Shine and Shadow from Quark Gluon Plasma

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7th Heavy Ion Pub at Osaka Univ.

2009/11/17

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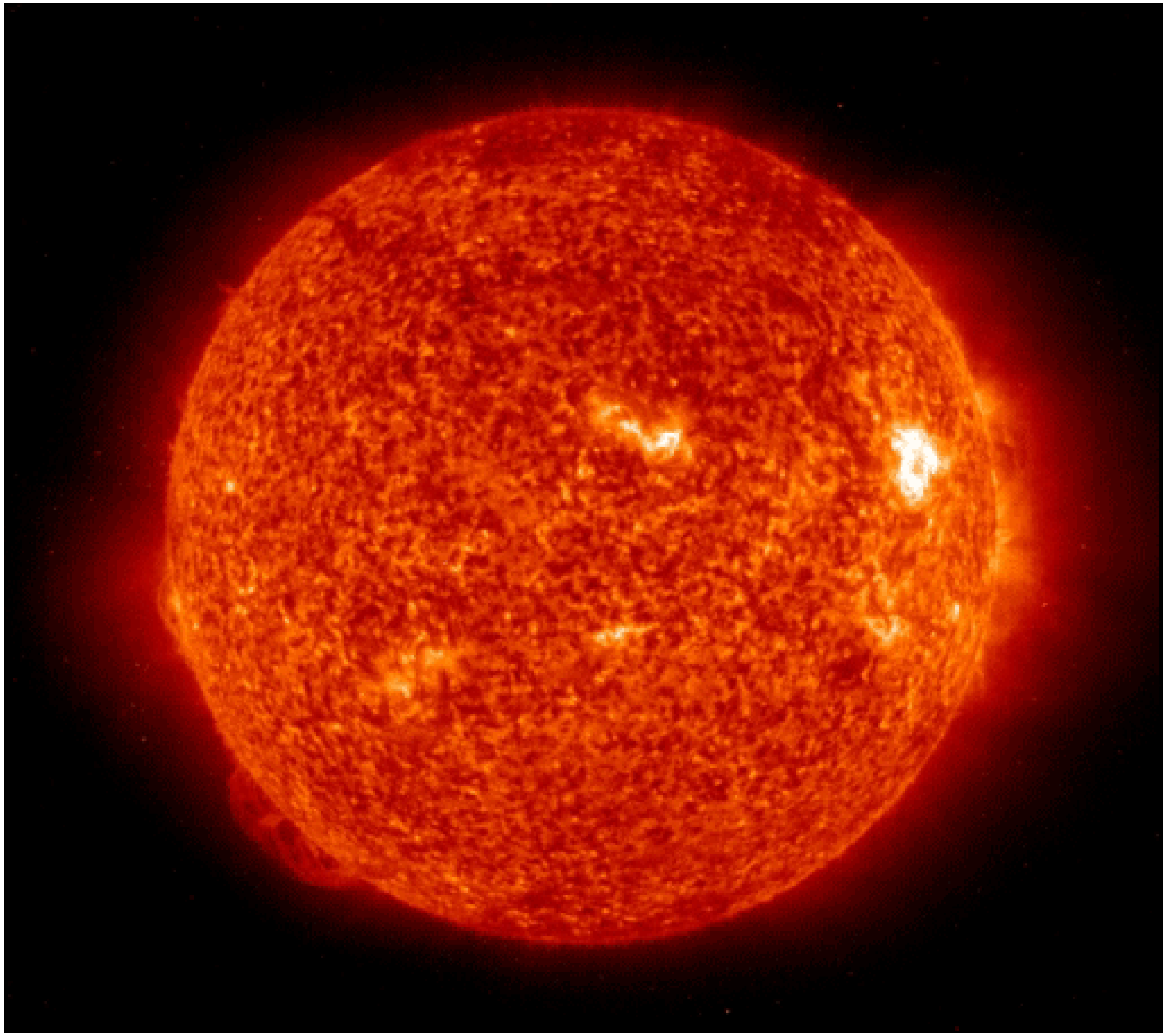
shine

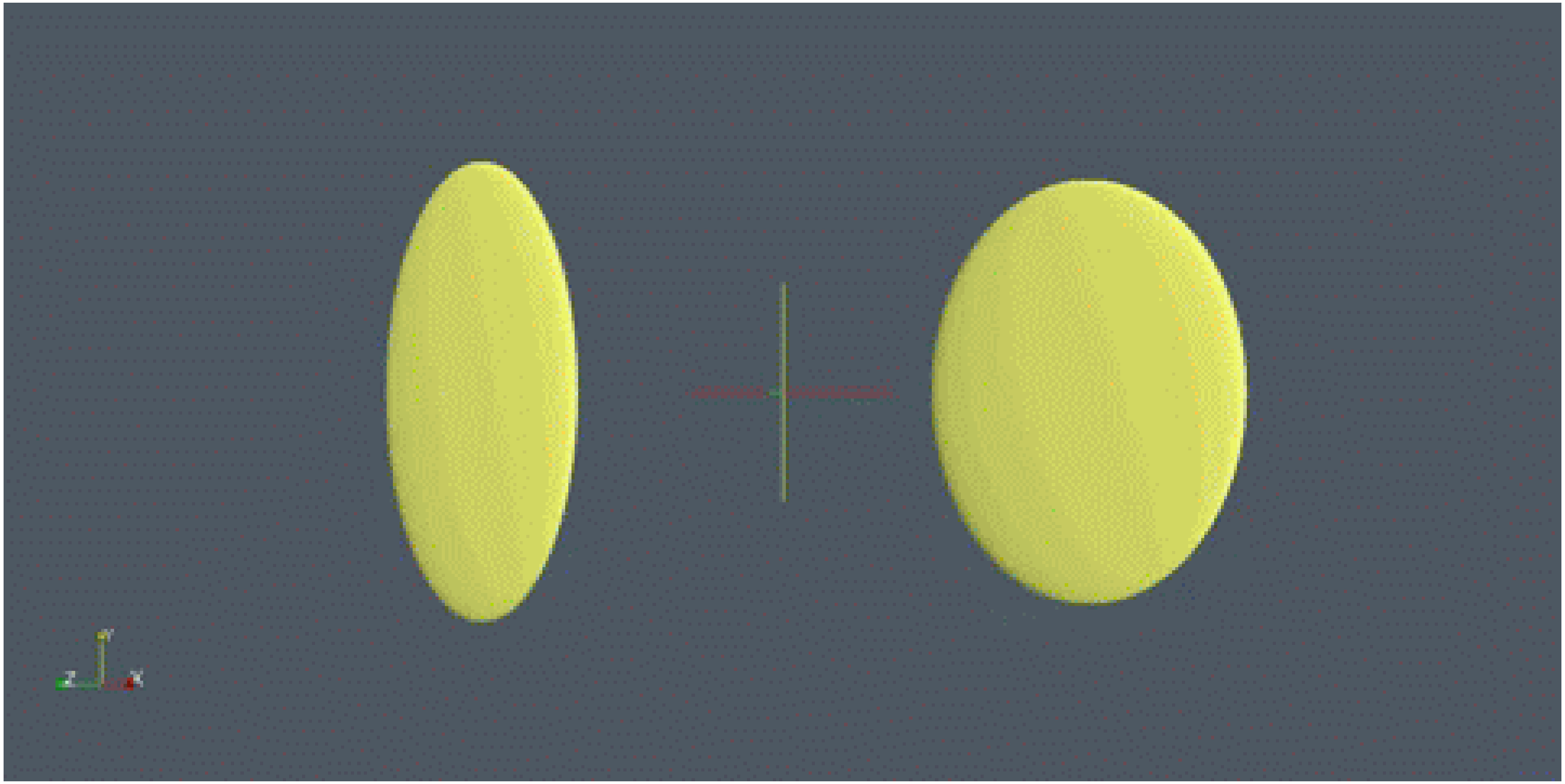
(v) to produce light
(n) the brightness that something has when light shines on it
[by longman dictionary]

Shine



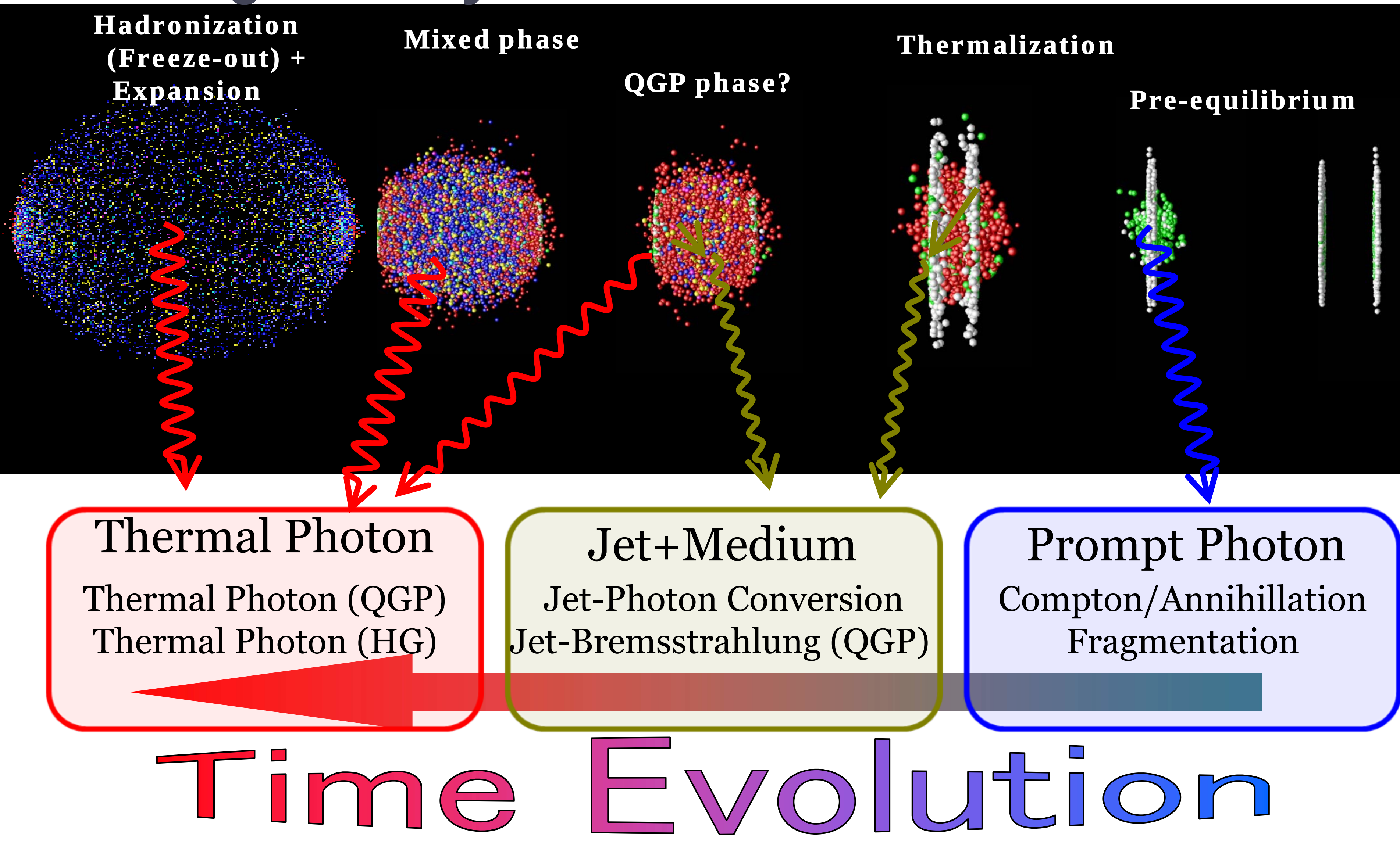
By NASA's Extreme ultraviolet Imaging Telescope (EIT) over the course of 6days from 27/6/2005
http://www.boston.com/bigpicture/2008/10/the_sun.html

Shine

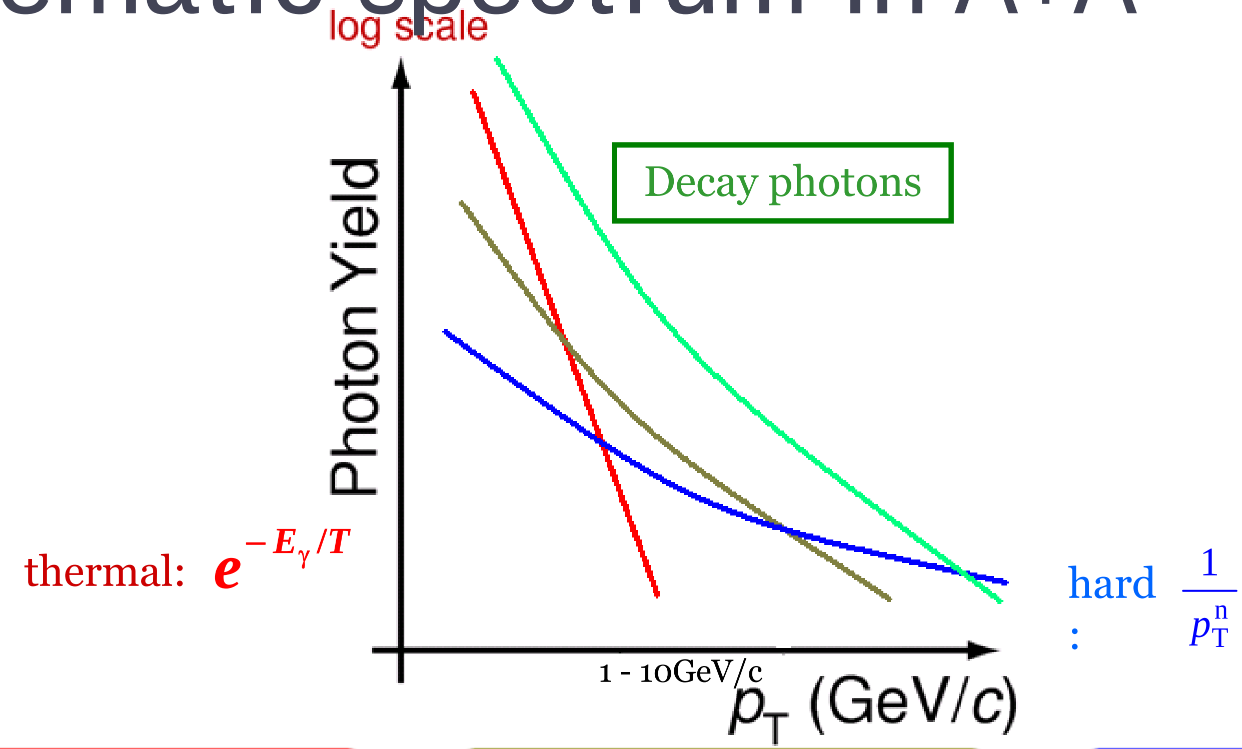


From Hirano-san's web page.

