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Priority U-Net: Detection of Punctuate White Matter Lesions in Preterm Neonate in 3D Cranial Ultrasonography

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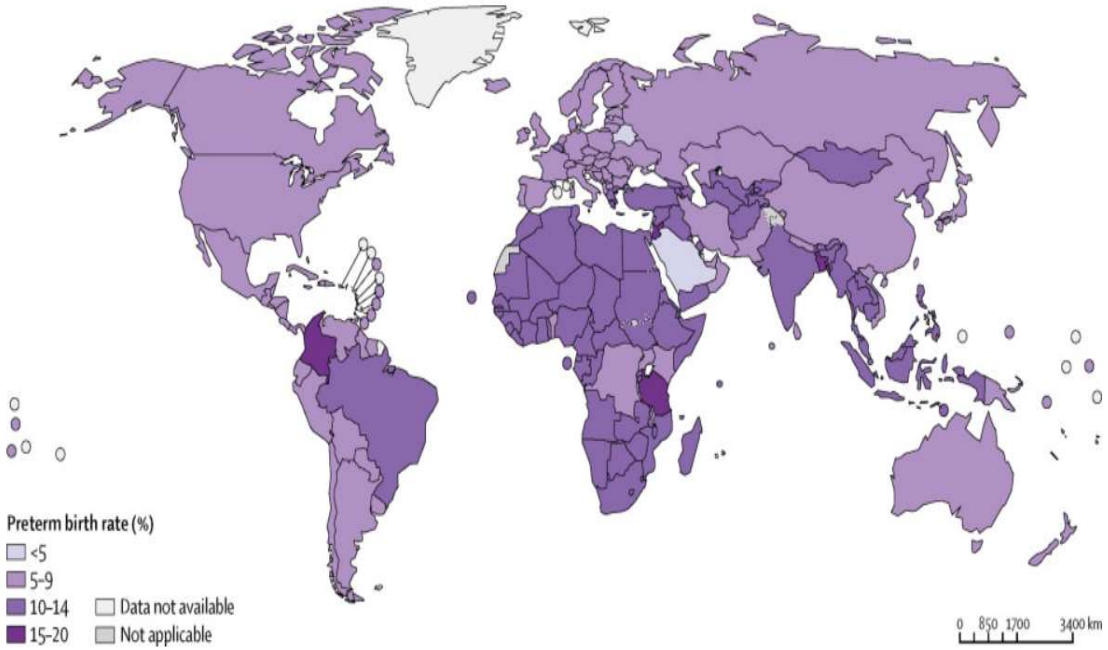
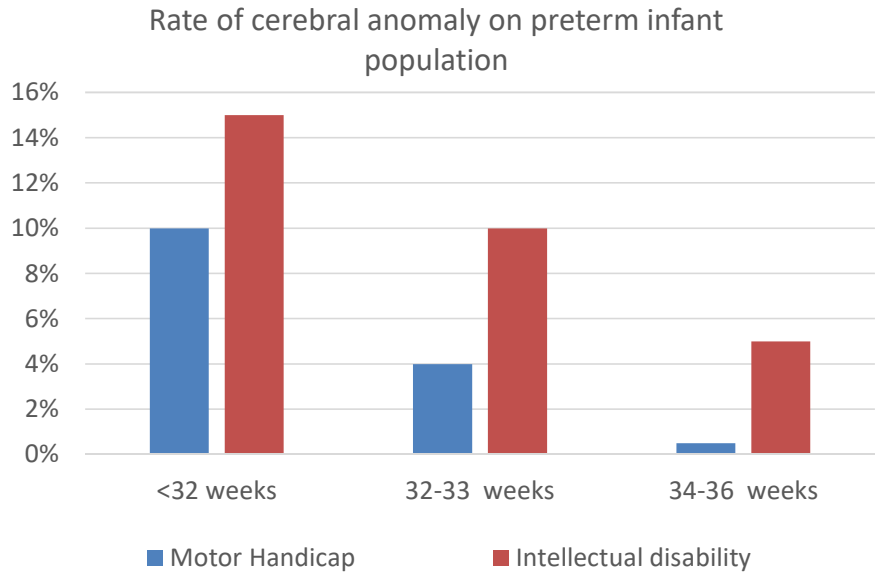
Preterm Birth and Punctuate White Matter Lesions (PWML)

