LAGUNA-LBNO Timeline



Conclusions

- Next phase of LAGUNA design study successfully started
  - Wider scope (LBNO) & more focus (sites, technologies)
  - Enlarged, stronger collaboration, and larger budget
- We are proposing a “realistic plan” for a European LBL programme with great discovery potentials, starting with mass hierarchy determination and incrementally leading to CP-violation.
- In parallel, ultimate search for proton decay and interesting neutrino astrophysics measurements.
- Submission (mid-2012) of an expression of interest is the next step in view of the update of the European Strategy Roadmap.
- Open to any collaborator – become a “LAGUNA-LBNO associated member” !

Pyhäsalmi is at the bimagic or magic distance from all 3 labs delivering neutrino beams!

Acknowledgements

- FP7 Research Infrastructure “Design Studies” LAGUNA (Grant Agreement No. 212343 FP7-INFRA-2007-1) and LAGUNA-LBNO (Grant Agreement No. 284518 FP7-INFRA-2011-1)

Backup slides

CERN SPS/CNGS power limitations

Int. per PS batch	# PS batches	Int. per SPS cycle	200 days, 100% efficiency, no sharing	200 days, 55% efficiency, no sharing	200 days, 55% efficiency, 60% CNGS sharing
		[prot./6s cycle]	[pot/year]	[pot/year]	[pot/year]
2.4×10^{13} - Nominal CNGS	2	4.8×10^{13}	**1.38×10^{20}**	**7.6×10^{19}**	**4.56×10^{19}**
3.5×10^{13} - Ultimate CNGS	2	**7.0×10^{13}**	2.02×10^{20}	1.11×10^{20}	6.65×10^{19}

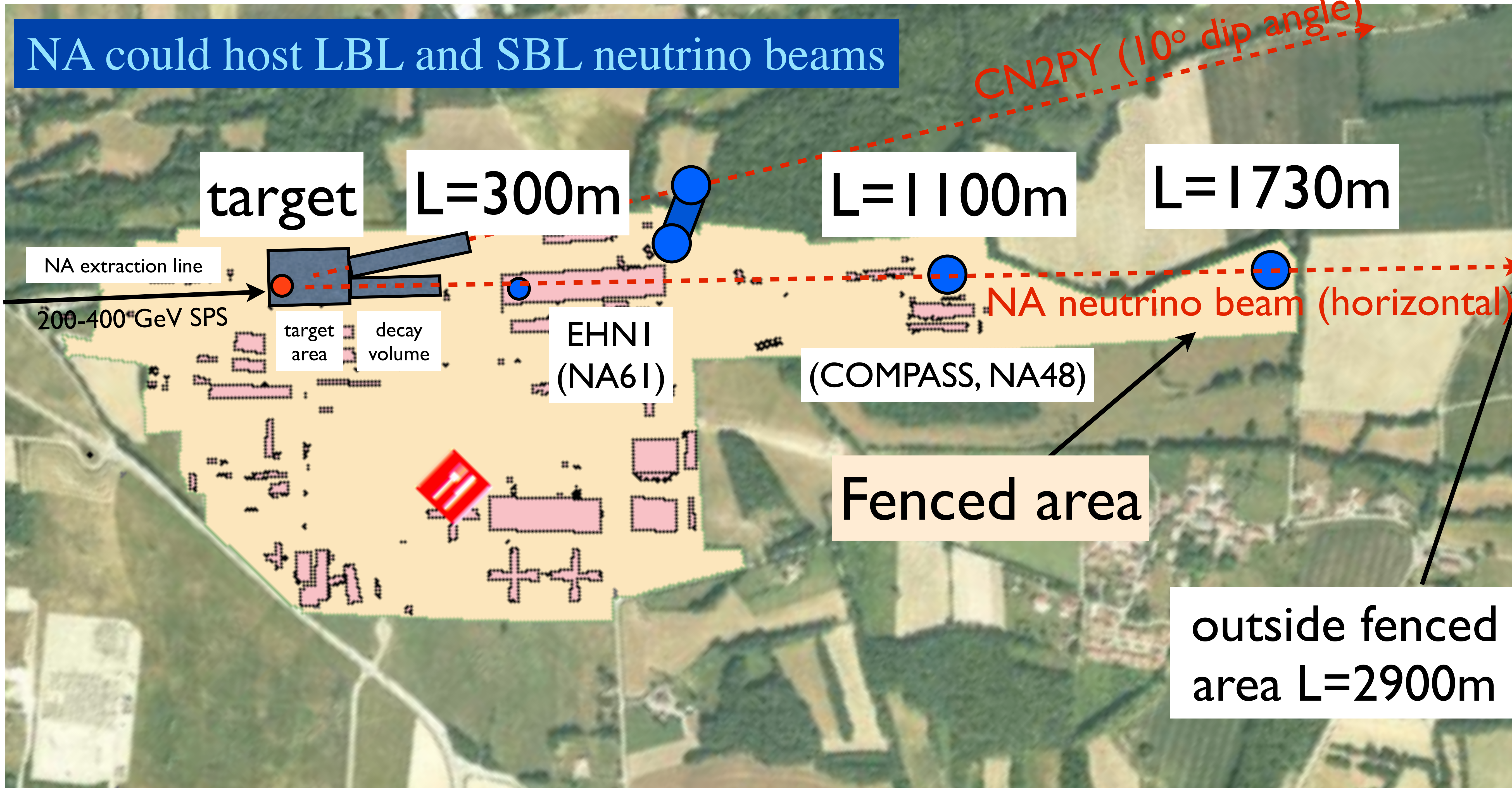
M.Meddahi, E.Schaposnicova - CERN-AB-2007-013 PAF

