RF photoinjector modeling and machine learning optimization in NSRRC

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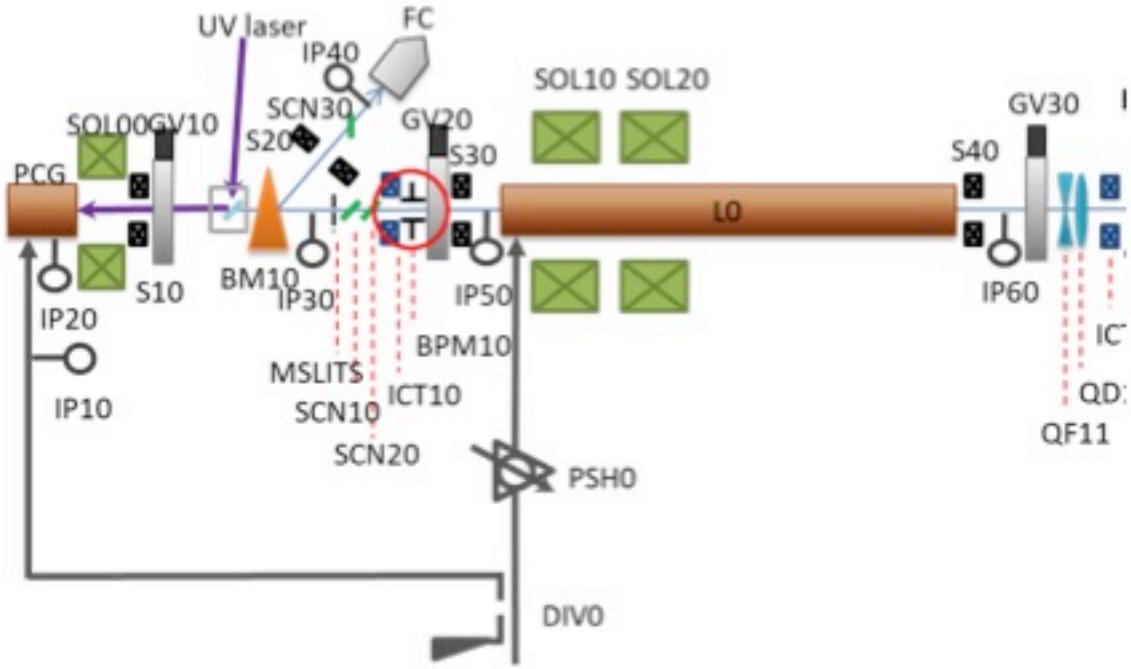
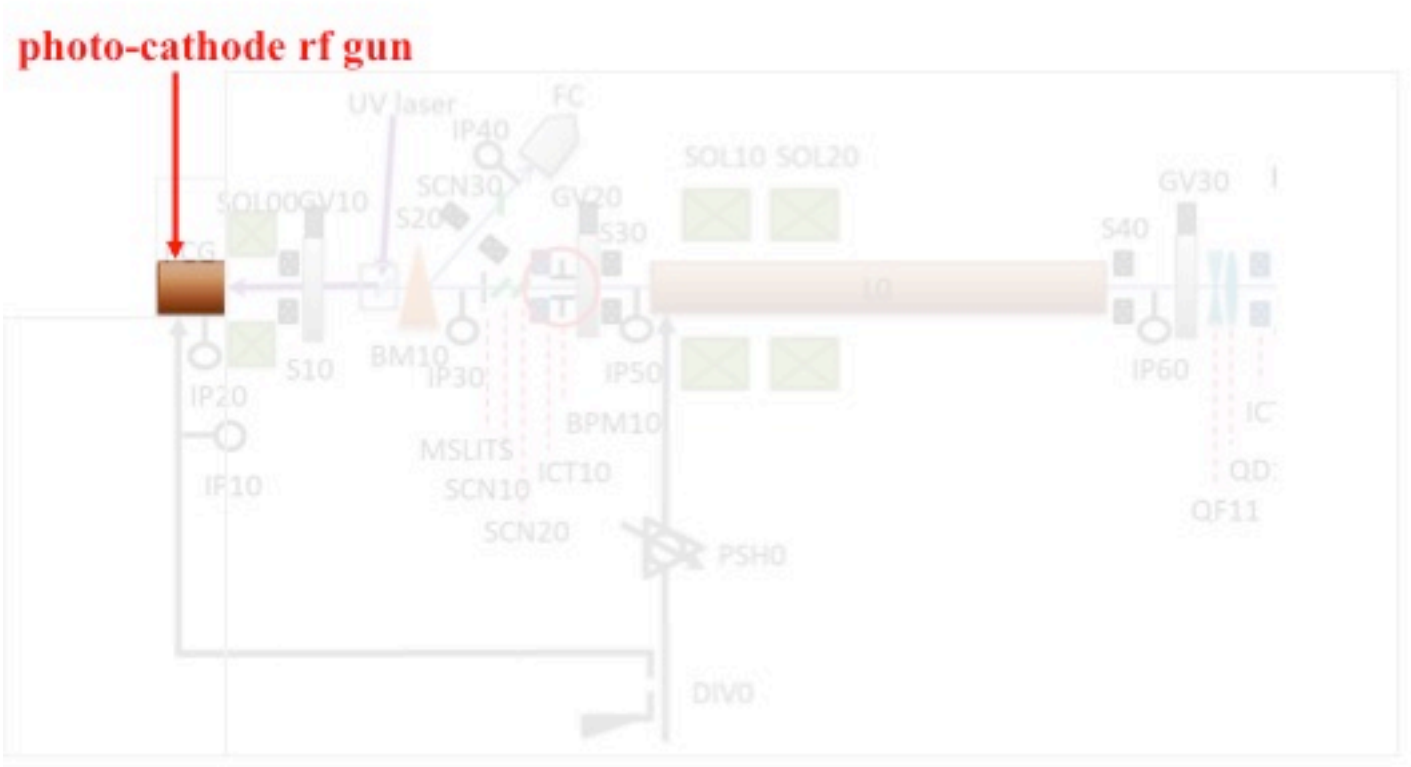
Outline