Shining Heavy Ion Collisions



Schematic Spectrum in A+A



Thermal Photon
Thermal Photon (QGP)
Thermal Photon (HG)

Jet+Medium
Jet-Photon Conversion
Jet-Bremsstrahlung (QGP)

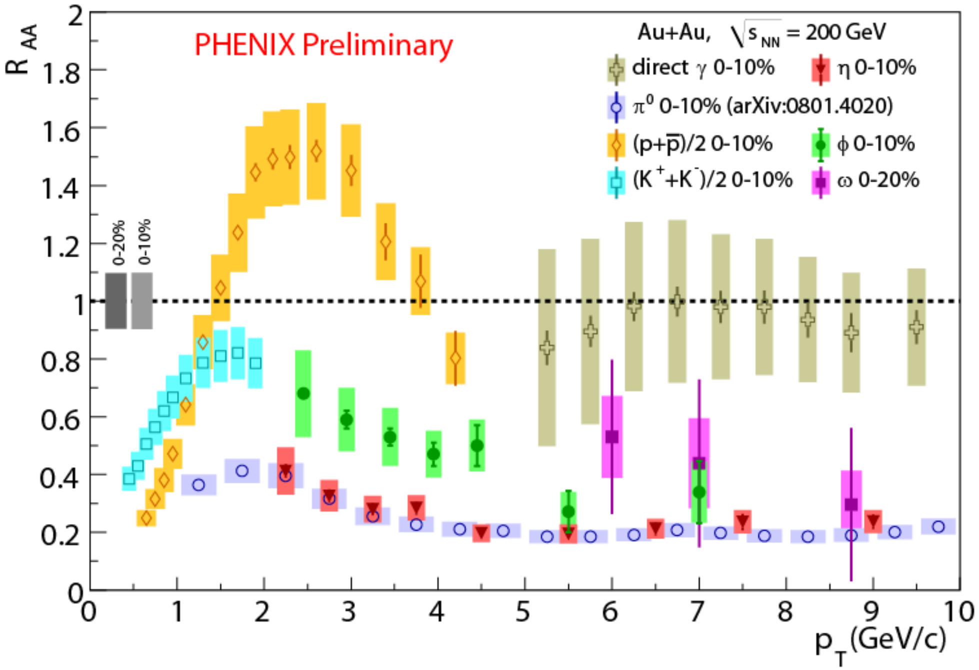
Prompt Photon
Compton/Annihillation
Fragmentation

+ photons from hadron decay

Photons are collective probes for various expansion stages of the hot matter

(1) High p_T Meson Identification

- quark flavor dependent suppression?
  - Interesting behavior of nuclear modification for various mesons and hadrons has been reported at RHIC



Photon from meson decay is a good tool of meson identification experimentally at high pT.

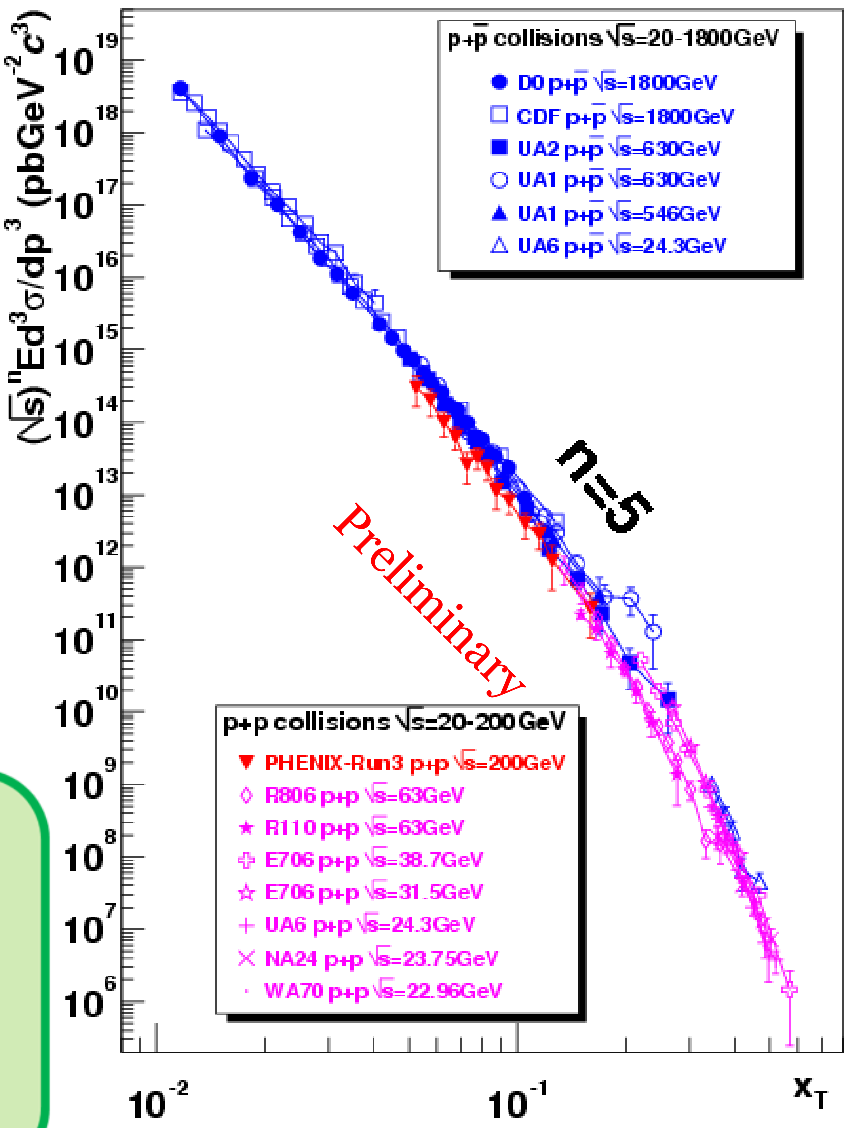
(2) Universality

- Direct photon production in p+p or p+p-bar shows universality

$$\sigma = \left(\sqrt{s}\right)^{-n} \times F\left(x_T\right)$$

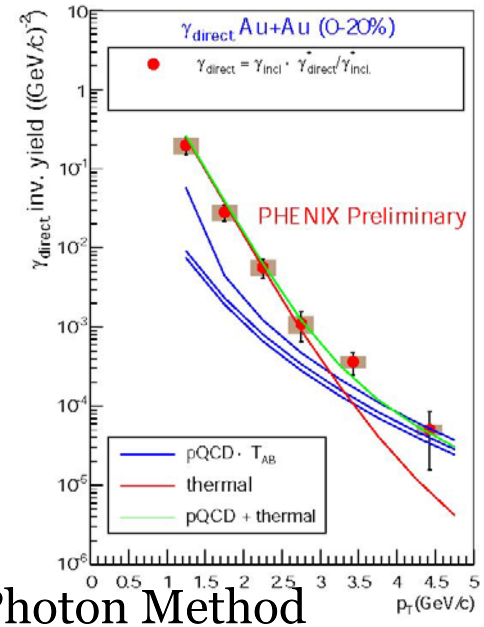
  - Consistency with pQCD prediction
  - Good probe for initial parton distribution

Any enhancement above the scaling (or pQCD calculation) can be new physics



(3) Temperature Sensor

RHIC

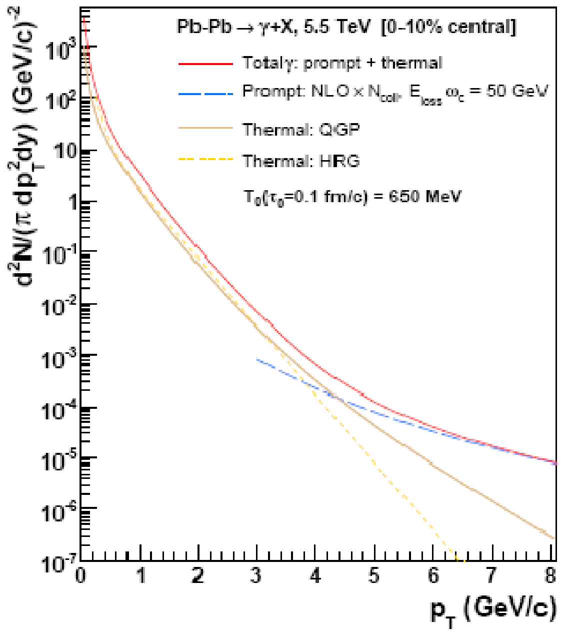


Indirect Photon Method

First Direct Photon Excess seen at low pT

Temperature from thermal photon measurement results in 300-500MeV

LHC Prediction



Photon excess is predicted at pT<10GeV

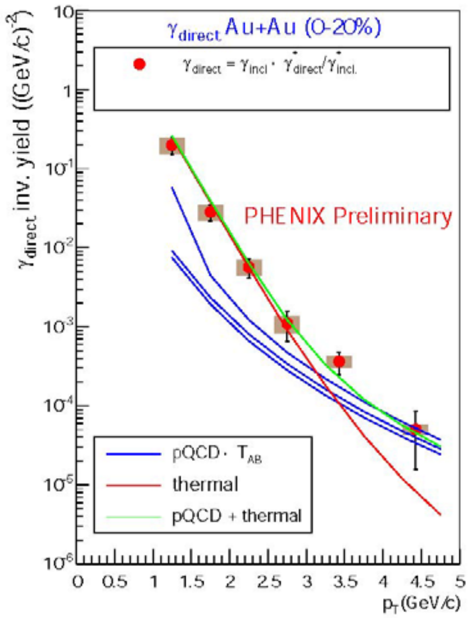
High multiplicity (~12000 h±/η)
Wide dynamic Range (0.1-80GeV)

Advantage at LHC

- Higher temperature, Longer QGP lifetime, Larger background photon suppression

(3) Temperature Sensor

RHIC



In-direct (Internal Conversion) method

First Direct Photon Excess seen at low pT by In-direct measurement at RHIC

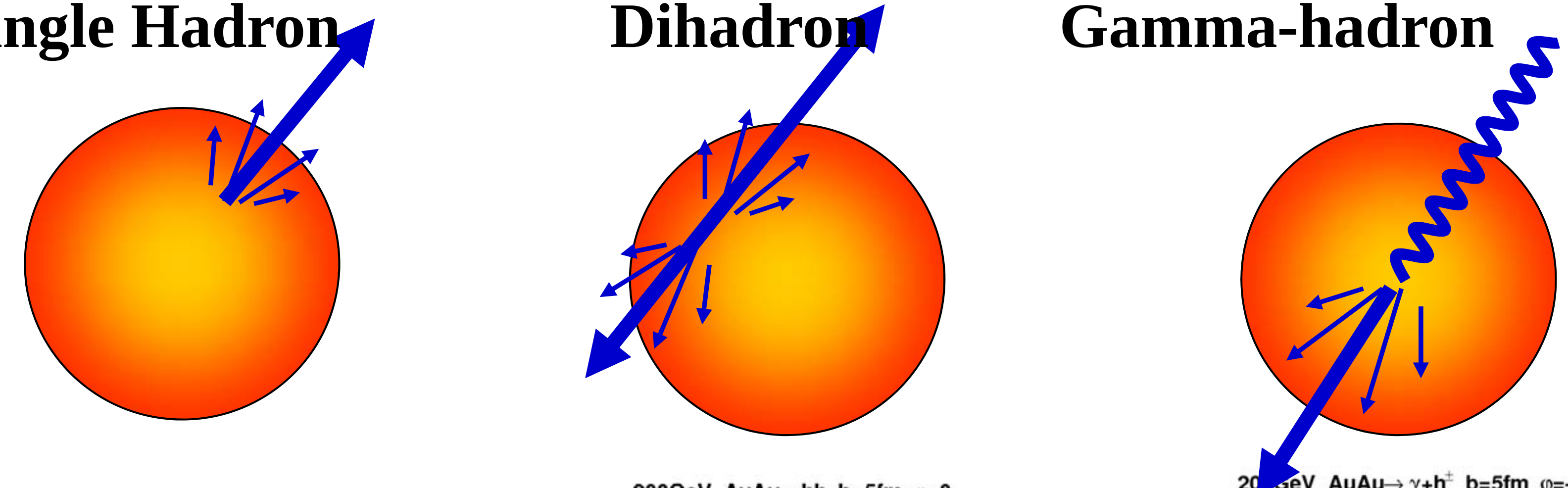
For Direct Measurement

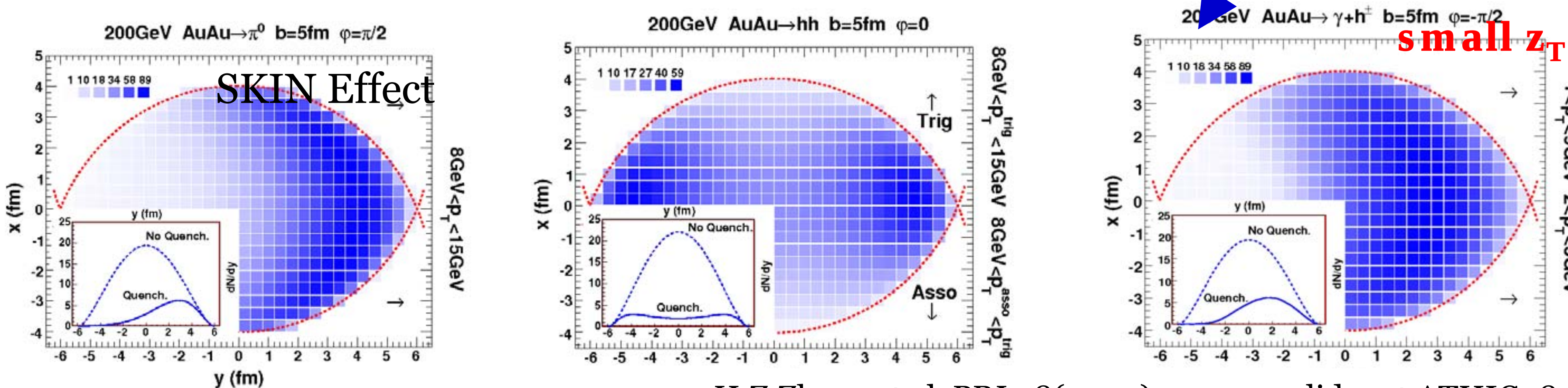
1. Higher Temperature ➔ High Energy=LHC
2. Improved Experimental Calorimeter

LHC with precise calorimeter and wide energy coverage (down to 0.1GeV)

(4) Transparency

Single Hadron **Dihadron** **Gamma-hadron**





H.Z.Zhang et al. PRL98(2007)212301 + slides at ATHIC08

Probe to the center of hot matter

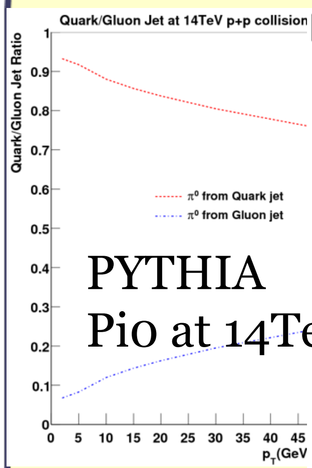
$$E_{photon} = E_{Jet}$$

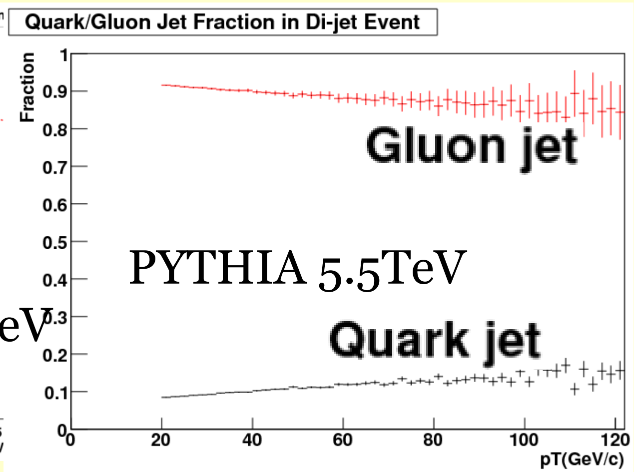
(5) Parton Identification

- Naively, gluon jet is quenched more than quark jet
  - Strong Interaction Color Factor C(A) : C(F) = 3 : 4/3
- Comparison between gluon and quark

➔ Extream test of quenching effect

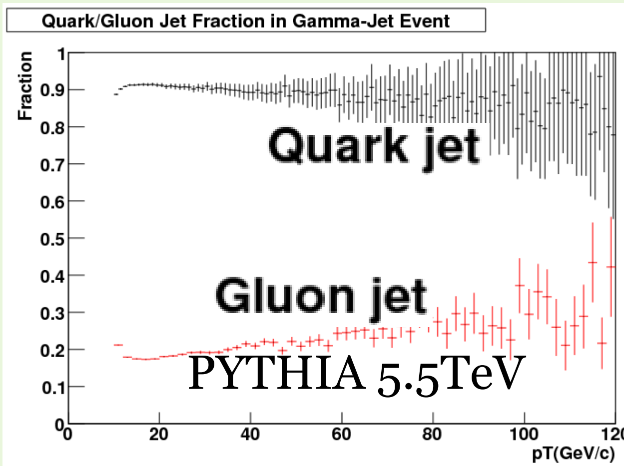
Single/Di-Hadrons/Jets





Gluon Dominant

Photon-Hadrons/Jets



Quark Dominant

Quark jet identification

shadow

(n) A dark shape that someone or something makes on a surface when they are between that surface and the light

[by longman dictionary]

Shadow

日本一大きな影

Largest shadow in Japan!!!
Taken from the top of highest mountain in Japan, Mt. Fuji.
Taken by H.T. in 1996 summer.

