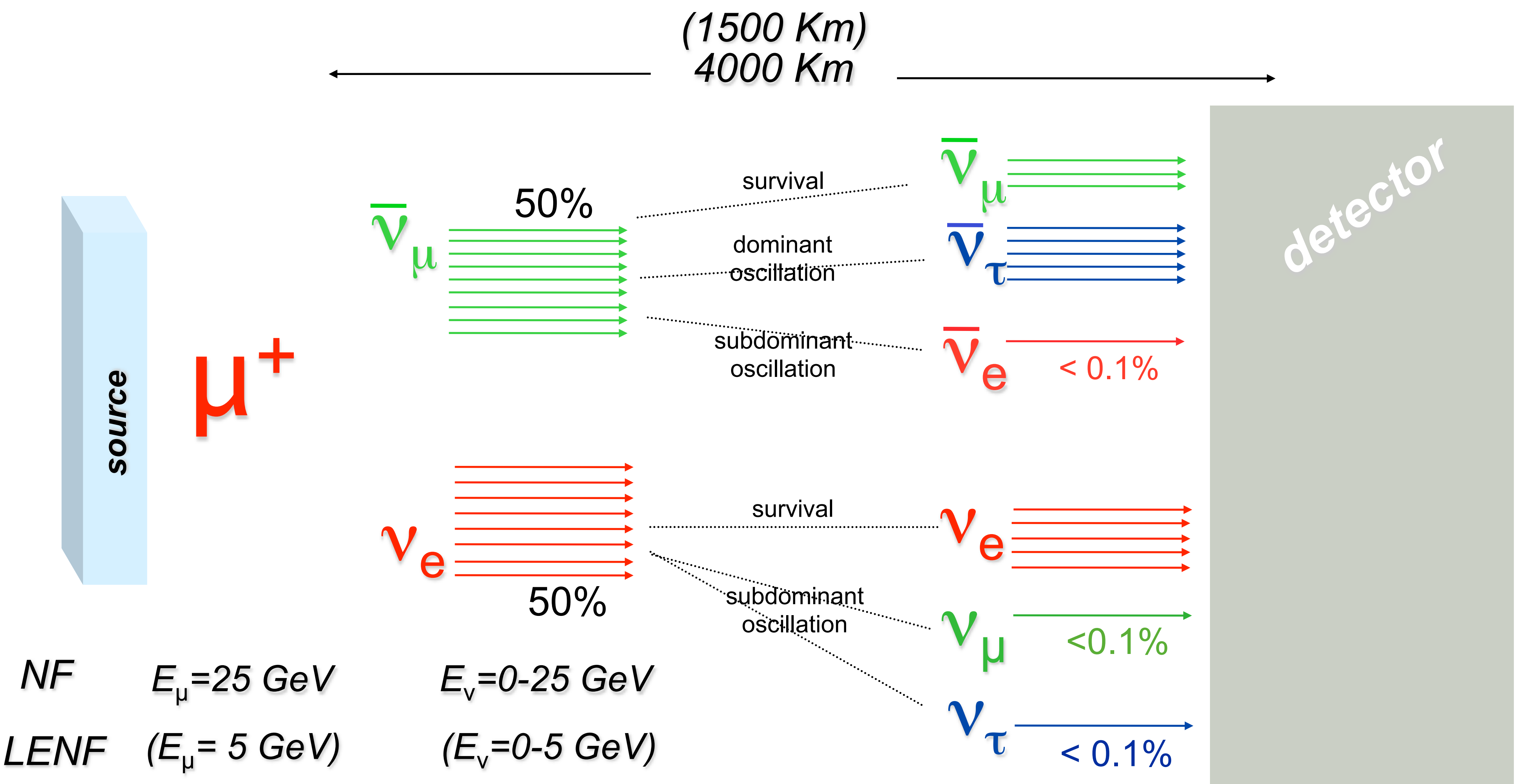
IDS-NF
FAR detectors intro

Anselmo Cervera Villanueva
IFIC (Valencia)

5th IDS-NF plenary meeting
Fermilab, 8 April 2010

Oscillation channels



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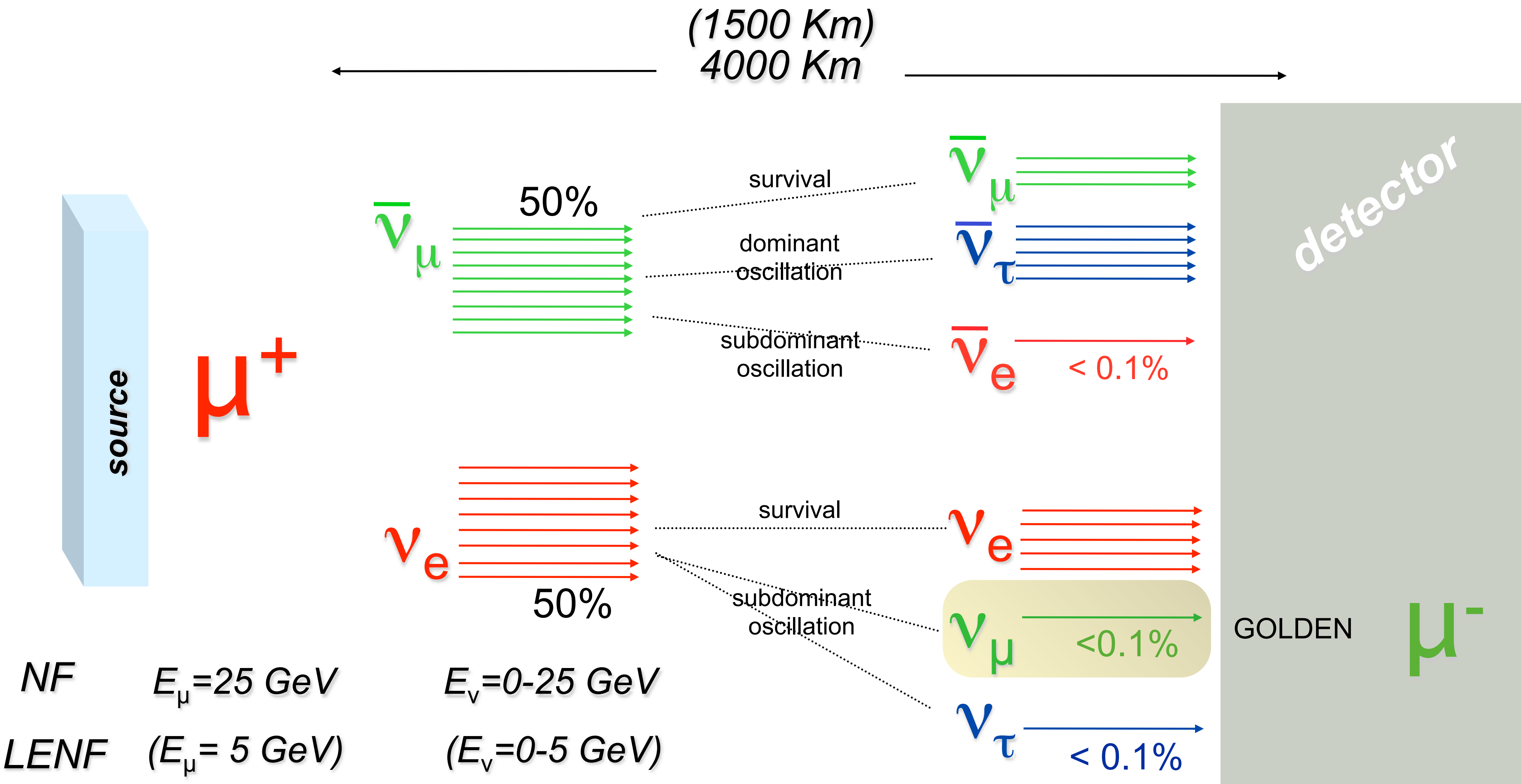

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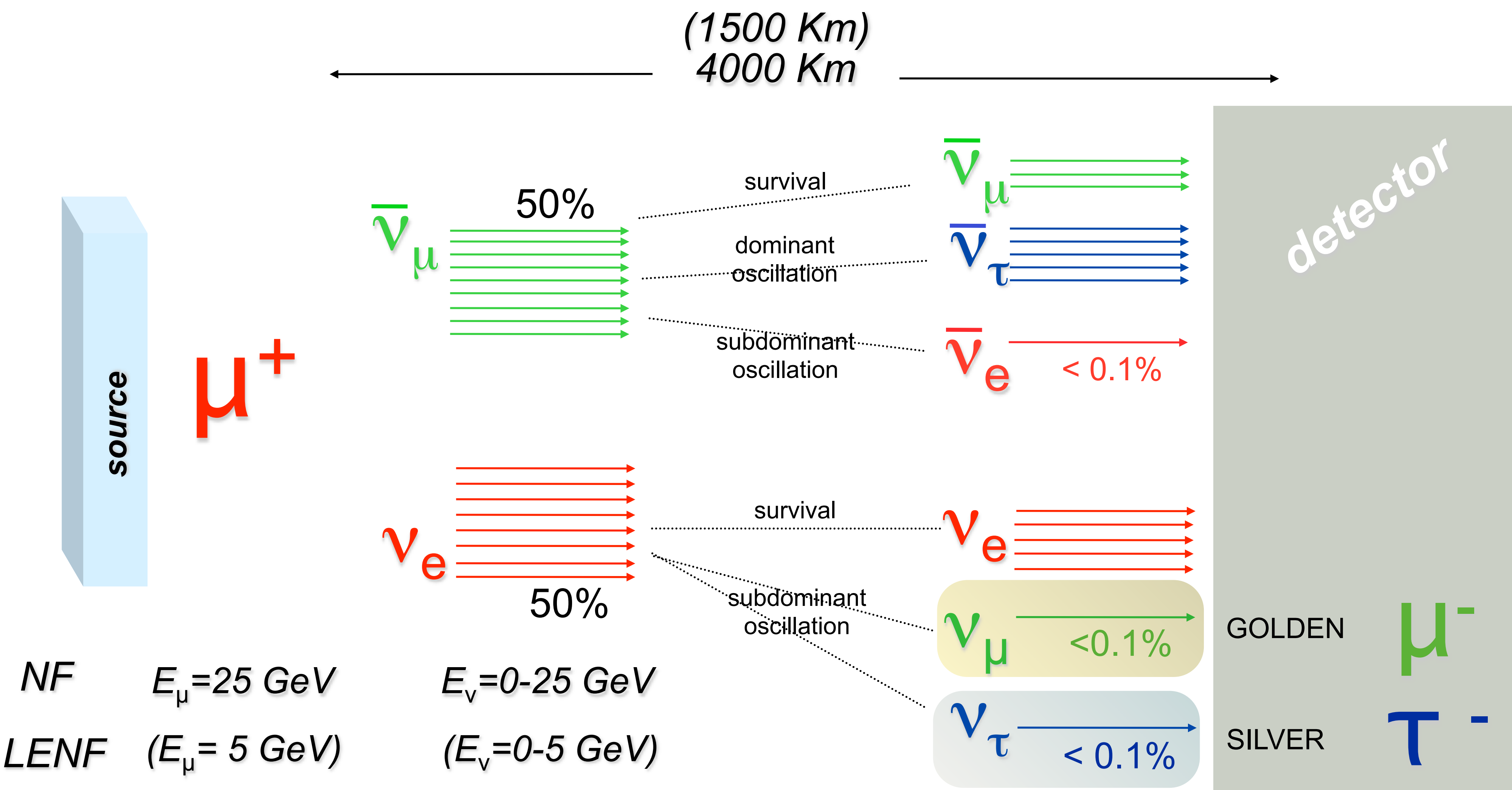

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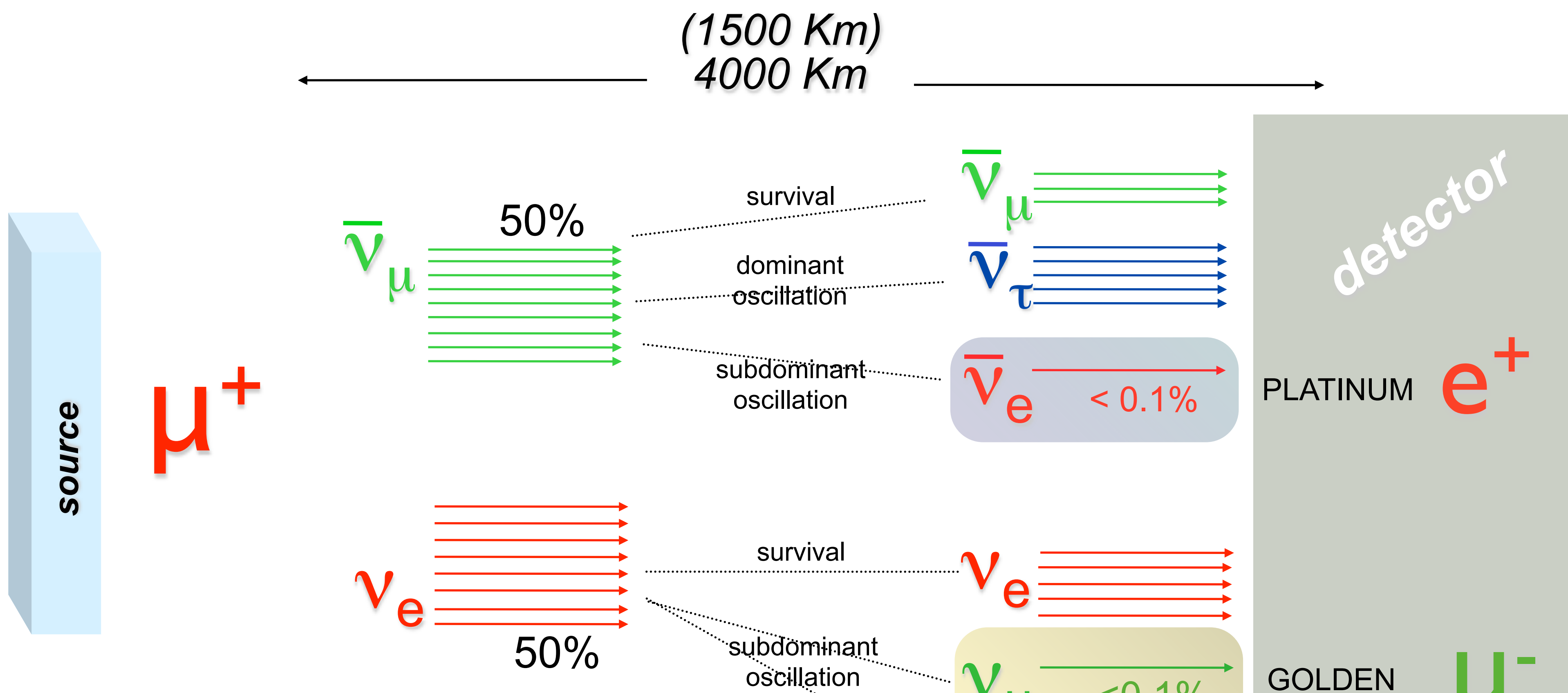


NF	E_μ=25 GeV	E_ν=0-25 GeV
LENF	(E_μ= 5 GeV)	(E_ν=0-5 GeV)

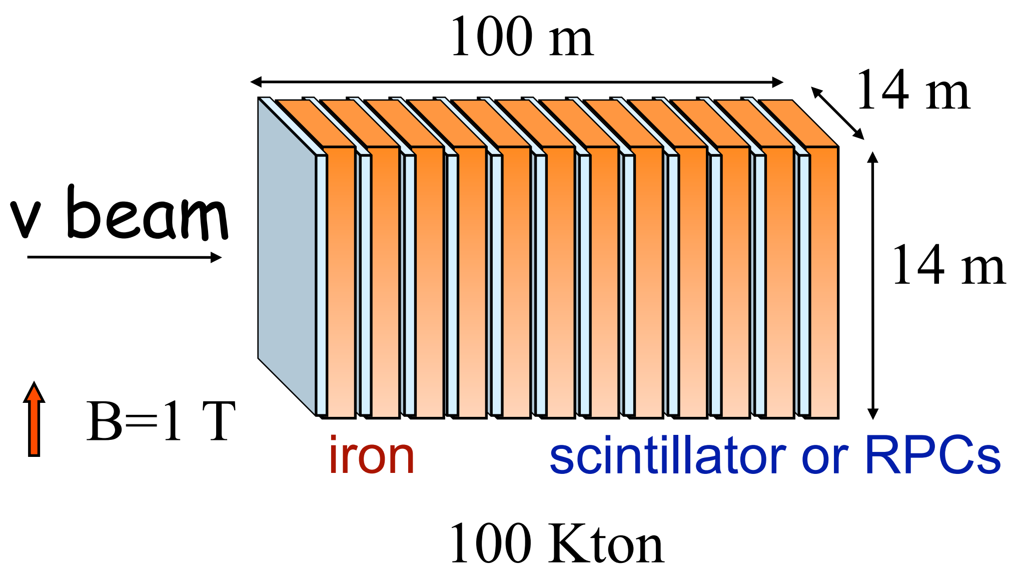
Detector options

	MIND	TASD	LArg	Emulsions
golden	yes	yes	yes	yes
silver	no	may be	may be	yes
platinum	no	may be	may be	may be
required R&D	*	**	****	**
cost	*	***	**** (?)	**
mass at reasonable cost and complexity	100 kton	20 kton	100 kton (?)	15 kton
status of simulations for (LE)NF	****	**		*

Baseline detectors

- MIND is baseline for conventional 25GeV NF. Why ?
  - Based on proven technology (MINOS). Extrapolation is ~simple
  - Golden is the main channel (more statistical power)
    - Other channels have small contribution to standard oscillation physics
  - TASD and MECC are proven technologies (except for the magnet) but are limited by mass
  - LArg is still in R&D phase
- TASD is baseline for LENF
  - Low threshold and excellent resolution
  - Proven technology (NOvA) except for magnet

The golden detector: MIND



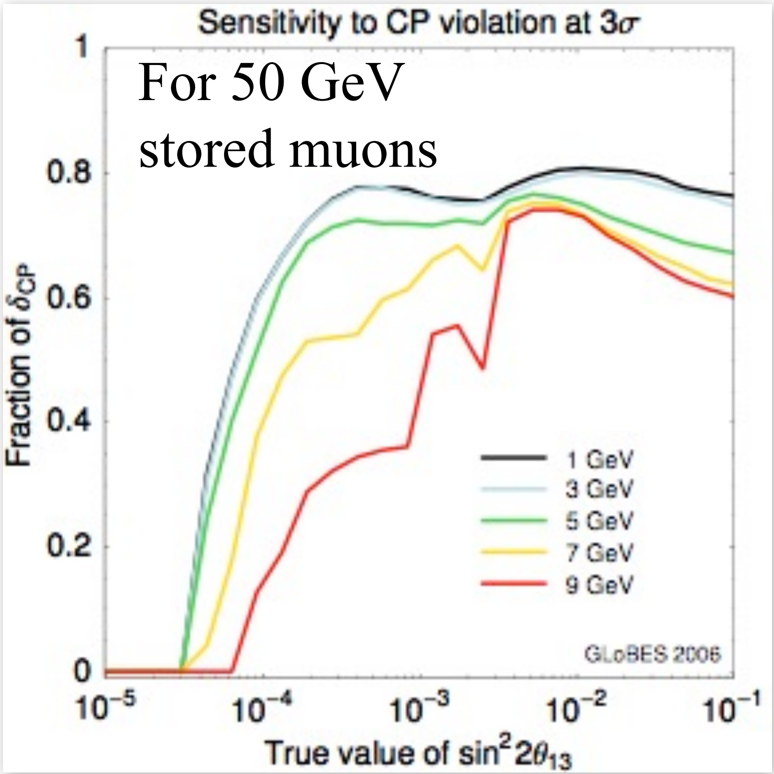
the energy threshold is high

cannot detect electrons or taus

- Mind simulation, reconstruction and analysis has evolved significantly (thanks to Andrew)
- Motivation of the ongoing analysis:
  - Realistic simulation and reconstruction
  - Reduce energy threshold

Energy threshold

CP sensitivity for different E_ν thresholds



This is the main parameter to be optimised

- Sensitivity saturates at 3 GeV (for 50 GeV muons)
- It should saturate around 2.5 for 25 GeV stored muons)
- We should aim for an efficiency plateau at ~2.5 GeV

1. Improvements in event reconstruction
2. Detector optimisation

Evolution of the analysis

<table>
<tr><th></th><th>Event generation</th><th>Detector</th><th>Particle transport simulation</th><th>Digitisation</th><th>Reconstruction</th><th>Analysis</th></tr>
<tr><td>1</td><td rowspan="2">DIS
(lepto)</td><td rowspan="4">old segmentation
(4+1)</td><td rowspan="2">G3</td><td rowspan="2">smearing
(1 cm)</td><td>smearing</td><td>L, P, Qt cuts</td></tr>
<tr><td>2</td><td rowspan="4">Full reconstruction for muon
(Pattern rec.
+ Kalman Filter)

Smearing for hadron shower</td><td rowspan="5">P, Qt
sigma_p/p,

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(assume perfect view matching)</td></tr>
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(2.5 + 2)

dipole field</td></tr>
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<tr><td>8</td><td>toroidal field</td><td>include toroidal field rec.</td></tr>
<tr><td>9</td><td>Optimise segmentation</td><td>Full digitisation</td><td>Optimise reconstruction</td><td>Optimise analysis</td></tr>
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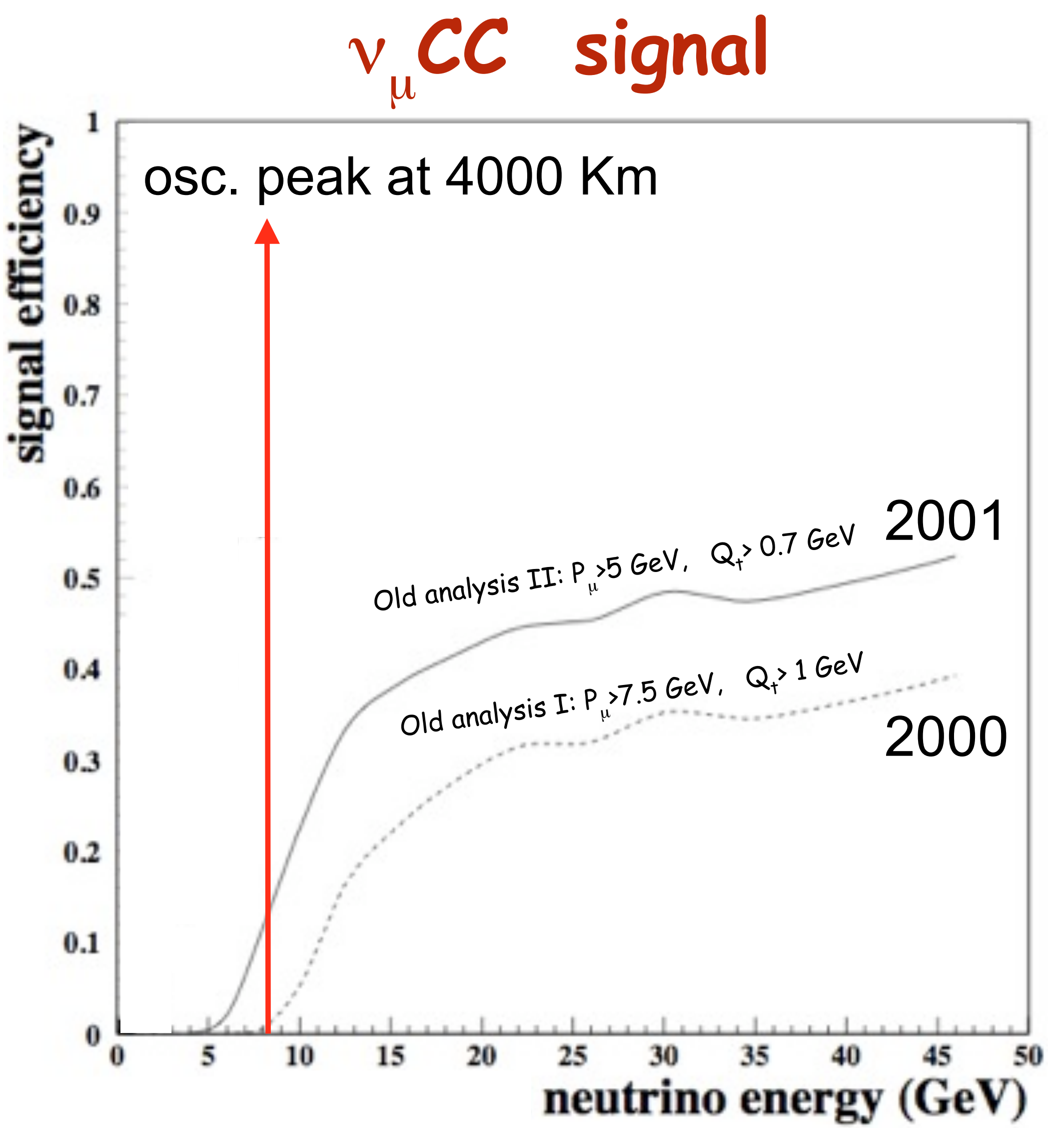
Evolution of the threshold

