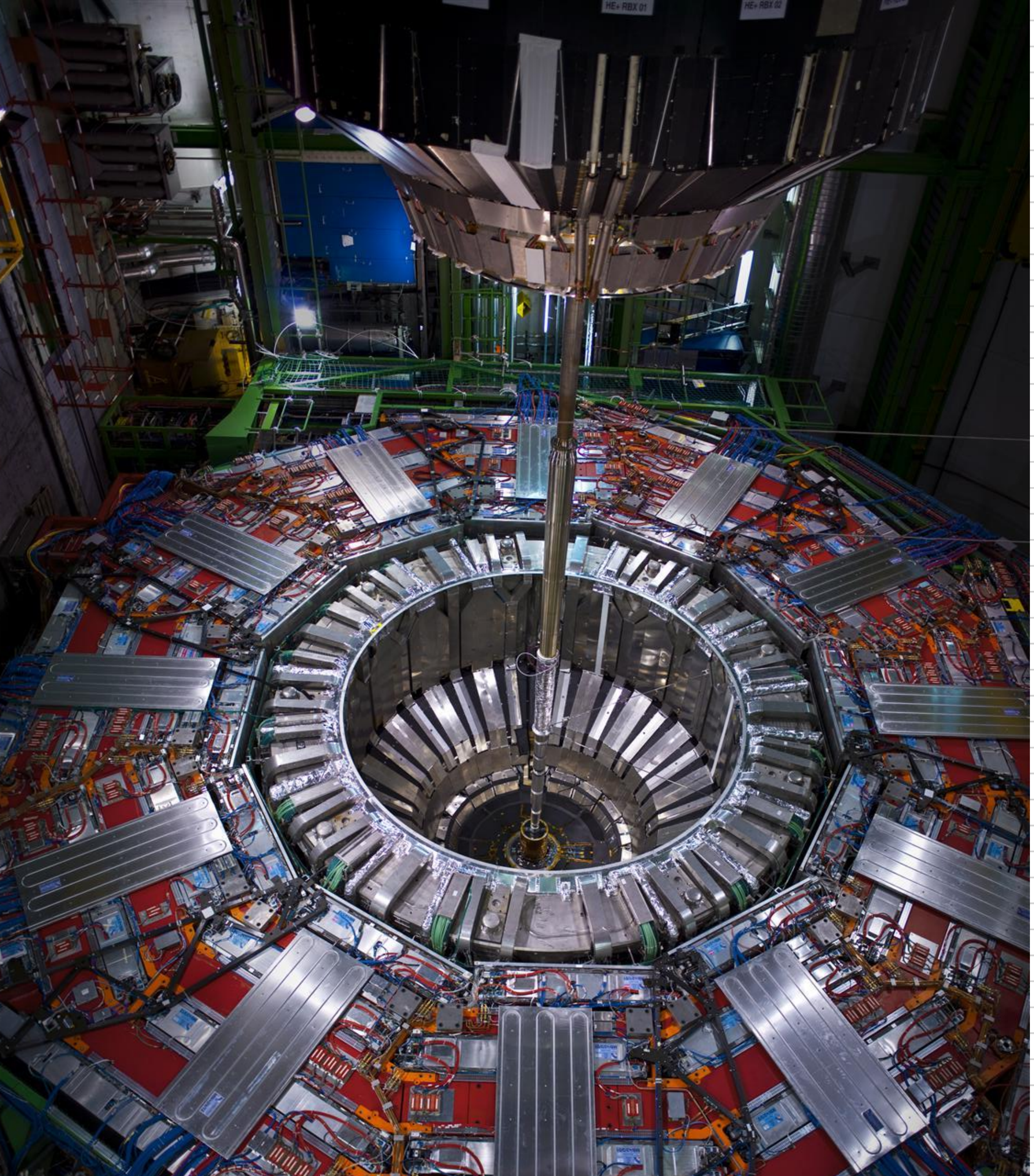


Particle physics

입자 가속기

물리학과

201410373

고예은

목차

프로젝트 소개

프로젝트 목표

Particle physics

✓새로운 물질을 밝혀내는 입자 가속기에 대한 탐구

✓물리적 원리와 이에 대한 결과물을 분석할 수 있는 탐구적 시각

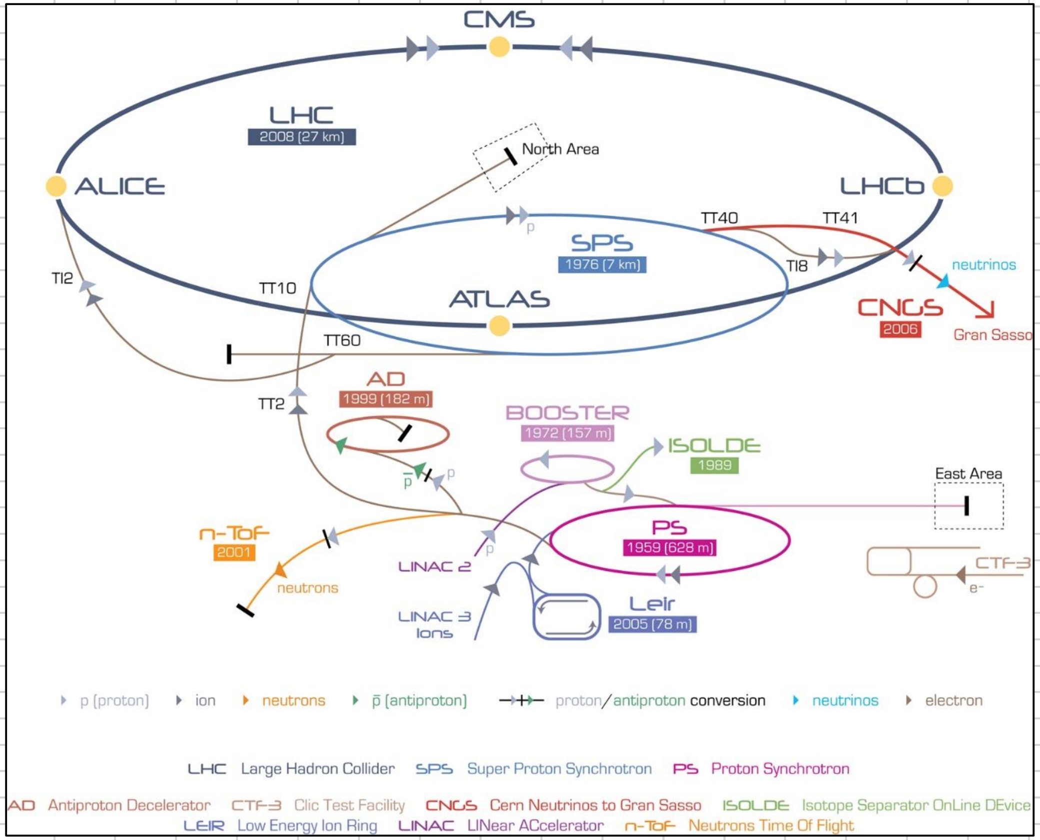


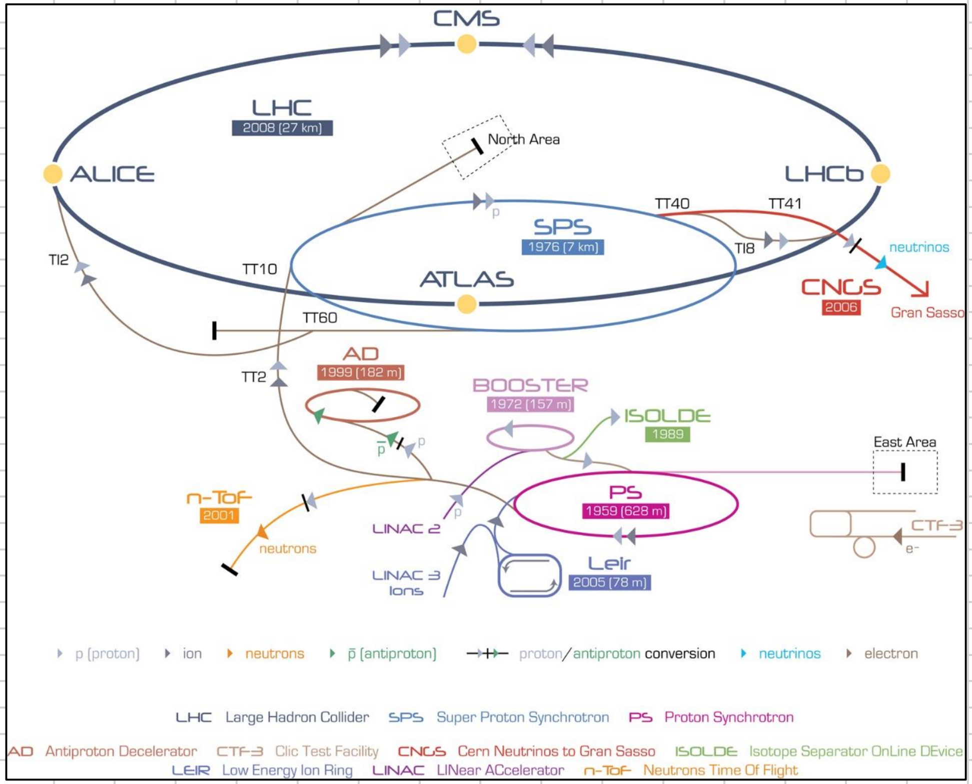
Figure 1. CERN(Conseil Européenne pour la Recherche Nucléaire) 의 LHC(Large Hadron Collider) 모식도
(https://home.cern/)