- RF photoinjector
- Simulation by ASTRA
- Machine learning
- Result
- Summary

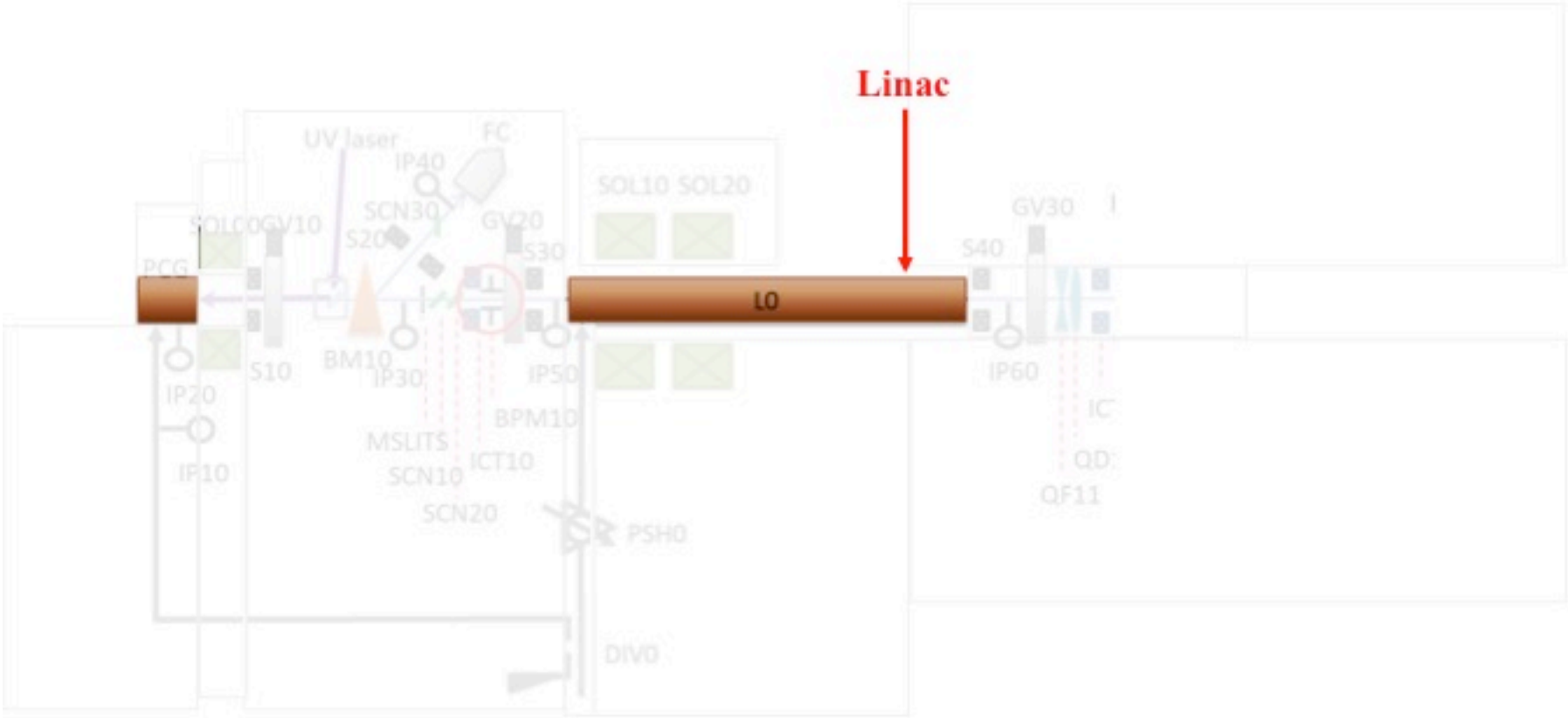
RF photoinjector



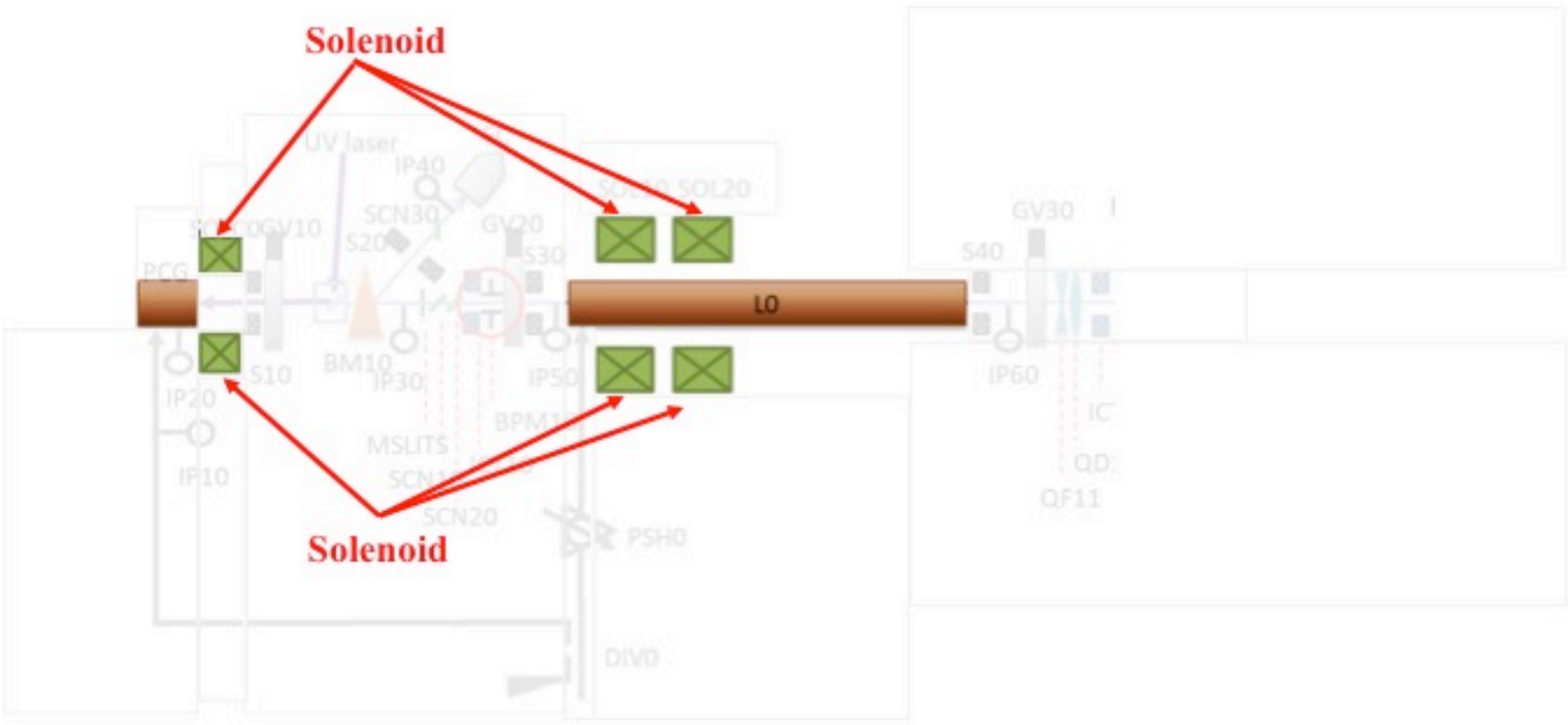
RF photoinjector



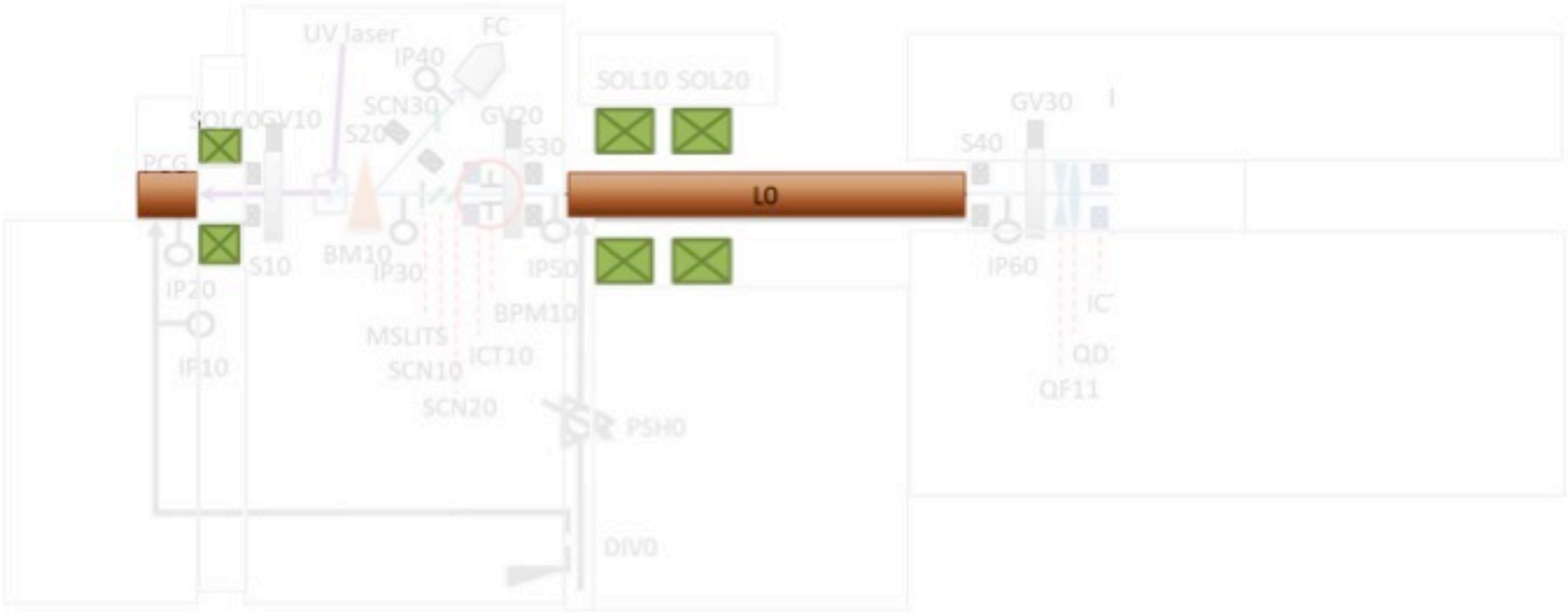
RF photoinjector



RF photoinjector



Simulation by ASTRA



Simulation by ASTRA

Input

Charge
E-gun
Phase-gun
B-gun
E-Linac
Phase-Linac
B-Linac
Schottky effect1
Schottky effect2

→ **simulation** →

Output

Charge
Particle Energy
Emittance
Energy Spread
Beam size
Charge Pattern

Simulation by ASTRA

Input

Charge
E-gun
Phase-gun
B-gun
E-Linac
Phase-Linac
B-Linac

→ **simulation** →

Output

Charge
Particle Energy
Emittance
Energy Spread
Beam size
Charge Pattern

Simulation by ASTRA

Input

Charge
E-gun
Phase-gun
B-gun
E-Linac
Phase-Linac
B-Linac

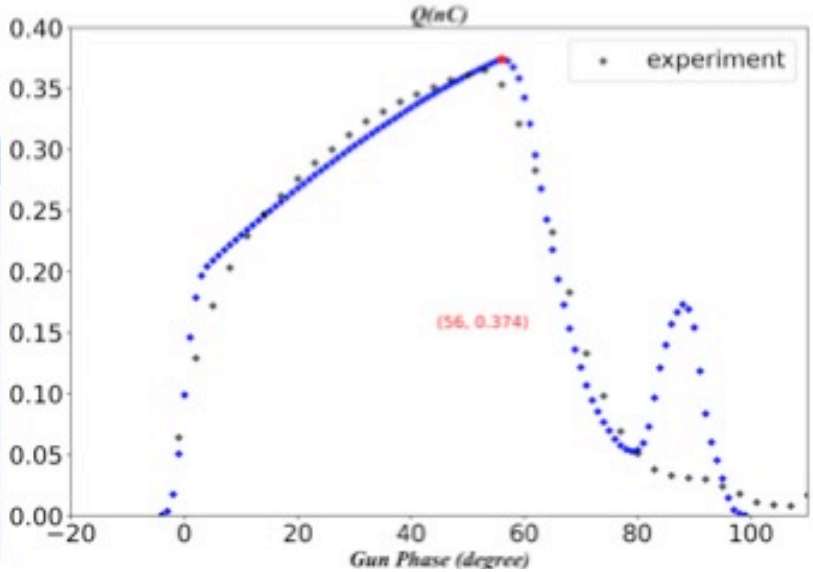
→ **simulation** →

Output

Charge
Particle Energy
Emittance
Energy Spread
Beam size
Charge Pattern

Simulation by ASTRA

	Simulation	Experiment
Qbunch (pC)	190	
Aperture(mm)	17.3	
Gun E field (MV/m)	51.4	51.4
Gun Phase (degree)		
Gun Solenoid B field (T)	0.1100	0.1413
SRT_Q_Schottky	0.0040	
Q_Schottky	0.0040	



Simulation by ASTRA

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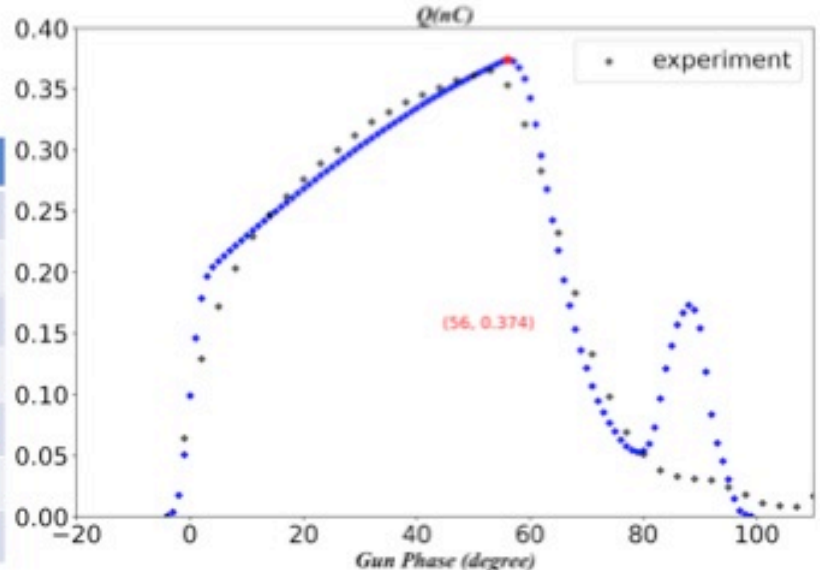
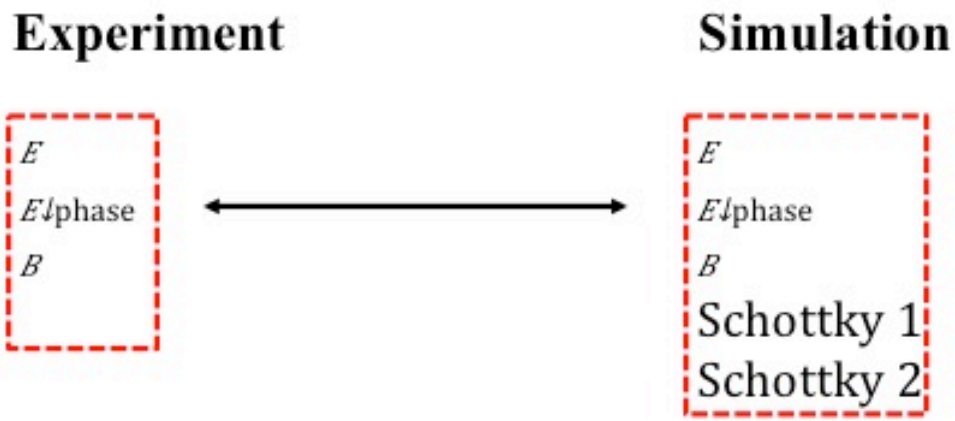