- 2000: optimised for very small θ_{13}
- 2001: “ “ “
- 2006: optimised for θ_{13}-δ
- 2009: include PR
- 2010: include QE (not shown but improves)



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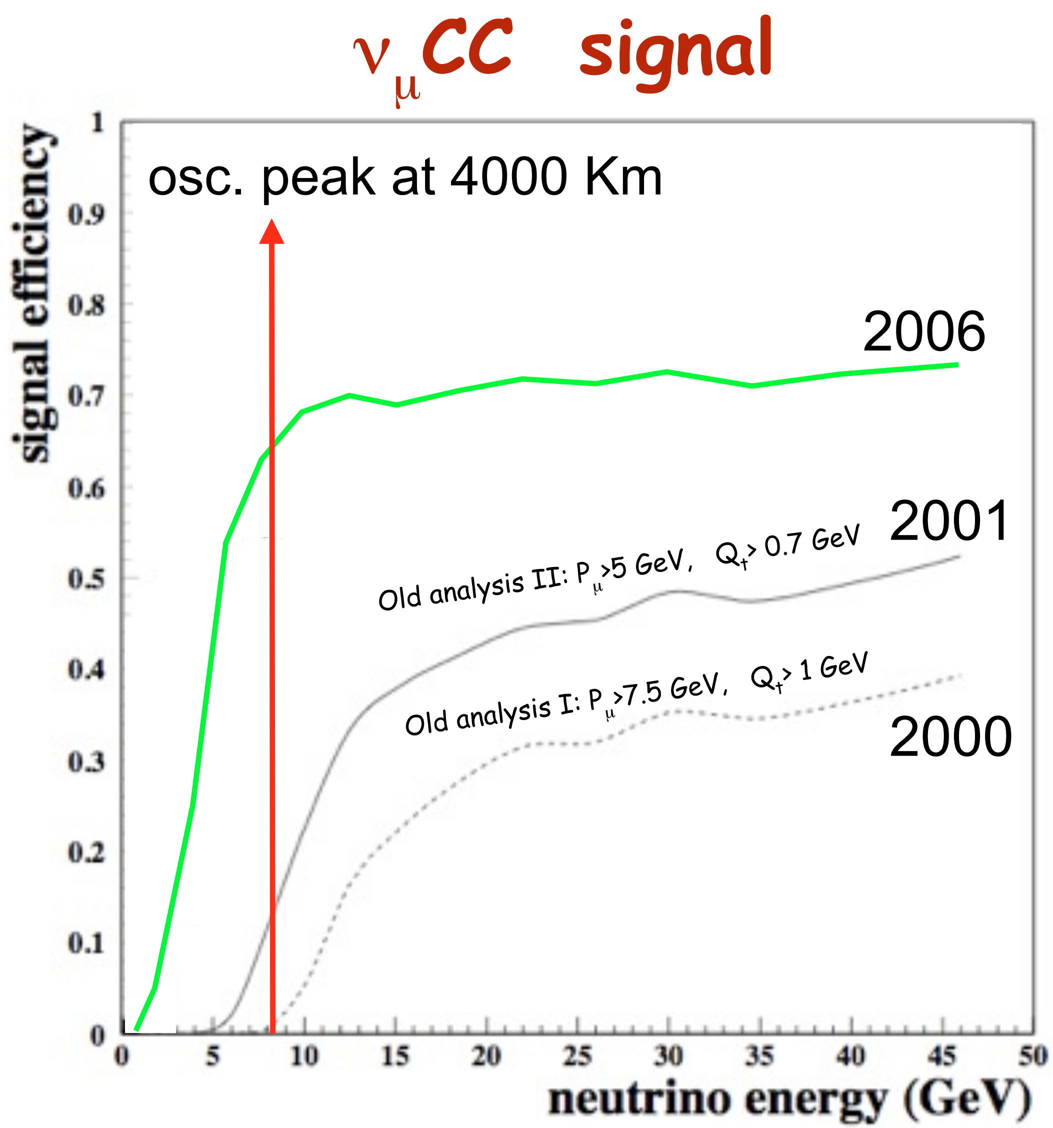

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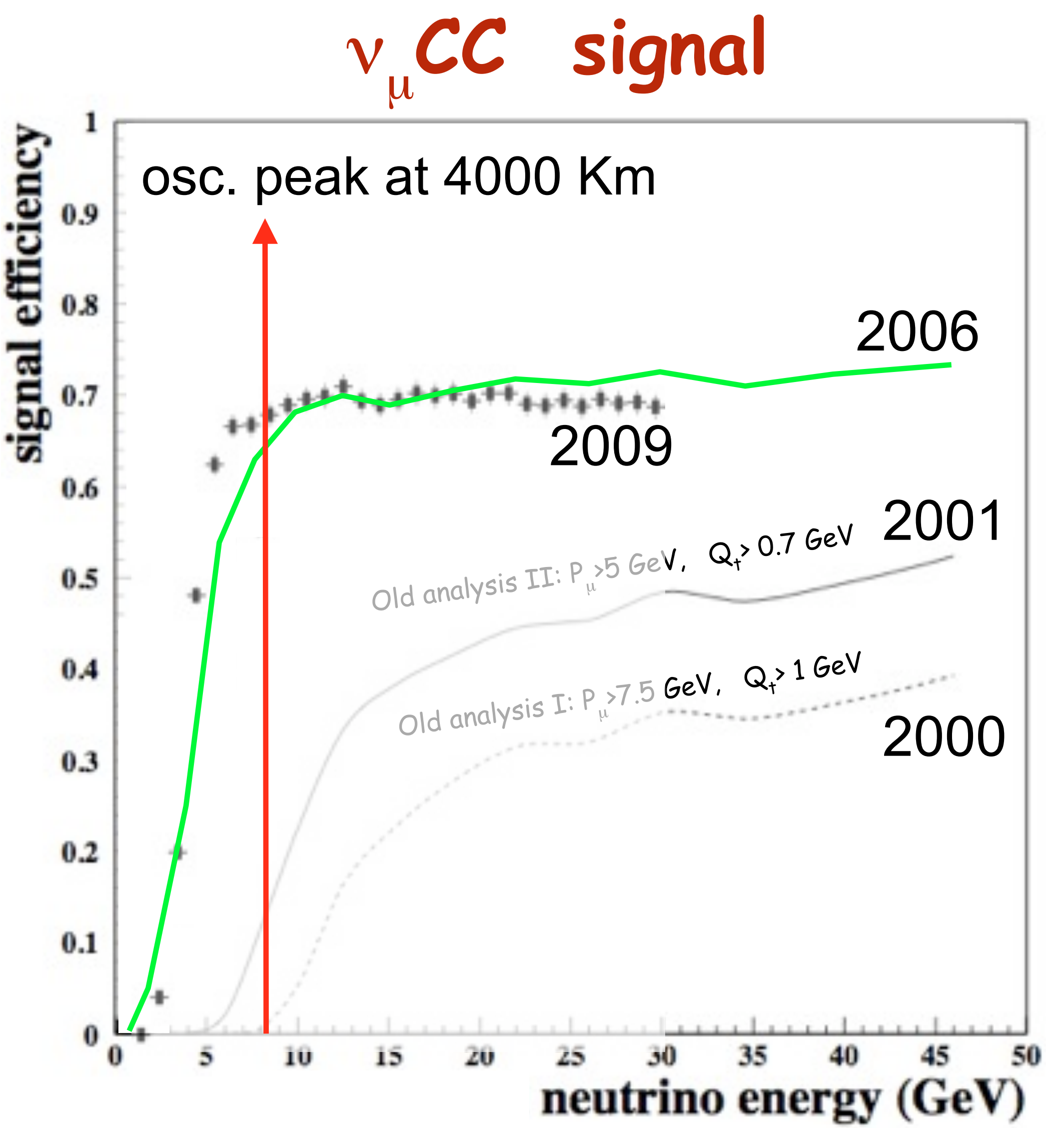
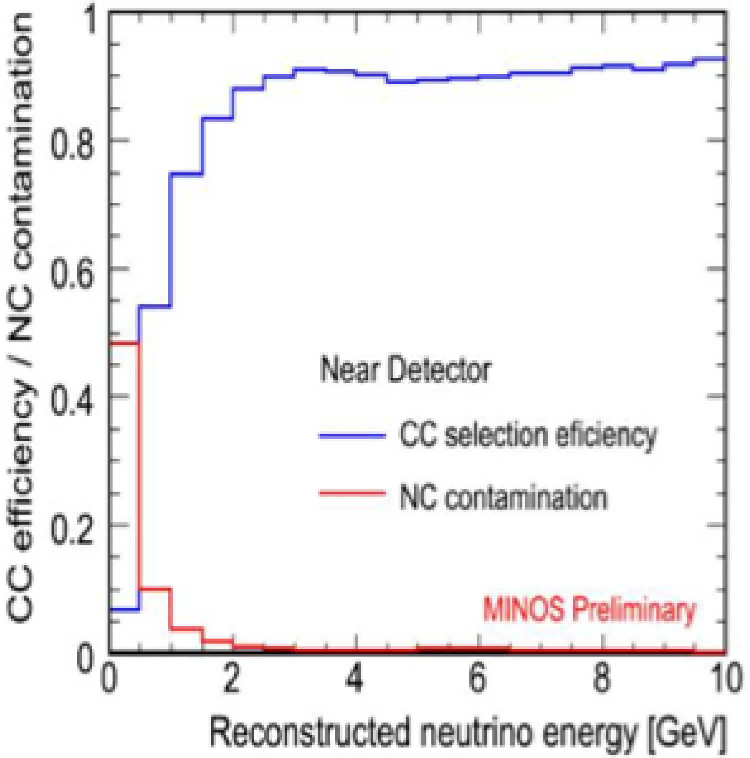


Comparison with MINOS

- Comparison with MINOS is very important for the credibility of the MIND analysis
- Current analysis uses CC/NC discriminators similar to MINOS
- Aim is to get similar efficiencies for similar cuts



Simulation

- MIND curve should improve when including QEL
- 4 cm iron against 2.5 in MINOS

Done !!!. **See Andrew's talk**

Reconstruction

- Use a more sophisticated algorithm to find muon candidate track
  - Improved cellular automaton
  - Pulse height information (MINOS)

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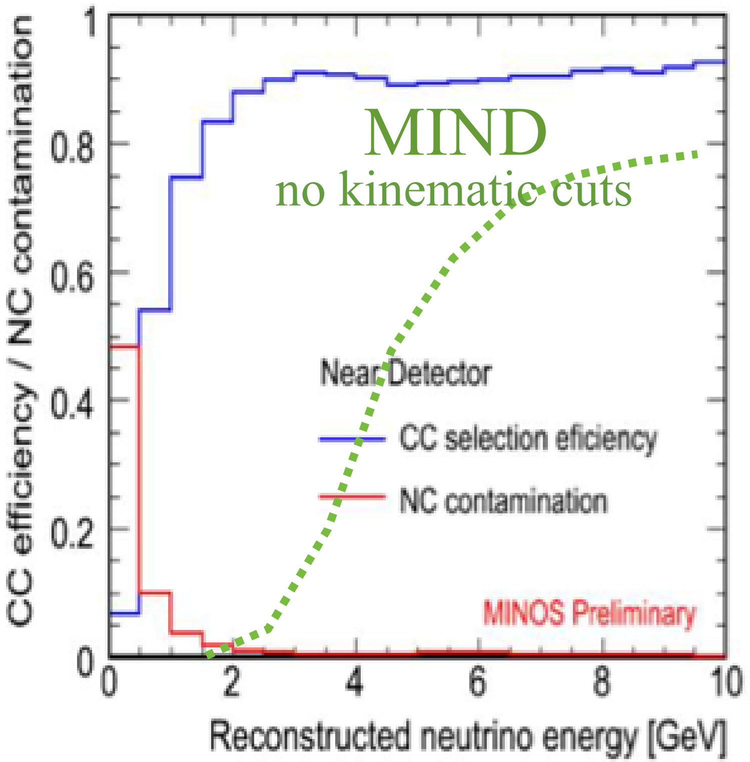

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Reconstruction

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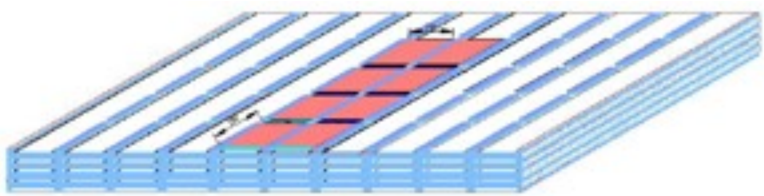
Beyond MINOS: optimisation

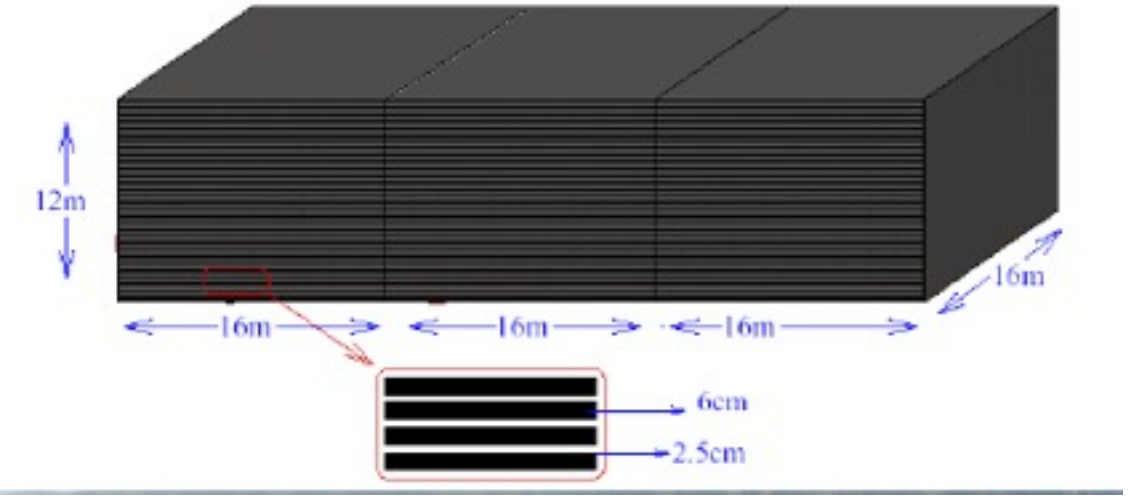
- MIND is essentially a 20 x MINOS detector with improved capabilities
- Size
  - Transverse x 2: **longer scintillator bars, attenuation ?**
  - Longitudinal x 5: straightforward
- B field: **20% increase** (feasible). **See talk by J. Kilmer**
- Segmentation: To be optimised, but higher than MINOS.
  - **Thinner scintillator bars: less light yield**
  - **Shape:**
    - Space resolution (triangular) vs light yield (rectangular)
- Performance: critical issues
  - Charge mis-id
  - Hadron shower angular resolution
    - Shower profiles, transverse segmentation

INO

- Indian Neutrino Observatory (INO):
  - Main purpose: atmospheric neutrinos
  - Can be used for beam neutrinos
- Detector size: 48 m x 16 m x 16 m
- Readout: RPCs
- B=1.5 T

See talk by S. Bheesette



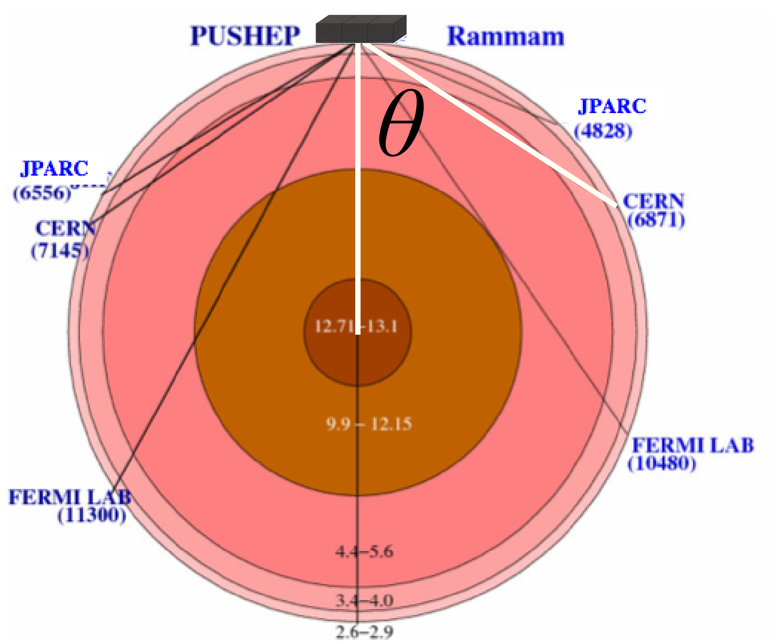


- Far detector at magic baseline of neutrino factory for most facilities:
  - CERN to INO: distance = 7152 km
  - JPARC to INO: distance = 6556 km
  - RAL to INO: distance = 7653 km

INO at ideal position!

Performance study with sim.

- No performance study exists for NF. MIND framework could be used



$$\lim_{\theta \to 0} \mathrm{INO}(\theta) \simeq \mathrm{MIND}$$

change the beam direction and exchange transverse/longitudinal sizes

(adjustable parameters)

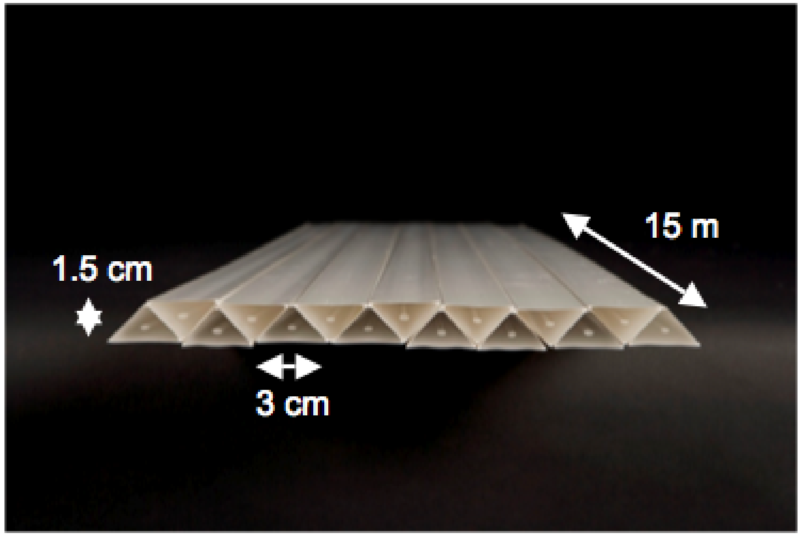
- Iron thickness is different: an adjustable parameter
- B field is different: a minor issue
- Active layers and electronics probably too. Different digitisation

Neutrino event generation | Detector transport | Digitisation | Event reconstruction | Analysis

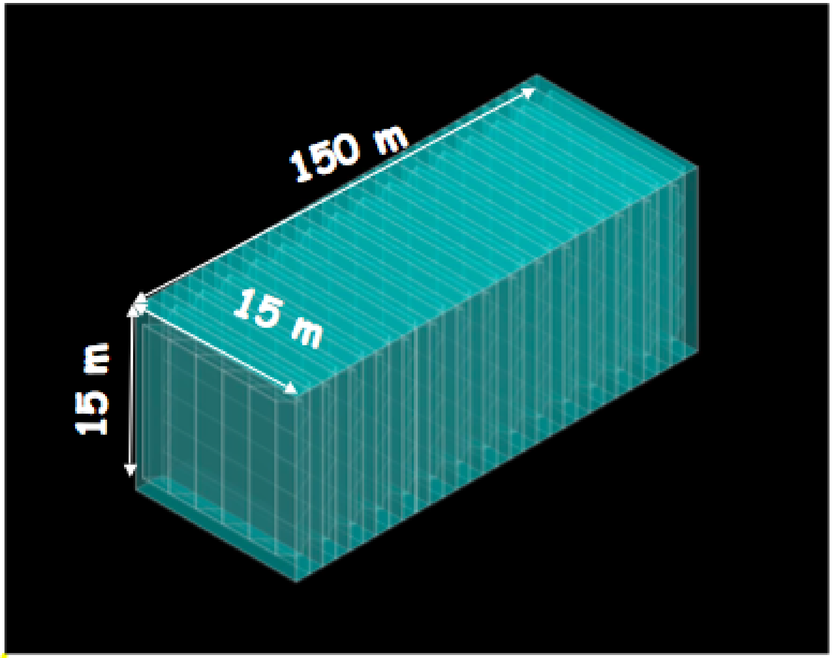
TASD

35 kT (total mass)
10,000 Modules (X and Y plane)
Each plane contains 1000 cells
Total: 10M channels

0.5 Tesla
Reconstructed position resolution ~ 4.5 mm



- Baseline detector for LENF
- Able to track muons very accurately
- Able to identify the e charge at low energies



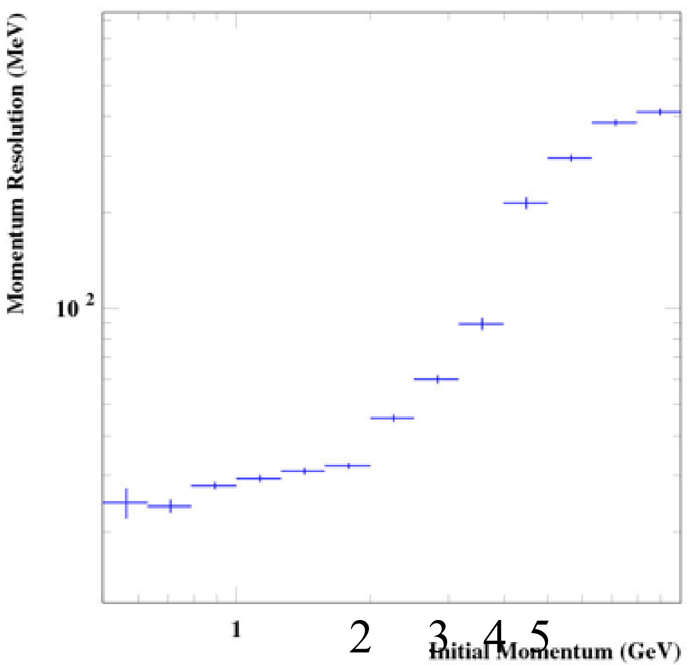
cost is still an issue

Not an option for standard NF

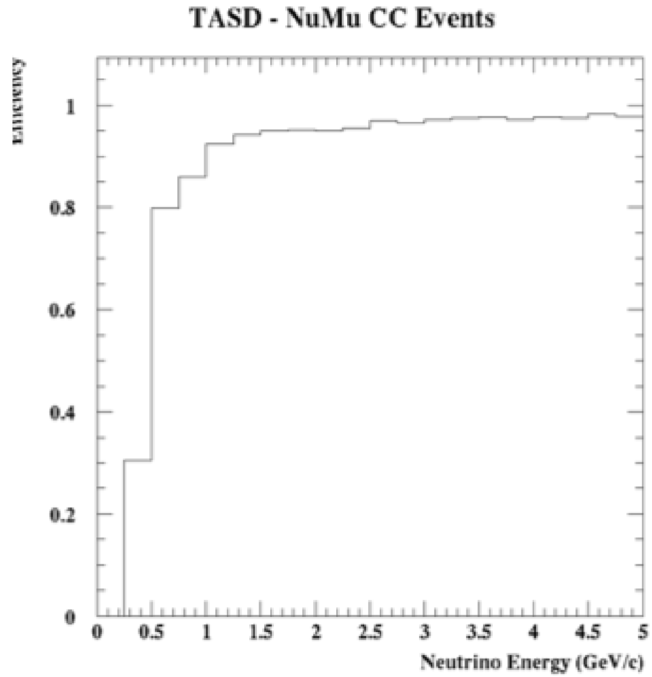
Why TASD ?