프로젝트 목표

Particle physics

시뮬레이션(시각화)

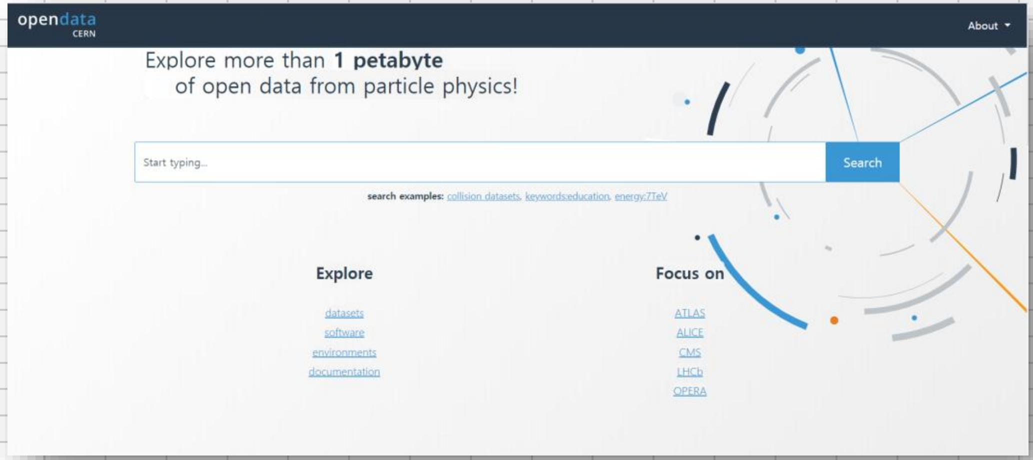
- Linac2 → PSB → PS → SPS → LHC



데이터 분석

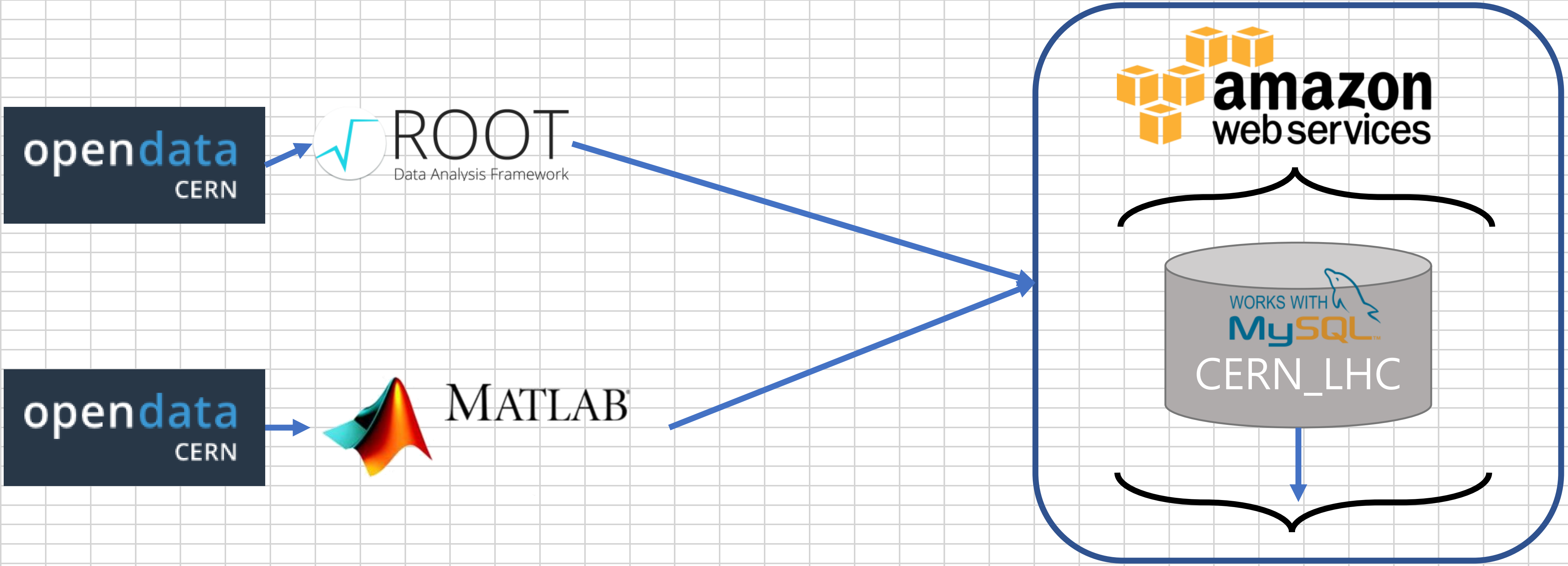
- 가속 중 특정 지점에서 측정한 입자의 데이터를 수집하여, 입자의 물리학적 상태를 측정한다.

CERN Open Data Portal



시스템 구조

✓ AWS(Amazon Web Service), MySQL, Matlab



Particle physics

프로젝트 진행

	10월 4주	11월 1주	11월 2주	11월 3주	11월 4주	12월 1주
물리적 이론 조사						
물리적 모델 설계						
입자 가속 계산						
시뮬레이션 생성						
충돌 데이터 분석						
코딩						
점검						

이론적 배경

Particle physics

이론적 배경

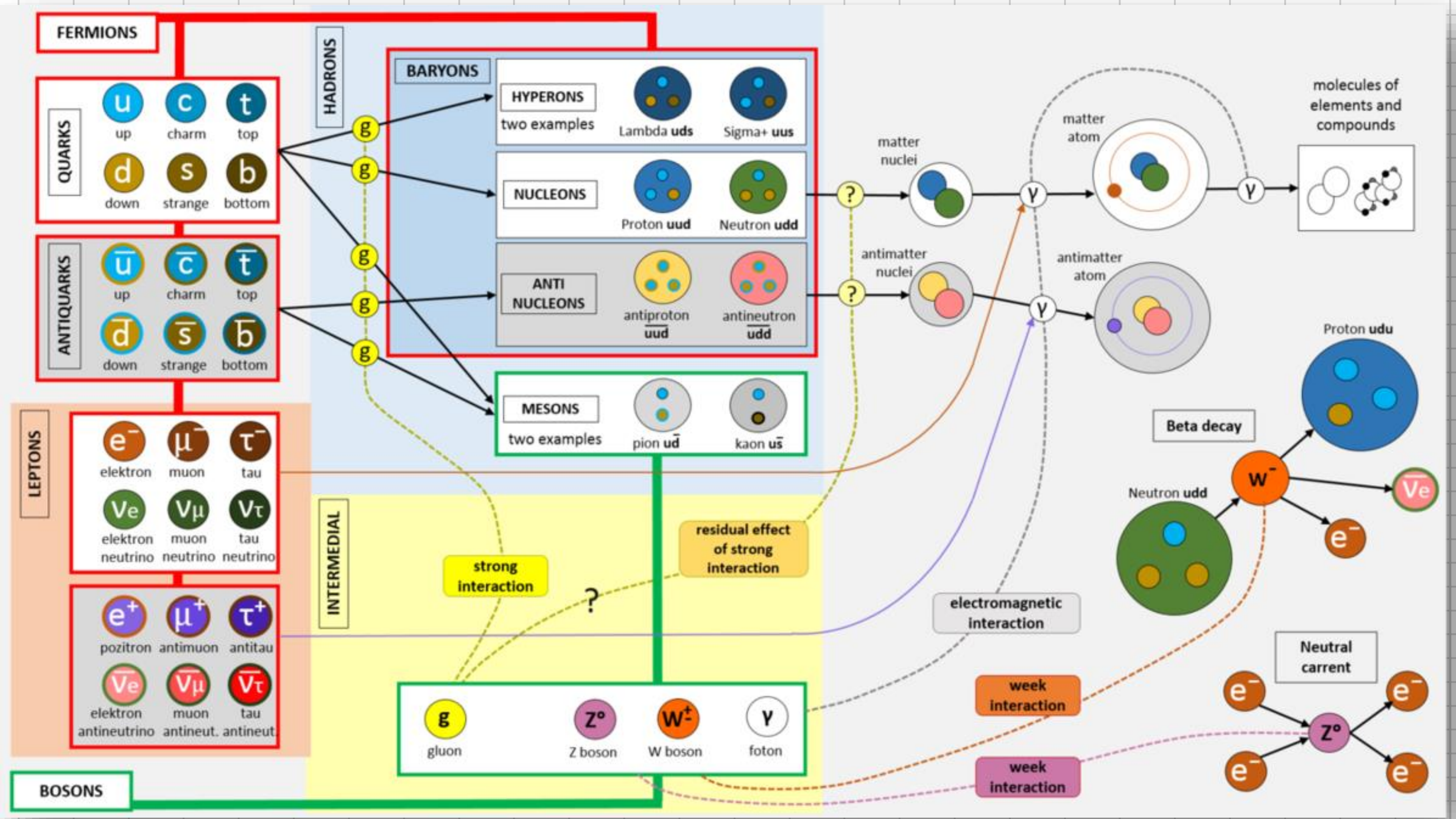
✓ 입자와 힘의 종류

- 입자(표준 모형, Standard Model)

  : 입자는 쿼크(Quark), 렙톤(Lepton), 보손(Boson)으로 이루어져 있다.

