Optimization of the high-γ β-beam

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IDS- EuroNu Meeting

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Based on collaborations with:

A. Donini, E. Fernández-Martínez and J. López-Pavón, JHEP 0805:050,2008

S. K. Agarwalla, S. Choubey, A. Donini, and E. Fernández-Martínez (in progress)

Outline

- The lepton flavour problem
- The one-baseline β-beam
    - The original β-beam proposal
    - The high-γ He/Ne β-beam
    - The Li/B alternative
- The two-baseline β-beam
    - Strong synergy between the two detectors
    - Previous proposals
- Improving the two-baseline β-beam
    - Our setup
    - Results & comparison with other facilities
- Conclusions

The lepton flavour problem

$$\mathcal{L}_\nu = \frac{g}{\sqrt{2}} U^*_{\alpha i}(\theta_{12}, \theta_{23}, \theta_{13}; \delta) \left(\overline{l_{\alpha L}} \, \gamma^\mu \, \nu_{iL} W^+_\mu + h.c. \right) + \mathcal{L}_{\mathrm{mass}}(m_{\nu_i}; m_{l_\alpha})$$

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$$\theta_{23},\ |\Delta m^2_{23}|$$

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$$\text{sign}(\Delta m^2_{23})$$

$$\delta\theta_{23} = \theta_{23} - \pi/4$$

Physics BSM??

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The one-baseline

β-beam

Previous studies on β-beams

Ion Production

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Ion Production

^{6}He/^{18}Ne $E_0 \sim 3$ MeV

Previous studies on β-beams

Ion Production

Acceleration

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Previous studies on β-beams

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SPS/PS $\gamma \sim 100$

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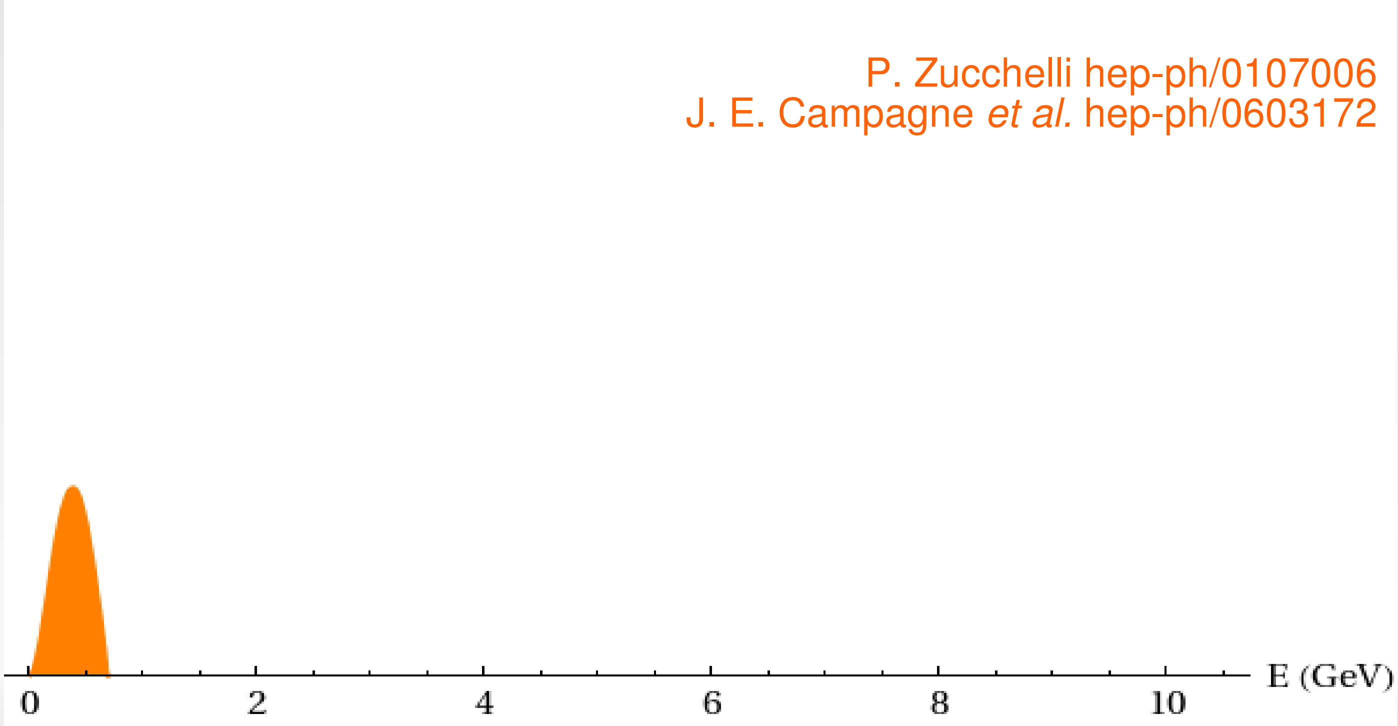


P. Zucchelli hep-ph/0107006
J. E. Campagne *et al.* hep-ph/0603172

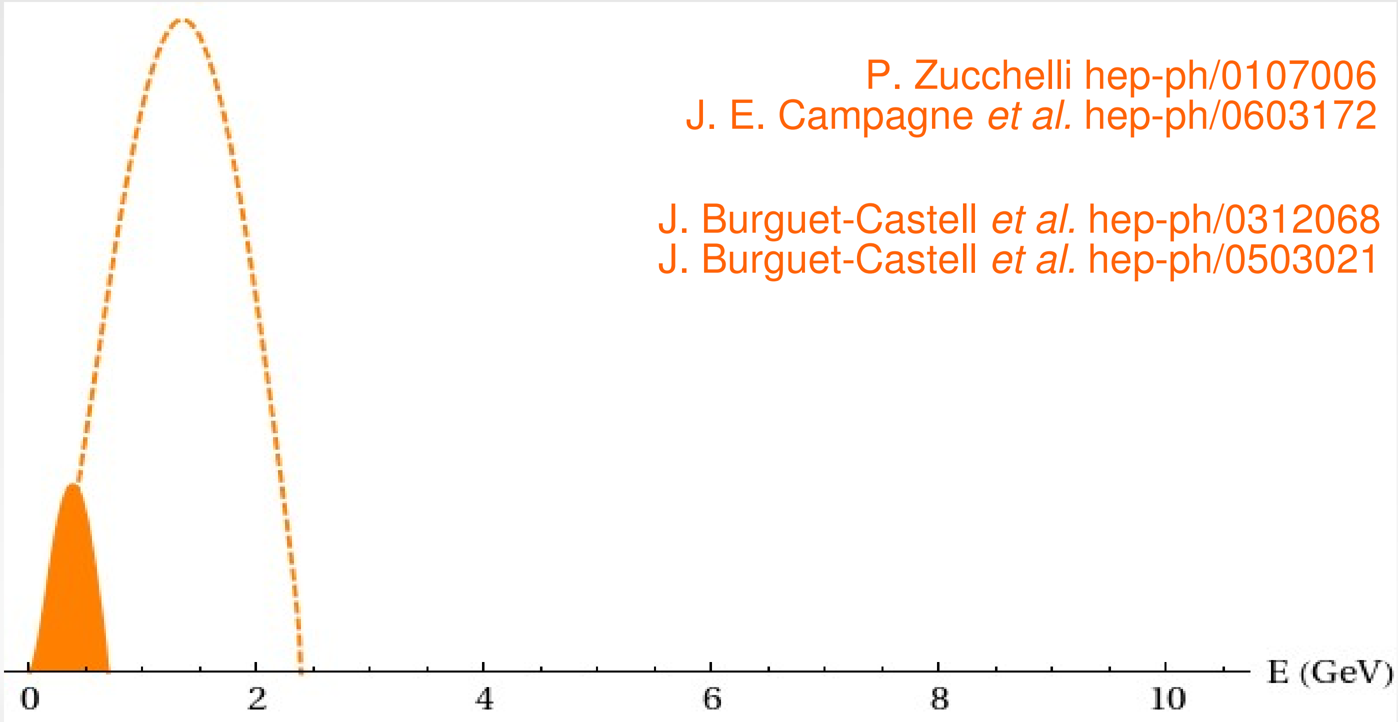
Previous studies on β-beams

Ion Production

Acceleration

^{6}He/^{18}Ne $E_0 \sim 3$ MeV

SPS/PS	$\gamma \sim 100$
SPS+/PS2	$\gamma \sim 350$



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J. Burguet-Castell *et al.* hep-ph/0312068
J. Burguet-Castell *et al.* hep-ph/0503021