Simulation by ASTRA



Simulation by ASTRA

Input

Charge
E-gun
Phase-gun
B-gun
Schottky 1
Schottky 2

→ **simulation** →

Output

Charge
Particle Energy
Emittance
Energy Spread
Beam size
Charge Pattern

Machine learning

Input

$[\blacksquare x\downarrow 1\ @x\downarrow 2\ @x\downarrow 3\ ]$

$\longrightarrow$ **Model** $\longrightarrow$

Output

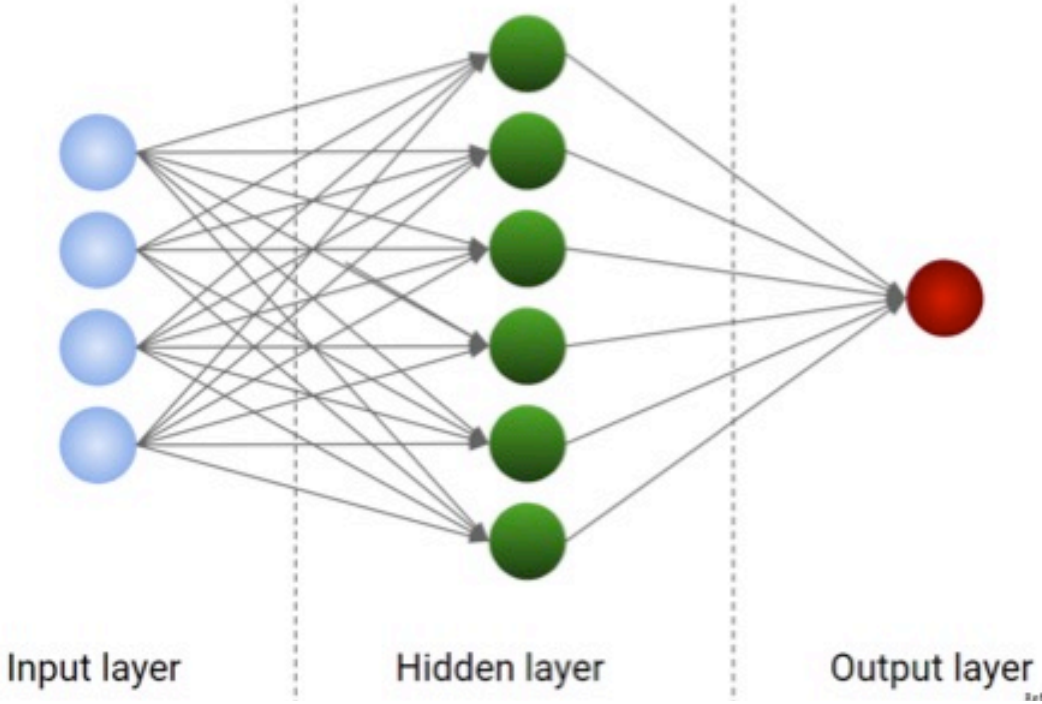
$[\blacksquare y\downarrow 1\ @y\downarrow 2\ @y\downarrow 3\ ]$

What
goal

Machine learning

Neural Network

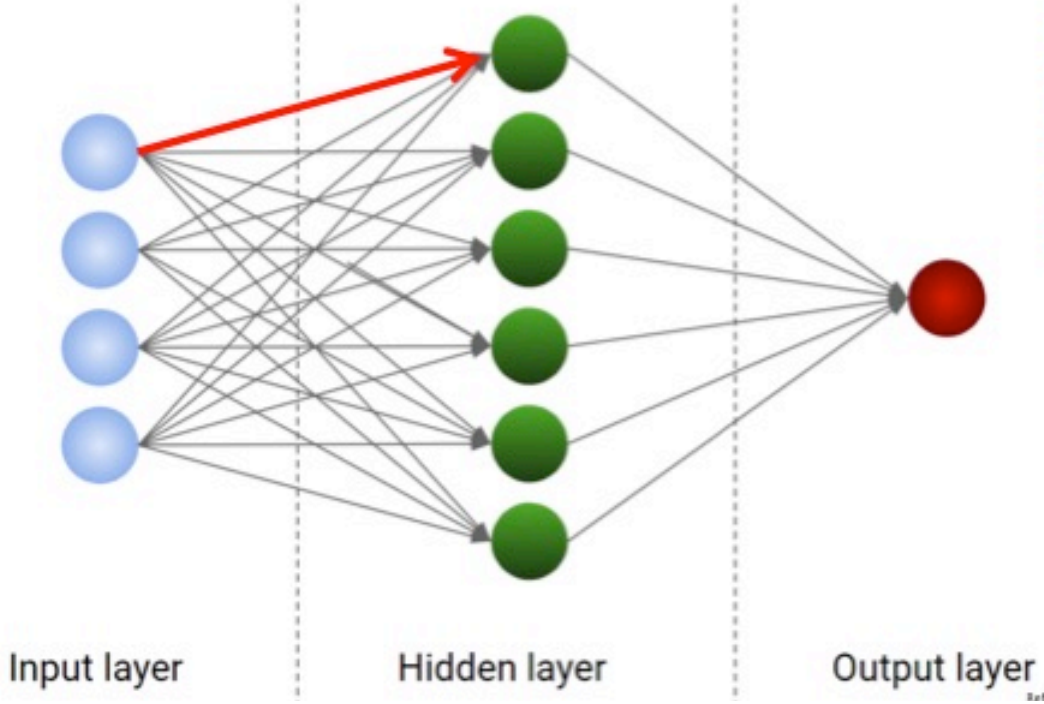
In
Model
out



Ref: https://www.yourdatateacher.com/2021/05/10/how-many-neurons-for-a-neural-network/

Machine learning

Neural Network



Hyper parameter

weight: w

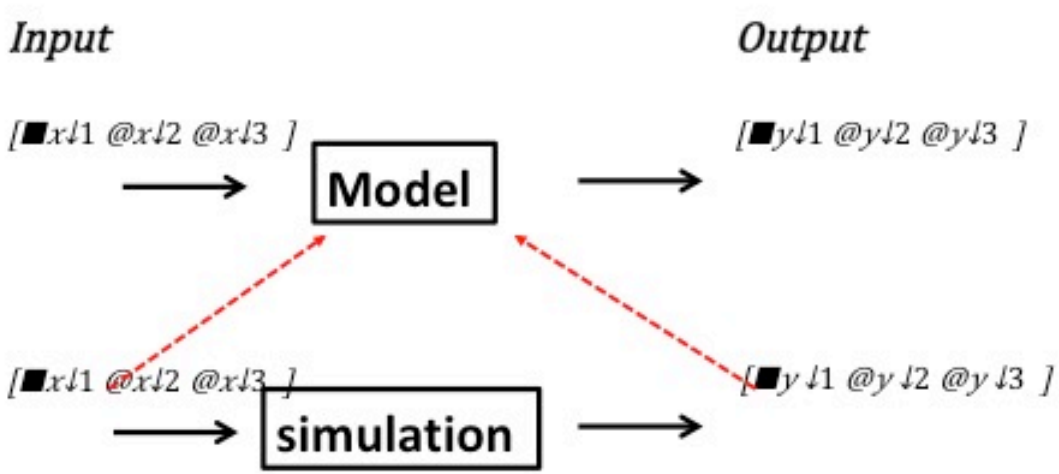
bias: b

constant: c

Activation function

Ref: https://www.yourdatateacher.com/2021/05/10/how-many-neurons-for-a-neural-network/

Machine learning



Train
model
simu

train

Machine learning

Goal

Input ***Output***

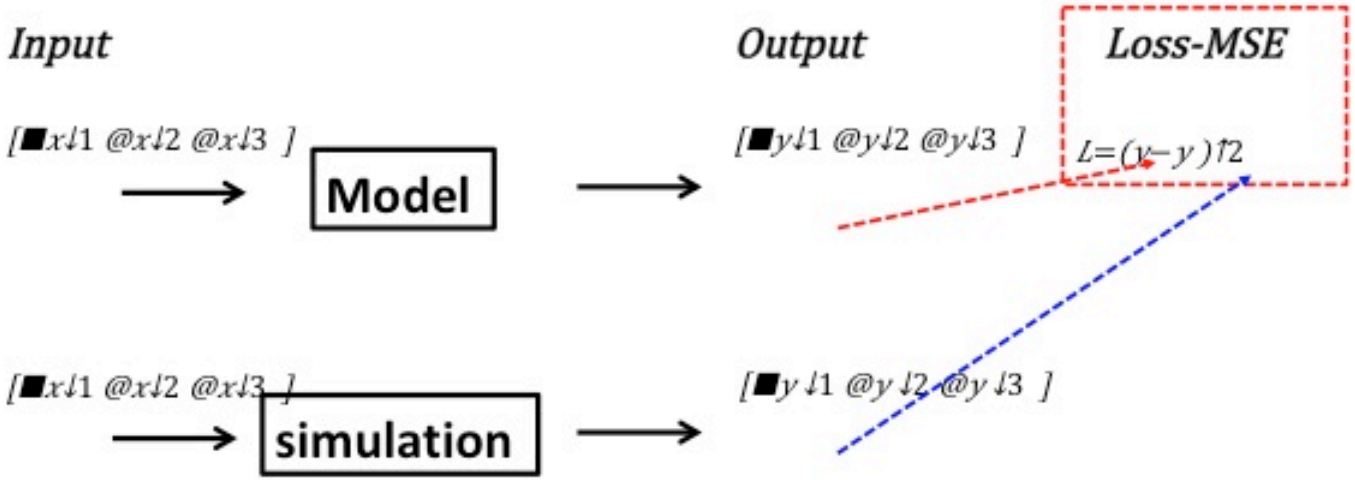
[■x↓1 @x↓2 @x↓3] → **Model** → [■y↓1 @y↓2 @y↓3]

||

[■x↓1 @x↓2 @x↓3] → **simulation** → [■y ↓1 @y ↓2 @y ↓3]