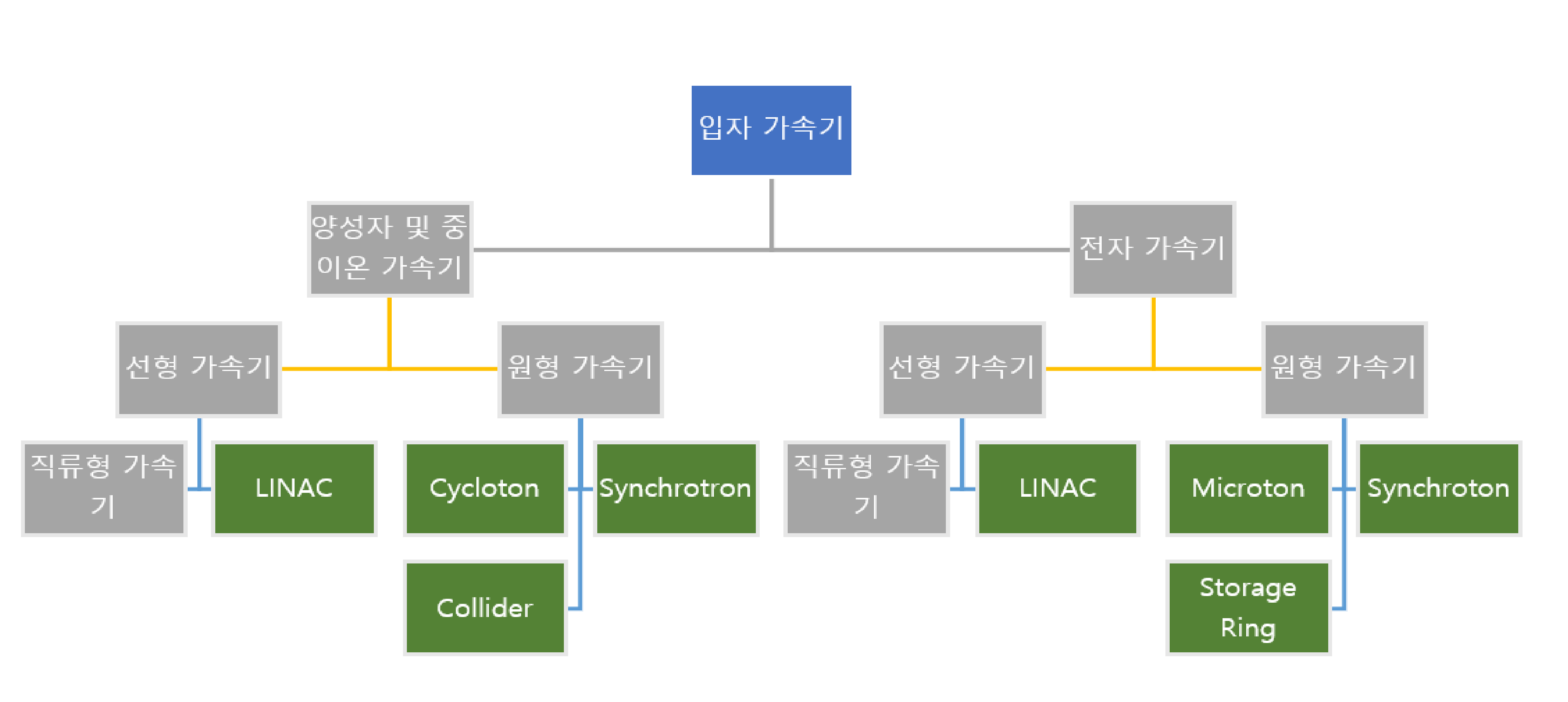
- 힘

  :힘은 중력, 전자기력, 강력, 약력으로 나뉜다.



이론적 배경

✓ 입자 가속기



입자 가속기의 종류(초록색: 교류형 고주파 가속기)

이론적 배경

✓ 선형 입자 가속기

$$\vec{E}(r,z,t) = E(r,z)\cos(\omega t) = E(r,z)\cos\left(\frac{2\pi}{\beta\lambda}\right)$$

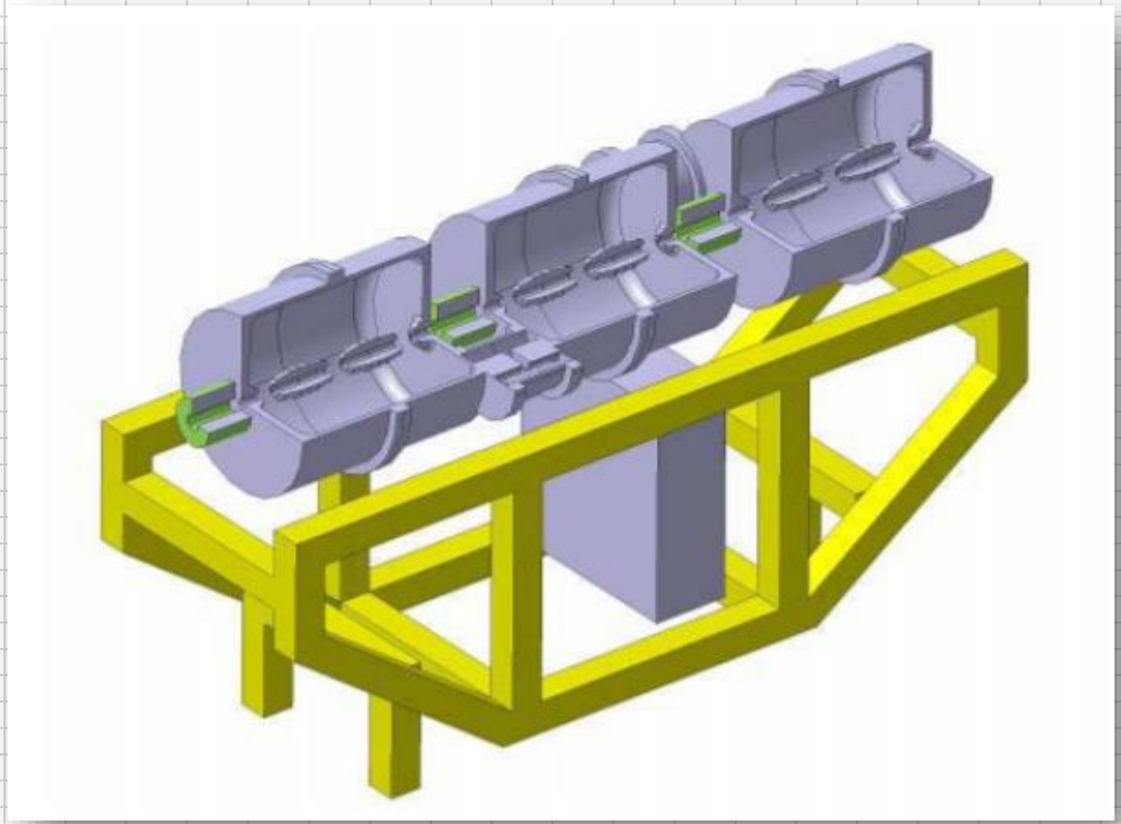
$$\Delta W = qe\int_{-\infty}^{+\infty} E(r,z)\cos(\omega t)\,dz$$

$$= qe\int_{-\infty}^{+\infty} E(r,z)\cos\left(\frac{\omega z}{\beta c}\right)dz$$

$$= qe\int_{-\frac{g}{2}}^{+\frac{g}{2}} \frac{V}{g} cos\left(\frac{2\pi}{\beta\lambda}z\right)dz = \mathrm{qV}\frac{\sin\left(\frac{\pi g}{\beta\lambda}\right)}{\frac{\pi g}{\beta\lambda}} \stackrel{\text{def}}{=} \mathrm{gVTcos\phi},$$

(g: gap length, T: transition time factor)

$$\left(\omega = 2\pi f, z = \beta ct, \lambda = \frac{c}{f} = \frac{2\pi c}{\omega}\right)$$