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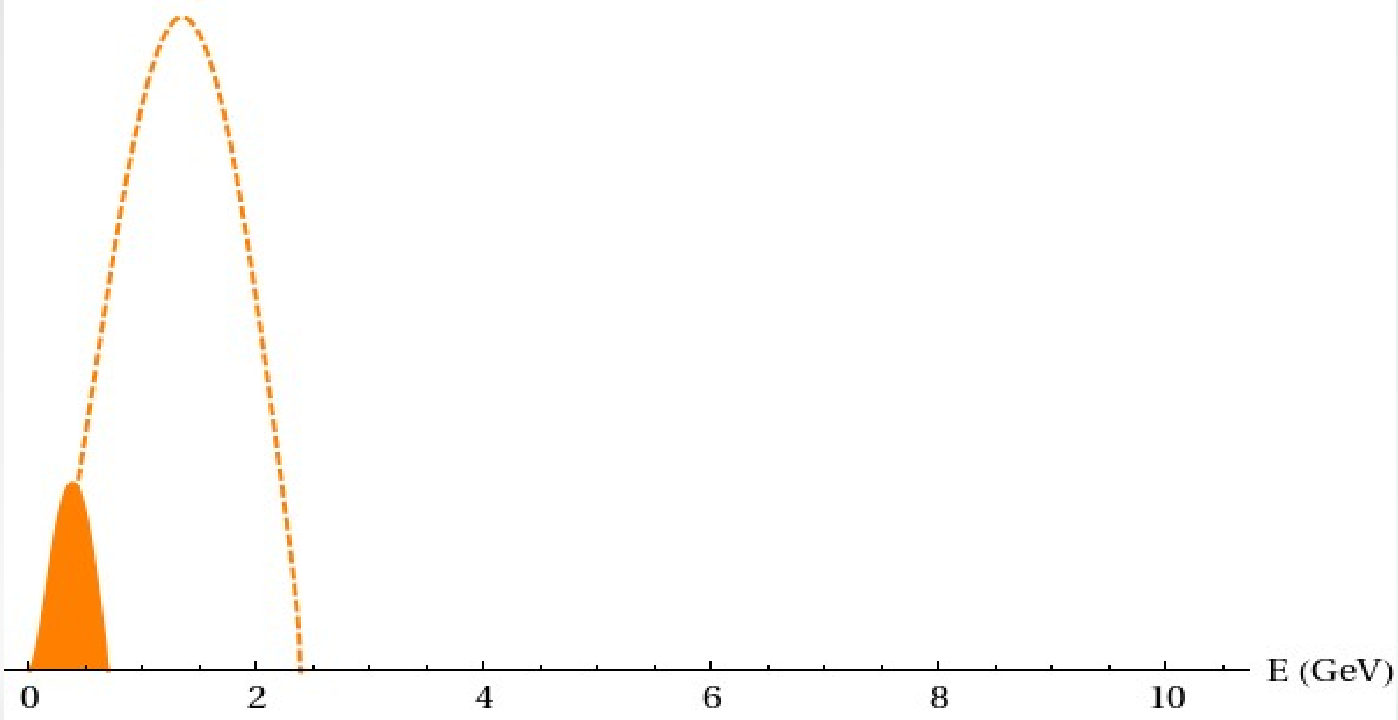
Ion Production

Acceleration

^{8}Li/^{8}B

$E_0 \sim 13$ MeV



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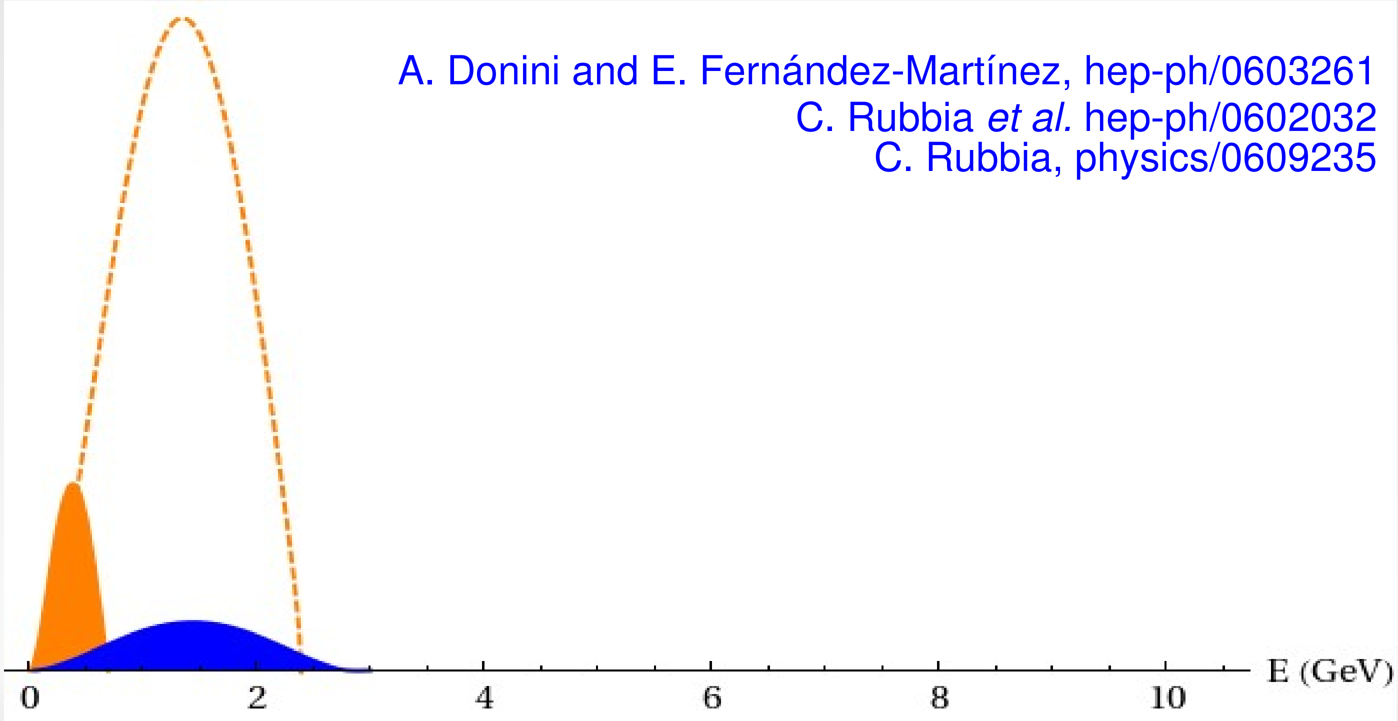
^{8}Li/^{8}B $E_o\sim 13$ MeV