- Because it has much lower energy threshold and much better space and energy resolution

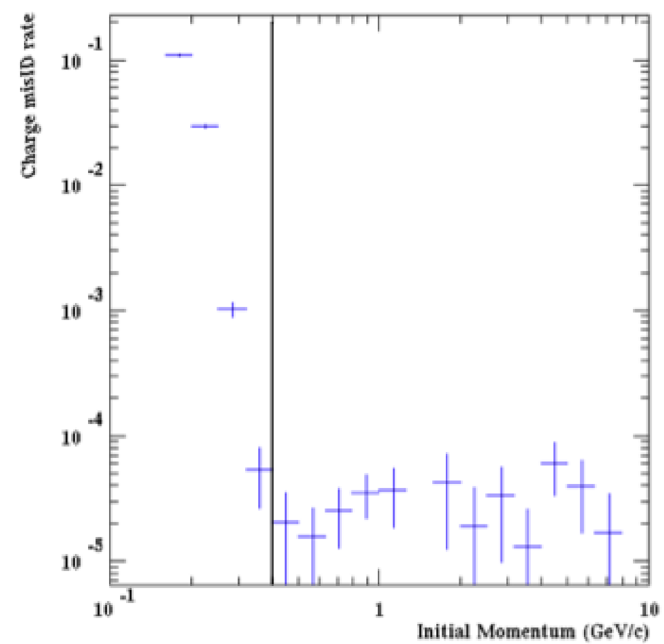
momentum resolution 2% at 3 GeV/c



Eff. plateau at 1 GeV



< 10^{-4} mis-ID above 0.4 GeV/c



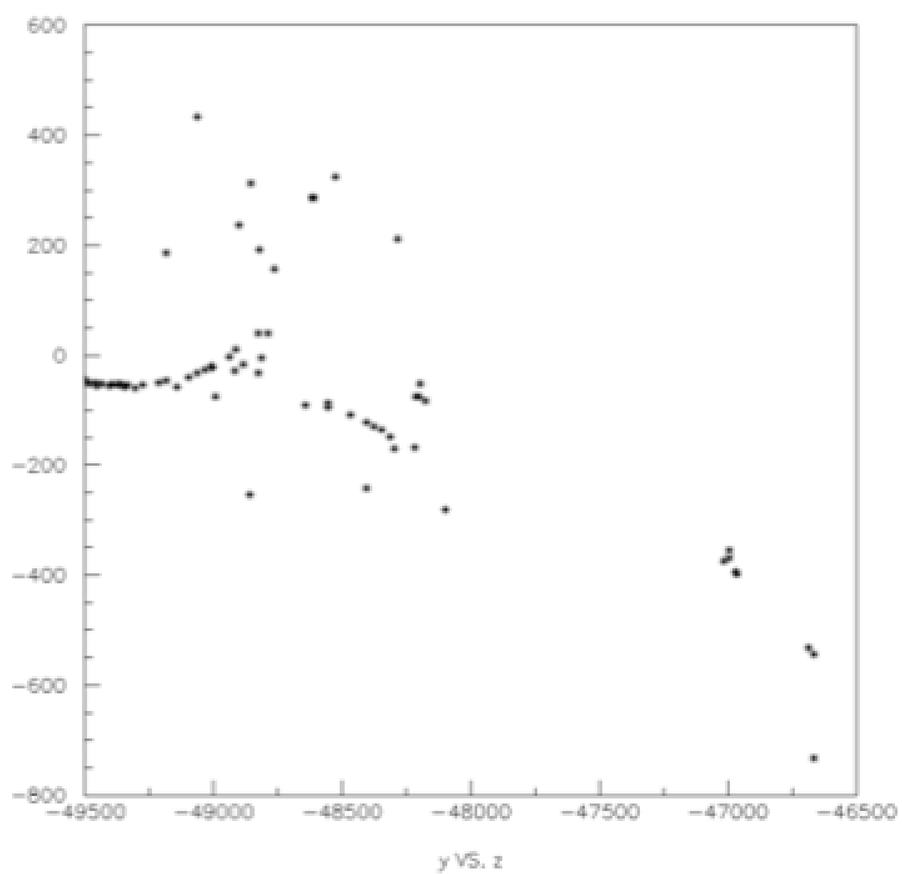
Which facility ?

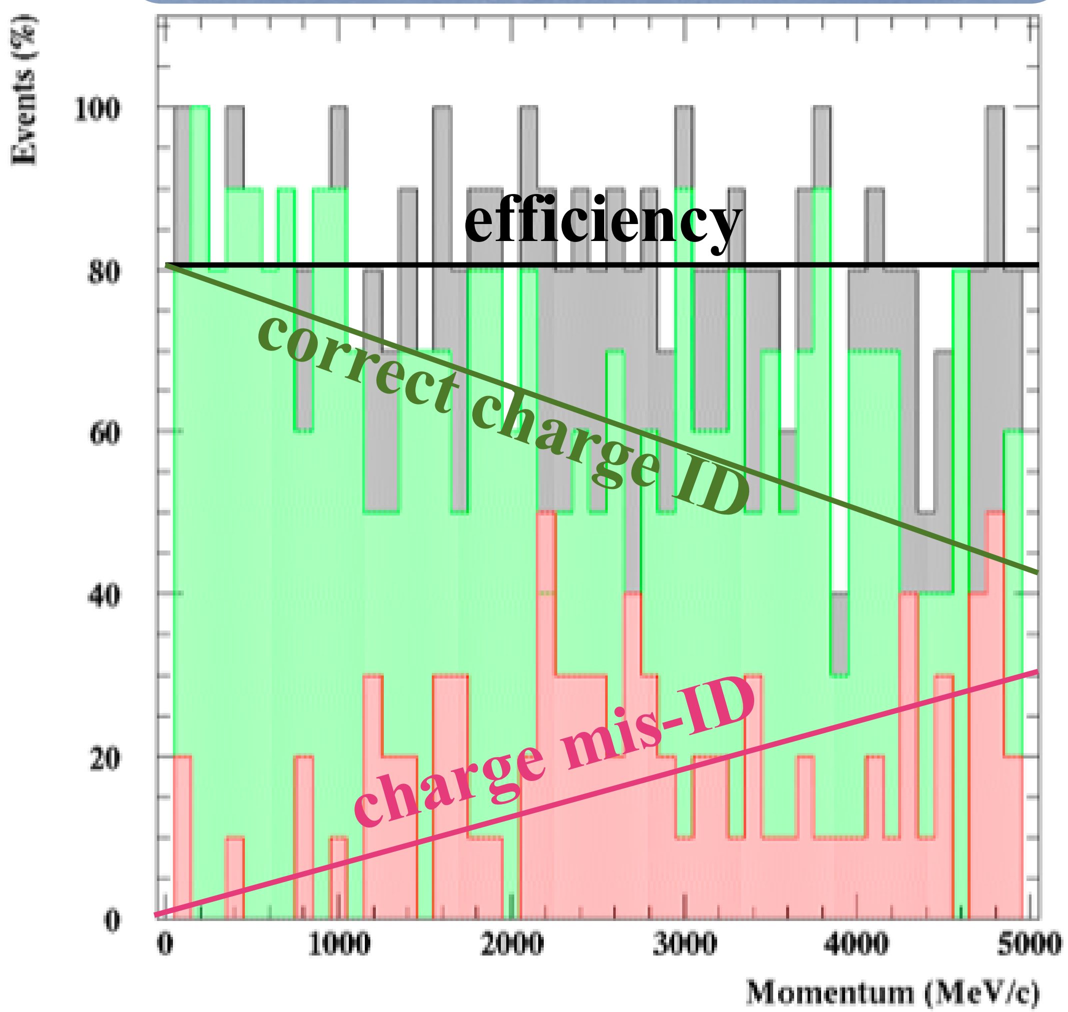
- TASD is not worth for standard NF (25 GeV)
  - No benefit below 3 GeV neutrino energy
  - Platinum channel only possible at low electron energies
  - MIND has more mass, which is not compensated by better resolution
- But it is very interesting for LENF (5 GeV)
  - High efficiency and small charge mid-ID above 0.5 GeV
  - Platinum channel is possible (at which efficiency ?)
  - **See talks by M. Ellis and T. Li**

Electron charge identification

- < 30% mis-ID for 80% eff
- Aim is 10^{-2} for 35% efficiency

- charge ID by visual scan





TASD simulations

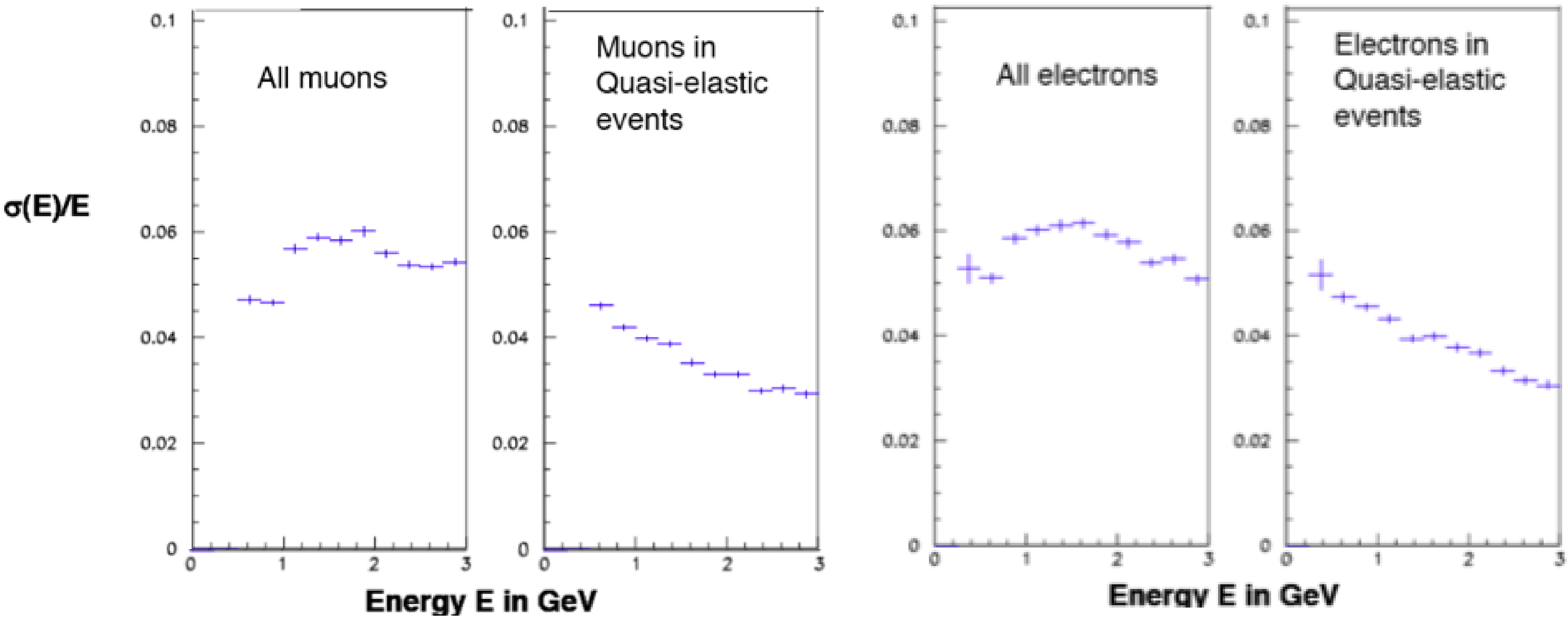
- A quite advanced digitisation exists for TASD
- However only single particles have been studied
  - Efficiency, resolution and charge mis-ID for muons
  - Charge mis-ID with visual scan for electrons
- A full reconstruction and analysis for neutrino events is missing
  - In principle one could use the MIND framework

$$\lim_{Fe \to 0} \mathrm{MIND(Fe)} = \mathrm{TASD}$$

  - Scintillator bars, PD and electronics are the same. This is the most difficult part
  - B field production is different: a minor issue

NOvA is a good TASD prototype

- Similar size and material
- In principle no other intermediate step should be needed



NOvA has 30% dead material (tubes containing liquid scintillator tubes)

Resolution should be better for TASD with only 5% dead material

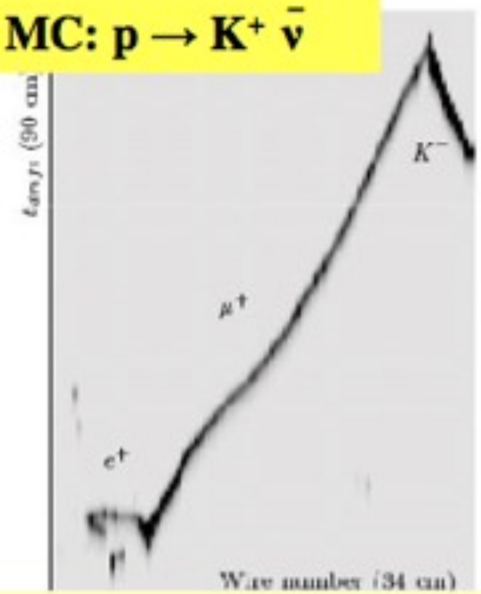
Beyond NOvA

- TASD have similar size but 20 times the number of channels
- Cost: NOvA =145 M$, TASD ~ 6xNOvA
  - Driven by scintillator, PD and electronics
  - Solid (6-10 $/Kg) vs liquid (~3 $/Kg). **Talk by A. Pla**
- Solid scintillator vs liquid in NOvA: not a problem, only cost
- B field: **No field in NOvA. This is a critical R&D issue**
- Segmentation: To be optimised, but higher than NOvA.
  - **Thinner scintillator bars: less light yield**
  - **Shape:**
    - Space resolution (triangular) vs light yield (rectangular)
- Performance: critical issues
  - Electron charge identification
  - Muons from hadron decay and pion to muon misidentification

Liquid Argon TPCs

- Motivation
  - Similar density to TASD but can also use scintillation and ckov light
  - Less mass limitation: number of channels increases with surface and not with volume
  - Good for proton decay searches

LAr MC: $p \rightarrow K^+ \bar{\nu}$

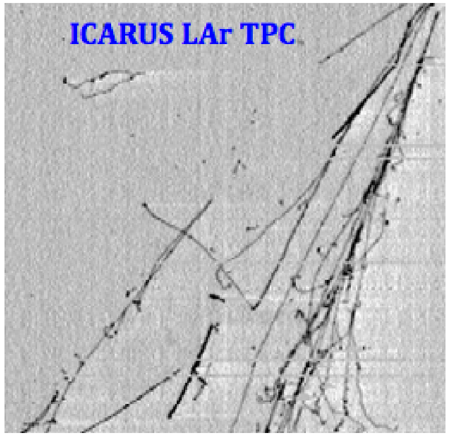


10x efficiency than WC
only way to reach 10^{35} years

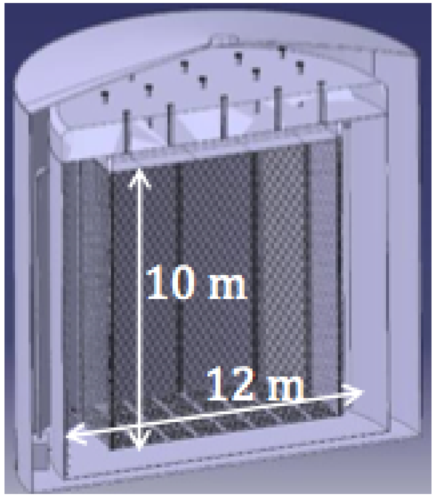
See talk by B. Baller

Status

- Efforts in US, Japan and Europe
- Important achievements:
  - Double phase readout, purity, magnetic field, etc
- Critical R&D items:
  - Long drift distances (20 m), purity, tanks
  - Magnetisation
- Performance:
  - **Need to complete MC studies for a NF**
  - **Need test beam:** to be proposed in 2010 (6 m^3)
- At least one intermediate step needed
  - GLACIER = 150 x ICARUS T600
  - 1 kton could be a good compromise →

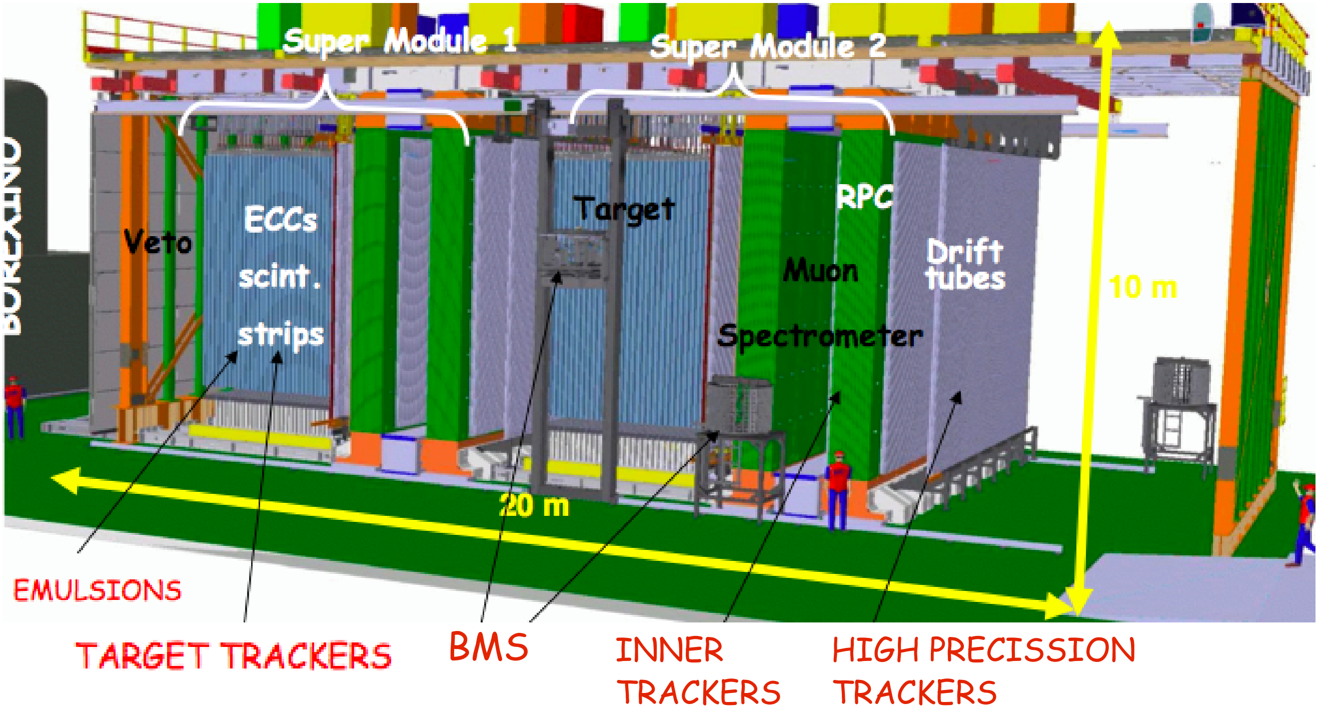


1Kton



Emulsions

- This technology could be able to detect all channels.
- It has been considered as a complementary detector at the intermediate baseline (4000 Km) mainly for the silver channel.
- Is this still the case ?
  - See next slides



(M)ECC issues

- Performance: Main issue is statistics. Solutions:
  - More mass
    - Scanning load is not the limiting factor
    - The problem is the cost. Possible solution is hybridisation.
  - Magnetising the emulsion part:
    - Improves the visible BR (x 3): $\tau \to h$, $\tau \to e$
    - Allows platinum: e-charge misid < 0.5 %
- Technology
  - "Not an issue" for non magnetic version. Basically scaled OPERA. But OPERA is very difficult !!!!
  - No studies for magnet: probably similar to TASD
- Cost
  - This is the limiting factor (Lead/emulsion is o.o.m. 10 M€/Kton)
  - Missing cost estimate for the magnet (in the case of MECC)

Is this still an option ?