이론적 배경

✓ 원형 입자 가속기

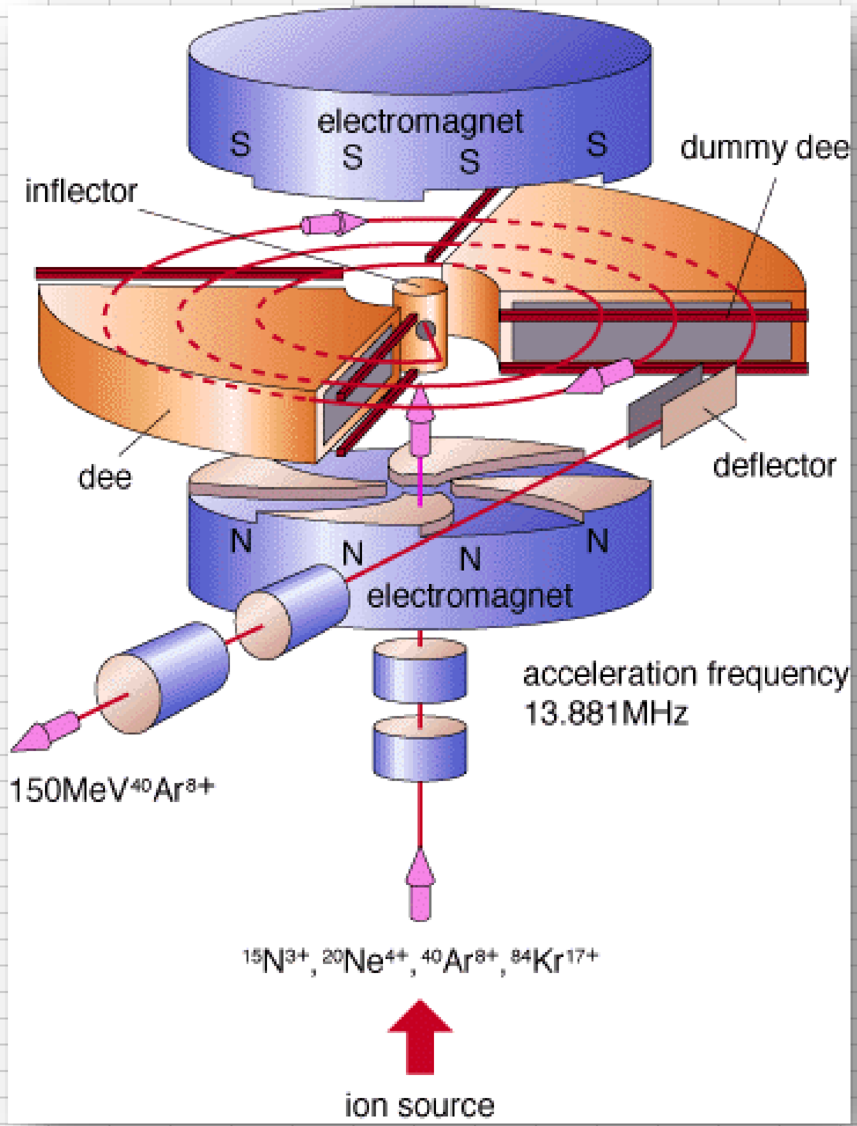
$$m = \frac{m_0}{\sqrt{1 - (\frac{v}{c})^2}}$$

$$\int \vec{\nabla} \cdot \vec{E}\, d\vec{\tau} = \oint \vec{E} \cdot d\vec{a} = \frac{Q}{\epsilon_0}$$

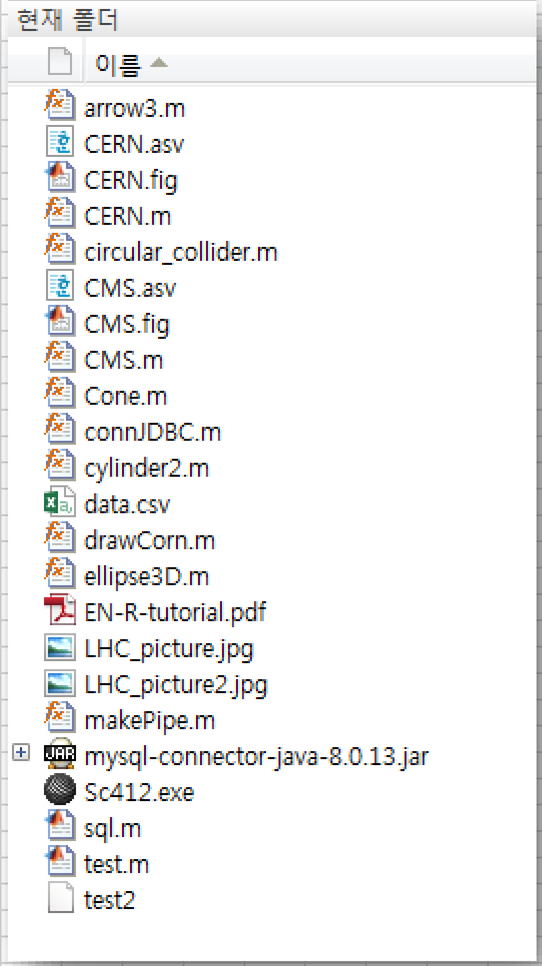
$$\vec{F} = q\vec{v} \times \vec{B}$$

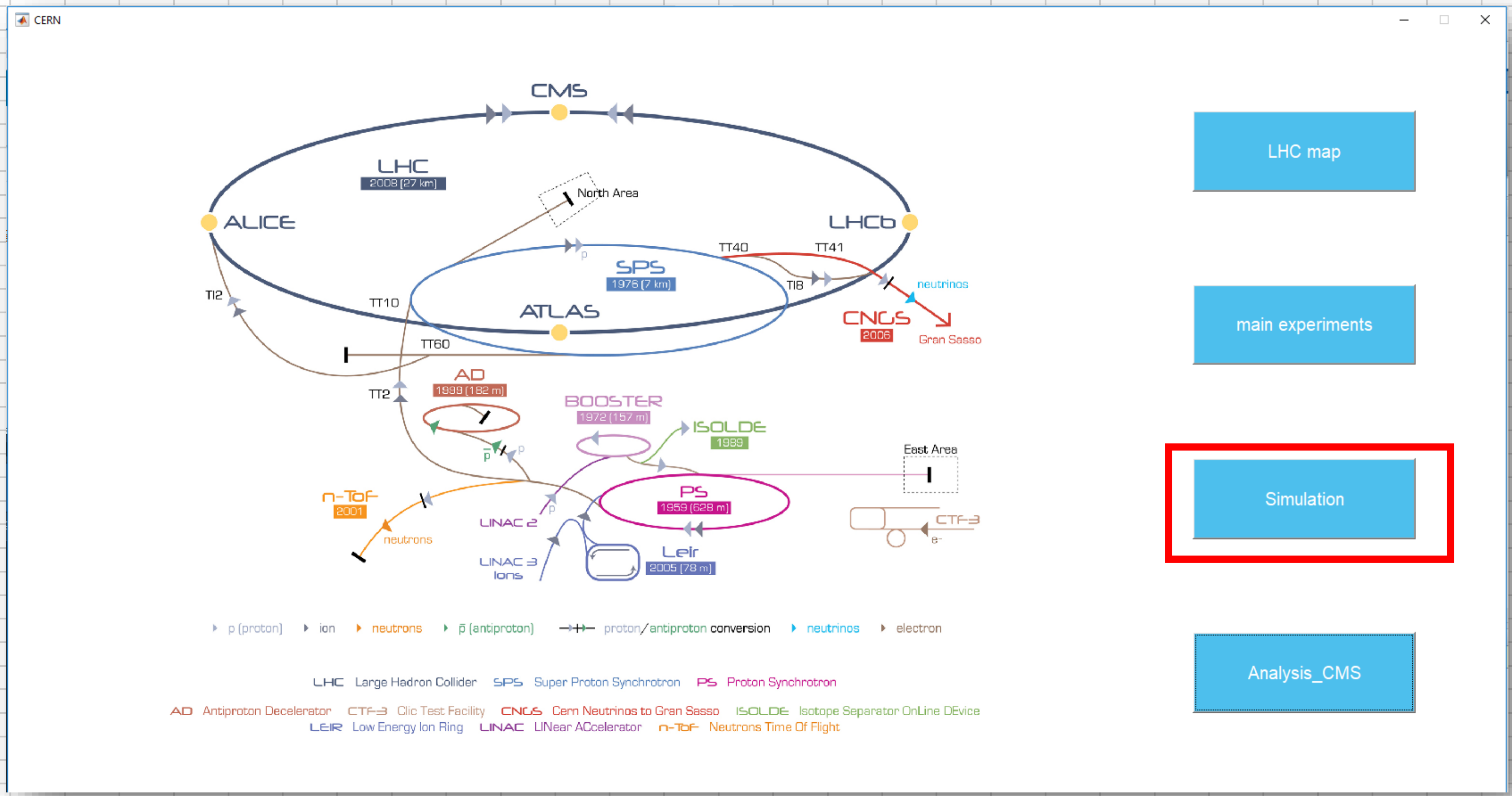
$$\frac{d}{dt}\vec{p} = \vec{f} = m_0 \frac{d}{dt}(\gamma\vec{v})$$

$$\frac{dE}{dt} = \frac{qc^2}{E}\, \vec{p} \cdot \left(\vec{E} + \vec{v} \Lambda \vec{B}\right) = \frac{qc^2}{E}\vec{p} \cdot \vec{E}$$