A. Donini and E. Fernández-Martínez, hep-ph/0603261
C. Rubbia *et al.* hep-ph/0602032
C. Rubbia, physics/0609235

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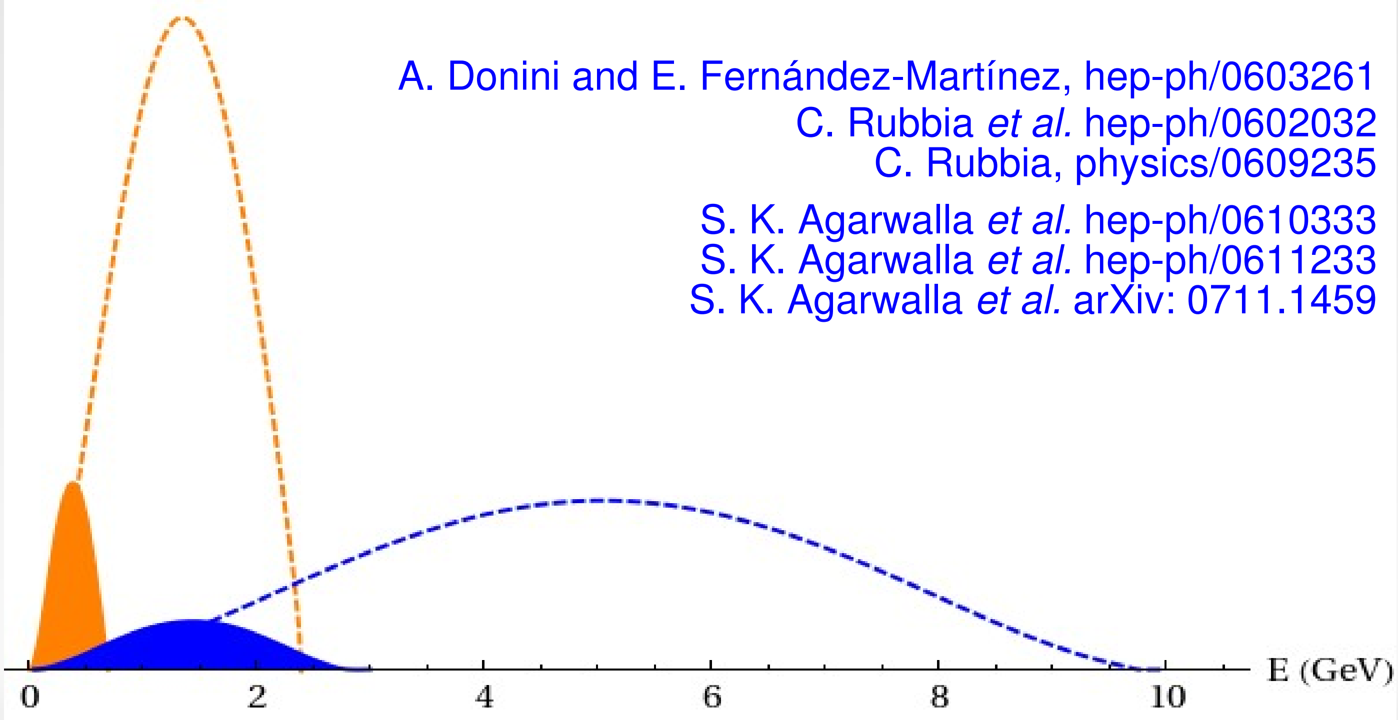

A. Donini and E. Fernández-Martínez, hep-ph/0603261
C. Rubbia *et al.* hep-ph/0602032
C. Rubbia, physics/0609235

S. K. Agarwalla *et al.* hep-ph/0610333
S. K. Agarwalla *et al.* hep-ph/0611233
S. K. Agarwalla *et al.* arXiv: 0711.1459

Previous studies on β-beams

Ion Production

Acceleration

^{8}Li/^{8}B

E_0 ~ 13 MeV

SPS/PS γ~100

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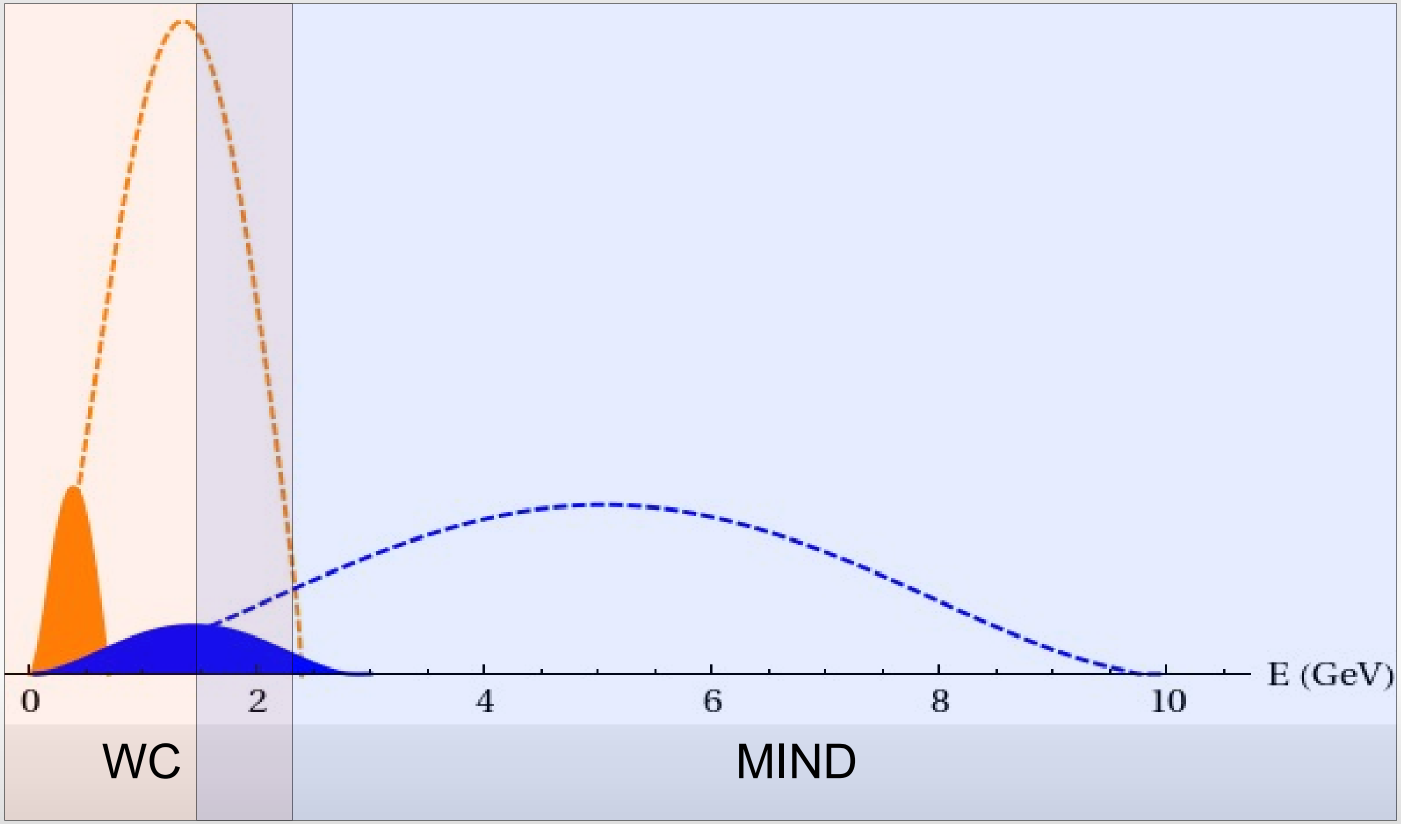