- It has been considered as a complementary detector at the intermediate baseline (4000 Km) mainly for the silver channel.
- Is this still the case ?
  - OPERA has demonstrated to be a very complicated detector
  - Scalability is not a trivial issue
  - Emulsions need visual scan (not an electronic devise !!!).
  - There is no R&D effort !!! (As far as I know)

Conclusions

- MIND performance is being understood. Full simulation/ reconstruction has evolve significantly
  - Threshold is going down
  - Almost at the level of comparing with MINOS data/MC
- INO R&D going on, but missing performance study with simulations
- TASD performance should be further understood
  - Electron charge identification
  - Efficiency and backgrounds in neutrino interactions
- A lot of progress in LArg R&D, but missing performance study with simulations

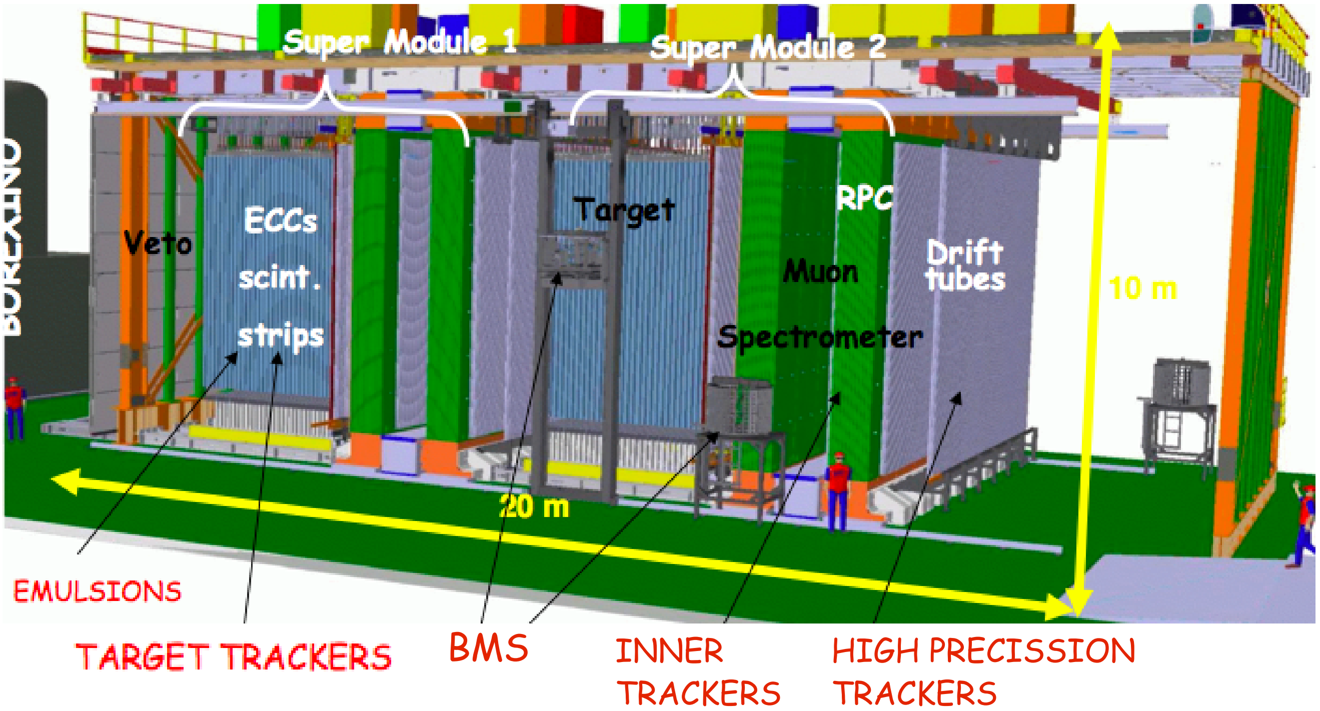
backup

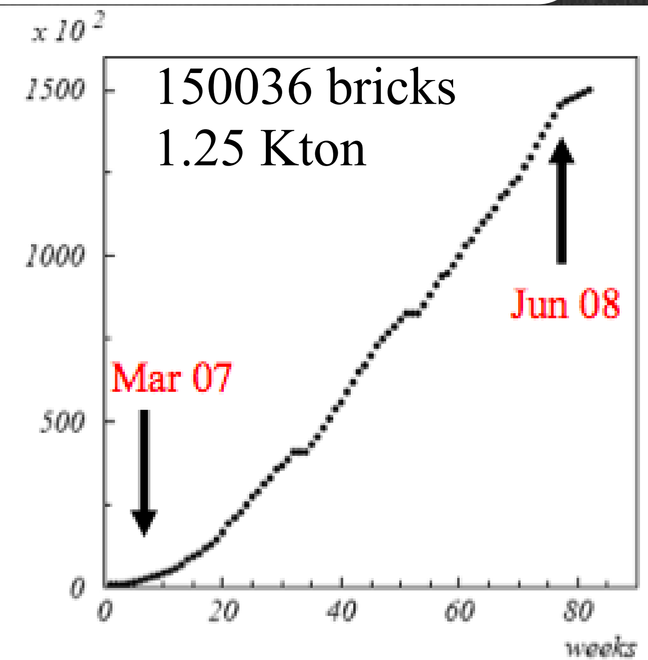
Conclusions

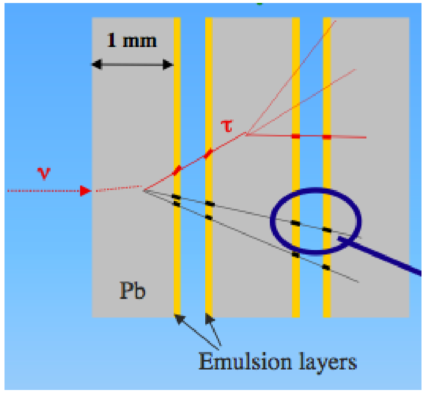
- Charge mis-ID in MIND should below 10^{-3} for low neutrino energies, and much lower for high neutrino energies. There is still room for improvement
- Focused now in recovering efficiency at low energy. Aim should be plateau at ~2.5 GeV
- Moving now to NC rejection using MINOS strategy
- TASD is now focused in LENF.
- Electron charge-ID seems to be possible at low energies. Aim should be 10^{-2} at ~35% efficiency, sufficient to improve oscillation parameters
- Full simulation/reconstruction of neutrino interactions needed to understand the final detector capabilities
- New common software framework (full sim/rec) is evolving fast. Once ready the performance evaluation process should accelerate for both detectors

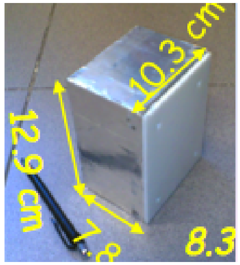
Status of OPERA

Talk by Luca Stanco (Padova)





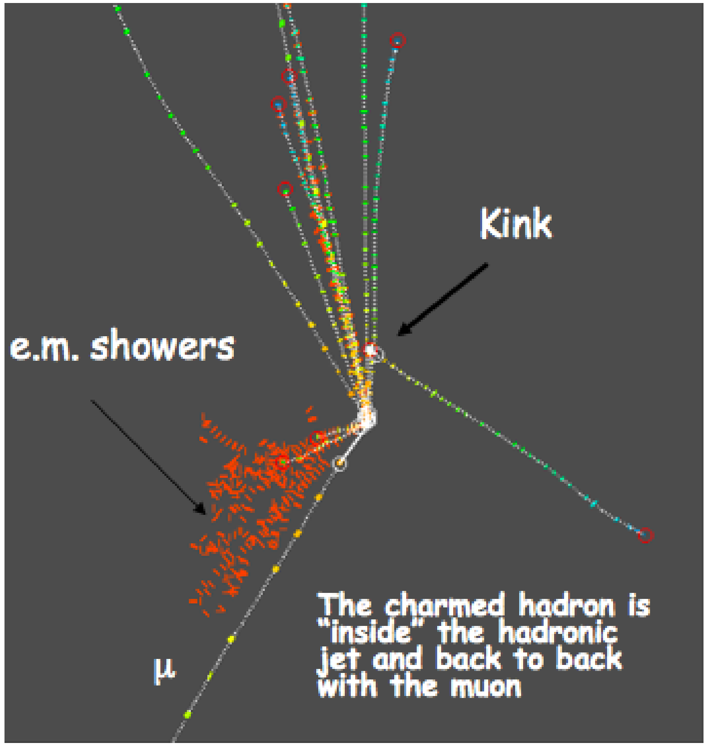


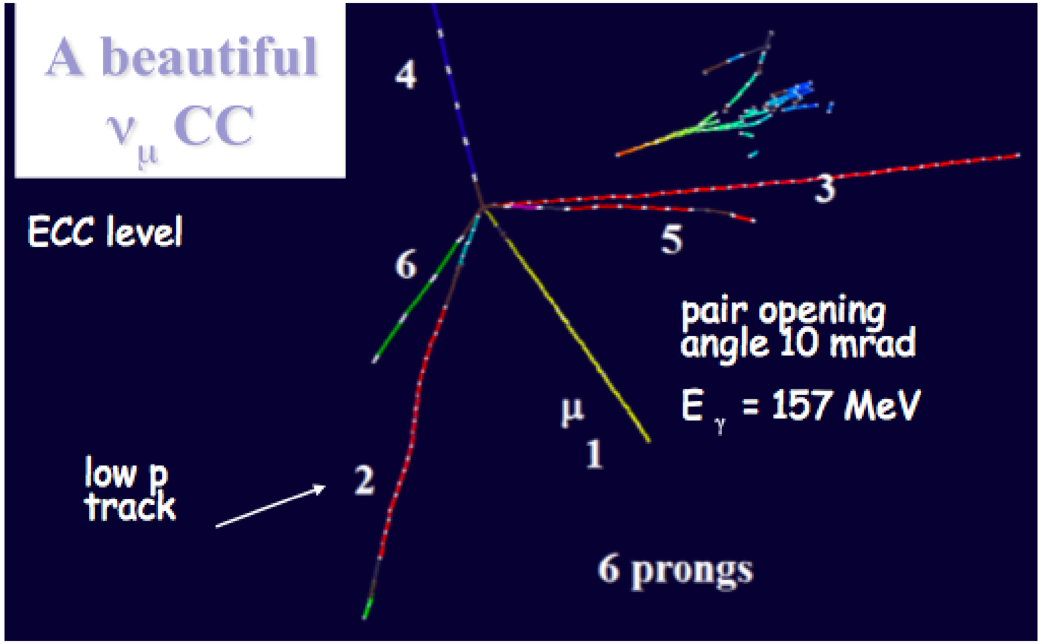


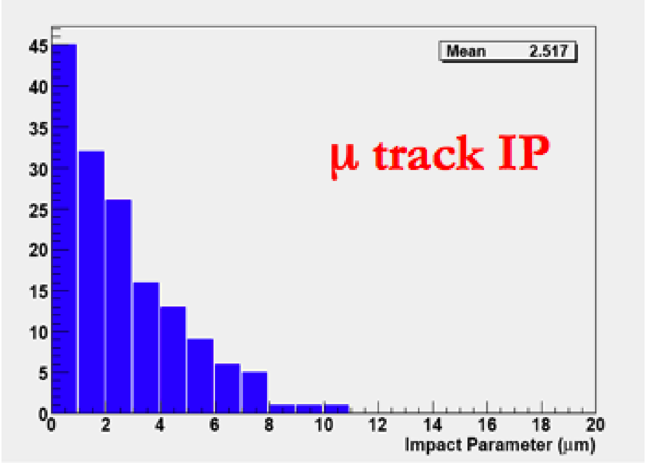
- Prediction of the brick where the interaction occurred — Part. validated
- Alignment and development of the Changeable Sheets — Fully validated
- Scanning of the Changable Sheets — Fully validated
- Extraction of the Bricks at the rate of CNGS events — Fully validated
- Identification of the primary vertex — In progress
- Kinematic reconstruction and decay search — In progress

Detector working beautifully

A charm event







Oscillations performance

Full mixing, 5 years run, 4.5×10^{19} pot / year and MD =1.3 Kton
Efficiency before τ identification: $\varepsilon_{trigger} \times \varepsilon_{brick} \times \varepsilon_{geom} \times \varepsilon_{vertex}$ location = 99% x (≥70%) x 94% x 90%

τ decay channels	ε(%)	BR(%)	Signal $\Delta m^2 = 2.5 \times 10^{-3}\ eV^2$	Signal $\Delta m^2 = 3.0 \times 10^{-3}\ eV^2$	Background
$\tau \rightarrow \mu$	17.5	17.7	2.9	4.2	0.17
$\tau \rightarrow e$	20.8	17.8	3.5	5.0	0.17
$\tau \rightarrow h$	5.8	49.5	3.1	4.4	0.24
$\tau \rightarrow 3h$	6.3	15	0.9	1.3	0.17
ALL	ε×BR=10.6%		**10.4**	**14.9**	**0.75**

2006: technical run, 0.76×10^{18} pot
2007: 0.824×10^{18} pot
2008: 1.78×10^{19}
2009: 3.6×10^{19} pot expected
2010: 4.5×10^{19} pot expected

Aim is $22.5\ 10^{19}$ total

With 2008-10 runs we may be able to exclude tau appearance with a reasonable probability

OR

at a not so large probab. to confirm tau appearance

(M)ECC issues

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  - More mass
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    - The problem is the cost. Possible solution is hybridisation.
  - Magnetising the emulsion part:
    - Improves the visible BR (x 3): $\tau \to h$, $\tau \to e$
    - Allows platinum: e-charge misid < 0.5 %
- Technology
  - Not an issue for non magnetic version. Basically scaled OPERA
  - No studies for magnet: probably similar to TASD
- Cost
  - This is the limiting factor (Lead/emulsion is o.o.m. 10 M€/Kton)
  - Missing cost estimate for the magnet (in the case of MECC)

Overview

Overview

- New **software** framework for MIND/TASD getting ready

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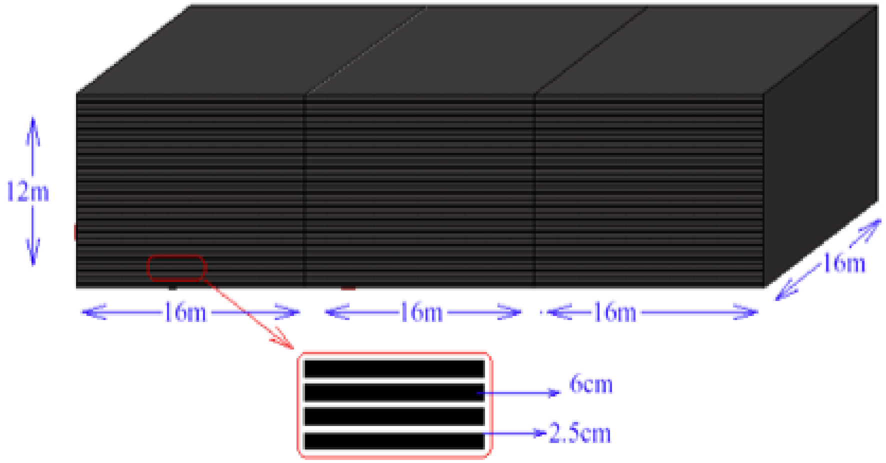
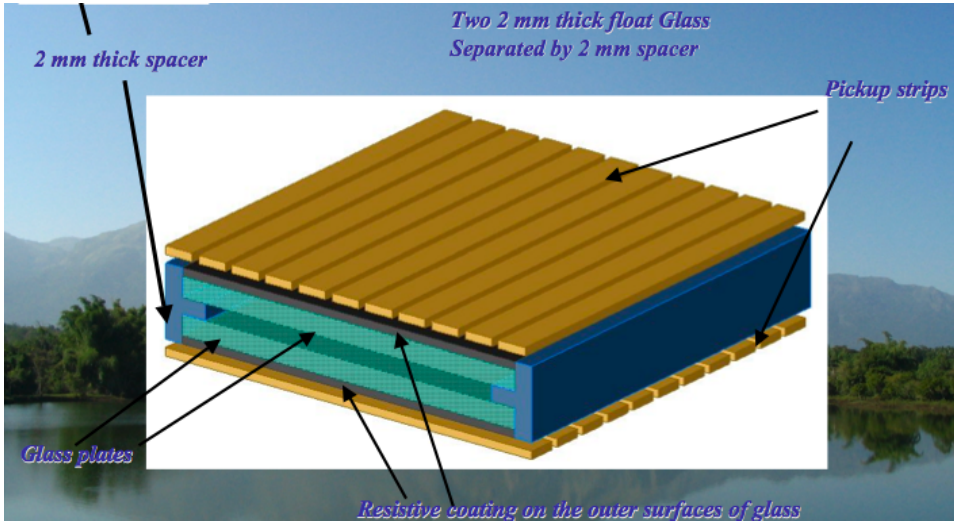
- **LArg-US** programme has almost completed phase on small prototypes and will go soon to the 90Ton MicroBooNE detector
- **OPERA** has reached the 1.25 Kton mass. The detector is working beautifully but they have luck of statistics (2.5 x 10^{19} pot instead of 15x10^{19} pot at this time). Probability of observing tau appearance still small

Indian Neutrino Observatory

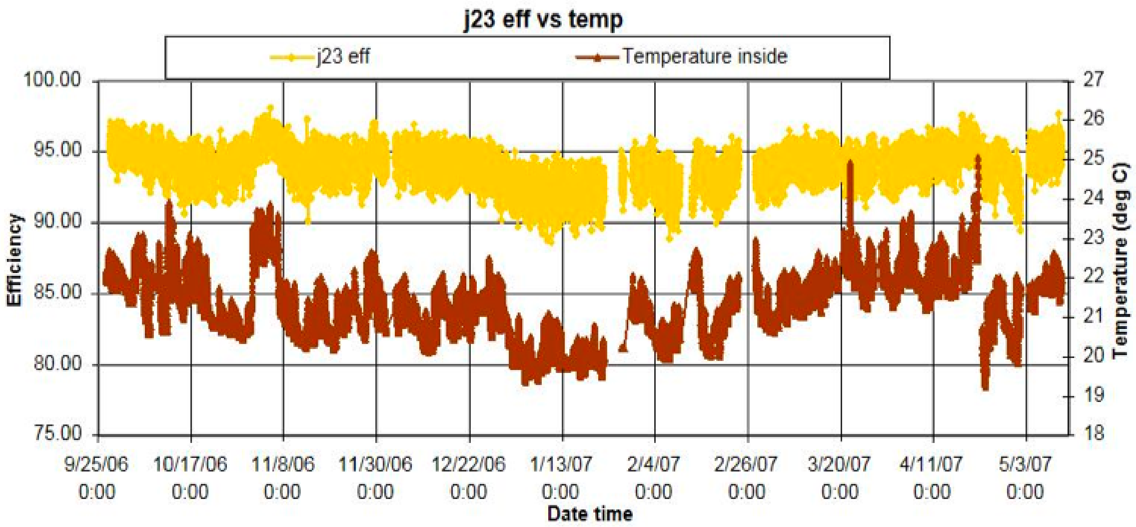
Talk by Naba Mondal (TIFR, Mumbai)

Magnetic 1.5 Tesla
RPC unit dimension 2 m X 2 m
Readout strip width 2 cm





RPCs



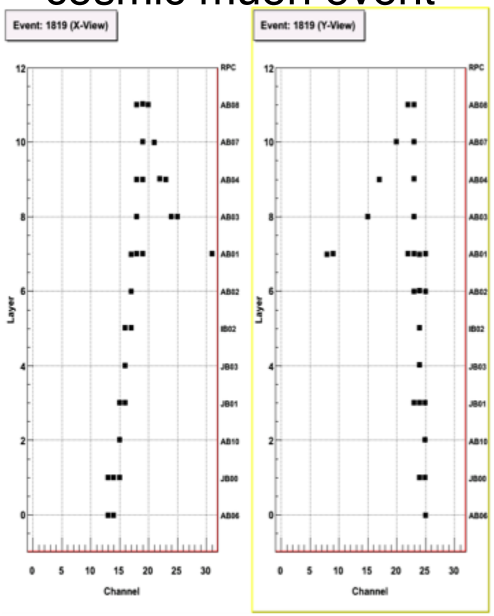
RPC long term stability

1m x 1m ready for mass production

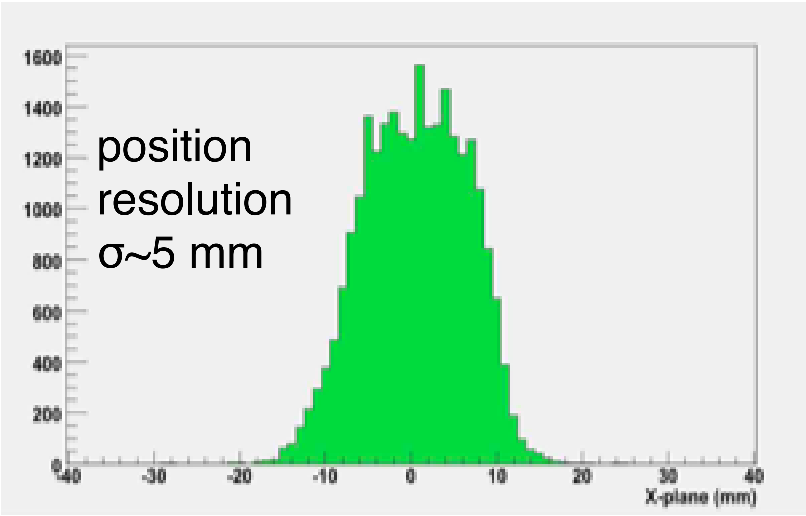
2m x 2m under test

Prototypes

cosmic muon event

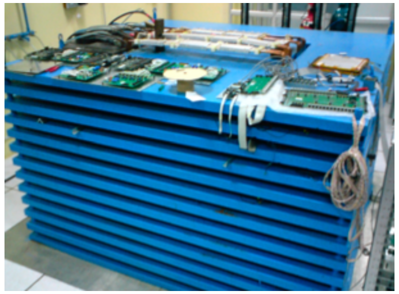


Prototype RPC Stack at TIFR tracking Muons



- *12, 1m² RPC layers*
- *13 layers of 5 cm thick magnetised iron plates*
- *About 1000 readout channels*
- *RPC and scintillation paddle triggers*
- *Hit and timing information*

Magnetised prototype at VECC



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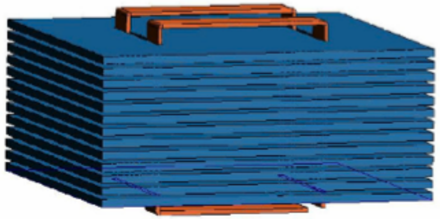
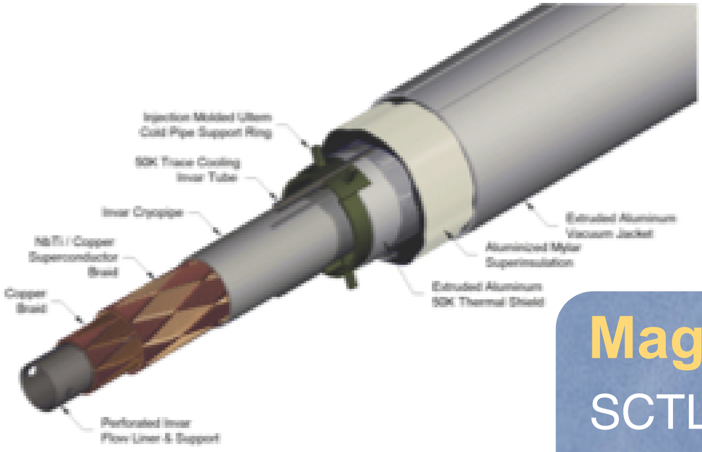