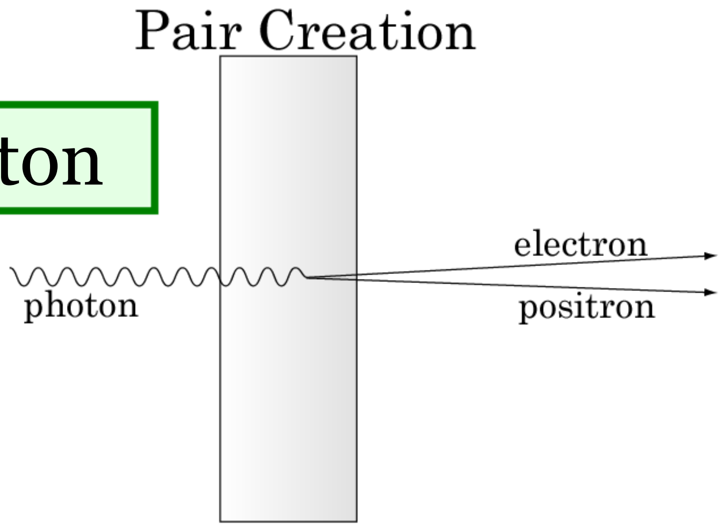
Shadow

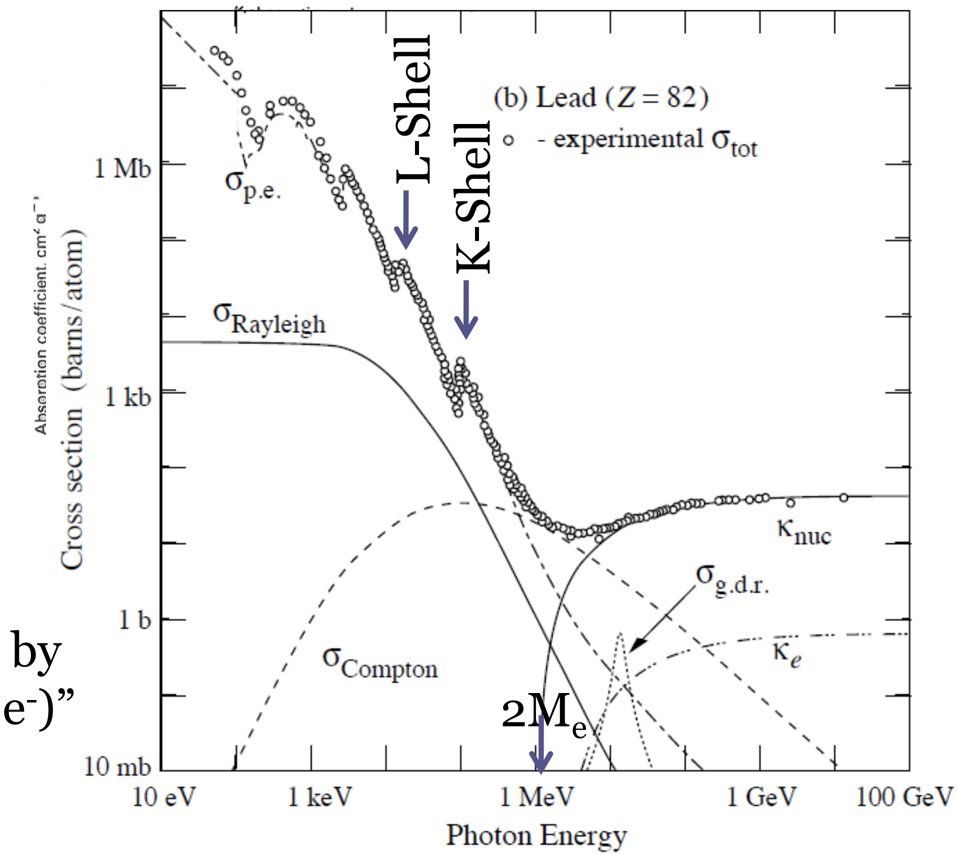
世界一高性能の(GeV光子)電磁カロリーメータ

Finest GeV-photon calorimeter in the world

Electro-Magnetic Interaction

photon





Photon lose energy or convert into electron by
"Photoelectron absorption (γ+atom → ion+e^-)"
"Compton ($\gamma+e^-$ → $\gamma+e^-$)" process

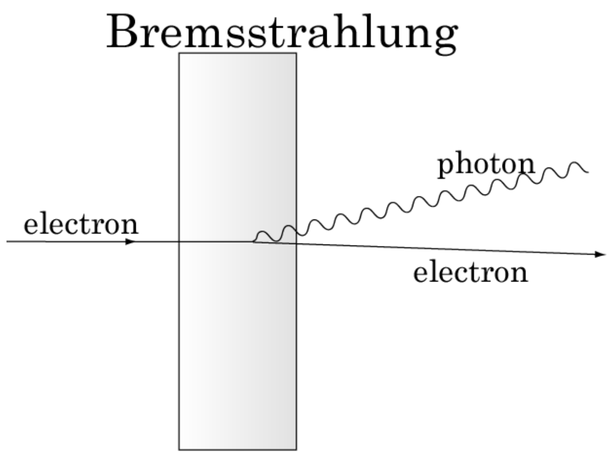
Pair creation dominates at > 10MeV (for Pb)
(cut of > $2M_e$)

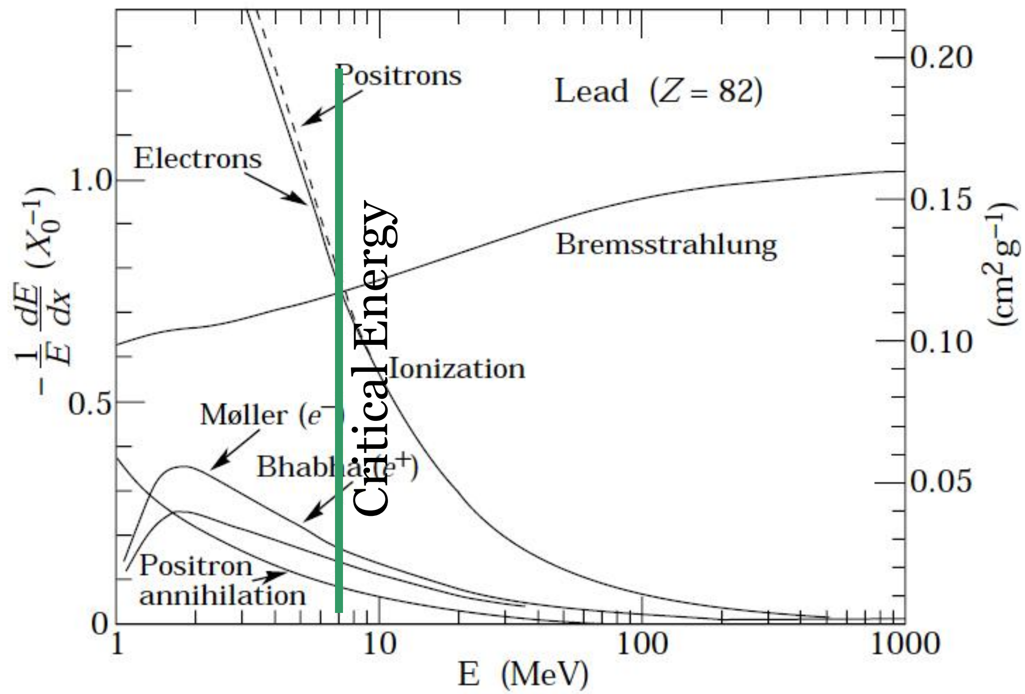
$$\sigma_{pair} \approx 4\alpha r_e^2 Z^2 \left(\frac{7}{9} \ln \frac{183}{Z^{\frac{1}{3}}} \right) \approx \frac{7}{9} \frac{A}{N_A} \frac{1}{X_0} \approx \frac{A}{N_A} \frac{1}{\lambda_{pair}}$$

Pair production probability after X0[cm] length is $1-e^{-7/9}$=54%.

Electro-Magnetic Interaction

electron/positron





Energy loss by bremsstrahlung is characterized by "Radiation Length"
(in the high energy limit where the ionization loss can be neglected)

$dE/E = - dx/X_o \Rightarrow \langle E \rangle = E_o * \exp(-x/X_o)$

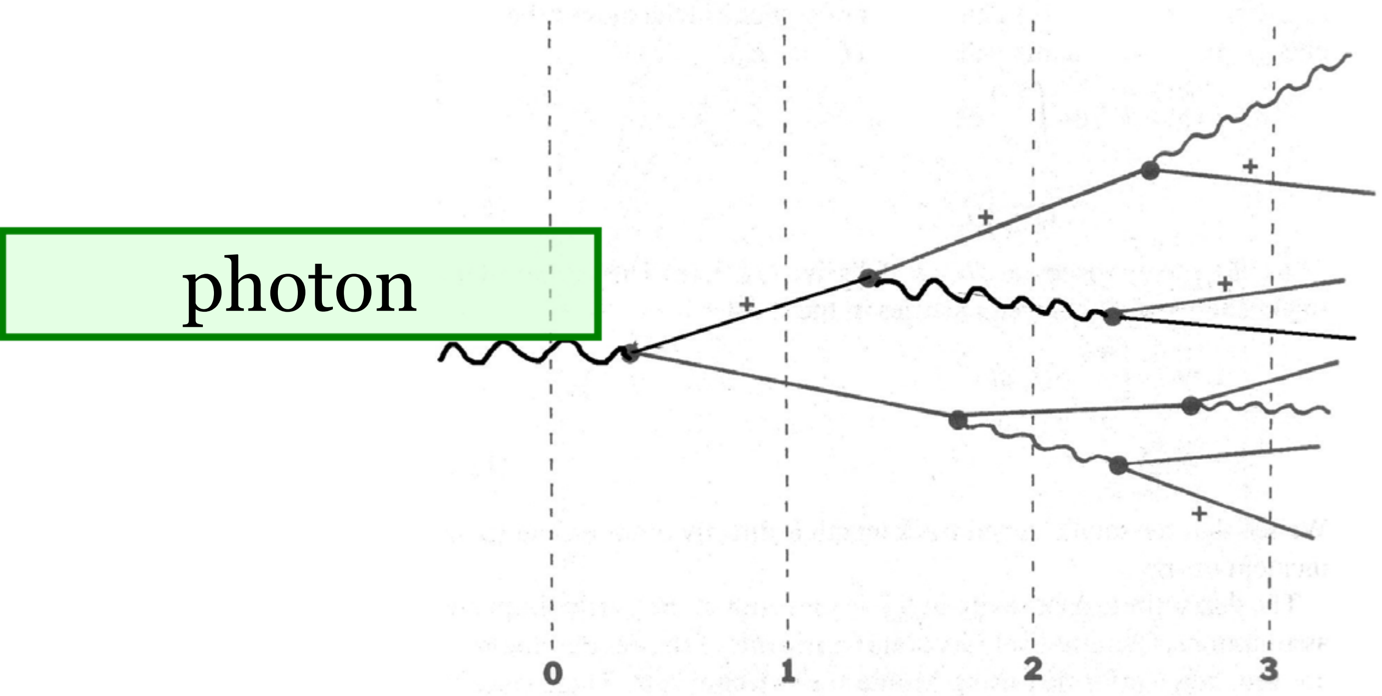
$$X_0 = \frac{A}{4\alpha N_A Z^2 r_e^2 \ln \frac{183}{Z^{1/3}}}$$

Critical Energy (E_c) : "Ionization loss = Bremsstrahlung loss"

E_c=6.9MeV for Pb $\quad E_C \approx 580 MeV/Z$

If the energy is less than E_c, the e-/e+ lost

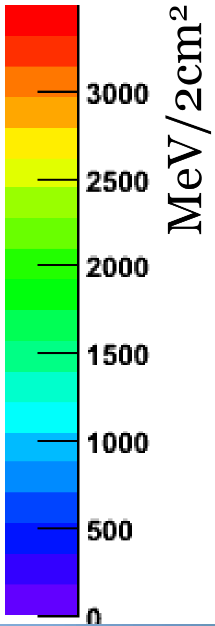
Electro-magnetic Shower



1. One pair creation on average after X_0, $Ee^+ \cong Ee^- \cong E_0/2$
2. e^+ and e^- radiate one photon after X_0.
3. e^+ and e^- deposit "ionization energy" through matter
4. Continue 1-3 until $Ee^+ \cong Ee^-$ is below the critical energy(Ec)
   - Electron <Ec stop after ~0.5cm(for Pb) due to ionization loss
   - Number of shower particles (2^d) increases exponentially with depth(d)

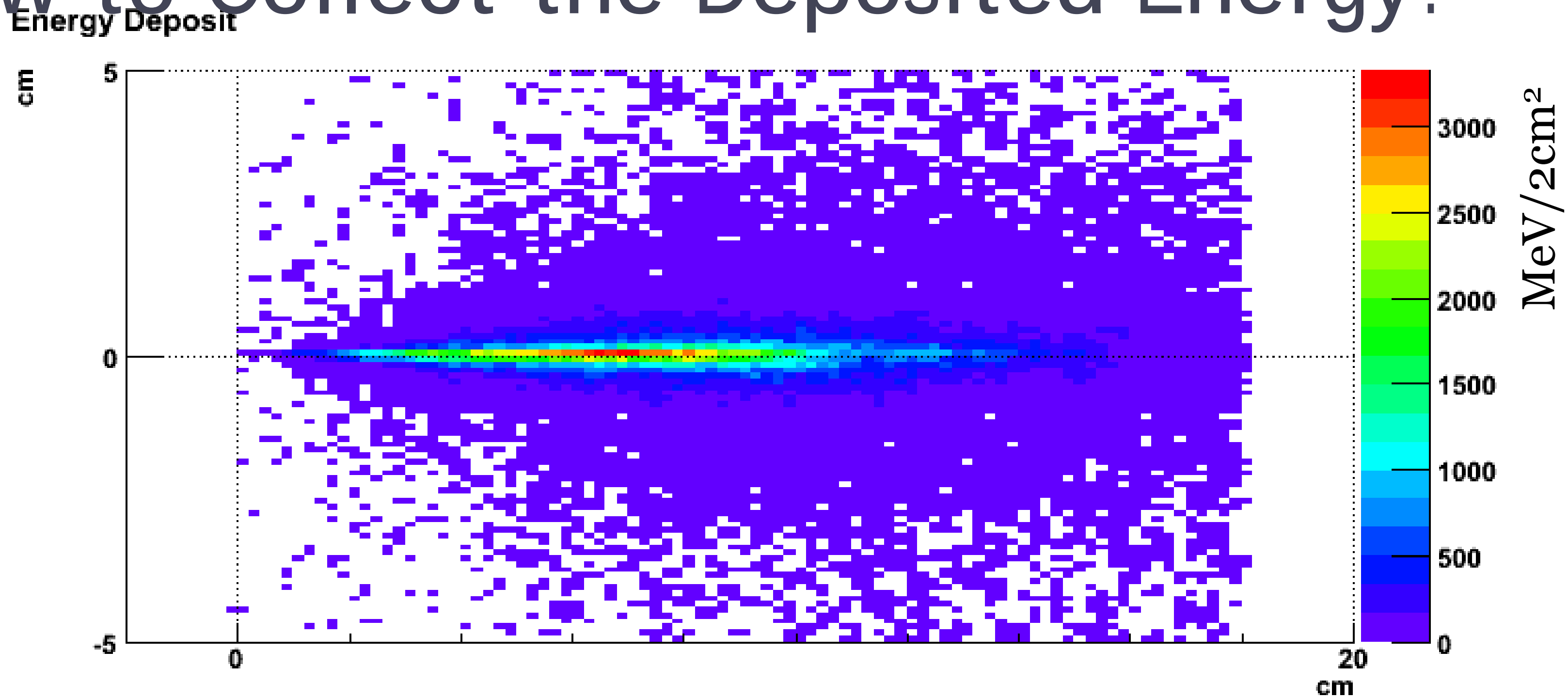
In real life…

000 psec



100GeV
photon

How to Collect the Deposited Energy?