Previous studies on β-beams

Ion Production

Acceleration

Maximum

N_{ions} still

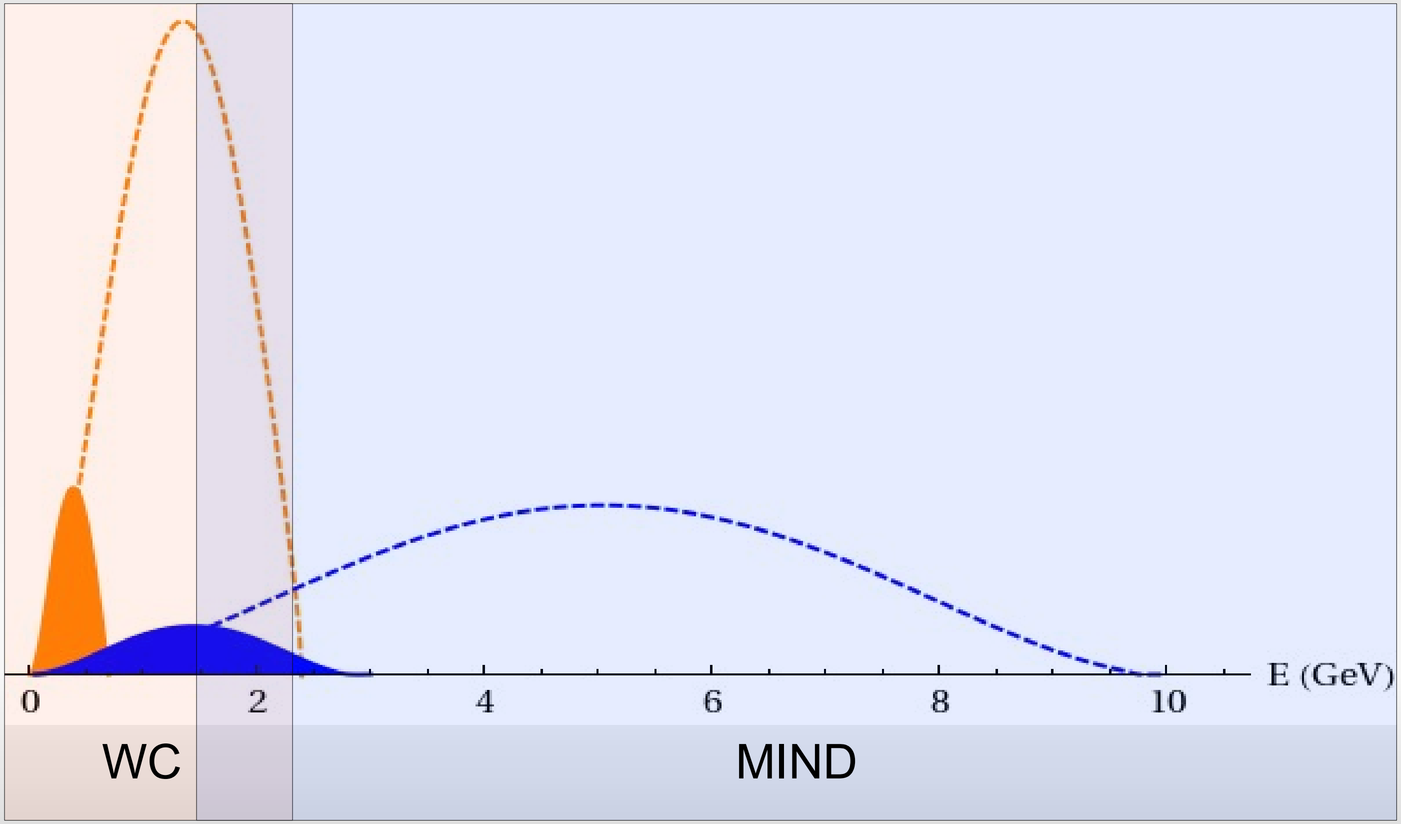
unknown...

^{8}Li/^{8}B

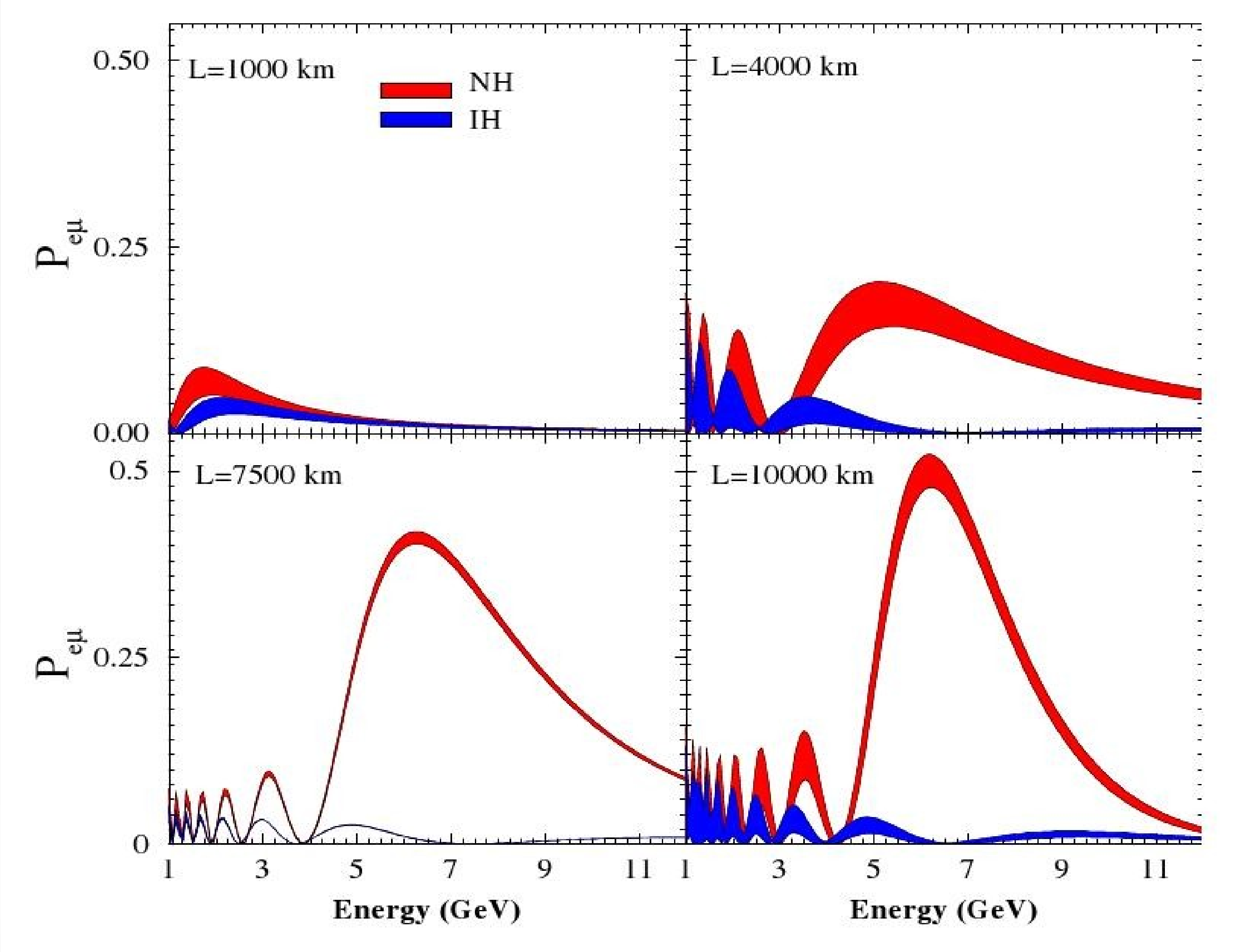
$E_o \sim$ 13 MeV

SPS/PS γ~100

SPS+/PS2 γ~350



Matter effects at the magic baseline



S.K. Agarwalla, S. Choubey and A. Raychaudhuri, hep-ph/0610333

The two-baseline
β-beam

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- Li/B: Higher energies → **higher distances** are now reachable
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- Two setups proposed up to now:
  - S. Agarwalla, S. Choubey and A. Raychaudhuri, arXiv: 0804.3007
    - He/Ne at 730 Km; $250 < \gamma < 650$; 50 kton-TASD detector
    - Li/B at 7150 Km; $\gamma = 650$; 50 kton-ICAL detector