Project status

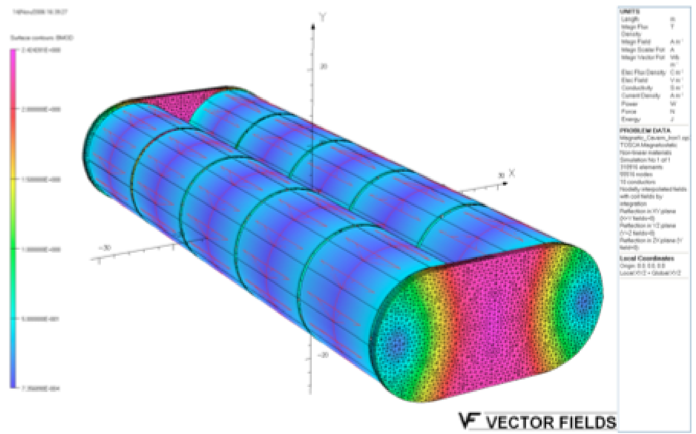
- *A prototype RPC stack is now operational at TIFR. A second prototype with the magnet is getting ready at VECC.*
- *Electronics DAQ for the prototype is operational. Final electronics for the 50 Kton detector is under design.*
- *A gas purification & recirculation system is under test.*
- *Long term stability test of RPCs continuing.*
- *INO-Engineering task force has prepared a Detailed Project Report (DPR) on the INO cavern and surface lab .*
- *Detailed Project Report for the detector structure with all engineering details is ready.*
- *We have approached environment and forest departments for necessary clearances.*
  - *MOEF clearance obtained.*
  - *State forest clearance awaited.*
- *Environmental Impact Assesment & Enviornmental Management Plan for the INO lab at Singara, Masinagudi has been prepared by reputed enviornmental organisations.*
- *EMP compliance report submitted to local state Government.*
- *Identification of sources for various components needed for mass production of glass RPCs is in progress.*
- *Land for INO centre at Mysore will be provided by Karnataka Govt.*

TASD R&D



Magnet

SCTL not a “concept” – prototyped, tested and costed for the VLHC Project at Fermilab



1 m iron wall thickness.
~2.4 T peak field in the iron.
Good field uniformity

Scintillators

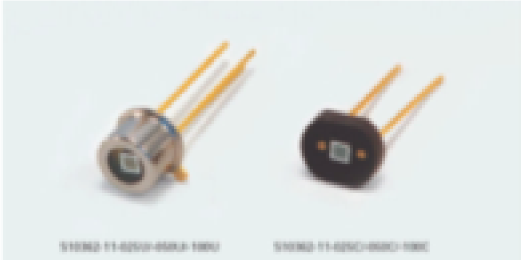
sinctillator: There are really no technical show-stoppers here. It is just a matter of cost reduction

Photodetectors

Here the R&D is already occurring all over the globe

- Silicon-PM, aka MPPD, aka MRSD
- Hamamatsu, RMD & many others

Potential to lower the channel cost to <$10/ch (Target <$5)



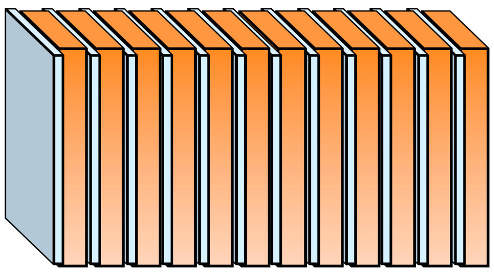
Detectors for Nufact

MIND

10-25 x MINOS

Magnetised Iron Neutrino Detector

50-100 Kton

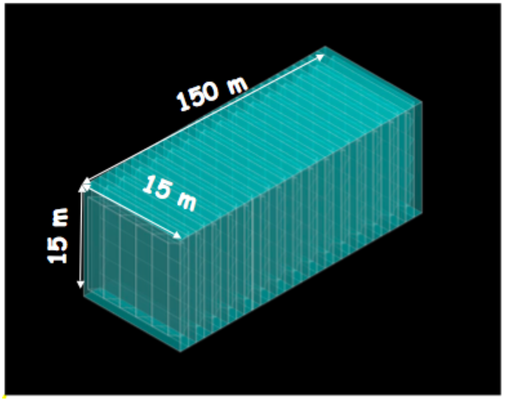


TASD

NOvA + B

Totally active Scintillating Detector

25 Kton

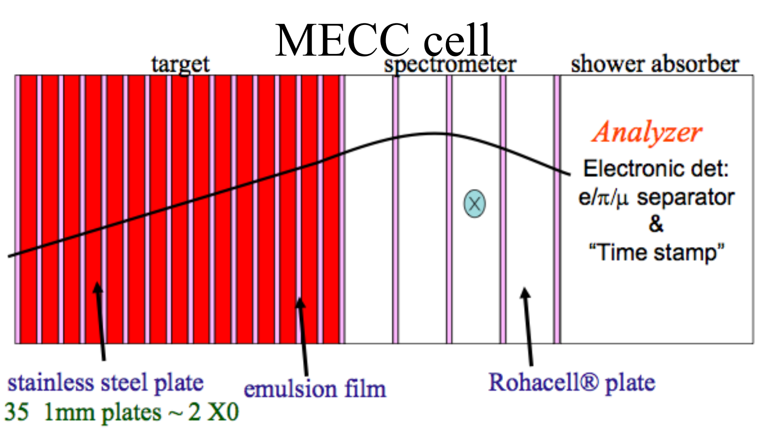


(M)ECC

(2-7)xOPERA (+ B)

(Magnetised) Emulsion Cloud Chamber

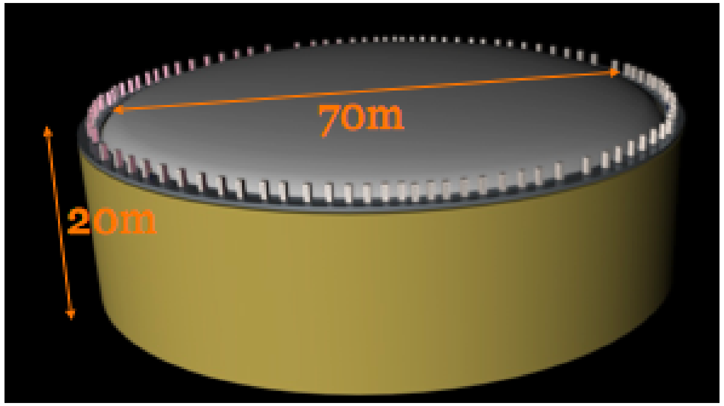
4-15 Kton



GLACIER

Giant Liquid Argon Charge Imaging ExpeRiment

100 Kton



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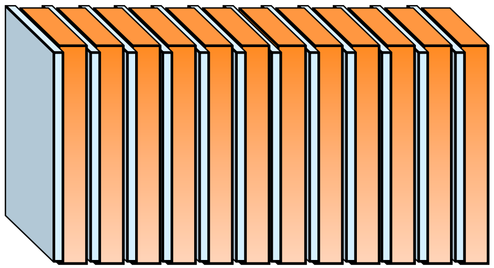

NOvA + B

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Totally active Scintillating Detector

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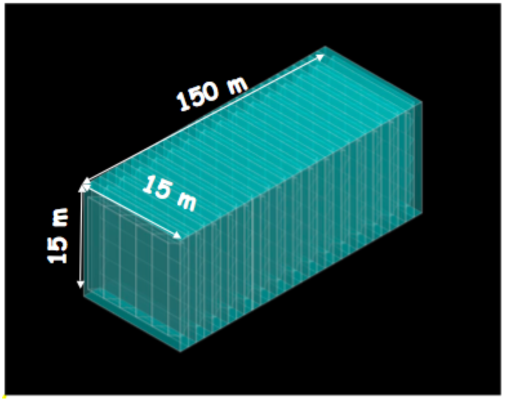
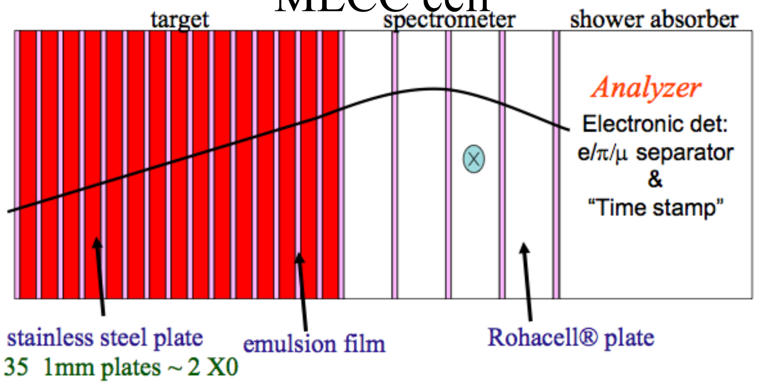


(2-7)xOPERA (+ B)

(M)ECC
(Magnetised) Emulsion Cloud Chamber

4-15 Kton

MECC cell



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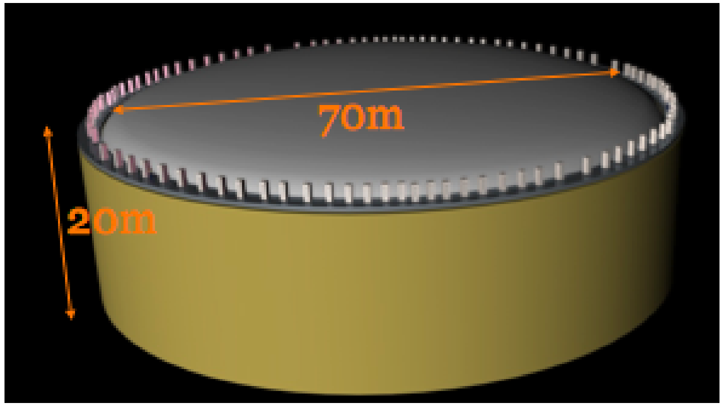
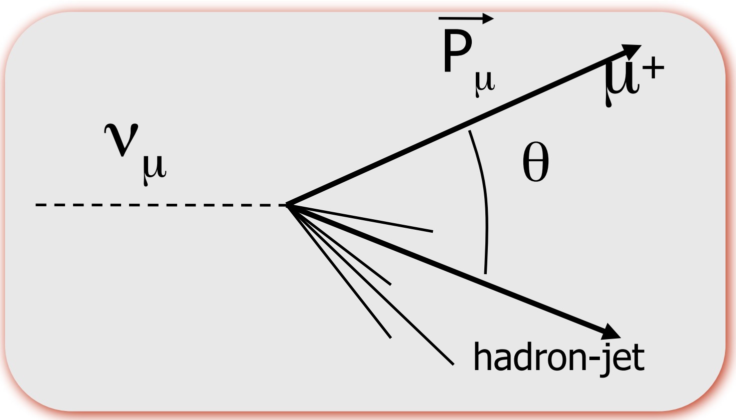


CC background

- Soft Combined cut in E_ν - P_μ and E_ν - Q_t planes, for E_ν >7 GeV
- Kills mostly high energy backgrounds

$P_\mu = |P_\mu|$

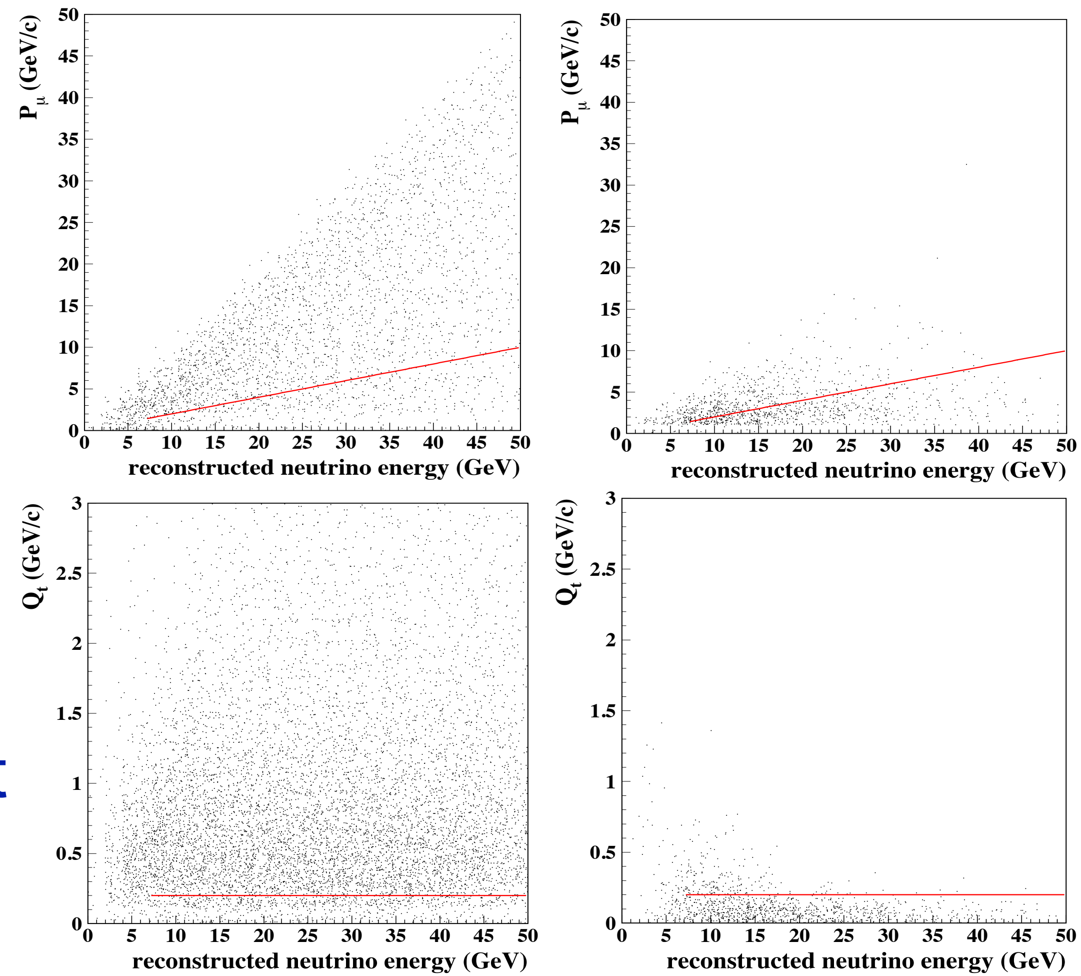
$Q_t = P_\mu \sin^2\theta$



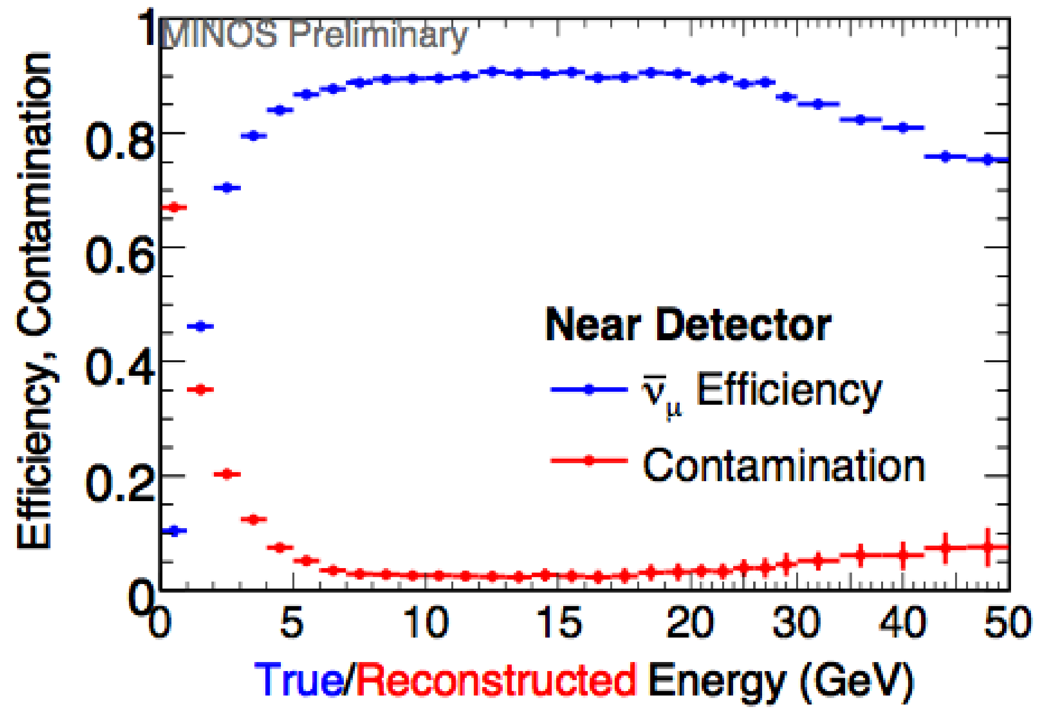
Signal | background

P_μ

Q_t



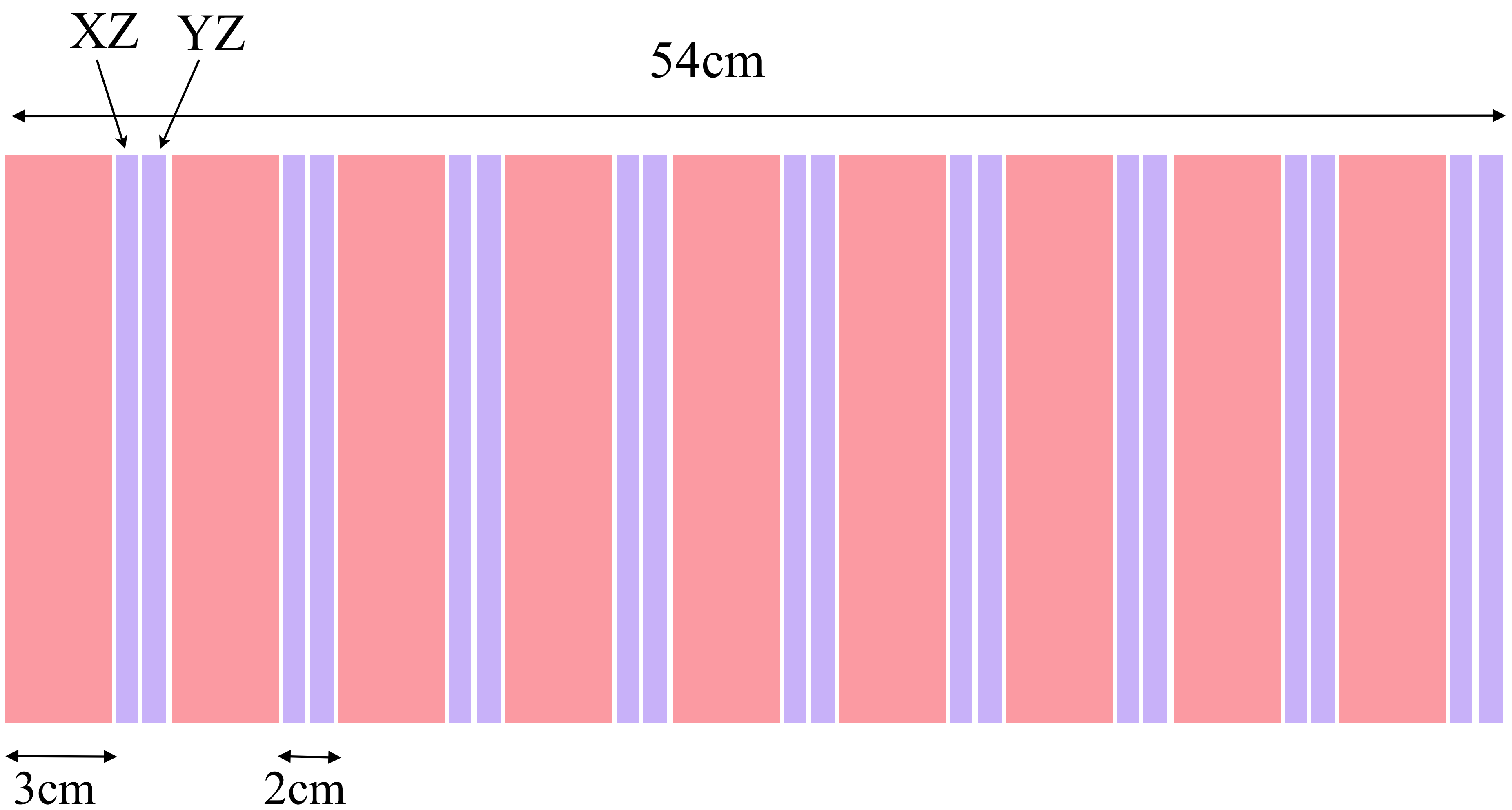
Charge ID in MINOS



Additional selections applied

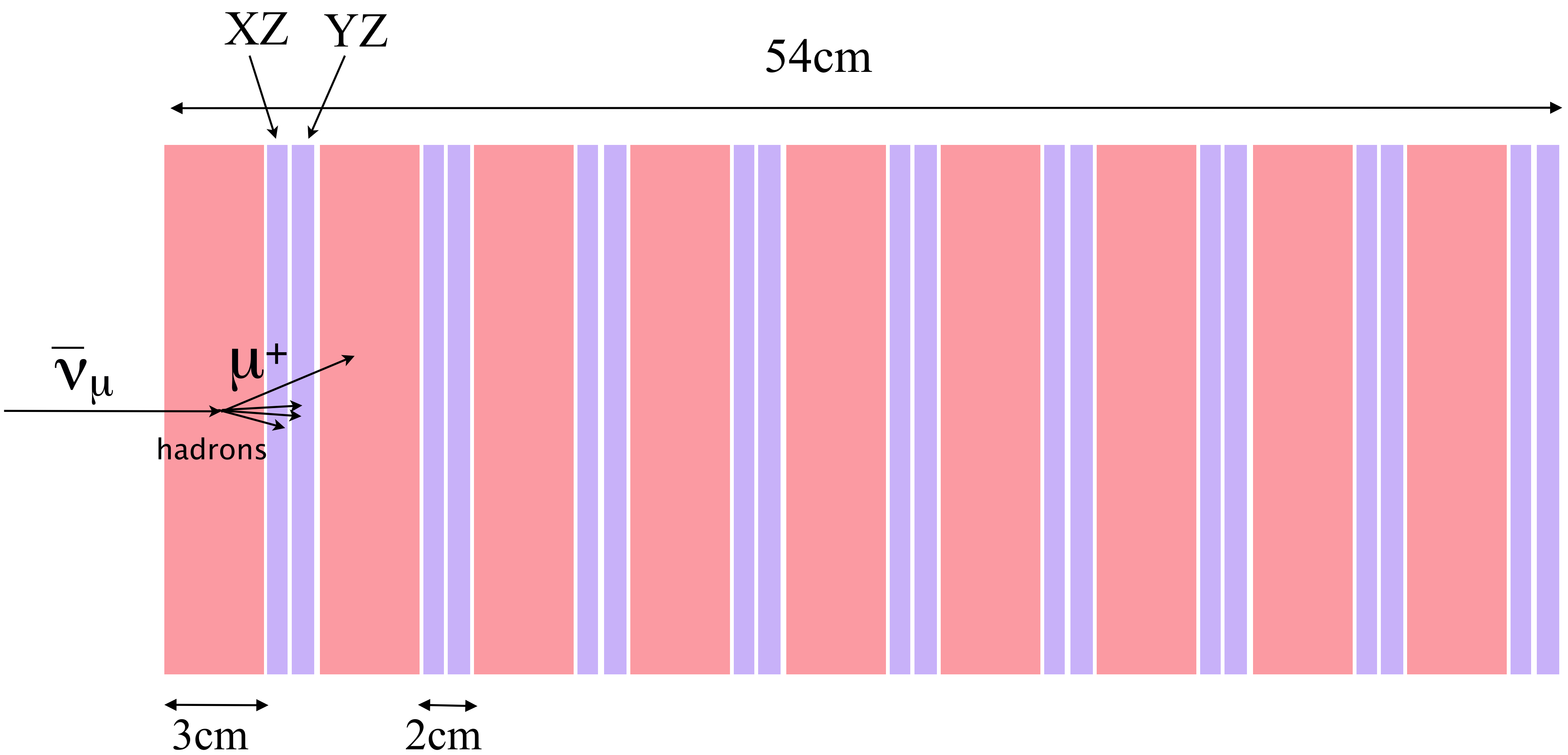
- Track-like properties (Event length, track pulseheight fraction, and pulseheight per plane) to remove NC contamination.
- Track fit quality and consistency of curvature to remove poorly measured track curvature events.