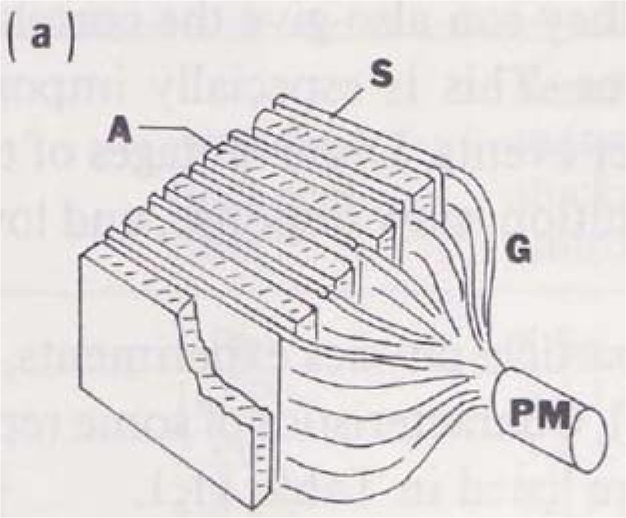


- Collect Ionization energy loss (or Cerenkov light) by e^+ and e^-
- Two type
  - Inhomogeneous or Homogeneous
    - Inhomogeneous
      - Sandwich with "heavy material" + "ionization energy loss detector"
    - Homogeneous
      - "heavy material" itself is "ionization energy loss detector"

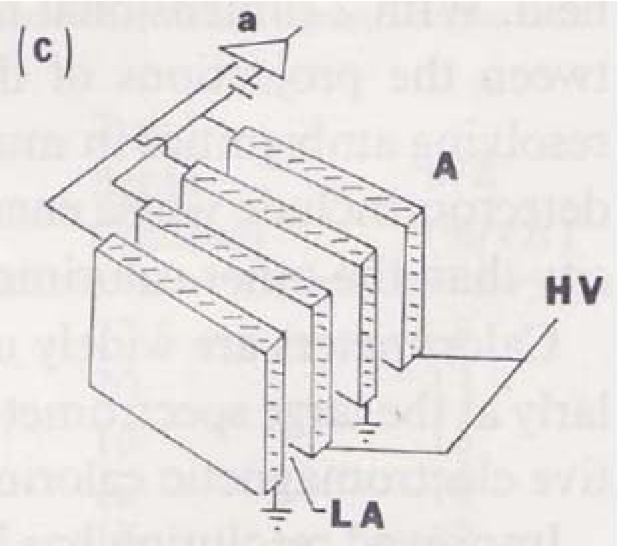
Inhomogeneous Calorimeter

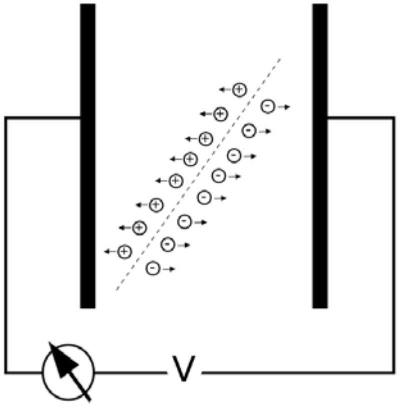
- Inhomogeneous : Sampling Calorimeter
  - Metal + “ionization energy loss detector”
    - Some exception is to utilize Cerenkov light emmission.
  - Disadvantage: “ionization energy loss” in metal is not detectable.
  - Three types for “ionization energy loss detector”
    - Solid or Liquid or Gas

Solid : Organic scintillator



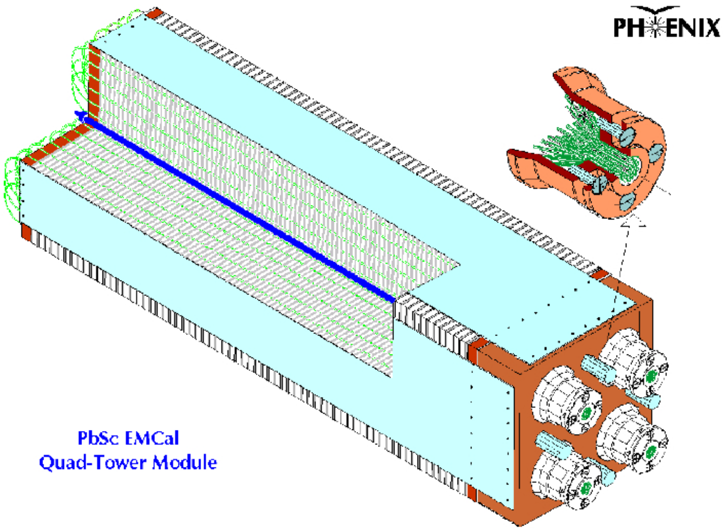
Solid(Silicon), Liquid(ex. LiAr), Gas(Ar+Co2, etc)



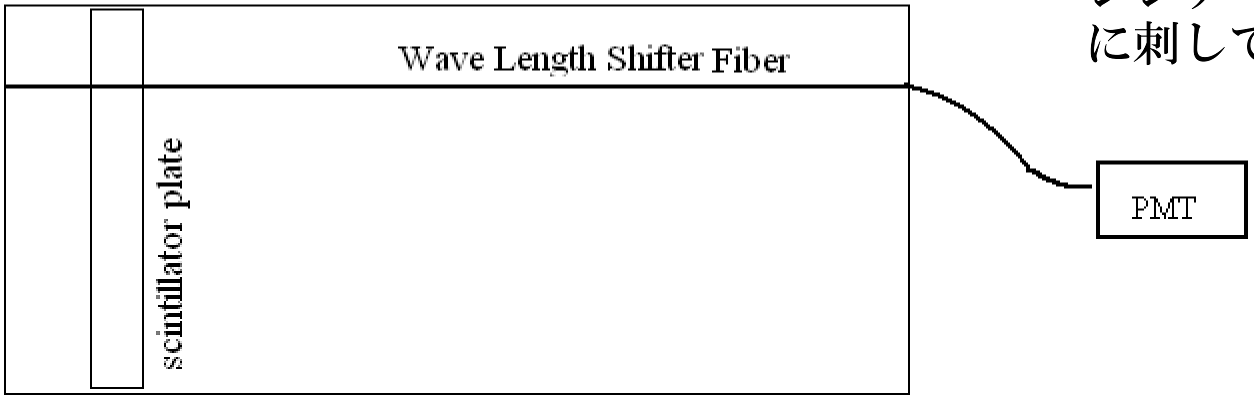


Example of Inhomogeneous Type

PHENIX PbSc Calorimeter



Shashlik type calorimeter

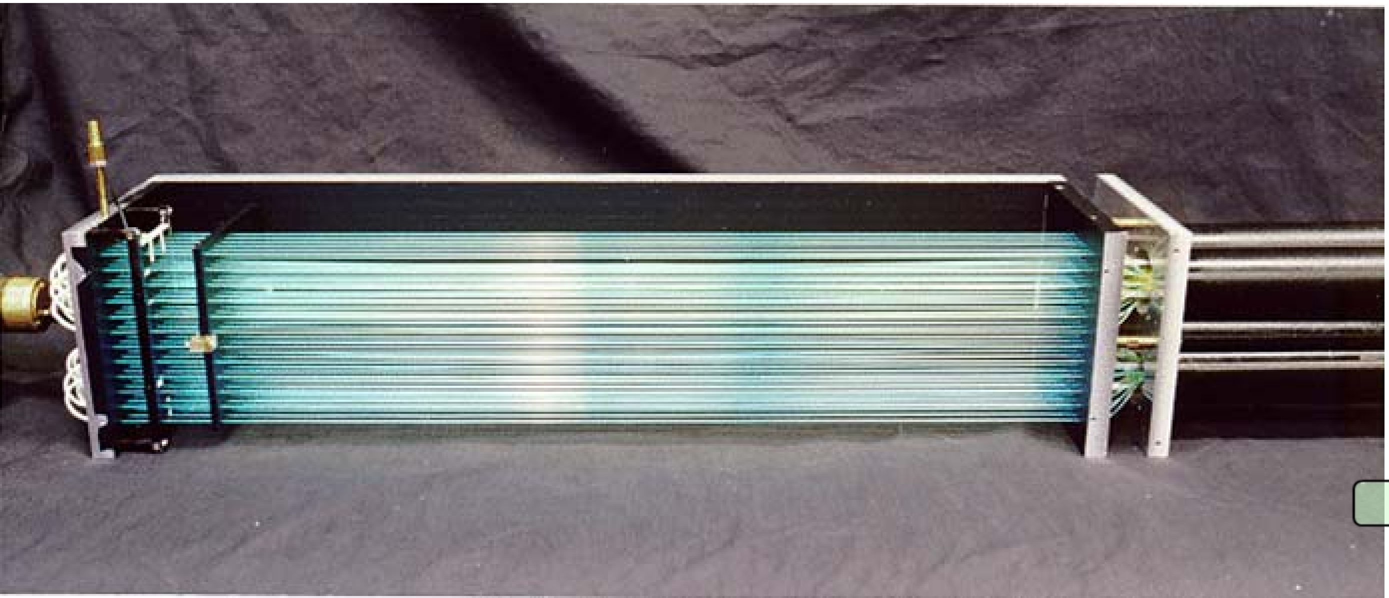


シシケバブ：四角形の肉を串に刺して焼いたトルコ料理

Example of Inhomogeneous : PHENIX PbSc

- Organic Scintillator
  - 5cm x 5cm x 4mm(thickness)
  - Aluminum vapor edge on four edge, one cornor is remained open for monitoring light input.
  - Scintillation light are gathered through wave length shifter fibers and collected into a PMT.

	PbSc
Size(cm x cm)	5.52 x 5.52
Depth(cm)	37.5
Number of towers	15552
Sampling fraction	~ 20%
η cov.	0.7
ϕ cov.	90+45deg
η/mod	0.011
ϕ/mod	0.011
X_0	18
Molière Radius	~ 3cm



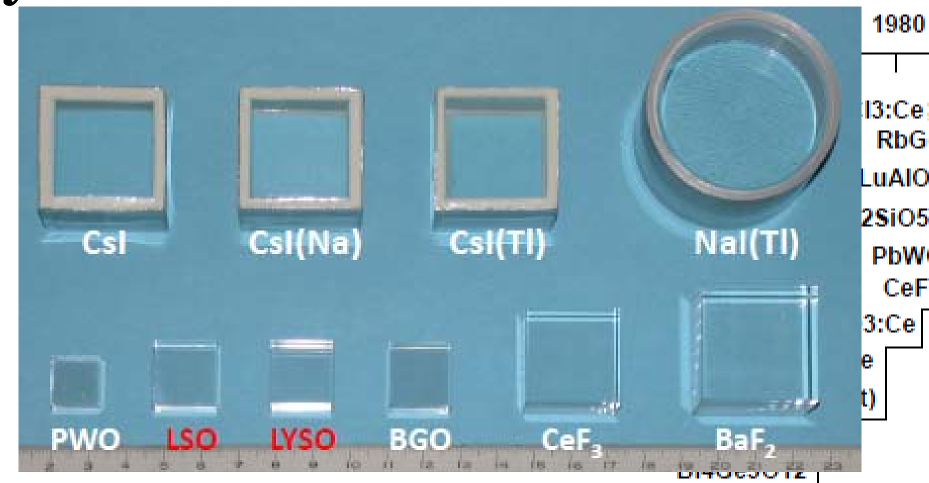
PbSc sector 2.0m x 4.0m

Homogeneous Type

- Homogeneous : Crystal Calorimeter
  - Crystal itself is “ionization energy loss detector”
    - NaI, CsI, Bi4G, GSO, BGO, PbWO4, LYSO
    - Scintillation radiation
  - Some exception is a glass (PbGl) as a Cerenkov radiator

Crystal Development

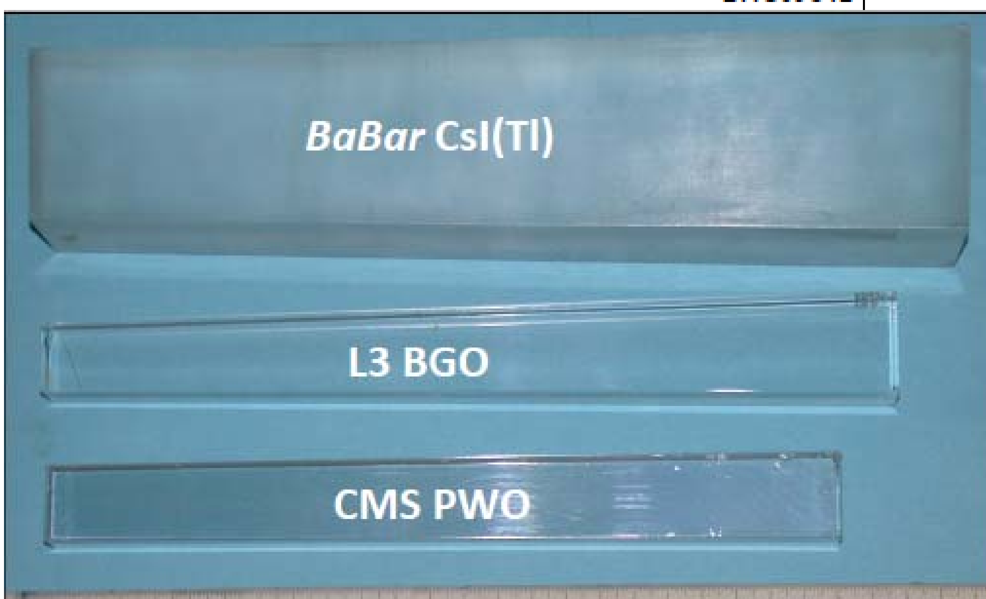
- ~100 years development



1.5 X_0 Cubic Samples:

Hygroscopic Halides

Non-hygroscopic



Full Size Crystals:

***BaBar* CsI(Tl): 16 X_0**

L3 BGO: 22 X_0

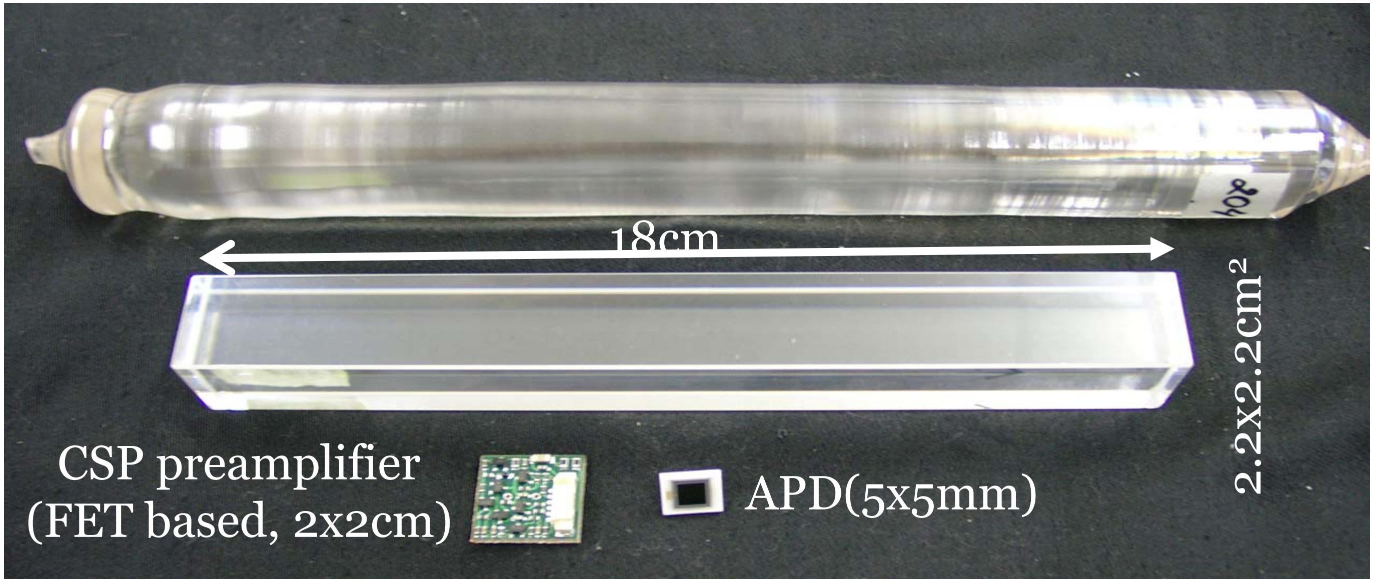
CMS PWO(Y): 25 X_0

Slide by Ren-Yuan Zhu at CALOR2008

Fig. 1. History of the discovery of major inorganic scintillator materials.