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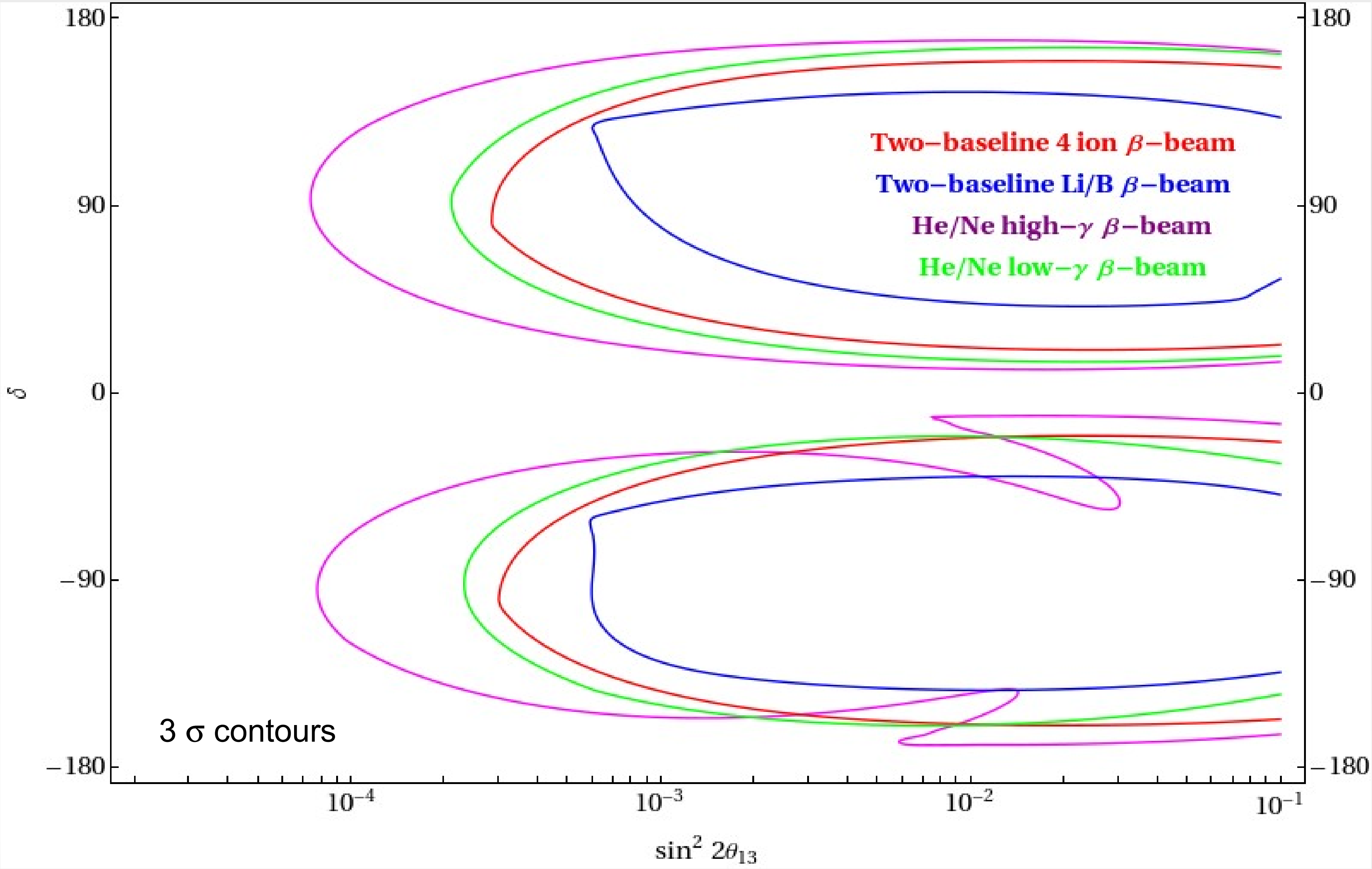
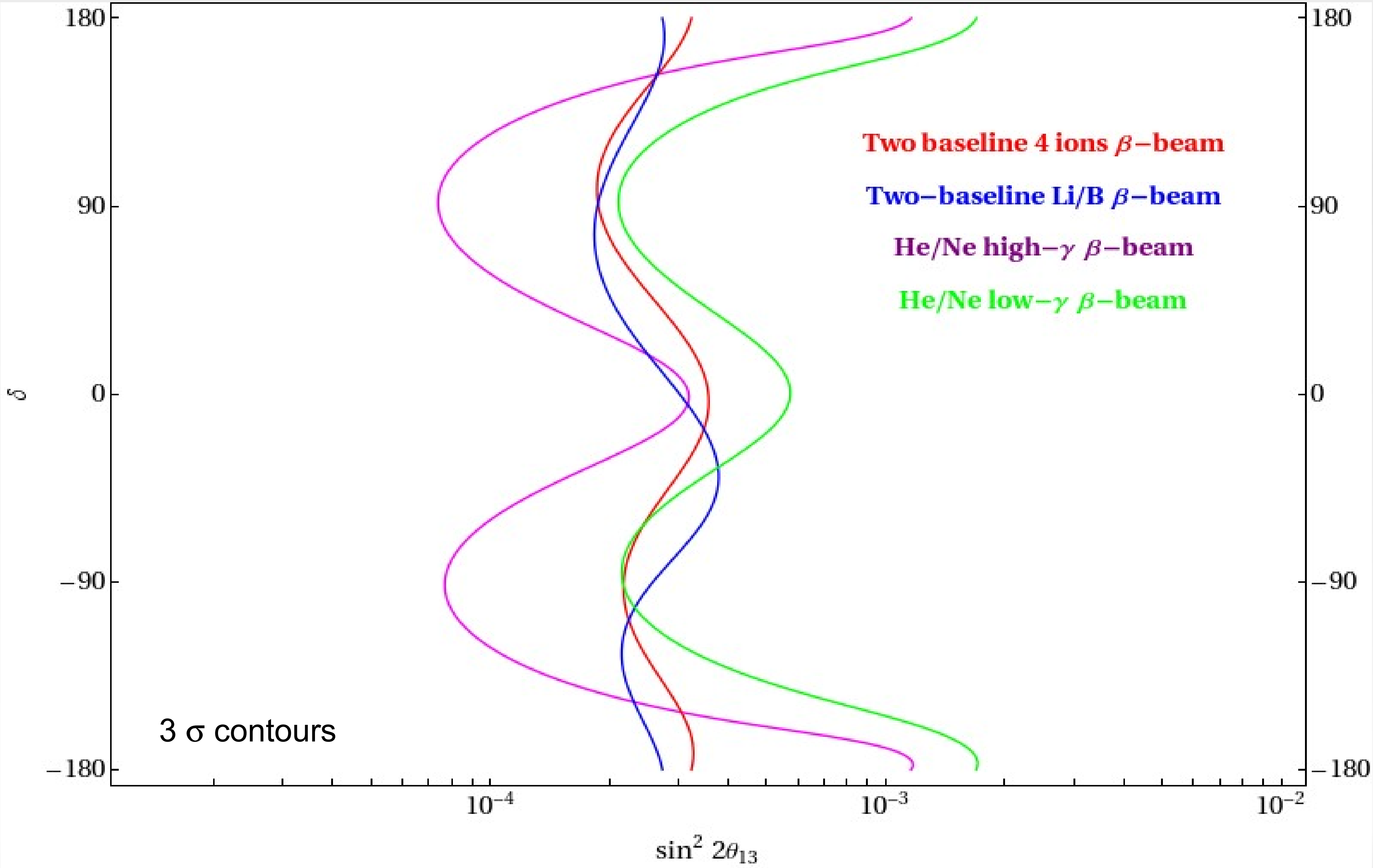
  - P. Coloma, A. Donini, E. Fernández-Martínez and J. López-Pavón, arXiv: 0712.0796
    - Li/B at 2000 Km; $\gamma = 350$; 50 kton-MIND detector
    - Li/B at 7000 Km; $\gamma = 350$; 50 kton-MIND detector