Steps



Steps

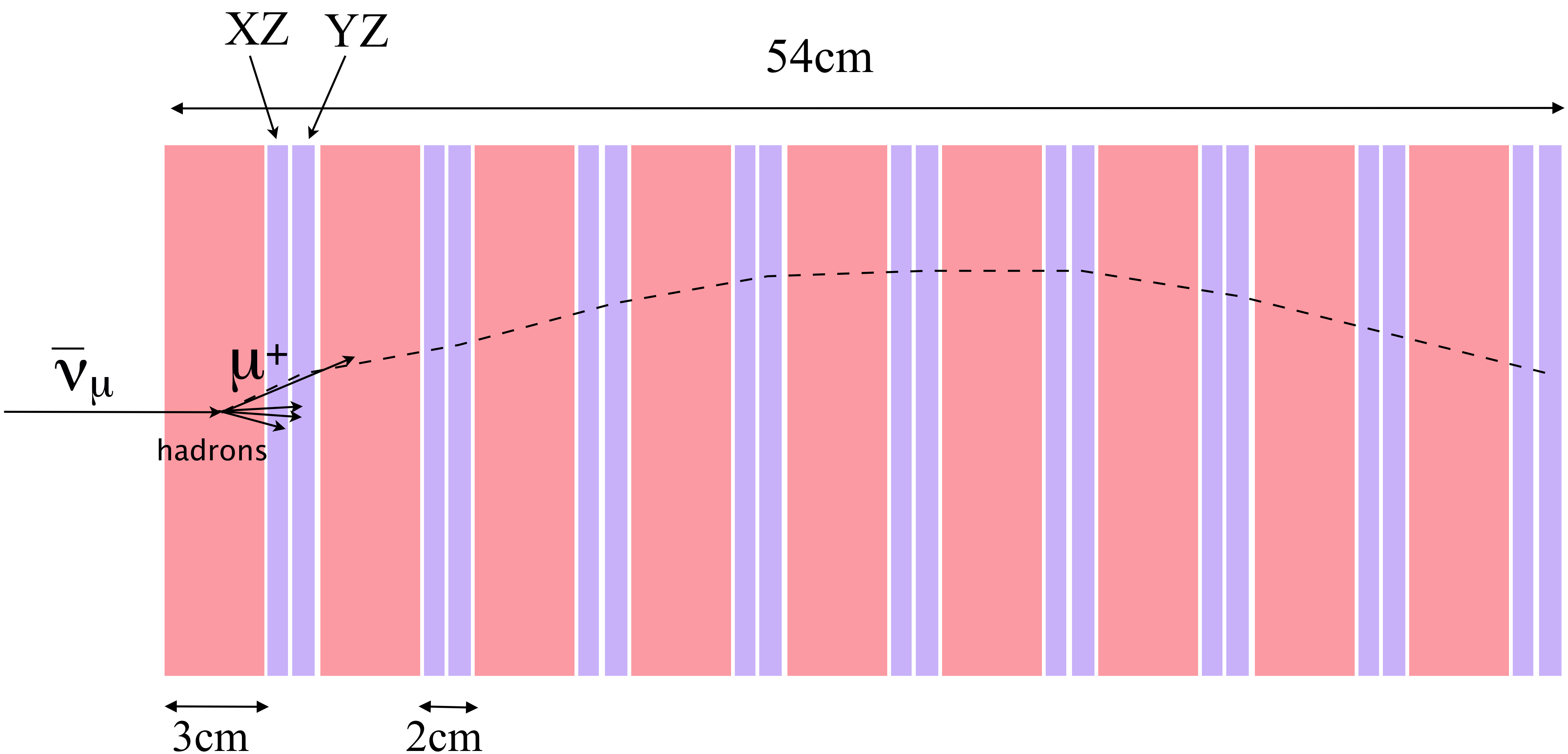
Neutrino
event generation



Steps

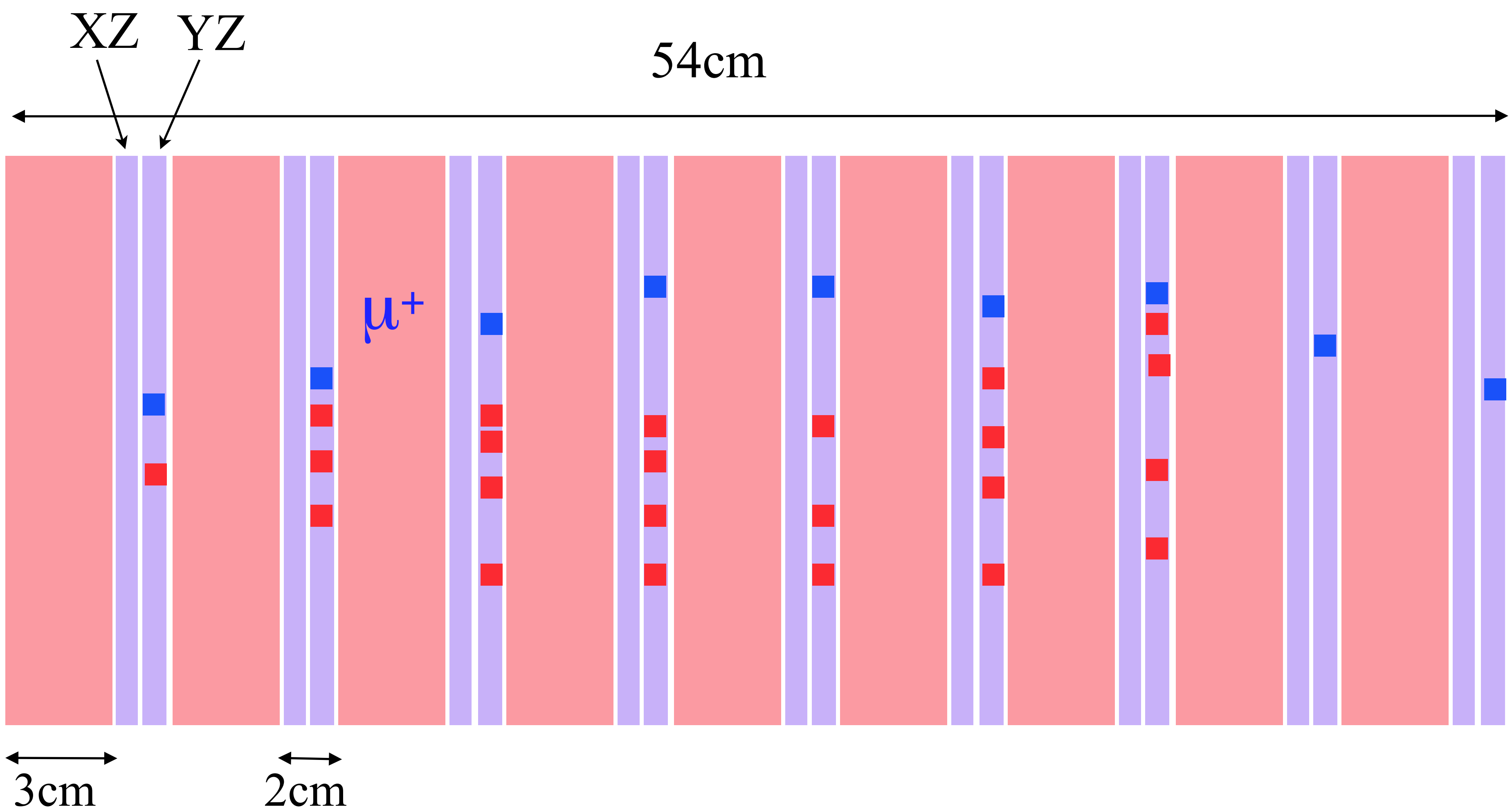
Neutrino event generation

Particle transport



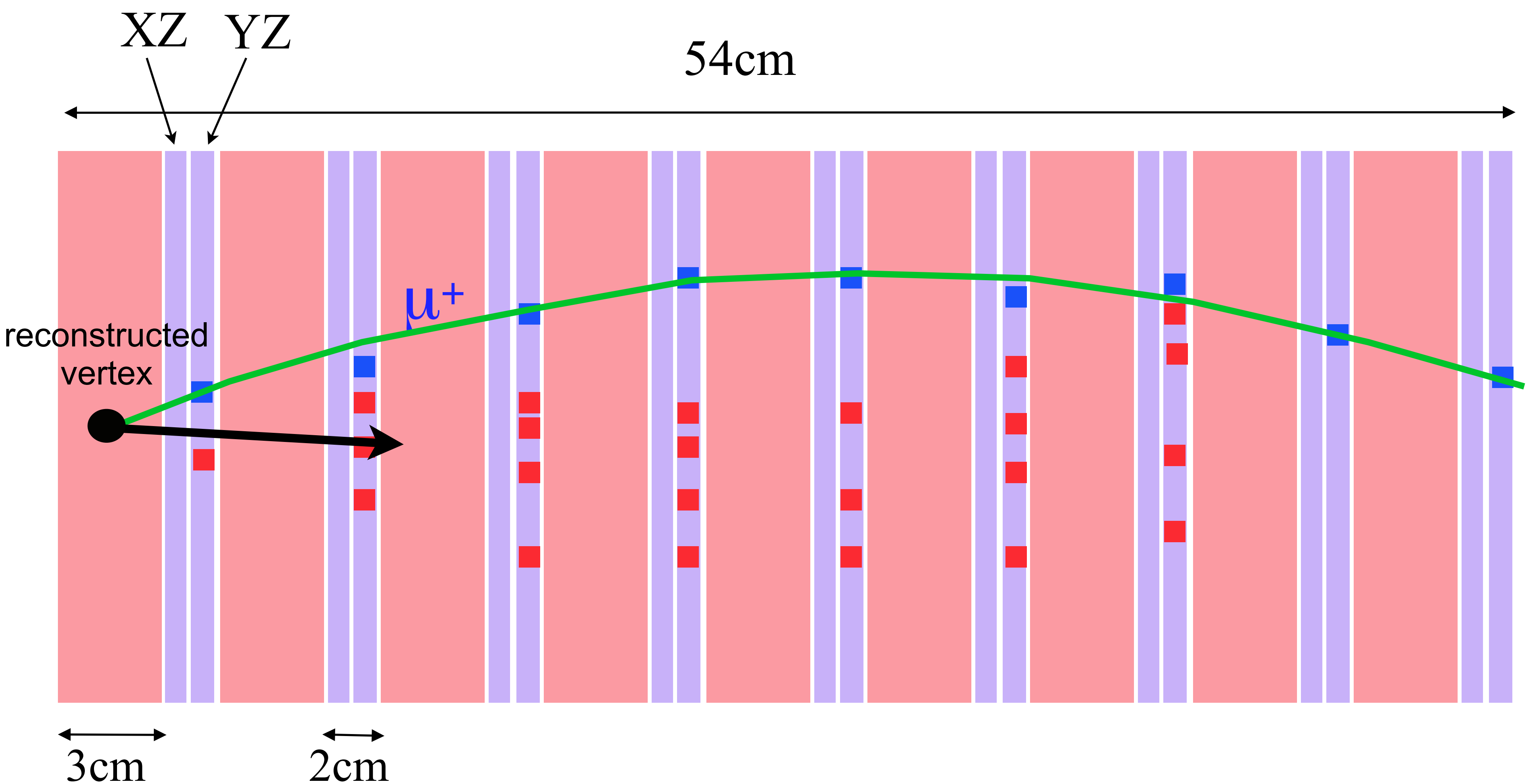
Steps

Neutrino event generation → Particle transport → Detector response



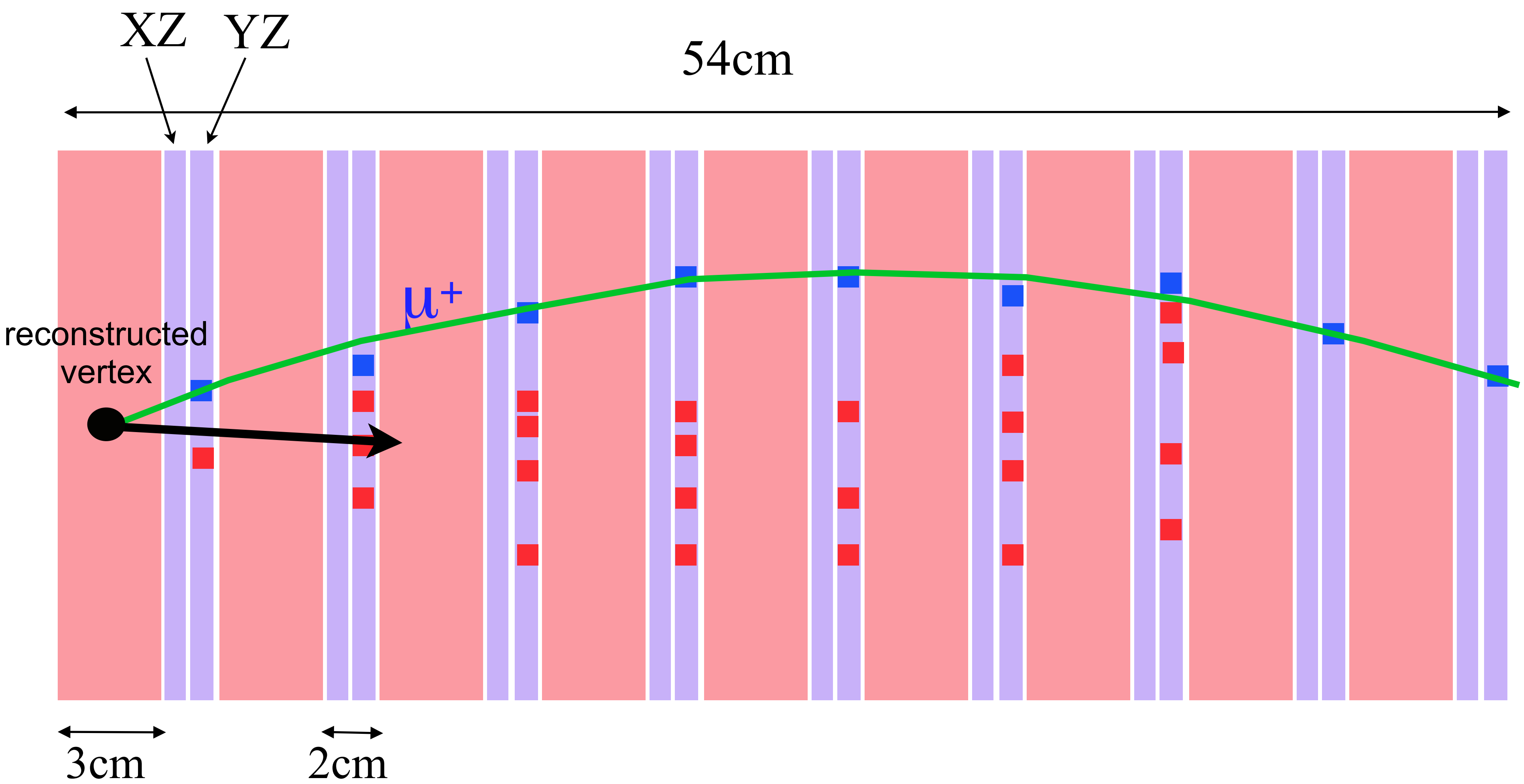
Steps

Neutrino event generation → **Particle transport** → **Detector response** → **Event reconstruction**



Steps

Neutrino event generation → Particle transport → Detector response → Event reconstruction → Analysis



OLD and NEW frameworks

Neutrino event generation	Particle transport	Detector response	Event reconstruction	Analysis

OLD and NEW frameworks

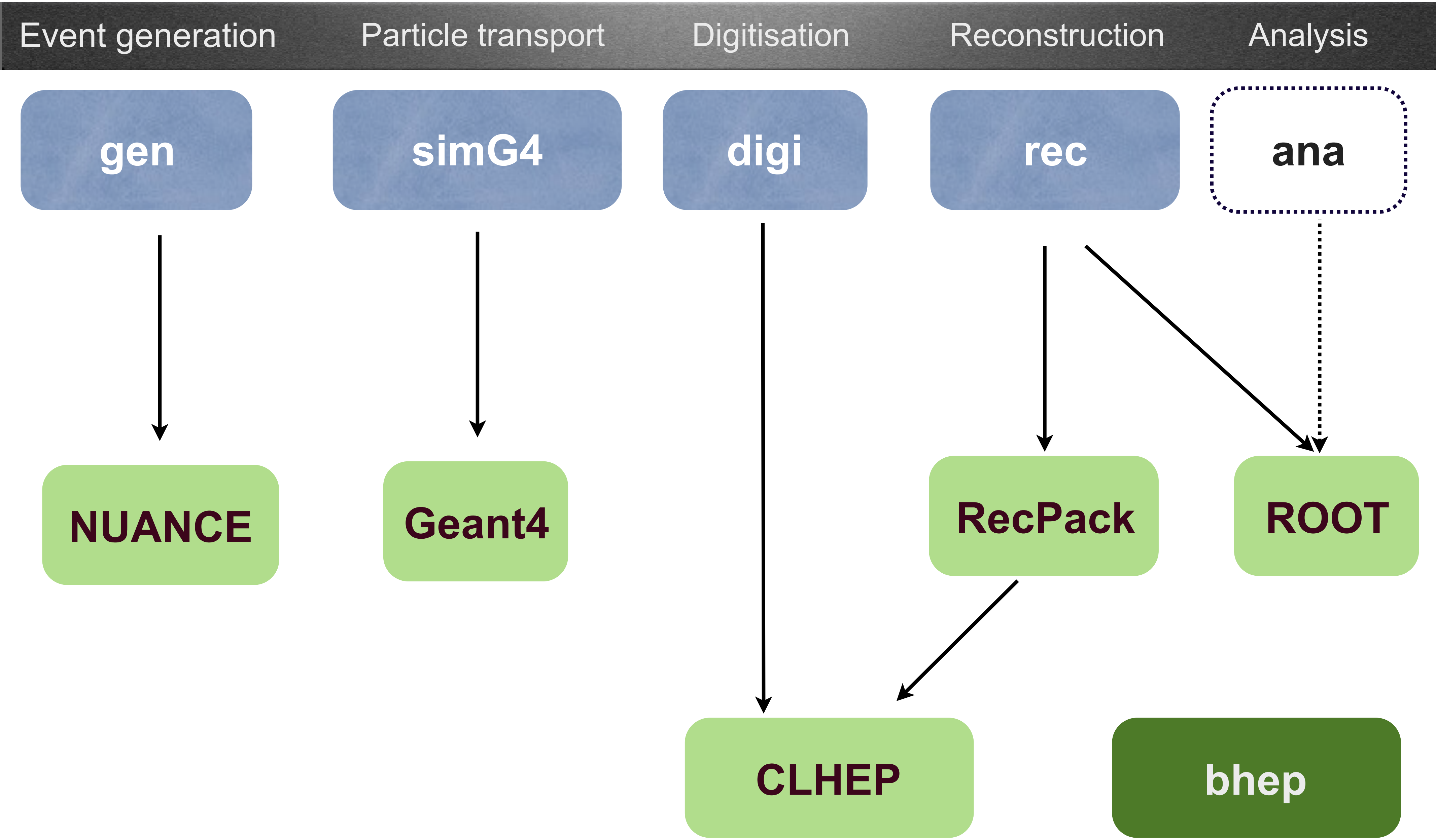
Steps

simulation

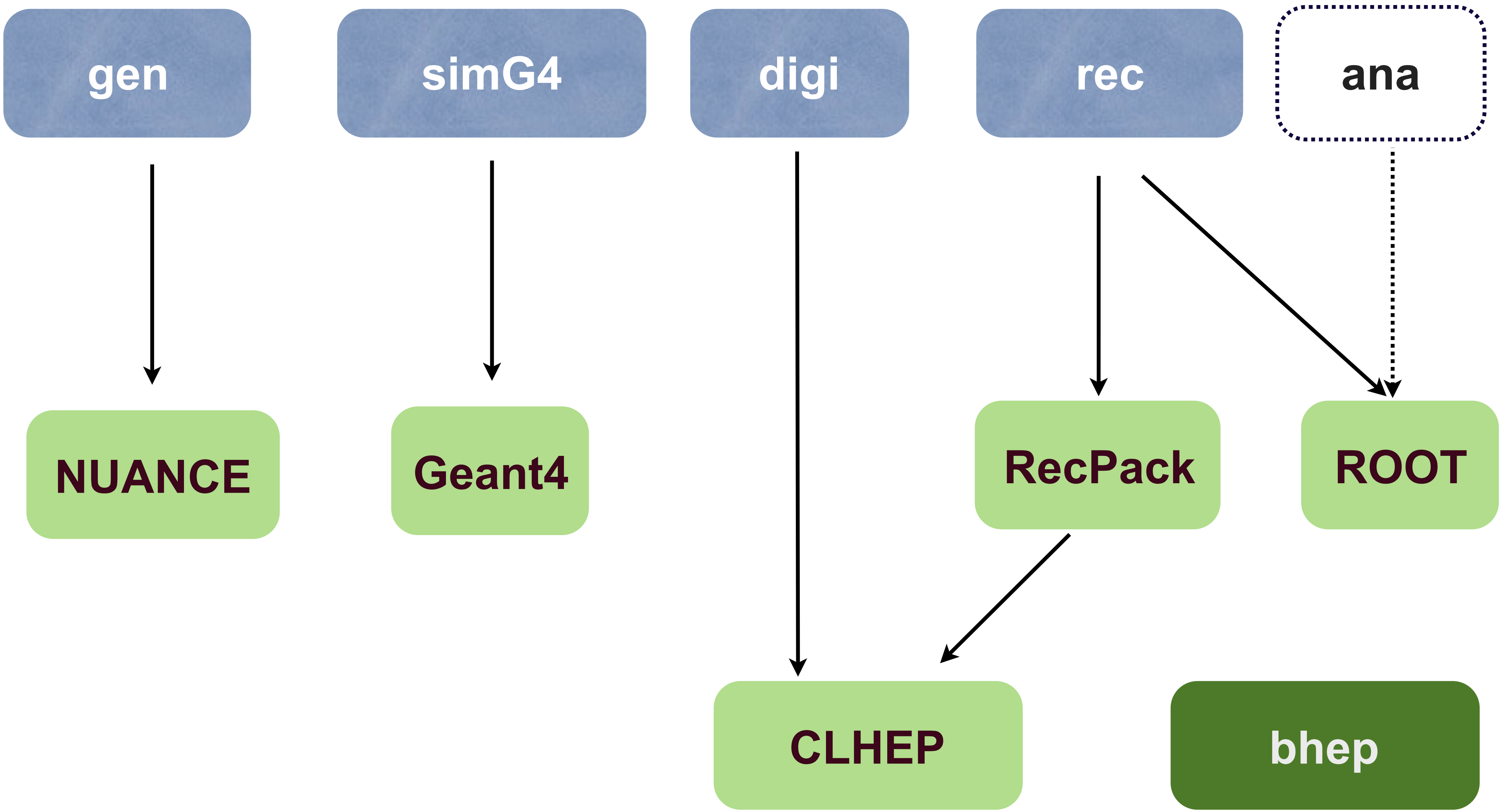
- **Neutrino event generation**
- **Particle transport**
- **Detector response**