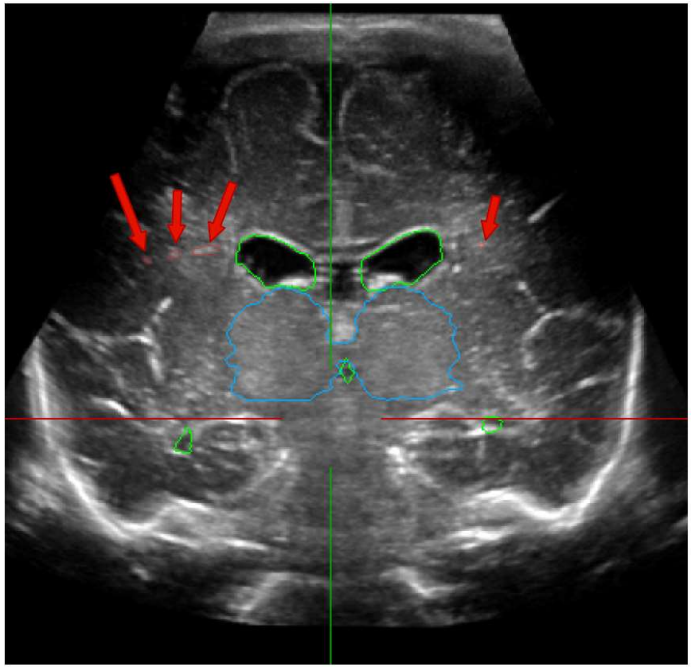


Estimated preterm birth rate, The Lancet 2014



Diagnostic of PWML

- Anomalies of the cerebral development in preterm infants include
  - **PWML** : Punctuate lesions in the surrounding white matter.
- Volume and position of PWM lesions are good indicators of the severity of sequelae
- **MRI** is the gold standard for assessing volume and position of PWML, but its access is limited
- **Cranial ultrasonography (cUS)** has shown promising performance in detecting PWML

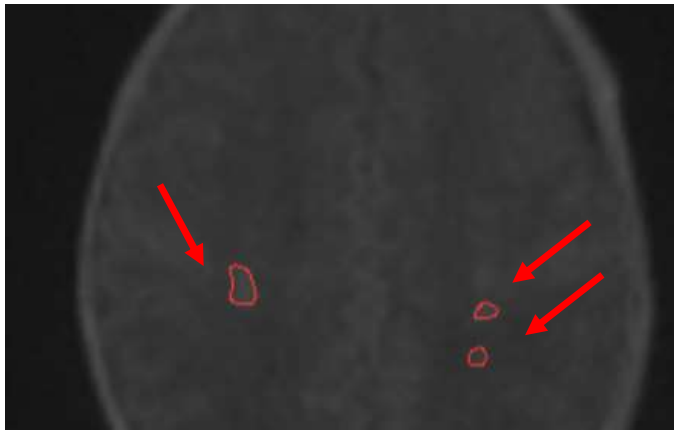


Coronal slice of cUS. PWML in Red, Thalamus in blue. Ventricular system in green.