시뮬레이션 설계


현재 폴더
이름
arrow3.m
CERN.asv
CERN.fig
CERN.m
circular_collider.m
CMS.asv
CMS.fig
CMS.m
Cone.m
connJDBC.m
cylinder2.m
data.csv
drawCorn.m
ellipse3D.m
EN-R-tutorial.pdf
LHC_picture.jpg
LHC_picture2.jpg
makePipe.m
mysql-connector-java-8.0.13.jar
Sc412.exe
sql.m
test.m
test2


CERN
CMS
LHC
2008 (27 km)
North Area
ALICE
LHCb
TT40
TT41
SPS
1976 (7 km)
TI8
neutrinos
TI2
TT10
ATLAS
CNGS
2006
Gran Sasso
TT60
AD
1999 (182 m)
TT2
BOOSTER
1972 (157 m)
ISOLDE
1989
East Area
n-ToF
2001
PS
1959 (628 m)
LINAC 2
CTF3
neutrons
LINAC 3
Ions
LEIR
2005 (78 m)
p (proton)
ion
neutrons
p̄ (antiproton)
proton/antiproton conversion
neutrinos
electron
LHC Large Hadron Collider
SPS Super Proton Synchrotron
PS Proton Synchrotron
AD Antiproton Decelerator
CTF3 Clic Test Facility
CNGS Cern Neutrinos to Gran Sasso
ISOLDE Isotope Separator OnLine DEvice
LEIR Low Energy Ion Ring
LINAC LINear ACcelerator
n-ToF Neutrons Time Of Flight
LHC map
main experiments
Simulation
Analysis_CMS

시뮬레이션 설계

✓ Matlab을 활용하여, 6개의 코스 Linac2 , PSB , PS , SPS , LHC를 지나는 양성자를 시뮬레이션 하였다.

- LINAC: 반지름 26.7km(=26700m) , 깊이 50~150m
- PSB: 반지름 6.9km(=6900m) , 깊이 40m
- PS: 반지름 628m , 깊이 40m
- SPS: 반지름 157m . 깊이 40m

시뮬레이션 설계

Particle physics

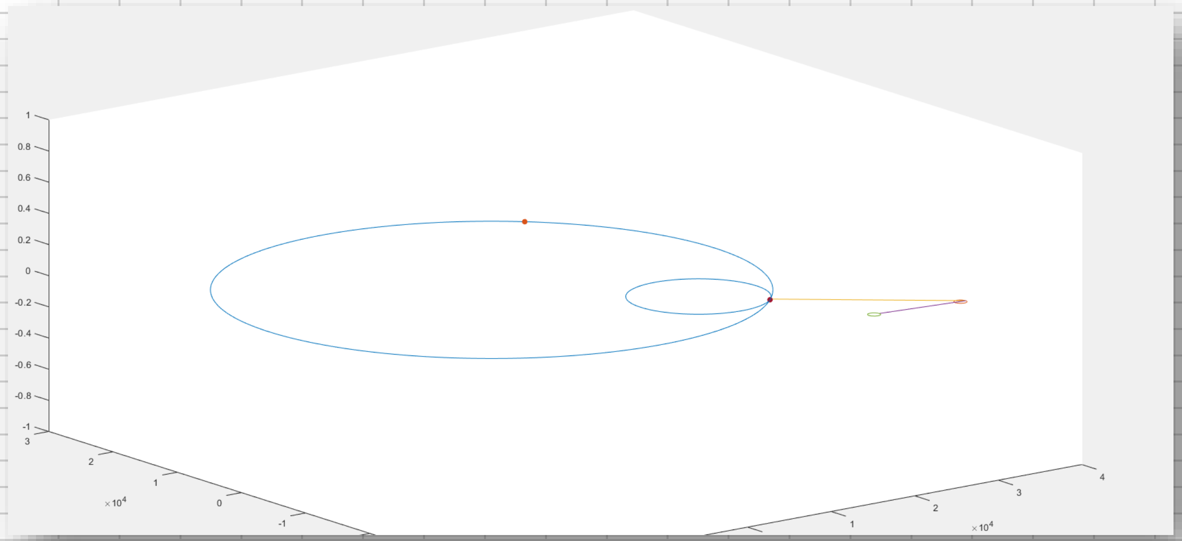
✓ 주된 함수: Pause 간격과 원의 점 개수를 조정하여 속도를 조정했다.

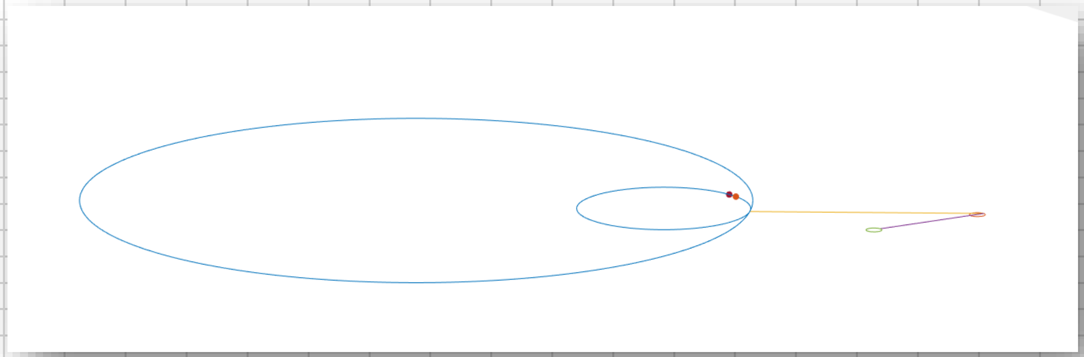
```
global coords_LHC coords_SPS coords_TTS2 coords_PS
[coords_LHC, h_LHC] = ellipse3D(26700, 26700, 0, 0, 0);
[coords_SPS, h_SPS] = ellipse3D(6900, 6900, 19800/sqrt(2), -19800/sqrt(2),  0);
[coords_PS, h_PS] = ellipse3D(628, 628,  32523 , -30743 , 0, 90);
points_number = 200;
coords_TTS2 = zeros(3,points_number );
coords_TTS2(1,:) = linspace( coords_PS(1,end), coords_SPS(1,262), points_number );
coords_TTS2(2,:) = linspace( coords_PS(2,end), coords_SPS(2,262), points_number );
[coords_PSB, h_PSB] = ellipse3D(628, 628, 22983 , -29693 , 0,80);
points_numb_iso = 250;
coords_iso =  zeros(3,points_numb_iso );
coords_iso(1,:) = linspace( coords_PSB(1,end), coords_PS(1,1), points_numb_iso );
coords_iso(2,:) = linspace( coords_PSB(2,end), coords_PS(2,1), points_numb_iso );

time_increase = 0.0005;


[coords_LHC, h_LHC] = ellipse3D(26700, 26700, 0, 0, 0);
```

```
for i=index
    hFig = figure(1);
    set(hFig,'units','normalized','outerposition',[0 0 1 1])
    px_SPS = coords_SPS(1,i);
    py_SPS = coords_SPS(2,i);
    pz_SPS = coords_SPS(3,i);

    px_SPS_opposite = coords_SPS(1,length(coords_SPS(1,:))-i+1);
    py_SPS_opposite = coords_SPS(2,length(coords_SPS(2,:))-i+1);
    pz_SPS_opposite = coords_SPS(3,length(coords_SPS(3,:))-i+1);

    plot3( coords_LHC(1,:), coords_LHC(2,:), coords_LHC(3,:)); hold on;
    plot3( coords_PS(1,:), coords_PS(2,:), coords_PS(3,:)); hold on;
    plot3( coords_TTS2(1,:), coords_TTS2(2,:), coords_TTS2(3,:)); hold on;
    plot3( coords_iso(1,:), coords_iso(2,:), coords_iso(3,:)); hold on;
    plot3( coords_PSB(1,:), coords_PSB(2,:), coords_PSB(3,:)); hold on;

    plot3( coords_SPS(1,:), coords_SPS(2,:), coords_SPS(3,:), px_SPS, py_SPS, pz_SPS,'.-', 'MarkerSize',20);
    hold on;
    plot3( coords_SPS(1,:), coords_SPS(2,:), coords_SPS(3,:), px_SPS_opposite, py_SPS_opposite, pz_SPS_opposite,'.-', 'MarkerSize',20);

    hold off;

    %pause(0.01)
    pause(0.01-time_increase *0.1*j);
    j=j+1;
end
```