M.J.Weber, J.Lumin 100(2002)35

Example of Homogeneous Type: PHOS

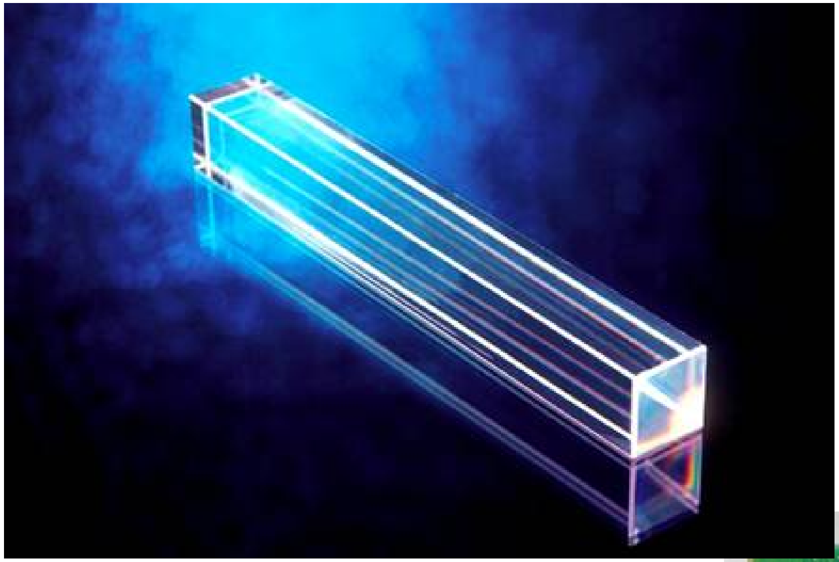


- $PbWO_4$ Crystal
  - 22 x 22 x 180 mm^3, ~20,000yen/crystal
  - ~2cm Moliere Radius, 20X_0, 8.2g/cm^3
  - Scintillation light (400nm-500nm)
  - Operation at -25deg → 25ns decay,230pe/MeV
  - With APD acceptance: 4.5pe/MeV@-25deg, 1.45pe/MeV@+20deg
  - North Crystal Co. Apatity in Russia

- Avalanche Photo Diode (APD) + Preamp
  - Hamamatsu Co., ~7,000yen/APD+~8,000yen/Preamp
  - S8148/S8664-55
  - High Q.E.(60%-80%)
  - Low noise and capacitance
  - Thin photo-sensor
  - Operational at low temperature and in magnetic field

Example of Homogenous Type : PHOS

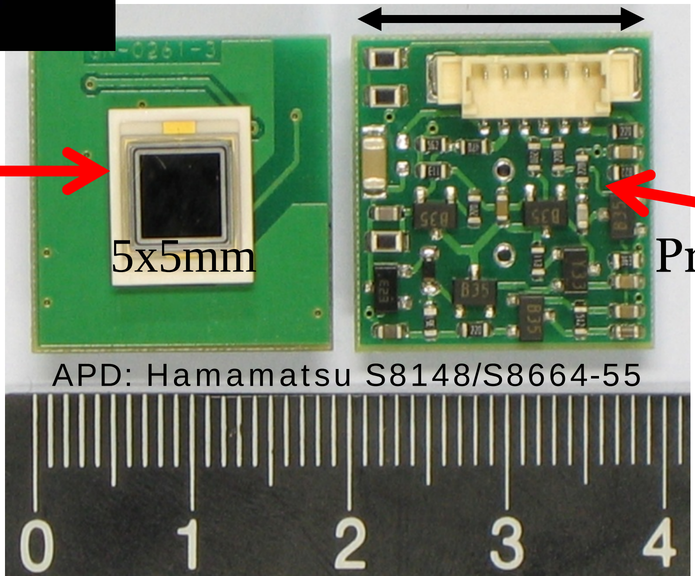
- PbWO4 Crystal



- Fast Signal (~nsec)
- Operation at -25deg ➔ 3 times large scintillation photon
- Smaller Moliere Radius (2cm) ➔ Good 2 photon Separation

5mmx5mm
Avalanche Photo Diode (APD)

- High Q.E.(60%-80%)
- Thin photo-sensor
- Operational in magnetic field



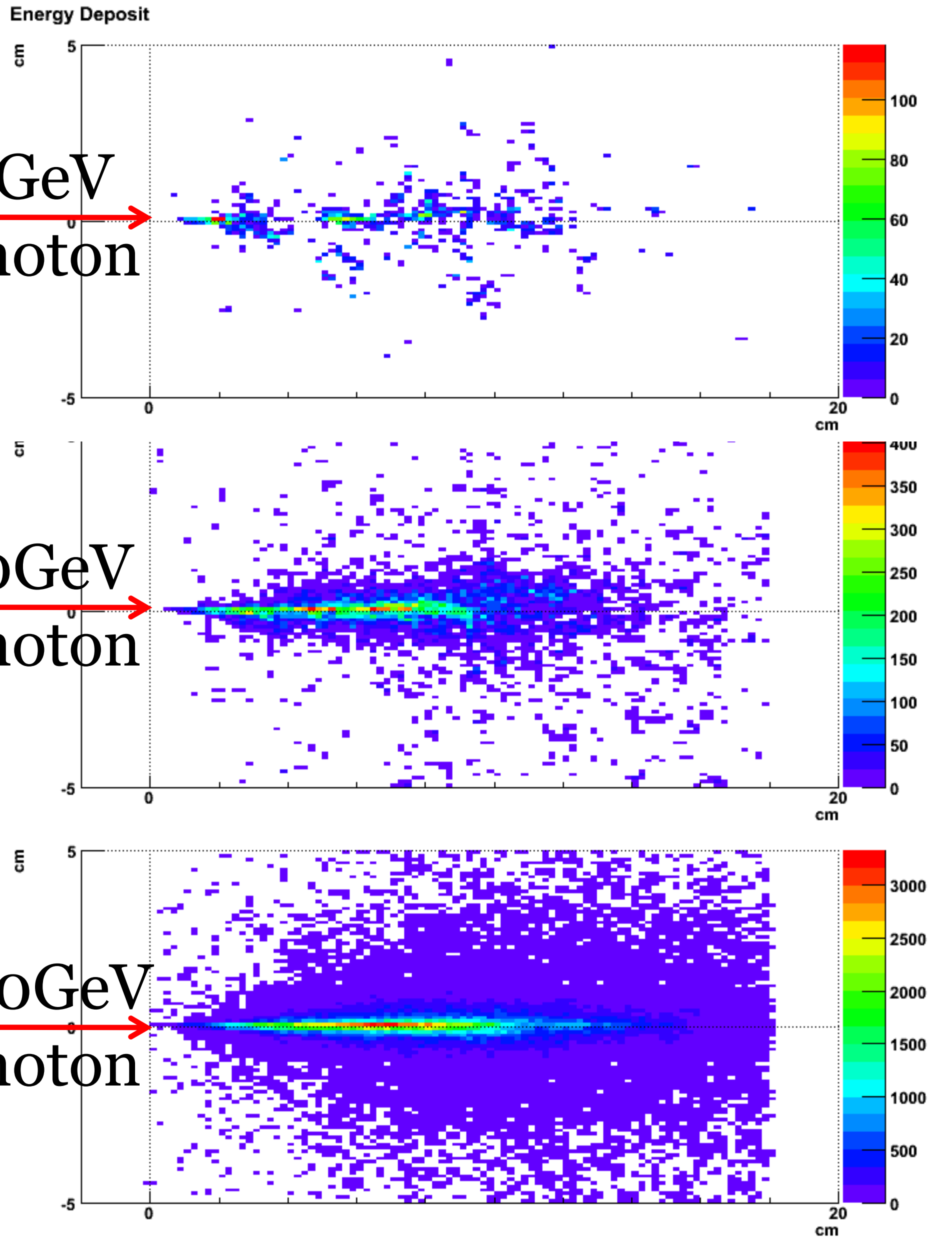
Detector Performance Requirement(1)

< Linearity >

1GeV photon

10GeV photon

100GeV photon

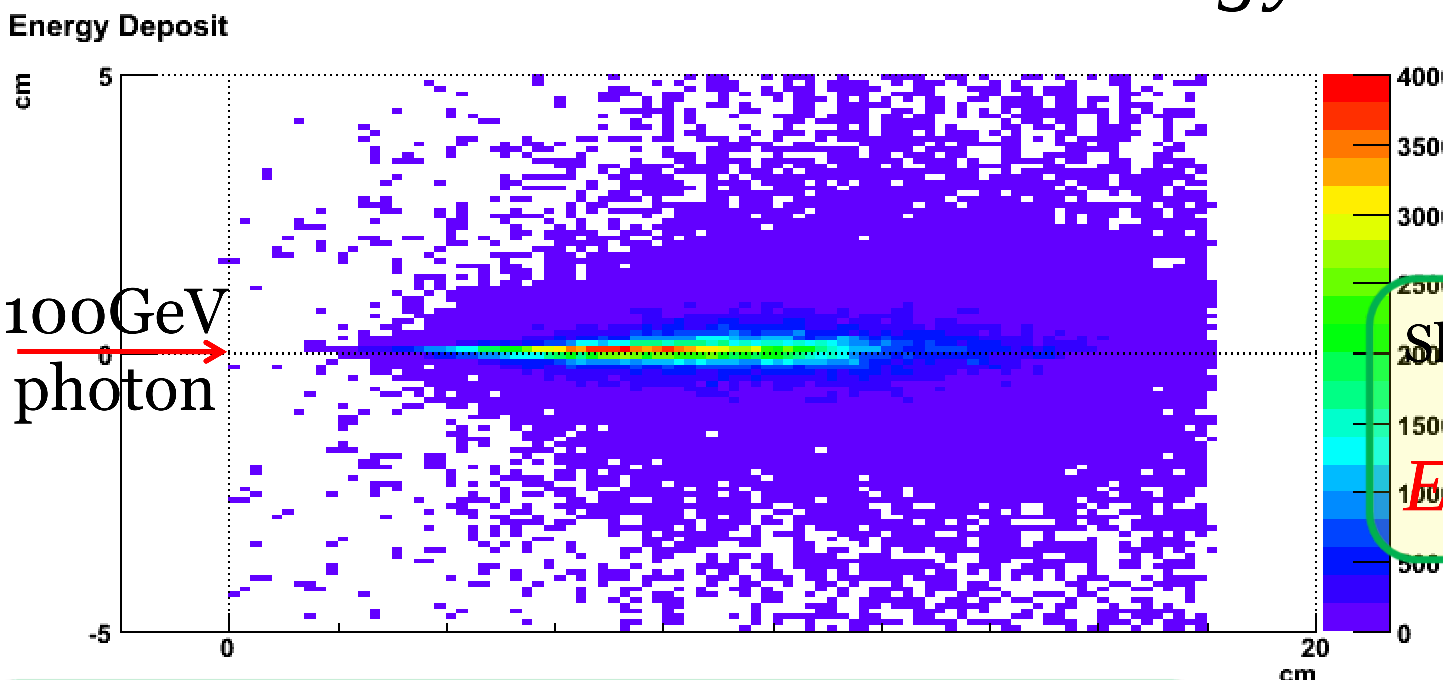


Larger energy photon produces deeper shower

Uniform detection and collection of the deposited energy plays an important role in detector performance, especially energy measurement linearity and energy resolution at high pT.
<keyword> is
Uniformity

Detector Performance Requirement(2)

<Energy Resolution>



100GeV photon

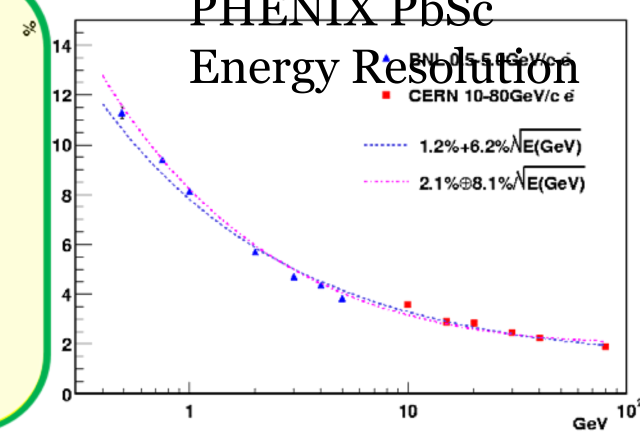
Shower Leackage
<keyword> is
Enough Size

From deposited energy into detectable object
ex. Number of scintillation photon
"The detectable object carry out part of all energy"
Statistical fluctuation ➔ Energy resolution ∝1/√E
<keyword> is

Efficient "ionization loss" detector

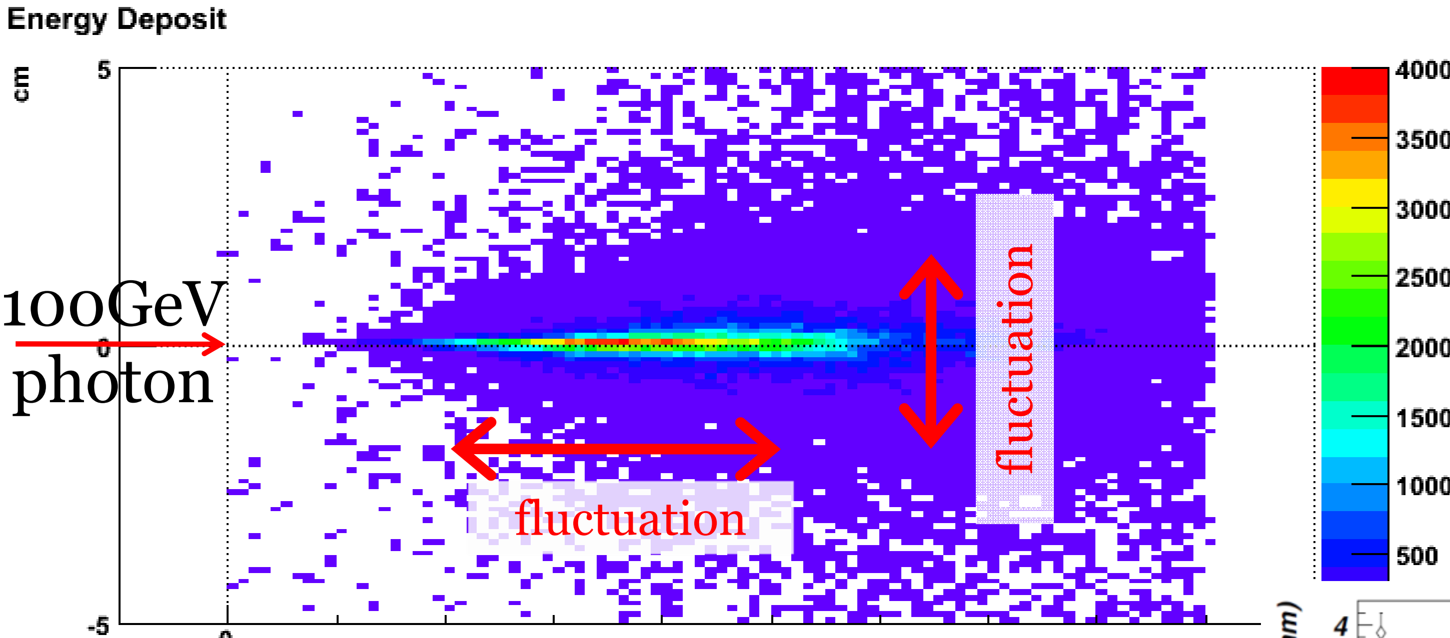
ex. large light emission, good efficiency, good sampling ratio

PHENIX PbSc
Energy Resolution

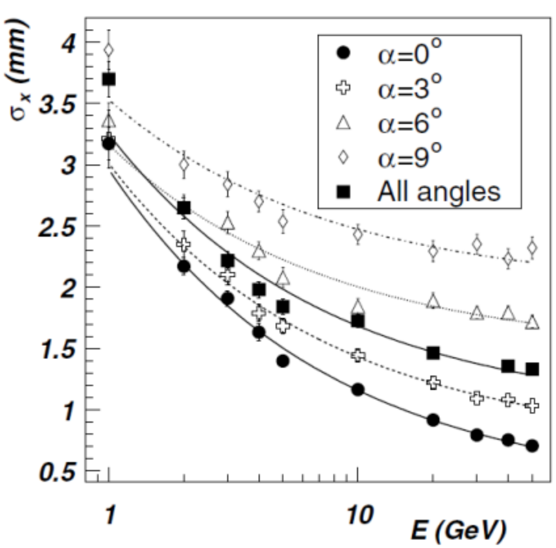


Detector Performance Requirement(3)

<Position Resolution>



ALICE PHOS
Lateral position Res.