Diagnostic of PWML

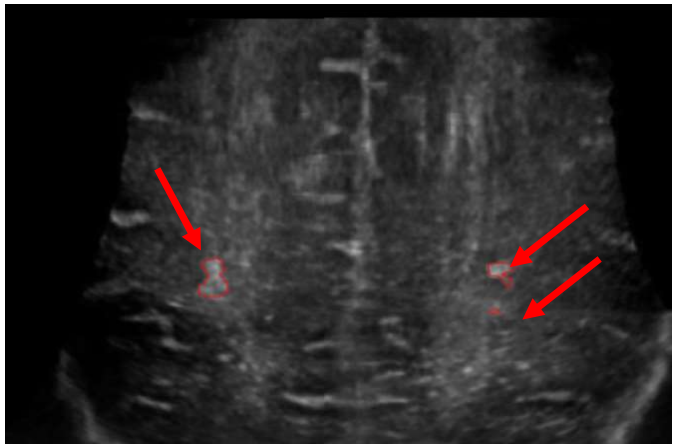
Same patient

Axial slice of MRI



PWML segmented by Liu's algorithm

Axial slice of 3D cUS



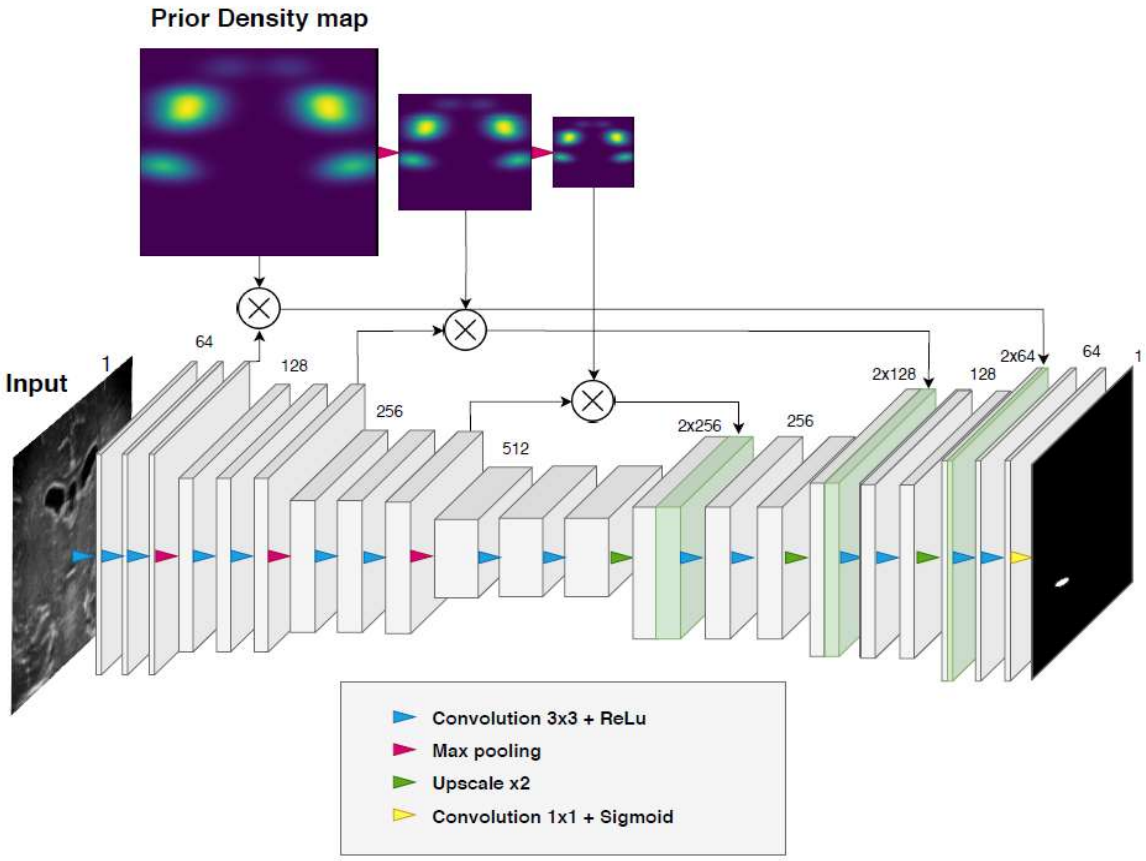
PWML segmented by an expert

- First attempts to automatically detect PMWL on MRI

[Mukherjee et al, 2019] : no learning
[Liu et al, 2020] : first DL approach

- No paper on automatic segmentation of PWML using cUS