750kW design limit for the target

working hypothesis for RP calculations

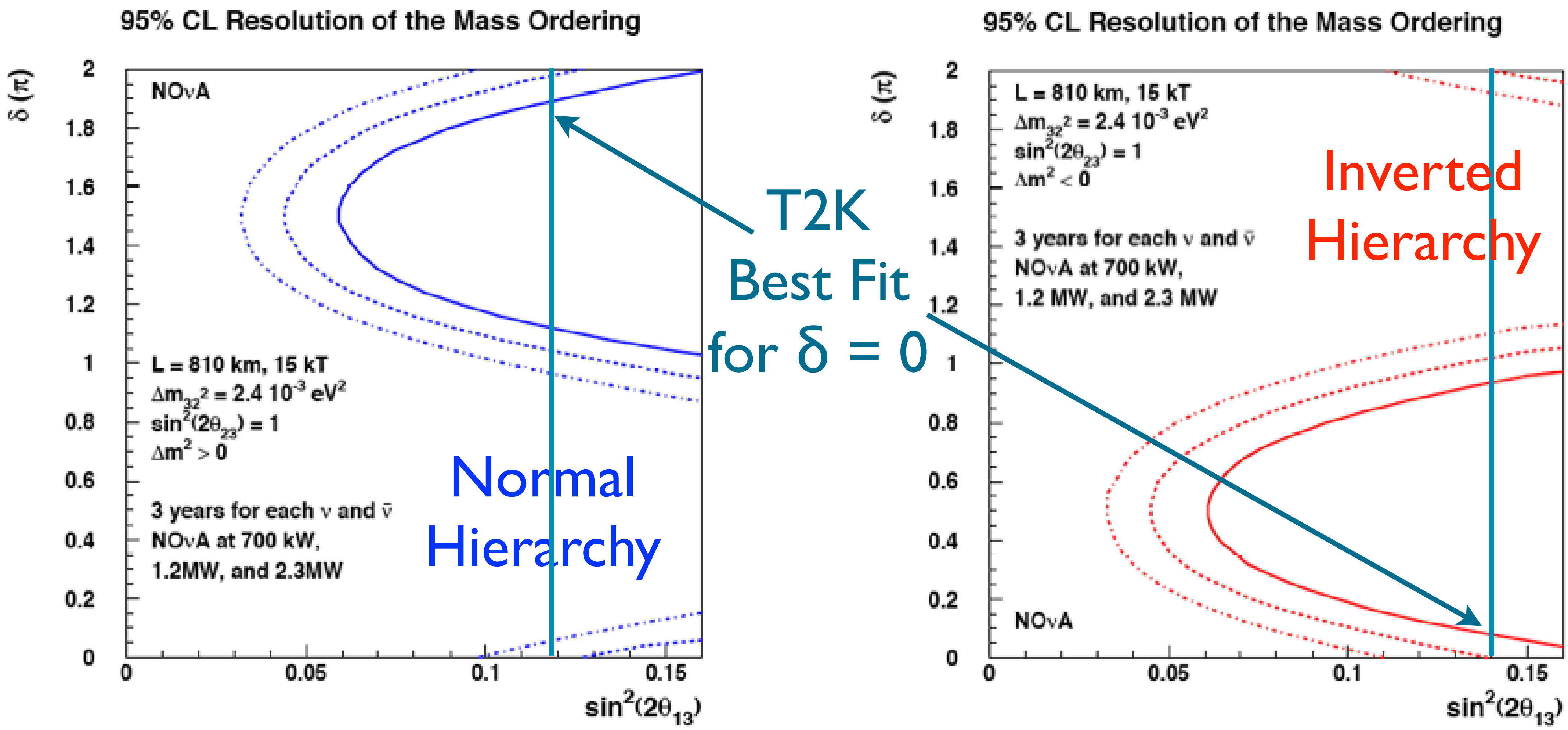
CERN SPS(+LIU) could deliver (1÷2)e20 pot/year in dedicated mode and depending on efficiency (in 2011 was ≈80%)

A low/high-energy neutrino (short baseline) beam in the CERN North Area



High and low energy beam options possible for detector R&D, cross-section measurements, oscillations @ L/E≈1 eV^2, electroweak physics,...