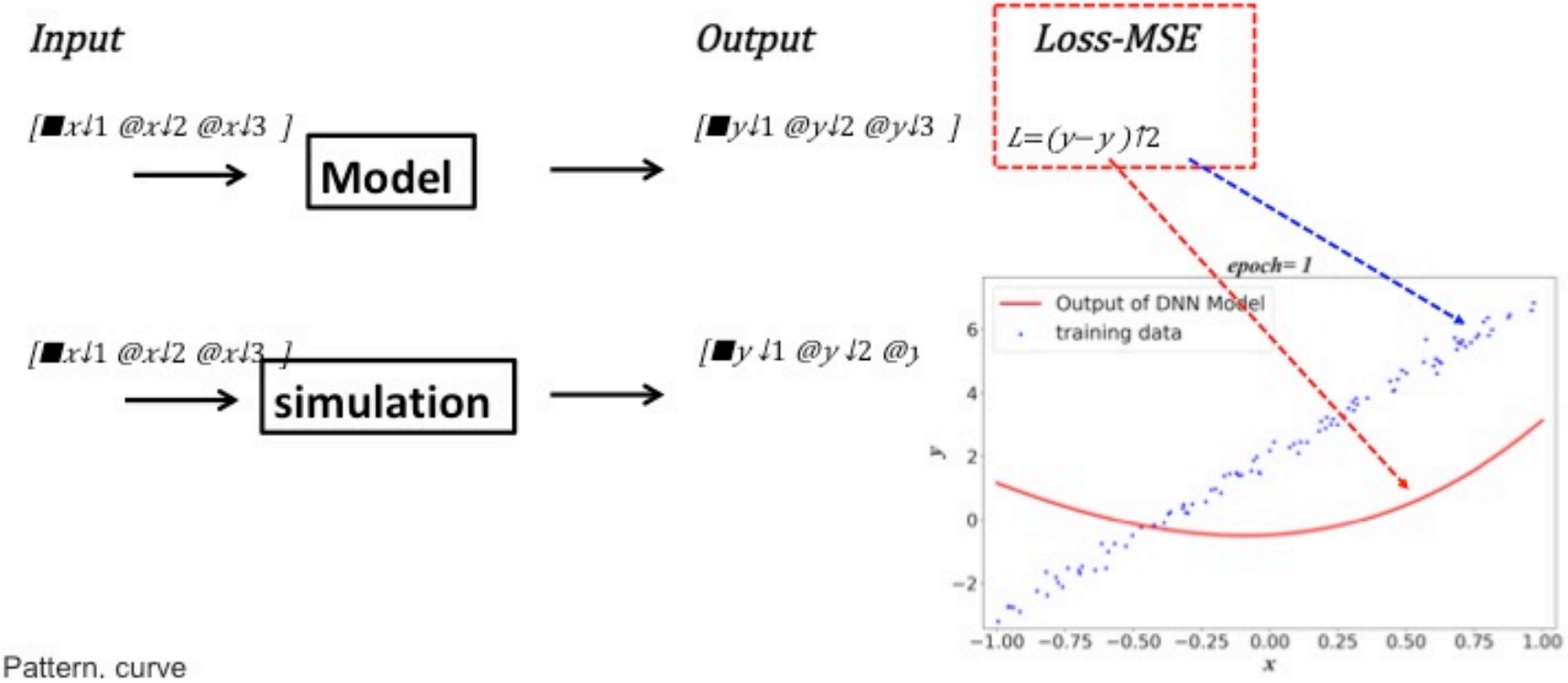
goal

Machine learning



loss

Machine learning



Pattern, curve

Machine learning

Input

[■x↓1 @x↓2 @x↓3]

→ **Model** →

Output

[■y↓1 @y↓2 @y↓3]

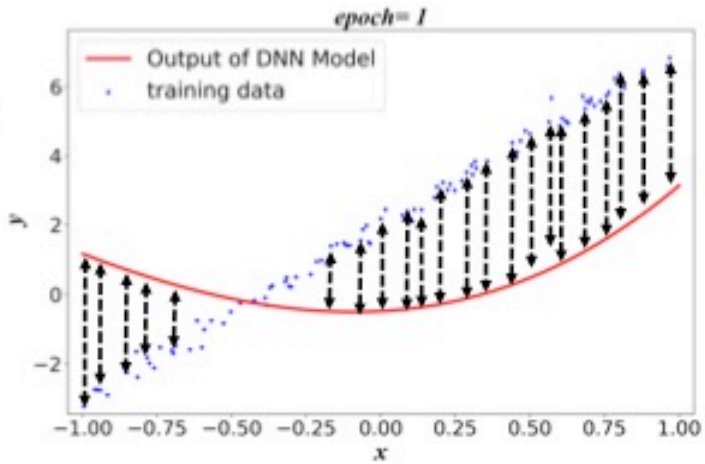
Loss-MSE

L=(y−y)↑2

[■x↓1 @x↓2 @x↓3]

→ **simulation** →

[■y ↓1 @y ↓2 @y



black

Machine learning

Loss-MSE

Input

Output

$L=(y-y)^2$

$[x_1\ x_2\ x_3]$ → **Model** → $[y_1\ y_2\ y_3]$

Gradient Descent

$\partial L/\partial w_n$, $\partial L/\partial b_n$, $\partial L/\partial c_n$

$[x_1\ x_2\ x_3]$ → **simulation** → $[y_1\ y_2\ y_3]$

$w_{n+1}=w_n-lr\times\partial L/\partial w_n$

$b_{n+1}=b_n-lr\times\partial L/\partial b_n$

$c_{n+1}=c_n-lr\times\partial L/\partial c_n$

gradient

Machine learning

Input

$[\blacksquare x_1 \ @x_2 \ @x_3 \ ]$

$\longrightarrow$ **Model** $\longrightarrow$

$[\blacksquare x_1 \ @x_2 \ @x_3 \ ]$

$\longrightarrow$ **simulation** $\longrightarrow$

Output

$[\blacksquare y_1 \ @y_2 \ @y_3 \ ]$

$[\blacksquare y_1 \ @y_2 \ @y_3 \ ]$

Loss-MSE

$L=(y-y)^2$

Gradient Descent

$\partial L/\partial w_n \ , \partial L/\partial b_n \ , \partial L/\partial c_n$

$w_{n+1} = w_n - lr \times \partial L/\partial w_n$

$b_{n+1} = b_n - lr \times \partial L/\partial b_n$

$c_{n+1} = c_n - lr \times \partial L/\partial c_n$

renew

Machine learning

Input

Output

[■x↓1 @x↓2 @x↓3]

→ **Model** →

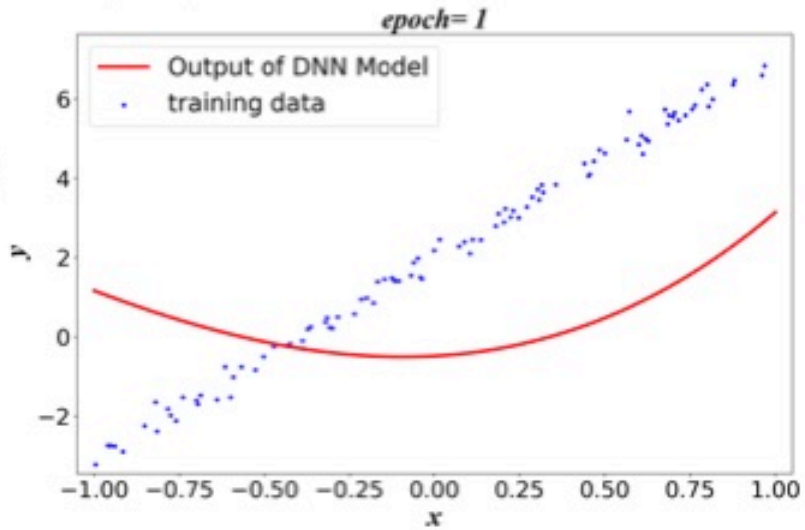
[■y↓1 @y↓2 @y↓3]

Stochastic gradient Descent (SGD)

[■x↓1 @x↓2 @x↓3]

→ **simulation** →

[■y ↓1 @



Regression Model, iteration

Machine learning

Input

Output

[■x↓1 @x↓2 @x↓3]

→ **Model** →

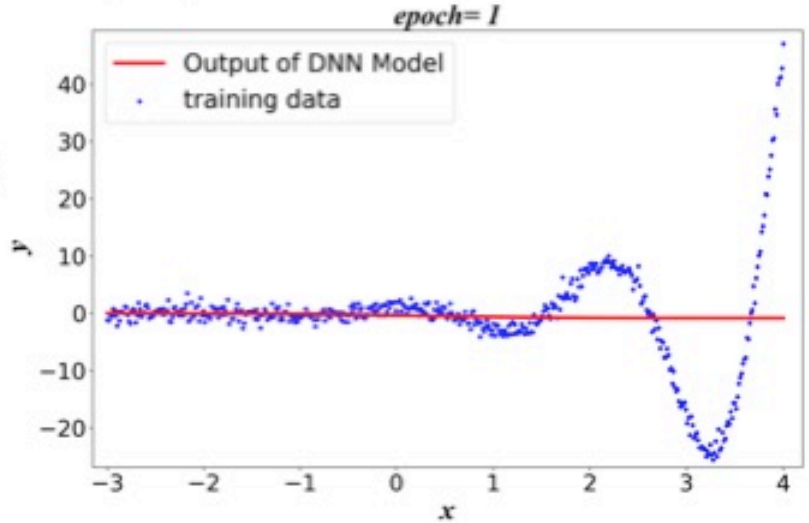
[■y↓1 @y↓2 @y↓3]

Stochastic gradient Descent (SGD)

[■x↓1 @x↓2 @x↓3]