- **Event reconstruction**
- **Analysis**

Software packages



Software packages



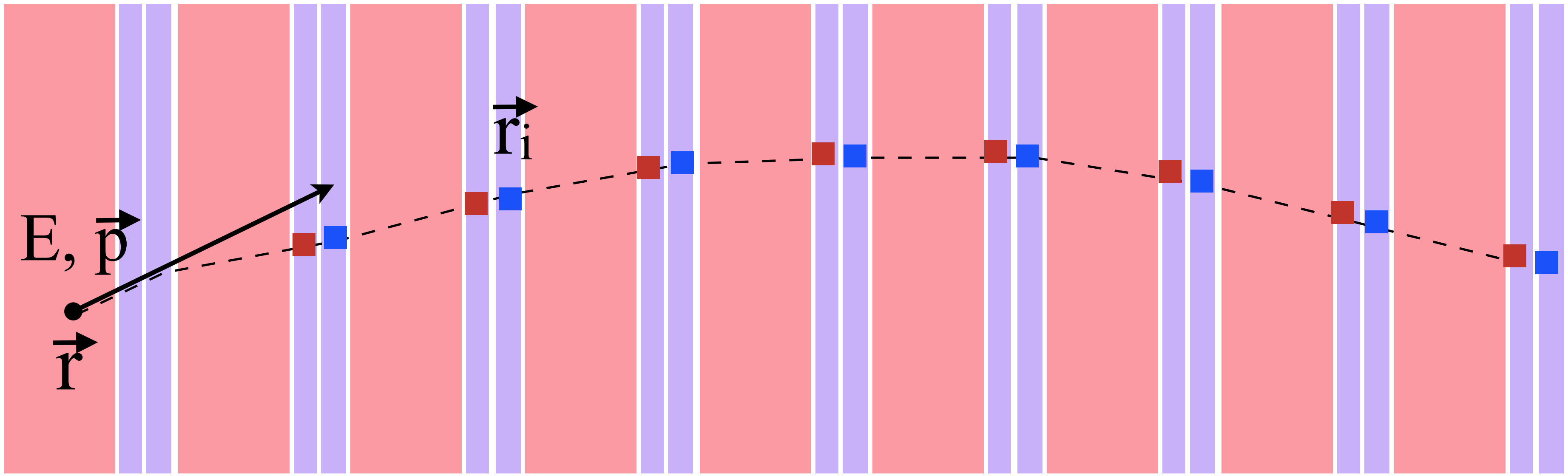
Event generation Particle transport Digitisation Reconstruction I/O Analysis

Particle transport

- Record for each particle:
  - Particle type
  - Vertex position
  - Four momentum
  - position at each active layer
  - energy deposited in active layer

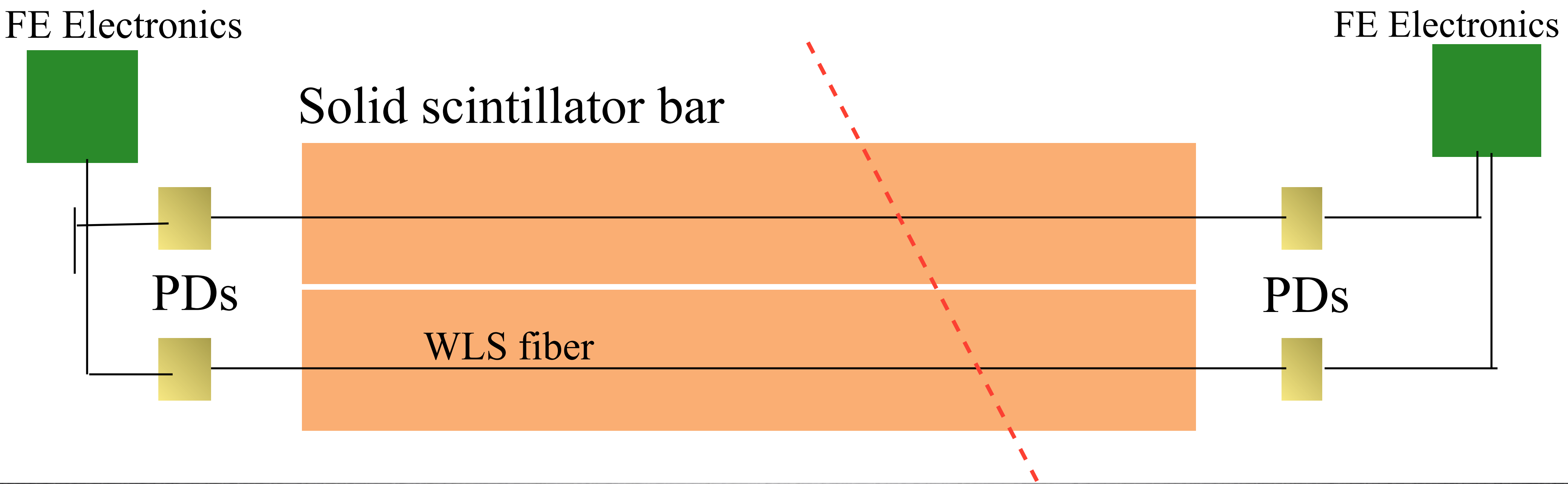
QGSP- Bertini
for hadronic interactions

Efficiency problem
under investigation

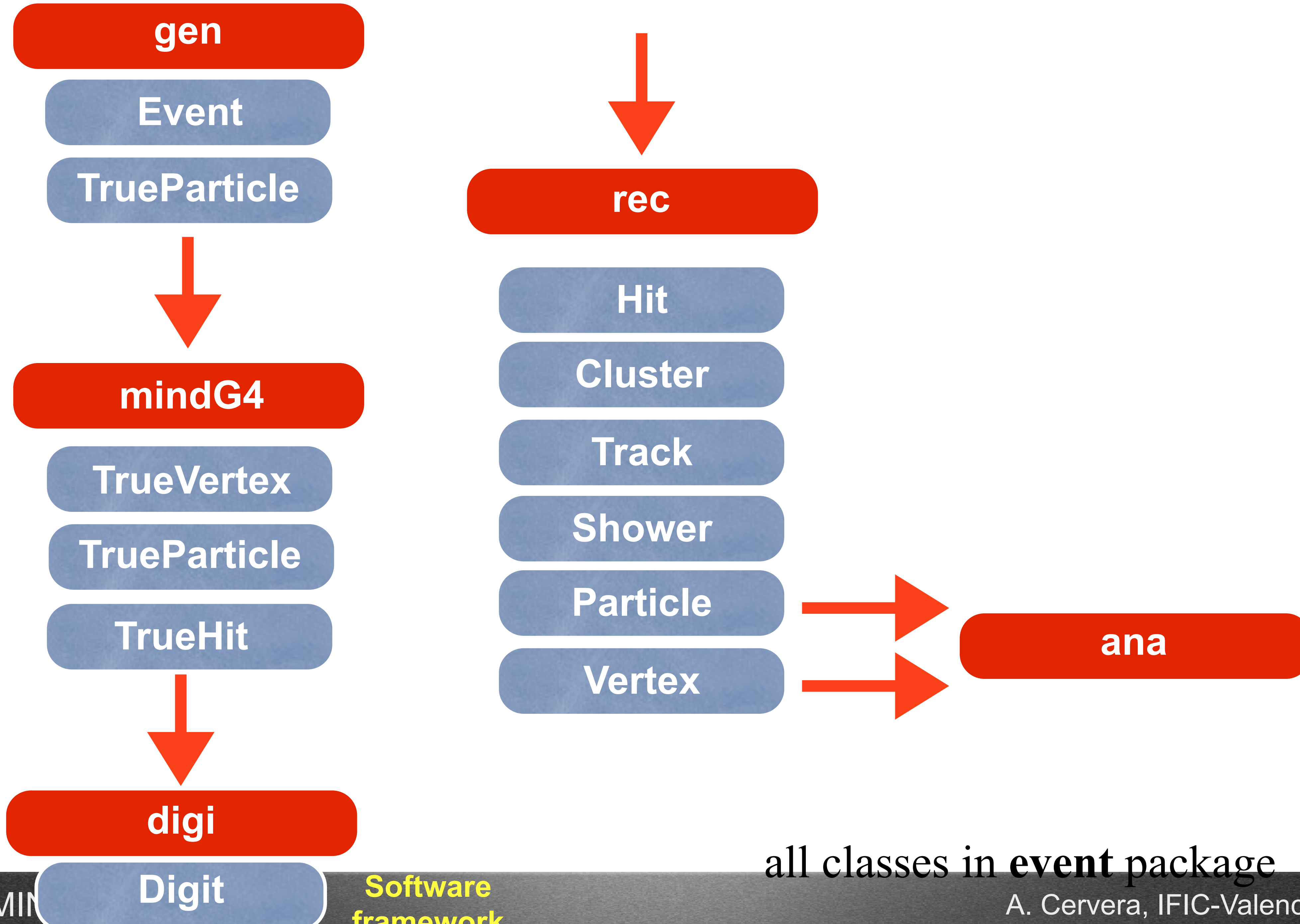


Detector response: **digi**

- mindG4 produces:
  - intersection point with active layer
  - energy deposition in active layer
- digi should simulate the detector response
  - Attenuation along the scintillator bars (double end readout ?)
  - Photodetector efficiency, gain and noise
  - Electronic gain and noise



Classes in **event** package



all classes in **event** package

Strategy

1st step

- Simple smearing as in the old G3 analysis
  - Smear hit position

Done

2nd step

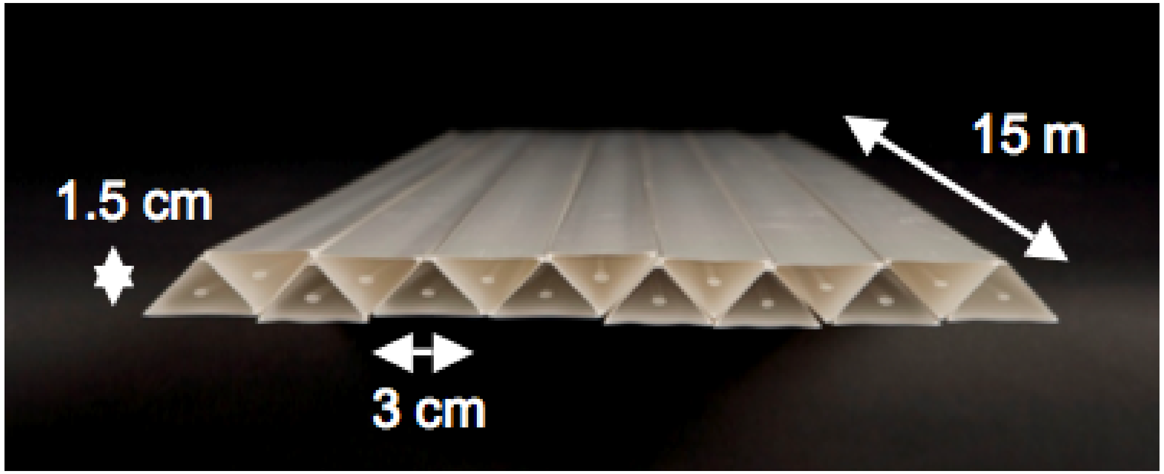
- Parameterization to take into account the main effects:
  - Attenuation, photodetector efficiency, ...

3rd step

- Full digitisation
  - Attenuation along the scintillator bars (double end readout ?)
  - Photodetector efficiency, gain and noise
  - Electronic gain and noise

Long scintillator bars

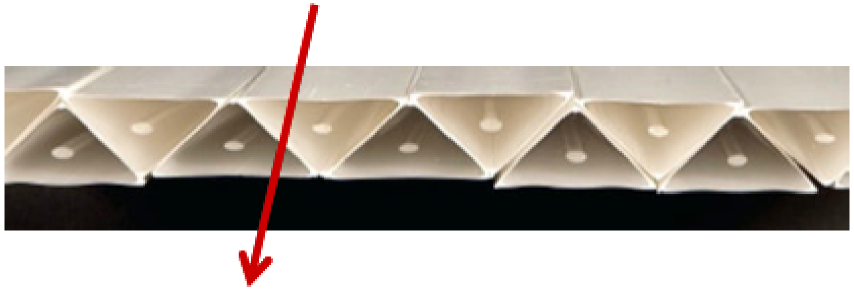
- NOvA uses similar length (15 m) but with higher cross section (6x3)
- MIND needs lower x-section cells in order to improve space resolution (charge mis-id) and pattern recognition (muon id)
- Attenuation length in thinner bars should be tested



- Double end readout could be an option to increase light yield if needed

Space resolution

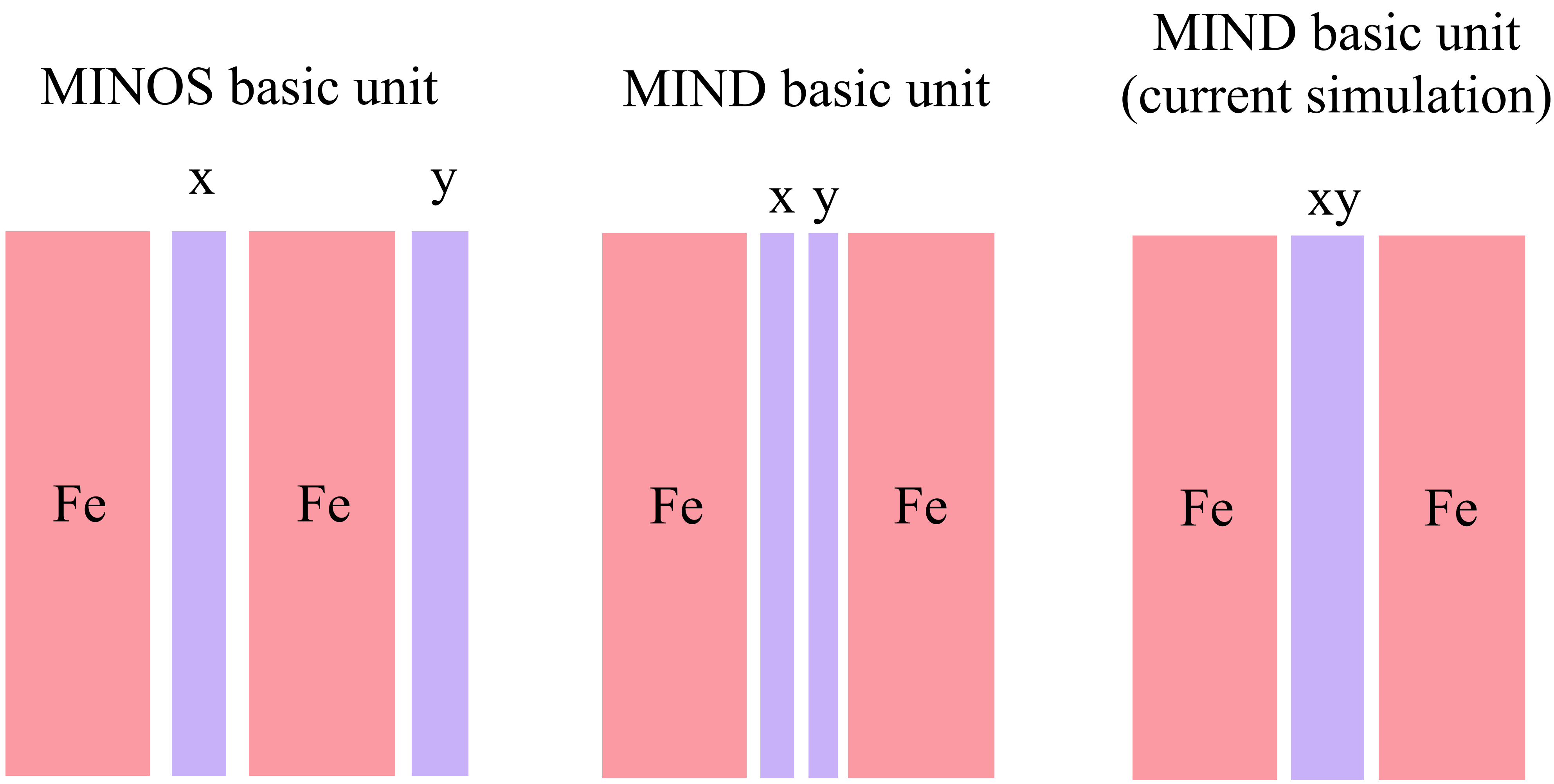
- Use triangles with light sharing to get the position
- σ = 2.5mm with 34mm wide cells in initial measurements
  - MINOS is 10mm for 41mm strips
- Can apply this technique to NOvA style liquid cells too



- However, one must be careful with the cells width, since pattern recognition in the region of hadronic activity might be a problem for very wide cells

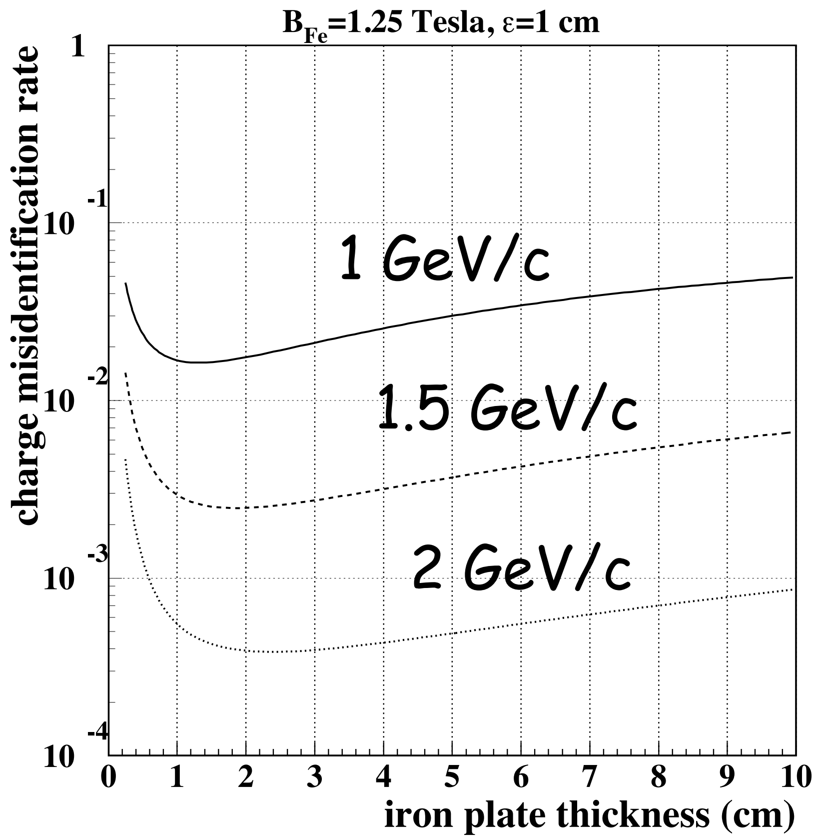
2D views

- To improve 2D views matching and pattern recognition MIND should probably have 2D views together



R&D II: segmentation

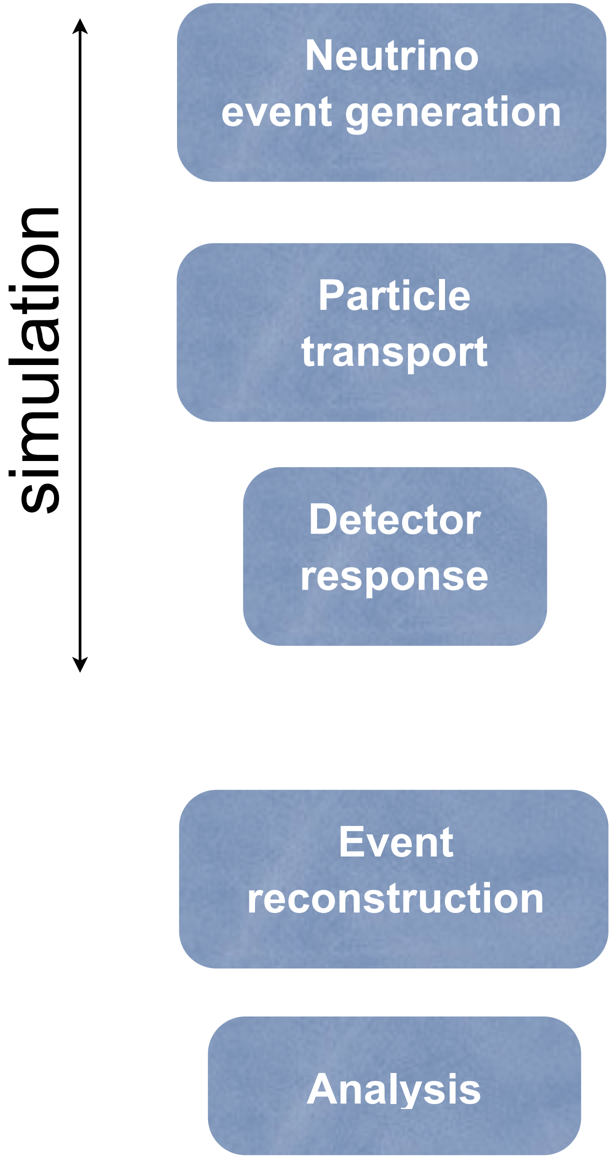
- Segmentation needs to be optimised
  - MINOS should be close to optimum (2.5 cm iron plates)