CP sensitivity



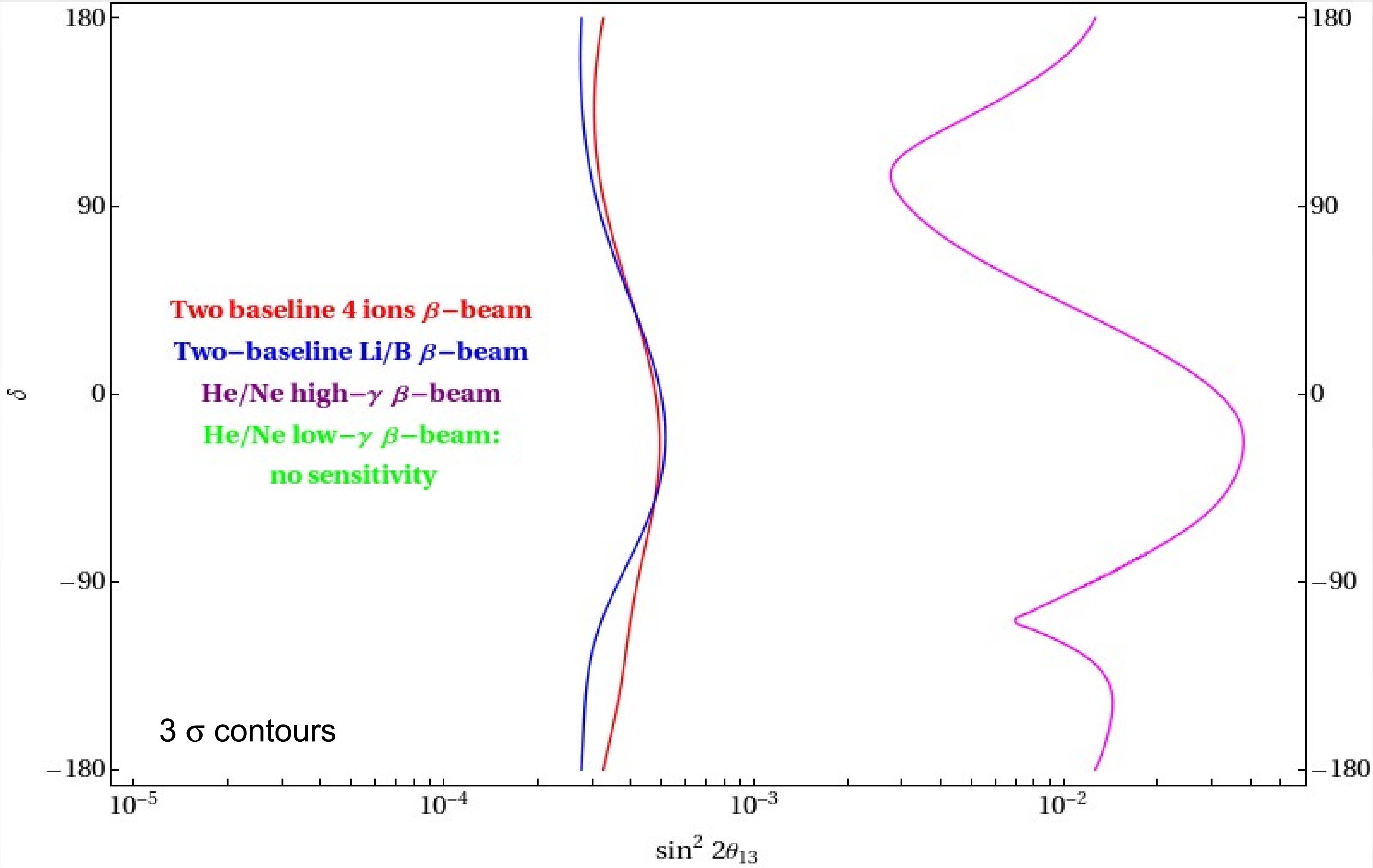
GloBES 3.0 simulated data

θ_{13} sensitivity



GloBES 3.0 simulated data

Sensitivity to the mass hierarchy



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How can we improve this?

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  - Matter resonance;
  - 50 Kton-Iron detector (MIND, ICAL);

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- He/Ne provides CP sensitivity:
  - On-peak;
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  - Matter resonance;
  - 50 Kton-Iron detector (MIND, ICAL);
- Advantages of increasing γ :
  - Higher statistics at the detector;
  - The number of ions at production stage can be relaxed.

Setup

WC

- $E_0 \sim 3$ MeV;
- $\gamma = 350$;
- 500 Kton fiducial mass;
- 650 Km (first osc.peak);
- 2.5 years/ion;
- $3.0 \cdot 10^{18}$ useful decays/year;
- 6 energy bins with ΔE=0.25 GeV;
  last bin with ΔE=0.5 GeV;
  energy range: [0.5,2.5] GeV;
- Migration matrices from hep-ph/0503021;
- Uncorrelated systematic errors: 2.5% and 5%.

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MIND

- $E_0 \sim 13$ MeV;
- $\gamma = 350 \cdot (A/Z)$;
- 50 Kton;
- 7000 Km (matter resonance);
- 2.5 years/ion;
- $3.0 \cdot 10^{18}$useful decays/ year;
- 17 energy bins with $\Delta E=1$ GeV ;
  energy range: [1.5,18.5] GeV;
- Efficiency: 65%;
- Energy smearing: 15%;
- Fractional background: 10^{-4};
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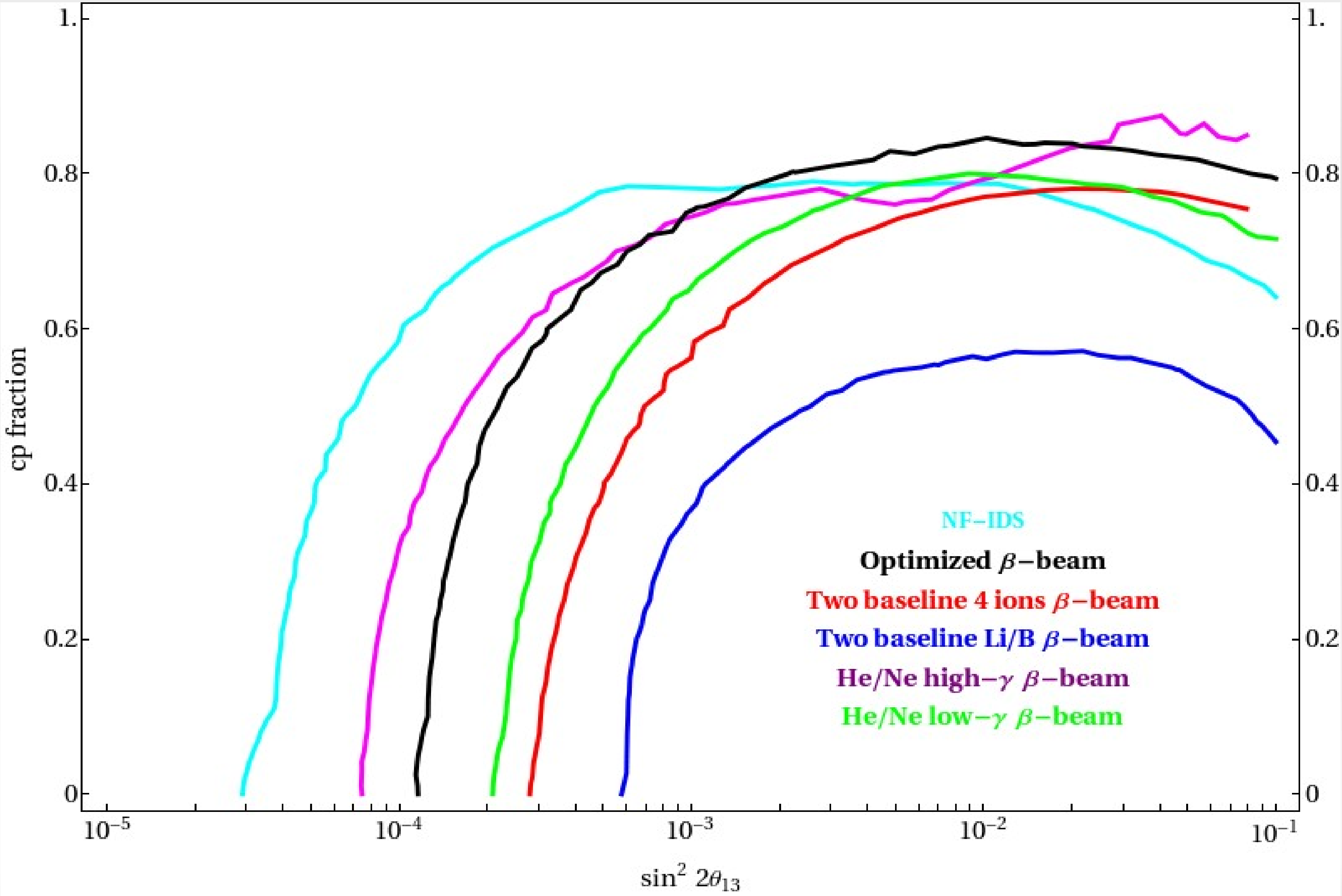
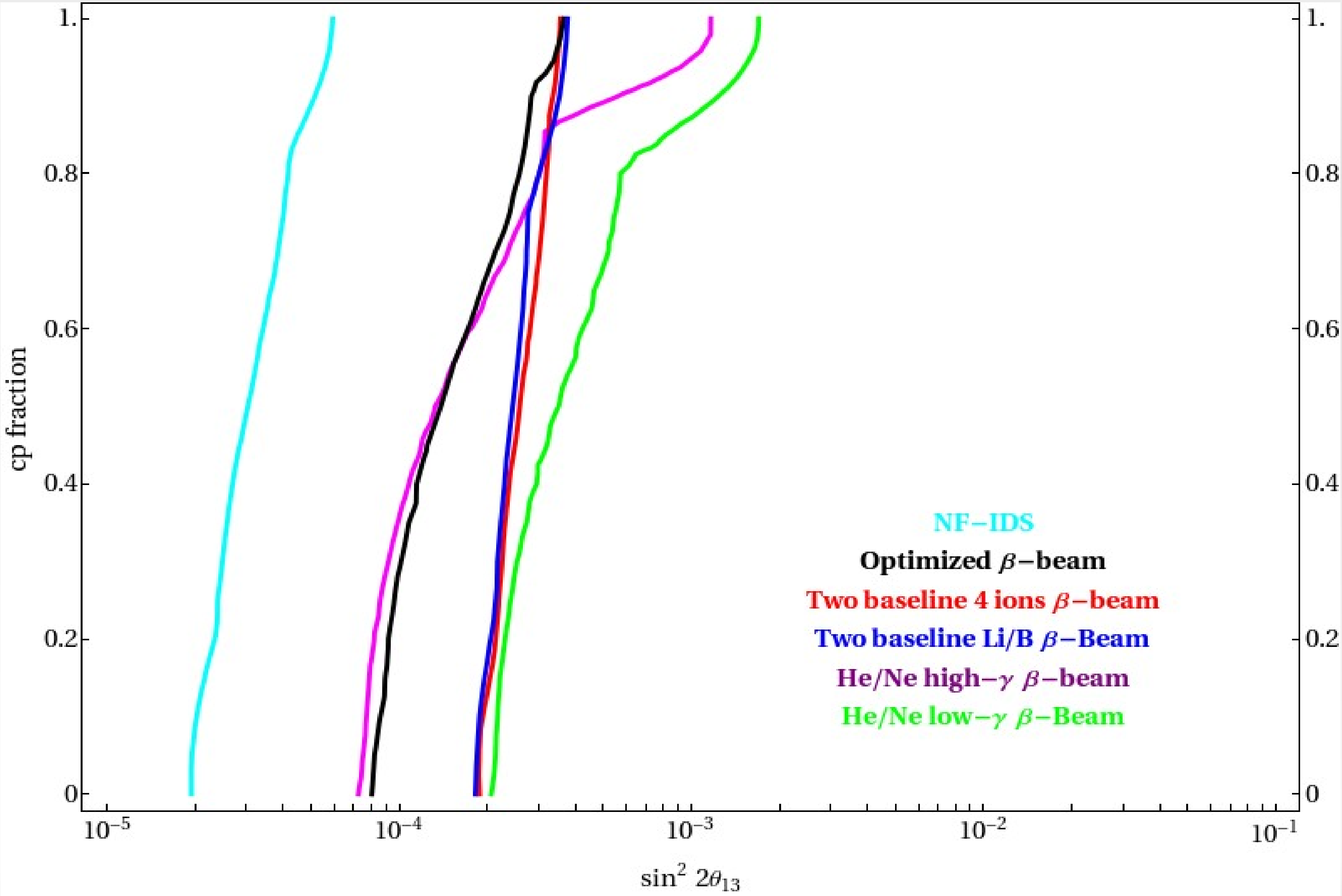