→ **simulation** →

[■y ↓1 @



complex

Result

Back
Build
F
s

Input

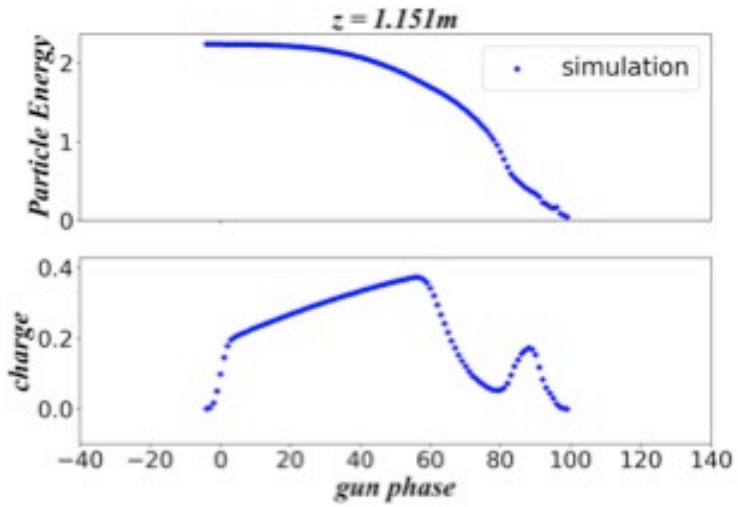
Charge
E-gun
Phase-gun
B-gun
Schottky 1
Schottky 2