Center of gravity is the measurement of the incident position and angle, which are affected by the lateral and longitudinal fluctuation.
<keyword> is

Small Radiation Length

➔Compact shower == small fluctuation
Measurement of fluctuation is another keyword.

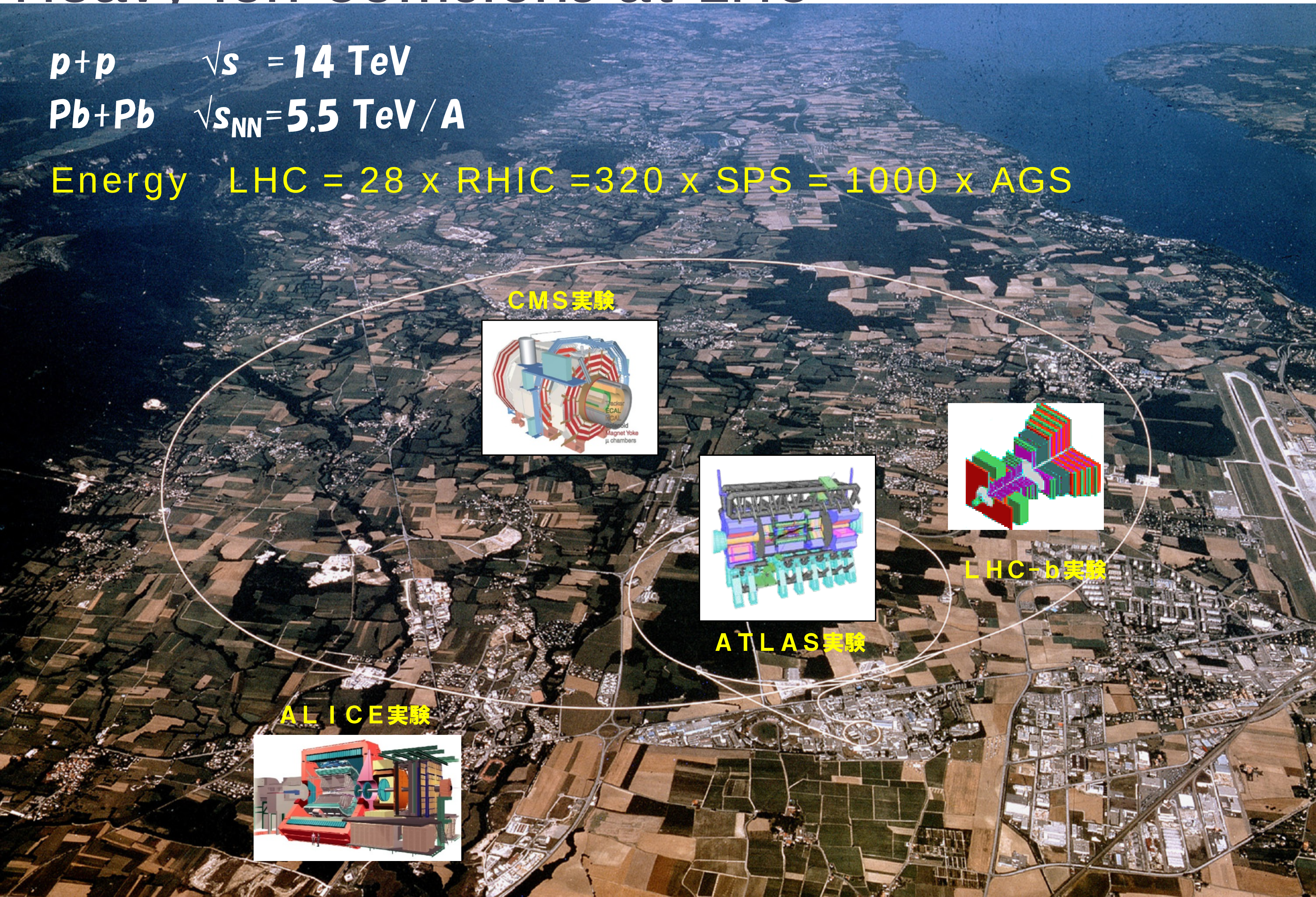
Time to measure shine(photon) by shadow(calorimeter) from QGP at LHC

Heavy Ion Collisions at LHC

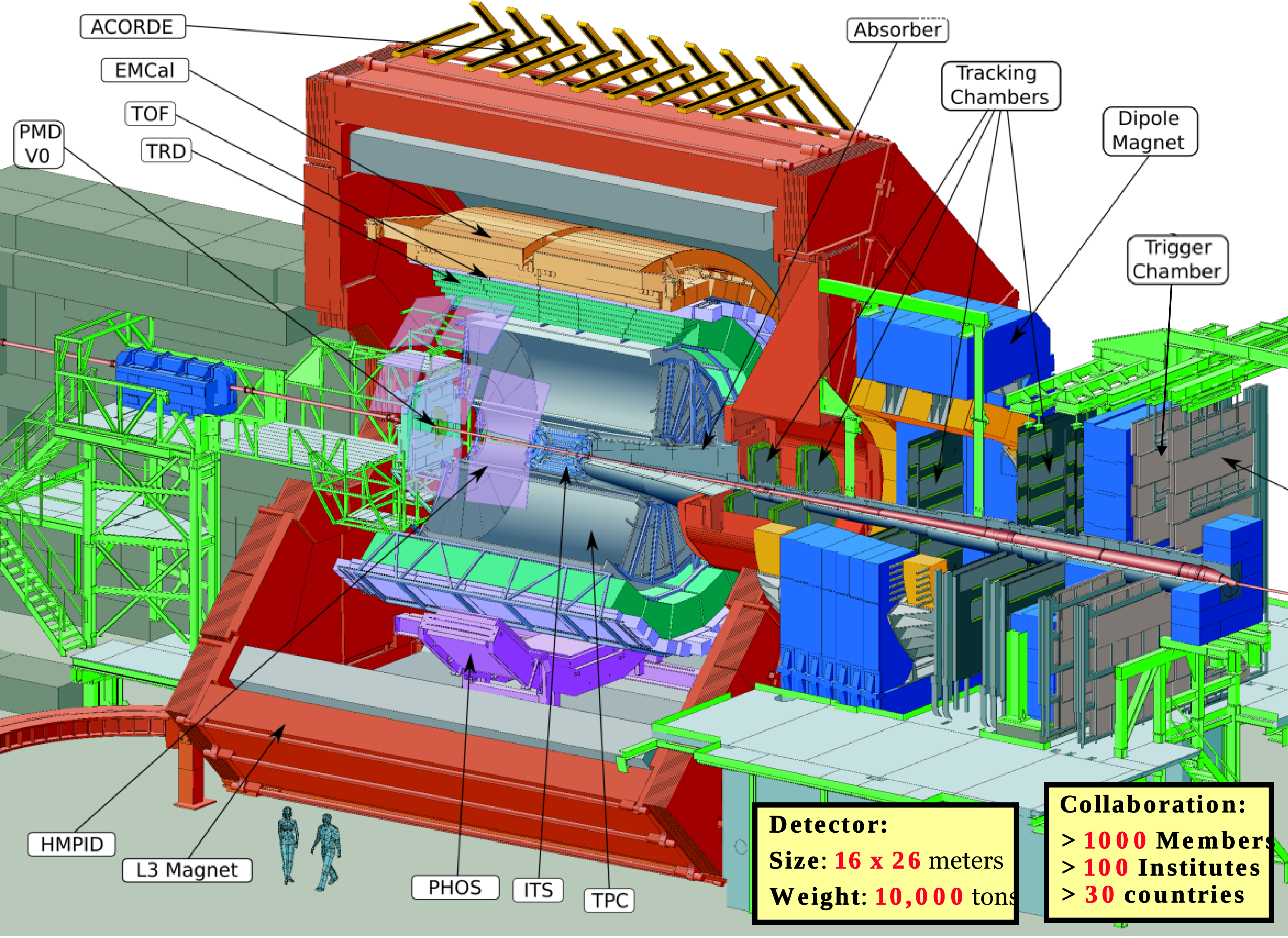
p+p $\sqrt{s} = 14$ TeV

Pb+Pb $\sqrt{s_{NN}} = 5.5$ TeV/A

Energy LHC = 28 x RHIC =320 x SPS = 1000 x AGS



ALICE at Point-2

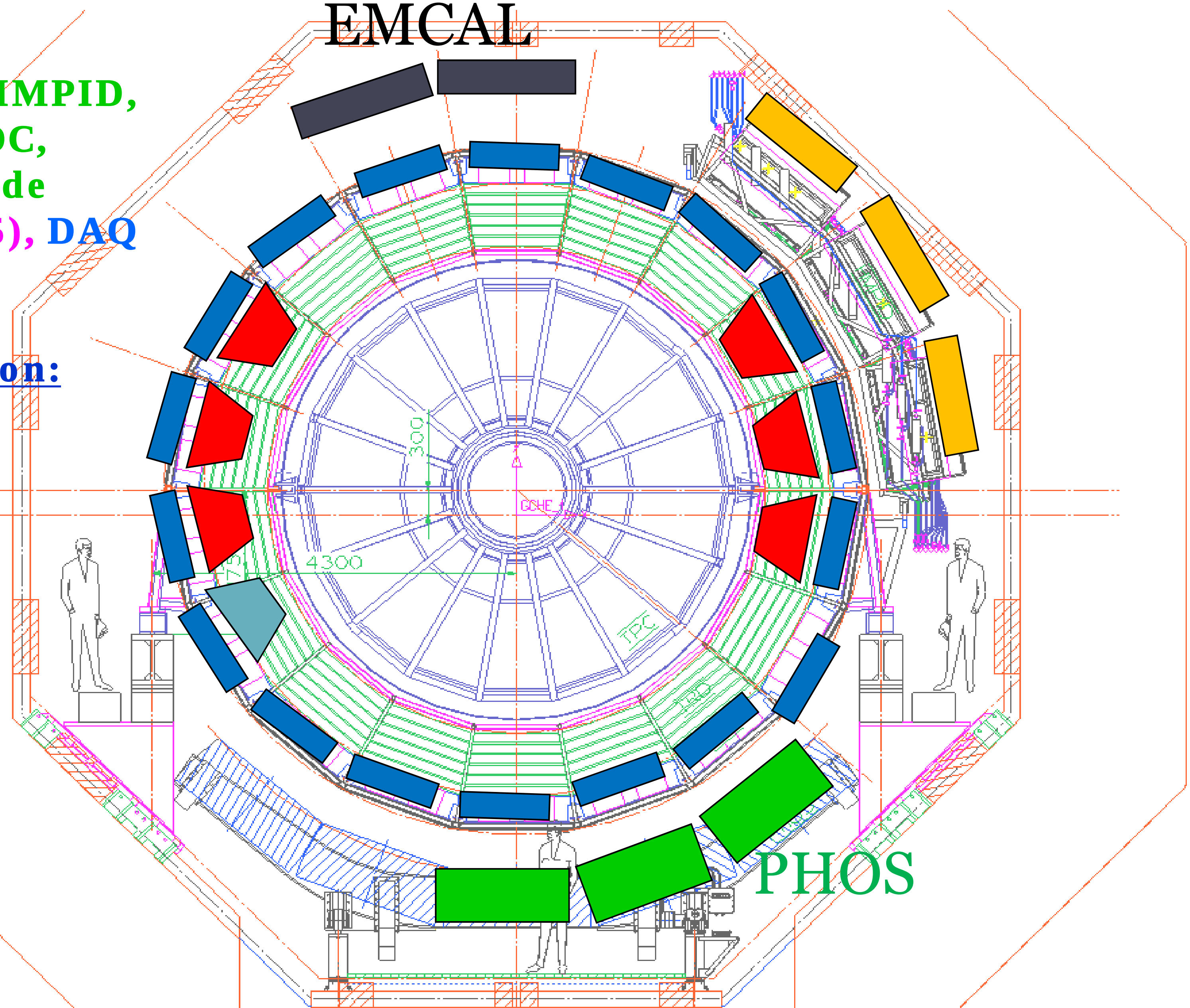

ACORDE
EMCal
TOF
TRD
PMD
V0
Absorber
Tracking
Chambers
Dipole
Magnet
Trigger
Chamber
HMPID
L3 Magnet
PHOS
ITS
TPC
Detector:
Size: 16 x 26 meters
Weight: 10,000 tons
Collaboration:
> 1000 Members
> 100 Institutes
> 30 countries

ALICE Installation Status in 2009

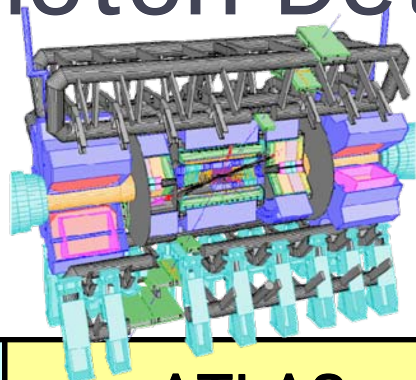
Complete:
ITS, TPC, TOF, HMPID, FMD, T0, V0, ZDC, Muon arm, Acorde
PMD , PHOS(3/5), DAQ

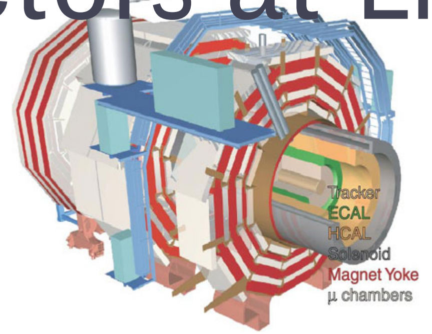
Partial installation:
7/18 TRD
4/12 EMCAL