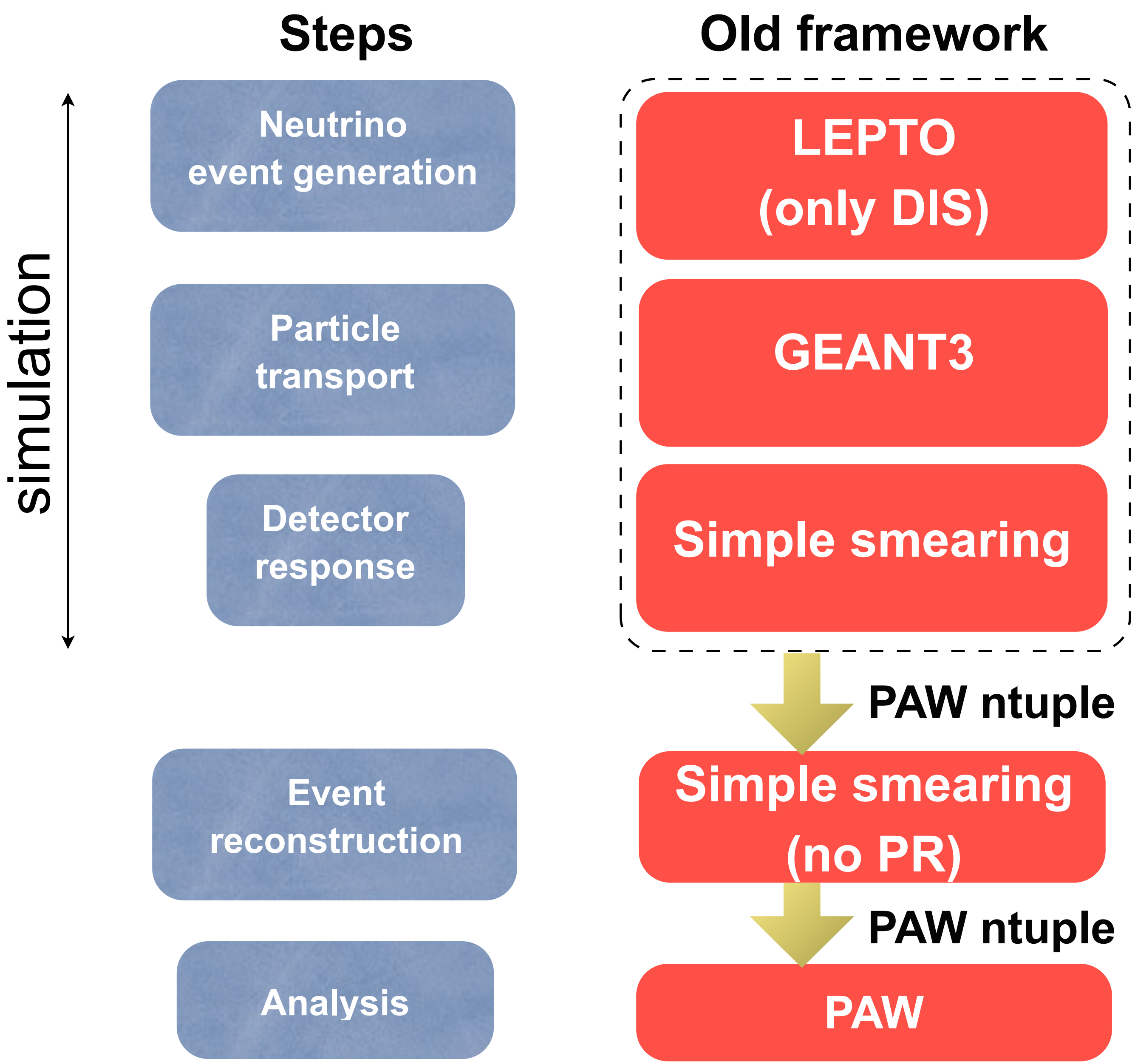
- Attenuation in long scintillator bars should be understood (2xMINOS)

OLD and NEW frameworks

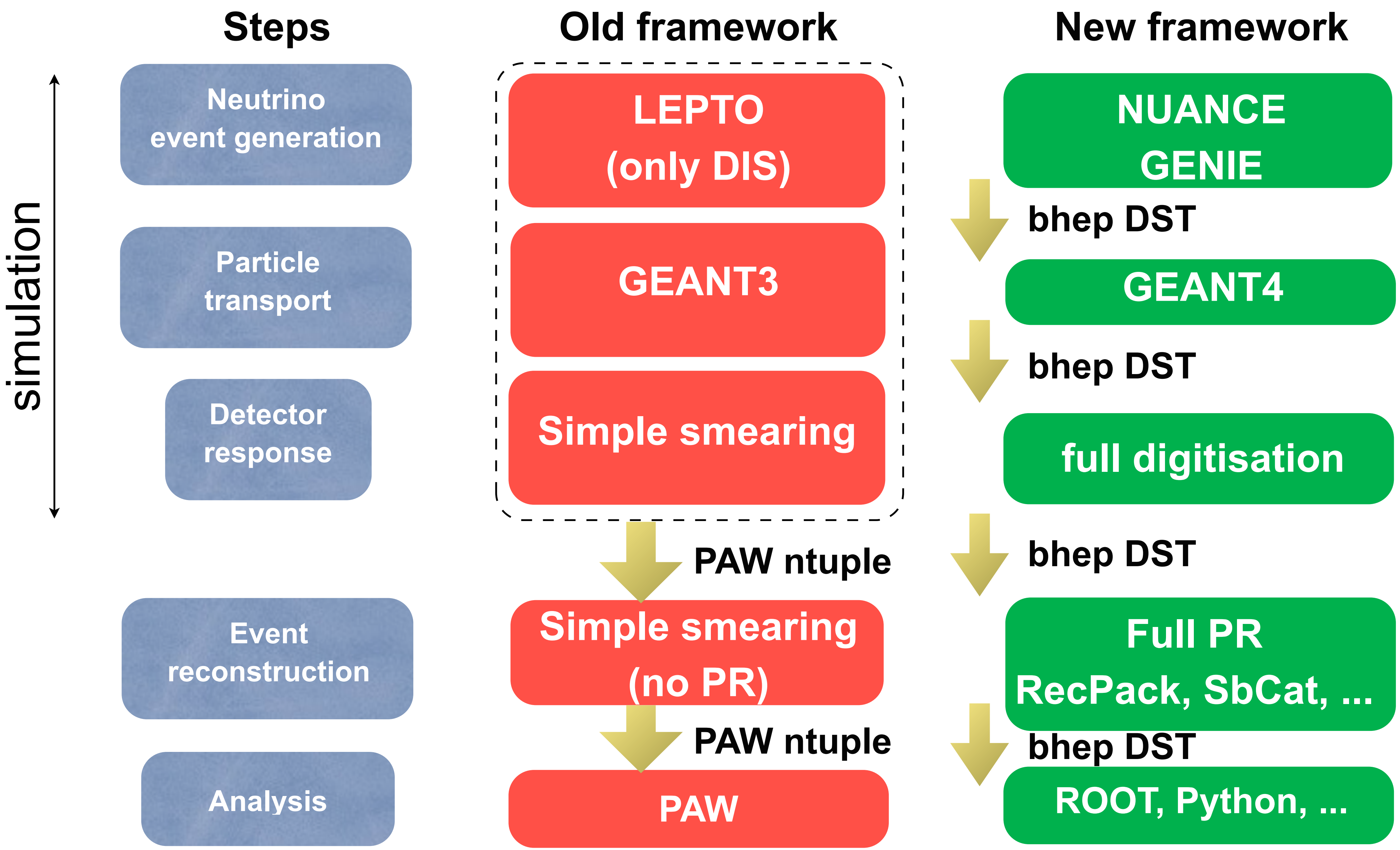
Steps



OLD and NEW frameworks

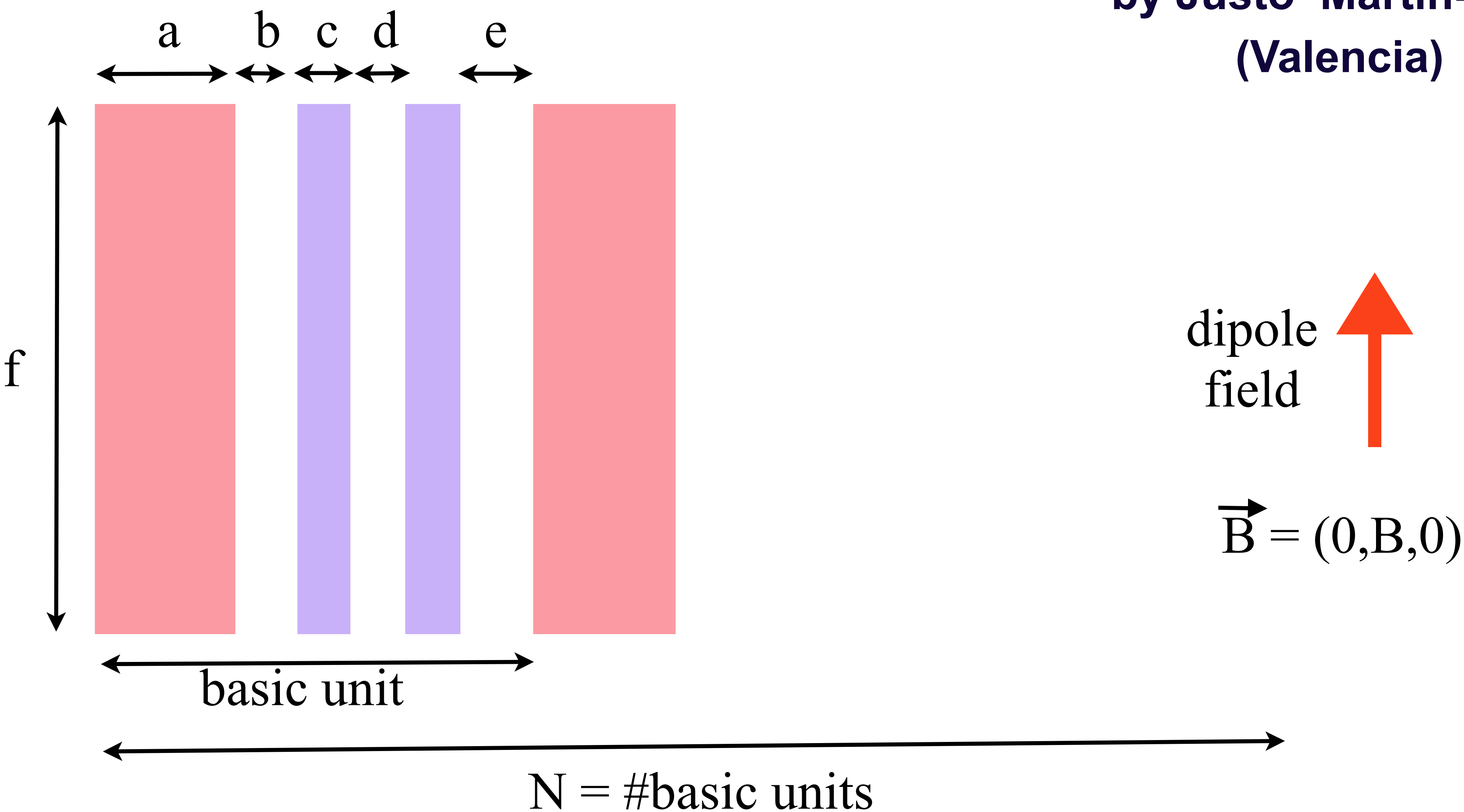


OLD and NEW frameworks



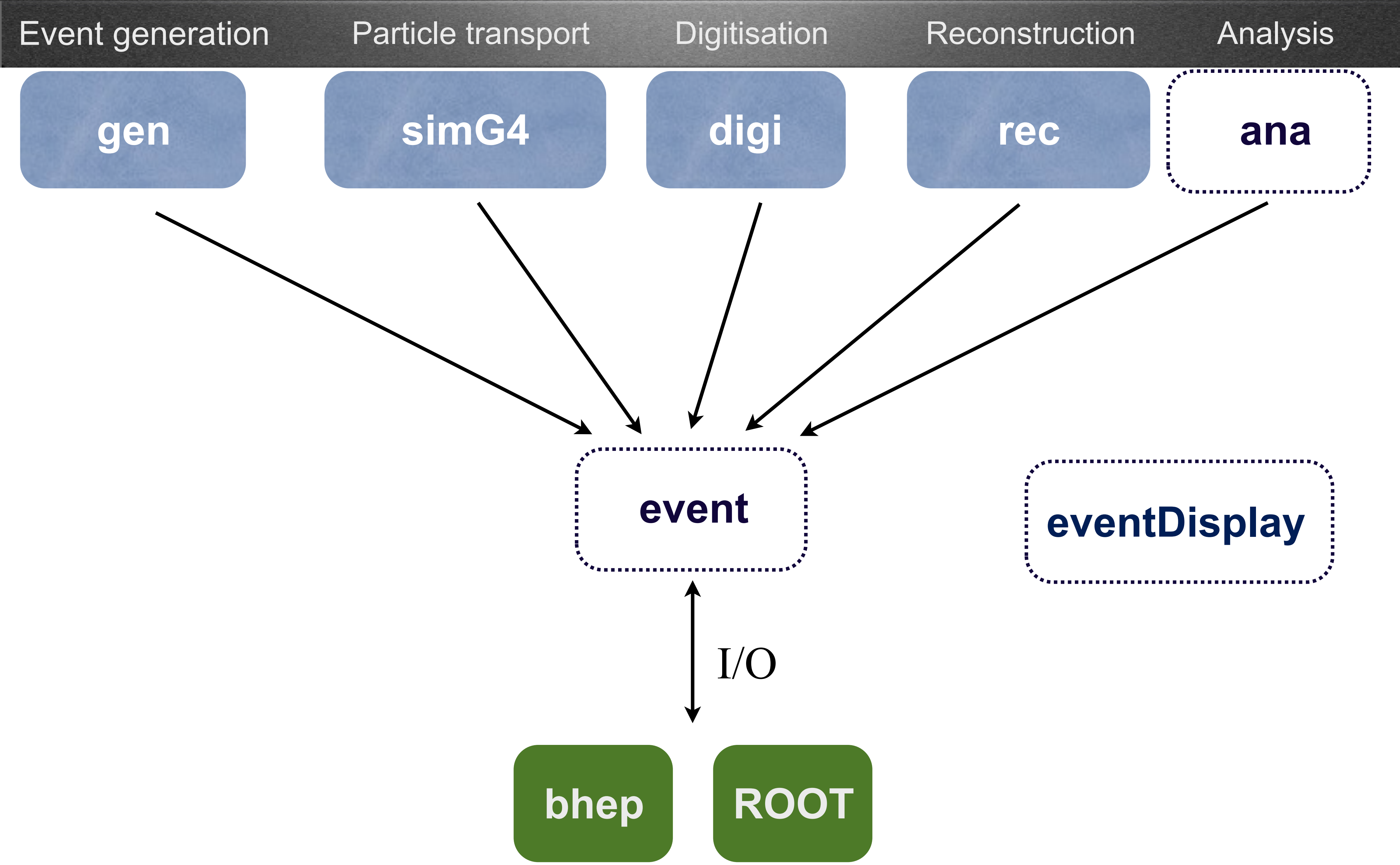
Current implementation in simG4

by Justo Martín-Albo
(Valencia)

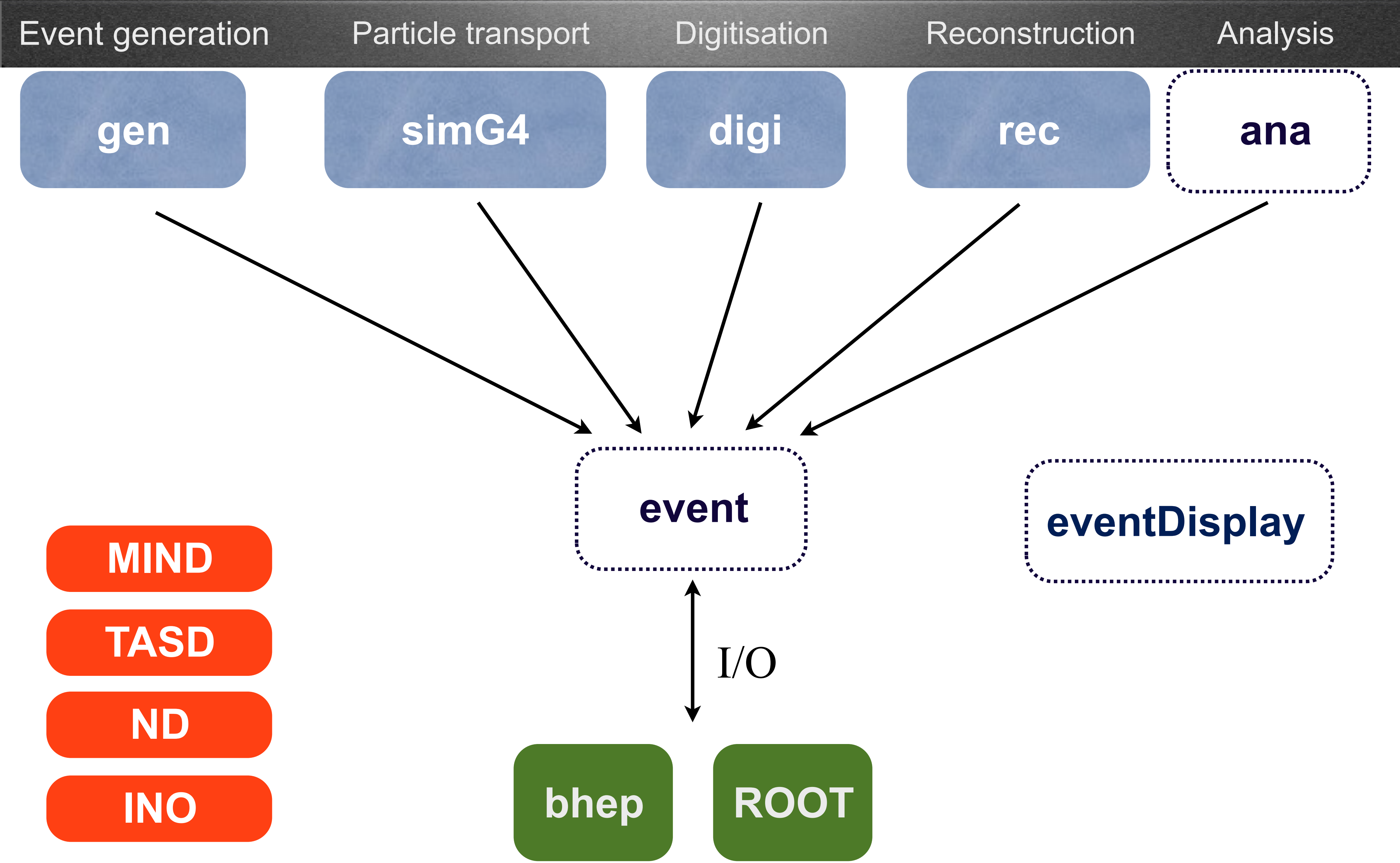


a,b,c,d,e,f, N,B are external tunable parameters

Software design

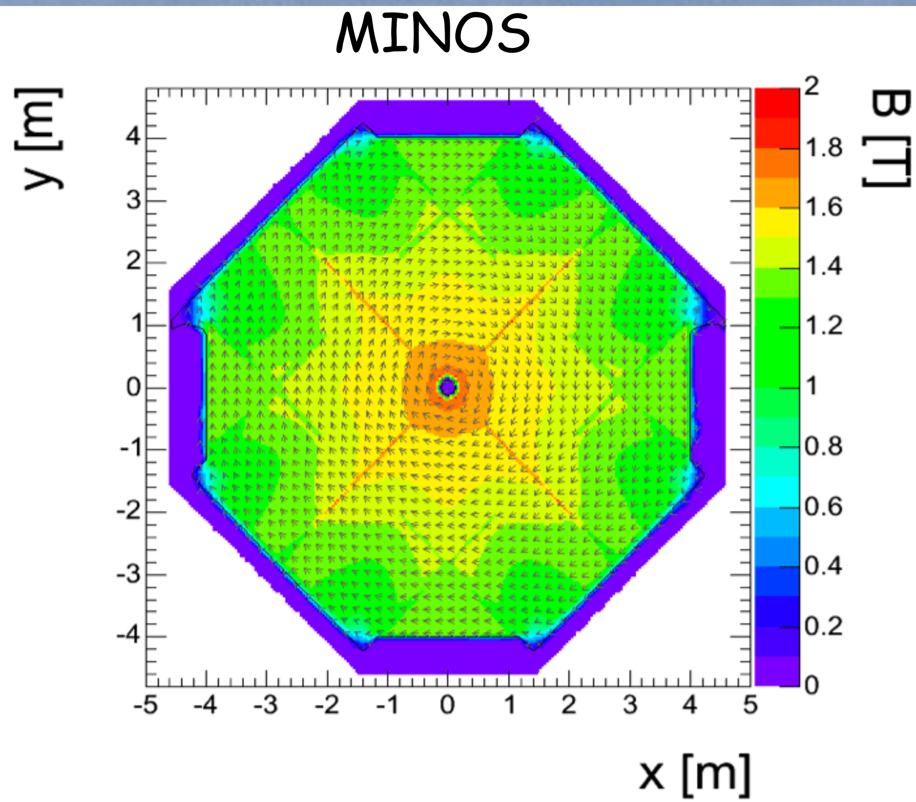


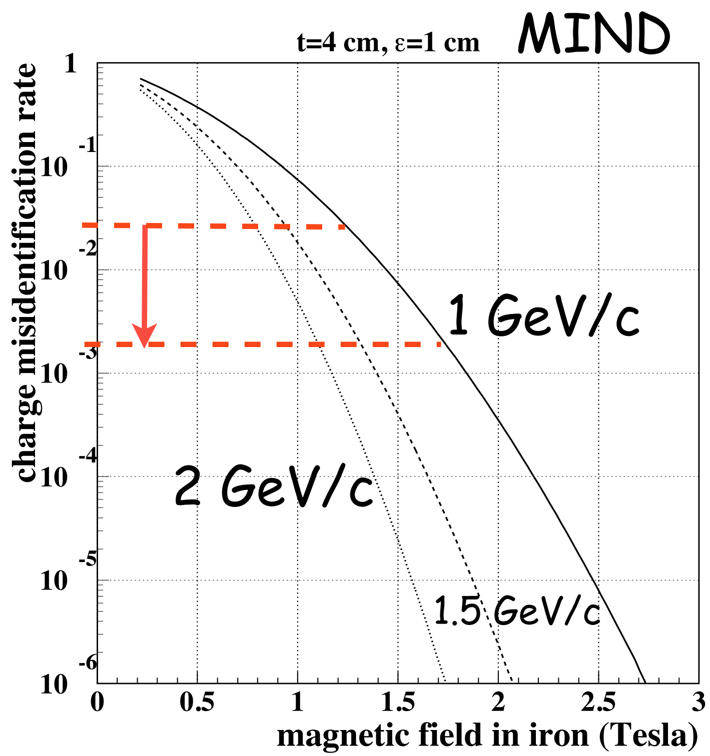
Software design



Charge mis-ID

- The magnetic field strength is the crucial parameter to be optimised
- 1.25 → 1.7 Tesla average is feasible ➠ 1. o.o.m improvement at 1 GeV/c





- Non gaussian MS tails could be a problem (low angle scatters mainly)
- 10^{-3} below 5 GeV needs to be demonstrated in a test-beam with 0.5-3 GeV muons

Hadron shower angle

- We know that the hadron shower angle is very useful to reject hadronic backgrounds
- MINOS did not reach the resolution quoted in the proposal

$$\delta\theta_{had} = \frac{16.67}{\sqrt{E}} + \frac{12.15}{E}$$

- mainly due to x-talk in the MA-PMTs
- Monolith test-beam measured

$$\delta\theta_{had} = \frac{10.4}{\sqrt{E}} + \frac{10.1}{E}$$

5 cm iron + 2 cm RPCs

- MIND should do better (less iron,
- We need a test beam with pions, protons (0.5-15 GeV) to test the angular resolution in a MIND prototype