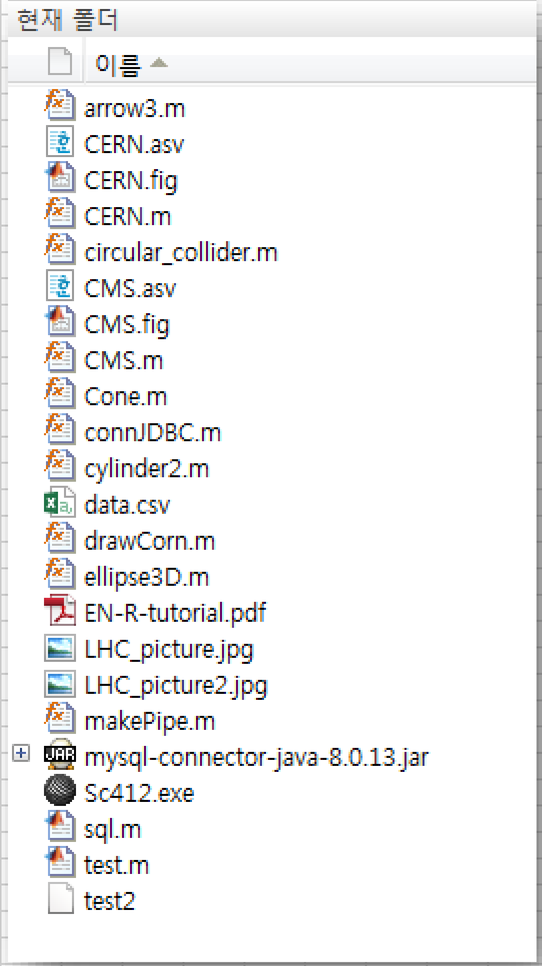
시뮬레이션 설계

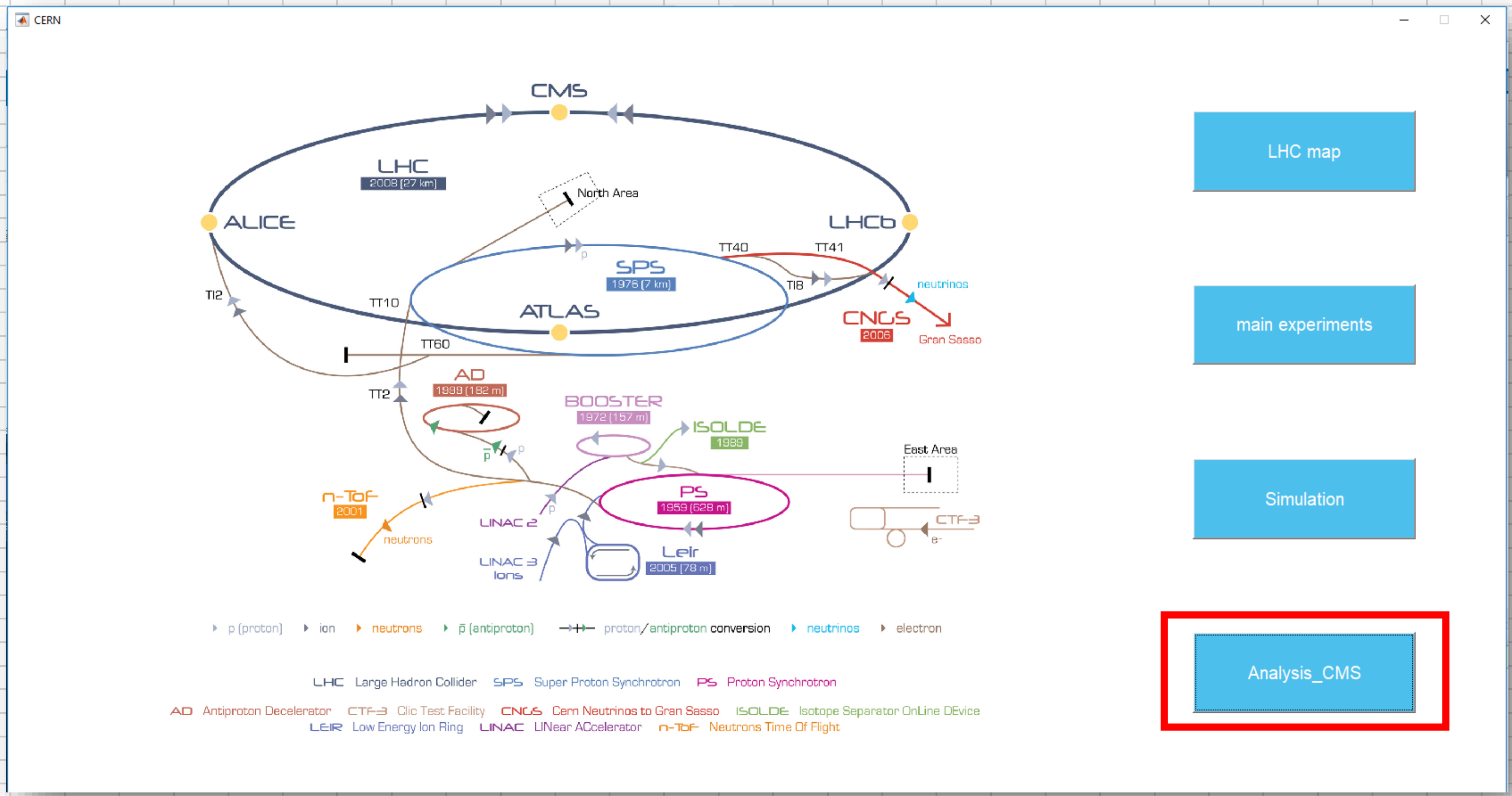
✓ 양성자 2개가 가속하다가 LHC(가장 큰 원)에서 충돌한다.





데이터 분석 및 DB 저장


현재 폴더
이름
arrow3.m
CERN.asv
CERN.fig
CERN.m
circular_collider.m
CMS.asv
CMS.fig
CMS.m
Cone.m
connJDBC.m
cylinder2.m
data.csv
drawCorn.m
ellipse3D.m
EN-R-tutorial.pdf
LHC_picture.jpg
LHC_picture2.jpg
makePipe.m
mysql-connector-java-8.0.13.jar
Sc412.exe
sql.m
test.m
test2


CERN
CMS
LHC
2008 (27 km)
North Area
ALICE
LHCb
SPS
1976 (7 km)
ATLAS
CNGS
2006
Gran Sasso
neutrinos
AD
1999 (182 m)
BOOSTER
1972 (157 m)
ISOLDE
1989
East Area
PS
1959 (628 m)
n-ToF
2001
neutrons
LINAC 2
LINAC 3
Ions
LEIR
2005 (78 m)
CTF3
p (proton)
ion
neutrons
p̄ (antiproton)
proton/antiproton conversion
neutrinos
electron
LHC Large Hadron Collider
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LINAC LINear ACcelerator
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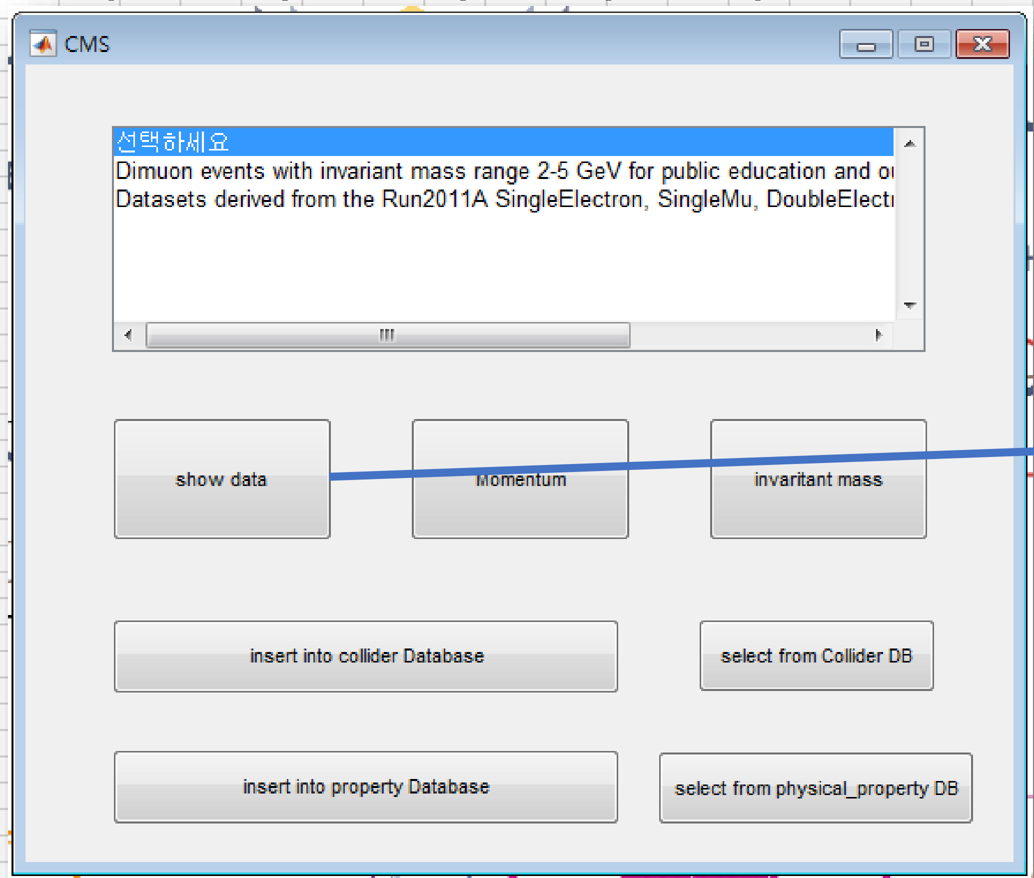
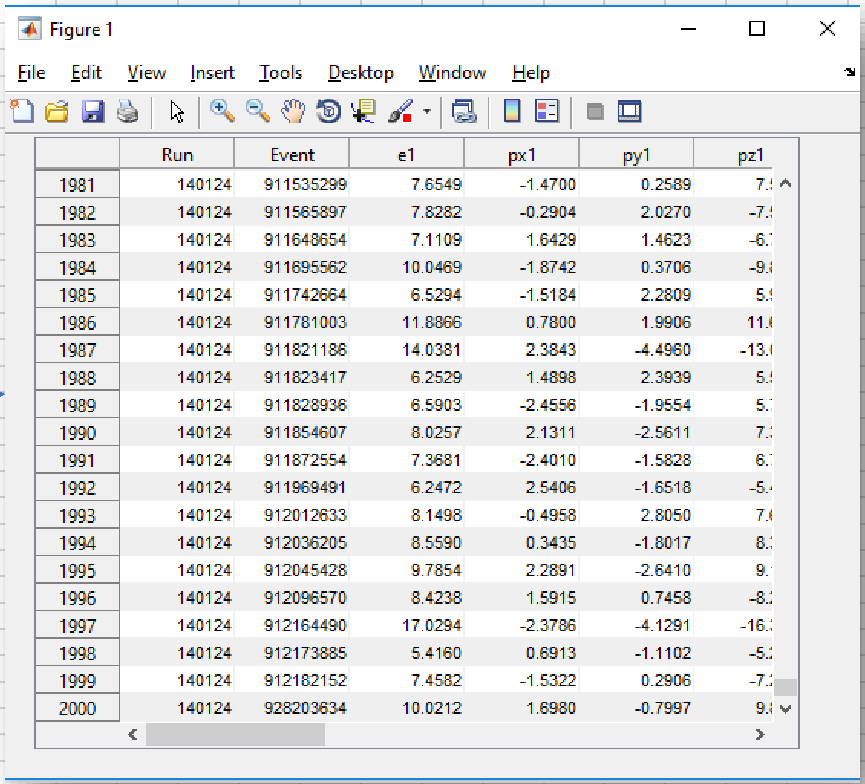
데이터 분석