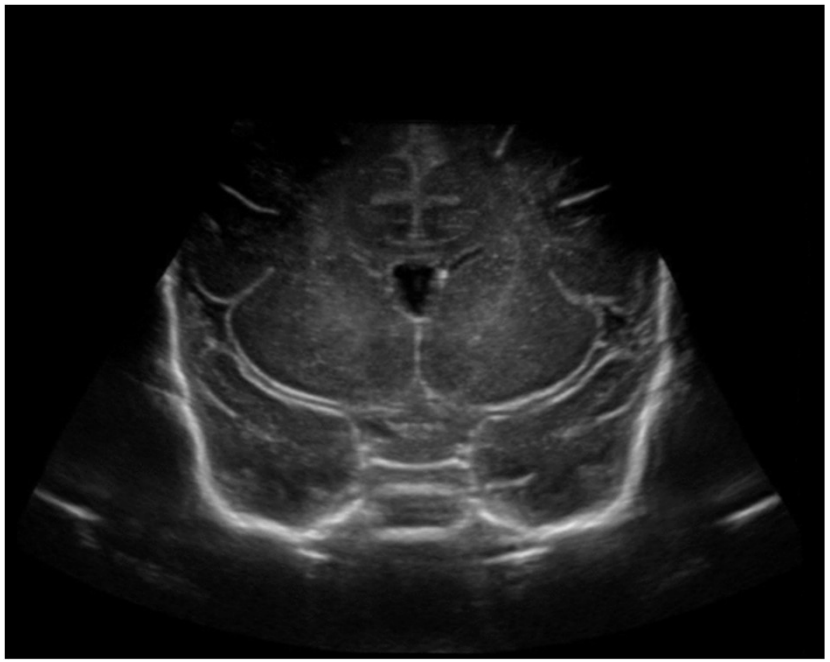
Our contribution: **Priority UNET**



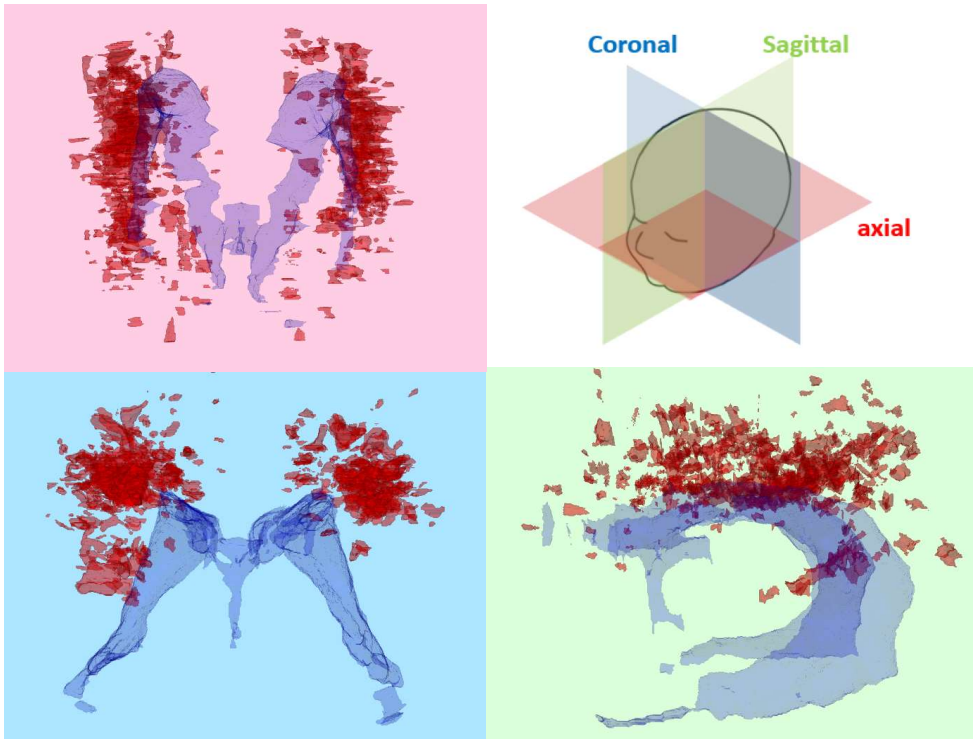
A novel end-to-end supervised architecture

- that performs detection and semantic segmentation of PWM lesions in 3D cUS images
- based on a **2D U-NET** segmentation network combined with
  - a soft attention model on PWM lesion localisation
  - a self-balanced focal loss (SBFL)