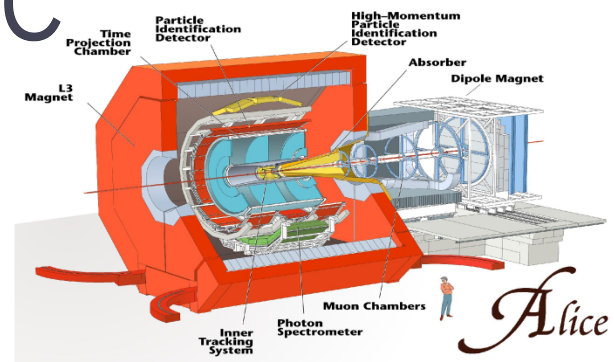
~ 60% HLT



Photon Detectors at LHC





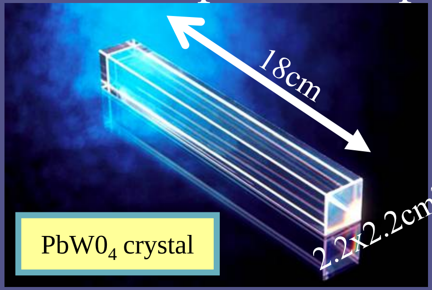


Exp.	ATLAS		CMS		ALICE	
Name	LAr Barrel	LAr Endcap	ECAL(EB)	ECAL(EE)	PHOS	EMCAL
Structure	Liquid Ar		PWO + APD		PWO + APD	Pb + APD
Coverage	$0<\|\eta\|<1.4$, 2π	$1.4<\|\eta\|<3.2$, 2π	$0<\|\eta\|<1.5$, 2π	$1.5<\|\eta\|<3.0$, 2π	$\|\eta\|<0.12$, 0.6π	Cover Jet Size $\|\eta\|<0.7$, 0.6π
Granularity $\Delta\eta \times \Delta\varphi$	0.003x0.100 0.025x0.025 0.025x0.050	0.025x0.100 0.025x0.025 0.025x0.050	0.0174x0.0174	0.0174x0.0174 to 0.05x0.05	Two Separation 0.004x0.004	0.0143x0.0143
Res.	$10\%/\sqrt{E} \oplus 0.5\%$	$10\%/\sqrt{E} \oplus 0.5\%$	$2.7\%/\sqrt{E} \oplus 0.55\%$	$5.7\%/\sqrt{E} \oplus 0.55\%$	Cover Low Energy $3.3\%/\sqrt{E} \oplus 1.1\%$	$7\%/\sqrt{E} \oplus 1.5\%$

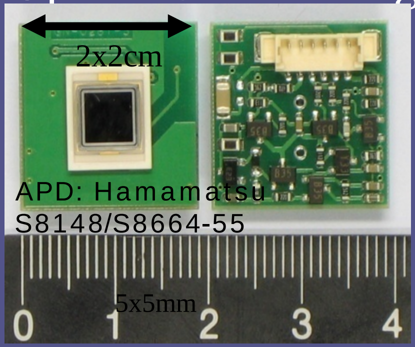
PHOS for low energy photon, EMCAL for jet energy

PHOS Calorimeter

$PbWO_4$ Crystal
- Fast Signal (~nsec)
- Operation at -25deg
- Smaller Moliere Radius (2cm)
  ➔ Good 2 photon Separation

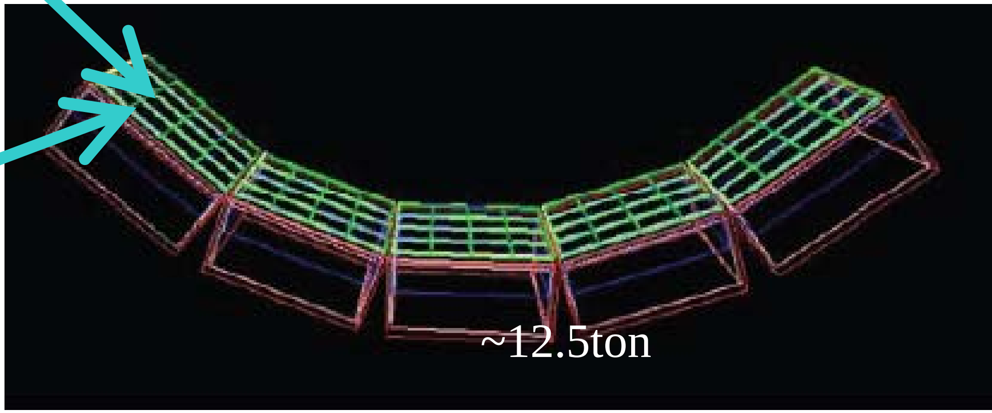


Avalanche Photo Diode (APD)
- High Q.E.(60%-80%)
- Thin photo-sensor
- Operational in magnetic



Combination of recent high technology.

- Total 17920 channel
  100deg -0.12<η<0.12



3/5 modules for 2009 runs
Under cosmic commissioning

EMCAL Calorimeter

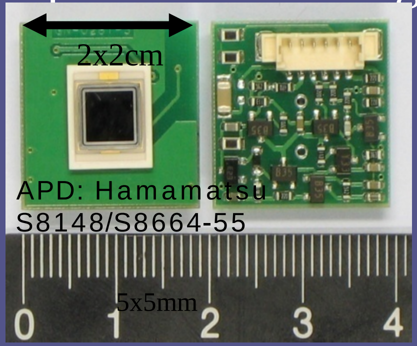
Pb/Sc Shashlik

77 x (1.44mm Pb + 1.76mm Sci.)

6.0x6.0x24.6cm³ active vol.

Avalanche Photo Diode (APD)

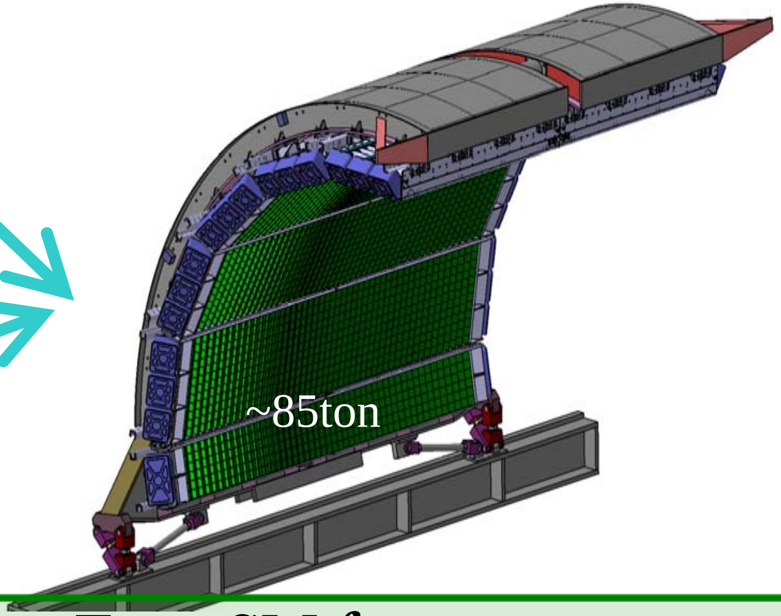
– High Q.E.(60%-80%)
– Thin photo-sensor
– Operational in magnetic



Approved 12/2008

- 10+2/3 Super Modules

  110deg $-0.7<\eta<0.7$

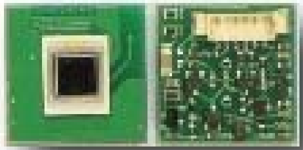


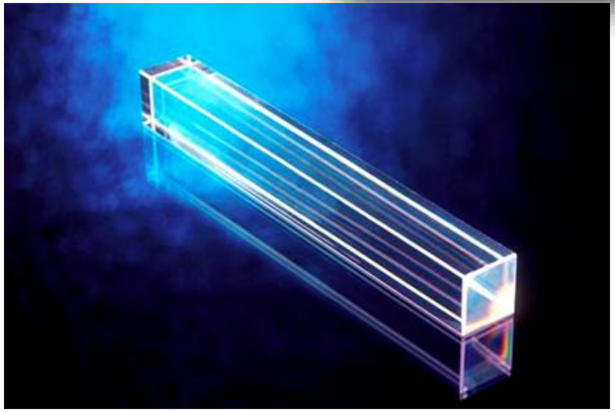
Four SM for 2009 run
Complete for 2011
Under cosmic commissioning

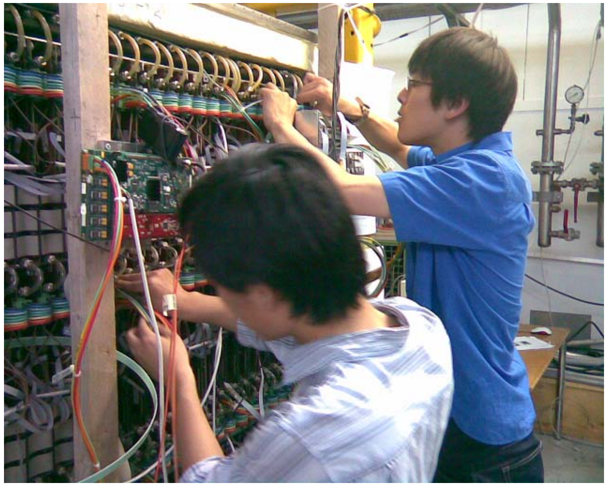
Photon Spectrometer (PHOS)

High-granularity, high-resolution EM calorimeter

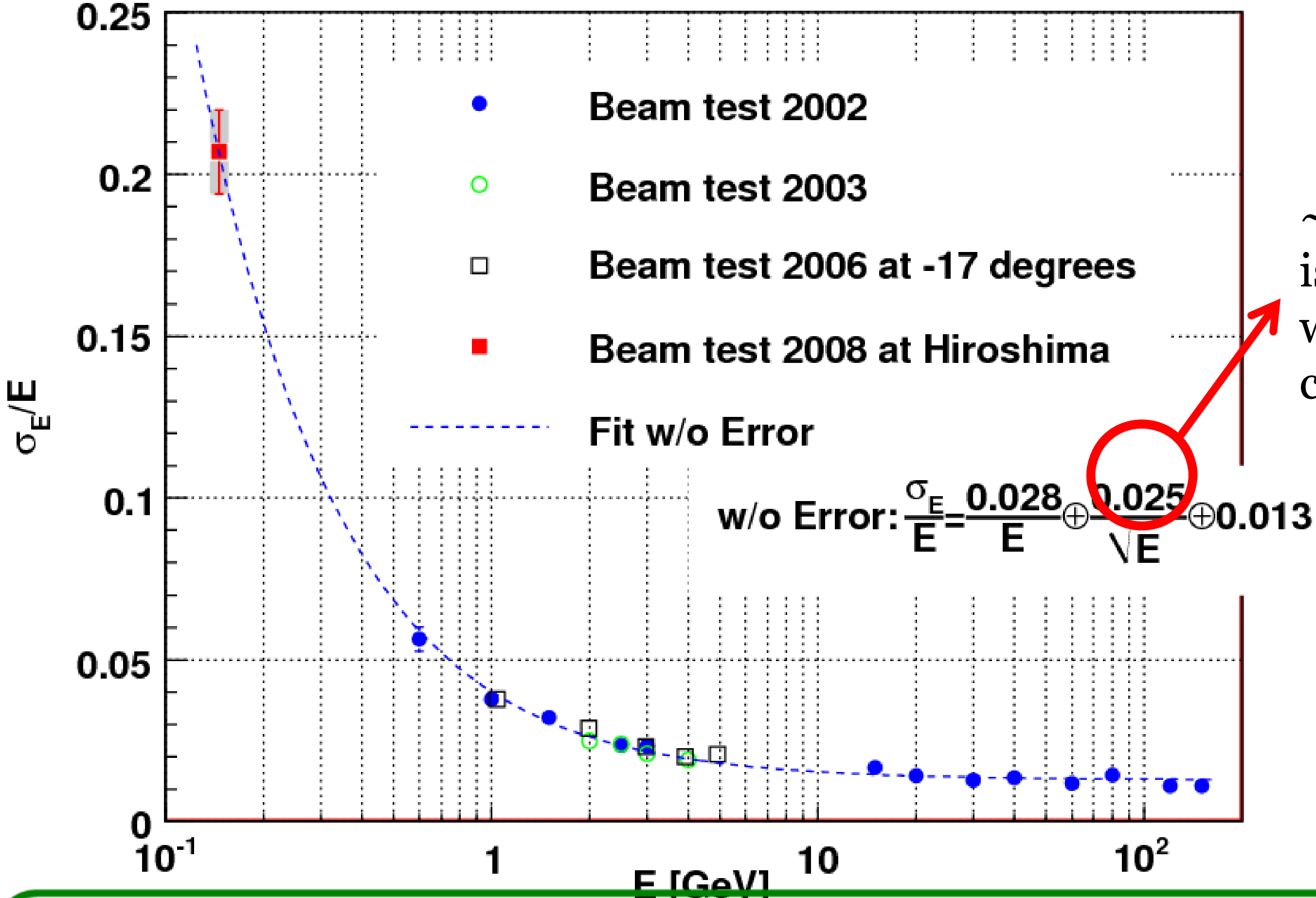
- 64x56x5 $PbWO_4$ crystals readout with APD/CSP
- Precise measurement of photons and neutral mesons
- level-0 and level-1 trigger
- Partial installation 3/5 as of 2009







PHOS Calorimeter

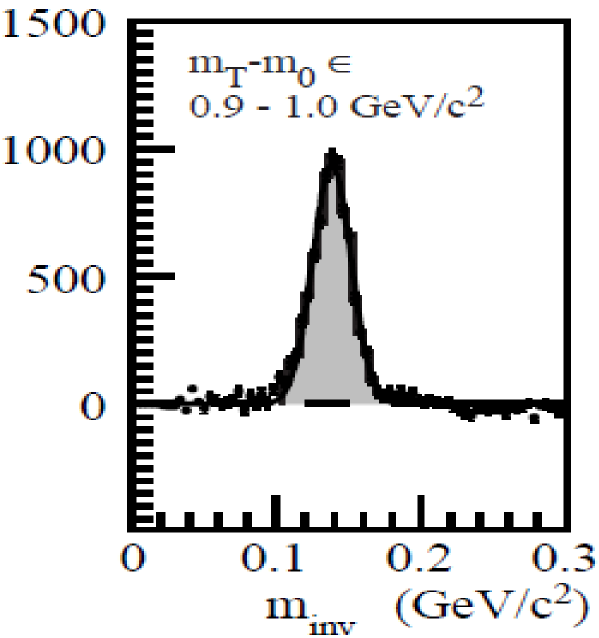


~3% fluctuation term is best value in the world for the working calorimeter.