Particle physics

✓ 충돌 지점 중, CMS에서의 데이터를 가져와 분석한 후 AWS의 DB에 분석 결과를 저장하였다.





	Run	Event	e1	px1	py1	pz1
1981	140124	911535299	7.6549	-1.4700	0.2589	7.
1982	140124	911565897	7.8282	-0.2904	2.0270	-7.
1983	140124	911648654	7.1109	1.6429	1.4623	-6.
1984	140124	911695562	10.0469	-1.8742	0.3706	-9.
1985	140124	911742664	6.5294	-1.5184	2.2809	5.
1986	140124	911781003	11.8866	0.7800	1.9906	11.
1987	140124	911821186	14.0381	2.3843	-4.4960	-13.
1988	140124	911823417	6.2529	1.4898	2.3939	5.
1989	140124	911828936	6.5903	-2.4556	-1.9554	5.
1990	140124	911854607	8.0257	2.1311	-2.5611	7.
1991	140124	911872554	7.3681	-2.4010	-1.5828	6.
1992	140124	911969491	6.2472	2.5406	-1.6518	-5.
1993	140124	912012633	8.1498	-0.4958	2.8050	7.
1994	140124	912036205	8.5590	0.3435	-1.8017	8.
1995	140124	912045428	9.7854	2.2891	-2.6410	9.
1996	140124	912096570	8.4238	1.5915	0.7458	-8.
1997	140124	912164490	17.0294	-2.3786	-4.1291	-16.
1998	140124	912173885	5.4160	0.6913	-1.1102	-5.
1999	140124	912182152	7.4582	-1.5322	0.2906	-7.
2000	140124	928203634	10.0212	1.6980	-0.7997	9.

데이터 분석

Particle physics

✓ momentum 과 위 치 (theta...), transverse enery, transverse momentum, 손실 값들을 기반으로 Invariant Mass 를 계산하여 이를 정규화한 그래프로 나타내었다.

```matlab
function pushbutton4_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton4 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Momentum
global px1 px2 py1 py2 pz1 pz2 e1 e2
global px py pz p

px = px1+px2;
py = py1+py2;
pz = pz1+pz2;

p = [px py pz];

assignin('base','px',px);
assignin('base','py',py);
assignin('base','pz',pz);
assignin('base','p',p);

figure('Name', 'Momentum', 'NumberTitle', 'off');
makePipe([abs(min(pz))+10], min(px)-30, max(px)+30 ); hold on
scatter3(px,py,pz,30,p,'filled');
title('Momentum');
xlabel({'px'}); ylabel({'py'}); zlabel({'pz'});
```

```matlab
% Invariant mass
global px1 px2 py1 py2 pz1 pz2 e1 e2 px py pz p type_n dxy met
global e sizeP mass
assignin('base','e',e);
assignin('base','sizeP',sizeP);
assignin('base','mass',mass);

if type_n==1
    disp('suc')
    e = e1+e2;
    sizeP = sqrt(px.^2 + py.^2 + pz.^2);    % no norm!
    mass = sqrt(e.^2 - sizeP.^2);


    figure('Name', 'Invariant Mass', 'NumberTitle', 'off');
    morebins(histogram(mass,50));
    % 'count', 'countdensity', 'cumcount', 'probability', 'pdf', 'cdf'
    % morebins(histogram(mass,50,'Normalization','countdensity'));
    % histM = hist(mass)./sum(mass);
    % bar(histM);
    title('Invariant Mass');
    xlabel({'mass'}); ylabel({'frequency'});
elseif type_n==2
%     mass = sqrt(
    figure('Name', 'Invariant Mass', 'NumberTitle', 'off');
    morebins(histogram(met,50));
end
```

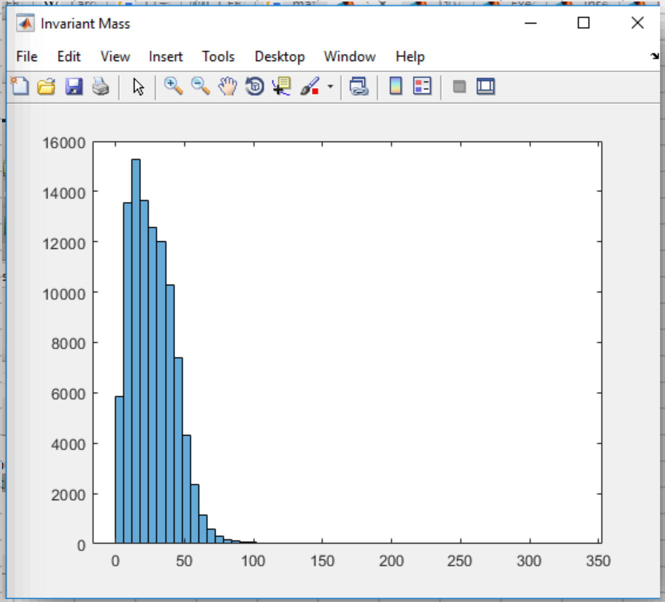
데이터 분석

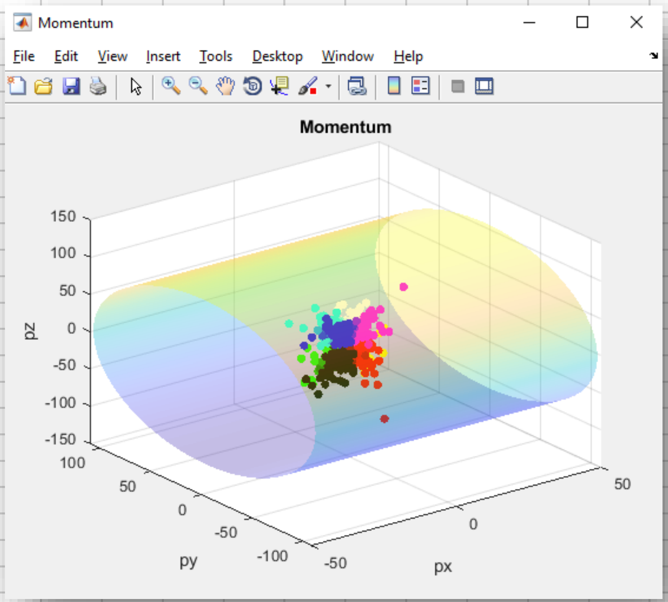
Particle physics

✓ momentum을 그래프로 나타낼 때에는, 가속관을 만드는 함수를 정의하여 만들었다

makePipe.m

```matlab
function [] = makePipe(R,heightStart,heightEnd)
%% description
% make the cylinder pipe that appears particle track
%
% [X,Y,Z] = CYLINDER2(R,D,N) forms the unit cylinder based on the symmetry axis D and the generator curve in the vector R. Vector R contains th
%
% [X,Y,Z] = CYLINDER2 default to R = [1 1], D = [0,0,1] and N = 20
%
% [X,Y,Z] = CYLINDER2(R) default to D = [0,0,1] and N = 20
%
% [X,Y,Z] = CYLINDER2(R,D) default to N = 20
%
% SURF(X,Y,Z) displays the cylinder.


%% Test :vertical 1
% [x,y,z] = cylinder(10,1000);
% surf(x,y,z)
% shading interp
% alpha(0.1)

%% Test :vertical 2
% [x,y,z] = cylinder(10,1000);
% h=surf(x,y,z);
% set(h,'linestyle','none');
% alpha(0.1);

%% horizontal
[x y z] = cylinder2(R,[1 0 0],1000);
x(1,:)=heightStart;
x(2,:) = heightEnd;
h = surf(x,y,z);
% set(h,'linestyle','none', 'FaceColor', [0,0,0]);
set(h,'linestyle','none');
% set(hgtransform, 'Matrix', makehgtform('scale', size));
alpha(0.3);

end
```