Estimation of the PWML density map

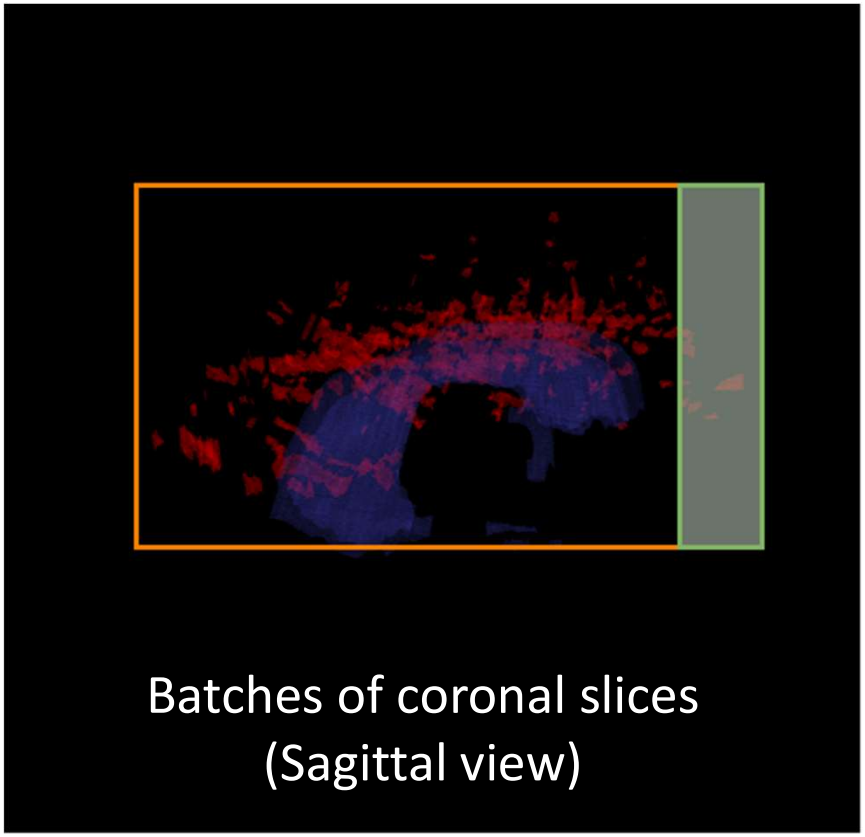


3D reconstructed cUS volume centered on the corpus callosum splenium



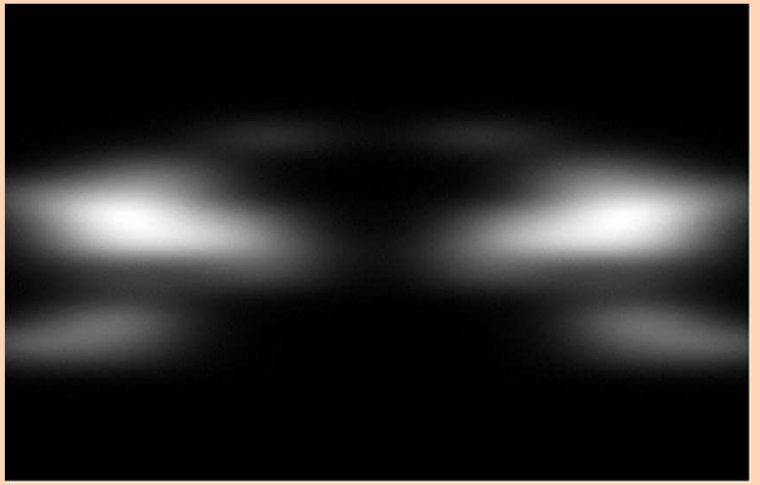
Localization of PWML concatenated from our 3D cUS dataset

Estimation of the PWML density map



Batches of coronal slices
(Sagittal view)

Parzen-Rosenblatt estimator



Computed density map for the selected batch
(Coronal view)

Loss terms

Two different loss terms are considered

- $\boldsymbol{Loss_{(DICE+BCE)}}$ Combination of Dice and Binary cross entropy (BCE)
- $\boldsymbol{Loss_{(DICE+SFBL)}}$ Combination of Dice and self-balanced focal loss (SBFL)

$$\boldsymbol{DICE}(p,\hat{p}) = 1 - \frac{2p\hat{p}}{p+\hat{p}}$$

$$\boldsymbol{BCE}(p,\hat{p}) = -(p\log(\hat{p}) + (1-p)\log(1-\hat{p}))$$

$\hat{p}$ output probability of the model
p ground truth probability of belonging to class lesion

Self-balanced focal loss

$$\boldsymbol{SBFL}(p,\hat{p}) = \beta \times FL_1 + (1-\beta) \times FL_0$$

$$\beta = \frac{0.4 \times \sum(FL_0)}{\sum(FL_0) + \sum(FL_1)} + 0.5$$

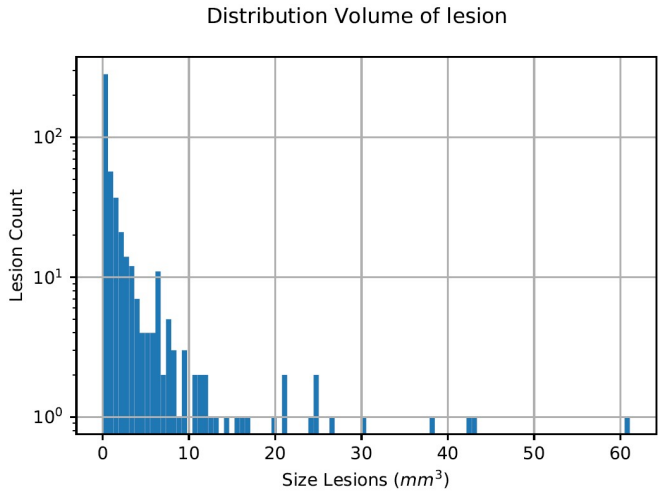
$$FL_0(p,\hat{p}) = -\hat{p}^{\gamma} \times (1-p) \times \log(1-\hat{p}+\epsilon)$$