→ **Simulation Model** →

Output

Charge
Particle Energy
Emittance
Energy Spread
Beam size
Charge Pattern

Result



Input

Charge
E-gun
Phase-gun
B-gun
Schottky 1
Schottky 2

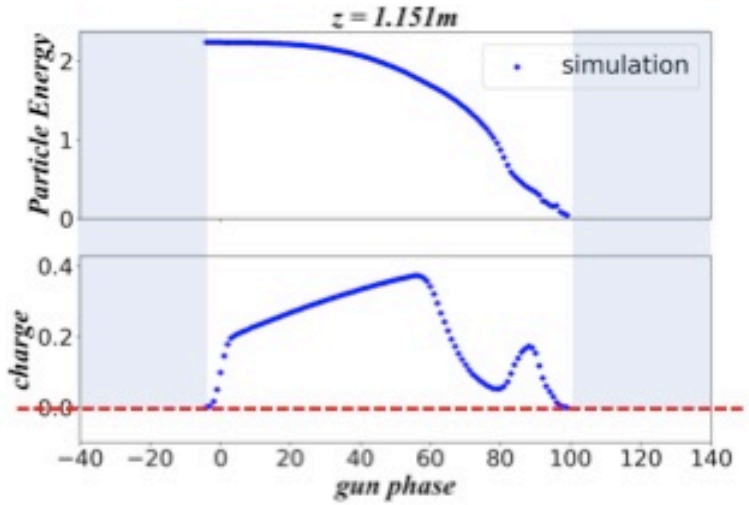
→ **Simulation** →

Output

Charge
Particle Energy

One of
Pattern
E
C

Result



Input

Charge
E-gun
Phase-gun
B-gun
Schottky 1
Schottky 2

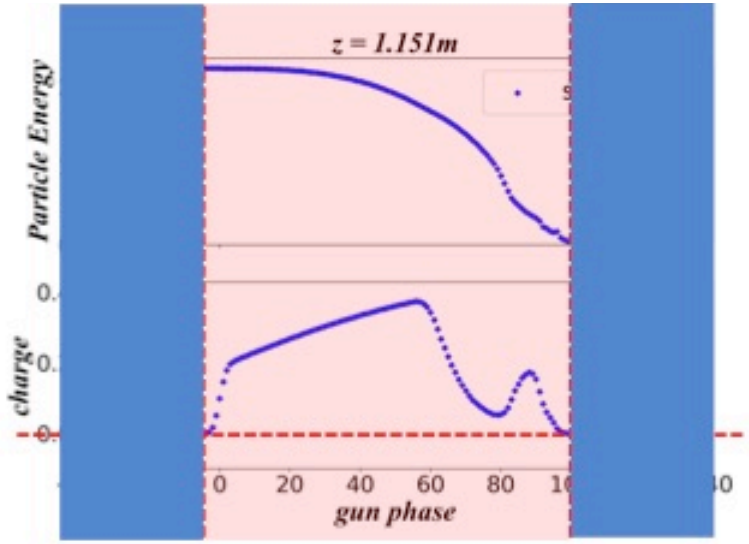
→ **Simulation** →

Output

Charge
Particle Energy

C zero
E

Result



$Loss=(target(C,E)-predict(C,E))\uparrow 2$

↑

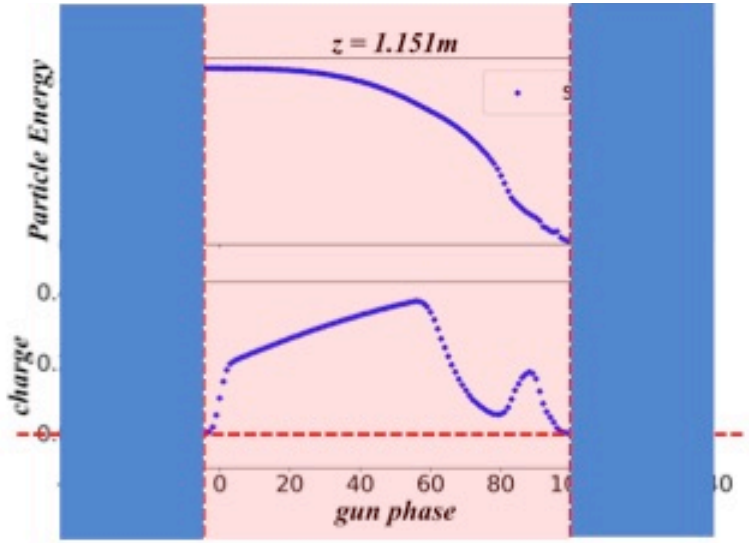
simulation

↑

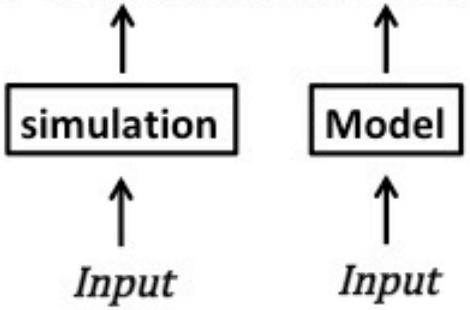
Input

Train
charge
Mse
Sim
model

Result

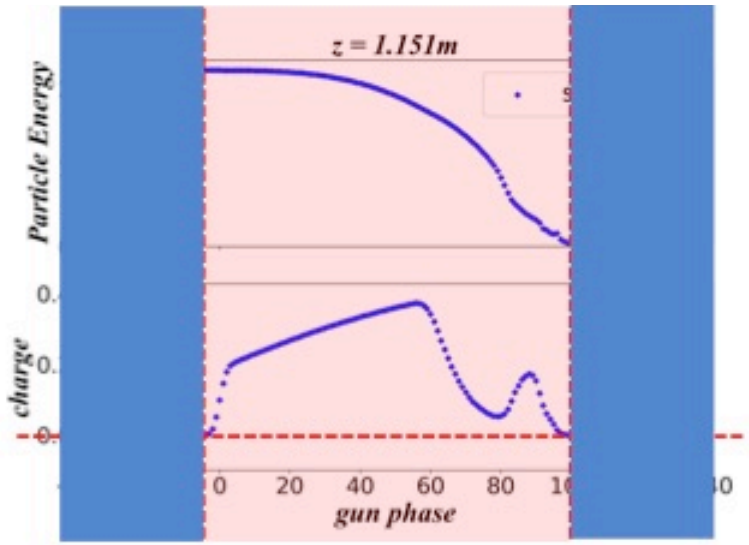


$$Loss=(target(C,E)-predict(C,E))\uparrow 2$$



Target
Predict
Charge
energy

Result

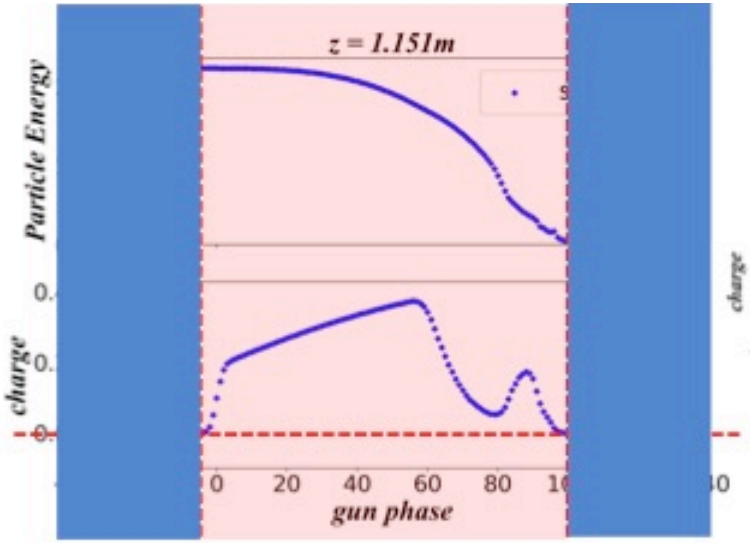


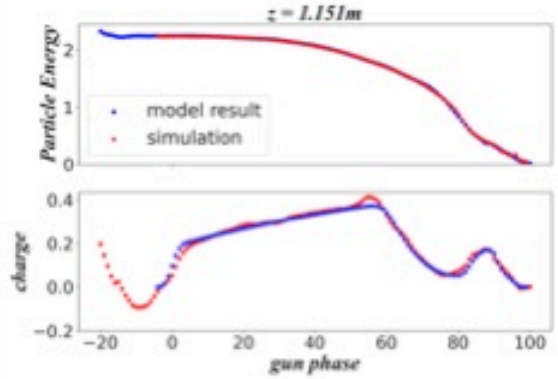
$$Loss=(target(C,E)-predict(C,E))^2$$

$$w_{n+1}=w_n-lr\times\partial L/\partial w_n$$

renew

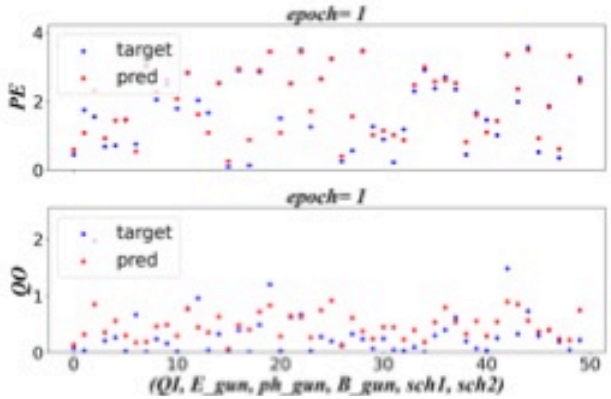
Result





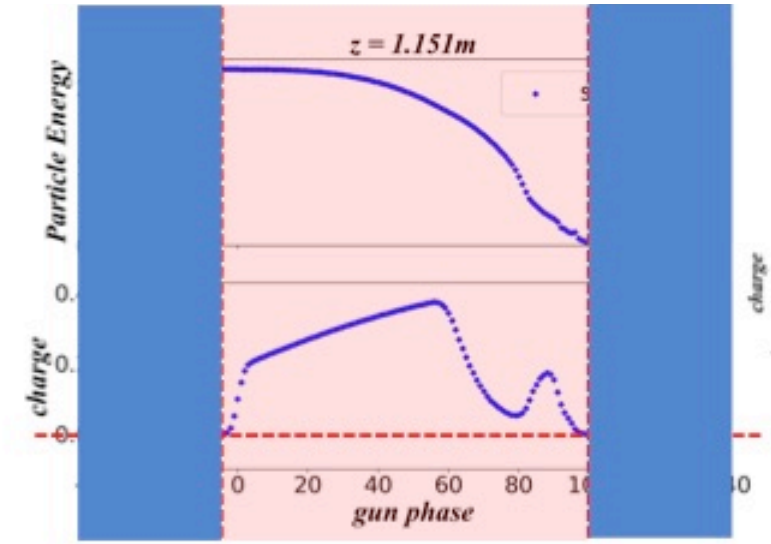
$$Loss=(target(C,E)-predict(C,E))\uparrow 2$$

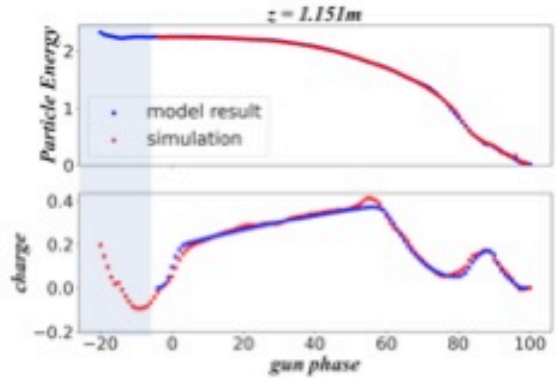
$$w\downarrow n+1=w\downarrow n-lr\times\partial L/\partial w\downarrow n$$



Blue
Red

Result

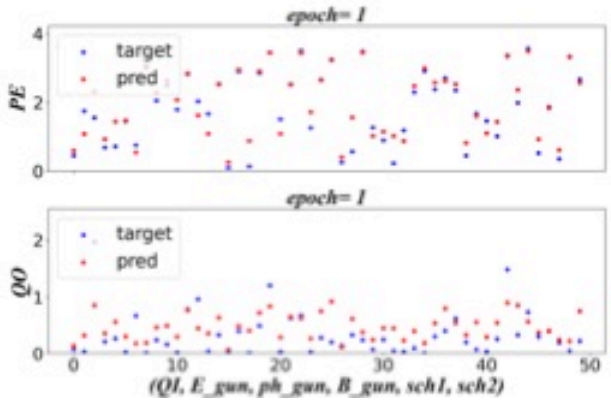




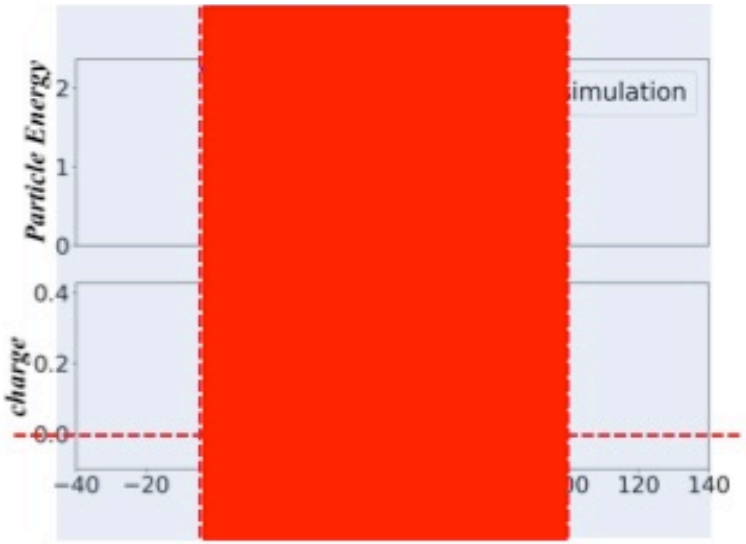
$Loss=(target(C,E)-predict(C,E))\uparrow 2$

$w\downarrow n+1=w\downarrow n-lr\times\partial L/\partial w\downarrow n$

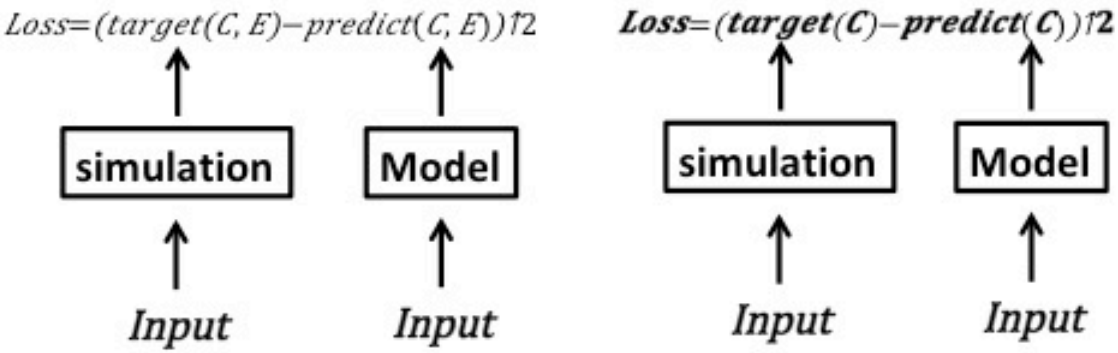
ignore



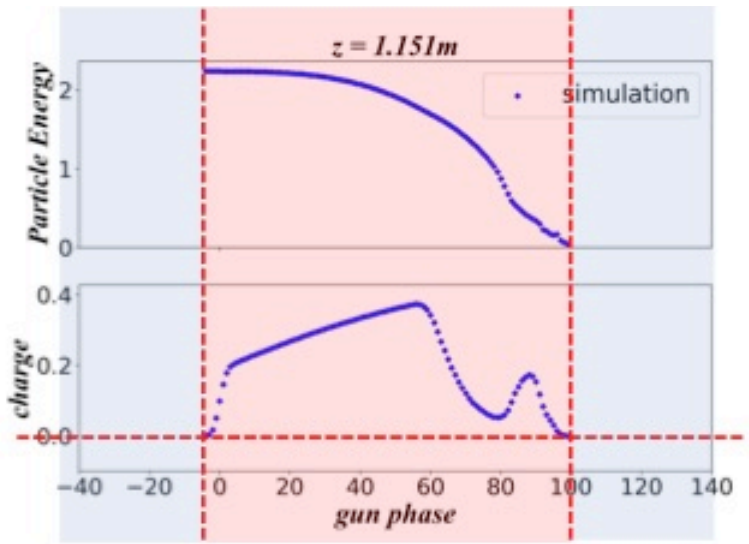
Result



another charge



Result

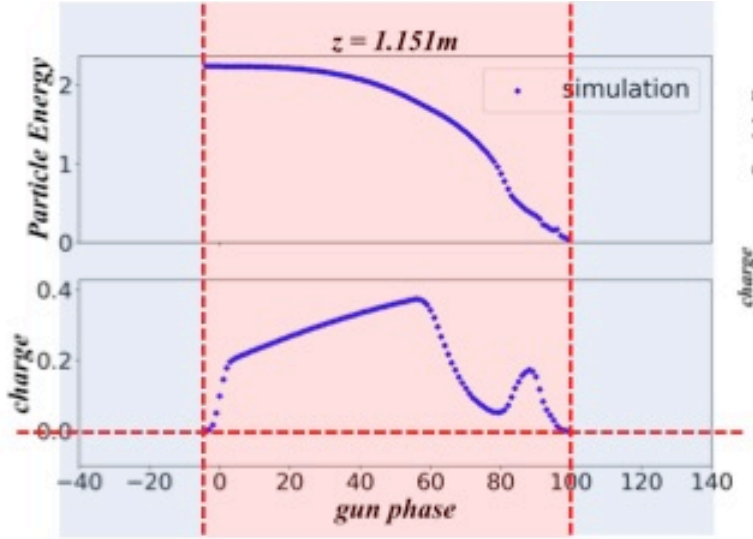


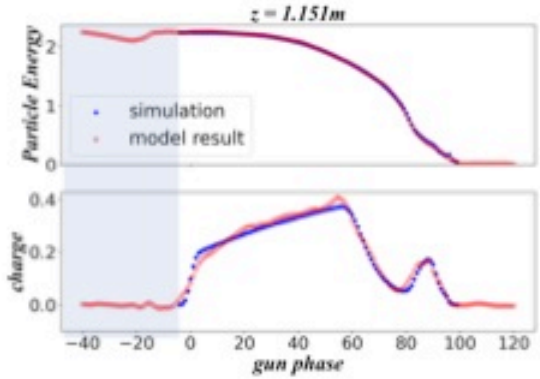
$Loss1=(target(C,E)-predict(C,E))\uparrow 2$ $Loss2=(target(C)-predict(C))\uparrow 2$

add $Loss=Loss1+Loss2$

renew $w\downarrow n+1=w\downarrow n-lr\times\partial L/\partial w\downarrow n$

Result



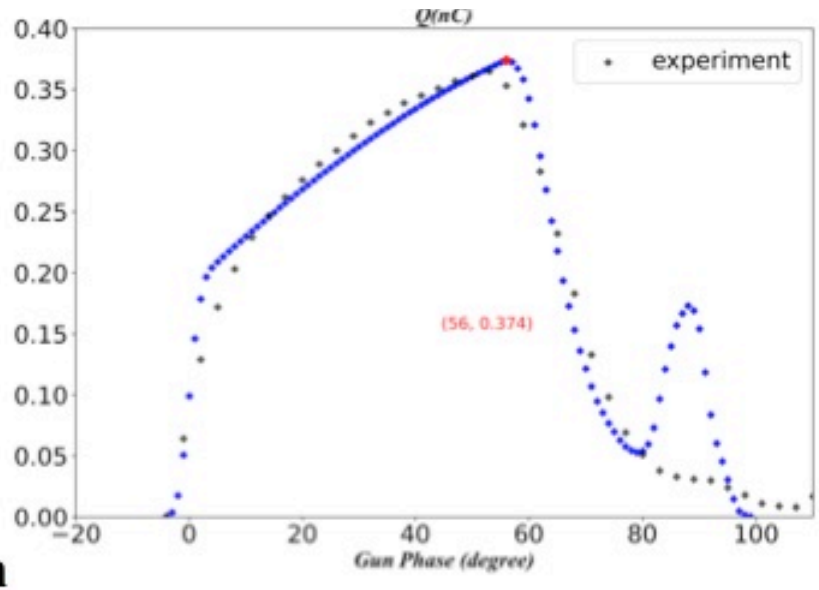


$Loss1=(target(C,E)-predict(C,E))\uparrow 2$ $Loss2=(target(C)-predict(C))\uparrow 2$