Database 설계 및 저장

Particle physics

- ✓ Collider table : 충돌 지점에 대한 정보를 저장
- ✓ Physial_property: 각 이벤트에 대한 정보를 저장

```
mysql> show tables;
+--------------------+
| Tables_in_CERN_LHC |
+--------------------+
| Collider           |
| Physial_property   |
+--------------------+
2 rows in set (0.00 sec)
```

```
set @@foreign_key_checks=0;
CREATE TABLE Collider
(
    collider_name   VARCHAR(10) NOT NULL,
    event_name   VARCHAR(100) NOT NULL,
    event_number   VARCHAR(100) NOT NULL,
    primary key (event_name, event_number)
);
```

```
CREATE TABLE Physial_property
(
    invariant_mass   Double,
    event_number   VARCHAR(100) NOT NULL,
    px   Double,
    py   Double,
    pz   Double,
    event_name   VARCHAR(100),
    primary key(event_number)

)ENGINE INNODB;

alter table  Physial_property
add foreign key (event_name, event_number)
references Collider(event_name, event_number);
```

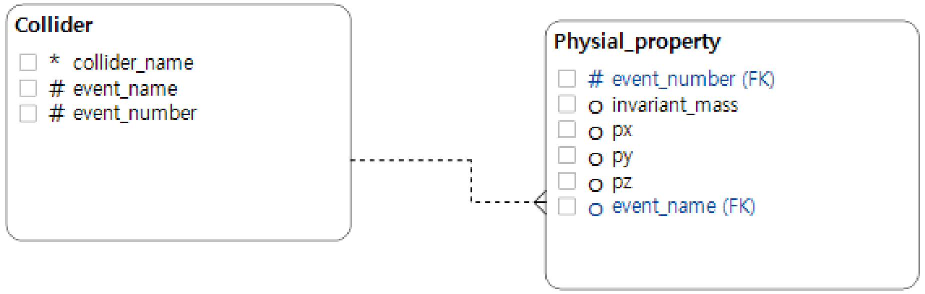


Figure 1. DB 논리적 설계

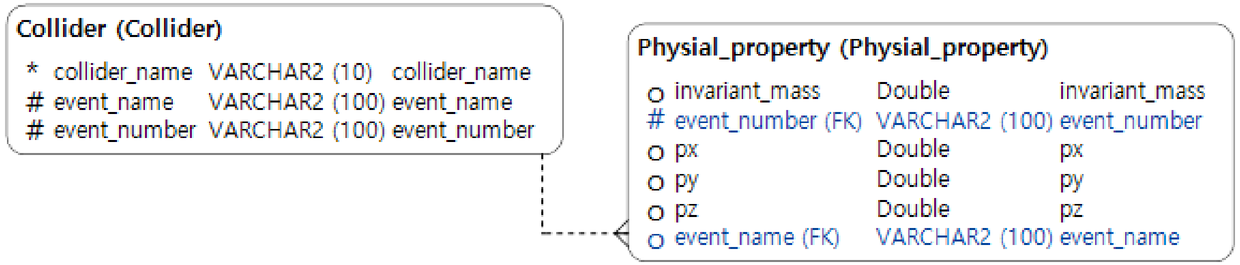


Figure 2. DB 물리적 설계

Database 설계 및 저장

✓ Matlab에서 mysql-java 드라이버를 경로에 추가하고 DB에 연결하도록 하는 connJDBC 함수를 생성하여 이를 기반으로 데이터를 삽입하고 선택하도록 하였다.

```
function [conn] = connJDBC()
%UNTITLED Summary of this function goes here
%   Detailed explanation goes here
javaaddpath('/mysql-connector-java-8.0.13.jar')
datasource = 'CERN_LHC';
username = 'root';
password = 'dbroot';
driver = 'com.mysql.cj.jdbc.Driver';
url = 'jdbc:mysql://18.191.183.16:3306/';
conn = database(datasource,username,password,driver,url);
end
```

Database 설계 및 저장

Particle physics

✓ insert 쿼리를 DB로 보내는 함수

```
function pushbutton6_Callback(hObject, eventdata, handles)
% Collider DB
% hObject    handle to pushbutton6 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
global conn event_name collider_name event_numb event templ data
conn = connJDBC();

event_numb = string(num2str(event));
collider_name = repmat("CMS",length(event_numb),1);
event_name = repmat(string(templ), length(event_numb),1);

assignin('base','conn',conn);

data = table(collider_name(1:10), event_name(1:10),event_numb(1:10),'VariableNames',{'collider_name' 'event_name' 'event_number' });
assignin('base','data',data);

 sqlwrite(conn, 'Collider', data);
```

Database 설계 및 저장

Particle physics

✓ select 쿼리를 DB로 보내는 함수

```
function pushbutton11_Callback(hObject, eventdata, handles)
% hObject    handle to pushbutton11 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)


global conn event_name collider_name event_numb event templ data
global mass px py pz
conn = connJDBC();

inv_mass = string(num2str(mass));
even_numb =  string(num2str(event));
px_s = string(num2str(px));
py_s = string(num2str(py));
pz_s = string(num2str(pz));
event_name = repmat(string(templ), length(event_numb),1);
data = table(mass(1:10), even_numb(1:10), px(1:10), px(1:10), px(1:10), event_name(1:10),'VariableNames', {'invariant_mass' 'event_number' 'p


assignin('base','conn',conn);

assignin('base','data',data);

sqlwrite(conn, 'Physial_property', data);
```

collider_name	event_name	event_number
CMS	Dimuon events with invarian...	1007912007
CMS	Dimuon events with invarian...	1007957044
CMS	Dimuon events with invarian...	1008000431
CMS	Dimuon events with invarian...	1008032300
CMS	Dimuon events with invarian...	1008075983
CMS	Dimuon events with invarian...	1008203315
CMS	Dimuon events with invarian...	1008209356
CMS	Dimuon events with invarian...	1008225333
CMS	Dimuon events with invarian...	1008234146
CMS	Dimuon events with invarian...	1008257850

invariant_mass	event_number	px	py	pz	event_name
4.5200	1007912007	4.2032	4.2032	4.2032	Dimuon eve...
2.7338	1007957044	-1.3739	-1.3739	-1.3739	Dimuon eve...
3.0733	1008000431	18.6478	18.6478	18.6478	Dimuon eve...
3.1325	1008032300	-7.3589	-7.3589	-7.3589	Dimuon eve...
2.1553	1008075983	2.3778	2.3778	2.3778	Dimuon eve...
2.1117	1008203315	0.6504	0.6504	0.6504	Dimuon eve...
2.1060	1008209356	2.3882	2.3882	2.3882	Dimuon eve...
2.2557	1008225333	2.4440	2.4440	2.4440	Dimuon eve...
2.3181	1008234146	-2.5530	-2.5530	-2.5530	Dimuon eve...
2.8344	1008257850	-1.6548	-1.6548	-1.6548	Dimuon eve...

Database 설계 및 저장

Particle physics

✓ DB 저장 확인(Collider table)

```
| collider_name | event_name                                                          | eve
nt_number |
+---------------+---------------------------------------------------------------------+----
----------+
| CMS           | Dimuon events with invariant mass range 2-5 GeV for public education and outreach | 100
7912007    |
| CMS           | Dimuon events with invariant mass range 2-5 GeV for public education and outreach | 100
7957044    |
| CMS           | Dimuon events with invariant mass range 2-5 GeV for public education and outreach | 100
8000431    |
| CMS           | Dimuon events with invariant mass range 2-5 GeV for public education and outreach | 100
8032300    |
| CMS           | Dimuon events with invariant mass range 2-5 GeV for public education and outreach | 100
8075983    |
| CMS           | Dimuon events with invariant mass range 2-5 GeV for public education and outreach | 100
8203315    |
| CMS           | Dimuon events with invariant mass range 2-5 GeV for public education and outreach | 100
8209356    |
| CMS           | Dimuon events with invariant mass range 2-5 GeV for public education and outreach | 100
8225333    |
| CMS           | Dimuon events with invariant mass range 2-5 GeV for public education and outreach | 100
8234146    |
```

향후 연구

향후 연구

✓CERN LHC 연구에 대한 이해와 데이터들의 자유로운 활용

✓DB의 삽입/선택에 대한 원활한 처리

✓시뮬레이션을 만들 때, 충돌지점을 find로 찾을 수 없어 knn 알고리즘을 활용하여 충돌지점을 찾았는데(knn search 함수를 이용하였다), 만족스러운 결과가 아니기에 결국 ginput(1)으로 직접 지점을 입력하여 사용하였다. 더욱 좋은 ML 알고리즘을 사용하여서 근삿값을 찾아보고 싶다.