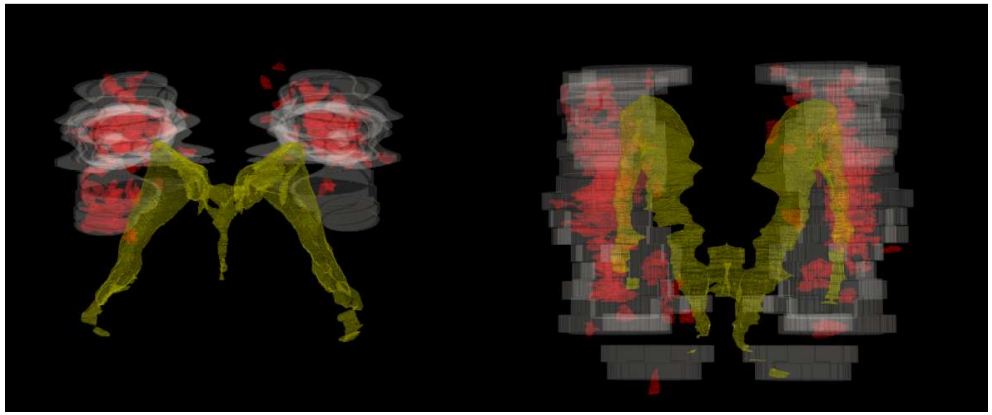
$$FL_1(p,\hat{p}) = -(1-\hat{p})^{\gamma} \times p \times \log(\hat{p}+\epsilon)$$

γ reduces the loss contribution for 'easy' examples

Dataset description

- **21 neonate patients** with mean age at birth of 31.6 ±2.5 weeks
- 3D cUS reconstructed volumes (360x400x380)
- Isotropic spatial resolution : 0.15 mm
- 547 3D lesions annotated by an expert pediatrician
- **131 lesions with a volume > 1.7 mm3**
- 3000 coronal slices with lesions





Coronal view (left) and Axial view (Right). Ventricular system in yellow, the Pool of PWML in red and the thresholded density map in white.

Experiments

- Evaluate performance of **Priority-UNET**
  - **Ablation study** to evaluate the impact of
    - the **loss** term : $\boldsymbol{Loss_{(DICE+BCE)}}$ and $\boldsymbol{Loss_{(DICE+SBFL)}}$
    - the **soft attention model**
- 10-fold cross-validation
- Performance metrics for
  - **detection tasks** : recall, precision at the lesion level
  - **segmentation tasks**: volumetric recall $\mathrm{R_V}$ and precision $\mathrm{P_V}$, DICE index

$$P_V = \sum_{i=1}^{N} a_i P_V^i$$

P_V^i **fraction of predicted lesional volume** over the total lesional volume for patient *I*

a_i fraction of true lesional volume for patient *i* over the total lesional volume in the database