$Loss=Loss1+Loss2$

$w\downarrow n+1=w\downarrow n-lr\times\partial L/\partial w\downarrow n$

Result



Experiment

E

B

Simulation

E

E↓phase

B

Charge

Schottky 1

Schottky 2

S

d

Match

Result

Experiment

E

B

Simulation

E

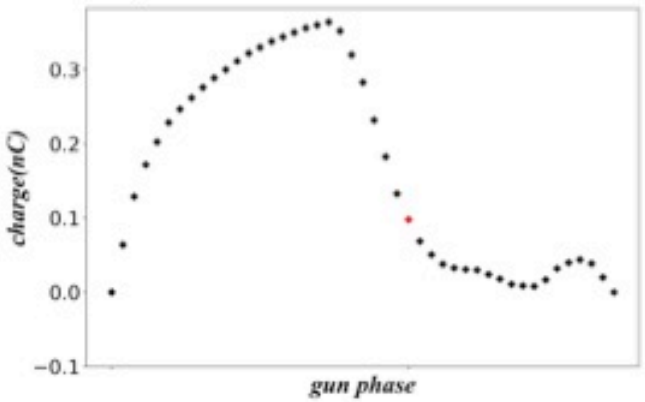
E↓phase

B

Charge

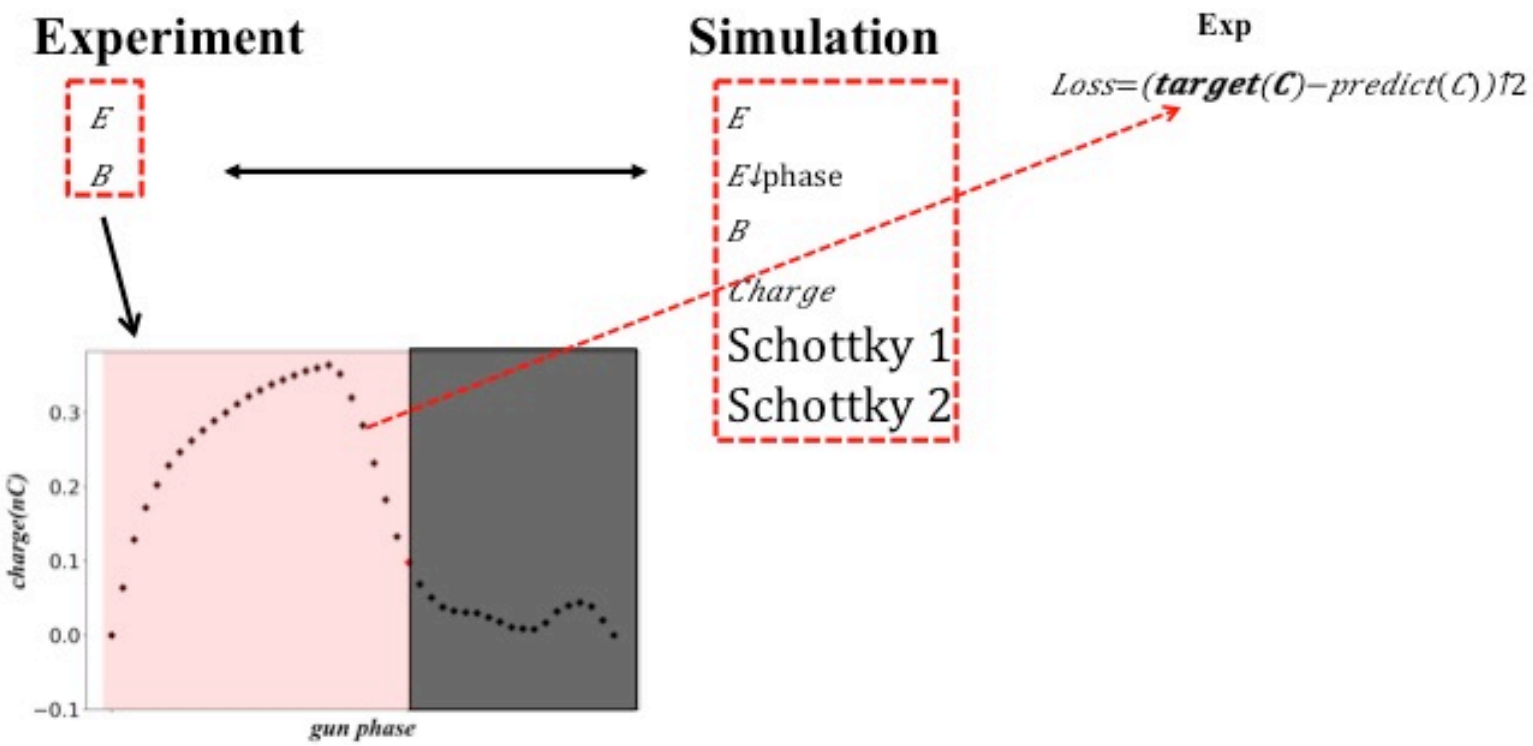
Schottky 1

Schottky 2

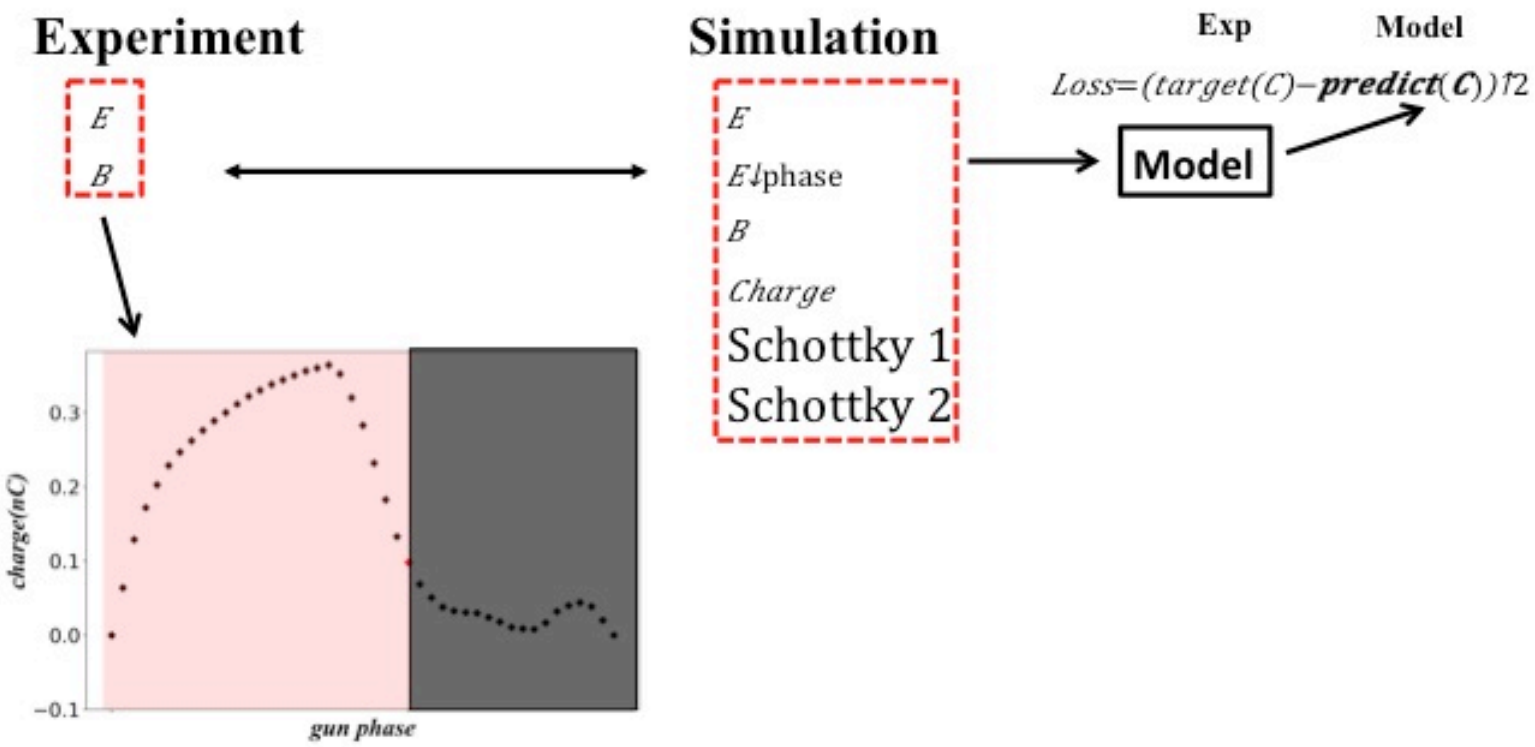


Only
set

Result


Experiment
E
B
Simulation
E
E↓phase
B
Charge
Schottky 1
Schottky 2
Exp
Loss=(target(C)−predict(C))↑2
charge(nC)
0.3
0.2
0.1
0.0
−0.1
gun phase