GloBES 3.0 simulated data

θ_{13} sensitivity



GloBES 3.0 simulated data

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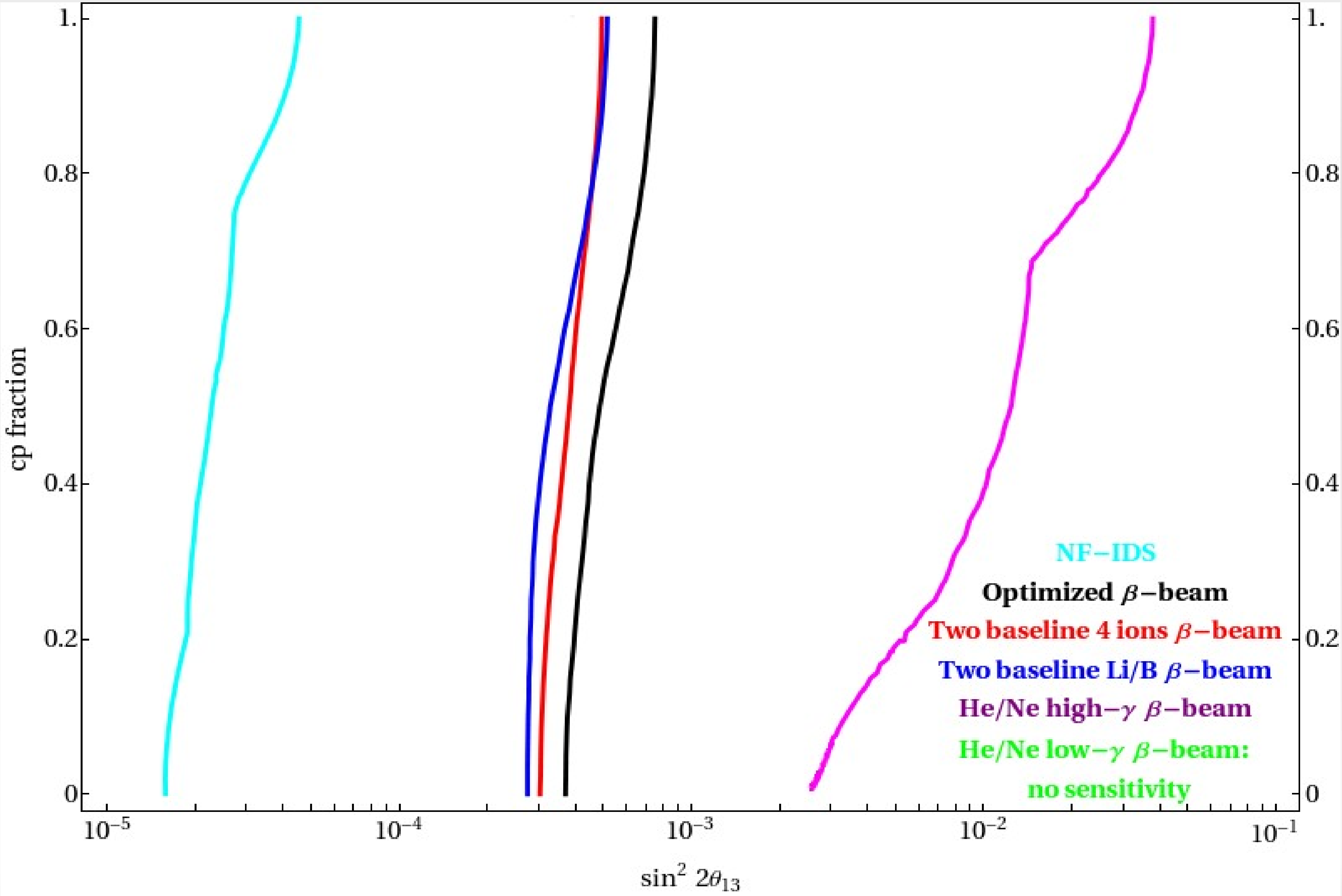

GloBES 3.0 simulated data

Conclusions

- CP sensitivity comparable to the high γ He/Ne β-Beam:
  - The setup would discover CP violation in more than 70% of parameter space for $\sin^2(2\theta_{13}) > 6 \cdot 10^{-4}$;
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- The large baseline provides sensitivity to the mass hierarchy for $\sin^2(2\theta_{13}) > 4 \cdot 10^{-4}$, only beaten by the NF;

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- The large baseline provides sensitivity to the mass hierarchy for $\sin^2(2\theta_{13}) > 4 \cdot 10^{-4}$, only beaten by the NF;
- The setup is statistics-dominated:
  - A study on the number of ions that could be **actually** produced is lacking...