Results

Detection task

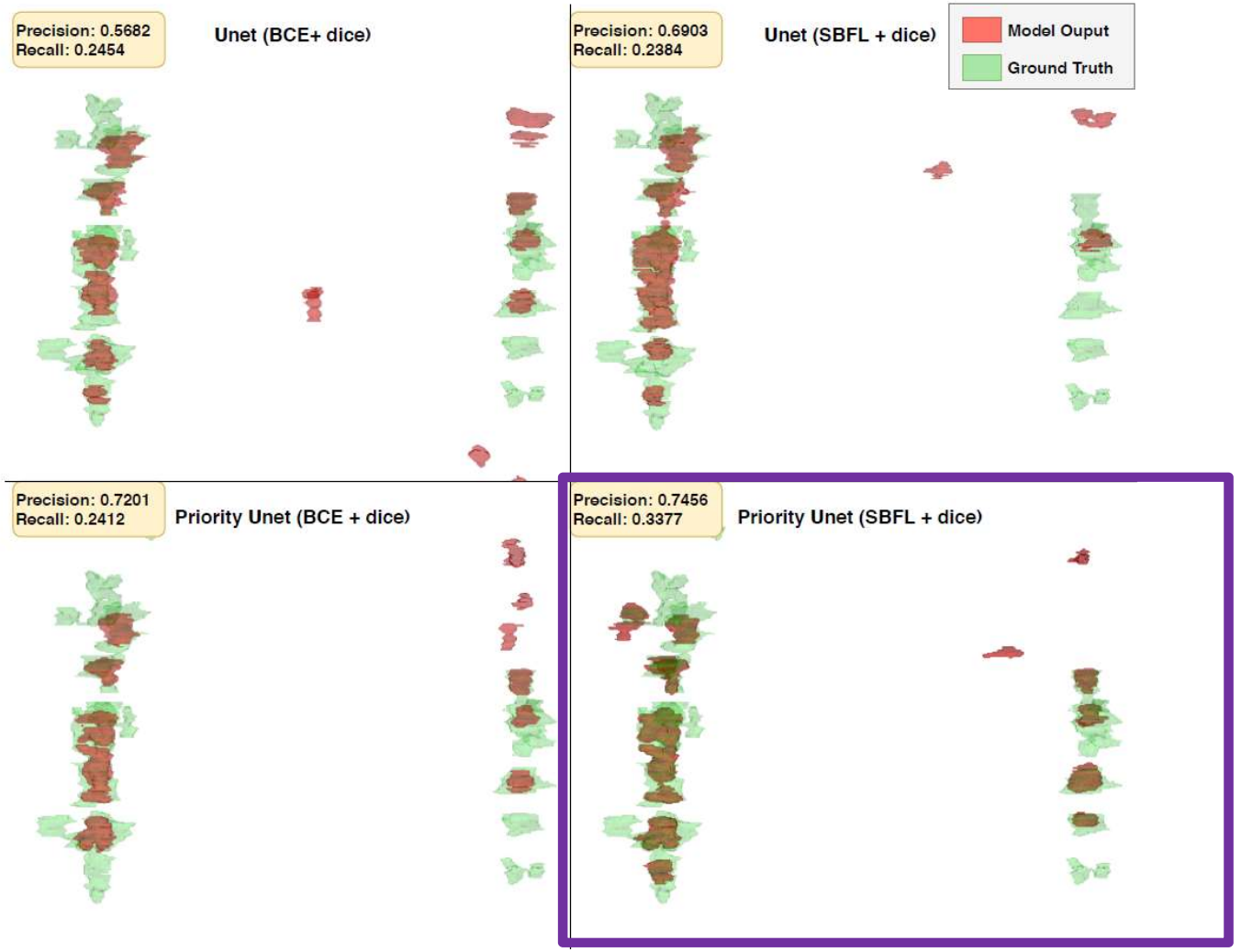
Model	Precision	Recall
U-net (BCE + Dice)	0.4404	0.3217
U-net (SBFL + Dice)	0.2347	**0.5510**
Priority U-net (BCE + Dice)	**0.4464**	0.4347
Priority U-net (SBFL + Dice)	**0.5370**	**0.5043**

Segmentation task

Model	P_V	P_V	Dice
U-net (BCE + Dice)	0.5004	0.2419	0.3040
U-net (SBFL + Dice)	**0.6043**	0.1806	0.2611
Priority U-net (BCE + Dice)	**0.5455**	**0.2789**	**0.3565**
Priority U-net (SBFL + Dice)	0.5289	**0.3206**	**0.3839**

Legend :
Ranked first
Ranked 2nd

Results



Example 3D visualization of PWML segmentation overlaid on reference lesions

Conclusion

- **First detection/segmentation of PWML** in Preterm Neonate **in 3D cUS**
- New deep architecture, called **Priority U-Net**, based on the 2D U-Net backbone combined with
  - the self balancing focal loss and a **soft attention model focusing on the PWML localisation**
- Performance of Priority-UNET Compared to the U-Net. Detection task:
  - Recall from 0.4404 to 0.5370 and precision from 0.3217 to 0.5043.
- Performance of cUS vs MRI for segmentation task:
  - Dice score 21.5% better in MRI in Liu at al
  - Spatial resolution, less than 0.04 mm3 for cUS vs around 0.8 mm3 for MRI