Result

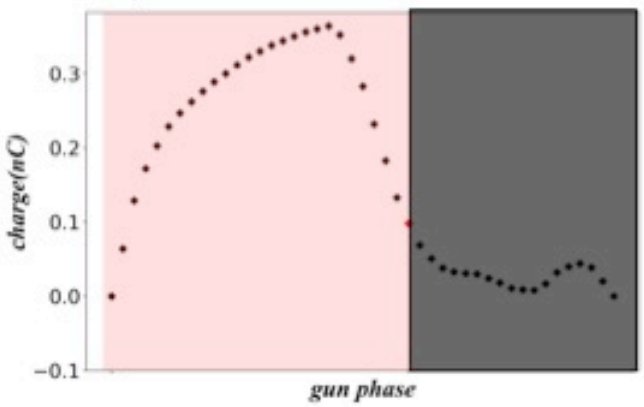

Experiment
E
B
Simulation
E
E↓phase
B
Charge
Schottky 1
Schottky 2
Exp
Model
Loss=(target(C)−predict(C))↑2
Model
charge(nC)
0.3
0.2
0.1
0.0
−0.1
gun phase

Result

Experiment

E

B



Simulation

E

E↓phase

B

$Charge$

Schottky 1

Schottky 2

Exp **Model**

$Loss=(target(C)-predict(C))↑2$

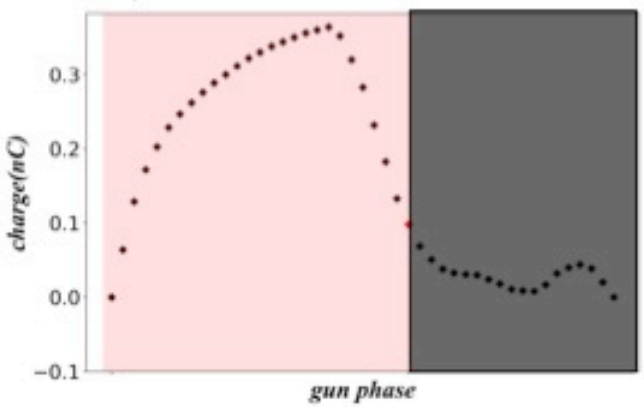
$w↓n+1=w↓n-lr\times\partial L/\partial w↓n$

Result

Experiment

E

B



Simulation

E

E↓phase

B

$Charge$

Schottky 1

Schottky 2

Exp **Model**

$Loss=(target(C)-predict(C))\uparrow 2$

$w\downarrow n+1=w\downarrow n-lr\times\partial L/\partial w\downarrow n$

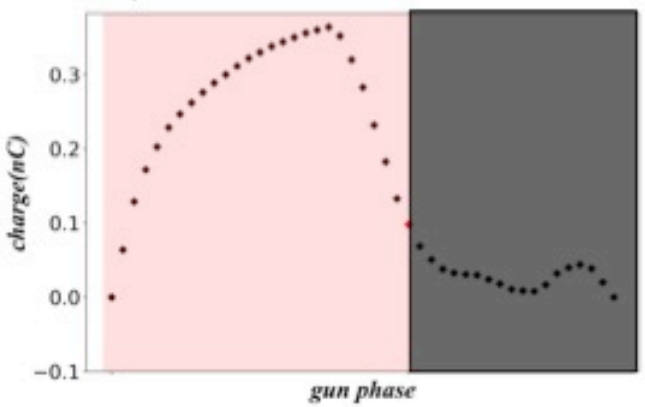
$Input\downarrow n+1=Input\downarrow n-lr\times\partial L/\partial Input\downarrow n$

Result

Experiment

E

B



Simulation

E

E↓phase

B

$Charge$

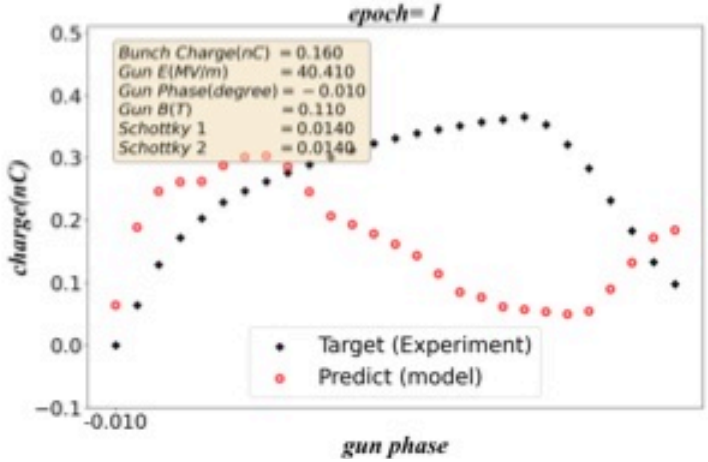
Schottky 1

Schottky 2

Exp **Model**

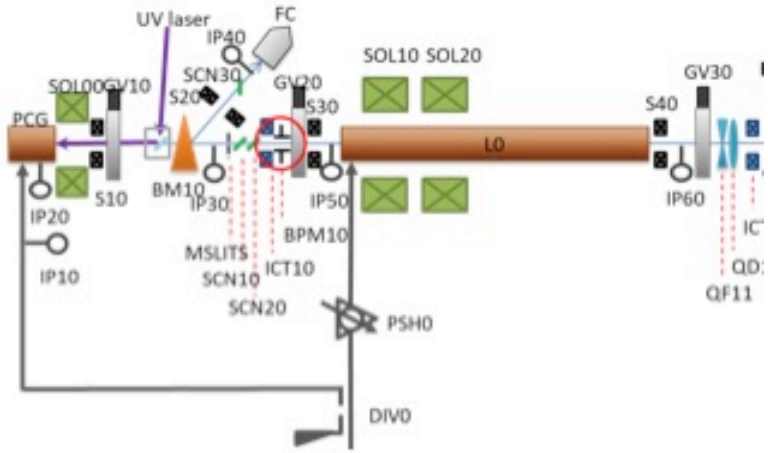
$Loss=(target(C)-predict(C))\uparrow 2$

$Input\downarrow n+1 = Input\downarrow n - lr \times \partial L/\partial Input\downarrow n$



Summary

- Simulation by ASTRA > 10 min
- Regression Model < 1 sec
- Introduce 2 loss
- Experiment is not match Simulation
- Relationship between Experiment and Model



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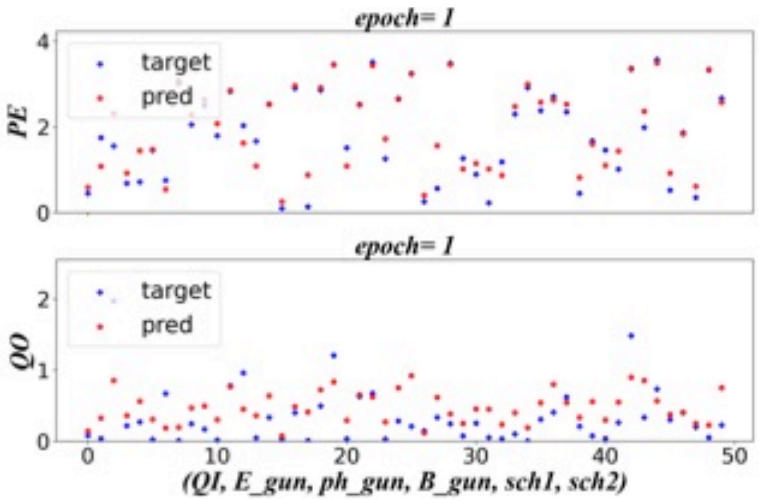

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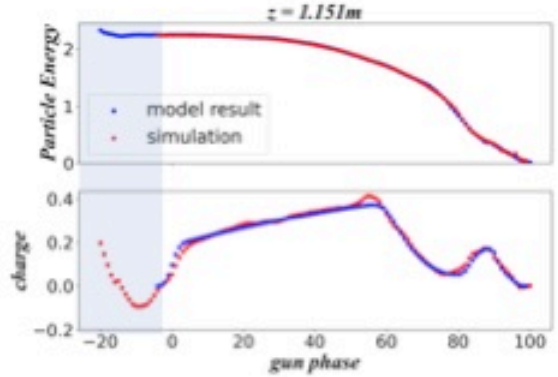

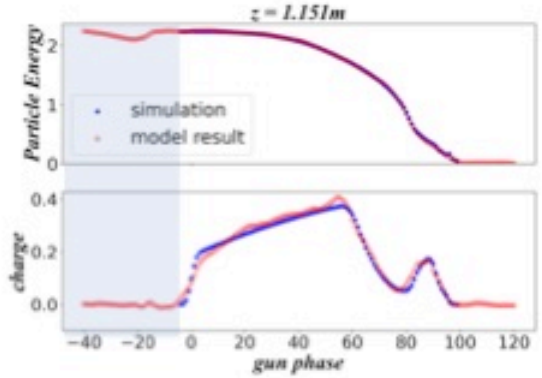

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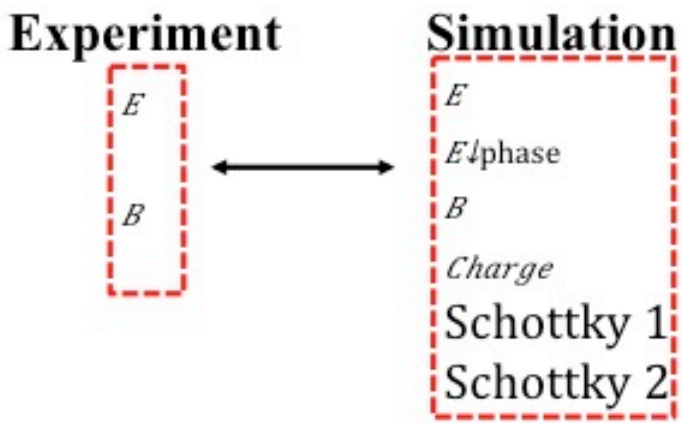

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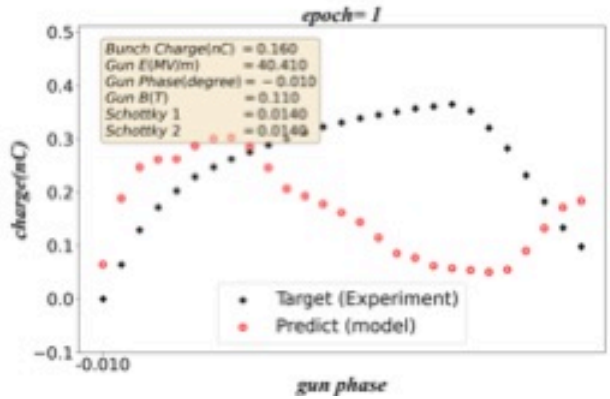

Thanks