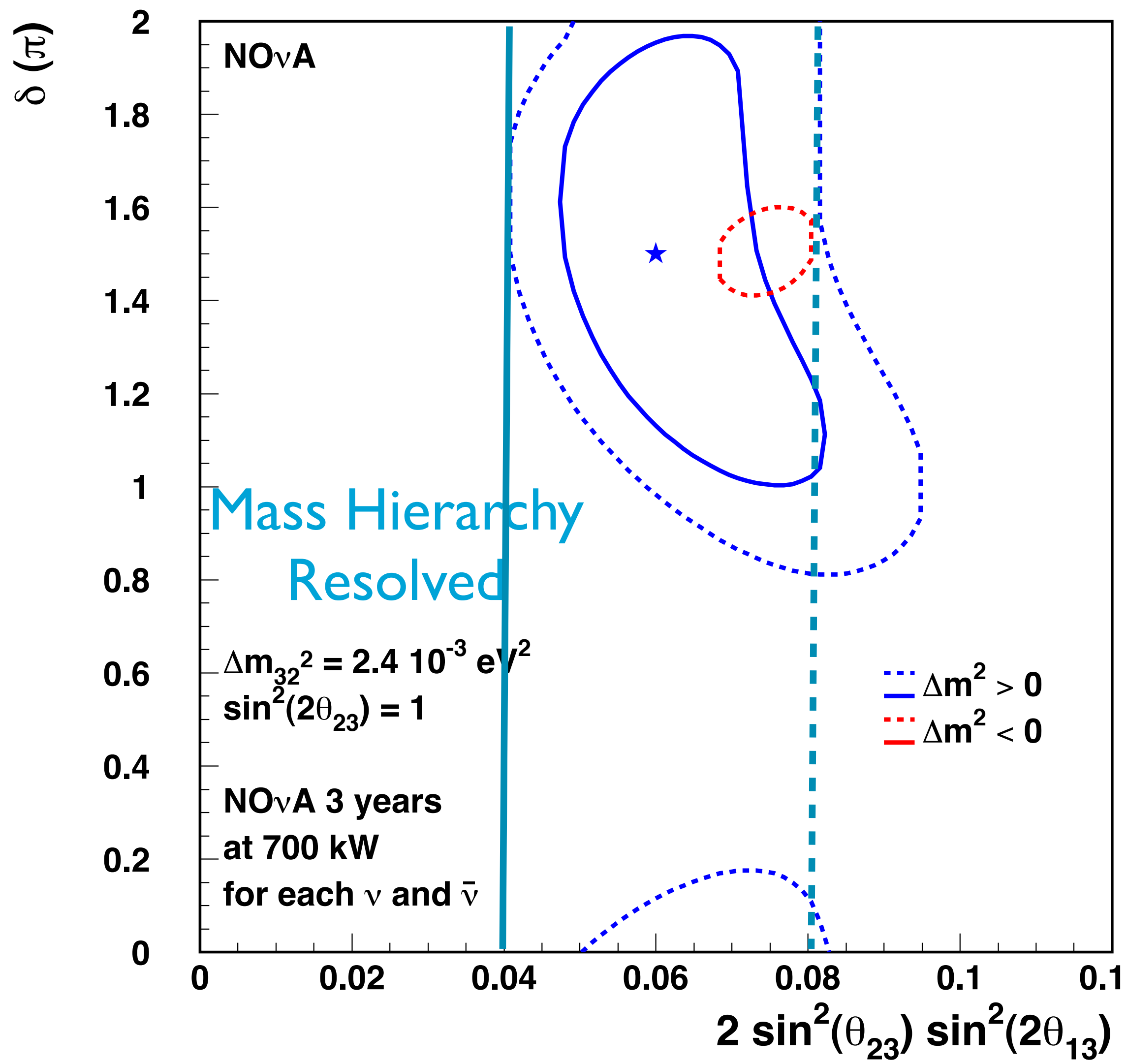
Sensitivity to Mass Ordering



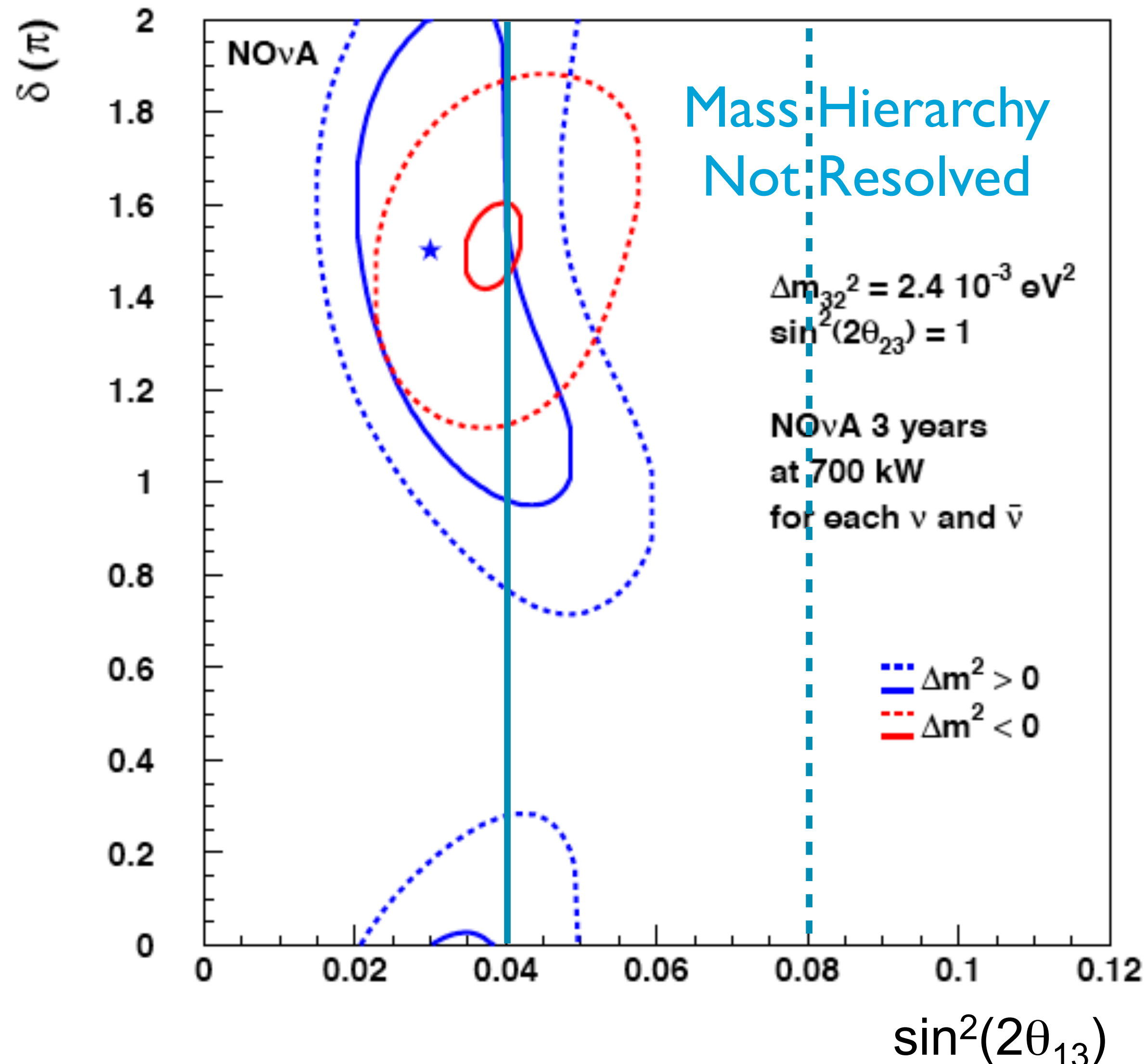
- 95% CL resolution for mass ordering shown for normal and inverted hierarchy, curves represent different beam powers
- Resolve mass ordering for large fraction of possible values of δ if T2K result is correct
- Even better resolution with information from another baseline
- Resolve ambiguity for values of $\sin^2(2\theta_{13})$ to the right of the curves

Sensitivity to CP Violating Phase δ

Contours for Starred Point for NOνA



1 and 2 σ Contours for Starred Point for NOνA



- Plots show 1 and 2σ contours for 700 kW beam with chosen point
- Vertical lines show MINOS best fit values for δ = 0, solid is normal hierarchy
- NOνA sensitivity includes δ = 0, π at 2σ
- Can point to which CP phase half plane to target for future measurement