Previous two baseline β–beams

S. Agarwalla, S. Choubey and A. Raychaudhuri,

arXiv: 0804.3007

- γ (He/Ne)= 575;
- γ (Li/B)= 650;
- 2.5 years/ion;
- $3.0 \cdot 10^{18}$ useful decays/year;
- At 730 Km: 50 Kton TASD detector
  - 10 energy bins with $\Delta E=0.2$ GeV; energy range: [0.5,2.5] GeV; energy smearing: $0.03 \cdot E^{1/2}$; fractional background: 10^{-3};
- At 7150 Km: 50 Kton ICAL detector
  - 18 energy bins with $\Delta E=1$ GeV; energy range: [1.0,19.0] GeV; energy smearing: $0.15 \cdot E$; fractional background: 10^{-4};
- Overall efficiencies: 80% for both detectors;
- Uncorrelated systematic errors: 2.5% and 5%.

Previous two baseline β–beams

P. Coloma, A. Donini, E. Fernández-Martínez and J. López-Pavón,

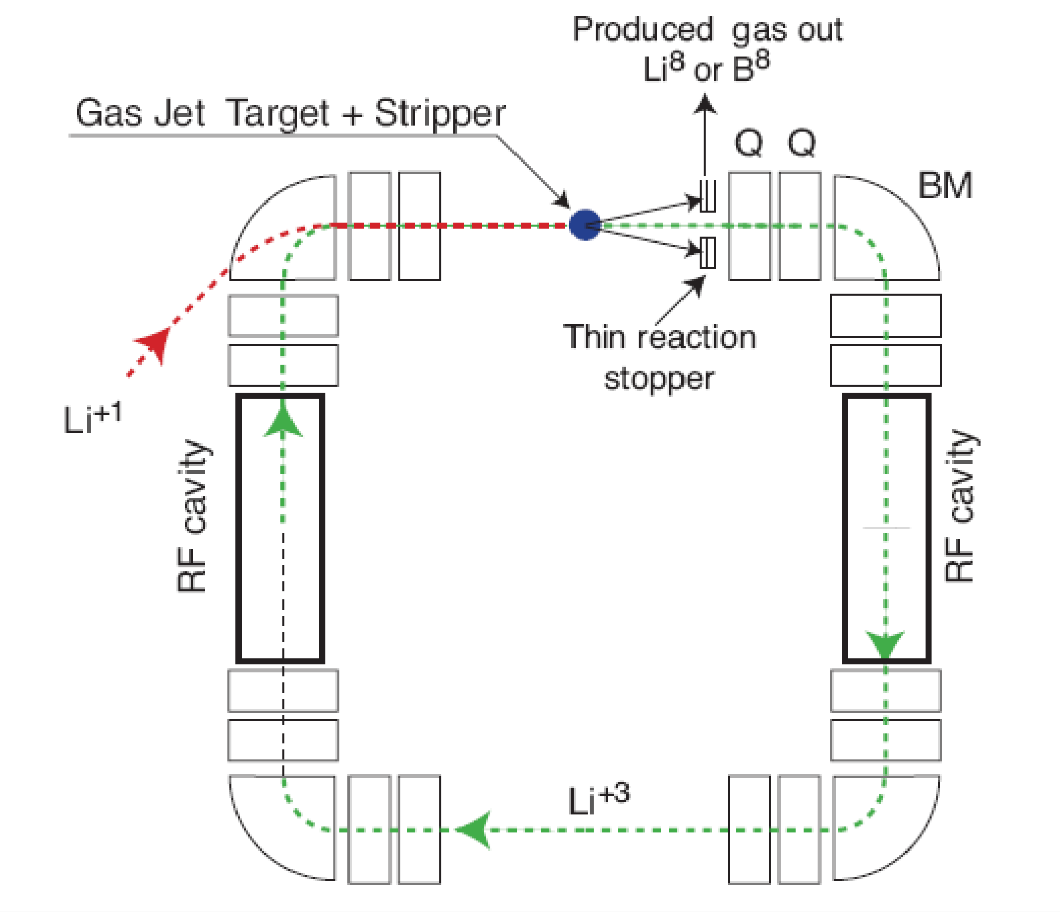
arXiv: 0712.0796

- Li/B;
- $\gamma = 350$;
- 5 years/ion;
- $3.0 \cdot 10^{18}$ useful decays/year;
- L1 = 2000 Km; L2 = 7000 Km;
- Two identical 50 Kton MIND detectors:
    - 10 energy bins, with ΔE=1 GeV; lower threshold at 1.5 GeV; fractional background: 10^{-4}; energy smearing: $0.15 \cdot E$;
- Overall efficiency: 65%;
- Uncorrelated systematic errors: 2.5% and 5%.

The ionization cooling procedure

$^7\mathrm{Li} + \mathrm{D} \rightarrow {}^8\mathrm{Li} + \mathrm{p}$

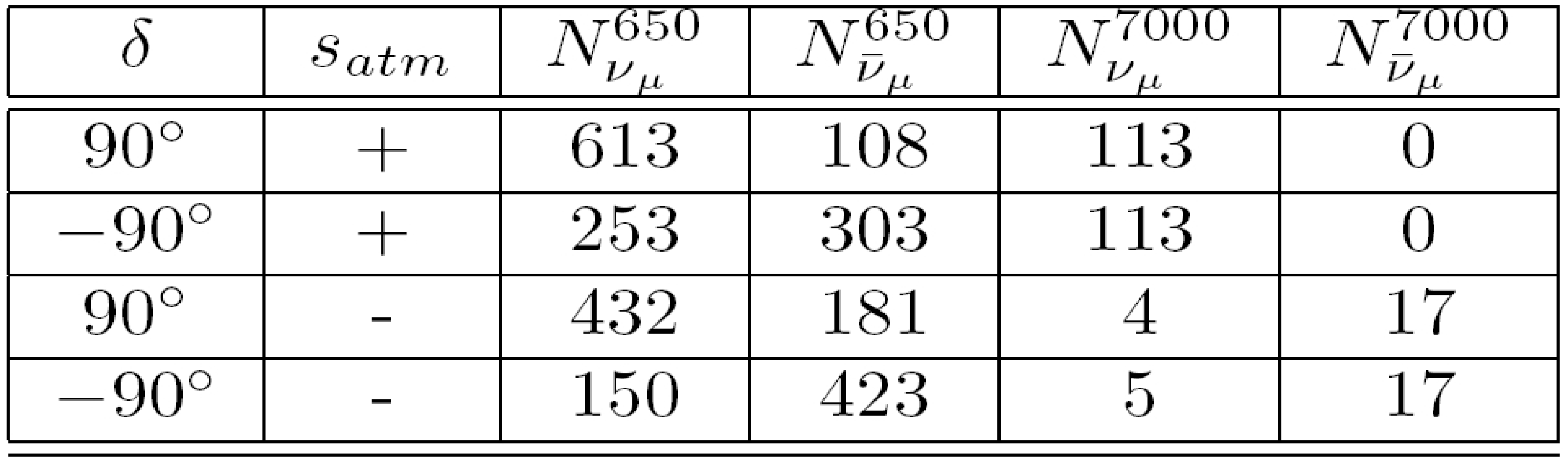
$^6\mathrm{Li} + {}^3\mathrm{He} \rightarrow {}^8\mathrm{B} + \mathrm{n}$



C.Rubbia *et al.* hep-ph/0602032

Number of events at the detector

- Total number of events for both detectors (per year), taking $\theta_{13}=5^o$



δ	s_{atm}	$N^{650}_{\nu_\mu}$	$N^{650}_{\bar{\nu}_\mu}$	$N^{7000}_{\nu_\mu}$	$N^{7000}_{\bar{\nu}_\mu}$
90°	$+$	613	108	113	0
-90°	$+$	253	303	113	0
90°	-	432	181	4	17
-90°	-	150	423	5	17