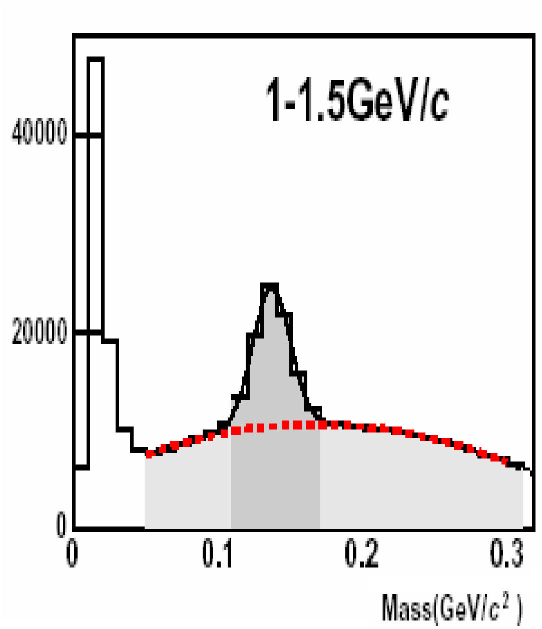
Well controlled performance (energy resolution) from 150MeV to 200GeV

Physics Potential: Neutral Pion in p+p

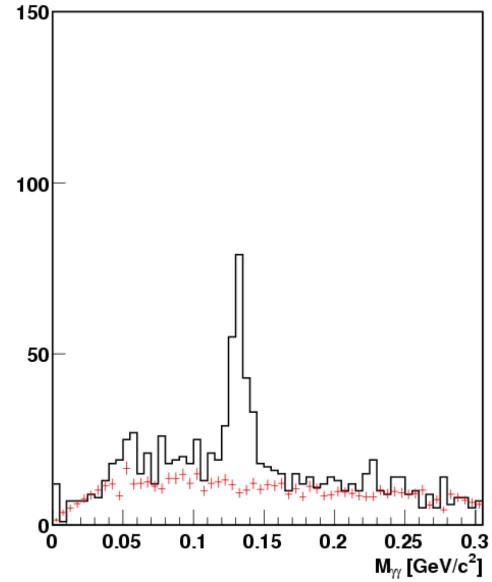
WA98(CERN) | PHENIX(BNL) | ALICE(CERN)



Pb+Pb 13GeV
nucl-ex/0108006



p+p 200GeV run2

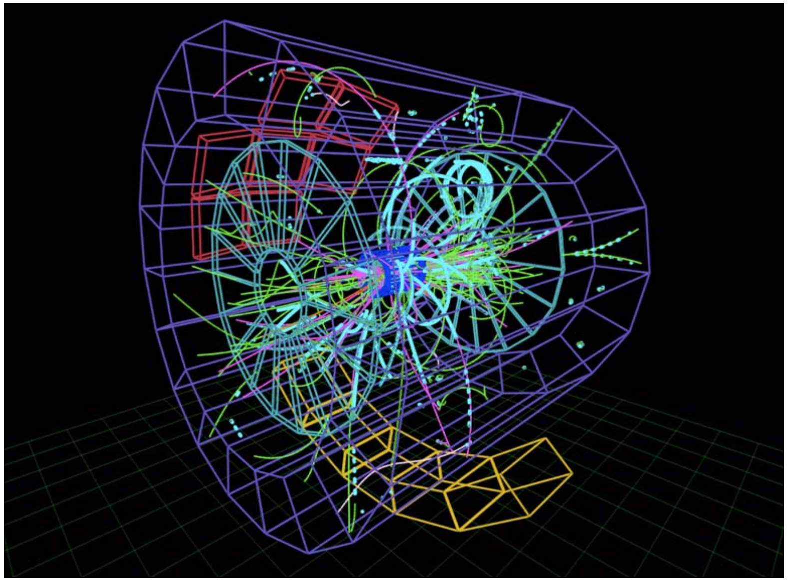


p+p 14TeV
GEANT simulation

13MeV width of π^0@1GeV/c → 5-6MeV

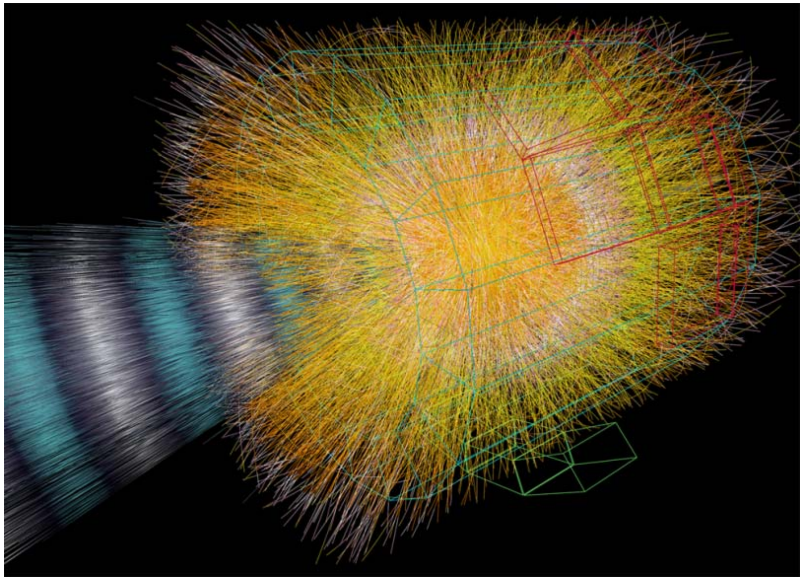
Improvement of particle identification compared to the other HI exp.

The Challenge in RHI Experiments



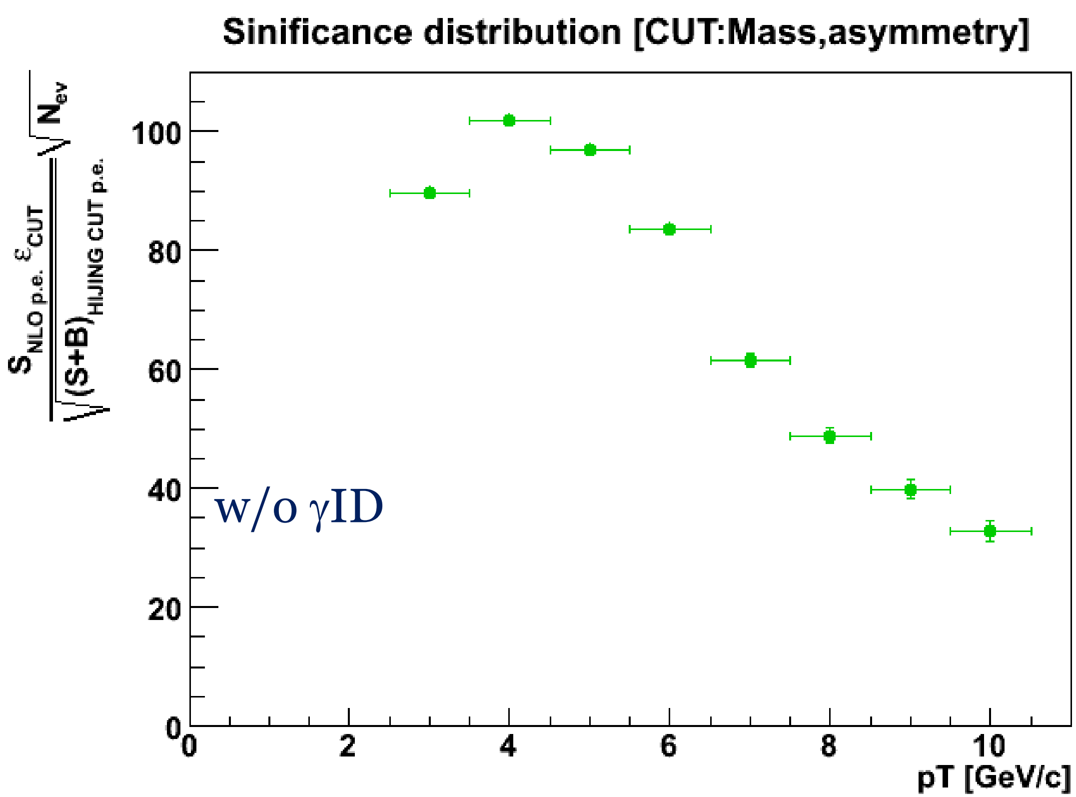
p+p at $\sqrt{s}$ = 14 TeV at ALICE

Pb+Pb at $\sqrt{s_{NN}}$ = 5.5 TeV at ALICE



Physics Potential: Neutral Pion in Pb+Pb

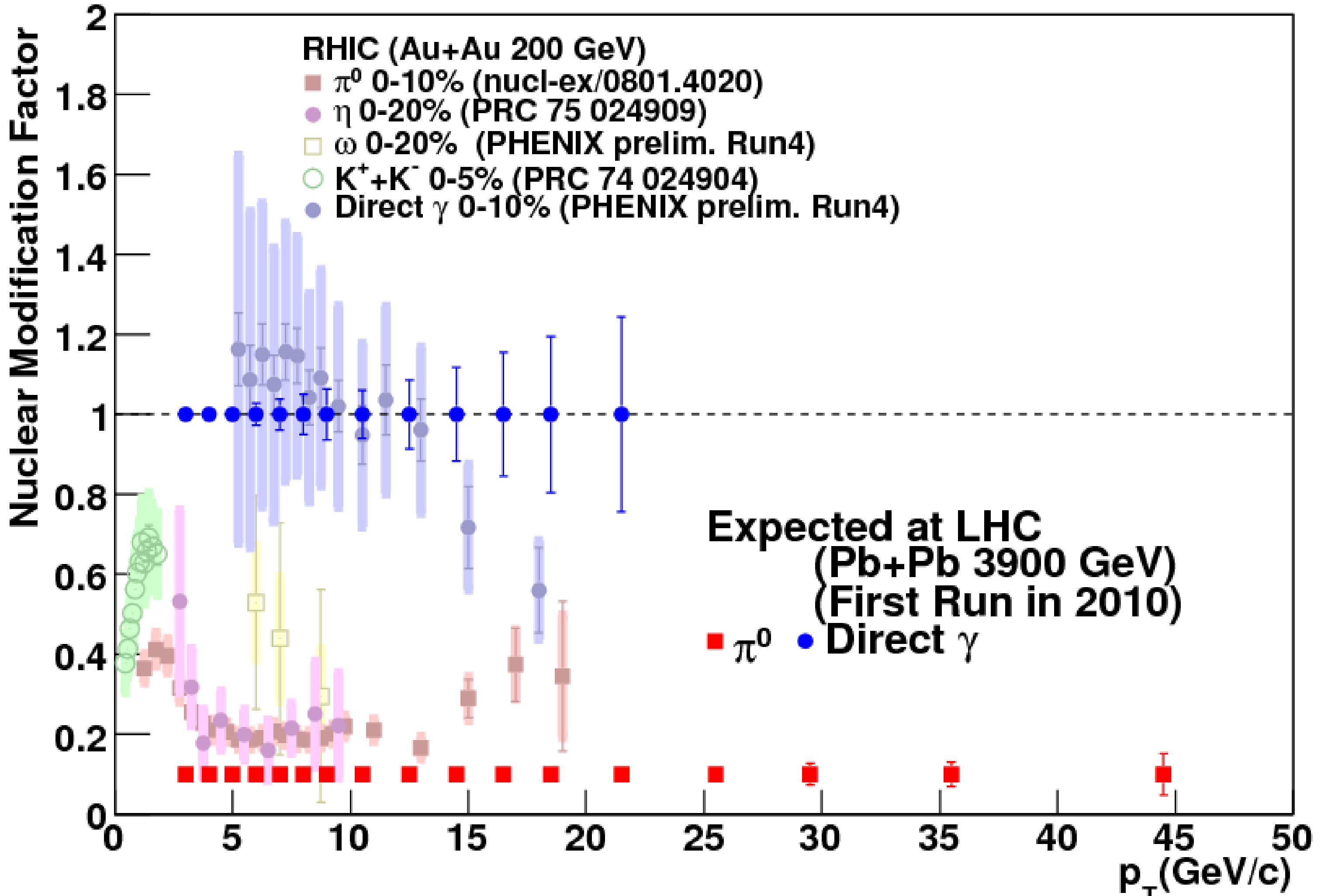
- Expected π^0 peak in central Pb+Pb HIJING



- Eno
  - more species (η, ω, K^o_s) under study

See talk (14th/Oct, Session BB-11) by Kenta Shigaki

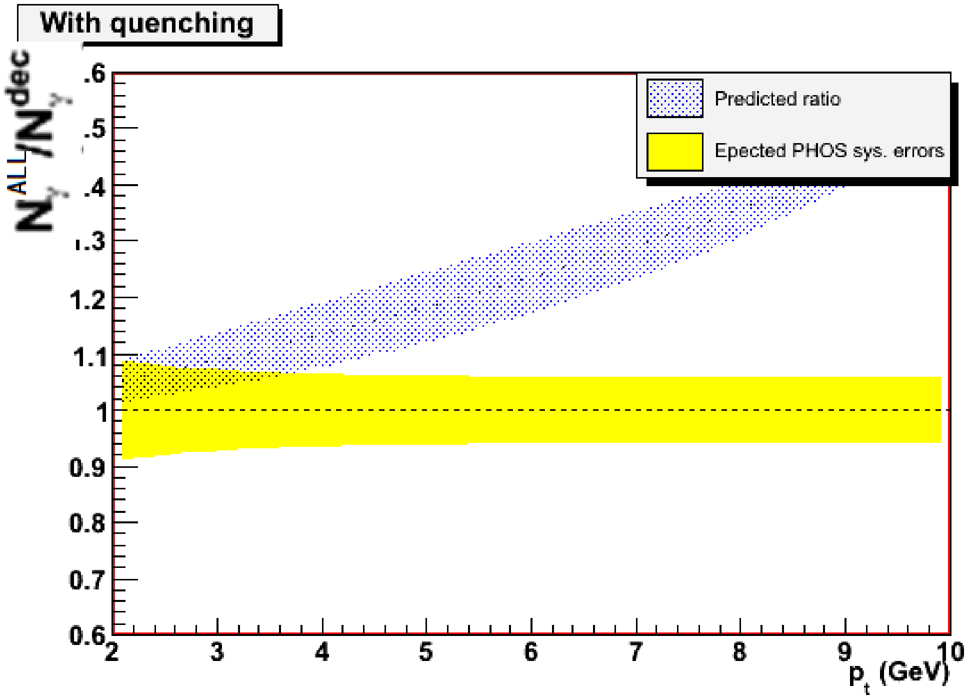
Physics Potential: LHC First Pb+Pb Year



RHIC 10 years and LHC 1st HI year

Physics Potential: Thermal Photon

- expected signal/background ratio
  - 4 ~ 10 % (3 GeV/*c*) – 25 ~ 50 % (10 GeV/*c*)
- expected systematic error with ALICE/PHOS
  - 8.9 % (2 GeV/*c*) – 5.7 % (10 GeV/*c*)

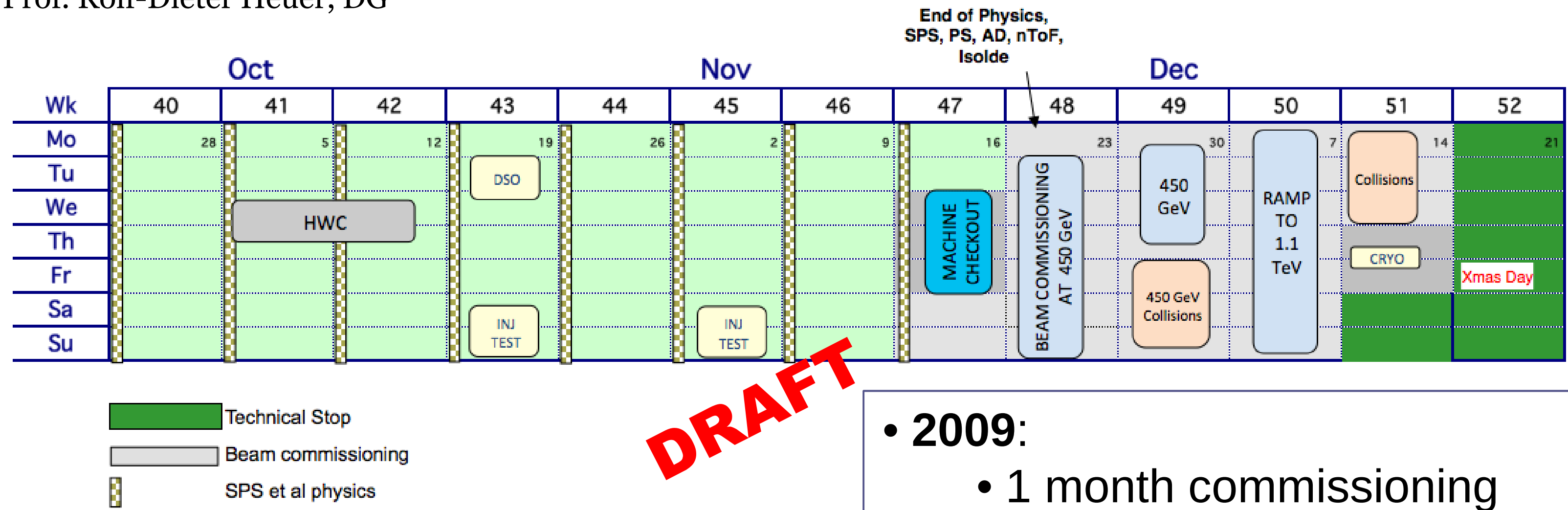


Systematic error in thermal photon measurement is well smaller than statistic error at the pT>3GeV/c

Current LHC RUN Plan

CERN DG message in Feb. 2009 from the Chamonix workshop:
"… foresees first beams in the LHC at the end of Sept. this year, with collisions following in late Oct. A short technical stop over Xmas period. Then run through to autumn next year, ensuring data … first new physics analyses … the possible collisions of lead ions in 2010."

Prof. Rolf-Dieter Heuer, DG



DG message in Feb. 2000 that
"The challenge now passes to RHIC and later to CERN's Large Hadron Collider."

- **2009**:
  - 1 month commissioning
- **2010**:
  - 1 month pilot & commissioning
  - 3 month 3.5 TeV
  - 1 month step-up (to be decided)
  - 5 month 4 - 5 TeV
  - ***1 month ions***

Let’s follow rabbit to wonderland!!!

Thank you